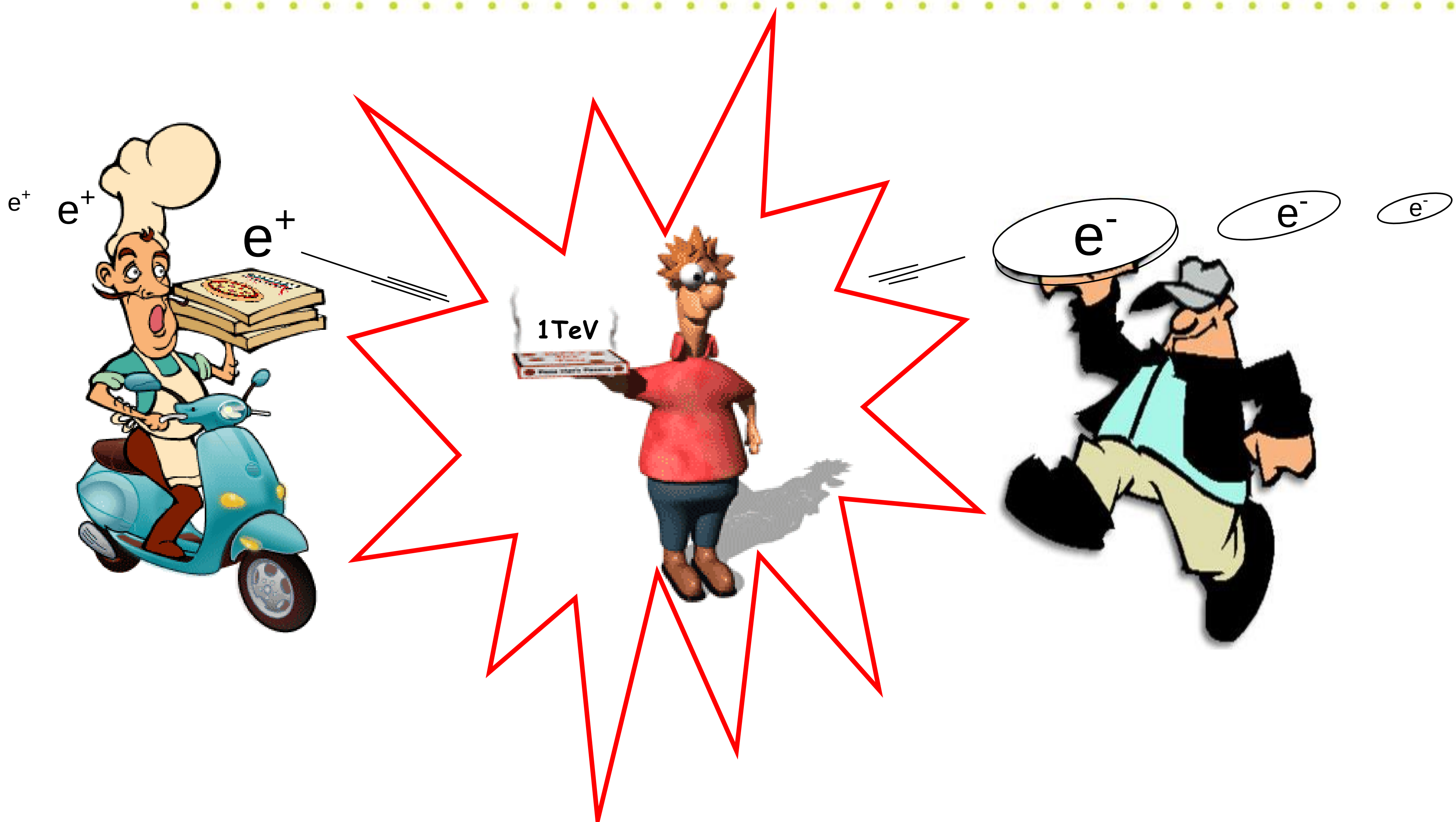
Accelerator Lecture A4 – PART 2

Beam Delivery & beam-beam

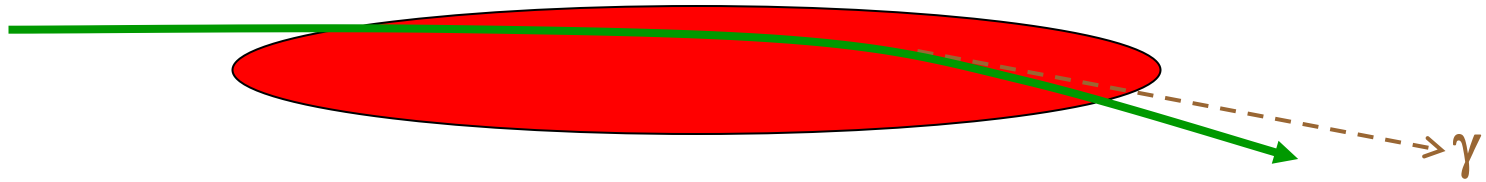
Andrei Seryi
John Adams Institute

Beam Delivered...



Beam-beam effects

Beam-beam interactions

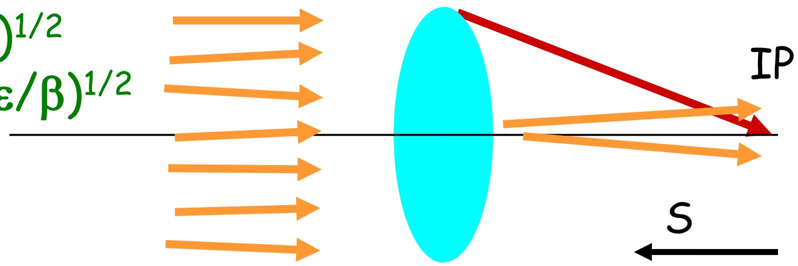


- Transverse fields of ultra-relativistic bunch
  - focus the incoming beam (electric and magnetic force add)
  - reduction of beam cross-section leads to more luminosity
    - H_D - the luminosity enhancement factor
  - bending of the trajectories leads to emission of beamstrahlung

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

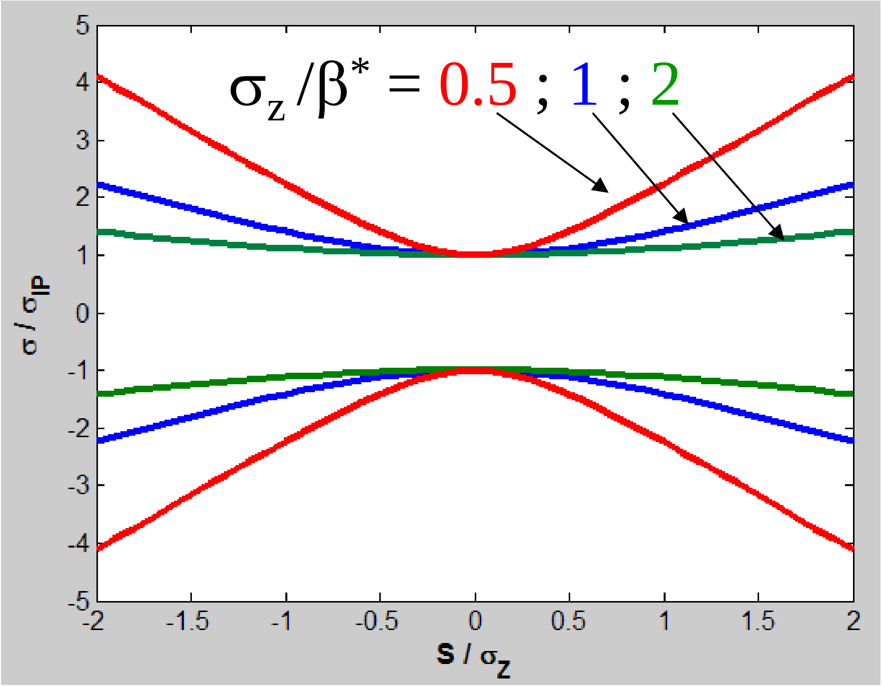


Size at IP: $L^* (\varepsilon/\beta)^{1/2}$

Beta at IP:

$L^* (\varepsilon/\beta)^{1/2} = (\varepsilon\, \beta^*)^{1/2}$

=> $\beta^* = L^{*2}/\beta$

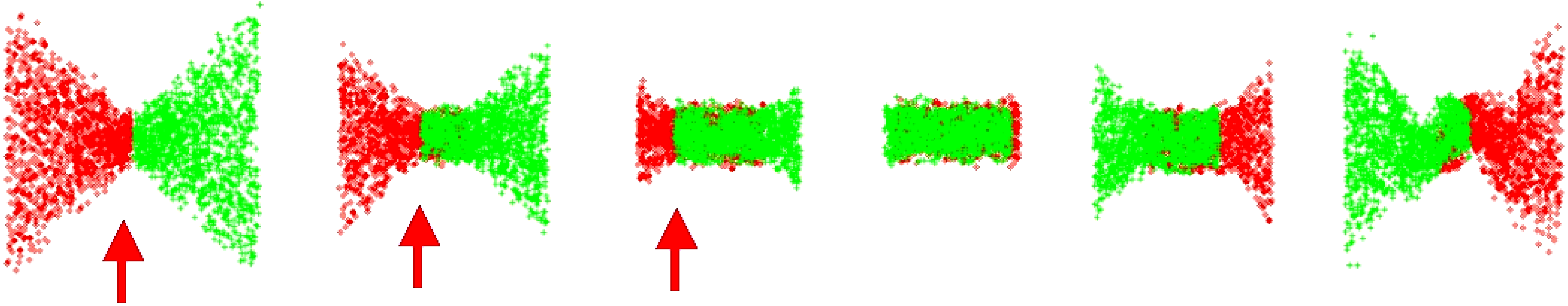


Behavior of beta-function along the final drift:

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

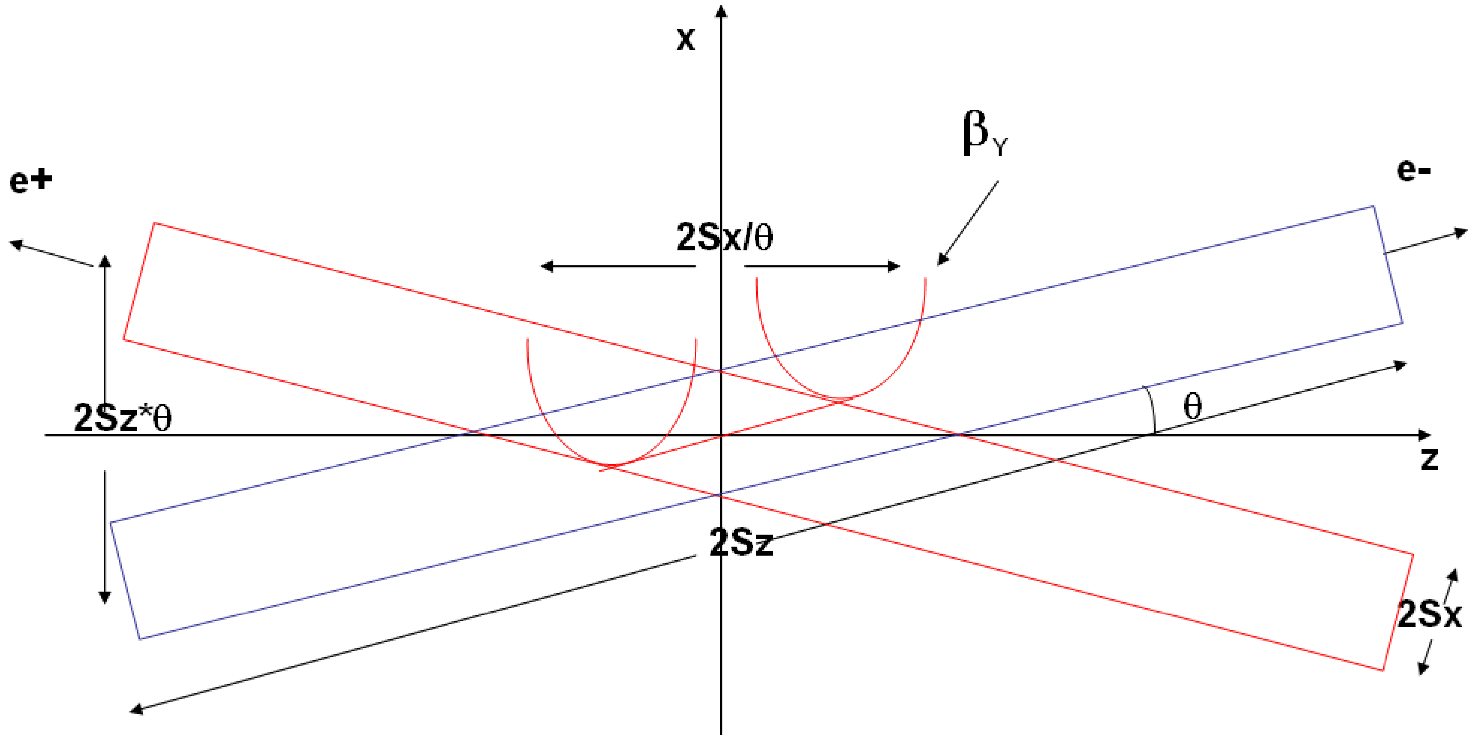
Reduction of β^* below σ_z does not give further decrease of effective beam size (<u>usually</u>)

Beam-beam: Travelling focus



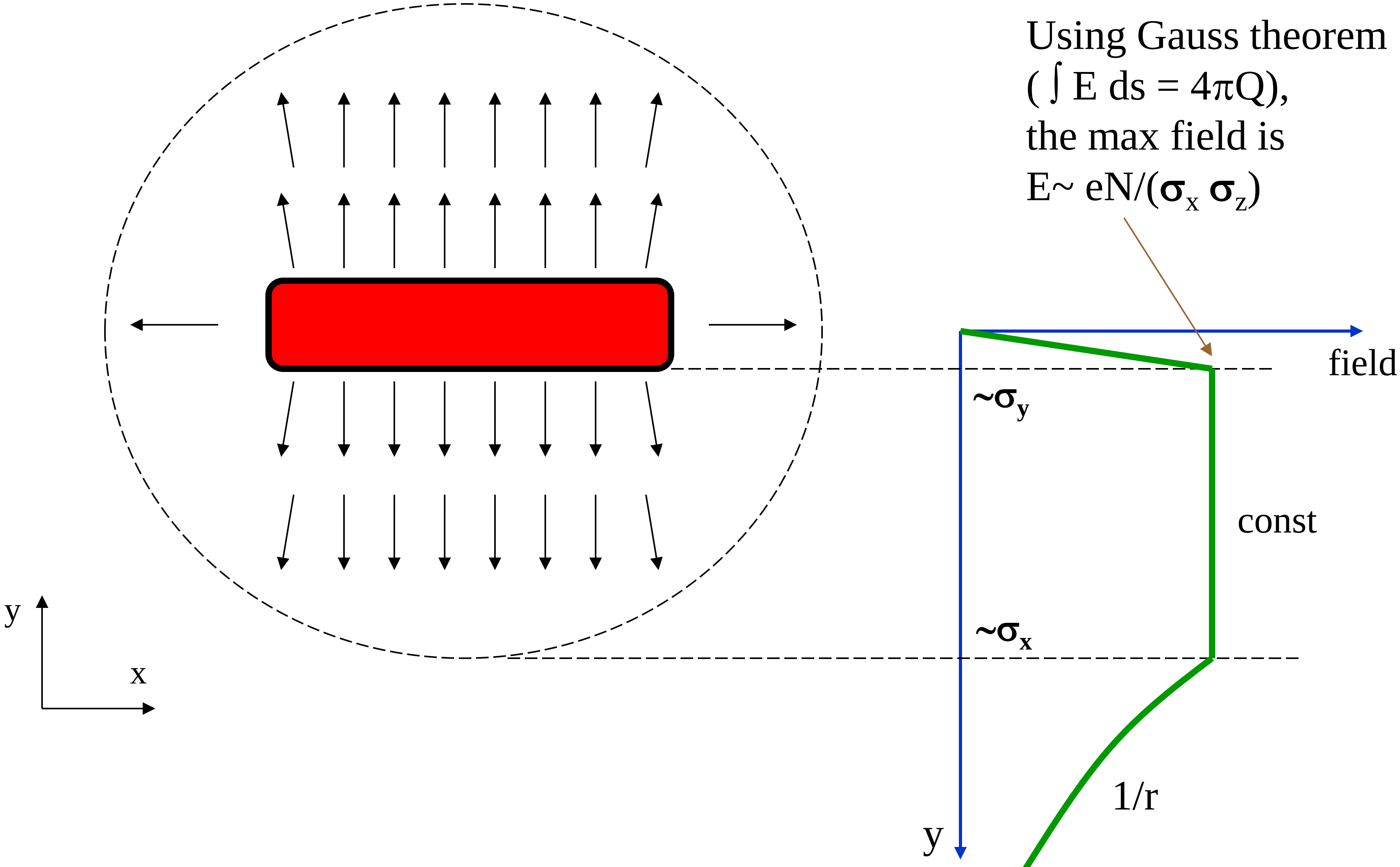
- Suggested by V.Balakin – idea is to use beam-beam forces for additional focusing of the beam – allows some gain of luminosity or overcome somewhat the hour-glass effect
- Figure shows simulation of traveling focus. The arrows show the position of the focus point during collision
- So far not yet used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

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

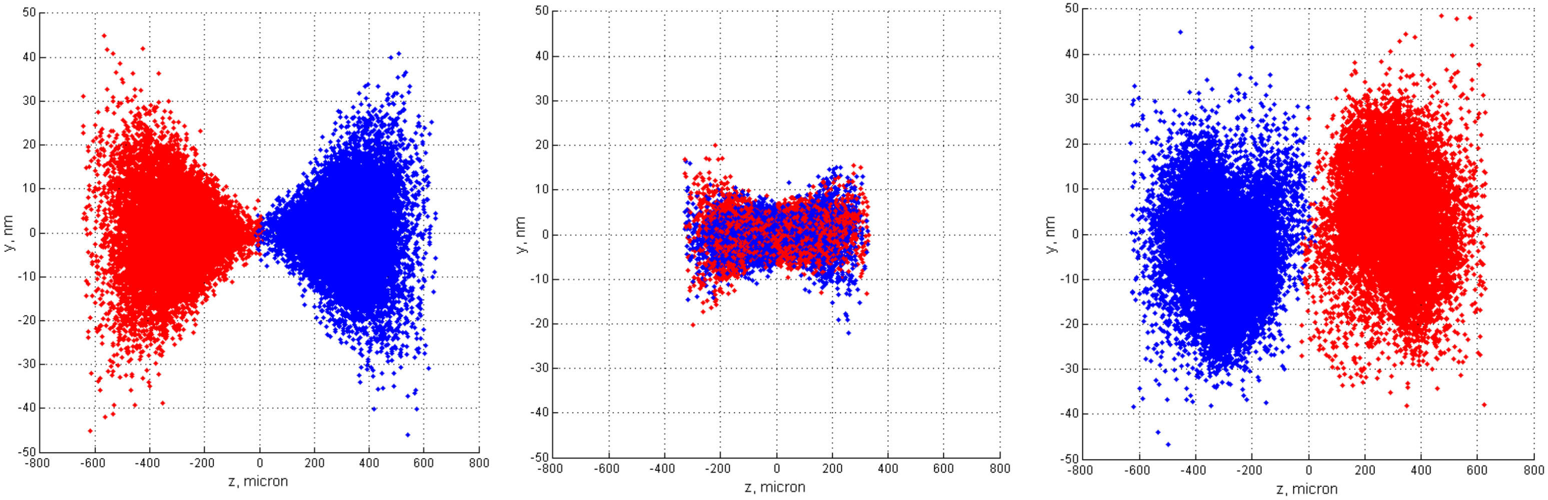
- "Disruption parameter" – characterize focusing strength of the field of the bunch ($D_y \sim \sigma_z / f_{beam}$)

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

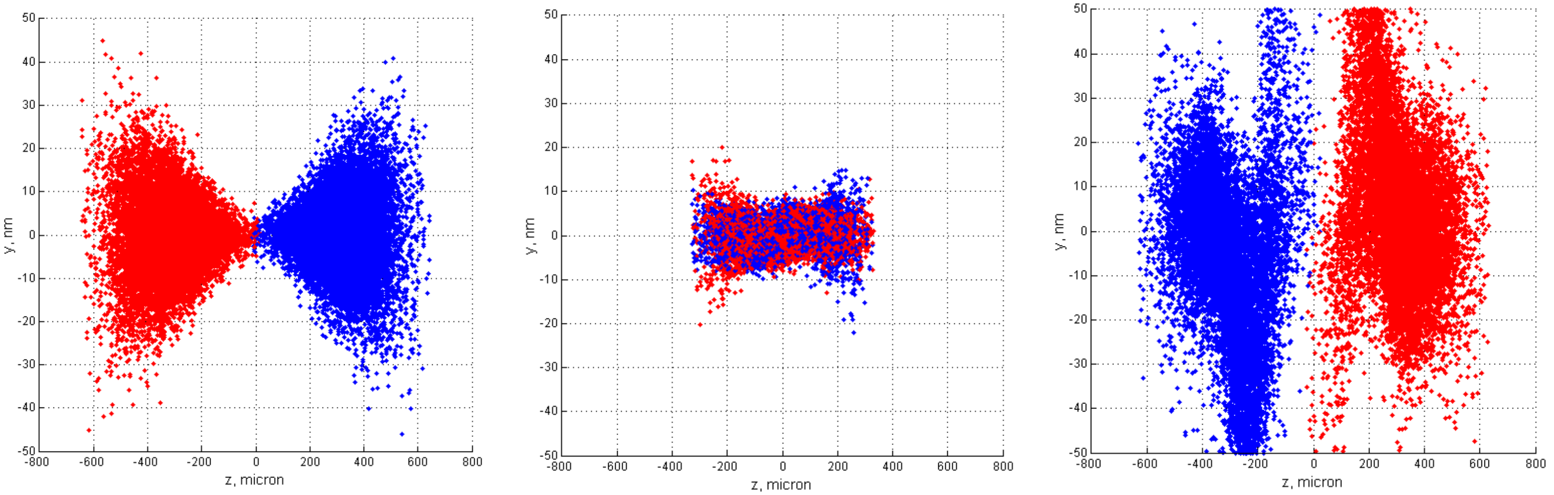
  - D << 1 – bunch acts as a thin lens
  - D >> 1 – particle oscillate in the field of other bunch
    - If D is bigger than ~20, instability may take place

Beam-beam effects
H_D and instability

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



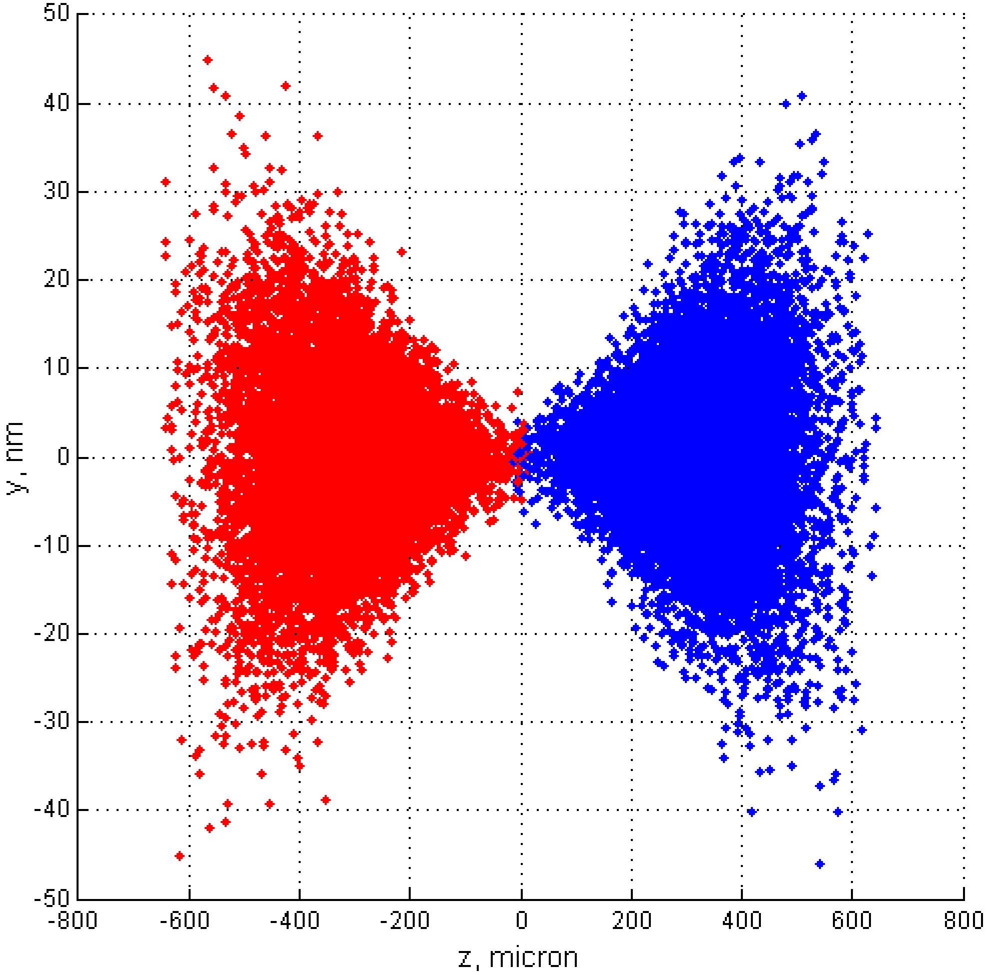
D_y~12



Nx2
D_y~24

Beam-beam effects

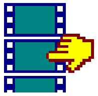
H_D and instability

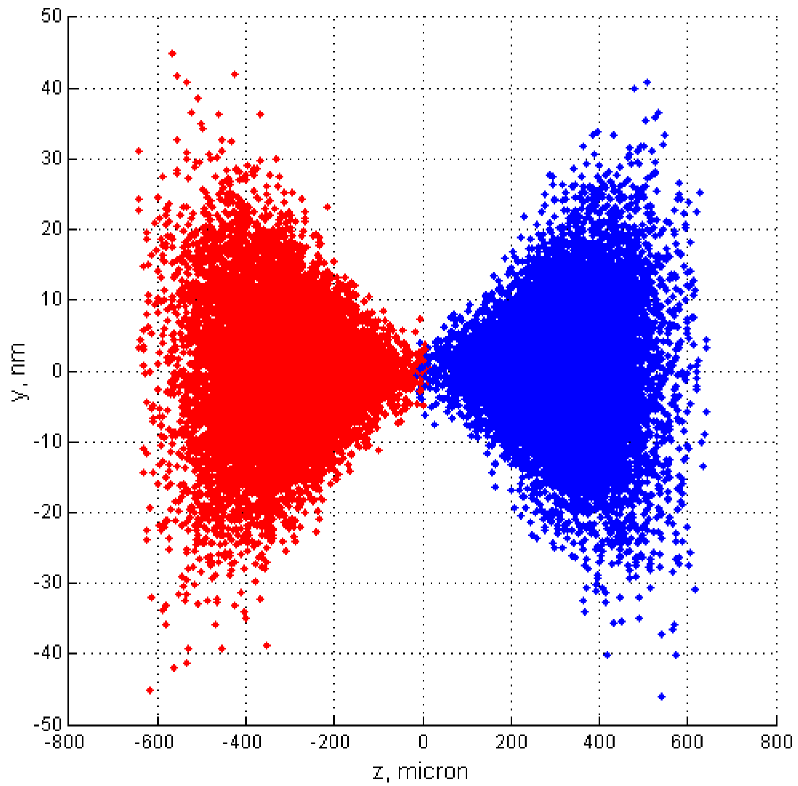


LC parameters
D_y~12

Luminosity enhancement
H_D ~ 1.4

Not much of an instability





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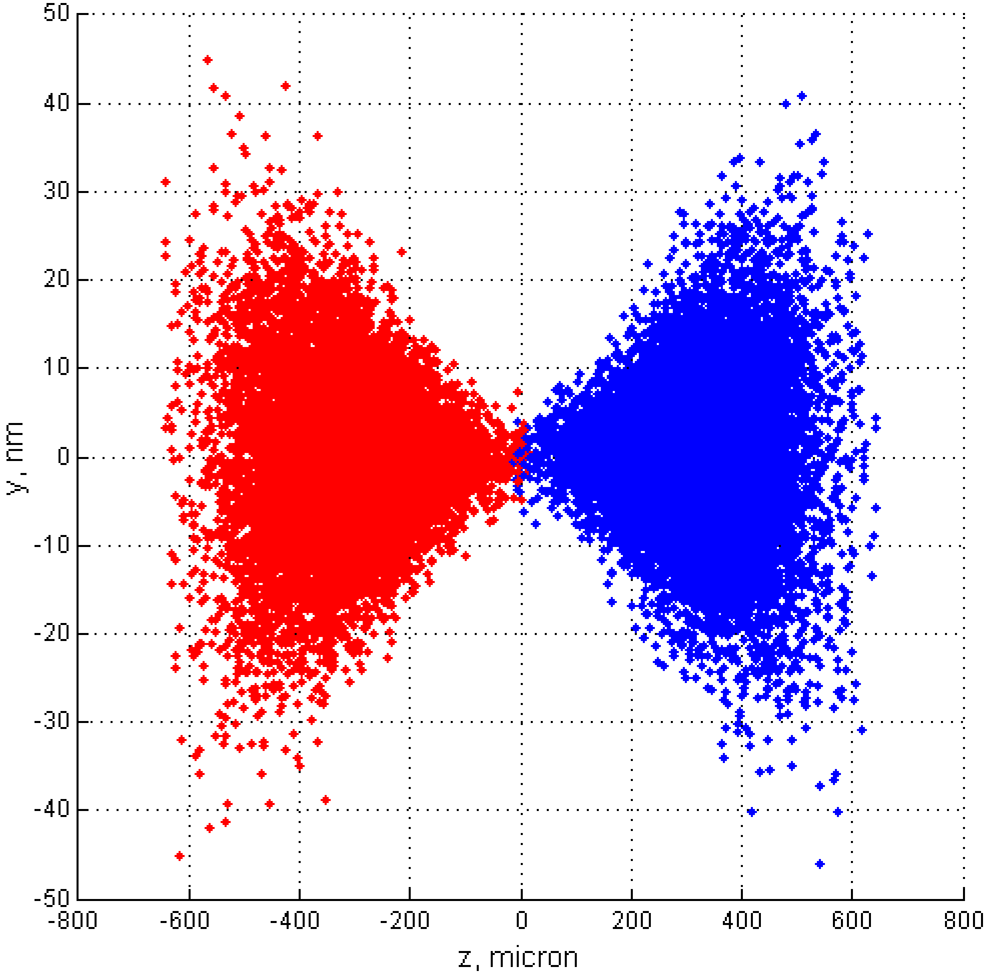
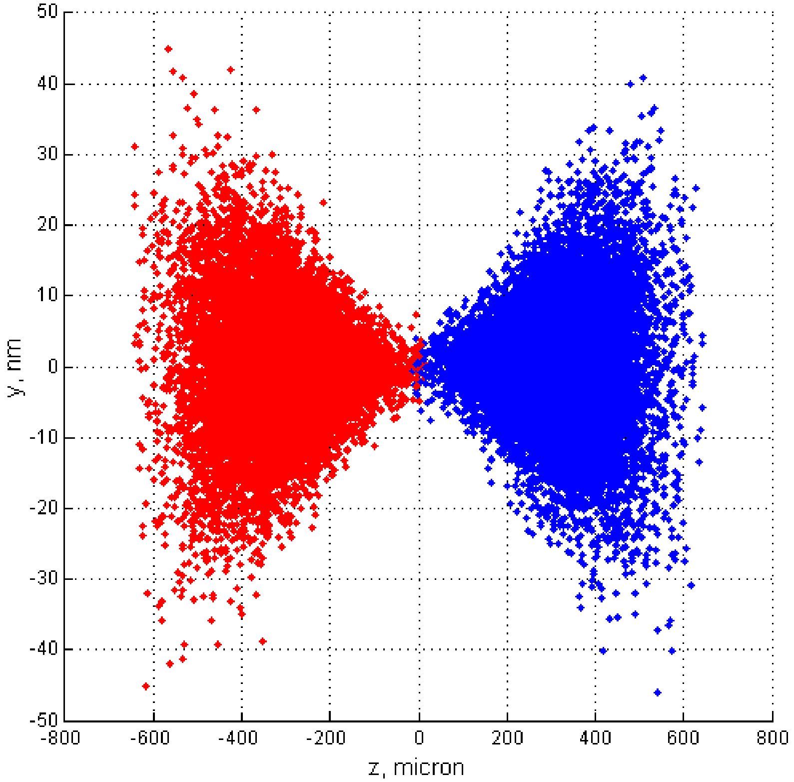
Beam-beam effects
H_D and instability



Nx2
D_y~24

Beam-beam instability is clearly pronounced

Luminosity enhancement is compromised by higher sensitivity to initial offsets



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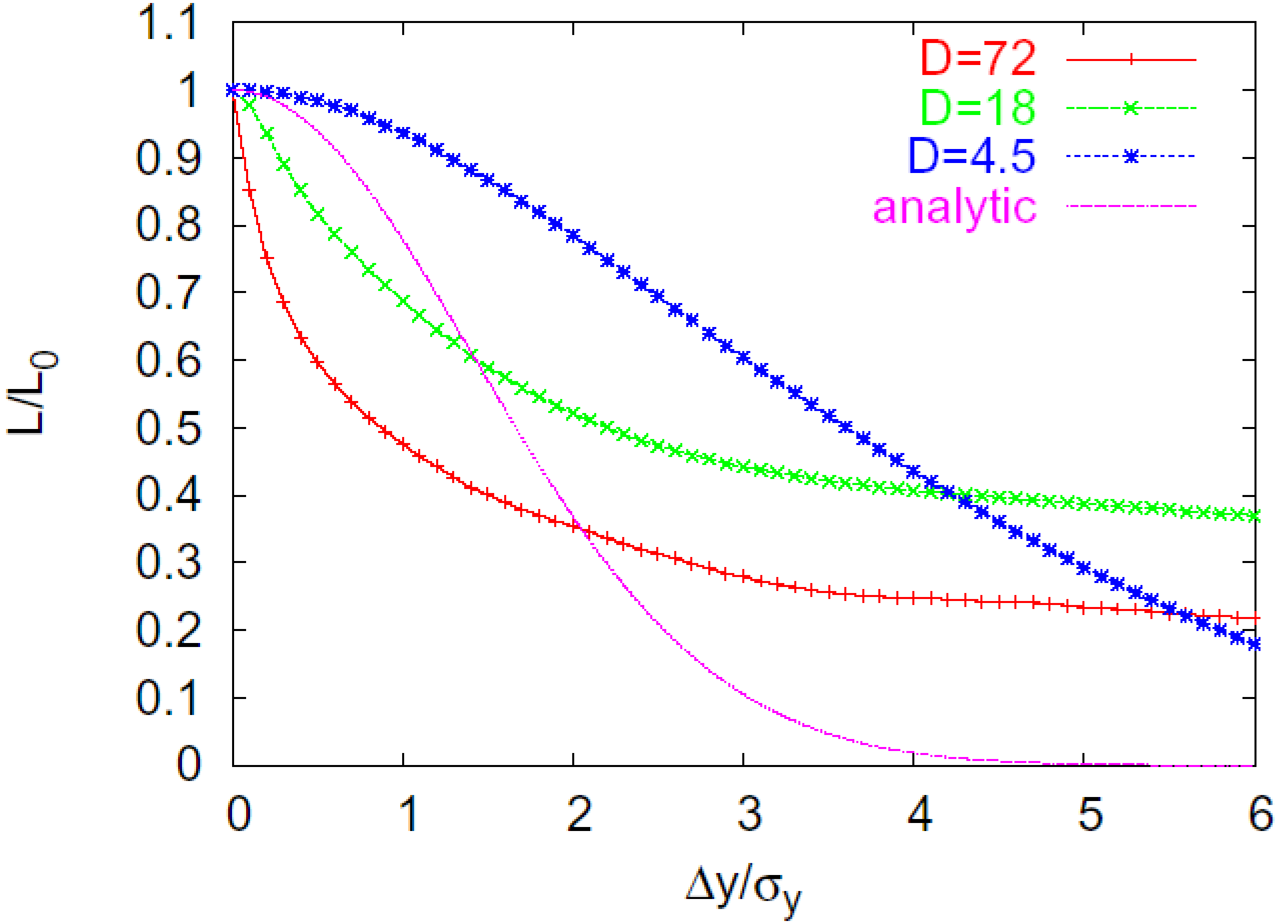
z, micron

Sensitivity to offset at IP



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

Beamstrahlung

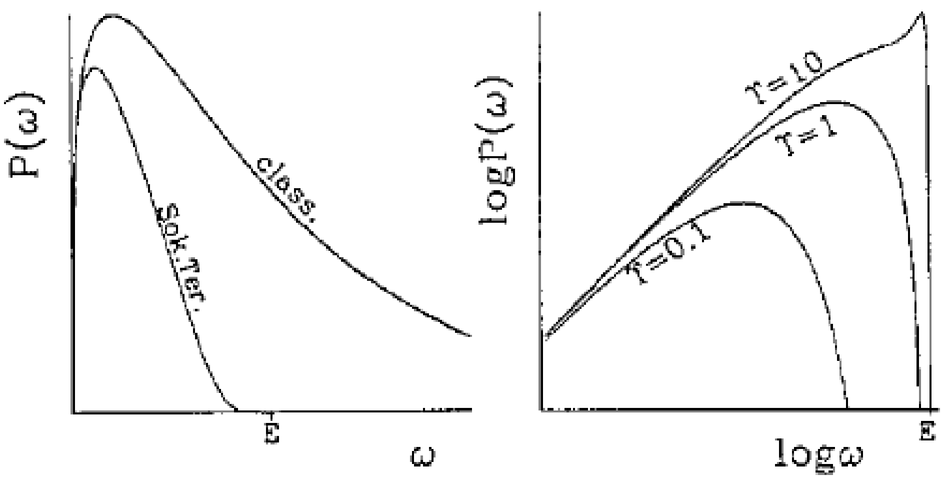
- Synchrotron radiation in field of opposite bunch
- Estimate R of curvature as R ~ $\sigma_z^2/(D_y\sigma_y)$
- Using formulas derived earlier, estimate ω_c and find that $h\omega_c/E \sim \gamma N r_e^2/(\alpha\sigma_x\sigma_z)$ and call it "Upsilon"

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

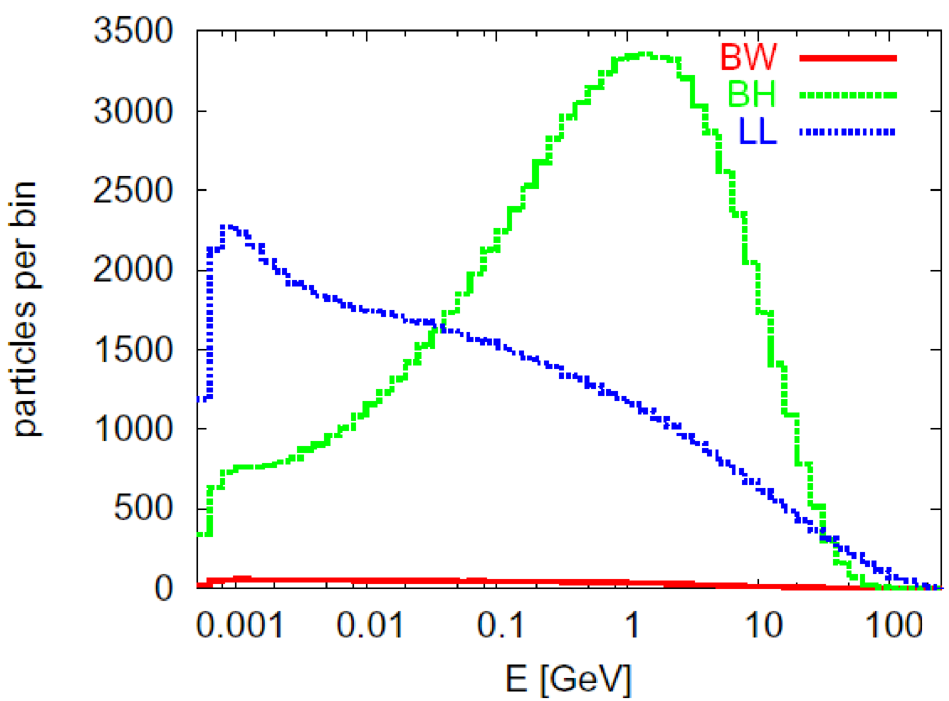
Classical and quantum regime

- 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 …

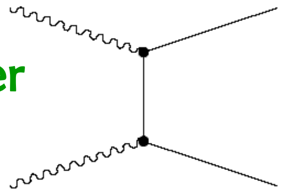


Incoherent* production of pairs

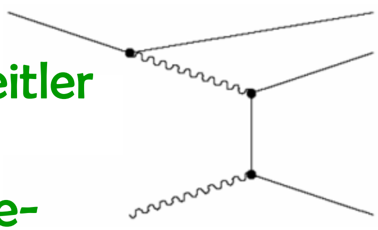
- Beamstrahling photons, particles of beams or virtual photons interact, and create e+e- pairs



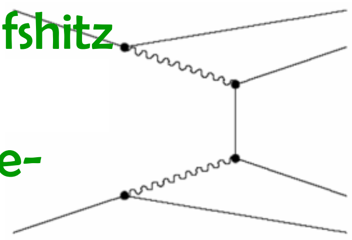
Breit-Wheeler process
$\gamma\gamma \rightarrow e+e-$



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

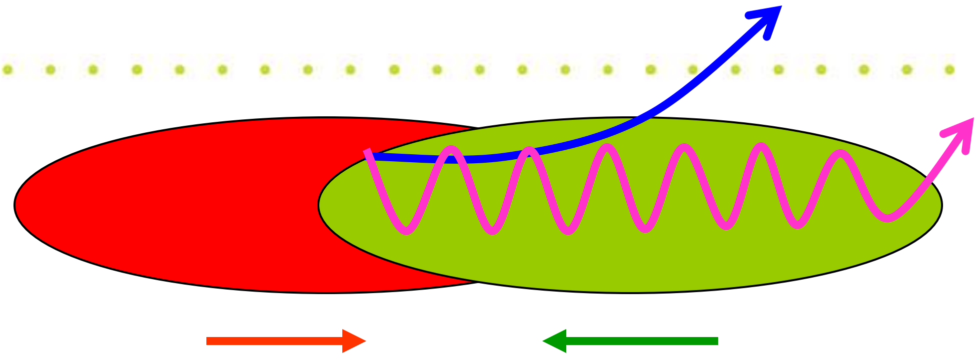


Landau-Lifshitz process
$ee \rightarrow eee+e-$



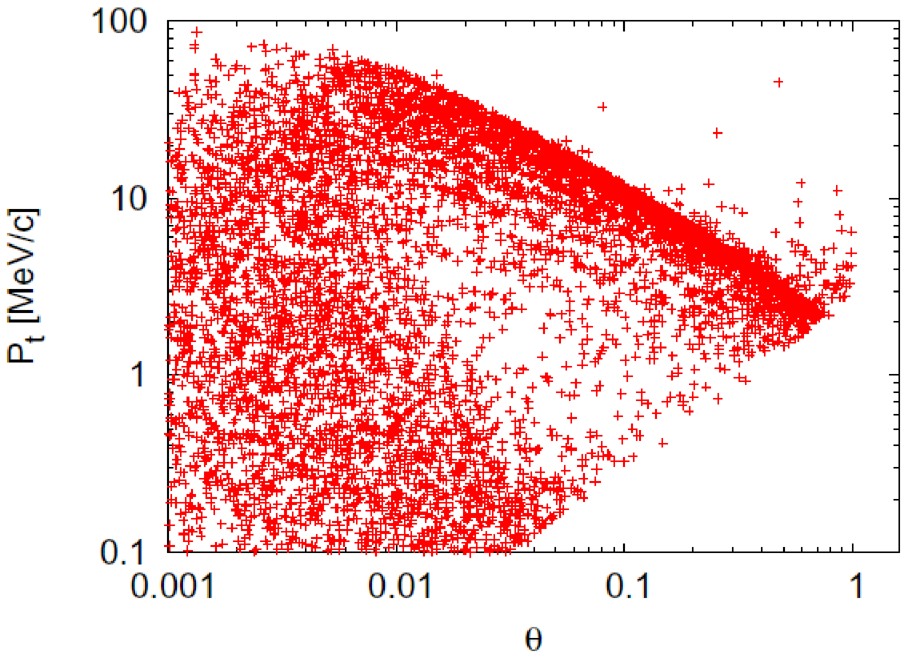
*) Coherent pairs are generated by photon in the field of opposite bunch. It is negligible for ILC parameters.

