Towards the highest precision detector at the LHC

The performance of the LHCb Upgrade VELO

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The University of Manchester

The LHCb detector

The LHCb Upgrade

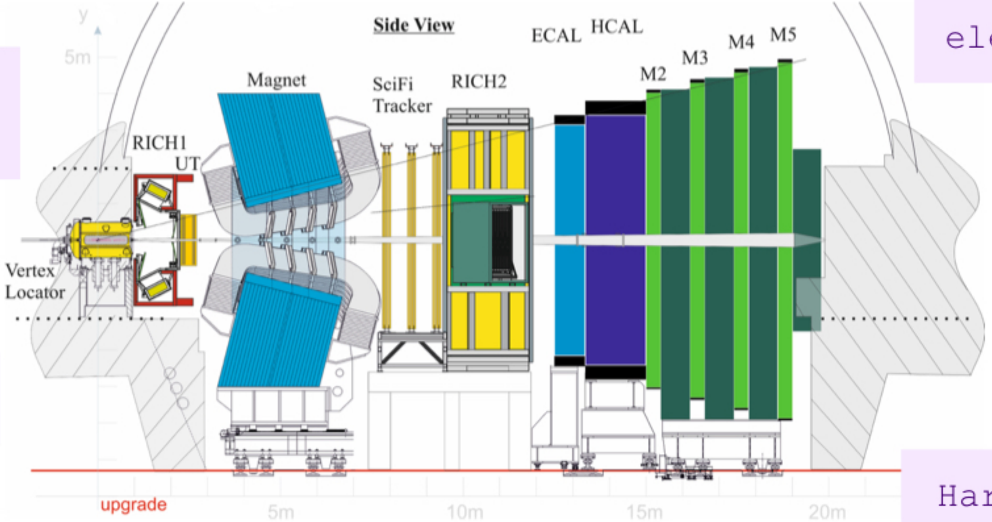
- To be installed during Long Shutdown 2 of the LHC (2018-2020)
- Already covered by Deepanwita and Vinicius

