HiLumi
HL-LHC PROJECT

# WP13 – Beam Instrumentation and Long-Range Beam-Beam Compensation

# Status and Plans

Rhodri Jones (CERN BEAM INSTRUMENTATION GROUP)

CERN

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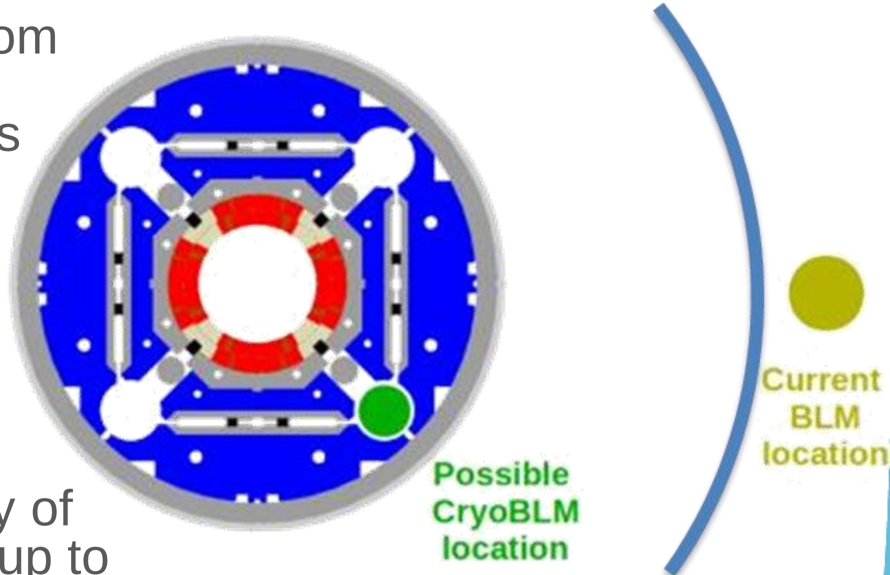
# Scope of WP13 – Beam Instrumentation and Long-Range Beam-Beam Compensation

- *Upgraded Beam Instrumentation for HL-LHC*
- *Long-Range Beam-Beam Compensation*
  - *Studies leading to proof of concept*
  - *Design study for possible final implementation*

| Task | Description |
|---|---|
| 13.1 | General R&D |
| 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 |

# Beam Loss Monitoring

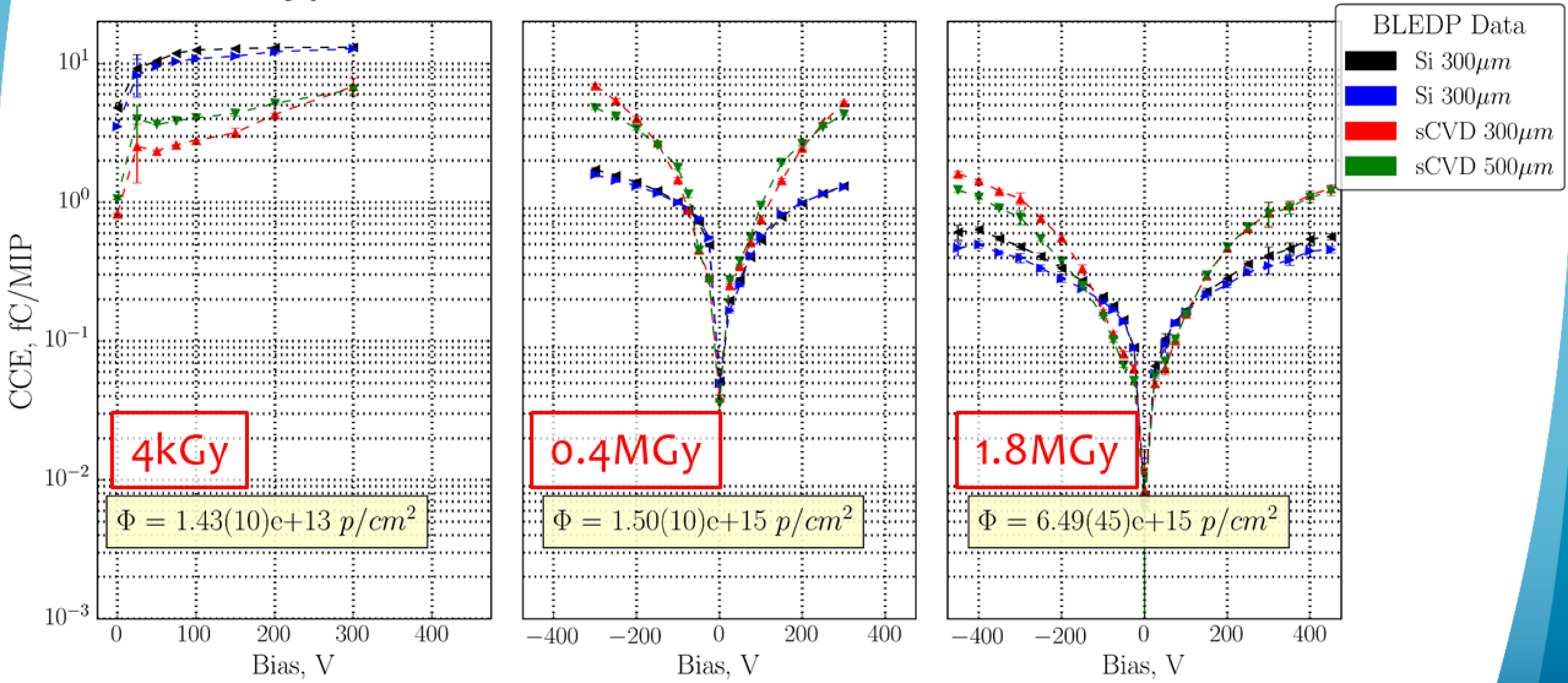
- Aim
  - Better distinguish beam losses from collision debris through use of cryogenic BLMs closer to the coils
- Challenges
  - Total radiation dose of 2MGy
  - Low temperature of 1.9K
  - Maintenance free operation
  - Magnetic field of 2T
  - Pressure of 1.1 bar with capability of withstanding a fast pressure rise up to 20bar in case of a magnet quench




