The LHC Beam Gas Vertex Detector (BGV)

Q. Veyrat

BI Day

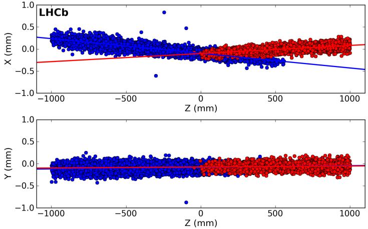
10 March 2016

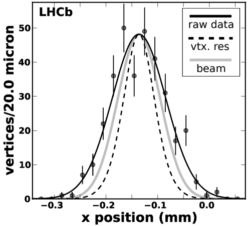
Outline

Beam Gas Vertex monitor (BGV)

- Development of a **transverse profile** monitor for **HL–LHC**
- Based on the *beam-gas imaging technique* pioneered in LHCb

  JINST 7 (2012) P01010, JINST 9 (2014) P12005
- Measurement principle: Tracks $\rightarrow$ beam-gas interaction vertices $\rightarrow$ transverse beam profile (2D)
- Can provide also (at low rate): beam position and angle, relative bunch populations, ghost charge, abort gap population, longitudinal profile (needs timing detector with $\sim$50 ps resolution)

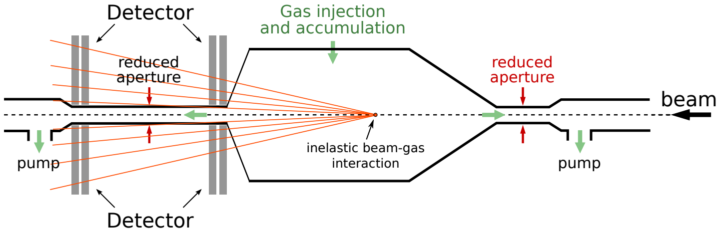




Development goals and approach

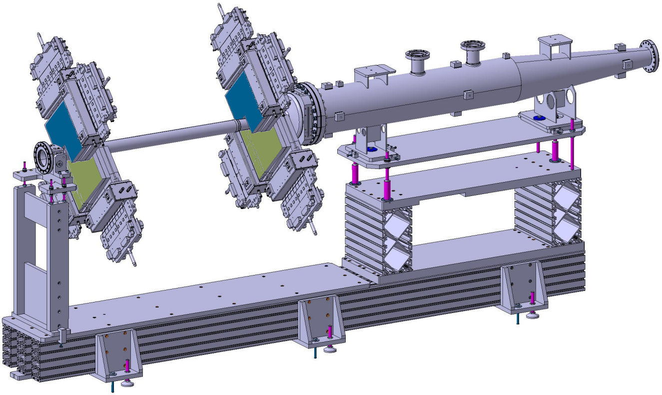
- **Phase 1**: **demonstrate the potential** by installing a prototype system **on one beam at the LHC** (BGV Demonstrator)
  - Make a sequence of measurements, full beam and b-by-b, also during ramp
  - Modest requirements on the measurement frequency, precision and accuracy
- **Phase 2**: build a **full-blown BGV** for each LHC ring
  - Bunch width resolution: < 5 % in $\Delta t < 1$ min
  - Absolute beam width accuracy: 2 %
- Collaboration required: BE-BI, TE-VSC, PH-LHCb, EPFL, Aachen
  BGV Demonstrator Collaboration Agreement

Demonstrator conceptual design



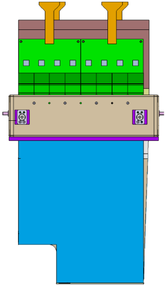
- Detector **external to the chamber**; No movable parts
- Expectations for the **Demonstrator** (see additional slides):
  - **Bunch width resolution**: 5 % in $\Delta t = 5$ min
  - **Absolute width accuracy**: 10 %
- Beam size, aperture, target gas $\Rightarrow$ BGV size
- Critical design parameters: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

