Accelerator Lecture A4

Beam Delivery & beam-beam

Andrei Seryi
John Adams Institute

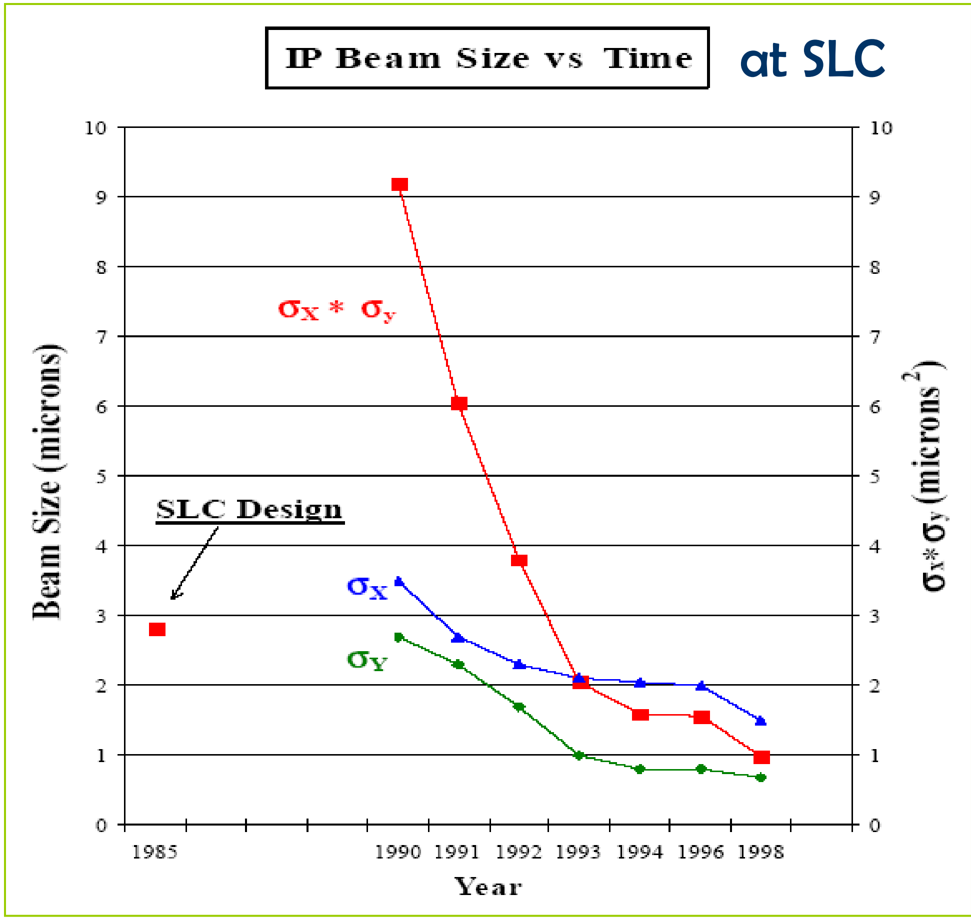
Linear Collider – two main challenges

- **Energy** – need to reach at least 500 GeV CM as a start

- **Luminosity** – need to reach 10^34 level

The Luminosity Challenge

- Must jump by a Factor of 10000 in Luminosity !!! (from what is achieved in the only so far linear collider SLC)
- Many improvements, to ensure this : generation of smaller emittances, their better preservation, …

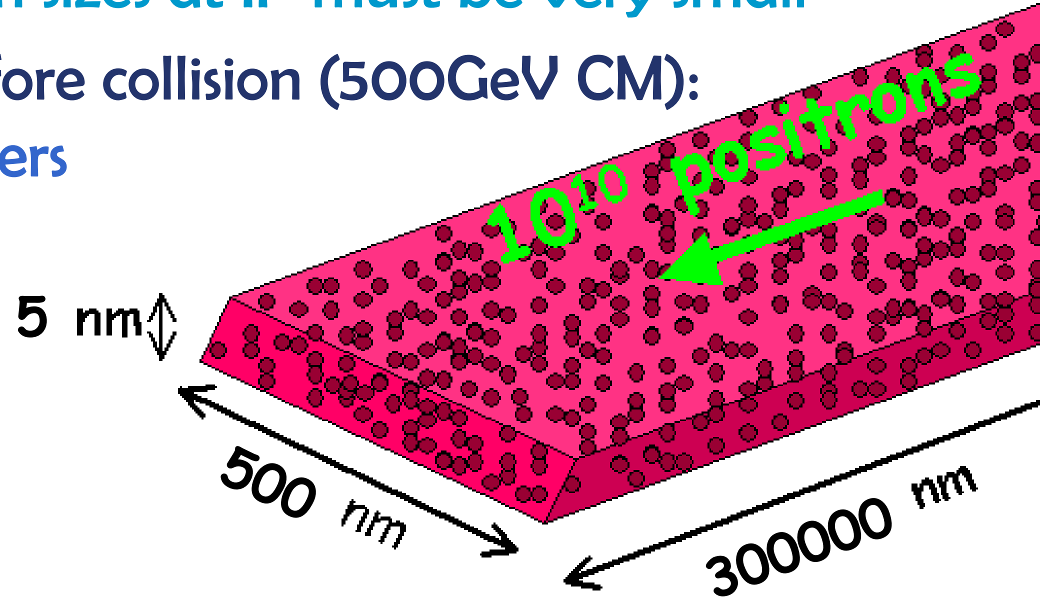


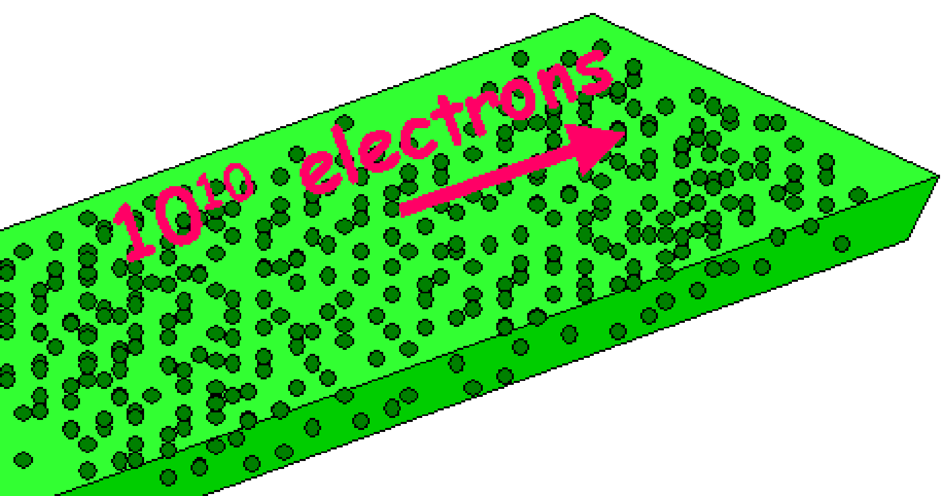
- Including better focusing, dealing with beam-beam, safely removing beams after collision and better stability

How to get Luminosity

- To increase probability of direct e^+e^- collisions (**luminosity**) and birth of new particles, beam sizes at IP must be very small
- E.g., ILC beam sizes just before collision (500GeV CM):
  500 * 5 * 300000 nanometers
  (x y z)

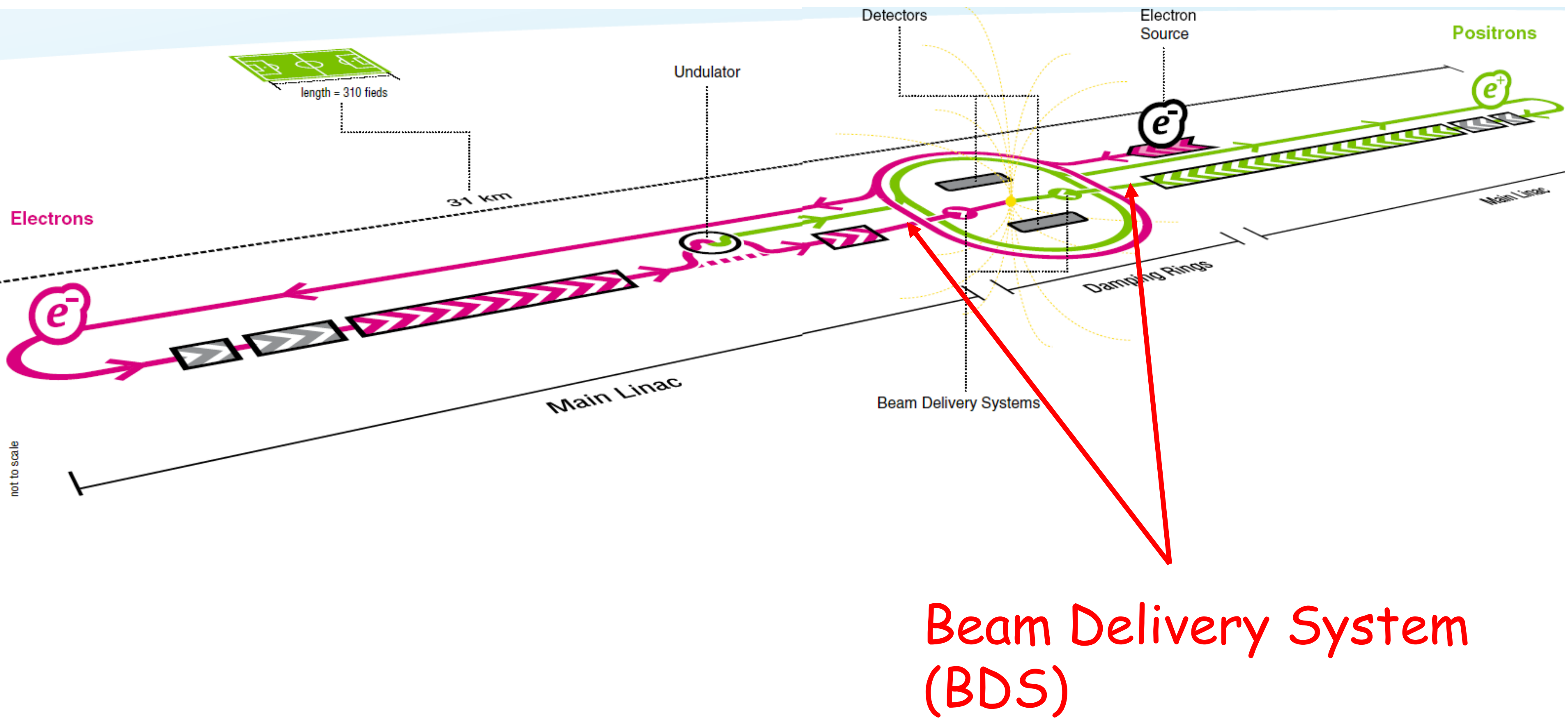
Vertical size is smallest





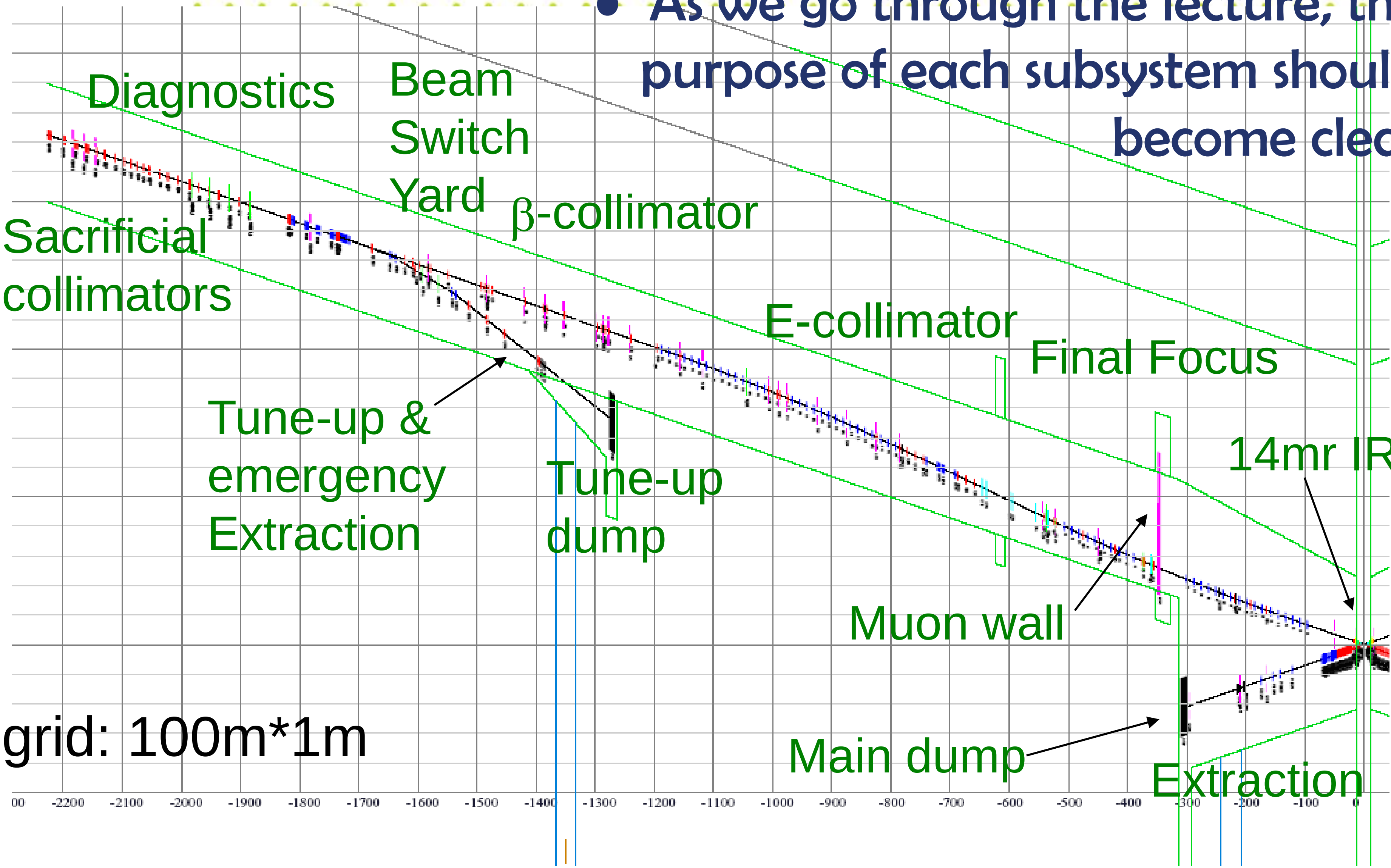
$$L = \frac{f_{rep}}{4\pi} \frac{n_b N^2}{\sigma_x \sigma_y} H_D$$

BDS: from end of linac to IP, to dumps



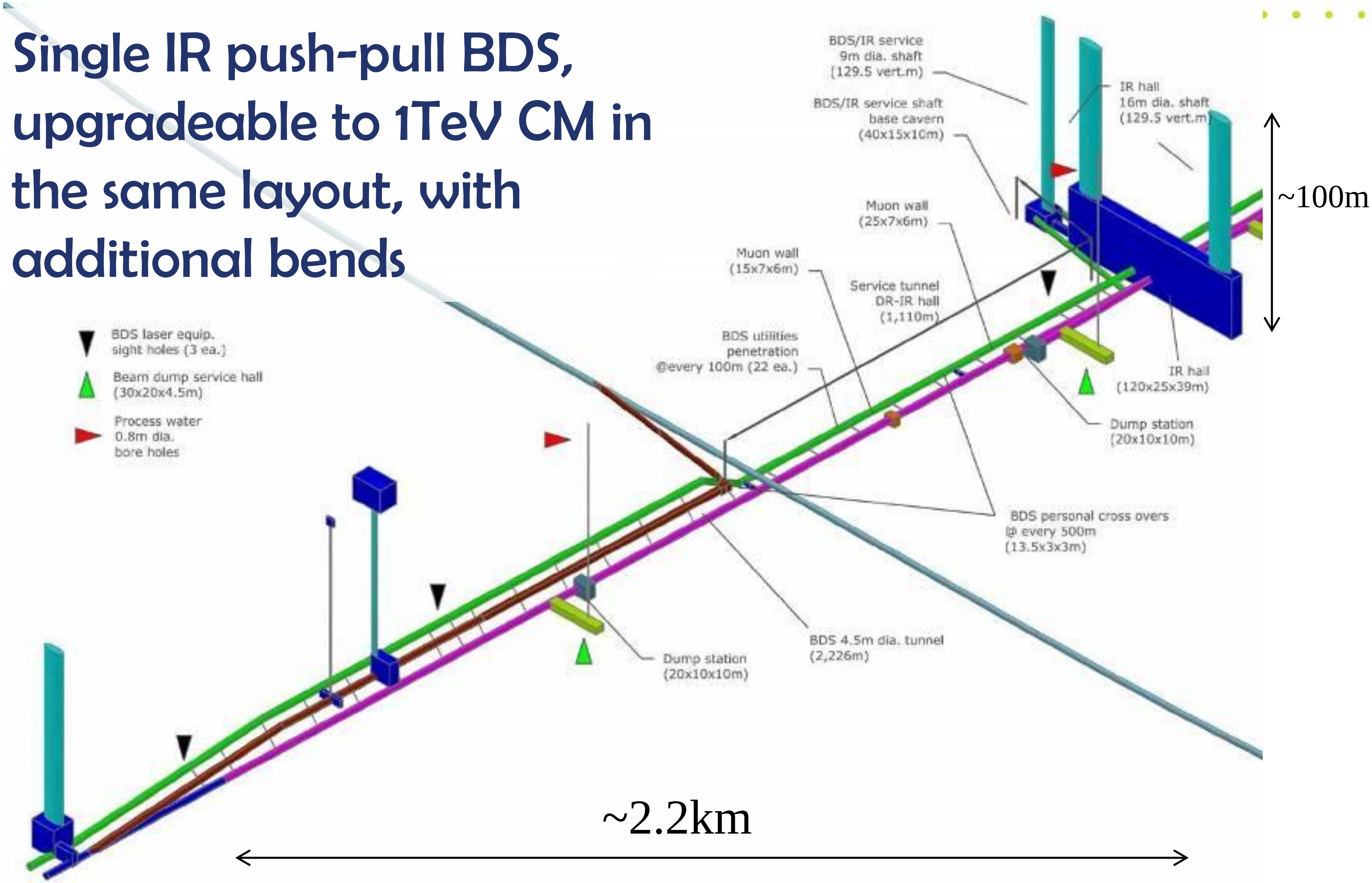
Beam Delivery subsystems

- As we go through the lecture, the purpose of each subsystem should become clear



Layout of Beam Delivery tunnels

- Single IR push-pull BDS, upgradeable to 1TeV CM in the same layout, with additional bends



Beam Delivery System challenges

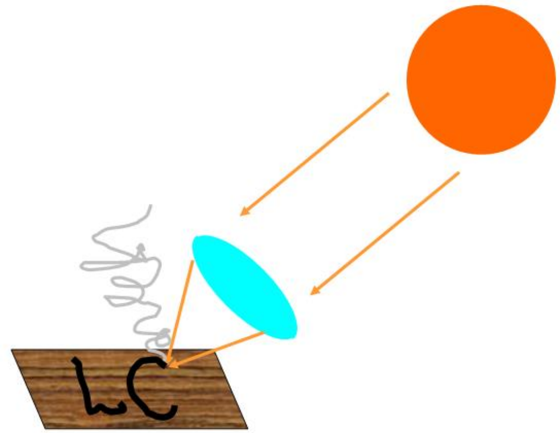
- measure the linac beam and match it into the final focus
- remove any large amplitude particles (beam-halo) from the linac to minimize background in the detectors
- measure and monitor the key physics parameters such as energy and polarization before and after the collisions
- ensure that the extremely small beams collide optimally at the IP
- protect the beamline and detector against mis-steered beams from the main linacs and safely extract them to beam dump
- provide possibility for two detectors to utilize single IP with efficient and rapid switch-over

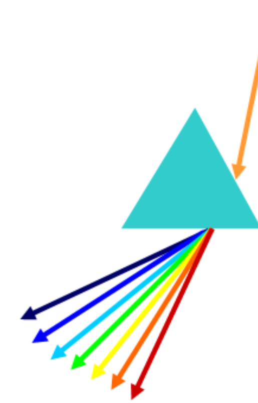
Parameters of ILC BDS

Length (linac exit to IP distance)/side	m	2226
Length of main (tune-up) extraction line	m	300 (467)
Max Energy/beam (with more magnets)	GeV	250 (500)
Distance from IP to first quad, L*	m	3.5-(4.5)
Crossing angle at the IP	mrad	14
Nominal beam size at IP, σ^*, x/y	nm	655/5.7
Nominal beam divergence at IP, θ^*, x/y	μrad	31/14
Nominal beta-function at IP, β^*, x/y	mm	21/0.4
Nominal bunch length, σ_z	μm	300
Nominal disruption parameters, x/y		0.162/18.5
Nominal bunch population, N		2×10^{10}
Max beam power at main and tune-up dumps	MW	18
Preferred entrance train to train jitter	σ	< 0.5
Preferred entrance bunch to bunch jitter	σ	< 0.1
Typical nominal collimation depth, x/y		8–10/60
Vacuum pressure level, near/far from IP	nTorr	1/50

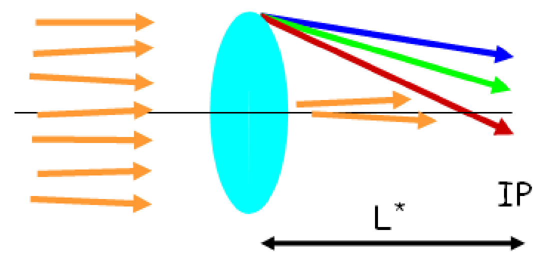
Factor driving BDS design

- Strong focusing

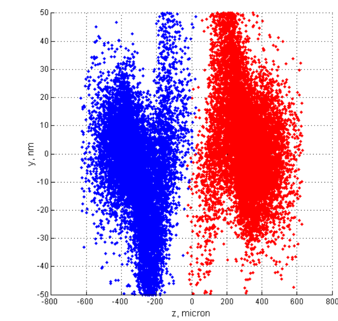




- Chromaticity



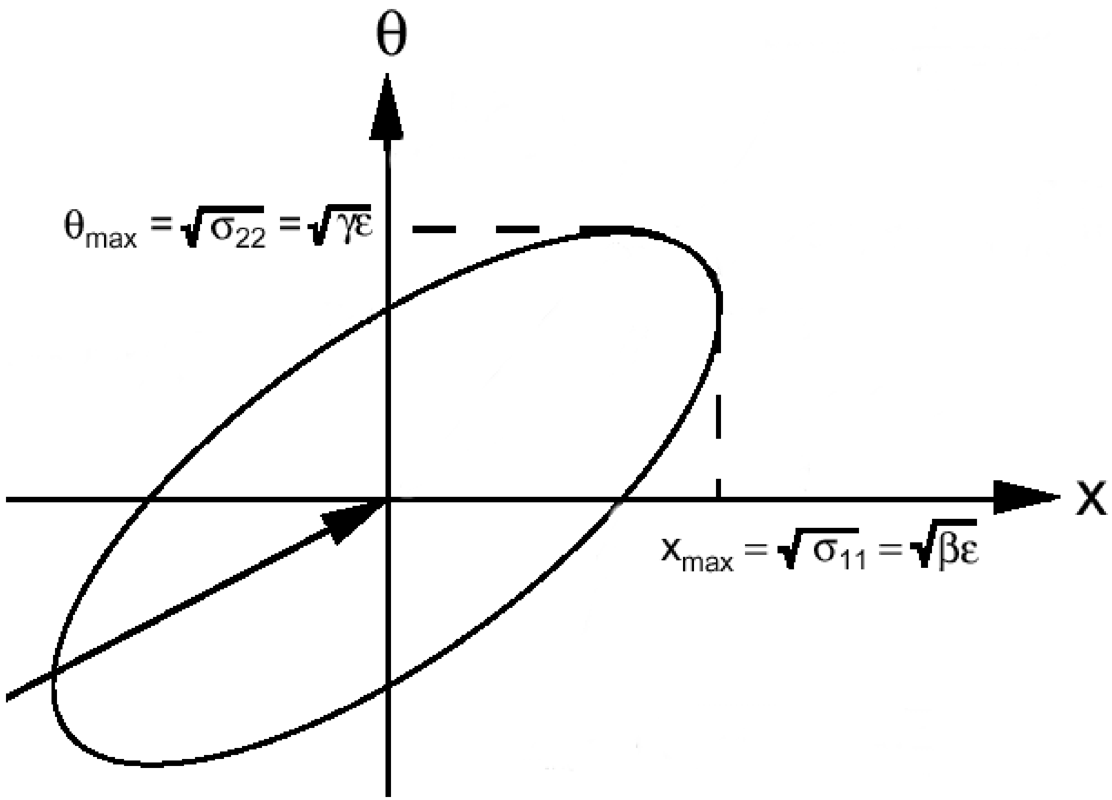
- Beam-beam effects



- Synchrotron radiation
  - let's consider some of this in more details

Recall couple of definitions

- Beta function β characterize optics
- Emittance ε is phase space volume of the beam
- Beam size: $(\varepsilon\ \beta)^{1/2}$
- Divergence: $(\varepsilon/\beta)^{1/2}$



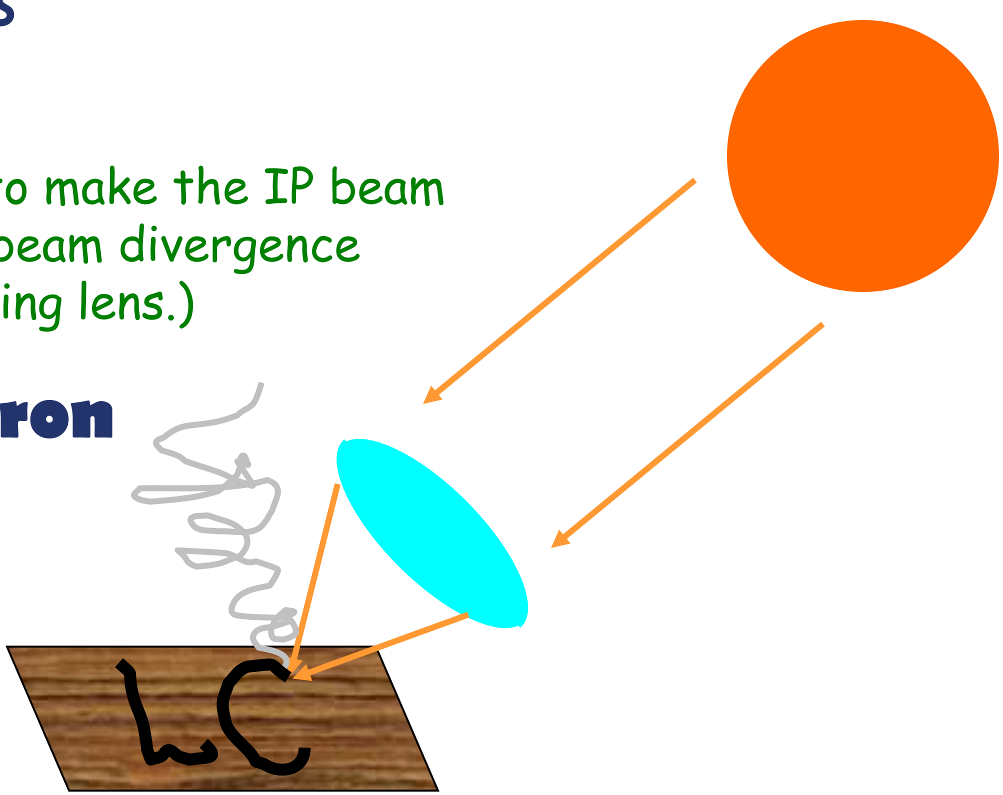
- Focusing makes the beam ellipse rotate with "betatron frequency"
- Phase of ellipse is called "betatron phase"

How to focus the beam to a smallest spot?

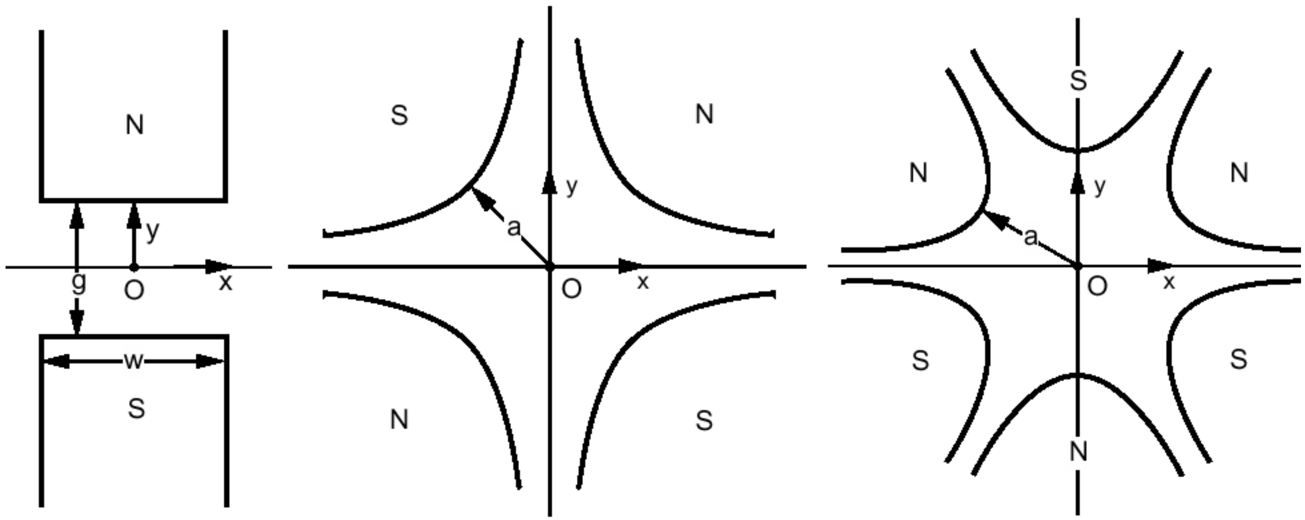
- If you ever played with a lens trying to burn a picture on a wood under bright sun, then you know that one needs a strong and big lens

(The emittance ε is constant, so, to make the IP beam size $(\varepsilon\ \beta)^{1/2}$ small, you need large beam divergence at the IP $(\varepsilon\ /\ \beta)^{1/2}$ i.e. short-focusing lens.)

- It is very similar for **electron** or **positron** beams
- But one have to use **magnets**



What we use to handle the beam



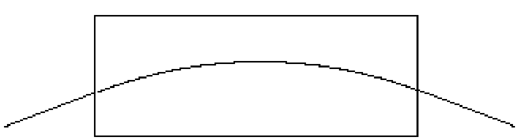
DIPOLE

QUADRUPOLE

SEXTUPOLE

Etc…

Just bend the trajectory



Focus in one plane, defocus in another:

$x' = x' + G\,x$

$y' = y' - G\,y$

Second order effect:

$x' = x' + S\,(x^2 - y^2)$

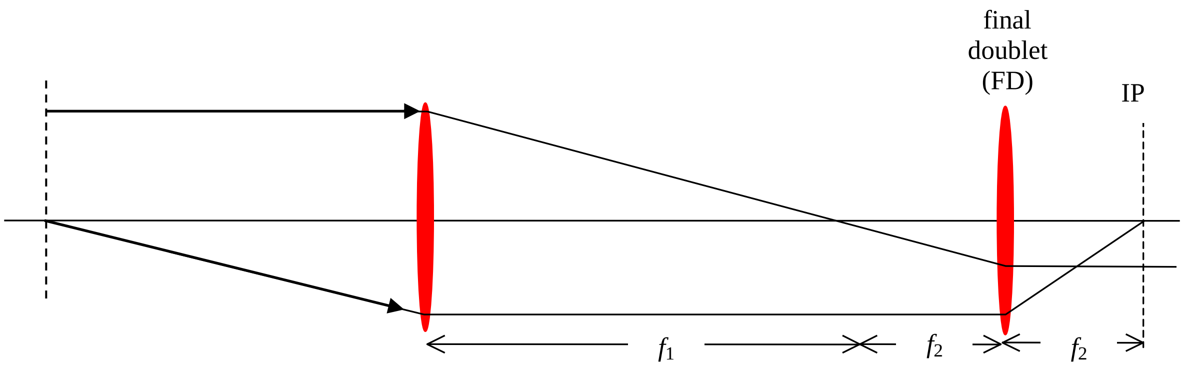
$y' = y' - S\,2xy$

Here x is transverse coordinate, x' is angle

Optics building block: telescope

Essential part of final focus is final telescope. It "demagnify" the incoming beam ellipse to a smaller size. Matrix transformation of such telescope is diagonal:

$$R_{X,Y} = \begin{pmatrix} -1/M_{X,Y} & 0 \\ 0 & -M_{X,Y} \end{pmatrix}$$



f_1 $\quad$ $f_2\ (=L^*)$

A minimal number of quadrupoles, to construct a telescope with arbitrary demagnification factors, is four.

Use telescope optics to demagnify beam by factor $m = f1/f2 = f1/L^*$

If there would be no energy spread in the beam, a telescope could serve as your final focus (or two telescopes chained together).

Matrix formalism for beam transport:

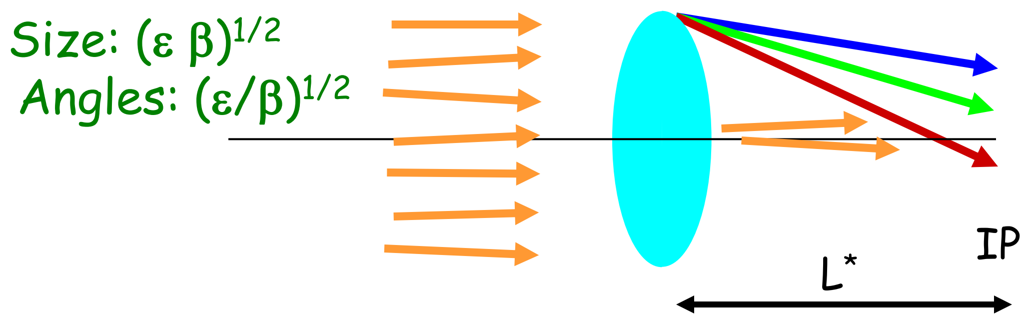
$$x_i^{out} = R_{ij}\ x_j^{in}$$

$$x_i = \begin{pmatrix} x \\ x' \\ y \\ y' \\ \Delta l \\ \delta \end{pmatrix}$$

Why nonlinear elements

- As sun **light** contains different colors, **electron beam** has energy spread and get dispersed and distorted => **chromatic aberrations**
- For **light**, one uses lenses made from different materials to compensate chromatic aberrations
- Chromatic compensation for particle beams is done with **nonlinear** magnets
  - Problem: Nonlinear elements create **geometric** aberrations
- The **task** of **Final Focus system** (FF) is to focus the beam to required size and compensate aberrations

How to focus to a smallest size and how big is chromaticity in FF?



Size at IP:
$L^* (\varepsilon/\beta)^{1/2}$
$+ \ (\varepsilon \beta)^{1/2} \sigma_E$

Beta at IP:
$L^* (\varepsilon/\beta)^{1/2} = (\varepsilon \beta^*)^{1/2}$
$\Rightarrow \ \beta^* = L^{*2}/\beta$

Chromatic dilution:
$(\varepsilon \beta)^{1/2} \sigma_E / (\varepsilon \beta^*)^{1/2}$
$= \sigma_E \ L^*/\beta^*$

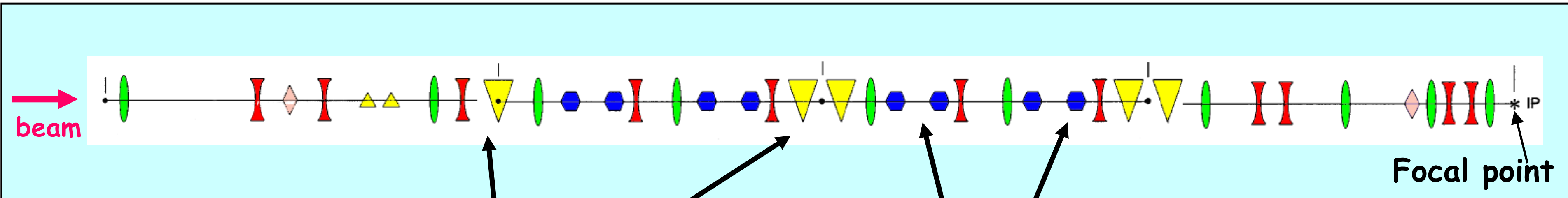
- The final lens need to be the strongest
  - (two lenses for both x and y => "Final Doublet" or FD)
- FD determines chromaticity of FF
- Chromatic dilution of the beam size is $\Delta\sigma/\sigma \sim \sigma_E L^*/\beta^*$

Typical: σ_E -- energy spread in the beam ~ 0.002-0.01
L^* -- distance from FD to IP ~ 3 - 5 m
β^* -- beta function in IP ~ 0.4 - 0.1 mm

- For typical parameters, $\Delta\sigma/\sigma \sim$ 15-500 too big !
- => Chromaticity of FF need to be compensated

Example of traditional Final Focus

Sequence of elements in ~100m long Final Focus Test Beam



Dipoles. They bend trajectory, but also disperse the beam so that x depend on energy offset δ

Sextupoles. Their kick will contain energy dependent focusing

$$x' \Rightarrow S\,(x+\delta)^2 \Rightarrow 2S\,x\,\delta + ..$$

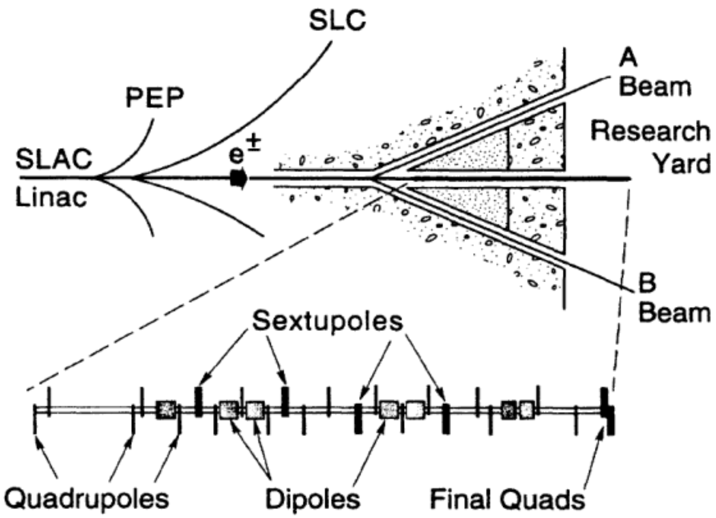
$$y' \Rightarrow -S\,2(x+\delta)y \Rightarrow -2S\,y\,\delta + ..$$

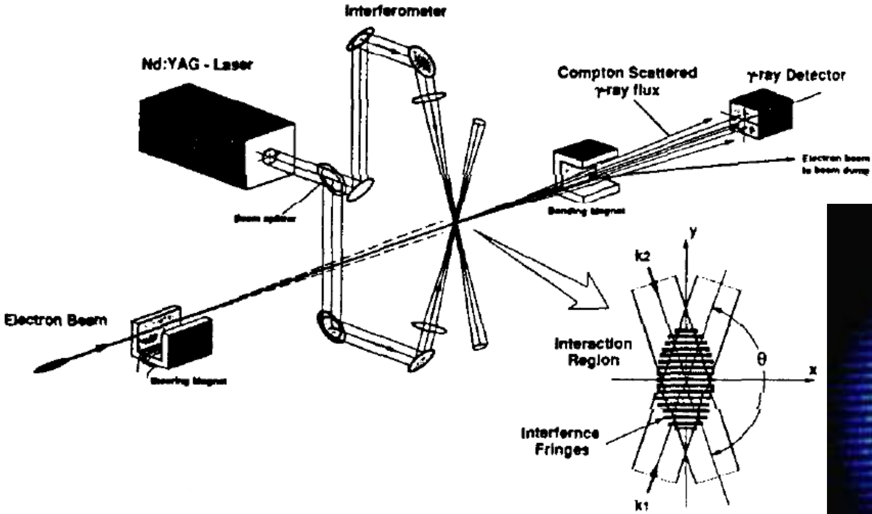
that can be used to arrange chromatic correction

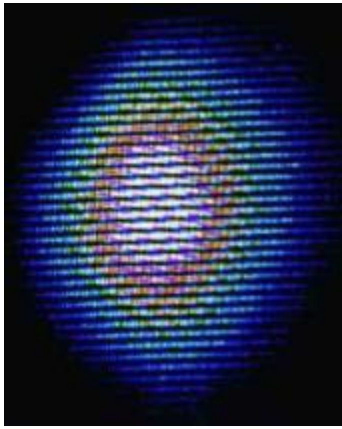
Necessity to compensate chromaticity is a major driving factor of FF design

Terms x^2 are geometric aberrations and need to be compensated also

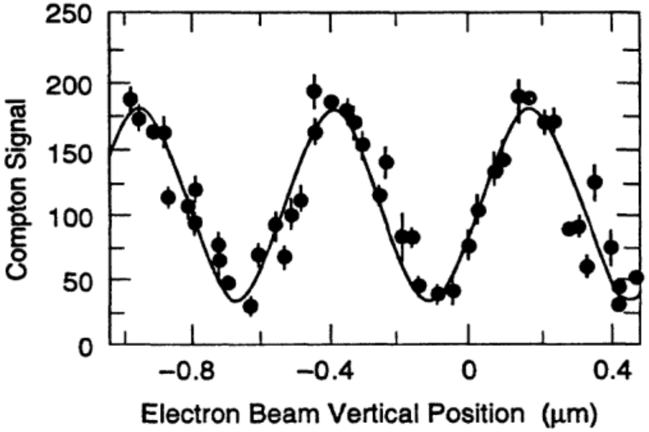
Final Focus Test Beam



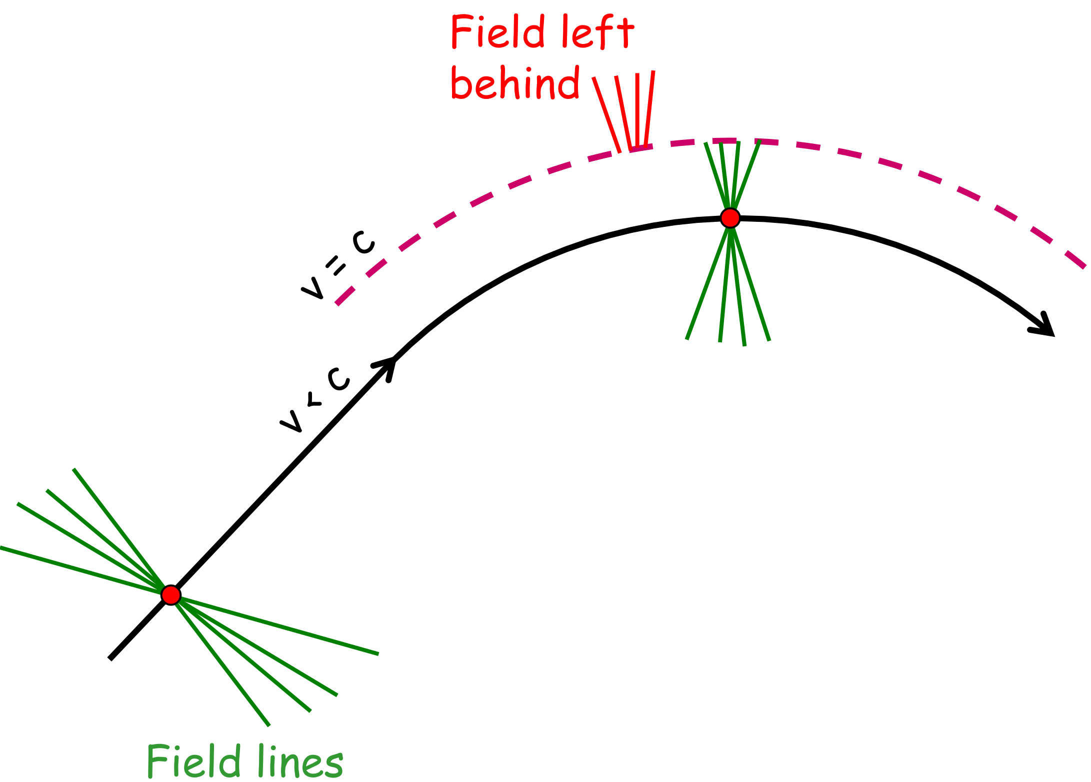




Achieved ~70nm vertical beam size



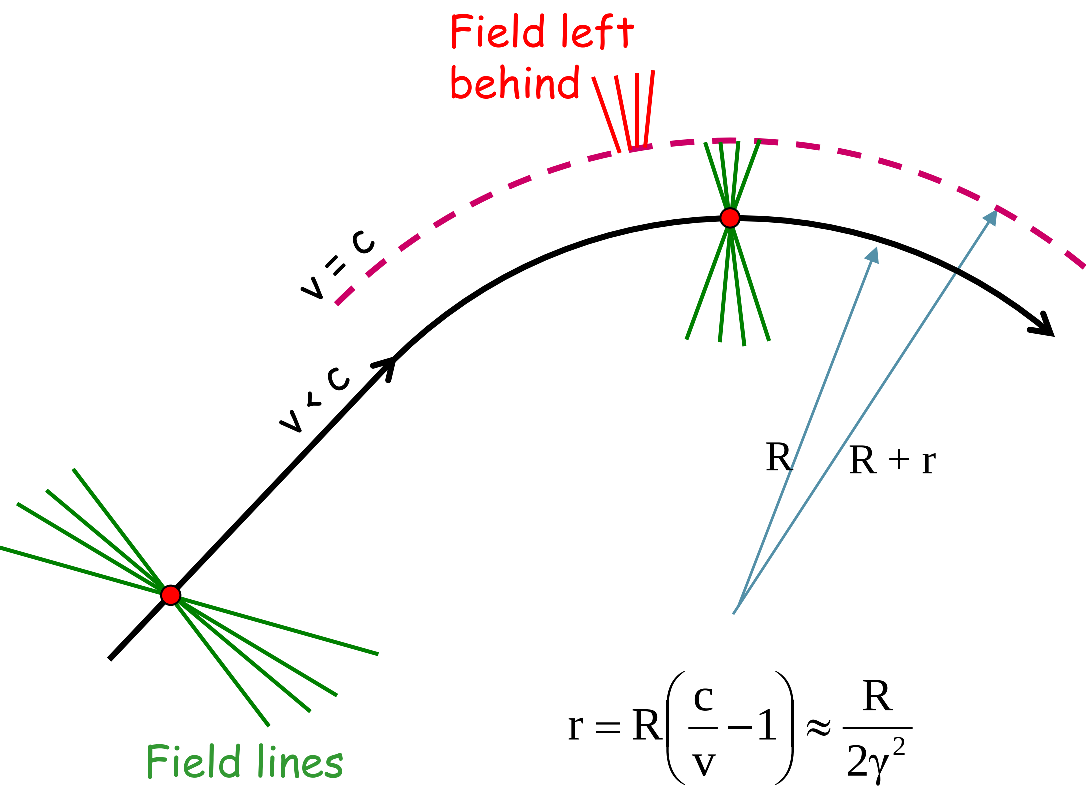
Synchrotron Radiation in FF magnets



- Bends are needed for compensation of chromaticity
- SR causes increase of energy spread which may perturb compensation of chromaticity
- Bends need to be long and weak, especially at high energy
- SR in FD quads is also harmful (Oide effect) and may limit the achievable beam size

Energy spread caused by SR in bends and quads is also a major driving factor of FF design

Let's estimate SR power



$$r = R\left(\frac{c}{v} - 1\right) \approx \frac{R}{2\gamma^2}$$

Energy in the field left behind (radiated !):

$$W \approx \int E^2\, dV$$

The field $E \approx \dfrac{e}{r^2}$ the volume $V \approx r^2\, dS$

Energy loss per unit length:

$$\frac{dW}{dS} \approx E^2 r^2 \approx \left(\frac{e}{r^2}\right)^2 r^2$$

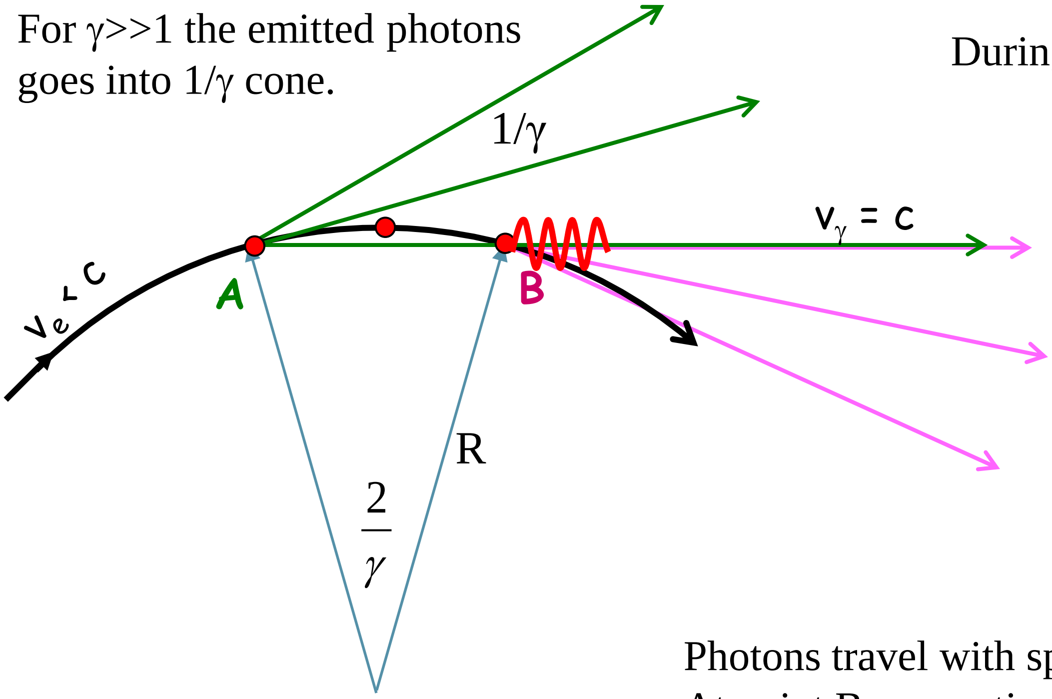
Substitute $r \approx \dfrac{R}{2\gamma^2}$ and get an estimate:

$$\boxed{\frac{dW}{dS} \approx \frac{e^2\gamma^4}{R^2}}$$

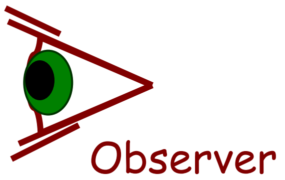
Compare with exact formula: $\dfrac{dW}{dS} = \dfrac{2}{3}\dfrac{e^2\gamma^4}{R^2}$

Let's estimate typical frequency of SR photons

For $\gamma >> 1$ the emitted photons goes into $1/\gamma$ cone.



During what time Δt the observer will see the photons?



Photons emitted during travel along the $2R/\gamma$ arc will be observed.

Photons travel with speed c, while particles with v.
At point B, separation between photons and particles is

$$dS \approx \frac{2R}{\gamma}\left(1 - \frac{v}{c}\right)$$

Therefore, observer will see photons during $\Delta t \approx \frac{dS}{c} \approx \frac{2R}{c\gamma}(1-\beta) \approx \frac{R}{c\gamma^3}$

Estimation of characteristic frequency $\boxed{\omega_c \approx \frac{1}{\Delta t} \approx \frac{c\gamma^3}{R}}$

Compare with exact formula: $\omega_c = \frac{3}{2}\frac{c\gamma^3}{R}$

Let's estimate energy spread growth due to SR

We estimated the rate of energy loss : $\frac{dW}{dS} \approx \frac{e^2 \gamma^4}{R^2}$

And the characteristic frequency $\omega_c \approx \frac{c\gamma^3}{R}$

The photon energy $\varepsilon_c = \hbar\omega_c \approx \frac{\gamma^3 \hbar c}{R} = \frac{\gamma^3}{R} \lambda_e mc^2$

where $r_e = \frac{e^2}{mc^2}$ $\alpha = \frac{e^2}{\hbar c}$ $\lambda_e = \frac{r_e}{\alpha}$

Number of photons emitted per unit length $\frac{dN}{dS} \approx \frac{1}{\varepsilon_c} \frac{dW}{dS} \approx \frac{\alpha\gamma}{R}$

(per angle θ : $N \approx \alpha\gamma\theta$)

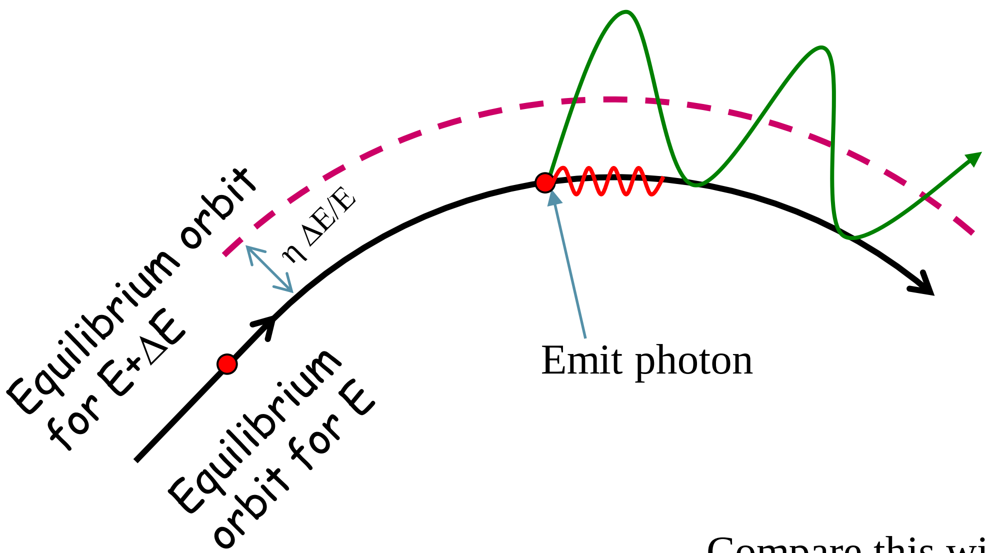
The energy spread $\Delta E/E$ will grow due to statistical fluctuations ($\sqrt{N}$) of the number of emitted photons :

$$\frac{d\left((\Delta E/E)^2\right)}{dS} \approx \varepsilon_c^2 \frac{dN}{dS} \frac{1}{(\gamma mc^2)^2}$$

Which gives: $\boxed{\frac{d\left((\Delta E/E)^2\right)}{dS} \approx \frac{r_e \lambda_e \gamma^5}{R^3}}$

Compare with exact formula: $\frac{d\left((\Delta E/E)^2\right)}{dS} = \frac{55}{24\sqrt{3}} \frac{r_e \lambda_e \gamma^5}{R^3}$

Let's estimate emittance growth rate due to SR



Dispersion function η shows how equilibrium orbit shifts when energy changes

When a photon is emitted, the particle starts to oscillate around new equilibrium orbit

Amplitude of oscillation is $\Delta x \approx \eta\, \Delta E/E$

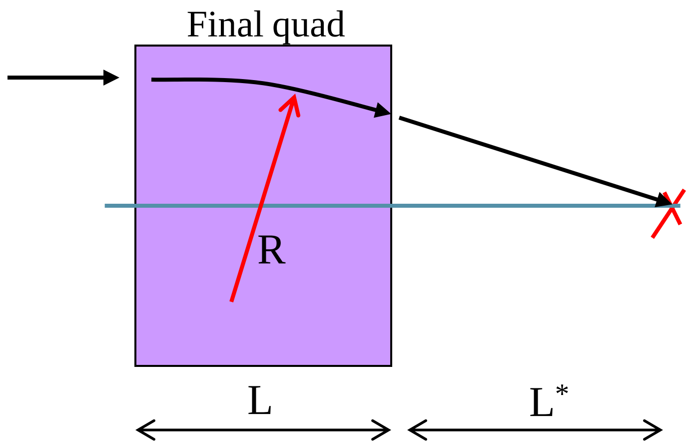
Compare this with betatron beam size: $\sigma_x = (\varepsilon_x\, \beta_x)^{1/2}$

And write emittance growth: $\Delta\varepsilon_x \approx \frac{\Delta x^2}{\beta}$

Resulting estimation for emittance growth: $$\frac{d\varepsilon_x}{dS} \approx \frac{\eta^2}{\beta_x} \frac{d\left((\Delta E/E)^2\right)}{dS} \approx \boxed{\frac{\eta^2}{\beta_x} \frac{r_e\, \lambda_e\, \gamma^5}{R^3}}$$

Compare with exact formula (which also takes into account the derivatives): $$\frac{d\varepsilon_x}{dS} = \underbrace{\boxed{\frac{\left(\eta^2 + (\beta_x \eta' - \beta_x' \eta/2)^2\right)}{\beta_x}}}_{=\mathcal{H}} \frac{55}{24\sqrt{3}} \frac{r_e\, \lambda_e\, \gamma^5}{R^3}$$

Let's apply SR formulae to estimate Oide effect (SR in FD)



IP divergence:

$$\theta^* = \sqrt{\varepsilon/\beta^*}$$

IP size:

$$\sigma^* = \sqrt{\varepsilon\beta^*}$$

Energy spread obtained in the quad:

$$\left(\frac{\Delta E}{E}\right)^2 \approx \frac{r_e \lambda_e \gamma^5 L}{R^3}$$

Radius of curvature of the trajectory: $R = L/\theta^*$

Growth of the IP beam size: $\sigma^2 \approx \sigma_0^2 + \left(L^* \theta^*\right)^2 \left(\frac{\Delta E}{E}\right)^2$

Which gives $\sigma^2 \approx \varepsilon\beta^* + C_1 \left(\frac{L^*}{L}\right)^2 r_e \lambda_e \gamma^5 \left(\frac{\varepsilon}{\beta^*}\right)^{5/2}$ (where C_1 is ~ 7 (depend on FD params.))

This achieve minimum possible value:

$$\sigma_{min} \approx 1.35\, C_1^{1/7} \left(\frac{L^*}{L}\right)^{2/7} \left(r_e \lambda_e\right)^{1/7} \left(\gamma\varepsilon\right)^{5/7}$$

When beta* is:

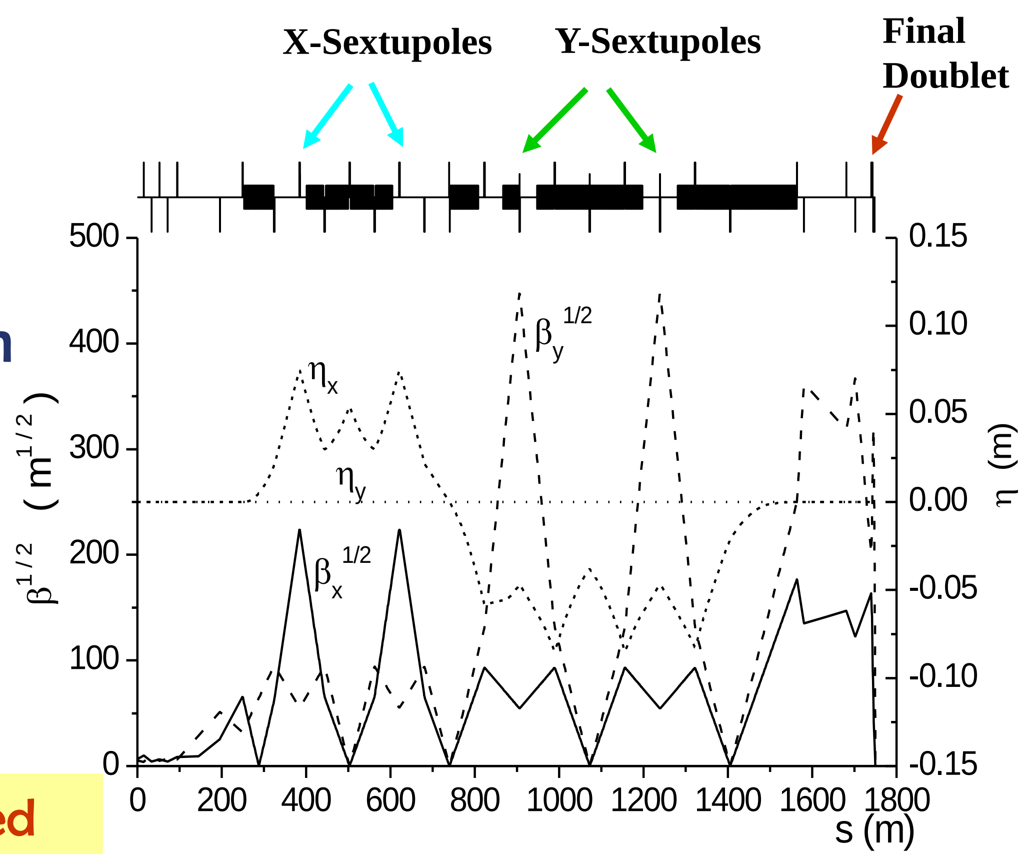
$$\beta_{optimal} \approx 1.29\, C_1^{2/7} \left(\frac{L^*}{L}\right)^{4/7} \left(r_e \lambda_e\right)^{2/7} \gamma \left(\gamma\varepsilon\right)^{3/7}$$

Note that beam distribution at IP will be non-Gaussian. Usually need to use tracking to estimate impact on luminosity. Note also that optimal β may be smaller than the σ_z (i.e cannot be used).

FF with non-local chromaticity compensation

- Chromaticity is compensated by sextupoles in dedicated sections
- Geometrical aberrations are canceled by using sextupoles in pairs with M= -I

Chromaticity arise at FD but pre-compensated 1000m upstream

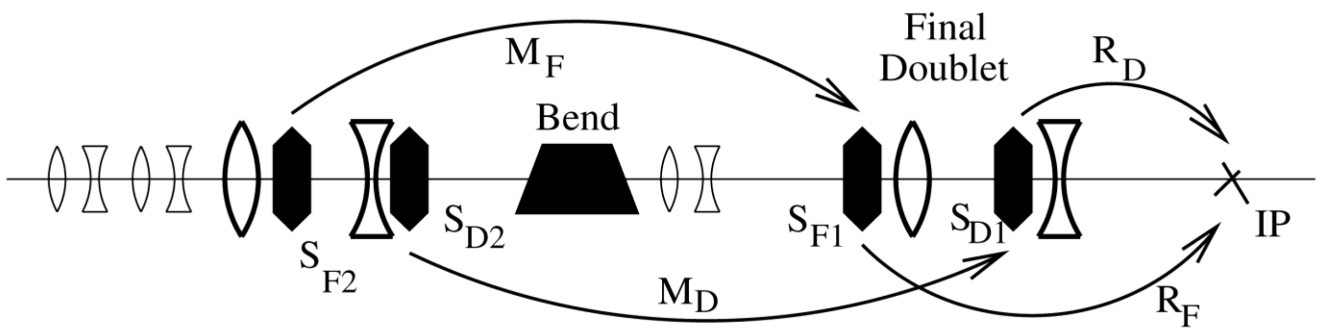


Traditional FF

Problems:

- Chromaticity not locally compensated
  - Compensation of aberrations is not ideal since $M \neq -I$ for off energy particles
  - Large aberrations for beam tails
  - ...

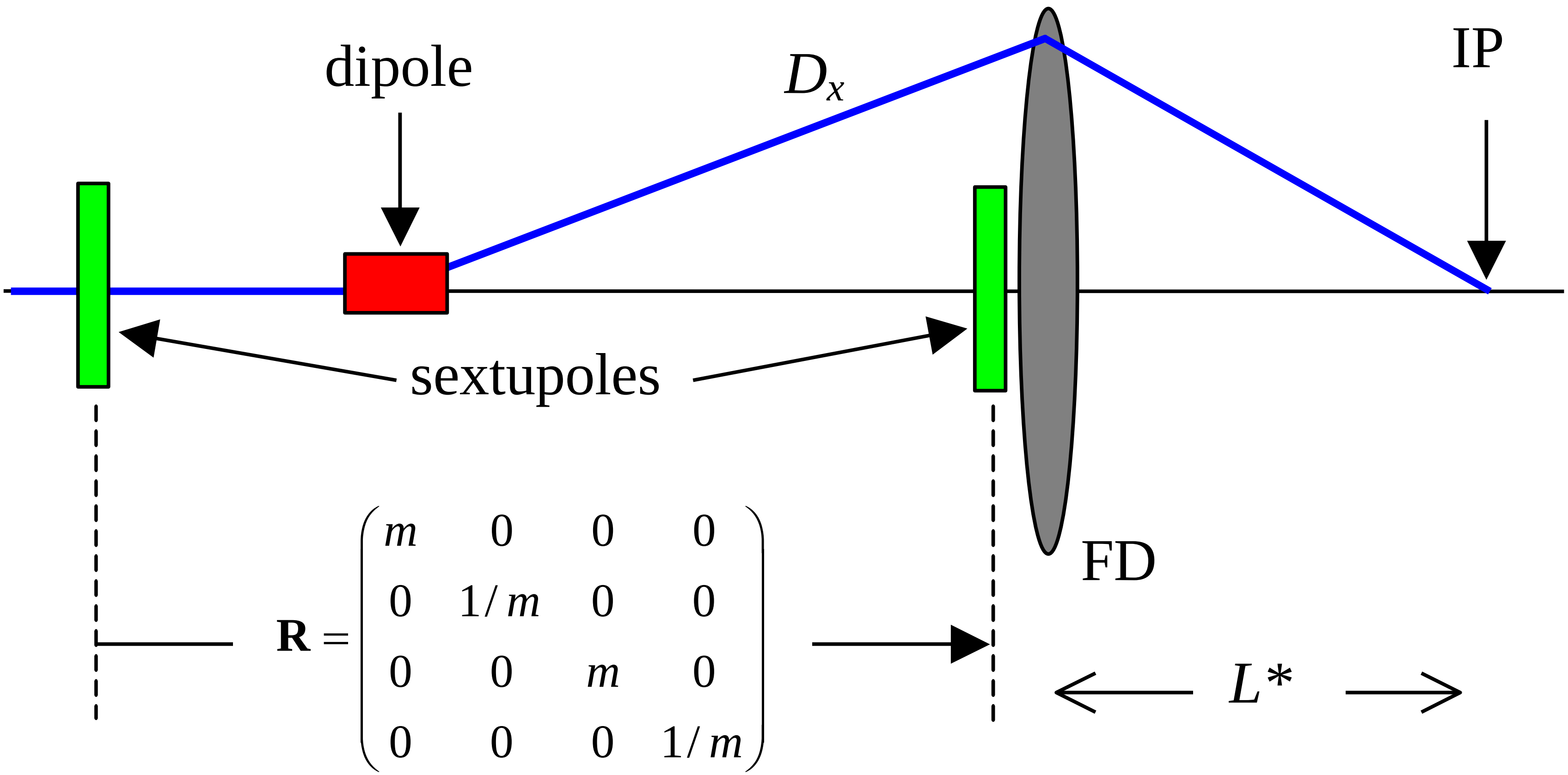
FF with local chromatic correction



- Chromaticity is cancelled locally by two sextupoles interleaved with FD, a bend upstream generates dispersion across FD

- Geometric aberrations of the FD sextupoles are cancelled by two more sextupoles placed in phase with them and upstream of the bend

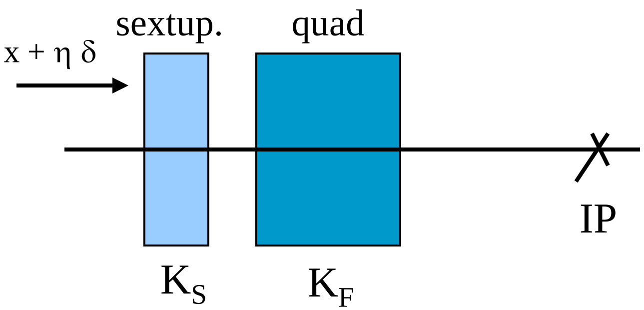
Local chromatic correction



$$\mathbf{R} = \begin{pmatrix} m & 0 & 0 & 0 \\ 0 & 1/m & 0 & 0 \\ 0 & 0 & m & 0 \\ 0 & 0 & 0 & 1/m \end{pmatrix}$$

- The value of dispersion in FD is usually chosen so that it does not increase the beam size in FD by more than 10-20% for typical beam energy spread

Chromatic correction in FD



- Straightforward in Y plane
- a bit tricky in X plane:

Quad: $$\Delta x' = \frac{K_F}{(1+\delta)}(x+\eta\delta) \Rightarrow K_F(-\delta x - \eta\delta^2)$$

chromaticity

Second order dispersion

Sextupole: $$\Delta x' = \frac{K_S}{2}(x+\eta\delta)^2 \Rightarrow K_S\eta(\delta x + \frac{\eta\delta^2}{2})$$

If we require $K_S\eta = K_F$ to cancel FD chromaticity, then half of the **second order dispersion** remains.

$$\Delta x' = \frac{K_F}{(1+\delta)}(x+\eta\delta) + \frac{K_{\beta\text{-match}}}{(1+\delta)}x \Rightarrow 2K_F(-\delta x - \frac{\eta\delta^2}{2})$$

$$K_{\beta\text{-match}} = K_F \qquad K_S = \frac{2K_F}{\eta}$$

Solution:
The β-matching section produces as much X chromaticity as the FD, so the X sextupoles run twice stronger and cancel the **second order dispersion** as well.

Definitions of chromaticity
1st : TRANSPORT

Storage Rings: chromaticity defined as a change of the betatron tunes versus energy.

In single path beamlines, it is more convenient to use other definitions.

$$x_i = \begin{pmatrix} x \\ x' \\ y \\ y' \\ \Delta l \\ \delta \end{pmatrix} \qquad x_i^{out} = R_{ij} \; x_j^{in}$$

The second, third, and so on terms are included in a similar manner:

$$x_i^{out} = R_{ij} \; x_j^{in} + T_{ijk} \, x_j^{in} \, x_k^{in} + U_{ijkn} \, x_j^{in} \, x_k^{in} \, x_n^{in} + \ldots$$

In FF design, we usually call 'chromaticity' the second order elements T_{126} and T_{346}. All other high order terms are just 'aberrations', purely chromatic (as T_{166}, which is second order dispersion), or chromo-geometric (as U_{32446}).

