Beam instrumentation developments for CLIC/HL-LHC

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Talk outline

- CLIC developments
  - Cavity beam position monitors
    - Goal to reach CLIC requirements with cavity triplet at CALIFES
  - Optical transition radiation
    - Project at ATF2
- HL-LHC electro-optic beam position monitors
  - Current status of experiment at SPS
  - Potential development at CALIFES
- General BI potential

Cavity Beam position Monitors

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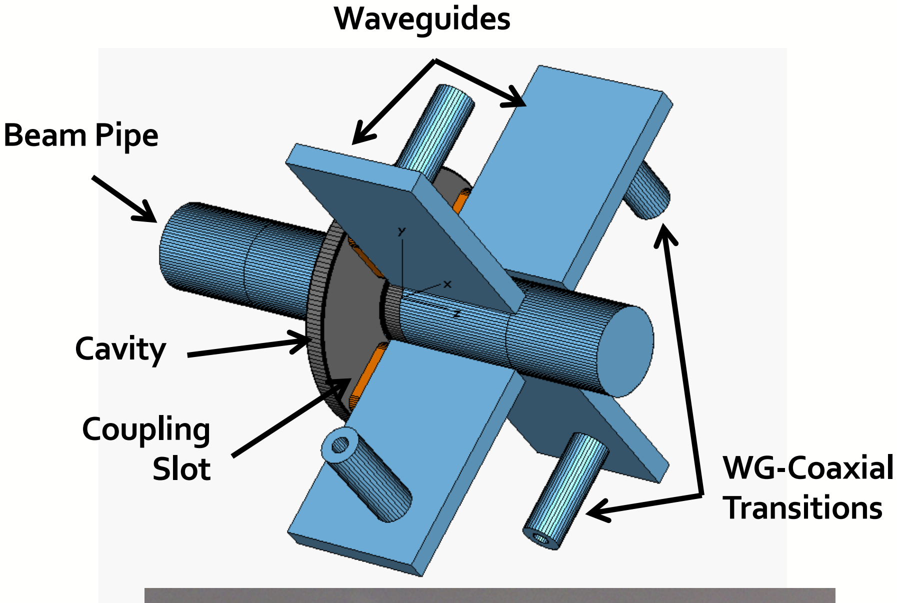
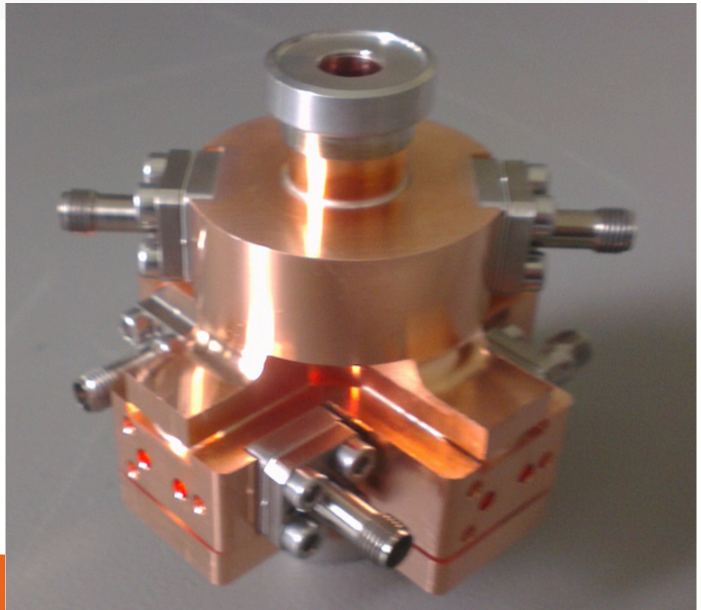
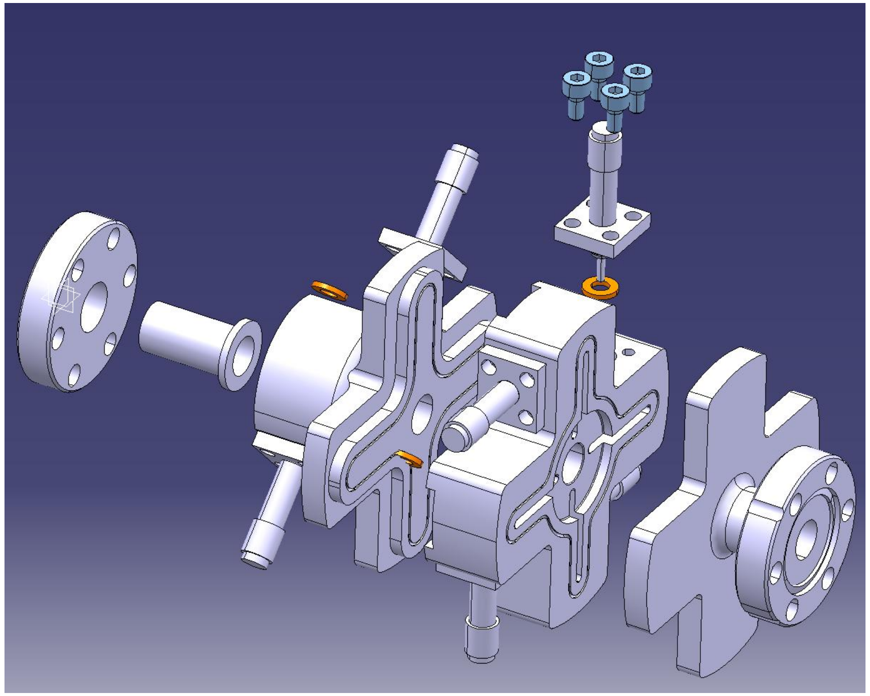
Position cavity





