Accelerator Lecture A4 – PART 2

Beam Delivery & beam-beam

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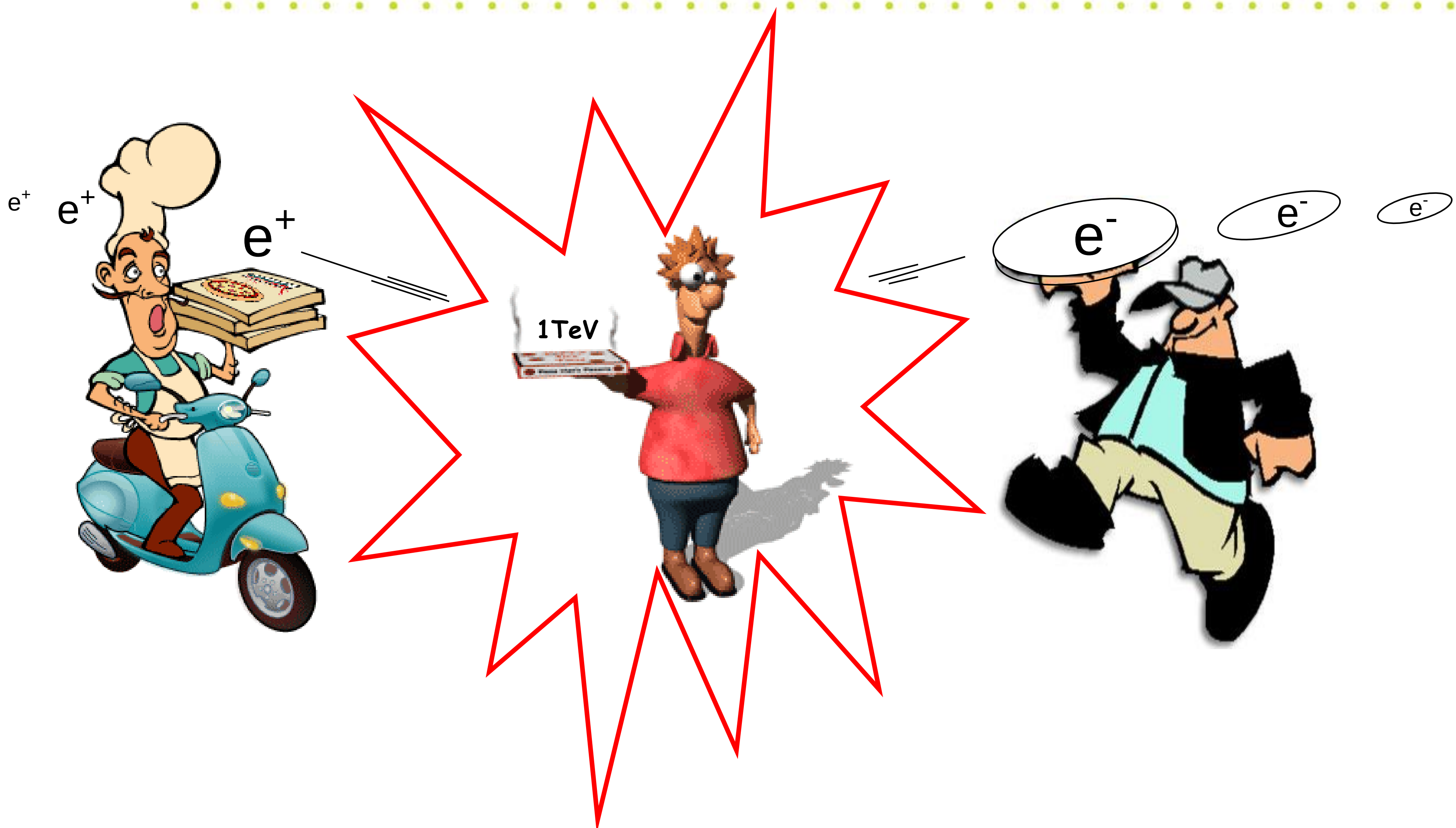
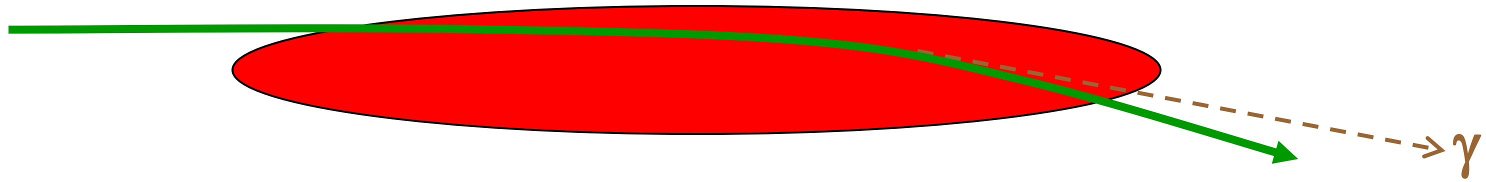
Beam Delivered…



Beam-beam effects

Beam-beam interactions



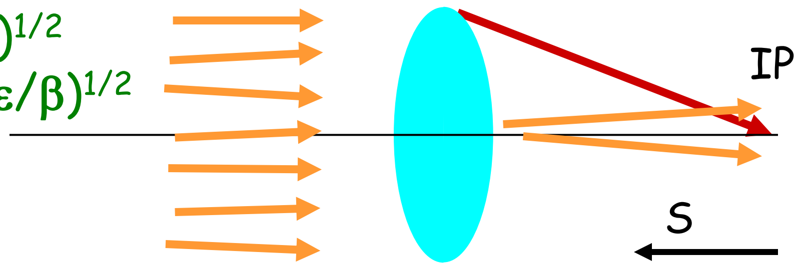
- Transverse fields of ultra-relativistic bunch
  - focus the incoming beam (electric and magnetic force add)
  - reduction of beam cross-section leads to more luminosity
    - H_D - the luminosity enhancement factor
  - bending of the trajectories leads to emission of beamstrahlung

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

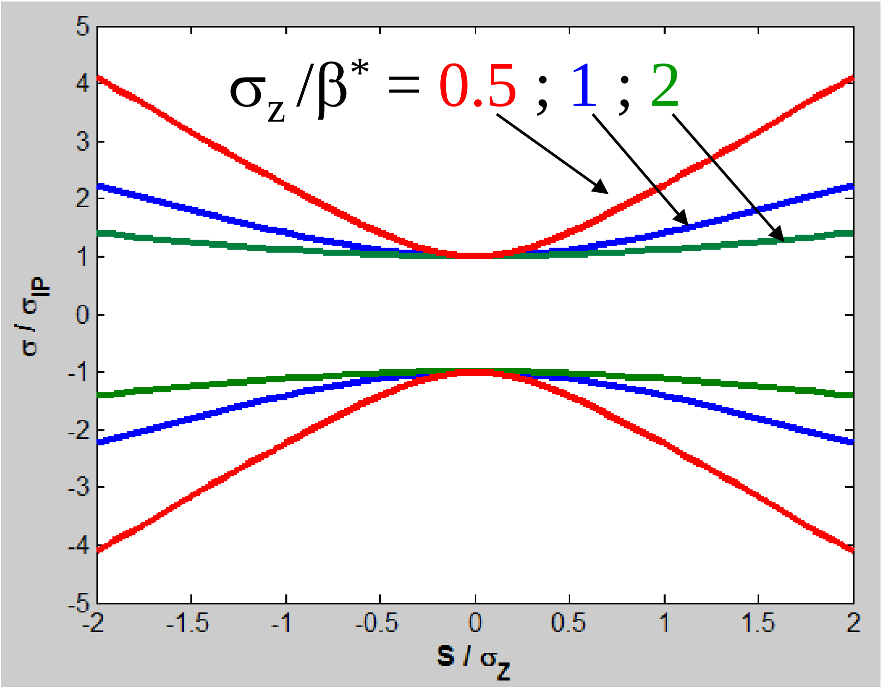


Size at IP: $L^* (\varepsilon/\beta)^{1/2}$

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

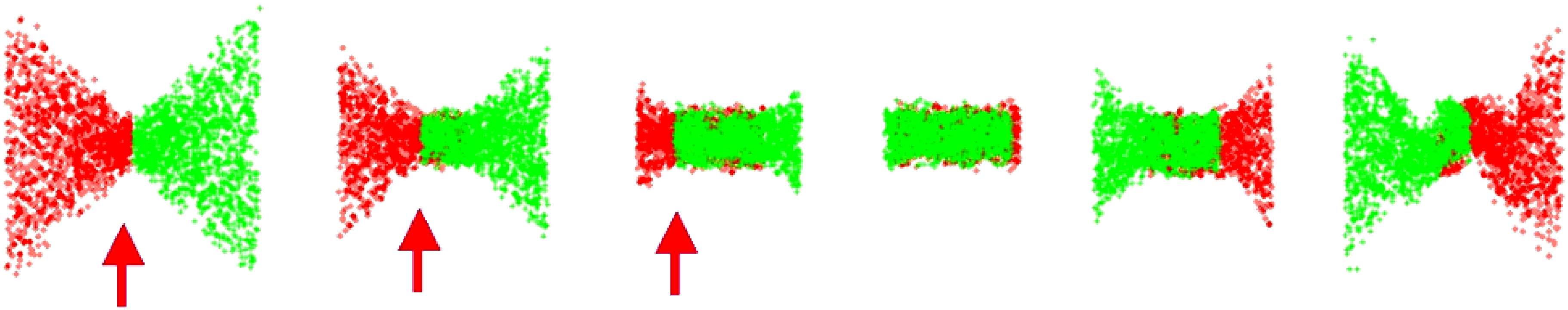
Behavior of beta-function along the final drift:

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



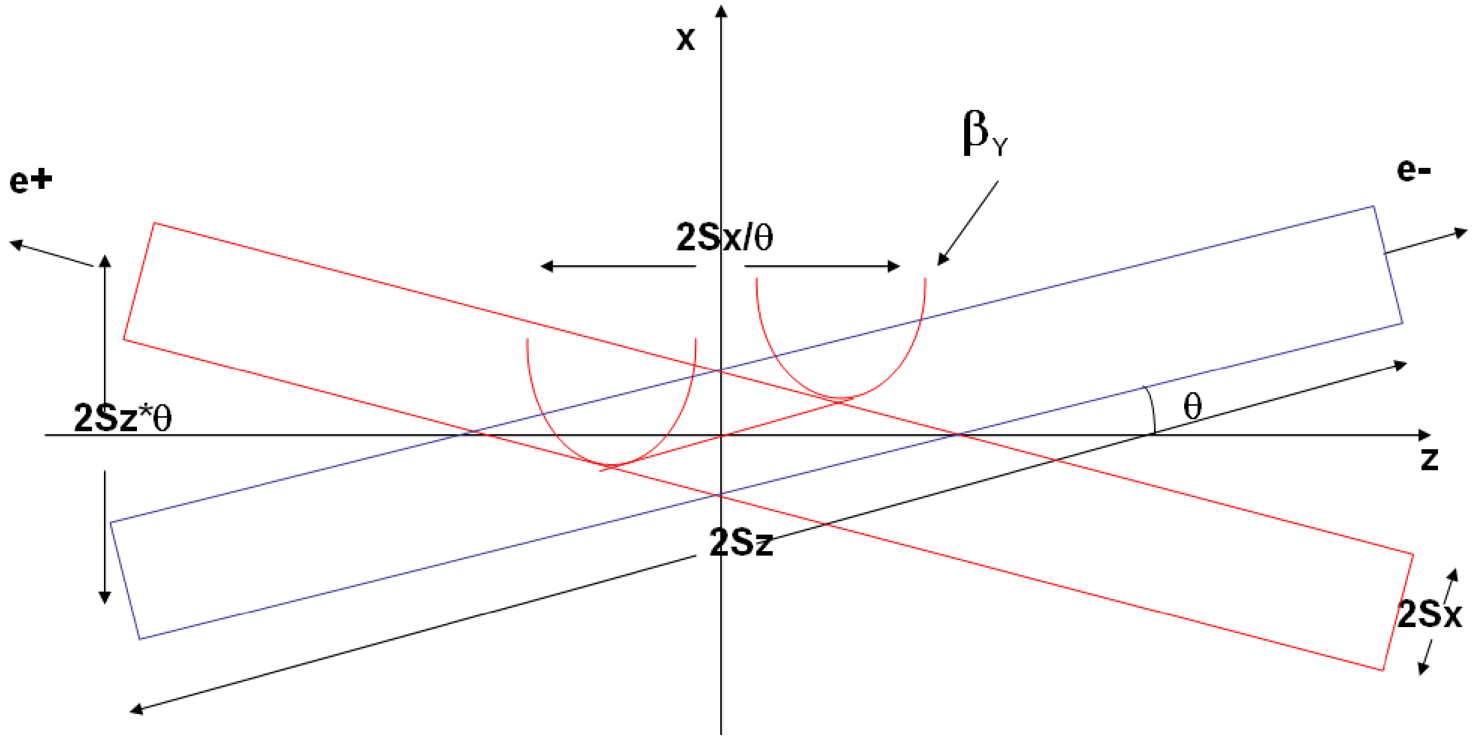
Reduction of β^* below σ_z does not give further decrease of effective beam size (usually)

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

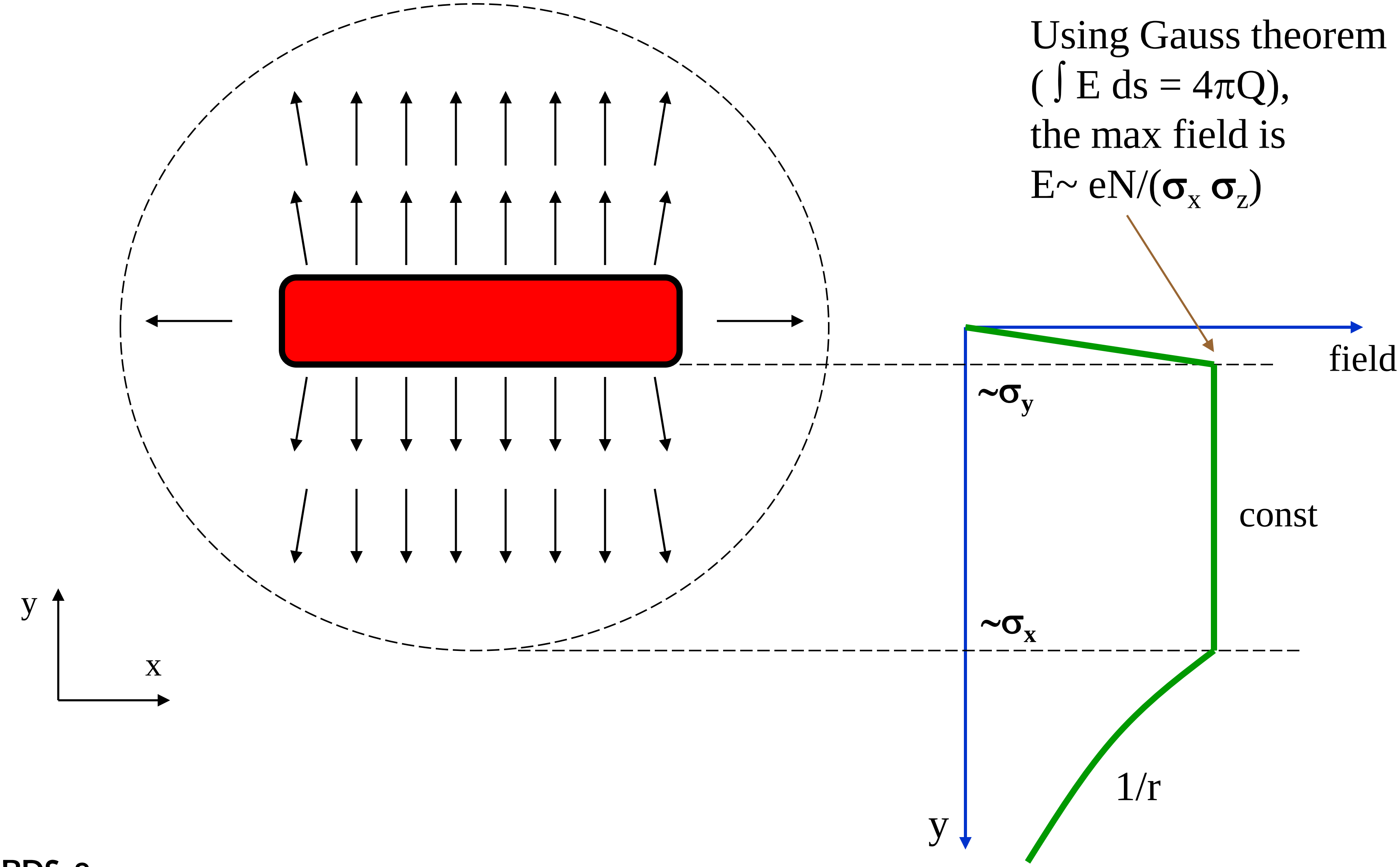
Beam-beam: Crabbed-waist



- 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

Using Gauss theorem
(∫ E ds = 4πQ),
the max field is
E~ eN/($\boldsymbol{\sigma}_x$ $\boldsymbol{\sigma}_z$)



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 ($D_y \sim \sigma_z/f_{beam}$)

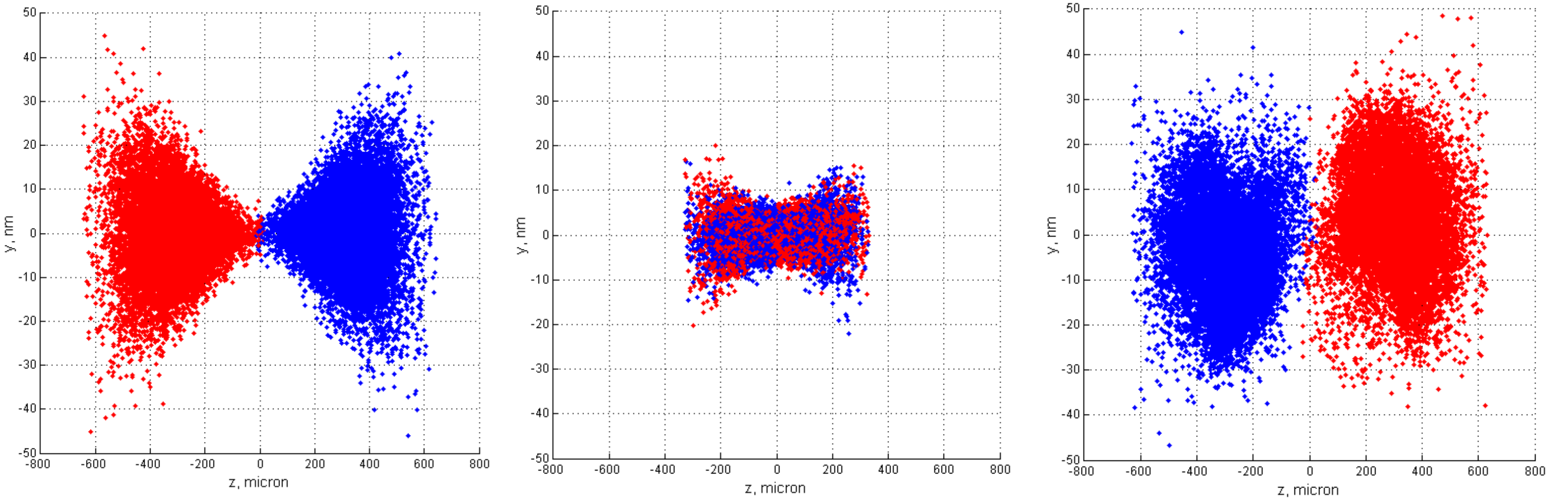
$$D_x = \frac{2Nr_e\sigma_z}{\gamma\sigma_x(\sigma_x+\sigma_y)} \qquad D_y = \frac{2Nr_e\sigma_z}{\gamma\sigma_y(\sigma_x+\sigma_y)}$$

- 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

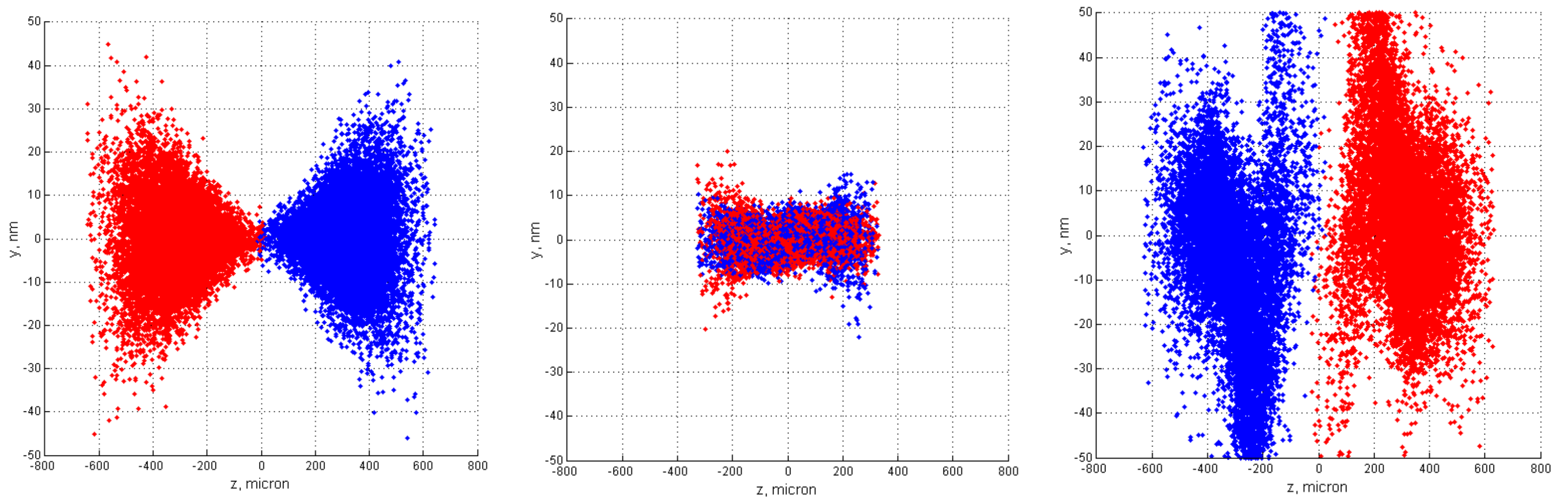
Beam-beam effects

H_D and instability

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



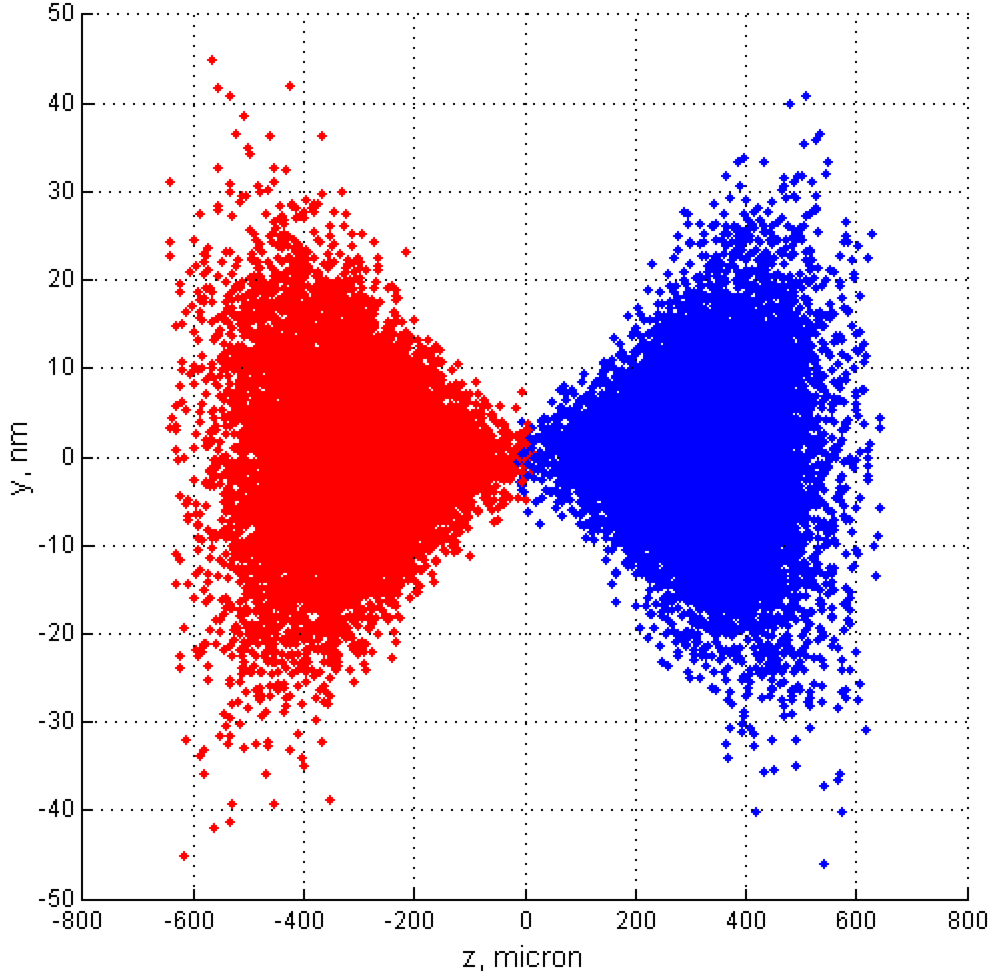
D_y~12



Nx2

D_y~24

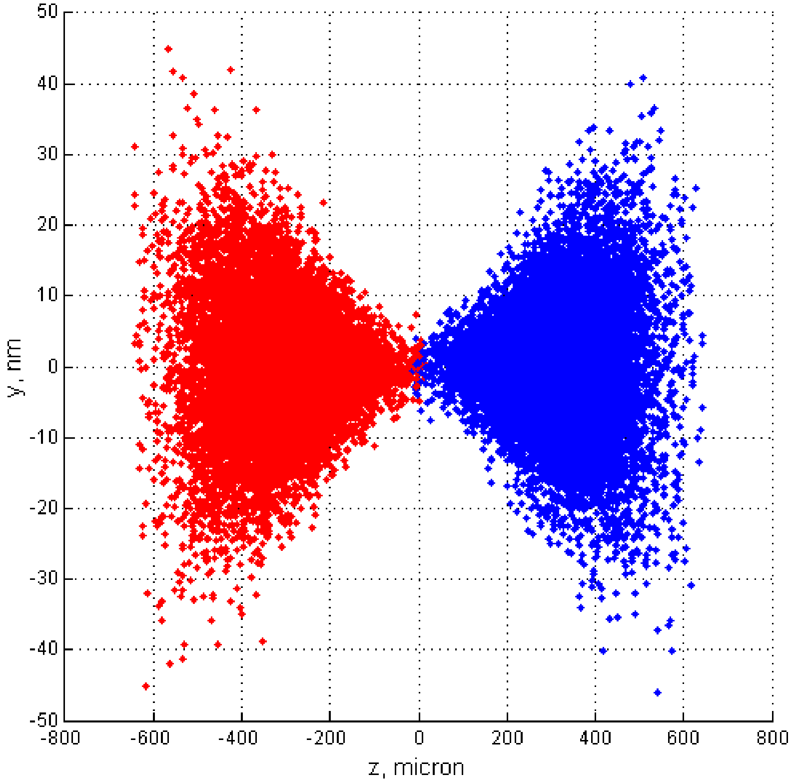
Beam-beam effects
H_D and instability



LC parameters
D_y~12

Luminosity enhancement
H_D ~ 1.4

Not much of an instability


y, nm
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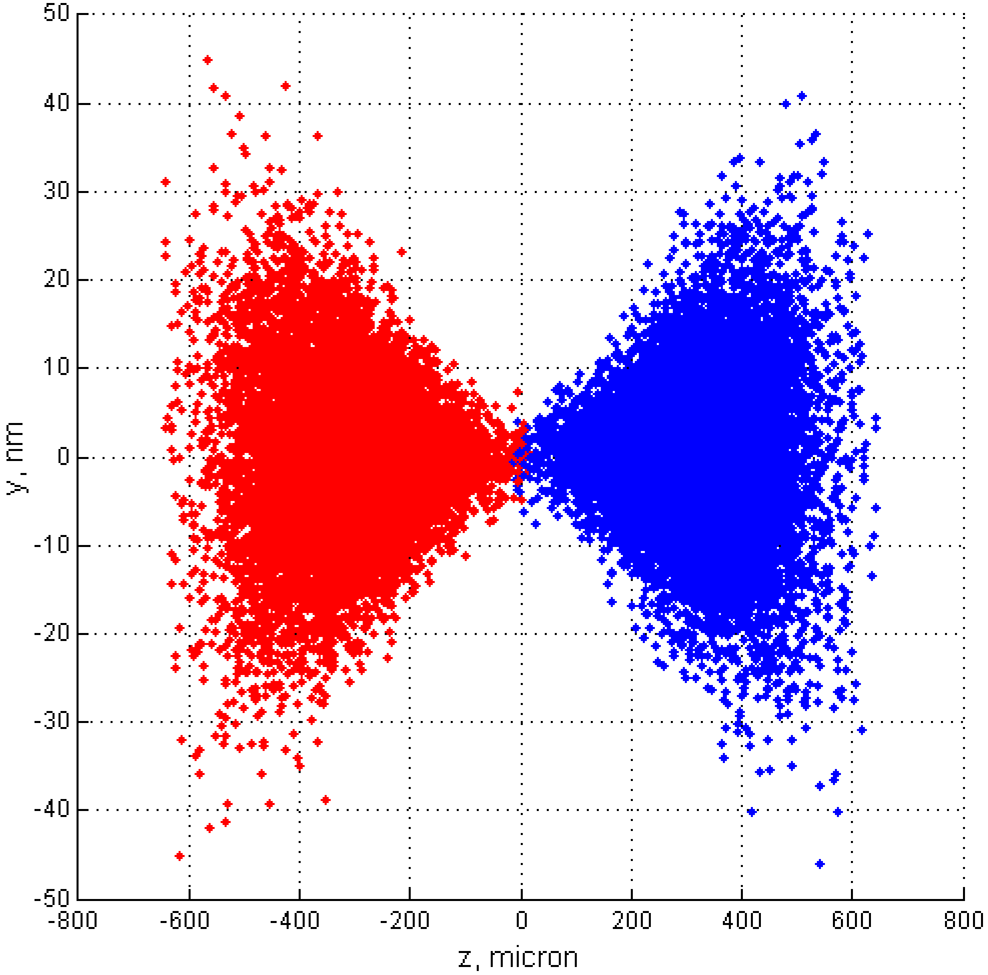
Beam-beam effects

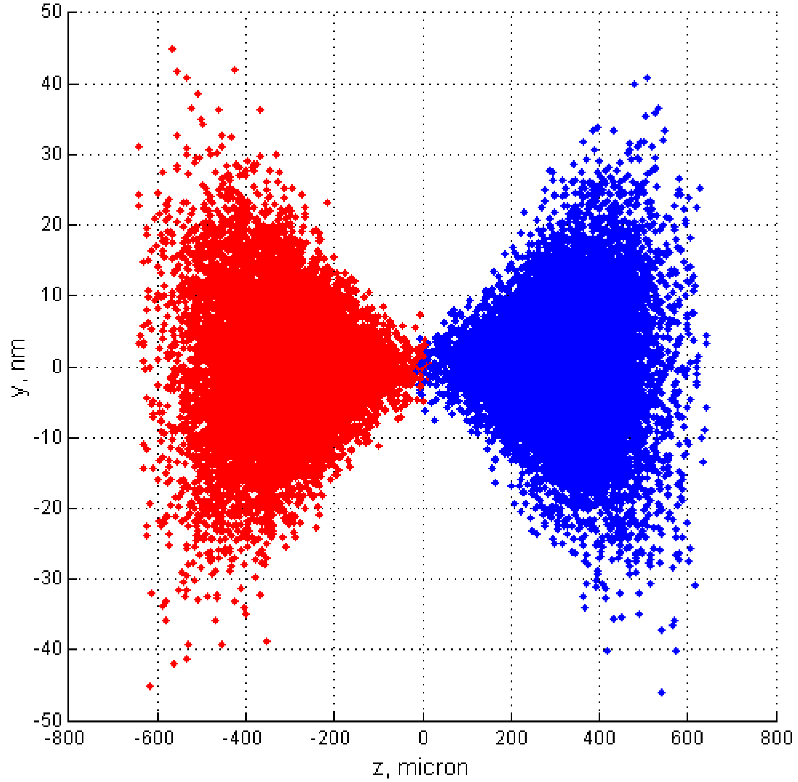
H_D and instability



Nx2
D_y~24

Beam-beam instability is clearly pronounced

Luminosity enhancement is compromised by higher sensitivity to initial offsets



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y, nm
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600
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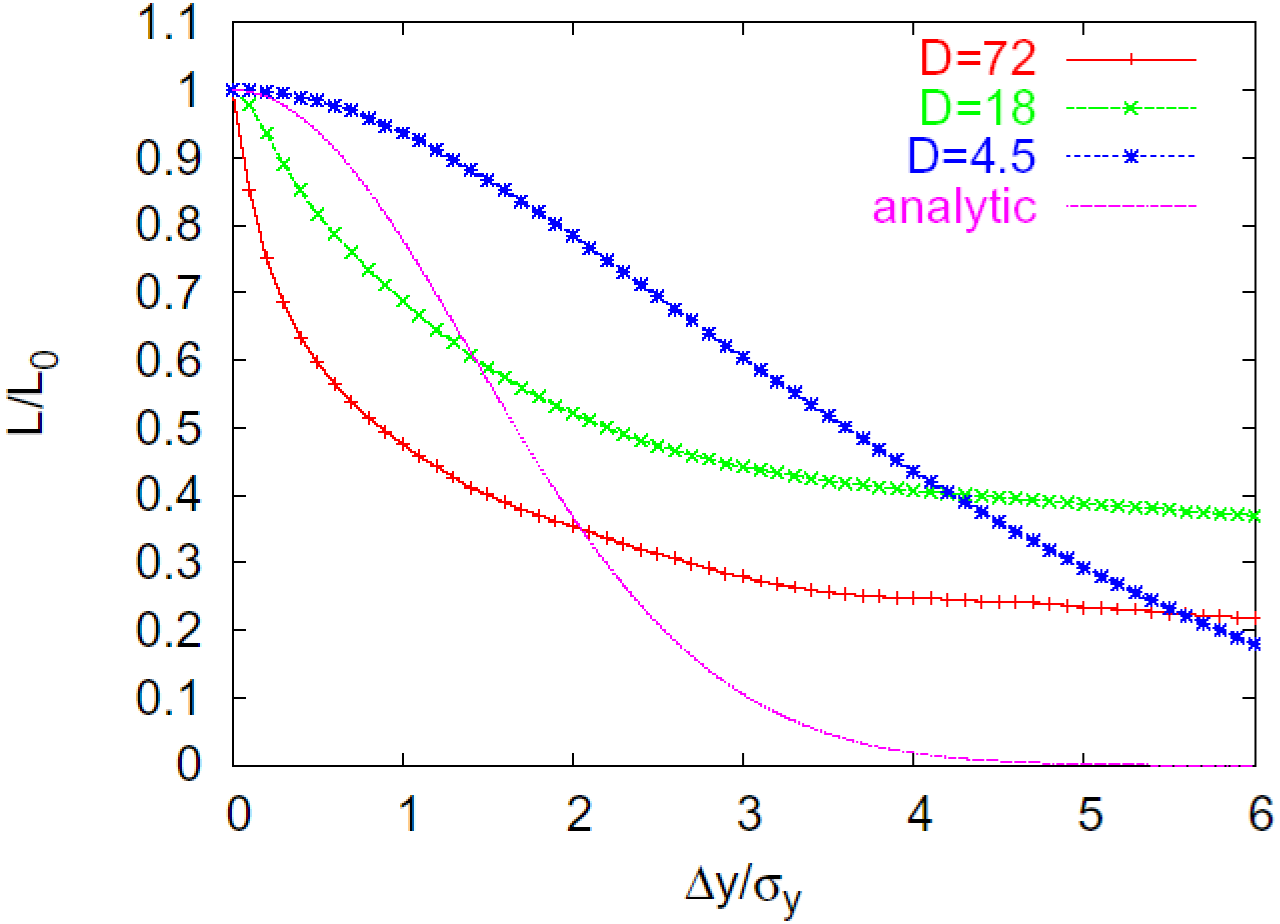
z, micron

Sensitivity to offset at IP



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

Beamstrahlung

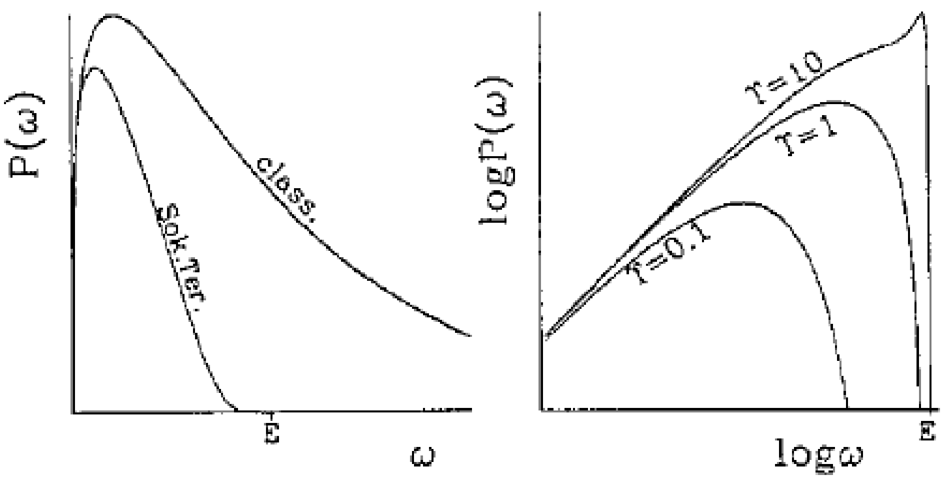
- Synchrotron radiation in field of opposite bunch
- Estimate R of curvature as $R \sim \sigma_z^2/(D_y\sigma_y)$
- Using formulas derived earlier, estimate ω_c and find that $h\omega_c/E \sim \gamma N r_e^2/(\alpha\sigma_x\sigma_z)$ and call it "Upsilon"

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

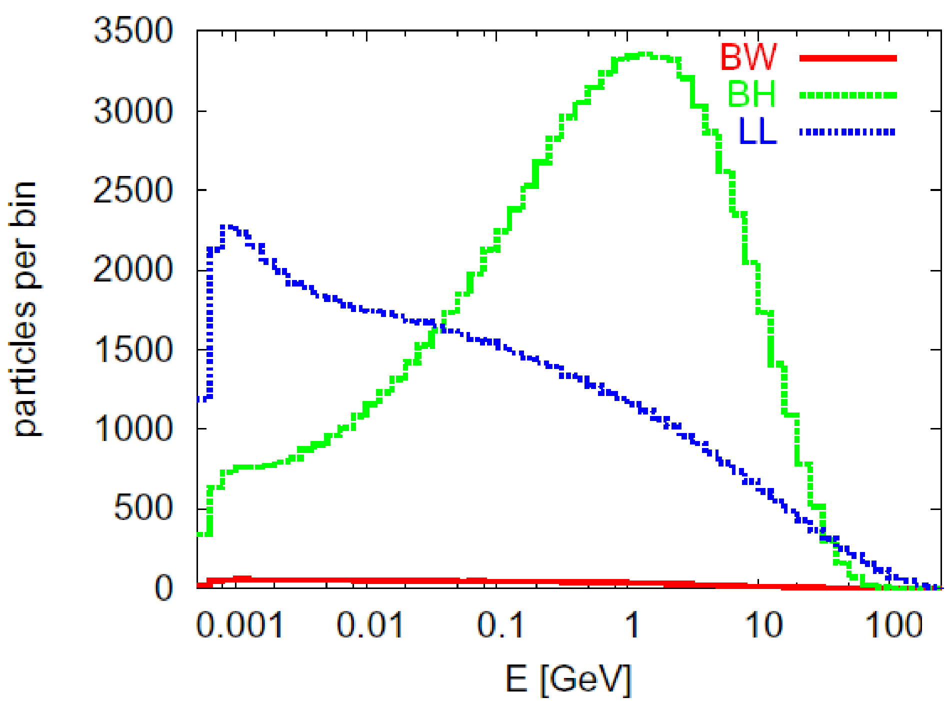
Classical and quantum regime

- 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 …

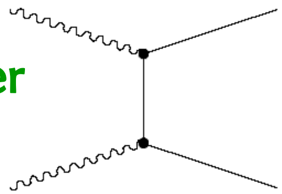


Incoherent* production of pairs

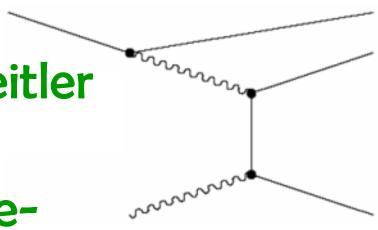
- Beamstrahling photons, particles of beams or virtual photons interact, and create e+e- pairs



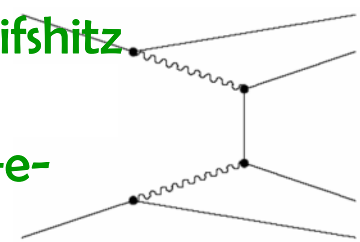
Breit-Wheeler process
$\gamma\gamma \rightarrow$ e+e-



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



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



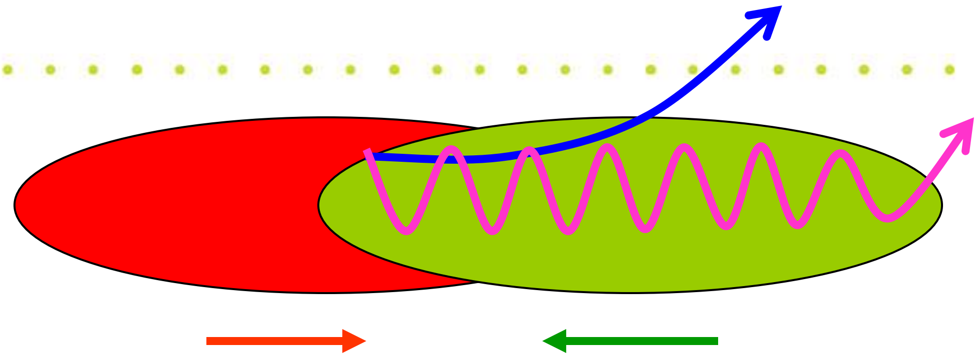
*) Coherent pairs are generated by photon in the field of opposite bunch. It is negligible for ILC parameters.