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):

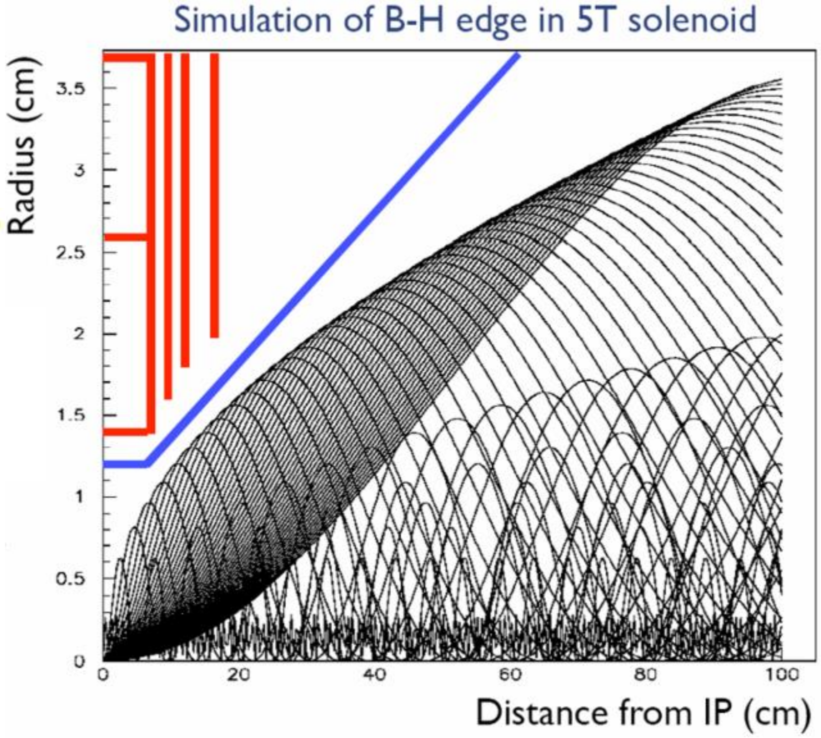
$$\theta_m = \sqrt{4\frac{\ln\left(\frac{D}{\epsilon}+1\right) D\sigma_x^2}{\sqrt{3}\epsilon\sigma_z^2}}$$

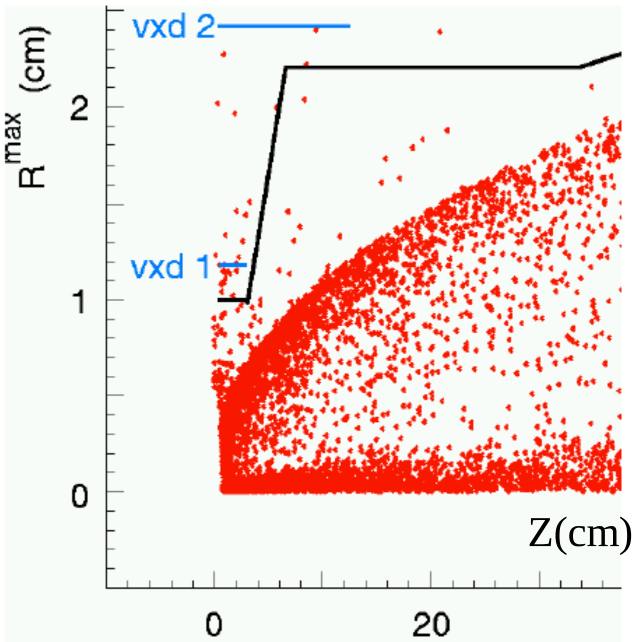


- Bethe-Heitler pairs have hard edge, Landau-Lifshitz pairs are outside

Deflection of pairs by detector solenoid

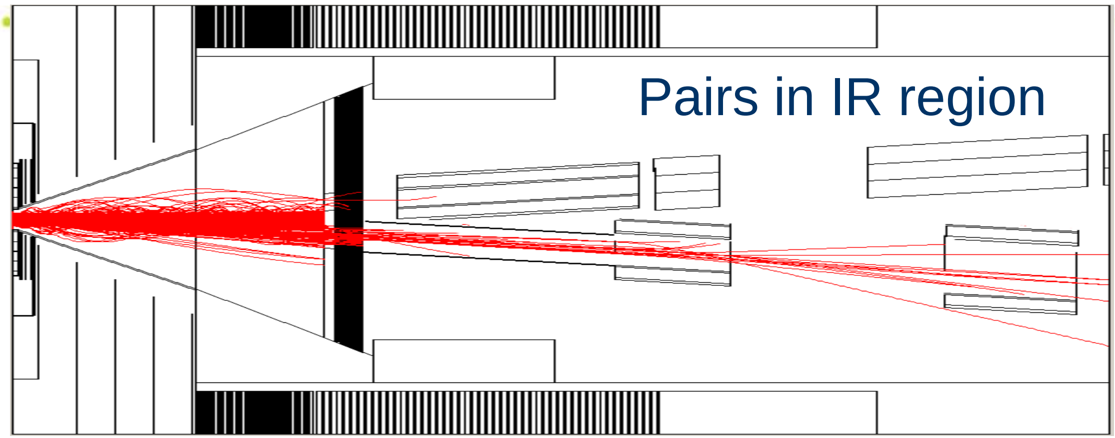
- Pairs are curled by the solenoid field of detector
- Geometry of vertex detector and vacuum chamber chosen in such a way that most of pairs (B-H) do not hit the apertures
- Only small number (L-L) of pairs would hit the VX apertures

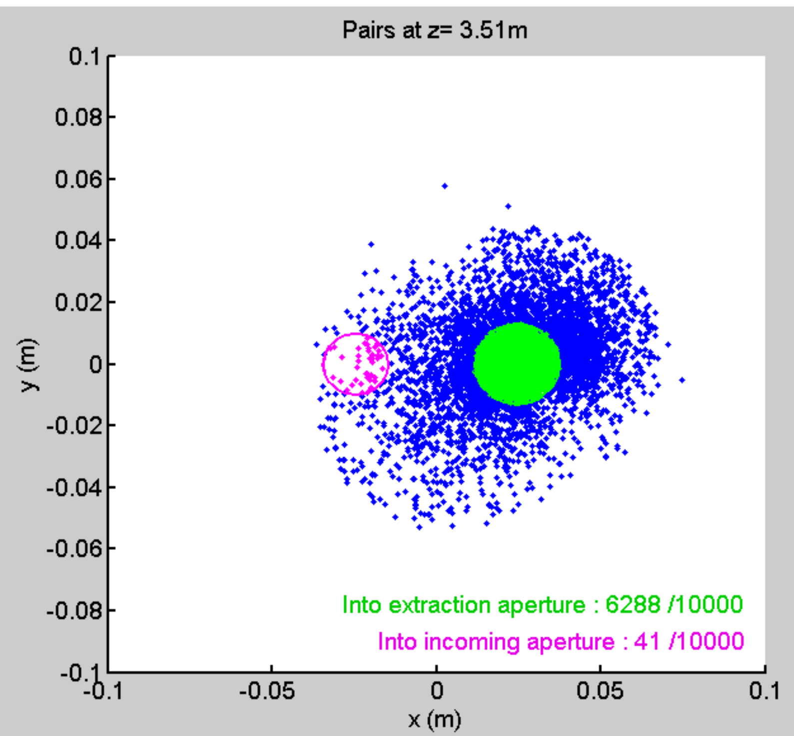


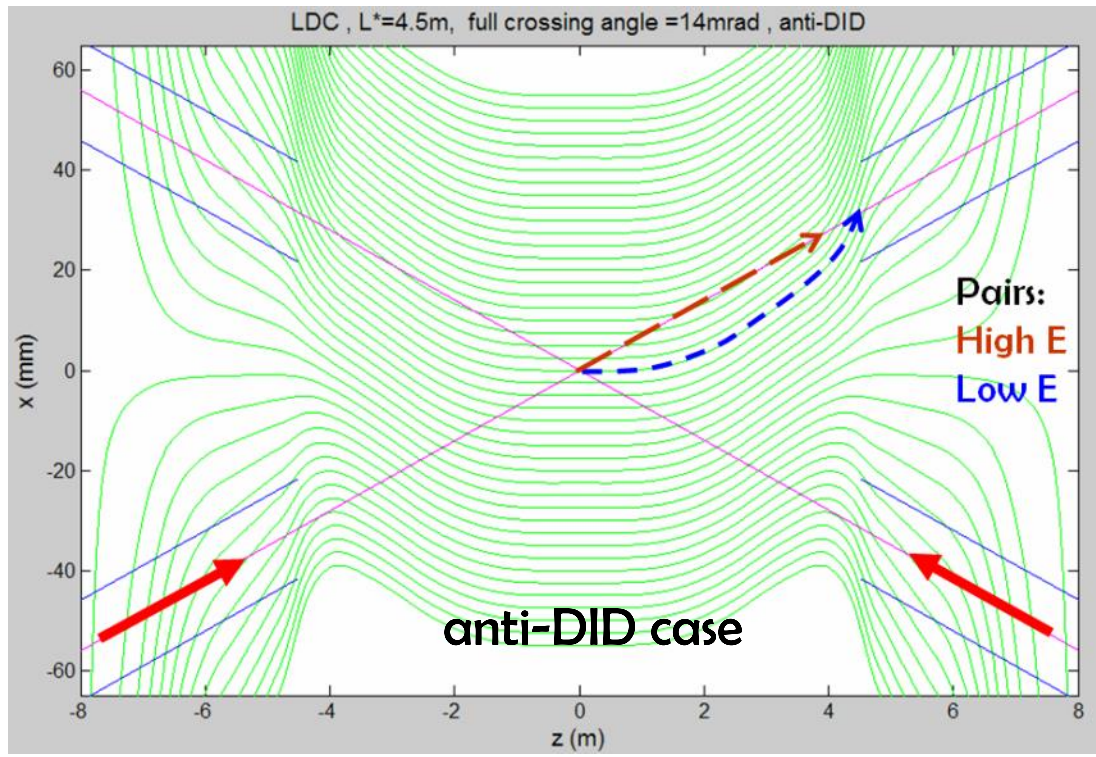


Use of anti-DID to direct pairs

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)

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

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

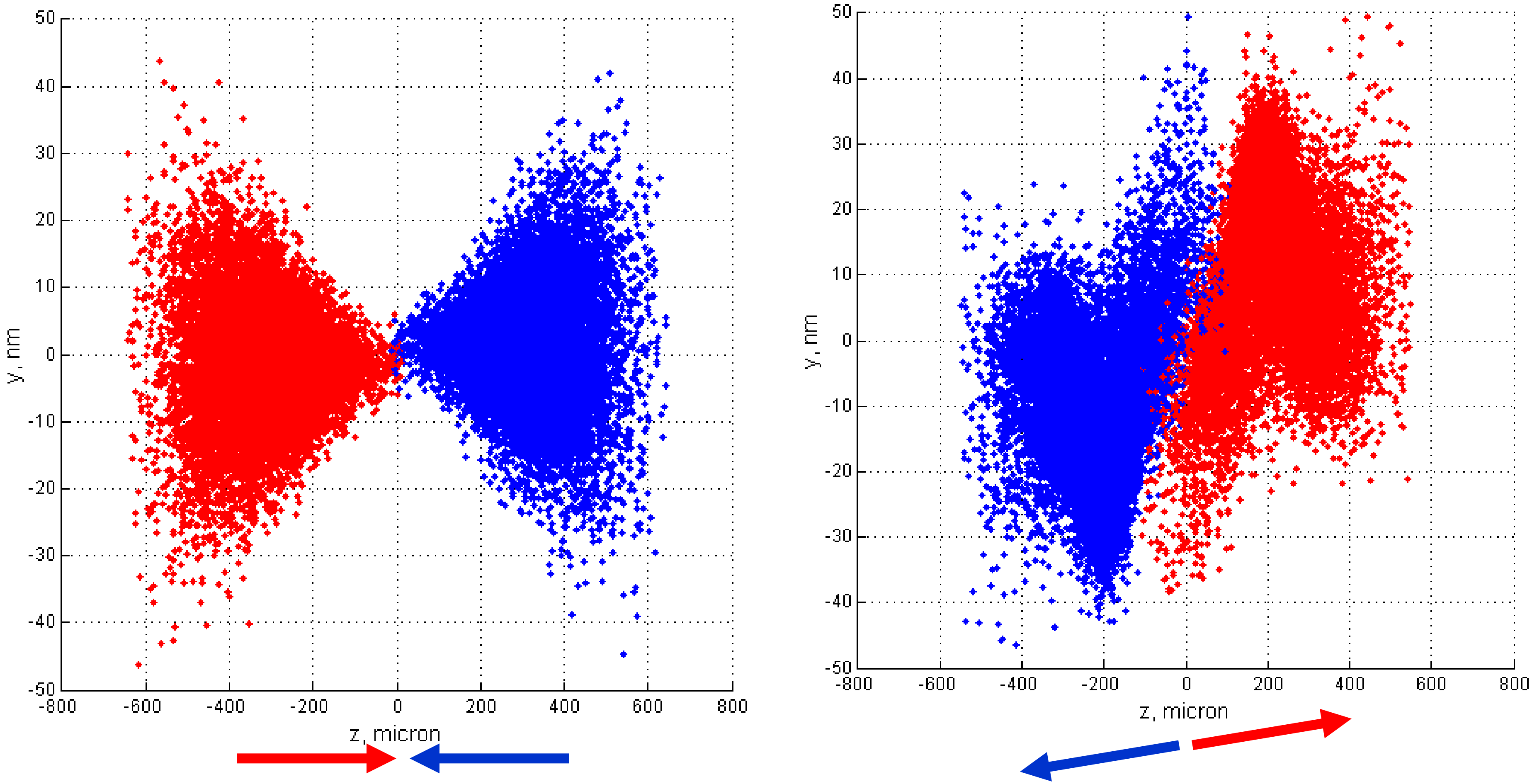
$$\delta_E \sim \frac{N^2 \gamma}{\sigma_x^2\,\sigma_z}$$

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

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

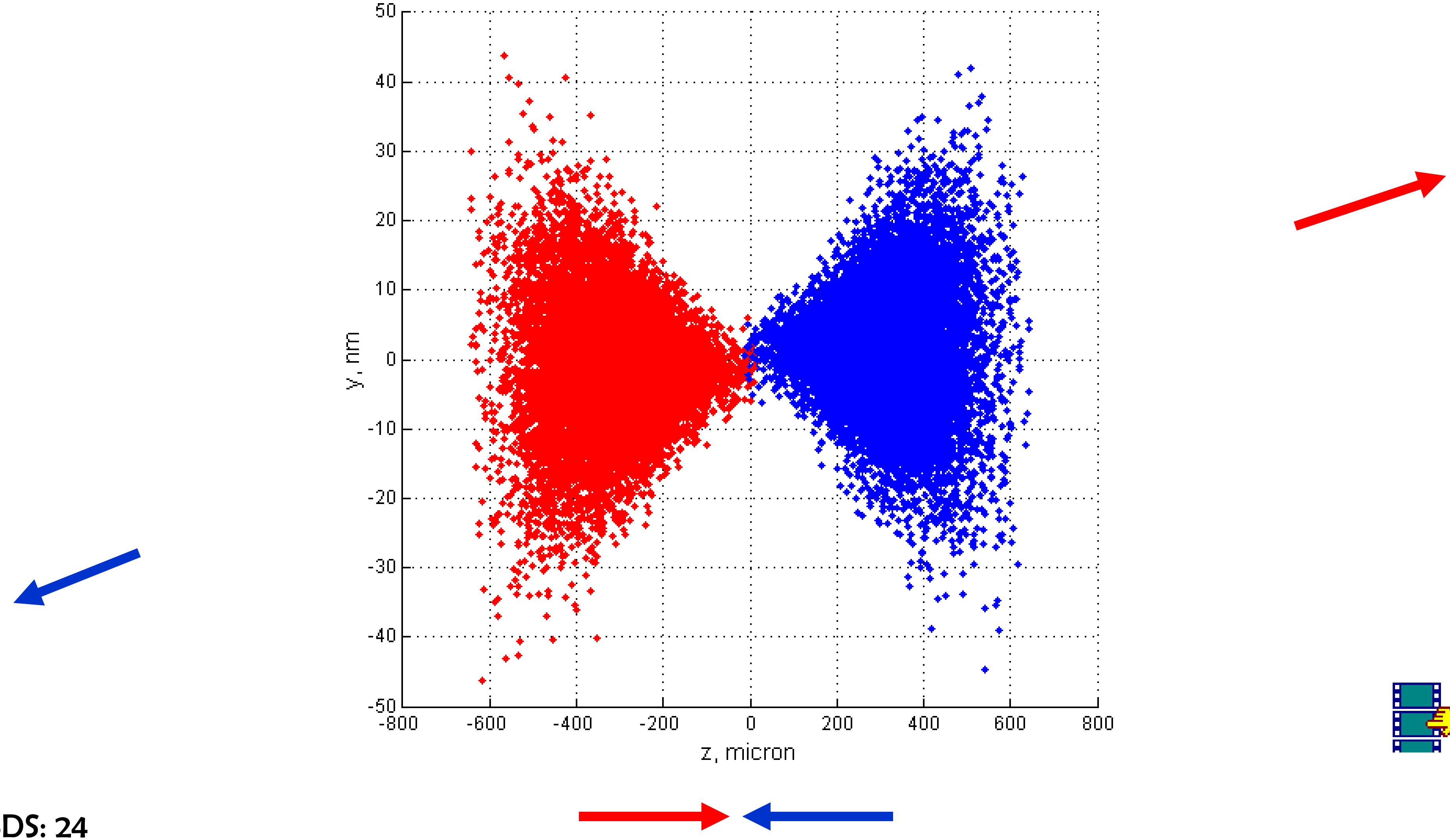
- Ratio of critical photon energy to beam energy (classic or quantum regime)

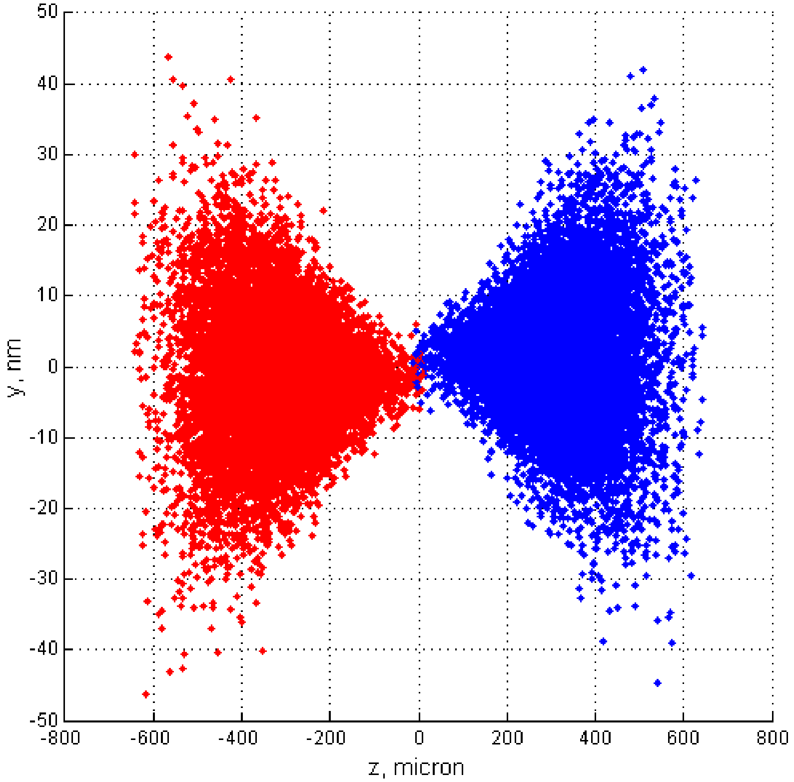
Beam-beam deflection



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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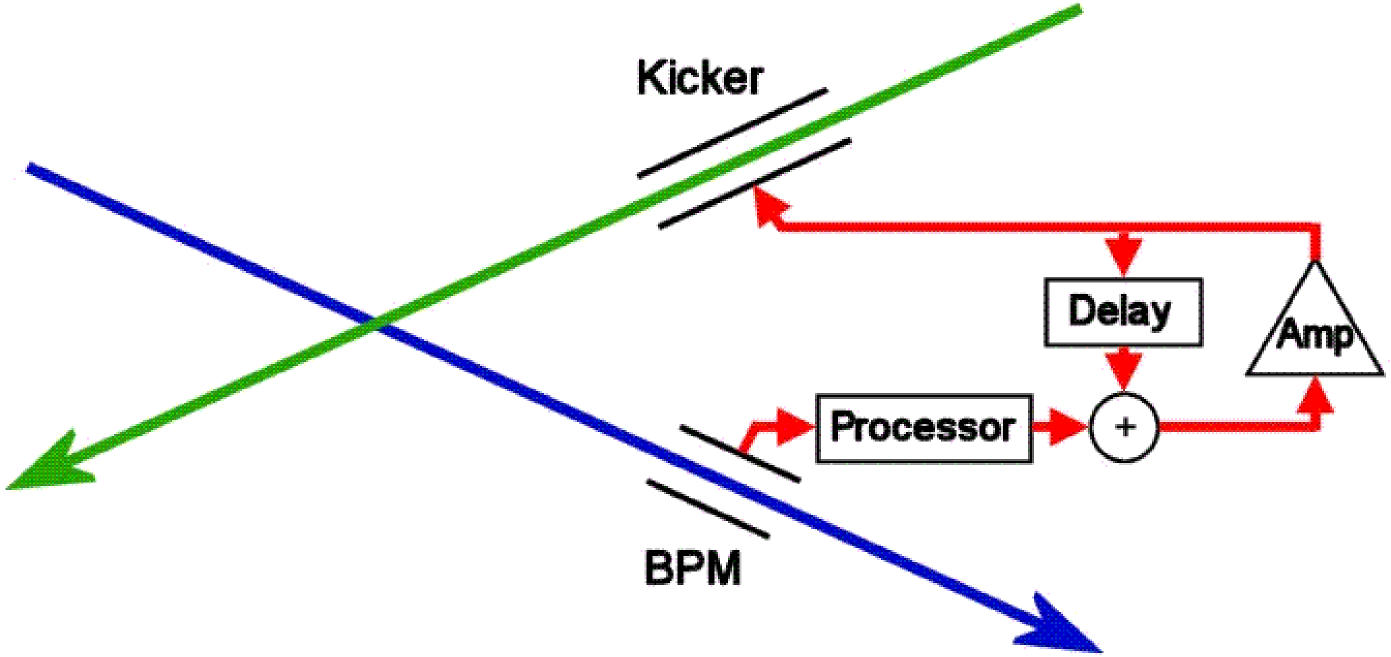
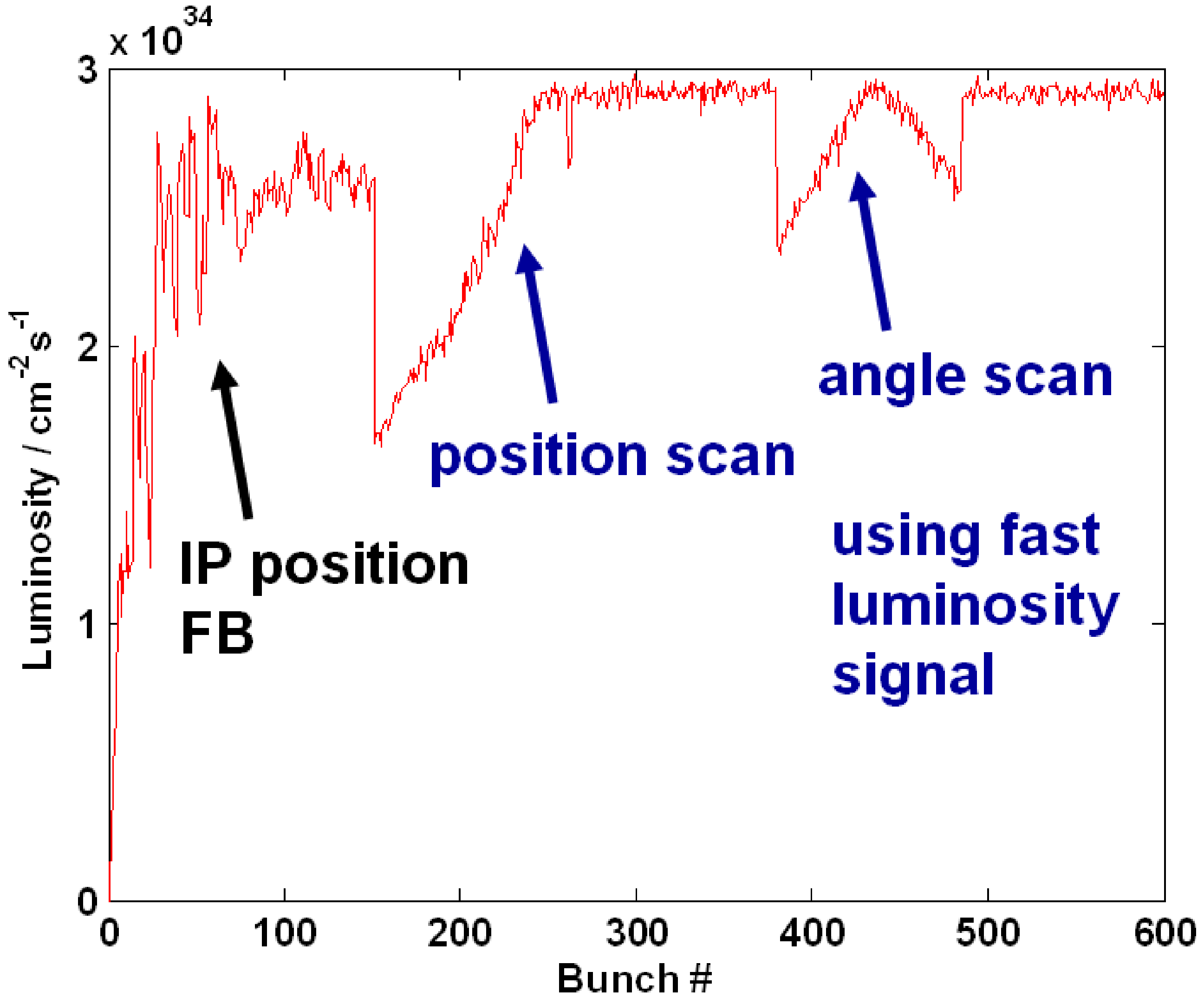
Beam-Beam orbit feedback



use strong beam-beam kick to keep beams colliding

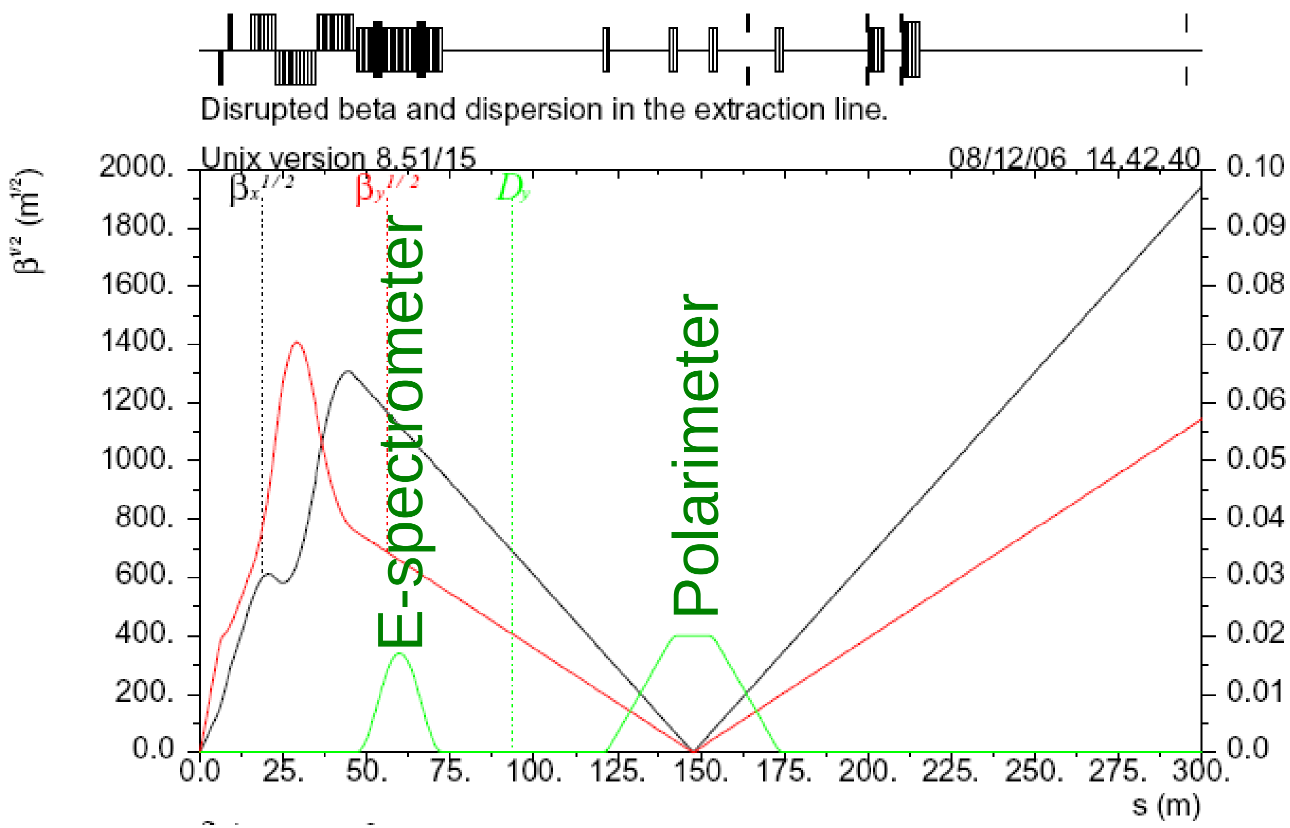
ILC intratrain simulation

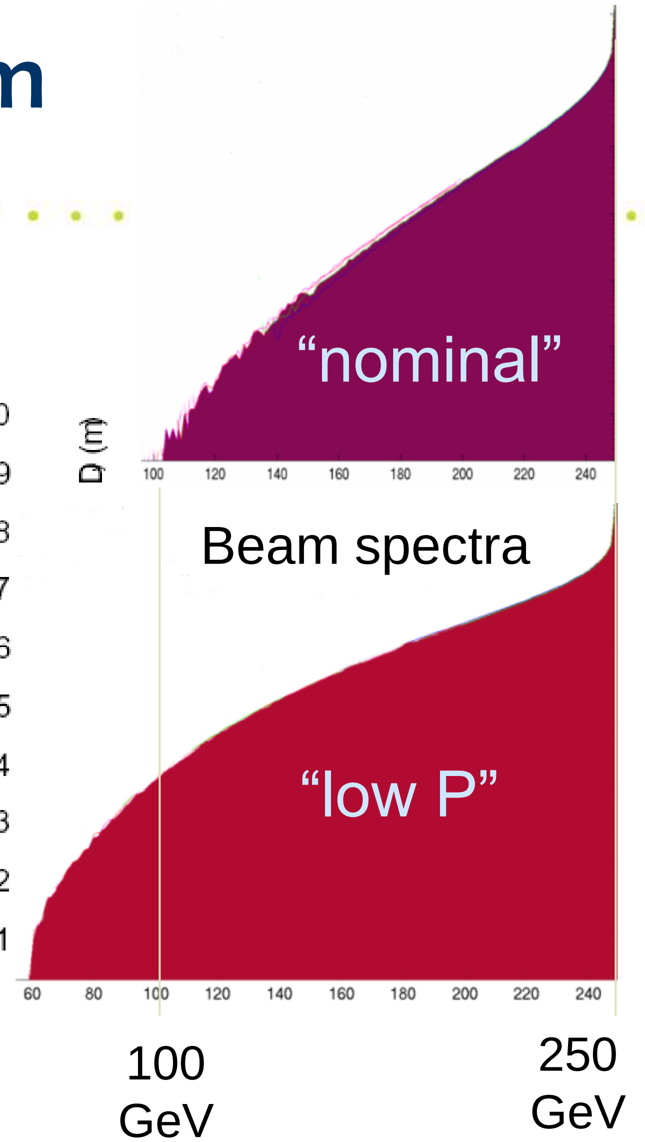
ILC intratrain feedback (IP position and angle optimization), simulated with realistic errors in the linac and “banana” bunches.



[Glen White]

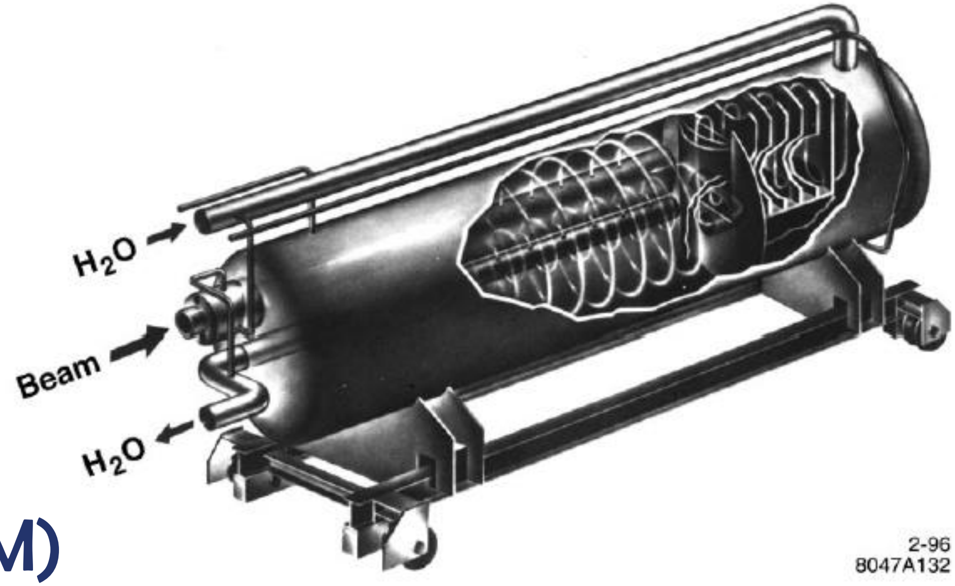
Optics for outgoing beam





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

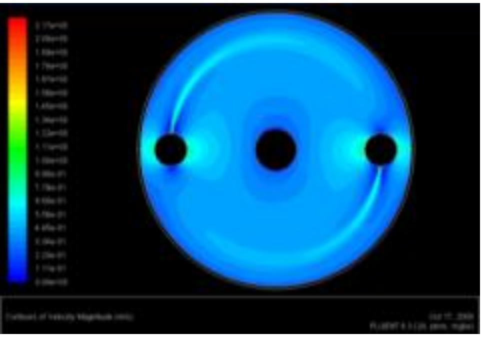
Beam dump



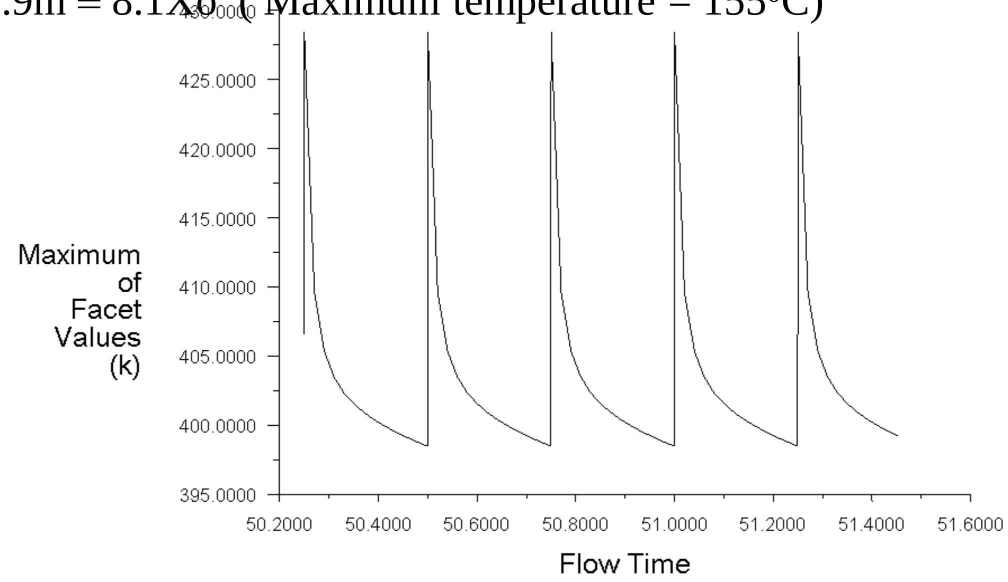
- 17MW power (for 1TeV CM)
- Rastering of the beam on 30cm double window
- 6.5m water vessel; ~1m/s flow
- 10atm pressure to prevent boiling
- Three loop water system
- Catalytic H_2-O_2 recombiner
- Filters for 7Be
- Shielding 0.5m Fe & 1.5m concrete

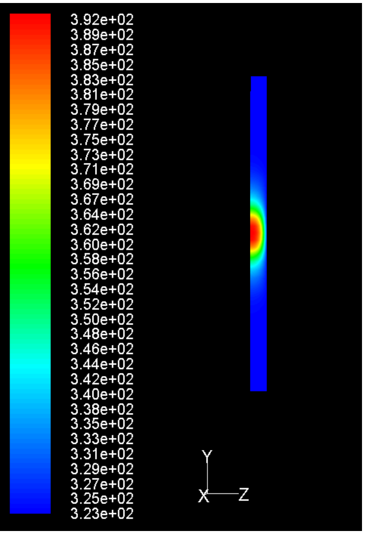
Beam dump design updates

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



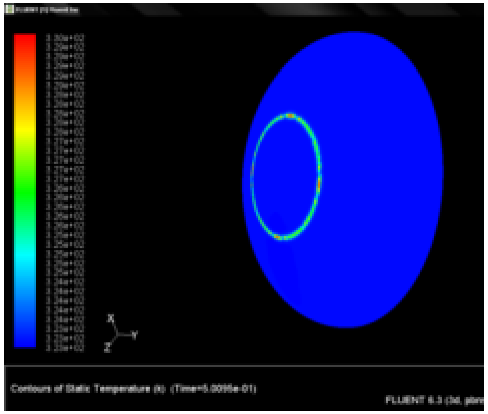
Velocity contours (inlet velocity: 2.17m/s, mass flux: 19kg/m/s)





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)

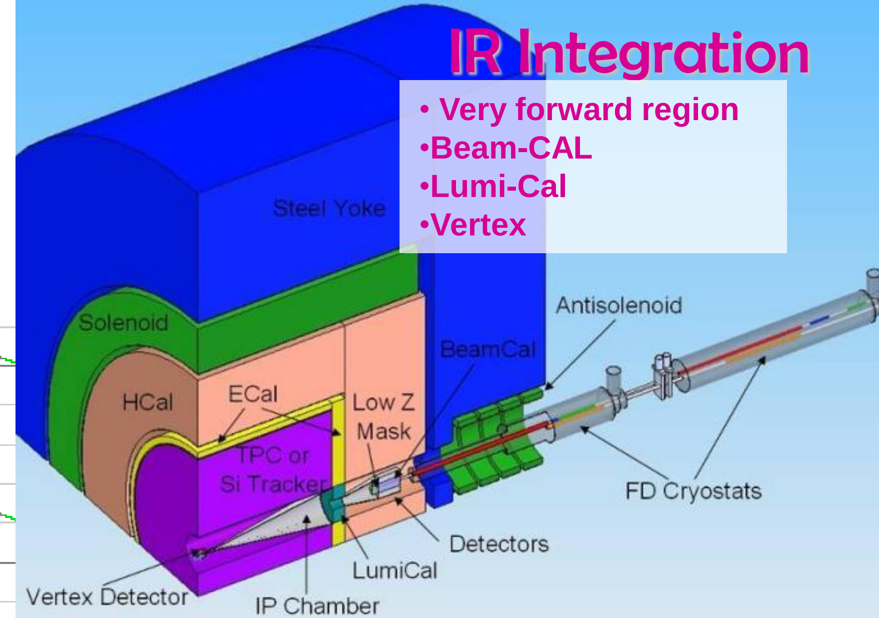


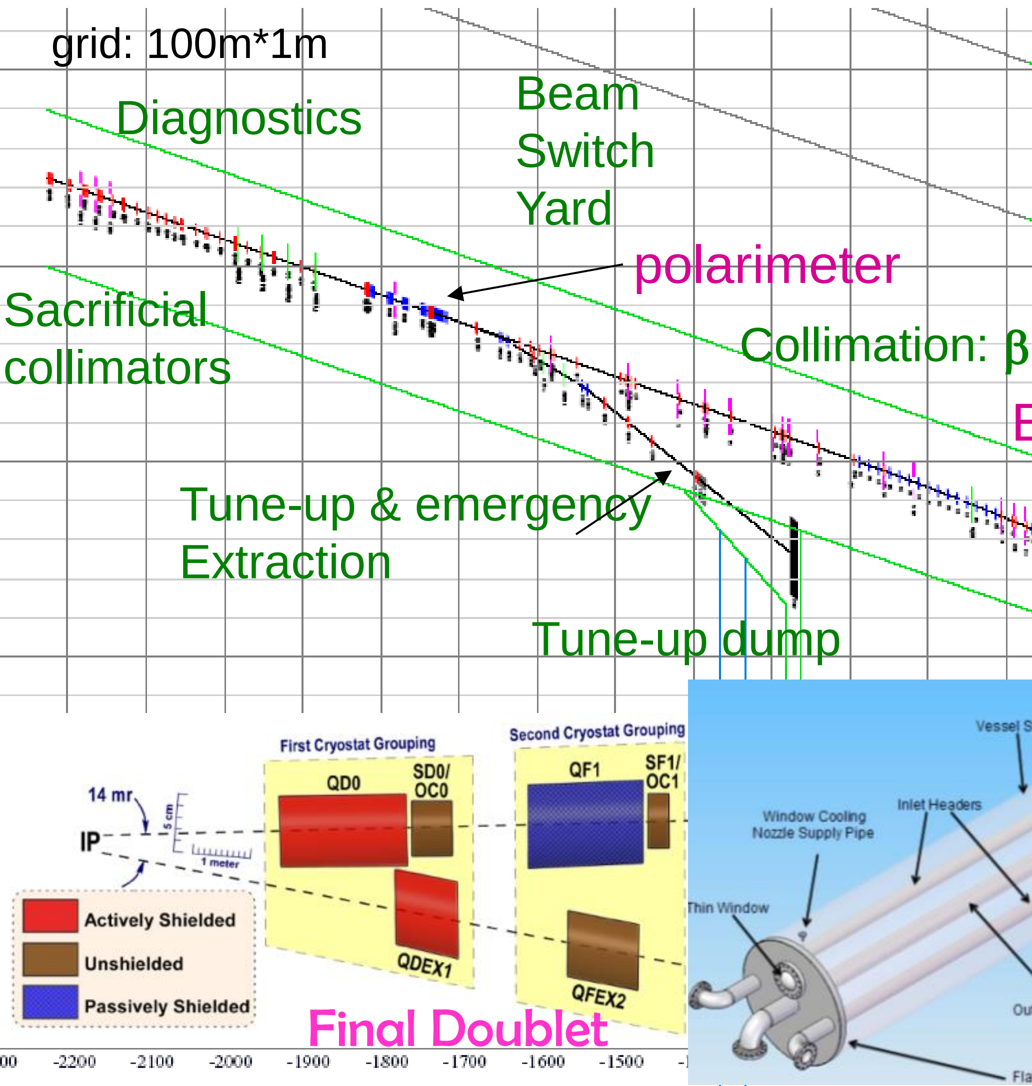
D. Walz , J. Amann, et al, SLAC
P. Satyamurthy, P. Rai, V. Tiwari, K. Kulkarni, BARC, Mumbai, India

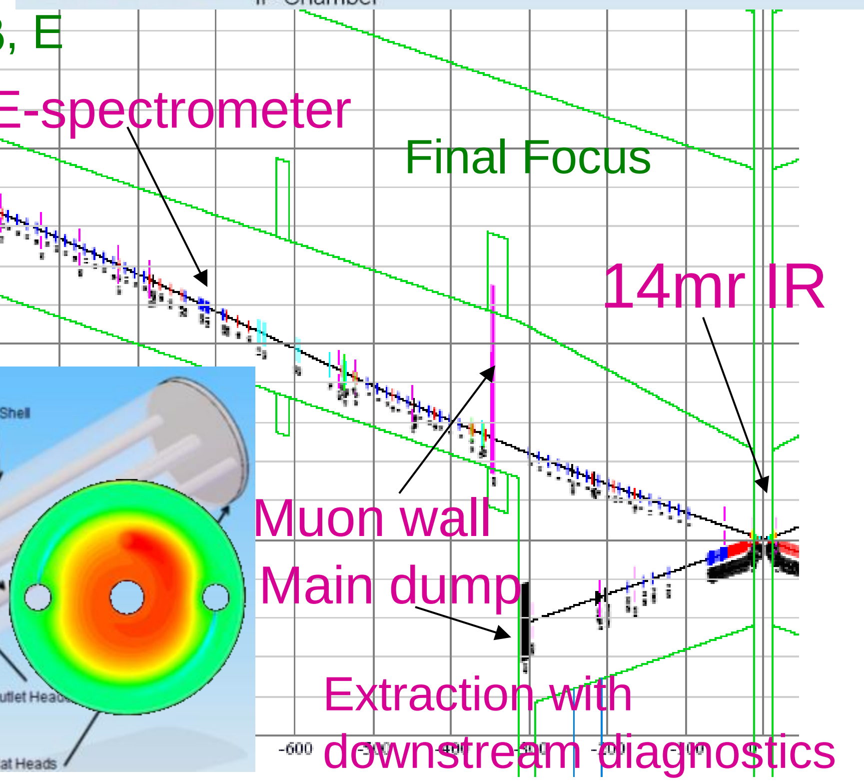
From IPAC10 paper

Beam Delivery & MDI elements

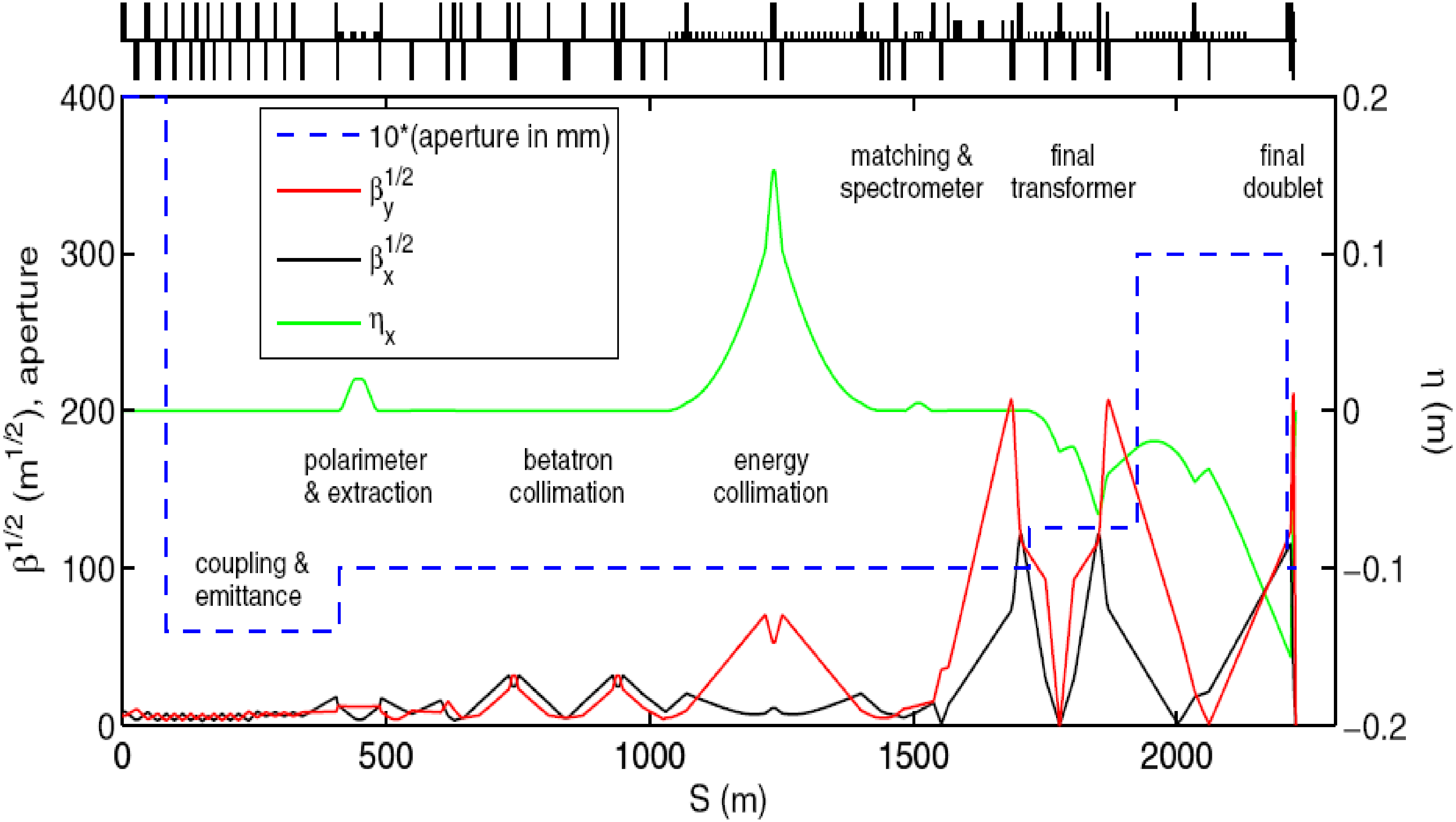
1TeV CM, single IR, two detectors, push-pull



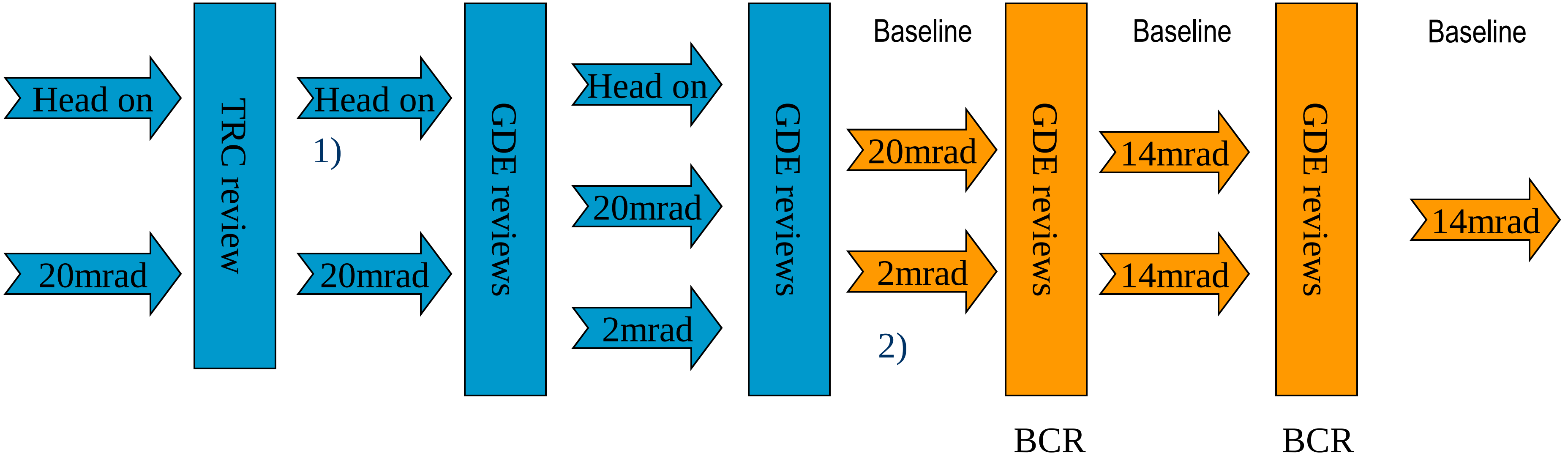




ILC BDS Optical Functions



BDS & MDI Configuration Evolution

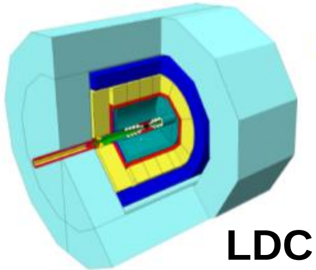


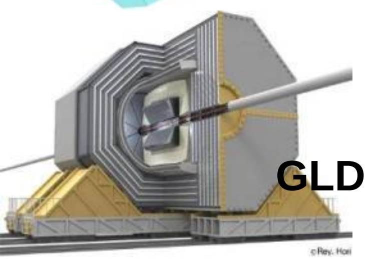
- **Evolution of BDS MDI configuration**
  - Head on; small crossing angle; large crossing angle

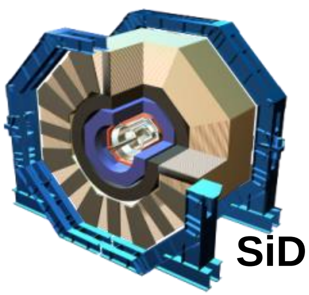
- MDI & Detector performance were the major criteria for selection of more optimal configuration at every review or decision point

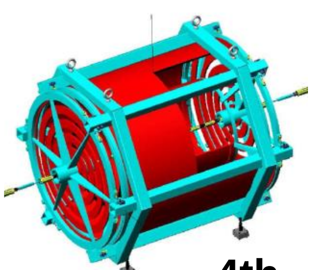
1) Found unforeseen losses of beamstrahlung photons on extraction septum blade
2) Identified issues with losses of extracted beam, and its SR; realized cost non-effectiveness of the design

Evolution of ILC Detectors









LDC → GLD → Merged to ILD design → ILD

SiD

4th

Thorough evaluation of performance, validation of the concepts

ILD validated

SiD validated

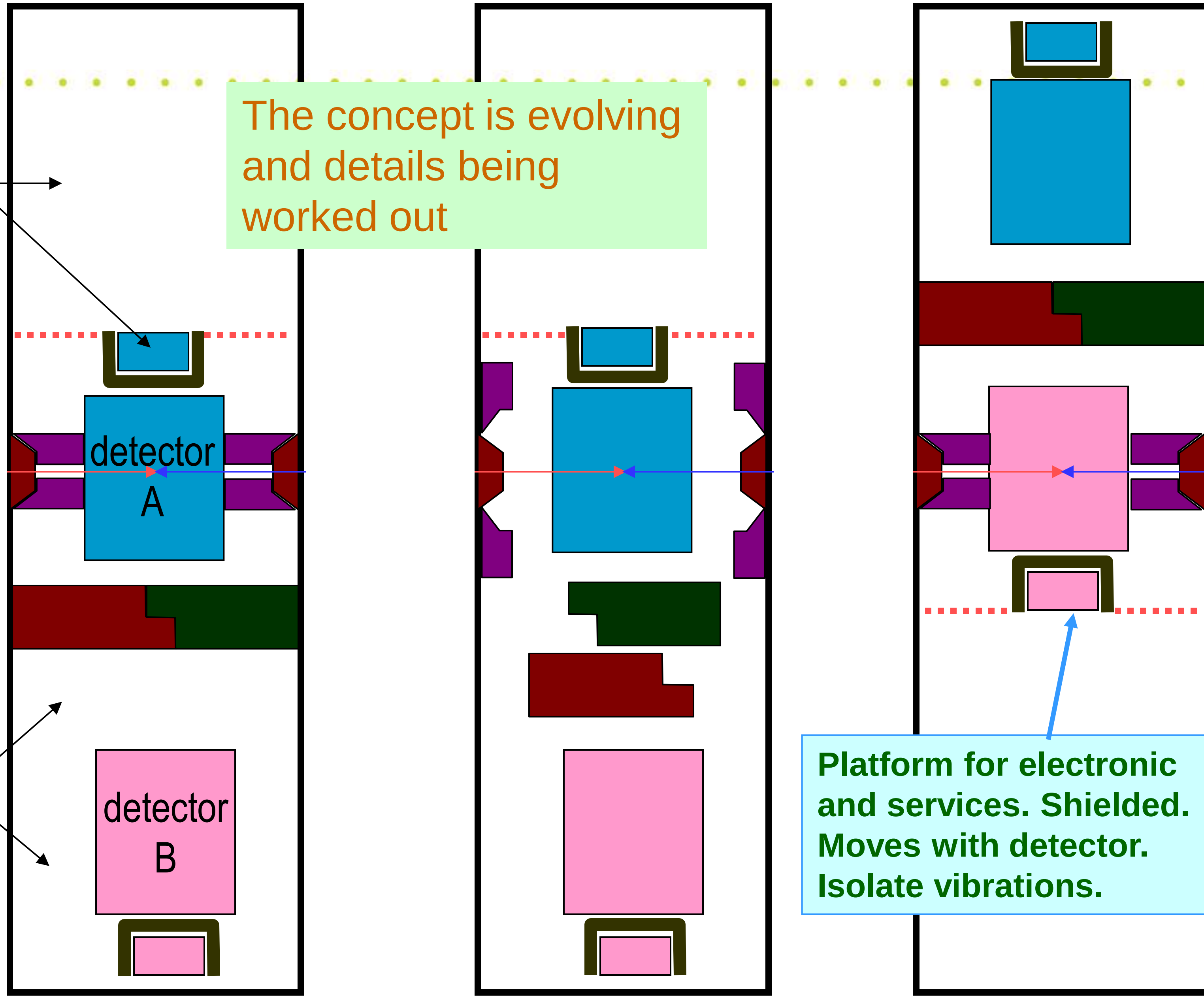
Technical design of detectors and R&D for critical sub-systems

- **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

may be accessible during run

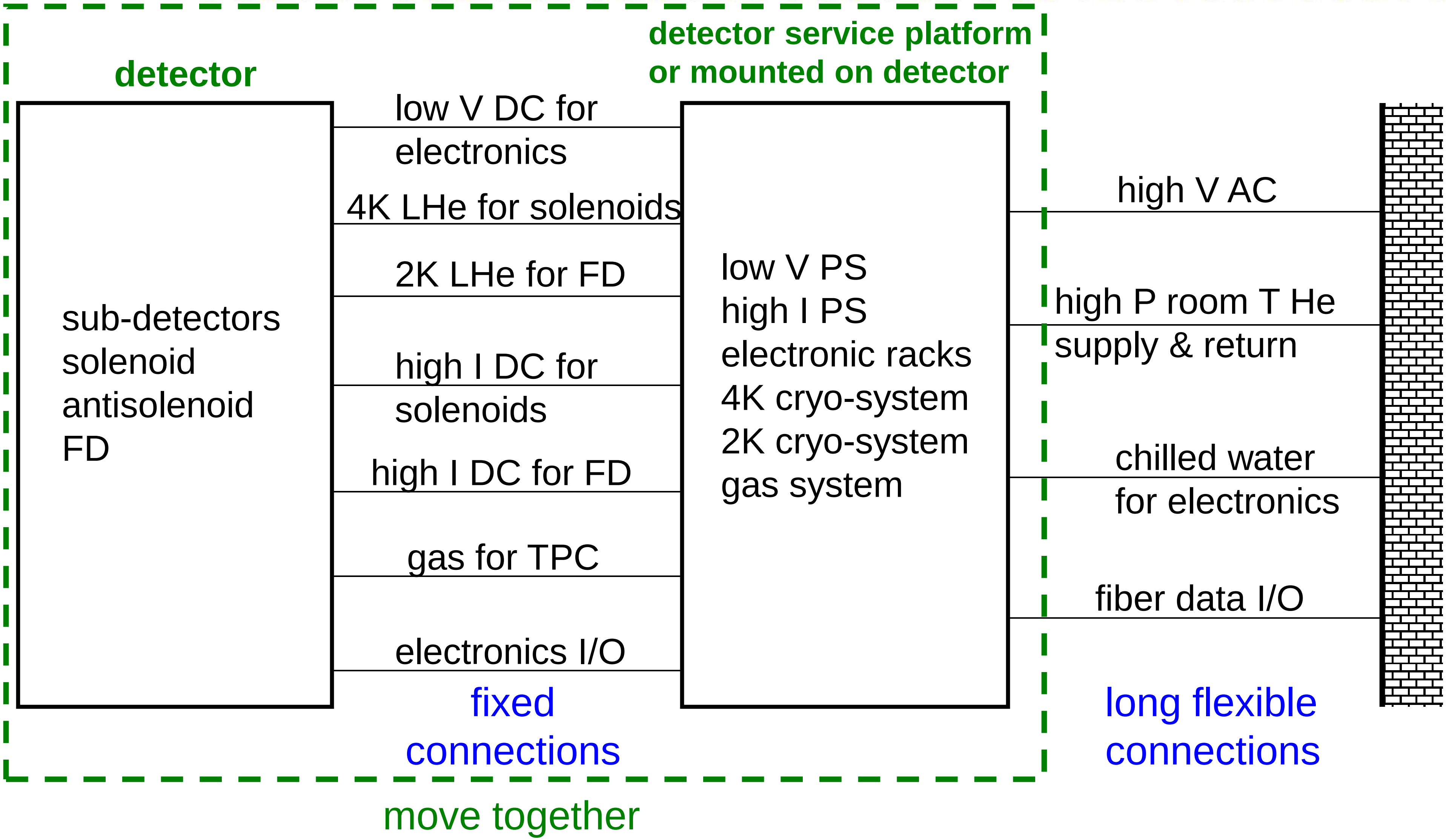
The concept is evolving and details being worked out



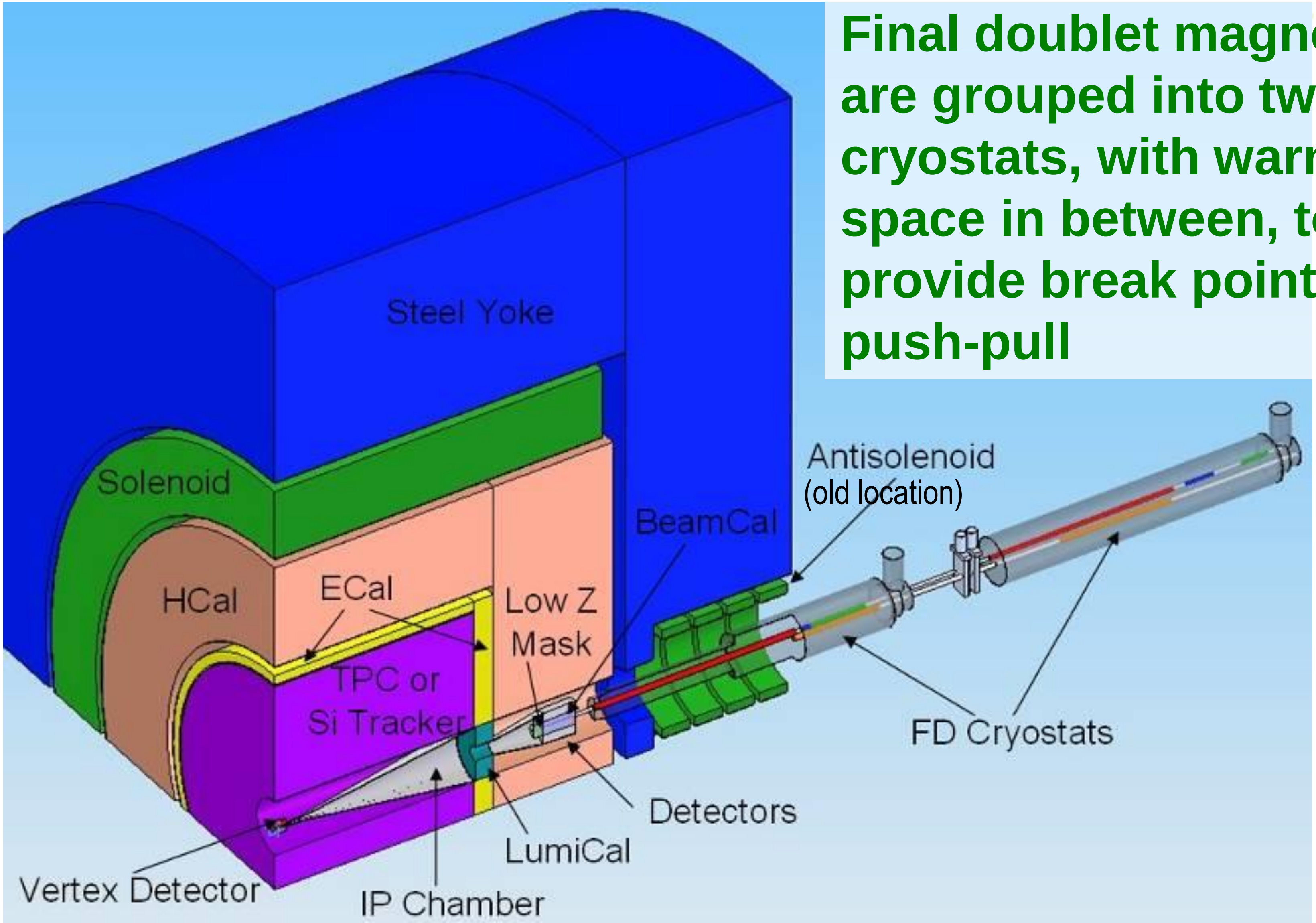
accessible during run

Platform for electronic and services. Shielded. Moves with detector. Isolate vibrations.

