Imaging the LHC beams with silicon and scintillating fibre vertex detectors

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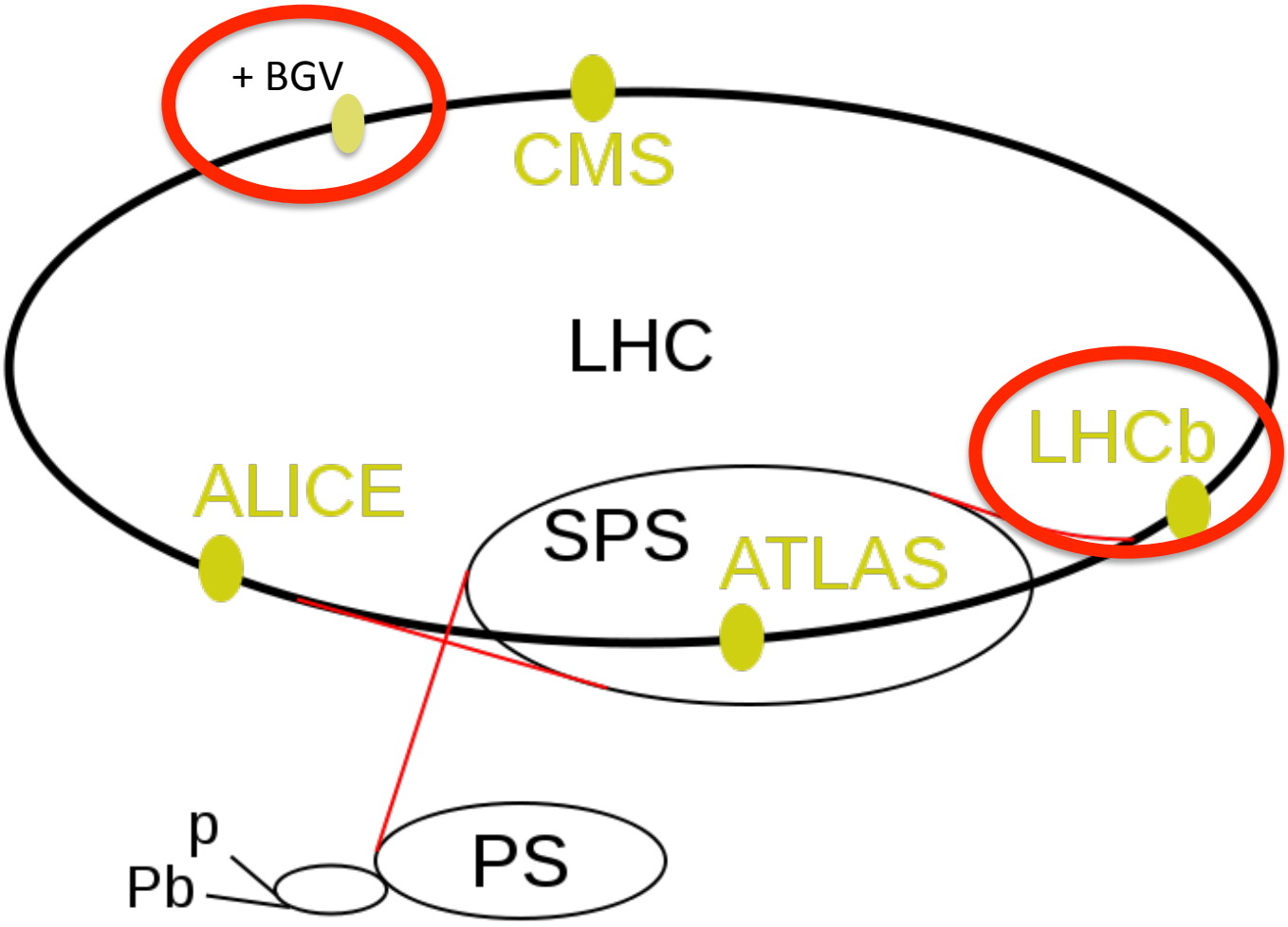
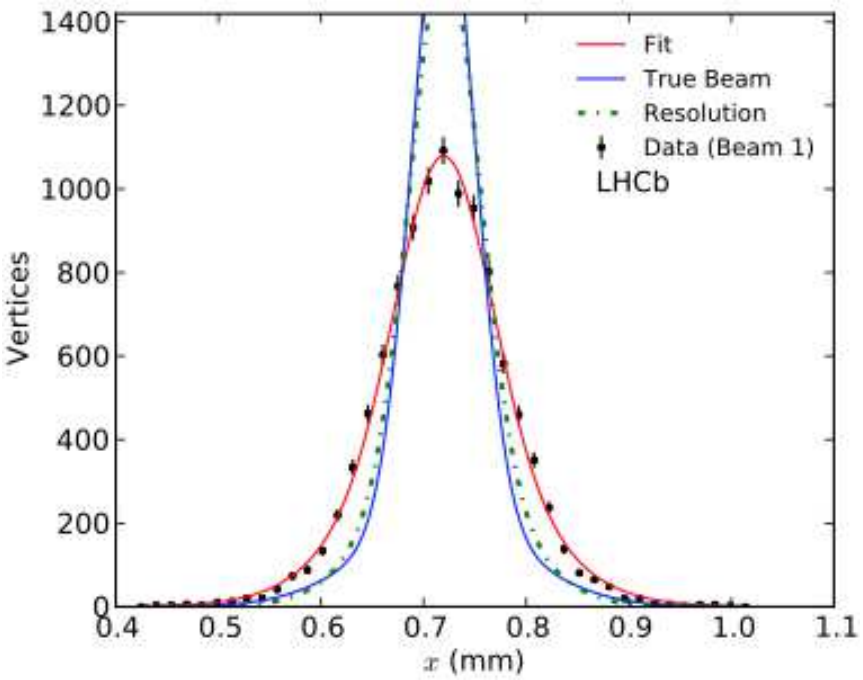
on behalf of the LHCb and BGV collaborations
Vienna Conference on Instrumentation
Feb. 16th 2016

The LHC at CERN



Why beam imaging?

- Single beam diagnostics for the accelerator
  - understand the performance
  - transverse beam profile -> beam size, emittance:
    $$\sigma^2 = \varepsilon\beta^*$$
  - beam angles and positions
  - Longitudinal profile (not discussed here)
  - Bunch intensity
- Luminosity for experiments
  - Combines beam diagnostics with physics experiments



Luminosity

Relates cross section σ to interaction rate R of accelerator based particle physics experiment:

$$R = L\sigma \quad \text{for simple single Gaussian:} \quad L \approx \frac{f N_1 N_2}{4\pi\sigma_x\sigma_y}$$

More complicated in reality:

$$L = f_{rev} N_1 N_2 \Omega$$

With Ω being the overlap integral:

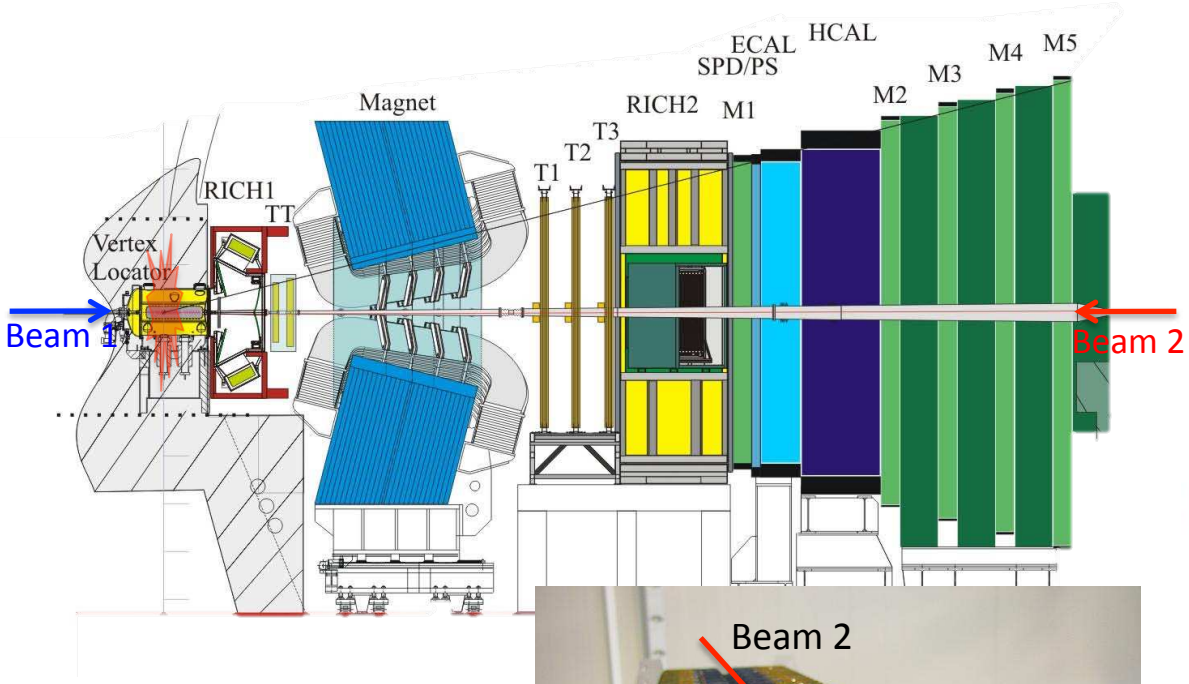
$$\Omega = 2c \int \rho_1(x,y,z,t)\rho_2(x,y,z,t)dxdydzdt$$

