A novel method to measure luminosity at LHC(b) and implications for PDFs

HERA and the LHC workshop

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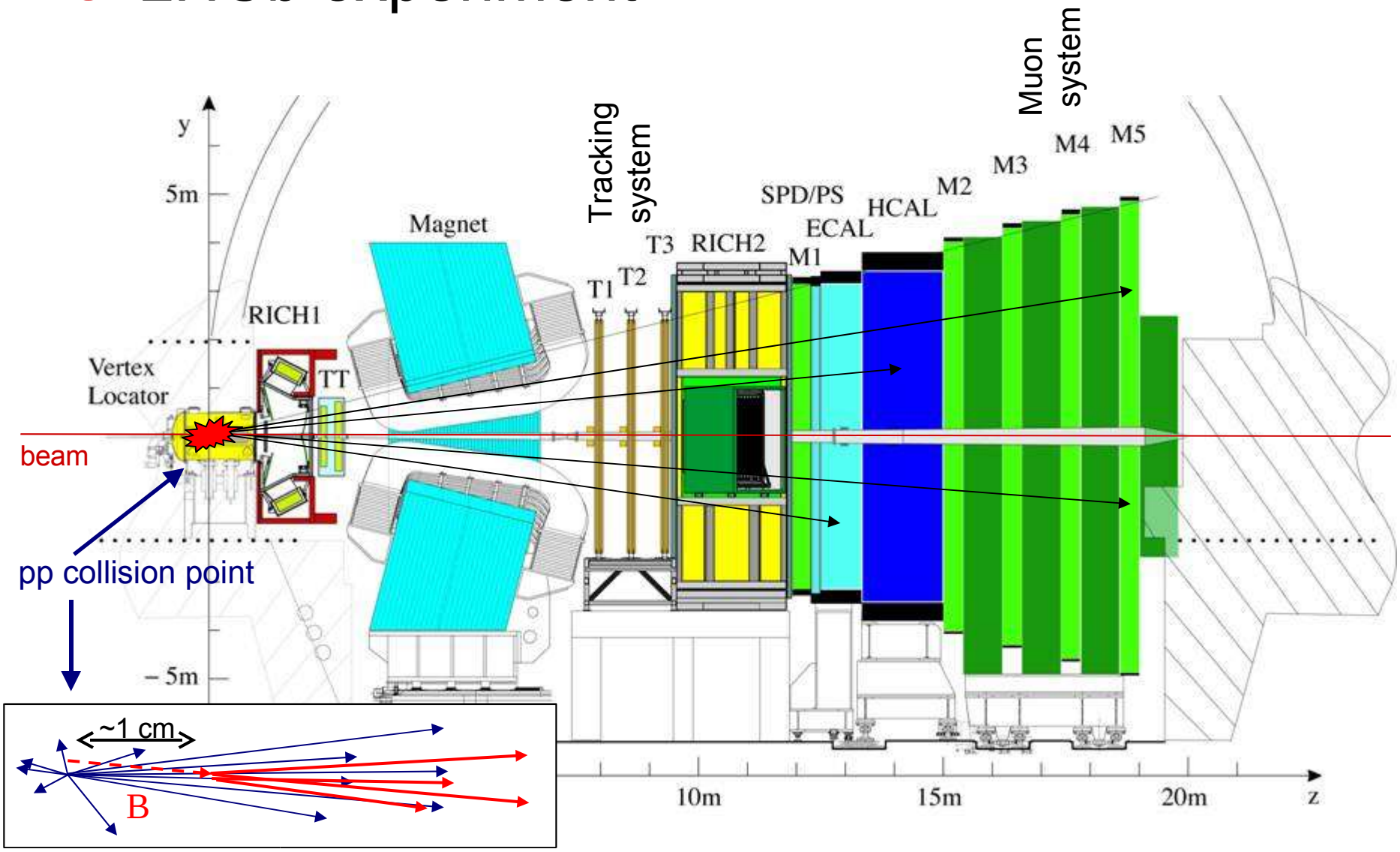
Overview

1. LHCb experiment
2. A novel method to measure luminosity at LHC(b)
3. $Z^0 \rightarrow \mu\mu$ channel in LHCb as a probe to determine PDFs at high Q^2, low x (very preliminary)
4. Summary

❶ LHCb experiment



❷ A novel method to measure luminosity

- Reminder of general formula for two counter-rotating bunches:
  - all particles in bunch **i** move with velocity $\mathbf{v}_i$ in the lab frame
  - position and time dependent density functions $\boldsymbol{\rho_i(x,t)}$ normalized to 1
  - the bunch populations $\mathbf{N}_i$
  - revolution frequency **f**