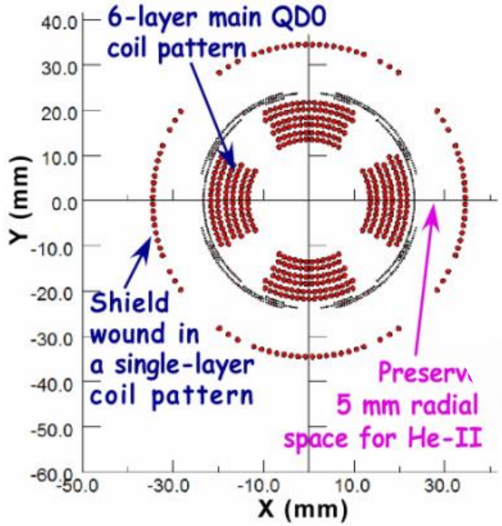
Concept of detector systems connections



IR integration

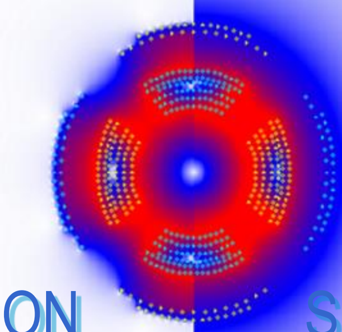


Final doublet magnets are grouped into two cryostats, with warm space in between, to provide break point for push-pull

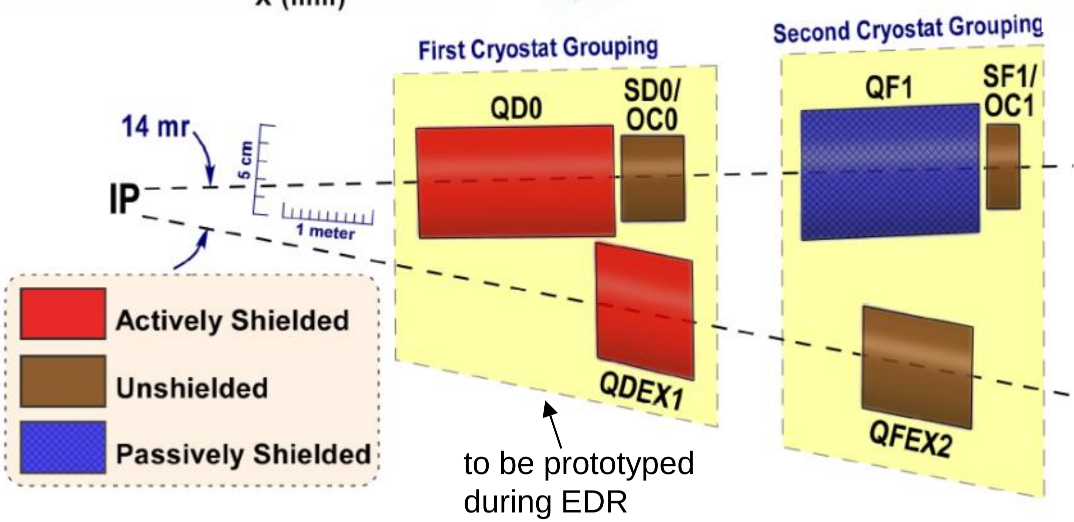


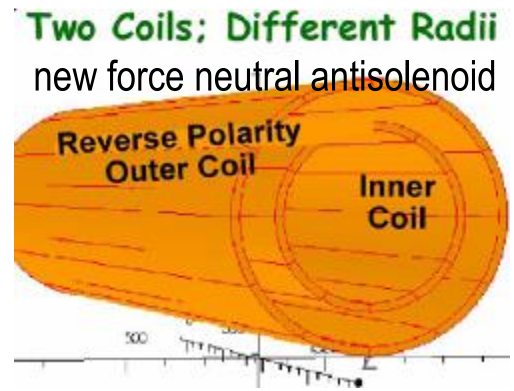
Actively shielded QD0

BNL



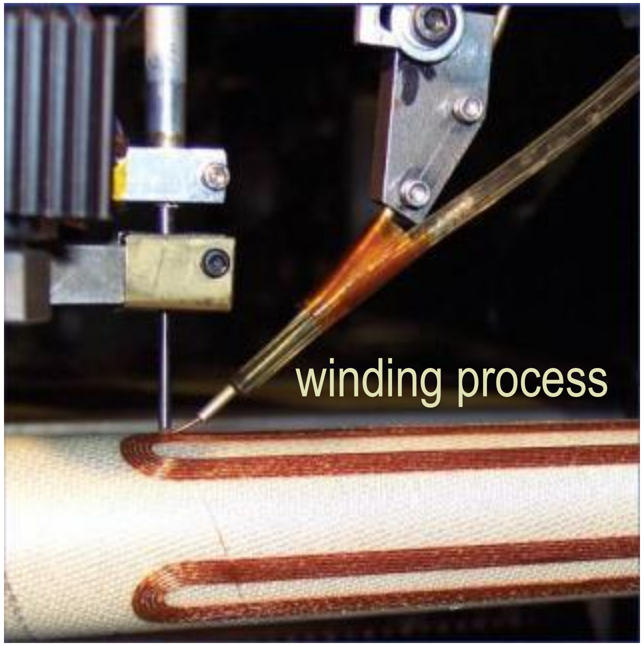
Intensity of color represents value of magnetic field.

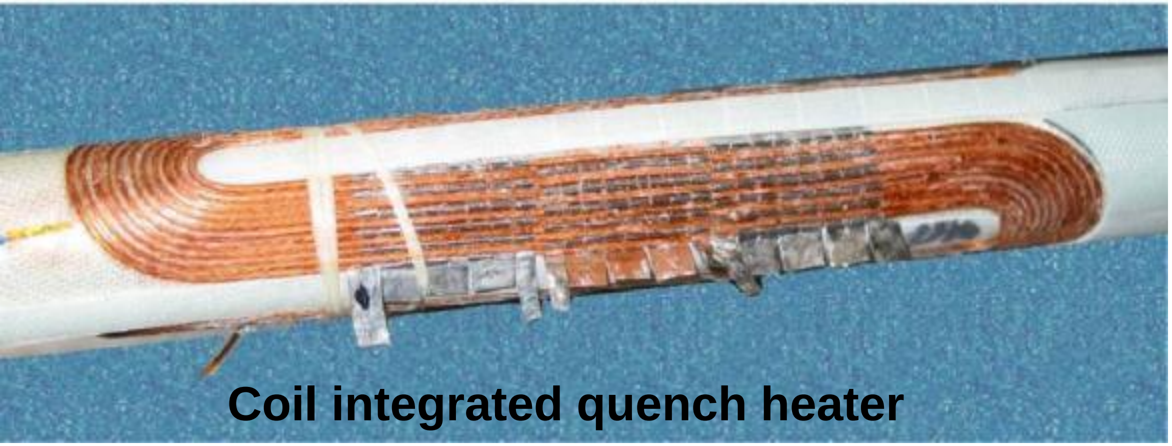


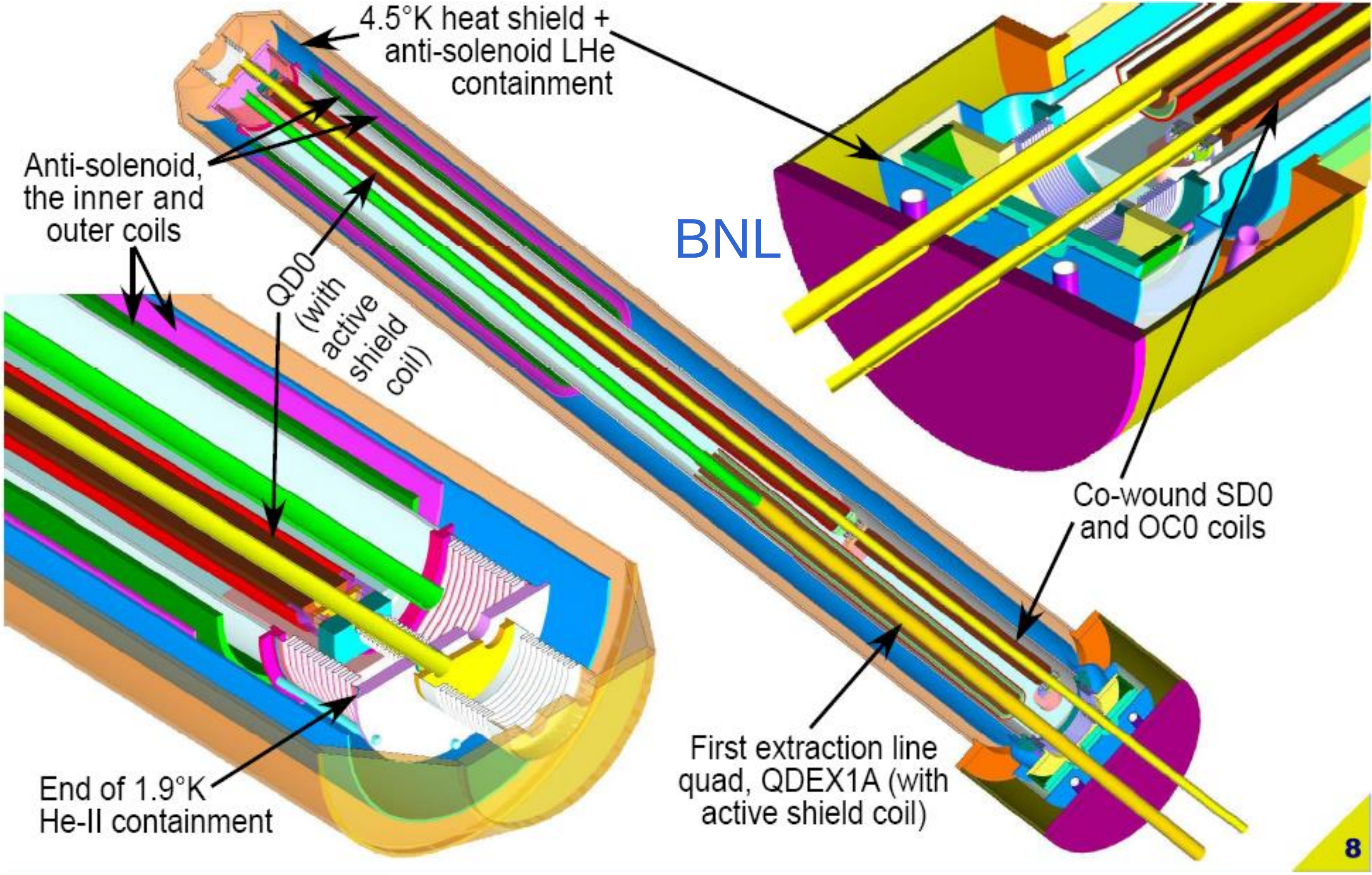


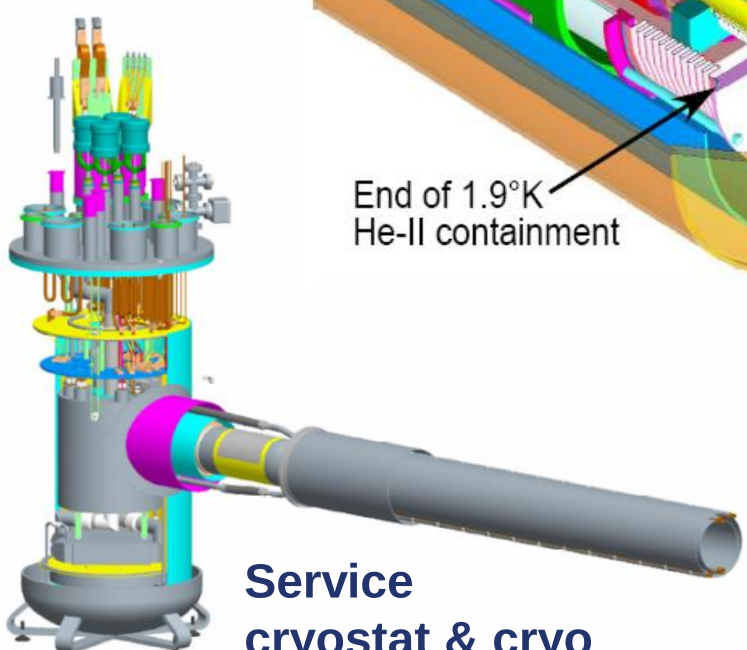
- Interaction region uses compact self-shielding SC magnets
- Independent adjustment of in- & out-going beamlines
- Force-neutral anti-solenoid for local coupling correction

IR magnets prototypes at BNL





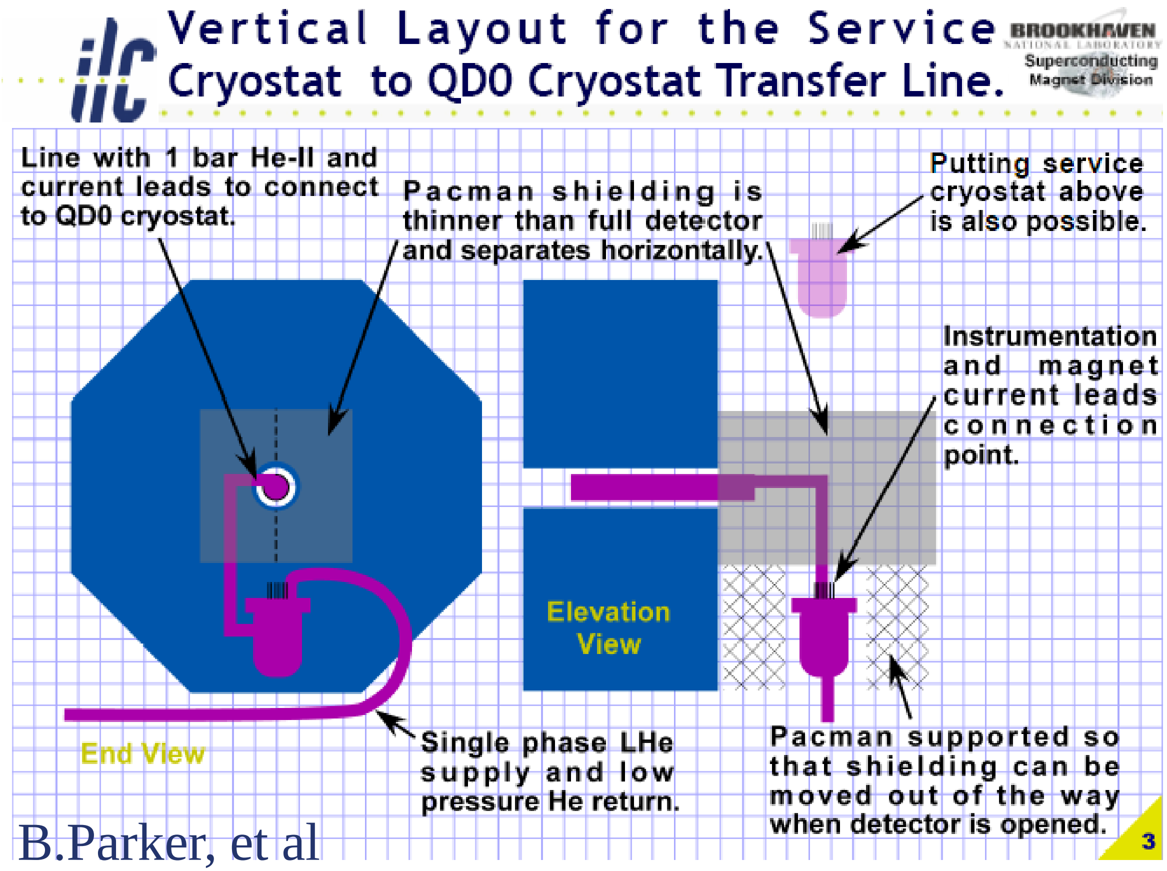


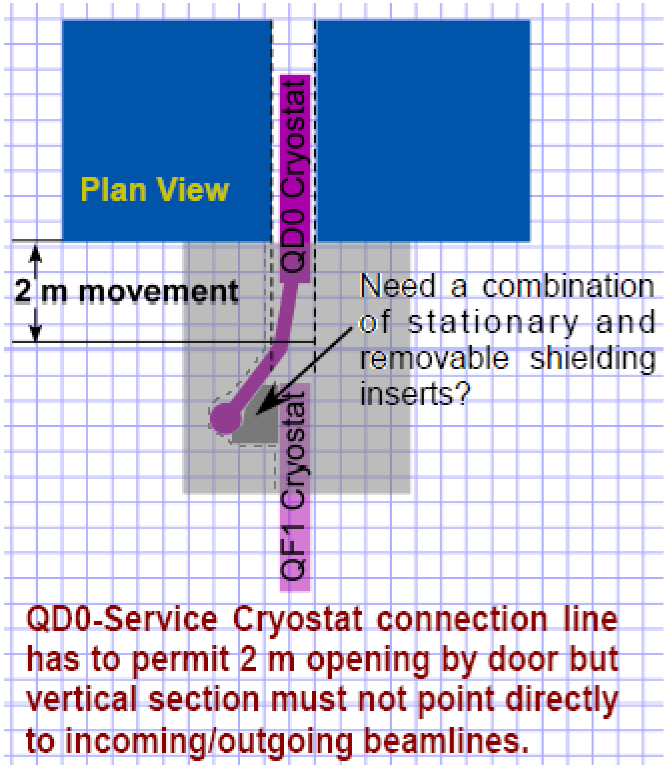


Service cryostat & cryo connections

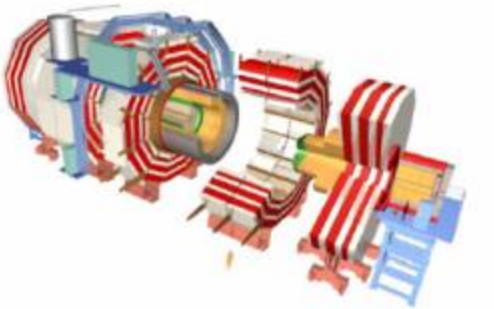
- **Detailed engineering design of IR magnets and their integration has started**

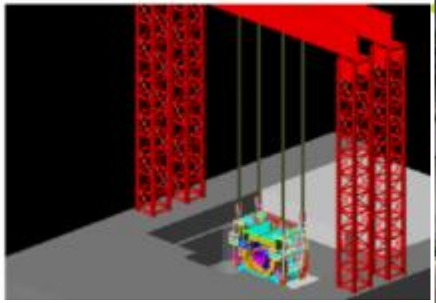
Present concept of cryo connection





Detector assembly

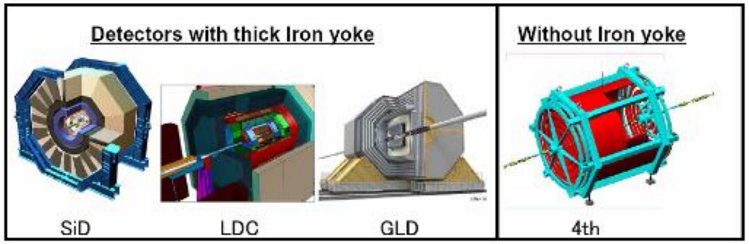


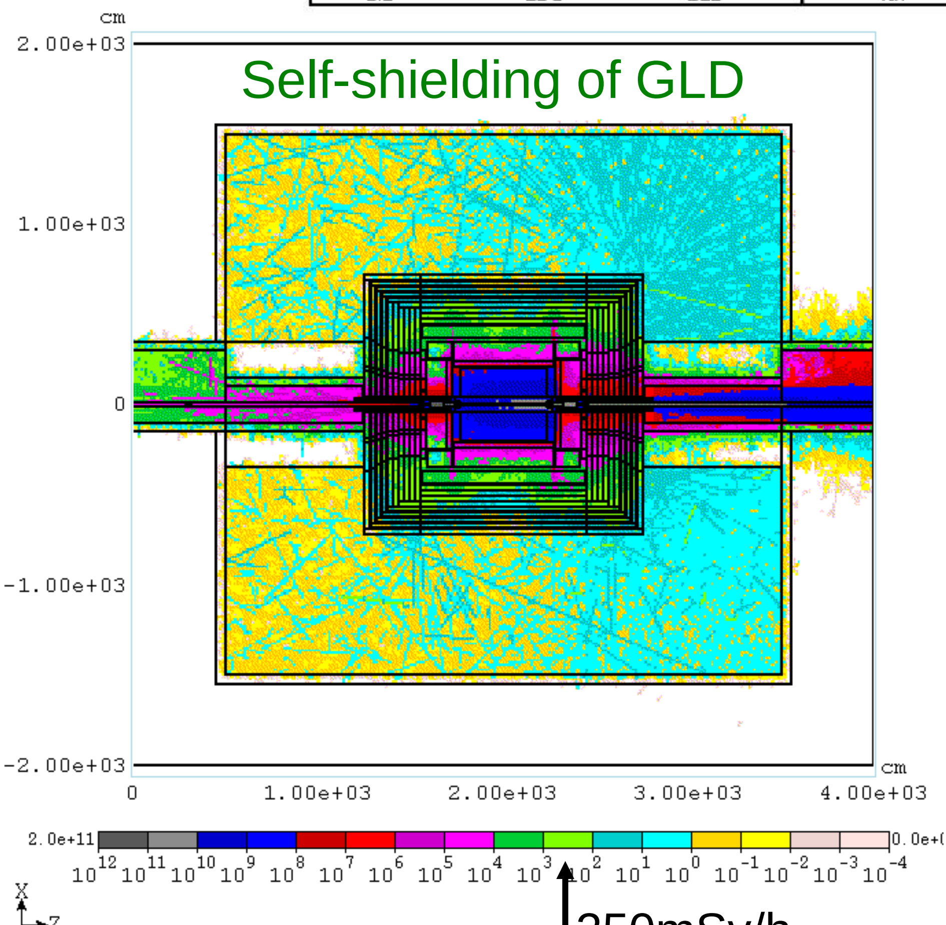


- CMS detector assembled on surface in parallel with underground work, lowered down with rented crane
- Adopted this method for ILC, to save 2-2.5 years that allows to fit into 7 years of construction

photos courtesy CERN colleagues

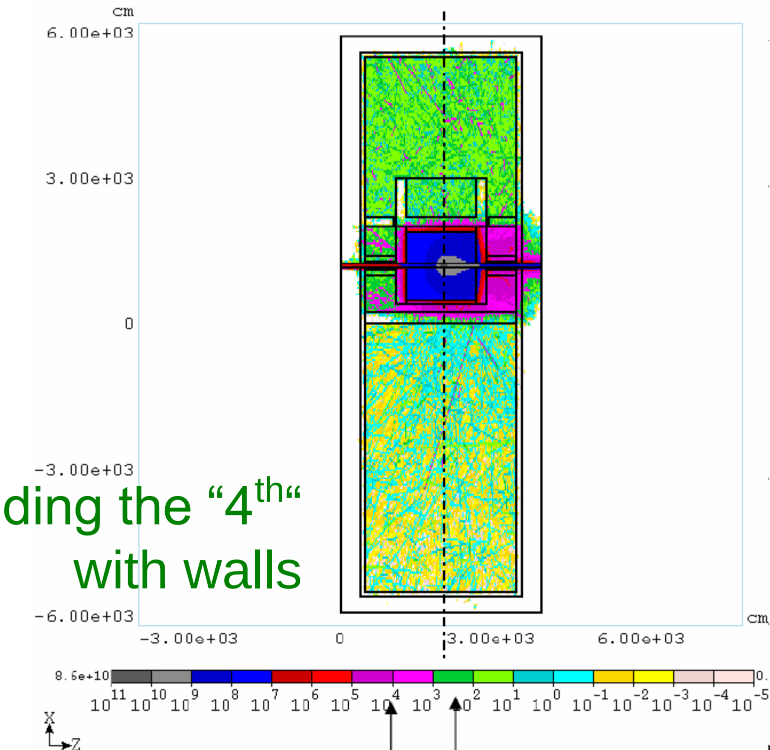
Shielding the IR hall



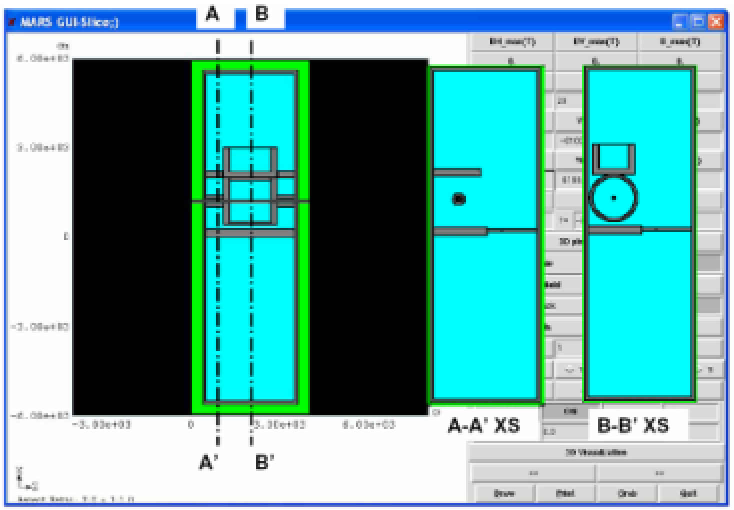


250mSv/h

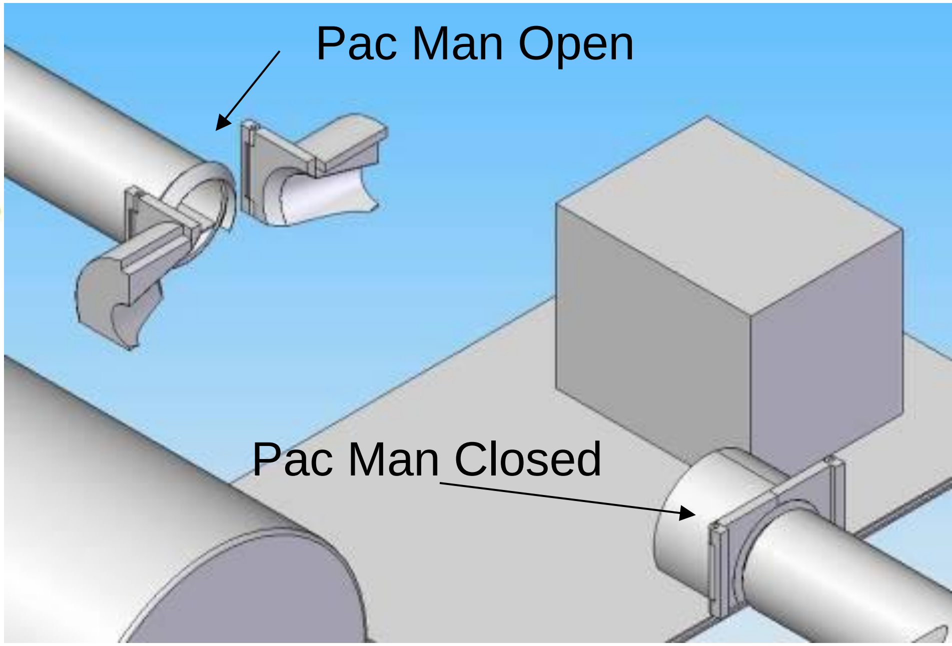
Shielding the "4th" with walls

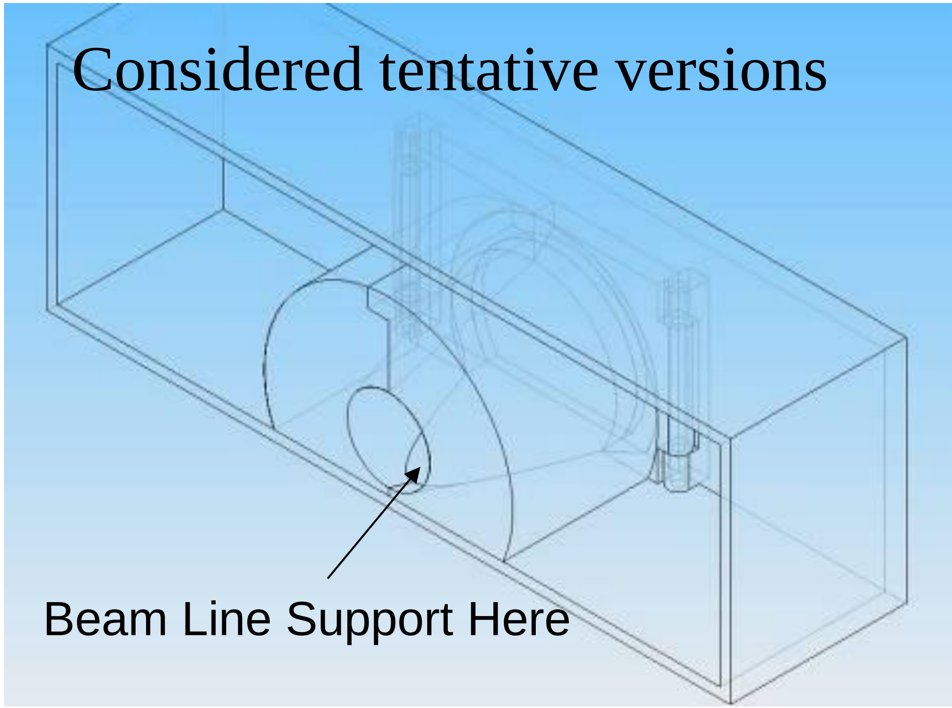


25rem/h@18MW

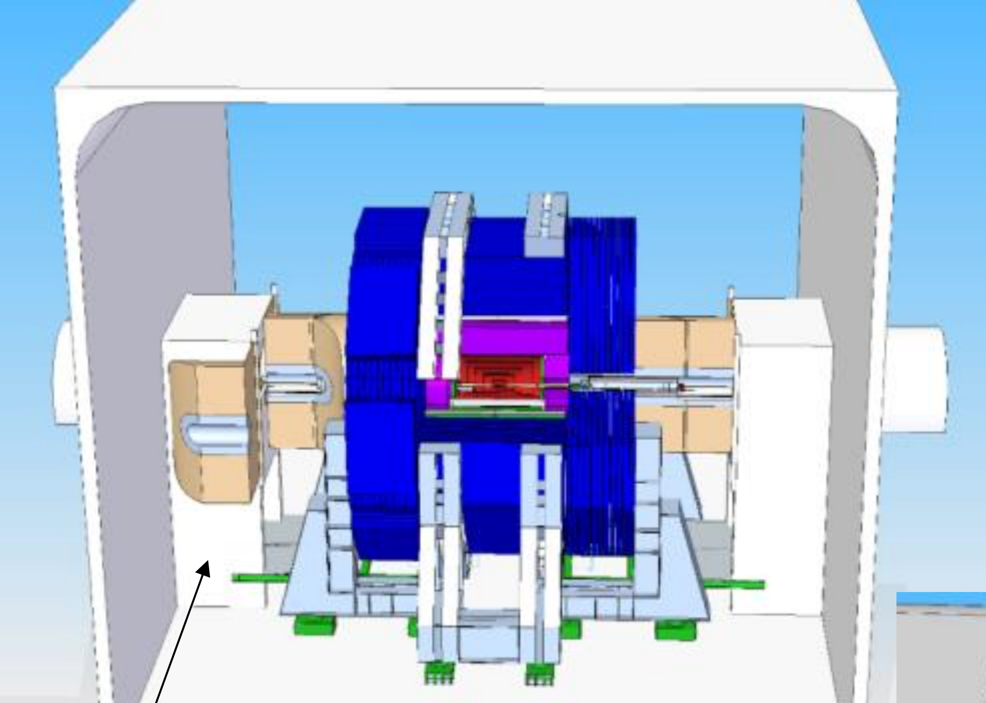


Pacman design



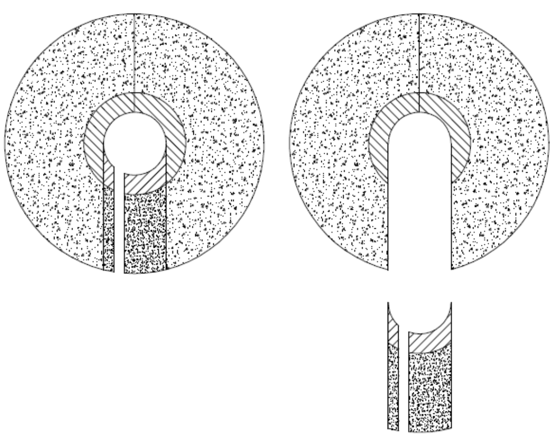


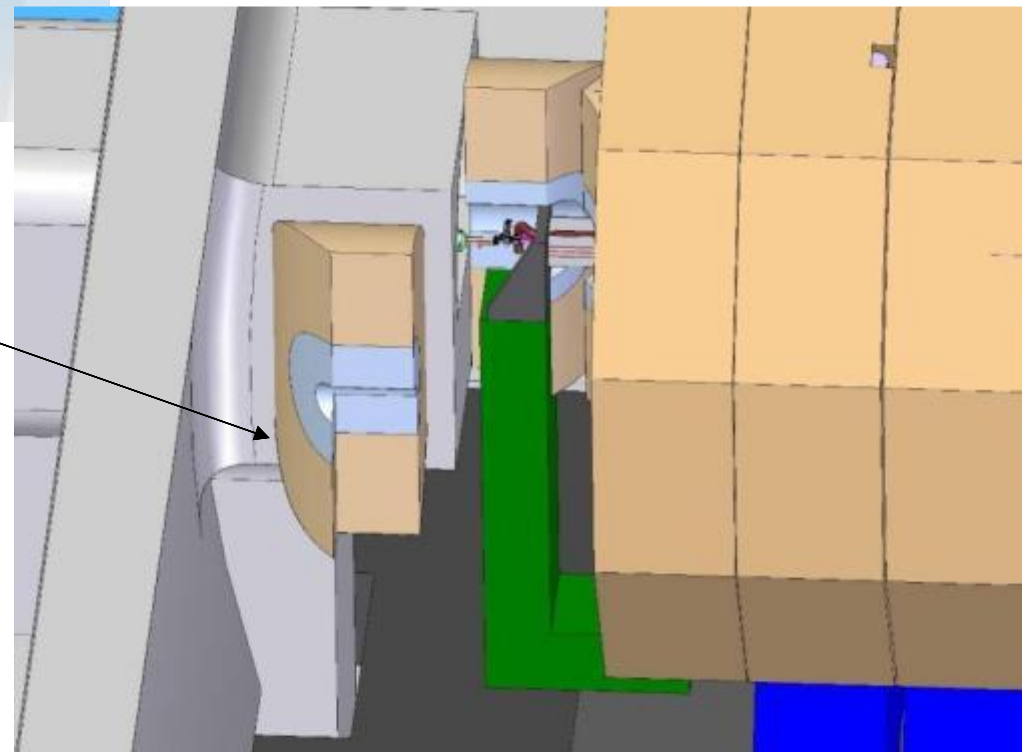
John Amann



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

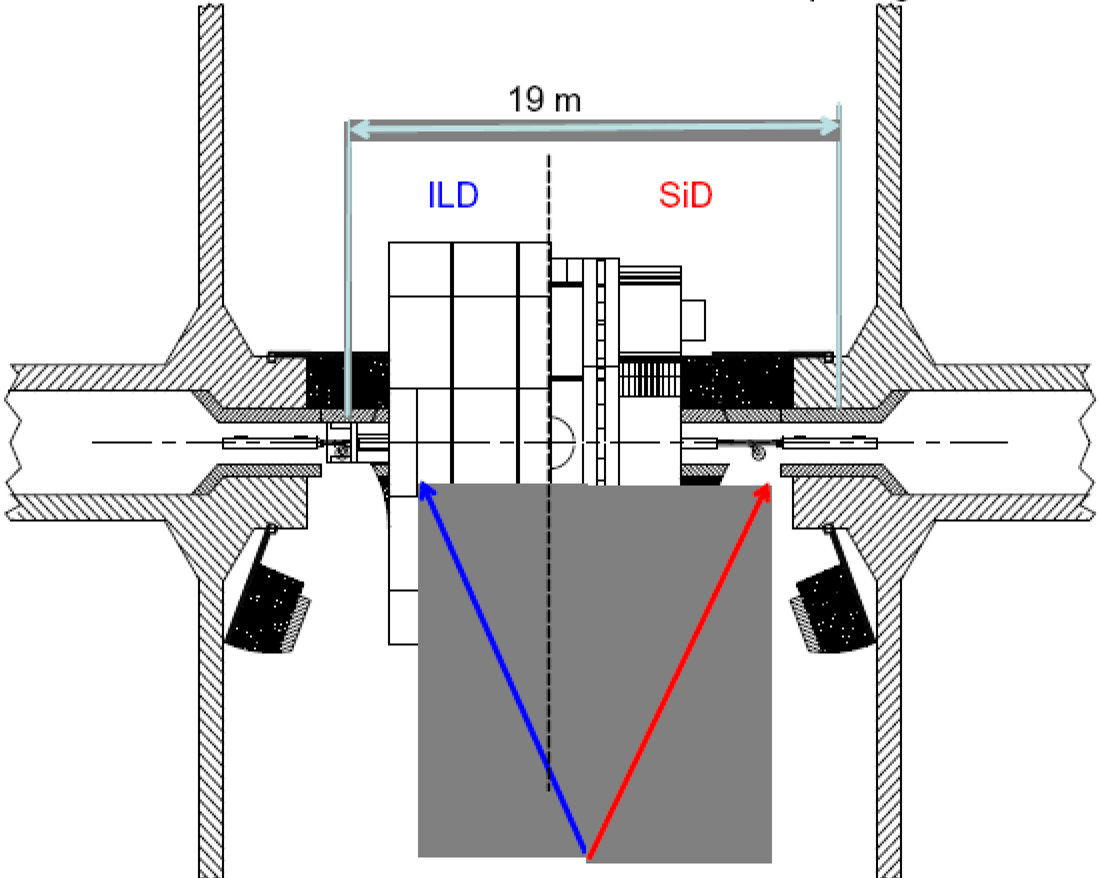




M.Oriunno, H.Yamaoka, A.Herve, et. al

Pacman compatible with SiD

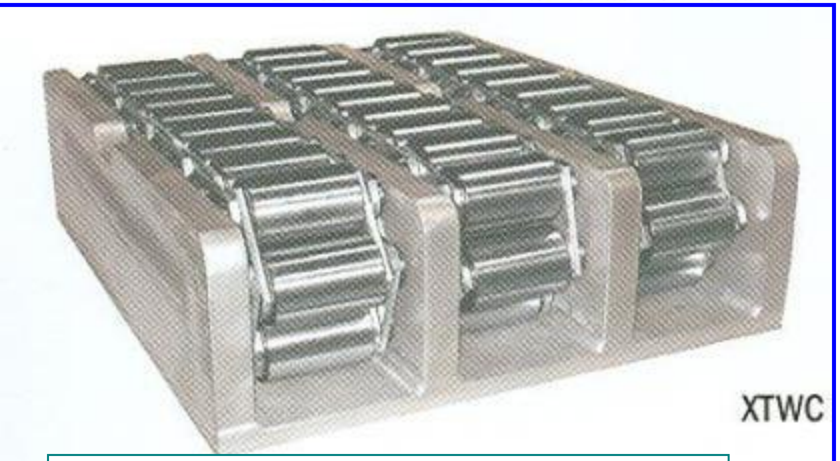
Pacmen closed: Modified to allow ILD opening



Interface pieces born by each experiment

From A. Hervé, K. Sinram, M. Oriunno

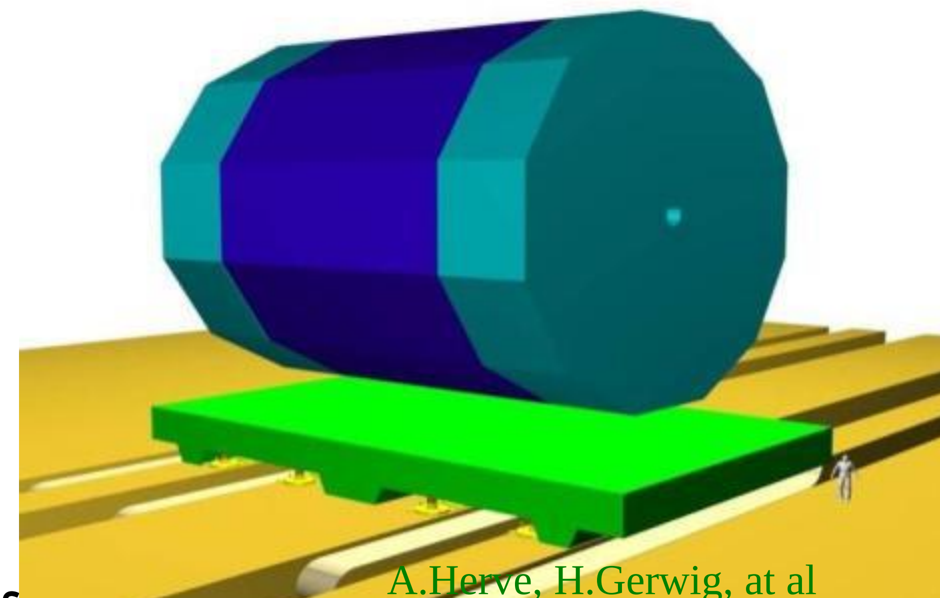
Moving the detector



5000 ton Hilman roller module

Air-pads at CMS – move 2000k pieces

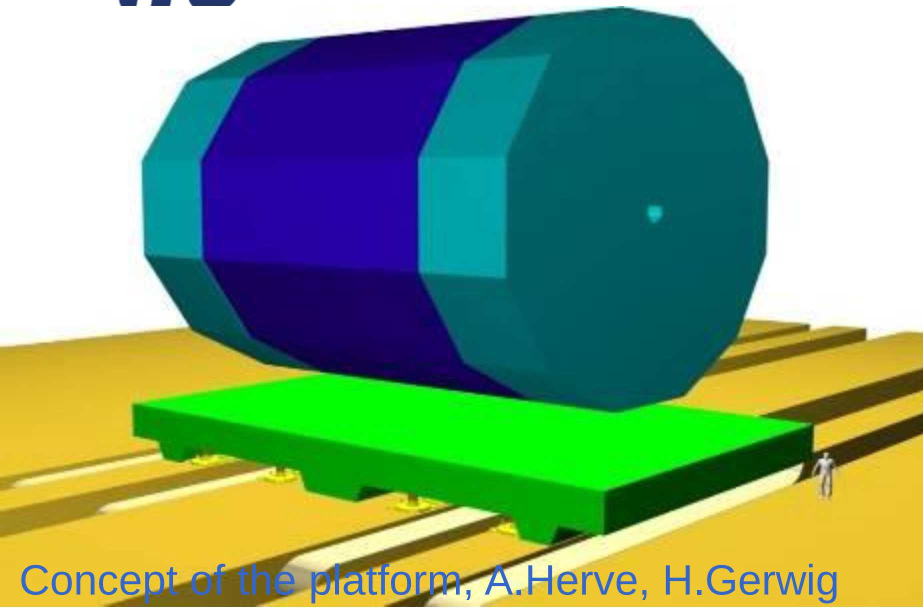
Is detector (compatible with on-surface assembly) rigid enough itself to avoid distortions during move?



