High Luminosity LHC

BEAM INSTRUMENTATION

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On behalf of the WP13

Progress with WP13 Tasks

- Cryogenic BLMs & Radiation Hard Electronics
  - **Cryogenic BLMs**
  - Radiation hard electronics (LHC CONS for R&D)
- **Insertion Region BPMs**
- **High Bandwidth Pick-ups**
- **Halo beam diagnostics using Synchrotron Light**
- Fast Wire Scanners (LIU for R&D)
- **Beam Gas Vertex Detector**
- Luminosity Monitors
- Long-Range Beam-Beam Compensator
  - Prototype (EN/STI) and collaboration on gas jet scanner with ULIV

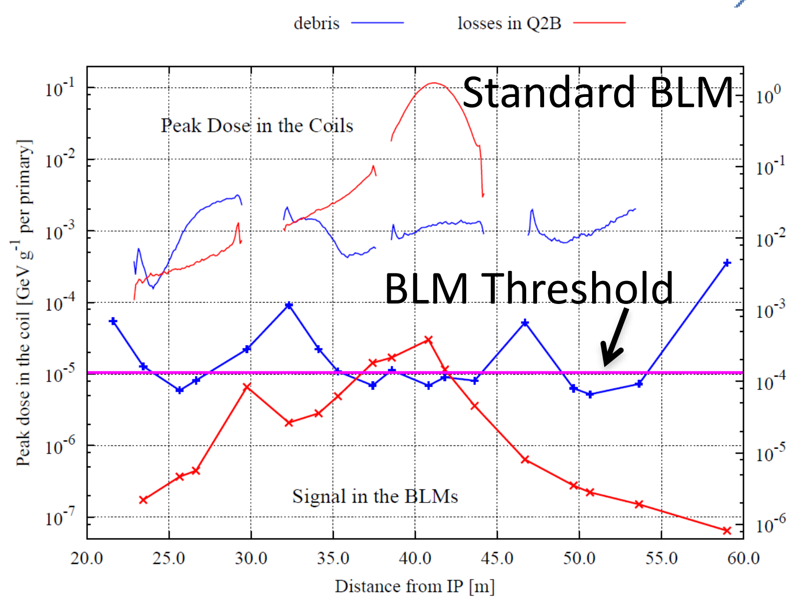
Beam Loss Monitoring for HL-LHC

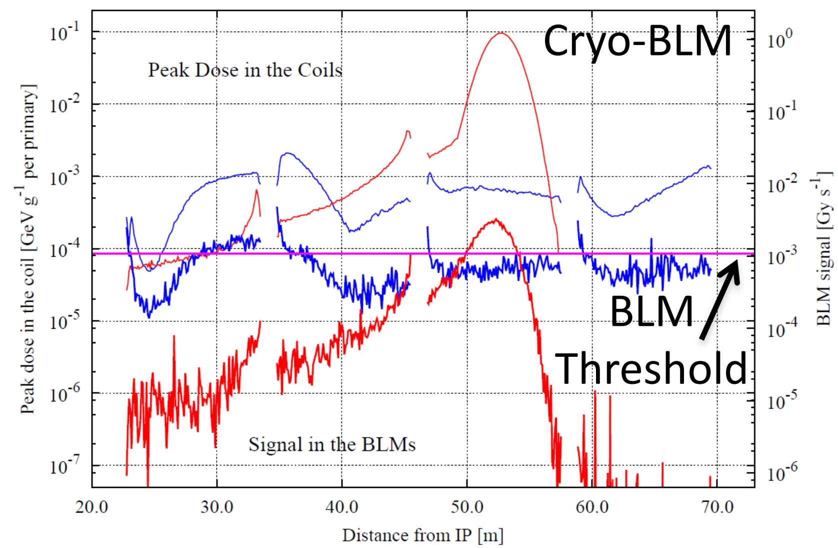
- Essential for safe & reliable operation of LHC
  - Prevents damage to accelerator components
  - Avoids quenches & associated time-consuming cryo recovery

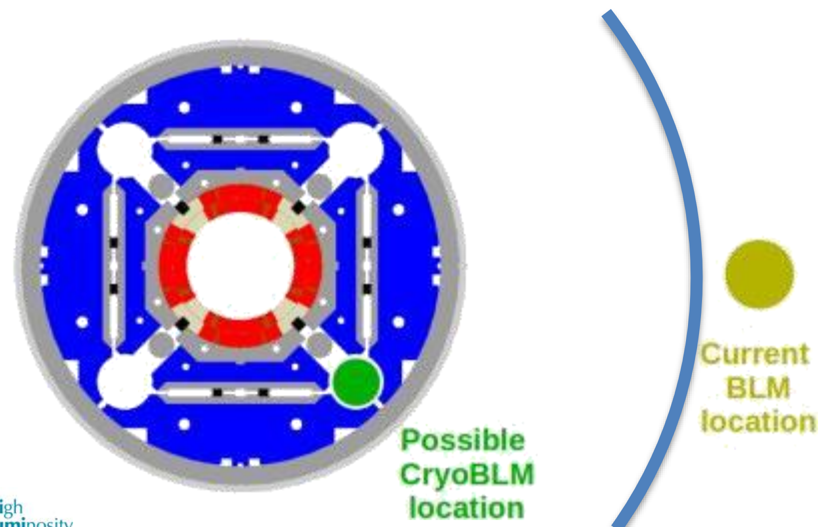
- Existing system
  - Meets needs of the HL-LHC in arc regions
    - ~3000 ionisation chambers
    - Radiation tolerant front-end electronics
- New requirements for high luminosity interaction points
  - Cryogenic beam loss monitors for triplet magnets
  - Radiation Hard front-end electronics

Cryogenic Beam Loss Monitors

- HL-LHC triplets running close to quench limit due to luminosity
- Current BLM thresholds factor 3 below quench level
    - Not possible for HL-LHC triplet
    - Need more precise measurement
- Cryo-BLMs give 2-3 times better separation of debris & loss



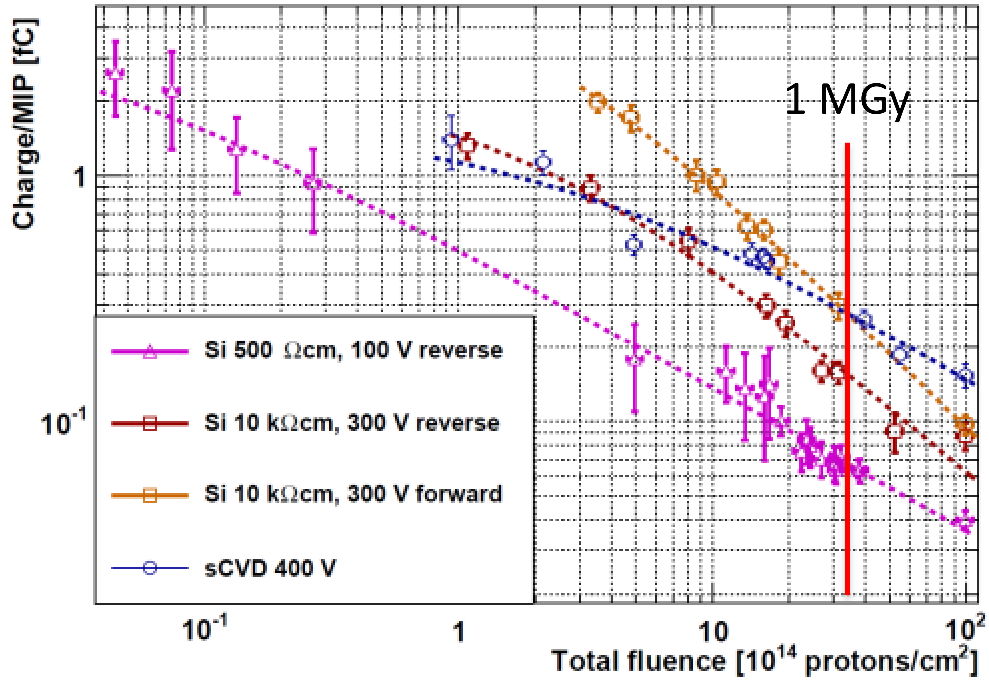




High Luminosity LHC

Cryogenic Beam Loss Monitors

- Two types of detectors tested under irradiation at cold (4K) up to several MGy at IRRAD
  - Single crystal chemical vapour deposition diamond (CIVIDEC)
  - p^+-n-n^+ silicon



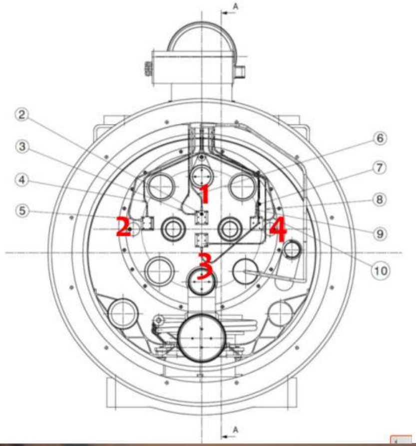
- At low irradiation doses, silicon has a larger sensitivity than diamond

- For very high radiation doses, diamond sensors perform better than Si

- The expected reduction in detector sensitivity after 2MGy irradiation is of a factor of 50 for Si under 300V reverse bias and 15 for diamond.

- Diamond not as reproducible as Si

Installation of detectors on a cold mass of Dipoles



1. 500µm scCVD diamond,
2. 100µm Si detector,
3. 300µm Si detector,
4. 300µm Si detector.

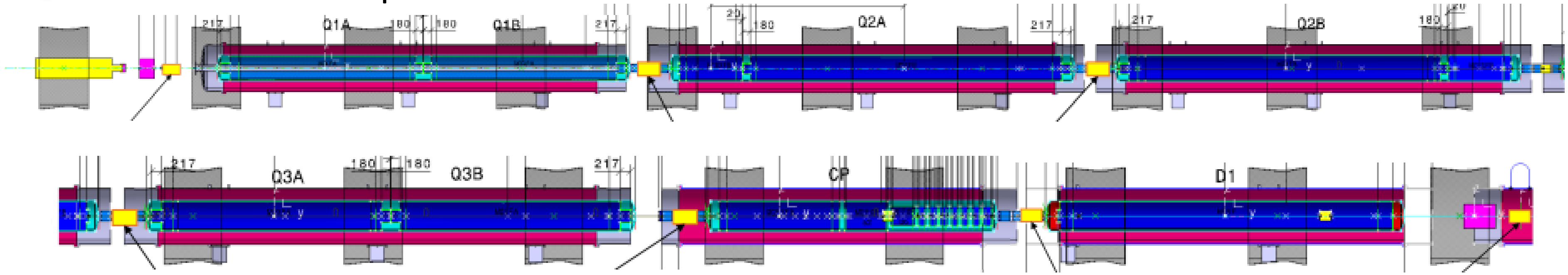
- One scCVD diamond detectors (bounded to FR-4 PCB, glass-reinforced epoxy laminate)
- Three Si detectors (on FR-4 PCB) in collaboration IOFFE Physical Technical Institute, St Peterburg
- Location: LHC bending magnet 9L5, 9R7
- Data are logged in logging database (first only from 9L5)

Beam Position Monitoring for HL-LHC

Beam Position Monitoring for HL-LHC

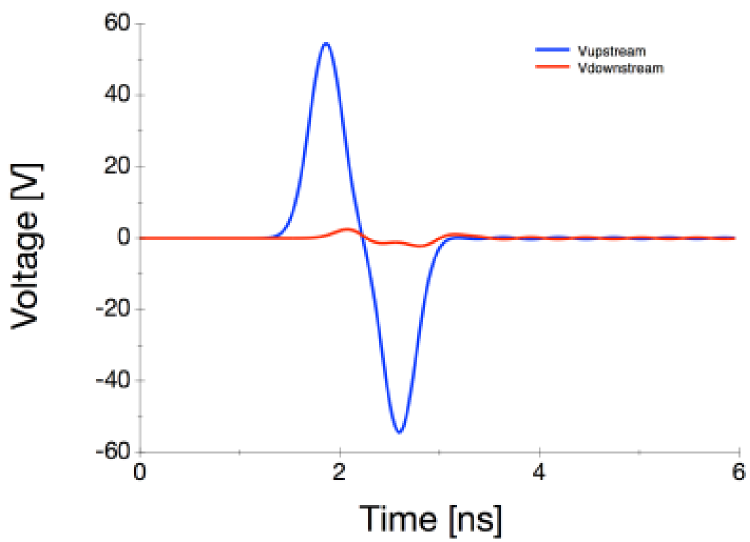
- LHC Beam Position System
  - Over 500 BPMs per beam capable of bunch by bunch acquisition
    - No performance increase required for arc BPMs
    - Renovation of the electronics foreseen for Long Shutdown 3 (2023-2025)
- New BPMs required for HL-LHC insertion regions
    - Directional stripline BPMs installed in triplet's interconnection
    - Distinguish between both beams (in same vacuum chamber)
    - Limited by signal isolation of one beam on the other
      - Location optimised for time separation
      - Directivity optimised by design

