ATF2 beam stability & future plans

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ATF2 "Goal 2" preparations
Plan for studies of ground motion impact
Plan / ideas / issues for lower IP beam sizes
Plan for beam halo measurement and collimation
Plan for non-linear QED studies

CLIC workshop, CERN, Geneva 31 January 2013

ATF / ATF2 Goals

- ❑ **Very small damping ring vertical emittance**
  - from ~ 10 pm → 4 pm (achieved !) → 1-2 pm

- ❑ **Small vertical beam size** *"goal 1"*
  - achieve σ_y ~ 37 nm (cf. 5 / 1 nm in ILC / CLIC)
  - validate "compact local chromaticity correction"

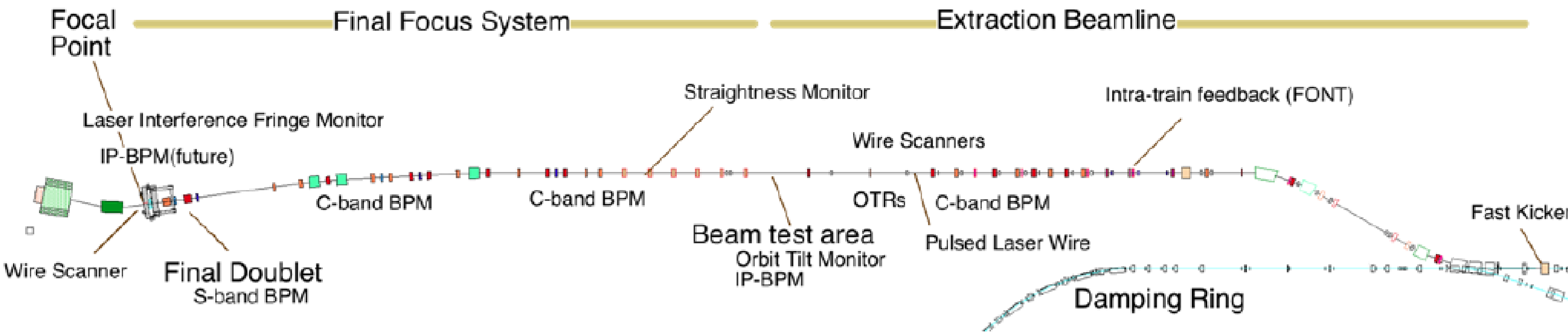
- ❑ **Stabilization of beam center** *"goal 2"*
  - down to ~ 2nm (~ 10nm for "goal 1")
  - bunch-to-bunch feedback (~ 300 ns, for ILC)

- ❑ **R&D on nanometer resolution instrumentation**

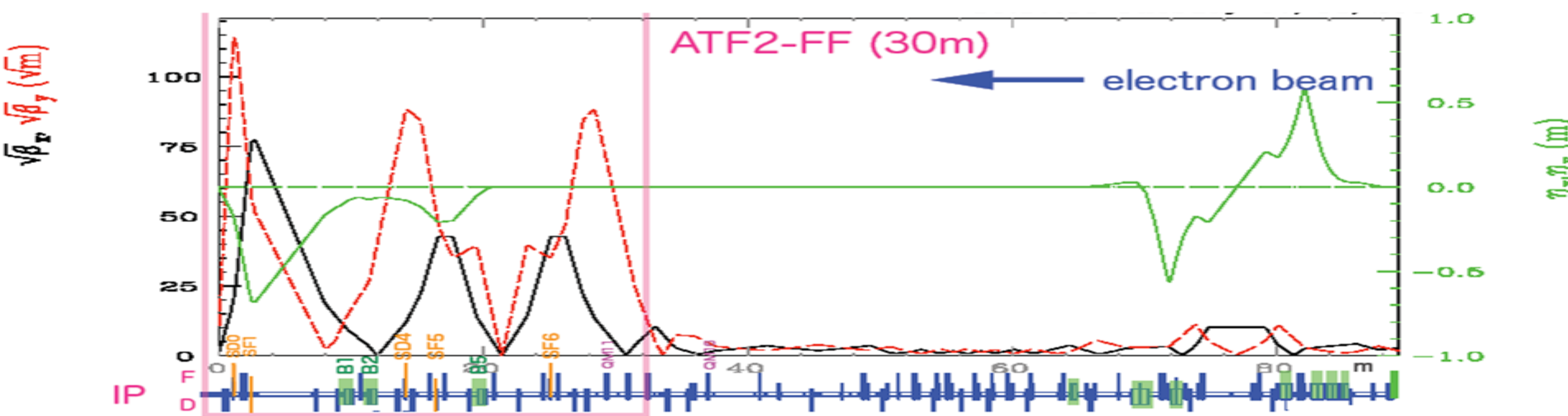
- ❑ **Train young accelerator scientists on "real system"**
  - maintain expertise by practicing operation

→ *open & unique facility*

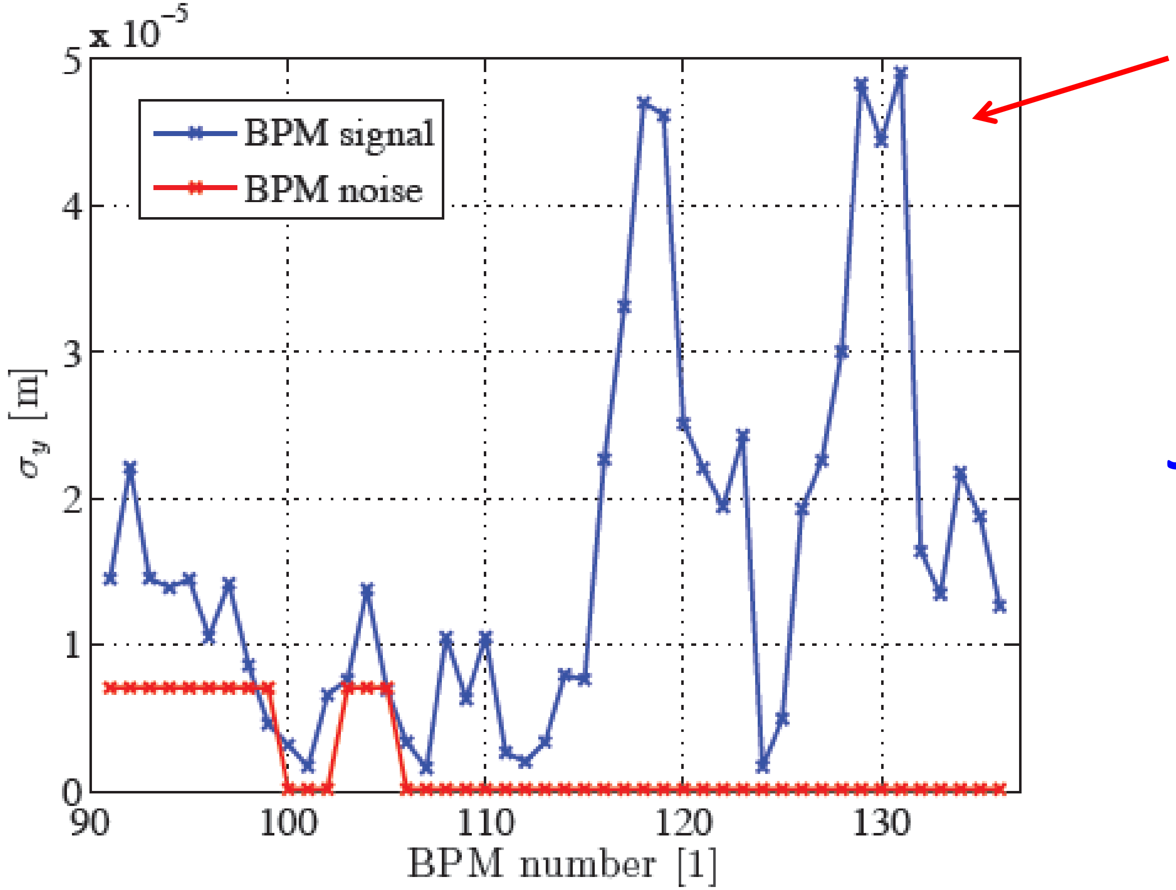
Issues for beam stability



Ground motion at Final Doublet and other high β quadrupoles	Kicker	Damping Ring



Signal and noise levels



Vertical beam size ~ 350 μm

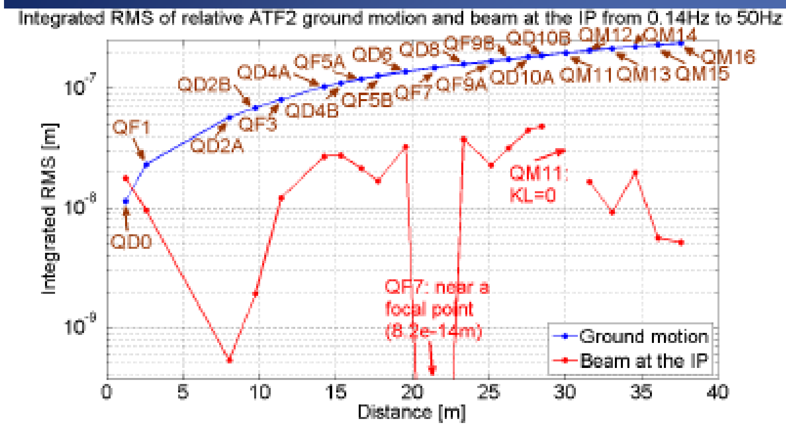
Jitter ~ 15 %

Scaling: expect @ IP ~ 6 nm ???

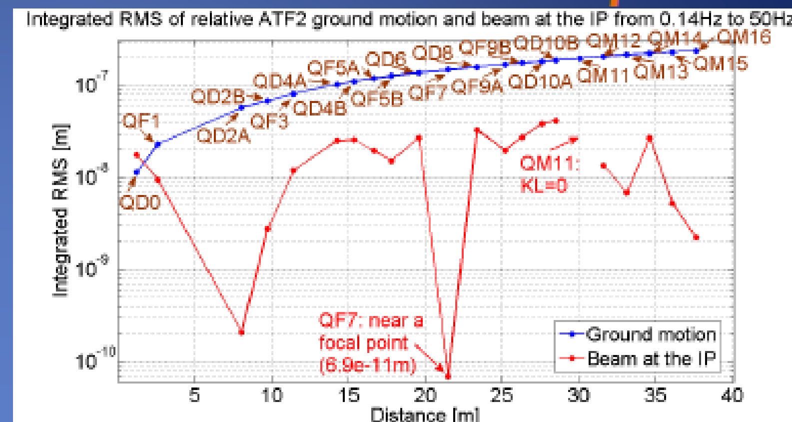
Expected IP motion *from each quad* using KEK site data-fitted GM model

Beam relative motion to IP due to jitter of each QFF_i

With the ATF2 nominal lattice



With the CLIC ultra-low β lattice



- ✓ Increase of relative ground motion to the IP with increase of distance
- ✓ Beam Relative Motion to IP from 0.1Hz to 50Hz due to motion of:

Beam RM due to:	Nominal	Ultra-low β
QD0/QF1FF (nm)	17.7/9.6	17.7/9.5
QD10A/B (nm)	44.6/48.1	38.7/41.8

→ **Low value:** high β but good coherence with the IP

→ **High value:** due to high β/coherence loss

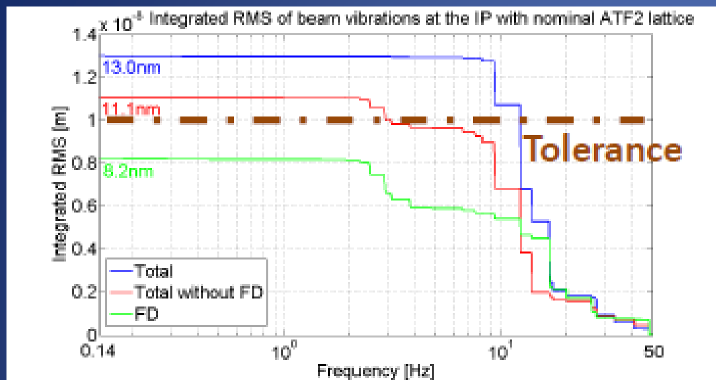
→ Necessity to look at beam relative motion due to jitter of all quads