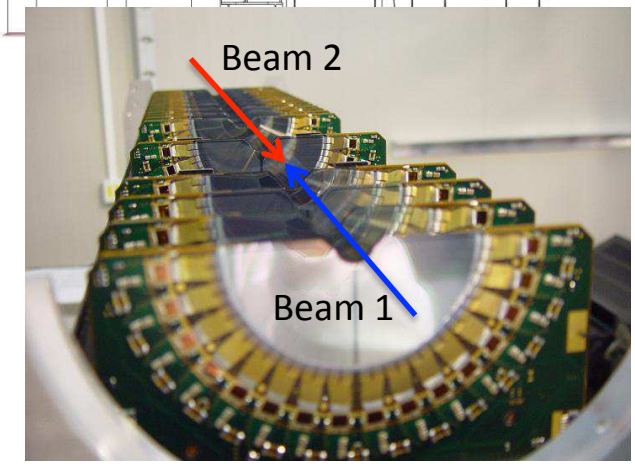
N_i: bunch population

f_{rev}: revolution frequency

ρ_i: spatial particle density distribution

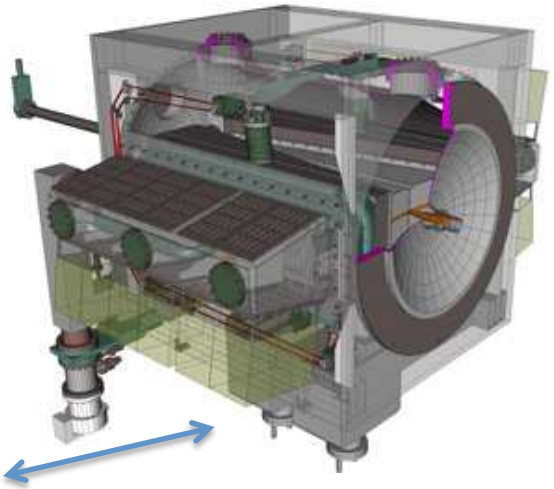
LHCb detector





Forward single arm spectrometer
VELO: silicon strip detector

See talks of:
K. Carvalho Akiba
and K. Hennessy



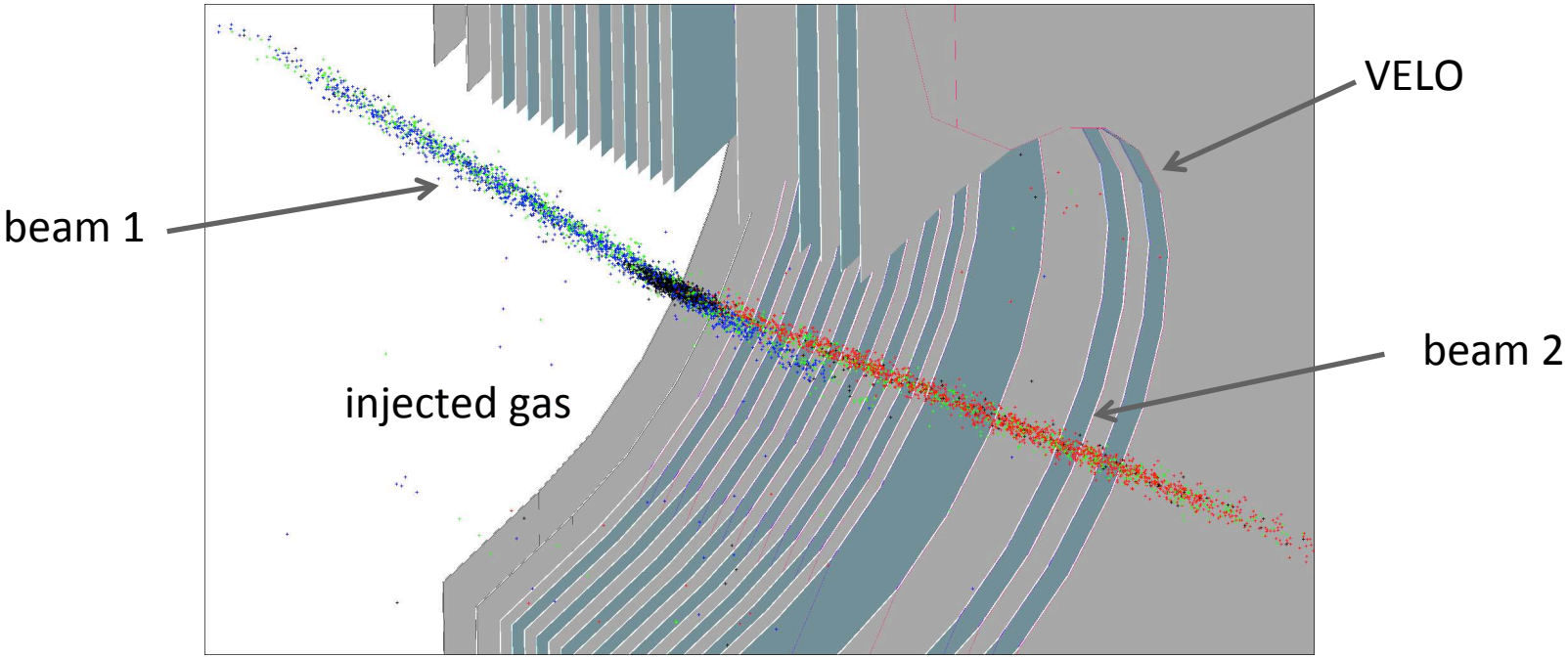
2008 JINST 3 S08005

Luminosity measurement at LHCb

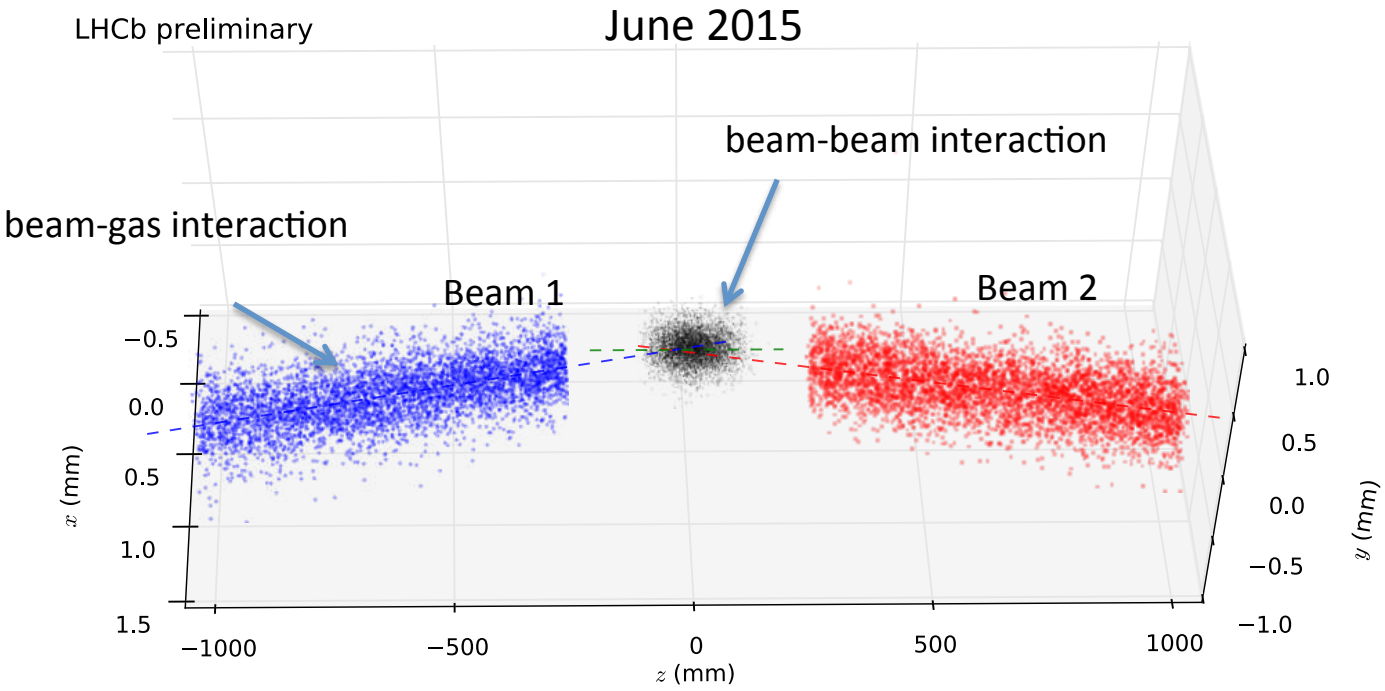
Two methods: Van-der-Meer scans and beam gas imaging (BGI)