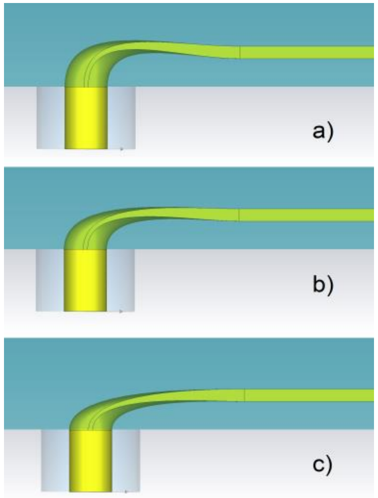
← Towards collision point



Directional Stripline Couplers

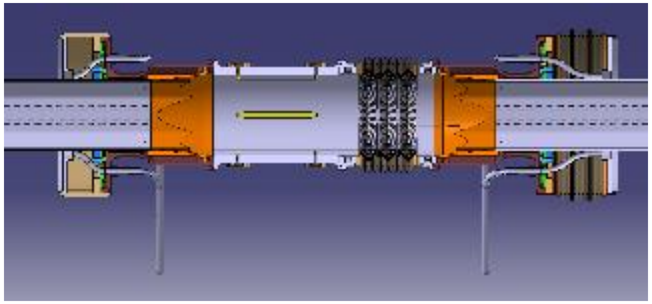
- Current BPMs suffer from limited directivity (~27 dB @ 70MHz)
  - Leads to position error from tens to hundreds of microns
- New designs being pursued to improve this
  - 7-10 dB improvement demonstrated in simulation
  - Next step is to turn this into mechanical design with all the constraints of a cryogenic BPM

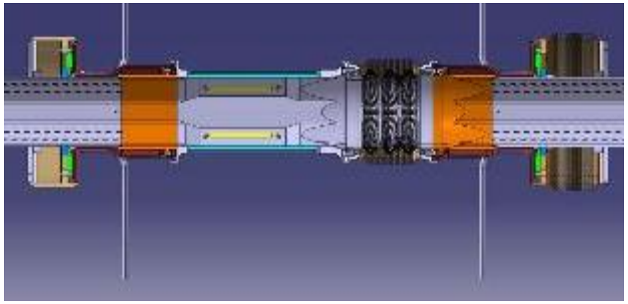




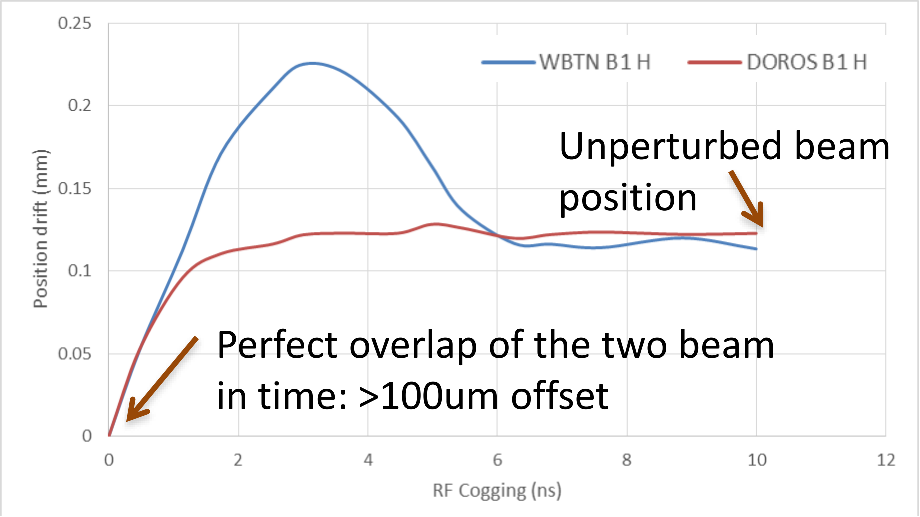
Interaction Region BPMs

- Mechanical design launched (aiming at 1st prototype in 2016)
  - Two designs being considered (circular & octagonal)
  - Fluka simulations being performed to confirm need of Inermet absorbers

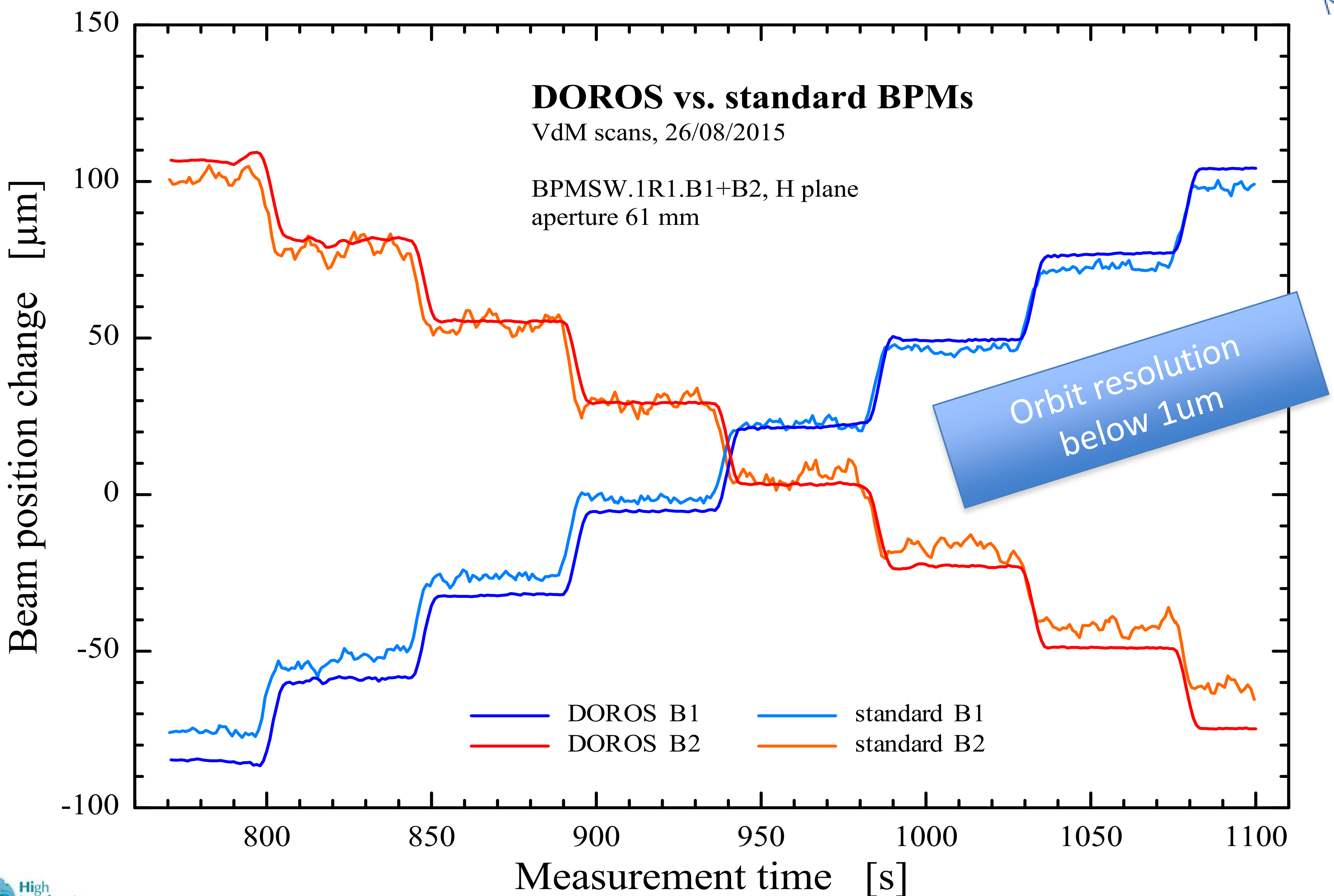




- LHC MD to check effect of directivity on electronics
  - Compared DOROS and WBTN (standard LHC orbit) electronics
  - First results show 'exclusion zone' of
    - ±6.5ns for WBTN
    - ±2.5ns for DOROS



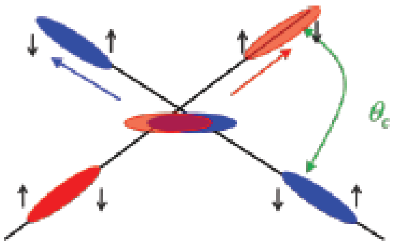
High resolution orbit measurement



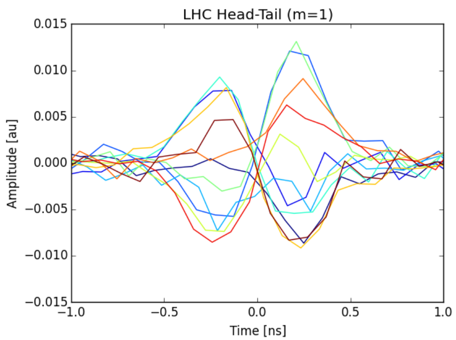
Intra-Bunch Diagnostics

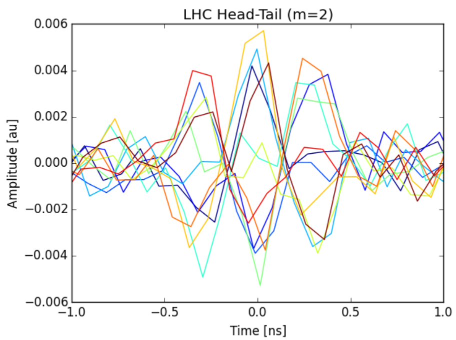
Intra-Bunch Diagnostics

- Already important for understanding instabilities
  - Electron cloud, impedance, beam-beam, ….
- Will also be essential for crab cavity diagnostics
  - Understanding their effect on the beam



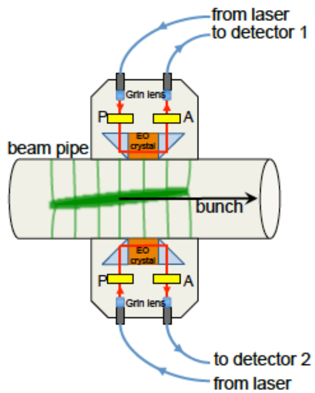
- Electromagnetic monitors already installed in LHC
  - Bandwidth of some 2 GHz

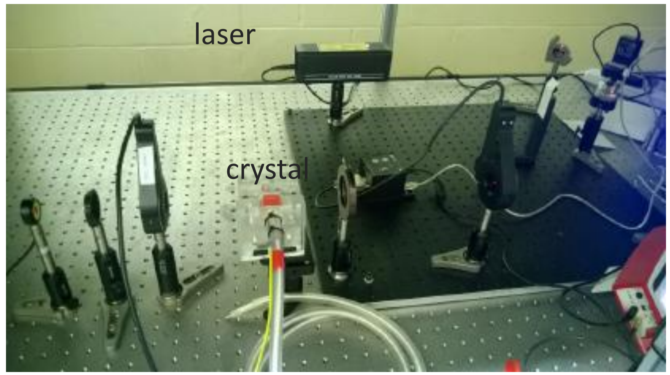


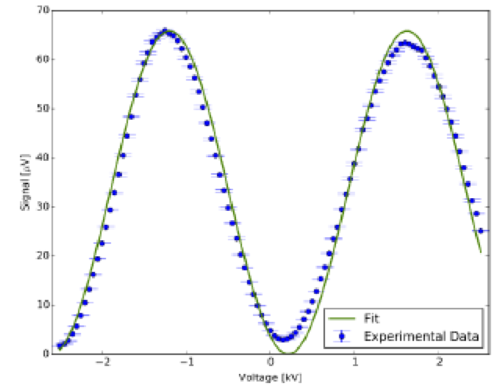


Higher Bandwidth BPMs

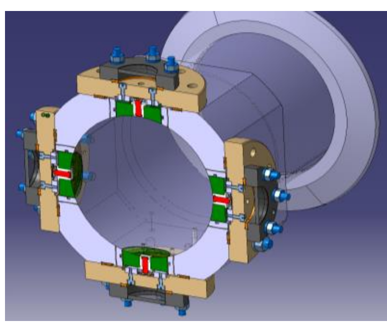
- Collaboration with RHUL on pick-ups based on electro-optical crystals and laser for higher bandwidth > 10 GHz