Definitions of chromaticity

2^{nd} : W functions

Lets assume that betatron motion without energy offset is described by twiss functions $\boldsymbol{\alpha_1}$ and $\boldsymbol{\beta_1}$ and with energy offset $\boldsymbol{\delta}$ by functions $\boldsymbol{\alpha_2}$ and $\boldsymbol{\beta_2}$

Let's define chromatic function **W** (for each plane) as $W = \left(i\,A + B\right)/\,2$ where $i = \sqrt{-1}$

And where: $B = \frac{\beta_2 - \beta_1}{\delta\,(\beta_2 \cdot \beta_1)^{1/2}} \approx \frac{\Delta\beta}{\delta\;\beta}$ and $A = \frac{\alpha_2\beta_1 - \alpha_1\beta_2}{\delta\,(\beta_2 \cdot \beta_1)^{1/2}} \approx \frac{\Delta\alpha}{\delta} - \frac{\alpha}{\beta}\frac{\Delta\beta}{\delta}$

Using familiar formulae $\frac{d\beta}{ds} = -2\alpha$ and $\frac{d\alpha}{ds} = K \cdot \beta - \frac{\left(1+\alpha^2\right)}{\beta}$ where $K = \frac{e}{pc}\frac{dB_y}{dx}$

And introducing $\Delta K = \frac{K(\delta(- K(0)}{\delta} \approx -K$ we obtain the equation for **W** evolution:

Can you show this?

$$\frac{dW}{ds} = \frac{2i}{\beta} W + \frac{i}{2}\beta\,\Delta K$$

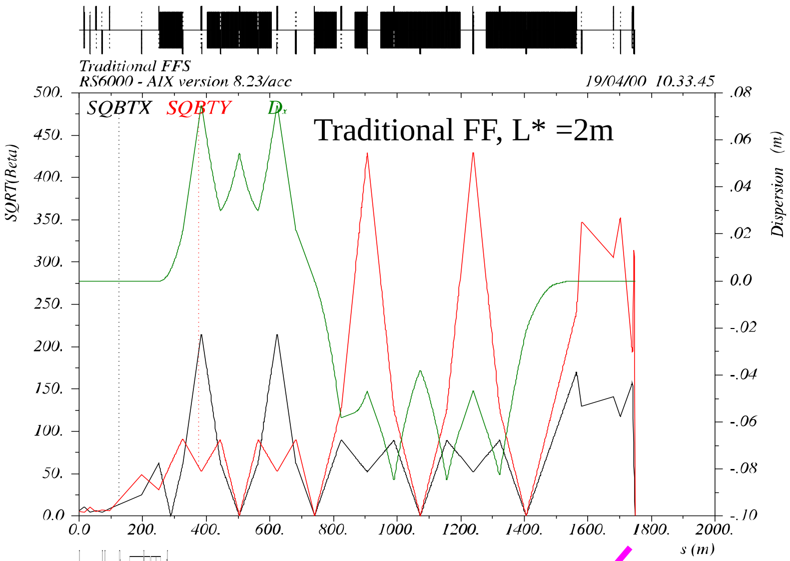
knowing that the betatron phase is $\frac{d\Phi}{ds} = \frac{1}{\beta}$

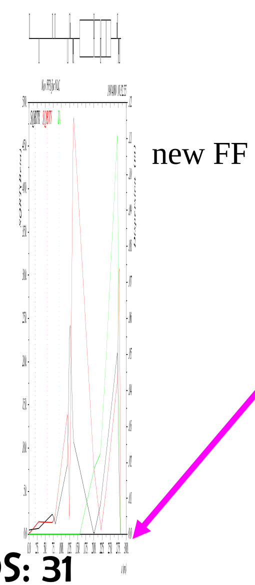
can see that if **ΔK**=0, then **W** rotates with double betatron frequency and stays constant in amplitude. In quadrupoles or sextupoles, only imaginary part changes.

Show that if in a final defocusing lens α=0, then it gives $\Delta W = L^*/(2\beta^*)$

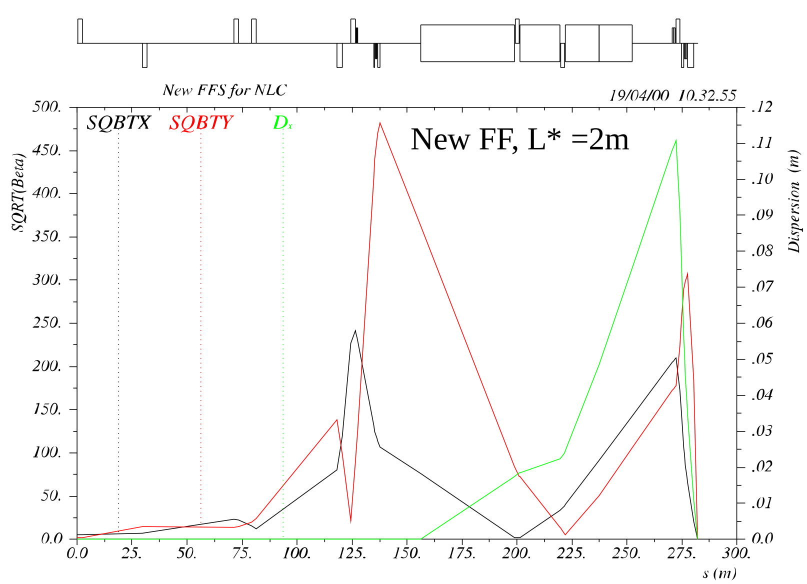
Show that if T_{346} is zeroed at the IP, the W_y is also zero. Use approximation $\Delta R_{34} = T_{346}{}^*\delta$, use $R_{34} = (\beta\beta_0)^{1/2} \sin(\Delta\Phi)$, and the twiss equation for $d\alpha/d\Phi$.

Compare FF designs

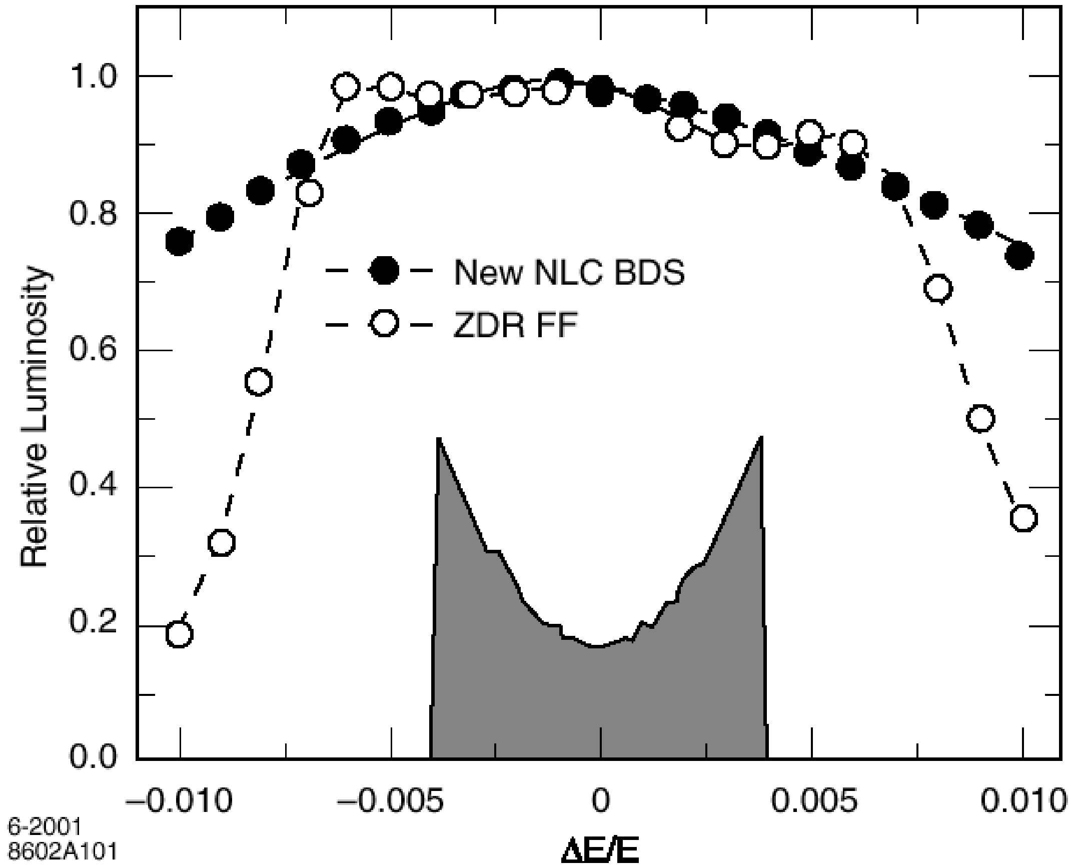




FF with local chromaticity compensation with the same performance can be ~300m long, i.e. 6 times shorter



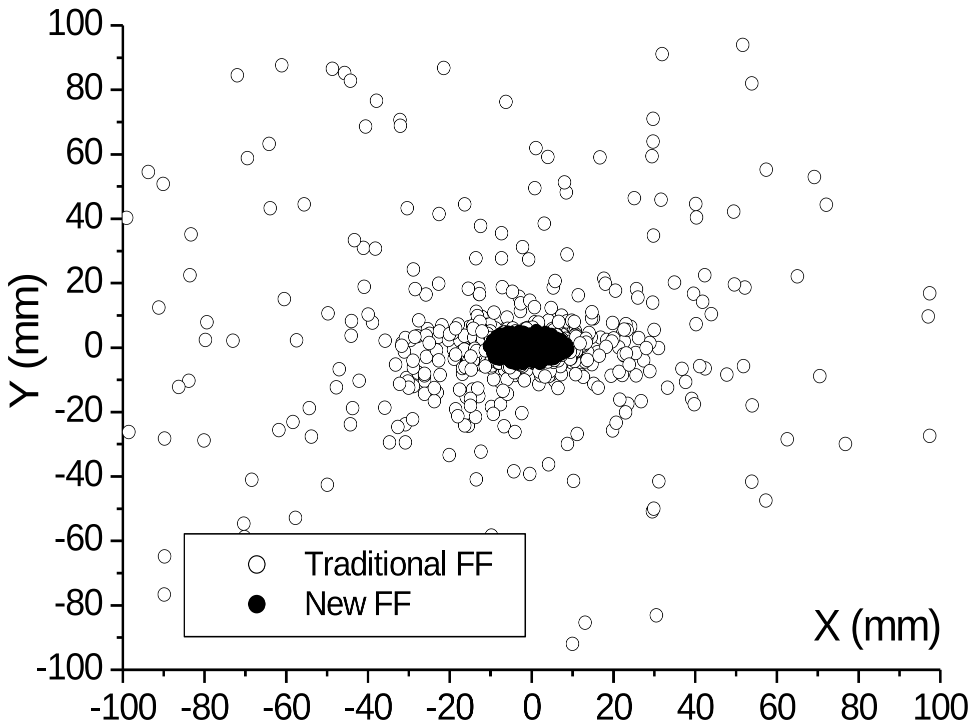
IP bandwidth



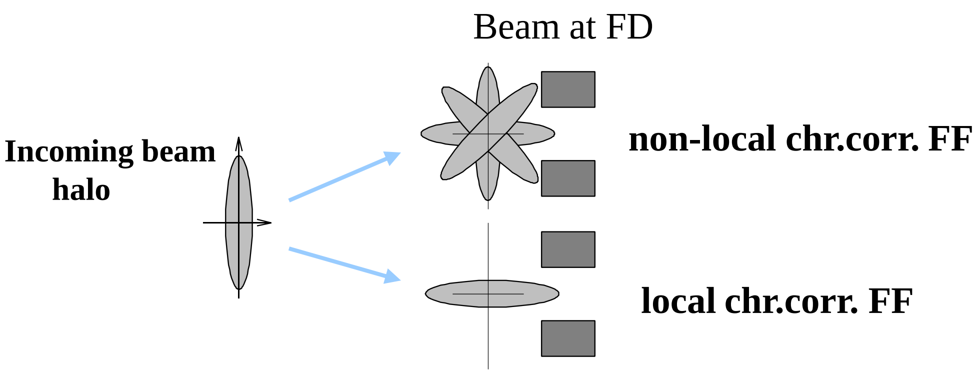
Bandwidth of FF with local chromaticity correction can be better than for system with non-local correction

Aberrations & halo generation in FF

- FF with non-local chr. corr. generate beam tails due to aberrations and it does not preserve betatron phase of halo particles
- FF with local chr. corr. has much less aberrations and it does not mix phases particles

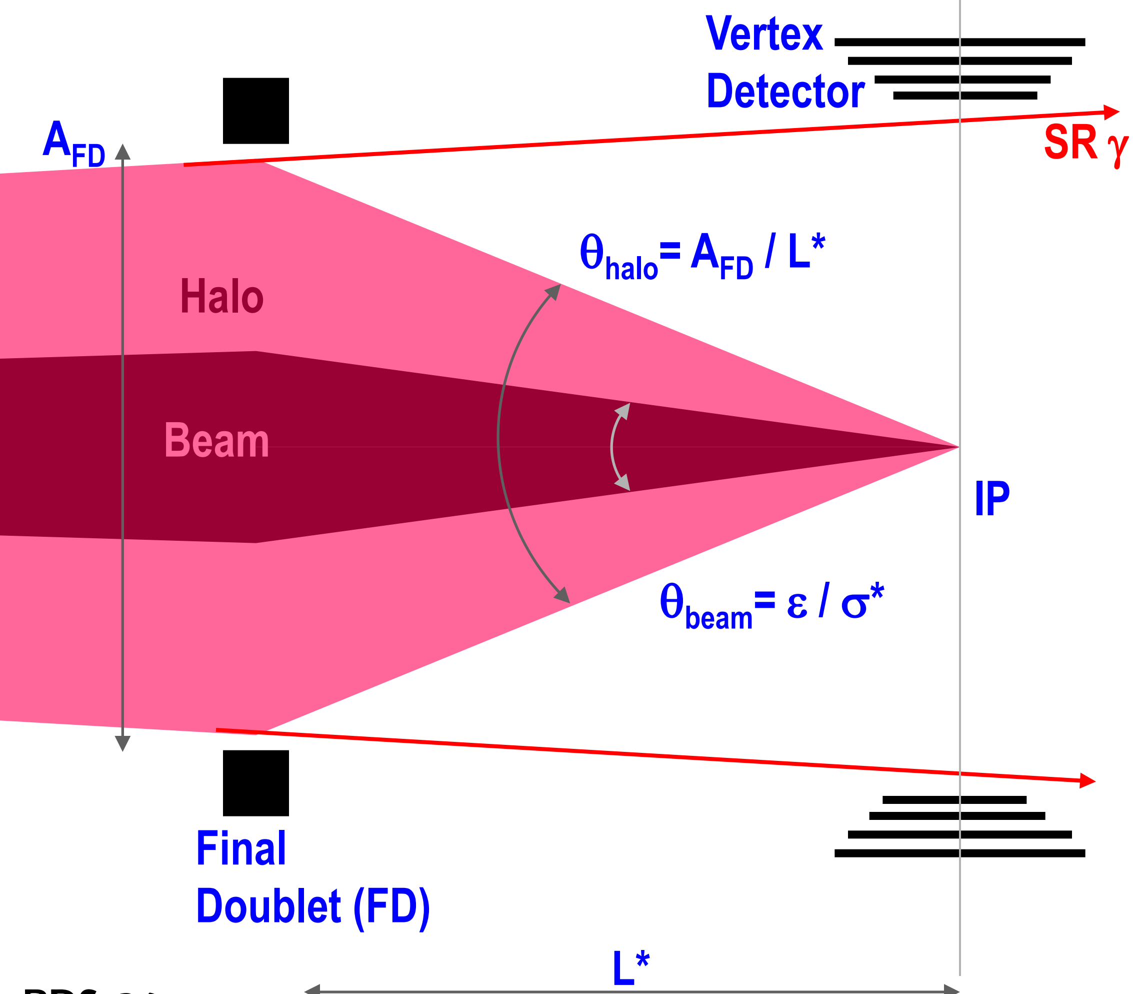


Halo beam at the FD entrance. Incoming beam is ~ 100 times larger than nominal beam



Beam halo & collimation

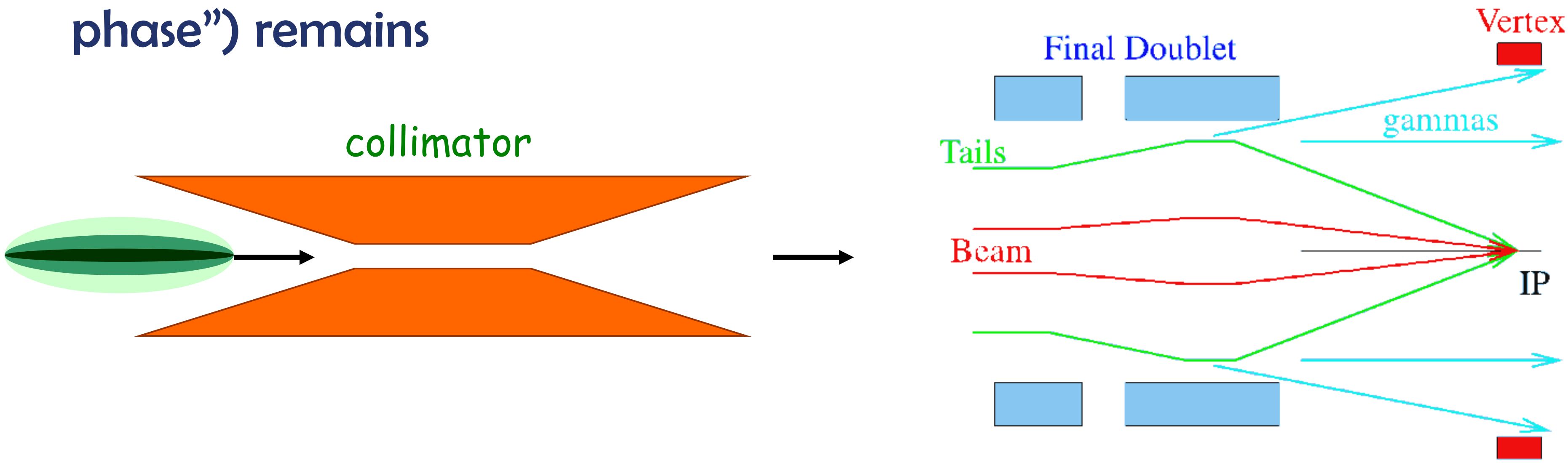
- Even if final focus does not generate beam halo itself, the halo may come from upstream and need to be collimated



- Halo must be collimated upstream in such a way that SR γ & halo e^{+-} do not touch VX and FD
- => VX aperture needs to be somewhat larger than FD aperture
- Exit aperture is larger than FD or VX aperture
- Beam convergence depend on parameters, the halo convergence is fixed for given geometry
  => $\theta_{halo}/\theta_{beam}$ (collimation depth) becomes tighter with larger L^* or smaller IP beam size
- Tighter collimation => MPS issues, collimation wake-fields, higher muon flux from collimators, etc.

More details on collimation

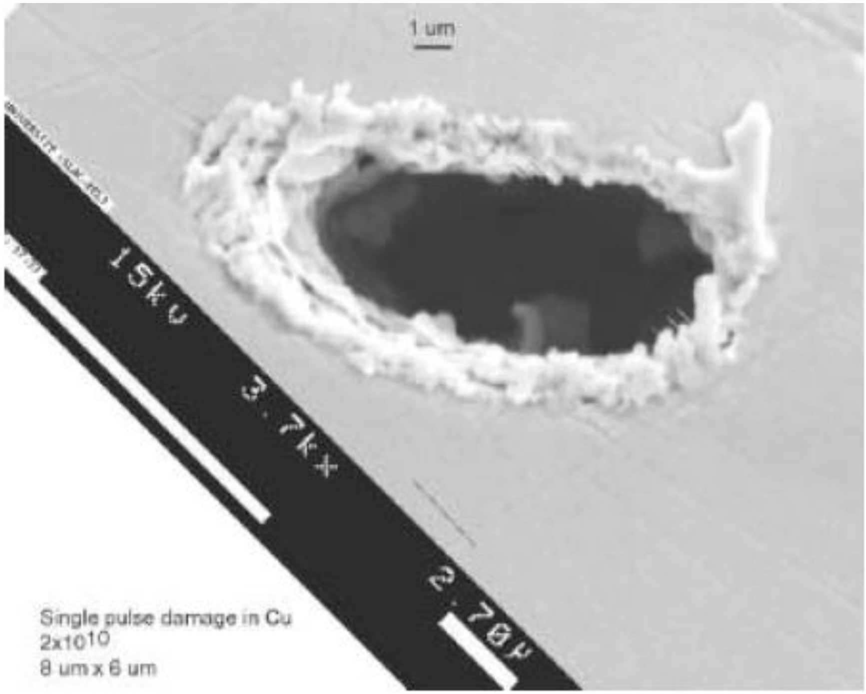
- Collimators has to be placed far from IP, to minimize background
- Ratio of beam/halo size at FD and collimator (placed in “FD phase”) remains



- Collimation depth (esp. in x) can be only ~10 or even less
- It is not unlikely that not only halo (1e-3 – 1e-6 of the beam) but full errant bunch(s) would hit the collimator

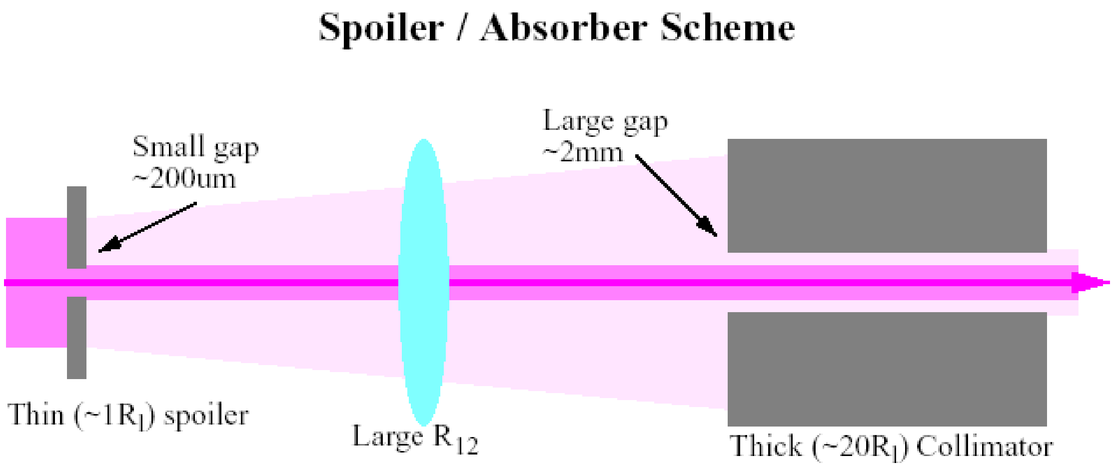
MPS and collimation design

- The beam is very small => single bunch can punch a hole => the need for MPS (machine protection system)
- Damage may be due to
  - electromagnetic shower damage (need several radiation lengths to develop)
  - direct ionization loss (~1.5MeV/g/cm^2 for most materials)
- Mitigation of collimator damage
  - using spoiler-absorber pairs
    - thin (0.5-1 rl) spoiler followed by thick (~20rl) absorber
  - increase of beam size at spoilers
  - MPS divert the beam to emergency extraction as soon as possible



Picture from beam damage experiment at FFTB. The beam was 30GeV, 3-20x10^9 e-, 1mm bunch length, s~45-200um^2. Test sample is Cu, 1.4mm thick. Damage was observed for densities > 7x10^{14}e-/cm^2. Picture is for 6x10^{15}e-/cm^2

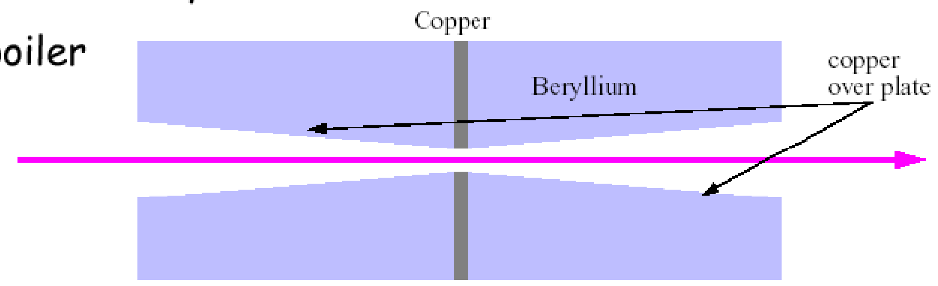
Spoiler-Absorber & spoiler design

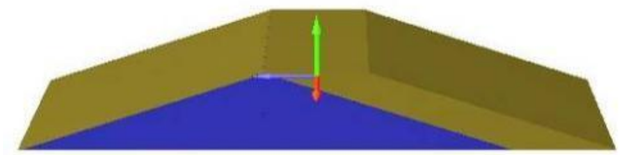


Thin spoiler increases beam divergence and size at the thick absorber already sufficiently large. Absorber is away from the beam and contributes much less to wakefields.

Tapered low resistivity surface for wakefields

Thin hi-Z spoiler





Recently considered design:
0.6 Xo of Ti alloy leading taper (gold), graphite (blue), 1 mm thick layer of Ti alloy

Need the spoiler thickness increase rapidly, but need that surface to increase gradually, to minimize wakefields. The radiation length for Cu is 1.4cm and for Be is 35cm. So, Be is invisible to beam in terms of losses. Thin one micron coating over Be provides smooth surface for wakes.

Spoiler damage

Spoiler material properties and temperature rise due to a single bunch of 1.25×10^{10} electrons within a beam spot with $\sigma_x = \sigma_y = 3.16$ μm.

	Be	C	Al	Ti	Cu	Fe
Radiation Length (cm)	35.7	21.7	9.0	3.7	1.4	1.8
dE/dx_{min} (MeV cm^{-1})	3.1	3.6	4.4	7.2	12.8	11.6
Specific Heat, C_p (J cm^{-3} °C^{-1})	3.3	1.9	2.5	2.4	3.5	3.8
Meltng Point, T_{melt} (°C)	1280	3600	660	1800	1080	1530
Stress Limit, T_{stress} (°C)	150	2500	140	770	180	135
Temperature Rise, ΔT (°C)	2350	4740	4403	7506	9150	7637
$\Delta T / T_{melt}$	1.8	1.3	6.7	4.2	8.5	5.0
$\Delta T / 4T_{stress}$	3.9	0.36	7.9	2.4	12.7	14.1

Temperature rise for thin spoilers (ignoring shower buildup and increase of specific heat with temperature):

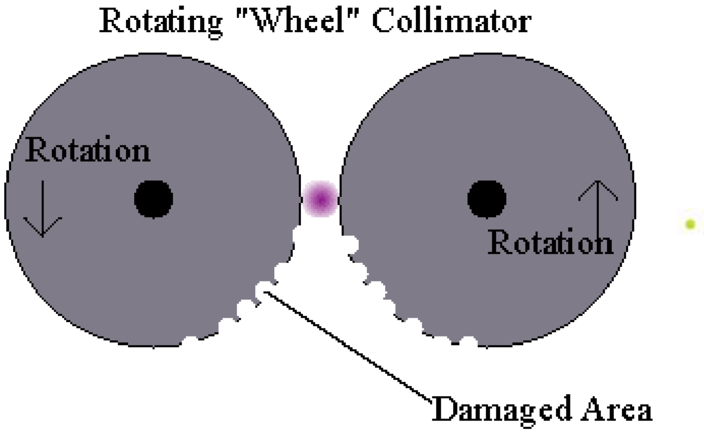
$$\Delta T = \frac{0.393 N}{\pi \sigma_x \sigma_y} \frac{dE/dx_{\min}}{C_p}$$

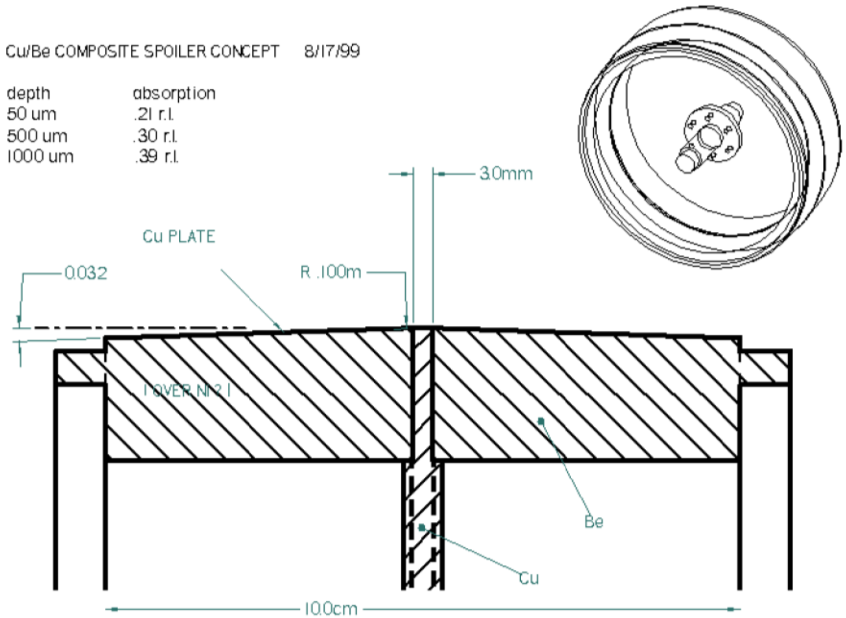
The stress limit based on tensile strength, modulus of elasticity and coefficient of thermal expansion. Sudden T rise create local stresses. When ΔT exceed stress limit, micro-fractures can develop. If ΔT exceeds $4T_{stress}$, the shock wave may cause material to delaminate. Thus, allowed ΔT is either the melting point or four time stress limit at which the material will fail catastrophically.

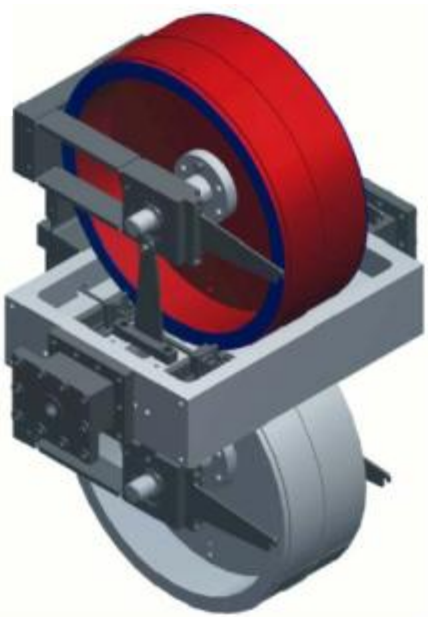
Survivable and consumable spoilers

- A critical parameter is number of bunches #N that MPS will let through to the spoiler before sending the rest of the train to emergency extraction
- If it is practical to increase the beam size at spoilers so that spoilers survive #N bunches, then they are survivable
- Otherwise, spoilers must be consumable or renewable

Renewable spoilers





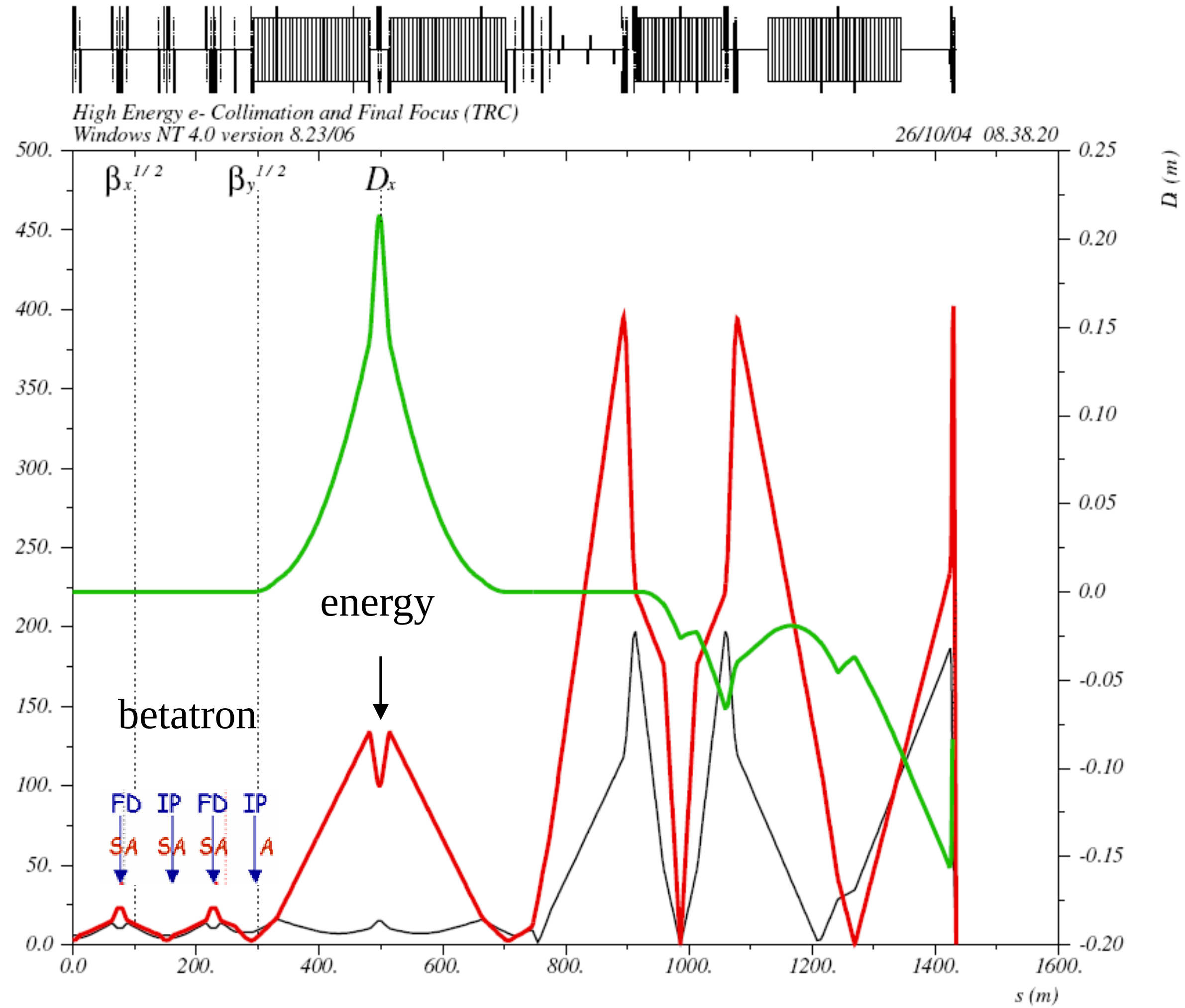


This design was essential for NLC, where short inter-bunch spacing made it impractical to use survivable spoilers.

This concept is now being applied to LHC collimator system.

BDS with renewable spoilers

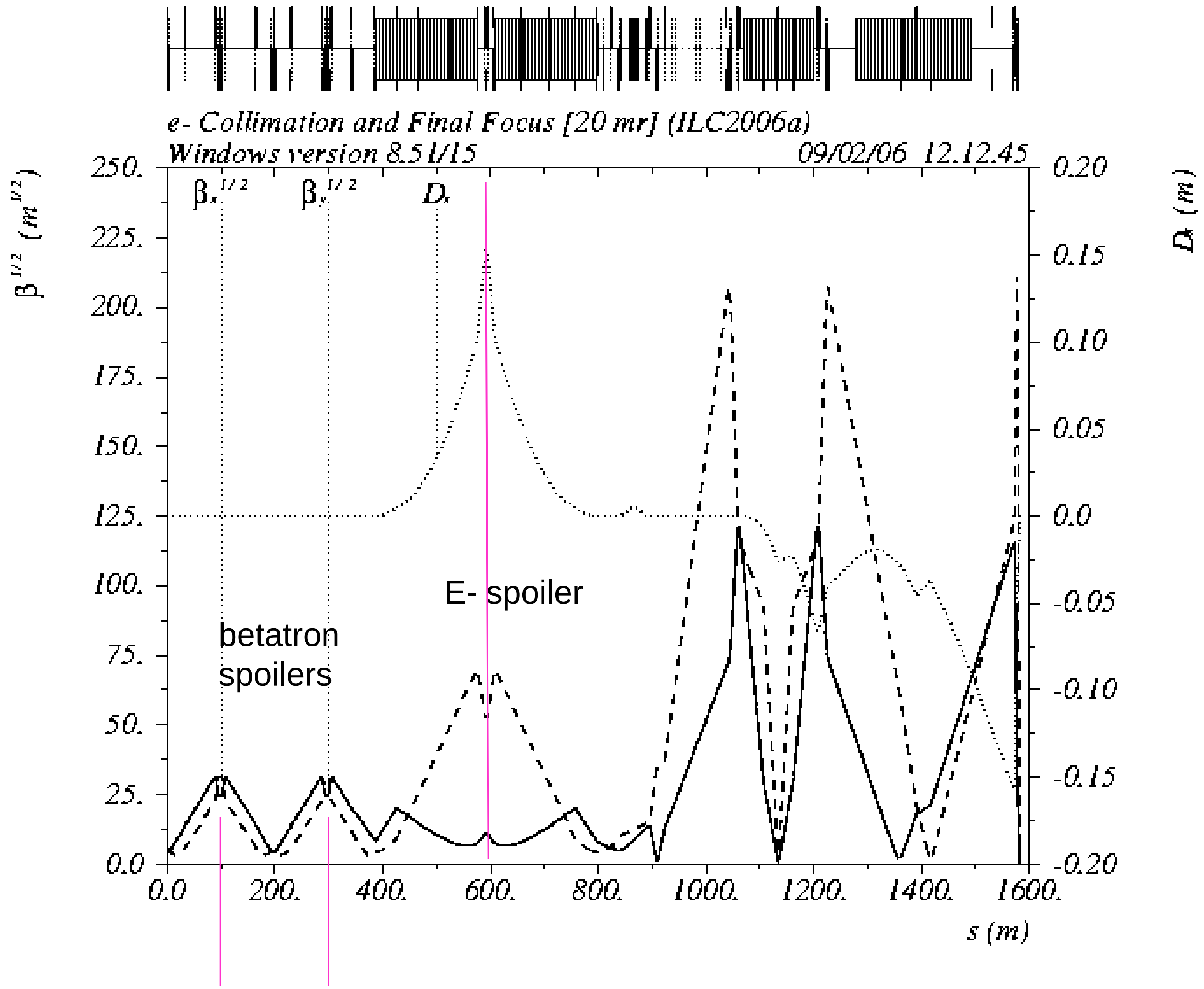
- Location of spoiler and absorbers is shown
- Collimators were placed both at FD betatron phase and at IP phase
- Two spoilers per FD and IP phase
- Energy collimator is placed in the region with large dispersion
- Secondary clean-up collimators located in FF part
- Tail folding octupoles (see below) are include

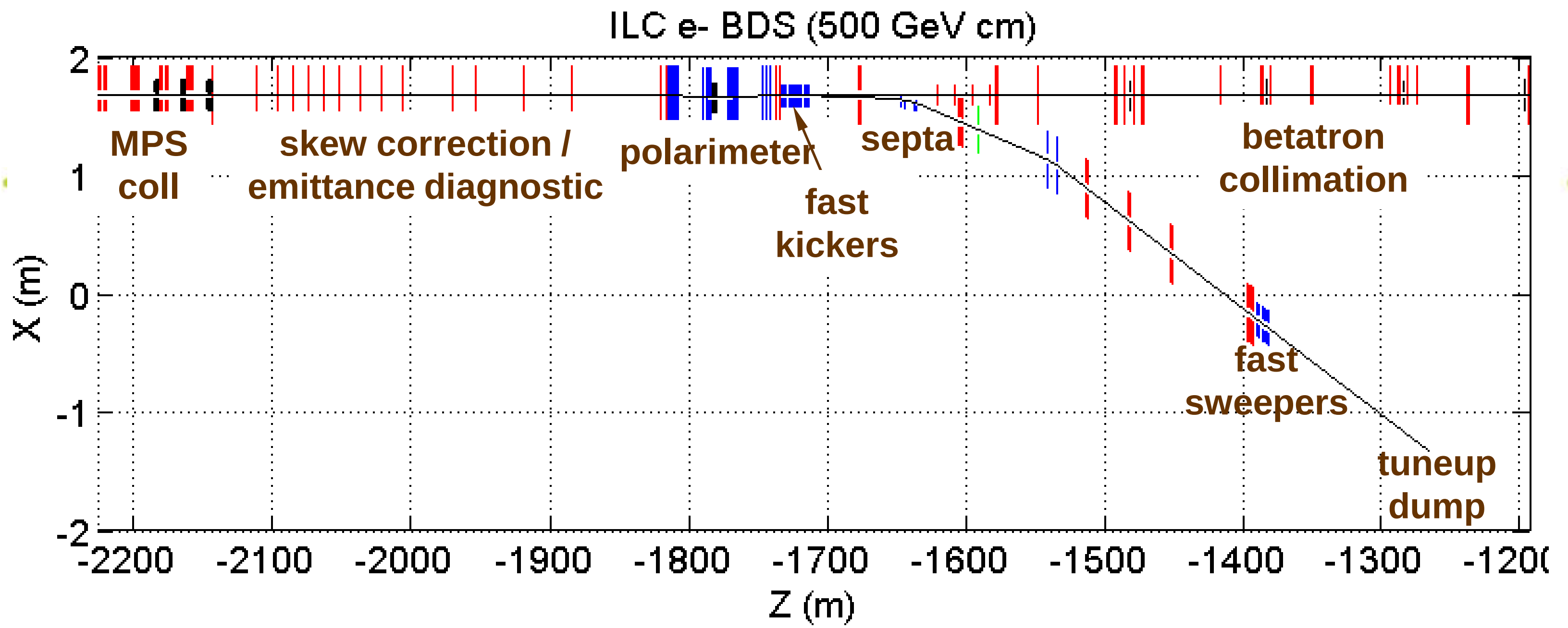


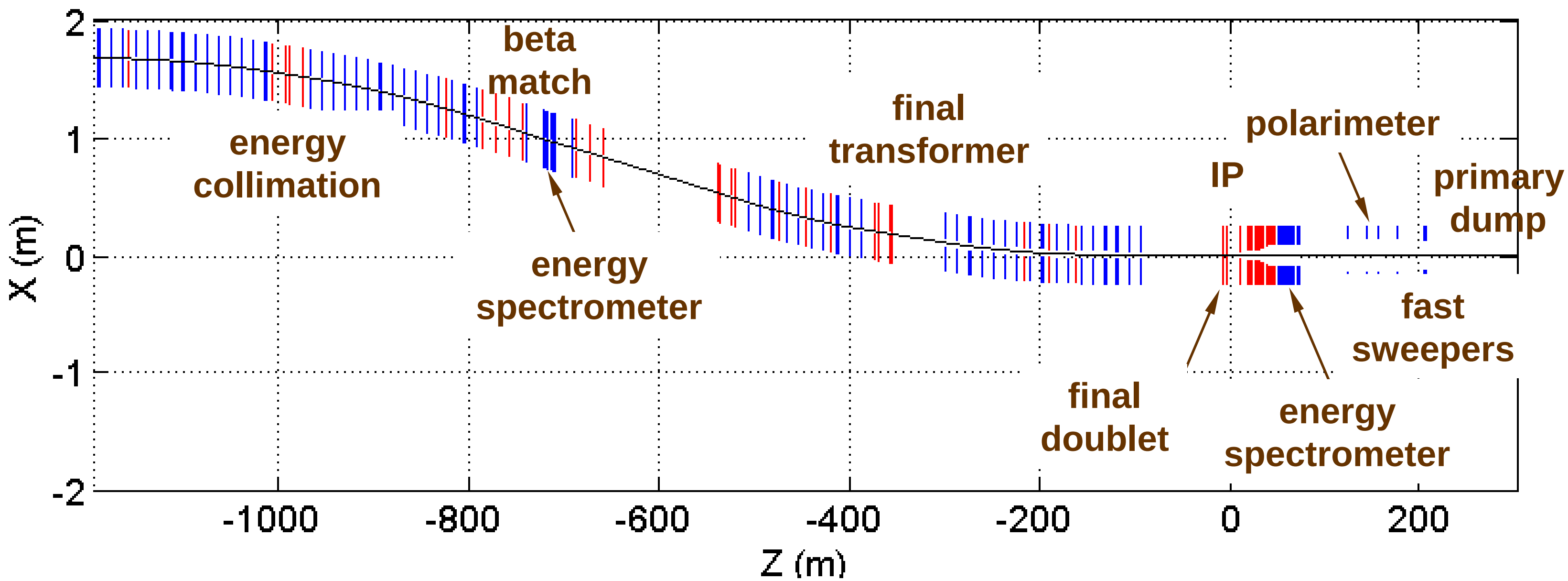
- Beam Delivery System Optics, an earlier version with consumable spoilers

ILC FF & Collimation

- Betatron spoilers survive up to two bunches
- E-spoiler survive several bunches
- One spoiler per FD or IP phase

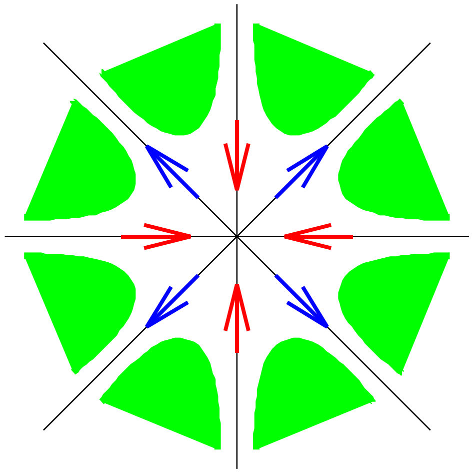



ILC e- BDS (500 GeV cm)
MPS coll
skew correction / emittance diagnostic
polarimeter
fast kickers
septa
betatron collimation
fast sweepers
tuneup dump
X (m)
Z (m)
2
1
0
-1
-2
-2200
-2100
-2000
-1900
-1800
-1700
-1600
-1500
-1400
-1300


beta match
energy collimation
energy spectrometer
final transformer
IP
polarimeter
primary dump
fast sweepers
final doublet
energy spectrometer
X (m)
Z (m)
2
1
0
-1
-2
-1000
-800
-600
-400
-200
0
200

Nonlinear handling of beam tails in ILC BDS

- **Can we ameliorate the incoming beam tails to relax the required collimation depth?**
- One wants to **focus beam tails** but not to change the core of the beam
  - use **nonlinear** elements
- **Several** nonlinear elements needs to be **combined** to provide **focusing in all directions**
  - (analogy with **strong focusing by FODO**)
- **Octupole Doublets (OD)** can be used for **nonlinear tail folding** in ILC FF



Single octupole focus in planes and defocus on diagonals.

An octupole doublet can focus in all directions !

Strong focusing by octupoles

- **Two octupoles** of different sign separated by **drift** provide **focusing in all directions for parallel beams**

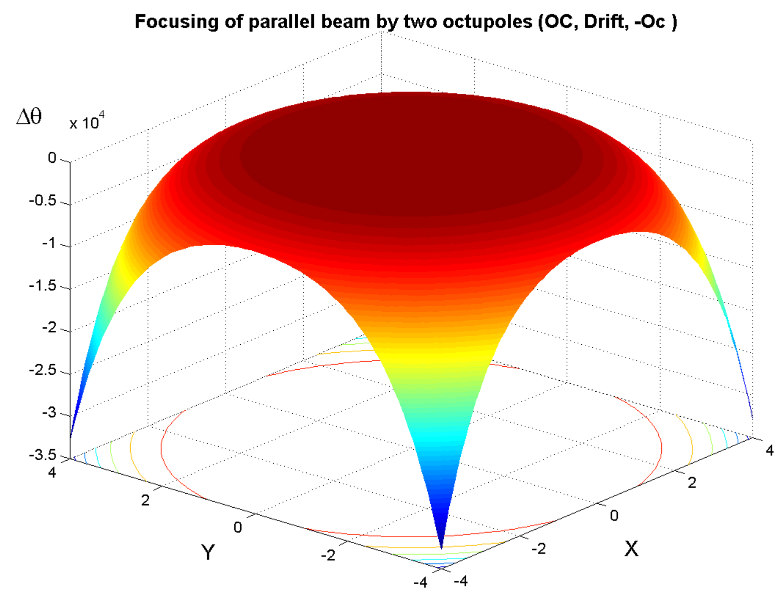
$$\Delta\theta = \alpha\, r^3 e^{-i3\varphi} - \left(\alpha\, r^3 e^{i3\varphi}\left(1+\alpha\, r^2 L\, e^{-i4\varphi}\right)^3\right)^*$$

$$x + iy = re^{i\varphi}$$

$$\Delta\theta \approx -3\alpha^2\, r^5 e^{i\varphi} - 3\alpha^3\, r^7 L^2 e^{i5\varphi}$$

Focusing in
<u>all directions</u>

Next nonlinear term focusing – defocusing depends on φ

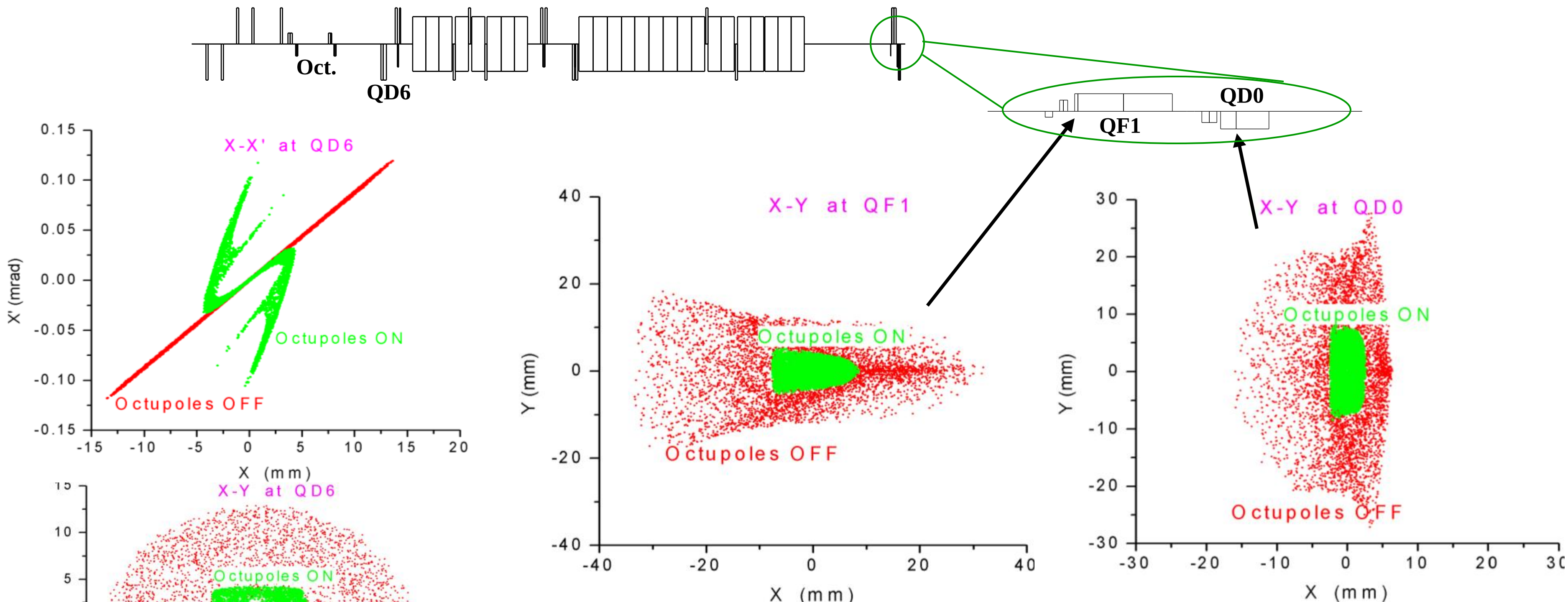


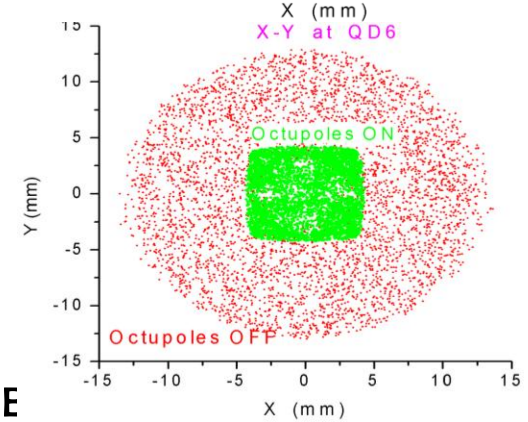
Effect of octupole doublet (Oc,Drift,-Oc) on parallel beam, ΔΘ(x,y).

- For this to work, the beam should have **small angles**, i.e. it should be parallel or **diverging**

Tail folding in ILC FF

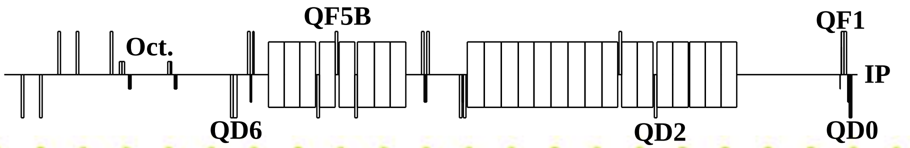
- **Two octupole doublets give tail folding by ~ 4 times in terms of beam size in FD**
- **This can lead to relaxing collimation requirements by ~ a factor of 4**

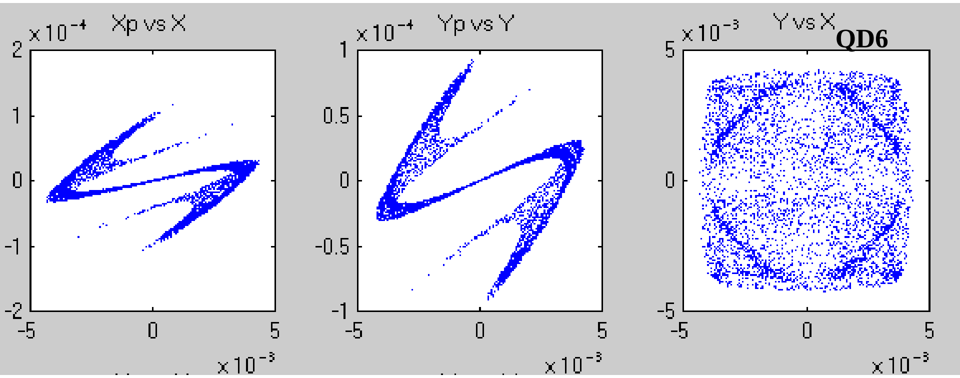


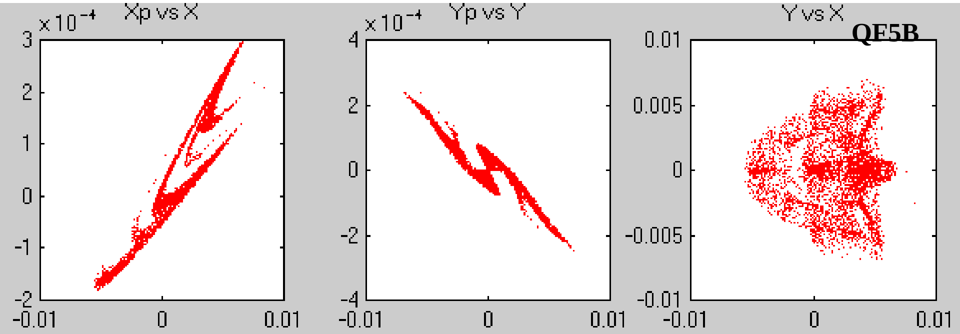


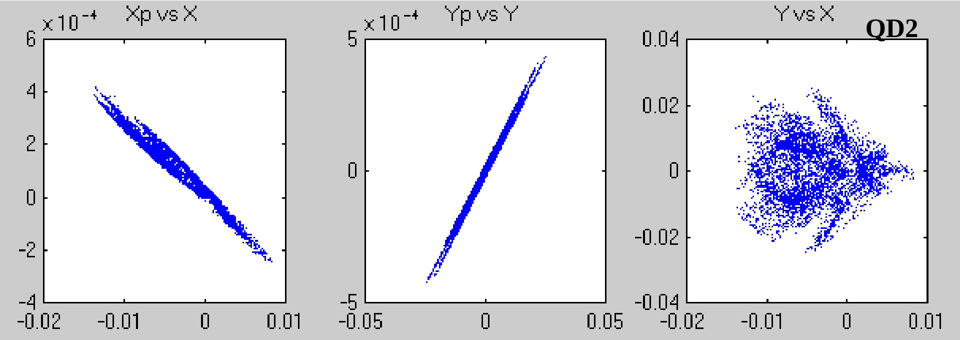
Tail folding by means of two octupole doublets in the ILC final focus
Input beam has (x,x',y,y') = (14µm,1.2mrad,0.63µm,5.2mrad) in IP units (flat distribution, half width) and ±2% energy spread, that corresponds approximately to N_σ=(65,65,230,230) sigmas with respect to the nominal beam

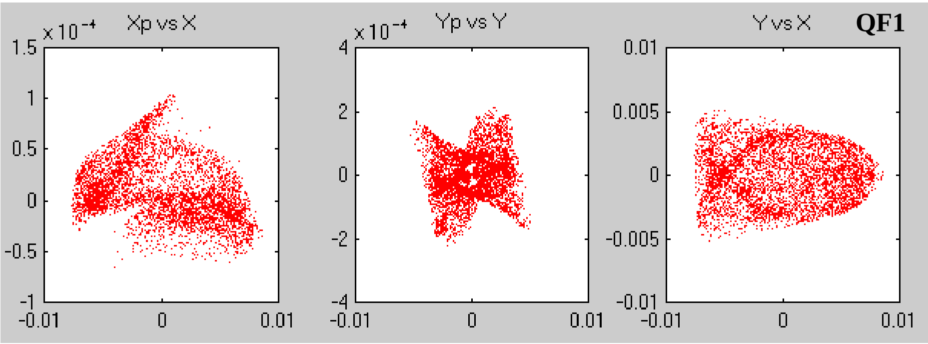
Tail folding
or Origami Zoo

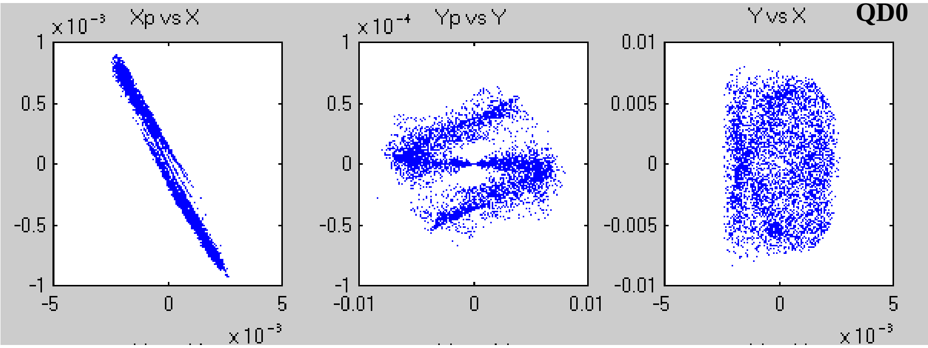


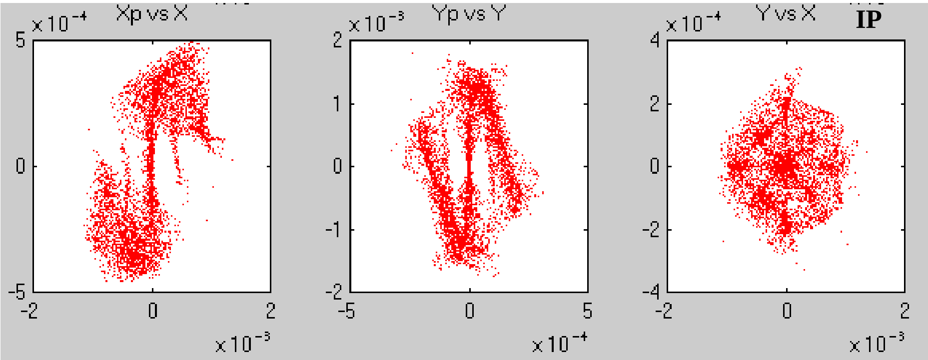




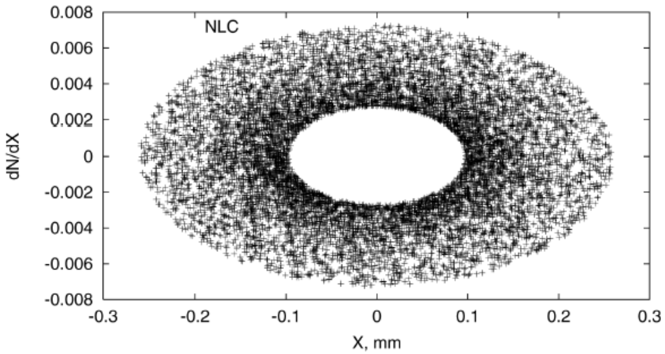


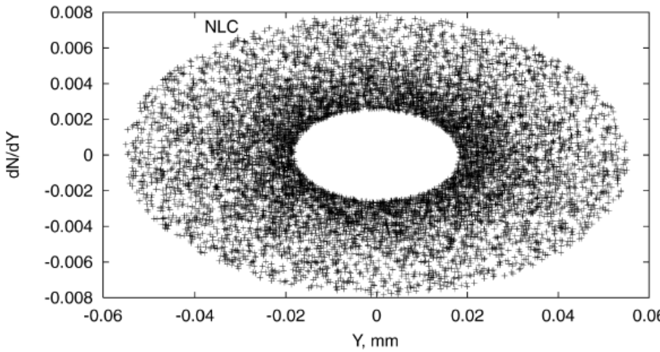




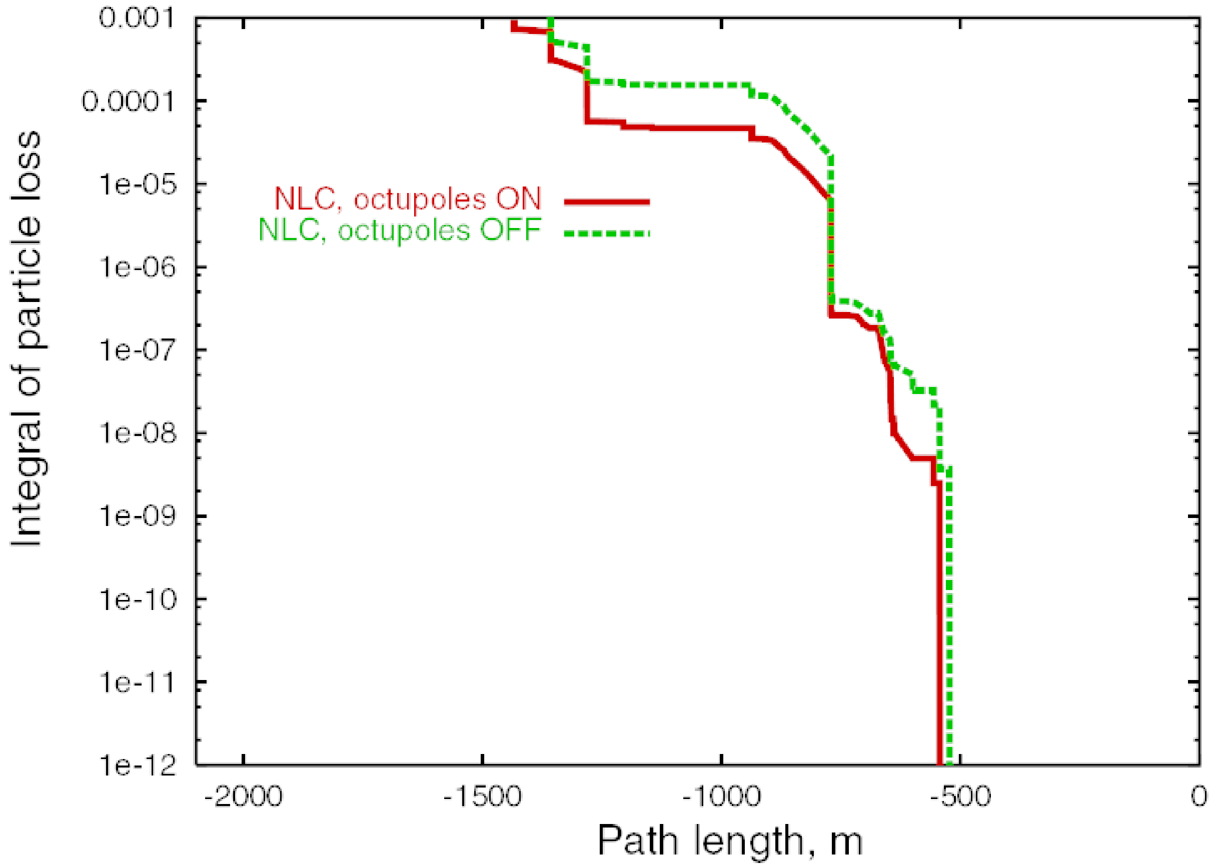


Halo collimation





Assumed halo sizes. Halo population is 0.001 of the main beam.



Assuming 0.001 halo, beam losses along the beamline behave nicely, and SR photon losses occur only on dedicated masks

Smallest gaps are +-0.6mm with tail folding Octupoles and +-0.2mm without them.

