Overview of WP13 activities

Genoa, October 2024

Thibaut Lefevre on behalf of WP13

Beam instrumentation for new hardware configuration

New hardware :

- Larger aperture, higher field quadrupole magnets
  - **New cryogenic directional Stripline beam position monitors with higher resolution**
- Radiofrequency deflecting cavities
  - **New intra-bunch diagnostic to measure beam crabbing and transverse instabilities (50ps time resolution needed)**
- New absorbers for neutral particles requiring **new luminosity monitors**

Beam instrumentation for improved beam parameters

- Increasing the bunch and beam intensity (2.310^{11} protons per bunch)
  - **Development of non-invasive transverse beam profile monitor**
    - ***Beam Gas Ionization monitor***
    - ***Beam Gas Curtain monitor using on beam induced fluorescence***
  - **Development of beam halo monitors**
  - **Upgrade of Beam loss monitoring system**

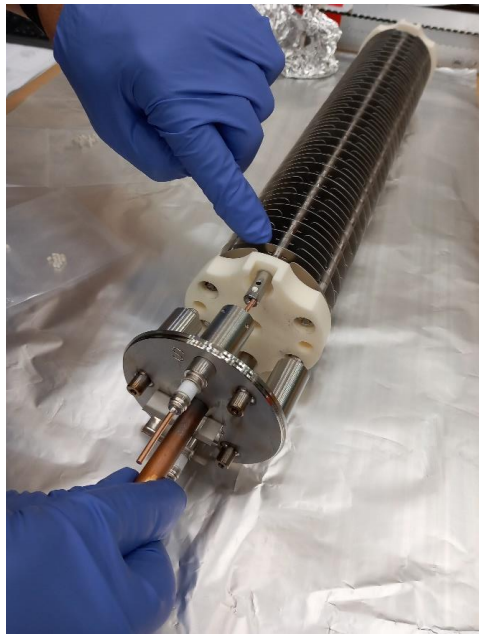
Overview WP 13 tasks

Task	Description	Equipment code
WP 13.1	Beam loss monitors	BLM
WP 13.2	Beam-gas curtain monitor	BGC
WP 13.3	Beam position monitors	BPM
WP 13.4	Luminosity monitors	BRANQ
WP 13.5	High-bandwidth BPM	BPW
WP 13.6	Synchrotron light diagnostics	BSR
WP 13.7	Beam-gas ionisation monitor [new technology baseline]	BGI

Task 13.1 Beam Loss Monitor Ionisation Chamber (IC) Production

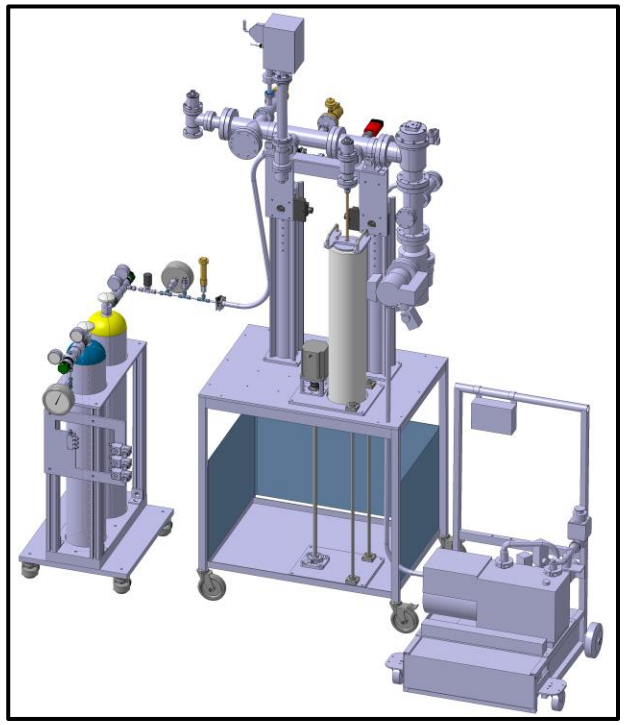
HL-LHC requires extension of existing BLM coverage with many new ICs

- Large-scale production being prepared
  - 1000 to produce for LS3, of which 200 for HL-LHC.
  - Prototyping with CERN groups EN-MME and TE-VSC

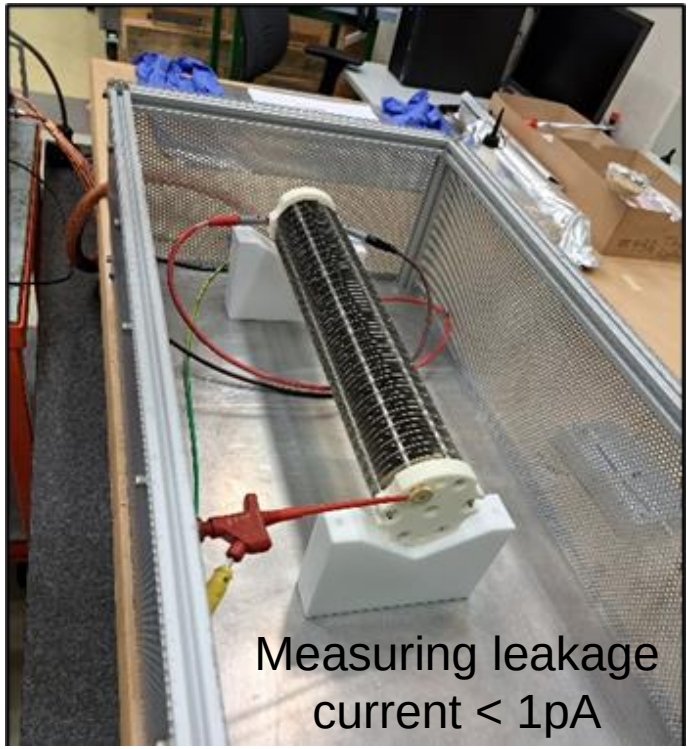


Task 13.1 Beam Loss Monitor Ionisation Chamber (IC) Production

New test-stands for bakeout and gas filling as well as electrical validation



BLM filling and bakeout stand

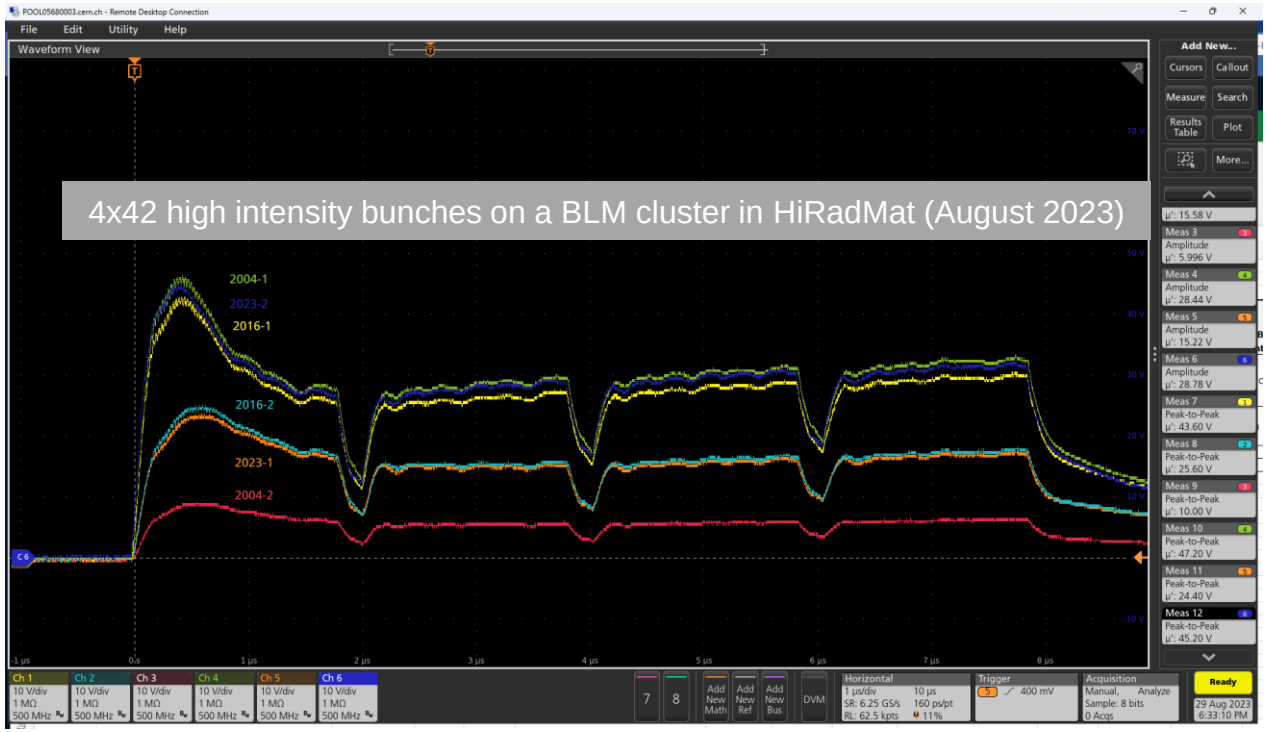


BLM electrical resistance test stand

Task 13.1 Beam Loss Monitor Ionisation Chamber (IC) Production

Successful preliminary tests of new prototypes in HiRadMat

- Two CERN-produced prototypes installed next to beam dump
- Comparison of beam loss signals for the previous production lots (2008, 2016, 2023) show acceptable dispersion



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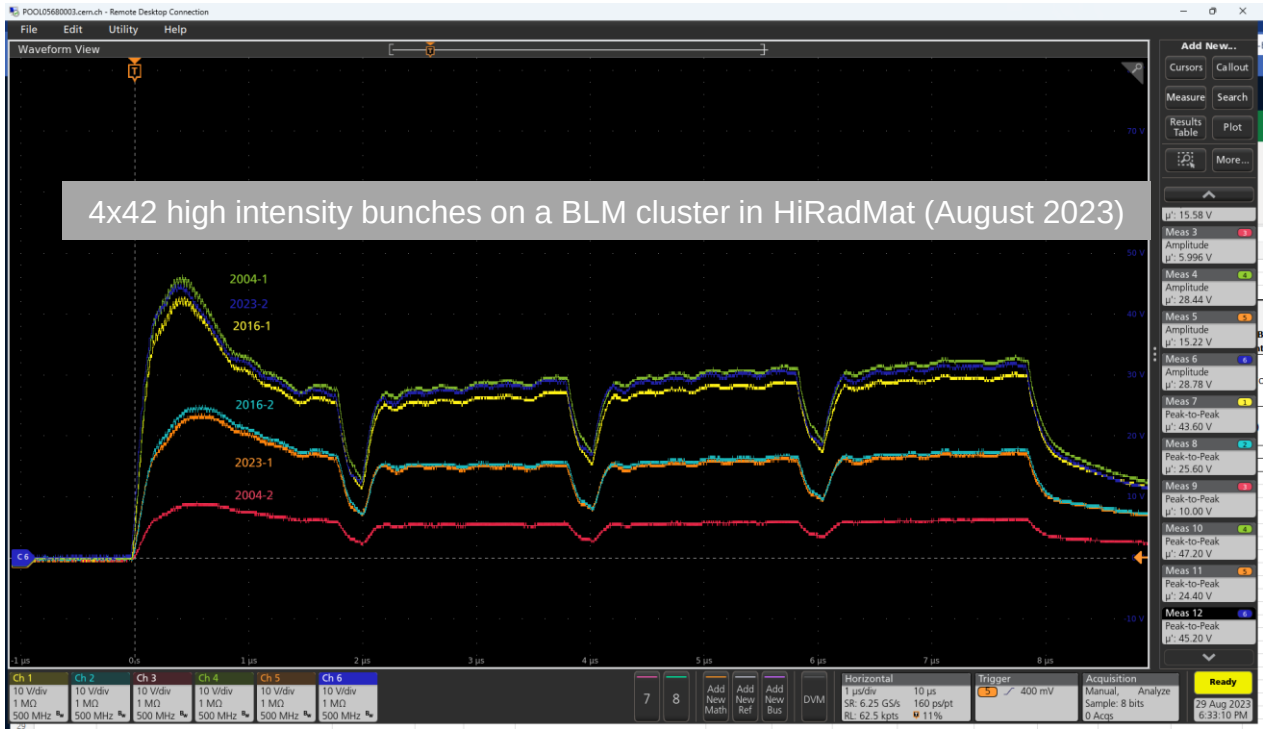


