Beam Instrumentation and Electronics for Accelerators

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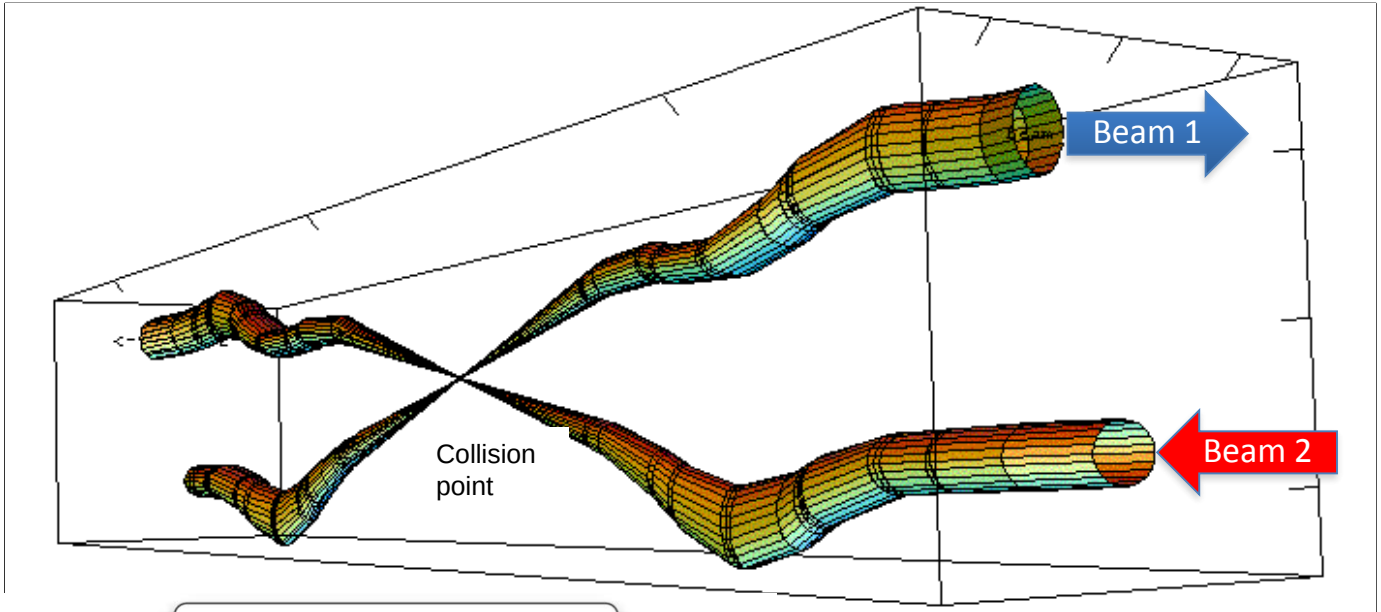
Beam instrumentation in the LHC

Beam Instrumentation

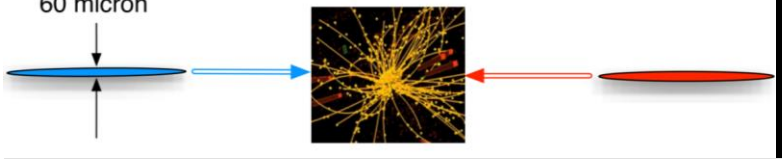
- Some numbers:
  - 2500+ instruments integrated into the beam vacuum system of the accelerators (the LHC and it's injectors)
  - 4500+ instruments close to the beamlines, in the accelerator tunnels
  - 5 New instrument concepts for HL-LHC
  - 200+ new in-vacuum instruments in design/production for LIU (2016-2020)
  - 100+ new in-vacuum instruments to be produced for HL-LHC (2019-2025)
- 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



