Beam Instrumentation and Electronics for Accelerators

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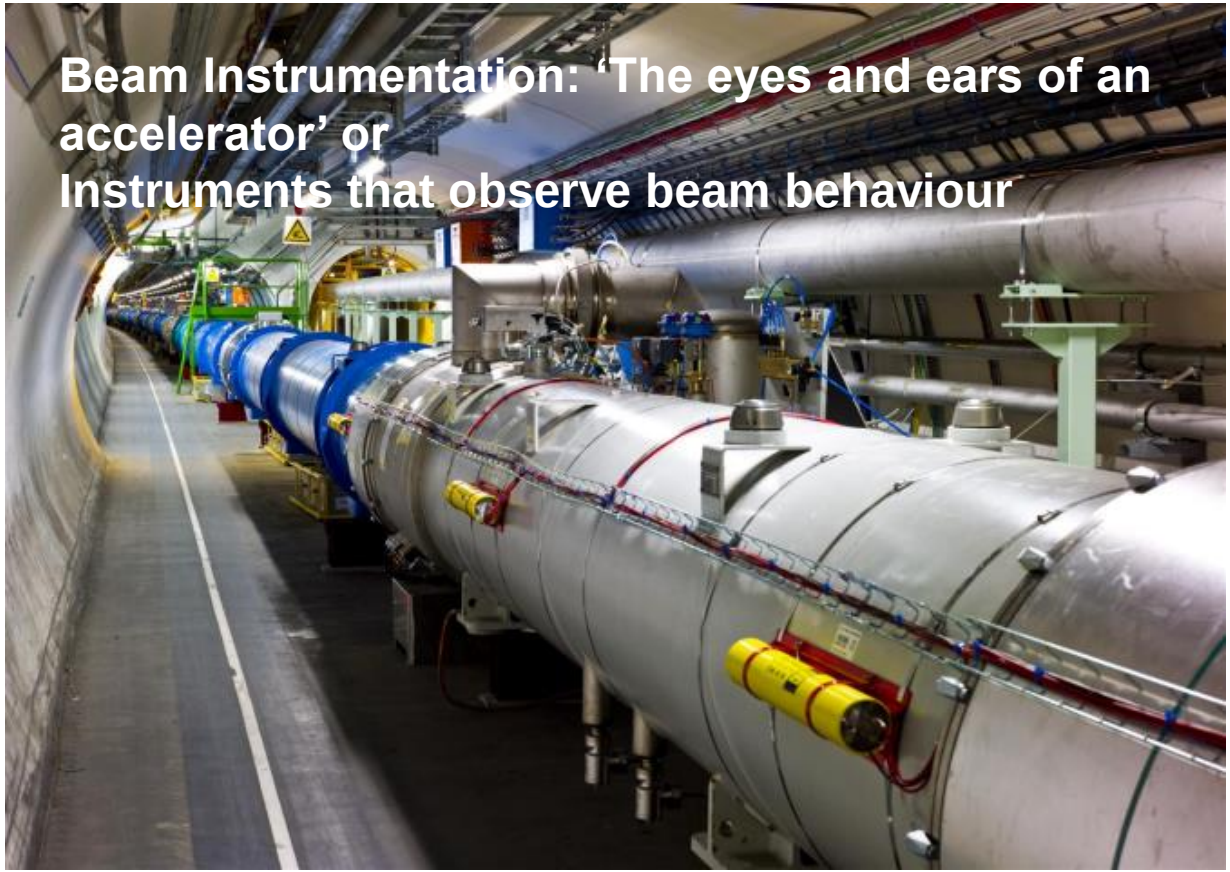
2nd High-Lumi Industry Day. Lisbon 31/10/16