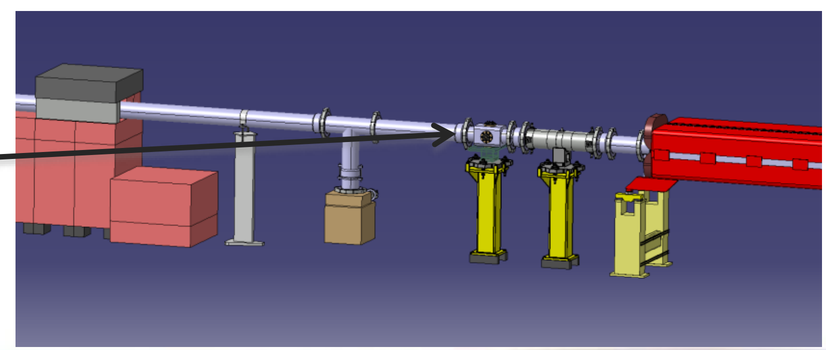






- Mechanical design (EN/MME) of first prototype finished - Aiming for installation of prototype in SPS-LSS4 during YETS15/16



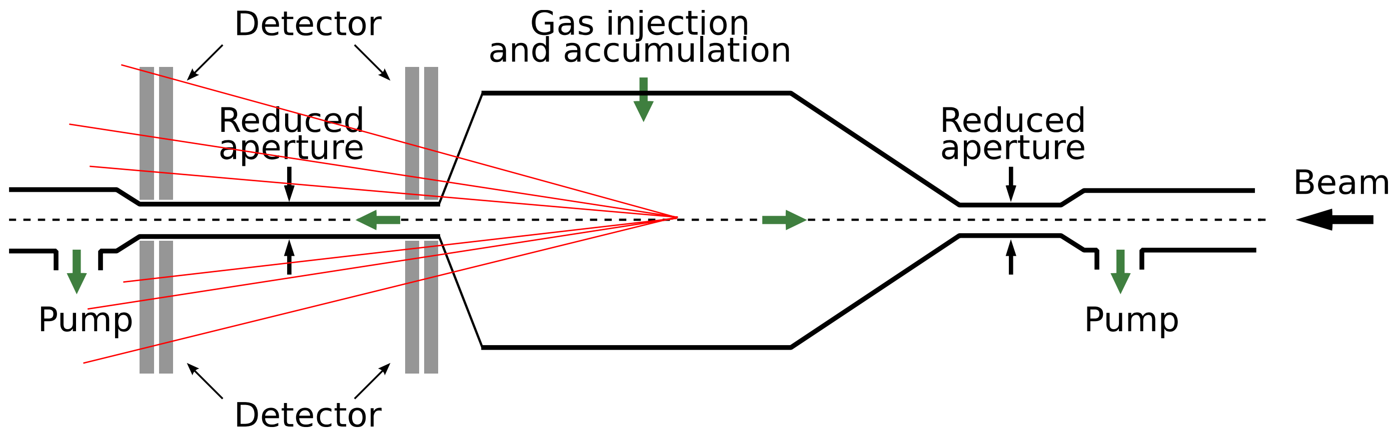


Non-invasive beam size measurement

To overcome limitations of wire scanner & synchrotron light

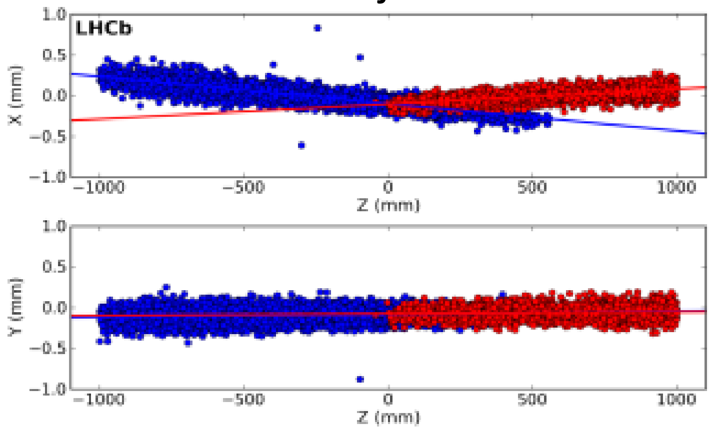
Non-invasive beam size measurement

- The Beam Gas Vertex Detector

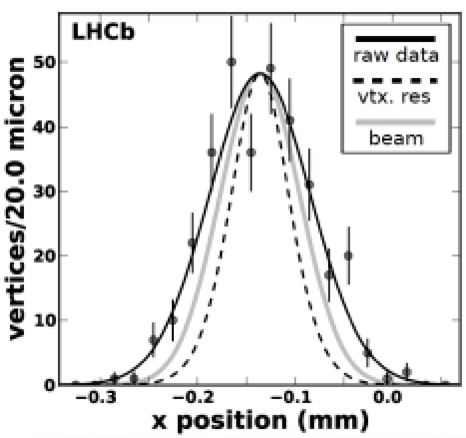


- Concept used by LHCb vertex detector (VELO)
  JINST 7 (2012) P01010, JINST 9 (2014) P12005
- Collaboration between CERN, EPFL (CH), RWTH (DE)

Beam Trajectories

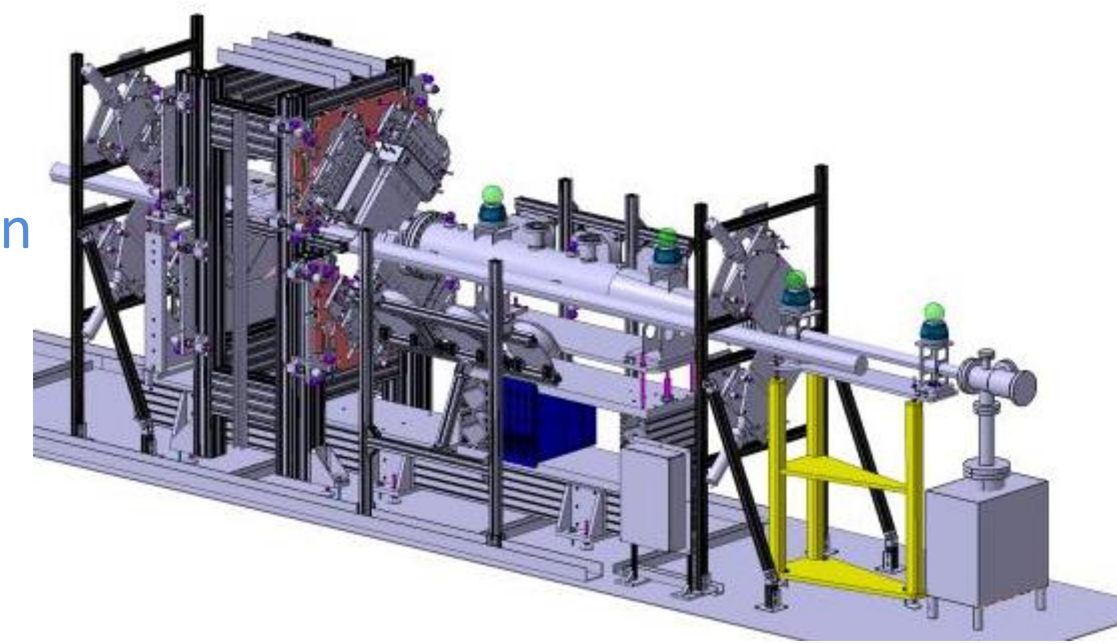


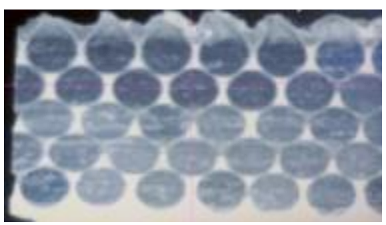
Beam Profile

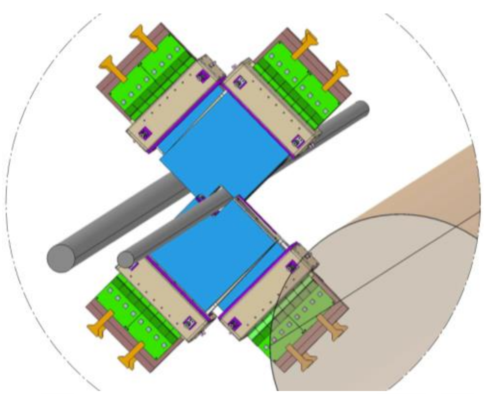


Non-invasive beam size measurement

- Prototype installed on one beam during LS1
  - Detectors based on scintillating fibres
  - Read-out with Silicon Photomultipliers



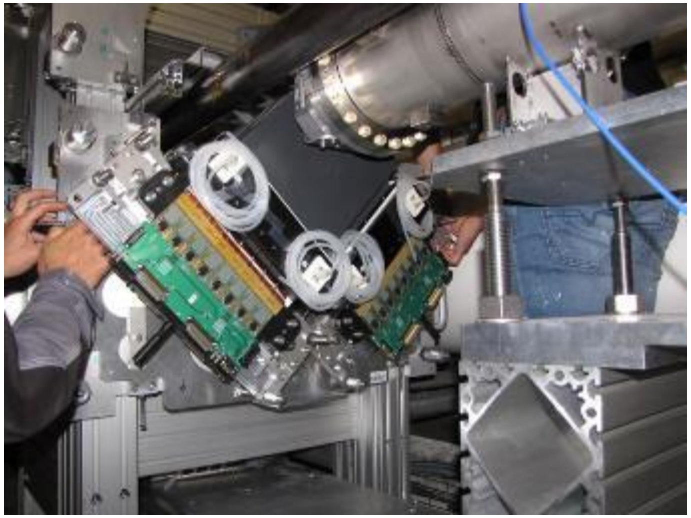




Quantity	Accuracy	Time interval	Key factors
Relative bunch width	5 %	< 1 min	vertex resolution stability
Absolute average beam width	2 %	< 1 min	σ_{beam}, σ_{MS}, σ_{extrap} (σ_{hit})

Beam Gas Vertex Detector

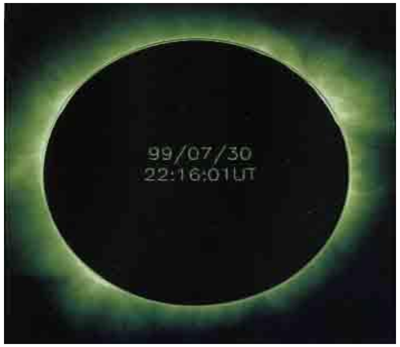
- 4 of the 8 scintillating fibre detector units installed in TS2
  - Remaining detectors foreseen for installation in TS3
- Detector cooling installed & commissioned in TS2
- Commissioning phase started
  - DAQ & Trigger all seem to behave as expected
  - On-line reconstruction being implemented

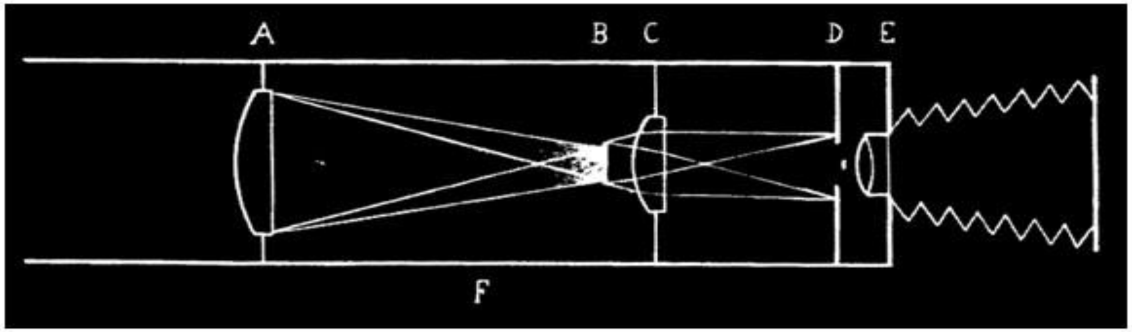


Halo Diagnostics for HL-LHC

Halo Diagnostics for HL-LHC

- No instrumentation currently installed in LHC to measure the beam halo
- Important diagnostic for HL-LHC to measure Halo creation and mitigation techniques based on
    - Hollow electron beam collimation
    - Long range beam-beam compensators
- Aiming at high dynamic range measurement (up to 10^{-5}) using non-Invasive technique
    - Optical techniques using synchrotron radiation in collaboration with KEK

