



# LHCb beam-gas imaging results

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for the LHCb Lumi group

*LHC Lumi Days*  
*13-14 January 2011, CERN*

1. Beam-gas luminosity method
2. Results from May 2010 data ( $\beta^* = 2\text{m}$ )

❖ Luminosity for 2 colliding bunches

$$L = f N_1 N_2 K \int \rho_1(x, t) \rho_2(x, t) d^3 x dt \quad \text{See Ref. [1]}$$

▶  $f$  : revolution frequency

▶  $N_i$  : bunch populations

▶ kinematic relativistic factor  $K = \sqrt{(\vec{v}_1 - \vec{v}_2)^2 - \frac{(\vec{v}_1 \times \vec{v}_2)^2}{c^2}} \approx 2c \cos^2 \alpha$

half crossing angle



▶ overlap integral  $\int \rho_1(x, t) \rho_2(x, t) d^3 x dt$

❖ Beam-gas imaging: reconstruct beam-gas vertices to measure beam angles, profiles and relative positions

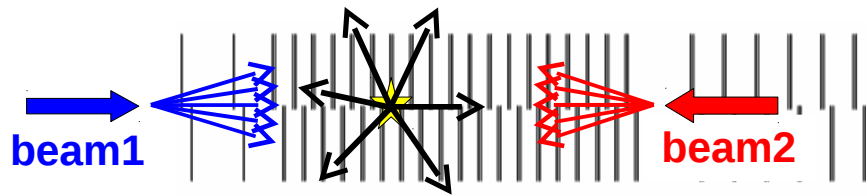
▶ Novel method to measure the overlap integral See Ref. [2]

▶ Advantage wrt VDM: don't move the beams - can be done during phys fill

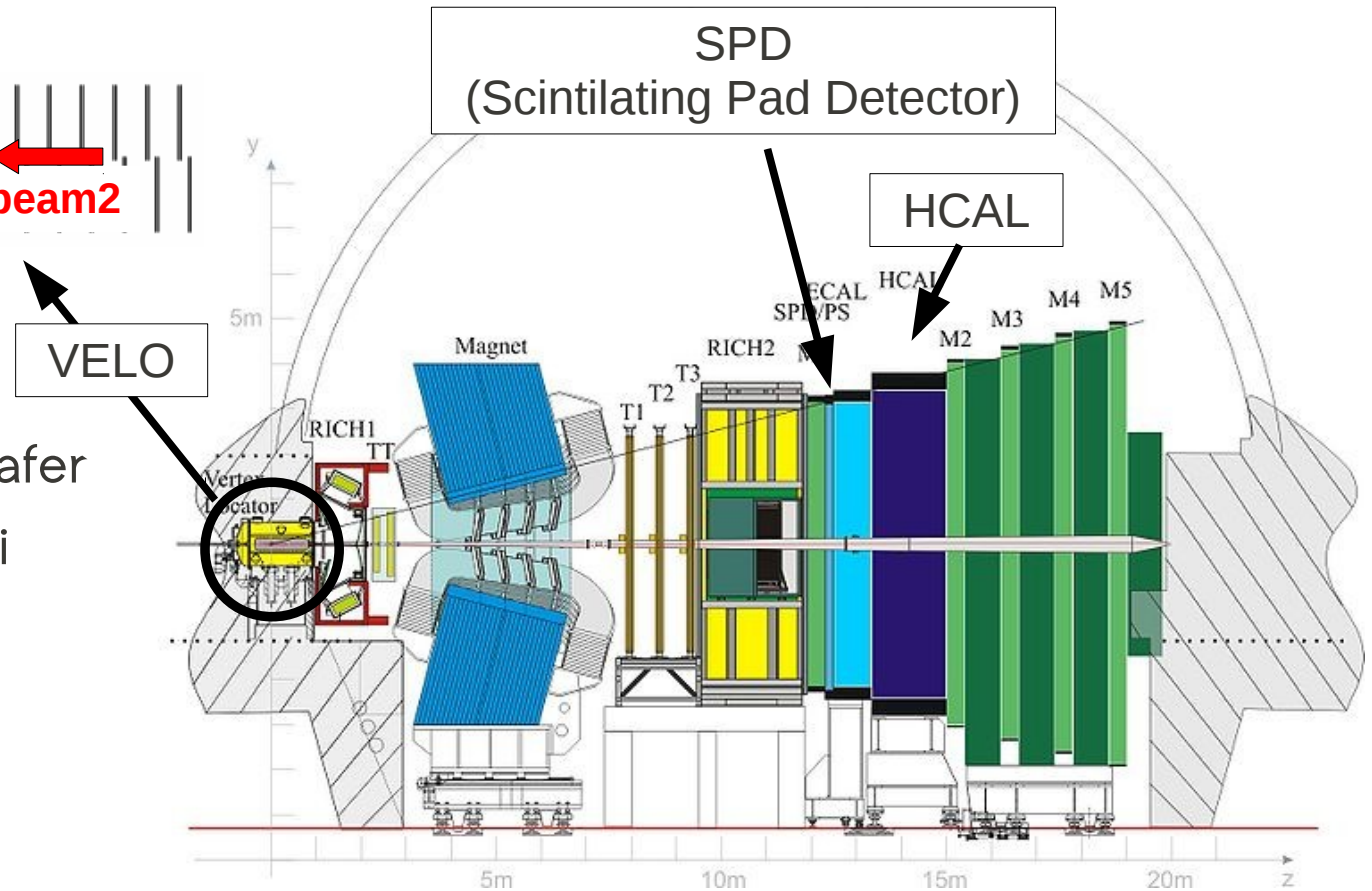
▶ Limitations:

- ♦ vertex resolution
- ♦ beam-gas rates - beam stability
- ♦ residual gas transverse density profile

▶ Common systematic with VDM: bunch currents



- ❖ Vertex Locator:
  - ▶ 21 stations of Si wafer pairs with r and phi strip readout
  - ▶ unique precision