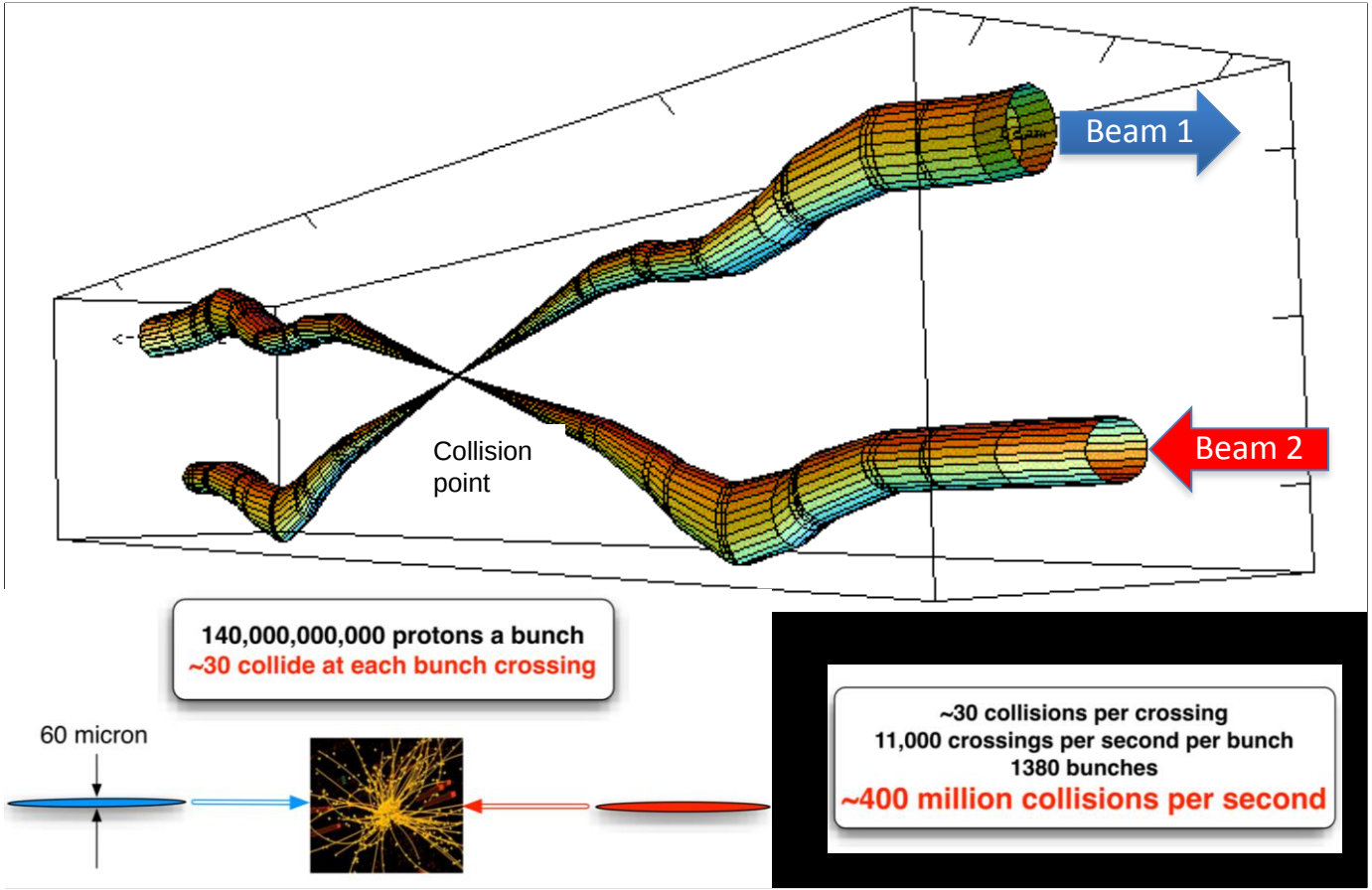
Beam instrumentation in the LHC



Beam Instrumentation

- Some numbers:
  - 2500+ instruments integrated into the beam vacuum system of the accelerators (the LHC and it's injectors)
  - 4500+ instruments close to the beamlines, in the accelerator tunnels
  - 5 New instrument concepts for HL-LHC
  - 100+ new beam vacuum instruments to be produced for HL-LHC
- What is an instrument?
  - Mechanics: vacuum chamber, movement systems, beam intercepting devices
  - Detectors: Cameras, scintillators, transformers, pickups
  - Electronics: Fast, radiation hard, analogue and digital
  - Software: acquisition, low-level controls
- For industry, this means