- Status
  - Various types of silicon & diamond detectors tested
    - Collaboration with Ioffe Physical Technical Institute (Russia)
    - Irradiation at 1.9K & tests in magnetic field at warm complete
    - Tests in magnetic field at cold being prepared
  - Decision on whether to go ahead with integration into the coldmass required for Spring 2017
    - Need to look at loss scenarios compared to collision debris with latest layout

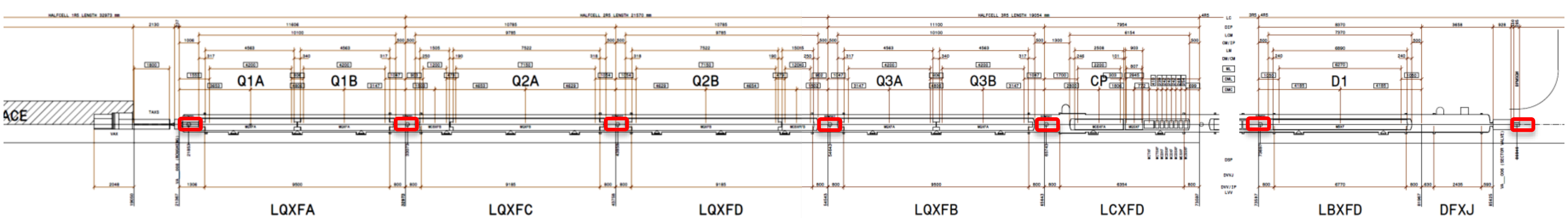
# Cryogenic Beam Loss Monitors

- Irradiation at 1.9K up to 2MGy
  - Diamond charge collection efficiency reduction less than a factor 5
  - Silicon charge collection efficiency reduction by factor 20
- Both types of detector still useable after irradiation



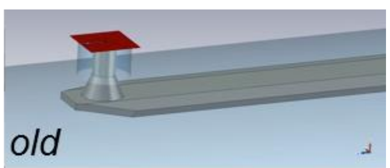
# Beam Position Monitors for the New Interaction Region Layouts in Point 1 and 5

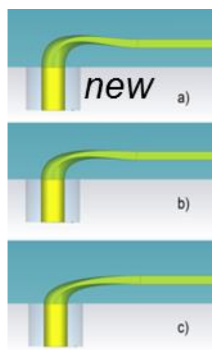
- New BPMs foreseen from Q1 to Q4
  - 24 cold directional stripline BPMs for Q1-D1 regions
  - 4 warm directional stripline BPMs for after D1
  - 8 warm button BPMs in front of D2
  - 8 cold “standard” button BPMs for Q4
- Challenges
  - Directivity of stripline BPMs that measure both beams
  - Tungsten shielding added to reduce irradiation to downstream magnets
- Status
  - Layout optimised - ensures that all BPMs located > 0.5m from parasitic encounter
  - Stripline optimised for directivity
  - Conceptual design completed for tungsten shielded BPM

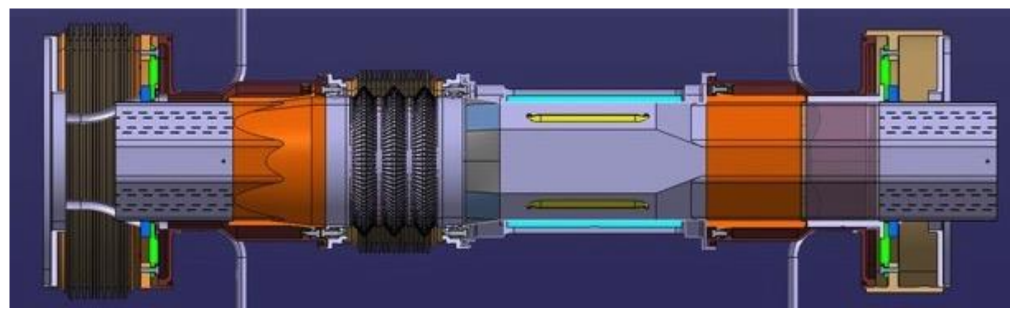


# HL-LHC Directional Stripline BPM

- RF simulations for stripline optimisation
  - Obtained 10dB improvement in broadband directivity by optimising electrode shape and strip to coaxial transition
- Implementation of BPM shielding
  - “Octagonal” BPM with striplines rotated by 45° to incorporate 18cm Inermet shielding in their mid-planes
  - Contributes further 15% reduction in peak dose deposited in the inner coils at the IP face of Q2B



