Progress with Electro-Optical Beam Position Monitor Development

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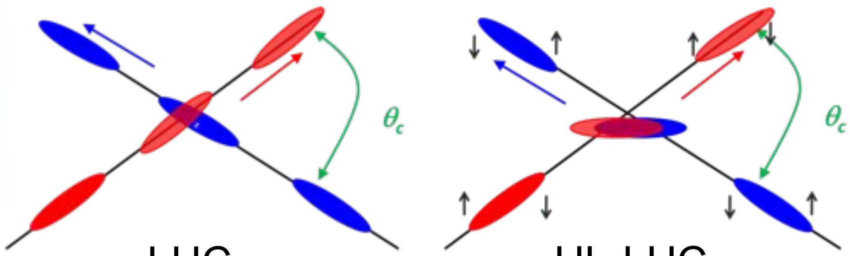
Outline

- Motivation
- Electro-optic BPM concept
- Prototype EO-BPM installation
- Results from the first prototype
- EM simulations of the electrode pick-up
- First tests of the electrode pick-up
- Future outlook

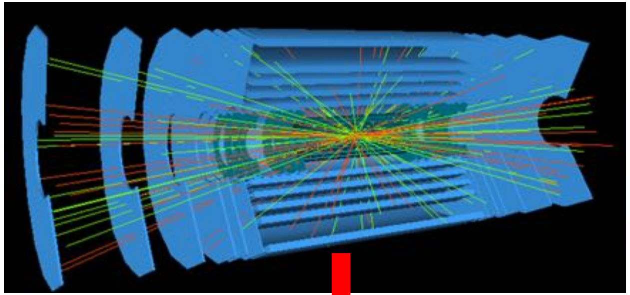
Motivation: Crab bunch rotation and pile-up at HL-LHC

- LHC luminosity is currently limited by geometrical overlap, due the crossing angle (285μrad) between beams.
- At HL-LHC, RF crab cavities will rotate the bunches to collide head on:

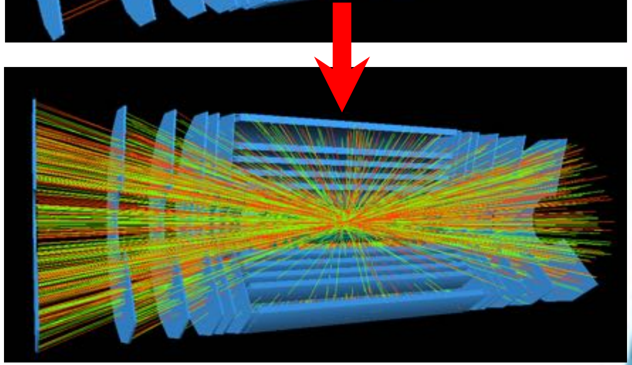


One bunch crossing in the ATLAS particle tracker:

23 interactions per bunch crossing at nominal LHC



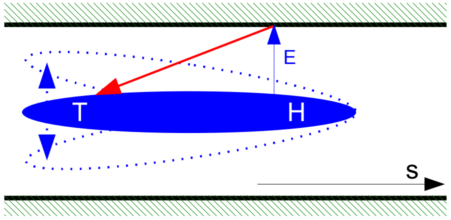
HL-LHC: pile up increases to ~**140** vertices per crossing.



To optimize the performance of the crab-cavities for HL-LHC, a new diagnostic tool is under development to monitor the bunch rotation.

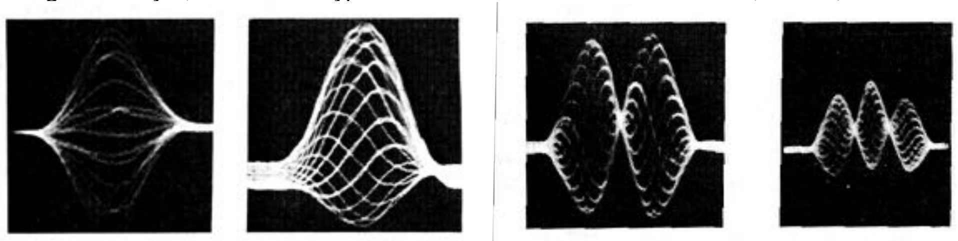
Intra-bunch diagnostics at CERN

- Head-tail monitors are the main instruments to visualize and study beam instabilities as they occur.