See e.g. in Napoly, Particle Acc., **40** (1993) 181.

$$L = f\, N_1\, N_2 \sqrt{(\mathbf{v}_1 - \mathbf{v}_2)^2 - \frac{(\mathbf{v}_1 \times \mathbf{v}_2)^2}{c^2}} \int_{4-\text{fold}} \rho_1(\mathbf{x}, t)\, \rho_2(\mathbf{x}, t)\, d^3x\, dt$$

bunch populations — crossing angle — beam overlap integral

- Velocity term taken out of integral if negligible angular spread

Luminosity via the beam profiles

- Set $v_1 = v_2 = c$ and crossing angle ϕ :

$$L = f\, N_1\, N_2\, 2c\, \cos^2(\phi/2) \int_{4-\text{fold}} \rho_1(\mathrm{x},t)\, \rho_2(\mathrm{x},t)\, d^3x\, dt$$

Measured by AB-BI

Measured by the experiments

- Proposed method:
  - Inject tiny bit of gas into the vtx detector region
  - Reconstruct bunch-gas interaction vertices
    - get beam angles, profiles & relative positions
    - calculate overlap integral
  - Simult., reconstruct bunch-bunch interaction vertices
    - calibrate 'reference' cross-section

Typical rates:

N=5x10^{10}, β*=34 m

10^{-7} mbar Xe

***p*-Xe** ~ 15 Hz per bunch per 20 cm z-bin

***pp*(7TeV)** ~ 1 kHz per bunch pair

Beam-gas method: main requirements

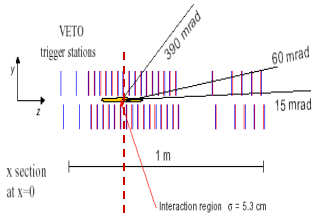
- Reconstruction and discrimination of beam1-gas, beam2-gas and beam1-beam2 events
- Vertex resolution in x and y < beam transverse sizes
- Any dependence on x and y (gas density, efficiency, ...) must be small (or known to some precision)
- Bunch charge normalization measured by accelerator group

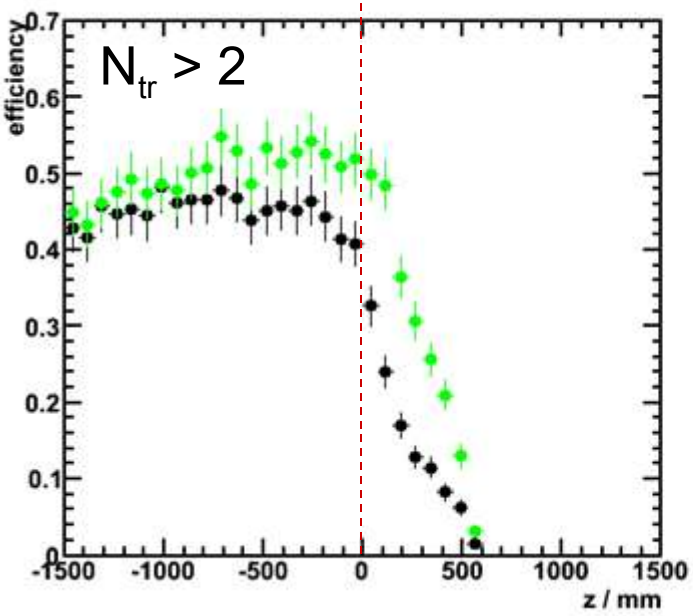
- For more info, see:
  - "Proposal for an absolute luminosity determination in colliding beam experiments using vertex detection of beam-gas interactions", MFL, CERN-PH-EP-2005-023
  - MFL, *Nucl. Instrum. Methods Phys. Res., A 553 (2005) 388-399*
  - CERN EP Seminar, MFL, 29.aug.2005
  - CERN AB Seminar, MFL, 30.mar.2006

