Vertex, Track Reconstruction & Luminosity Monitoring at LHCb

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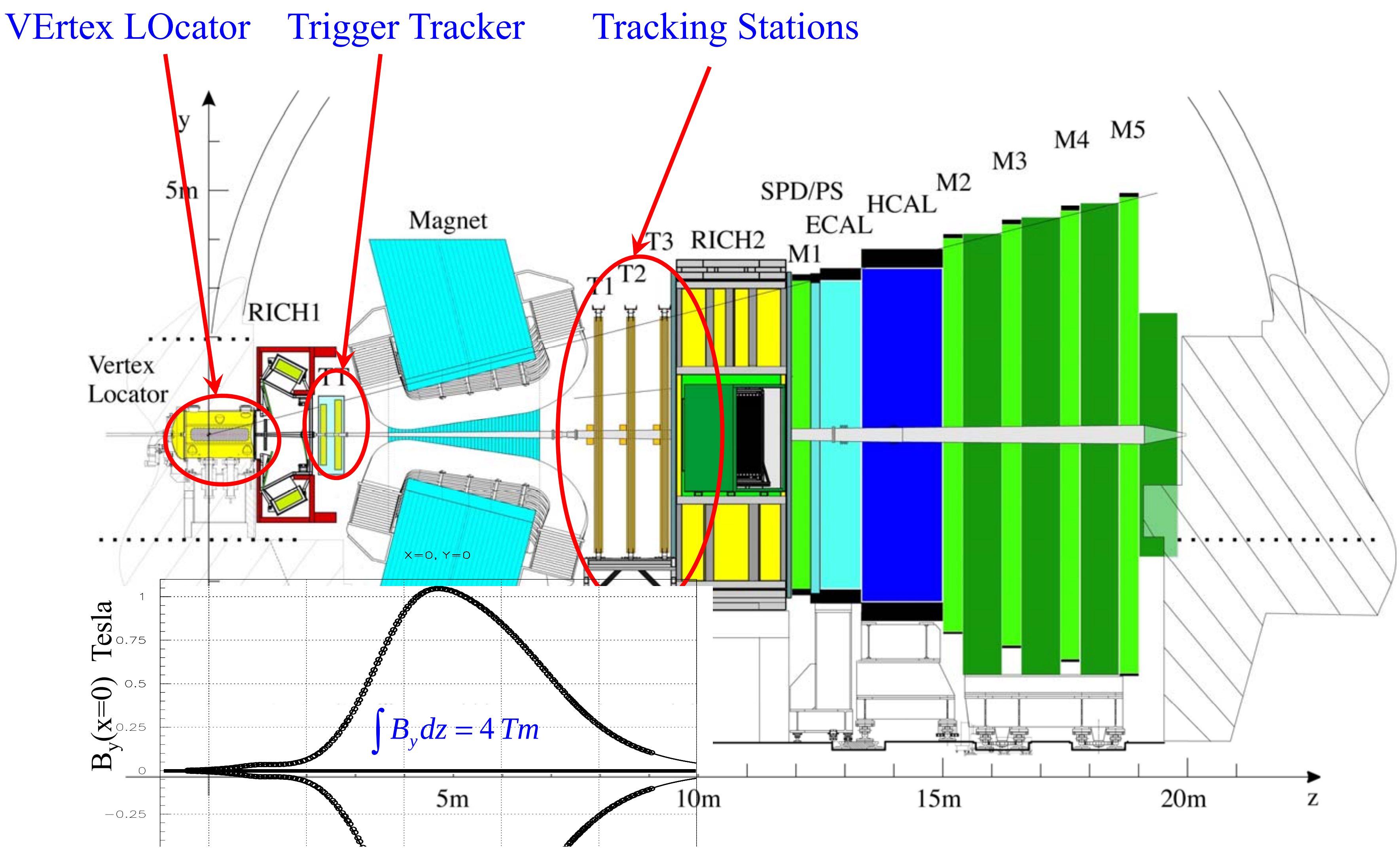
Outline

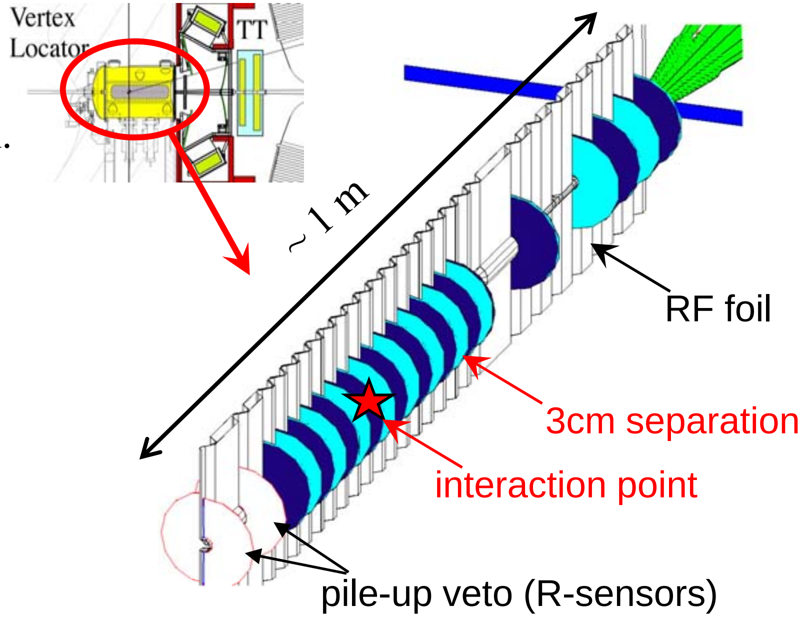
- *The tracking detectors*
- *Track & Vertex Reconstruction*
- *VELO Testbeam*
- *Luminosity Monitor*
- *Summary*

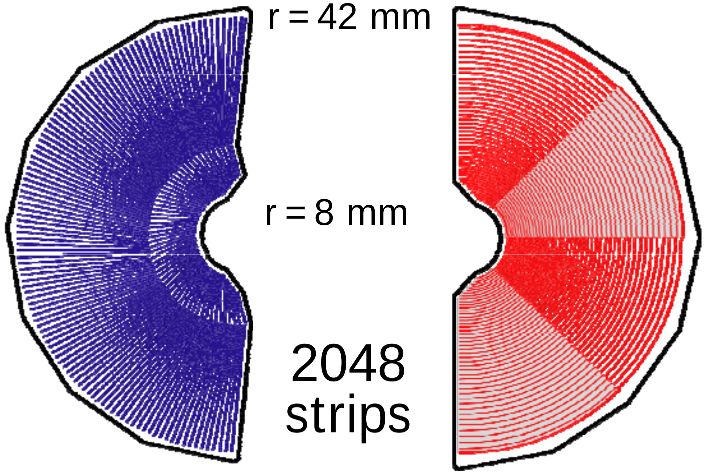
The LHCb Detector



Vertex Locator

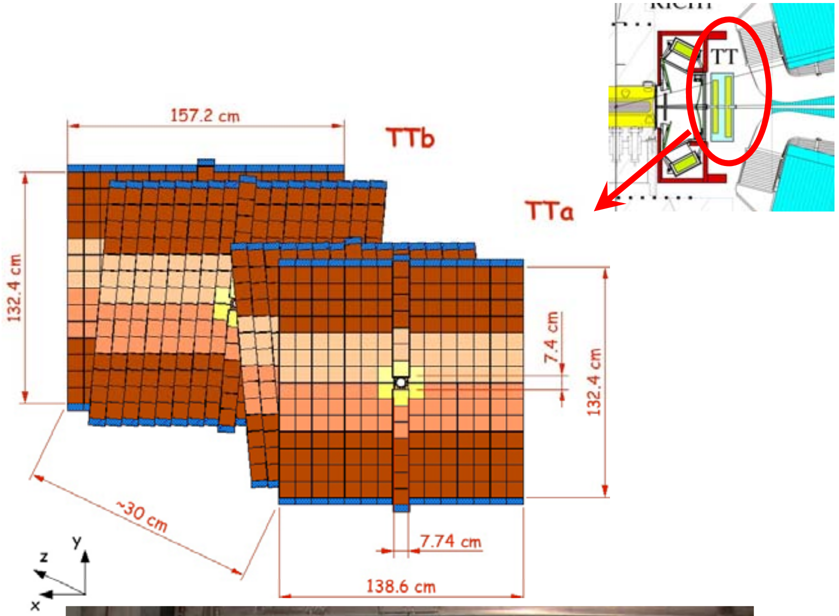
- Silicon micro-strip, n+ in n-bulk sensors.
- Detector halves retractable (by 30mm) for injection.
- 21 tracking stations per side.
- R-Φ geometry, 40–100μm pitch, 300μm thickness.
- Optimized for
  - tracking of particles originating from beam-beam interactions.
  - fast online 2D (R-z) tracking.
  - fast offline 3D tracking in two steps (R-z then ϕ).