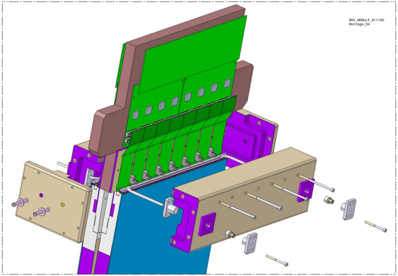
Overview



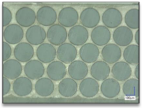
- **Vacuum system**: Designed and produced by CERN (+outsourcing)
- **Detector**: **Scintillating fibres** read out with **SiPMs**
  - Developed by EPFL and RWTH Aachen
  - **Same technology as for the LHCb upgrade**

Detector

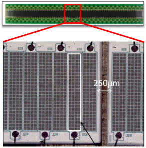




SciFi mat



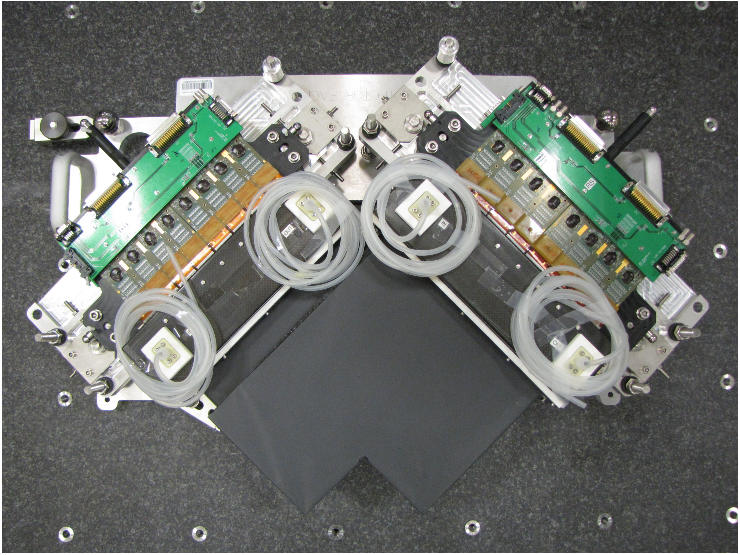
SiPM



Double sided detector modules – 2° “stereo” angle mattresses produced at **Aachen**, mechanics and electronics – at **EPFL**

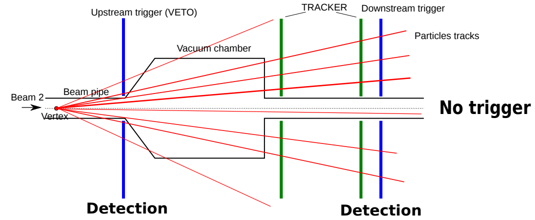
- **Scintillating fibre mattress**
  - 260 × 340 mm
  - Optimized geometry (corner cut)
  - Fibre diameter 250 μm (Kuraray)
  - 4 and 5 layer mats
- **SiPMs**
  - 128–channel arrays (Hamamatsu)
  - Channel size = 0.25 × 1.2 mm
  - Noise increases with radiation
    ⇒ **cooling** to reduce noise

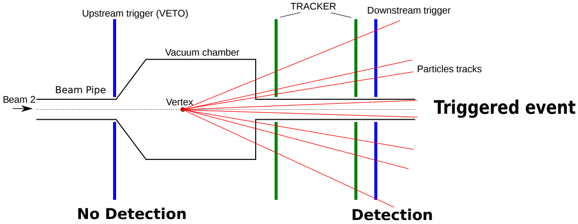
Detector



2 tracking modules : X, X' and Y, Y'

Trigger scintillators (Level–0 trigger) 1/2





Provide information which bunch-crossings should be read out (DAQ limited to 1 MHz)

4 scintillators

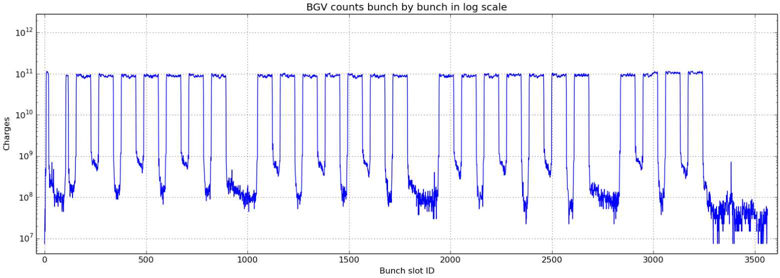
2 upstream of the gas tank: veto upstream events

