Status of Beam Instrumentation (WP13)

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for the HL-LHC Beam Instrumentation Team

9th HL-LHC Collaboration Meeting, Fermilab, Batavia, USA
14-16 October 2019

Scope of WP13

- ***New and Upgrades of Beam Instrumentation for the HL-LHC***
- Long-Range Beam-Beam Compensation
  - *Studies leading to proof of concept*
  - *Design study for possible final implementation*
- Electron Beam Test Stand (in frame of the hollow electron
  - *Construction and operation of a test stand at CERN*
  - *Coordination of e-beam simulations*

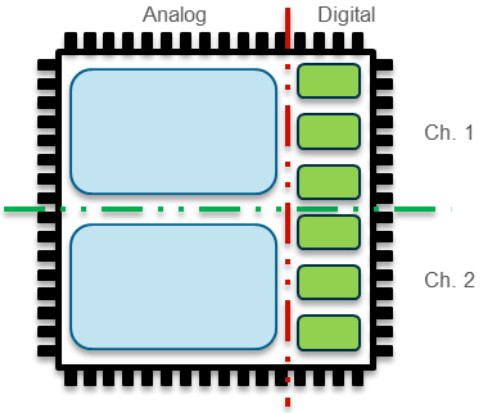
Thursday
WP2/WP13
Satellite mee

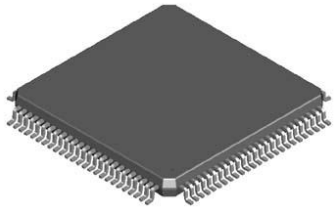
Tue, 16:00
One West
S. Sadovich

Task	Description
13.1	**Radiation Hard BLM Electronics**
13.2	**Gas Curtain Monitor**
13.3	**New BPMs Q1 to Q5 with dedicated acquisition electronics**
13.4	**Luminosity Monitors**
13.5	**Electro-optical BPM**
13.6	**Upgrade of the Synchrotron Light Monitor**
13.7	**Beam Gas Vertex Detector**
13.8	Long Range Beam-Beam Compensator Studies
13.9	Electron Beam Test Stand