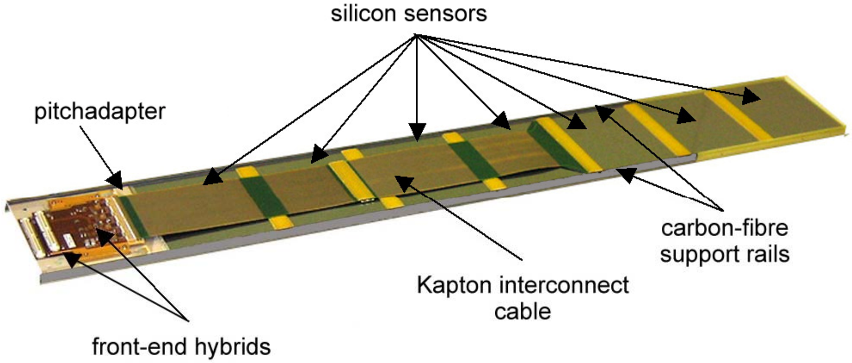


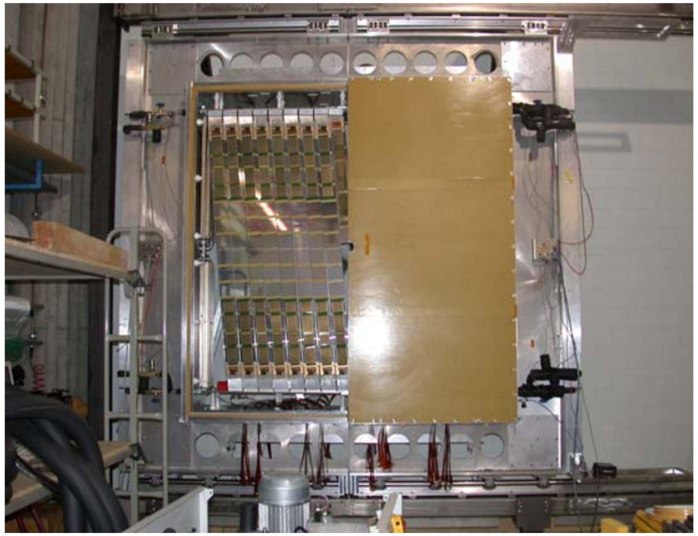


Trigger Tracker

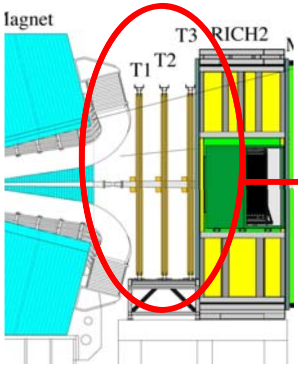
- Two retractable half-stations, four planes (0°, +5°, -5°,0°) in 2 groups separated by 30 cm.
- P-type sensor, strip pitch 183 μm, 500 μm thick, readout length up to 37.6 cm.
- 7-sensor long ladders. Hybrids outside active area.
- Part of tracking (inside $\int B_y dZ \sim 0.12$ Tm), important for long-lived particle and soft tracks.
- Provides p_T information in the HLT trigger (*see Themis Bowcock's talk*).



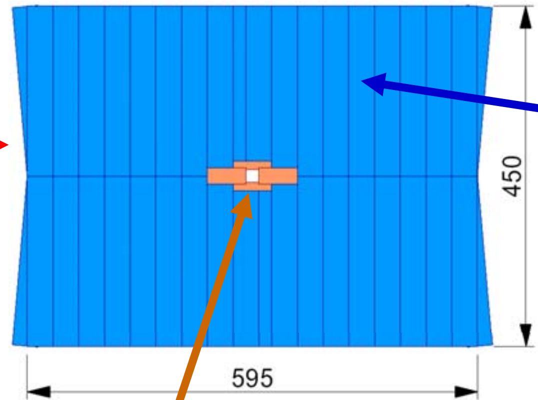




Tracking Stations



3 Stations (T1,T2,T3)

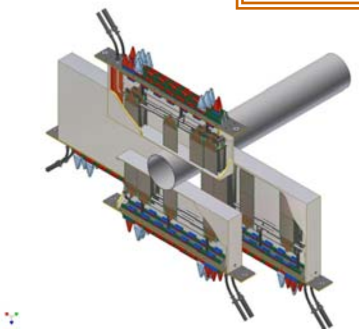


Outer Tracker (OT)

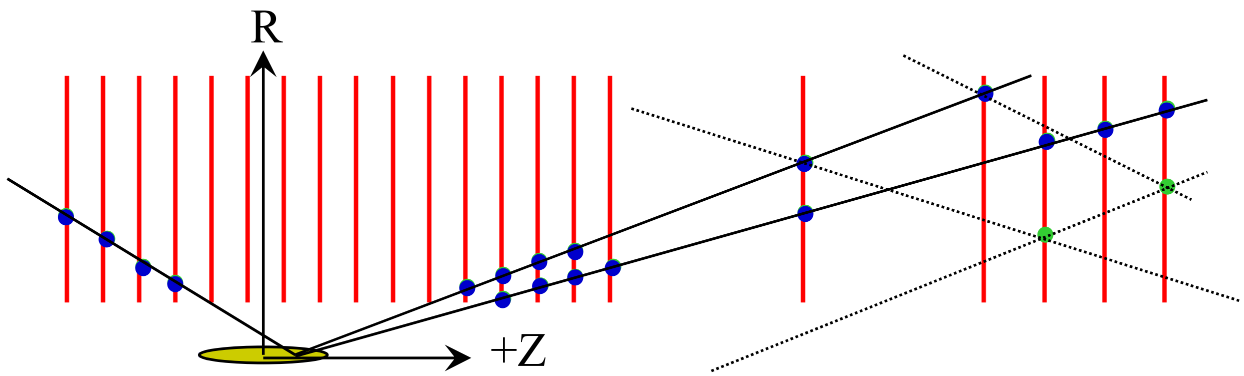
- Kapton/Al straw drift tubes d=5 mm.
- 4 double-layers (0°, +5°, -5°,0°) in each station.

Inner Tracker (IT)

- 4 layers (0°, +5°, -5°,0°) of P-type silicon strip sensors.
- 2% of area, 20% of tracks
- ~200 µm pitch, 320/410 µm thickness 11/22 cm long strip readout

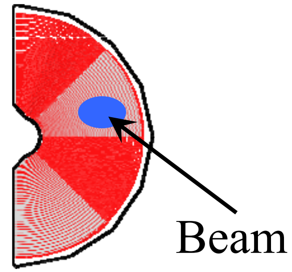


Standard 2D/3D VELO Tracking

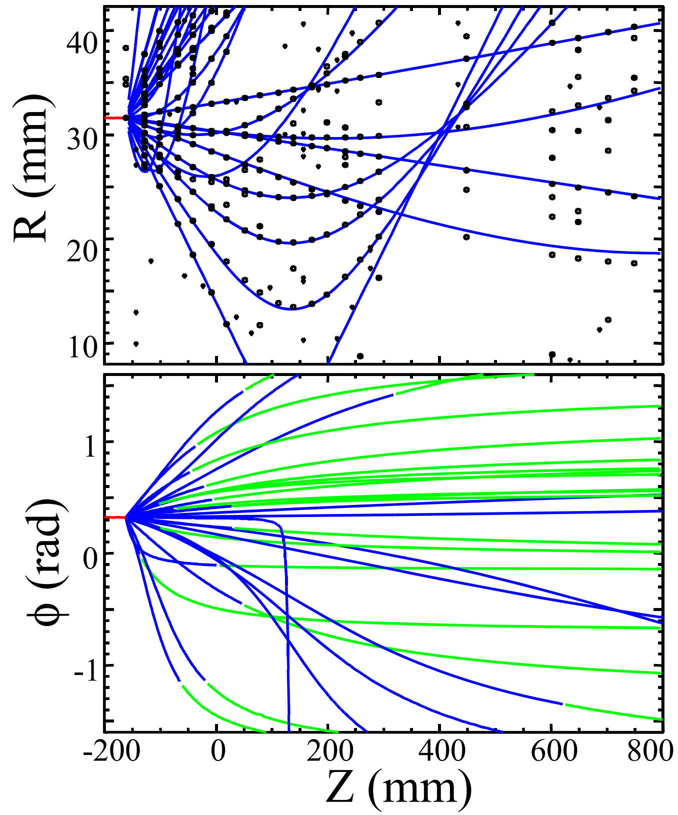


- Tracks originated from beam-beam interactions are about constant in φ-z and linear in R-z projections.
- VeloRTracking (2D: R-z): R doublets ⇒ straight line extrapolation ⇒ range of production restriction ⇒ R triplets ⇒ more R hits.
- VeloSpaceTracking(3D) projected R ⇒ ϕ doublets ⇒ more ϕ hits.
- Efficiency = 97%, ghost rate < 5%.