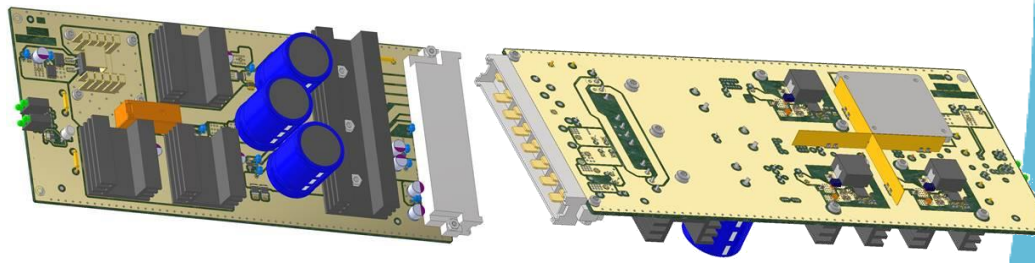
Talk by Gerhard for IC production status and strategy

Task 13.1 Beam Loss Monitor DAQ

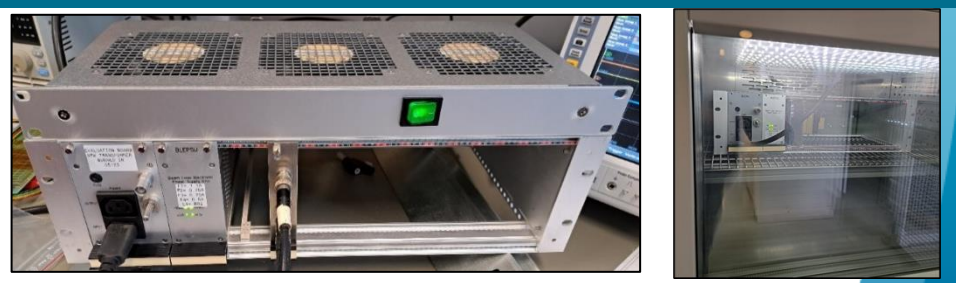
- New Rad-Hard card Front-End to allow reduced cable lengths and improve S/N ratio
  - First deployment at strategic locations during LS3 to complete and validate development in parallel to the current electronics
  - Full electronics deployment during LS4 as part of the Consolidation project
  - BLM ASIC production completed in 2024, VTRx and LpGBT under production with EP-ESE

- New rad-hard power supplies
  - Necessary for radiation resistance and replacing obsolete systems
  - Developed in common for BLMs and BPMs, in collaboration with EP-ESE and BE-CEM with likely CERN-wide usage
  - v3 based on bPOL (rad-hard ASIC)
  - Recent v4 prototype validation completed*, optimised for tunnel environment
  - All tests and validations completed, e.g.
    - @CHARM/CERN (reached ~ 1500 Gy accumulated)
    - Climatic chamber (150h stress-test up to 100°C)

New BLEIC card with application-specific IC (ASIC) so fewer componants



3-D models of BLEPSU v4



Set-up for CHARM and climatic test-chamber

*https://edms.cern.ch/item/EDA-03919-V4-0/0

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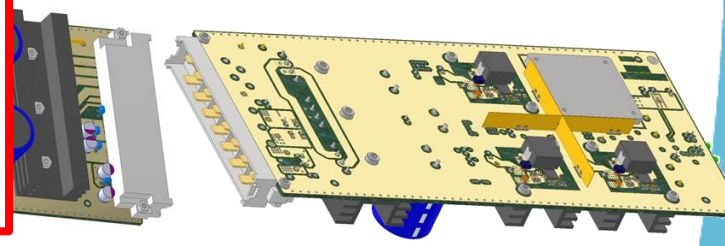
Talk by Christos on HL BLM system development

Talk by Sara on Beam loss limitations and proposed changes



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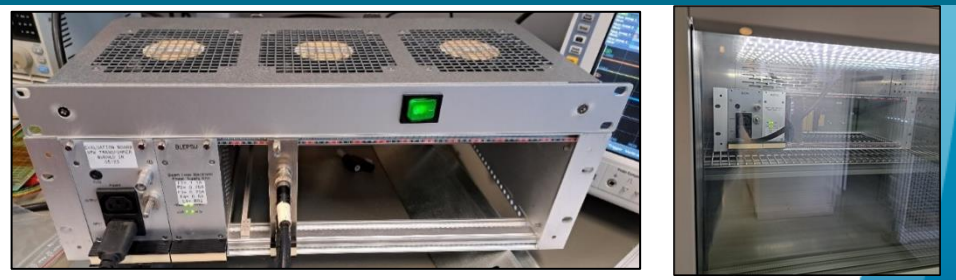

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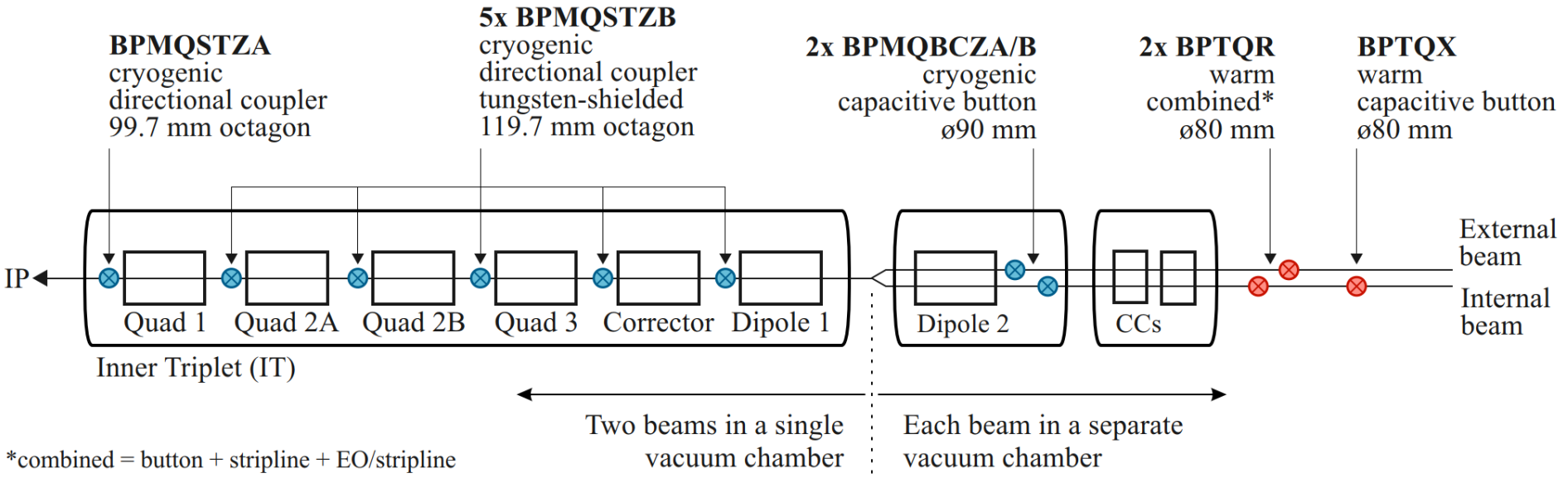
Task 13.3 - New Beam Position Monitors (BPMs) - Overview

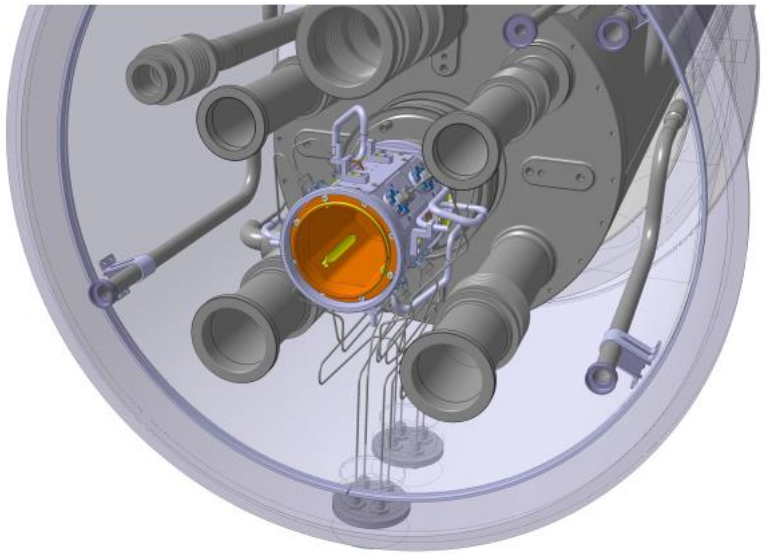


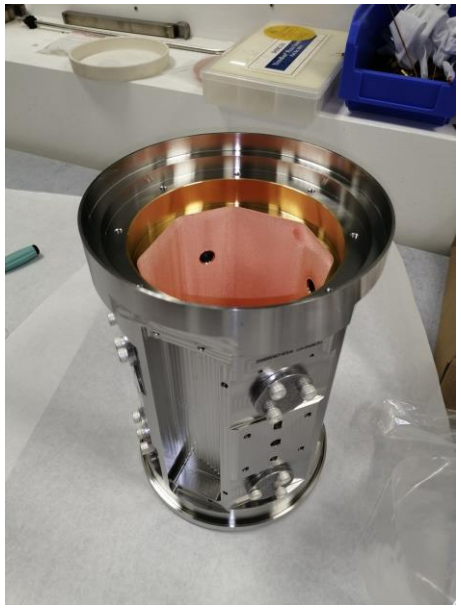
- 44 new BPMs to be built and installed for HL-LHC baseline
  - Cryogenic ‘directional’ couplers (with 2 variants) in the triplets
    - Stripline pickups sensitive to beam direction for the cryogenic combined beam sections
  - Cryogenic capacitive button BPMs
    - In the dual aperture separation dipole cryostats

Task 13.3 - New BPMs between Q1 to Q5

- Design
  - Octagonal body with copper transitions
  - Gold, copper and aCarbon coated
  - Integrated tungsten absorbers with active cooling

- Status of cryo-BPM body production
  - In-house Production (MME/VSC)
    - Design frozen following Production Readiness Review in October 2022
    - 5 pre-series bodies have been successfully produced
    - Coatings and cooling tube integration ongoing
    - Series of 33 units plus spares in production
    - Cryo-cable integration and installation access in progress
  - Procurement for 558 cryogenic SiO2 RF cable





Coated pre-series body at CERN

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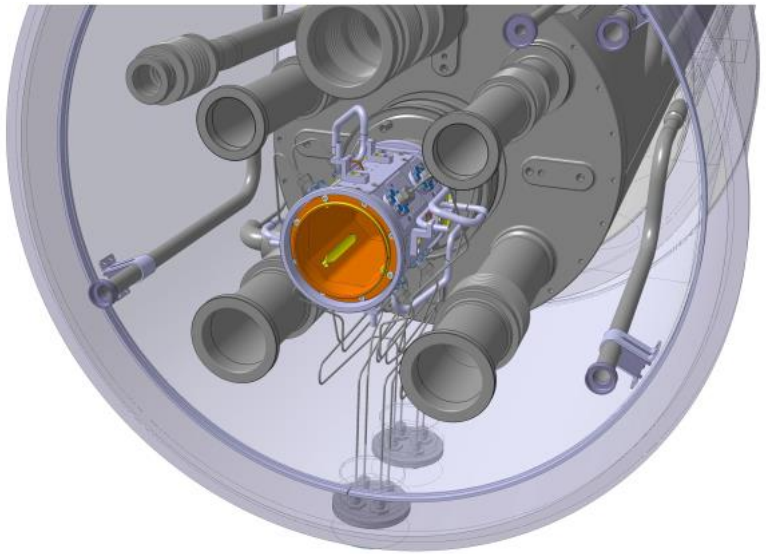
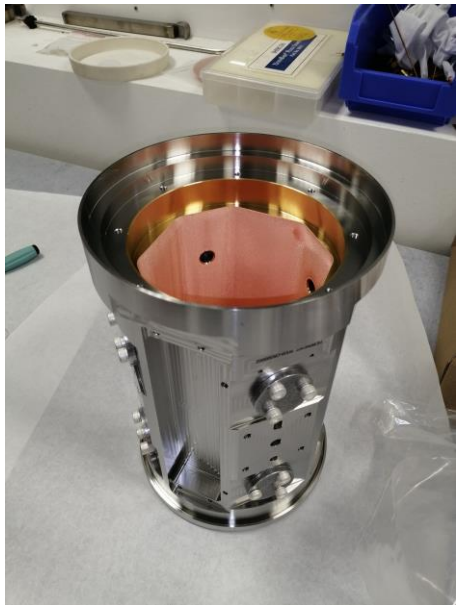
Talk by Emma for status of BPM body production