2 downstream of the detector: require certain signal to readout the event

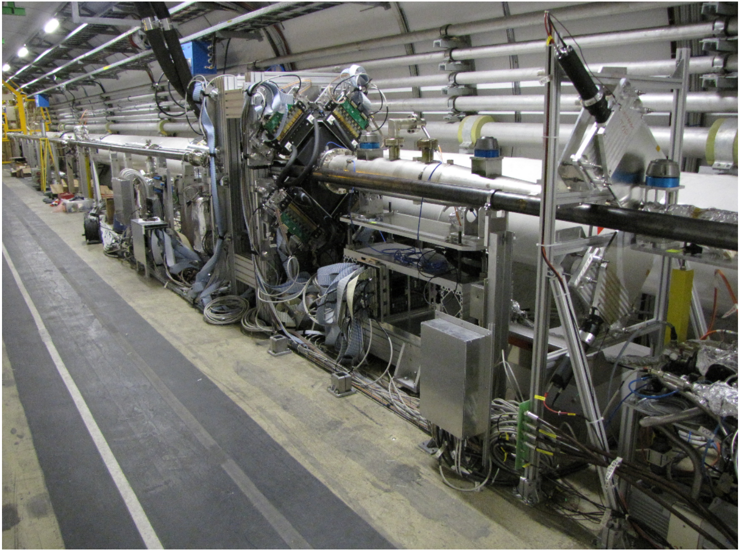
Events with losses from the other beam do not trigger

Trigger scintillators (Level–0 trigger) 2/2

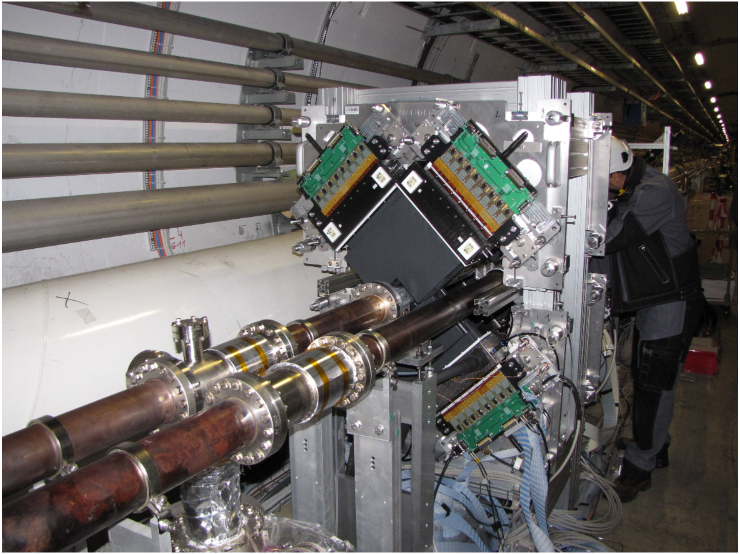
- Can provide **standalone measurement** of the **relative bunch populations** and **ghost charge**
- Data shown for fill 4479 (Oct 2015)



TS3 2015

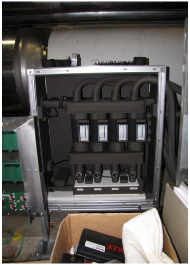


TS3 2015

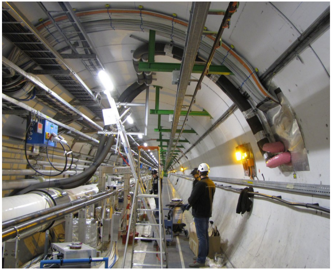


Detector cooling 1/2

- Developed system to cool the SiPMs down to $-40\ ^{\circ}\mathrm{C}$
- Will **start without cooling**, later decrease T gradually
- **Standalone chiller** in the service tunnel
- Used C_6F_{14}, considering also Novec 649
- **Transfer line** and a **distribution manifold** in the LHC tunnel