New downstream tracker

New Scintillating Fibre Tracker

All readout electronics replaced

5x higher luminosity 10^34/cm^2/s



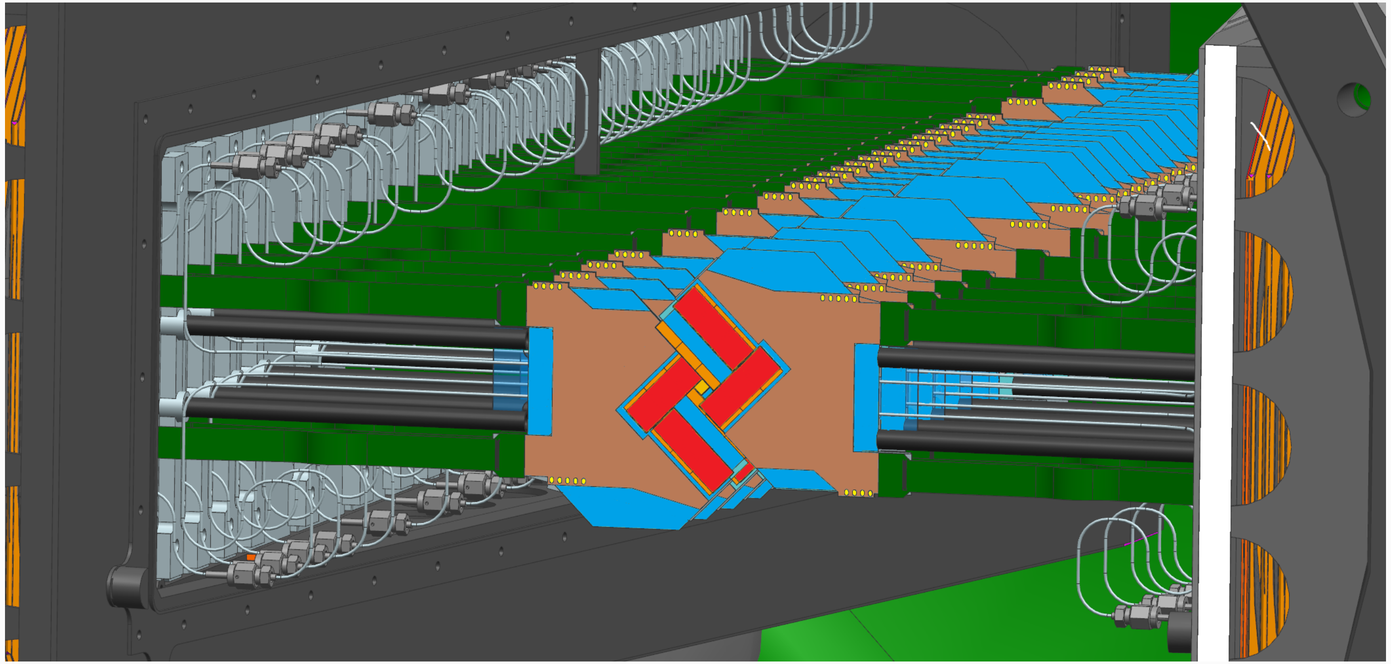
All new Velo

Hardware trigger removed entirely

30MHz readout

New mirrors and MAPMTs in RICH 1 & 2

The LHCb upgrade Velo

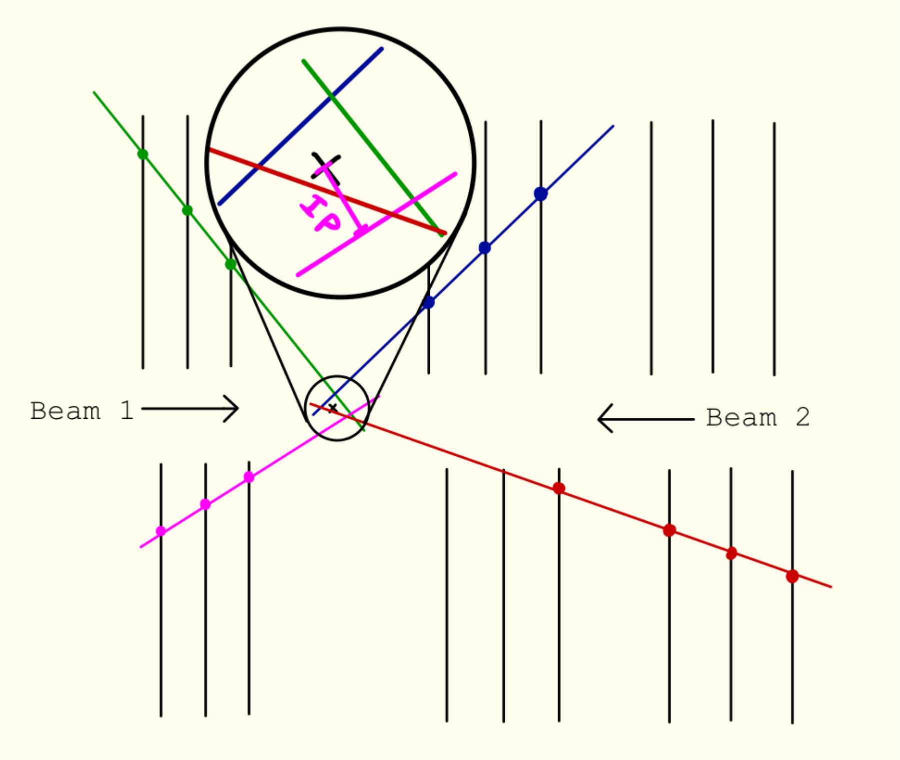


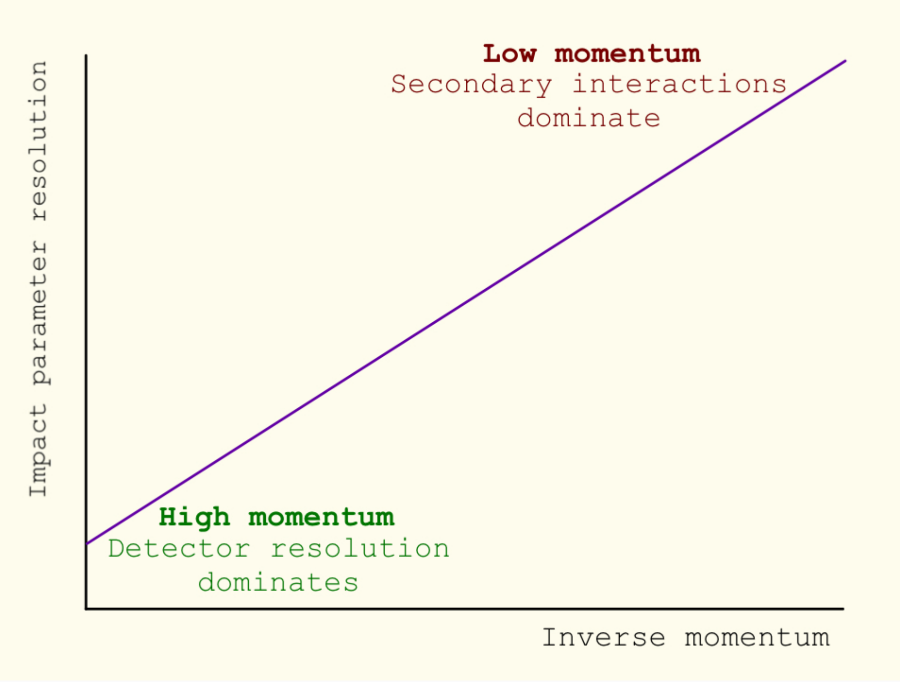
- The LHCb Velo is already the most precise detector at the LHC
- Aim to keep this performance while allowing for 5x higher luminosity by:
  - Pixels instead of strips
  - Closer to the beam (8.2mm → 5.1mm)
  - More modules (42 → 52)

Definitions

Definitions

- Primary vertex is the point of a proton-proton collision
- IP is the closest distance between the reconstructed PV and a prompt track
  - Resolution is approximately linear with respect to $\frac{1}{p_T}$

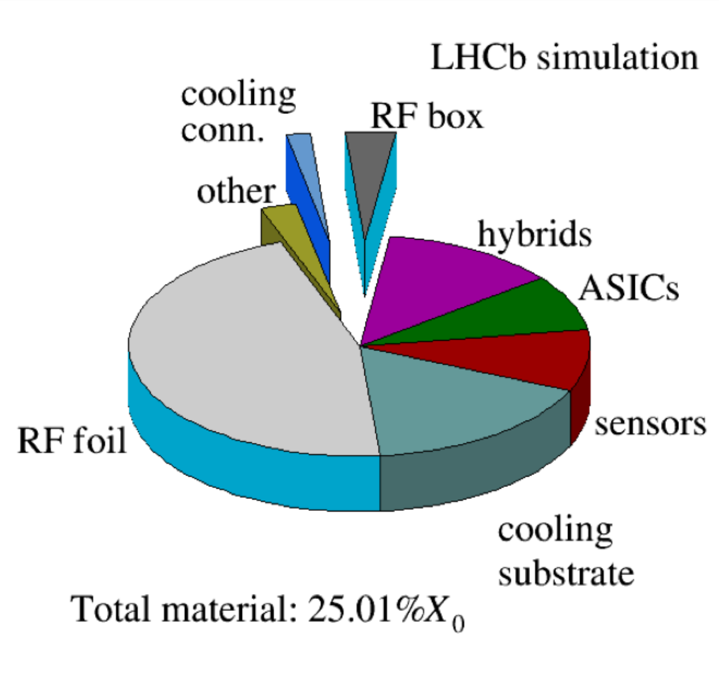


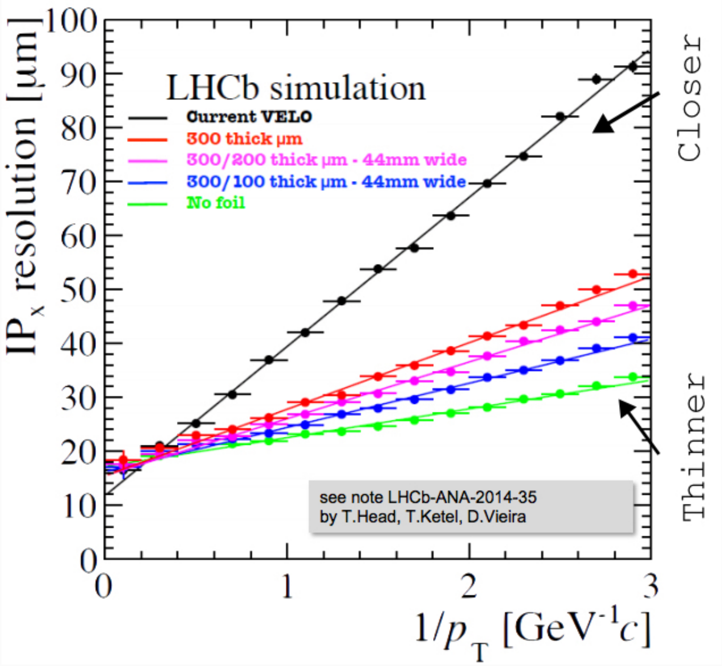


Material

Material studies

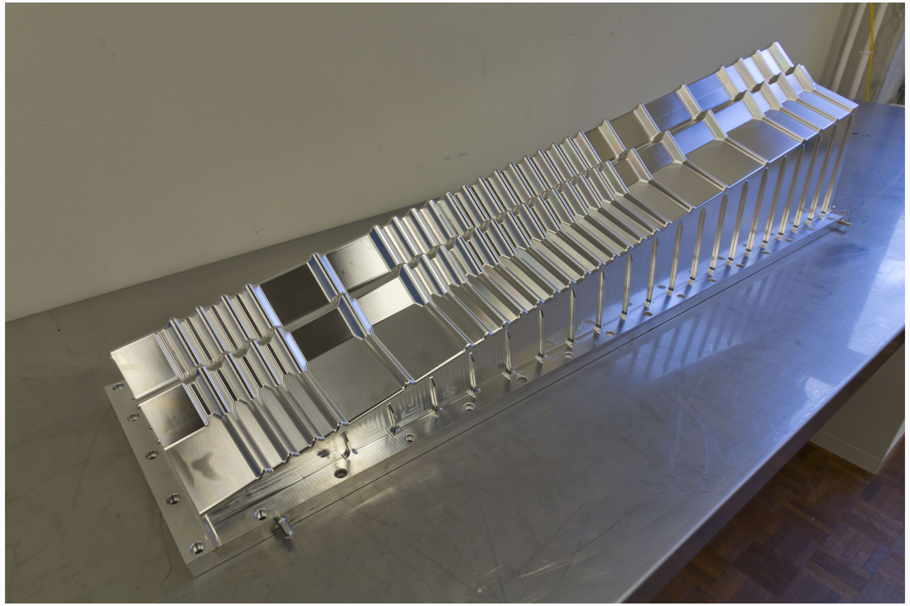
- The Velo is placed inside the LHC beam pipe
  - The only material is from LHCb itself
- Impact of the Velo material has been studied using GEANT4 based simulations
  - Including the mechanics and RF box
- Material before the first hit has significant impact on performance
  - Especially for secondary vertices which only have 2-4 tracks

