ATF2: the **linear collider** final focus prototype at KEK

- an international telescope for nanometre size beams -

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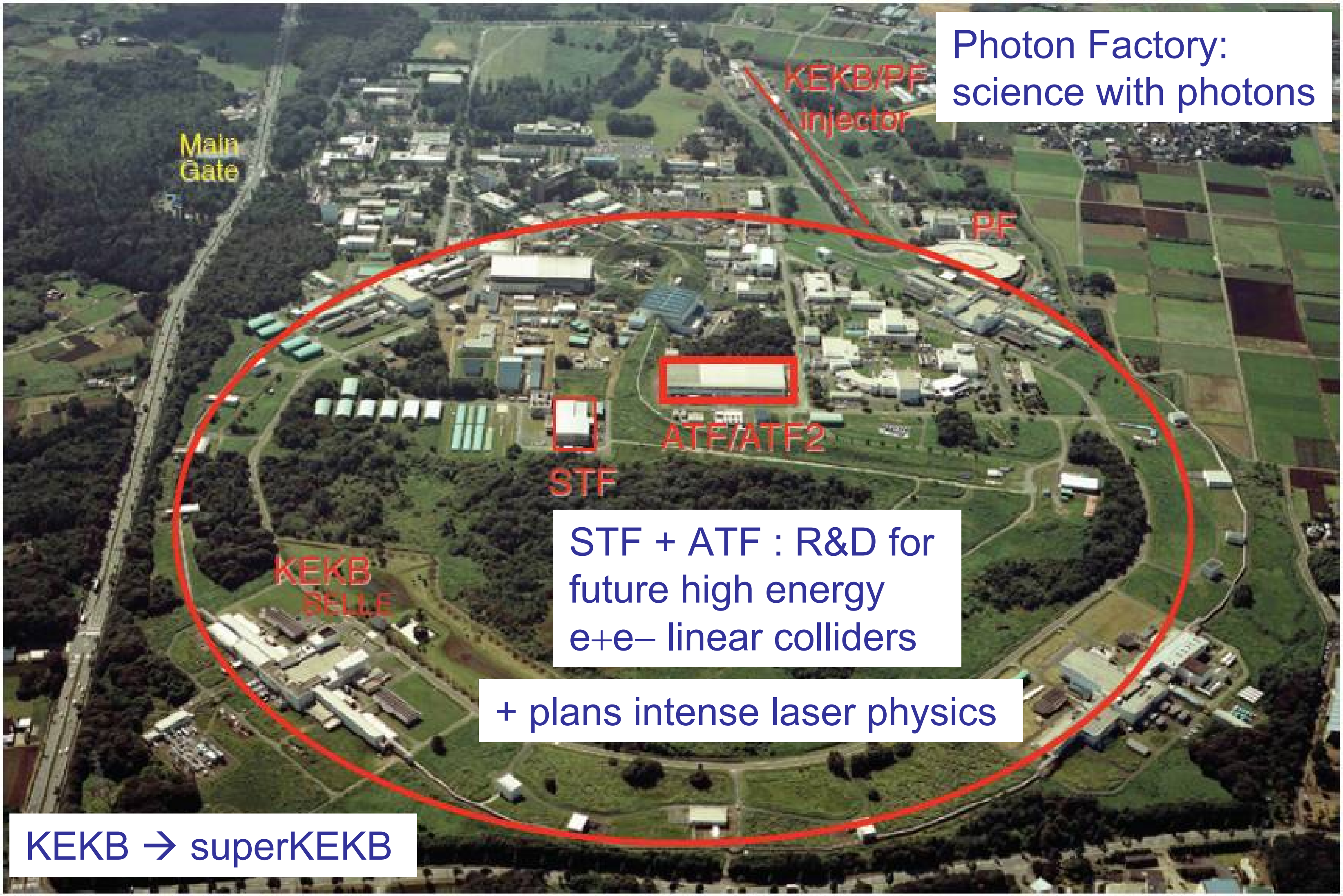
Université Paris 11, Orsay, France

Accelerator Seminar at Paul Scherrer Institute, Villigen 7 February 2011

KEK High Energy Accelerator Research Organization, Tsukuba site, Japan



ATF International Collaboration

CERN
DESY
IN2P3
- LAL
- LAPP
- LLR

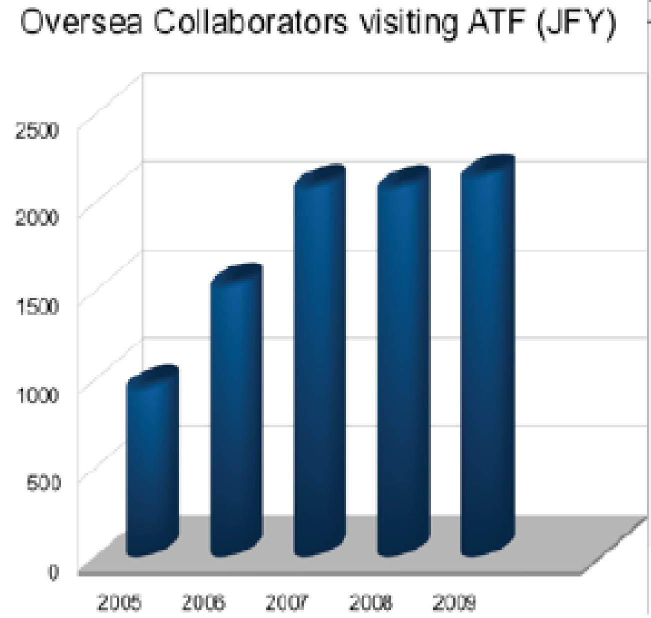
John Adams Inst.
- Oxford Univ.
- Royal Holloway Univ.

Cockcroft Inst.
- STFC, Daresbury
- Univ. of Manchester
- Univ. of Liverpool

University College London
INFN, Frascati
IFIC-CSIC/UV
Tomsk Polytechnic Univ.

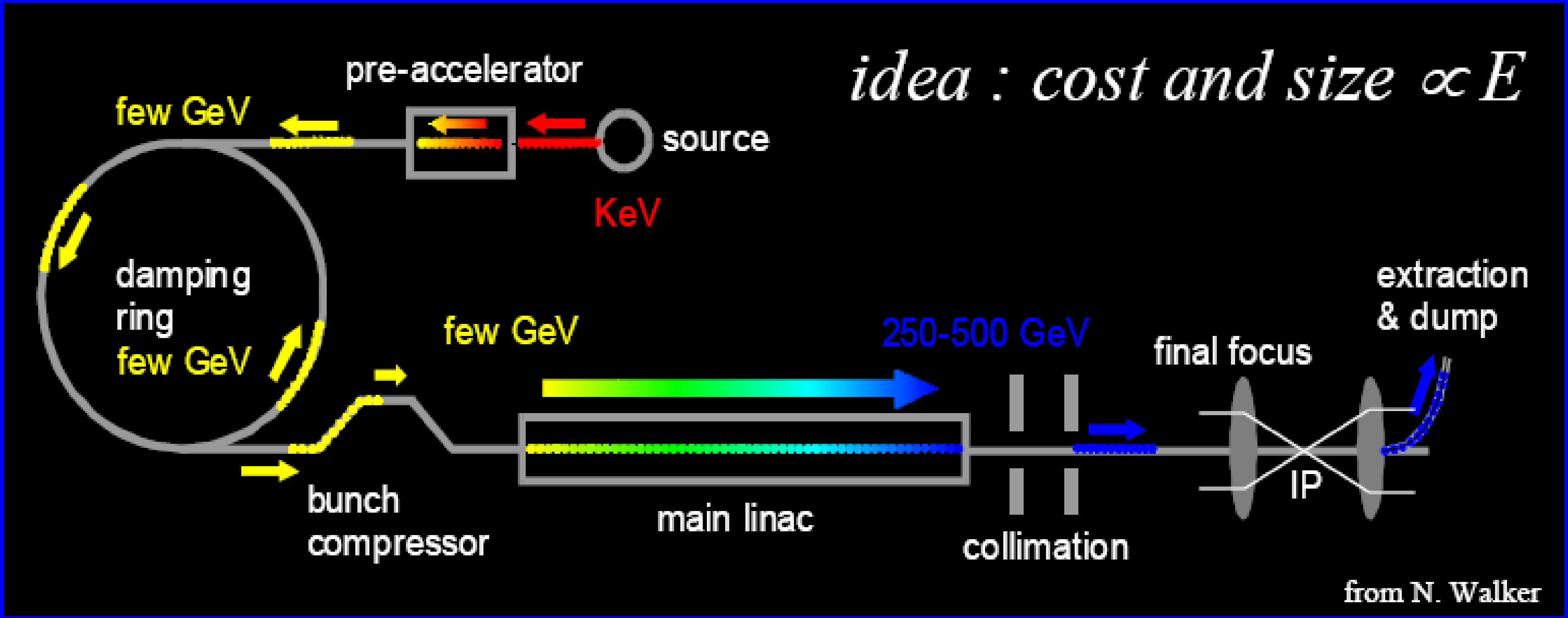
KEK
Waseda U.
Nagoya U.
Tokyo U.
Kyoto U.
Tohoku Univ.
Hiroshima U.
IHEP
PAL
KNU
RRCAT

SLAC
LBNL
FNAL
Cornell Univ.
LLNL
BNL
Notre Dome Univ.



Overseas
25 Institutes,
~70 people,
~2000 people-days per year
+
KEK and Japanese Universities(6)

Linear collider concept



focus { RF technology (gradient, efficient power transfer)
beam phase-space control and stability

→ synchrotron radiation still drives design…

ATF & ATF2 R&D for linear colliders

$$\text{Luminosity} \sim \frac{\eta_{efficiency} P_{elec}}{E_{cm}} \frac{N_e}{\sigma_x \sigma_y}$$

$$\rightarrow \frac{\eta_{efficiency} P_{elec}}{E_{cm}} \sqrt{\frac{\delta_{beamstrahlung}}{\varepsilon_{y,normalised}}}$$

linac RF + sources

⇕ trade-off

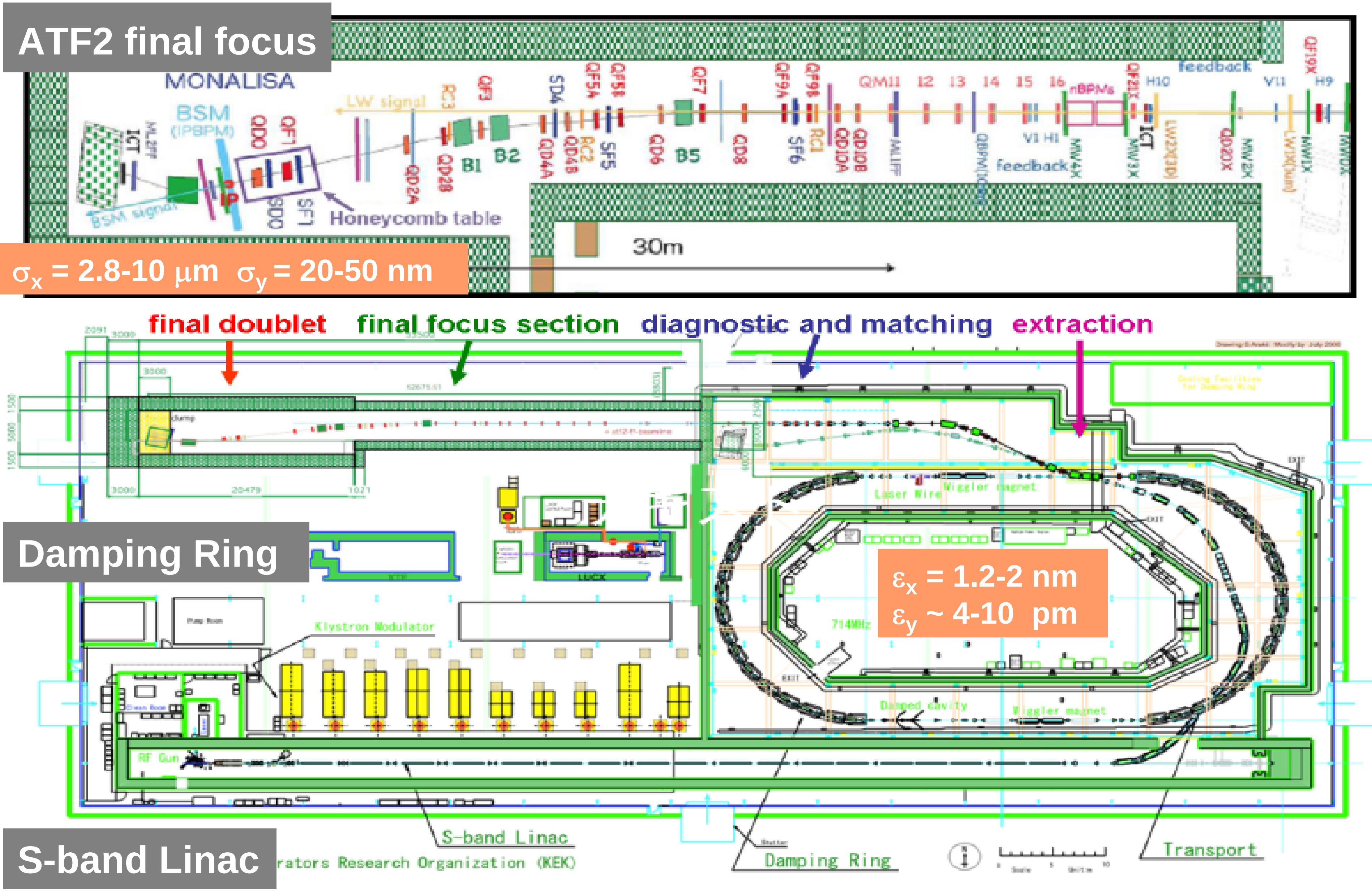
beam size control & stability

↓

cost & feasibility

Parameters	**ATF2**	**ILC**	**CLIC**
Beam Energy [GeV]	1.3	250	1500
L* [m]	1	3.5 - 4.5	3.5
$\gamma\varepsilon_{x/y}$ [m.rad]	**5E-6 / 3E-8**	**1E-5 / 4E-8**	**6.6E-7 / 2E-8**
IP $\beta_{x/y}$ [mm]	**4 / 0.1**	**21 / 0.4**	**6.9 / 0.07**
IP η' [rad]	0.14	0.0094	0.00144
δ_E [%]	~ 0.1	~ 0.1	~ 0.3
Chromaticity	**~ 1E4**	**~ 1E4**	**~ 5E4**
Number of bunches	1-3 (goal 1)	~ 3000	312
Number of bunches	3-30 (goal 2)	~ 3000	312
Bunch population	1-2E10	2E10	3.7E9
IP σ_y [nm]	**37**	**5.7**	**0.7**

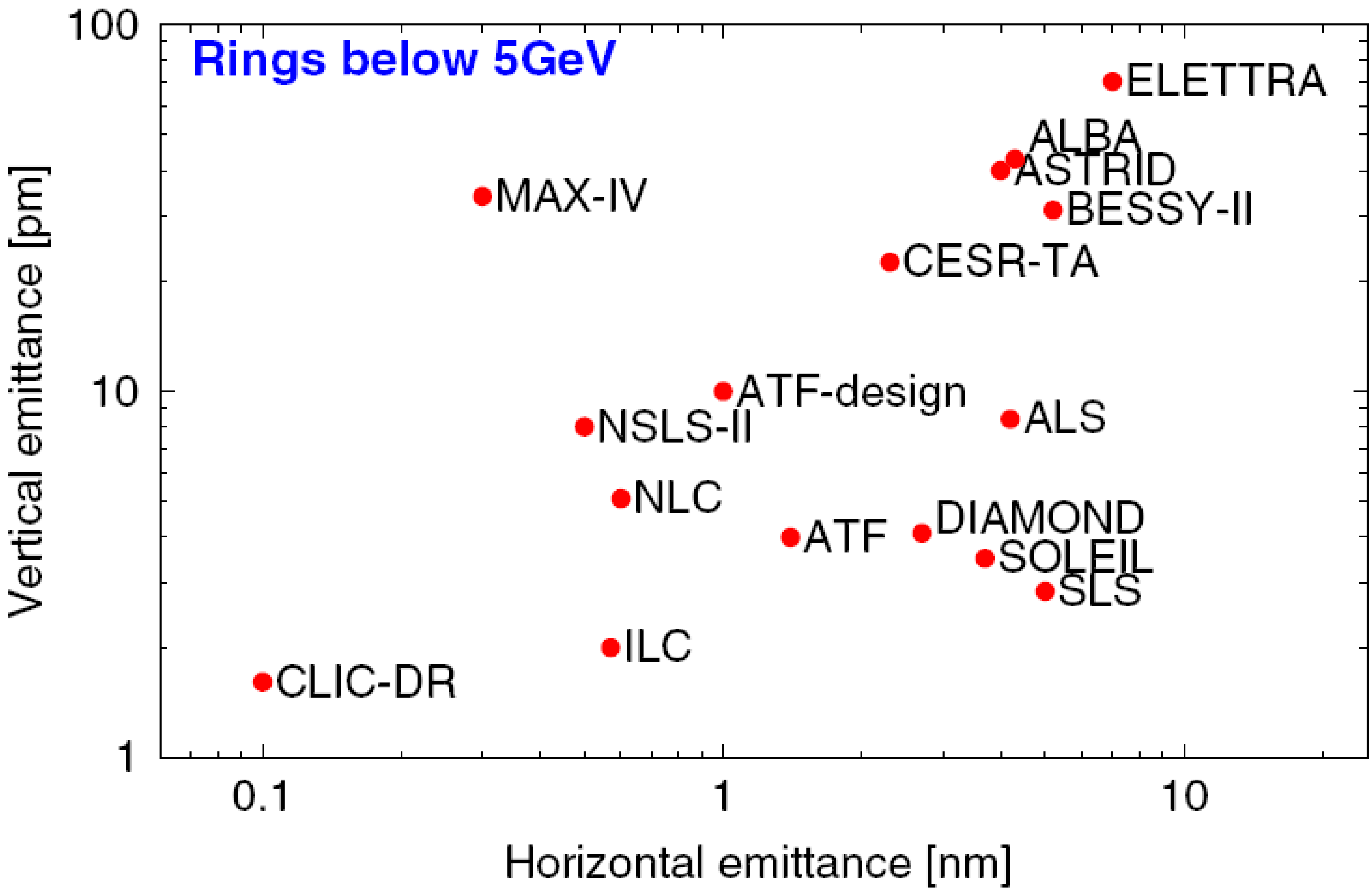
Accelerator Test Facility @ KEK



R&D deliverables from Test Facilities for ILC BDS and DR

Test Facility	Deliverable	Date
Hardware development, Optics and stabilisation demonstrations:		
ATF	Demo. of reliable operation of fast kickers meeting the specifications for the ILC damping ring.	2010
	Generation of ε_y = 1 pm-rad emittance beam	2009
ATF2	Demo. of compact Final Focus optics (design demagnification, resulting in a nominal 35 nm beam size at focal point).	2010
	Demo. of prototype SC and PM final doublet magnets	2012
	Stabilisation of 35 nm beam over various time scales.	2012
Electron cloud mitigation studies:		
CESR-TA	Re-config. (re-build) of CESR as low-emittance e-cloud test facility. First meas. of e-cloud build-up using instrumented sections in dipoles and drifts sections (large emittance).	2008
	Achieve lower emittance beams. Meas. of e-cloud build up in wiggler chambers.	2009
	Characterisation of e-cloud build-up and instability thresholds as a func. of low vertical emittance (≤20 pm)	2010
DAΦNE	Fast kicker design and pulser reliability check	2010
	Characterisation of e-cloud build-up and instability thresholds	2010
SLAC/LLNL	Fast kicker pulser development	2010

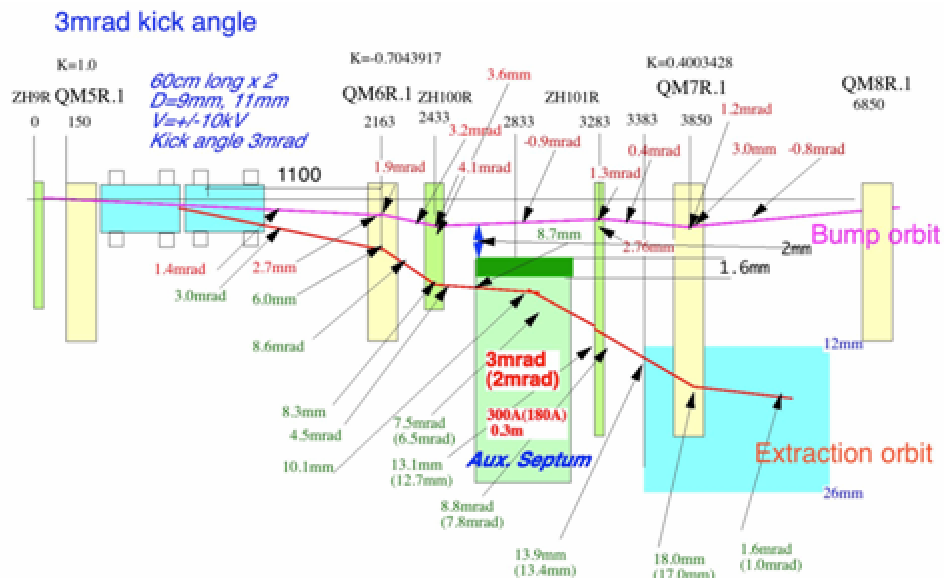
ATF meets ILC **normalised** emittance challenge

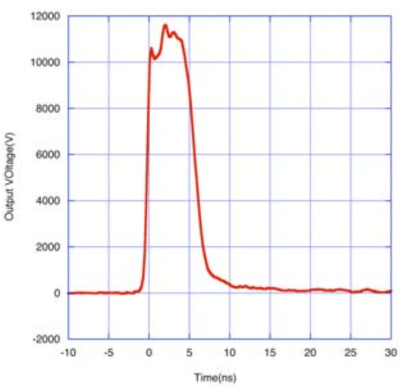


Beam extraction with fast strip-line kicker

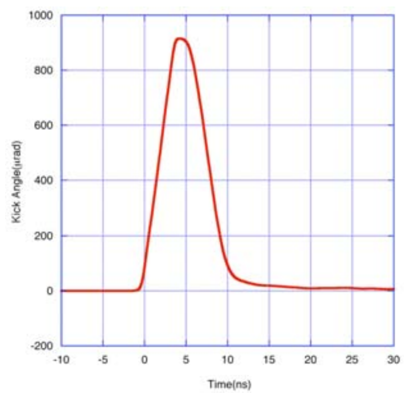
T. Naito (KEK), ATF2 project meeting, Jan. 2011

- *The beam extraction test was carried out to confirm the performance of the strip-line kicker.*
- *The pulsed magnet kicker was replaced to two units of 60cm long strip-line kicker.*
- *To help the lack of the kick angle, a local bump orbit and an auxiliary septum is used.*

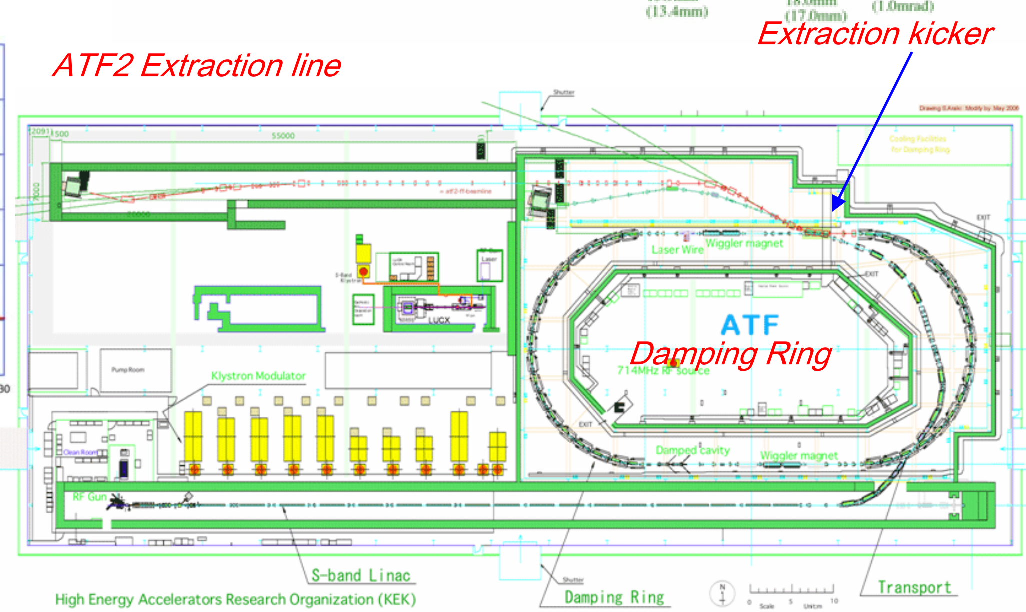




Kicker pulse (10kV)



