Nanometer stabilisation at ATF2 within FJPPL and FKPPL

A.Jeremie

For FJPPL A-RD-10: Nanometer stabilisation at ATF2

For FKPPL A-RD-: ATF2

Joint France-Japan-Korea Project!

Outline

- Participants
- KEK*: host, organisation, installation, ATF2
- KNU*: IP-BPMs and associated electronics
- LAL*: IP-chamber, in-vacuum diamond sensor
- LAPP*: GM sensors, QF1 relative displacement
- Application for 2014

*principal contributor although collaborative work

Participants

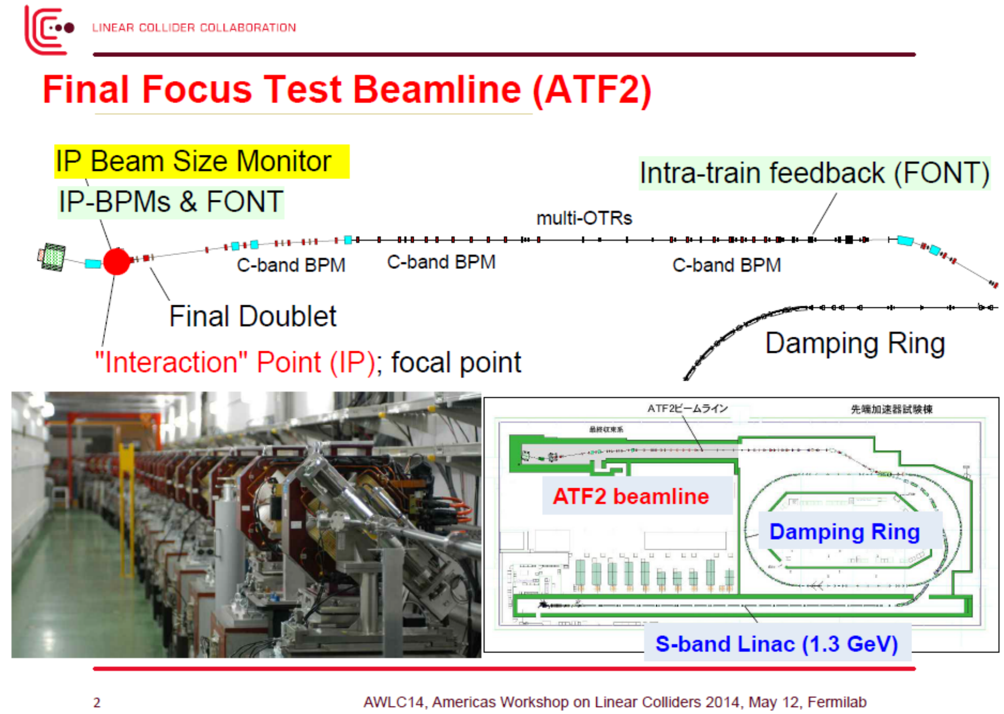
FJPPL

ID[1]:A_RD_10	Title: Nanometer stabilization studies at ATF2					
	French Group			**Japanese Group**		
	Name	**Title**	**Lab./Organis.[2]**	**Name**	**Title**	**Lab/Organis.[3]**
Leader	Andrea Jeremie	IR1	LAPP	Nobuhiro Terunuma	A.Prof.	KEK
Members	Philip Bambade	DR2	LAL	Toshiaki Tauchi	A.Prof	KEK
	Oscar Blanco	PhD	LAL	Junji Urakawa	Prof	KEK
	Shan Liu	PhD	LAL	Kiyoshi Kubo	A.Prof	KEK
	Sandry Wallon	IR2	LAL	Shigeru Kuroda	R.A.	KEK
	Frédéric Bogard	IE2	LAL	Toshiyuki Okugi	R.A.	KEK
	Patrick Cornebise	IE2	LAL	Sakae Araki	Eng	KEK
	Alexis Gamelin	Master	LAL	Hiroshi Yamaoka	Eng	KEK
	Post-doc		LAL			
	Nicolas Geffroy	IR2	LAPP			

FKPPL

ID: Title	A_RD_ATF2: LAL -KNU collaboration on the IP-BPM nanometer beam measurement and stabilization project at ATF2					
List of participants	**French Group**			**Korean Group**		
	Name	**Title**	**Affiliation**	**Name**	**Title**	**Affiliation**
	Leader: Philip Bambade	DR	LAL	Leader: Eun-San Kim	Prof.	KNU
	Oscar Blanco	PhD	LAL/CERN	Si-Won Jang	PhD	KNU
	Sandry Wallon	IR	LAL	Yumi Lee	Master	KNU
	Frédéric Bogard	IE	LAL	Woongwha Park	Postdoc	KNU
	Patrick Cornebise	AI	LAL			
	T.B.N. (from April)	Postdoc	LAL			
	Alexis Gamelin	Master	LAL			

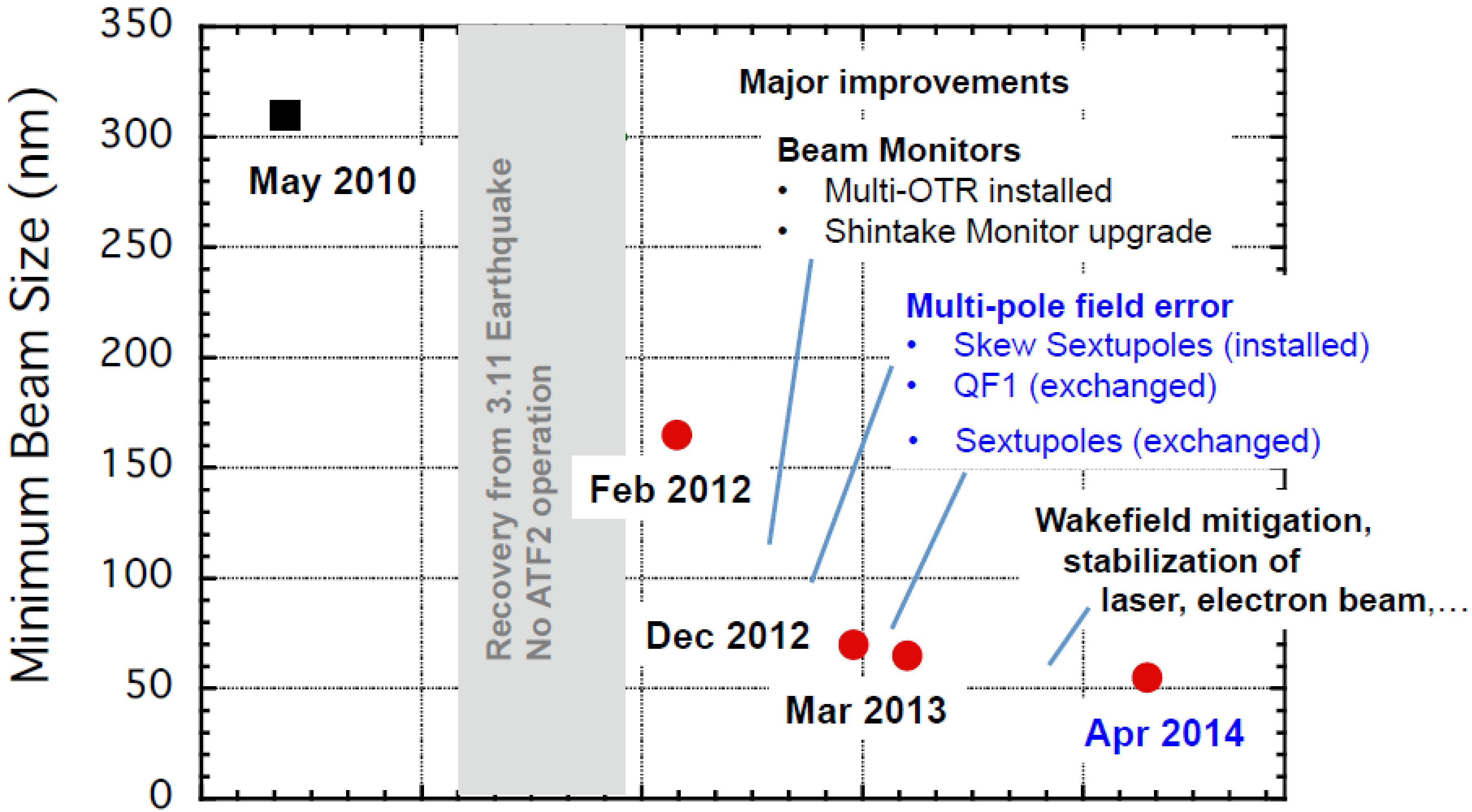
ATF2



Goals of ATF2 project

- **Produce and Confirm Small Beam Size (Goal-1)**
  - Achievement of **37 nm (σ)** beam size (ε_y 12 pm, β_y^* 0.1 mm)
  - Demonstration of a compact final focus system based on local chromaticity correction
  - Maintaining the small beam size over an extended period of time
- **Produce and Confirm Stable Beam (Goal 2)**
  - Demonstration of beam trajectory stabilization with nano-meter precision at the IP
  - Establishment of techniques for controlling beam jitter at the nanometer level with an ILC-like beam

