ATF2 and Final Focus/MDI

A.Jeremie

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SYMME/U. de Savoie: B.Caron, C.Hernandez

LAL: P.Bambade, Shan Liu , S.Wallon, F.Bogard, O.Blanco, P.Cornebise, I. Khvastunov

And fruitful work with KEK, KNU, IFIC, IHEP, UK and CERN colleagues (not listed)

In2p3

What was done by the French teams around ATF2 and the Final Focus/MDI

- ATF2
  - Intro
  - FD support and relative displacement
  - GM feedforward test => can be used for GM survey
  - IP-BPM and chamber
  - Beam-halo evaluation (diamond detectors, simulation)
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  - New optics
  - Integrated feedback studies
  - Stabilisation
  - CLIC MDI: QD0 dummy test
- Conclusion Outlook

Major R&D Goals for Technical Design

Test Facilities

- **ATF2 - Fast Kicker tests and Final Focus design/performance EARTHQUAKE RECOVERY**
- **CesrTA - Electron Cloud tests to establish electron cloud mitigation strategy**
- **FLASH – Study performance using ILC-like beam and cryomodule (systems test)**

B.Barish

22-Oct-12
LCWS12 - Arlington, TX

CLIC R&D proposals for ATF/2/3

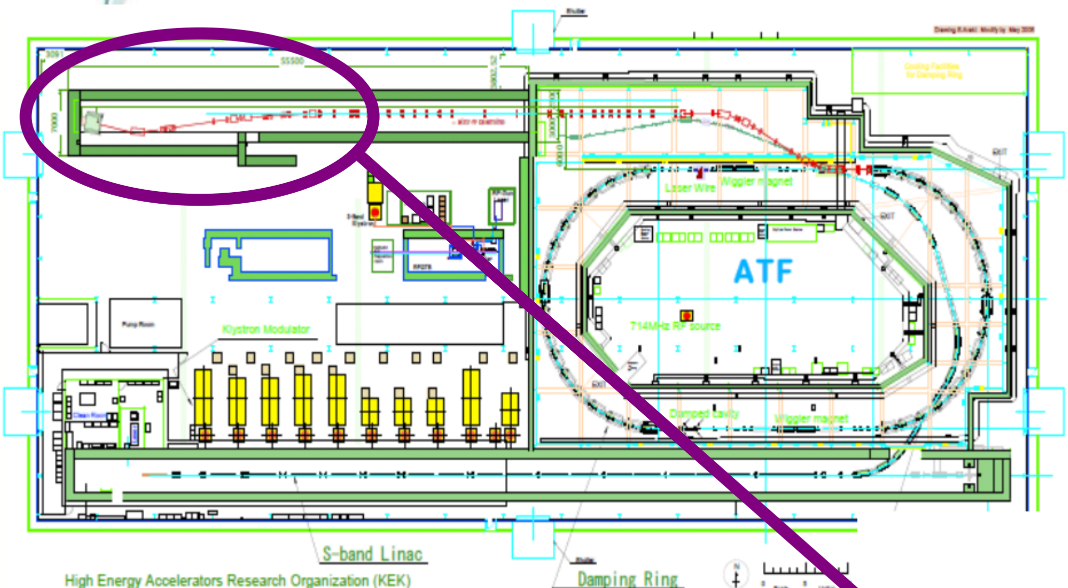
R.Tomas

- CLIC challenges are pushing technology in different areas of linear colliders
- Beam tests are a major aspect of the feasibility demonstration
- ATF facility (being half a collider!) represents a unique opportunity for the following topics:
  - **Ground motion orbit feed forward**
  - **Ultra-low beta***
  - **CLIC DR extraction kickers**

Test major items on a working accelerator!

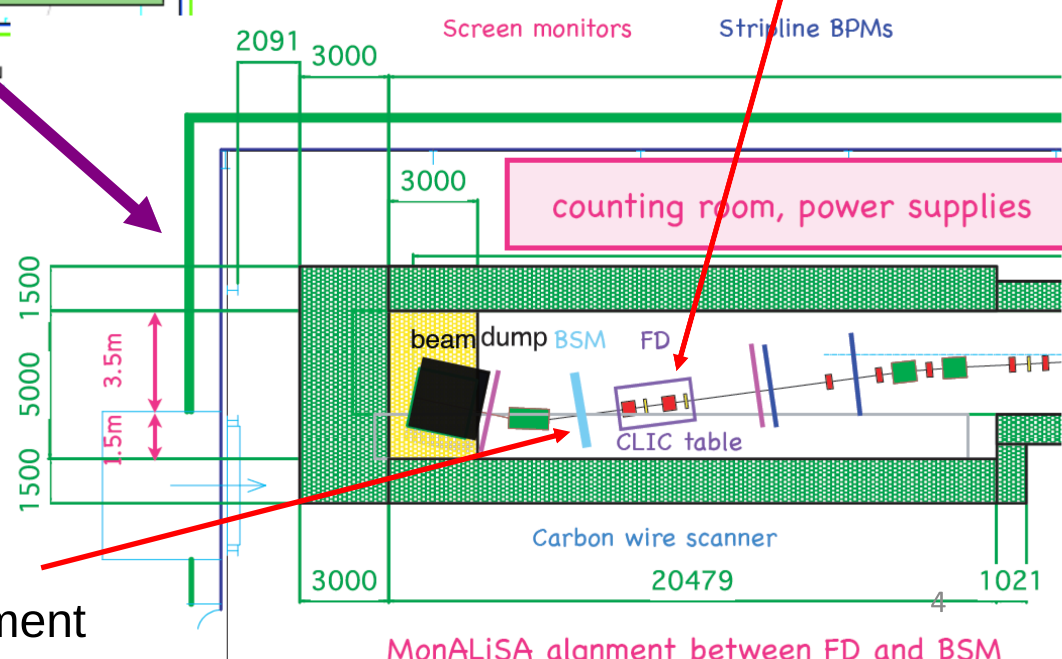
ATF2 layout

- ***Final Doublet relative displacement measurements :***



- Goal 1: 37 nm beam at the focal point in a stable and reproducible manner
- Goal 2: Stable trajectory (Δ<2nm) and ILC-like intra-train feedback

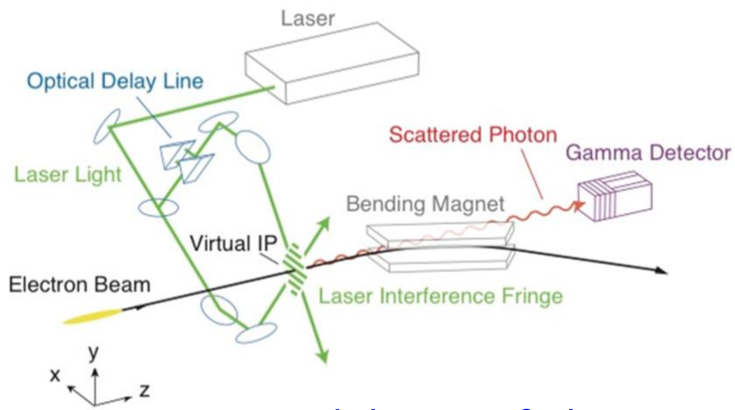
FD : Final Doublet

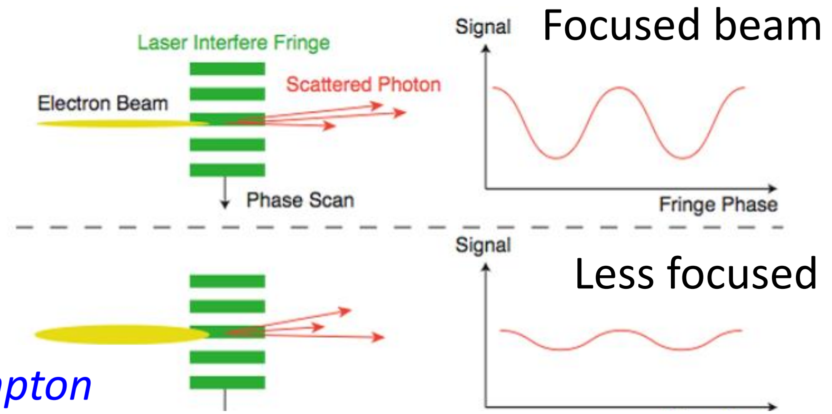


Shintake monitor :
beam size measurement

"Routinely" produce 65 nm beams at ATF2!