  - Precision and state-of-the-art, small-medium series, high added value
  - Collaboration with industry and institutes to develop new technology

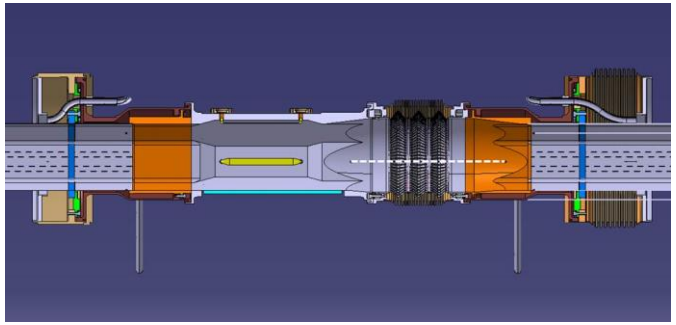
HL-LHC Goal: Maximising Particle Collisions

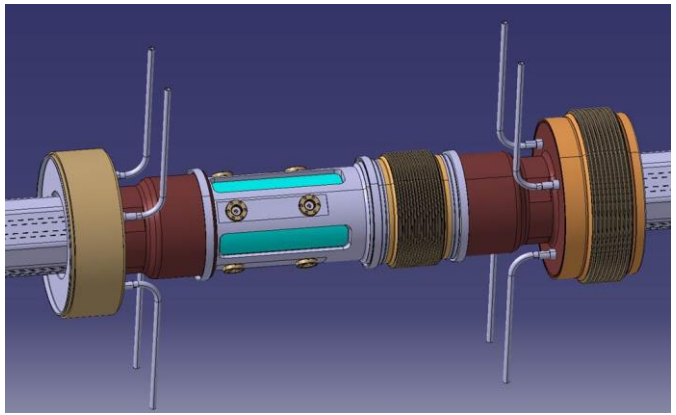


HiLumi HL-LHC PROJECT

Beam Position Monitors (BPMs) in the Final Focus

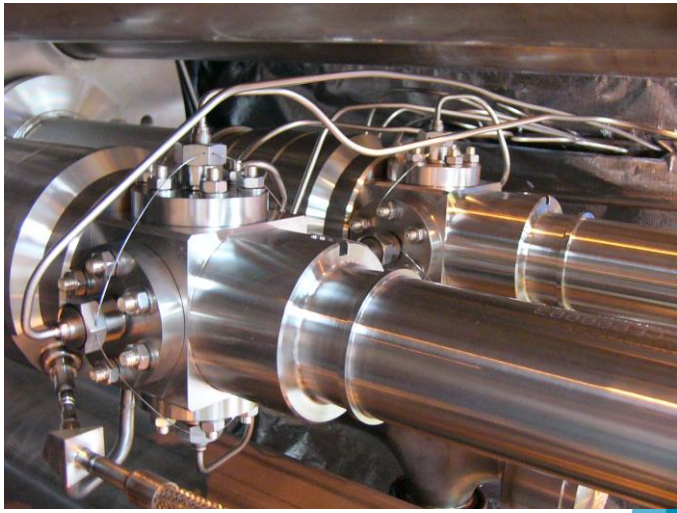
- Overview
  - Measure beam positions as they approach collision, means sub-micron beam orbit resolution
  - Strip-line pick-ups (with 8 feedthroughs/BPM) operating at 2 Kelvin
  - Integrated radiation absorbers (tungsten alloy)
- Requirements
  - 48 installed in high-lumi triplet magnets