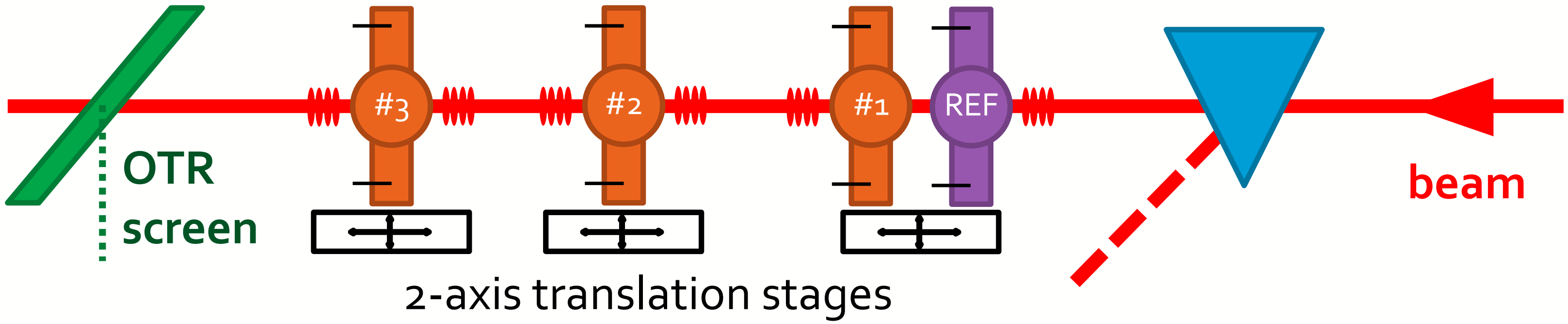


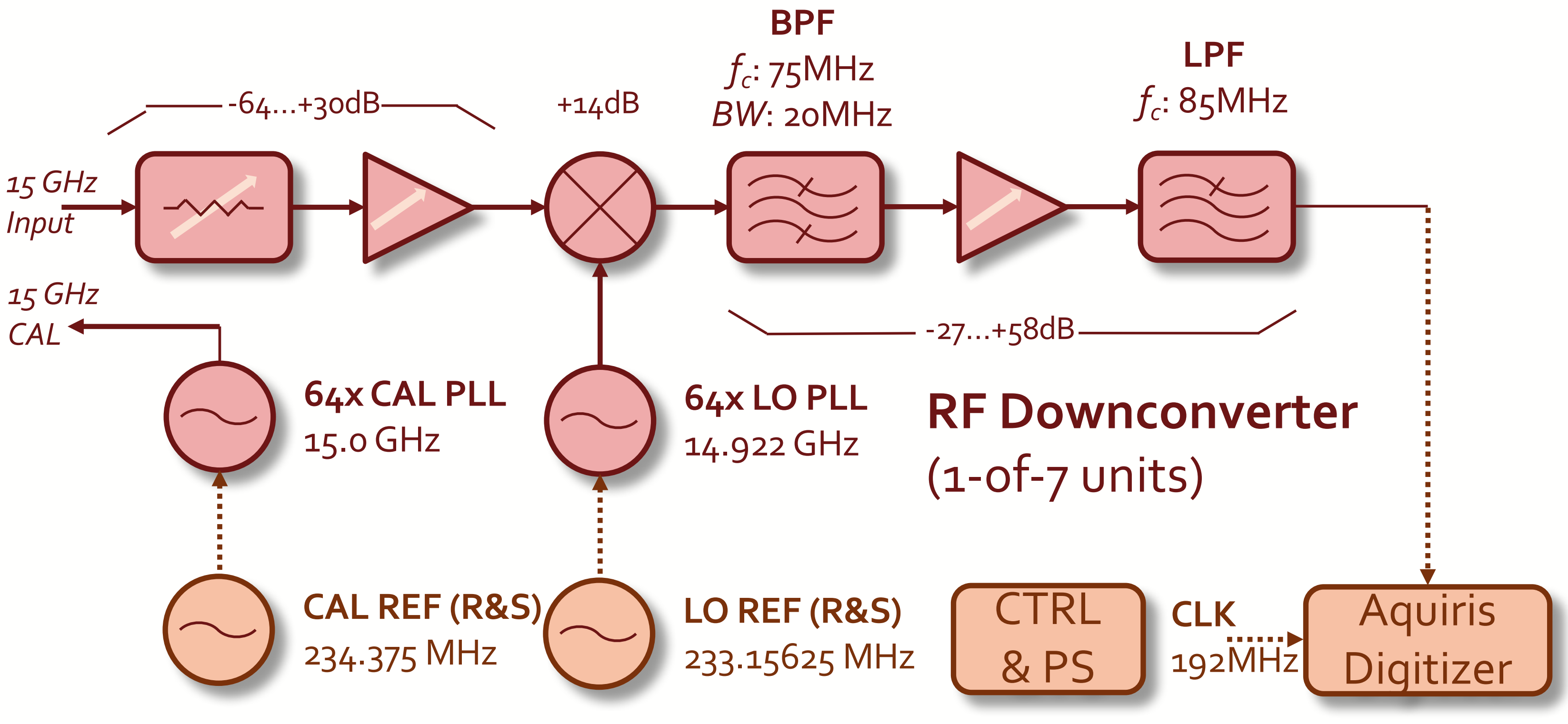
Cavity	Q_L	F_o /GHz
Reference	938	14.772
Predicted	500	15.0
Position	~830	14.996
Predicted	524	15.0

Cavity BPM R&D : CTF Hardware

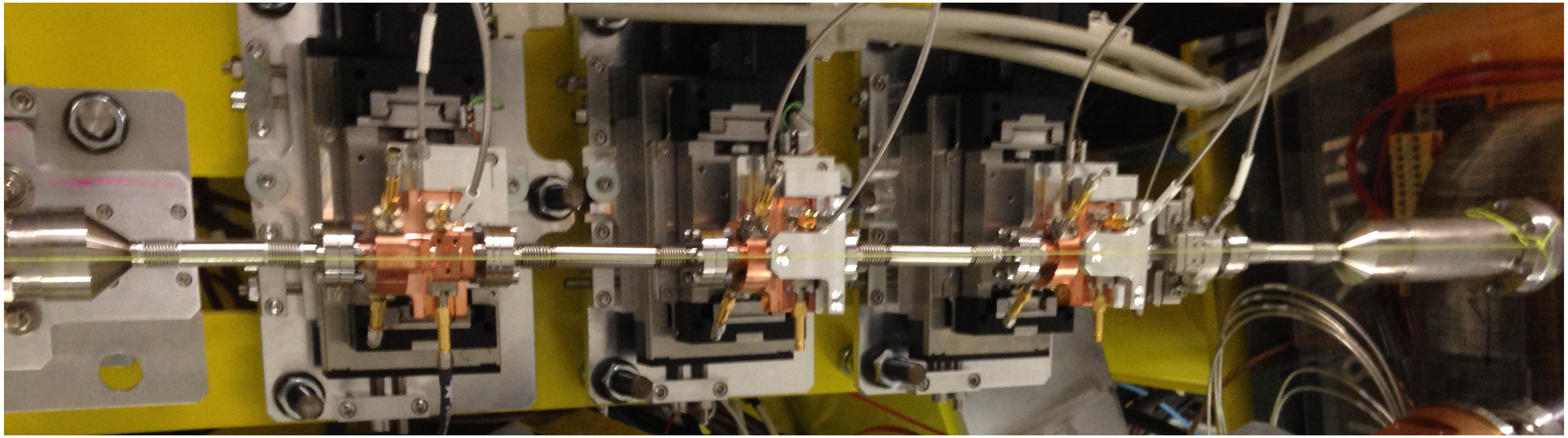
3x position BPM (Cu), 1x ref BPM (SS)
(on ballistic trajectory)