B. Bolzon, ATF2 project meeting, December 2009

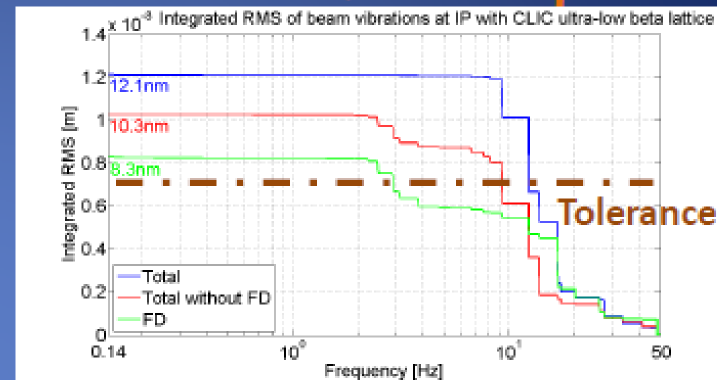
Expected IP motion *with ALL quad* using KEK site data-fitted GM model

Beam relative motion to IP due to jitter of all QFF_i

With the ATF2 nominal lattice



With the CLIC ultra-low β lattice



✓ Beam relative motion to IP from 0.1Hz to 50Hz due to jitter of:

Beam RM due to (nm):	Nominal	Ultra-low β
Both QD0/QF1	8.2	8.3
All FF quads except FD	11.1	10.3
All FF quads (tolerance)	**13.0 (10)**	**12.1 (6.8)**
Tolerance achievement	**Almost OK**	**Factor 1.8 above**

Both QD0/QF1: Low: D/F compensation

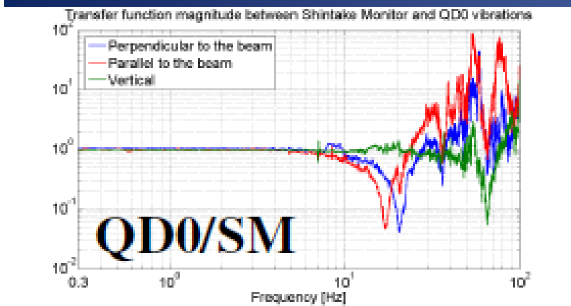
All FF quads except FD / All FF quads: low: lucky compensation

✓ It was checked changing 4 times the generator parameters (slightly and not slightly) that this lucky compensation is robust and not fortuitous

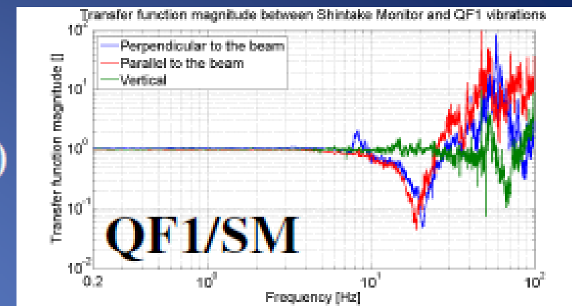
B. Bolzon, ATF2 project meeting, December 2009

Uncertainties in KEK site data-fitted GM model at short distances ??

✓ Vibration measurements of transfer function between FD and SM

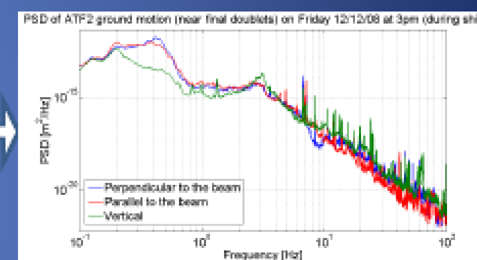


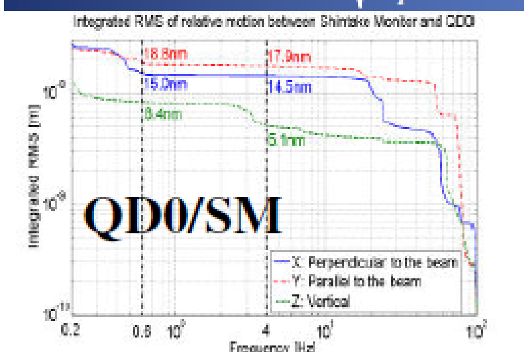
H(k)= Vibration Transfer Function (TF) between FD and SM

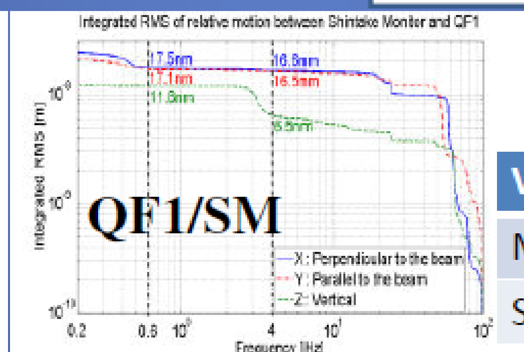


✓ Relative motion calculation by taking the representative GM

$$RMS_{int\ y-x}(k) = \sqrt{\sum_{k_1}^{k_2} [H(k)-1][H^*(k)-1] PSD_x(k) \Delta f}$$







Vertical RM	QD0/SM	QF1/SM
Measured	5.1nm	6.5nm
Simulated	11.4nm	23.1nm

- Below 4Hz: overestimation due to small error on TF measurements (around 1%) amplified by two huge peaks of GM (0.2-0.4Hz and 3.5Hz)
- Difference between measurements and simulations: due to underestimation of correlations by simulations below 4m

B. Bolzon, ATF2 project meeting, December 2009

Nano-meter Beam Position Stabilization

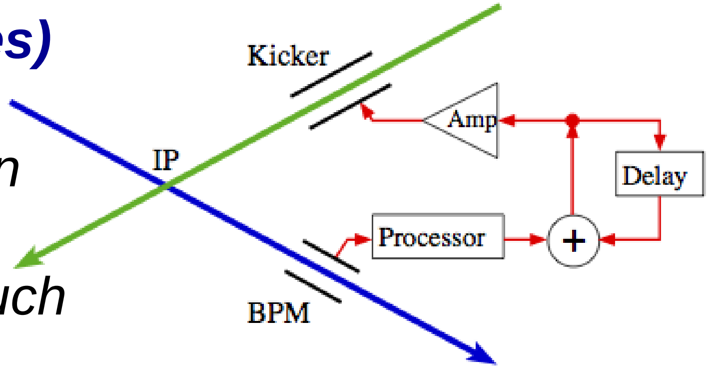
Oxford / KNU / RHUL / KEK

One of the challenging goals for ATF2

1. *achieving of the 37 nm vertical beam size*
2. ***Stabilize a beam in a few nanometer level at the IP.***

FONT (Feedback On Nano-Second Timescales) has been developed

- *as a prototype of a beam-based intra-train feedback system for IP of LCs.*
- *Correct the impact of fast jitter sources such as the vibration of magnets.*



FONT1~FONT3

Analogue feedback system for very short bunch-train LCs.

Latency FONT3(ATF) 23 ns.

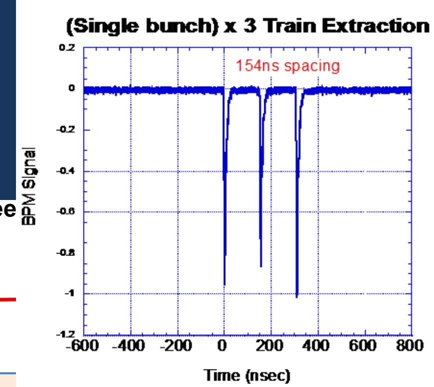
FONT4 & FONT5 (ATF2)

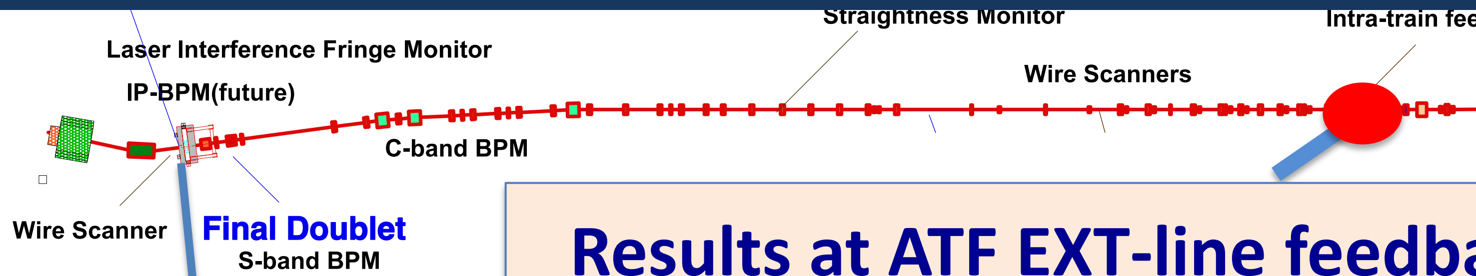
Digital feedback system for long bunch-train ILC.

allow the implementation of more sophisticated algorithms

Phil Burrows, Glenn Christian, et al. (Oxford)

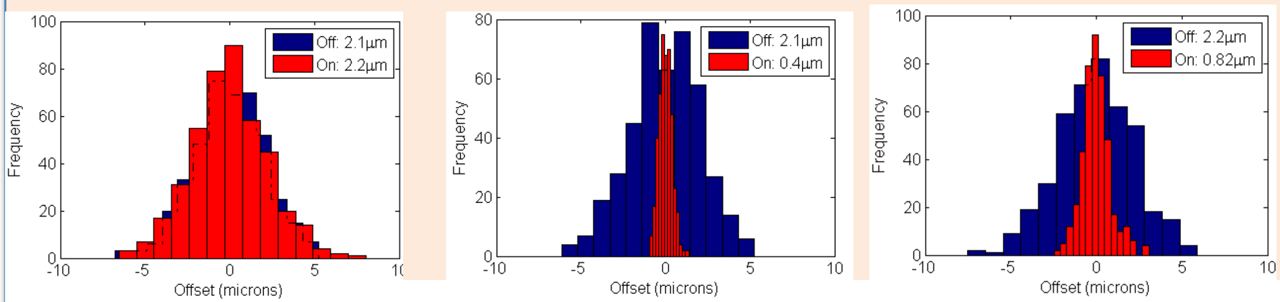
Results of the fast feedback





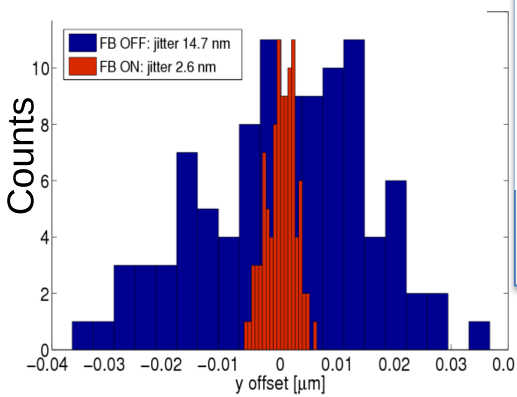
Results at ATF EXT-line feedback

Bunch 1 | Bunch 2 | Bunch 3



2.1 um → 0.4 um → 0.8 um

Jitter comparison at ATF2-IP (simulation)



Assuming perfect lattice, no further imperfections (!)