A.Herve, H.Gerwig, at al

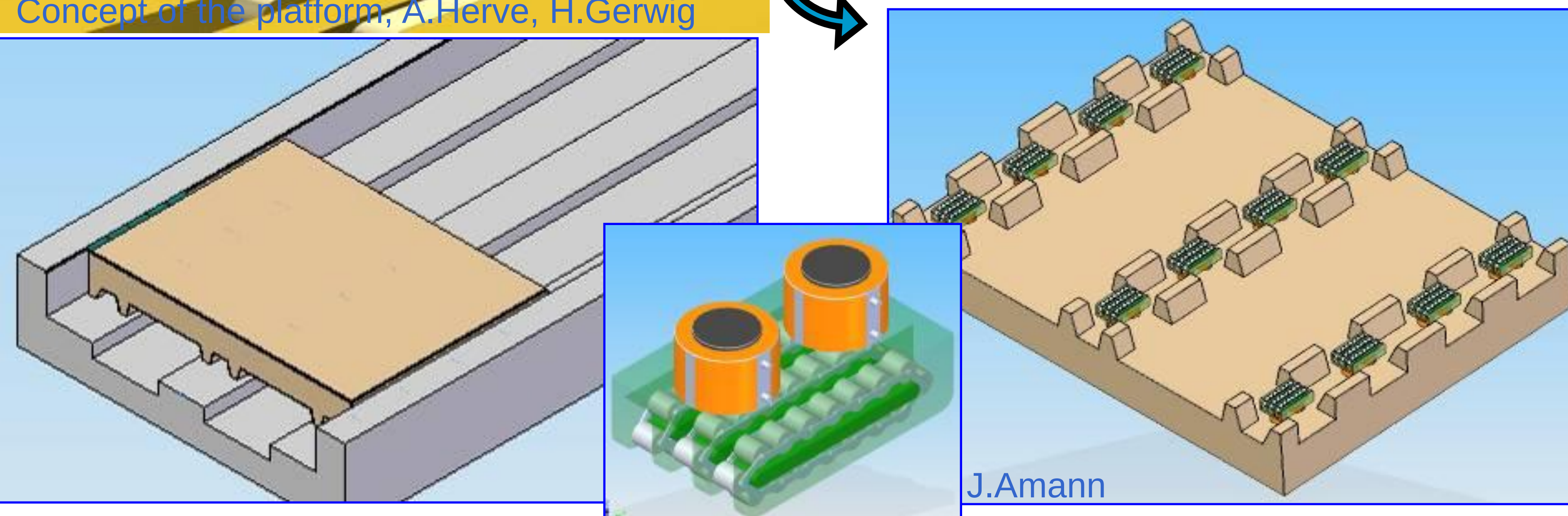
Concept of the platform to move ILC detector

Moving the detector



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

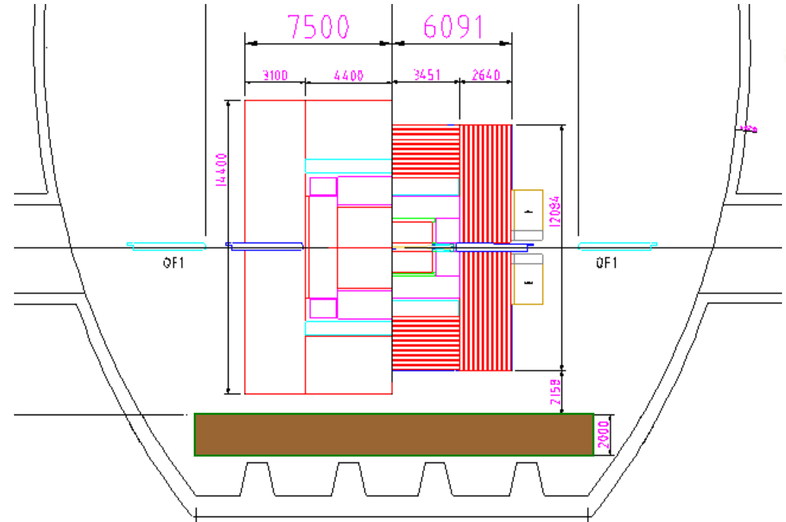
Air-pads at CMS – move 2000k

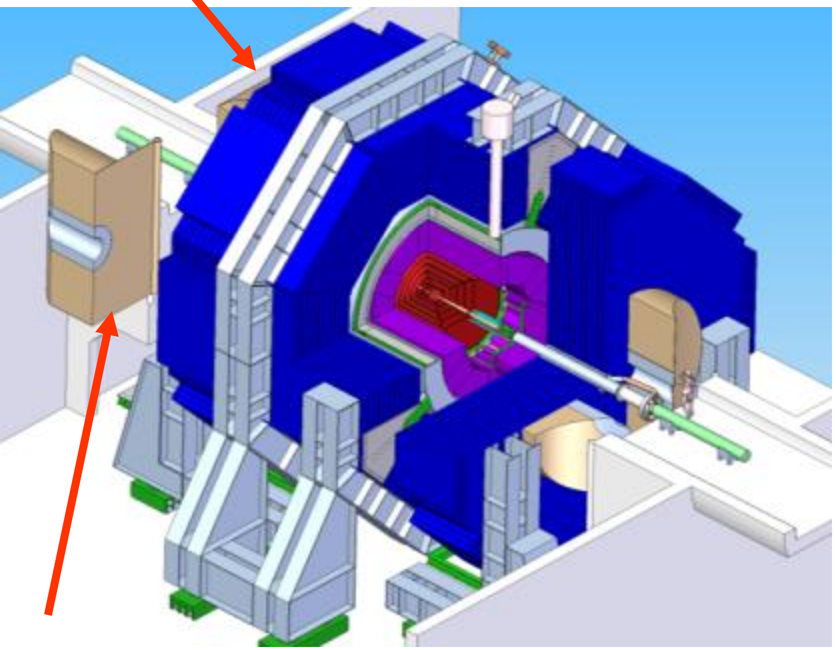


J.Amann

Example of MDI issues: moving detectors

Detector motion system with
or without an intermediate platform

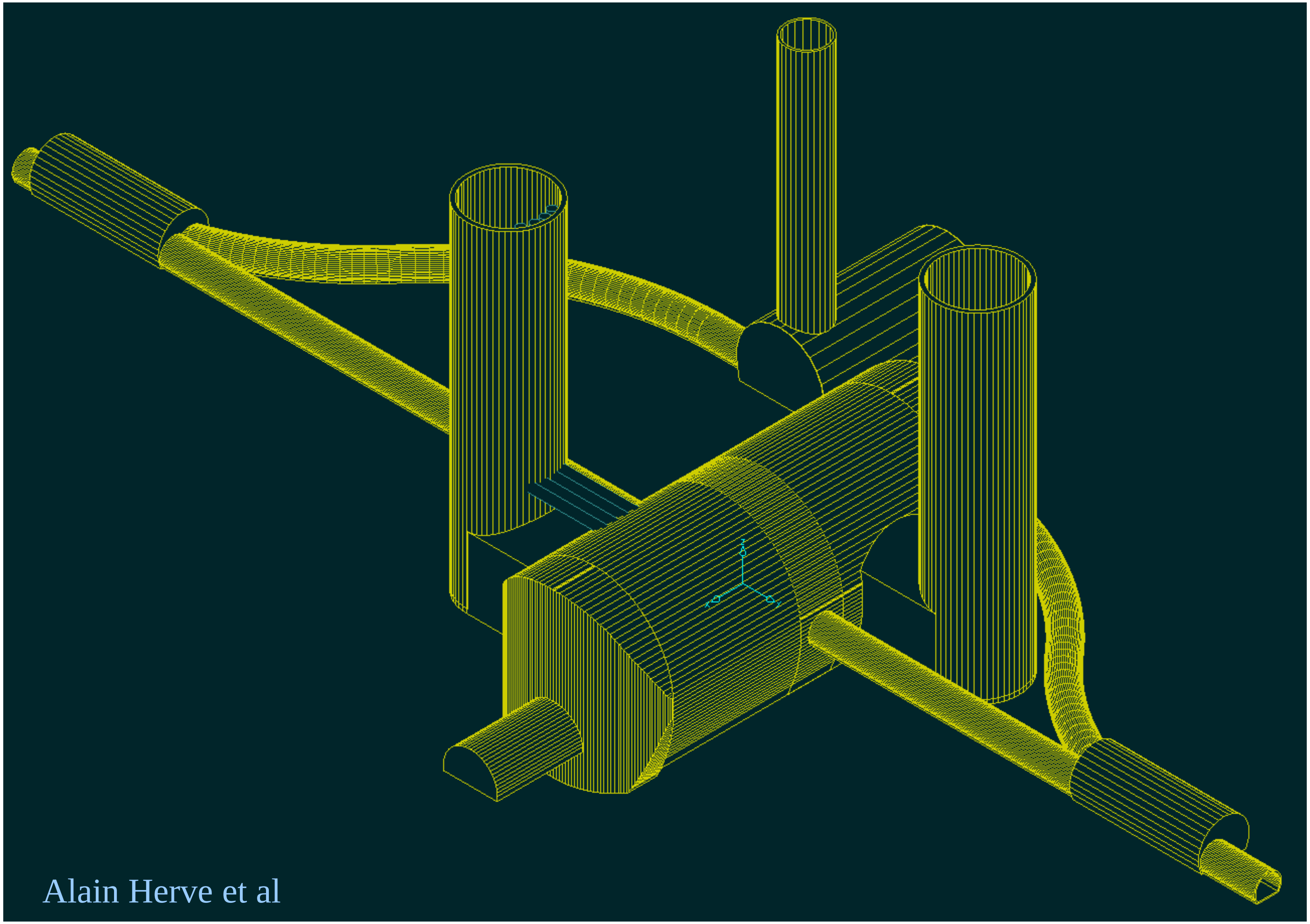




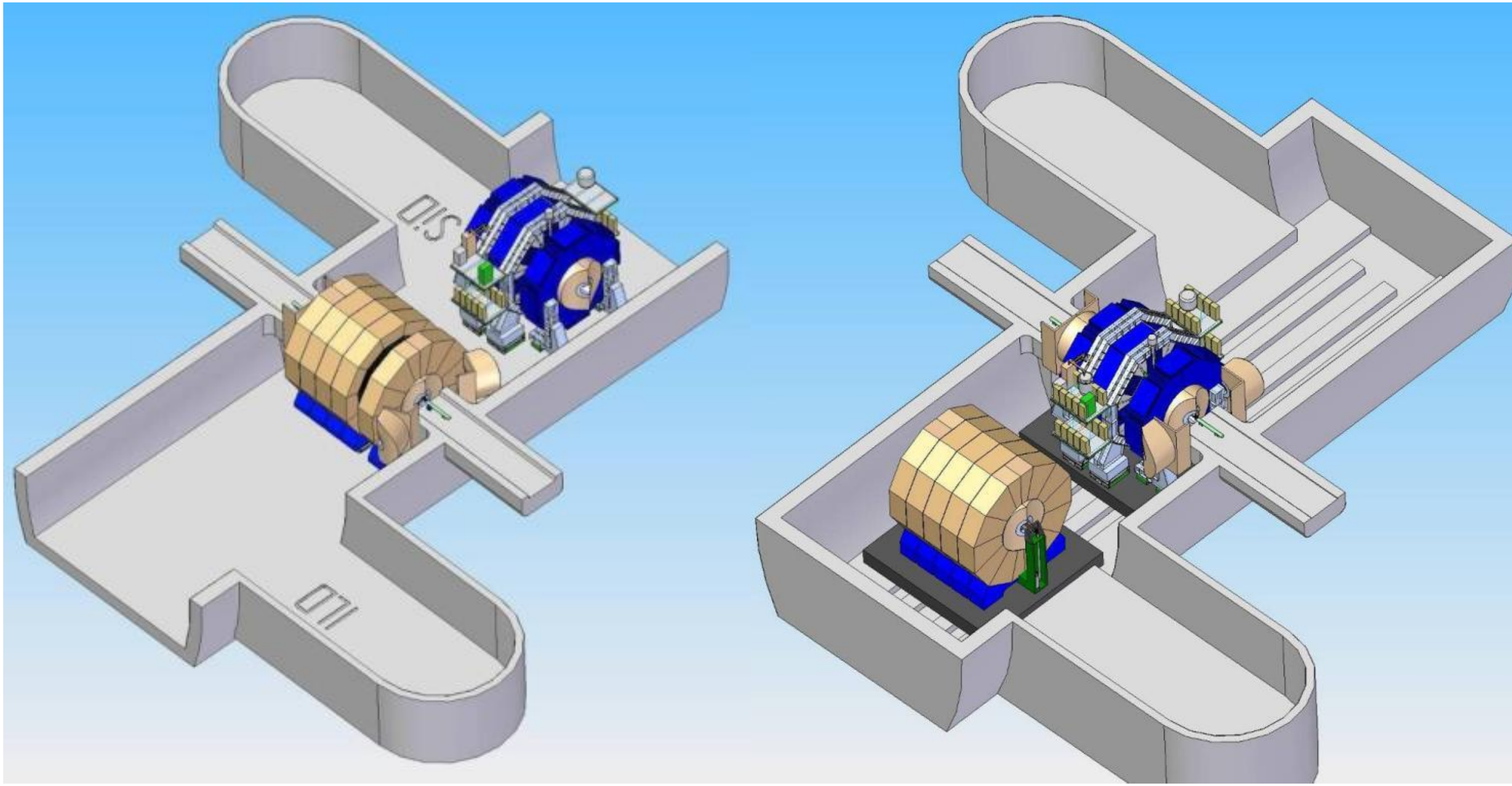
Detector and beamline shielding elements

CMS platform – proof of principle for ILC

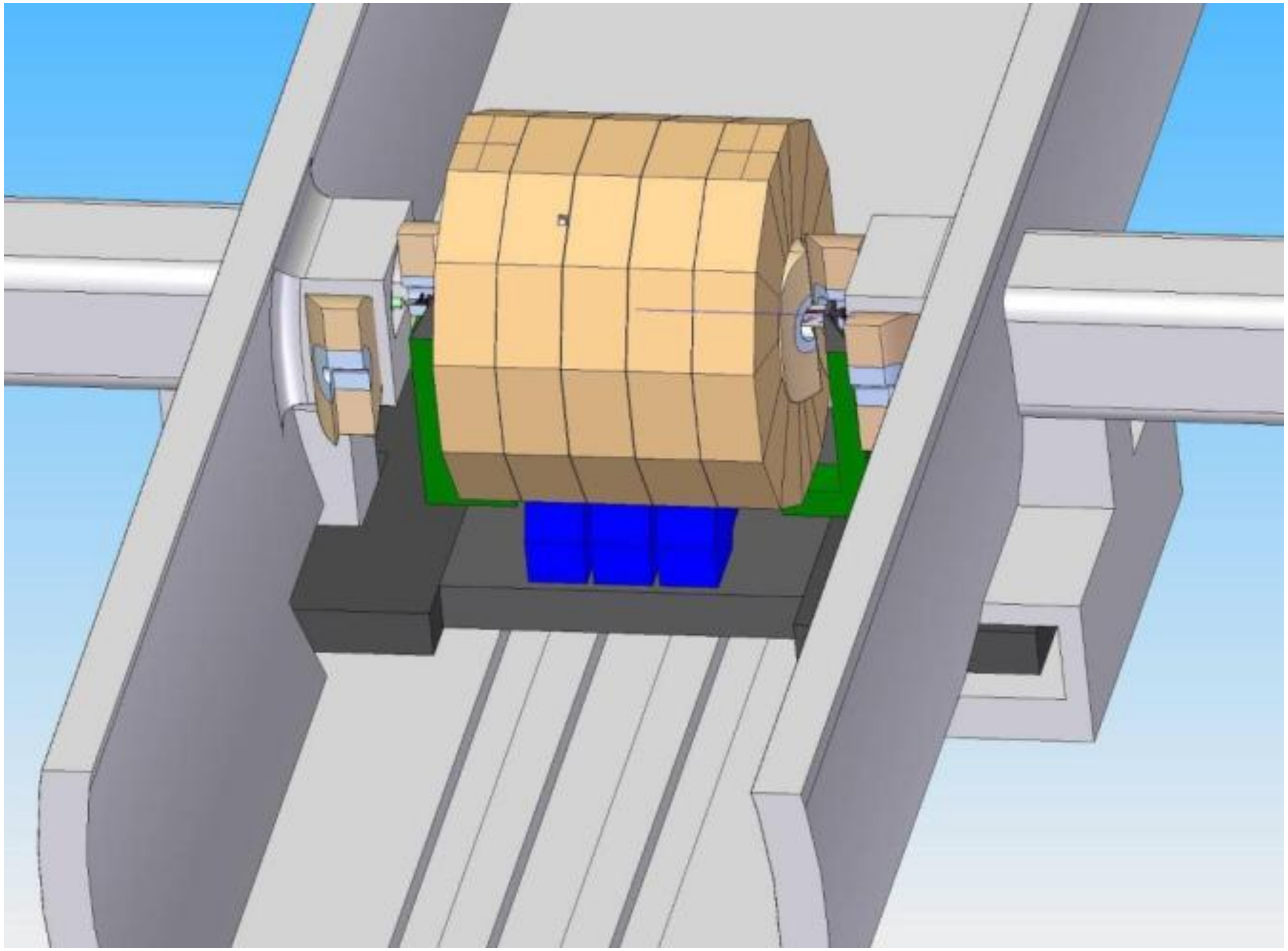
Configuration of IR tunnels and halls



All detectors without / with platform

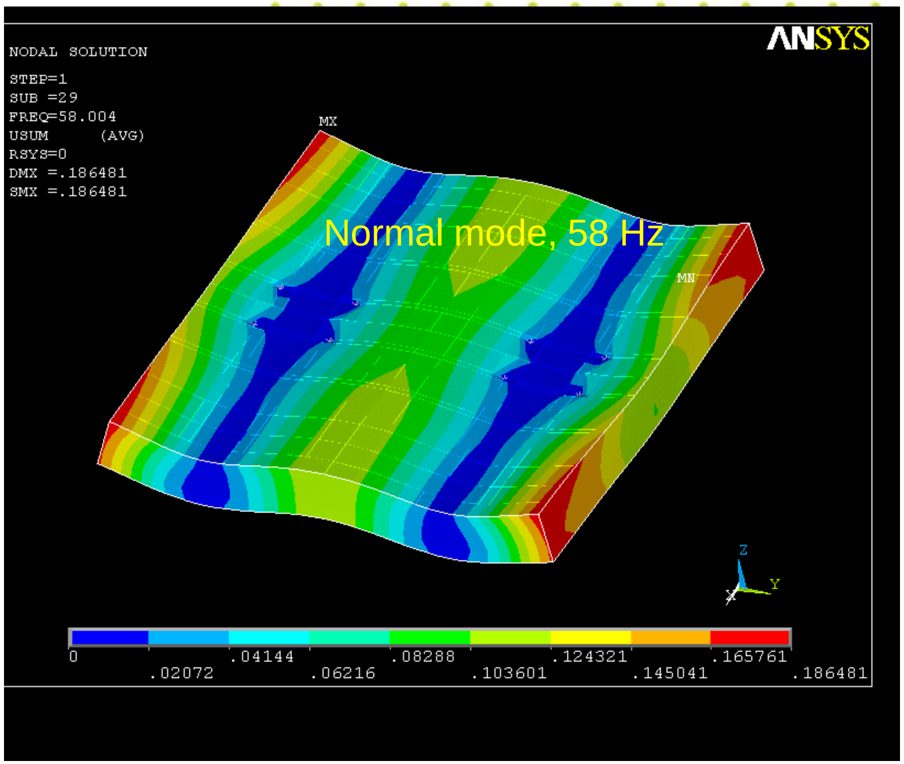


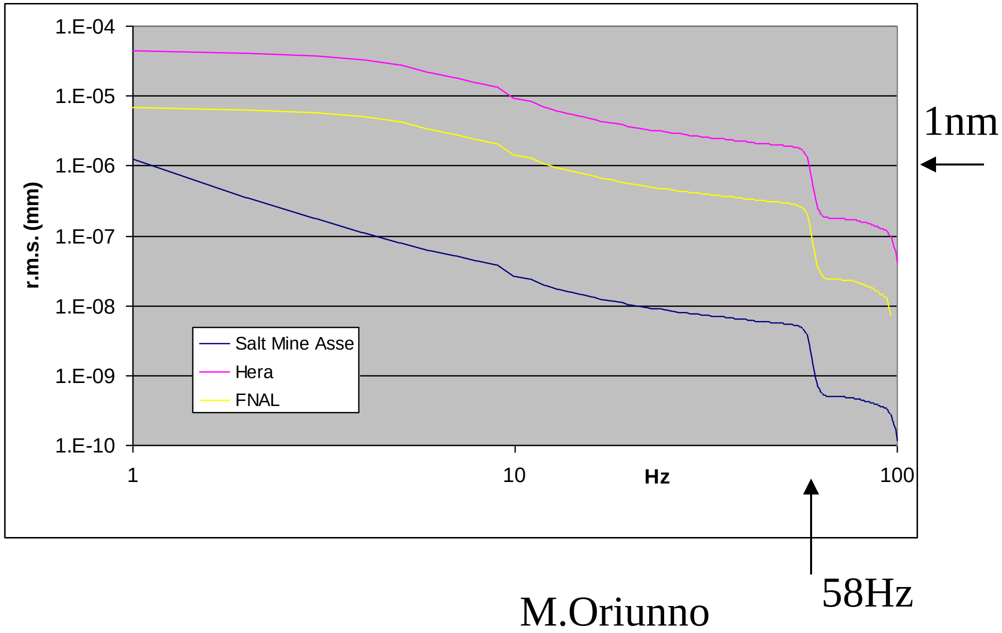
Half Platform w/ Pocket Storage



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

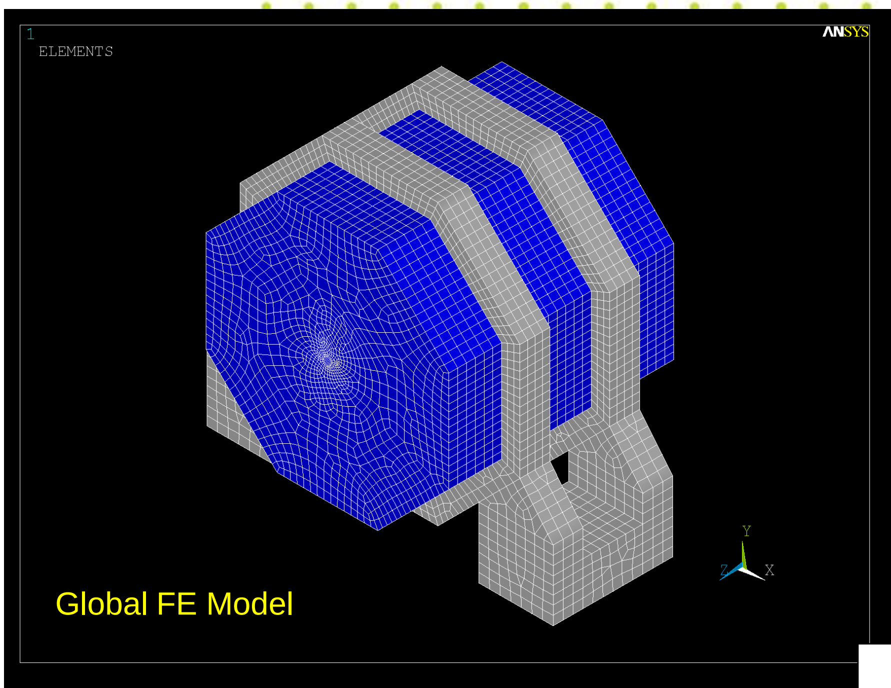
Preliminary
ANSYS analysis of Platform

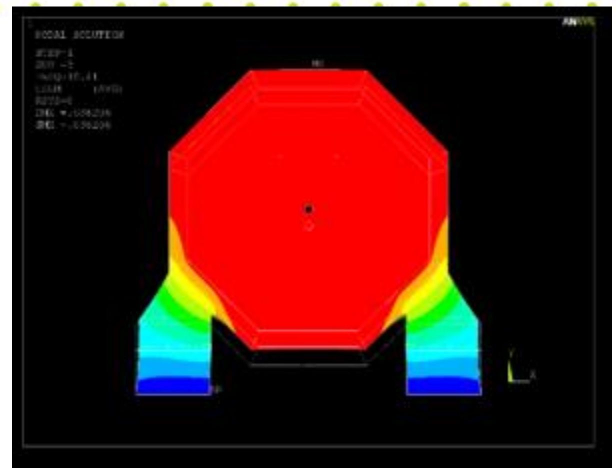




- First look of platform stability look rather promising: resonance frequencies are rather large (e.g. 58Hz) and additional vibration is only several nm

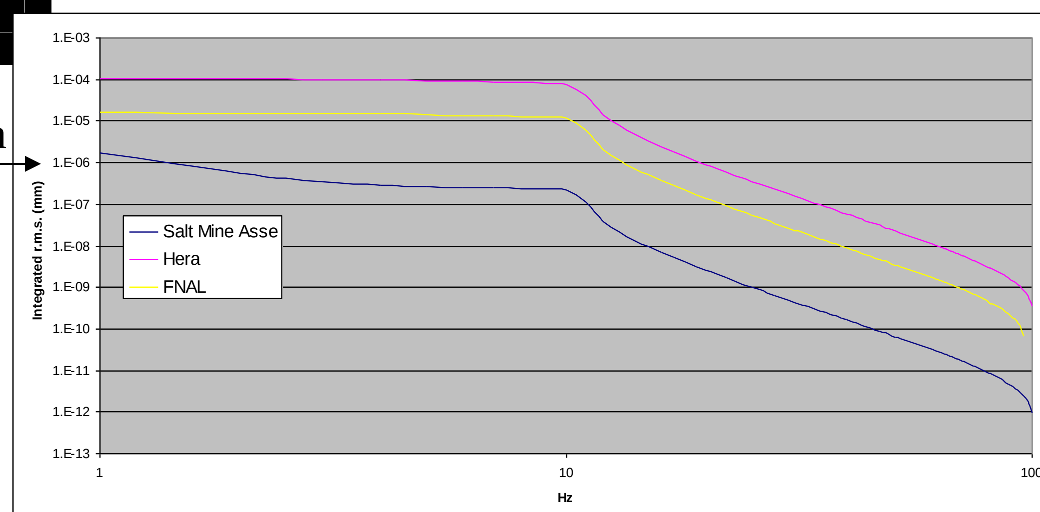
Detector stability analysis (SiD)





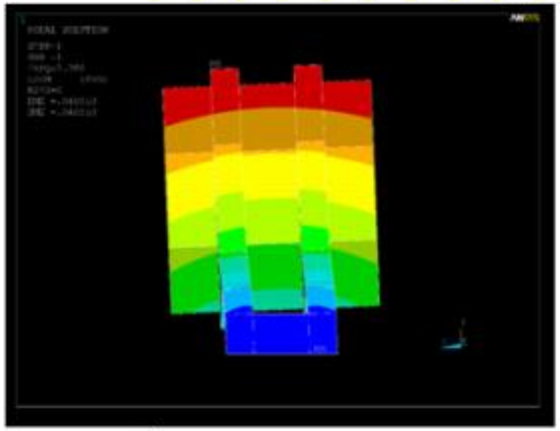
First vertical motion mode, 10.42 Hz

1nm

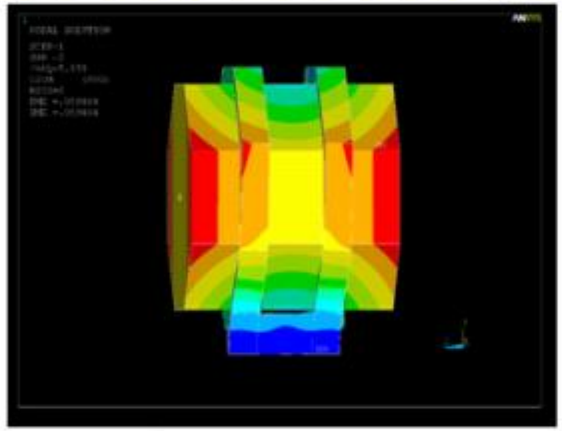


- First analysis shows possibilities for optimization
  - e.g. tolerance to fringe field => detector mass => resonance frequency

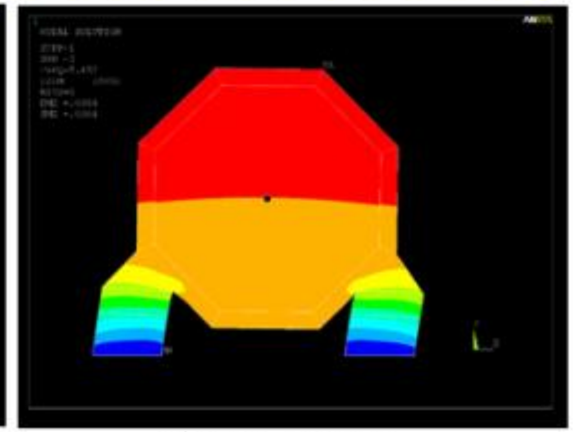
Free vibration modes of SiD



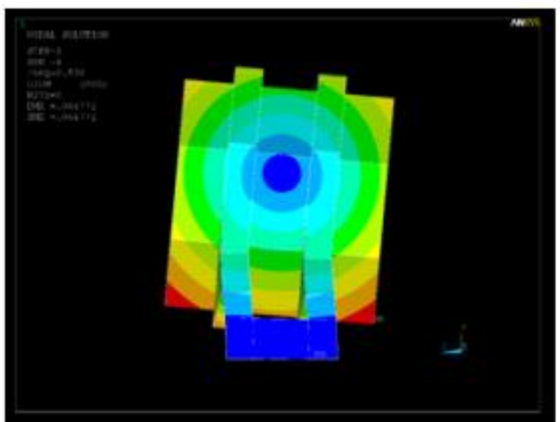
1st Mode, 2.38 Hz



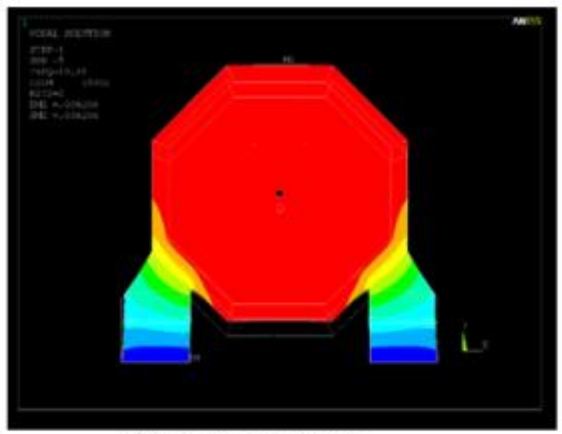
2nd Mode, 5.15 Hz



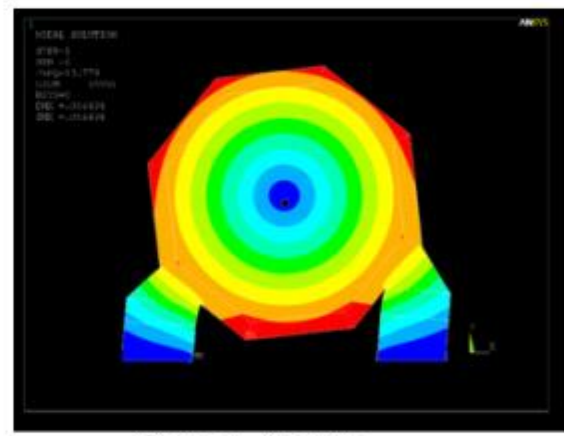
3rd Mode, 5.45 Hz



4th Mode, 6.53 Hz



5th Mode, 10.42 Hz

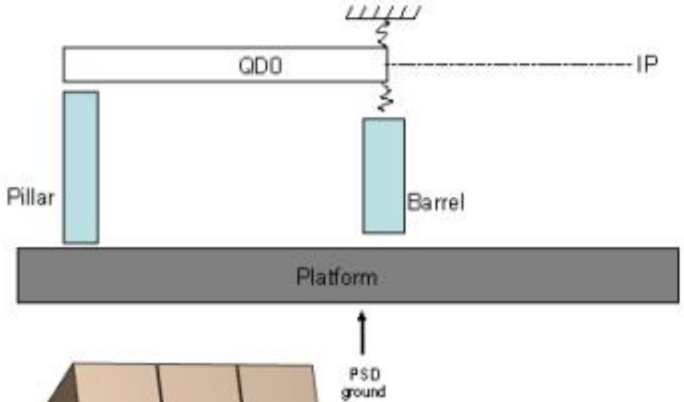


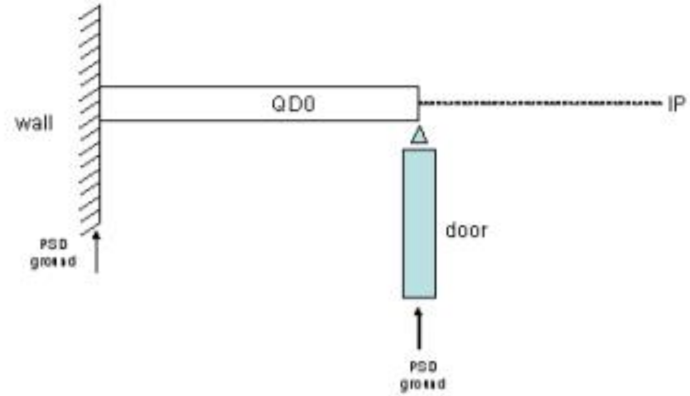
6th Mode, 13.7 Hz

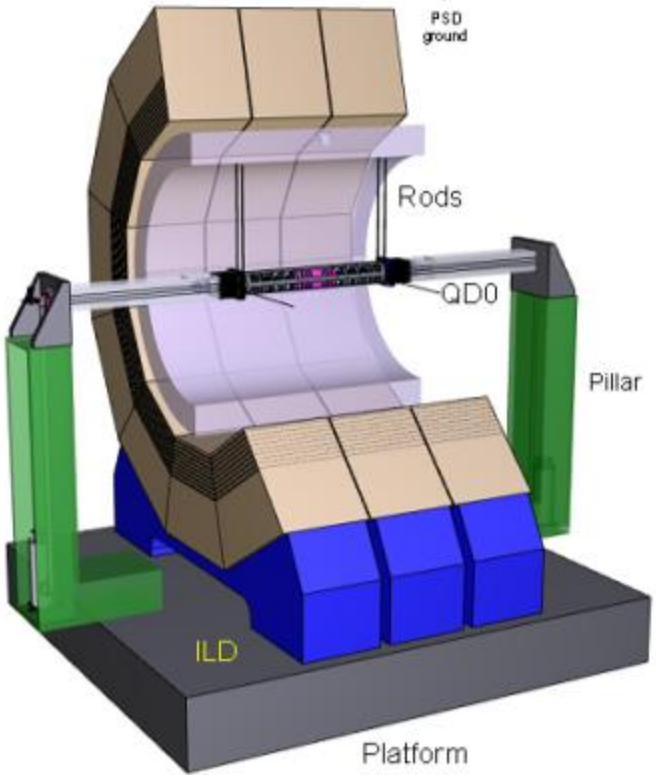
M.Oriunno

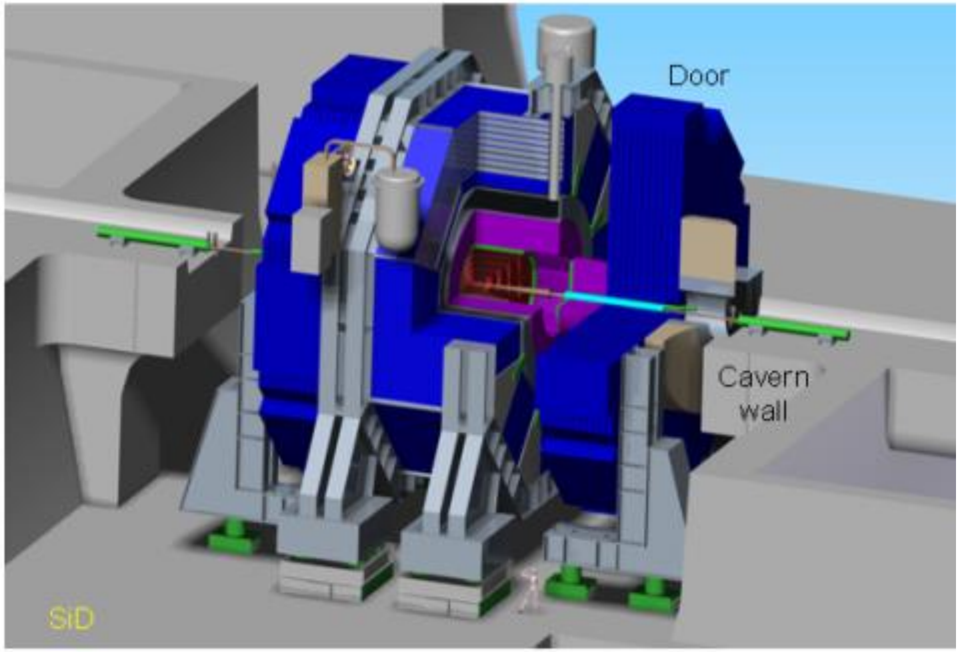
Vertical motion

QD0 supports in ILD and SiD





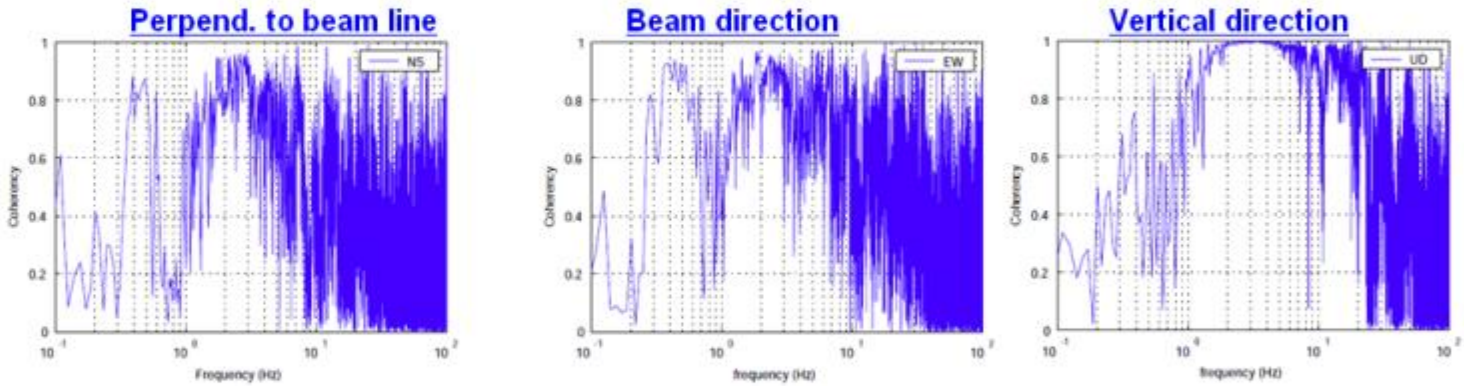


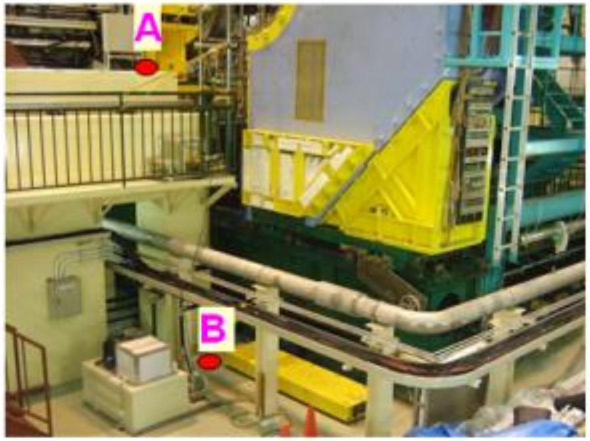


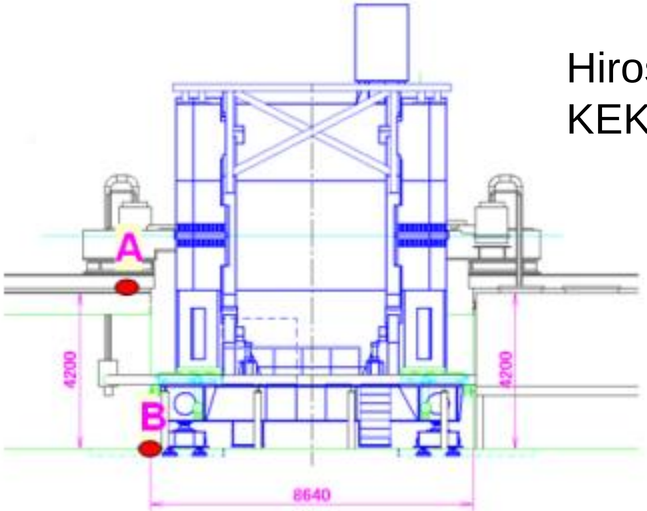
Stability studies at BELLE

Measurement: B

How is the coherency between the tunnel and floor?







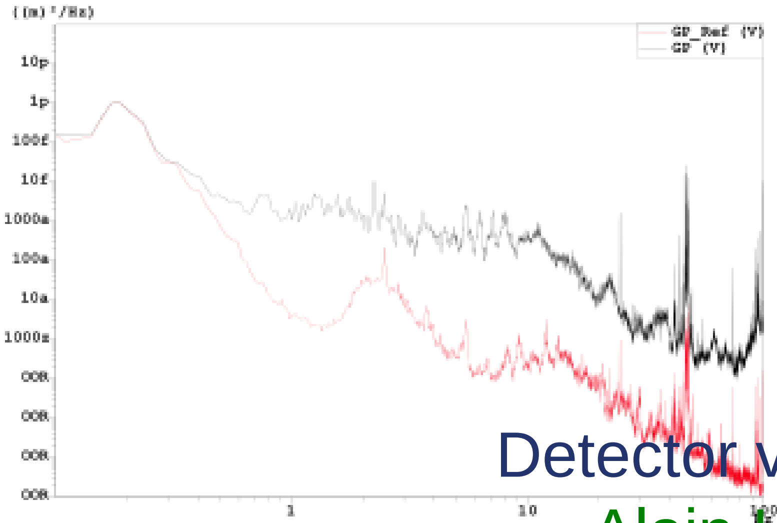
Hiroshi Yamaoka, KEK

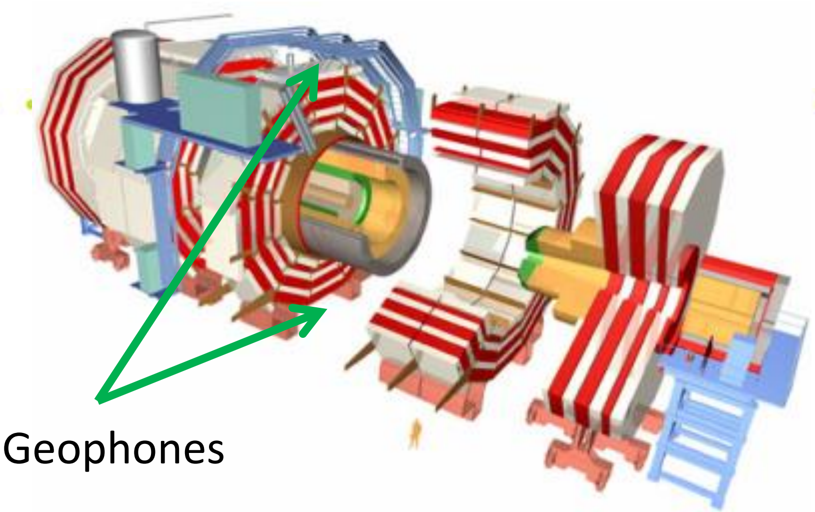
- Horizontal dir.: 0.~Hz, ~3Hz
- Vertical dir.: 1 ~ 20Hz

16

CMS top of Yoke measurement

PSD of the signals Vertical direction



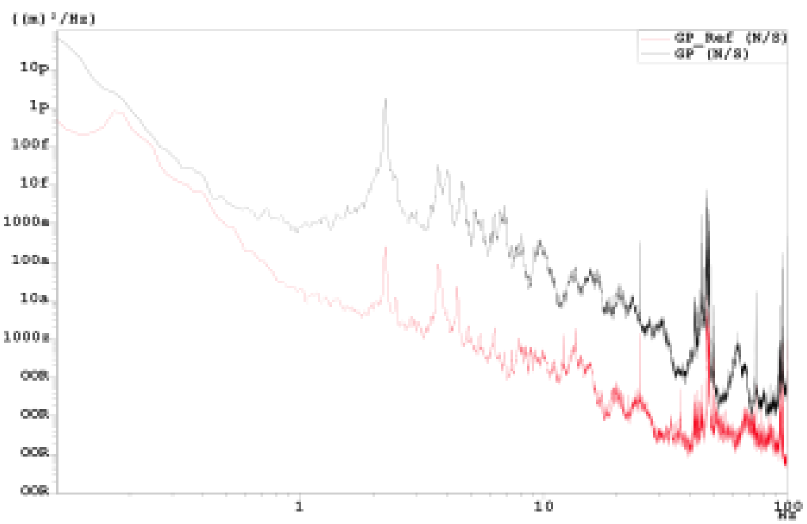


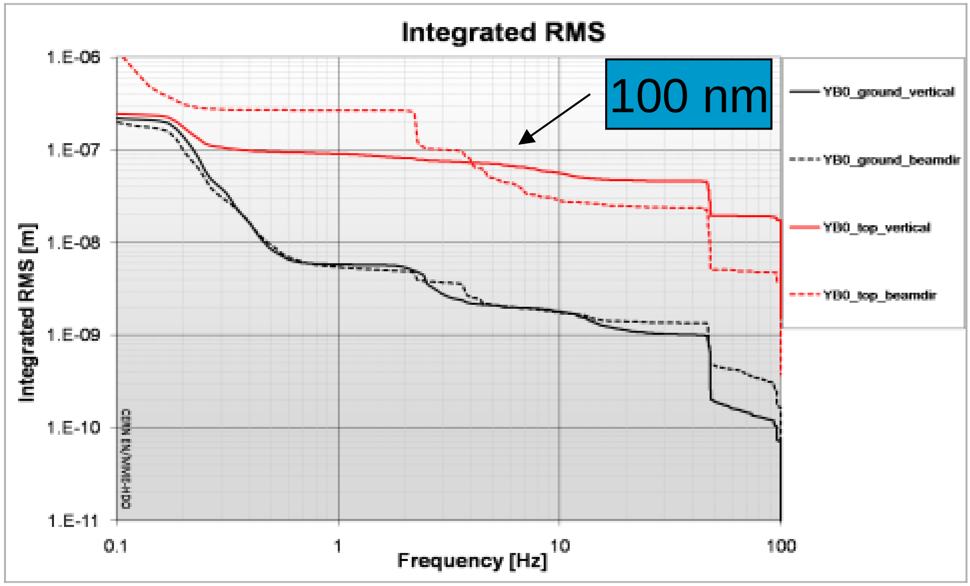
Detector vibrations and QD0 support

Cooling system OFF

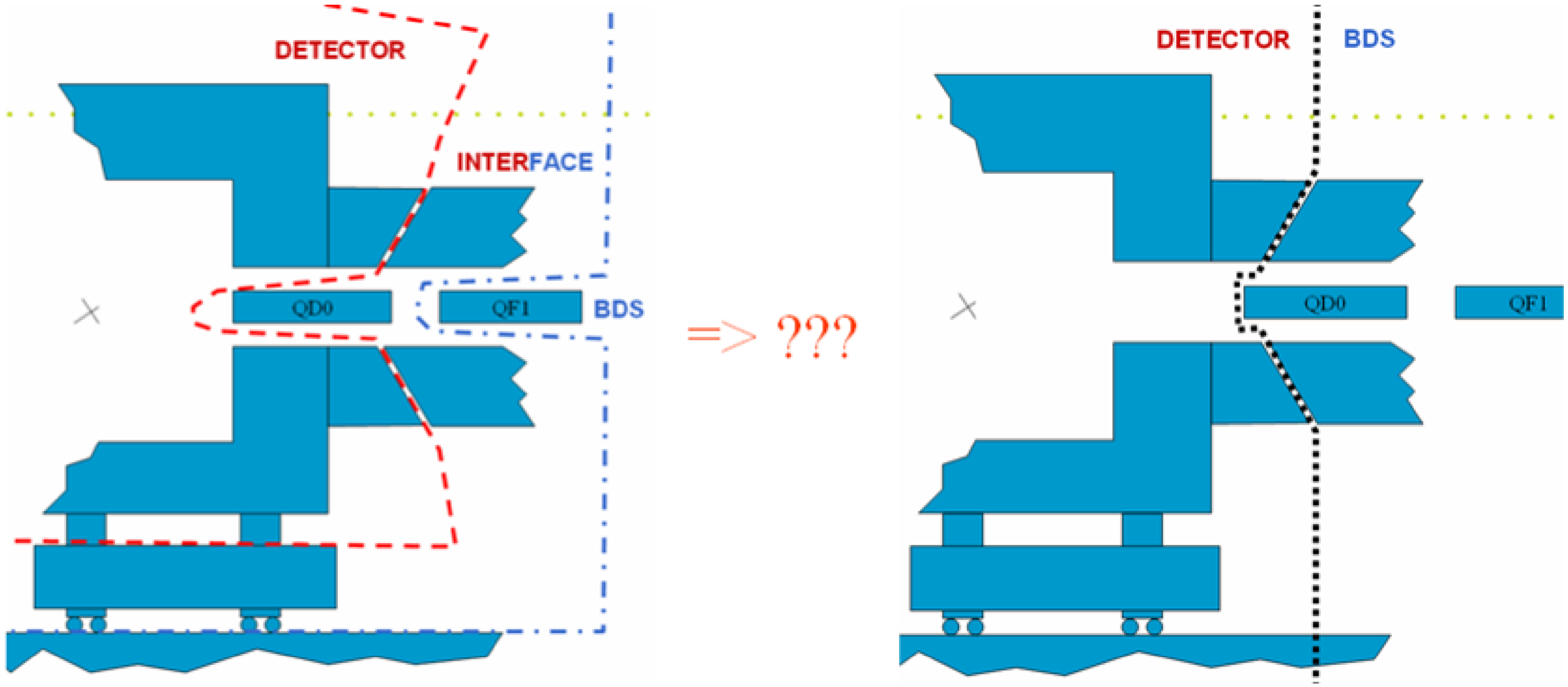
Alain Herve (ETH Zurich)

PSD of the signals Beam direction





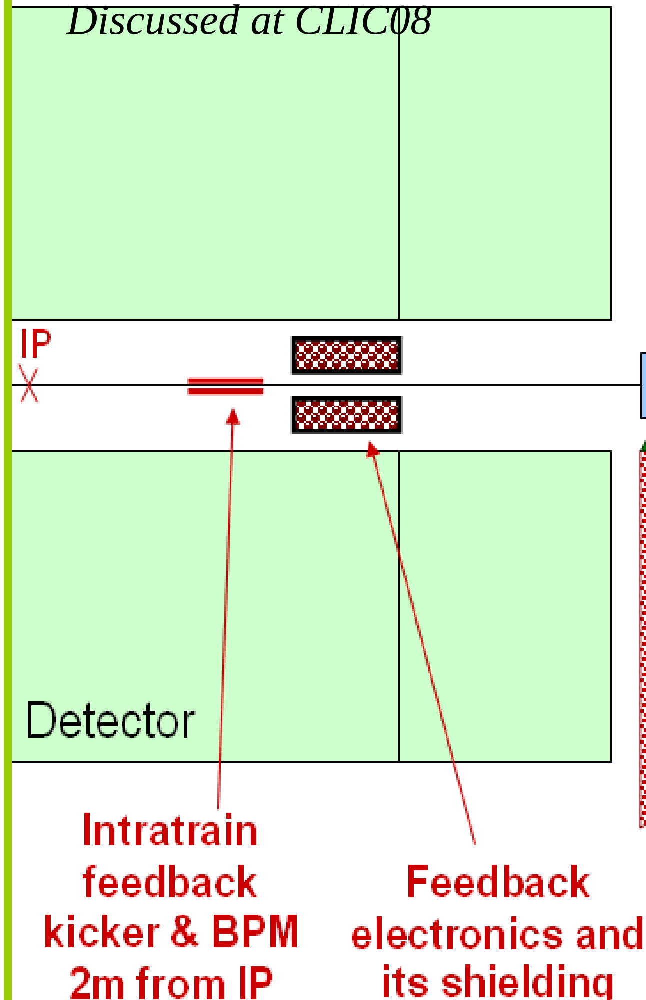
Longer L* → Simplified MDI?

