Z production at LHCb

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on behalf of the LHCb Collaboration

Rencontres de Physique de la Vallée d'Aoste

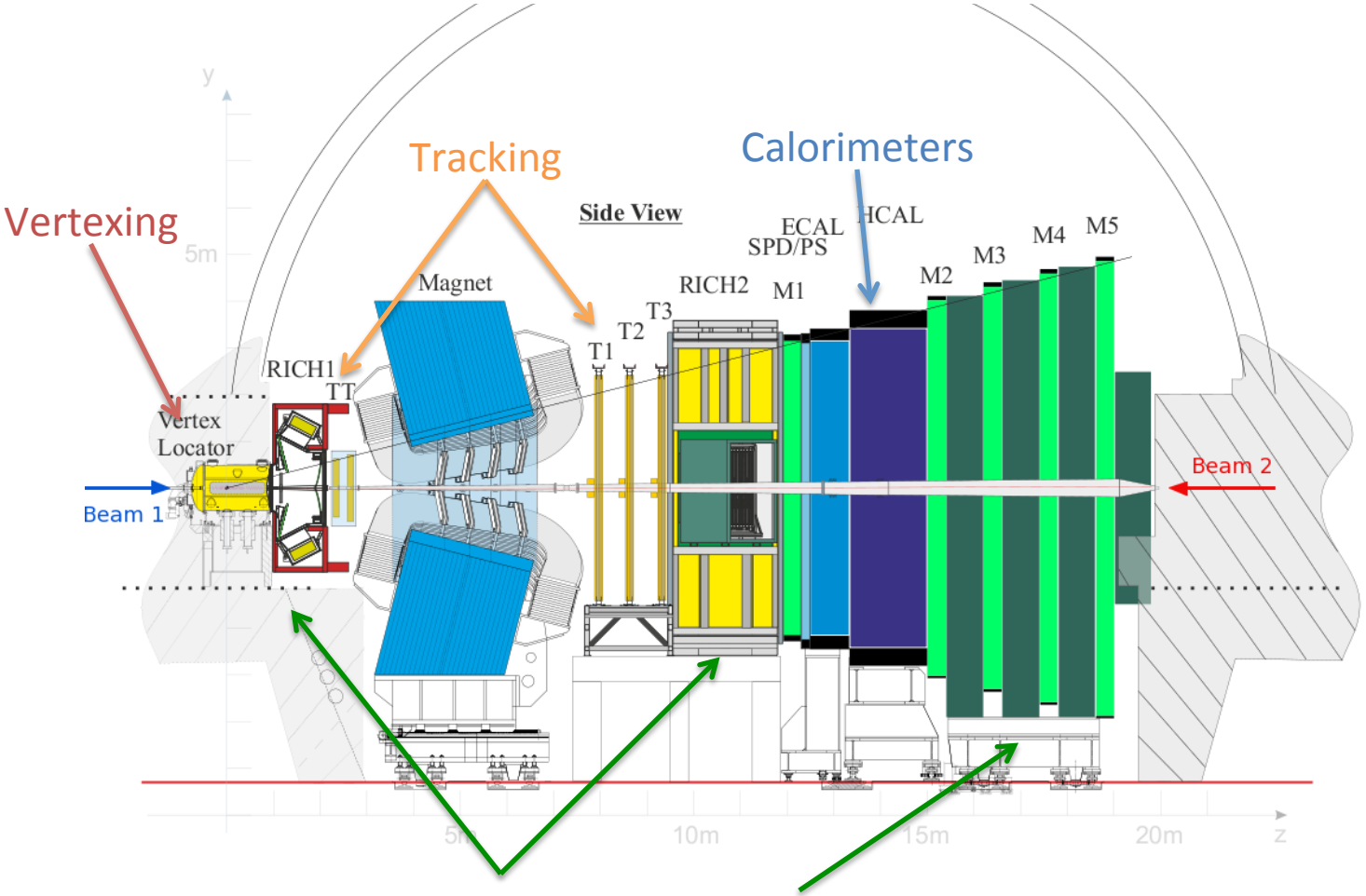
Outline

- Z → ee at 8 TeV
- Direct luminosity calibration
  - beam-gas imaging method
  - van der Meer scan method

$$\sigma = \frac{N}{\int L\,dt}$$

NEW	**Z → ee at 8 TeV**	arXiv:1503.00963
	Z + b-jet at 7 TeV	JHEP 01 (2015) 064
	Z + jet at 7 TeV	JHEP 01 (2014) 033
	Z → ee at 7 TeV	JHEP 02 (2013) 106
	Z → ττ at 7 TeV	JHEP 01 (2013) 111
	Z → μμ at 7 TeV	LHCb-CONF-2013-007
NEW	**Luminosity**	JINST 9 (2014) P12005