BGI uses gas injection (noble gas) in VELO

Measures interactions of beam on beam, beam on gas and empty bunches on gas



2015 results



BGI measurements used for luminosity calibrations:

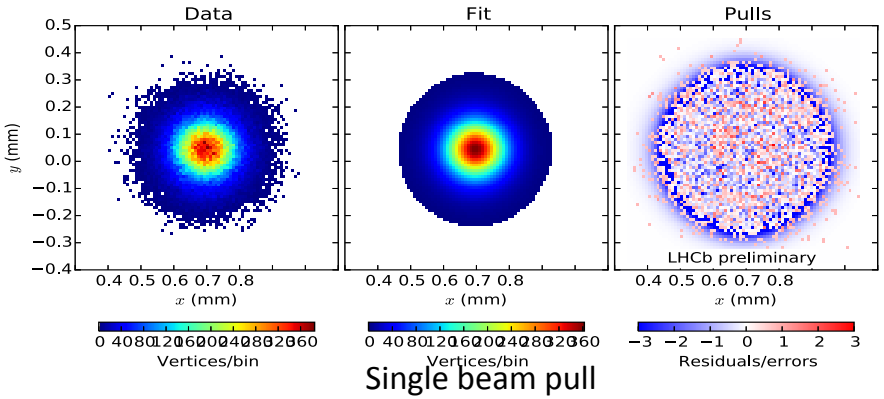
p-p, 6.5TeV June -> preliminary calibration, fast result obtained" parasitically, e.g. no dedicated BGI fill

absolute reference cross section: 63.40 mb ±2.47 mb (±3.9%)

To achieve results need:

imaging of luminous region (black), imaging of beam 1 (blue) and imaging of beam 2 (red)

2015 results

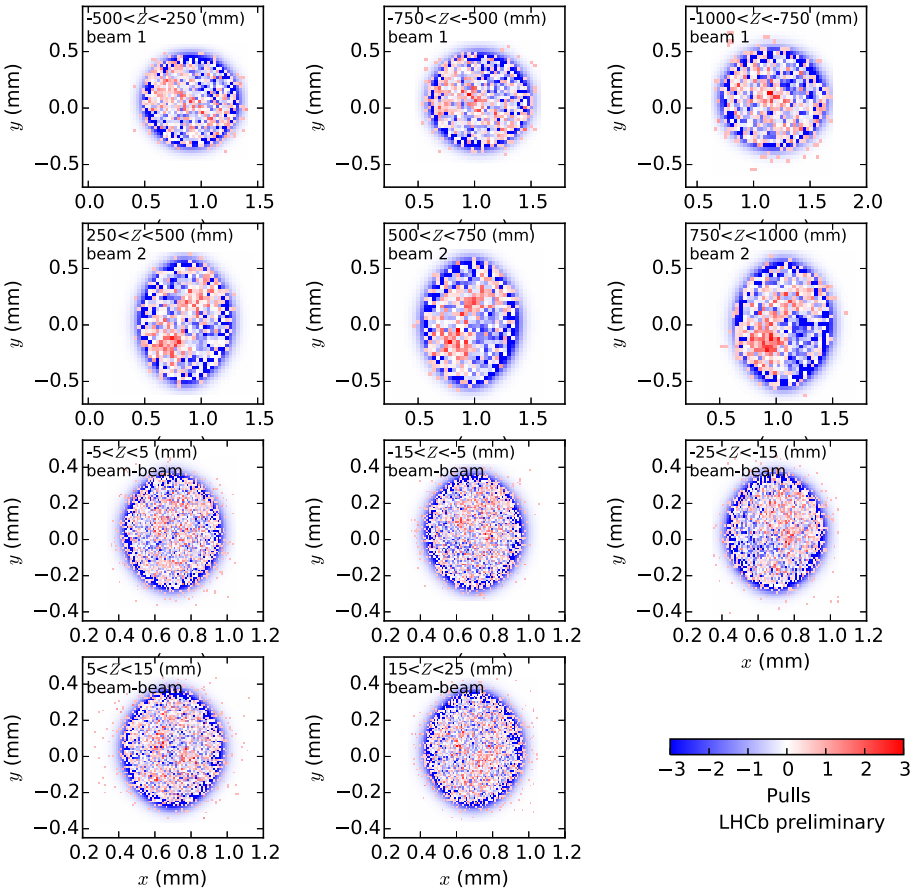


Single beam pull

Procedure used already in Run1 in 2012, achieved 1.4% precision on luminosity measurement for pp at $\sqrt{s}$ = 8 TeV

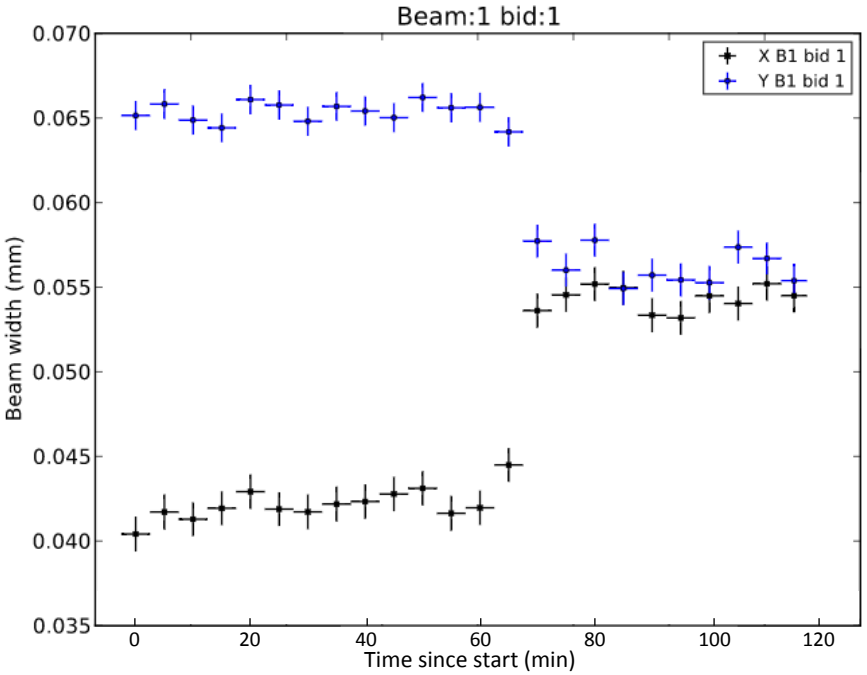
Data and fit. Pull represent the significance of the deviation of the data to the model.

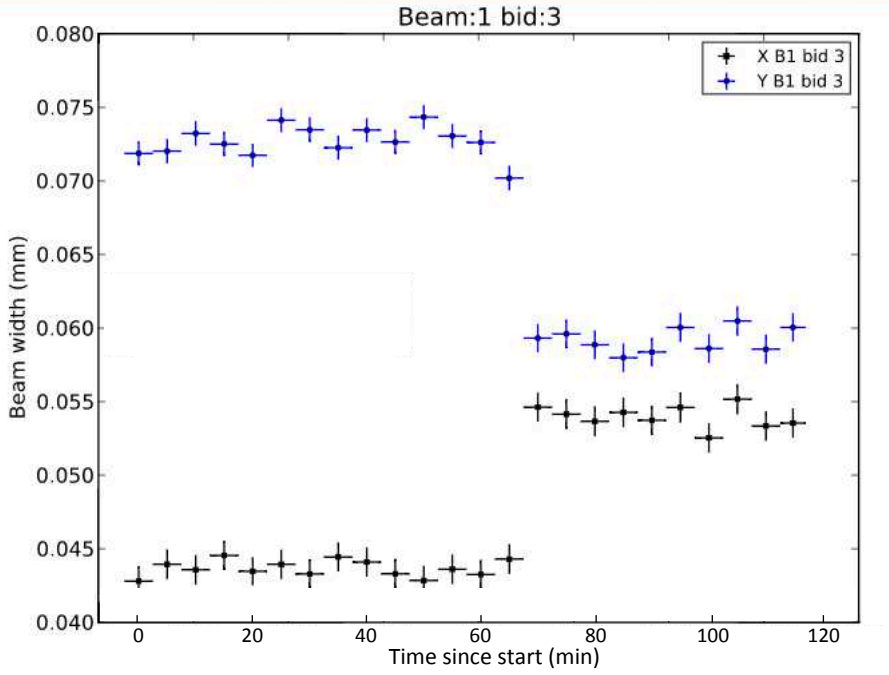
The method is explained in detail in luminosity paper:
2014 JINST 9 P12005



