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Faraway tracking at LHCb

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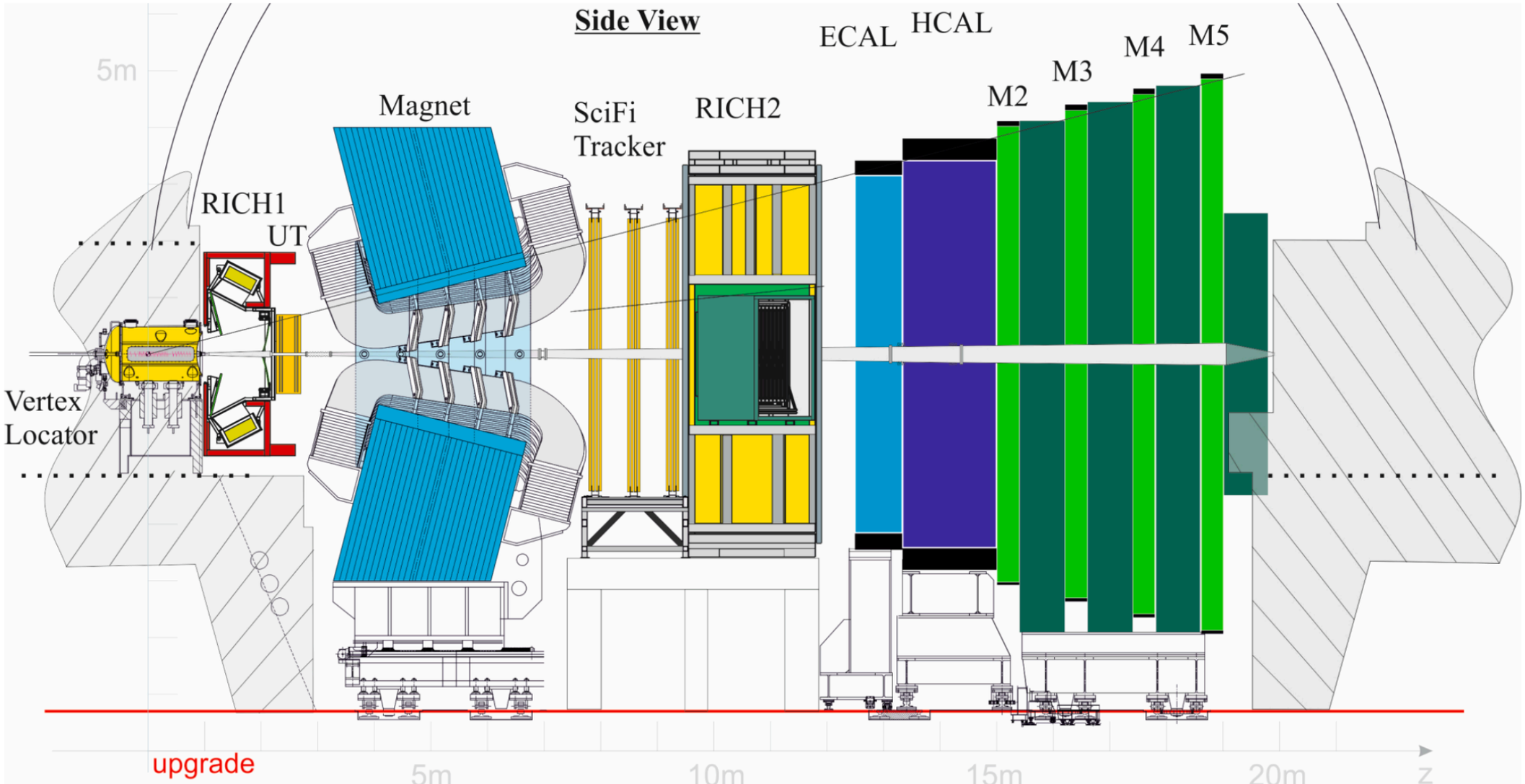
Overview

- Track types at LHCb experiment
- Why do we need Faraway reconstruction? (Motivation)
- LHCb Trigger, Magnet, and SciFi systems
- Faraway track momentum measurement
- Faraway track extrapolation, vertexing, and selection
- Track reconstruction prospects