Shintake Monitor: essential for beam tuning

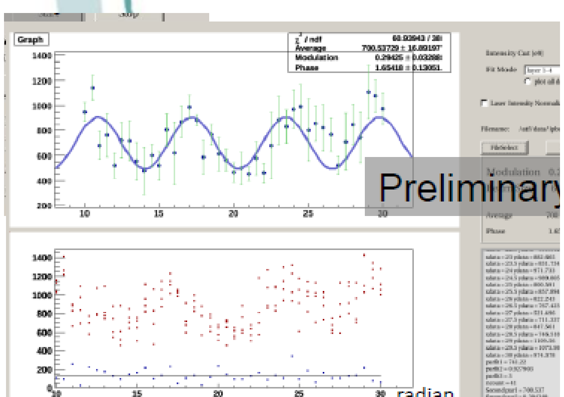


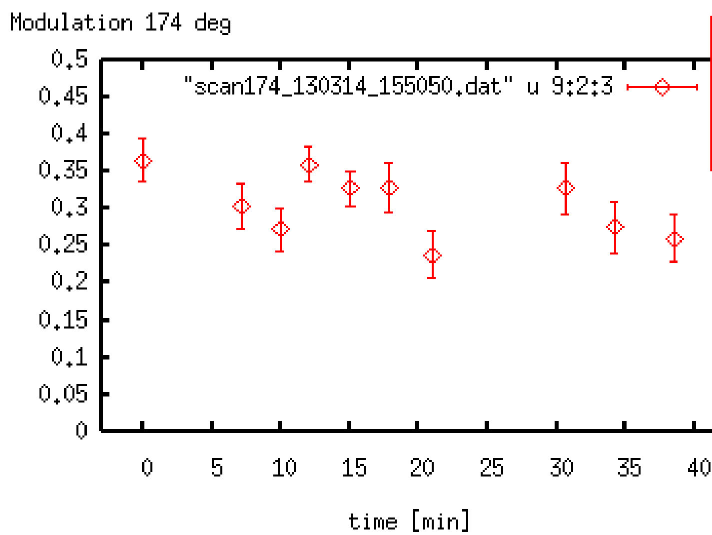


Modulation of photon rate by Compton diffusion on interference fringes

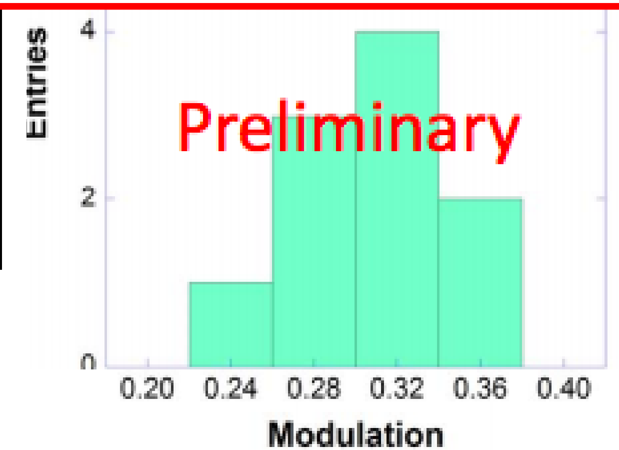
2013/03 /14

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





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



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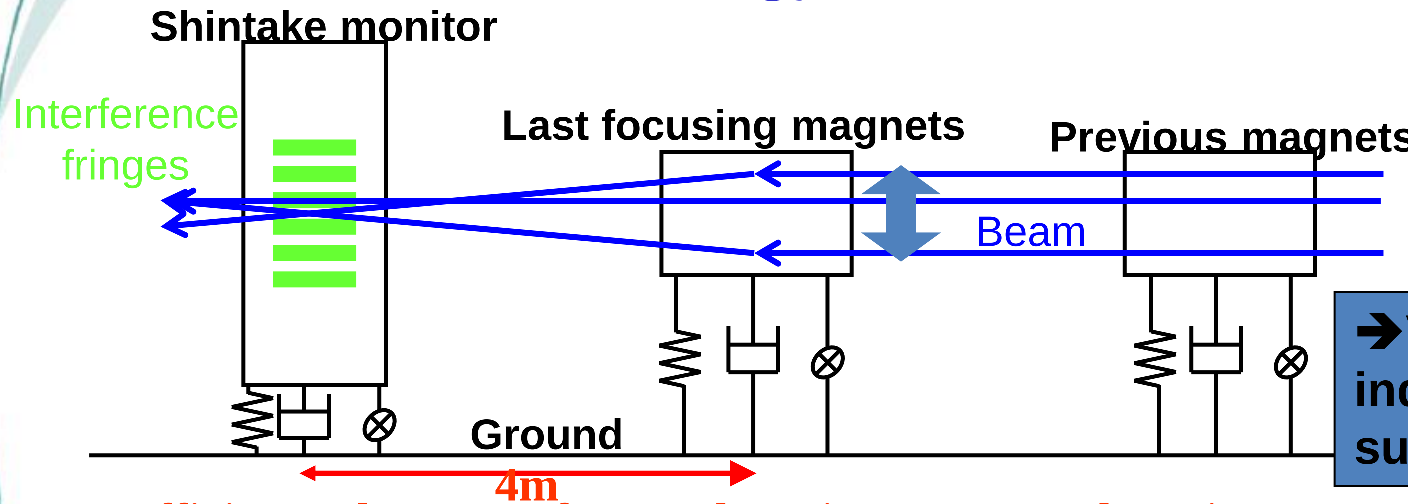
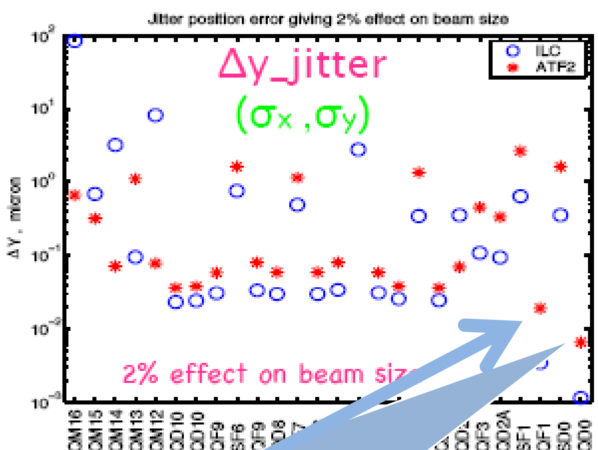
ATF2 – Strategy of stabilization

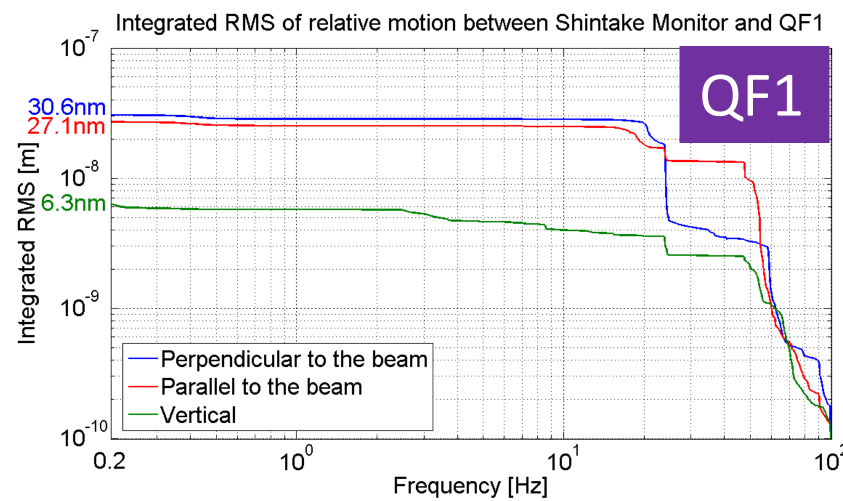


➔Very rigid and independent supports

Efficient coherence of ground motion: measured on site

ATF2 Proposal vol 1



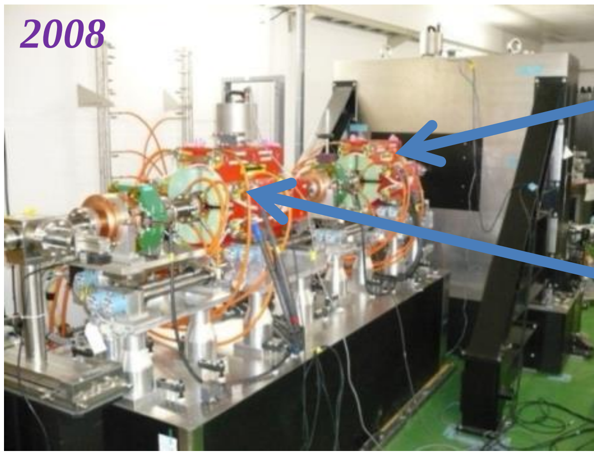


For QD0 at ATF2: 7 nm tolerance
For QF1 at ATF2: 20 nm tolerance

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

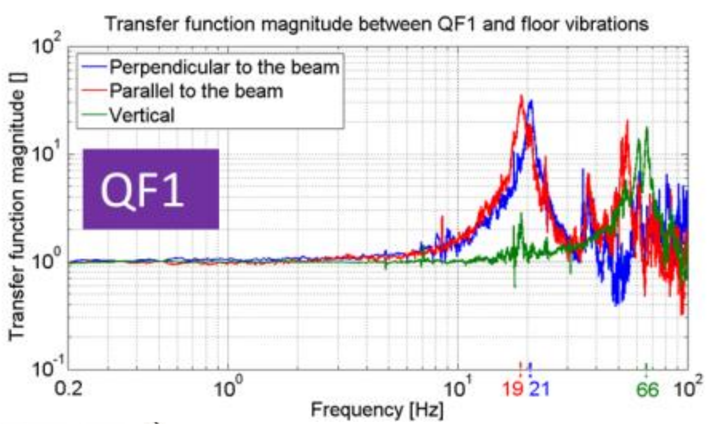
ATF2 - Why make new vibration measurements?