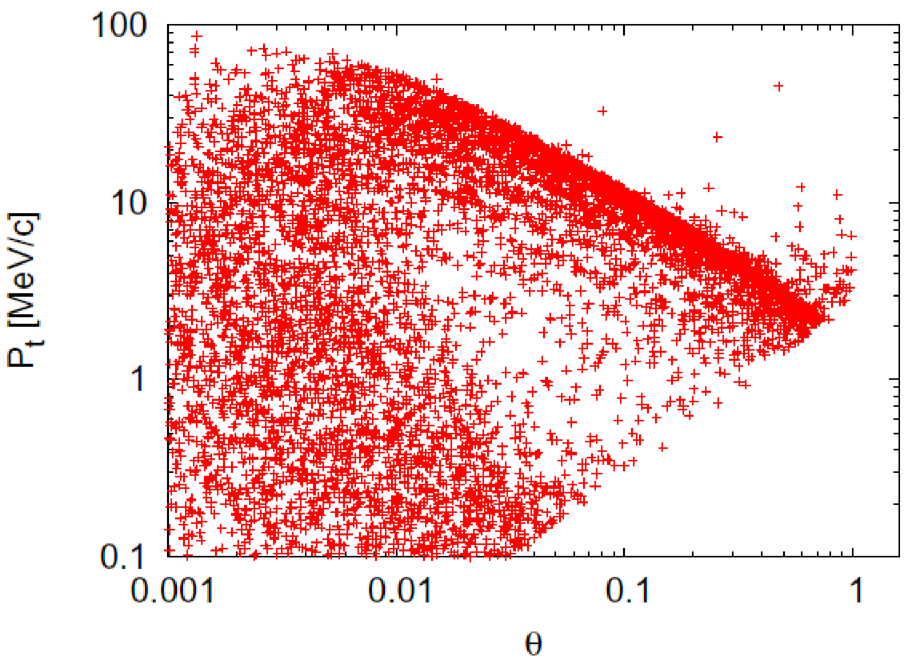
Deflection of pairs by beam

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

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

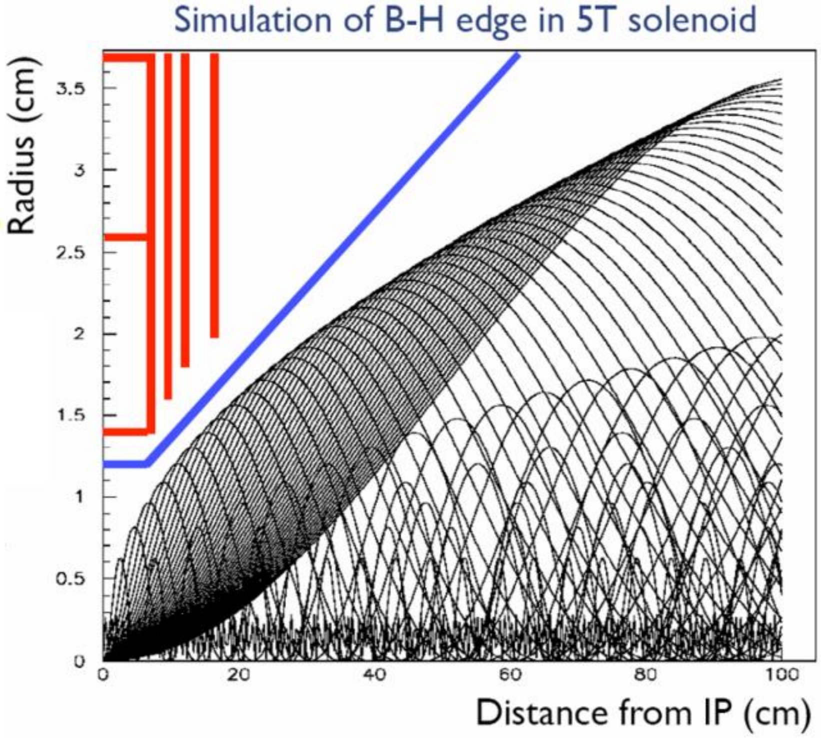
- Bethe-Heitler pairs have hard edge, Landau-Lifshitz pairs are outside

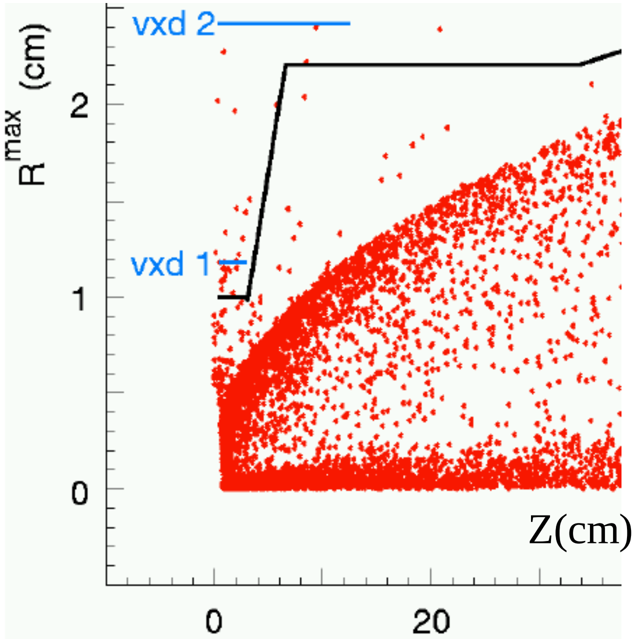




Deflection of pairs by detector solenoid

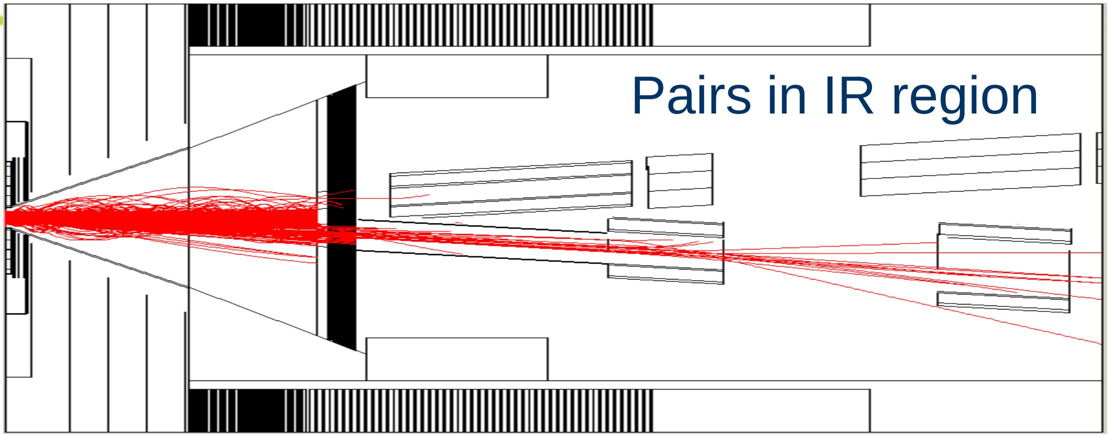
- Pairs are curled by the solenoid field of detector
- Geometry of vertex detector and vacuum chamber chosen in such a way that most of pairs (B-H) do not hit the apertures
- Only small number (L-L) of pairs would hit the VX apertures

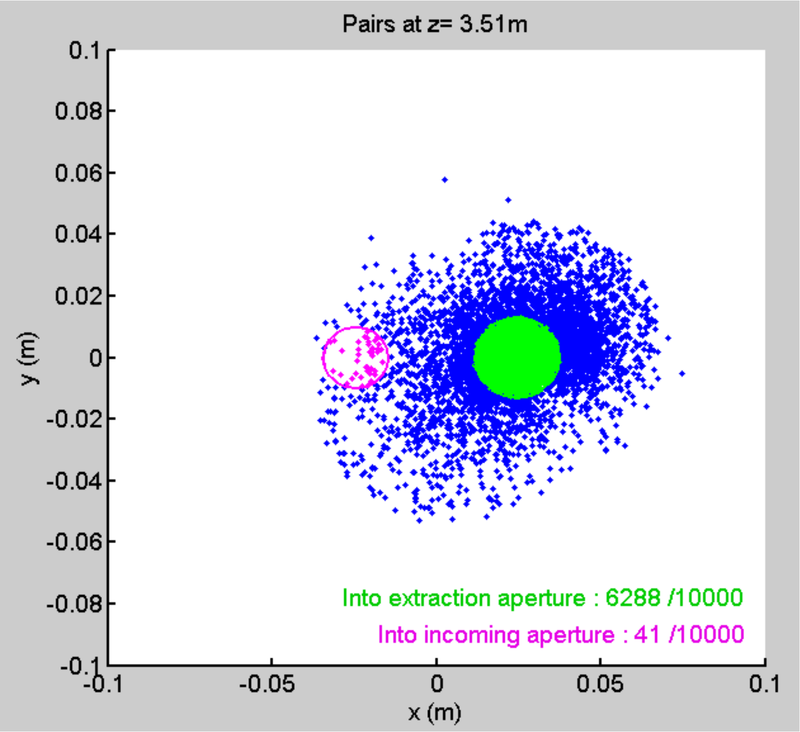


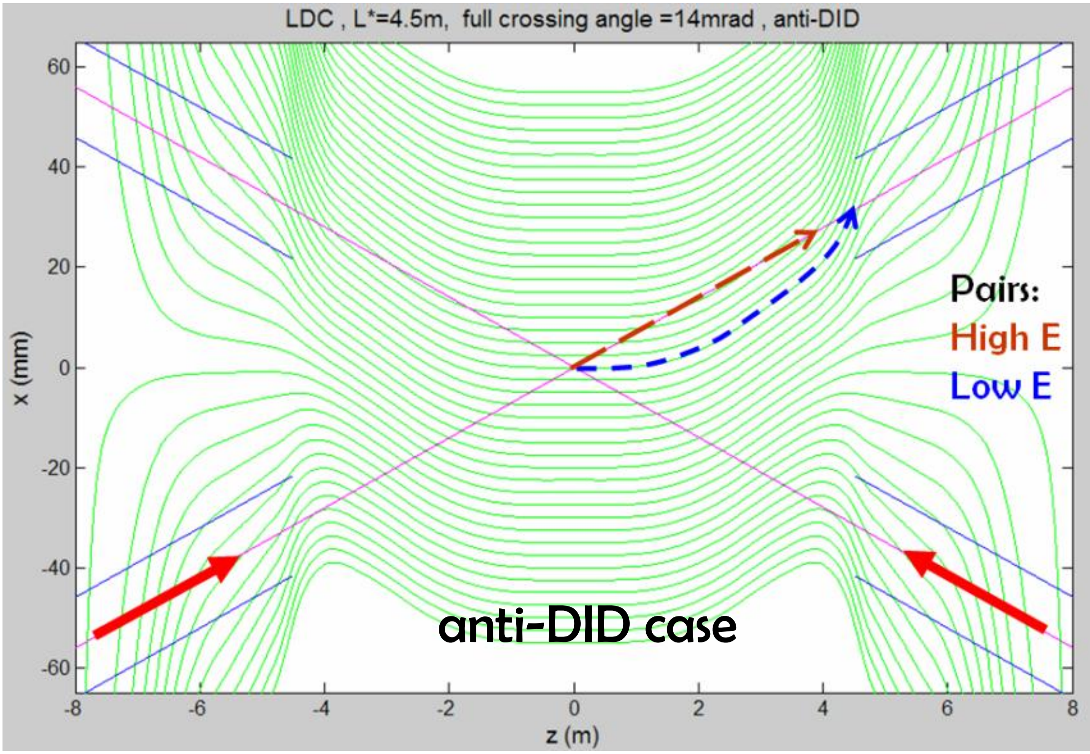


Use of anti-DID to direct pairs

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)

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

- 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 ($D_y \sim \sigma_z/f_{beam}$)

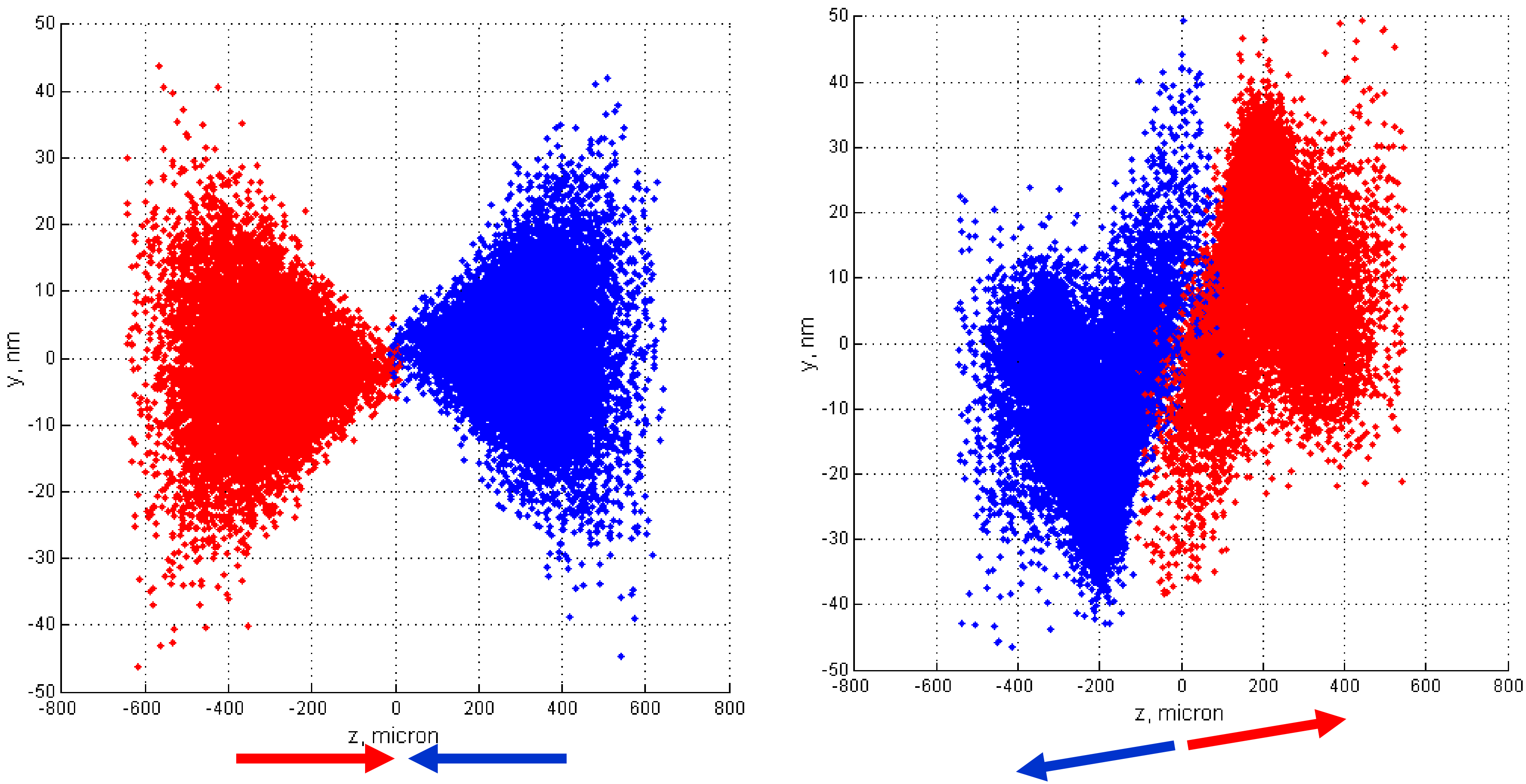
$$\delta_E \sim \frac{N^2\,\gamma}{\sigma_x^2\;\sigma_z}$$

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

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

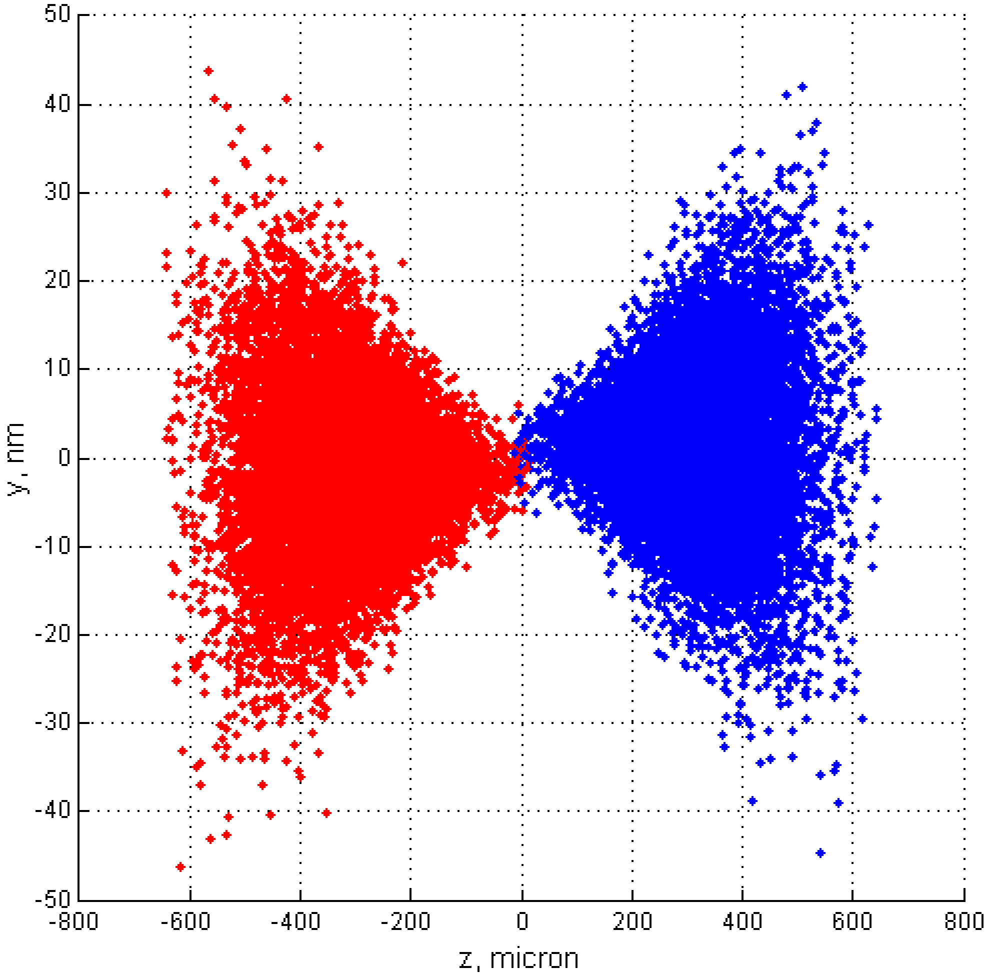
- Ratio of critical photon energy to beam energy (classic or quantum regime)

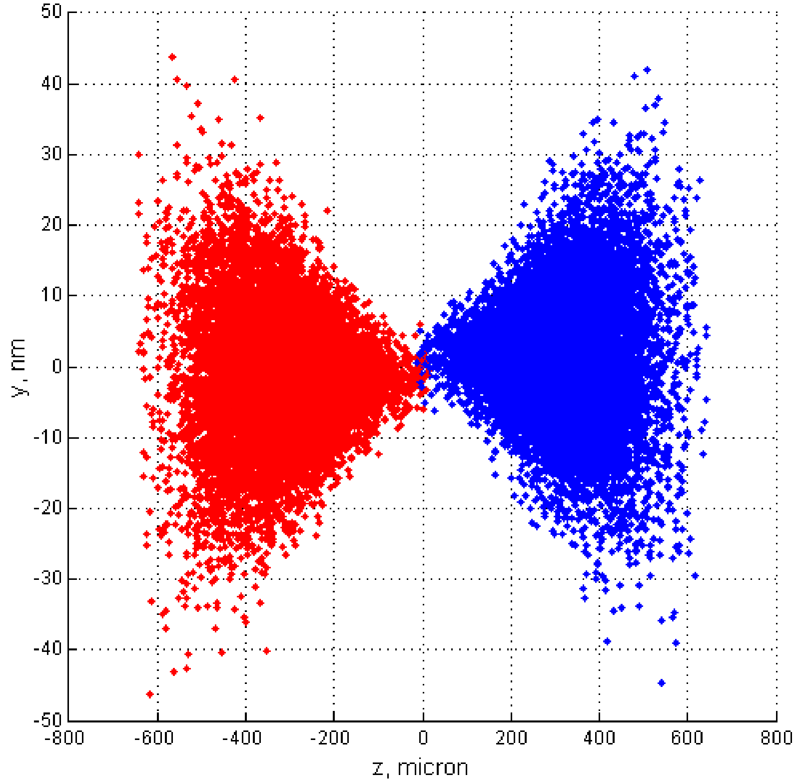
Beam-beam deflection



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

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y, nm
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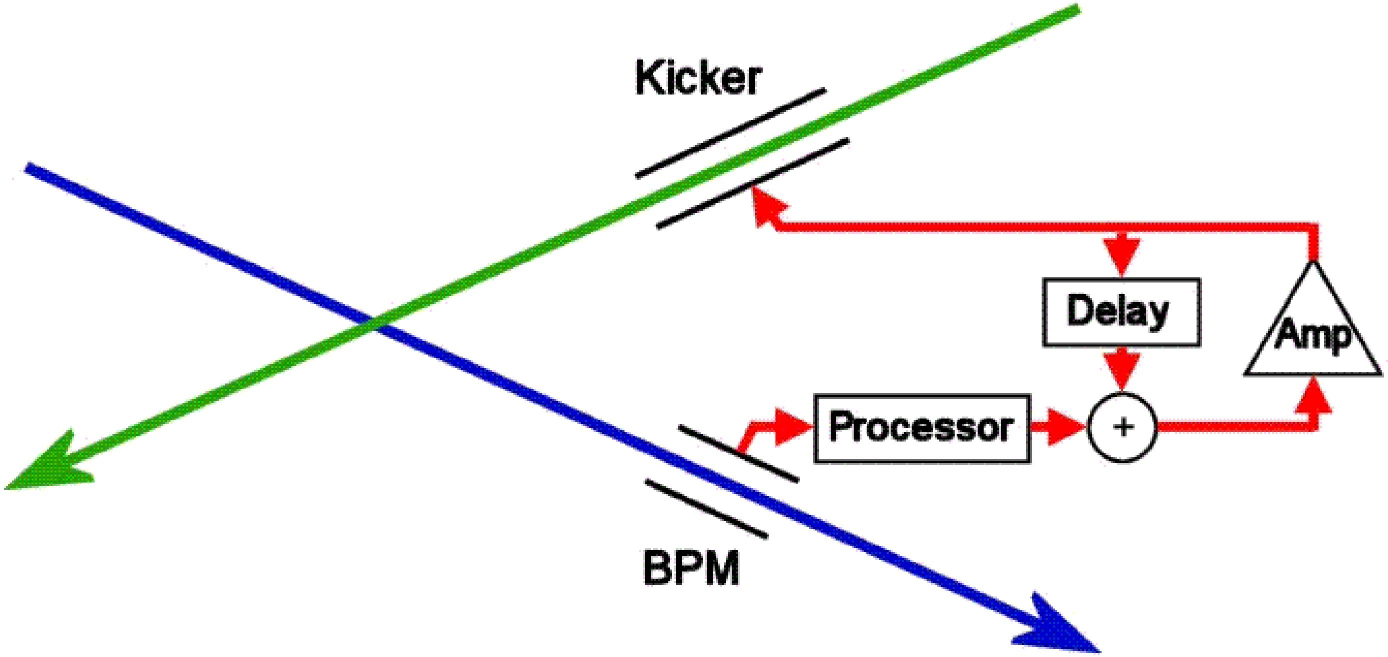
z, micron

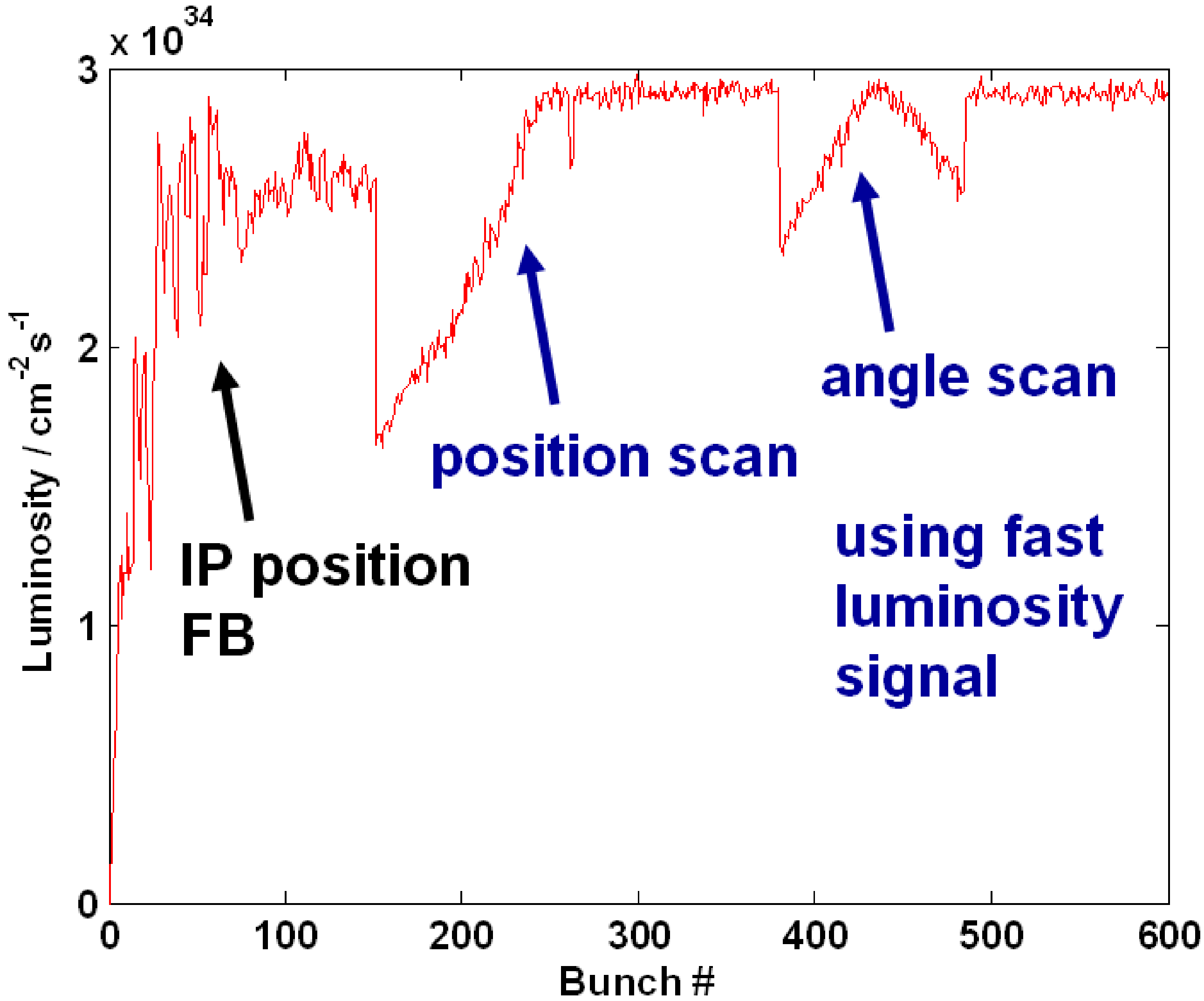
Beam-Beam orbit feedback



use strong beam-beam kick to keep beams colliding

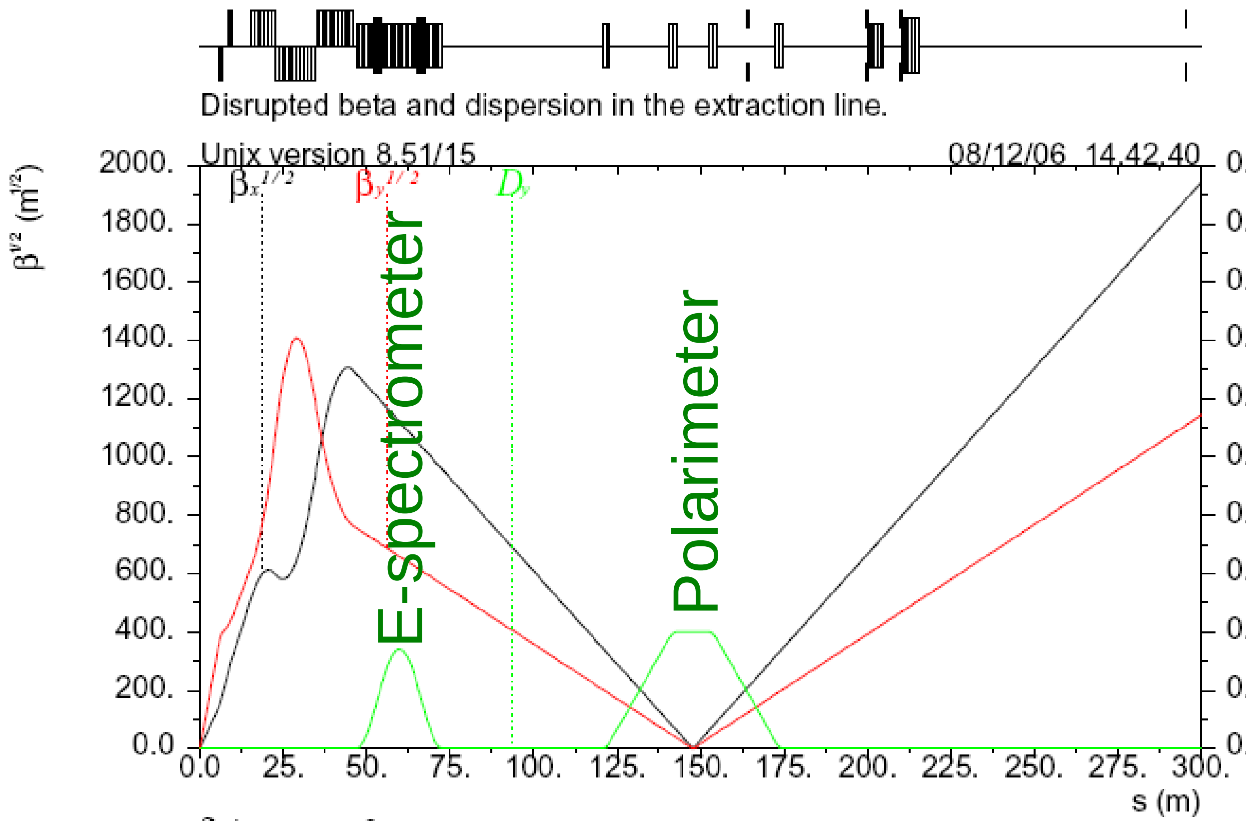
ILC intratrain simulation

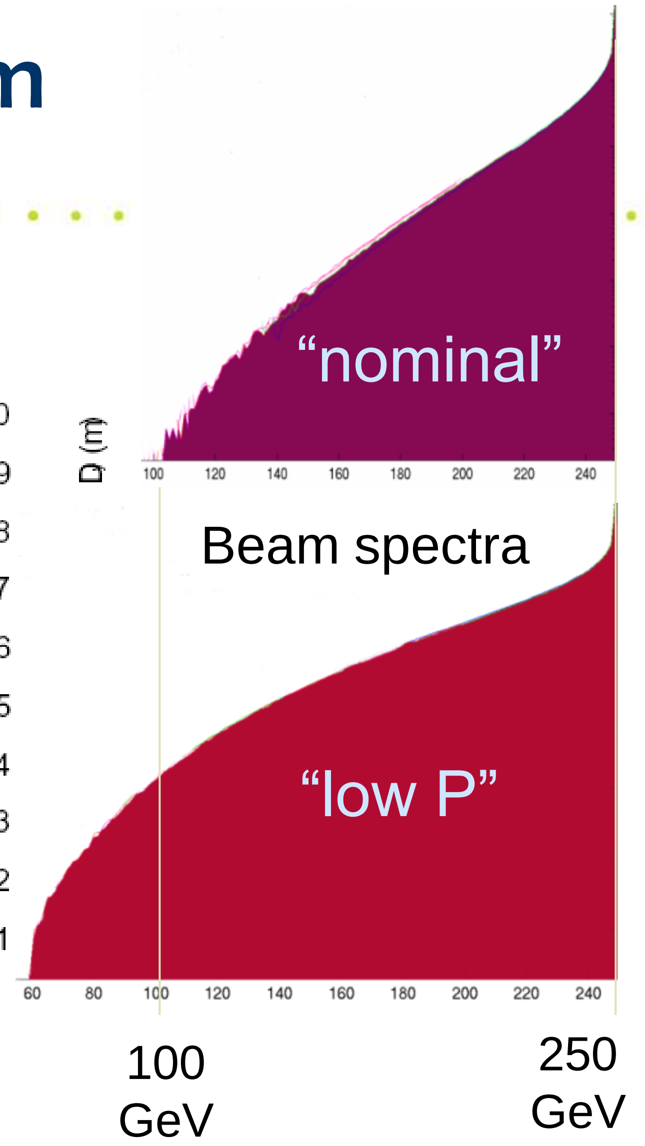
ILC intratrain feedback (IP position and angle optimization), simulated with realistic errors in the linac and “banana” bunches.



[Glen White]

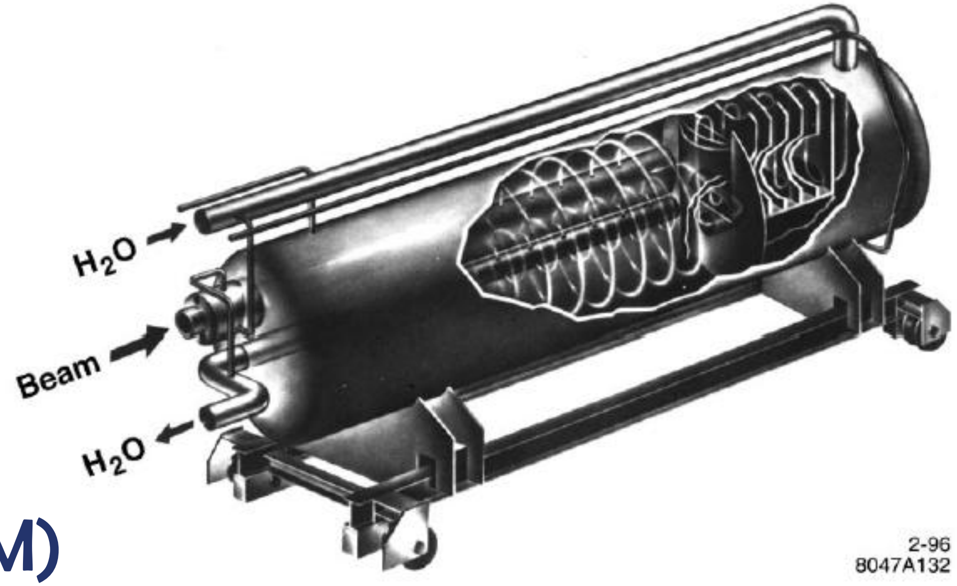
Optics for outgoing beam





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

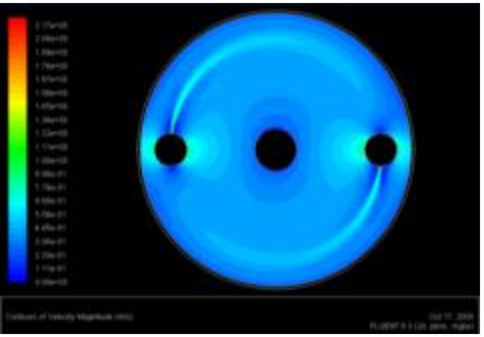
Beam dump



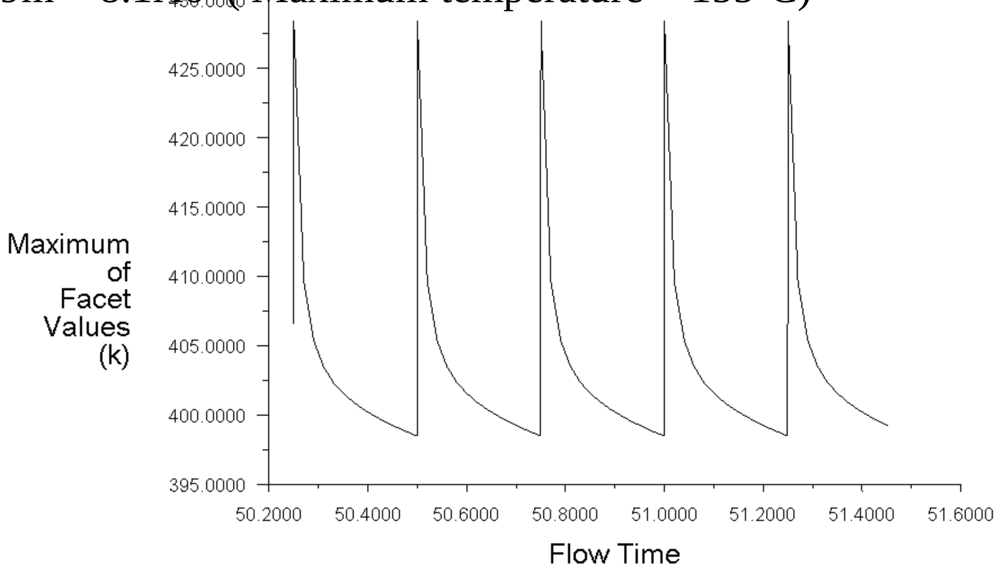
- 17MW power (for 1TeV CM)
- Rastering of the beam on 30cm double window
- 6.5m water vessel; ~1m/s flow
- 10atm pressure to prevent boiling
- Three loop water system
- Catalytic H_2-O_2 recombiner
- Filters for 7Be
- Shielding 0.5m Fe & 1.5m concrete

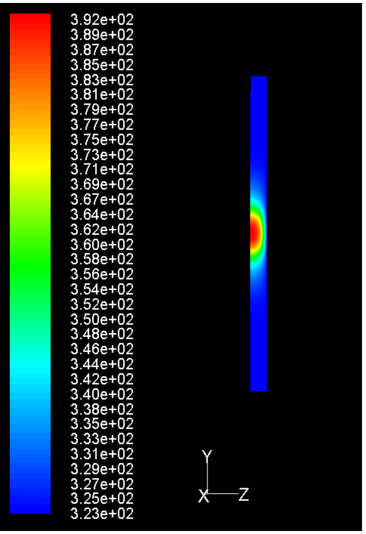
Beam dump design updates

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



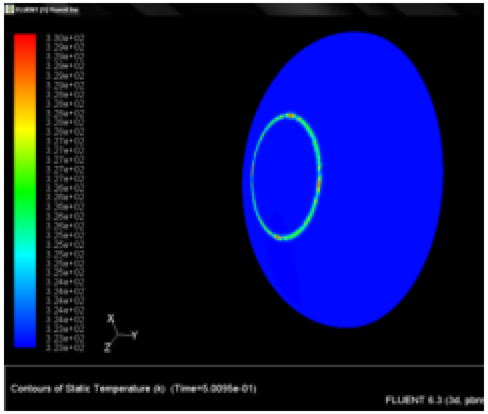
Velocity contours (inlet velocity: 2.17m/s, mass flux: 19kg/m/s)





Temperature distribution across the cross-section of the End plate

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

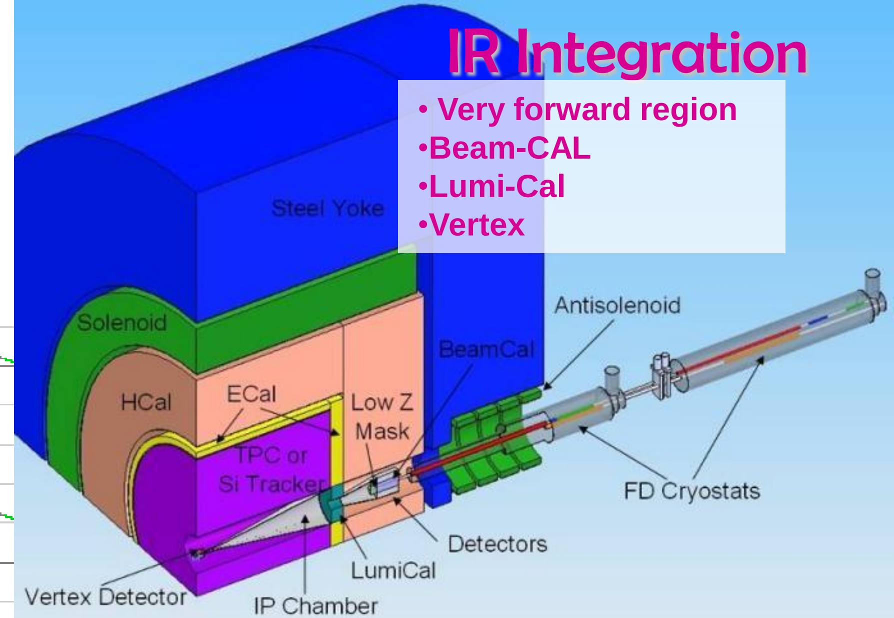


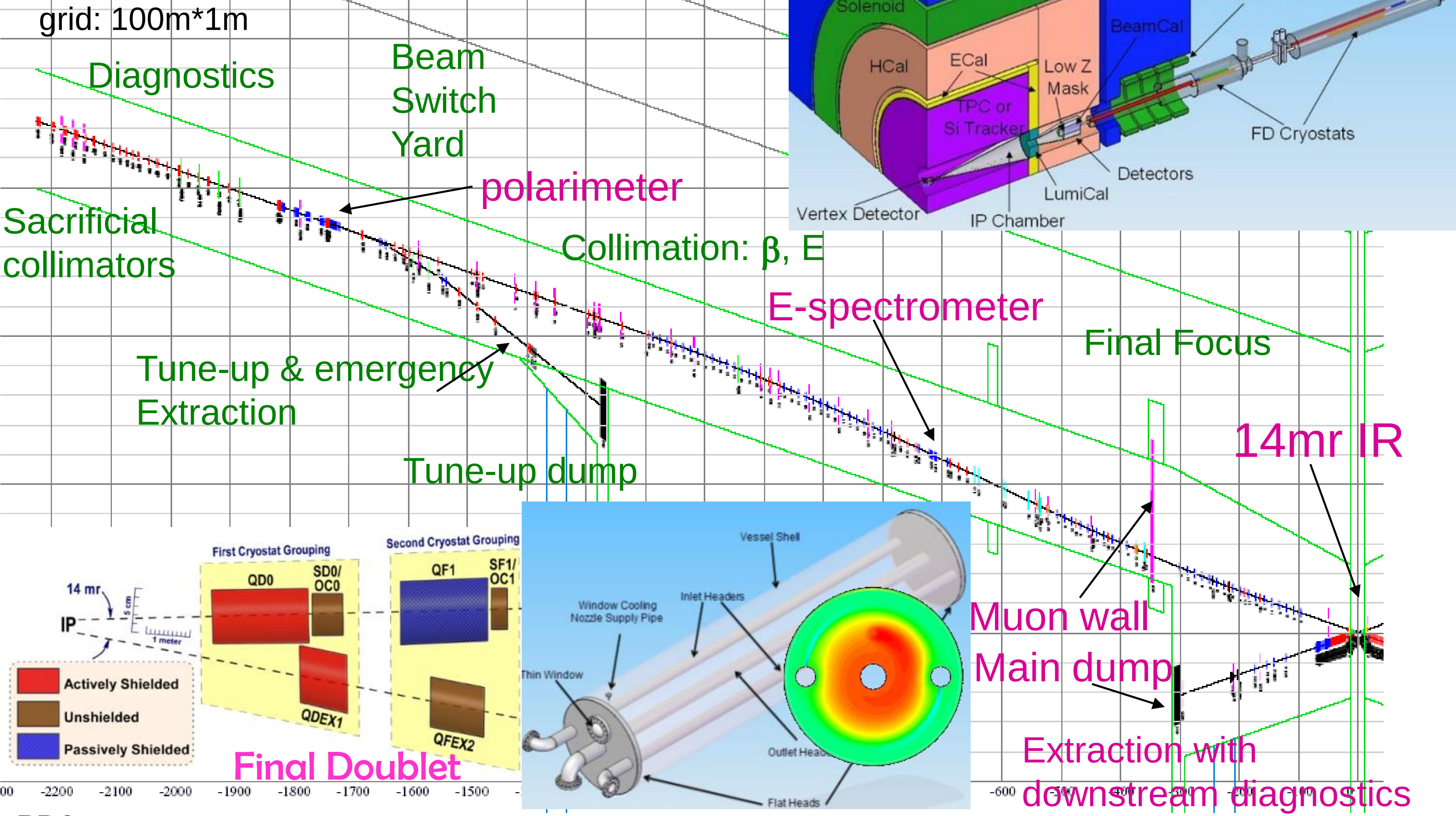
D. Walz , J. Amann, et al, SLAC
P. Satyamurthy, P. Rai, V. Tiwari, K. Kulkarni, BARC, Mumbai, India

From IPAC10 paper

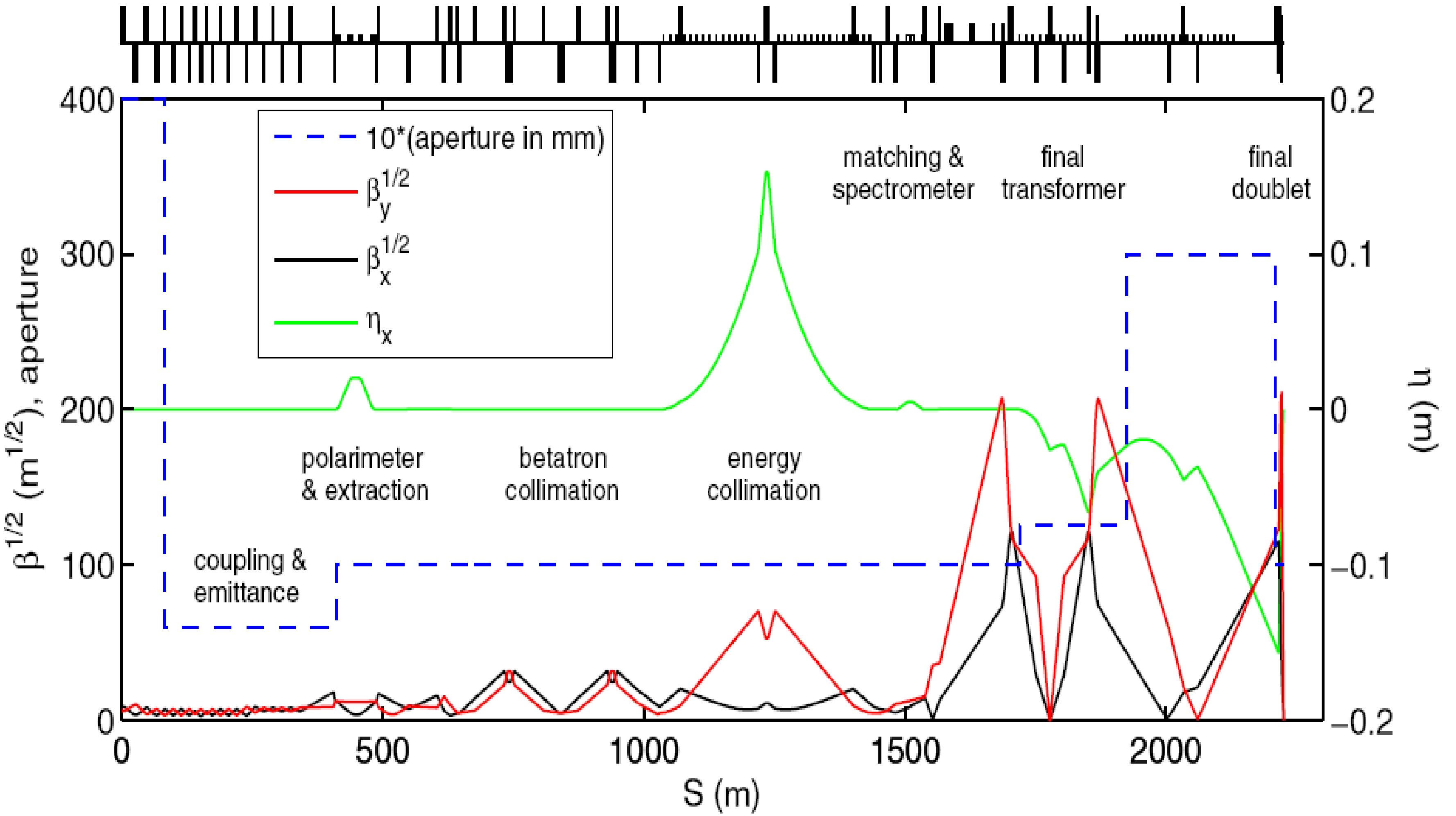
Beam Delivery & MDI elements

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

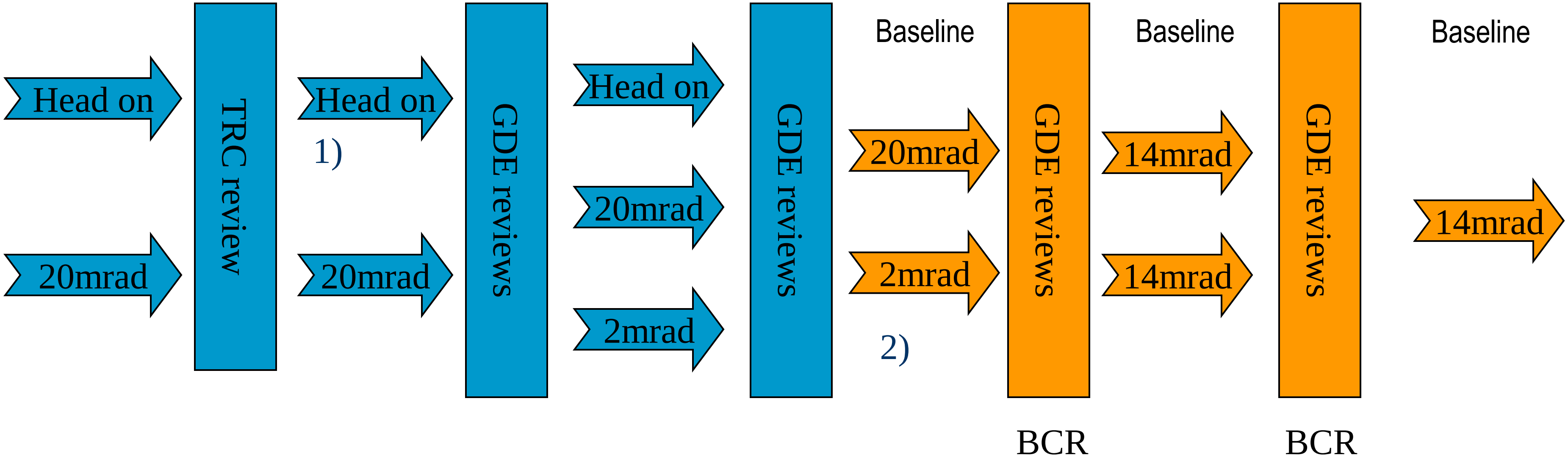




ILC BDS Optical Functions



BDS & MDI Configuration Evolution

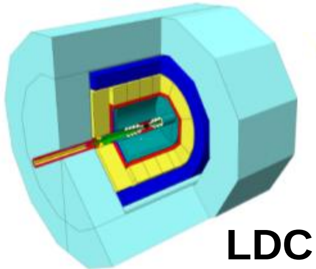


- **Evolution of BDS MDI configuration**
  - Head on; small crossing angle; large crossing angle