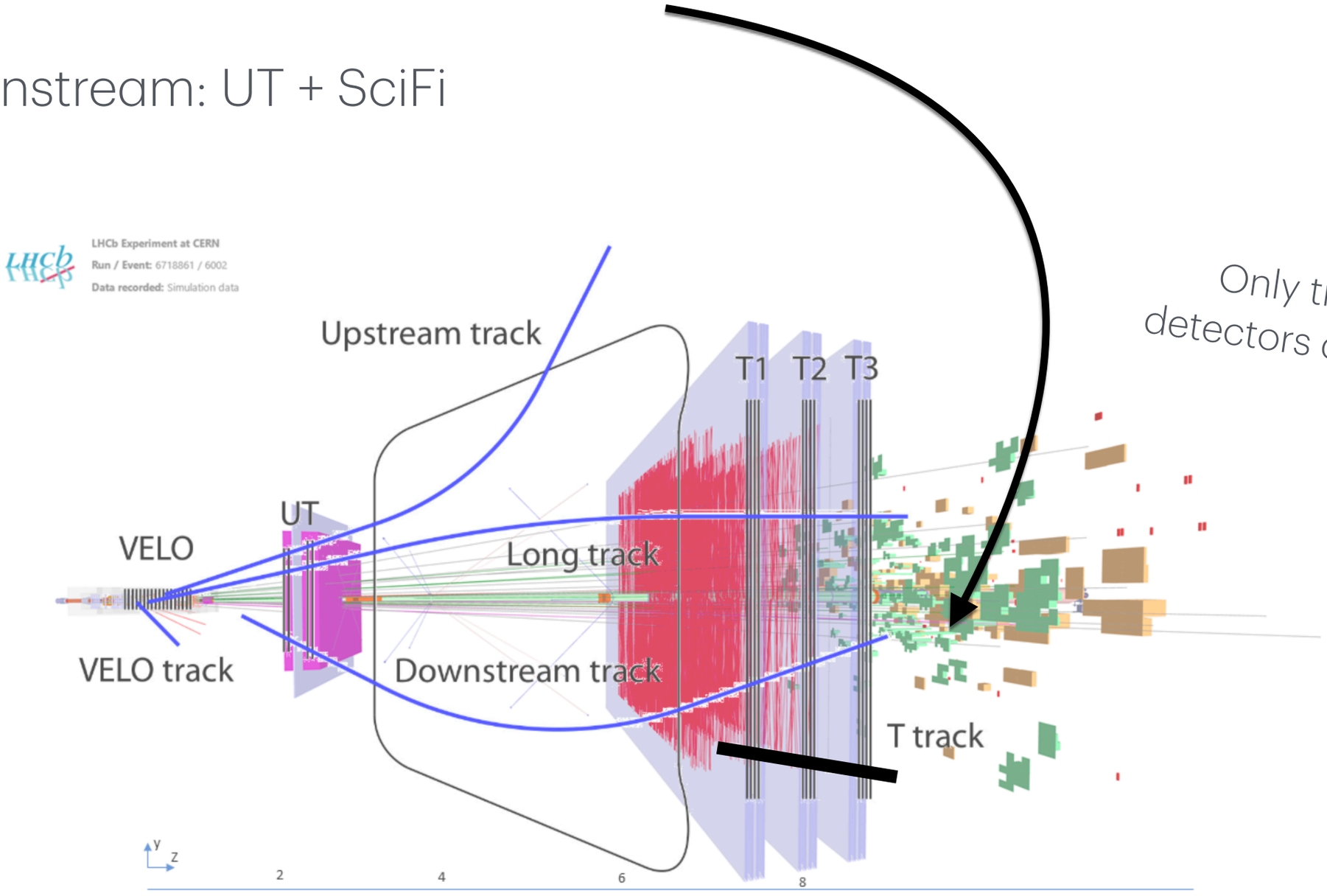
LHCb experiment

- Forward spectrometer ($2 < \eta < 5$)
- Excellent tracking and PID performance



Track types at LHCb

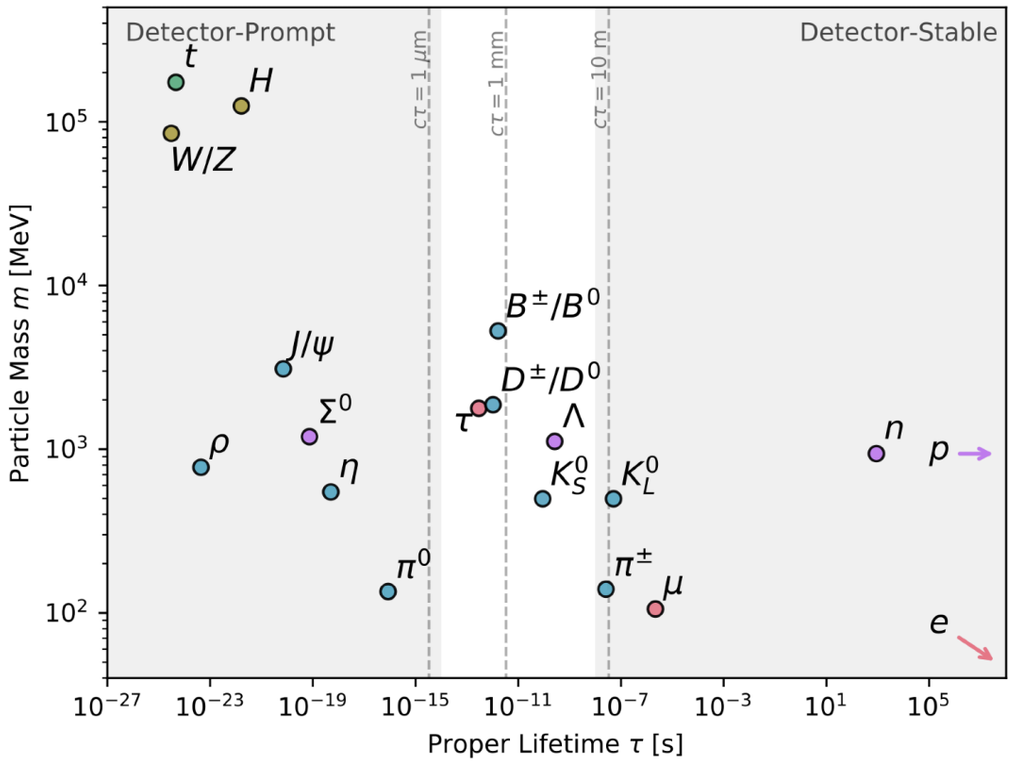
- Track type is determined by the detectors, particle flies through:
  - Faraway (viz. T-Track): SciFi only
  - Downstream: UT + SciFi

