First Results from the LHCb Vertex Locator

12th Topical Seminar on Innovative Particle and Radiation Detectors
9 June 2010

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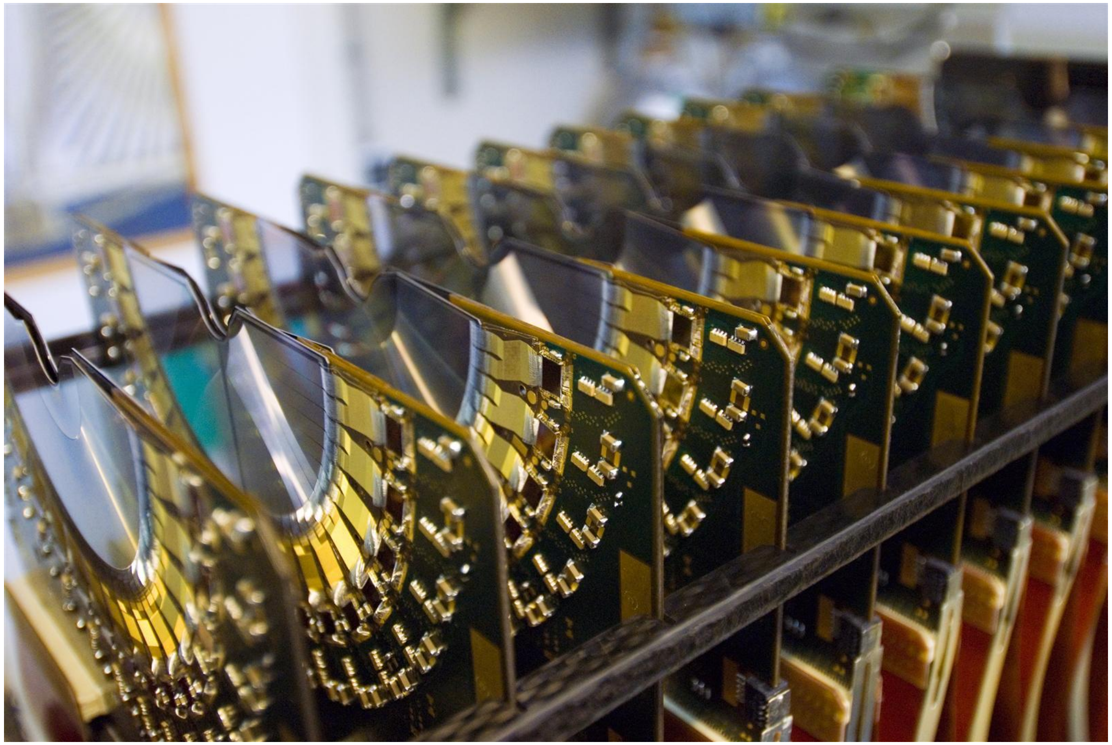
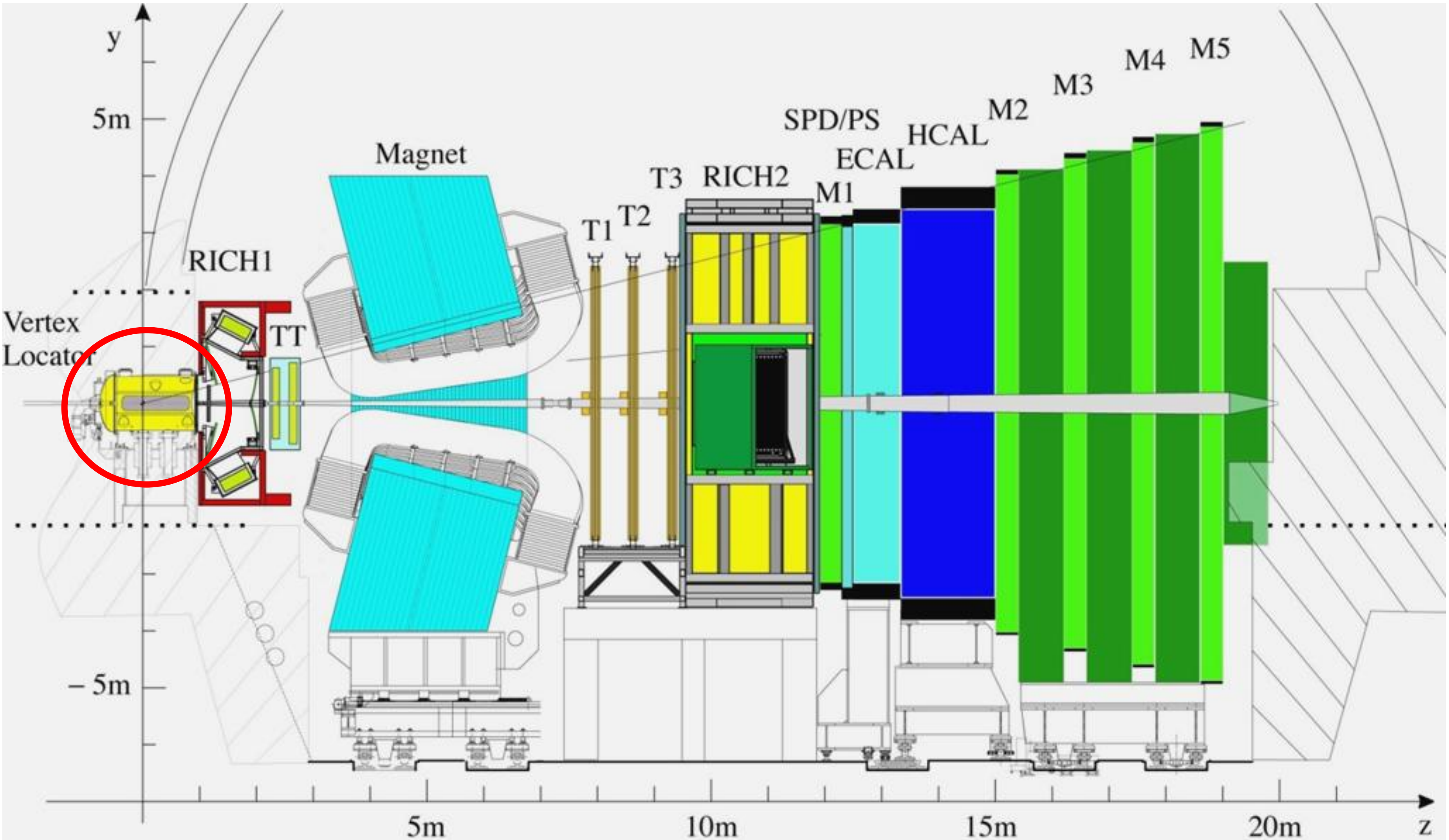
University of Manchester

Overview

1) Introduction to LHCb and the VELO
2) VELO Design
3) Recent Results



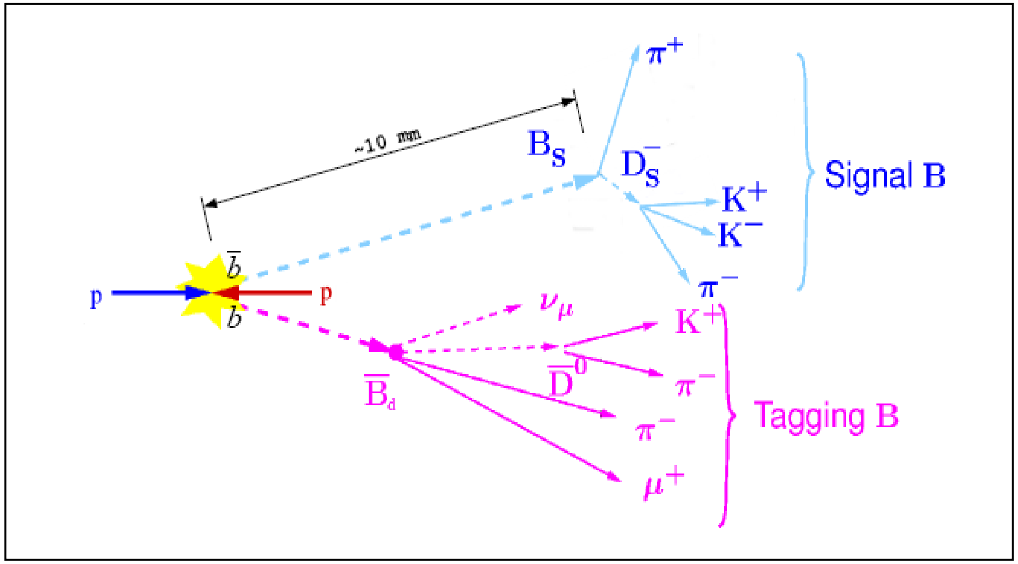
LHCb: A Forward Spectrometer

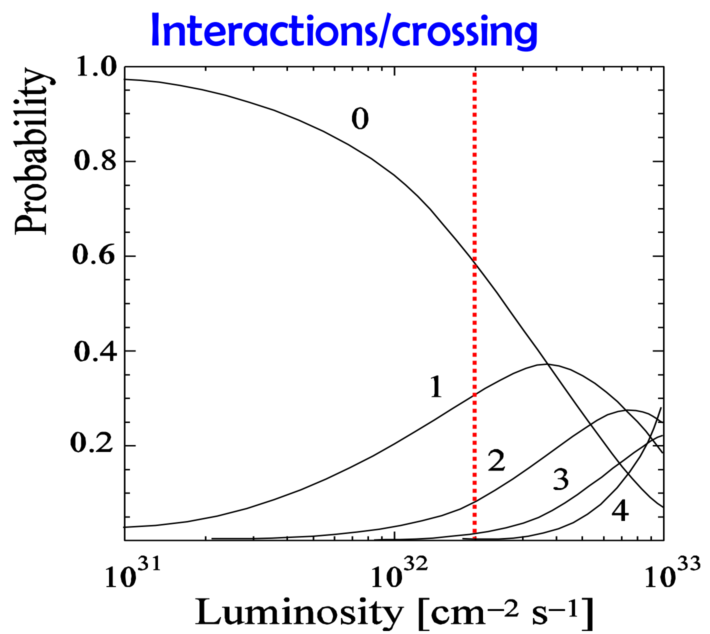


LHCb: Experimental Program

LHCb was built to study flavour physics at the LHC.

- CP-violation in the *b* sector
- Constrain unitarity triangles
- Rare *b* decays
- Search for new physics in loop processes

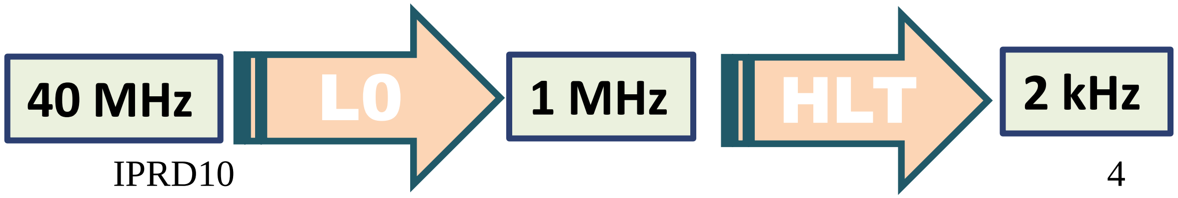




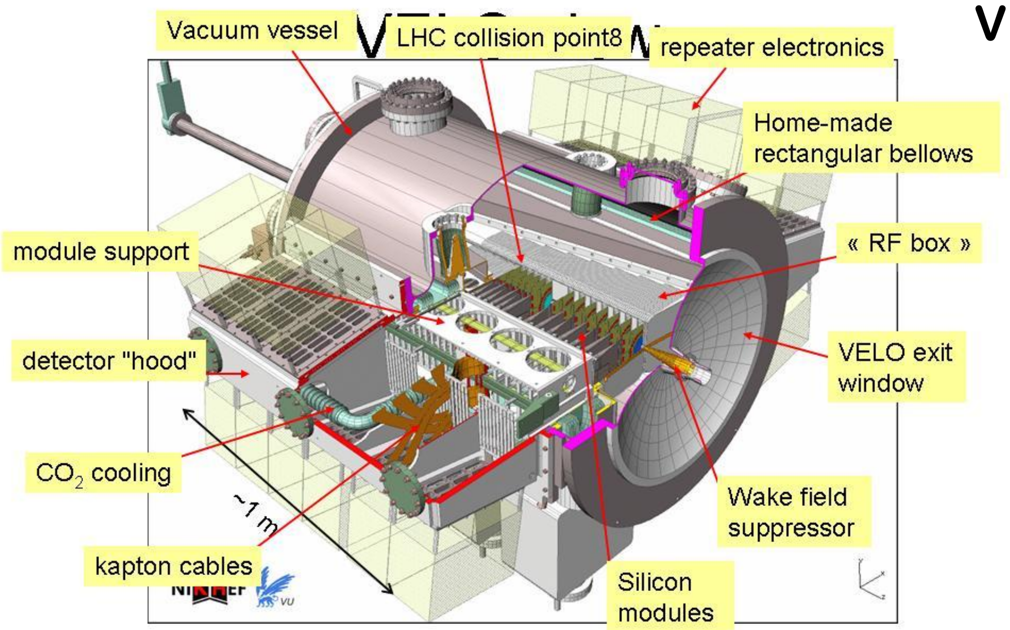
Several important detector requirements:

- An efficient trigger
- Excellent vertex finding and tracking
- Particle ID

At high luminosity pile-up will be a problem, so choose 2×10^{32} cm^{-2} s^{-1}



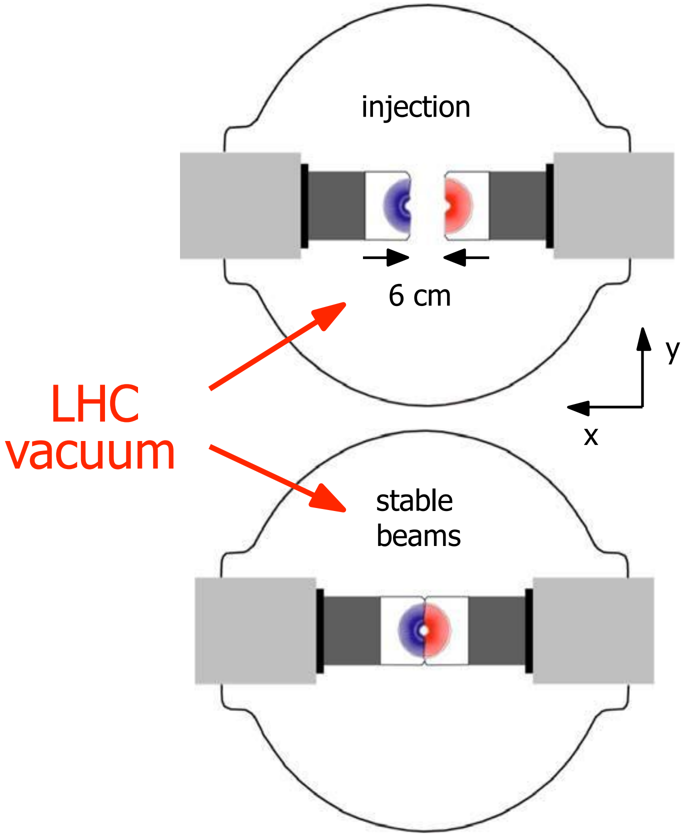
The Vertex Locator (VELO)



VELO Requirements:

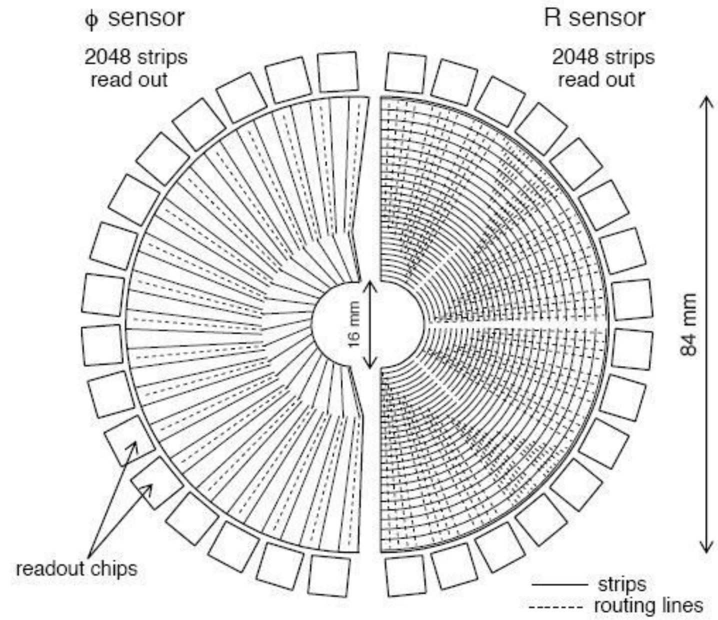
- Precision tracking
- Low mass (~10% X_0)
- Good vertex resolution to separate primary/secondary vertices.
- Survive in a high-radiation environment
- Function in the high-level trigger

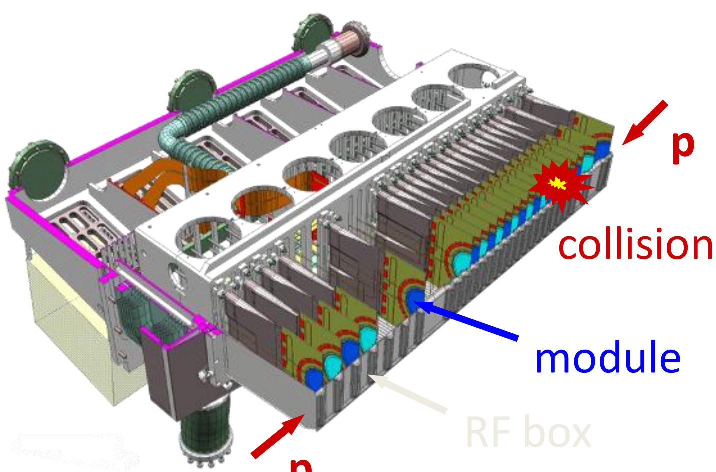
- Two retractable halves which move to within 8mm of the stable beams.
- 21 stations per half with an R and ϕ sensor
- Operates in secondary vacuum
- 300 μm foil separates detector from beam vacuum
- Has a two-phase CO_2 cooling system

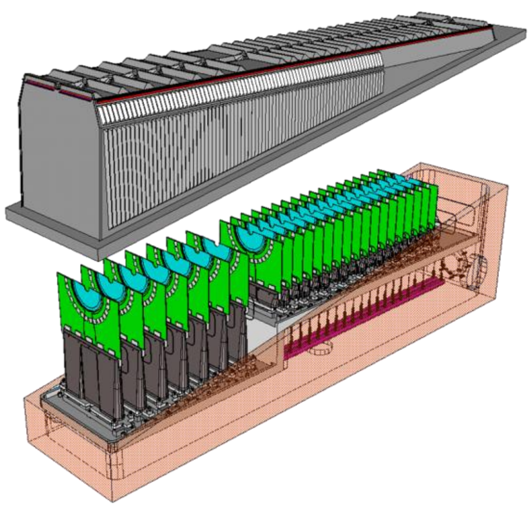


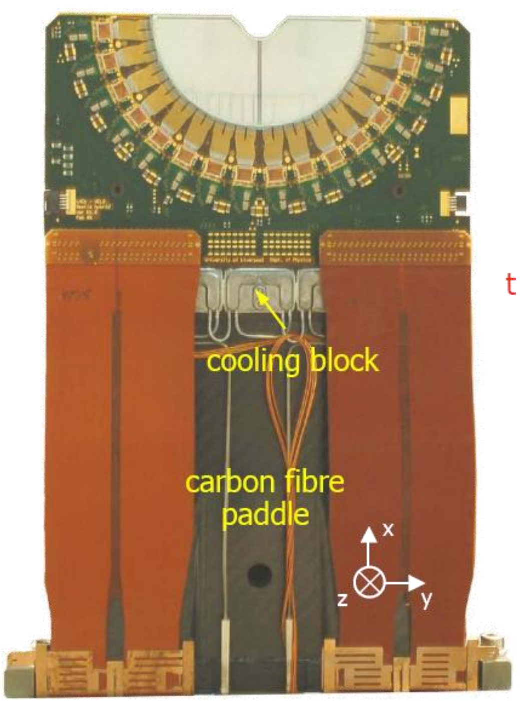
VELO Modules

- n-*on*-n & 1 n-*on*-p
- Two semi-circular designs, measuring R and Phi
- Double metal layer readout
- 2048 strips, 40-100 µm pitch
- .25 µm Analogue Readout
- TPG core Hybrid, CF paddles