- Next Steps
  - Study heat load & integrate the cooling circuitry
  - Study mechanical deformation during thermal cycle
  - Finalise design and construct prototypes for laboratory testing and use in the String test

# Luminosity Monitors

IP2 & IP8

- Luminosity monitors upgraded in LS1 based on Cherenkov in quartz
- Radiation damage study underway with a prototype installed in IP1
  - Early indications show detector is radiation hard enough for HL-LHC

IP1 & IP5

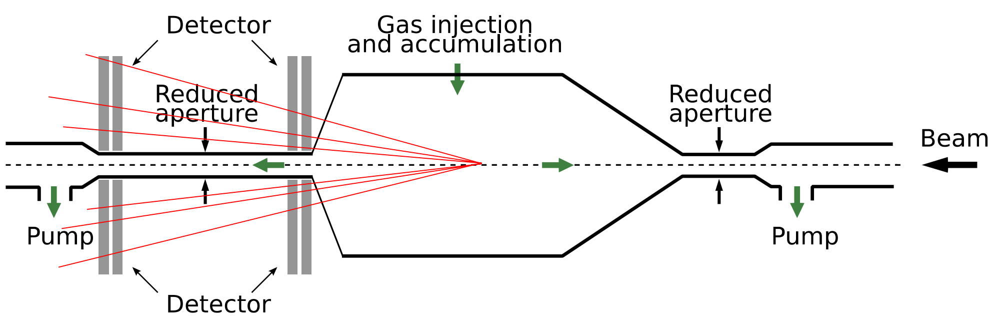
- Current monitors housed in TAN & based on gas ionisation detectors
  - These are degrading and will need to be replaced for HL-LHC
- Proposal to replace with combined Cherenkov detectors in the TAXN
  - Low luminosity (first / probe collisions): Cherenkov light in quartz
  - High luminosity (physics fills): Cherenkov light in gas

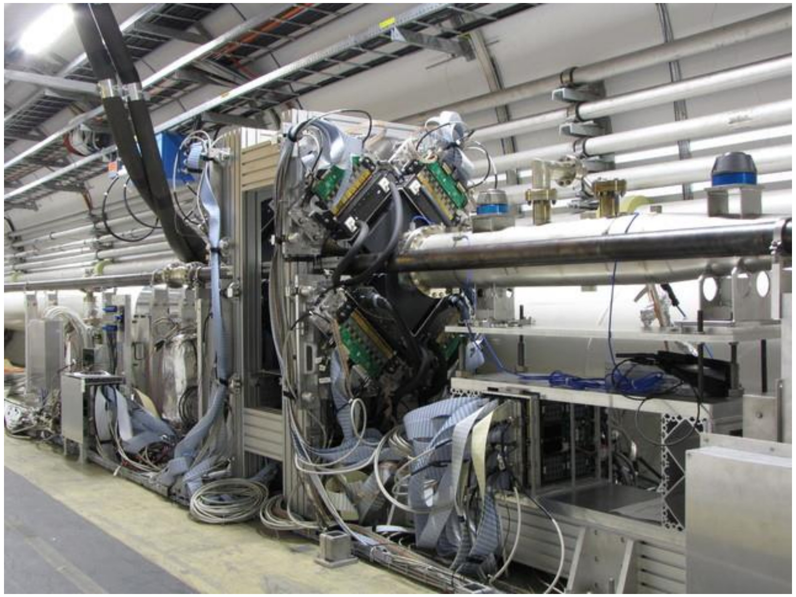
Status

- Proof of concept prototype installed in IP1 for entire 2016 run
  - Based on these results such design seems feasible for HL-LHC
- Next Steps
  - Continue testing with beam in 2017
  - Start the design of the HL-LHC detector
  - Remote handling, vacuum bakeout, motorisation ….