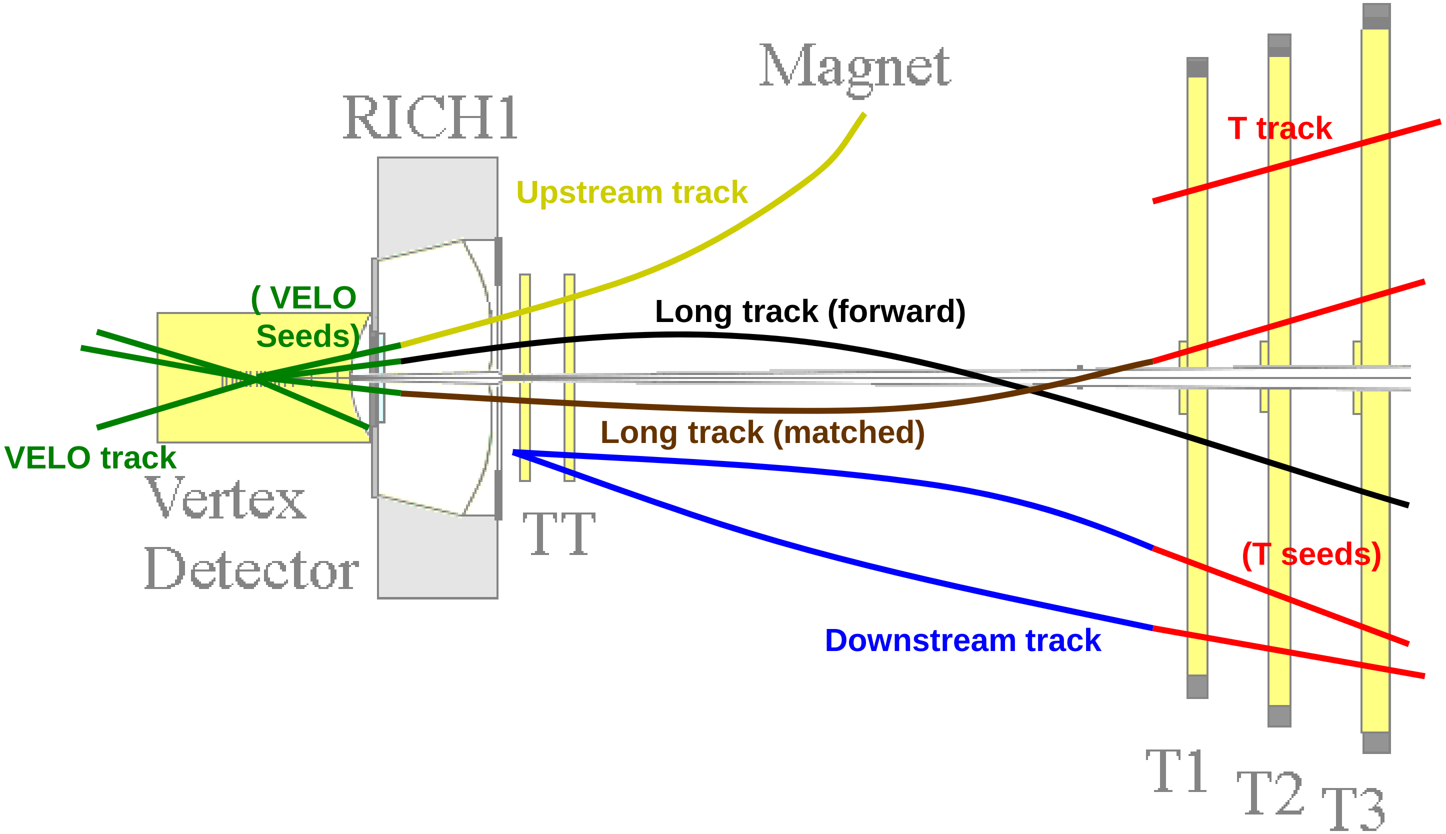
Special VELO Tracking



- Standard 2D/3D tracking assumes tracks originated from beam-beam interaction region.
- There are scenarios that it fails
  - Beam-gas event for luminosity monitor.
  - K_s decay, photon conversion, …
  - Beam monitor with open VELO.
  - Testbeam.
- Special pattern recognition algorithms that do not assume track direction or the range of production.



More LHCb Tracking

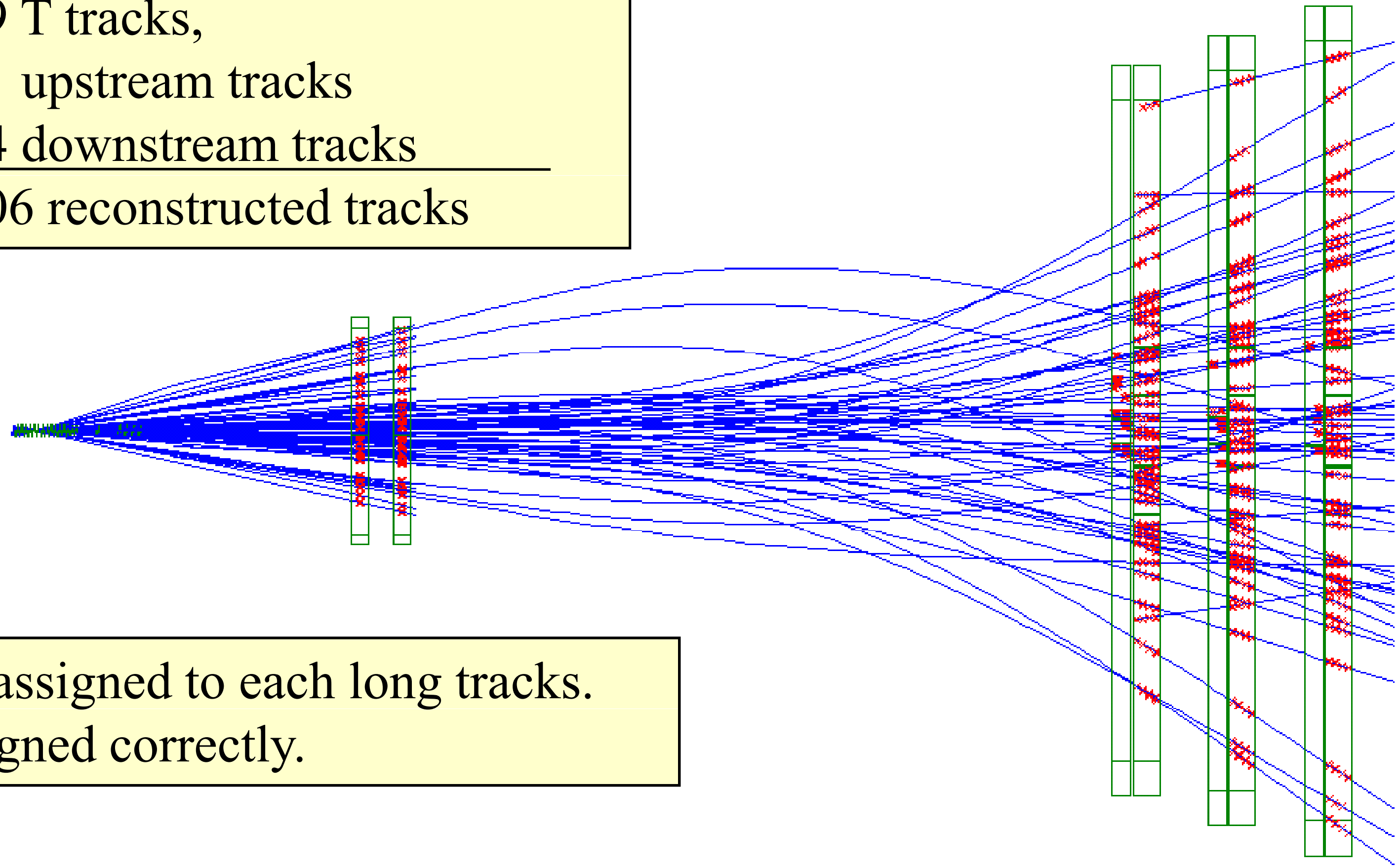


VELO tracks	⇒	**useful for primary vertex reconstruction (good IP resolution)**
Long tracks	⇒	**highest quality for physics (good IP & p resolution)**
Downstream tracks	⇒	**needed for efficient K_S finding (good p resolution)**
T tracks	⇒	**useful for RICH2 pattern recognition**
Upstream tracks	⇒	**lower p, worse p resolution, but useful for RICH1 pattern recognition**

Number of Different Tracks

Average number of tracks in bb events:

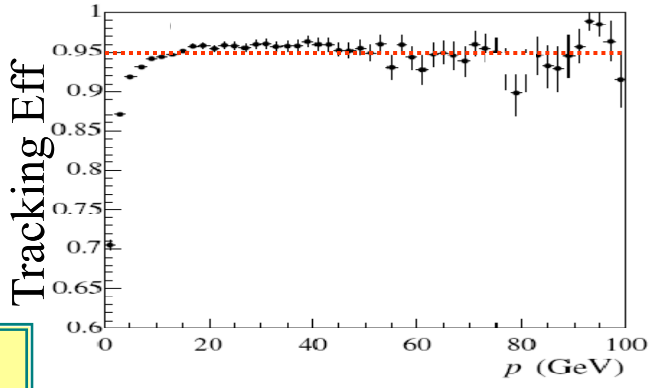
	34 VELO tracks,
	33 long tracks,
	19 T tracks,
	6 upstream tracks
	14 downstream tracks
Total	106 reconstructed tracks



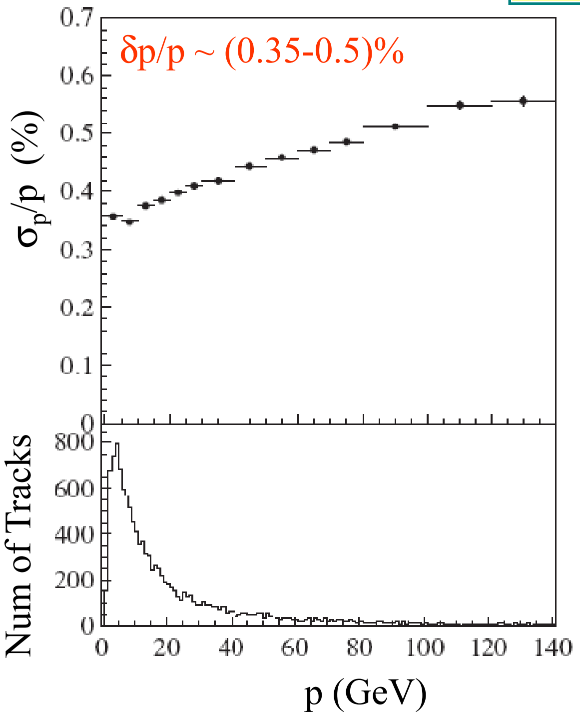
20-50 hits assigned to each long tracks.
98.7% assigned correctly.

