Beam-gas vertex detector for beam profile monitoring at (HL) LHC

Plamen Hopchev (EPFL)
on behalf of the BGV Collaboration

Joint Annual Meeting of the Swiss and Austrian Physical Society
21–25 Aug 2017, Geneva, Switzerland

BGV profile monitor for (HL) LHC

- Aim to develop a transverse beam profile monitor for HL–LHC
  - The beam-width (σ) is used to determine the beam emittance (ϵ), which is essential for the collider operation and performance: $\boxed{\sigma^2 = \epsilon\ \beta}$

    (the optics β–function is provided by independent measurement or model)
- Complement and overcome limitations of the existing profile monitors
  - Absolute calibration and measurements during ramp

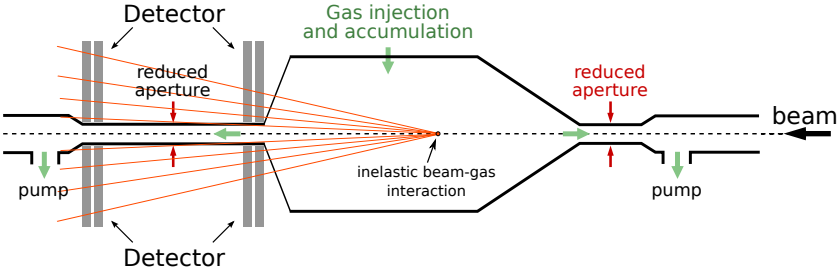
BGV profile monitor for (HL) LHC

- Aim to develop a transverse beam profile monitor for HL–LHC
  - The beam-width (σ) is used to determine the beam emittance (ϵ), which is essential for the collider operation and performance: $\boxed{\sigma^2 = \epsilon\ \beta}$
    (the optics β–function is provided by independent measurement or model)
- Complement and overcome limitations of the existing profile monitors
  - Absolute calibration and measurements during ramp
- Development approach

  Phase 1 – LHC Run 2&3: demonstrate the potential of the method by installing a prototype system on one beam at the LHC (BGV Demonstrator)
  - Make a sequence of measurements, full beam and b-by-b, also during ramp
  - Modest requirements on the measurement frequency, precision and accuracy

  Phase 2 – HL–LHC: build a full-blown BGV for each ring
  - Bunch width resolution: < 5 % in $\Delta t < 1$ min
  - Absolute beam width accuracy: 2 %

Beam-gas vertexing method

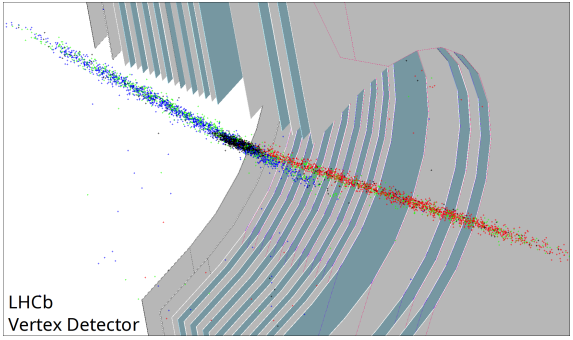


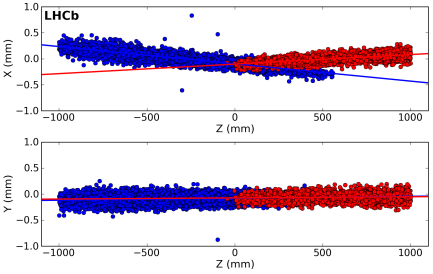
- Use inelastic beam-gas interactions
  - Control rate by injecting locally a small amount of gas (e.g. Neon) to 6×10^{-8} mbar. Method is non-distruptive to the beam (nominal LHC vacuum is $\sim 10^{-10}$ mbar)
- Measure the produced tracks with high-resolution detectors
- Reconstruct and accumulate vertices and obtain an image of the beam
- Method pioneered and currently used at the LHCb experiment
  - Determine geometrical properties of the LHC beams and the absolute luminosity
  - JINST 7 (2012) P01010, JINST 9 (2014) P12005

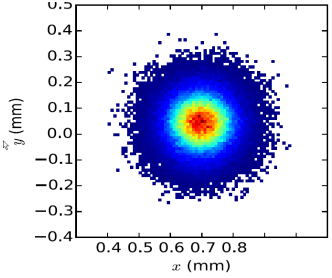
Beam imaging in LHCb

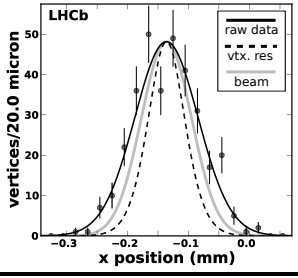
The method can provide (at low rate):