History of ATF2 minimum beam size

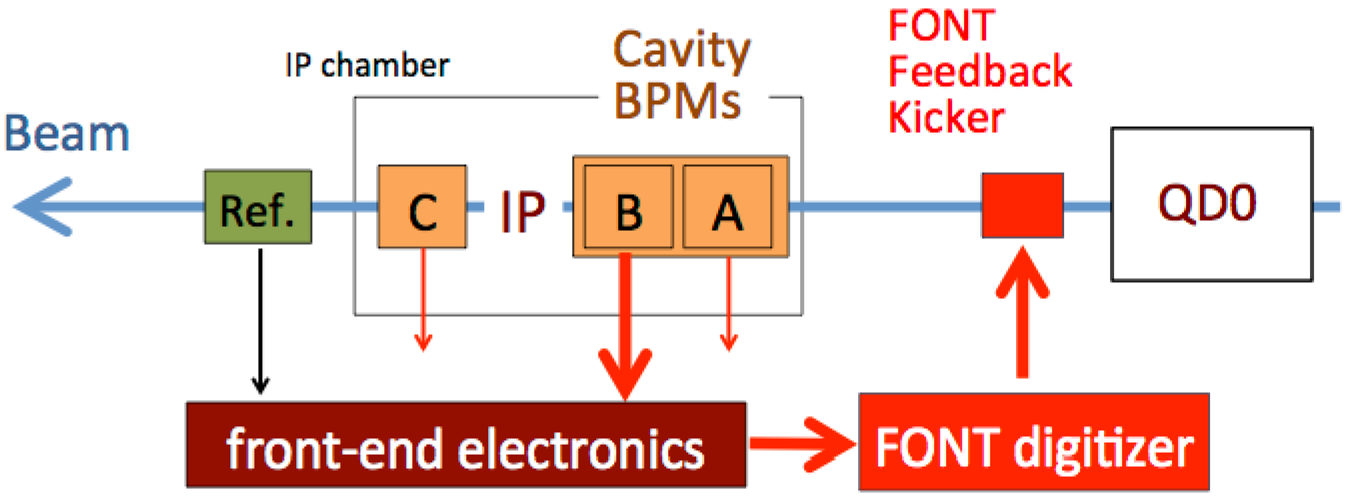


IP-BPMs, associated electronics
IP-BPM chamber

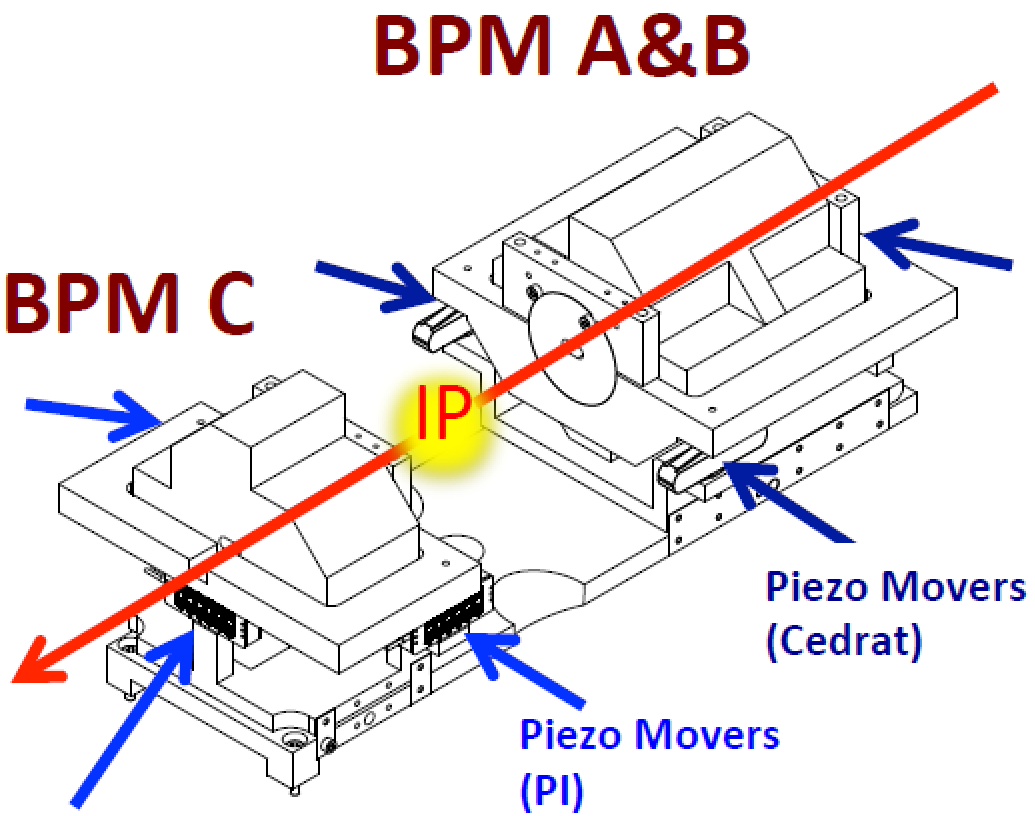
Nanometer level beam position stabilization

IP-FONT(Intra-train feedback loop “at ATF2-IP”)

- **Cavity BPMs optimized for ATF2-IP (2 nm Resolution) on the piezo movers**
- Stripline kicker for the second bunch correction



In vacuum IP-BPM with piezo movers



BPMs

- **Low Q for multi-bunch beam. Short decay time**
- Bolted aluminum plates, no brazing because of In-vacuum.
- BPM A&B bolted together.
- BPM C is independent.

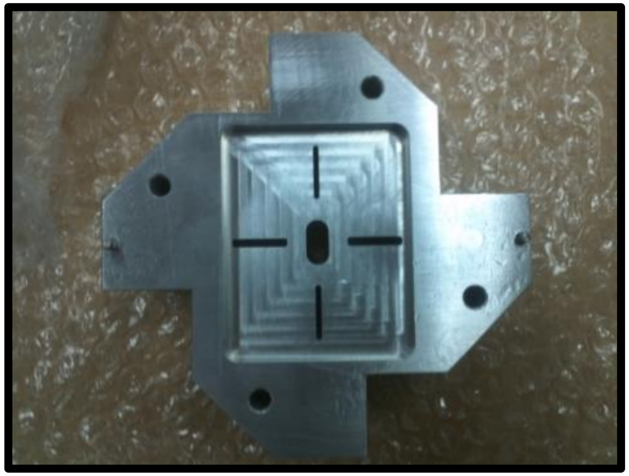
Piezo movers

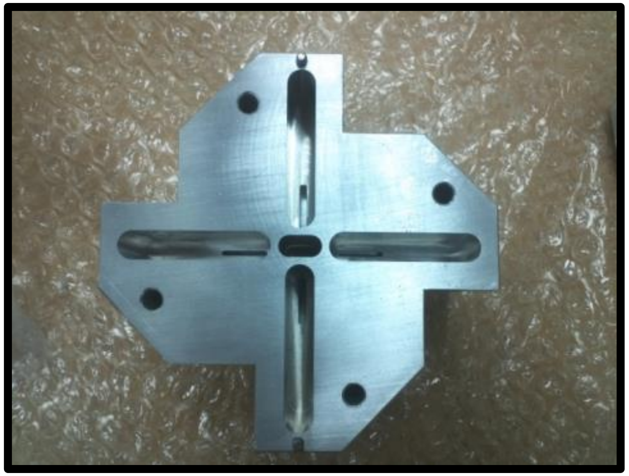
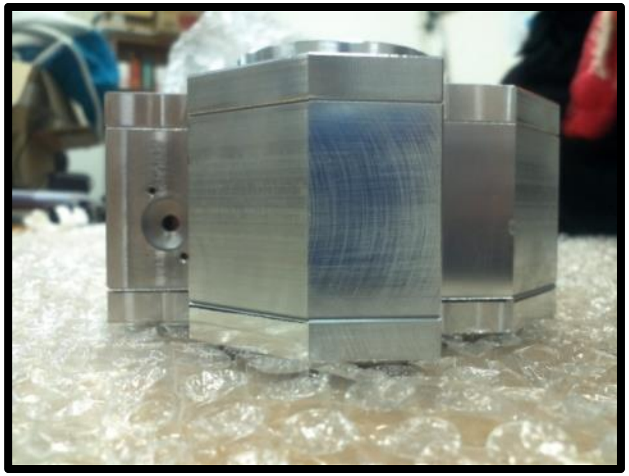
- (vertical x3, lateral x1) / cradle
- **Dynamic range**

  x,y: +/- 150 um.

Tested Double block IP-BPM

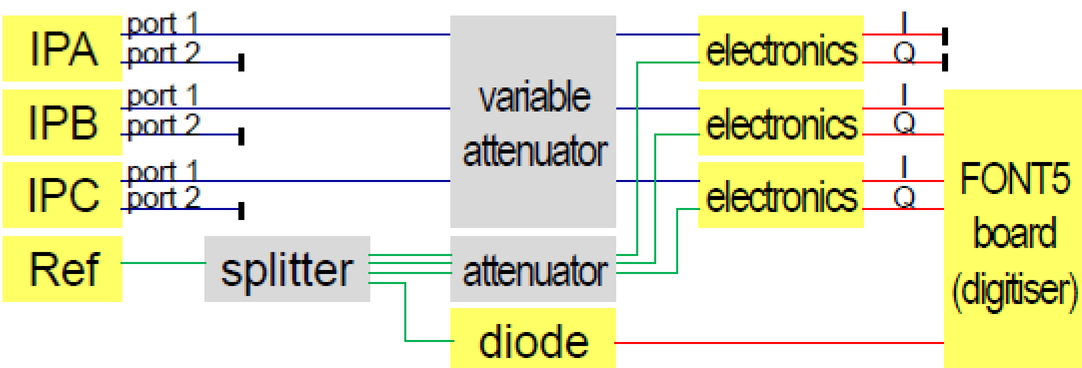
- Made by Aluminum (2kg for double block)



IP-BPM signal to FONT5 board

IP BPM signal processing



- IP BPM C-band signal
- Reference C-band signal
- Base-band signal

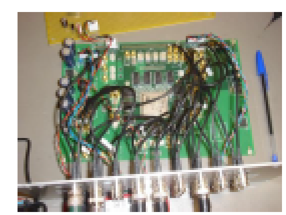
} 6.4 GHz (y) / 5.7 GHz (x)

based on S. Jang

N. Blaskovic FJPPL-FKPPL Workshop on ATF2 5

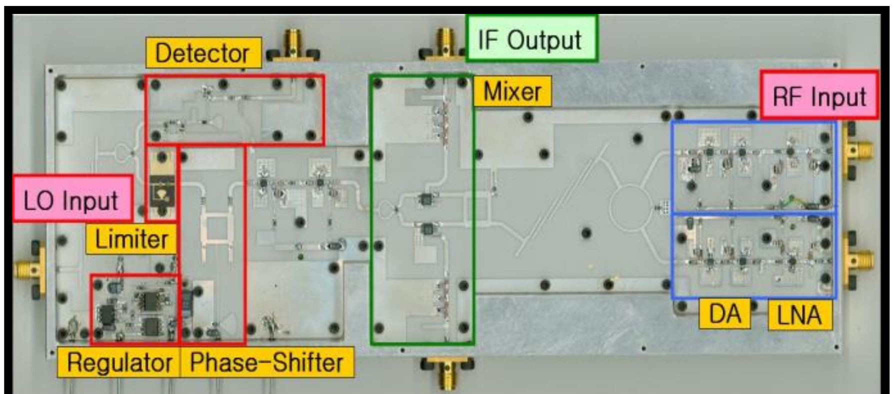
FONT5 board

- 9 ADCs (analogue-to-digital convertors)
- Sampling at 357 MHz (2.8 ns)
- 13 bit: ± 4095 ADC counts for ± 0.5 V
- Based on a Xilinx Vertex 5 FPGA



N. Blaskovic FJPPL-FKPPL Workshop on ATF2

Electronics for Y-ports



Y-port Electronics

I-Q signal with 90° difference

I-Q tuning by phase shifter

- 20ns decay time for feedback System.

Design Frequency

LO: 6426 MHz

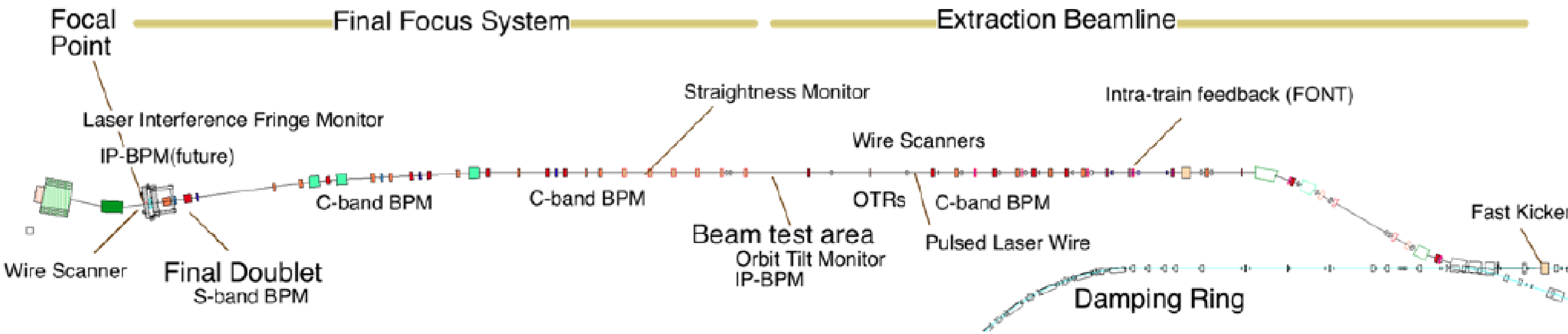
RF: 6426 MHz

Some upgrade was necessary:

- 12 mixer parts were replaced
- The resistors were back to original values.
- The total conversion gain of electronics was set to 54dB.
- The IF offset voltage was set to 0mV (±700uV).

After repair, the electronics was tested and commissioning ongoing at ATF2.

