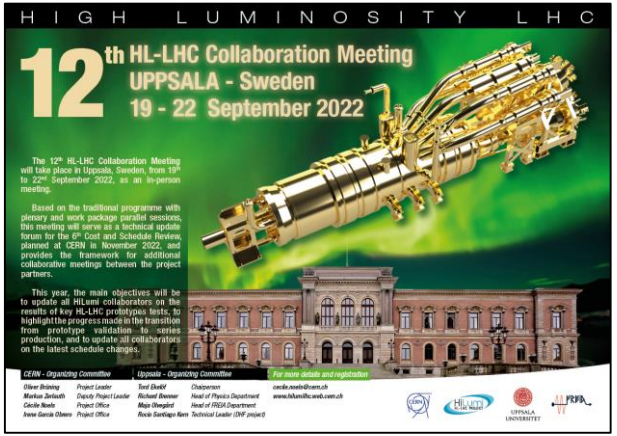


EO-BPM studies & PU(s) for CC diagnostics

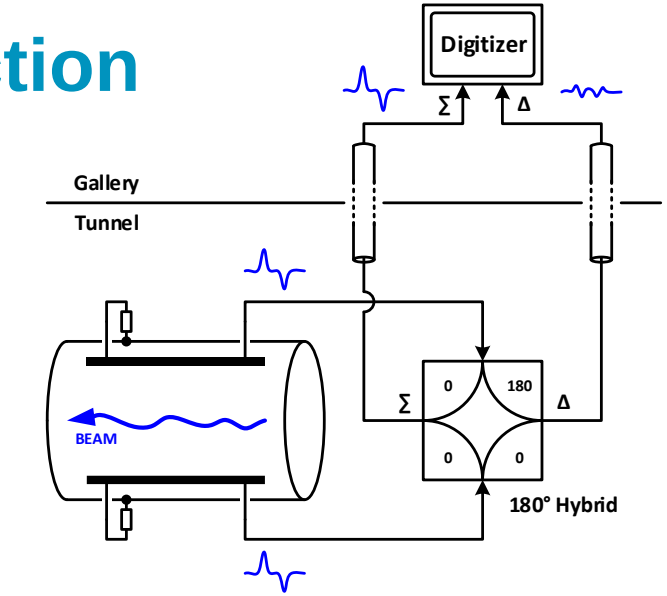
T. Levens, T. Lefevre, M. Krupa (CERN SY-BI)
S. Gibson, A. Arteche (RHUL)

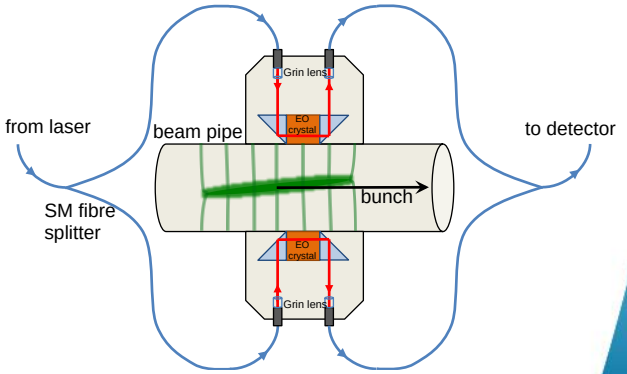
12th HL-LHC Collaboration Meeting, 19-22 September 2022, Uppsala

EO-BPM studies

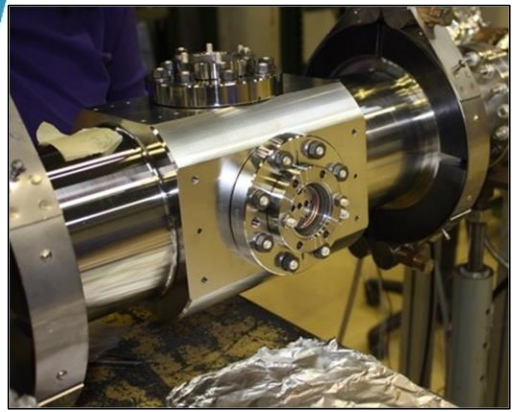
EO-BPM introduction

- Existing high-bandwidth “Head-Tail” monitors
  - Measurement of transverse instabilities
  - Measurement of crab-cavities
- Limited in bandwidth & resolution by imperfections of pick-up, hybrid & cables
  - Difficult to achieve significant improvements
- Electro-Optical (EO) BPMs are being studied by WP13, in collaboration with RHUL, as a potential upgrade for higher bandwidth
  - Using birefringent crystals to modulate a laser signal in response to the bunch EM field
  - Fiber coupled interferometer utilises the coherence of light to suppress common mode signal
  - Difference signal measured directly at photodetector

