WP13 – Beam Instrumentation, Long-Range Beam-Beam Compensation & Electron Beam Test Stand

Status and Plans

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Scope of WP13

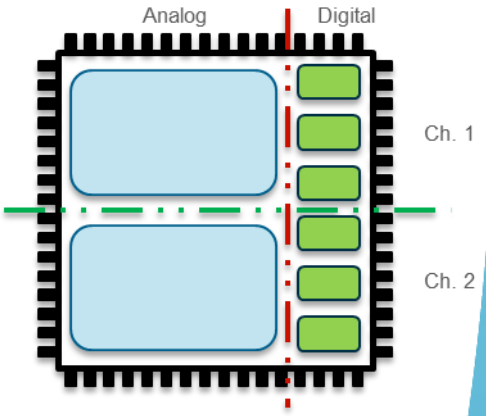
- *Upgraded Beam Instrumentation for HL-LHC*
- *Long-Range Beam-Beam Compensation*
  - *Studies leading to proof of concept*
  - *Design study for possible final implementation*
- *Electron Beam Test Stand*
  - *Construction and operation of test stand at CERN*
  - *Coordination of e-beam simulations*

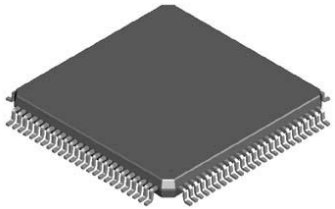
Task	Description
13.2	~~Cryogenic BLMs &~~ Radiation Hard BLM Electronics
13.3	New BPMs Q1 to Q5 with dedicated electronics
13.4	Luminosity Monitors
13.5	High Bandwidth Transverse Pick-ups
13.6	Upgrade to Synchrotron Light Monitor
13.7	Beam Gas Vertex Detector
13.8	Long Range Beam-Beam Compensator Studies
13.9	Electron Beam Test Stand

Beam Loss Monitoring

- Need for cryogenic BLMs removed
  - Updated simulations including addition of tungsten shielding and latest magnet geometries show no advantage over standard BLMs for all realistic loss scenarios

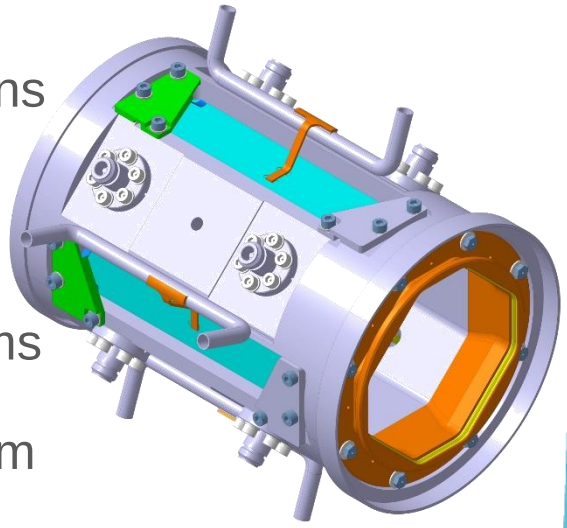
- Radiation Hard ASIC development
  - Collaboration with EP-ESE-ME
  - Two fully functional custom chips being developed to evaluate performance of two different architectures:
    - Current to Frequency Converter
      - Better for large currents & quickly varying signals
    - Delta-Sigma
      - High accuracy due to oversampling & filtering
  - Aim to test first prototypes before end 2019