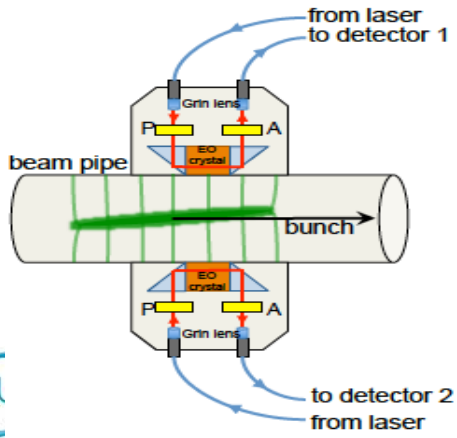
Cables for Cryogenic BPMs

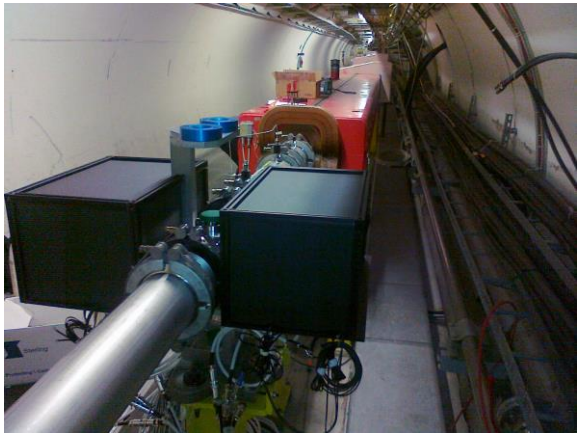
- Overview
  - 50 Ω co-axial cable to bring the signal from the cryostat
  - Ultra-high vacuum compatible and leak tight, operating at 2 Kelvin (weldable)
  - Very low hysteresis vs temperature and motion, with consistent phase and loss values (SiO_2 dielectric)
- Requirements
  - 250+ cables for different applications

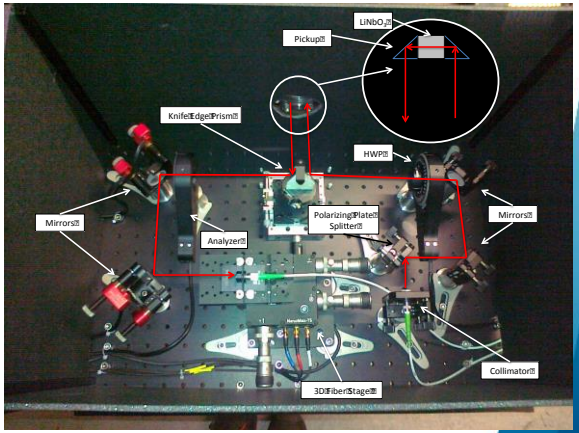


High Bandwidth BPMs

- Overview
  - Required for intra-bunch diagnostics (Instabilities & crab cavities), so will resolution require bandwidth > 10 GHz
  - New concept, developed in collaboration with Royal Holloway, University of London based on electro-optical crystals with prototype testing under-way at CERN.
- Requirements
  - Radiation tolerance qualification of crystals, industrialisation
  - Fast electronics, Femto-second laser optics