140,000,000,000 protons a bunch
~30 collide at each bunch crossing

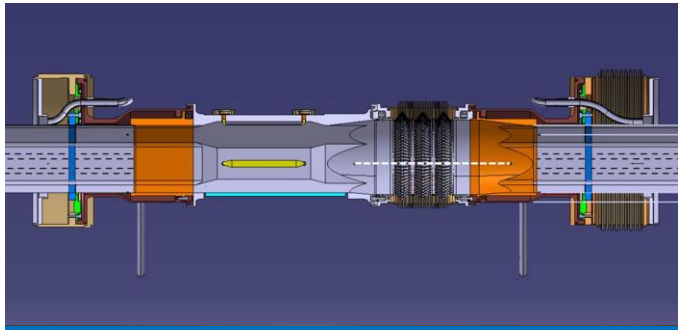
60 micron



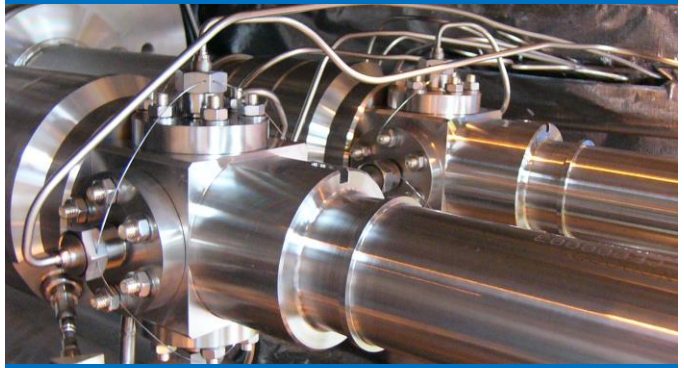
~30 collisions per crossing
11,000 crossings per second per bunch
1380 bunches
~400 million collisions per second

Beam Position Monitors (BPMs) in the Final Focus

- Overview
  - Measure beam positions as they approach collision, means sub-micron beam orbit resolution
  - Operating at 2 Kelvin (-271 C) with integrated tungsten alloy radiation absorbers
  - Special high-stability, welded, 50 Ω co-axial cables to bring the signal from 2 K to atmosphere
- Requirements
  - 48 BPMs installed in high-lumi triplet magnets
  - 250+ special cryogenic co-axial cables