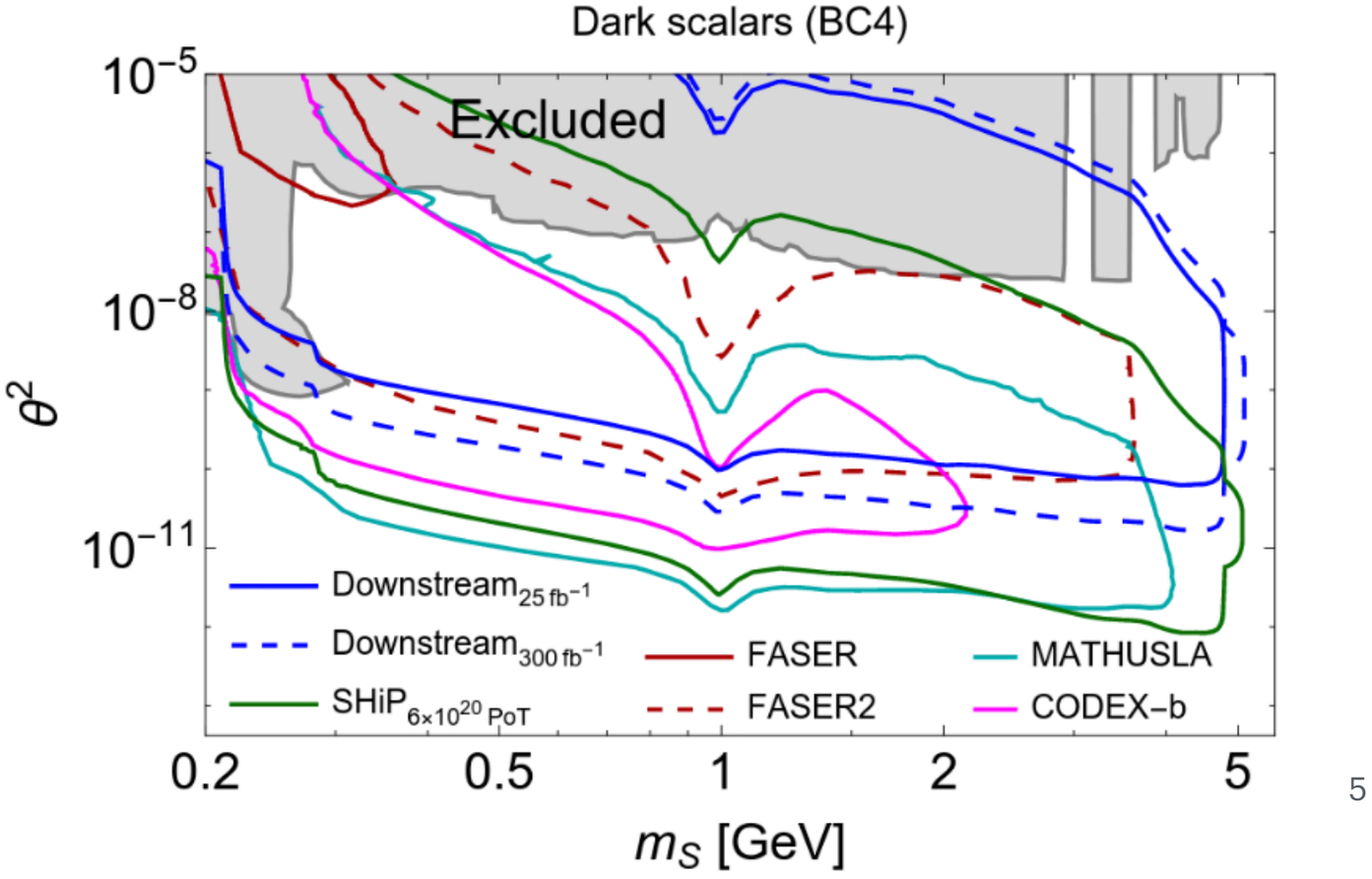


Only tracking detectors are shown!