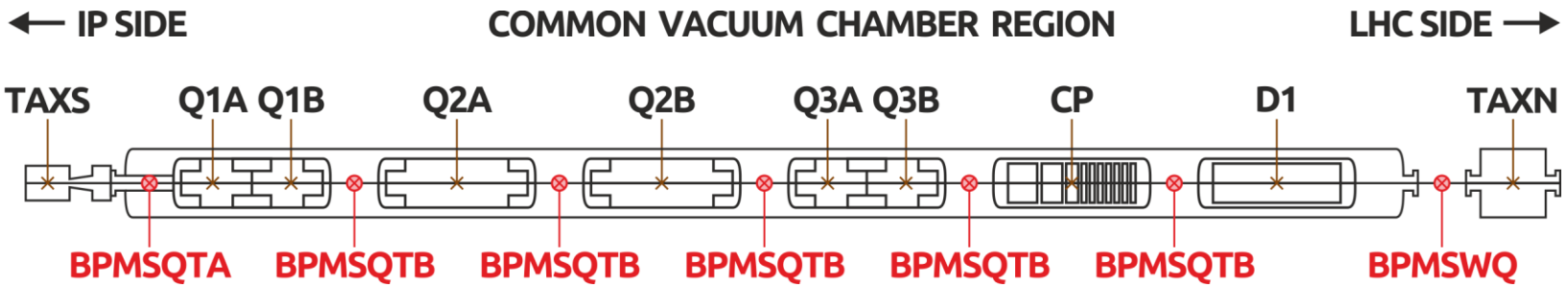




Beam Position Monitors for the New Interaction Region Layouts in Point 1 and 5

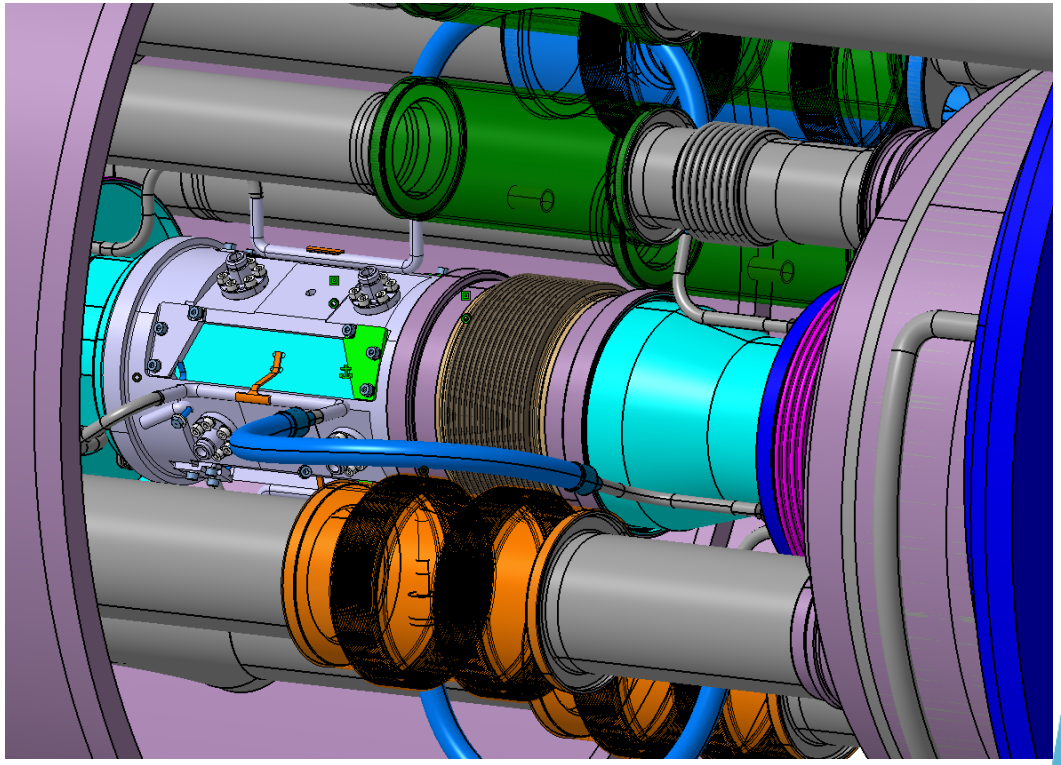
- New BPMs foreseen from Q1 to Q4
  - 24 cold directional stripline BPMs for Q1-D1 regions
  - 4 warm directional stripline BPMs for after D1
  - 8 warm button BPMs in front of D2 (or inside D2)
- Challenges
  - Directivity of stripline BPMs to measure both beams
  - Complex design including tungsten absorbers for collision debris and active cooling with liquid helium
    - Collaboration with WP 3,9,10,12,15
- Status
  - Layout optimised
    - All BPMs located away from parasitic encounters
  - Initial design completed for tungsten shielded BPM





New BPMs for HL-LHC IP1/5

- Major integration effort in 2018 in collaboration with WP 3,12,15
- BPM prototype production launched
- Starting large procurement of tungsten absorbers (with WP12) and cryogenic RF feedthroughs
- String Test BPM validation campaign planned
- Internal Review of Design held in May 2018
  - Highlighted 20 actions to be followed-up



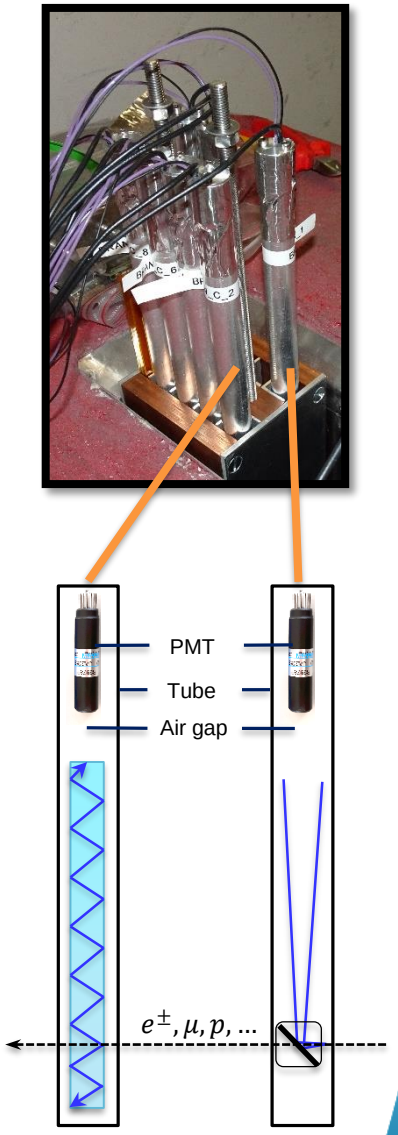
Luminosity Monitors

IP1 & IP5

- Currently
  - Gas ionisation detectors housed in TAN
  - Degrading & need to be replaced for HL-LHC
- Proposal
  - Replace with Cherenkov detectors in TAXN
  - Investigate Cherenkov light in quartz & air

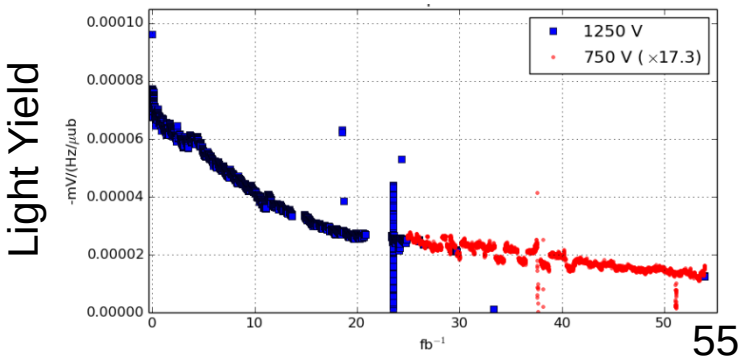
Status

- Proof of concept prototypes installed in 2016
  - Continued testing with beam since 2016
  - To be considered
    - Remote handling, vacuum bakeout, motorisation ….