Acceptance for beam1 - ^{1}H events

work by Tomáš Laštovička

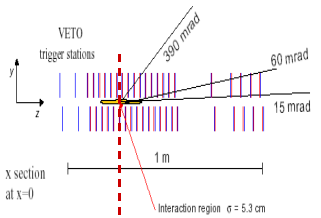
beam1

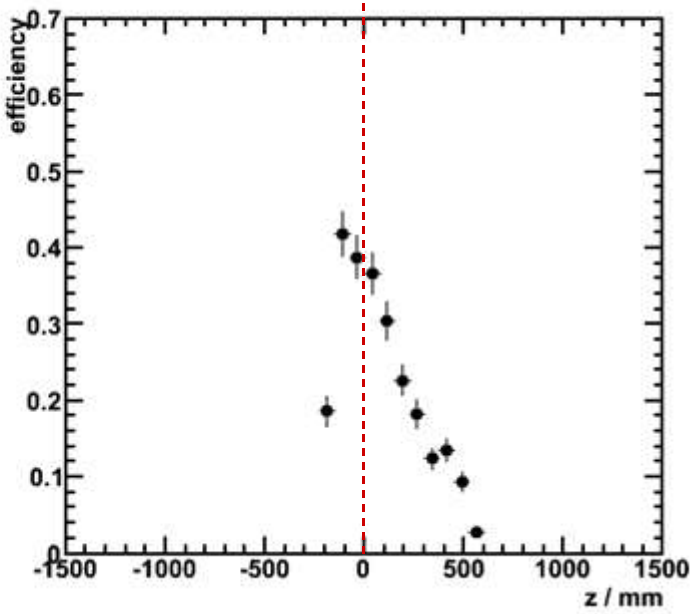




Generic PatRec

beam1





Standard PatRec
designed for *pp* collisions...

Full LHCb simulation framework!

Beam1-gas vertex resolution vs Z

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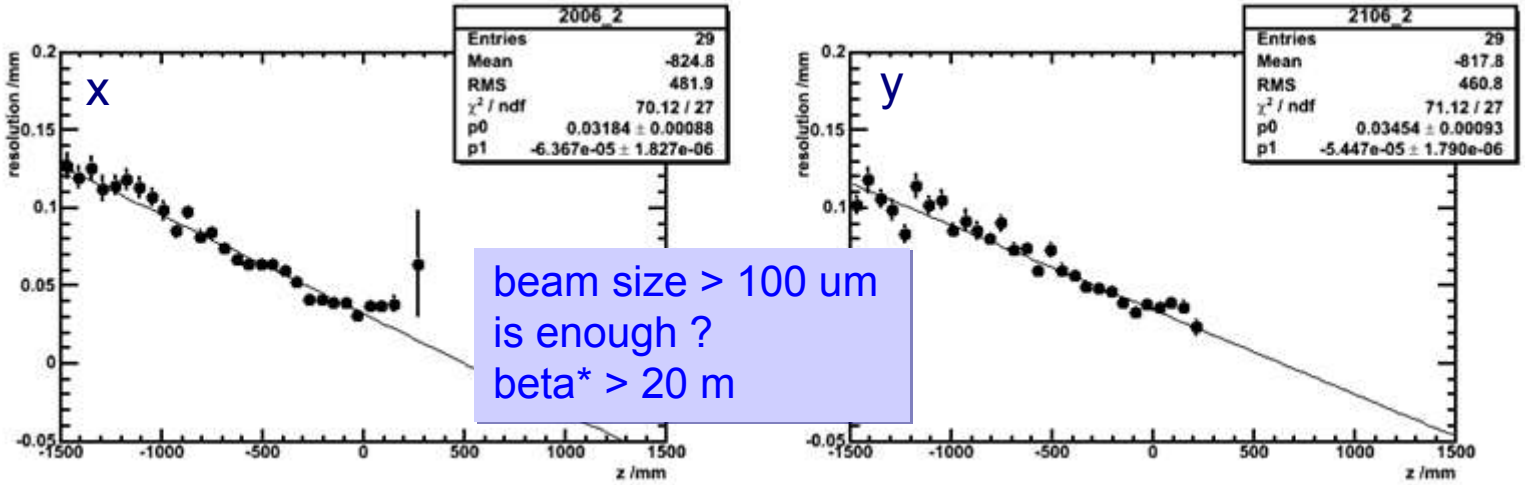
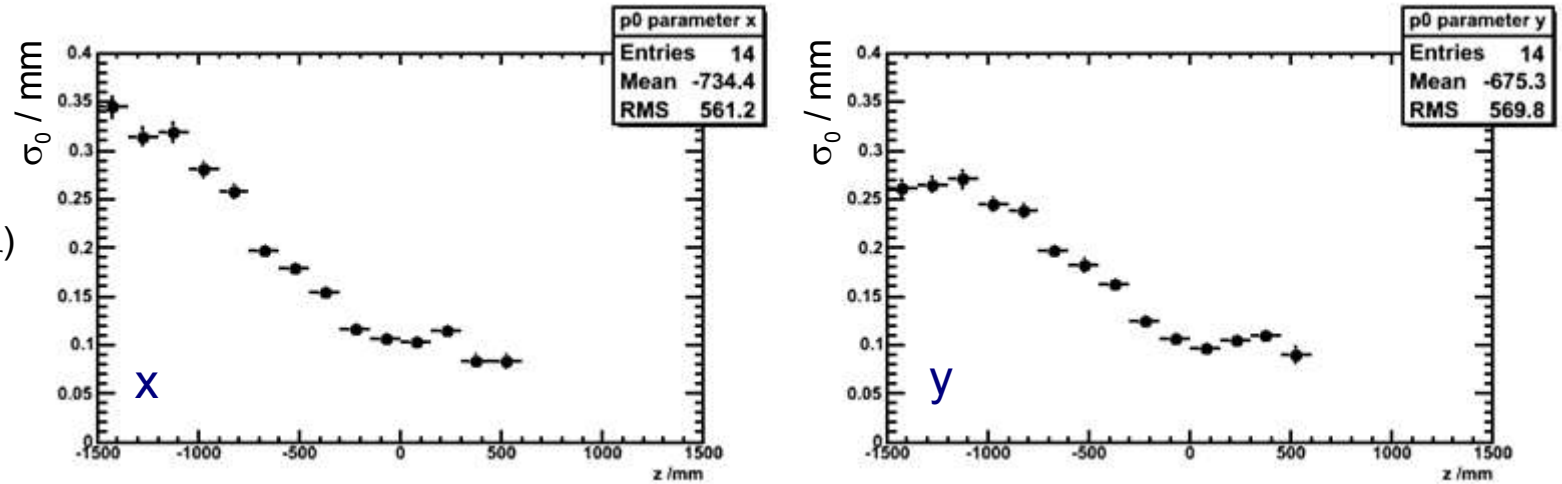
$N_{tr} > 5$