Motivation

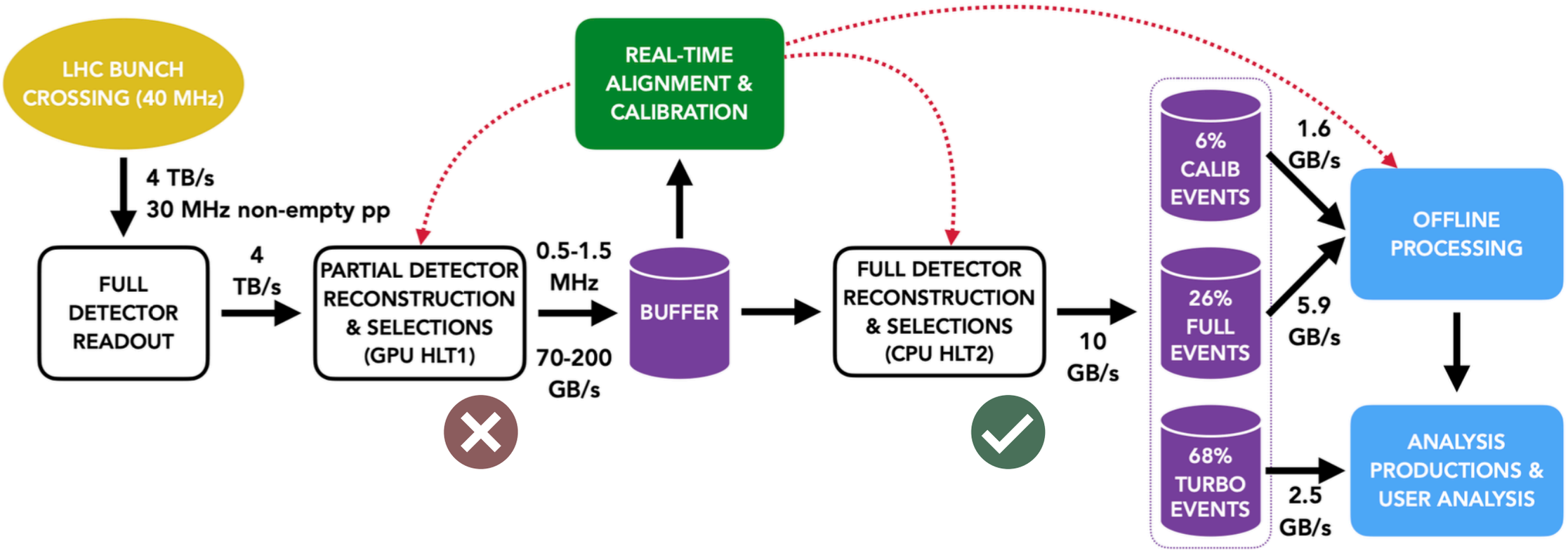
- Studies with Long-living particles (LLPs), K_s^0 and Λ^0
- Potential for EDM measurements
- Possibility to extend LHCb sensitivity region for BSM searches





