This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

I.FAST WP10.7 Progress & Discussions: *Development of Electro-optical Waveguide Sensors*

I.FAST WP10 meeting, November 16th 2021

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John Adams Institute for Accelerator Science

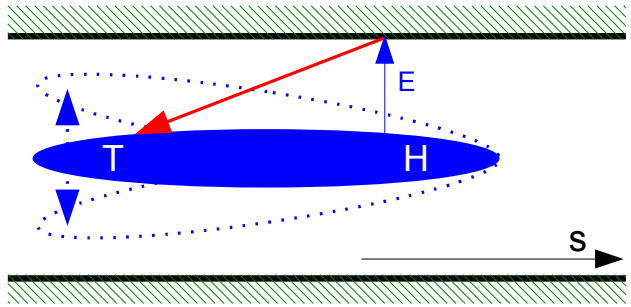
iFAST

Task objectives

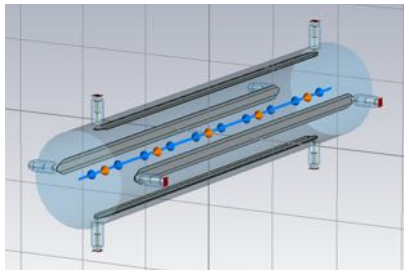
- **Task 10.7: Development of electro-optical waveguide sensors as beam electric field sensors.** M1 – M24 by RHUL & CERN + industry.
- Develop **novel electric-field sensors** based on electro-optic waveguides to address new challenges in fast time response (<50ps) beam instrumentation.
- **Demonstrate the capability** to optically measure the intra-bunch transverse displacement of a passing relativistic bunch, with a bandwidth that is beyond state-of-the-art.

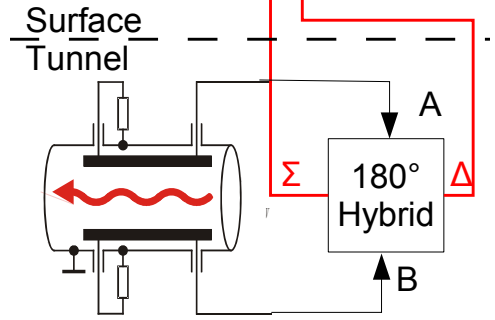
How to make beam Instrumentation FASTer?

- ***Challenge of rapid diagnostics***
  - Beam instrumentation at current and future particle accelerators would **benefit from an improved time response** in multiple areas:
    - Bunch arrival time/ ToF; crabbed bunch rotation; temporal longitudinal profiles; measuring rapid, intra-bunch transverse instabilities…
  - **Bandwidth** of conventional diagnostics is typically **limited** to a few GHz by the pick-ups, hybrid, cables and acquisition system.



Standard approach: stripline BPM

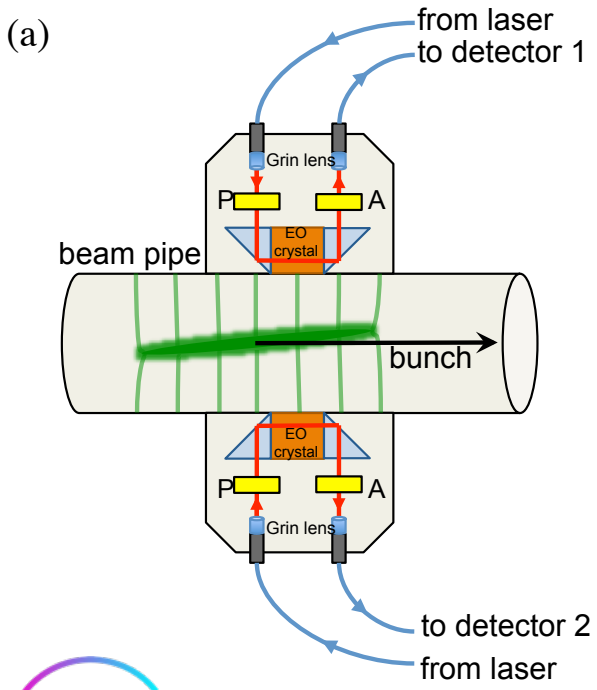




- ***A new technology is needed***
  - replace capacitive pick-ups with fast electro-optic crystals
  - replace electric cables by optical-fibre readout

Electro-optic BPM

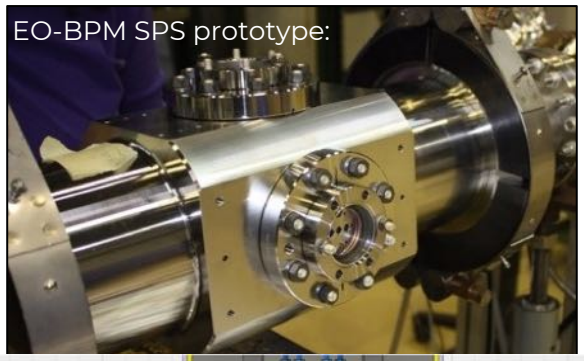
- ***Basic principle:***
  - Monitor the polarisation of light in birefringent crystals in response to the electric-field of a passing bunch