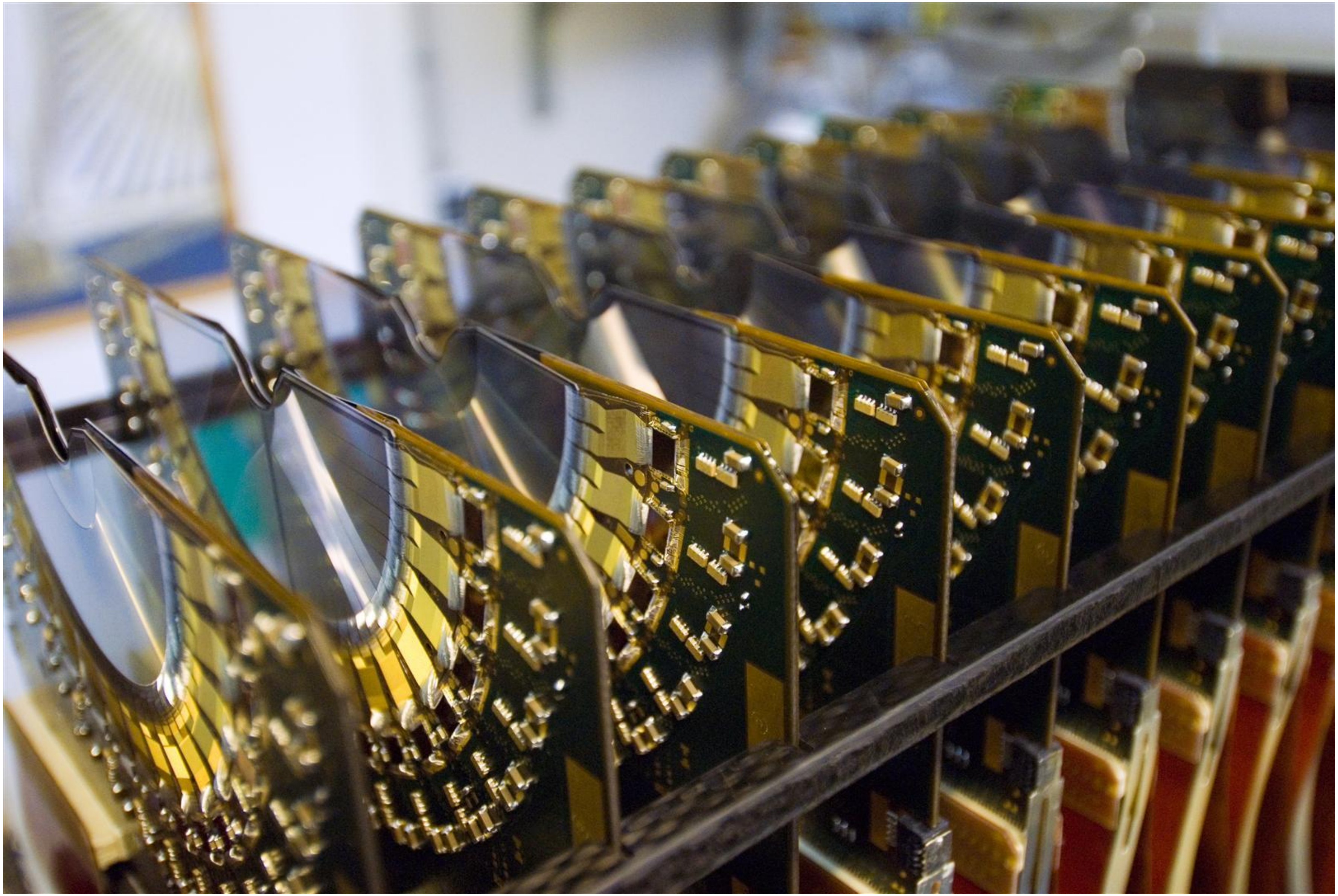




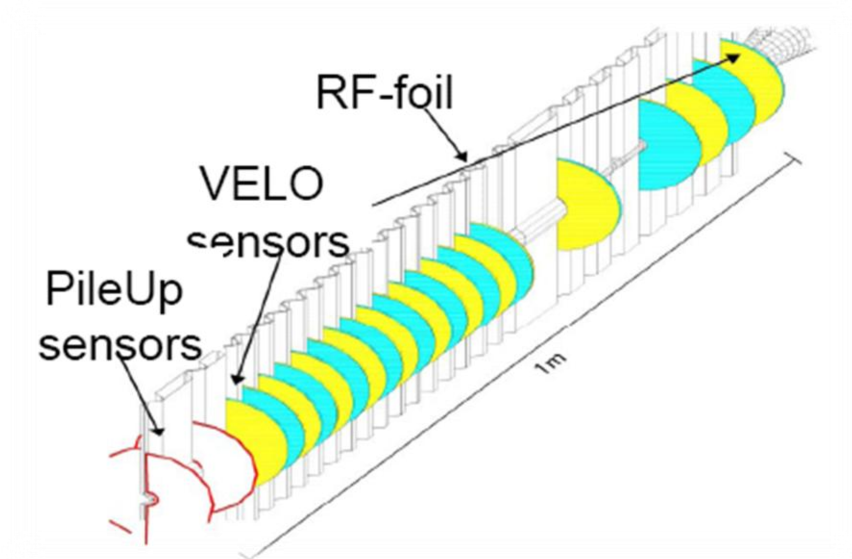




VELO Module



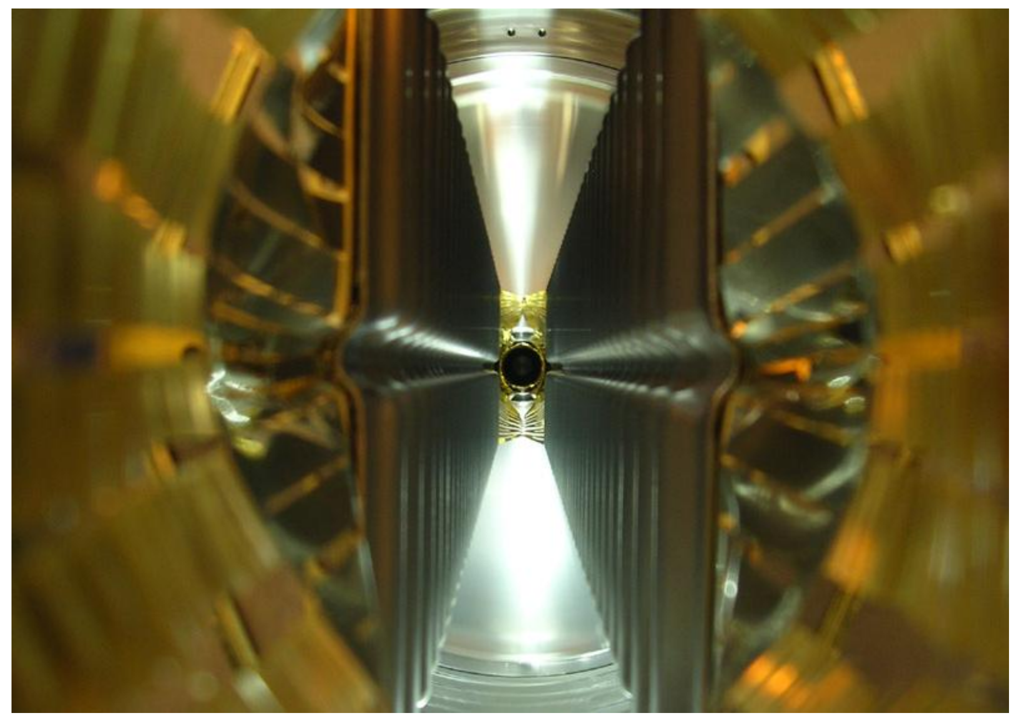
Vacuum System



The VELO has it's own secondary vacuum.

The sensors are housed in a 300 μm Al (3% Mg) RF shield which acts as the beam-pipe in the VELO region.

The shape allows sensors to overlap.



This is what Beam1 sees during injection.

Operations

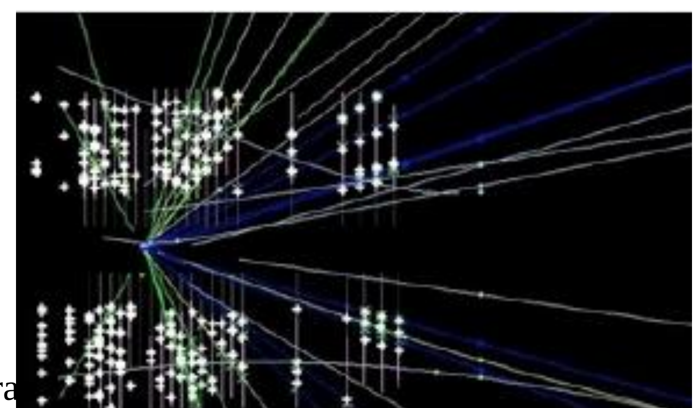
In the long term, the VELO may be entirely operated by the central LHCb shifter.

But for 2009-2010 we have a small number of people:

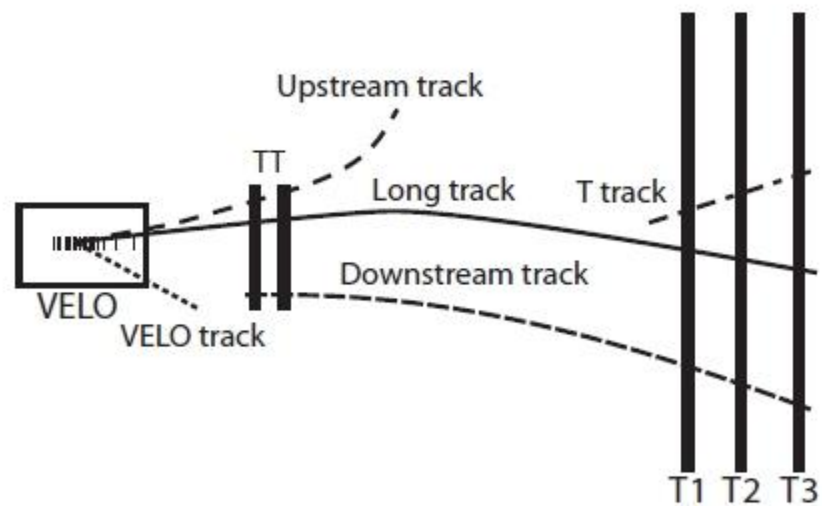
- VELO Run Co-ordinator
  - Post now held for two weeks
- On-call experts ("piquets")
  - Four in total who cover all aspects of operation in the pit, can call hardware experts.
- Shifters
  - About 40 from 12 institutes.

Track Reconstruction

- Track reconstruction relies on the VELO
- VELO sensors measure R and Φ
- 2-stage VELO tracking:
  - RZ tracking in 45° sectors
    fast vertexing and displaced track finding in trigger
  - RΦZ (=3D) tracking
    confirm RZ seeds plus combining leftover RΦ pairs



- Track fitting with bi-directional Kalman filter
- VELO half positions measured by hardware system after each movement, picked up immediately in trigger and stored for offline reconstruction



Time Alignment

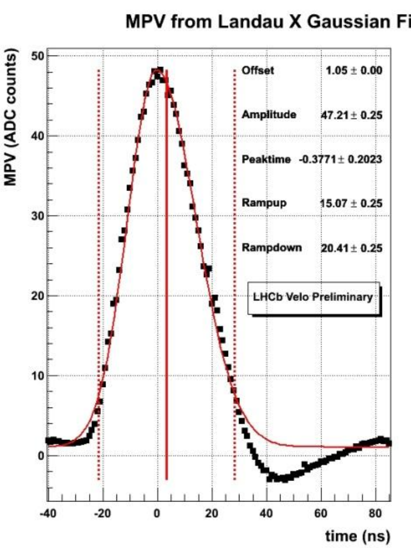
The sampling time of the front-end chips can be tuned.

They are optimised for:

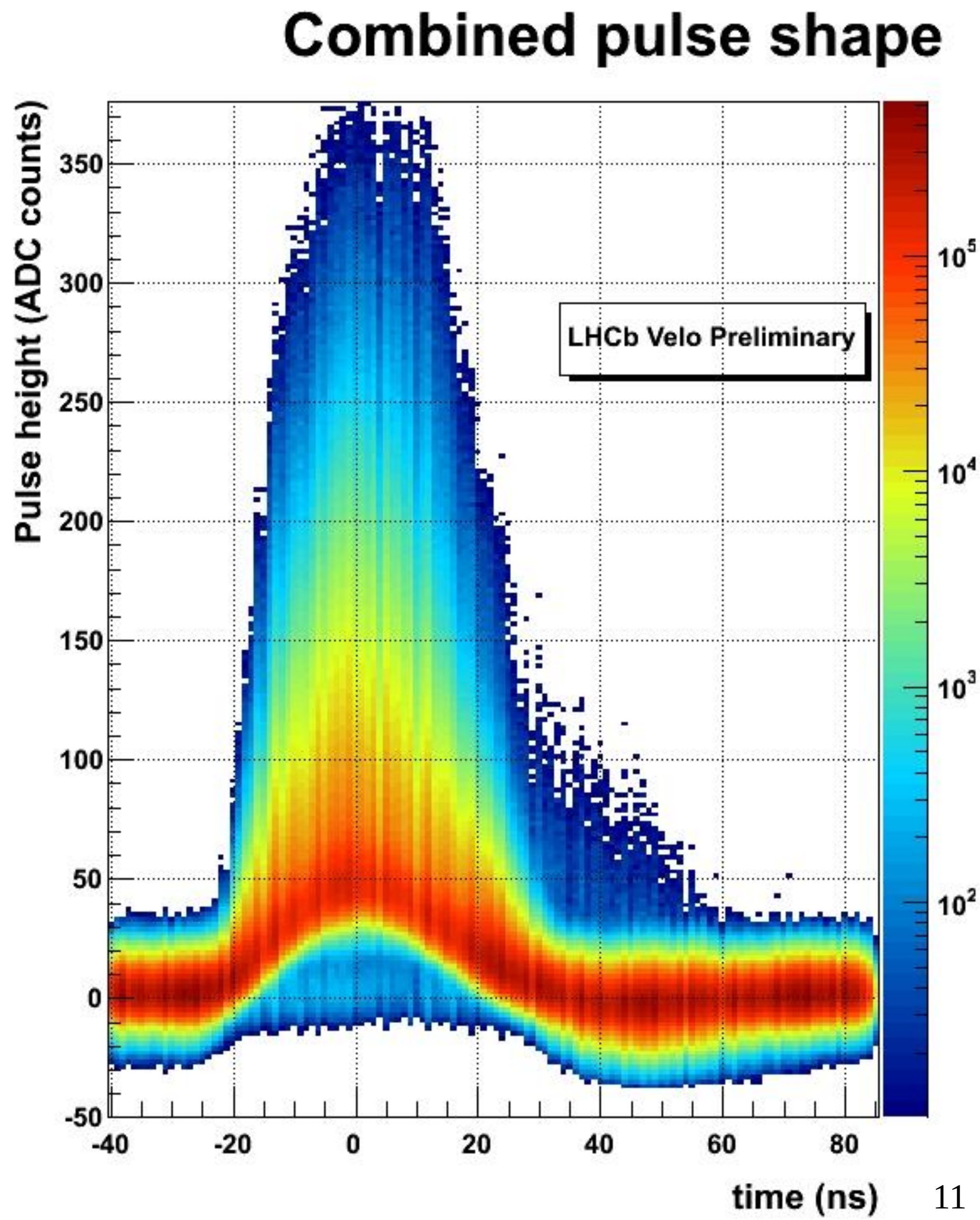
- Maximum signal
- Minimum spillover

Each sensor adjusted separately to account for:

- Time of flight
- Cable length



40 MHz collision rate = 25 ns sampling time



Alignment

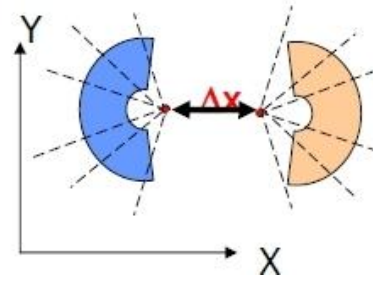
Alignment has two parts:

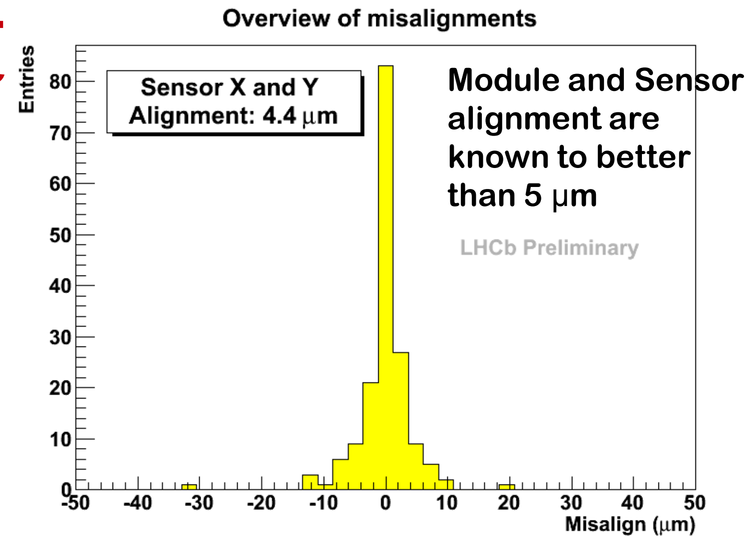
1)

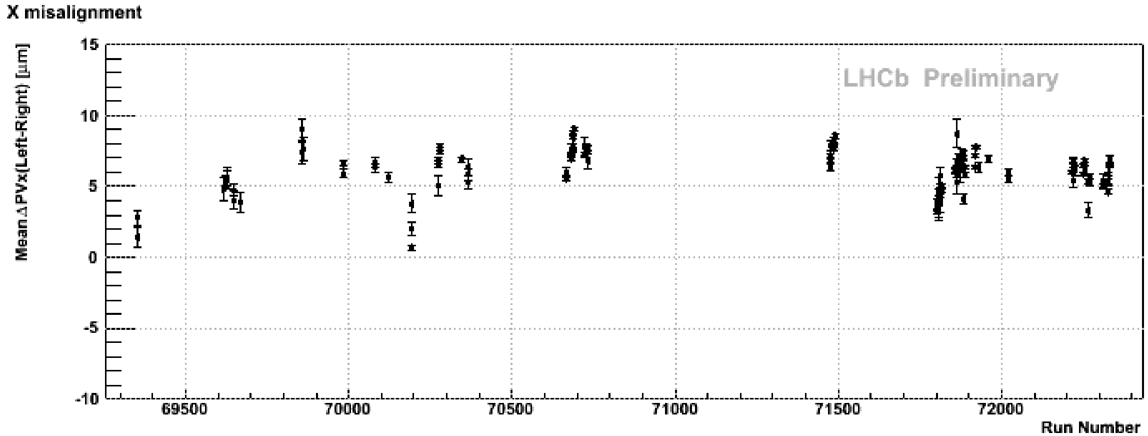
Relative alignment of sensors: fit to residual distribution
Module alignment: Millepede algorithm with linear track fit
VELO half alignment: align with PV halves and overlap tracks

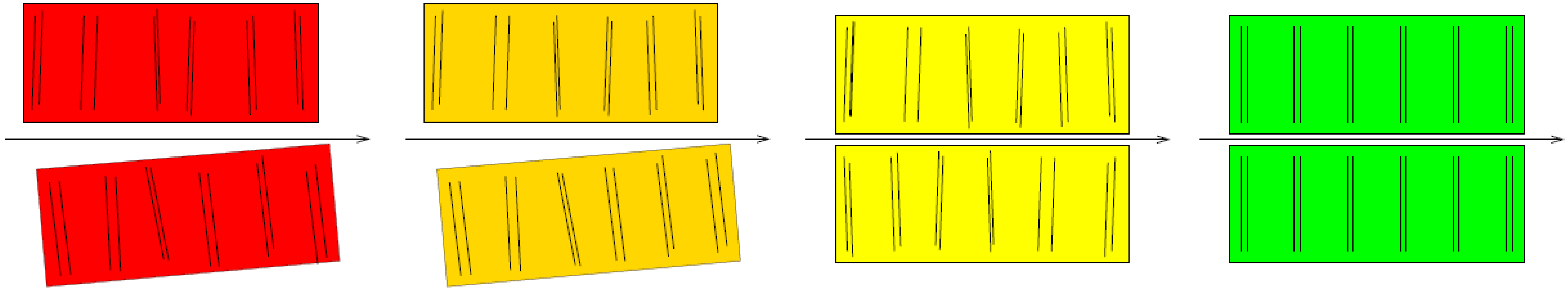
2)

Global $\chi 2$ minimisation based on Kalman track fit residuals



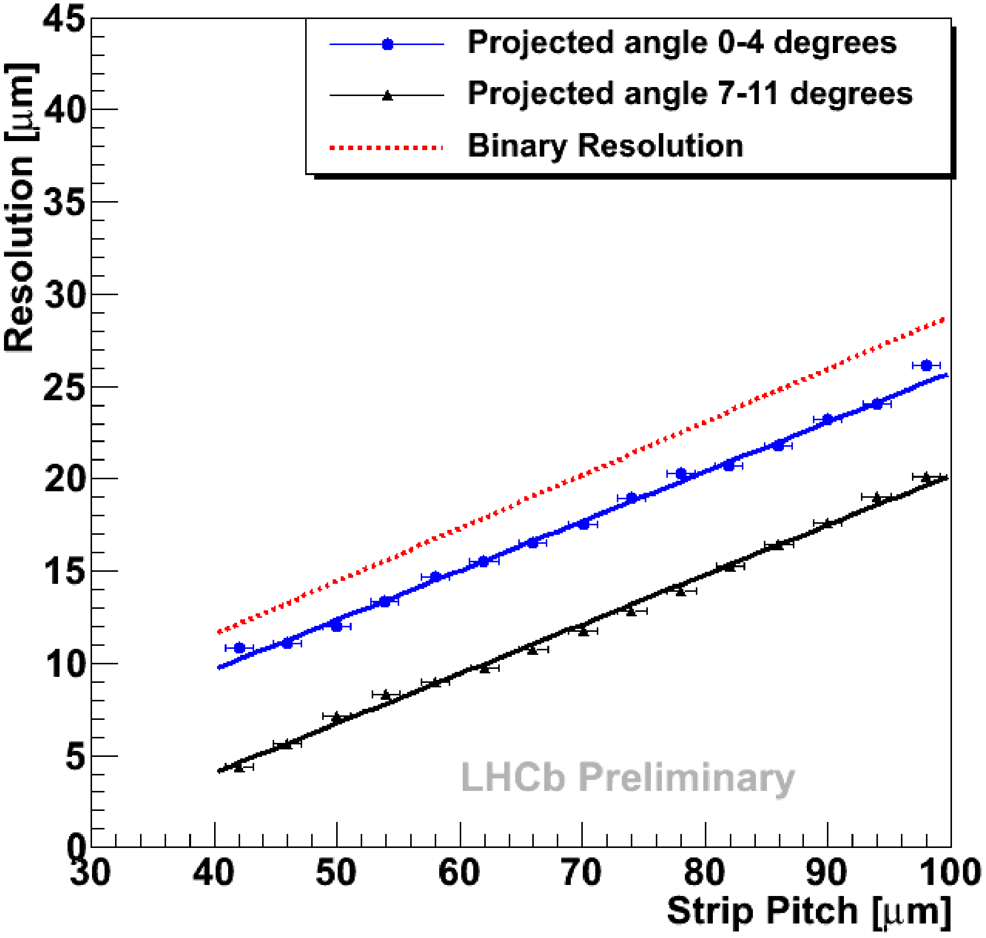


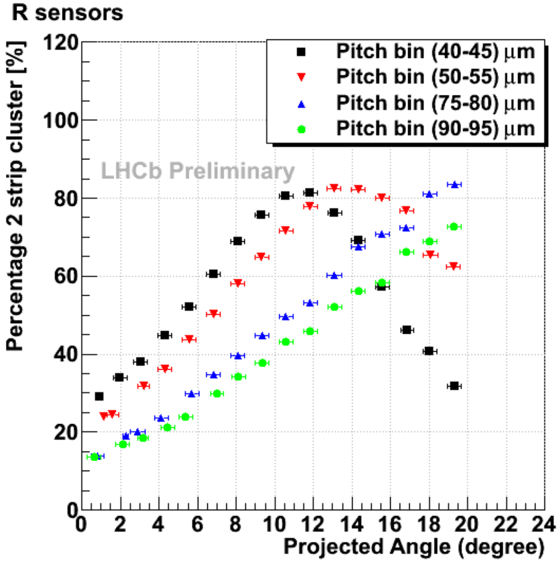




Single Hit Resolution

- We can measure hit resolution as fraction of strip pitch and track angle
- Resolution is based on hit residuals
- The resolution improves as charge sharing increases (weighted cluster centre)
- Optimal track angle depends on pitch
- Best resolution ~4 μm



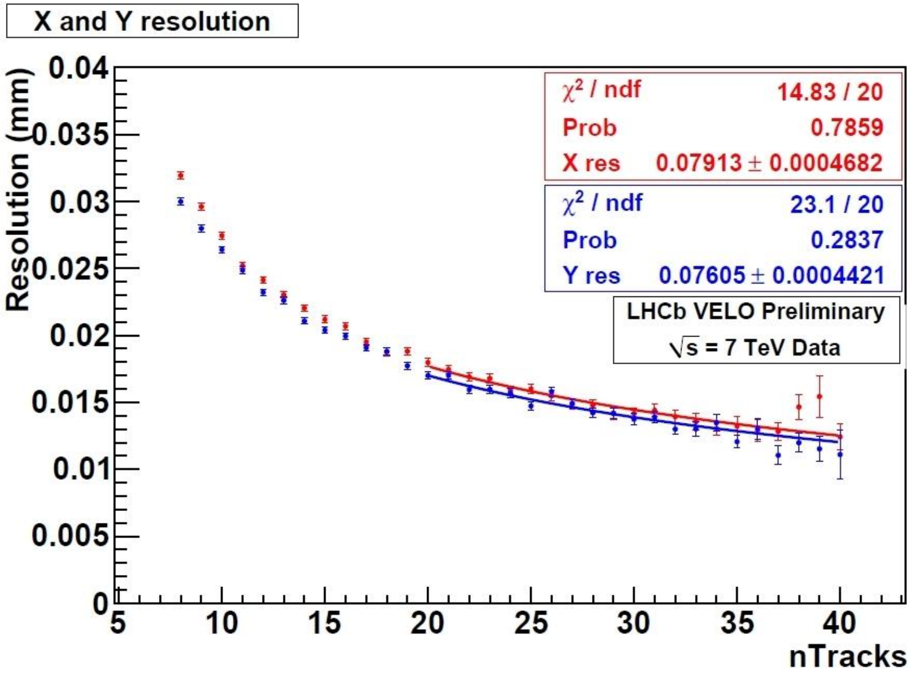


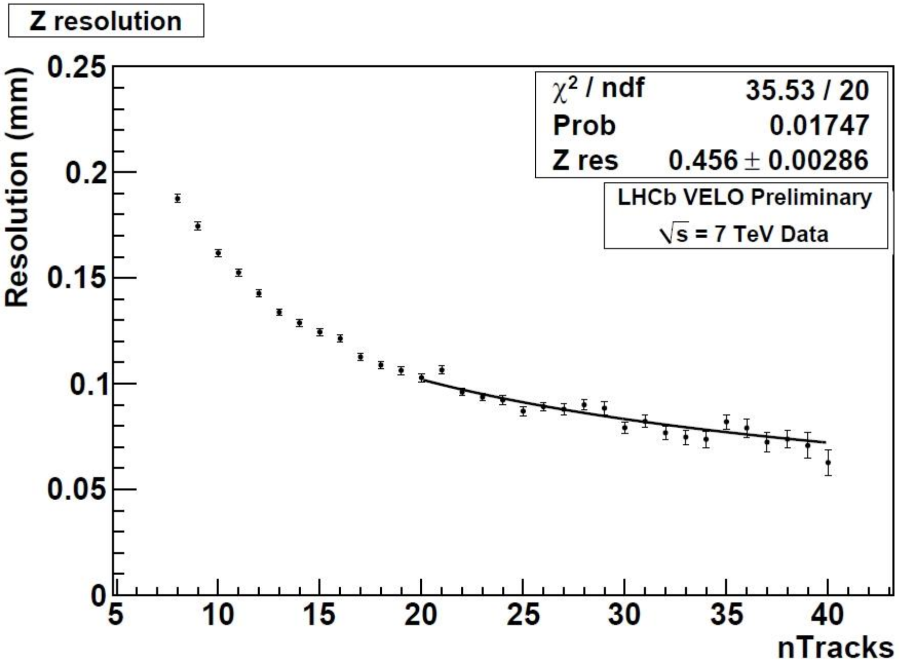
Vertex Resolution

- Combine tracks in all directions from primary vertex
- Measure resolutions by randomly splitting track sample in two and comparing vertices of equal multiplicity
- The resolution is related to the width of the residual distribution