# 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
  - Fully commissioned in 2016



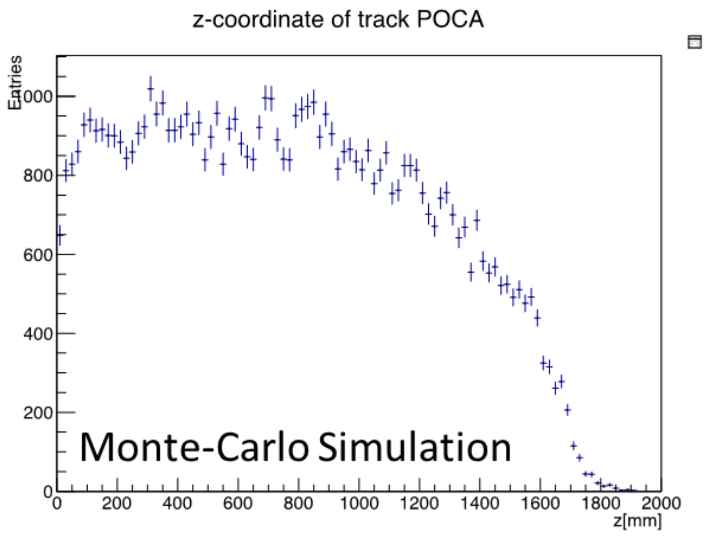



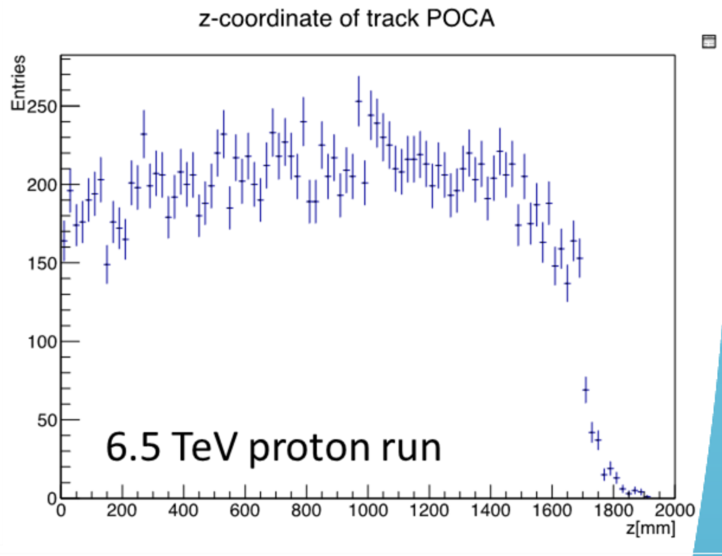
# Beam Gas Vertex Detector

- Status
  - Detector fully commissioned (Dead channels ≤ 1%)
    - SciFi detector planes, Trigger, Read-out, CPU farm, Control & DAQ SW
  - Gas injection system operational
  - Data-taking campaigns during 2016 under various beam conditions

**BGV**
**First Data**

Vertex distribution along the gas target chamber




- Next Steps
  - Offline analysis for high precision track & vertex reconstruction ongoing
  - Implement analysis software in CPU farm for real-time measurement
  - Establish data logging and measurement publishing towards CCC

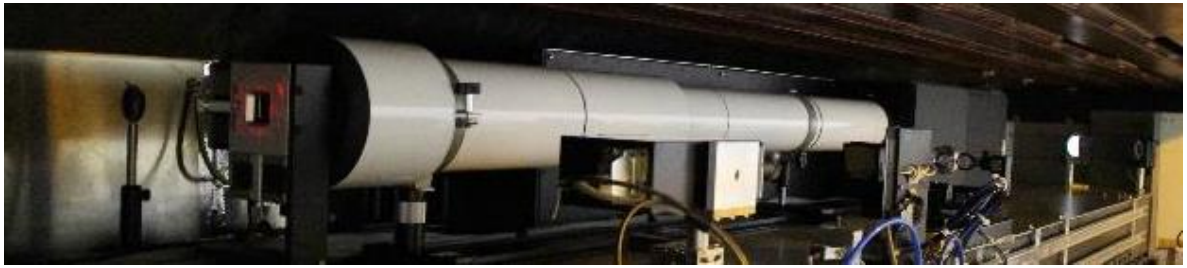
# Upgrade of Synchrotron Light Diagnostics

Baseline

- New Light Extraction Path to Optical Dark Room in UA43/UA47
  - Required for additional measurement stations such as for Halo Diagnostics or Streak Cameras for intra-bunch measurement

Status

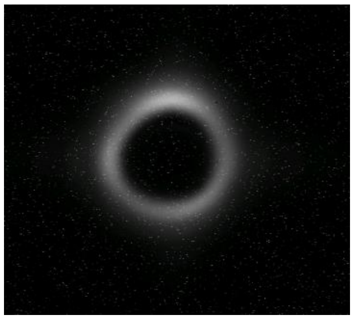
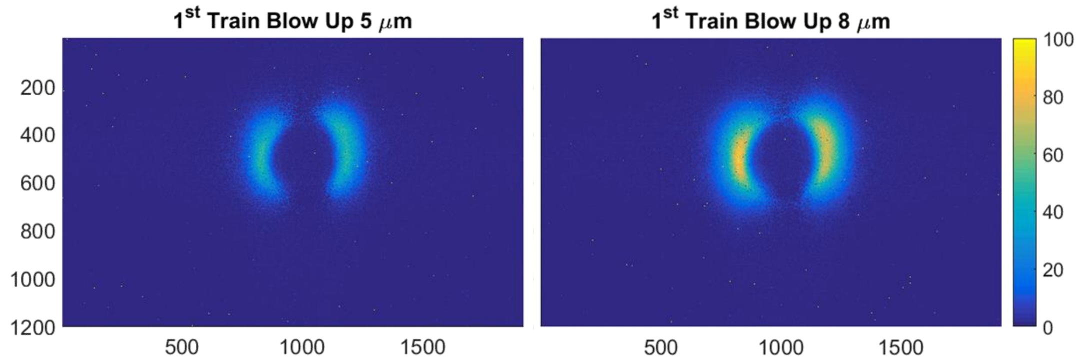
- Prototype coronagraph for halo diagnostics installed in LHC
  - KEK collaboration providing expert manpower & optical components
  - First measurements taken during machine development periods
  - Parasitic light at 6.5TeV observed and needs to be understood
  - Contrast of $2 \times 10^{-3}$ already demonstrated with early tests at 450GeV