Methodology for stabilization



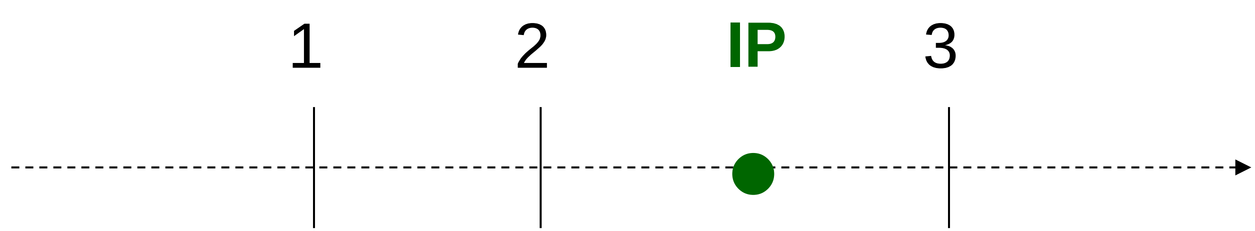
Goal 1 (beam size ~ 37 nm) **beam jitter < 10 nm**

Goal 2 (nm-scale stability with feedback) **beam jitter ~ 2 nm**

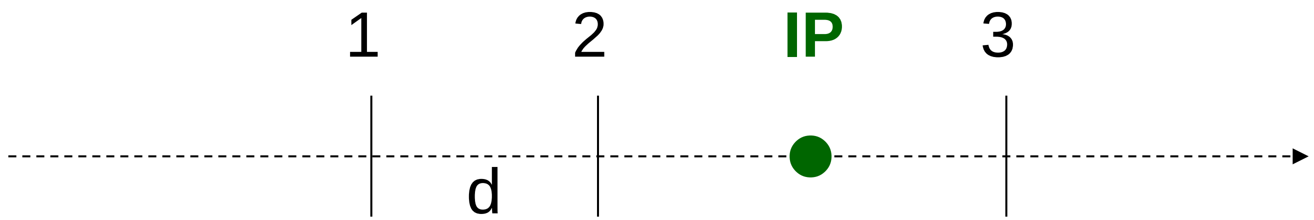
1. Measure stability at one of IP-BPMs after shifting the beam waists there
2. Infer position from measurements at the two other IP-BPMs
3. Use fast kicker just upstream to correct second bunch within ATF2 train

in all cases → must first calibrate scale factors and study system resolution

beam kicker



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



$d \sim 0.1$ m
$\varepsilon_y \sim 12$ pm
$\sigma_{jitter} / \sigma \sim 10\%$

$\theta_{IP} = (y_2 - y_1) / d$ $\quad\xi$ = calibration error of 1 relative to 2

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

1. **Determination of resolution**
2. **Feedback to IP or to 3rd IP-BPM**

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

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

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

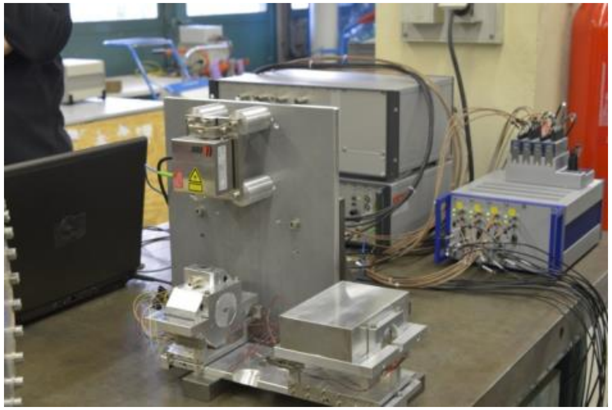
Residual $\sim 2\, (\varepsilon / \beta)^{0.5}\, d\, (\sigma_{jitter} / \sigma)\, \xi \sim 10^{-5}\, \xi \Rightarrow$ **$\xi \sim 10^{-4/-3}$ for 1 / 10 nm error**

New IP-BPMs and IP-chamber

A precise mover system (piezo movers PI and Cedrat) has been designed

→ precise remote internal mechanical alignment of IP-BPMs with respect to beam line components and IP-BSM

→ mechanical calibrations of IP-BPM scale factors with required precision (instead of moving the beam as before); their calibration, reproducibility and linearity below 10^{-4}



Piezo-mover performance was checked at LAL before installation at ATF2 IP using a Sios interferometer, with a weight representing IP-BPM block 1&2 and identical cabling

Each block can be moved independantly

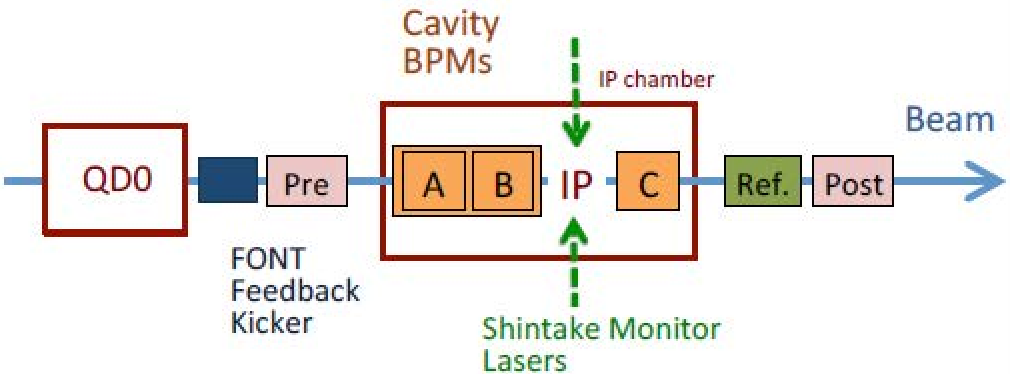
- Closed-loop stability
- Open-loop stability

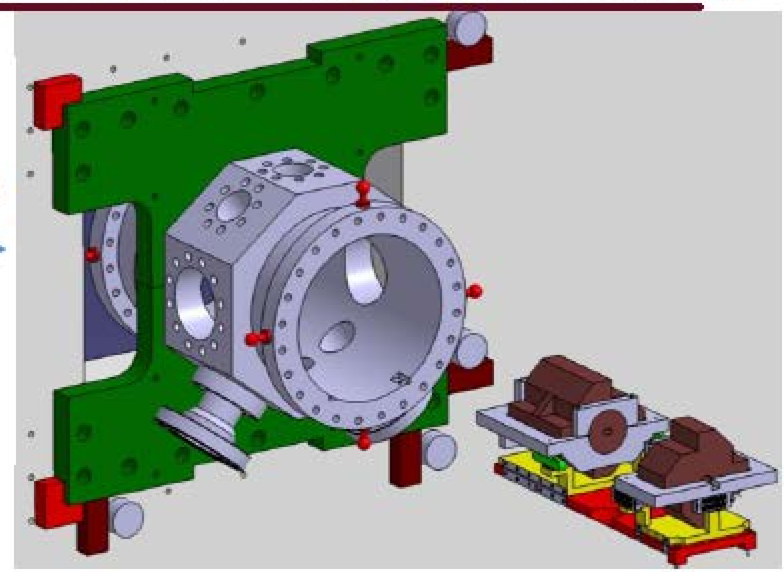
- Setting accuracy
- Calibration

- Thermal effects
- Vibration mitigation

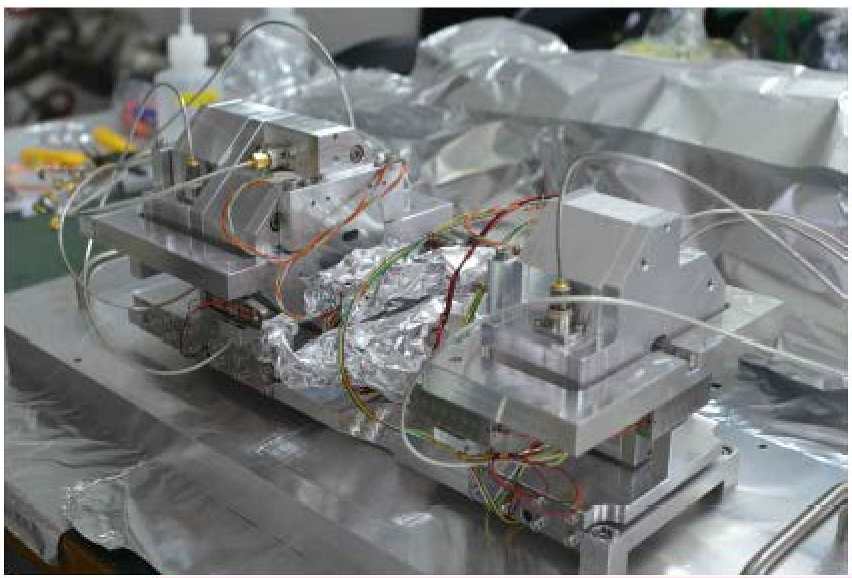
Piezo movers (PI) showed linearity at least to 10^{-4} as needed

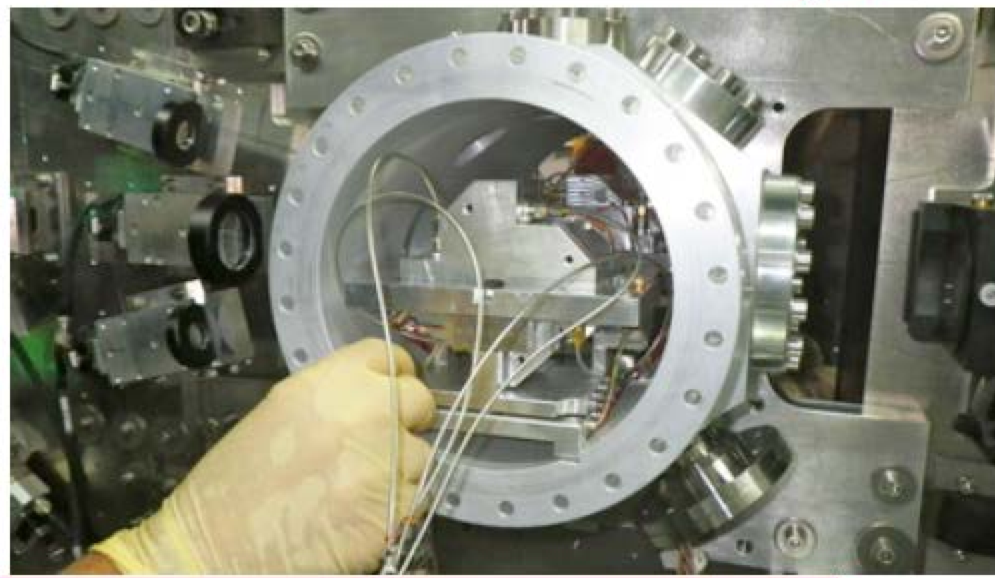
ATF2 IP-BPM installation



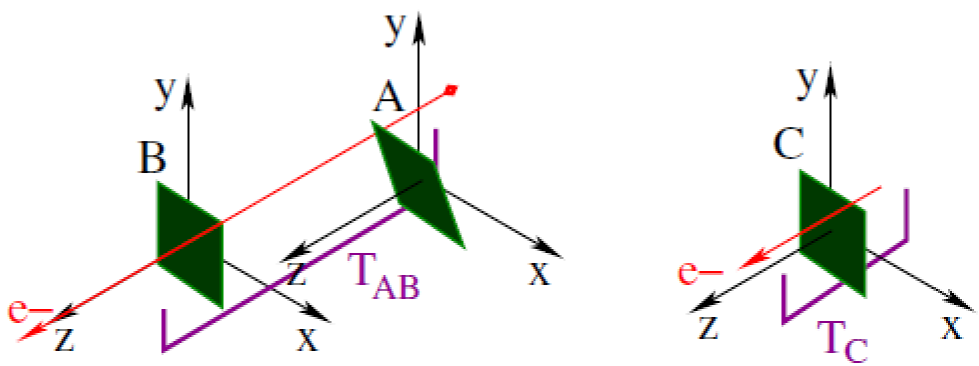


BPM cavities (AB & C)





Alignment of the IP-BPMs



Using BPMB as reference, $1000\beta_y$ optics

	Beam test 1		Beam test 2
	B	A	C
x_0 [μm]	0 ± 5	53 ± 5	$180? \pm ?$
y_0 [μm]	0 ± 3	$\mathbf{-34 \pm 3}$	$\mathbf{-55 \pm 23}$
z_0 [mm]	not meas.	not meas.	not meas.
θ_{p0} [mrad]	0 ± 0.1	$\mathbf{1.6 \pm 0.1}$	$< \mathbf{1.6}$
θ_{r0} [mrad]	not meas.	not meas.	not meas.
θ_{y0} [mrad]	not meas.	not meas.	not meas.