Simulation

FB OFF: jitter 14.7 nm

FB ON: jitter 2.6 nm

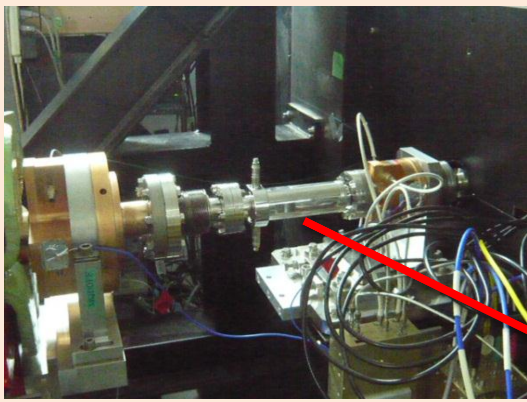
FONT + IP-BPM

"for ATF2 Goal 2"

Preparation for the nm-beam position stabilization IPBPM+FONT

FONT-kicker

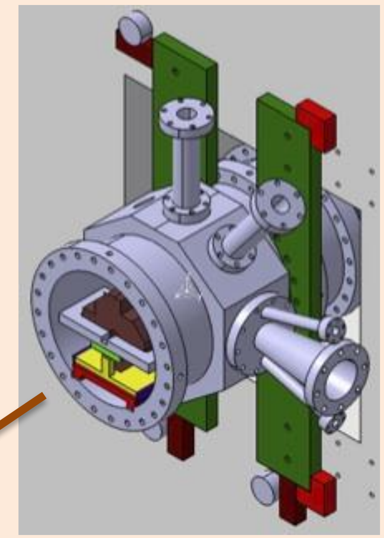
Installed near the ATF2-IP.
Tested in June 2012.

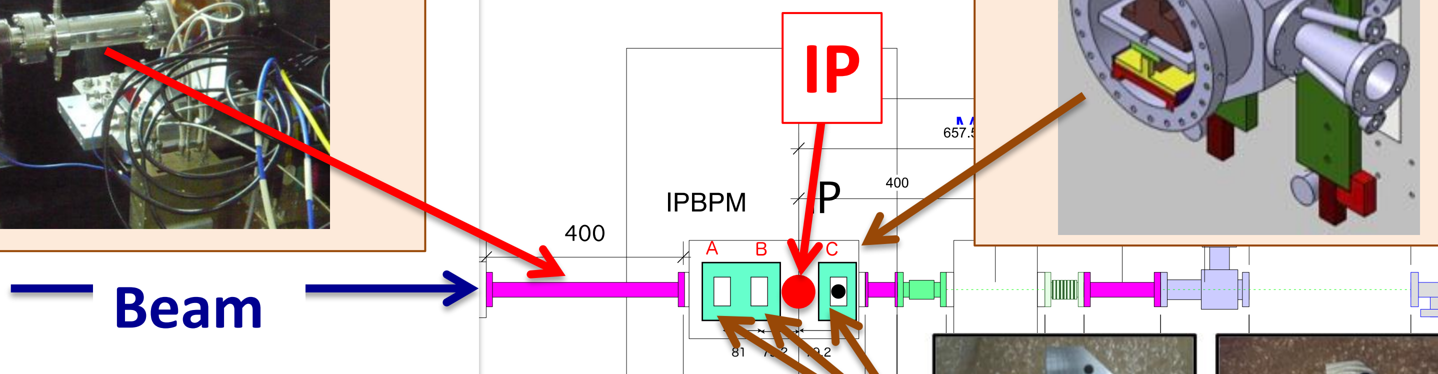


Setup will be fully assembled at IP in spring 2013.

New vacuum chamber

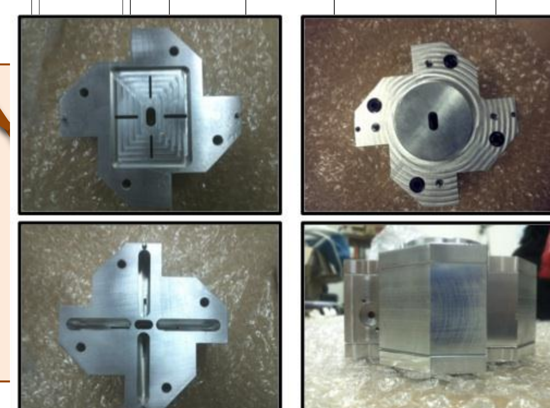
Precise positioning of IPBPM triplet. Fabrication at LAL.



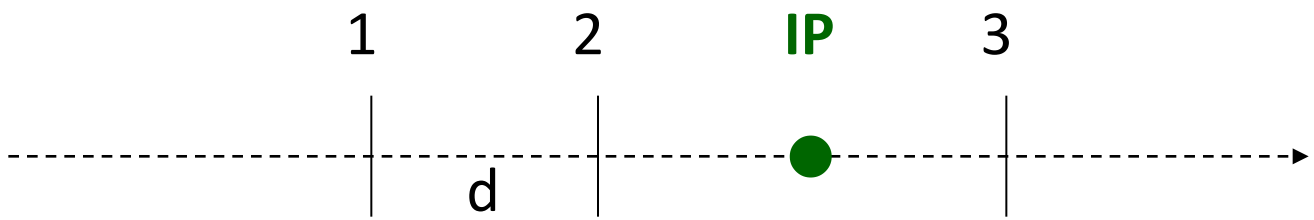


IPBPM

Triplet of the Low-Q cavity BPM. Fabricated by KNU.
Sensitivity tested at ATF LINAC.
Readout electronics tested at ATF2.



Required precision on relative IP-BPM scale factors depends on beam parameters



$d \sim 0.1$ m

$\varepsilon_y \sim 12$ pm

$\sigma_{jitter} / \sigma \sim$ 10%

$\theta_{IP} = (y_2 - y_1) / d$

$y_{IP} = 2\, y_2 - y_1$

ξ = calibration error of 1 relative to 2

$\rightarrow\ 2\, y_2 - y_1 \sim\ y_{IP} + 2\, \xi\, \theta\, d$

$\beta \sim 1$ m (e.g. diagnostic section)

$\theta_{jitter} \sim (\varepsilon / \beta)^{0.5}\, d\, (\sigma_{jitter} / \sigma) \sim 10^{-7}$ rad $\rightarrow\ \xi \sim 10^{-2}$ for 1 nm error

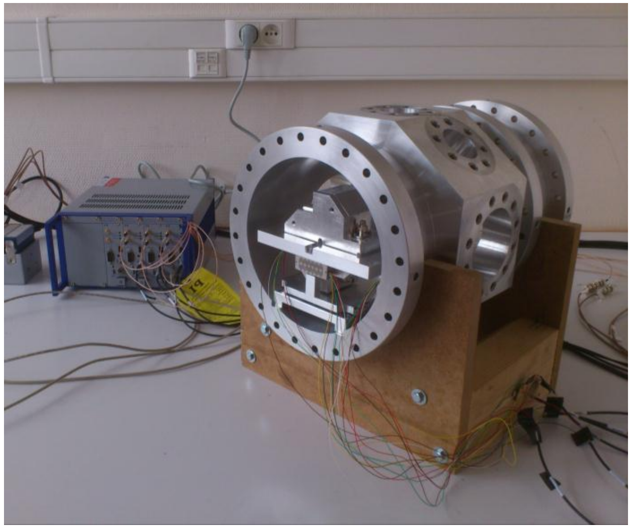
$\beta \sim 10^{-4}\ 10^{-3}$ m (interaction point : nominal 10 x optics)

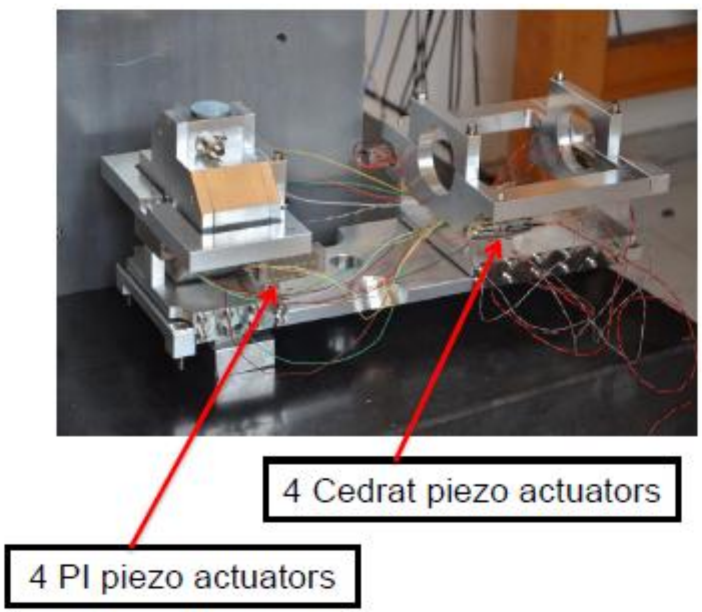
$\theta_{jitter} \sim (\varepsilon / \beta)^{0.5}\, d\, (\sigma_{jitter} / \sigma) \sim 10^{-9}$ rad $\rightarrow$ **$\xi \sim 10^{-4}$ for 1 nm error**

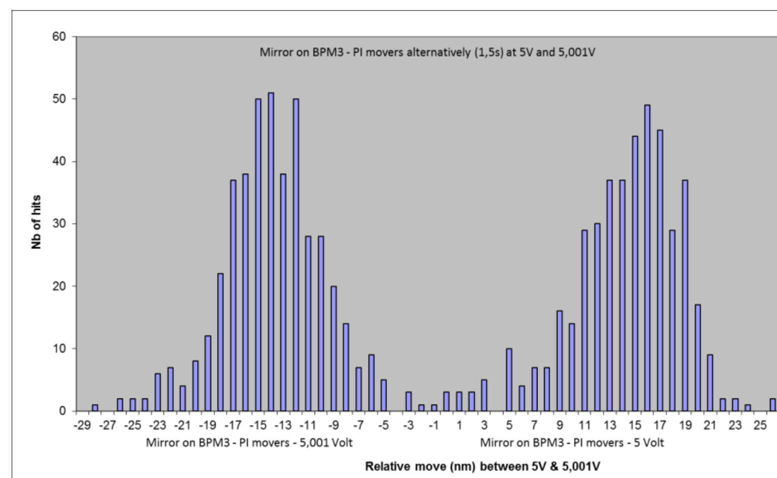
$\xi \sim 10^{-3}$ for 10 nm error

$\xi \sim 3\ 10^{-3}$ for 1 nm error

IP-BPM chamber with precise in-vacuum positioning and calibration
Designed and presently undergoing many checks and tests at LAL



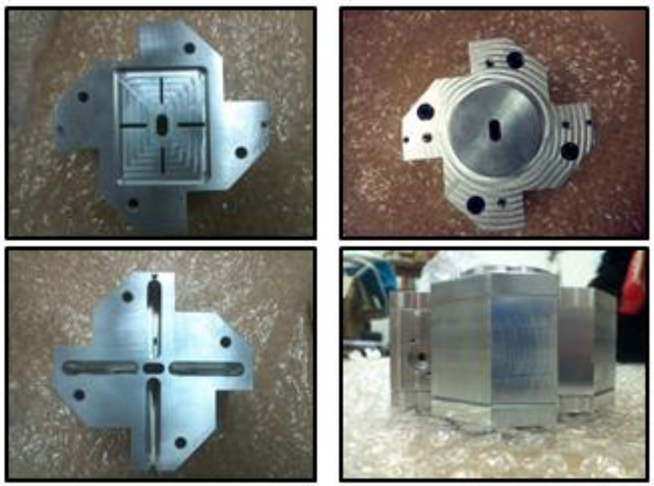




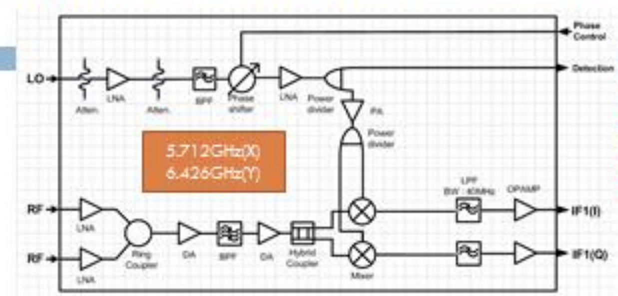
Design and test of IP-BPMs and electronics at Kyungpook National University

Tested Double block IP-BPM

- Made by Aluminum (2kg for double block)



Simplified schematic of new electronics



Total conversion
Gain: 54dB->35dB
To get the more wide Dynamic range at the IP-region

Simplified schematic of the IP-BPM signal processing electronics.