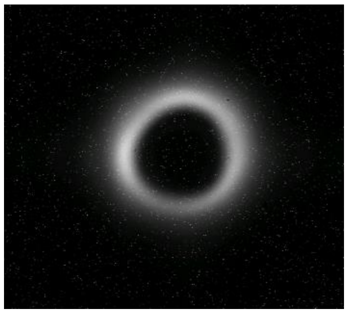


- Additional light extraction possibility for HL-LHC identified
  - D4 magnet for incoming beam either side of Point 4
    - Without additional undulator only provides diagnostics from 2TeV onwards
  - Study to be started for design of light extraction path

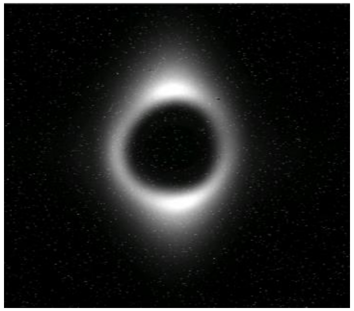
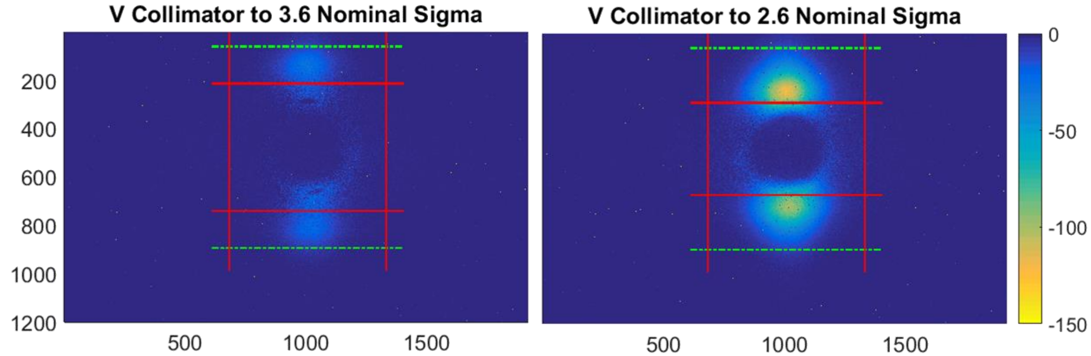
# Prototyping the Coronagraph in LHC

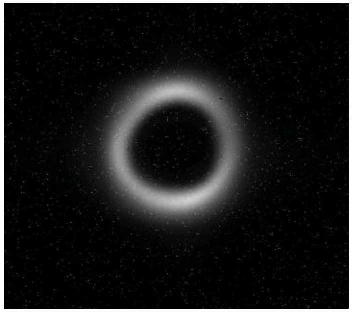
- Coronagraph images during controlled blow-up



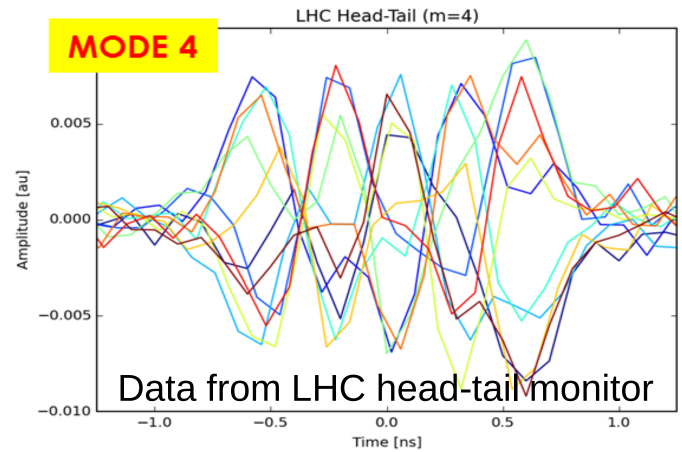
- Coronagraph images during controlled scraping