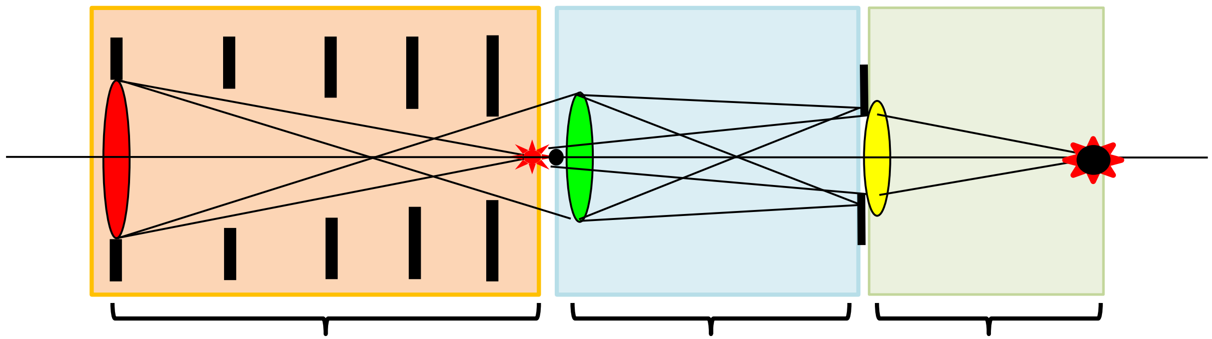




Lyot's Solar Coronagraph, 1936

Coronagraph for Halo Diagnostics

- Coronagraph based on masking techniques with re-diffraction system (eliminating diffraction fringes)

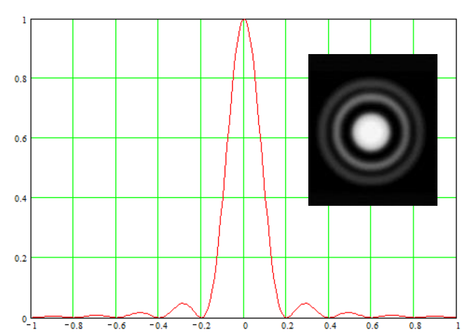


Objective lens system
F 2000mm – 25x25mm

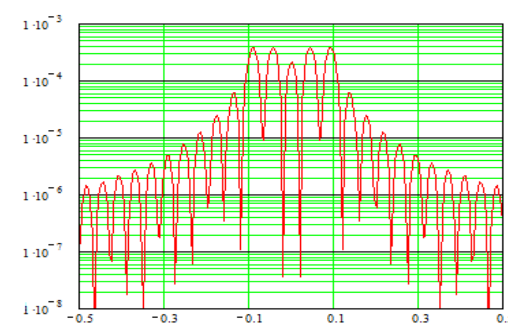
Mask radius: 110um
Field lens F 800mm

Liot stop (± 5mm aperture)
Relay lens F 500mm

- Project Phase 1 – Design and Test a first coronagraph in LHC based on an existing design developed at KEK in 2005 by T. Mitsuhashi
  - Aiming for halo observation with 10^{-3}-10^{-4} dynamic range (from simulations - 3.7 10^{-4})
  - Install on B2 possibly in 2016



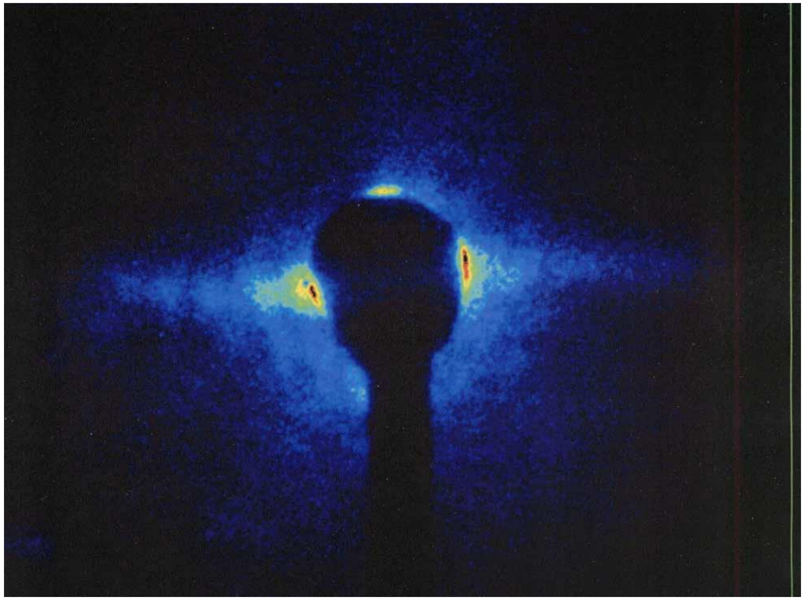
1st image plane

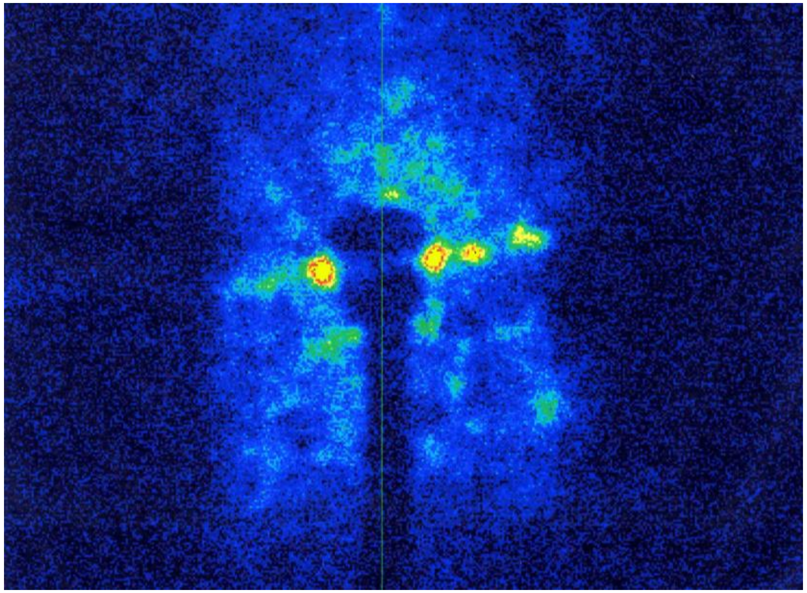


Final image plane

Coronagraph for Halo Diagnostics

- Project Phase 2: Design and implementation of a fully optimised system aiming at 10^{-5}-10^{-6} contrast ratio
  - Reducing background and noise to the maximum
    - Lens's surface quality (scratches and digs), spurious reflections in the telescope, noise from dust in air





Courtesy of Toshiyuki Mitsuhashi

Summary

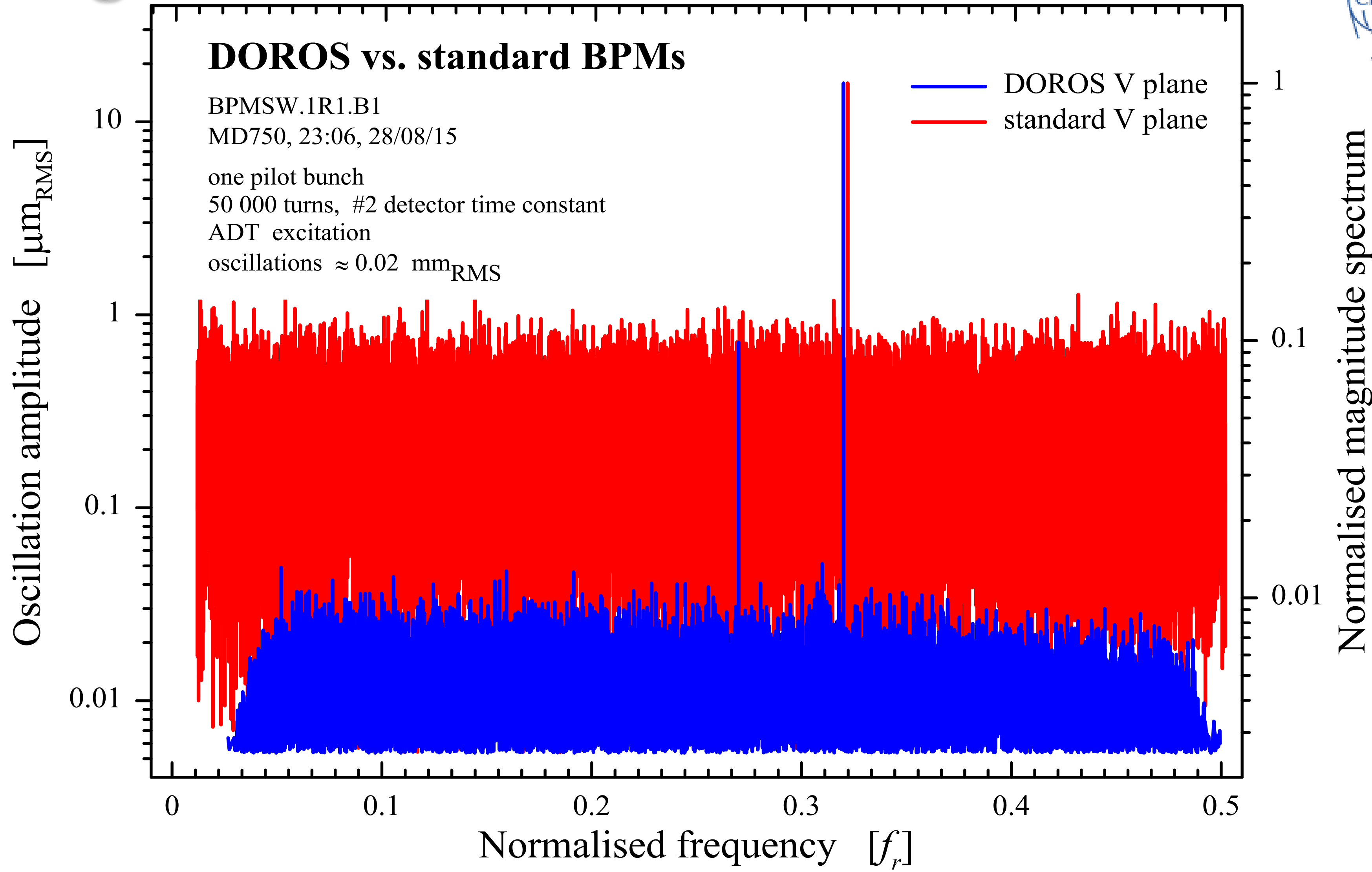
- LHC constructed with comprehensive suite of beam diagnostic devices
  - These play an important role in its safe & reliable operation
- HL-LHC will push the performance of LHC even further
  - Requires a deep understanding of beam related phenomena
- Can only be delivered through its beam instrumentation
  - Upgrade to many of the existing systems
  - Development of new diagnostics to address specific needs
- BI R&D for HL-LHC is now progressing well relying on the support of many external collaborators

Special Thanks to all external collaborators and CERN colleagues who contributed to this talk