- Beam position and angle
- 2D transverse profile
- Relative bunch populations
- Ghost charge & abort gap population
- Longitudinal profile (needs precise timing detector)

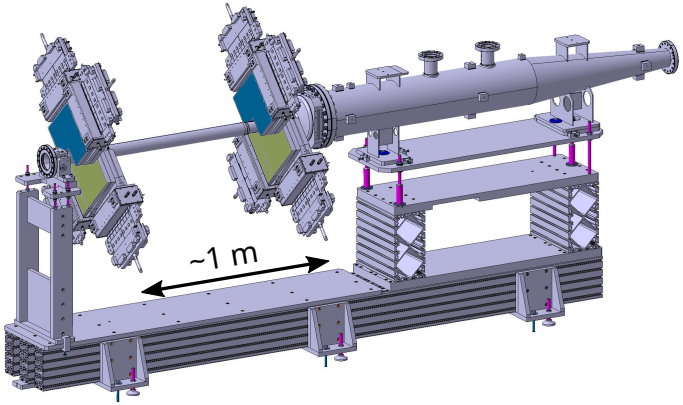








BGV Demonstrator

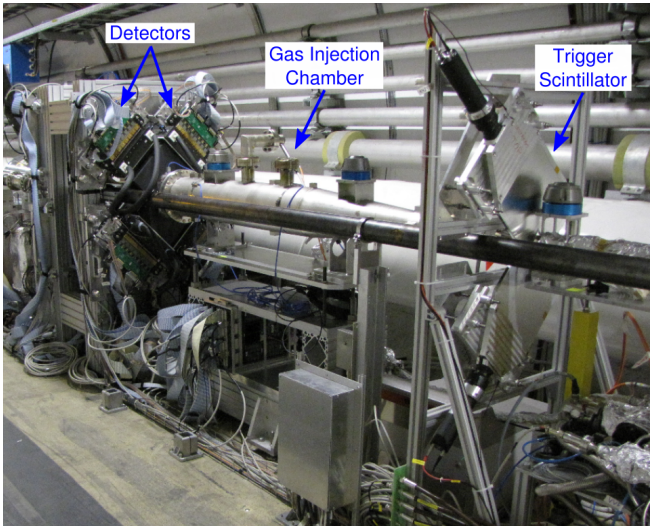


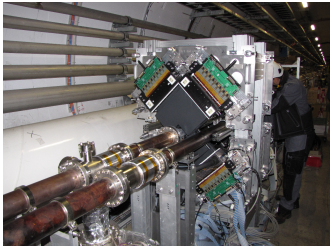
Installed in LHC P4

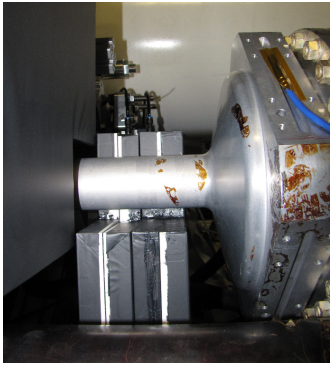
Currently under commissioning

- **Detector**: Scintillating fibres read out with SiPMs
  - Developed by EPFL and RWTH Aachen
  - Same technology as the LHCb upgrade SciFi tracker
- **Vacuum system**: Designed and produced by CERN (+outsourcing)