With 25 tracks per PV, resolutions are:
in x: 15.7 microns
in y: 15.4 microns
in z: 90.4 microns

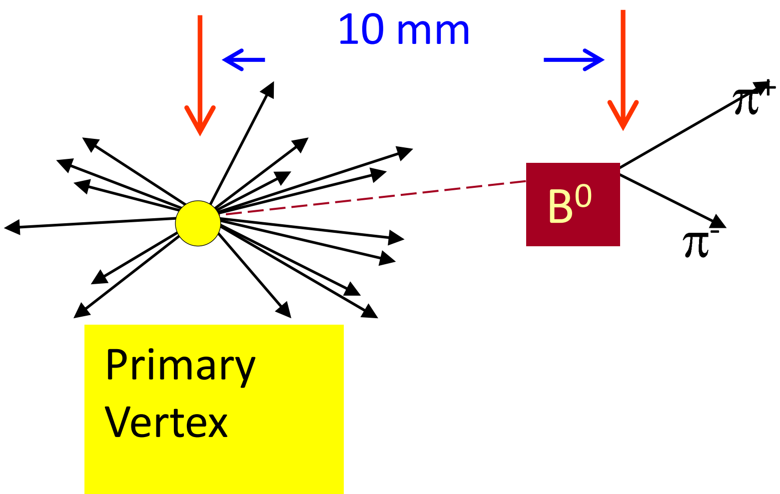
$res_x = 79\mu m/\sqrt{N}$
$res_y = 77\mu m/\sqrt{N}$
$res_z = 456\mu m/\sqrt{N}$

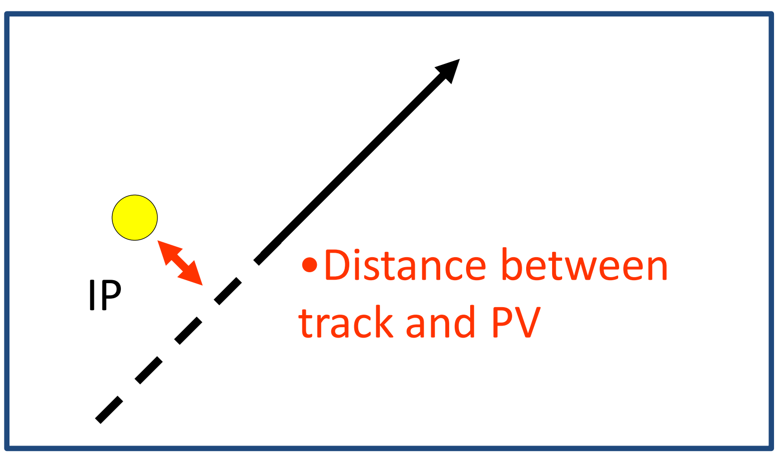


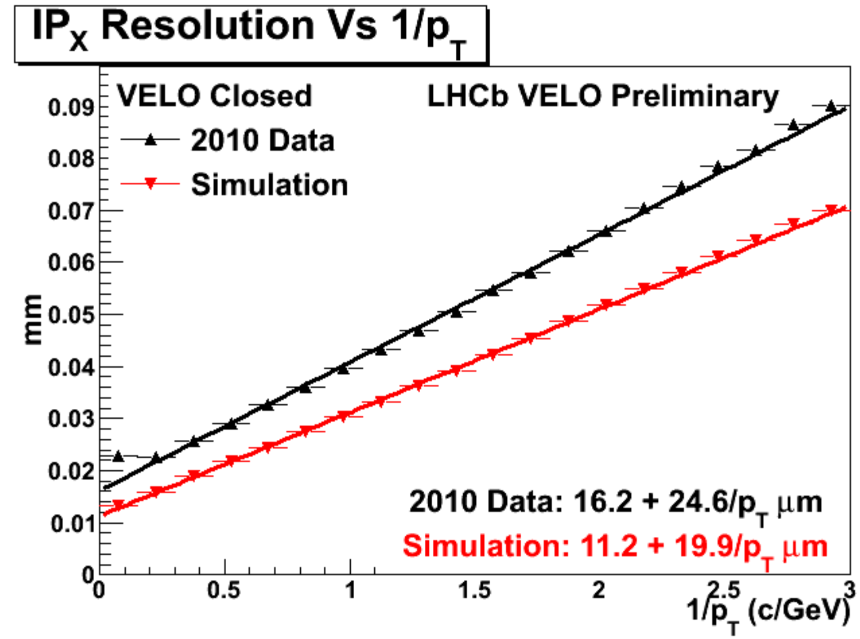


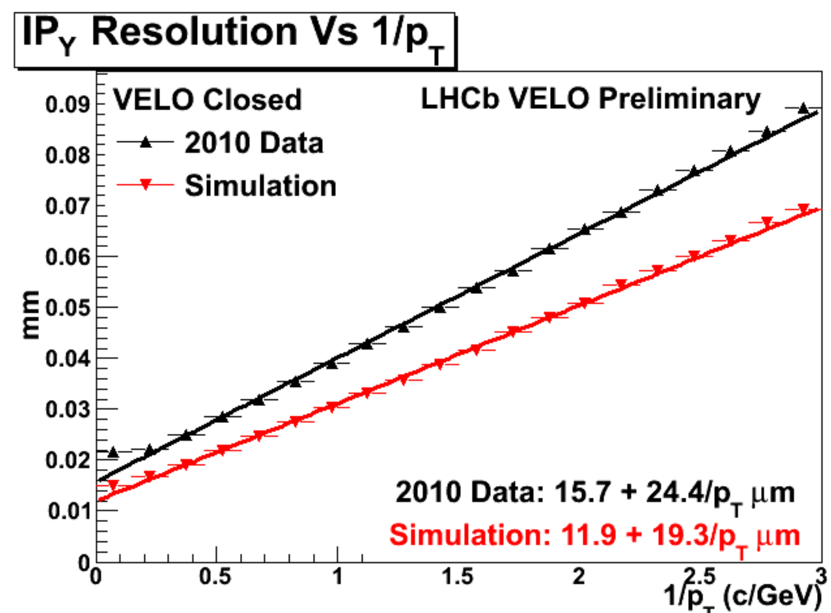
Impact Parameter Resolution

The Impact Parameter (IP) is an important quantity for identifying *B* meson decays.

