Luminosity monitor at LHCb

January 26, 2007

LHC workshop on the luminosity monitoring and measurement

Tomáš Laštovička (*CERN*)

on behalf of the LHCb Collaboration

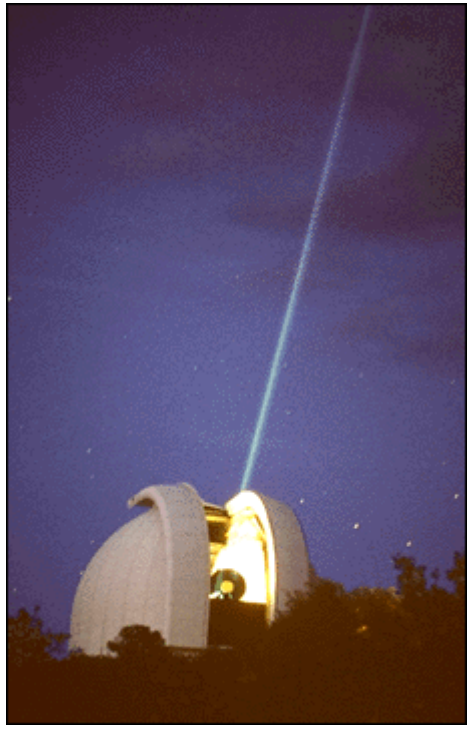
Overview

1. A method to measure absolute luminosity
2. LHCb case study - simulations
3. 2007 LHC pilot runs
4. Outlook

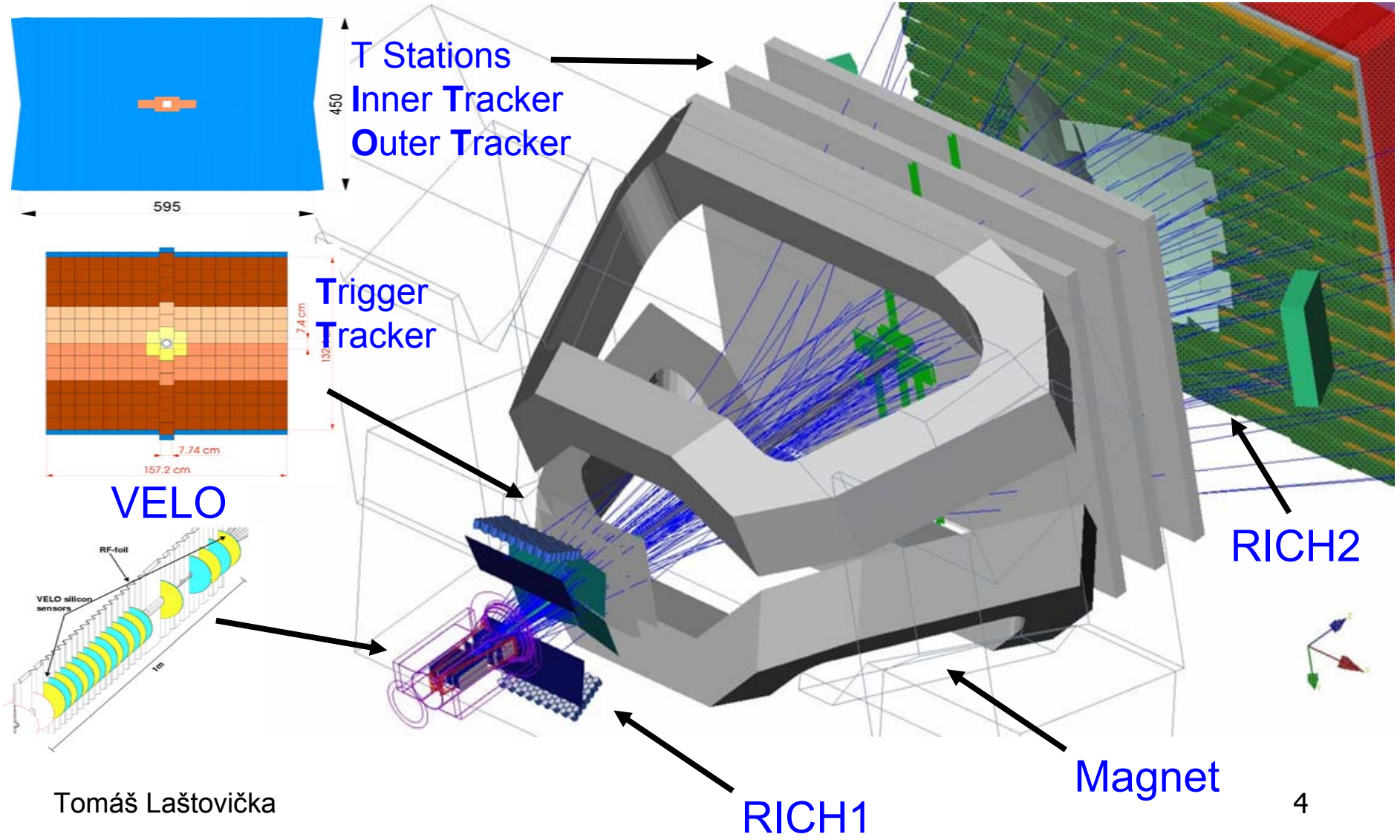
I will focus on a novel ‘beam-gas’ absolute luminosity measurement method. A (‘zero-counting’) method to measure the relative luminosity was presented on this workshop in the past (2002).