beam size > 100 um
is enough ?
beta* > 20 m

resol=
$\sigma_0/\sqrt{N_{tr}}$



Beam-gas method: a first outlook

- First study with beam1 - ^{1}H, full simulation:
  - transverse resolution $\sigma_{vtx\_x,y} \sim \sigma_0 / \mathrm{sqrt}(N_{tr})$ with $\sigma_0 \sim 200...100$ um in region -70 cm < z_{vtx} < 50 cm
  - luminosity is linear with beam variance $\sigma_{x,y}$, while $\sigma_{vtx\_x,y}$ adds in quadrature with $\sigma_{x,y}$
  - beam size > 100 um is good enough (?) => β^* > 20 m
- Better with heavier gas target ? (higher multiplicity)
- How much rate loss if request a minimum multiplicity ?
- Any reconstruction dependence on x_{vtx} and y_{vtx} ?
- What about beam2 ?

Beam-gas method: proposed strategy

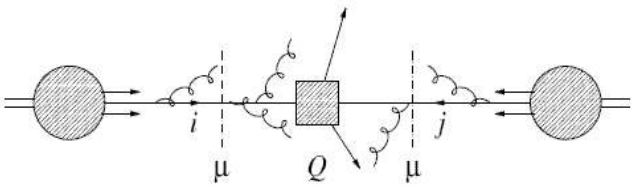
- try method early on with residual gas, if OK => pursue
- dedicated run (few days, large β^*, 0 crossing angle):
  - inject gas (Xe), measure L and a reference cross section σ_{ref}
    - σ_{ref} is a large and "experimentally robust", not required to be theoretically interpretable, nor transferable to an other interaction point
- then, during normal running:
  - measure $\sigma_{phys} = \sigma_{ref} \; R_{phys} \; / \; R_{ref}$ (R = rate) , any physics cross section
  - properly chosen σ_{phys} may allow comparison or cross-calibration between experiments
  - physics: heavy flavour production, inelastic cross section, PDFs, ...

First study: Z -> mu mu

Weak boson production at LHC

- See e.g. Dittmar, Pauss & Zürcher, PRD **56** (1997) 7284:

  ‘ Measure the x distributions of sea and valence quarks and the corresponding luminosities to within ±1% … using the **l** ± pseudorapidity distributions from the decay of weak bosons. ’



$$\frac{d\sigma}{dX} = \sum_{i,j}\sum_{\tilde{X}} \int dx_1 dx_2 \; f_i(x_1,\mu^2) f_j(x_2,\mu^2) \times \hat{\sigma}_{ij}^{\tilde{X}}(\alpha_S(\mu^2), Q^2, \mu^2)\; F(\tilde{X} \to X, \mu^2)$$