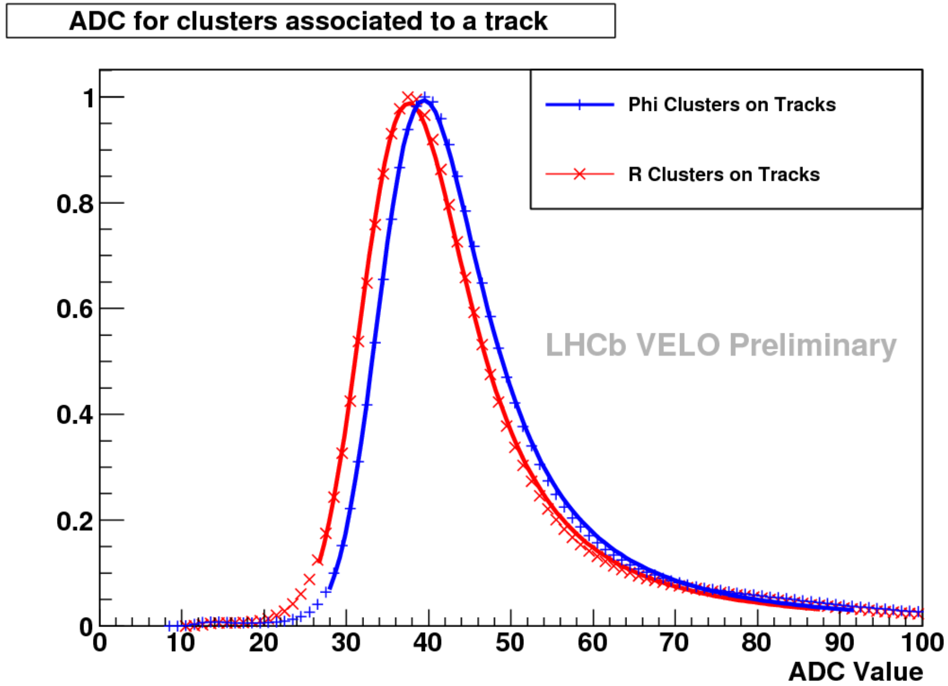


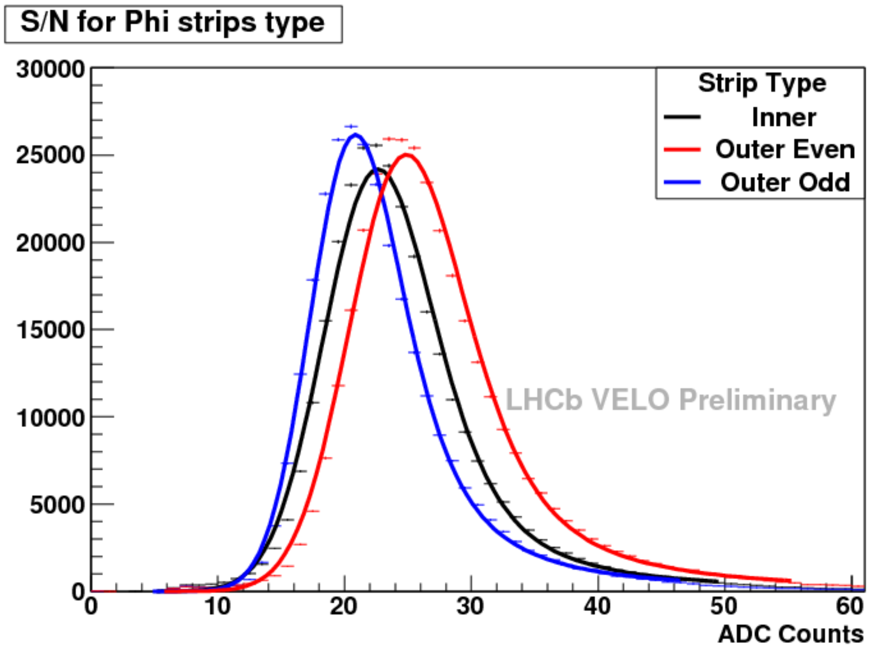






Cluster ADCs



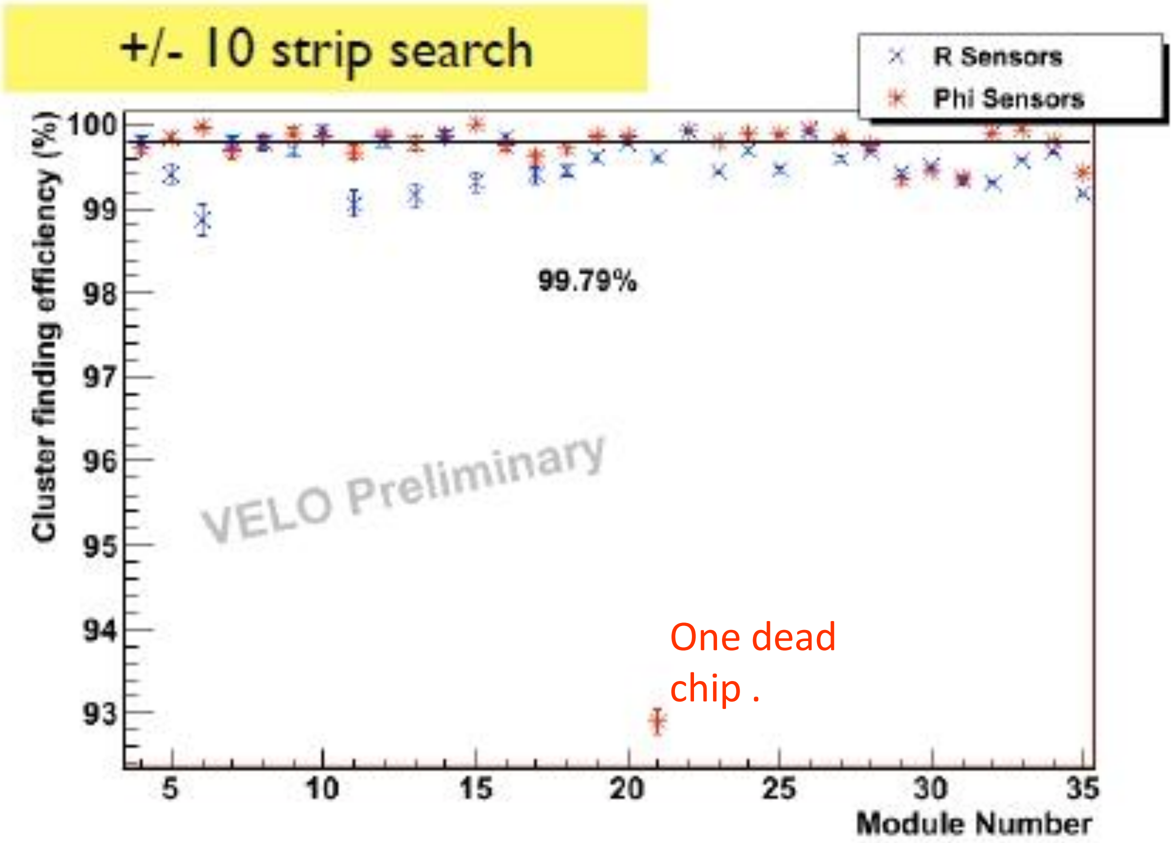


Detector	S/N
R	18.3
Phi Inner Strips - Routed over outer strips	21.2
Phi Outer Strips - *No* overlaid routing lines	23.3
Phi Outer Strips - Overlaid routing lines	19.6

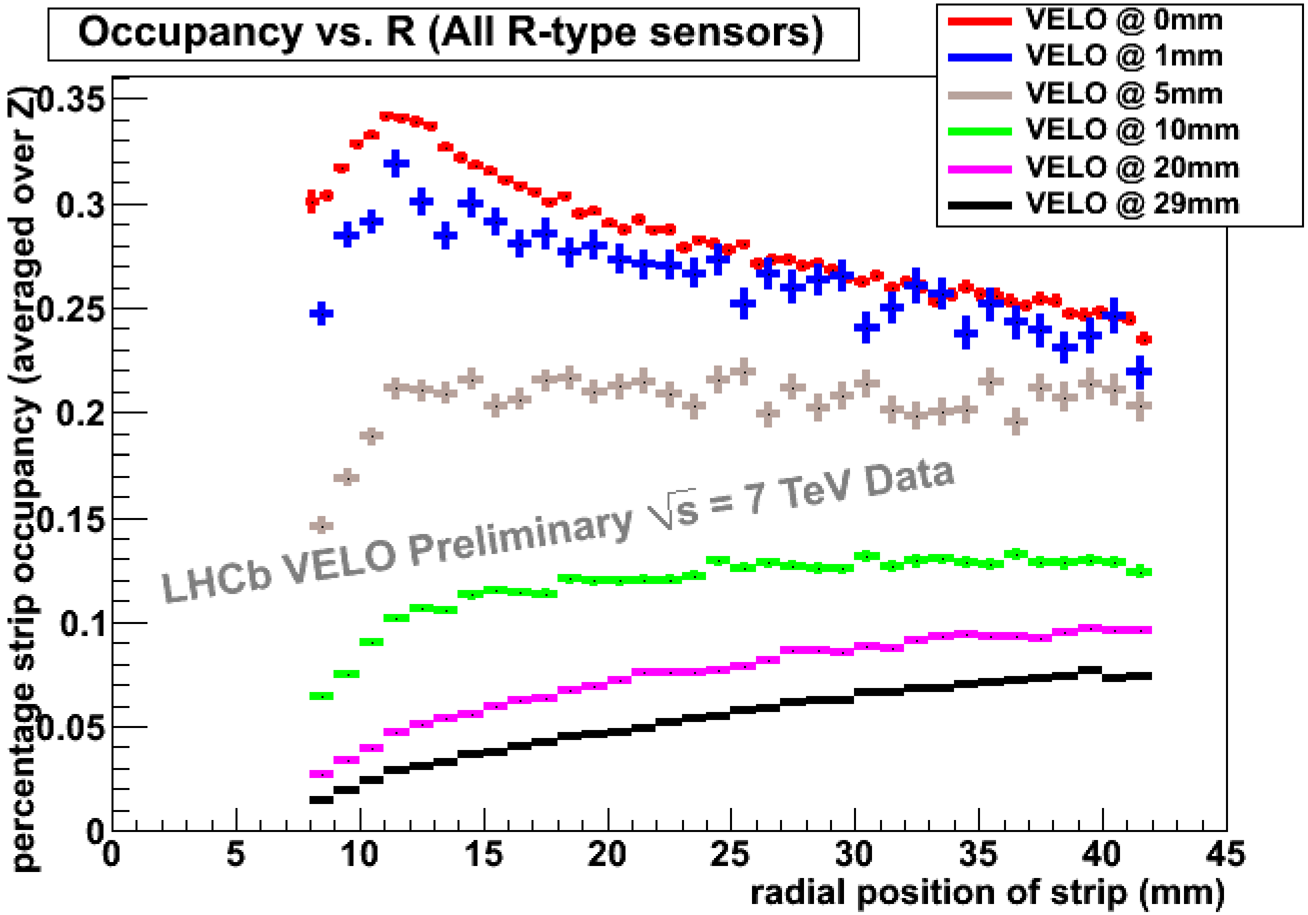
After several years of operation expect S/N to drop to O(10).

Cluster Finding

The VELO has close to 100% cluster finding efficiency.



Occupancy

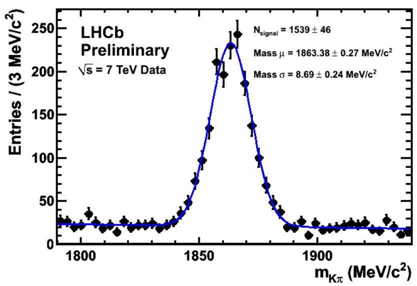


Even when closed, strip occupancies are well below 1%.

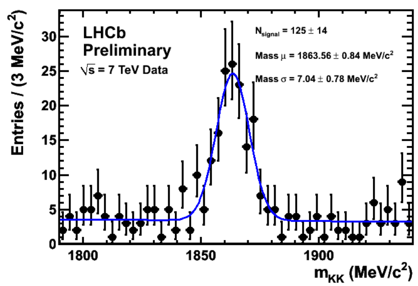
Early Results

The tracking detectors were well calibrated since startup.

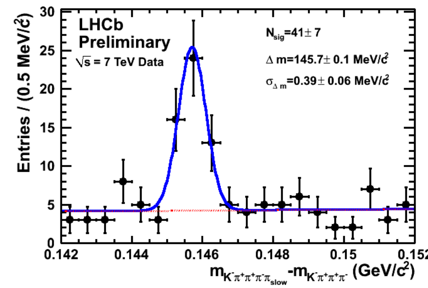
$D^0 \to K\pi$



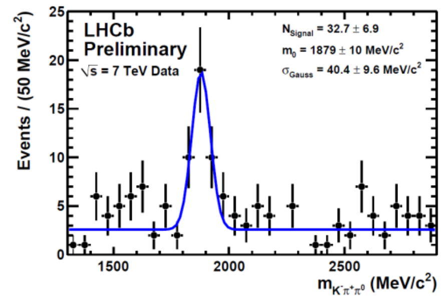
$D^0 \to KK$



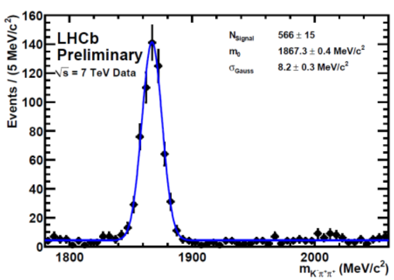
$D^* \to D^0\pi,\ D^0 \to K\pi\pi\pi$



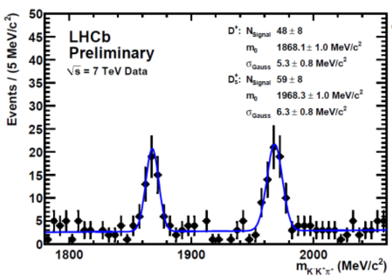
$D^0 \to K\pi\pi^0$



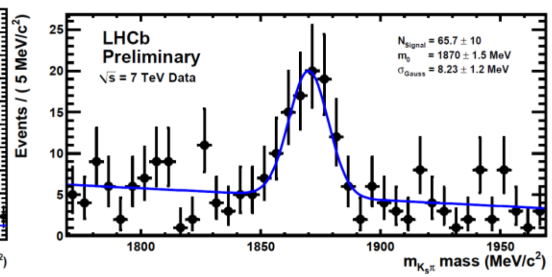
$D^+ \to K\pi\pi$



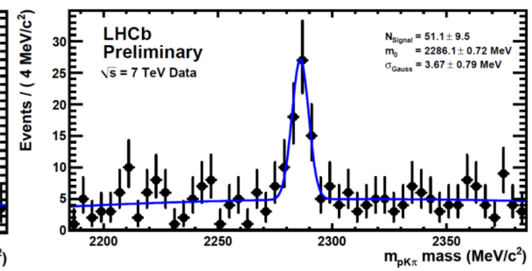
$D^+, D_s \to KK\pi$



$D^+ \to K_S\pi$



$\Lambda_c \to pK\pi$



Many mass peaks found – in good agreement with the Particle Data Group.

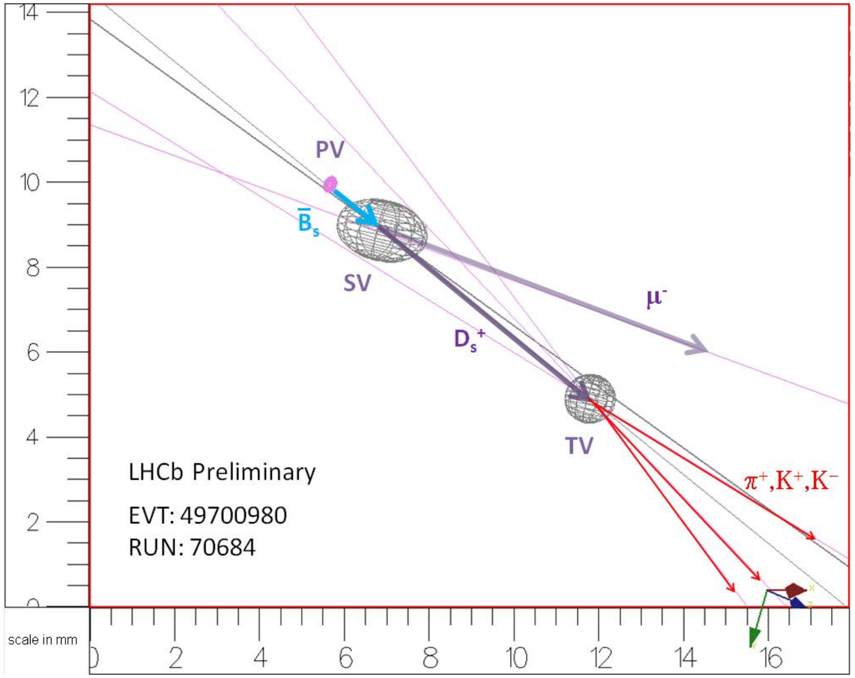
Summary

LHCb is running!