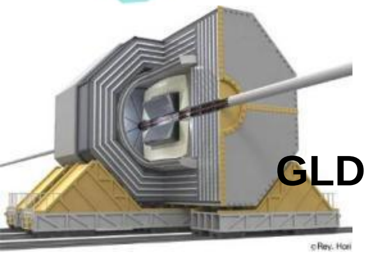
- MDI & Detector performance were the major criteria for selection of more optimal configuration at every review or decision point

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

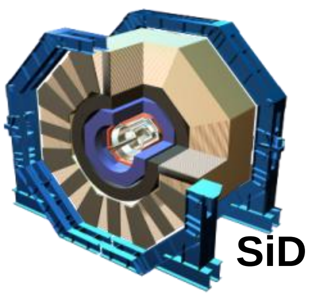
Evolution of ILC Detectors



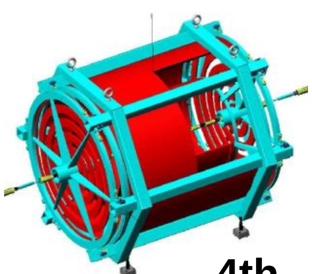
LDC



GLD



SiD



4th

LDC

GLD

Merged to ILD design

ILD

SiD

4th

Thorough evaluation of performance, validation of the concepts

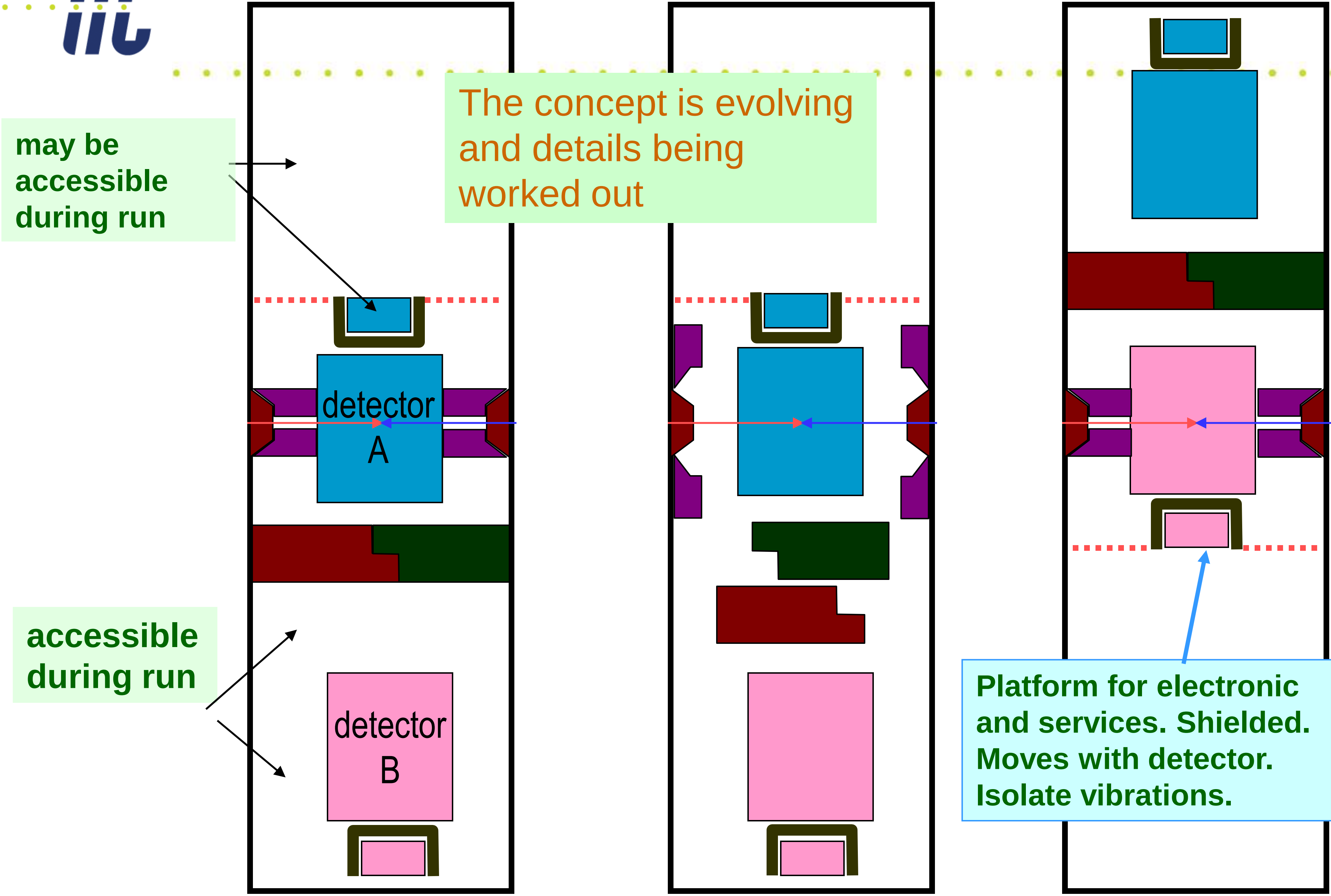
ILD validated

Technical design of detectors and R&D for critical sub-systems

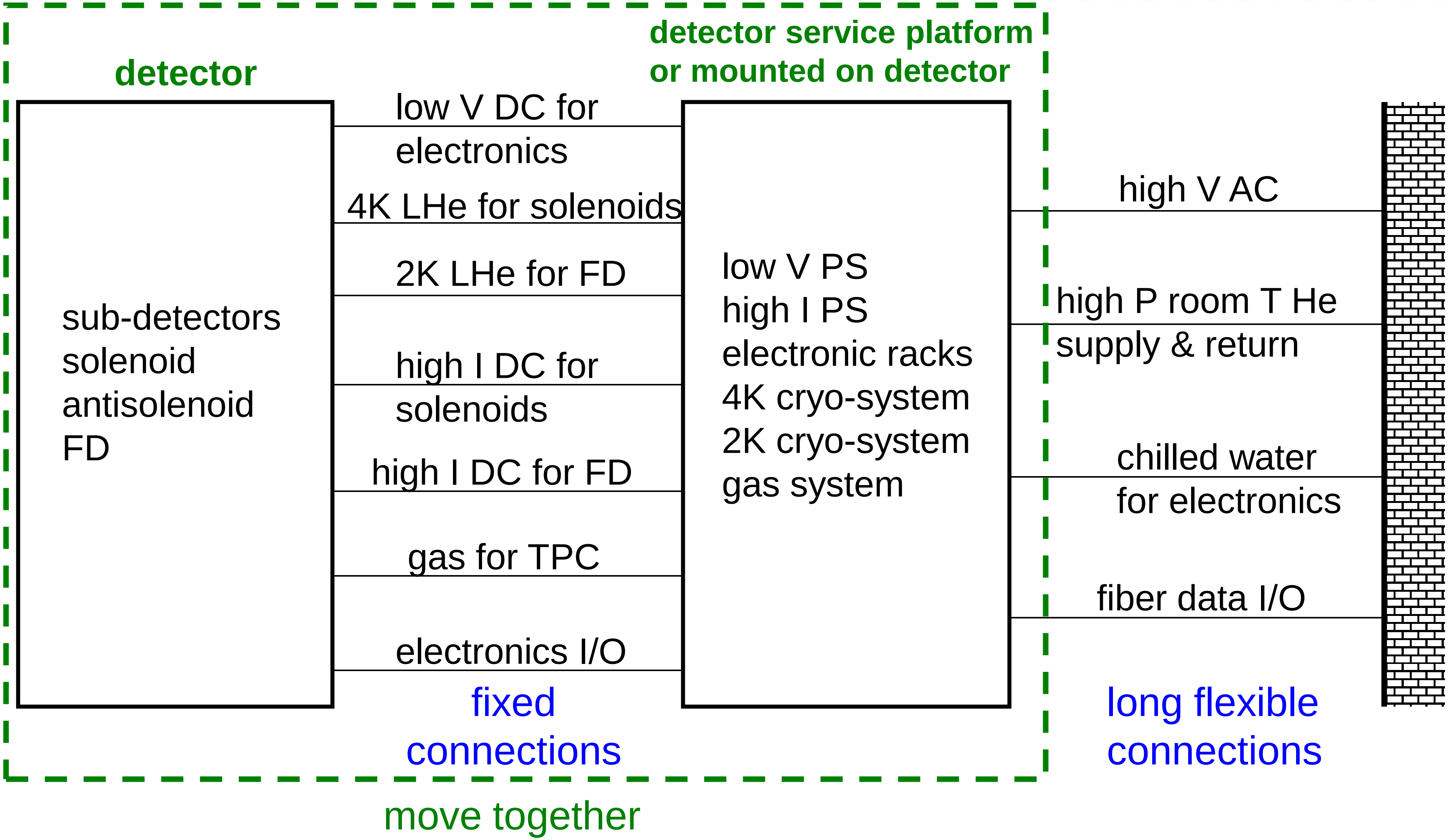
SiD validated

- **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

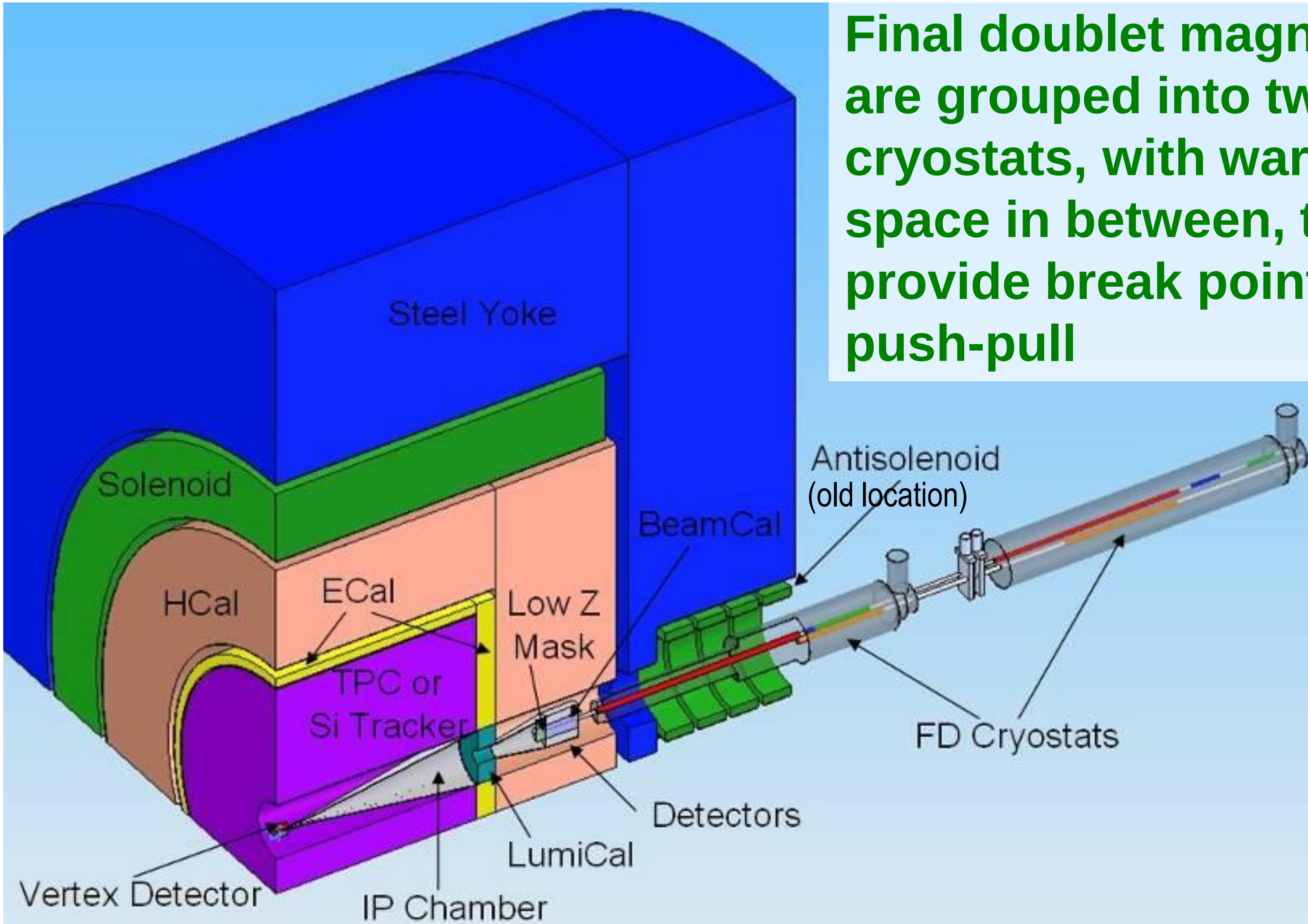


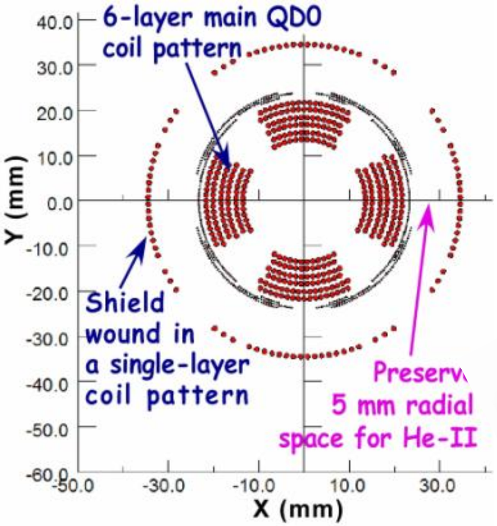
Concept of detector systems connections



IR integration

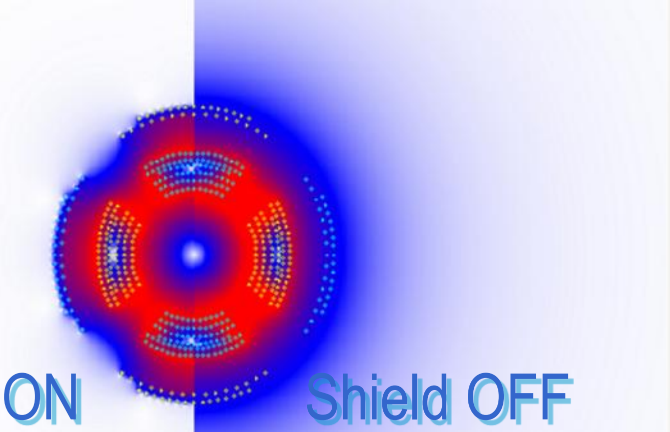
Final doublet magnets are grouped into two cryostats, with warm space in between, to provide break point for push-pull



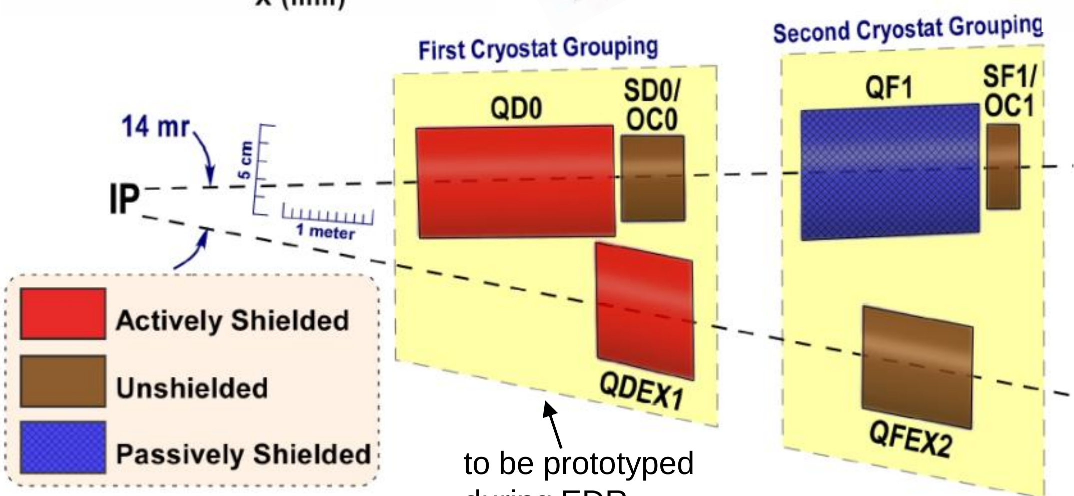


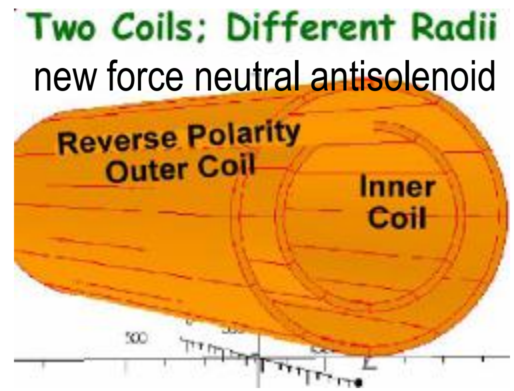
Actively shielded QD0

BNL



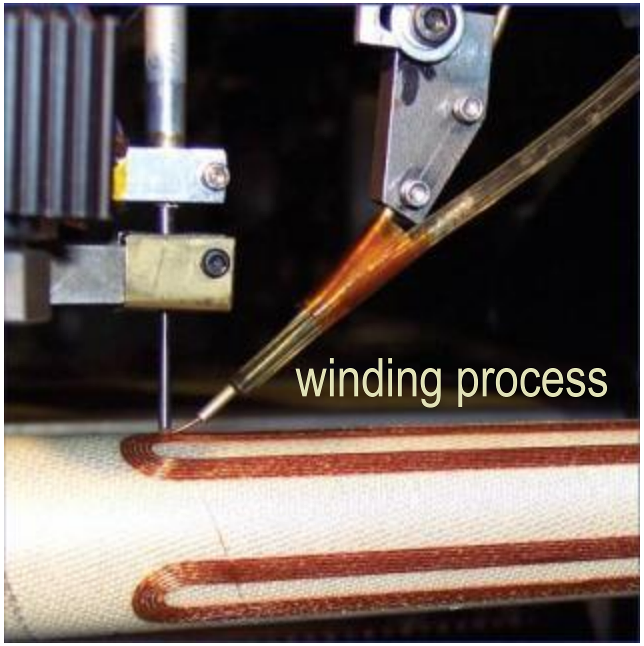
Intensity of color represents value of magnetic field.

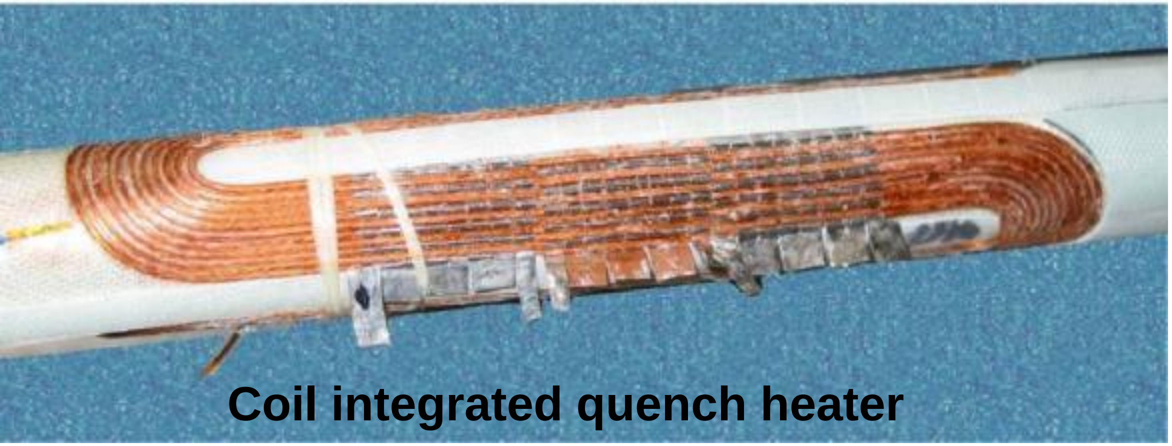


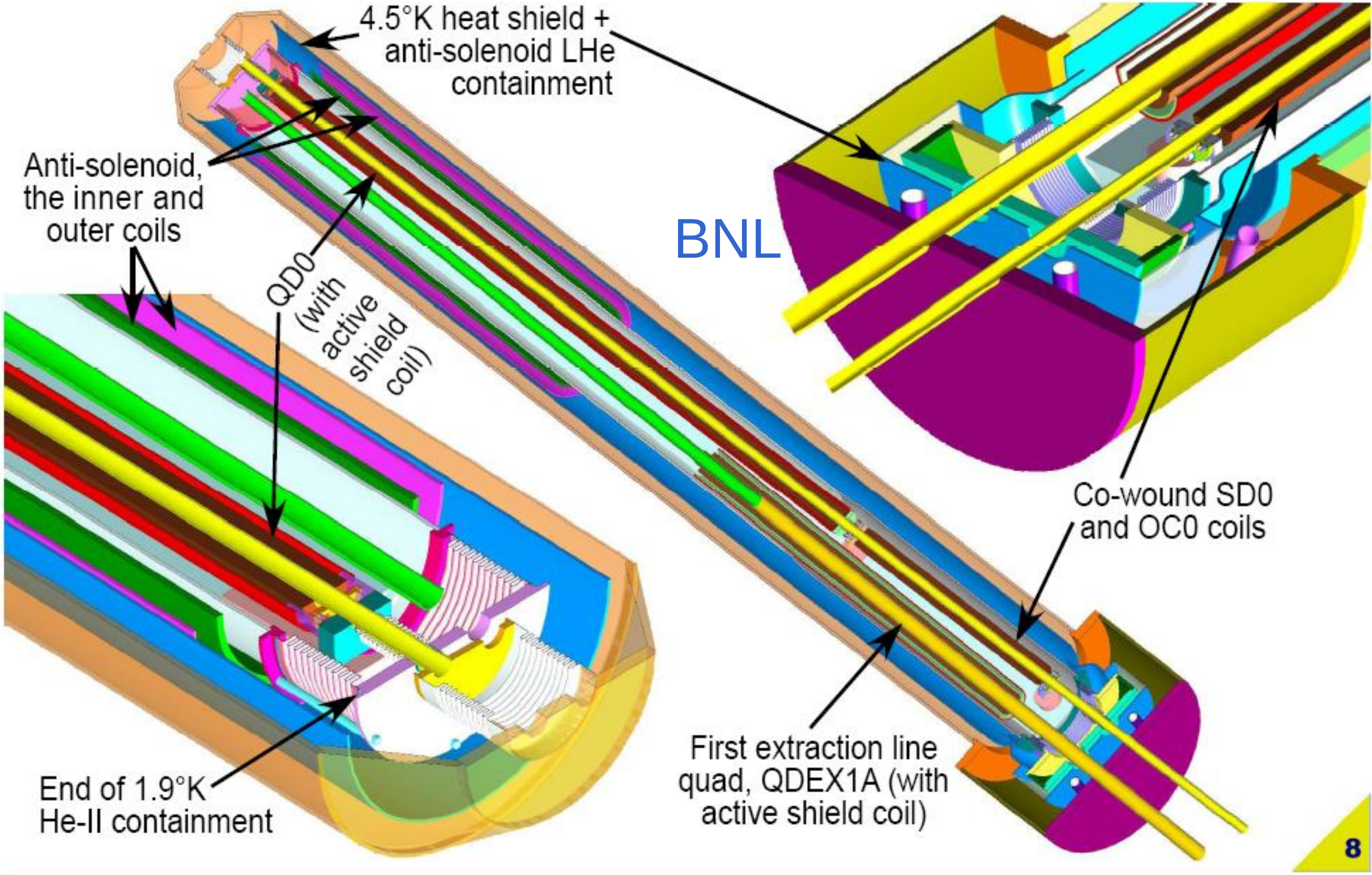


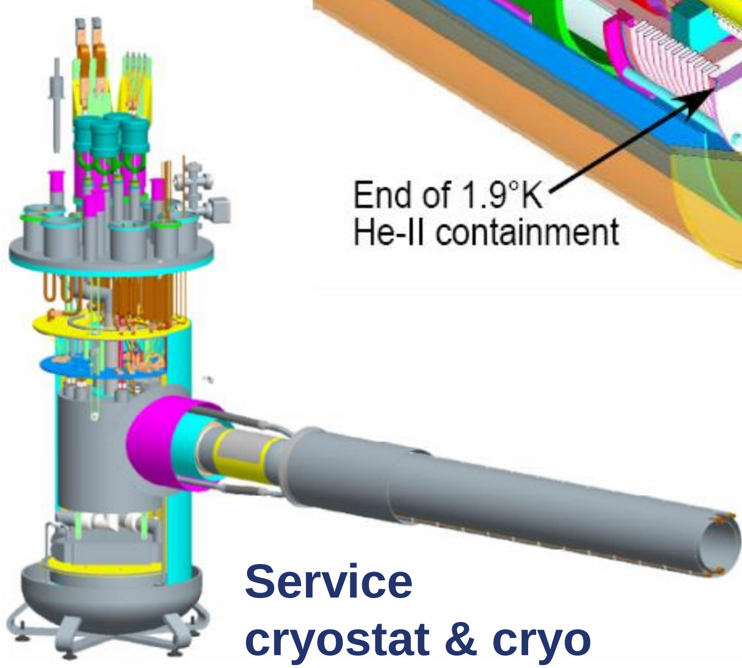
- Interaction region uses compact self-shielding SC magnets
- Independent adjustment of in- & out-going beamlines
- Force-neutral anti-solenoid for local coupling correction