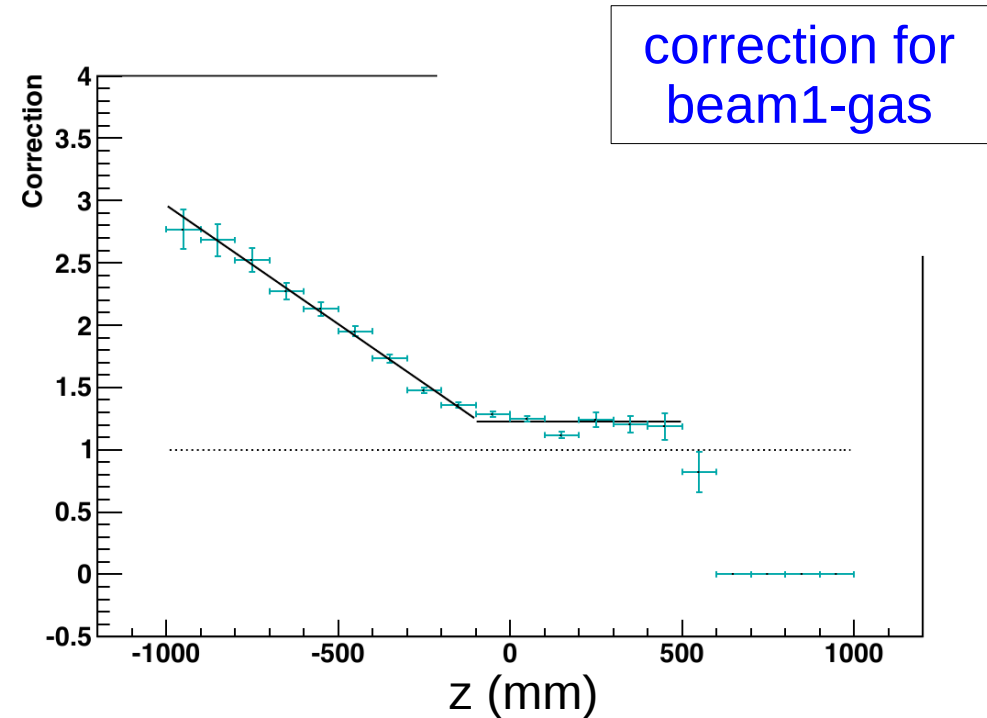
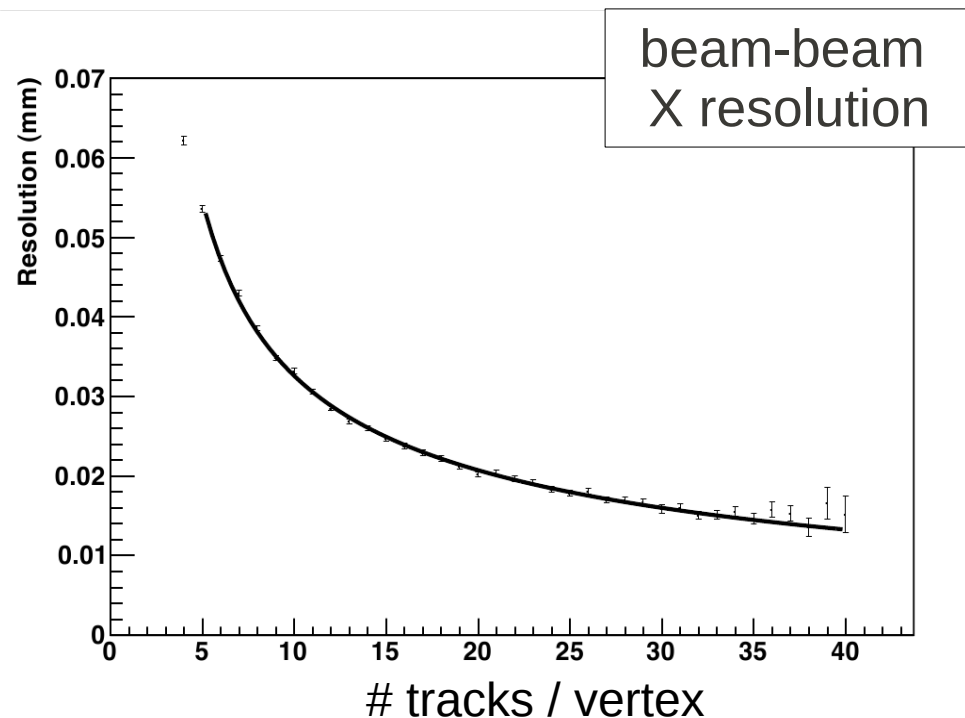


- ❖ Trigger:
  - ▶ Loose min-bias: (# hits in one of the PU stations > 3) OR (#SPD hits > 2 AND at least 1 HCAL cluster with  $E_T > 240$  MeV)
  - ▶ Dedicated beam-gas triggers in beam-empty and beam-beam crossings

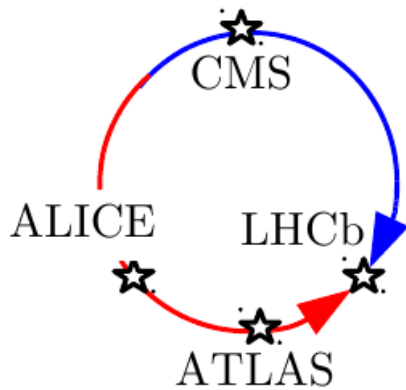
# VELO Primary Vertex Resolution

- ❖ Data method: randomly split the tracks in 2 equal samples and reconstruct 2 vertices. Resolution<sub>N/2</sub> is determined from  $d(V_1 - V_2) / \sqrt{2}$
- ❖ Parametrize with double Gaussian in 2 steps:
  1. Get the resolution for beam-beam vertices as function of the number of tracks per vertex, N
  2. Apply a correction for the beam-gas vertices including the z-dependence