Spares slides

High
Luminosity
LHC

High resolution orbit measurement

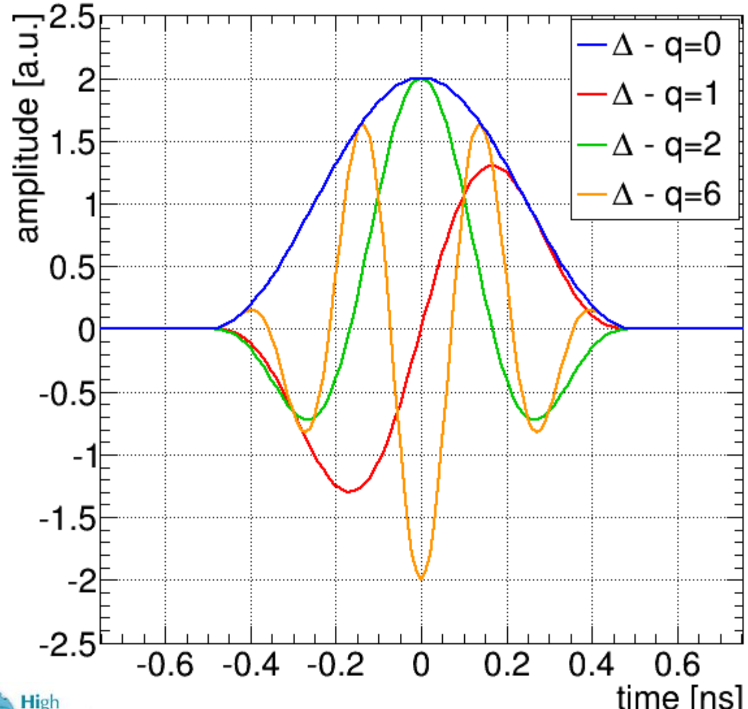


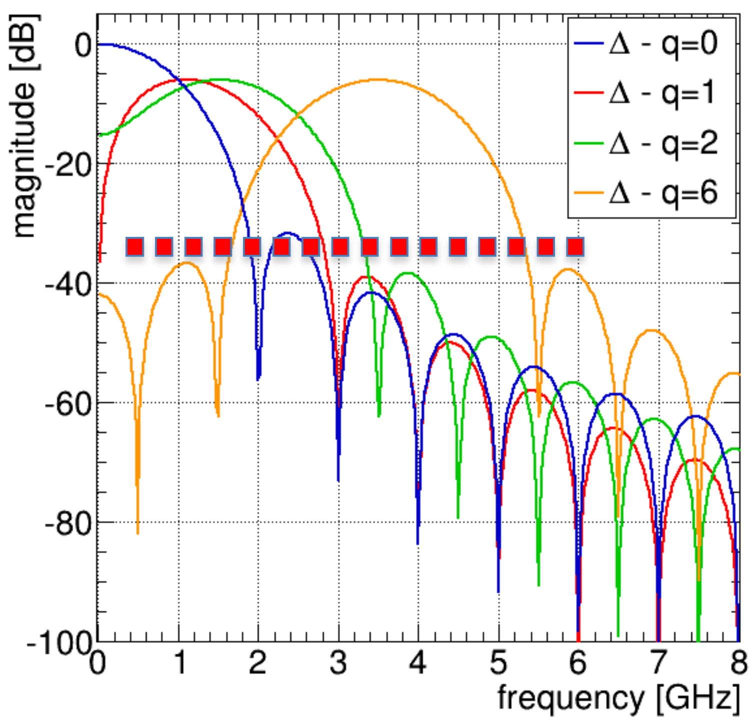
NOTE: For better visibility the upper frequency axis for the standard BPM data is slightly shifted with respect to the bottom axis of the DOROS data.

25ns – Measuring Instabilities

Intra-bunch measurements

- Multiband Instability Monitor – currently being developed
  - 16 bands @ Δf_b = 400 MHz
  - Use filter bank followed by direct diode detection for high sensitivity
  - Can infer mode of oscillation and be used to trigger other systems

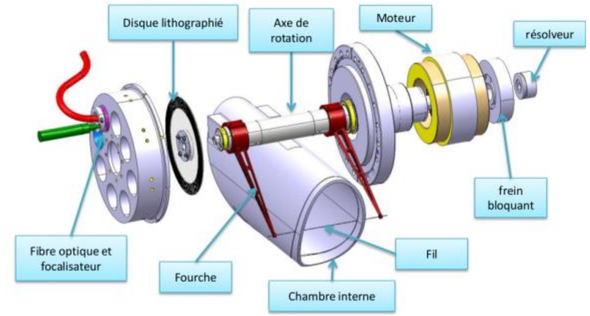


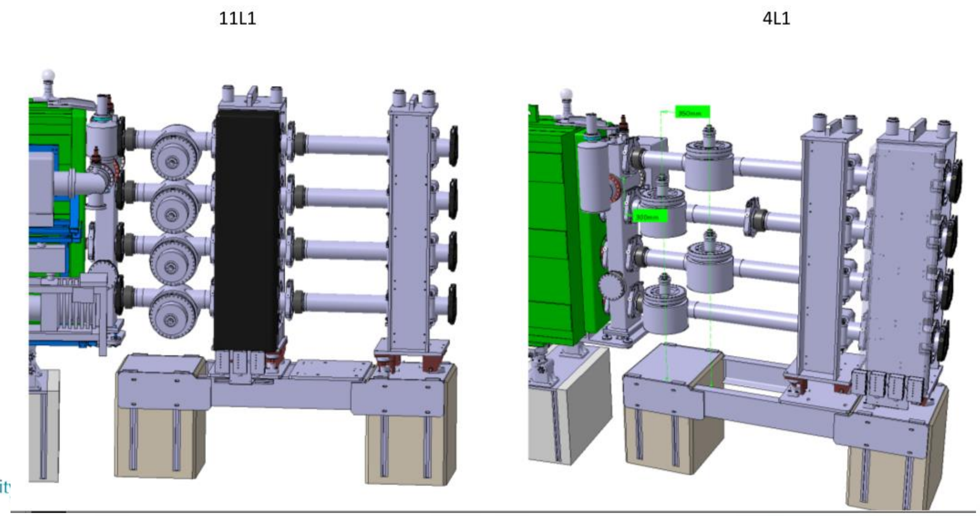


High Luminosity LHC

New wire scanners

- New wire scanner test in the SPS foreseen for November
  - Prototype of new control electronics ready
- Conceptional design of scanner in the BOOSTER finished
  - The BOOSTER design will be the base design for all other scanners
    - Same actuator design for all rings
    - Different fork and vacuum tanks
  - Installation of prototype stop 2016/17
- LS2 installation foreseen for BOOSTER, PS, SPS and LHC (prototype proposed)



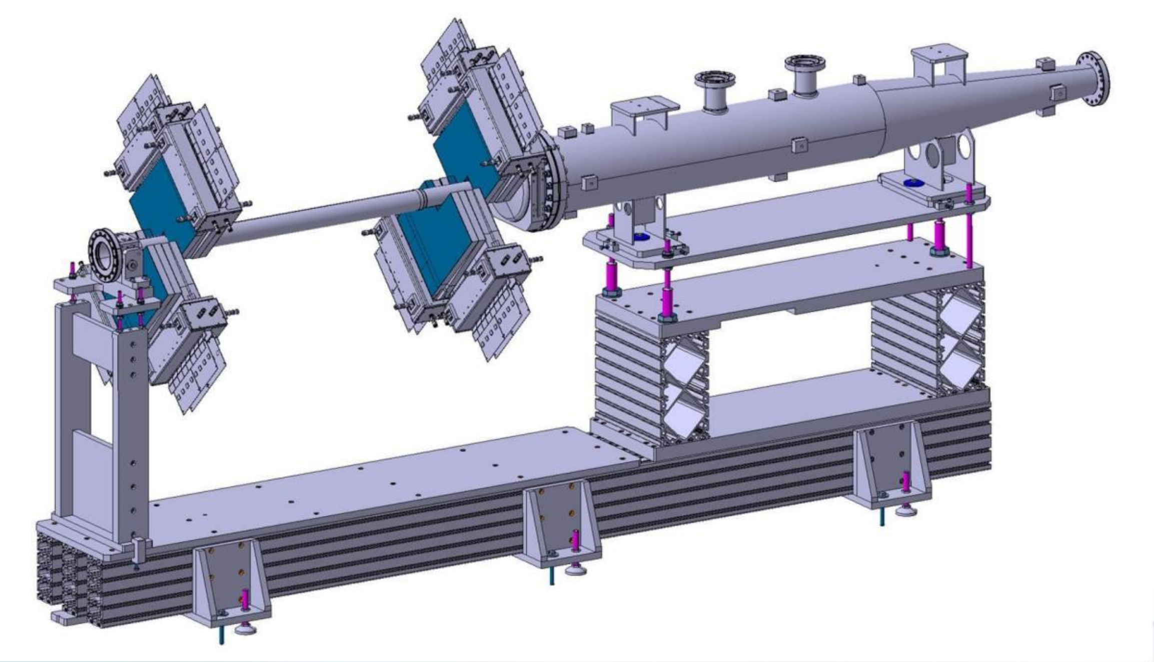


BGV Demonstrator

Date	Milestone
10-2012	First design studies
03-2013	LMC supports continued development
03-2014	BGV Demonstrator ECR (https://edms.cern.ch/document/1324635/1.0)
03-2014	BGV Collaboration Agreement (CERN, RWTH Aachen, EPFL Lausanne)
07-2014	**Installed vacuum system**
09-2015	**Installed half detector and DAQ**