❶ *Luminosity measurement at LHCb*

- LHCb does not have a devoted system to measure absolute luminosity
  - not needed for vast majority of measurements
  - however, if it comes ‘for free’ there are interesting applications
- A novel method proposed:
  use high precision vertex locator (VELO) to measure parameters of both beams
- To actually ‘see’ the beams we employ beam-gas interactions
- It is just like to light a laser beam (LHC beam) in fog (gas)

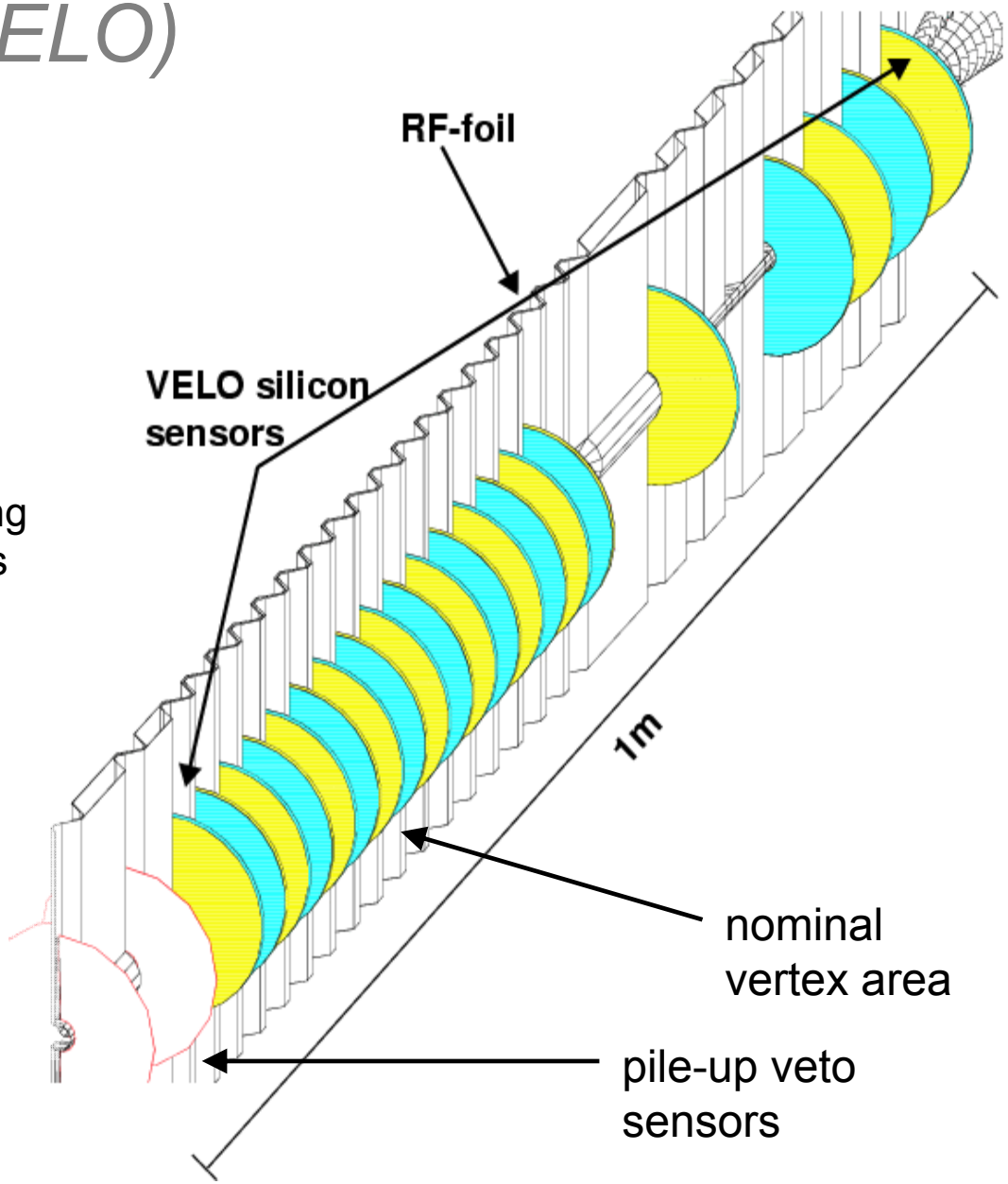


LHCb experiment



Vertex Locator (VELO)