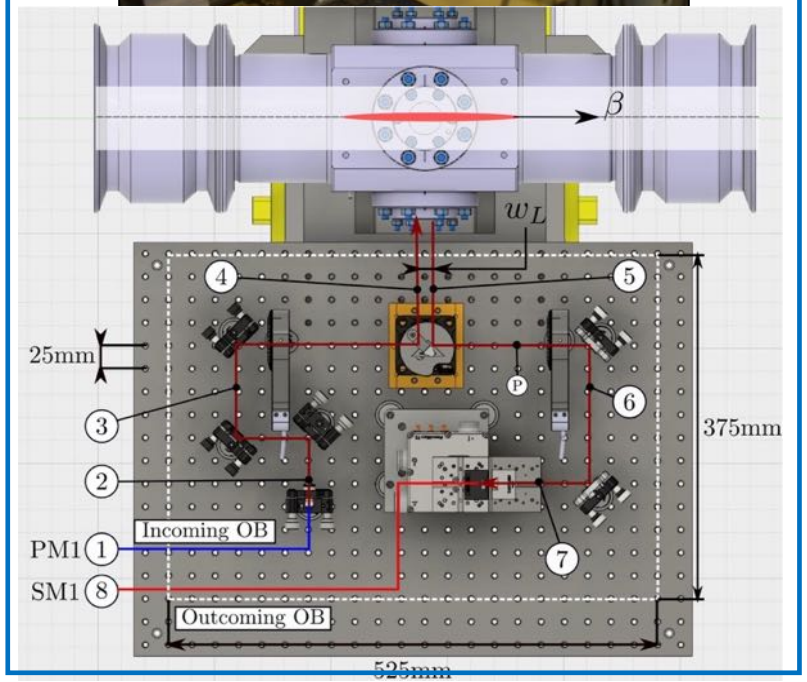


- Effectively a BPM in which the electrodes are replaced by eo-crystals
- Transverse position along passing bunch is measured
- A fibre coupled laser source and photodetector read-out are housed away from the accelerator tunnel.
- As polarised light passes through the crystal, the electric field of the bunch induces a change in polarisation state by the linear Pockels effect.

- **I.FAST Task 10.7 focuses on developing miniaturised e-field sensors based on *electro-optic waveguides***

EO-BPM developments: free-space to waveguides

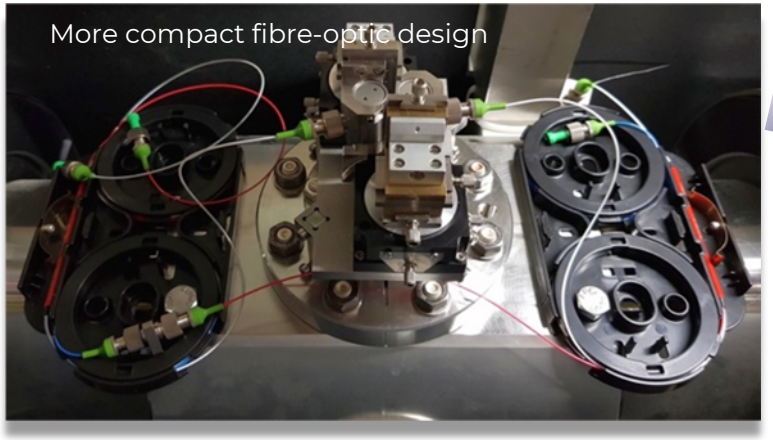




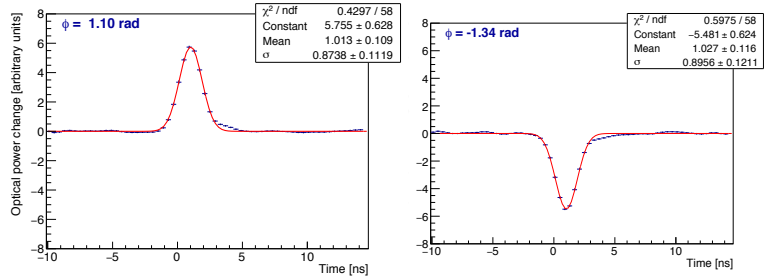
Bulky free-space optics

Miniaturisation of EO-pickup

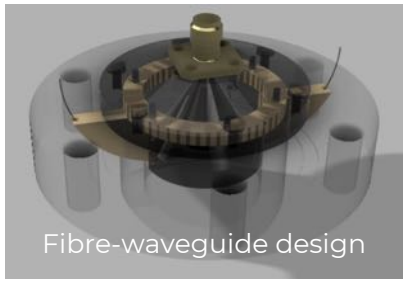
Side boxes for optics replaced by compact fibre-optics.

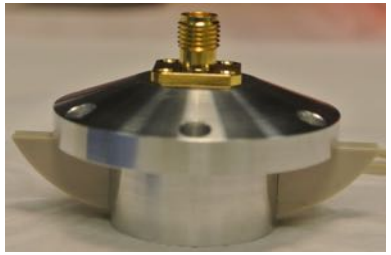


Optical response to SPS bunch – IPAC18:



Compact design based on eo-waveguides





Partners fabrication & test facilities

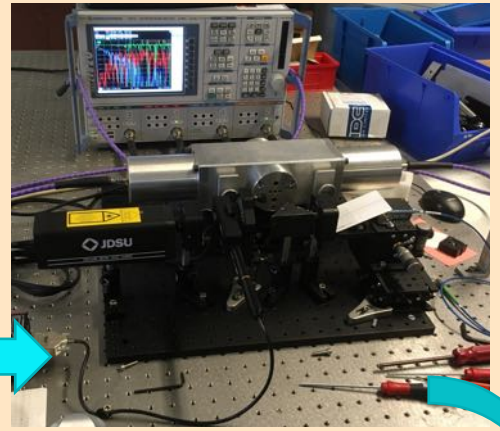
- **Pickup development and bench tests at RHUL**