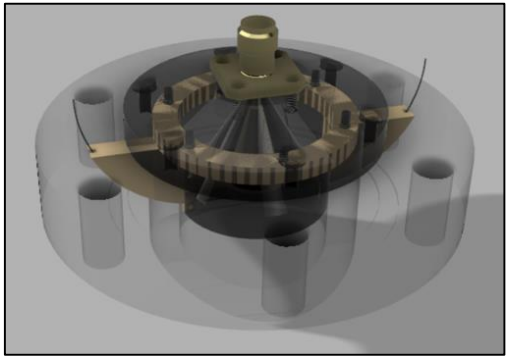




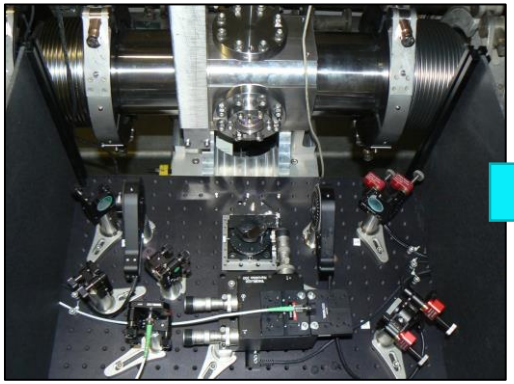
EO-BPM development history

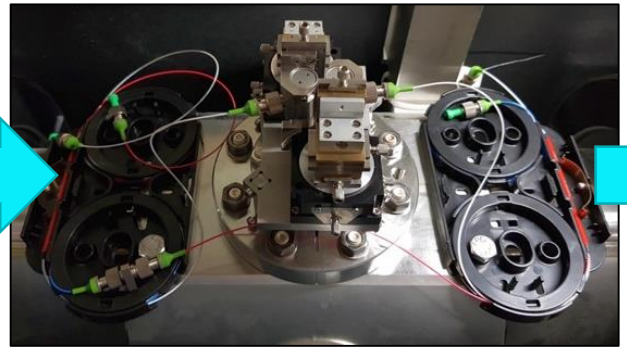


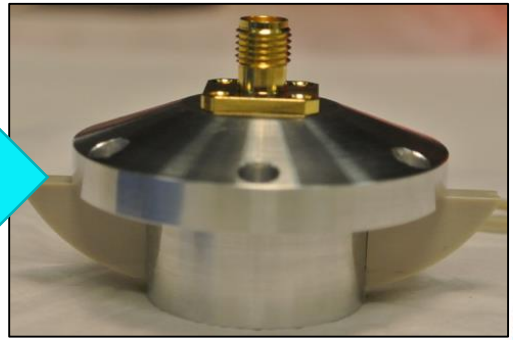
1. **2016:** Original SPS design using bulky free-space optics with a polariser/analyser
2. **2018:** Installation of a compact interferometric design in SPS
3. **2021:** Optimised fully fiber-coupled waveguide design



© RHUL

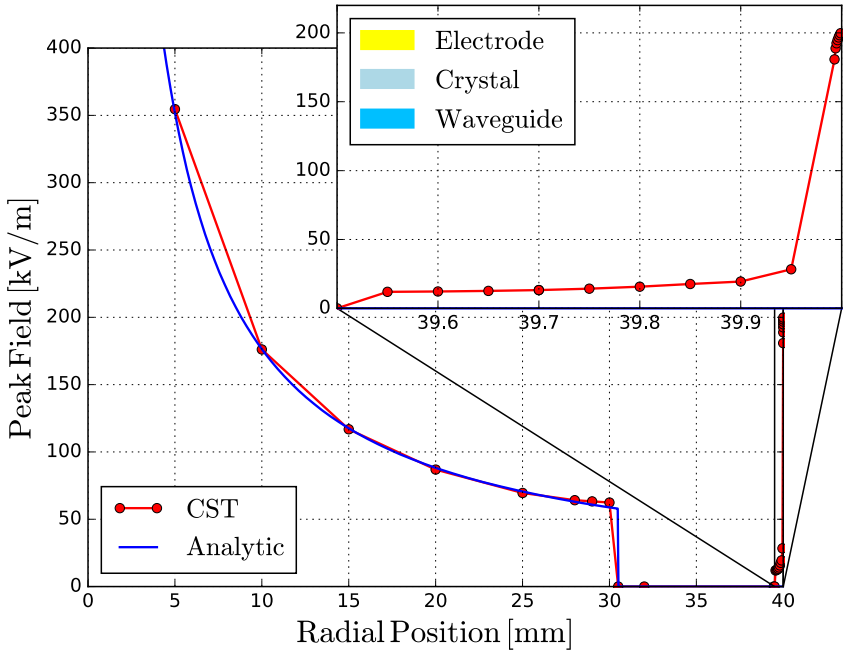






Simulated performance improvements

- The EO-BPM prototypes tested at the SPS (2016-2018) successfully delivered a weak (1-2 kV/m) proof-of-concept signal while operating at a radial position of 66.5mm from the beam.
- The optimisation work (2018-2020) focused on an improved pickup design capable of generating a highly magnified image field replica of the Coulomb field within an optical waveguide.
- The result is a highly optimised opto-mechanical design, fully fibred-coupled, capable to enhance the field up to ~200kV/m.