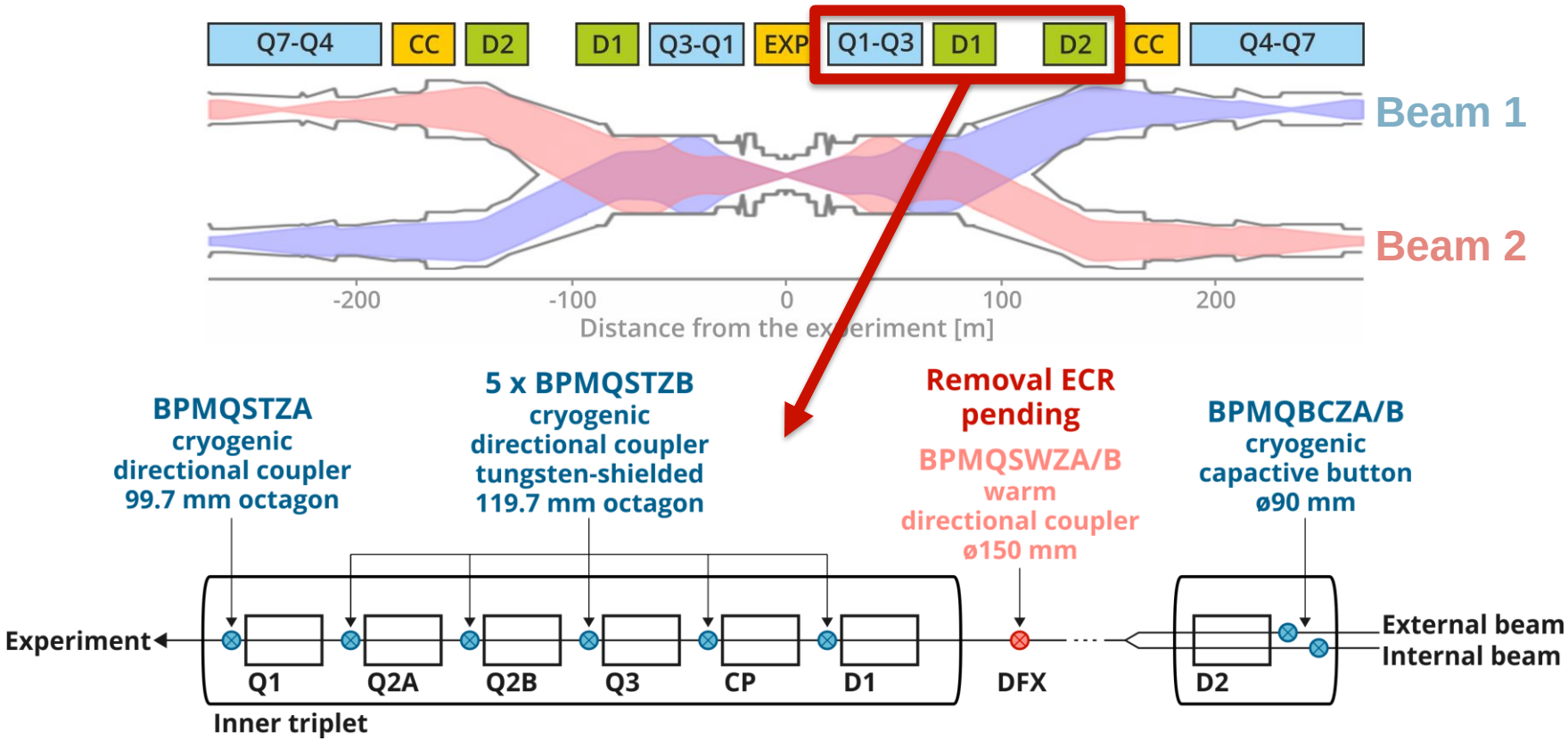
Beam Loss Monitoring

- Need for cryogenic BLMs removed
- Radiation Hard ASIC development
  - Minimize length of cables ⇒ improve S/N
    - Requires rad-tolerant electronics in the tunnel
  - Collaboration with EP-ESE-ME
  - Two fully functional custom chips being developed to evaluate performance of two different architectures:
    - Current to Frequency Converter
      - Better for large currents & quickly varying signals
    - Delta-Sigma ADC
      - High accuracy due to oversampling & filtering
  - Milestones:
    - Test of a prototype by end of 2019
    - Design to be completed by 2020
    - Series production start in 2021





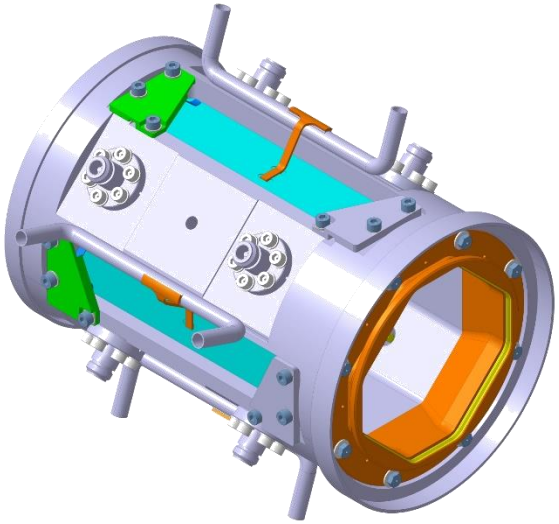
BPMs for the Interaction Regions (P1 & P5)



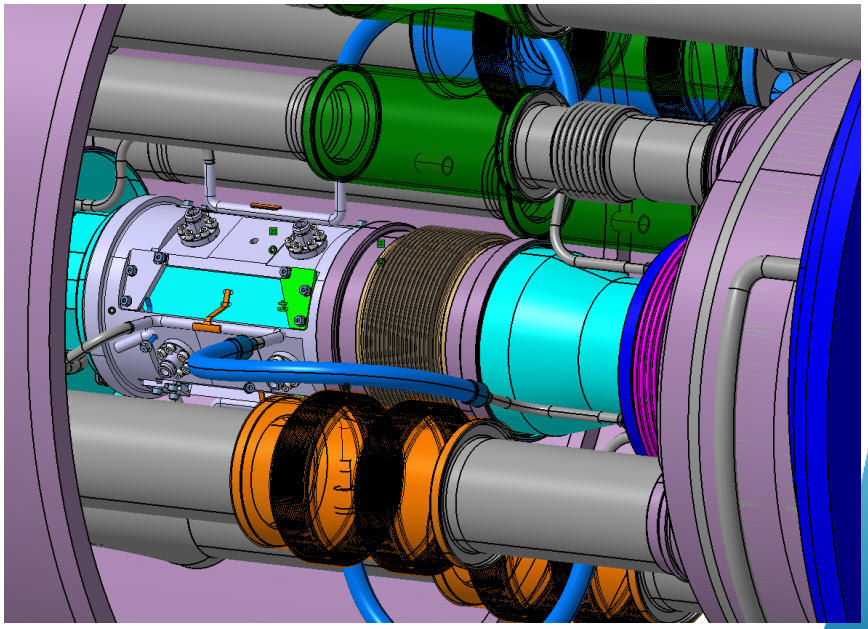
- A total of 32 “cold” BPM pickups
  - Requiring new, dedicated acquisition electronics

“Cold” Directional-Coupler BPMs

- **Technology**
  - High directivity required to disentangle B1/B2 signals
  - Tungsten shielding:
    lower TID on Q2B magnet by ~15 %
  - Amorphous carbon coating:
    Electron cloud effects decreased by 40x
  - Active cooling with liquid He:
    To evacuate up to 6 W of head load