LHCb detector



JINST 3 (2008) S080005

LHCb explored kinematics

$$\sigma_{AB}(x,Q^2) = \int f_{a/A}(x_a,Q^2) f_{b/B}(x_b,Q^2) \sigma_{ab}(x_a,x_b,Q^2)\, dx_a\, dx_b$$

$$Q^2 = M^2$$

$$x_{ab} = \frac{M}{\sqrt{s}} e^{\pm y}$$

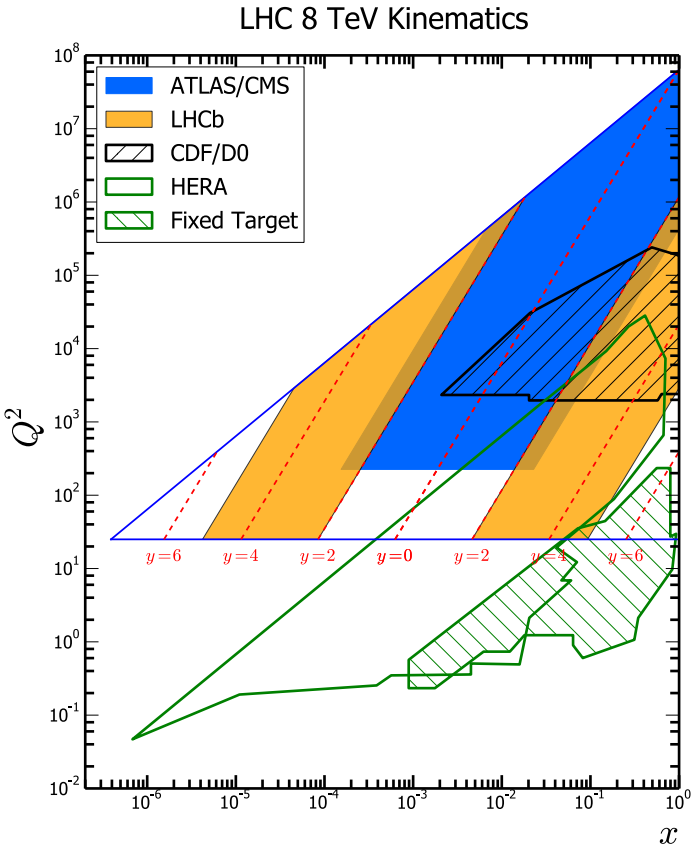
hadronic cross-section

proton structure parame-terized with PDFs: O(2-8%)

partonic cross-section
NNLO: O(2-8%) in forward region

- LHCb probes two regions
  - high x (PDFs well known)
  - low x (PDFs unknown)

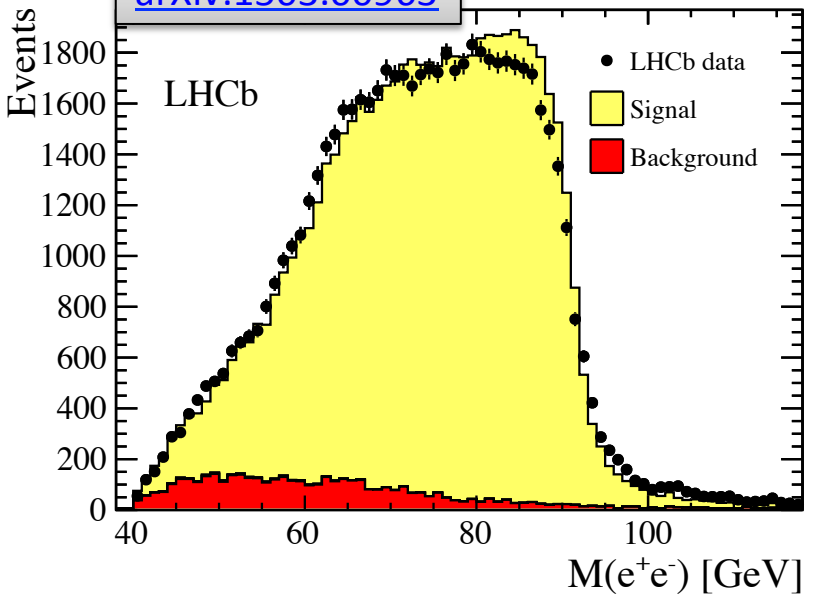
- PDF uncertainties are large (5-8%) at the rapidity accessible to LHCb (2 < y < 5)
- Electroweak measurements at LHCb provide valuable input for the PDF fits