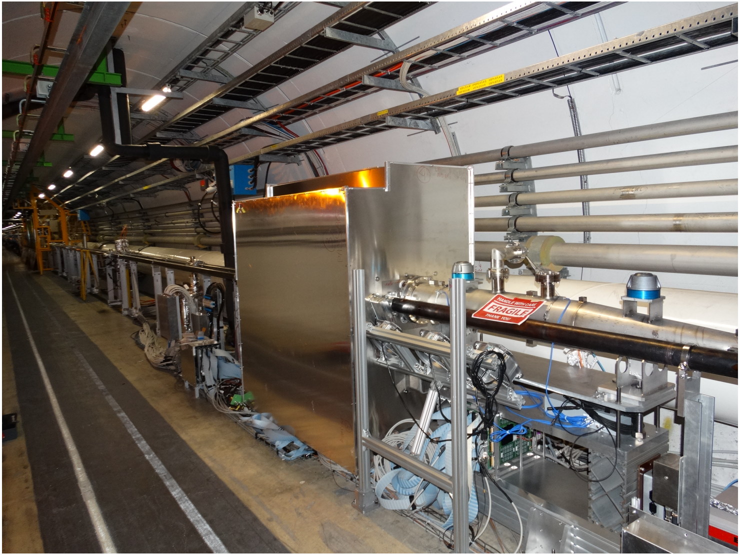


Detector cooling 2/2



- **Problem encountered**: slow diffusion of the cooling liquid through the Silicon tubes
- Solution : use rigid **copper** tube for transfer line
- Cooling delayed, long transfer line installed during **YETS**

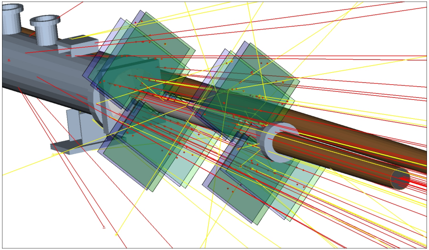
YETS 2015



"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
- **Initial versions of the algorithms are ready**

Status and next steps

- The BGV Demonstrator installation was **completed in TS3 2015**
- **Data recorded** during November and December 2015
  - Protons and ions fills recorded
  - Gas injected during one fill (but low pressure)
- Light-protection cover ("tent") installed during **YETS**
- **Priority for this year**:
  - Treatment of raw signals, corrections, zero-suppressed readout
  - Track and vertex reconstruction
  - Develop online profile measurement application
  - Publishing and logging of event data and measurements
- End of cooling installation for **TS1 2016**

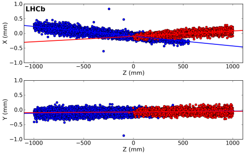
Additional slides

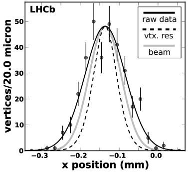
ADDITIONAL SLIDES

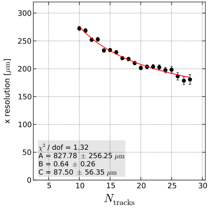
Beam width measurement and error 1/3

- Accumulate vertices over certain time Δt
- Determine beam angle in the $x - z$ and $y - z$ planes
- Fit a Gaussian to the transverse distributions
- The **statistical precision** on σ_{beam} is determined by the N_{vertices} used in the fit (scales as $1/\sqrt{2N}$)
  - Want high rate of interactions $\Rightarrow$ inject gas
  - Demonstrator designed to get $\sim$ 50 Hz of "good" vertices per nominal bunch (see details in the backup slides)

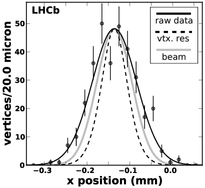
  $\Rightarrow$ For $\Delta t = 5$ min, we get stat. precision ≈ 4 %
- The main **systematic error** on σ_{beam} comes from the vertex resolution
  - Want precise detector, minimum material, and high track multiplicity
  - Selecting high multiplicity events reduces the rate of "good" vertices







Beam width measurement and error 2/3



- For a beam with Gaussian transverse shape:

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

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

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

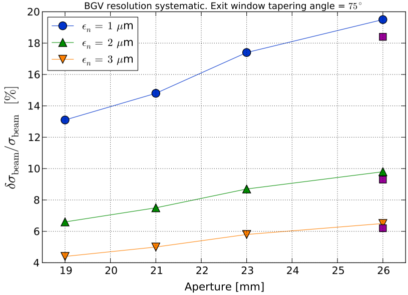
  - The vertex resolution $\sigma_{vtx.res}$ depends on z_{vtx} and N_{tracks}
  - It can be determined from data alone (track splitting method)
  - The determination of the uncertainty of the vertex resolution $\frac{\delta\sigma_{vtx.res}}{\sigma_{vtx.res}}$ requires simulation (compare results of track splitting and MC-truth methods)
  - For the BGV Demonstrator aim for $\frac{\delta\sigma_{vtx.res}}{\sigma_{vtx.res}} = 10$ % (LHCb has achieved 5 %)
  - σ_{beam} depends on E_{beam} and ϵ_{n}
    - accuracy for larger beam (at injection and with large emittance)

Beam width measurement and error 3/3

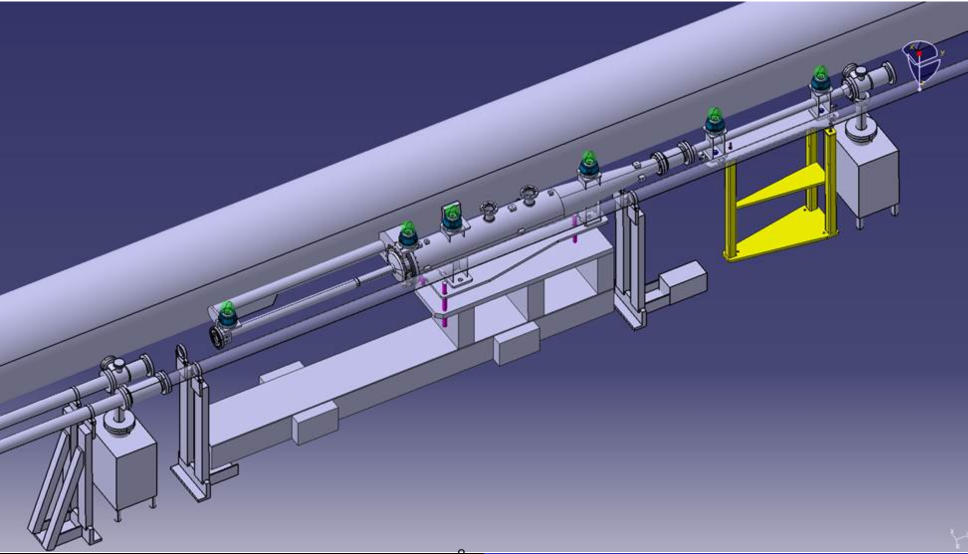
- Plot of the systematic error from vertex resolution
  - during the early design studies (later, the minimal aperture was fixed to 26 mm)
  - The plot is for $E_{\mathrm{beam}} = 6.5$ TeV
- These results are obtained with a simplified simulation application
  - More details can be found in BGV #20, BGV #22 and Emitt. meeting Nov 2013
- Strong cuts were applied on N_{tracks} (select 1 out of 1000 events)

For $\epsilon_{\mathrm{n}} = 2\mu m$ expect:

- $\frac{\delta\sigma_{beam}}{\sigma_{beam}} < 5$ % (0.45 TeV)
- $\frac{\delta\sigma_{beam}}{\sigma_{beam}} = 10$ % (6.5 TeV)



Vacuum system 1/3



Vacuum system 2/3

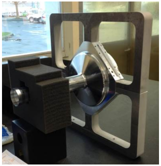
Engineering design N. Chritin (EN-MME) and P. Magagnin (BE-BI)

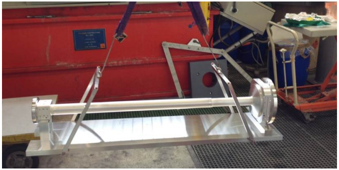
Production

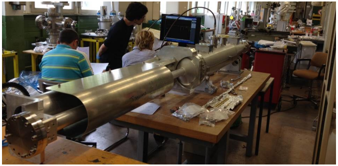
- Managed by the main workshop
- Window chamber most complex and delicate
- Al block forging (Imbach, CH), machining and EB welding (CERN)