Limitations of VELO BGI method

High precision beam profile measurement only during closed VELO
Performance is reduced if LHC is not in “STABLE BEAMS”
Change in beam width measured during ramp with open VELO:



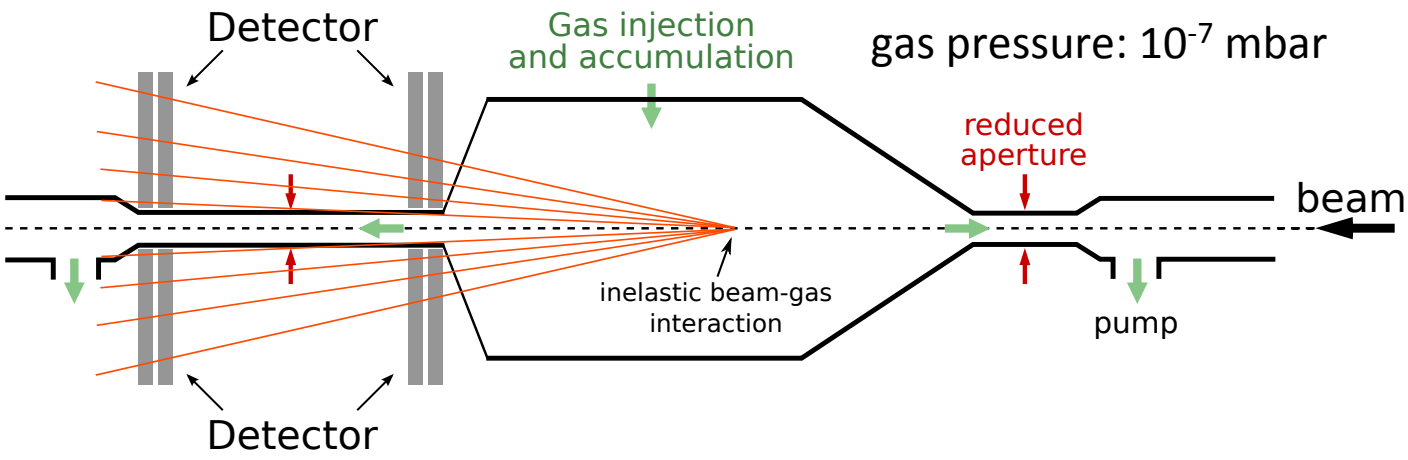


Beam diagnostics: measure beam profiles during injection and energy ramping
-> want dedicated device that can measure beam gas interactions and beam profiles during all energies of the beam in the LHC

Beam Gas Vertex Detector - BGV

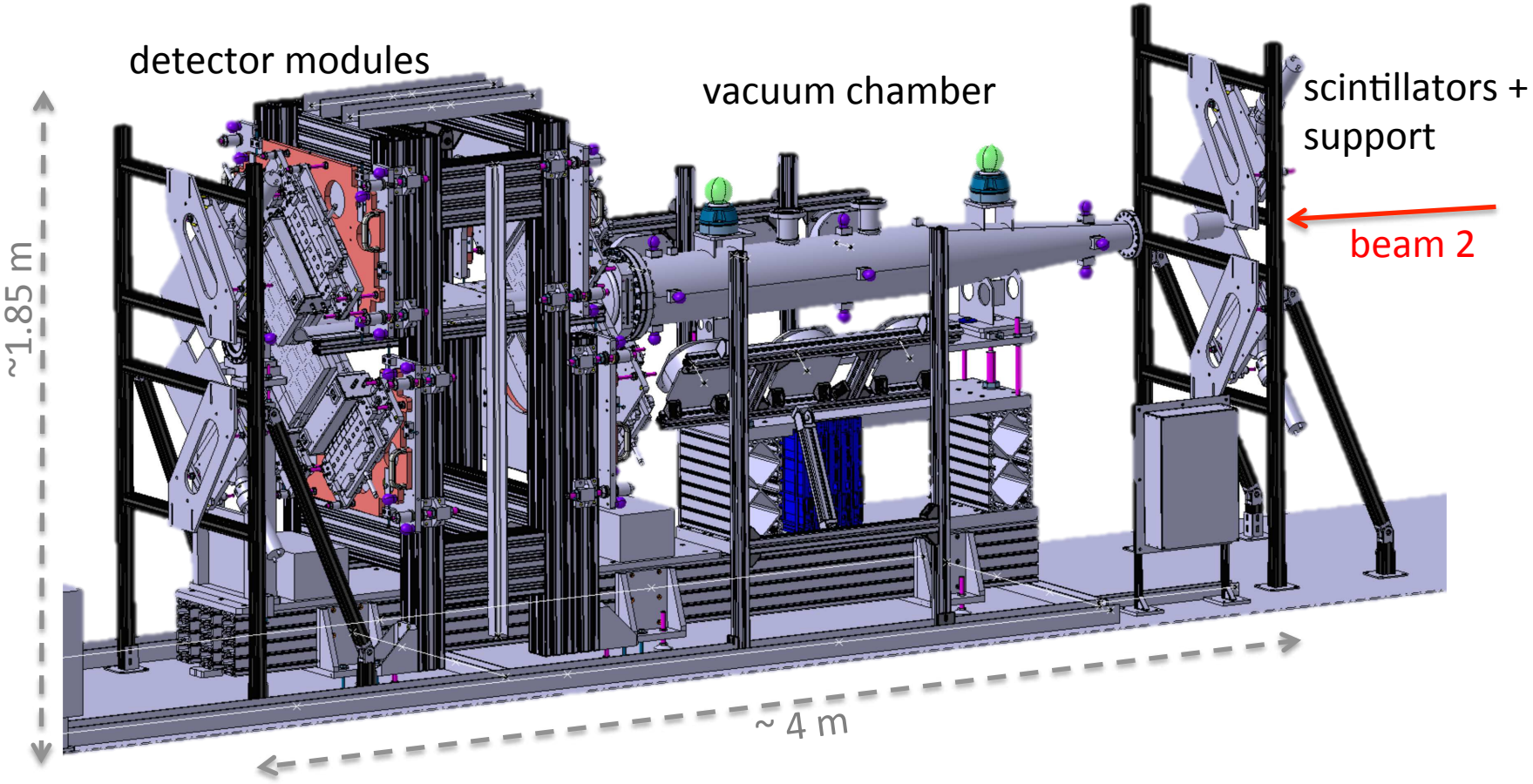
Same principle as BGI in VELO but demonstrator on one LHC beam line