Although there will be many improvements, the VELO is already performing well

Preliminary VELO performance:

- 99.8% Cluster Finding Efficiency
- Vertex resolutions of ~15 μm in x and y
- At optimal angles the VELO can achieve resolutions of 4 μm
- Better than 5 μm sensor alignment



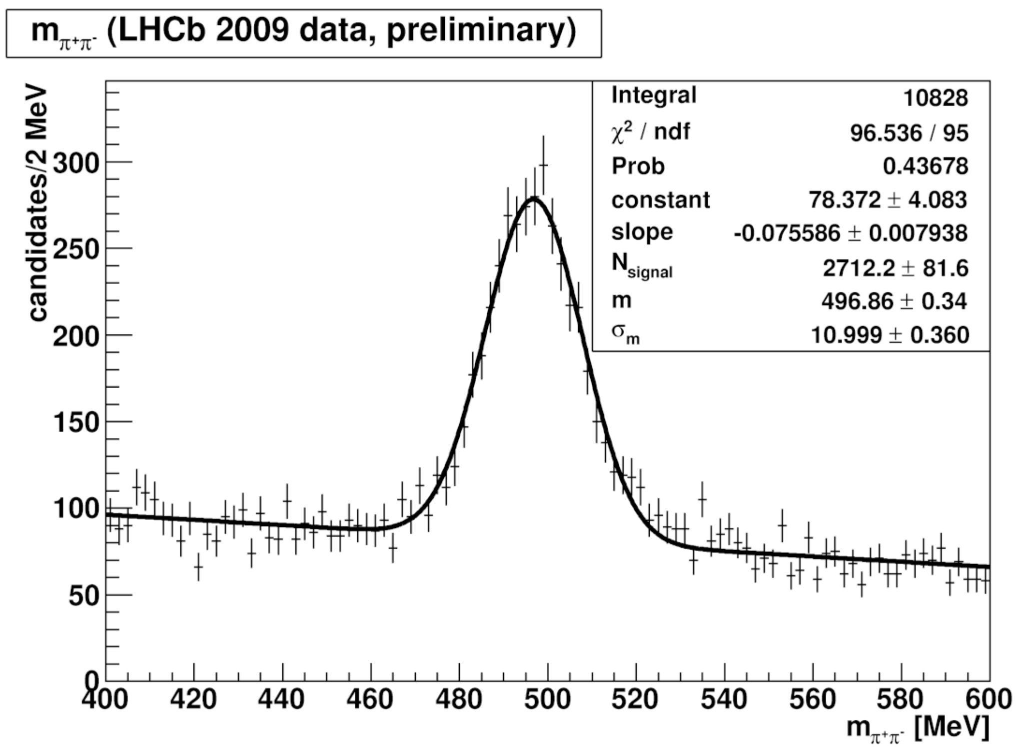
VELO upgrade planning underway

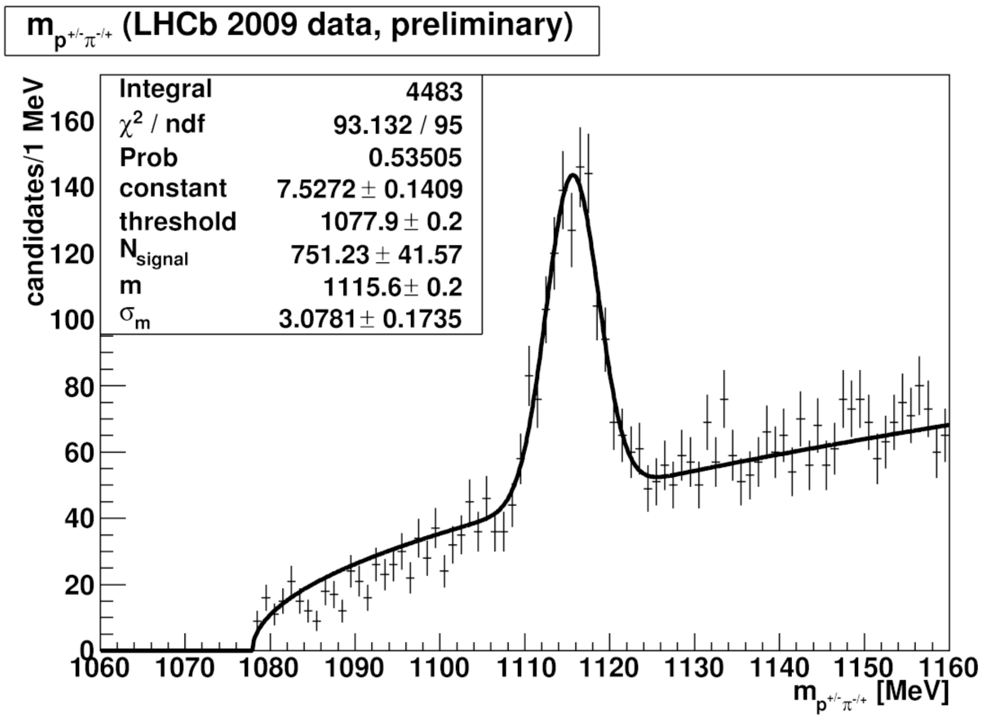
Backup

K_S and Λ

- Without VELO

Tracking detectors were well calibrated at the start-up !



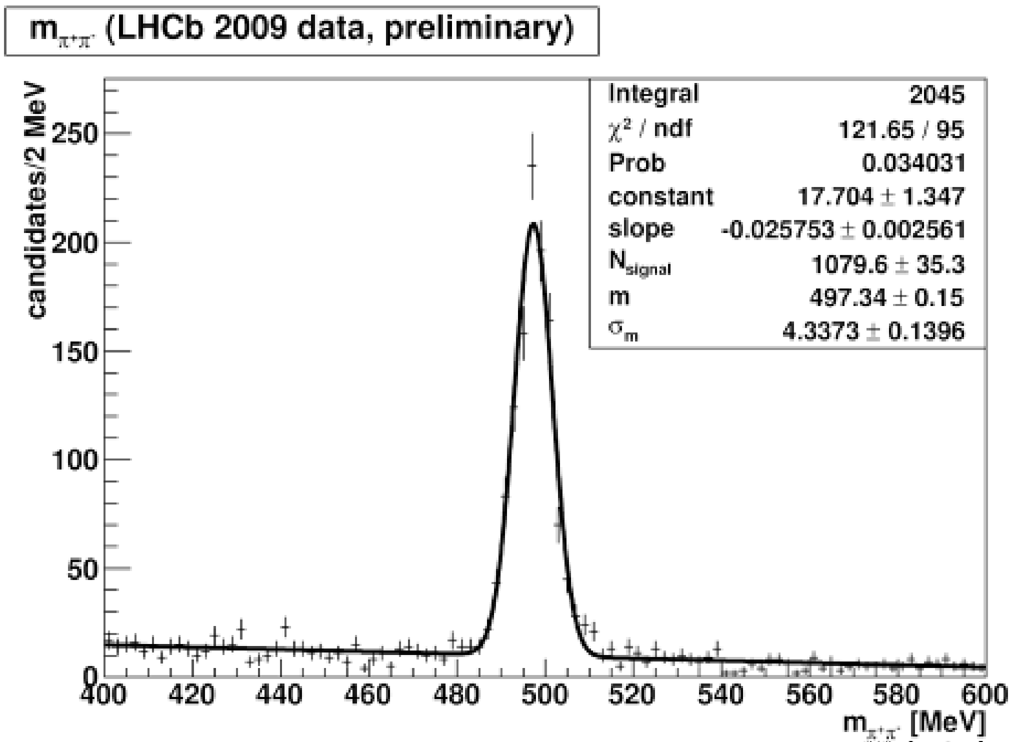


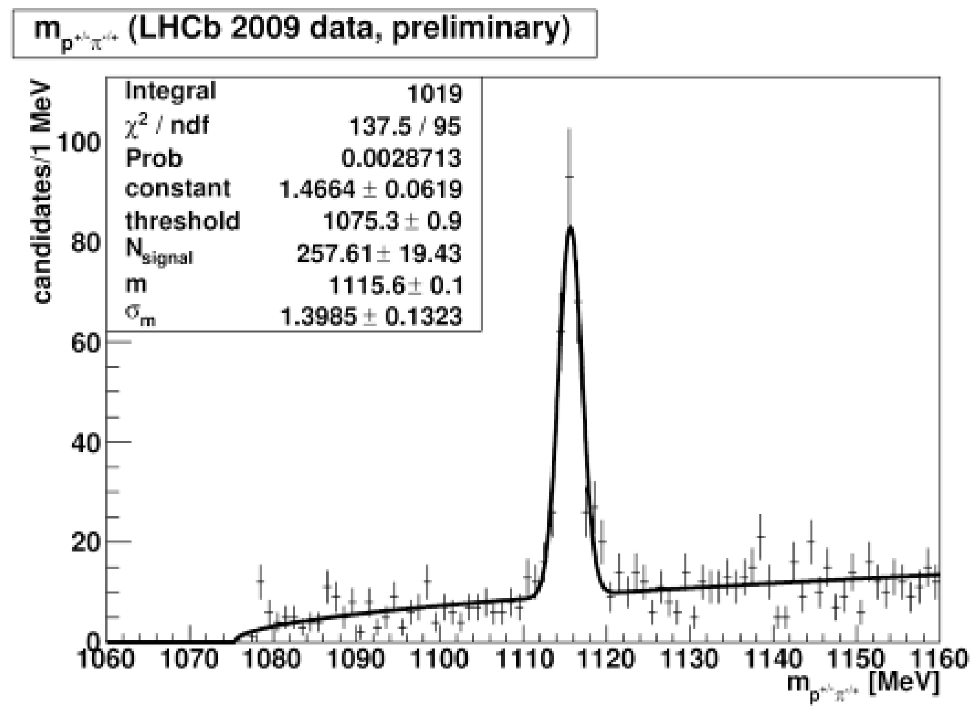
σ	= 11.0 ± 0.4	MeV/c²	σ	= 3.1 ± 0.2	MeV/c²
M(Ks)	= 496.9 ± 0.3	MeV/c²	M(Λ)	= 1115.6 0.2	MeV/c²
M(Ks^PDG)	= 497.7	MeV/c²	M(Λ^PDG)	= 1115.7	MeV/c²

K_S and Λ

- With VELO (15mm)

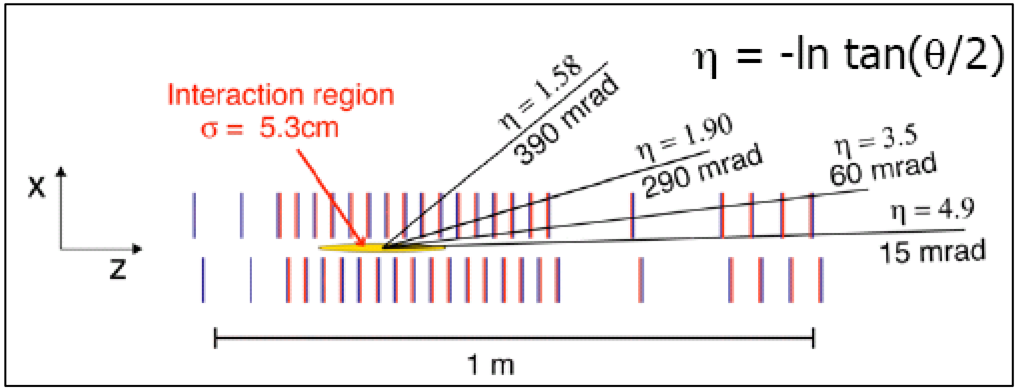
Power of precision vertexing – even with VELO 15mm open