Collimator wakes

- Effect from offset of the beam at the collimator:

$$\Delta y' = K\, y$$

- Assume that beam jitter is a fixed fraction of the beam size

$$\frac{\Delta y'}{\sigma_{y'}} = K \frac{\sigma_y}{\sigma_{y'}} \frac{y}{\sigma_y}$$

- Jitter amplification factor

$$A_\beta = K \frac{\sigma_y}{\sigma_{y'}}$$

For locations with α=0 => $A_\beta = K\, \beta$

- If jitter is fraction of size in all planes, and y & y' not correlated , the fractional incoming jitter increases by

$$\sqrt{1 + A_\beta^2}$$

Following P.Tenenbaum, LCC-101 and G.Stupakov, PAC2001

Wakes for tapered collimators

- Rectangular collimators

3.1 r/h   0.37 $\sqrt{\alpha\, r / \sigma_z}$

$$K = \frac{\sqrt{\pi}}{2} \frac{N\, r_e}{\gamma} \frac{\alpha\, h}{\sigma_z\, r^2}$$

$$K = 2.7 \frac{N\, r_e}{\gamma} \sqrt{\frac{\alpha}{\sigma_z\, r^3}}$$

$$K = \frac{N\, r_e}{\gamma} \frac{1}{r^2}$$

- where α is tapering angle, r is half gap, h is half width

Following P.Tenenbaum, LCC-101 and G.Stupakov, PAC2001

Wakes for tapered collimators

- Circular collimators

$2\sqrt{\pi}$ $\qquad \alpha\, r / \sigma_z$

$$K = \frac{N\, r_e}{\gamma} \frac{\alpha}{\sqrt{\pi}\, \sigma_z\, r}$$

inductive regime (smooth transition)

$$K = \frac{N\, r_e}{\gamma} \frac{2}{r^2}$$

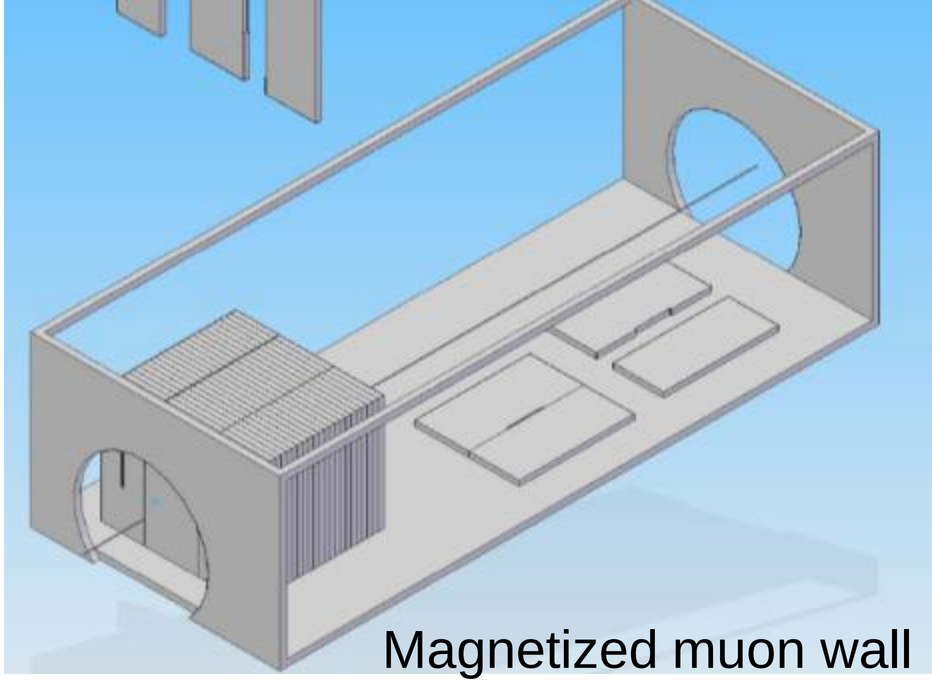
diffractive regime (sudden transition)

- where α is tapering angle, r is half gap

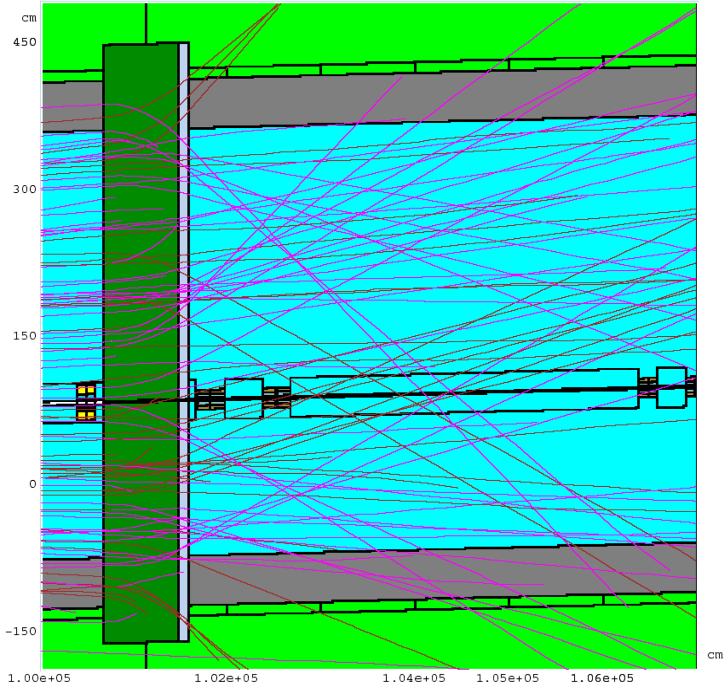
Following P.Tenenbaum, LCC-101 and G.Stupakov, PAC2001

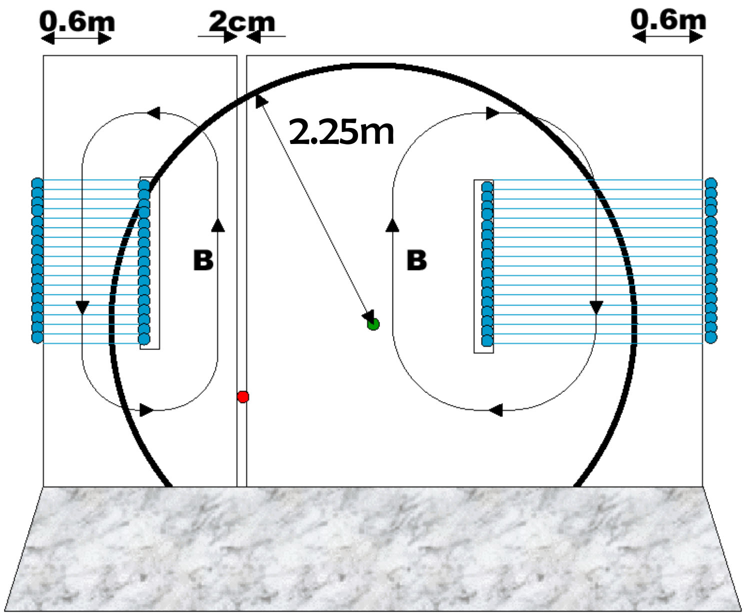
Dealing with muons in BDS

- Muons are produced during collimation
- Muon walls, installed ~300m from IP, reduce muon background in the detectors

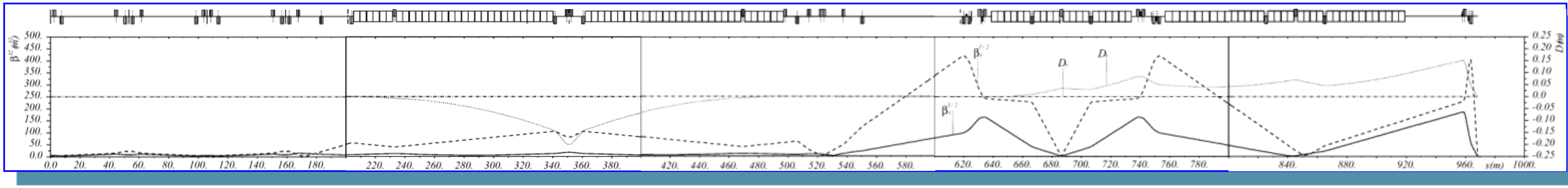


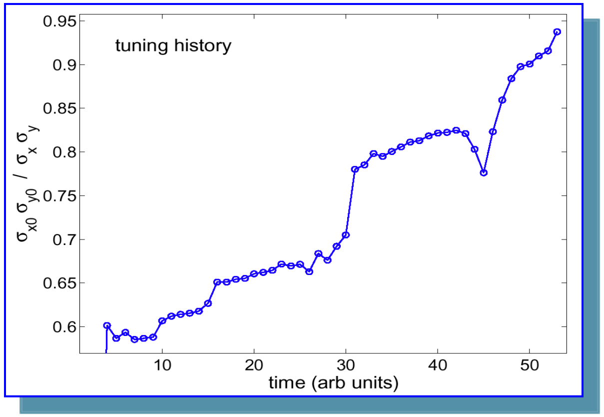
Magnetized muon wall



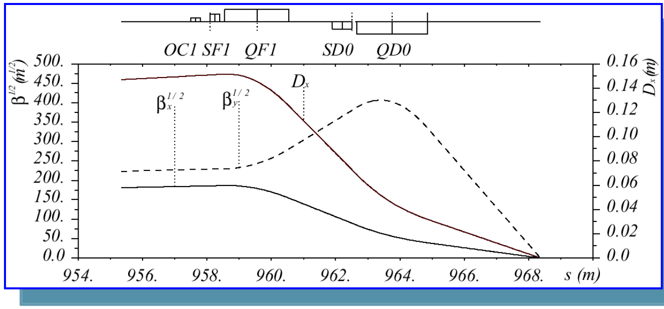


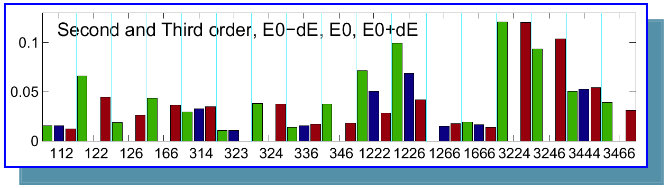
BDS design methods & examples

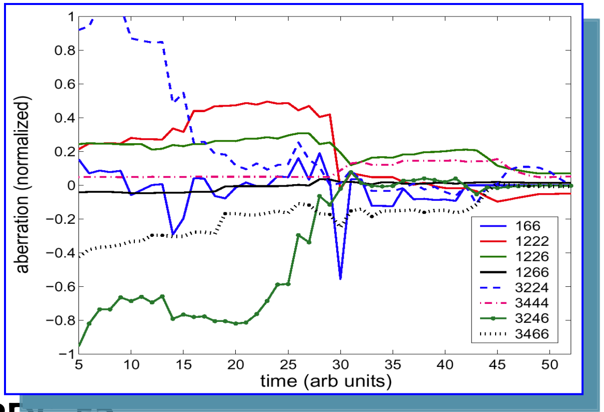


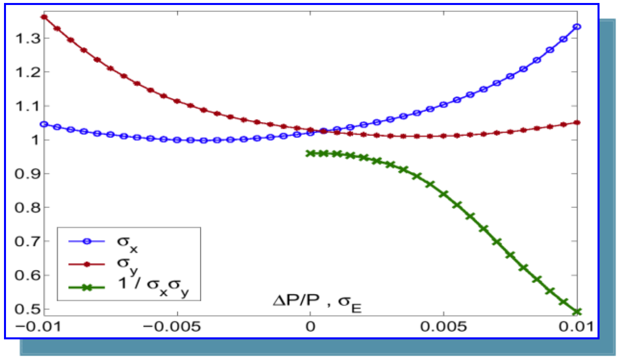


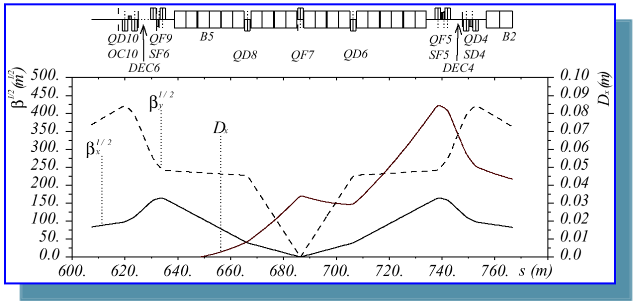
Example of a 2nd IR BDS optics for ILC; design history; location of design knobs





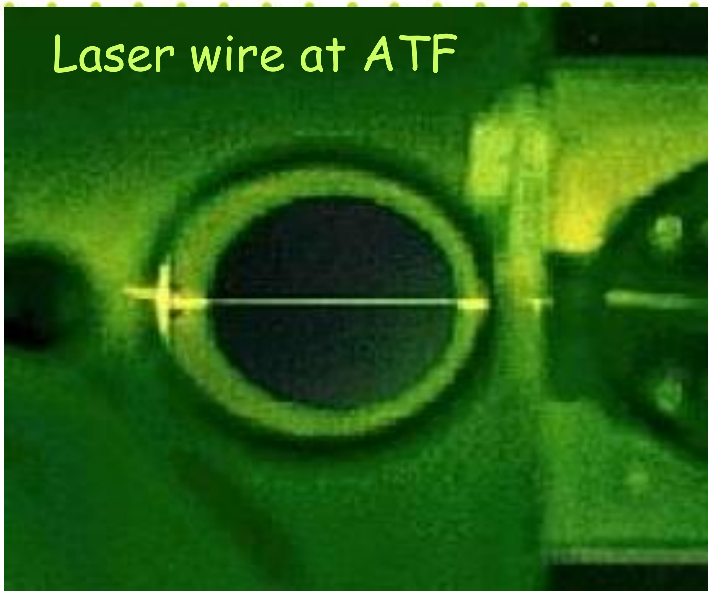






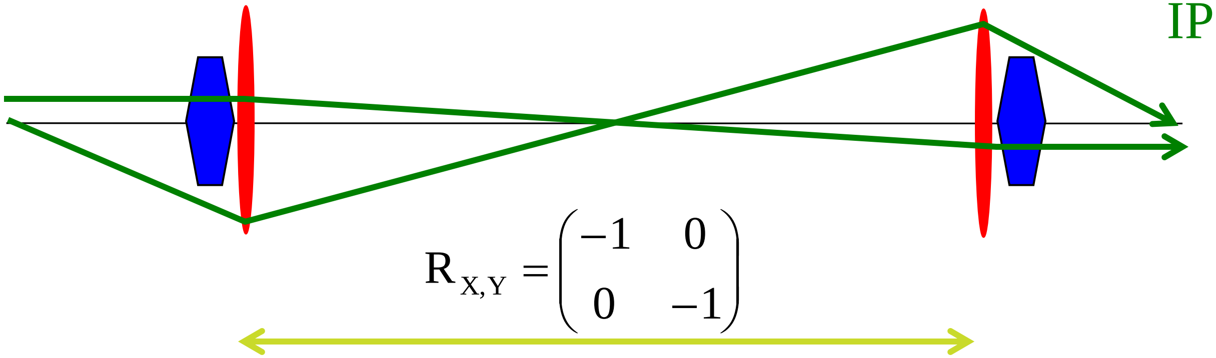
In a practical situation …

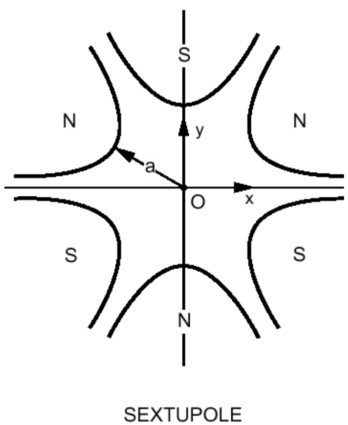
- While **designing** the FF, one has a **total control**
- When the system is built, one has just limited number of observable parameters (measured orbit position, beam size measured in several locations)
- The system, however, may initially have **errors** (errors of strength of the elements, transverse misalignments) and initial aberrations may be large
- **Tuning** of FF is done by optimization of "**knobs**" (strength, position of group of elements) chosen to affect some particular aberrations
- Experience in SLC FF and FFTB, and simulations with new FF give confidence that this is possible



Laser wire will be a tool for tuning and diagnostic of FF

Sextupole knobs for BDS tuning



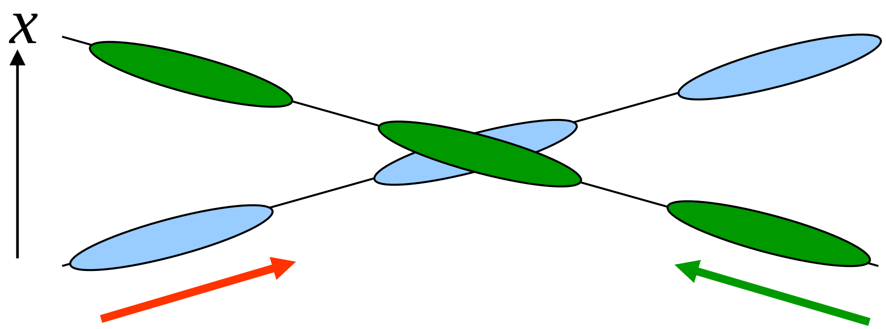


Second order effect:
$x' = x' + S\,(x^2-y^2)$
$y' = y' - S\,2xy$

- Combining offsets of sextupoles (symmetrical or anti-symmetrical in X or Y), one can produce the following corrections at the IP
  - waist shift
  - coupling
  - dispersion

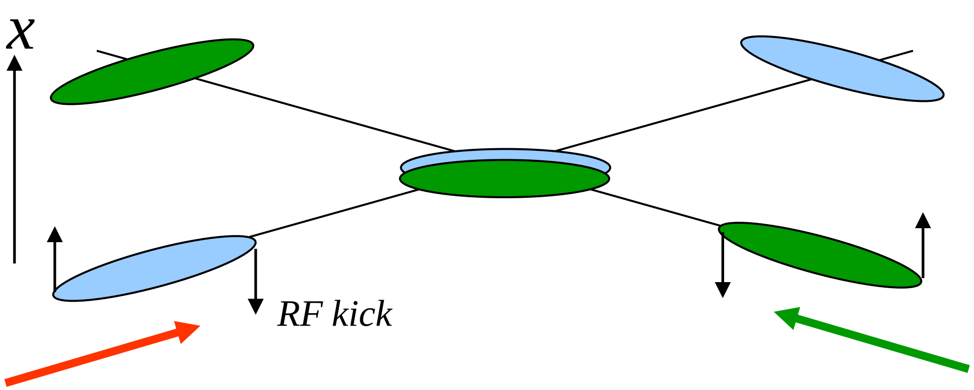
To create these knobs, sextupole placed on movers

Crab crossing

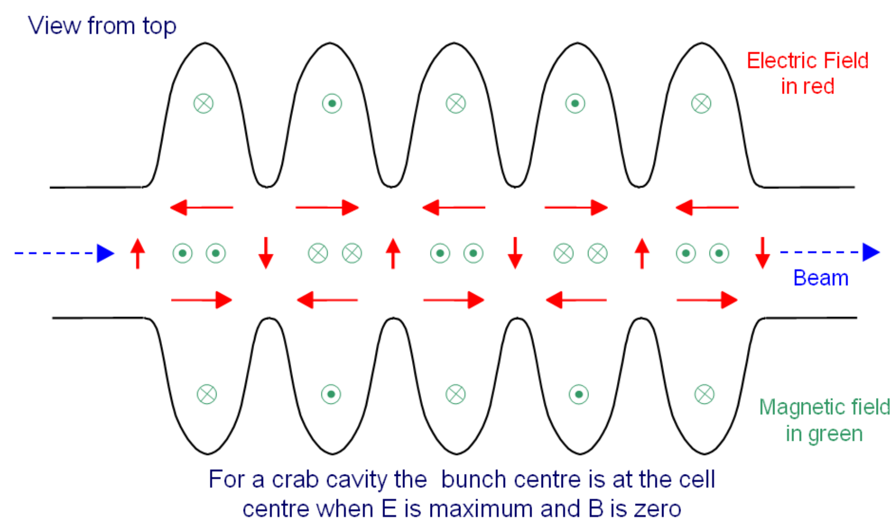


With crossing angle θ_c, the projected x-size is $(\sigma_x{}^2+\theta_c{}^2\sigma_z{}^2)^{0.5} \sim \theta_c\sigma_z \sim 4\mu m$

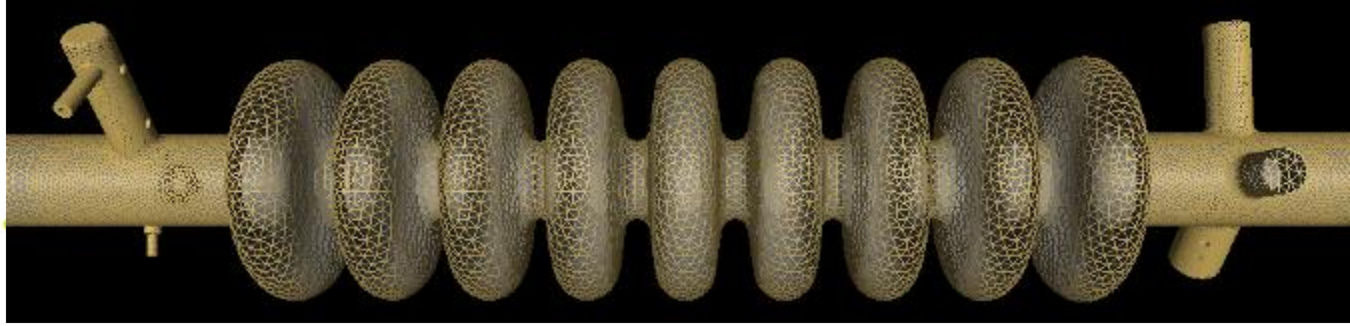
→ several time reduction in *L* without corrections



Use transverse (crab) RF cavity to 'tilt' the bunch at IP



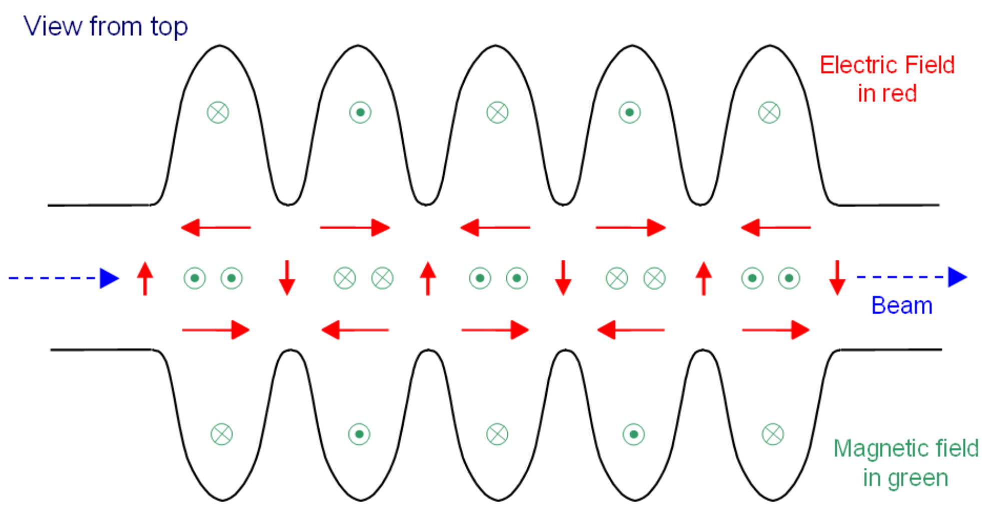
Crab cavity design



FNAL 3.9GHz 9-cell cavity in Opega3p. *K.Ko, et al*

- Prototypes of crab cavity built at FNAL and 3d RF models
- Design & prototypes been done by UK-FNAL-SLAC collaboration

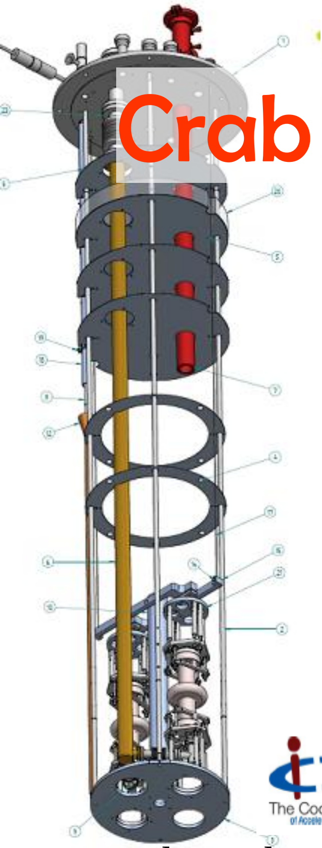
3.9GHz cavity achieved 7.5 MV/m (FNAL)



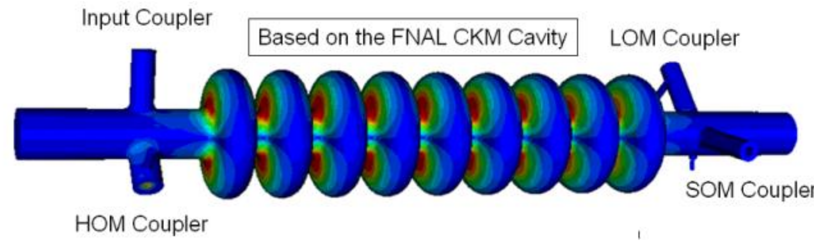
For a crab cavity the bunch centre is at the cell centre when E is maximum and B is zero

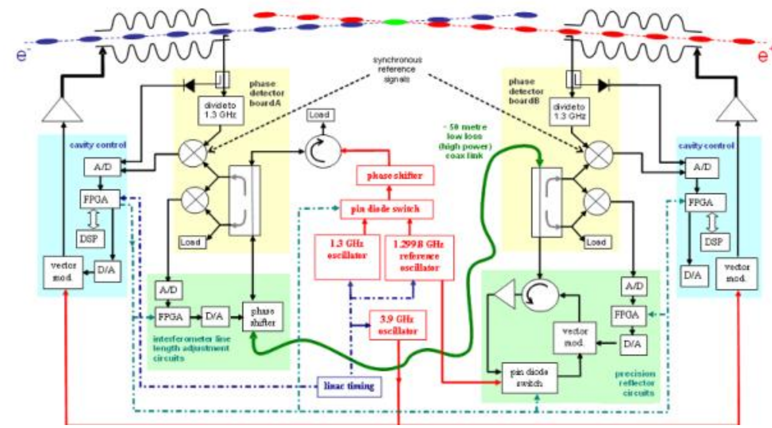
TM110 Dipole mode cavity

Crab cavity



Cavities limited in gradient to 1 MV/m (~40kV/cell) – shielding implications.





SLAC ACD

Independent phase lock achieved for both cavities:

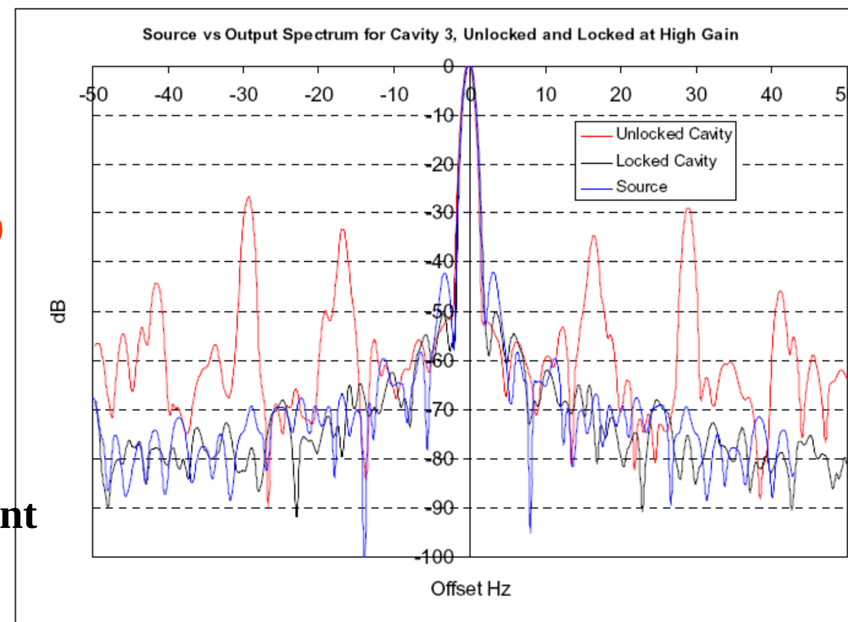
– **Unlocked => 10º r.m.s.**

– **Locked => 0.135º r.m.s.**

• Performance limited by:

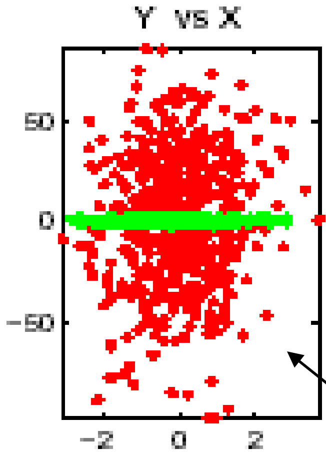
– **Source noise (dominant); ADC noise; Measurement noise; – Cavity frequency drift; Microphonics**

• Improvements being made; new tests being prepared



P.McIntosh at al

IR coupling compensation

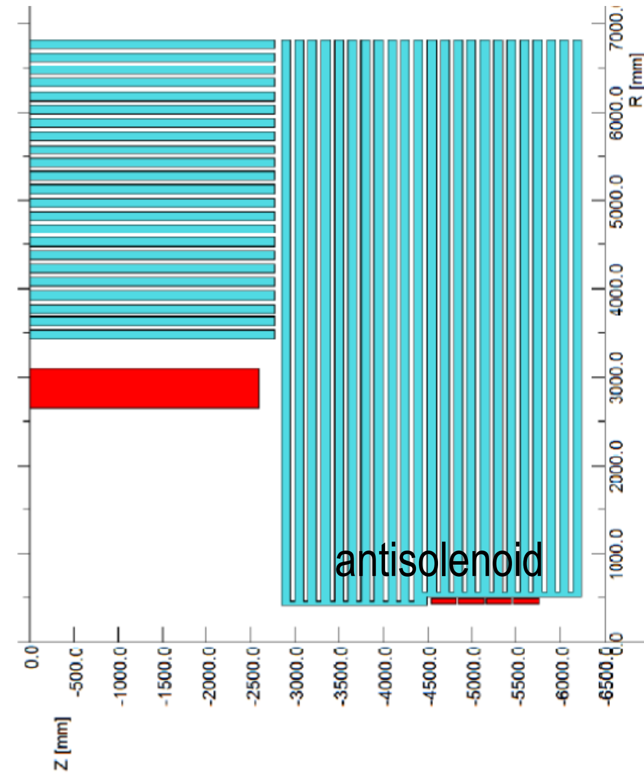


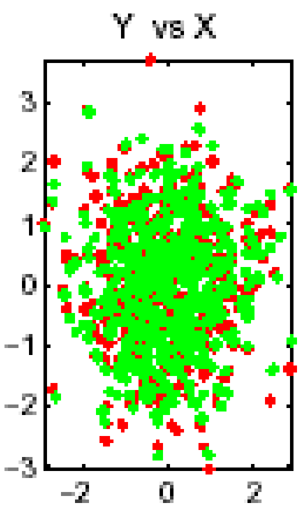
without compensation

$\sigma_y / \sigma_y(0) = 32$

When detector solenoid overlaps QD0, coupling between y & x' and y & E causes large (30 – 190 times) increase of IP size (green=detector solenoid OFF, red=ON)

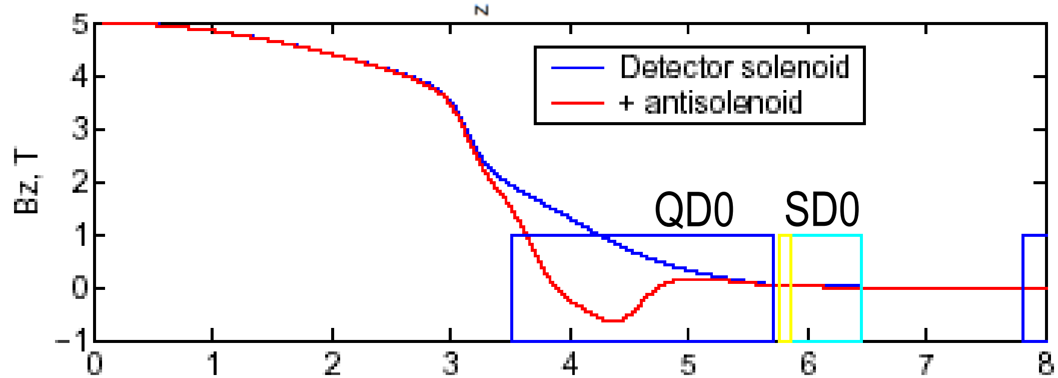
Even though traditional use of skew quads could reduce the effect, the local compensation of the fringe field (with a little skew tuning) is the most efficient way to ensure correction over wide range of beam energies





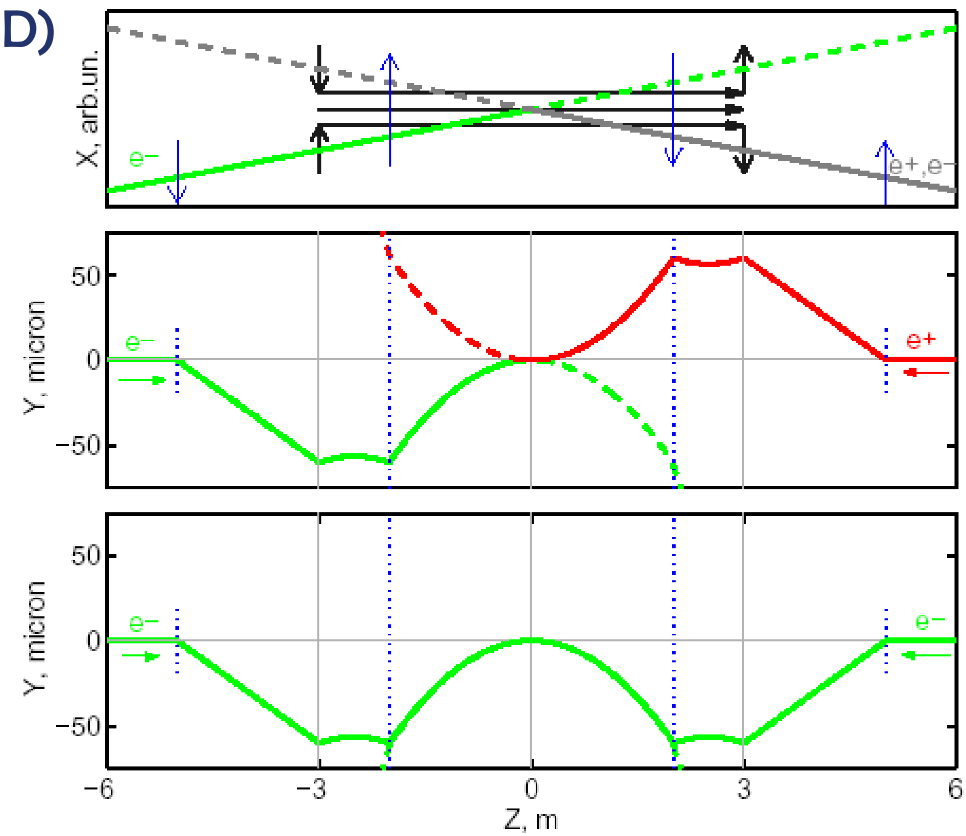
with compensation by antisolenoid

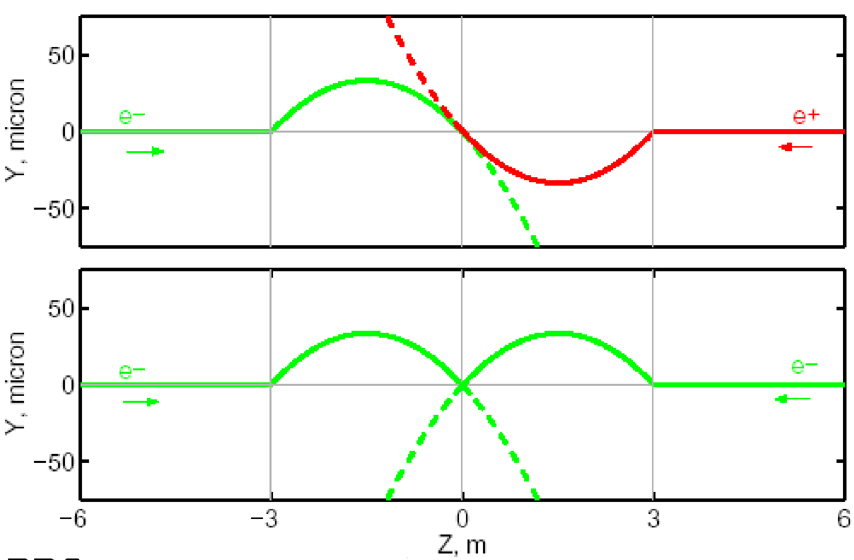
$\sigma_y / \sigma_y(0) < 1.01$



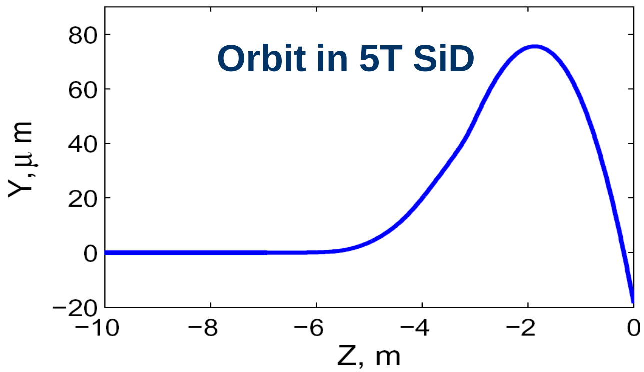
Detector Integrated Dipole

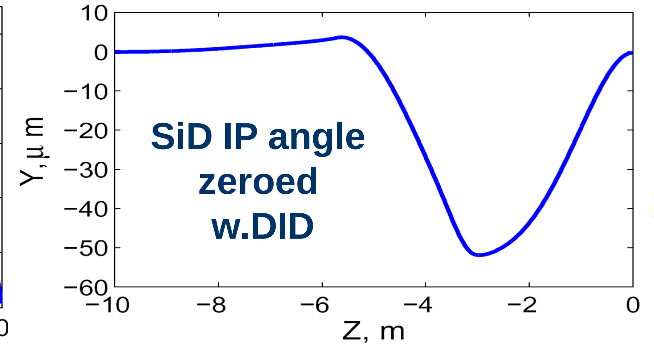
- With a crossing angle, when beams cross solenoid field, vertical orbit arise
- For e+e- the orbit is anti-symmetrical and beams still collide head-on
- If the vertical angle is undesirable (to preserve spin orientation or the e-e- luminosity), it can be compensated locally with DID
- Alternatively, negative polarity of DID may be useful to reduce angular spread of beam-beam pairs (anti-DID)





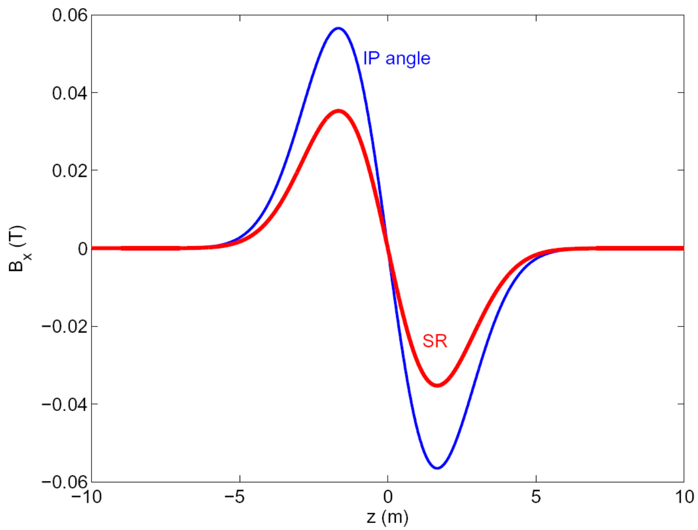
Use of DID or anti-DID

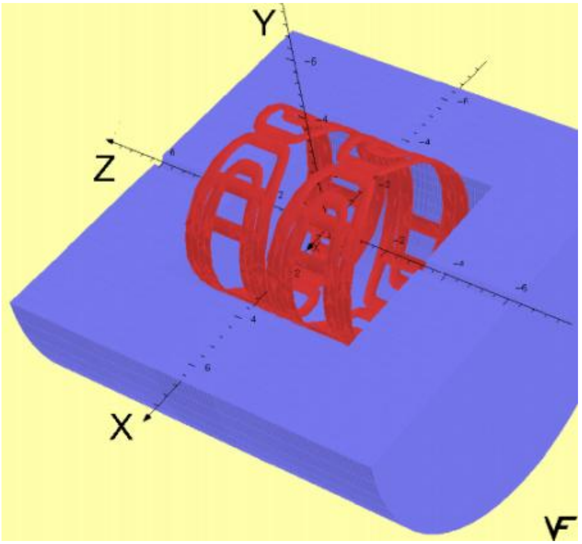




DID case

DID field shape and scheme

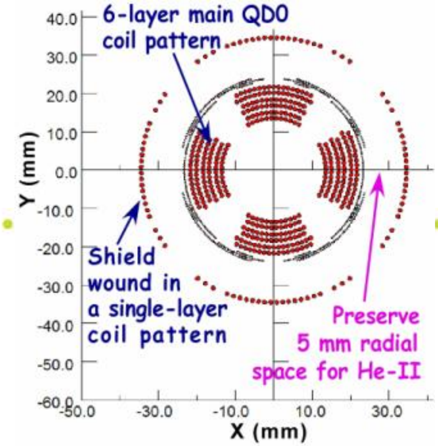




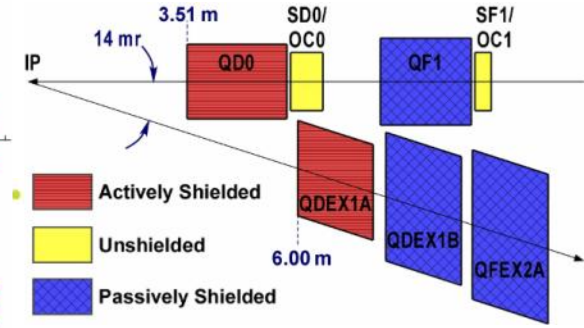
- The negative polarity of DID is also possible (called anti-DID)

- In this case the vertical angle at the IP is somewhat increased, but the background conditions due to low energy pairs (see below) and are improved

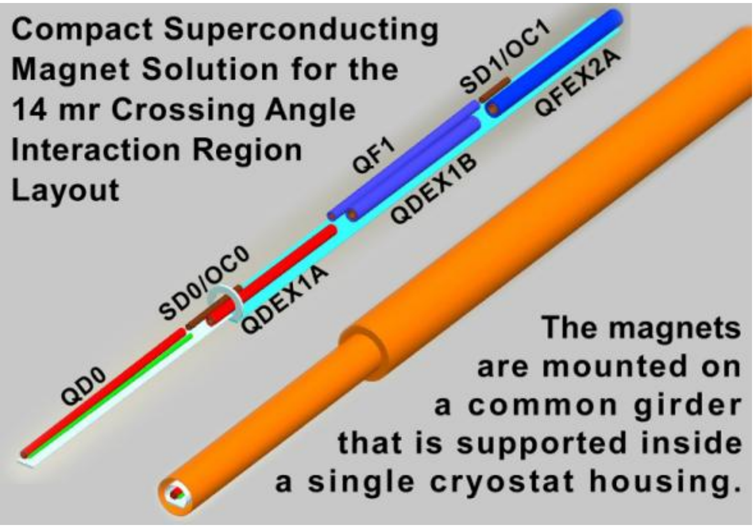
14 mrad IR



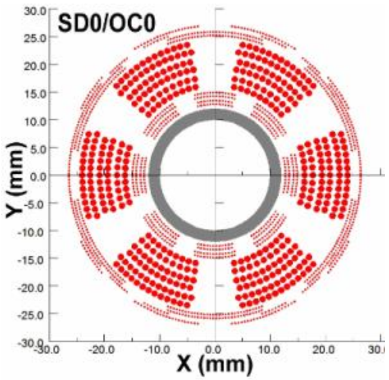
6-layer main QD0
coil pattern
Shield
wound in
a single-layer
coil pattern
Preserve
5 mm radial
space for He-II
Y (mm)
X (mm)



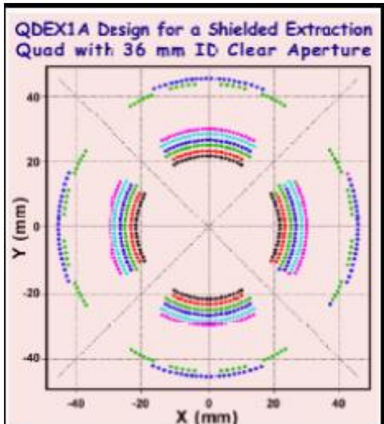
3.51 m
SD0/
OC0
SF1/
OC1
14 mr
IP
QD0
QF1
Actively Shielded
Unshielded
Passively Shielded
QDEX1A
QDEX1B
QFEX2A
6.00 m



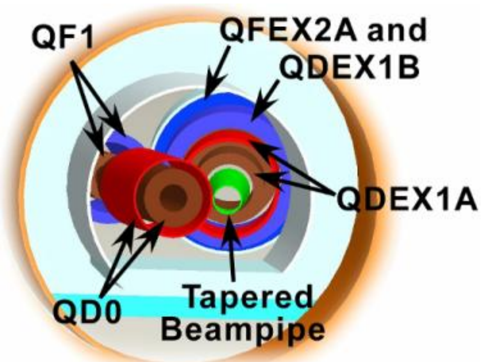
Compact Superconducting
Magnet Solution for the
14 mr Crossing Angle
Interaction Region
Layout
SD1/OC1
QFEX2A
QF1
QDEX1B
SD0/OC0
QDEX1A
QD0
The magnets
are mounted on
a common girder
that is supported inside
a single cryostat housing.



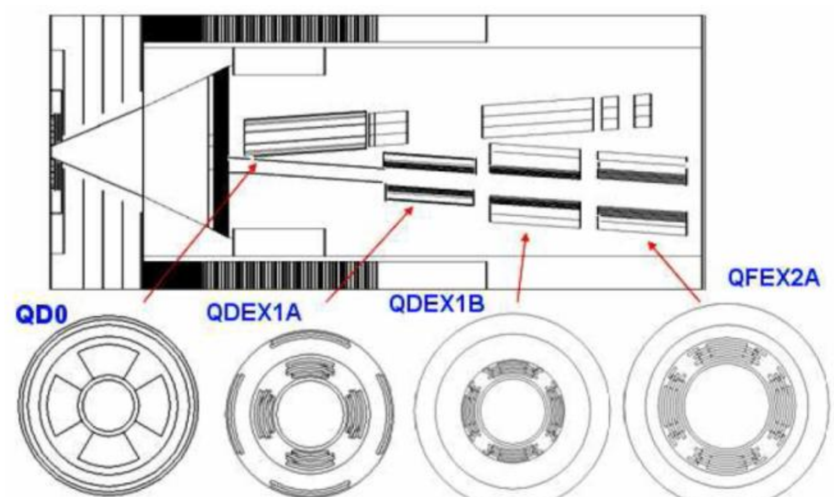
SD0/OC0
Y (mm)
X (mm)



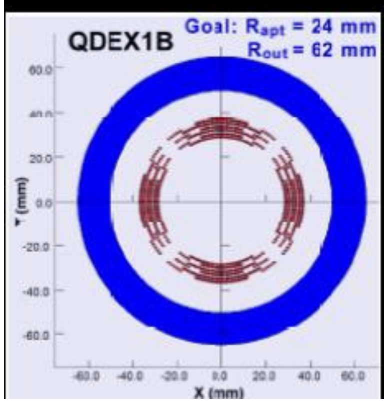
QDEX1A Design for a Shielded Extraction
Quad with 36 mm ID Clear Aperture
Y (mm)
X (mm)



QF1
QFEX2A and
QDEX1B
QDEX1A
QD0
Tapered
Beampipe

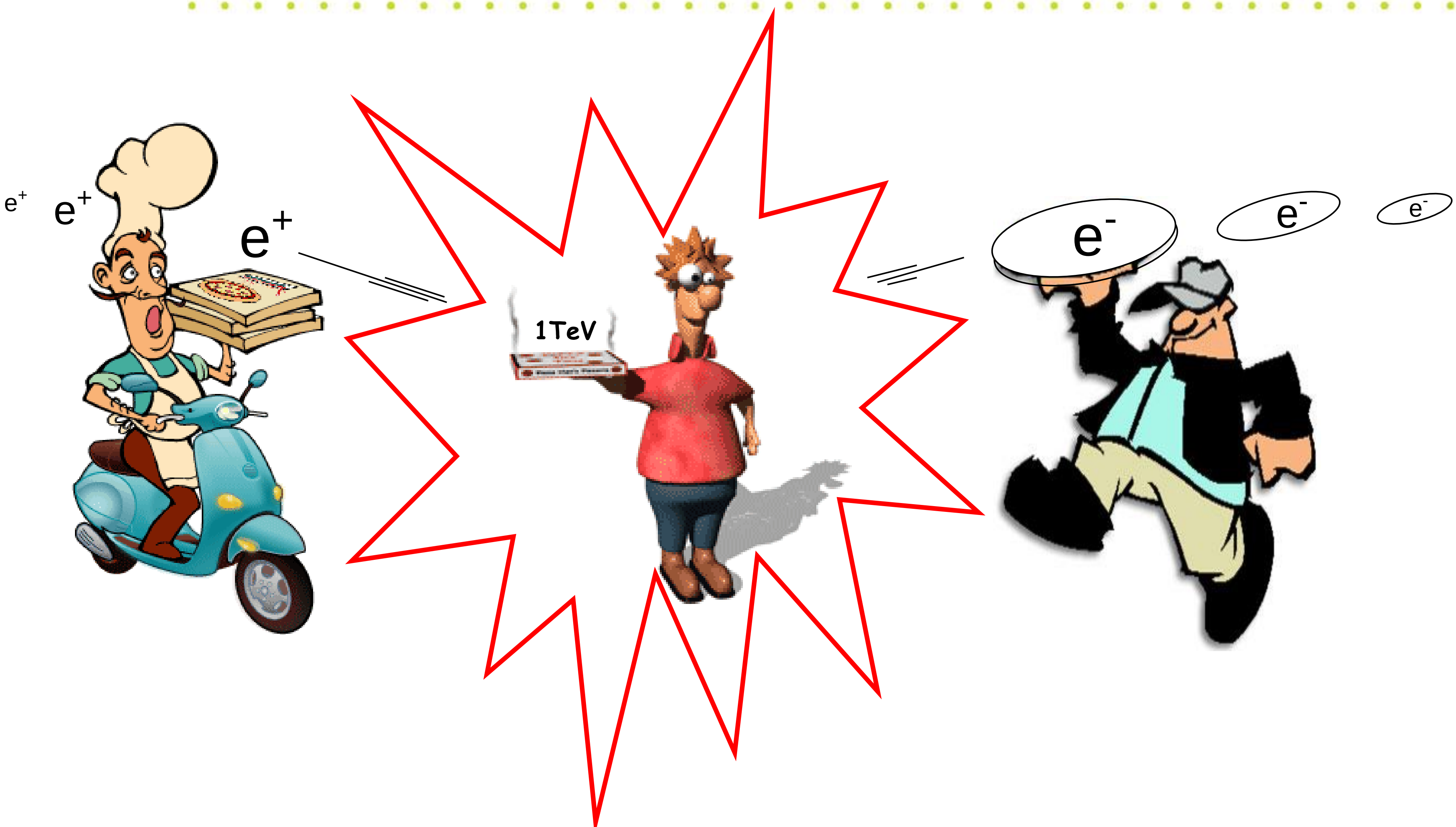


QD0
QDEX1A
QDEX1B
QFEX2A



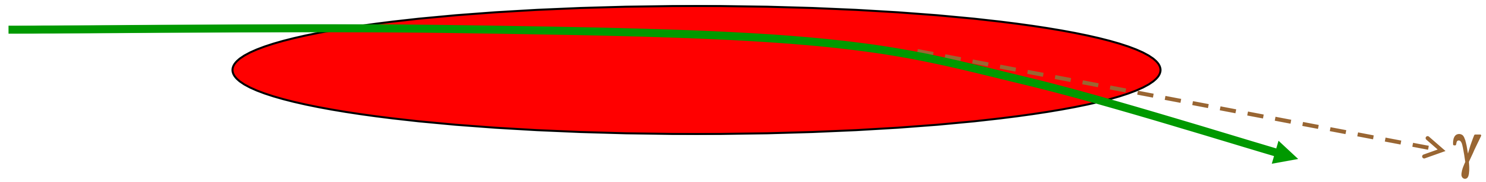
QDEX1B
Goal: R_{apt} = 24 mm
R_{out} = 62 mm
X (mm)

Beam Delivered...



Beam-beam effects

Beam-beam interactions



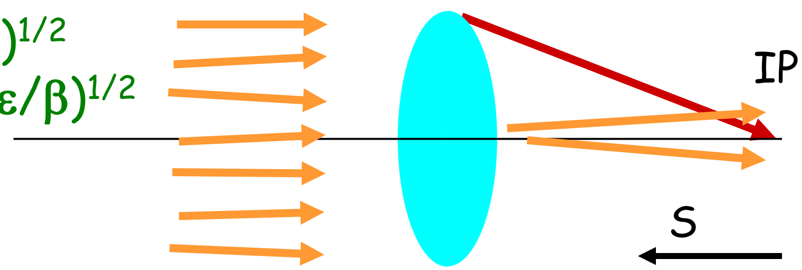
- Transverse fields of ultra-relativistic bunch
  - focus the incoming beam (electric and magnetic force add)
  - reduction of beam cross-section leads to more luminosity
    - H_D - the luminosity enhancement factor
  - bending of the trajectories leads to emission of beamstrahlung

Parameters of ILC BDS

Length (linac exit to IP distance)/side	m	2226
Length of main (tune-up) extraction line	m	300 (467)
Max Energy/beam (with more magnets)	GeV	250 (500)
Distance from IP to first quad, L*	m	3.5-(4.5)
Crossing angle at the IP	mrad	14
Nominal beam size at IP, σ^*, x/y	nm	655/5.7
Nominal beam divergence at IP, θ^*, x/y	μrad	31/14
Nominal beta-function at IP, β^*, x/y	mm	21/0.4
Nominal bunch length, σ_z	μm	300
Nominal disruption parameters, x/y		0.162/18.5
Nominal bunch population, N		2×10^{10}
Max beam power at main and tune-up dumps	MW	18
Preferred entrance train to train jitter	σ	< 0.5
Preferred entrance bunch to bunch jitter	σ	< 0.1
Typical nominal collimation depth, x/y		8–10/60
Vacuum pressure level, near/far from IP	nTorr	1/50

Hour-glass effect

Size: $(\varepsilon\ \beta)^{1/2}$
Angles: $(\varepsilon/\beta)^{1/2}$

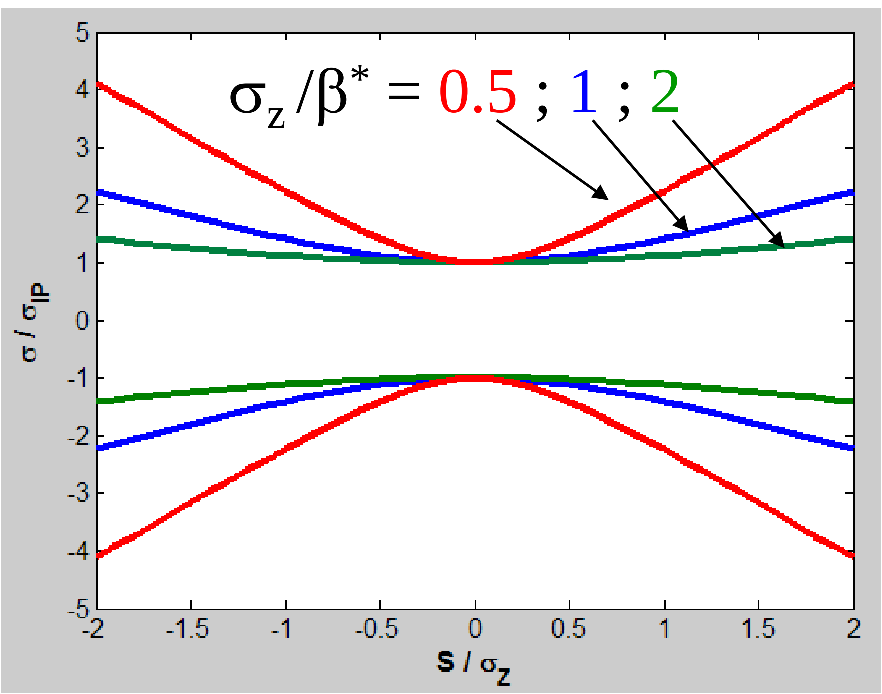


Size at IP: $L^*\ (\varepsilon/\beta)^{1/2}$

Beta at IP:
$L^*\ (\varepsilon/\beta)^{1/2} = (\varepsilon\ \beta^*)^{1/2}$
=> $\beta^* = L^{*2}/\beta$

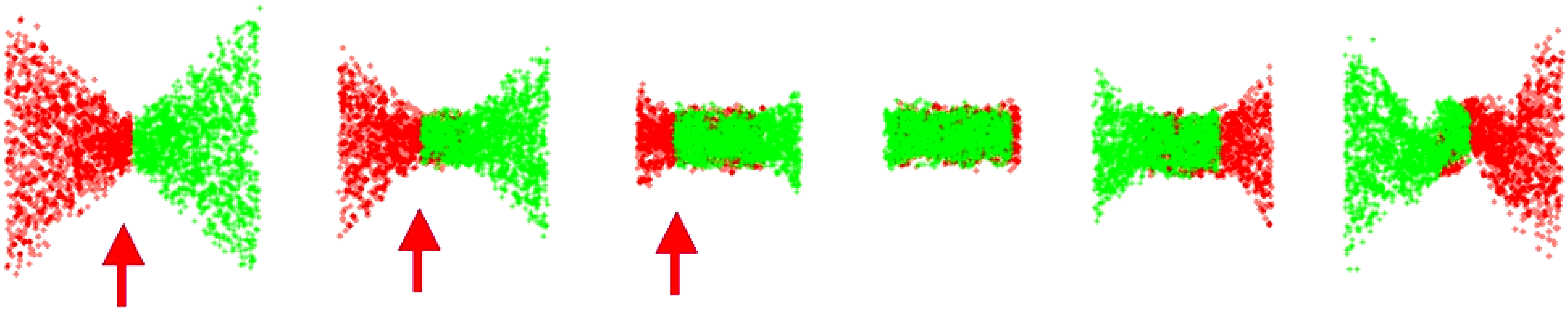
Behavior of beta-function along the final drift:

$(\beta)^{1/2} = (\beta^* + S^2/\beta^*)^{1/2}$



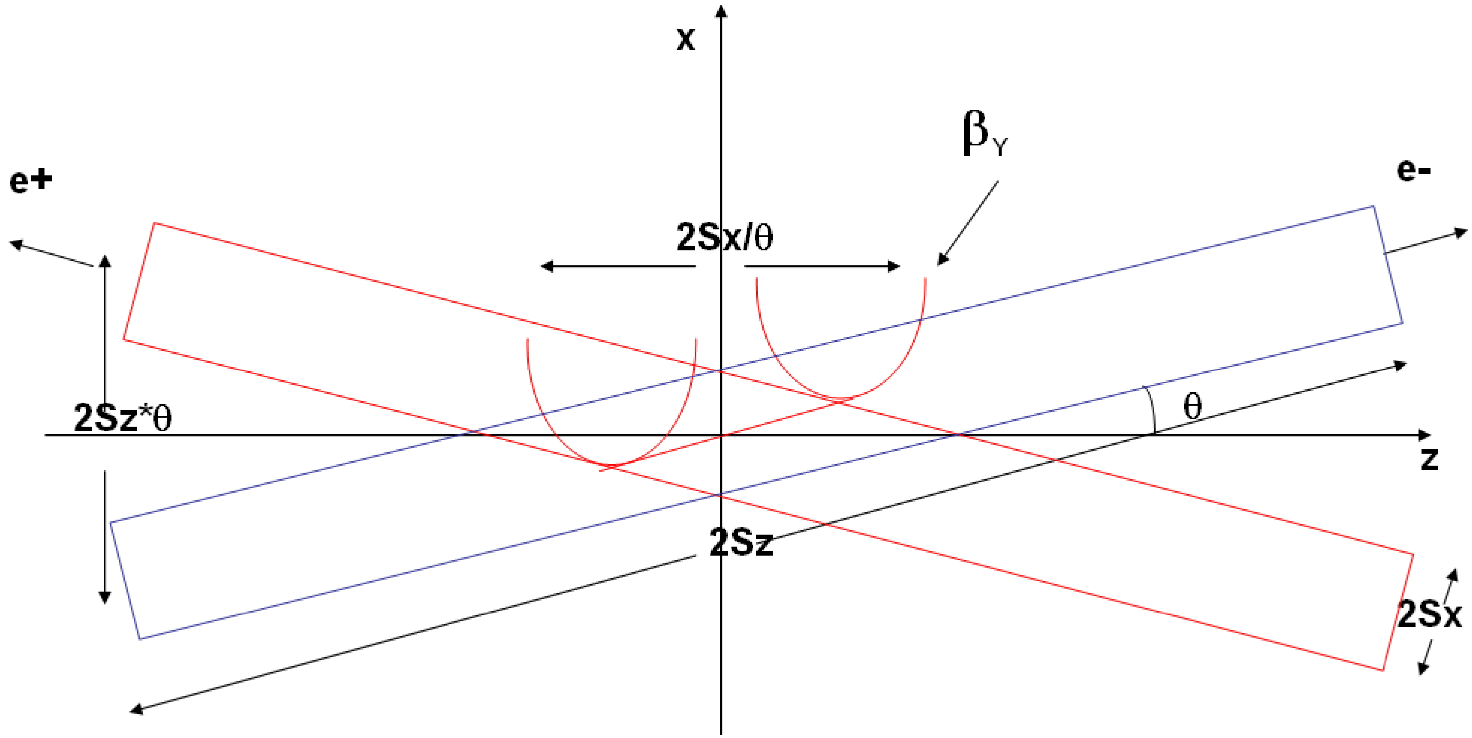
Reduction of β^* below σ_z does not give further decrease of effective beam size (<u>usually</u>)

Beam-beam: Travelling focus



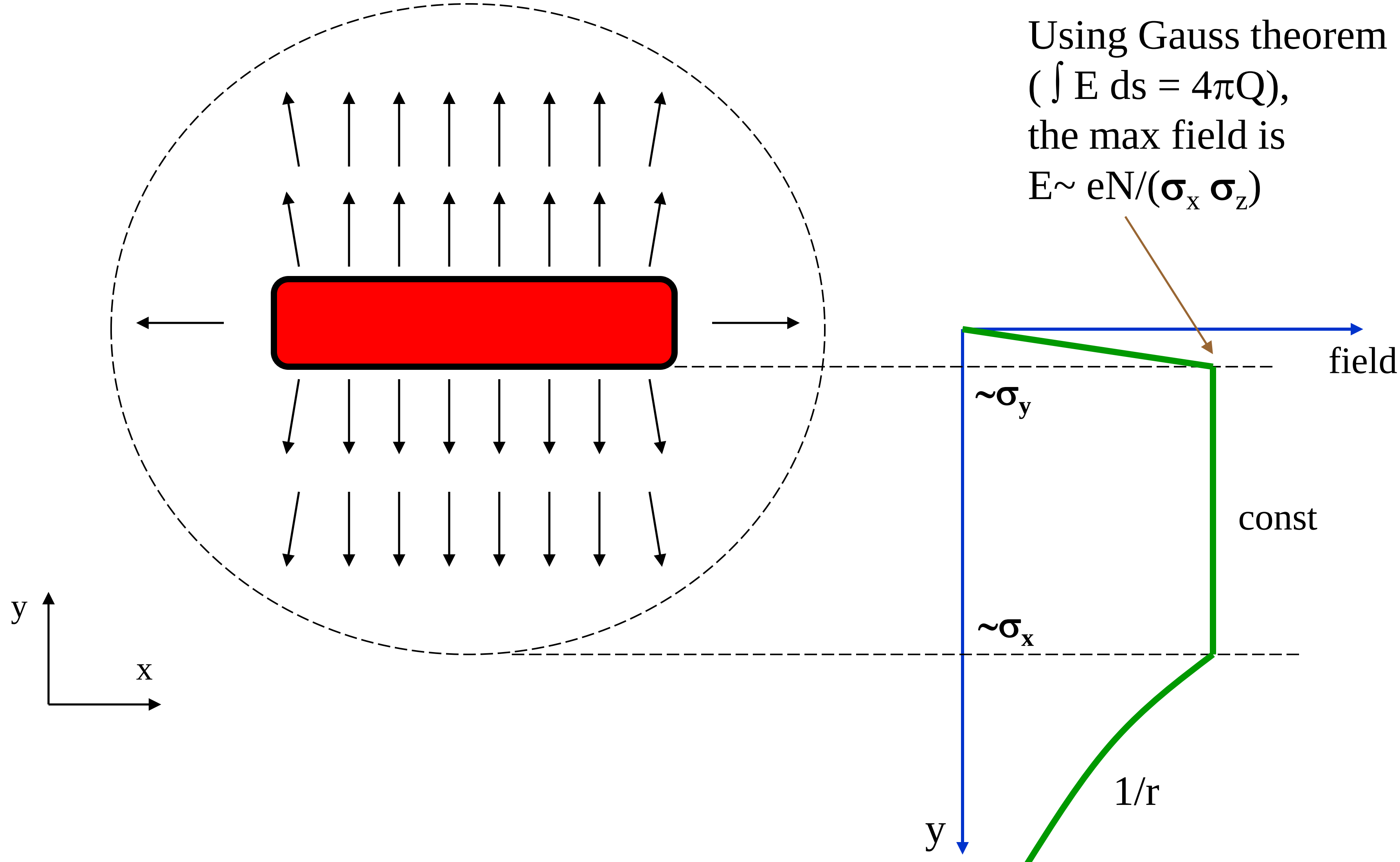
- Suggested by V.Balakin – idea is to use beam-beam forces for additional focusing of the beam – allows some gain of luminosity or overcome somewhat the hour-glass effect
- Figure shows simulation of traveling focus. The arrows show the position of the focus point during collision
- So far not yet used experimentally

Beam-beam: Crabbed-waist



- Suggested by P.Raimondi for Super-B factory
- Vertical waist has to be a function of X. In this case coupling produced by beam-beam is eliminated
- Experimentally verified at DAFNE

Fields of flat bunch, qualitatively



Disruption parameter

- For Gaussian transverse beam distribution, and for particle near the axis, the beam kick results in the final particle angle:

$$\Delta x' = \frac{dx}{dz} = -\frac{2Nr_e}{\gamma\sigma_x\left(\sigma_x+\sigma_y\right)}\cdot x \qquad \Delta y' = \frac{dy}{dz} = -\frac{2Nr_e}{\gamma\sigma_y\left(\sigma_x+\sigma_y\right)}\cdot y$$

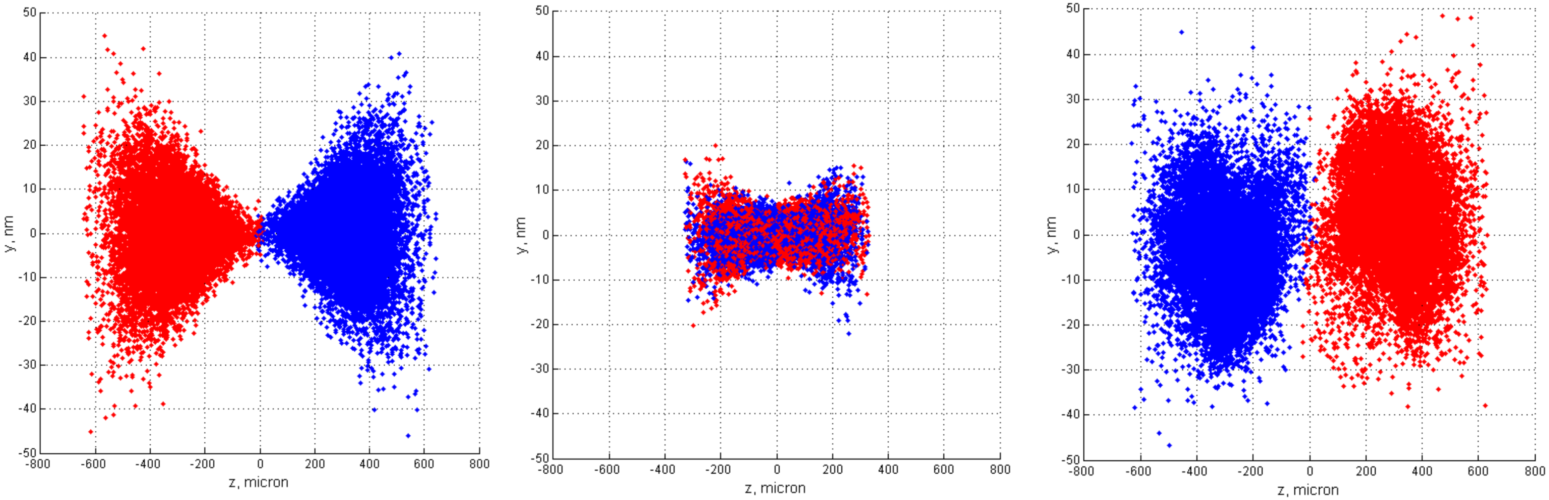
- "Disruption parameter" – characterize focusing strength of the field of the bunch ($D_y \sim \sigma_z/f_{beam}$)

$$D_x = \frac{2Nr_e\sigma_z}{\gamma\sigma_x(\sigma_x+\sigma_y)} \qquad D_y = \frac{2Nr_e\sigma_z}{\gamma\sigma_y(\sigma_x+\sigma_y)}$$

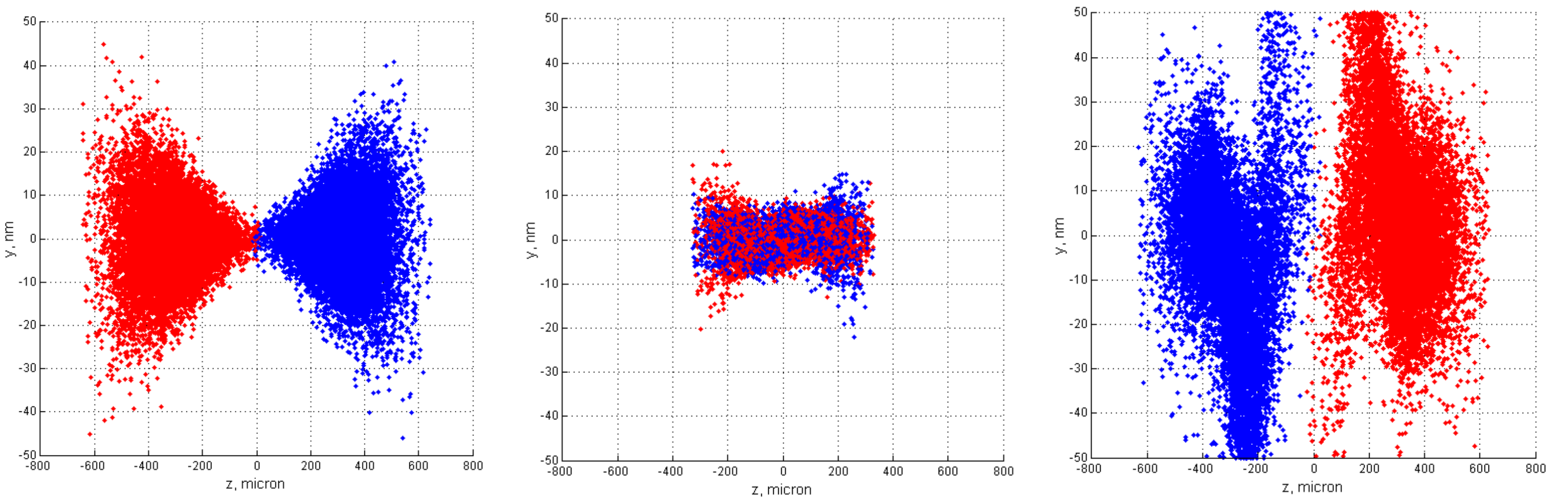
- D << 1 – bunch acts as a thin lens
- D >> 1 – particle oscillate in the field of other bunch
  - If D is bigger than ~20, instability may take place