Z → ee cross-section

- $\int L = 2\ fb^{-1}$ (2012)
- trigger on high-p_T single-electron signal
- selection: electron and positron with
  $p_T > 20$ GeV/c and $2.0 < \eta < 4.5$
- particle identification by high-energy electron signature in the calorimeters
- $M(ee) > 40$ GeV/c^2
- peak degraded by bremsstrahlung that is not fully recovered in the calorimeters
- compared to Z → μμ: independent sample and different sources of systematic uncertainties

arXiv:1503.00963



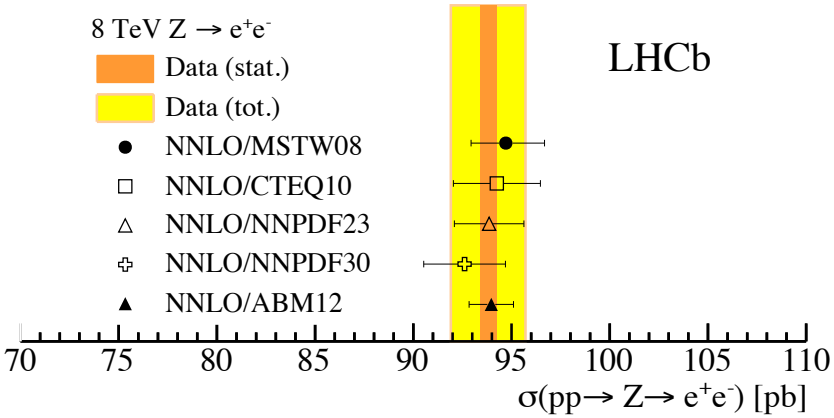
data (65.6k)
simulated signal
background from same-sign data (4.6k)

	Average value	Fractional uncertainty Uncorrelated	Correlated
ϵ	0.319	0.002	0.016
f_{MZ}	0.969	0.001	—
Background estimation	—	—	0.004
$\int \mathcal{L} dt$ / pb^{-1}	1976	—	0.012

Z → ee cross-section

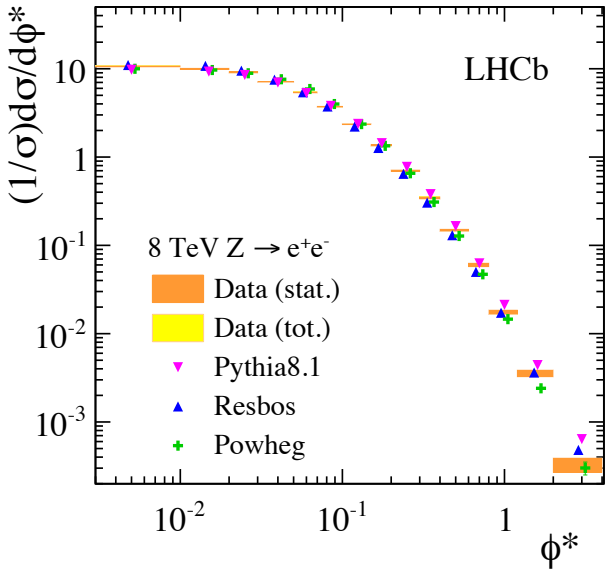
arXiv:1503.00963

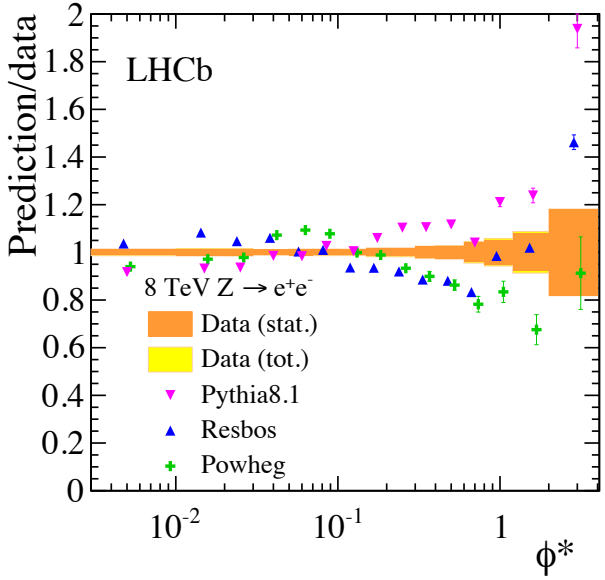
$$\sigma(pp \to Z \to e^+e^-) = 93.81 \pm 0.41(stat) \pm 1.48(syst) \pm 1.14(lumi)\ pb$$