$$R(N) = \frac{\sigma_0}{N^{0.5 + \frac{\delta}{N^2}}} + \epsilon$$

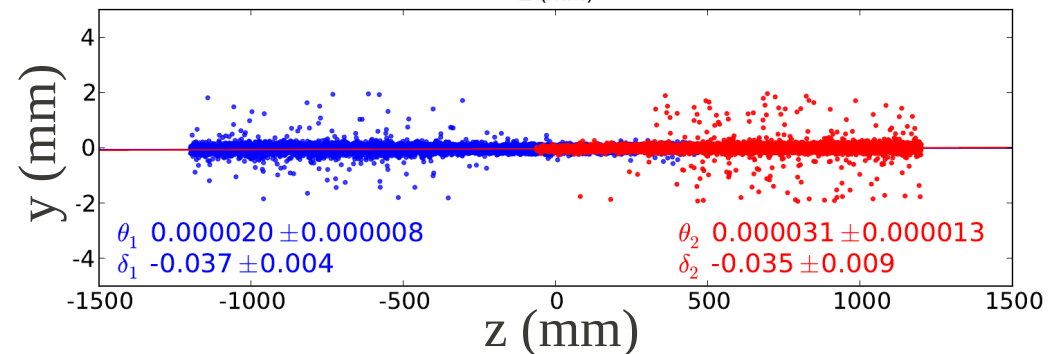
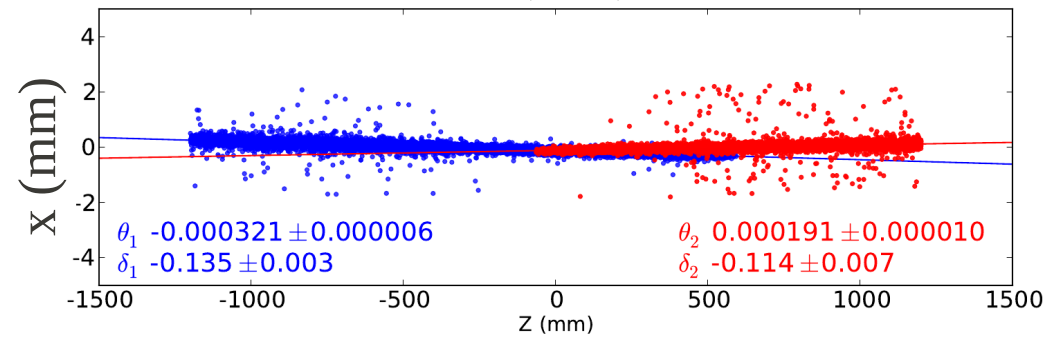
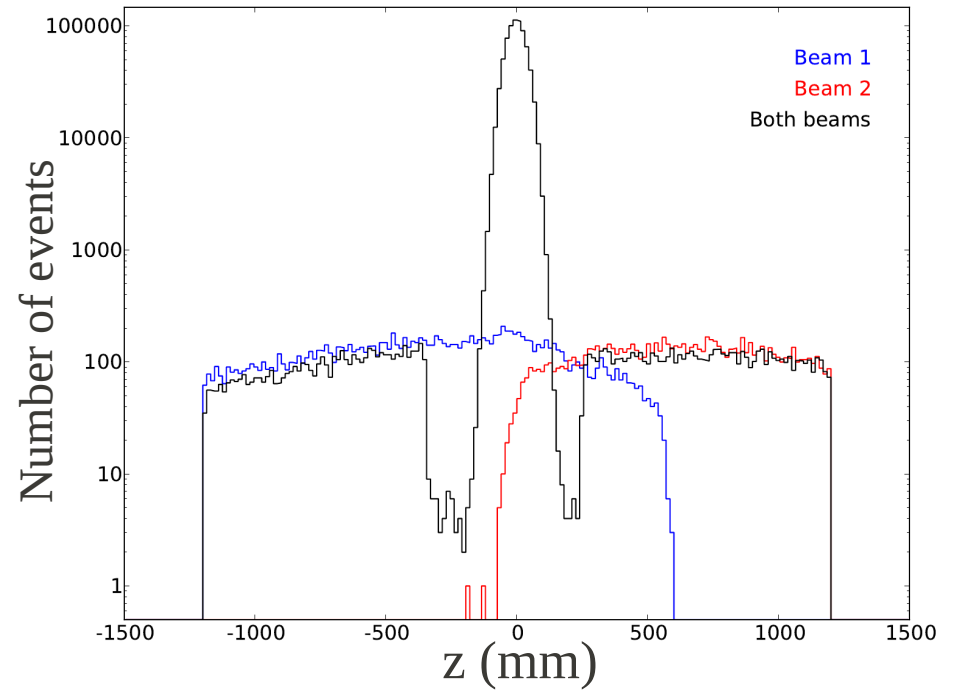


- ❖ Visualize the beams with beam-gas interaction vertices
- ❖ Fill 1101: 4 bunches/beam, 2 colliding pairs in LHCb

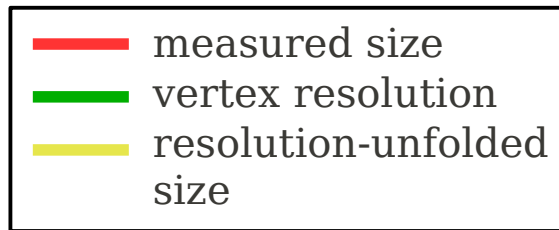


- ❖ Crossing angle [ $\mu\text{rad}$ ]:
 

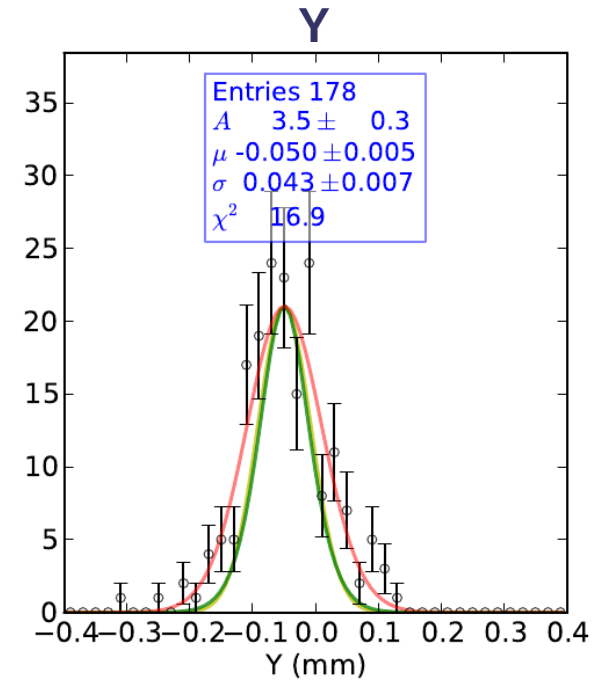
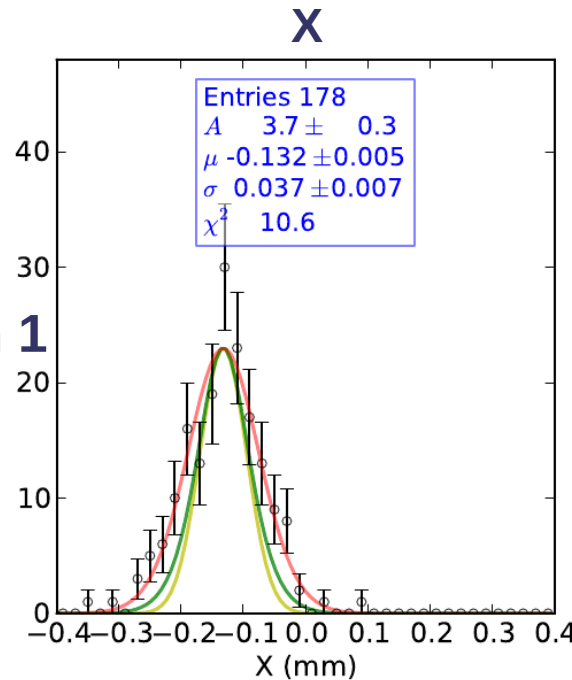
|                   | measured     | expected |
|-------------------|--------------|----------|
| horizontal plane: | $512 \pm 16$ | 540      |
| vertical plane :  | $11 \pm 21$  | 0        |



- Using beam-gas interactions measure the x- and y-profiles of the colliding bunches