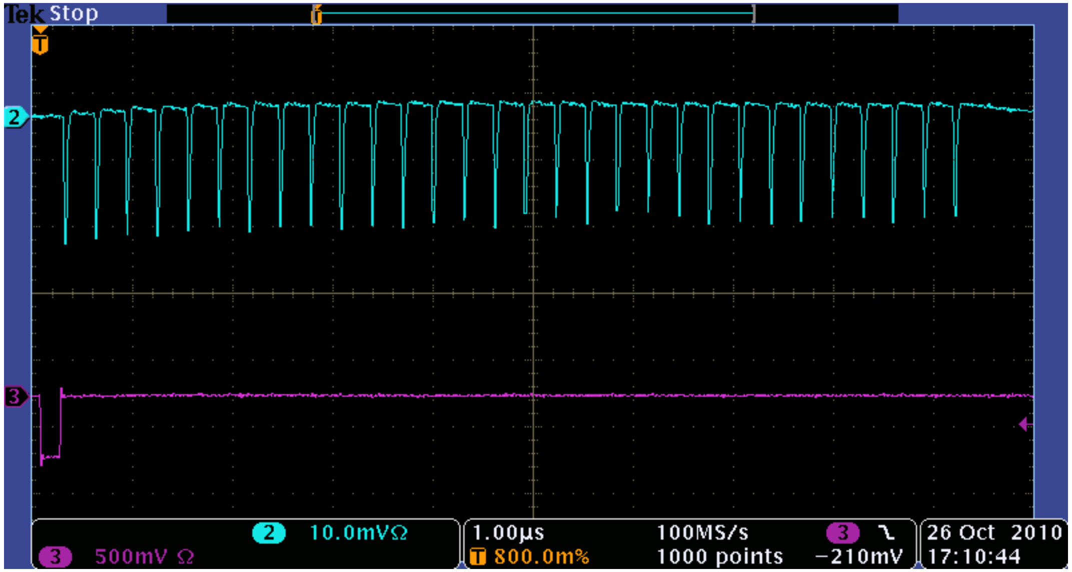
Kicker field



Multi-bunch Beam in the DR and the extraction line

3 trains of 10 bunches are stored in the DR

5.6 ns separation



Stable beam extraction confirmed to the dump without any beam loss

~ 300 ns separation

R&D deliverables from Test Facilities for ILC BDS and DR

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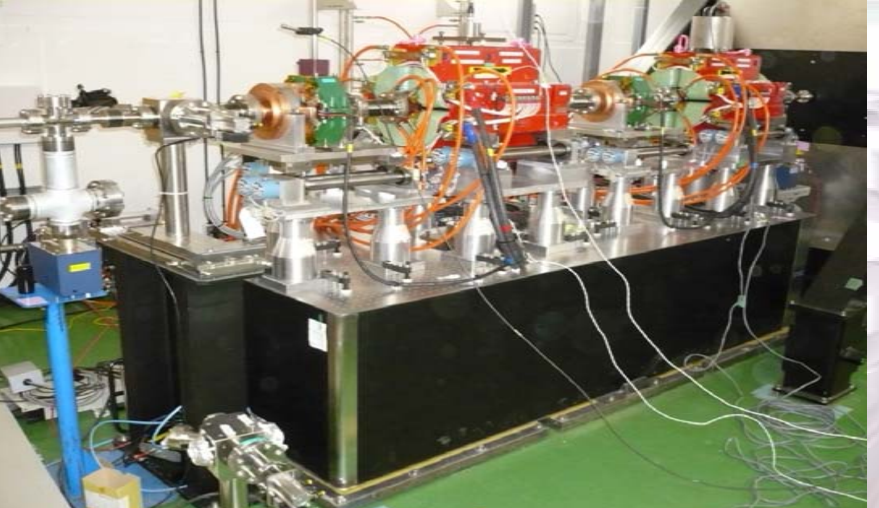
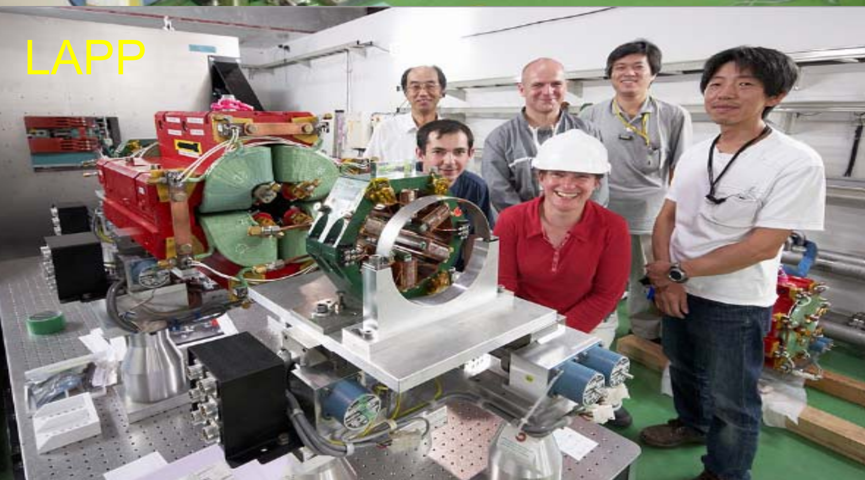
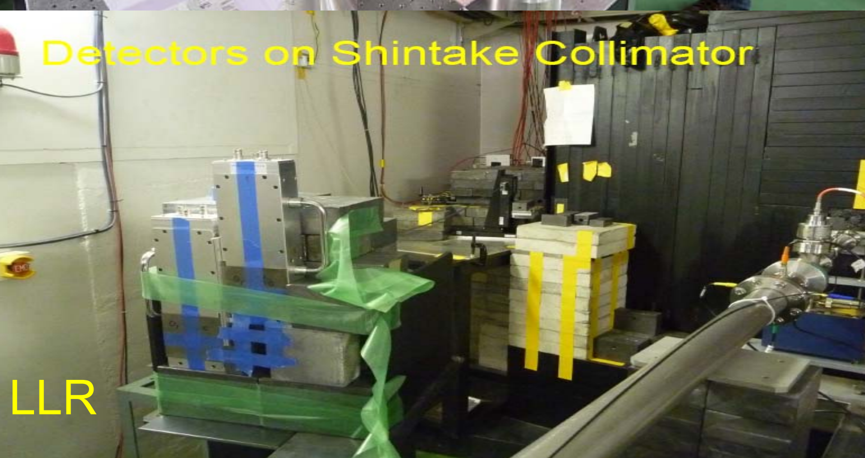
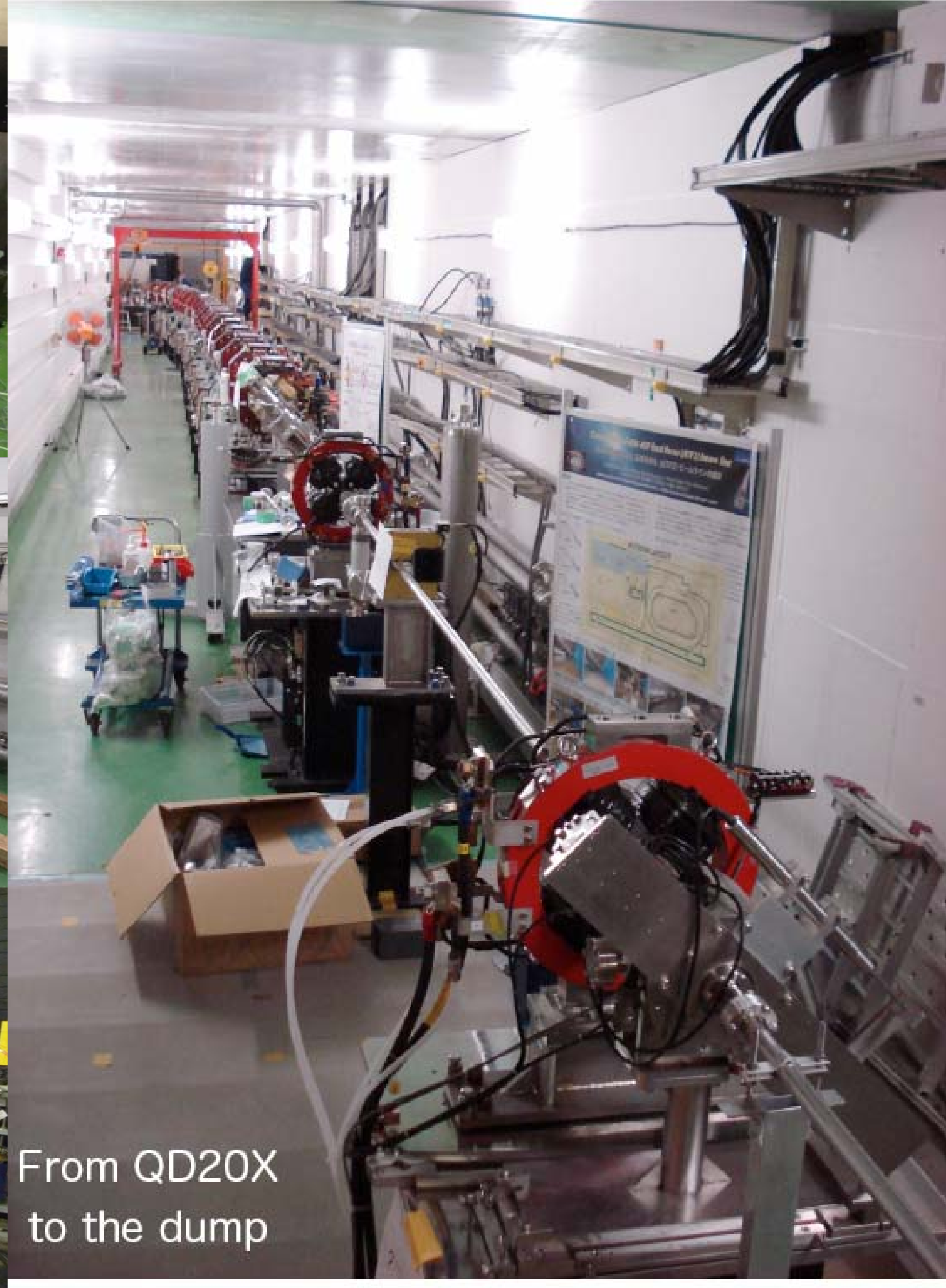
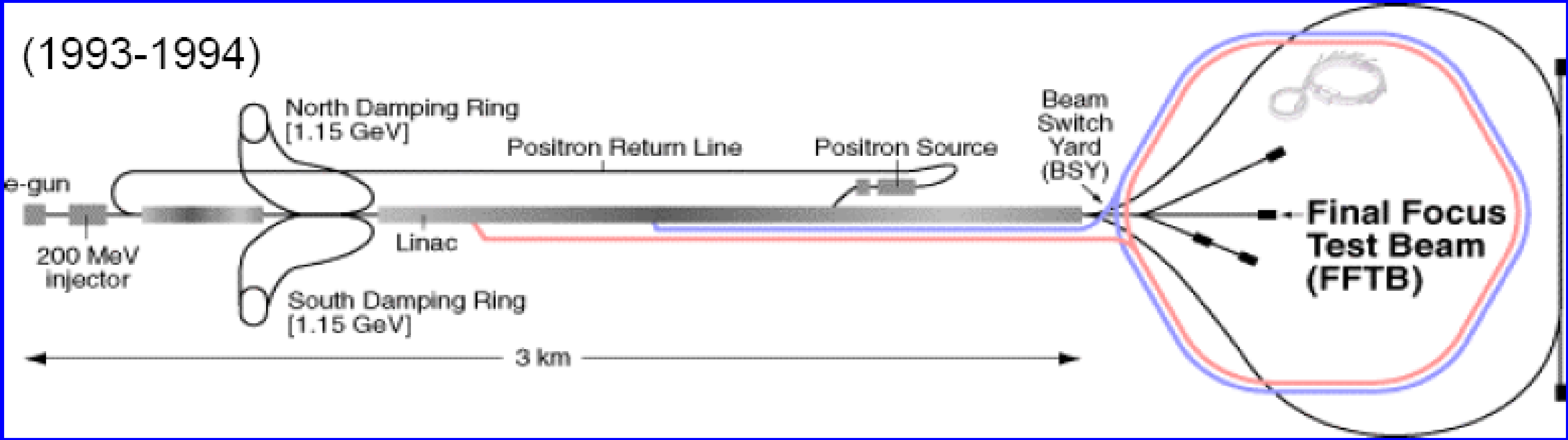



LAPP


Detectors on Shintake Collimator
LLR


From QD20X
to the dump

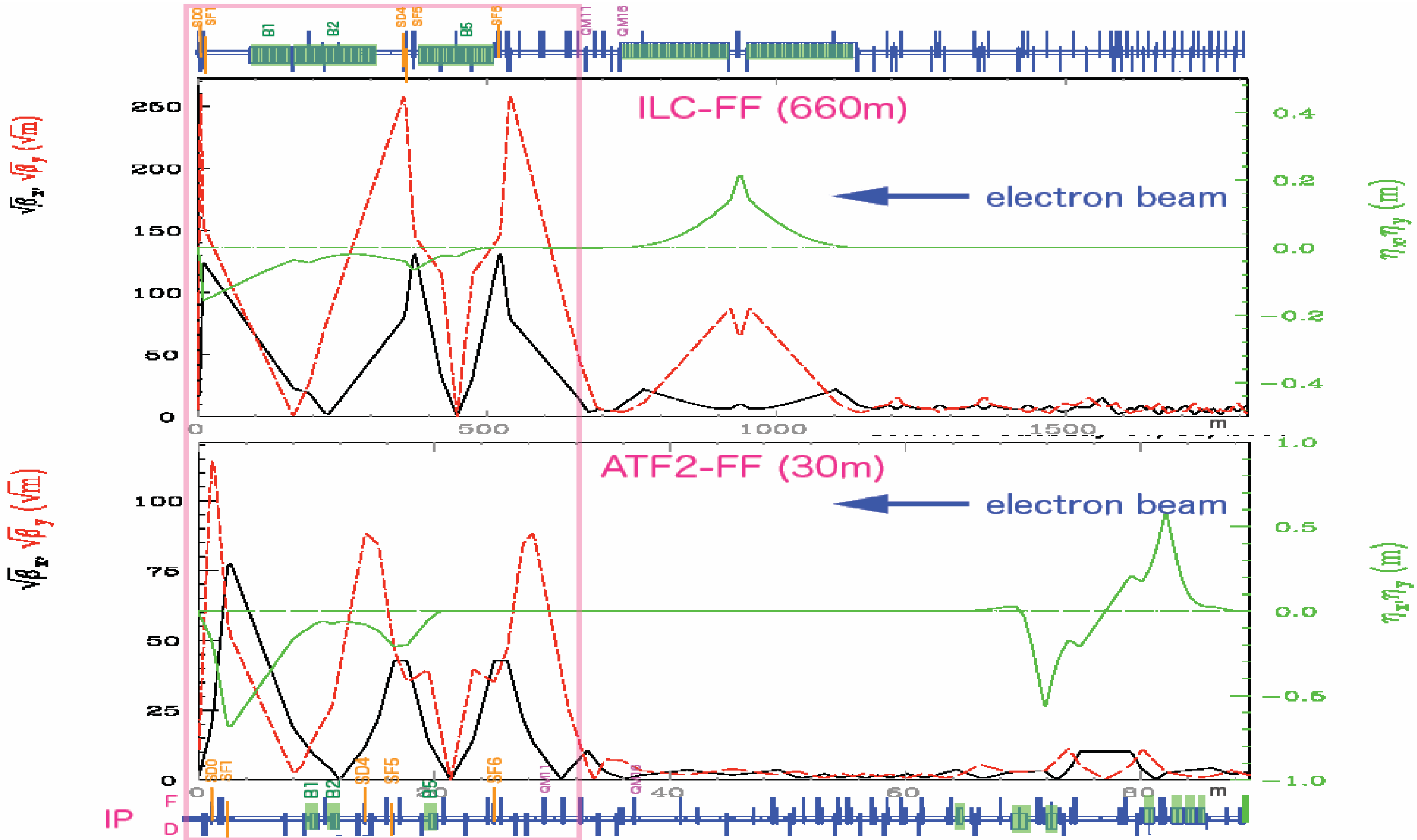
Wasn't FFTB sufficient ?



1. Not operated as dedicated facility
   → small beam sizes shown but little reproducibility and systematic study
2. Long-term stabilisation issues not addressed
3. Final Focus not based on new principle of local chromaticity correction

ATF2 = scaled ILC & CLIC final focus
→ new **local** chromaticity correction

P. Raimondi and A. Seryi, Phys. Rev. Lett. 86, 3779 (2001)



Project goals

Goal A : nanometer beam size
- obtain σ_y ~ 35 nm at focal point
- reproduce reliably σ_y ,maintain in time

Goal B : trajectory stabilization
- 1-2 nm at focal point
- intra-train feedback (ILC-like trains)

1. Instrumentation R&D for nano-beams
2. User-based operation through international multi-partner collaboration
3. Co-education for young accelerator physicists and engineers

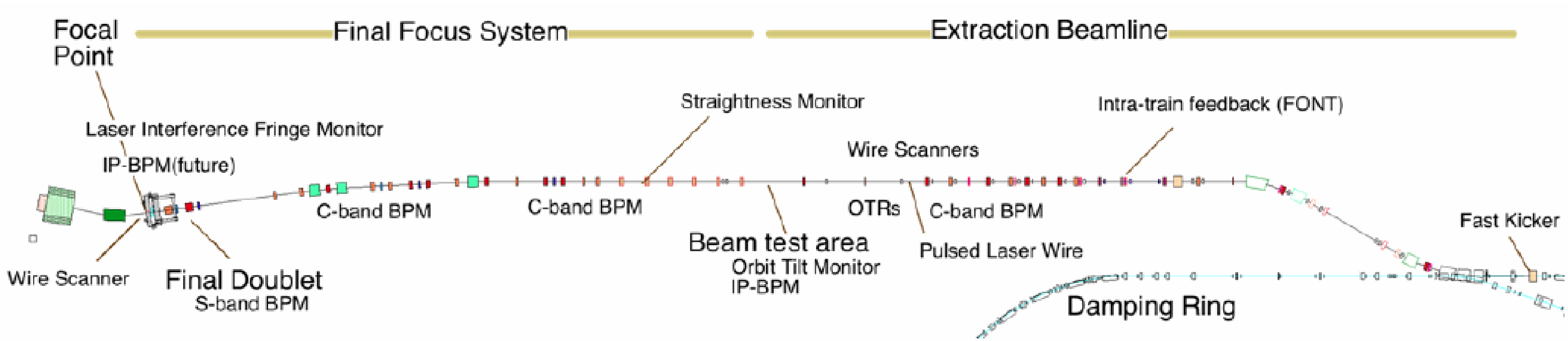
Planning

- Construction & installation completed in 2008
- 2009 / 2010 commissioning and testing
- 2011 / 2012 goals A & B + instrumentation R&D
- After 2013, continue Linear Collider R&D + physics with intense laser

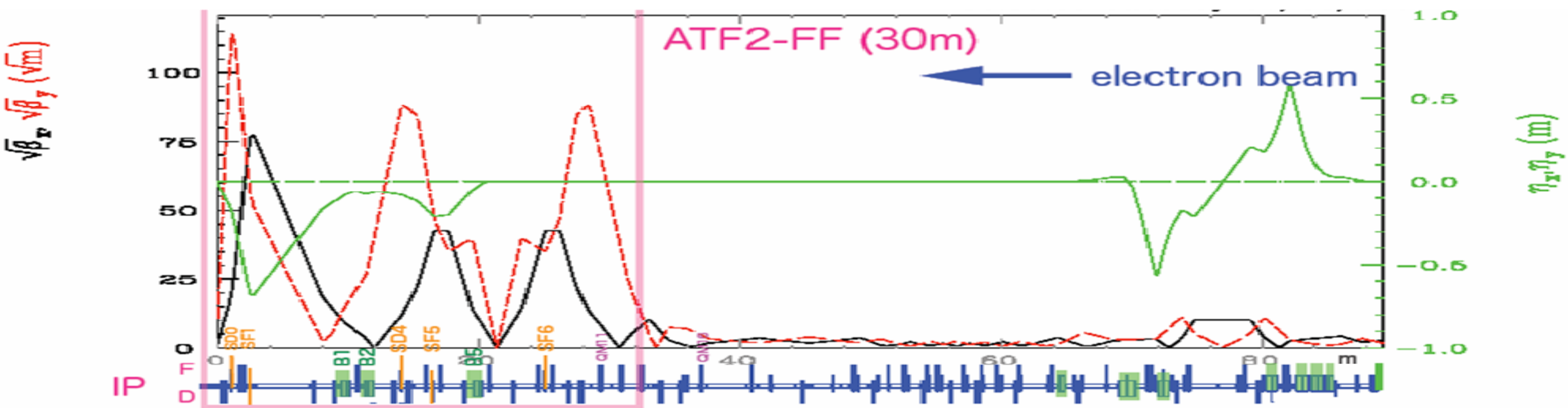
ATF2 COST : ~ 6 M$ ➔ mainly from Asia, with US & EU contributions

Daily operation meeting in control room

ATF2 operation & instrumentation R&D



2nd order telescope	Match optics into FF	DR extraction
fine tuning of local errors	*buffer section for input errors*	*setup, stability*



Commissioning periods

Dec. 2008 → 3 weeks

2009 → 21 weeks (=1+2+4+3+3+1+2+2+3)

Jan. – Jun. 2010 → 14 weeks (=3+2+2+3+2+1+1) **1st continuous week**

Autumn 2010 → 7 weeks (=2+2+3) **2nd continuous week**

2011 → 6 continuous shifts with 3 rotating teams, each composed of 3 primary experts (ATF2 tuning, "Shintake" monitor, ATF general operation) + supporting staff

→ # Beam time scheduling

50% fraction for ATF2 & 4 days per week operation

Individual RD tasks & common goals

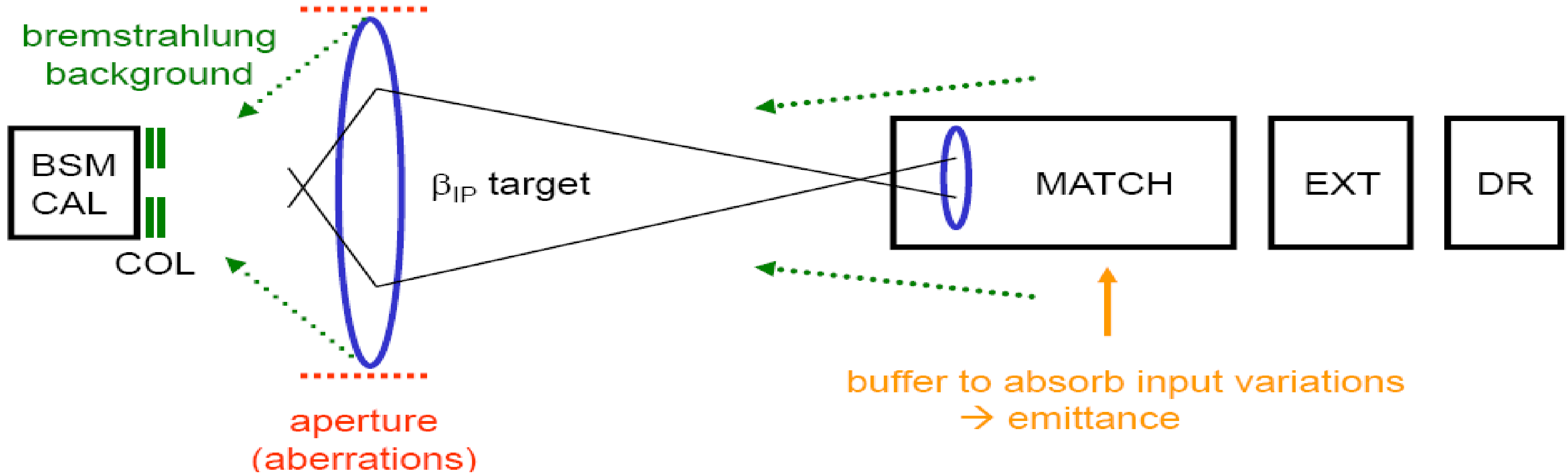
KEK, KNU, Tokyo, Sendai, **SLAC**, IHEP, UK, France, Spain, **CERN**,…