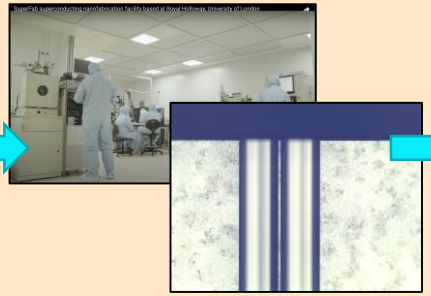


EO waveguide fabrication for beam tests

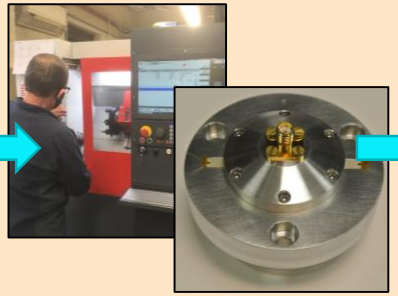
Pickup development and bench tests at RHUL

ROYAL HOLLOWAY UNIVERSITY OF LONDON

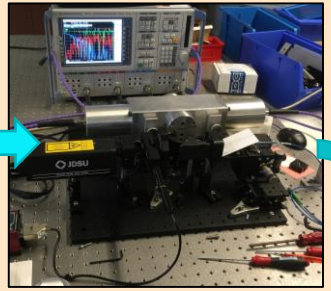
Waveguide fabrication in photonics industry



