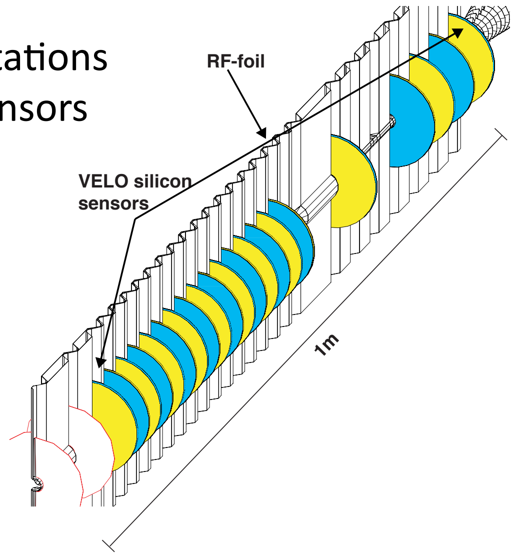
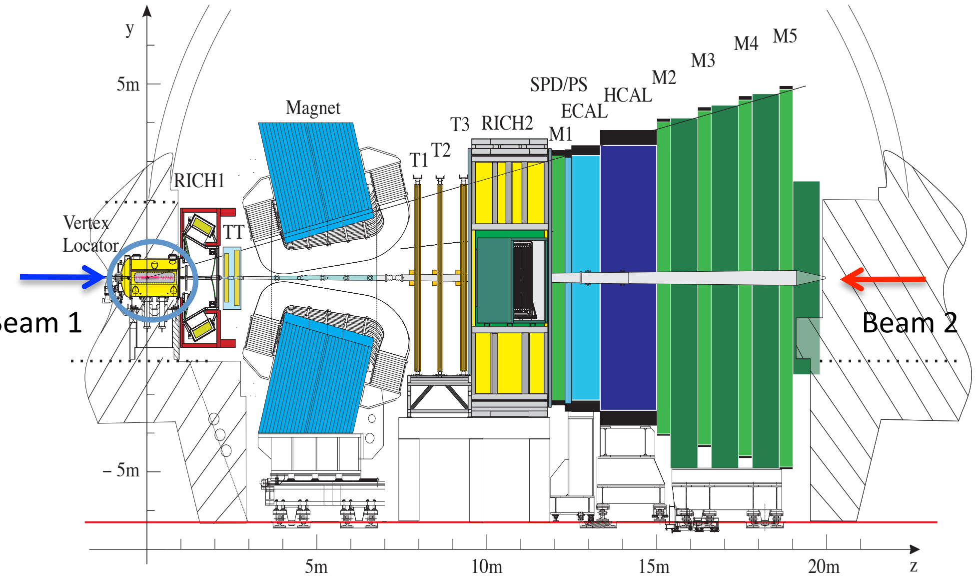
Beam gas imaging at LHCb

Colin Barschel

LHCb beam gas imaging

VELO:
2x21 stations
R-Φ sensors

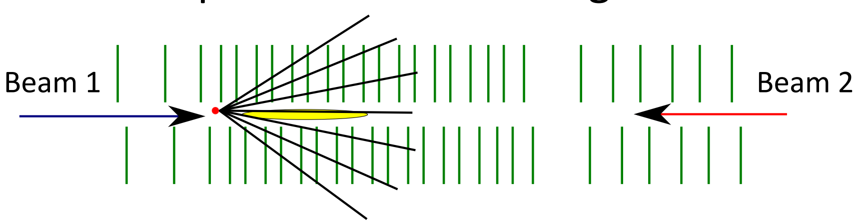




Individual beams "visible" with residual gas interactions

- Measure single beam shape, position, angle
- Measure single bunch relative intensity
- Measure charges outside filled bunches (so-called ghost charge)

Collision proton <–> residual gas molecule



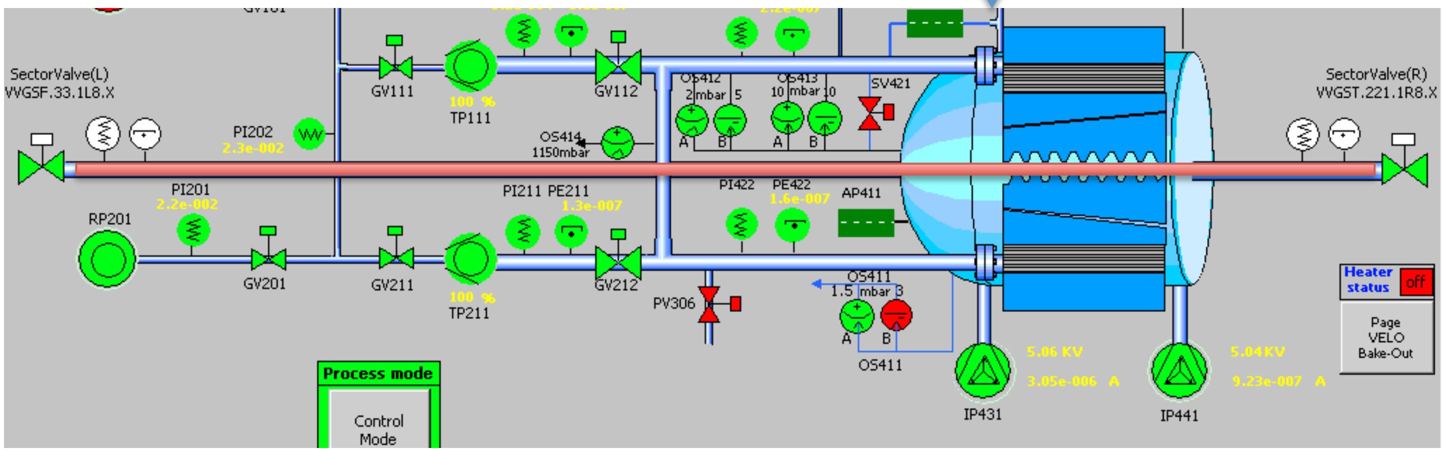
Accuracy is limited by:

- Statistics
- Resolution wrt beam width

Improve statistics: SMOG

Inject neon during dedicated fills to increase pressure in VELO beam vacuum

SMOG

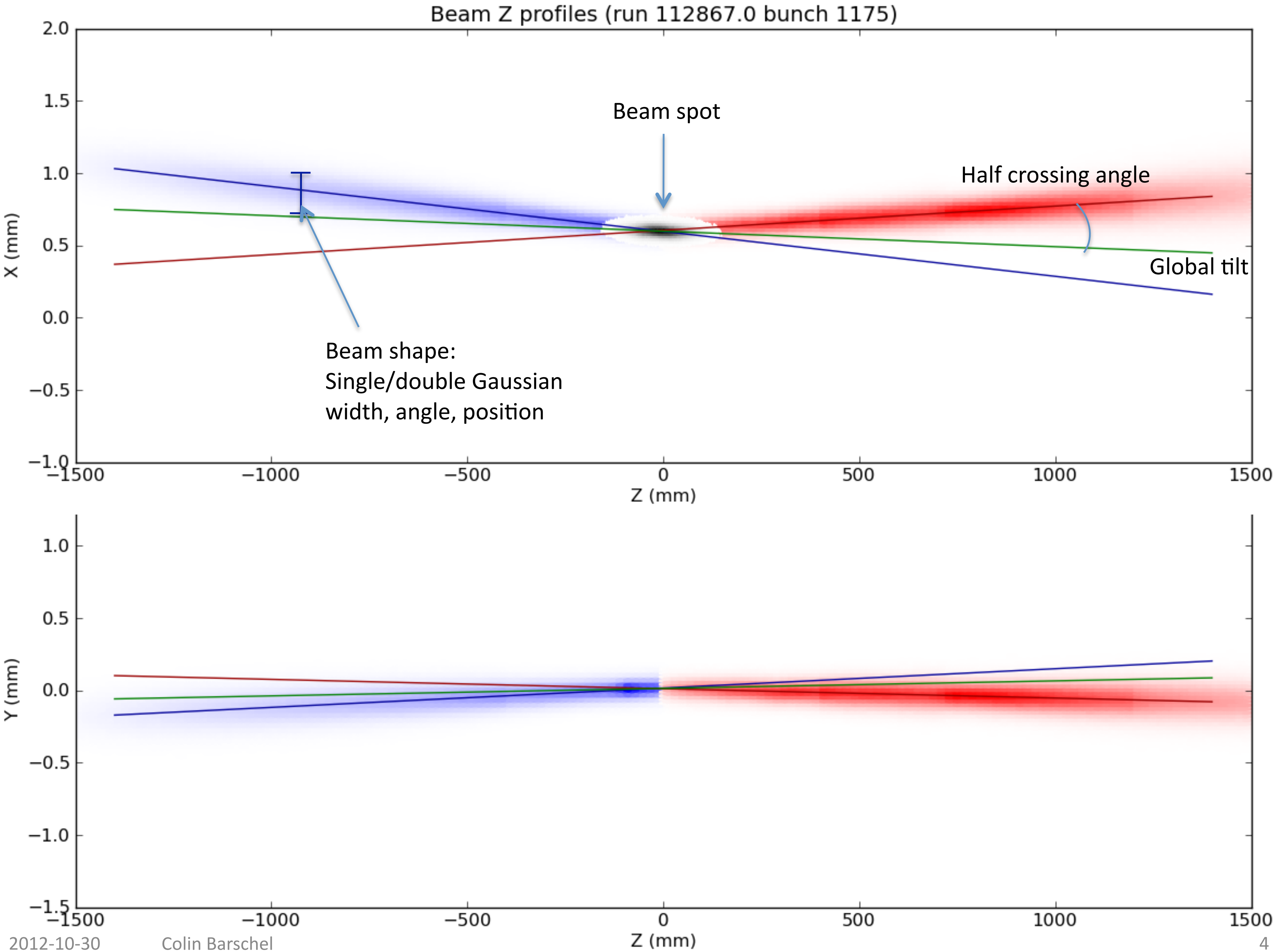


Nominal:
VELO pressure≈ 1-2×10^{-9} mbar
≈ 0.1 Hz/10^{11} protons

With SMOG:
≈ 2×10^{-7} mbar
≈ 20-40 Hz/10^{11} protons

Commissioning Nov 2011 and 1st test with p-Pb beam in 2011