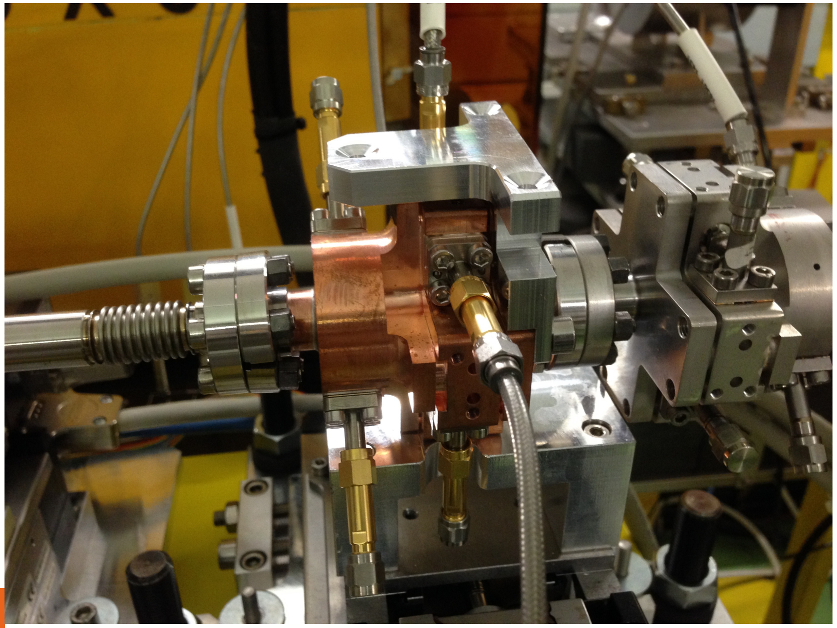
Spectrometer dipole





Photos of installed BPMs on beamline





Photos of installed movers and electronics

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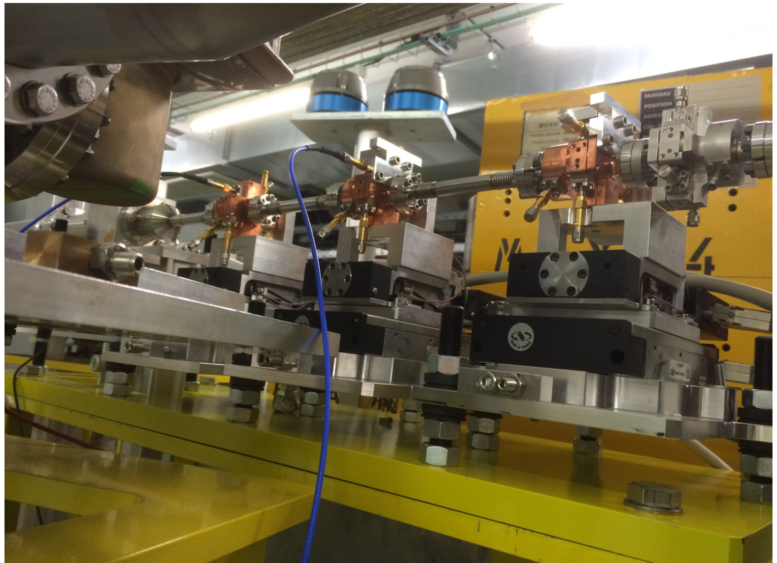
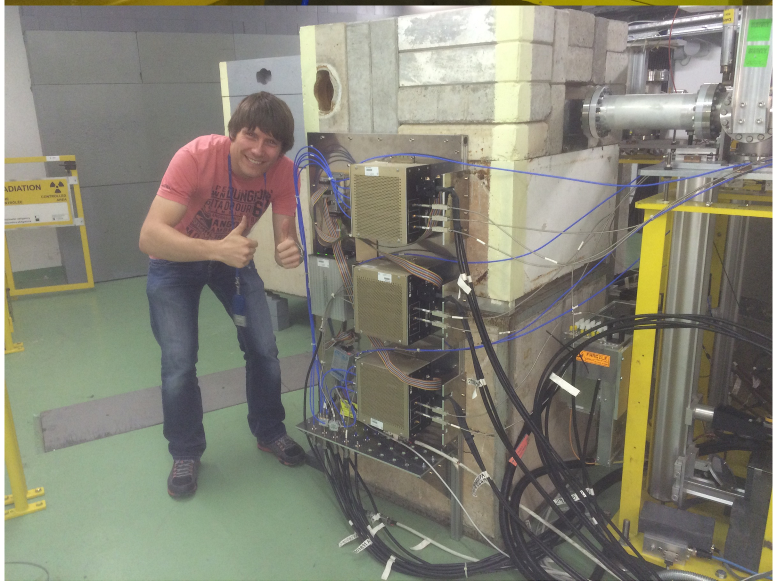
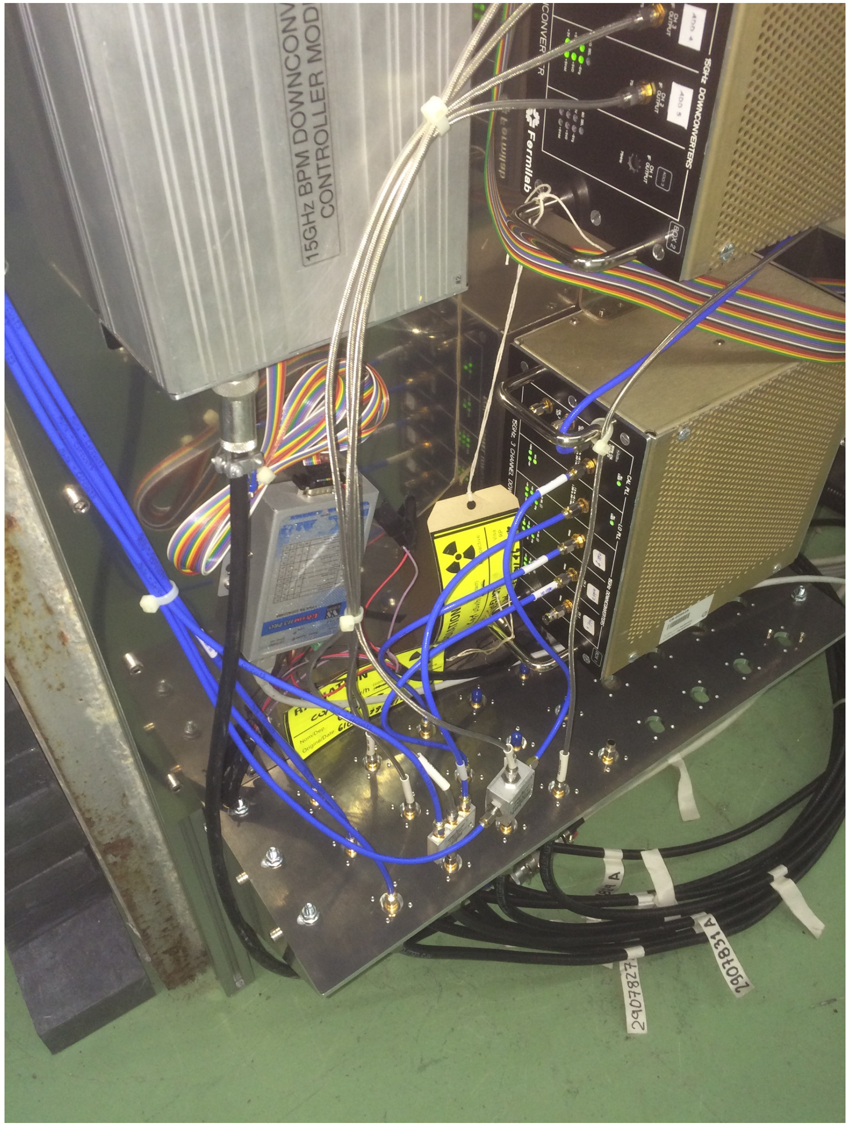


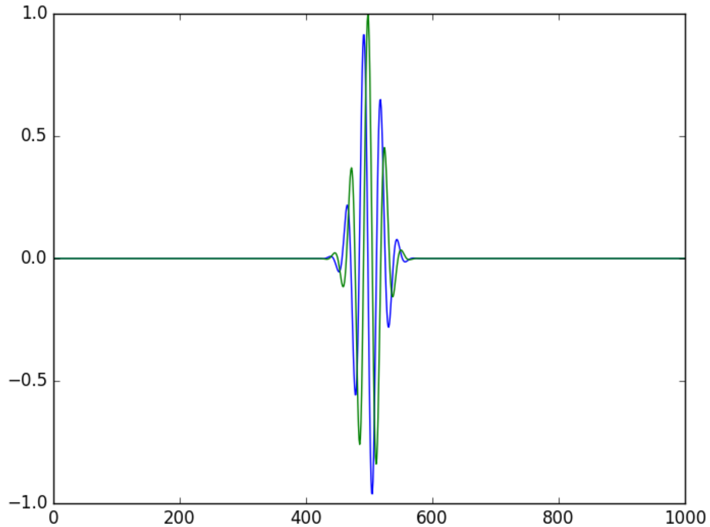




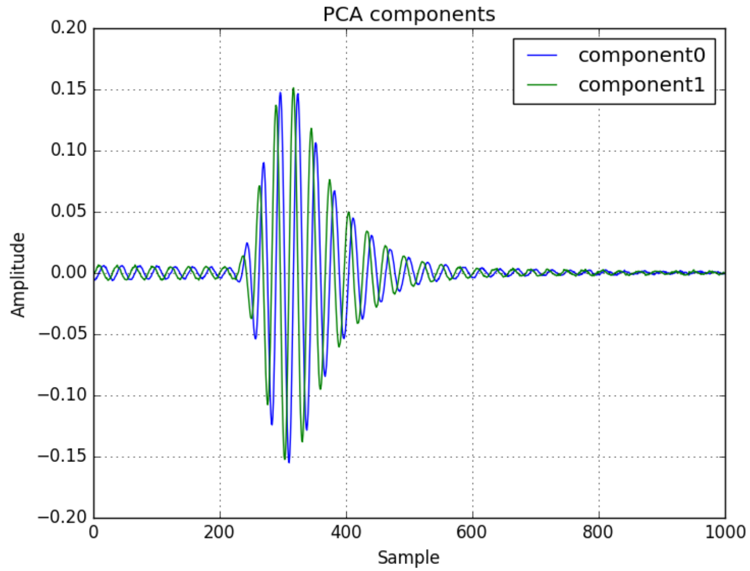
Signal processing

- 2 types of analysis used: Digital Down-Conversion (DDC) and Principal Component Analysis
- In both cases use a basis of windowed 2 orthogonal sin/cos-like signals
- DDC: Gaussian window, positioned arbitrarily
- PCA: Signal-derived window

DDC (sin/cos with gaussian filter)



PCA components



BPM Calibration

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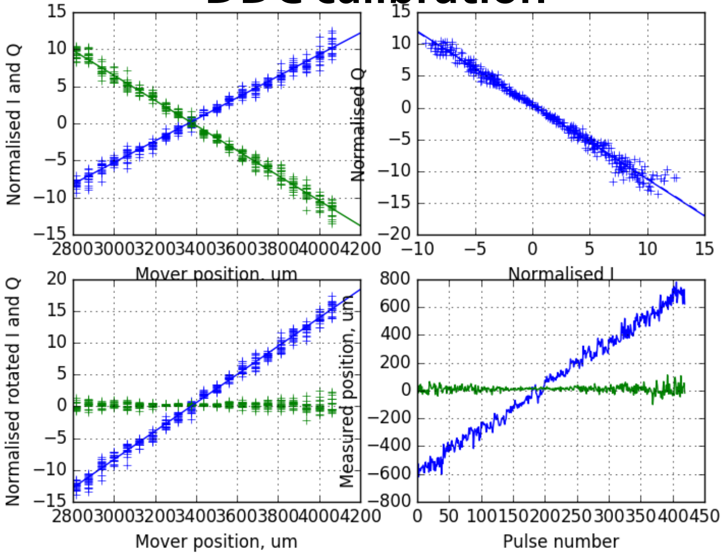
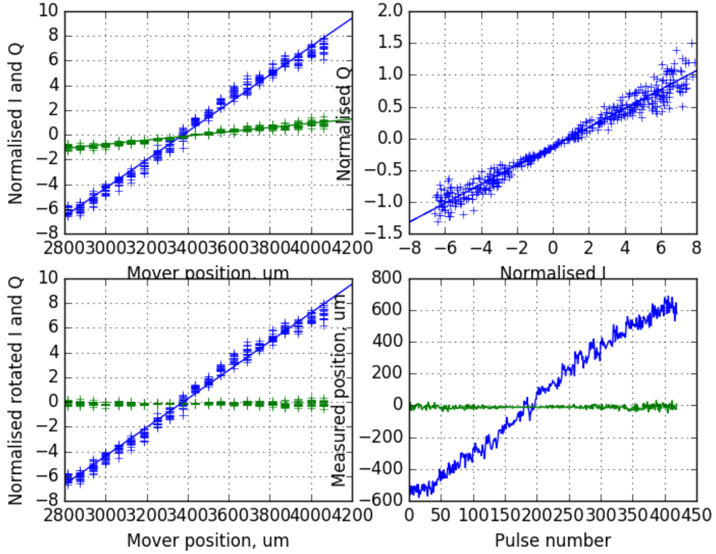
- Find the phase corresponding to the position
- Determine the position scale
- Use mover stages to ensure pure position offset (no angle) and high precision
- Currently 8-bit digitiser, so the dynamic range is reduced