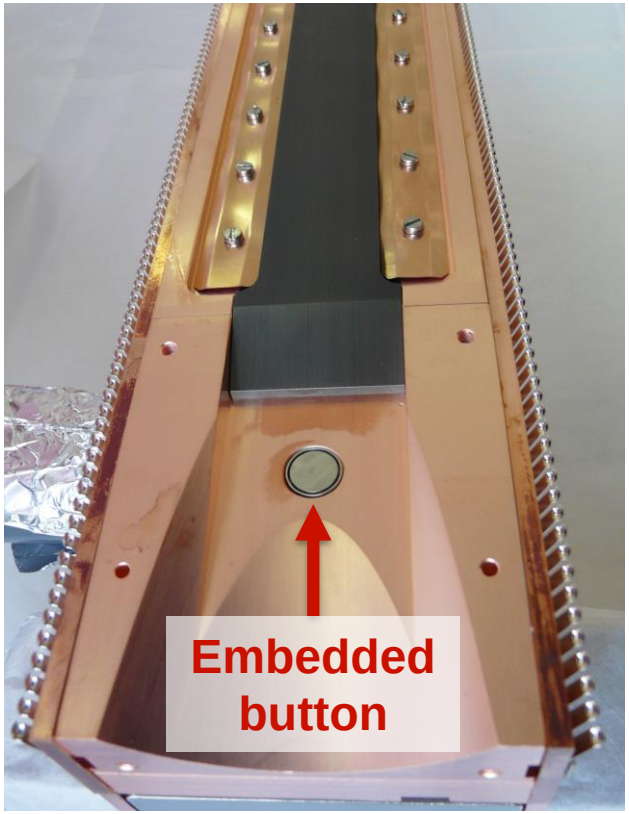


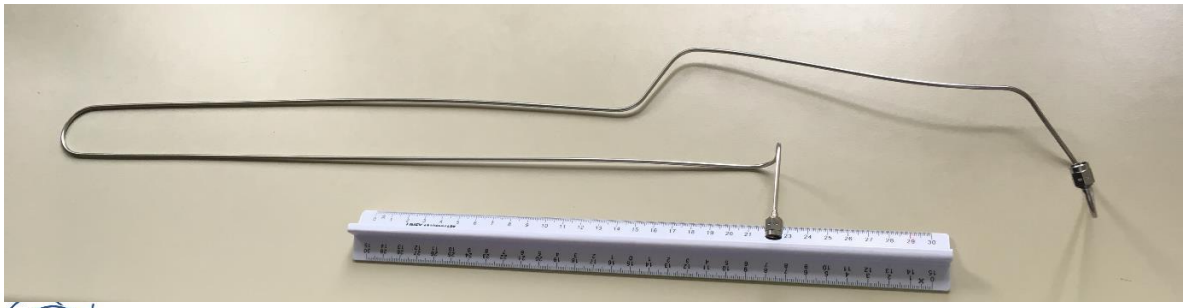
- **Status / Milestones**
  - BPM prototype production launched
  - Started procurement of tungsten absorbers (with WP12) and cryogenic RF feedthroughs
    - *Qualification of RF feedthroughs mid 2020*
  - In-kind contribution of BPM body manufacturing
    - *Collaboration agreement with Russia finalized*
  - Coaxial SiO_2 RF cables
    - *Market survey and procurement start for mid 2020*
    - *In combination with cables required for the collimator BPMs*



“Button” BPMs embedded in collimators

- Buttons embedded in collimator jaws to speed up set up since 2013
- Uses high-precision DOROS BPM acquisition system
- Collimator jaw position now interlocked on BPM readings
- Challenging integration and component procurement: coaxial SiO_2 RF cables
- All HL-LHC collimators will be equipped with BPMs