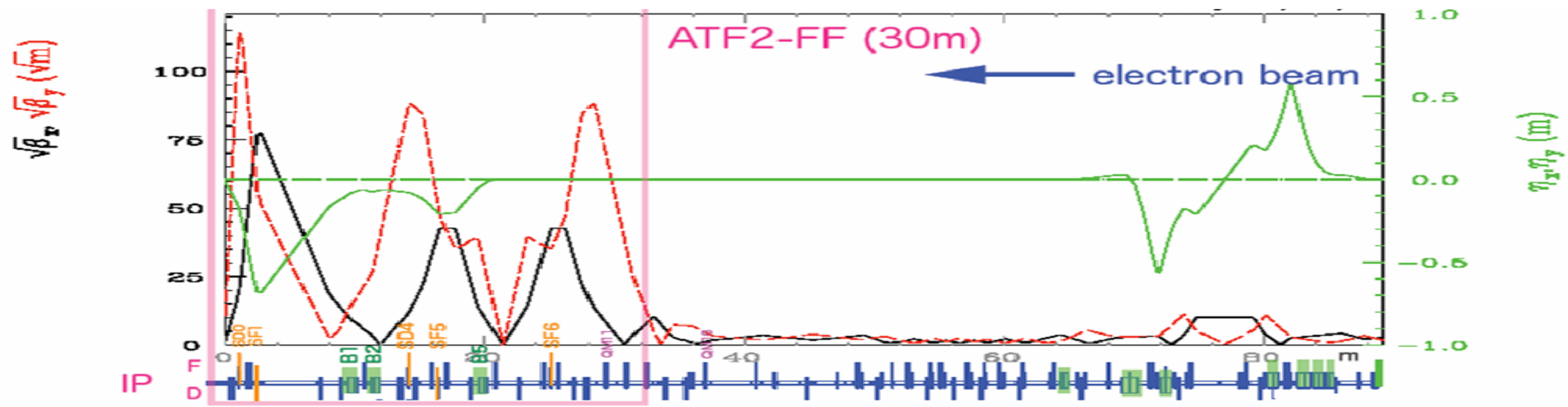
→ # ATF2 educational function

Several PhD & young post-doc researchers in accelerator science

Commissioning → gradual $\beta_{x,y}^*$ (demagnification) reduction paced by

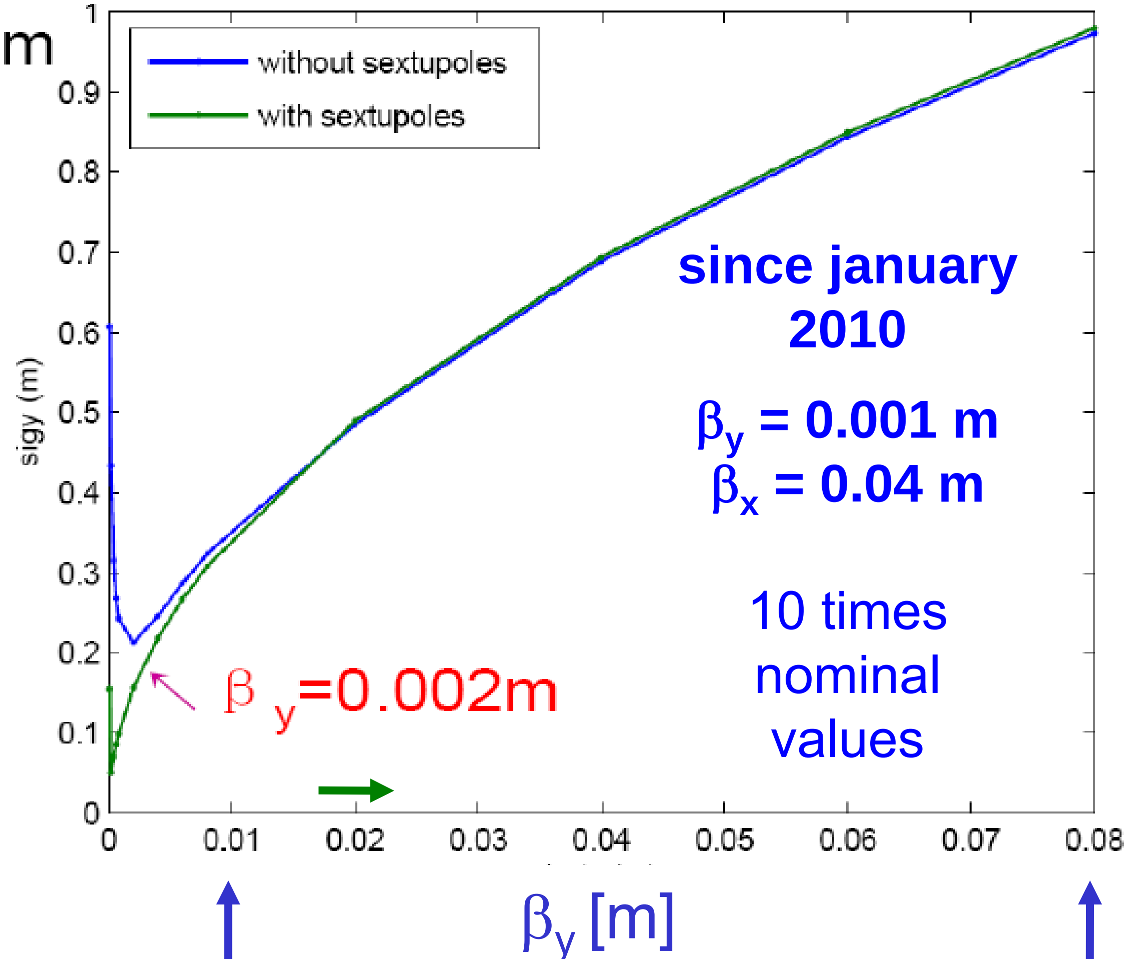
beam tuning | instrumentation (BSM / other) | background study





Variable β_{IP} at ATF2

S. Bai (IHEP, LAL), 2008-2009

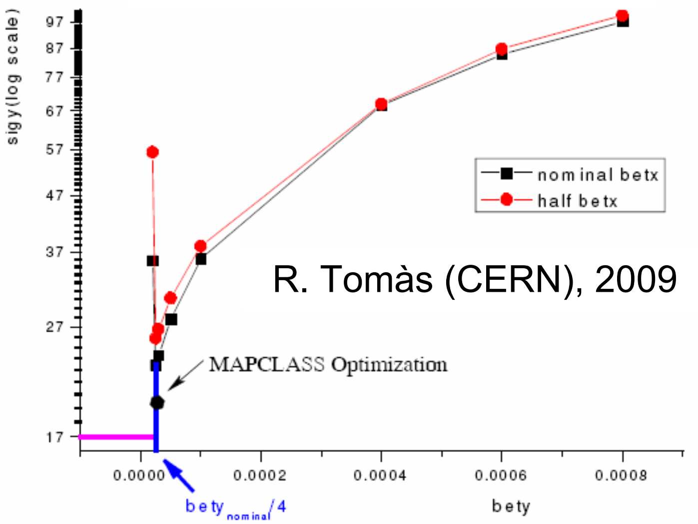


April - December 2009

March 2009

nominal value
β_y = 0.0001 m
β_x = 0.004 m

ultra-low β upgrade
factors 2-4
(CLIC & low P. ILC)



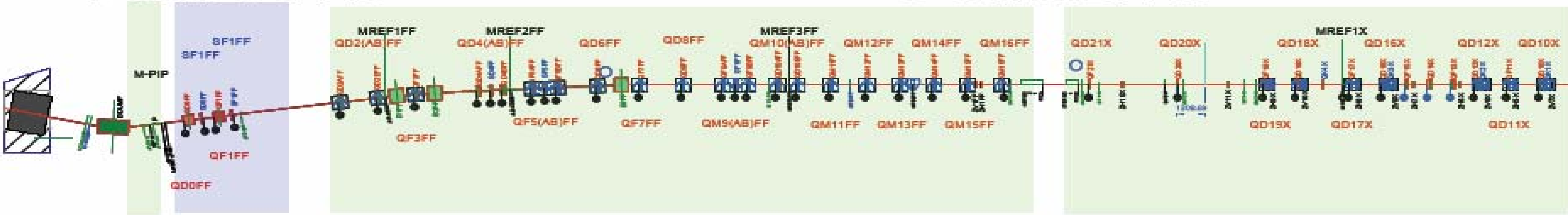
R. Tomàs (CERN), 2009

Now { **nominal β_y**
nominal β_x × 2.5

ATF2 BPM systems

S-Band BPMs

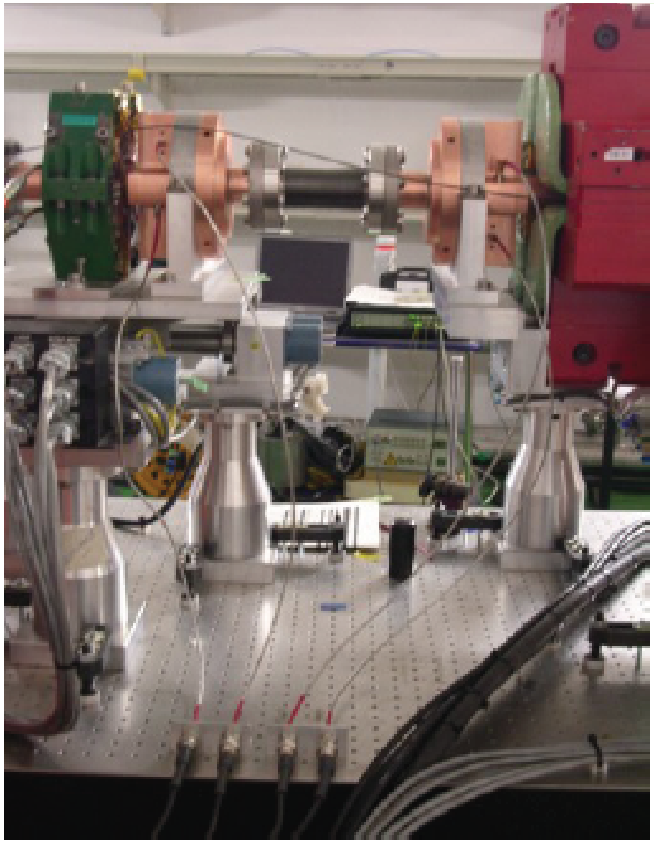
C-Band BPMs

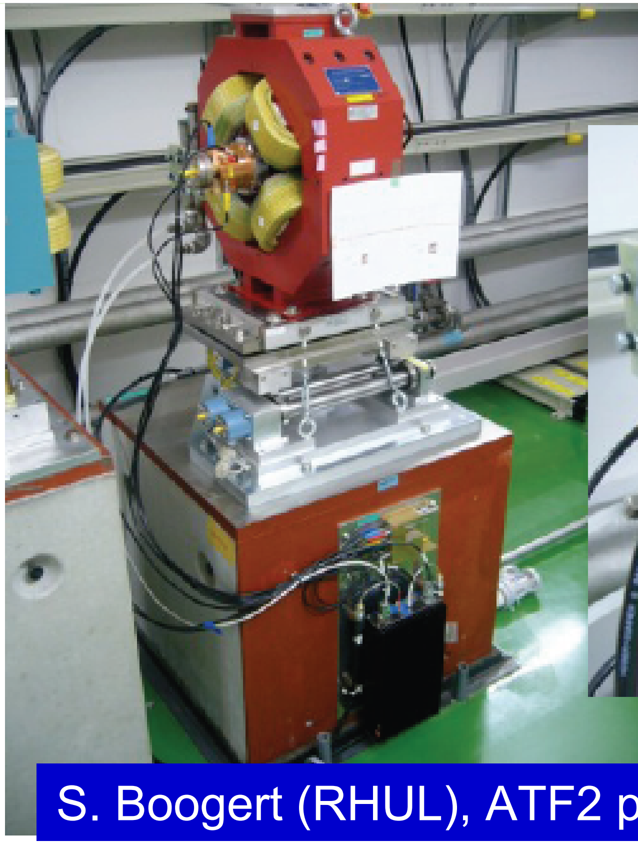


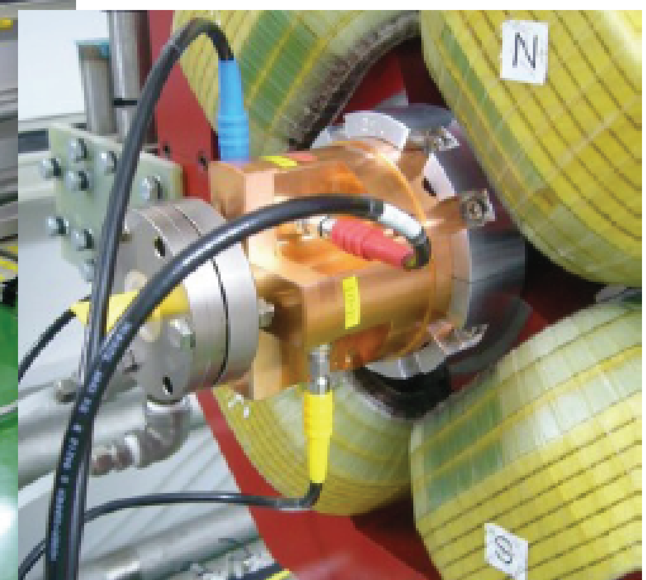
IP BPMs

Mover

Corrector

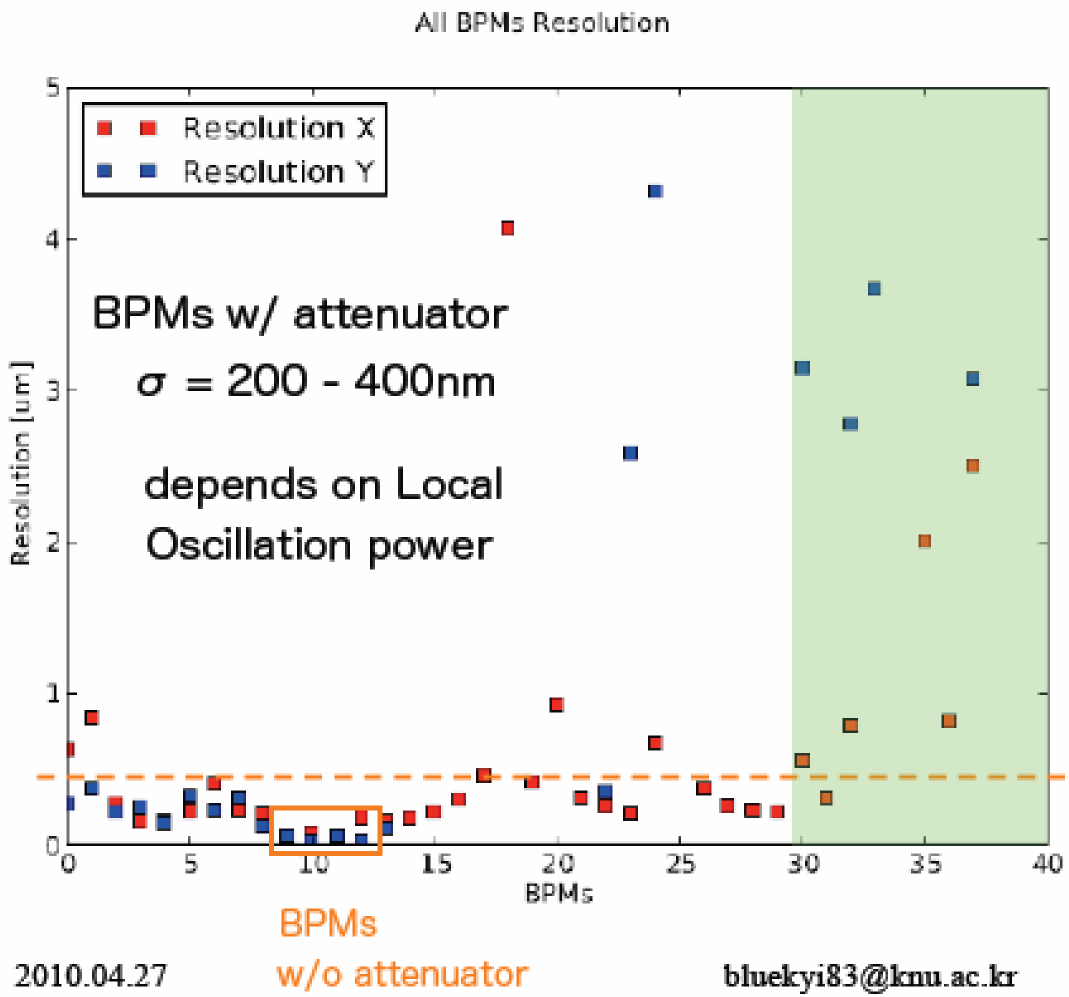


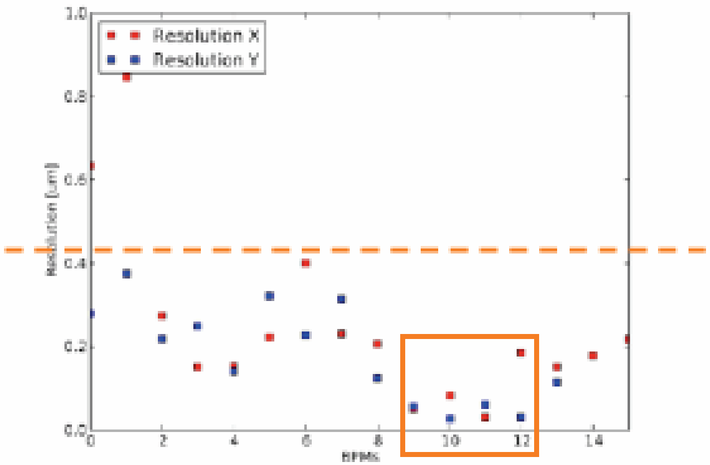


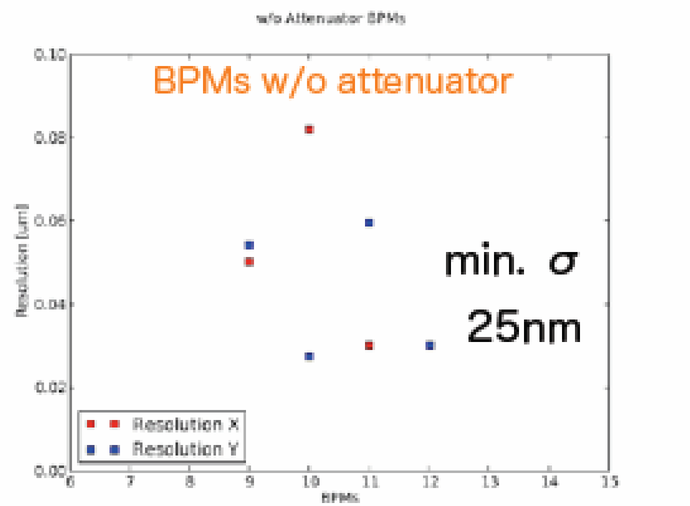


S. Boogert (RHUL), ATF2 project meeting, Jan. 2011

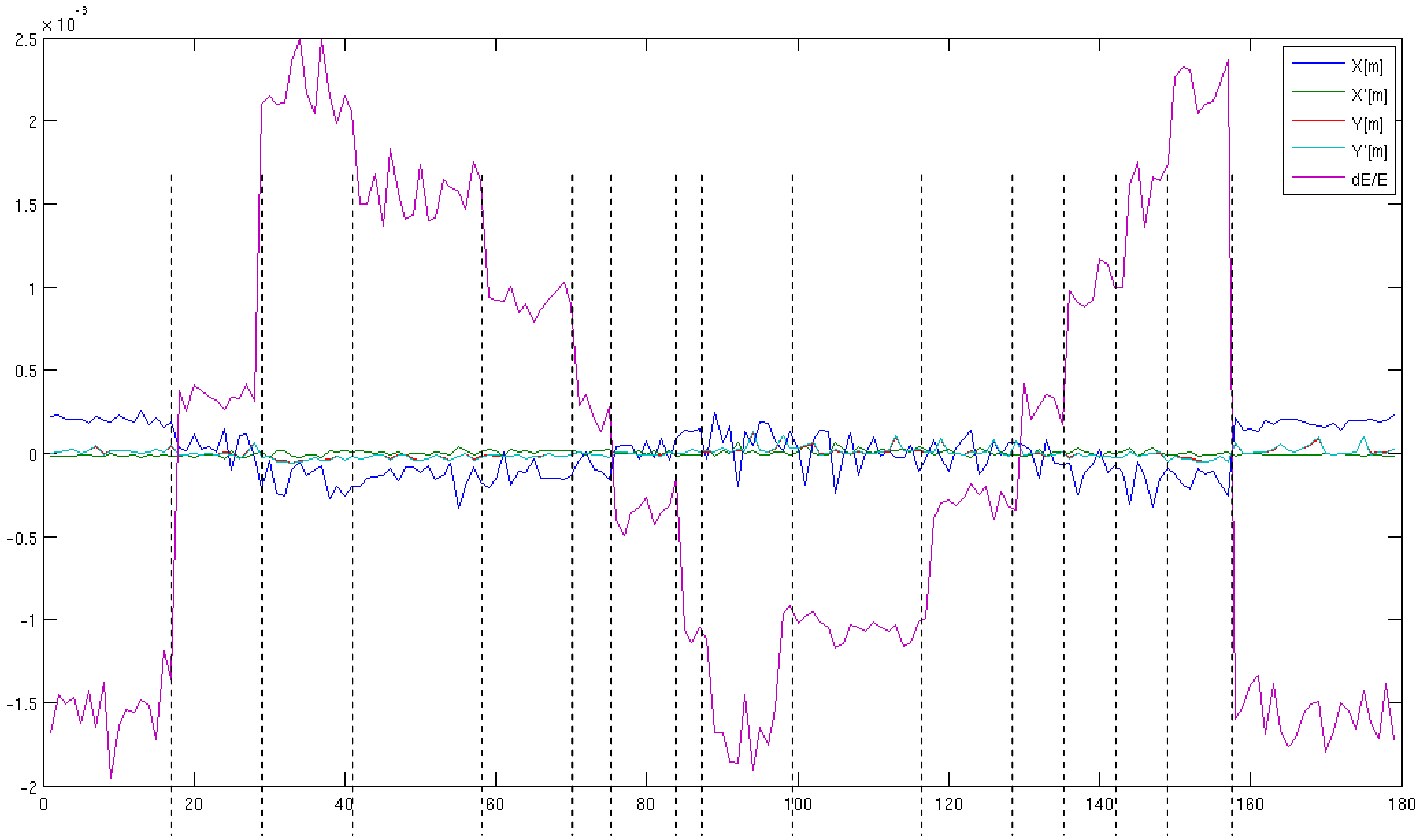
All BPM Resolution Determination







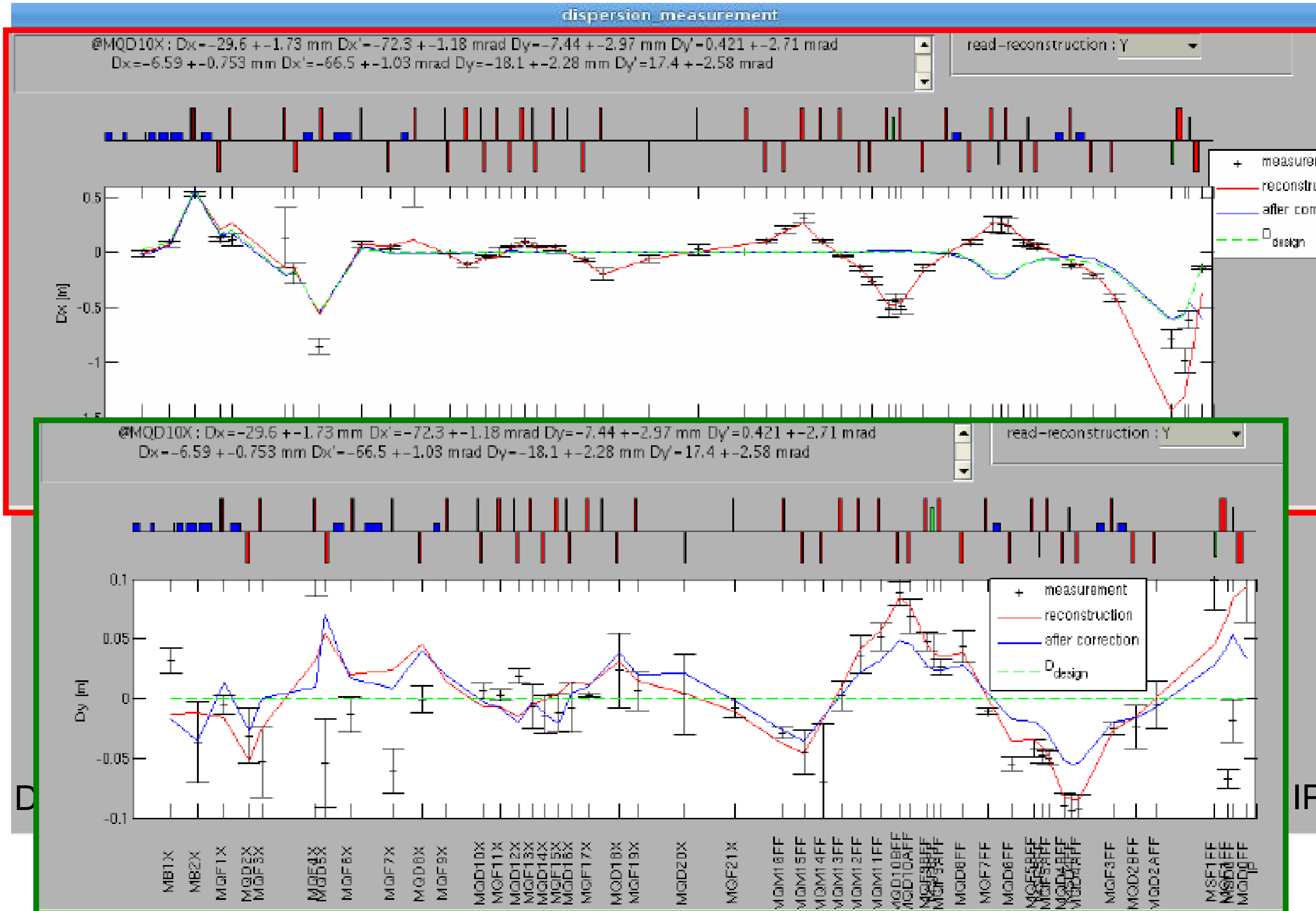
Reconstructing variations at injection (during dispersion measurements)