DDC calibration



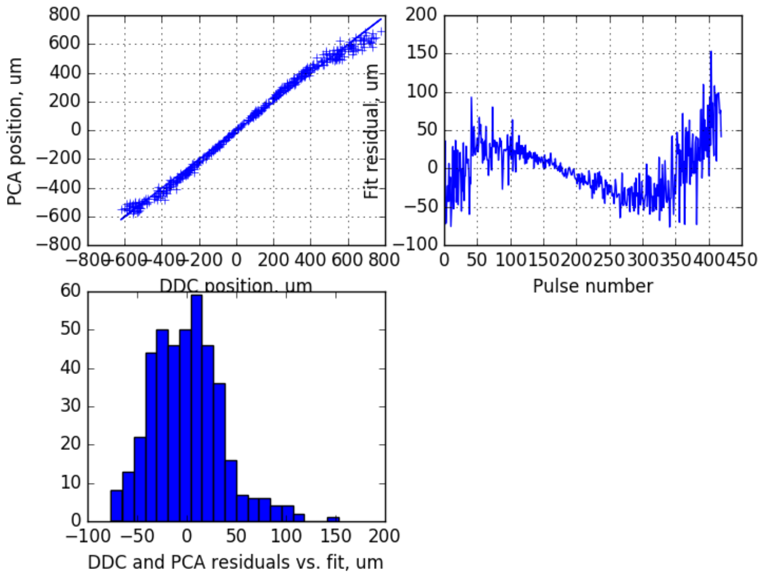
PCA calibration



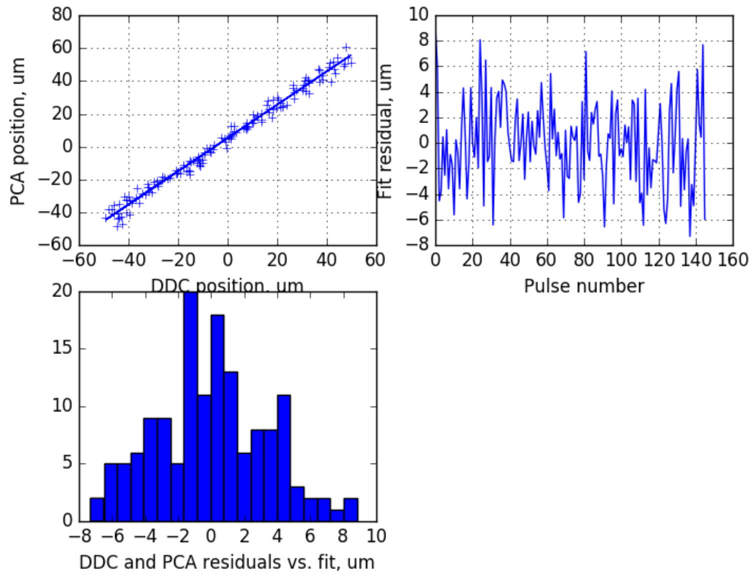
BPM Resolution

- Still commissioning BPM triplet (compare DDC and PCA to determine resolution for single BPM)
  - 6.2 um spread without a position cut
  - 3.3 um spread with a +/-50 um position cut

Wide range calibration(1 mm)



Narrow range calibration(100 um)



Optical Transition Radiation

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Optical Transition Radiation (OTR)
Optical Diffraction Radiation (ODR)

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Robert Kieffer, Thibaut Lefevre, Stefano Mazzoni

CERN: European Organization for Nuclear Research

Michele Bergamaschi, Pavel Karataev, Konstantin Kruchinin,

John Adams Institute at Royal Holloway, University of London

Alexander Aryshev, Nobuhiro Terunuma, Junji Urakawa

KEK: High-Energy Accelerator Research Organization

Aim:

- Develop a high resolution single shot beam size and emittance diagnostics station:
  - Non-invasive beam size measurement using Optical Diffraction Radiation;
  - Sub-micrometer beam size diagnostics using Optical Transition Radiation;
- Simple in use, robust technique for CLIC and ILC