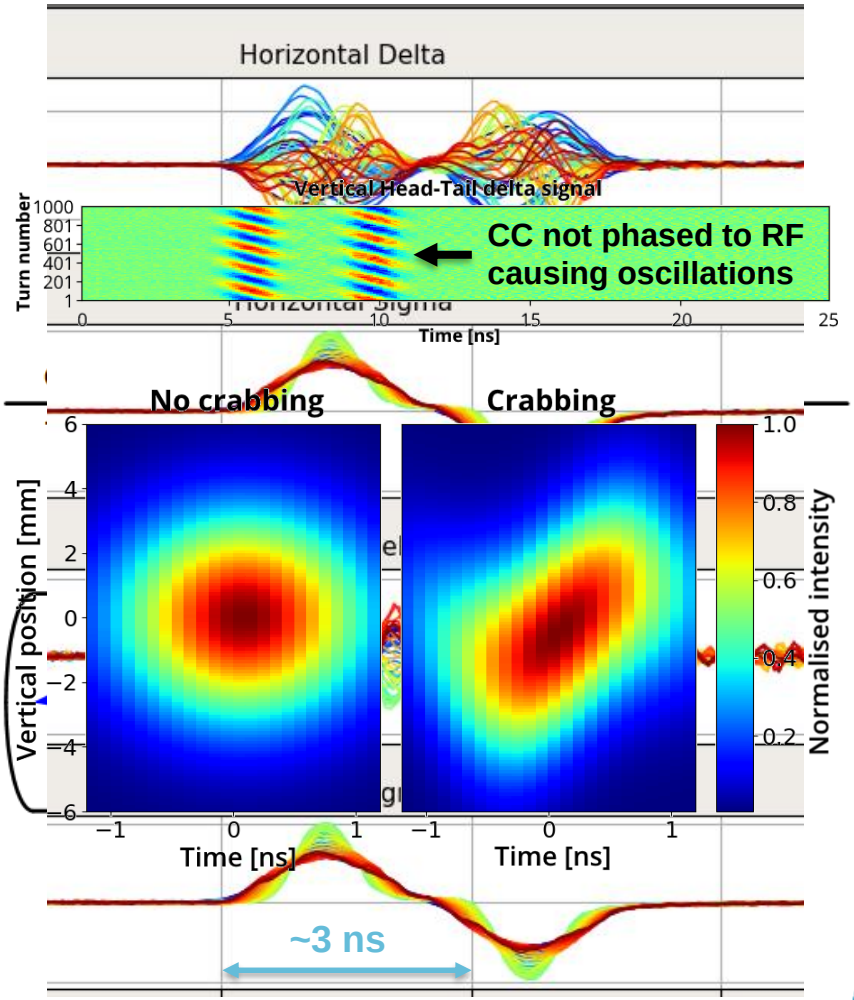




Crab-Cavity diagnostics – EM Head-Tail monitor

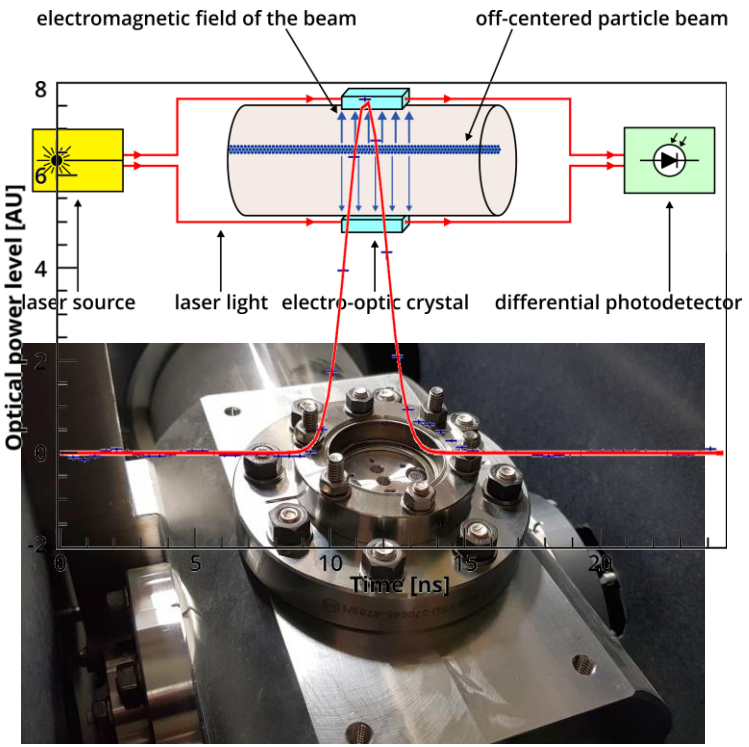
SPS Head-Tail monitor

- Wideband BPM measuring intra-bunch beam position
- 180º RF hybrid + high-speed oscilloscope
- Used primarily for instability diagnostics
- SPS HT monitor used in 2018 for crab cavity diagnostics
- Requires ±90º phase advance and large beta functions
- For HL-LHC: insufficient resolution and bandwidth



Crab-Cavity diagnostics – Electro-optic BPM

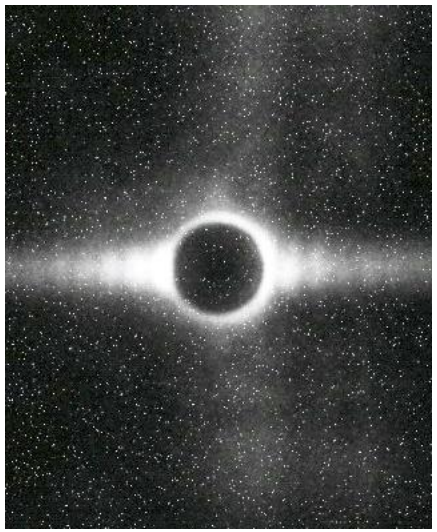
- **Technology**
  - Birefringent crystals encoding the electric field of the beam onto a laser light (polarisation rotation)
  - Ultrafast crystals used by telecoms, components commercially available
- **Status / Milestones**
  - Fully in-vacuum prototype installed in the SPS in 2016, modified 2017-2018
  - First electro-optic measurements of a proton bunch
  - Design on-going for an HL-LHC out-of-vacuum electro-optic BPM
  - Functional prototype in 2021

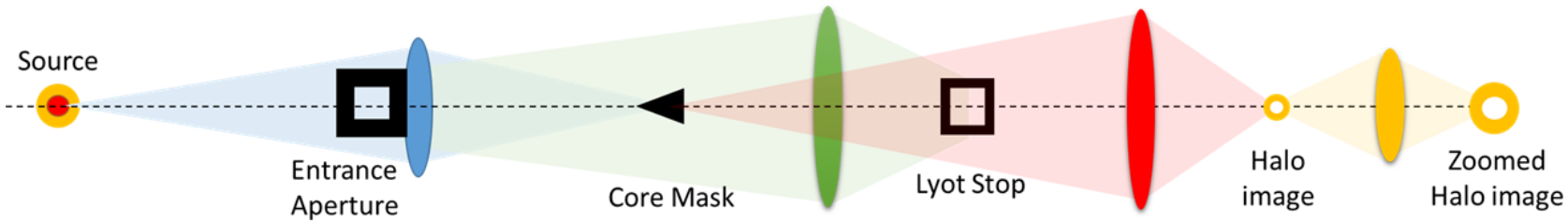


Beam halo monitoring – coronagraph

Principle of operation

- Beam halo monitoring crucial for adequately adapting the HL-LHC machine protection systems
- Coronagraphs used to view the Sun's corona
- Real image is created by an objective lens
- A mask blocks the bright core
- To deal with light diffracted from the limited entrance aperture, a field lens together with a well-dimensioned stop are used
- Final performance defined by contrast