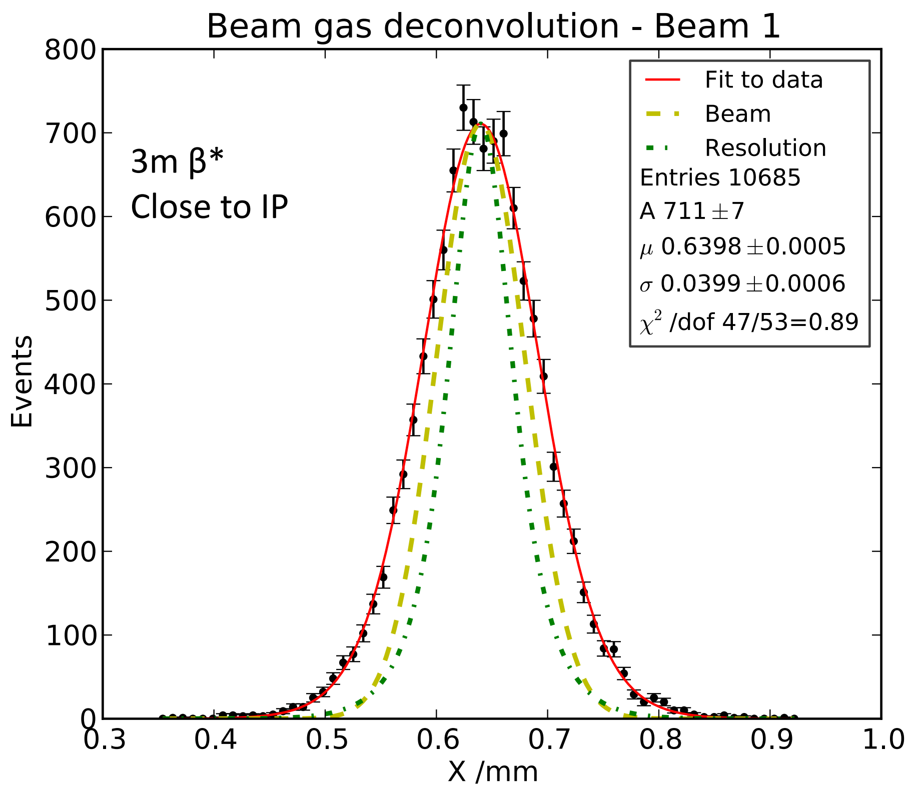
- SMOG operational - has been used during 8 fills including 1 MD and 1 p-Pb
- SMOG usage is fully transparent from LHC point of view (no effect on beam)

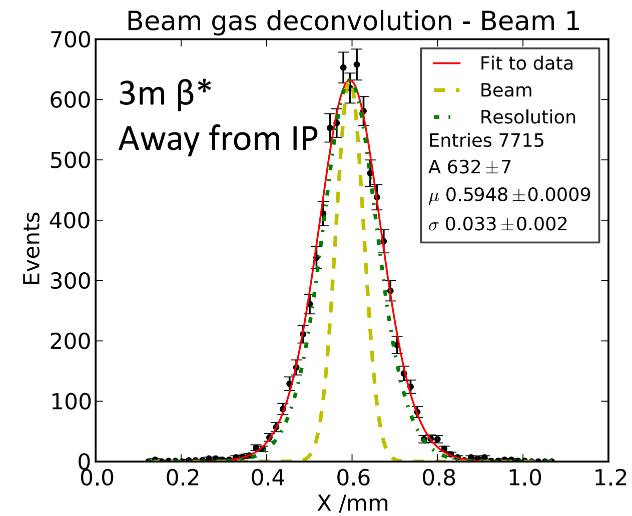

Beam Z profiles (run 112867.0 bunch 1175)
Beam spot
Half crossing angle
Global tilt
Beam shape:
Single/double Gaussian
width, angle, position
X (mm)
Z (mm)
Y (mm)
Z (mm)