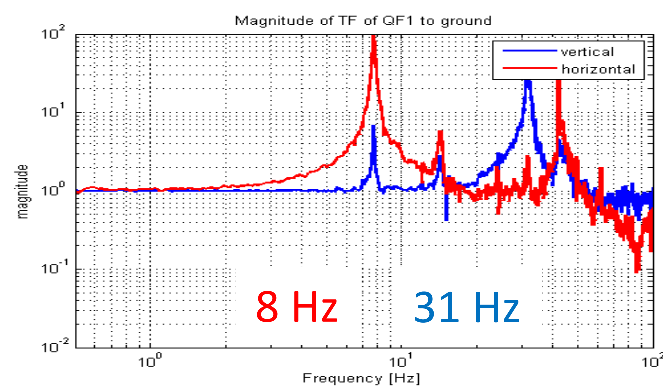
QF1FF has been replaced by a heavier magnet with better field quality and larger radius



QD0

QF1





With ground motion, relative motion at 1 Hz of Shintake to [QD0; QF1] :

2008 by B. BOLZON	Tolerance	Measurement [SM-QD0]	Measurement [SM-QF1]
Vertical	7 nm (for QD0) 20 nm (for QF1)	4.8 nm	6.3 nm
Perpendicular to the beam	~ 500 nm	30.7 nm	30.6 nm
Parallel to the beam	~ 10,000 nm	36.5 nm	27.1 nm
2013 by A. JEREMIE	**Tolerance**	**Measurement [SM-QD0]**	**Measurement [SM-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

- New QF1 : relative motion of Shintake monitor to new QF1 > Tolerance
- Outside tolerance for 2% effect on beam!
- Study new steadier support
- Effect on beam needs more evaluation

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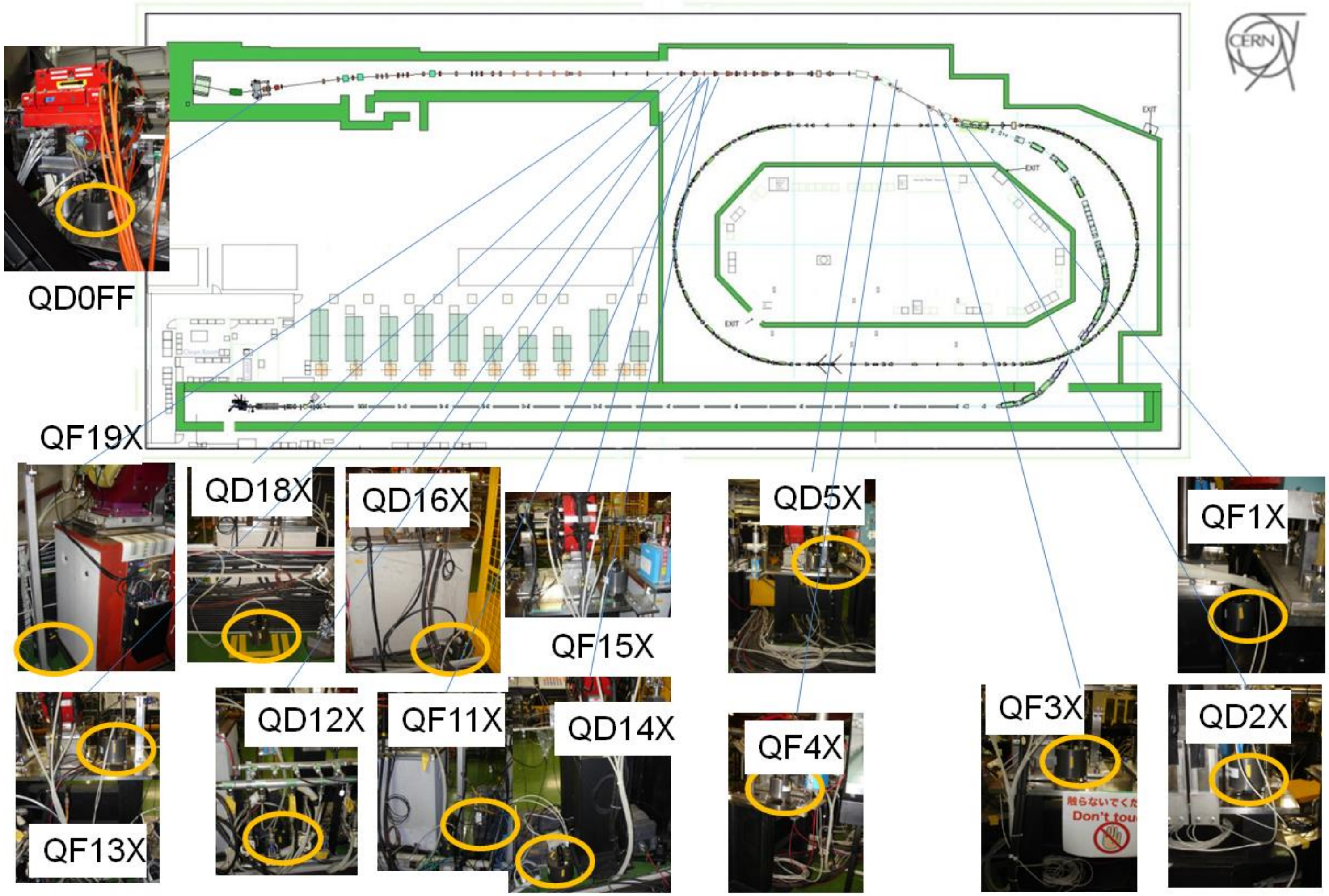
ATF2 GM feedforward test

- Goal
  - Predict Ground Motion (GM) effect on beam trajectory with GM sensors
  - Compare with BPM reading
- Motivation
  - Probably the first time GM sensors are compared to BPMs
  - Demonstrate feasibility of a feedforward based on GM sensors (feedforward will not be tested at ATF2)
  - Feedforward would allow trajectory correction based on GM sensors (get independant information between pulses)
  - Possible big savings by relaxing mechanical quadrupole stabilisation specifications at CLIC

14 Guralp 6T sensors all along ATF2



- Guralp 6T: 0,5Hz-100Hz, two directions connected (vertical and horizontal can be placed parallel or perpendicular to beam direction); sensors similar to the ones used in 2008

Simulations

Evaluation of the results

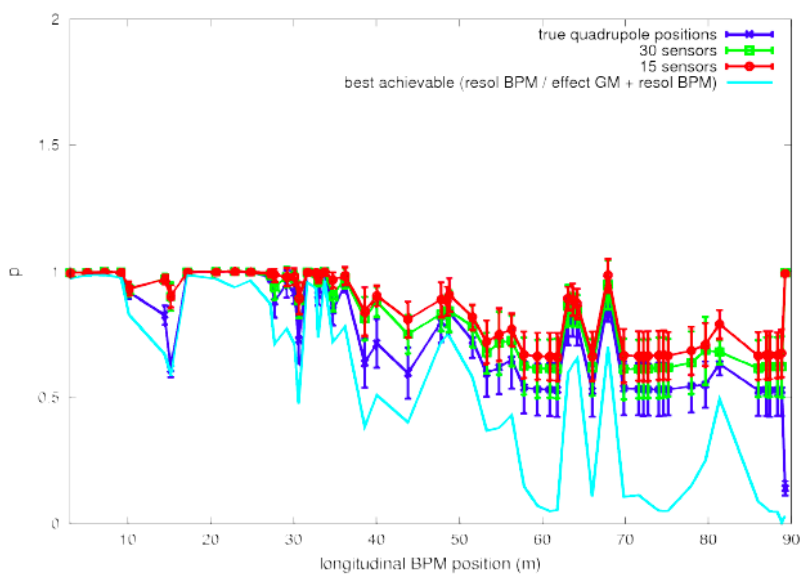
- R_1 is the GM effect obtained from GM sensors.
- R_2 is the GM effect obtained from BPMs.

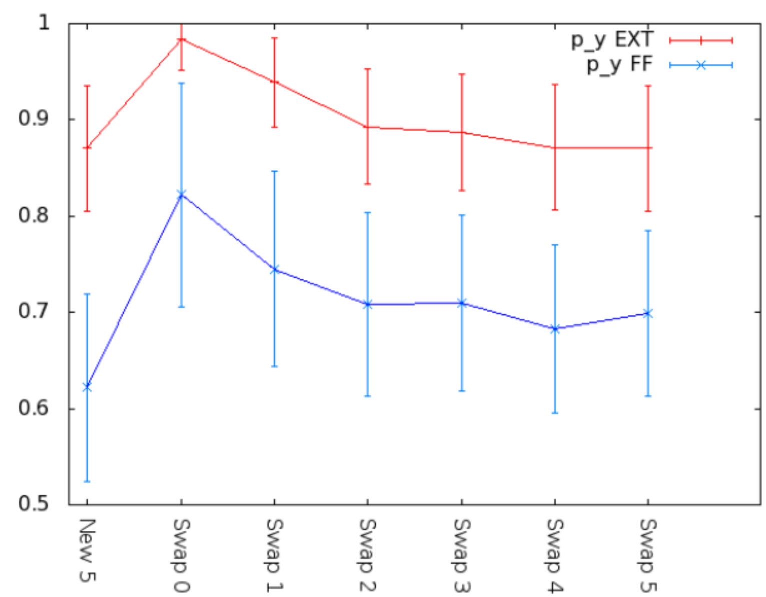
$$p = \frac{||R_1 - R_2||_2}{||R_1 + R_2||_2}$$

.