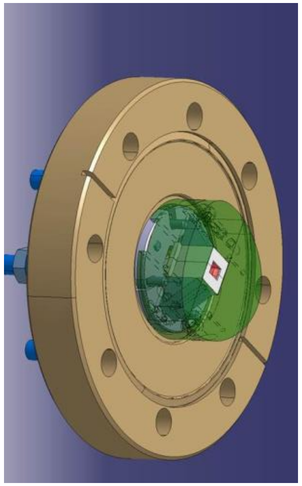


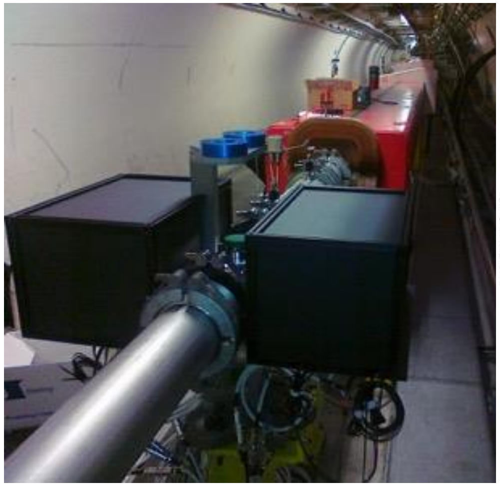
# Development of High Bandwidth BPMs

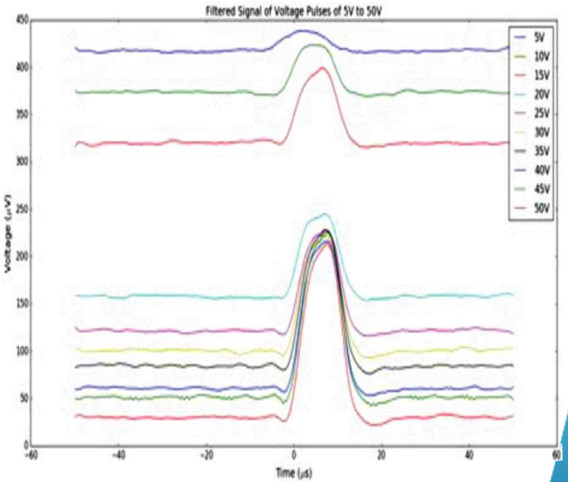
- Important for understanding instabilities
  - Electron cloud, impedance, beam-beam, ...
- Also essential for crab cavity diagnostics
  - Monitoring non-closure




- For higher resolution require bandwidth up to 10 GHz
  - Collaboration with Royal Holloway University of London (UK) to study possible use of electro-optical methods
  - Prototype installed in SPS – tests ongoing

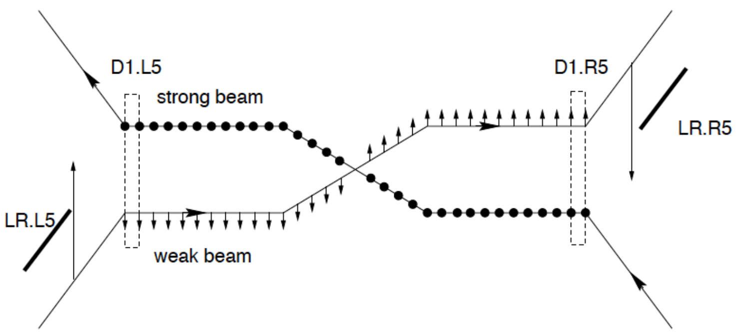


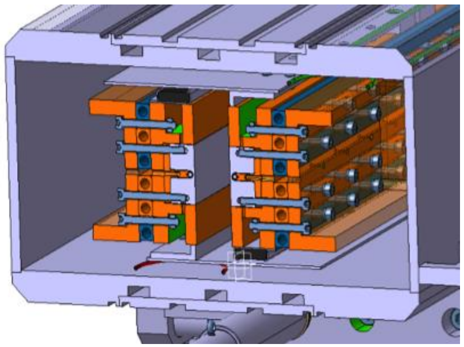


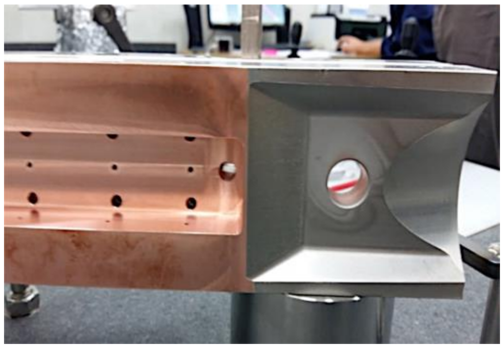


# Long-Range Beam-Beam Compensation

- Adriana Rossi replaces Hermann Schmickler as Task Leader
- Studies leading to proof of concept
  - 2 wire-in-jaw collimators to replace IR5 tertiary collimators this winter
    - Up to 350A in a wire < 3mm from collimation surface
  - First beam tests during machine development foreseen in 2017