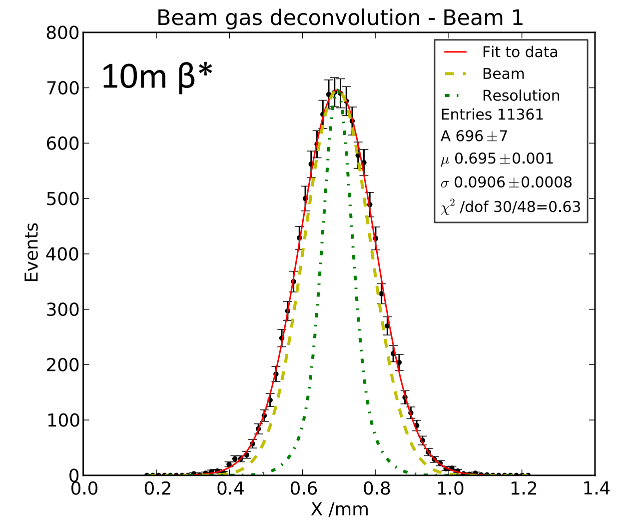
How to extract true beam width

Measured beam width is a convolution of true beam with the resolution
With Gaussian beam we get:

$$\sigma^2_{raw} = \sigma^2_{beam} + \sigma^2_{resolution}$$







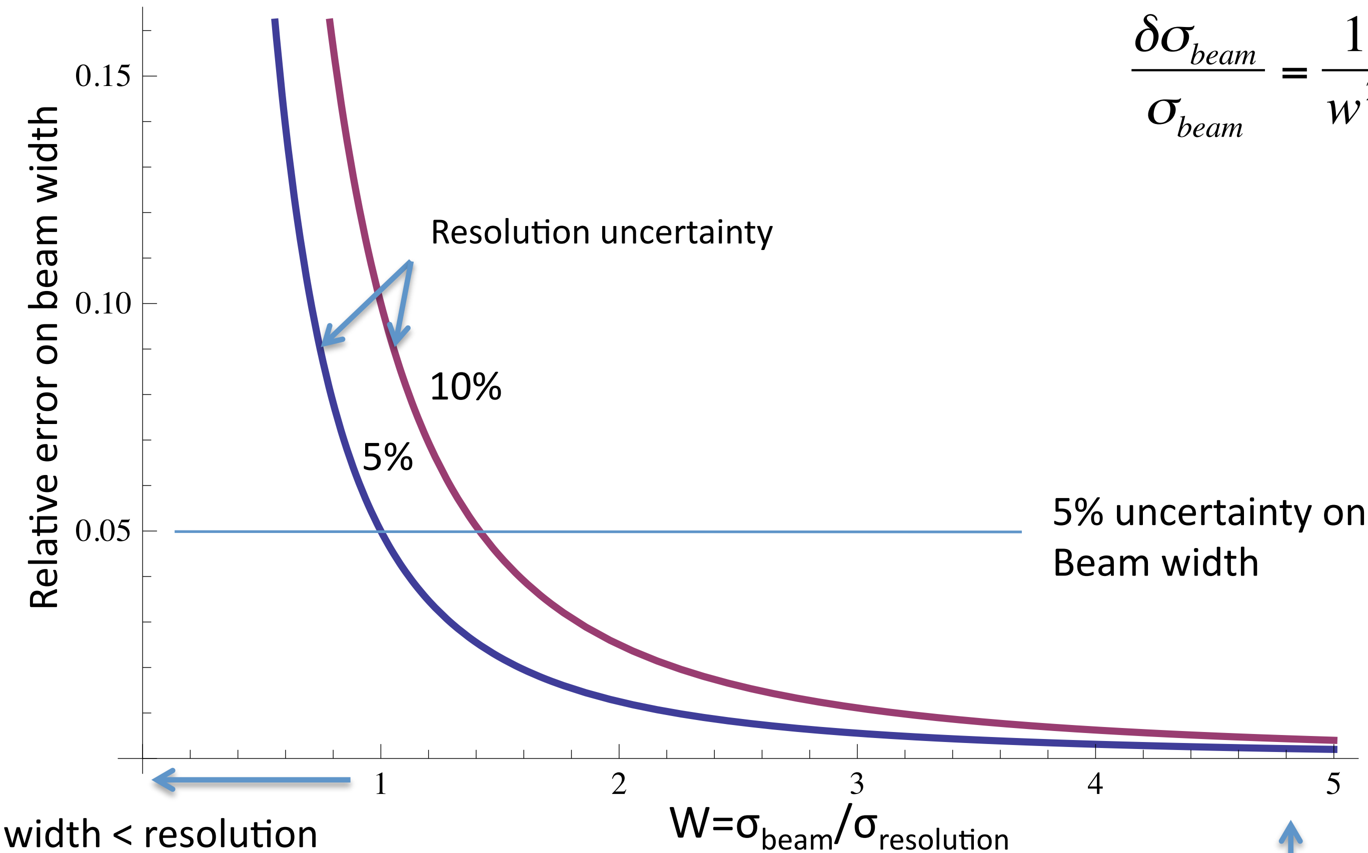
Resolution

What is important (and why):
- Know resolution to better than 10%
- True beam width > resolution

$$\sigma_{raw}^2 = \sigma_{beam}^2 + \sigma_{resolution}^2$$

$$w = \sigma_{beam} / \sigma_{resolution}$$

$$\frac{\delta\sigma_{beam}}{\sigma_{beam}} = \frac{1}{w^2}\frac{\delta\sigma_{resolution}}{\sigma_{resolution}}$$