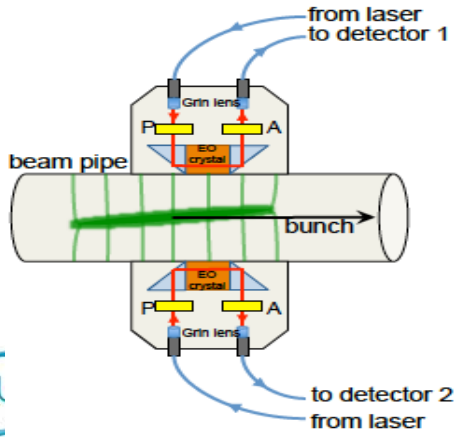
Cryogenic BPM

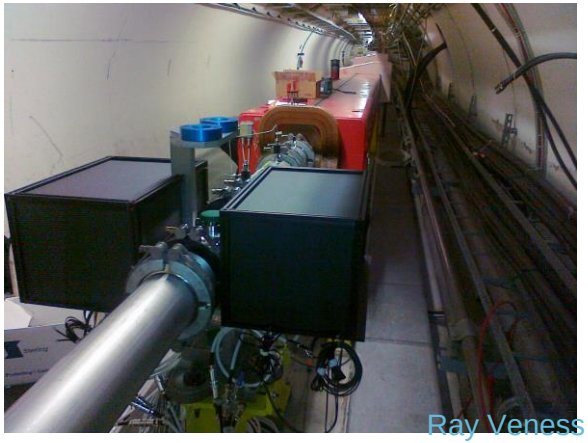


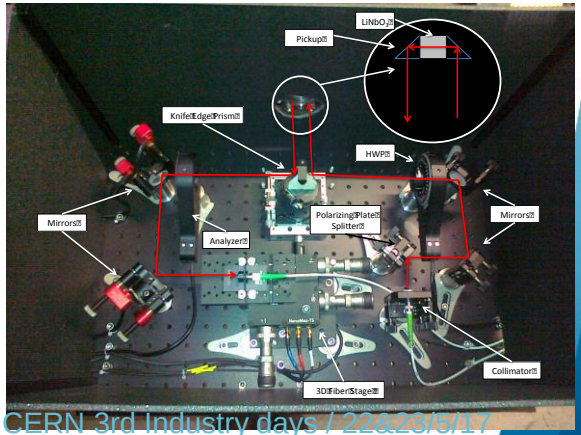
Cryogenic co-axial cables

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



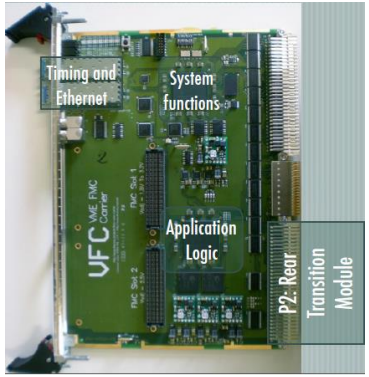




Optical Signal Processing

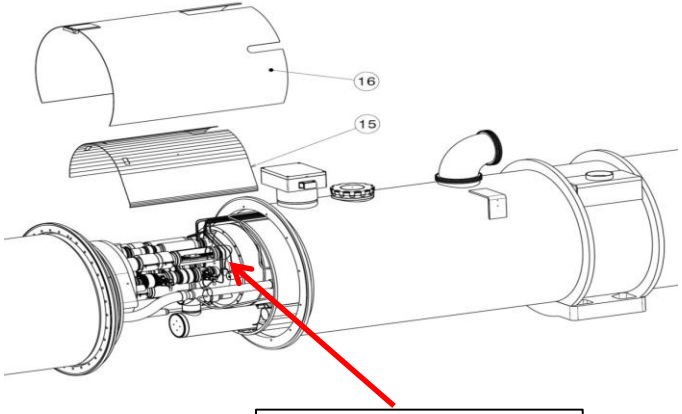
Fibre optic transmission

- 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

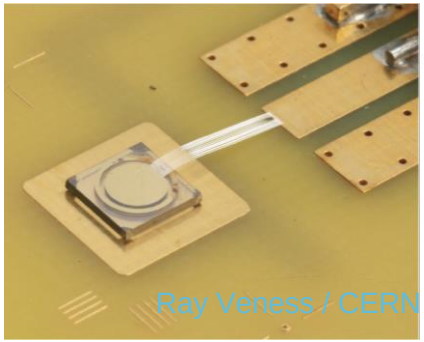


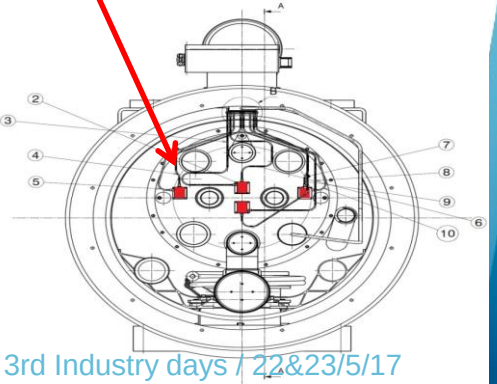
Cryogenic Beam Loss Monitors (BLMs)

- Overview
  - BLMs measure particles lost from the machine, critical for machine protection and performance optimisation
  - New concept, based on silicon or diamond semiconductor detectors will allow fast localisation of beam losses in critical areas
  - Required to withstand 2 MGy 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