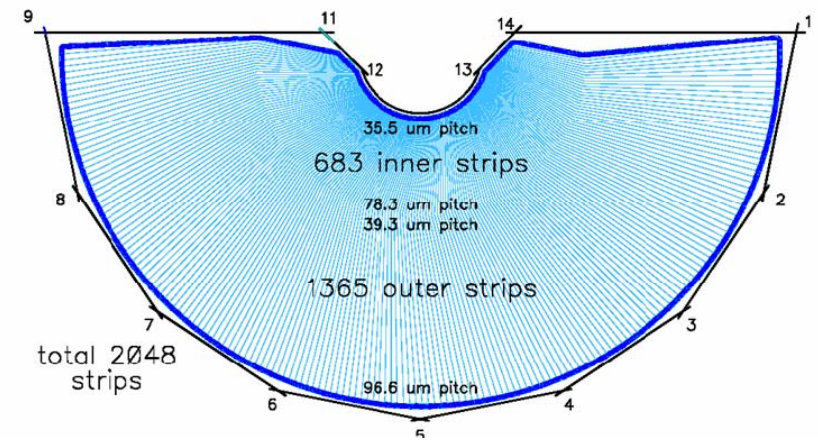
- 21 tracking stations on two sides
  - 42 modules, 84 sensors
  - plus pile-up sensors
- Optimised for
  - tracking of particles originating from beam-beam interactions
  - fast online 2D (R-z) tracking
  - fast offline 3D tracking in two steps (R-z then phi)
- Velo halves move from the LHC beams (by 30mm) during the beam injection and tuning



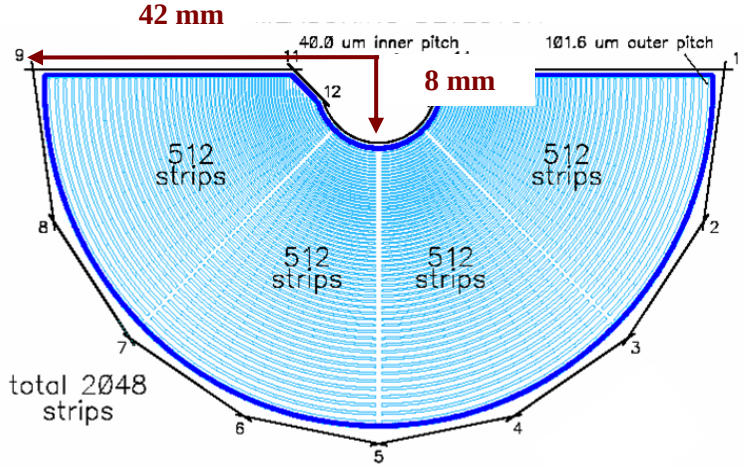
Vertex Locator (VELO)

- Each module consists of 2 sensors: R and φ type (Δz ~ 2mm)
- Each sensor contains 2048 strips in total distributed in 4 (R) and 2 (φ) zones with pitch varying from ~40um (inner region) to ~100um (outer region).
- Primary vertex reconstruction resolution <10um in x-y plane, ~50um in z-coordinate, IP~14+35/p_T um

φ-sensors
2048 strip in inner and outer regions
strip pitch increase with R : 36um→97um



R-sensors
2048 strip in 45° sectors
strip pitch increase with R : 40um→100um



A 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 beam-gas interactions

For more, see e.g. the last Hera-LHC wkshp, MFL&TL, and refs therein

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

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

Measured by AB-BI

Measured by the experiments

- Proposed method:
  - Inject a tiny bit of gas (if needed at all) into the vertex detector region
  - Reconstruct bunch-gas interaction vertices
    - get beam angles, profiles & relative positions (note $\sigma_{x,y}$ ~ 70um)
    - calculate overlap integral
  - Simultaneously reconstruct bunch-bunch interaction vertices
    - calibrate ‘reference’ cross-section

Method requirements

- Vertex resolution in *x* and *y* significantly smaller than beam transverse sizes and well understood
  - much less tracks than beam-beam events → worse resolution
- Sufficiently high beam-gas interaction rate
  - data must be taken in time << min ($t_{\text{beam decay}}$, $t_{\text{beam drift}}$)
- Ability to reconstruct/distinguish beam1-gas and beam2-gas events
  - and to trigger on them !
- Any dependence on *x*/*y* (gas density, efficiency, ...) must be small
  - or known to some precision
- Conditions to start with
  - zero crossing angles – large bunch spacing
  - wide beam profile (large beta*)

