HL-LHC: BGV

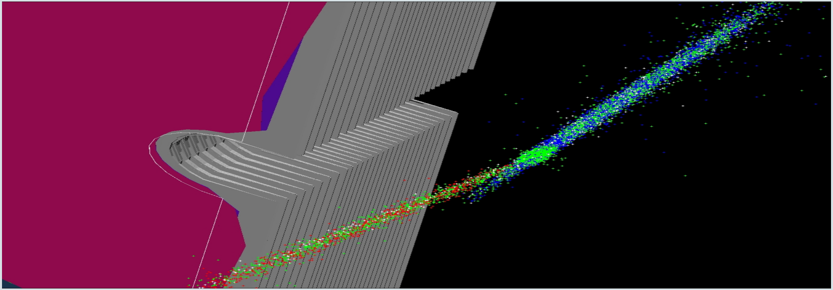
Beam Gas Vertex beam profile monitor

Plamen Hopchev (BI-BL)
with help from B. Dehning, M. Ferro-Luzzi, P. Magagnin

BI Day – 16 Oct 2014

Beam Gas Vertexing technique

- Use the gas in the primary vacuum as a beam visualising medium
- Measurement based on the detection of inelastic beam-gas interactions (vertices)
  - Tracking detector to measure the produced charged particles
  - Determine vertex position
- Accumulate vertices to measure the transverse beam profile and other beam properties



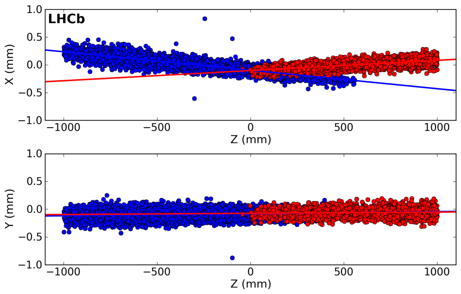
Application in LHCb

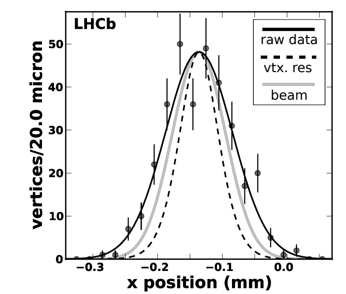
- Beam gas imaging for absolute luminosity calibration in LHCb

  [M. Ferro-Luzzi, NIM A 553, 3 (2005) 388]

- Applied for a first time in 2009

- Since 2011 the SMOG gas-injection system is used in special fills
  - Increase rate of useful events by 3 orders of magnitude





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References

- Precision luminosity measurements at LHCb: http://cds.cern.ch/record/1951625
- CERN-THESIS-2011-210, CERN-THESIS-2013-301
- BCNWG Notes: https://lpc.web.cern.ch/lpc/bcnwg.htm

Possible beam measurements

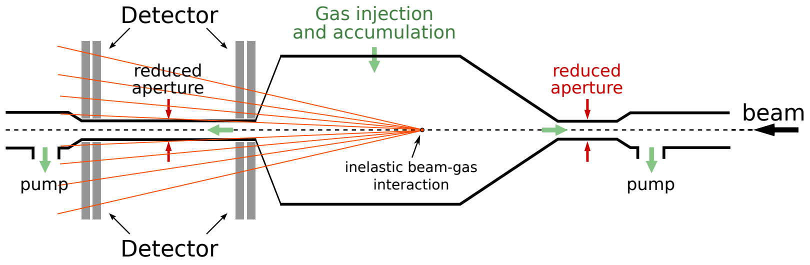
- Beam position and angle
- **Transverse beam profile**
  - Main interest for BI
  - Full beam and b-by-b, absolute scale, cover full LHC cycle
- Longitudinal profile
  - Need timing information ($\sim$50 ps resolution)
- Relative bunch charges
  - Compare rates between bunch slots
- Ghost charge, abort gap population
  - Normalize rate to filled bunch slots