To measure the transverse beam profiles at any LHC beam intensity

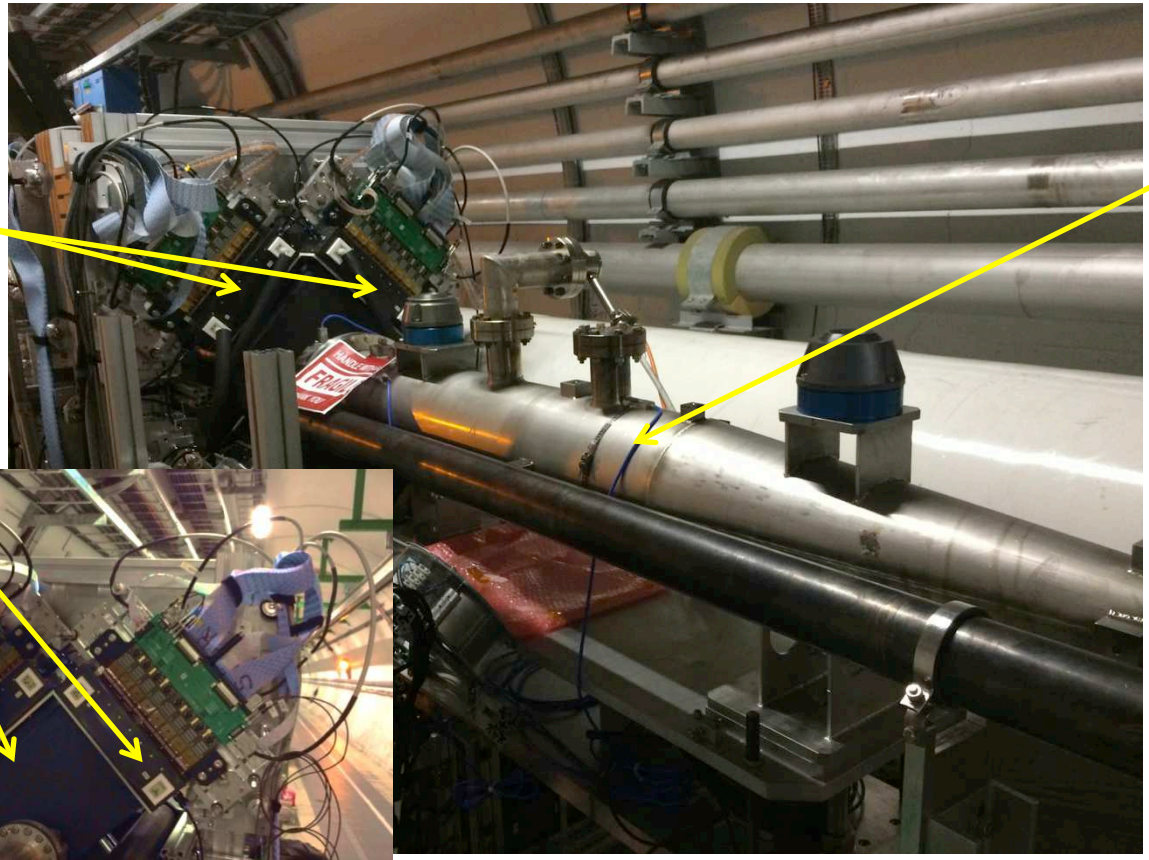


estimated interaction rate:
~70 Hz per bunch

BGV demonstrator



BGV demonstrator



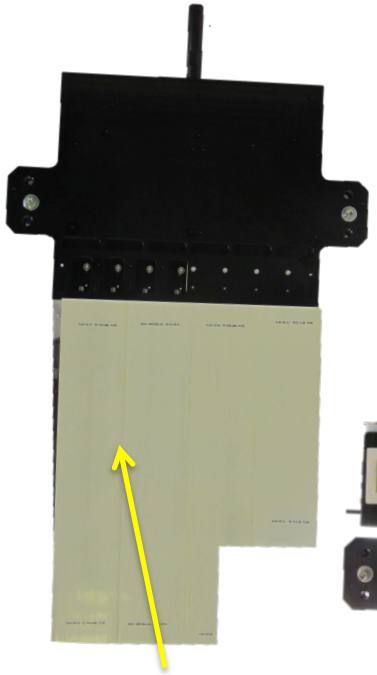
scintillating fibre mats + SiPMs

vacuum chamber with Ne gas injection

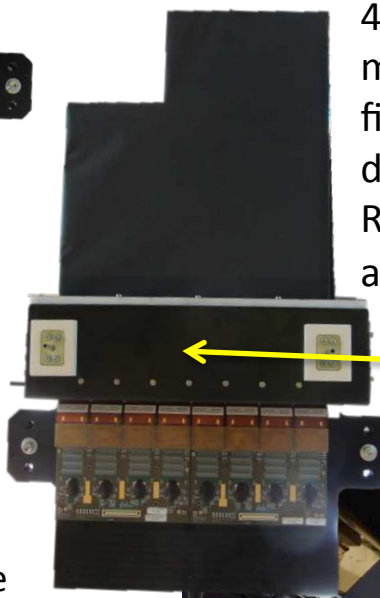
beam line 2

beam line 1

Detector modules

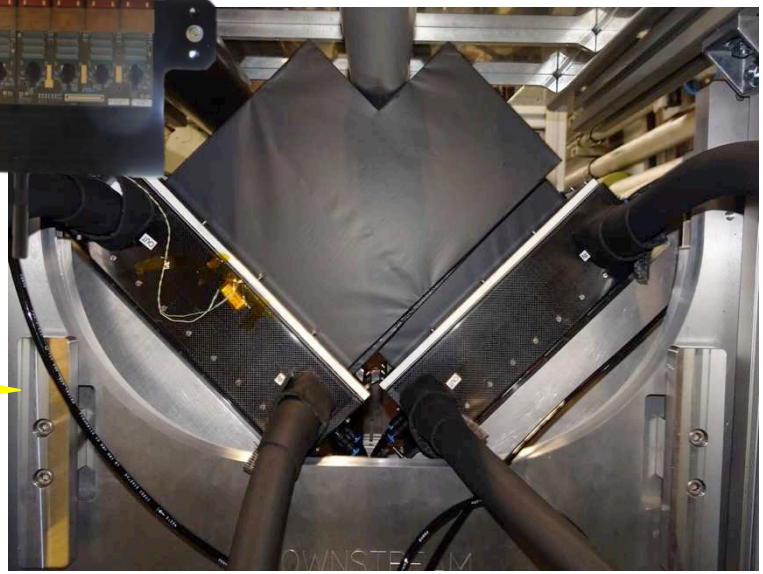


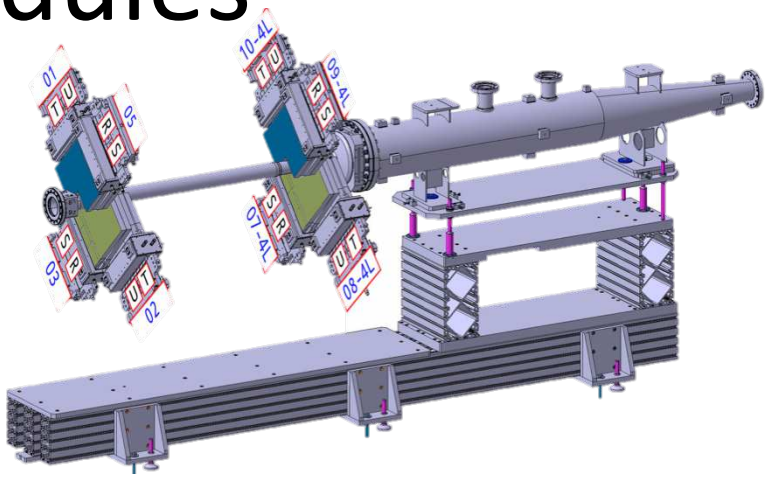
Scintillating fibre mats

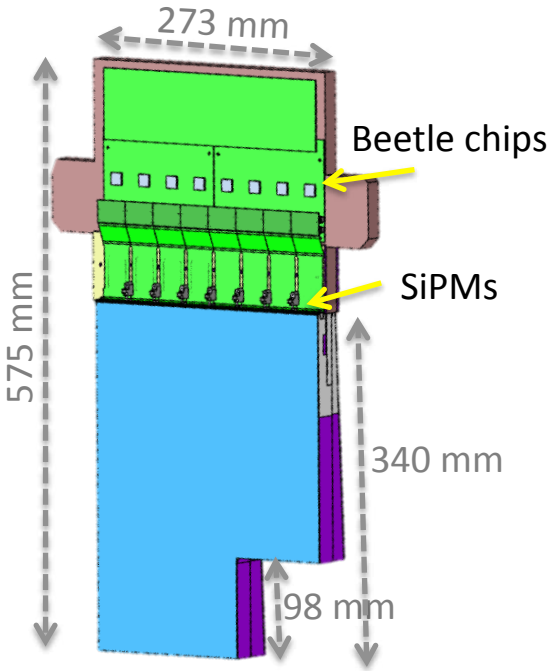


4- and 5-layer modules scintillating fibers with a diameter of 250µm
Read out with SiPMs and Beetle chip