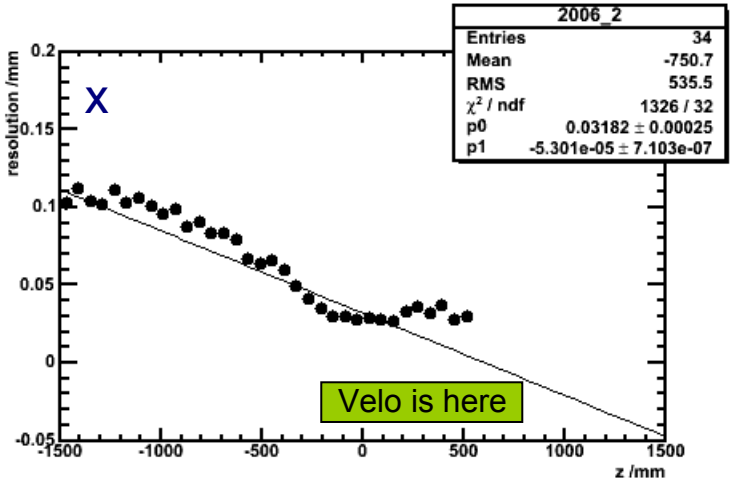
2 *First studies at LHCb*

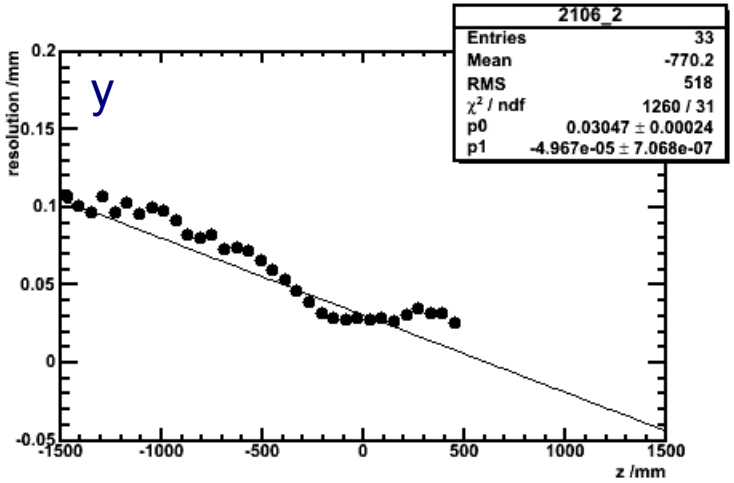
- Beyond 14TeV pp simulations:
  - Pythia pp 115 GeV (p-hydrogen)
  - Hijing p-nucleus 115 GeV – Xenon simulated
- Analysis performed so far:
  - Beam-gas vertex reconstruction resolution
  - Beam-gas acceptance
  - Dependence on target species