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**

In collaboration with CERN BI, T. Lefevre et al

CERN

HiRadMat
High-Radiation to Materials

Beam test of waveguide signal

clear

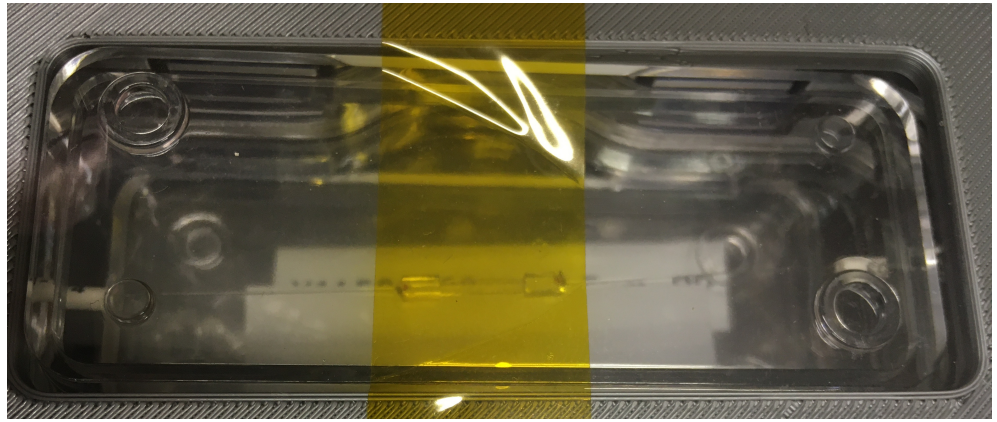
Beam test of waveguide bandwidth

Task WP10.7 activities

1. ***Waveguide design and optimisation***
   - Electromagnetic simulation of waveguide response.
   - Optimisation of design in collaboration with photonics industry.
2. ***Development and manufacture***
   - Fabrication in photonics industry of fibre-coupled EO waveguides.
   - Manufacture and integration into EO pick-ups in RHUL clean rooms.
3. ***Test and validation***
   - Bench tests of waveguide pick-ups at RHUL & design optimisation.
   - Beam tests at CERN facilities: HiRadMat & CLEAR.
   - ➢ **Deliverable 10.6: Electro-optic performance report** M24
     Final report on the performance of the electro-optic pick-up prototype with beam

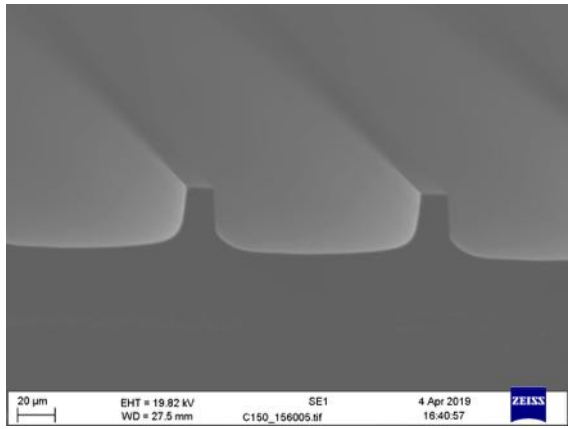
Waveguide optimisation and fabrication

- Electromagnetic simulations of pick-up performed in CST to optimise field strength at waveguide.
- Partnered with UK industry to produce waveguides suitable for our custom design:

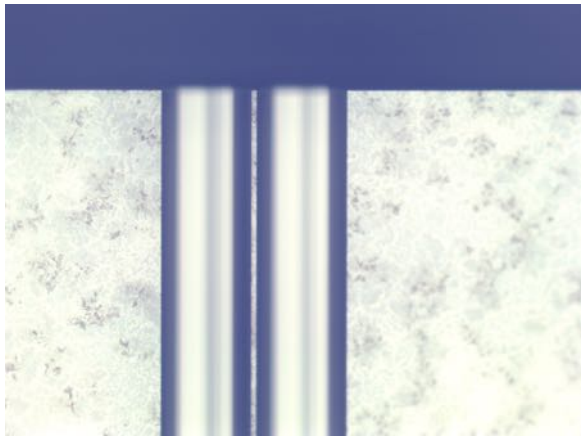


- Custom waveguides tuned for 780nm.
- High optical power handling.
- High contrast in refractive index gives better guiding than proton exchange waveguides.

- SEM image of typical ridge waveguide structure.