IR magnets prototypes at BNL





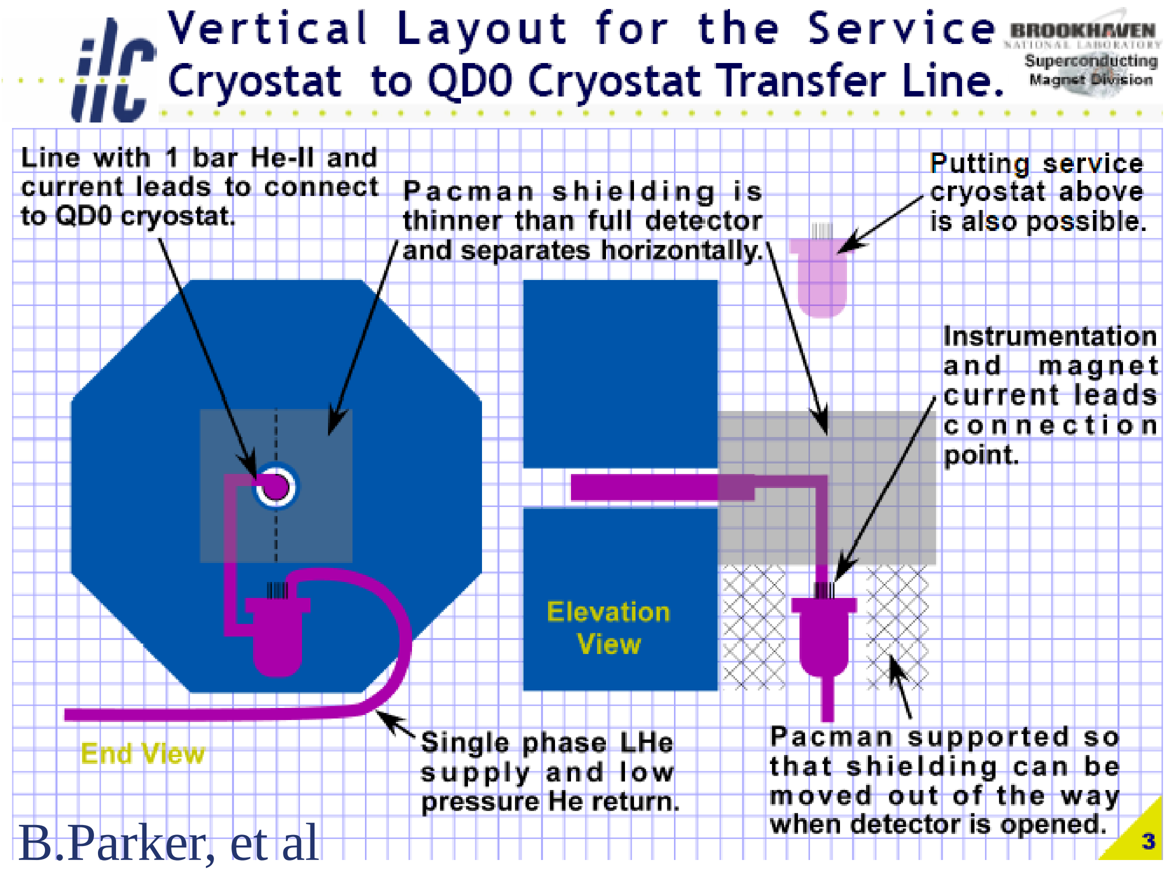


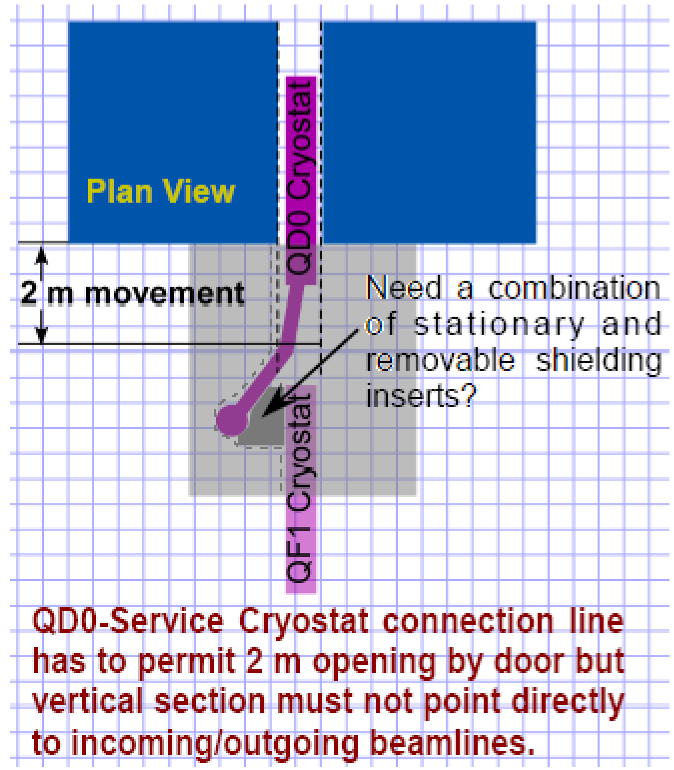


Service cryostat & cryo connections

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

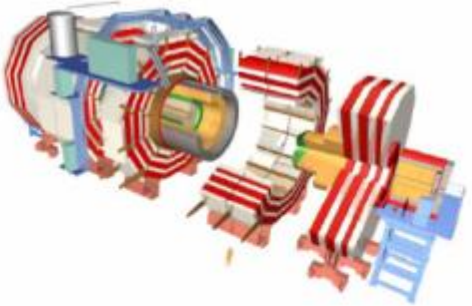
Present concept of cryo connection

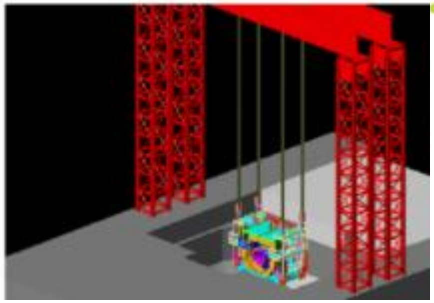




B.Parker, et al

Detector assembly

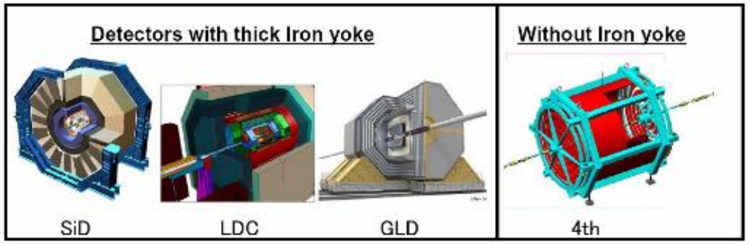




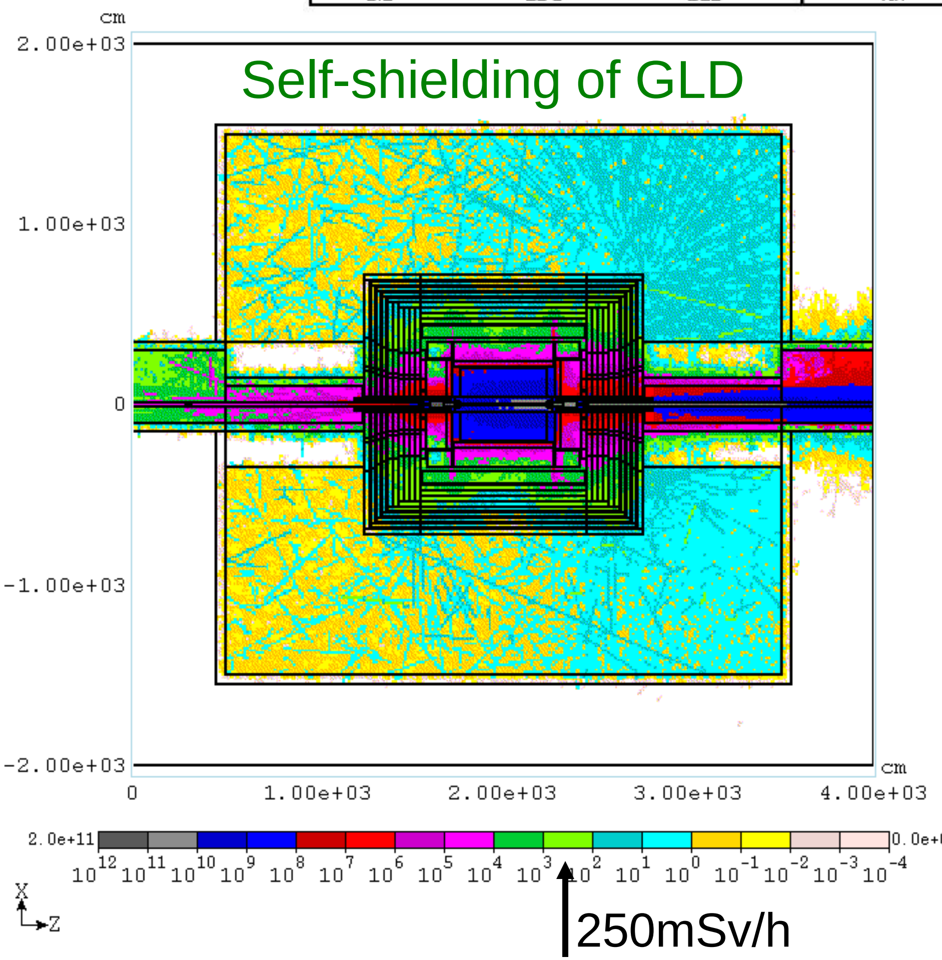
photos courtesy CERN colleagues

- 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

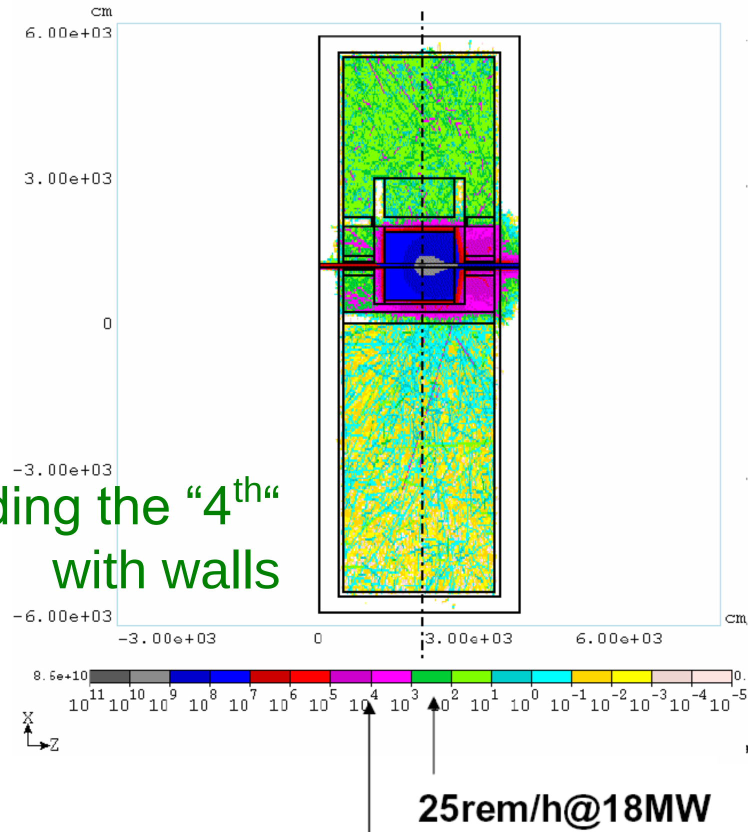
Shielding the IR hall

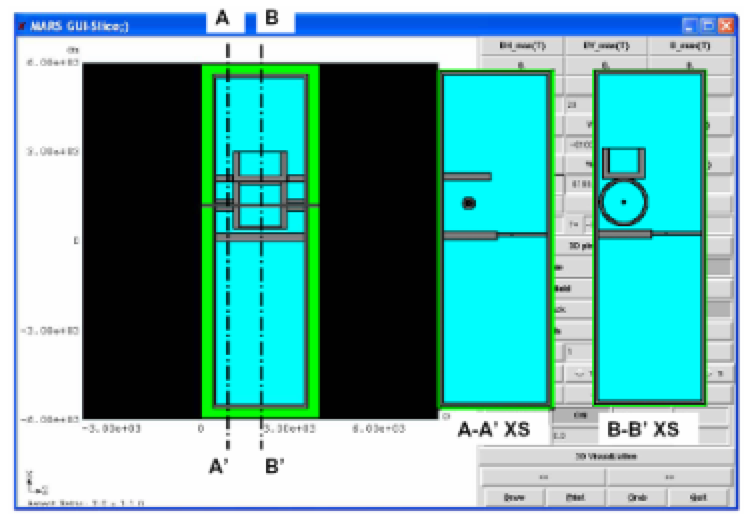


Self-shielding of GLD

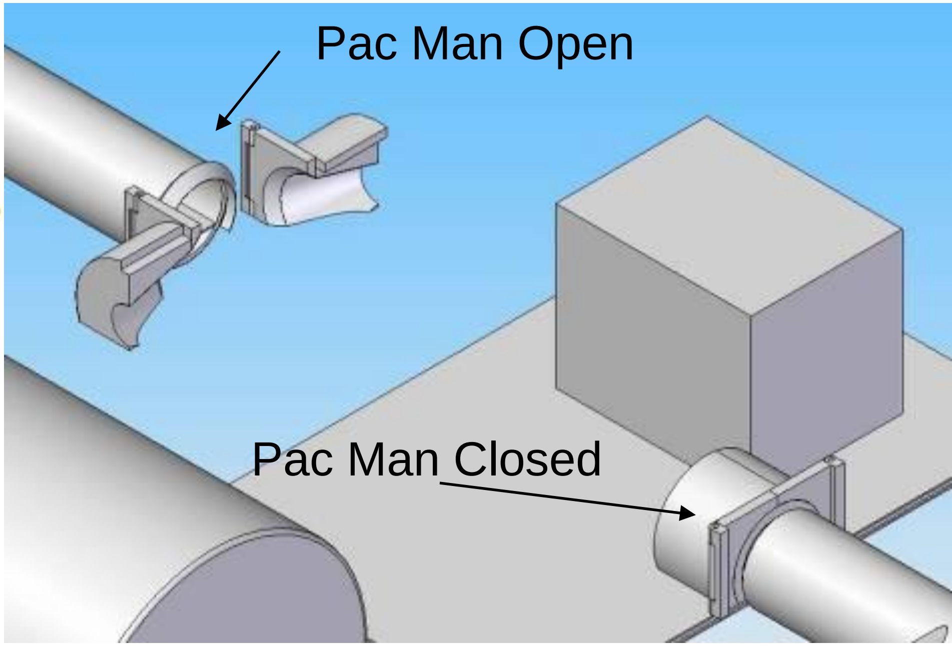


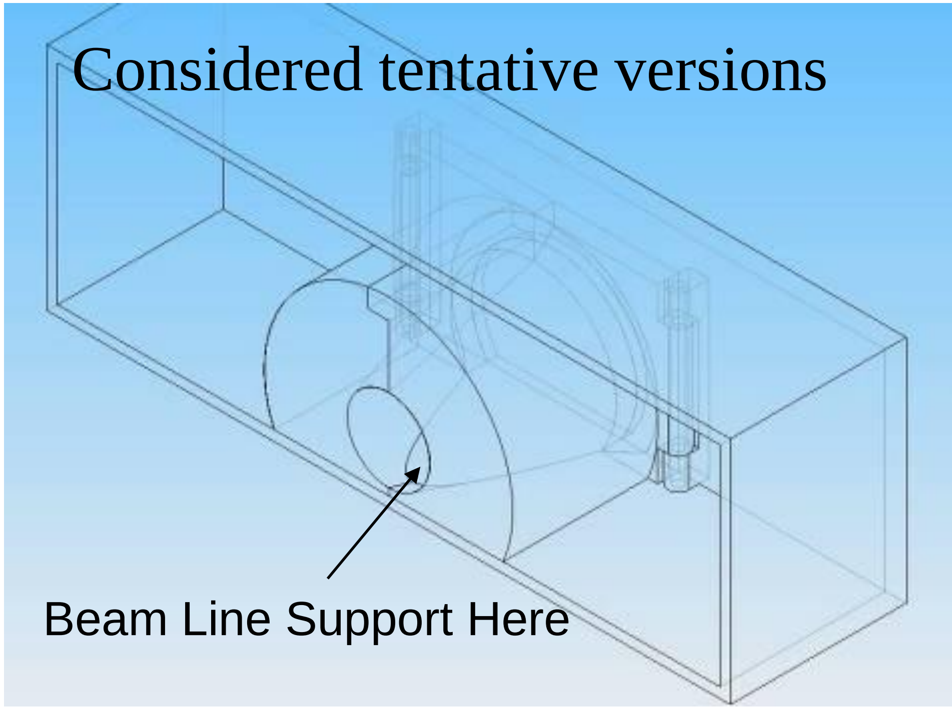
Shielding the "4th" with walls



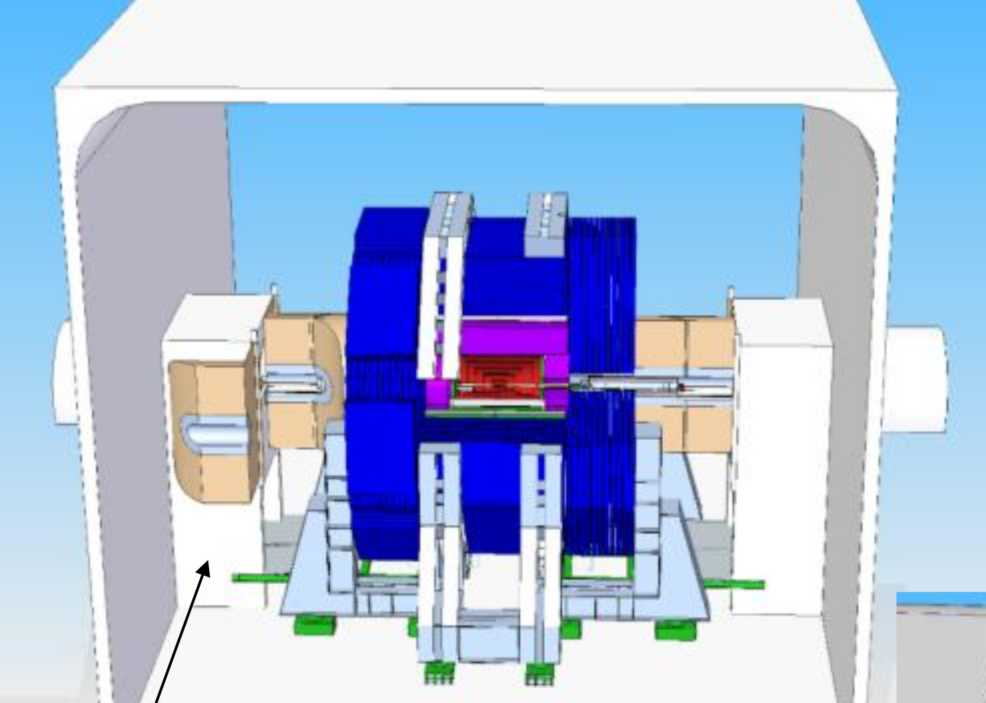


Pacman design

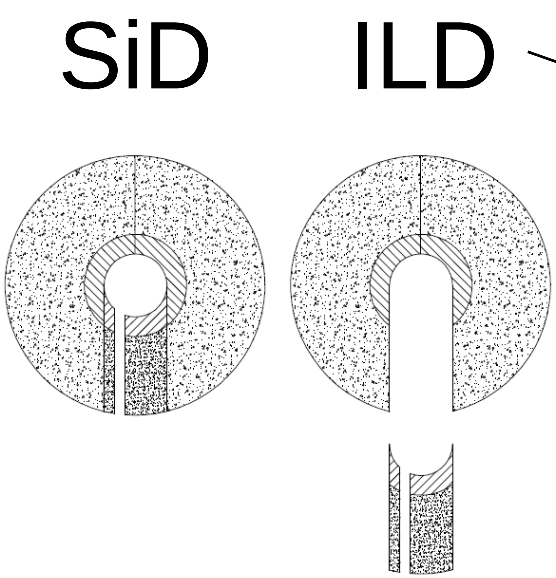


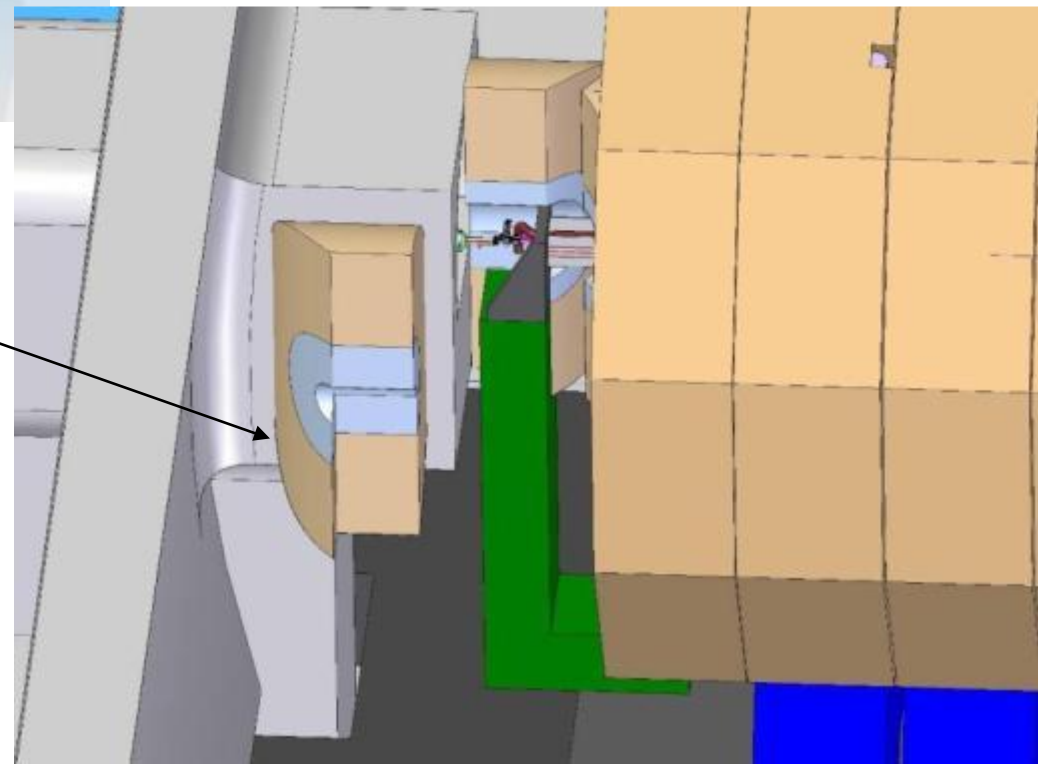


John Amann



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

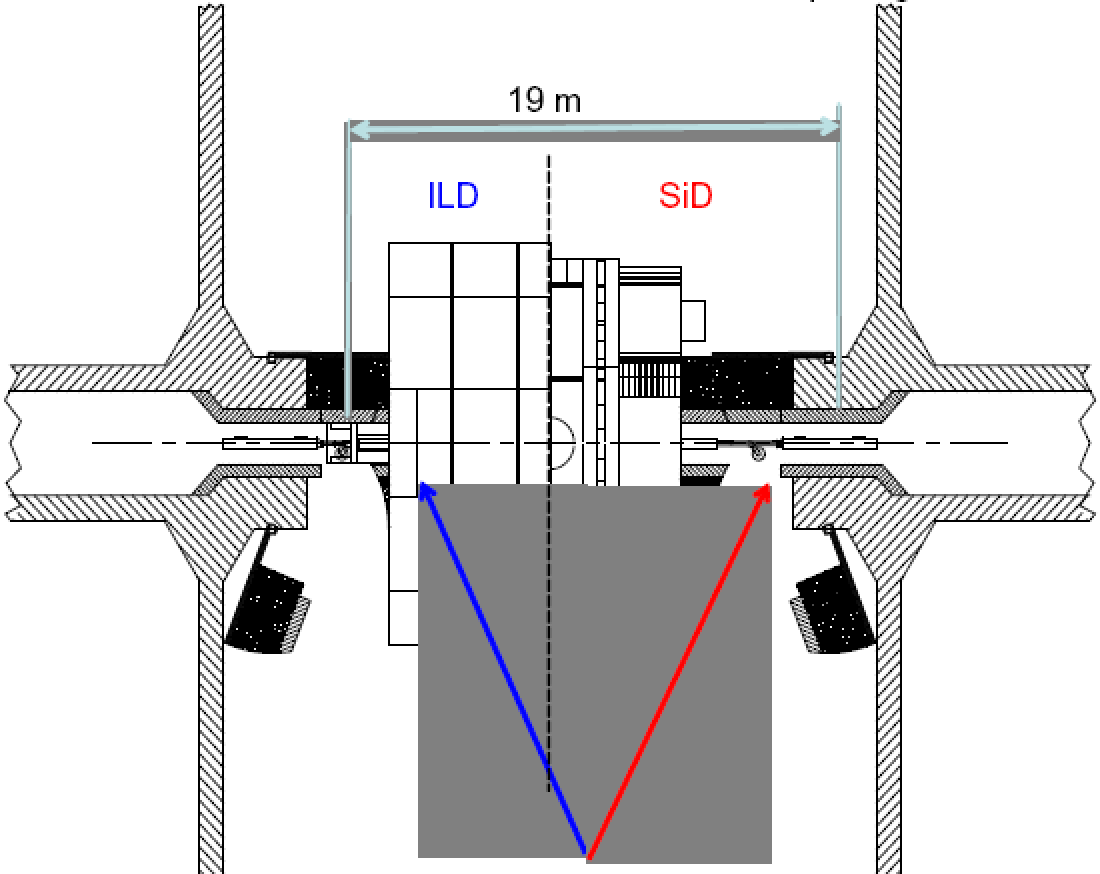




M.Oriunno, H.Yamaoka, A.Herve, et. al

Pacman compatible with SiD

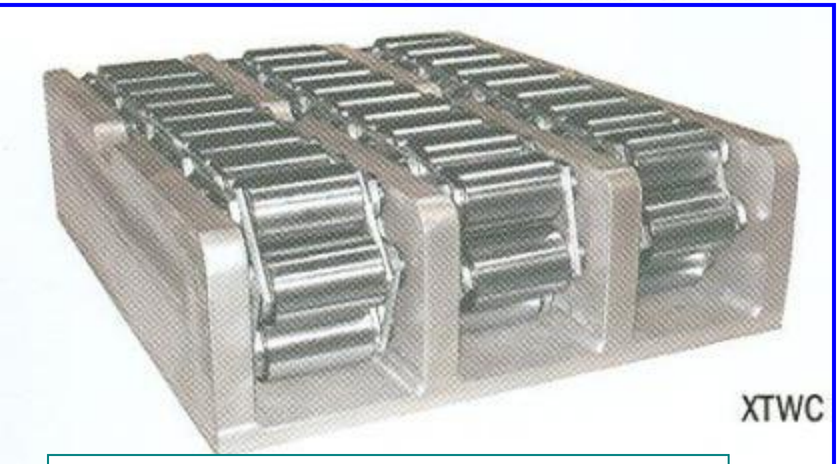
Pacmen closed: Modified to allow ILD opening



Interface pieces born by each experiment

From A. Hervé, K. Sinram, M. Oriunno

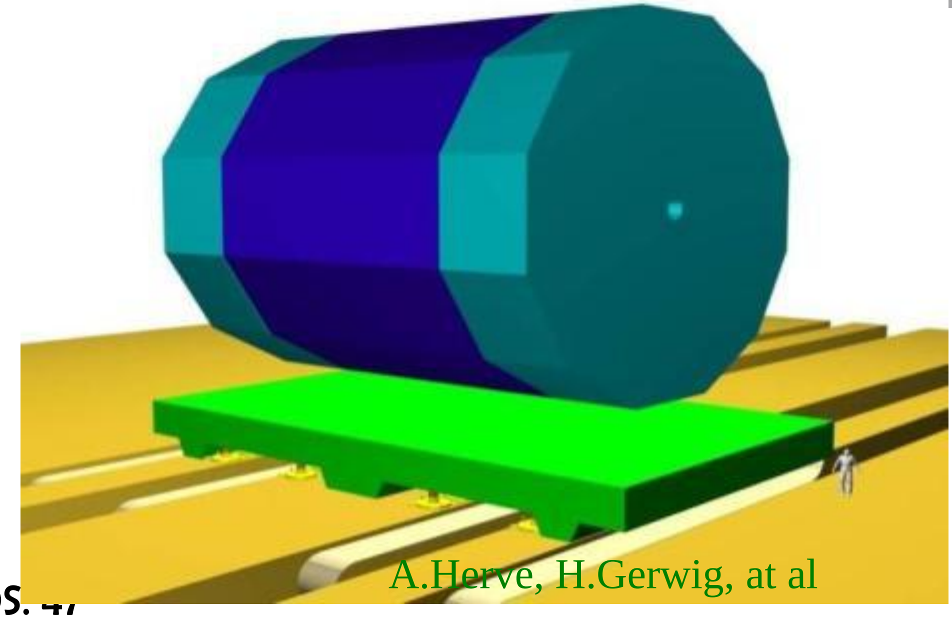
Moving the detector



5000 ton Hilman roller module

Air-pads at CMS – move 2000k pieces

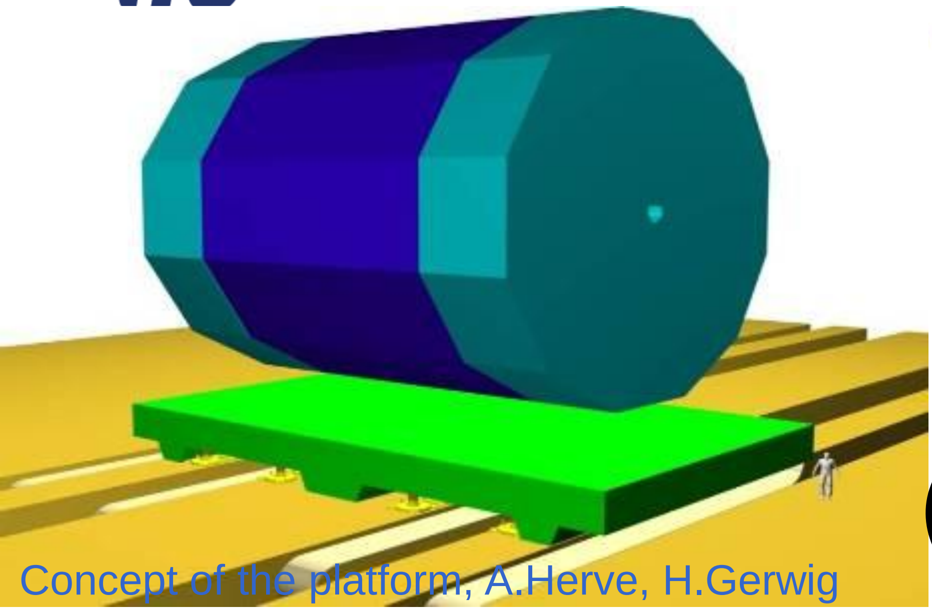
Is detector (compatible with on-surface assembly) rigid enough itself to avoid distortions during move?



A.Herve, H.Gerwig, at al

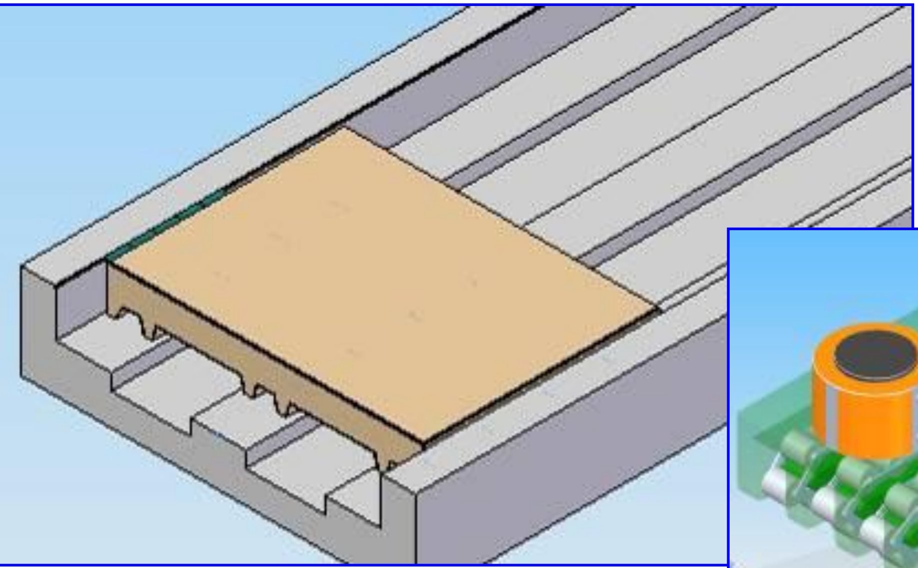
Concept of the platform to move ILC detector

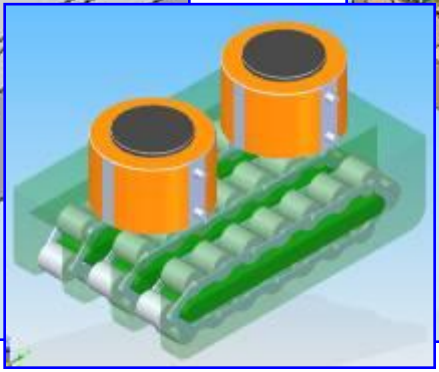
Moving the detector

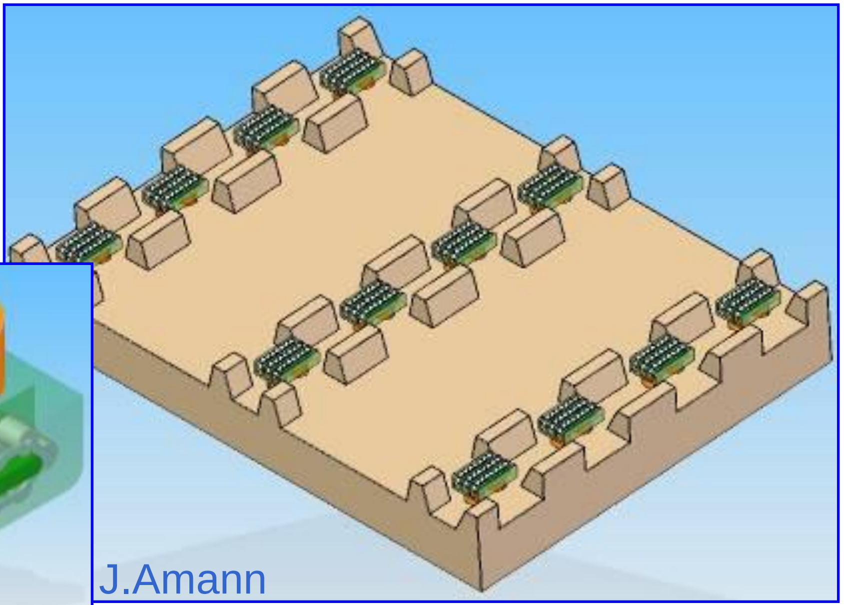


Concept of the platform, A.Herve, H.Gerwig

Air-pads at CMS – move 2000k



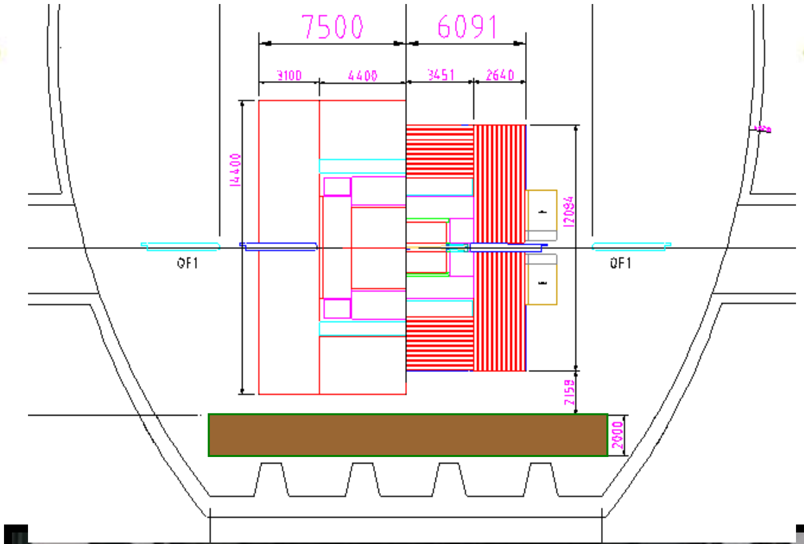


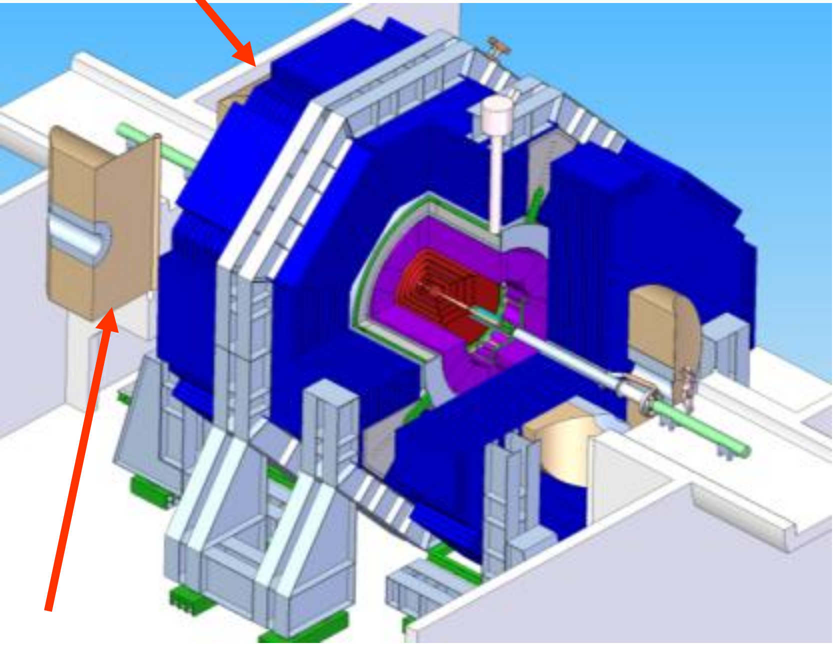


J.Amann

Example of MDI issues: moving detectors

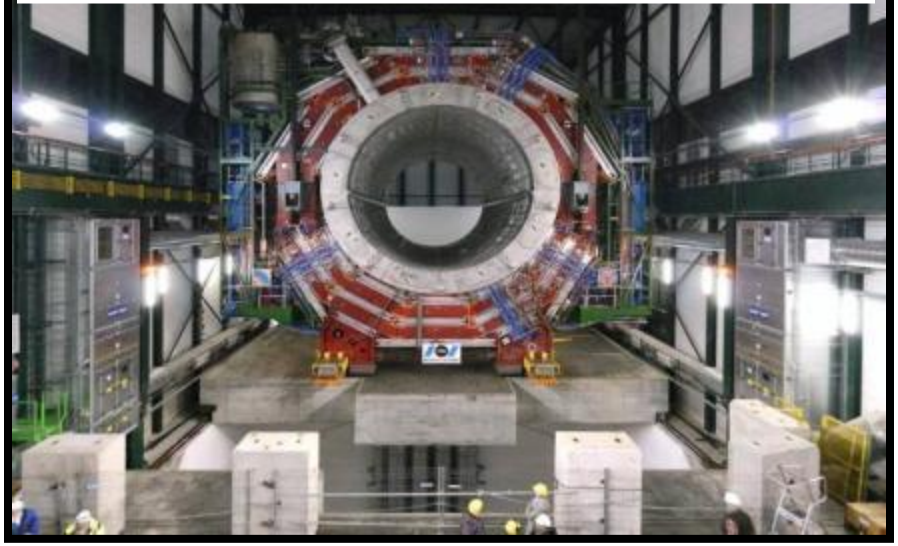
Detector motion system with
or without an intermediate platform



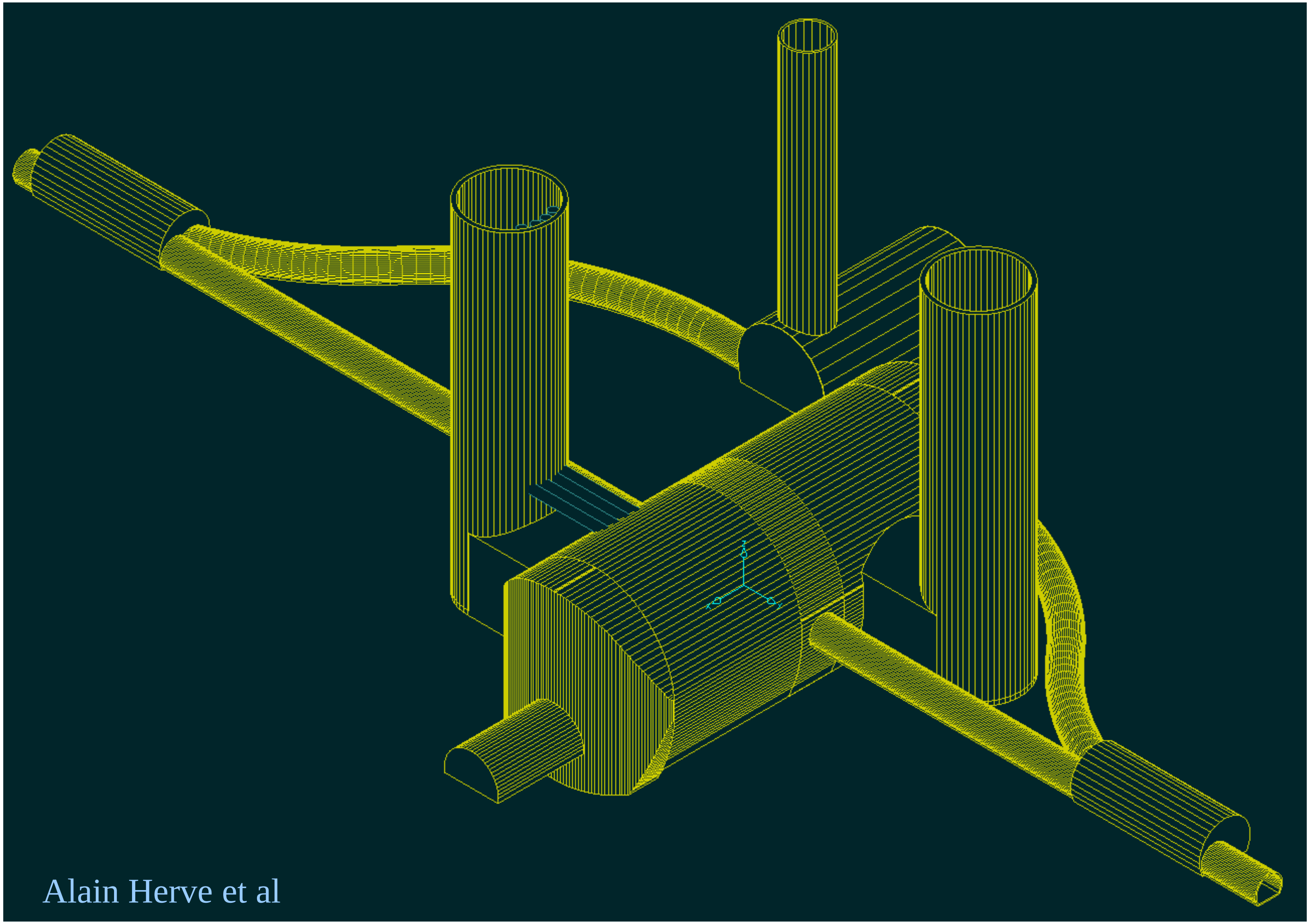


Detector and beamline shielding elements

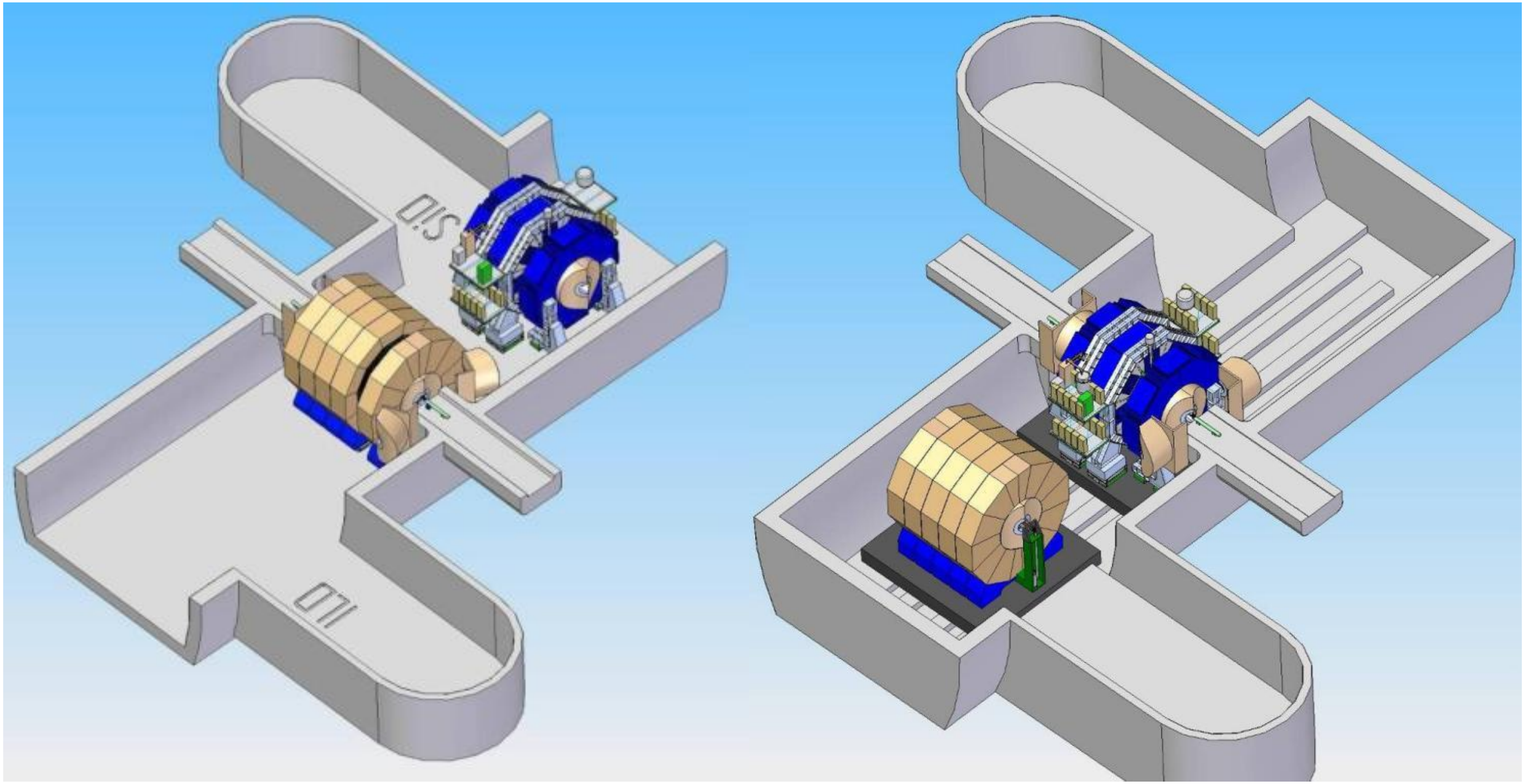
CMS platform – proof of principle for ILC



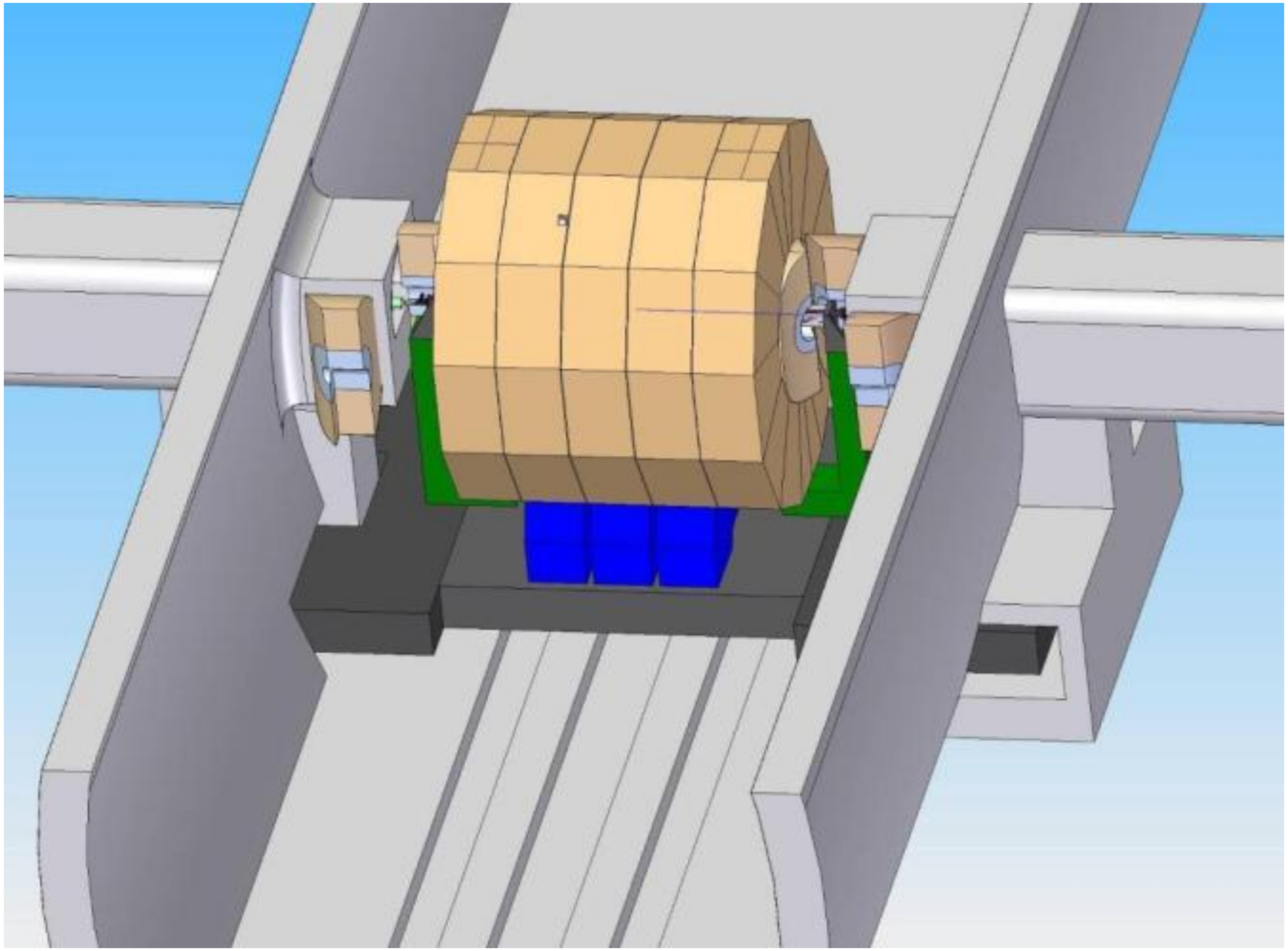
Configuration of IR tunnels and halls



All detectors without / with platform

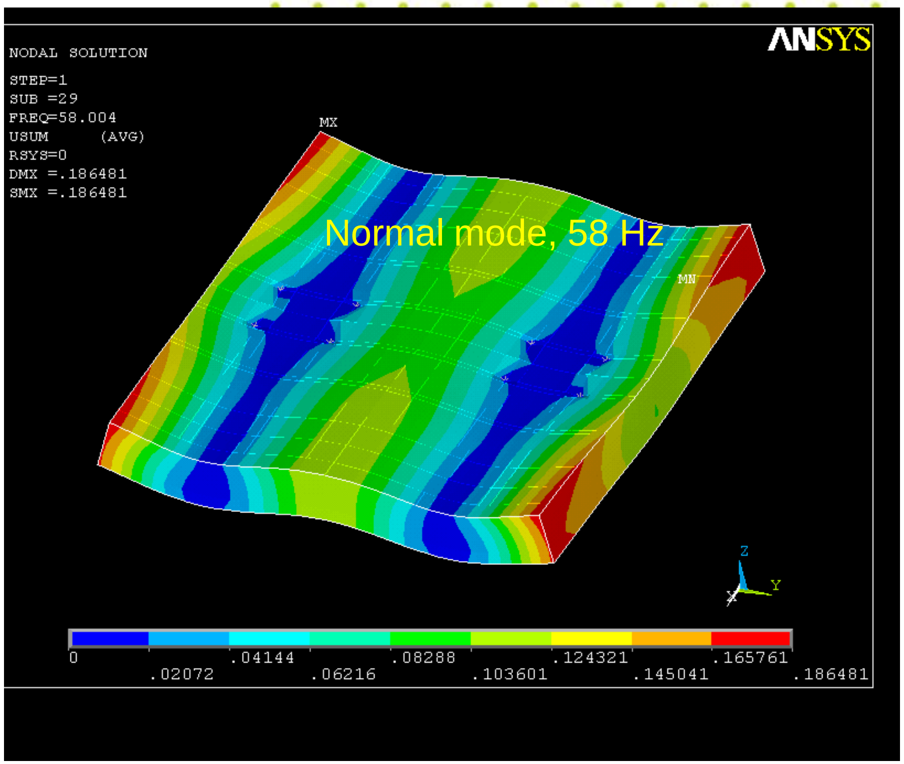


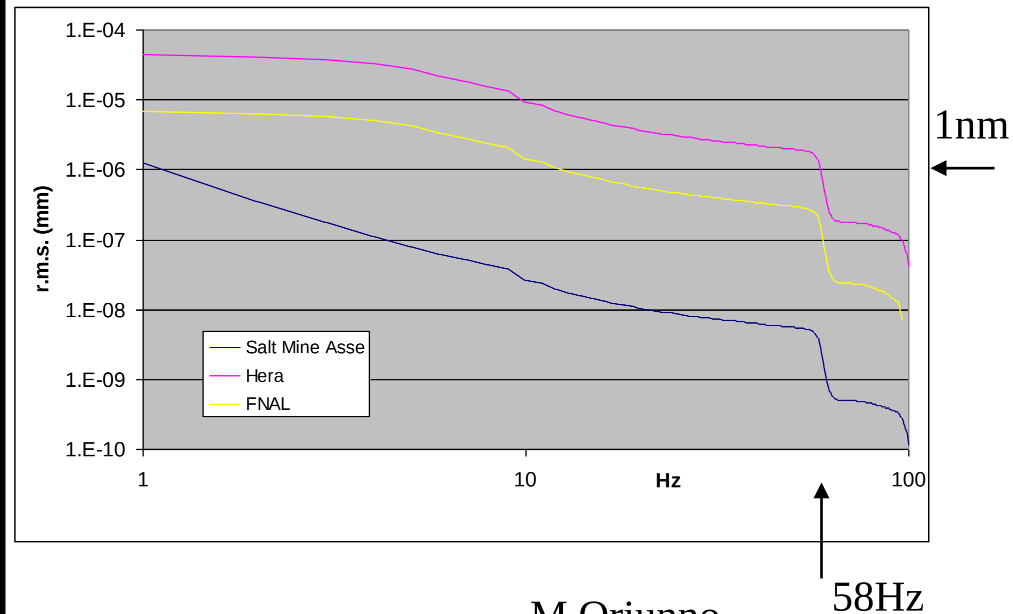
Half Platform w/ Pocket Storage



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

Preliminary
ANSYS analysis of Platform

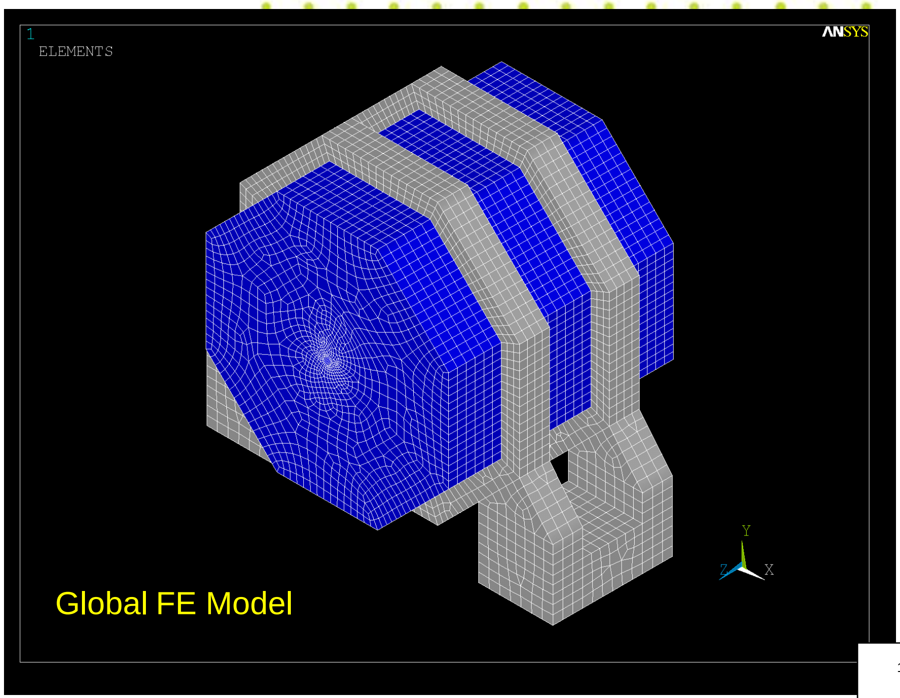


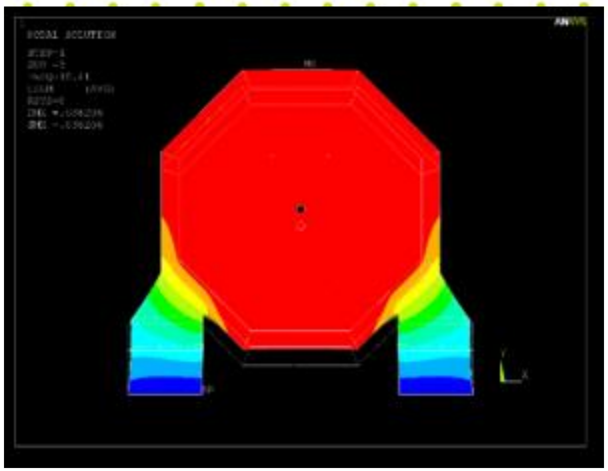


M.Oriunno

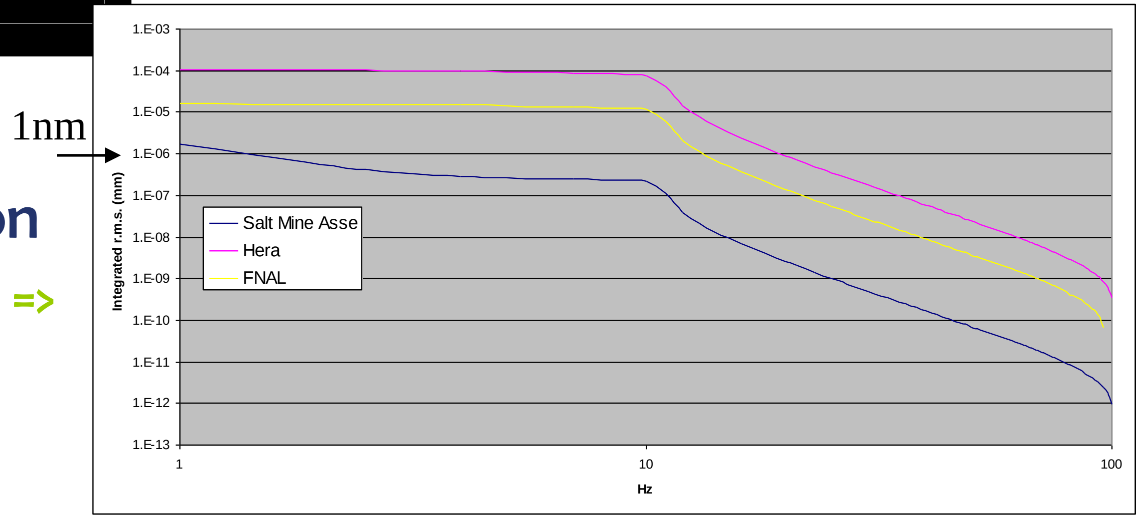
- First look of platform stability look rather promising: resonance frequencies are rather large (e.g. 58Hz) and additional vibration is only several nm

Detector stability analysis (SiD)



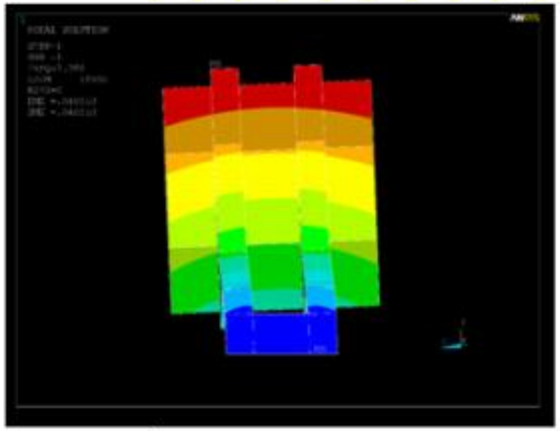


First vertical motion mode, 10.42 Hz

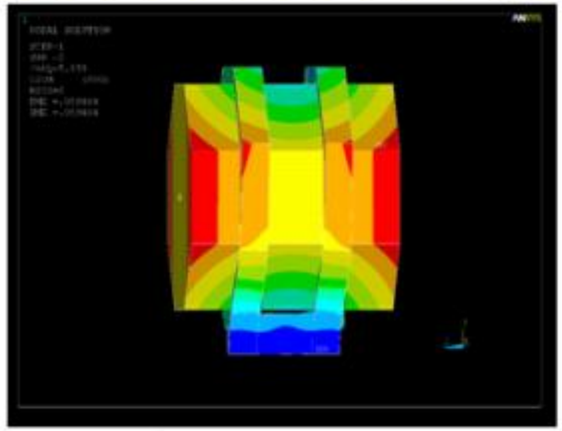


- First analysis shows possibilities for optimization
  - e.g. tolerance to fringe field => detector mass => resonance frequency