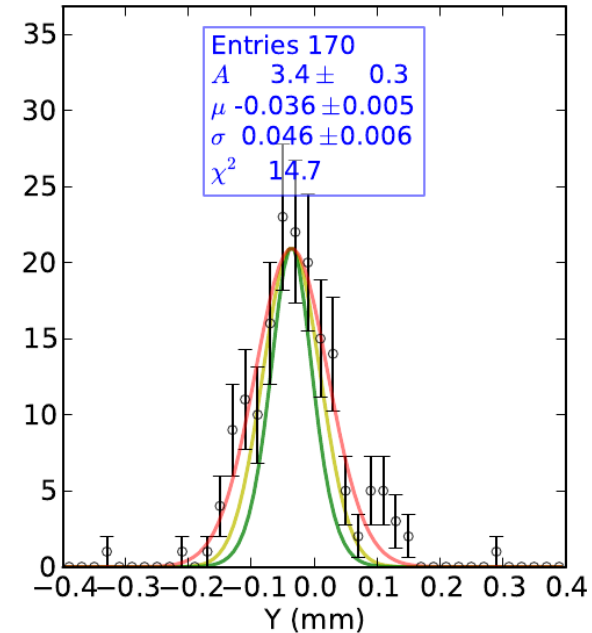
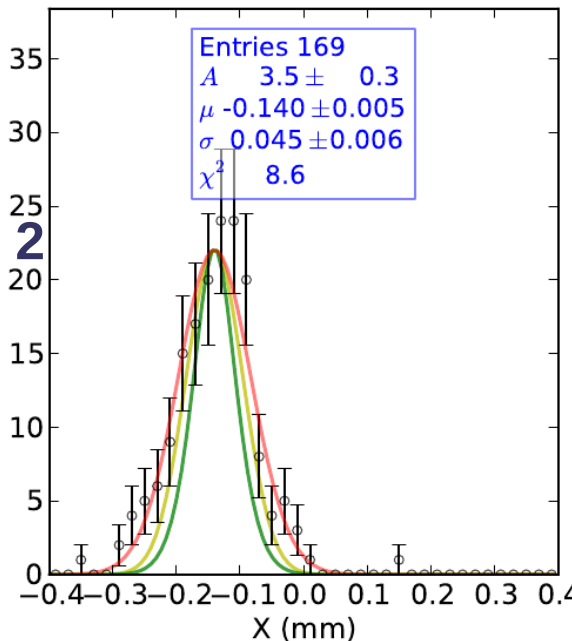
**Bunch 1**



- Figures from fill 1104 BCID 1786

- use beam-gas interactions with  $z_{\text{vtx}}$  in 200 to 600 mm from the IP

**Bunch 2**



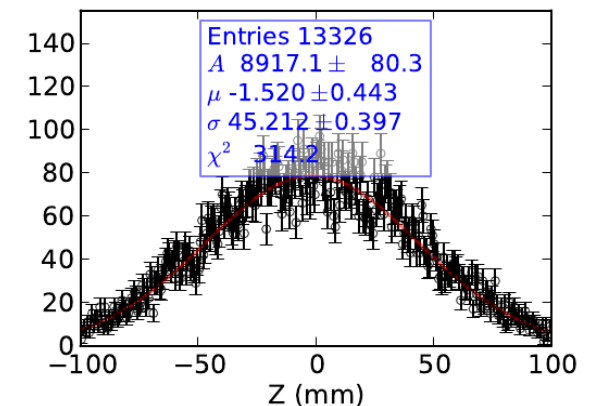
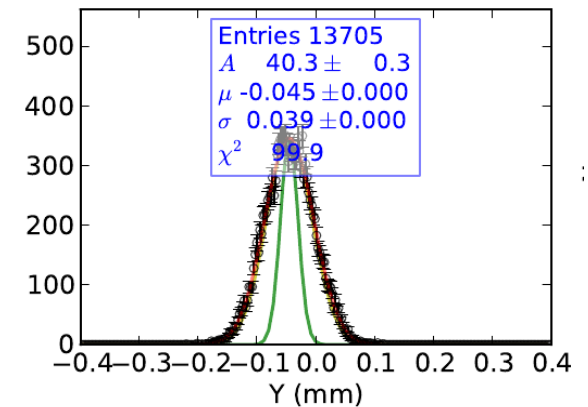
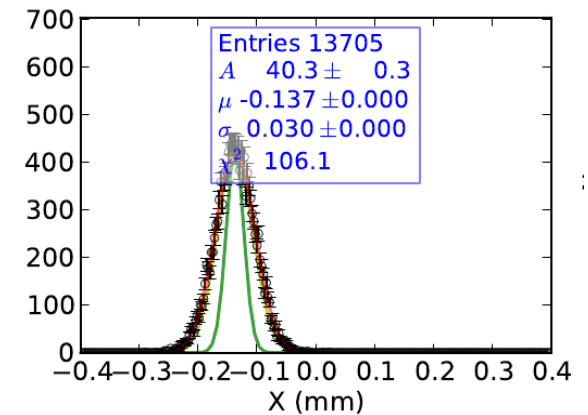
- Fit with VELO resolution added in quadrature for every bin in Z and # tracks

- ❖ Relations between the transverse sizes and positions of two colliding bunches and the luminous region they produce, valid for Gaussian bunches

$$\sigma_{BB}^2 = \frac{\sigma_1^2 \sigma_2^2}{\sigma_1^2 + \sigma_2^2} \quad \mu_{BB} = \frac{\mu_1 \sigma_2^2 + \mu_2 \sigma_1^2}{\sigma_1^2 + \sigma_2^2}$$

- ❖ Can be used as constraints to fit 4 parameters using 6 measurements (fit parameters are the b1 and b2 position and width)