Stolen from K. Ellis, HCP2005

Here, we propose to measure proton luminosities at LHCb and use weak boson production to constrain parton modeling

❸ Monte Carlo Simulations, $Z^0 \rightarrow \mu^+\mu^-$

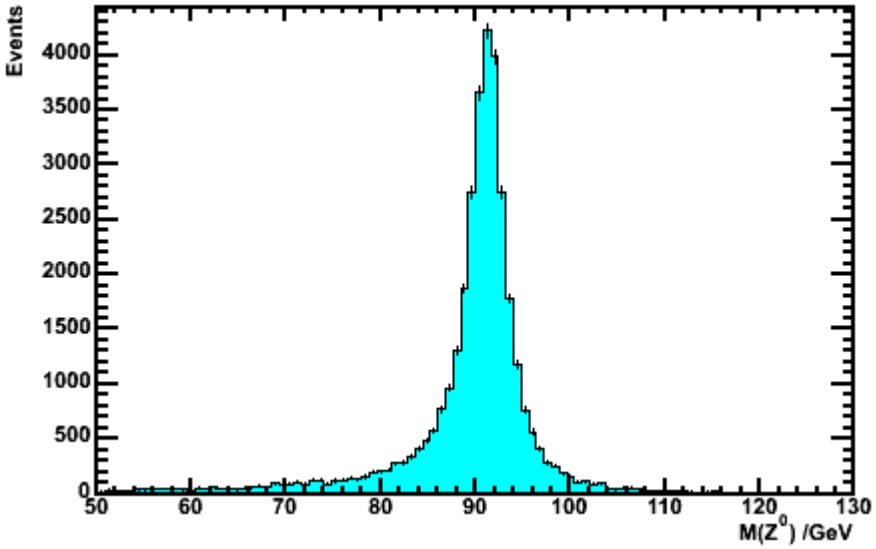
work by Tomáš Laštovička

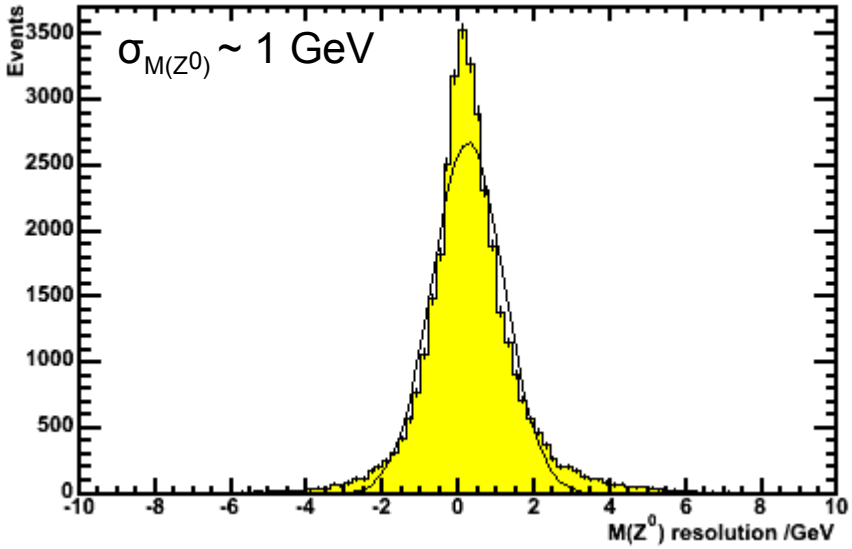
- Full LHCb detector simulated
  - about 100'000 $Z^0 \rightarrow \mu\mu$ events generated with Pythia
  - generator cuts applied: request at least one *e* or μ (not necessarily from Z^0) to be at θ<400 mrad, p_T>4GeV, p_z>0.
  - no trigger requirements

- Disclaimer
  - Presented results does not exactly represent a real analysis.
  - No background studies, efficiencies, …
  - The point is to see where we could measure and with which sensitivity
  - In the following, if two Z^0 muons are found (reconstructed and correctly identified) in LHCb, they are used to determine kinematics – no combinatorics issues since we know they are from Z^0