BGV TWiki:
https://twiki.cern.ch/twiki/bin/view/BGV/

Completion of the installation planned for TS3 and YETS 2015



Vacuum system

Designed and produced at CERN

Detector

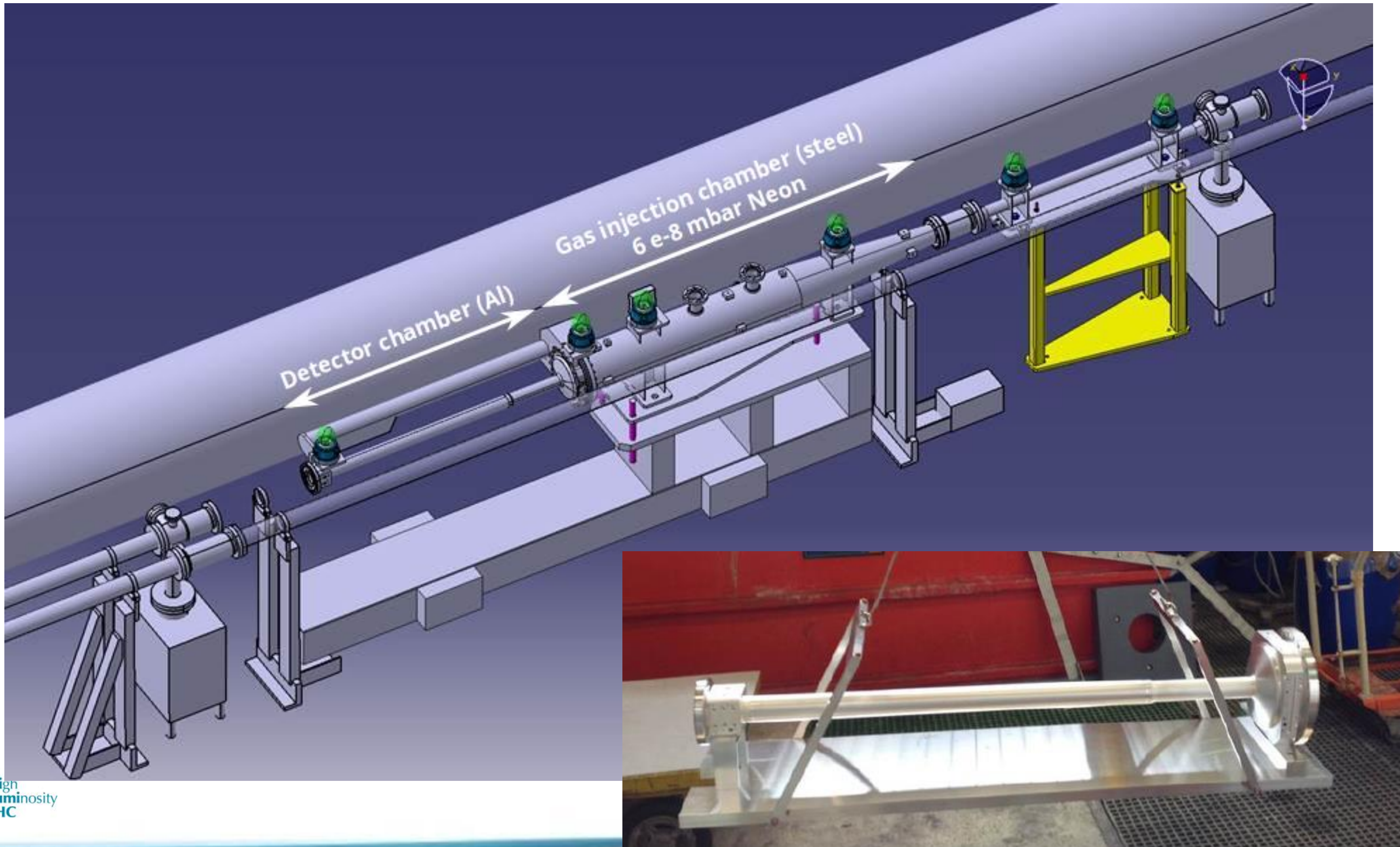
Scintillating fibres read out with S

Developed by EPFL and RWTH

Same technology as for the LHCb

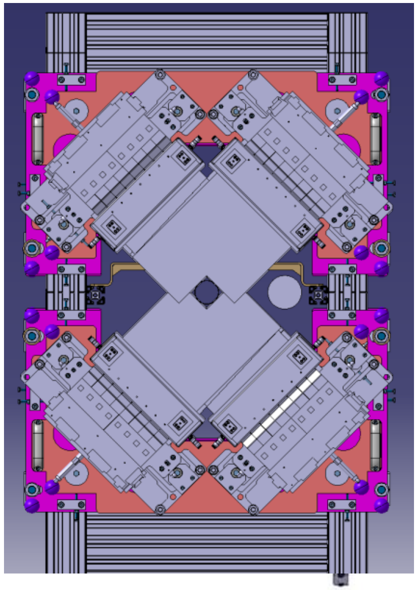
Vacuum system

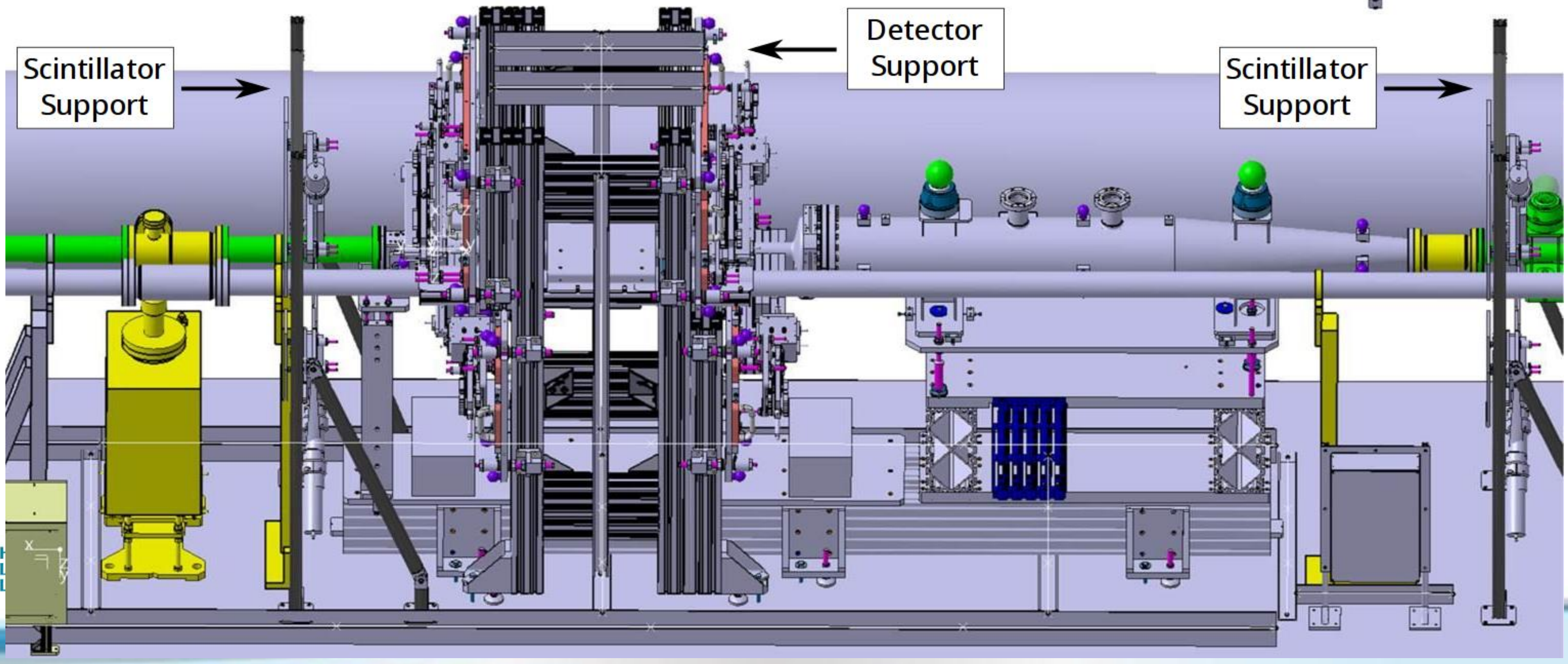
- Installed and aligned (July 2014)
- Gas injection system commissioned (Sep 2015)



Detector

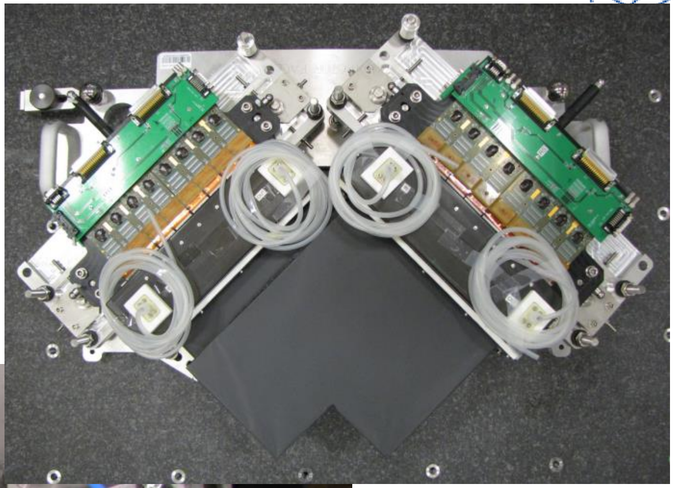
- Scintillating fibres (250 um) and SiPMs
- Challenges:
  - Light tightness
  - SiPM cooling & dry air
  - Metrology & alignment

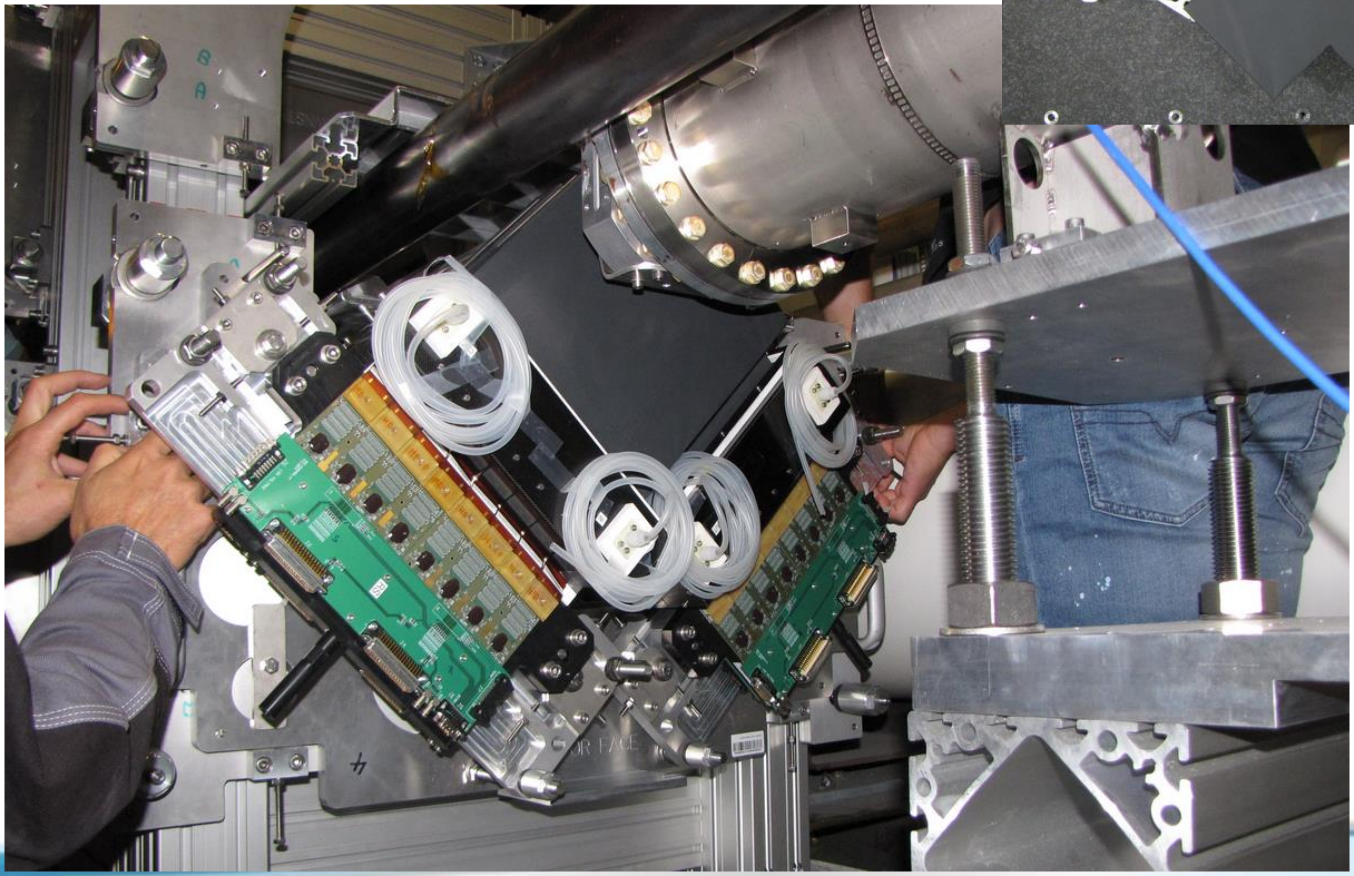




Detector

- In total 8 detector modules
  - 4 installed in TS2 2015
  - 4 being prepared for installation in TS3 2015





Detector cooling

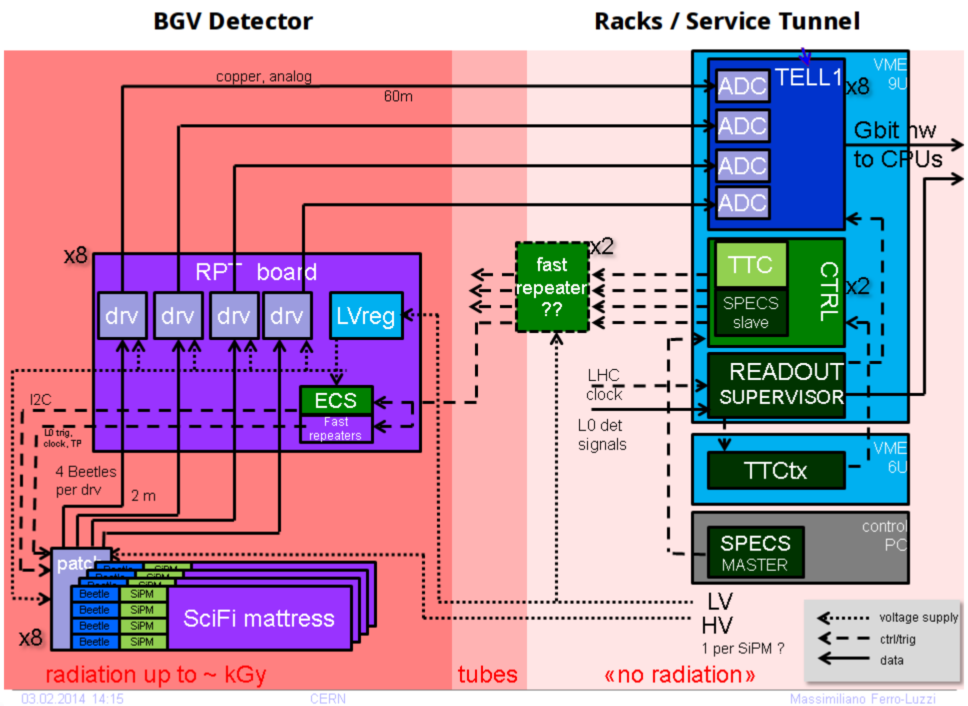
- SiPM noise increases with radiation
- System developed to cool SiPMs to -40 C
- Installed a standalone chiller in the service tunnel and a transfer line
- Circulation tests ongoing