~30um for Ntr>5 around z=0
is it enough?
beam size > 100 um,beta* > 20 m

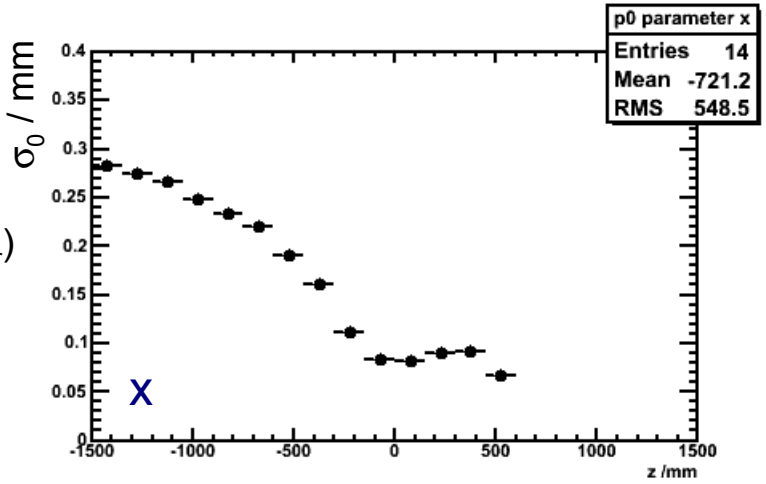
Beam1 – ^1H simulations

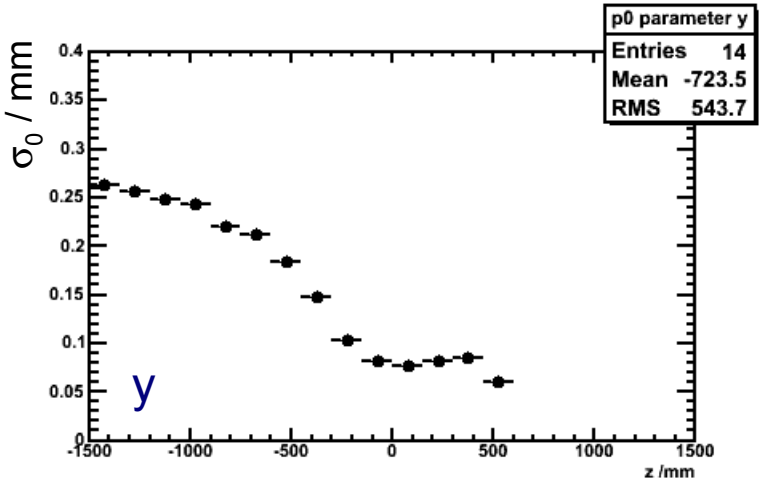
$N_{tr} > 5$





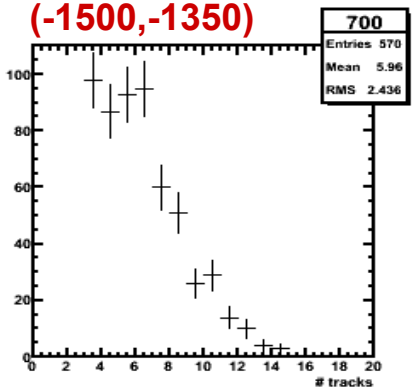
resol=
$\sigma_0/\mathrm{sqrt}(N_{tr})$



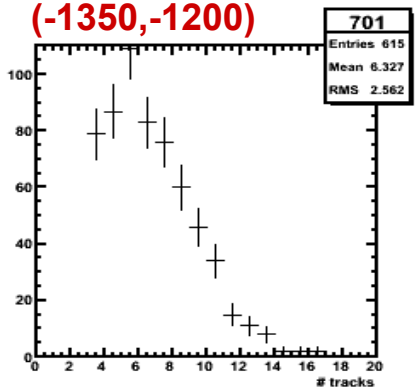


Number of tracks per vertex *(beam1-^{1}H)*

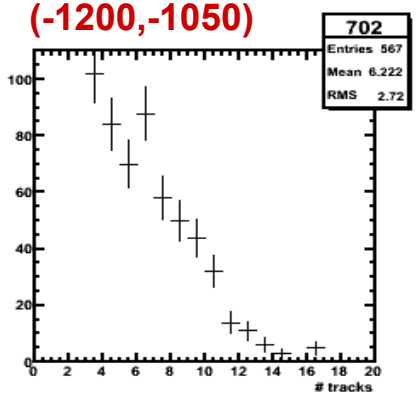
(-1500,-1350)



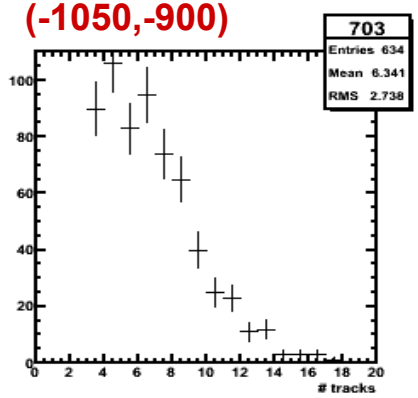
(-1350,-1200)



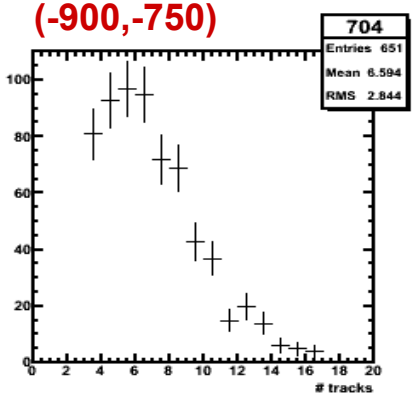
(-1200,-1050)



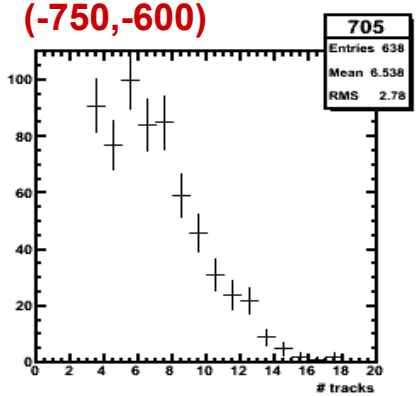
(-1050,-900)



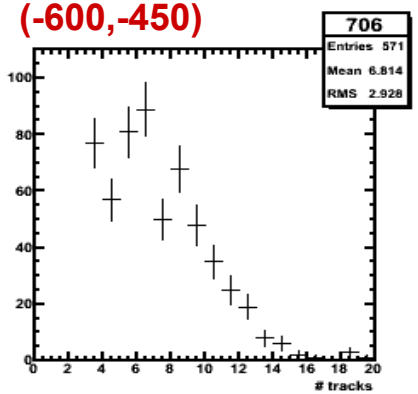
(-900,-750)



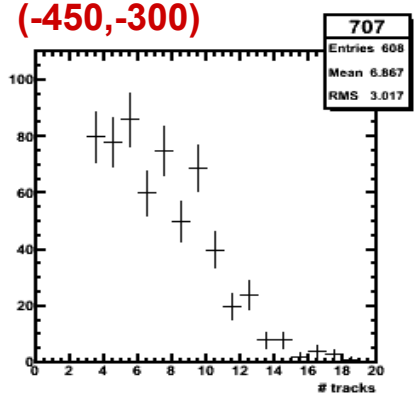
(-750,-600)



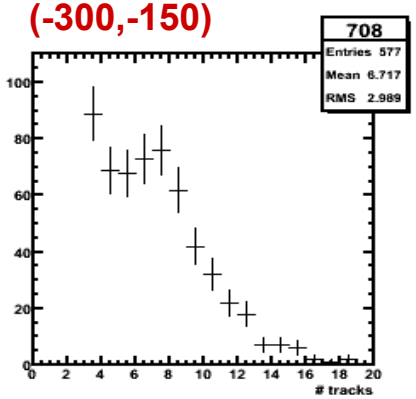
(-600,-450)