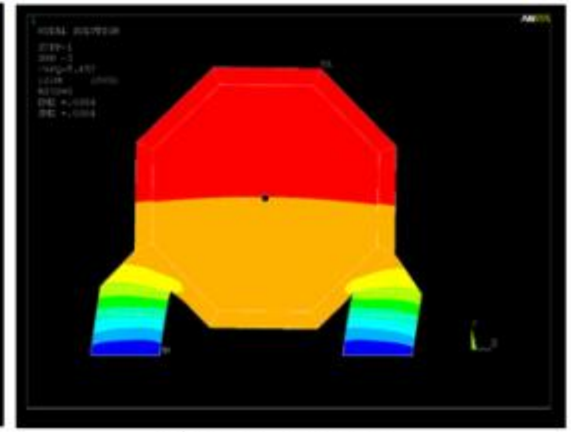
Free vibration modes of SiD



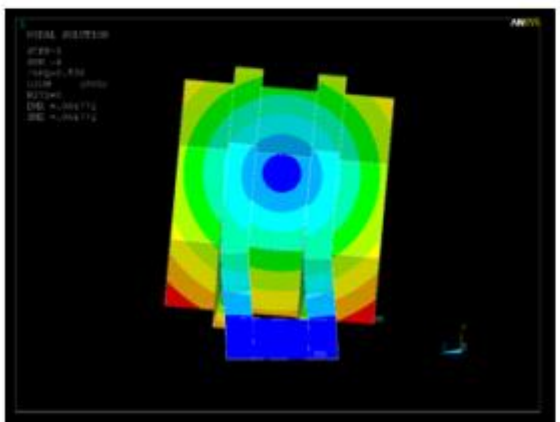
1st Mode, 2.38 Hz



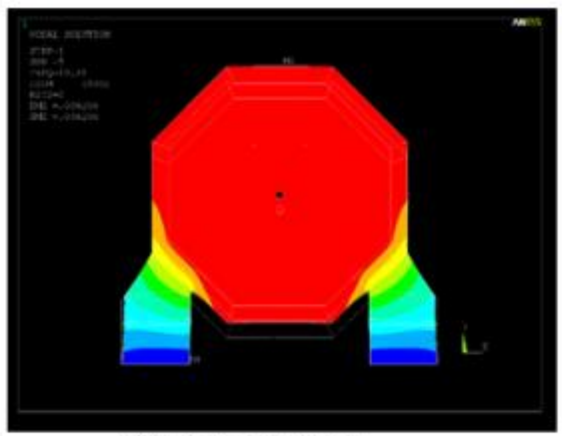
2nd Mode, 5.15 Hz



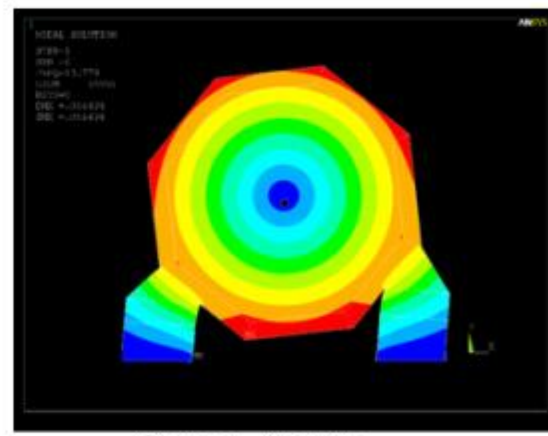
3rd Mode, 5.45 Hz



4th Mode, 6.53 Hz



5th Mode, 10.42 Hz

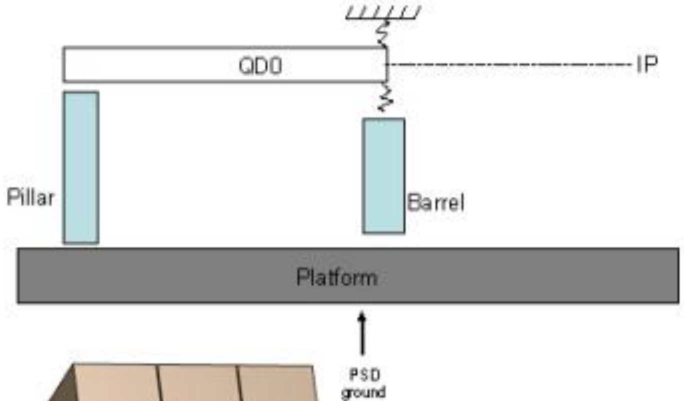


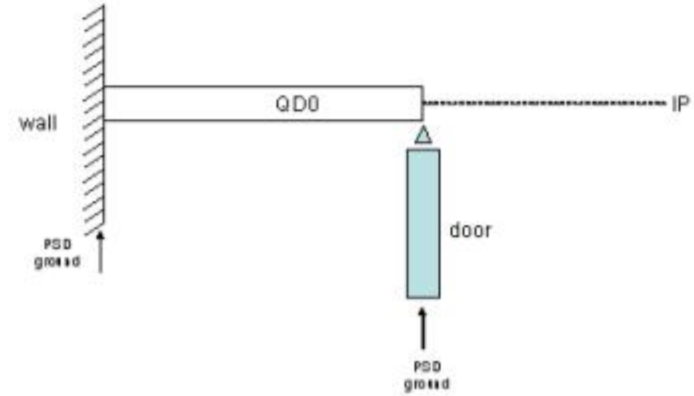
6th Mode, 13.7 Hz

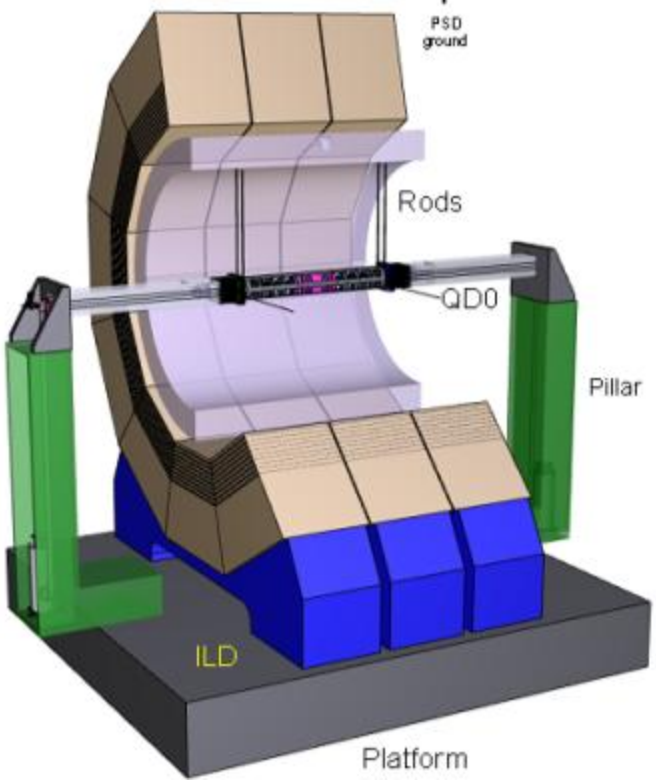
M.Oriunno

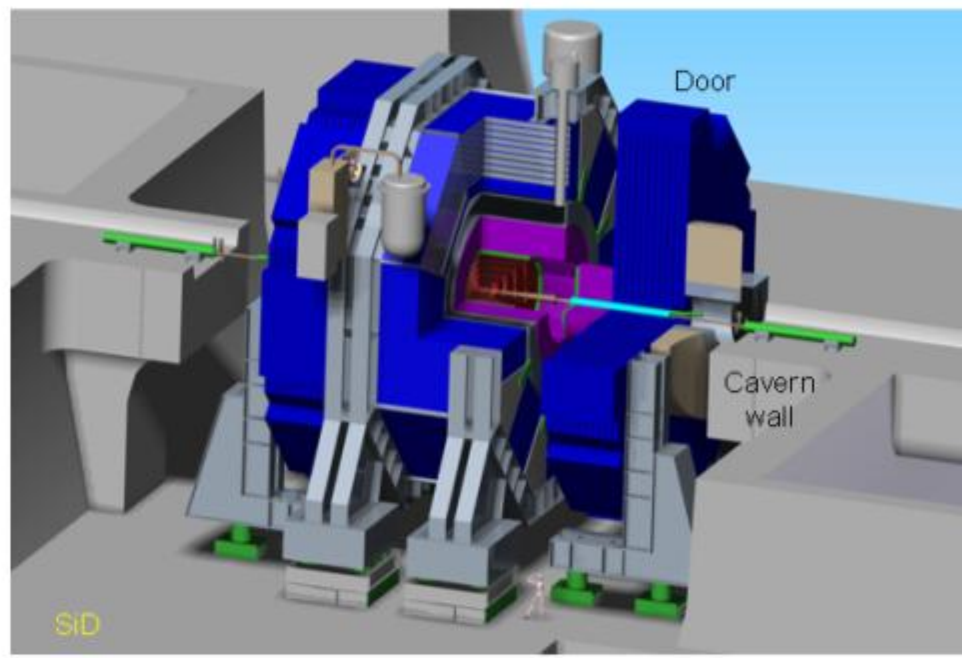
Vertical motion

QD0 supports in ILD and SiD





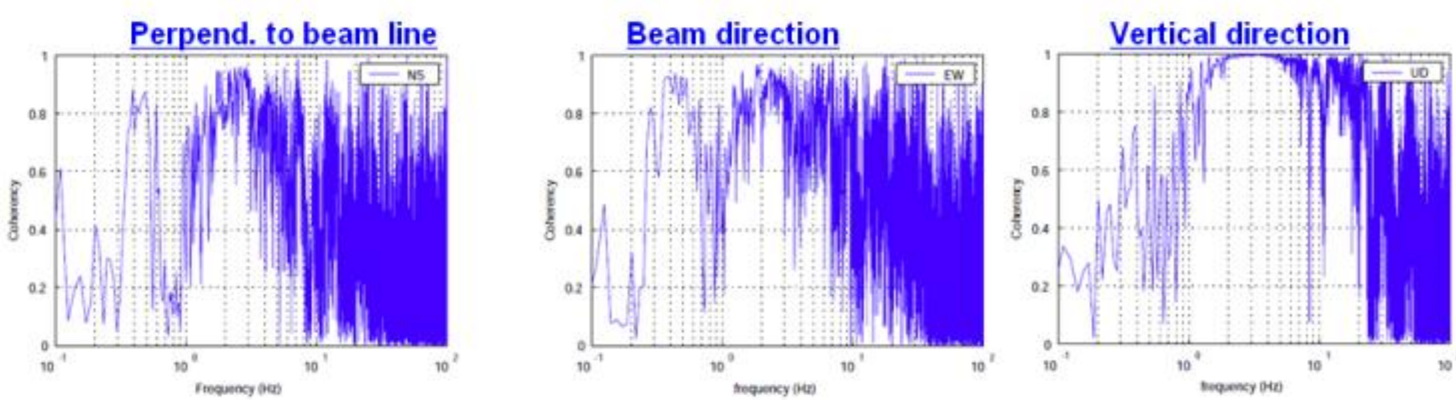


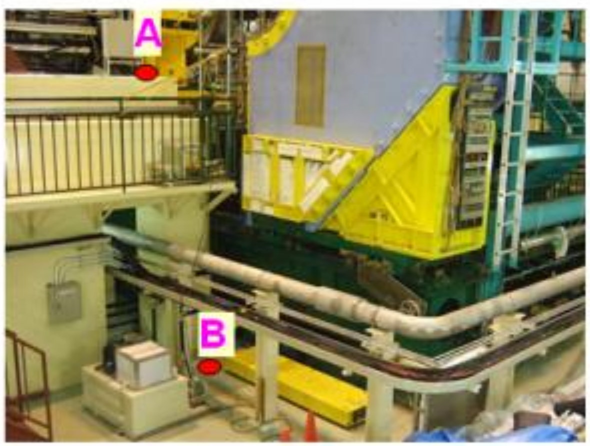


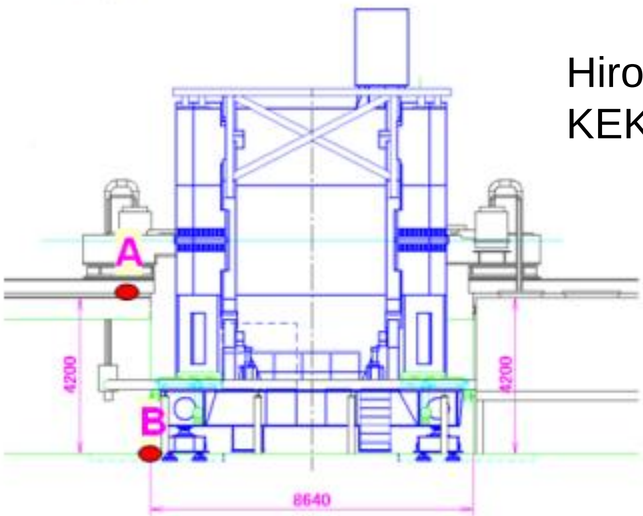
Stability studies at BELLE

Measurement: B

How is the coherency between the tunnel and floor?





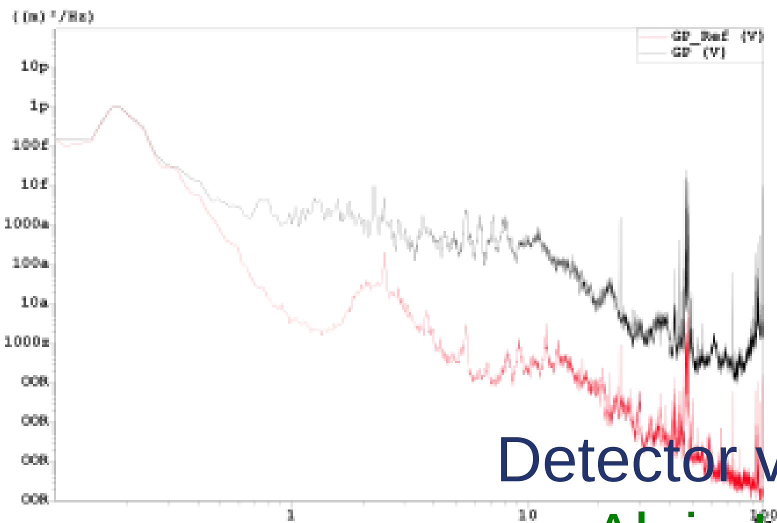


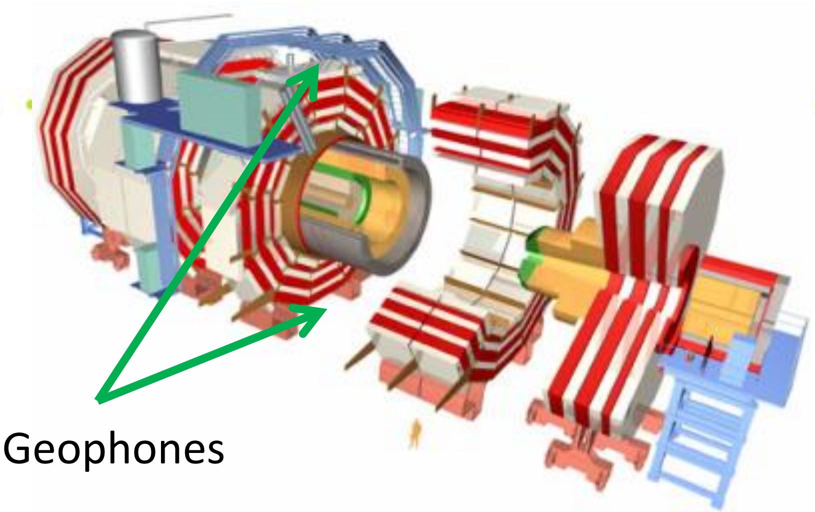
Hiroshi Yamaoka, KEK

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

CMS top of Yoke measurement

PSD of the signals Vertical direction



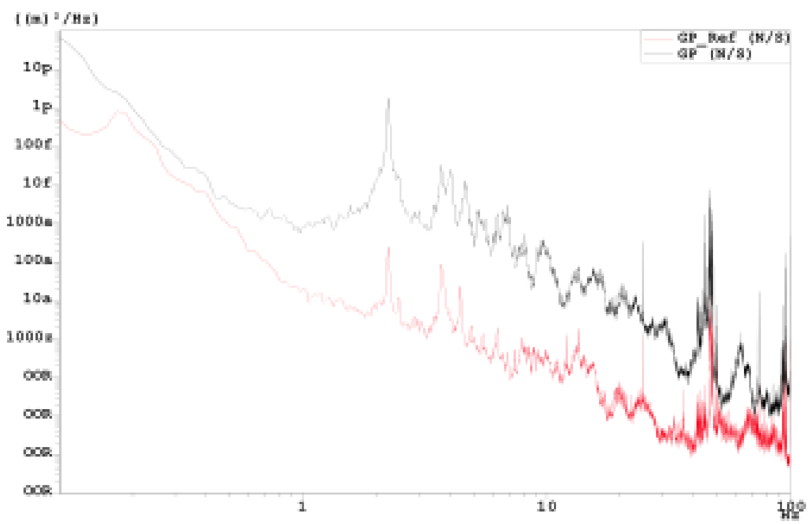


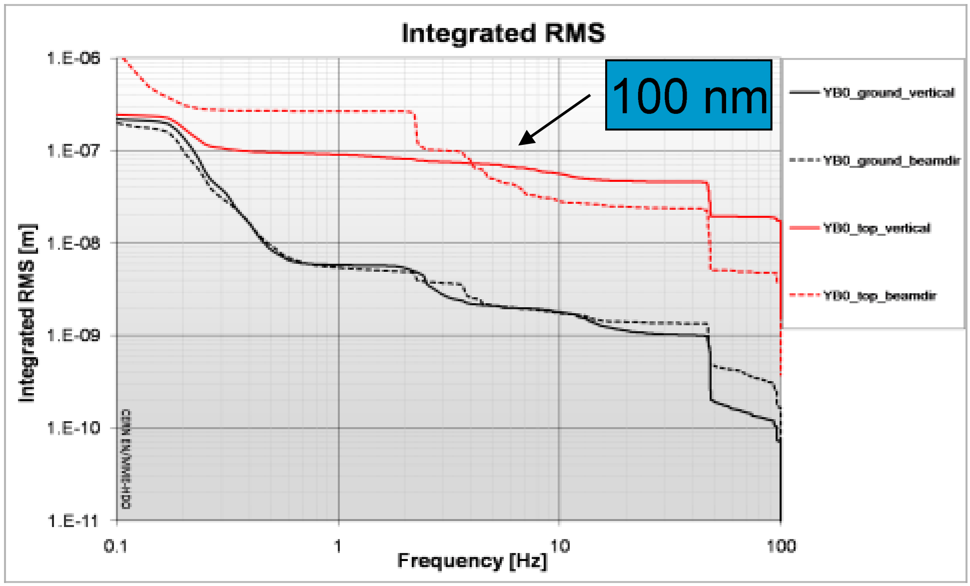
Detector vibrations and QD0 support

Alain Herve (ETH Zurich)

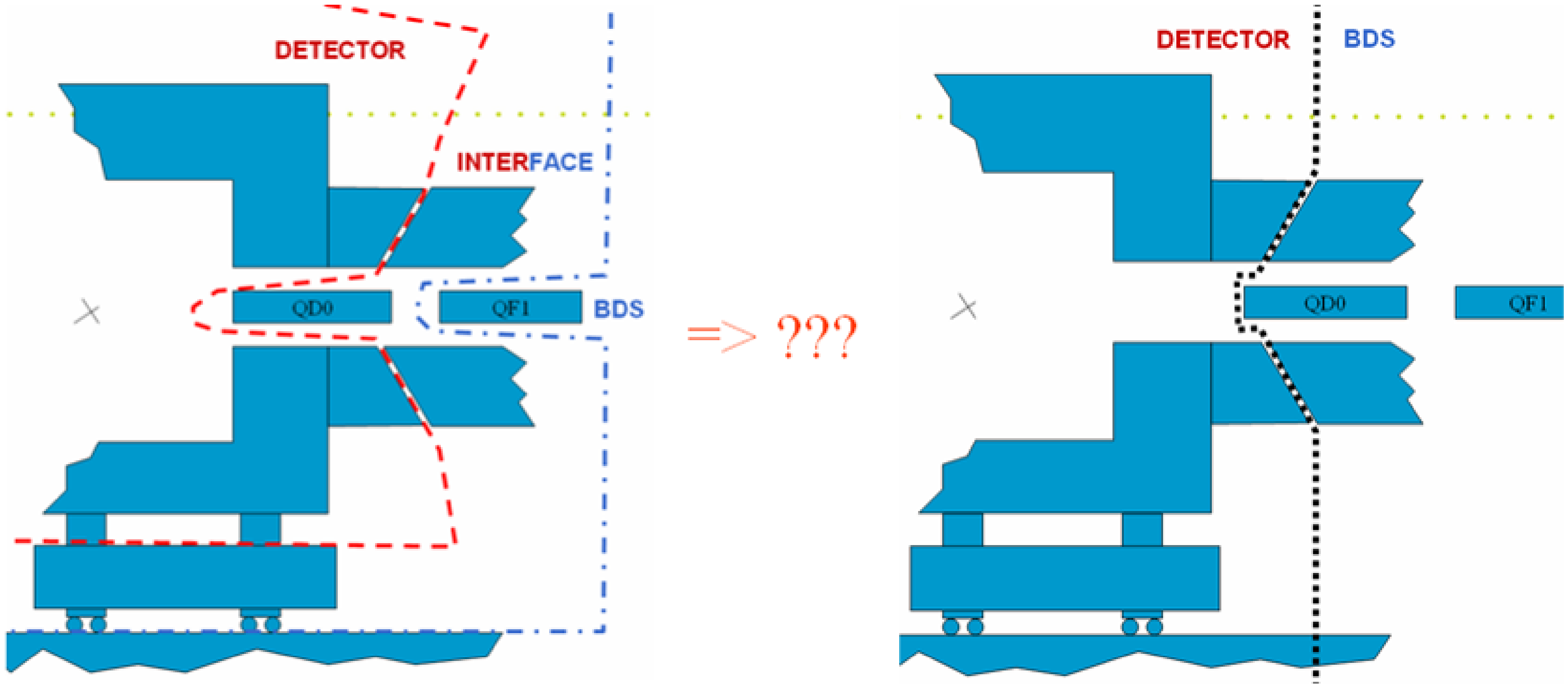
Cooling system OFF

PSD of the signals Beam direction





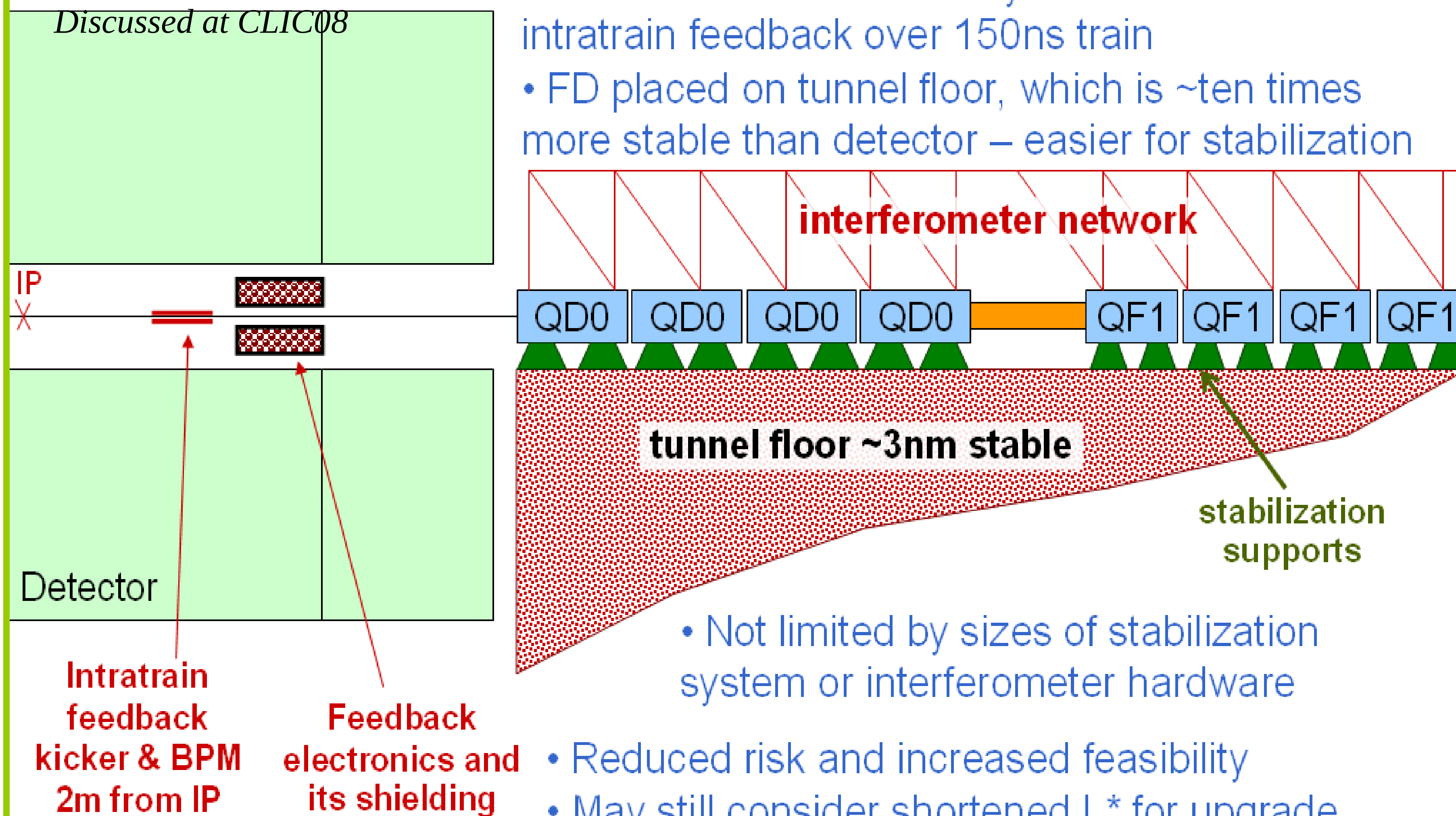
Longer L* → Simplified MDI?



- <u>If</u> doubled L* is <u>feasible and acceptable</u> 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

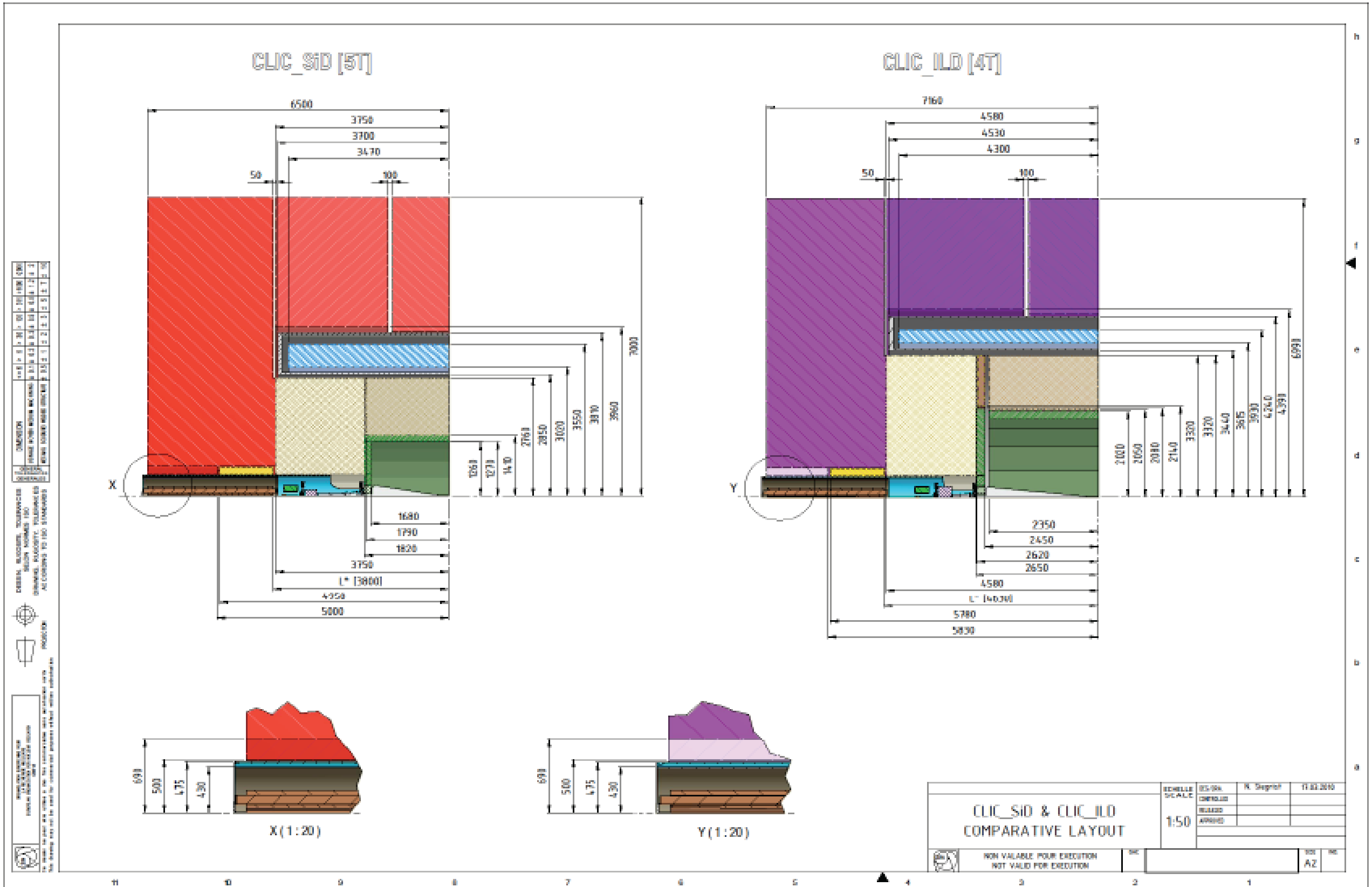
[14] http://clicr.web.cern.ch/CLICr/

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

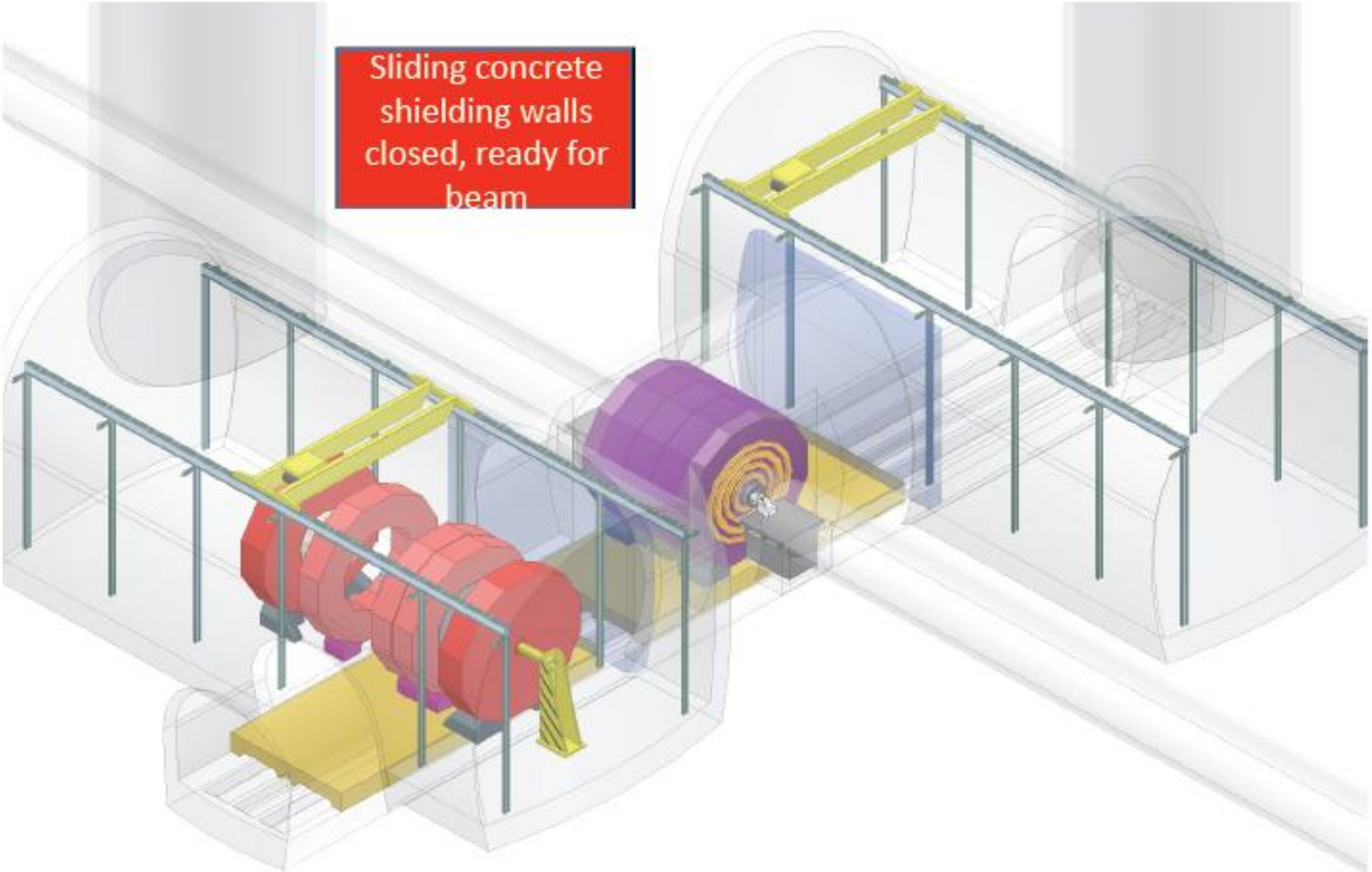
CLIC detector comparison



BDS: 62

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 σ_z*2*3$^{1/2}$

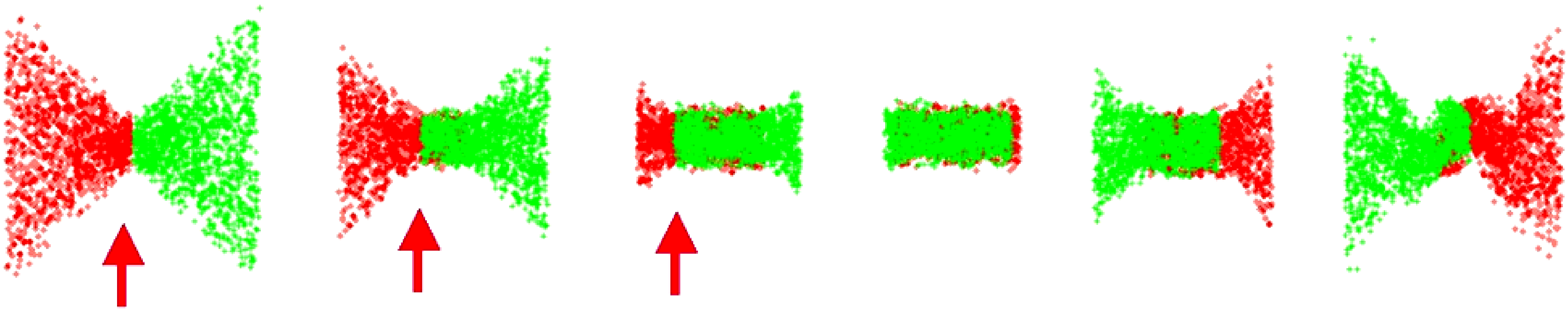
Travelling focus allows to lengthen the bunch

Thus, beamstrahlung energy spread is reduced

Focusing during collision is aided by focusing of the opposite bunch

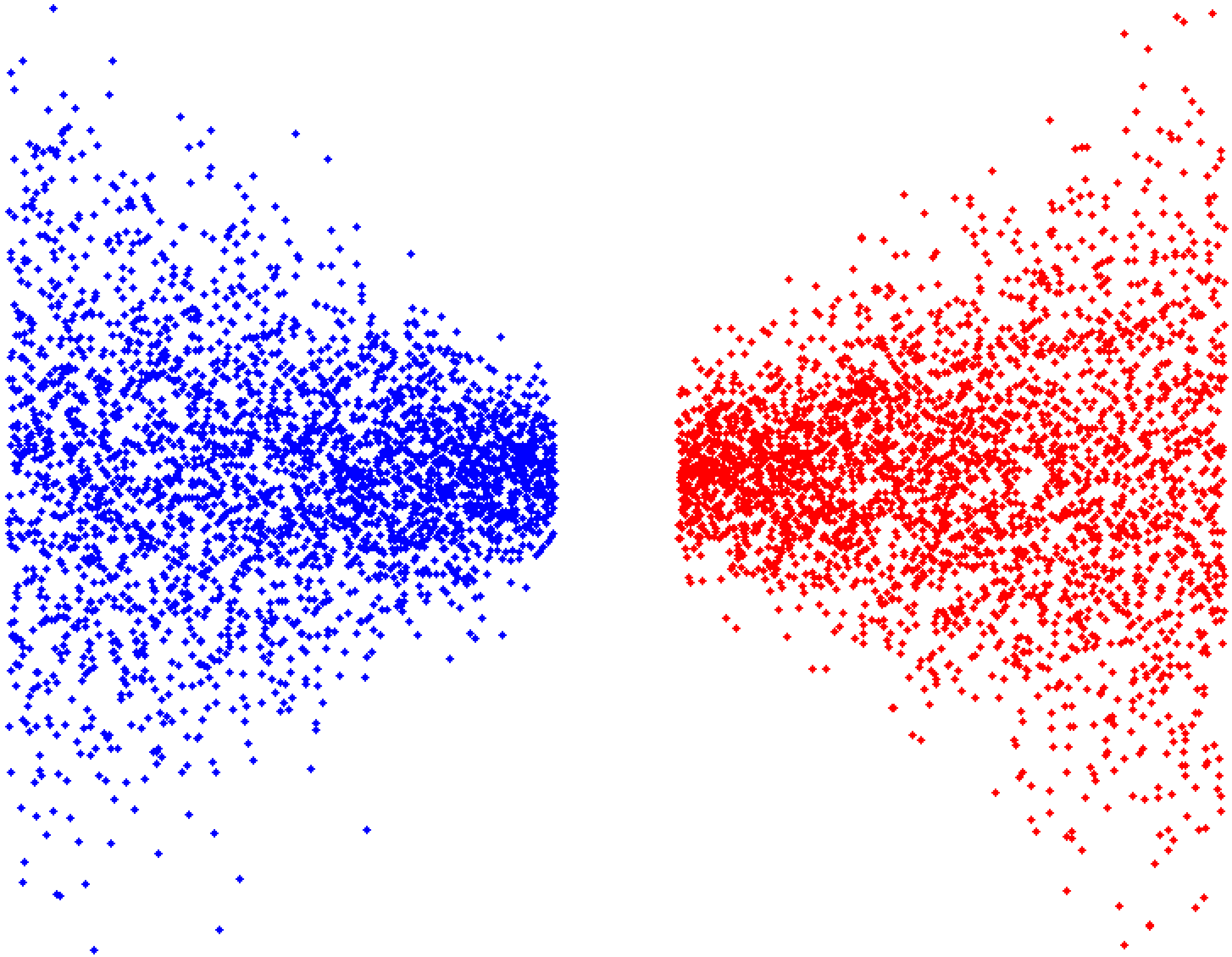
Focal point during collision moves to coincide with the head of the opposite bunch

Beam-beam: Travelling focus

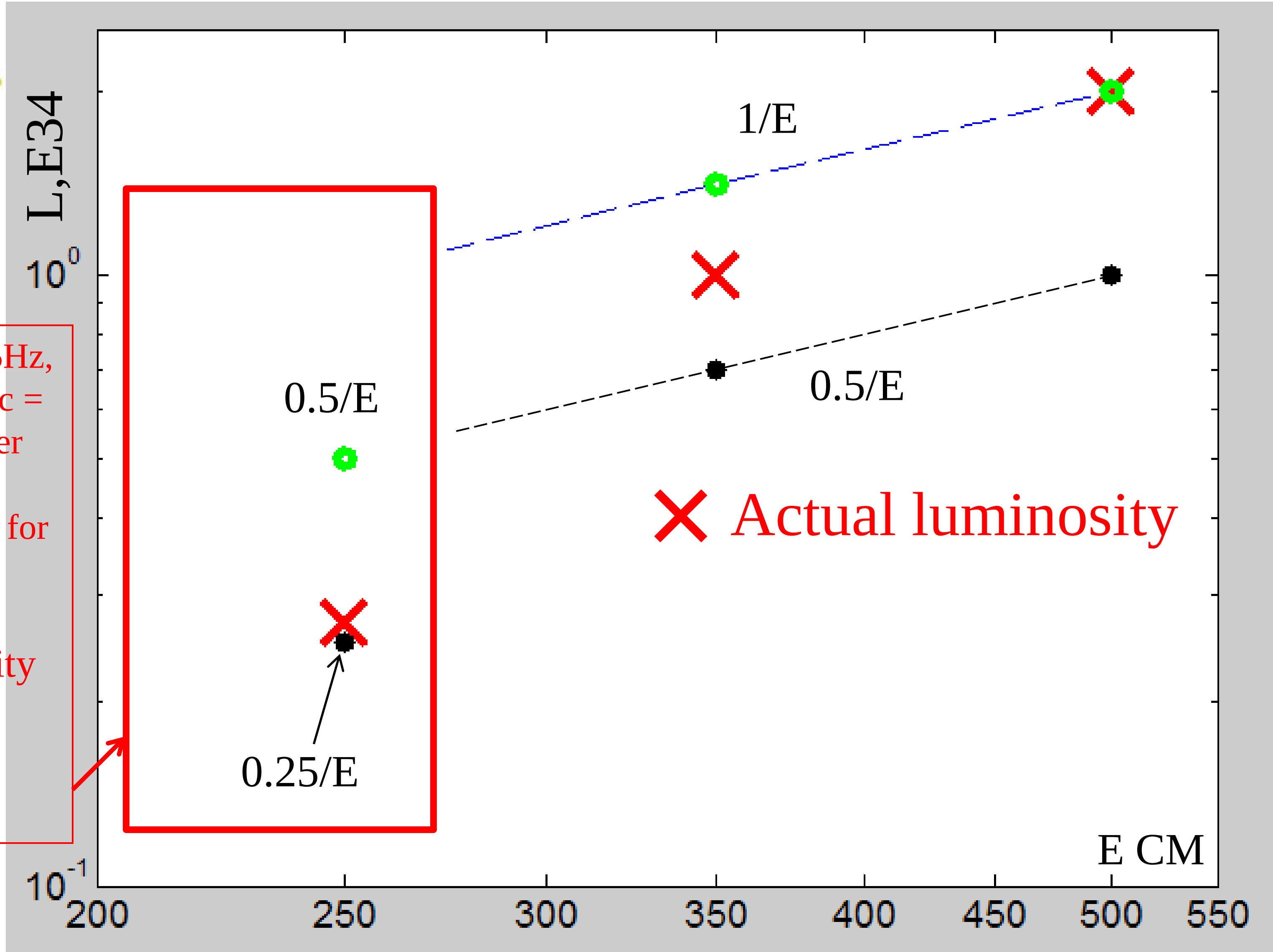


- Suggested by V.Balakin in ~1991 – idea is to use beam-beam forces for additional focusing of the beam – allows some gain of luminosity or overcome somewhat the hour-glass effect
- Figure shows simulation of traveling focus. The arrows show the position of the focus point during collision
- So far not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

Collision with travelling focus



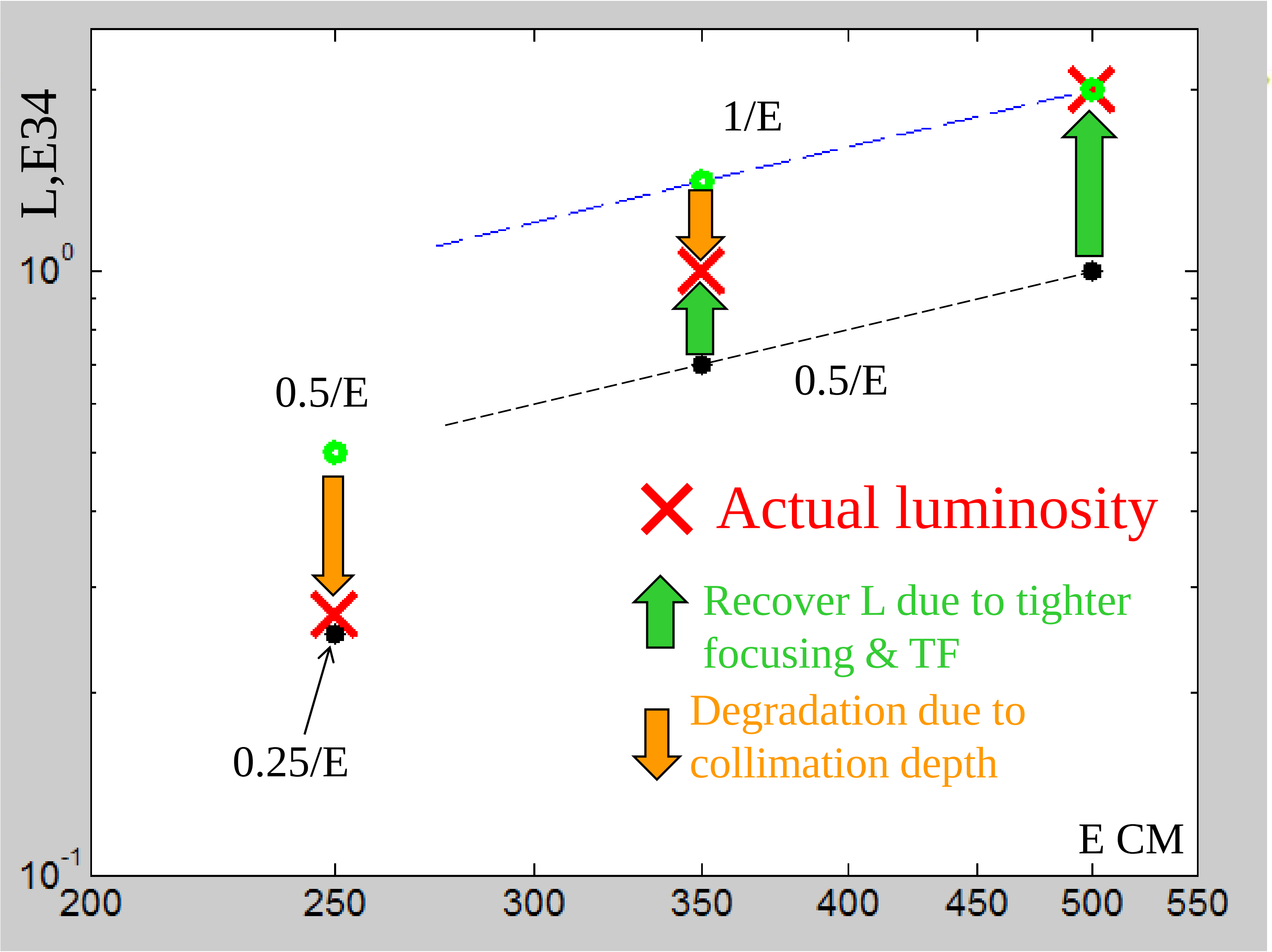
SB2009 Lumi



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
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
E CM
10^0
10^{-1}
200
250
300
350
400
450
500
550

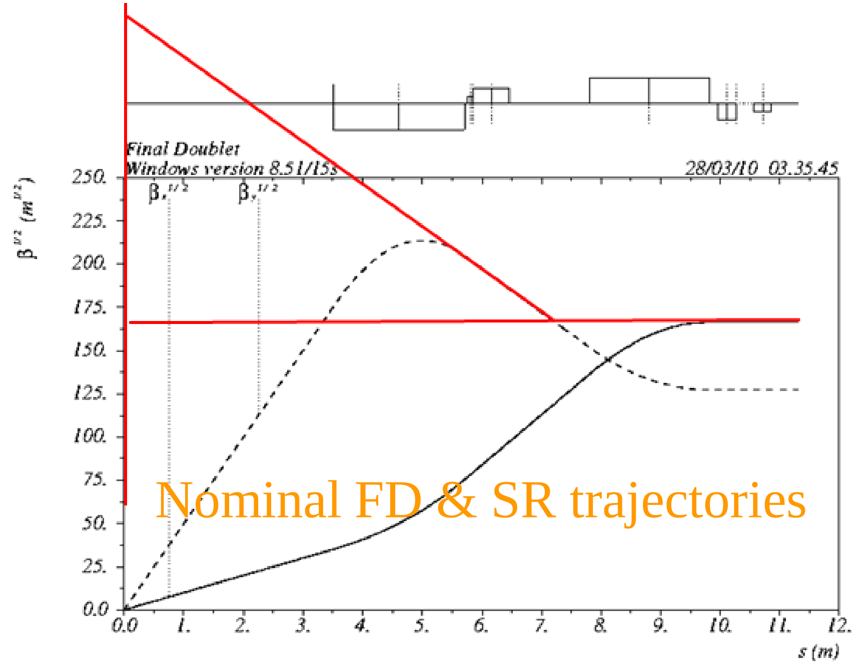
- The travelling focus can be created in two ways.
- The first way is to have small uncompensated chromaticity and coherent E-z energy shift $\delta E/\delta z$ along the bunch. One has to satisfy $\delta E\ k\ L^{*}_{eff} = \sigma_z$ where k is the relative uncompensated chromaticity. The δE needs to 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:

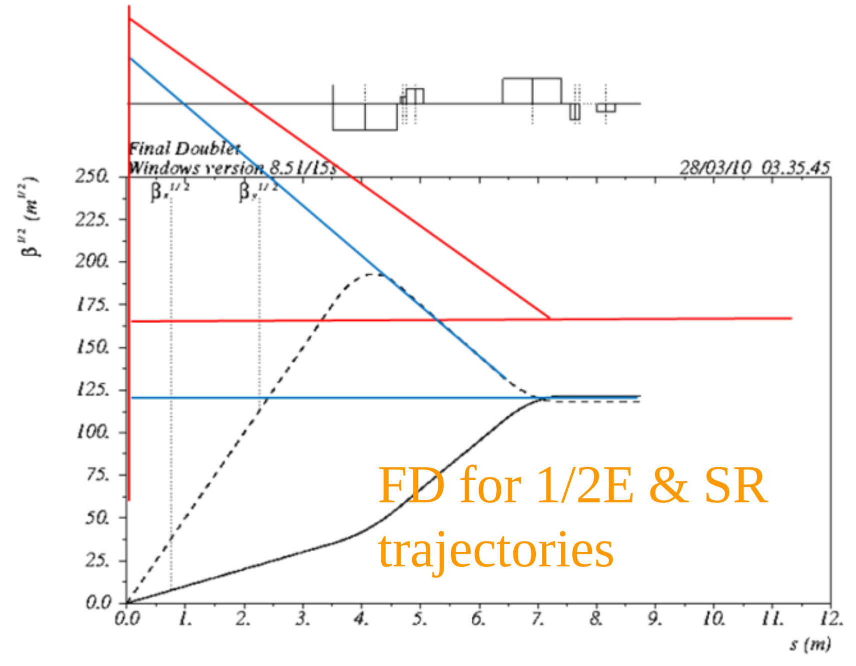
- The second way to create a travelling focus is to use a transverse deflecting cavity giving a z-x correlation in one of the FF sextupoles and thus a z-correlated focusing
- The cavity would be located about 100m upstream of the final doublet, at the $\pi/2$ betatron phase from the FD
- The needed strength 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.