Luminosity Monitors

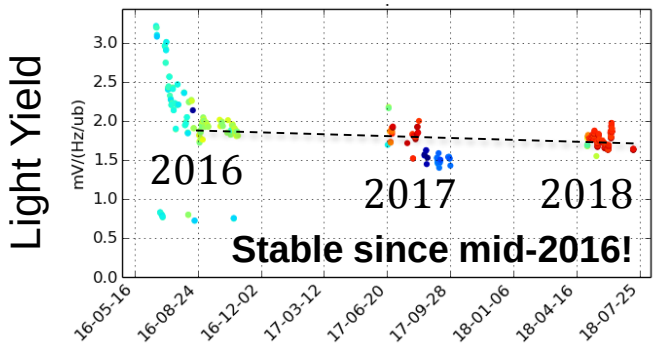
- Cherenkov in air
  - 80% loss in light yield for first 55 fb^{-1} in 2018
  - Not a feasible option in current state

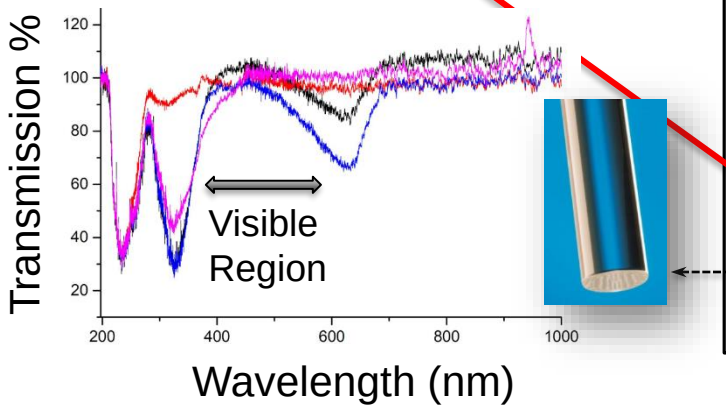


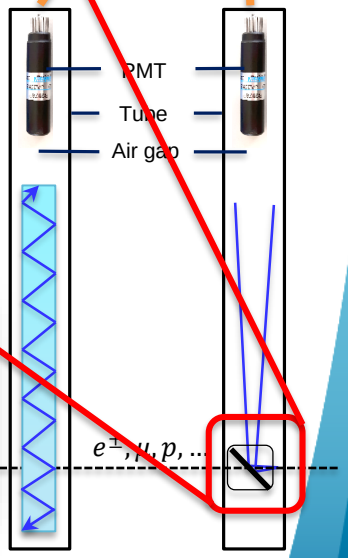
55 fb^{-1}

Aluminum mirror

- Fused Silica Rods after 1-2 years of LHC operation
  - Loss in UV-region but visible region intact
  - Promising candidate for final solution

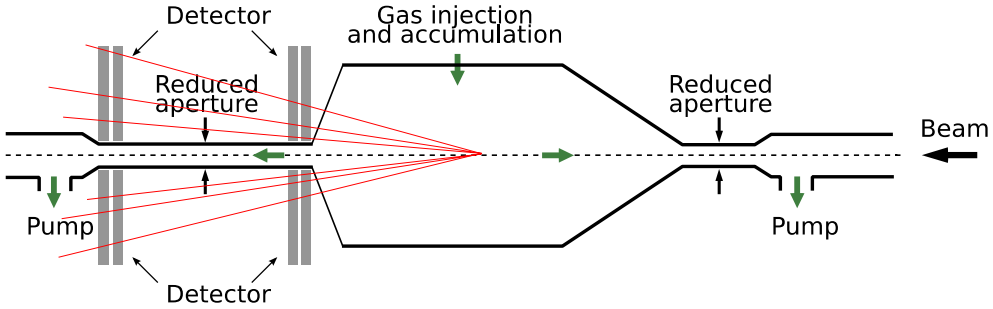


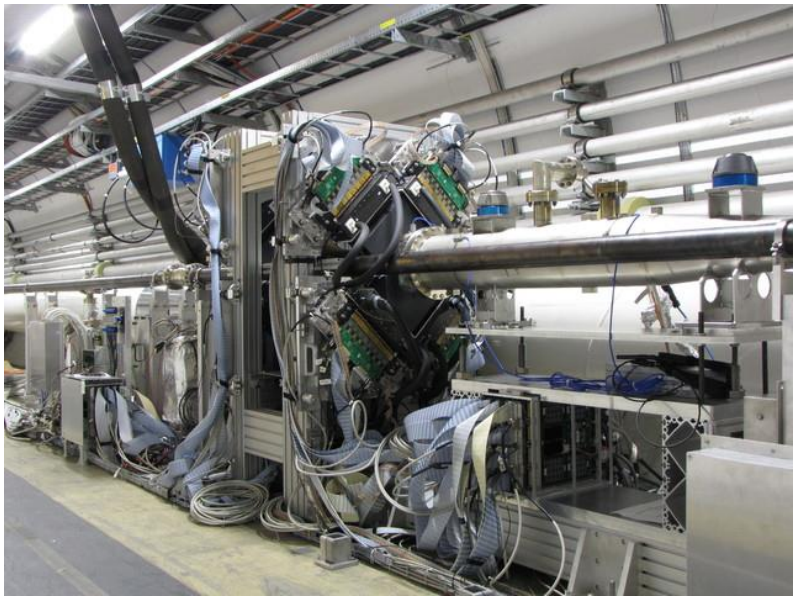




Beam Gas Vertex Detector

- Aim
  - Use tracks from beam-gas interactions to reconstruct beam spot in a non-invasive way
  - Provide bunch-by-bunch size with a 5% resolution within 1 minute
    - Demonstrator aims at 5% within 5 minutes
  - Provide average beam size with absolute accuracy of 2% within 1 minute
    - Demonstrator aims at 10% within 5 minutes
- Demonstrator
  - Collaboration with Aachen University, EPFL & LHCb
  - Installed during LS1 on Beam 2
  - In test since 2016