Treatment and Qualification

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

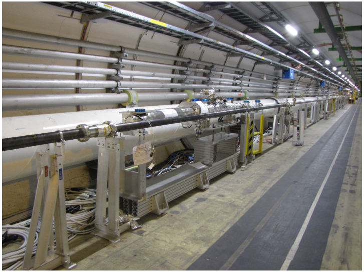


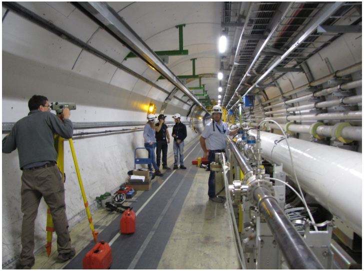




Vacuum system 3/3

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



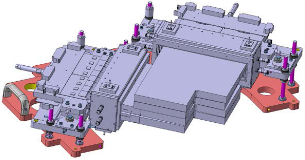


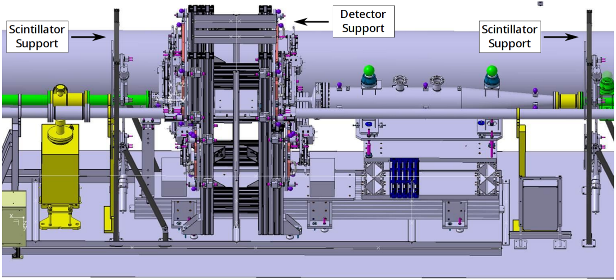
Additional systems:

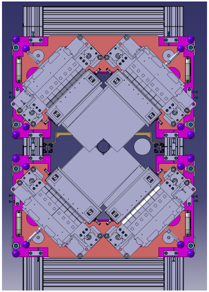
- Chamber temperature monitoring (help from TE-ABT)
- Forced-air chamber cooling (against RF heating)
- This year we observed T increase up to 2 °C (fill with 2200 bunches)

Detector 2/2

- 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





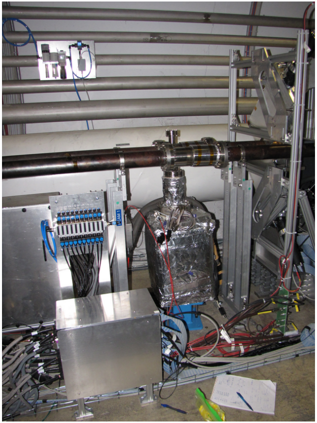


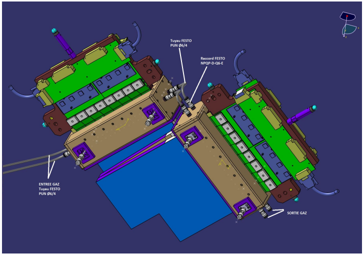
Detector cooling 1/2

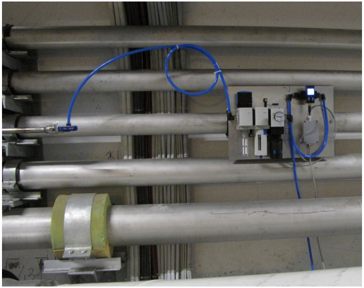
- Developed system to cool the SiPMs down to $-40\ ^\circ C$
- Will **start without cooling**, later decrease T gradually
- **Standalone chiller** in the service tunnel
- Used C_6F_{14}, considering also Novec 649
- **Transfer line** and a **distribution manifold** in the LHC tunnel
- Silicon tubes and Armaflex insulation

Dry air

Using **compressed air** as **dry air**
Dew point $= -40\ ^\circ$C,
$p < 0.1$ bar
Thanks to EN-CV