$p_T(e^{\pm}) > 20$ GeV/c and $2.0 < \eta(e^{\pm}) < 4.5$
$60 < M(ee) < 120$ GeV/c^2

Good agreement with NNLO predictions using 5 different PDF sets
* ABM12 and NNPDF include some LHC measurements





Comparison with leading-log calculations: data falls between models

$$\phi^* \equiv \frac{\tan((\pi - |\Delta\phi|)/2)}{\cosh(\Delta\eta/2)} \approx \frac{p_T}{M}$$

Absolute luminosity calibration

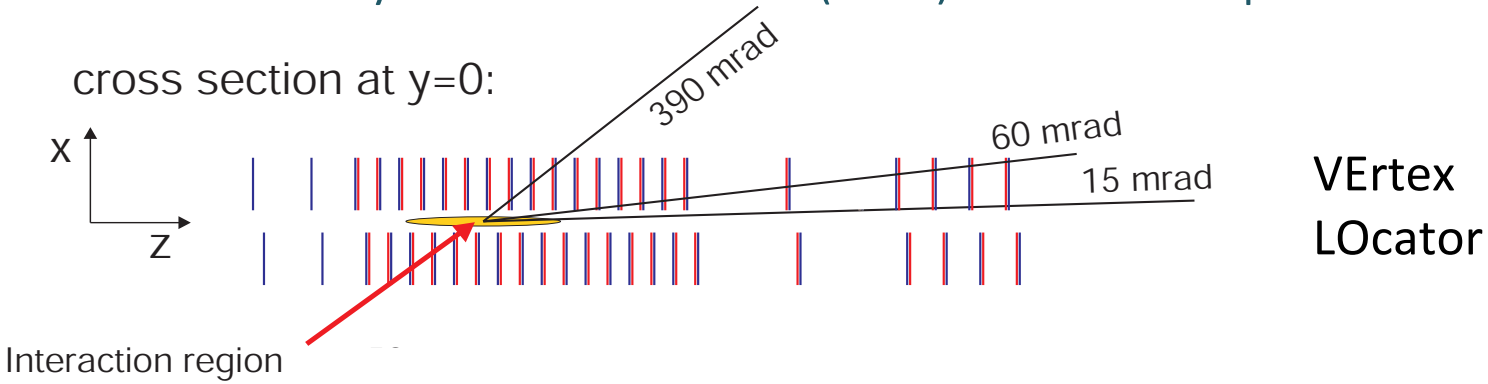
$$R = \sigma L = \sigma f_{rev} N_1 N_2 \int \rho_1(x,y)\rho_2(x,y)\,dx\,dy$$

absolute calibration

LHC instruments

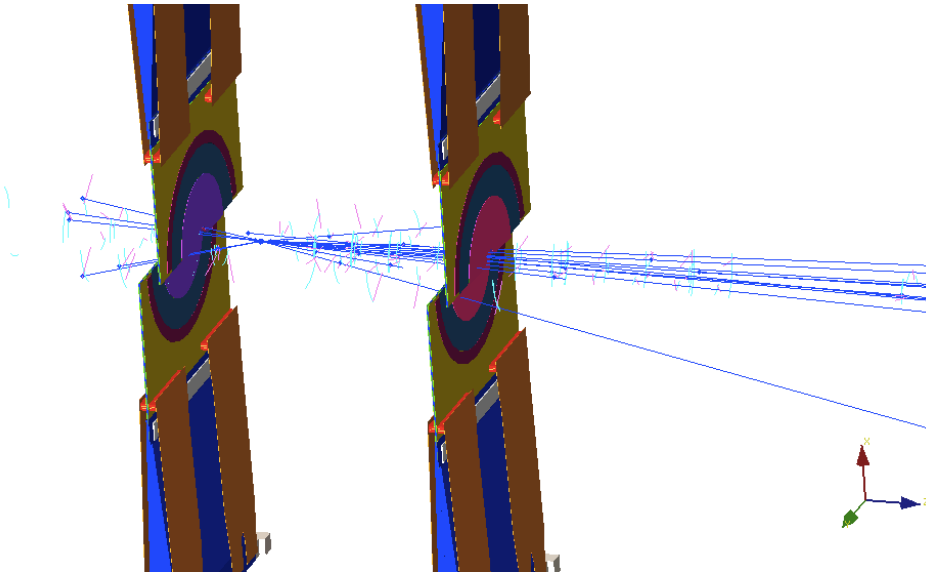
overlap integral

- R and σ correspond to a stable effective process
  - e.g. events with >= 1 track
- Bunch intensities (N_1N_2) measured by LHC instruments
- Overlap integral depends on beam properties
  - measure "directly" with beam-gas imaging (BGI): **exclusive to LHCb!**
  - measure "indirectly" with van der Meer (VDM) scans: all 4 experiments