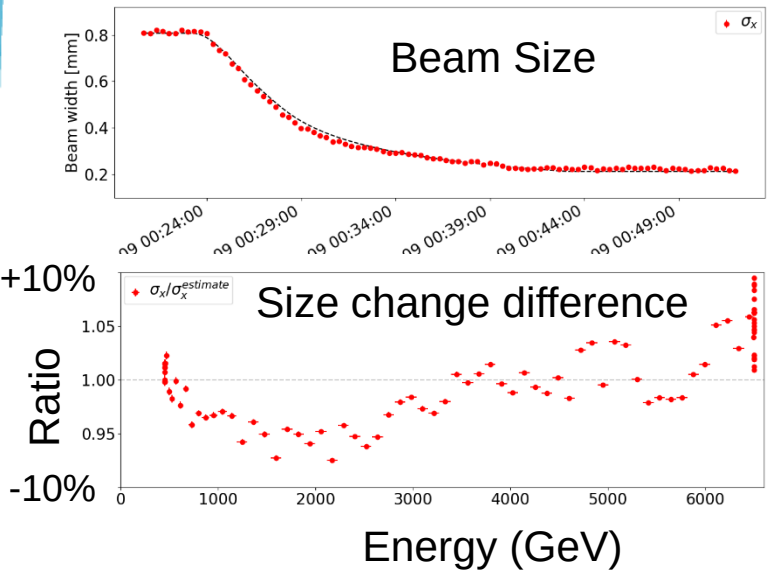




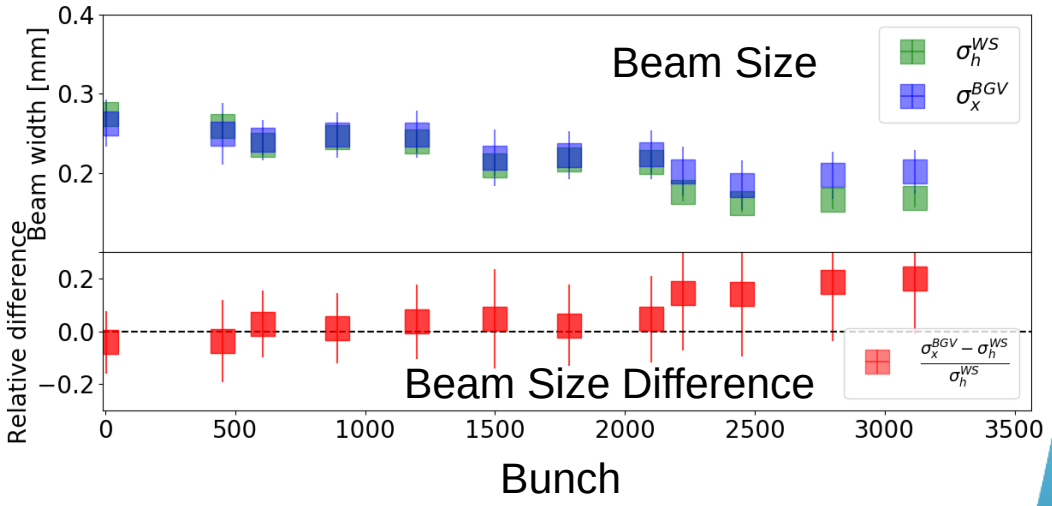
Beam Gas Vertex Detector

- Demonstrator has achieved its goal
  - Shown feasibility of beam size measurement from vertex reconstruction
  - Achieved real-time track reconstruction & analysis
  - Demonstrated statistical accuracy within specifications
    - Systematic effects still to be fully understood