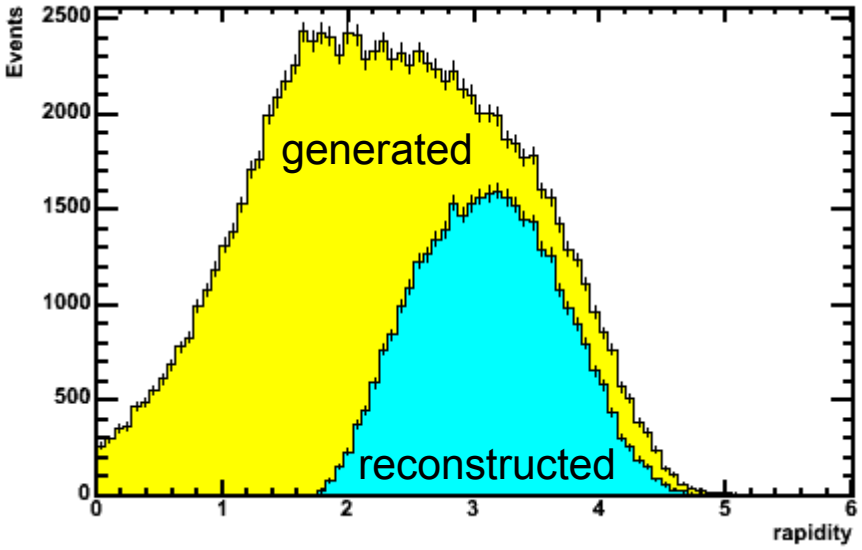
Z^0 reconstruction

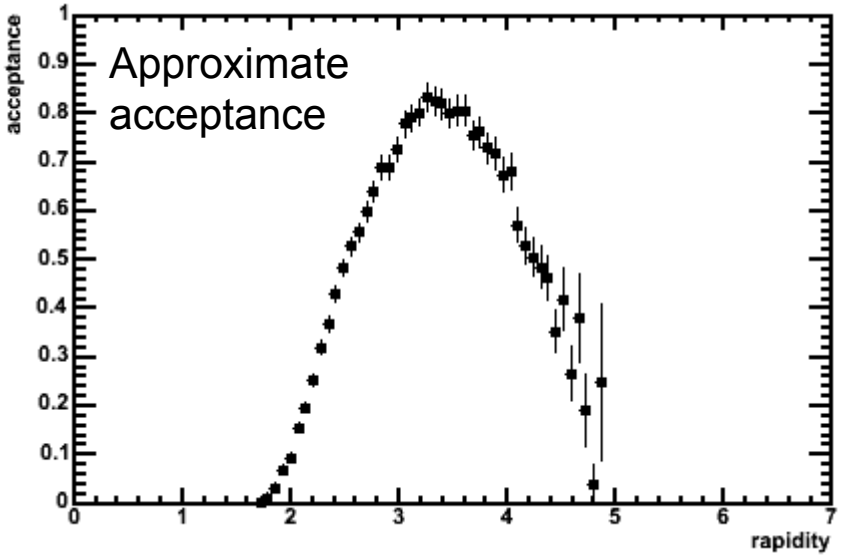
- $\mu^+ \mu^-$ pair combined into Z^0
- Reconstructed mass and mass resolution are fine