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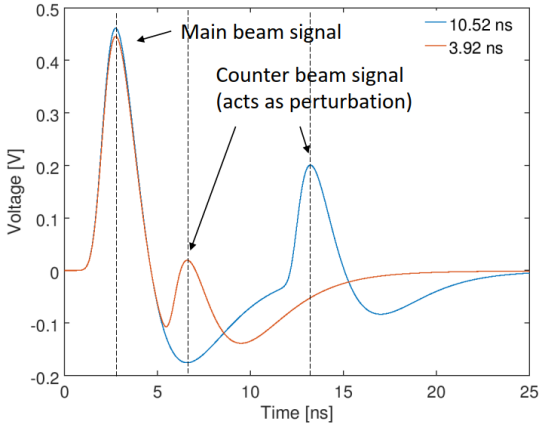
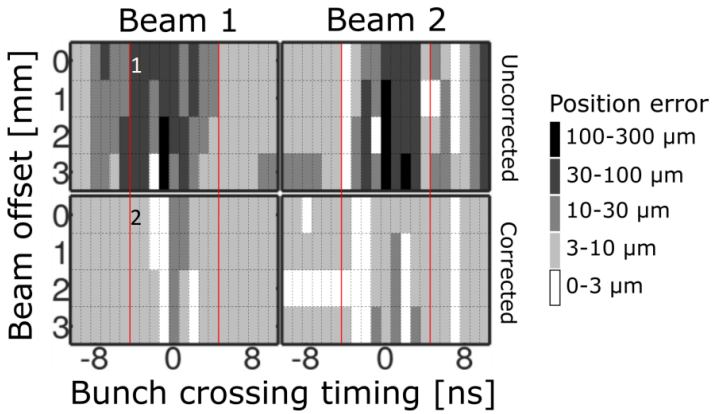
Task 13.3 - New BPM acquisition electronics in IP1/5

- Good progress with development of proof-of-principle data acquisition system
  - Based on a commercial evaluation board with a state-of-the-art RFSoC chip
  - Large amount of beam data acquired during a dedicated MD in 2022; Results presented at IPAC 2023. Now sent to peer-reviewed journal
  - Integration into CERN controls infrastructure (Linux, FESA, timing etc.) tested and further developed now in close collaboration with CTTB SoC project (led by Irene Degl'Innocenti)
- Procurement of RFSoC in progress
- Custom analogue and digital front-end extension boards under design





https://www.ipac23.org/preproc/doi/jacow-ipac2023-thpl089/index.html
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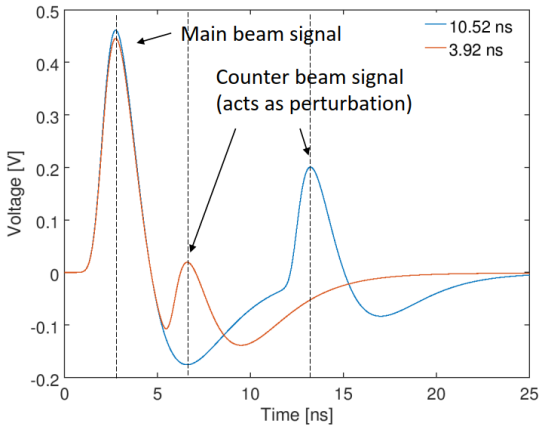
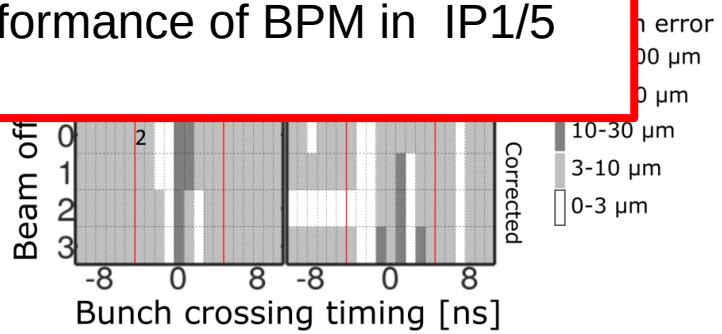


Talk by Michal on the expected performance of BPM in IP1/5



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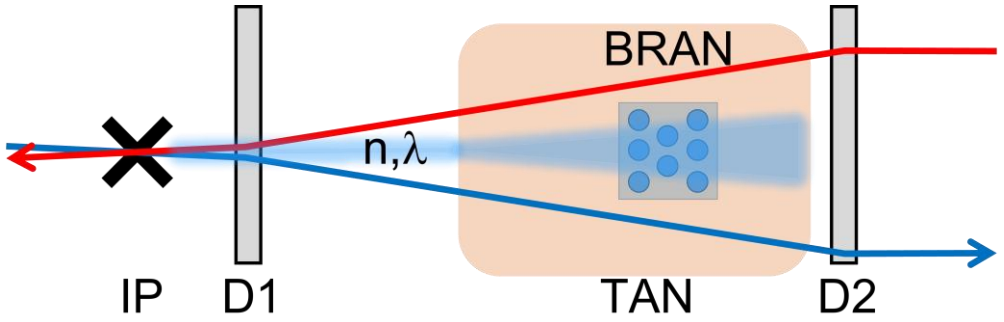
Task 13.4 - New luminosity monitors for IP 1/5

- Provides a relative luminosity measurement for LHC experiments
  - Used for optimising collision rates and
  - Cross-checking the absolute monitors in each experiment
  - Detects the electro-magnetic showers in the TAXN
- New design for HL
  - Based on Cherenkov radiation produced in fused silica rods
  - Four prototypes installed in IR1/5. New firmware and data acquisition system
  - Recent tests with beam in the LHC confirm wide luminosity range to $2x10^{14}$ µb/Hz and very good resolution
- Future plans for the final HL version
  - Based on the same SiO_2 bars, adapted to the new TAXN absorber and optimised for full HL intensity



Luminosity monitor concept and schematic

BRAN-D 1R, Fill 9072, 16/7/2023, full 2.1e04 lumi range.

Yang et al. 'Optical transmission characterization of fused silica materials irradiated at the CERN Large Hadron Collider', NIM A **1055**, 168523 (2023)

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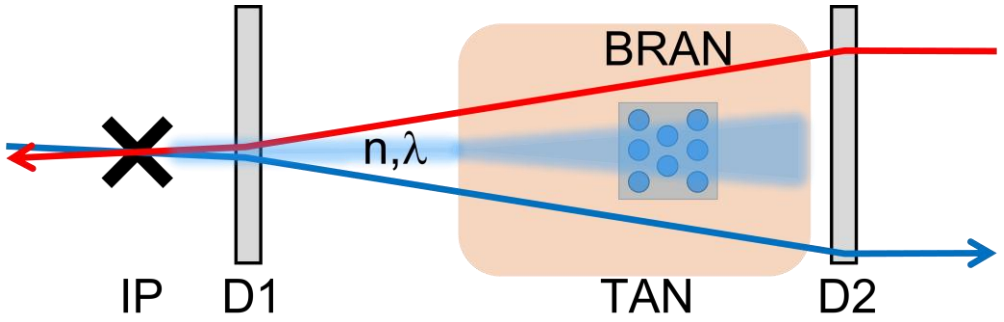
Talk by Stefano on the final design of the BRAN in TAXN



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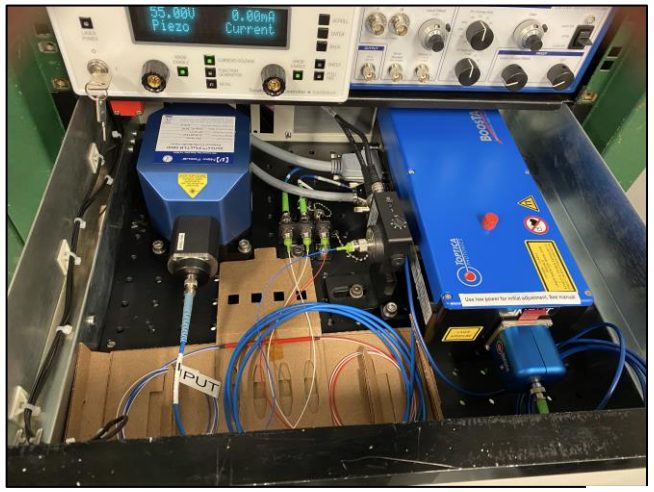
Task 13.5 - High Bandwidth BPM (BPW)

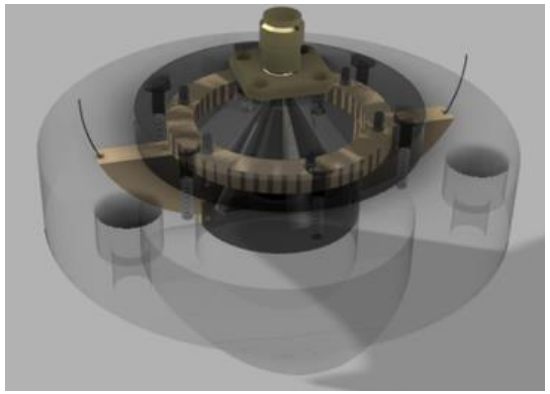
- Measuring intra-bunch motion with high bandwidth and high sampling rate
  - With the goal to provide a better instrument than the classical Head-Tail monitor (Stripline BPM, hybrid Δ/Σ and fast sampling oscilloscope)
- A full electro-optical BPM developed with Royal Holloway University of London since 2016
- Hybrid solution being investigated using commercial electro-optical modulators and time stretch techniques (short laser pulses)
- Technology review to be organized in December 2024

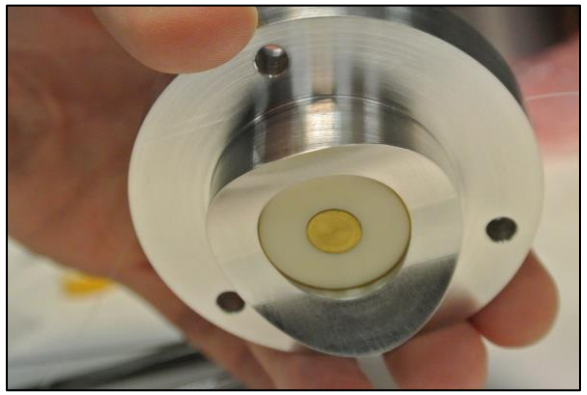
Task 13.5 - High Bandwidth BPM (EOBPM)