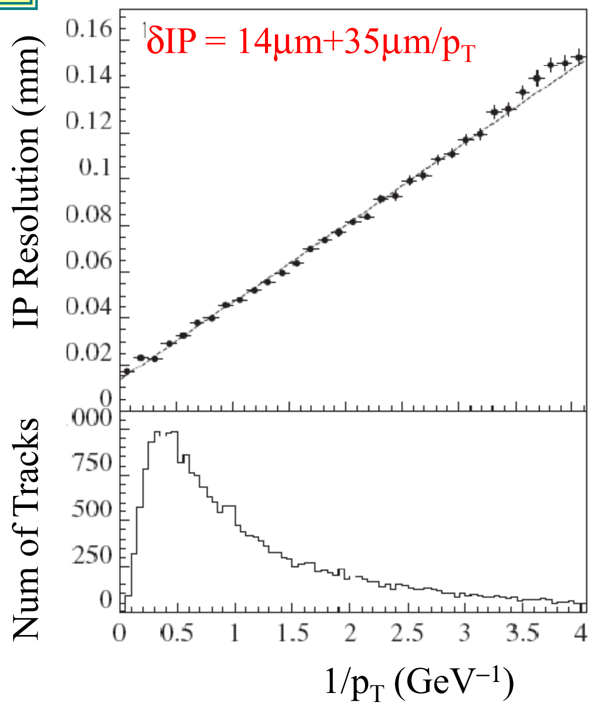
Tracking Performance

- Fit in bi-directional Kalman filter.
- ~38 measurements per long track.
- For long tracks of B decay products:
  - Tracking efficiency >95% (high p).
  - Ghost rate ~ 4% (P_T > 0.5GeV).
  - σ_p/p ~ (0.35 - 0.5) %.
  - σ(IP) ~ 14 μm at high P_T.
  - $\sigma(M_B)$ ~ 15 MeV.



MC B decays



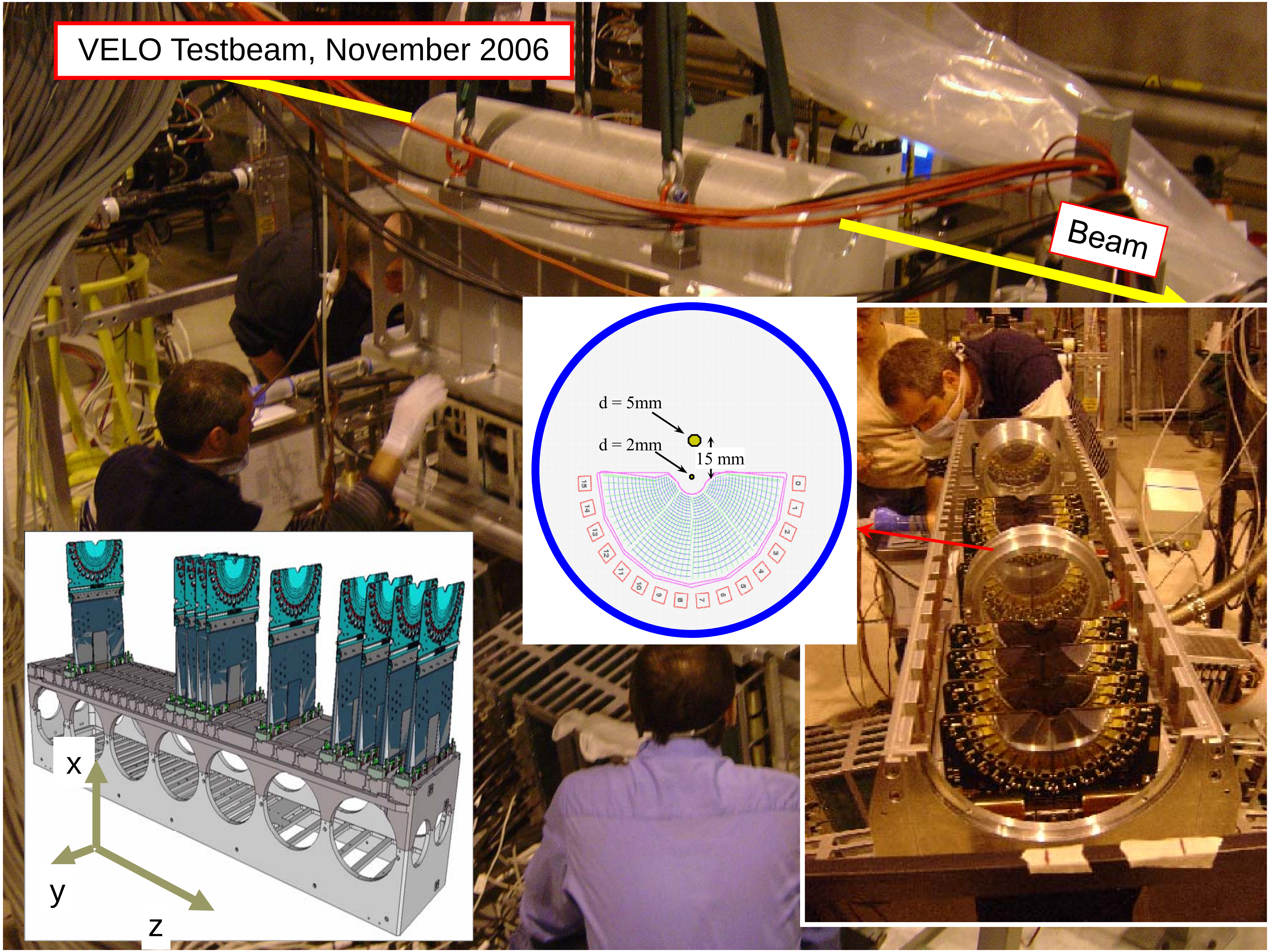


Primary Vertex Reconstruction

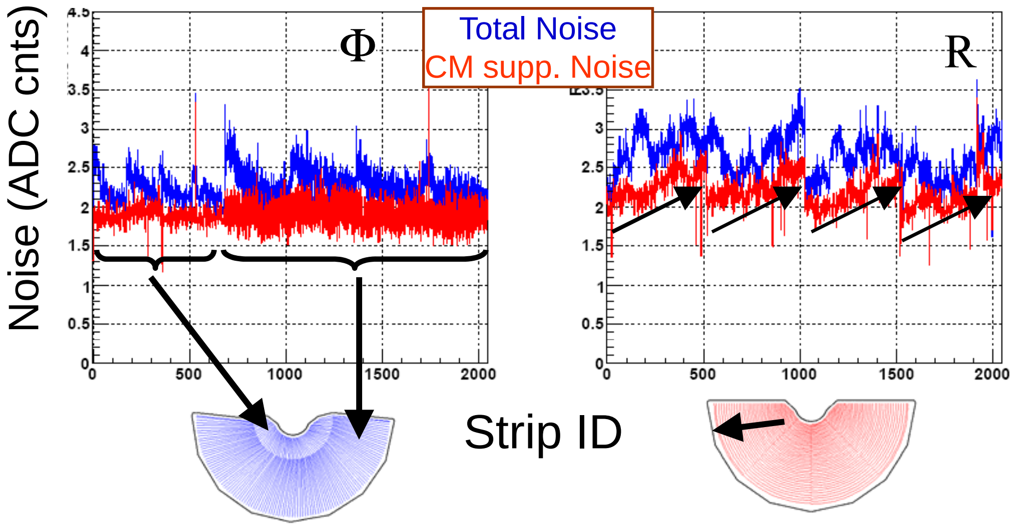
- All VELO tracks, long tracks, and upstream tracks are used in construction of primary vertices.

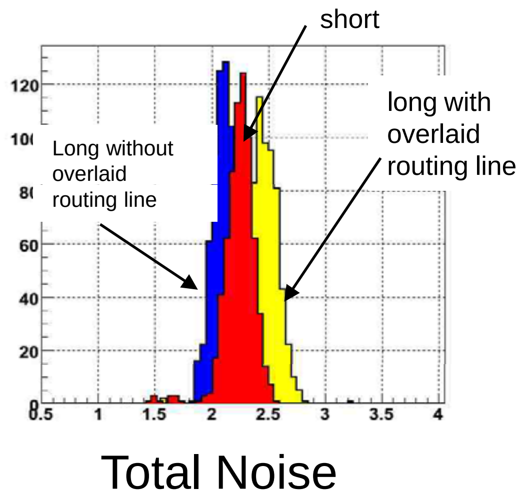
- Procedure to construct primary vertices:
  - PV seeding: find point of closest approach to the beam, determine the population dense region, and select all those tracks as PV seeds.
  - PV fitting: through iterations remove tracks that seem not sharing a common vertex with others.
  - Make next PV from tracks that are not in the reconstructed PV's.

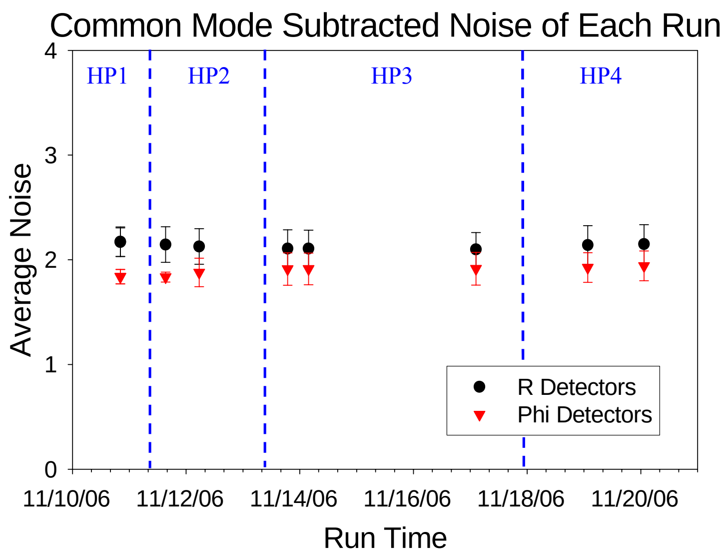
- Performance from MC simulation,
  - PV efficiency ~98%, fake rate~8%.
  - Primary vertex resolution, ~10 μm in X/Y, ~50 μm in Z.
  - B proper time resolution ~ 40 fs.