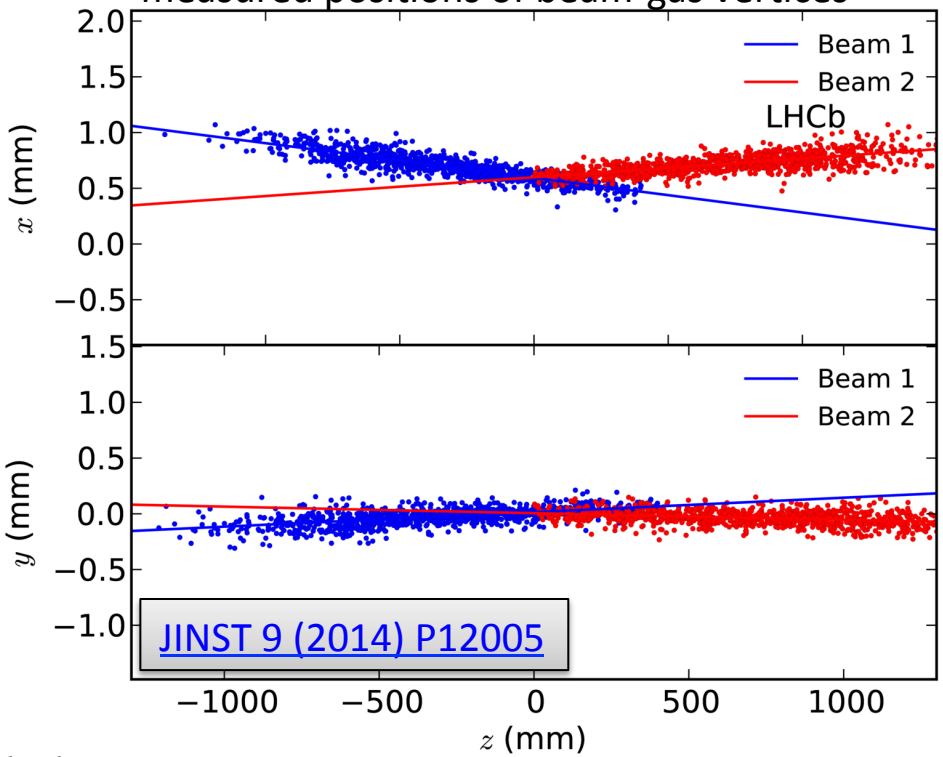


Beam-gas imaging (BGI)

VELO event display



measured positions of beam-gas vertices



$$Overlap = \int \rho_1(x,y,z,t)\rho_2(x,y,z,t)\, dxdydzdt$$

Single bunch density function of colliding bunch pair
(e.g. double Gaussian profile)

method proposed: NIM A553 (2005) 388

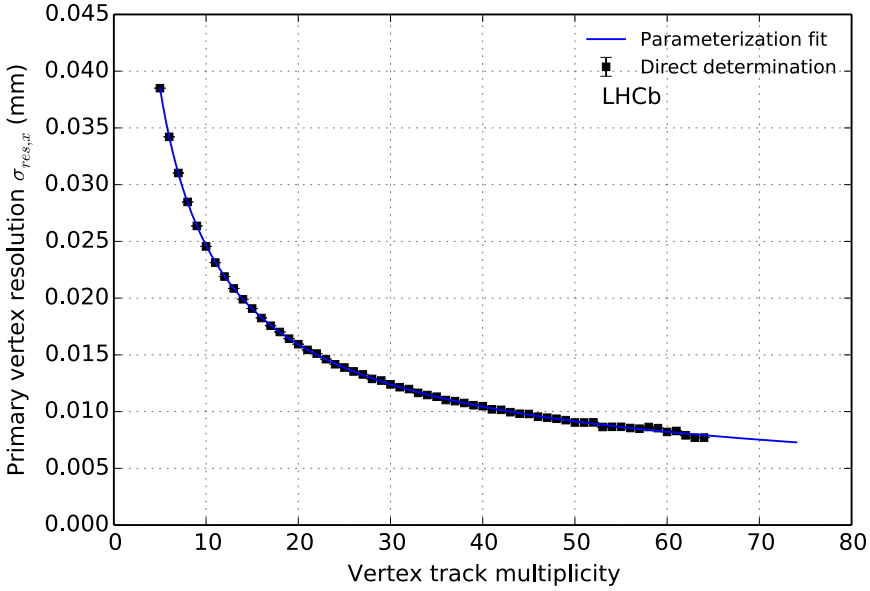
Overlap integral depends on:
- Single bunch profiles (X,Y width, shape)
- Beam crossing angle
- Offset (head-on or displaced)