transverse

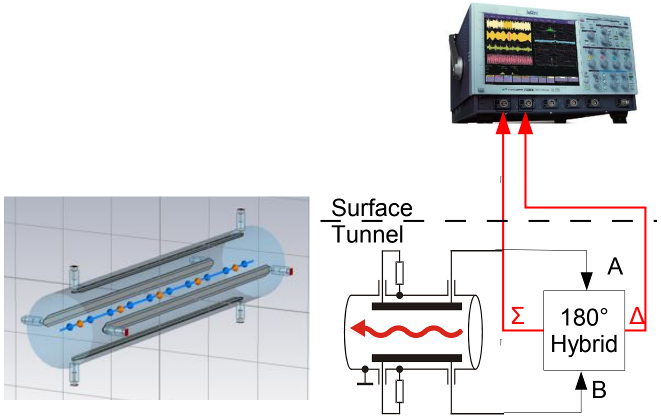
e.g. J. Gareyte, “Head-Tail Type Instabilities in the PS and Booster”, CERN, 1974



a) mode m = 0, χ = 0   b) m = 0, χ = 2.3 radians   b) m = 1, χ = 6.9 radians   d) m = 2, χ = 6.9 radians

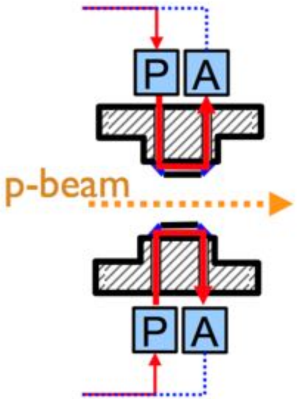
- Standard approach:
  - Stripline BPMs + fast sampling oscilloscopes.
- Limitation:
  - Bandwidth up to a few GHz, limited by the pick-up, cables and acquisition system.
- A new technology is needed:

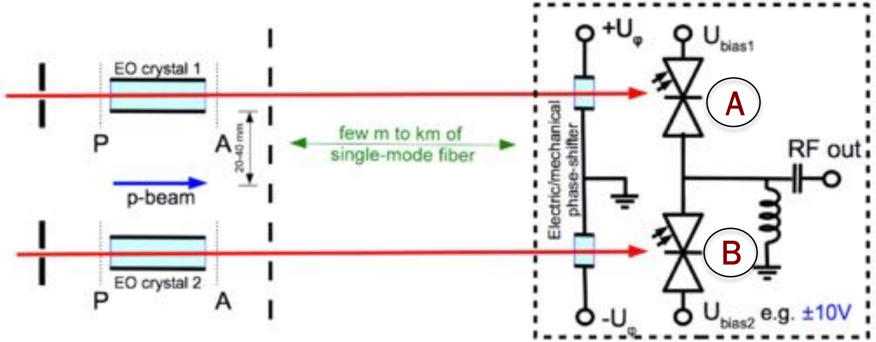
Fast electro-optic pick-up

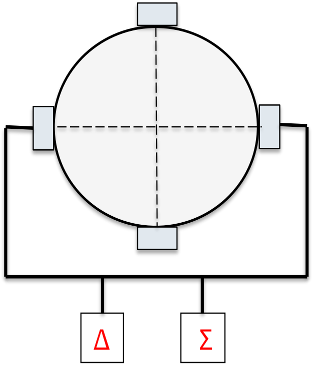


Electro-Optic Beam Position Monitor Concept

- Replace the pick-ups in a button BPM with electro-optic crystals.
- The electric field from a passing relativistic bunch of charged particles interacts with a birefringent (polarisation sensitive) crystal.



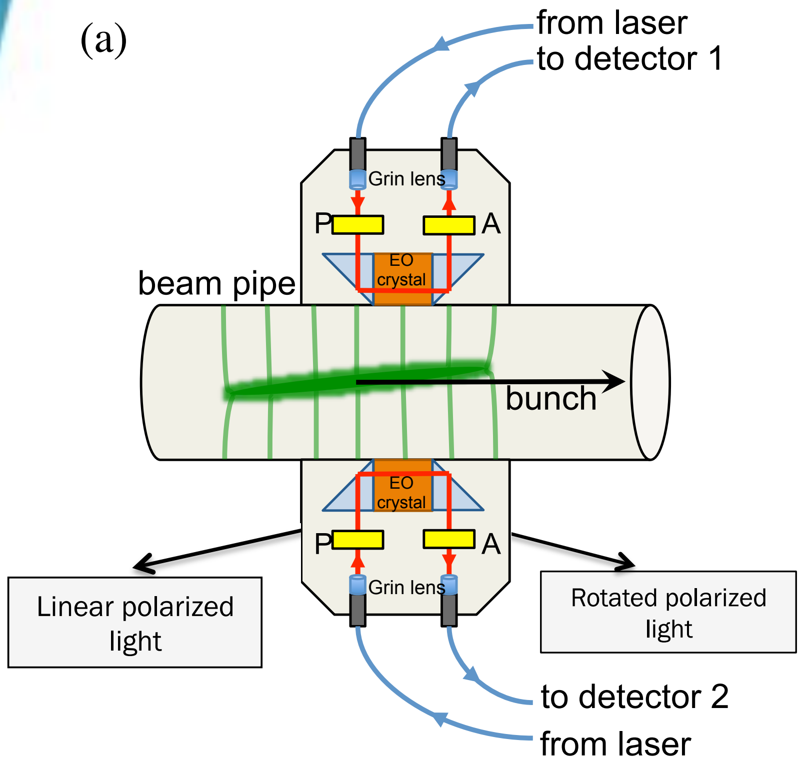




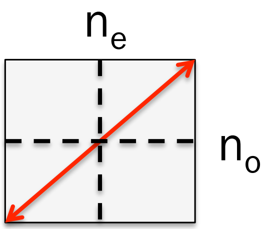
The 1ns LHC particle bunch induces a change in the polarization of laser light in the crystal, so the beam position along the bunch can be monitored.