VELO Testbeam, November 2006
Beam
d = 5mm
d = 2mm
15 mm
x
y
z

Noise Performance

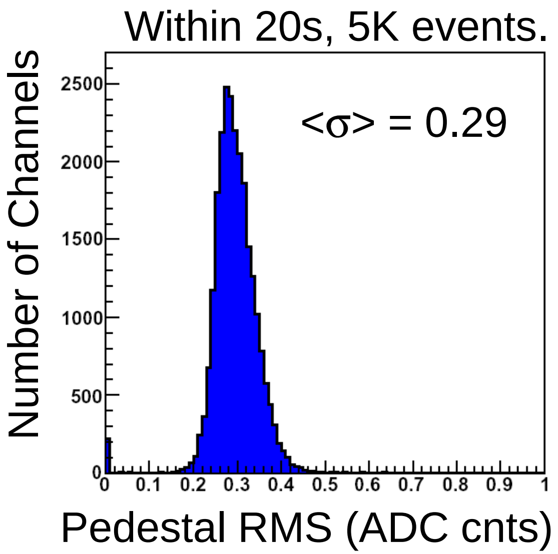


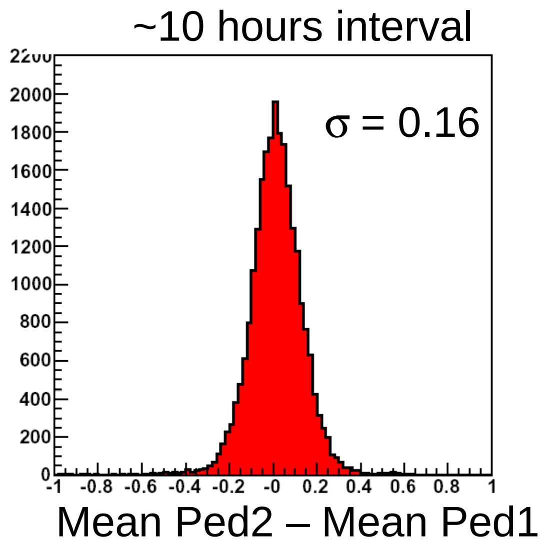


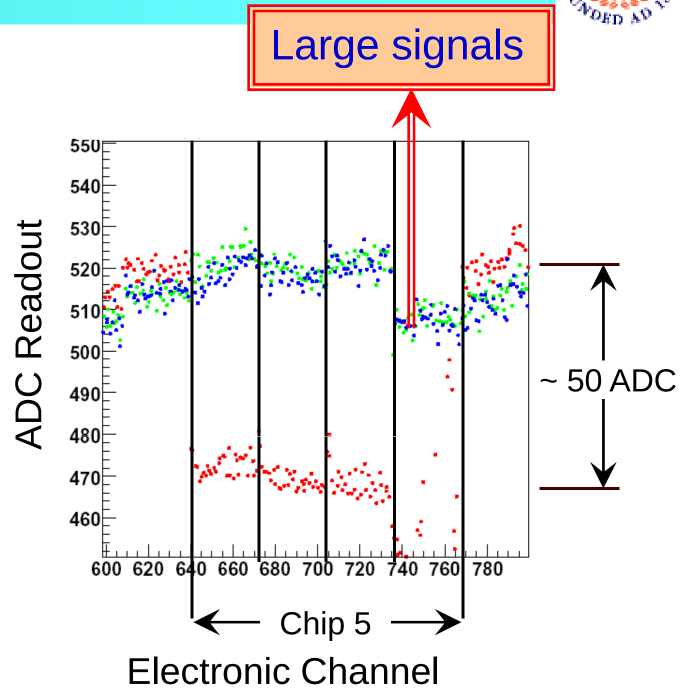


- CM noise of 32 channels in each link is suppressed.
- Noise:1.9-2.6 ADC counts for R sensors and 1.7-2.2 ADC counts for ϕ sensors.
  (1 ADC ~ 500 e)
- Different noise levels due to sensor types, strip sizes, routing traces, cable, ADC, …
- Noise level is stable over long period.

Pedestal Stability

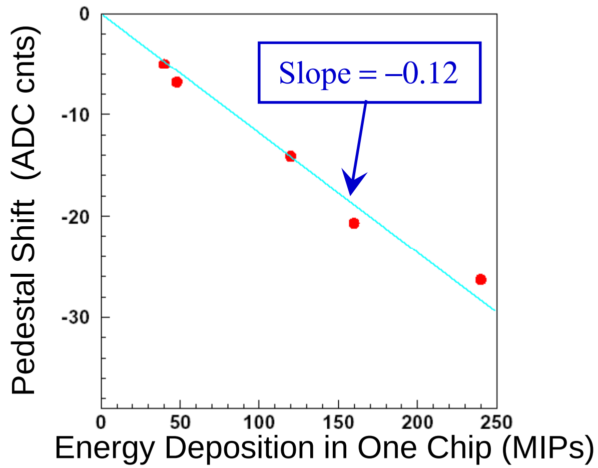






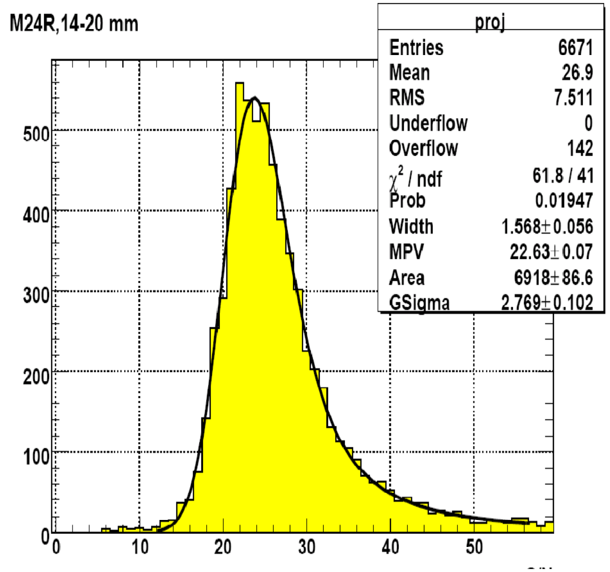
- A running pedestal calculation of 100 events.
- Within a run of 20s (5K events) the calculated pedestal fluctuation is 0.29 ADC.
- The average pedestal within a run per channel is quite stable over long time interval.
- Pedestal drift in a whole readout chip (128 channels) at event level has been observed. The source is found to be large energy deposition. Such drift is corrected to recover signals in the rest channels.

Could it be a common problem?

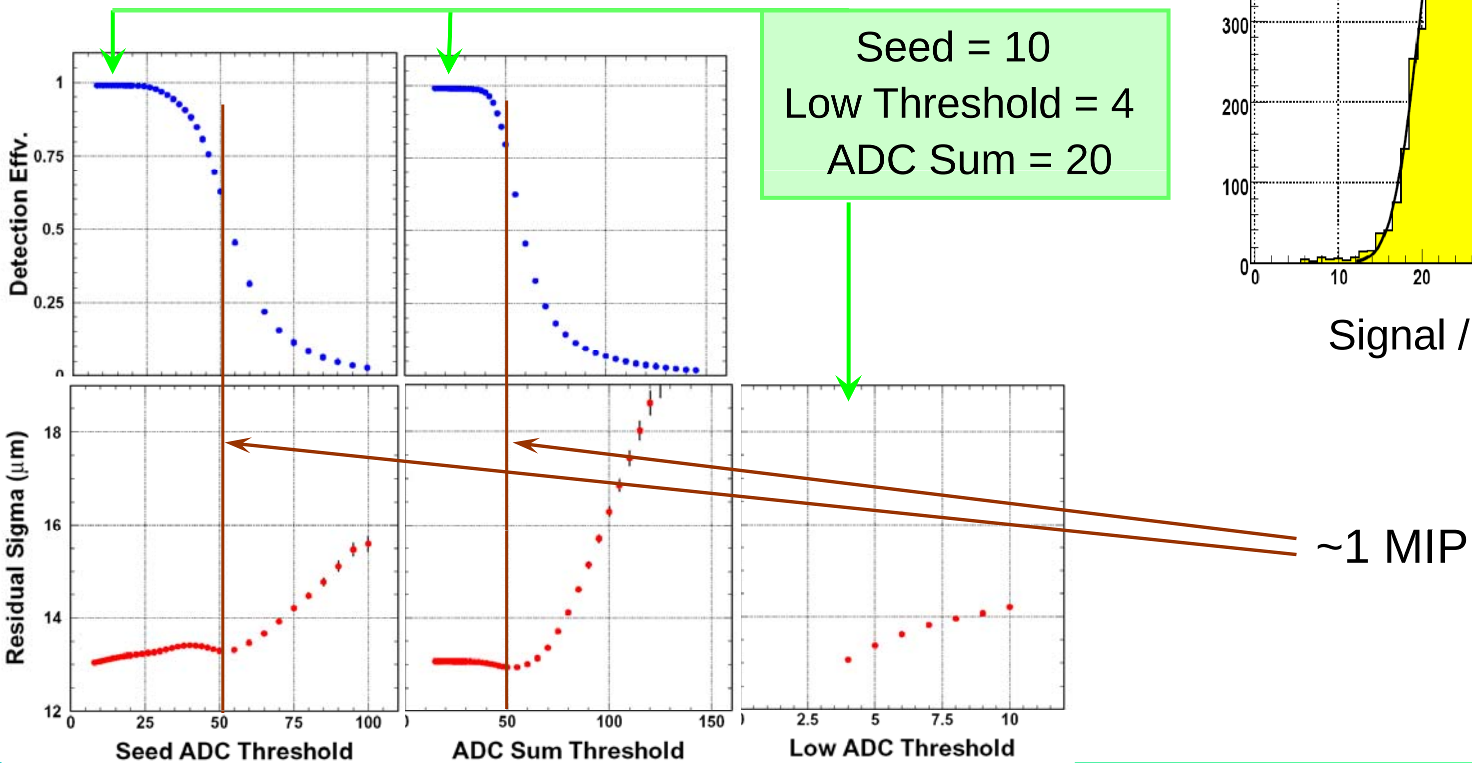


Clustering and Signal to Noise Ratio

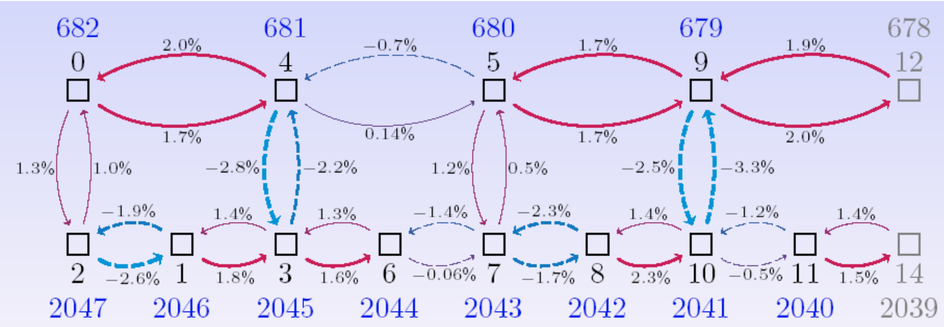
- Three thresholds for cluster hit: seed threshold, low threshold (side strip), & ADC sum
  ⇒ Maximally use charge sharing information.
- Signal / Noise ~ 20-24 for R sensors, 24-29 for ϕ sensors.
- Tuning thresholds for optimal detection eff. & resolution.