Δf_{RF} [kHz] = off 0 +3 +2 +1 0 -1 -2 -3 -2 -1 0 +1 +2 +3 off

Y. Rénier (LAL), ATF2 project meeting, Dec. 2009

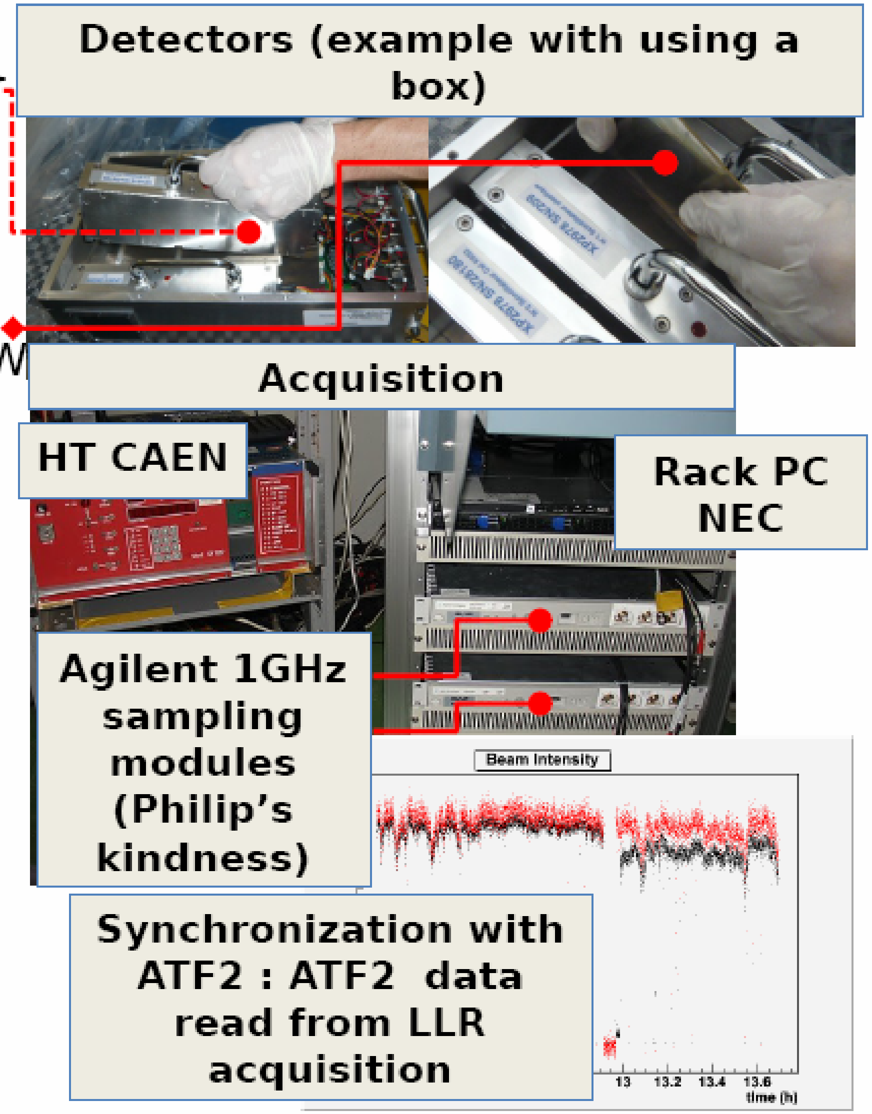
Y dispersion from energy fluctuations < 1e-4



Neutron and EM background study

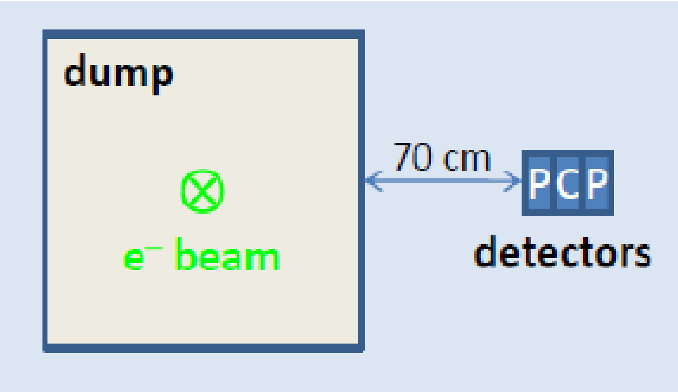
H. Guler & M. Verderi (LLR), ATF2 project meeting, Jan. 2011

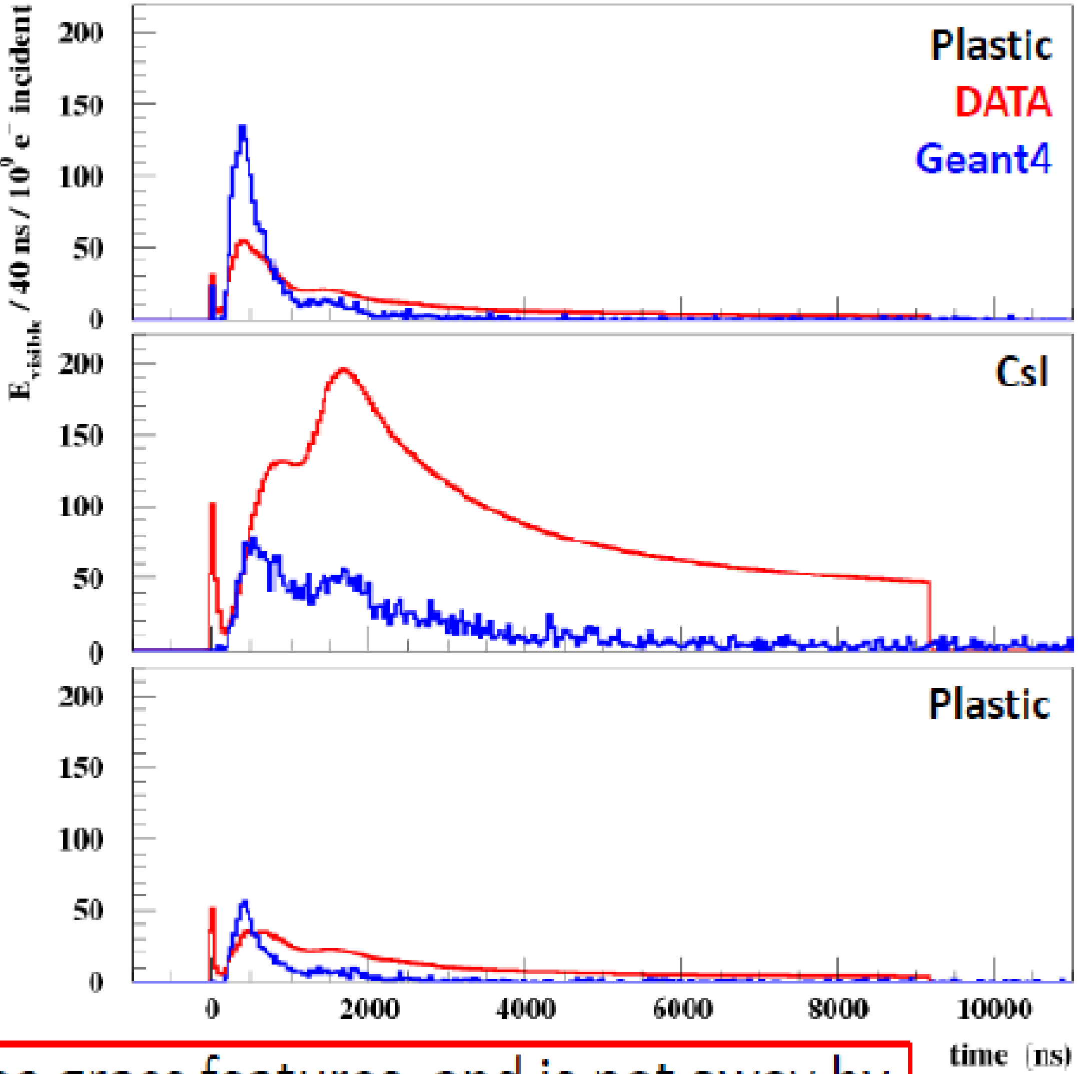
- Made a set of 8 simple detectors = {scintillator + photomultiplier}
  - That can be used alone
  - Or assembled in boxes to form « mini-calorimeters » with longitudinal segmentation (with W insertion if needed)
- Scintillator = plastic or pure CsI
  - Fast : allows TOF
  - Distinguish background sources
  - Separate (prompt) EM and (delayed) neutron backgrounds
  - Different response to neutrons:
  - Plastic sensitive to fast neutrons
  - Intermediate neutrons for CsI



Preliminary Geant4/data comparison

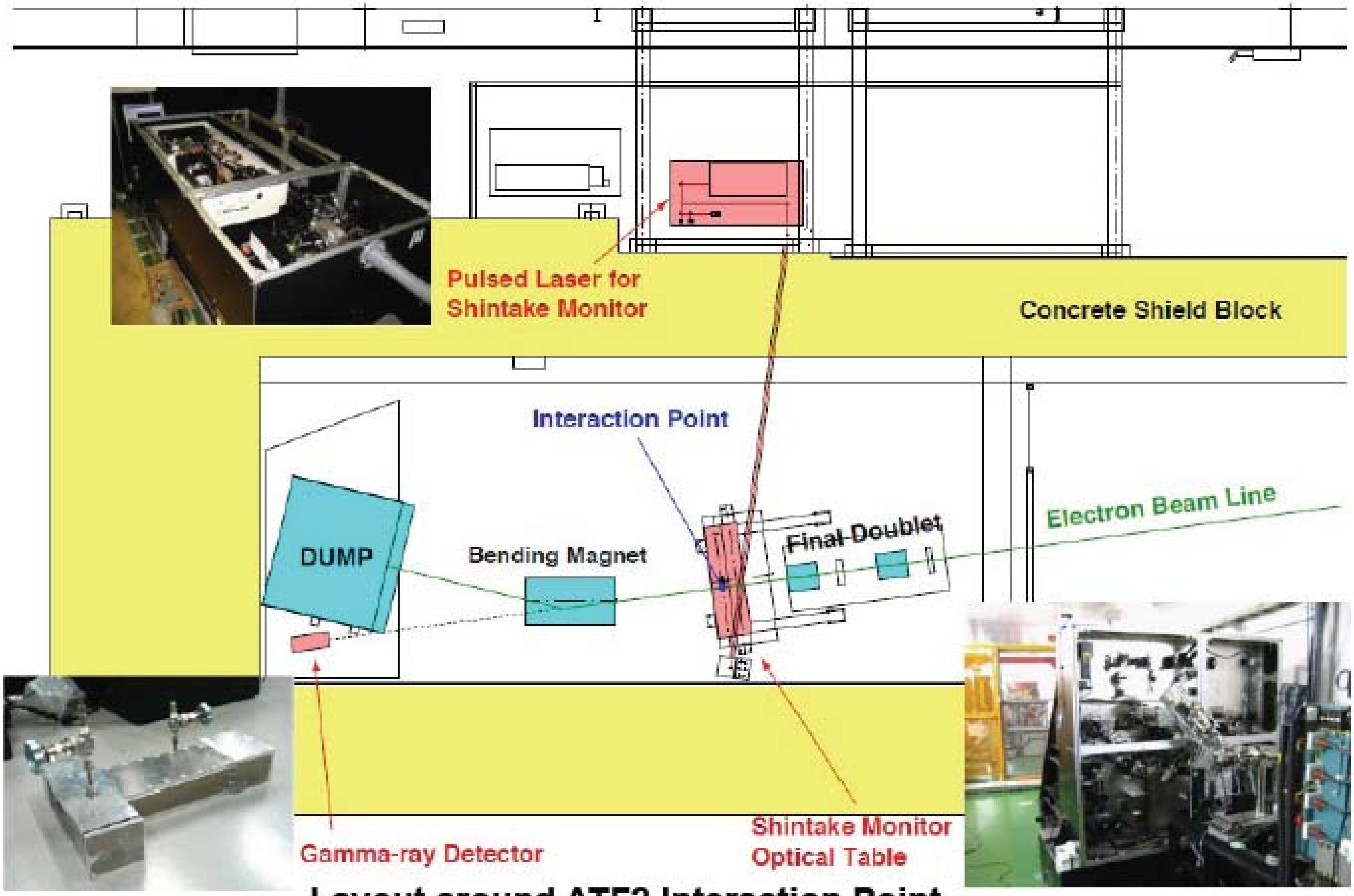
- Experimental setup:
  - Plastic, CsI, plastic
  - 70 cm to dump on lateral side (opposite to Shintake photon detector)





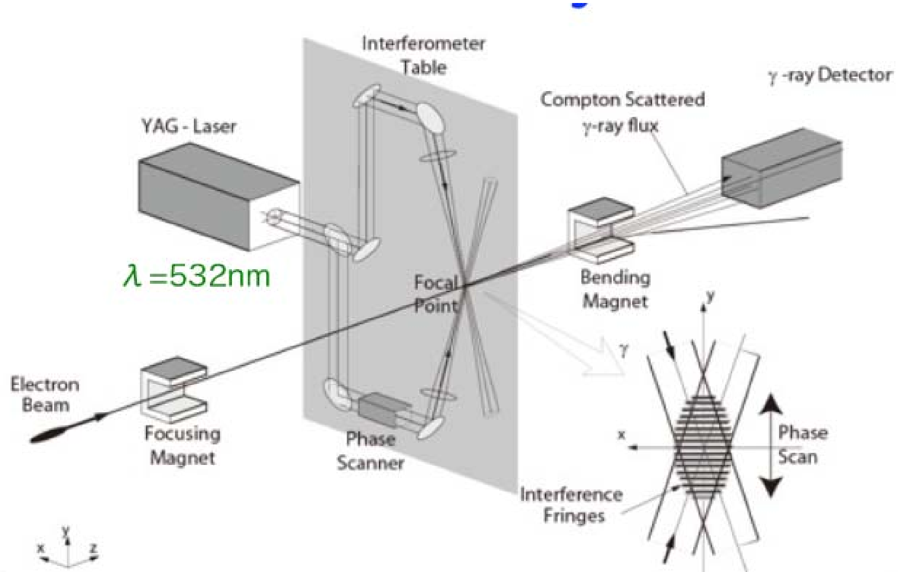
- Plots normalized to 10^9 incident 1.3 GeV e^-.
- Significant differences
- But Geant4 reproduces the gross features, and is not away by order of magnitudes.

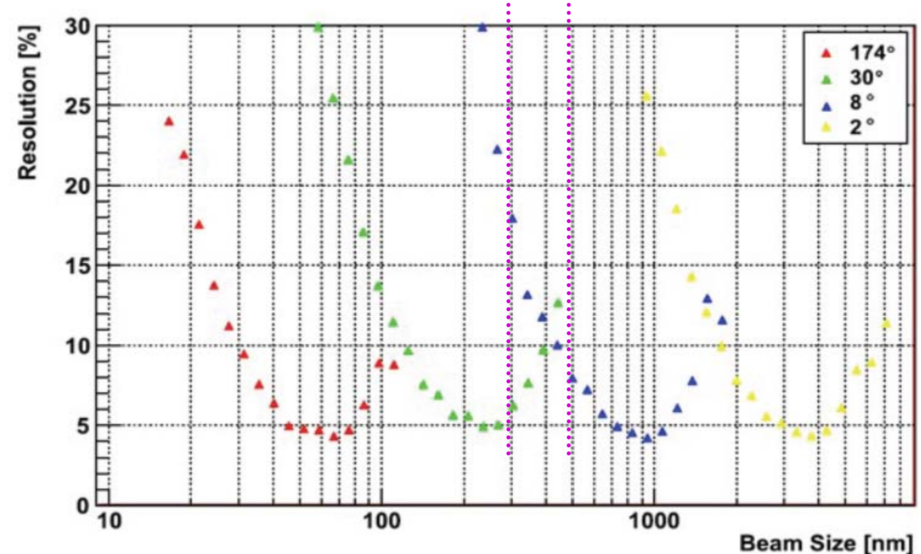
Shintake Monitor : Layout



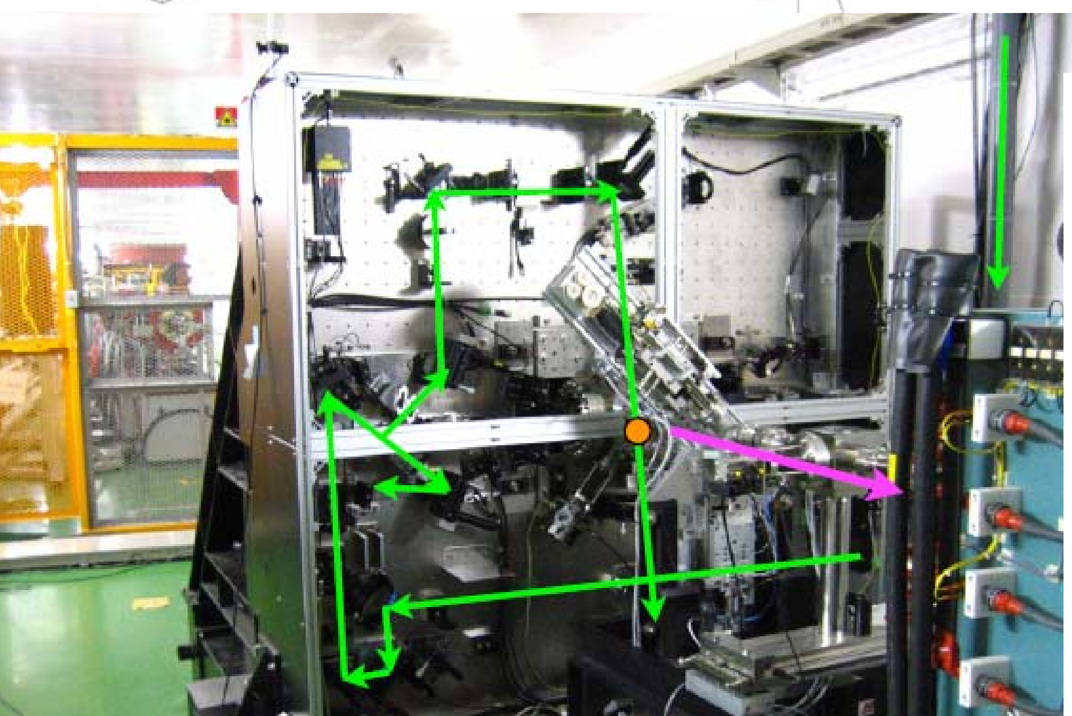
Layout around ATF2 Interaction Point

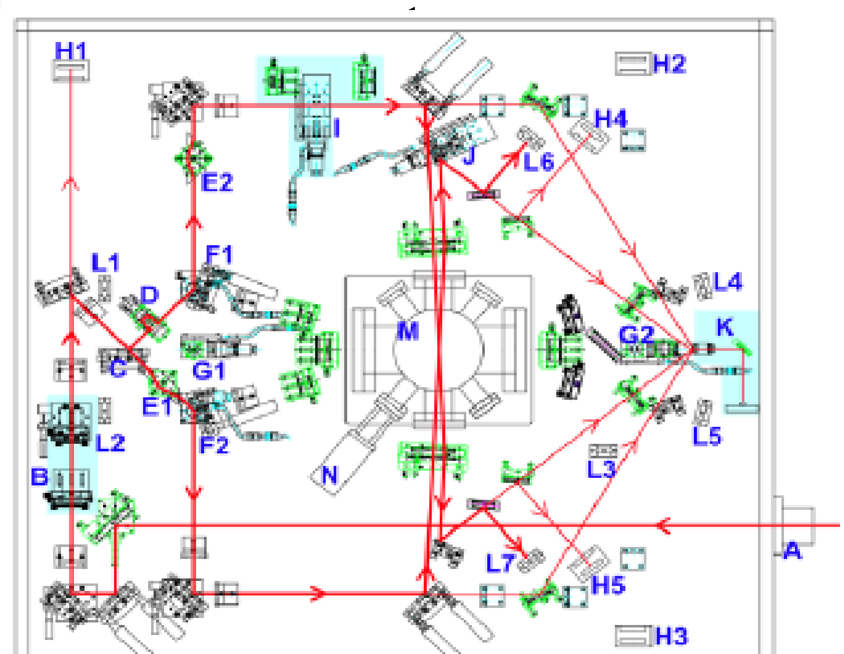
“Shintake” beam size monitor at IP



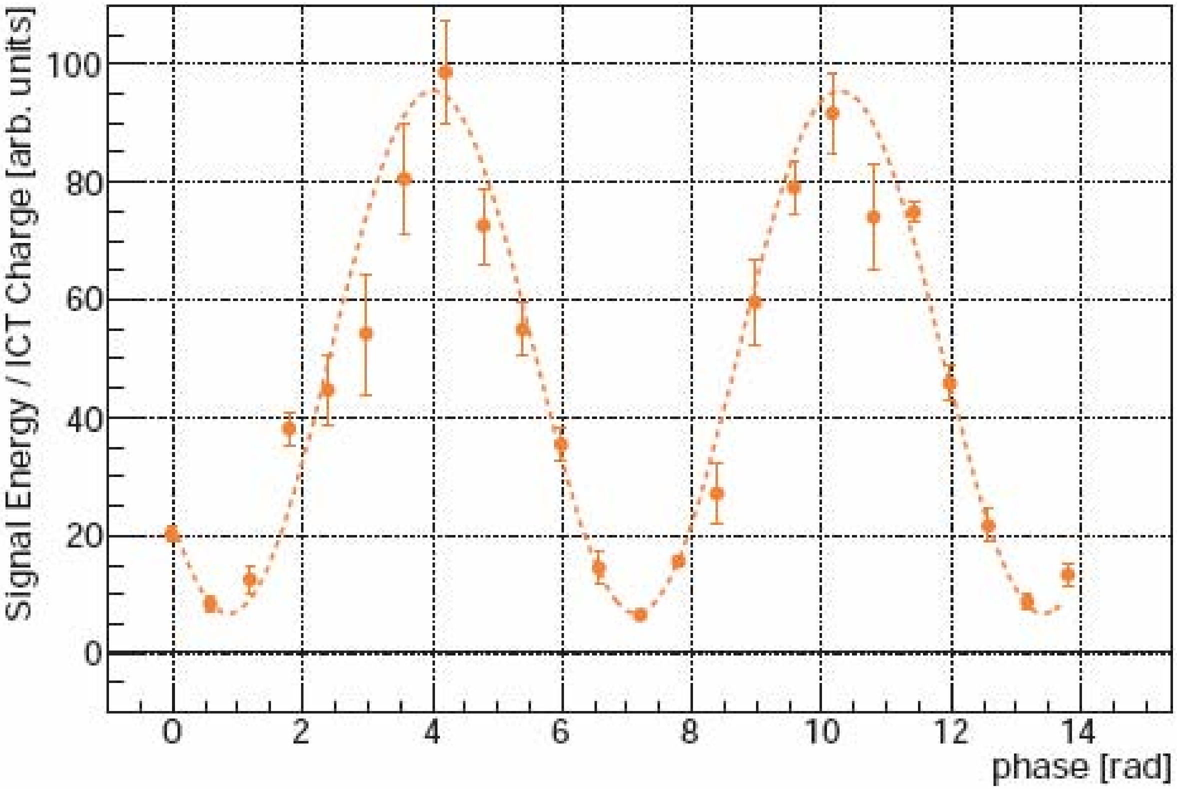


Sensitivity ranges of crossing angles





Shintake Monitor Best Result , 20 May 2010



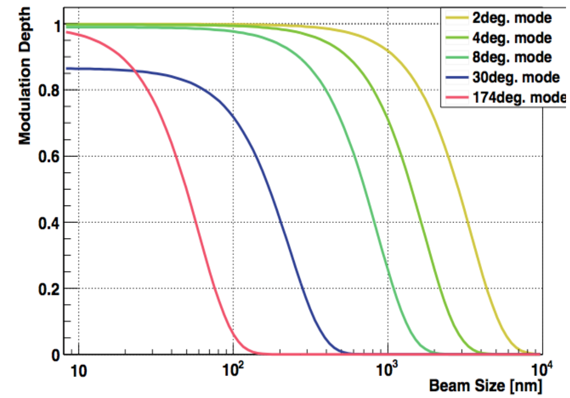
Crossing angle (θ) : 8°

Pitch : 3.81 μm

Modulation (M) : 0.87

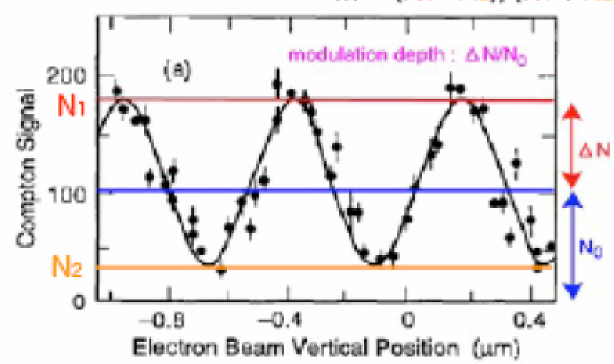
Beam size (σ_y) : 310 ± 30 nm

+ systematics…



How it works as follows

M = (N1 - N2)/(N1 + N2)



$$\sigma_y = \frac{d}{2\pi}\sqrt{2 \cdot \ln(|\cos\theta|/M)} \qquad d = \frac{\lambda}{2 \cdot \sin\frac{\theta}{2}}$$