Beam-beam effects
H_D and instability

$$D_y = \frac{2r_e}{\gamma}\frac{N\sigma_z}{\sigma_x\sigma_y}$$

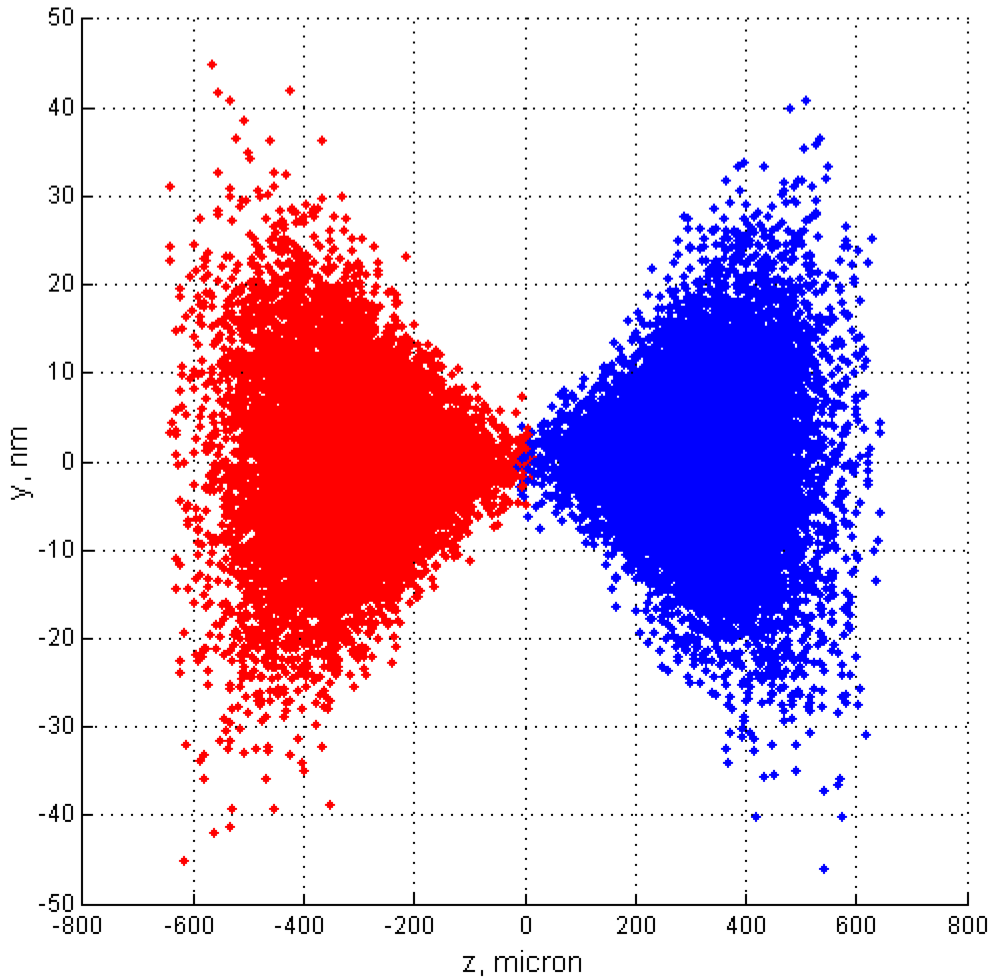


D_y~12



Nx2
D_y~24

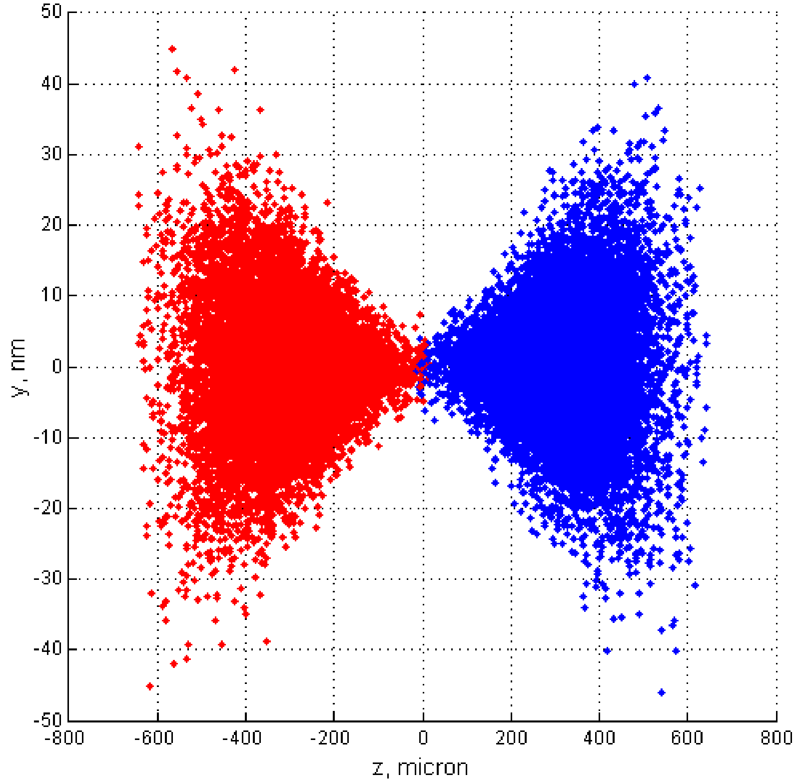
Beam-beam effects
H_D and instability



LC parameters
D_y~12

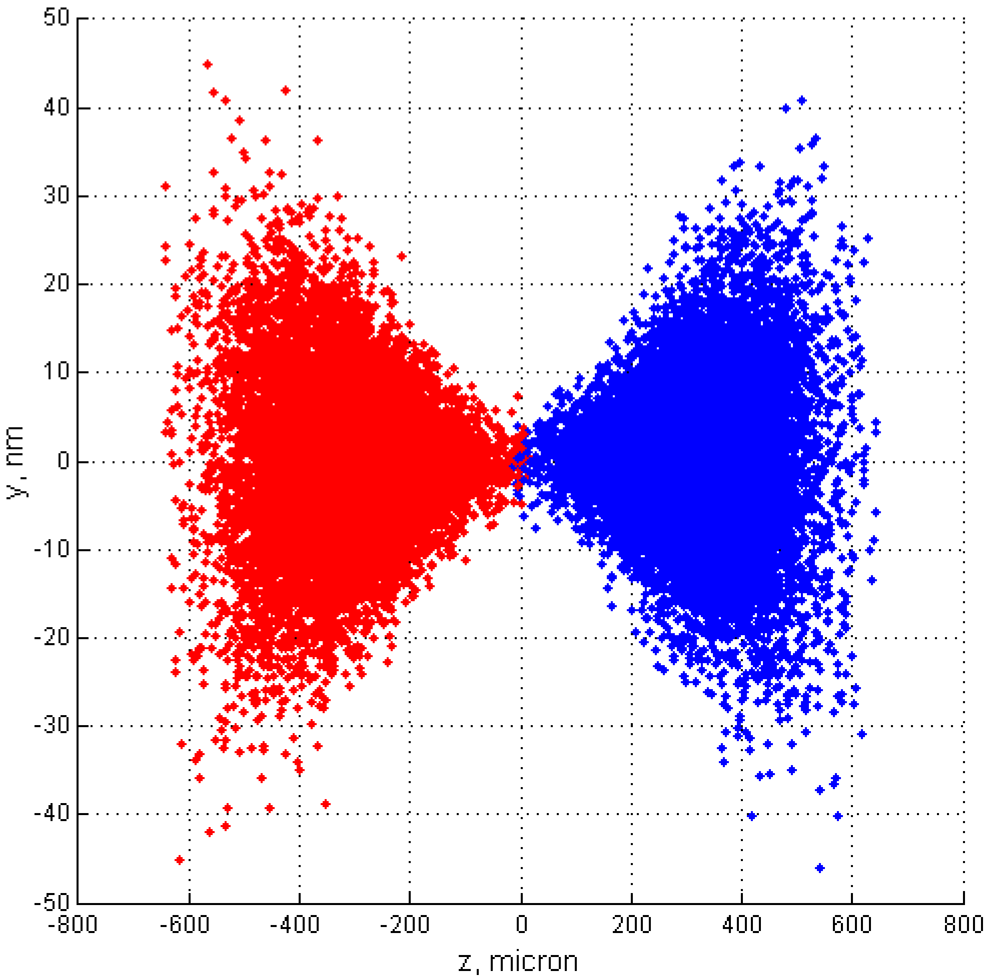
Luminosity enhancement
H_D ~ 1.4

Not much of an instability



50
40
30
20
10
0
-10
-20
-30
-40
-50
y, nm
-800
-600
-400
-200
0
200
400
600
800
z, micron

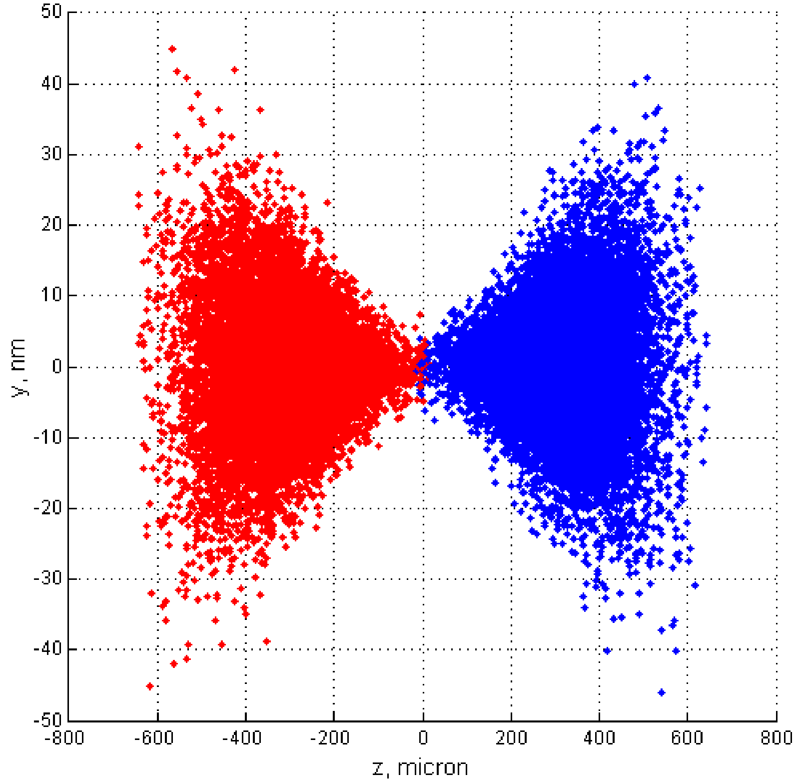
Beam-beam effects
H_D and instability



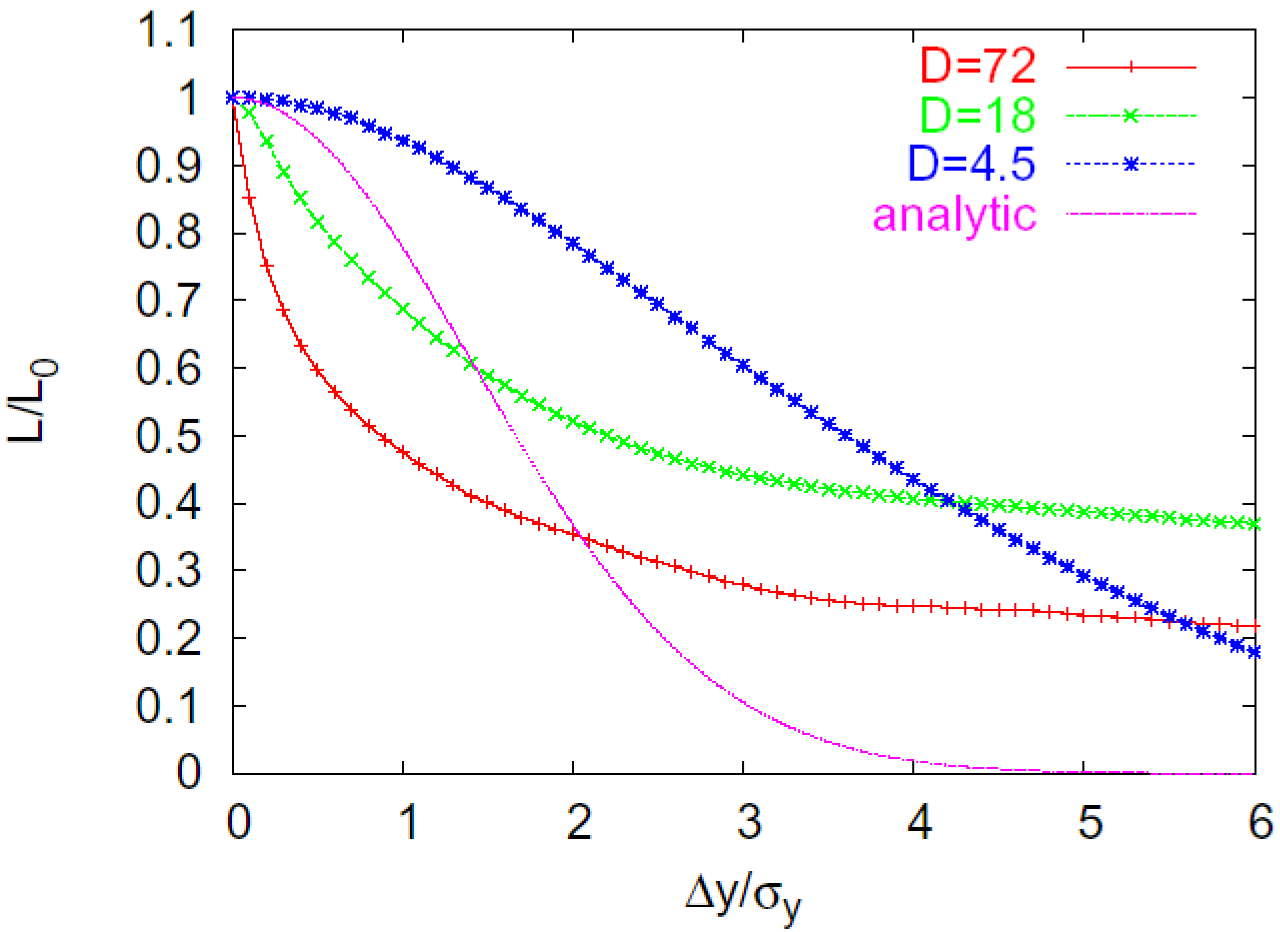
Nx2
D_y~24

Beam-beam instability is clearly pronounced

Luminosity enhancement is compromised by higher sensitivity to initial offsets


50
40
30
20
10
0
-10
-20
-30
-40
-50
y, nm
-800
-600
-400
-200
0
200
400
600
800
z, micron

Sensitivity to offset at IP



- Luminosity (normalized) versus offset at IP for different disruption parameters

Beamstrahlung

- Synchrotron radiation in field of opposite bunch
- Estimate R of curvature as R ~ $\sigma_z^2/(D_y\sigma_y)$
- Using formulas derived earlier, estimate ω_c and find that $h\omega_c/E \sim \gamma N r_e^2/(\alpha\sigma_x\sigma_z)$ and call it "Upsilon"

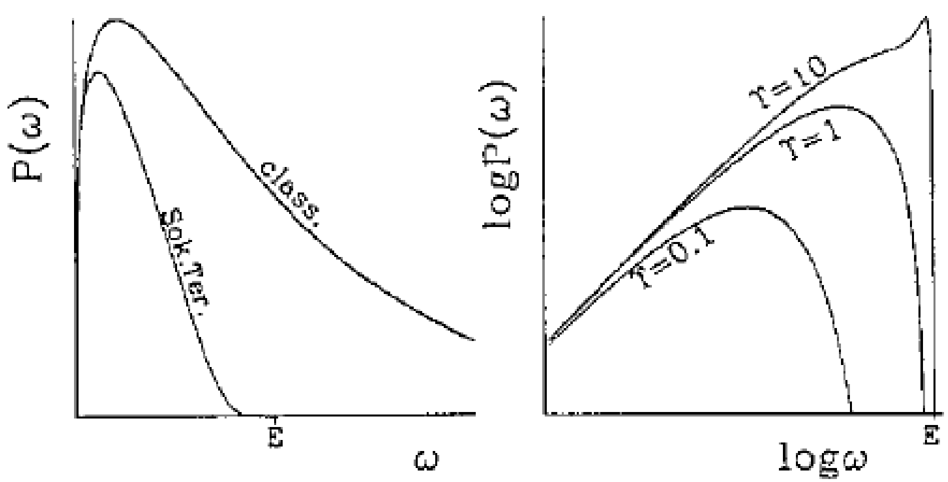
More accurate formula:

$$\Upsilon_{avg} \approx \frac{5}{6}\frac{N r_e^2 \gamma}{\alpha\sigma_z\left(\sigma_x + \sigma_y\right)}$$

- The energy loss also can be estimated from earlier derived formulas: $dE/E \sim \gamma r_e^3 N^2 / (\sigma_z \sigma_x^2)$
  - This estimation is very close to exact one
- Number of γ per electron estimated $n_{\gamma/e} \sim \alpha r_e N/\sigma_x$
  - which is usually around one γ per e

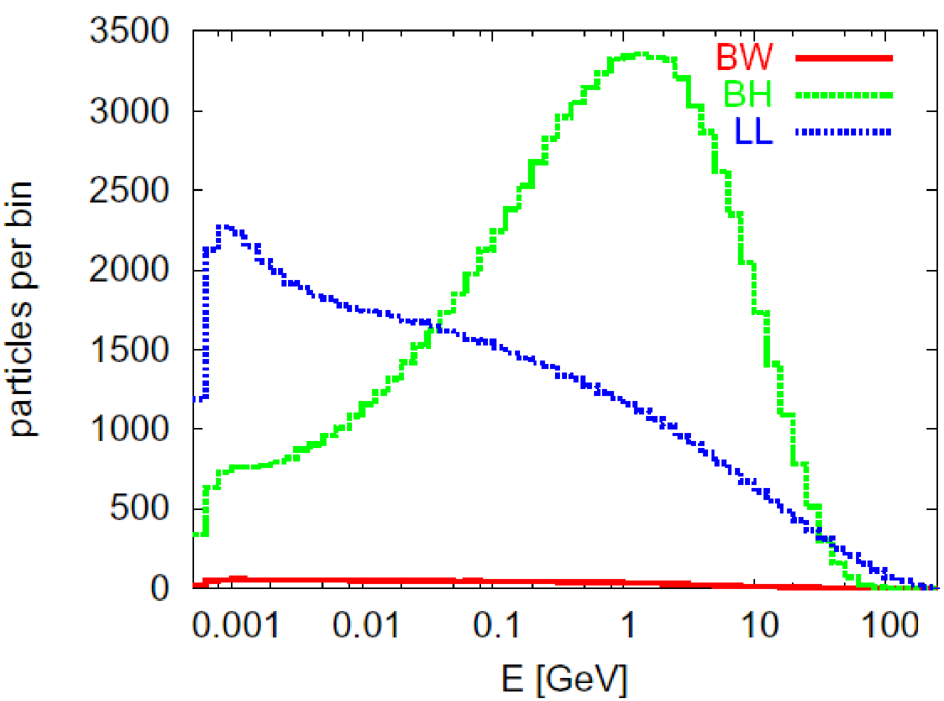
Classical and quantum regime

- The “upsilon” parameter, when it is <<1, has meaning of ratio of photon energy to beam energy
- When Upsilon become ~1 and larger, the classical regime of synchrotron radiation is not applicable, and quantum SR formulas of Sokolov-Ternov should be used.
- Spectrum of SR change …

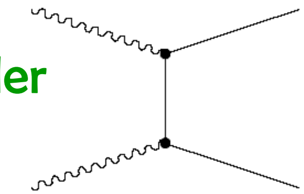


Incoherent* production of pairs

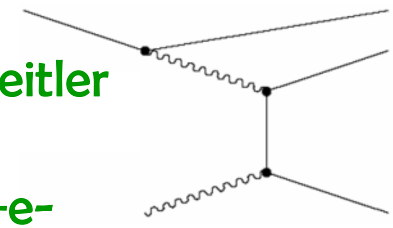
- Beamstrahling photons, particles of beams or virtual photons interact, and create e+e- pairs



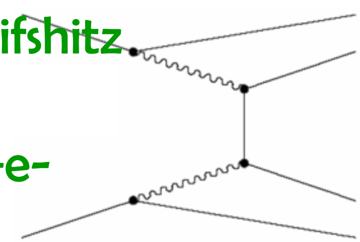
Breit-Wheeler process
$\gamma\gamma \rightarrow$ e+e-



Bethe-Heitler process
$e\gamma \rightarrow$ ee+e-



Landau-Lifshitz process
ee $\rightarrow$ eee+e-



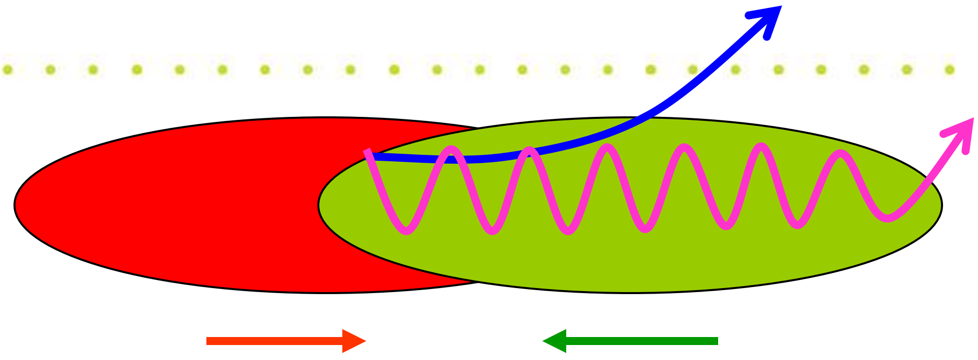
*) Coherent pairs are generated by photon in the field of opposite bunch. It is negligible for ILC parameters.

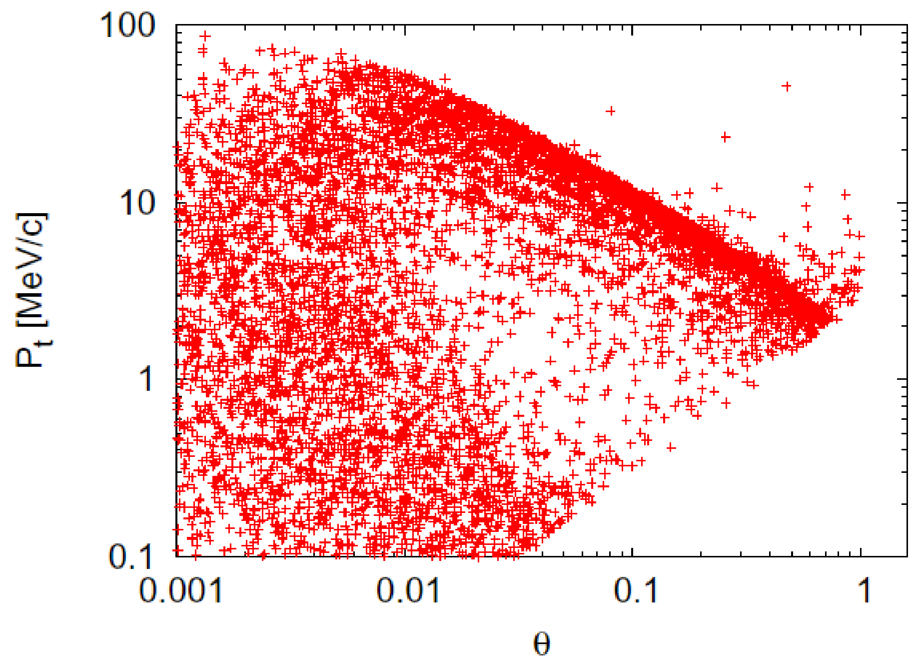
Deflection of pairs by beam

- Pairs are affected by the beam (focused or defocused)
- Deflection angle and P_t correlate
- Max angle estimated as (where ϵ is fractional energy):

$$\theta_m = \sqrt{4\frac{\ln\left(\frac{D}{\epsilon}+1\right) D\sigma_x^2}{\sqrt{3}\epsilon\sigma_z^2}}$$

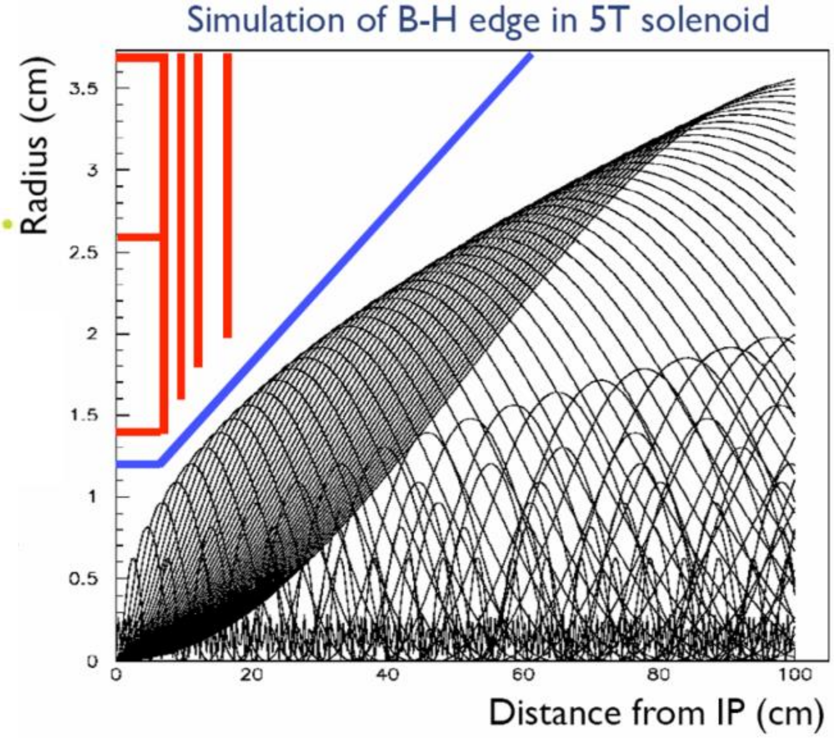
- Bethe-Heitler pairs have hard edge, Landau-Lifshitz pairs are outside

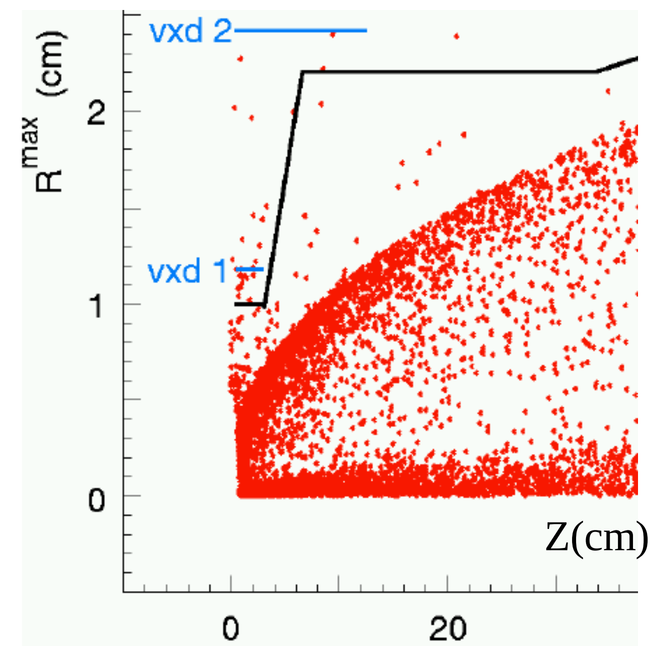




Deflection of pairs by detector solenoid

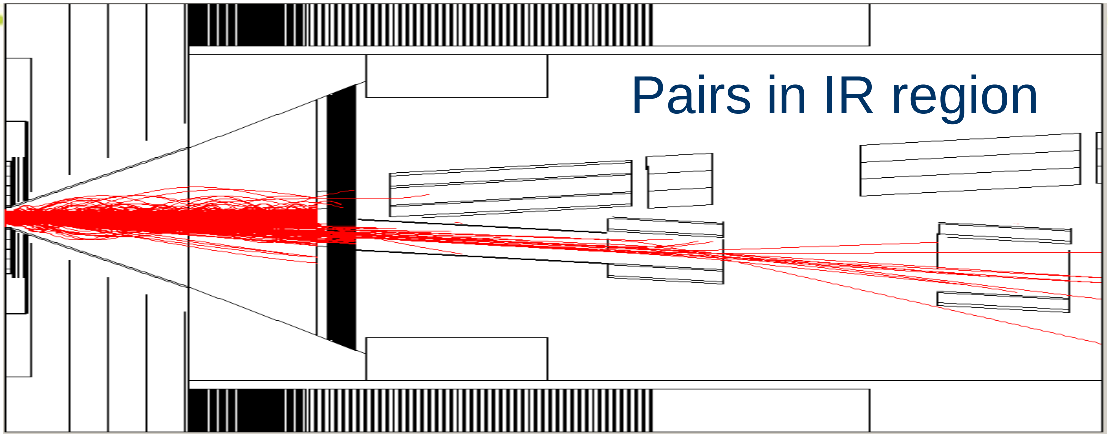
- Pairs are curled by the solenoid field of detector
- Geometry of vertex detector and vacuum chamber chosen in such a way that most of pairs (B-H) do not hit the apertures
- Only small number (L-L) of pairs would hit the VX apertures

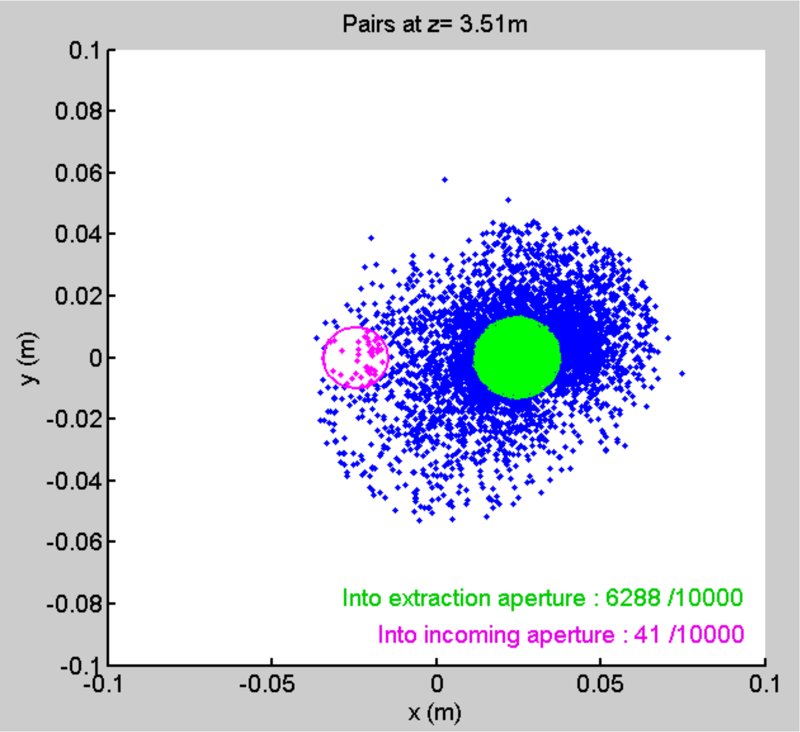


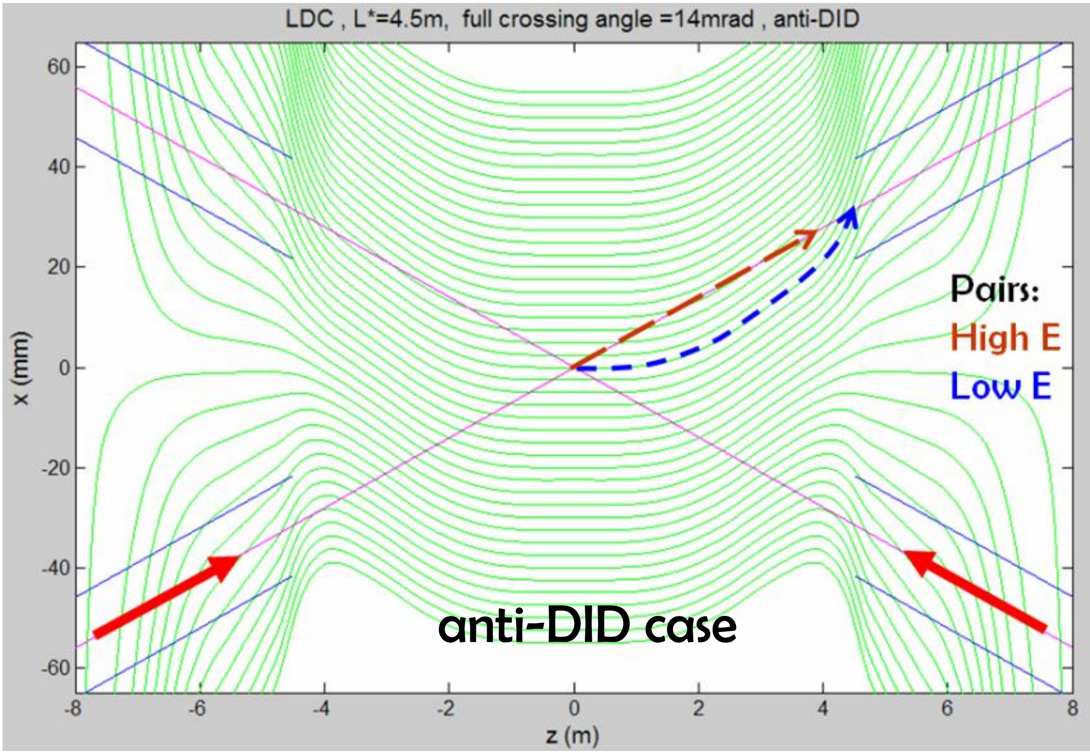


Use of anti-DID to direct pairs

Anti-DID field can be used to direct most of pairs into extraction hole and thus improve somewhat the background conditions







Overview of beam-beam parameters (D_y, δ_E , Υ)

$$\mathrm{Lumi} \sim H_D \frac{N^2}{\sigma_x \sigma_y}$$

- Luminosity per bunch crossing. H_D – luminosity enhancement

$$D_y \sim \frac{N\,\sigma_z}{\gamma\,\sigma_x \sigma_y}$$

- "Disruption" – characterize focusing strength of the field of the bunch ($D_y \sim \sigma_z / f_{beam}$)

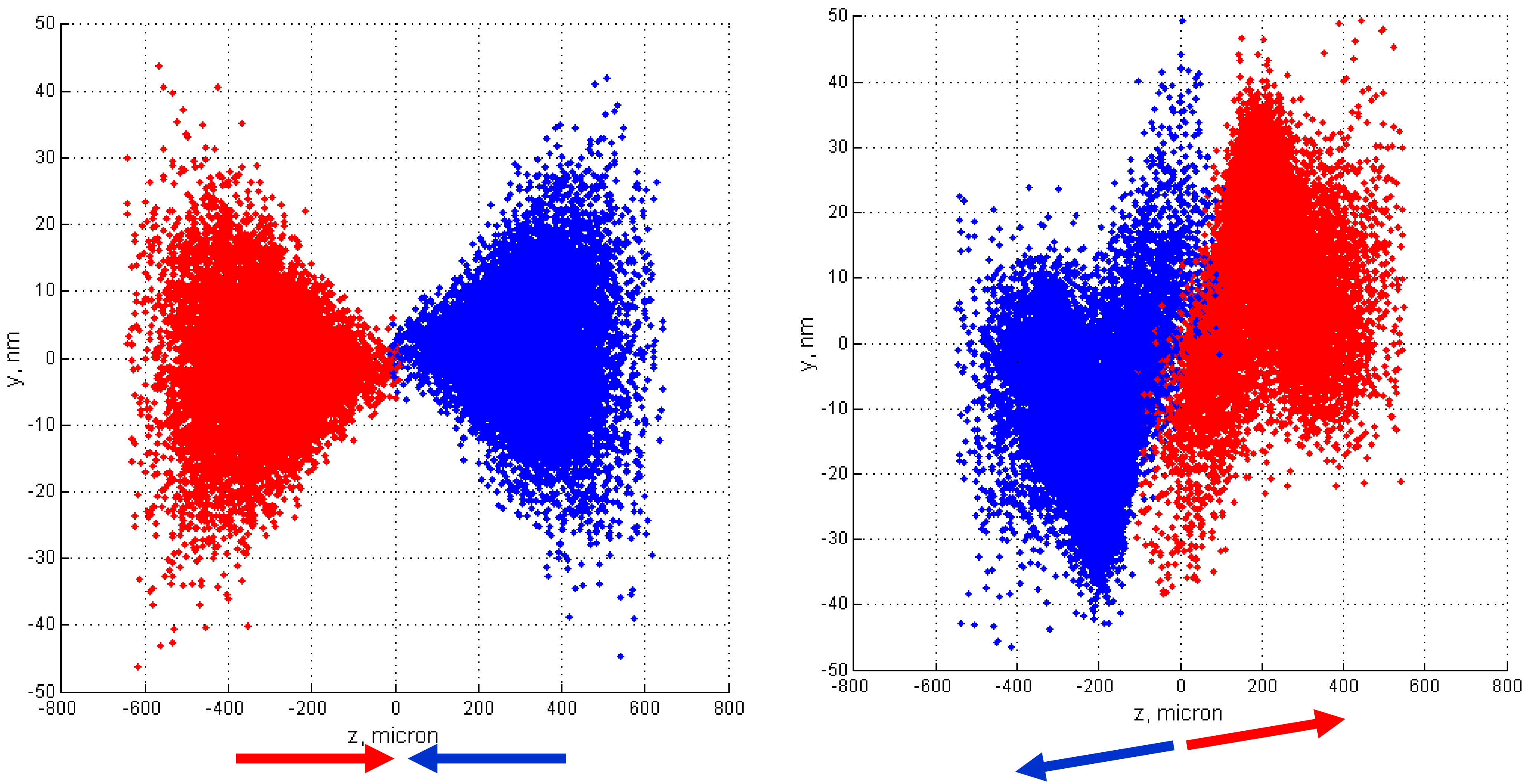
$$\delta_E \sim \frac{N^2 \gamma}{\sigma_x^2\,\sigma_z}$$

- Energy loss during beam-beam collision due to synchrotron radiation

$$\Upsilon \sim \frac{N\,\gamma}{\sigma_x \sigma_z}$$

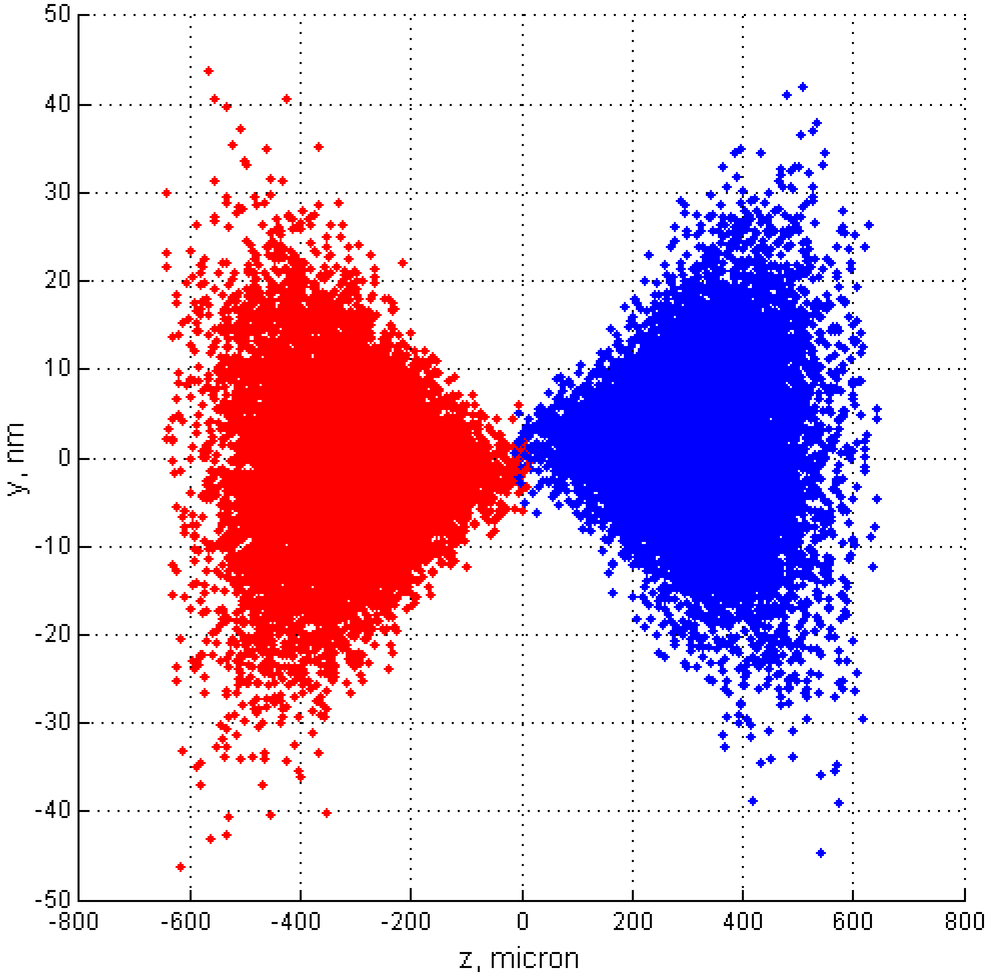
- Ratio of critical photon energy to beam energy (classic or quantum regime)

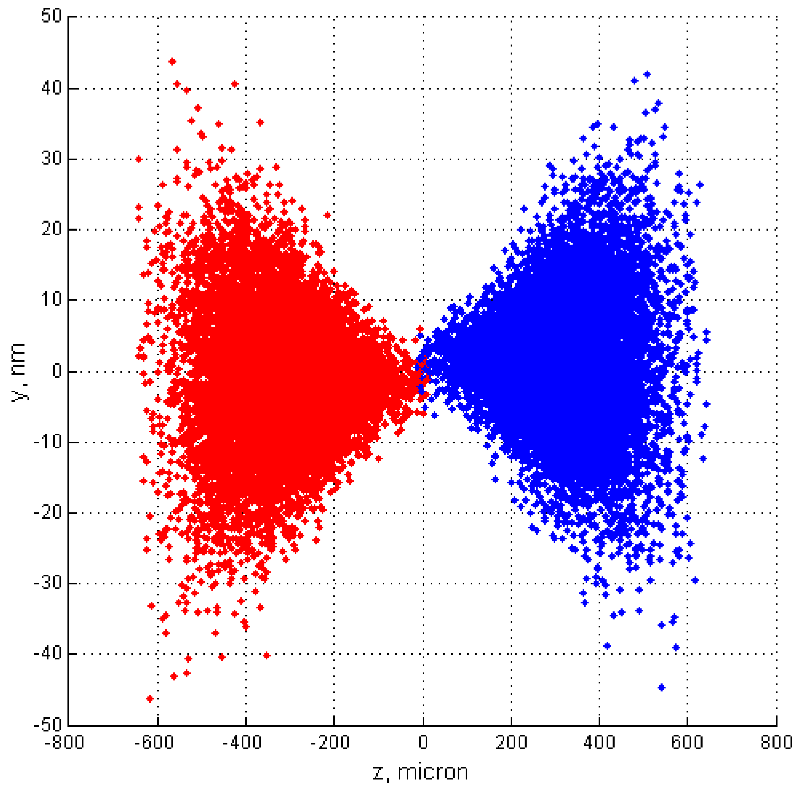
Beam-beam deflection



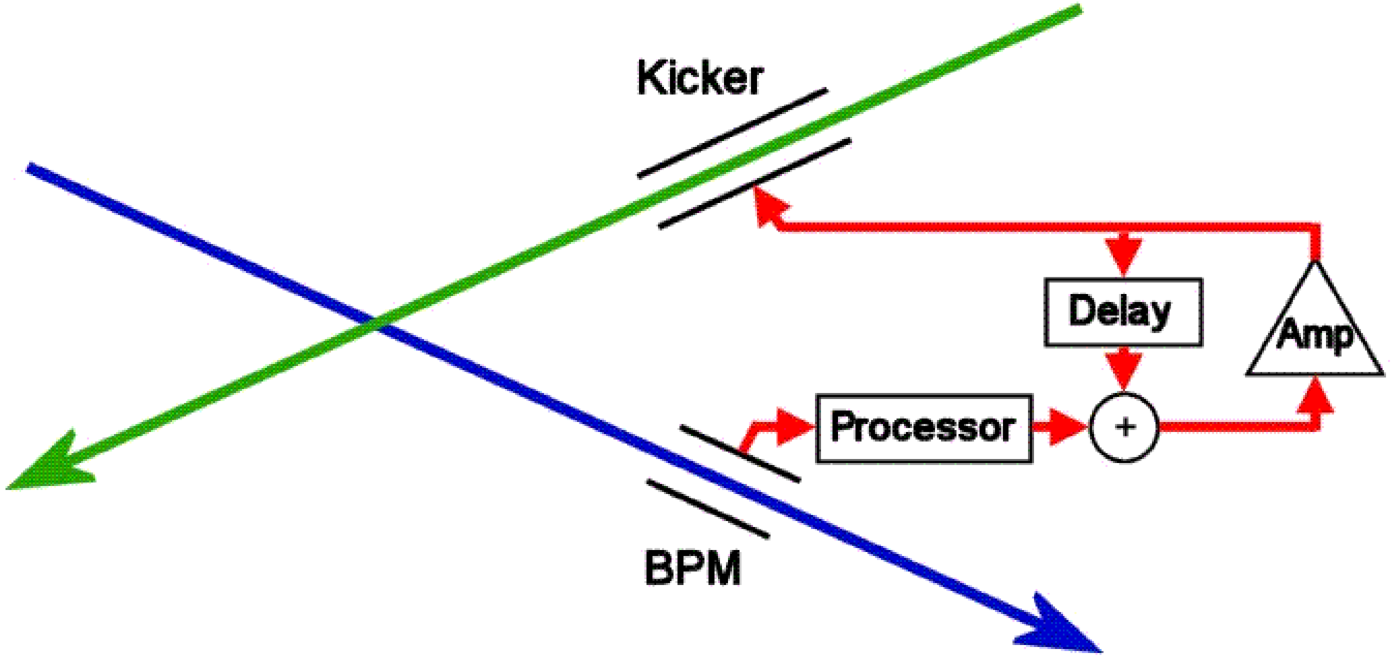
Sub nm offsets at IP cause large well detectable offsets (micron scale) of the beam a few meters downstream

Beam-beam deflection allow to control collisions




50
40
30
20
10
0
-10
-20
-30
-40
-50
y, nm
-800
-600
-400
-200
0
200
400
600
800
z, micron

Beam-Beam orbit feedback

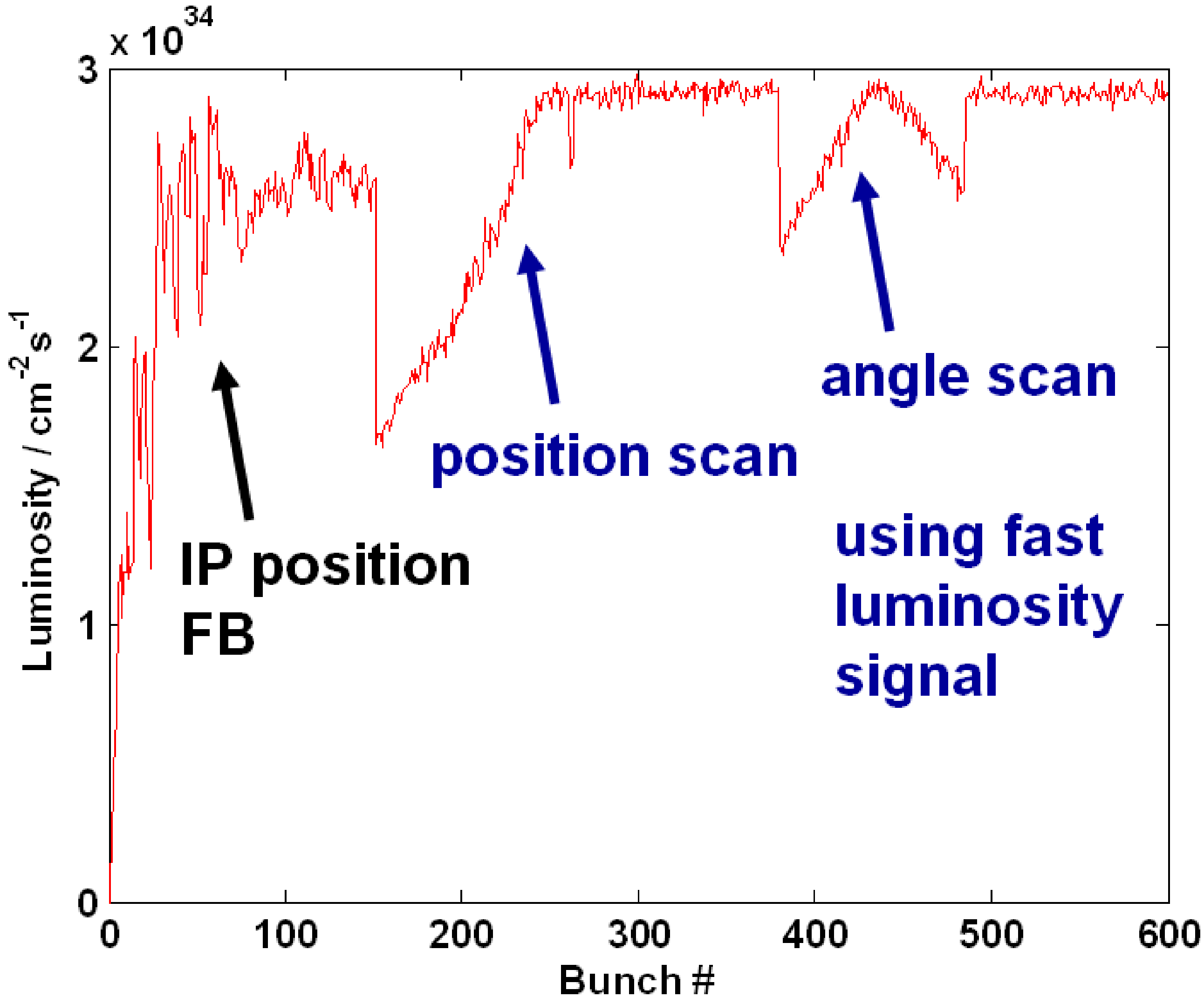


use strong beam-beam kick to keep beams colliding

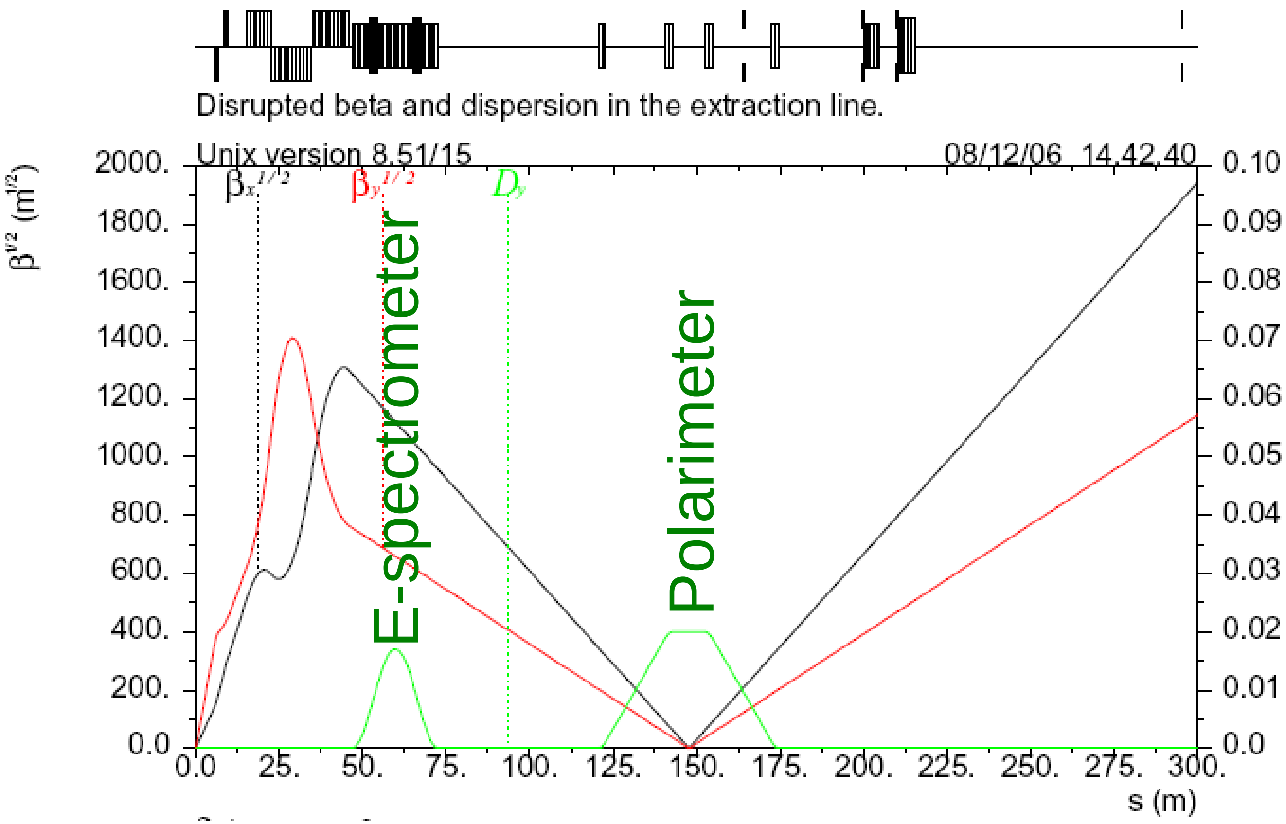
ILC intratrain simulation

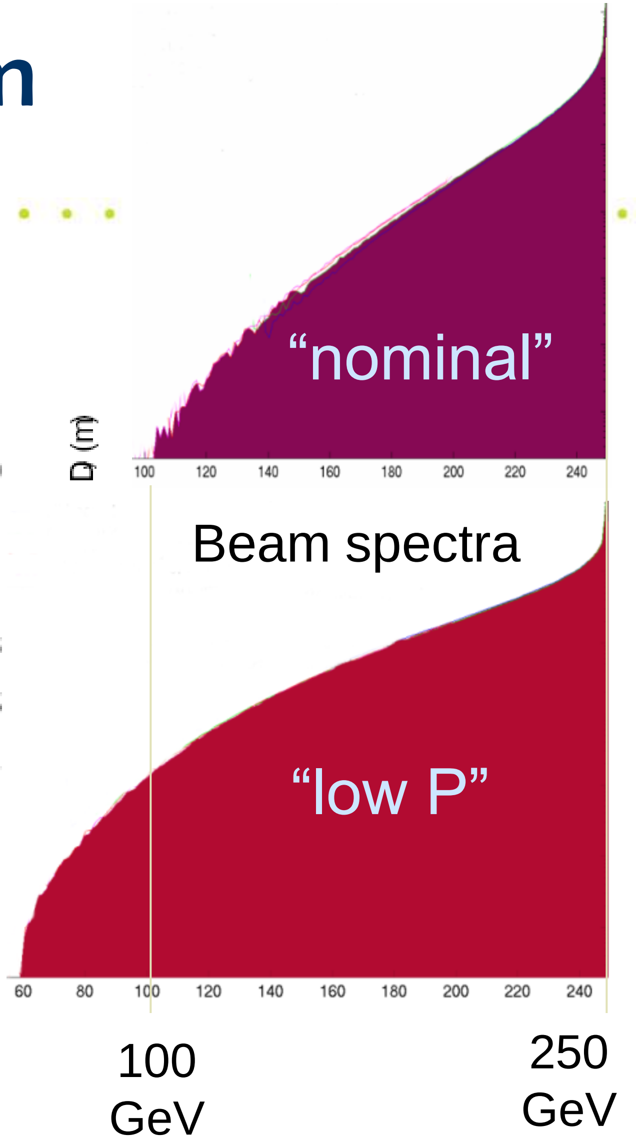
ILC intratrain feedback (IP position and angle optimization), simulated with realistic errors in the linac and “banana” bunches.

[Glen White]



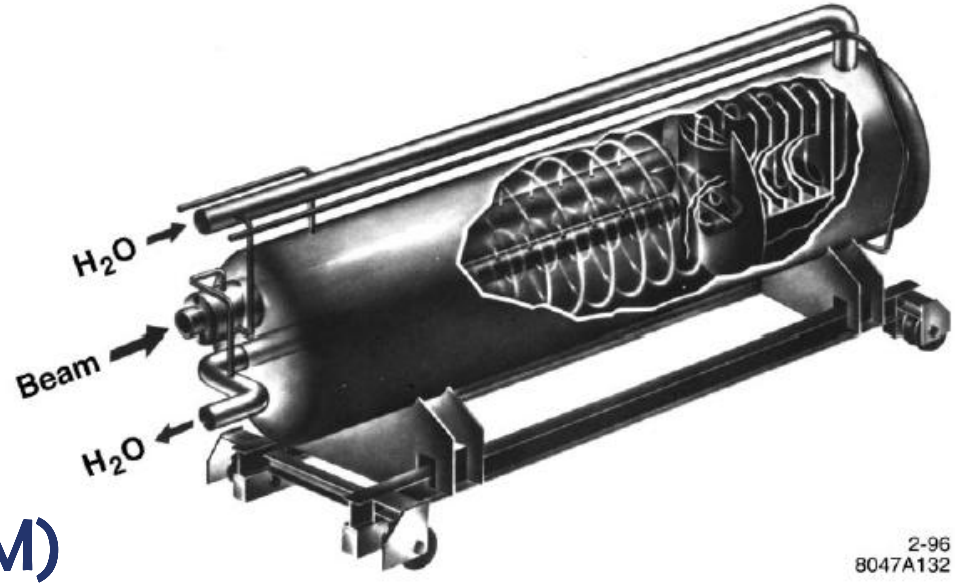
Optics for outgoing beam





Extraction optics need to handle the beam with ~60% energy spread, and provides energy and polarization diagnostics

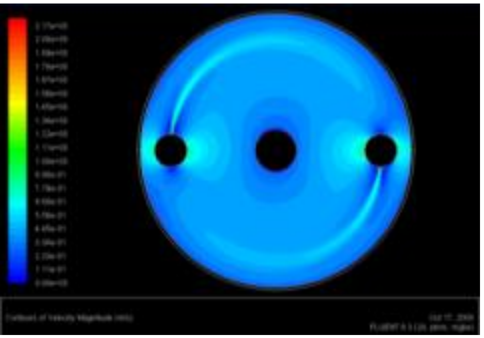
Beam dump



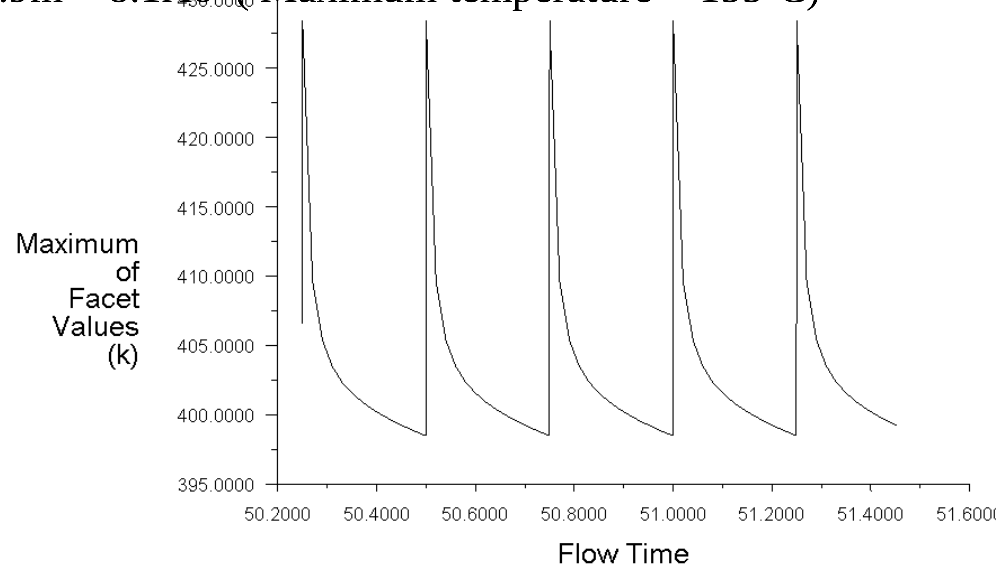
- 17MW power (for 1TeV CM)
- Rastering of the beam on 30cm double window
- 6.5m water vessel; ~1m/s flow
- 10atm pressure to prevent boiling
- Three loop water system
- Catalytic H_2-O_2 recombiner
- Filters for 7Be
- Shielding 0.5m Fe & 1.5m concrete

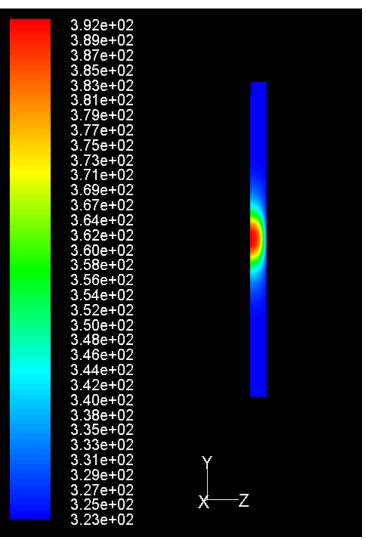
Beam dump design updates

Maximum temperature variation as a function of time at z = 2.9m ≡ 8.1Xo. (Maximum temperature = 155^{0}C)



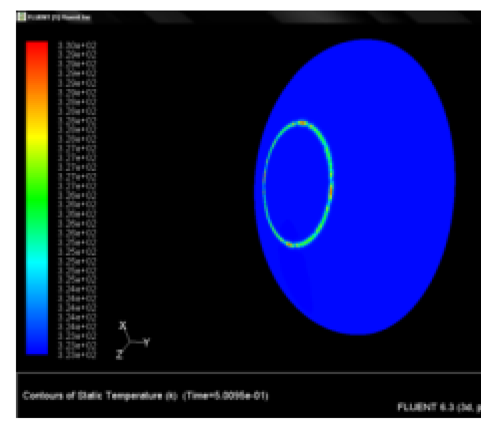
Velocity contours (inlet velocity: 2.17m/s, mass flux: 19kg/m/s)





Temperature distribution across the cross-section of the End plate

Window temperature distribution just when the beam train completes energy deposition. (Max temp : 57^{0}C)

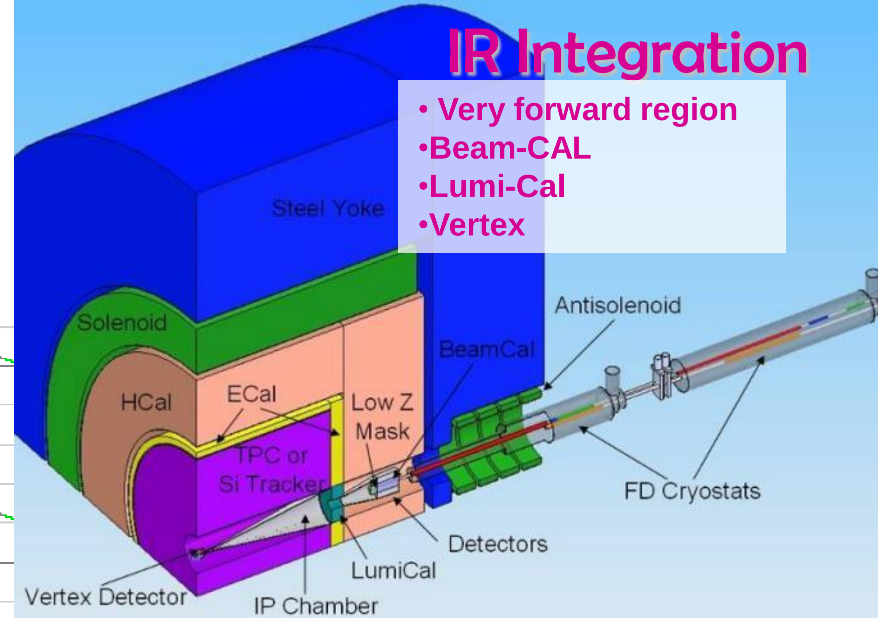


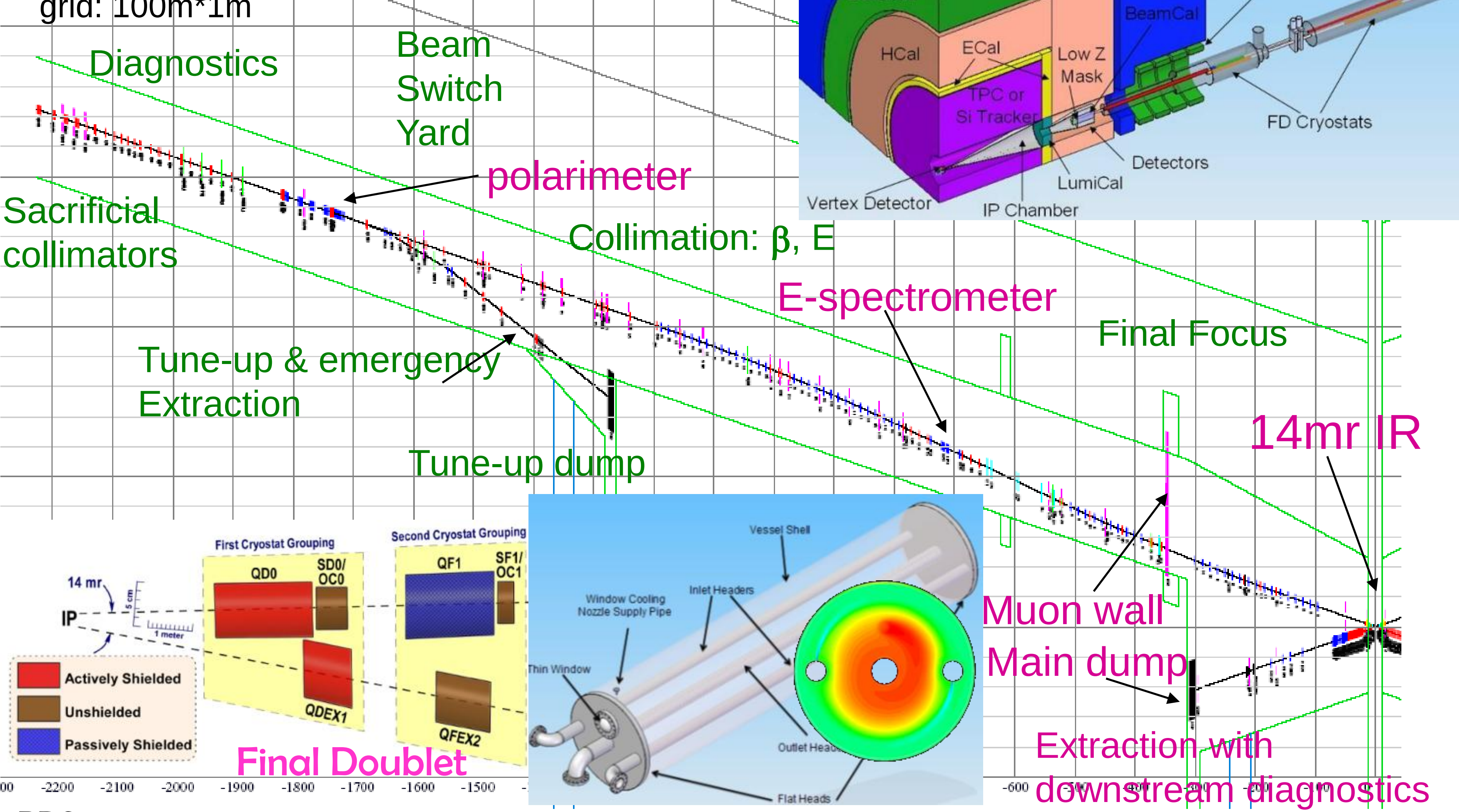
D. Walz , J. Amann, et al, SLAC
P. Satyamurthy, P. Rai, V. Tiwari, K. Kulkarni, BARC, Mumbai, India