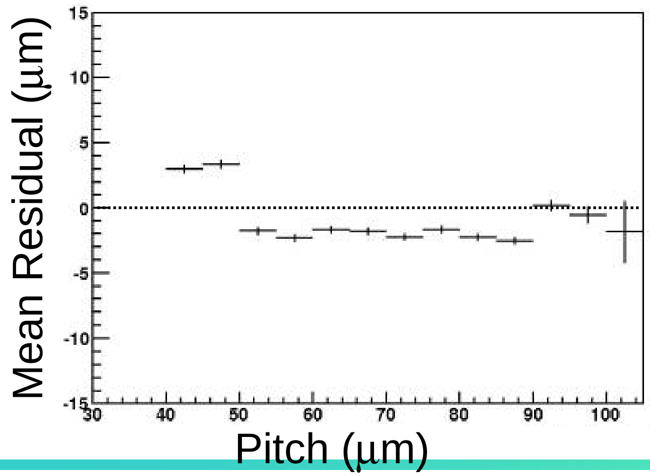
Signal / Noise

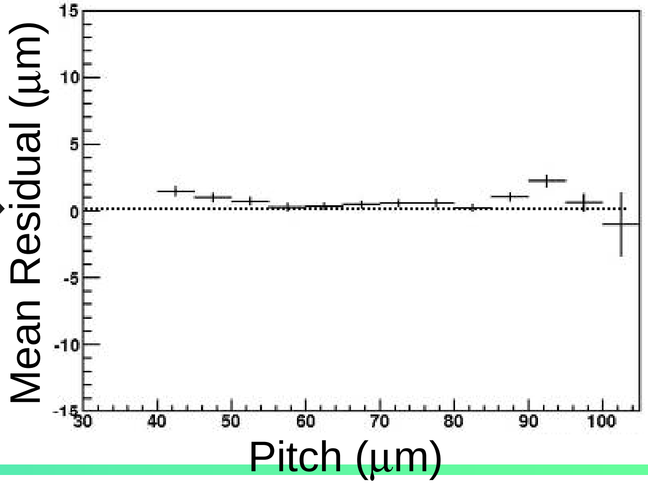


Cross Talk Between Channels



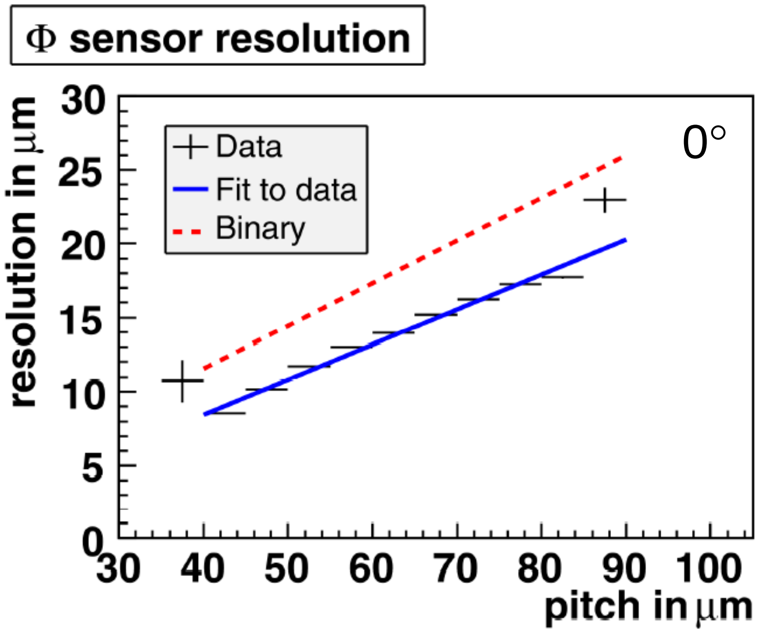
- Cross talk is the modulation of neighbor channel pedestal induced by a signal in a channel N.
- Such crosstalk is affected by: the distance from channel hit (1st, 2nd neighbor,…), asymmetry between channels N-1 & N+1, ADC phase, sensor type (R/ϕ), even/odd outer ϕ strips, …
- The crosstalk can reach ~5% for certain pairs of strips in ϕ sensor.
- Dramatic improvement in residual distributions after cross talk correction (*see Sebastien Viret's presentation*).

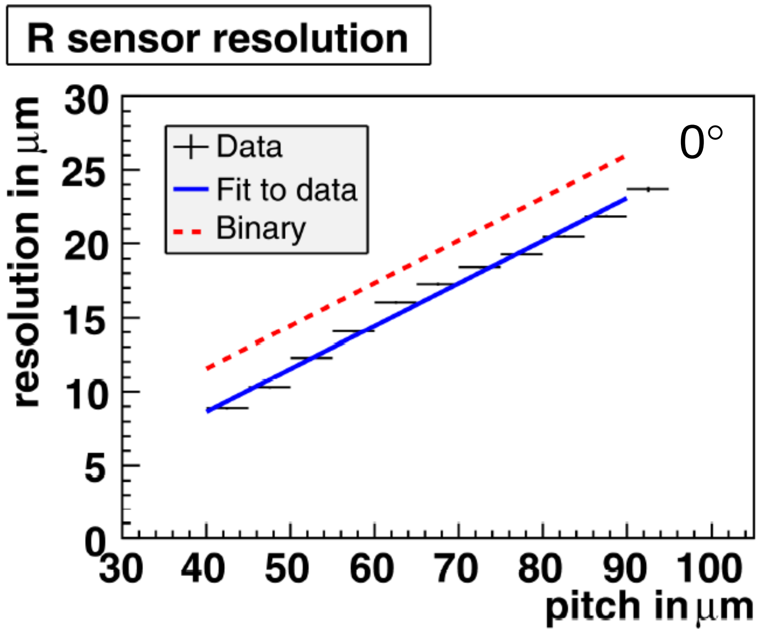




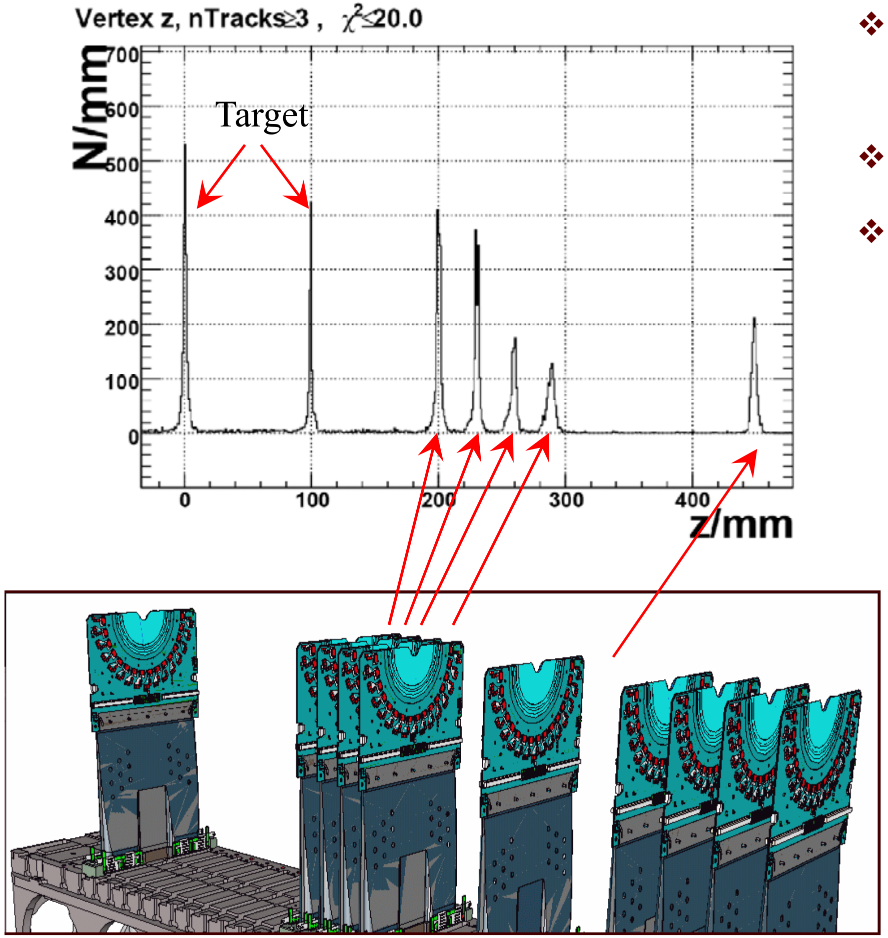
Spatial Resolution

- Spatial resolution is measured using beam tracks.
- The tracking projection error can be removed for perpendicular tracks.
- Resolution ~ 8.4 μm (ϕ) and 8.6 μm (R) at pitch=40μm.
- Applying η correction will further improve the resolution.