BGV for beam diagnostics

- **Goal: develop a transverse profile monitor for HL-LHC**
  - Bunch width resolution $< 5\%$, $\Delta t < 1$ min
  - Absolute beam width accuracy: 2%
- **Phase 1**: demonstrate the potential by installing a prototype system on one beam at the LHC (LS1)
  - Make a sequence of measurements, bunch-by-bunch, during the ramp
- **Phase 2**: build a full-blown BGV for each LHC ring (LS2)
  - Further developments possible until HL-LHC (LS3)

- Collaboration required: BE-BI, TE-VSC, PH-LHCb, EPFL, Aachen
  - Agreement outlining the contributions

Demonstrator conceptual design



- Detector external to the chamber; No movable parts
- Goal for the Demonstrator:
  - Bunch width resolution $< 5\%$, $\Delta t < 5$ min
  - Absolute beam width accuracy: 10%
- Beam size, aperture, target gas $\Rightarrow$ BGV size
- Critical design parameters: minimal approach to the beam, polar angle acceptance, and material budget (window $x/X_0 \approx 1\ \%$) [Ref.]

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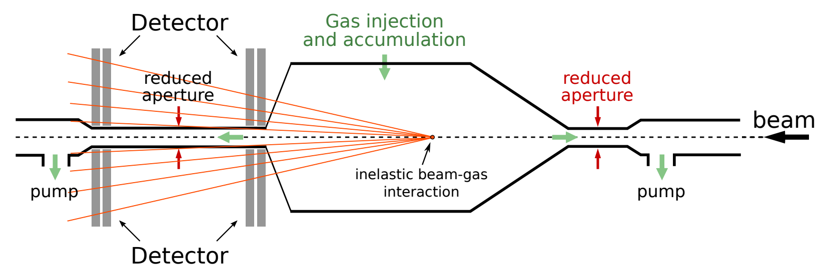

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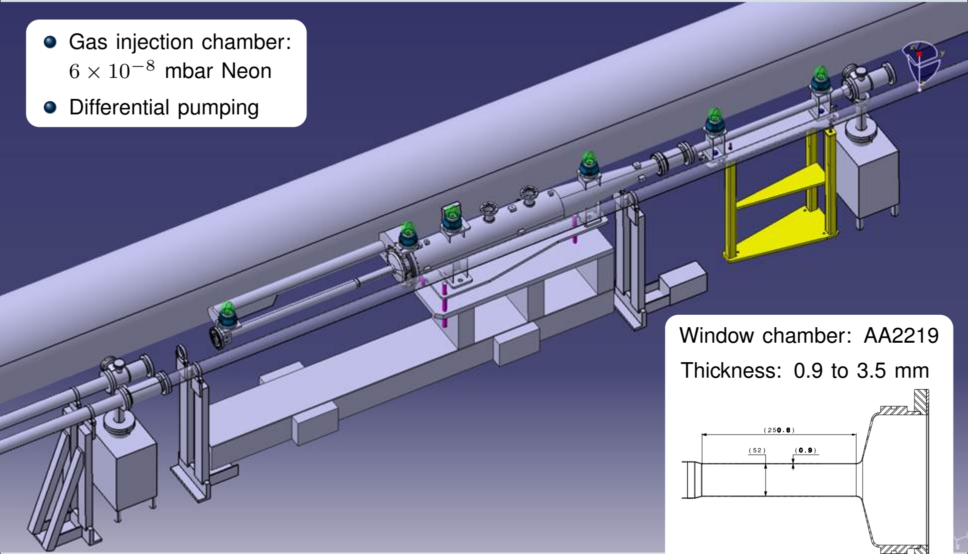
BGV Demonstrator ECR:
https://edms.cern.ch/document/1324635/1.0

Vacuum system



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

Window chamber: AA2219

Thickness: 0.9 to 3.5 mm

Vacuum system

Engineering design

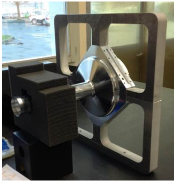
- N. Chritin (EN-MME)

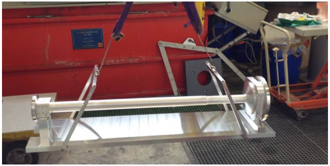
Production

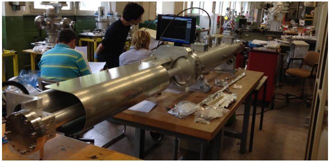
- Managed by the main workshop
- Window chamber most complex and delicate
  - Al block forging (Imbach, CH), machining and EB welding (CERN)