Inspection in new nanofabrication clean-room facility at RHUL



Precision manufacture & waveguide integration

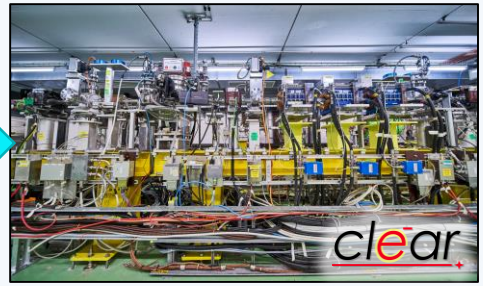


Bench tests on RF coaxial line / laser labs

Beam tests of waveguides at CERN

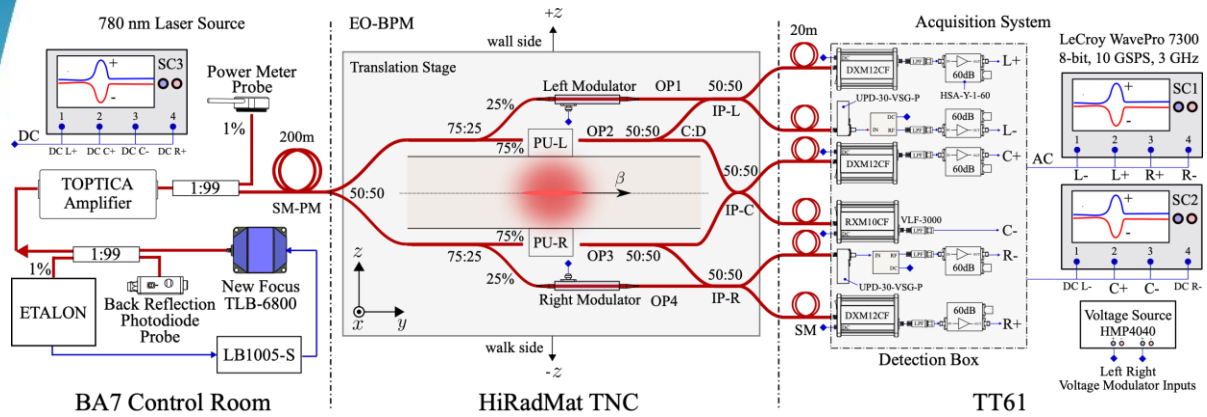
CERN

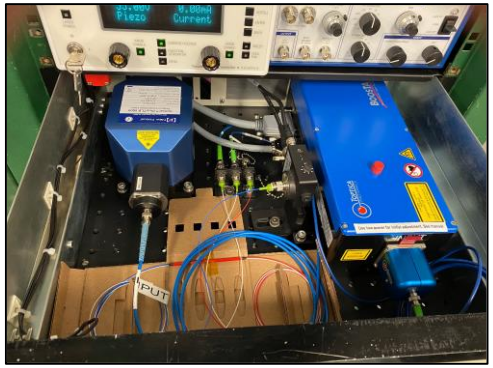
Beam test of waveguide signal



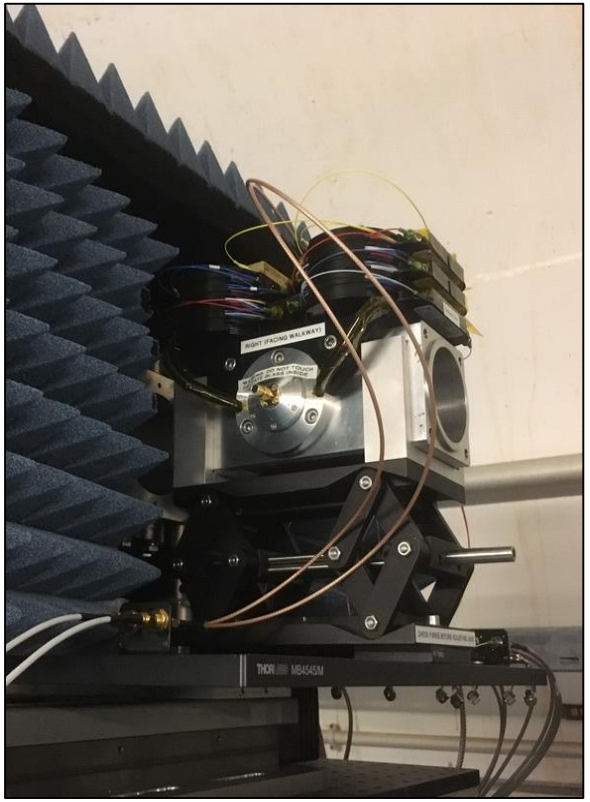
Beam test of waveguide bandwidth

EO-BPM tests in HiRadMat (2021)



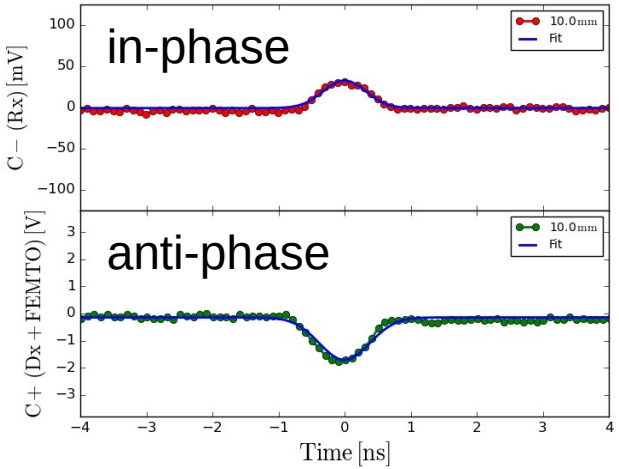


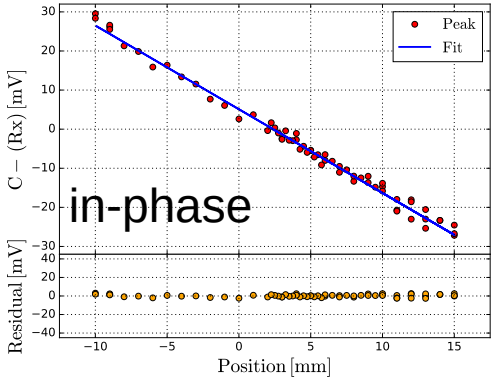
EO-BPM tests in HiRadMat (2021)

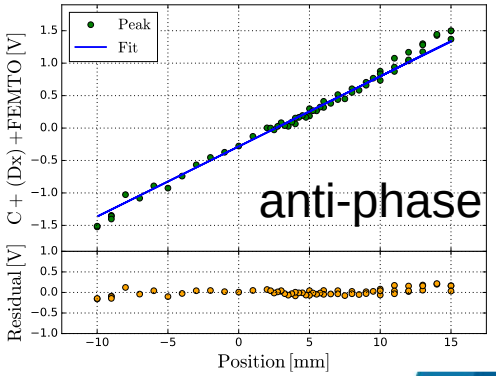


EO-BPM tests in HiRadMat (2021)

- New waveguide design enabled first single-shot measurements
- Laser scanning technique developed to automate operation of electro-optical interferometer
- Mechanical translation of EO-BPM allowed beam position scans
- More details presented by S. Gibson at IBIC ‘22 (contribution TU1I1)