OTR/ODR Experimental layout

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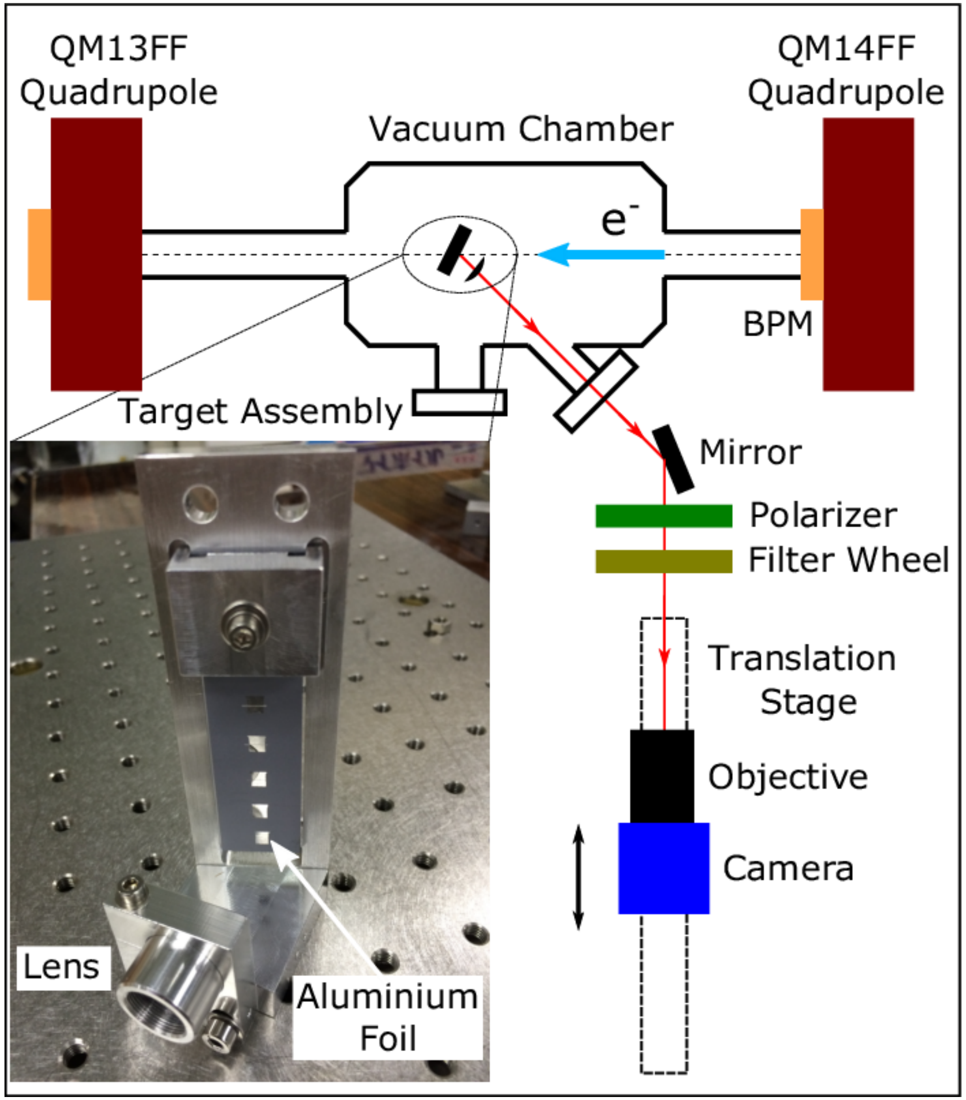
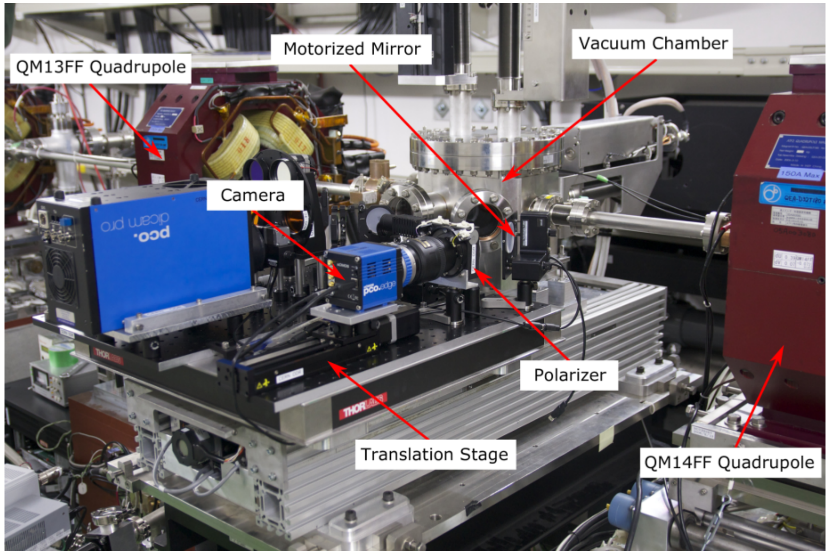
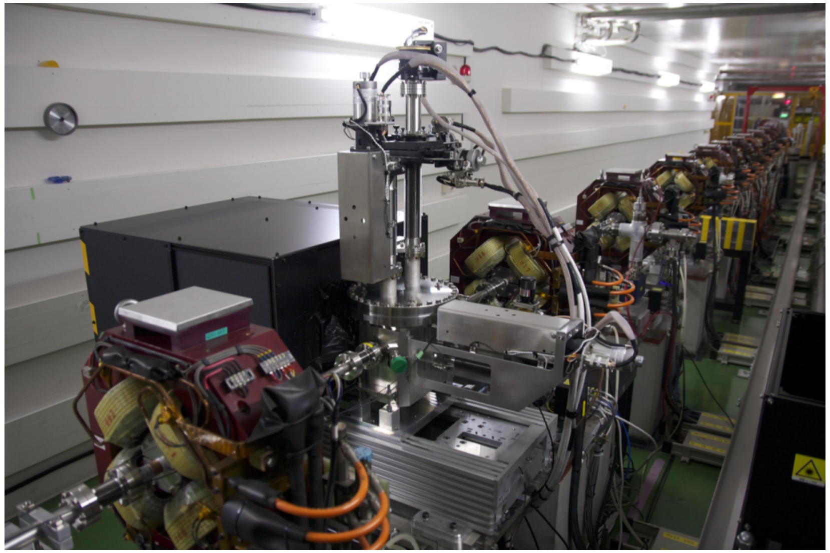
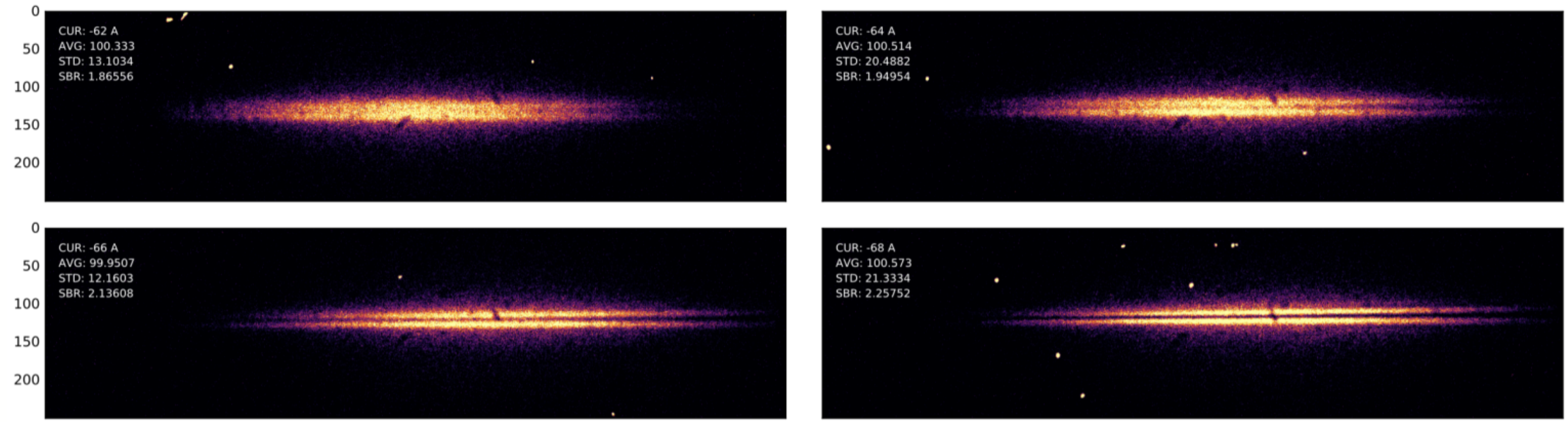