Beam width < resolution

Beam width = resolution

Beam width = 2×resolution
LHCb 3m β*

Beam width ≈ 5×resolution
LHCb 10m β*

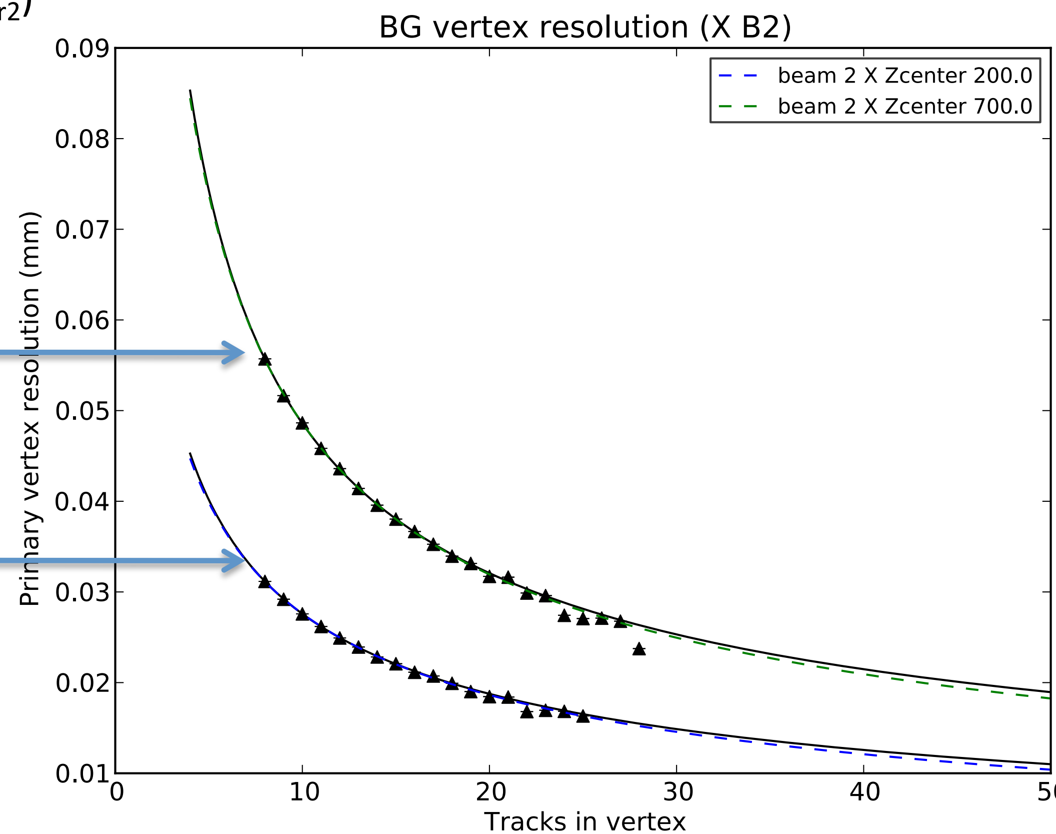
Vertex resolution

Measure vertex resolution **from data**:

•Every event reconstructed with 2 track containers with random pair of tracks N_{tr1},N_{tr2} -> 2 vertices v1, v2
•Separation of two vertices is convolution of both resolutions:
•$dX = v1-v2 = sqrt(\sigma^2_{Ntr1} + \sigma^2_{Ntr2}) = f(N_{tr1},N_{tr2})$
•Uncertainty of 5% is realistic
•Depends on N tracks and Z position