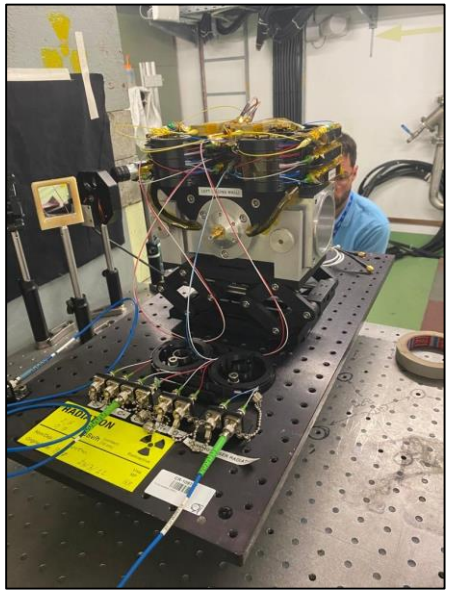


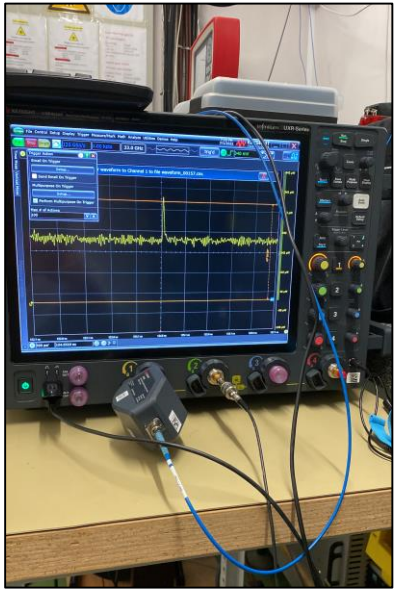


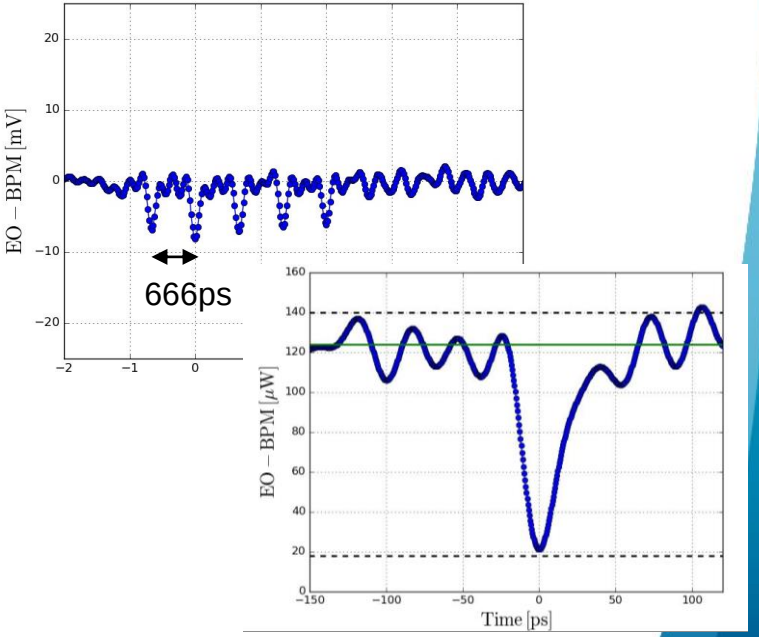


EO-BPM tests in CLEAR (2022)

- In-air EO-BPM installed in CLEAR to test time resolution with short (5ps) electron bunches, acquisition with 33 GHz oscilloscope and optical probe
- Preliminary results show time resolution is within the required <50ps specification for HL-LHC