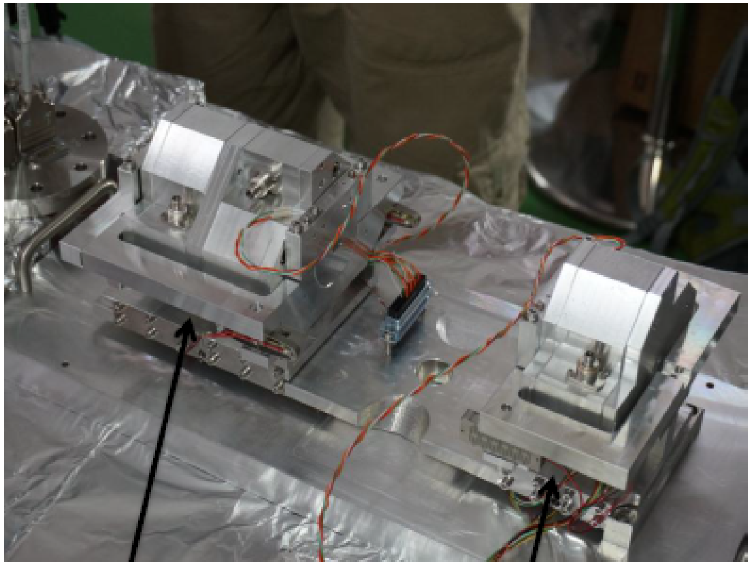
by Blanco Oscar (LAL)

Evaluate the BPM offset by I/Q signals.

- alignment by shims
- **found a significant level of BPM offset and tilt, especially between A and B.**
- obstacles to the BPM-resolution study because of the dynamic range of readout electronics
- **New BPMs will be prepared in this summer.**

Actuators checks

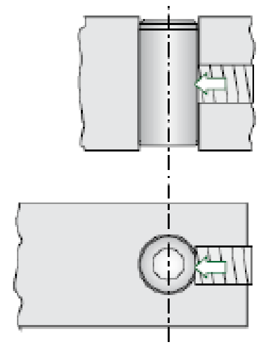
Alternative solution for in-situ measurement : capacitive sensors



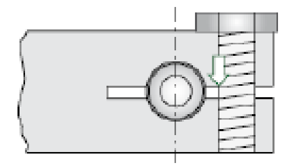
Mounting cylindrical sensors

All sensors can be installed as either freestanding or flush mounted. Fastening is carried out using a clamp or collet.

Mounting with grub screw (plastic)



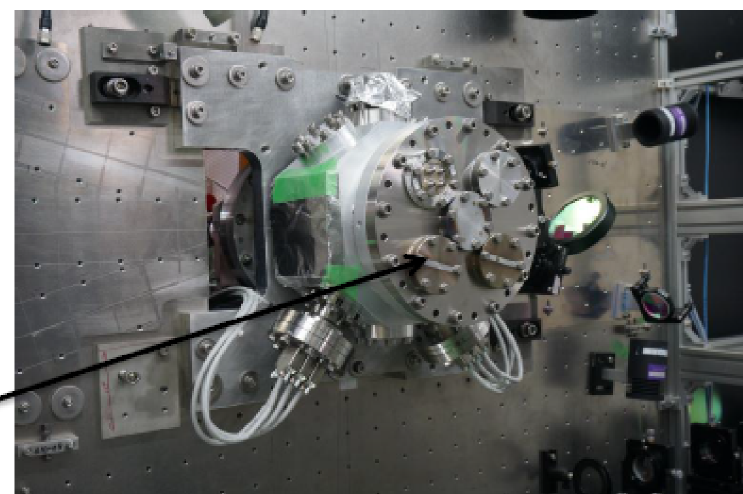
Mounting with collet



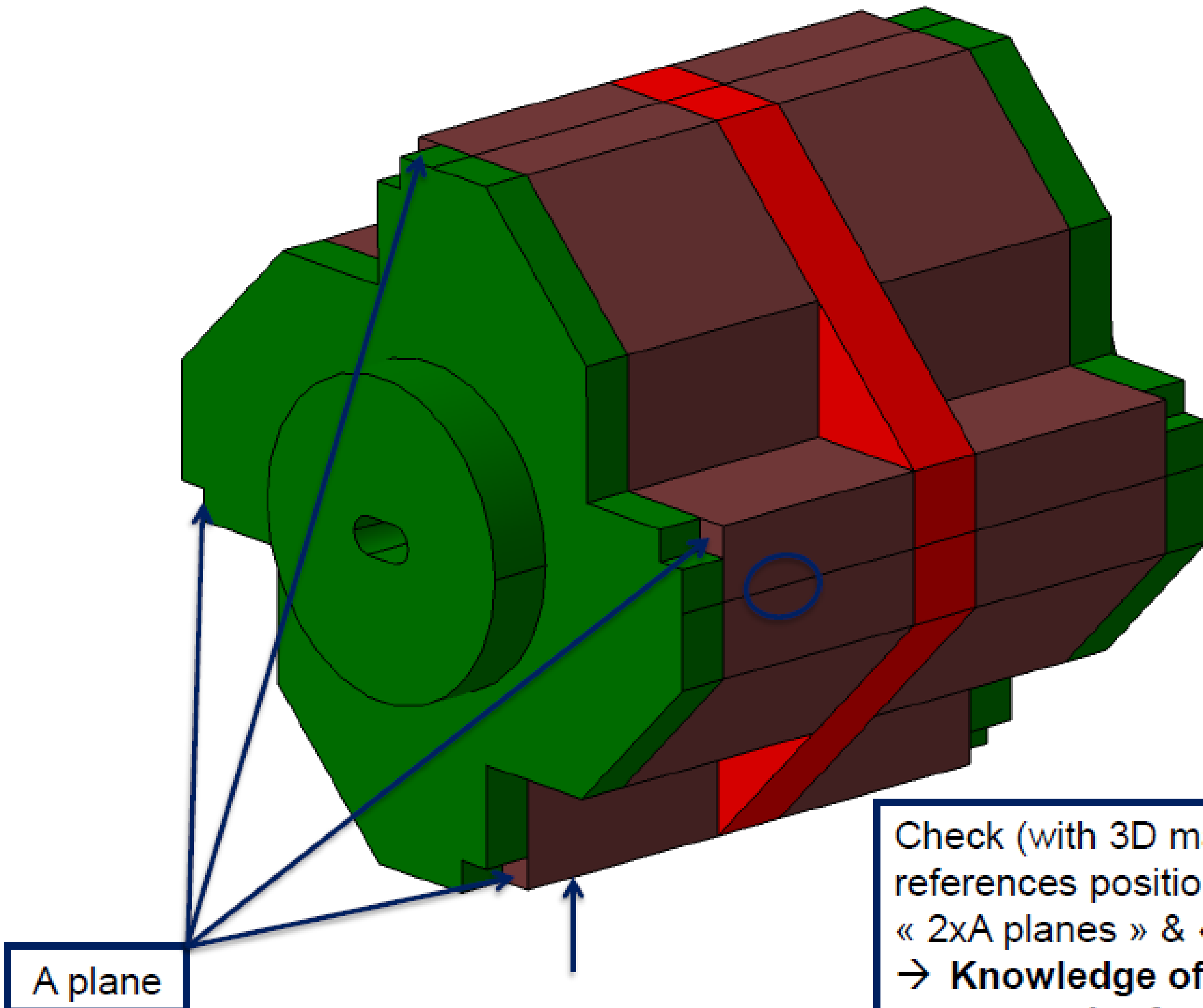
Install capacitive sensors

→ At least 2 sensors (1 / BPM) to monitor BPMs vertical displacement

- Easy mounting
- Vacuum compliant
- Resolution < 1 nm @ 2 Hz (static)
- Signal output through free DN40 flange
- Pretty cheap (sensor)



BPMs – 3D checking : First Step



S.Wallon from LAL will visit KNU this week to discuss BPM fabrication and make sure pertinent alignment references are included

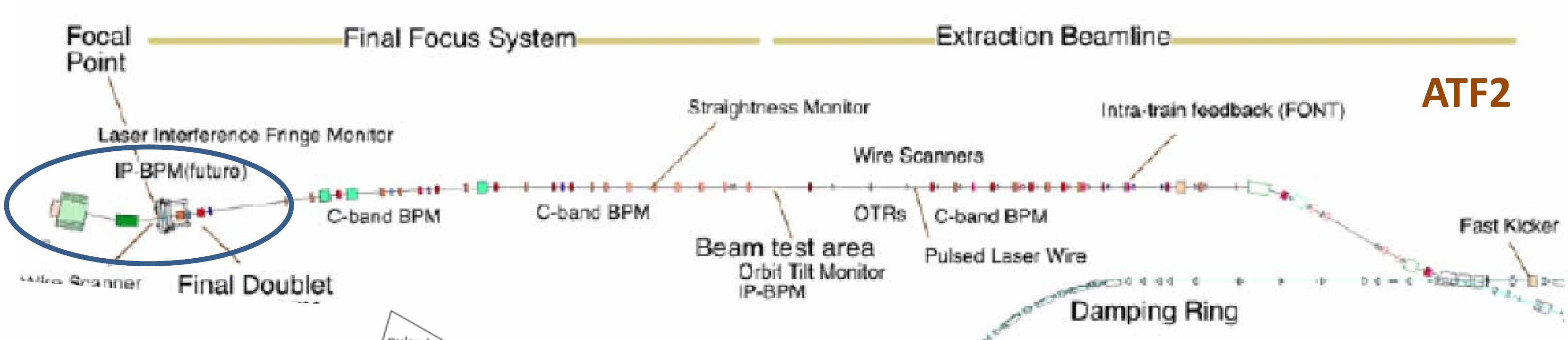
Check (with 3D machine) external references position with respect of « 2xA planes » & « 2x4 flat spots »

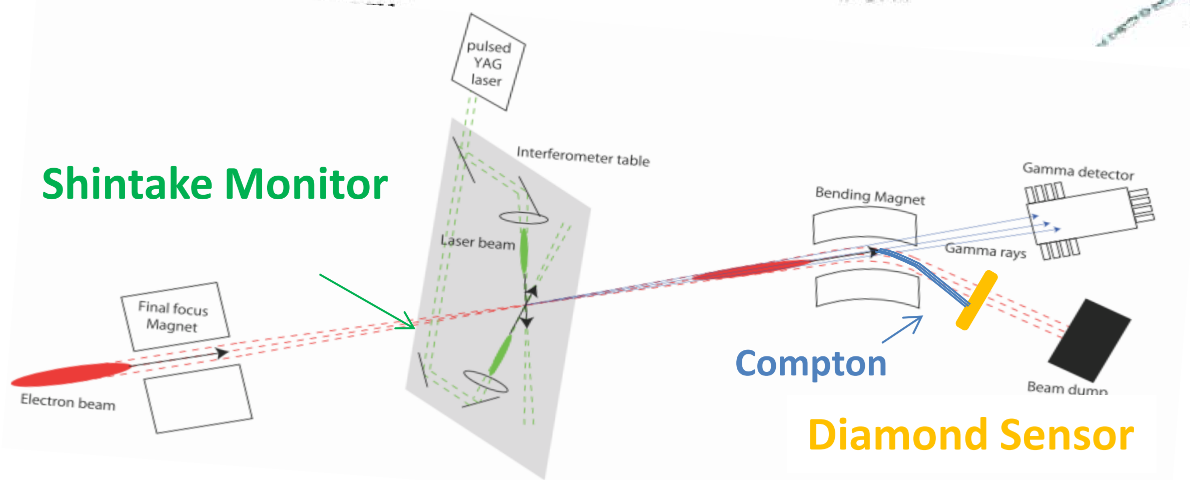
→ **Knowledge of cavities position / external references**