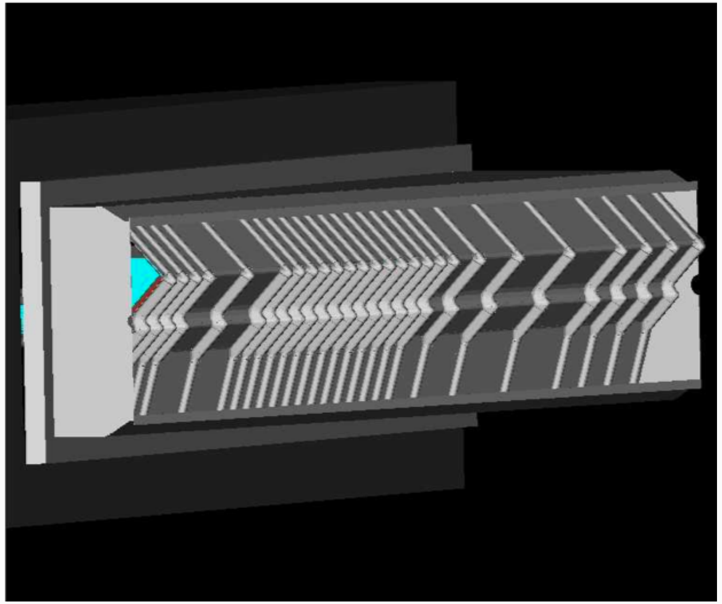




RF foil

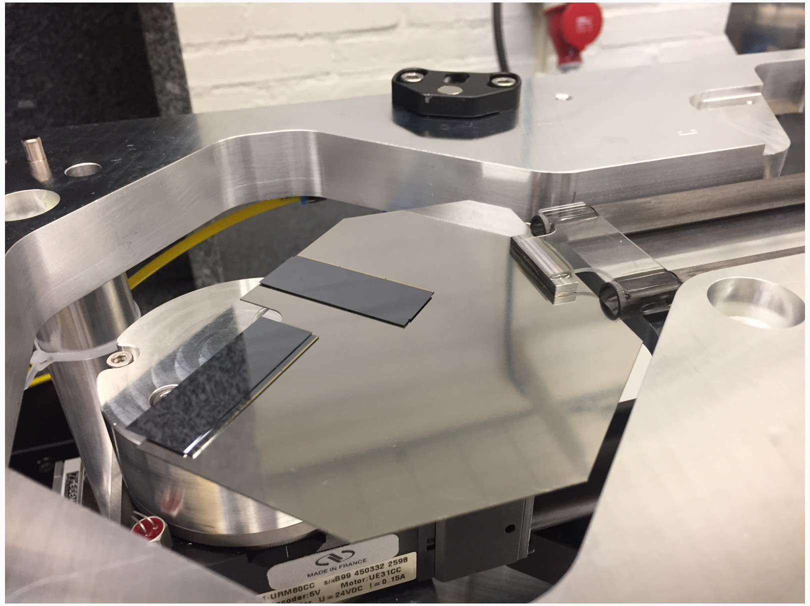
- Required for RF shielding and to conduct the "mirror image" of the beam
- Responsible for about half of the material before the first hit
- Chemically etched to be as thin as possible while remaining vacuum tight
- Detector description created to represent this in simulation (250μm thick)