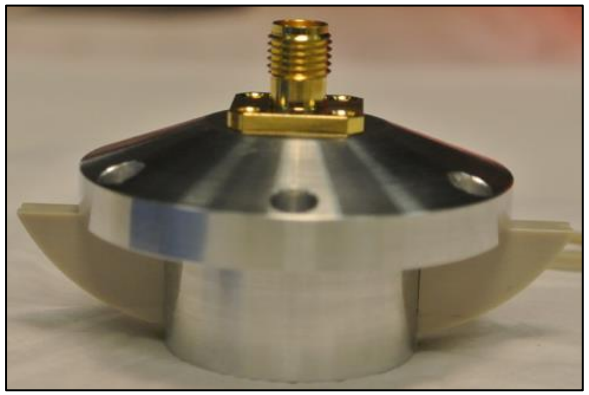
780nm DC Laser Source

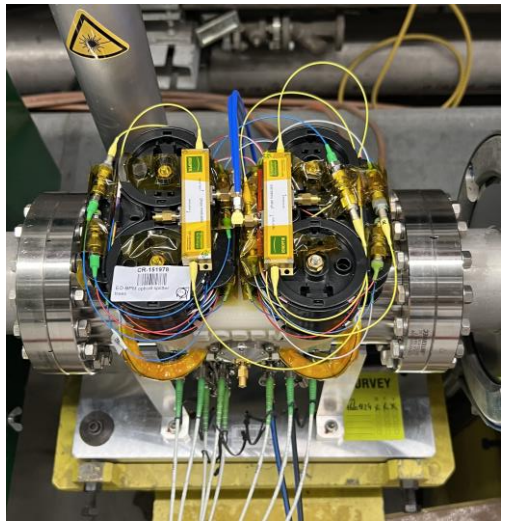


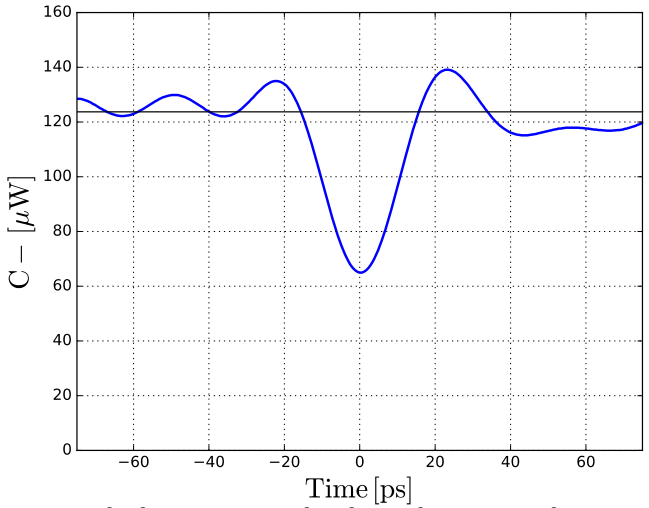
Electrode signal encoded on a laser beam passing through a fiber-based E-O waveguide manufactured by UK industry





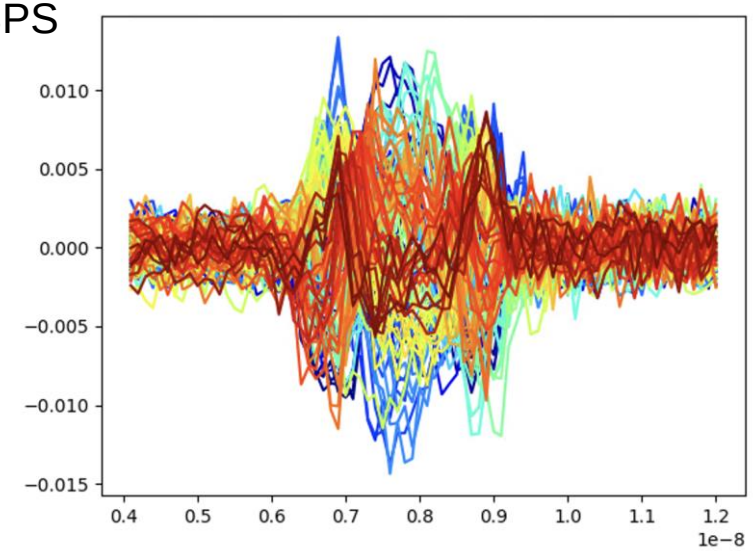






Measured time resolution better than 50ps using a 33GHz, 250MSa/s oscilloscope @ CLEAR

Example of beam injection oscillations of proton bunch at 26GeV@SPS



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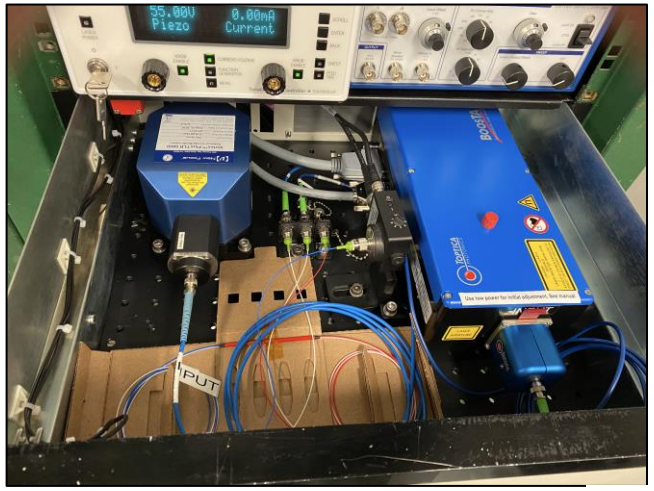

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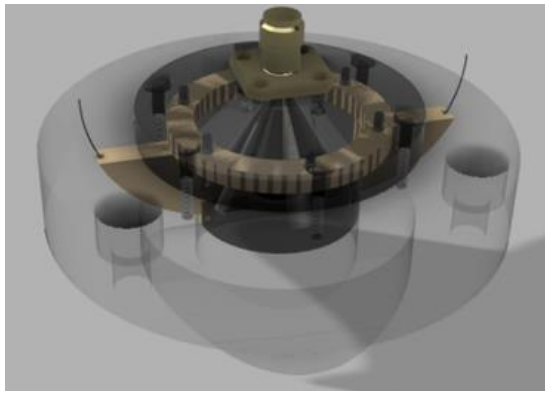
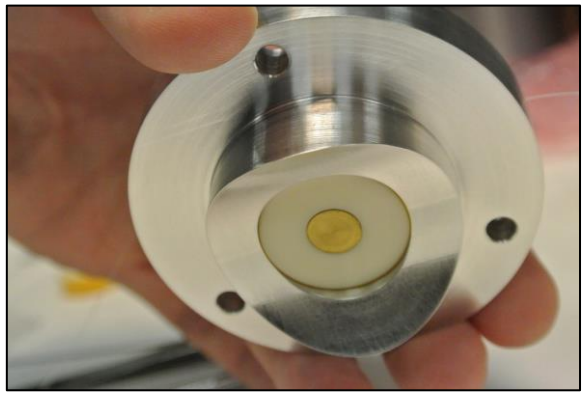
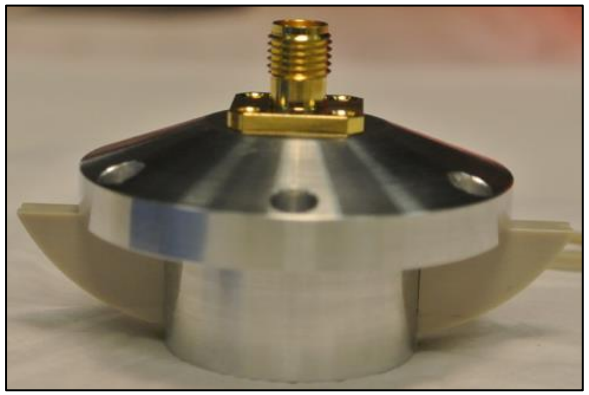
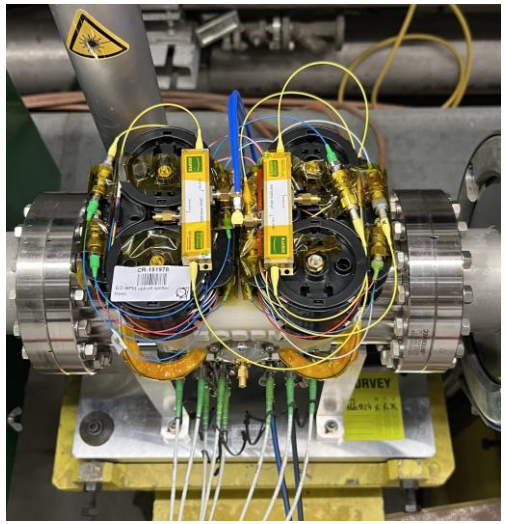
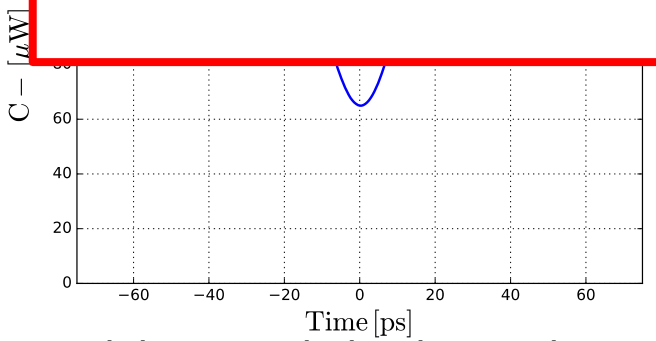








Talk by Max on the latest results of EO BPM tests in SPS



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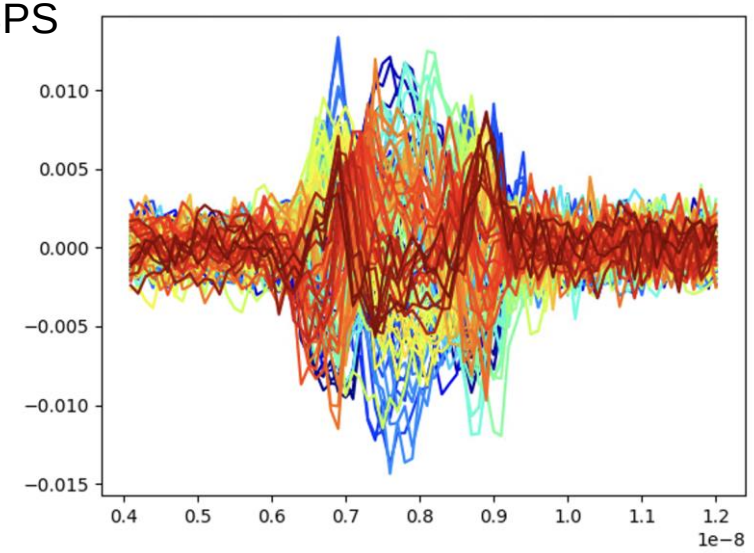


Task 13.5 - High Bandwidth BPM (EOMTS)

Electro-Optical Modulator Time-Stretch acquisition system with >40GHz and >100GSa/s