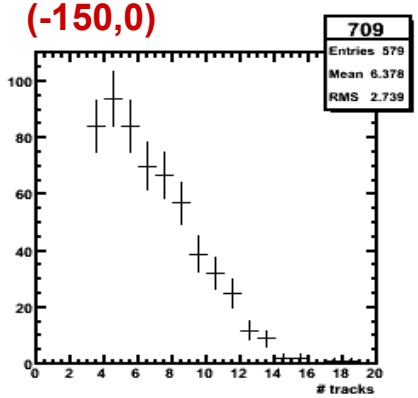
(-450,-300)



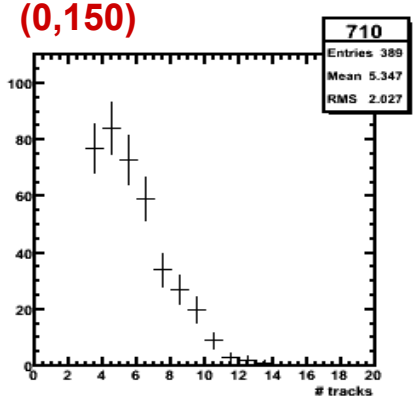
(-300,-150)



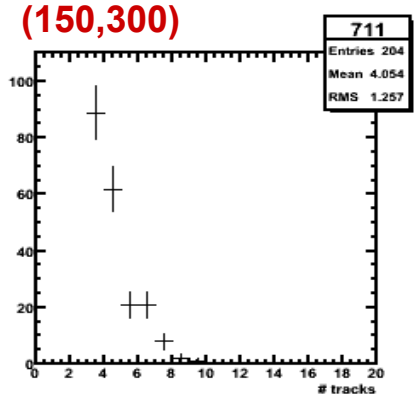
(-150,0)



(0,150)



(150,300)

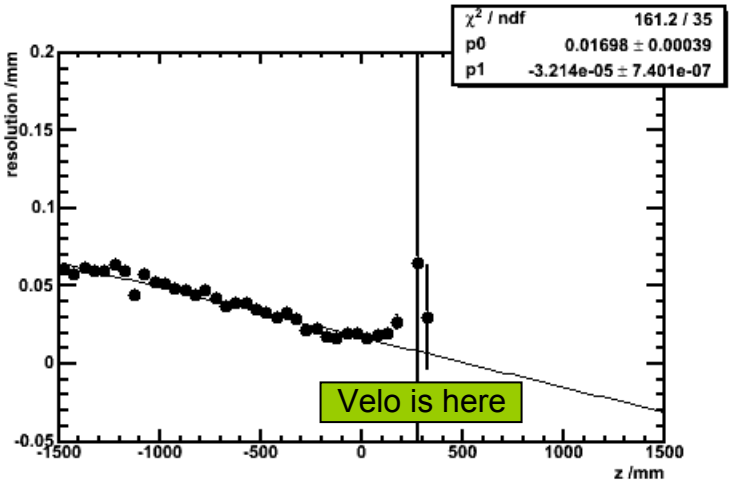


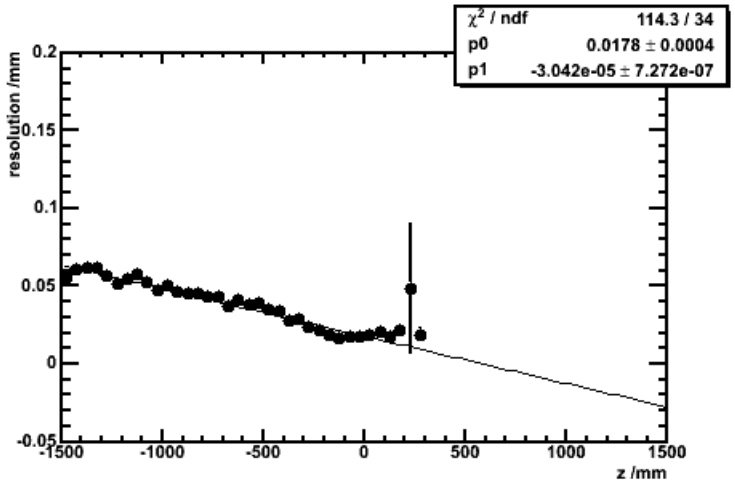
Beam1 – Xe simulations

- Available data tell us that
  - cross section $\sigma_{pA}(A) \sim A^{0.71}$
  - track multiplicity $N_{pA}(A) \sim A^{1/3}$