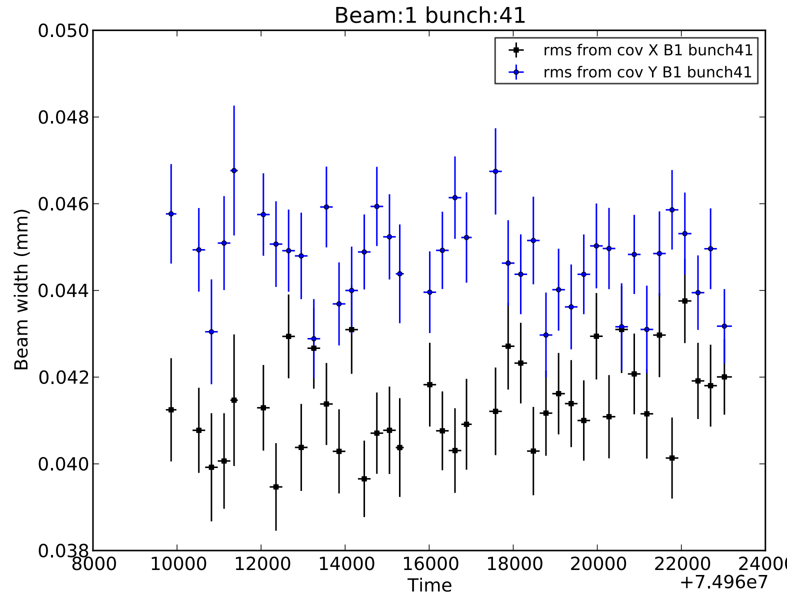
Away from interaction point

Close to interaction point

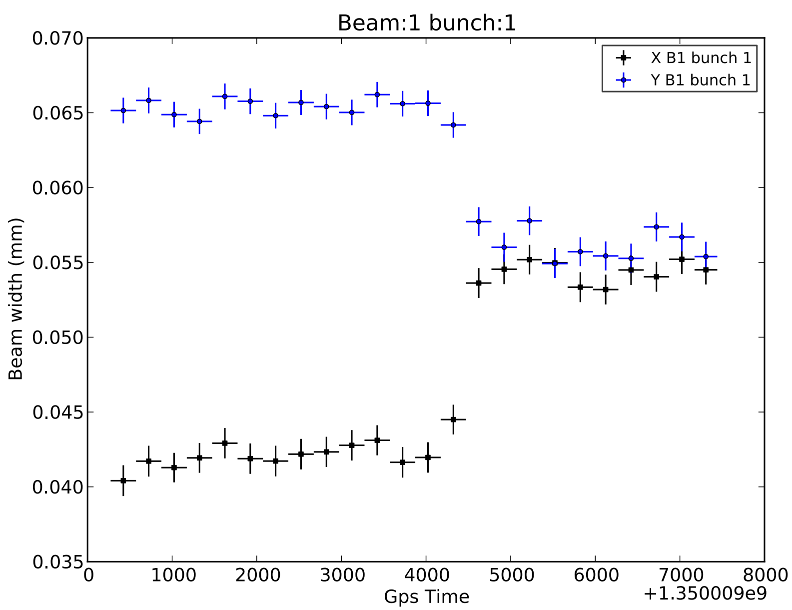


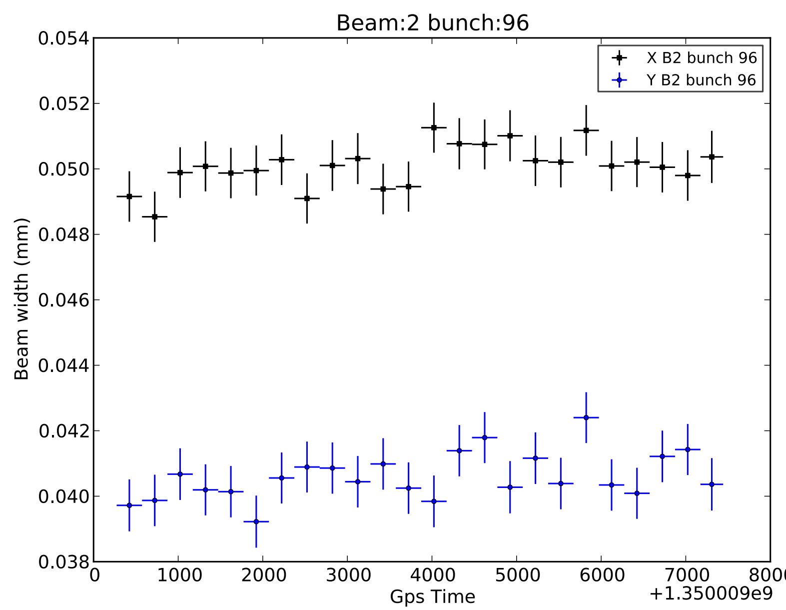
Examples (3m β*)

Beam width evolution for ATLAS/CMS
April fill 2520 (3m β*) 48 bunches/beam
(5 min time bins, ca. 3% uncertainty)



Beam width evolution for LHC MD
Sep fill 3060 (3m β*) 24 bunches/beam
(5 min time bins, ca. 2% uncertainty)