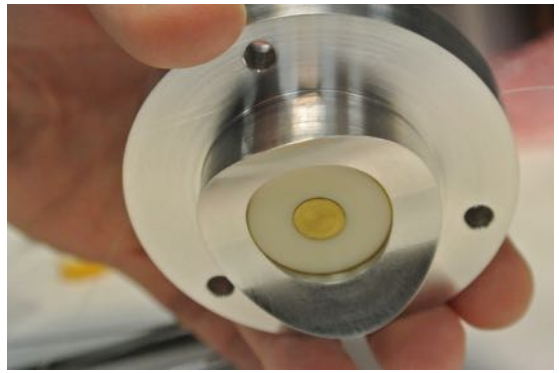


Optical inspection in RHUL clean room

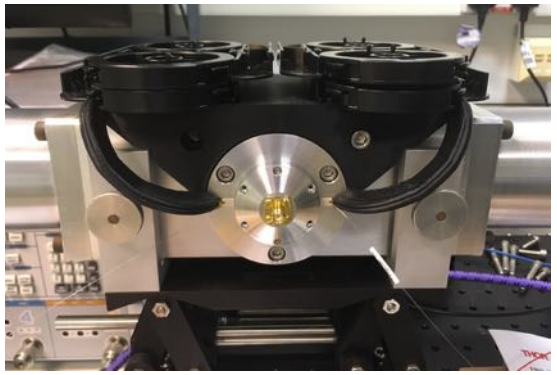


Manufacture of EO-pick-ups at RHUL

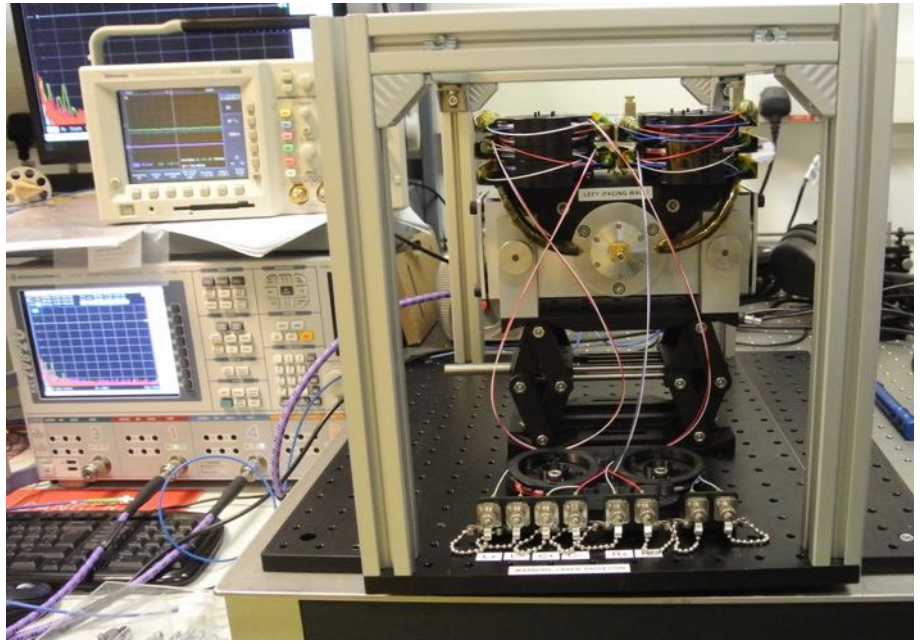
- Compact fibre-coupled waveguide pickups manufactured at RHUL



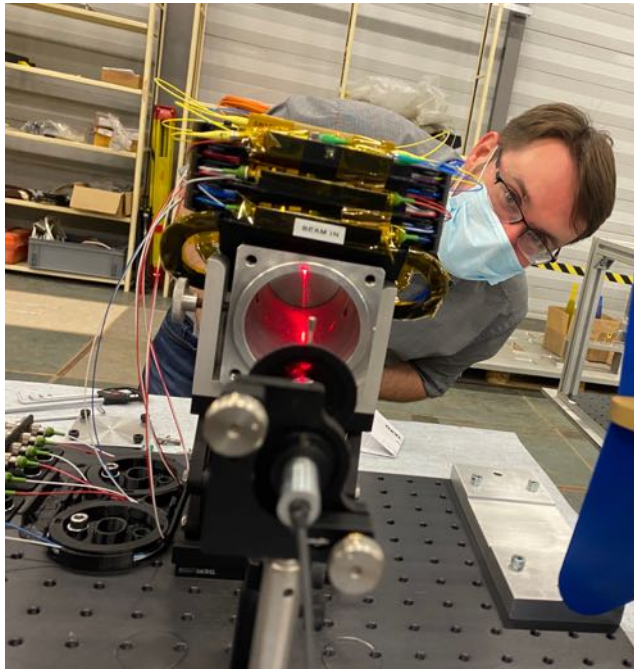
- 3D-printed supports for fibre splitter tree

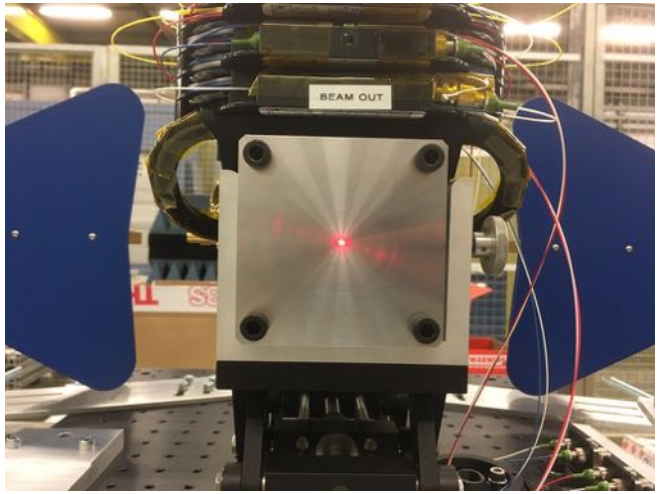


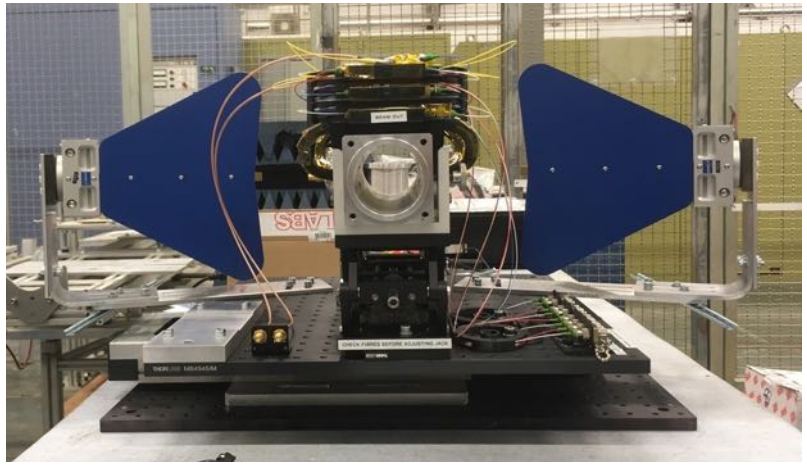
- New EO-pick-ups under coaxial line test in RHUL clean room, prior to shipping to CERN