From IPAC10 paper

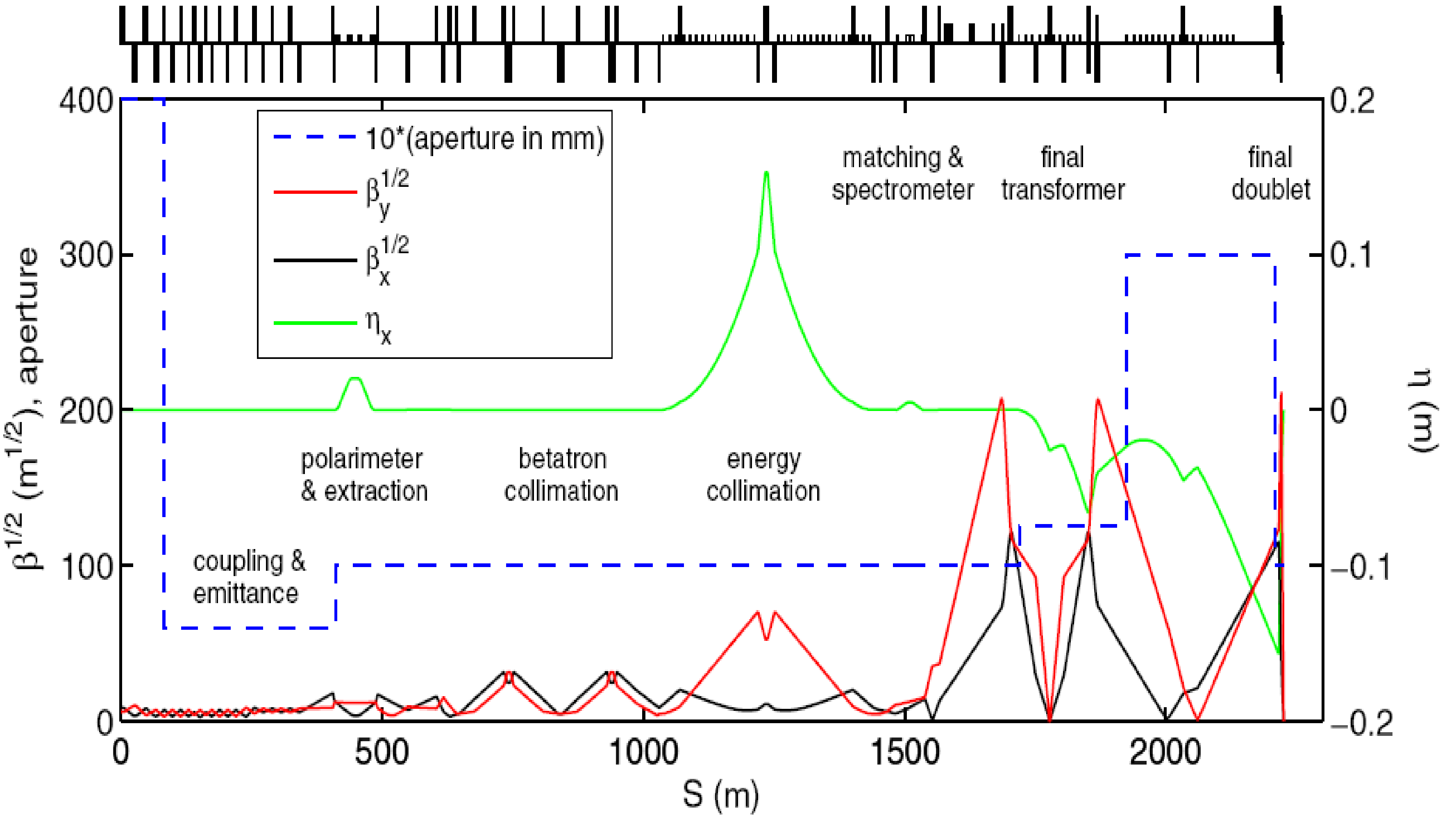
Beam Delivery & MDI elements

1TeV CM, single IR, two detectors, push-pull

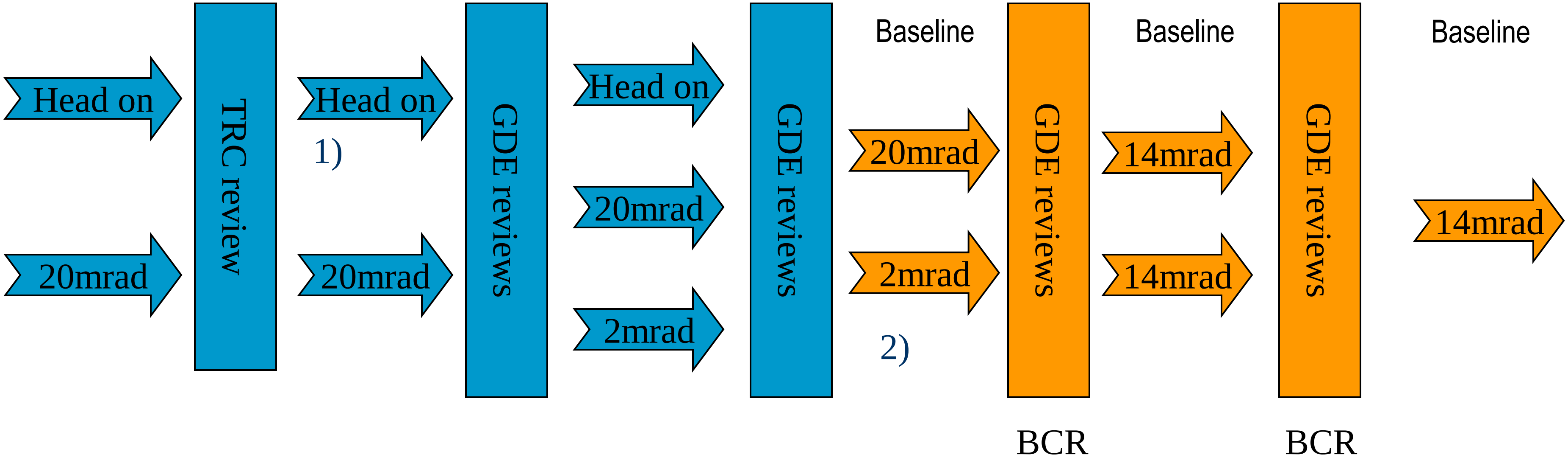




ILC BDS Optical Functions



BDS & MDI Configuration Evolution

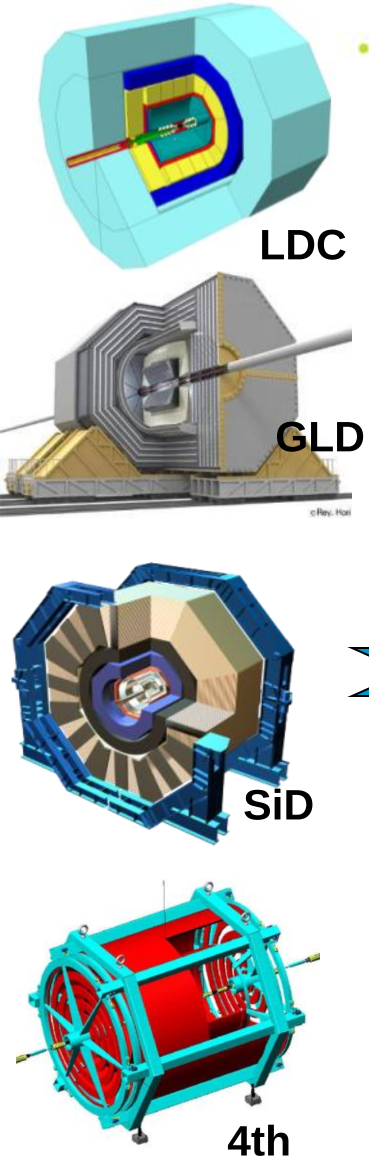


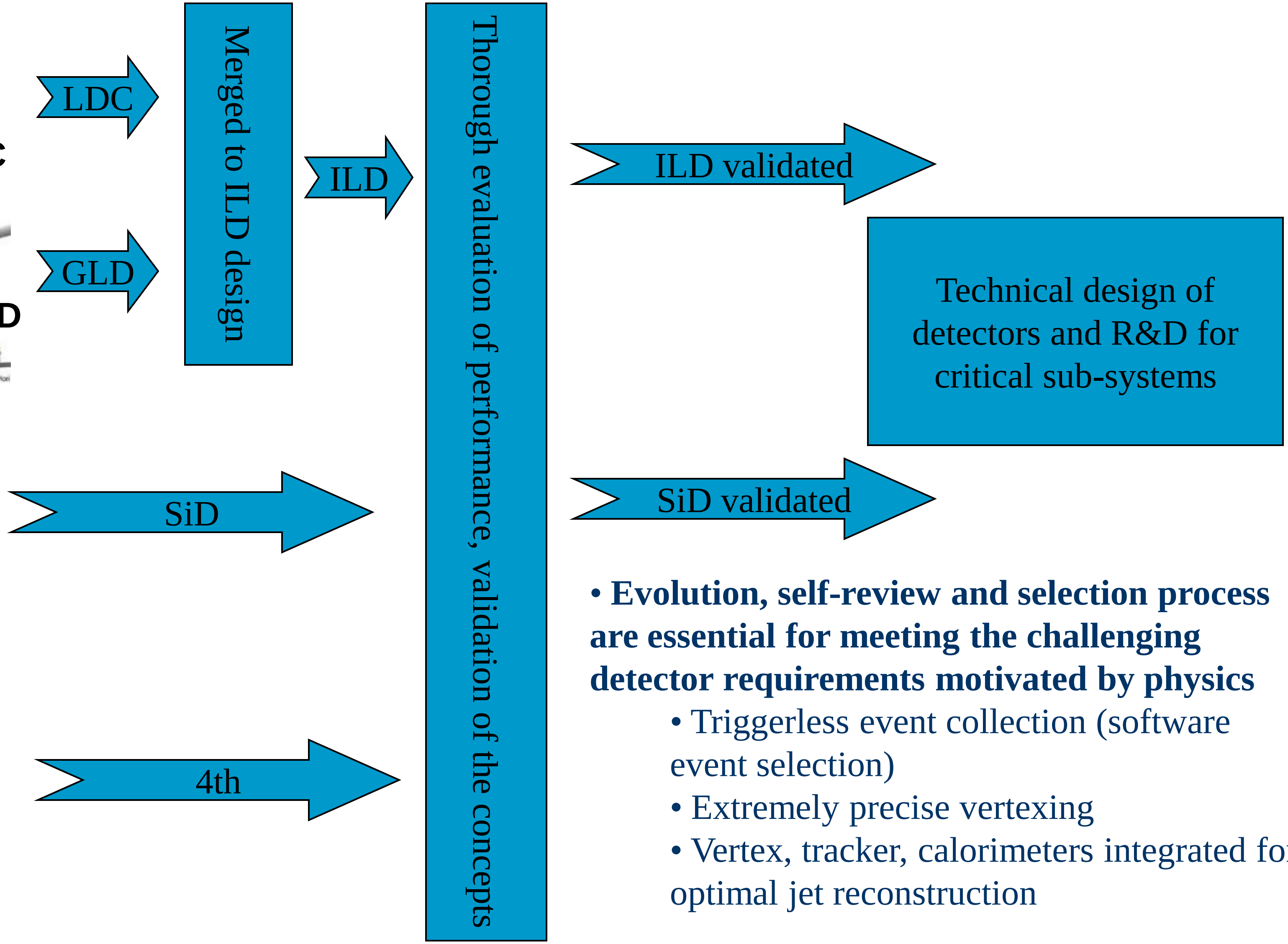
- **Evolution of BDS MDI configuration**
    - Head on; small crossing angle; large crossing angle

- MDI & Detector performance were the major criteria for selection of more optimal configuration at every review or decision point

1) Found unforeseen losses of beamstrahlung photons on extraction septum blade
2) Identified issues with losses of extracted beam, and its SR; realized cost non-effectiveness of the design

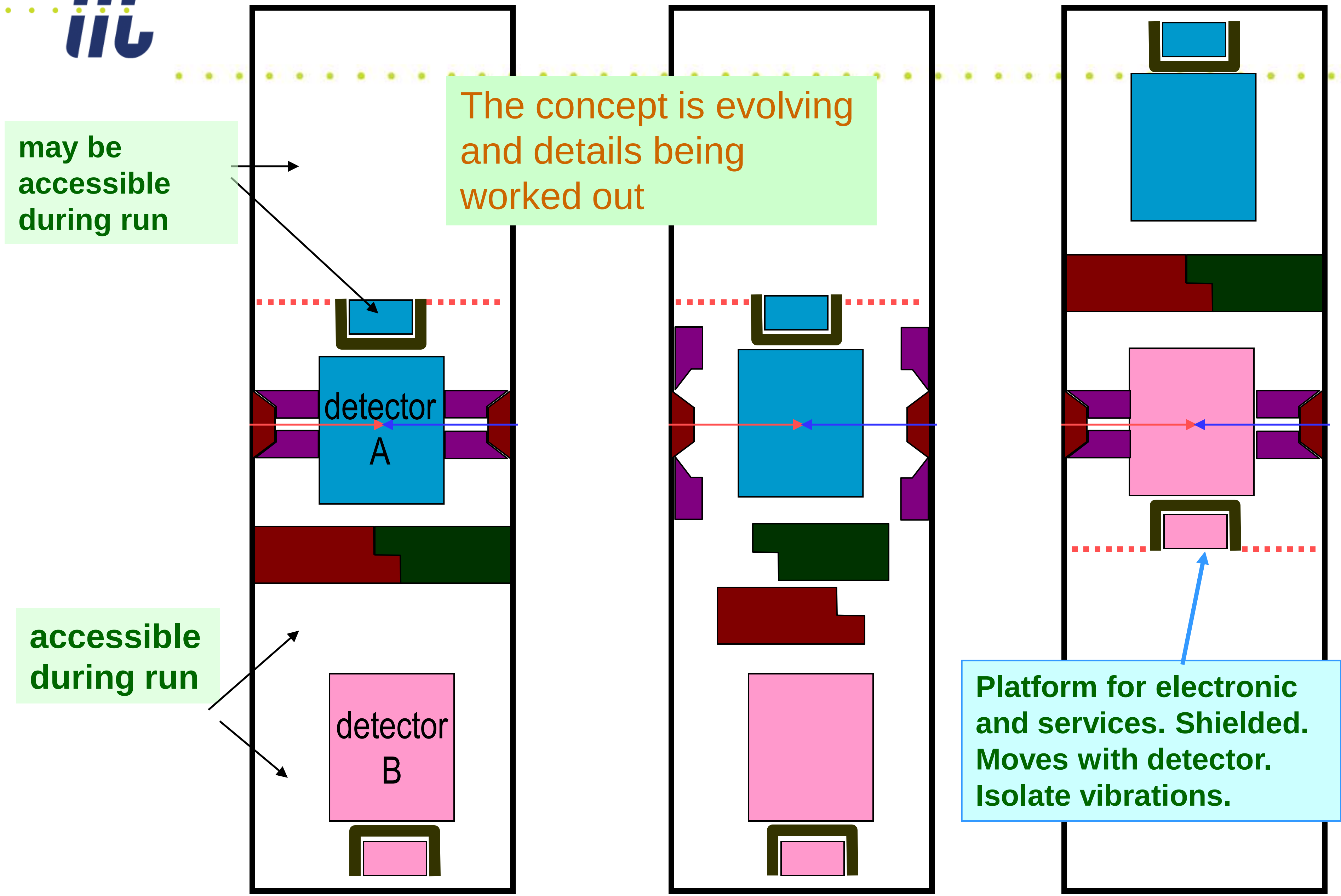
Evolution of ILC Detectors



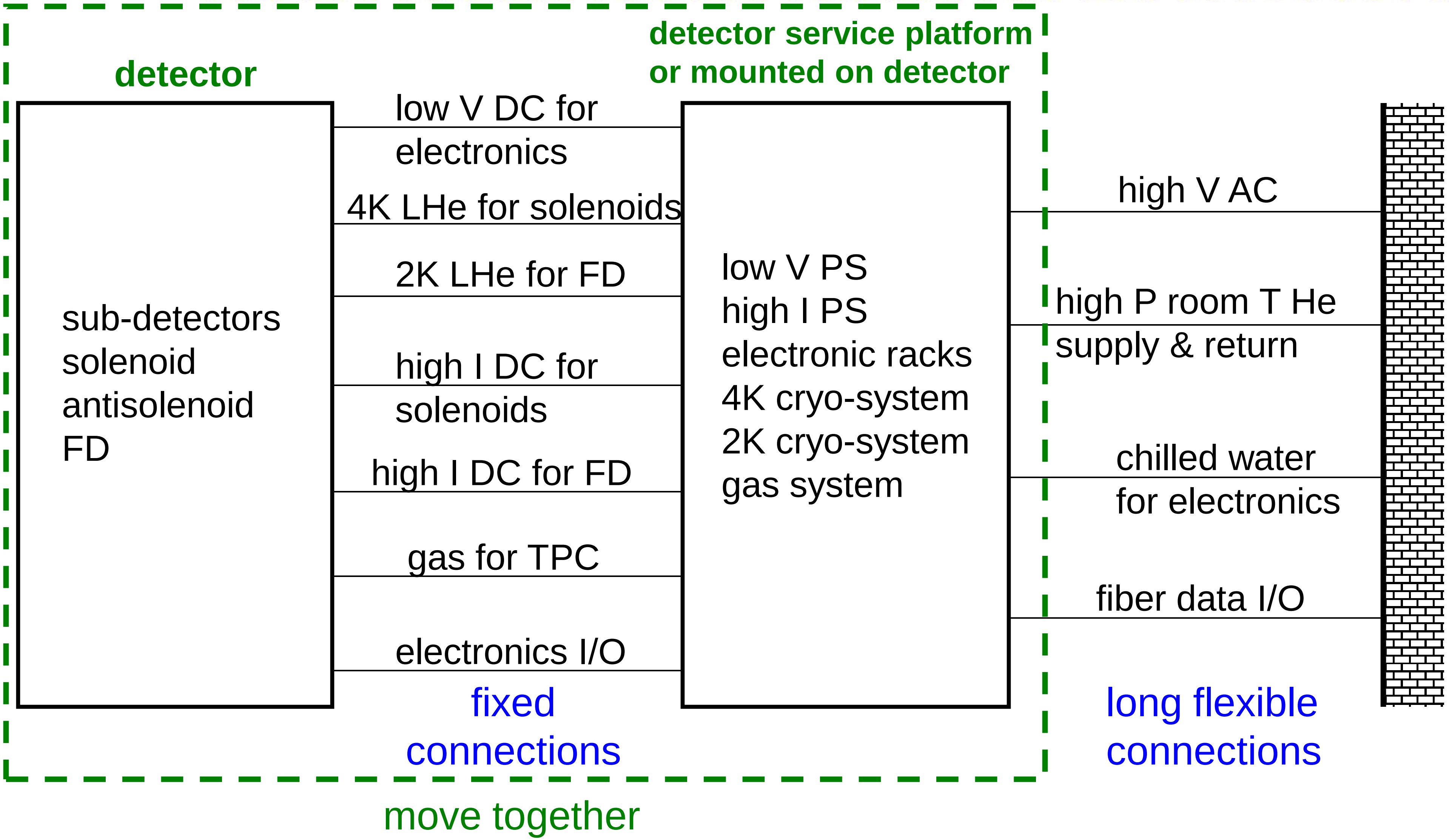


- **Evolution, self-review and selection process are essential for meeting the challenging detector requirements motivated by physics**
    - Triggerless event collection (software event selection)
    - Extremely precise vertexing
    - Vertex, tracker, calorimeters integrated for optimal jet reconstruction

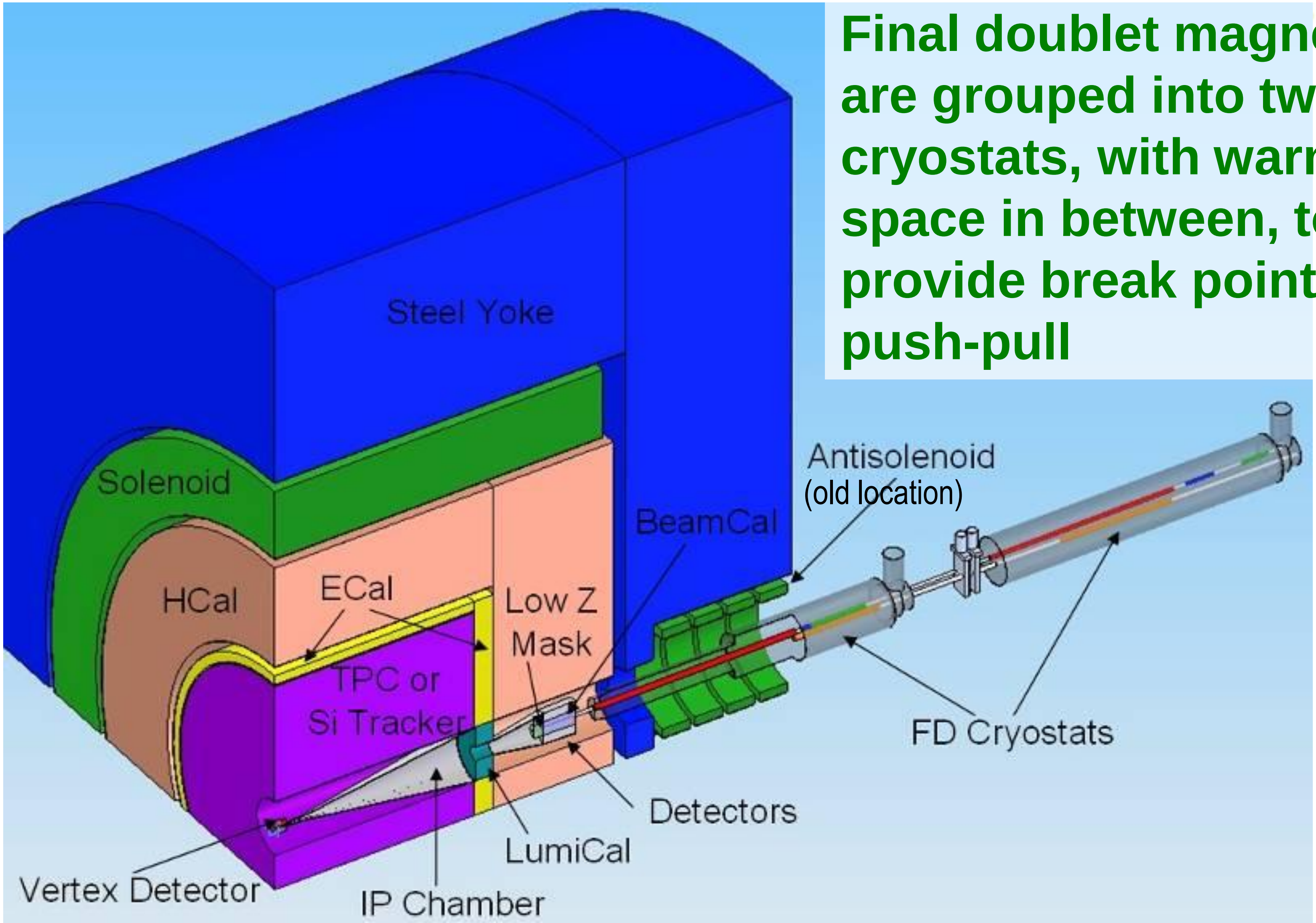
Concept of single IR with two detectors



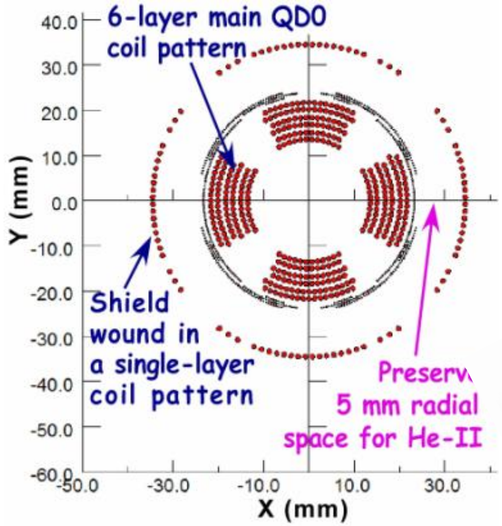
Concept of detector systems connections



IR integration

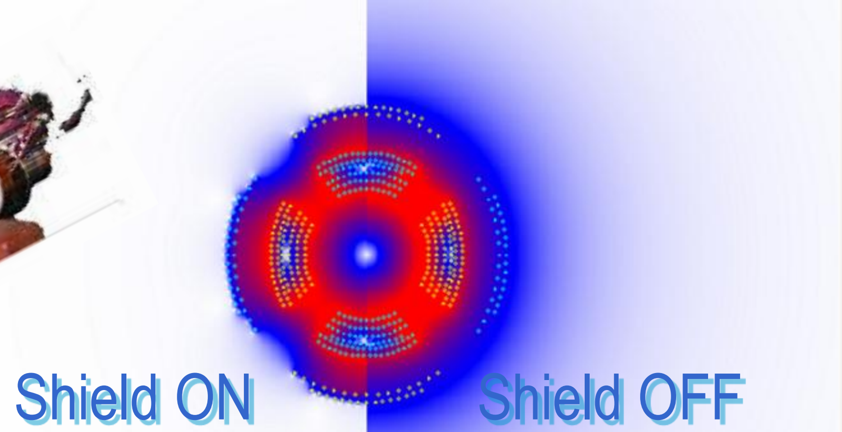


Final doublet magnets are grouped into two cryostats, with warm space in between, to provide break point for push-pull

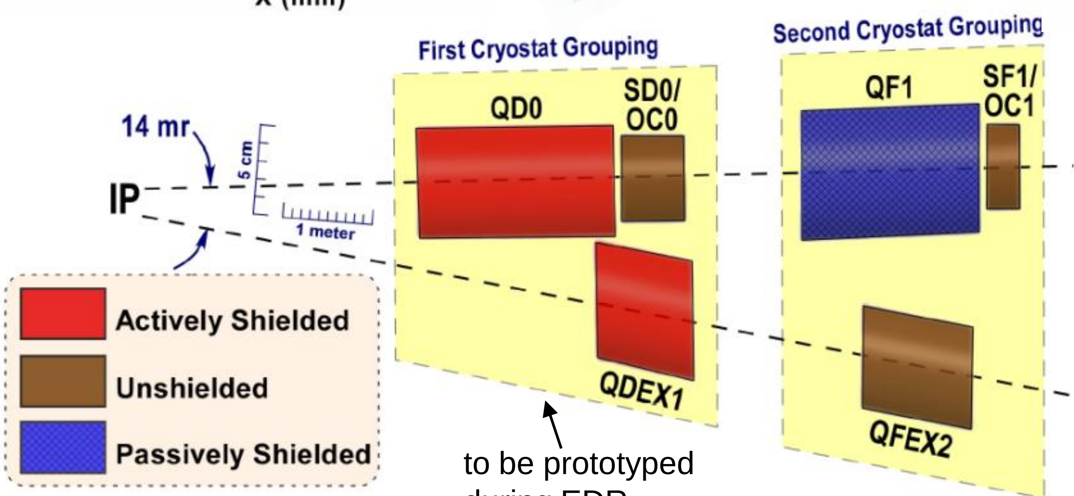


Actively shielded QD0

BNL

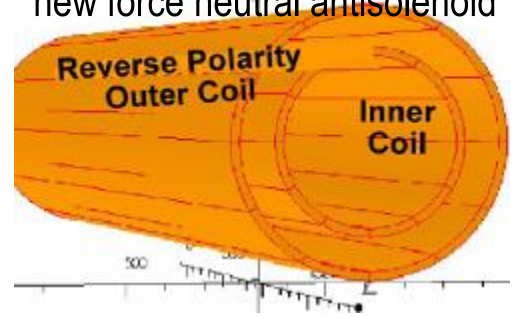


Intensity of color represents value of magnetic field.



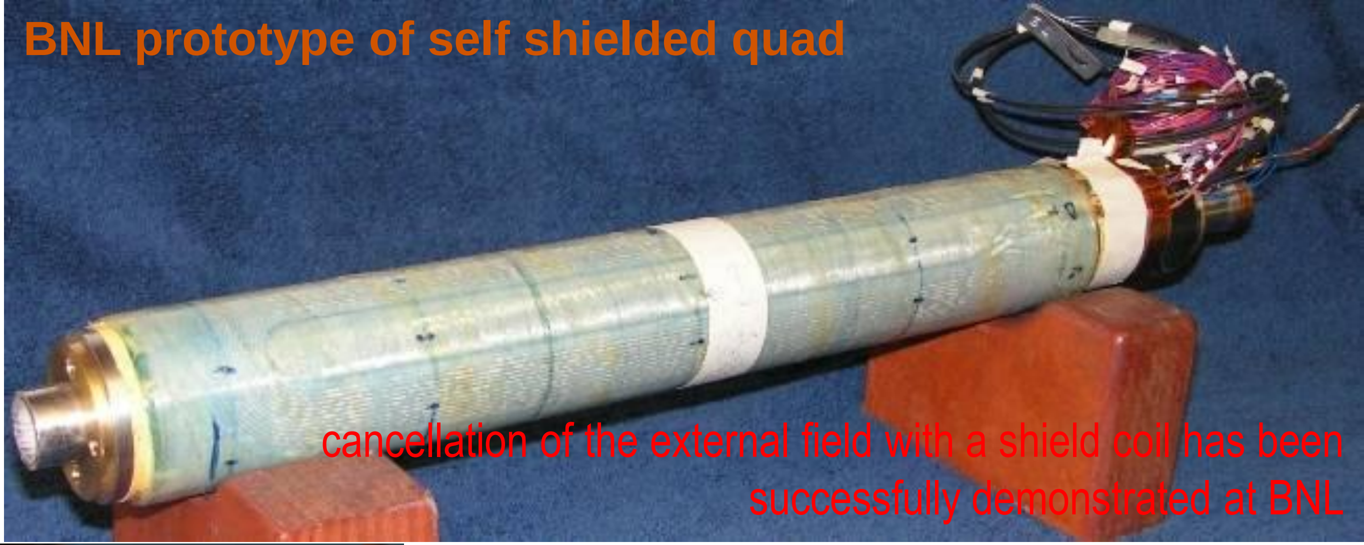
Two Coils; Different Radii

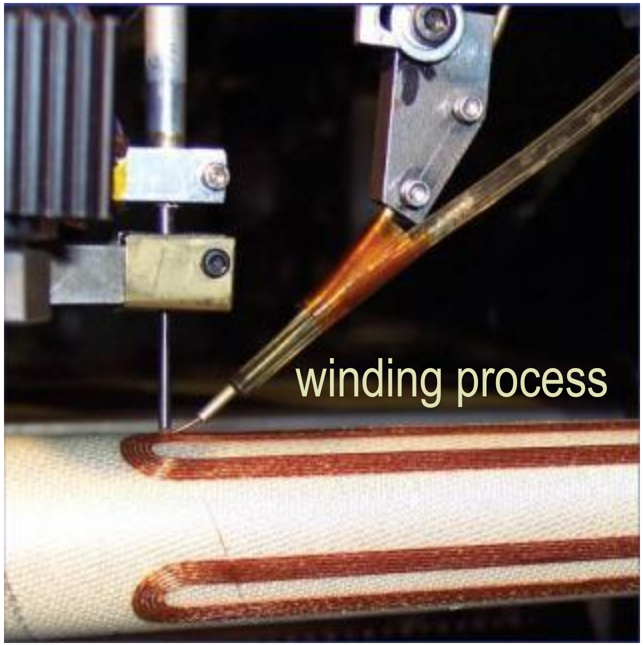
new force neutral antisolenoid

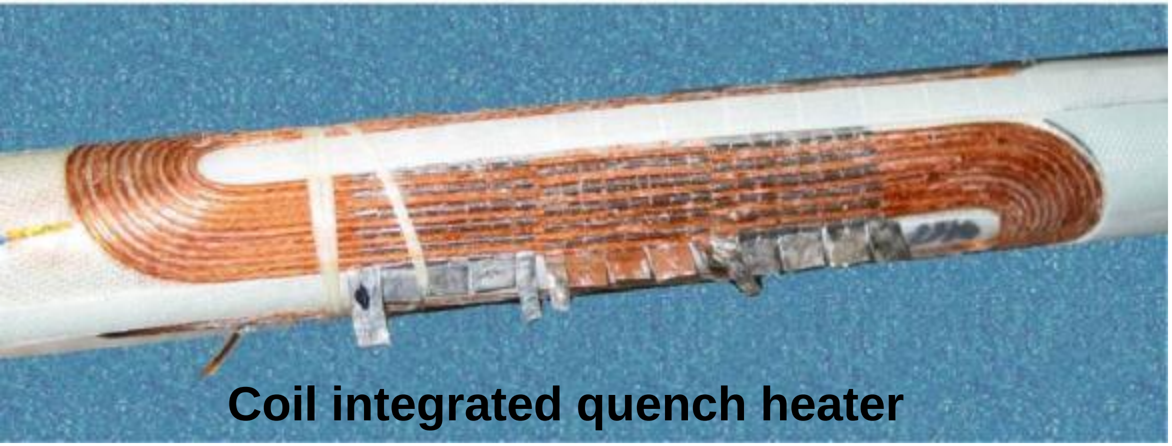


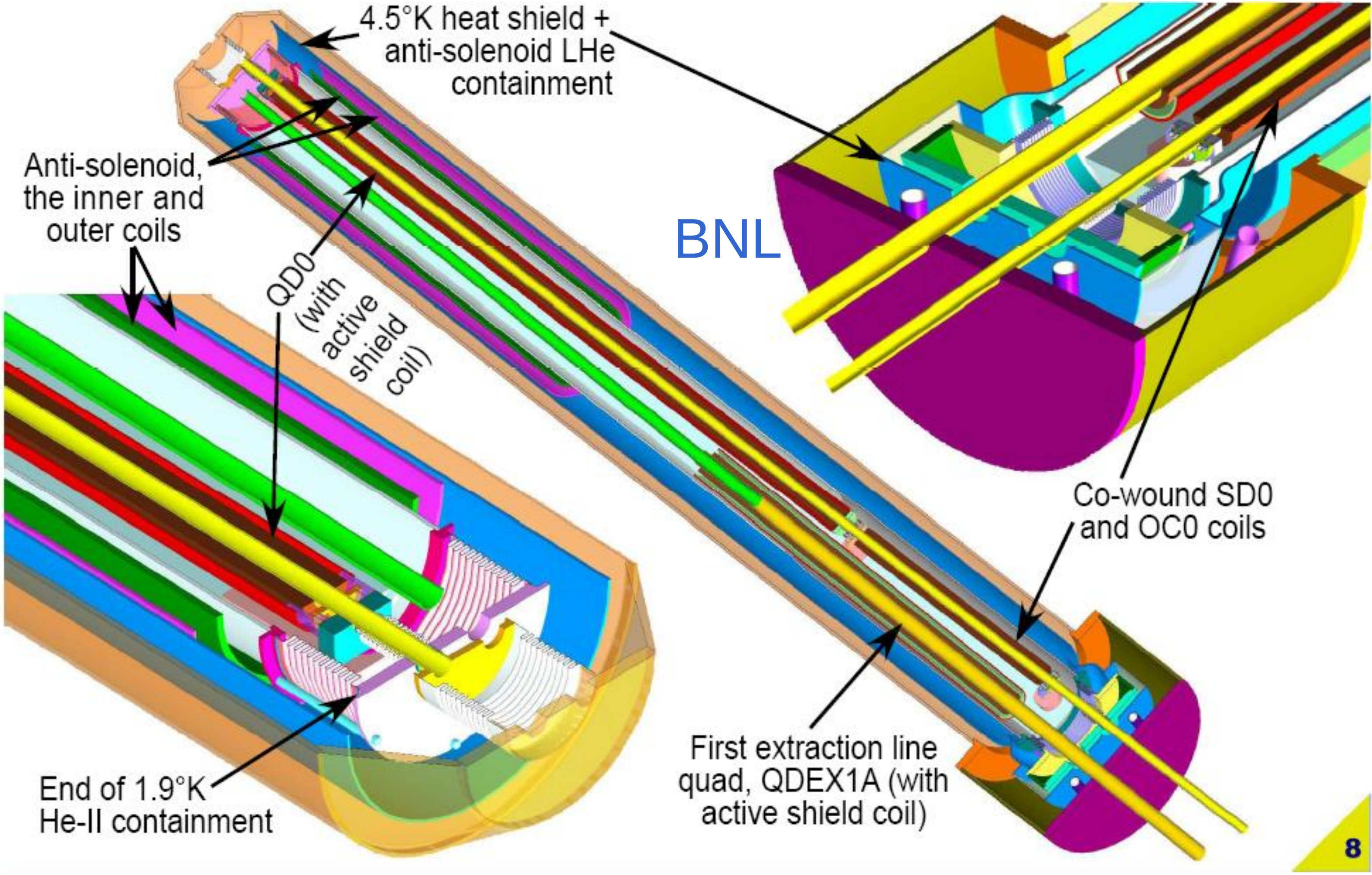
- Interaction region uses compact self-shielding SC magnets
- Independent adjustment of in- & out-going beamlines
- Force-neutral anti-solenoid for local coupling correction

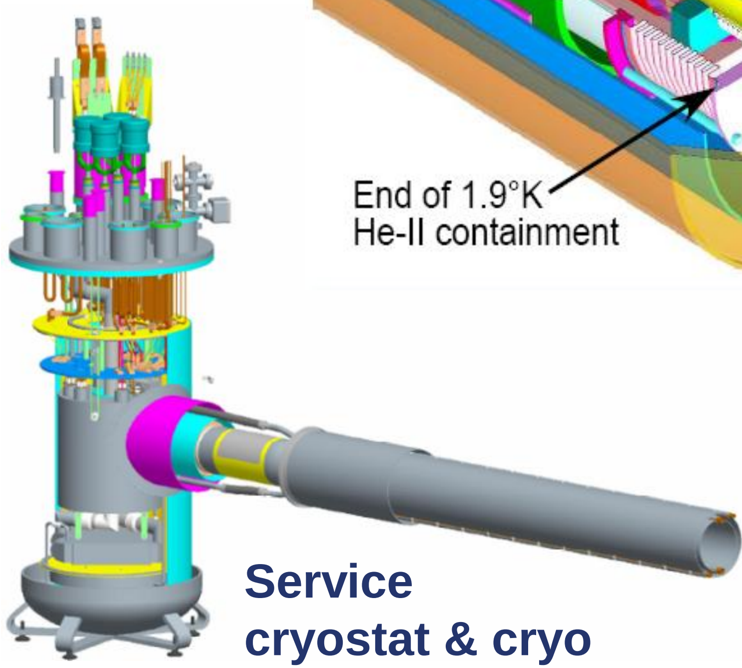
IR magnets prototypes at BNL







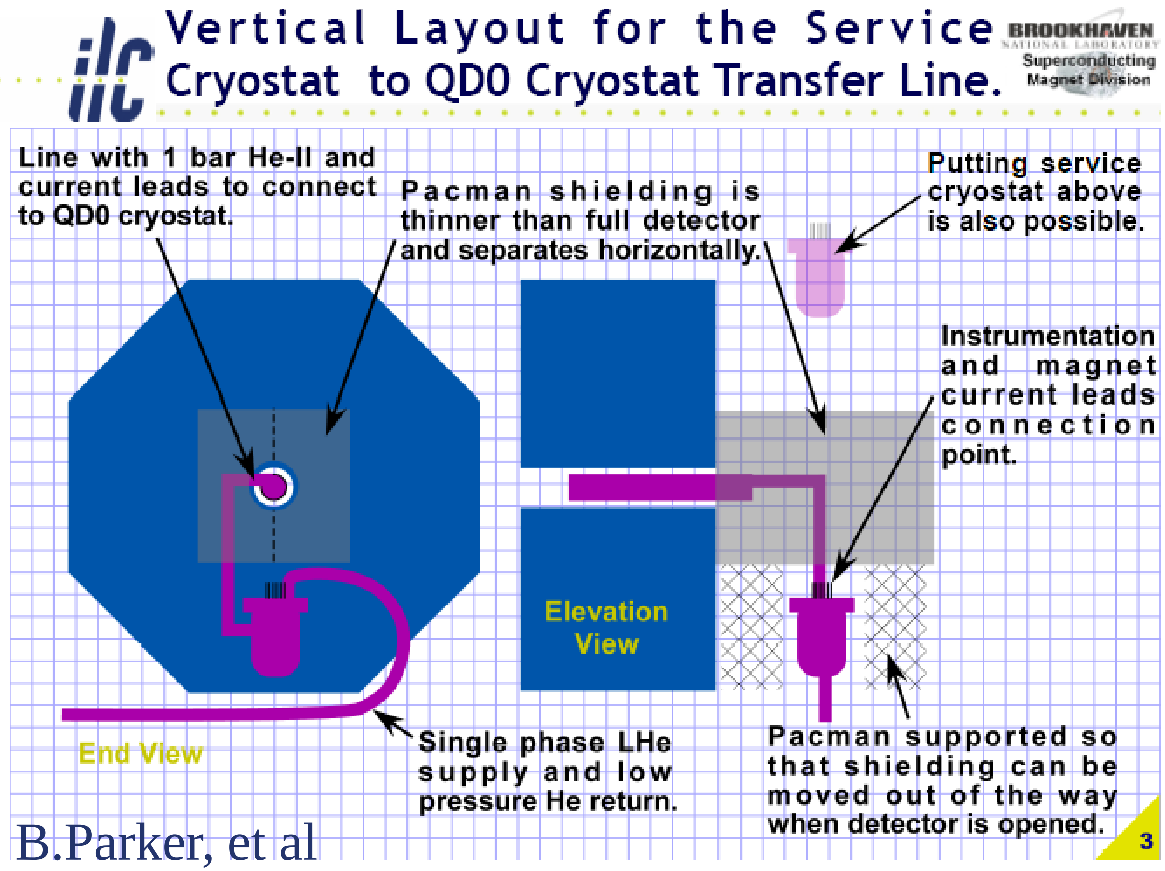


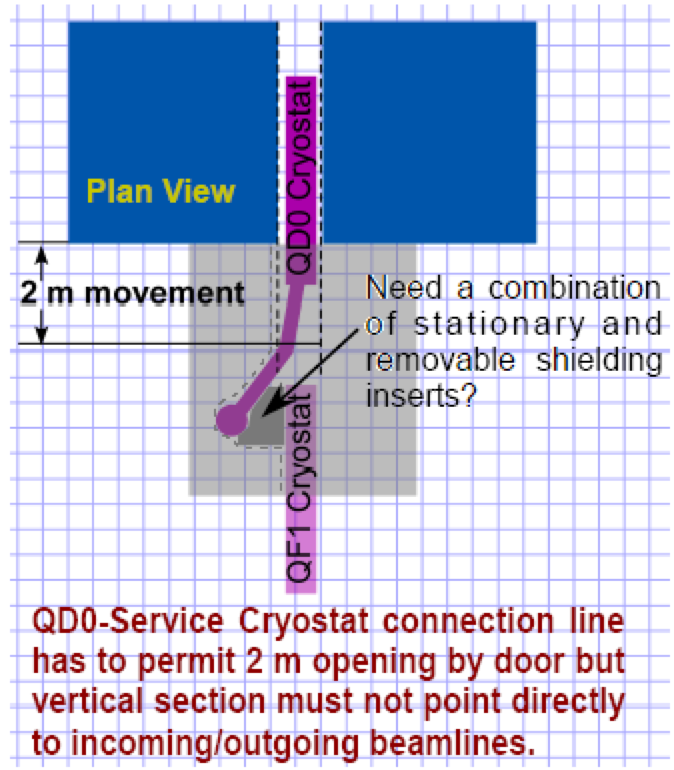


Service cryostat & cryo connections

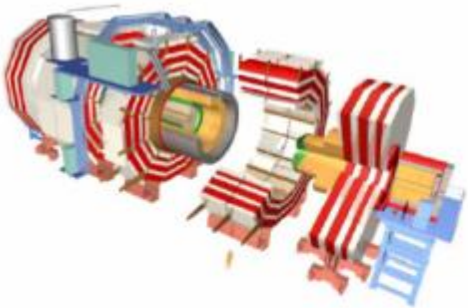
- **Detailed engineering design of IR magnets and their integration has started**

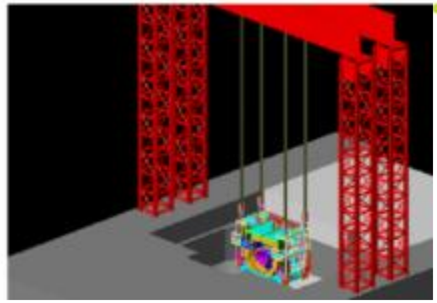
Present concept of cryo connection





Detector assembly

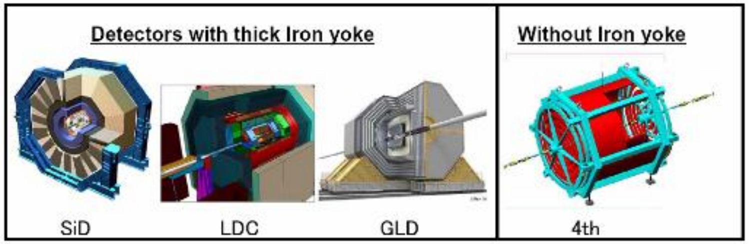




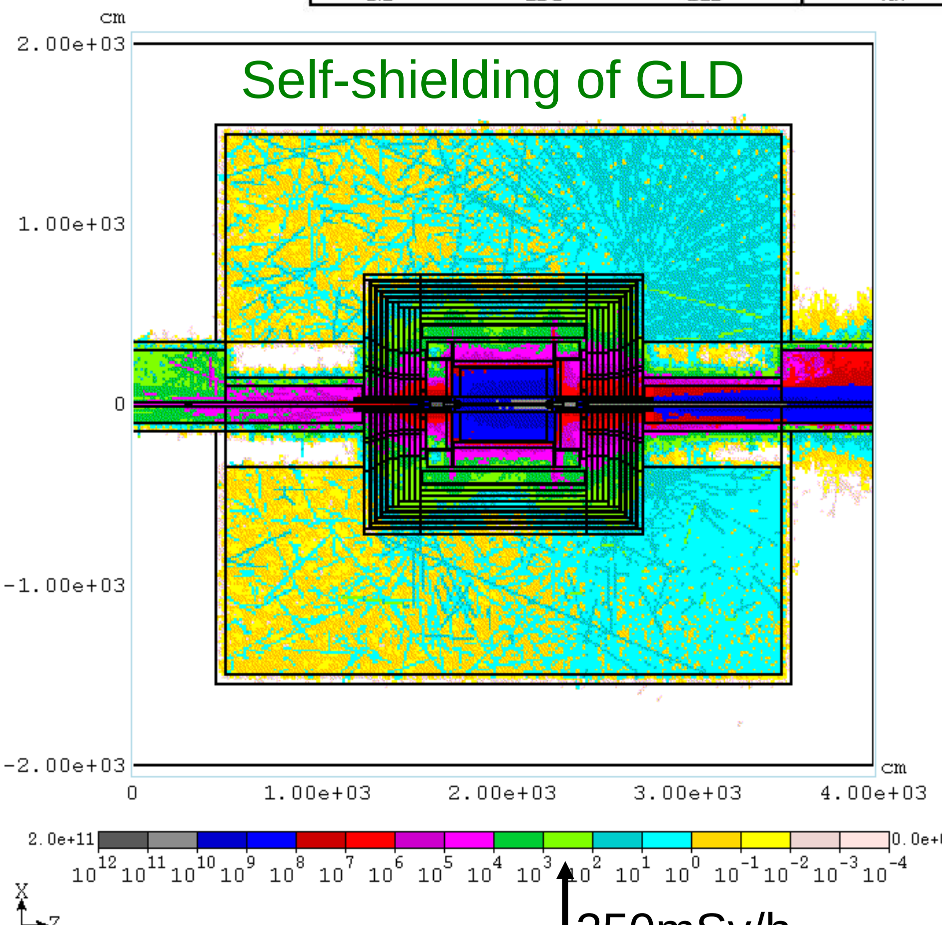
- CMS detector assembled on surface in parallel with underground work, lowered down with rented crane
- Adopted this method for ILC, to save 2-2.5 years that allows to fit into 7 years of construction

photos courtesy CERN colleagues

Shielding the IR hall

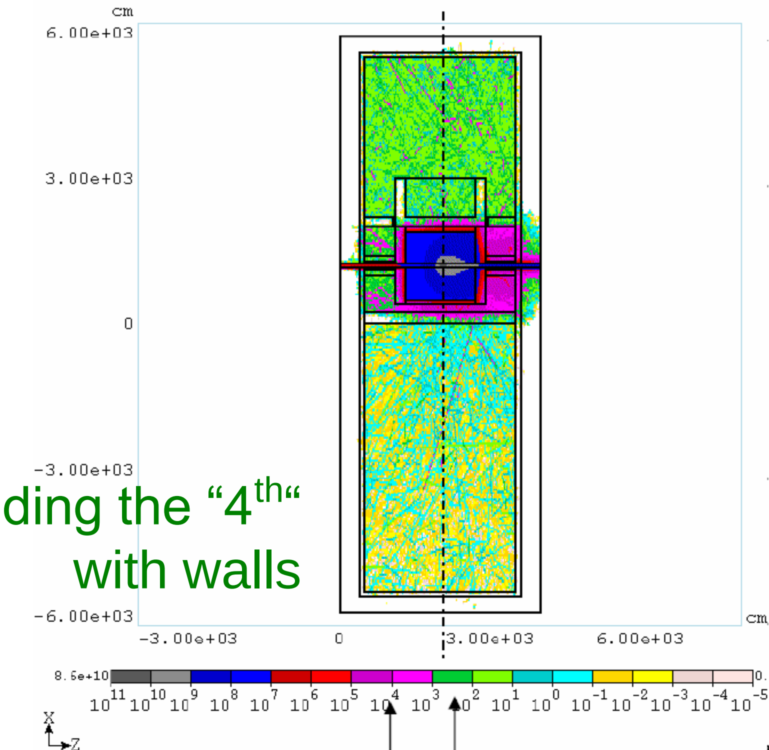


Self-shielding of GLD

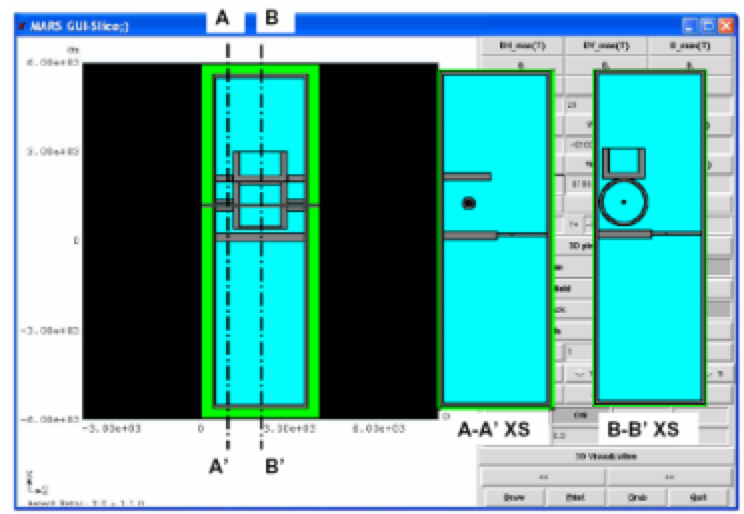


250mSv/h

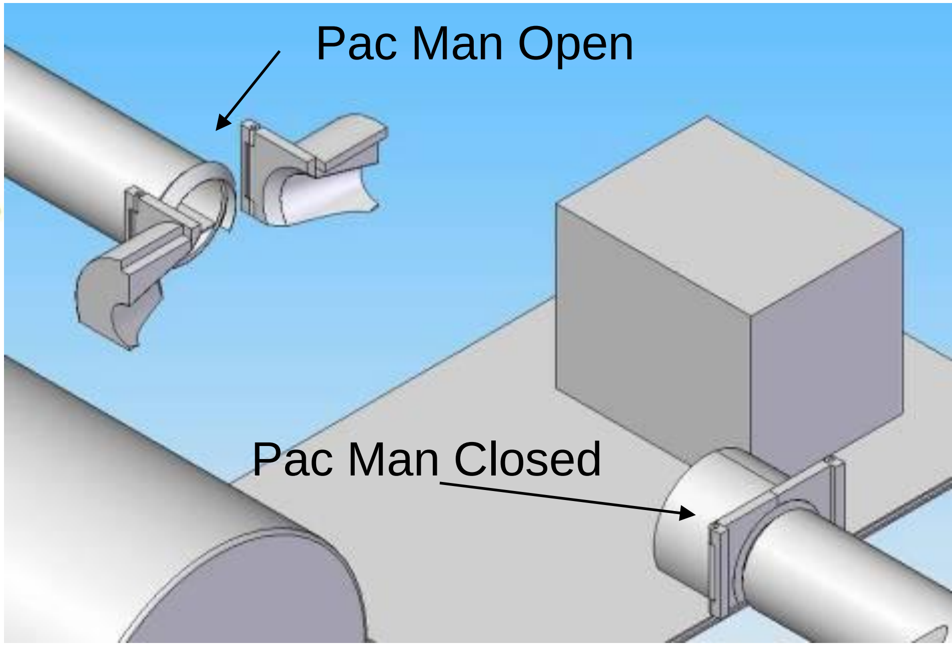
Shielding the “4th“ with walls

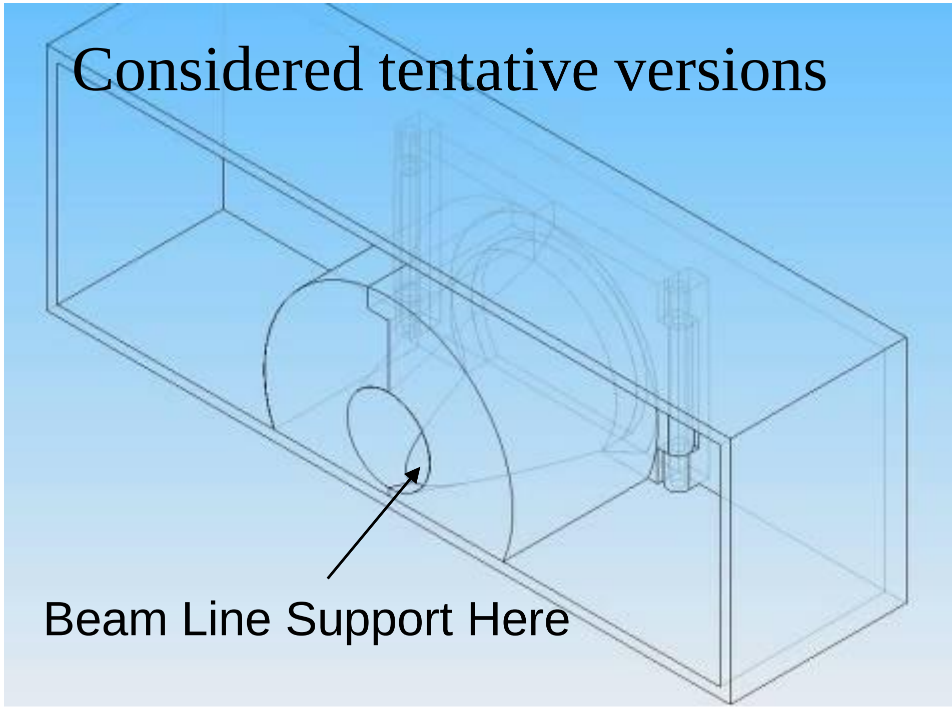


25rem/h@18MW

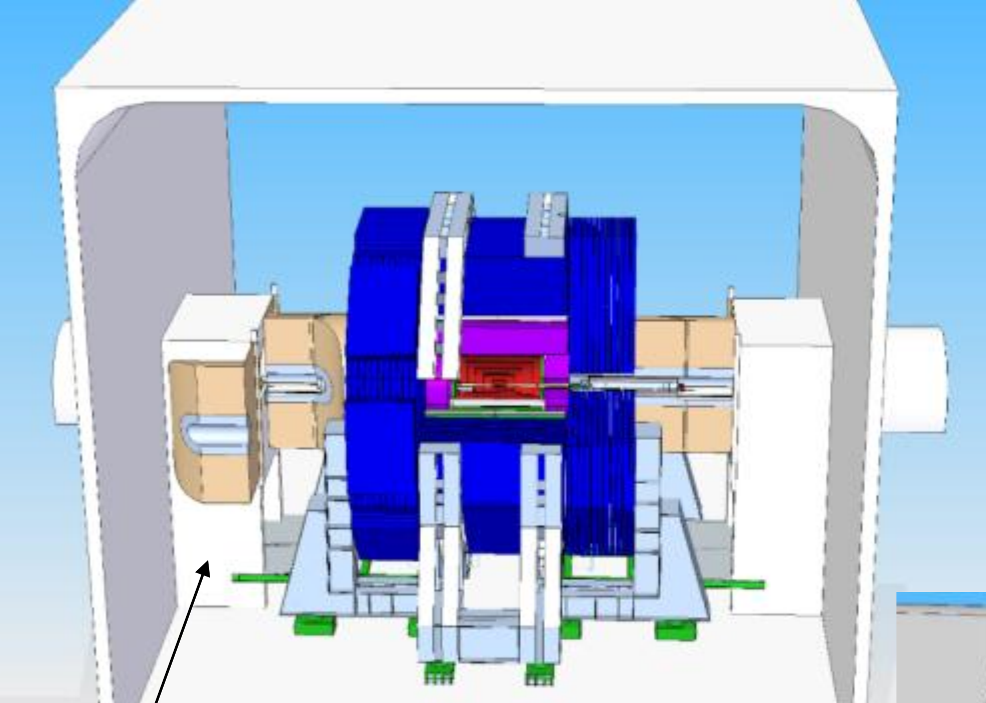


Pacman design

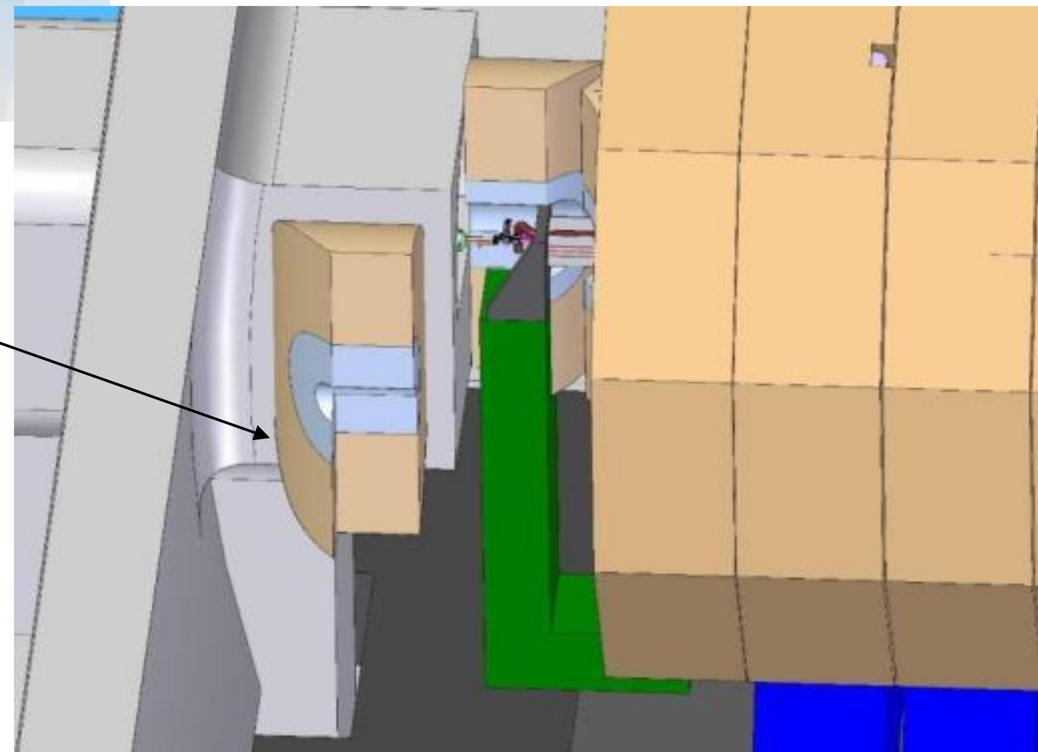




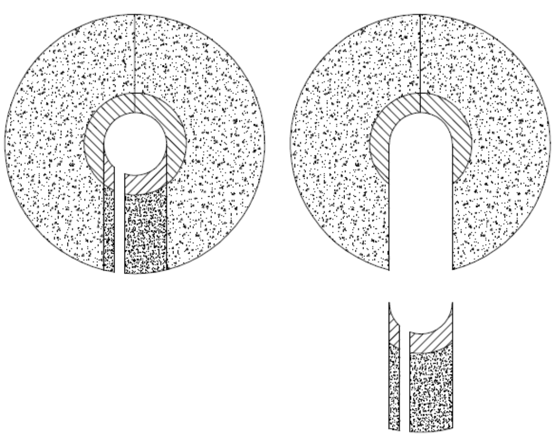
John Amann



Example of system where initially different designs converged on a single compatible solution:
CMS-Inspired Hinged PacMan
w/ Cut-outs for ILD Pillar and Plugs



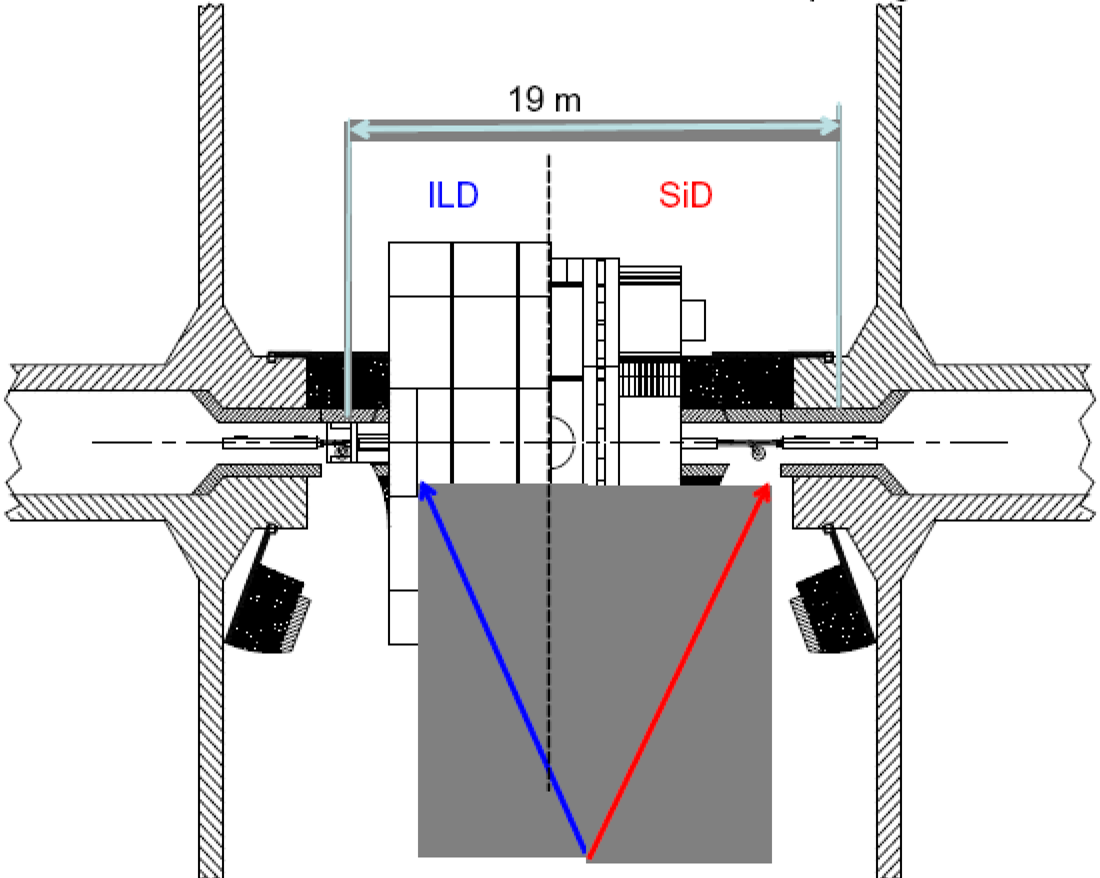
SiD ILD



M.Oriunno, H.Yamaoka, A.Herve, et. al

Pacman compatible with SiD

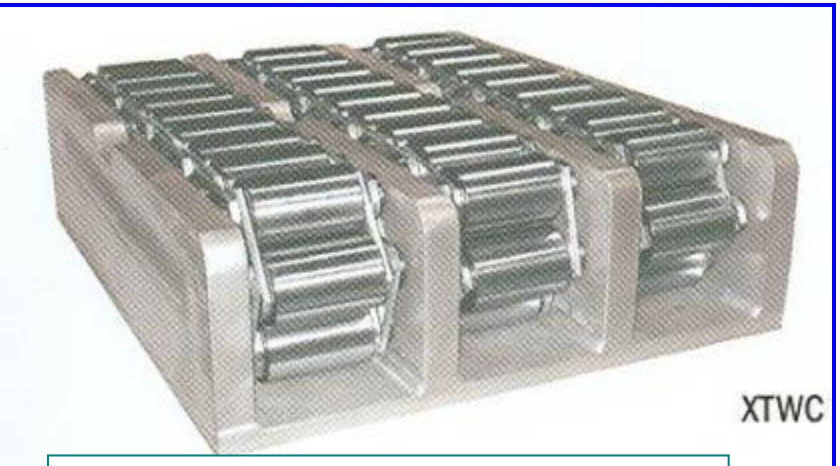
Pacmen closed: Modified to allow ILD opening



Interface pieces born by each experiment

From A. Hervé, K. Sinram, M. Oriunno

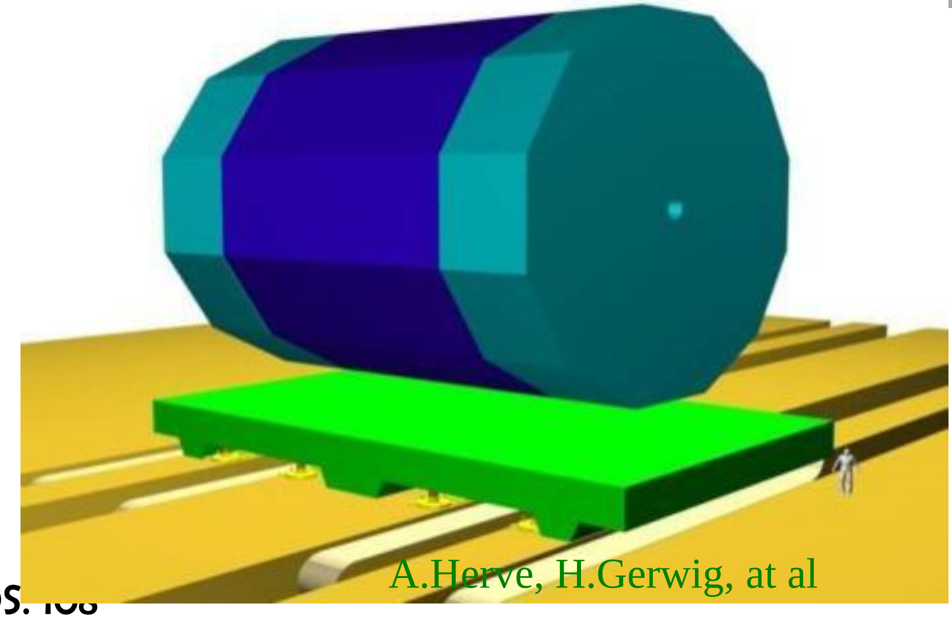
Moving the detector



5000 ton Hilman roller module

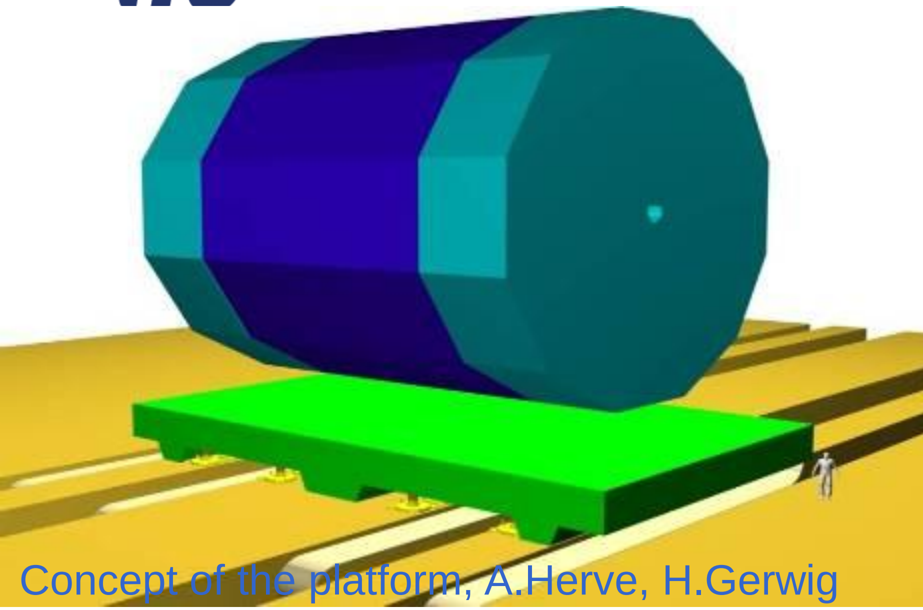
Air-pads at CMS – move 2000k pieces

Is detector (compatible with on-surface assembly) rigid enough itself to avoid distortions during move?