## Lumi Region Profiles



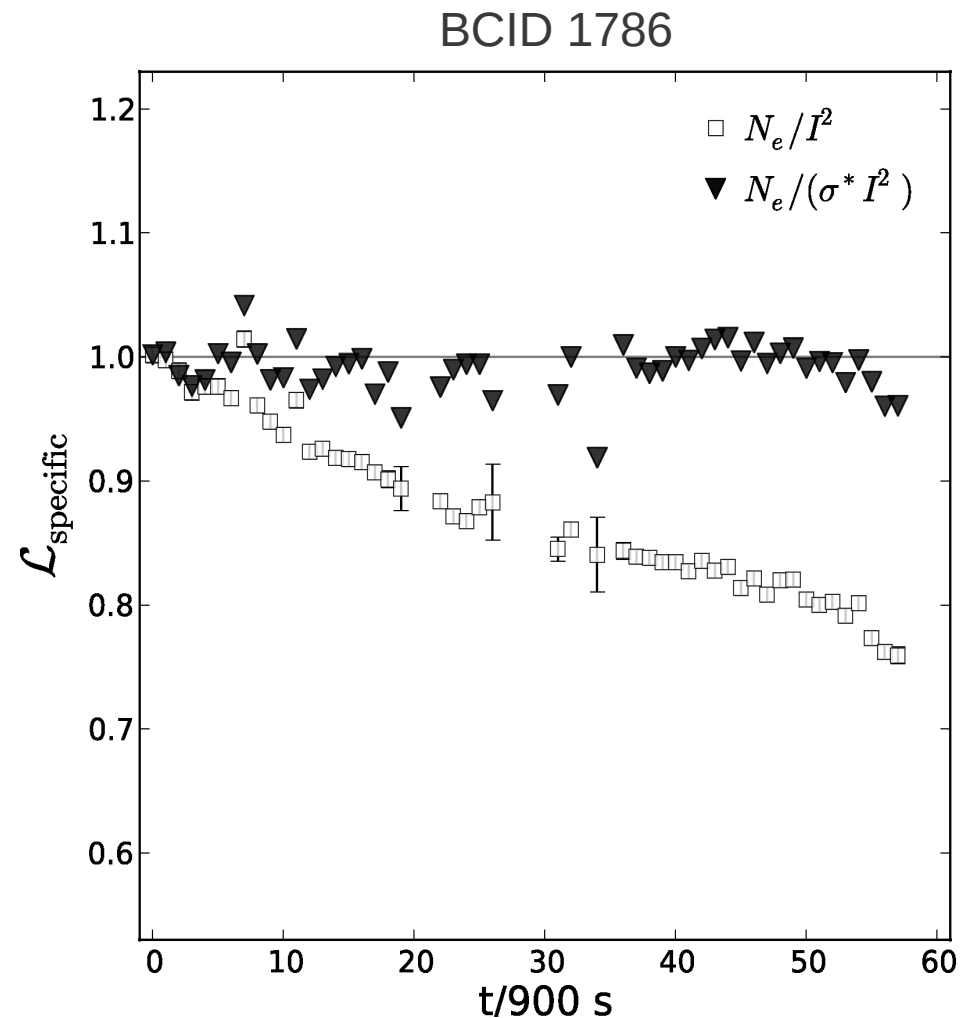
$$\int L dt = f \times \int N_1 N_2 dt \times \sum_{\text{bunches}} A^{-1} \times \frac{1}{\epsilon_{\text{cross angle}}}$$

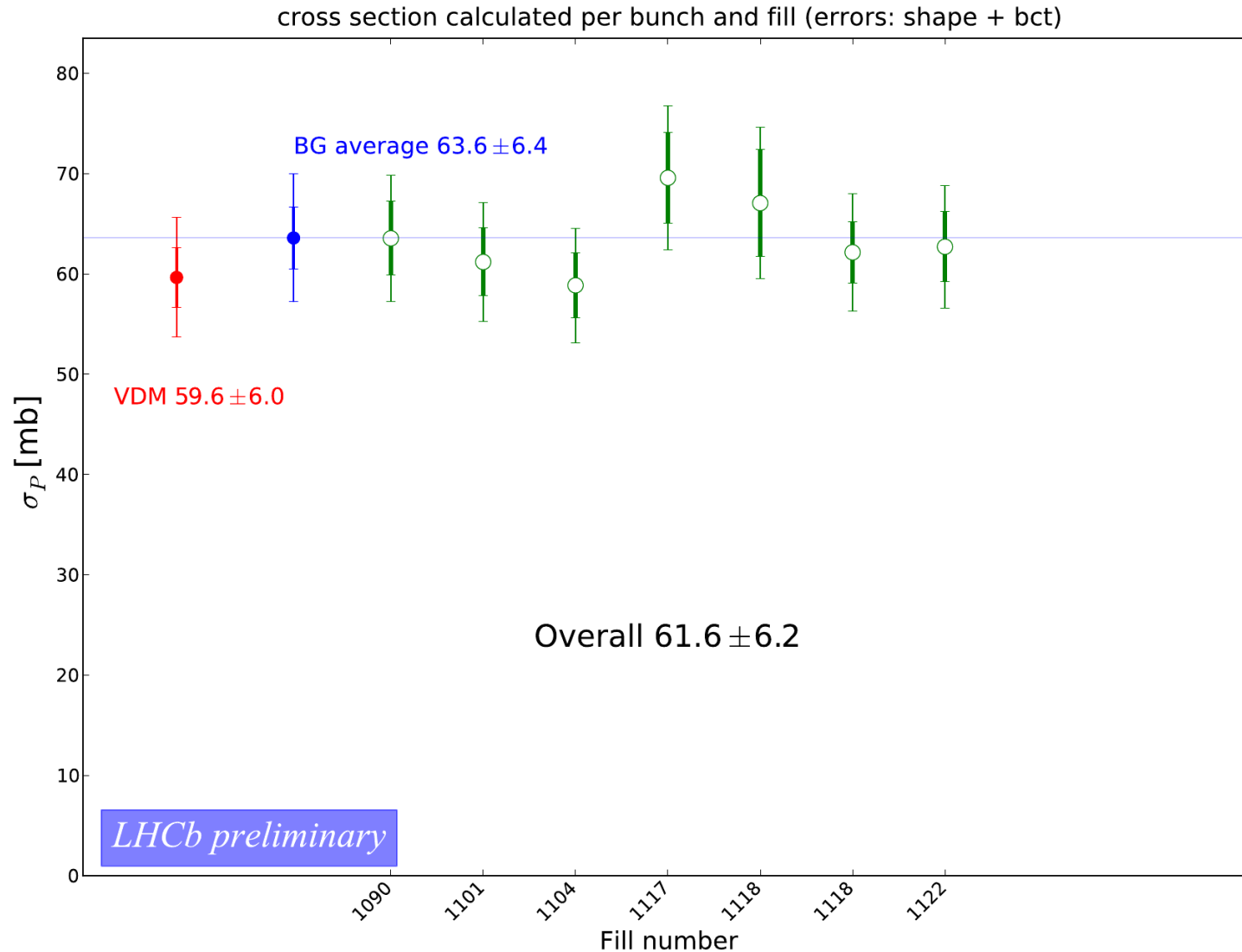
typical uncertainties

|   |                                    |           |
|---|------------------------------------|-----------|
| $f$                                       | - revolution frequency (11.25 KHz) | --        |
| $\int N_1 N_2 dt$                         | - integrated intensity product     | (± 5 %)   |
| $\sum_{\text{bunches}} A^{-1}$            | - overlap integral:                |           |
|   | width                              | (± 1-3 %) |
|   | offset (not head-on)               | (± 3 %)   |
| $\frac{1}{\epsilon_{\text{cross angle}}}$ | - crossing angle correction        | (± 1 %)   |



- ❖ Check the Luminosity trend for a single colliding bunch-pair after factoring-out the effects from:
  - ▶ current decay ( $\square$ )
  - ▶ current decay + emittance blow-up ( $\blacktriangledown$ )
- ❖  $N_e \sim$  luminosity
- ❖  $\sigma = \frac{1}{\sigma_x \sigma_y}$  : beam-width luminosity factor (assuming ideal head-on and equal bunches)
- ❖ Conclusion: any further correction is constant over the fill