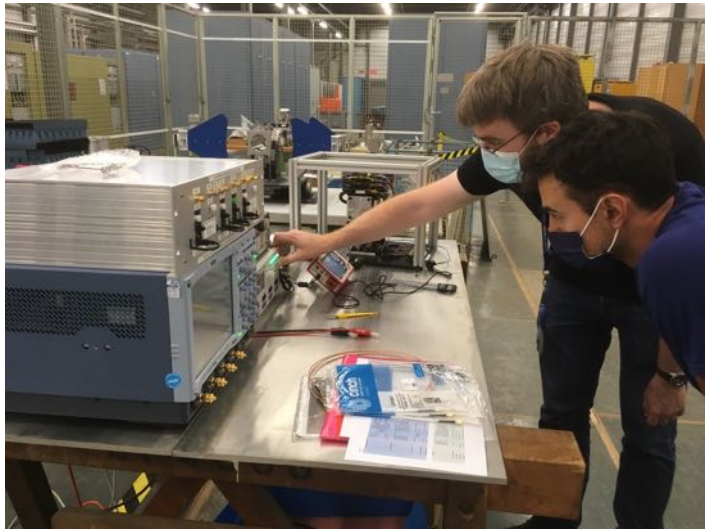


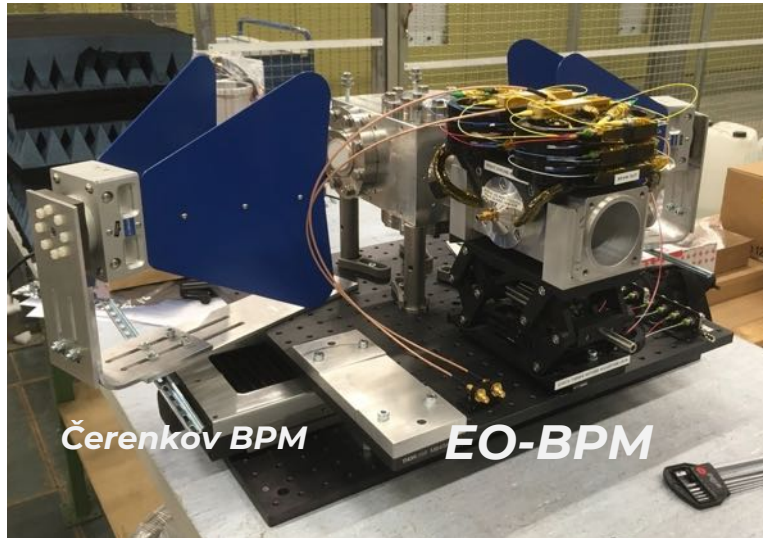
EO-BPM reception in surface lab at CERN





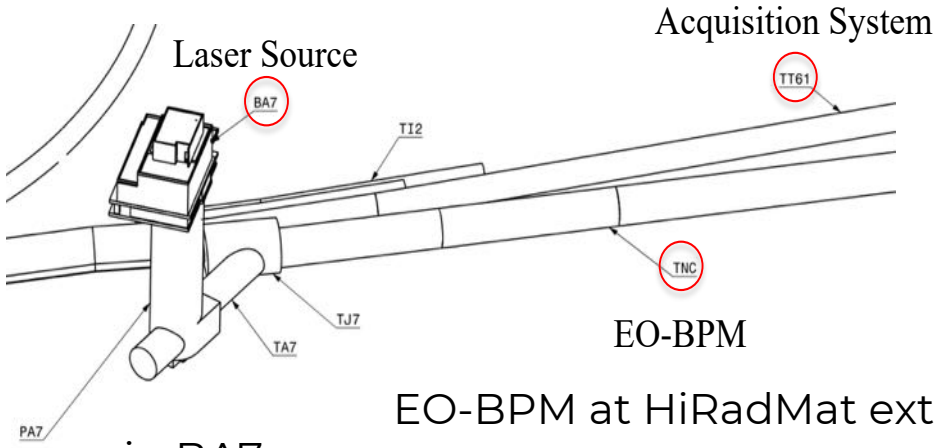




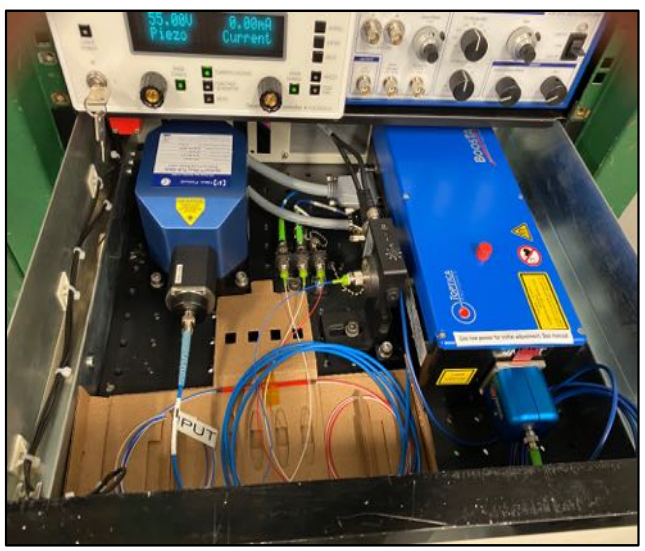


- EO-BPM reception tested at CERN and laser- aligned with dielectric BPM on shared translation stage table.