- $p = 1$ 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

- Final focus region is most sensitive
- Algorithm assumes perfect system knowledge and perfect jitter localisation
- Very optimistic to see something although effect should be visible





If the position of « good » BPMs is optimized (swapping), p could get better

Conclusion and plans

- GM sensors work well
- Synchronization between GM sensors ad BPMs is operational
- Jitter subtraction did not work on real data as expected. Possible reasons:
  - Residual model-mismatch
  - Jitter is not coming from the beginning of the beam line (kicker)
- Simulations show that jitter subtraction is critical and that swapping BPMs gives great improvement
- Plans:
  - Ask for additional BPM swapping to make jitter subtraction easier
  - => use the IP-BPM as « good » BPMs?
  - Continue to investigate jitter subtraction problem

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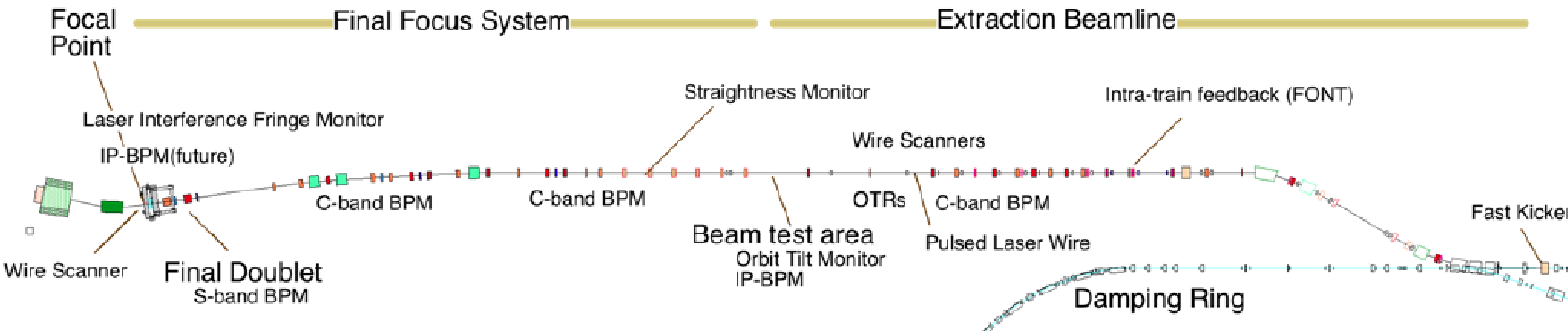
Methodology for stabilization

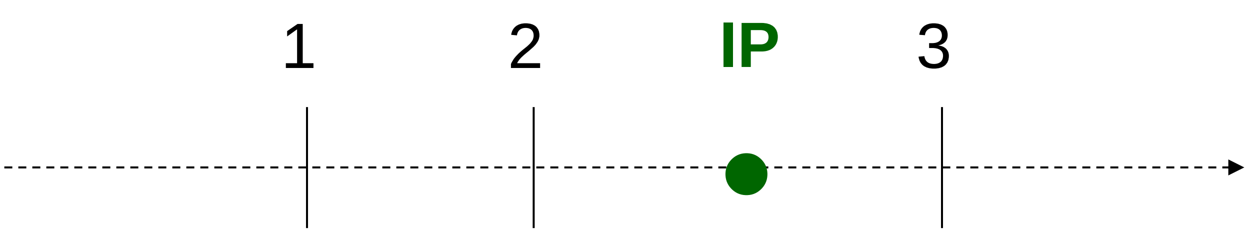


Goal 1 (beam size ~ 37 nm) **beam jitter < 10 nm**
Goal 2 (nm-scale stability with feedback) **beam jitter ~ 2 nm**

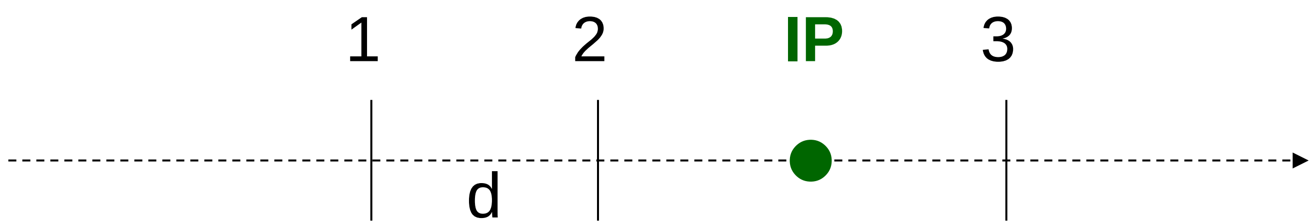
1. Measure stability at one of IP-BPMs after shifting the beam waists there
2. Infer position from measurements at the two other IP-BPMs
3. Use fast kicker just upstream to correct second bunch within ATF2 train

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

$\theta_{IP} = (y_2 - y_1) / d$ $\quad$ ξ = 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 mechanical alignment of IP-BPMs

→ 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

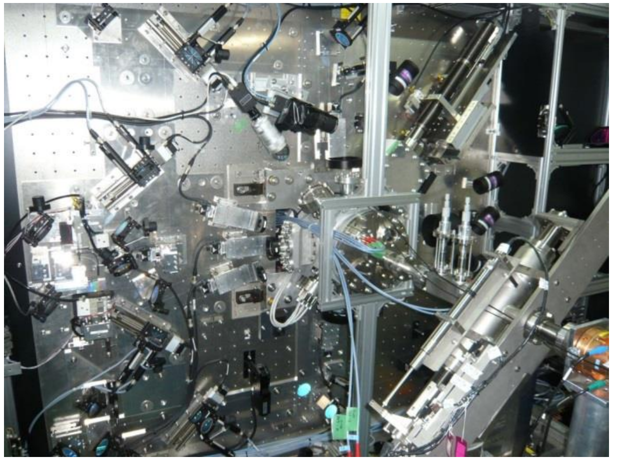
- Thermal effects
- Vibration mitigation

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

New IP-BPMs and IP-chamber

First checks after installation at ATF2-IP (done last week)

Variable attenuation (dB)	Calibration using BPM mover ((ADC/ADC)/um)	Calibration using AQD0FF mover ((ADC/ADC)/um)
0	-3.95, -3.35	-3.55
10	-1.45	-1.50
20	-0.42	-0.40



Agreement between 2 calibration methods

Presented by N. Blaskovic at ATF2 meeting

Everything is installed at ATF2, operational and taking data: experimental tests ongoing

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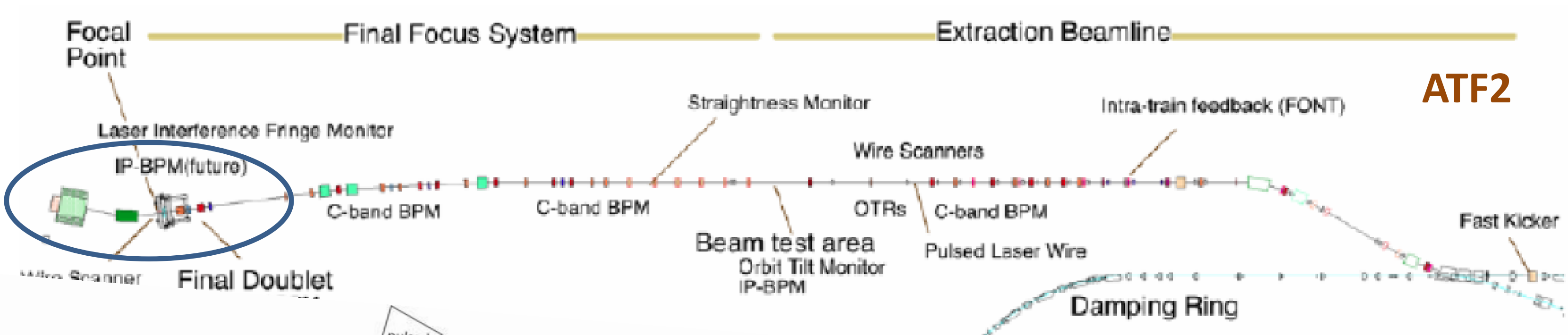
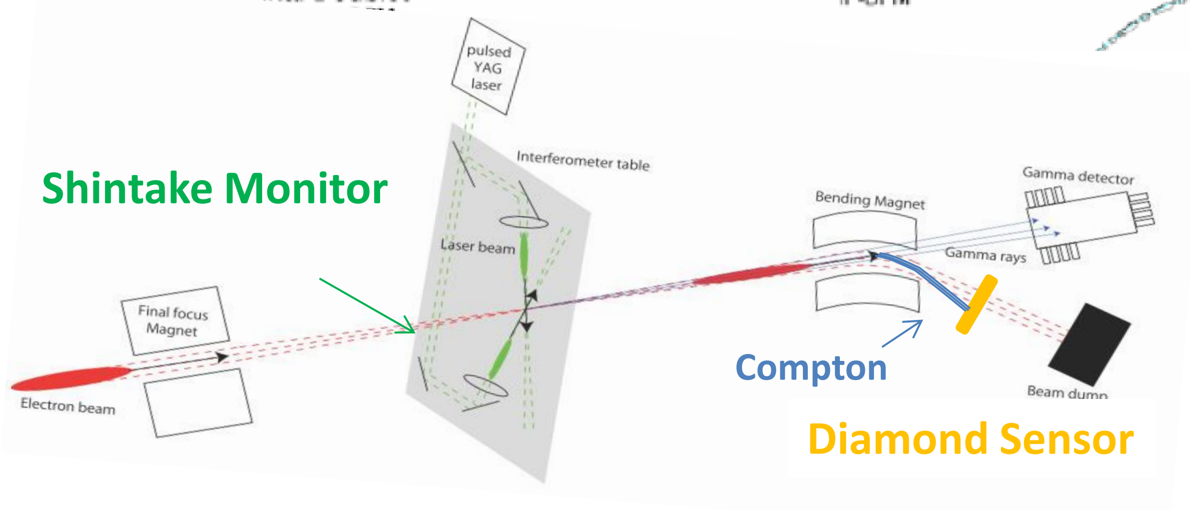
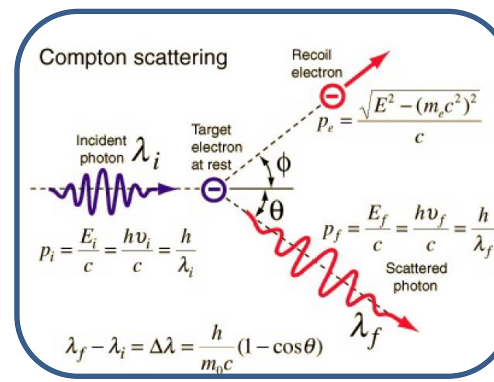