HLT status

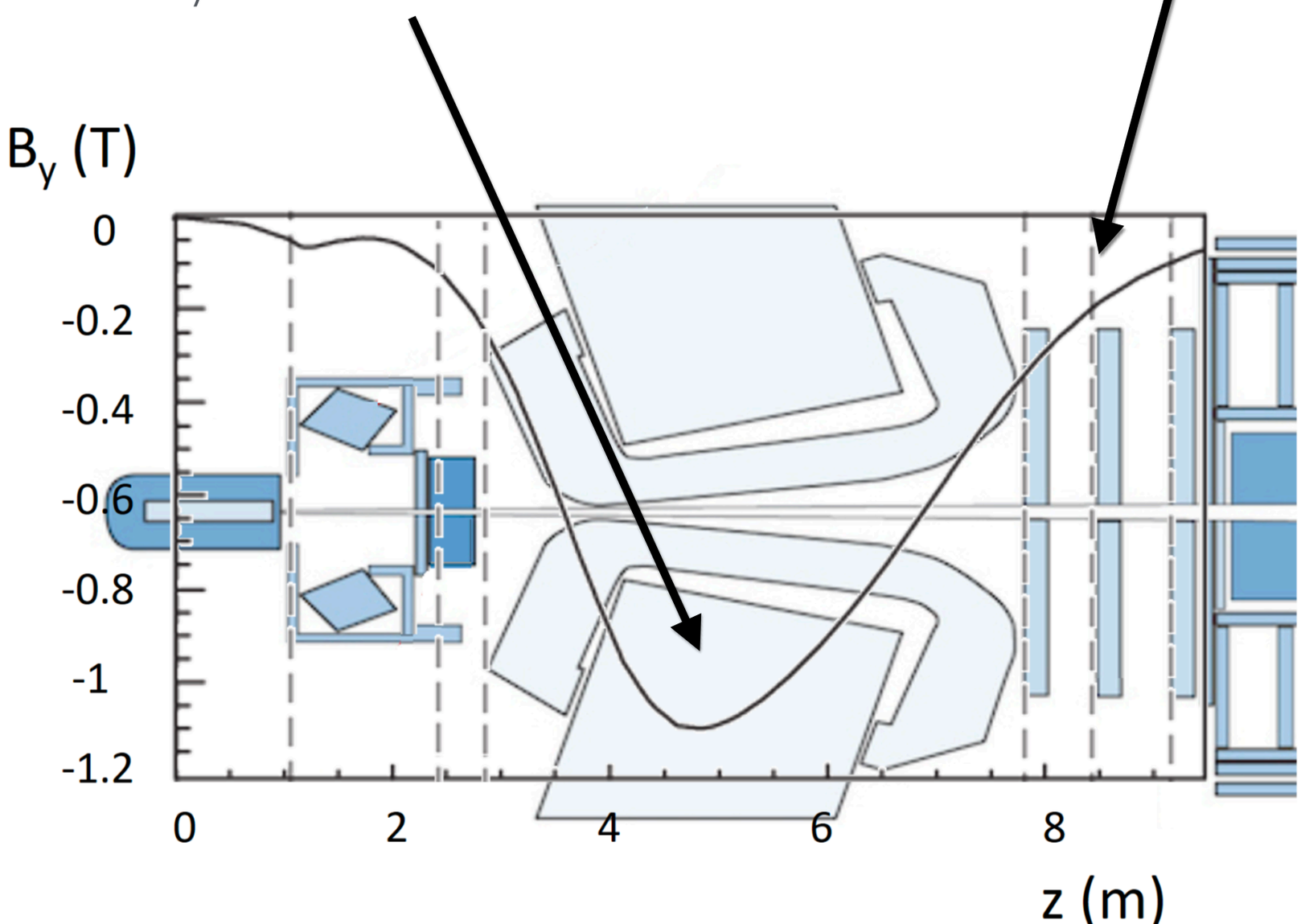
- Faraway selection already exists on the HLT2 level
- No reconstruction is available on HLT1, **which is the topic of this talk!**
- Very tight throughput requirement → need to use simple algorithms



LHCb magnet field

Contained in the extrapolation area of Faraway tracks

The residual magnetic field in the SciFi region allows approximate momentum measurement of Faraway tracks



HybridSeeding

- HybridSeeding is an algorithm for the reconstruction of SciFi track segments

- The track model takes into account the curvature due to the magnet:

$$x(z) = a_x + b_x\bar{z} + c_x\bar{z}^2(1 + \frac{\Delta B}{B}\bar{z})$$

- Is used as a starting point in Faraway reconstruction

- However, the reconstruction assumes that tracks originate from IP, which may affect Faraway reconstruction (studies are ongoing)