Treatment and Qualification

- Cleaning, copper plating and NEG coating (TE-VSC)
- RF test (BE-ABP), bakeout and vacuum qualification (TE-VSC)
- Metrology (EN-MME)

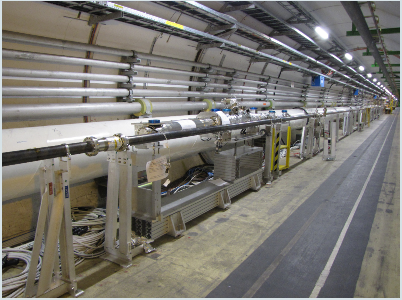


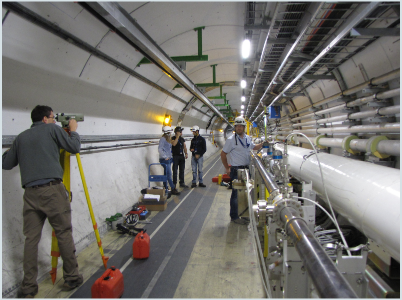




Vacuum system

- BGV chambers installed in July 2014 (EN-HE)
- Alignment (Survey) and bakeout (TE-VSC) done



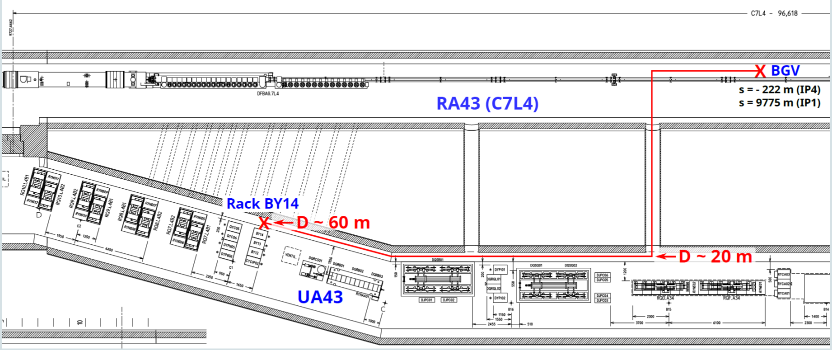


In preparation:

- Chamber temperature monitoring (TE-ABT)
- Forced-air chamber cooling (use in case of need)

Cabling

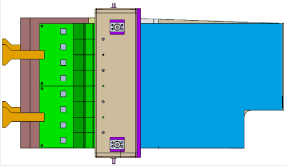
- BGV located at DCUM ≈ 9775 m (C7L4)
- Readout electronics will be placed in racks BY12 – BY14
- Cabling campaign in May 2014
  - About 100 cables for detector readout, control, LV, HV, trigger
  - About 30 cables for vacuum pumps, gas injection, gauges (racks VY05,12,20)

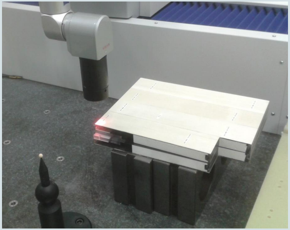


Detector

- Scintillating fibre (SciFi) modules, read out with SiPMs
  - Fibre diameter: 250 μm
  - 1-d hit resolution: 60 μm
- Same technology will be used in the LHCb upgrade
- Fibre mattresses produced at Aachen, mechanics and electronics – at EPFL

- SiPM noise increases with radiation
- Will use liquid cooling to -40° C
  - ECR in preparation
  - Chiller to be installed in the service tunnel





In total:

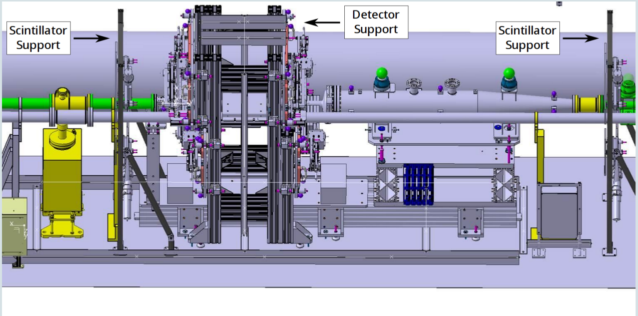
- 8 SciFi modules
- 16 384 channels

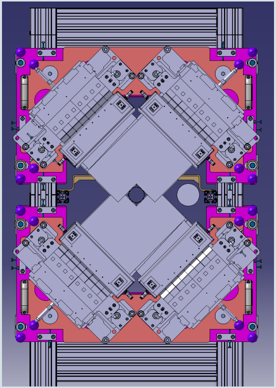
Detector

In production:

- Detector support
- Scintillators and support
- Electronics for the SciFi modules

Installation planned in LS1 and 2015

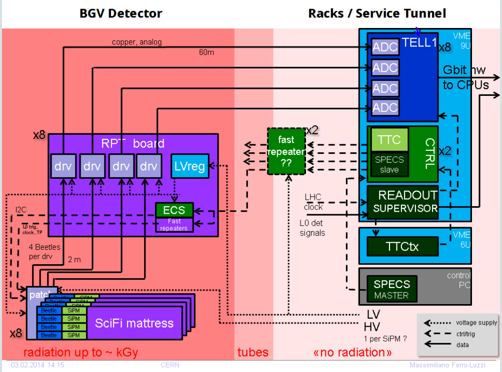




- BGV readout based on LHCb VELO
  - EPFL/CERN expertise
  - Components available
- Readout supervisor as in LHCb
  - 25 ns, 1 MHz maximum readout rate
  - Readout trigger provided by scintillators

Control

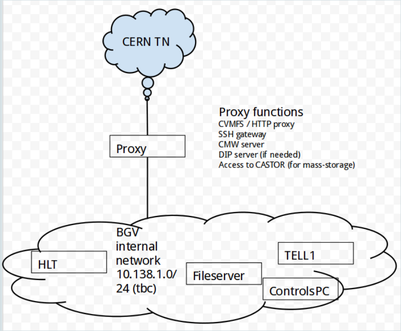
- Based on PVSS/WinCC-OA (copy LHCb)
- Interface to LHC CMW to exchange data and commands



DAQ network

- Under development, with the help of BE-CO
- A single chassis (HP ProLiant) hosts the proxy server and CPU boards
- A switch connects the readout (TELL1) and the CPU farm (HLT)

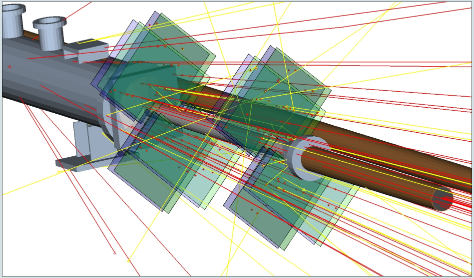
HP ProLiant BLc7000



"Physics" software

Based on the LHCb software framework

GAUDI: a set of SW components for developing event simulation, reconstruction, visualisation, etc. applications. SW development facilities and interfaces to 3rd party SW (e.g. PYTHIA and GEANT4). Used by several HEP experiments.



- Simulation
  - Generate beam-gas interactions
  - Geometry description and detector response
  - Develop event reconstruction algorithms
  - Study vertex resolution systematic
- Event reconstruction
  - Pattern recognition and track fitting
  - Vertex reconstruction

Status & Plans

- **Vacuum system** – essentially ready
  - Ongoing: chamber T meas. and cooling, gas injection system
- **Detector** – under active preparation
  - Installation planned for 2014 and early 2015
- **Readout and Control** – development ongoing
  - Setup to be finished at P8, then move to P4

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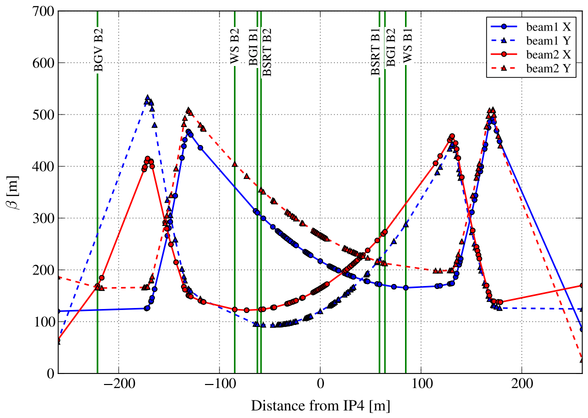
BGV TWiki: https://twiki.cern.ch/twiki/bin/view/BGV/WebHome