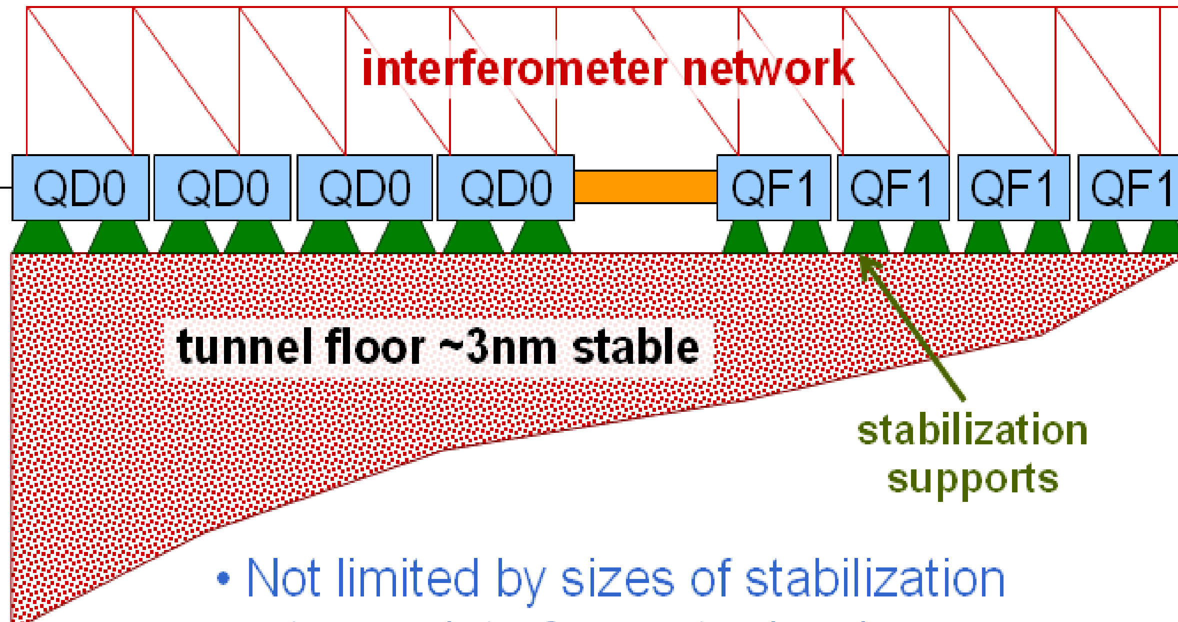


- <u>If</u> doubled L* is <u>feasible and acceptable</u> then the MDI may be simplified tremendously
  - » and cost is reduced – do not need two extra sets of QD0
- An option of later upgrade for shorter L* may always be considered
- Has to be studied further

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

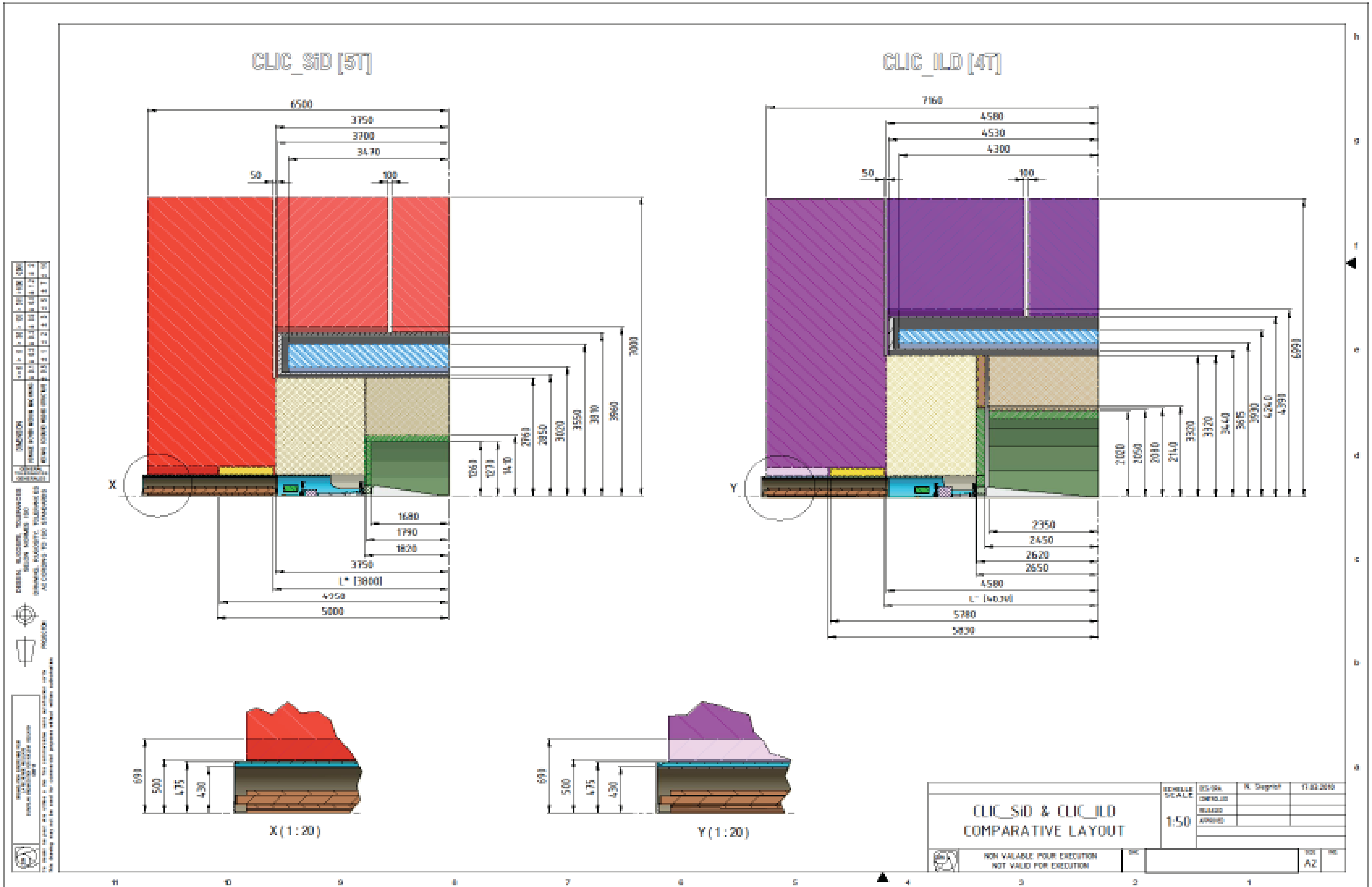
[14] http://clicr.web.cern.ch/CLICr/

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

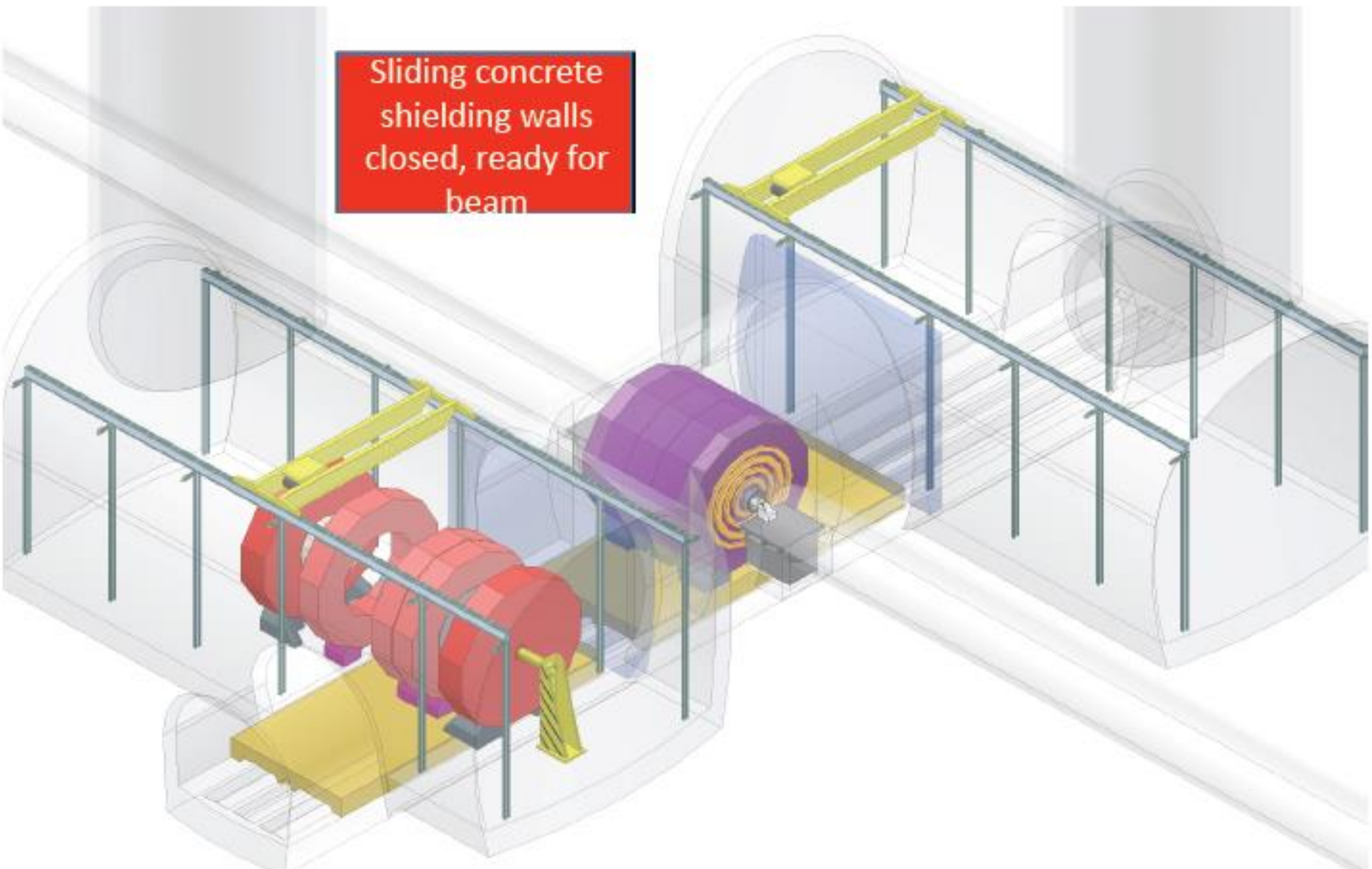
CLIC detector comparison



BDS: 62

New concept of CLIC push-pull

Experiment 2 sliding on IP, shielding walls closed



March 28, 10 H. Gerwig - LCWS10/ILC10 28

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 δE/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*$3^{1/2}$

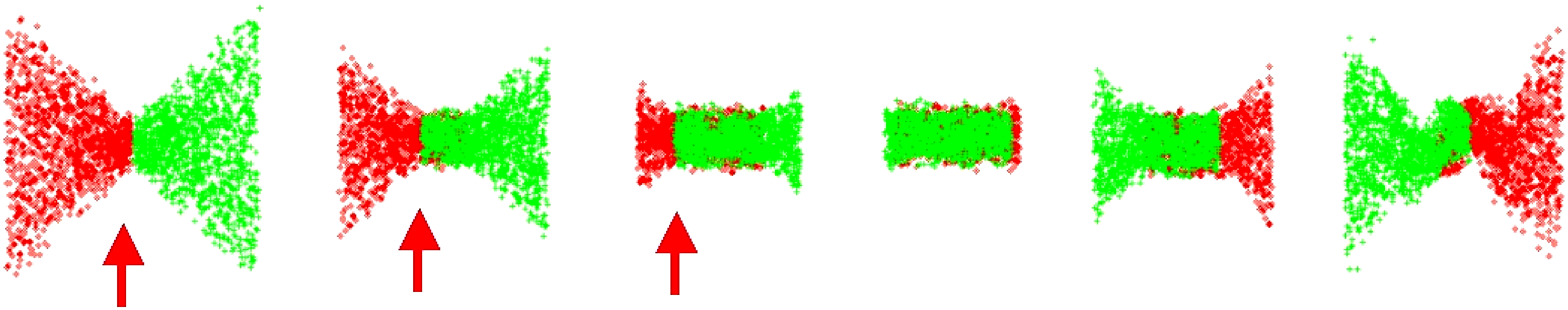
Travelling focus allows to lengthen the bunch

Thus, beamstrahlung energy spread is reduced

Focusing during collision is aided by focusing of the opposite bunch

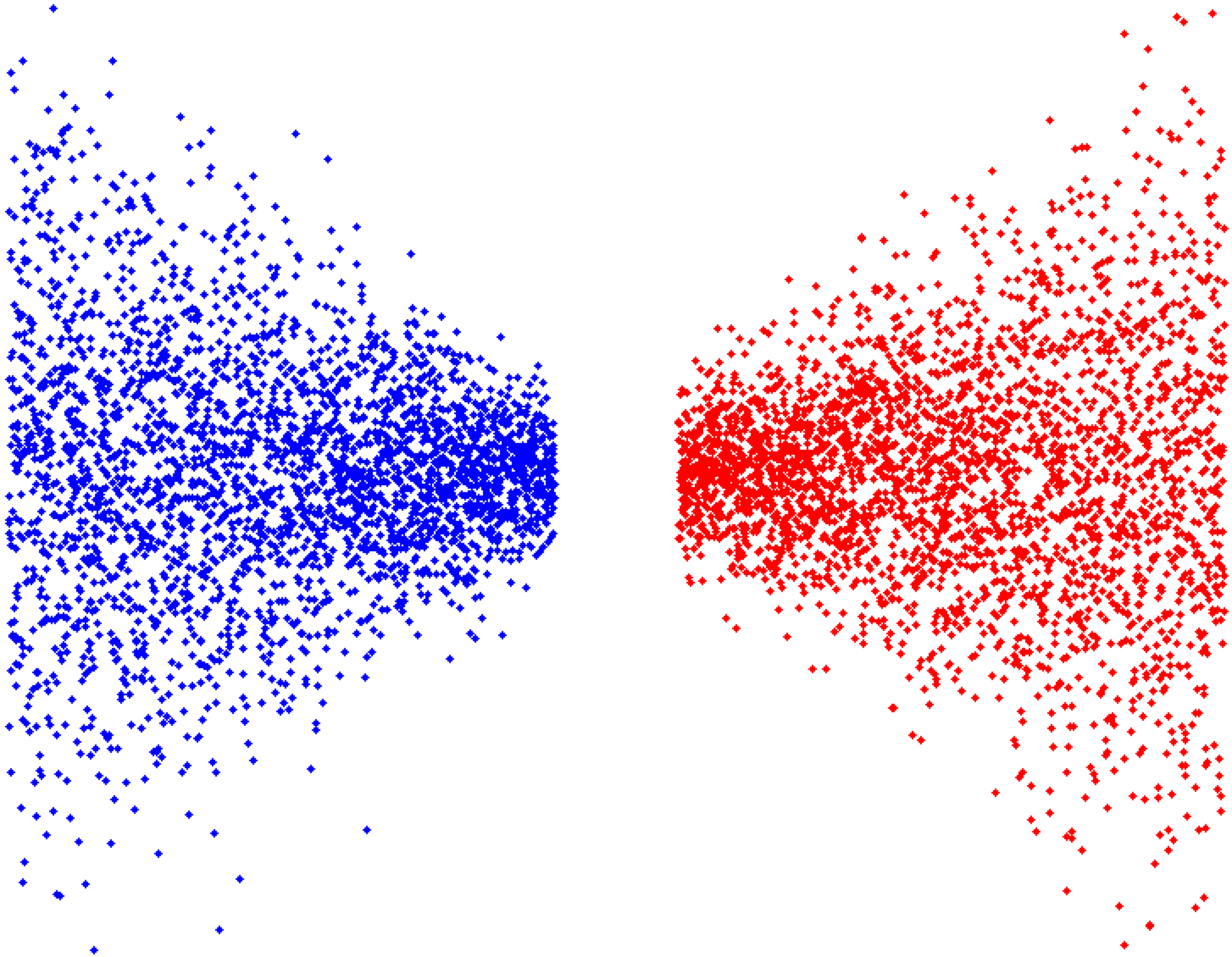
Focal point during collision moves to coincide with the head of the opposite bunch

Beam-beam: Travelling focus

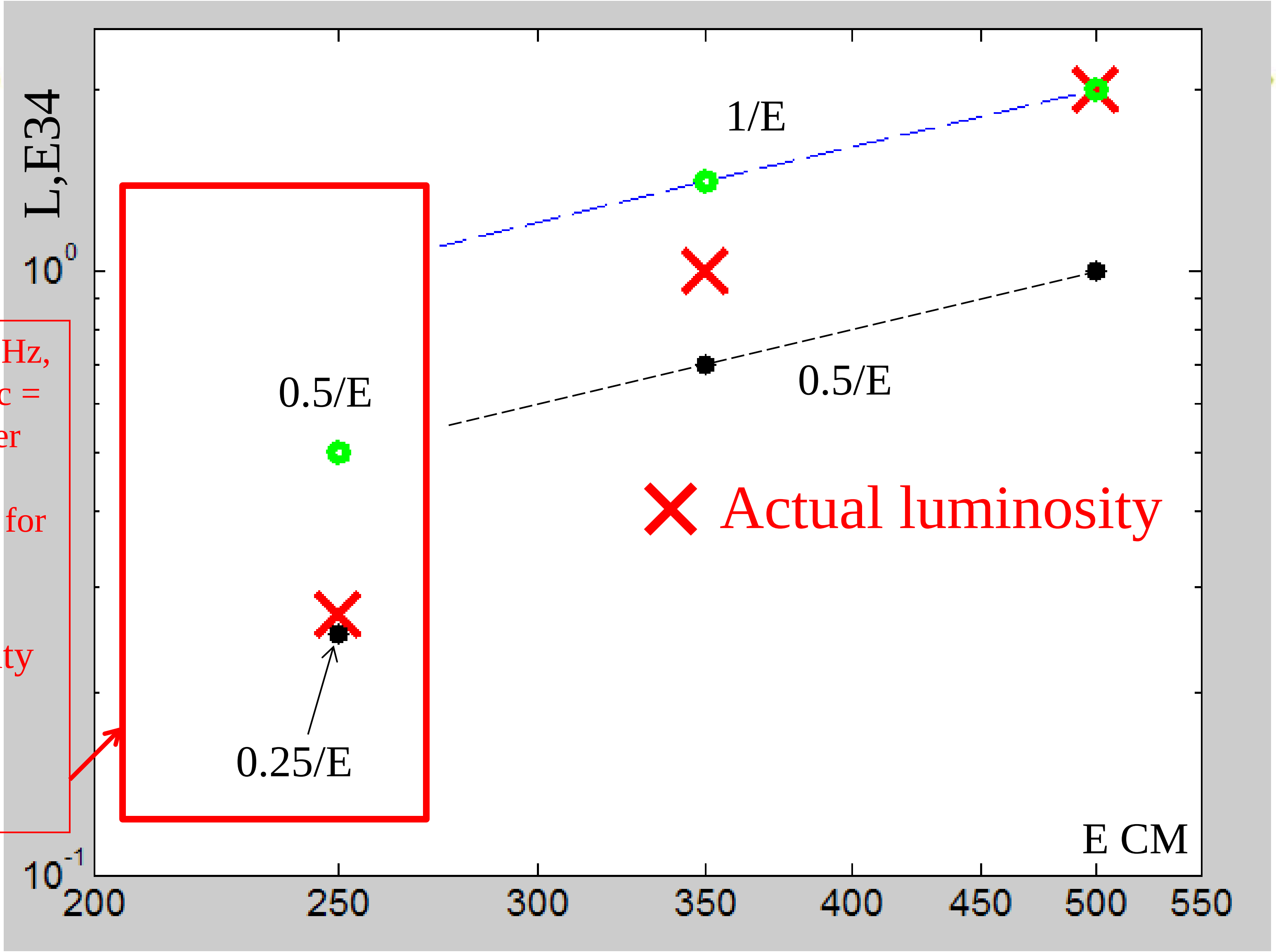


- Suggested by V.Balakin in ~1991 – idea is to use beam-beam forces for additional focusing of the beam – allows some gain of luminosity or overcome somewhat the hour-glass effect
- Figure shows simulation of traveling focus. The arrows show the position of the focus point during collision
- So far not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

Collision with travelling focus



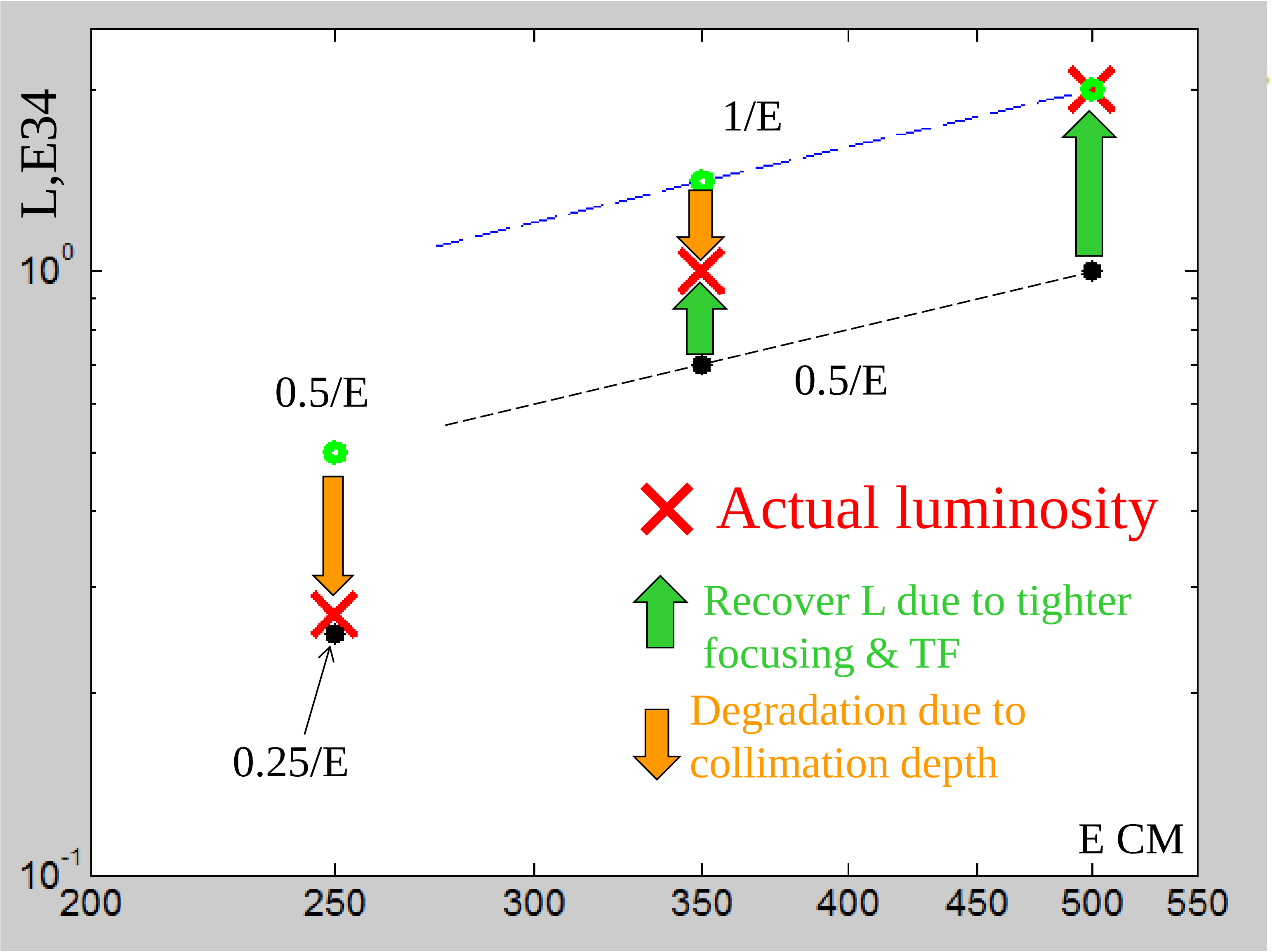
SB2009 Lumi



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
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

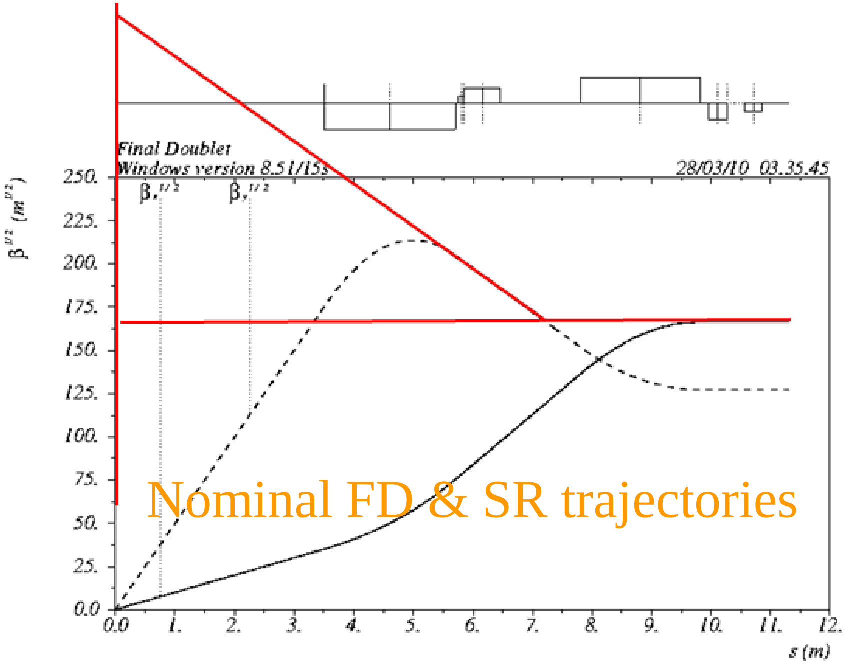
- The travelling focus can be created in two ways.
- The first way is to have small uncompensated chromaticity and coherent E-z energy shift $\delta E/\delta z$ along the bunch. One has to satisfy $\delta E\ k\ L^{*}_{eff} = \sigma_z$ where k is the relative uncompensated chromaticity. The δE needs to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

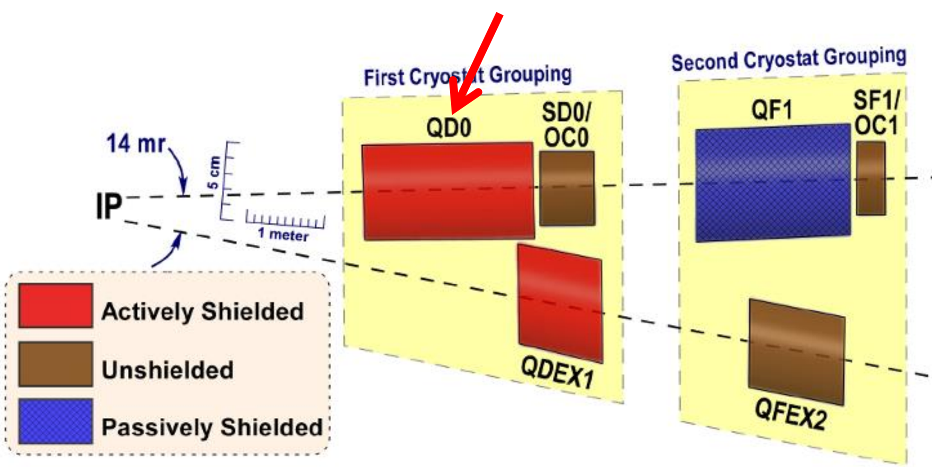
- The second way to create a travelling focus is to use a transverse deflecting cavity giving a z-x correlation in one of the FF sextupoles and thus a z-correlated focusing
- The cavity would be located about 100m upstream of the final doublet, at the $\pi/2$ betatron phase from the FD
- The needed strength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

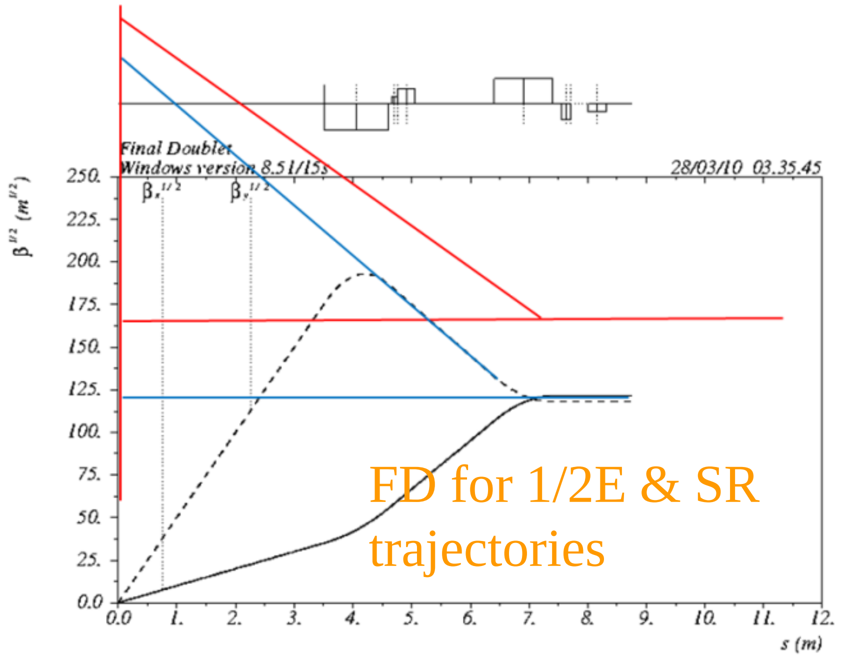
FD for low E

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

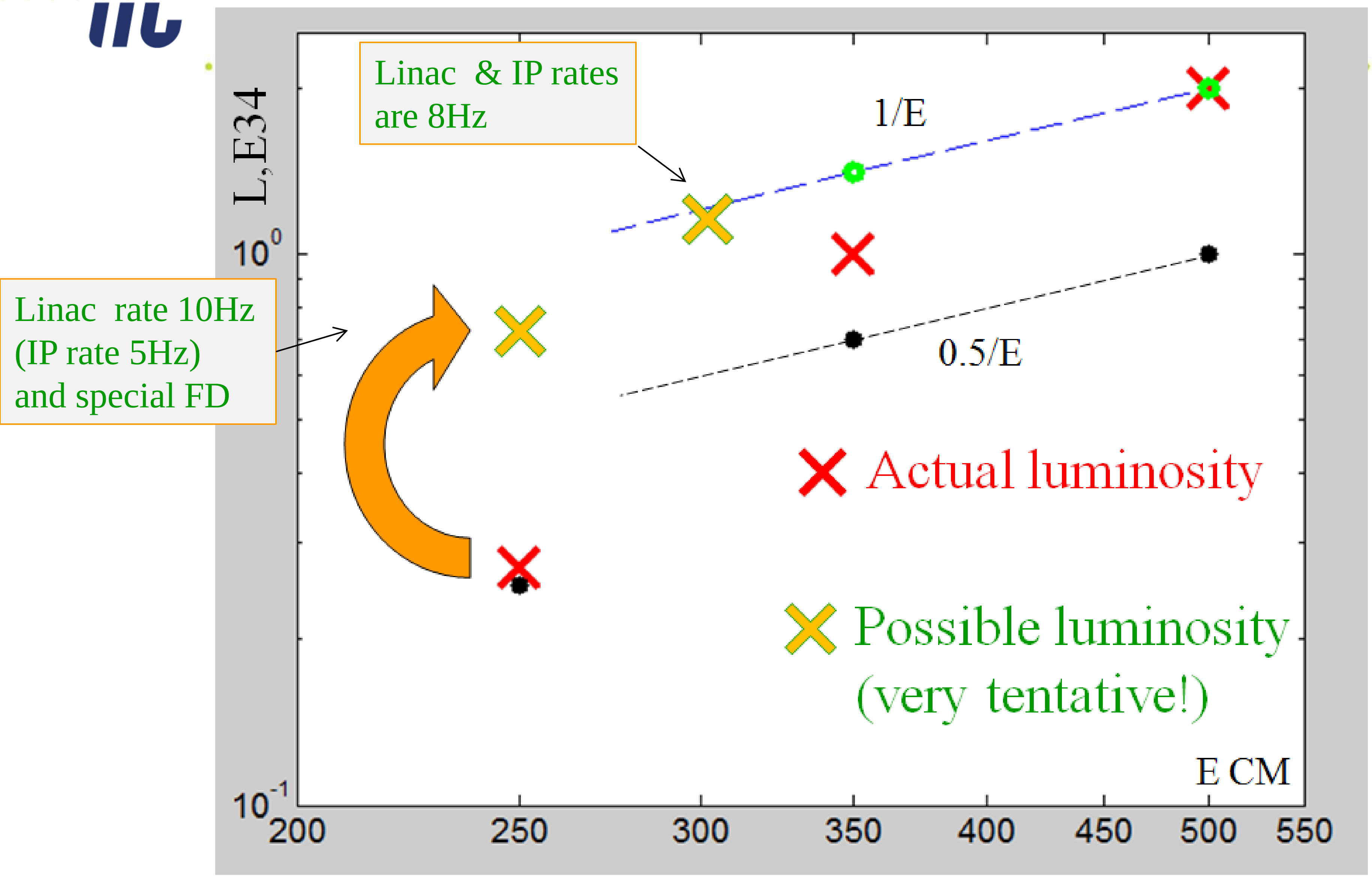
- One option would be to have a separate FD optimized for lower E, and then exchange it before going to nominal E
- Other option to be studied is to build a universal FD, that can be reconfigured for lower E configuration (may require splitting QD0 coil and placing sextupoles in the middle)



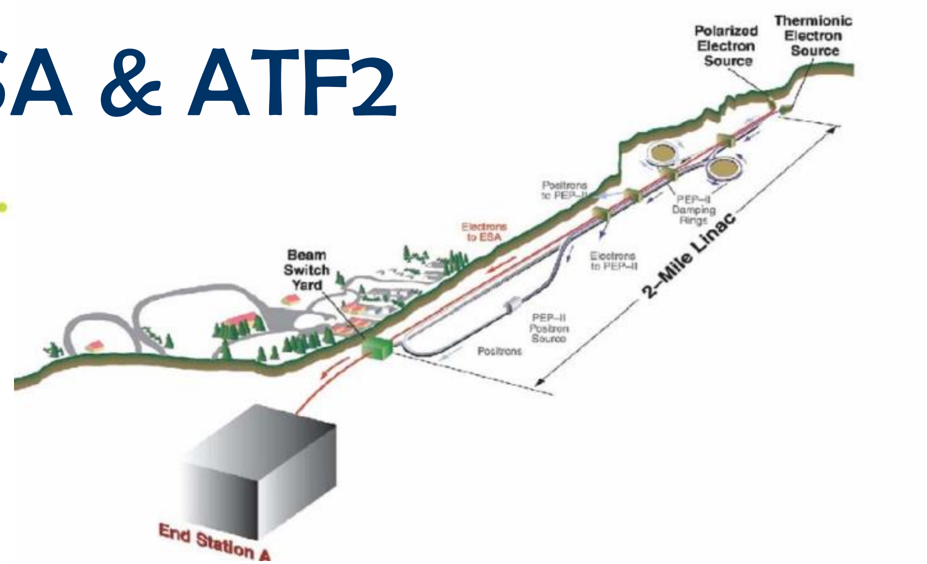




SB2009 Lumi

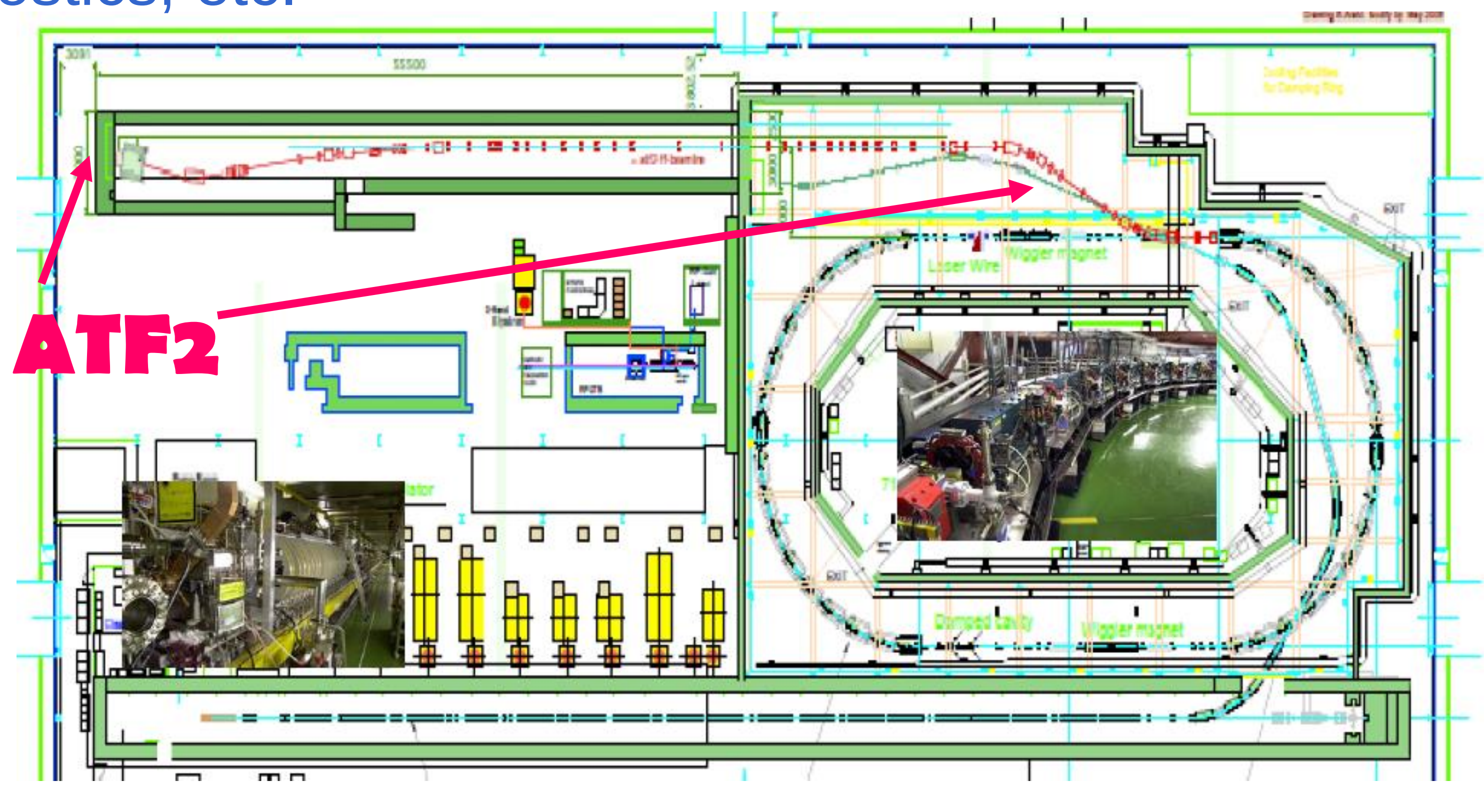

Linac & IP rates
are 8Hz
1/E
0.5/E
Linac rate 10Hz
(IP rate 5Hz)
and special FD
L, E34
10^0
10^{-1}
Actual luminosity
Possible luminosity
(very tentative!)
E CM
200
250
300
350
400
450
500
550

Test facilities: ESA & ATF2

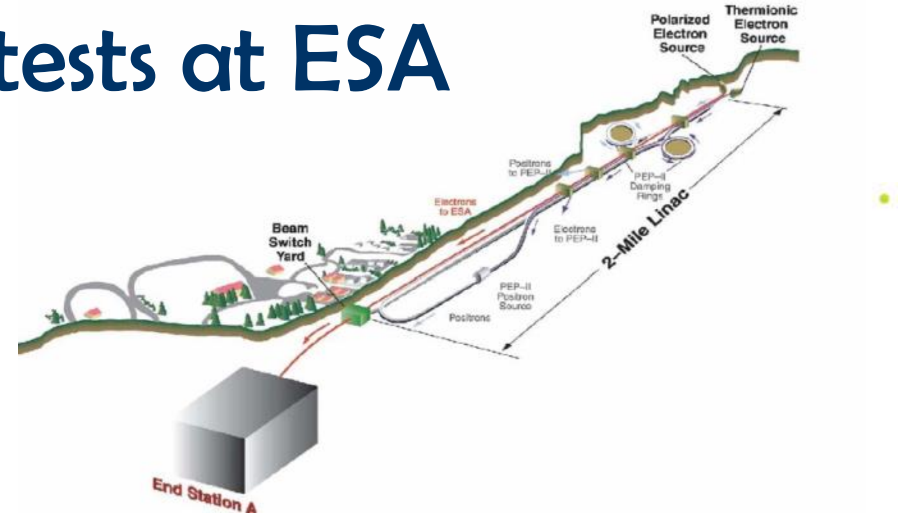


ESA: machine-detector tests; energy spectrometer; collimator wake-fields, etc.

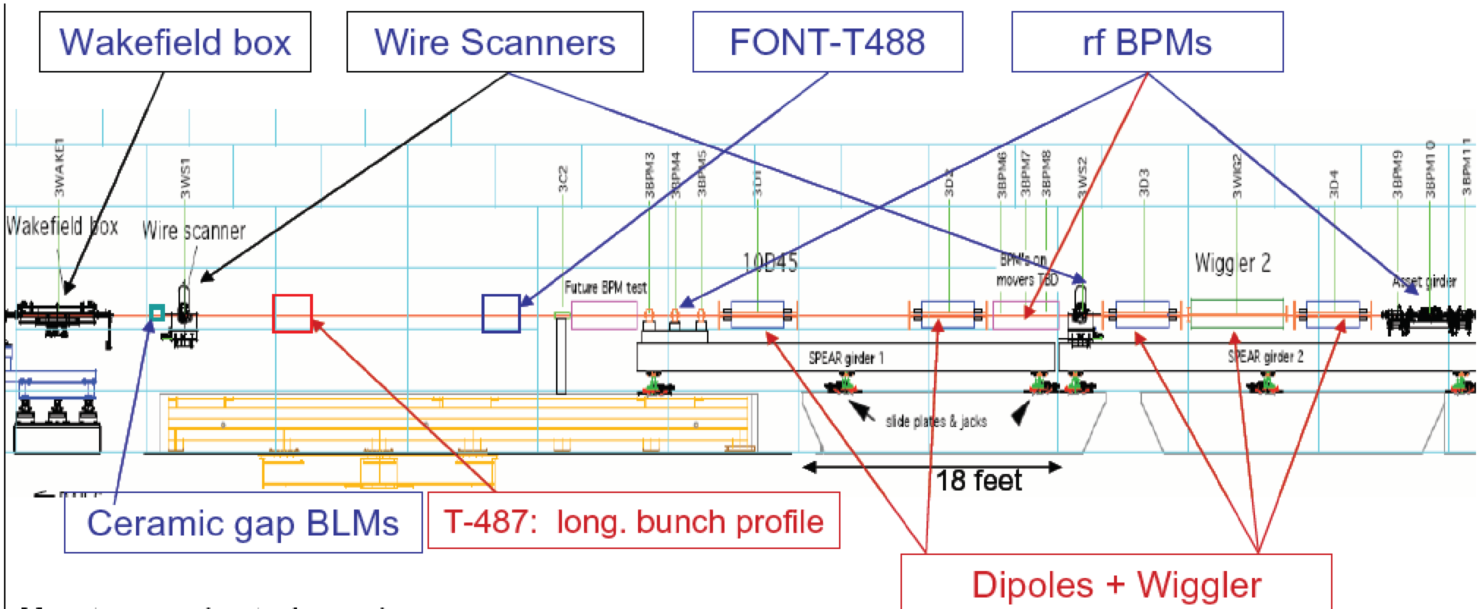
ATF2: prototype FF, develop tuning, diagnostics, etc.



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



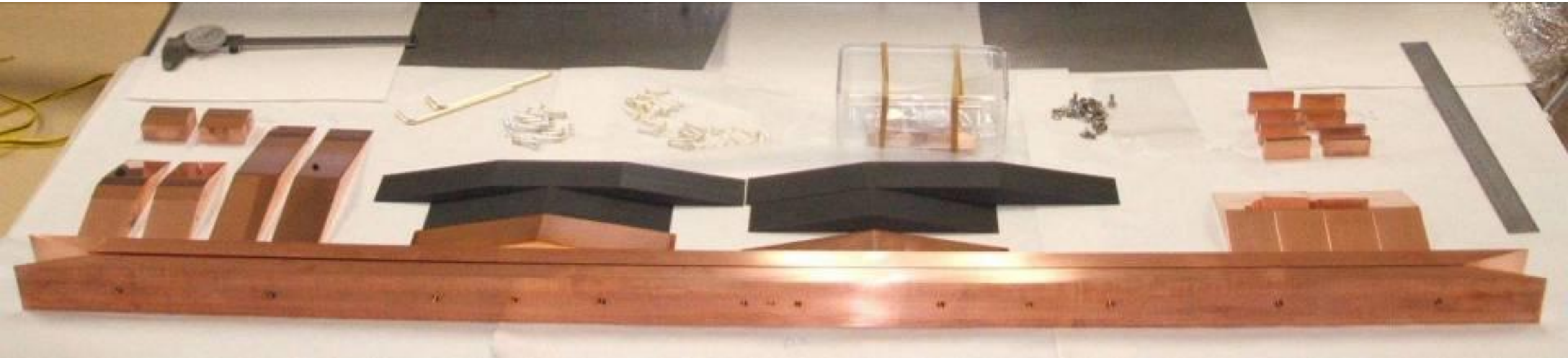
Upstream (not shown)

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

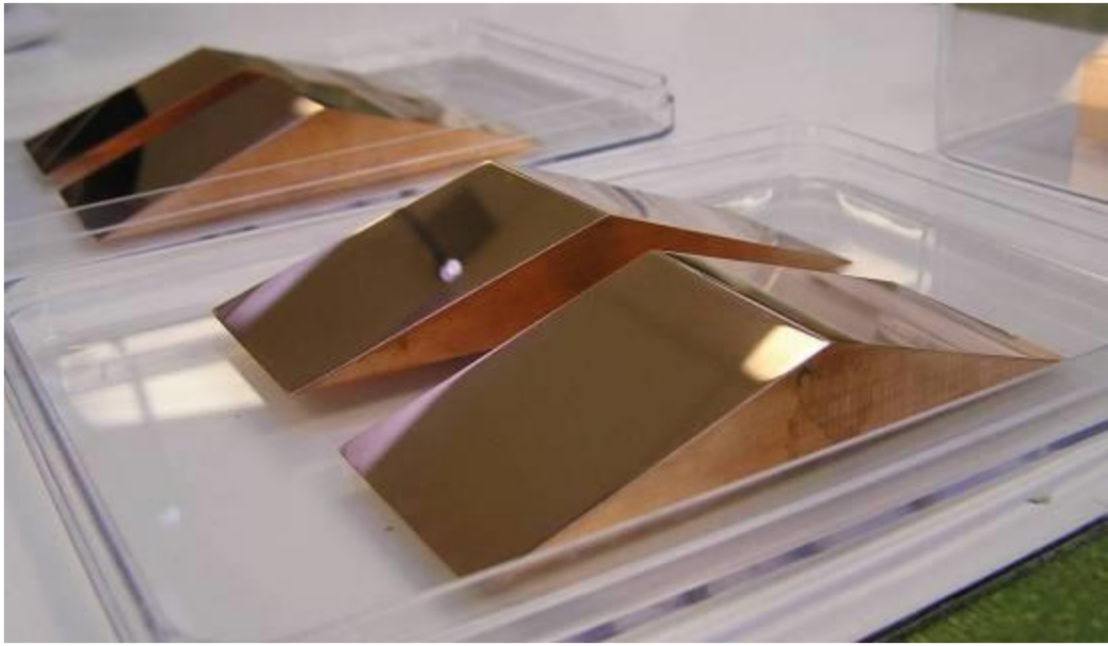
Downstream (not shown)

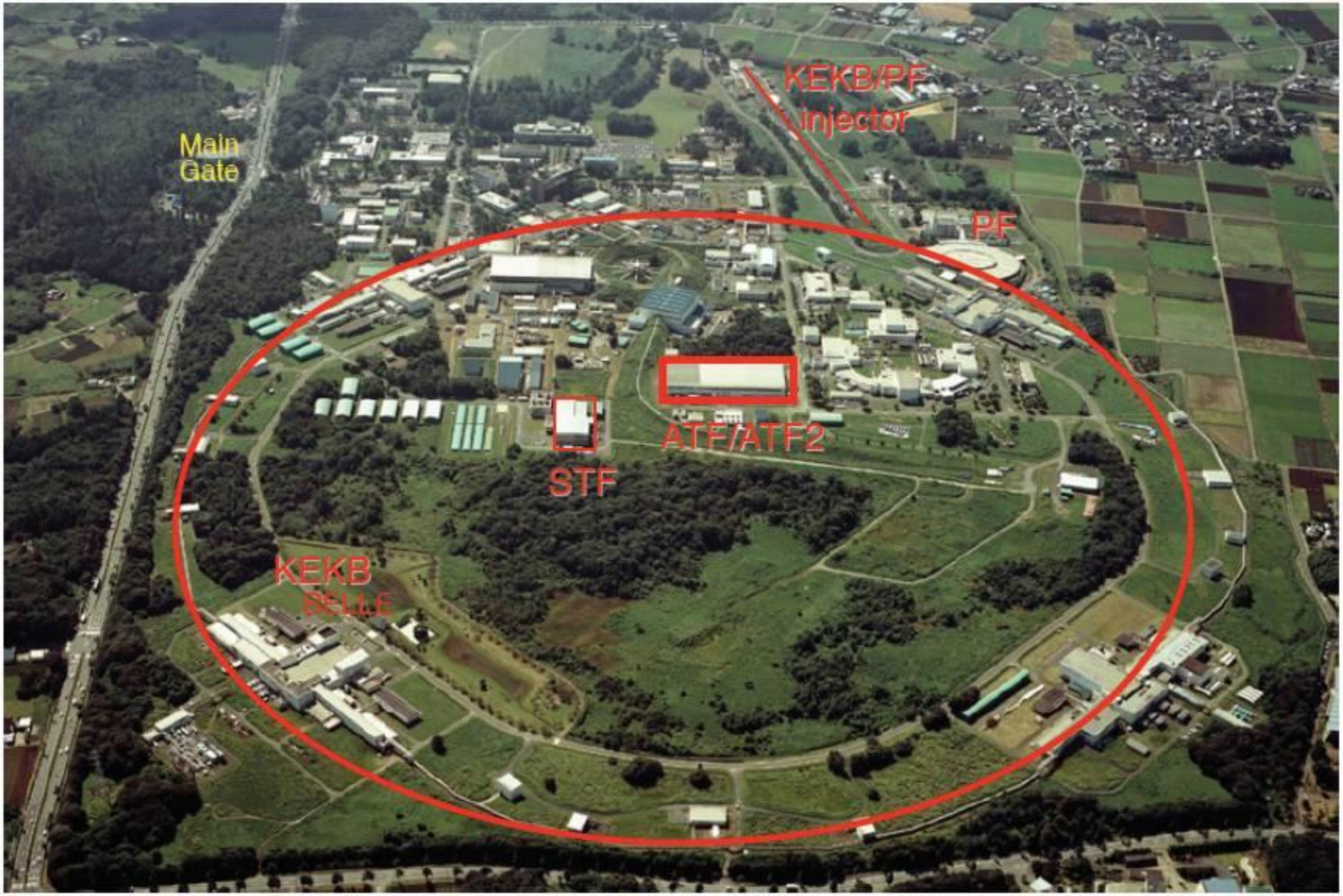
Ceramic gap for EMI studies
T475 Detector for Wiggler SR stripe