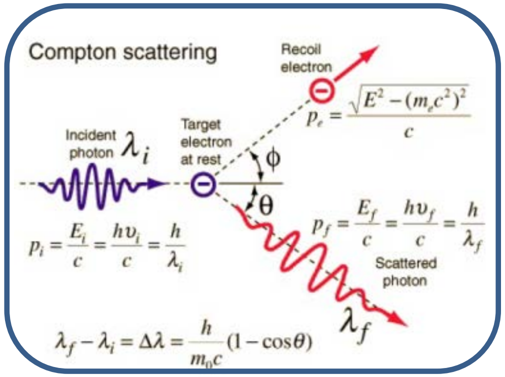
→ **Knownledge of cavity A position / cavity B**

Diamond sensor

Introduction







Motivations:

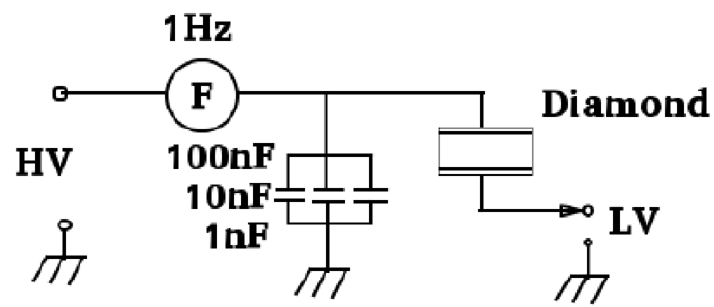
- ***Beam halo transverse distribution unknown → investigate halo model & propagation***
- ***Monitor beam halo to control backgrounds by means of collimation and tuning***
- ***Probe Compton recoil electron→ (possibly, in future, higher order contributions)***

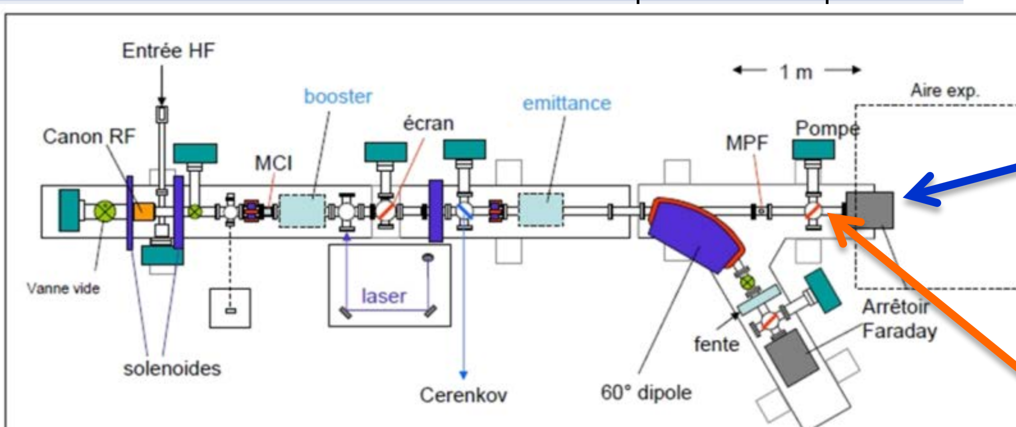
Diamond Detector Features

Property	Diamond	Silicon
Density (g m^{-3})	3.5	2.32
Band gap (eV)	5.5	1.1
Resistivity (Ω cm)	>10^{12}	10^5
Breakdown voltage (V cm $^{-1}$)	10^7	10^3
Electron mobility (cm^2 V^{-1} s^{-1})	1700	1500
Hole mobility (cm^2 V^{-1} s^{-1})	2100	500
Saturation velocity (μm ns^{-1})	141 (e$^-$) 96 (hole)	100
Dielectric constant	5.6	11.7
Neutron transmutation cross-section(mb)	3.2	80
Energy per e-h pair (eV)	13	3.6
Atomic number	6	14
Av.min.ionizing signal per 100 μm (e)	3600	8000

ADVANTAGES

- *Large band-gap ⇒ low leakage current*
- *High breakdown field*
- *High mobility ⇒ fast charge collection*
- *Large thermal conductivity*
- *High binding energy ⇒ Radiation hardness*
- *Fast pulse ⇒ several ns*





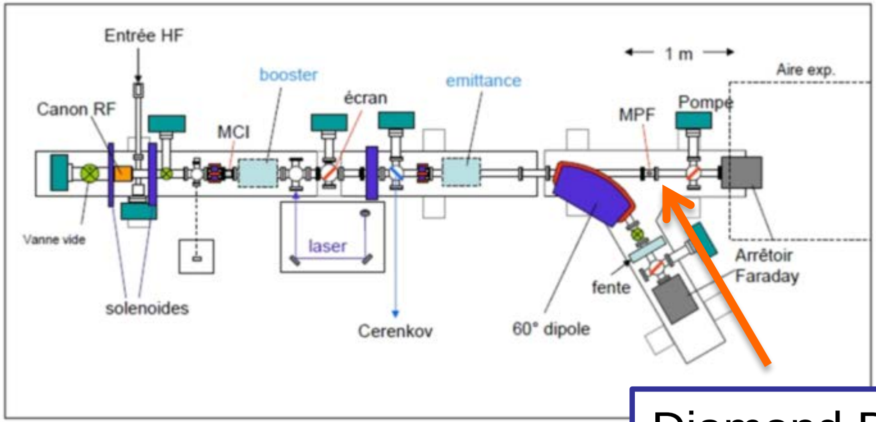
Diamond detector test at PHIL

Test of fast remote readout (fast heliax coax cable + high BW scope) with particles at end of beam line, using existing single crystal 4.5x4.5mm CVD diamond pad sensor

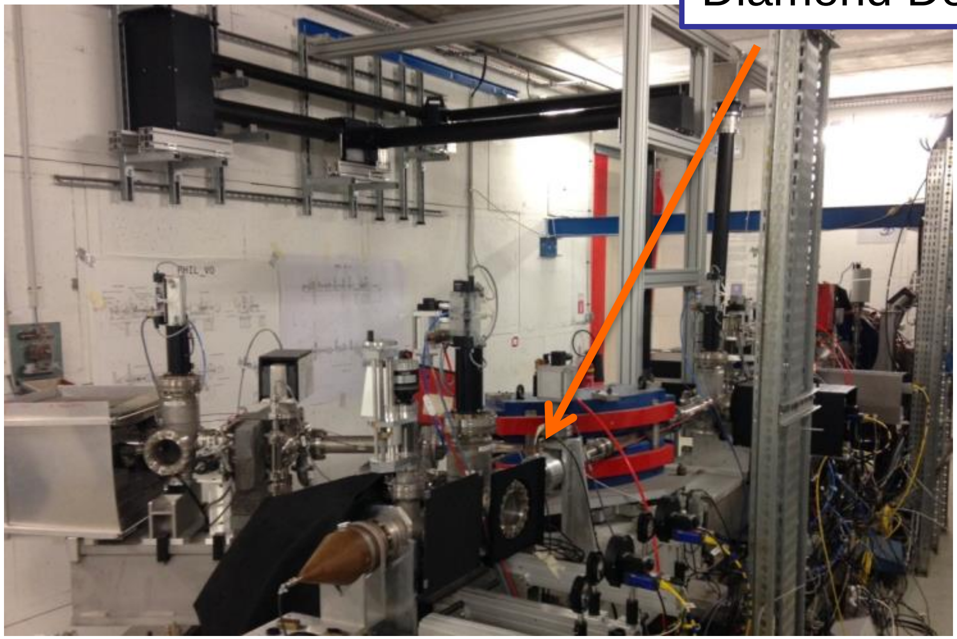
In-vacuum single crystal CVD diamond sensor profile scanner -> for PHIL and ATF2 diagnostic ("plug compatible" design)

PHIL @ LAL

ATF2 @ KEK

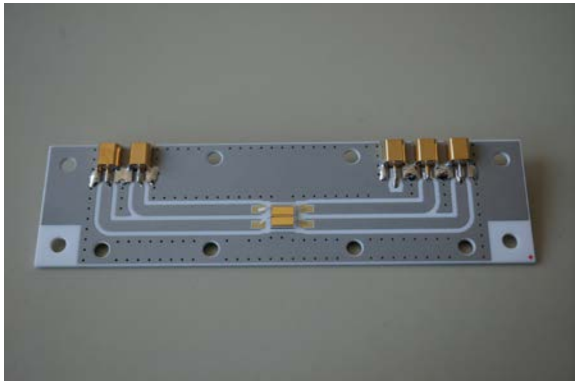


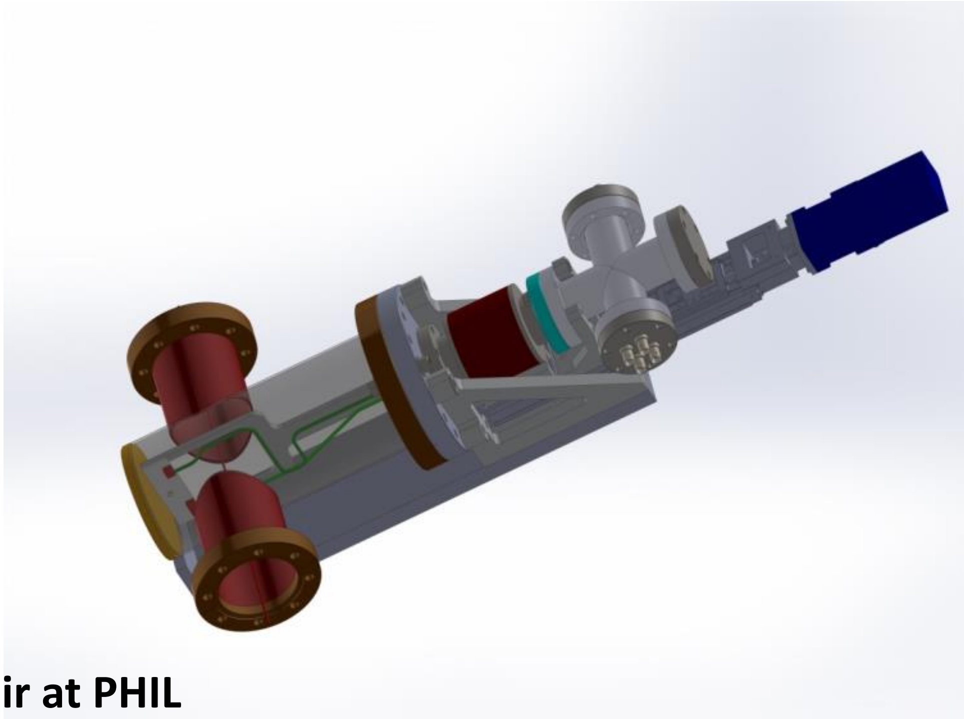
Diamond Detector



Same "plug compatible" design for PHIL and ATF2: fabrication will be completed in April 2014 before testing in May-June at PHIL.