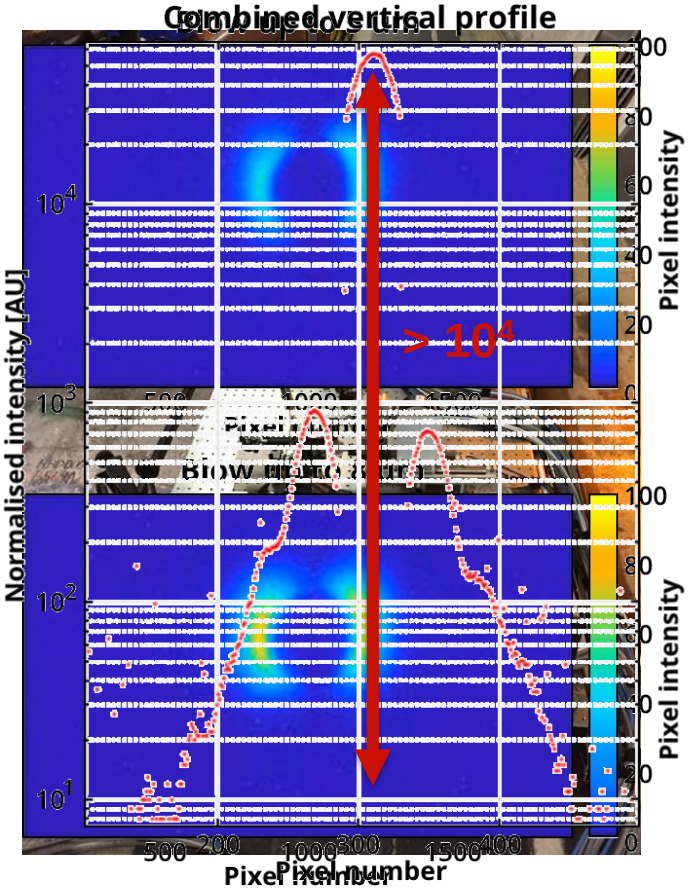




LHC coronagraph

Status / Milestones

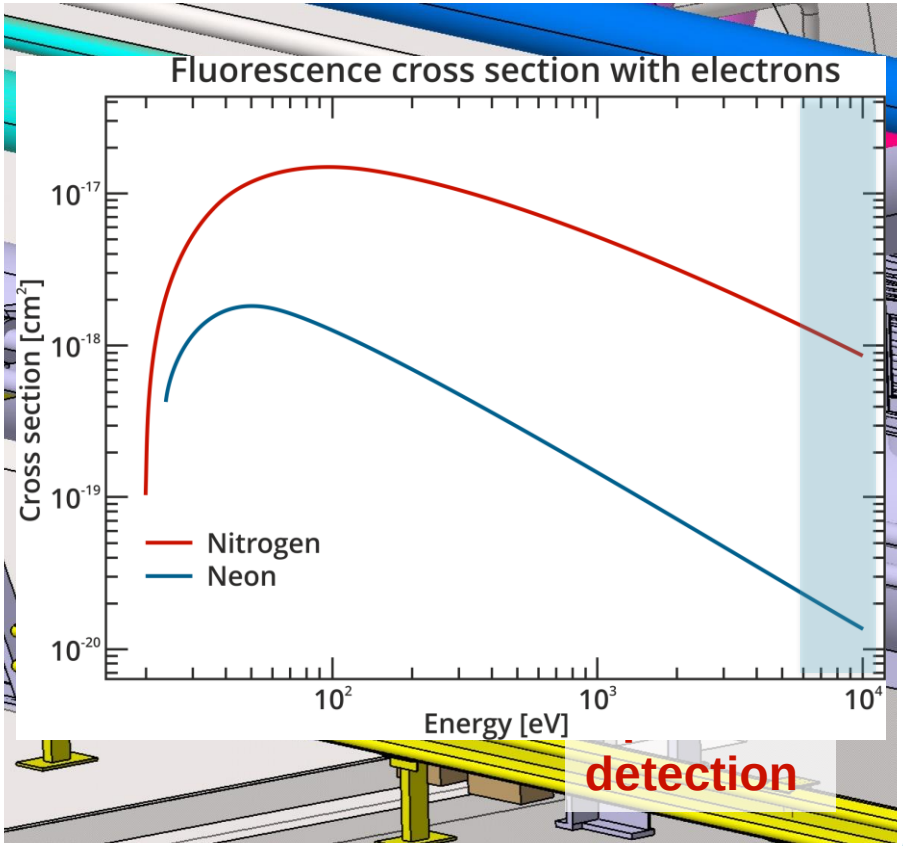
- 1st prototype (v1) based on KEK photon factory optics installed together with other synchrotron light diagnostics
  - *First successful beam halo observation in 2016 using undulator-produced SR*
  - *Demonstrated contrast ~10^{-4}*
- 2nd, improved prototype (v2) to be installed by end of LS2 on one beam for testing in Run 3
  - *Higher magnification to achieve the 10^{-5} contrast design goal*
- The final HL version (LS3) will be on a dedicated synchrotron dipole radiation optical line