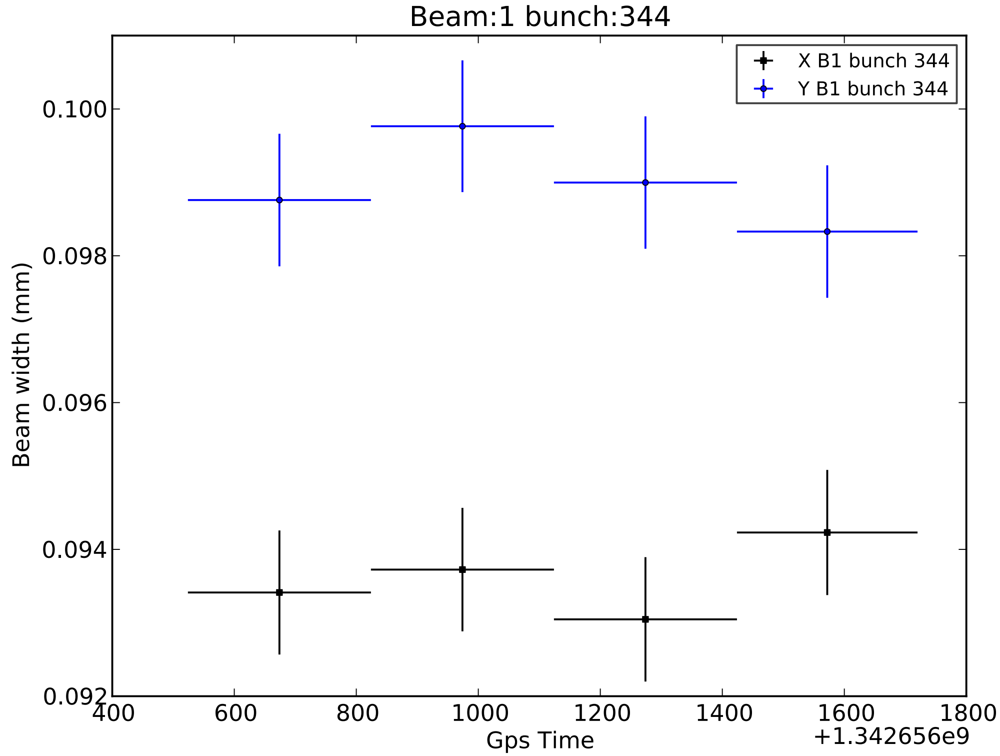




Examples (10m β*)

Beam width evolution LHCb vdM fill
April fill 2853 (10m β*)
(5 min time bins)

Ideal conditions:
Raw width ≈ 100 μm
Resolution ≈ 20 μm
Beam width ≈ 94 μm



High precision possible under ideal conditions:

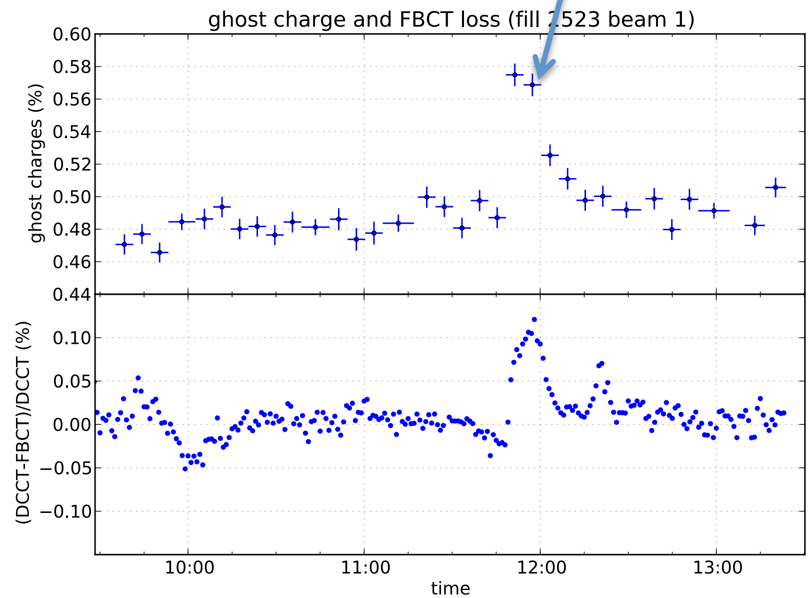
Uncertainties in 5 minutes (≈10k vertices):
Statistical: ±0.7 μm (±0.8%)
Systematic: ±0.5 μm (±0.5%)

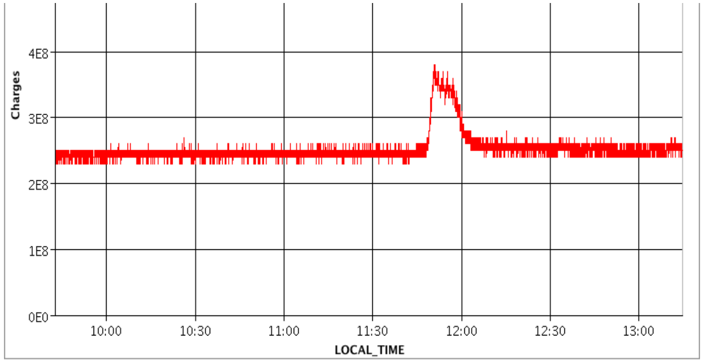
Ghost charges

i.e. charges outside nominal bunches

- With SMOG we can measure charges in empty bunches
- Important and non negligible correction for experiments
- Even sensitive to debunching

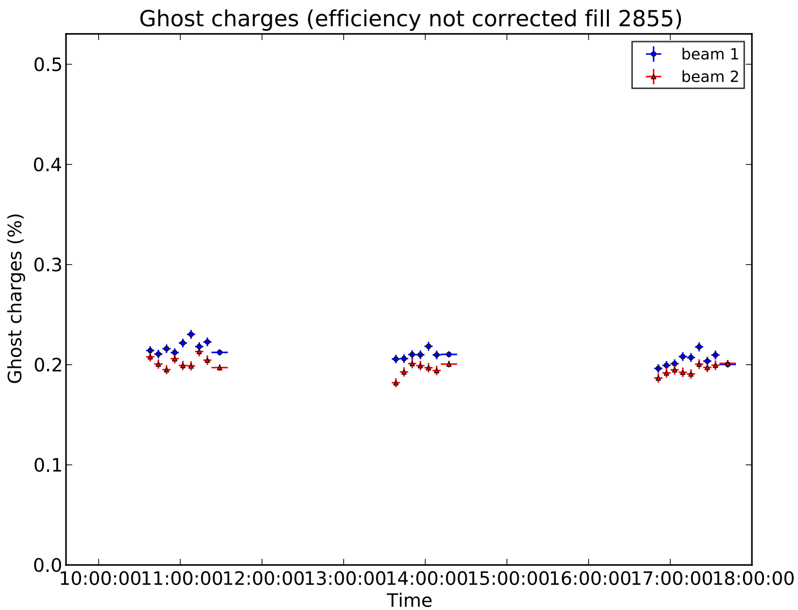
Strange behavior identified as beam debunching