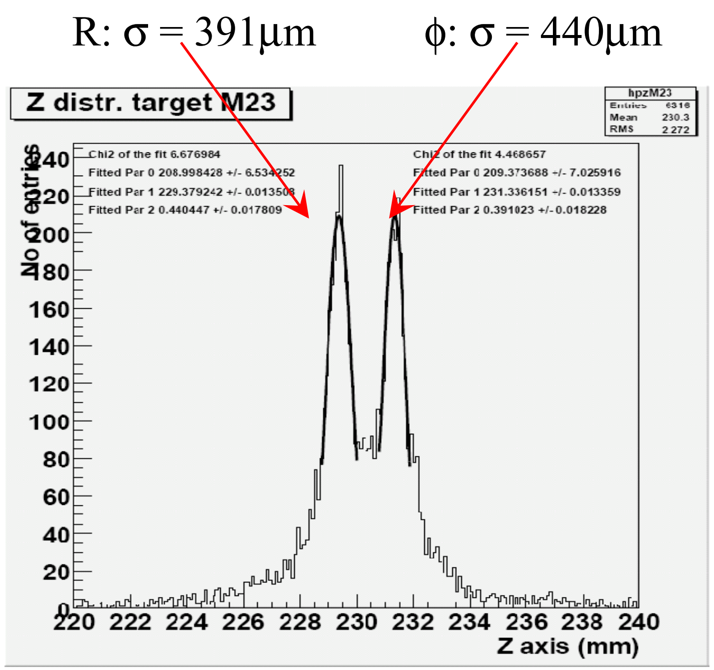




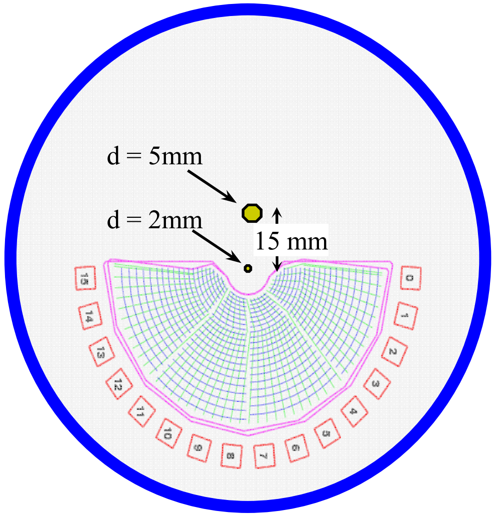
Vertex in Sensor

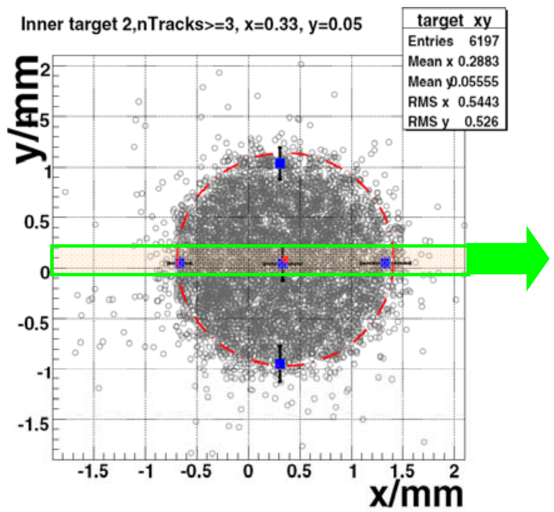


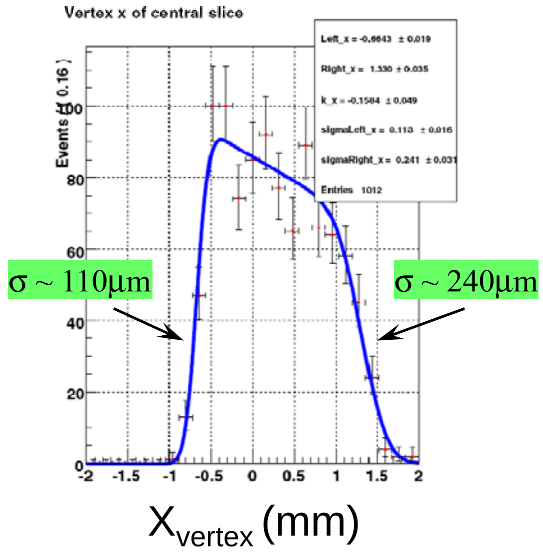
- Trigger on interaction (*see Niko Neufeld's talk*).
- Vertex reconstructed from interaction between proton beam (180 GeV) and sensors/targets.
- Gap between R & ϕ sensors ~ 2mm.
- The vertex reconstruction has been tested and optimized.



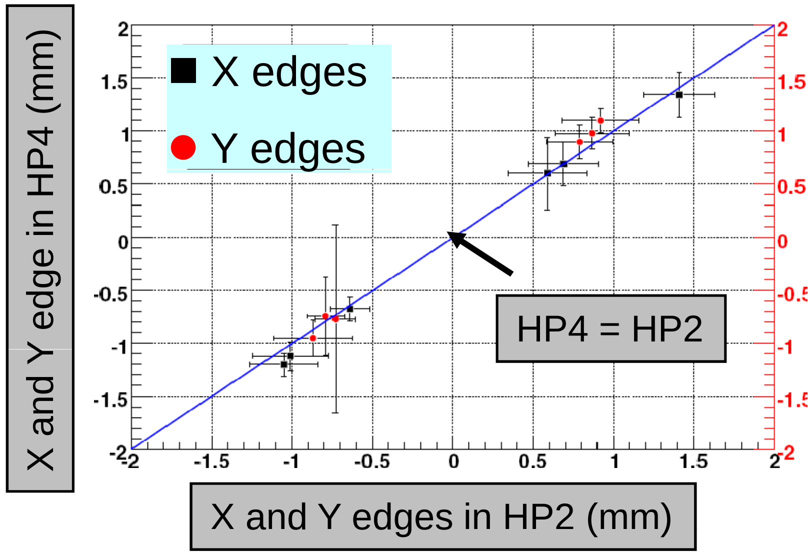
Vertex in Beam-Target Event







- ❖ 180 GeV proton interacts with 200/300 μm thickness Pb targets.
- ❖ Use vertices reconstructed at coin edge ⇒ x/y resolution.
- ❖ Emulate open and closed VELO, but with only half side, less modules, and much less tracks.
- ❖ Edge positions measured are consistent for different detector configurations.



See A. Papadelis, LHCb note 2007-109 for more details

Luminosity Monitor

- Motivations
  - Relative luminosity monitor provides fast control of running condition and feedback to beam control.
  - Most LHCb physics measurements are independent on absolute luminosity.
  - Some interesting topics rely on absolute luminosity, e.g. W, Z production rate in forward region, inelastic differential cross section, new physics.

- Detectors and methods at LHCb
  - BRAN-B uses CdTe disc sensors to measure the flux of neutrons and photon produced in beam interactions, with very short decay time ~5ns.
  - PileUp detector determines relative luminosity from its trigger event classes (e.g. zero-counting).
  - VELO in beam-gas events to determine absolute luminosity (aim: 10% for 1st year run and <5% later).

Absolute Luminosity with Beam-Gas Events

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

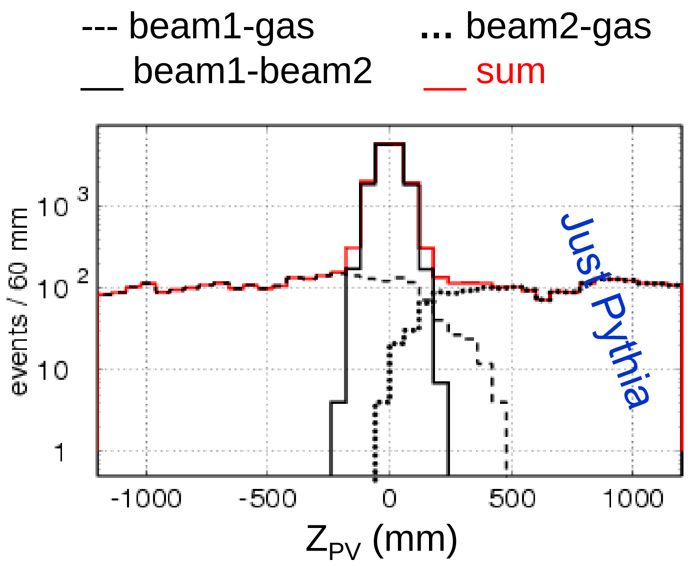
Measured by AB — Measured by the experiment

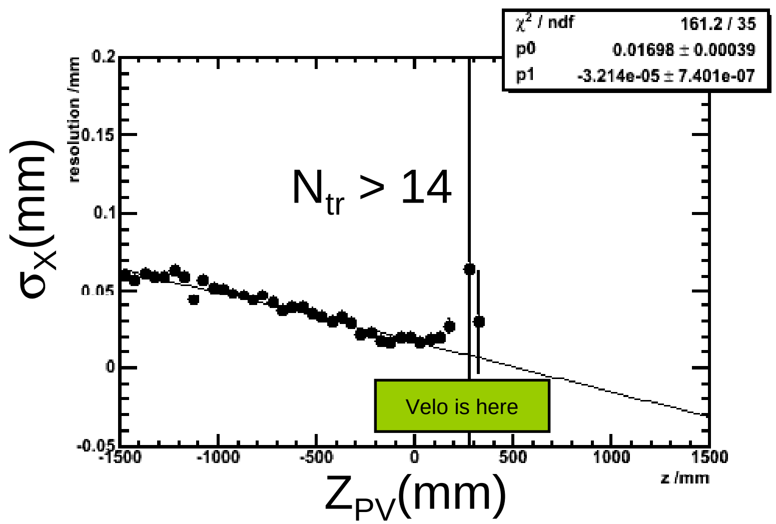
- Inject Xe gas (10^{-7} torr) into VELO region.
- Reconstruct bunch-gas interaction vertices. Thus get beam angles, profiles & relative positions to calculate overlap integral.
- Simultaneously reconstruct bunch-bunch interaction vertices to calibrate 'reference' cross-section.
- Requirements:
  - Vertex resolution in X/Y substantially smaller than beam transverse sizes.
  - Dependence on X/Y (gas density, efficiency, ...) must be small or well known.
  - Ability to distinguish beam1-gas beam2-gas and beam1-beam2 interaction.