Beam Gas Curtain monitor - BGC

Technology

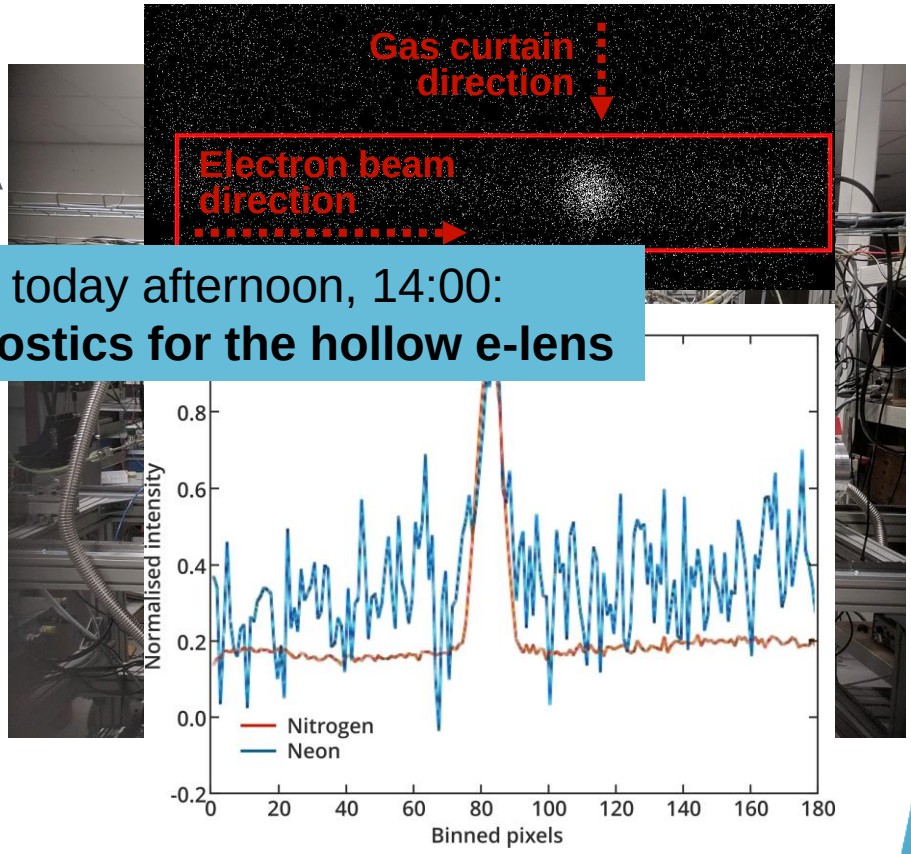
- Use case:
  Hollow Electron Lens (HEL)
  - *Beam halo collimation*
  - *Proton and hollow electron beam must be concentric*
- 2D image of both beams on supersonic gas “screen”
- Beam Induced Fluorescence: minimally invasive and unaffected by a strong solenoid field
- Compatible with both, low and high energy beams
- Gases under study:
  N_2, Ne, Ar



BGC prototype

Status / Milestones

- Prototype BGC built at Cockcroft Institute (UK)
- Three different gases tested with a 5 keV electron beam at 0.65 mA
- Fluorescence observed with all gases
- HL-LHC H current ~5 A – much higher photos flux
- Challenges: Low X-section with p at high energies
- Extensive simulation and engineering work put into gas curtain generation
- Installation foreseen in LS2

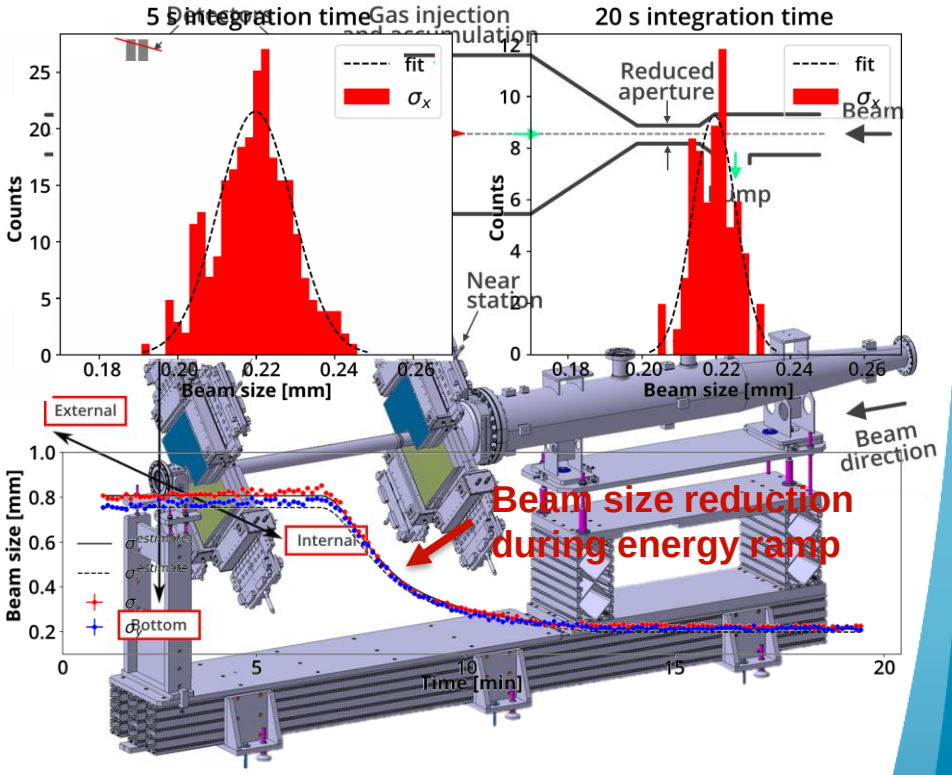


see also the presentation today afternoon, 14:00:
H. Zhang, Gas jet diagnostics for the hollow e-lens