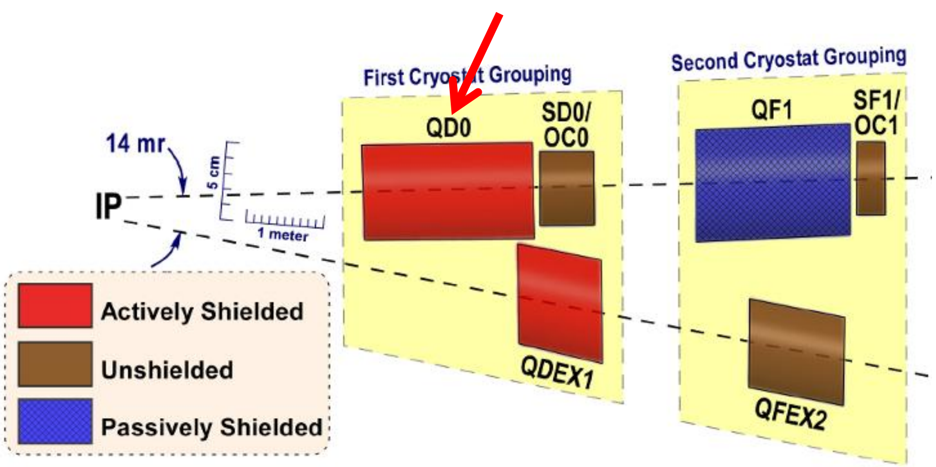
FD for low E

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

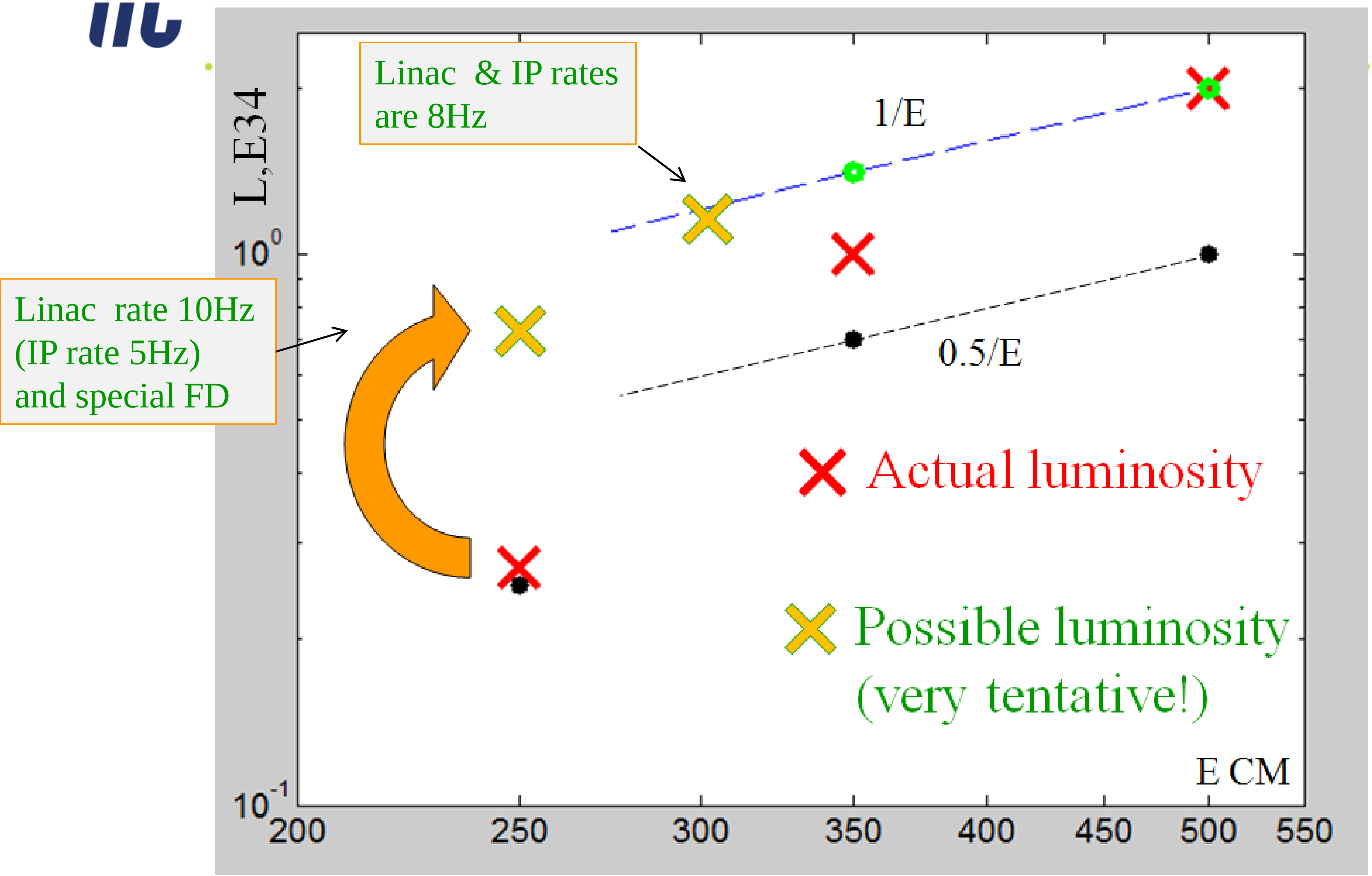
- One option would be to have a separate FD optimized for lower E, and then exchange it before going to nominal E
- Other option to be studied is to build a universal FD, that can be reconfigured for lower E configuration (may require splitting QD0 coil and placing sextupoles in the middle)



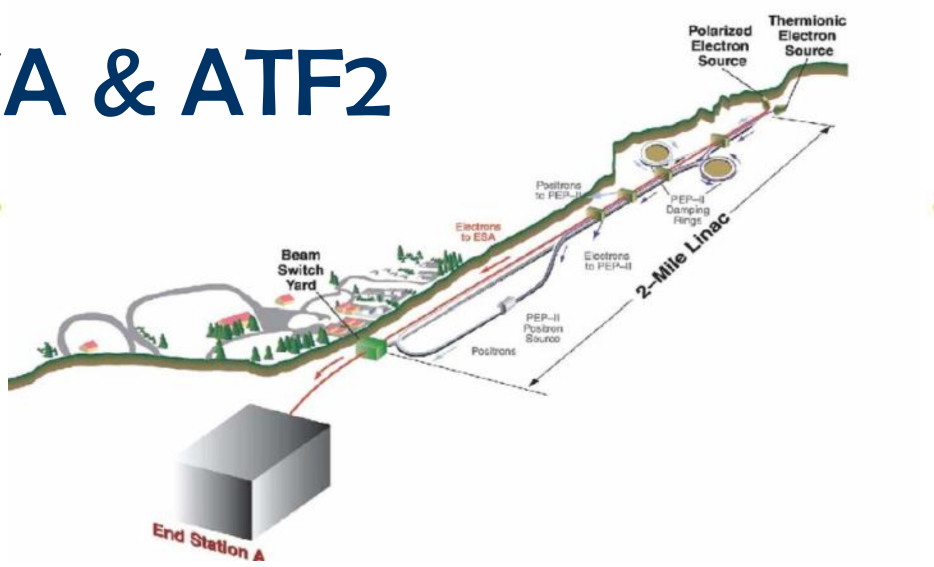




SB2009 Lumi

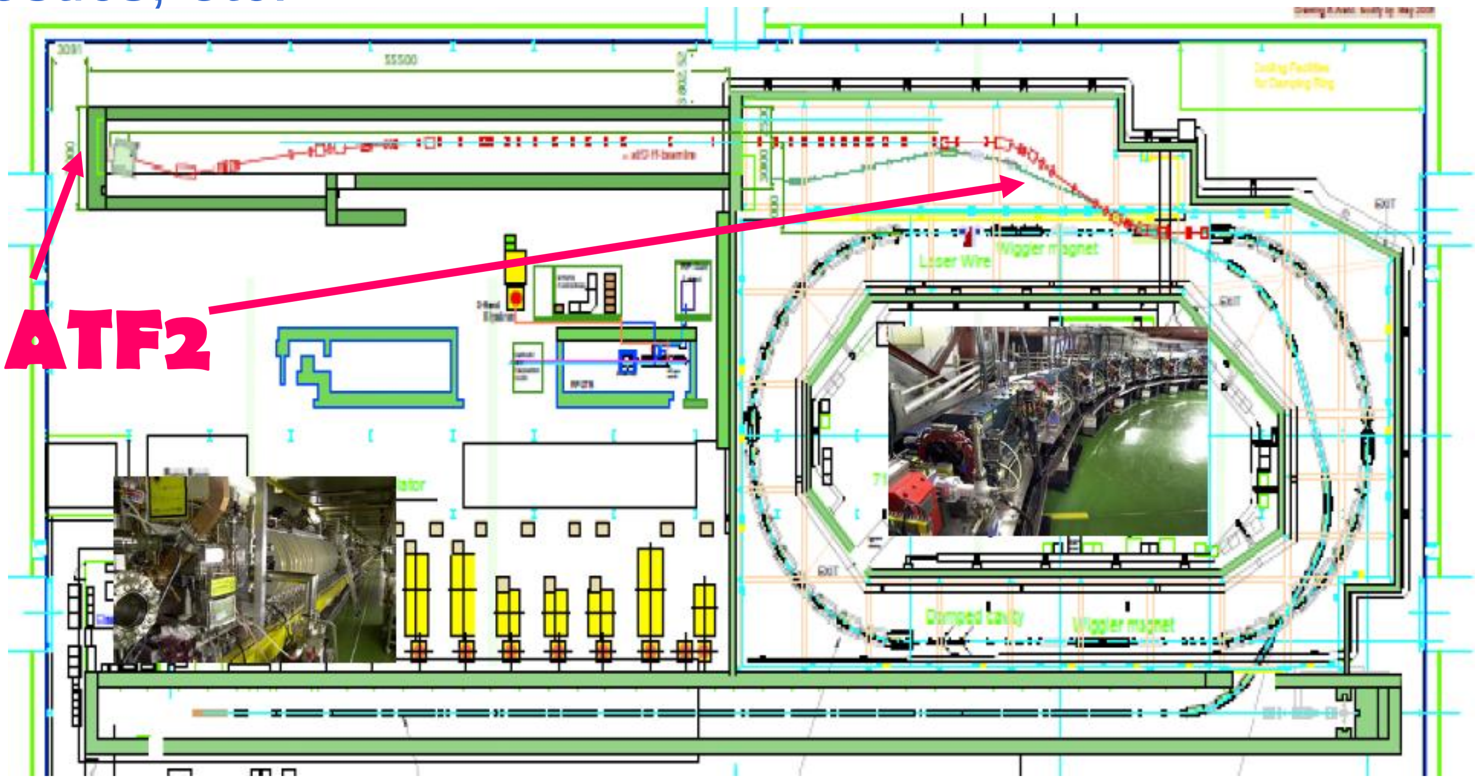

Linac & IP rates
are 8Hz
1/E
0.5/E
Linac rate 10Hz
(IP rate 5Hz)
and special FD
Actual luminosity
Possible luminosity
(very tentative!)
L, E34
10^0
10^{-1}
E CM
200
250
300
350
400
450
500
550

Test facilities: ESA & ATF2

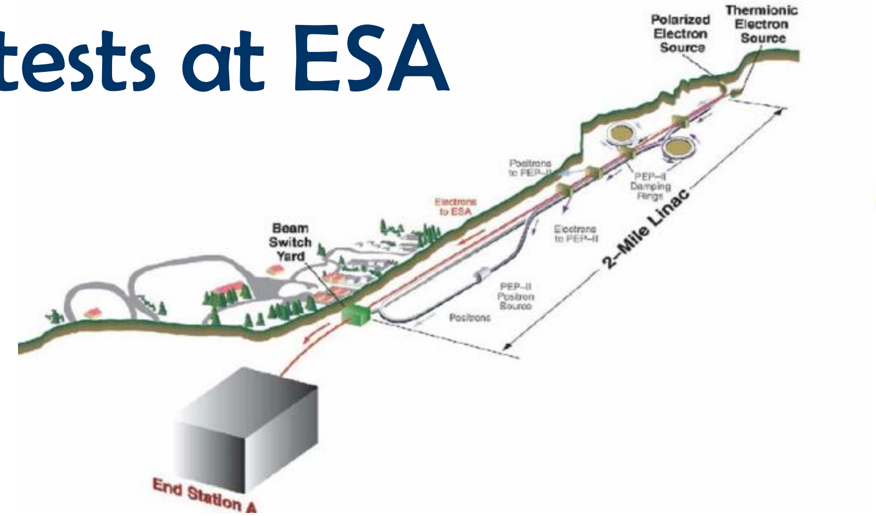


ESA: machine-detector tests; energy spectrometer; collimator wake-fields, etc.

ATF2: prototype FF, develop tuning, diagnostics, etc.



BDS beam tests at ESA



Study:

BPM energy spectrometer

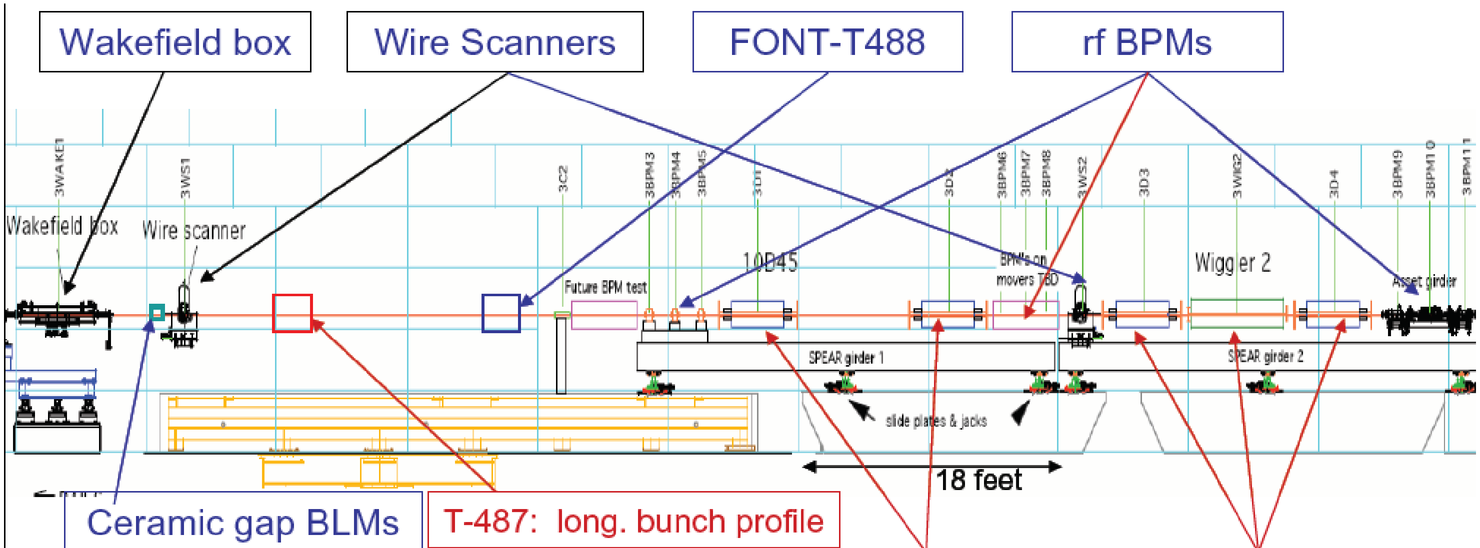
Synch Stripe energy spectrometer

Collimator design, wakefields

IP BPMs/kickers—background studies

EMI (electro-magnetic interference)

Bunch length diagnostics



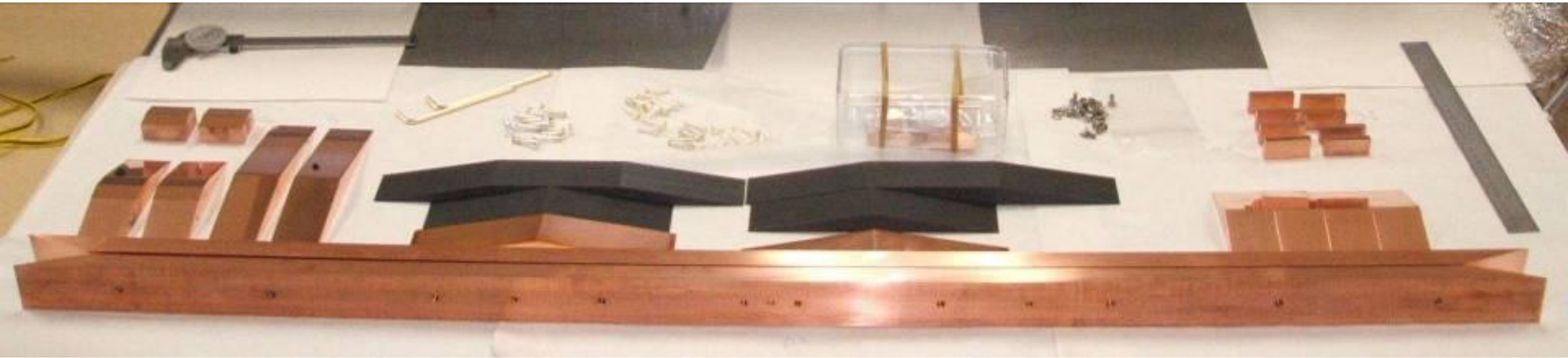
Upstream (not shown)

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

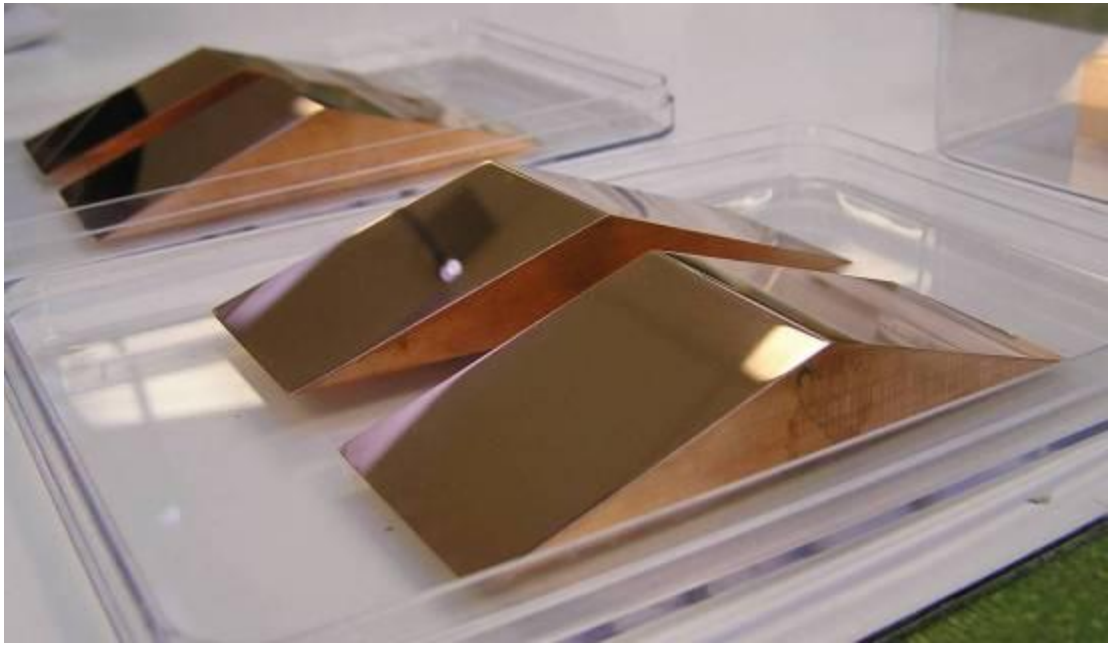
Downstream (not shown)

Ceramic gap for EMI studies
T475 Detector for Wiggler SR stripe

Collimator Wakefield study at ESA



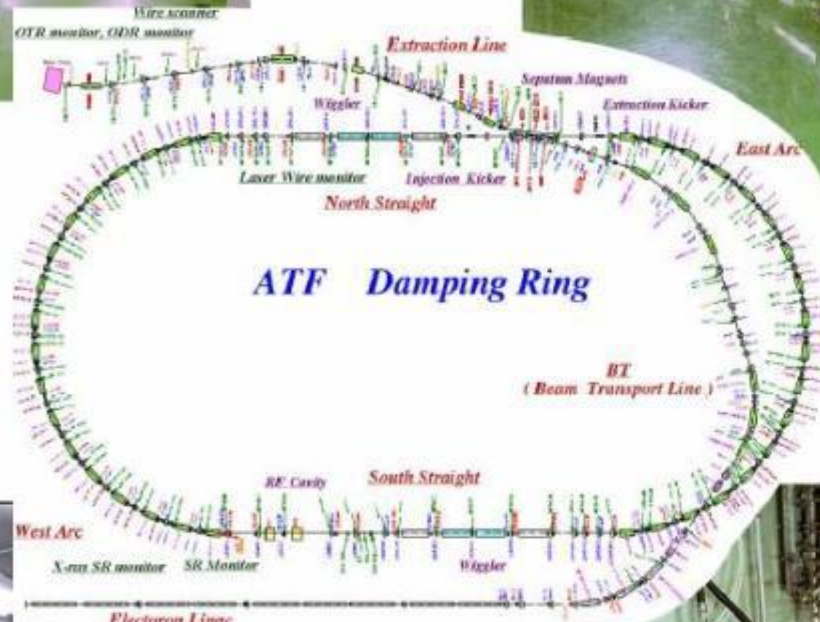
- Spoilers of different shape investigated at ESA (N.Watson et al)
- Theory, 3d modeling and measurements are so far within a factor of ~2 agreement



ATF and ATF2

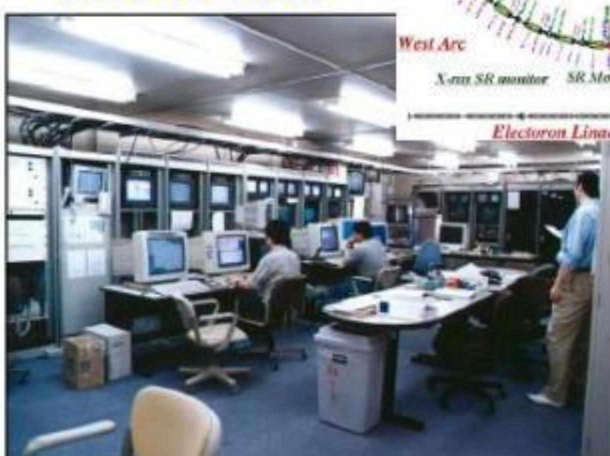
Extraction Line

Damping Ring



Linac

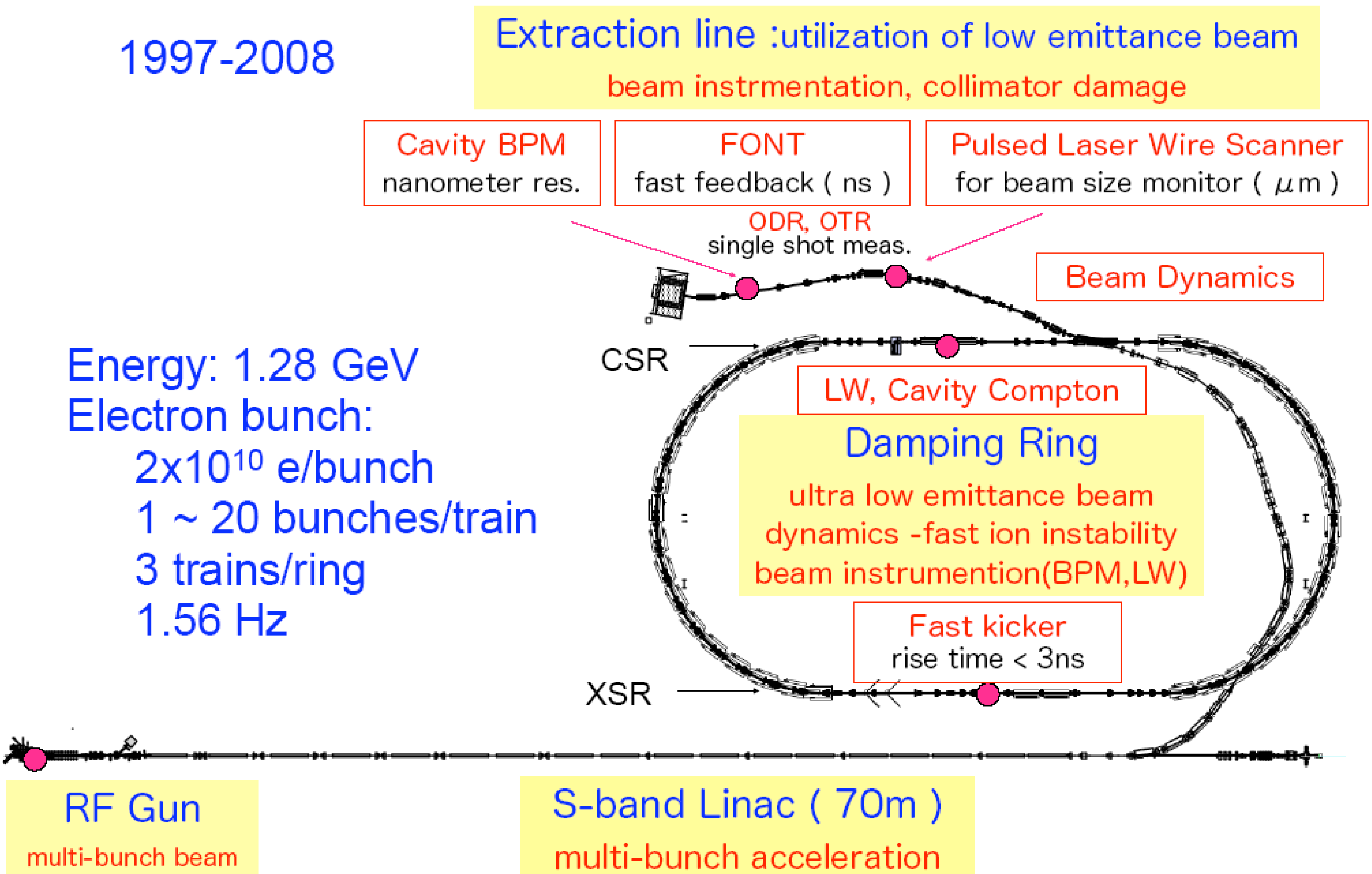
Control Room

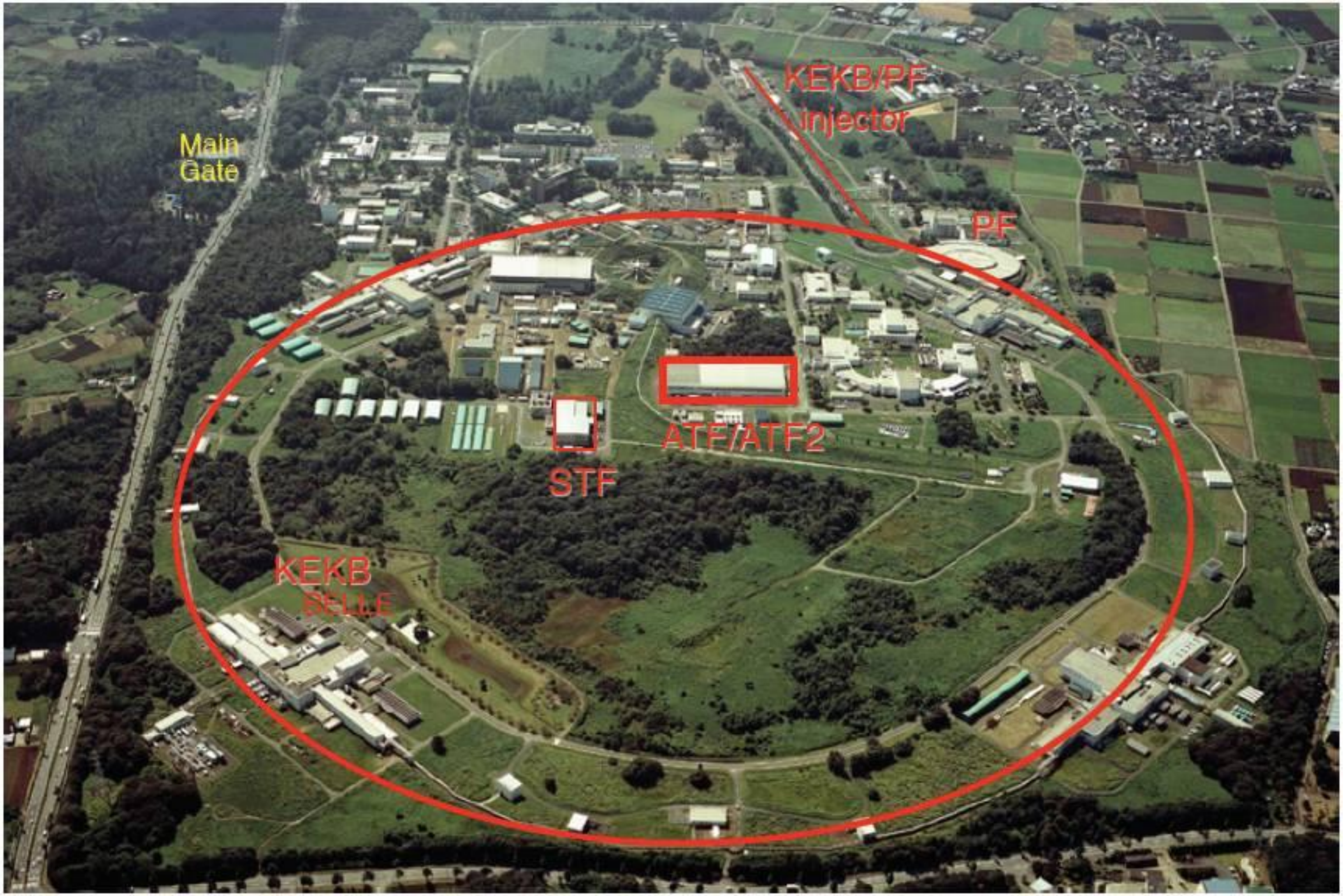


Accelerator Test Facility, KEK

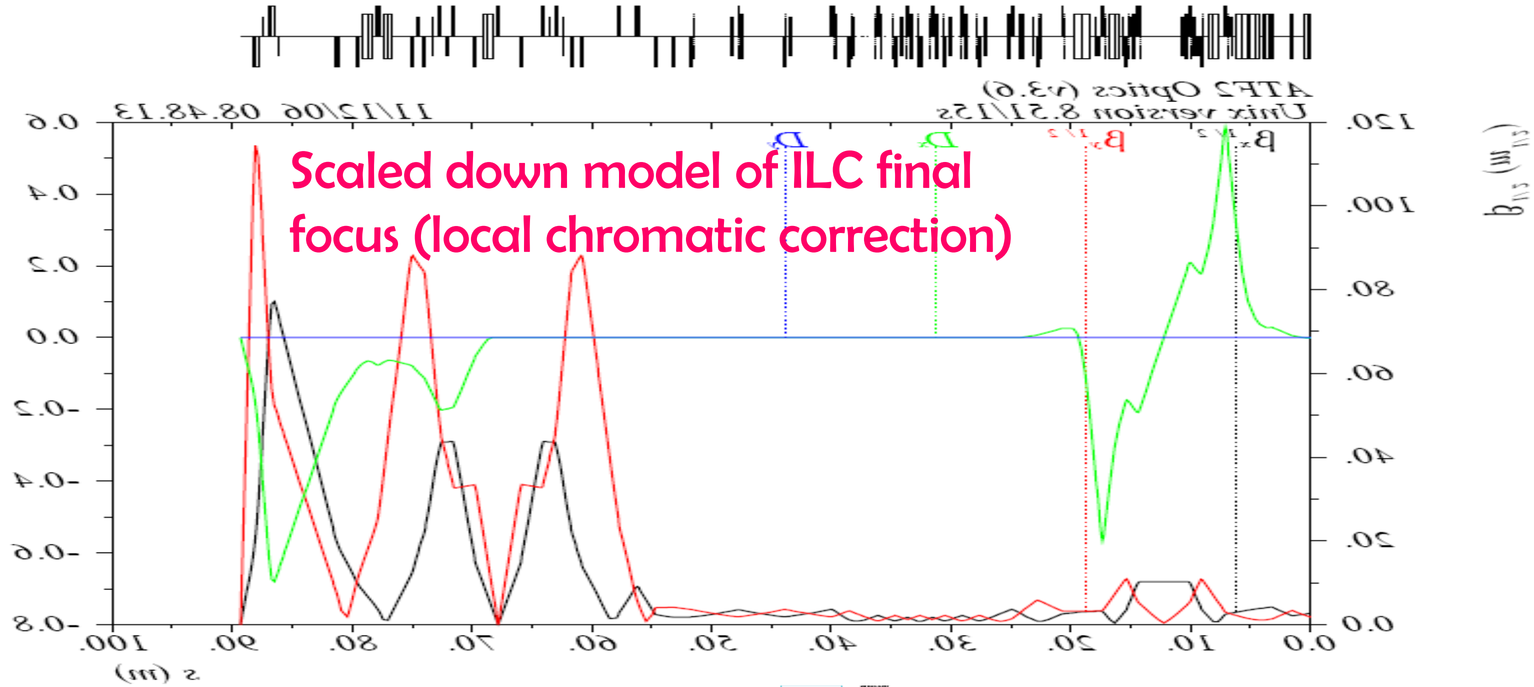
1997-2008

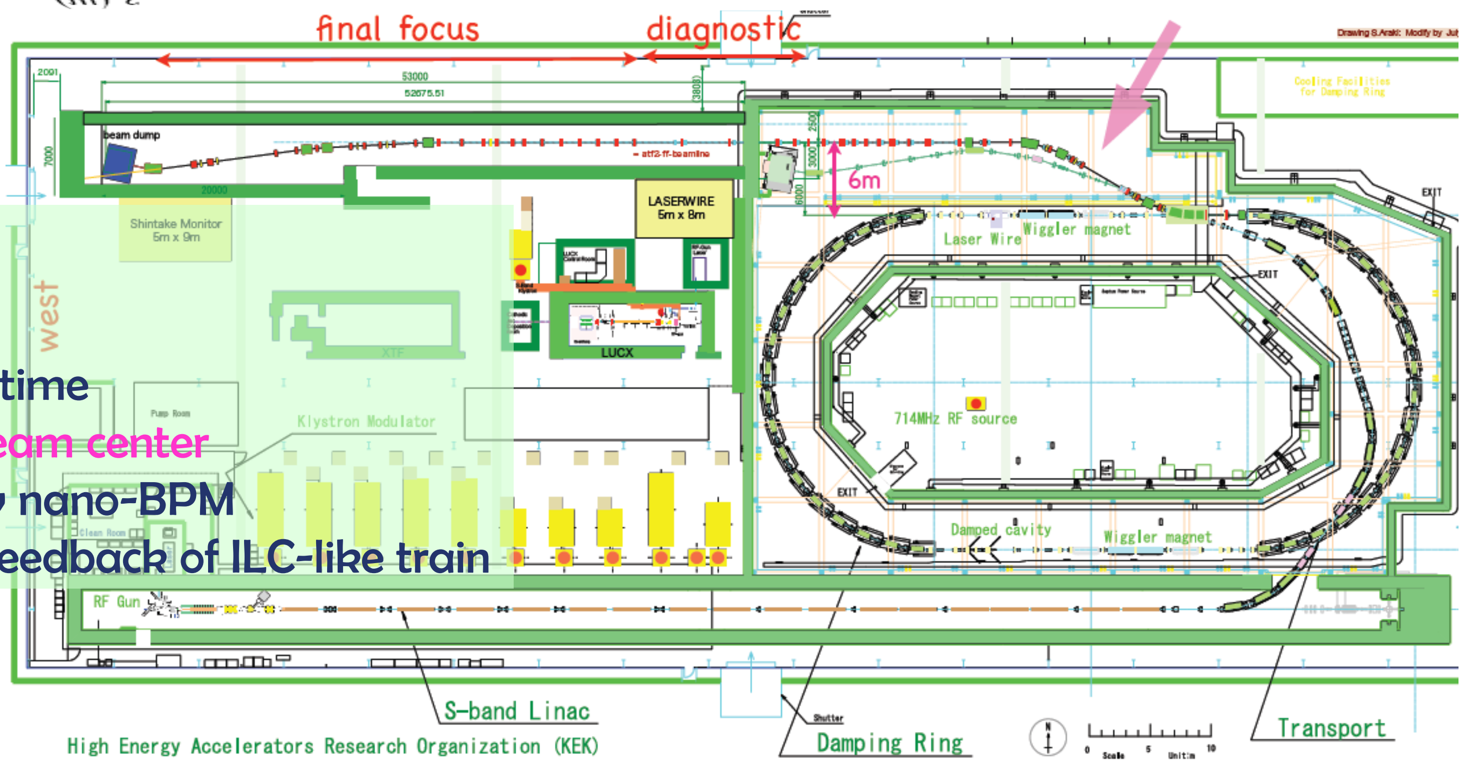
Energy: 1.28 GeV
Electron bunch:
- 2×10^{10} e/bunch
- 1 ~ 20 bunches/train
- 3 trains/ring
- 1.56 Hz




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

ATF2 – model of ILC BDS





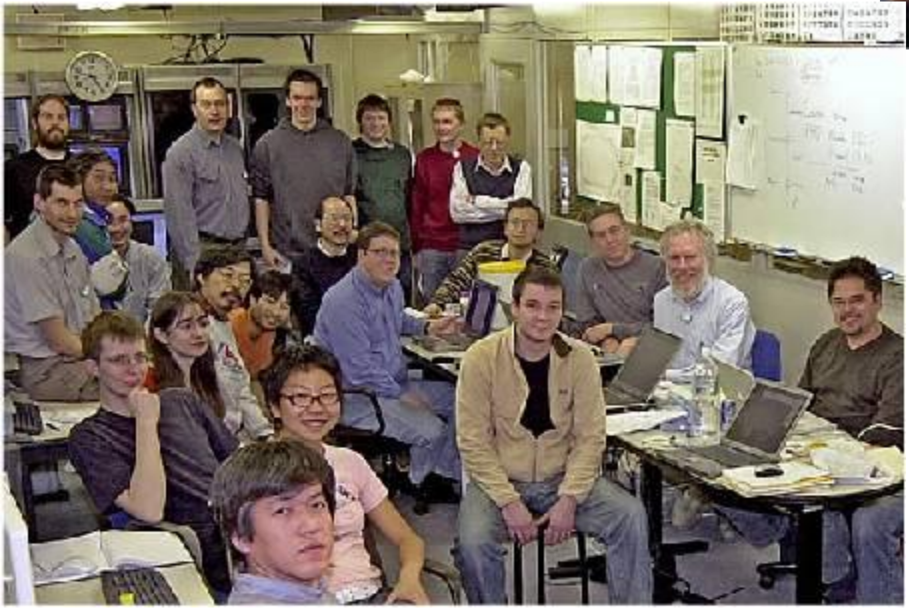
ATF2 goals

(A) Small beam size
  Obtain σ_y ~ 35nm
  Maintain for long time

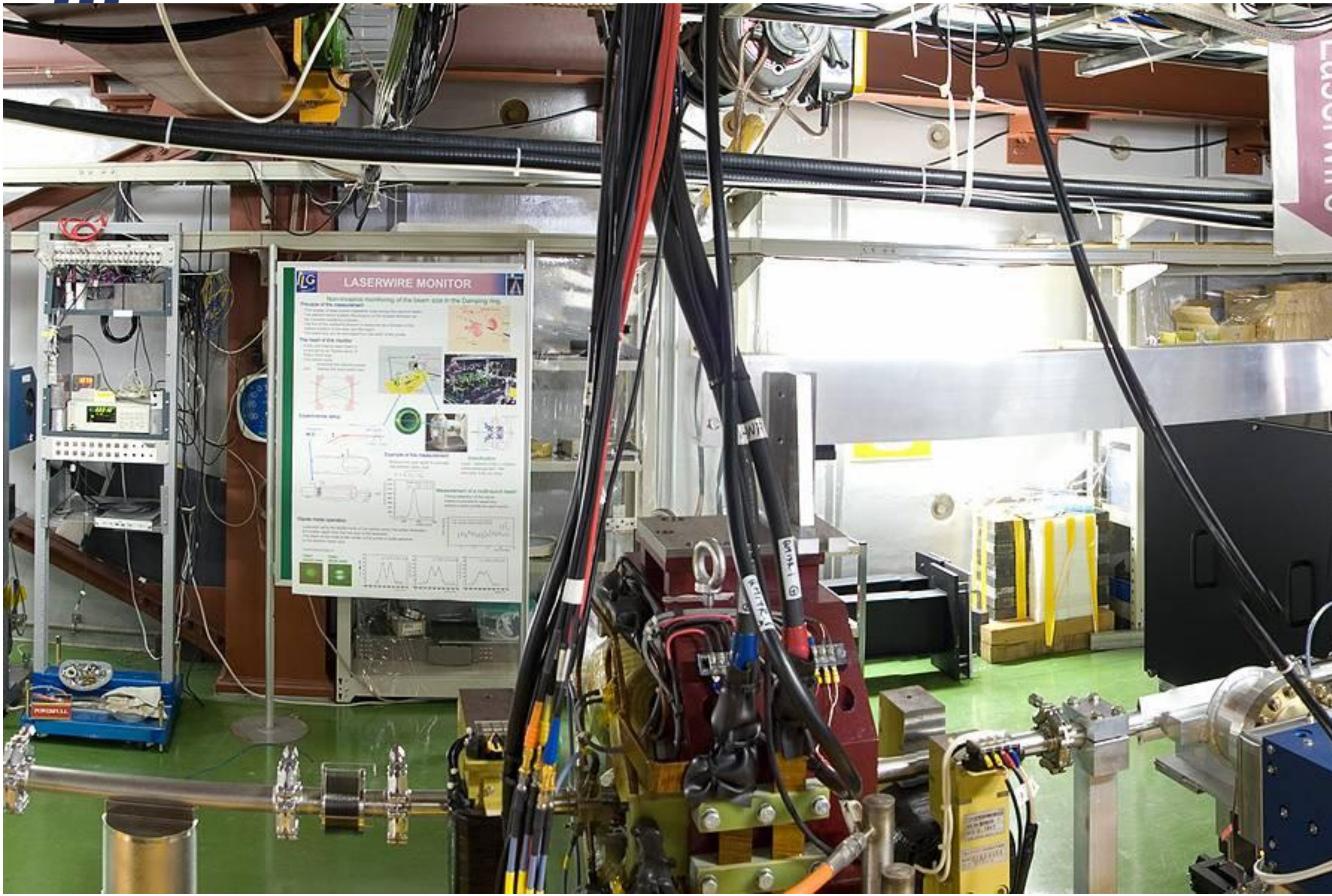
(B) Stabilization of beam center
  Down to < 2nm by nano-BPM
  Bunch-to-bunch feedback of ILC-like train

ATF collaboration & ATF2 facility

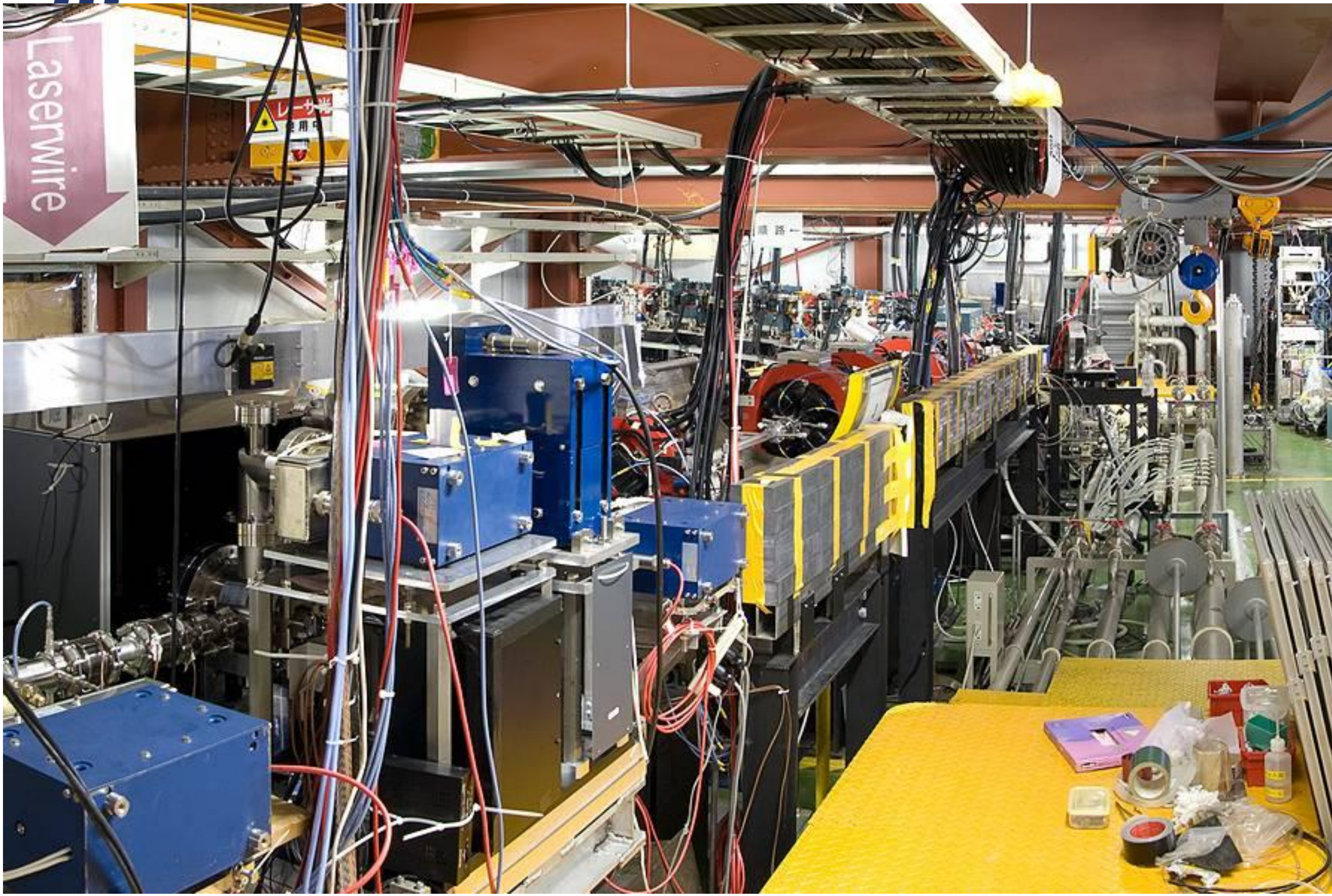
- ATF2 will prototype FF,
- help development tuning methods, instrumentation (laser wires, fast feedback, submicron resolution BPMs),
- help to learn achieving small size & stability reliably,
- potentially able to test stability of FD magnetic center.