Δ / Σ

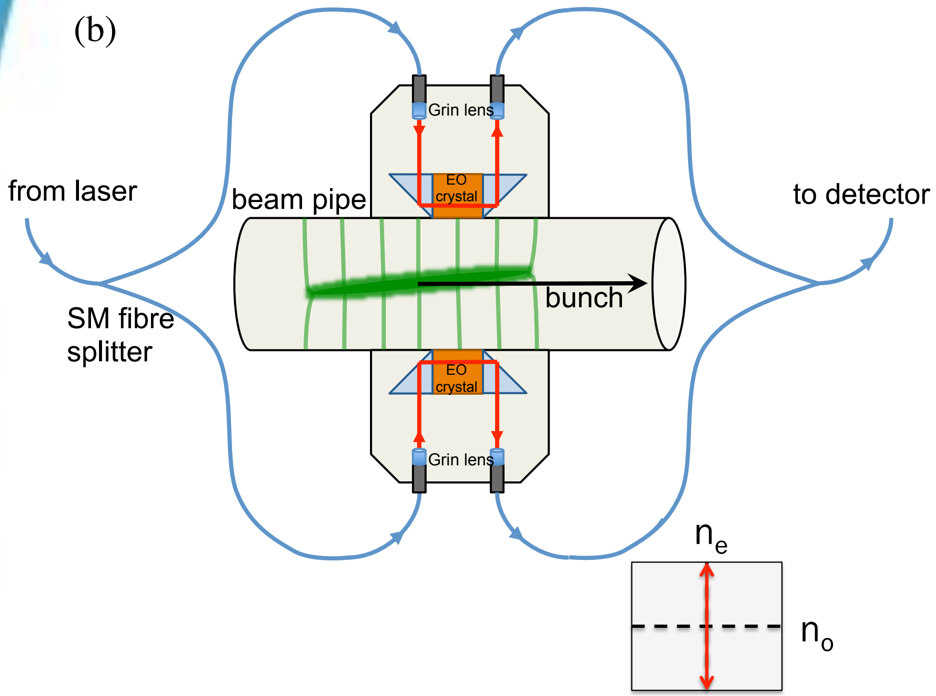
EO-BPM: polarizer-analyser robust design



- Effectively a button BPM based on eo-crystals.
- Transverse position is monitored.
- A fibre-coupled design with laser and detectors 160 m away from accelerator tunnel.
- Incoming light is collimated by a GRIN lens and polarized before entering the crystal.
- The passing bunch induces ***polarization change*** by changing the crystal properties.
- Light emerges through an analyser and is read-out by a fibre-coupled photodetector.



EO-BPM: interferometric design



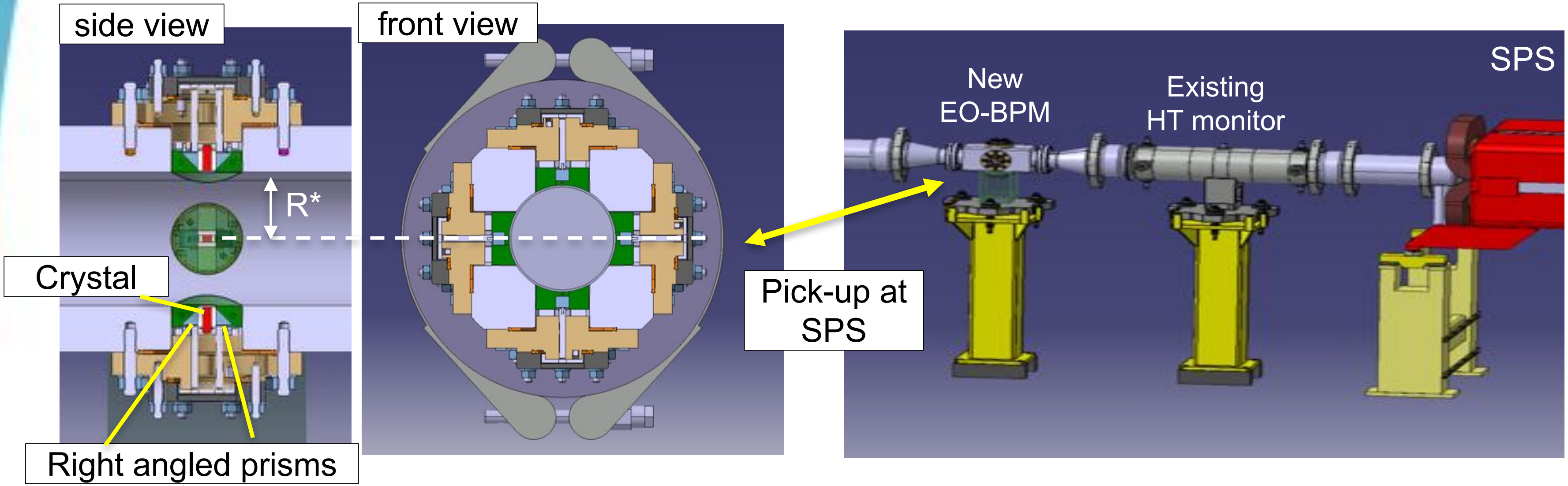
- Mach-Zehnder Interferometer topology
- Uses ***phase modulation*** rather than a polarization-analyser.
- Short, equal fibre lengths between the splitters to improve tolerance to thermal instabilities. and provide synchronization between pick-ups