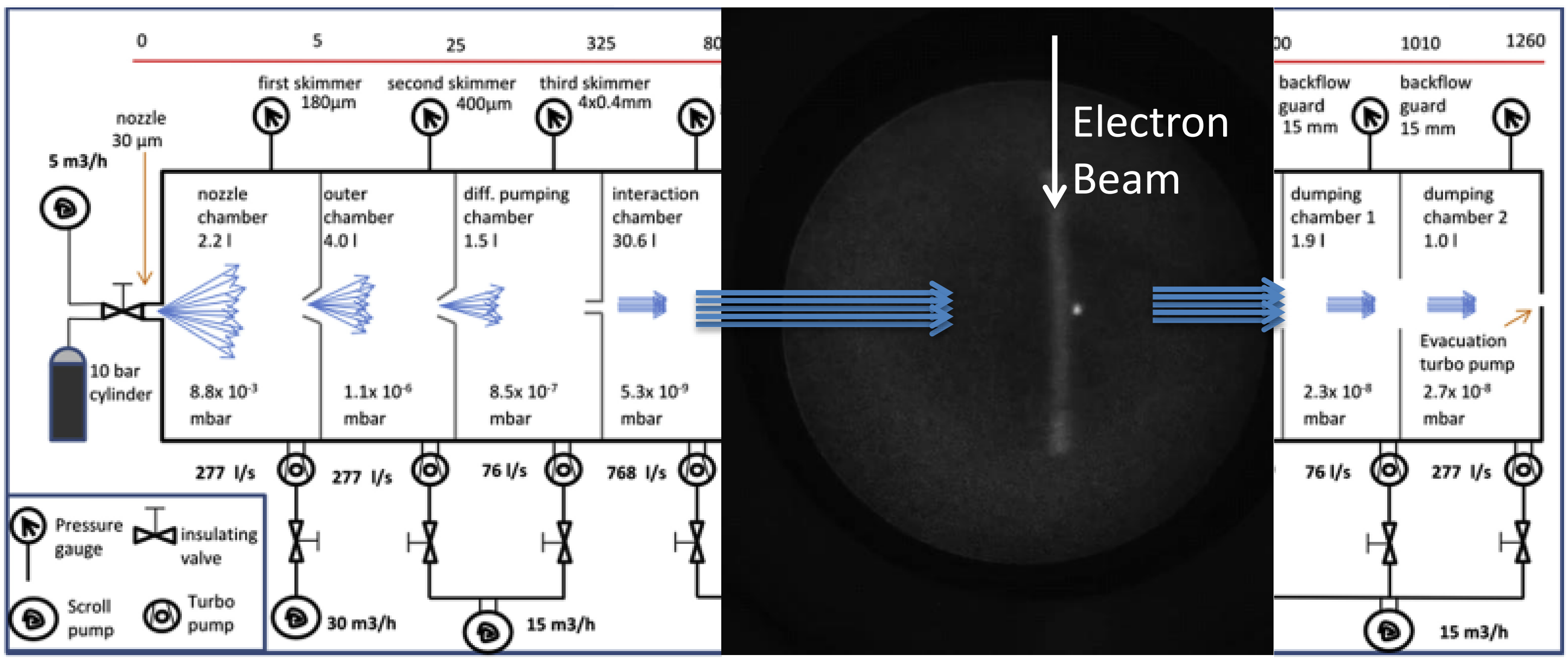


- Design study for possible final implementation
  - Feasibility of high current electron beam to replace wire under study
    - Collaboration with FNAL, BINP, EU ARIES
    - Looking at production and confinement of 20A electron beams
  - Test stand to be constructed (WP3 synergy – hollow e-beam studies)
    - Test of high current (& hollow) e-guns & non-invasive diagnostics
      - Gas sheet profiler - collaboration with Liverpool (UK) & GSI

A big thanks to all involved, in particular the Collimation Team, EN-STI, EN-MME, TE-EPC, BE-ABP, BE-BI