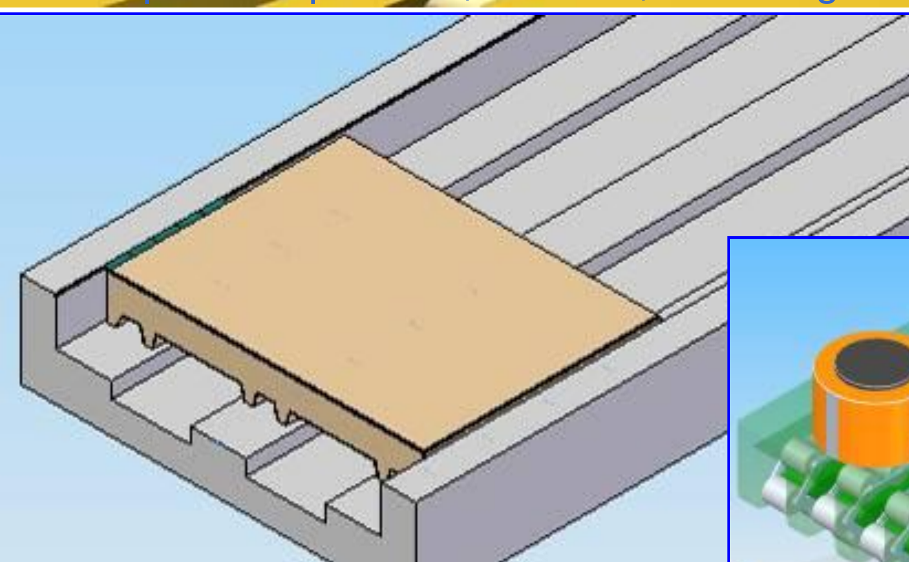


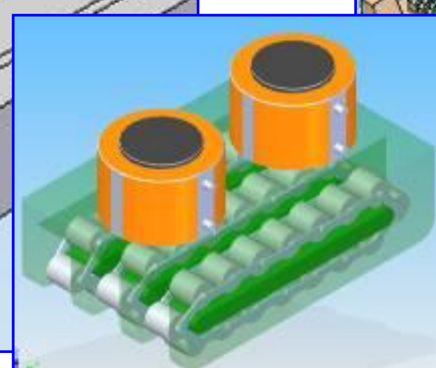
Concept of the platform to move ILC detector

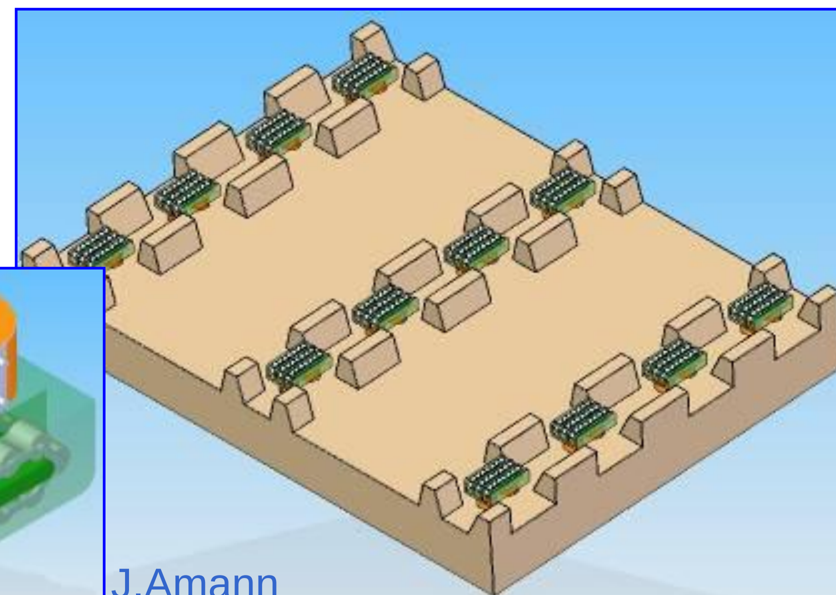
Moving the detector


Concept of the platform, A.Herve, H.Gerwig


Air-pads at CMS – move 2000k

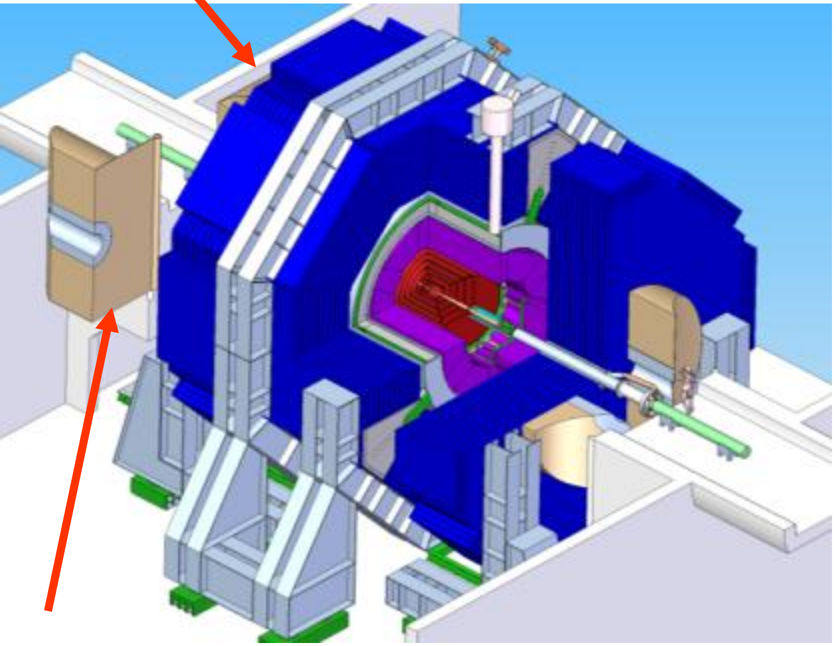


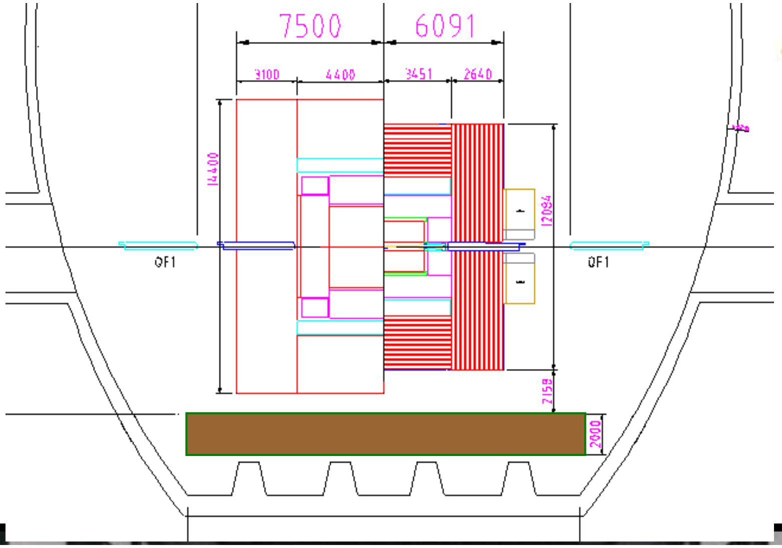



J.Amann

Example of MDI issues: moving detectors

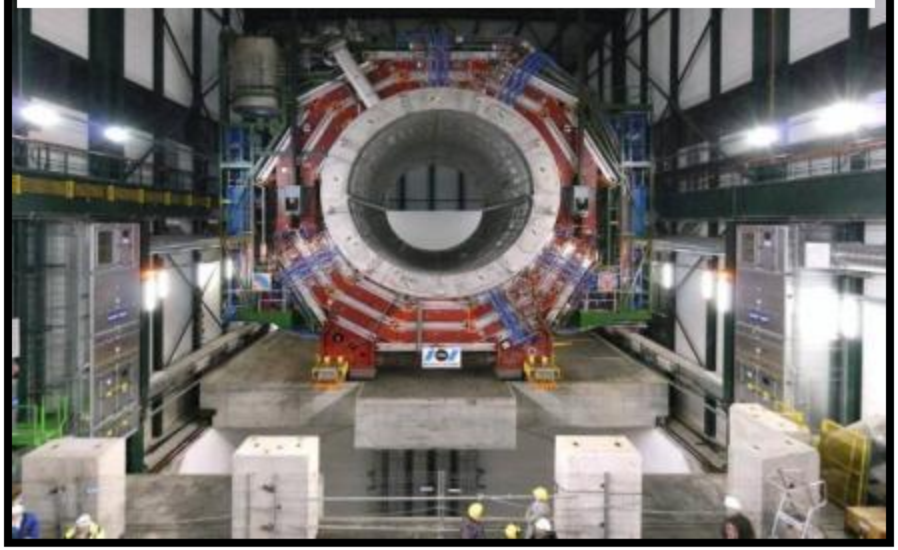
Detector motion system with
or without an intermediate platform



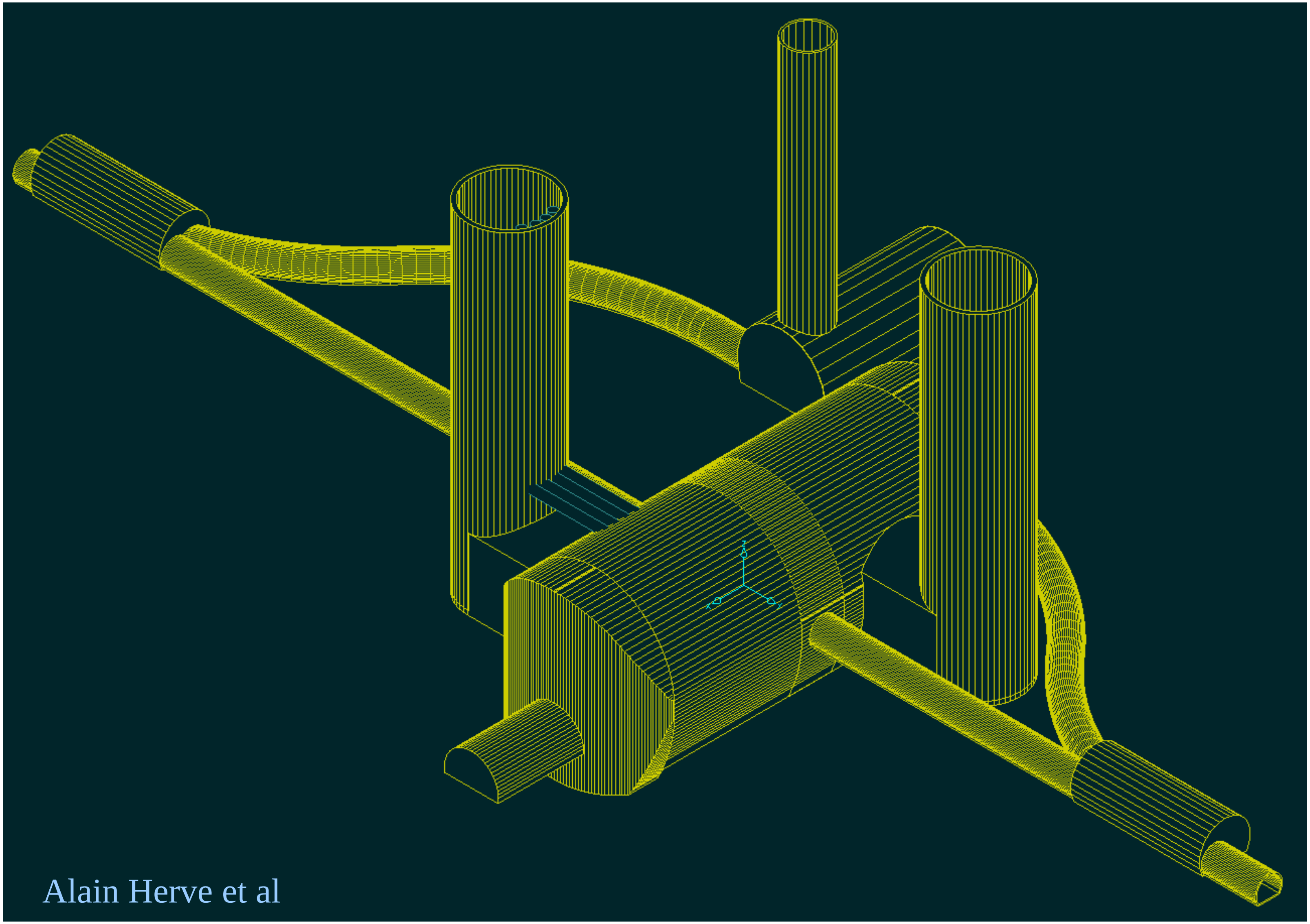


Detector and beamline shielding elements

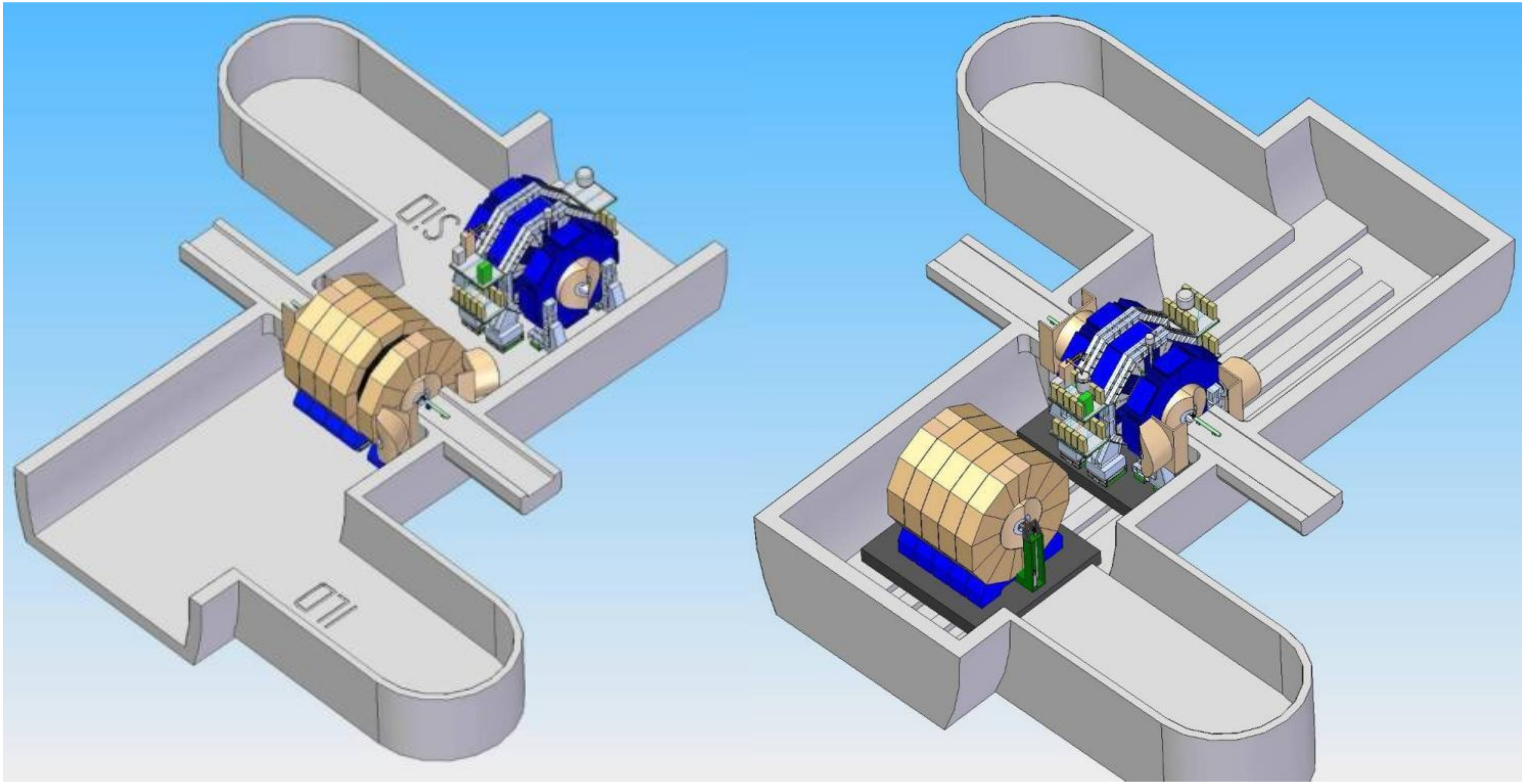
CMS platform – proof of principle for ILC



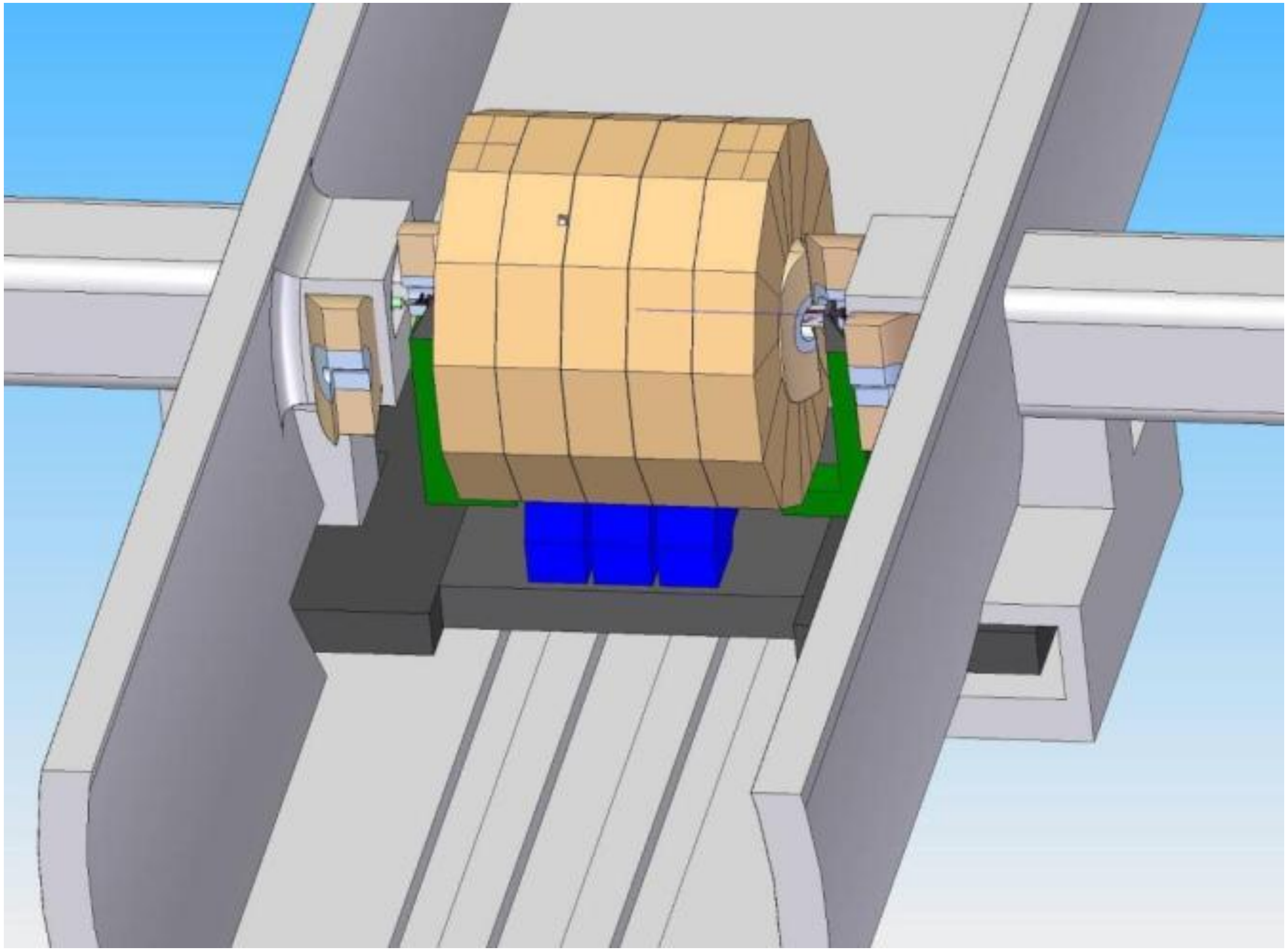
Configuration of IR tunnels and halls



All detectors without / with platform

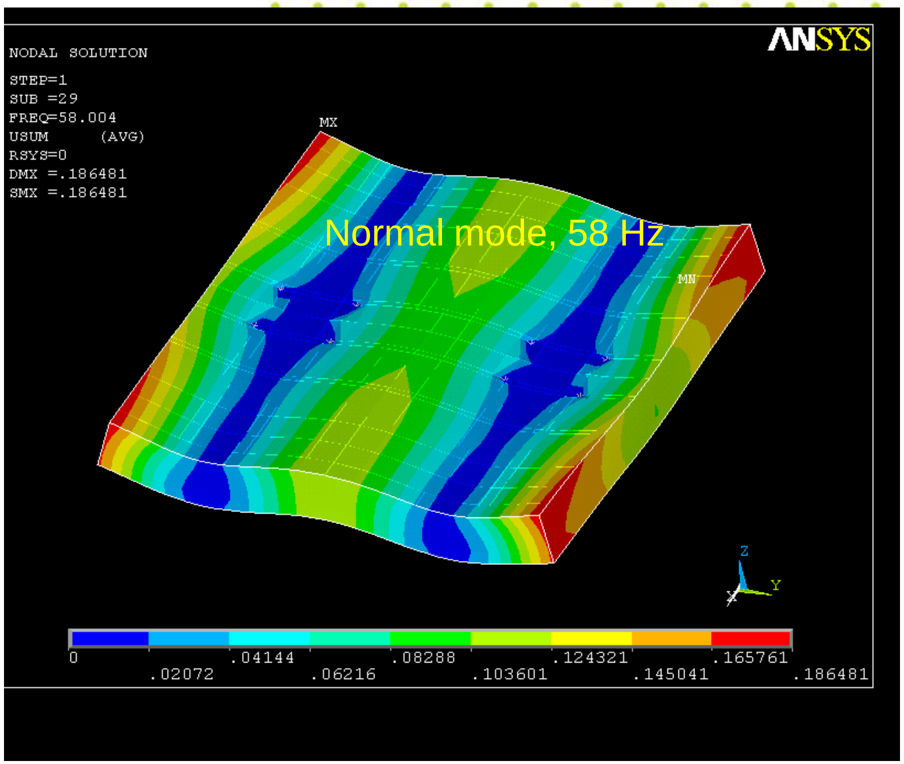


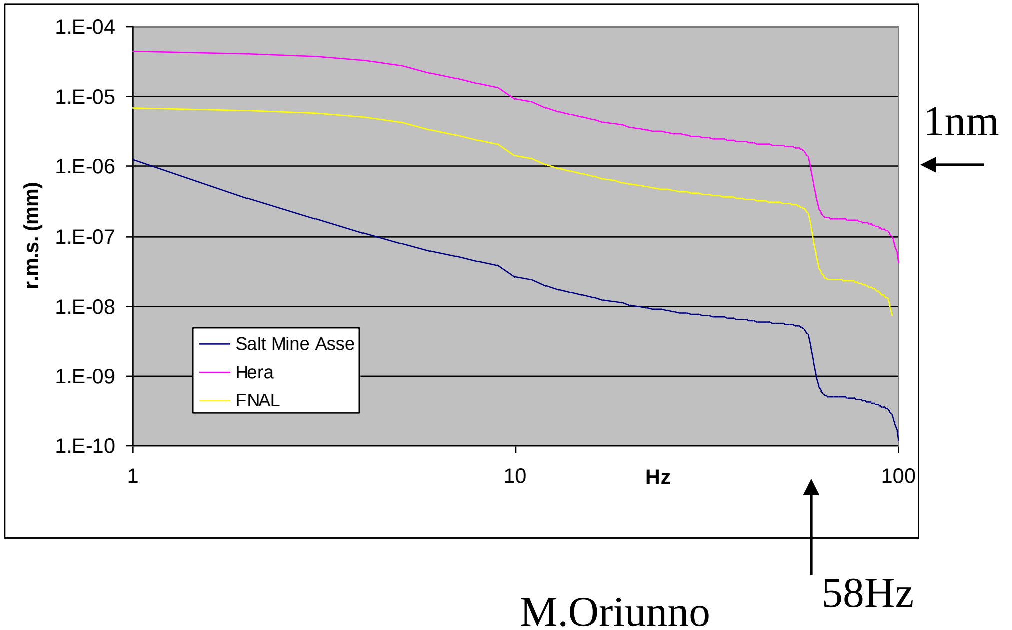
Half Platform w/ Pocket Storage



A.Herve, M.Oriunno, K,Sinram, T.Markiewicz, et al

Preliminary
ANSYS analysis of Platform

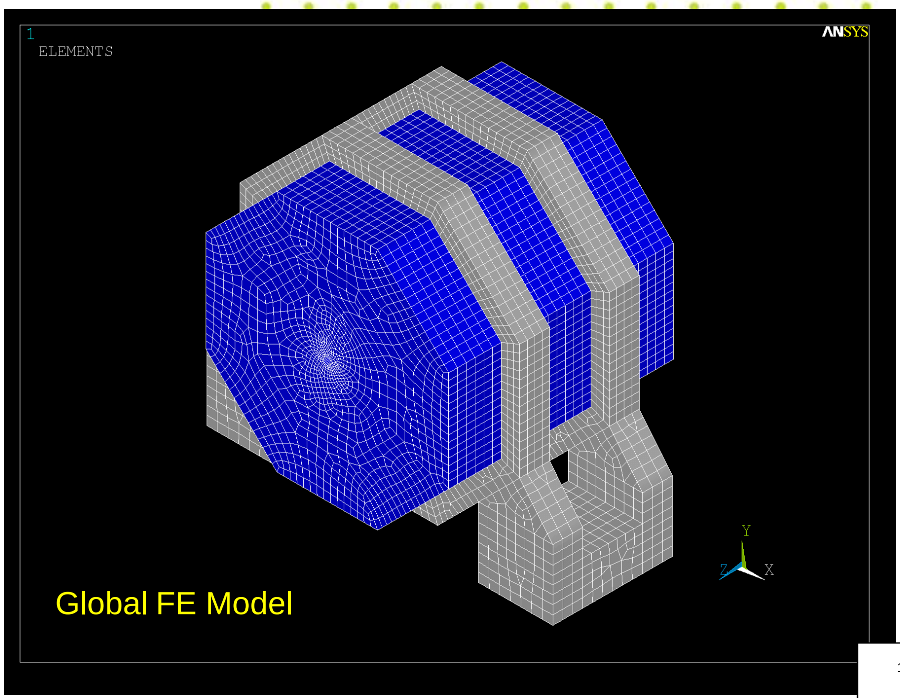


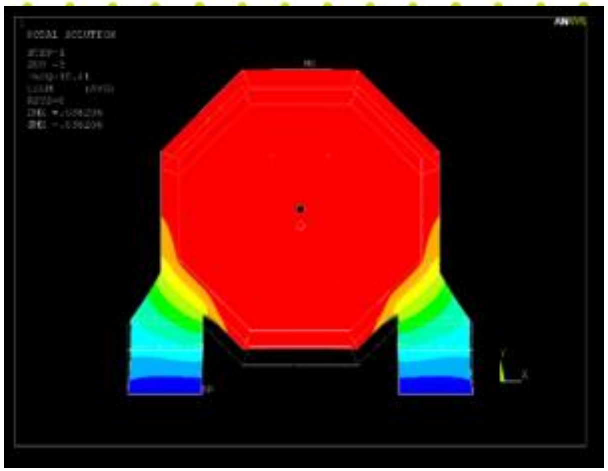


M.Oriunno

- First look of platform stability look rather promising: resonance frequencies are rather large (e.g. 58Hz) and additional vibration is only several nm

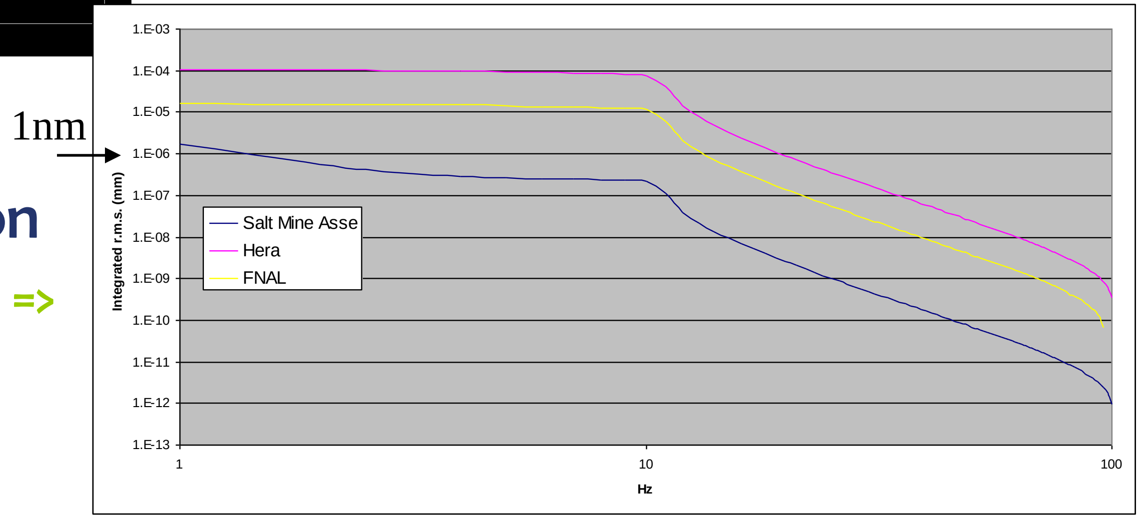
Detector stability analysis (SiD)



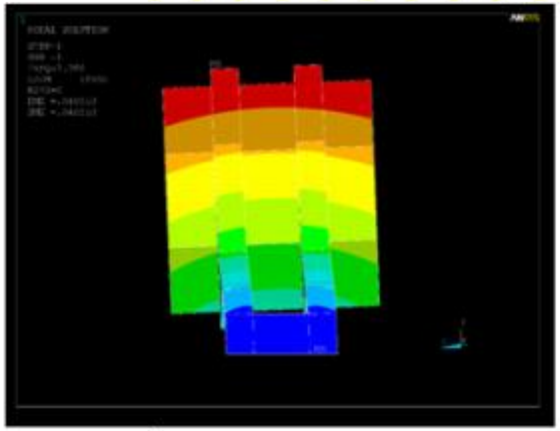


First vertical motion mode, 10.42 Hz

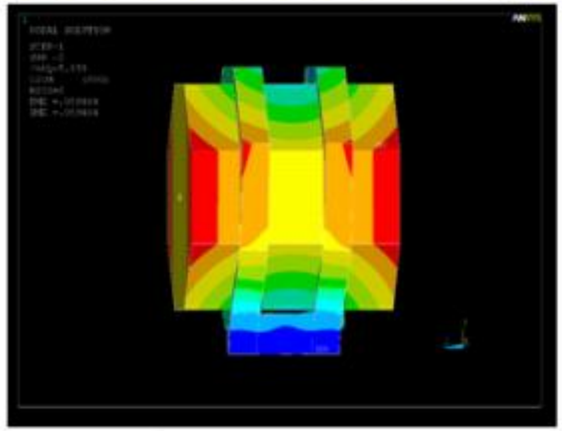
- First analysis shows possibilities for optimization
  - e.g. tolerance to fringe field => detector mass => resonance frequency



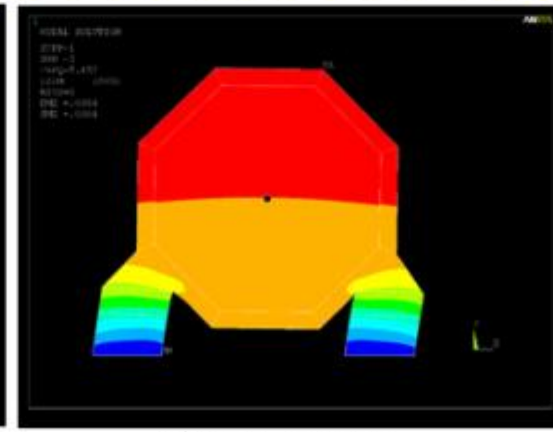
Free vibration modes of SiD



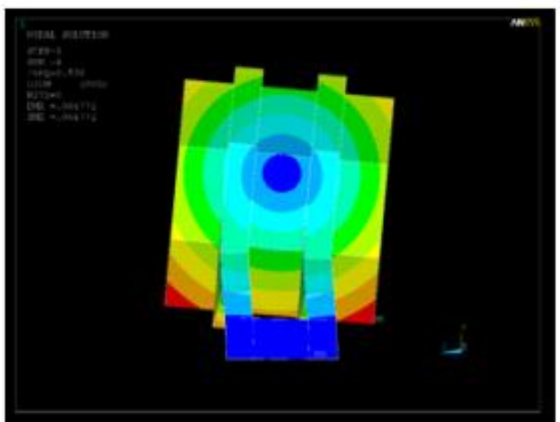
1st Mode, 2.38 Hz



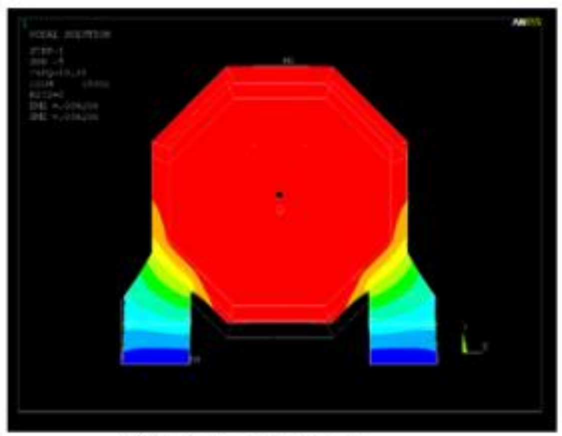
2nd Mode, 5.15 Hz



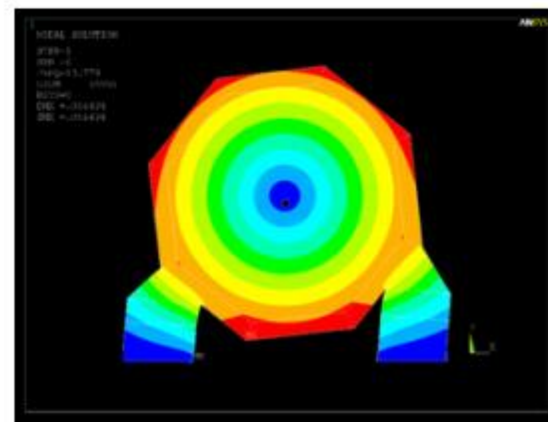
3rd Mode, 5.45 Hz



4th Mode, 6.53 Hz



5th Mode, 10.42 Hz

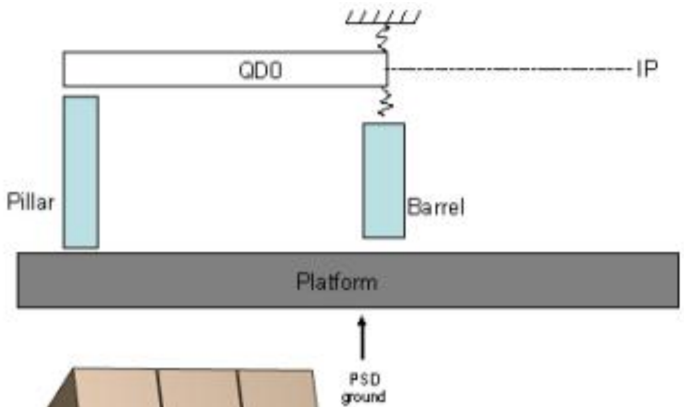


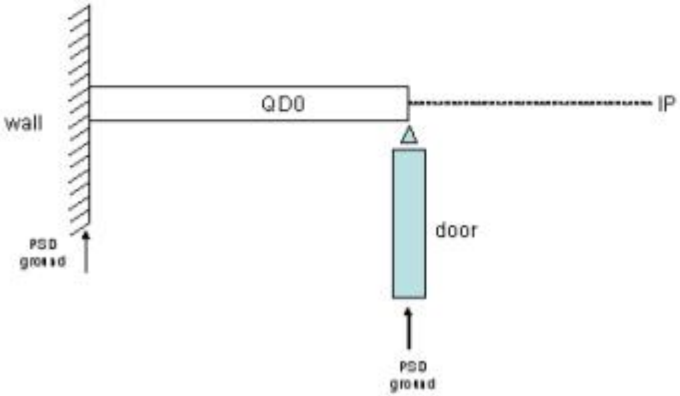
6th Mode, 13.7 Hz

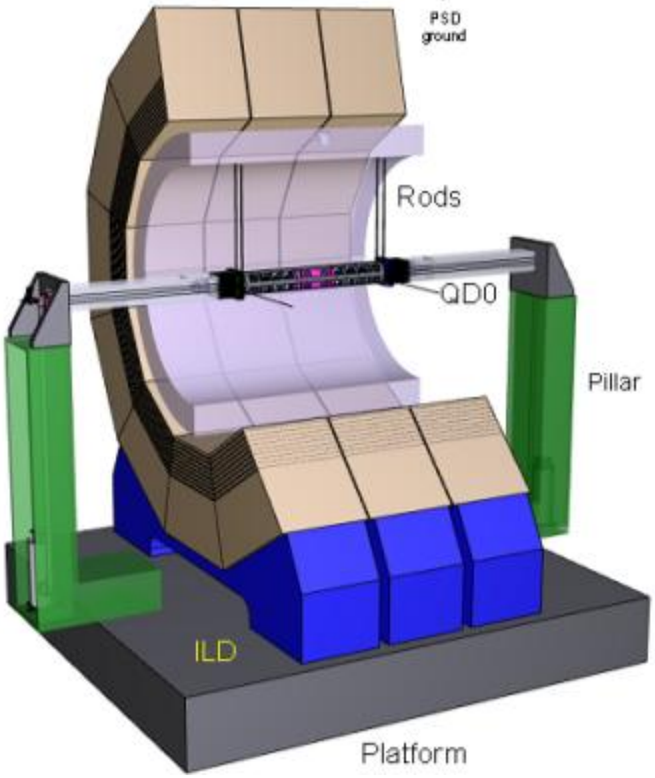
Vertical motion

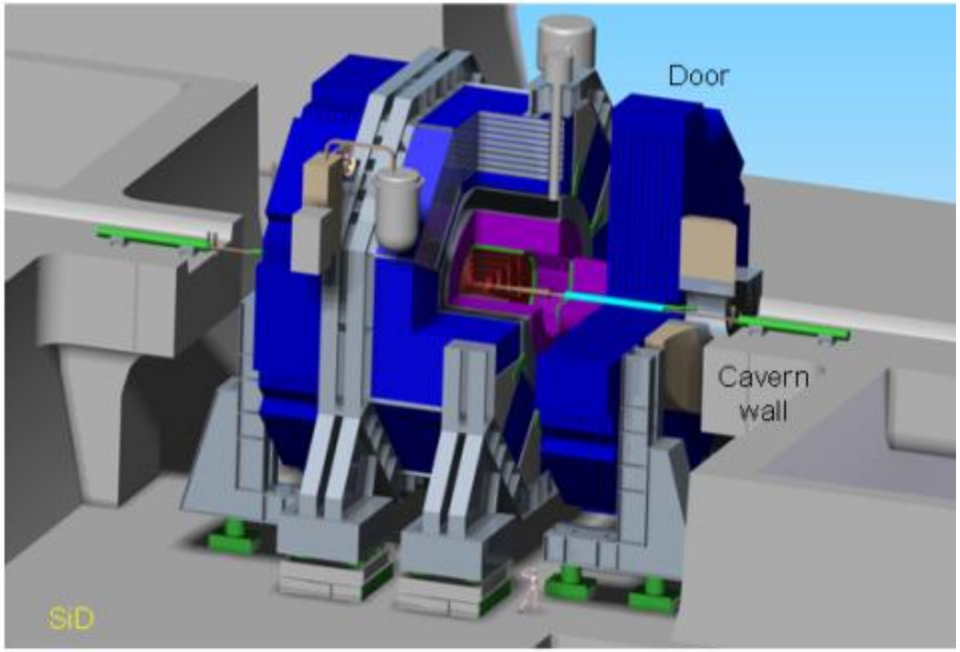
M.Oriunno

QD0 supports in ILD and SiD







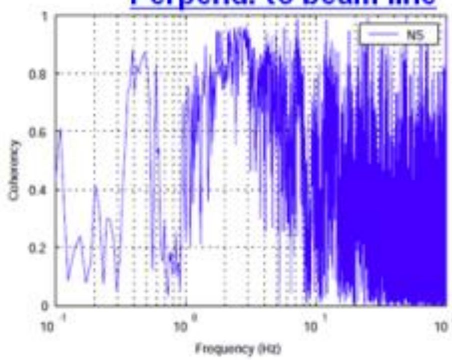


Stability studies at BELLE

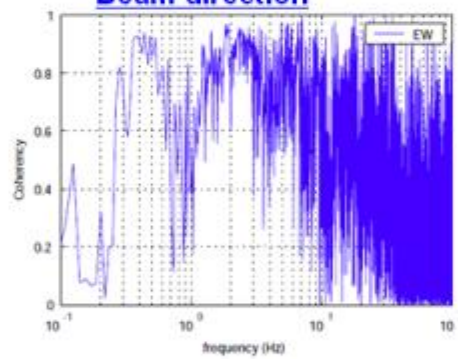
Measurement: B

How is the coherency between the tunnel and floor?

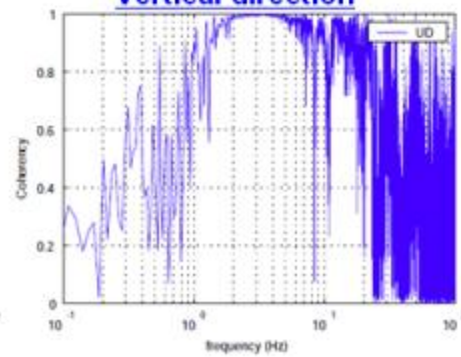
Perpend. to beam line

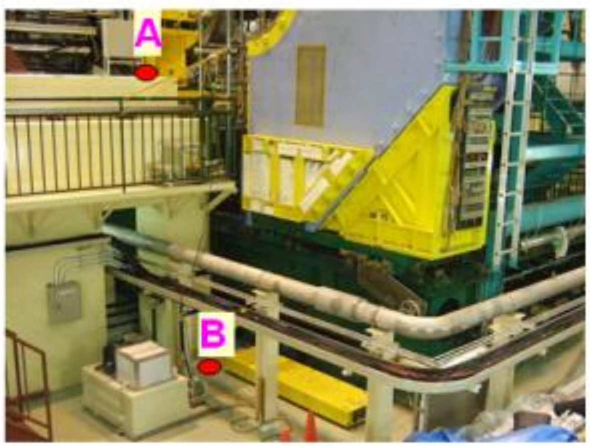


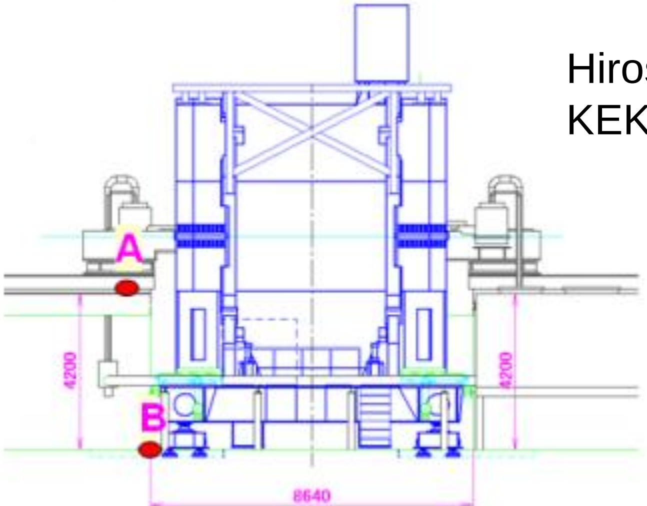
Beam direction



Vertical direction





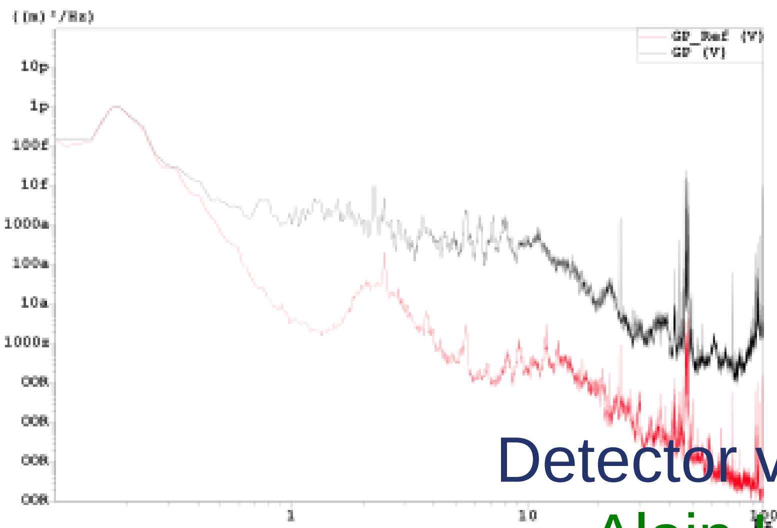


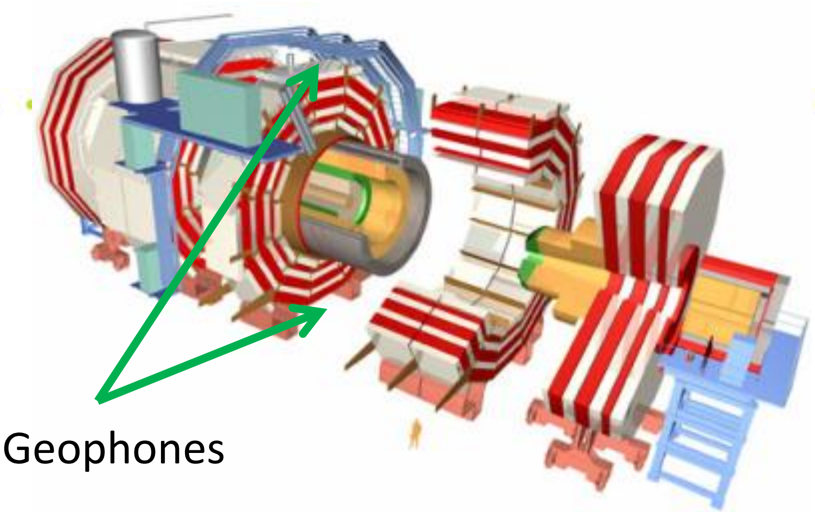
Hiroshi Yamaoka, KEK

- Horizontal dir.: 0.~Hz, ~3Hz
- Vertical dir.: 1 ~ 20Hz

CMS top of Yoke measurement

PSD of the signals Vertical direction



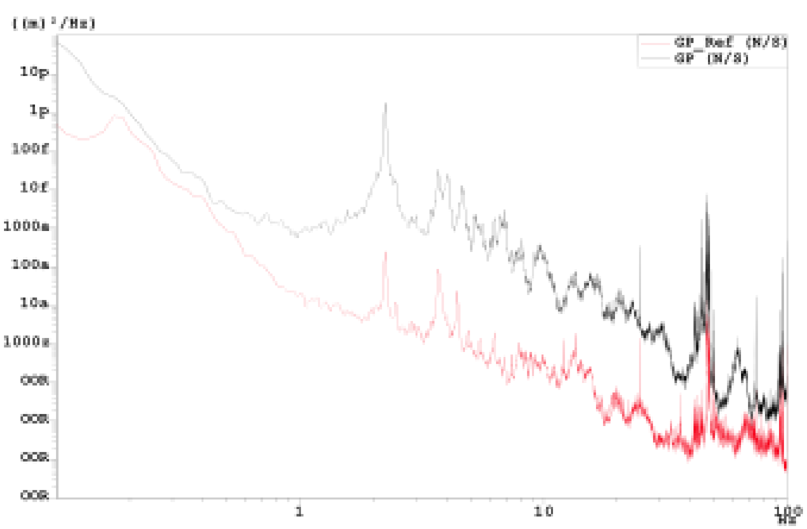


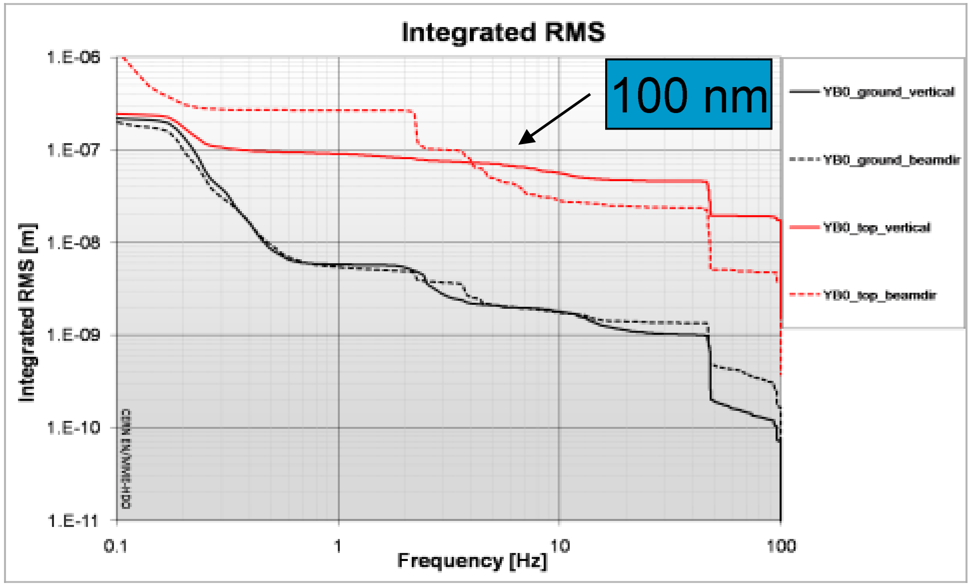
Detector vibrations and QD0 support

Cooling system OFF

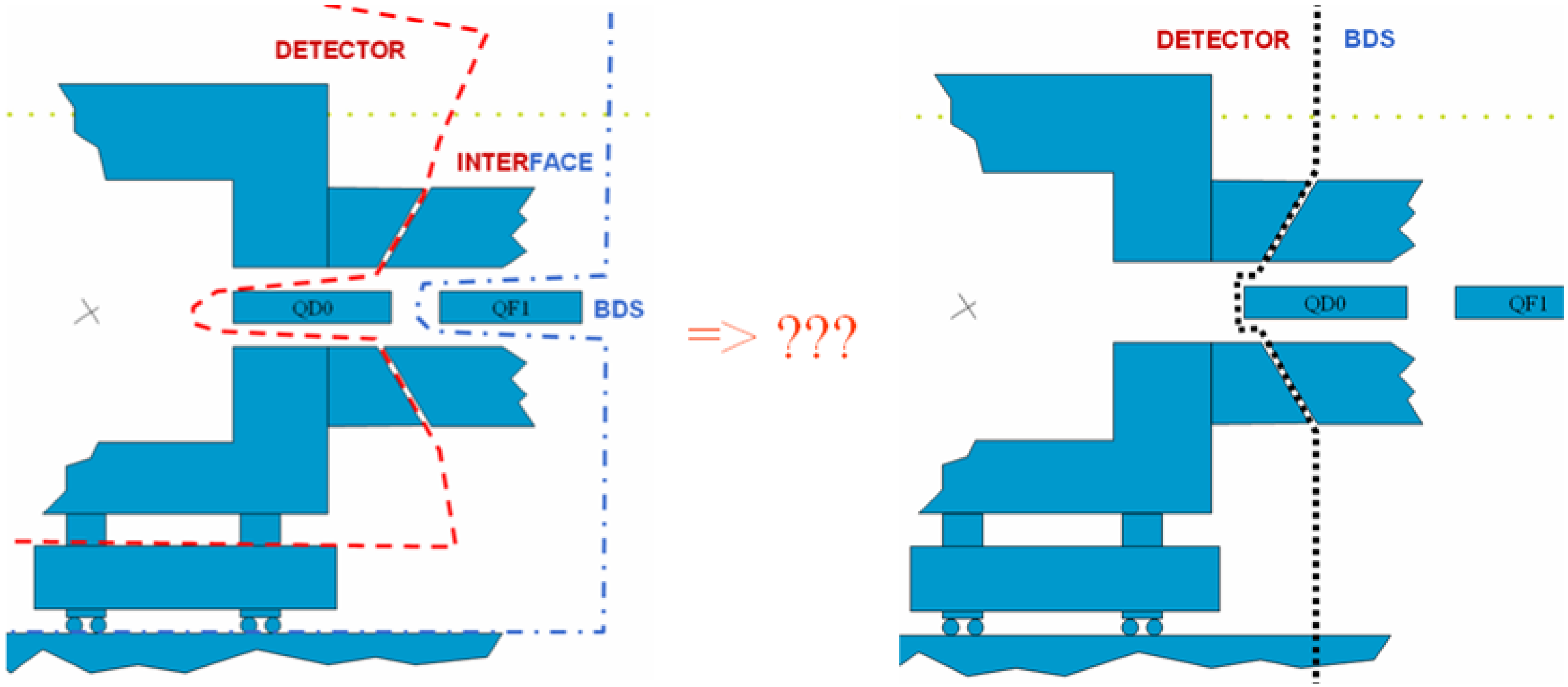
Alain Herve (ETH Zurich)

PSD of the signals Beam direction





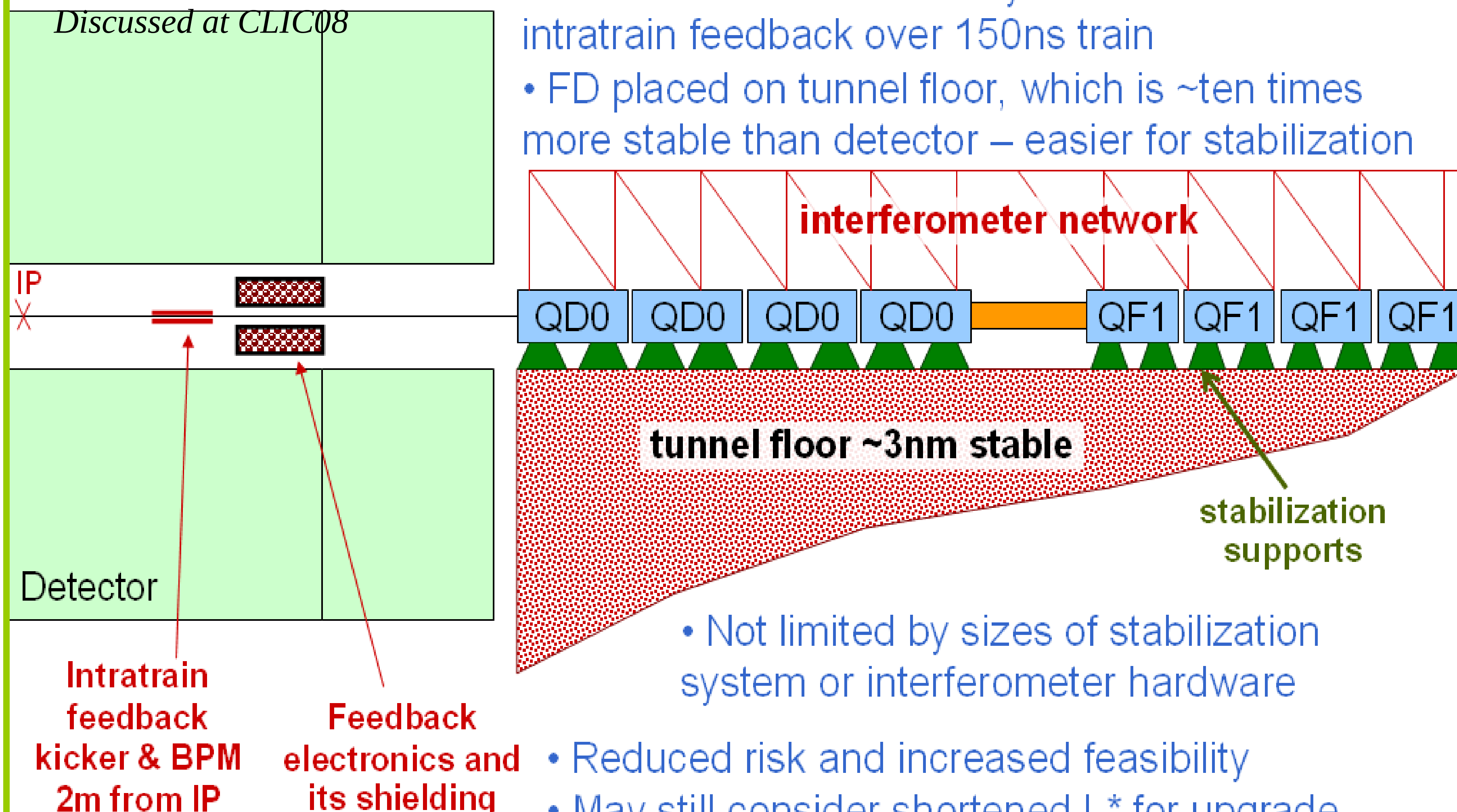
Longer L* → Simplified MDI?



- If doubled L* is feasible and acceptable then the MDI may be simplified tremendously
  - » and cost is reduced – do not need two extra sets of QD0
- An option of later upgrade for shorter L* may always be considered
- Has to be studied further

Doubled L* perhaps **necessary** for CLIC, where the FD stability requirement is ~0.1 nm

- Slower than 1/L* dependence of Lum => ↑L*
- Reduced feedback latency – several iteration of intratrain feedback over 150ns train
- FD placed on tunnel floor, which is ~ten times more stable than detector – easier for stabilization



- Not limited by sizes of stabilization system or interferometer hardware
- Reduced risk and increased feasibility
- May still consider shortened L* for upgrade

CLIC BDS & L*

FFS WITH L*=6M

In [12] it was proposed to use a longer L* to ease the QD0 stabilization challenge by supporting the FD on the tunnel. The initial lattice featured a L*=8m with about 30% lower luminosity than the current design and tighter pre-alignment tolerances to guarantee a successful tuning [2]. In the meantime the CLIC experiments have proposed to reduce the length of the detector to 6 m [13]. Consequently a new FFS has been designed with an L*=6m by scaling the old CLIC FFS with L*=4.3 m [14]. This lattice currently features IP spot sizes of $\sigma_x = 60.8$ nm and $\sigma_y = 1.9$ nm. Table 1 shows the total and energy peak luminosities for the different available FFS systems. Luminosity clearly decreases as L* increases. The L*=6 m case has a 16% lower peak luminosity than the nominal one (L*=3.5 m). Figure 5 displays the luminosity versus relative energy offset for all the FFS designs, showing a similar energy bandwidth in all cases.

L* $[m]$	Total luminosity $[10^{34}cm^{-2}s^{-1}]$	Peak luminosity $[10^{34}cm^{-2}s^{-1}]$
3.5	6.9	2.5
4.3	6.4	2.4
6	5.0	2.1
8	4.0	1.7

Table 1: Total and Peak luminosities for different L* lattices.

[12] A. Seryi, "Near IR FF design including FD and longer L* issues", CLIC08.

[13] CLIC09 Workshop, 12-16 October 2009, CERN , http://indico.cern.ch/conferenceDisplay.py?confId=45580

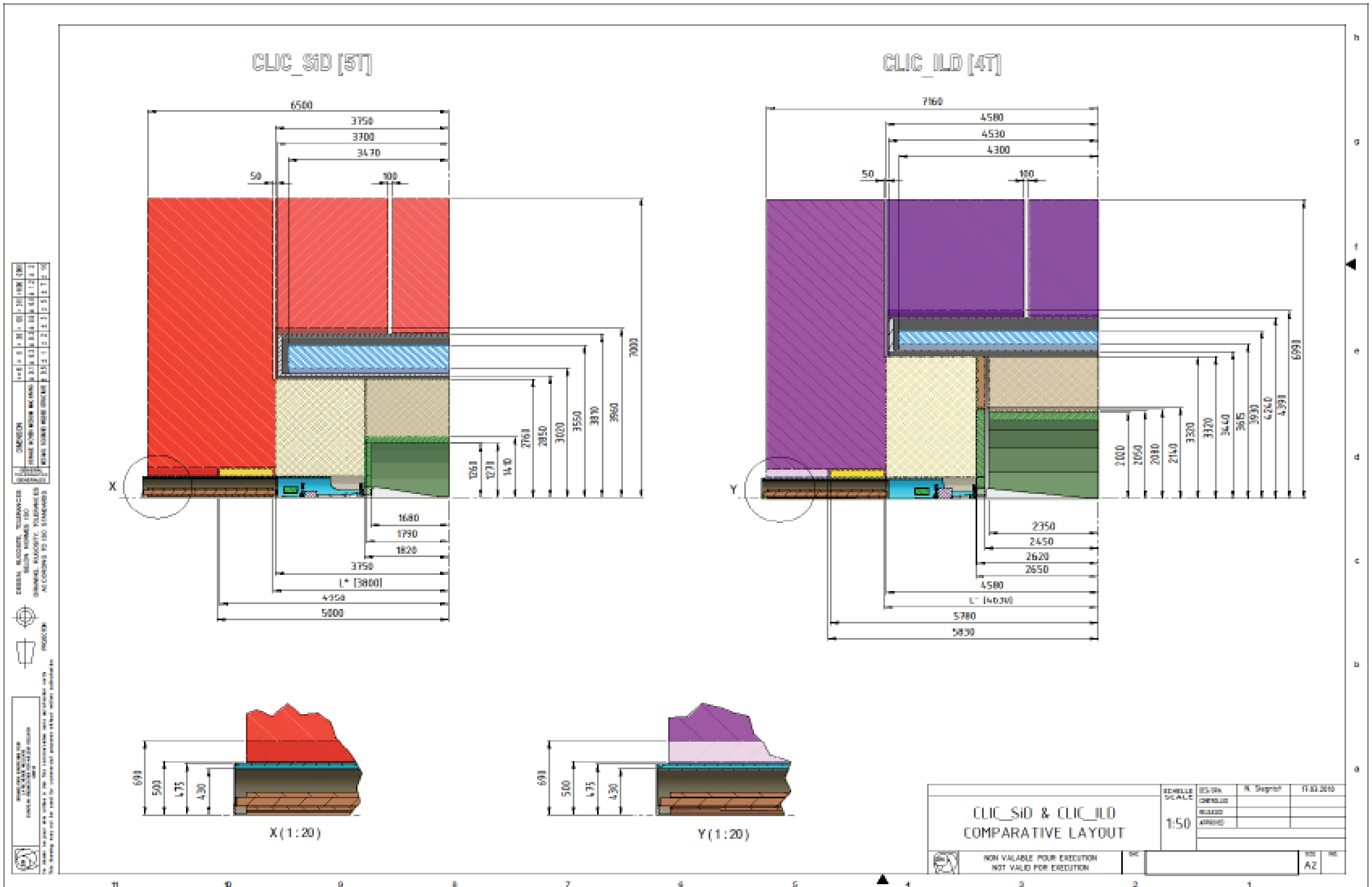
[14] http://clicr.web.cern.ch/CLICr/

The CLIC Beam Delivery System towards the Conceptual Design Report

IPAC10

D. Angal-Kalinin, B. Bolzon, B. Dalena, L. Fernandez, F. Jackson, A. Jeremie, B. Parker
J. Resta López, G. Rumolo, D. Schulte, A. Seryi, J. Snuverink, R. Tomás and G. Zamudio

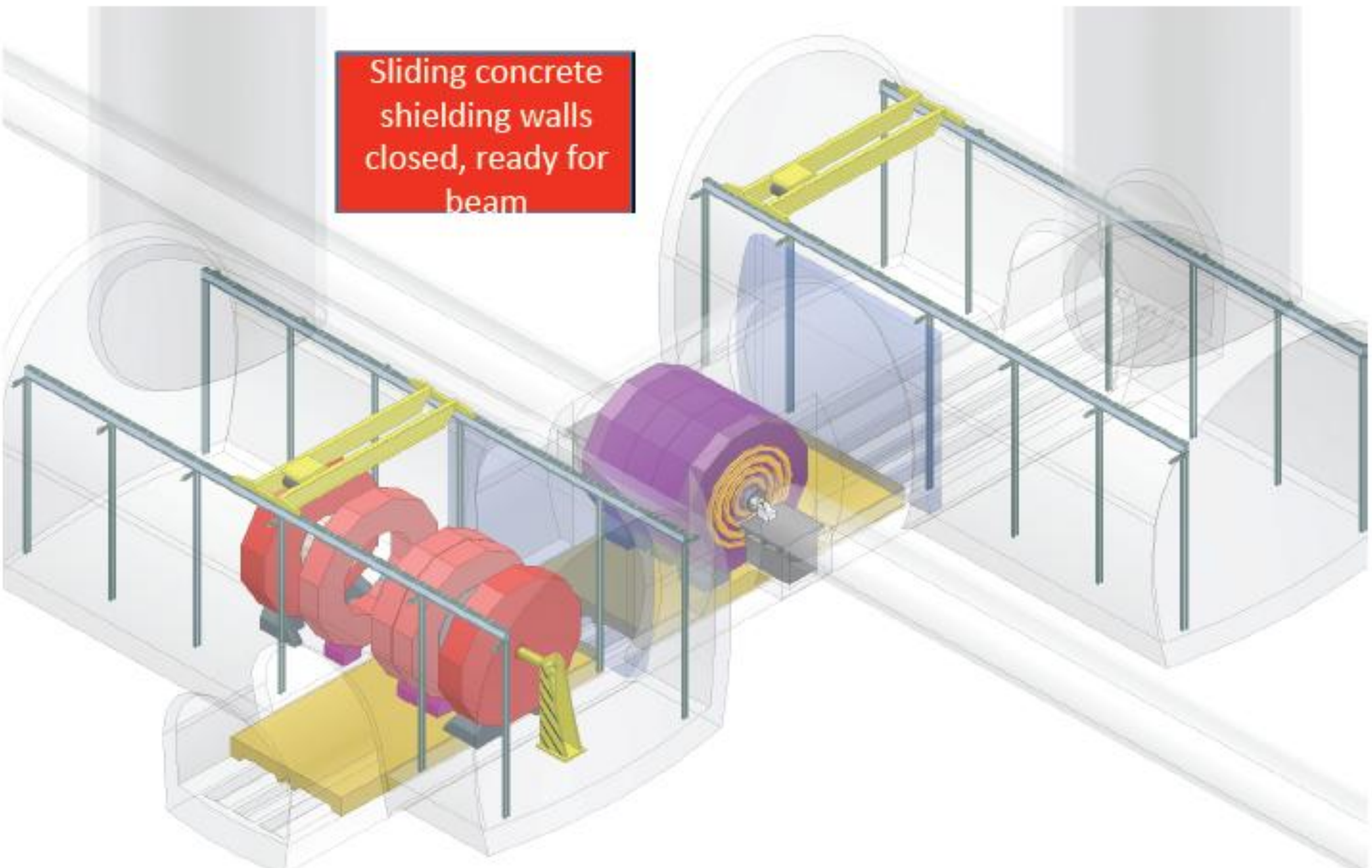
CLIC detector comparison



BDS: 123

New concept of CLIC push-pull

Experiment 2 sliding on IP, shielding walls closed



New Low P parameter set

	Nom. RDR	Low P RDR	new Low P
Case ID	**1**	**2**	**3**
E CM (GeV)	500	500	500
N	2.0E+10	2.0E+10	2.0E+10
n_b	2625	1320	1320
F (Hz)	5	5	5
P_b (MW)	**10.5**	**5.3**	**5.3**
$\gamma\varepsilon_X$ (m)	1.0E-05	1.0E-05	1.0E-05
$\gamma\varepsilon_Y$ (m)	4.0E-08	3.6E-08	3.6E-08
βx (m)	2.0E-02	1.1E-02	1.1E-02
βy (m)	4.0E-04	2.0E-04	2.0E-04
Travelling focus	No	No	**Yes**
Z-distribution *	Gauss	Gauss	Gauss
σ_x (m)	6.39E-07	4.74E-07	4.74E-07
σ_y (m)	5.7E-09	3.8E-09	3.8E-09
σ_z (m)	3.0E-04	2.0E-04	**3.0E-04**
Guinea-Pig $\delta E/E$	**0.023**	**0.045**	**0.036**
Guinea-Pig L ($cm^{-2}s^{-1}$)	**2.02E+34**	**1.86E+34**	**1.92E+34**
Guinea-Pig Lumi in 1%	1.50E+34	1.09E+34	1.18E+34

*for flat z distribution the full bunch length is $\boldsymbol{\sigma}_z*2*3^{1/2}$

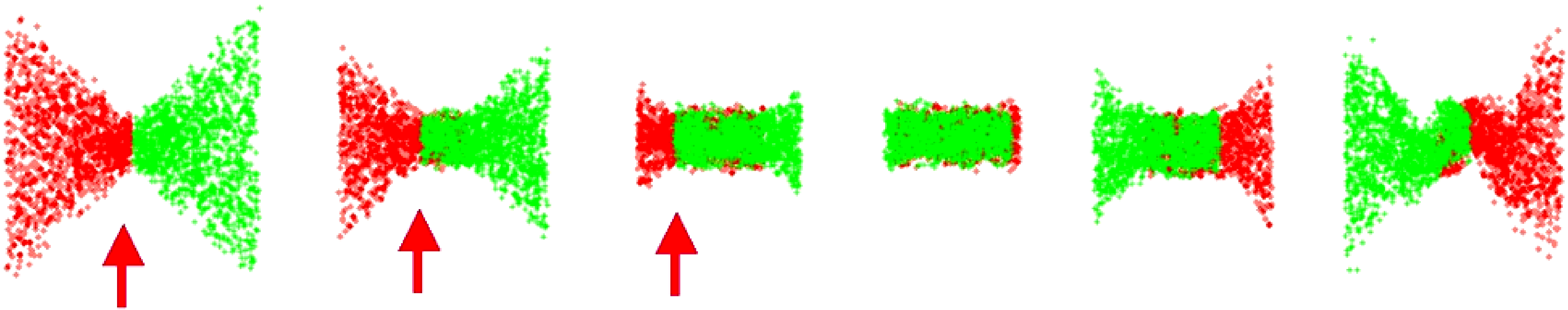
Travelling focus allows to lengthen the bunch

Thus, beamstrahlung energy spread is reduced

Focusing during collision is aided by focusing of the opposite bunch

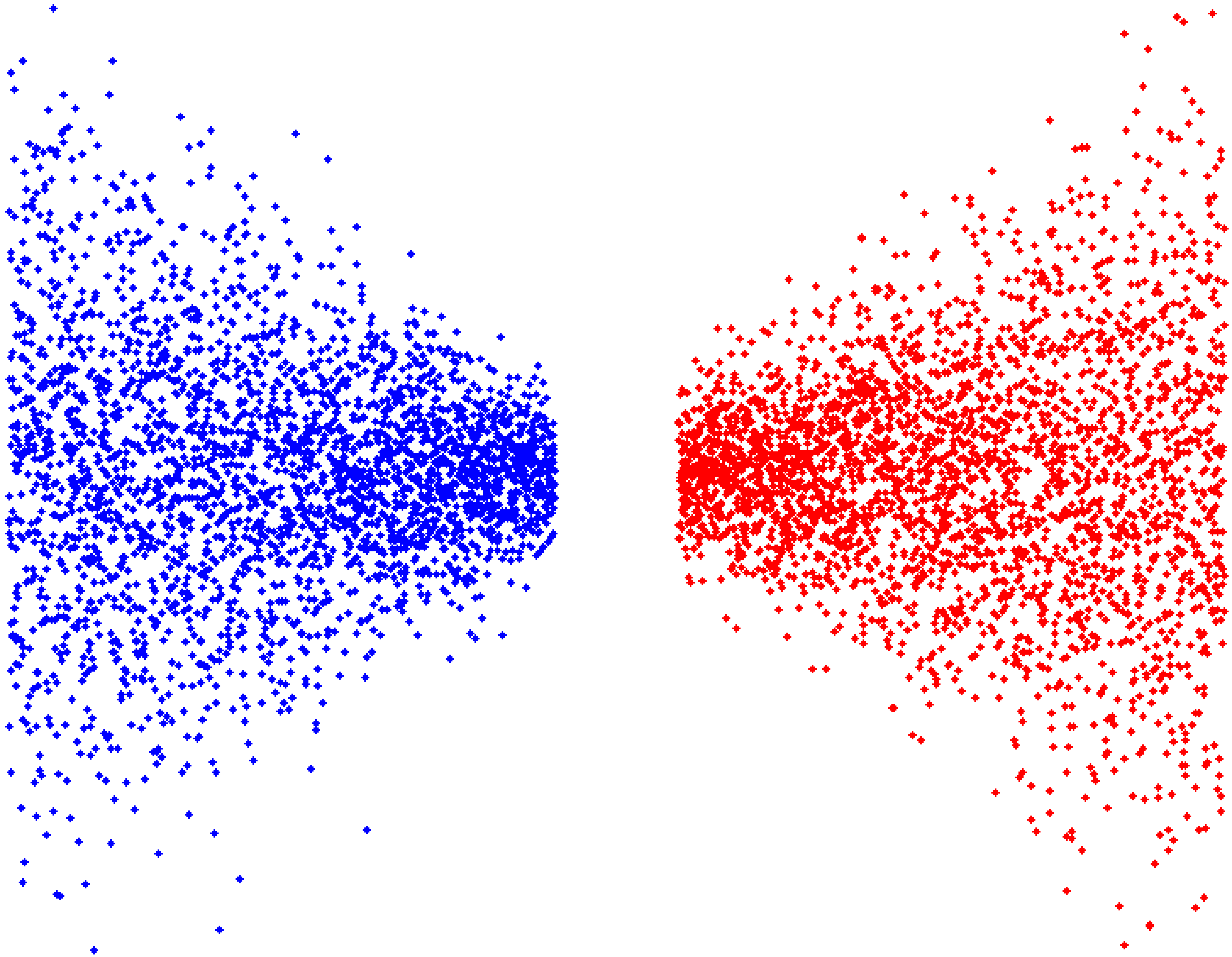
Focal point during collision moves to coincide with the head of the opposite bunch

Beam-beam: Travelling focus

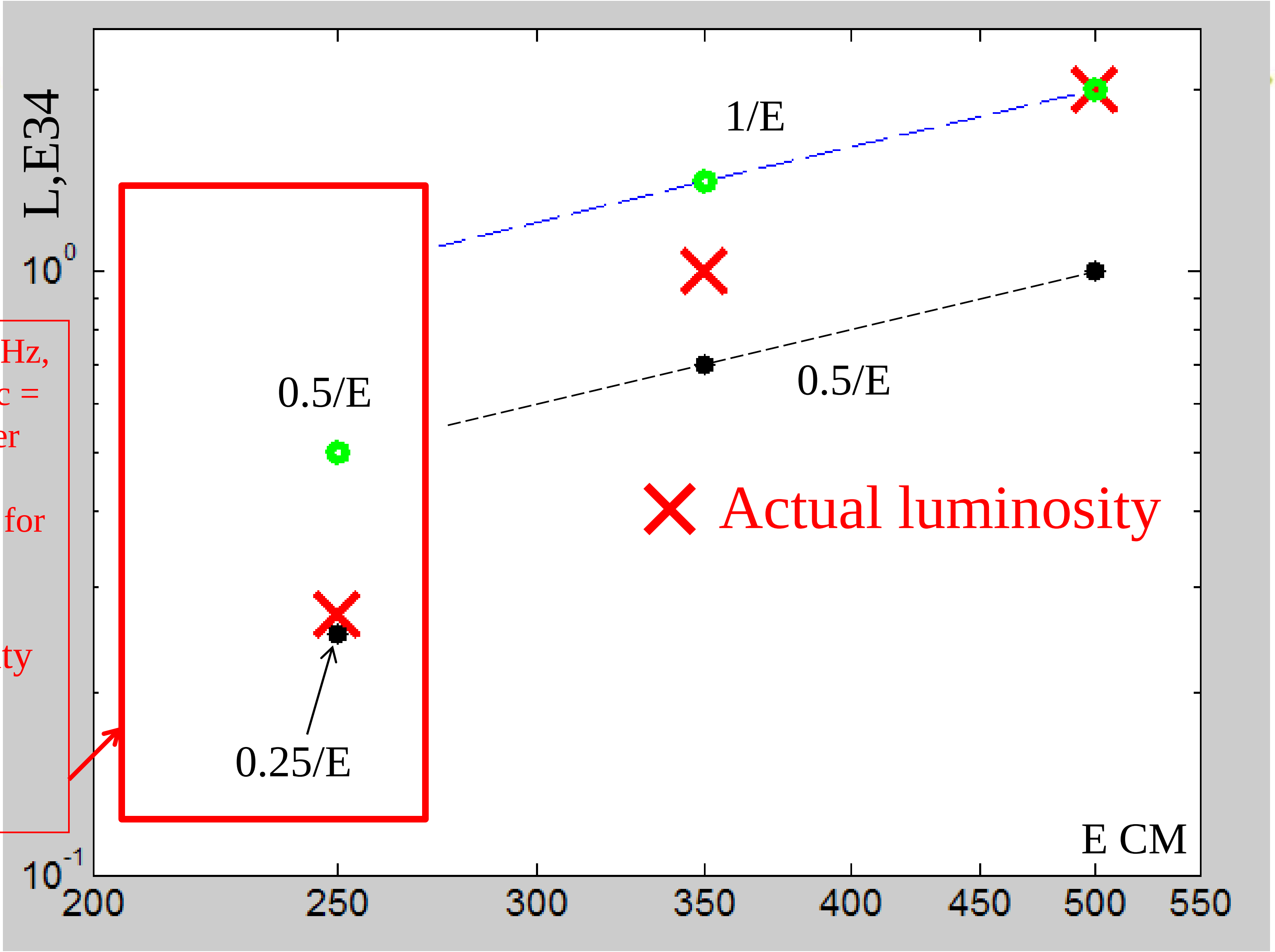


- Suggested by V.Balakin in ~1991 – idea is to use beam-beam forces for additional focusing of the beam – allows some gain of luminosity or overcome somewhat the hour-glass effect
- Figure shows simulation of traveling focus. The arrows show the position of the focus point during collision
- So far not yet used experimentally

Collision with travelling focus



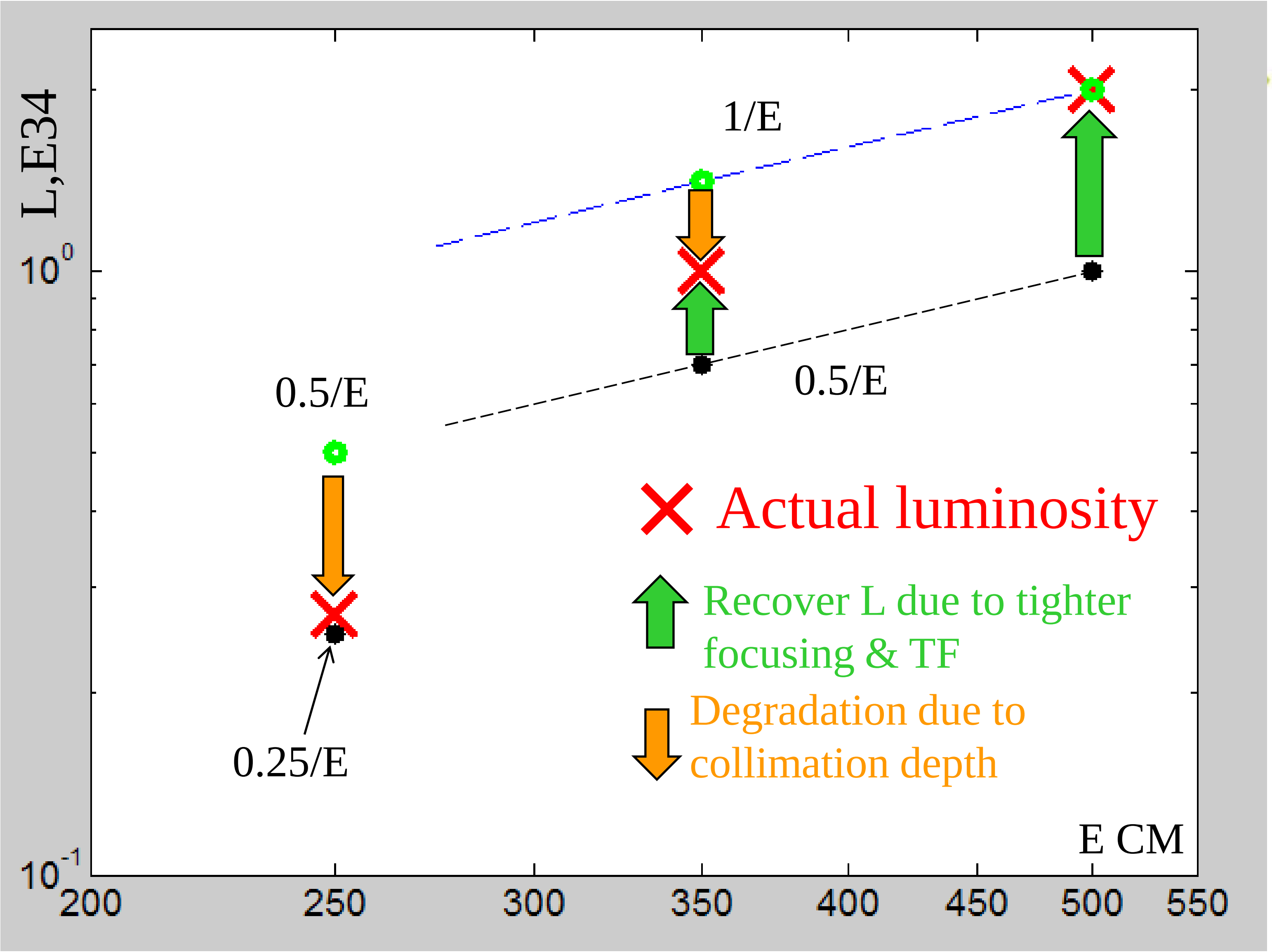
SB2009 Lumi



Rate at IP = 2.5Hz, Rate in the linac = 5Hz (every other pulse is at 150GeV/beam, for e+ production)

Low luminosity at this energy reduces the physics reach

SB2009 Lumi



L,E34
10^0
10^{-1}
200
250
300
350
400
450
500
550
E CM
1/E
0.5/E
0.5/E
0.25/E
Actual luminosity
Recover L due to tighter focusing & TF
Degradation due to collimation depth

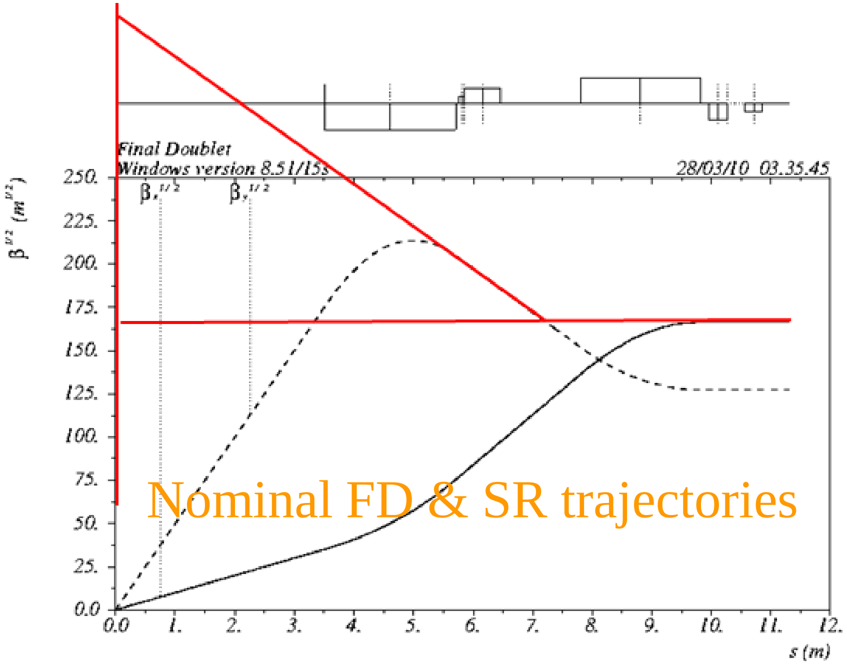
- The travelling focus can be created in two ways.
- The first way is to have small uncompensated chromaticity and coherent E-z energy shift $\delta E/\delta z$ along the bunch. One has to satisfy $\delta E\ k\ L^{*}_{eff} = \sigma_z$ where k is the relative uncompensated chromaticity. The δE needs to be 2-3 times the incoherent spread in the bunch. Thus, the following set may be used: δE=0.3%, k=1.5%, L^{*}_{eff} =6m.
- It is clear that additional energy spread affect the physics. Therefore, second method is considered:

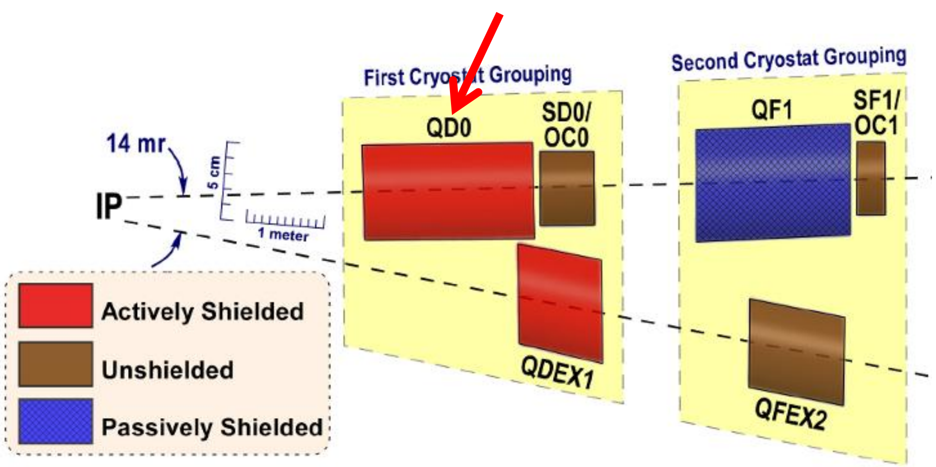
- The second way to create a travelling focus is to use a transverse deflecting cavity giving a z-x correlation in one of the FF sextupoles and thus a z-correlated focusing
- The cavity would be located about 100m upstream of the final doublet, at the $\pi/2$ betatron phase from the FD
- The needed strength of the travelling focus cavity can be compared to the strength of the normal crab cavity (which is located just upstream of the FD):
  - $U_{trav.cav.}/U_{crab.cav.} = \eta_{FD} R_{12}^{cc} / (L^{*}_{eff}\ \theta_c\ R_{12}^{trav})$.
  - Here η_{FD} is dispersion in the FD, θ_c full crossing angle, R_{12}^{trav} and R_{12}^{cc} are transfer matrix elements from travelling focus transverse cavity to FD, and from the crab cavity to IP correspondingly.
- For typical parameters η_{FD} =0.15m, θ_c =14mrad. R_{12}^{cc} =10m, R_{12}^{trav} =100m, L^{*}_{eff} =6m one can conclude that the needed strength of the travelling focus transverse cavity is about 20% of the nominal crab cavity.