Dry air and cooling







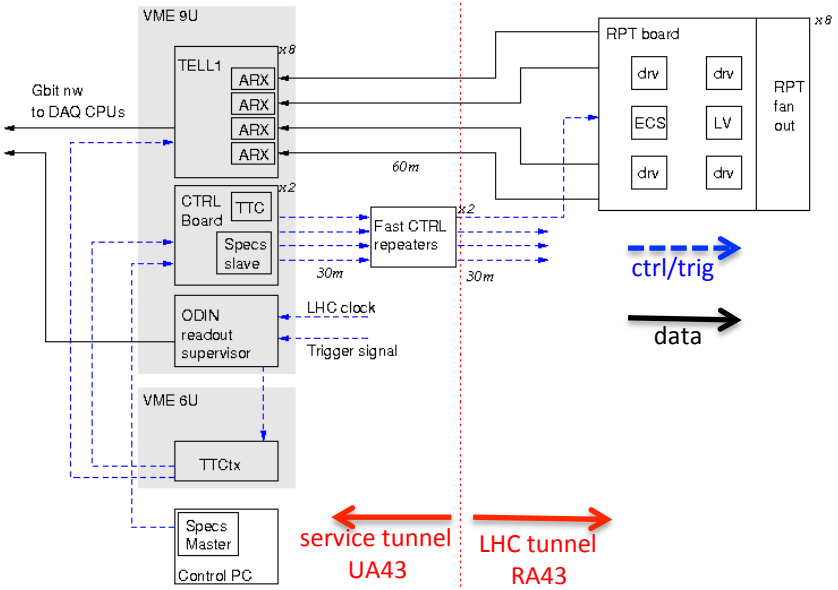
See talk of:
T. Kirn

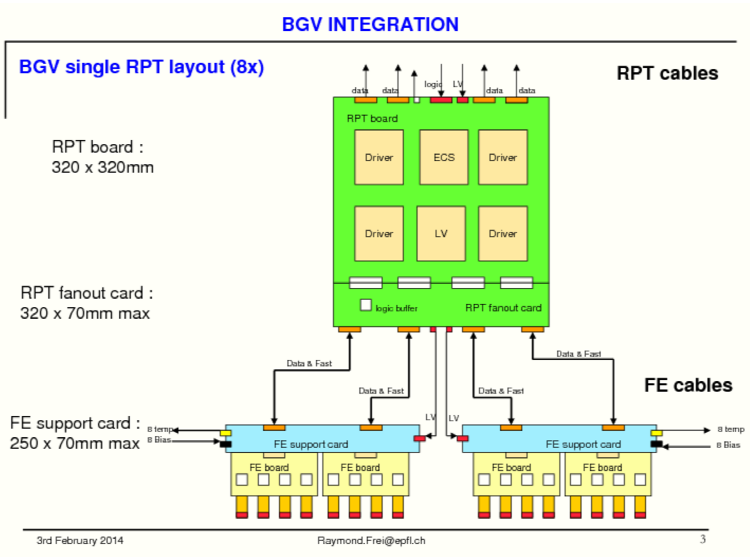
DAQ FE readout

SiPM signal read out by Beetle chips (radiation hard analogue, developed for LHCb)

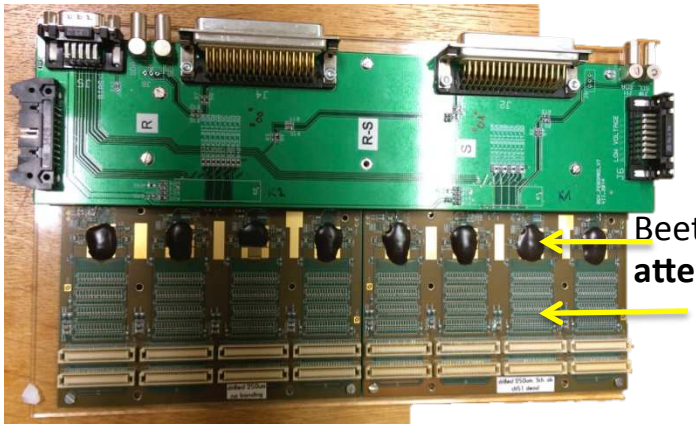
16 Beetles per modules, 2048 channels per module

Further DAQ components: repeater boards, Tell1 ADC, computing farm, offline analysis



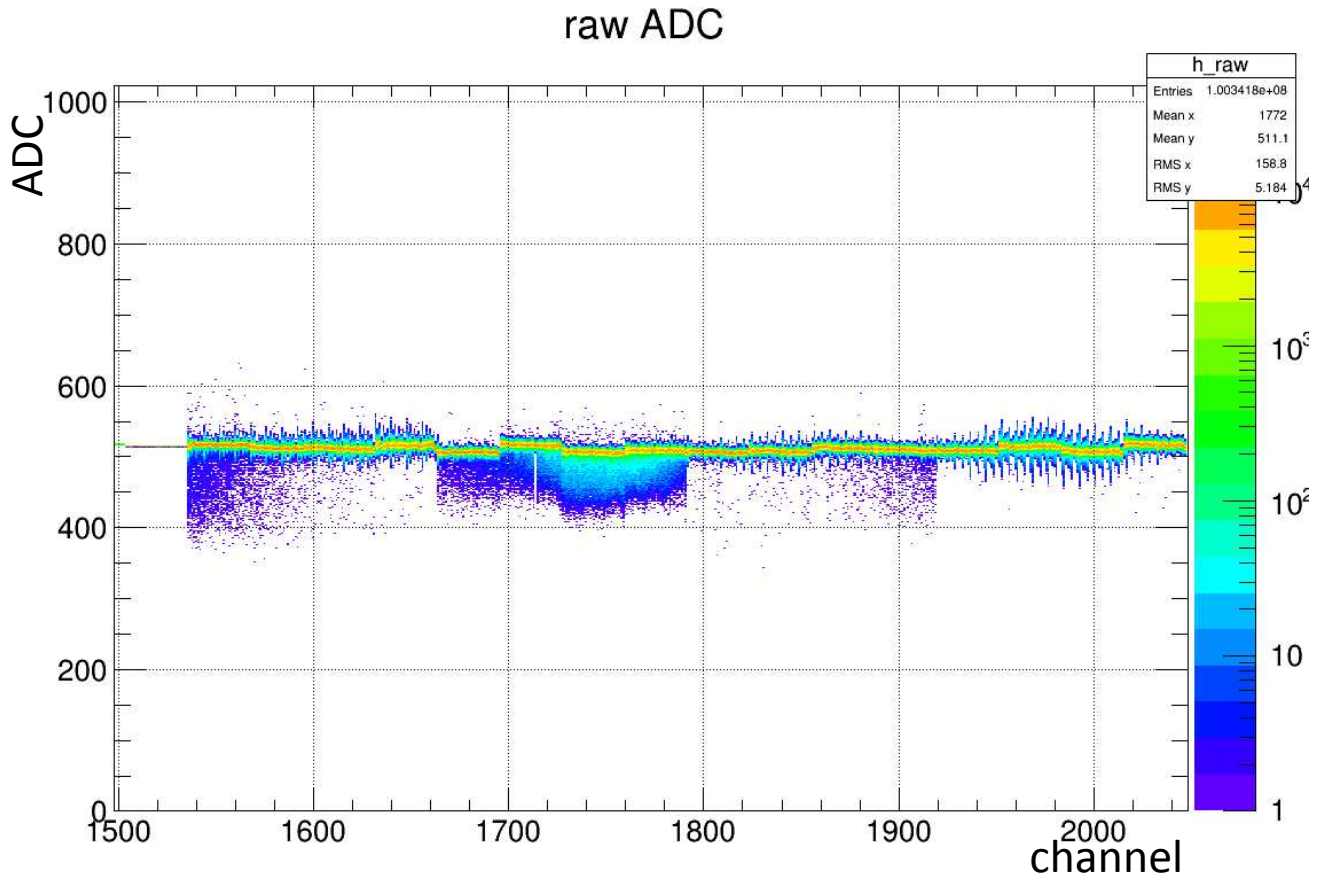


Specific front end boards to adapt for the SiPM chips



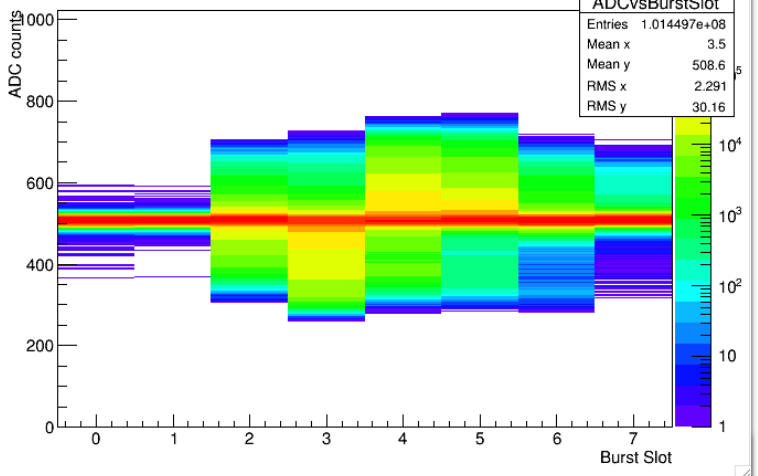
Module quality tests

Ensure that modules worked after transport from Lausanne to CERN. Dead channels act as finger print for each module.
Dark counts at low temperatures and with Sr source