# Gas Jet Monitor

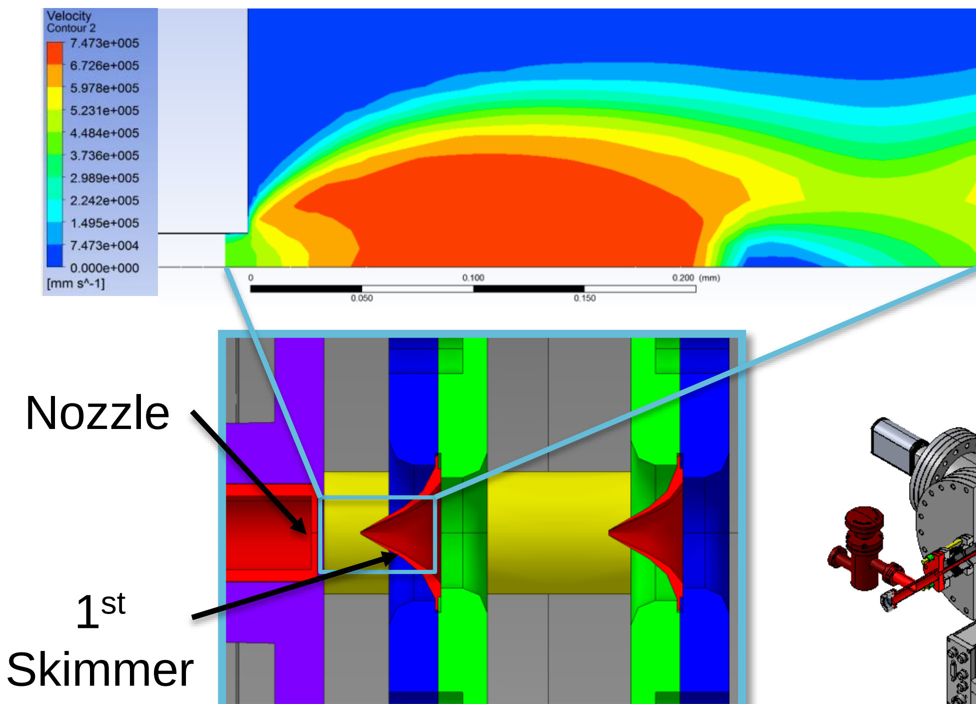
- Aims to provide a non-invasive method of aligning electron beam devices with the proton beam
  - Hollow electron lens or long-range beam-beam compensator
- Gas sheet in combination with luminescence
- Collaboration partners
  - **University of Liverpool** for development of the gas sheet
  - **GSI** for the luminescence detection

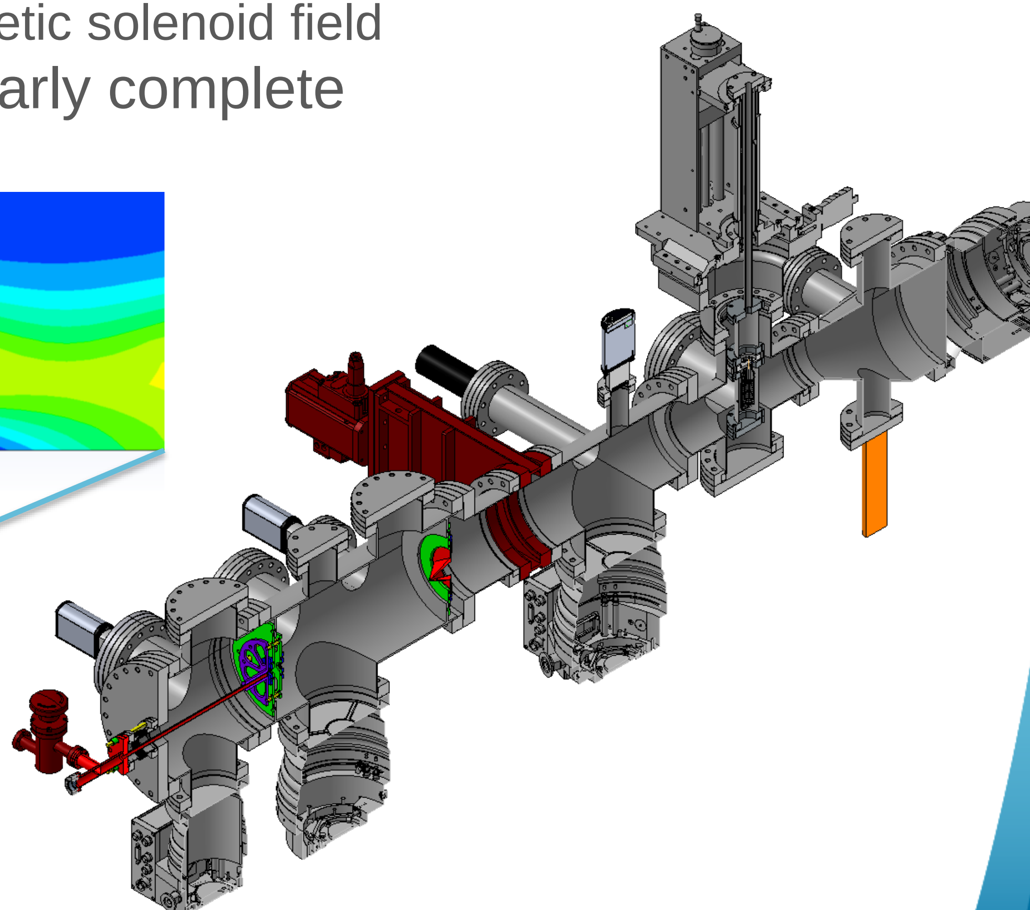



6th HL-LHC Collaboration Meeting, Paris, Nov 2016 Rhodri Jones (CERN)

# Gas Jet Monitor

- Studies to optimise supersonic gas sheet generation ongoing
- Optical system under development
  - Choice of gas fluorescence line
  - Influence of strong magnetic solenoid field
- First prototype design nearly complete



# 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)
  - EPFL (Switzerland)
  - FNAL (US-LARP)
  - GSI (Germany)
  - Ioffe Physical Technical Institute (Russia)
  - KEK (Japan),
  - LHCb (CERN)
  - Royal Holloway University of London (UK)
  - University of Liverpool (UK)