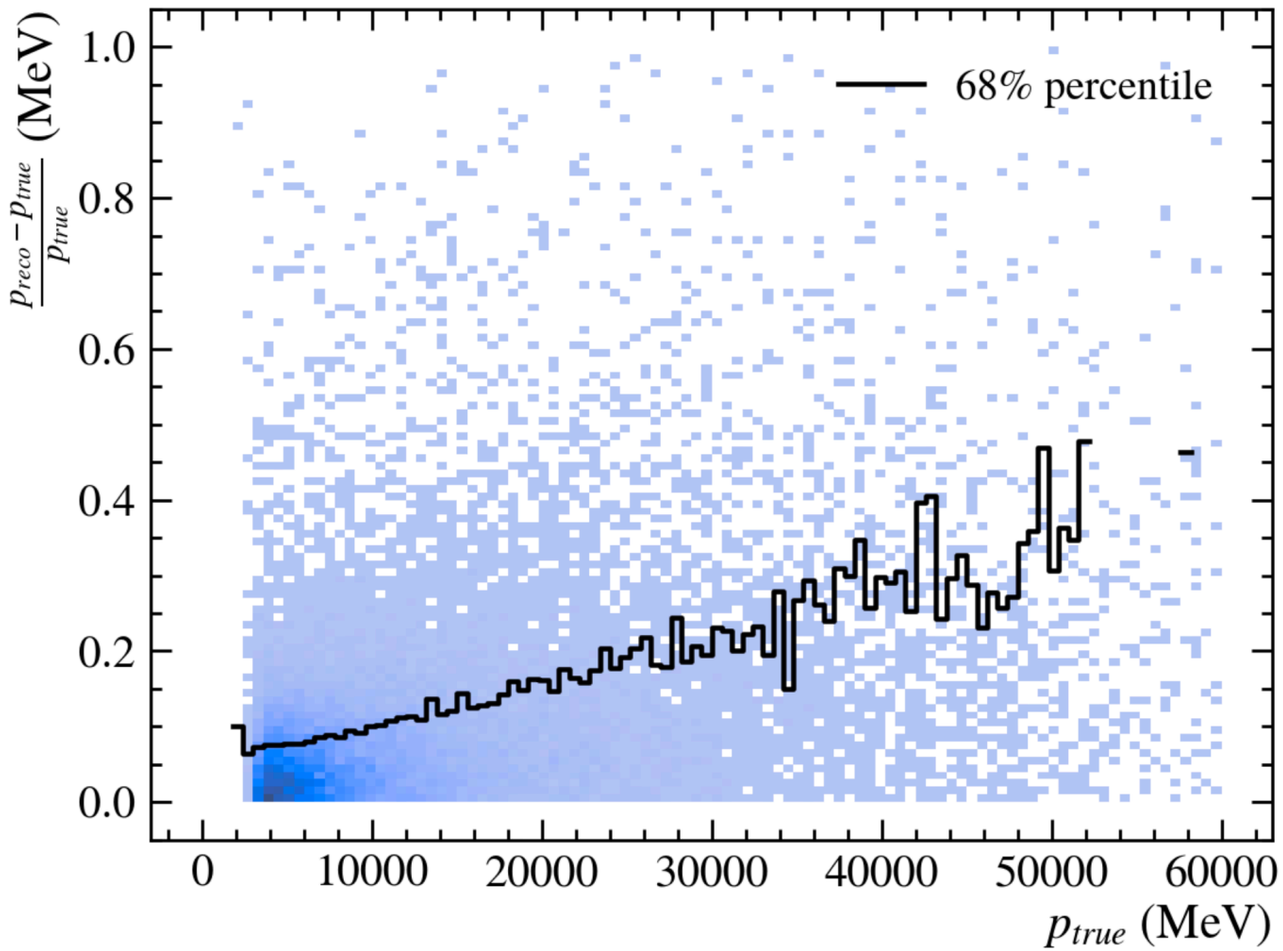
Momentum resolution

- Momentum resolution may be approximated using the radius of track curvature in $x - z$ a plane:

$$R(z) = \frac{(1 + x'(z)^2)^{\frac{3}{2}}}{|x''(z)|}$$

$$\frac{q}{p} = \frac{C}{R(\bar{z}_{qop})}$$

Choosen with MC in order to minimize error



Track extrapolation

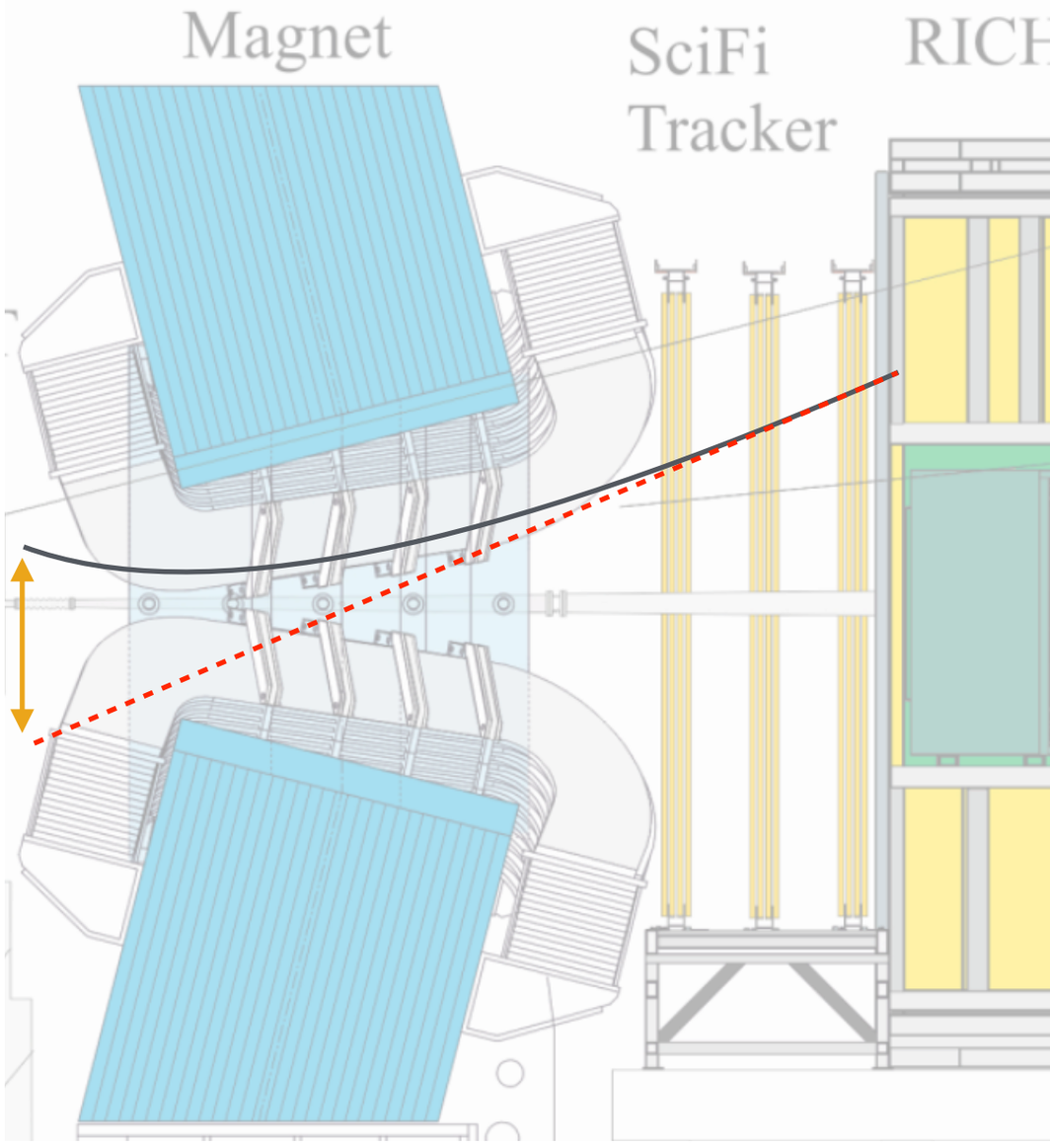
Attempt to make an extrapolation simple and fast!