In-vacuum diamond halo sensor





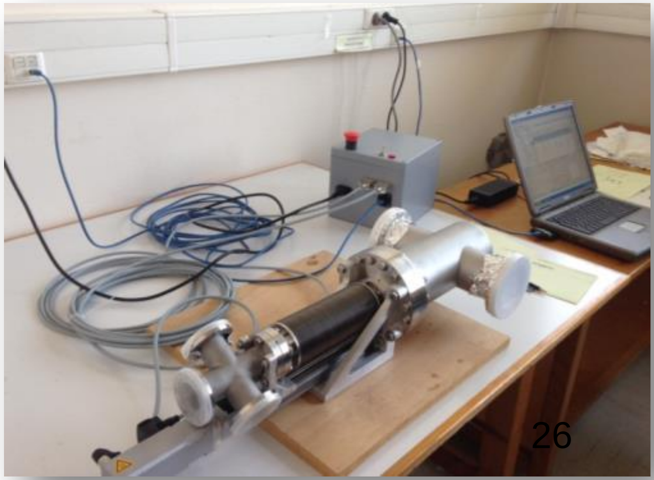
✓Several tests of diamond detector done in air at PHIL

✓S/N ratio of these measurements needs to be studied

✓Two sets (diamond sensor + mechanics) is ordered for application in vacuum → one for PHIL, another for ATF2. Plan test at PHIL June 2014 and install at ATF2 in September

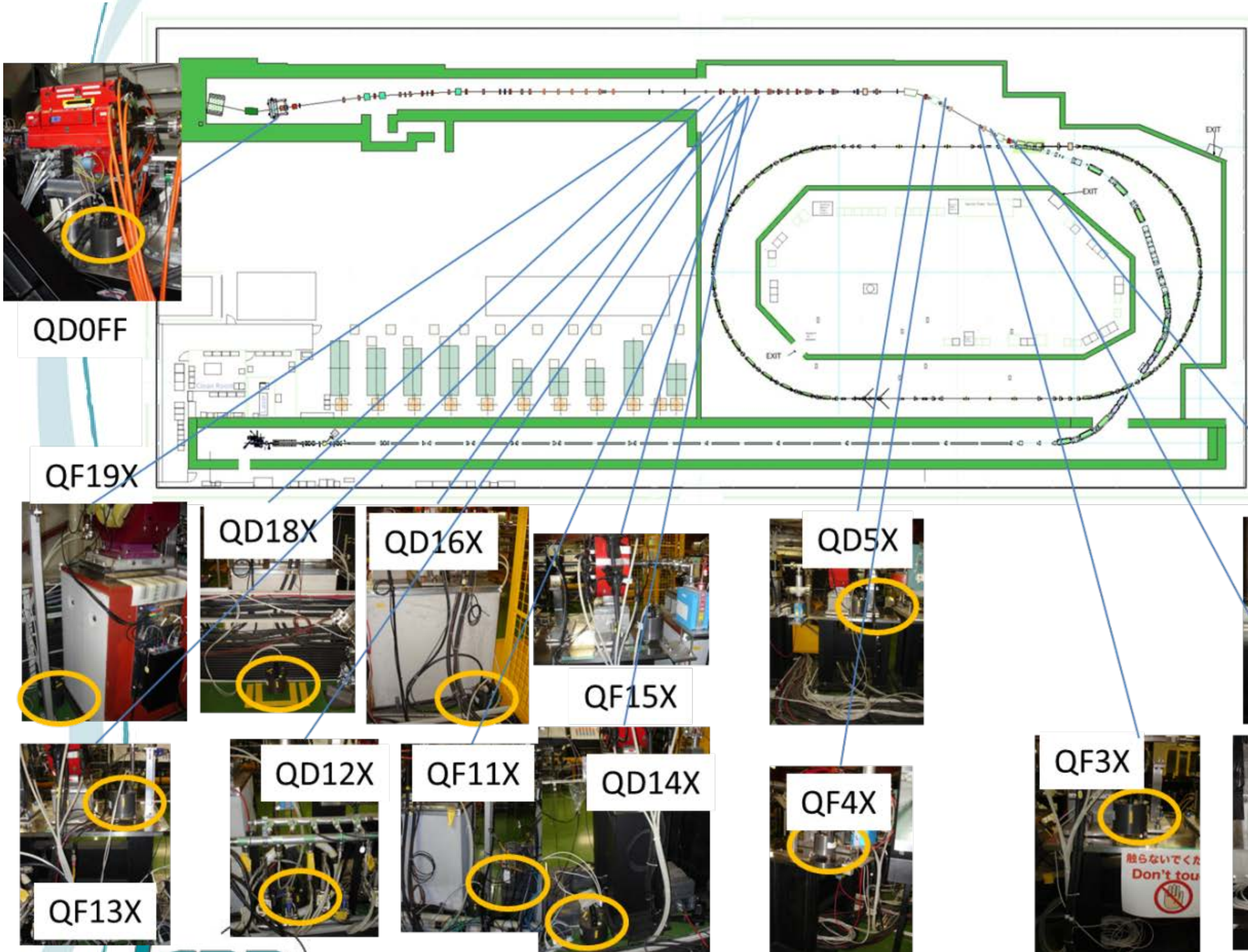
✓Proposal for horizontal & vertical moveable halo collimators being prepared with IFIC group

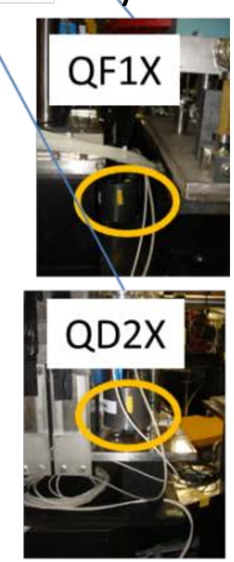
✓Simulation (BDSIM, CMAD) and analytical work for halo modeling



GM sensors

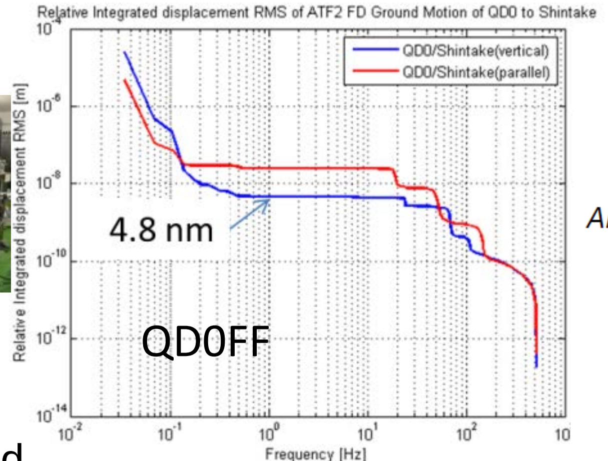
14 GM sensors have been installed in EXT and FD



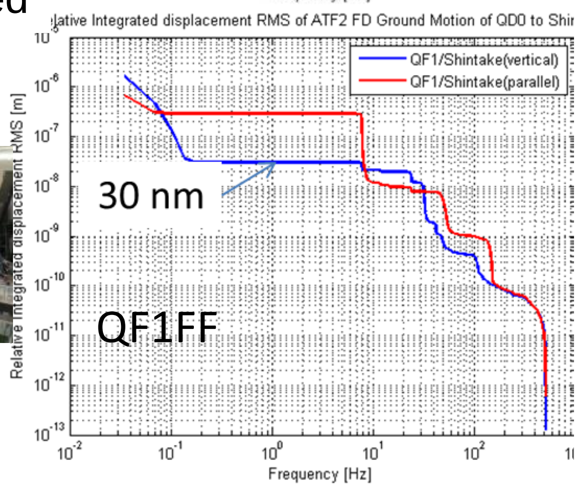


- Measurements are available
- BPM and ground motion data have been taken in parallel.
- Setup works very well.

System has also been used for Relative Displacement studies at FD



QF1 replaced



Presented by Okugi-san (Sept 27, 2013)

Andrea presented the FD magnet position jitter at ATF2 meeting on 8/30/2013

2013 by Andrea JEREMIE (same analysis)	Tolerance	Measurement (between QD0)	Measurement (between new QF1)
Vertical	7 nm (for QD0) 20 nm (for QF1)	4.8 nm	30 nm
Parallel to the beam	~ 10,000 nm	25 nm	290 nm

Outside tolerance for 2% effect on beam!

The magnet position jitter was converted to the IP vertical beam size contribution

	QD0	QF1
Vertical	7.3 nm	12.6 nm
Parallel	0.4 nm	0.8 nm

Total IP vertical beam size contribution of magnet position jitter is 14.6 nm.
37.0 nm -> 39.8 nm (7.5% of IP vertical beam size growth)

=> Vibration mitigation under study

Goal and motivation of the ATF2 experiment

Goal

- Predict Ground Motion (GM) effect on beam trajectory with GM sensor.
- Compare with BPM reading.

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/relaxing specification of quadrupole stabilization in CLIC)

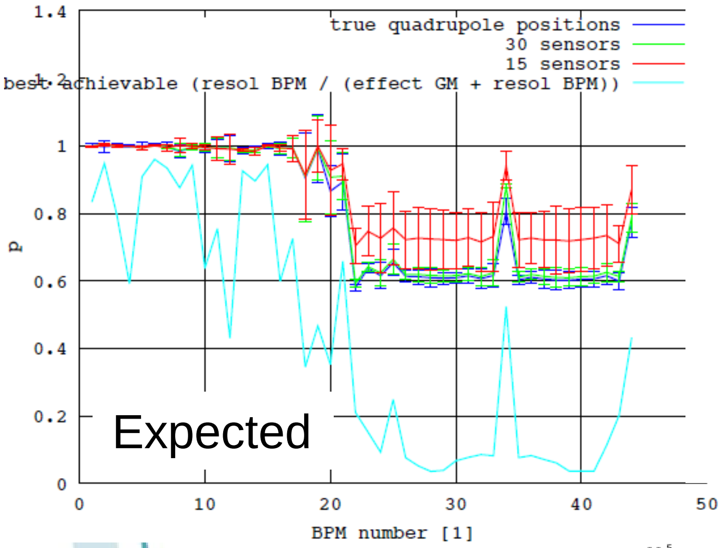
Evaluation of the results

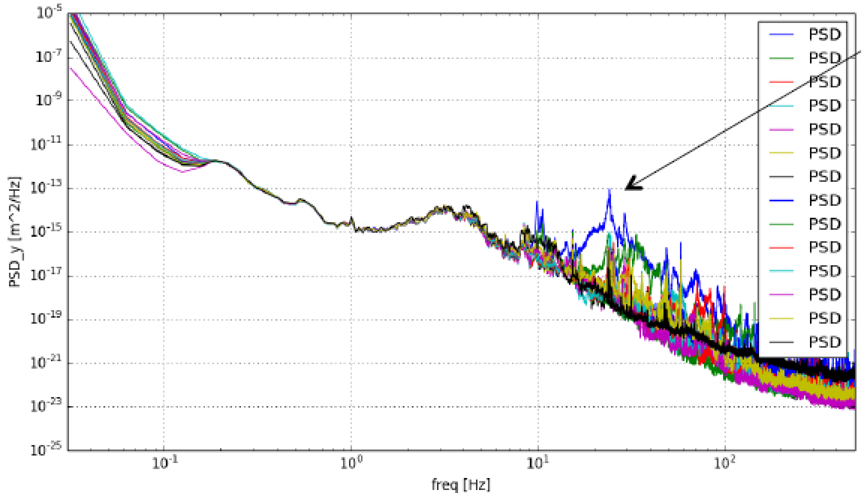
- R_1 is the GM effect obtained from GM sensors.
- R_2 is the GM effect obtained from BPMs.

$$p = \frac{||R_1 - R_2||_2}{||R_1 + R_2||_2}$$

.

- $p = 1$ if R_1 and R_2 independent.
- $p = 0$ if $R_1 = R_2$ (ideal case).
- The lower p is, the best is the determination from the GM sensors.