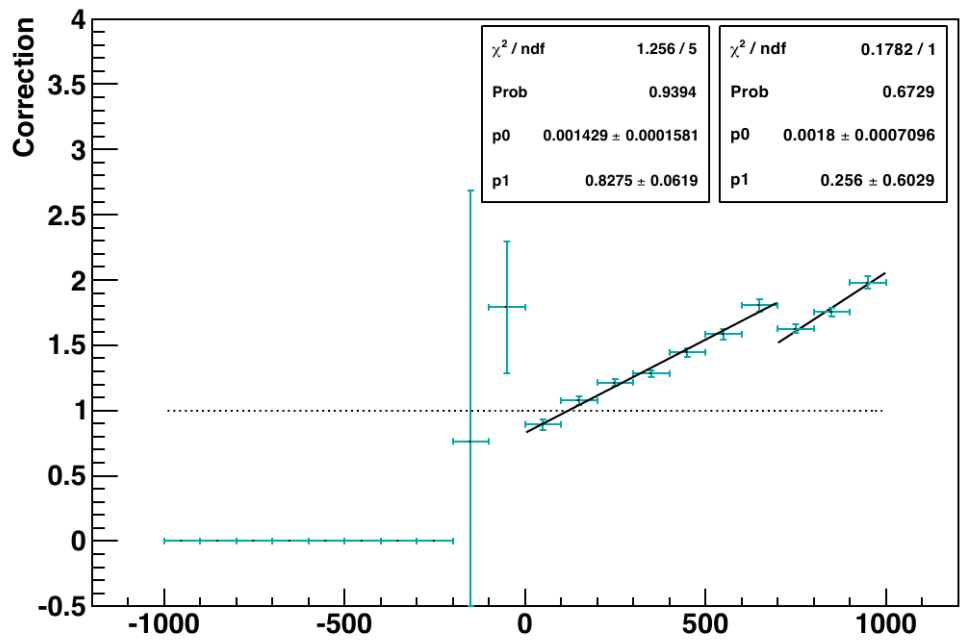
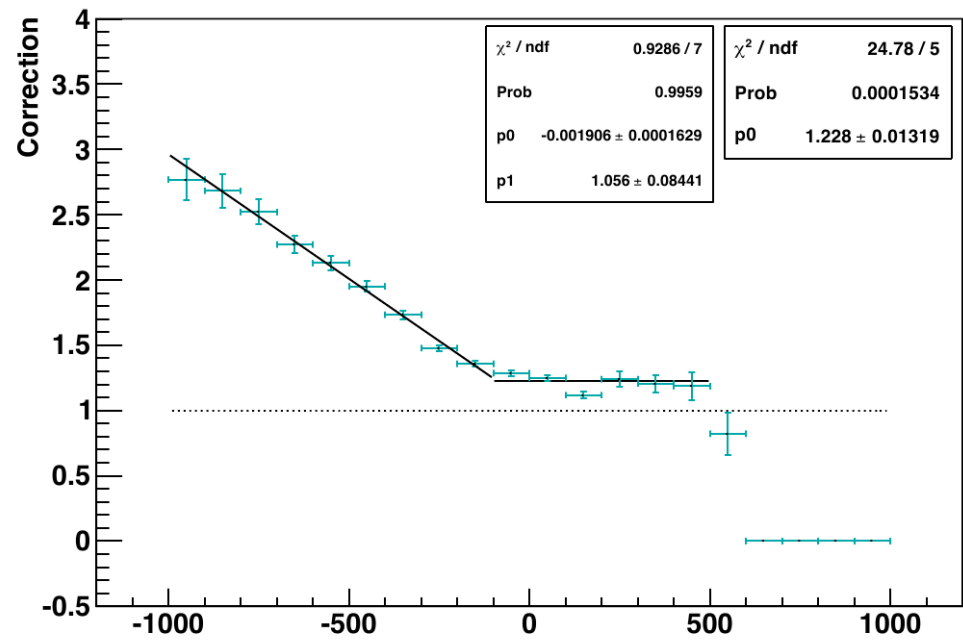
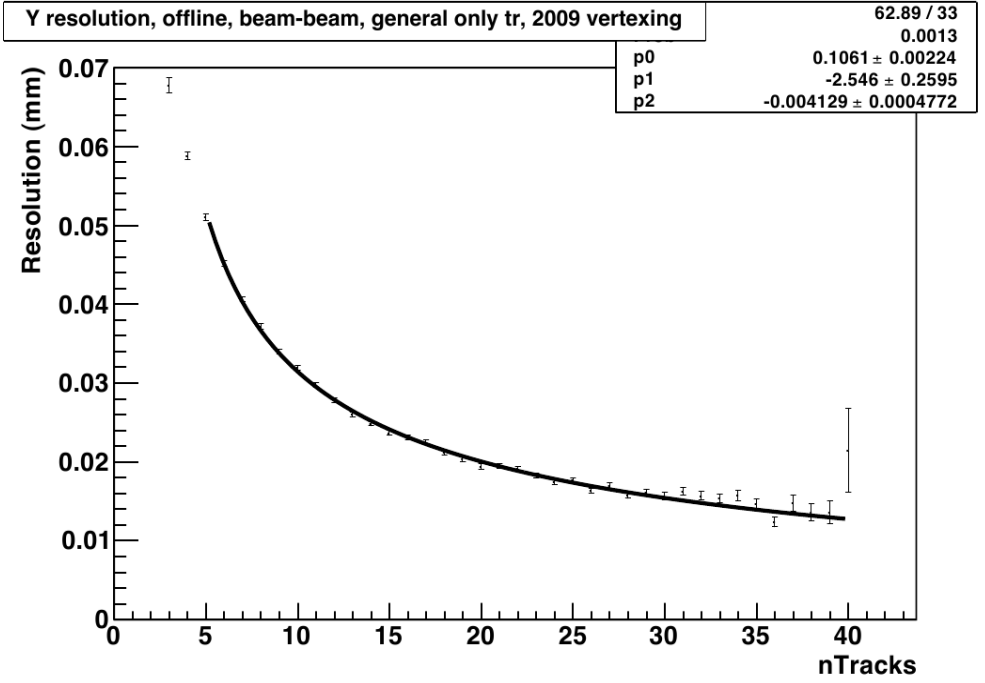
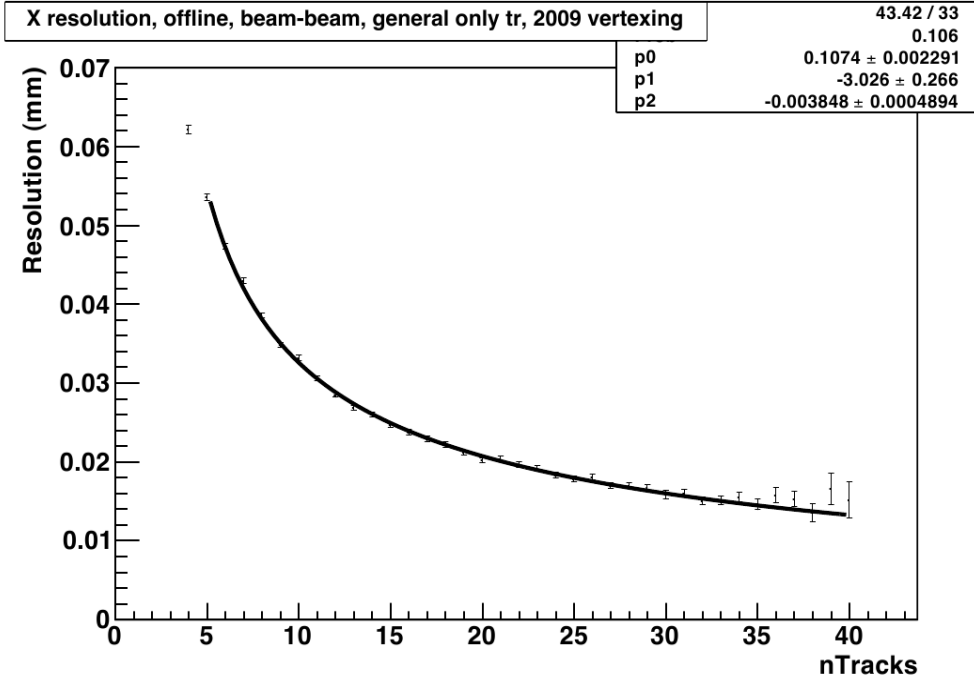
- ❖ Bunch current uncertainties used here are the ones available in July 2010 (preliminary)