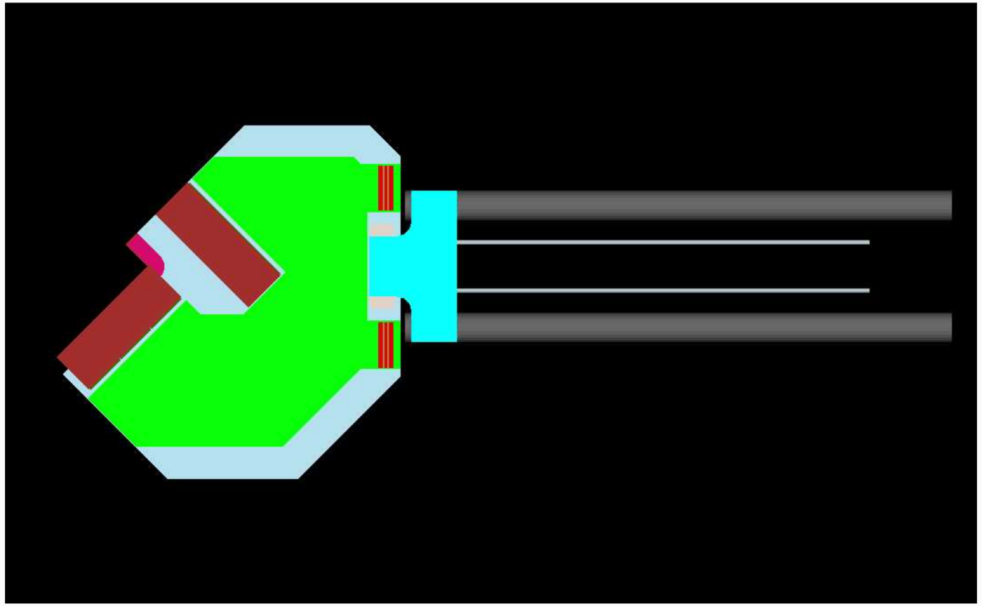




Modules

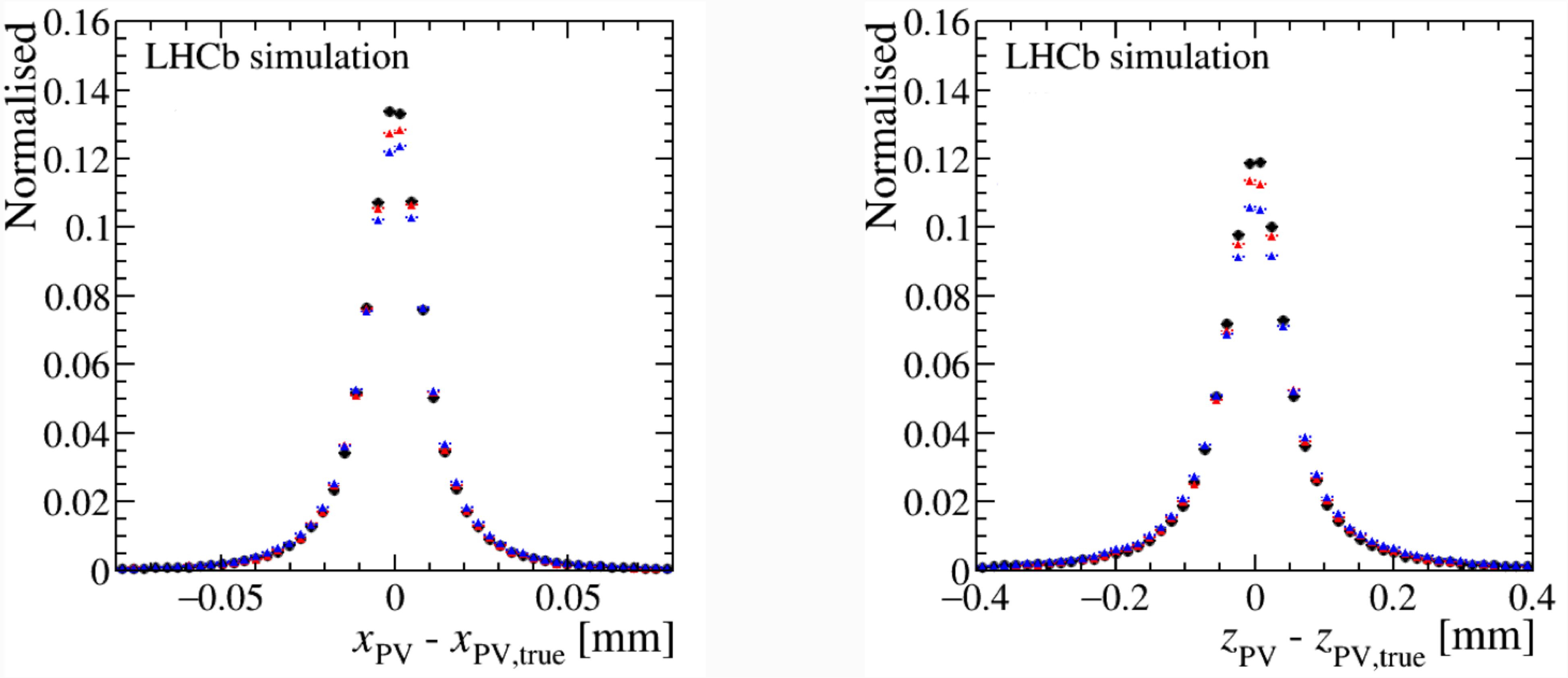
- Modules are comprised of many components which add material
  - Cooling, ASICs, substrate, sensors, etc.
- Has also been implemented in software using a realistic model





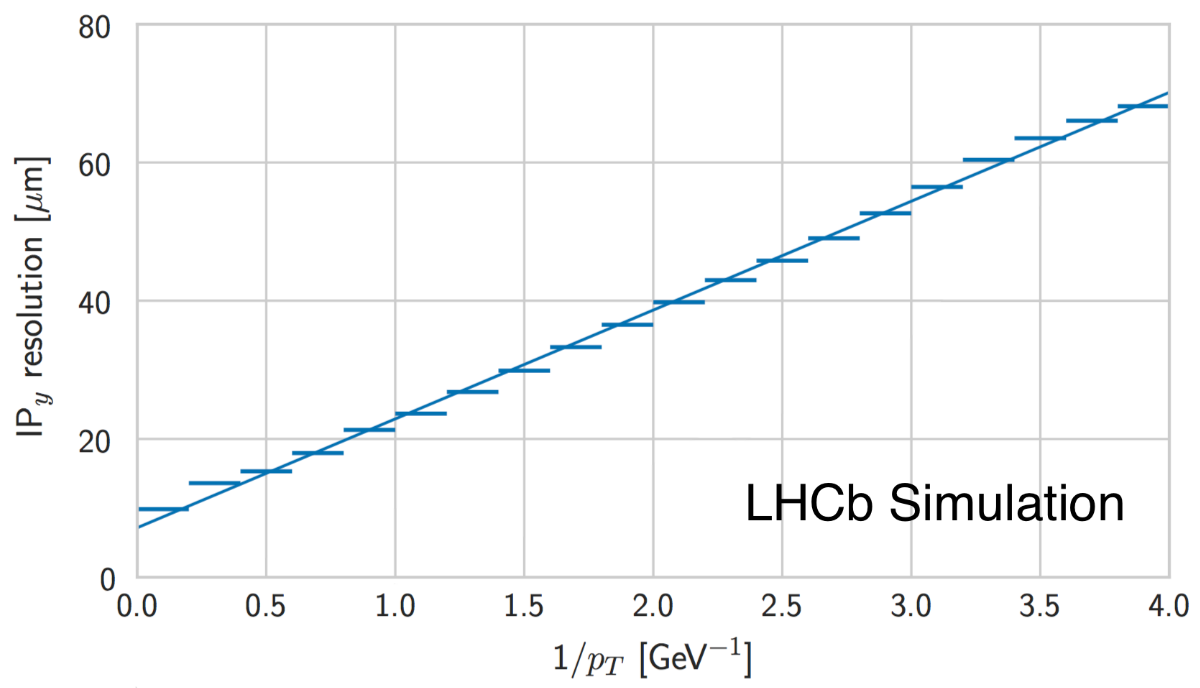
PV resolution

- Use full simulation and reconstruction to examine the PV resolution
  - 15.5μm in x/y
  - 92μm in z



IP resolution

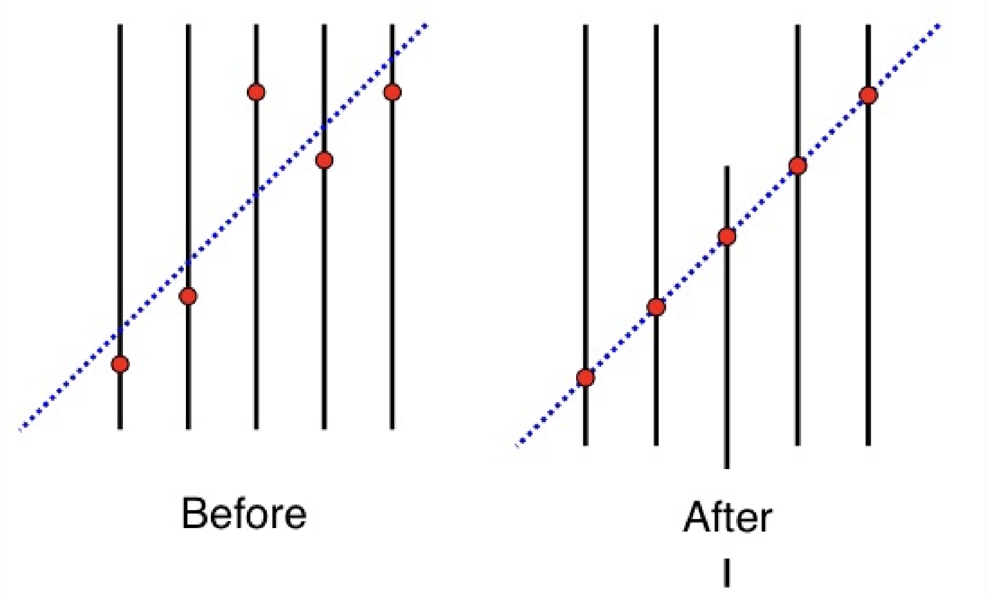
- Also use full simulation and reconstruction to examine the IP resolution
  - 16.1μm in the best case (high momentum tracks - currently 15μm)
  - Degrades to ~70μm for 300 MeV tracks (currently ~100μm)