All parameters are measured using interactions between beam and residual gas

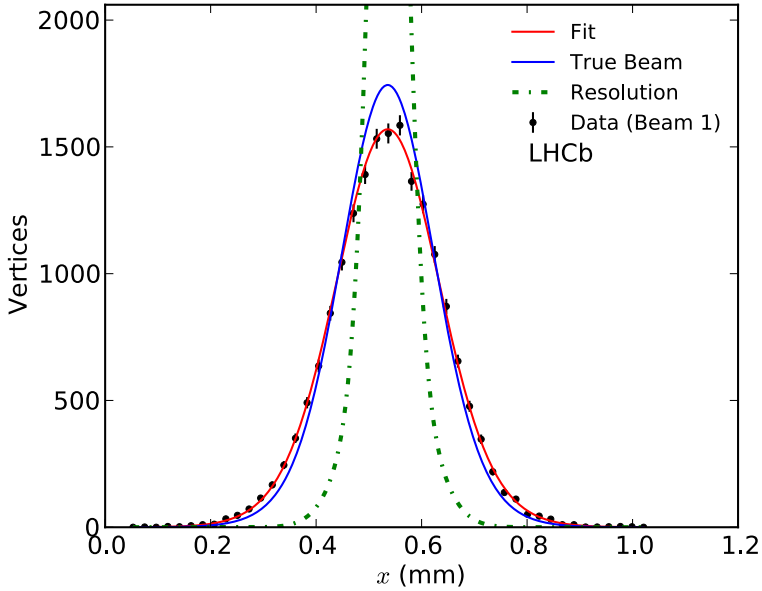
Vertex resolution

- Beam-gas vertices are measured with VELO
  - high precision silicon strip detector surrounding the beam spot
  - excellent resolution in the transverse vertex position
- Important to know the resolution
- Resolution depends on
  - Z position, number of tracks