Measurement throughout the ramp

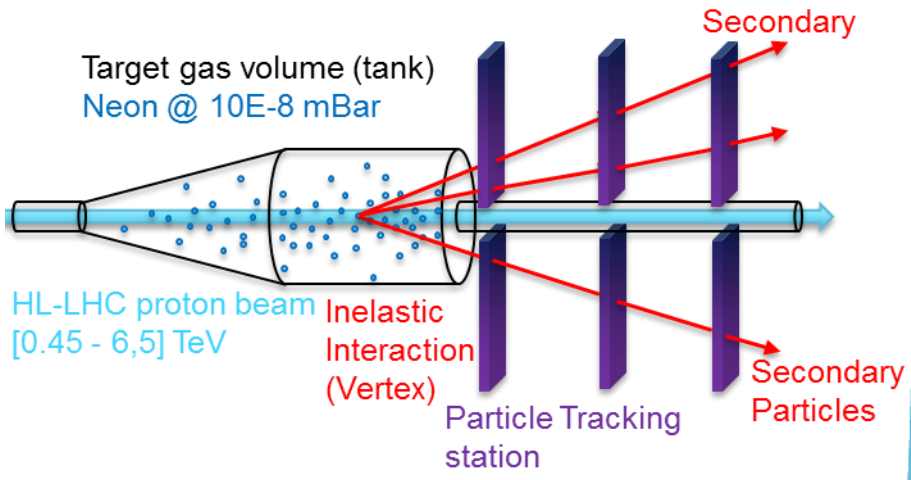


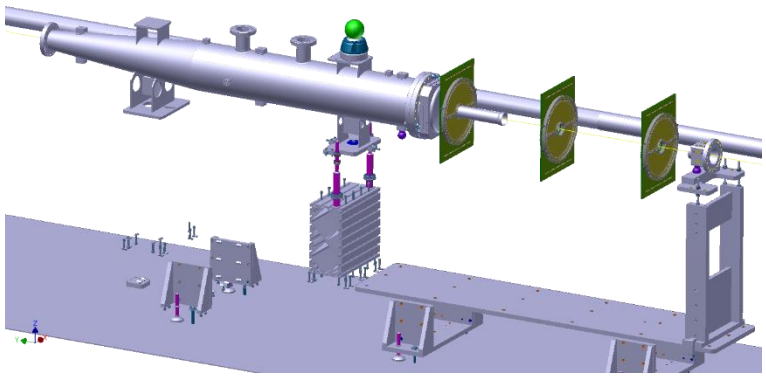
Comparison with wirescanners



Beam Gas Vertex Detector – The Future

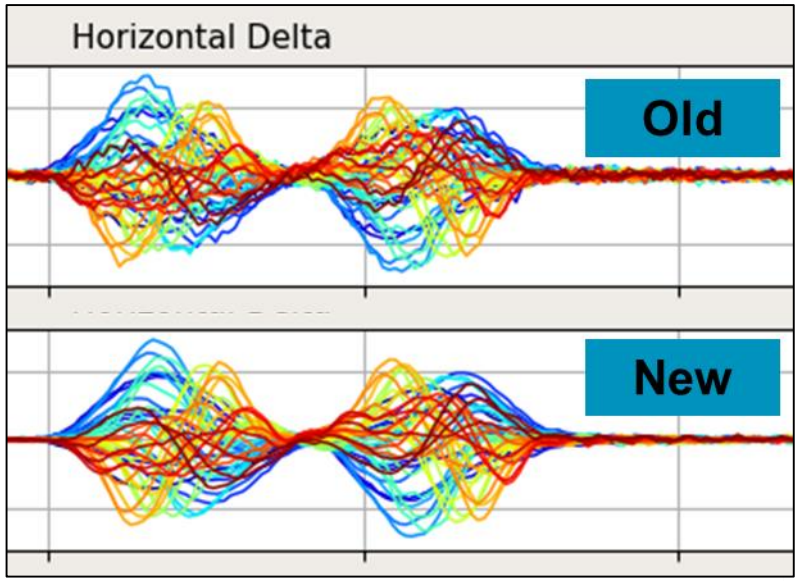
- Project recently approved construction of two final version BGV Detectors for HL-LHC
- Material budget study & detector technology comparison ongoing
  - Four candidates under evaluation:
    - Gaseous GEM/Micromegas
    - Silicon detectors
    - Scintillating fibers
  - Readout & online processing using BI standard acquisition system & adapted detector ASIC
  - Development of pattern recognition algorithms adapted to new sensor technology
- Review of all beam size measurement systems in 2019
  - Decision on technology to use for final HL-LHC systems

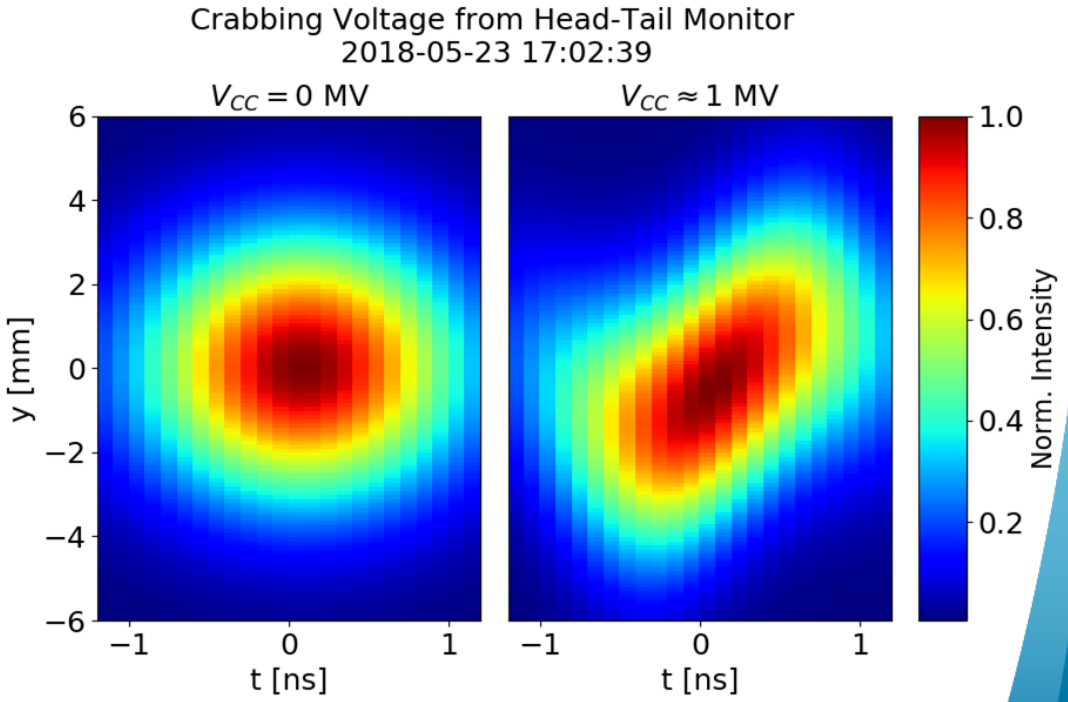




Development of High Bandwidth BPMs

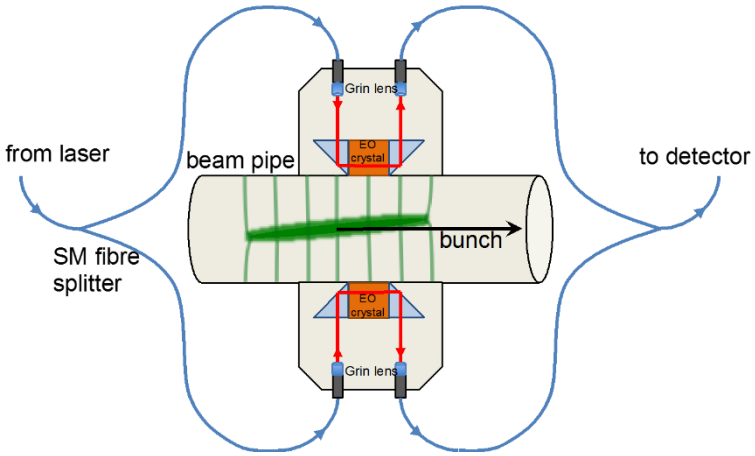
- Important for understanding instabilities
  - Electron cloud, impedance, beam-beam, ...
- Also essential for crab cavity diagnostics
- Currently based on head-tail monitor
  - Installed & recently upgraded in both SPS and LHC