Collimator Wakefield study at ESA

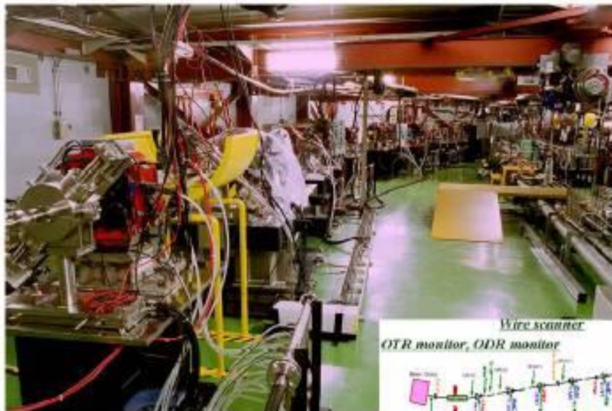


- Spoilers of different shape investigated at ESA (N.Watson et al)
- Theory, 3d modeling and measurements are so far within a factor of ~2 agreement

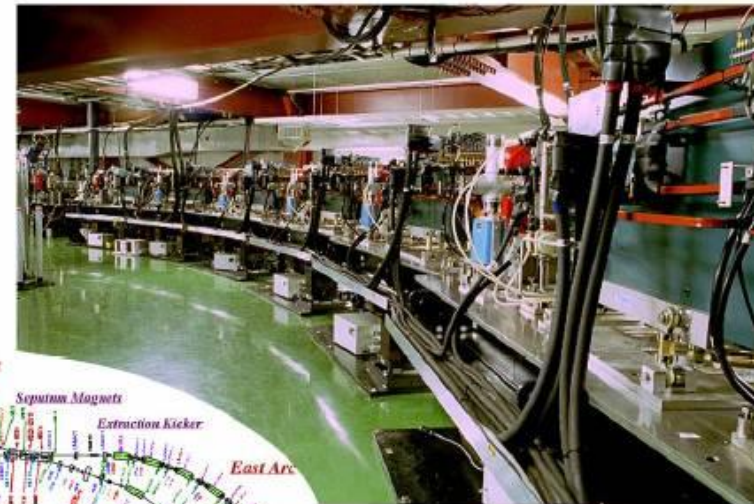



Main Gate
KEKB/PF injector
PF
ATF/ATF2
STF
KEKB
BELLE

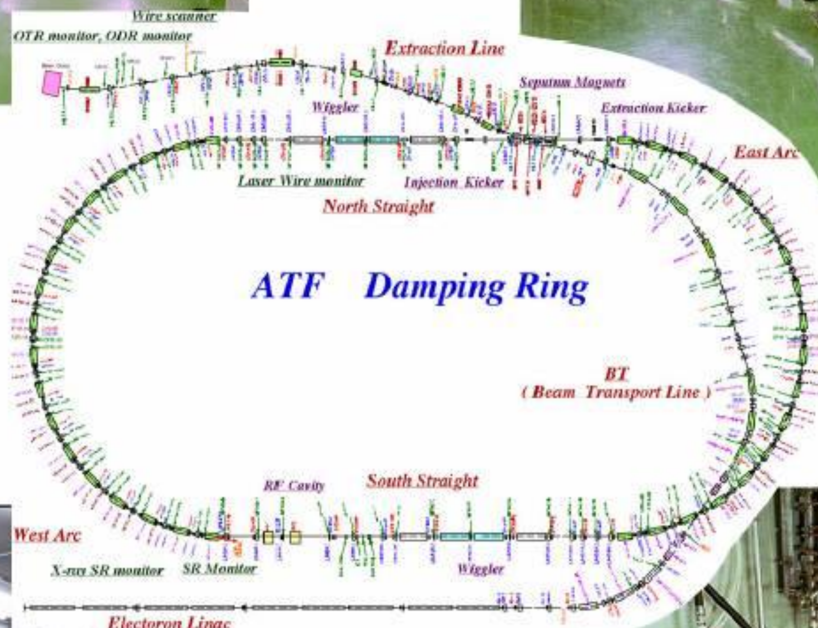
ATF and ATF2



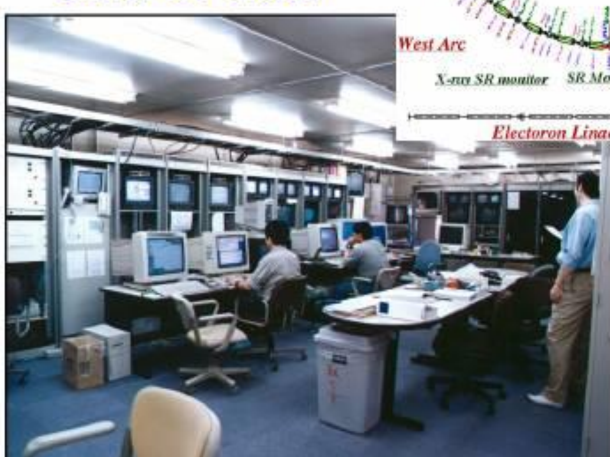
Extraction Line



Damping Ring

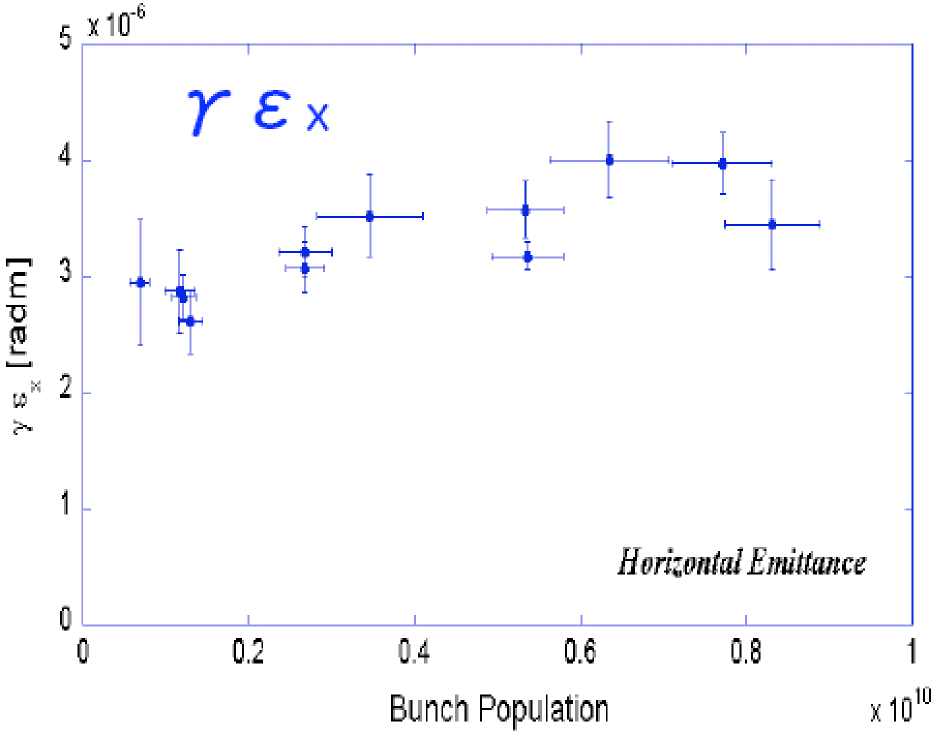


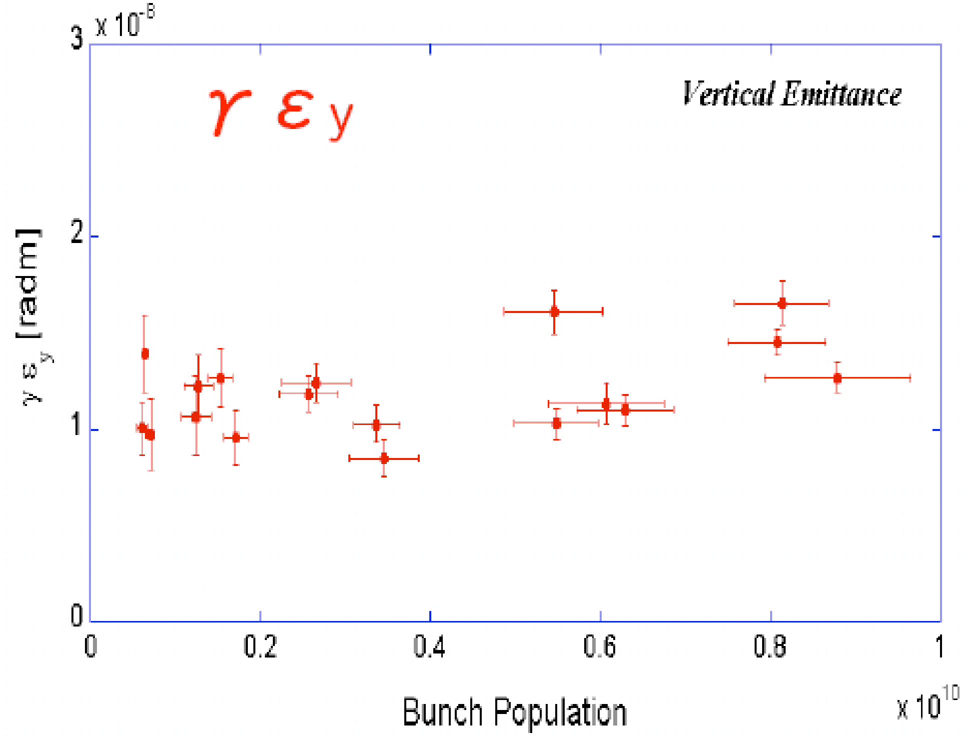
Control Room



Linac

Low emittance in ATF



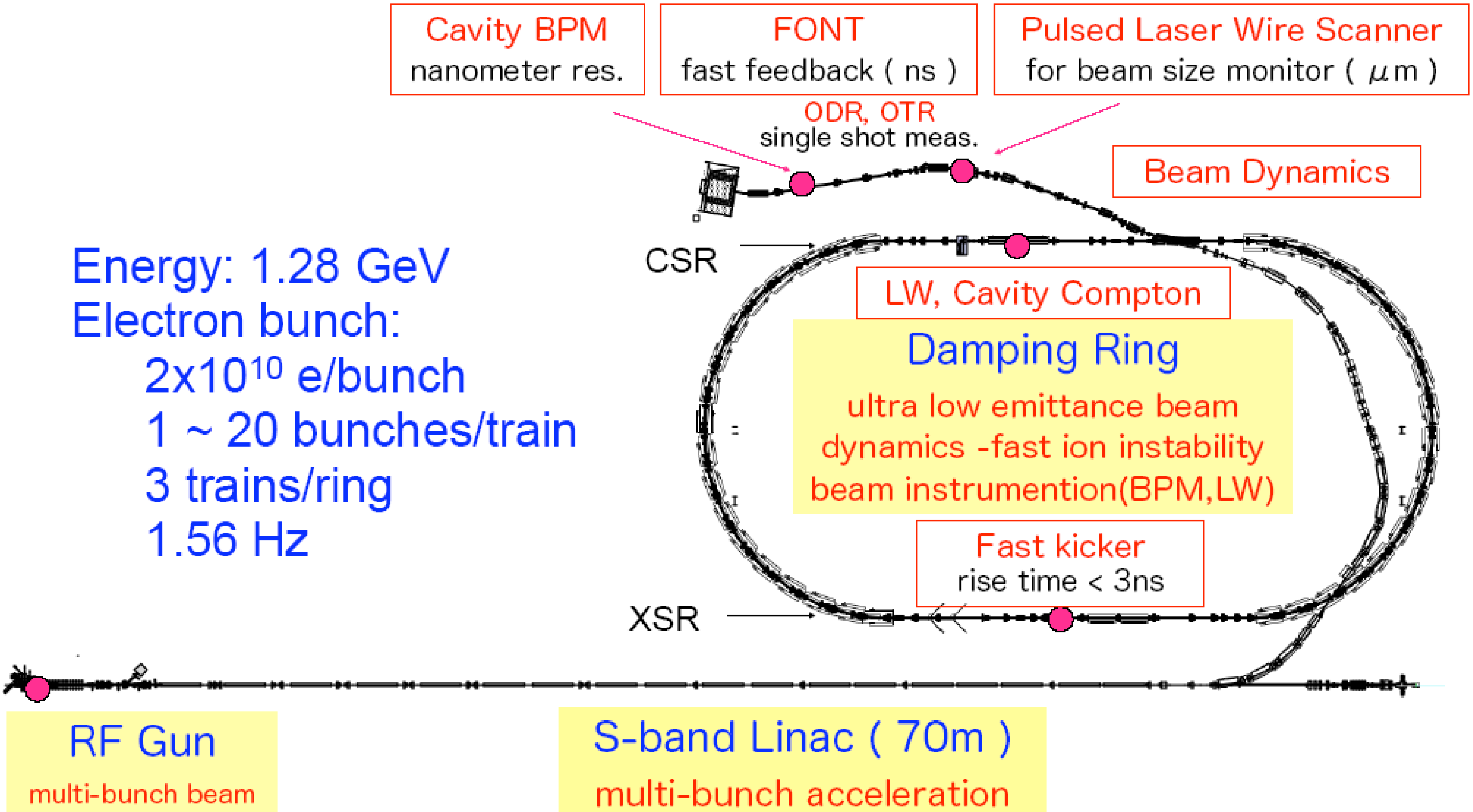


Accelerator Test Facility, KEK

1997-2008

Extraction line :utilization of low emittance beam
beam instrmentation, collimator damage

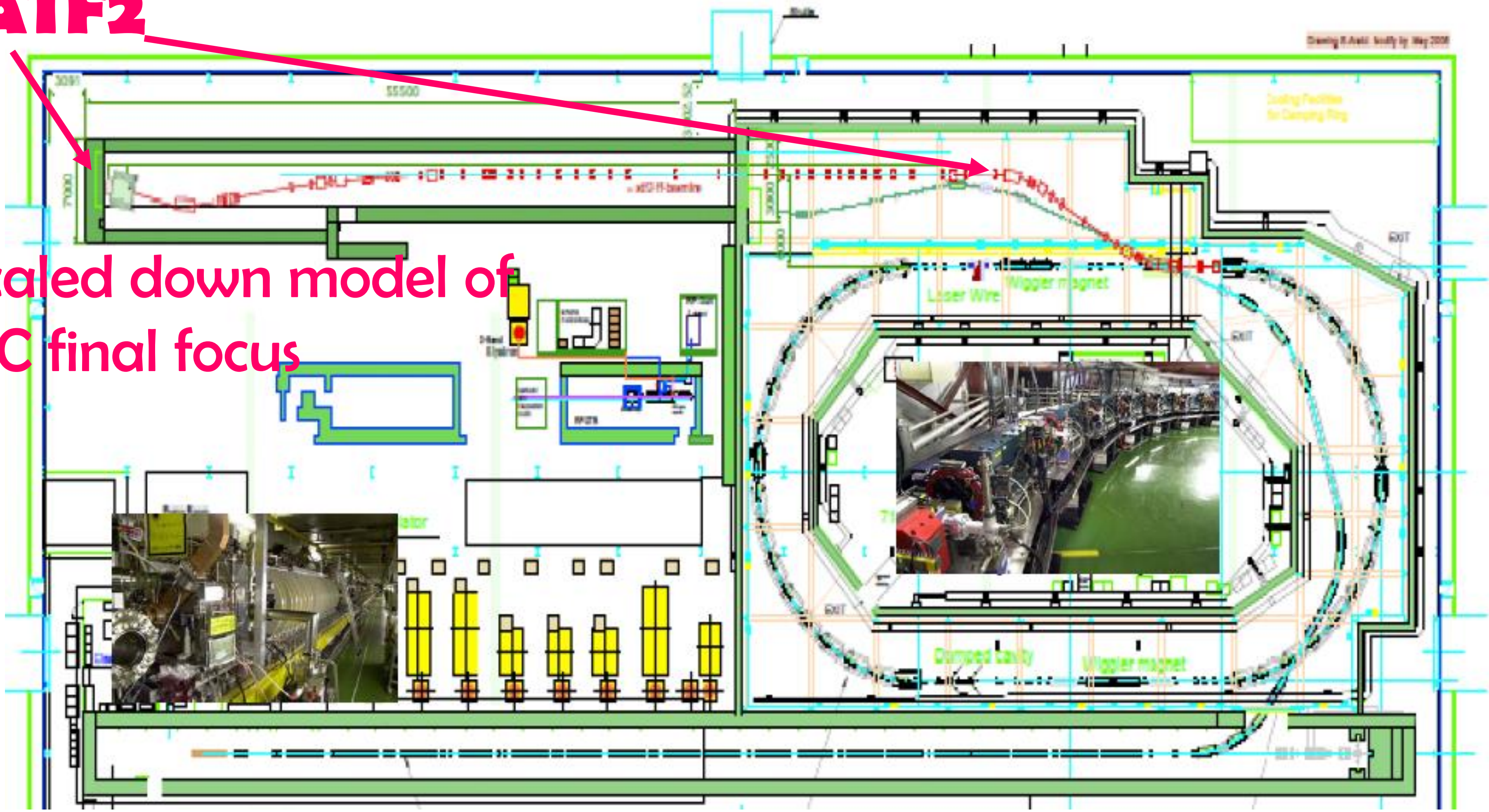
Energy: 1.28 GeV
Electron bunch:
- $2x10^{10}$ e/bunch
- 1 ~ 20 bunches/train
- 3 trains/ring
- 1.56 Hz



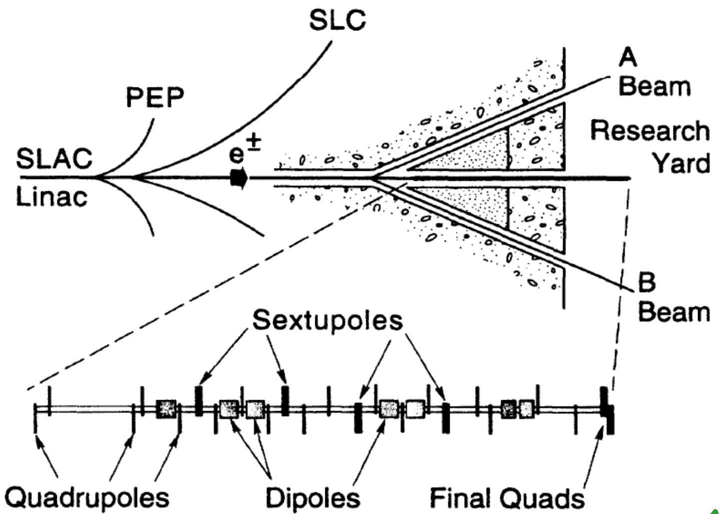
ATF
Accelerator Test Facility at KEK

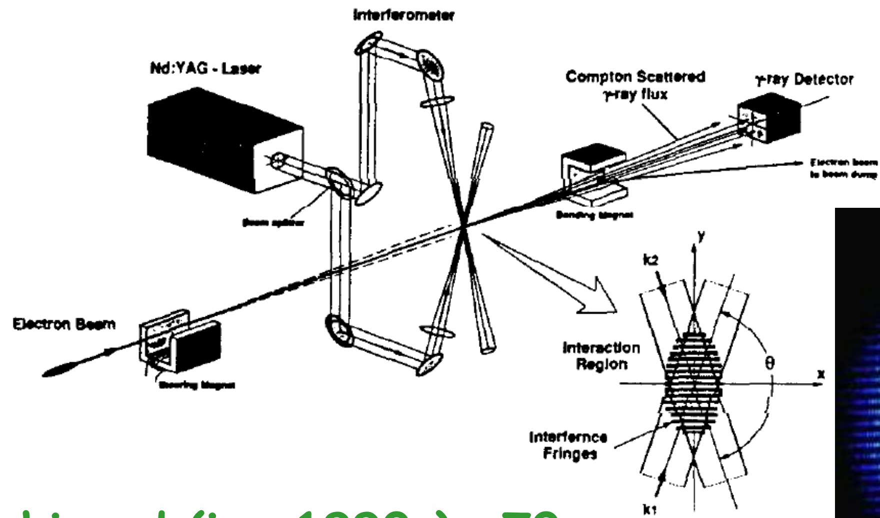
ATF2

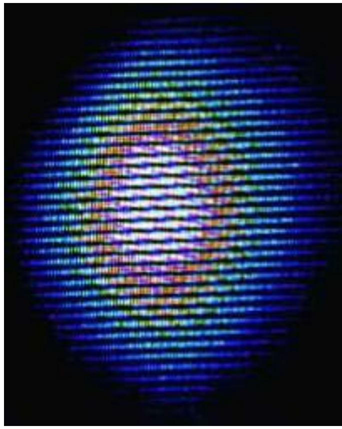
Scaled down model of ILC final focus



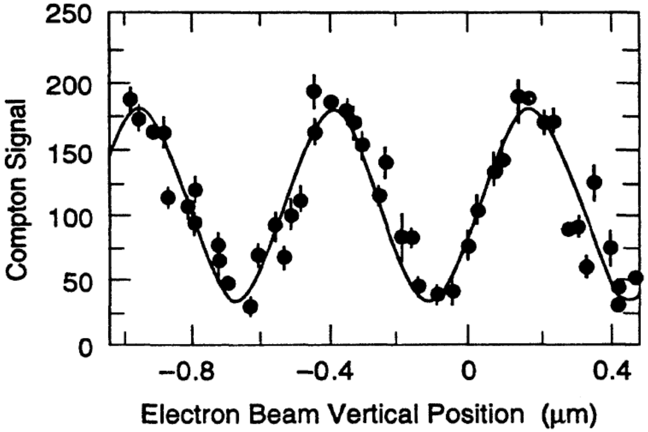
Final Focus Test Beam –
optics with traditional non-local chromaticity compensation





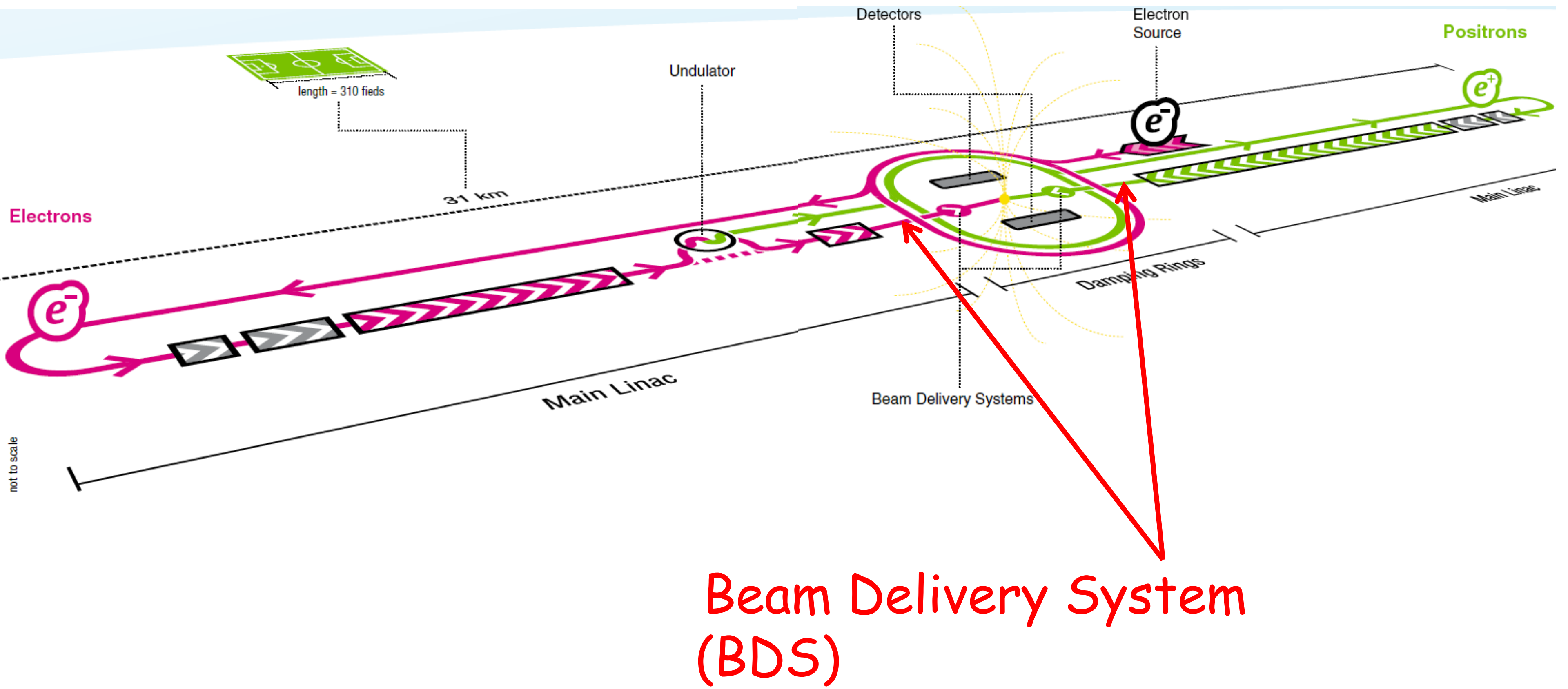


Achieved (in ~1990s) ~70nm vertical beam size



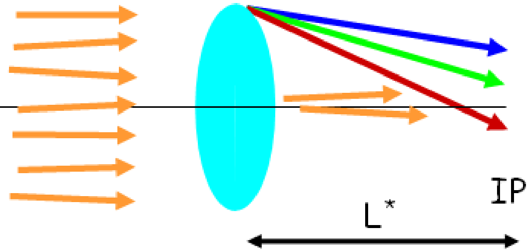
ILC BDS: from end of linac to IP

International Linear Collider

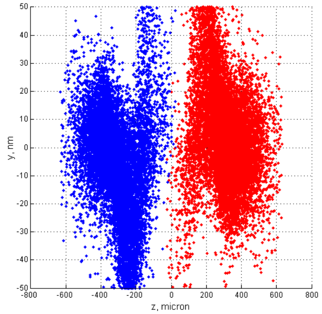


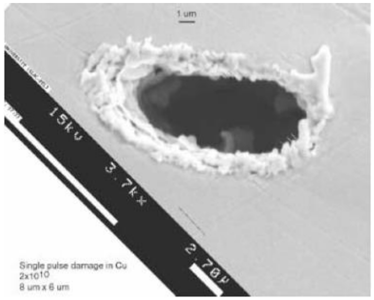
BDS includes:
Final Focus (FF), Collimation System, Diagnostic Section, Extraction line, etc.

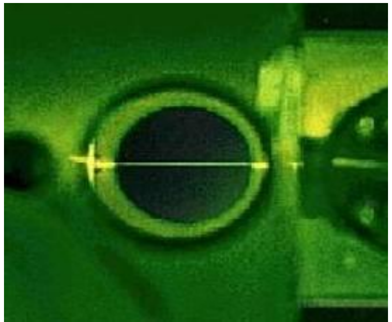
Factors driving design of BDS



- Final Doublet chromaticity
  - local compensation of chromaticity
- Beam-beam effects
  - background, IR and extraction design
- SR emittance growth in BDS bends
  - weak and long
- Halo collimation
  - survivability of spoilers
- Beam diagnostics
  - measurable size at laser wires
- ...

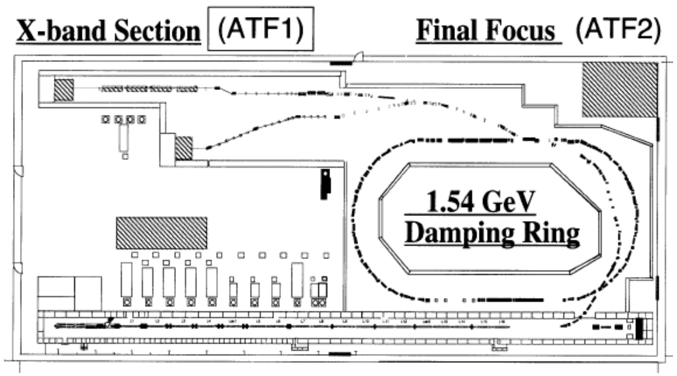






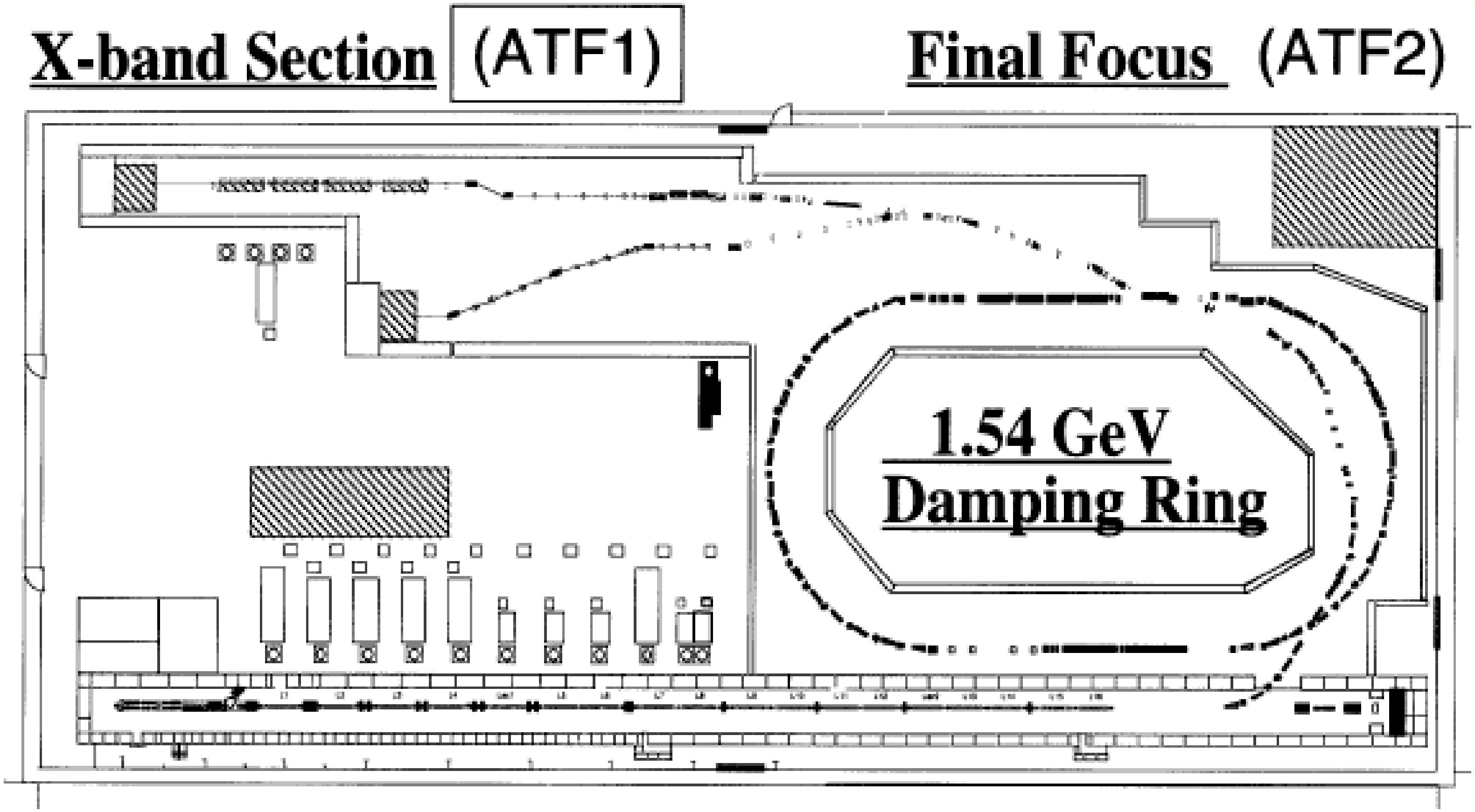
ATF2

- The idea of a new test facility at ATF, to prototype the **advanced final focus, for linear collider**, was conceived in **2002** at Nanobeam workshop in Lausanne
- Idea evolved, and has now been realized in iron and concrete



Early scheme presented by Junji Urakawa

- ATF2 goals
  - prototype ILC Final Focus system
  - develop FF tuning methods, instrumentation (laser wires, fast feedback, submicron resolution BPMs)
  - learn achieving ~37nm size & ~nm stability reliably
- ATF2 final goal – help to ensure collisions of nanometer beams, i.e. luminosity of ILC



Early scheme as presented by
Junji Urakawa at Nanobeam 2002

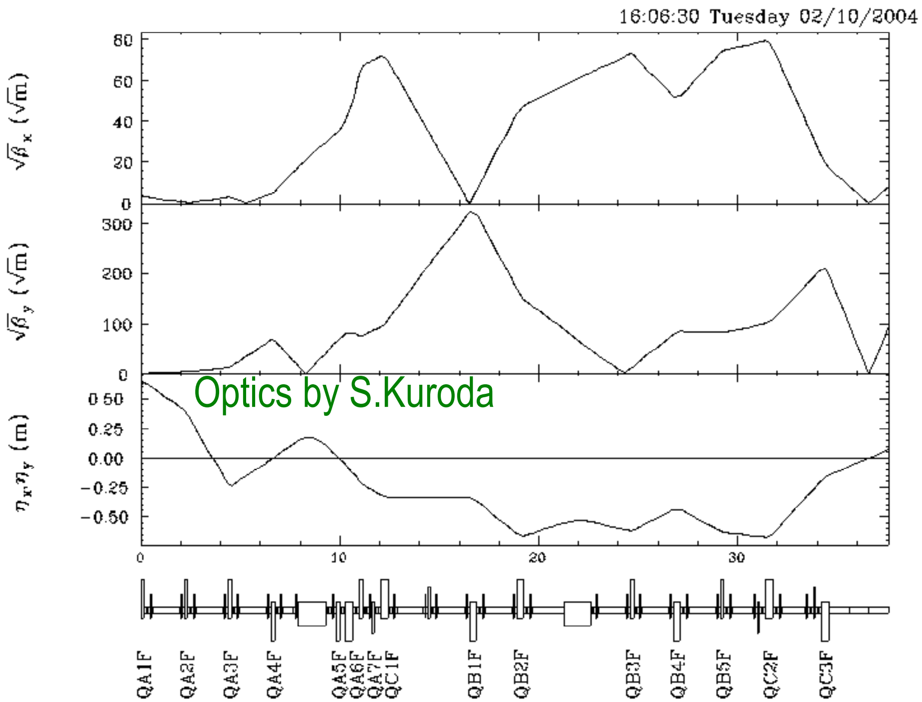
ATF2 major milestones

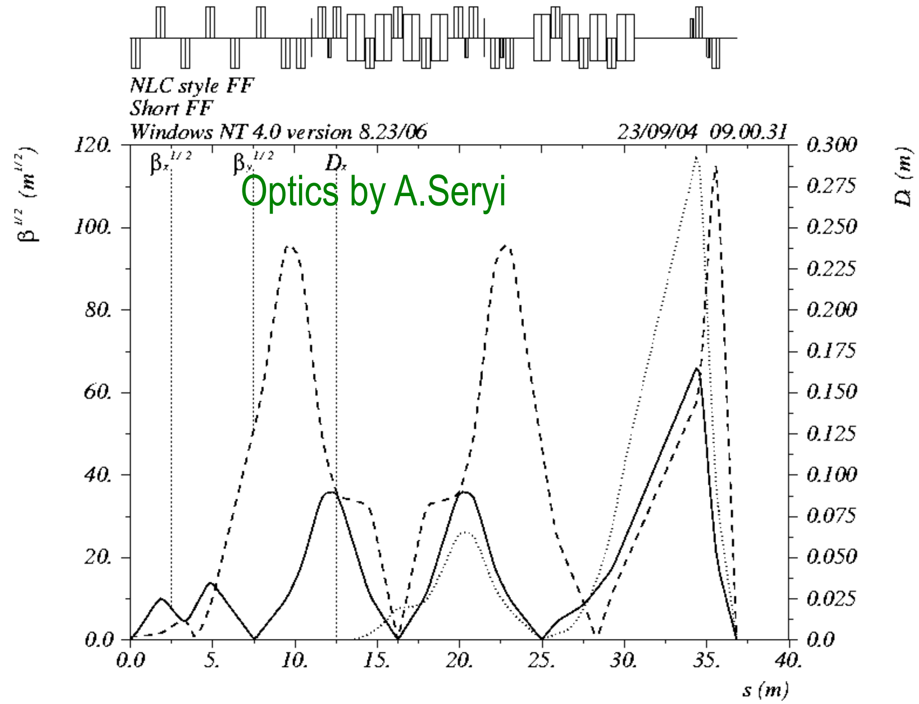
- September 2002, Nanobeam workshop, Lausanne
  - idea of new Final Focus test facility at ATF
- January 2005, SLAC, first ATF2 workshop
  - compared two optics versions, selected ILC-like design
  - stated the need to document the Proposal
- May 2005, ATF2 mtg at KEK
  - collaboration organization & MOU, task sharing, 1st version of schedule (commissioning start range: 02.2007-02.2008)
- August 2005
  - ATF2 Proposal, Vol.1 (technical description) released

ATF2 Proposal: 110 authors, 25 institutions

- February 2006, SLAC, 1st ATF2 Project Meeting
  - ATF2 Proposal, Vol.2 (organization, cost & contributions) released
- May 2006, KEK, 2nd ATF2 Project Meeting …
  - detailed design & role sharing
- … May 2008, BINP Novosibirsk, 6th ATF2 Project Meeting
  - Review of construction status and commissioning readiness
- … *To date: 14 ATF2 Project Meetings*

Optics considered for ATF2 in 2005



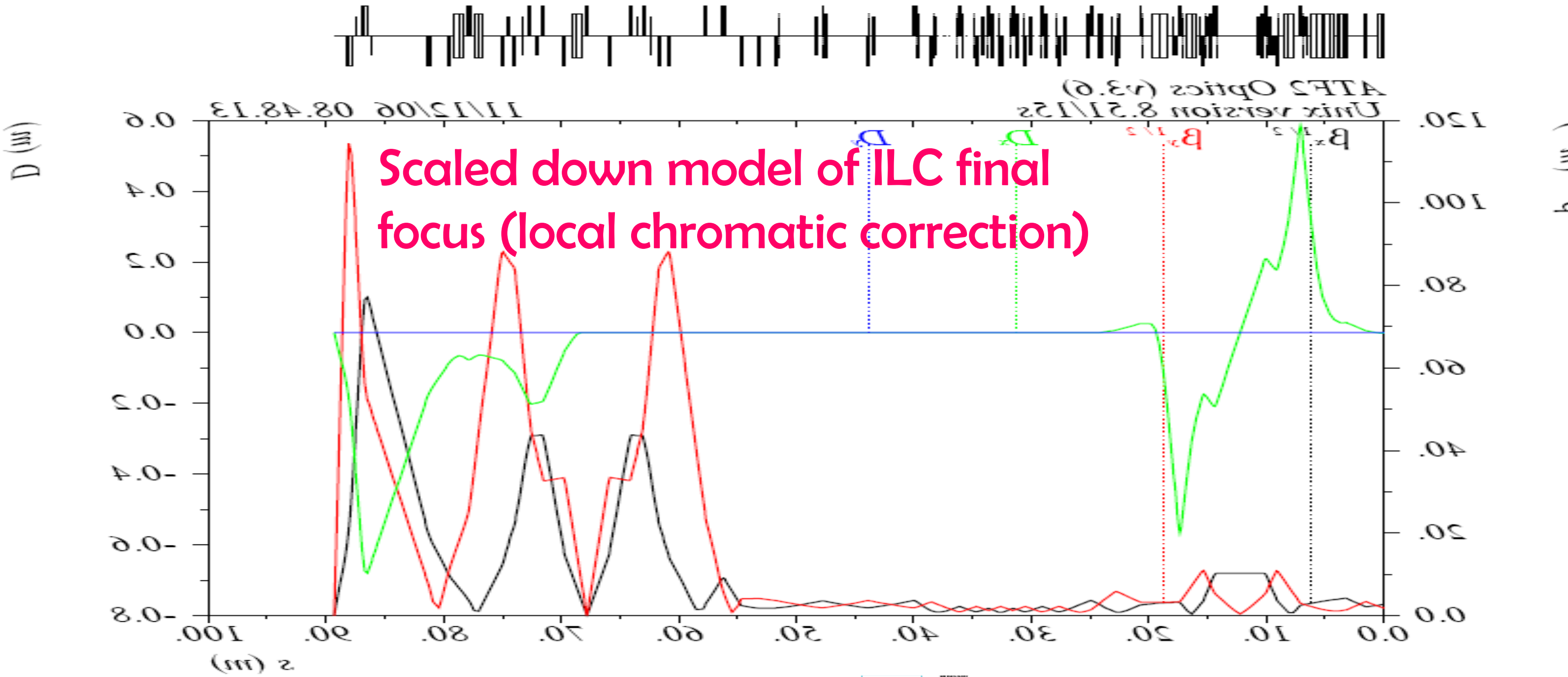


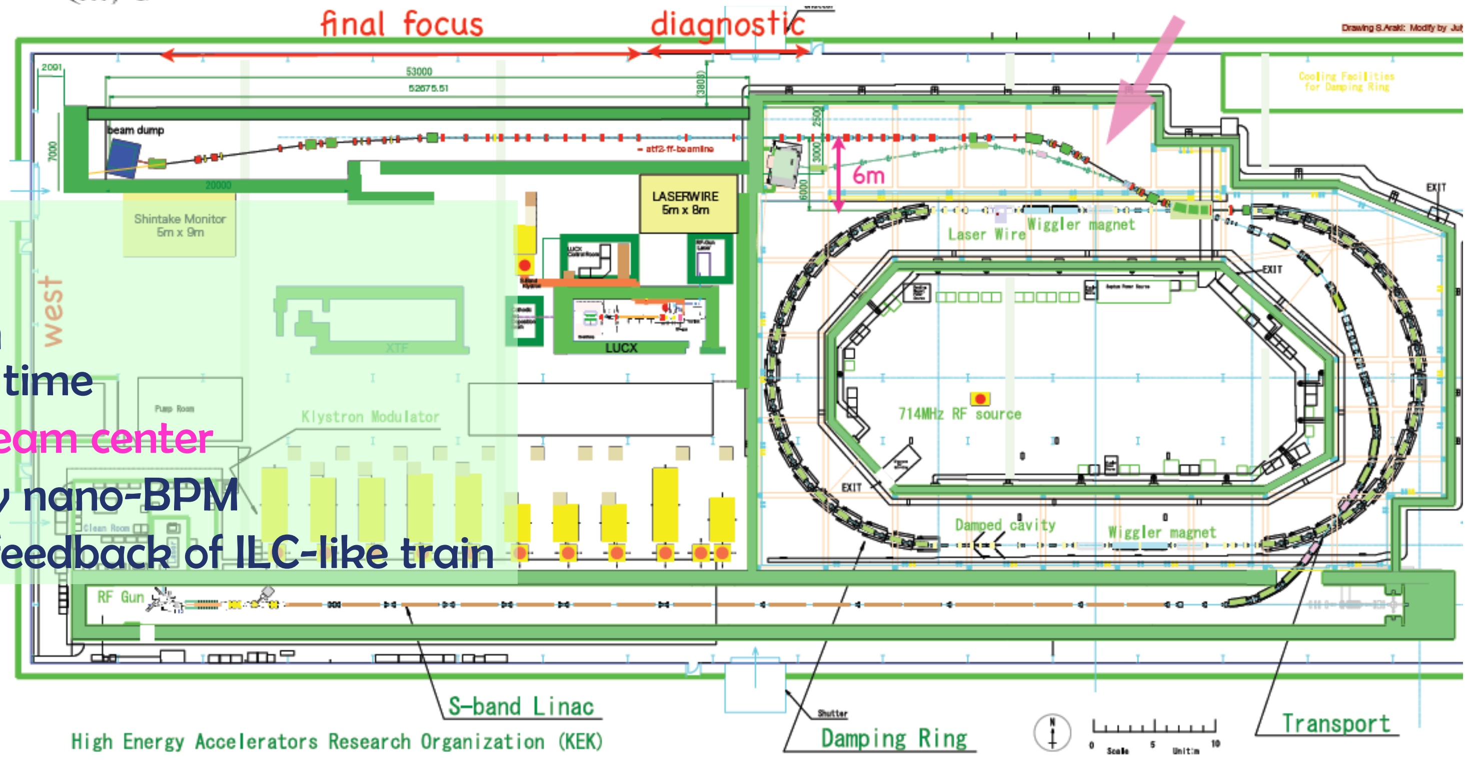
Optics with L*=1m, and IP β_x=4mm, β_y=0.1mm (same Y chromaticity as present ILC parameters)

Parameters used

$\gamma\varepsilon_x$=3e-6 m , $\gamma\varepsilon_y$=3e-8 m, E=1.54 GeV

ATF2 – model of ILC BDS

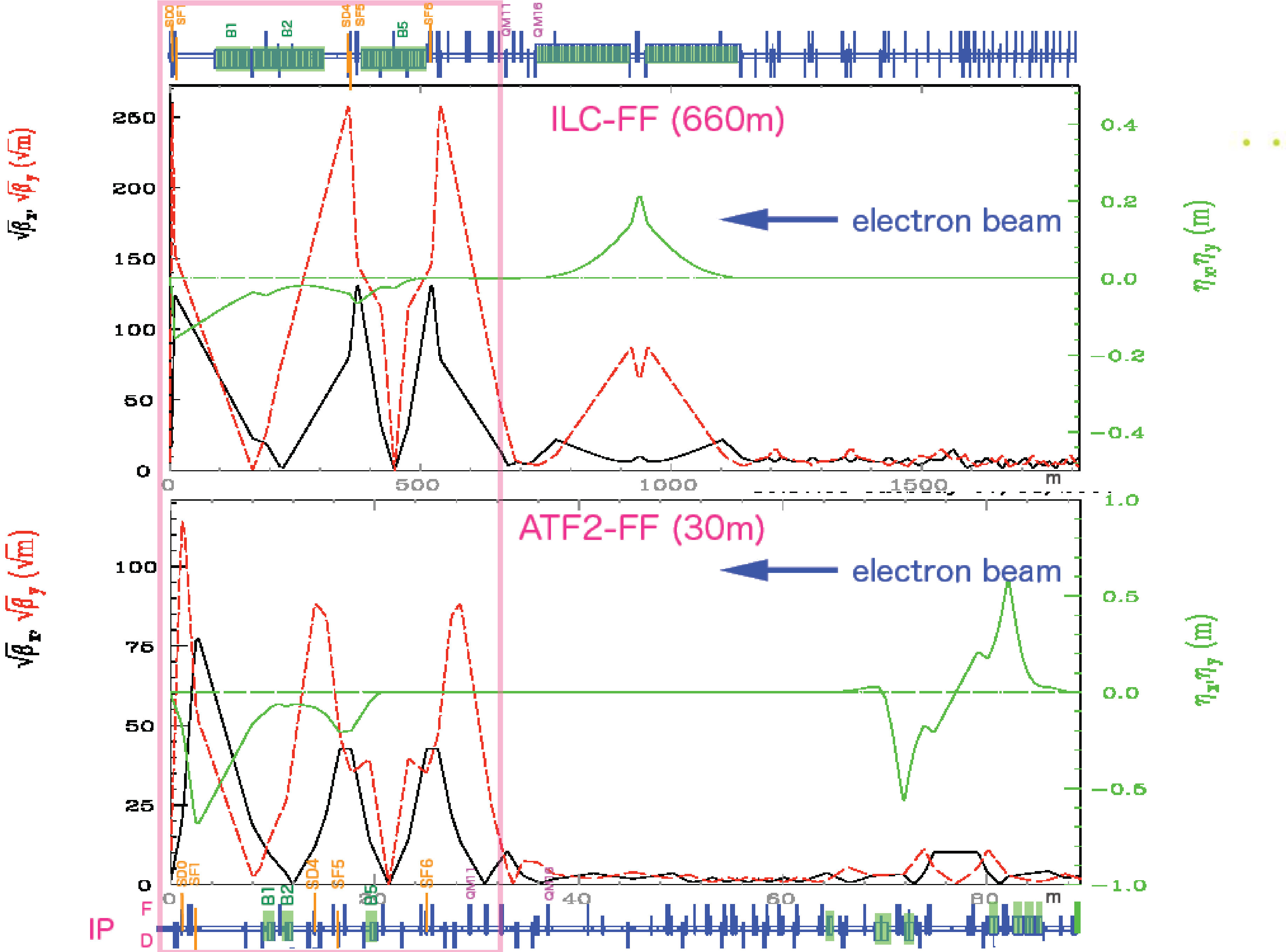




ATF2 goals

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

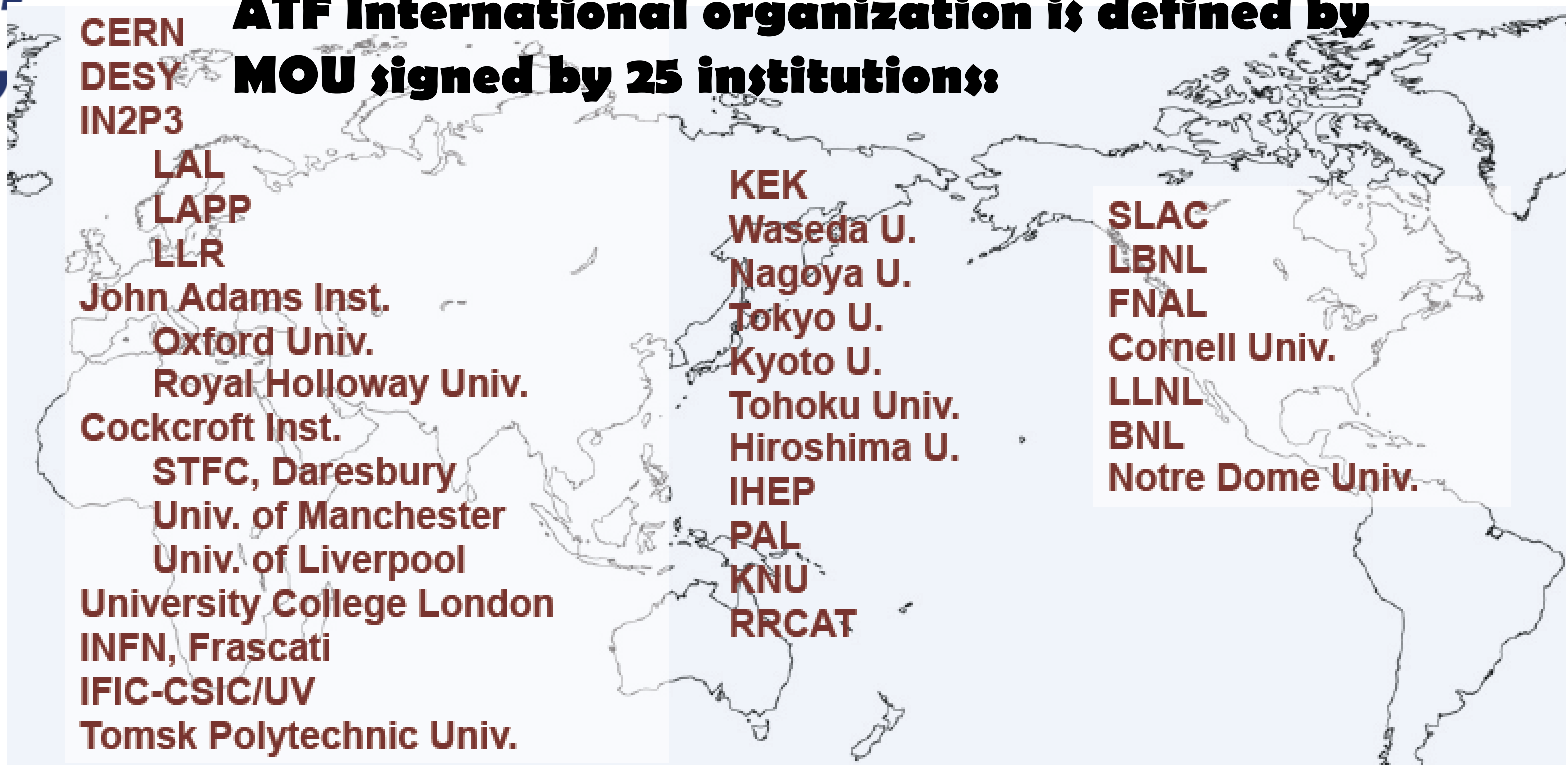
(B) Stabilization of beam center
- Down to < 2nm by nano-BPM
- Bunch-to-bunch feedback of ILC-like train