Key Advantage:

- Coherent light suppresses the common mode signal, so the difference signal is directly measured by the photodetector:
- ***Signal proportional to $\Delta E \rightarrow$ better resolution.***

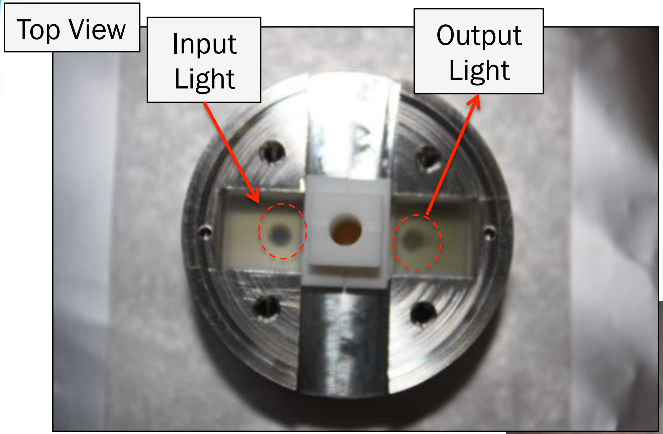
First Prototype for the CERN SPS

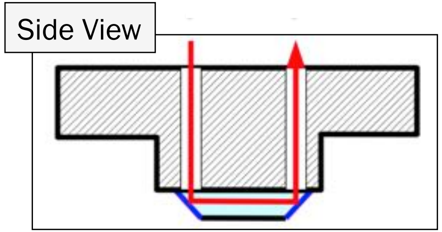
- A preliminary EO-BPM design was developed for initial tests at the SPS:
  - SPS proton bunch parameters most similar to HL-LHC
  - Located next to existing Head-Tail monitor (stripline BPM) for comparison and triggering.