σ	= 4.3 ± 0.1	MeV/c^2	σ	= 1.4 ± 0.1	MeV/c^2
M(Ks)	= 497.3 ± 0.2	MeV/c^2	M(Λ)	= 1115.6 0.1	MeV/c^2
M(Ks^{PDG})	= 497.7	MeV/c^2	M(Λ^{PDG})	= 1115.7	MeV/c^2

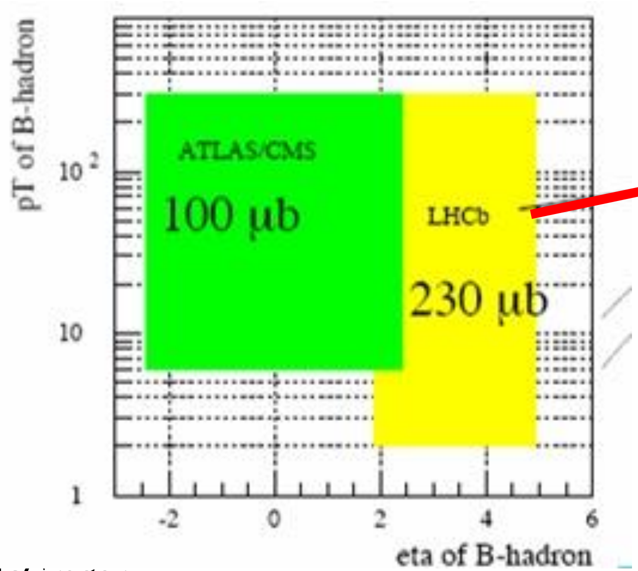
LHCb: A Forward Spectrometer

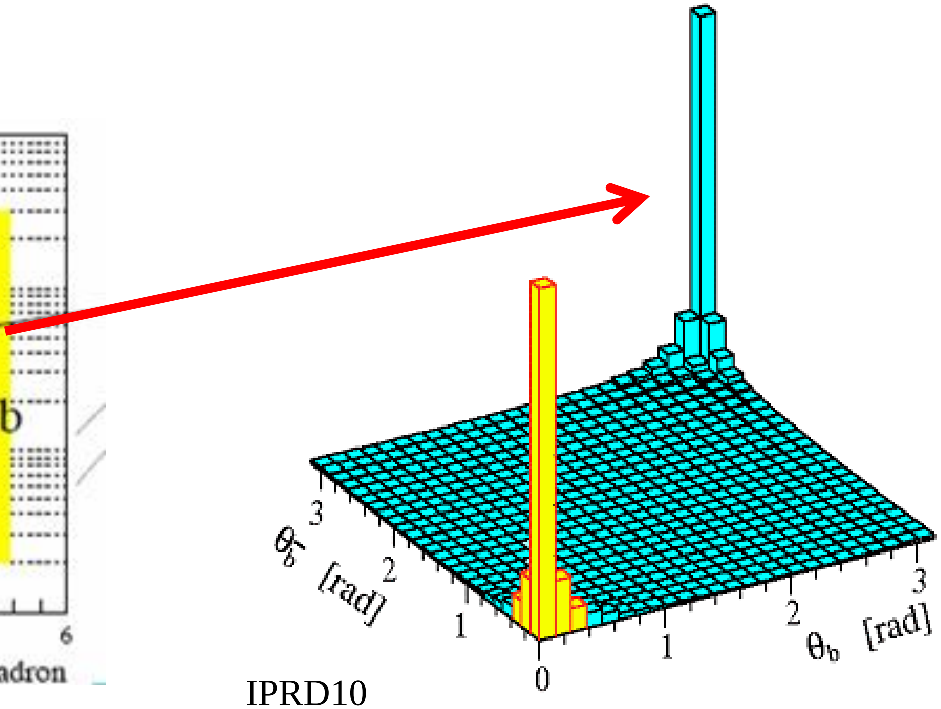


LHCb is a forward spectrometer with an angular acceptance of 10 – 250 mrad (*pseudo-rapidity* of 1.9 – 4.9).

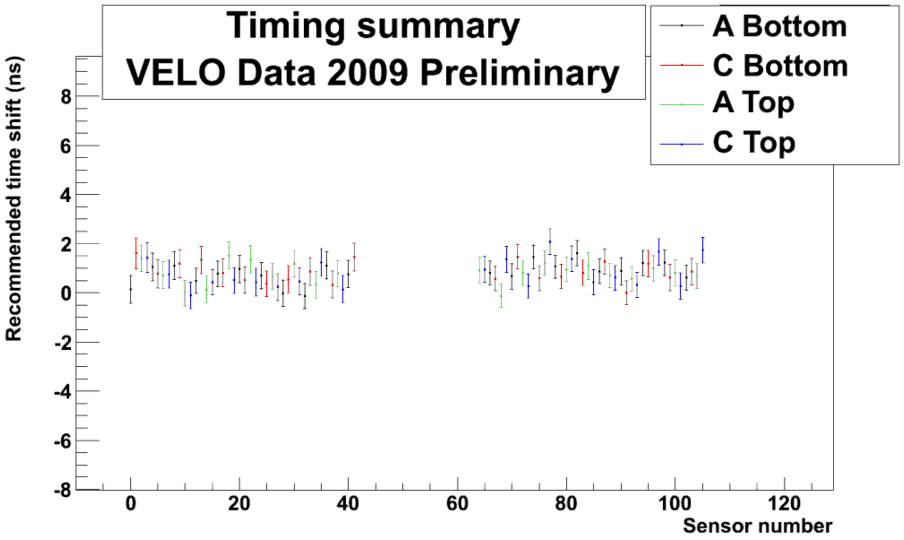
At design luminosity and energy, LHCb will see around 10^{12} *bb* pairs per year.

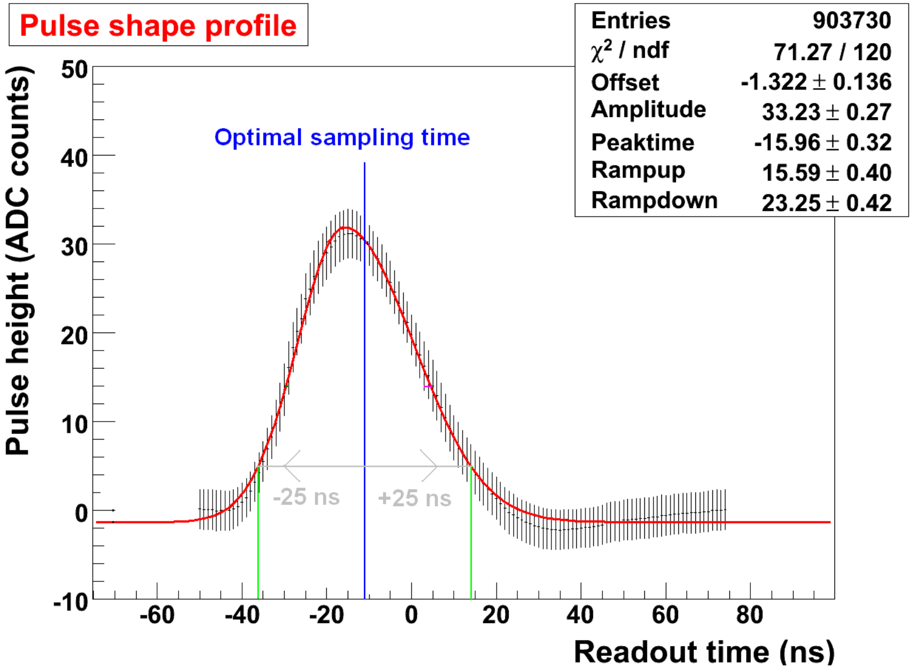
The *bb* pairs are strongly correlated and forward peaked.



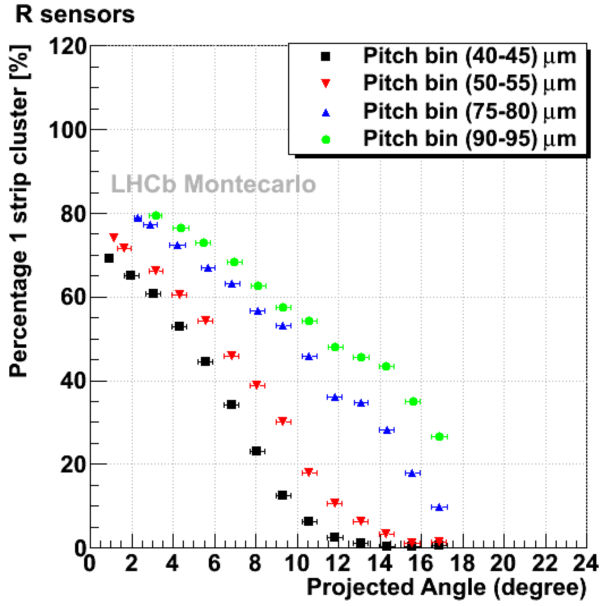


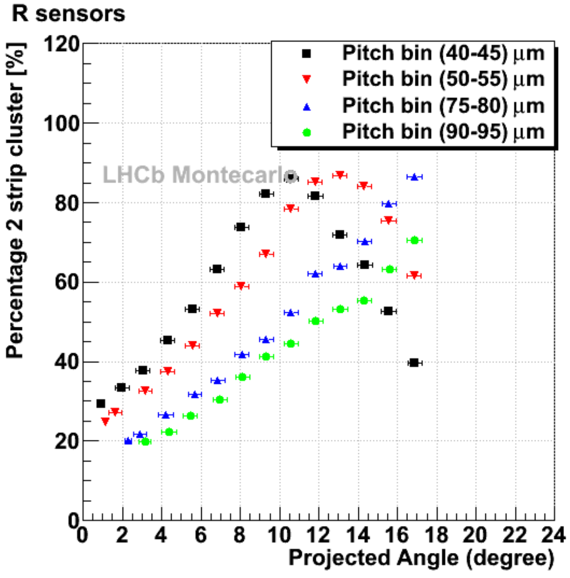
Time Alignment II

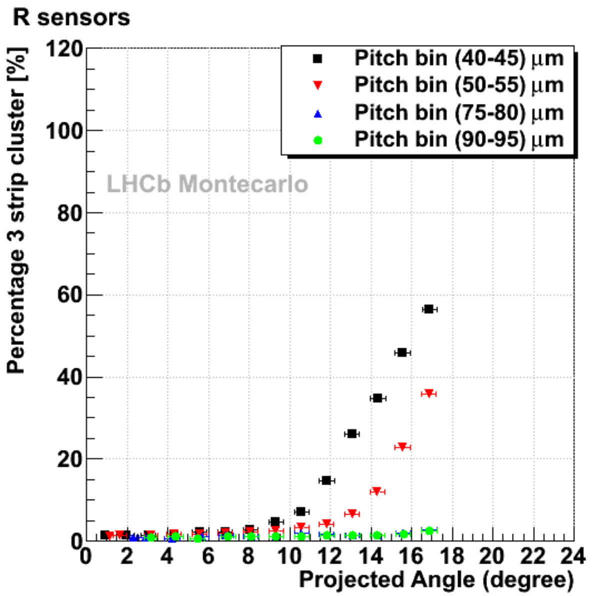


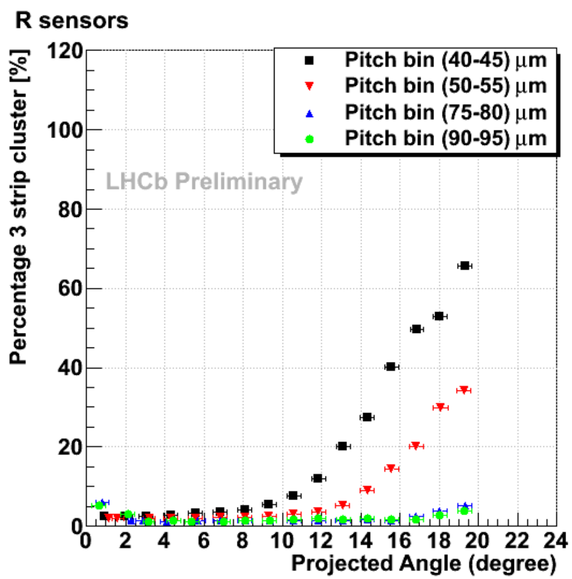


Cluster Size









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