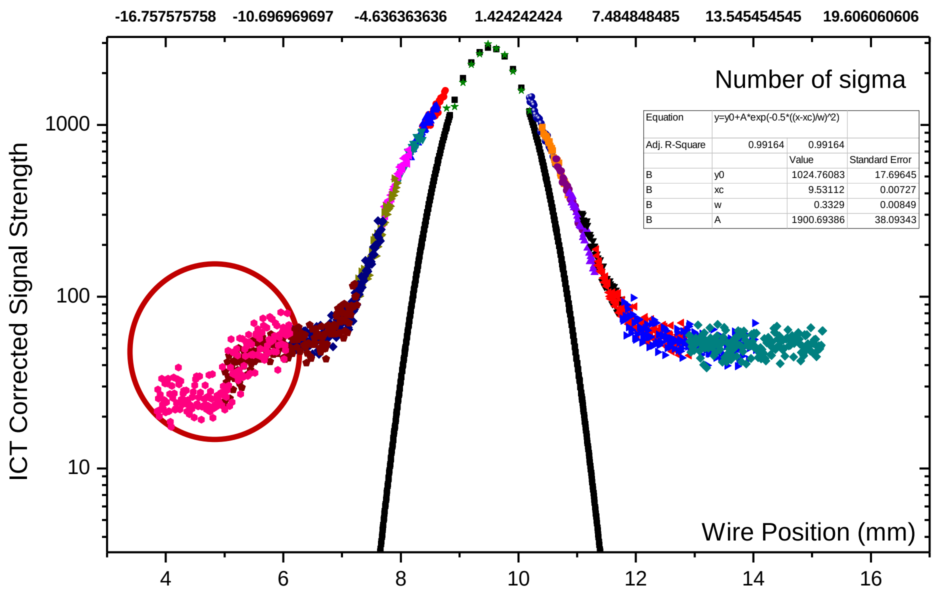




Motivations:

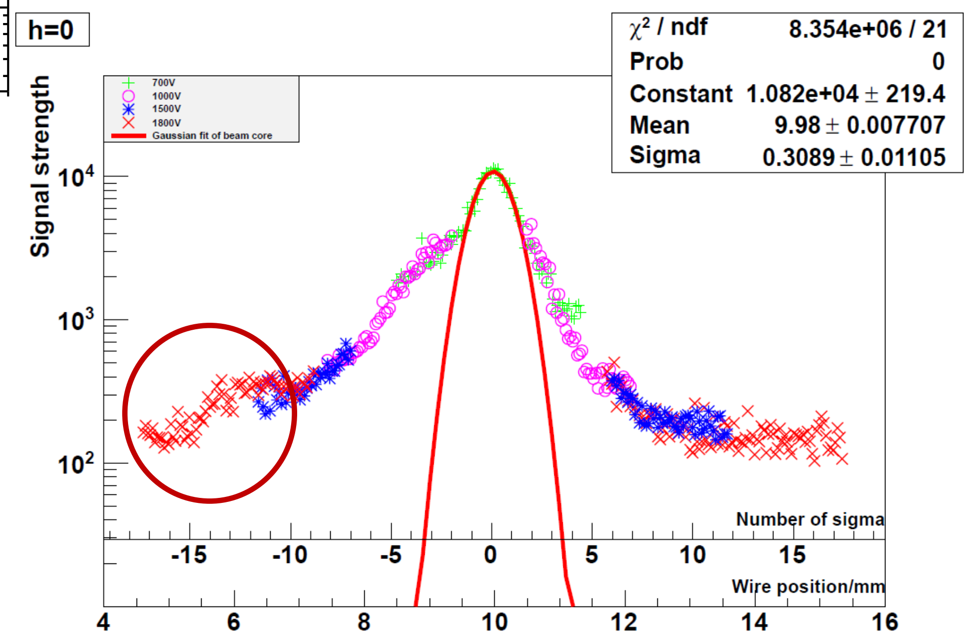
- ***Beam halo transverse distribution unknown → investigate halo model & propagation***
- ***Monitor beam halo to control backgrounds by means of collimation and tuning***
- ***Probe Compton recoil electron→ (possibly, in future, higher order contributions)***

Halo Distribution at Post-IP



→ Data taken in April 2013

Data taken in June 2013 ←



Edge of cutting almost at the same position -> -14σ

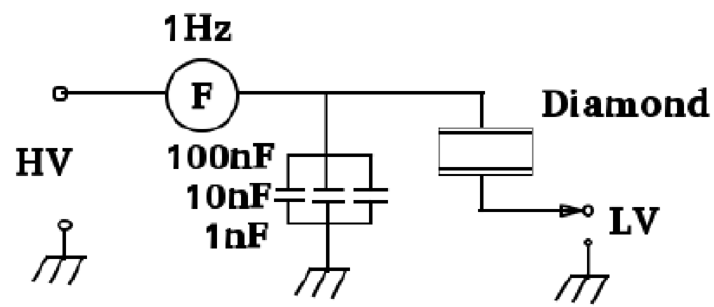
-> Beam was not centered?