Located in Surface building

40MHz - 50fs
1550nm laser

PM Fiber transport down

3ns

to the tunnel's equipment

1st time stretch stage

40GHz ***E-O Modulator***

Laser encoding

40 MHz
beam signals

H⁻ H⁺

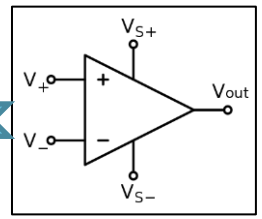
LHC Stripline BPM

1ns

Laser-encoded beam signal

Photon detection and DAQ

RFSoC at 5GSa/s



Photodiode

Optical Fiber back

to surface building

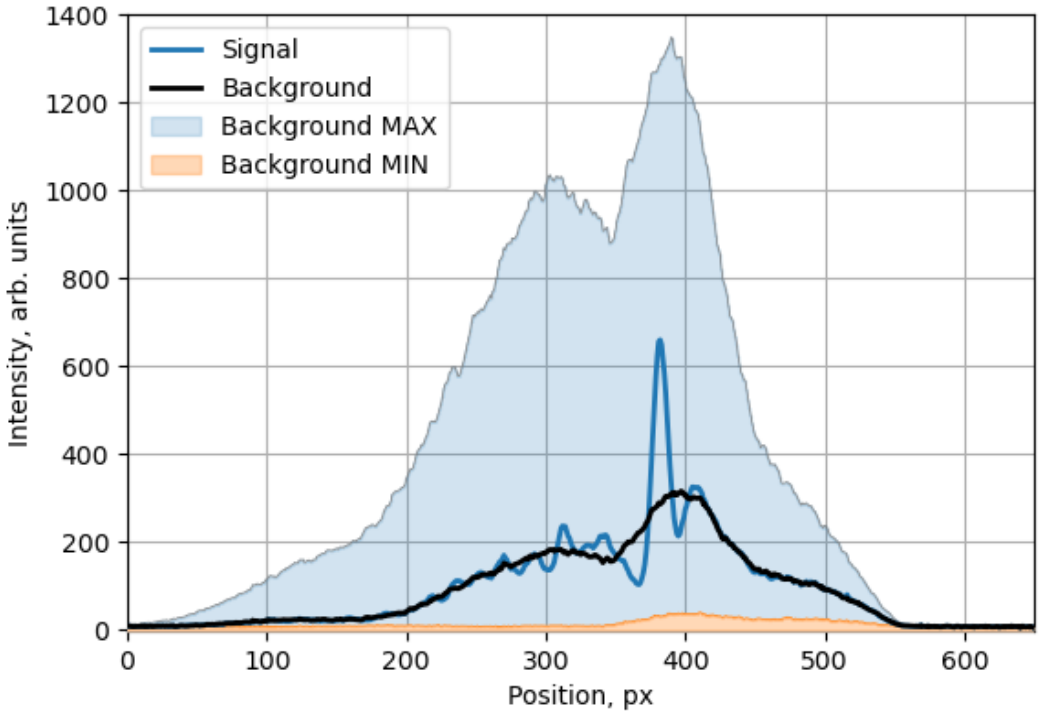
Located in Tunnel

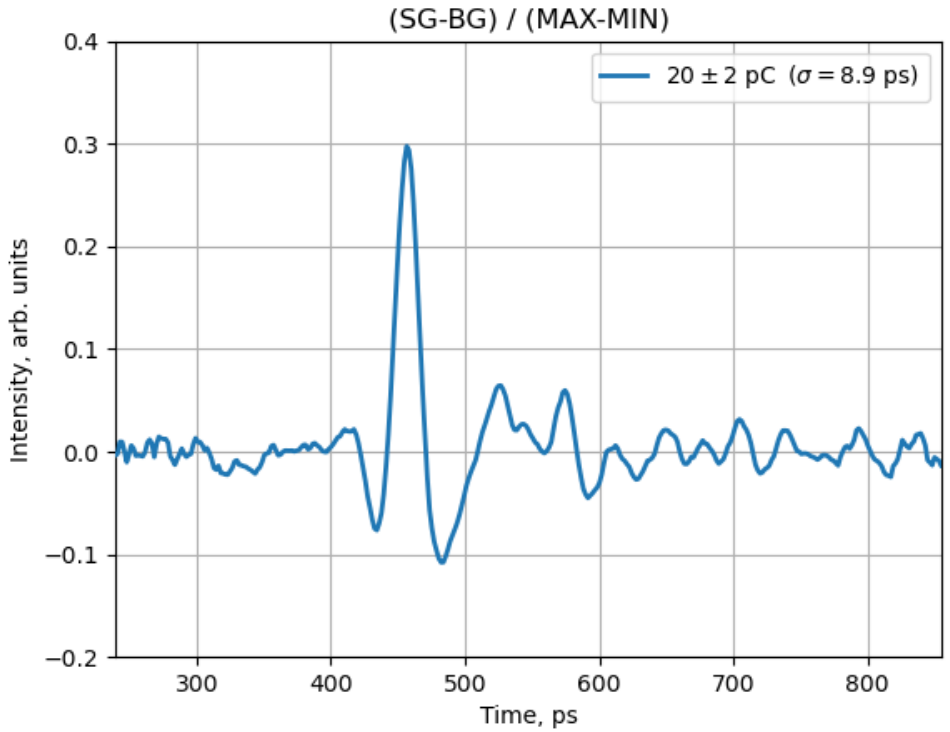
20ns

2nd time stretch stage

Task 13.5 - High Bandwidth BPM (EOMTS)

- Initial results at CLEAR show very high potential with pulse response **< σ = 10 ps**

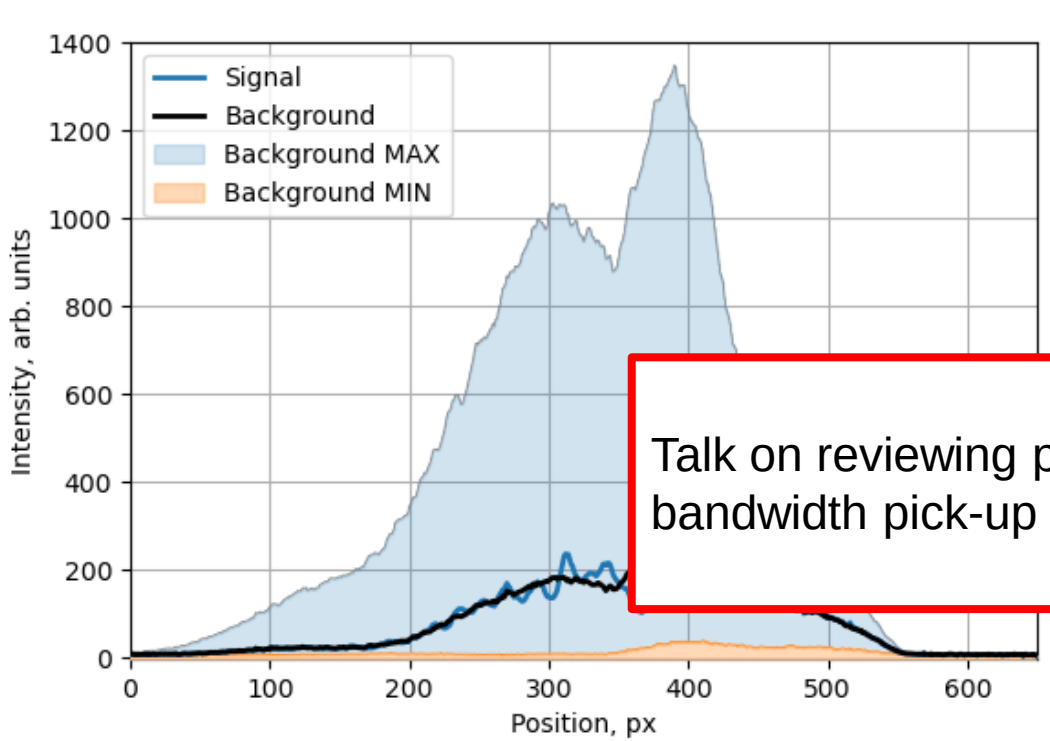


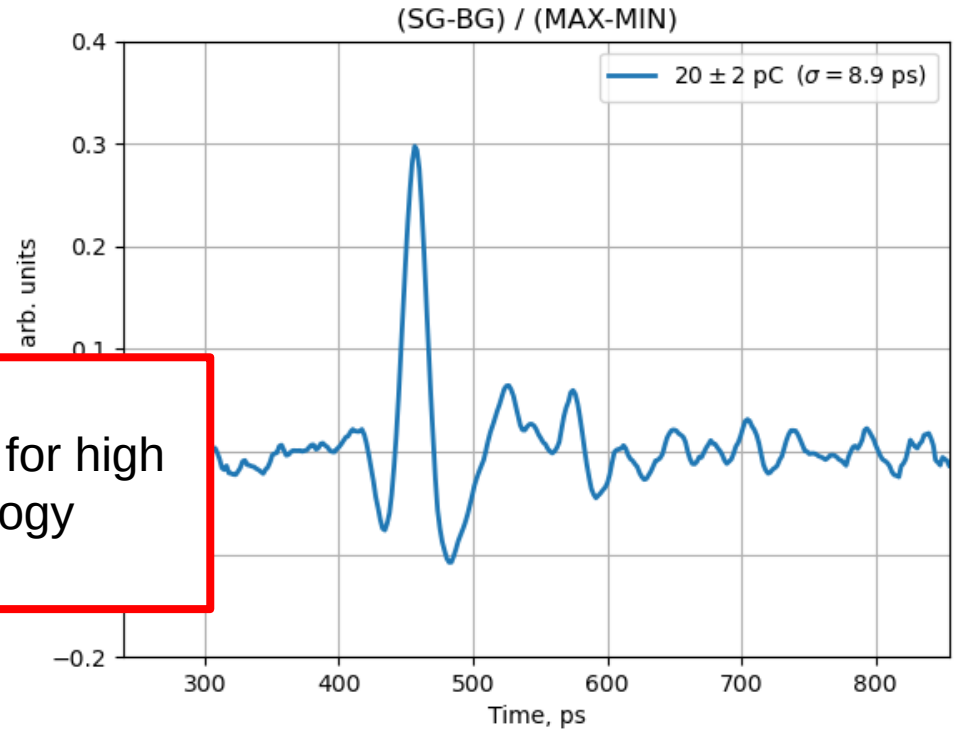


See: A. Schlögelhofer, invited talks @ IBIC 2024 Beijing

Task 13.5 - High Bandwidth BPM (EOMTS)

- Initial results at CLEAR show very high potential with pulse response **< σ = 10 ps**





Talk on reviewing process for high bandwidth pick-up technology

See: A. Schlögelhofer, invited talks @ IBIC 2024 Beijing

Task 13.6: Synchrotron light diagnostics (BSR)

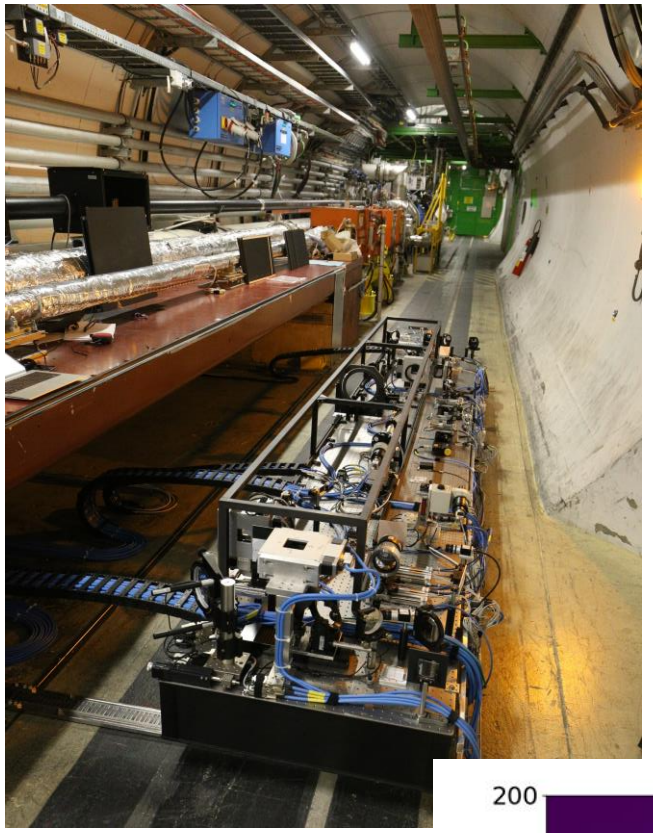
- Beam Halo monitoring with a SR Coronagraph
  - Built in collaboration with KEK and installed on BSR
  - Detailed simulations using SRW software showed fundamental limitation with source diffraction
    - Suggesting HL specification (10e-5 contrast) not achievable with this instrument, ultimate reach to be confirmed by experiment
  - Commissioning and tests resumed in 2024

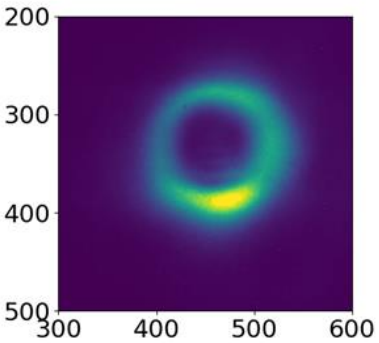
    See the talk by Jan in the afternoon