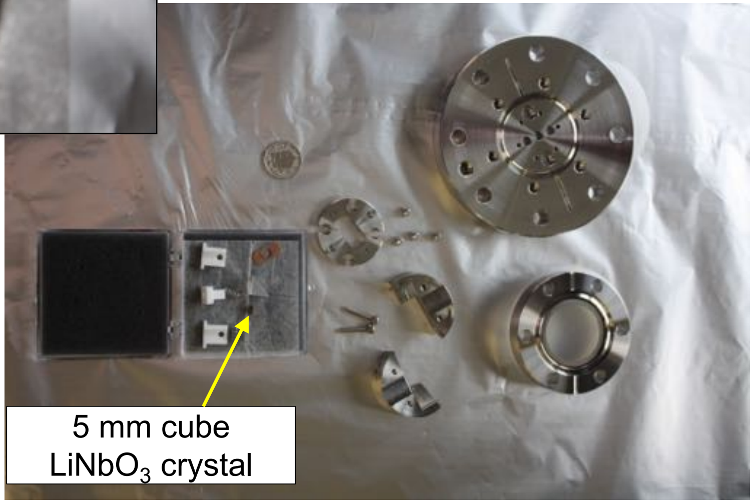


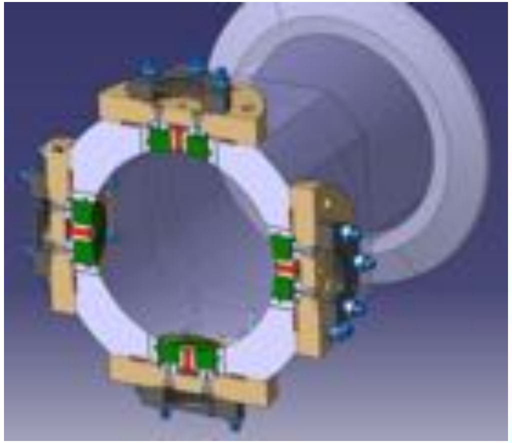
**Original design R = 40 mm*

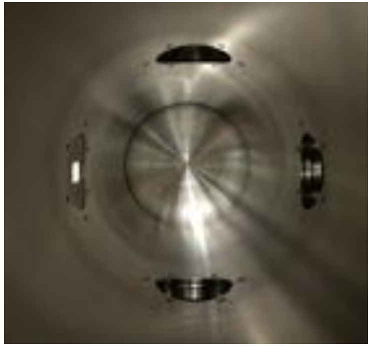
Electro-Optic Pick-up Design

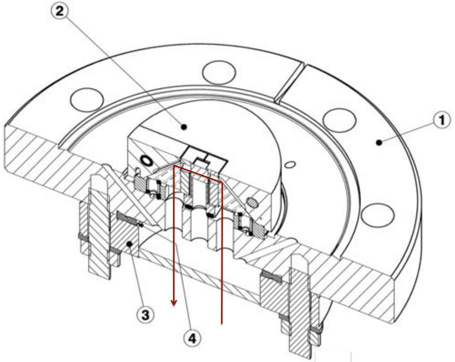






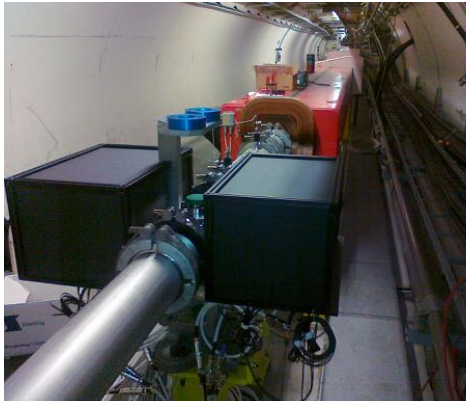


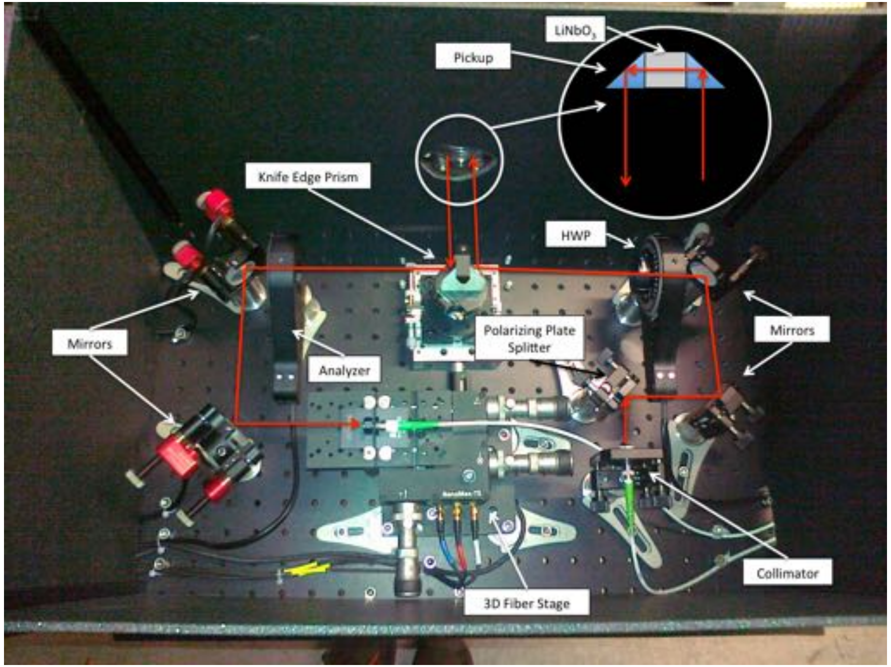




EO-BPM Optics Installation

- Prototype EO-BPM has been installed on the CERN SPS.
- The horizontal pick-ups are both equipped with optical breadboards.