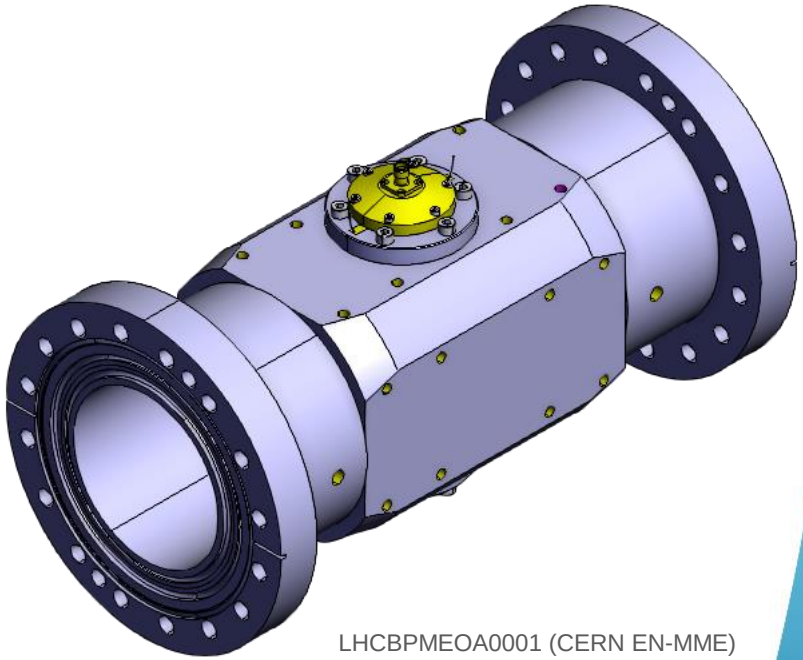






HL-LHC EO-BPM design

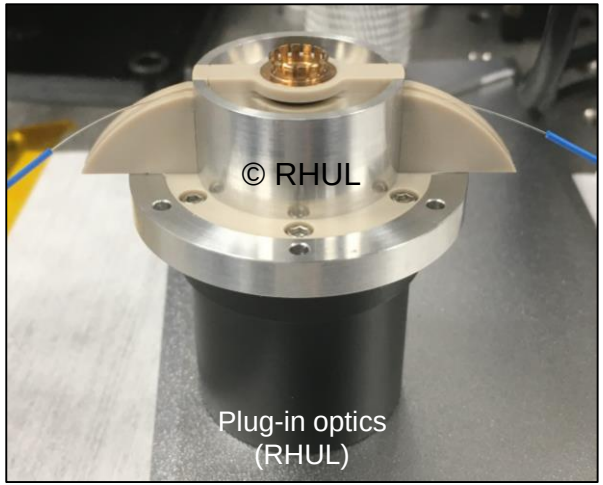
- Design of a vacuum compatible EO-BPM body completed in collaboration with CERN EN-MME
- Evolution of the in-air design used for HiRadMat & CLEAR tests
- Increase from ⌀60mm to ⌀80mm aperture for compatibility with installation in HL-LHC IR1/5 close to the crab-cavities
- Plug-in optics module that is designed to be dismountable in-situ for bake-out



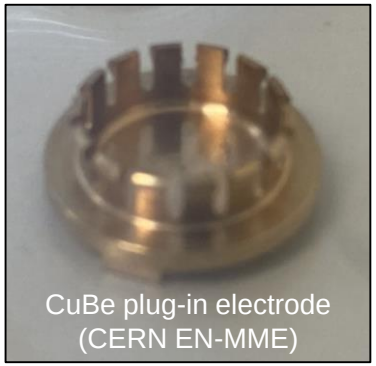
LHCBPMEOA0001 (CERN EN-MME)

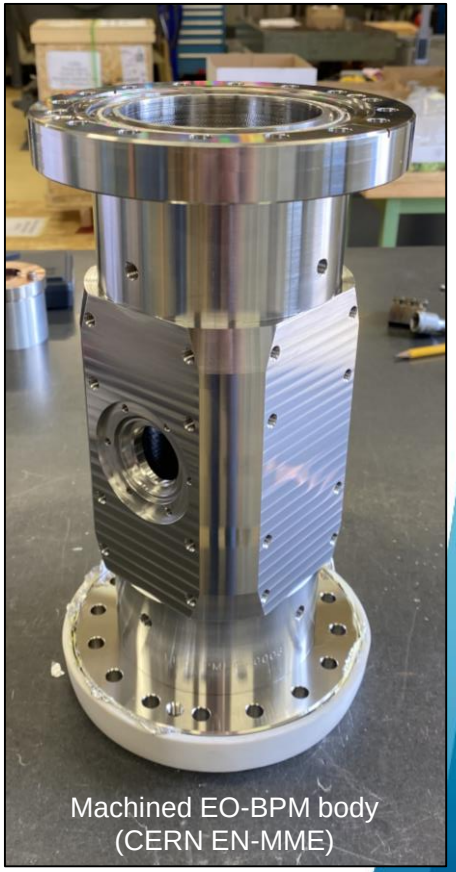
HL-LHC EO-BPM manufacturing

- Manufacturing of two prototype EO-BPMs of the HL-LHC design underway:
  - Vacuum body – CERN
  - Plug-in optics – RHUL
- Waiting for delivery of ceramic washers before brazing (due end Sept.)
- On track for installation of a prototype in the SPS during YETS 22-23



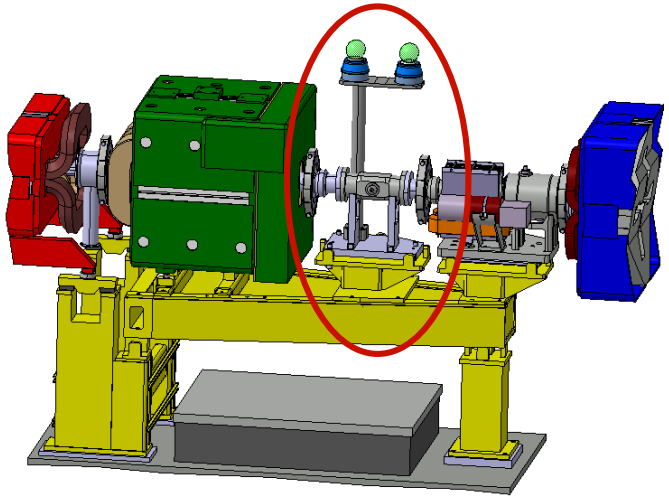
Plug-in optics (RHUL)