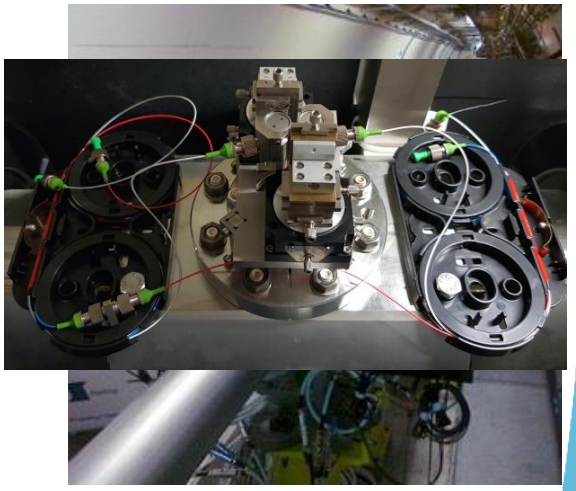




Development of High Bandwidth BPMs

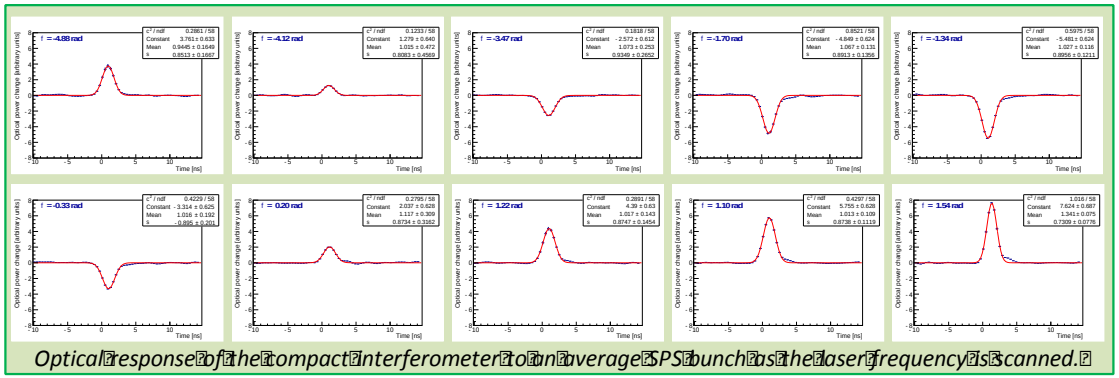
- Development of more sensitive, higher bandwidth system
  - Collaboration with Royal Holloway University London (RHUL) – HL-UK
- Prototype electro-optical pick-up installed in SPS
  - Upgraded for 2018 with compact fibre-optic interferometer design
- Next steps
  - Improve pick-up sensitivity with $LiNbO_3$ waveguides & better acquisition system





Working Point Scan

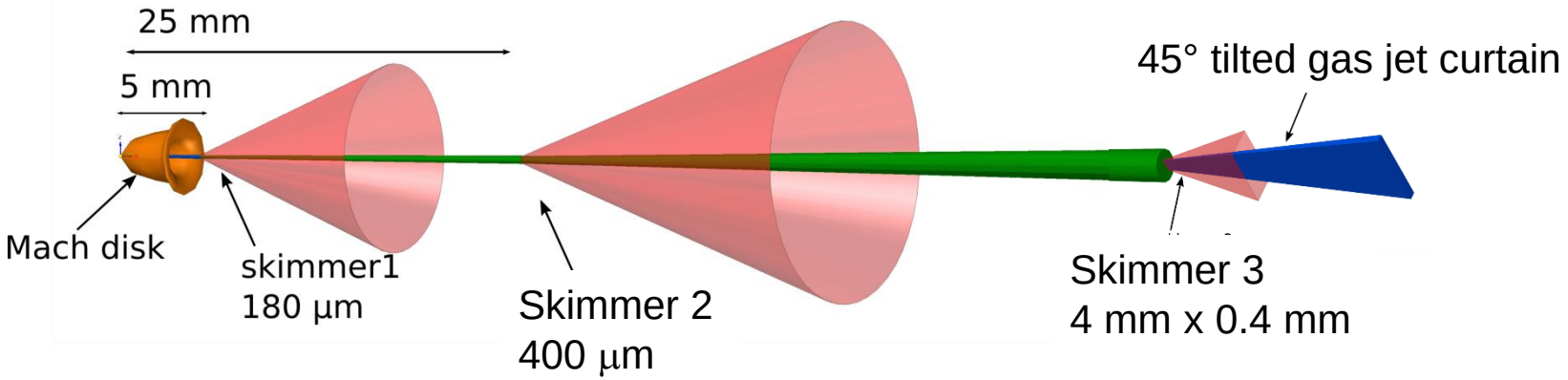
Rotation of laser polarisation by electro-magnetic field of circulating bunch



Optical response of the compact interferometer to an average SPS bunch as the laser frequency is scanned.