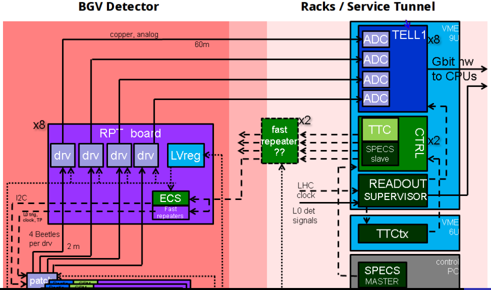


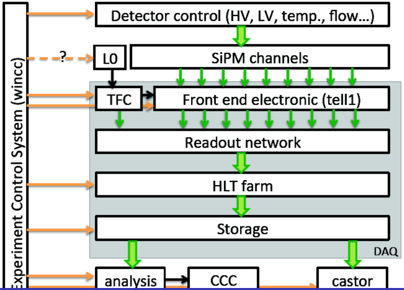




Readout & Control

- BGV readout based on LHCb VELO
- 25 ns, 1 MHz maximum rate
- Readout trigger provided by scintillators
- Control based on PVSS/WinCC-OA (copy LHCb)
- Interface to LHC CMW to exchange data and commands (**in preparation**)



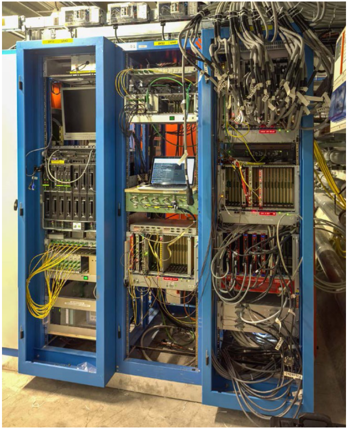


Readout specifics

- SiPM ⇒ Beetle chip ⇒ Repeater ⇒ 60 m ⇒ TELL1 board
- **Beetle chip**
  - Radiation tolerant analog readout chip developed for LHCb
  - Integrates 128 channels with low-noise charge-sensitive pre-amplifiers and shapers
  - Accepts trigger rates up to 1.1 MHz
  - The output is multiplexed onto 4 ports at 40 MHz (32 channels/port)
- **TELL1 board**
  - Readout board used in LHCb for optical or analogue data from the front-end electronics
  - 8-bit ADC sampling at 40 MHz
  - FPGA-based pre-processing (common mode correction and zero suppression)

DAQ

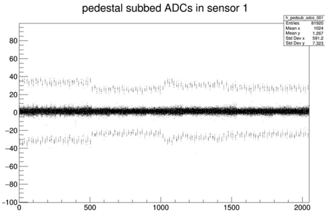
- DAQ installed in TS2 2015
- All systems functional
- A single chassis (HP ProLiant "Blade") hosts the control server and CPU boards
- Thanks to BE-CO

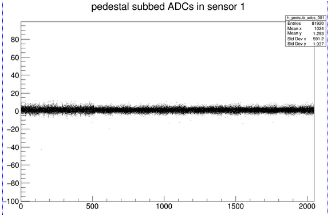


Racks layout Rack photos

Readout commissioning 1/2

- **ADC DELAY SCAN**
  - Special data-taking configuration used to optimize the sampling time of the TELL1 boards with respect to the output produced by the Beetle chips
  - Scan the 16 possible fine delay settings on the TELL1 boards
  - Uses test pulses produced by the Beetle (no beam)
  - **Data taken with bad and good ADC delay setting (Beetle headers visible)**



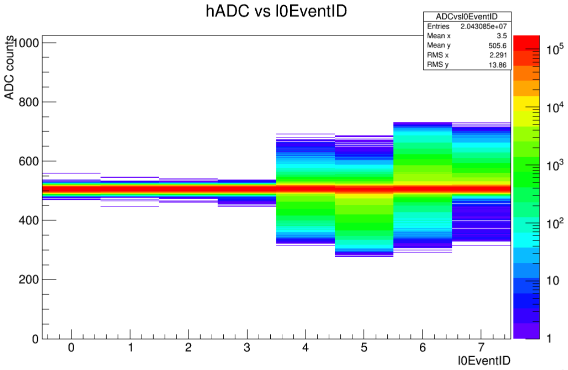


- **PULSE SHAPE SCAN**

- Special data-taking configuration used to adjust the common TELL1/beetle phase with respect to the LHC clock

Readout commissioning 2/2

- **L0 trigger latency**
  - **Optimal setting found (25-ns granularity)**
  - Beetle pulse shape visible: starts negative, tail is positive, extends over a few 25-ns slots



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