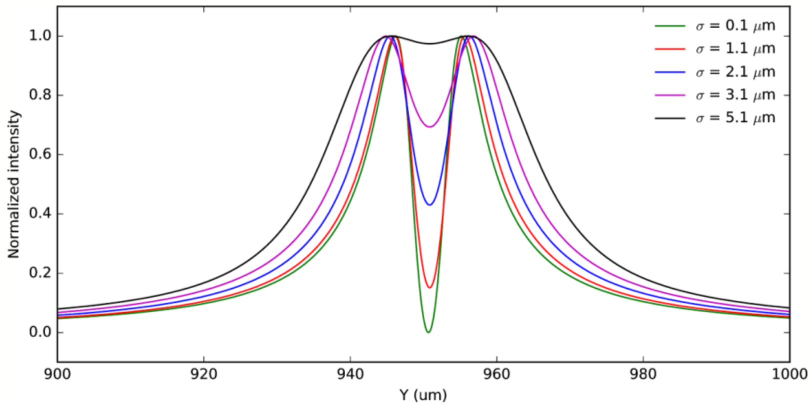


OTR Measurements

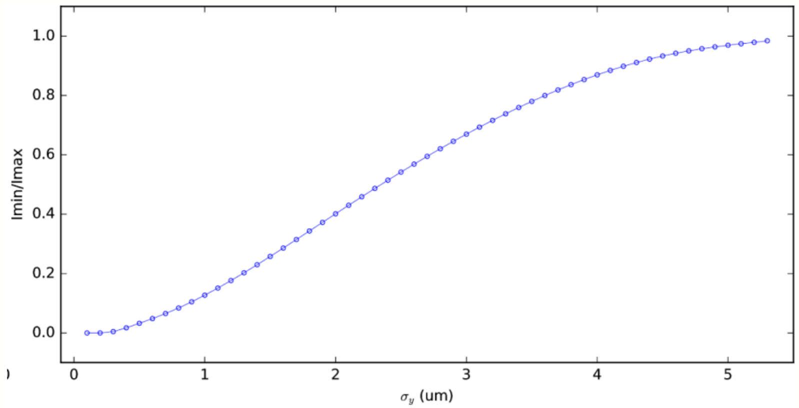
OTR images



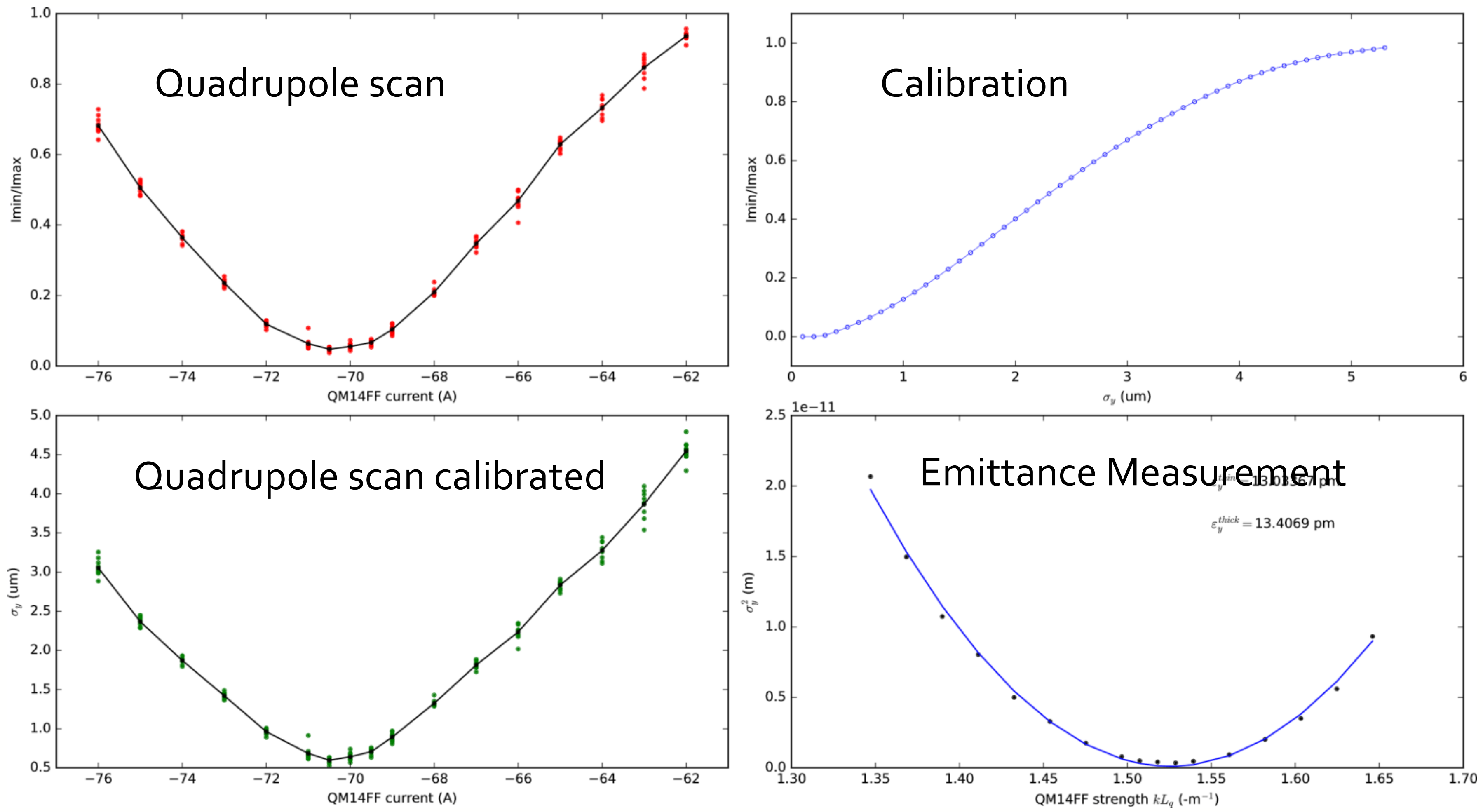
Beam size effect



Calibration

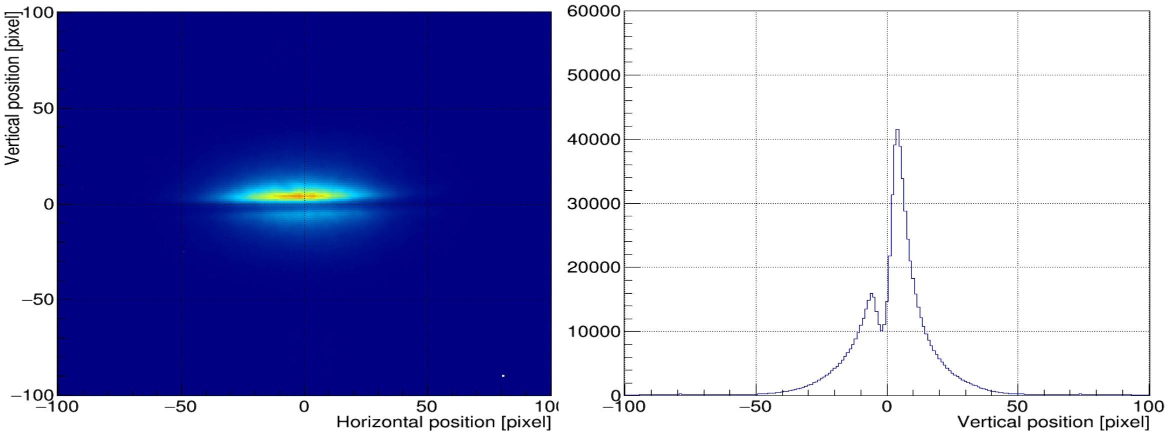


OTR Results


Quadrupole scan
Imin/Imax
QM14FF current (A)
Calibration
Imin/Imax
σ_y (um)
Quadrupole scan calibrated
σ_y (um)
QM14FF current (A)
Emittance Measurement
1e−11
$\epsilon_y^{thick} = 13.4069$ pm
σ_y^2 (m)
QM14FF strength kL_q (-m^{-1})

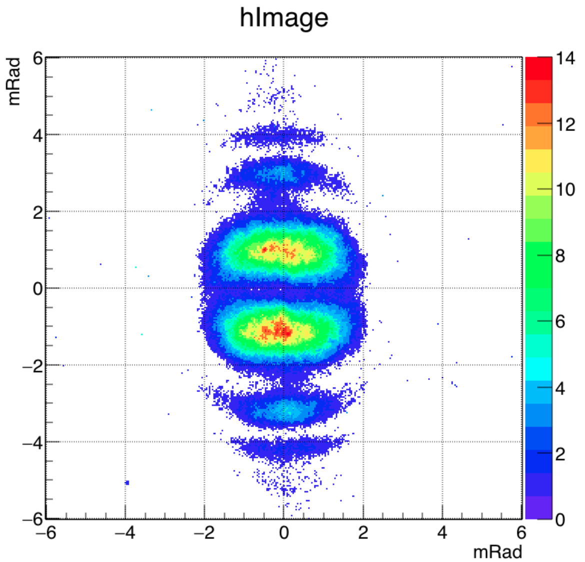
ODR Measurements

ODR is generated when a charged particle moves through a slit in a metal screen in vacuum



ODR imaging: gives an opportunity to diagnose the beam position wrt to the slit center with micron-scale accuracy

ODR angular distribution: gives an opportunity to diagnose the beam size.
These measurements were done for 30 micron predicted beam size



Electro-optic BPM

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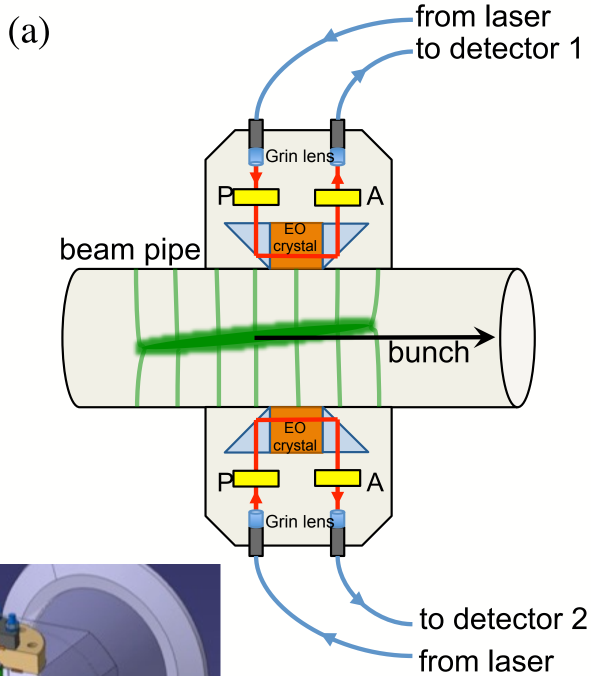
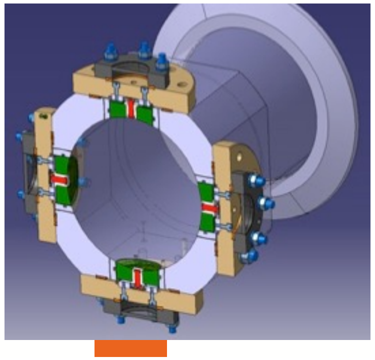
Alberto Arteche, Alessio Bosco, Stephen Gibson, Thibaut Lefevre,

Example development: Electro-Optic Beam Position Monitor

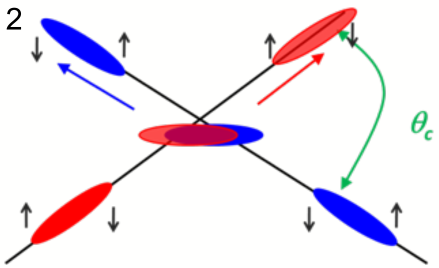
- Aim to develop novel diagnostics capable of rapidly (< 50 ps) monitoring transverse intra-bunch perturbations for the HL-LHC.
- Essential a button BPM with pick-ups replaced by electro-optic crystals:
  - laser + detectors are away from the accelerator, readout via a 160m optical fibre. Not limited by cable bandwidth.
- The electric field from a passing relativistic bunch of charged particle interacts with a birefringent (polarization sensitive) crystal.