- Track extrapolation through magnetic field may be written as:

$$x(z) = x_0 + t_x \bar{z} + \frac{q}{p} f(\bar{z}, \vec{s}_{scifi})$$

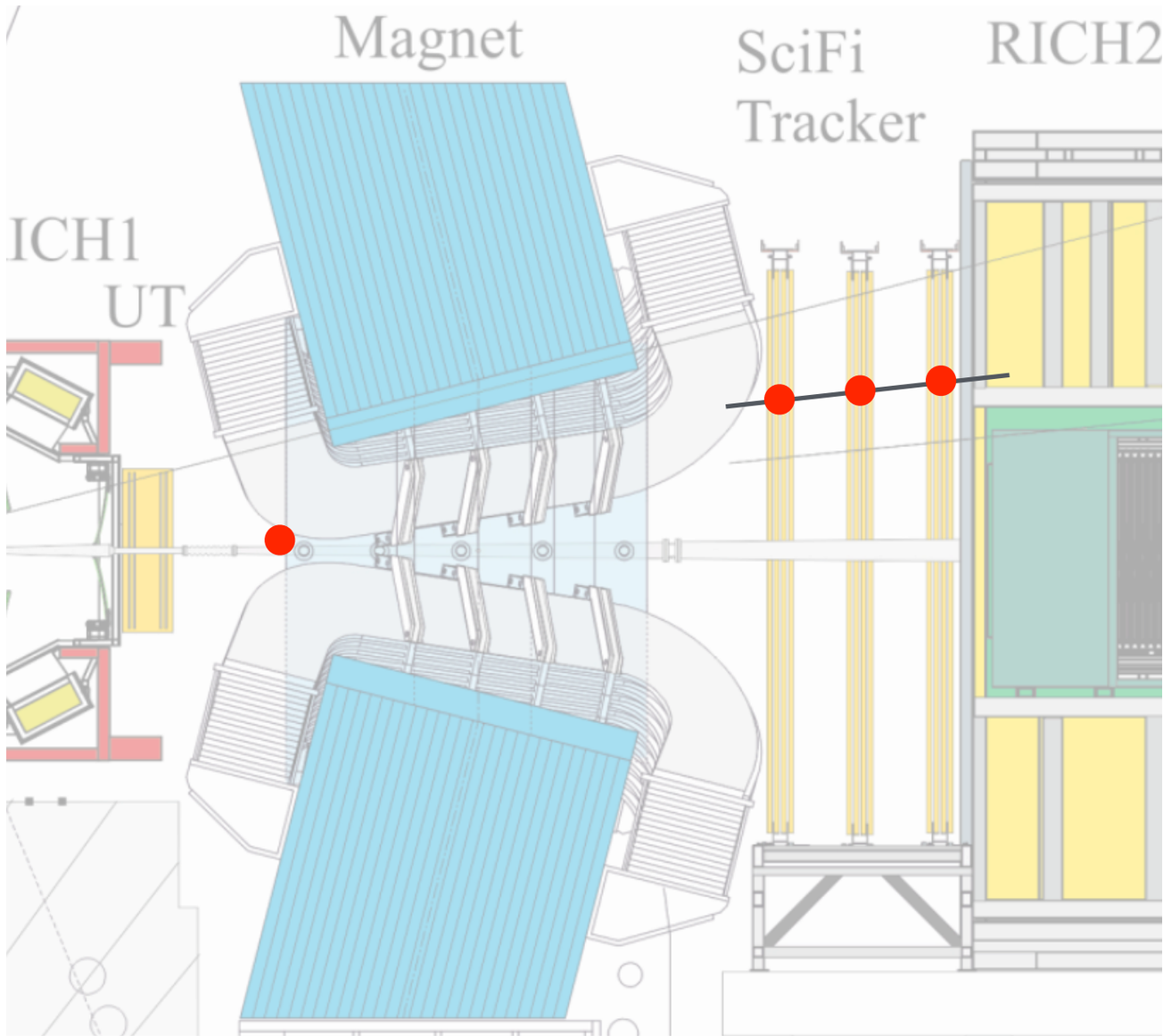
Trajectory function (Unknown)