- Options for Beam Halo measurement
  - New working group launched in 2024 to review specifications and study alternatives options

    See presentation by Federico in the afternoon

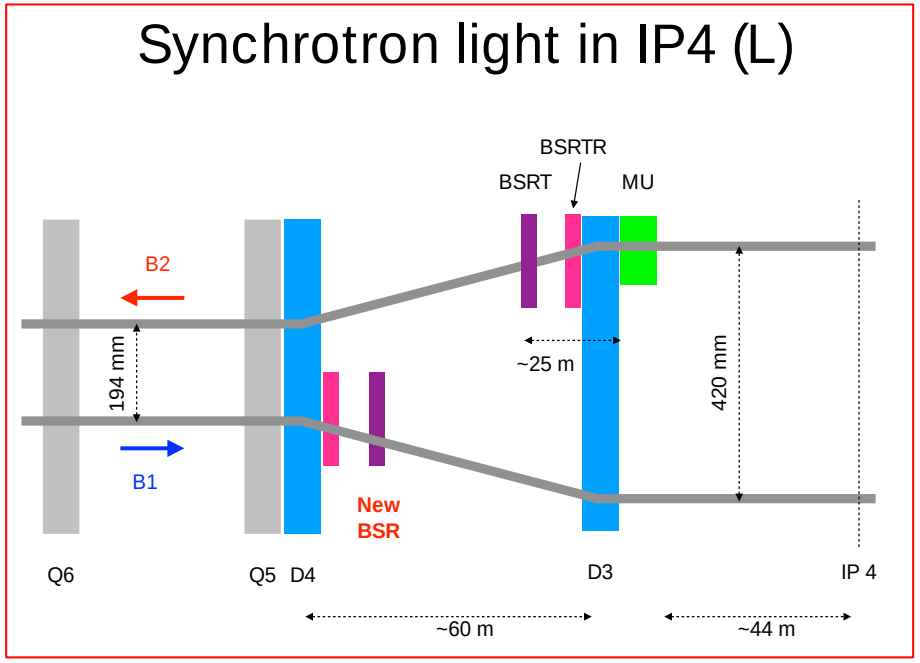
- Beam halo review scheduled for December 2024



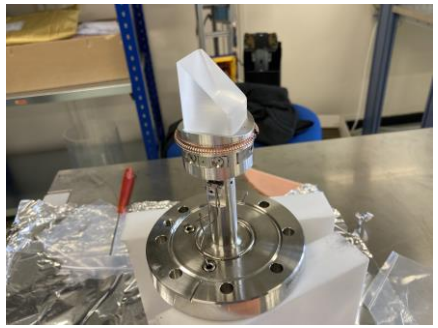


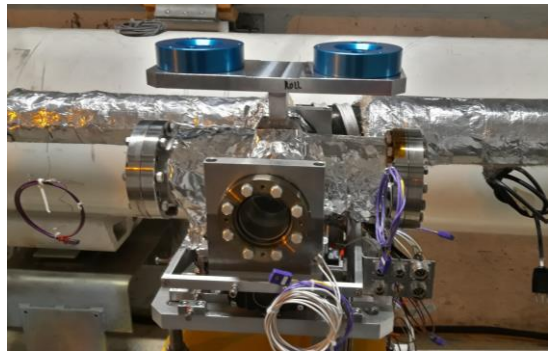
Task 13.6: Synchrotron light diagnostics (BSR)

- New SR light extraction tank with mirror (BSRTM)
  - Installed in LHC 4L, equipped with new mirror design, proved to be ok w.r.t. to impedance since 2022



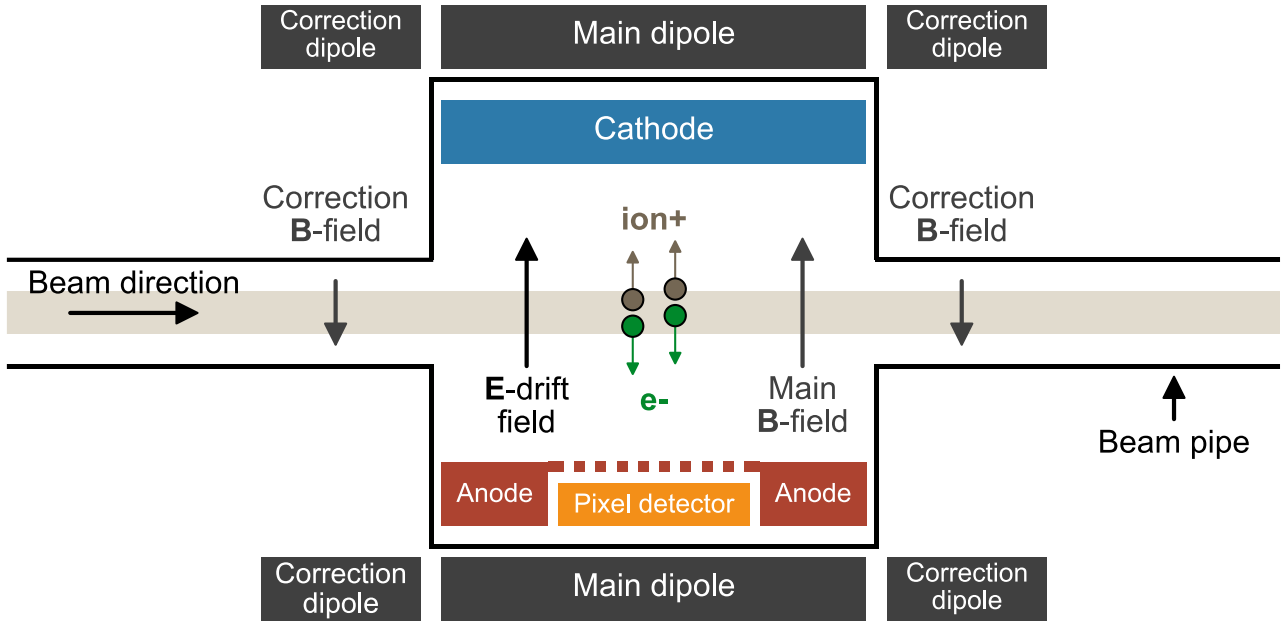
New SR extraction mirror and new extraction tank in IR4L





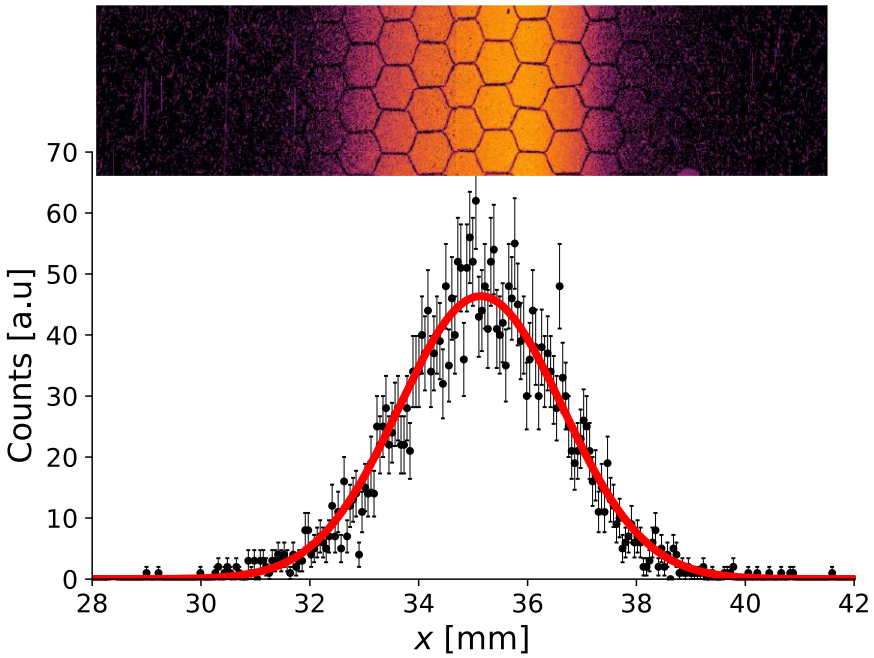
Task 13.7 - Beam Gas Ionisation (BGI) monitor

- Non-destructive transverse beam profiles with continuous bunch-by-bunch measurements throughout the acceleration cycle.
  - Following the BGV/BGI review in Oct. ’22 the BGI became the HL-LHC baseline
- BGI detects ionization electrons produced by beam-gas interactions



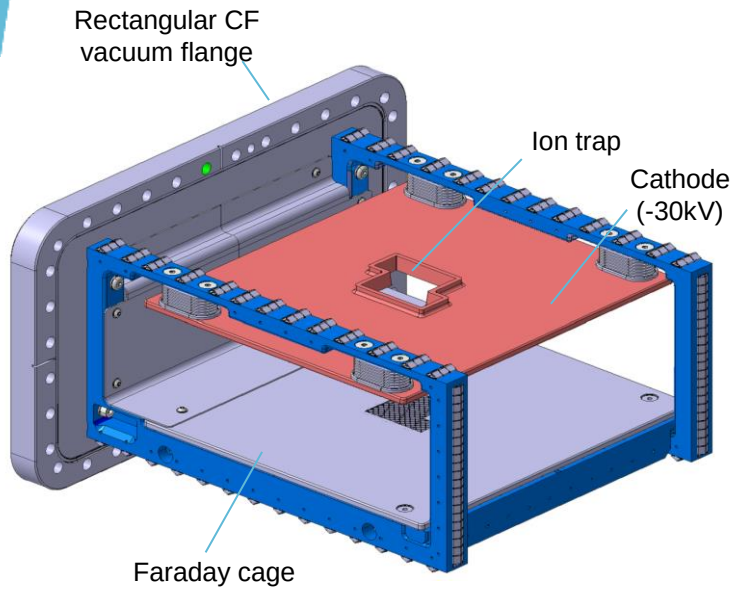
https://medipix.web.cern.ch/technology-chip/timepix3-chip

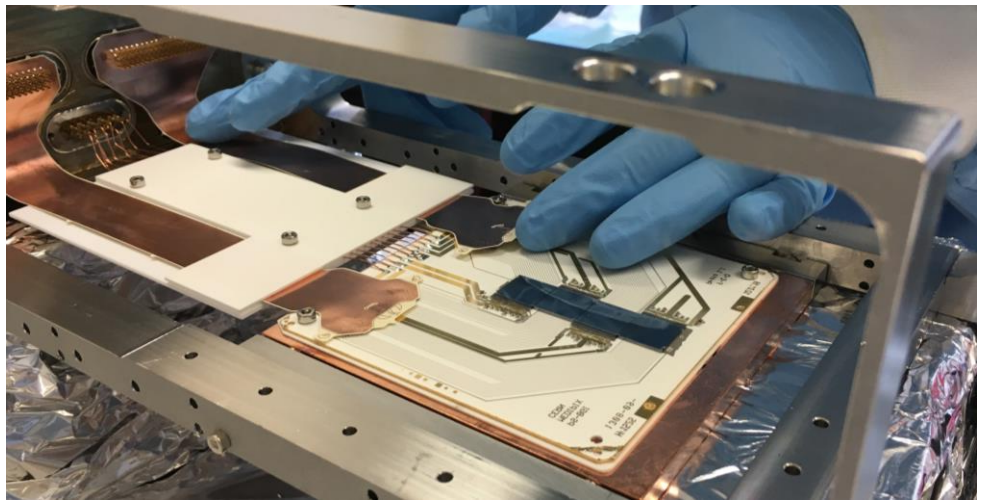
Beam profile is measured by counting the number of detector ionisation electrons