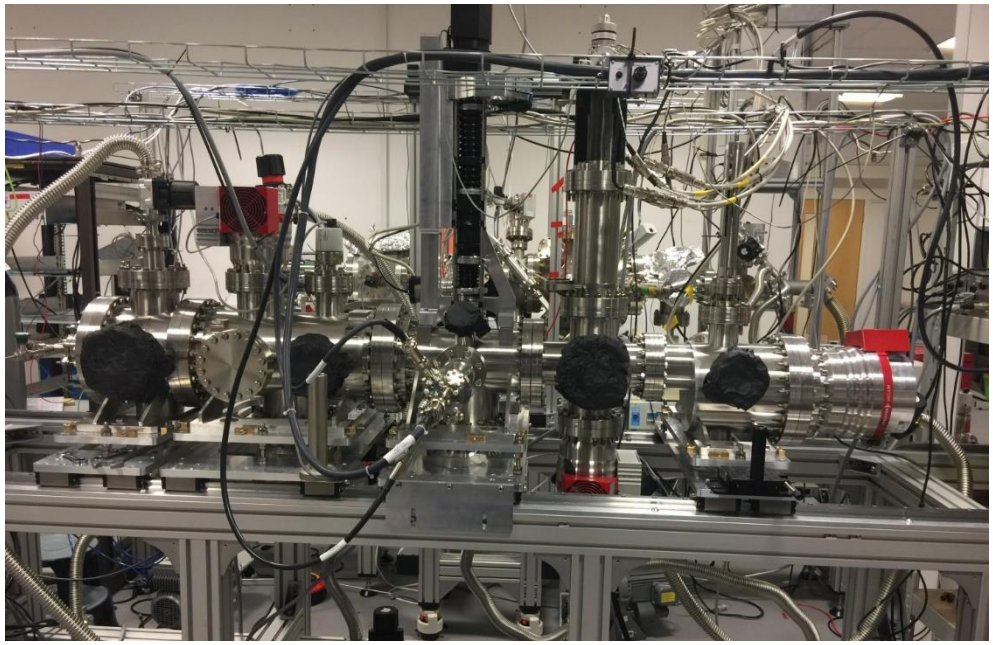
Gas Curtain Monitor

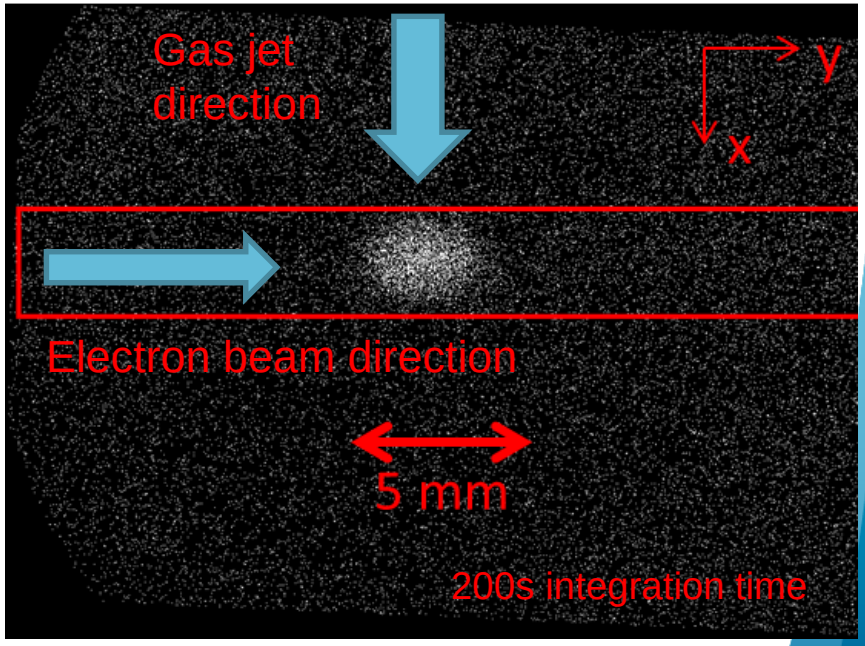
- Aims to provide a non-invasive method of aligning electron beam devices with the proton beam
  - E.g. hollow electron lens
- Gas sheet in combination with luminescence
- Collaboration partners
  - **Cockcroft/University of Liverpool** for hardware prototyping
  - **GSI** for the luminescence detection
  - **TE-VSC & Wroclaw University** for gas jet simulations
  - **EN-MME** for nozzle manufacture



Gas Curtain Monitor

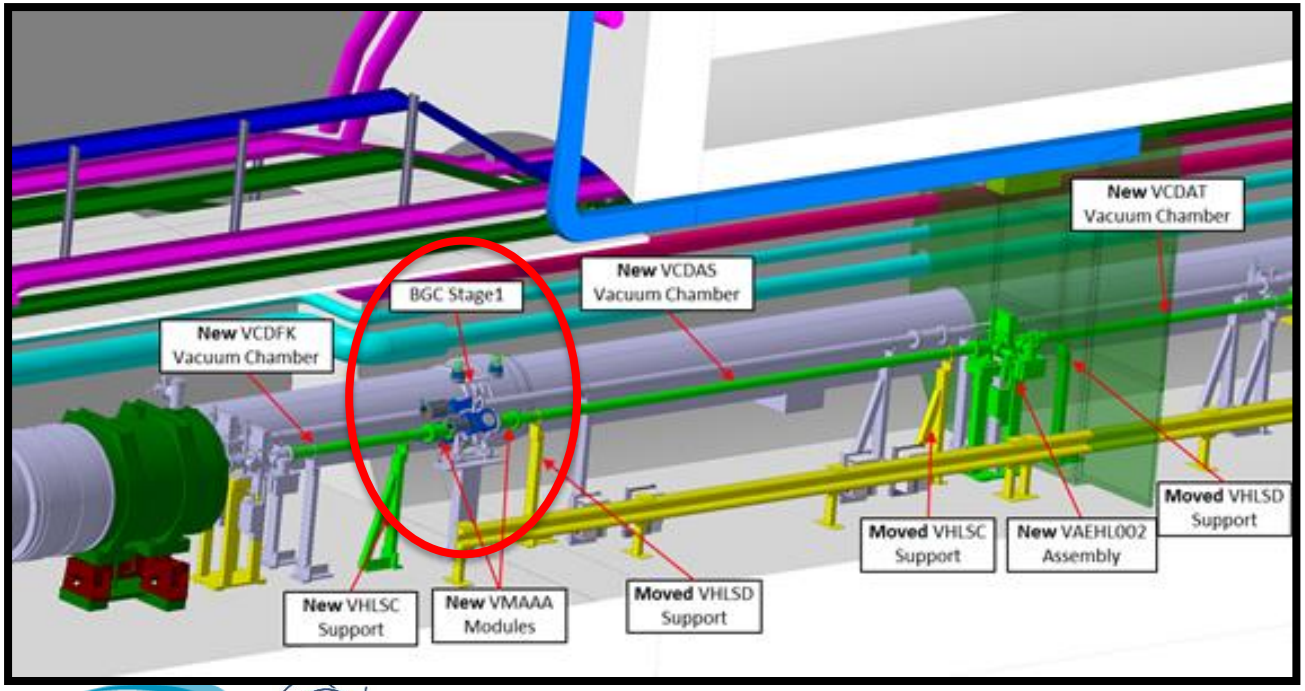
- Testing at Cockcroft
  - New test station designed, installed & commissioned
  - First tests with Nitrogen & Neon
    - Demonstrated gas jet formation
    - Validated optical system for luminescence detection