- ❖ The beam-gas luminosity method has been used in LHCb for measurements with Dec 2009 and May 2010 data, the former one being the very first application of the method. The obtained results are compatible with the ones from the VDM scans, while both methods have comparable uncertainties
- ❖ The beam-gas vertex reconstruction provides additional applications like beam-angle and ghost charge measurements
- ❖ Means of improving the precision:
  - ▶ higher gas pressure - to get higher beam-gas rate
  - ▶ broader beams - to decrease the effect of the vertex resolution uncert.
  - ▶ combined beam-gas and VDM fill

- 1) “The luminosity for beam distributions with error and wakefield effects in linear colliders”, O. Napoly, Part. Acc. 40, 180 (1993)
- 2) “Proposal for an absolute luminosity determination in colliding beam experiments using vertex detection of beam-gas interactions”, M. Ferro-Luzzi, Nucl. Instrum. Methods A553 (2005) 388

# ❖ BACKUP SLIDES

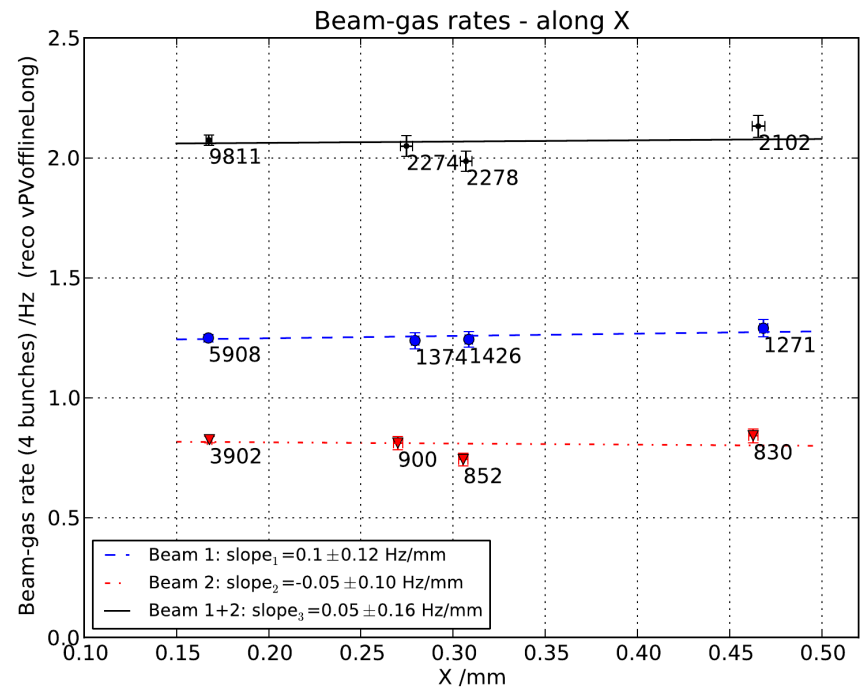
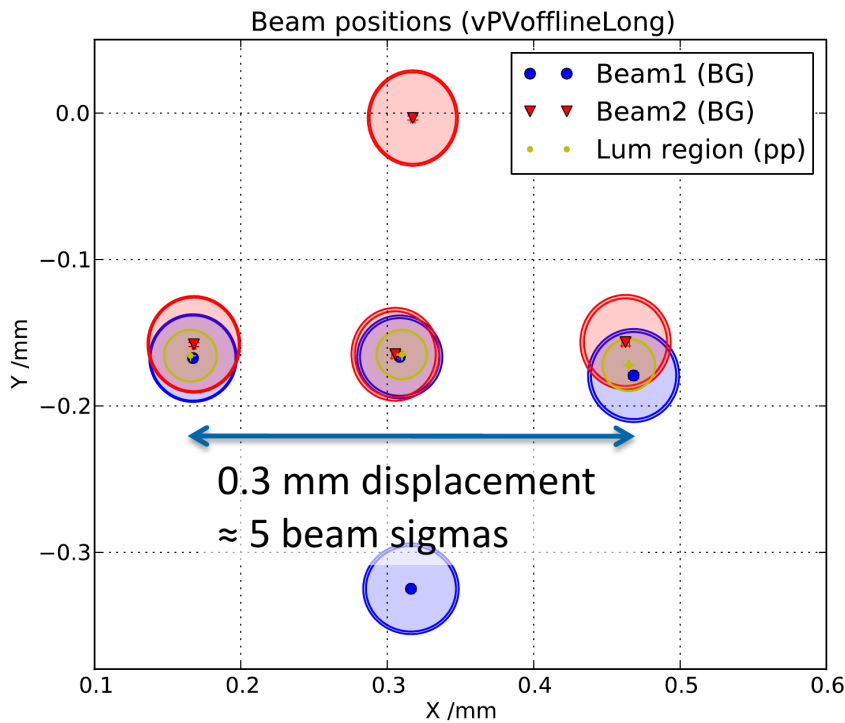
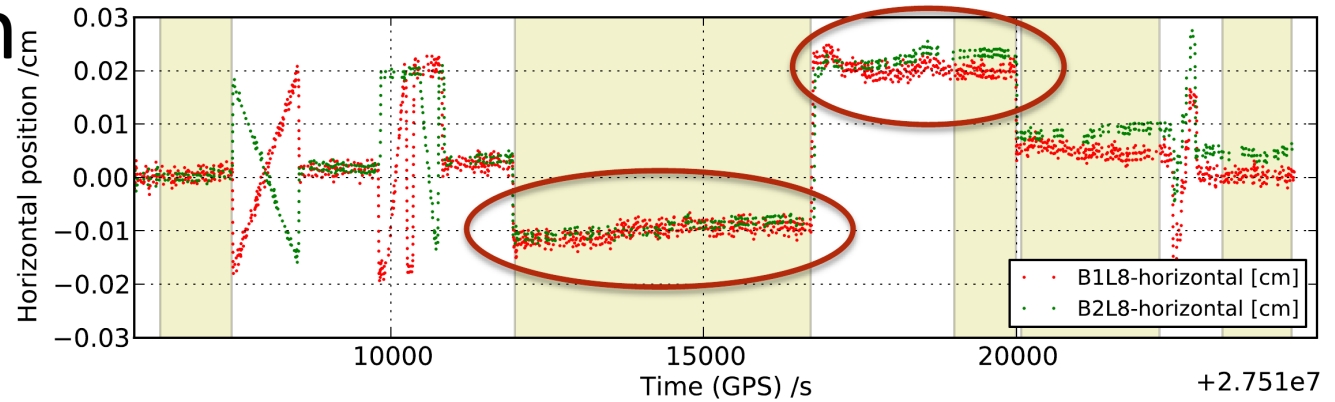
# VELO PV Resolution