Beam Gas Vertex monitor - BGV

Technology

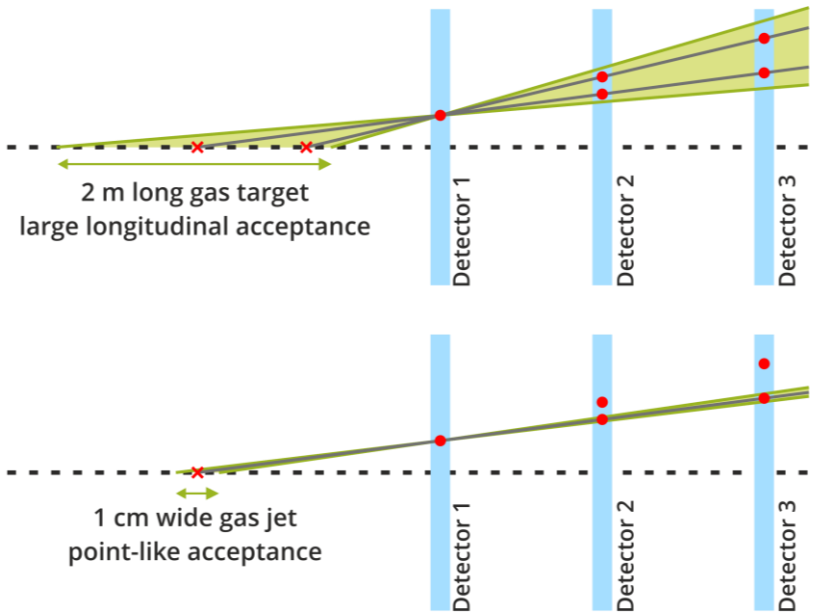
- Beam-gas interaction vertex reconstruction under study as a non-invasive beam profile measurement
- Demonstrator installed in 2014 using neon at $5 \cdot 10^{-8}$ mbar and scintillating fibres from LHCb
- Demonstrated beam size measurements throughout the energy ramp
  - Demonstrated the required precision in a reasonable integration time (2% within 20s)
  - Still, need to demonstrate the absolute accuracy and profile measurement through vertexing.



HL-LHC BGV design

Status / Milestones

- BGV is a candidate instrument for HL-LHC beam size measurements
- Final design proposal by the end of 2020
- Performance target:
  - 5% resolution with a single bunch
  - 2% absolute accuracy with the whole beam
  - < 1 minute integration time
- Various improvements under study:
  - Addition of a third detector plane
  - Other detector technologies (silicon, gaseous)
  - Using a gas jet instead of large gas volume to reduce longitudinal acceptance region
- Optimal location to be identified: symmetric optical functions, large beam size, small aperture



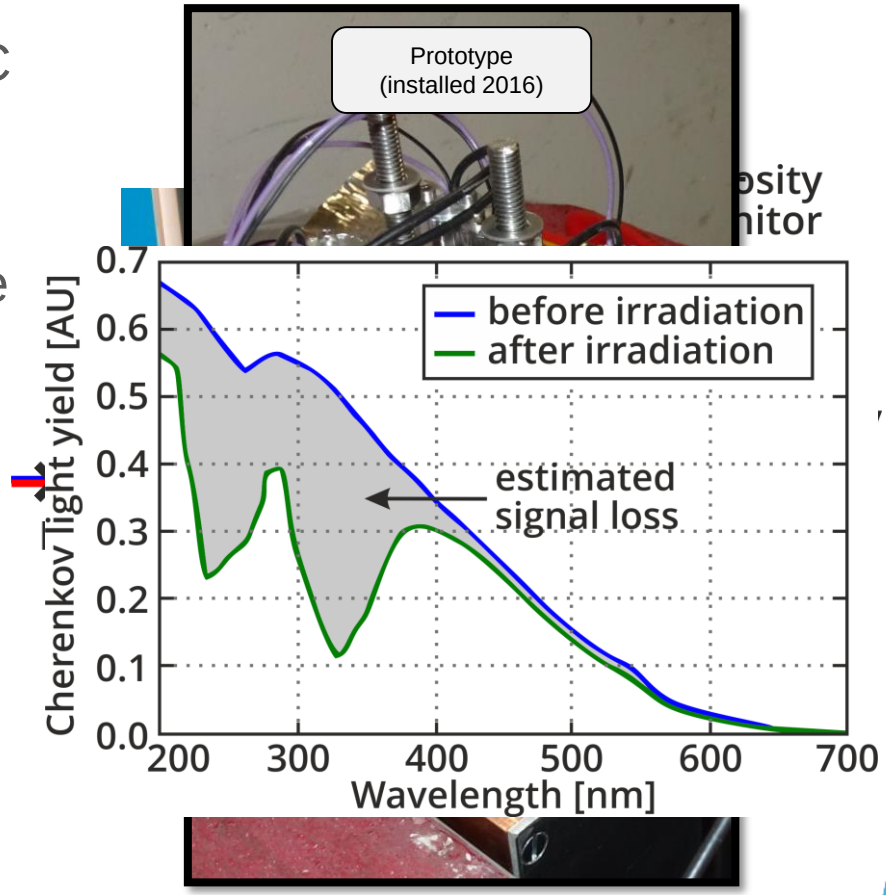
LHC Beam Size Measurement Review, 1-2 Oct. 2019