  } look for a heavy gas

$N_{tr} > 14$



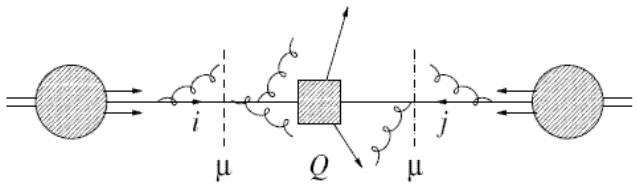


- Many more tracks allow for improved resolution, below 20um.
  - Acceptance is even increasing when moving more far from VELO, due to many flat tracks

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 $l^{\pm}$ pseudorapidity distributions from the decay of weak bosons.* '



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

K. Ellis, HCP2005

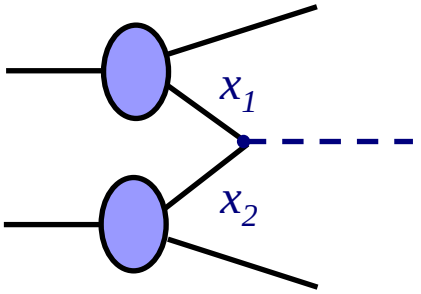
Here, we propose the opposite: to measure proton luminosities at LHCb and use weak boson production to constrain and check PDFs.

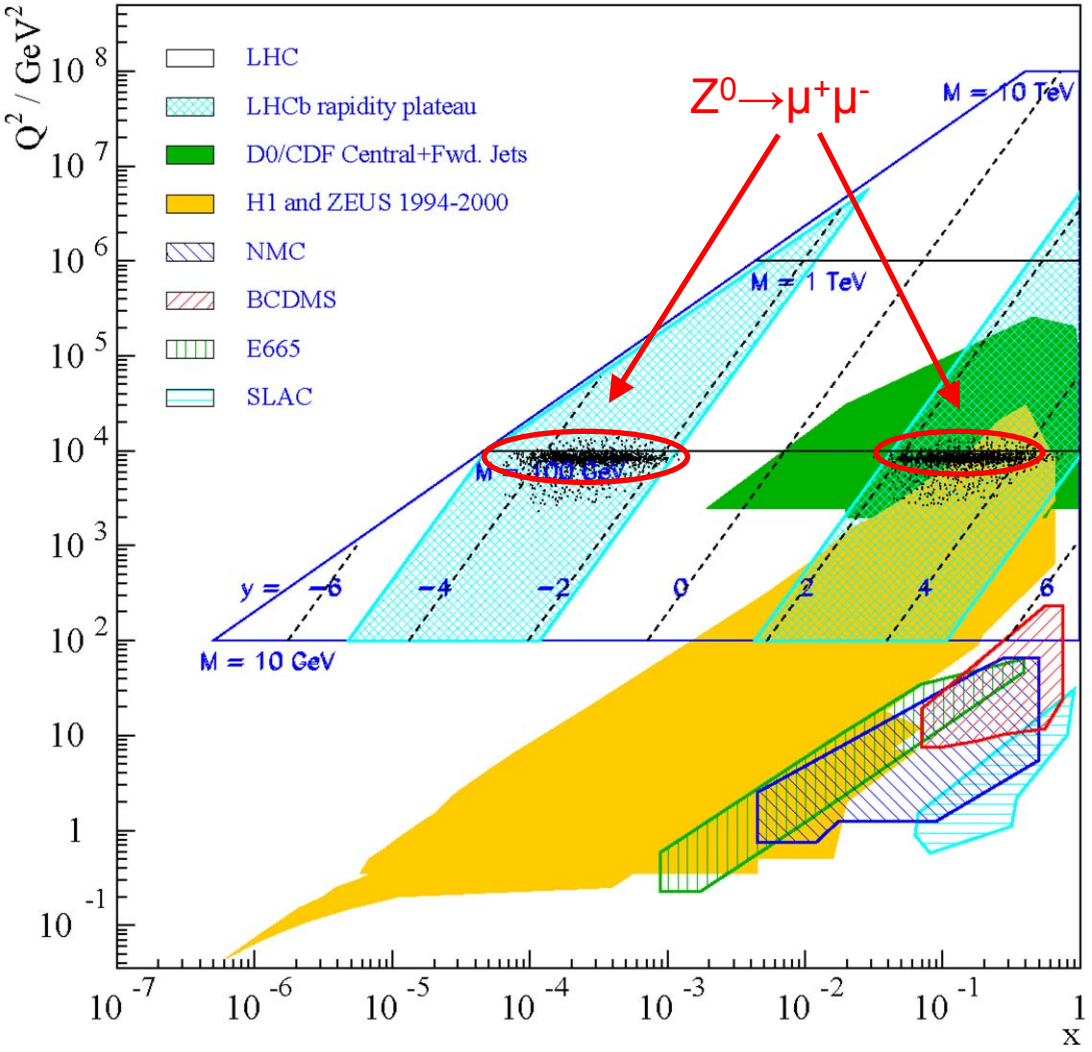
$Z^0 \rightarrow \mu^+\mu^-$ kinematic coverage

- At LHC center of mass energy is $\sqrt{s}$ = 14TeV
- LHCb acceptance in terms of rapidity:

  $1.8 < y < 5$
- Corresponds to a mixture of high/low x at high values of Q^2

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



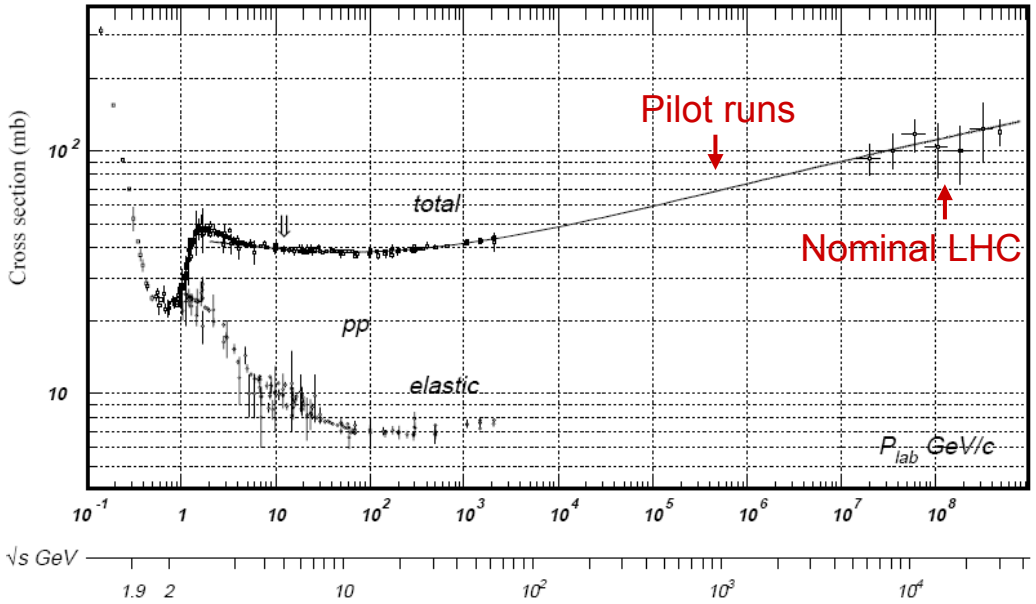


❸ 2007 LHC pilot runs

- LHC beam commissioning is expected to start in November 2007
  - beam energy 450GeV
  - we should be able to see first beam-gas events
  - VELO will be in its open position → worse acceptance
- After few weeks first beam-beam collisions @ $\sqrt{s}$=900GeV
  - 43 bunches on 43 scheme (4 are displaced for LHCb)
  - zero crossing angle
  - β^* = 10m at point 8 → large beam size $\sigma_{x,y}$ = 280μm
  - bunch charge N ~ 3.10^{10}
  - longer bunches (that at 7TeV) σ_z = 11.2cm (instead of 7.5cm)
  - LHCb magnet off
  - VELO opened or semi-opened
    - risk for closed VELO and B=0 to be assessed
    - very unlikely to have Velo closed and field ON

LHC pilot runs – physics?

- Pilot runs will play a major role in LHCb commissioning.
- Opportunity to practicise reconstruction of beam-gas events.
- Is there any physics we could do?
  - Only a handful of visible b-events.
  - How large is pp cross section? It could be measured…



Expected event rates

- pp inelastic @ √s=900GeV
  - estimated to be around 50Hz per bunch pair
- "useful" beam-gas rate @ √s=29GeV
  - assumed ^{1}H and the predicted vacuum of $10^{-10...-11}$ mbar
  - over 0.5m *z*-range

  1 mHz per bunch
- The beam-gas rate is very low, we may need to help it…
  - VELO system adaptation to control the residual gas pressure
    - in a range roughly 10^{-10} mbar to 10^{-7} mbar
      (still very high vacuum not affecting the beam lifetime)
  - Expected to be tested and estimated in Q1/2007
    - 1Hz per bunch and 50cm seems realistic (~10^{-8} mbar pressure)

Expected event rates - 7TeV conditions

- For comparison below are the estimates for nominal running conditions
  - gas injection for luminosity measurement
  - and larger beam ($\beta^* = 34\text{m} \rightarrow \sigma_{x,y} = 130\mu\text{m}$)
- pp inelastic @ $\sqrt{s}$=14TeV
  - estimated to be around 3.3 kHz per bunch pair
- "useful" beam-gas rate @ $\sqrt{s}$=114.5GeV
  - assumed Xe injection and vacuum of 10^{-7} mbar
  - bunch population 10^{11}
  - over 0.5m *z*-range

~80 Hz per bunch

Summary & Outlook

- Beam-gas lumi method is being studied at LHCb from the reconstruction side
  - 7 TeV already advanced
  - now starting on 450 GeV – LHC pilot runs
- Technical implementation of the "residual gas target"
  - residual gas for LHC pilot runs – tests to be done in the coming months.
  - gas injection for 2008 or later, conceptual design being worked out, to be discussed within LHCb and with AT-VAC
- Trigger implementation to be studied
  - concerns especially beam2-gas events