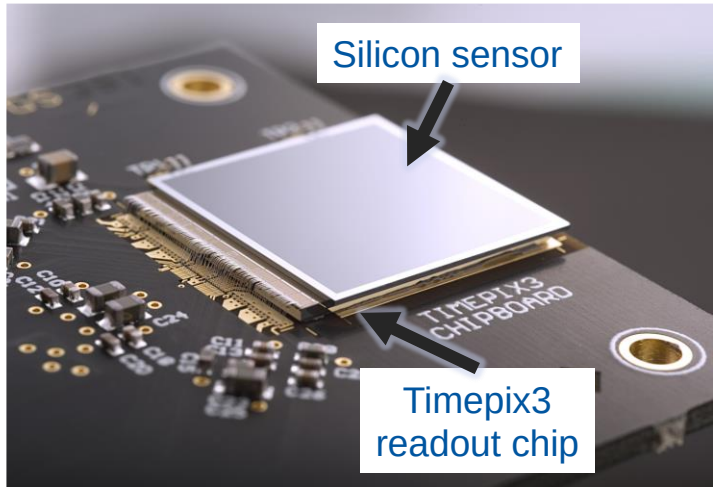


Task 13.7 - Beam Gas Ionisation (BGI) monitor

HL-LHC device is developing from the instrument built for LIU-PS, installed in LS2 and the SPS-CONS instrument installed during YETS 23/24







https://cds.cern.ch/record/2253263

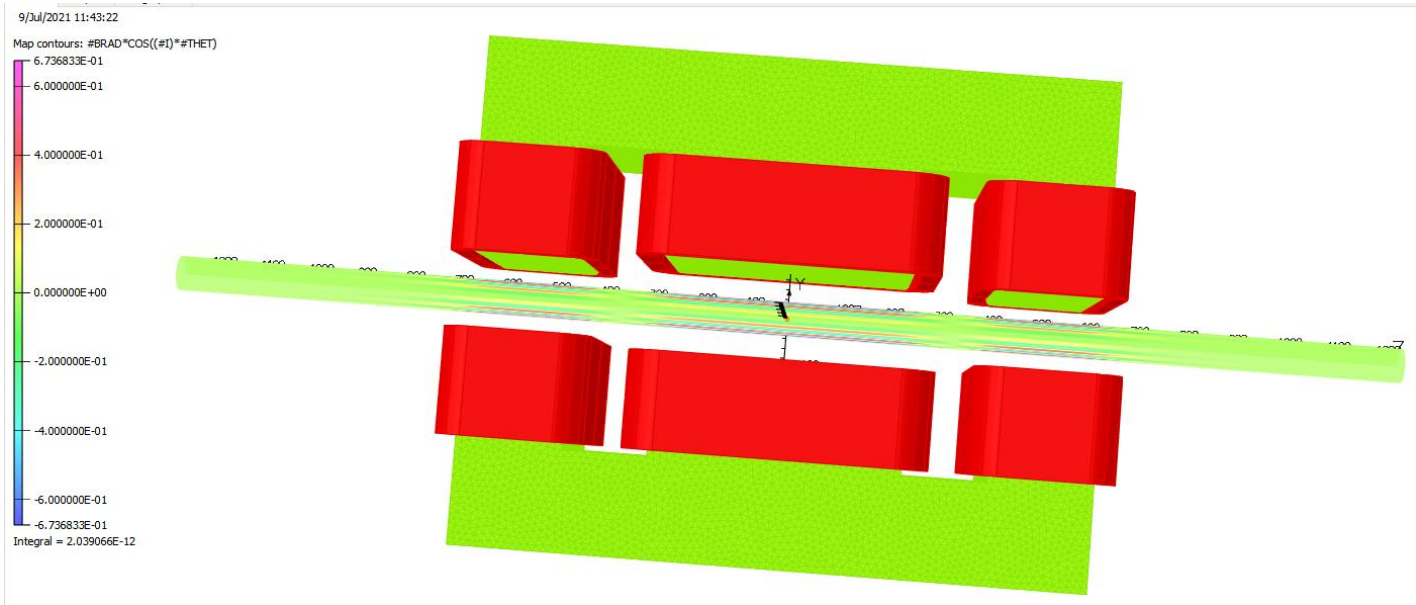
Task 13.7 - Beam Gas Ionisation (BGI) monitor

Even bigger Challenges for HL BGI

- Need to **reduce the impedance further** (and sensitivity to electromagnetic interference due to shorter bunches)

- Smaller beam size require **higher magnetic field** (minimum of 0.6 T)

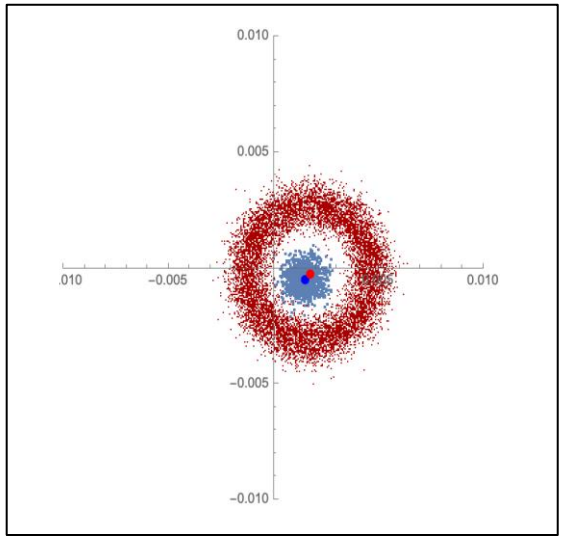
Talk by James

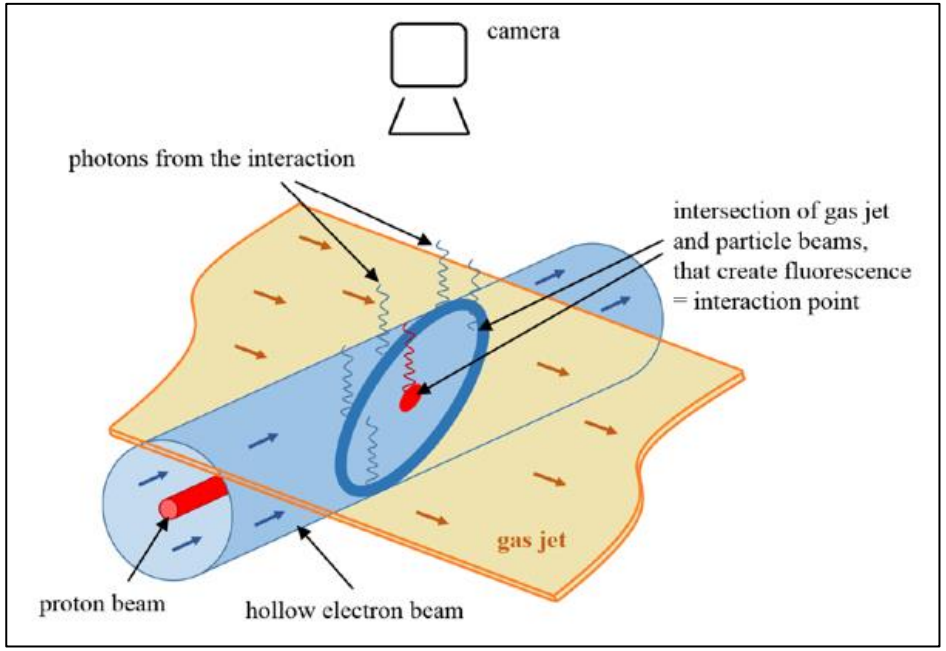


Preliminary electromagnet design - 0.6T self-compensating dipole magnet [D.Bodart (TE-MSC)]

Task 13.2 - Beam Gas Curtain monitor

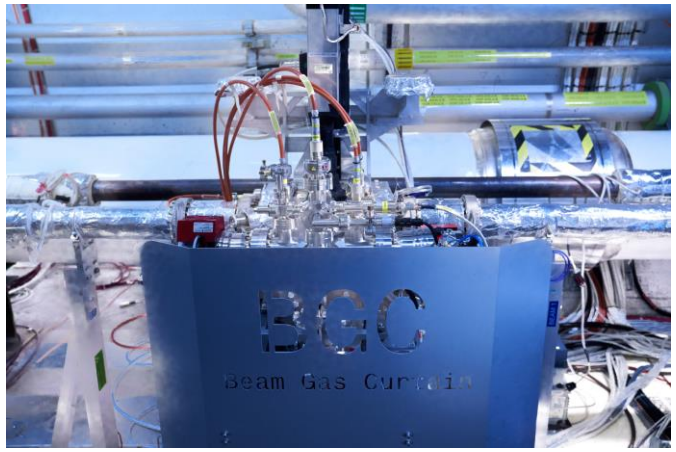
- Collaboration between CERN, UNILIV and GSI
- Part of HL-UK2 collaboration framework – In-kind from UNILIV
- Designed as a beam overlap monitor between protons/ions and Hollow Electron Lens
- Image the fluorescence of a gas (curtain) jet interacting with the beams

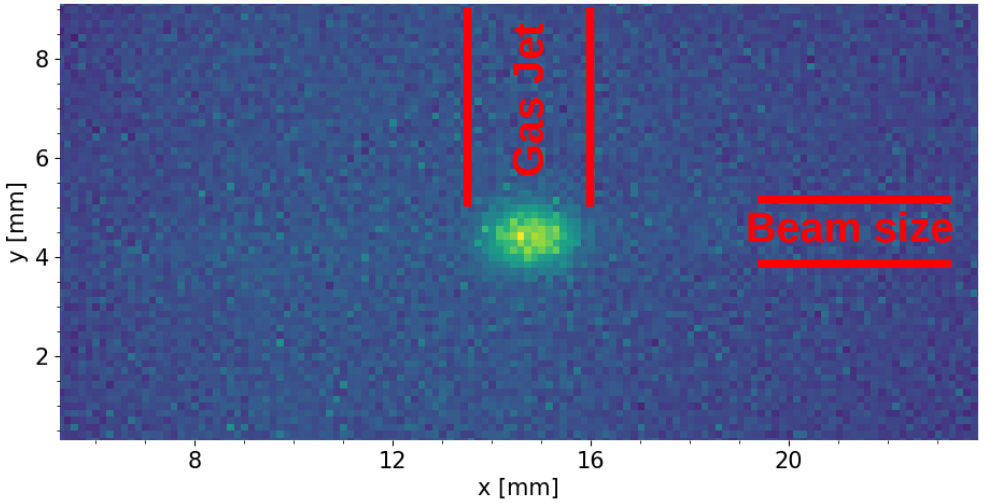


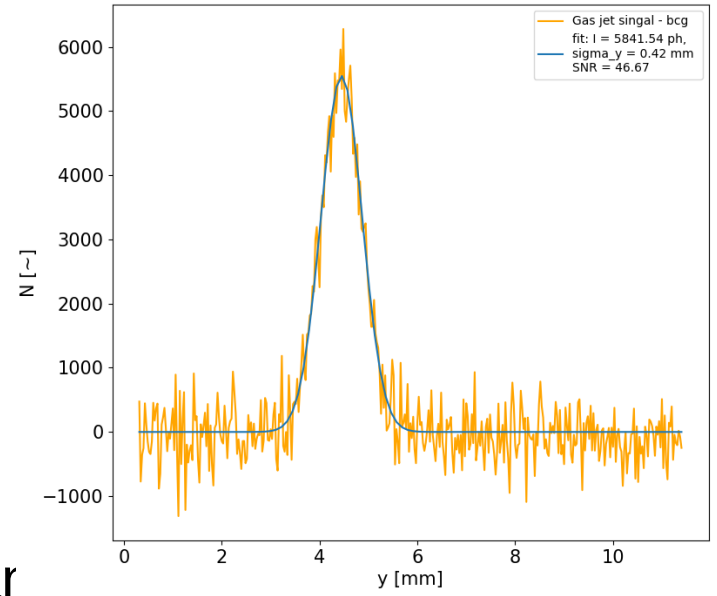


Task 13.2 - Beam Gas Curtain monitor

- BGC tested successfully on the Hollow Electron test-stand at CERN in 2023
- BGC measurements in LHC look very promising in 2023 with heavy ions







- In 2024 systematic measurements with protons at injection ar
  - Measuring the spatial resolution of the monitor with cross-calibration against other monitors
  - Assess the usefulness of the monitor for emittance monitoring in LHC