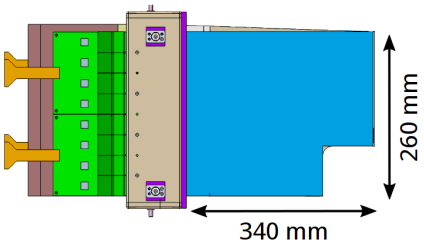
BGV Demonstrator – P4 @ LHC

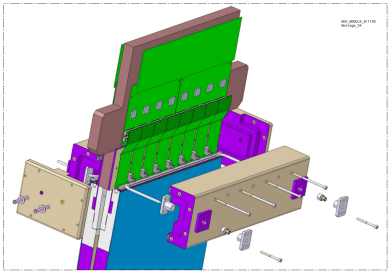


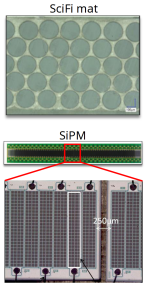




Detector



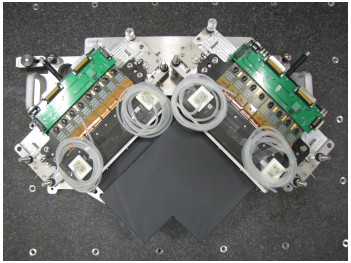


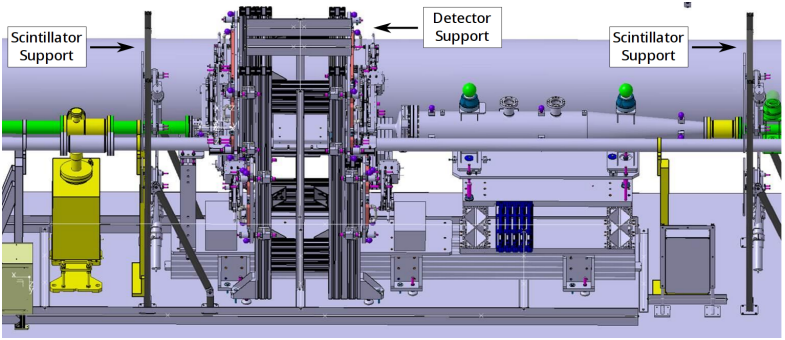


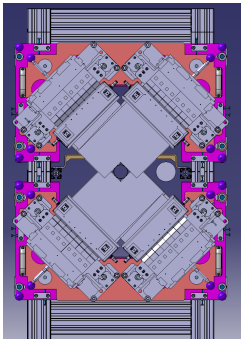
- Double sided detector modules – 2° “stereo” angle
- Fibre mattresses produced at Aachen, mechanics and electronics at EPFL
- Scintillating fibre mattress
  - 260 × 340 mm
  - Optimized geometry (corner cut)
  - Fibre diameter 250 μm (Kuraray)
  - 4 and 5 layer mats
- Hit resolution: $\sim$ 40 μm
- SiPMs
  - 128–channel arrays (Hamamatsu)
  - Channel size = 0.25 × 1.2 mm
  - Noise increases with radiation
    $\Rightarrow$ cooling to reduce SiPM noise

Detector

- Two modules fixed together on a common plate: “2-module assembly”
- **In total:**
  - 8 detector modules arranged in 2 “planes”
  - $8 \times 2048 = 16\,384$ channels

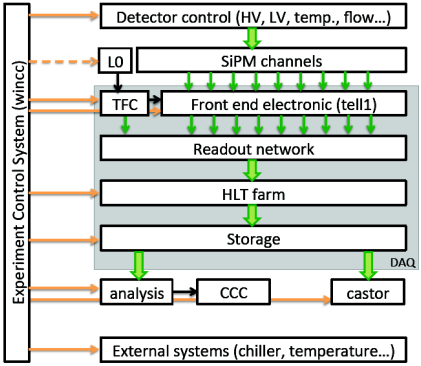


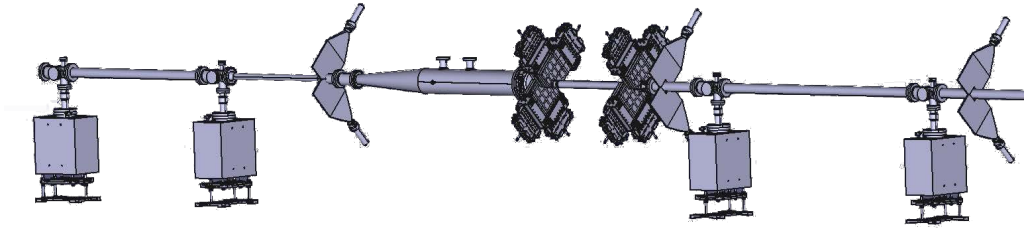




Other systems

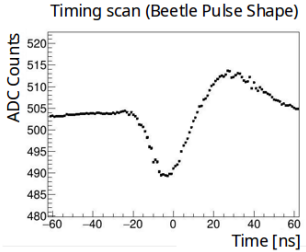
- **Detector Readout** based on LHCb VELO
  - 25 ns, 1 MHz maximum rate
  - Readout trigger provided by scintillators
- **Experiment Control** uses WinCC-OA (copy LHCb)
  - Interface to LHC communication infrastructure
- **Hardware trigger** with scintillator plates
  - Three measurement stations (“veto”, “signal”, and “confirm”)