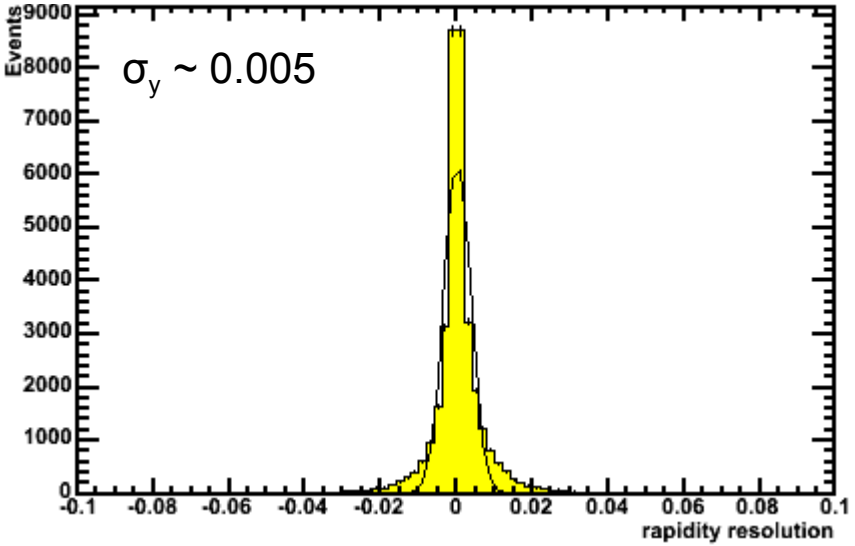




Z^0 reconstruction - rapidity







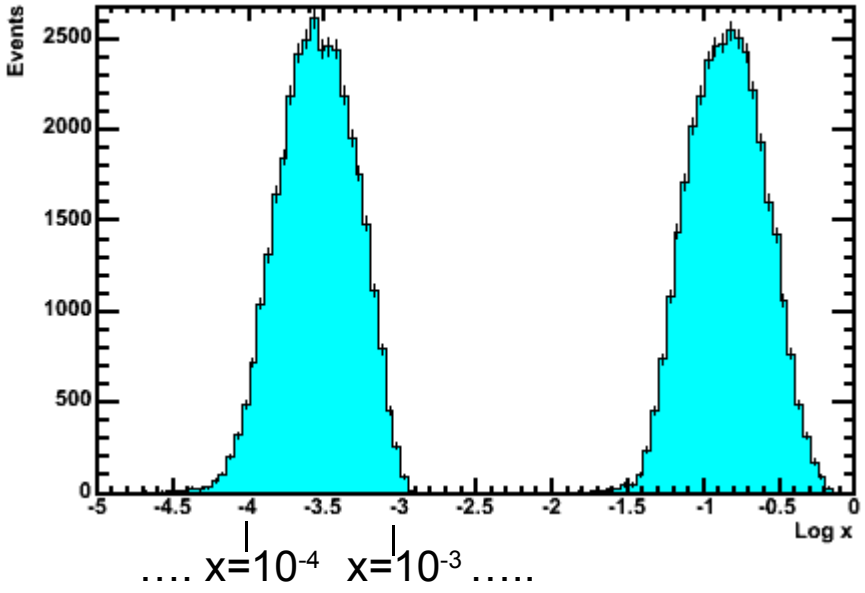
- LHCb has acceptance of $1.8 < y < 5$ in terms of Z^0 rapidity
  - which can be reconstructed with very high precision

Z^0 reconstruction – Bjorken x

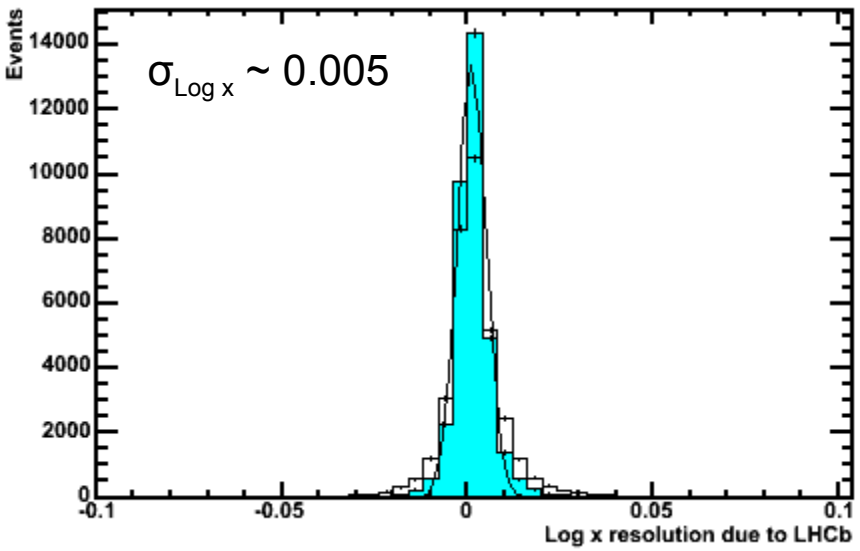
- In leading order and neglecting parton showers
- LHCb can access low $x=10^{-4} - 10^{-3}$ and high x at $Q^2 \sim 10000$ GeV^2
- Excellent Bjorken x reconstruction "resolution" due to LHCb detector