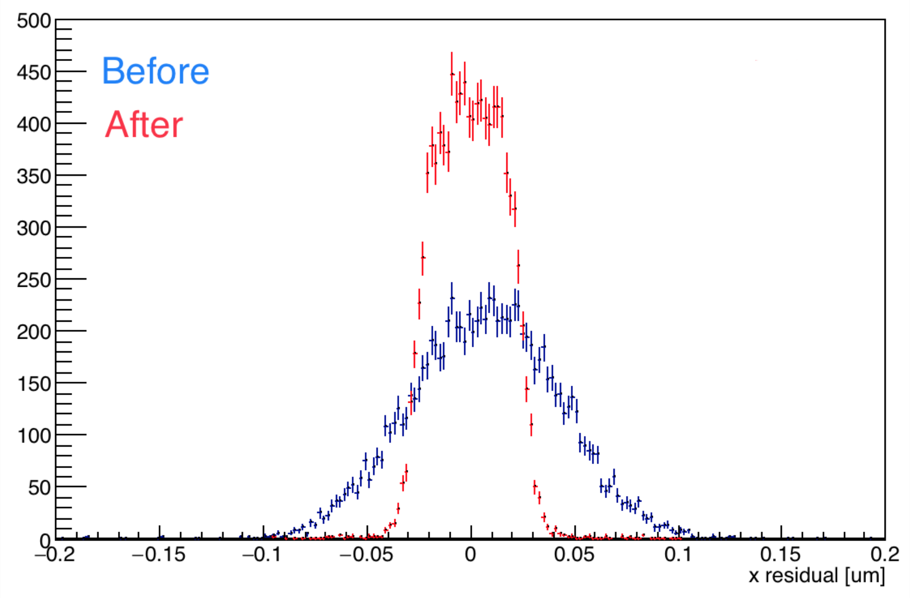


Alignment

Why do we need alignment?

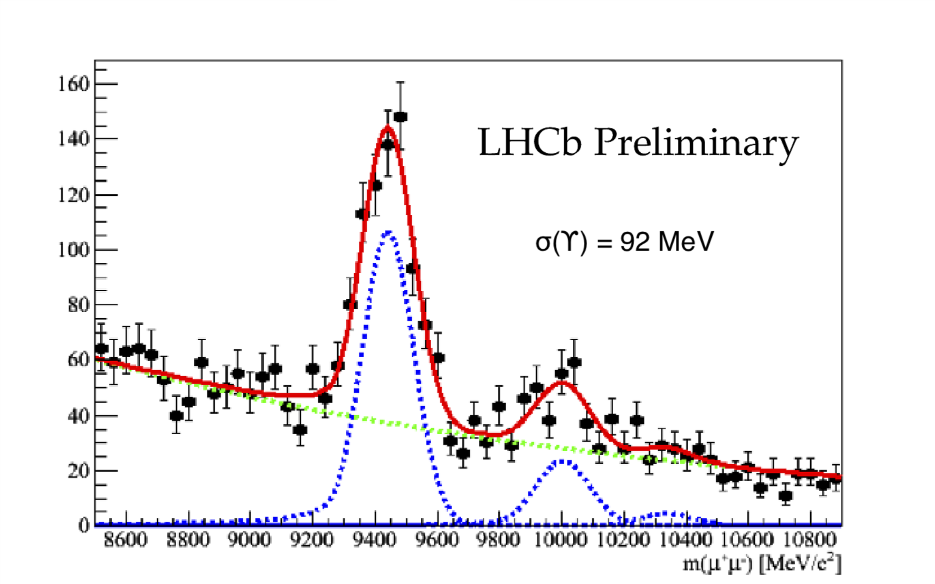
- The Velo can measure positions more precisely than it can be built
  - This is exaggerated by the Velo moving at the beginning of each fill
- Survey measurements are better, but still not good enough!
- Must use a track based alignment procedure:
  - Examine the residual between hits and tracks
  - Calculate deltas for each sensor to correct it's position

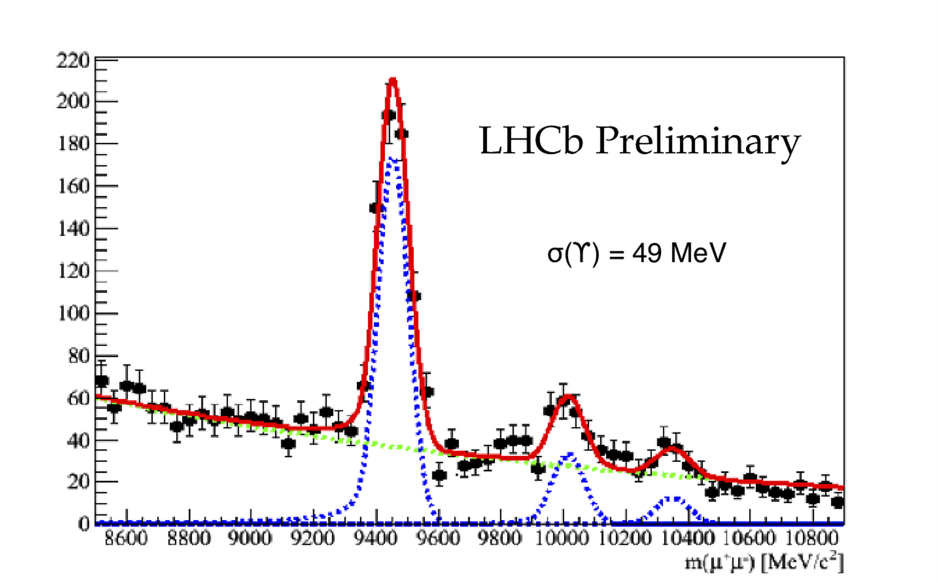




How important is this

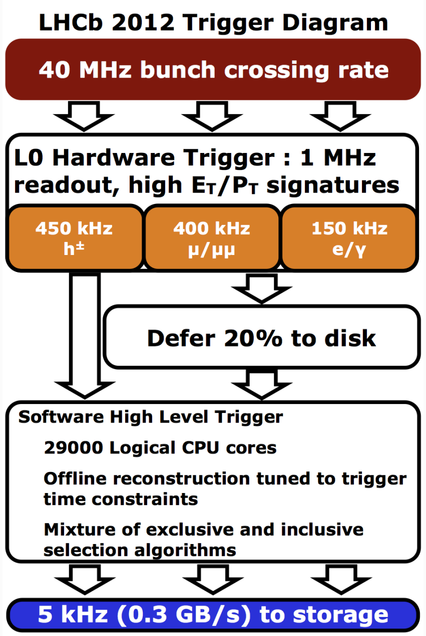
- When LHCb first started taking data a survey based alignment was used
- Later a track based alignment provided significantly better resolution
- These plots contain the same data, reconstructed using different alignments:

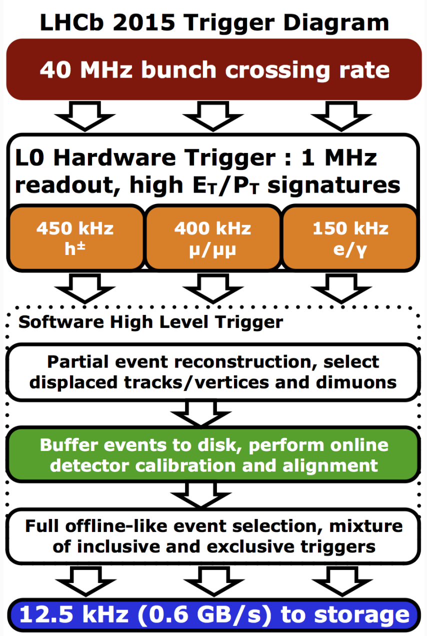


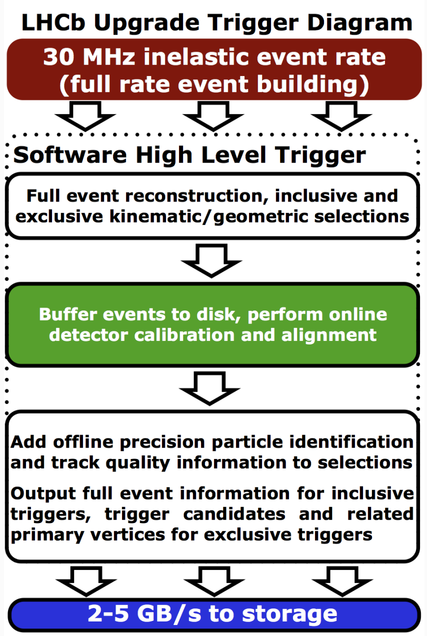


Online alignment

- Significant improvement in efficiency is made by removing the L0 trigger
- However this, combined with the increased luminosity, causes problems:
  - The rate of interesting events exceeds the available output bandwidth
  - Already showing in Run 2 that storing only higher level objects is helpful
- This model means that misalignment must be corrected for online



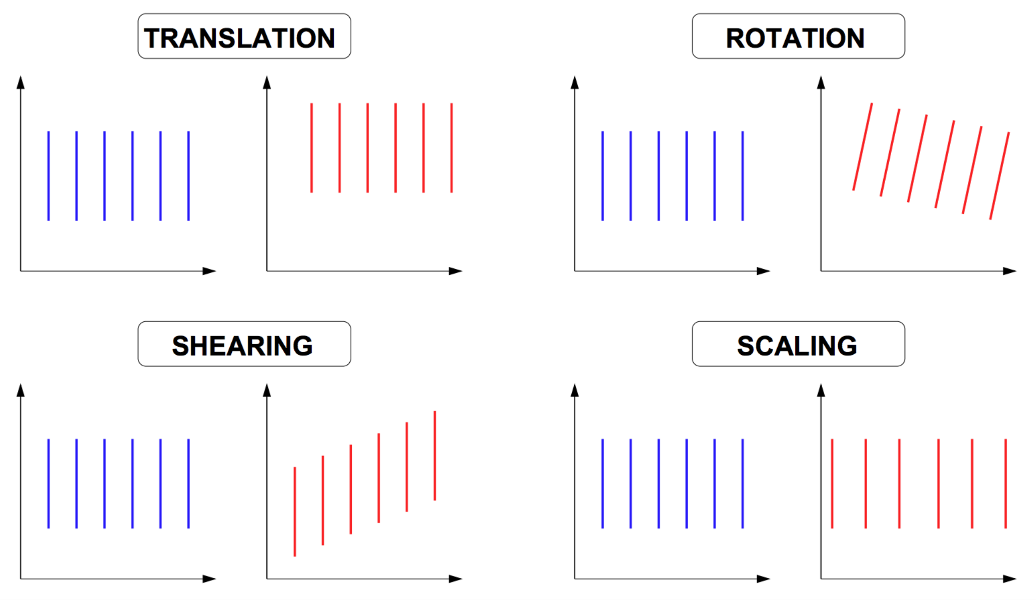




10.1088/1742-6596/664/8/082010

Not all misalignments are the same

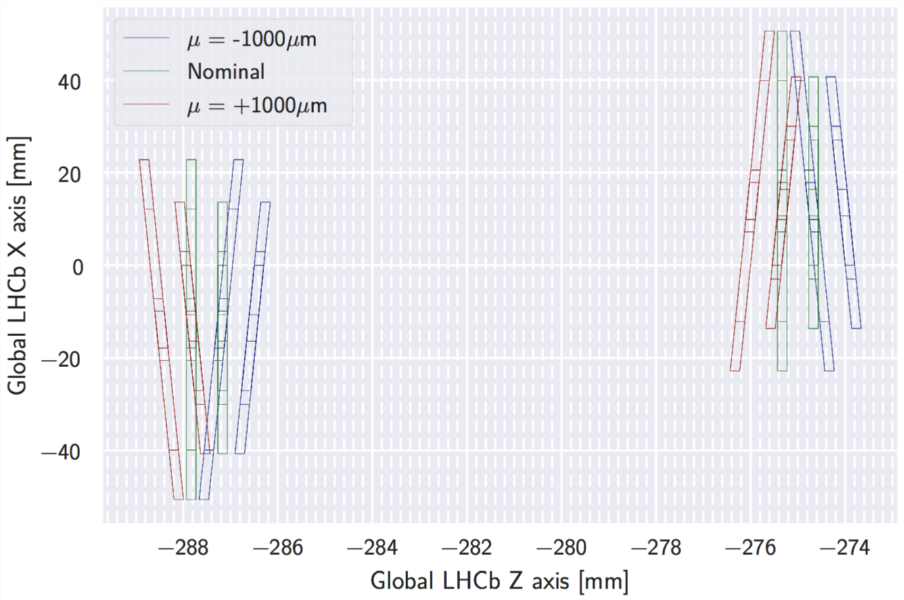
- Some forms of misalignment are difficult and/or impossible to correct for
  - Known as “weak modes”
- Known to be the dominant systematic for some lifetime-like measurements
- For the Velo geometry the weak modes are:



10.1016/j.nima.2008.07.153

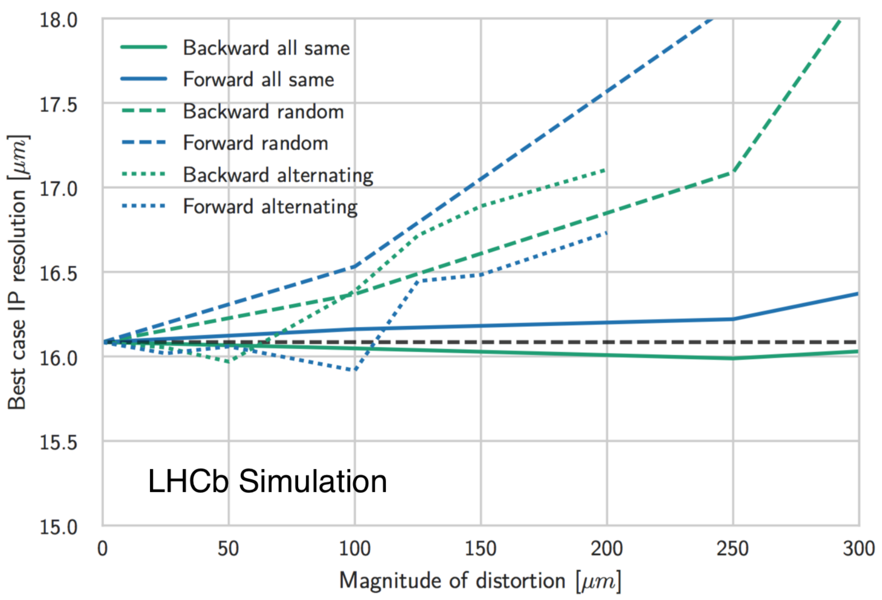
Misalignment studies

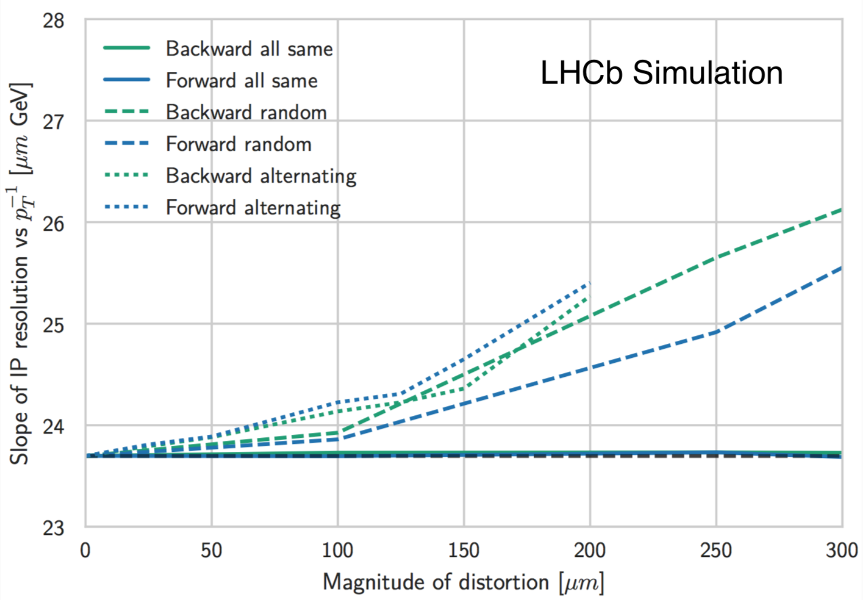
- Studies have been performed using the full LHCb simulation
  - Using input from lab measurements of prototype modules
- Uncorrected misalignment along beam axis (z) is the most concerning
  - Could easily occur when cooled to the operating temperature of -30°C
  - Hardest to align using survey or track based methods
- Several different scenarios considered for the variation between modules



Effects on IP & PV resolution

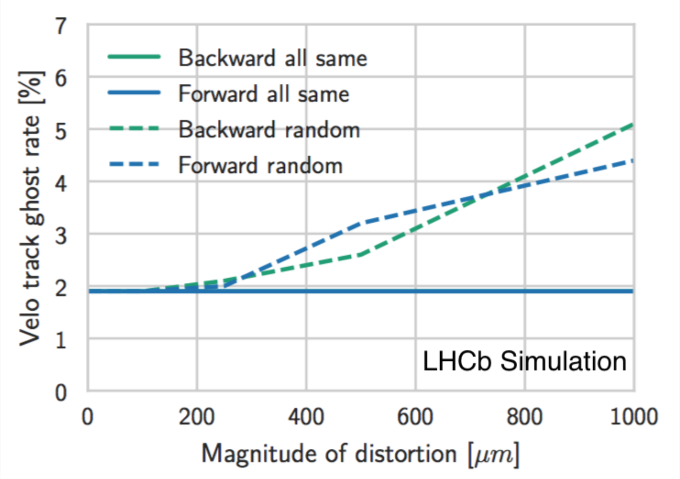
- IP and PV resolution is robust against misalignments in z
  - Expected as it would be easier to correct for if large effects were seen

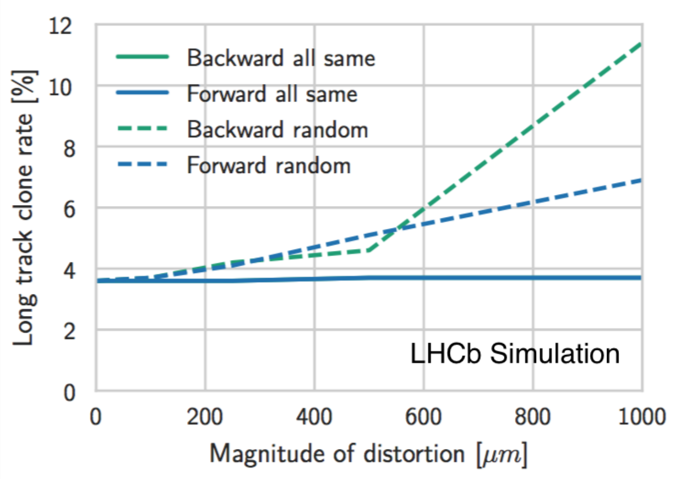


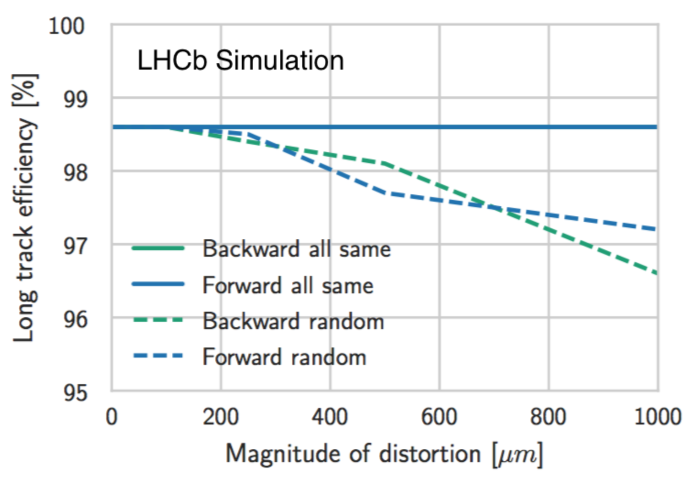


Effects on tracking performance

- Tracking performance is also robust against misalignments in z
  - **Clone rate:** Multiple reconstructed tracks from a single charged particle
  - **Ghost rate:** Reconstructed track which doesn't correspond to a real particle