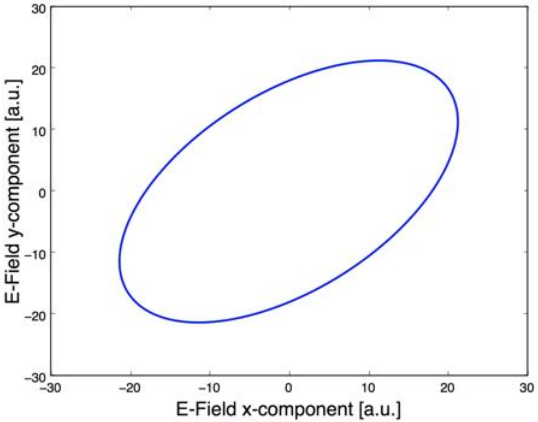


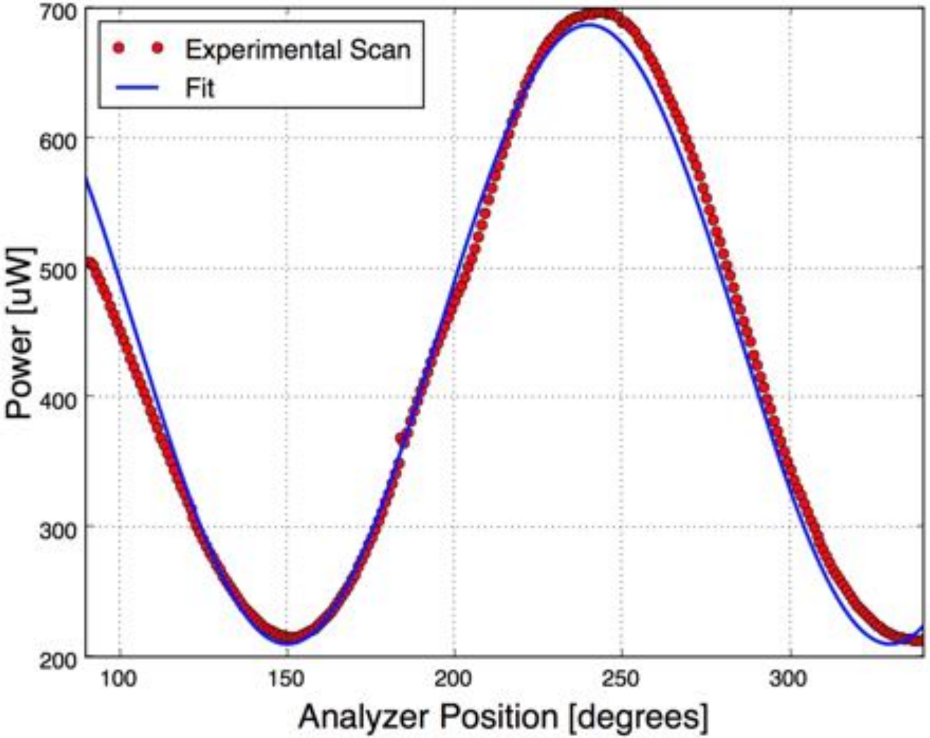
Internal view of the fibre-coupled polarisation optics.

Results from the First Prototype

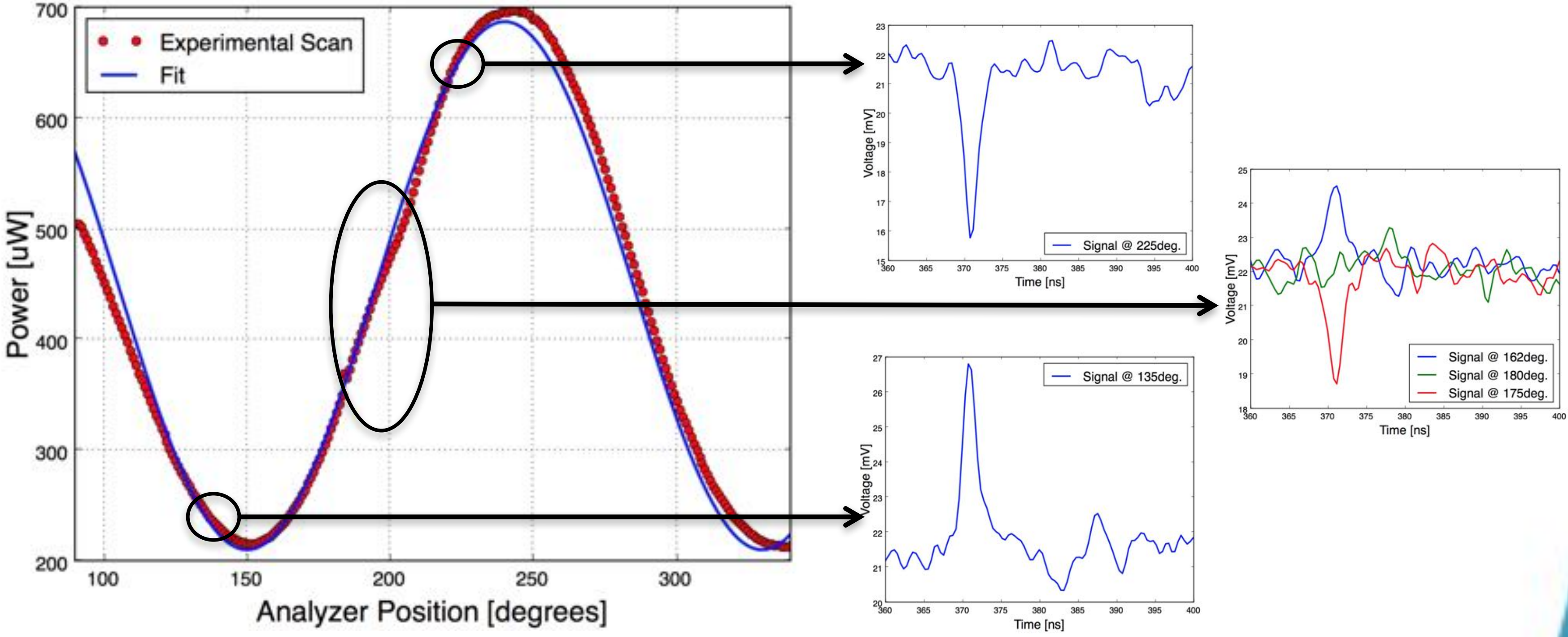
Beam conditions: AWAKE
Bunch length = 1.8ns
Intensity flat top = 2.8E11