$x^{MC}_{1,2}$ - $x_{1,2}$ with $x_{1,2} = \frac{M}{\sqrt{S}} \exp(\pm y)$

y from reconstructed Z^0

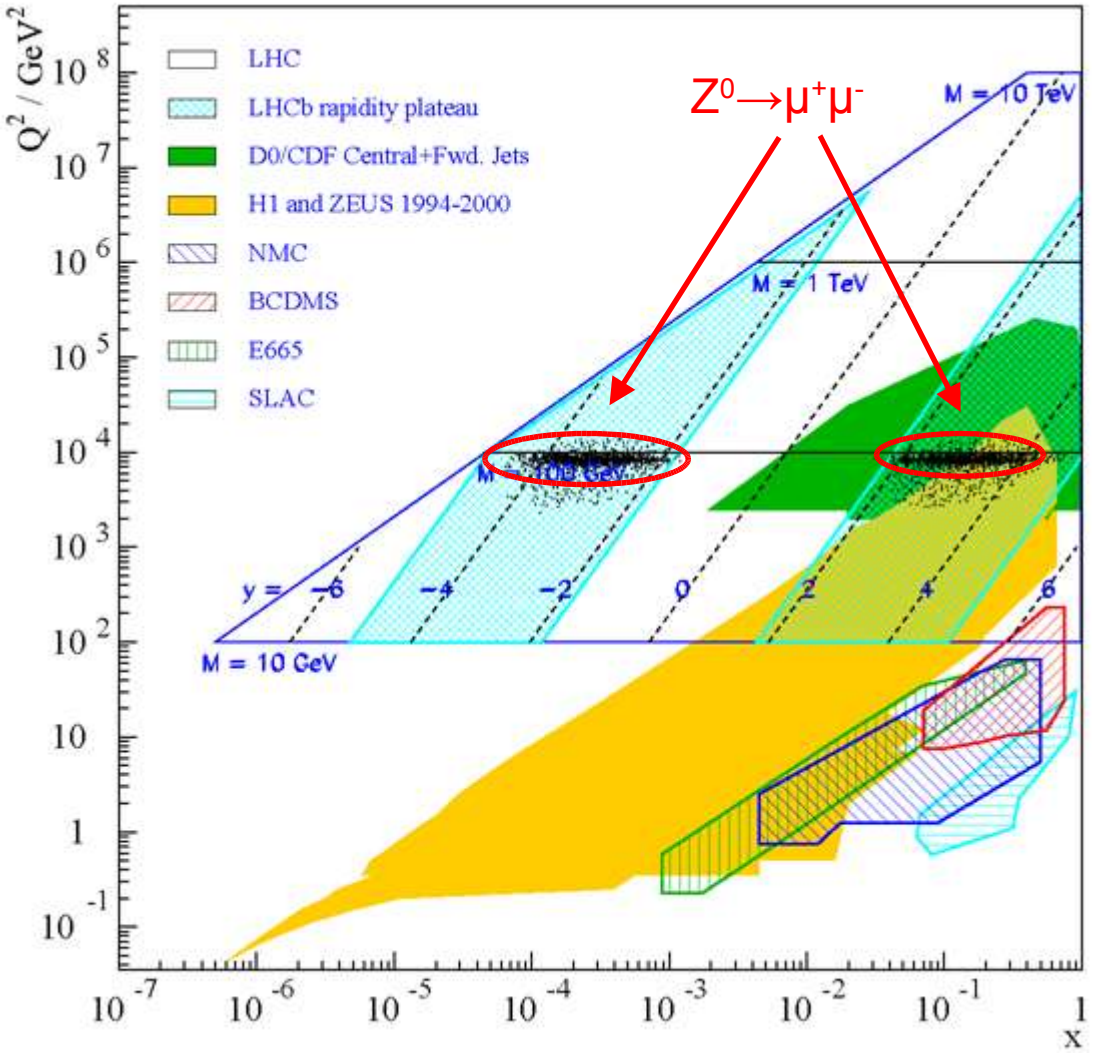


…. $x=10^{-4}$ $x=10^{-3}$ …..



Kinematic coverage

- Reconstructed events overlayed
  - $Q^2 = M_{Z0}^2$
  - leading order Bjorken x
- LHCb at high x overlaps with D0/CDF and HERA
- A very nice opportunity to pinpoint/cross-check PDFs at low x !
- Overlap between LHC experiments ?
- Expected reconstructed rate ? 10^5 / year ?



❹ Summary

- A novel method was proposed to measure absolute luminosity at LHCb experiment aiming for few % precision
  - note that LHCb does not have luminosity measurement system, proposed method is based on the vertex detector and tiny amount of gas injected inside the beam pipe
- Knowledge of luminosity would allow to measure $Z^0 \rightarrow \mu^+\mu^-$ cross section in the rapidity region of $1.8 < y < 5$
  - access to PDFs at low x (+high x) and at high $Q^2 \sim 10'000\ GeV^2$
- Future
  - trigger and event rate studies
  - background
  - measurement systematics
  - W^+ W^- production
  - waiting for LHC data…

LHCb cavern – May 2006

LHCb kinematic coverage

- At LHC center of mass energy is $\sqrt{S}$ = 14TeV
- LHCb acceptance in terms of pseudorapidity:
  $1.8 < \eta < 5$
- Corresponds to a mixture of high/low x at high values of Q^2

$$x_{1,2} = \frac{M}{\sqrt{S}} \exp(\pm y)$$