Wave length 532nm, width=8ns

$\Delta\nu/\nu$=1.6 x 10^{-7}

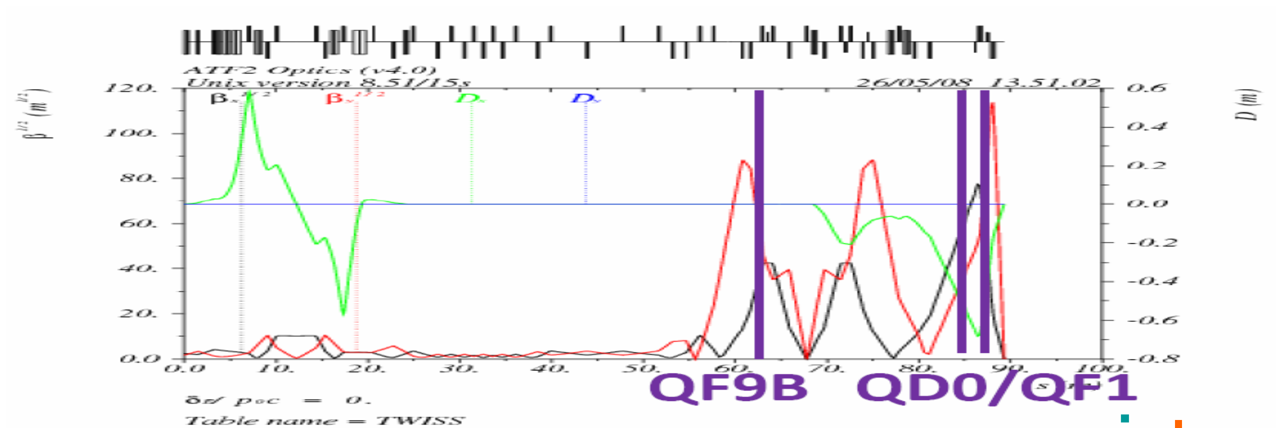
Laser intensity = 2.8 x 10^{13} W/cm^2

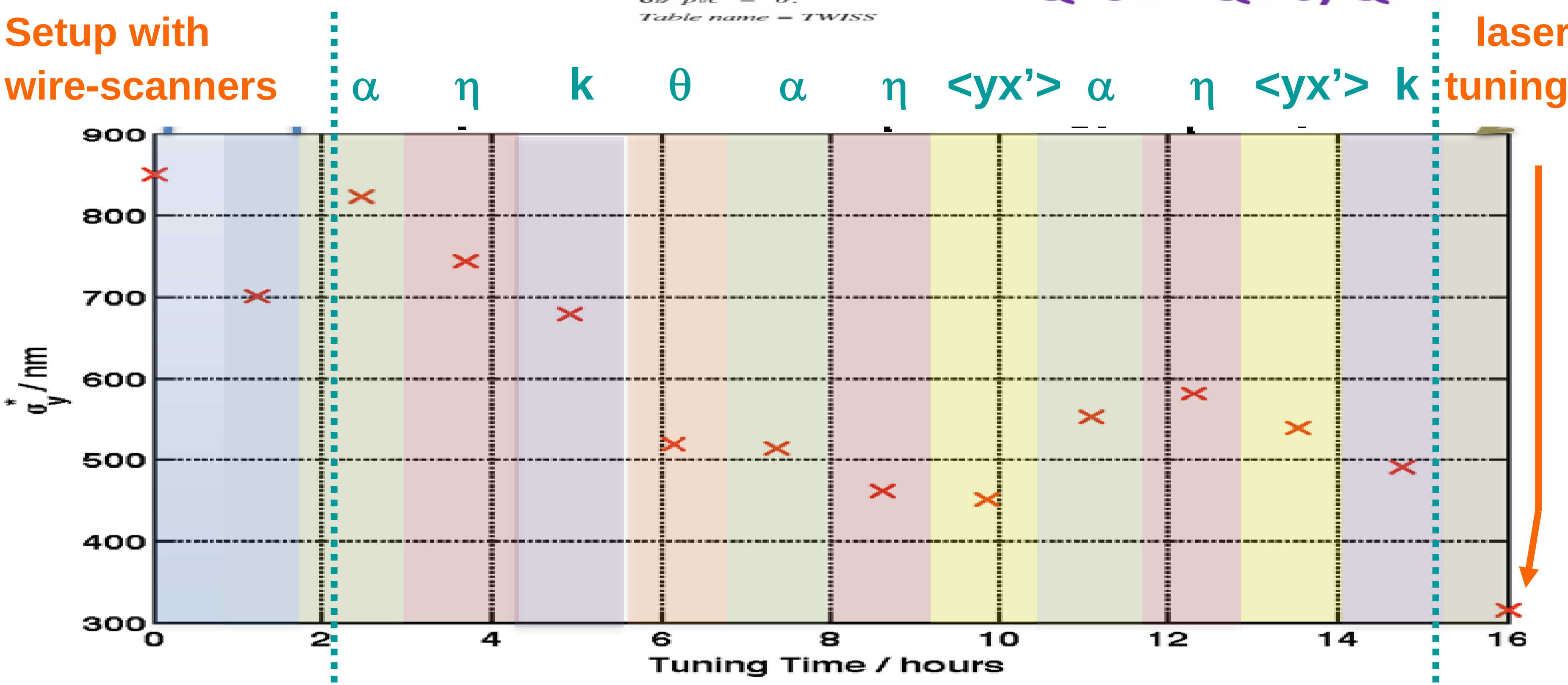
a_0 = 1.7 x 10^{-4}

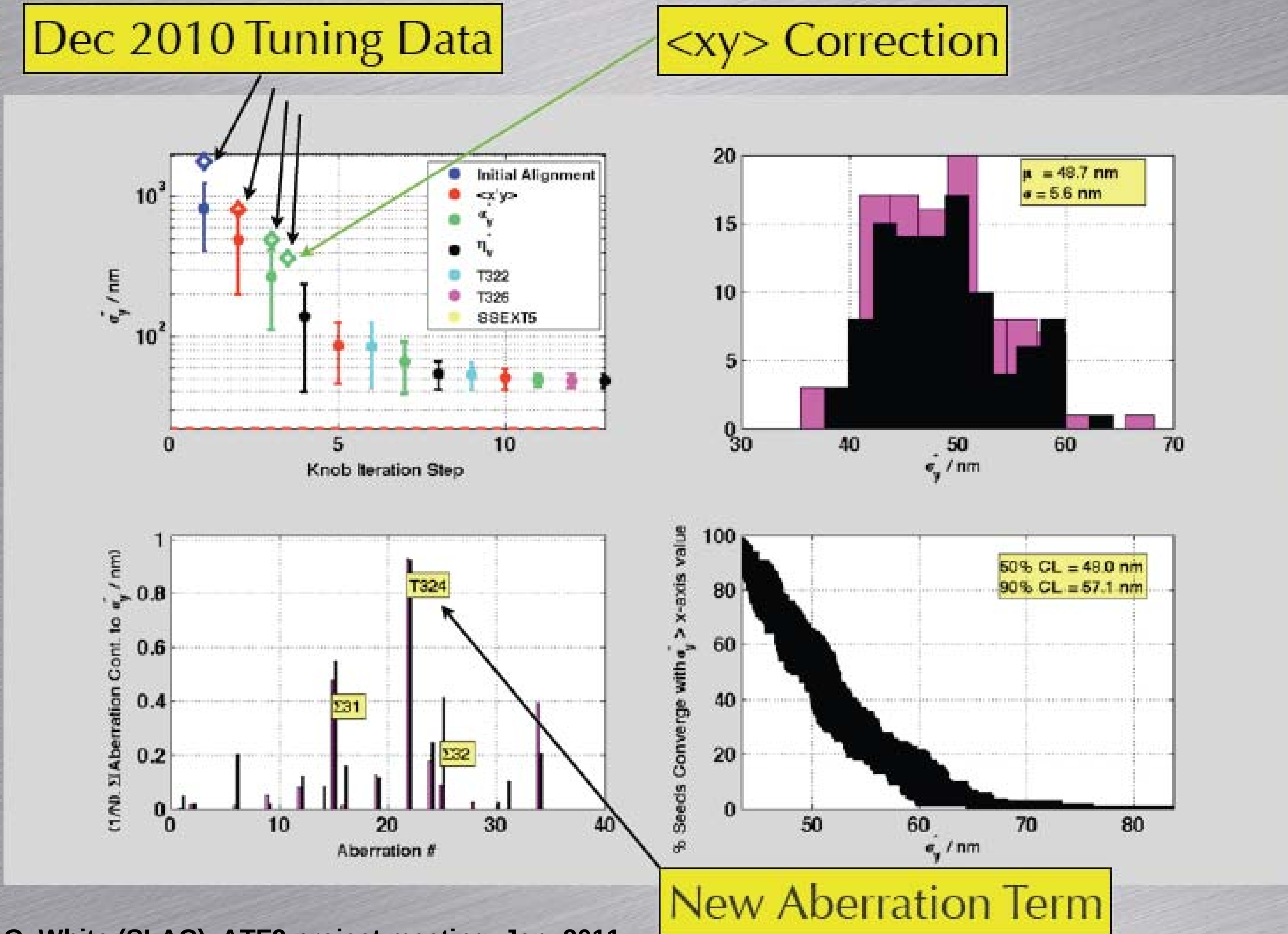
Multiknobs for $\langle xx'\rangle$, $\langle yy'\rangle$, $\langle yx'\rangle$, $\langle x\delta_E\rangle$ and $\langle y\delta_E\rangle$ control

First ATF2 continuous tuning run, Dec. 2009

Example with 3 FFS quads for x&y waists and hor. disp.





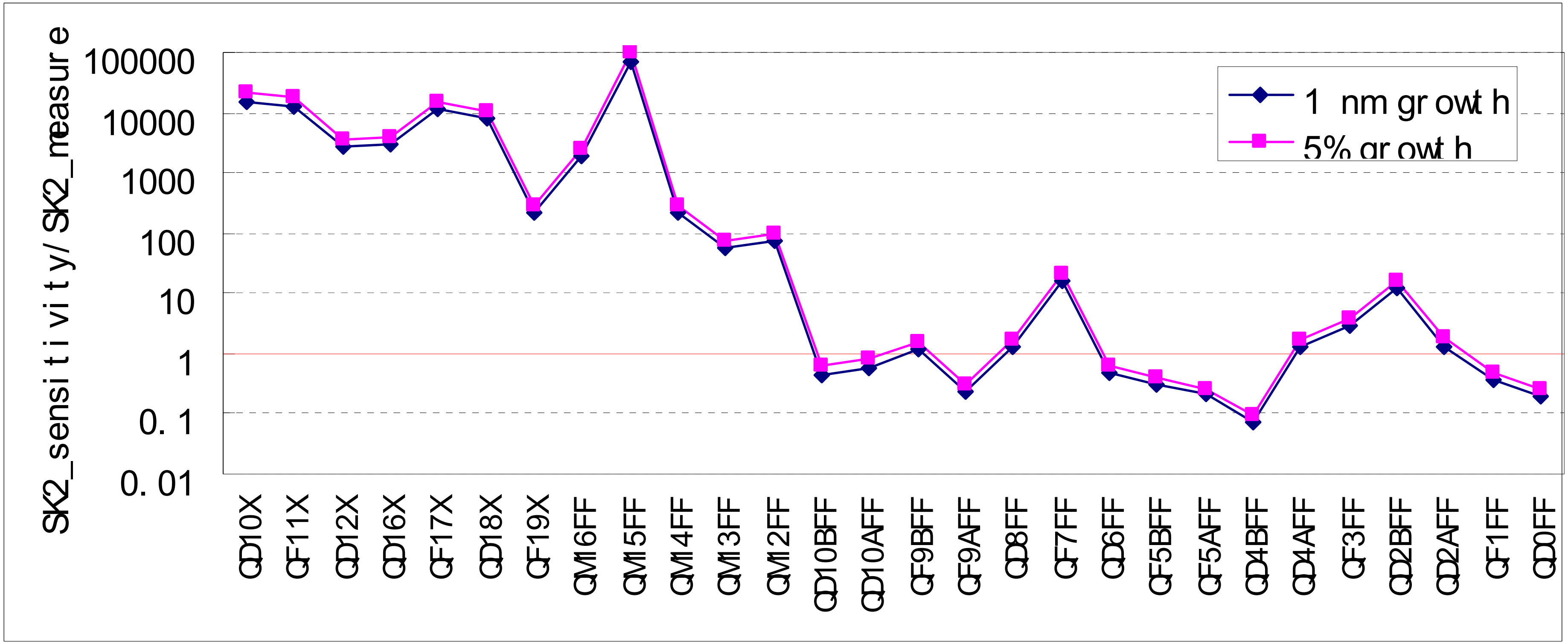


G. White (SLAC), ATF2 project meeting, Jan. 2011

skew sextupole tolerance compared to the measurement for the quadrupoles

Best quadrupoles: QM15FF, QD10X, QF11X, QF17X, QD18X

Worst quadrupoles:QD4BFF, QD0FF, QF5AFF, QF9AFF, QF5BFF



D. Wang (IHEP), ATF2 project meeting, Jan. 2011

Conclusions and prospects

- Success of ATF ➔ federation of independent R&D teams

  ➔ flexible & open – user-operated – facility

- Post-Docs, PhD & Master students – international co-supervision

- Excellent progress with instrumentation: stripline & cavity BPMs, "Shintake" beam size monitor and several other ATF2 R&Ds

- 1st and 2nd ATF2 continuous beam tuning run in May & December

  ➔ 300 nm vertical spot (target was ~ 100 nm)

  ➔ Issue of "operational stability" for extended runs

  ➔ New "goal 1 dedicated" operation mode in 2011

- ATF operation guaranteed for dedicated LC R&D to end of 2012

- Program continuation for LC + extension to other science goals (e.g. strong field physics with intense laser) beyond 2012

May, 2010

Dr Theses

Year	university	country	Name	title	publication
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	Nuclear Instruments and Methods in Physics Research A 616 (2010) 1–8
2009.4.14	Royal Holloway, University of London	UK	Lawrence Deacon	A Micron-Scale Laser-Based Beam Profile Monitor for the International Linear Collider	PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS submitted (May 2010)
2010.6.8	UNIVERSITAT DE VALÈNCIA	Spain	Maria 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	Paper with title "First beam waist measurements at the Accelerator Test Facility 2 at KEK" submitted to PRSTAB
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	

Publication of First Results by May 2009

in PR-STAB 13, 042801 (2010)

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 13, 042801 (2010)

Present status and first results of the final focus beam line at the KEK Accelerator Test Facility

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(ATF Collaboration)

[1]LAL, Université Paris-Sud, CNRS/IN2P3, Orsay, France
[2]Instituto de Fisica Corpuscular (CSIC–University of Valencia), Valencia, Spain
[3]SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA
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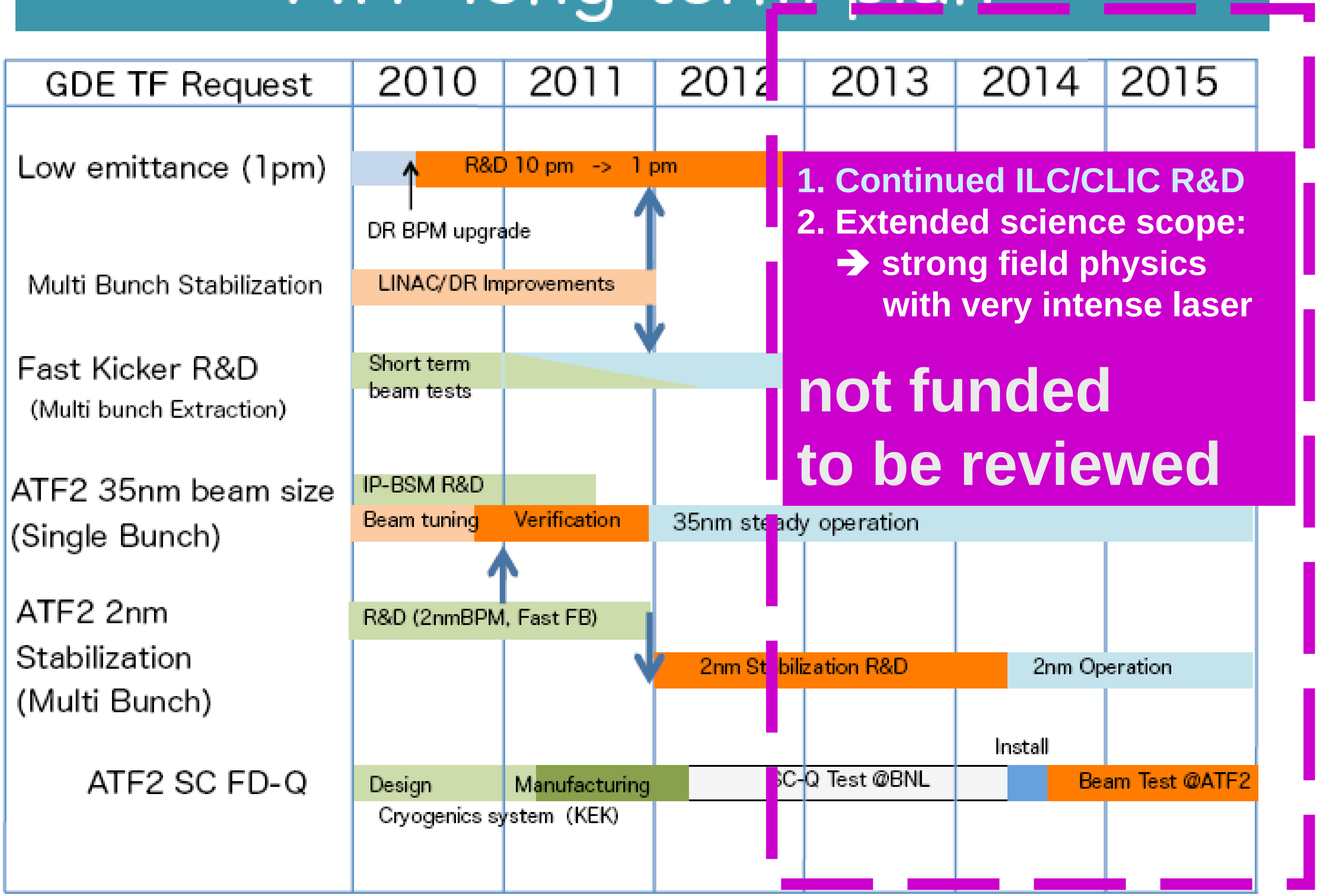
[11]Deutsches Elektronen-Synchrotron, Hamburg, Germany
[12]Fermi National Accelerator Laboratory, Batavia, Illinois 60510-5011, USA
[13]Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Palaiseau, France
[14]Kyungpook National University, Korea
[15]PAL, Korea
[16]Kyoto ICR, Japan
[17]The University of Tokyo, Japan
[18]UCL, London, United Kingdom
[19]Tohoku University, Japan
[20]Brookhaven National Laboratory, Upton, New York 11973-5000, USA
[21]Cockcroft Institute, University of Manchester, United Kingdom
[22]Hiroshima University, Japan
[23]Cockcroft Institute, University of Liverpool, United Kingdom
(Received 1 November 2009; published 21 April 2010)

ATF2 is a final-focus test beam line which aims to focus the low emittance beam from the ATF damping ring to a vertical size of about 37 nm and to demonstrate nanometer level beam stability. Several advanced beam diagnostics and feedback tools are used. In December 2008, construction and installation were completed and beam commissioning started, supported by an international team of Asian, European, and U.S. scientists. The present status and first results are described.