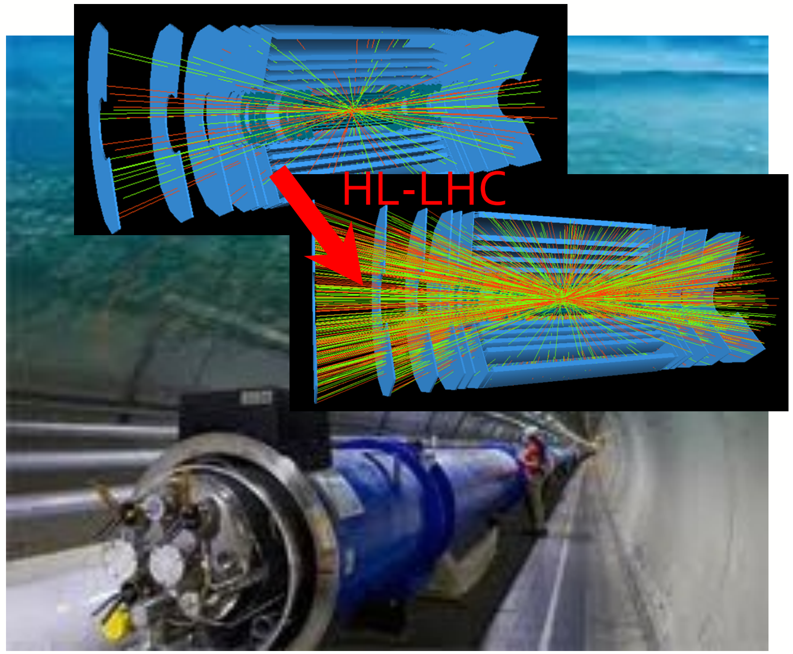


The 1ns LHC particle bunch induces a change in the polarization of laser light in the crystal, so the beam position along the bunch can be monitored.



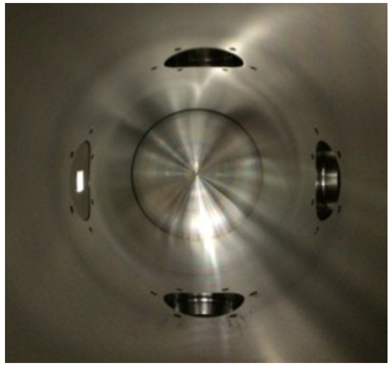
Useful for measuring particle bunch rotation at HL-LHC

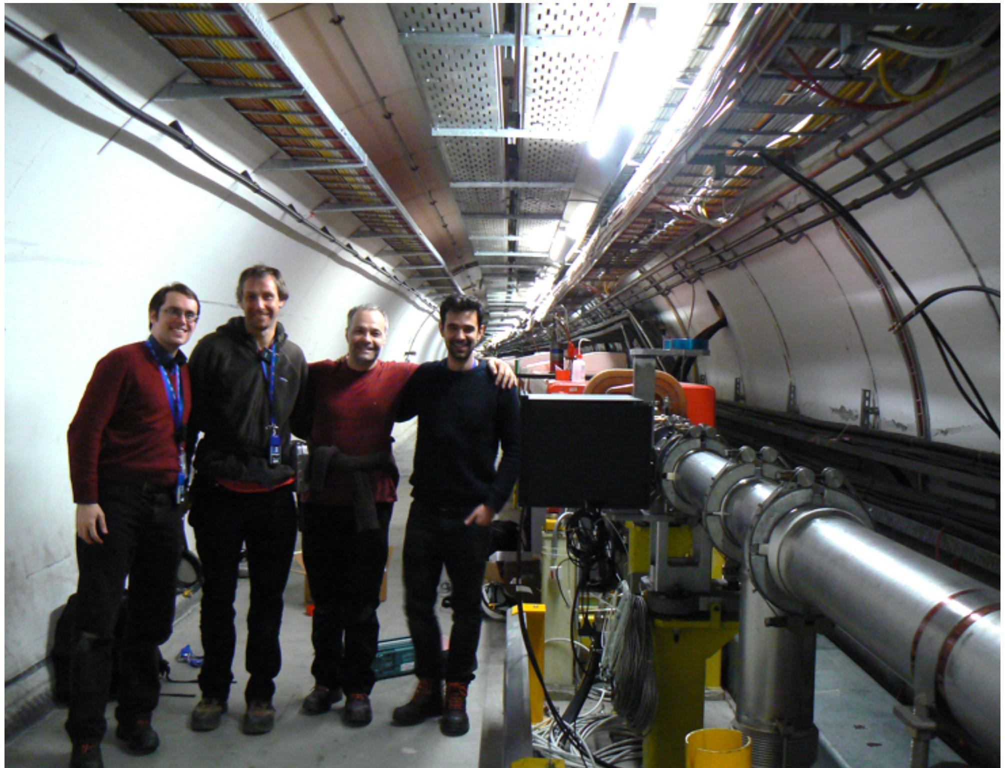


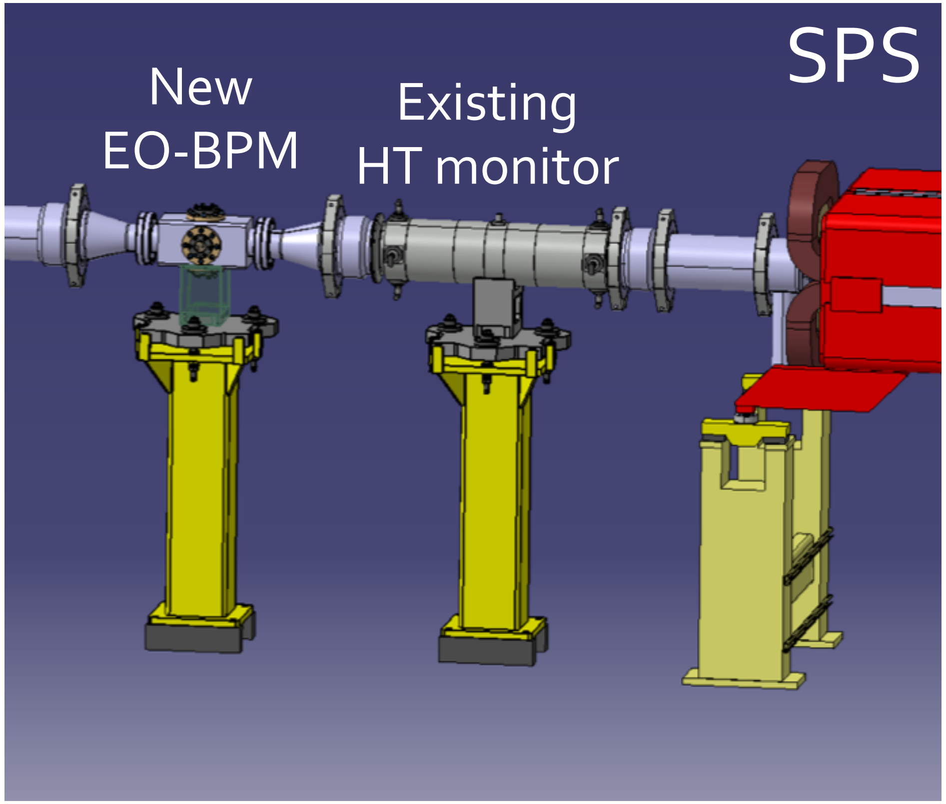


Installation of EO-BPM in CERN SPS

- Location selected next to SPS for prototype development:
  - allows tests with proton bunch parameters closest to HL-LHC
  - installed next to existing Head-Tail monitor (stripline BPM) for comparison and triggering.
- However, access is extremely limited, due to LHC schedule
  - Installed EO-BPM body + first pick-up & optics in February 2016, just before SPS closed.
  - Next opportunity for access was 24hr Technical Stop in June 2016.