- Invited talk by Hao Zhang at IBIC 2024 – Talks by Daniele and Ray later this afternoon

Summary

- Excellent progress made in the large scale production of BLMs and BPMs
  - Critical cold BPM manufacture is back on-schedule despite the end of the Russian in-kind contribution – first Cryo BPM to be delivered to TE-VSC in Q1 2025
  - BLM ionization chamber also back under control following urgent reverse-engineering and prototyping

- Exciting results from beam tests on newly developed technologies
  - On-going performance assessment of halo monitor and high bandwidth pick-up
  - Successful tests made with the BGC, both for hollow electron beams and as a profile monitor in the LHC are being continued

- Some decisions to be taken in coming months:
  - Production strategy for series BLM ionization chambers
  - Beam halo monitoring – review of specifications and technologies in December 2024
  - High-bandwidth pickup technology review in December 2024

- Global emittance monitoring review (BGI and BGC) by mid 2025 – for now we follow up both options (integration work and cabling requests)

Collaboration partners

KEK 大学共同利用機関法人 高エネルギー加速器研究機構

The Cockcroft Institute of Accelerator Science and Technology

ROYAL HOLLOWAY UNIVERSITY OF LONDON

CERN

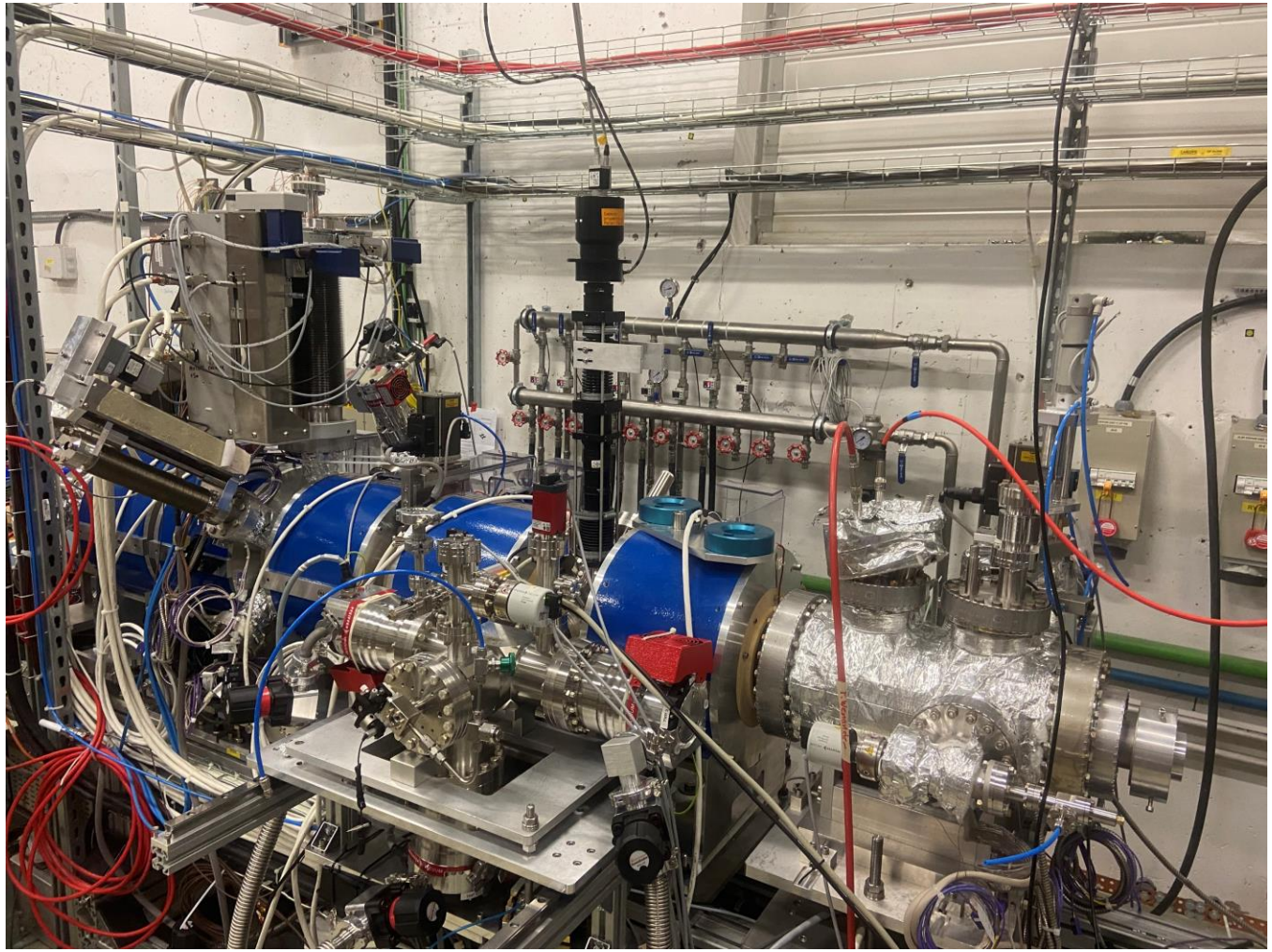
UNIVERSITY OF LIVERPOOL

UNIVERSITY OF OXFORD

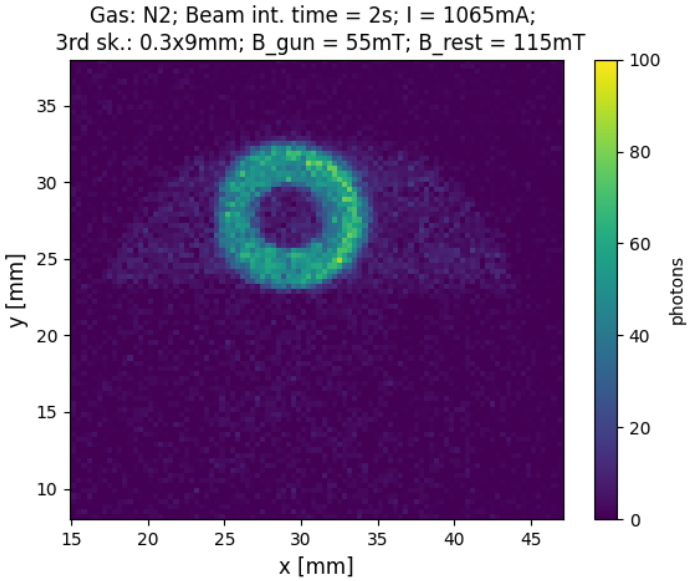
John Adams Institute for Accelerator Science

GSI

Beam Gas Curtain monitor

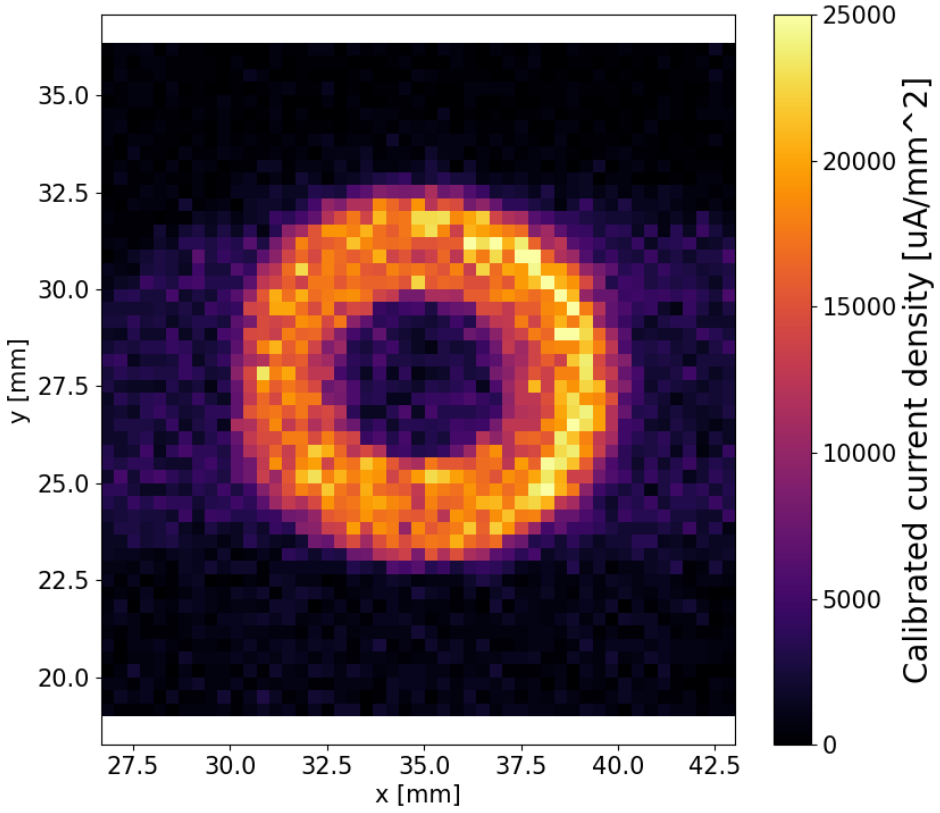


- BGC v3 installed in October 2022 on Electron Beam Test Stand (EBTS), operated until December 2022
- Hollow Electron Beam observed with Nitrogen and Neon gas



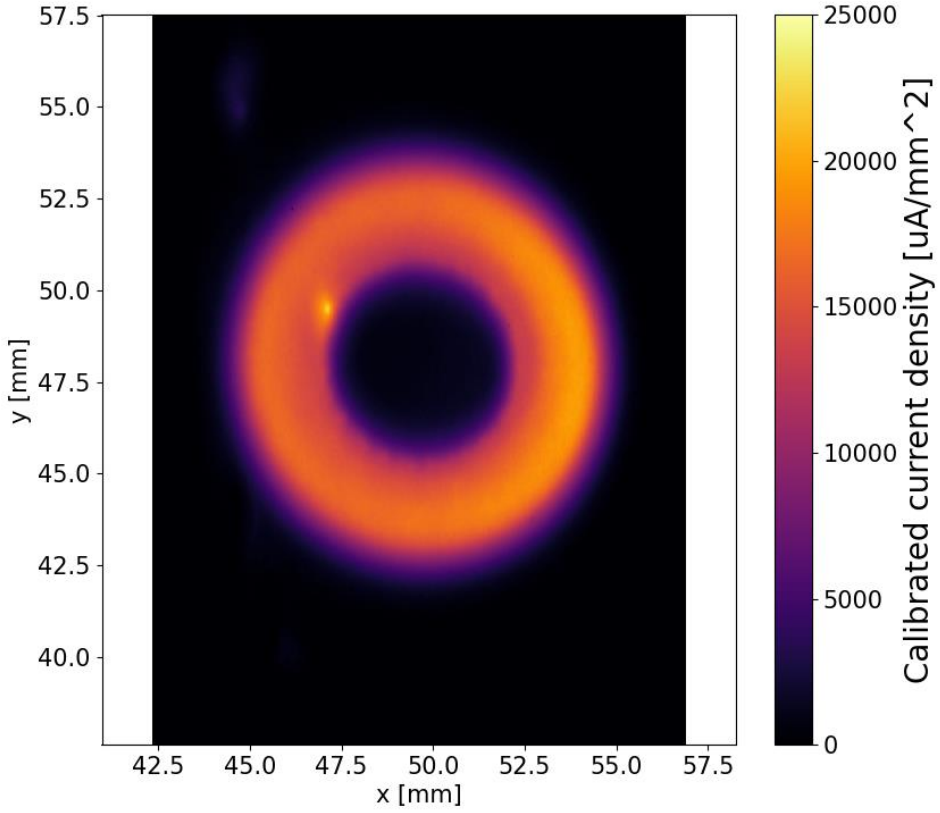
Beam Gas Curtain monitor

BGC
Gas: N2, Integration time: 2s



Beam
1.1 A, 100us

OTR
Integration time: 2.5ms



- Size agrees within 0.1mm
- General distribution shape agrees
- BGC higher noise, as it is designed to measure DC beam