ATF long term plan



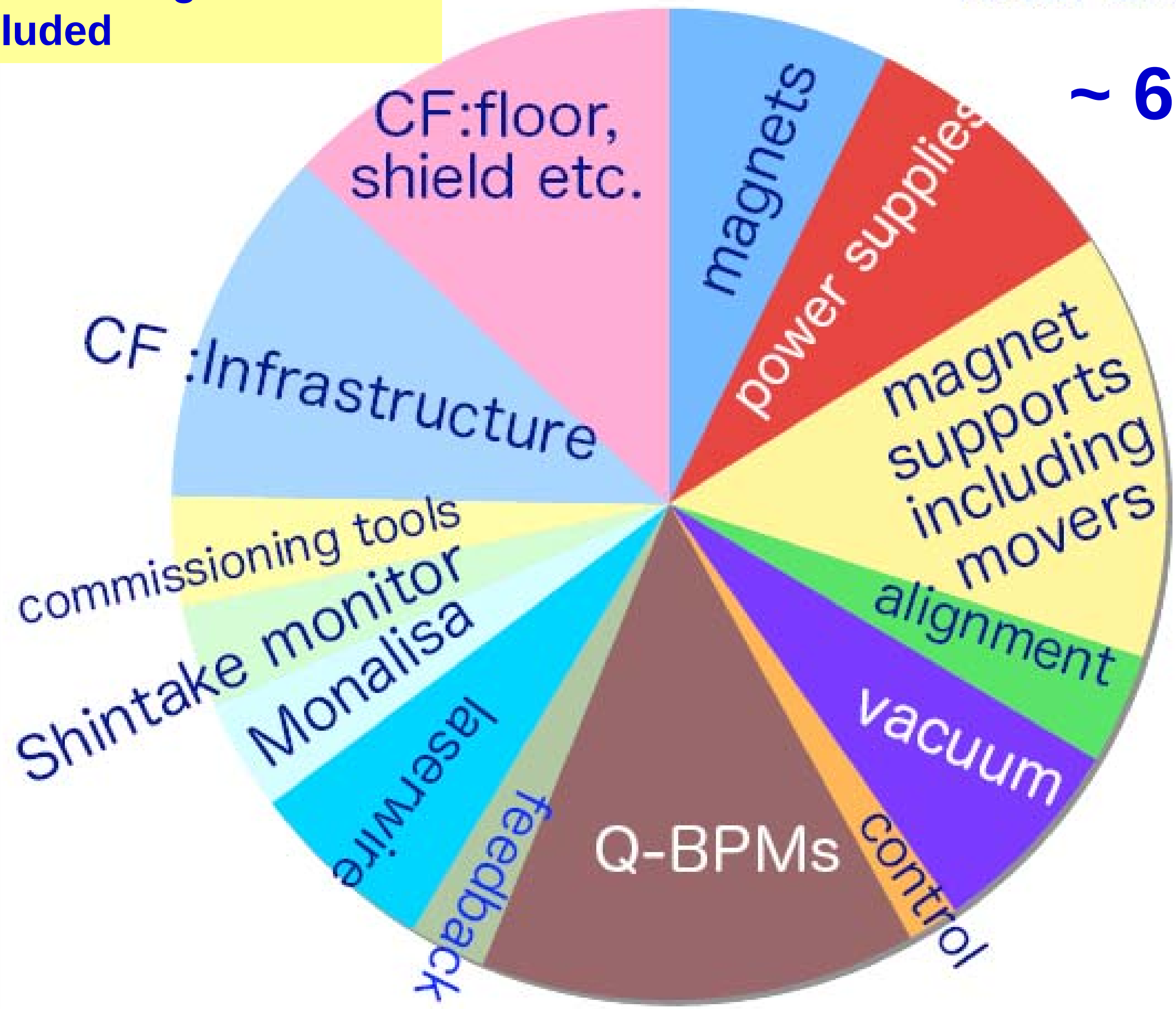
Additional slides

Cost Breakup, May 2010

Multi-OTR & Bkgd Monitors not included

Total 5.7 Oku-yen

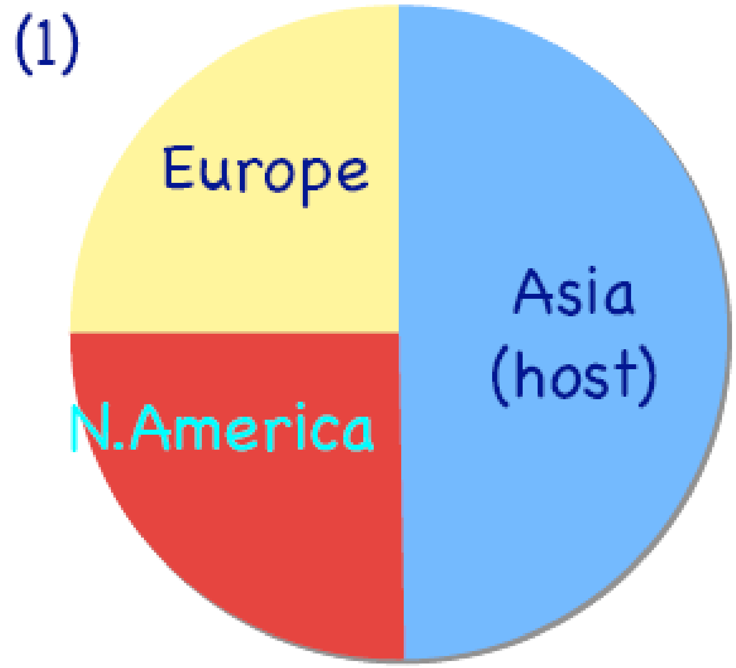
~ 6 M$



May 2010

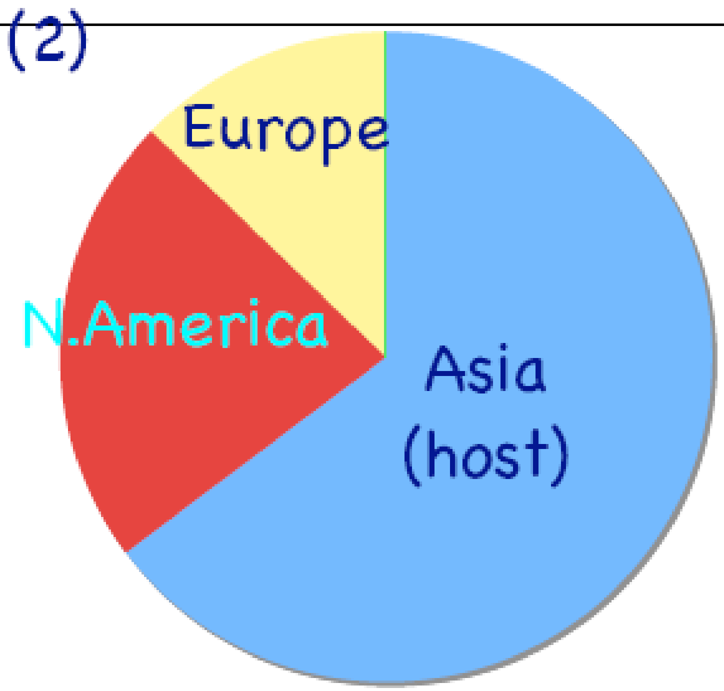
(1) mini-ILC model

equal sharing on the components, while the host country prepares the conventional facility.



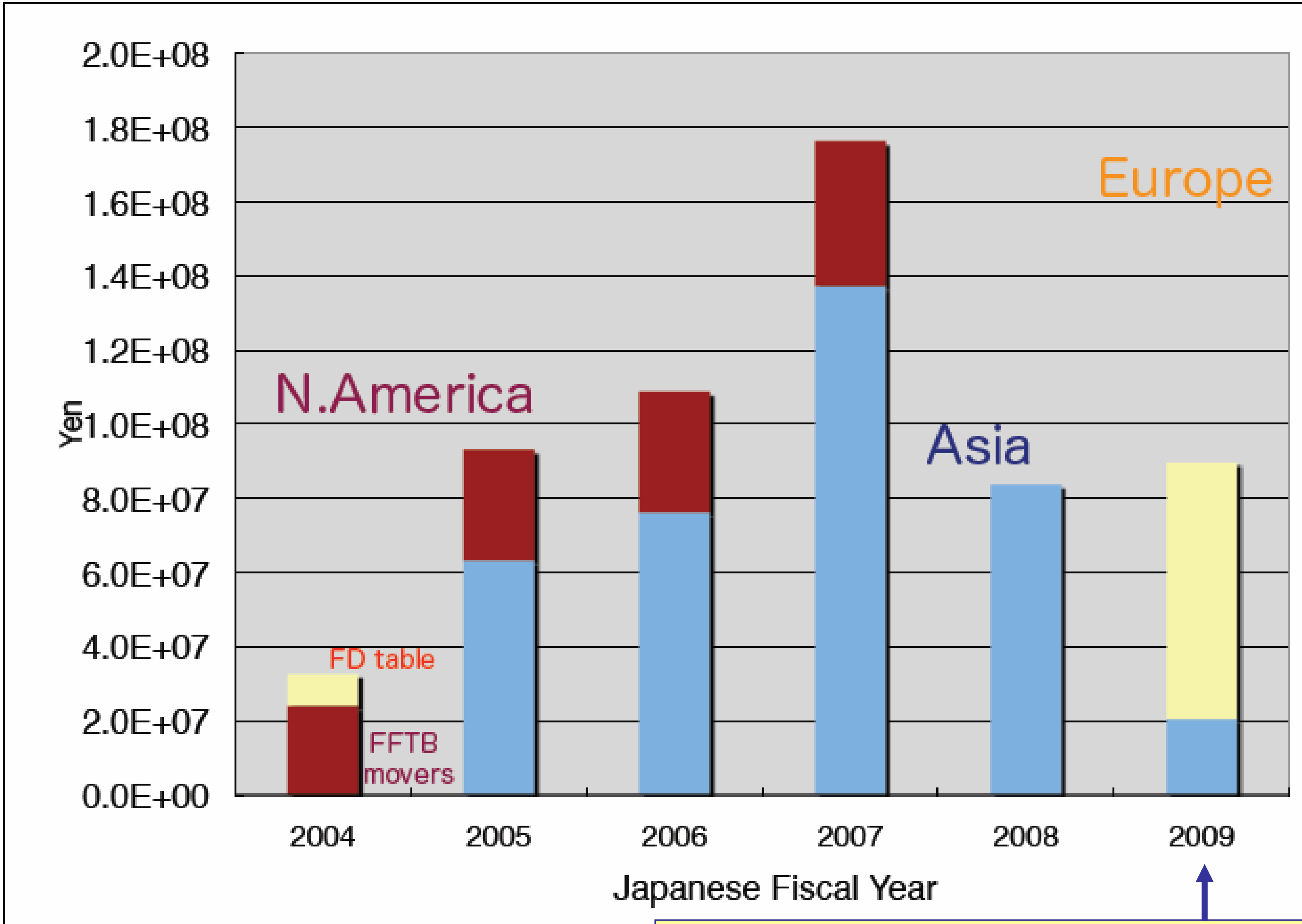
(2) present status

a la Japanese costing rule



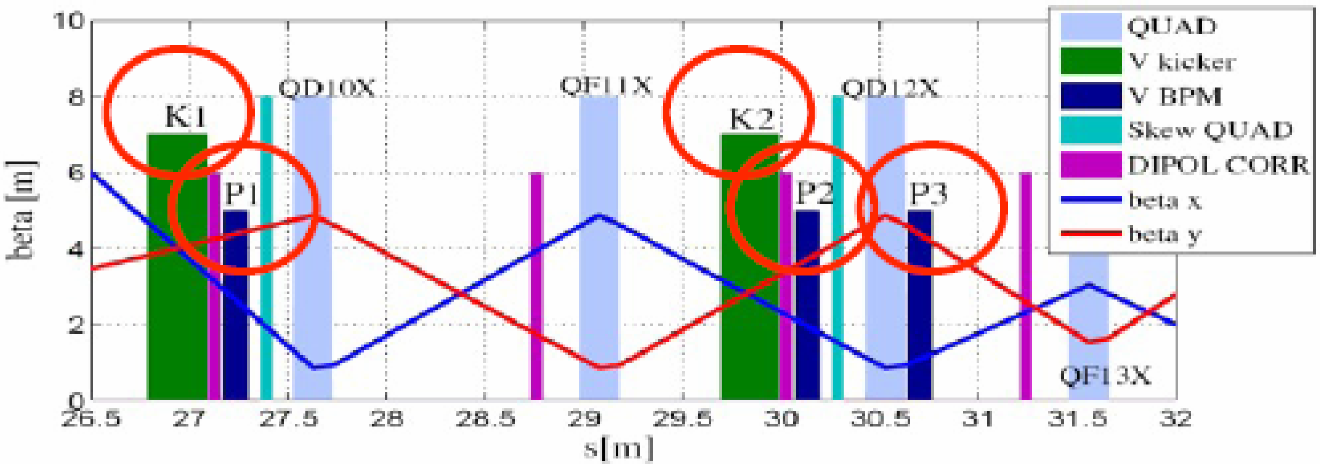
Multi-OTR & Bkgd Monitors not included

May,2010



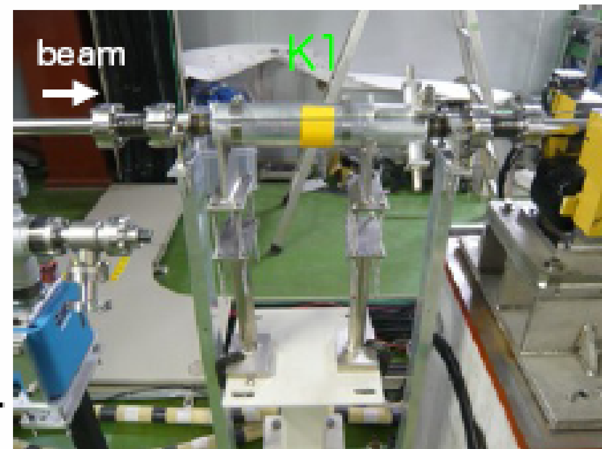
Multi-OTR & Bkgd Monitors to be added

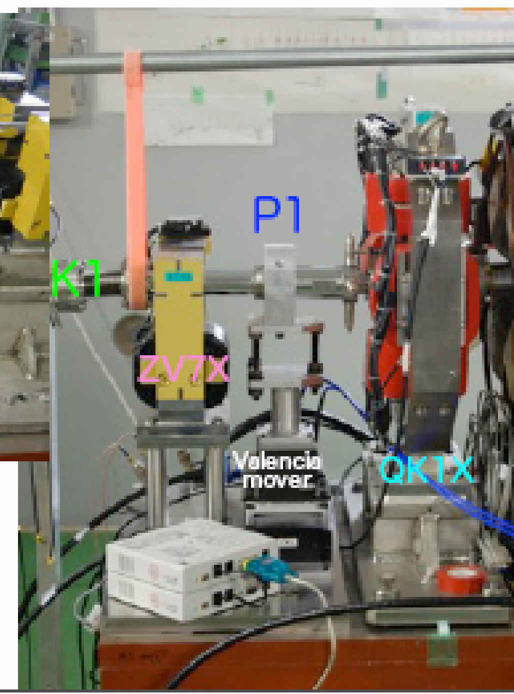
ATF2 FB system: FONT5 (Oxford,KEK)



Dedicated system:

- **2 stripline kickers (K1 , K2) + fast drive amplifiers**

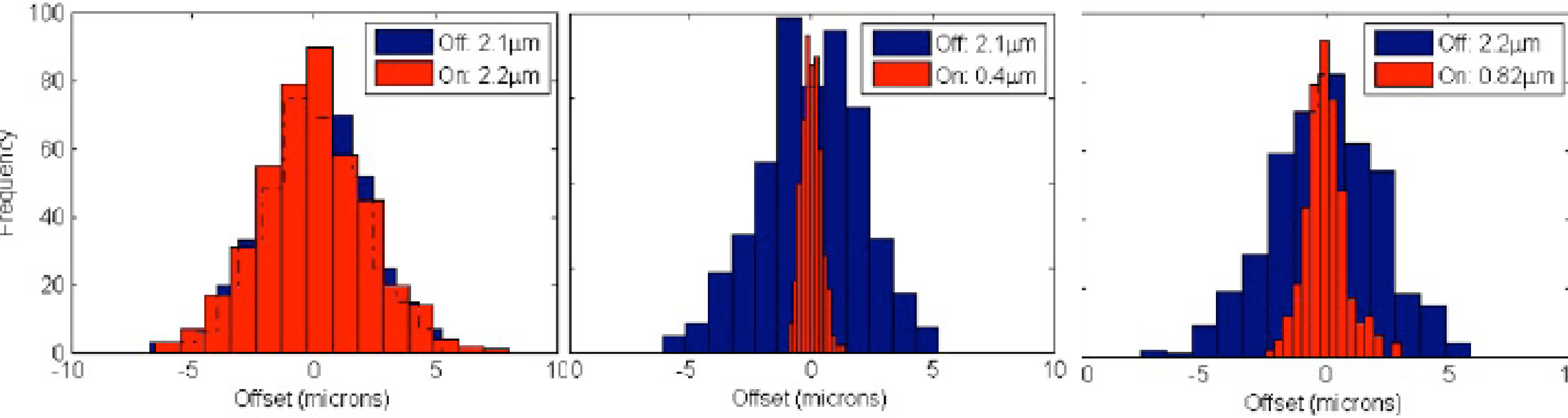




- **3 stripline BPMs(P1,P2,P3) + fast analogue front-end electronics 9-channel digital FB processor**

P2 → K1 loop jitter reduction
(April 16 2010)

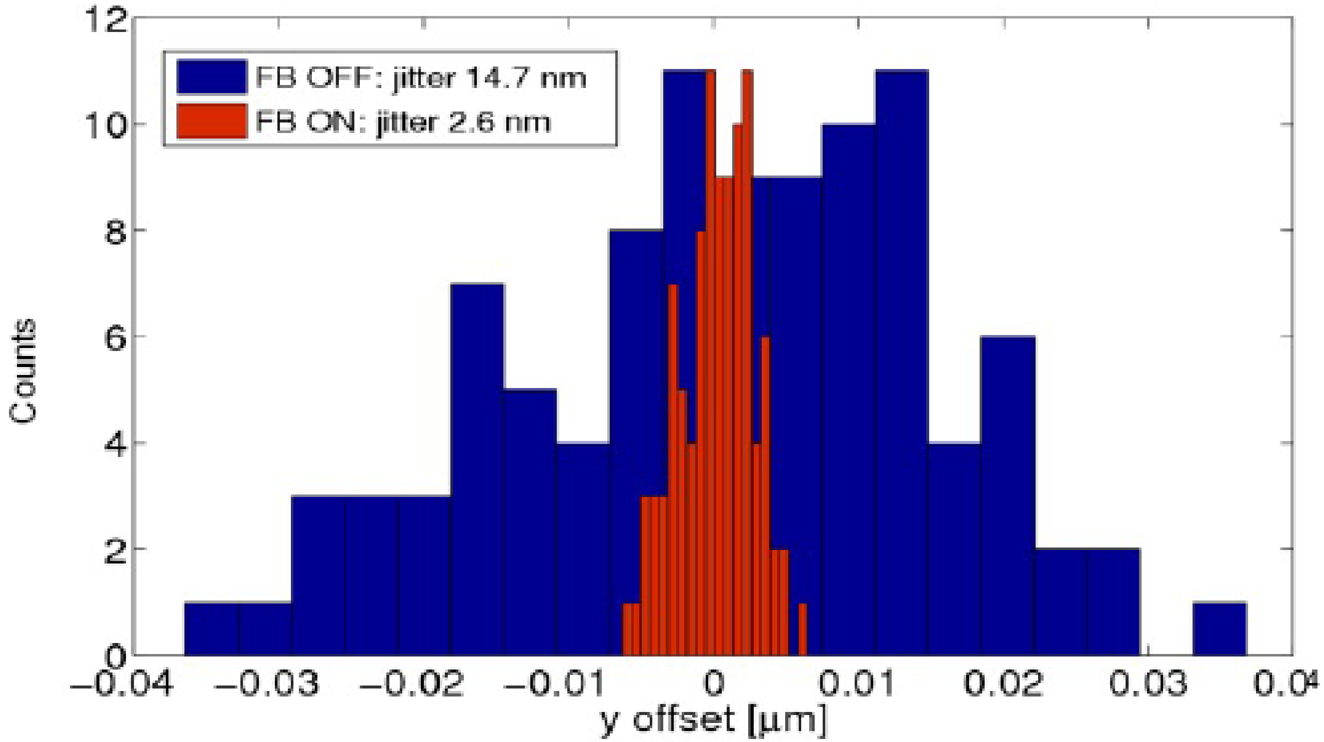
Bunch 1 **Bunch 2** **Bunch 3**



2.1 um → 0.4 um → 0.8 um

Jitter comparison at IP

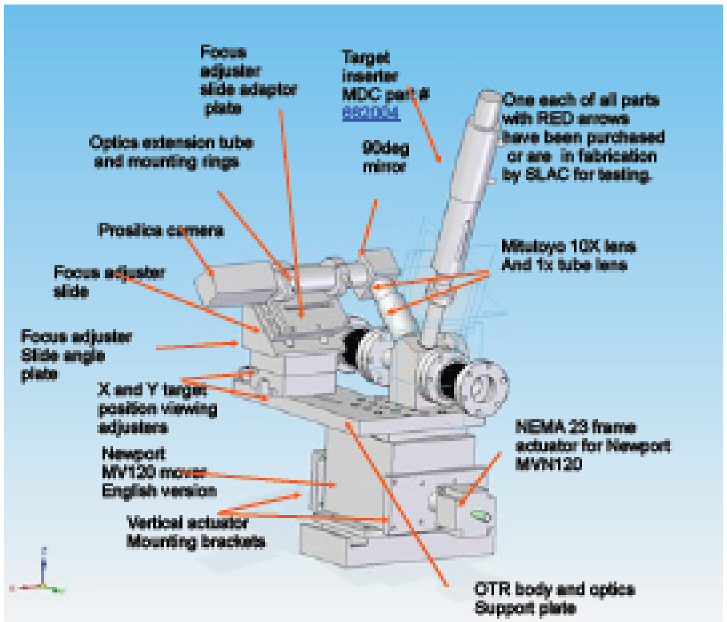
Assuming perfect lattice, no further imperfections (!)



Multi-Optical Transition Radiation System for ATF2

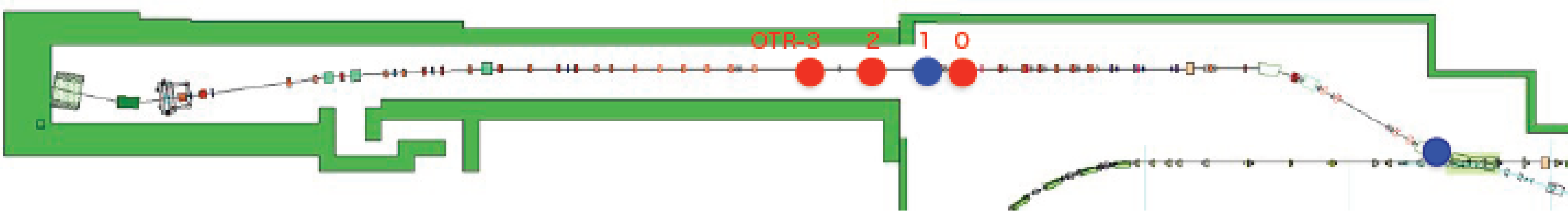
for Fast Emittance Measurement

A.Faus-Golfe, J.Alabau-Gonzalvo, C.Blanch, J.V.Civera, J.J.García Garrigós
IFIC (CSIC-UV)
D.McCormick, G.White, J. Cruz
SLAC
and
KEK team



1. Most parts have been arrived at ATF.
2. Two persons from IFIC visited ATF in March, 2010 and assembled the OTRs on the test stands.
3. Control cables were put between the beamline and a control hut.

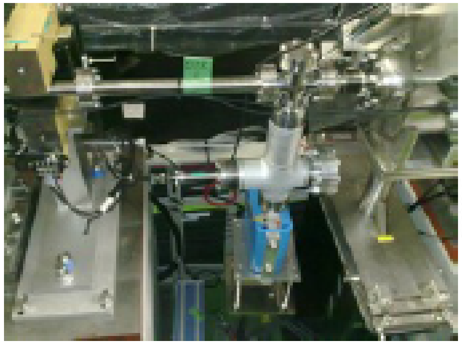
- One of 4 OTRs was installed in May, and 3 OTRs will be installed after IPAC10.