Si-Won Jang, ATF2 project meeting, January 2013

GM feedback and GM effect detection

Y. Renier ,J. Pfingstner, K. Artoos,D. Schulte, R. Tomas (CERN)
A. Jeremie (LAPP)

CLIC Workshop 2013
30 of January 2013

Goal and motivation of the ATF2 experiment

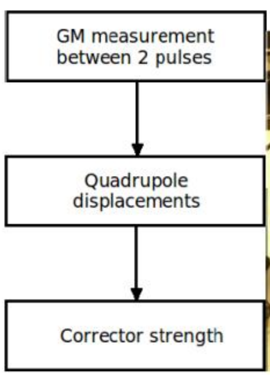
Goal

- Detect Ground Motion (GM) effect on beam trajectory.

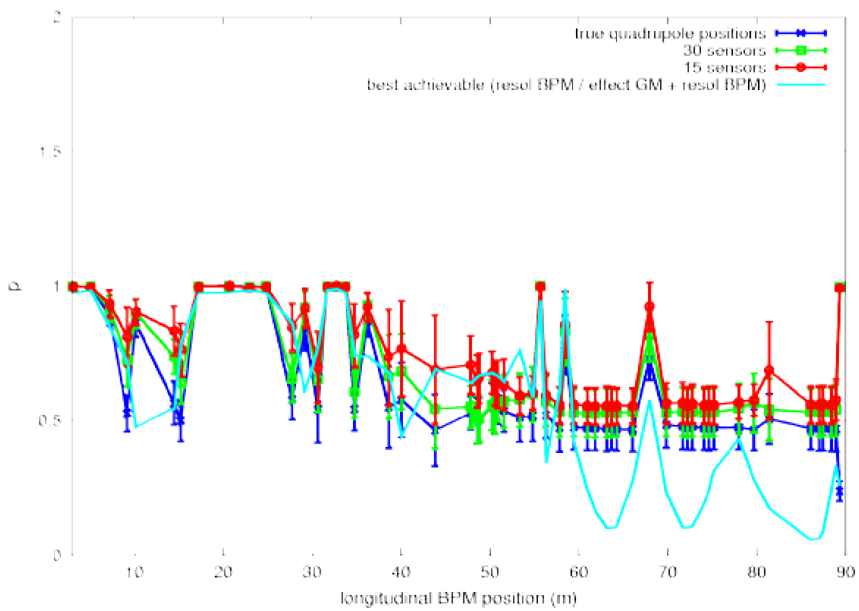
Motivation

- GM sensors are usually only compared to other GM sensors
- It would demonstrate possibility to make a feed forward with GM sensors.
- Feed forward would allow trajectory correction based on GM measurements in CLIC.
- Feed forward would allow big saving (avoid quadrupole stabilization in CLIC)

Concept of Feed Forward with GM Sensors



Nominal Lattice with 5 Improved BPMs(Y)



Is 37 nm vertical size the limit at ATF2 ?

- Study explores to what extent can be varied the β^*
- Originally motivated to start ATF2 with larger β^* values
  - More comfortable situation, less sensitive to errors (non-linear optics…)
- Study shows that beam size down to ~17 nm might be achievable !
  - Of large interest for CLIC machine, to demonstrate the its chromaticity regime is feasible
  - Such low β^* values are also of interest for alternative (more economical) ILC setups with "pushed" IP parameters

CERN – IHEP – KEK – LAL – SLAC

For the ATF2, CLIC and ILC projects

Exploring ultra-low β^* values in ATF2 -R&D Programme proposal

P. Bambade, S. Bai, Y. Renier, *LAL (France)*
H. Braun, J.P. Delahaye, D. Schulte, R. Tomás[1],
F. Zimmermann, *CERN (Switzerland)*
J. Gao, D. Wang, *IHEP (China)*
J. Urakawa, T. Tauchi, T. Okugi, S. Kuroda, Y. Honda *KEK (Japan)*
A. Seryi, M. Woodley *SLAC (USA)*

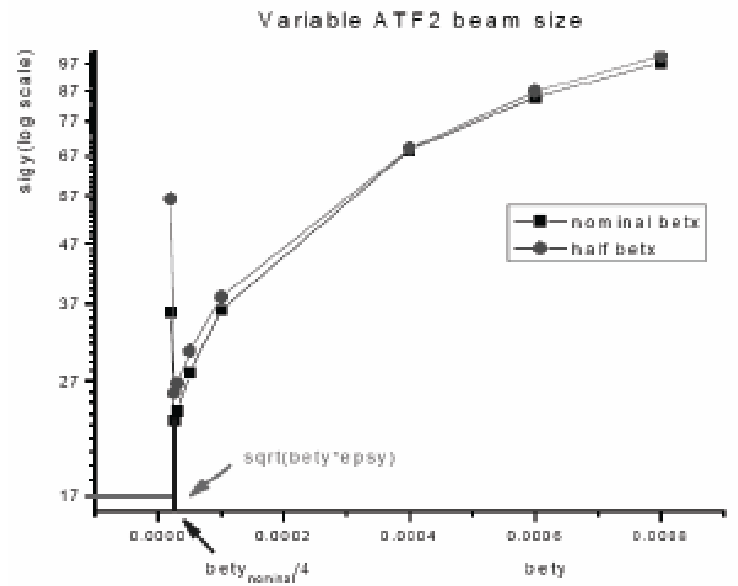
Abstract

We propose to explore the beam sizes and performance of the ATF2 Final Focus System for reduced IP beta functions up to a factor between 2 and 4 below its design. The results will demonstrate the feasibility of the system in a chromaticity regime of interest for CLIC and ILC.

[1] Corresponding author: rogelio.tomas@cern.ch

Geneva, Switzerland

May 7, 2008



Sha Bai (IHEP, LAL) et al.

Ultra-low β* program for high chromaticity regime at CLIC and ILC

ATF2 Ultra-low beta studies

Edu Marin
emarinla@slac.stanford.edu

CLIC WORKSHOP
Accelerator / Parameters & Design Activities session
January 29th, 2013

CLIC Workshop

QF1FF field quality

The PEPII magnet was installed in November 2012

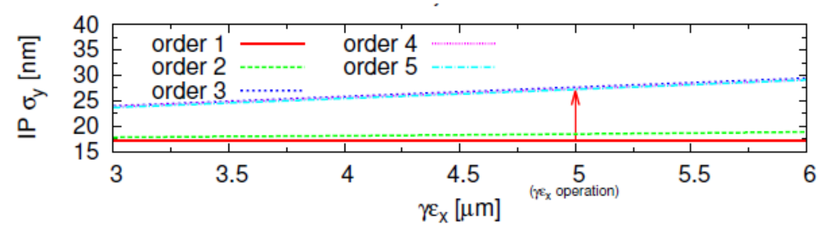
CLIC Workshop

ATF2 lattices optimization

Obtained σ^* when replacing QF1FF by the LER quadrupole and optimizing the sextupoles:

ATF2 Nominal lattice	ATF2 Ultra-low lattice
$\sigma_x^* = 3.2\ \mu m$	$\sigma_x^* = 3.2\ \mu m$
$\sigma_y^* = 37$ nm	$\sigma_y^* = 31$ nm

To further reduce σ_y^* of the ATF2 Ultra-low β^* lattice it would be required to replace QD0FF. Assuming the same multipole components of the PEPII magnet for QD0FF:



ATF2 Ultra-low lattice with PEPII FD:
$\sigma_x^* = 3.2\ \mu m$ $\sigma_y^* = 27$ nm

CLIC Workshop

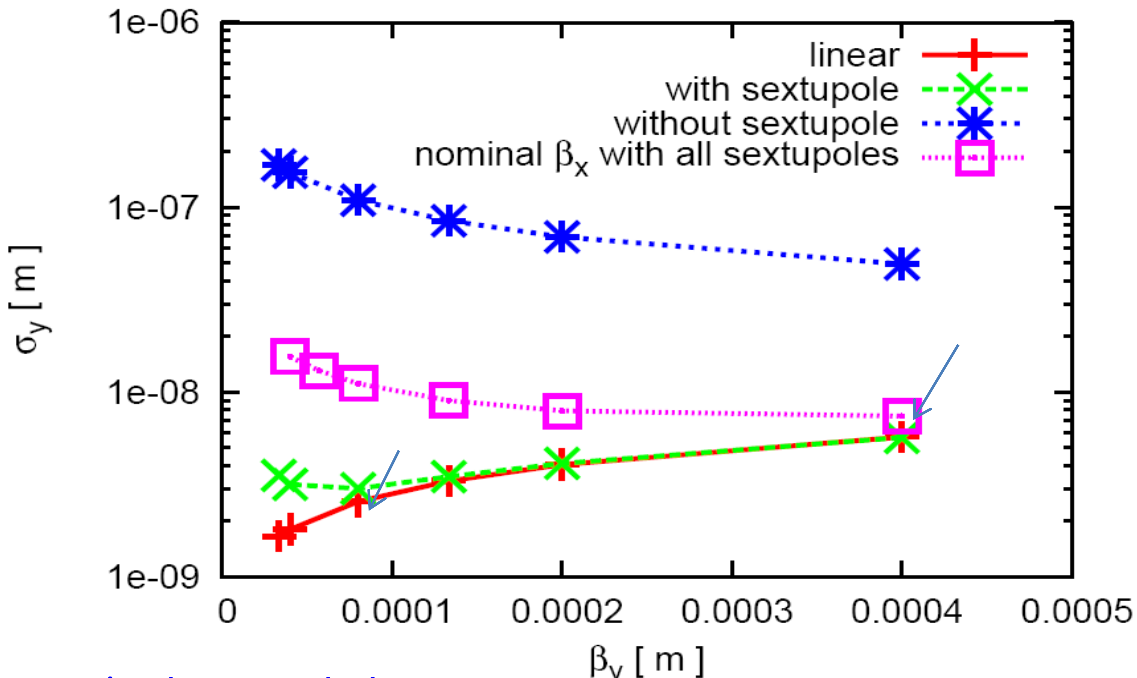
Chromatic correction concentrated on the vertical plane

- enlarged βx*=45mm, variable βy*
  - choose βx*=45mm: as without chromatic correction, σx* minimized
  - with chromatic correction mainly in the vertical plane (green line): σy* minimized when βy*= 0.08mm
  - σy*=0.4·σy_nom* (σx*=3·σx_nom*)
  - Luminosity recovery seems possible and there's room for optimization.