- **HL-LHC requirements**
  - Beam size, beam profile (1D, 2D), non-Gaussian beams, beam halo
- **Run 2 experience and possible upgrades**
  - Wire-scanners, synchrotron light (BSRT), BGV demonstrator, quadrupolar BPMs, ionization profile monitor (BGI), gas jet diagnostics (BGC)
- **Main outcome**
  - Wire-scanners for calibration purposes continue to be essential
  - Identified BGV (current HL baseline) and BGI as most promising candidates to fulfill all HL-LHC beam profile measurement requirements
    - *BGI based on Timepix/Medipix technology demonstrated in the CERN-PS, but requires redesign and a new, compact 0.6T dipole magnet*

Luminosity monitoring - BRANQ

Technology

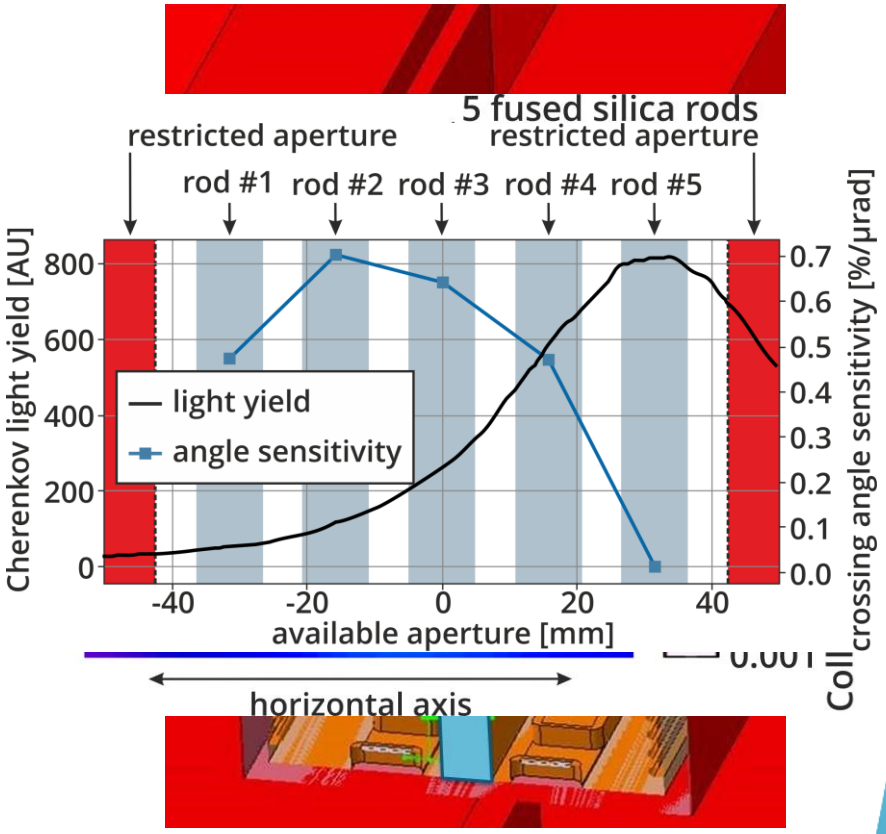
- Independent monitoring of the LHC luminosity
  - Not related to Atlas/CMS data
- LHC:
  ionisation chambers measuring the shower created by forward neutral debris
- HL-LHC:
  fused silica rods producing Cherenkov radiation under study
- Prototype installed and tested in the LHC
- Some rod darkening observed within the first 10 fb^{-1}
  - Only at lower wavelength <400 nm
  - stable beyond initial irradiation



Luminosity monitoring under varying X-ing angle

Challenges / Status

- Beams collided at an angle
- Different crossing planes for ATLAS and CMS experiments
- Luminosity monitor installed in the same orientation for both crossing planes
- In the horizontal X-ing case (IP1) not all rods irradiated with the same power
- Sensitivity to the crossing angle ~10% for a 15 µrad change



Progress of other WP13 Tasks

- **Upgrade of synchrotron light diagnostics**
  - D4 exit in LSS4 identified as source for new light extraction line
    - *Design of extraction tank & optics started*
- **Beam position system electronics**
  - New requirements for the HL-LHC final focus BPMs in IR1 & 5
    - *Will be used to prototype a full LHC BPM system renovation post LS3*
    - *Funded by R2E, CONS and HL-LHC*
- **Long Range Beam-Beam compensation**
  - Workshop following this meeting
  - 4 wire-in-jaw collimators successfully demonstrated compensation in Run 2
  - HL funding study for final technical design as part of WP13 for possible future option
- **Electron beam test stand**
  - To test components for a hollow electron lens
  - Installation ongoing
  - Accompanied by e-beam simulations (collaboration with BINP)

Summary

- LHC constructed with comprehensive suite of beam diagnostic devices
  - These play an important role in its safe & reliable operation
- HL-LHC will push the performance of LHC even further
  - Requires a deep understanding of beam related phenomena
  - Can only be delivered through its beam instrumentation
- Significant progress made on all tasks thanks to our many collaborators
  - Aachen University (Germany)
  - ARIES (EU)
  - BINP (Russia)
  - CERN EP Department
  - The Cockr
  - EPFL (Swi
  - FNAL (US-
  - GSI (Germ
  - KEK (Japan),
  - LHCb (CERN)
  - Royal Holloway University of London (UK)
  - Wroclaw University (Poland)
  - University of Liverpool (UK)

Thank you!