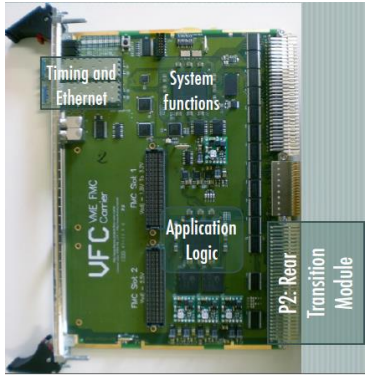




Optical Signal Processing

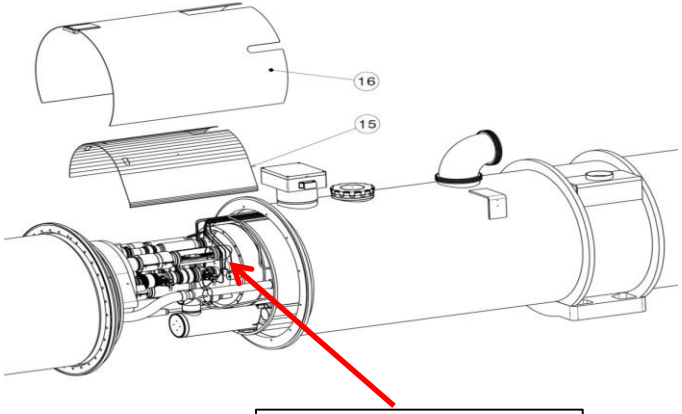
Fibre optic transmission

- Analogue and digital optical links
  - Distributed LHC beam instrumentation transmits information from radiation hard front-end electronics to surface electronics
    - 500+ stations with over 3000 links
    - Over 5000km of fibre-optic cabling
    - Radiation hard transmitters/receivers & optical fibres
- Next Generation
  - Radiation hard Gbit Links (GBT developed by CERN Physics Department)
  - Digital signal processing on custom FPGA motherboard

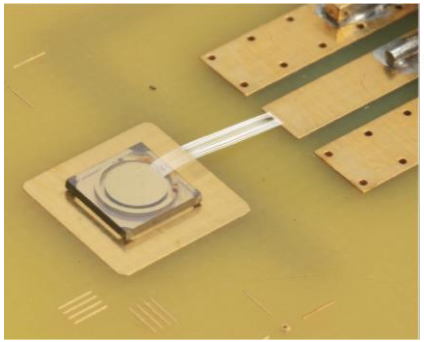


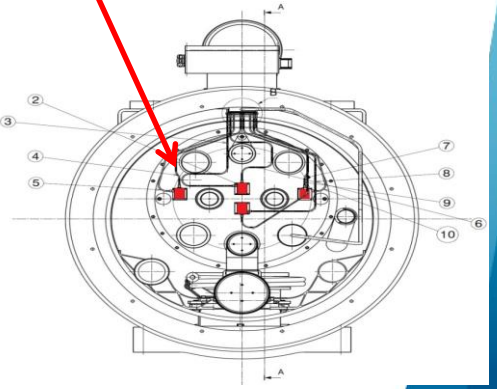
Cryogenic Beam Loss Monitors (BLMs)

- Overview
  - New concept, based on silicon or diamond semiconductor detectors will allow fast localisation of beam losses in critical areas
  - Required to withstand 2MGy over 10 years
  - New BLM front end based on an ASIC under development.
  - Project fully based on radiation-tolerant-by-design active components (VTRx, GBTx)
- Requirements
  - Partners for industrialisation
  - Fast, radiation-hard electronics
  - 32 detectors planned for installation