- ❖ L0 (hardware trigger)
  - ▶ beam-empty crossings: dedicated L0 channels
    - ◆ beam1 - gas : PUStation1 Mult  $< 40$  && CALO  $\Sigma E_T > 3$  GeV
    - ◆ beam2 - gas : PUStation1 Mult  $> 9$  && CALO  $\Sigma E_T < 6$  GeV
  - ▶ beam-beam crossings (beam-gas overlapped with pp): no special trigger, implying pre-scaling of the number of beam-gas events. In the last 2010 proton fills several BCIDs were *enhanced*
- ❖ HLT (software trigger)
  - ▶ in both beam-empty and beam-beam crossings look for accumulation of tracks on a point on the beam axis (pseudo-vertex)
  - ▶ In the case of beam-beam crossings veto the lumi region - no other (quick) way to distinguish the beam-gas and beam-beam events

# Residual Gas Gradient Test

VDM scan  
fill 1422

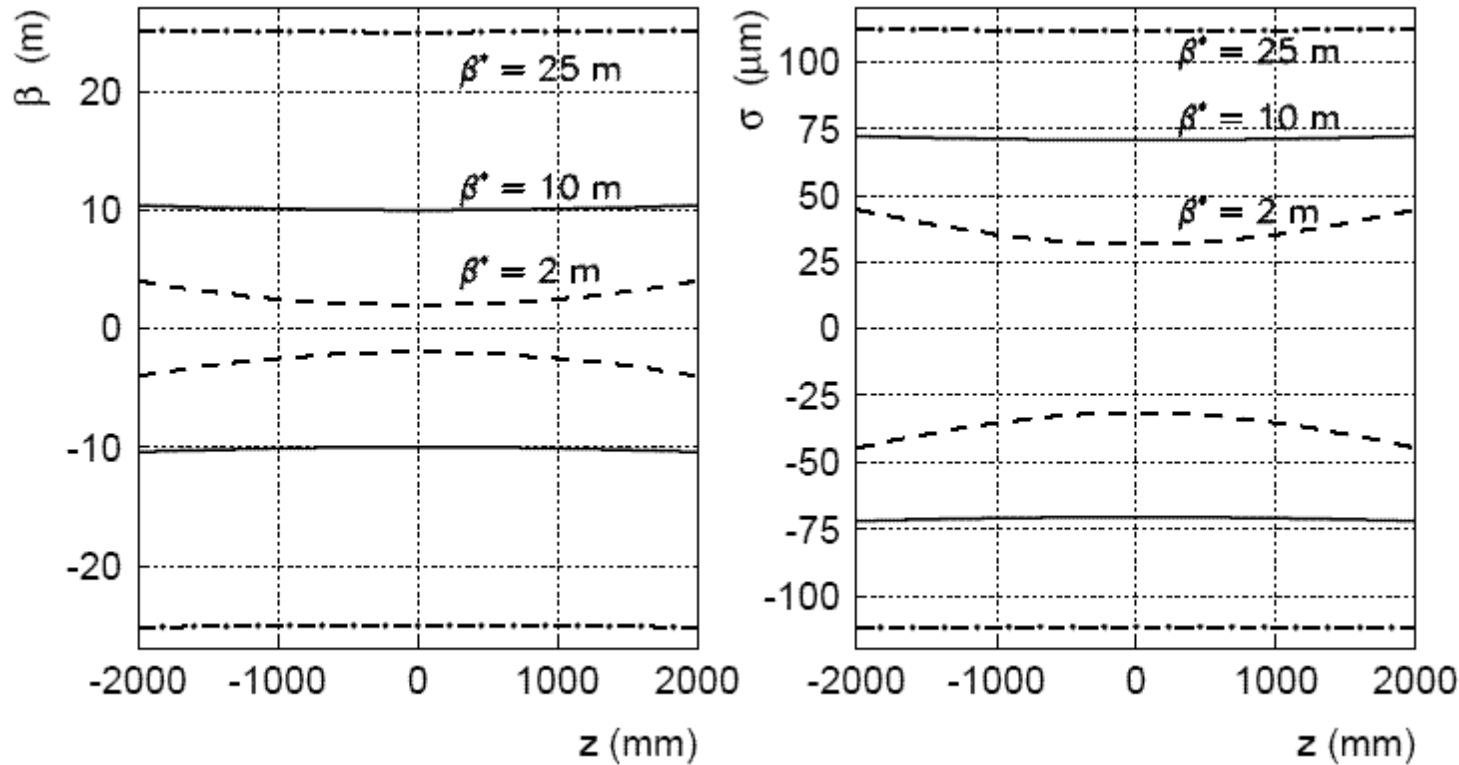


Residual gas pressure gradient  
limit: 0.50 Hz/mm (95%CL.)



Error on overlap integral < 0.05 %





$$\beta(z) = \beta^* \left[ 1 + \left( \frac{z}{\beta^*} \right)^2 \right]$$

$$\sigma(z) = \sqrt{\beta(z)} \epsilon$$

- ❖ For  $\beta^* = 3.5$  m,  $\sigma_{\text{beam}}$  increases by  $\sim 4\%$  over 1 m
  - That is 2  $\mu\text{m}$  increase for a 50  $\mu\text{m}$  beam
- ❖ Such precision is not yet available from the beam-gas vertex resolution analysis
- ❖ For  $\beta^* = 2$  m, the increase is  $\sim 12\%$  over 1 m