Polarisation state after crystal:





Results from the First Prototype

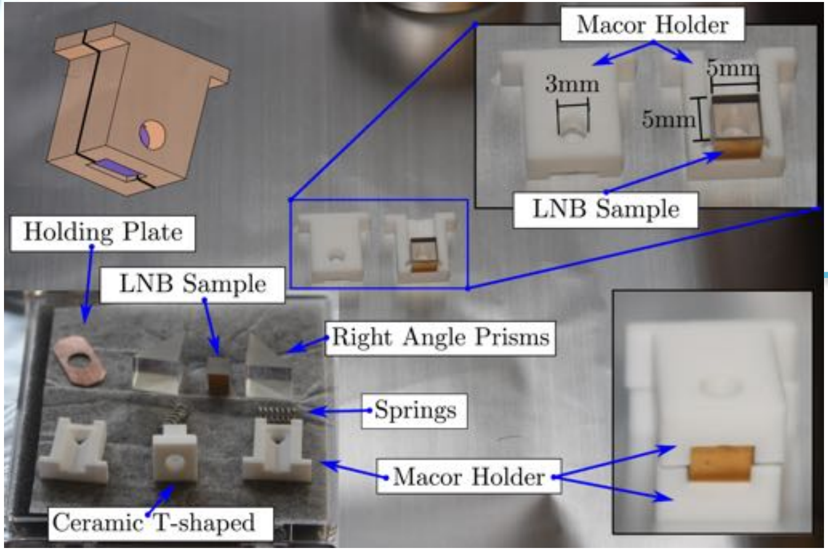


Correct optical behavior: Proof of concept achieved

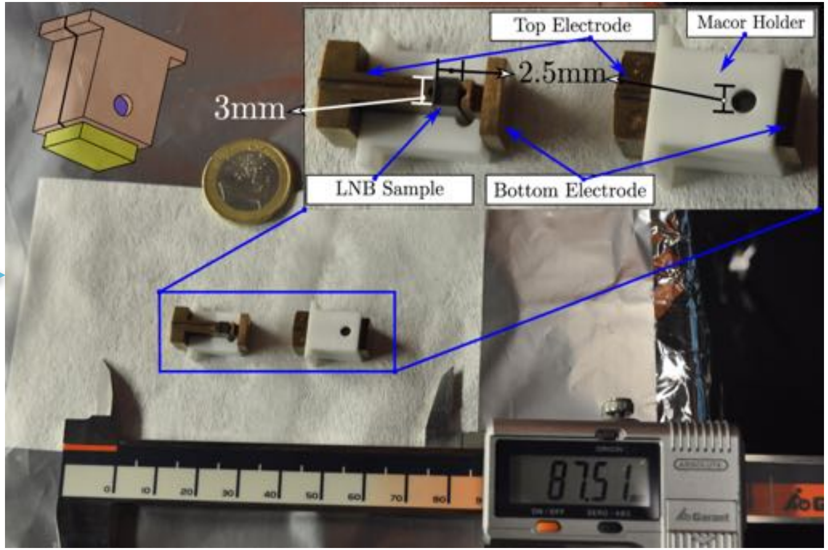
Results from the First Prototype

Proof of concept achieved!
Next aim: improve EO-BPM sensitivity

Electrode Pick-up Design



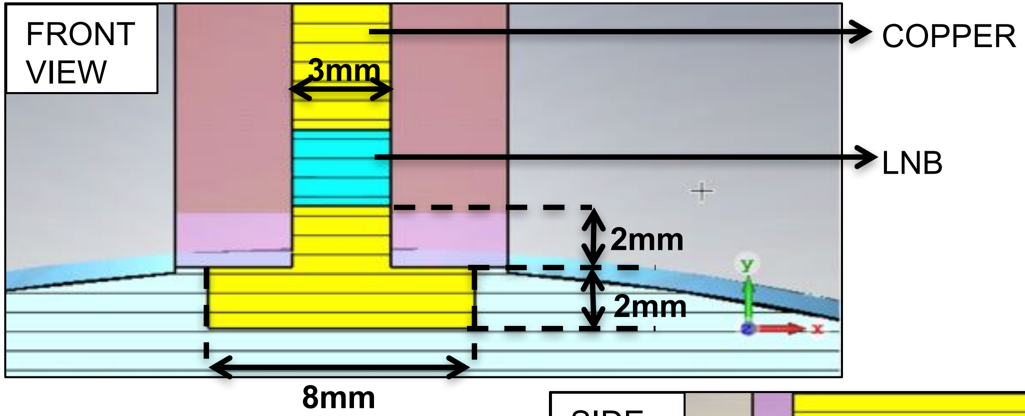
Prototype 0

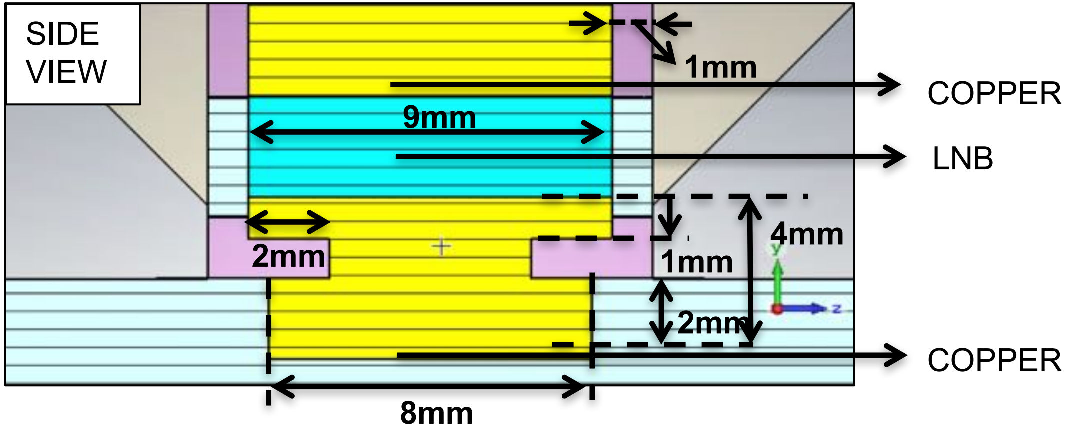


Prototype 1

Reused the buttons with new crystal length of 9mm and electrode pieces now included in the design.

Electrode Pick-up Design





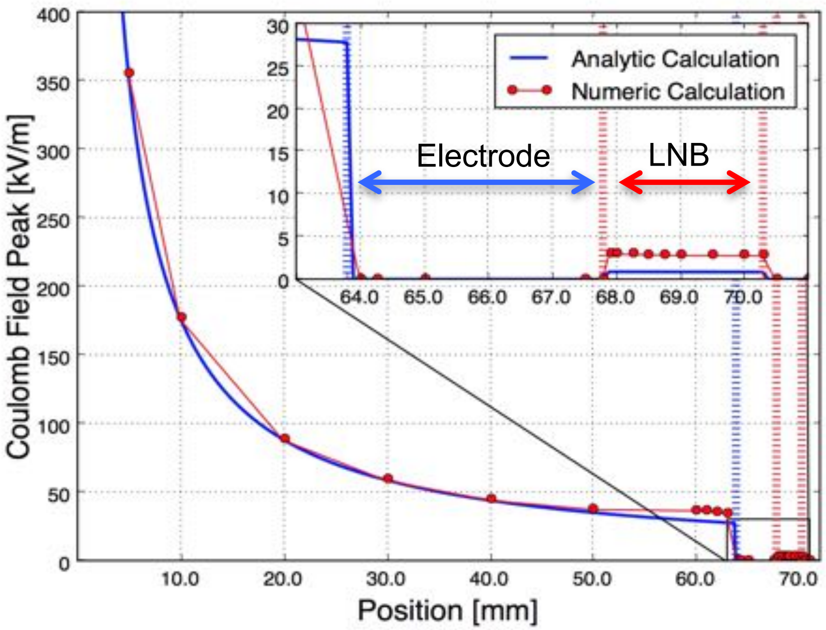
EM Simulations of Electrode Pick-up

Prototype 0	→	Prototype 1
0.65 kV/m	→	2.8 kV/m

E-field increase factor ~ 5

Considering doubling crystal length :

Overall increase signal factor ~ 8



Position [mm]	68.0	68.5	69.0	69.5	70.0
Electric Field [kV/m]	2.94	2.86	2.79	2.75	2.77

First Tests of Electrode Pick-up

- Initial results are promising!
- Signal detected in box with electrode pick-up installed.
- Preliminary analysis indicates improvement of ~ factor 5.
- Further analysis required for final confirmation.

Future Outlook

- Planned bench tests with fast voltage beam signal from conventional pick-ups using an external EO-modulator.
- Interferometric design to be investigated on the test bench at RHUL.
- Review of EO-BPM project at CERN in September.
- Begin 18 month Long Term Attachment (LTA) at CERN in October.
- Plans being discussed currently to test an EO-BPM at Diamond Light Source and/or CLEAR during the CERN long shutdown in 2019.

Thank you for listening!

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