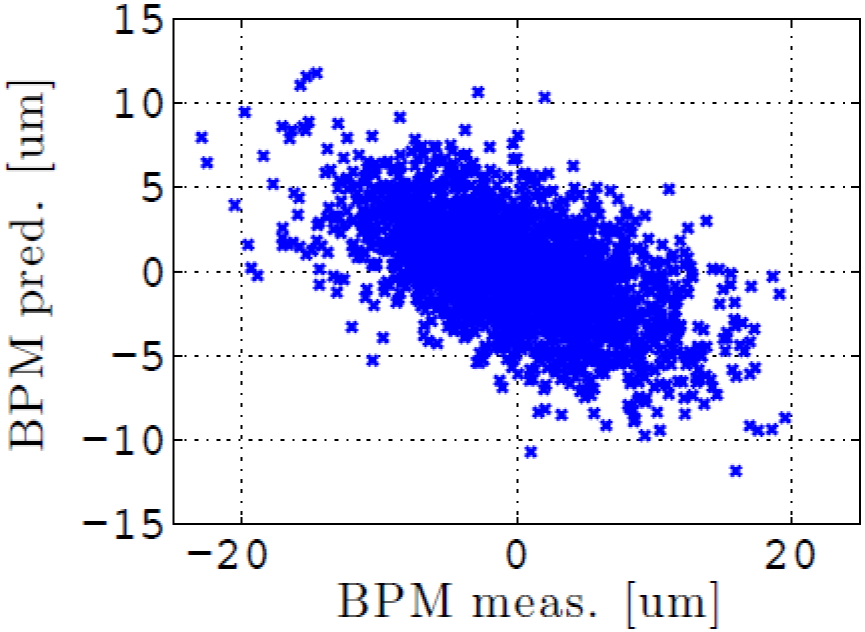




Identified spot in ATF2 where GM signal higher, thus better suited for correlation studies

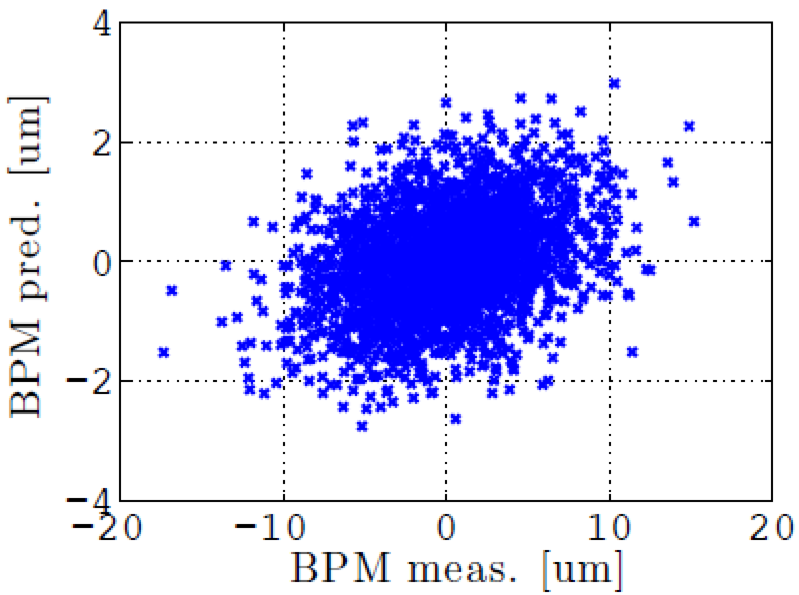
Correlation plots of measured and predicted BPM motion for the most favorable BPMs

QM18X (horizontal)



$r_x = 0.56$

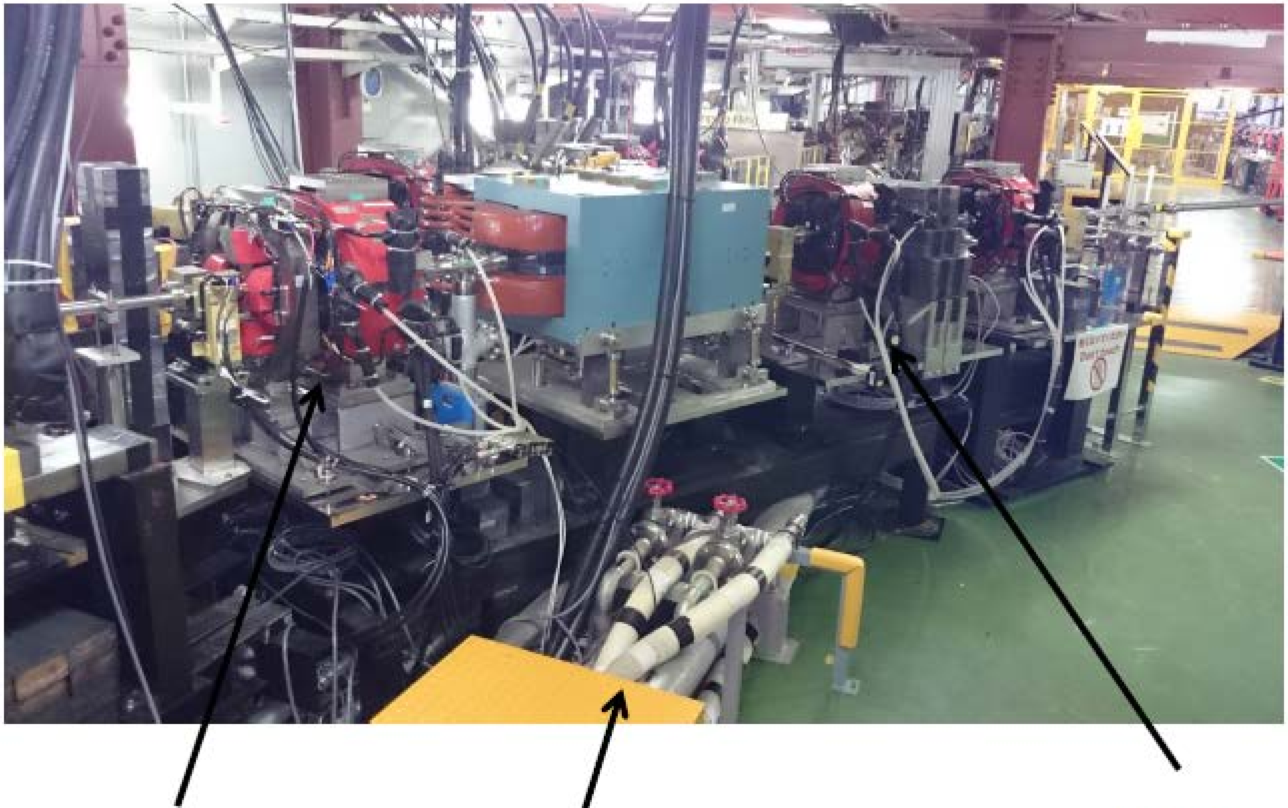
QM12X (vertical)



$r_y = 0.34$

Made possible thanks to work with KEK on improved synchronisation signal

Region with strong ground motion source



- Two noticable things:

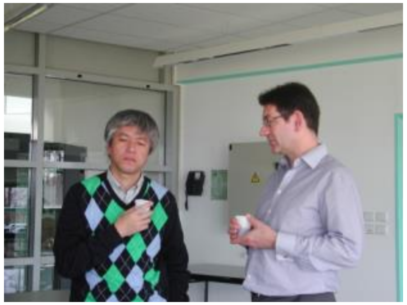
1. Water pipes under girder (probably touching at one point)
2. Heavy objects one the girder (lead bricks, Dipole magnet). This could lower resonance frequency.

Plans:
- new instrumentation will help determine a better “machine” model
- Identify higher vibration source
  - Move sensor from girder to top of quadrupole
  - Turn off cooling water

Joint France-Japan-Korea project!

FJPPL-FKPPL ATF2 Workshop in Annecy March 2014






Common integration work at KEK



2013 Report

- KEK/ATF2: Routine vertical beam size at low intensity of 55nm
- KNU: IP-BPMs and associated electronics tested, updated and currently under evaluation
- LAL: IP-chamber installed at ATF2 IP, piezo movers operational; diamond sensor development and testing
- LAPP: GM sensors installed, first results under study; QF1 relative displacement measured
- Publications

Application

Plans for 2014

- KEK/ATF2: Concentrate on ATF2 Goal 2 for Nanometer beam stabilisation
- KNU: New BPM fabrication, electronics evaluation
- LAL: improve IP-BPM alignment strategy; in-vacuum diamond sensor testing at ATF2
- LAPP: Identify vibration sources and enhance correlation capabilities; QF1 vibration mitigation study

FJPPL application for 2014

Funding Request from France				
Description	€/unit	Nb of units	Total (€)	Requested to[4]:
LAPP travel to KEK and FJPPL (meetings and measurements with sensors and beam)		2 travels	5000	IN2P3
LAL travel to KEK and FJPPL (meetings, installation work, beam tests)		4 travels	10000	IN2P3
LAL diamond scanner transport to KEK		1 transport	1500	IN2P3
Total			16500	

Funding Request from KEK				
Description	k¥/Unit	Nb of units	Total (k¥)	Requested to:
Travel	150	3 travel	450	KEK
Visit to France	20/day	27.5	550	
Total			1000	

Additional Funding from France			Additional Funding from Japan		
Provided by/Requested to[5]	Type	€	Provided by/Requested to[6]	Type	k¥
LABEX P2IO	R&D support (2012-2014)	55000 (over 3 years)			
Total			Total		

FKPPL application for 2014

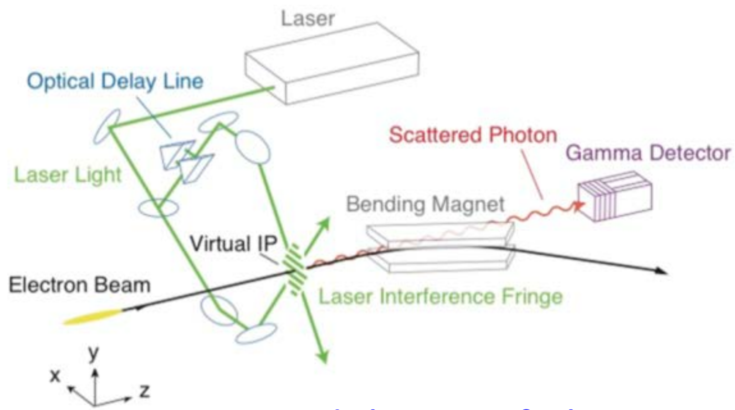
Requested LIA specific funding from France				
Description	**Euro/unit**	**Nb of units**	**Total (euros)**	**Requested to: ***
Travel to Daegu (KNU)	1000	2	2000	IN2P3
Local expenses in Daegu (5 days)	750	2	1500	IN2P3
Total			3500	IN2P3

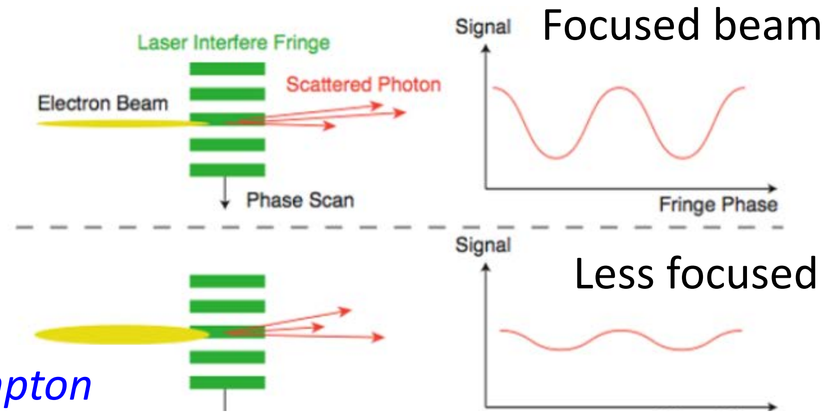
Requested funding from Korea				
Description	**Won/Unit**	**Nb of units**	**Total (kWon)**	**Requested to: ****
Travel to LAL for meeting	1000	1	1000	KNU
Local expenses in LAL (5days)	750	1	750	KNU
Total			1750	

backup

"Routinely" produce 65 nm beams at ATF2!