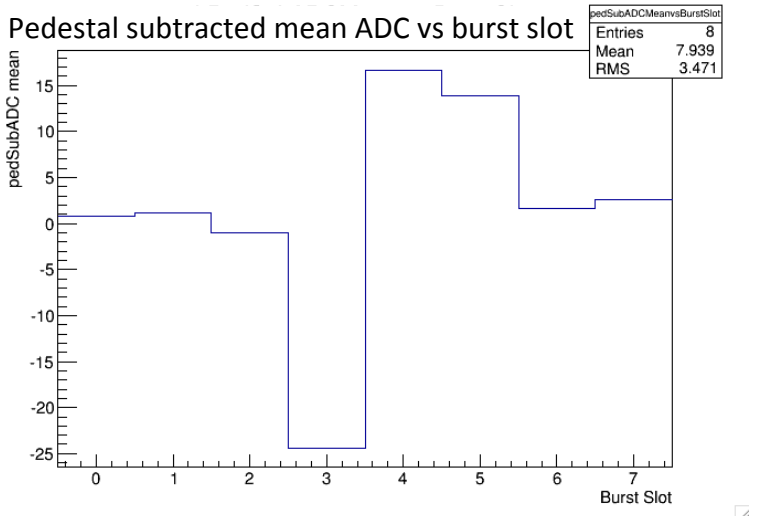


BGV Commissioning - timing

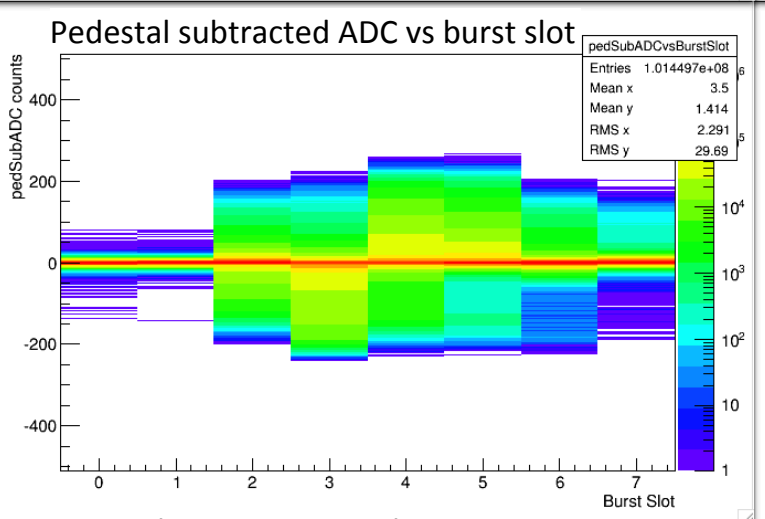
ADC vs burst slot



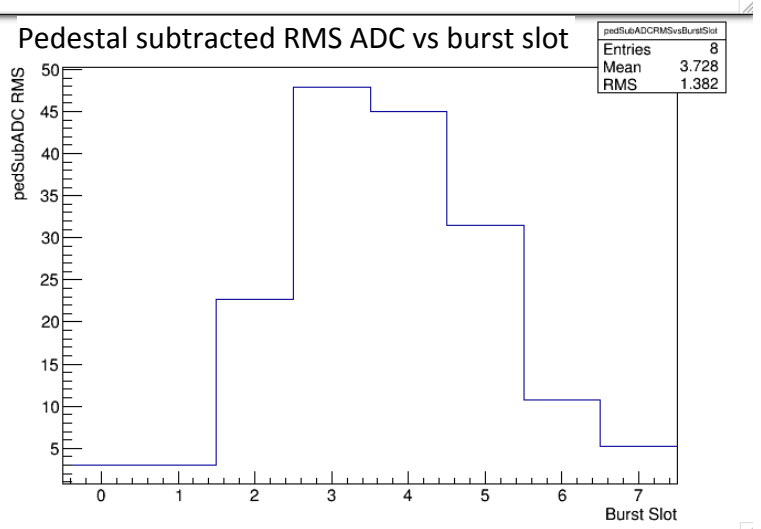
Pedestal subtracted mean ADC vs burst slot



Pedestal subtracted ADC vs burst slot

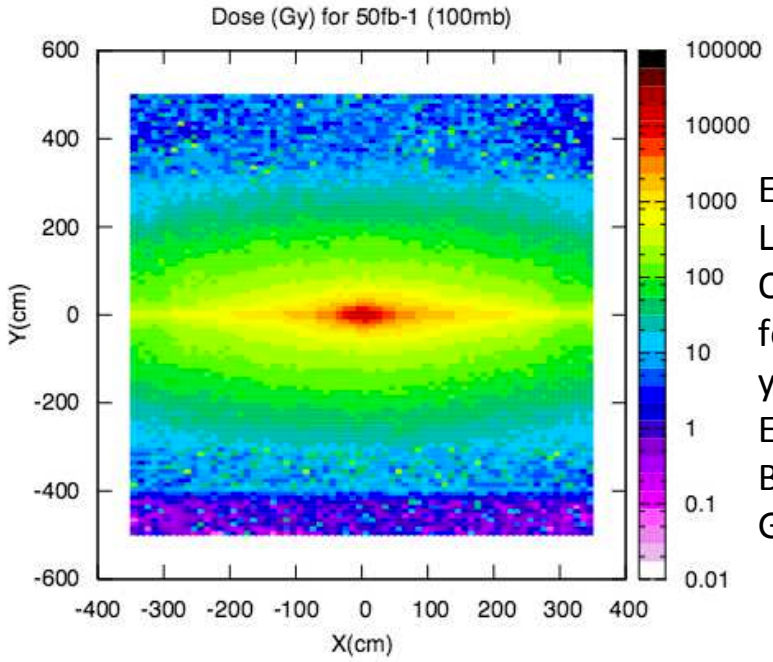


Pedestal subtracted RMS ADC vs burst slot

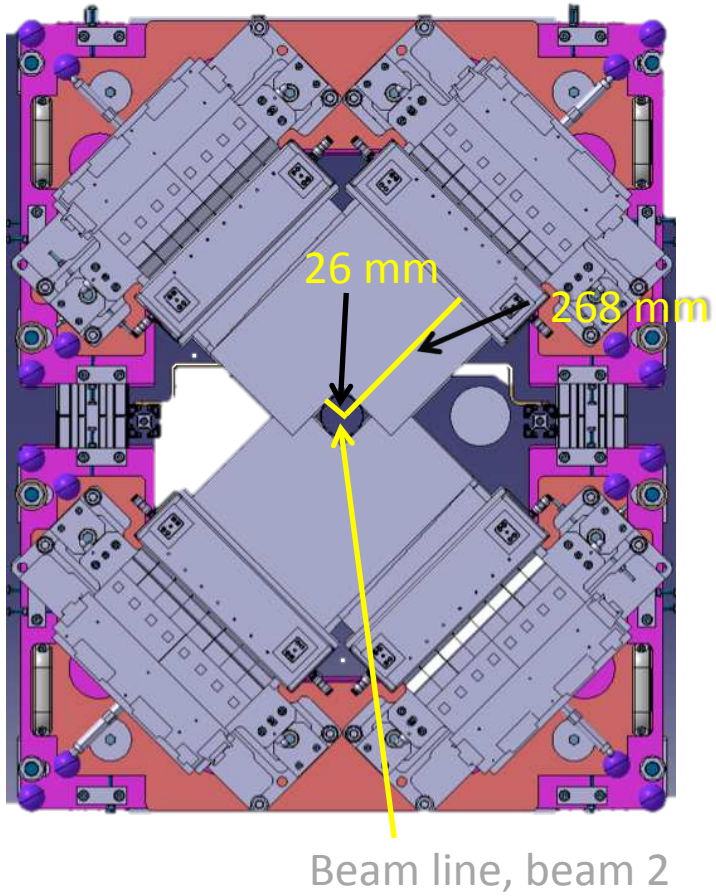


Burst slot:25ns spacing between triggers

Radiation impact, cooling



Expectation for LHCb SciFi tracker: Order of 100 Gy for SiPMs over 10 years
Expectation for BGV: order of 10 Gy/year on SiPMs



Radiation affects mainly SiPMs:
dark current, noise clusters
-> cooling needed:

C_6F_{14}, up to minus 40°C

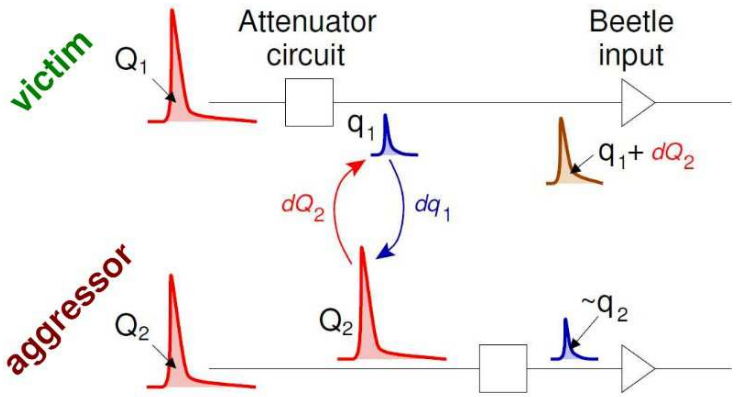
dry air system to avoid condensation

BGV ongoing work

Corrections:

Pedestals, noise,

header cross talk (attenuator circuit induces cross talk in neighbouring channels, is deterministic and can be corrected for)