CuBe plug-in electrode (CERN EN-MME)


Machined EO-BPM body (CERN EN-MME)

2nd SPS EO-BPM test installation

- HL-LHC EO-BPM prototype will be installed in SPS
  - Benefit from reuse of existing fiber infrastructure in SPS LSS4
- Beam tests planned during 2023
  - Focusing on resolution and long-term stability of the EO-BPM
  - Benefit from possible 2023 crab-cavity tests as a validation step
- Technical review at end of 2023
  - Decision to install EO-BPMs or “traditional” strip-lines in HL-LHC



Integration of EO-BPM on SPS girder GHY.42101 (EN-ACE)

PU(s) for CC diagnostics

BPMs for crab cavity feedback in IP1/5

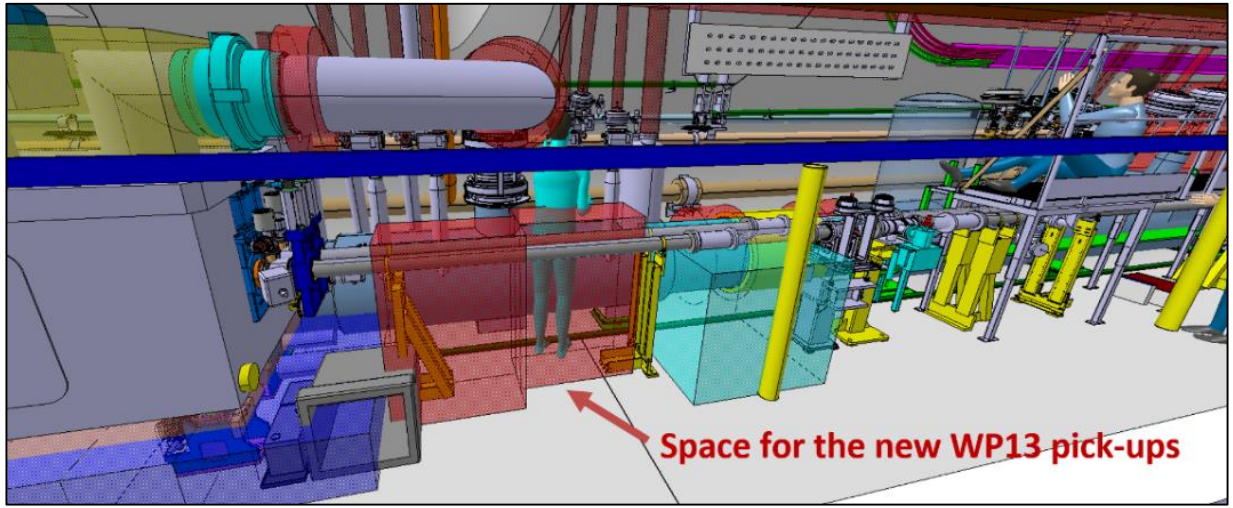
- 8 wall current monitors (APWL) put as placeholders for LLRF in IR1/5 – 1 per beam per IR side
  - Mechanically complex, wide-bandwidth, longitudinal PUs
- Desired functionalities from WP4 (TCC 02/12/2021):
  A. Phasing crabbing with beam
  B. Filtering of direct beam coupling
  C. CC noise feedback

  Can be served by less complex button BPM

  Requires a transverse PU
- Agreement between WP4 and WP13 to replace the APWLs by a combined button and strip-line PU designed by WP13 to cover the three functionalities
  - ECR LHC-BPMQ-EC-0002 (EDMS 2499201)