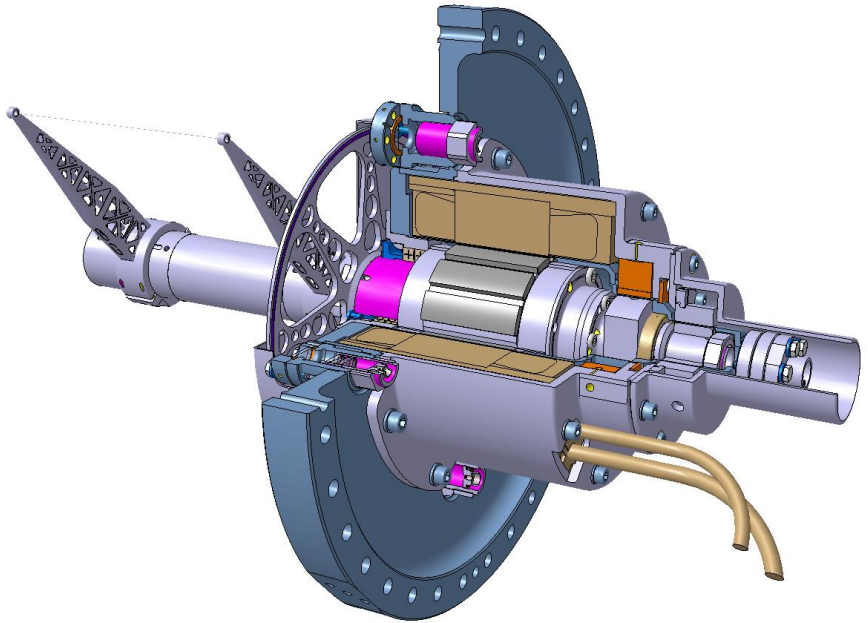
Position of Cryogenic BLMs



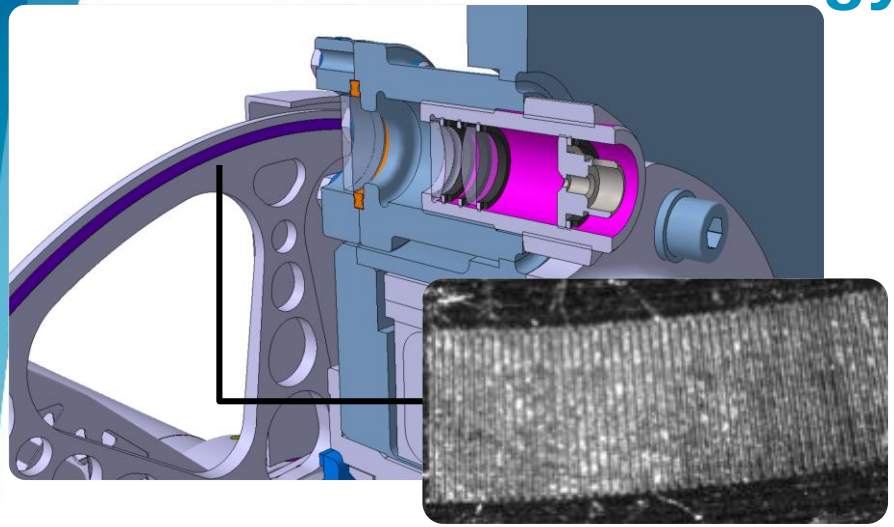


New Wire Scanners for the High-Lumi era

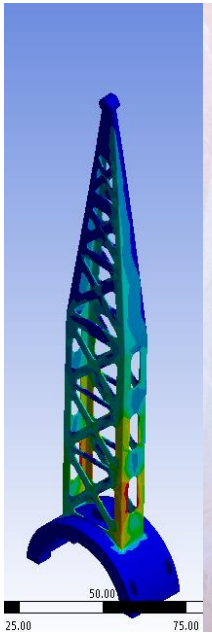
- Overview
  - Wire scanners give beam profile measurements, used for optimising machine performance
  - Small HL-LHC beams mean a new, fast scanning, micron-precision instrument is required for the High-Lumi era
- Requirements
  - Ultra-high vacuum, precision mechanics with associated control and acquisition system
  - Some 30 instruments for 2019 with more later
  - UHV feedthroughs, laser optics, electro-mechanics



New Technology for Wire Scanners



- Optical disk made of Aluminium for lower inertia and vacuum bakeout
- Optical slits made by Laser Engineered Surface Structures (LESS) technology (Collaboration with Dundee University)