- 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

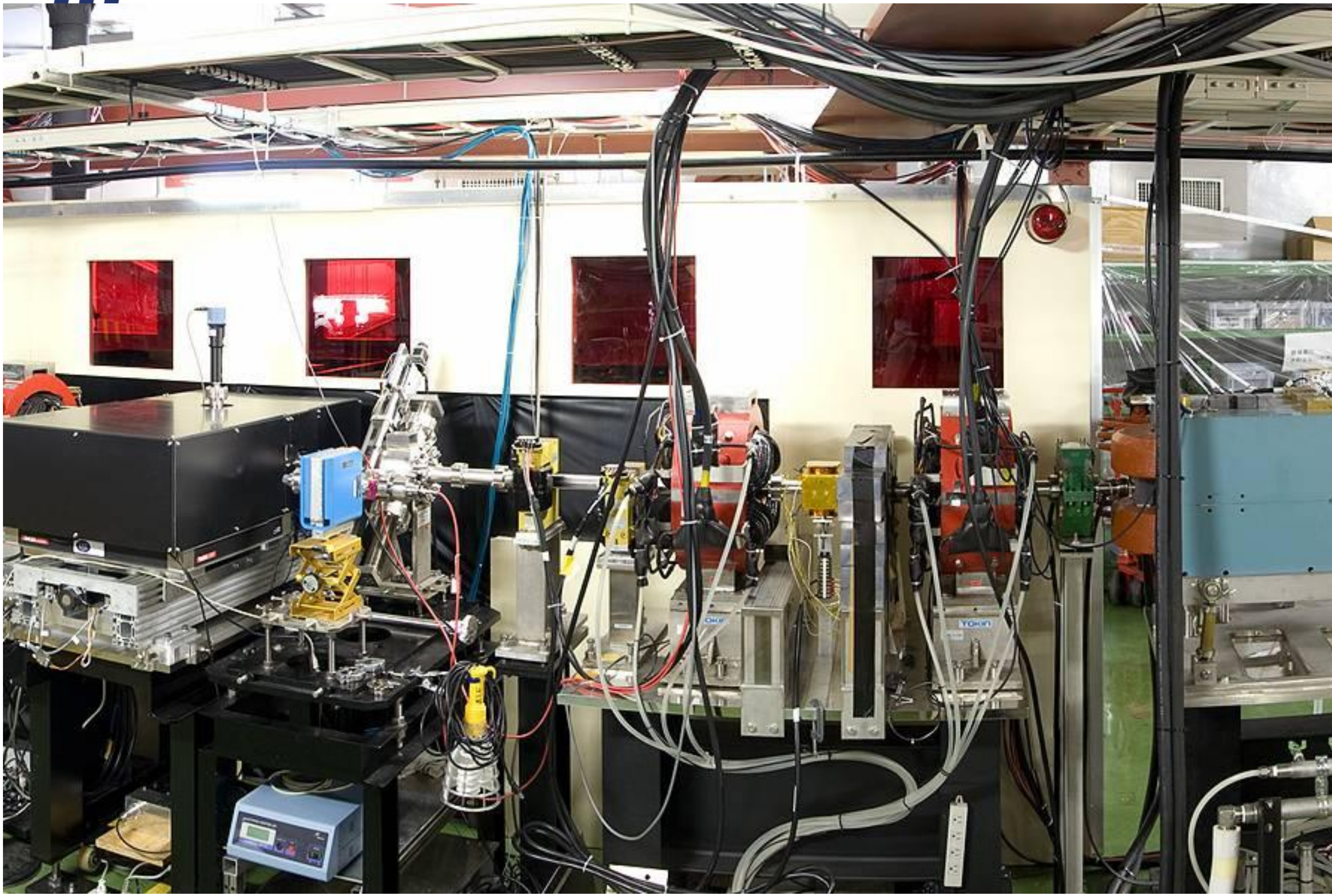


Panoramic photo of ATF beamlines, N.Toge

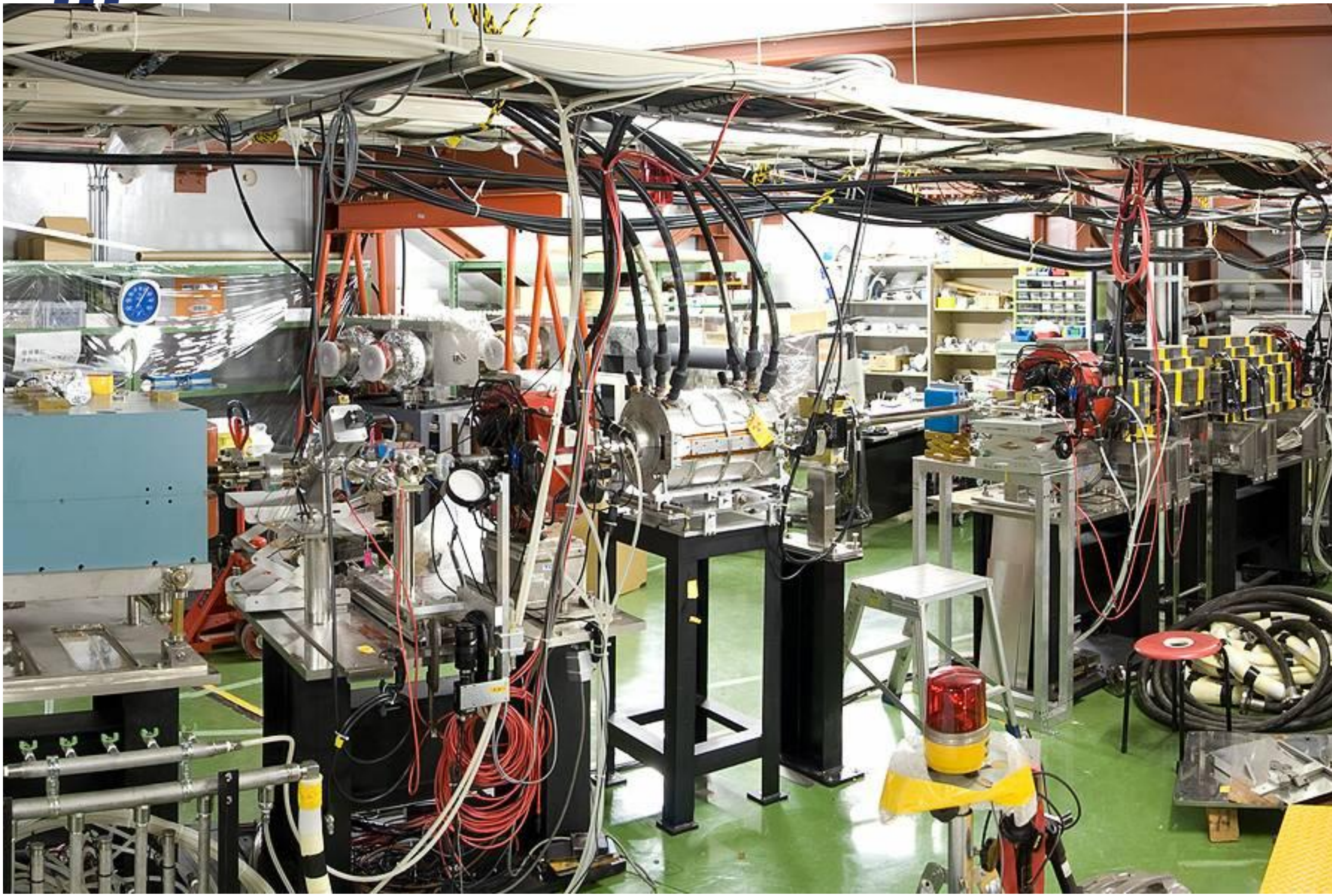


Panoramic photo of ATF beamlines, N.Toge

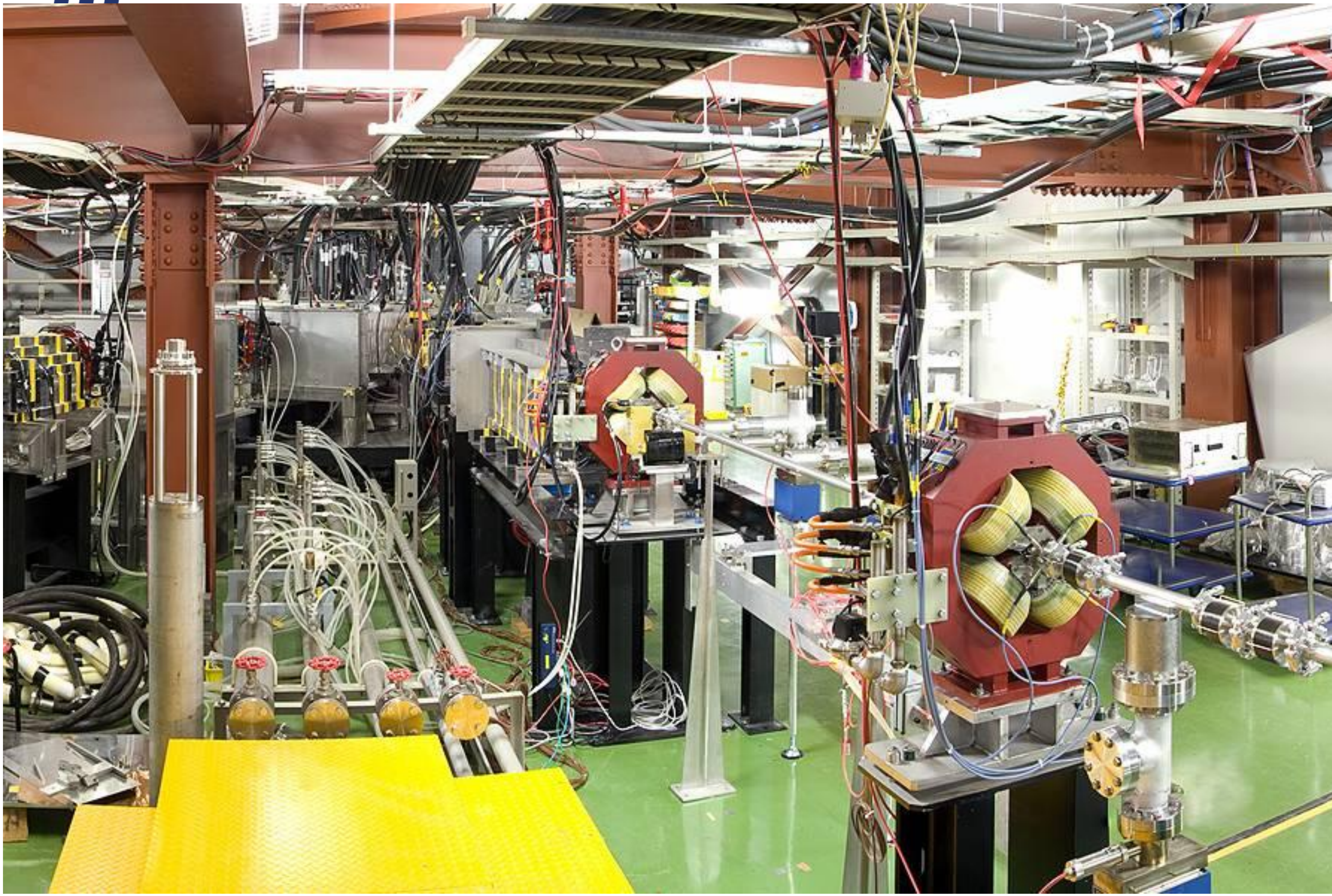
Panoramic photo of ATF beamlines, N.Toge



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

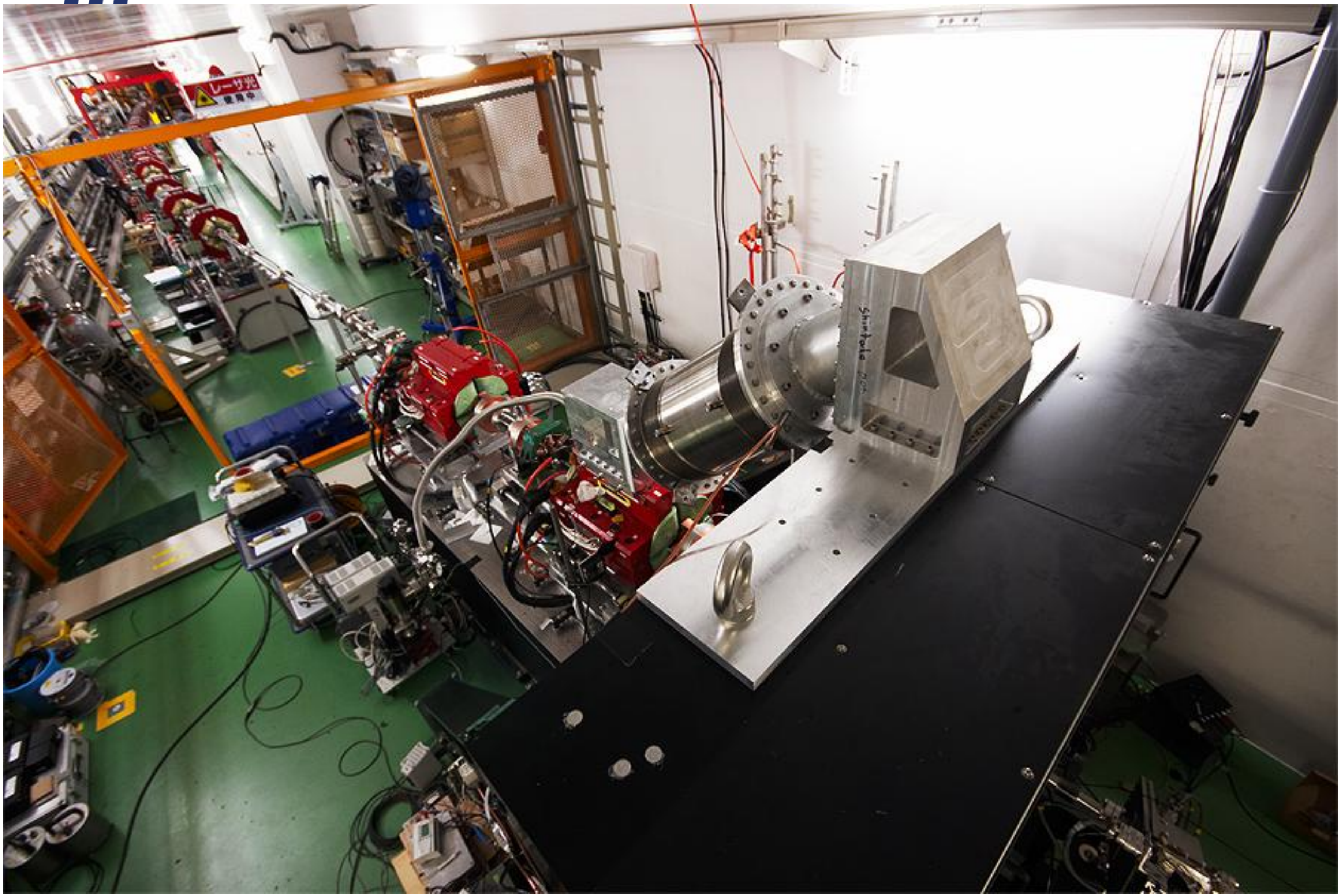
Photos from ATF2 construction, N.Toge

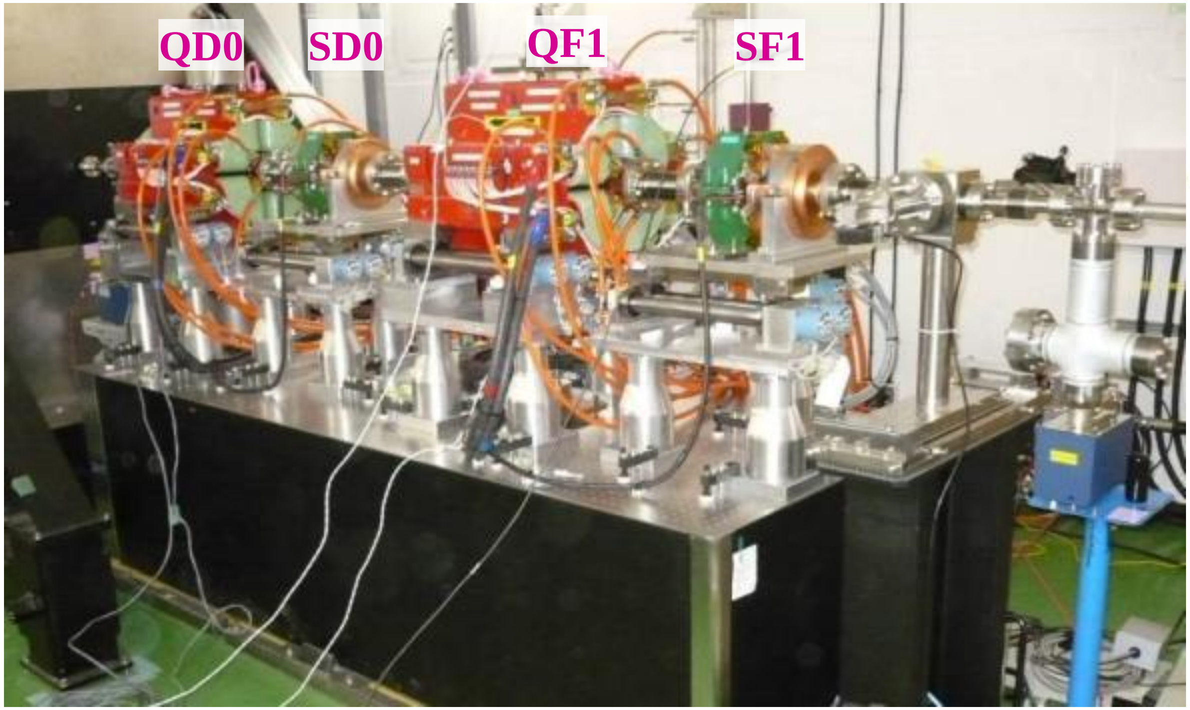
Building the reinforced floor

Photos from ATF2 construction, N.Toge

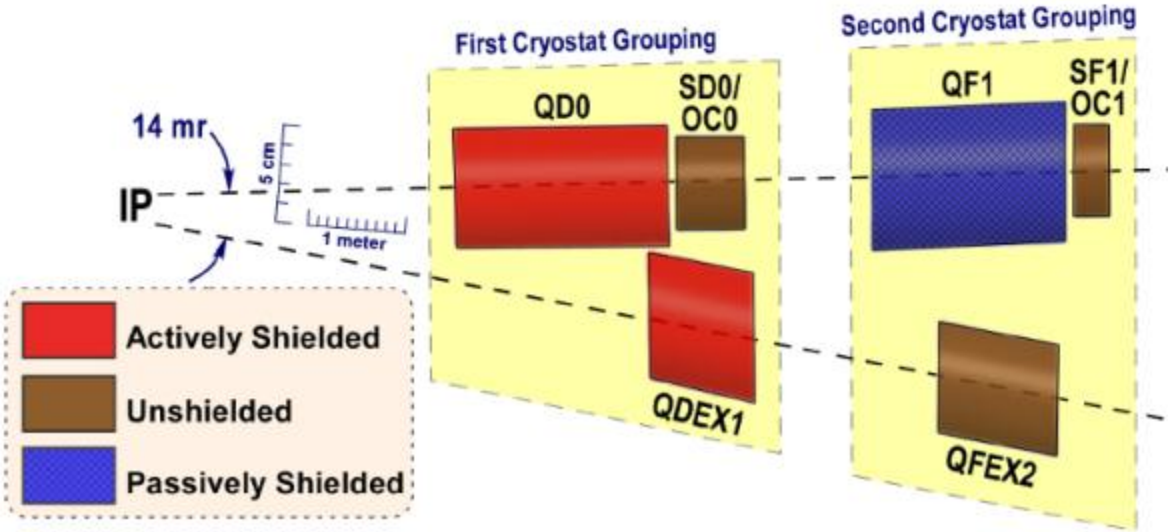
Finished reinforced floor for ATF2

Photos from ATF2 construction, N.Toge


レーザ光



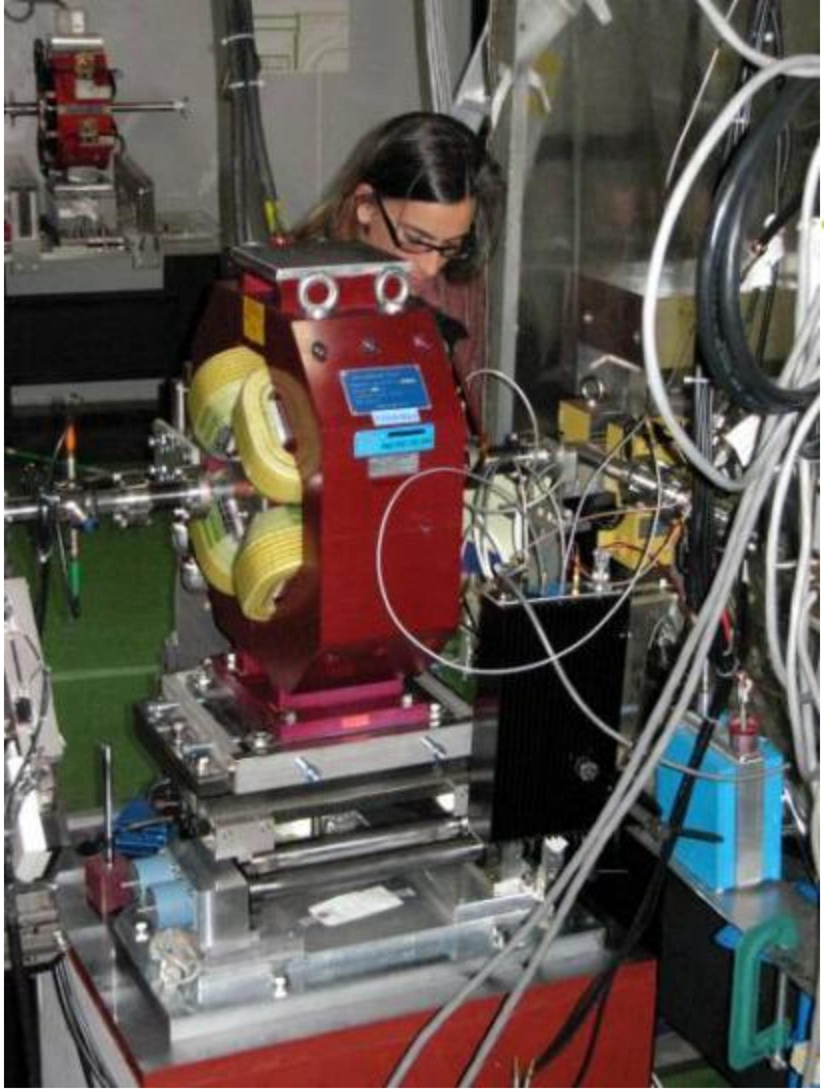
ATF2 final doublet



ILC Final Doublet layout

ATF & ATF2

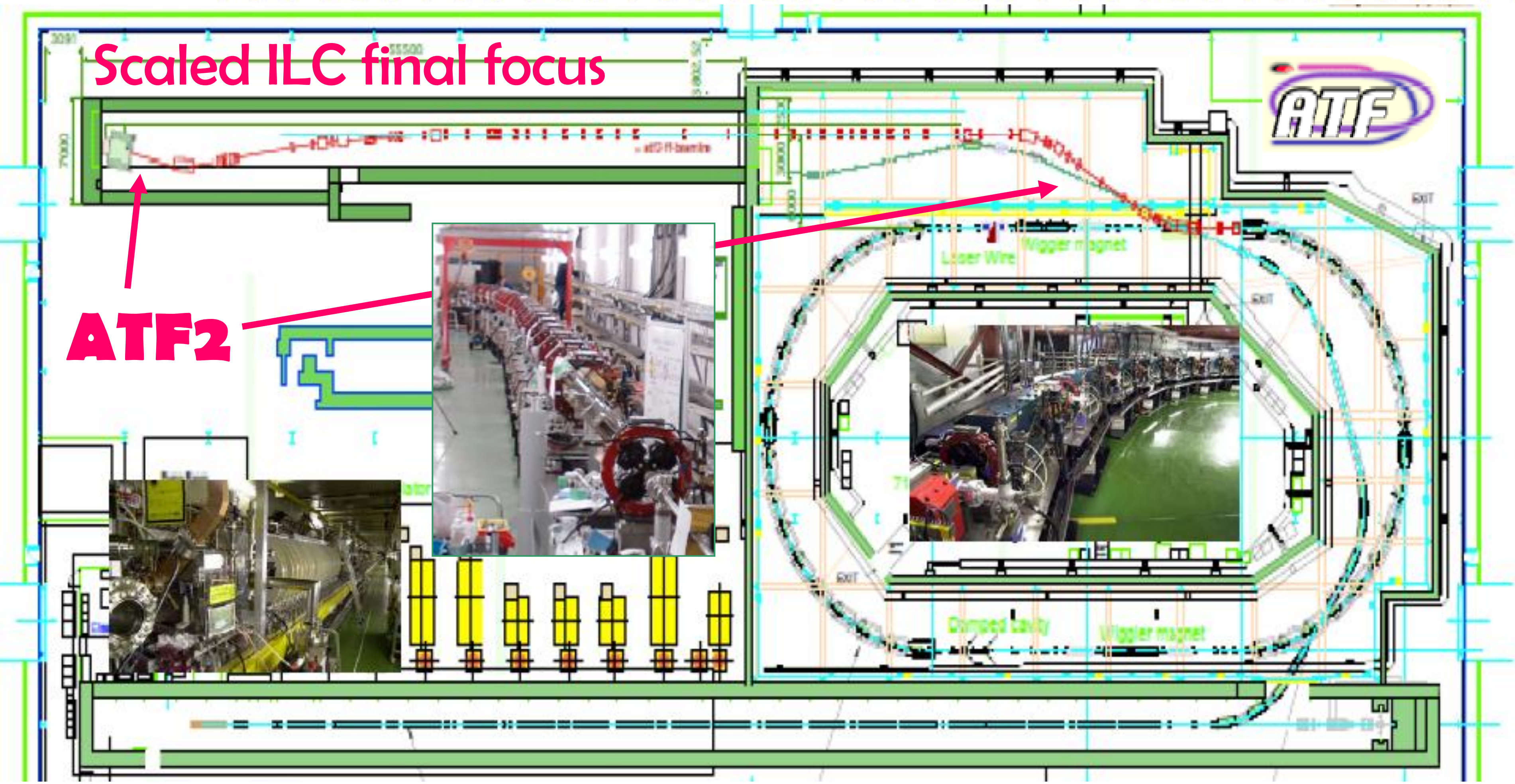
J.Nelson (at SLAC) and T.Smith (at KEK) during recent "remote participation" shift. Top monitors show ATF control system data. The shift focused on BBA, performed with new BPM electronics installed at ATF by Fermilab colleagues.



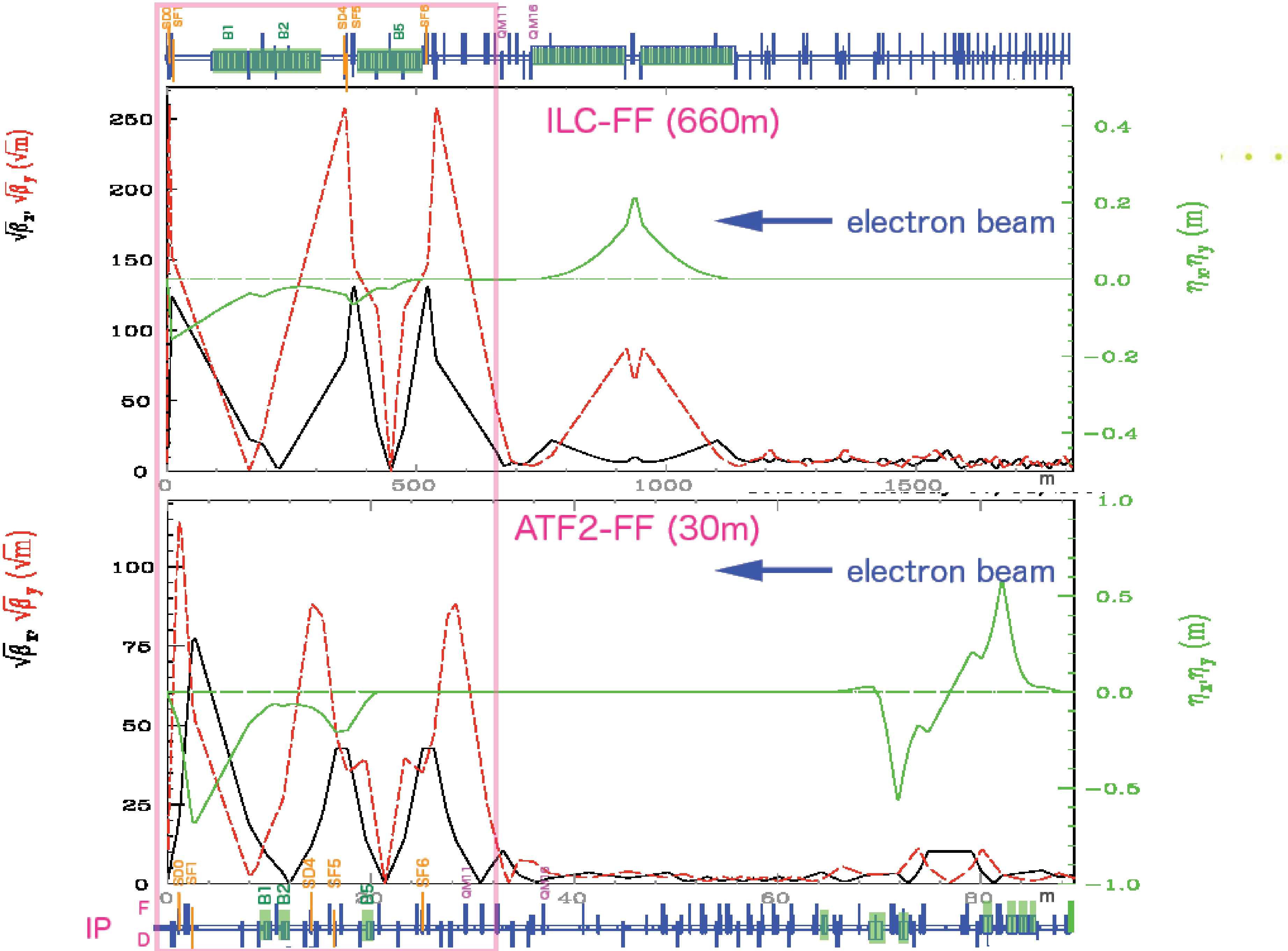
T.Smith is commissioning the cavity BPM electronics and the magnet mover system at ATF beamline

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
IP
F
D
SD0
SF1
B1
B2
SD4
SF5
B5
SF6
QM11
QM16

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 $\gamma\varepsilon_y$ $[10^{-8}\mathrm{m}]$	1.5	3	3
Extr. $\gamma\varepsilon_y$ $[10^{-8}\mathrm{m}]$	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 $\gamma\varepsilon_y$ $[10^{-8}\mathrm{m}]$	3.0 – 4.5	3	3
Extr. $\gamma\varepsilon_y$ $[10^{-8}\mathrm{m}]$	~ 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	$\sim 10^4$	$\sim 10^4$

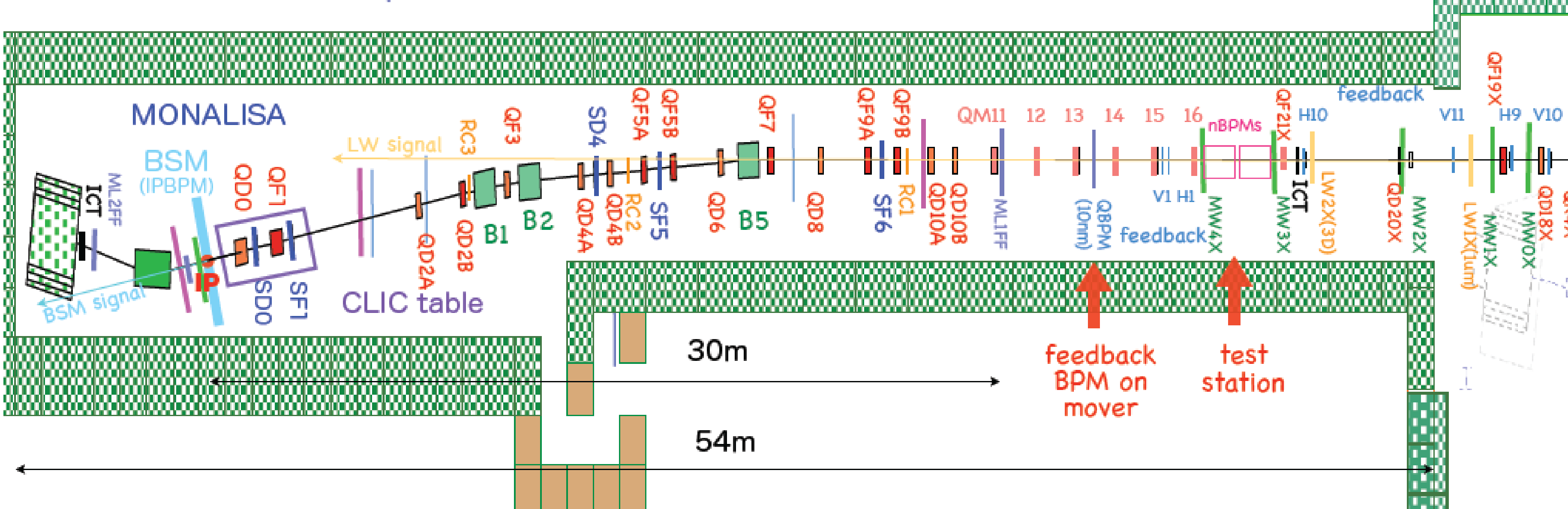
Magnets and Instrumentation at ATF2

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)

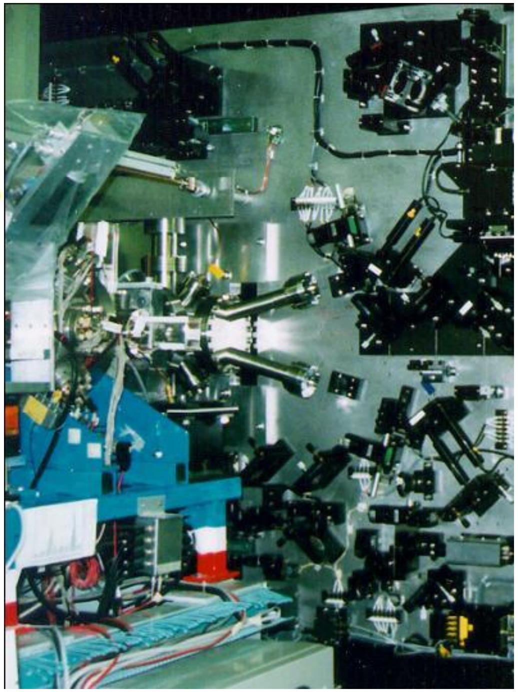
IP intra-train feedback system with latency of less than 150ns (FONT)

Magnet movers for Beam Based Alignment (BBA)

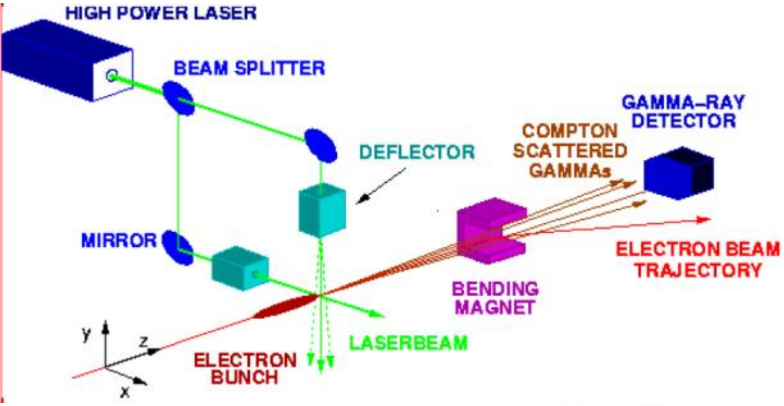
High Available Power Supply (HA-PS) system for magnets

Advanced beam instrumentation at ATF2

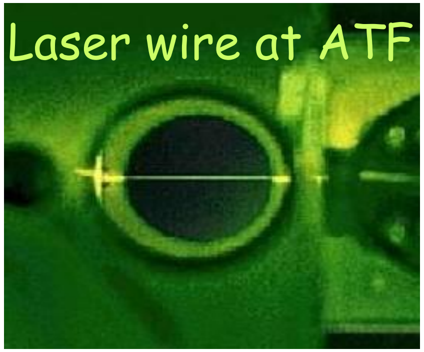
- BSM to confirm 35nm beam size
- nano-BPM at IP to see the nm stability
- Laser-wire to tune the beam
- Cavity BPMs to measure the orbit
- Movers, active stabilization, alignment system
- Intratrain feedback, Kickers to produce ILC-like train

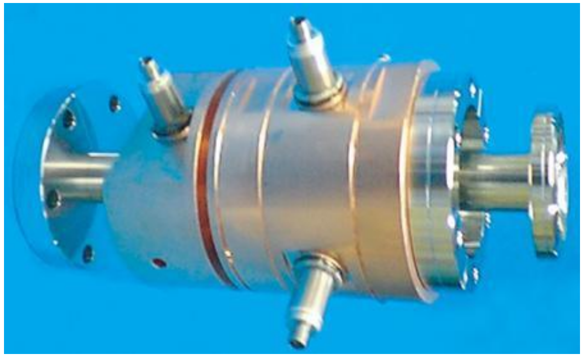


IP Beam-size monitor (BSM)
(Tokyo U./KEK, SLAC, UK)

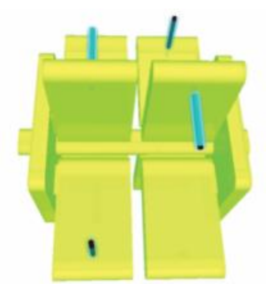


Laser-wire beam-size Monitor (UK group)





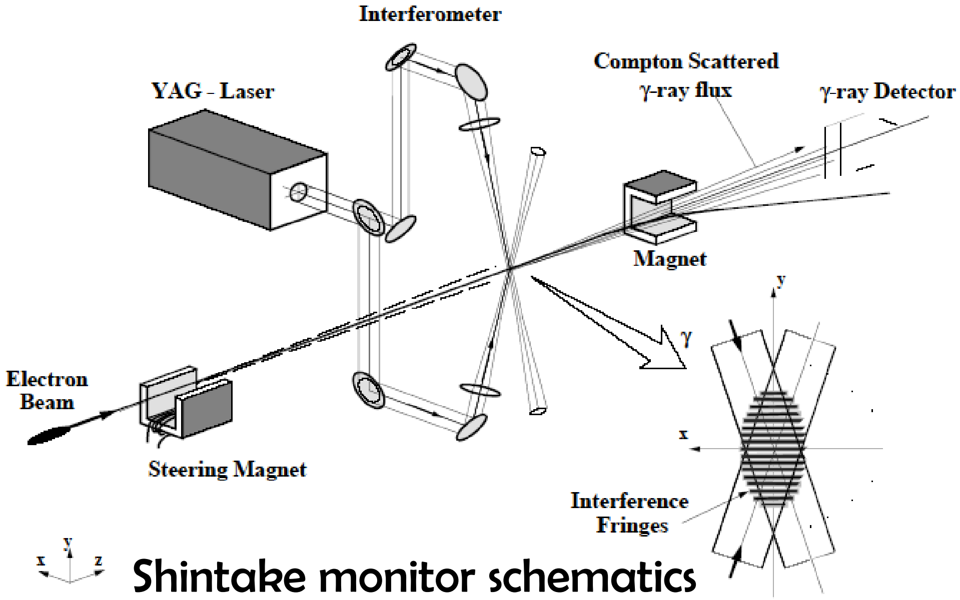
Cavity BPMs, for use with Q magnets with 100nm resolution (PAL, SLAC, KEK)