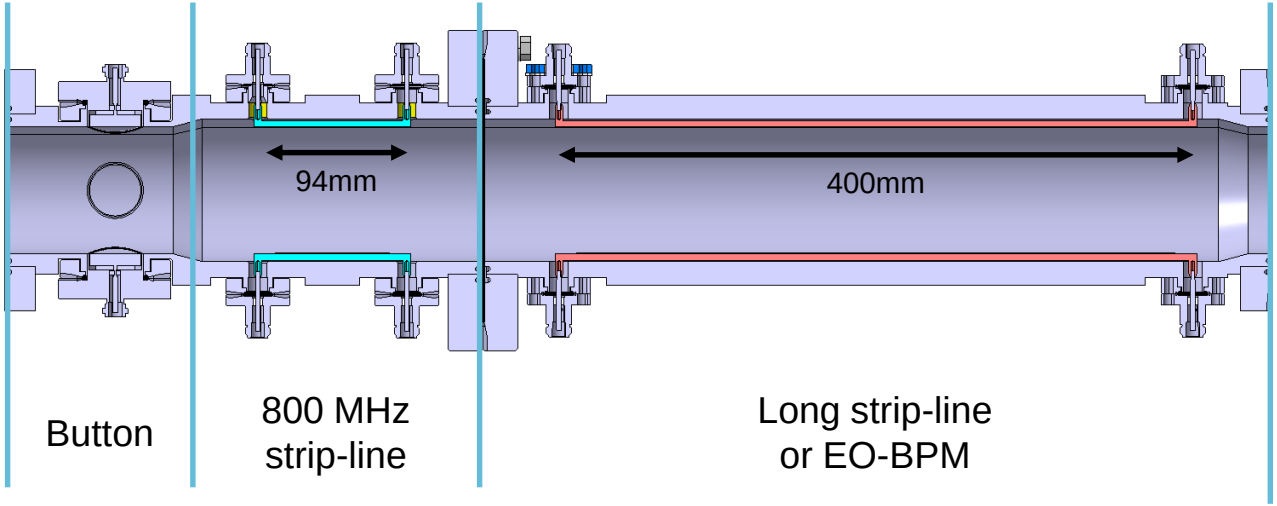
BPMs for crab cavity feedback in IP1/5

- Based on analysis by WP2 (link), the optimal location for the crab-cavity diagnostics is beside the cavities in IR1/5
  - Expected ~30µm residual crabbing signal, independent of optics
- 800mm/beam longitudinal space has been reserved for the combined feedback BPMs and either a long stripline or an EO-BPM



BPMs for crab cavity feedback in IP1/5

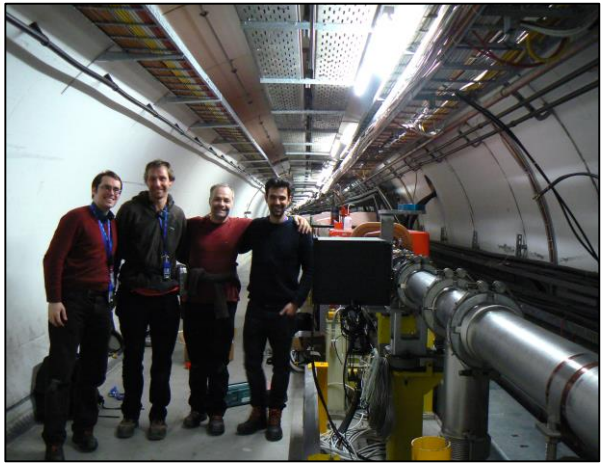
- First conceptual combined PU design (M. Krupa)
  - Dual plane button – WP4 “functions A/B”
  - Single plane 800MHz strip-line – WP4 “function C”
  - Single plane long strip-line or EO-BPM – WP13 “BPW”

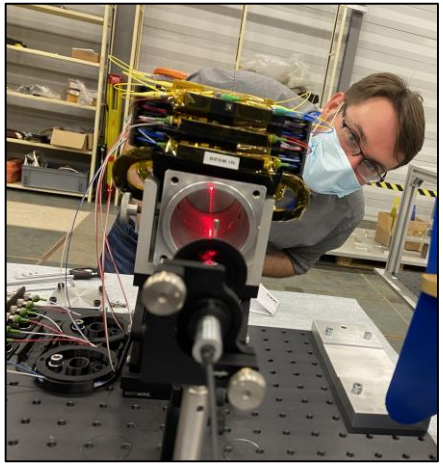


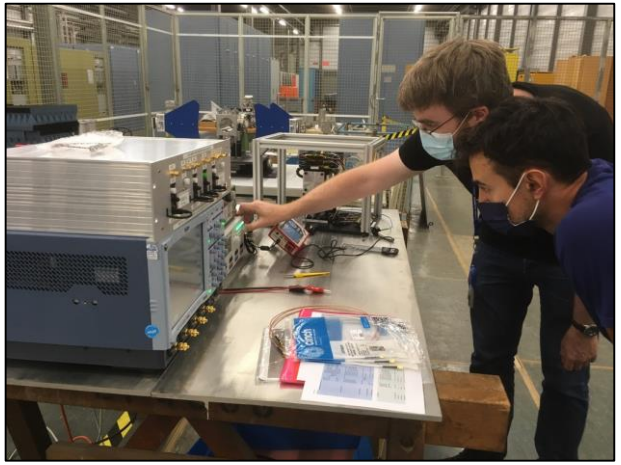
Summary

- After tests of an initial prototype EO-BPM in SPS (2016-2018), significant optimisation work has been done leading to a fully fiber-coupled waveguide design
- Successful in-air tests completed with proton bunches in HiRadMat (2021) and short electron bunches in CLEAR (2022)
- Vacuum compatible design completed and is being manufactured for installation in SPS during YETS 22-23 for beam tests in 2023

- Agreement reached between WP4 and WP13 to replace APWL by combined button and stripline and space reserved in IP1/5







Thank you!

Special thanks to: Nicolas Chritin and Fritz Motschmann (EN-MME) for their help with the design; and Pascal Simon (BE-EA) and the SPSOP, HiRadMat & CLEAR teams for their help during the beam tests!

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