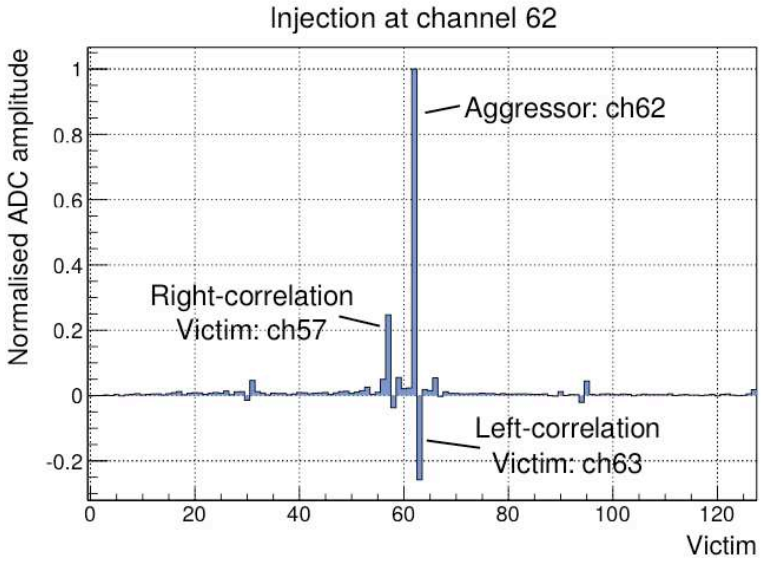


Find clusters:

Run tools to make clusters which are the base for tracks and vertices

Live monitor of transverse beam profile on beam 2

Cooling, timing

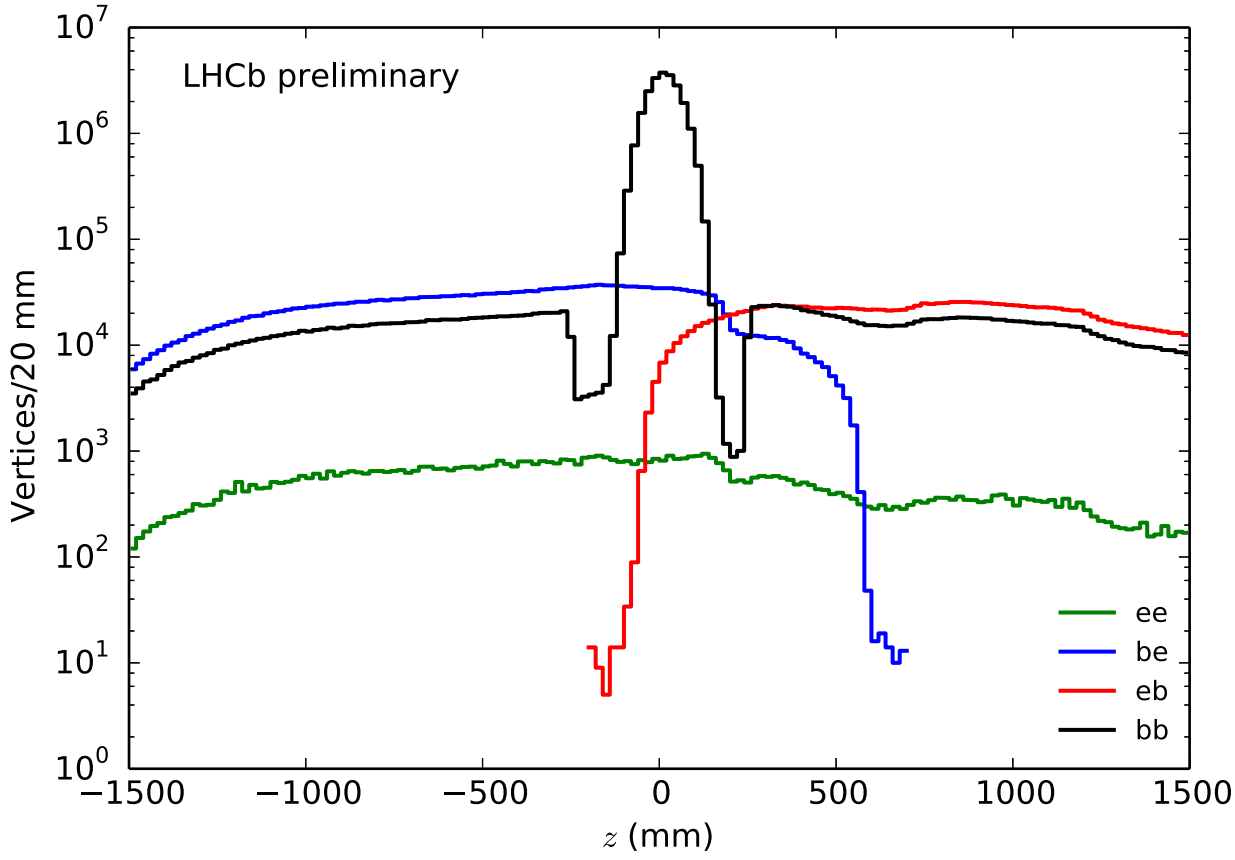


Summary

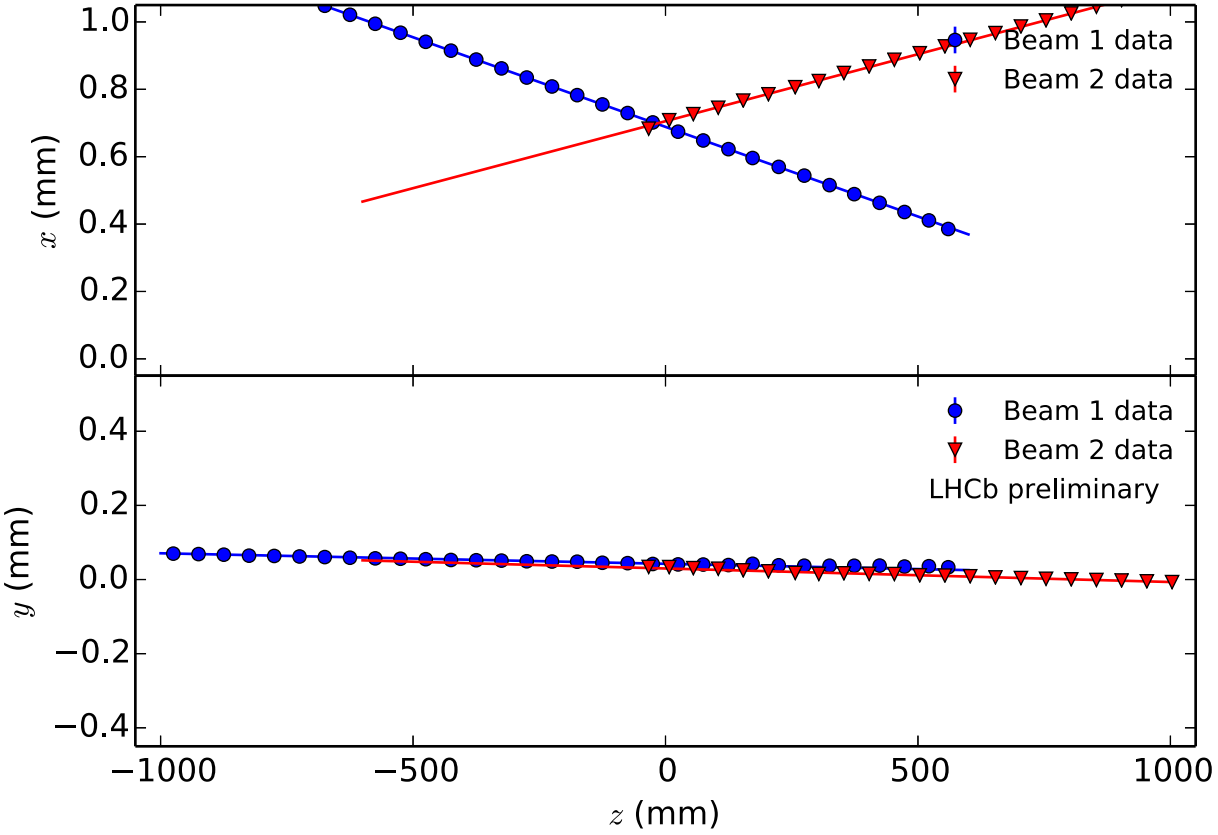
- demonstrated the usability of LHCb BGI method for beam imaging
- BGI used for luminosity measurements, in good agreement with VdM scans
- dedicated device to measure transverse beam profiles, using beam gas imaging-> BGV
- Synergies with SciFi tracker development at LHCb
- BGV currently under commissioning
- BGV system will be used in the 2016 LHC run, results presented soon

Backup slides

2015 results -> backup



2015 results



Angles between beam 1 and beam 2 in x and y axis

sciFi module with cooling