ILC-FF (660m)
electron beam
ATF2-FF (30m)
electron beam
IP
F
D

ATF2 & ILC parameters

Parameters	ATF2	ILC
Beam Energy, GeV	1.3	250
L*, m	1	3.5-4.2
$\gamma\varepsilon_{x/y}$, m*rad	3E-6 / 3E-8	1E-5 / 4E-8
IP $\beta_{x/y}$, mm	4 / 0.1	21 / 0.4
IP η', rad	0.14	0.094
σ_E, %	~0.1	~0.1
Chromaticity	~1E4	~1E4
$n_{bunches}$	1-3 (goal A)	~3000
$n_{bunches}$	3-30 (goal B)	~3000
N_{bunch}	1-2E10	2E10
IP σ_y, nm	37	5

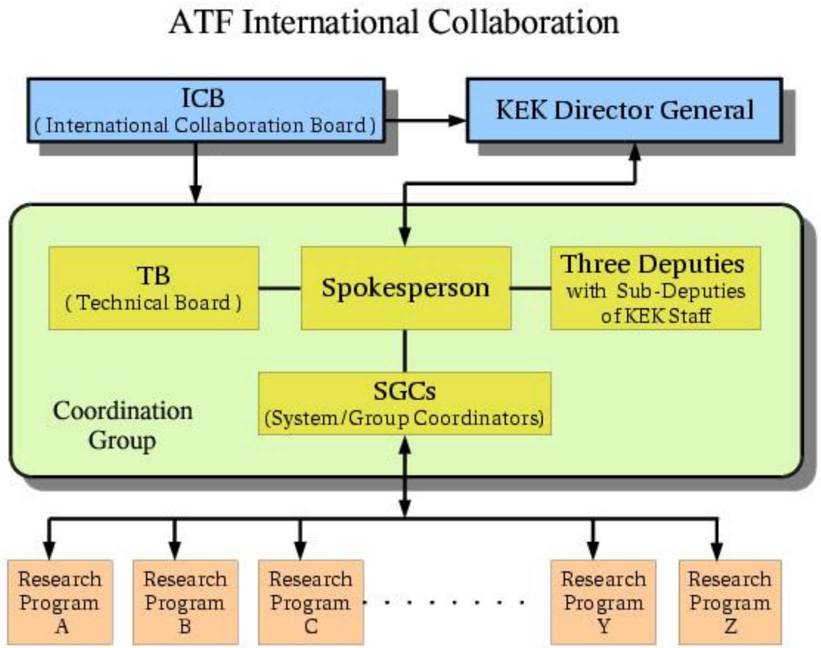
ATF International organization is defined by MOU signed by 25 institutions:



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.

http://atf.kek.jp/



ICB: decision making body for executive matters related to the ATF collaboration (chair: Ewan Paterson, SLAC)

TB: assist the Spokesperson in formulating the ATF Annual Activity Plan, including the budget and beamtime allocation and assist the ICB in assessing scientific progress. (co-chairs: A.Wolski, CI, E.Elsen, DESY)

Spokesperson:
direct and coordinate the work required at ATF/ATF2 in accordance with the ATF Annual Activity Plan, report the progress to ICB and the progress and the matters related to KEK budget to director of KEK
(Junji Urakawa, KEK):

Org. snapshot ~2010

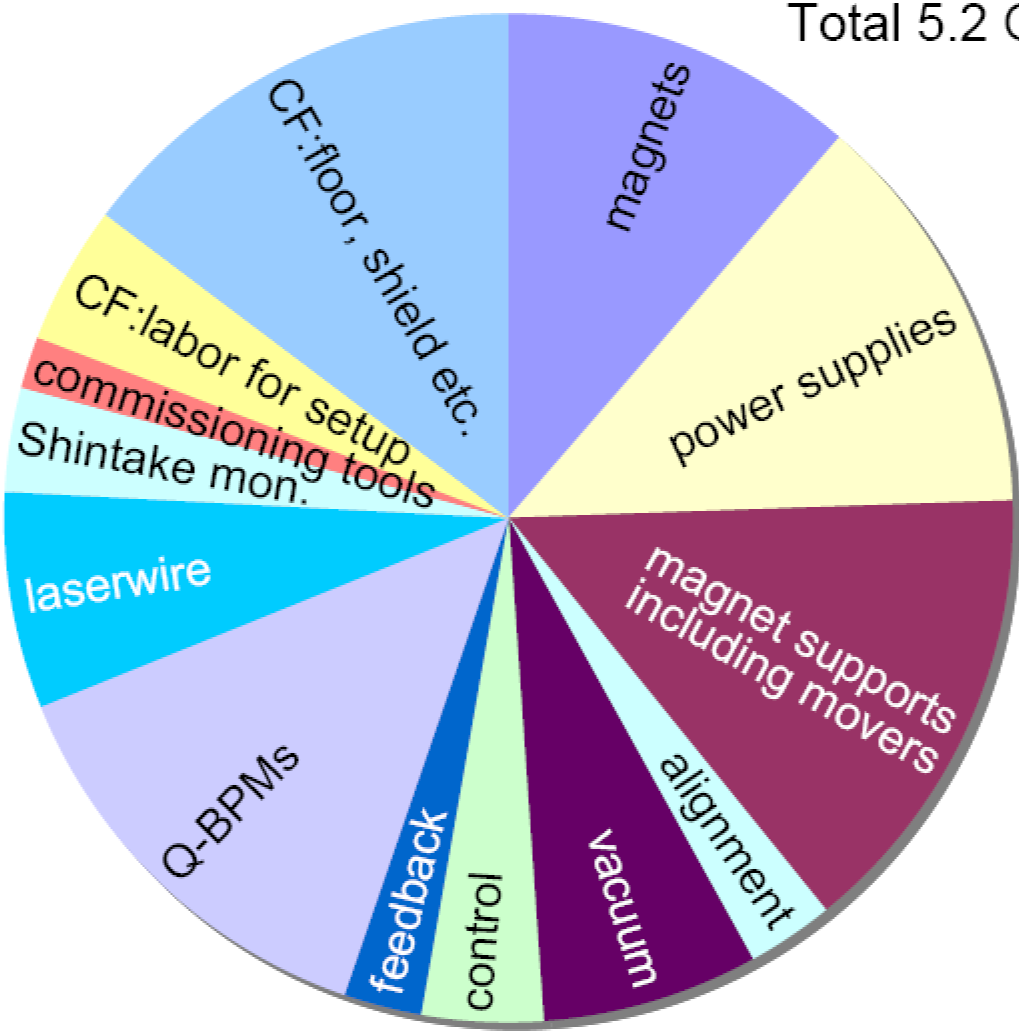
Deputies of Spokesperson: carry out tasks in the areas of

- Beam operation (Shigeru Kuroda, KEK)

- Hardware maintenance (Nobuhiro Terunuma, KEK)

- Design, construction and commissioning of ATF2 (Andrei Seryi, SLAC)

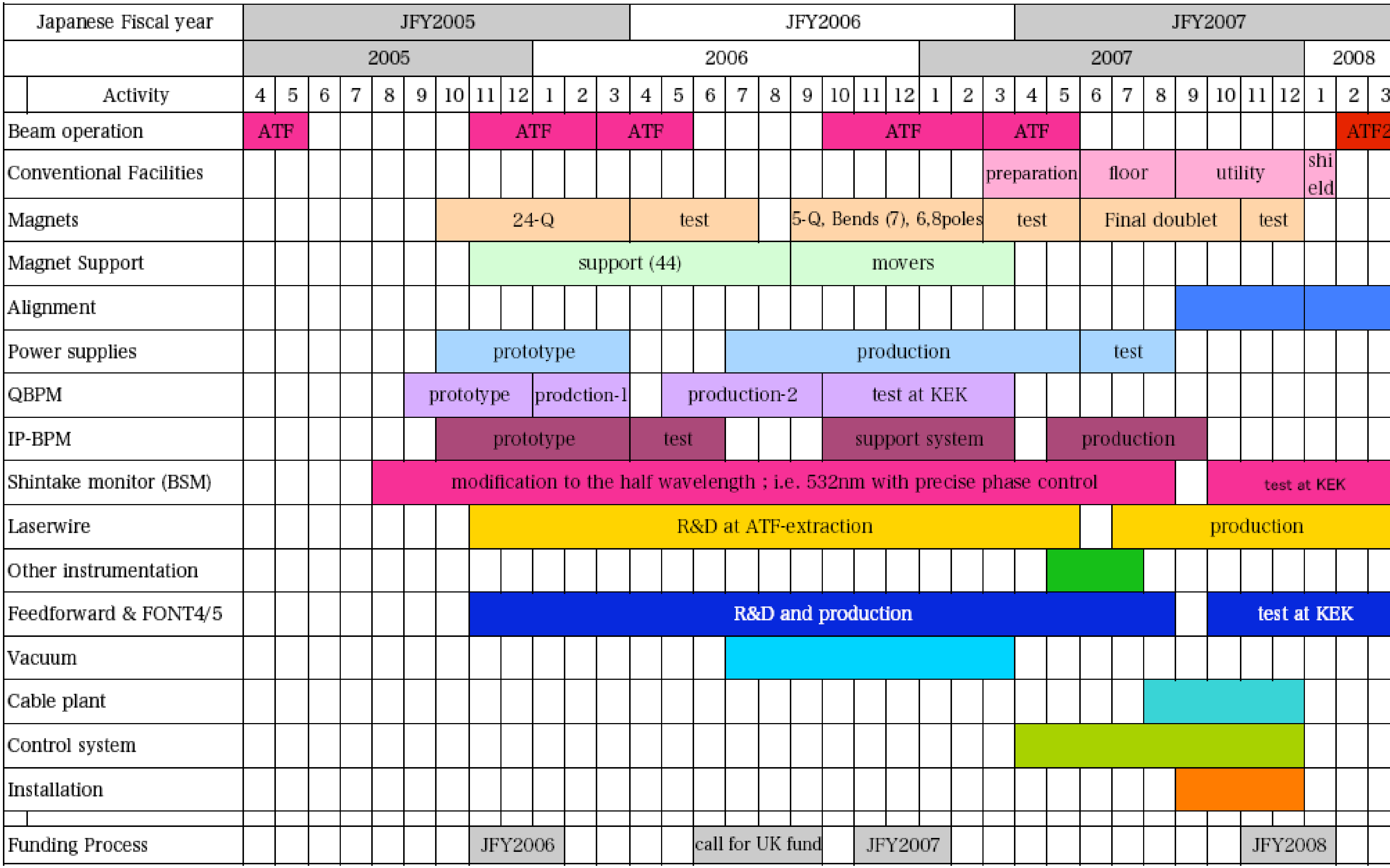
ATF2 cost



Cost distribution of the components normalized by the total cost, where the in-kind ones are also included

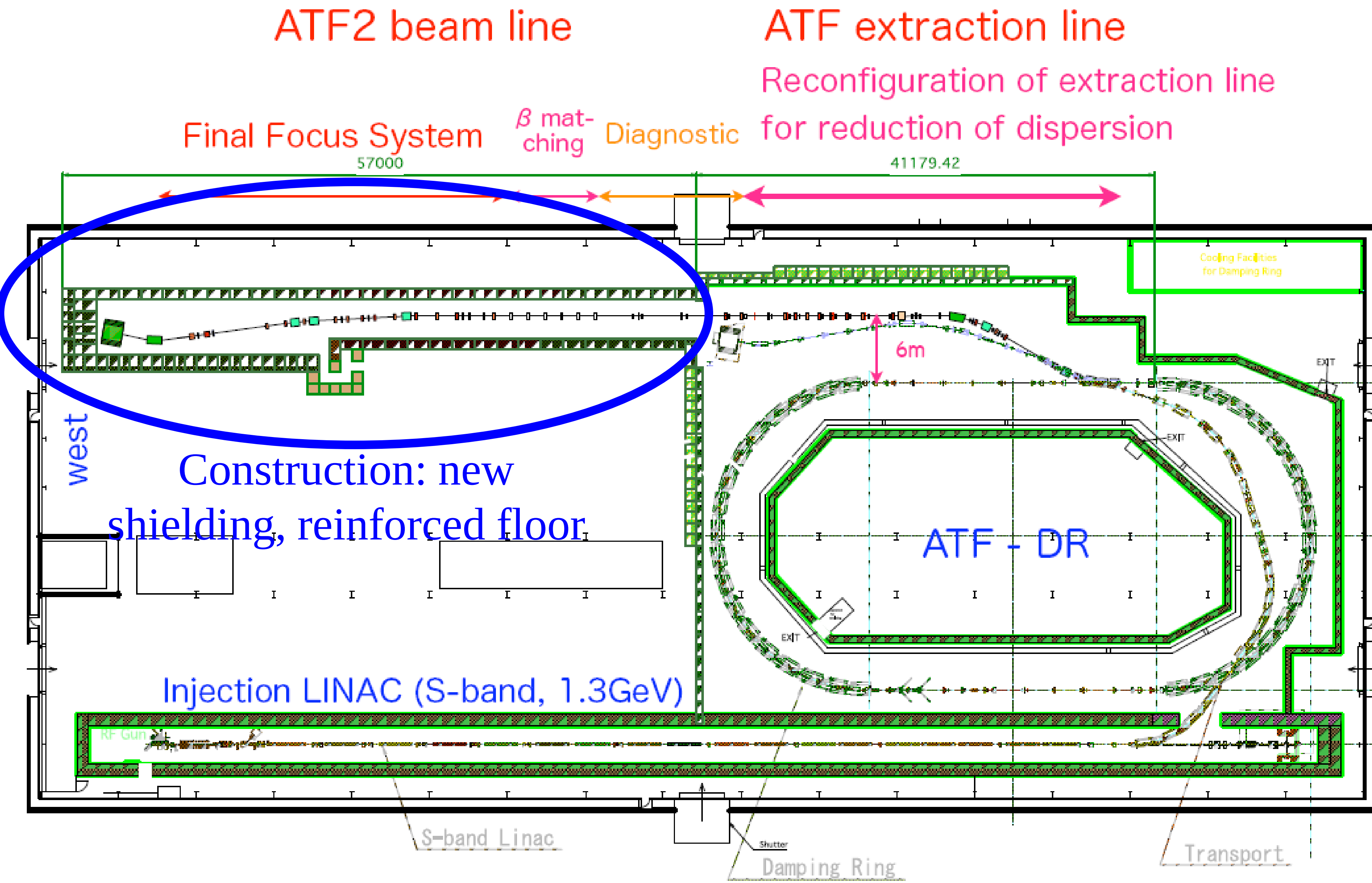
as seen in mid 2005 (from ATF2 Proposal, Volume 2)

(Oku-yen is 100*1E6 yen)



Outline of the ATF2 time schedule, as seen in mid 2005 (from ATF2 Proposal, Volume 2)

Layout & civil construction



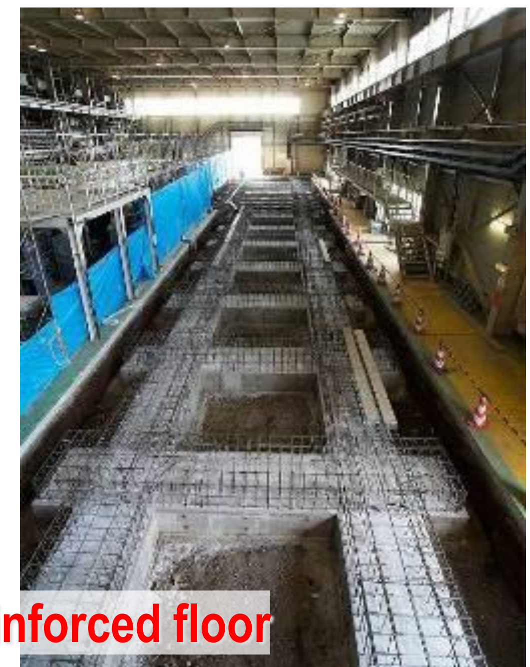
ATF2 construction in 2007

Aug – Dec

Assembly hall before construction

Assembly hall emptied for construction

Photos:
Nobu Toge



Construction of reinforced floor

Construction of shielding

ATF2 floor piles

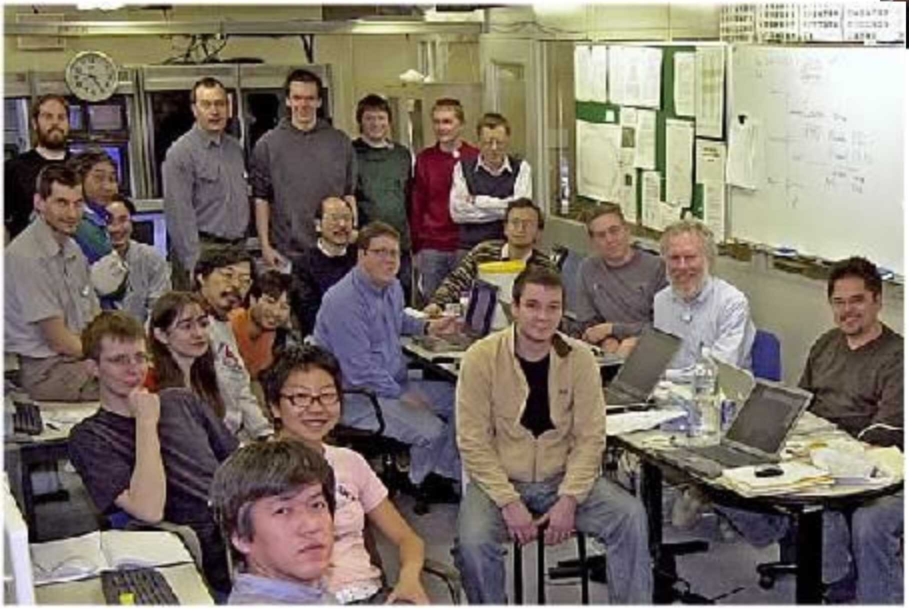
~ 13m x 38 sets

ATF2 floor base structure

Finalizing the ATF2 floor

ATF collaboration & ATF2 facility

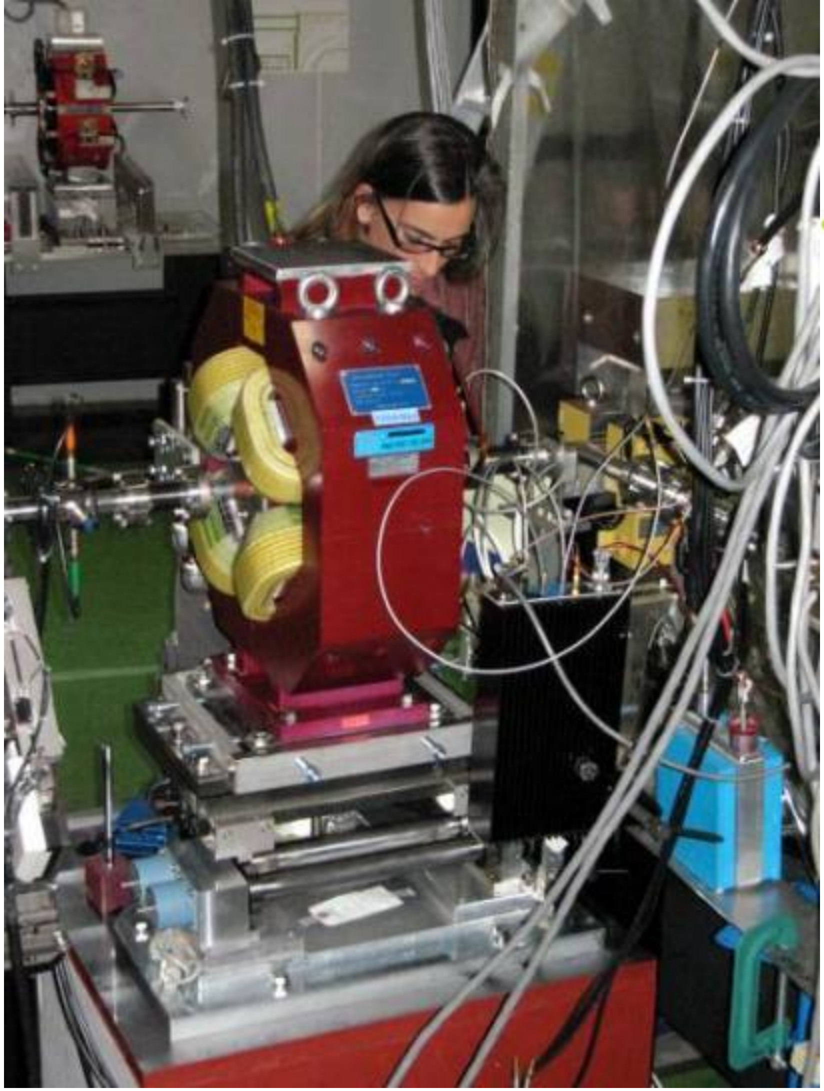
- ATF2 will prototype FF,
- help development tuning methods, instrumentation (laser wires, fast feedback, submicron resolution BPMs),
- help to learn achieving small size & stability reliably,



- 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**

ATF & ATF2

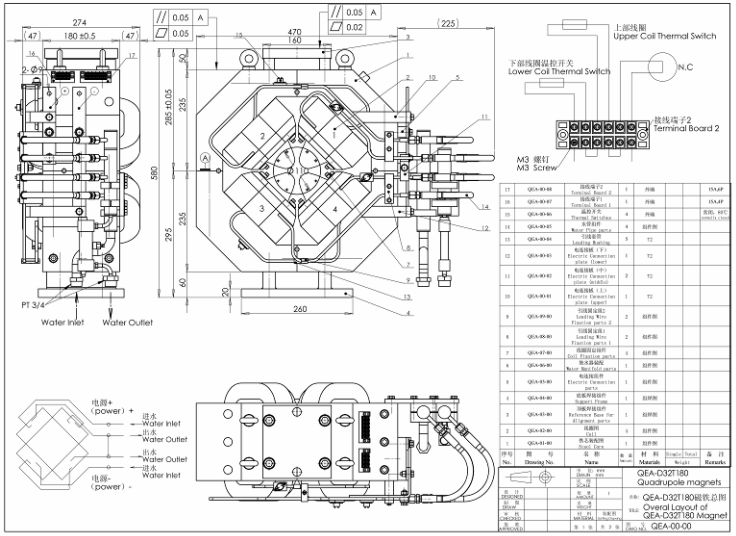
J.Nelson (at SLAC) and T.Smith (at KEK) during recent "remote participation" shift. Top monitors show ATF control system data. The shift focused on BBA, performed with new BPM electronics installed at ATF by Fermilab colleagues.



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

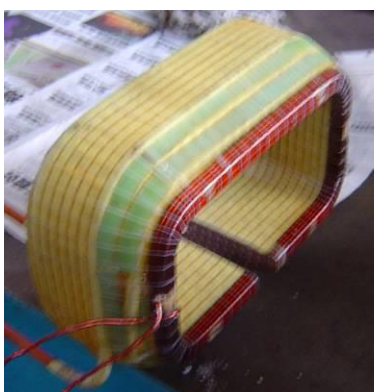
Power Supplies and Magnet system

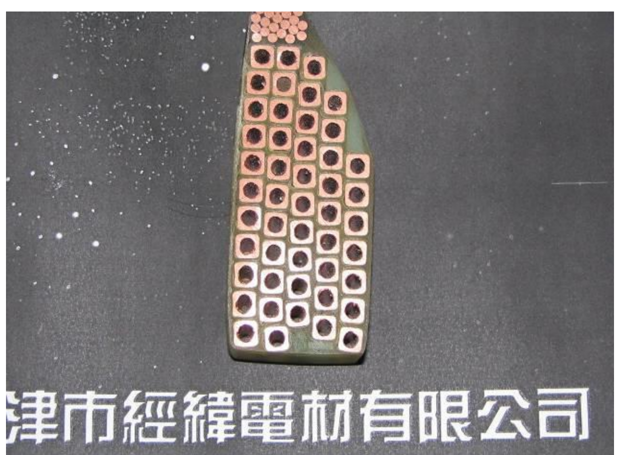
SLAC-built High Availability Power Supplies installed, connected and tested at ATF2



C.Spencer (SLAC) at IHEP, Beijing, Dec 2005

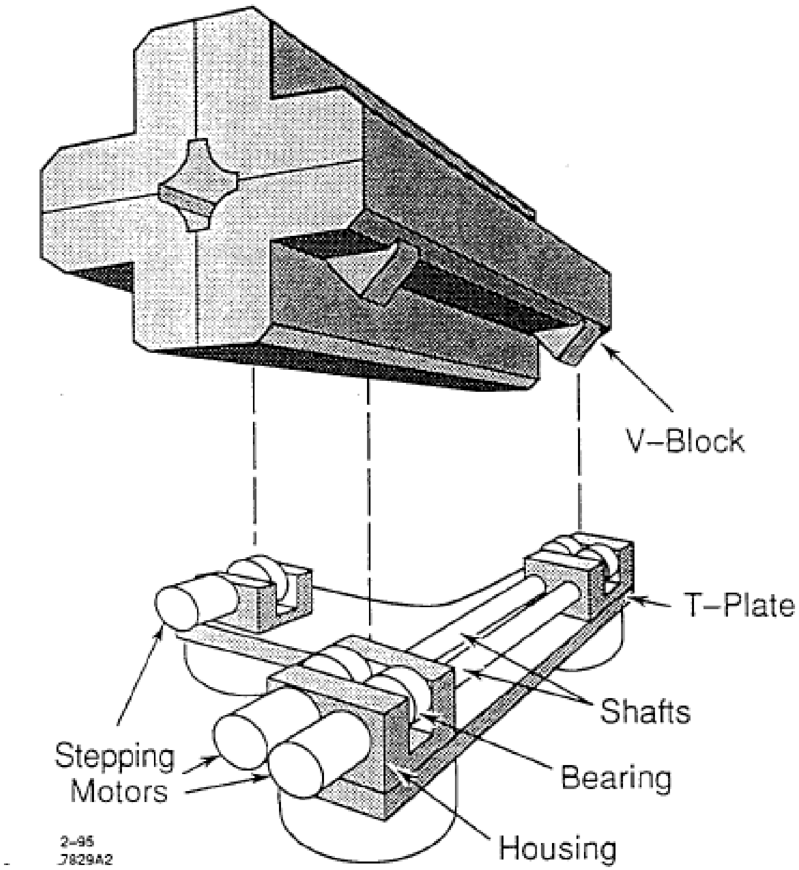
Beamline quads: SLAC / IHEP design, QC / production, measurements

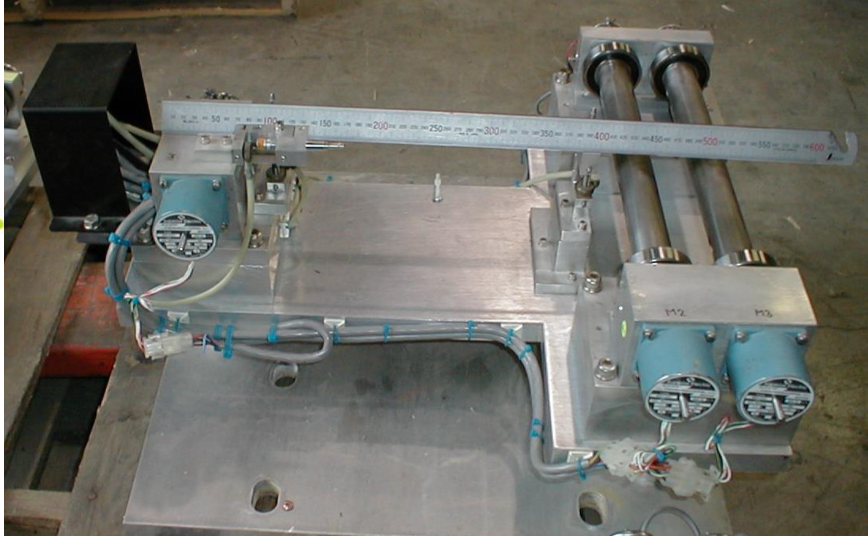




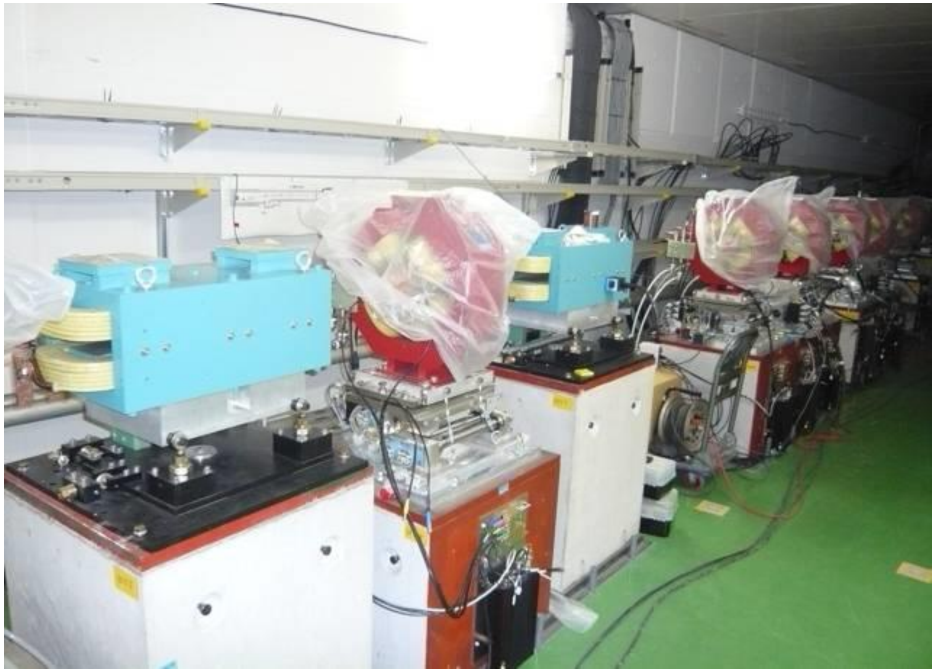
First ATF2 quad, Jan 2006

Beamline movers





- FFTB cam movers were refurbished and used for all and magnets of ATF2 (except bends)



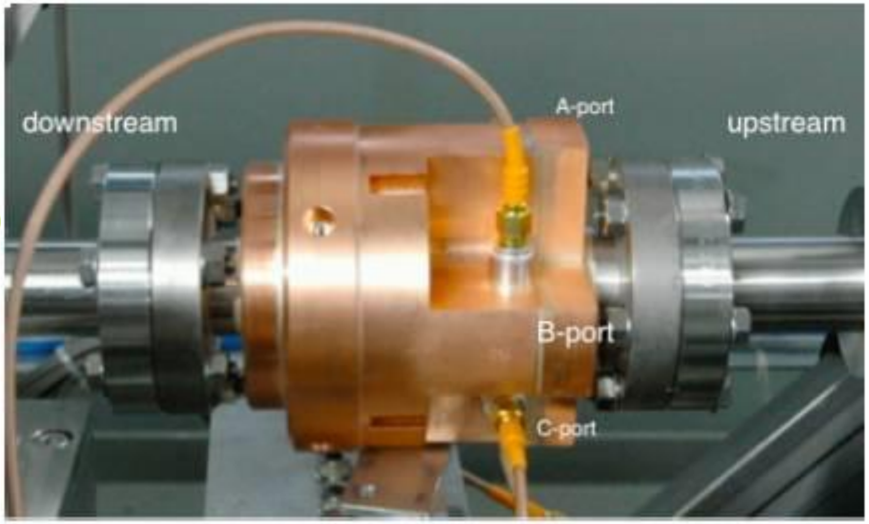
ATF2 construction – January 2008

The last regular quadrupole is going to the destination

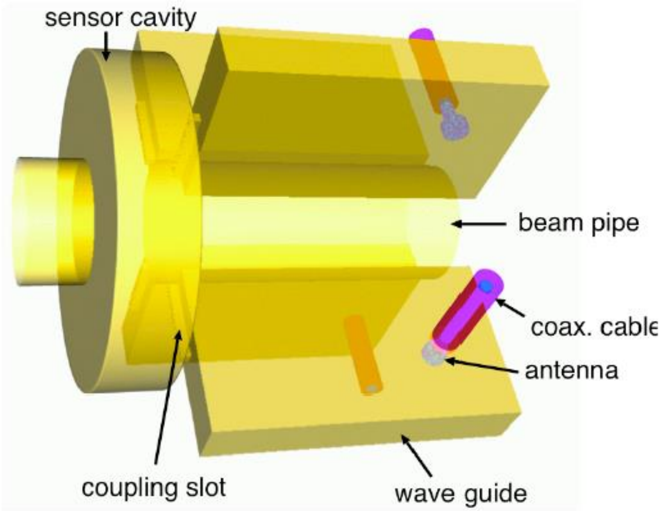
~20 sets of supports, movers & quads were installed in January. R.Sugahara et al

Cavity BPMs

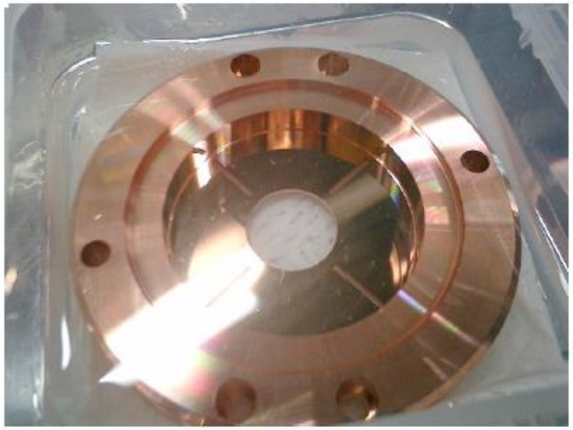
ATF2 beamline magnets equipped with cavity BPMs



Prototype at PAL



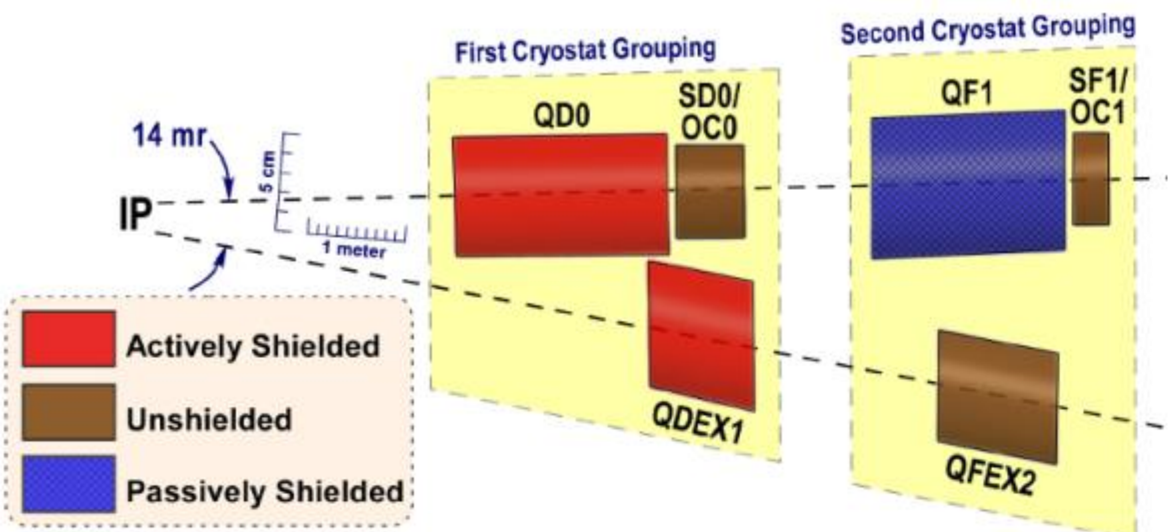
C-band
Sub 100 nanometer resolution
Large dynamic range >500um



Cavity BPMs

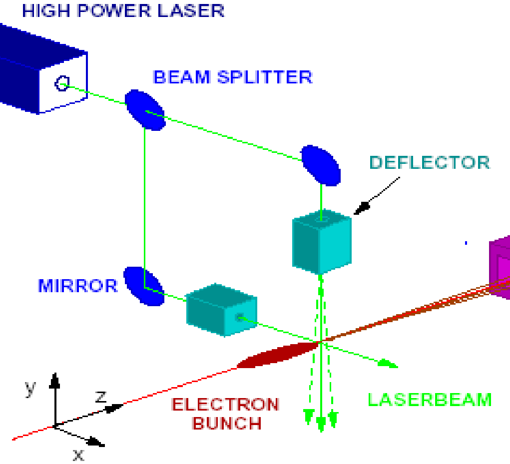
Cavity BPMs and SLAC front-end electronics modules provide sub-micron resolution of beam position

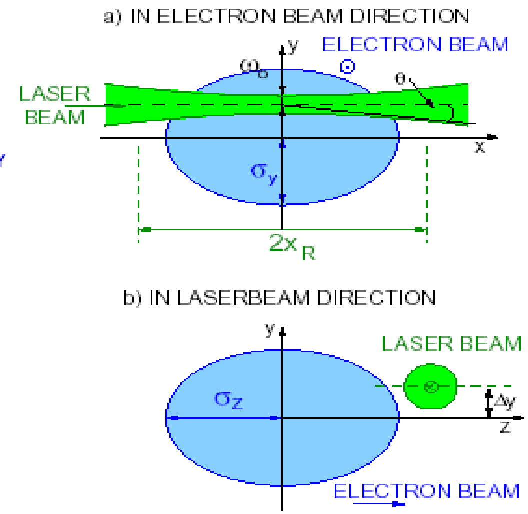
ATF2 final doublet



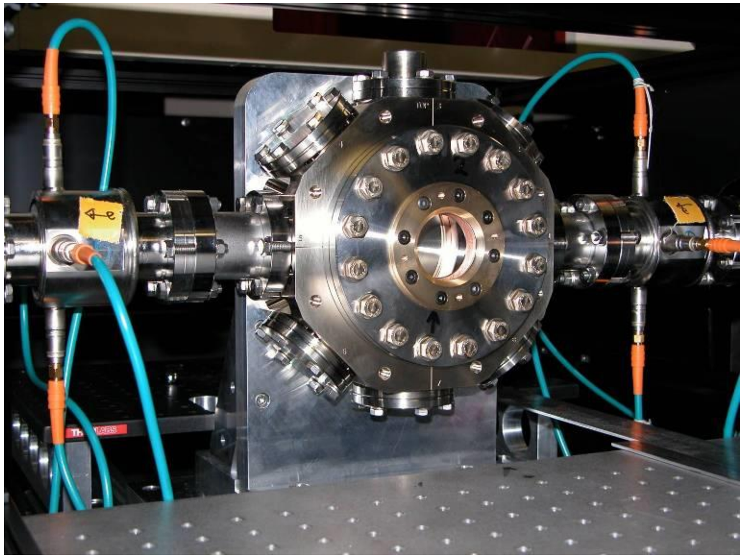
ILC Final Doublet layout

Laser wires





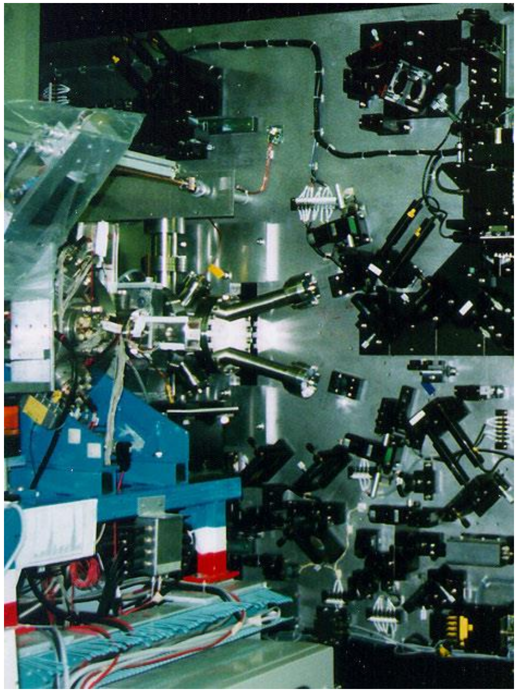
- Goal: non-destructive diagnostics for ILC
- (ATF2 is tuned with carbon wires and OTRs)
- Studies in ATF extraction line
- Aim to measure 1 μm spot beam
- Aim at 150ns intra-train scan
- Located at ATF2 in a place with μm spot
- Presently achieved resolution ~1μm



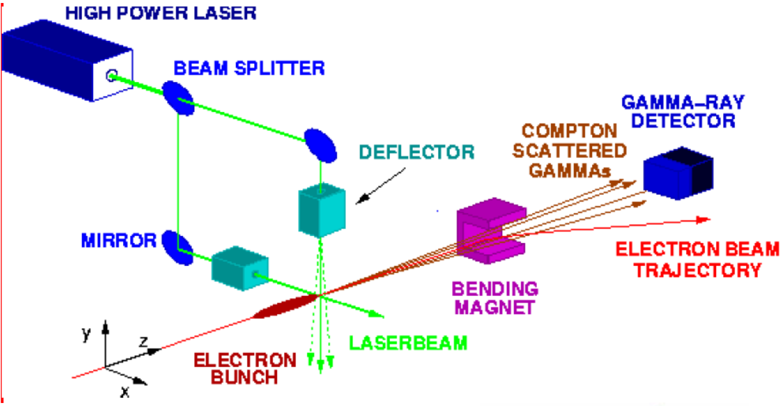
Laser wire chamber at ATF, JAI

Advanced beam instrumentation at ATF2

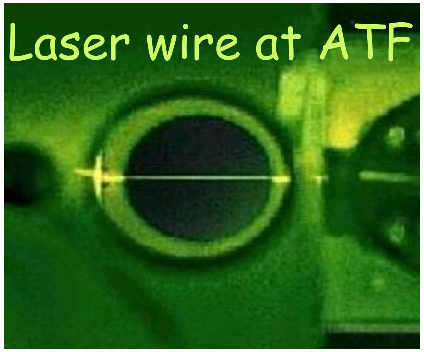
- BSM to confirm 35nm beam size
- nano-BPM at IP to see the nm stability
- Laser-wire to tune the beam
- Cavity BPMs to measure the orbit
- Movers, active stabilization, alignment system
- Intratrain feedback, Kickers to produce ILC-like train

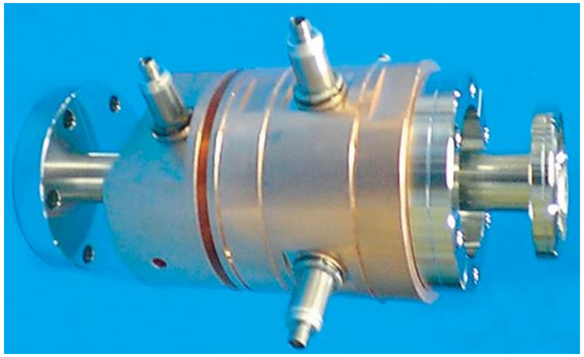


IP Beam-size monitor (BSM) (Tokyo U./KEK, SLAC, UK)



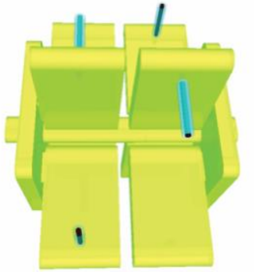
Laser-wire beam-size Monitor (UK group)





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

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



Magnets and Instrumentation at ATF2

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

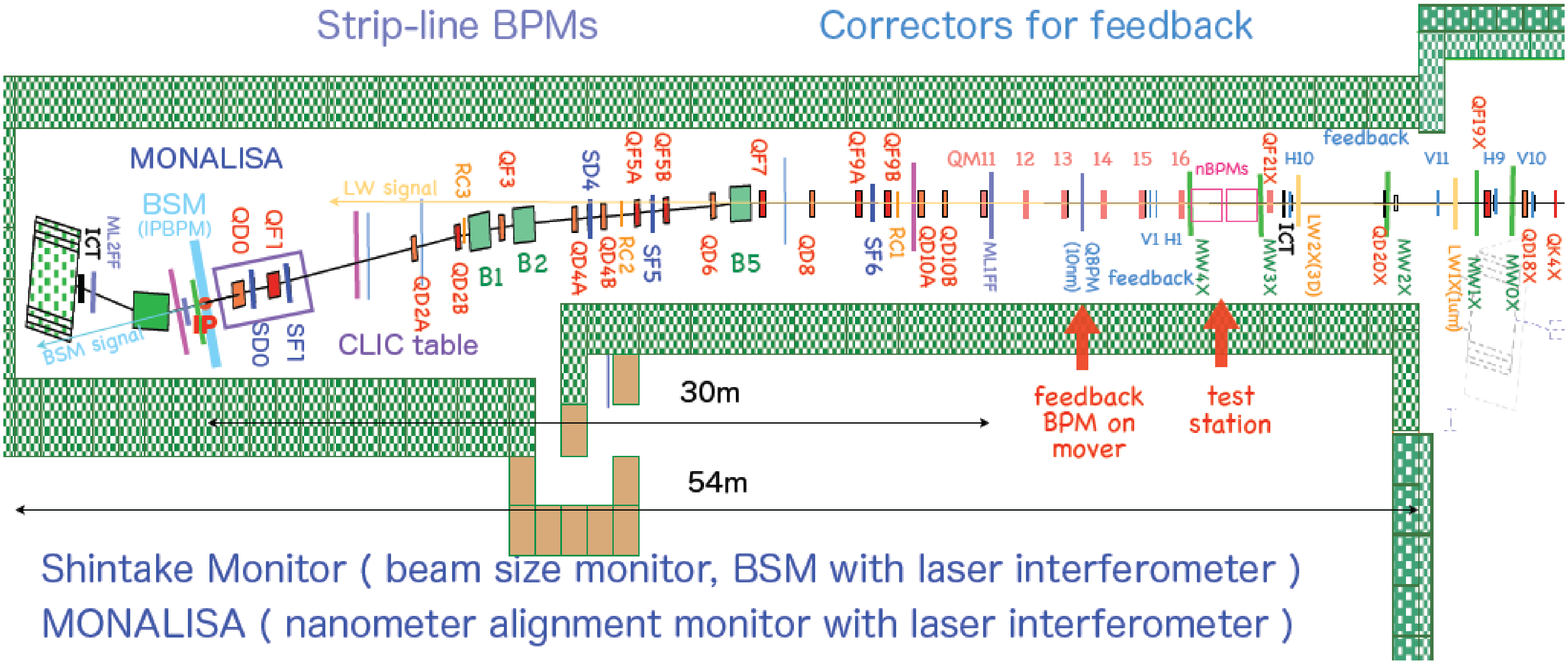
All Q- and S-magnets have cavity-type beam position monitors(QBPM, 100nm).