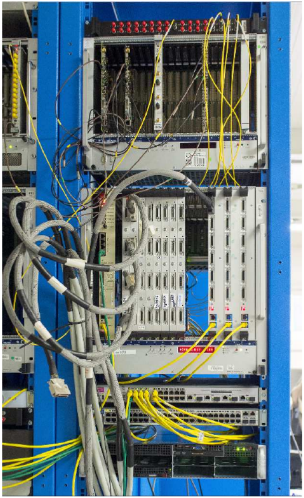
Additional Slides

- Plot of the Nominal optics in Run 1
- At the BGV location:
  - $\beta_x \approx \beta_y \approx 170$ m
  - $\sigma_{\mathrm{beam}} = 220\ \mu$m ($E = 6.5$ TeV, $\epsilon_{\mathrm{n}} = 2\ \mu$m)



DAQ

- DAQ development at P8, slide from M. Rihl



Rack with TFC, 8 Tell1s, 3 control boards.

5/8 Tell1's are pingable and working

3/3 control boards working

1/1 working TFC (currently with constraints)

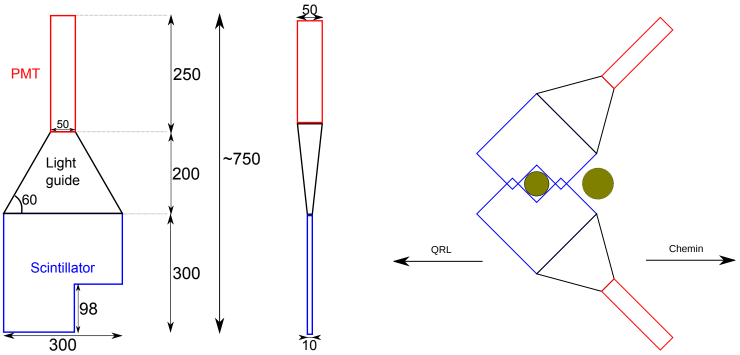
connection Beetles – Repeater Boards – Control board

and

connection Beetles – Repeater Boards – Tell 1 established

2

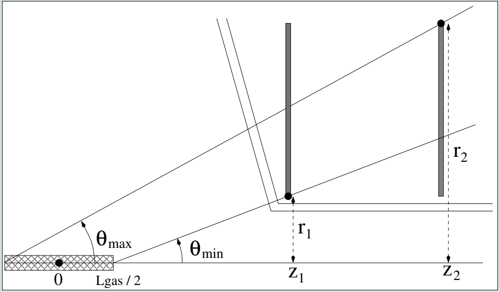
- Slide from Q. Veyrat



Size of scintillating plates choosen to be 300*mm* and the cut-out is the same as the trackers 98*mm*.

Angular acceptance

- **Determine the position and the size of the sensors, needed to cover certain**
  - **Range of angles** $[\theta_{\mathbf{min}}, \theta_{\mathbf{max}}]$
  - **Target length** $\mathbf{L_{gas}}$

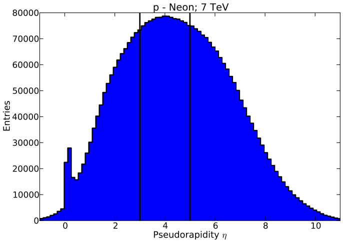


- **Aim at minimal** r_1

Values used in the design study:

- $\mathrm{L_{gas}} = 1000$ mm
- $\theta_{\mathrm{min}} = 14$ mrad ($\eta_{\mathrm{max}} = 5$)
- $\theta_{\mathrm{max}} = 100$ mrad ($\eta_{\mathrm{min}} = 3$)

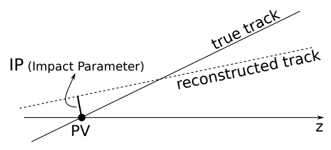
Simulated $\mathrm{p} - \mathrm{Ne}$ collisions