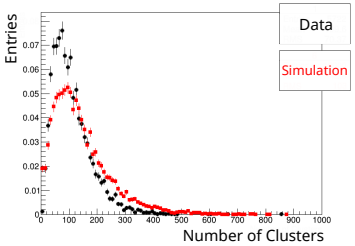




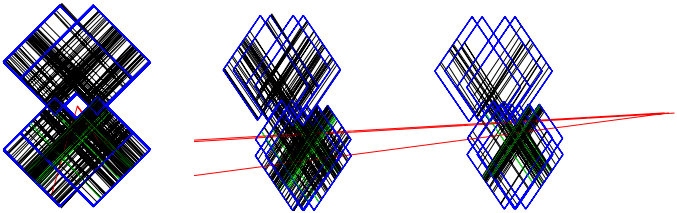
Data taking and Reconstruction

- Detector commissioning ongoing
- All systems functional, setup of L0 trigger and timing scans done
- Small data samples taken at different settings and conditions
- Development of reconstruction algorithms ongoing: clusters, tracks and vertices
  - BGV uses the LHCb software framework (Gaudi) and detector-specific algorithms
- Important next step: alignment with reconstructed tracks





Event display from 2016 data (tracks in red)



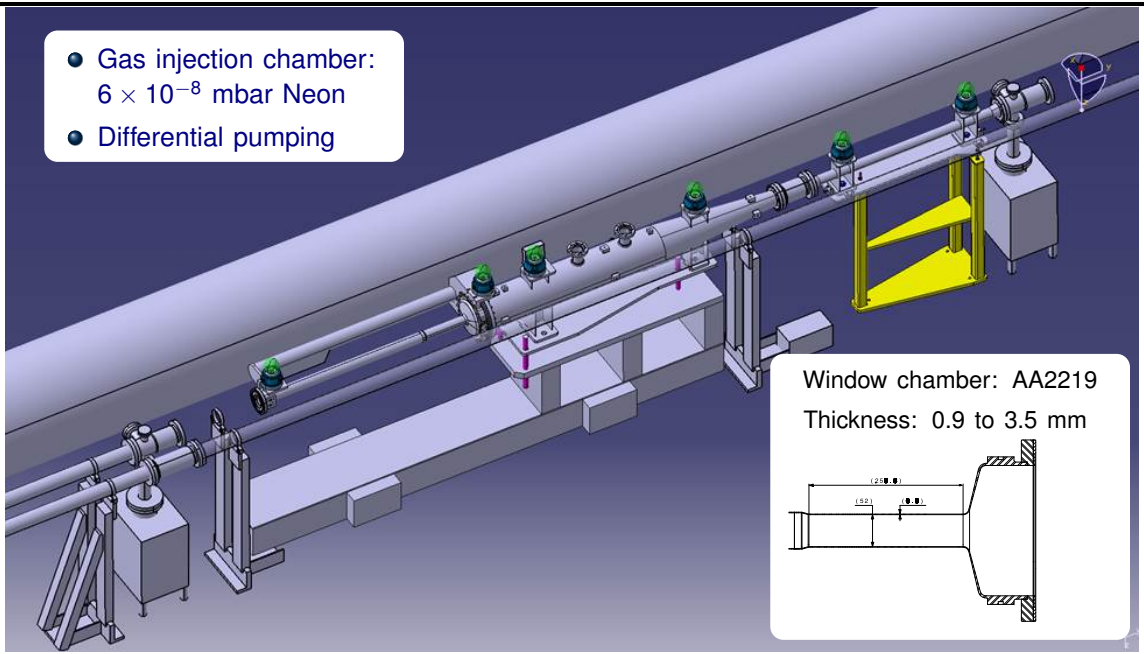
Summary

- The BGV project applies the beam-gas imaging technique for beam diagnostics at the LHC
- The BGV Demonstrator, installed in P4 at the LHC, is in its final commissioning stage
- Effort is concentrated on the development of reconstruction algorithms and data analysis
- Looking forward to first beam-size measurements

Additional Slides

Vacuum system

- Gas injection chamber: 6×10^{-8} mbar Neon
- Differential pumping



Window chamber: AA2219

Thickness: 0.9 to 3.5 mm

Detector cooling

- System to cool the SiPMs down to $-40\ ^{\circ}C$
- Standalone chiller in the service tunnel
  - Using C_6F_{14}, considering also Novec 649
- Transfer line and a distribution manifold in the LHC tunnel
  - ~~Silicon~~ Copper tubes and Armaflex insulation