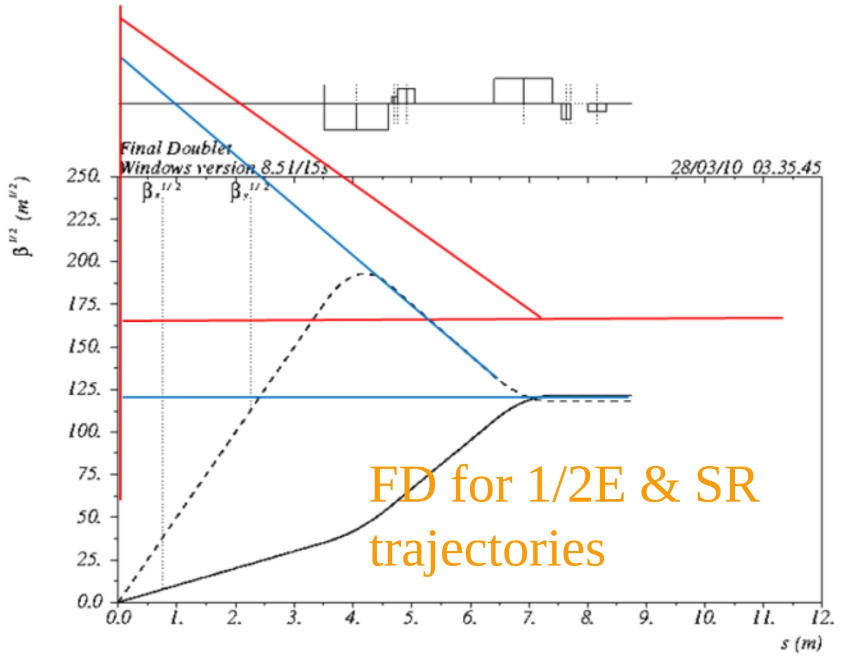
FD for low E

FD optimized for lower energy will allow increasing the collimation depth by ~10% in Y and by ~30% in X (Very tentative!)

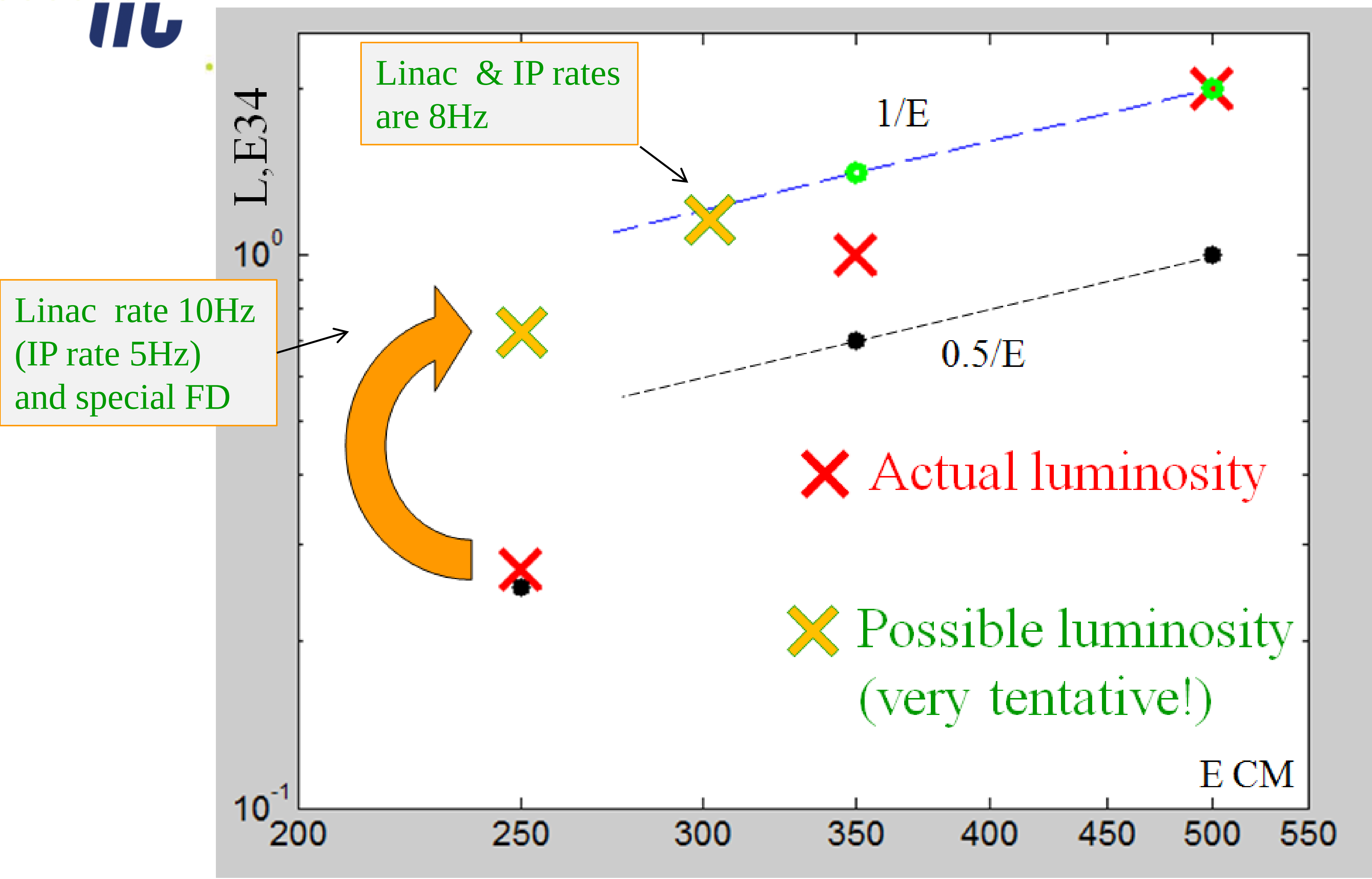
- One option would be to have a separate FD optimized for lower E, and then exchange it before going to nominal E
- Other option to be studied is to build a universal FD, that can be reconfigured for lower E configuration (may require splitting QD0 coil and placing sextupoles in the middle)







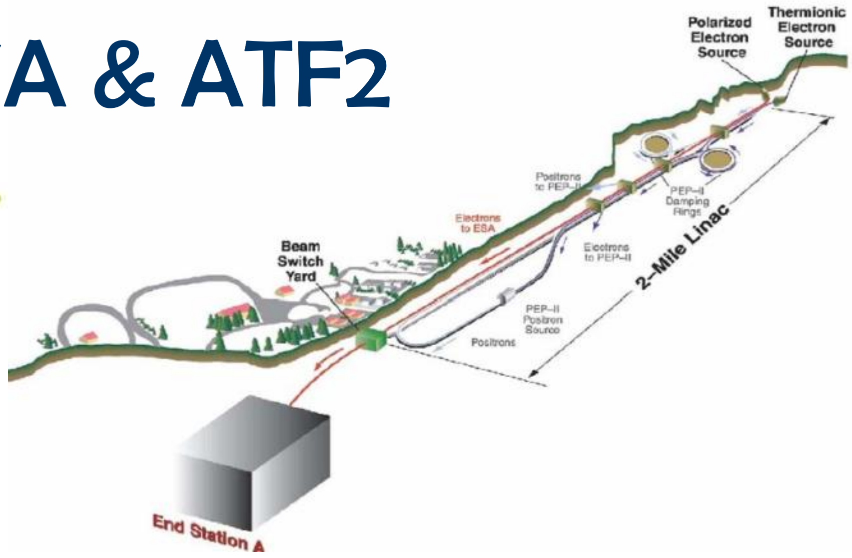
SB2009 Lumi

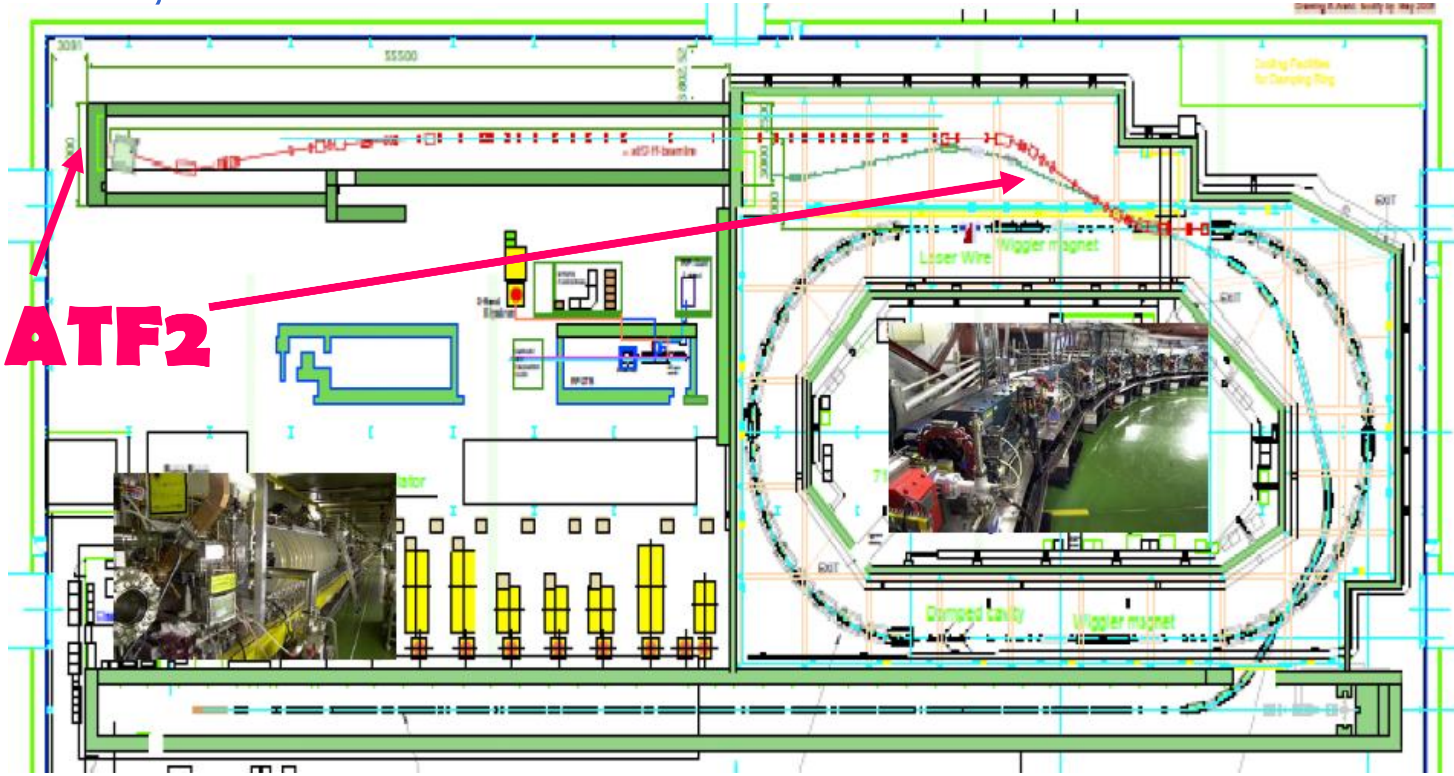


Linac & IP rates
are 8Hz
1/E
L, E34
10^0
Linac rate 10Hz
(IP rate 5Hz)
and special FD
0.5/E
Actual luminosity
Possible luminosity
(very tentative!)
E CM
10^{-1}
200
250
300
350
400
450
500
550

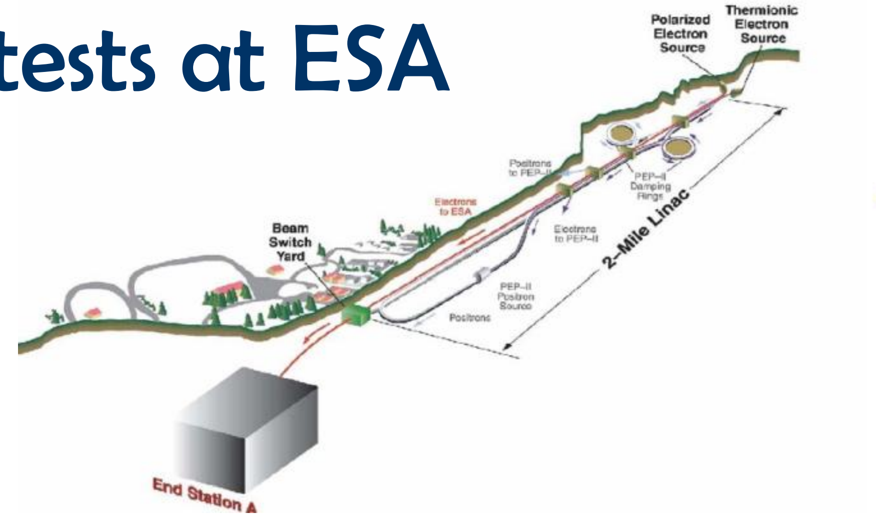
Test facilities: ESA & ATF2

ESA: machine-detector tests; energy spectrometer; collimator wake-fields, etc.
ATF2: prototype FF, develop tuning, diagnostics, etc.

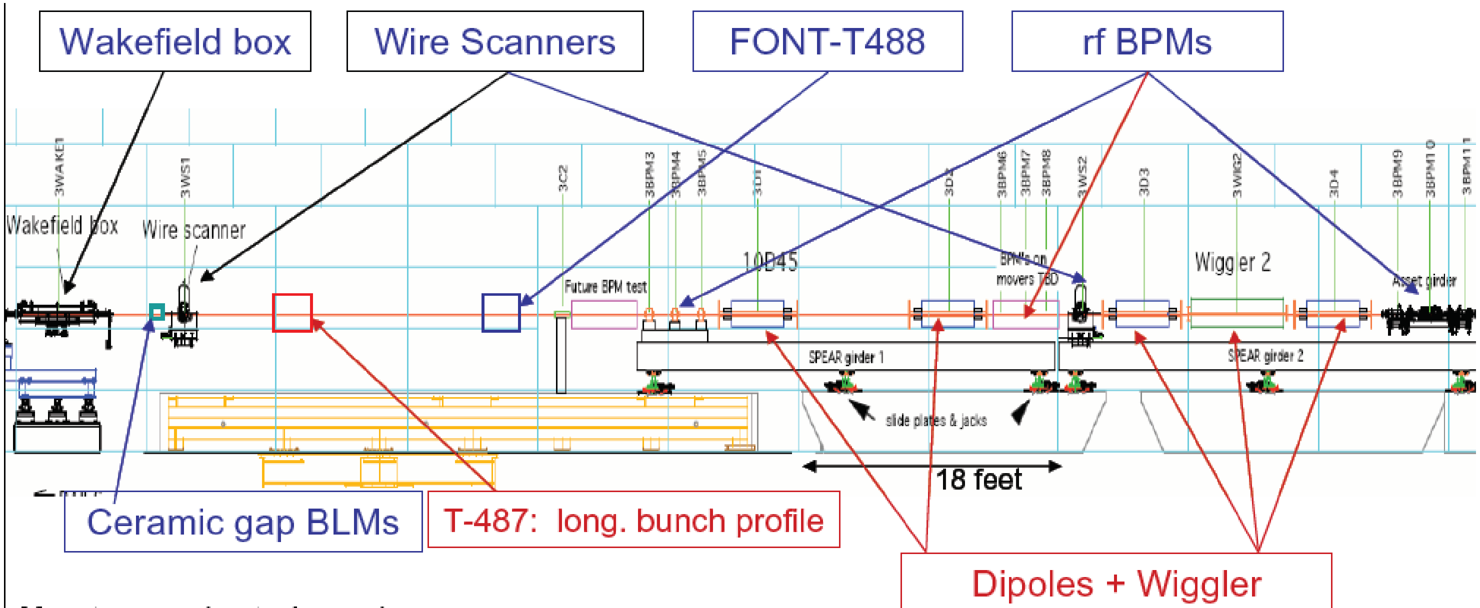




BDS beam tests at ESA



Study:
BPM energy spectrometer
Synch Stripe energy spectrometer
Collimator design, wakefields
IP BPMs/kickers—background studies
EMI (electro-magnetic interference)
Bunch length diagnostics



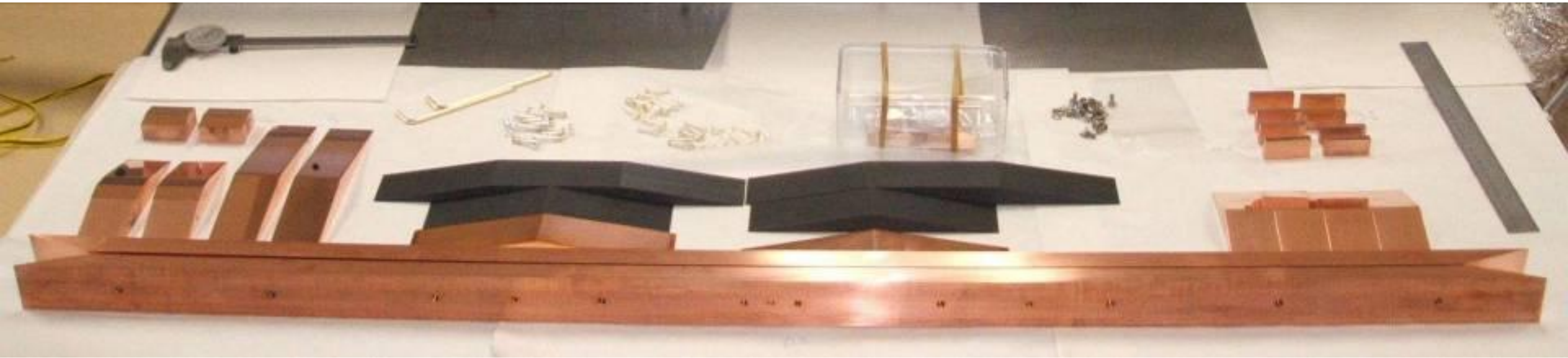
Upstream (not shown)

4 rf BPMs for incoming trajectory
Ceramic gap w/ rf diode detectors (16GHz, 23GHz, and 100GHz) and 2 EMI antennas

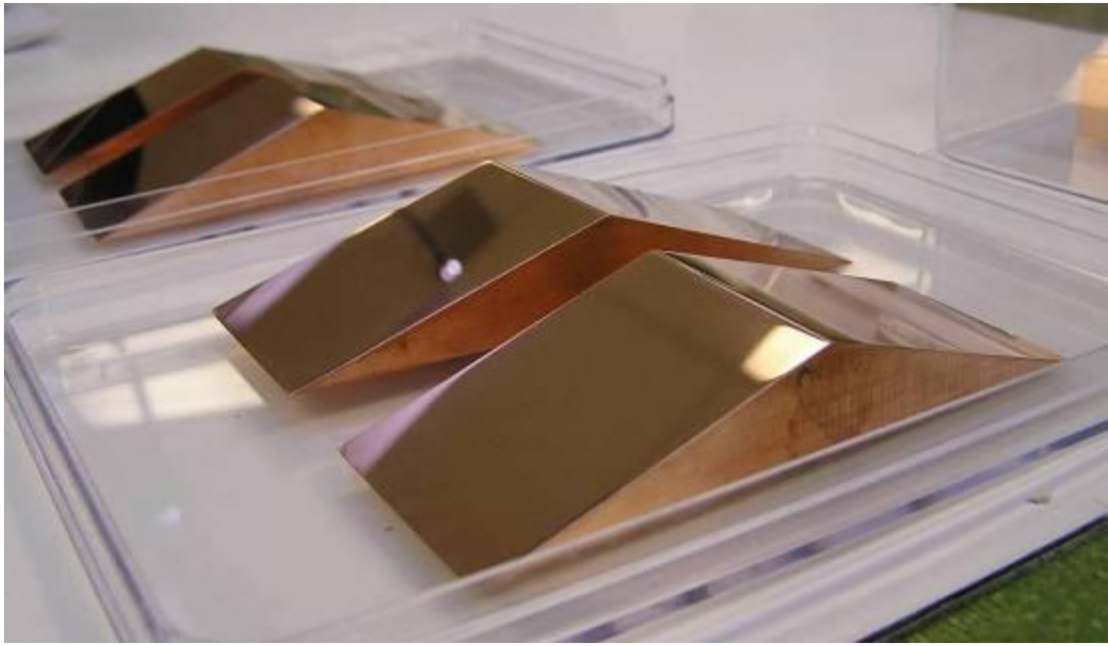
Downstream (not shown)

Ceramic gap for EMI studies
T475 Detector for Wiggler SR stripe

Collimator Wakefield study at ESA



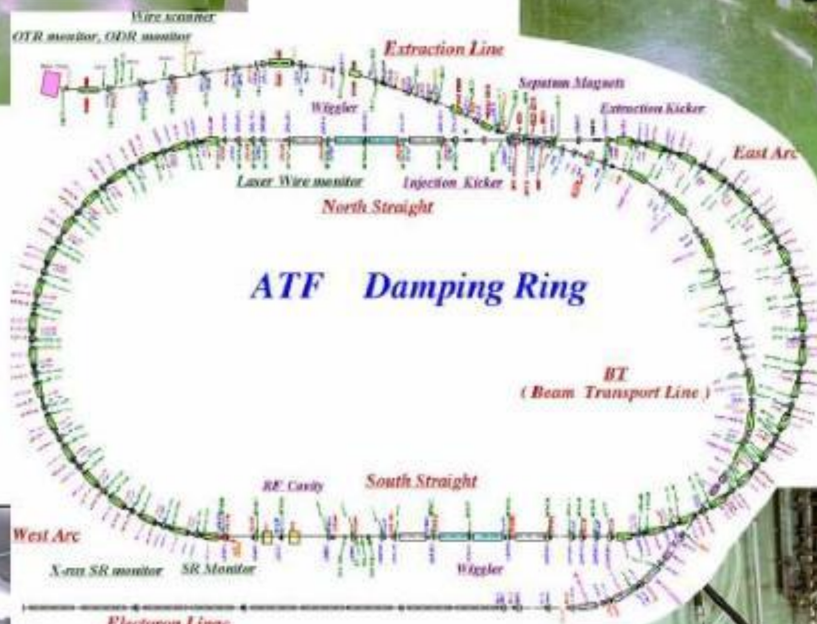
- Spoilers of different shape investigated at ESA (N.Watson et al)
- Theory, 3d modeling and measurements are so far within a factor of ~2 agreement



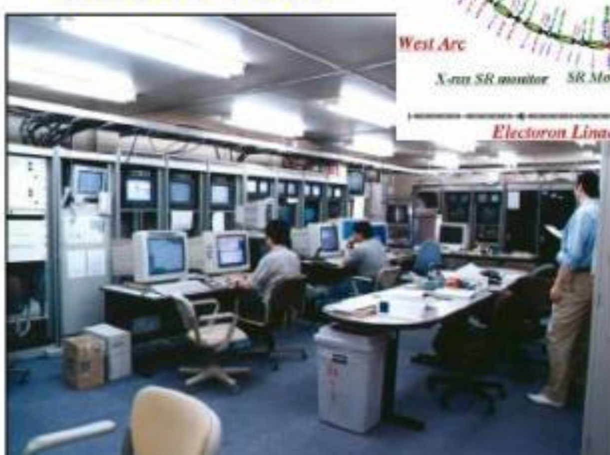
ATF and ATF2

Extraction Line

Damping Ring



Control Room



Linac

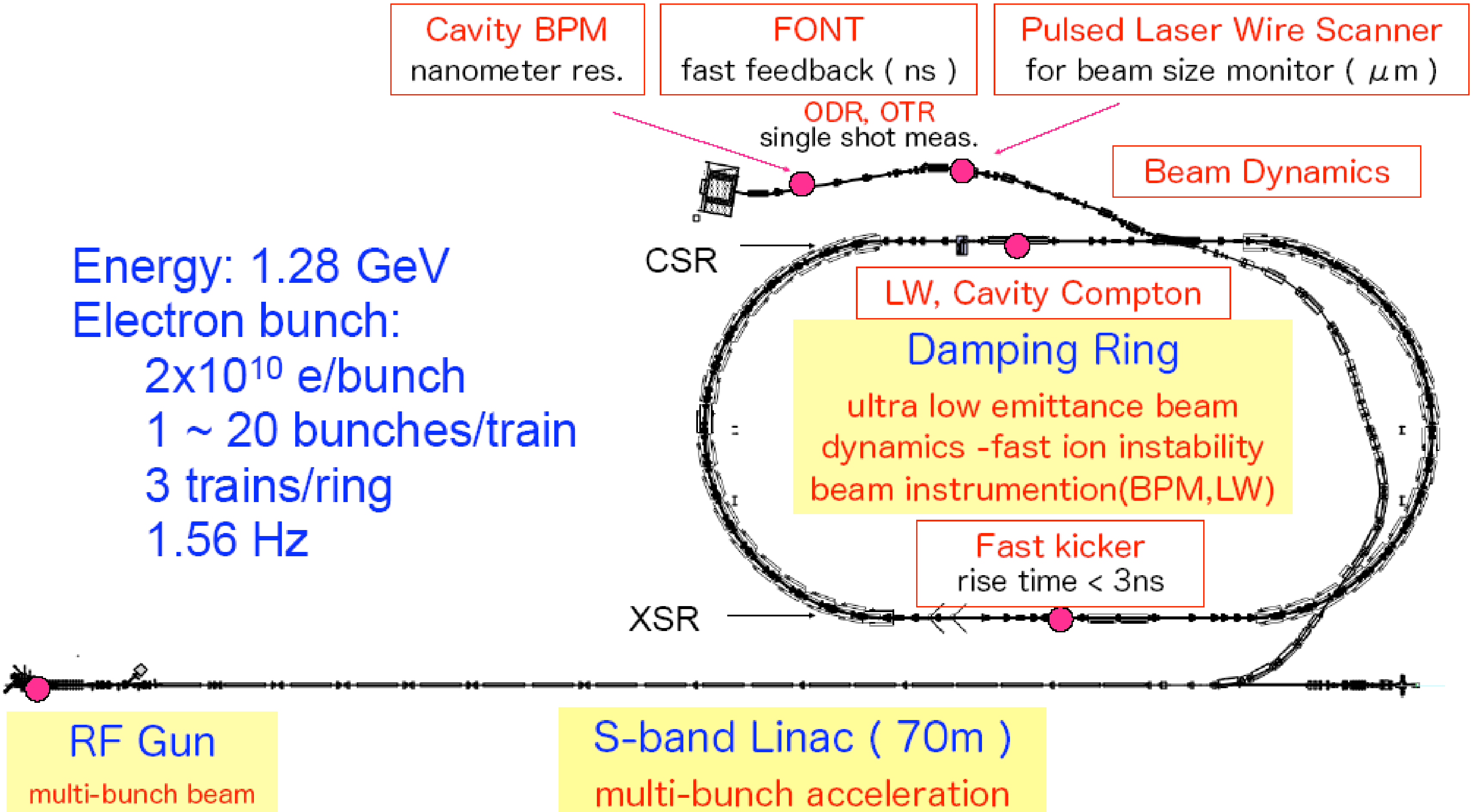
Accelerator Test Facility, KEK

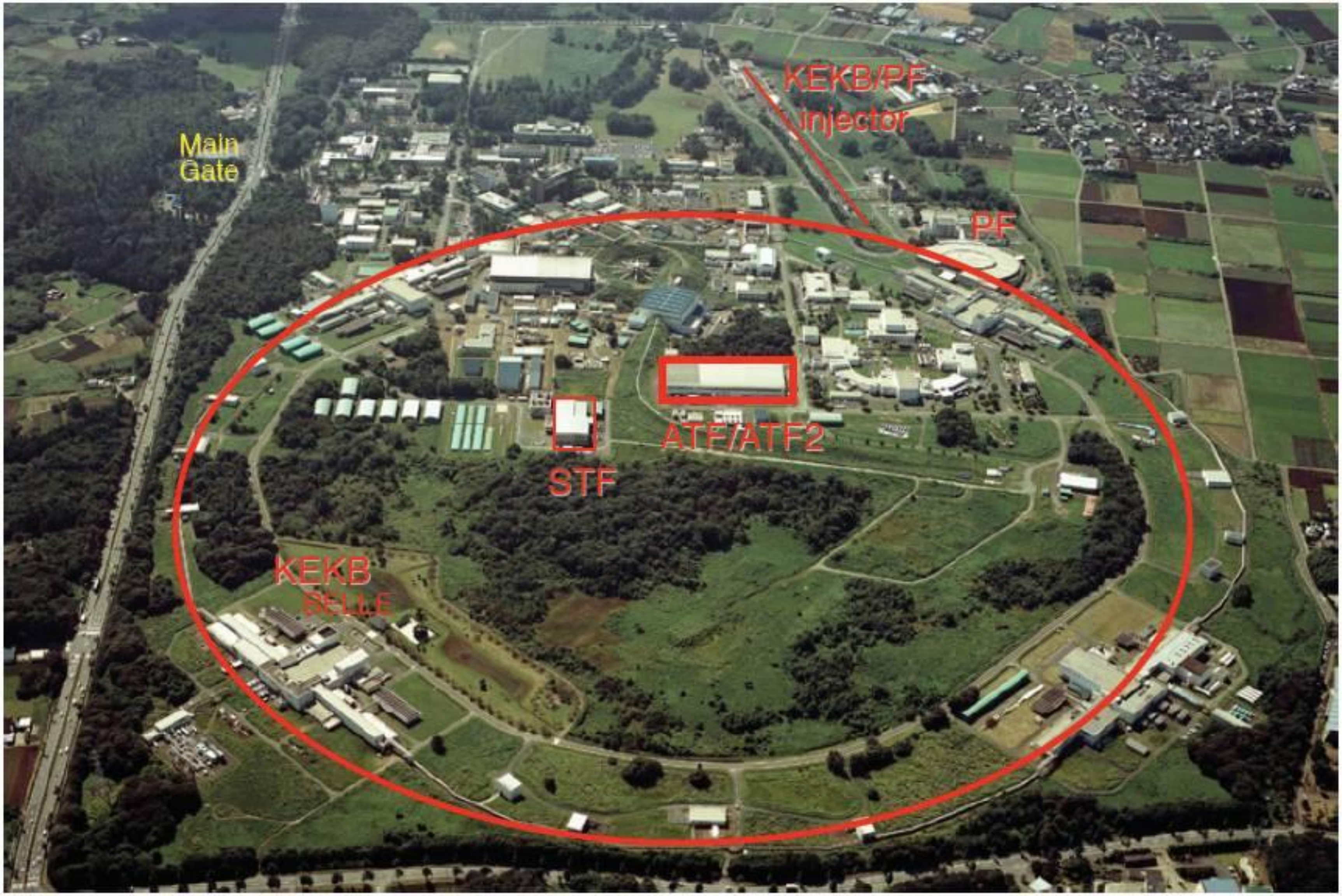
1997-2008

Extraction line :utilization of low emittance beam

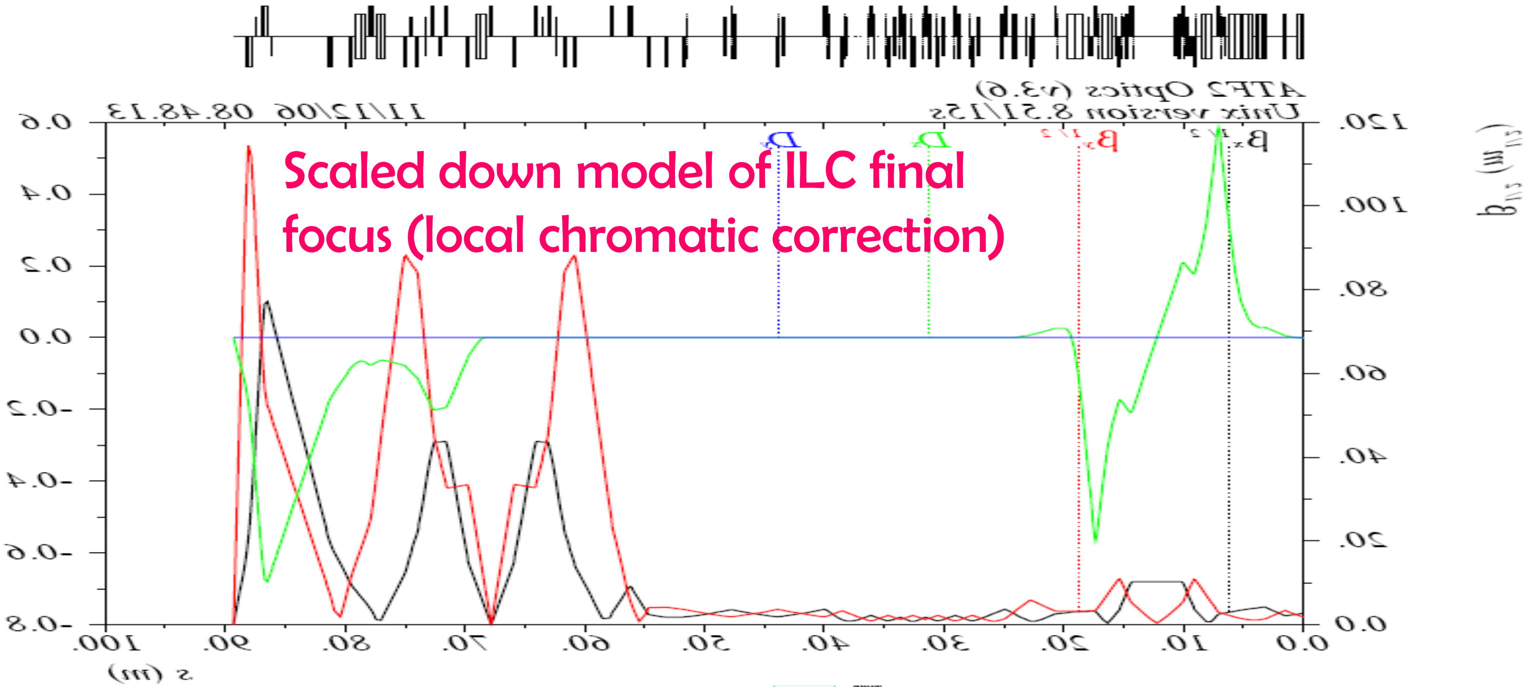
beam instrmentation, collimator damage

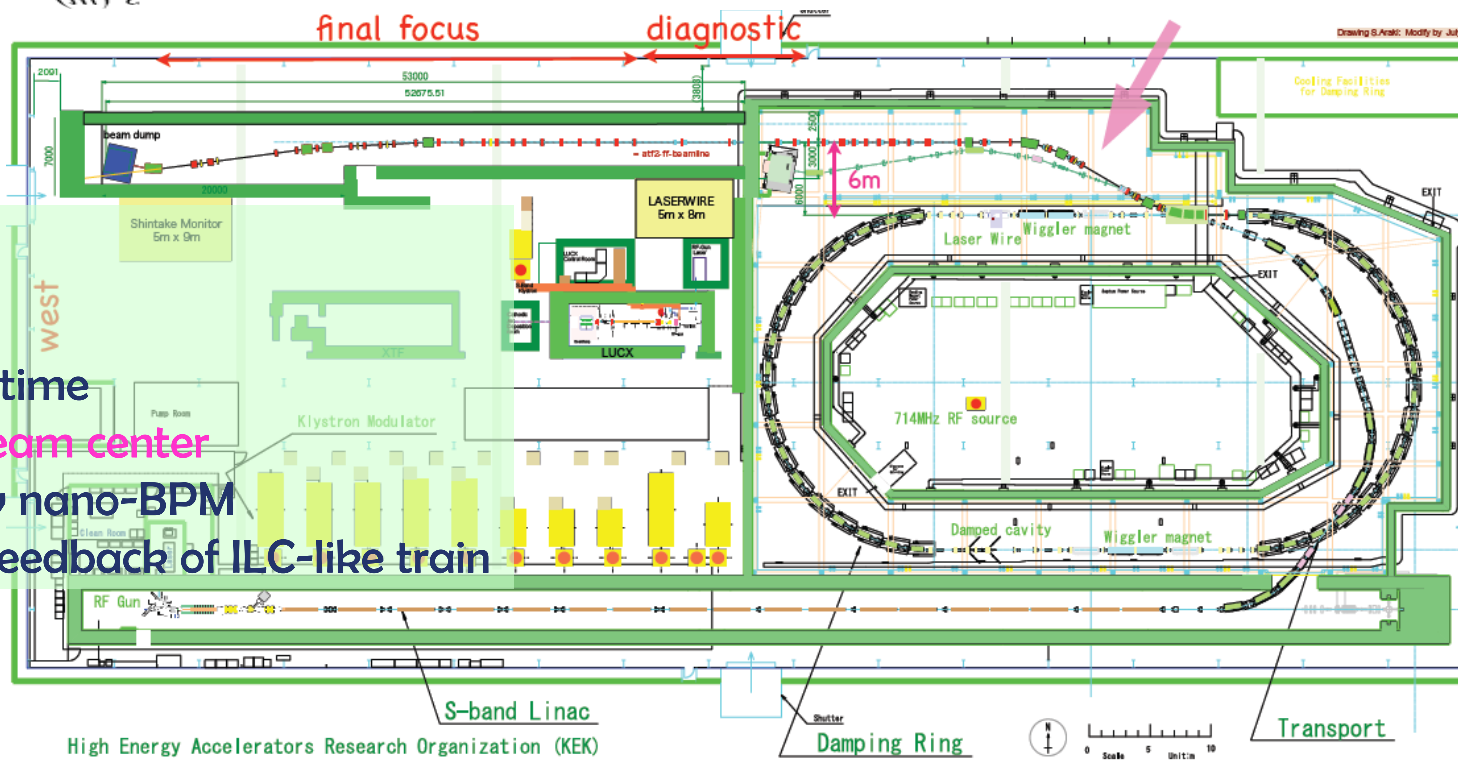
Energy: 1.28 GeV
Electron bunch:
- 2×10^{10} e/bunch
- 1 ~ 20 bunches/train
- 3 trains/ring
- 1.56 Hz




KEKB/PF
injector
Main
Gate
PF
ATF/ATF2
STF
KEKB
BELLE

ATF2 – model of ILC BDS





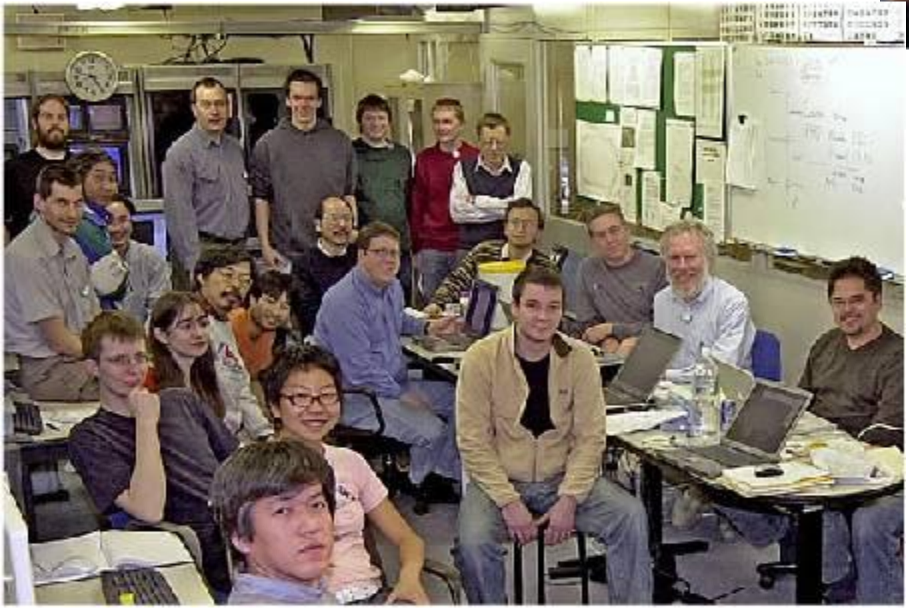
ATF2 goals

(A) Small beam size
- Obtain $\sigma_y \sim 35$nm
- Maintain for long time

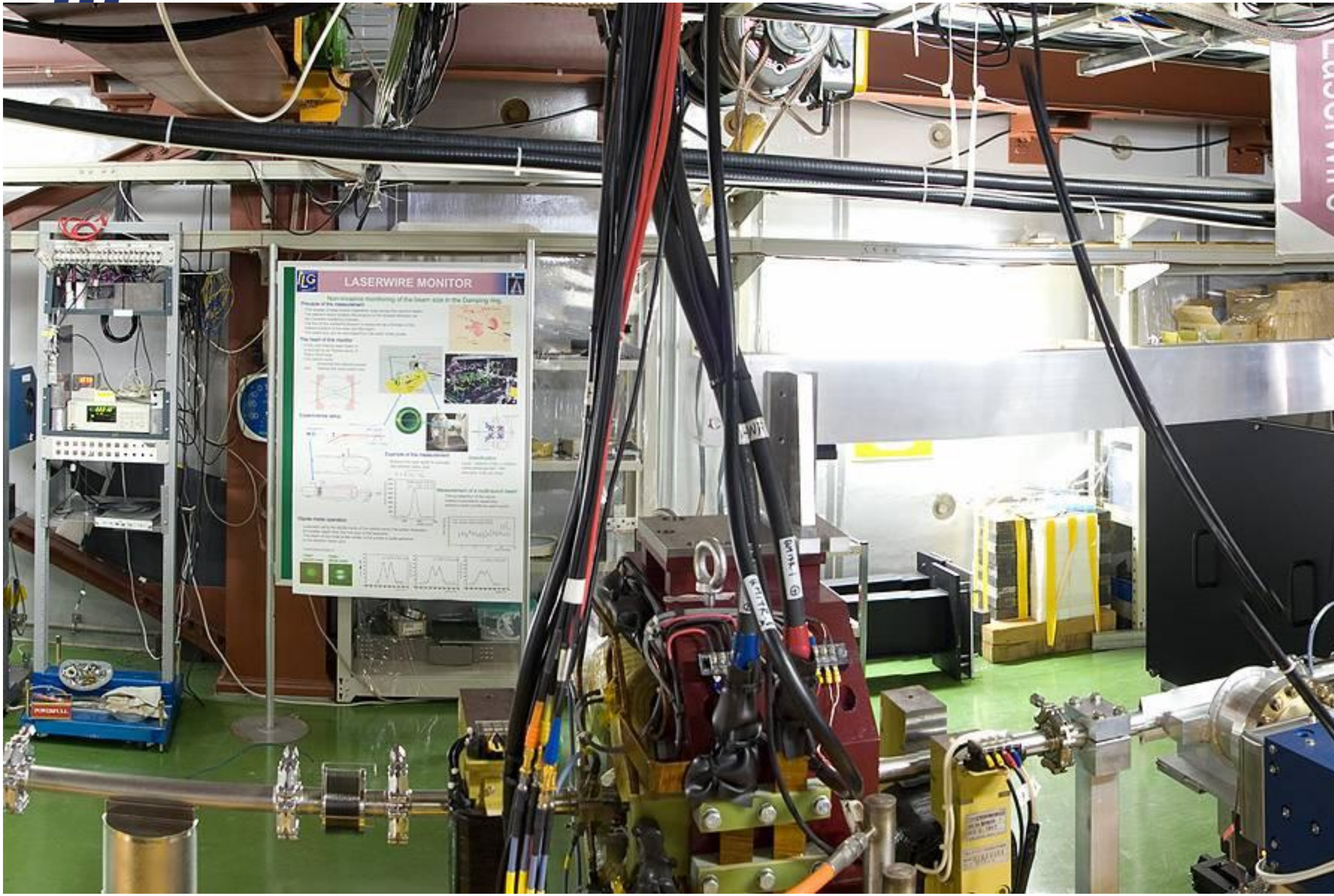
(B) Stabilization of beam center
- Down to < 2nm by nano-BPM
- Bunch-to-bunch feedback of ILC-like train

ATF collaboration & ATF2 facility

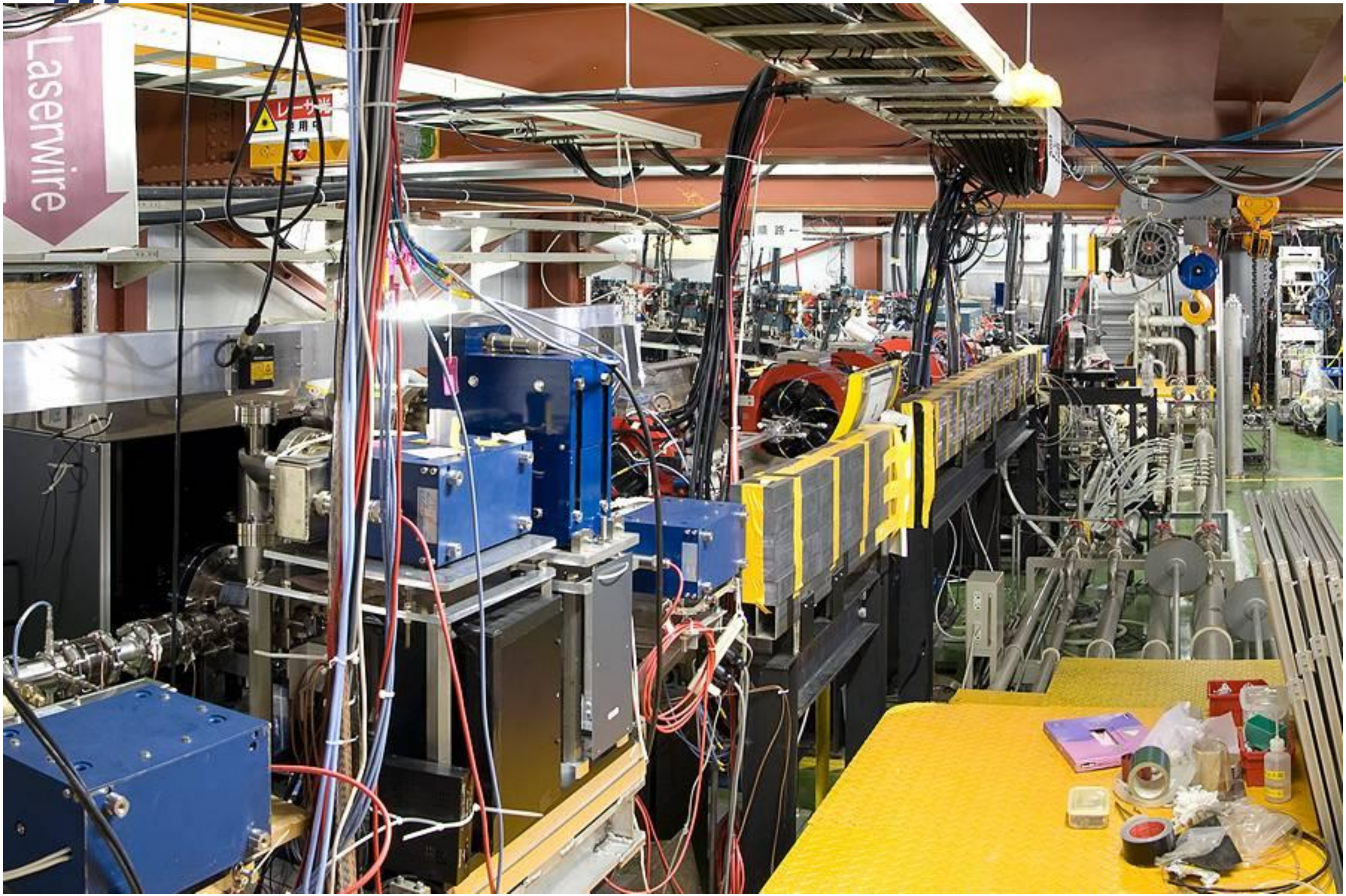
- ATF2 will prototype FF,
- help development tuning methods, instrumentation (laser wires, fast feedback, submicron resolution BPMs),
- help to learn achieving small size & stability reliably,
- potentially able to test stability of FD magnetic center.



- ATF2 is one of central elements of BDS EDR work, as it will address a large fraction of BDS technical cost risk.
- Constructed as ILC model, with in-kind contribution from partners and host country providing civil construction
- ATF2 commissioning will start in Autumn of 2008

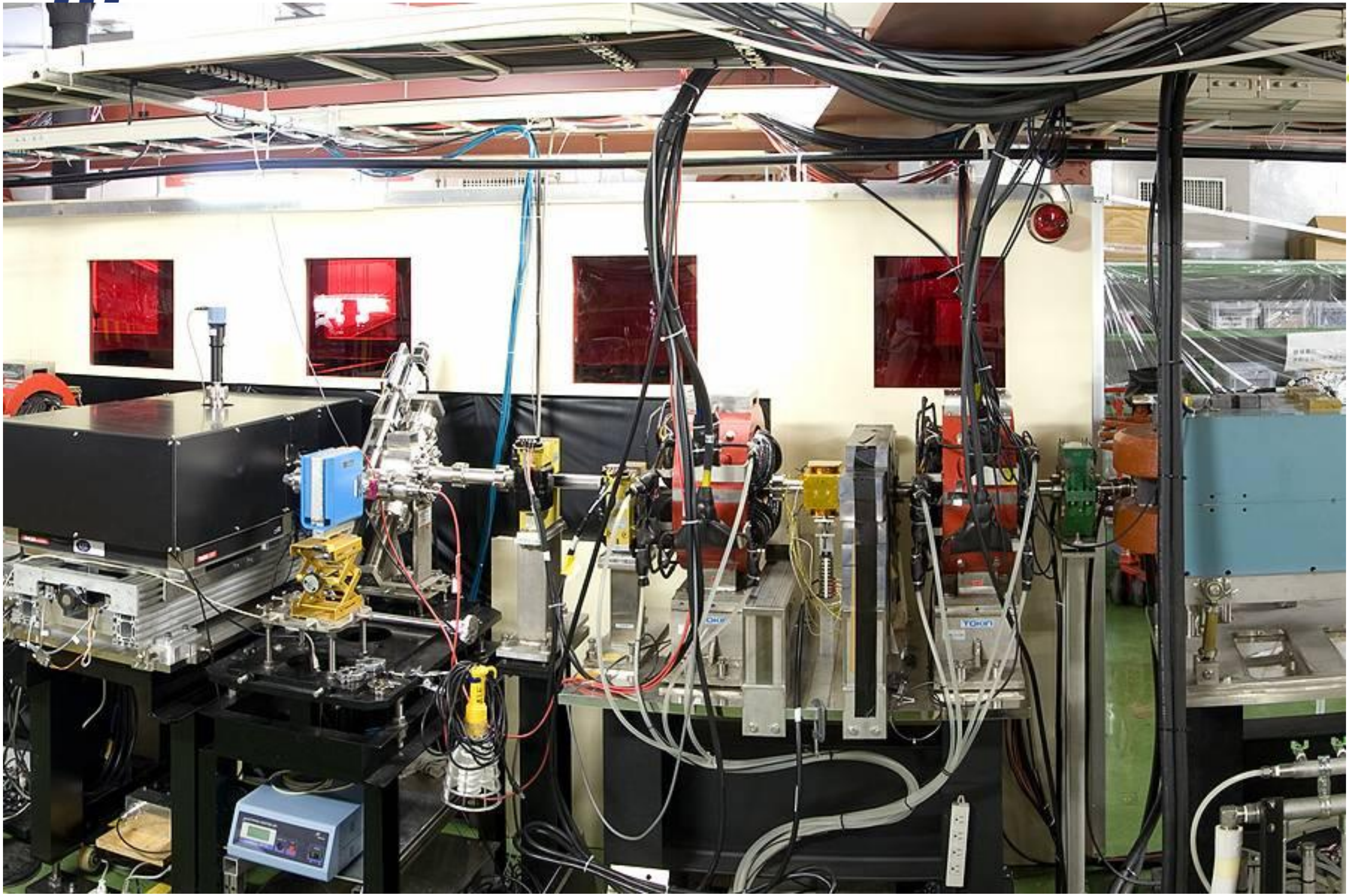


Panoramic photo of ATF beamlines, N.Toge

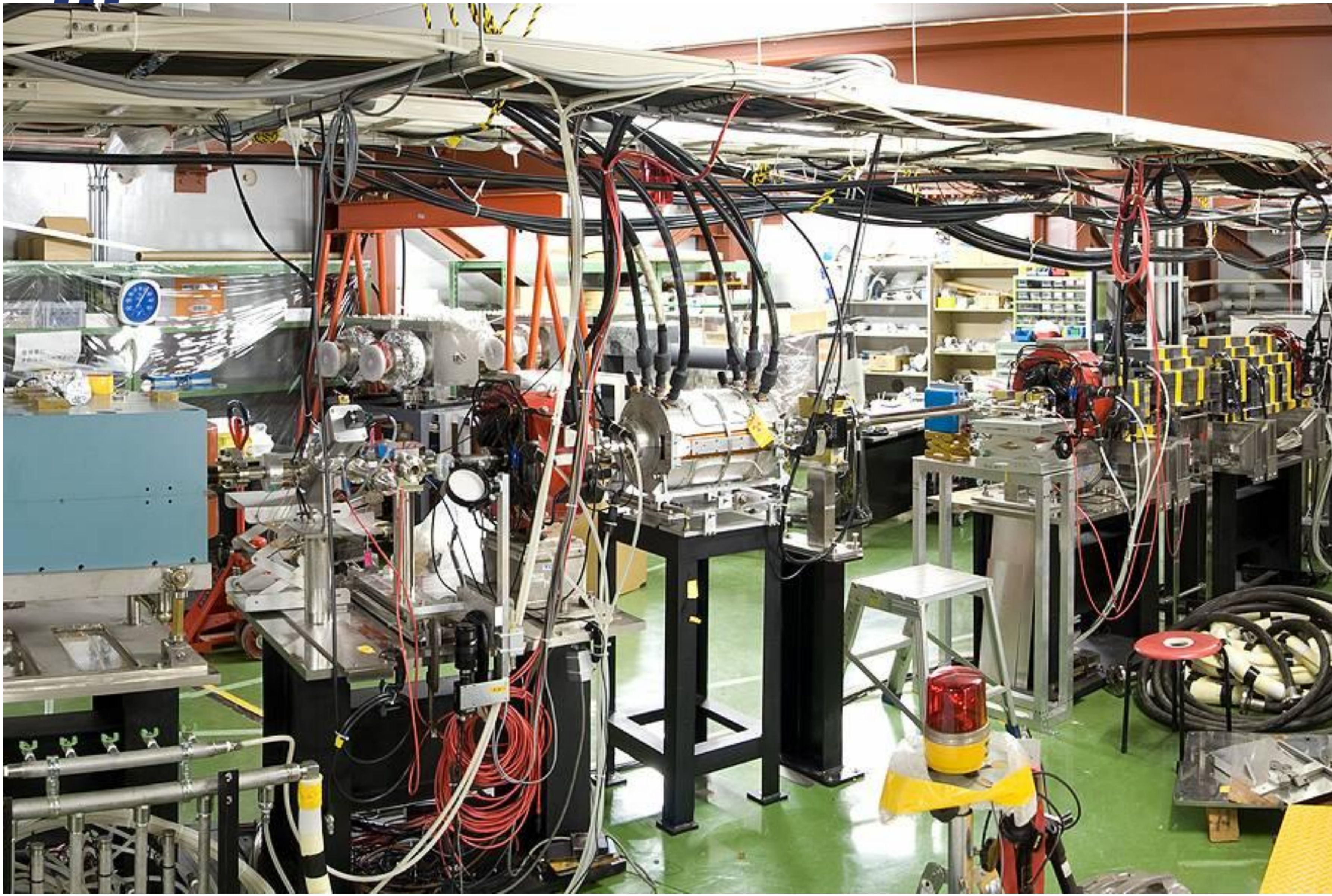


Panoramic photo of ATF beamlines, N.Toge

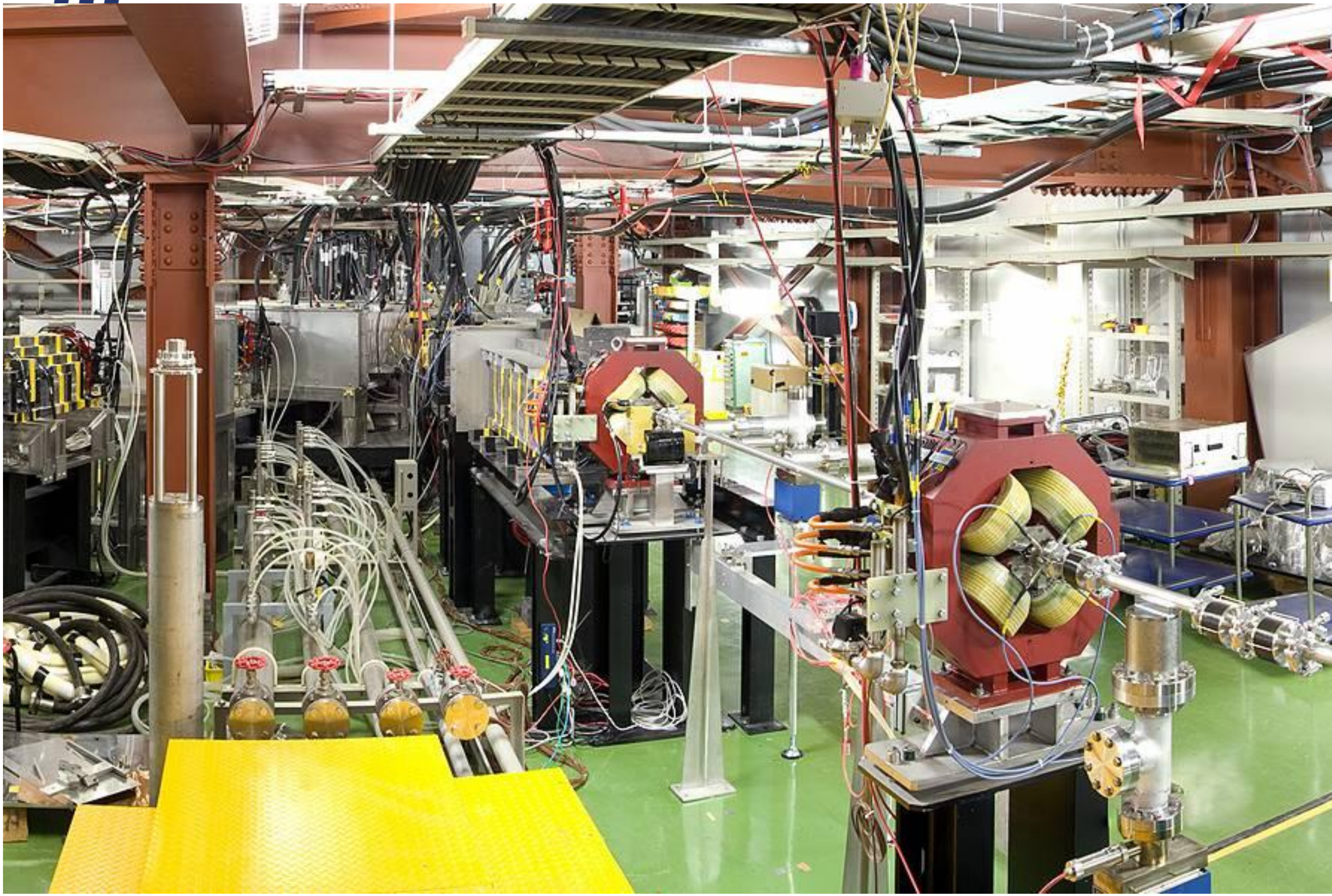
Panoramic photo of ATF beamlines, N.Toge