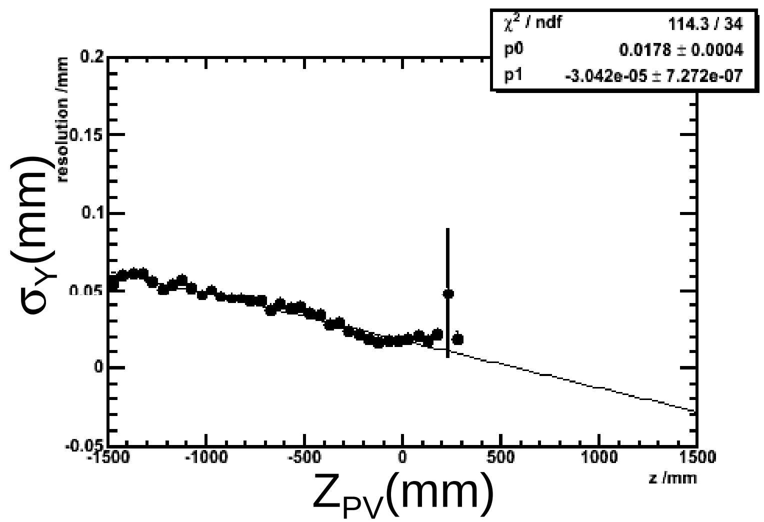
see *M. Ferro-Luzzi, NIMA553:388-399,2005* for more details.

Vertex Reconstruction in Beam-Gas Events

- ❖ Inject Xe gas (10^{-7} torr) in the VELO volume.
- ❖ ~ 30 tracks in beam-Xe interaction.
- ❖ Reconstruct vertices in different regions to separate different beam-gas or beam-beam events.
- ❖ Nominal population 10^{11}/bunch and a slice of 20 cm Xe $\Rightarrow$ useful event rate ~ 30Hz.
- ❖ Vertex X/Y resolution in VELO region ~ 20μm (beam size ~70μm).







Summary

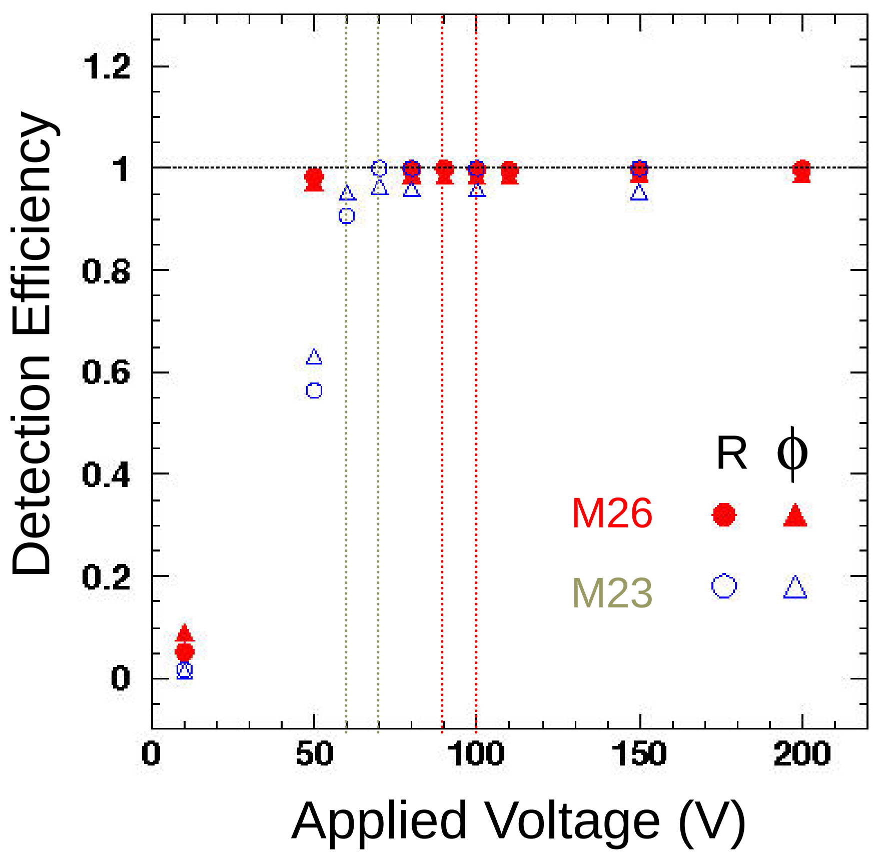
- LHCb uses VELO, TT, & T stations as tracking detectors.
- The tracking system provides tracks with p resolution of 0.35-0.5%, and impact parameter resolution of 14 μm at high P_T.
- LHCb relies on VELO for precision vertex detection. The proper time resolution ~ 40 fs.

- Partially installed VELO detector had been tested under 180 GeV p beam.
- Various running experience and knowledge have be obtained through this beamtest.
- The signal/noise ratio ~ 20-29. Spatial resolution ~ 8.5 – 25 μm, varies with increasing strip sizes.

- LHCb uses BRAN-B and PU for relative luminosity monitor and use beam-gas event for absolute luminosity monitor.

Backup Slides

Sensor Efficiency vs HV



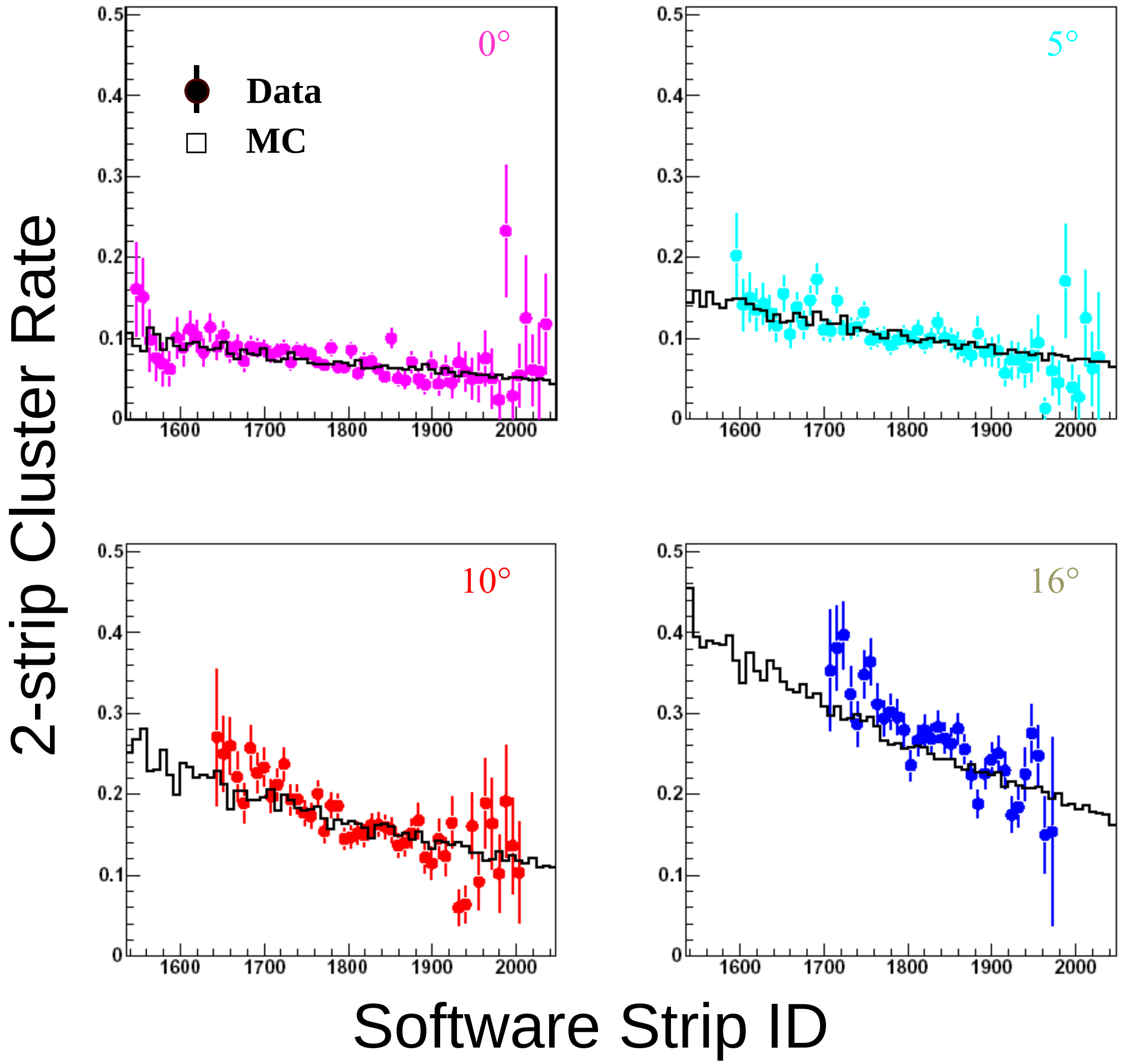
4° data

M23 inefficiency (~1.5%) due to a dead link is corrected.

M26 V_{dep}: 100(R), 90(ϕ)

M23 V_{dep}: 70(R), 60(ϕ)

Charge Sharing



ACDC2 (200μm)

Flat threshold 8 ADC

Radius and pitch size increase with strip ID.

MC agrees with data.