Tracking accuracy

The impact parameter $\boldsymbol{\sigma_{\mathrm{IP}}}$ is determined by:

- $\boldsymbol{\sigma_{\mathrm{MS}}}$ – IP induced by multiple scattering (MS)
    - Minimizing the amount of material $(\boldsymbol{x/X_0})$ is essential
- $\boldsymbol{\sigma_{\mathrm{extrap}}}$ – IP induced by detector hit resolution and extrapolation distance
    - Use high-resolution detectors and minimize the longitudinal distance (related to the aperture)



$$\sigma_{\mathrm{IP}}^2 = \sigma_{\mathrm{MS}}^2 + \sigma_{\mathrm{extrap}}^2$$

$$\sigma_{\mathrm{MS}} \approx r_1 \frac{13.6\ \mathrm{MeV}}{p_T} \sqrt{\frac{x}{X_0}}$$

$$\sigma_{\mathrm{extrap}} \approx \sqrt{\frac{z_1^2 + z_2^2}{(z_2 - z_1)^2}} \cdot \sigma_{\mathrm{hit}}$$

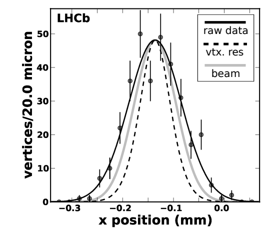
Vertex resolution

- For a beam with Gaussian transverse shape:

$$\sigma^2_{\text{raw}} = \sigma^2_{\text{beam}} + \sigma^2_{\text{vtx.res}}$$

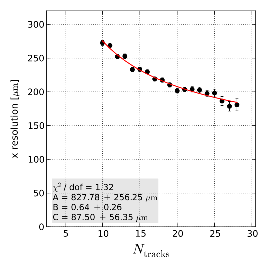
- When $\delta\sigma_{\text{raw}}/\sigma_{\text{raw}} \to 0$:

$$\frac{\delta\sigma_{\text{beam}}}{\sigma_{\text{beam}}} = \frac{\sigma^2_{\text{vtx.res}}}{\sigma^2_{\text{beam}}} \cdot \frac{\delta\sigma_{\text{vtx.res}}}{\sigma_{\text{vtx.res}}}$$



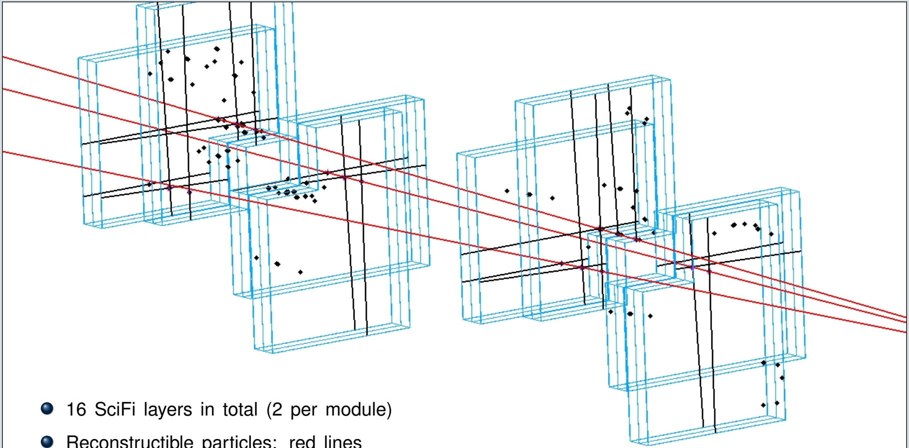
Therefore, it is important to have

- Small $\delta\sigma_{\text{vtx.res}}$ / $\sigma_{\text{vtx.res}}$: aim at 10 % (resolution parametrization)
- Small ratio $\sigma^2_{\text{vtx.res}}$ / σ^2_{beam}: preferably < 1



- The vertex resolution depends on:
  - σ_{IP}
  - N_{tracks} (vertex reconstruction)
  - z_{vtx} (extrapolation distance)

Event display



- 16 SciFi layers in total (2 per module)
- Reconstructible particles: red lines
- Energy deposits (hits): black dots
- Fired fibres/channels: black lines (only a subset is drawn)