3 Screen Monitors

5 Wire Scanners, Laserwires

Strip-line BPMs

Correctors for feedback



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

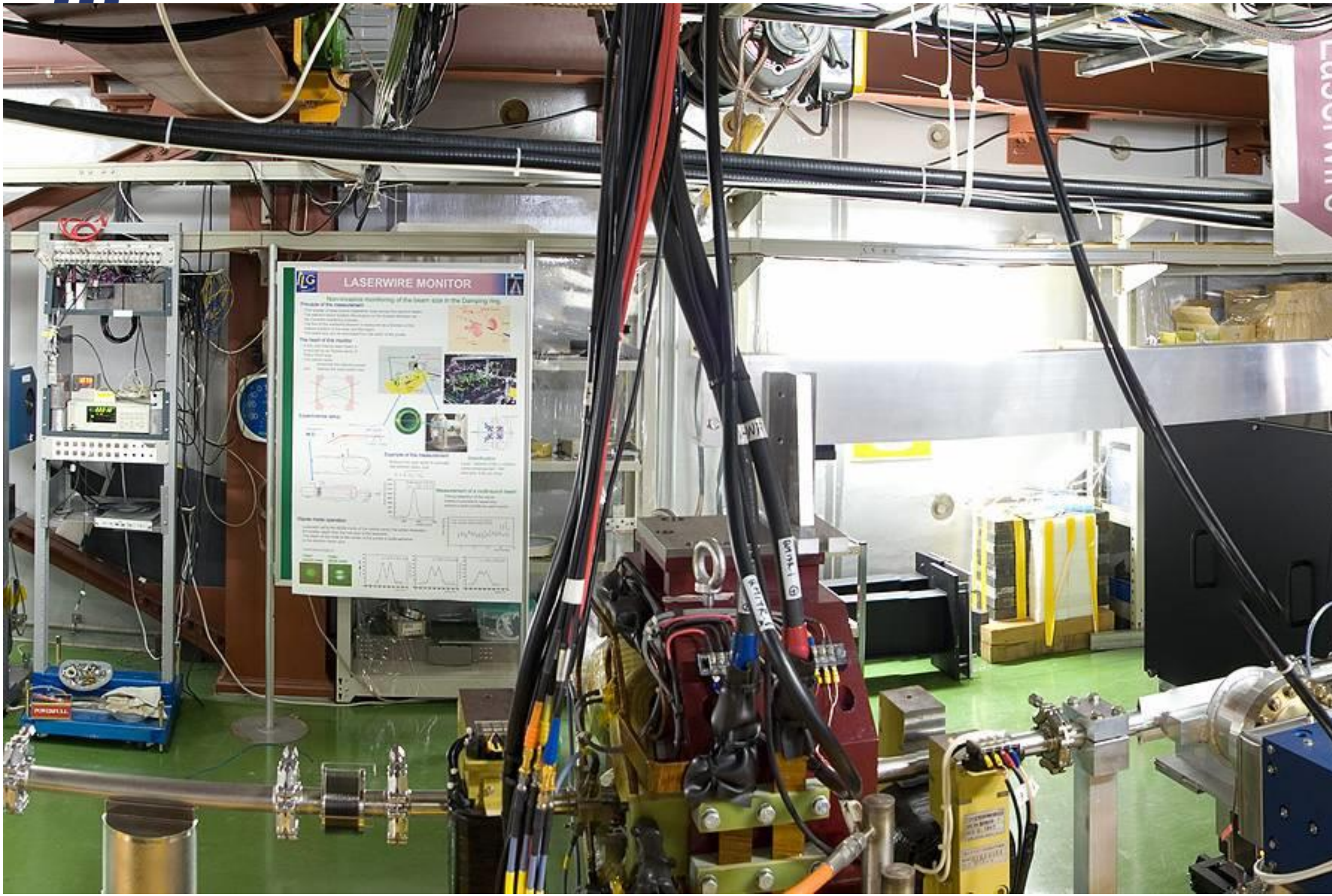
MONALISA (nanometer alignment monitor with laser interferometer)

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

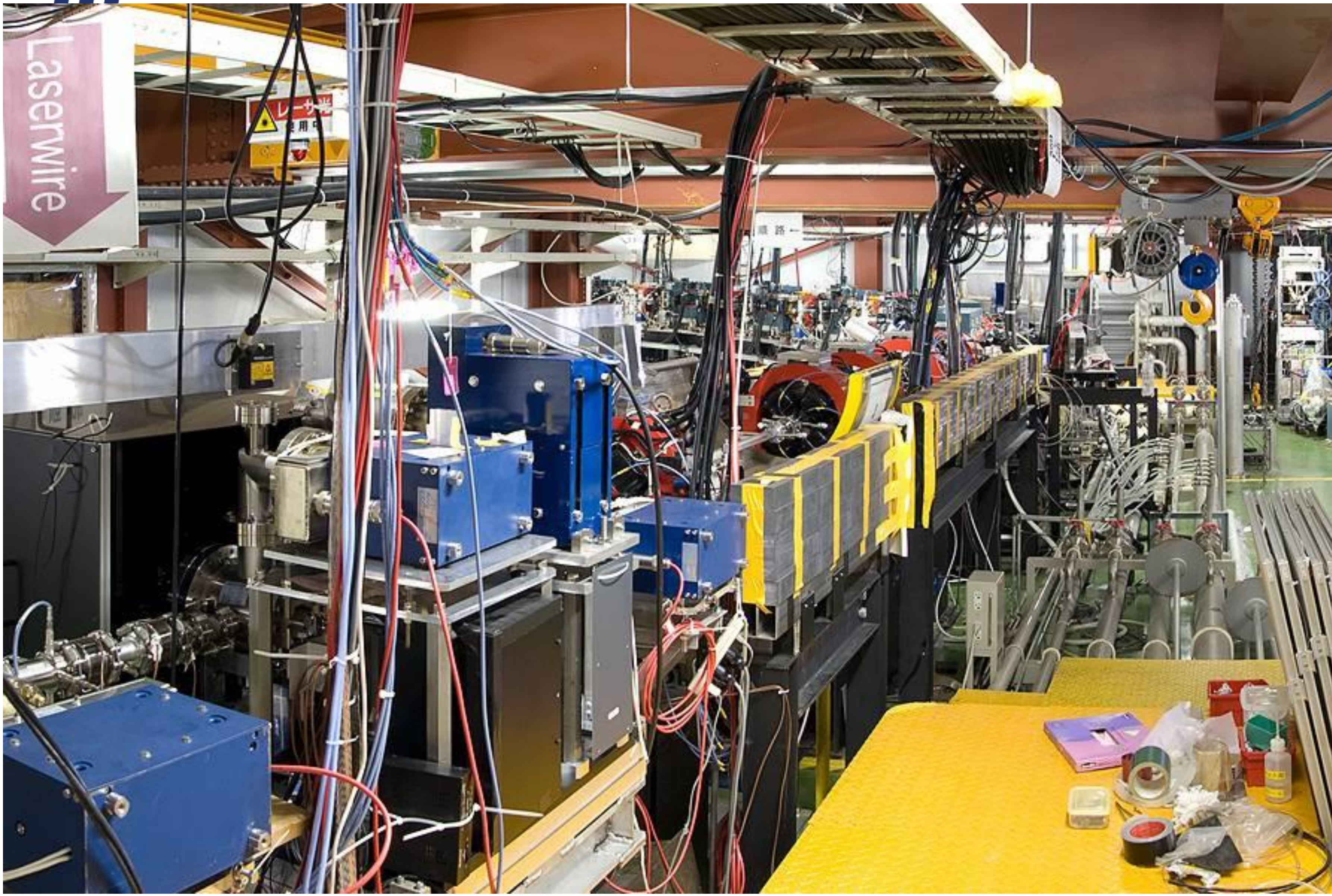
IP intra-train feedback system with latency of less than 150ns (FONT)

Magnet movers for Beam Based Alignment (BBA)

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



Panoramic photo of ATF beamlines, N.Toge



Panoramic photo of ATF beamlines, N.Toge

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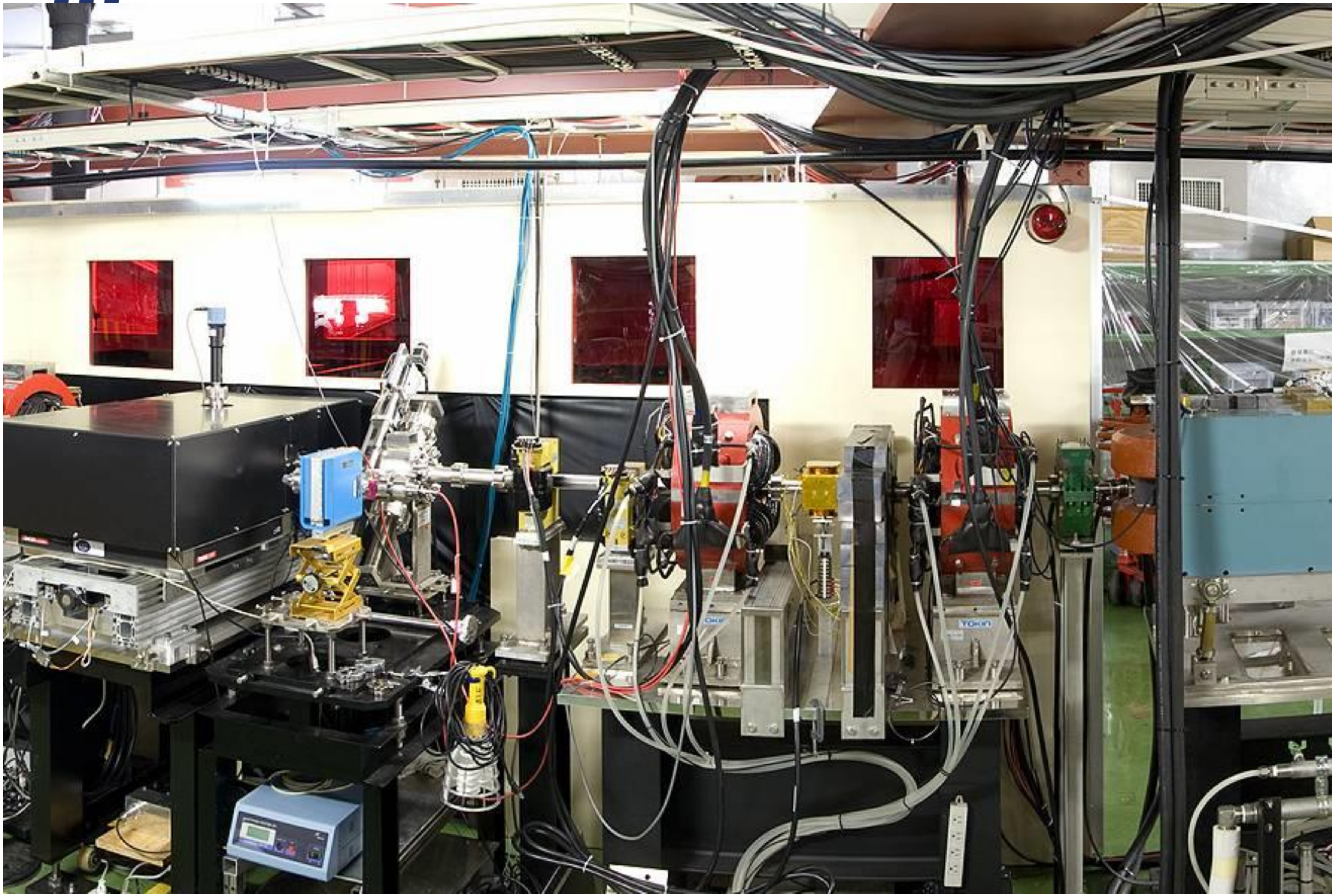

Panoramic photo of ATF beamlines, N.Toge

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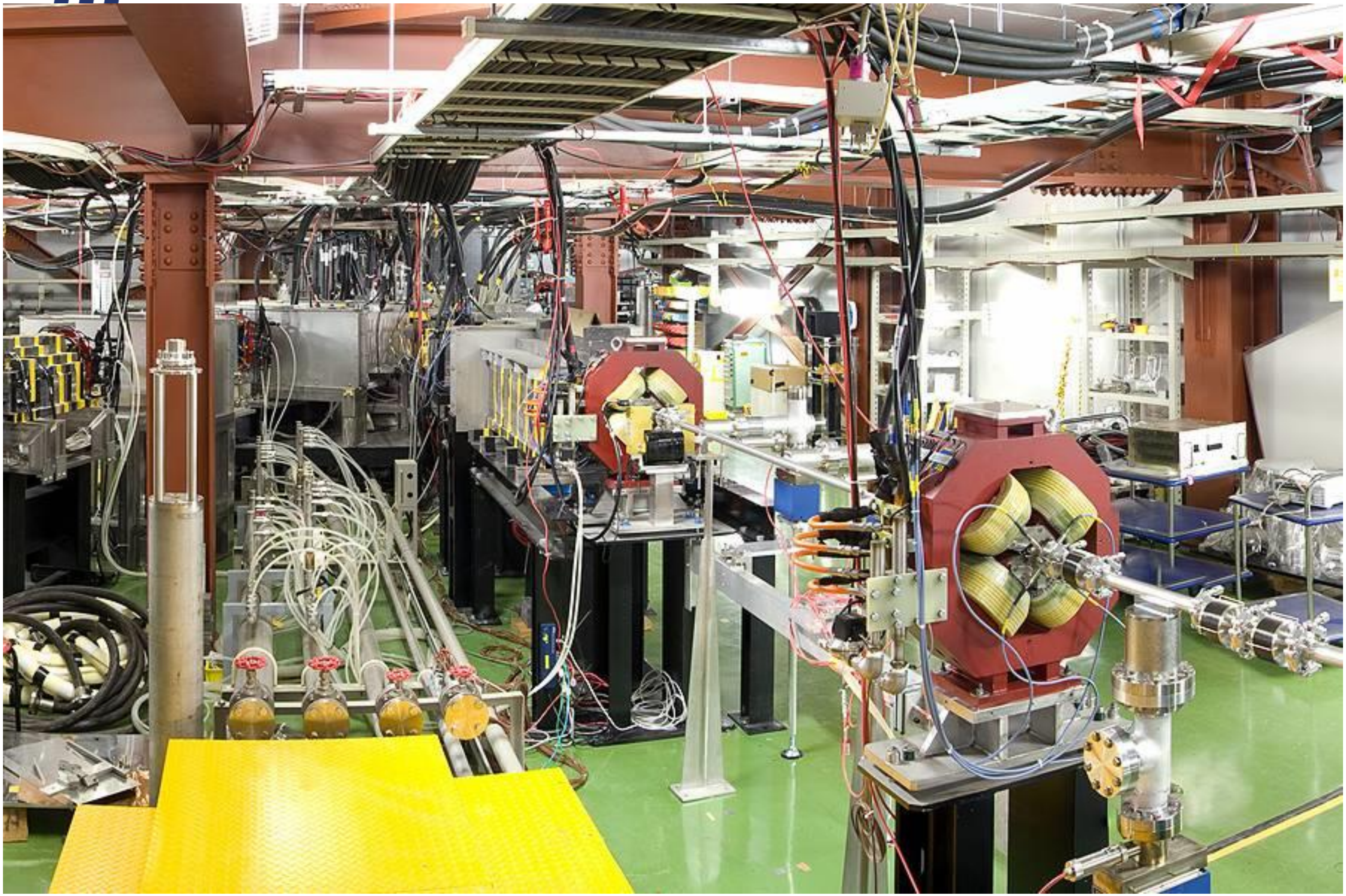


Panoramic photo of ATF beamlines, N.Toge

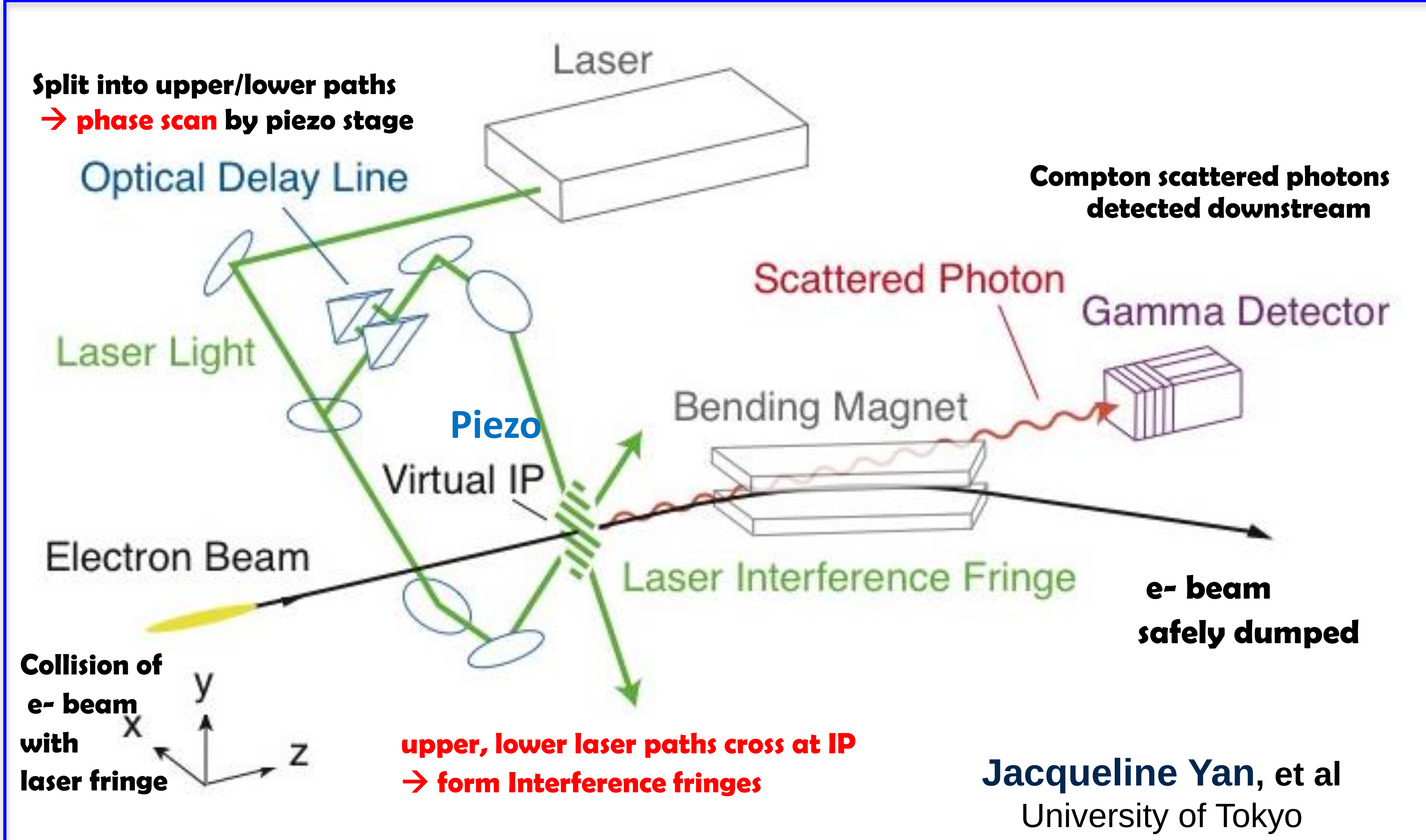
Panoramic photo of ATF beamlines, N.Toge

Beam Size Monitor

- Use **laser interference fringes** as target for e- beam

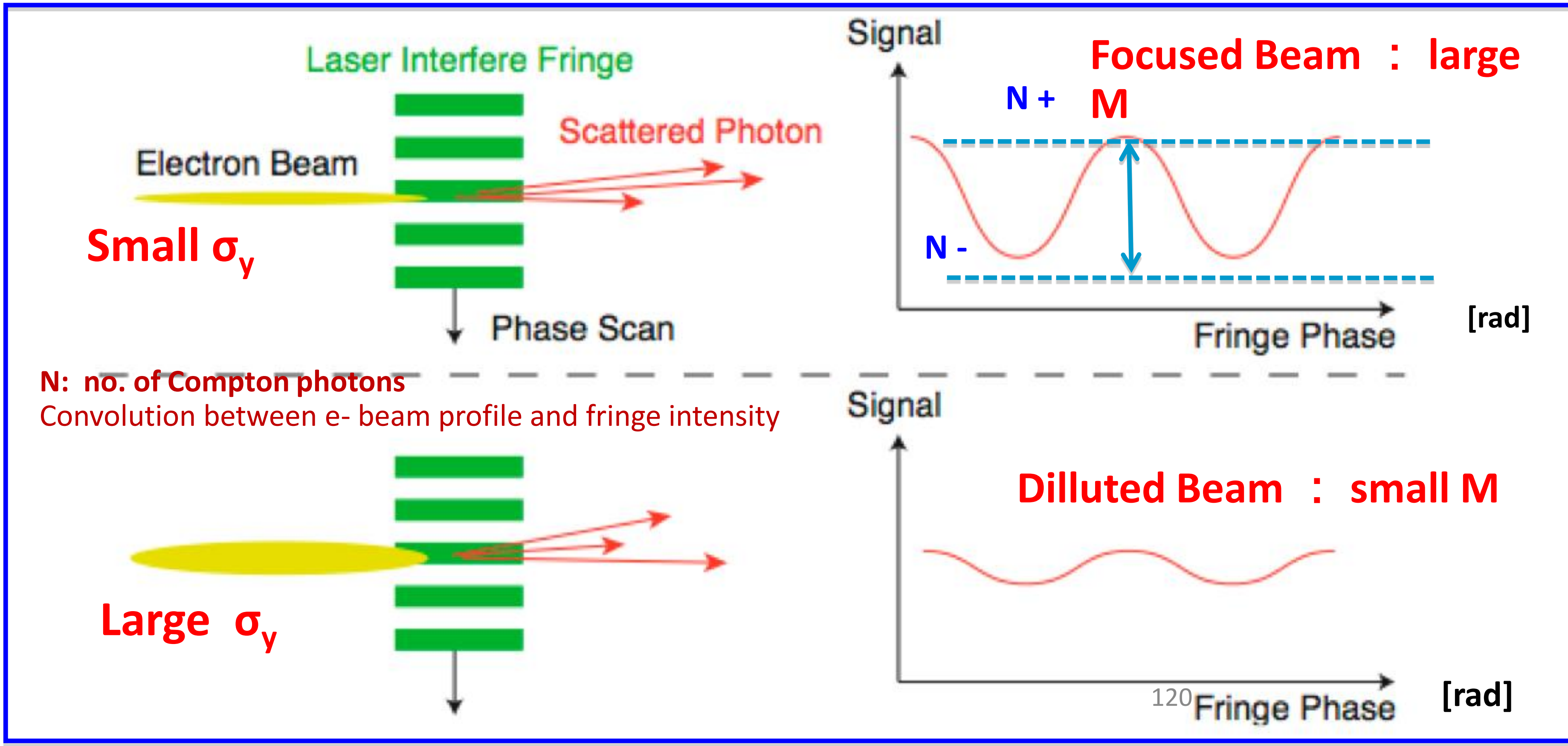
The only device able to measure σ_y < 100 nm !!

- Crucial for ATF2 beam tuning and realization of ILC



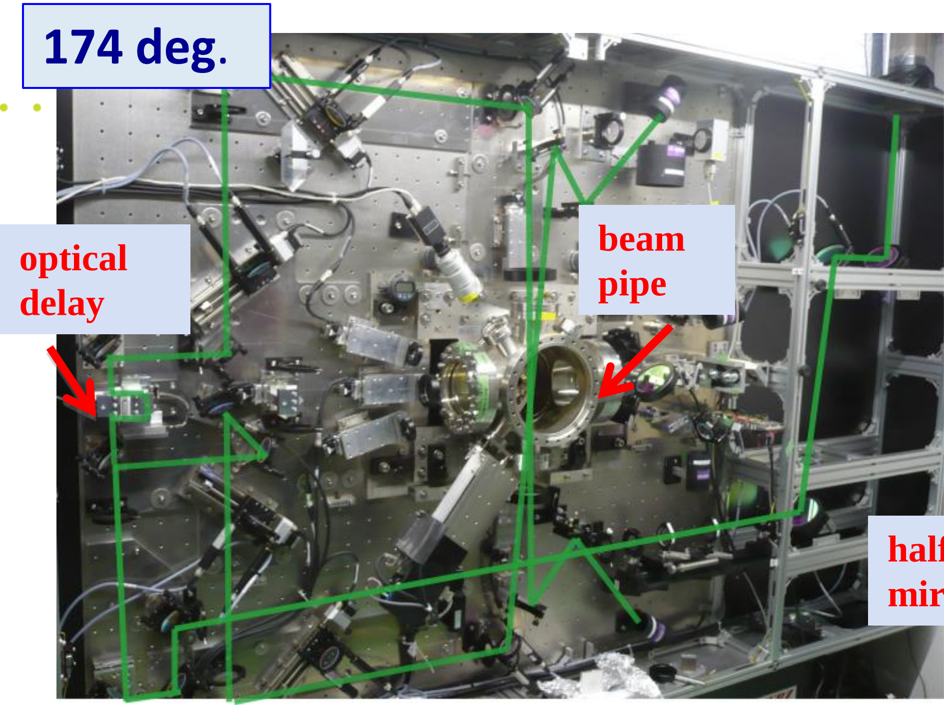
Jacqueline Yan, et al
University of Tokyo

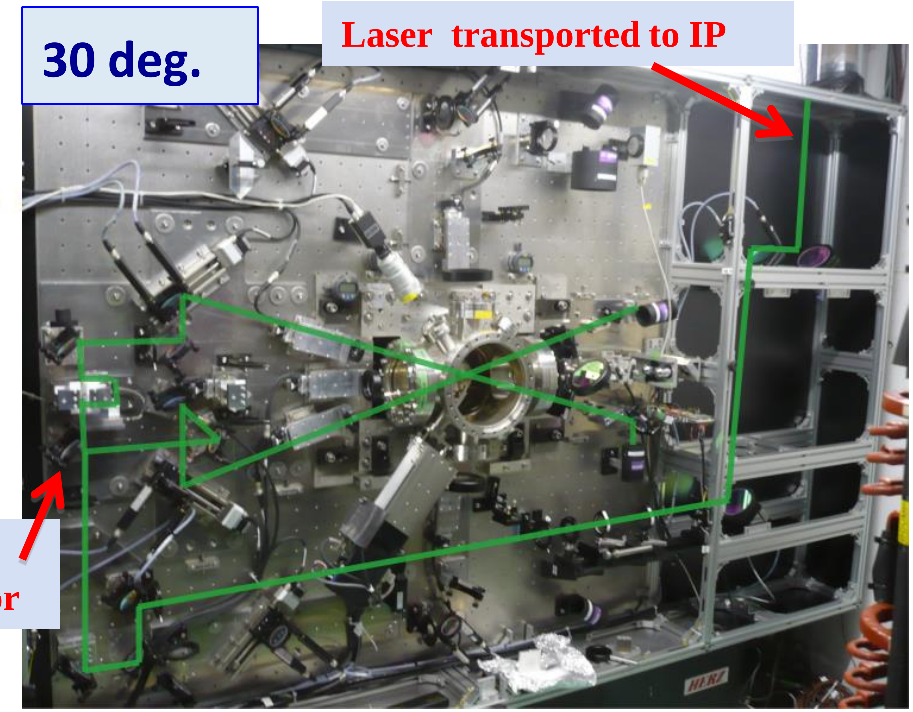
Detector measures signal **Modulation Depth "M"**

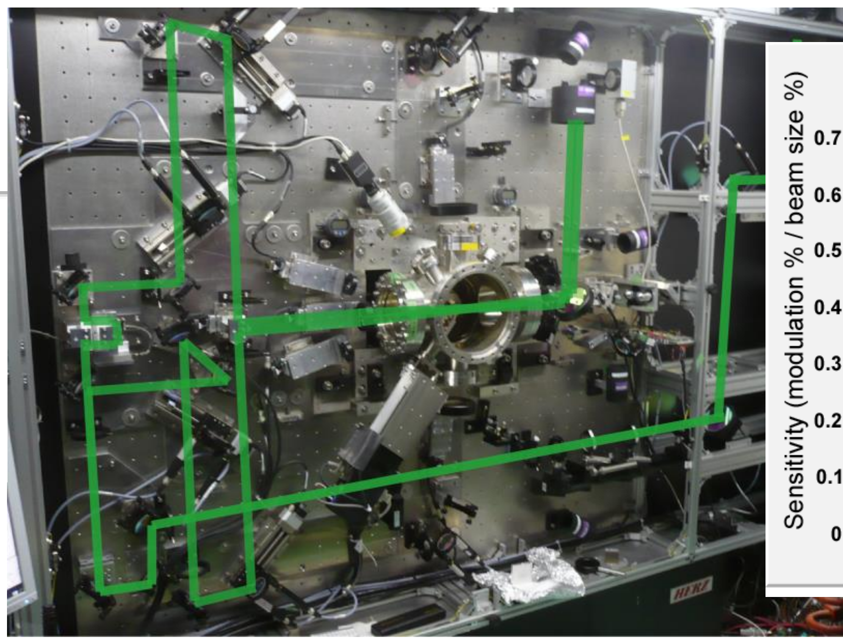


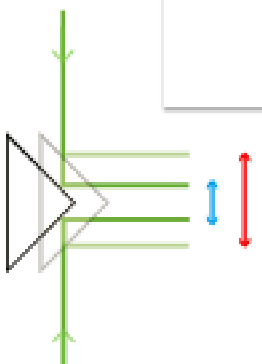
120

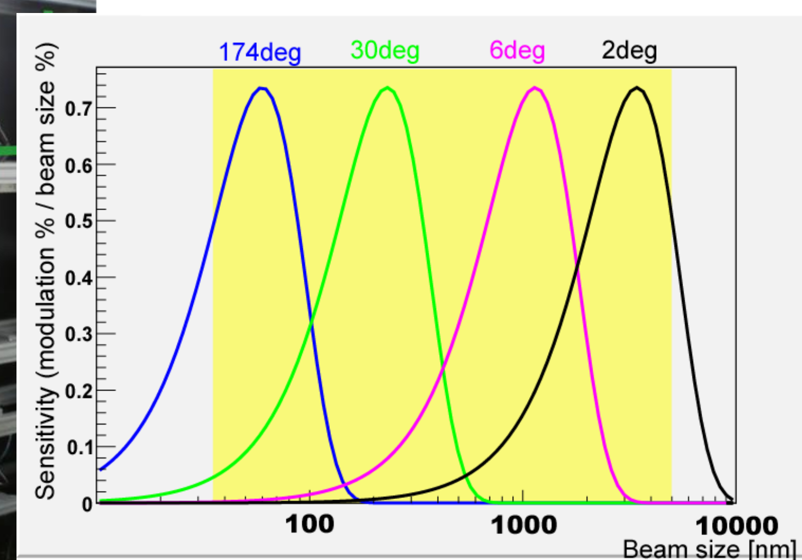
Jacqueline Yan, et al
University of Tokyo



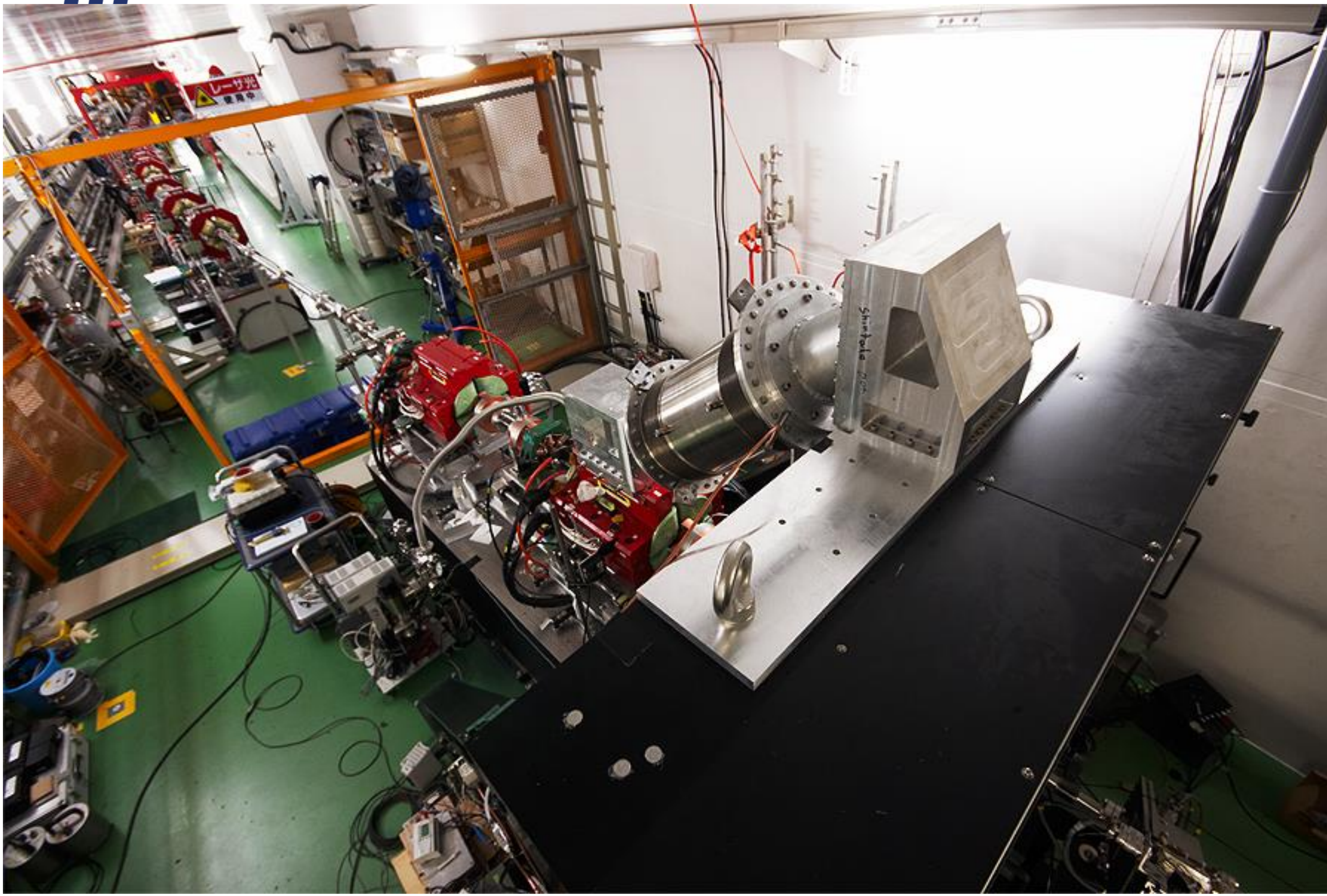




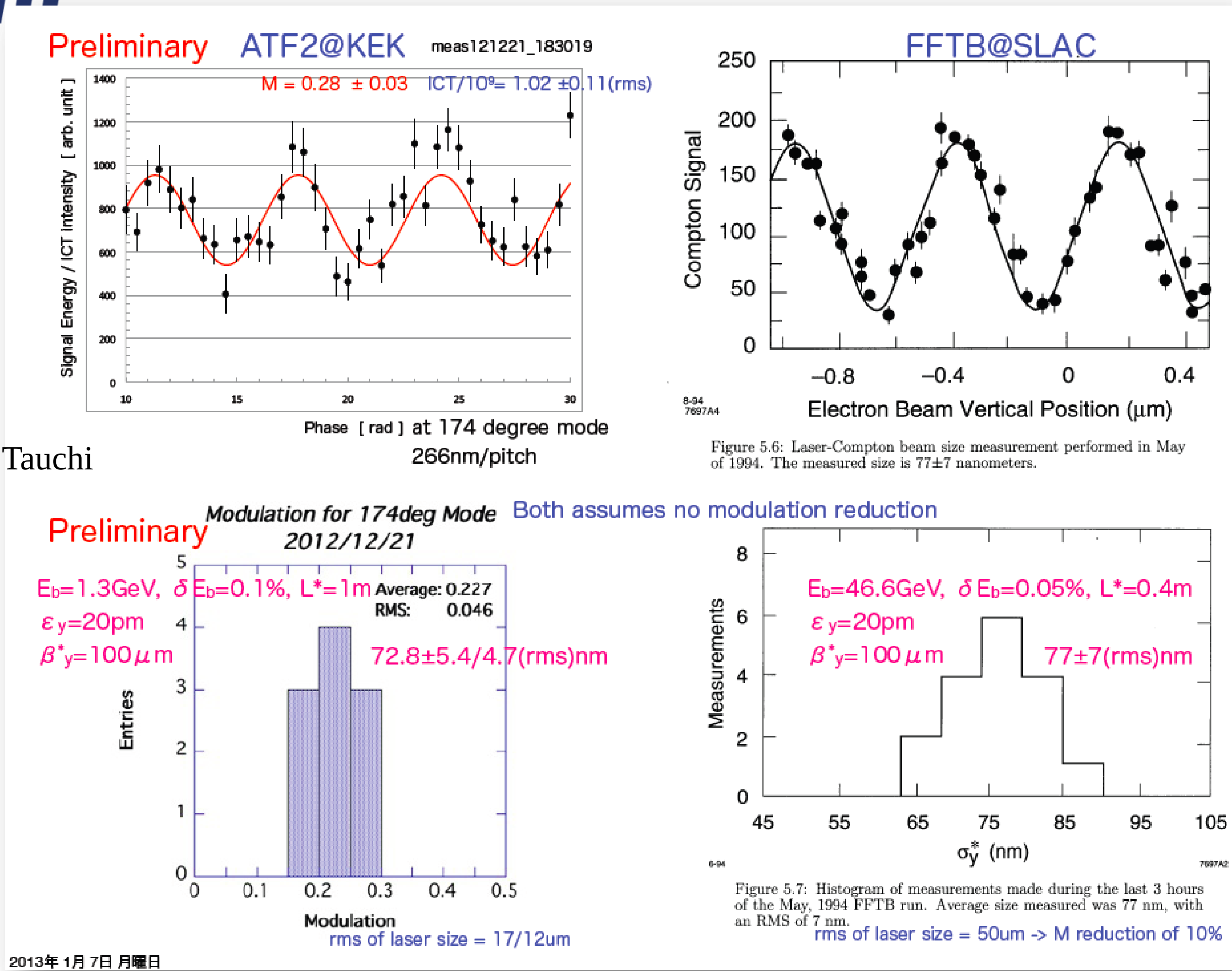




Crossing angle continuously adjustable by prism

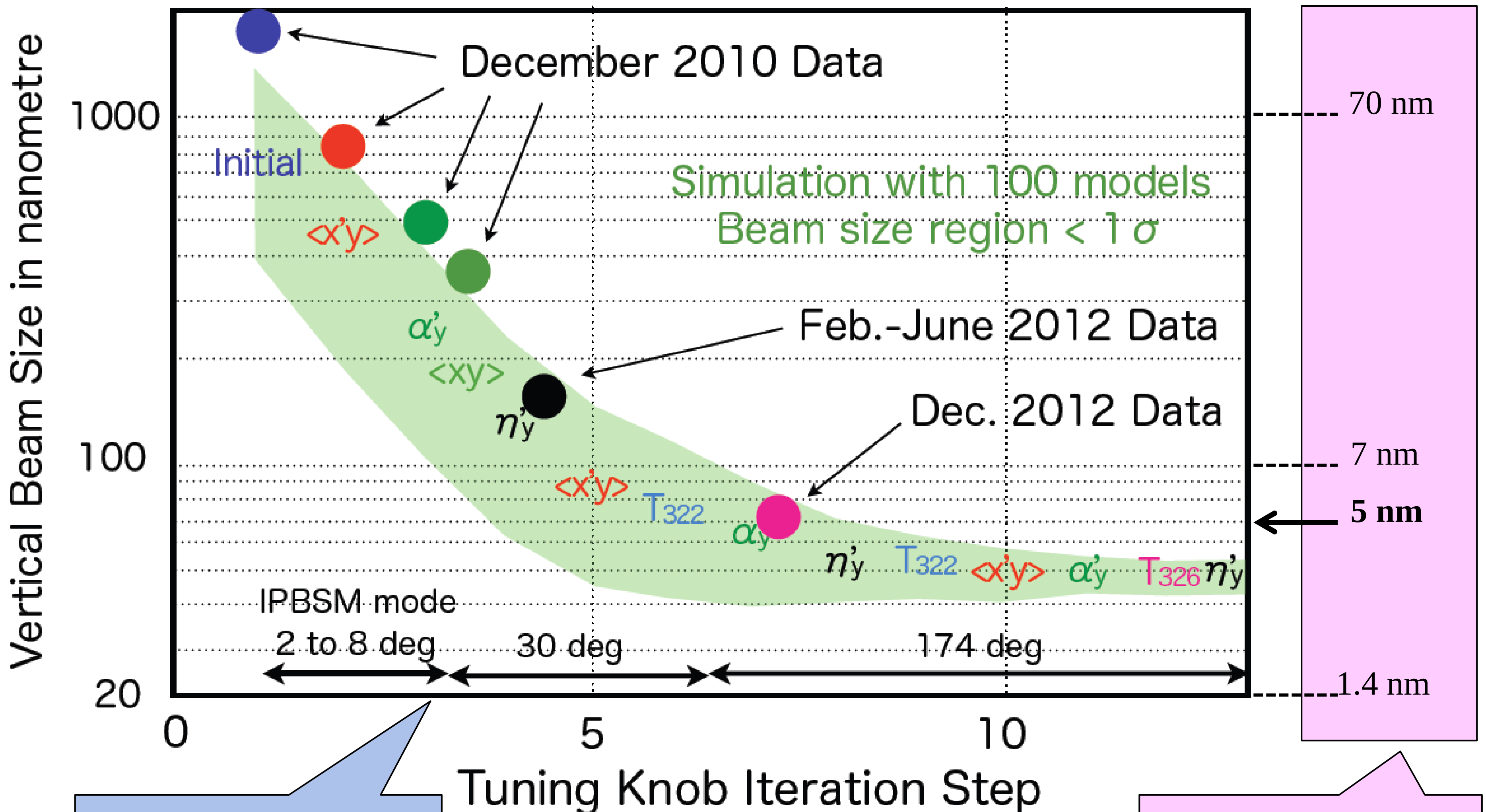

レーザ光
使用中

ATF2 results – December 2012



Slide: T.Tauchi

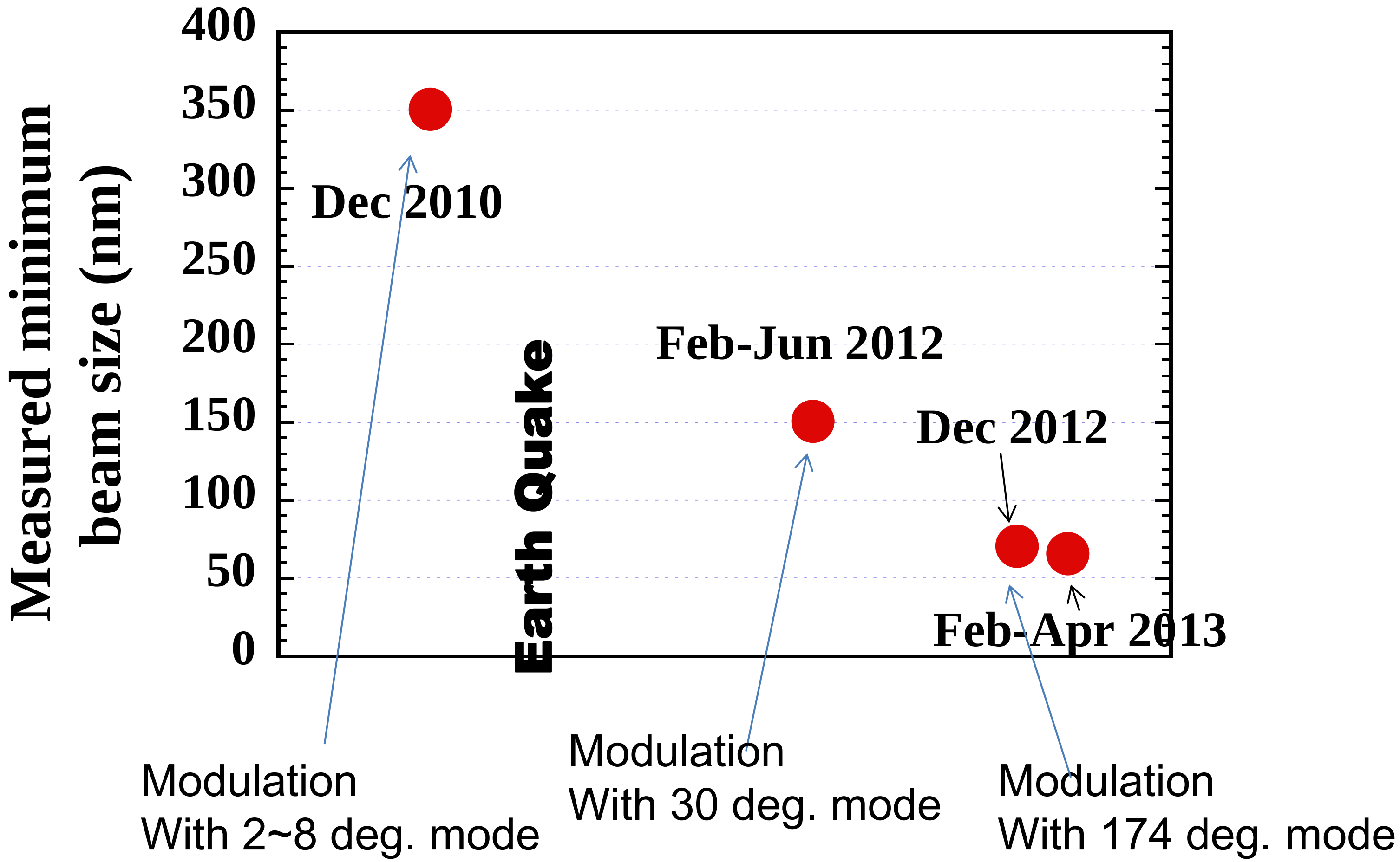
ATF2 results & scaling to 250GeV/beam



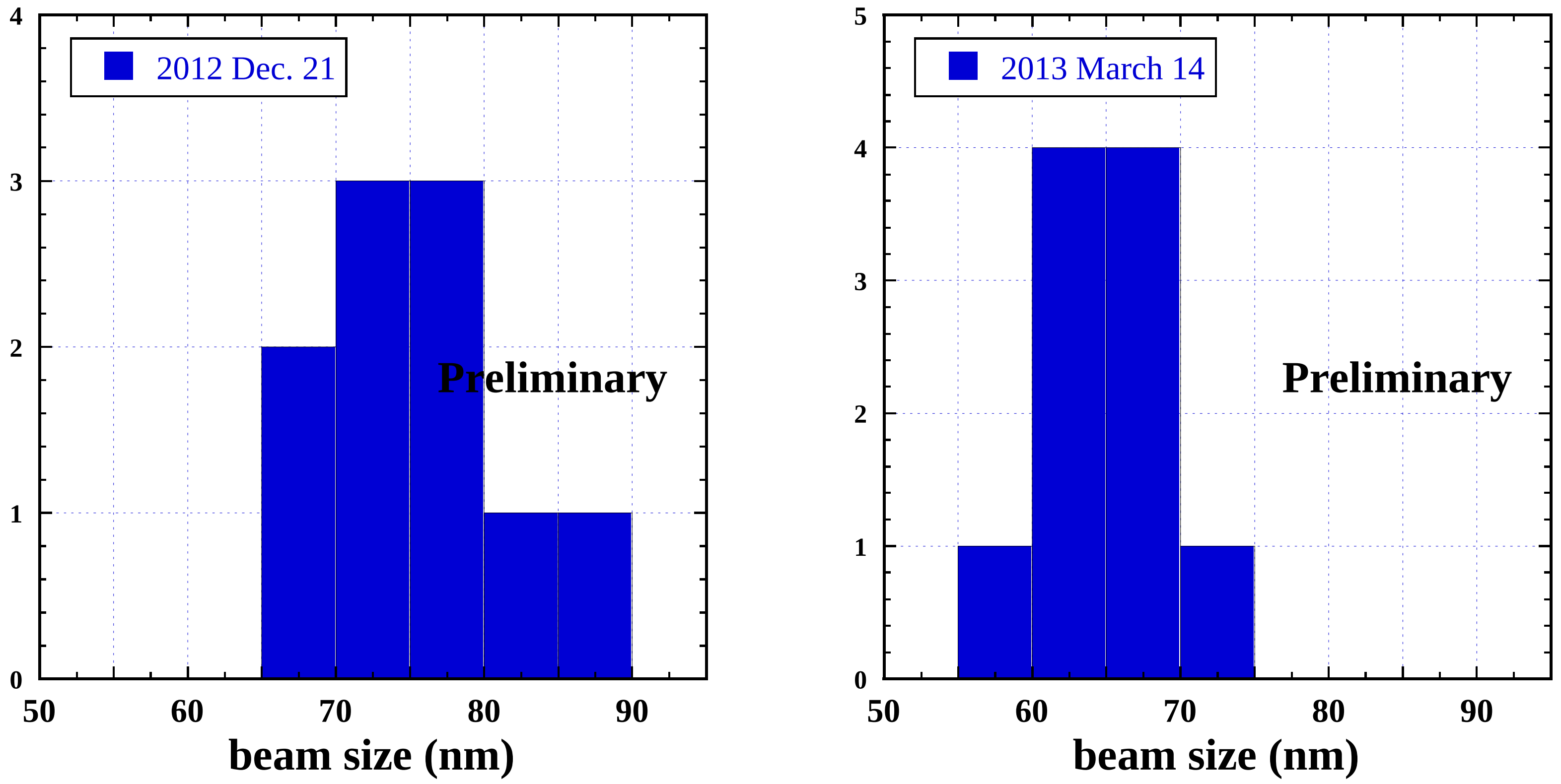
ATF2 results at 1.26 GeV/ beam

Rescaled to 250 GeV/beam

History of measured beam size



<70 nm beam size confirmed first in Dec. 2012, and continuously observed



Beam size evaluated assuming no systematic error of the beam size monitor.

ATF2 review by ILC GDE, Apr 2013:

ATF2 review: General statements

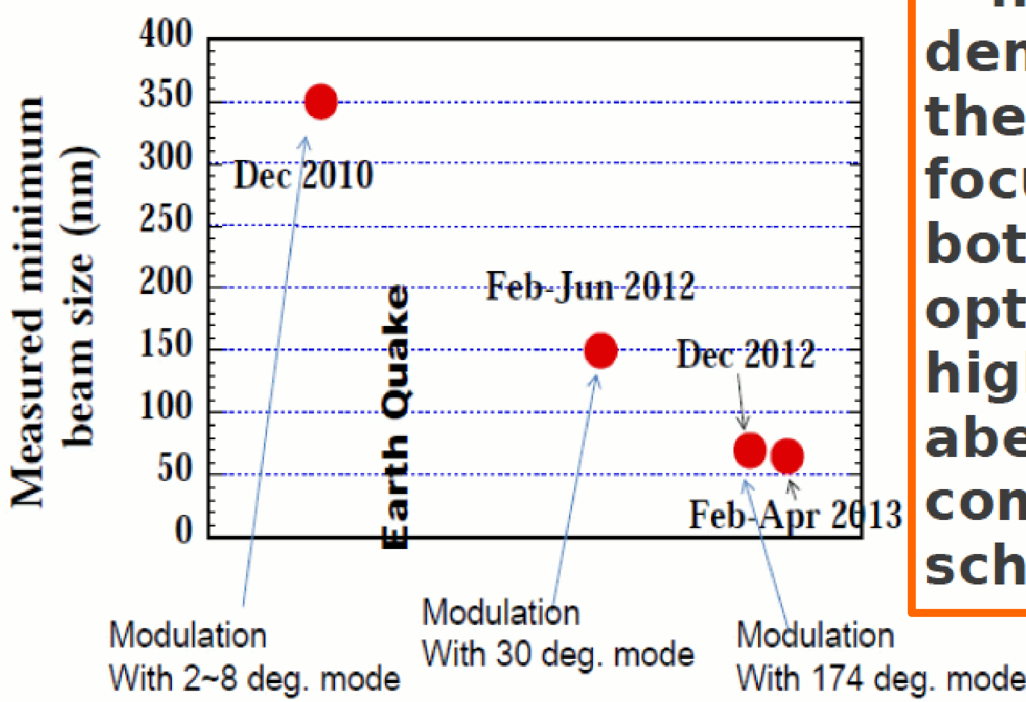
"...The extensive upgrades and improvements to the machine itself, including critical sub-systems such as the **IPBSM**, together with the **organized approach to shifts and personnel training**, have resulted in significant gains in terms of understanding and characterizing the accelerator, resulting in a best-recorded beam size of **64 nm.**"

ATF2 review by ILC GDE, Apr 2013:

Goal 1: 37 nm

- Reached 64 nm
- Tuning from ~3000 nm
- Suppression of aberrations confirmed to about ~90%
- Bunch charge ~10^9 e-!!
- **"…successful demonstration of the compact final focus optics and both the linear optics tuning and high-order aberration compensation schemes involved"**

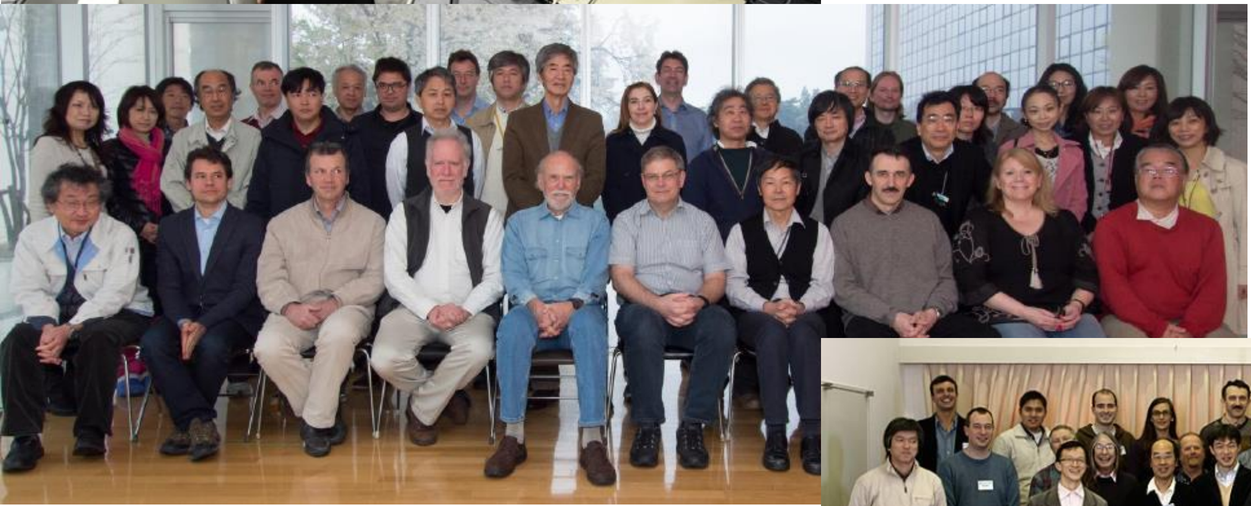
Kubo



summary of FF development

- Final Focus with local chromatic correction works in theory and in practice
- The ATF/ATF2 international collaboration successfully demonstrated operation of ILC-like final focus system
- The ATF2 project was realized as ILC-like international project, with in-kind contributions
- The ATF2 is a great training and advanced accelerator research facility

Thanks to all colleagues in the ATF Collaboration!



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
ILC
ILC
ERMC
ELK RIVER MACHINE CO.
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!