Reduced nb of sextupoles: 5→2

less beamstrahlung

<u>Further work</u>: reduce vertical chromaticity removing intermediate focus



ILC

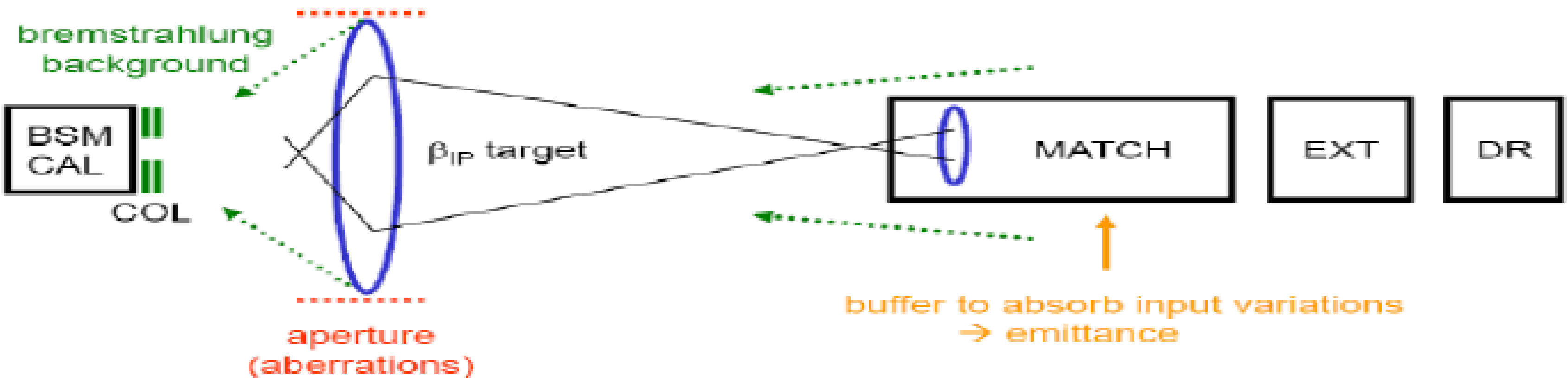
↓

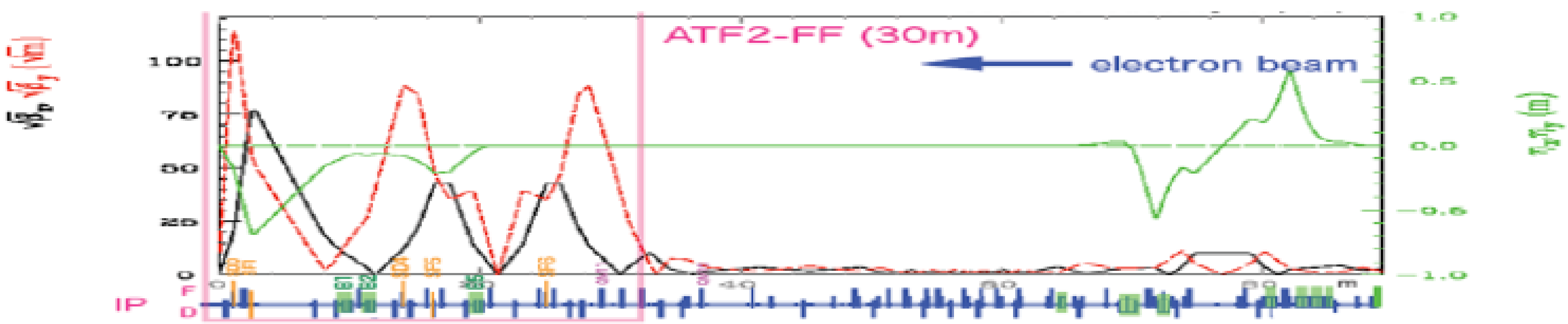
ATF2

Yiwei Wang (IHEP, LAL), this workshop

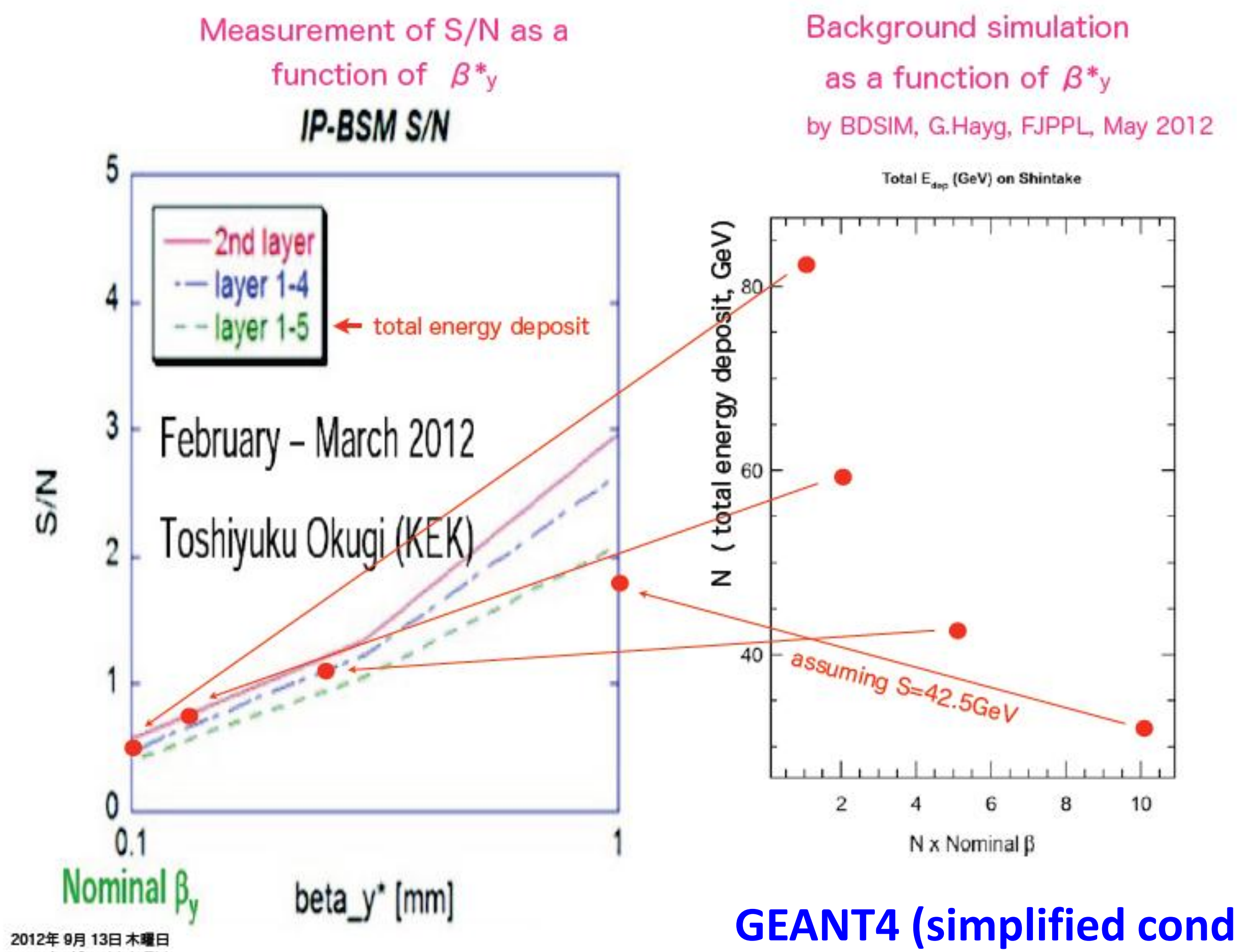
Issue of beam halo in HEP colliders and ATF2

1. Beam halo → major issue for IR backgrounds at many colliders, e.g. future linear colliders, B factories – also an important problem at ATF2 !
2. Control of halo via collimation / optics essential to enable the most aggressive optics configurations for luminosity performance





Beam halo and BSM background issues

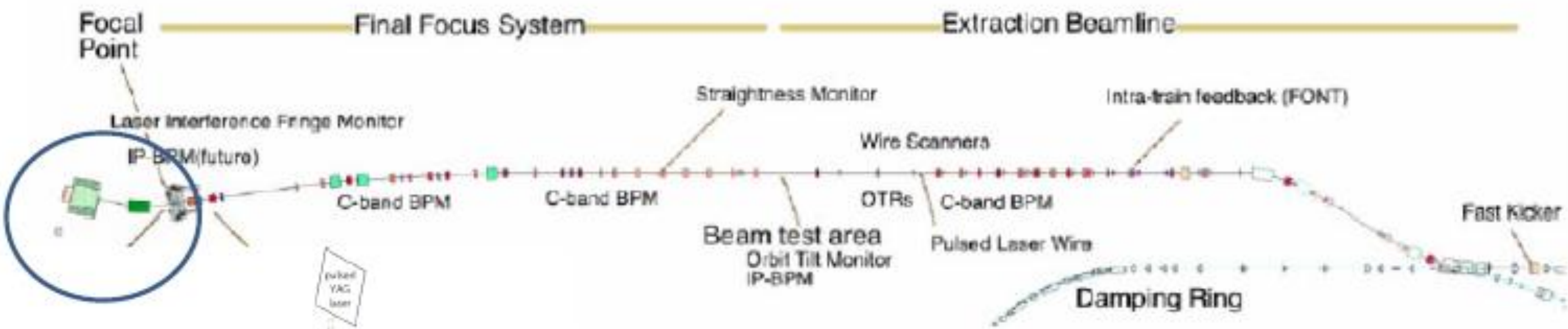


GEANT4 (simplified conditions)

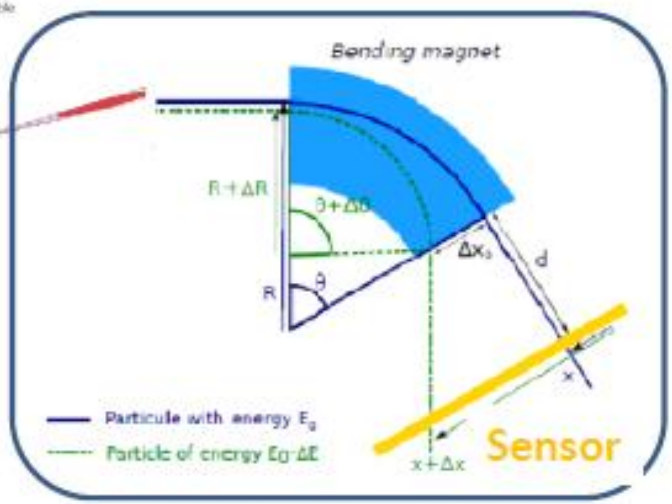
Halo intercepted on
- **post-IP bend magnet vertical gap**
- **final doublet beam pipe**
- **chromatic correction c-band BPM apertures**

under study…

ATF2 & Beam Halo Measurement



Shintake Monitor

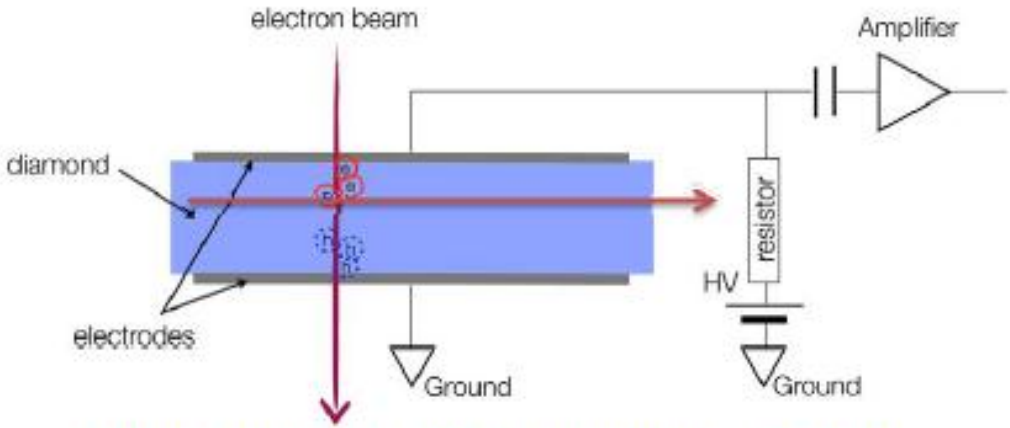


Shan Liu (LAL)