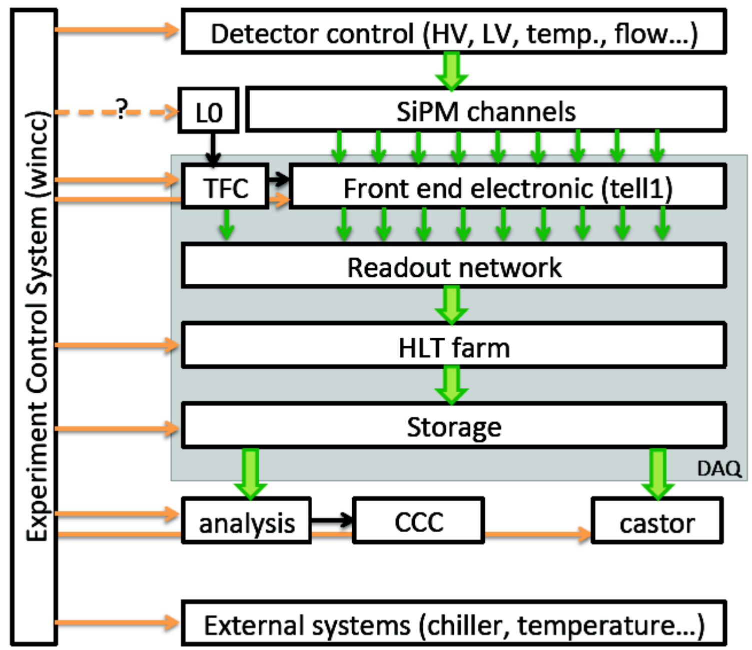
Other sub-systems

- Chamber temperature monitoring and cooling fans
- Trigger scintillators; Dry air distribution

Readout & Control

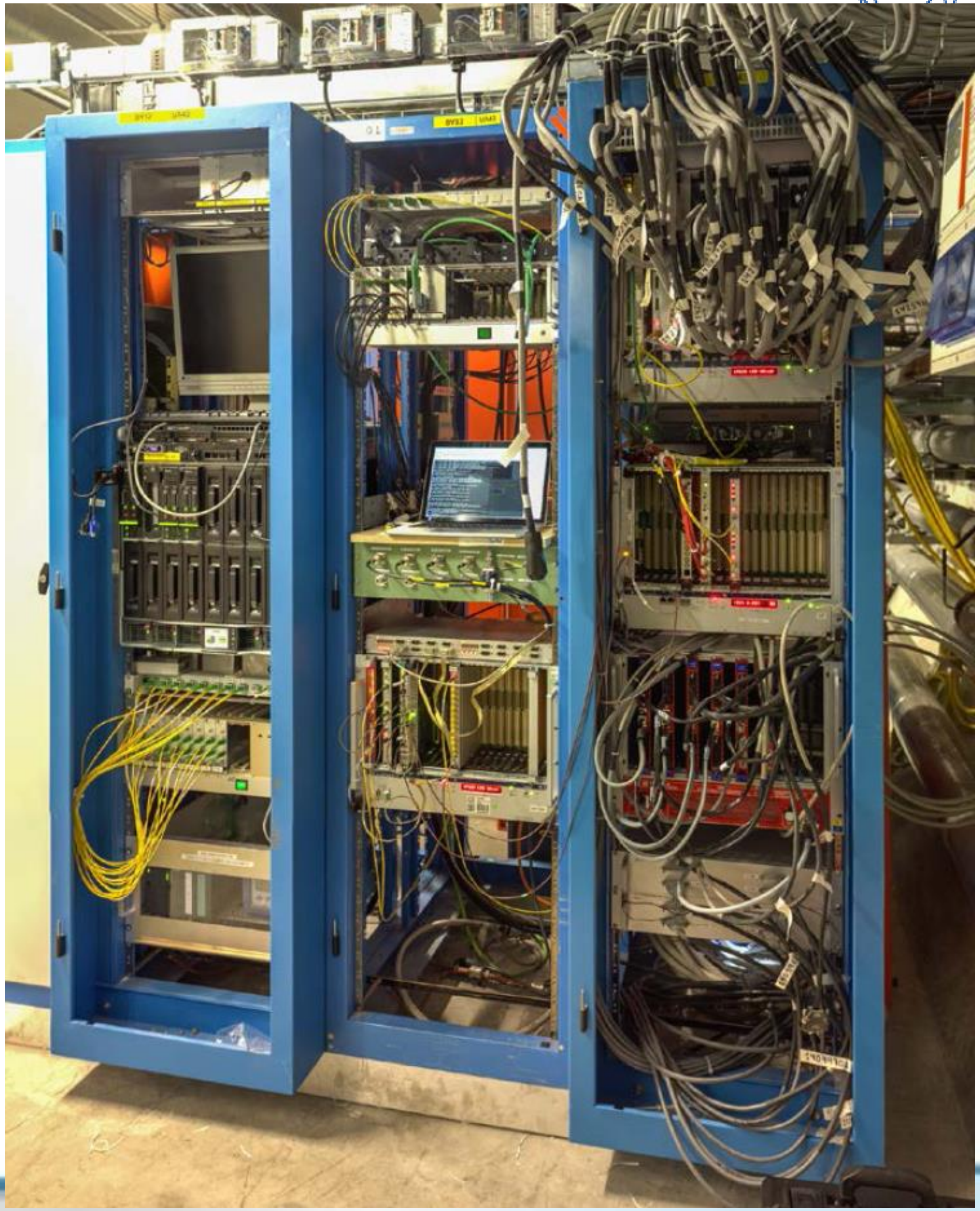
- BGV readout based on LHCb VELO
  - 25 ns, 1 MHz maximum rate
- Control based on PVSS/WinCC-OA (copy LHCb)
  - Interface to LHC CMW to exchange data and commands





DAQ Installation

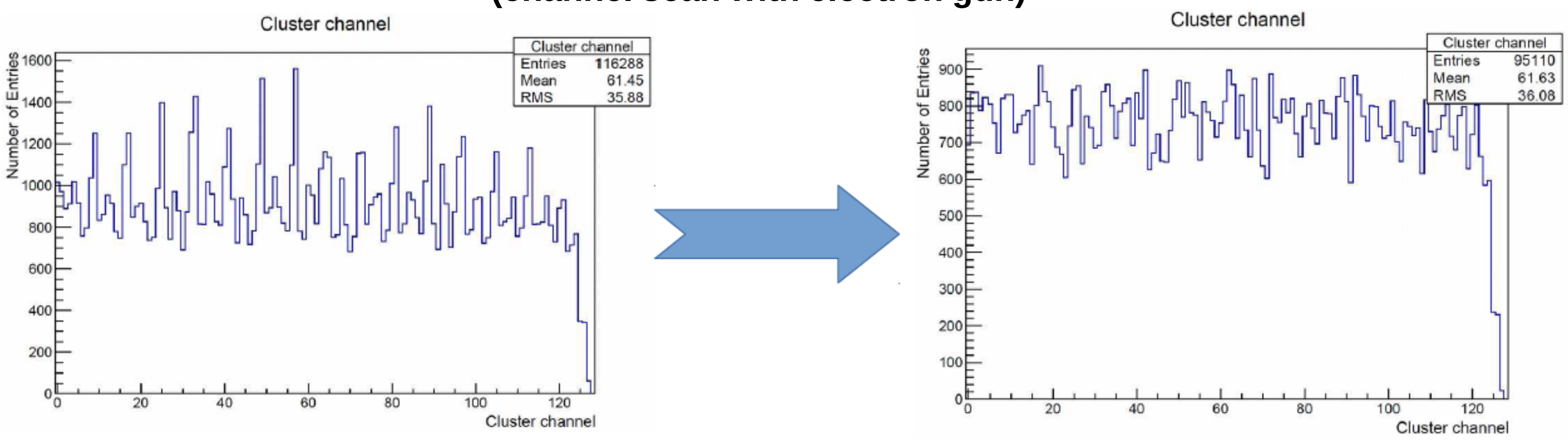
- DAQ installed in TS2 2015
- All systems functional
- Commissioning ongoing



Status and prospects

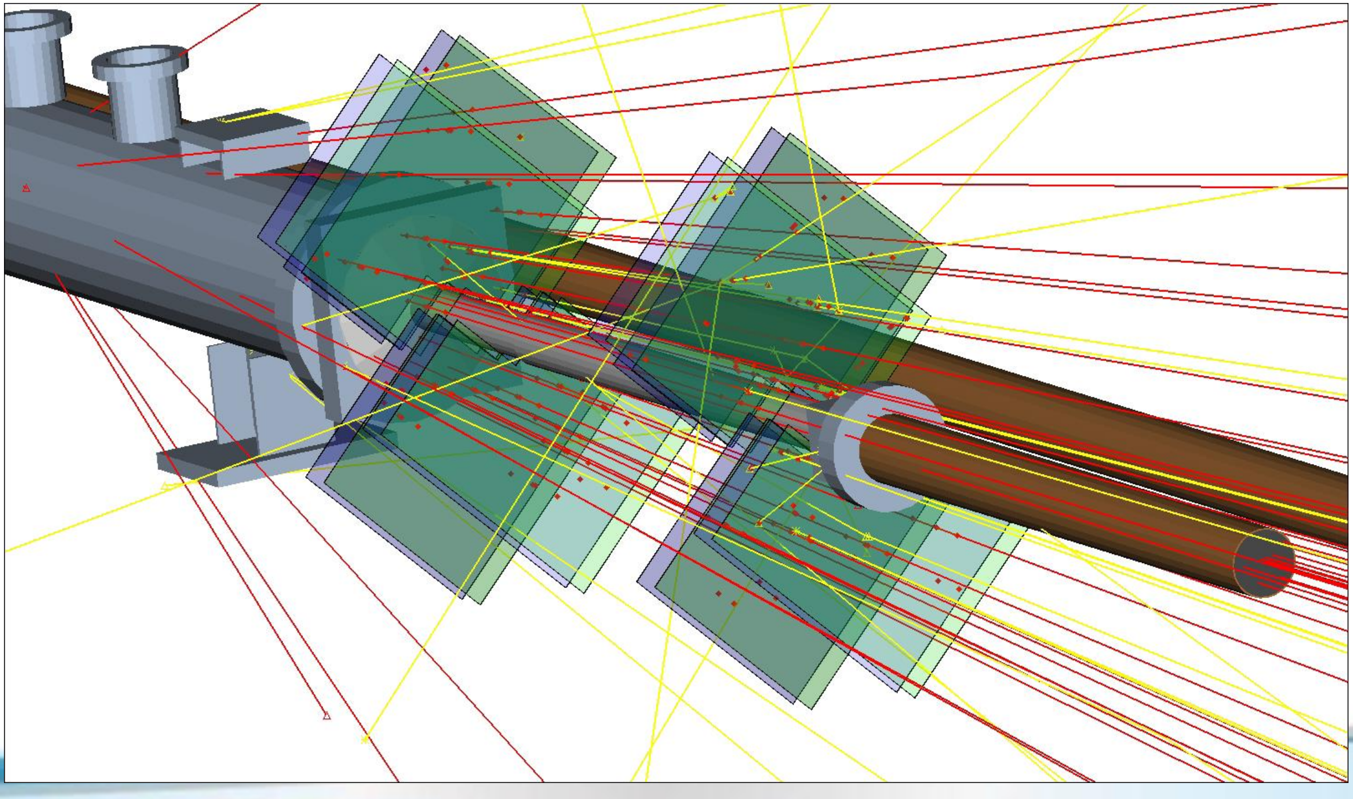
- The BGV Demonstrator installation is almost complete
- Commissioning of detector and readout ongoing
- Milestones to first beam profile measurement
  - Tuning of readout timing (ADC delay scan)
  - Commission trigger
  - Apply SiPM signal correction; zero-suppressed readout
  - Track and vertex reconstruction

SiPM channel uniformity before and after correction
(channel scan with electron gun)



Analysis software

- Using the LHCb framework (Gaudi)
- Work ongoing on the event reconstruction algorithms
- Next development steps:
  - Online application to accumulate the reconstructed vertices and determine the beam profile
  - Transmission and logging of event data and measurements



Measurement of small beam sizes using the synchrotron light monitor

Problem

During Run1 :