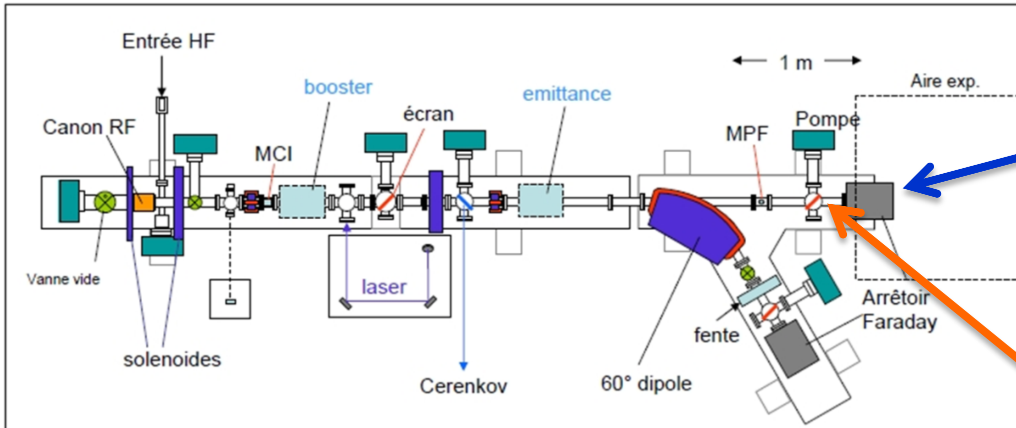
Diamond Detector Features

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*





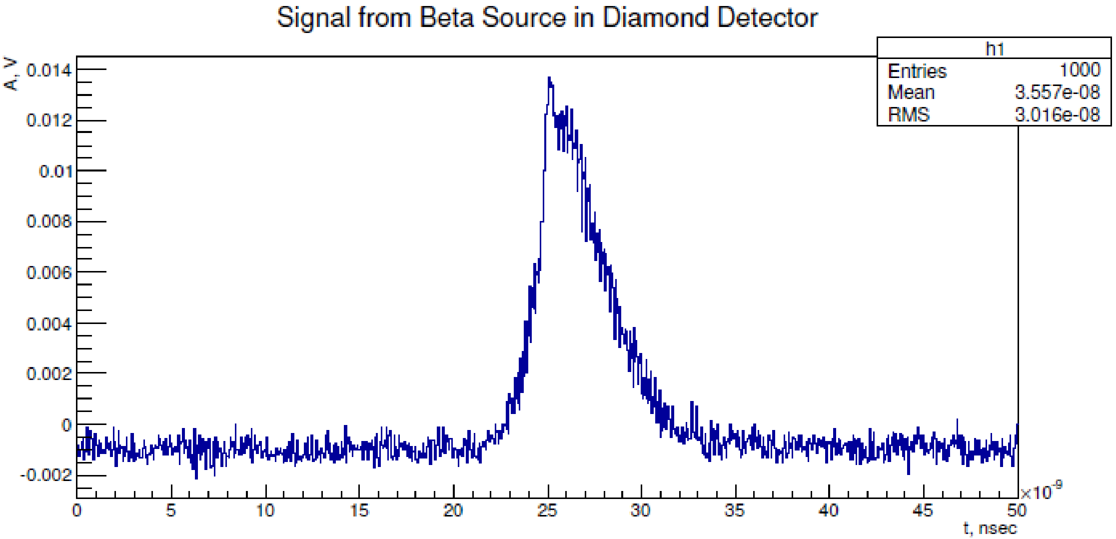
Diamond detector test at PHIL

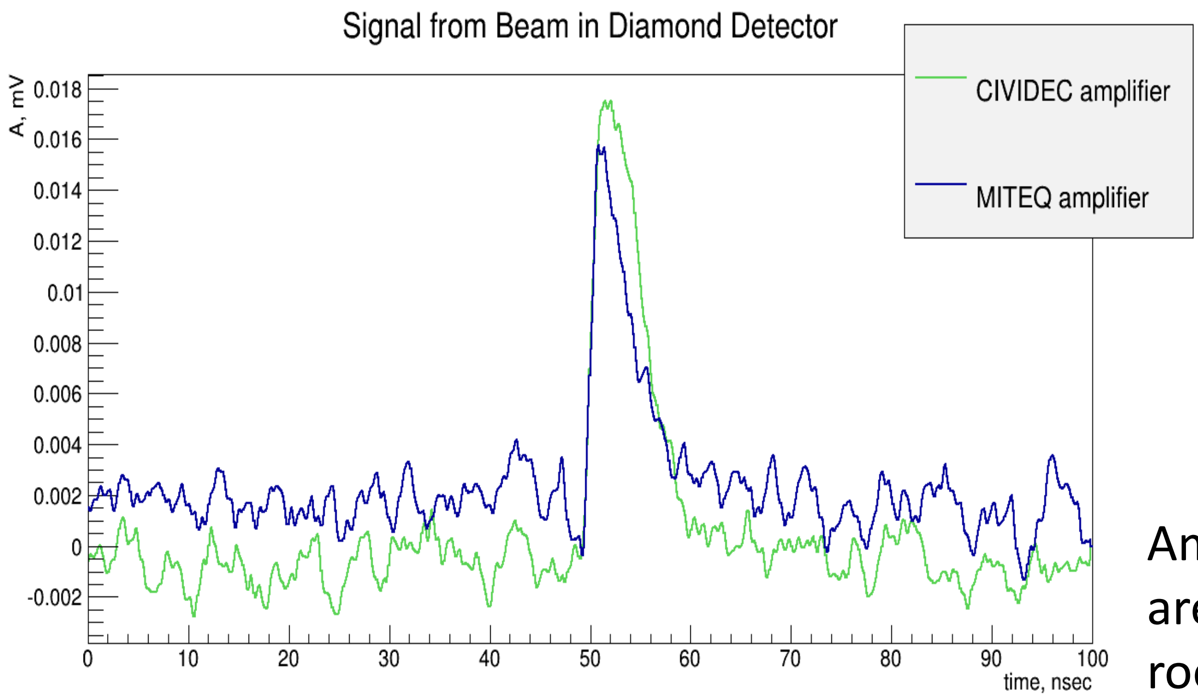
Test of fast remote readout (fast heliax coax cable + high BW scope) with particles at end of beam line, using existing single crystal 4.5x4.5mm CVD diamond pad sensor

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

~ 1 MIP from ^{90}Sr β source in a clean room

- Energy decay for Sr-Y90: 0.546 MeV and 2.28 MeV





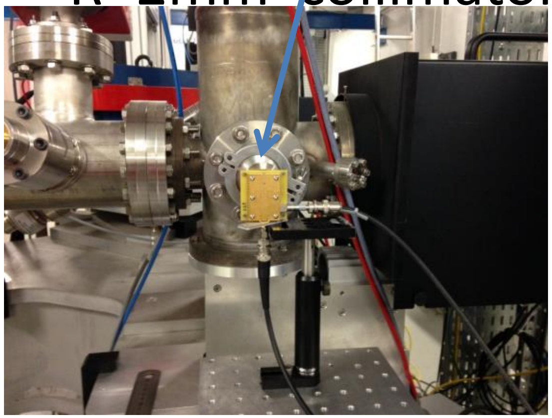
Single electrons detection at PHIL ?

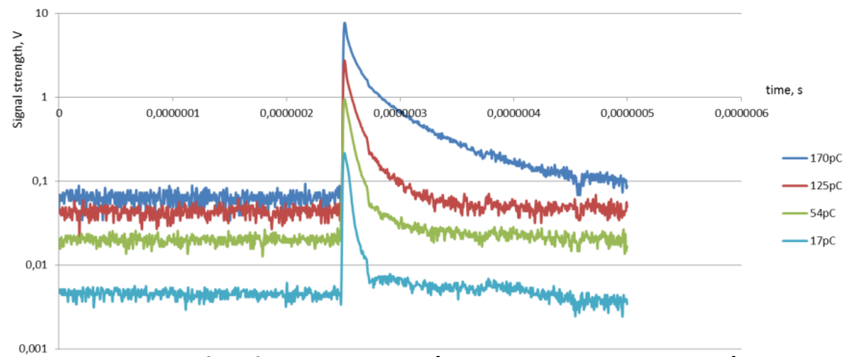
(sensor displaced 7cm from beam axis)

Amplitude and (lack of) noise are almost the same in clean room with source and at PHIL

Test without external shielding box

R=2mm collimator

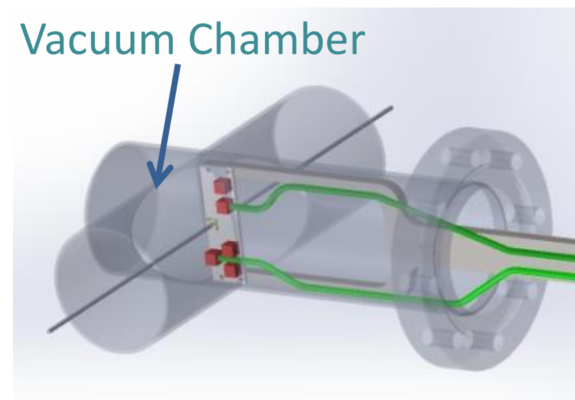




100 m ¼ heliax coax (same as FONT)
+ 24 dB attenuator before scope

Signal pulse develops tail for increasing beam charge
16 pC → 10^8 electrons

- ✓**Several tests of diamond detector done in air at PHIL**
- ✓**Observe long tail for large signals from PHIL beam → due to electronics or other physics effects ? Issue of linearity…**
- ✓**S/N ratio of these measurements needs to be studied**
- ✓**Two sets (diamond sensor + mechanics) will be ordered for application in vacuum → one for PHIL, another for ATF2. Plan test at PHIL early 2014 and install at ATF2 in June/July**
- ✓**Proposal for horizontal & vertical moveable halo collimators being prepared with IFIC group**
- ✓**Simulation (BDSIM, CMAD) and analytical work for halo modeling**



Plug-compatible design for PHIL and ATF2

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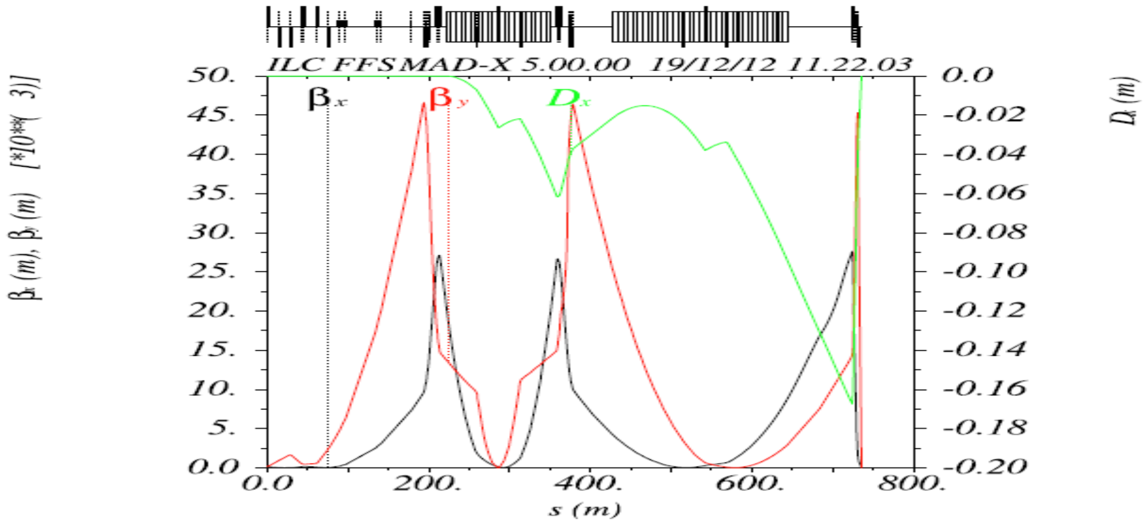
RE-OPTIMIZATION OF THE FINAL FOCUS SYSTEM OPTICS MAINLY WITH VERTICAL CHROMATIC CORRECTION

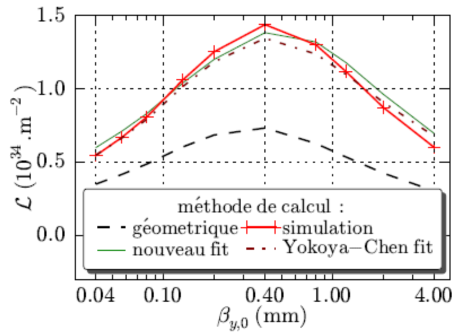
- Idea of chromatic correction mainly in the vertical plane
  - for a small enough beam energy spread and enlarged βx*

  => chromaticity on horizontal plane will be smaller
  - It may be possible to get a smaller vertical beam size with chromatic correction mainly in the vertical plane using fewer sextupoles: 2 or 3 instead of 5
  - If it works, we will also not need the first peak of β, which will reduce overall vertical chromaticity. This can lead to a simpler and more compact FFS optics.