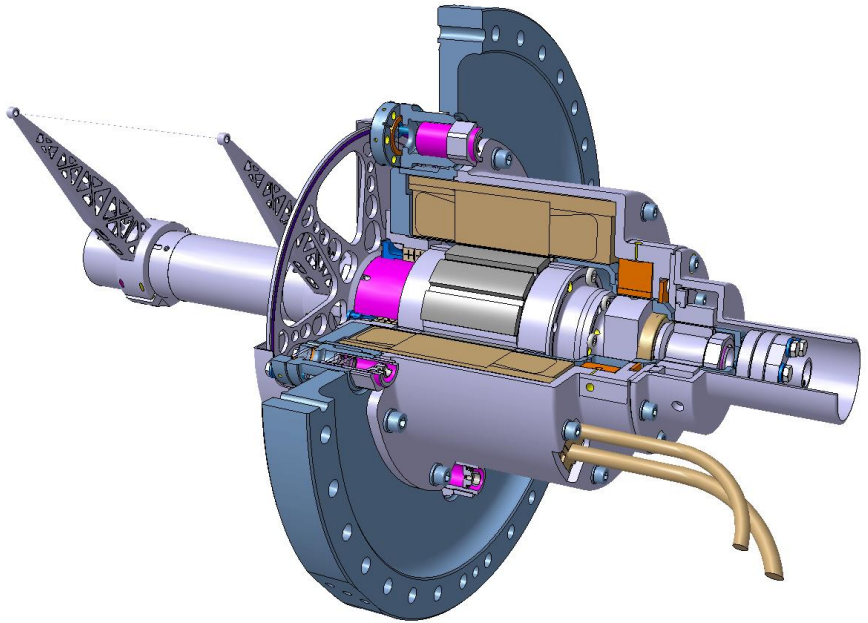
Position of Cryogenic BLMs





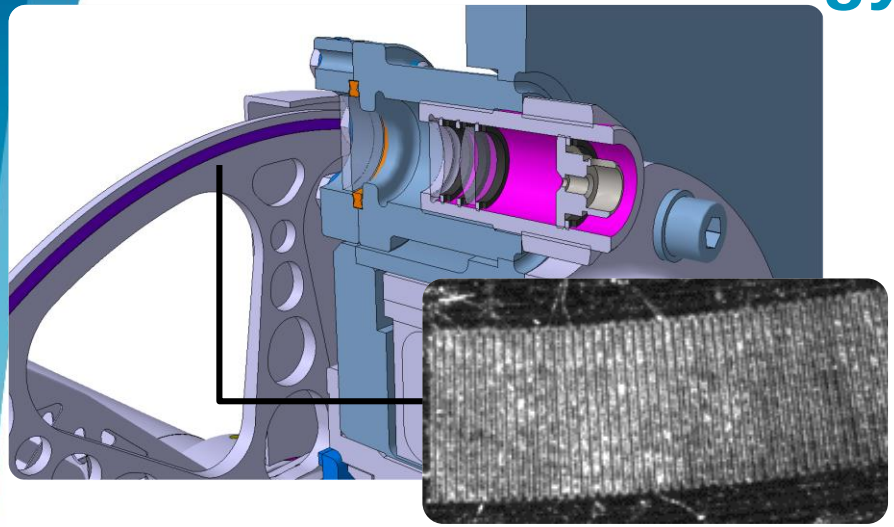
New Wire Scanners for the High-Lumi era

- Overview
  - Wire scanners give a very direct measurement of the beam profile, used for optimising machine performance
  - Small HL-LHC beams mean a new, fast scanning, micron-precision instrument is required for the High-Lumi era
  - Accelerates at 15’000 rads/s, but precise to 10 um
- 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
  - The first Market Survey (MS 4303) for this project is now circulating



HiLumi HL-LHC PROJECT

New Technology for Wire Scanners

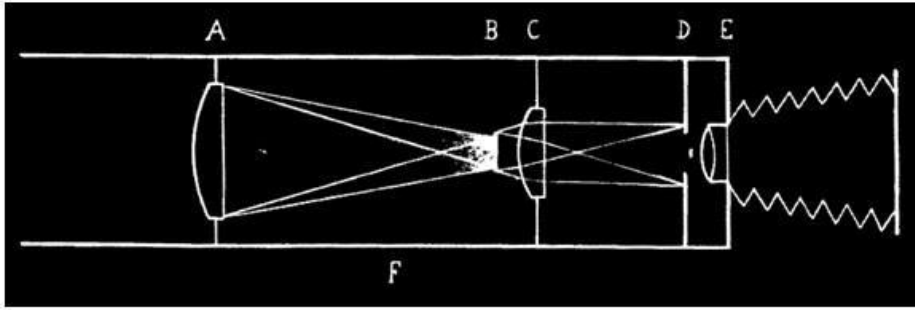


- Optical disk made of Aluminium for lower inertia and vacuum bakeout
- Optical slits made by Laser Engineered Surface Structures (LESS) technology (Collaboration with Dundee University)