Installation at surface, TNC and TN61 tunnels

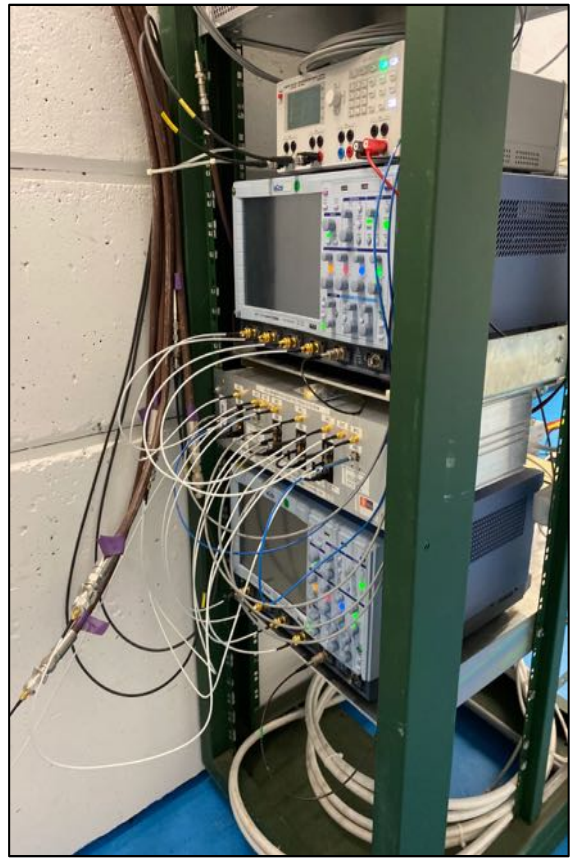


780nm laser source in BA7

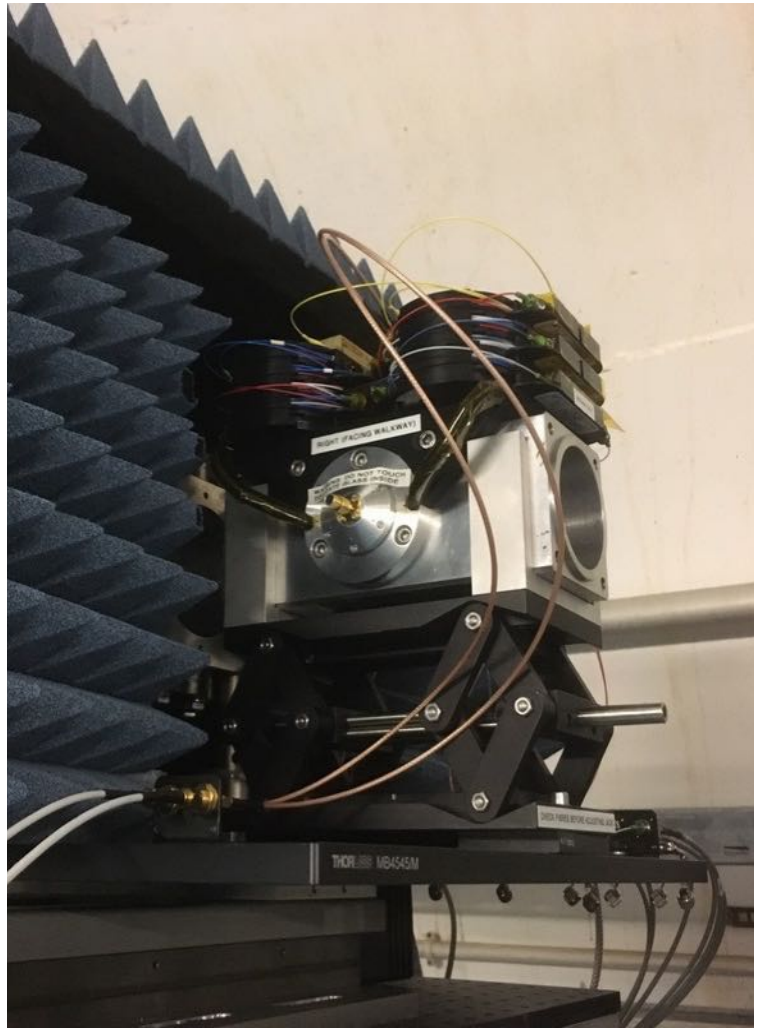


EO-BPM at HiRadMat extraction line

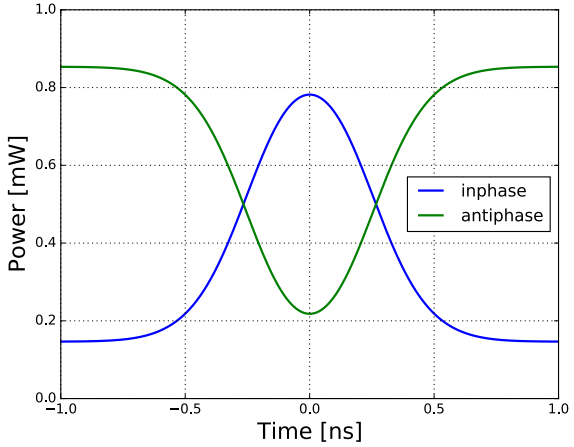
Acquisition system:

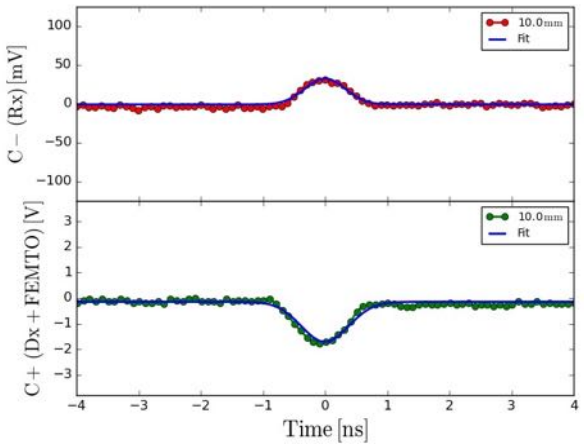


Installation at HiRadMat facility

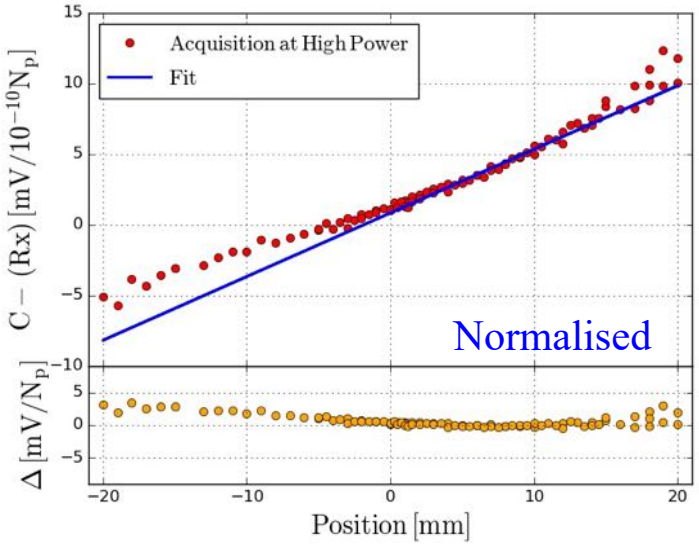


Successful first beam test at HiRadMat





Single-shot measurements using optical difference signal



- **Waveguide design** enabled **first single-shot measurements of each passing bunch**.
- EO-BPM also **sensitive to low intensity bunches**.
- Laser scanning technique developed to **automate operation** of electro-optic interferometer.
- Translation of EO-BPM across the HiRadMat extraction line: ***first bunch by bunch position measurements.***

Future plans & discussion

Beam tests envisaged with current waveguide prototype

- Complete data analysis from the three beam tests to date at HiRadMat and quantitative evaluation of performance:
  - Signal strength from individual waveguide and optical difference signals
- Beam tests at CLEAR to evaluate bandwidth performance:
  - Improvements to the data acquisition system to reach higher bandwidths.

Further optimise design in collaboration with photonics industry;

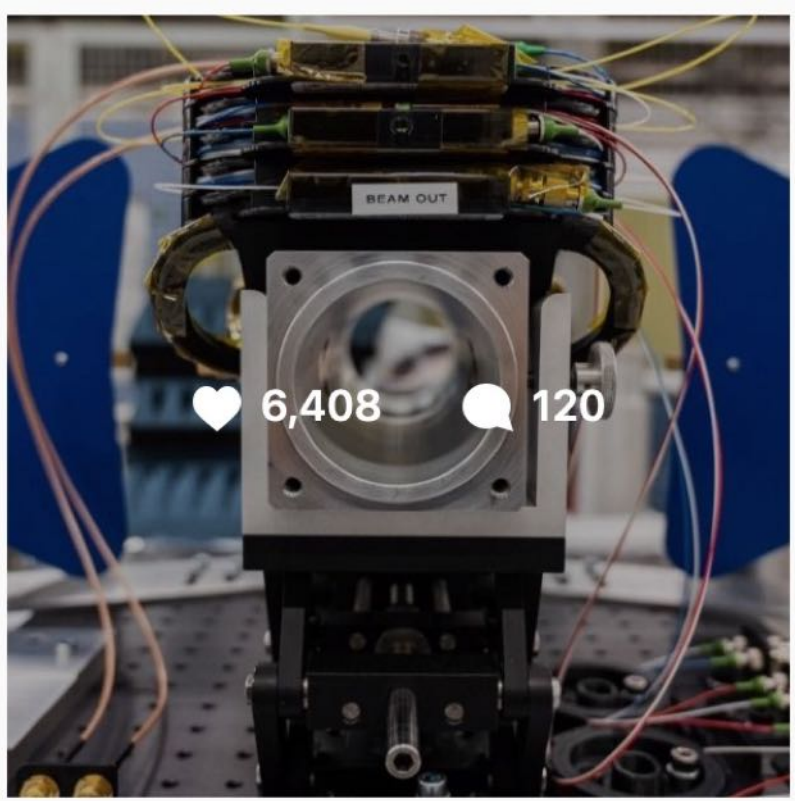
- Incorporation of gold coating onto waveguide to further improve electromagnetic coupling.
- Improve opto-mechanical design for handling, assembly and precise alignment of delicate components.
- Investigation of further waveguide configurations for interferometric enhancement of signal.