Example for July: clean fill

Ghost charges ≈ 0.2%



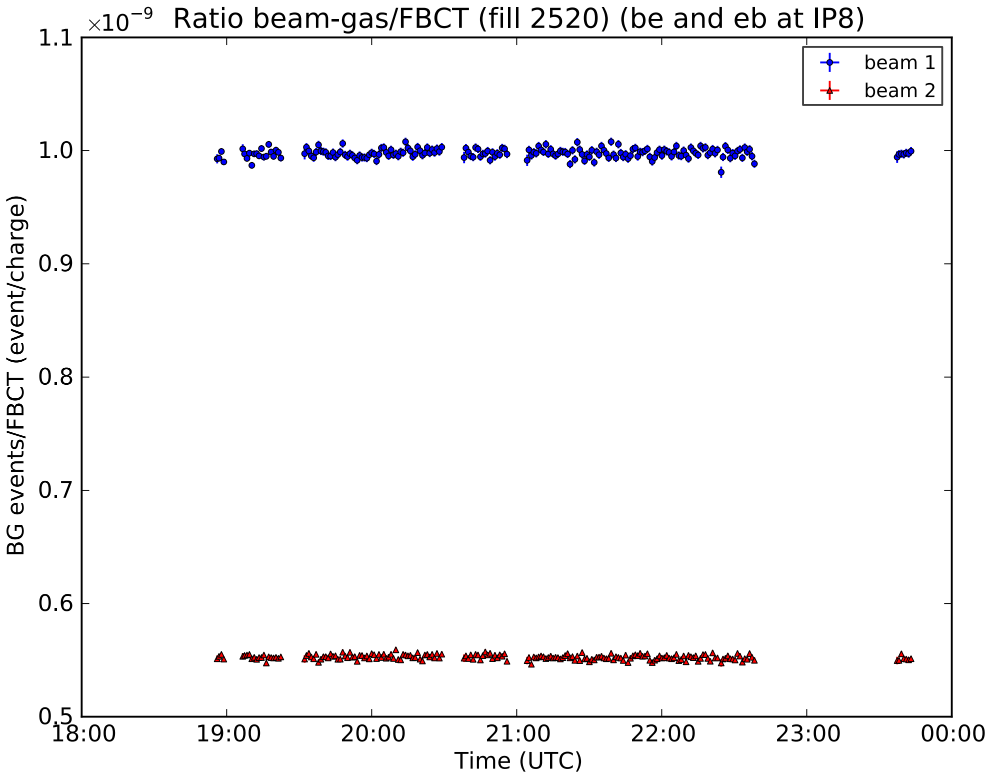
FBCT uncertainties

Relative bunch intensity: FBCT and BPTX (from ATLAS). High accuracy O(0.1%)
However:

- Non linearity observed
- Signal affected by bunch length, position
- Uncertain integration time within 25 ns (problem for satellite charges)

With the SMOG we can simply count vertices per bunch and get direct relative intensity measurement.

- Error is purely statistic
- Accuracy ≈ 0.5% per bunch in 20 minutes



Summary

We use the BGI method for luminosity measurements at LHCb:

- Measure all relevant beam parameters (shape, position, angle) better than 1%
- Ghost charge
- Bunch intensity

But also:

- Single/Double Gaussian shape: not identical in X and Y
- Transverse distribution of ghost charges
- Emittance evolution with time
- Ghost charge evolution with time

References

1. "*LHC Bunch Current Normalisation for the April-May 2010 Luminosity Calibration Measurements*" G. Anders et al. (BCNWG note1), CERN-ATS-Note-2011-004 PERF
2. "*LHC Bunch Current Normalisation for the October 2010 Luminosity Calibration Measurements*" A. Alici et al. (BCNWG note2), CERN-ATS-Note-2011-016 PERF
3. "*Study of the Relative LHC Bunch Populations for Luminosity Calibration*", G. Anders et al. (BCNWG note3), CERN-ATS-Note-2012-028 PERF.
4. "*Study of the LHC Ghost Charge and Satellite Bunches for Luminosity Calibration*", A. Alici et al. (BCNWG note4), CERN-ATS-Note-2012-029 PERF
5. "*Absolute luminosity measurements with the LHCb detector at the LHC*", LHCb Collaboration, 2012 JINST 7 P01010 doi:10.1088/1748-0221/7/01/P01010