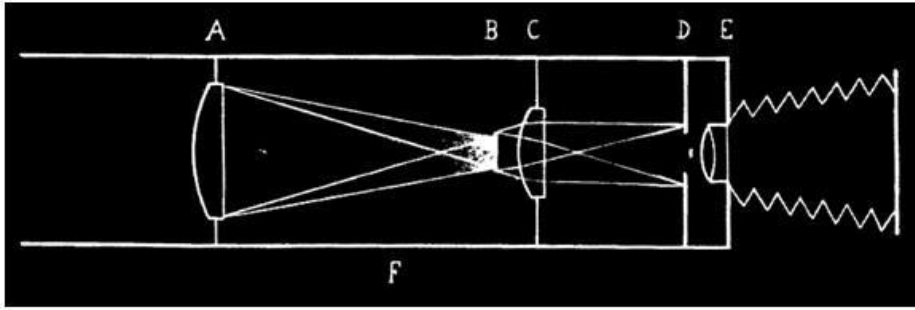


- Wire fork geometry inspired by topological optimisation code
- Produced by 3D additive machining and qualified for use in ultra-high vacuum (3T RPD)

HiLumi HL-LHC PROJECT

Beam Halo Monitoring

- Overview
  - Required alongside novel ‘beam cleaning’ techniques to handle the high-intensity HL beams
  - New concepts with synergies with solar and exoplanet studies
- Requirements
  - High dynamic range cameras with state-of-the-art range (upto 28-bit)
  - Digital intensified cameras with nano-second time resolution and high-resolution gated image intensifier

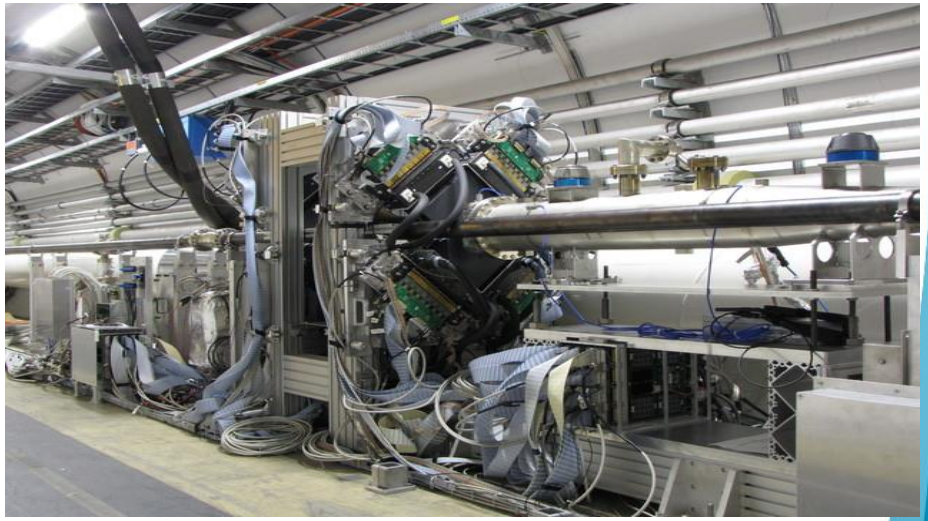


Lyot's Solar Coronagraph, 1936

Beam Gas Vertex Detector (BGV)

Non destructive beam size measurement for HL-LHC

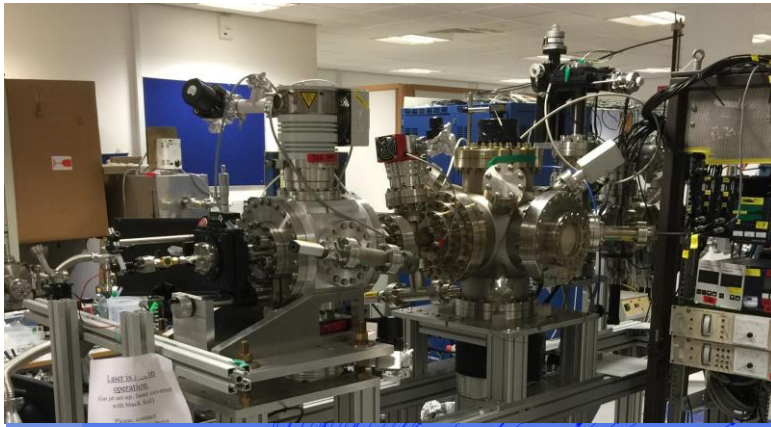
- Overview
  - Non-destructive beam size measurement at high energy
  - New concept, based on HEP detector technology (LHCb) to re-construct beam-gas tracks
  - Collaboration between CERN, EPFL (CH), RWTH (DE)
- Requirements
  - Precision mechanics
  - Silicon trackers and associated electronics