Write up the report on electro-optic performance for deliverable 10.6 by M24:

"Final report on the performance of the electro-optic pick-up prototype with beam"

CERN social media yesterday:

Instagram

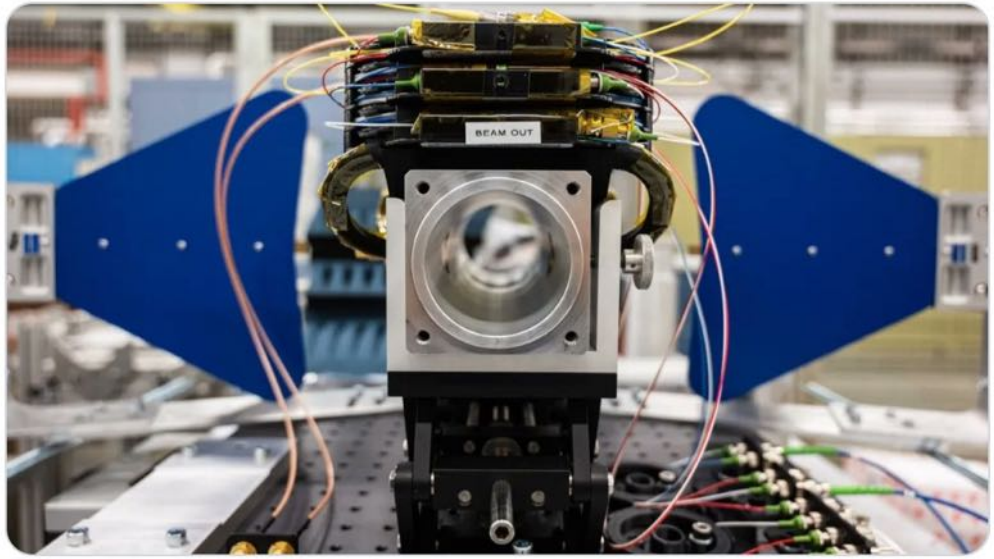


CERN
@CERN

This is a prototype electro-optical beam position monitor for the #HiLumiLHC.

It was recently tested in the HiRadMat facility at CERN, a place designed to test accelerator components and materials.

HiRadMat celebrates its 10th anniversary this year: home.cern/news/news/expe...



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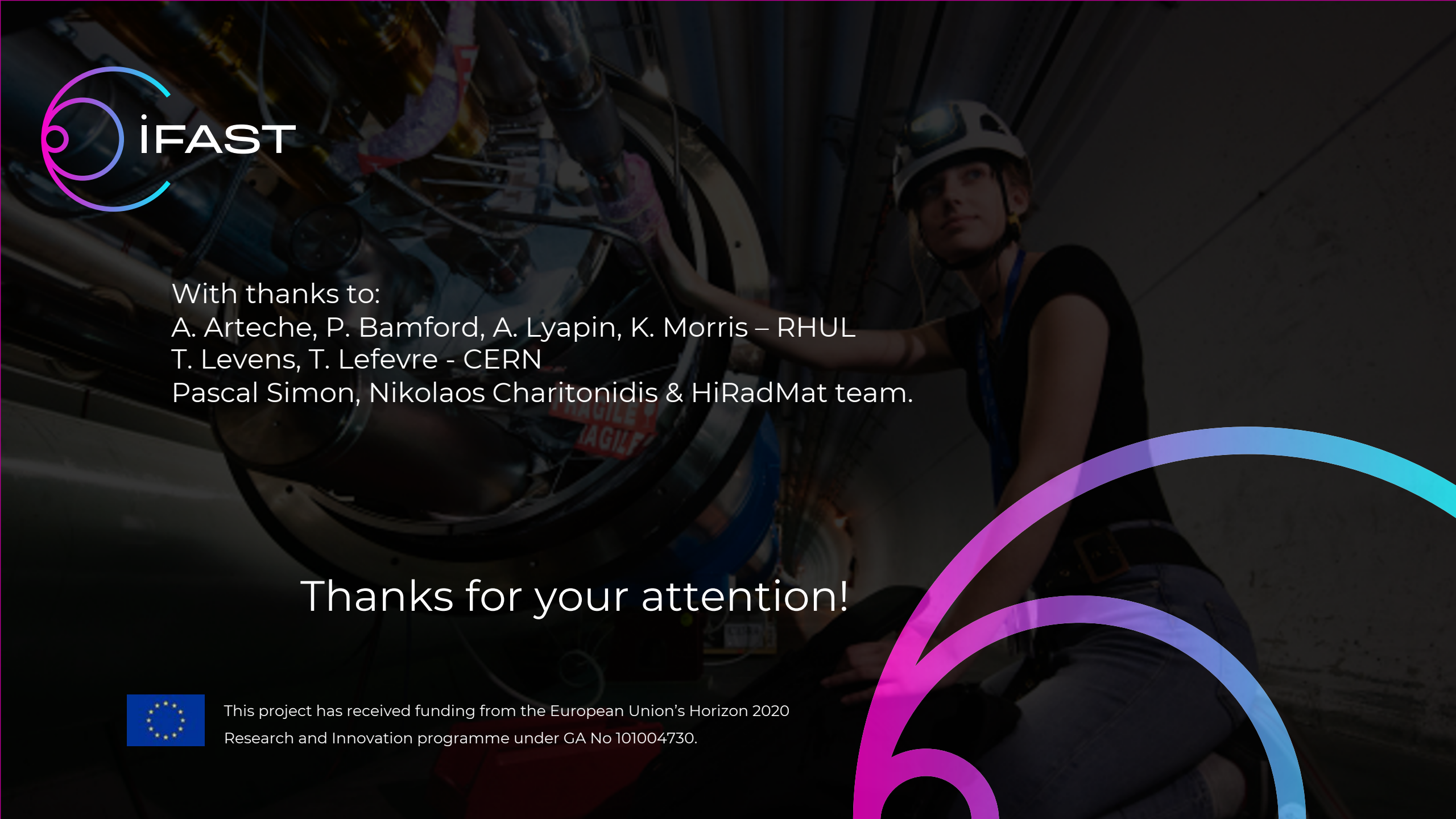

With thanks to:
A. Arteche, P. Bamford, A. Lyapin, K. Morris – RHUL
T. Levens, T. Lefevre - CERN
Pascal Simon, Nikolaos Charitonidis & HiRadMat team.

Thanks for your attention!

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