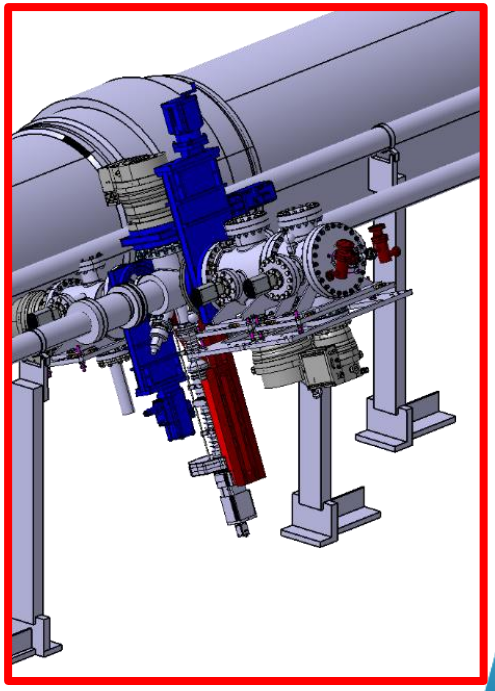




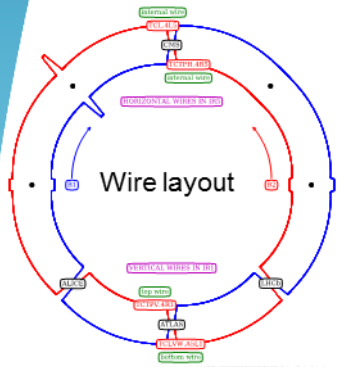
Gas Curtain Monitor

- Demonstrating feasibility for LHC
  - Installation of fluorescence test station in 2018
    - Tests with Neon gas volume (not curtain) with high intensity/energy beams
    - Cross-section expected to be very low for protons
    - Tests ongoing - no luminescence seen yet - high background from losses & SR
  - Installation of full “compact” prototype instrument during LS2
    - Will allow complete system validation during Run 3





Long Range Beam-Beam Compensation

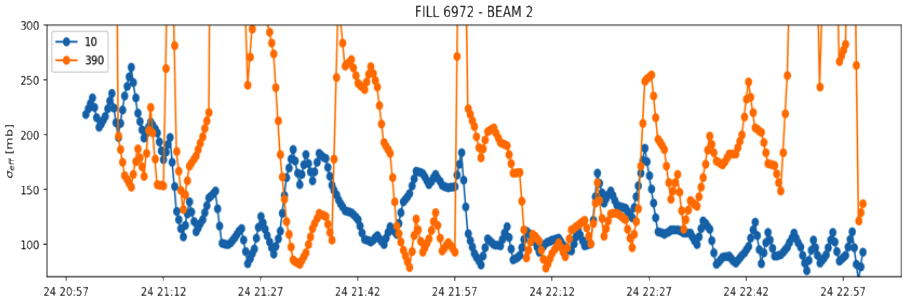


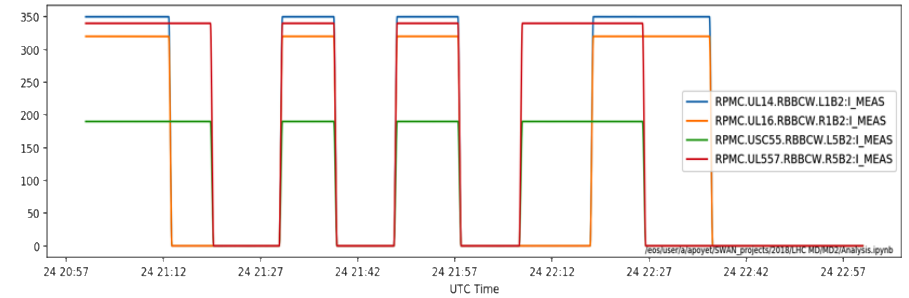
Status

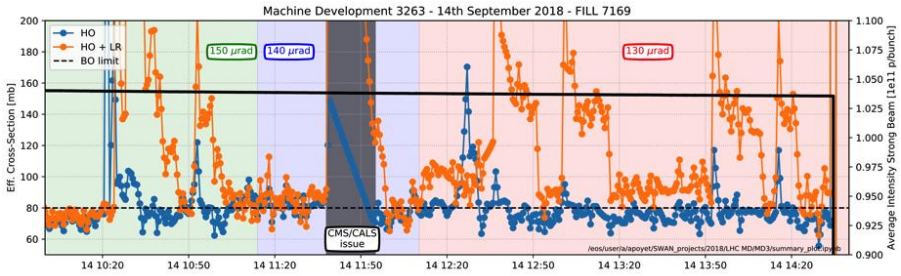
- Full set of wire-in-jaw collimators installed for B2
- One either side of IR1 & 5

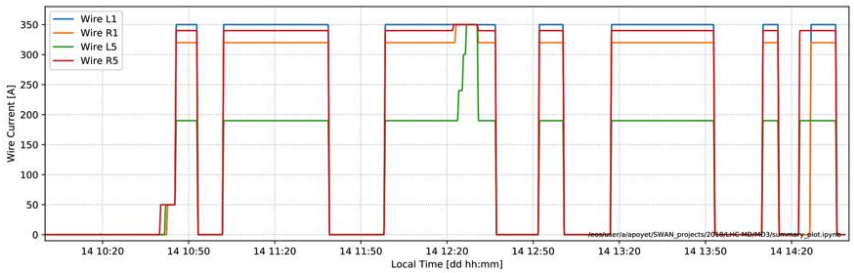
MD#2

- Efficiency of wires in IR5 confirmed with improvement of lifetime for bunches suffering long-range interactions









MD#3

- Wire reduces losses to burn-off level
- Crossing angle reduced during test
- Down to 130 urad, **still observing compensation!**

MD#4 – still to come

- 2 wires powered in parallel per collimator

Future

- Design of HL compatible device started

Progress with other WP13 Tasks

- Upgrade of synchrotron light diagnostics
  - New halo monitor will be installed in LS2
    - Collaboration with KEK
    - Aim to demonstrate contrast of 10^{-5}
  - D4 exit in LSS4 identified for new light extraction line
    - Design of extraction tank & optics to start in 2019
- Beam position system electronics
  - Large scale consolidation launched for LHC BPM system
    - Funded by consolidation project, R2E & HL-LHC
    - Will address requirements for HL-LHC final focus in IR1 & 5
- Electron beam test stand
  - To test components for possible 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
  - EPFL (Switzerland)
  - FNAL (US-LARP)
  - GSI (Germany)
  - KEK (Japan),
  - LHCb (CERN)
  - Royal Holloway University of London (UK)
  - Wroclaw University (Poland)
  - University of Liverpool (UK)