Example resolution parameterization for p-p interactions

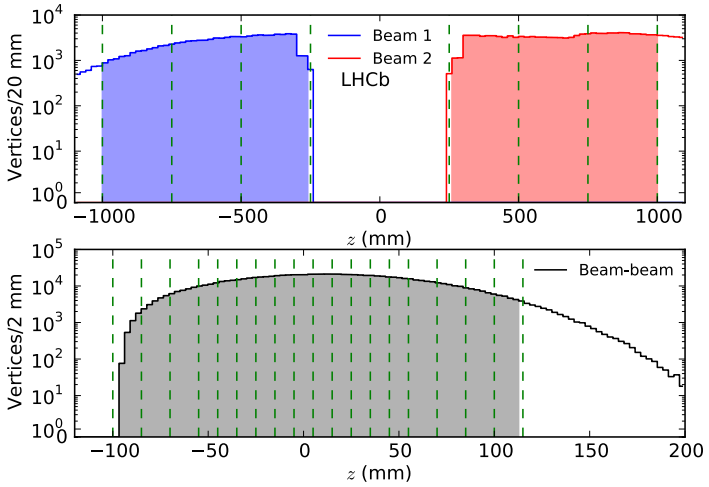


Deconvolution example with true beam width of 93 μm

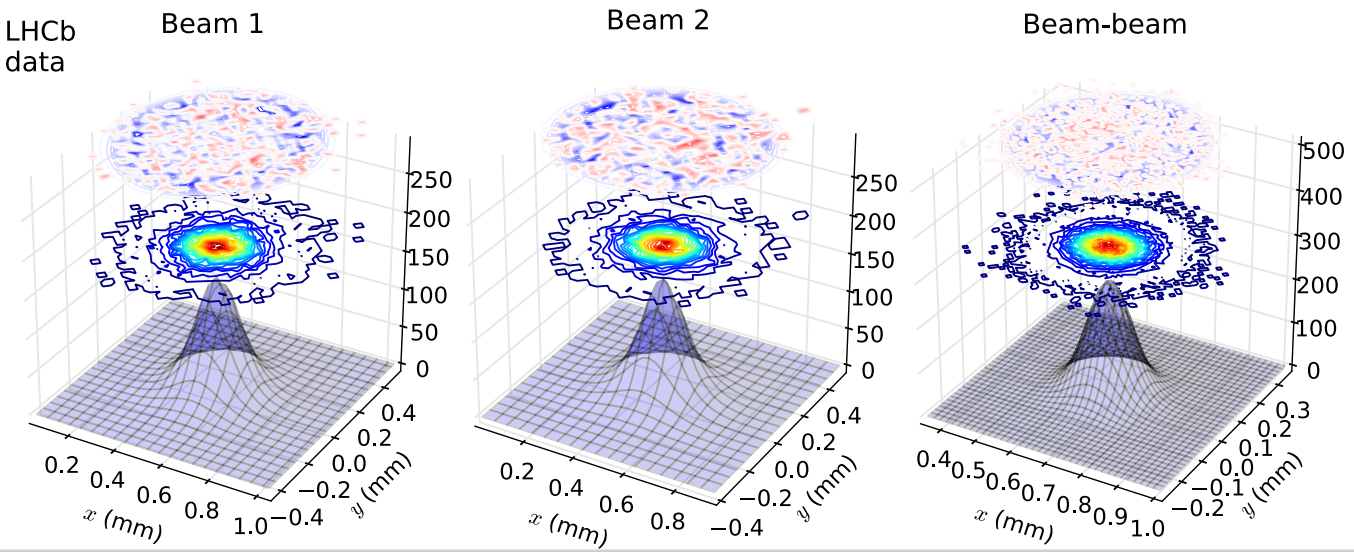


Global fit

- 10^5 beam-gas and 10^6 beam-beam vertices per bunch pair per 20 min
- Fit single beams and luminous region in one global fit
  - parameters: beam widths (multiple components), position, angle
  - strong constraint from beam spot



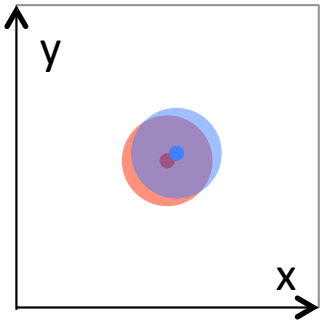
- Reached 1.4% uncertainty at √s = 8 TeV!



Van der Meer scans

$$\mu = \frac{R}{f_{rev}} = \frac{\sigma L}{f_{rev}} = \sigma N_1 N_2 \int \rho_1(x,y)\rho_2(x,y)\,dx\,dy$$

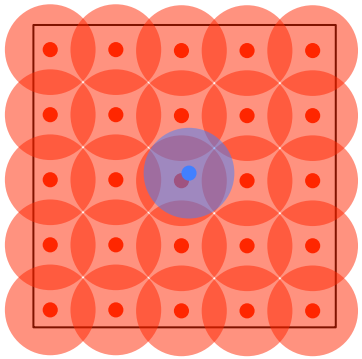
μ – average number of interactions per bunch crossing



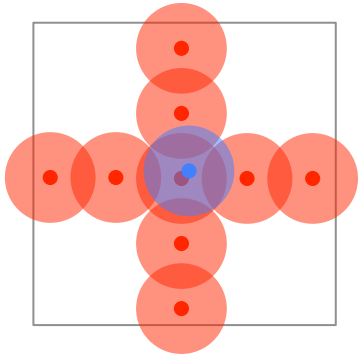
- Simon van der Meer's idea: separate beams and integrate rate as function of separation

$$\mu(\Delta x,\Delta y) = \sigma N_1 N_2 \int \rho_1(x,y)\rho_2(x+\Delta x, y+\Delta y)\,dx\,dy$$

$$\int \mu(\Delta x,\Delta y)\,d\Delta x\,d\Delta y = \sigma N_1 N_2 \underbrace{\int \rho_1(x,y)\rho_2(x+\Delta x, y+\Delta y)\,dx\,dy\,d\Delta x\,d\Delta y}_{=1}$$



- Raster scan not practical, would be too slow
- Do single direction scans in Δx and Δy
  - sufficient if $\rho_i(x,y)$ are x-y factorizable
  - method is simple and robust (only rates are measured)