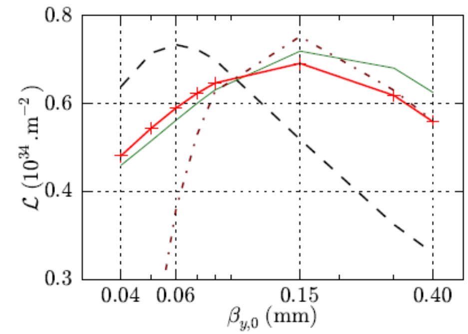


Preliminary results

Originally proposed scheme with only 2 sextupoles to correct only the vertical chromaticity would require unreasonably small bunch length to maintain the luminosity



Nominal



New

→ factor 2 loss even with σ_z reduced to 0.15 mm…

An intermediate scheme seems feasible (keeping an equivalent number of sextupoles), which retains some of advantages of flat beams (beam with “flatter” dimensions) while keeping high luminosity

- weaker and / or fewer sextupoles for easier handling of the FFS
- less beamstrahlung

It can be considered as alternative parameter set of the existing design, not a new design

There is room for optimization

If flatter beams are studied for ILC, may still consider new / simplified FFS design ideas

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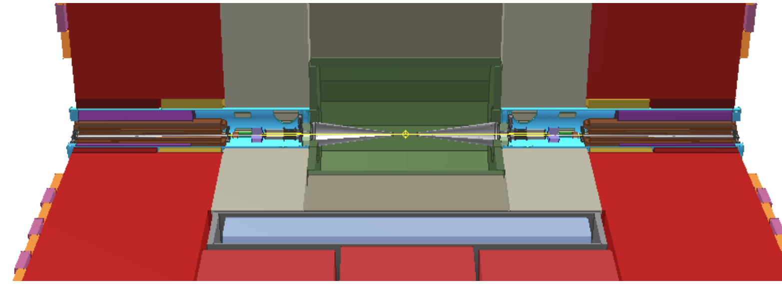
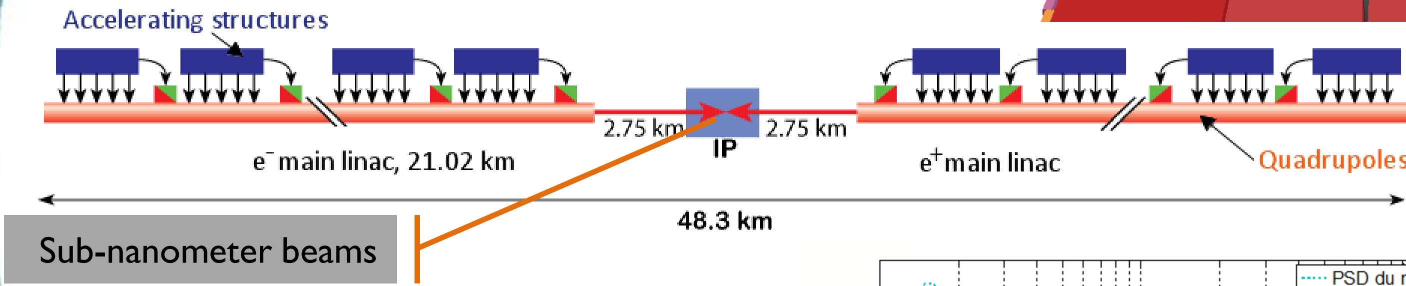
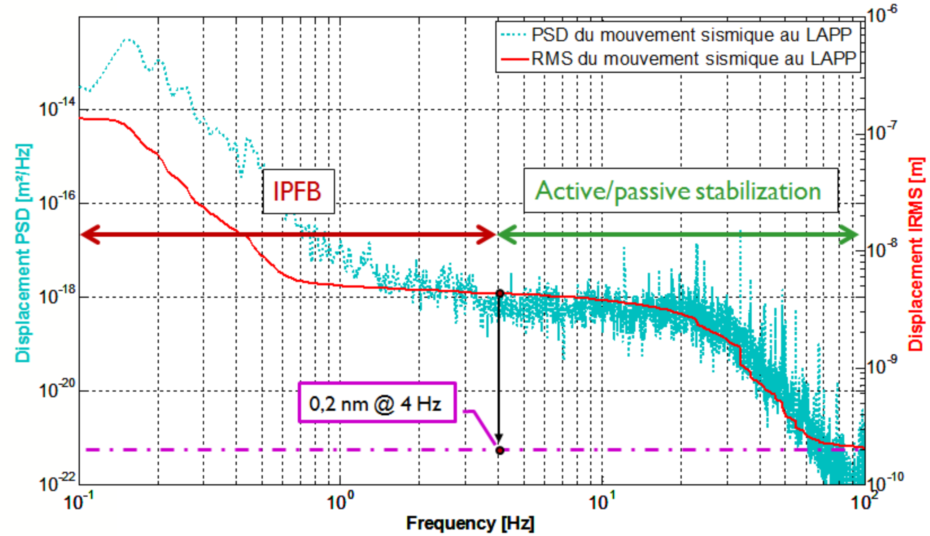


- ***Final focus : beam stabilization strategy***



$$L(\sigma_{x,y}, \Delta_{x,y}) \sim \frac{e^{-\frac{1}{4}\left(\left(\frac{\Delta x}{\sigma_x}\right)^2+\left(\frac{\Delta y}{\sigma_y}\right)^2\right)}}{\sigma_x \sigma_y}$$

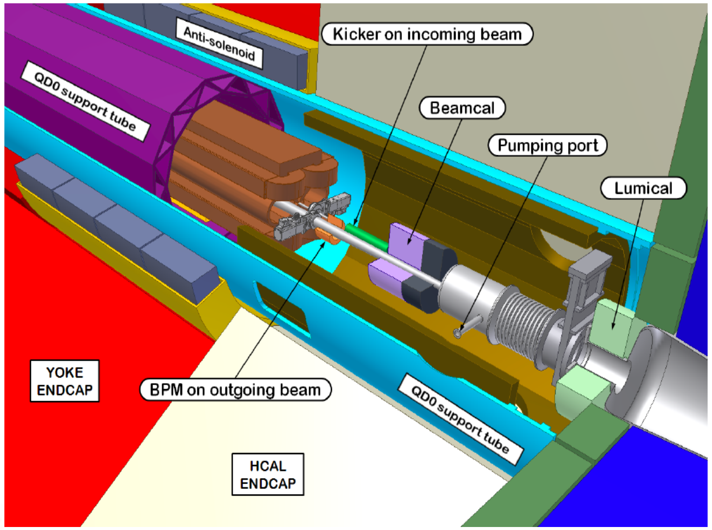


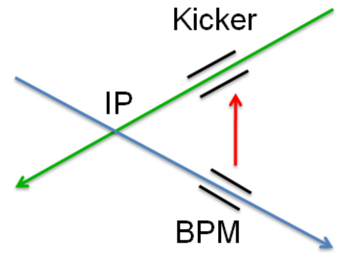
➢ At the IP (mechanical + beam feedback), we aim at **0,2nm at 0,1Hz**

- **IP Beam based feedback : already developed in collaboration with CERN since 2010**
- **Mechanical stabilization has to be achieved**

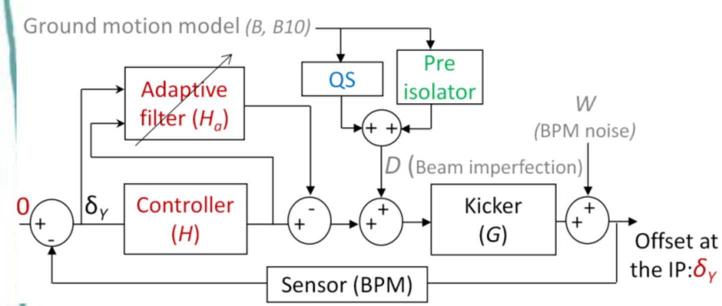
IP feedback

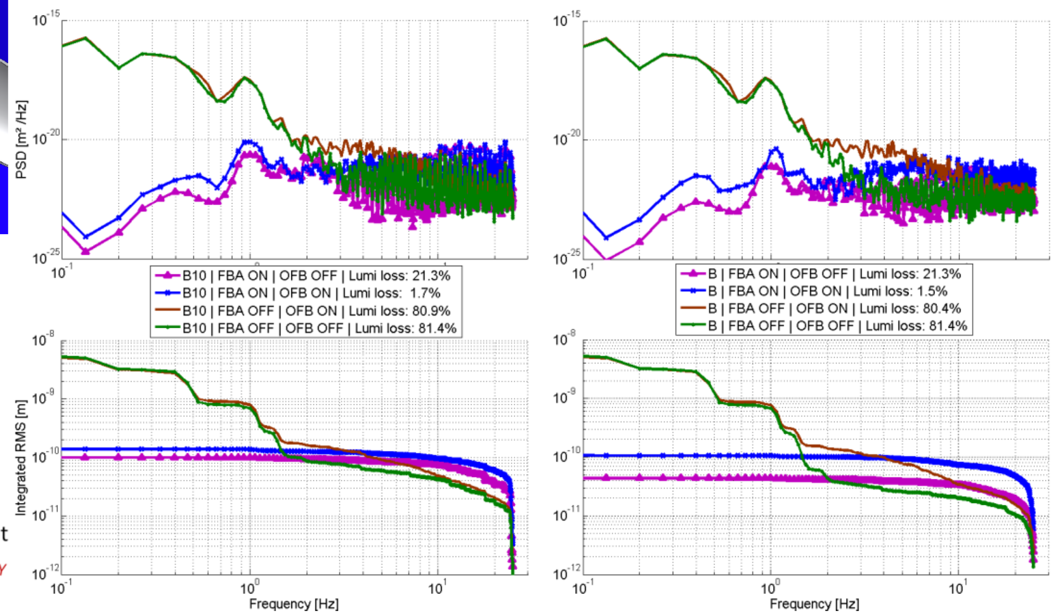
- ***Beam trajectory control : simulation under Placet***