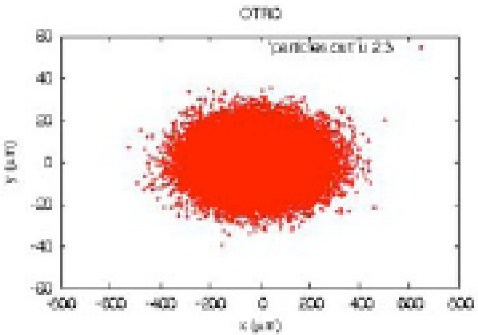


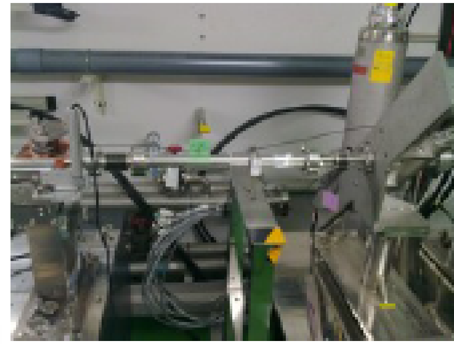
H/W

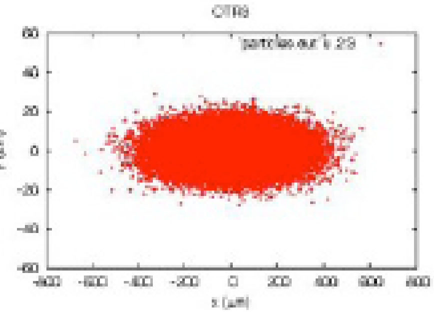
Summary of multi-OTR Status

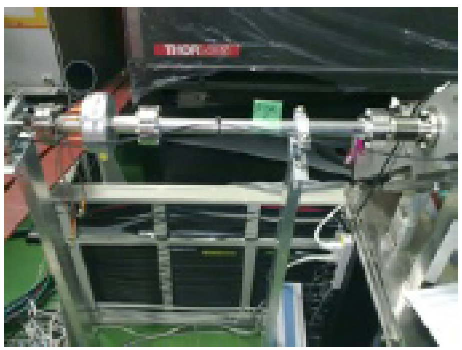
Locations

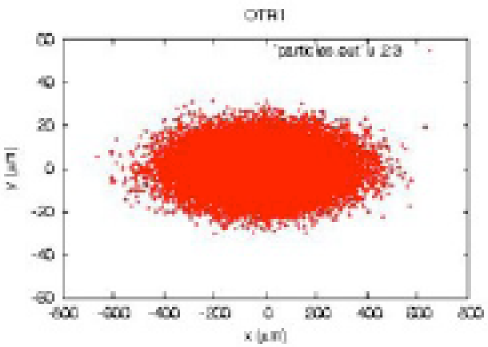


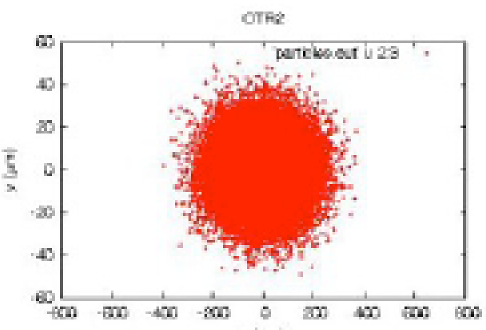










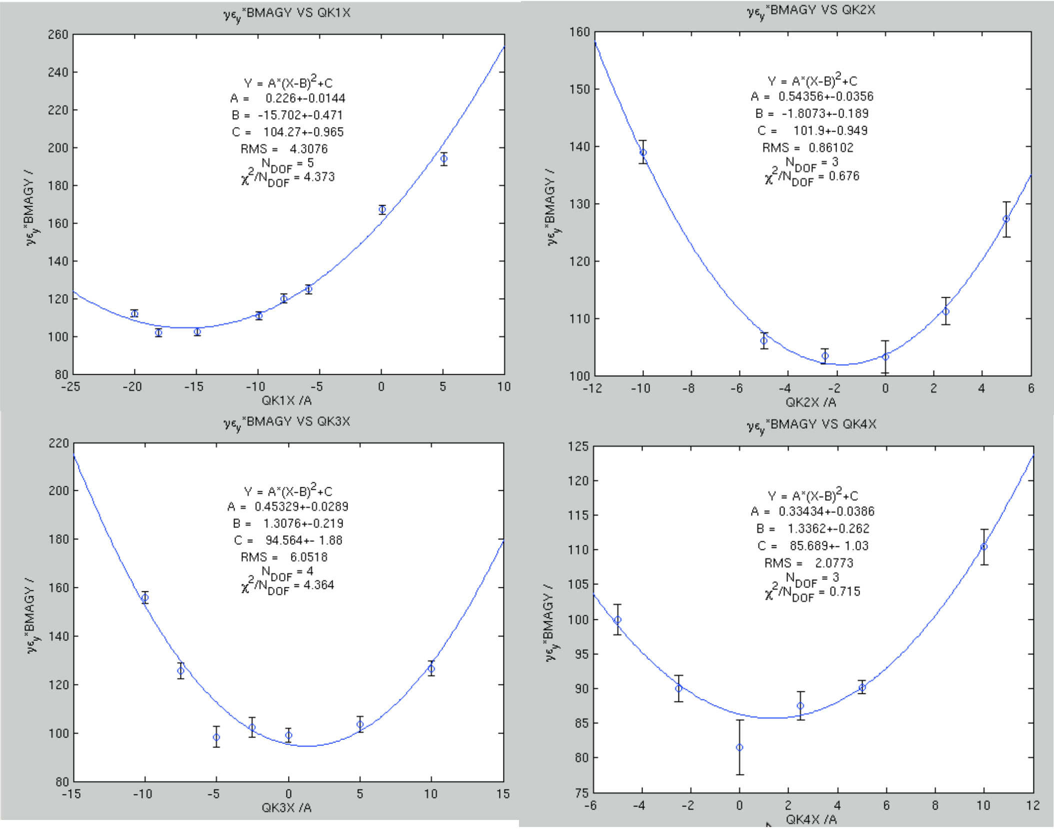


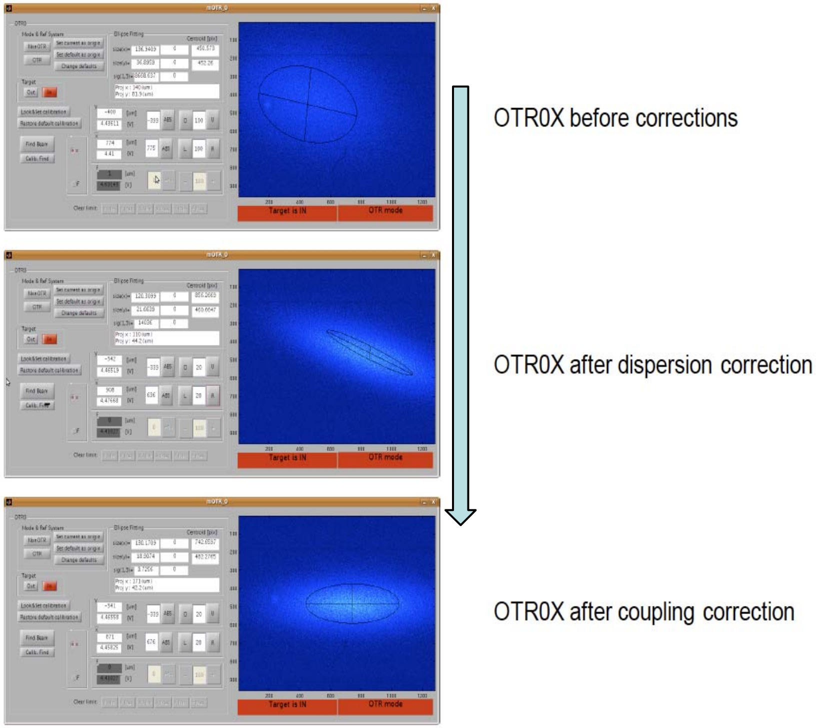
Tracking comparison with Wire Scanners

OTR0 σx: 118 um σy: 9 um	WS0 σx: 82 um σy: 11 um
OTR1 σx: 148 um σy: 8 um	WS1 σx: 157 um σy: 7 um
OTR2 σx: 92 um σy: 12 um	WS2 σx: 88 um σy: 13 um
OTR3 σx: 144 um σy: 7 um	WS3 σx: 151 um σy: 6 um

OTR resolution = 2 μm

Multi-OTR System December 2010: Coupling Correction

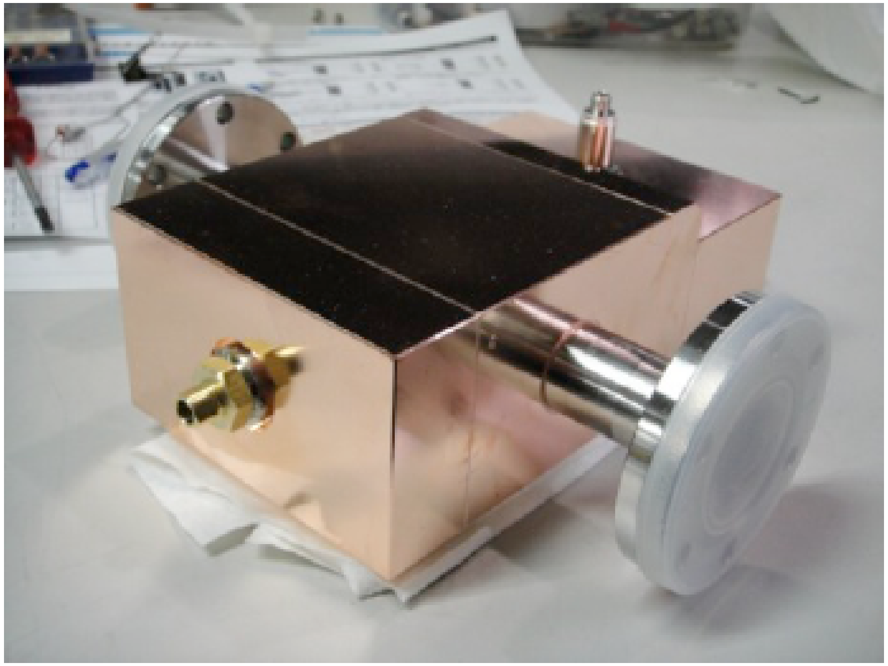




Coupling correction in the EXT achieved by **scanning each of the 4 EXT skew quads**. For each scan the quantity **(vertical normalised emittance)*BMAGY** is plotted and taken the optimal from a parabolic fit.

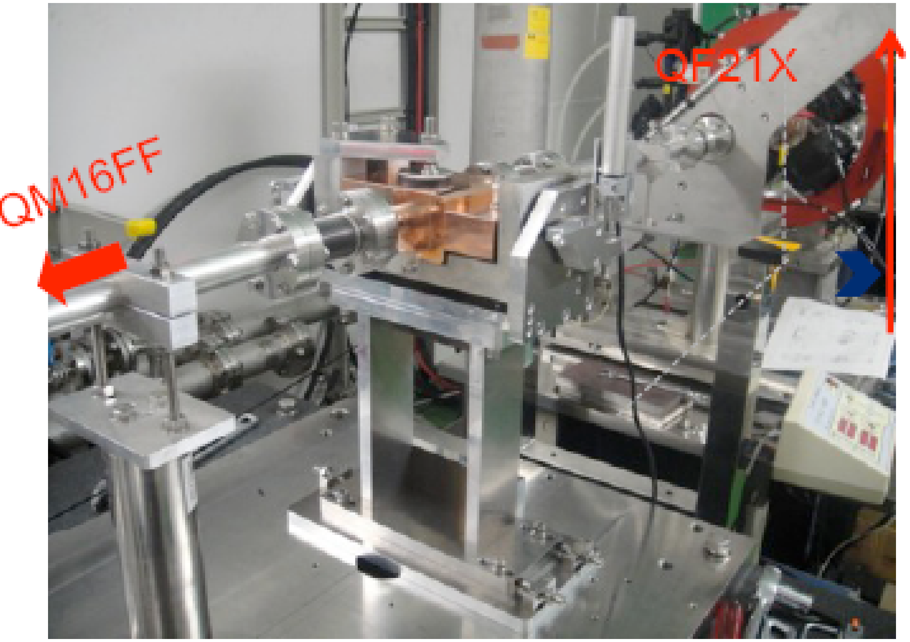
A. Faus-Golfe (IFIC)

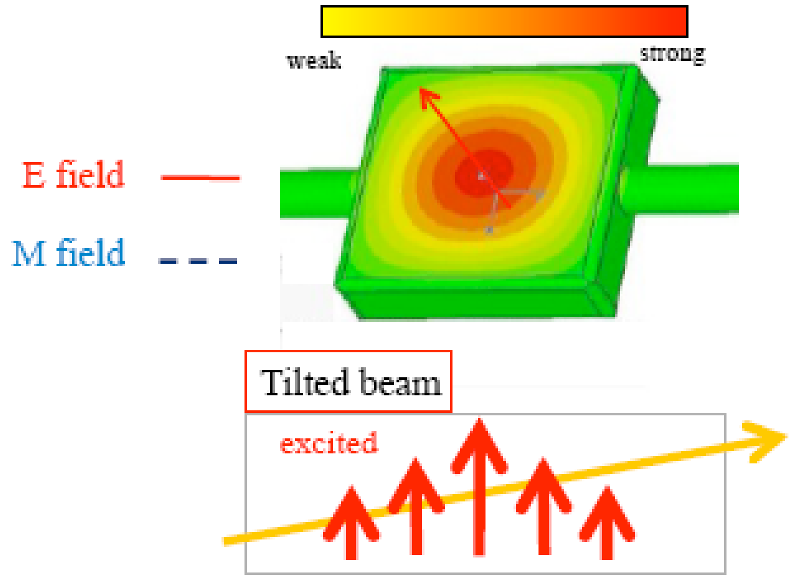
Tilt Monitor : Prototype and tested



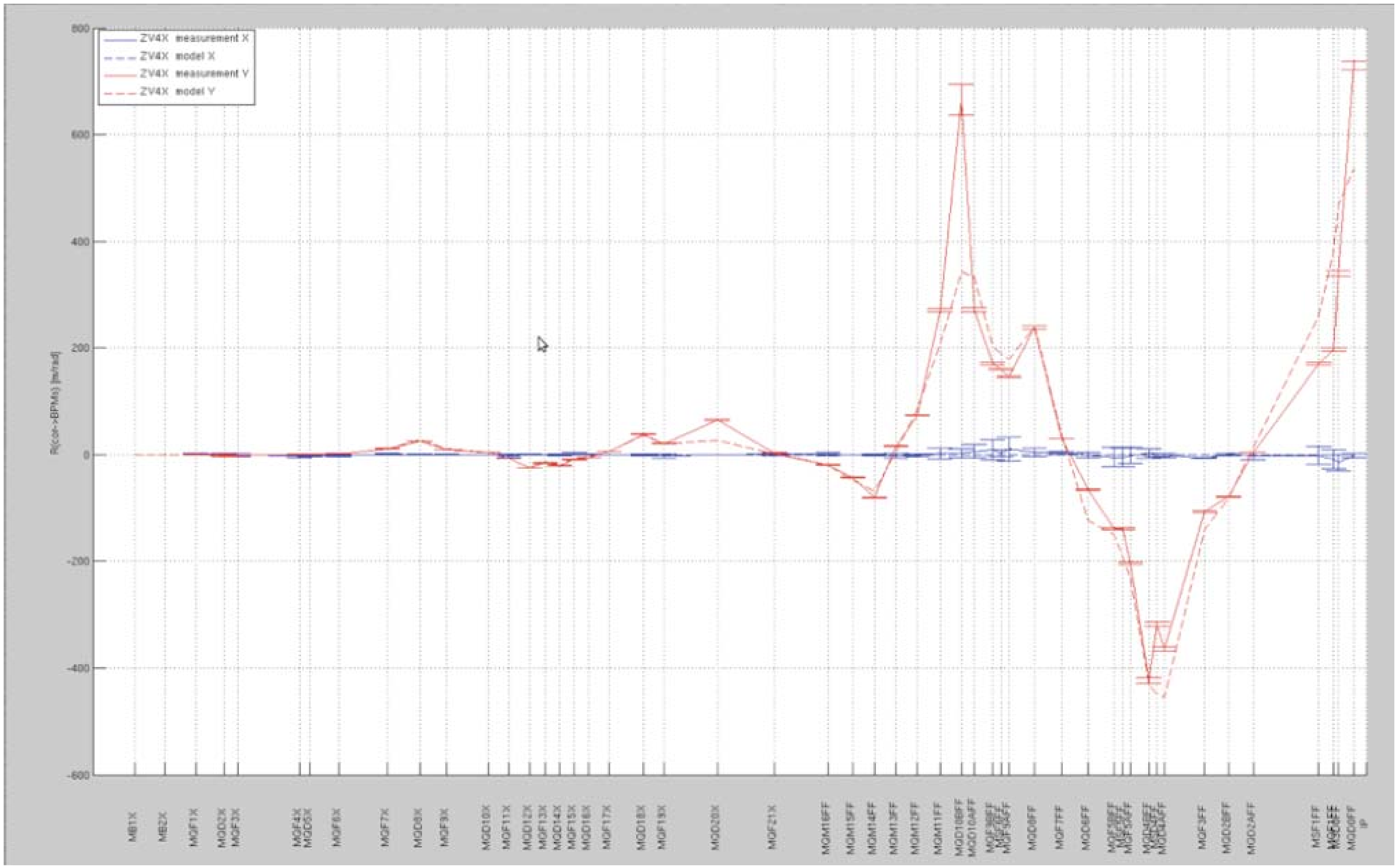
	Parameters measured	Design
frequency	2.8553 GHz	2.856 GHz
Loaded Q	2978	2650
Qwall	10128	10000
Qext	4220	3350
Decay time	156nsec	150nsec

Expected resolution : 30nrad



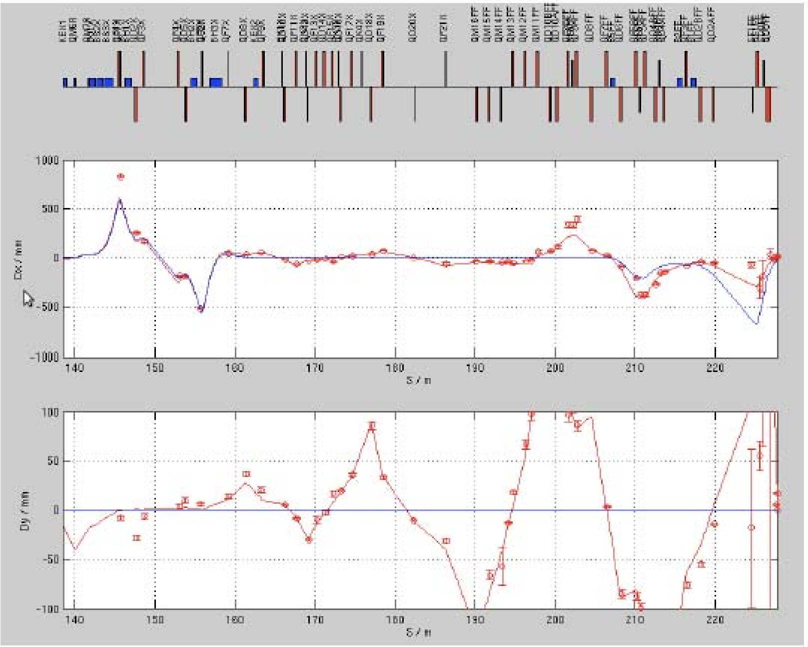


BPM-Model Response



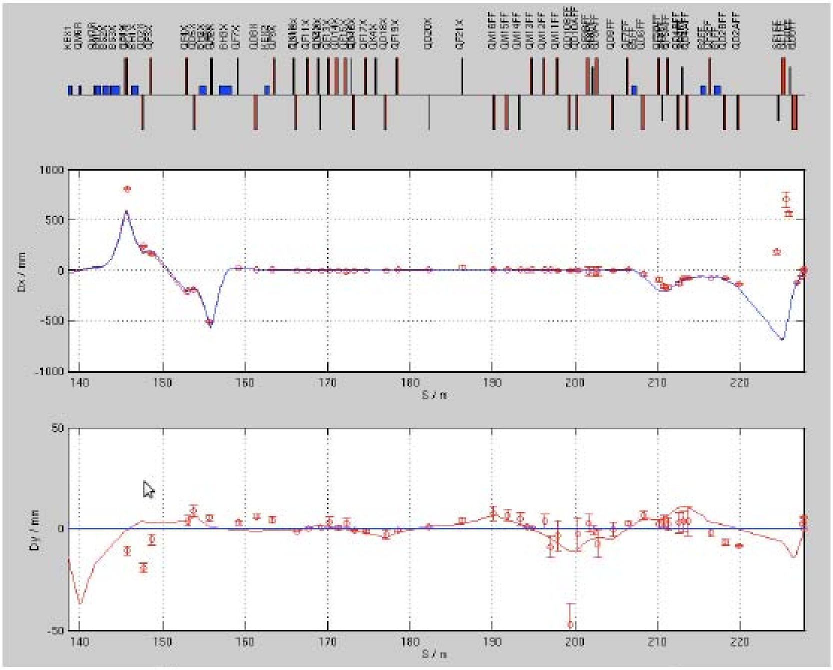
Dispersion Correction

Before Correction



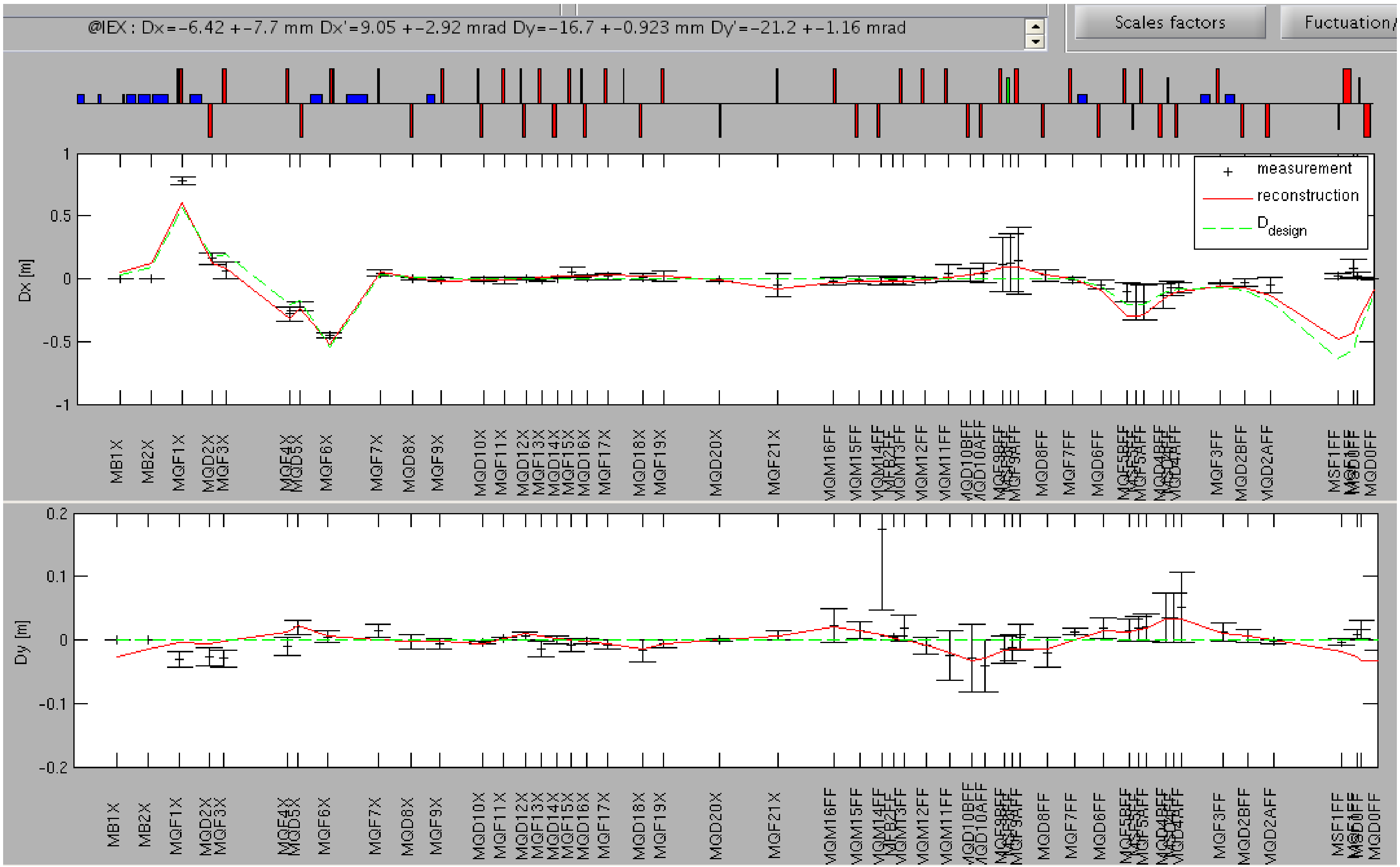
Fitted dispersion values for BEAMLINE element 1923 (IP):
eta x = 6.84 +- 0.134 mm
eta x' = 64.5 +- 2.02 mrad
eta y = 0.405 +- 0.00726 mm
eta y' = -236 +- 3.78 mrad

After Correction



Fitted dispersion values for BEAMLINE element 1923 (IP):
eta x = 0.487 +- 0.152 mm
eta x' = 140 +- 2.31 mrad
eta y = -0.0163 +- 0.00544 mm
eta y' = 12.6 +- 1.93 mrad

Improved dispersion measurement using energy fluctuations reconstructed in extraction line



Y. Rénier (CERN), Jan. 2011

Higgs boson production at threshold

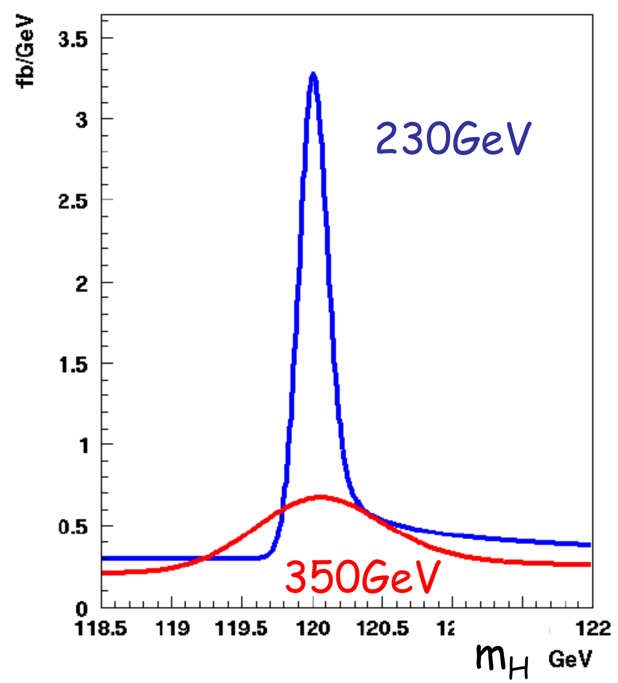
Proposal to run near threshold (√s=230GeV) for a light Higgs (120GeV)

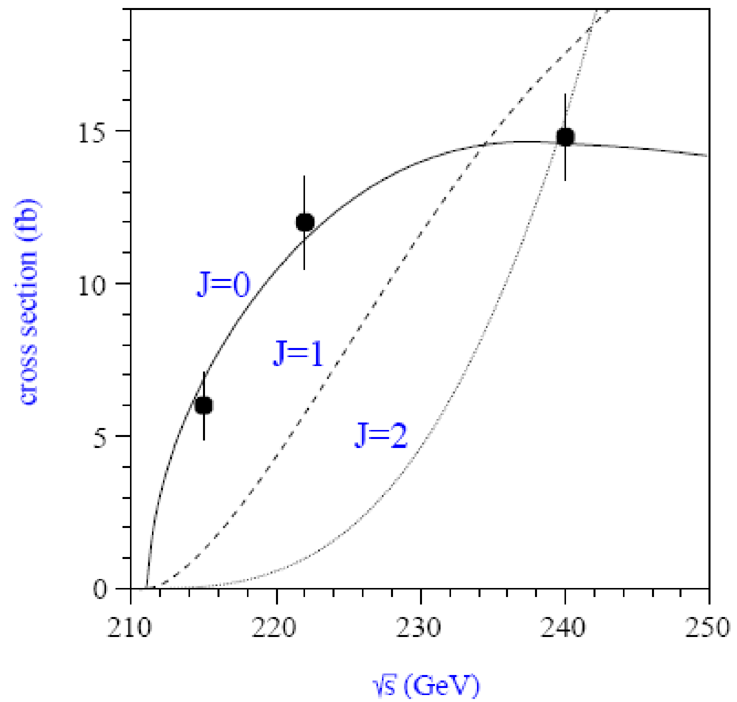
LAL 07-03
F. Richard et al.