Panoramic photo of ATF beamlines, N.Toge



Panoramic photo of ATF beamlines, N.Toge



Panoramic photo of ATF beamlines, N.Toge

Panoramic photo of ATF beamlines, N.Toge

ATF hall before ATF2 construction

ATF hall emptied

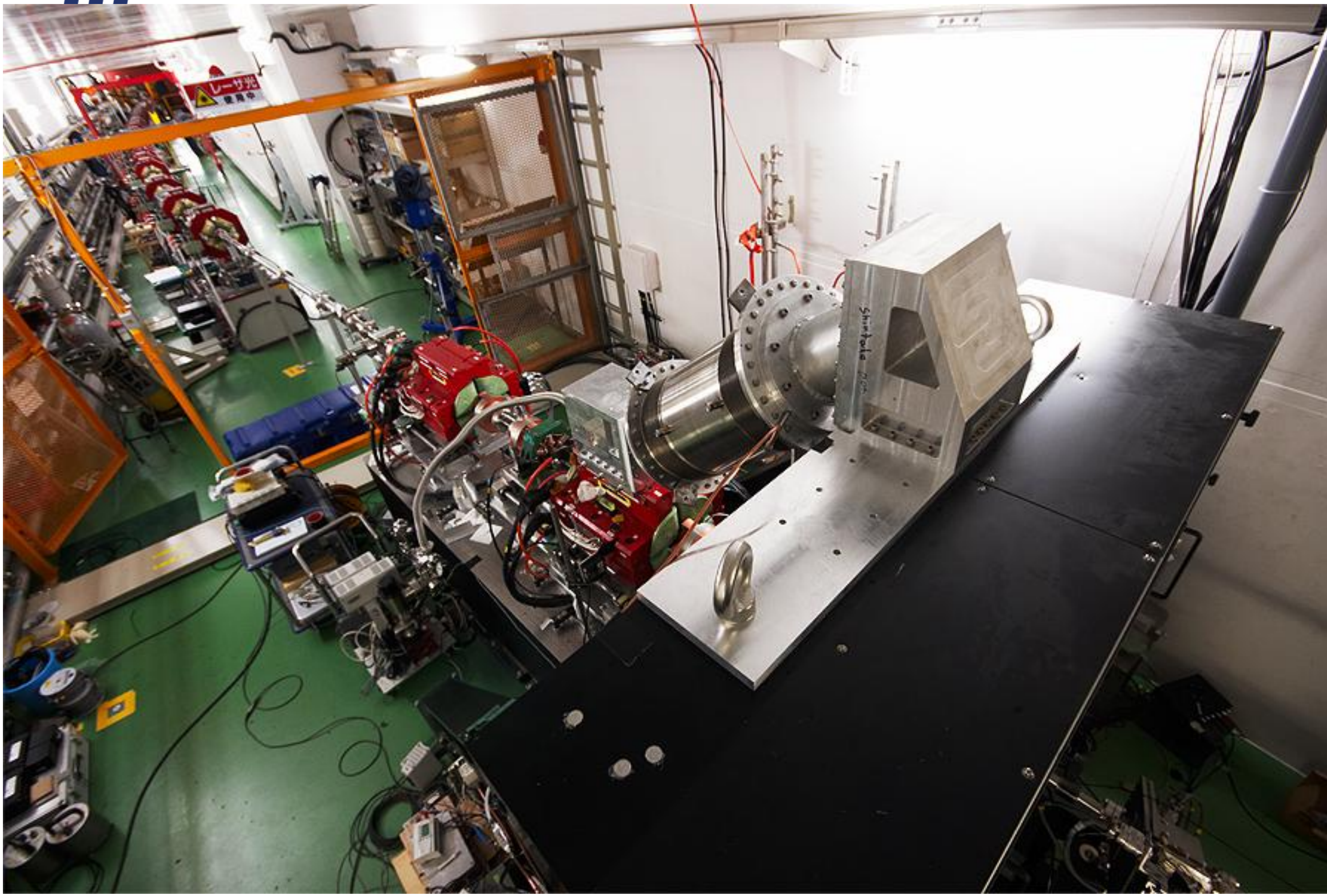
Photos from ATF2 construction, N.Toge

Building the reinforced floor

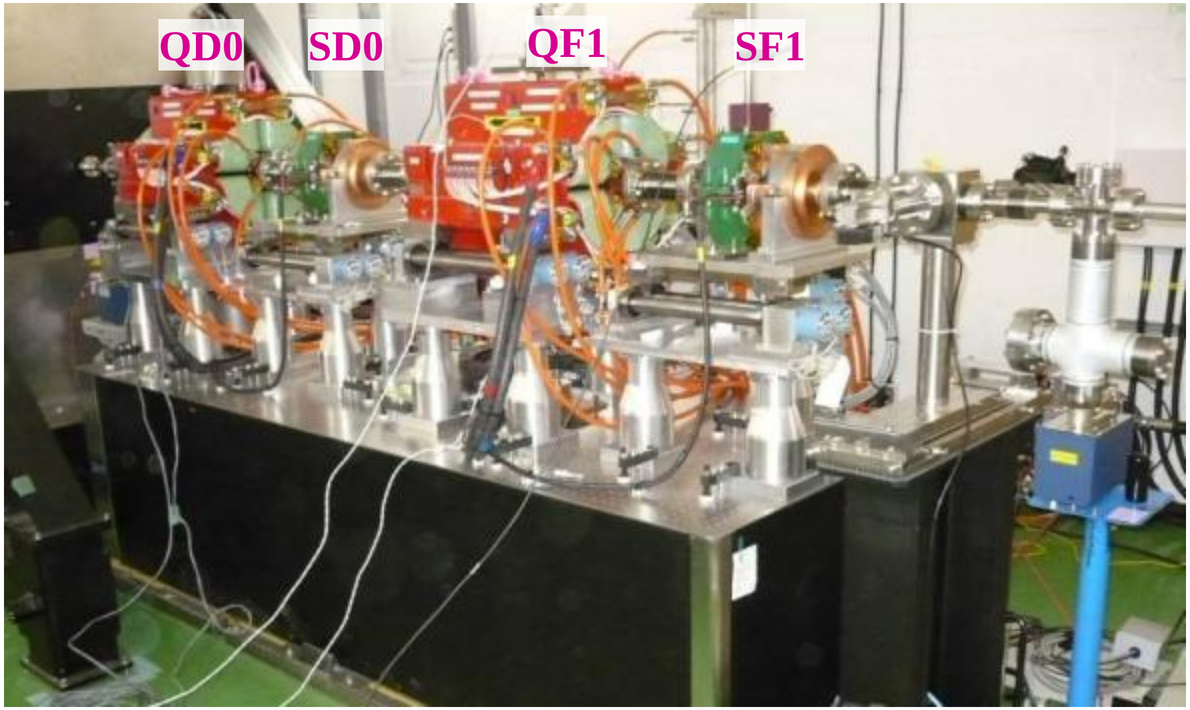
Photos from ATF2 construction, N.Toge

Finished reinforced floor for ATF2

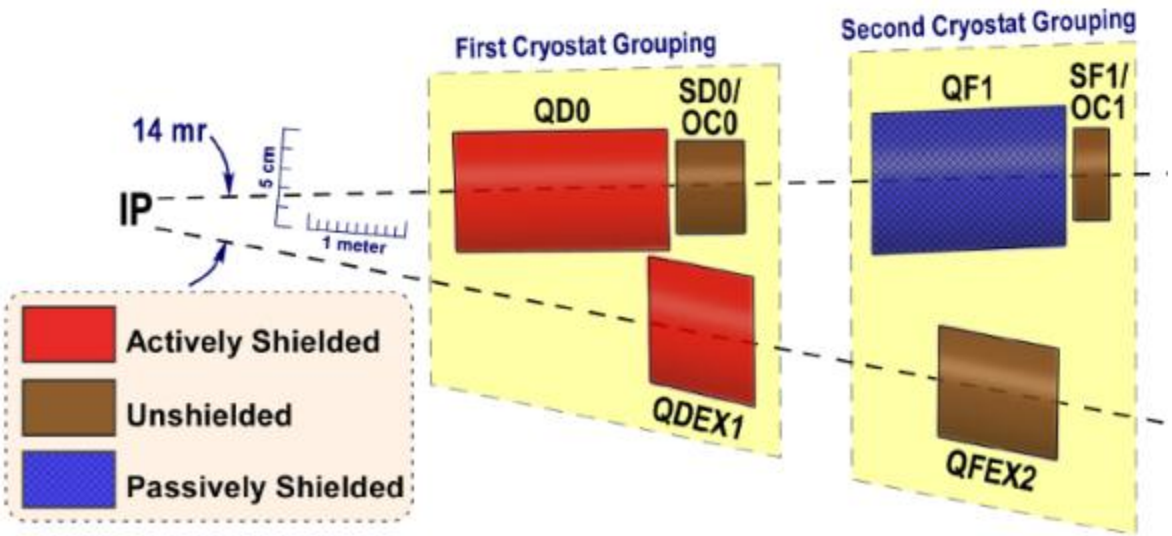
Photos from ATF2 construction, N.Toge



BDS: 153



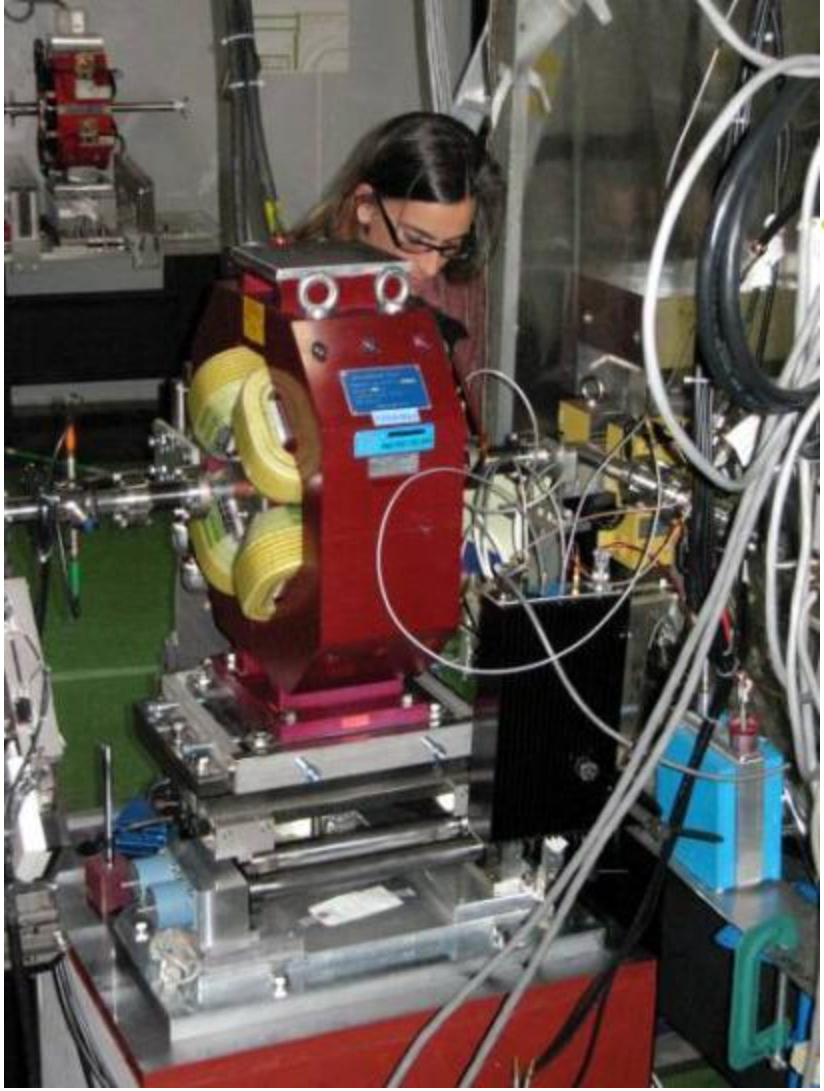
ATF2 final doublet



ILC Final Doublet layout

ATF & ATF2

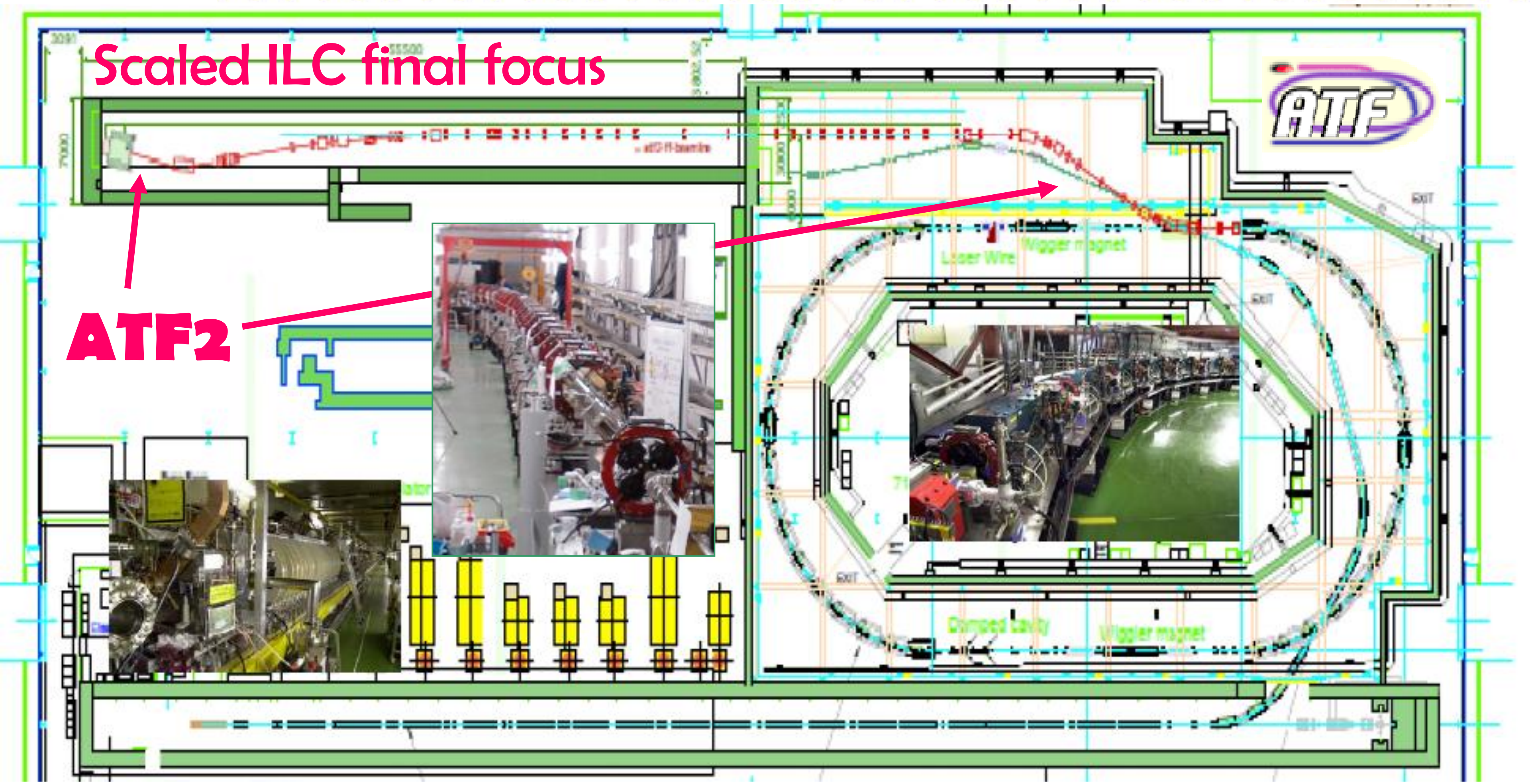
J.Nelson (at SLAC) and T.Smith (at KEK) during recent "remote participation" shift. Top monitors show ATF control system data. The shift focused on BBA, performed with new BPM electronics installed at ATF by Fermilab colleagues.



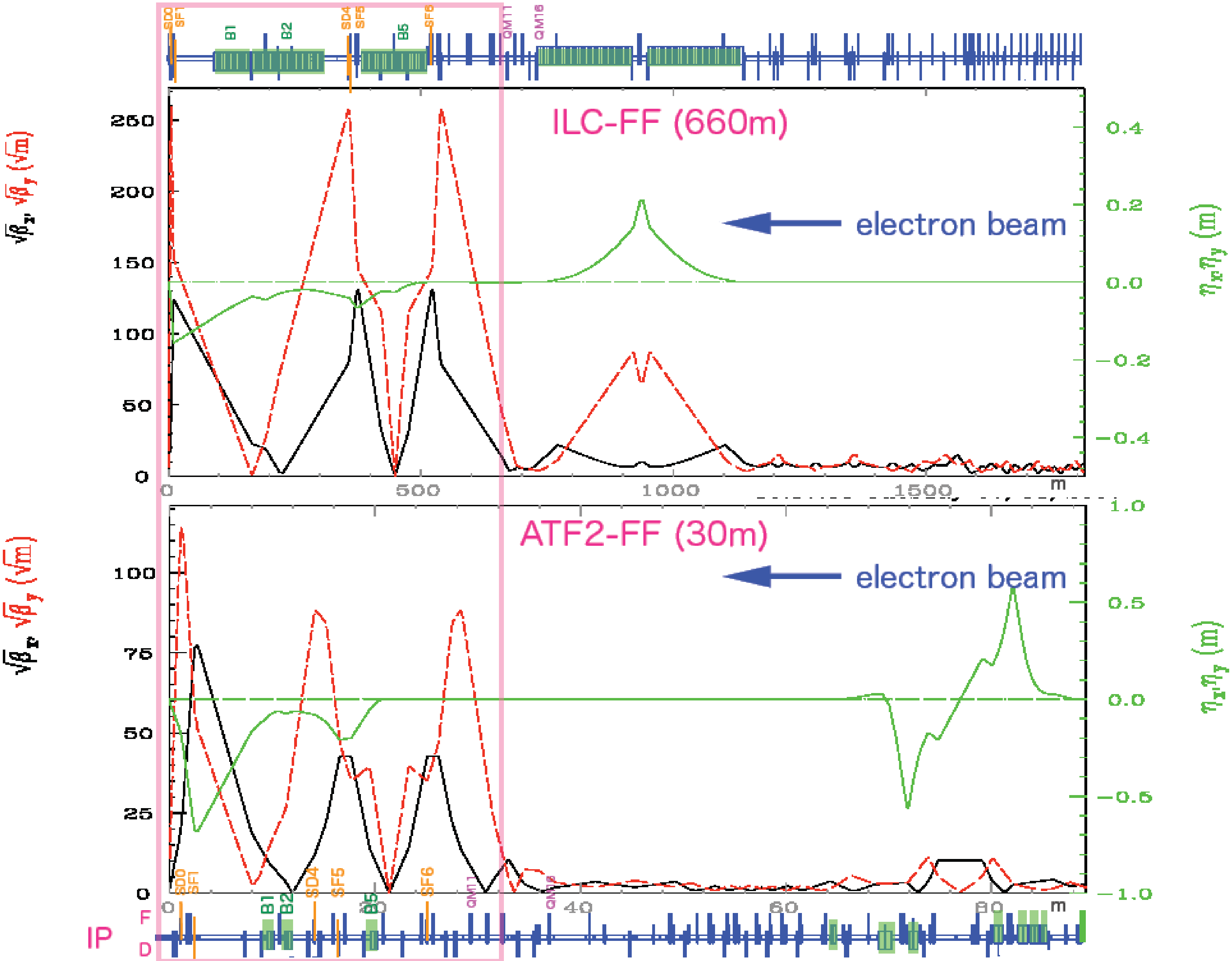
T.Smith is commissioning the cavity BPM electronics and the magnet mover system at ATF beamline

ATF2: model of ILC beam delivery

goals: ~37nm beam size; nm level beam stability



- Dec 2008: first pilot run; Jan 2009: hardware commissioning
- Feb-Apr 2009: large β; BSM laser wire mode; tuning tools commissioning
- Oct-Dec 2009: commission interferometer mode of BSM & other hardware


ILC-FF (660m)
electron beam
ATF2-FF (30m)
electron beam
$\sqrt{\beta_x}$, $\sqrt{\beta_y}$ ($\sqrt{m}$)
η_x, η_y (m)
IP
F
D
SD0
SF1
B1
B2
SD4
SF5
B5
SF6
QM11
QM16

BDS: 157

ATF2 parameters & Goals A/B

Beam parameters achieved at ATF and planned for ATF2, goals A and B. The ring energy is E0 = 1.3 GeV, the typical bunch length and energy spread are σ_z =8 mm and $\Delta E/E$ = 0.08 %.

	Measured	(A)	(B)
Single Bunch			
N_{bunch} $[10^{10}]$	0.2 – 1.0	0.5	0.5
DR $\gamma\varepsilon_y$ $[10^{-8}\text{m}]$	1.5	3	3
Extr. $\gamma\varepsilon_y$ $[10^{-8}\text{m}]$	3.0 – 6.5	3	3
Multi Bunch			
$n_{bunches}$	20	1 – 20	3 – 20
N_{bunch} $[10^{10}]$	0.3 – 0.5	0.5	0.5
DR $\gamma\varepsilon_y$ $[10^{-8}\text{m}]$	3.0 – 4.5	3	3
Extr. $\gamma\varepsilon_y$ $[10^{-8}\text{m}]$	~ 6	3	3
IP σ_y^* [nm]		37	37
IP $\Delta y/\sigma_y^*$ [%]		30	5

ATF2 proposed IP parameters compared with ILC

Parameters	ATF2	ILC
Beam Energy [GeV]	1.3	250
L^* [m]	1	3.5 – 4.2
$\gamma\,\epsilon_x$ [m-rad]	3×10^{-6}	1×10^{-5}
$\gamma\,\epsilon_y$ [m-rad]	3×10^{-8}	4×10^{-8}
β_x^* [mm]	4.0	21
β_y^* [mm]	0.1	0.4
η' (DDX) [rad]	0.14	0.094
σ_E [%]	~0.1	~0.1
Chromaticity W_y	$\sim 10^4$	$\sim 10^4$

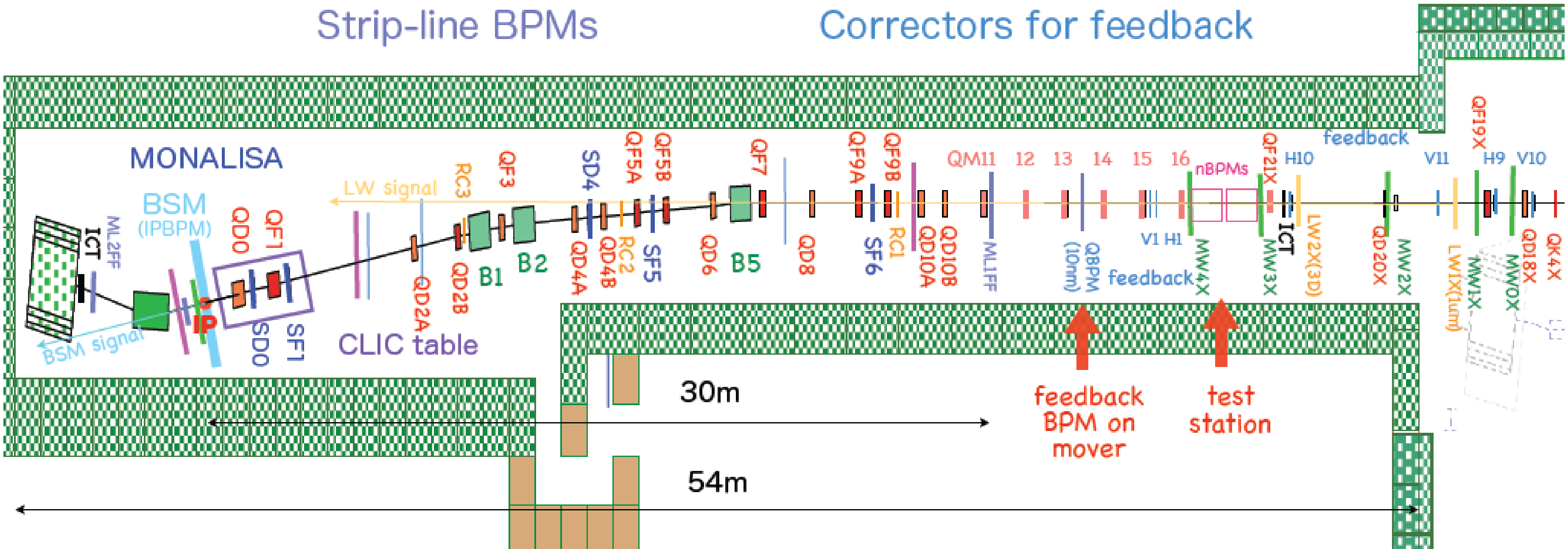
Magnets and Instrumentation at ATF2

22 Quadrupoles(Q), 5 Sextupoles(S), 3 Bends(B) in downstream of QM16

All Q- and S-magnets have cavity-type beam position monitors(QBPM, 100nm).

3 Screen Monitors 5 Wire Scanners, Laserwires

Strip-line BPMs Correctors for feedback



Shintake Monitor (beam size monitor, BSM with laser interferometer)

MONALISA (nanometer alignment monitor with laser interferometer)

Laserwire (beam size monitor with laser beam for 1 μm beam size, 3 axies)

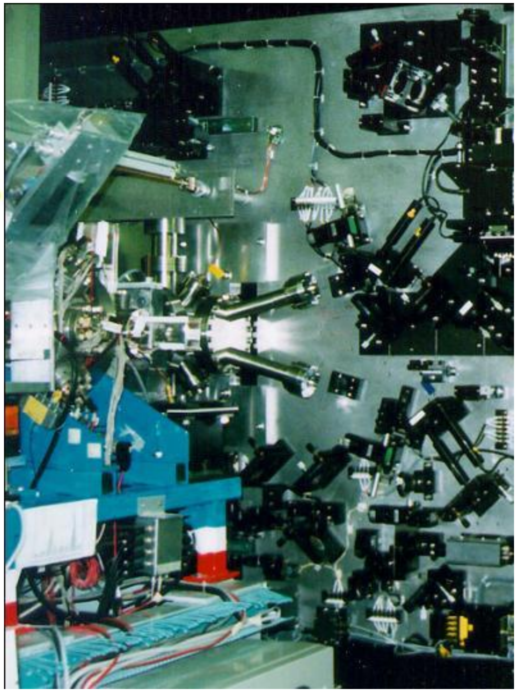
IP intra-train feedback system with latency of less than 150ns (FONT)

Magnet movers for Beam Based Alignment (BBA)

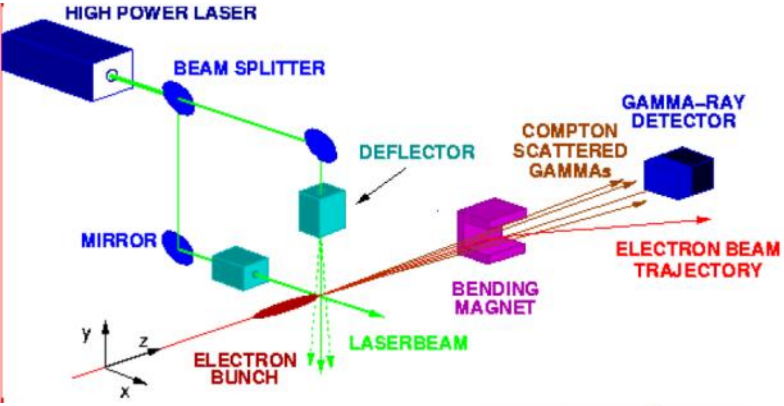
High Available Power Supply (HA-PS) system for magnets

Advanced beam instrumentation at ATF2

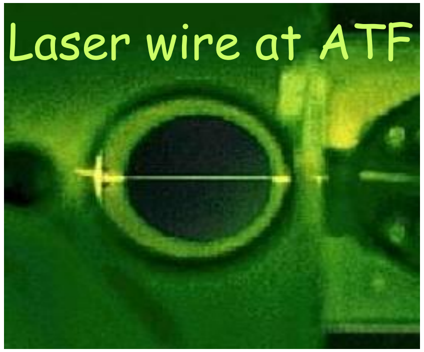
- BSM to confirm 35nm beam size
- nano-BPM at IP to see the nm stability
- Laser-wire to tune the beam
- Cavity BPMs to measure the orbit
- Movers, active stabilization, alignment system
- Intratrain feedback, Kickers to produce ILC-like train

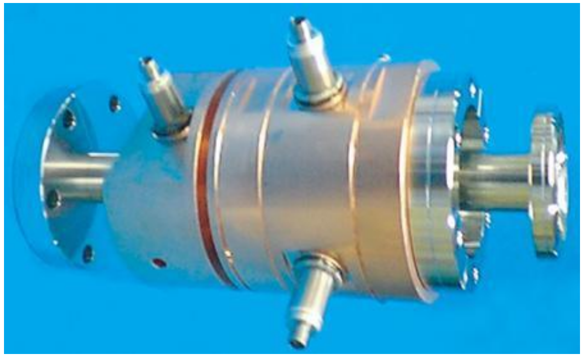


IP Beam-size monitor (BSM) (Tokyo U./KEK, SLAC, UK)



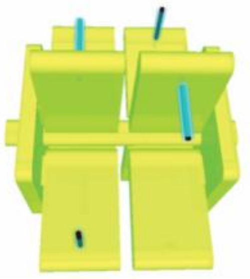
Laser-wire beam-size Monitor (UK group)





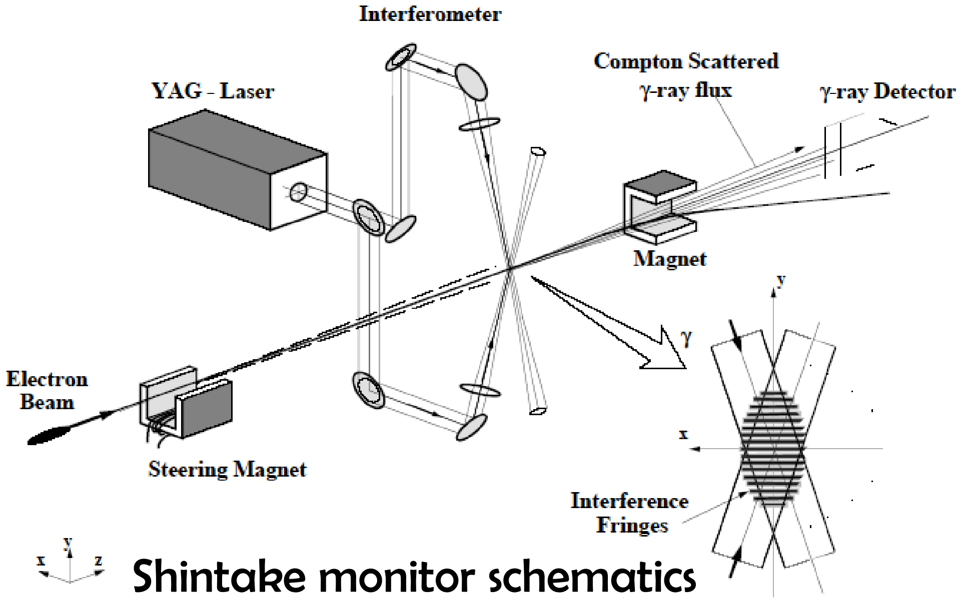
Cavity BPMs, for use with Q magnets with 100nm resolution (PAL, SLAC, KEK)

Cavity BPMs with 2nm resolution, for use at the IP (KEK)

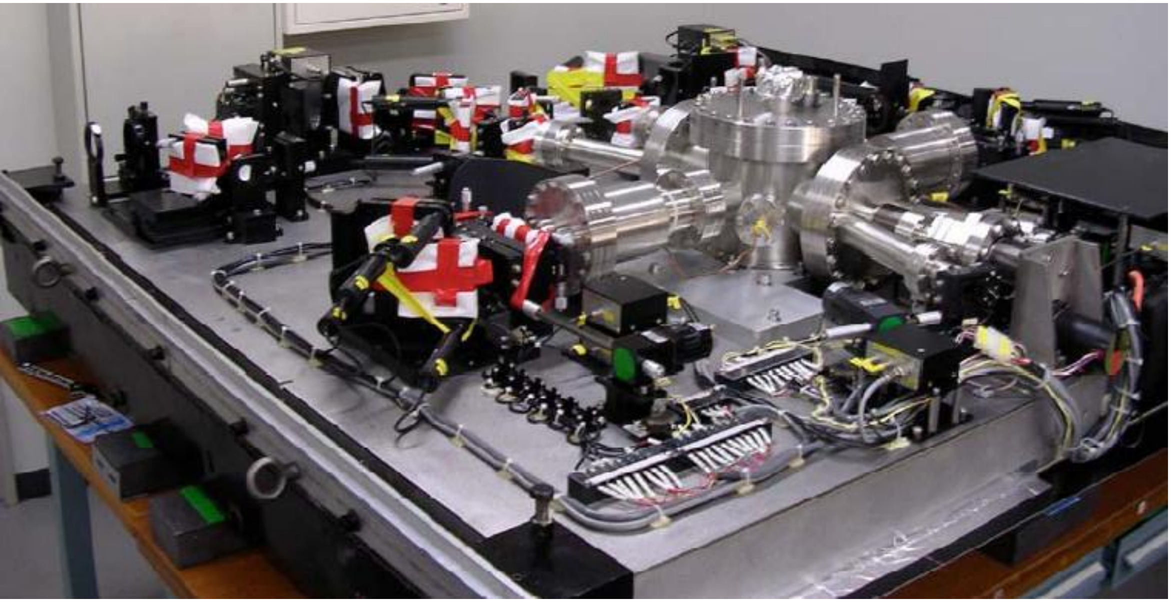


IP Beam Size monitor

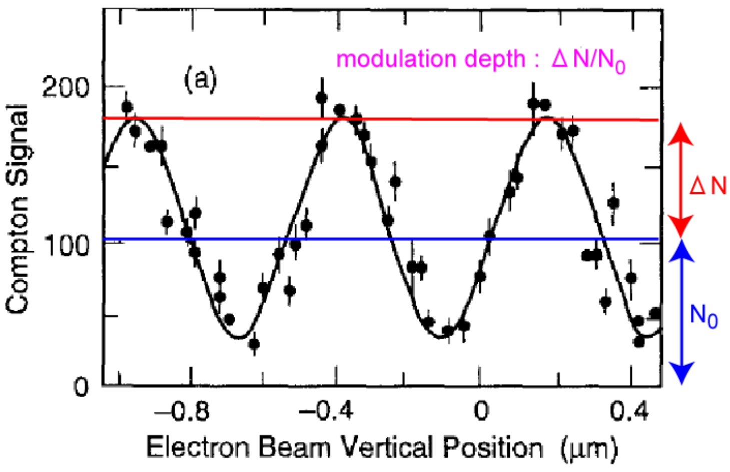
- BSM:
  - refurbished & much improved FFTB Shintake BSM
  - 1064nm=>532nm



Shintake monitor schematics



Jul 2005: BSM after it arrived to Univ. of Tokyo



FFTB sample : σ_y = 70 nm

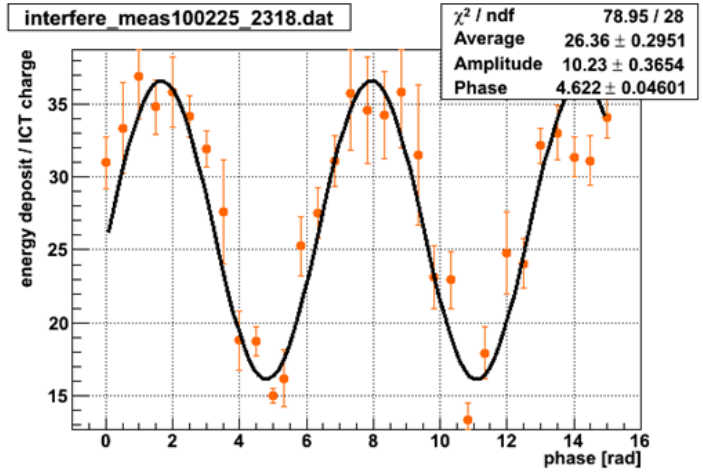
Ongoing R&Ds at ATF/ATF2

- **ATF**
- **low emittance beam**
  - Tuning, XSR, SR, Laser wire,…
- **1pm emittance** (DR BPM upgrade,.
- **Multi-bunch**
  - Instability (Fast Ion,…)

  Extraction by Fast Kicker

Others
  - Cavity Compton
  - SR monitor at EXT
- **ATF2**
- **35 nm beam size**
  - Beam tuning (Optics modeling, Optics test, debugging soft&hard tools,…)
  - Cavity BPM (C&S-band, IP-BPM)
  - Beam-tilt monitor
  - IP-BSM (Shintake monitor)
- **Beam position stabilization (2nm)**
  - Intra-train feedback (FONT)
  - feed-forward DR->ATF2

Interfere mode scan

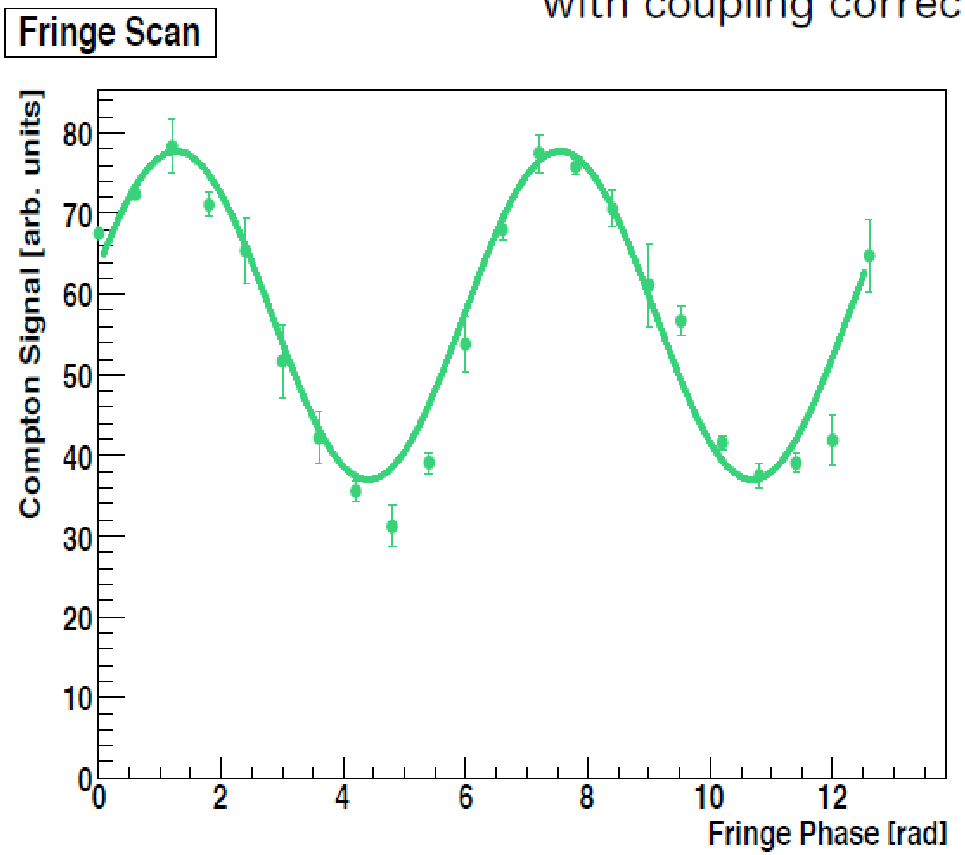


Beam size ~ 2.4 μm
Wire scanner measurement ~ 3.1 μm

Others
- Pulsed 1um Laser Wire
- Cold BPM
- Liquid Pb target
- **Permanent FD Q**
- **SC Final doublet Q/Sx**

Fringe Scan Results (2 degree mode)

with coupling correction at PIP by QK1-4X (rough)

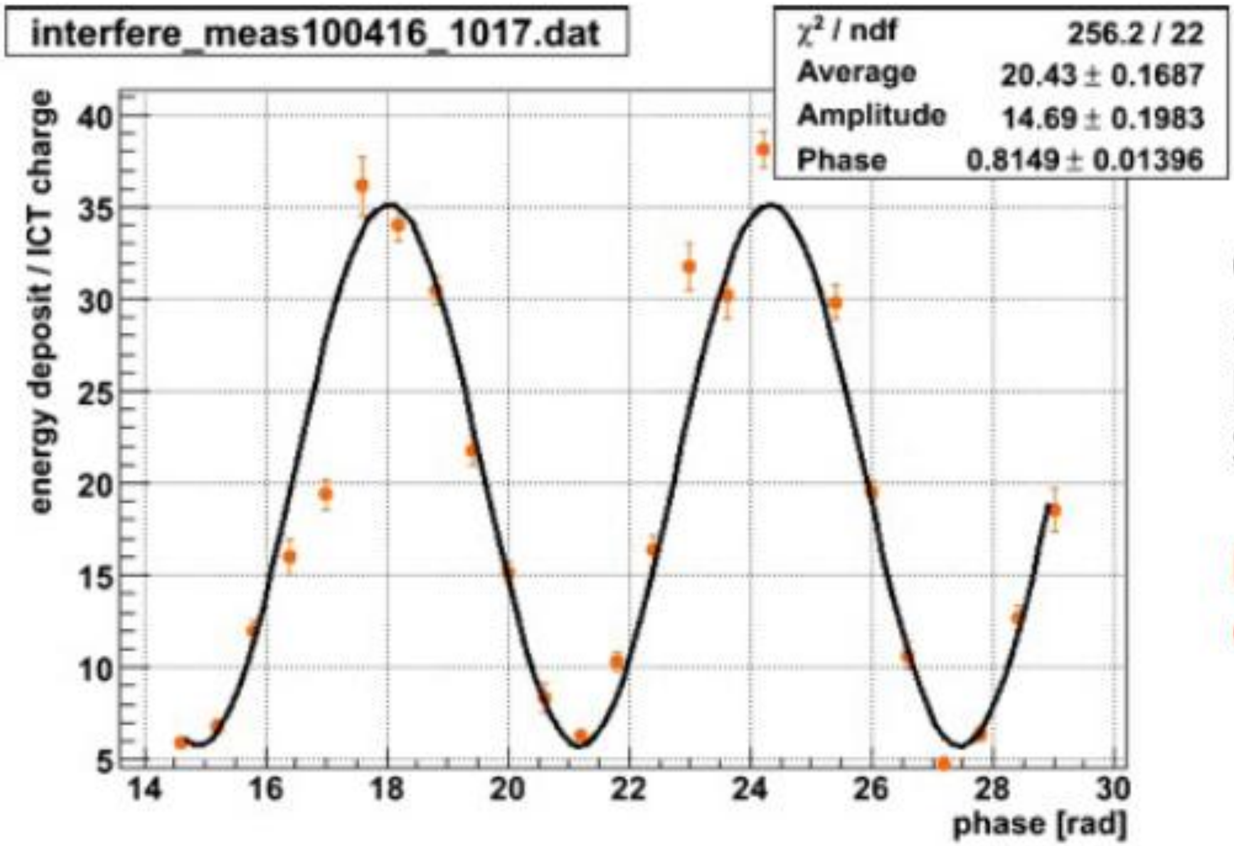


Crossing angle : 2.29 [deg]
Average of 4 bunches/point
Scan range 13.2[rad]
with a step of 600mrad

Fringe Pitch 13.3 um

Modulation = 0.35±0.01
σy = 3.1± 0.03 um
QD0 current at 129 A

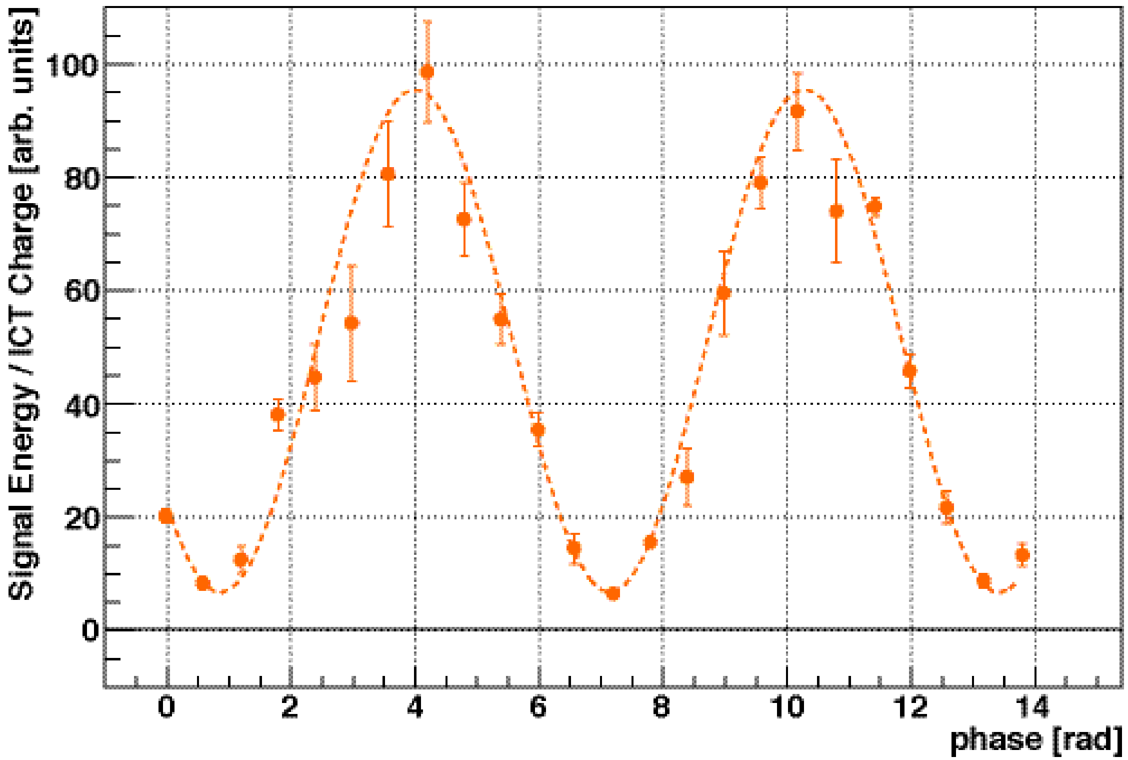
as expected from the PIP beam size measurements !



Crossing angle :4.12 [deg]
20 average
Fringe pitch 600 mrad
Scan range 13.2[rad]

Modulation ~ 0.72
σ_y ~ 950[nm]

Best result of continuous tune week: May 17-21, 2010



Yoshio Kamiya and Shintake monitor group.
Modulation Depth = 0.87 @ 8.0 deg. mode
Beam Size is 310 +- 30 (stat.) +0-40 (syst.) nm

[atf2-commissioning 380] ATF2 continuous operations week

- We completed our first 1 week "continuous operations run" of ATF2 tuning, May 17 - May 21. During the run we reached a minimum IP vertical spot size of about 300nm. The run was a successful integration of tuning tasks tested in past shifts and has provided a lot of information on how to move forward from here. Below is a brief bullet-point summary of events during the week, more detail can be found on the wiki (http://atf.kek.jp/collab/md/atfwiki/?Scheduling%2F2010May17May21).
- DR tuning (ey ~10pm)
- 10* IP beta_x/beta_y optics loaded for EXT+FFS (4cm/1mm)
- Magnets standardised
- EXT dispersion correction
- EXT ey measured at ~11pm, no coupling correction required
- Cavity BPM systems calibrated
- Beam size brought to ~normal in x <2um in y at IP with W and C wirescanners (some wirescanners cut during scanning)
  - x and y waists brought to IP with alpha knobs
  - y beta function looks correct to within ~20% from PIP measurements with waist at IP
- vertical beam size acquired with IPBSM, starting size ~850nm
- Beam size reduced to 300nm with sextupole waist, coupling, dispersion multiknobs, qd0 current and roll scans.
- Beam size verified in 30-degree and 8-degree IPBSM modes.
- Could not scan with 30-degree mode as could not resolve larger size beam
- Attempted IP beta reduction to 0.5mm, but could not re-acquire beam
- Switch back to 8-degree mode, restore optics and tune back to ~350nm (reproducibility!)

Glen White (SLAC), on behalf ATF2 commissioning team.

Special ATF Session on 28th

- Target of ATF/ATF2; R&D for ILC
  - Generation of 2 pm-rad low emittance beam
  - Demonstration of ILC Final Focus optics (ATF2 Goal-1)
    - 37 nm vertical beam size at IP
  - Stabilization of 37 nm beam (ATF2 Goal-2)
- Goal of this session
  - **Review/understand the present status of ATF and ATF2 after the great earthquake in details.**
  - **Discuss the machine schedule and planning for the goal-1 in this Fall and by end of this year.**
- This session is composed by Joint with AWGs

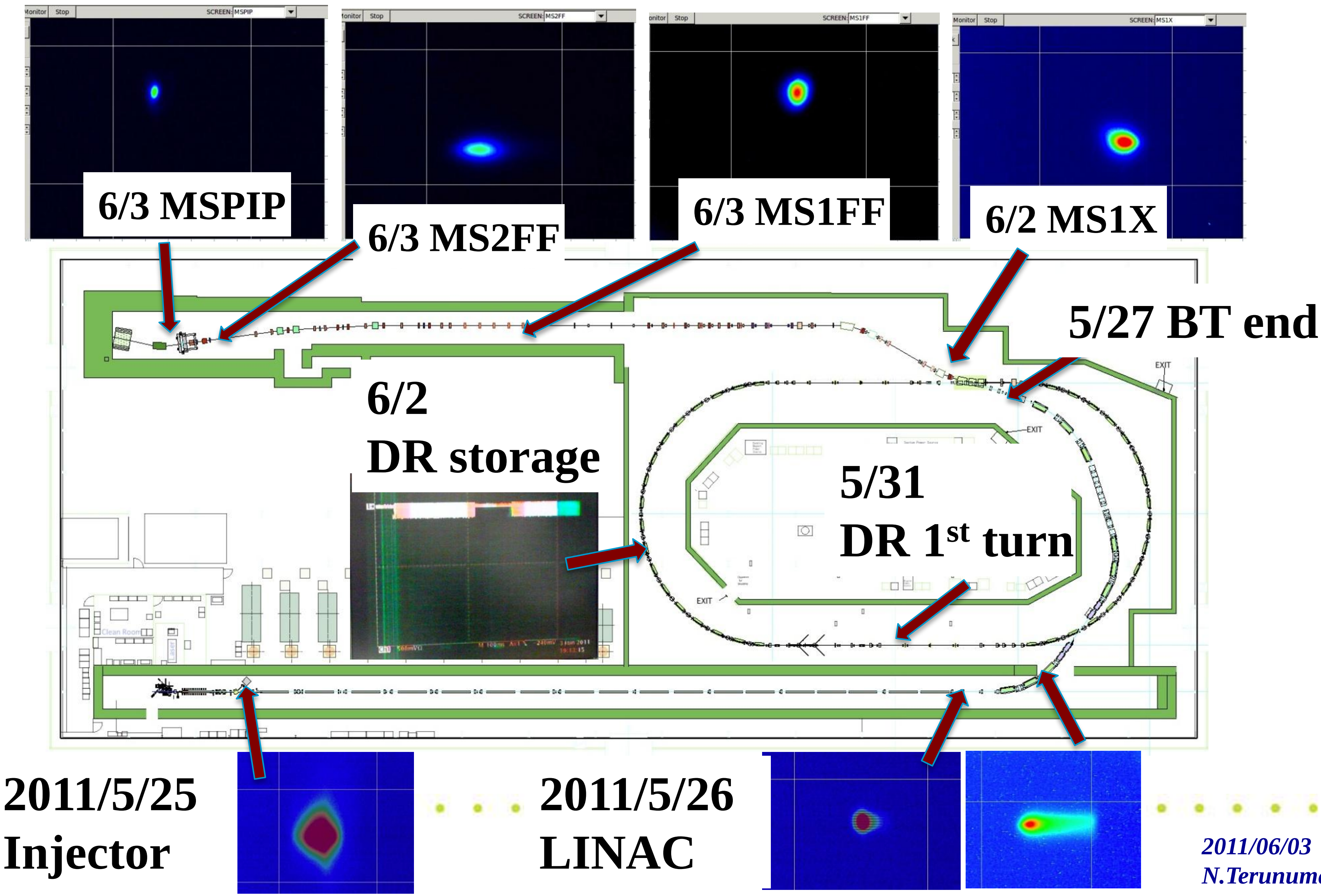
  Damping Rings (**WG2**), Beam Delivery (**WG5**), Low Emittance Beam Dynmacis (**WG7**), Instrumentation and Technical Systems (**WG8**)

Recovery after the earthquake

continued work -

A test beam passes all beamline

Single bunch, 0.78 Hz, 0.3 x 10^{10} e/bunch DR&ATF2

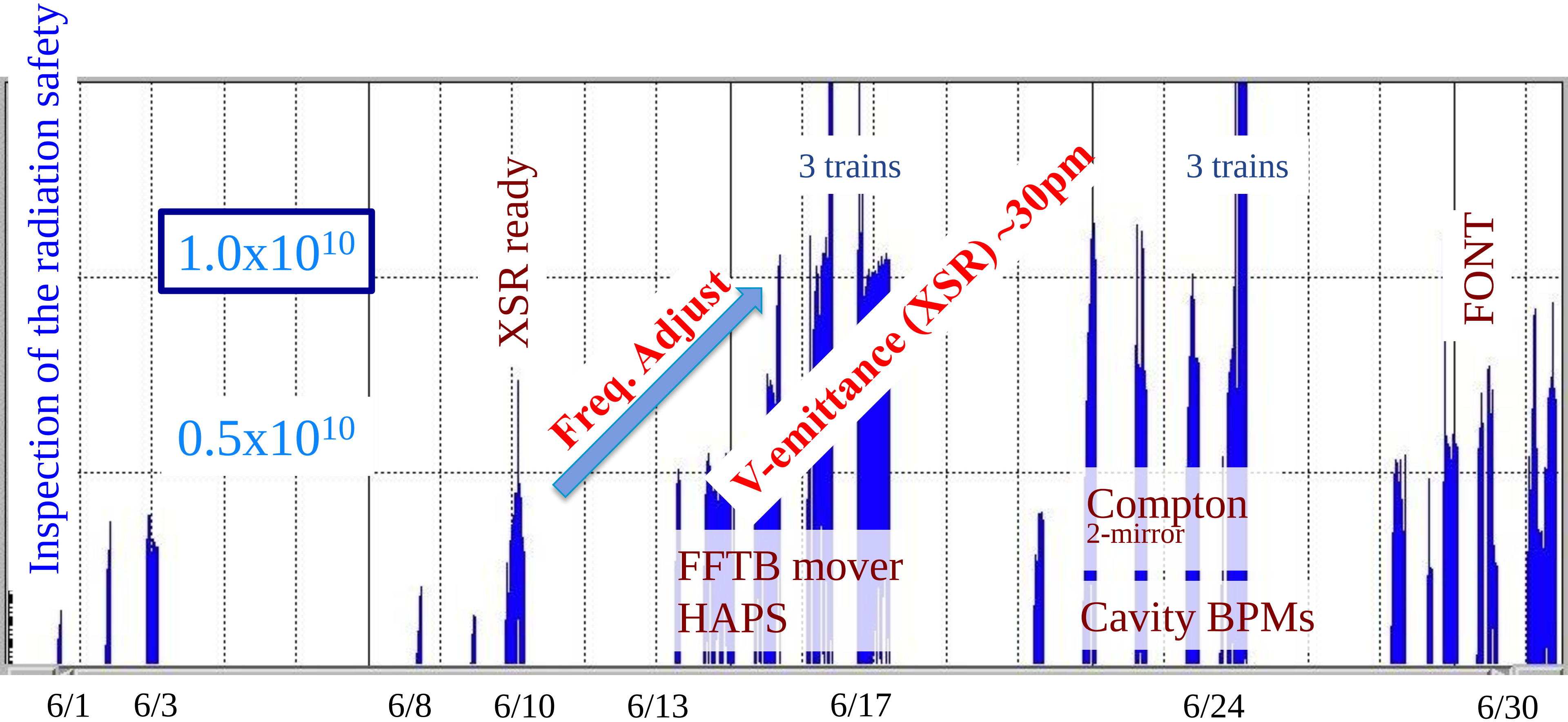


2011/06/03
N.Terunuma

Stored beam in DR ($x10^{10}$ e/bunch)

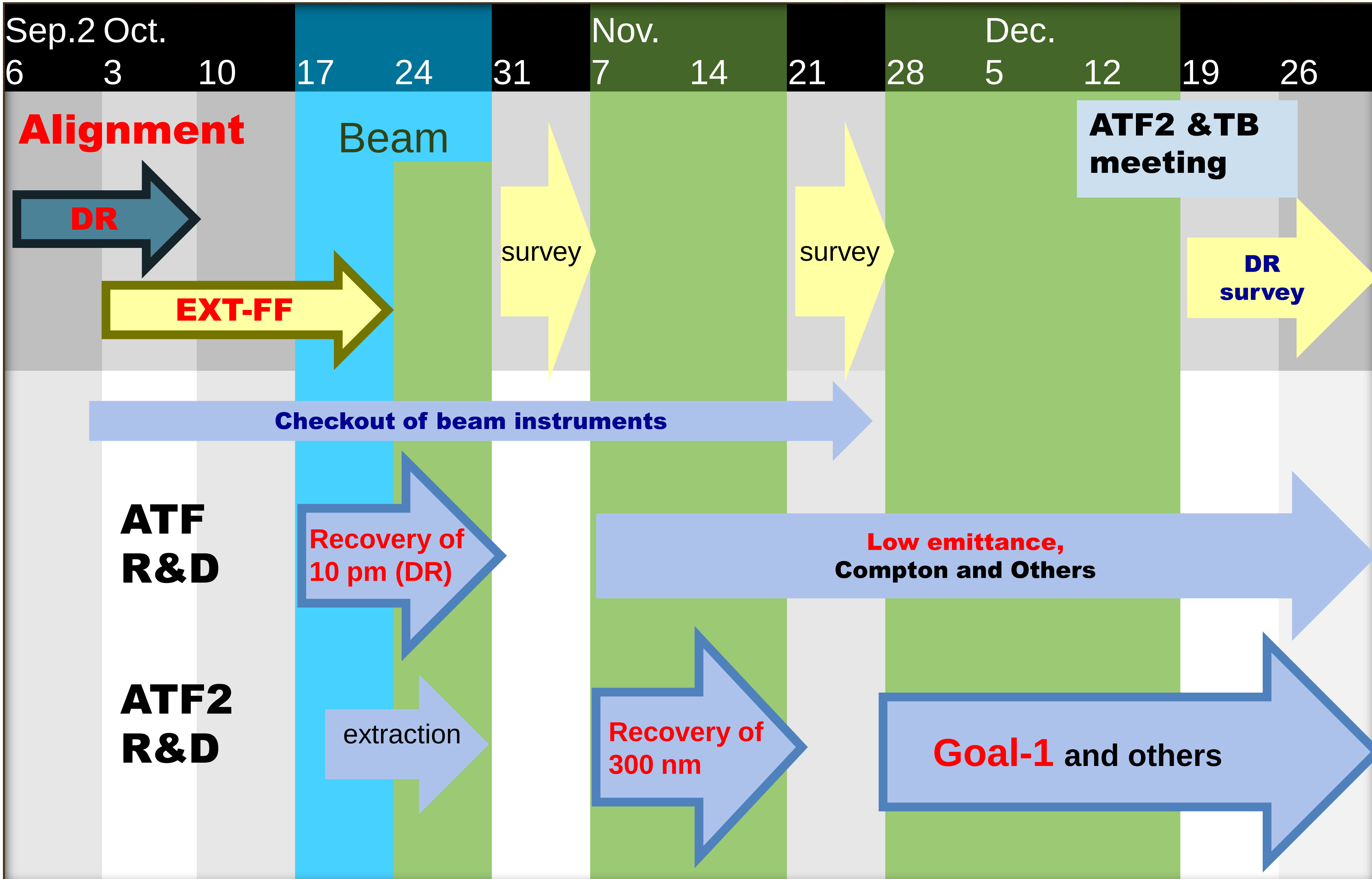
A stored beam was delivered to the dump of ATF2.

No critical damage on the accelerator was found.

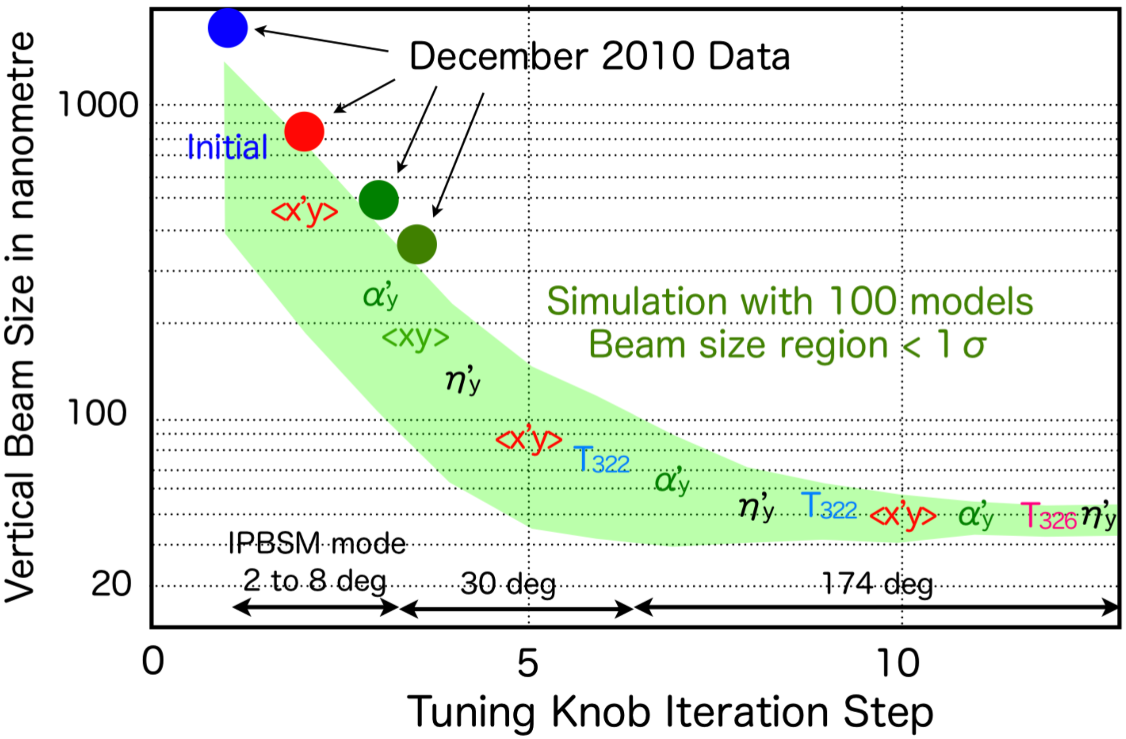


DR rough alignment for checkout was continued in daytime.

ATF Schedule (draft)



Measurement of the vertical beam size at ATF2



A smaller beam size, 37 nm, is one of the target of Goal-1.

The reached size was 300 nm before the Great East Japan earthquake.

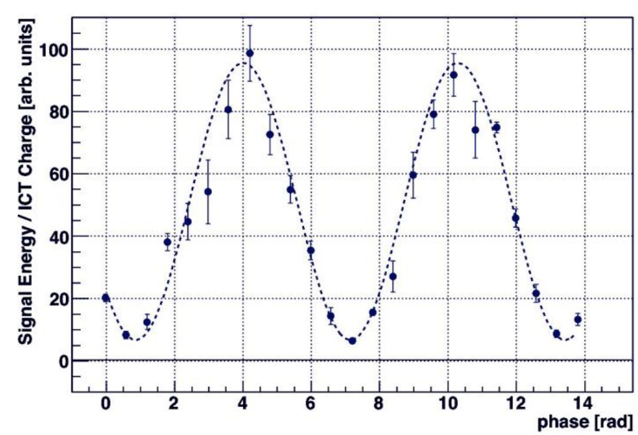
Recover 300nm again, then continue the tuning down to 37 nm.

Example:

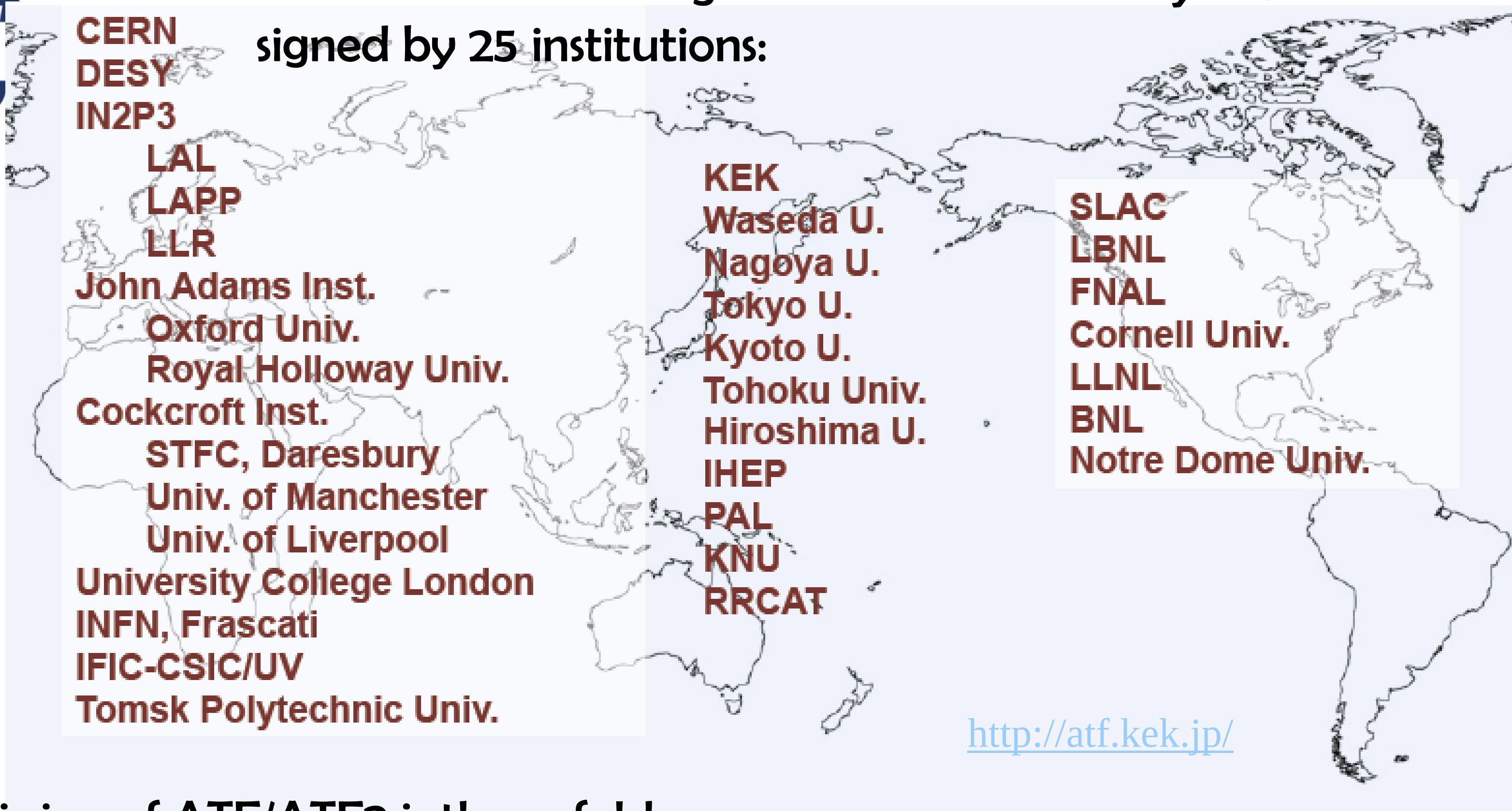
A beam size measured (2010/May/20)

Modulation Depth = 0.87 @ 8.0 deg. mode

σ_y = 310 +- 30 (stat.) +0-70 (syst.) nm



ATF International organization is defined by MOU signed by 25 institutions:



MOU: Mission of ATF/ATF2 is three-fold:

- ATF, to establish the technologies associated with producing the electron beams with the quality required for ILC and provide such beams to ATF2 in a stable and reliable manner.
- ATF2, to use the beams extracted from ATF at a test final focus beamline which is similar to what is envisaged at ILC. The goal is to demonstrate the beam focusing technologies that are consistent with ILC requirements. For this purpose, ATF2 aims to focus the beam down to a few tens of nm (rms) with a beam centroid stability within a few nm for a prolonged period of time.
- Both the ATF and ATF2, to serve the mission of providing the young scientists and engineers with training opportunities of participating in R&D programs for advanced accelerator technologies.

Ph.D. thesis at ATF2 (as of May 2010)

Year	university	country	Name	title
2007.11.12	Université de Savoie	France	Benoit Bolson	Etude des vibrations et de la stabilisation a l'echelle sous-nanometrique des doublets finaux d'un collisionneur lineaire
2007.12.21	University of Tokyo	Japan	Taikan Suehara	Development of a Nanometer Beam Size Monitor for ILC/ATF2
2009.4.14	Royal Holloway, University of London	UK	Lawrence Deacon	A Micron-Scale Laser-Based Beam Profile Monitor for the International Linear Collider
2010.6.8	UNIVERSITAT DE VALÈNCIA	Spain	María del Carmen Alabau Pons	Optics Studies and Performance Optimization for a Future Linear Collider: Final Focus System for the e-e- Option (ILC) and Damping Ring Extraction Line (ATF)
2010.5.8	IHEP CAS	China	Sha Bai	ATF2 Optics System Optimization and Experiment Study
2010.6.11	Université Paris-Sud 11	France	Yves Renier	Implementation and Validation of the Linear Collider Final Focus Prototype ATF2 at KEK (Japan)
	Oxford university	UK		FONT studies
2011.12.1	University of Tokyo	Japan	Masahiro Oroku	Beam Tuning with the Nanometer Beam Size Monitor at ATF2
2011.12.1	Kyungpook National University	Korea	Youngim Kim	IPBPM and BBA
2011.12.1	University of Manchester	UK	Anthony Scarfe	Tuning and alignment of ATF2 and ILC
2012.2.xx	University of Tohoku	Japan	Taisuke Okamoto	cavity-type tilt monitor of beam orbit for ILC
2012.12.1	Kyungpook National University	Korea	Siwon Jang	IPBPM and BBA
2012.12.1	CERN	Spain	Eduardo Marin Lacoma	Ultra Low Beta Optics
	Oxford university	UK		FONT studies
	ICIF, Valencia university	Spain	Javier Alabau-Gonzalvo	emittance, coupling measuremwnts with multiple OTR system

Beam Delivery

Thanks to Bill Barletta for the picture

- Many thanks to colleagues whose slides, results or photos were used in this lecture, namely Tom Markiewicz, Nikolai Mokhov, Daniel Schulte, Mauro Pivi, Nobu Toge, Brett Parker, Nick Walker, Timergali Khabibouline, Kwok Ko, Cherrill Spencer, Lew Keller, Sayed Rokni, Alberto Fasso, Joe Frisch, Yuri Nosochkov, Mark Woodley, Takashi Maruyama, Eric Torrence, Karsten Busser, Graeme Burt, Glen White, Phil Burrows, Tochiaki Tauchi, Junji Urakawa, Nobuhiro Terunuma and many other

Thanks to you for attention!

Homework and exams

- Homework for tonight
- Final exam