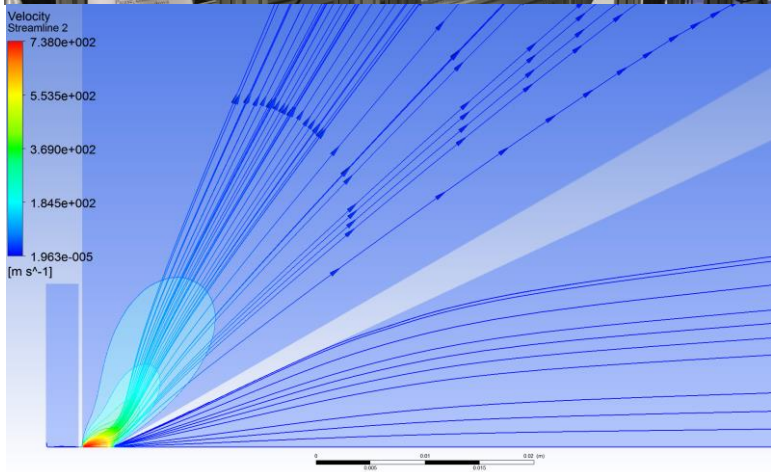


BGV Demonstrator, installed in the LHC

Beam-Gas Jet Diagnostics

- Overview
  - Required to observe electron and proton beams simultaneously
  - New concept using a collimated gas jet, developed by the Cockcroft institute
  - Development in progress to turn the proven principle into a workable instrument
- Requirements
  - Vacuum equipment (pumps, gauges, valves, controllers)
  - Optics





Summary

- Beam Instrumentation for High-Lumi means:
  - Applied Physics
    - Electromagnetic detector technology
    - Gas detector technology
    - Solid state detector technology
    - Electro-optical systems
  - Mechanical Engineering
    - In-vacuum, high-precision mechanics & electro-mechanics
  - Electronic & Software Engineering
    - Radiation tolerance
    - Digital signal processing
    - High frequency electronic engineering
    - Low noise, low current measurement
- But it also means:
  - Fruitful collaboration, leading to new technology and new products

HiLumi HL-LHC PROJECT

Overview of instruments for High-Lumi

- New BPMs in the final focus
- High-bandwidth electro-optical BPMs
- Cryo-BLMs
- Wire scanners (LIU + HL-option)
- Beam halo monitors
- Beam gas vertex detector
- Beam gas jet monitor (option)

Thanks for your attention

Thanks to the BI group for their many contributions

Main procurement identified

What and When		
Description	**Quantity**	**When**
Semi-Rigid, Radio Frequency, Coaxial Cables utilizing glass-metal or brazed ceramic sealing technology for use in cryogenic and radiation environments.	250-350	2018-2020
Radio frequency UHV feedthroughs utilising glass-metal or brazed ceramic sealing technology for use in cryogenic and radioactive environments.	250-350	2018-2020
Packaged CVD diamond detectors for the measurement of particle beams	80-100	2017-2020
Scientific CMOS cameras Scientific High Dynamic Range Cameras Scientific Streak Cameras	5 1 + 2 2	2023 2016, 2023 2019

Instrumentation needs will continue to develop upto and beyond HL-LHC start-up

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