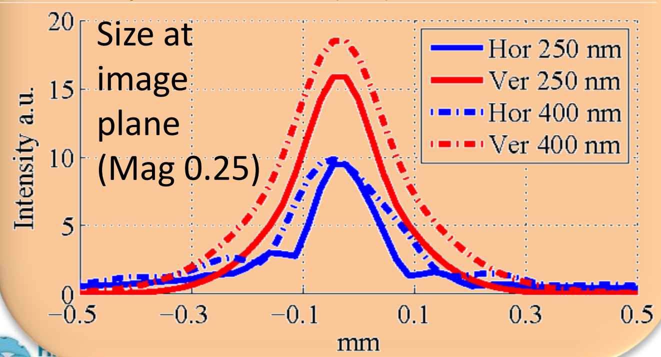
imaging accuracy compromised by extraction mirror heating and coating blistering

→light scattering, image blurring

@ 6.5-7 TeV when imaging in the UV (e.g. 250nm):

contribution from diffraction (~250μm) > beam size (180μm)

Line Spread Function (LSF) @ 7 TeV



Proposed Solution

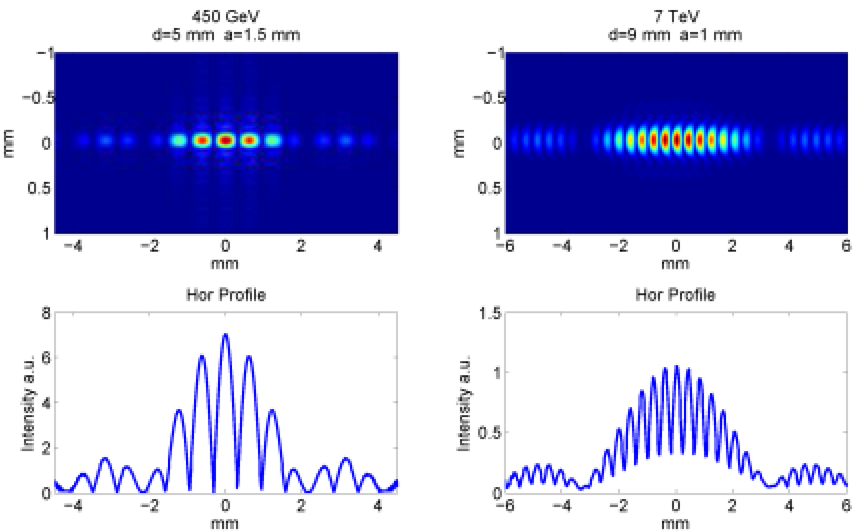
- New extraction mirror design
- Wave-front distortion measurements (Shack-Hartman mask method) with and without beam
- Imaging a narrow band in the near UV to reduce diffraction
  - 250nm focusing lenses
  - UV sensitive CCD camera photocathode
- Interferometry (not diffraction limited)
  - New optical line (in parallel to imaging, after splitting)

Measurement of small beam sizes using the synchrotron light monitor

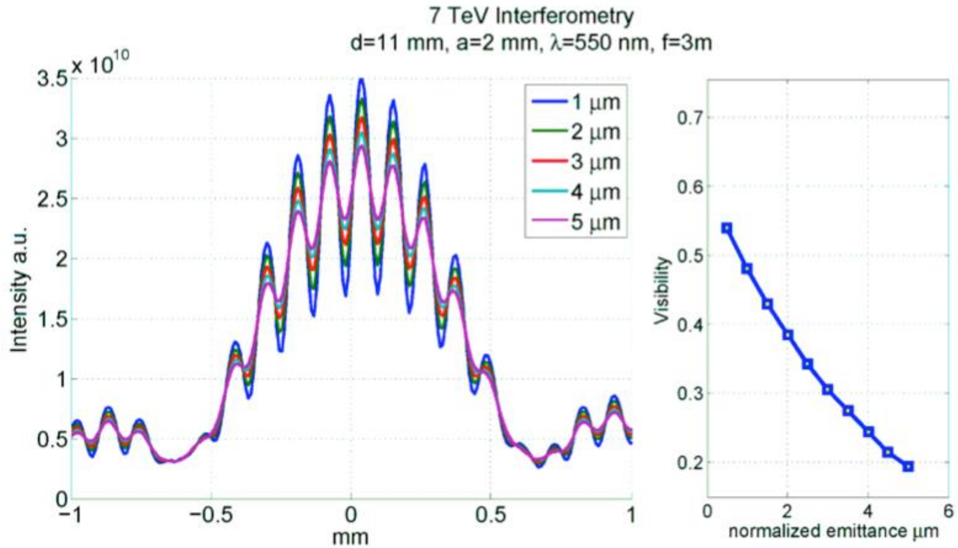
Interferometry

- Non-diffraction limited & widely used in e^- machines for very small beam sizes
- New project in collaboration with KEK, SLAC & CELLS-ALBA

Injection 7 TeV



Simulated interference fringes with ZEMAX

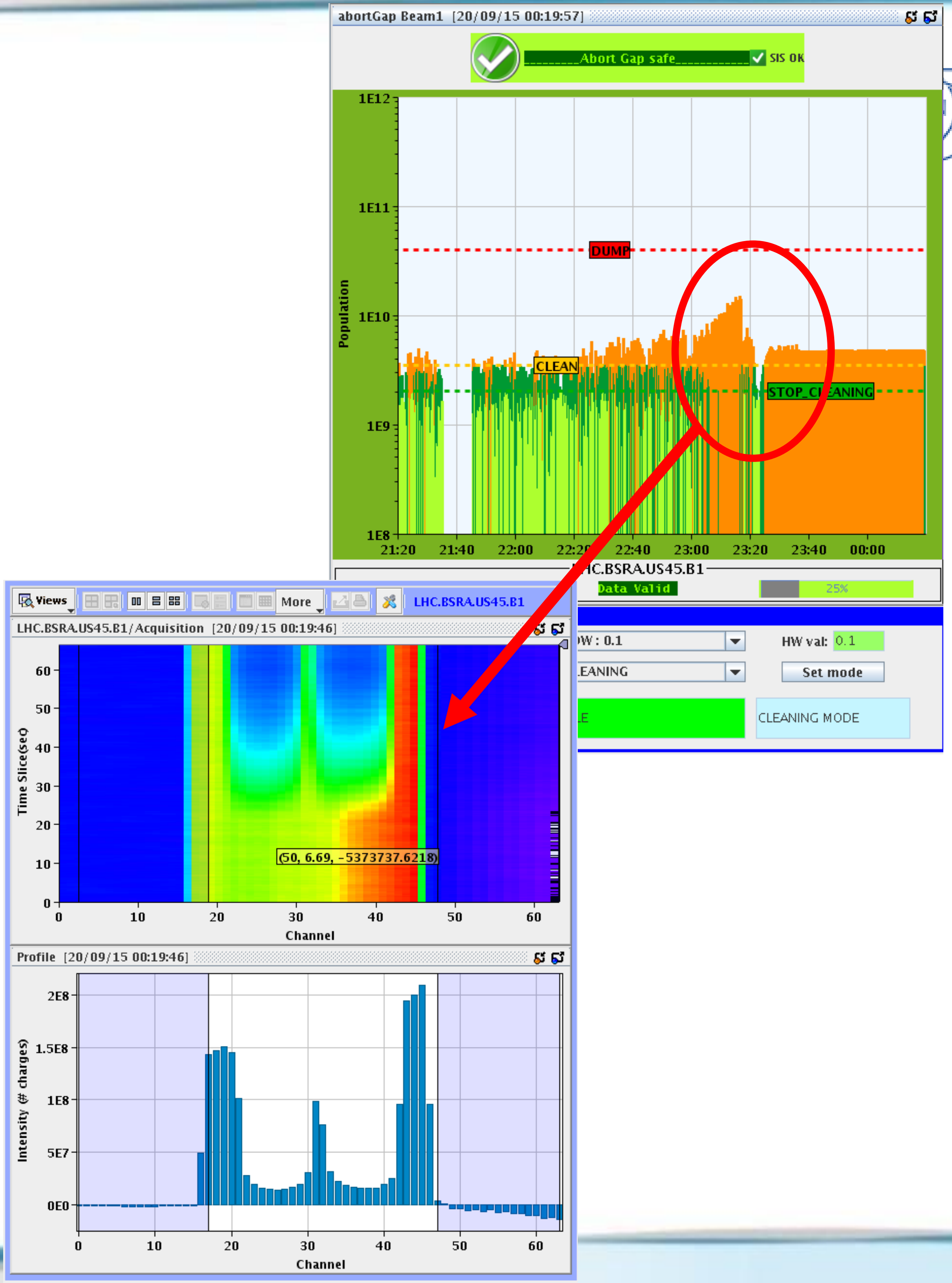


Interference fringes for different emittances & predicted visibility as function of emittance

High Luminosity LHC

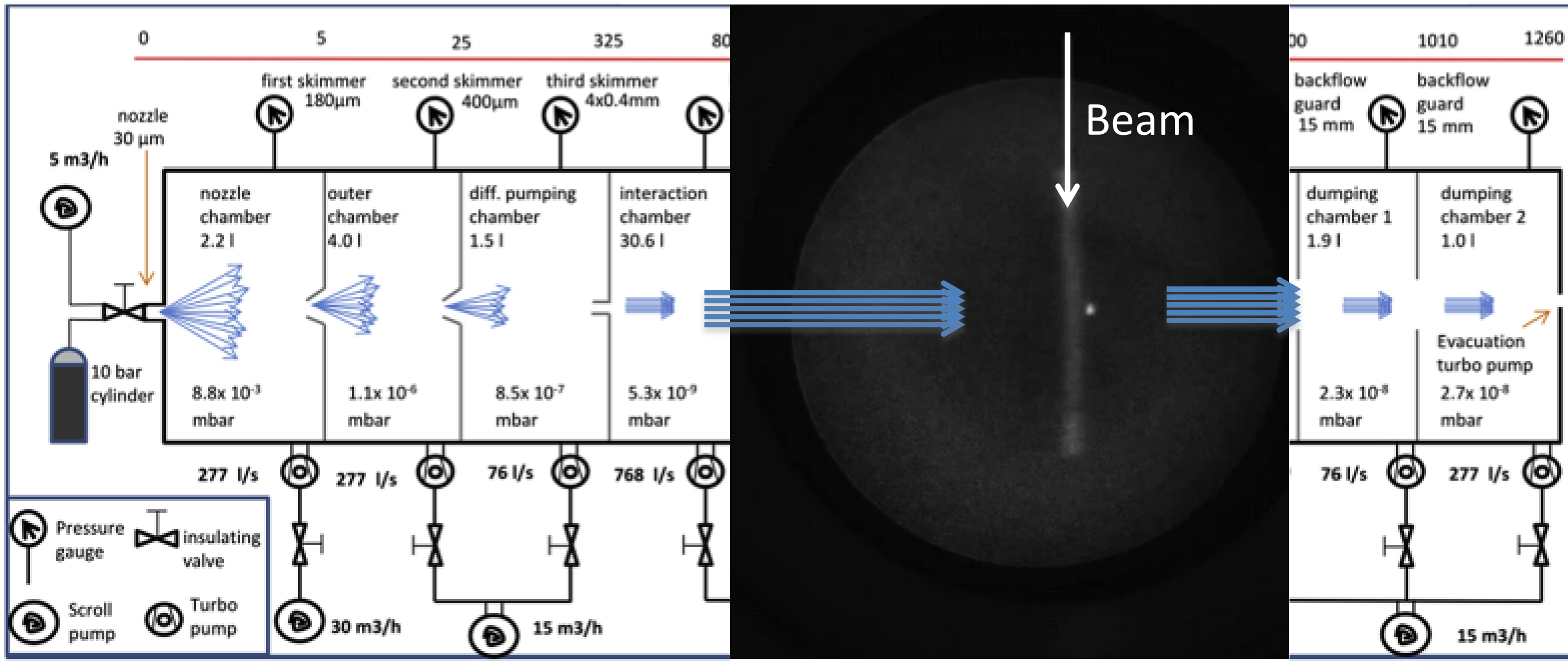
BSRA update

- Abort Gap Monitor (BSRA) now connected to the software interlock system (SIS).
- Automatic AG cleaning tested in July 2015, now routinely implemented
- Automatic calibration procedures required for reliable operation. Internal PMT Gain calibration now part of sequencer, periodic calibration against FBCT to be finalised.



Gas Jet Techniques

- Gas sheet & luminescence (University of Liverpool (UK) & CERN)
  - Being considered for hollow electron lens diagnostics



- Gas jet scanner - alternative to wire-scanner
  - Use of atomic sieve to focus neutral gas atoms
    - Quantum interference
  - Scan faster/slower for core/halo