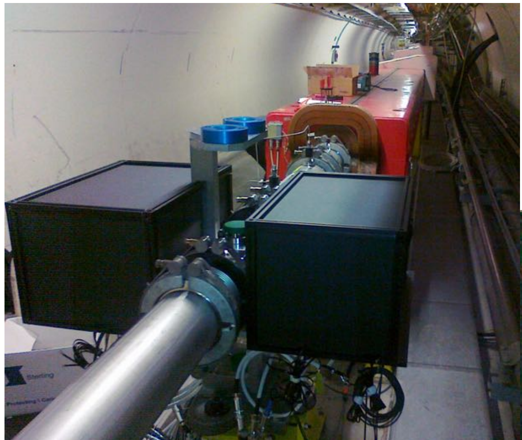






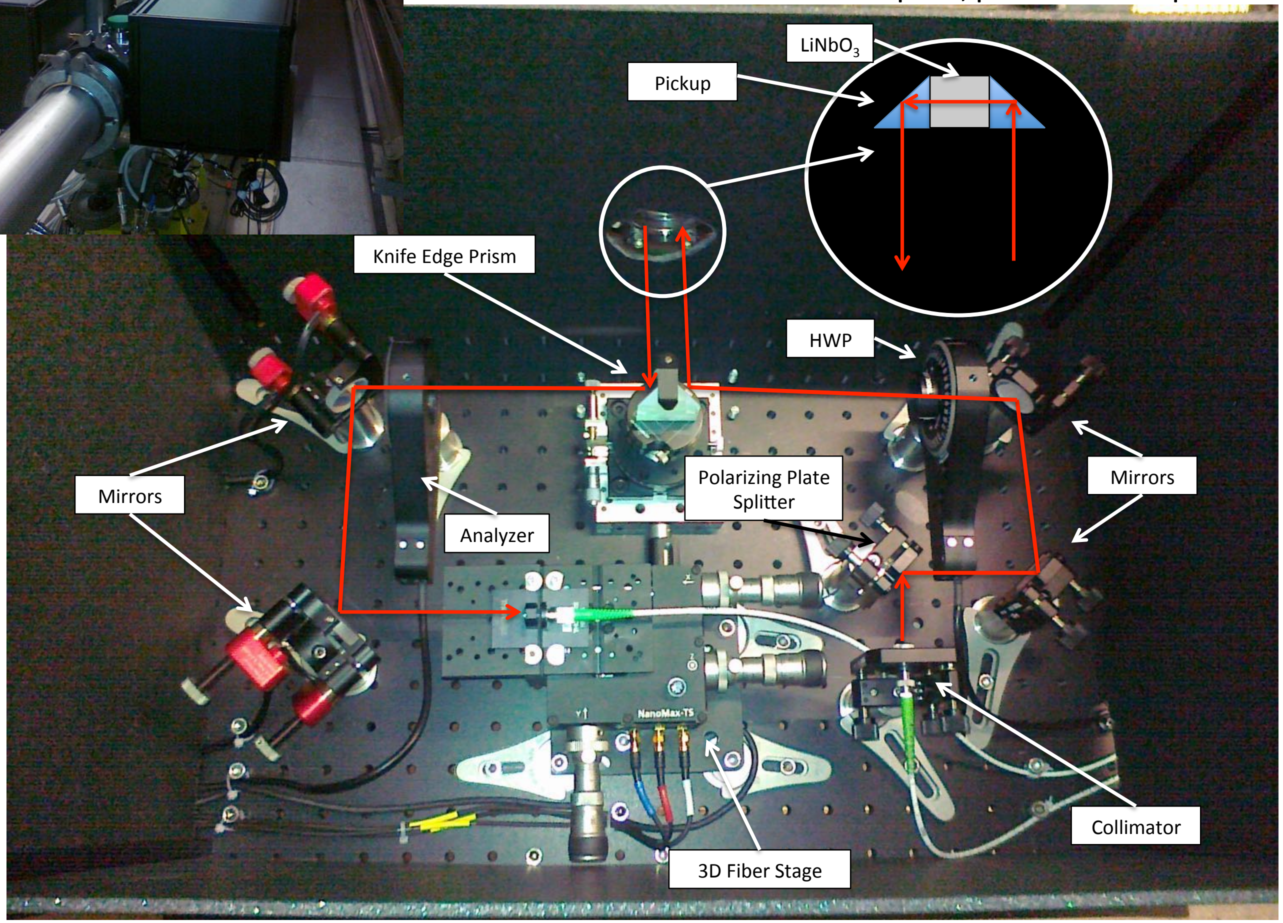
Installation of EO-BPM in CERN SPS

- Remaining three pick-ups and second optics box installed in TS on 7th June.
- Laser installed / optics aligned in 8hr access during TS on 14th September 2016.
- Next opportunity for SPS access is 2017 shutdown…

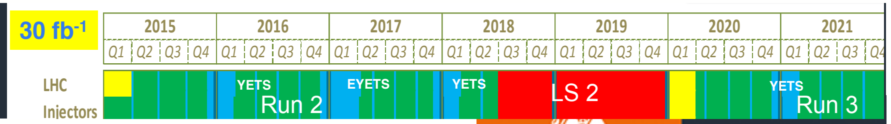


Prototype EO-BPM installed in the CERN SPS. Opposing horizontal pick-ups are each equipped with adjacent, optical breadboards.

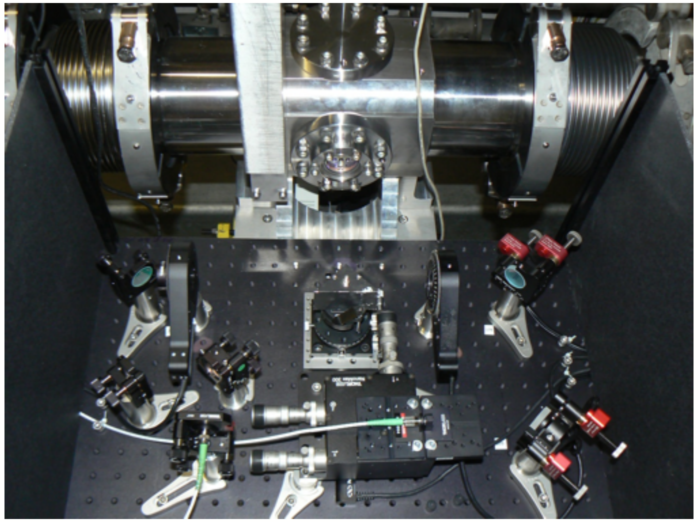
Internal view of the fibre-coupled, polarization optics.



Challenge of prototype at CERN SPS



- An excellent opportunity for tests with LHC bunches, however, SPS is a challenging environment for such prototype development work:
  - Only < 36 hrs access, since installation in February 2016.
- Overcome by use of remote controlled optics, though not without issues:
  - Need to drive stages over long distances.
  - Requires radiation tolerant components (optics + stages without optical encoders).
  - Minimal adjustment possible due to risk of losing fibre coupling alignment



- Sparse opportunities for intervention to adjust setup or replace parts:
- Allowed radius of beam pipe is much larger than LHC: less signal expected
- Beam tests are parasitic to SPS operation: no direct control of beam.
- Trains of high intensity bunches (1.1.x10^{11} protons/ bunch) available typically only for a short times during LHC injection.

A test stand for parallel EO-BPM development:

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What would be the ideal test area?

- In a surface building with relative ease of access for quick reconfiguration of beam-line components.
- Dedicated test stand: not an accelerator required for LHC operation.
- Ability to break the vacuum to reconfigure pick-ups, without impact on accelerator operations.
- Direct control over delivered beam parameters:
  - Adjustable bunch intensity.
  - Varied bunch /train structure to check FFT of signal
  - Steerable beam to pick-up.
- Availability of bunch timing for triggering.

Some possible areas:

HiRadMat High-Radiation to Materials

- ***HiRadMat:*** 450GeV protons, upto 288 bunches 25ns with $3\ 10^{13}$ protons/pulse.
- ***CALIFES:***
  - 200 MeV electrons, *similar γ as on SPS*
  - Single bunch to trains with *similar bunch spacing* as at LHC (1ns, 5ns, 25ns, 50 ns).
  - Short bunches possible (few ps) for fast EO-tests.

Summary

- Potential to continue developments of high precision electron beam instrumentation
- Beam position monitors (high resolution/bandwidth, applications for FELs, electron beam driven plasma wake acceleration)
- Beam size and emittance measurement using OTR and ODR
- Resolution limit systems (<1 um impossible at CALIFES, but OTRI, debugging of systems before installation at ATF/CesrTA etc)
- Other beam instrumentation related to X-band FEL and ILC
- Proof of principle tests of HL-LHC beam instrumentation possible
- Access to facility important!
- Vibrant and diverse activity group at the JAI@RHUL to contribute to BI activities at a future Califes facility.