<u>Reason</u> → Higgs mass resolution determined from Higgs-strahlung process
e+e- → HZ (Z→ μ+μ-, e+e-) with the recoil mass method:

$$m_H^2 = s + m_Z^2 - 2E_Z\sqrt{s}$$

is the best due to
- better momentum resolution of m±, e± at low energy
- larger cross section at 230GeV than at e.g. 350GeV





Comparison of Results

ZH->μμX channel

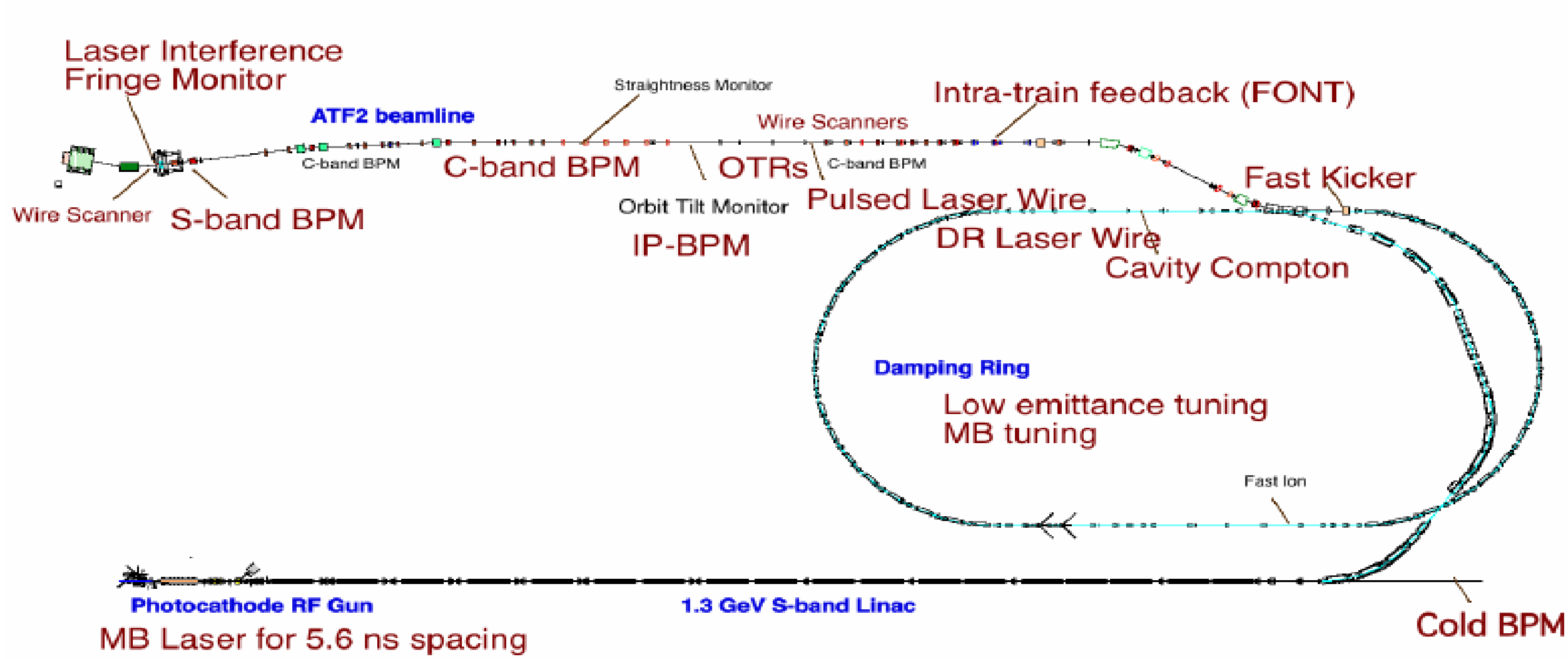
Polarization: e^-: -80% e^+: +30%

Beam Par	$\mathcal{L}_{\rm int}$ (fb^{-1})	ϵ	S/B	M_H (GeV)	σ (fb) ($\delta\sigma/\sigma$)
RDR 250	188	55%	62%	120.001 ± 0.043	11.63 ± 0.45 (3.9%)
RDR 350	300	51%	92%	120.010 ± 0.087	7.13 ± 0.28 (4.0%)
SB2009 w/o TF 250	55	55%	62%	120.001 ± 0.079	11.63 ± 0.83 (7.2%)
SB2009 w/o TF 350	175	51%	92%	120.010 ± 0.110	7.13 ± 0.37 (5.2%)
SB2009 w/TF 250	68	55%	62%	120.001 ± 0.071	11.63 ± 0.75 (6.4%)
SB2009 w/TF 350	250	51%	92%	120.010 ± 0.092	7.13 ± 0.31 (4.3%)
NB w/o TF 250	175	61%	62%	120.002 ± 0.032	11.67 ± 0.42 (3.6%)
NB w/o TF 350	200	52%	84%	120.003 ± 0.106	7.09 ± 0.35 (4.9%)
NB w/TF 250	200	63%	59%	120.002 ± 0.029	11.68 ± 0.40 (3.4%)
NB w/TF 350	250	51%	89%	120.005 ± 0.093	7.09 ± 0.31 (4.4%)

Comparison:

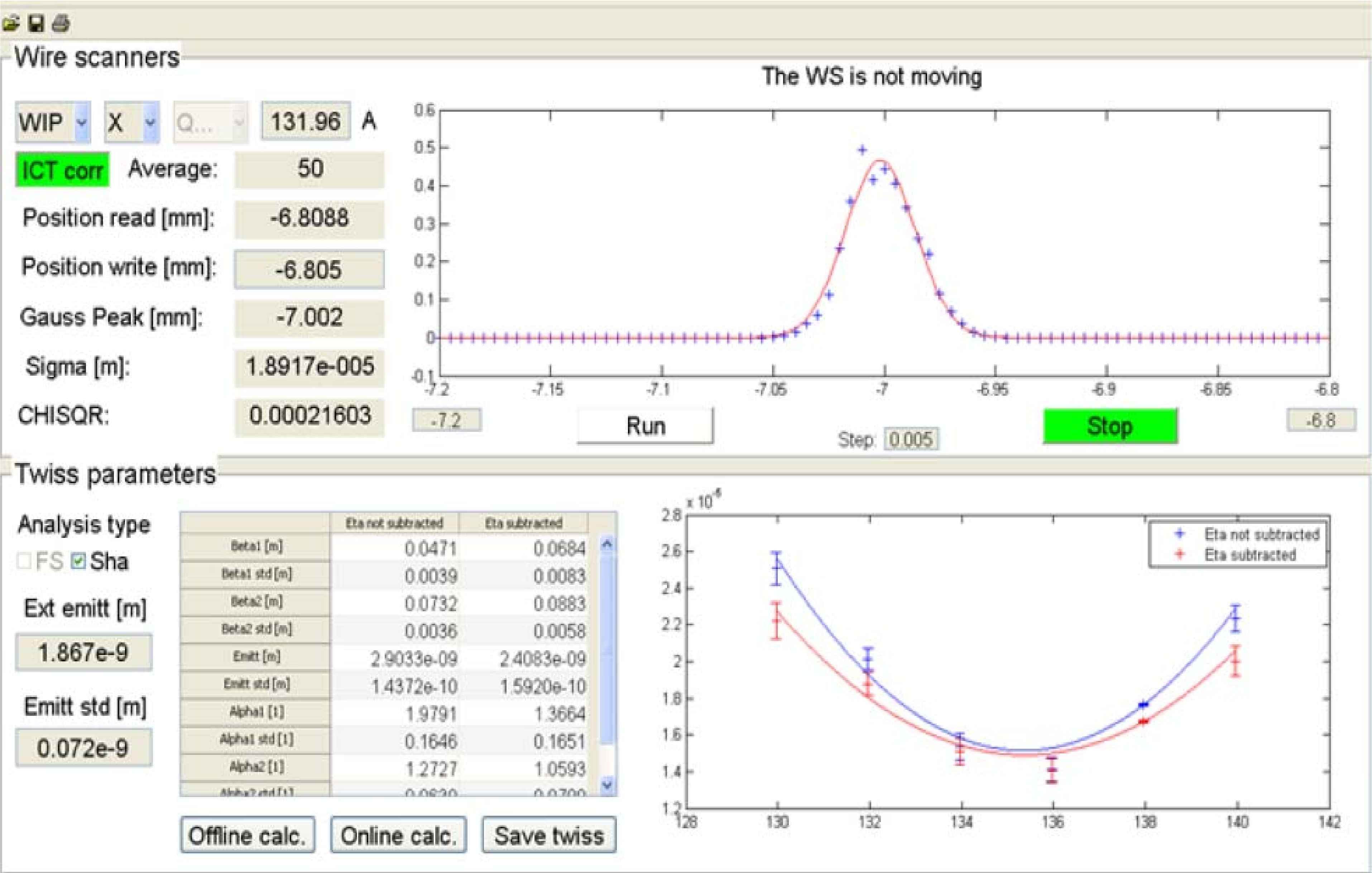
- New Baseline design @ 250 GeV gives the best results: better than the RDR design
- Importance at the low energy: Even with 4 times smaller luminosity (68fb^{-1}/250fb^{-1}), SB2009 @ 250 GeV can still give better result on the Higgs mass measurement than SB2009 @ 350GeV.
- 350 GeV center of mass energy gives better signal over background (S/B)

Instrumentation preparation and R&D

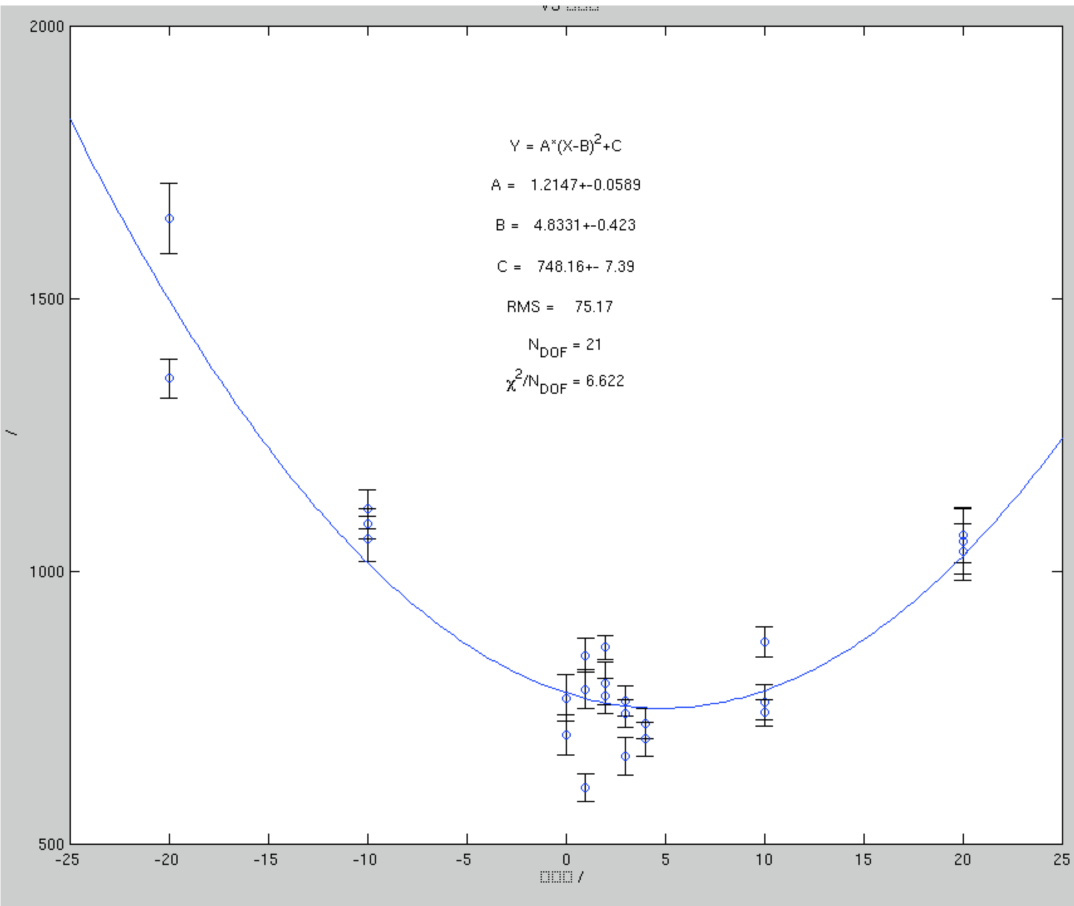


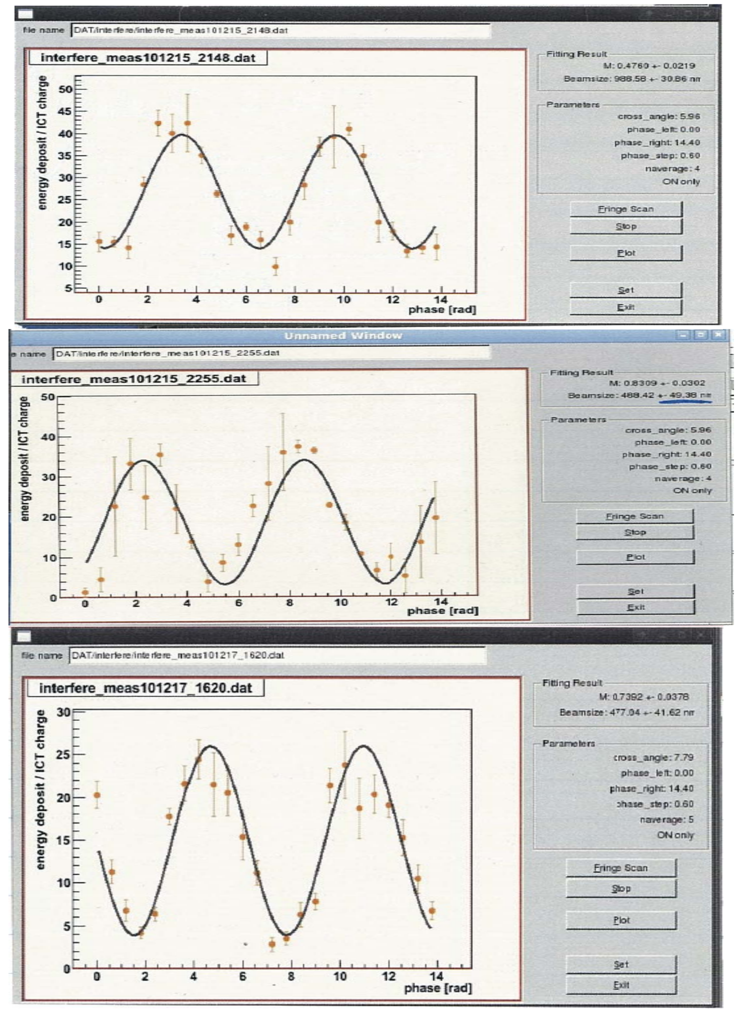
- Stripline BPMs, C and S band cavity BPMs, BSM “Shintake”, wire-scanners
  - ➔ in most part commissioned and operating satisfactorily (few improvements underway)
- IP-cavity BPMs, tilt monitor, OTR profile, LW, FONT
  - ➔ actively studied as R&D in preparation for goal 2 (and 1)
- Background monitors: PLIC optical fibre + dedicated instrumentation
  - ➔ simulation effort coupled to measurements needed to assess ultra low β^* feasibility

Automated IP waist scans & Twiss measurements

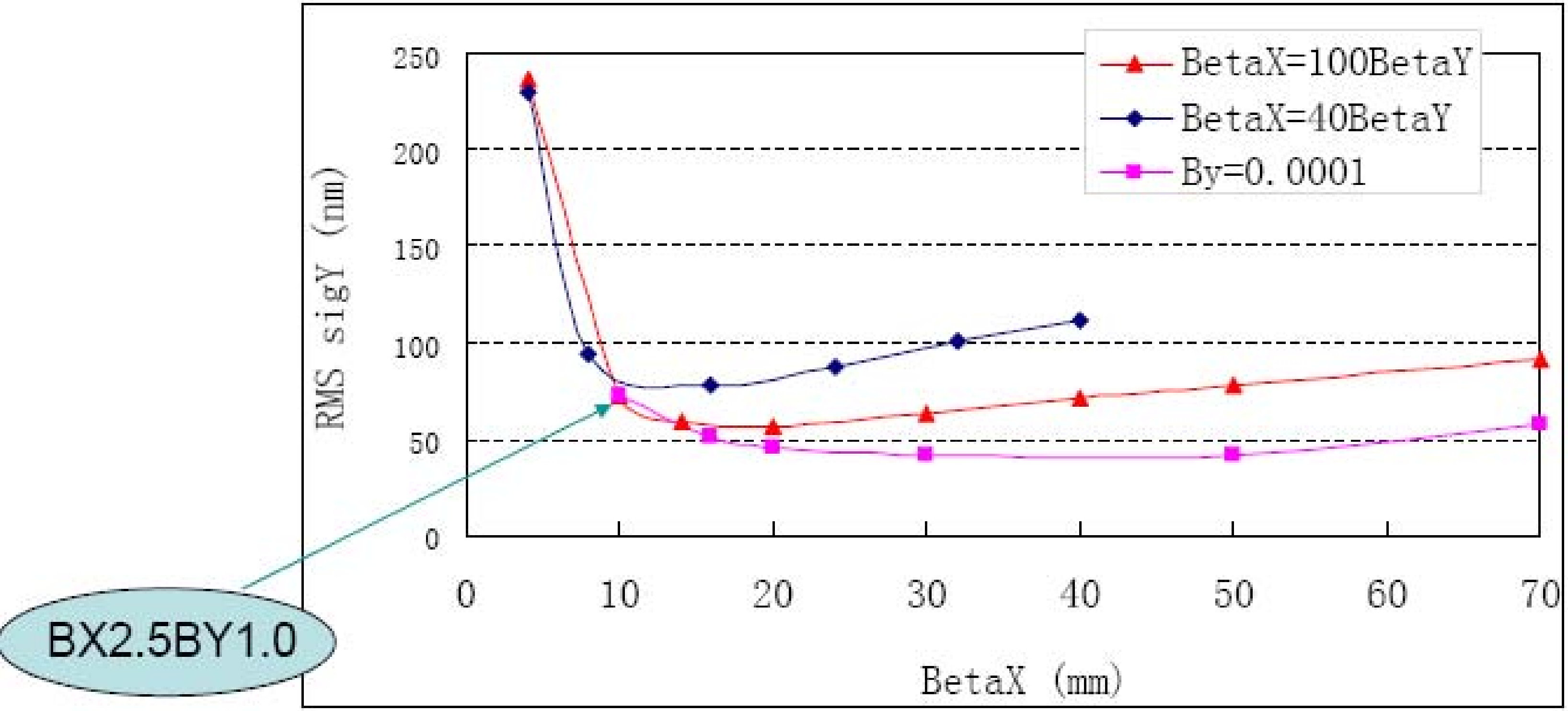


IPBSM Scans (alpha_y)





betaX* optimization



• When betaX*>1 cm, the effect of multpoles become weaker.

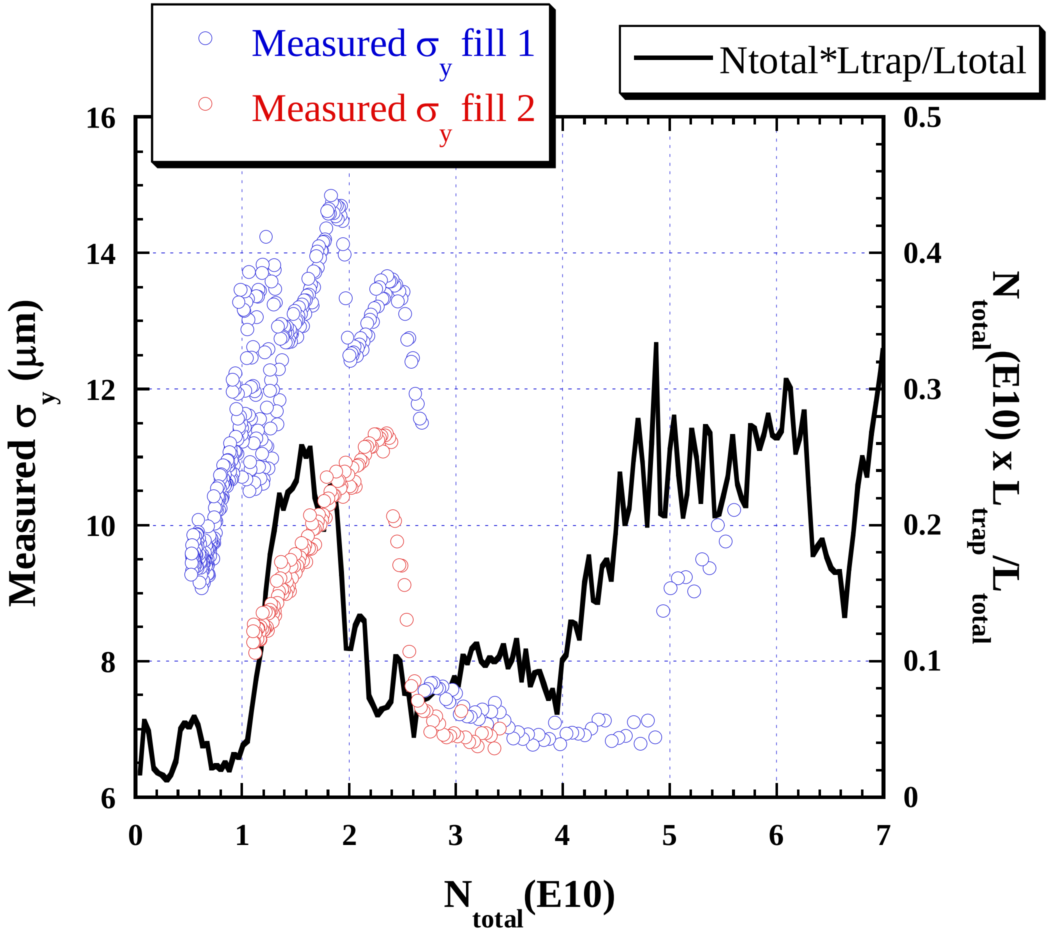
• A new lattice has be designed using MADX and MAPCLASS, namely BX2.5BY1.0.

D. Wang (IHEP), ATF2 project meeting, Jan. 2011

Compare measurement and ion trap calculation

instability observed beyond 6 bunches / train

Preliminary



3 train, 7 bunch/train

K. Kubo (KEK), ATF2 project meeting, Jan. 2011