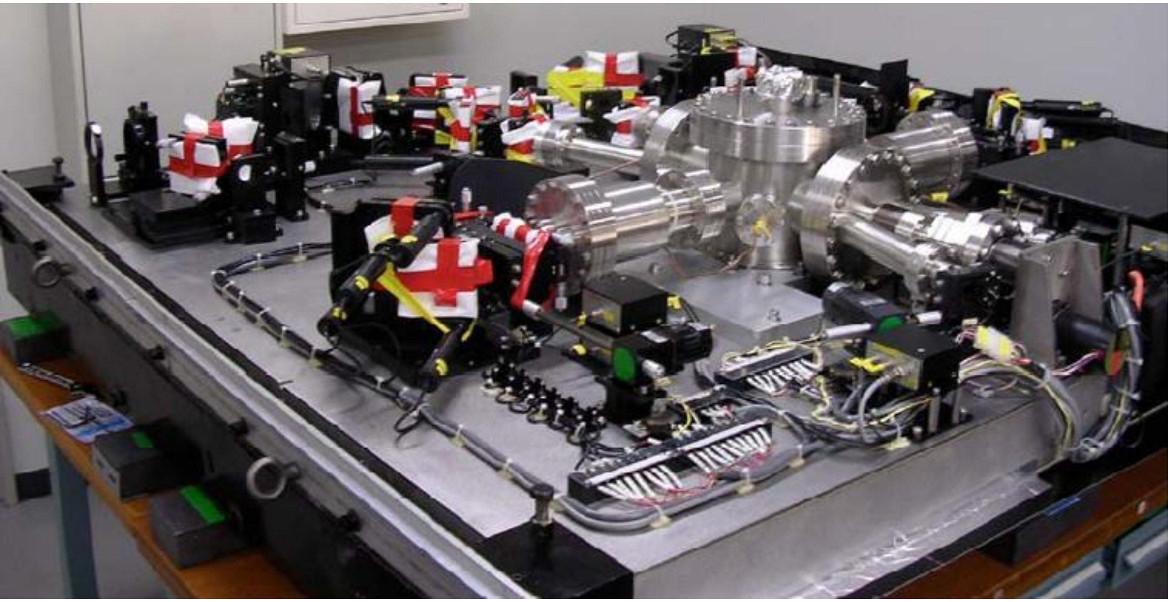
Cavity BPMs with 2nm resolution, for use at the IP (KEK)

IP Beam Size monitor

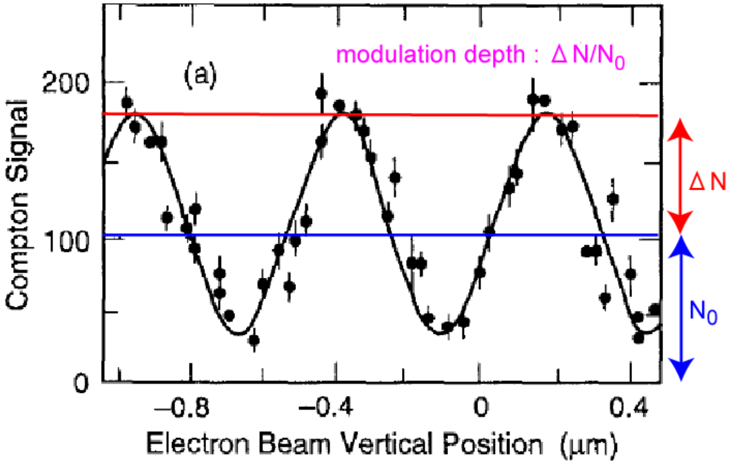
- BSM:
  - refurbished & much improved FFTB Shintake BSM
  - 1064nm=>532nm



Shintake monitor schematics



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



FFTB sample : σ_y = 70 nm

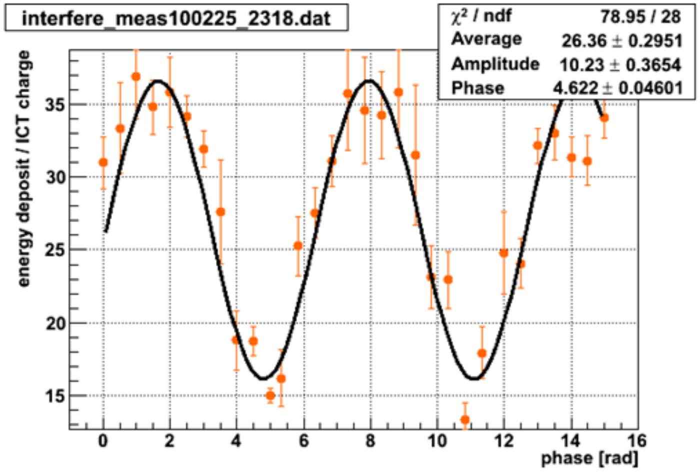
Ongoing R&Ds at ATF/ATF2

- **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

Interfere mode scan



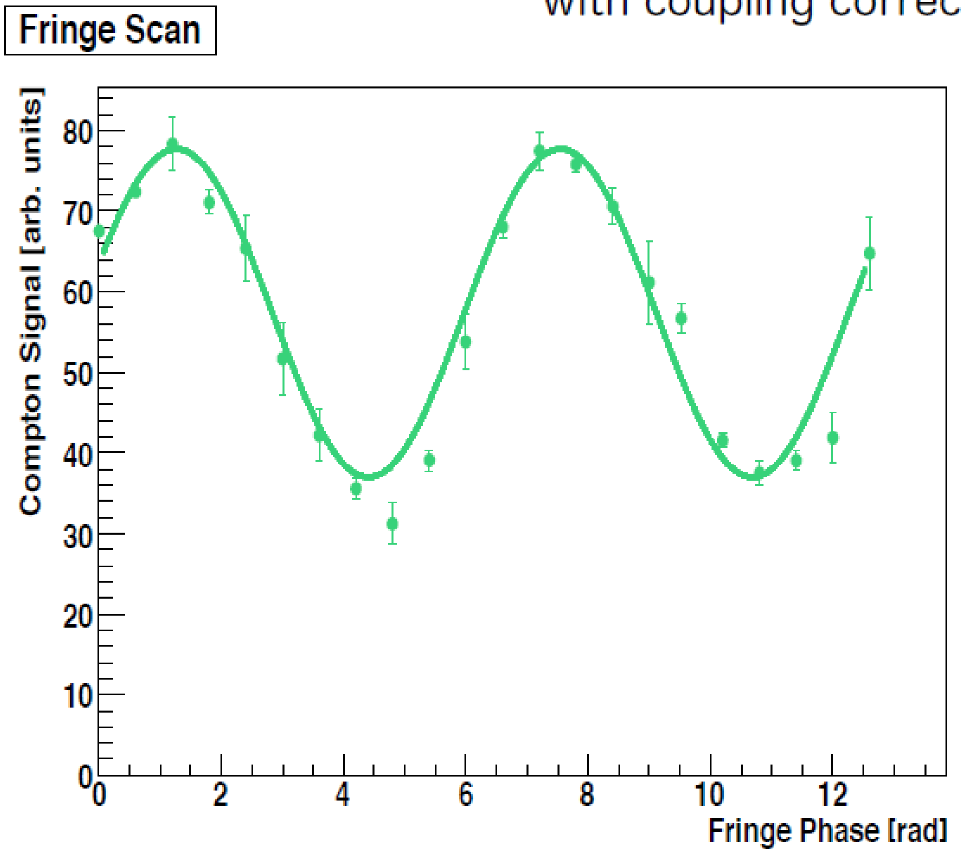
Beam size ~ 2.4 μm
Wire scanner measurement ~ 3.1 μm

- **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

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

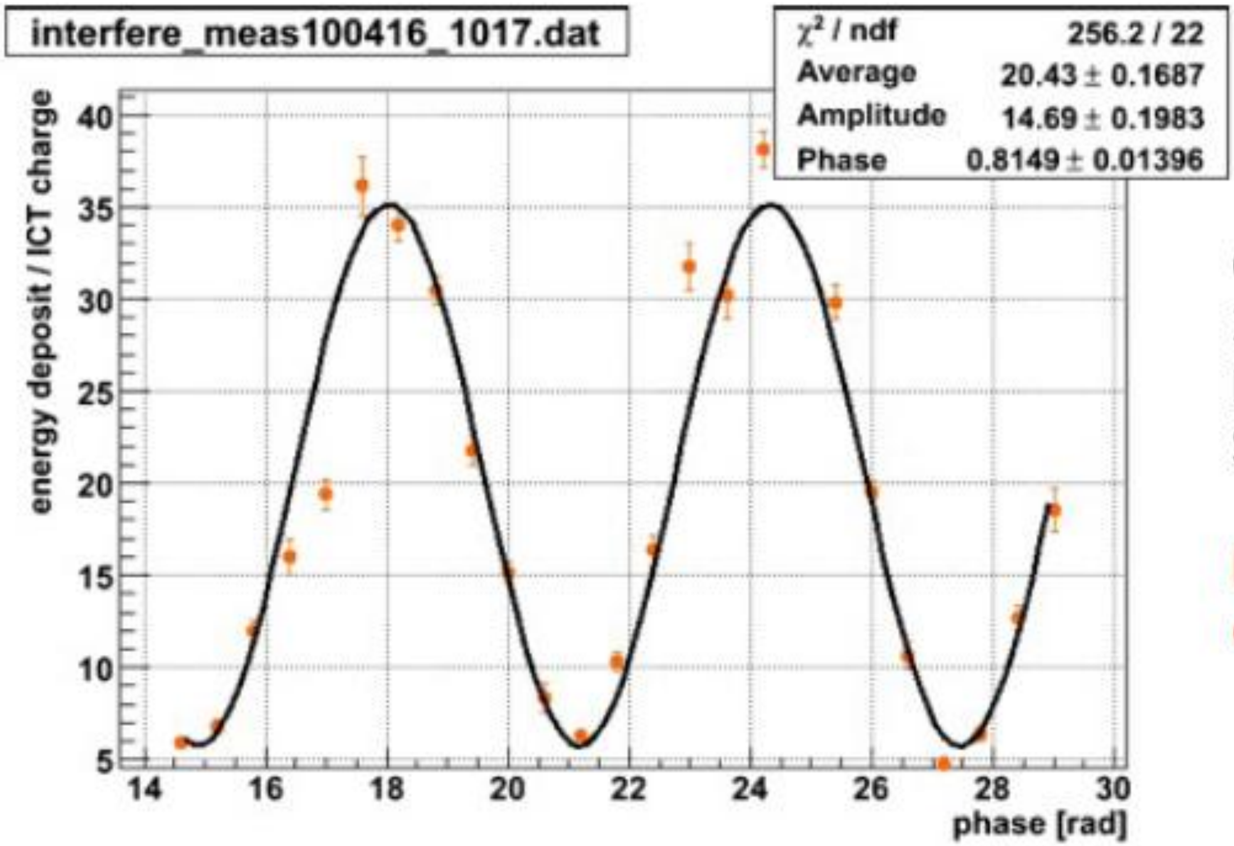
Fringe Pitch 13.3 um

Modulation = 0.35±0.01

σy = 3.1± 0.03 um

QD0 current at 129 A

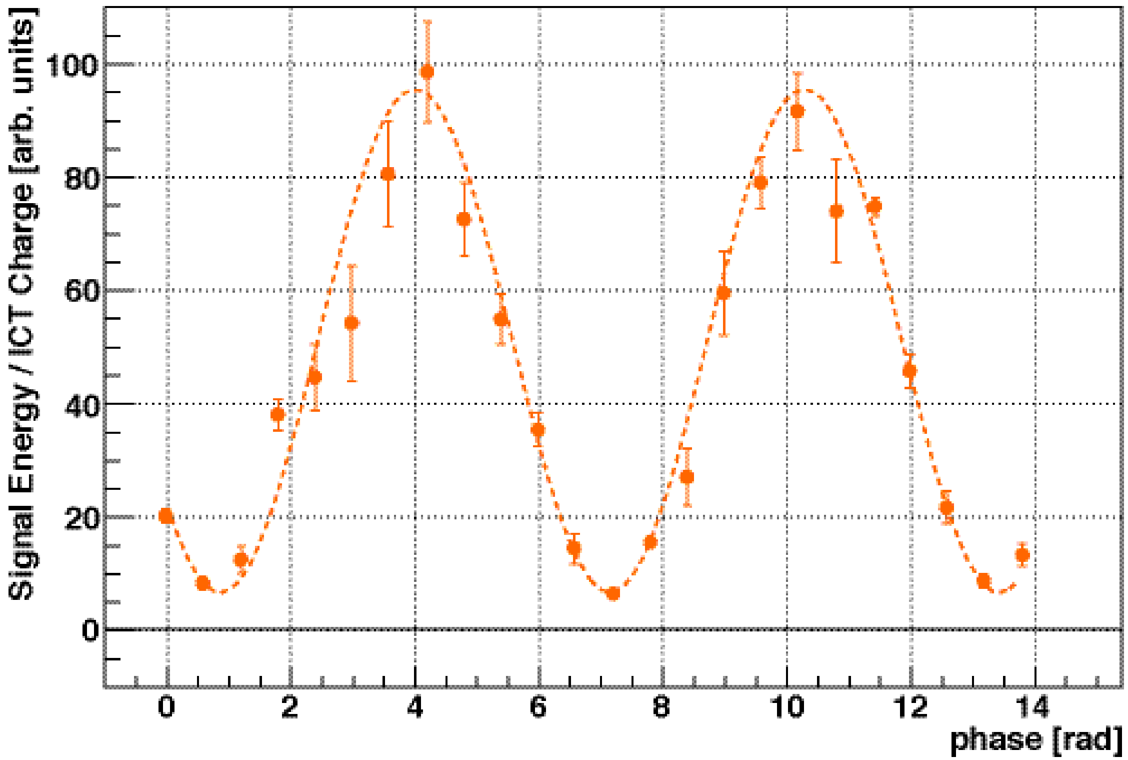
as expected from the PIP beam size measurements !



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



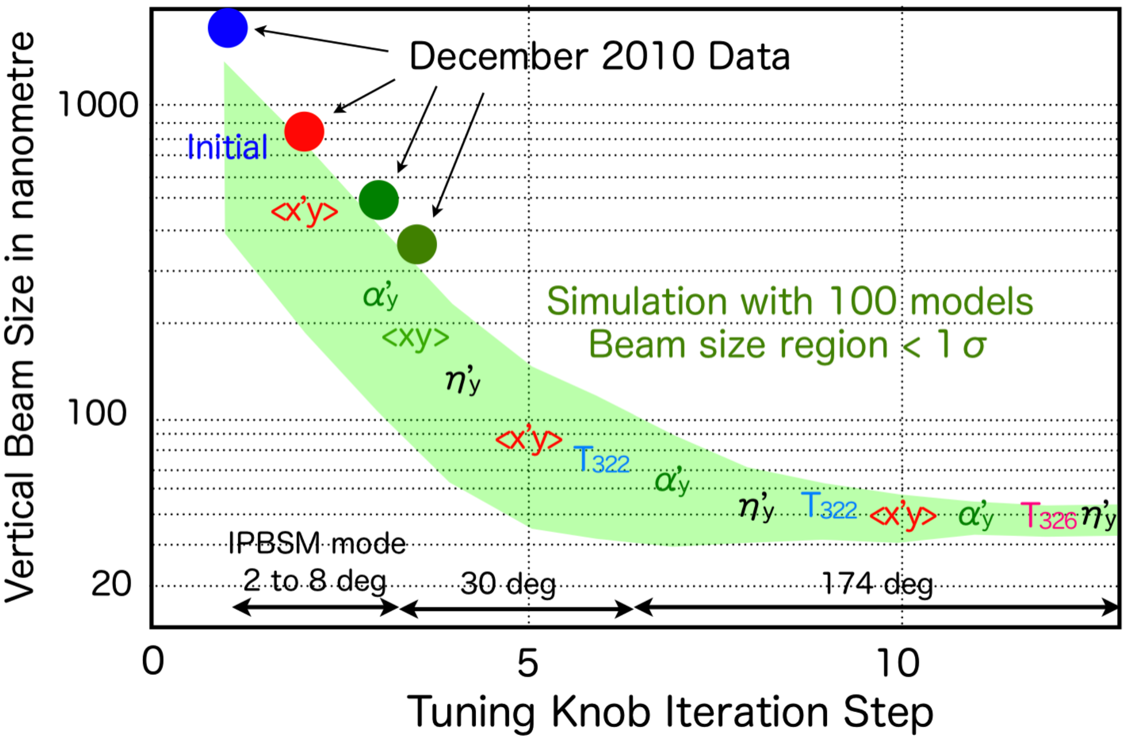
Yoshio Kamiya and Shintake monitor group.
Modulation Depth = 0.87 @ 8.0 deg. mode
Beam Size is 310 +- 30 (stat.) +0-40 (syst.) nm

[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.

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.

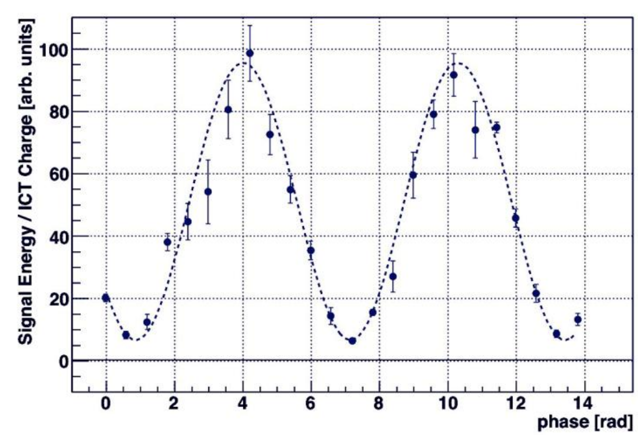
Recover 300nm again, then continue the tuning down to 37 nm.

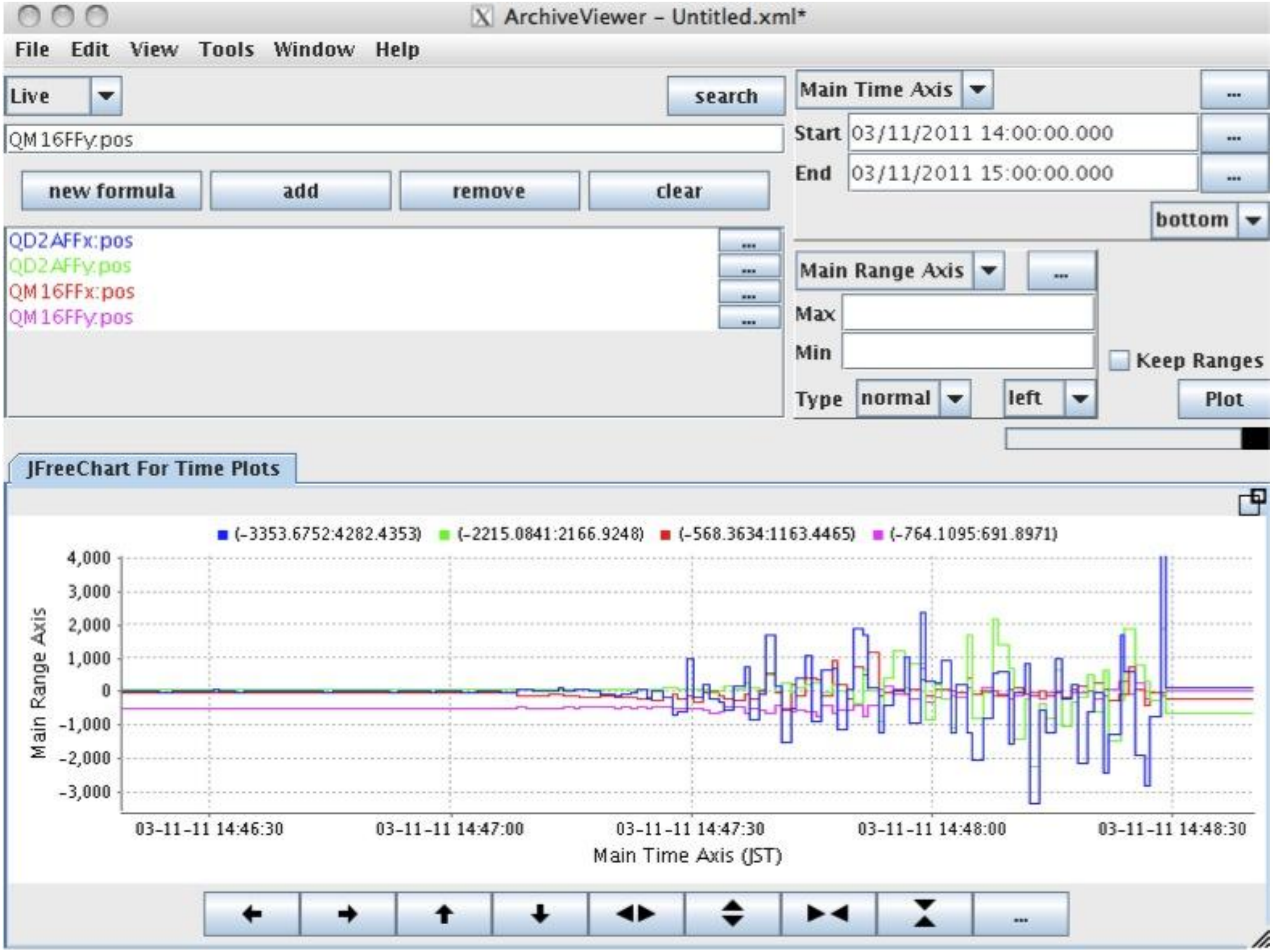
Example:

A beam size measured (2010/May/20)

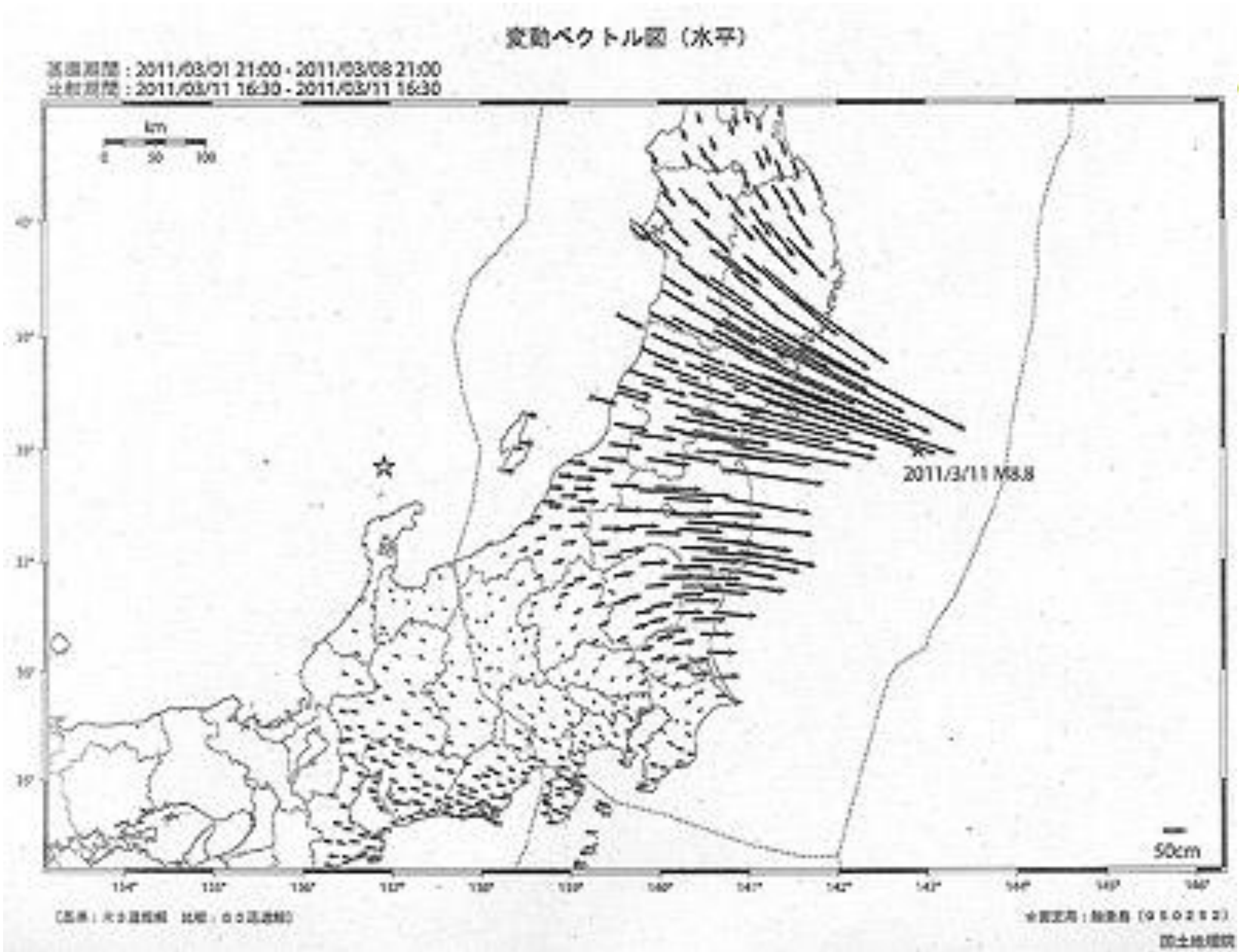
Modulation Depth = 0.87 @ 8.0 deg. mode

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





The 3.11.2012 earthquake signals seen by the ATF BPM system



GPS measurements of the coseismic displacement of the Japan earthquake on 11 March 2011 by GEONET (reference provided by Prof. Hashimoto). This displacement chart shows the direction of ground movement. (GEONET)

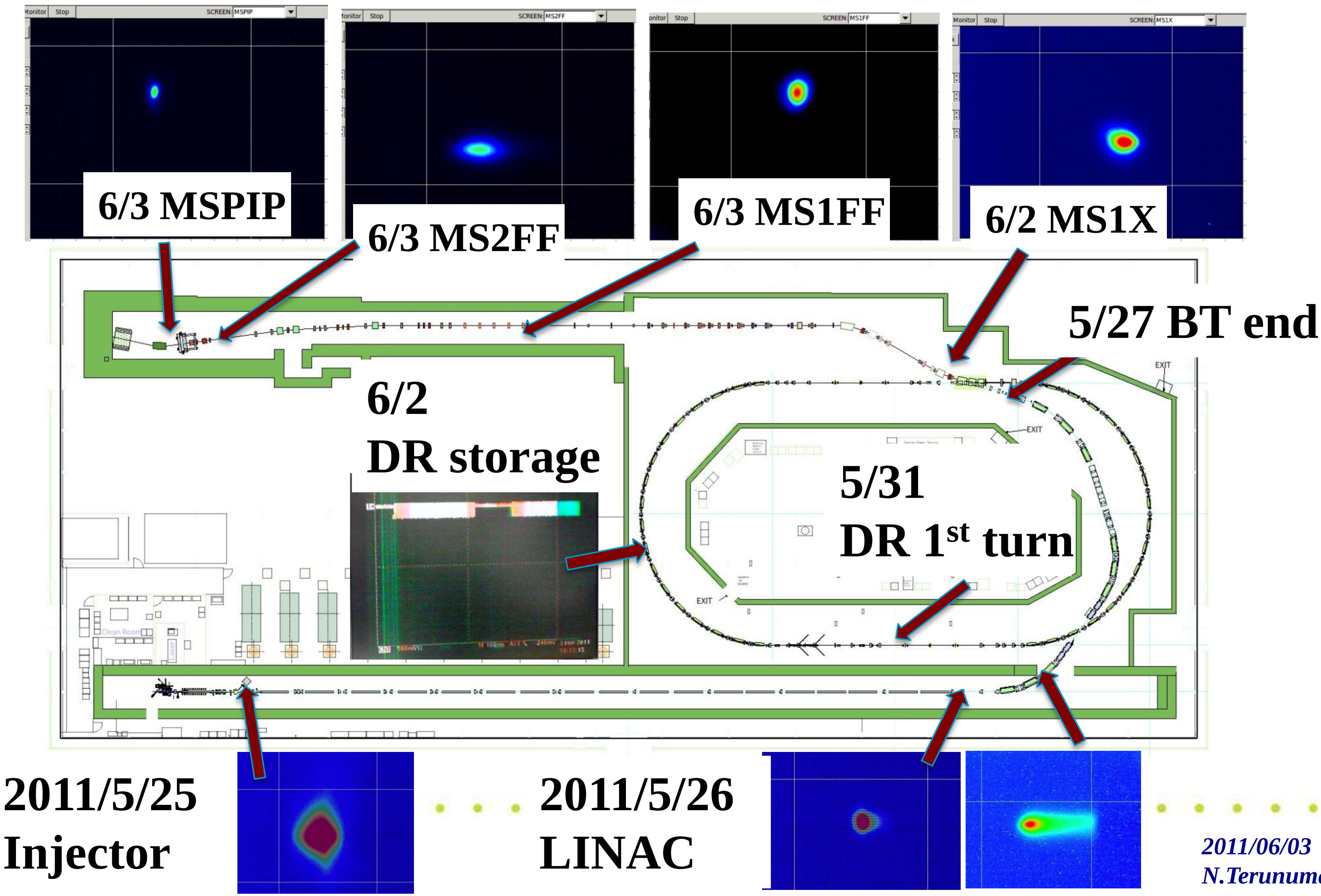
Recovery after the earthquake

work finished




Beam restored in all beamlines

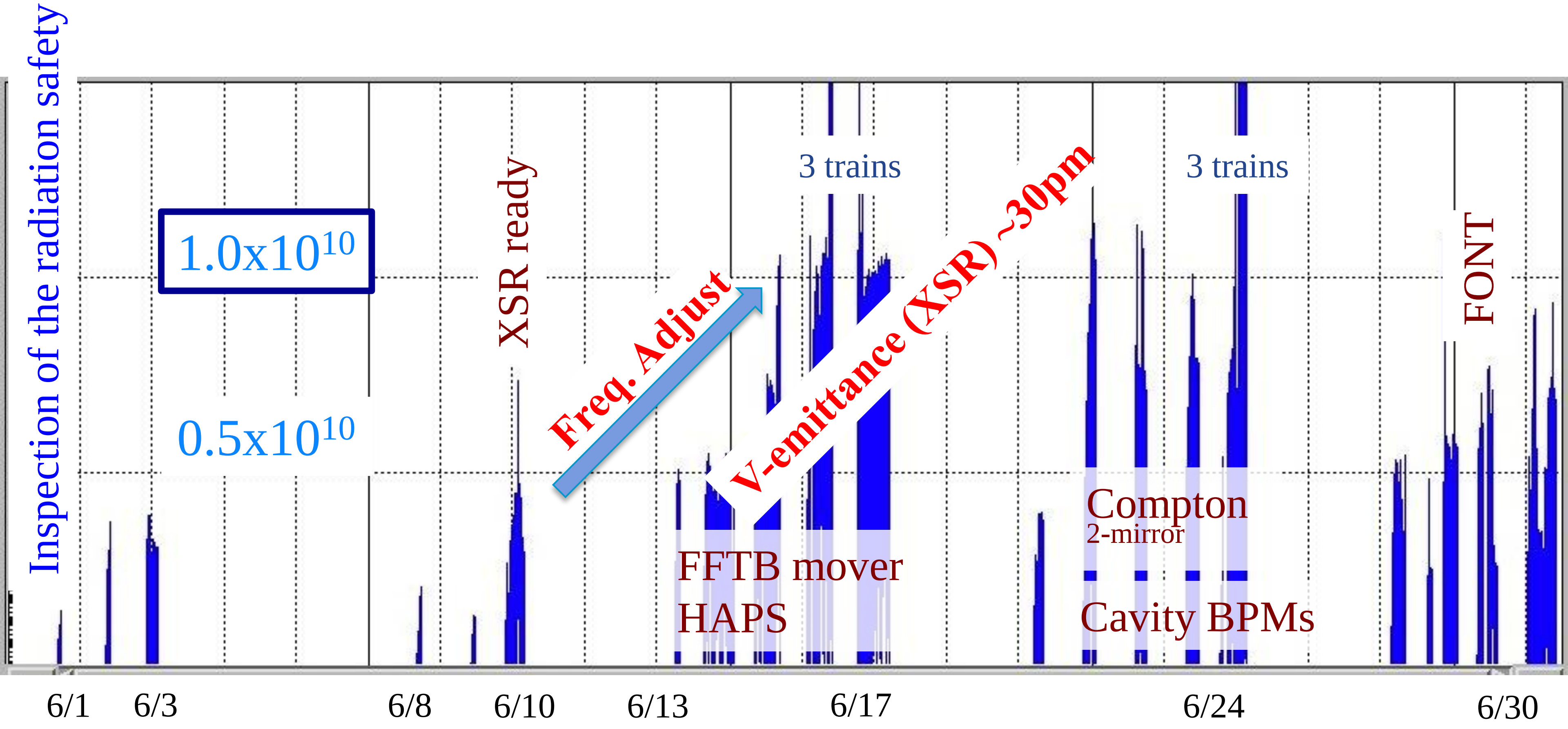
Single bunch, 0.78 Hz, 0.3 x 10^{10} e/bunch DR&ATF2



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.



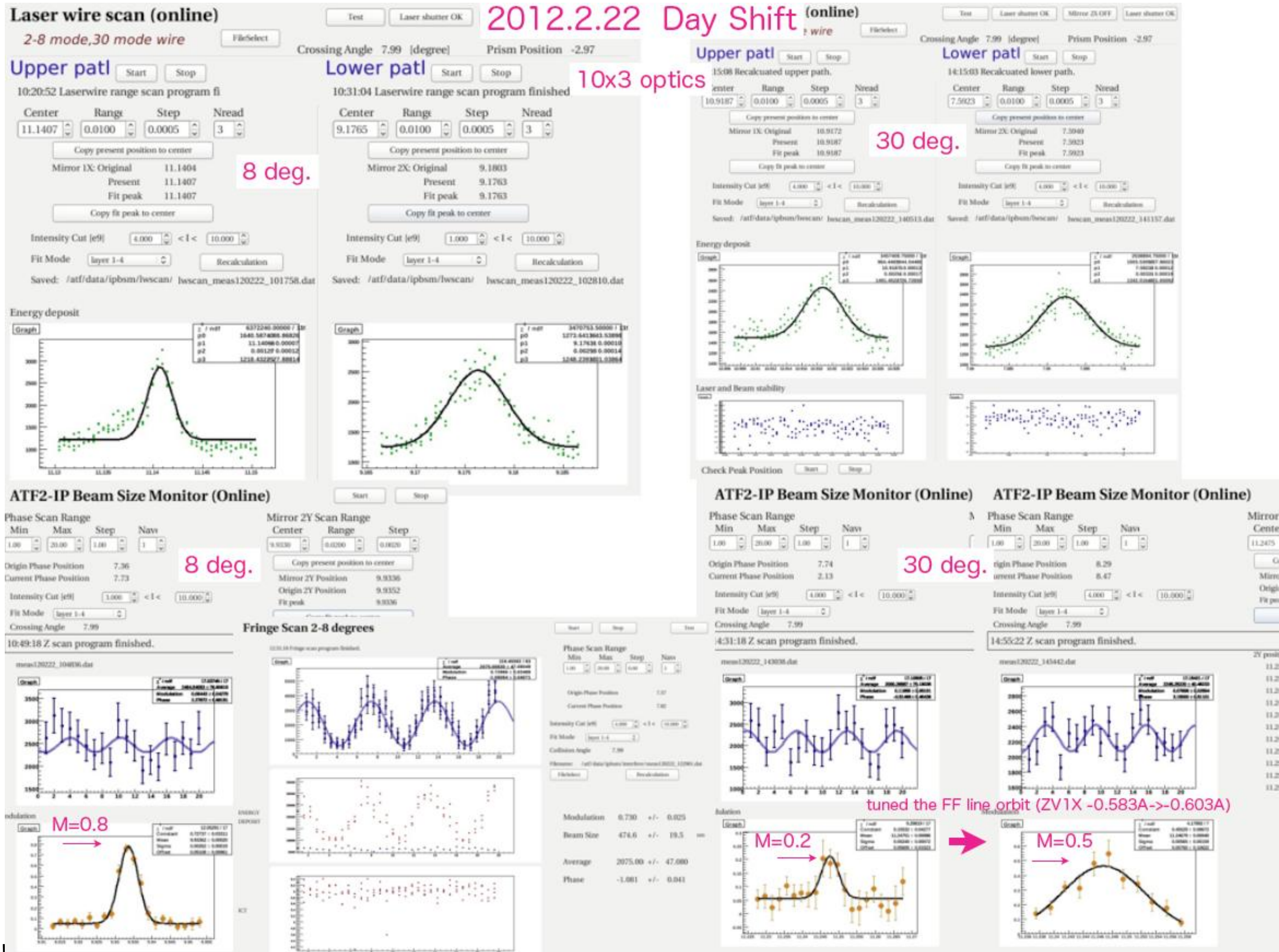
DR rough alignment for checkout was continued in daytime.

Status as of June 2012

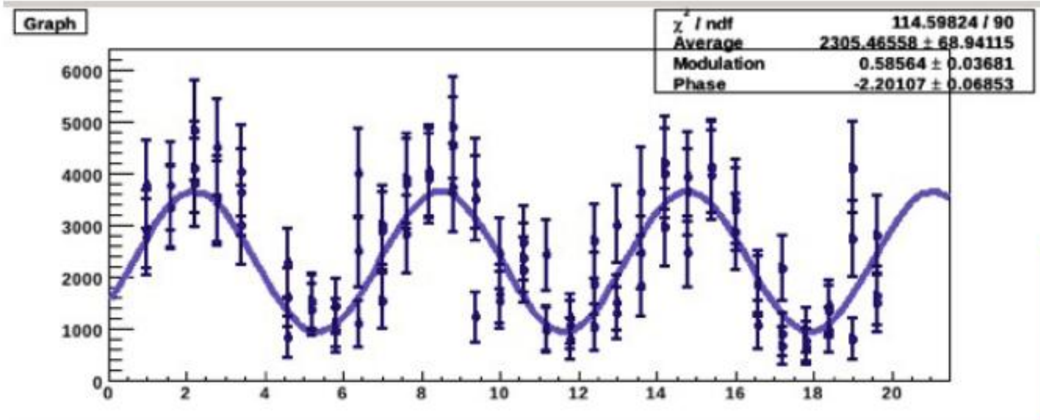
Parameters at ATF2

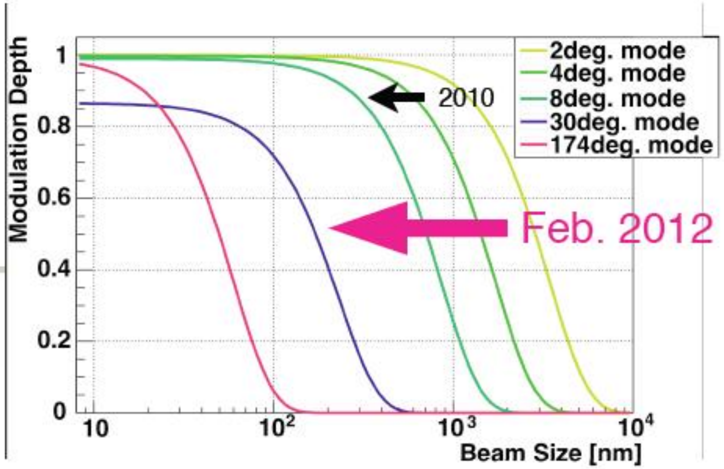
3.11 Earthquake

IP Parameter	nominal	May 2010	Feb 2011	Dec 2011	Feb 2012
Beam energy	1.3GeV	1.3GeV	1.3GeV	1.3GeV	1.3GeV
Emittance in x	2 nm	1.7nm	1.8-1.7nm	2nm	1.8nm
Emittance in y	12 pm	<10pm	27-28pm	~50 pm wakefield@mOTR	15.6 pm
Beta function in x	4 mm	4cm	10mm	1cm	4cm
Beta function in y	0.1mm	1mm	0.1mm	0.5mm	0.3mm
beam size in x	2.8 μm	~10 μm	-	9.2μm/2	11.2μm
beam size in y	35 nm	300 nm 8deg.mode	1.8um@PIP C-wire	850nm 5deg.mode	165nm 30deg.mode


2012.2.22 Day Shift
Laser wire scan (online)
2-8 mode,30 mode wire
Upper patl
Lower patl
10x3 optics
8 deg.
30 deg.
Energy deposit
ATF2-IP Beam Size Monitor (Online)
8 deg.
30 deg.
Fringe Scan 2-8 degrees
M=0.8
M=0.2
M=0.5
tuned the FF line orbit (ZV1X -0.583A->-0.603A)

30 deg mode fringe scan on Feb 23, 2012





$$M = 0.52 \pm 0.010 \text{ (stat)}$$

$$\sigma_y^* = 167.9 \pm 1.8 \text{ (stat) [nm]}$$

2/23: 30 deg	M	ΔM	σ_y^*	$\Delta\sigma_y^*$	avg E_{sig}/ beam current [GeV / 10^9e]
13:12	0.583	0.032	145.55	6.77	2227
13:16	0.480	0.032	177.73	5.55	2293
13:20	0.543	0.037	157.93	7.16	2285
13:22	0.463	0.040	182.91	6.72	2222
13:26	0.586	0.037	144.69	7.86	2306
13:29	0.520	0.040	165.23	7.44	2301
13:32	0.521	0.037	164.86	6.97	2318
13:35	0.532	0.021	159.99	4.024	2198
13:42	0.472	0.021	180.333	3.53	2121

- 10 β^*_x x 3 β^*_y optics
- S/N ~ 1
- Signal jitter ~ 22%
- BG fluctuation ~ 10%

Table 1.2: M and σ_y^* measured from 9 consecutive stable interference scans at 30 deg mode. Errors are from fitting using a new automated scan software at ATF2 that uses energy deposit from the 4 front detector layers and ON/OFF method

Autumn 2012 run

Major issues at the 13th ATF2 project meeting

5. Effect of the Multipole components in the FF

especially important for beam with $\sigma^*_y < 100$ nm

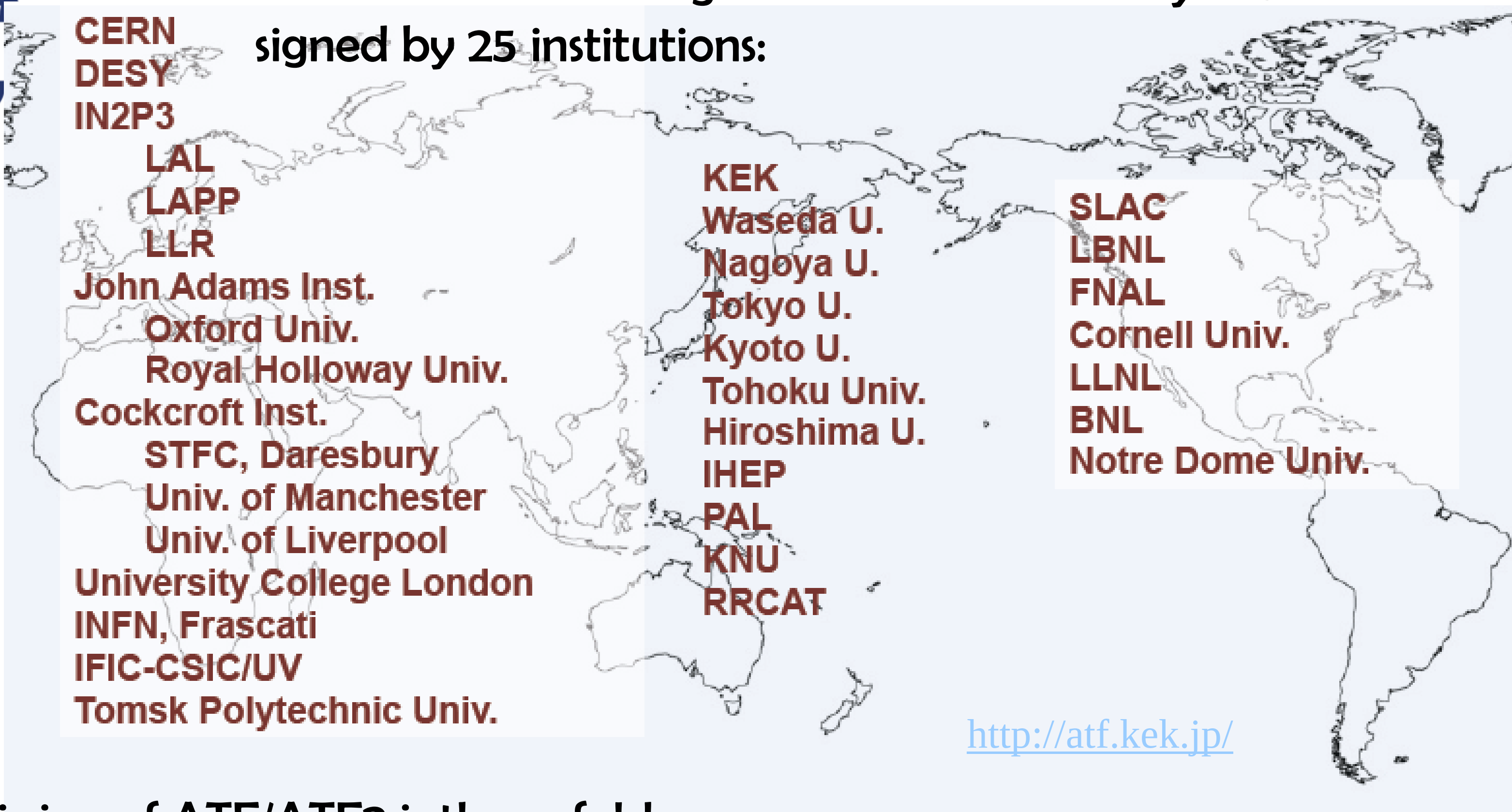
mitigation by 2.5 times nominal horizontal beta function at IP

2012年 6月 25日 月曜日

- One of the improvements:
  - Replace QF1 with higher quality magnet
  -

SLAC replacement magnet from PEP II

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!