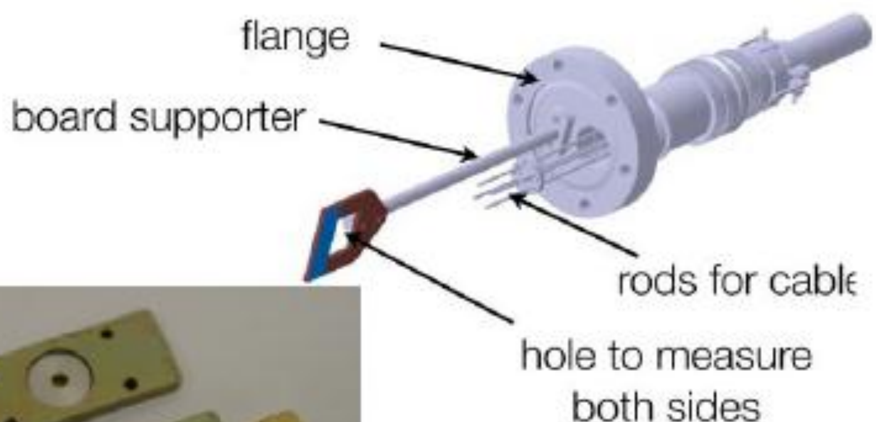
Motivations:

- ***Beam halo transverse distribution unknown → investigate halo model***
- ***Probe Compton recoiled electron→ investigate the higher order contributions to the Compton process***

Diamond Detector Characteristics



Charge created by 1MIP in diamond → 2.74 fC



Diamond detectors

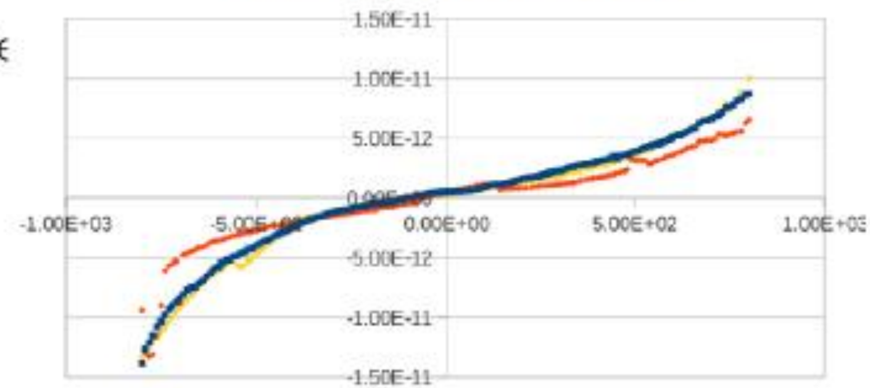
Configurations:

- ***Pads : mm² x 500 µm***
- ***Strips & pixels***
- ***Membranes (→5 µm)***

Types:

- ***Poly crystalline diamond***
- ***Single crystalline diamond***

Current Measurement

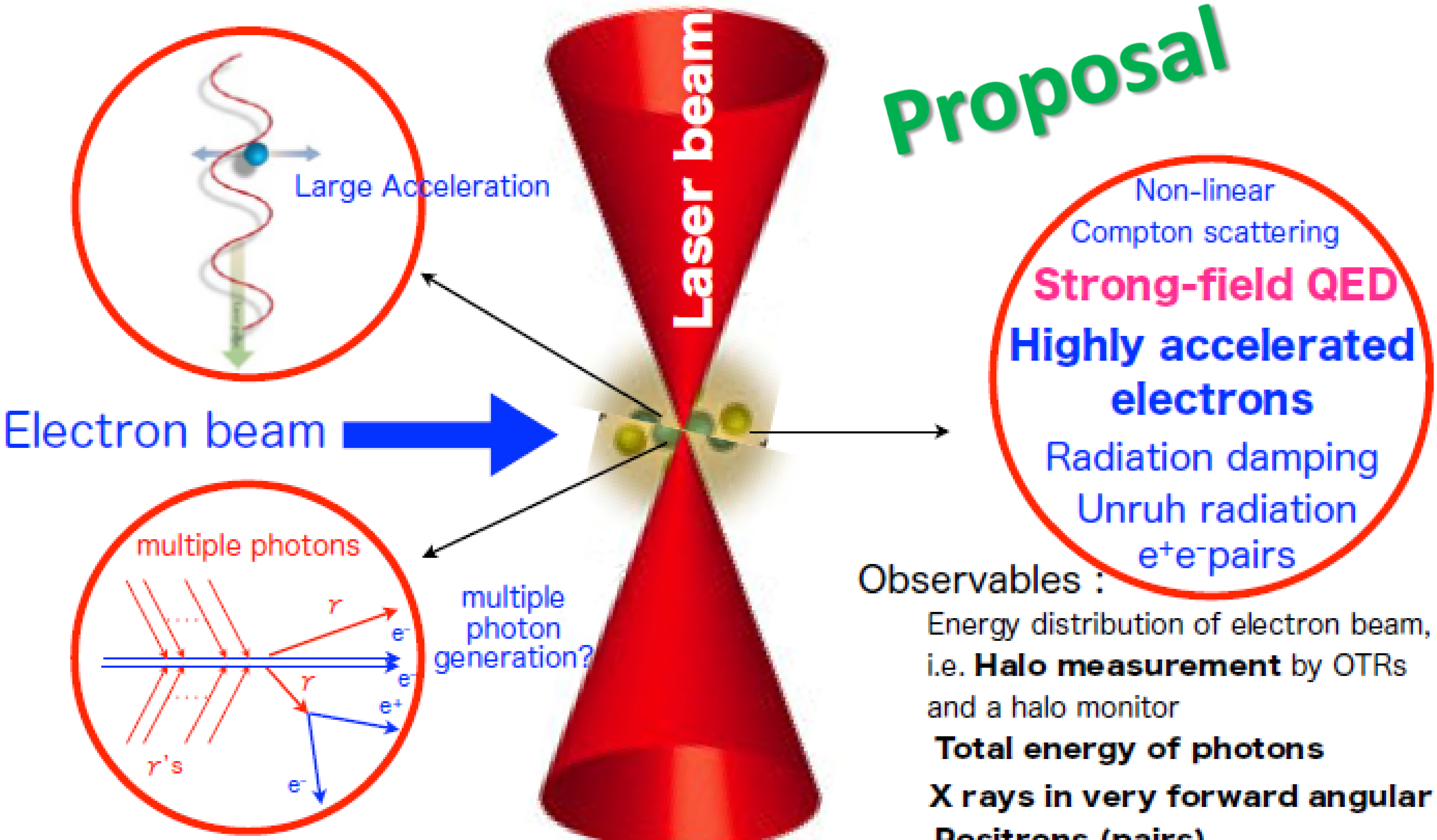


Shan Liu (LAL)

Experimental Study on Strong-Field QED

by collisions between electron beam and high intensity laser

QED is the most precise theory tested in the perturbation regime but very few in the Strong field; GRB, magnetar, Lepton epoch in the Universe.



Observables :

Energy distribution of electron beam, i.e. **Halo measurement** by OTRs and a halo monitor

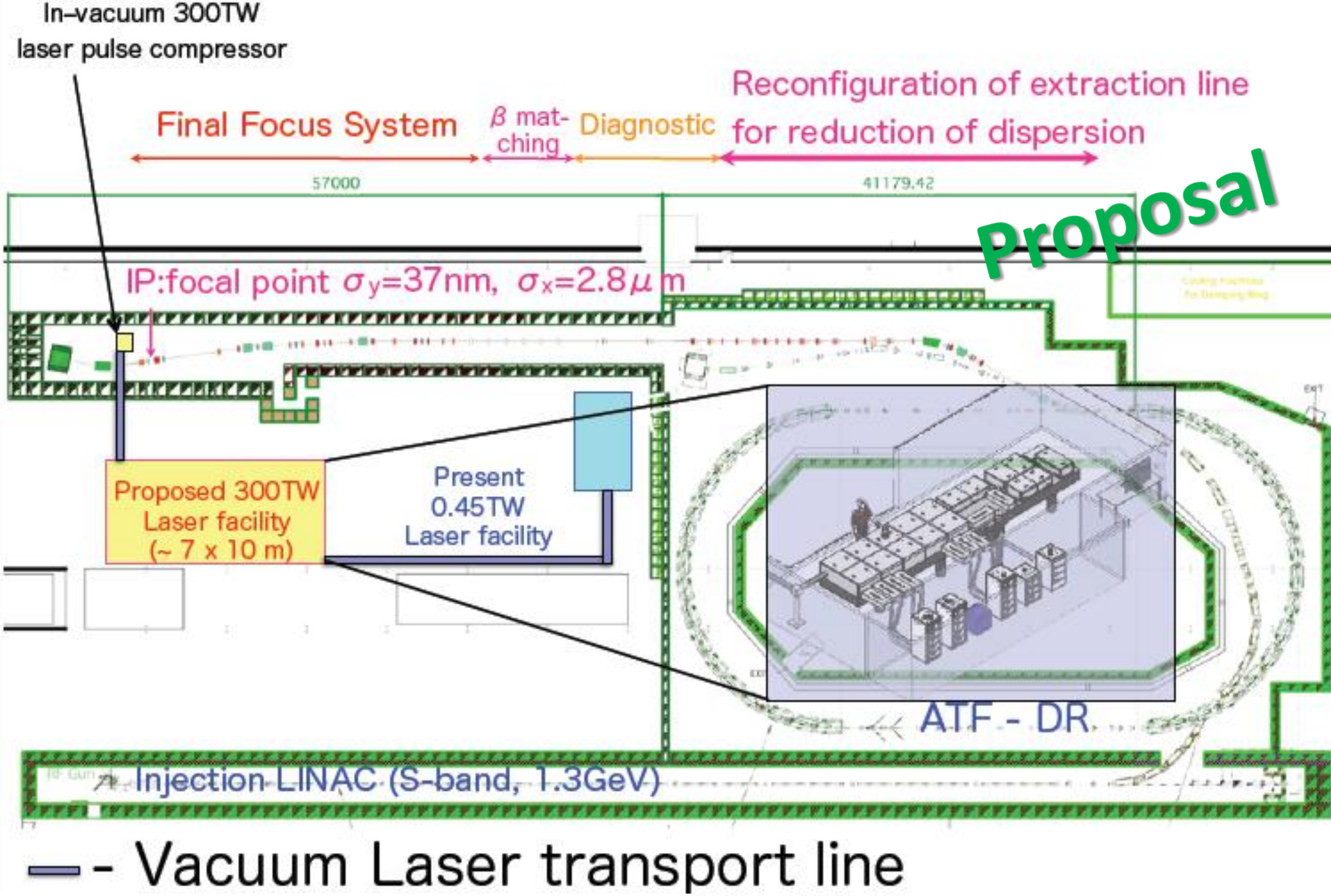
Total energy of photons

X rays in very forward angular region

Positrons (pairs)