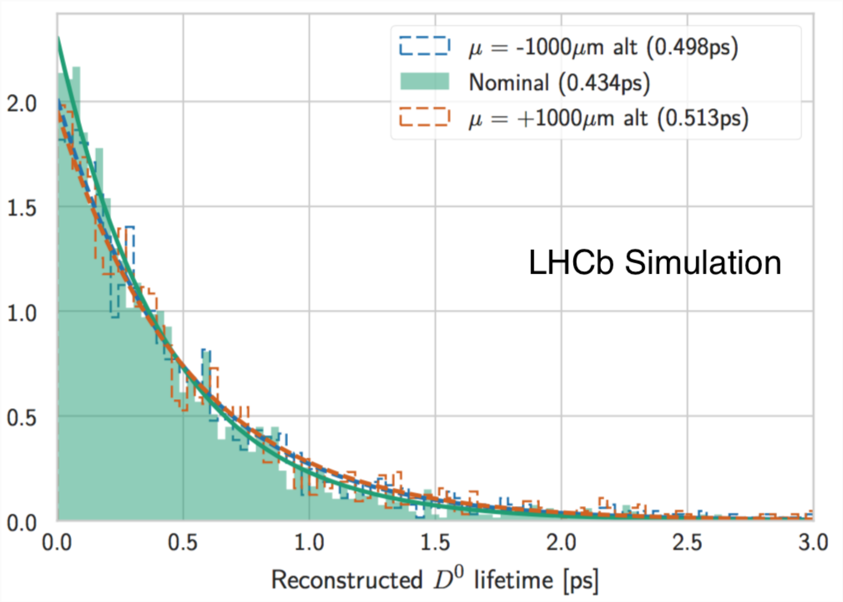


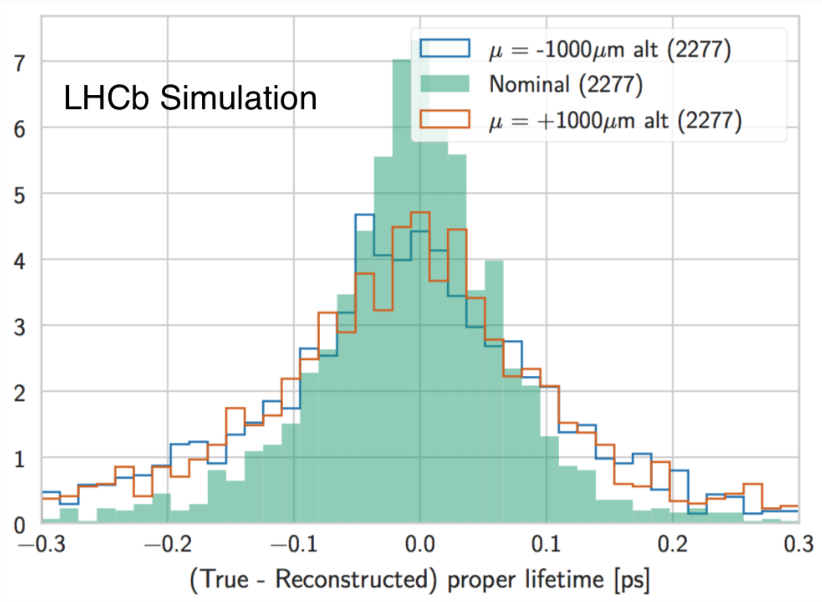




Higher level quantities

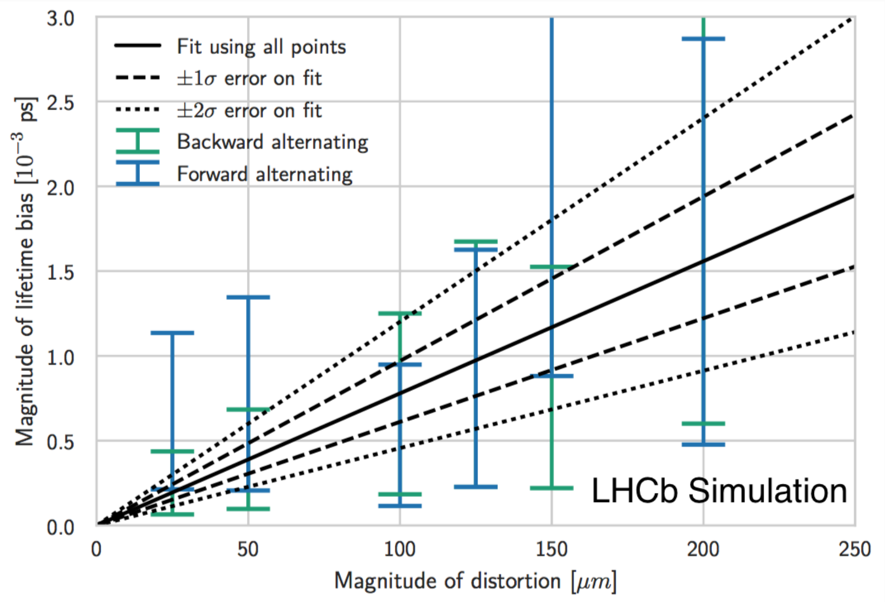
- Measure D^0 lifetime using $D^{*+} \to (D^0 \to K^+K^-)\,\pi^+$ decays
- Use full LHCb reconstruction
- Selected using MC truth information
- Same underlying particles used so statistic effects are correlated

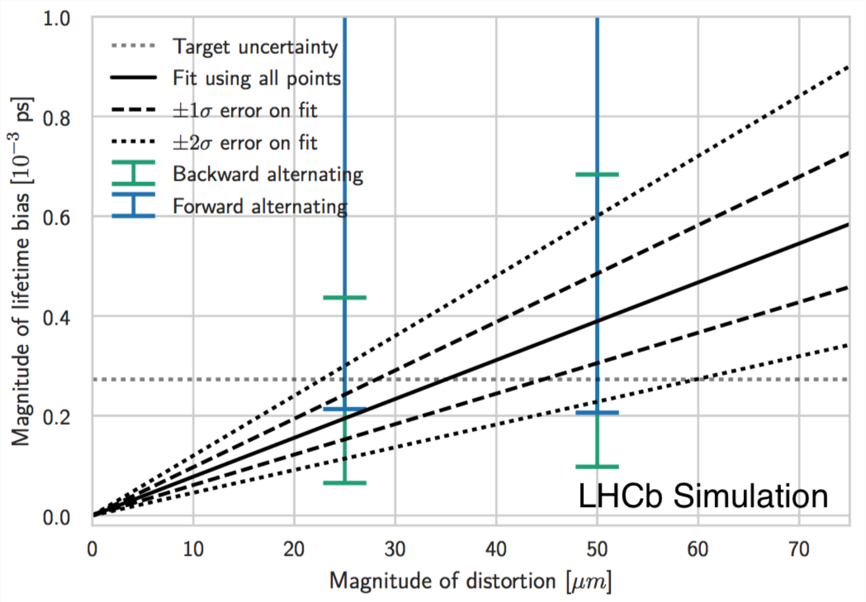




Effects on lifetimes

- Fit results to calculate the effect of different misalignments
- Set target uncertainty by extrapolating existing measurements
    - Aim for equal statistical and systematic uncertainty
- Results in a target module z uncertainty of ~35µm





Conclusions

- The upgraded LHCb Velo is expected to be the most precise LHC detector
  - Comparable performance with 5-10x higher luminosity
- Systematic uncertainties are going to become ever more important
  - Especially challenging as LHCb moves toward online only data processing


Any questions?