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

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

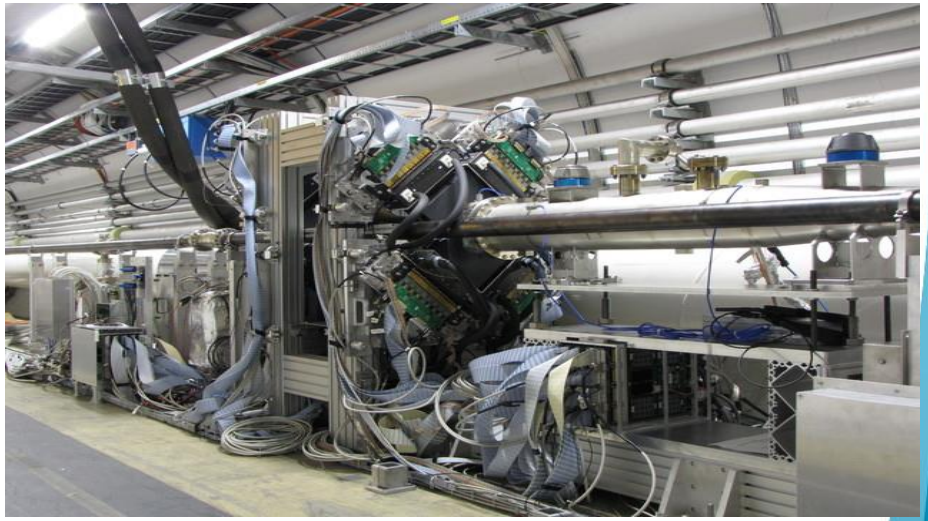


Lyot's Solar Coronagraph, 1936

Beam Gas Vertex Detector (BGV)

Non destructive beam size measurement for HL-LHC

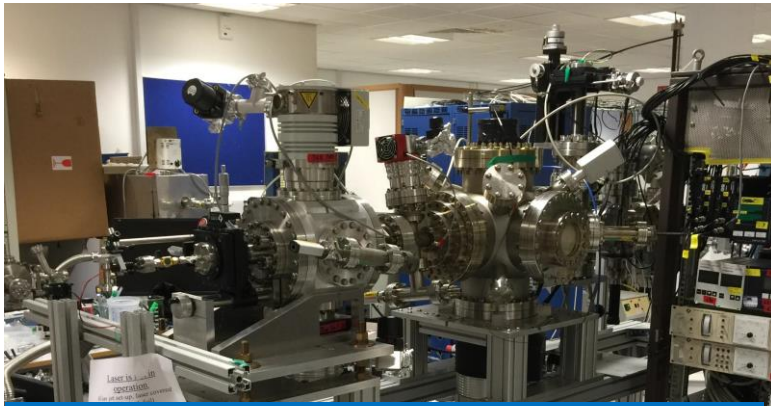
- Overview
  - Non-destructive beam size measurement at high energy
  - New concept, based on High Energy Physics detector technology (LHCb) to re-construct beam-gas tracks
  - Collaboration between CERN, EPFL (CH), RWTH (DE)
- Requirements
  - Precision mechanics
  - Silicon trackers and associated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



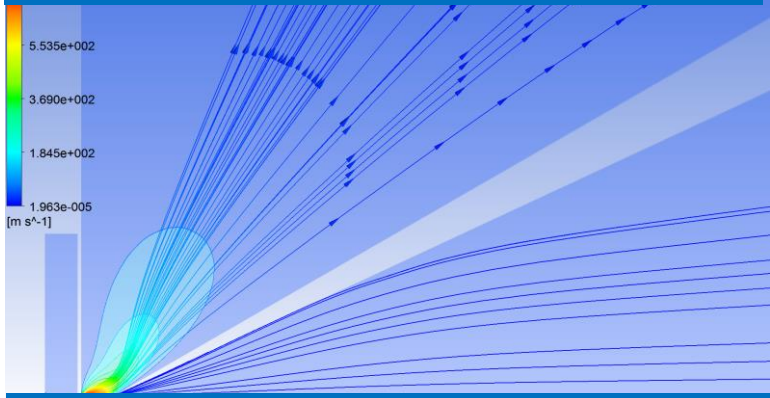
BGV Demonstrator, installed in the LHC

Beam-Gas Jet Diagnostics

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



Experimental set-up at Cockcroft



Gas jet simulations at CERN

Summary

- Beam Instrumentation for High-Lumi means:
  - Applied Physics
    - Electromagnetic, gas and solid-state detector technology
    - Optical and 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
  - The CERN ‘spill-over’ effect: Cutting-edge developments for the LHC quickly become the new standard for the much wider accelerator market worldwide

Overview of new 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 and to our many partners in industry and academia for their 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