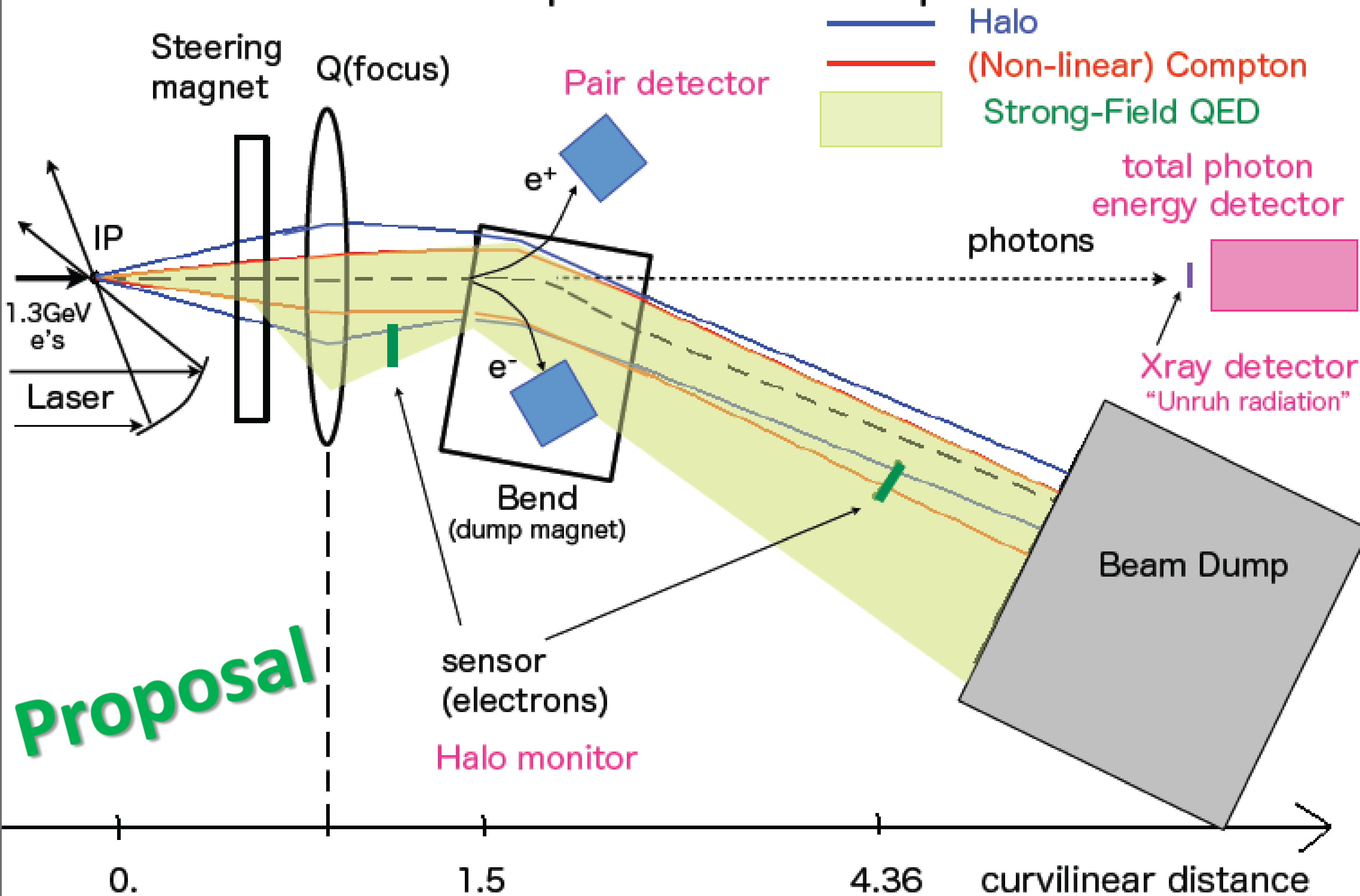
Toshiaki Tauchi (KEK)

ATF2 : 1.3 GeV Electron Beam



Toshiaki Tauchi (KEK)

Experimental Setup



Toshiaki Tauchi (KEK)

Stay tuned for our progress with both goal 1 and goal 2 in 2013 !

ATF/ATF2 plans activities (smaller beam sizes, stabilization, other…) for a number of years leading up to the future linear collider.

ATF/ATF2 unique as R&D facility, especially for instrumentations
Invaluable training of early stage accelerator scientists on "real systems", in collaborative, flexible, yet competitive environment

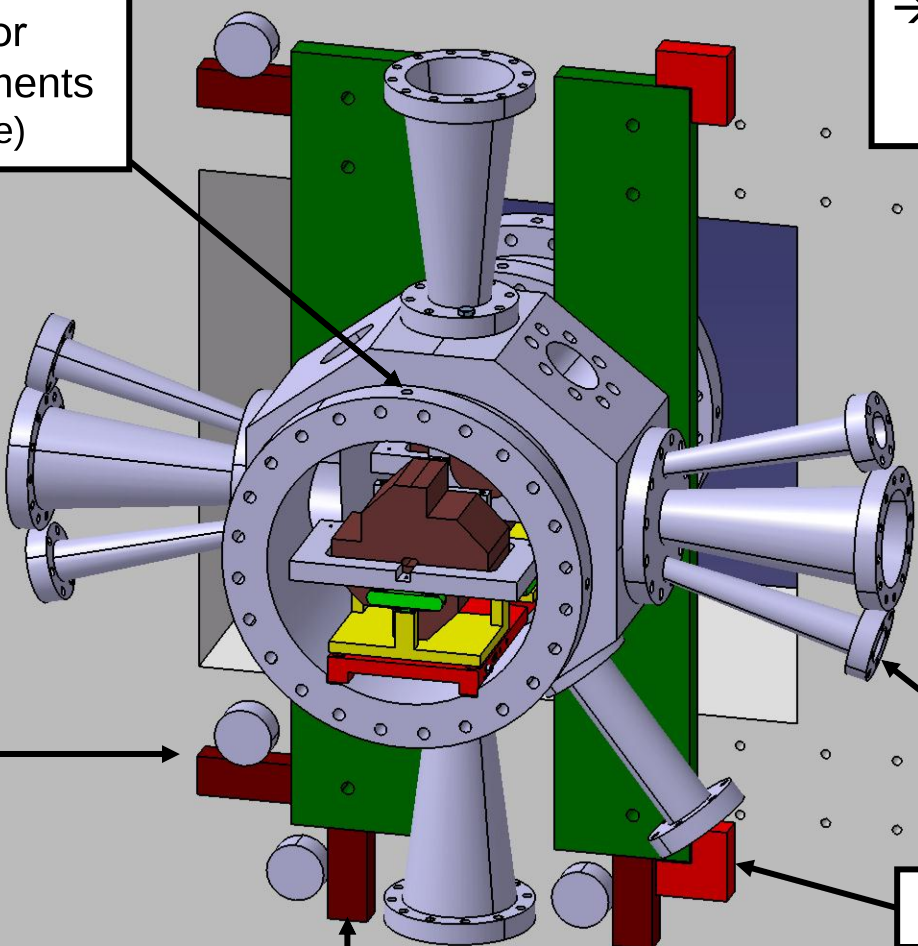
FJPPL-FKPPL workshop at LAL on ATF2 goal 2 and future plans
February 11-13, 2013: http://events.lal.in2p3.fr/ATF2-2013/

Thank you for your attention !

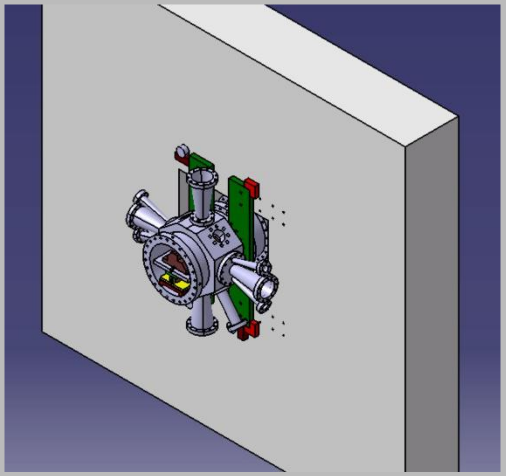
Additional slides

New IP Chamber

Targets' holes for surveyor measurements (4 holes per flange)



→ External references bring IP Chamber axis, vertical and horizontal planes



Large aperture viewports / windows

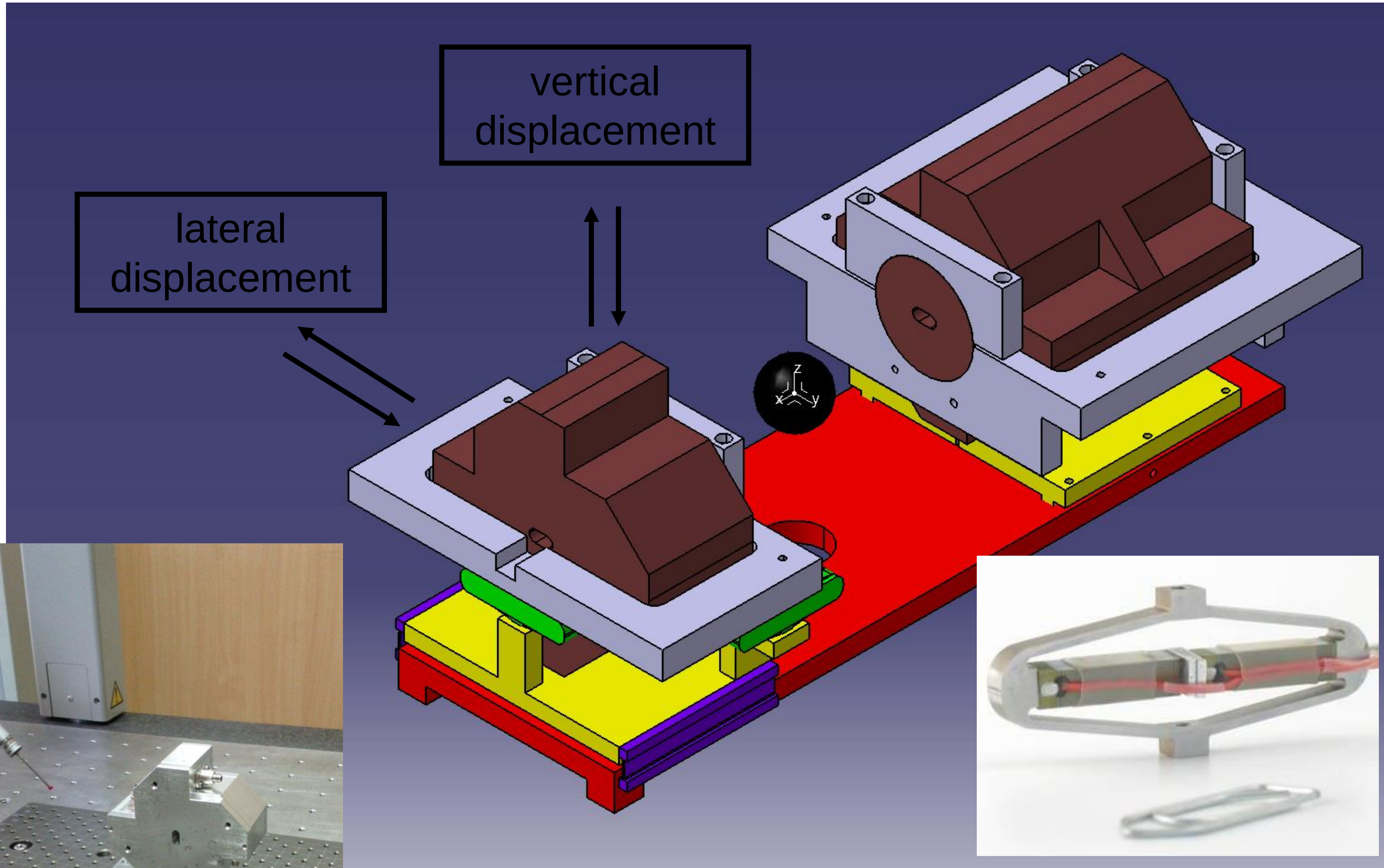
2 Shims holders

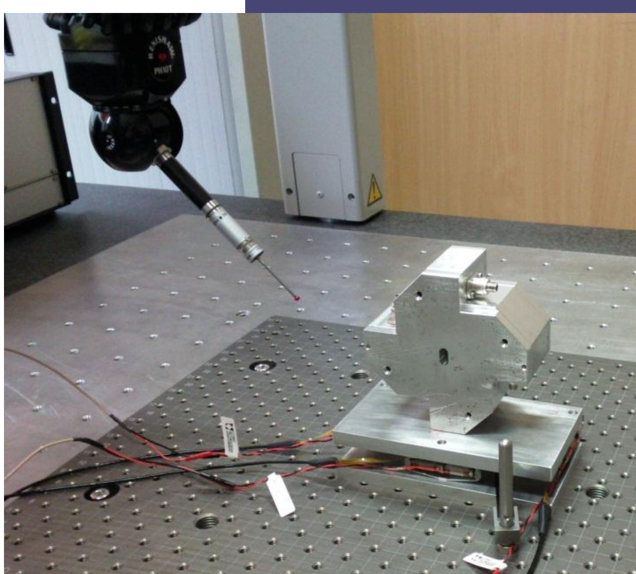
Downstream side

4 External (manual) movers to adjust IP-Chamber position

Sandry Wallon & Frédéric Bogard (LAL)