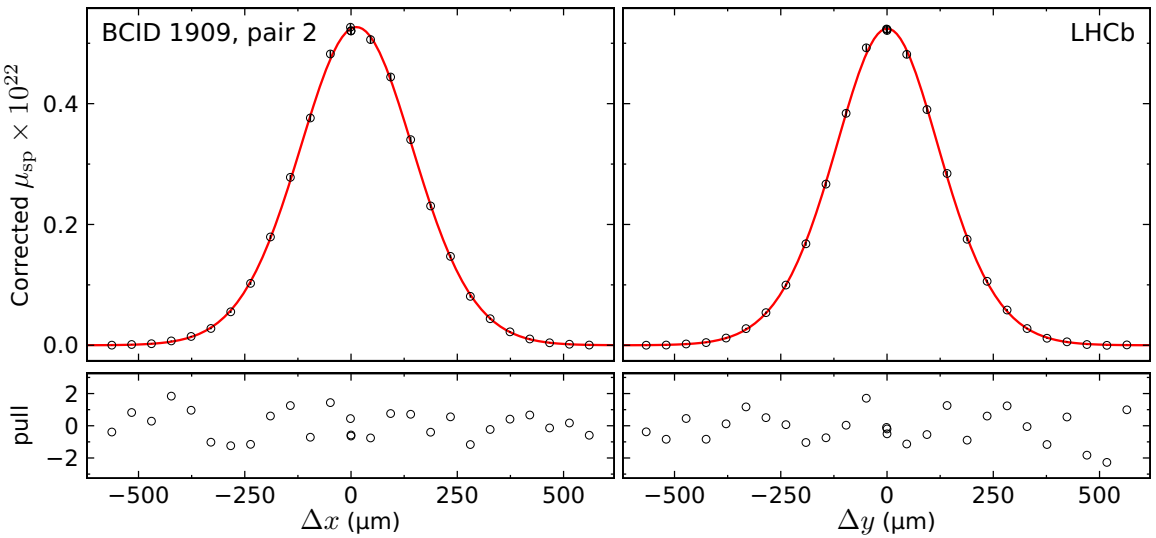


*In reality: finer steps and move both beams

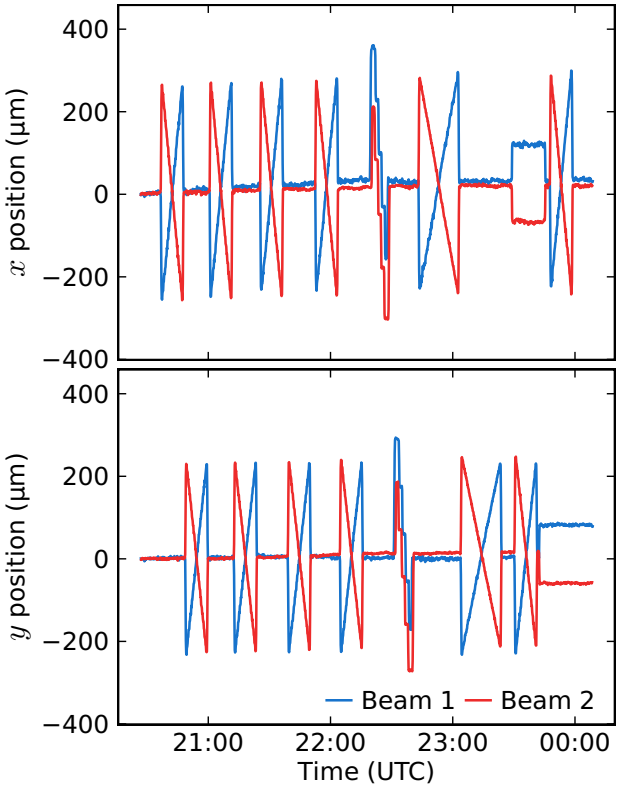
Van der Meer scans

- Sequence of several X-Y scan pairs
- Main sources of systematic uncertainty
  - knowledge of beam separation
  - assumptions for the 2-d profile shape
- Reached 1.5% uncertainty at √s = 8 TeV!

data and fit for one X-Y scan pair and one bunch pair



Beam movements recorded by beam position monitors



Summary and outlook

- Z → ee cross-section measured with high precision
  - systematic uncertainty of 1.6% (without luminosity)
  - luminosity is no longer limiting
  - valuable input to models for soft gluon emission and PDF fits
- Unprecedented precision on the luminosity determination
  - combined precision of 1.2% at √s = 8 TeV, using the two methods
  - most precise so far at a bunched beam hadron collider
- More electroweak results at 7 and 8 TeV coming soon

Thank you!