- *Luminosity vs control ON or OFF and vs model of seismic motion (deal under Placet)*





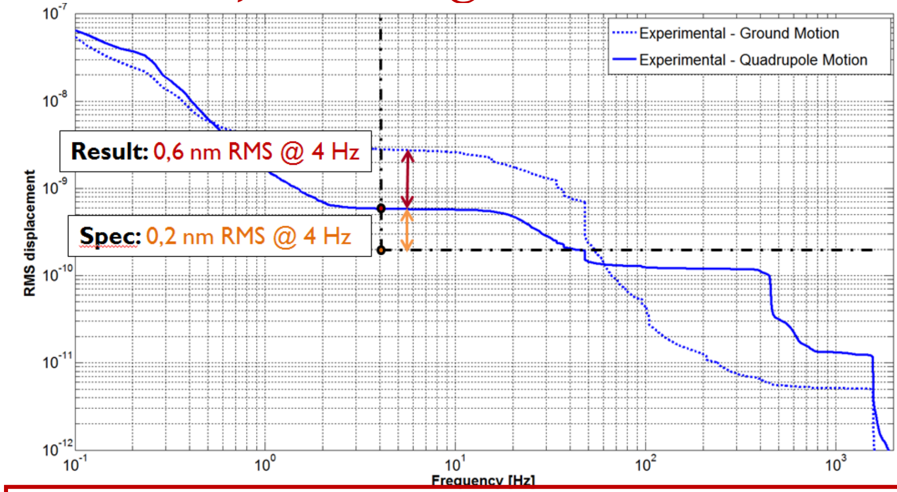
- *Caron B et al, 2012, "Vibration control of the beam of the future linear collider", Control Engineering Practice.*
- *G. Balik et al, 2012, " Integrated simulation of ground motion mitigation, techniques for the future compact linear collider (CLIC) ", Nuclear Instruments and Methods in Physics Research*

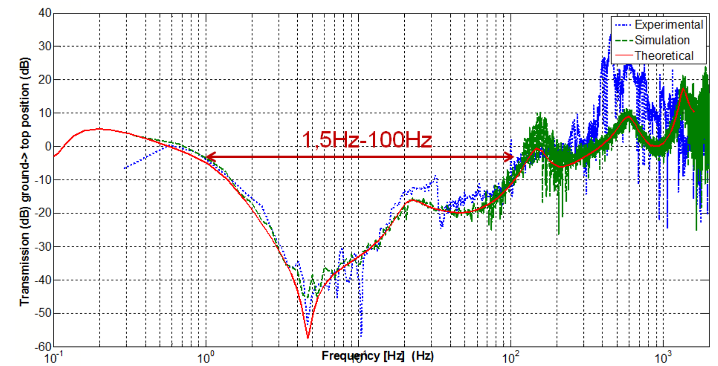
What was done by the French teams around ATF2 and the Final Focus/MDI

- ATF2
  - Intro
  - FD support and relative displacement
  - GM feedforward test => can be used for GM survey
  - IP-BPM and chamber
  - Beam-halo evaluation (diamond detectors, simulation)
- CLIC/ILC
  - New optics
  - Integrated feedback studies
  - Stabilisation
  - CLIC MDI: QD0 dummy test
- Conclusion Outlook

Active control demonstration

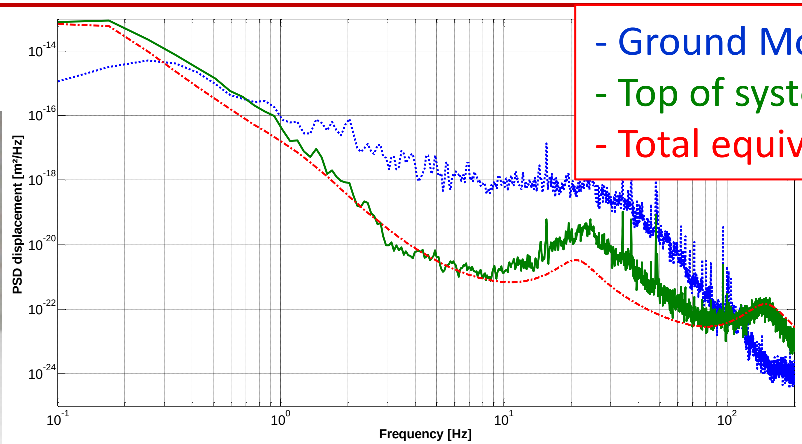
- ***Results : control with commercial sensors (2 geophones and 2 accelerometers)***
  - **0,6 nm RMS@4Hz.**





Balik et al, "Active control of a subnanometer isolator", JIMMSS.

➤ Main limitation : SENSOR (simulation and experiment).



- Ground Motion
- Top of system
- Total equiv. noise

Sensor study and development: patent pending

Sensor adapted to control, cheaper, smaller!

Already promising results for control

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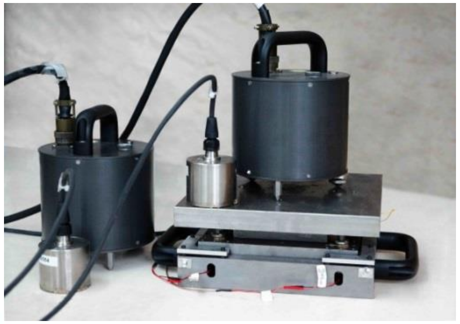
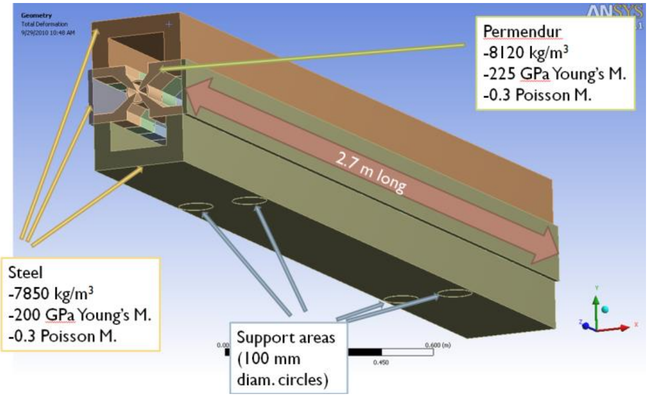
Transfer active stabilisation on a close-to-reality dummy QD0

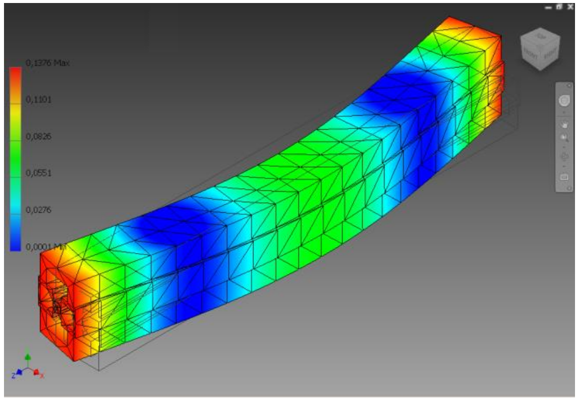
- ***Demonstration active table to QD0 active control ?***



One active foot



Several active feet



- ➢ FEM : dynamics of the quadrupole given its modal response
- ➢ State-space model and control strategy
- ➢ Test : on a real-scale prototype – "dummy QD0 magnet"

- ***Mecatronics challenge***

- ▪ Structure : QD0 Magnet
- ▪ Sensors
- ▪ Actuators
- ▪ Integration: control, data processing, real time…

▪Several aspects have to be defined
- *Location and number of active feet*
- *Type of active feet*
- *Degrees of freedom*
- *Type of control (SISO, MIMO)*
- *To adjust the specifications of actuators and sensors*
- *Conditioning, real time processing…*

Actuator

- ***No commercial solution for dynamics, resolution, load, stiffness…***
  - ➢ Two challenging ways : internal development or <u>industrial partnership</u>…
- ***Industrial solution : PZT actuator***
  - Manufacturer identified
  - Past "similar" developments for vibration control dedicated to machining
  - Specifications will be the result of the whole simulation (prototype, sensor…)
  - Collaboration with another French laboratory for the powering part.

Small size PZT actuator

Example of an large actuator

➢ Funding plan is needed

- A French proposal (to ANR agency) has been recently submitted…

➢ Has to be tested on the dummy magnet prototype

What was done by the French teams around ATF2 and the Final Focus/MDI

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Conclusion Outlook

- Contribute significantly to ATF2 Goal 2
  - GM measurements, Evaluate the impact of vibrations on beam , Halo measurements, Use the IP-BPMs
- Contribute to ILC and CLIC
  - CLIC MDI: sub-nanometre stabilisation, GM feedforward evaluation following CLIC development phase (2012-2016)
  - Follow study on alternative optics
- Successful in several Collaborations (EUROTeV, EuCARD, French ANR funding…) => New applications have been submitted around e+-e- beams and actuator development
- Publications and conferences, Training of students on a working accelerator (preparing future)
- We will be ready to be an important part of the future effort!