Shintake Monitor: essential for beam tuning



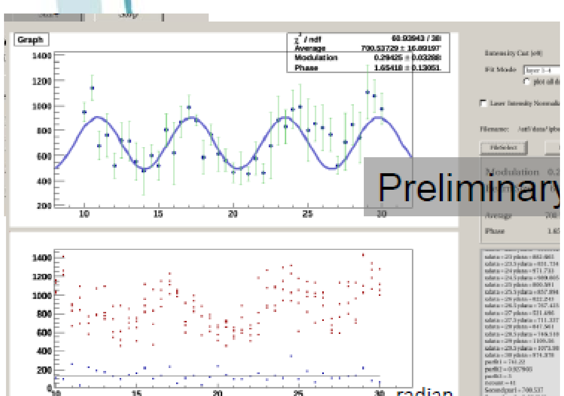


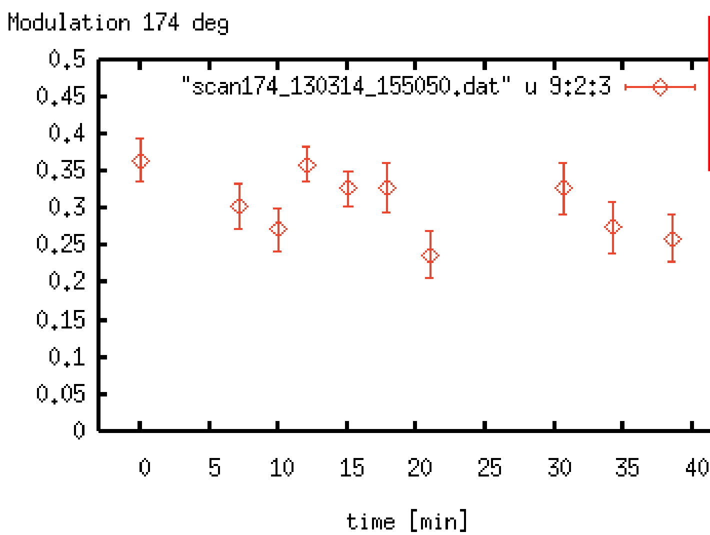
Modulation of photon rate by Compton diffusion on interference fringes

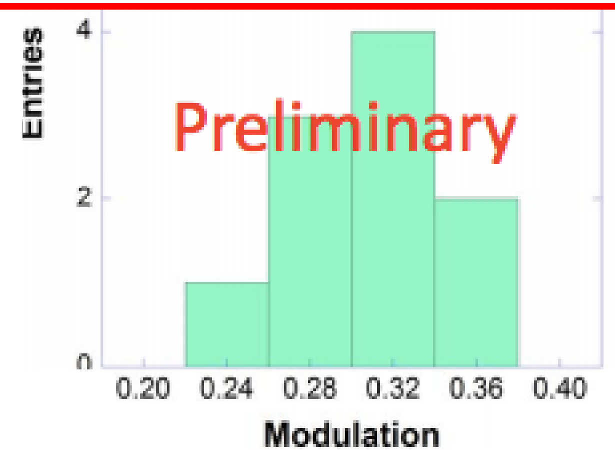
2013/03 /14

after IP-BSM roll alignment
after IP-BSM pitch alignment

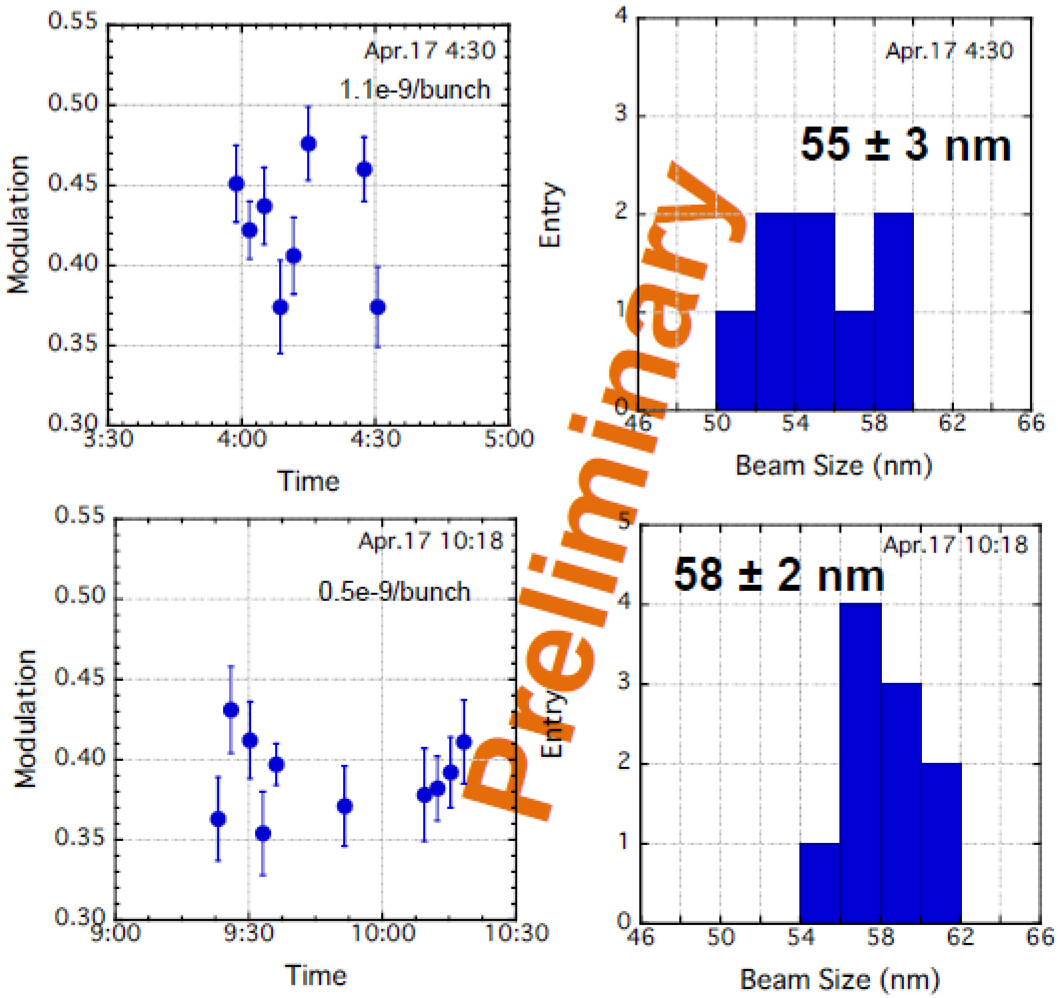
M ~ 0.306 ± 0.043 (RMS)
correspond to σy ~ 65 nm







Successive Beam Size Scans; Apr. 2014



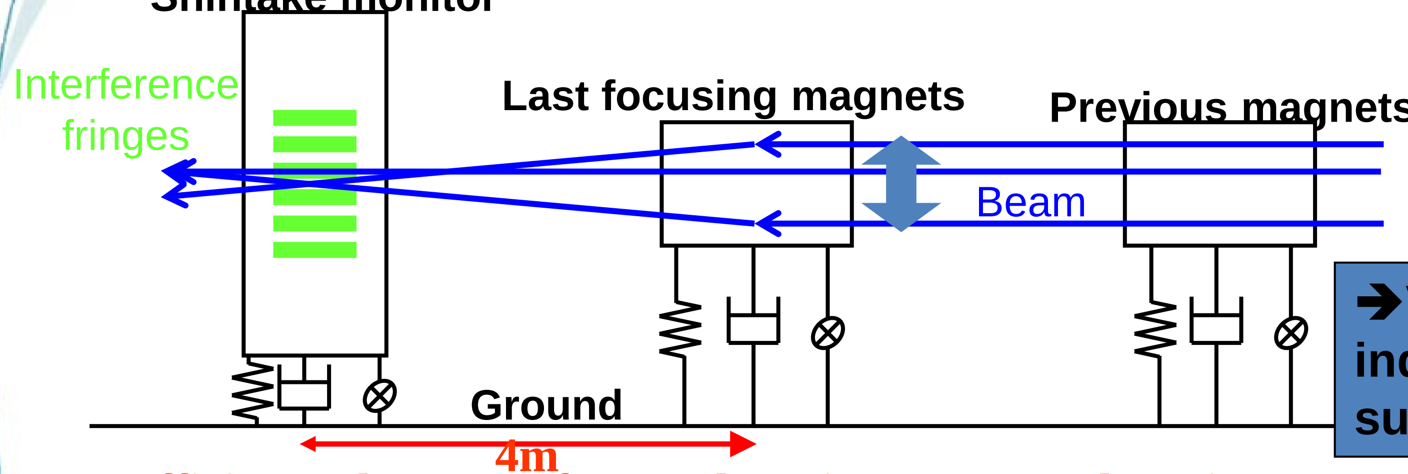
Two sets of successive scans were conducted over 0.5~1.5 hours after linear/non-linear knob scans.

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

Observed higher modulation
→ **Beam size 50 ~ 60 nm**

Continue the R&D toward the goal-1: ~37 nm.

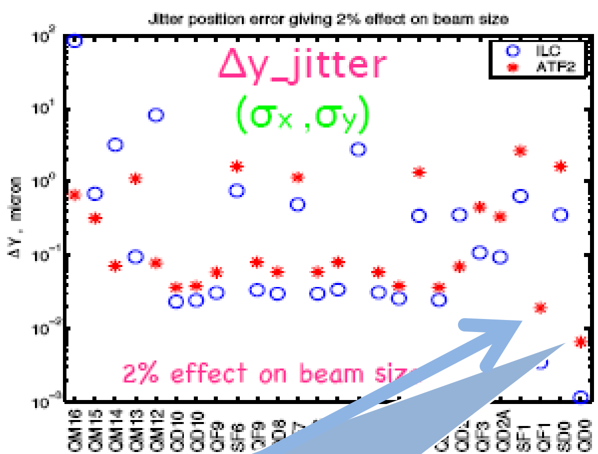
ATF2 – Strategy of stabilization

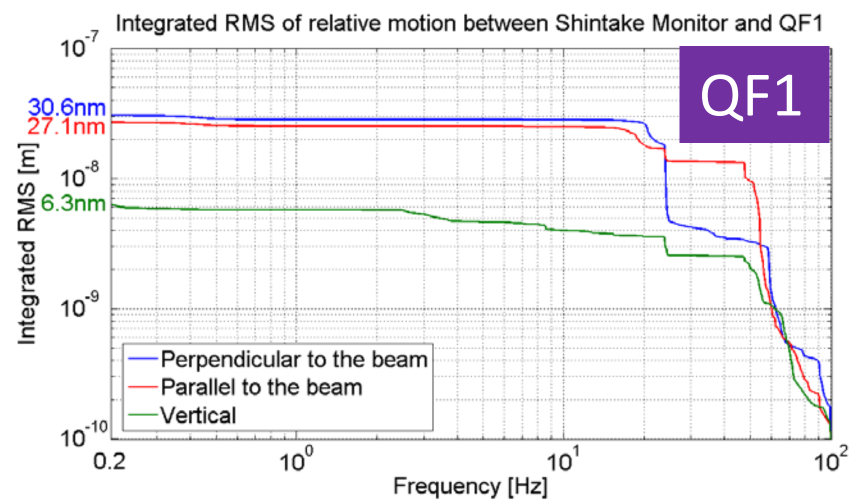


➔Very rigid and independent supports

Efficient coherence of ground motion: measured on site

ATF2 Proposal vol 1





For QD0 at ATF2: 7 nm tolerance
For QF1 at ATF2: 20 nm tolerance

Measurements by B.Bolzon in 2008: better than tolerances
QD0 to IP relative displacement of **4.8 nm and QF1 of 6.3 nm**

IP-BPM requirement

- **prototype system**
  - about 5 nm resolution was evaluated (single bunch)
- **for Goal-1**
  - single bunch for jitter evaluation
  - **~ 20 nm resolution with +/- 30 um dynamic range**
  - use attenuator for BPM signals
- **for Goal-2**
  - multi bunch for intra-train feedback
    - ATF2: 2 or 3 bunches, 300 or 150 ns spacing
  - **a few um resolution**
  - no attenuator for BPM signals