BPM displacement

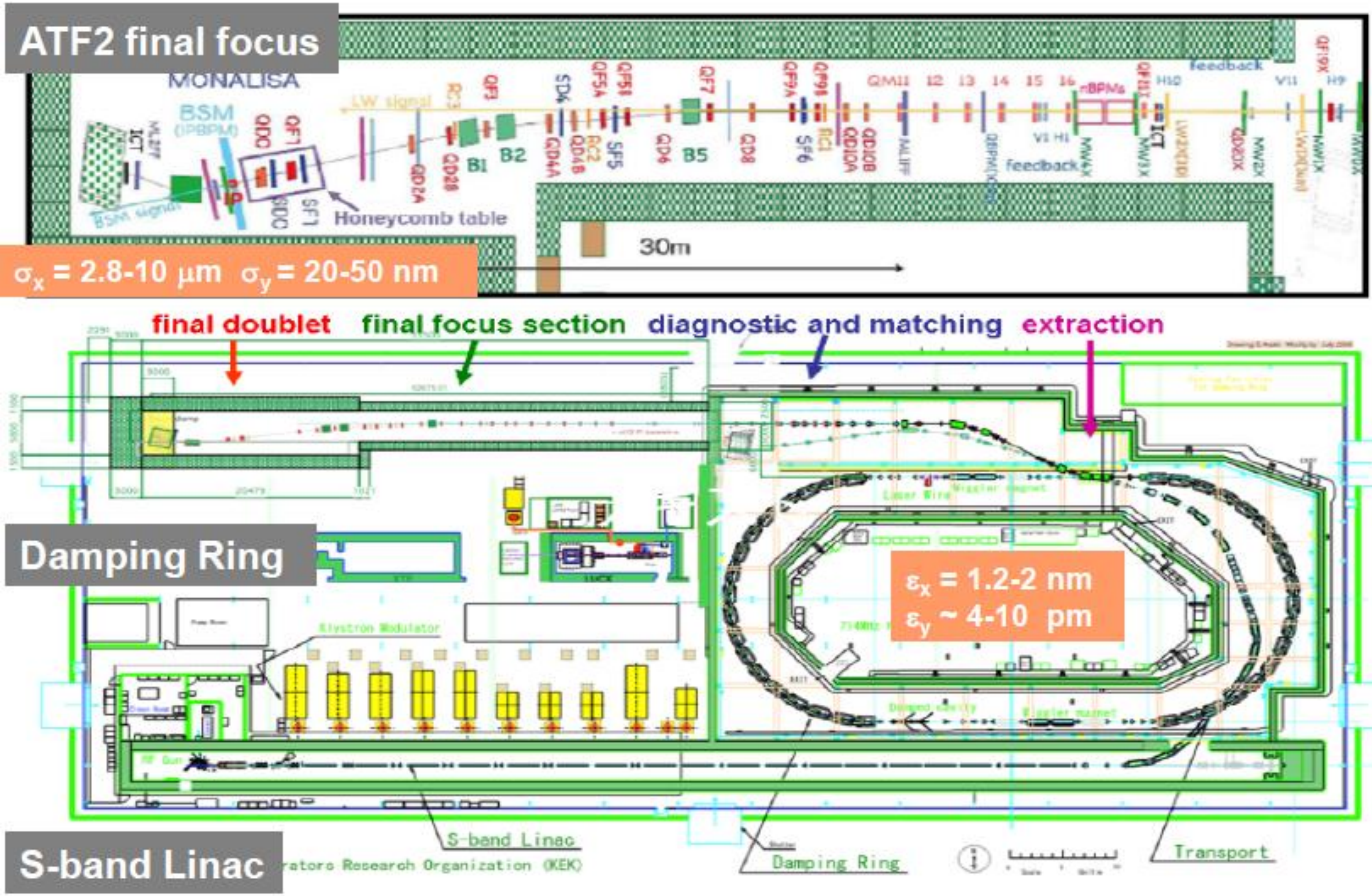




BPM tripod 3d motion test
(Bruno Leluan)

piezo actuator
(Cedrat APA200M)

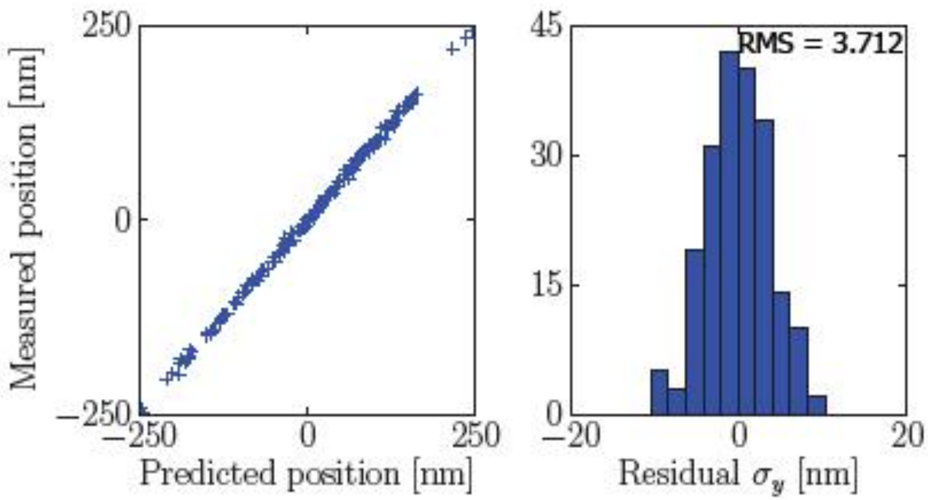
Accelerator Test Facility @ KEK



For Goal 2 :

Preliminary result of IPBPM

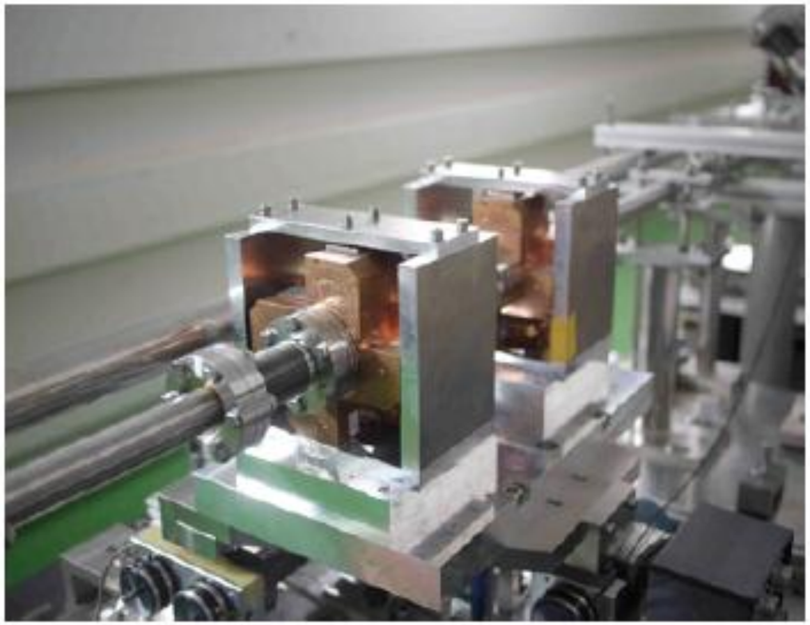
PhD thesis, YoungIm Kim (KNU)



RMS = 3.7 nm

Charge > 0.70 10^{10} electron/pulse

diagnostic section



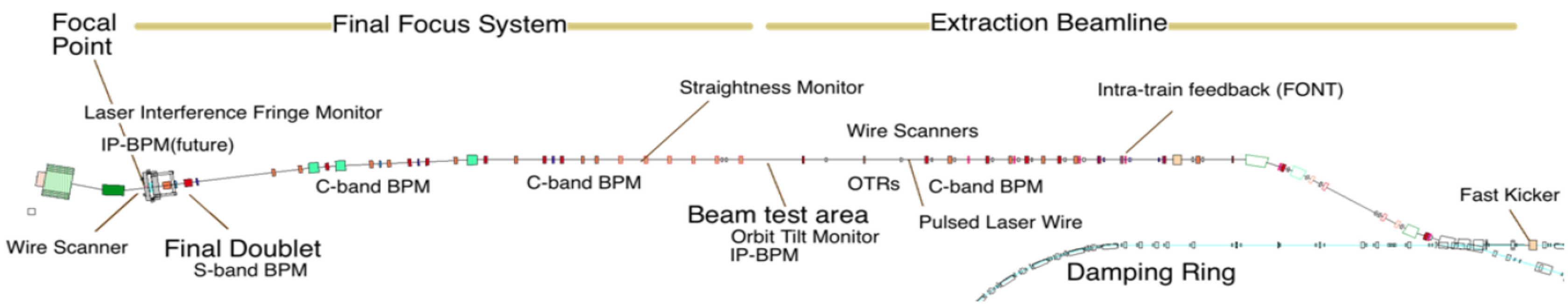
Data taken three shifts in three weeks in November to December, 2011, i.e. 1shift/week and 8h/shift

Published resolution :

8.72 +- 0.28 (stat.) +- 0.35 (sys.) nm

Y. Inoue et al, Phys. Rev. ST Accel. Beams 11, 062801 (2008)

Recent progress towards “goal 2”



New IP chamber being built in Orsay to house ‘Shintake’ BSM and new set of lower Q high resolution cavity BPMS from KNU

- **Expected to be installed early 2013**

Meanwhile, new kicker installed near IP. Use existing higher Q IP-BPMs (with the vertical waist shifted) to investigate:

- **Effect of the upstream FB system on IP stability (ultimate performance of upstream system)**
- **Feed-forward from upstream BPMs (eg P2 & P3) to the IP kicker**
- **Local FB correction (problem: no independent monitor of the FB performance on beam)**

Check whether any significant jitter at IP originates from motion of final doublet

Main LC BDS issues addressed by ATF/ATF2

validate concept(s), develop, practice, train,...

- Beam instrumentation
  - nm-level position
  - profile (x, y, tilt)
- Stabilization
  - passive / active mechanical stabilization
  - beam / vibration measurement based feed-back/forward
- 4+1 dim. phase space tuning & control for IP spot minimization
  - emittance minimization via radiation damping
  - mitigation of 1st, 2nd and 3rd order optical aberrations
  - convergence time ↔ dynamical errors (sismic & thermal effect)
- Halo control
  - modeling, generation, propagation, monitoring…
  - collimation (physical, optics)

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 ~ β / L*	**~ 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**

$$L \sim \frac{n_b N_e^2 f}{4\pi\sigma_x\sigma_y} H_D$$

$$L \sim \eta \frac{P_{electrical}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\varepsilon_{n,y}}} H_D$$

$$\sigma^2 = \varepsilon_N \beta / \gamma$$

ATF2 =

- ✓ **scaled ILC FFS**
- ✓ **start point of CLIC FFS**

concept of local compact chromaticity correction