- Trajectory function may be studied in two ways:
  - With standard LHCb MC
  - Particle gun (will be discussed later)



Standard LHCb MC

- Available true information:
  - Vertex: $\vec{r}_{ovtx}, \vec{p}_{mother}$
  - SciFi hits (approximate position)
- To get state at SciFi, one has to fit SciFi hits
  - HybridSeeding model can be used for this



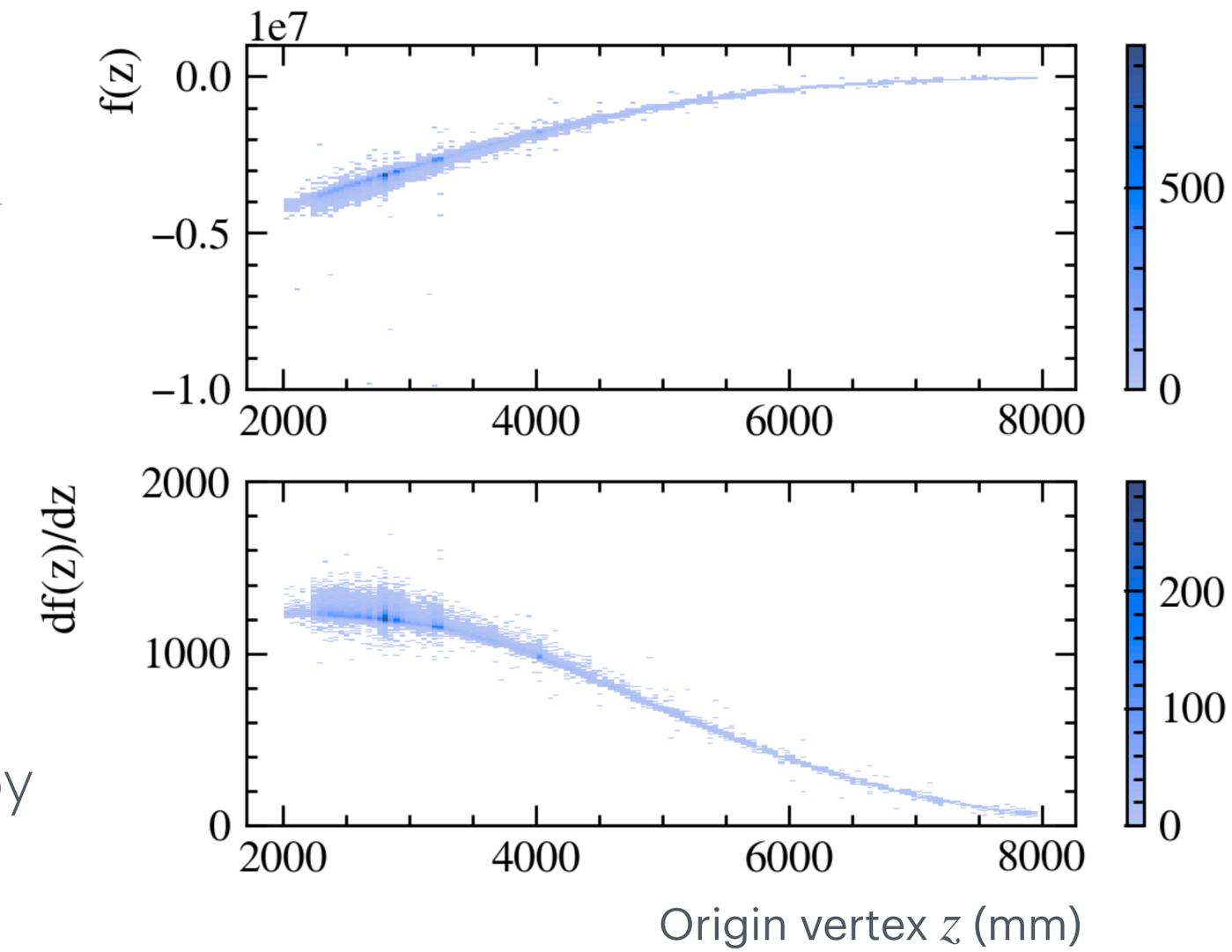
$f(z, \ldots)$ with standard LHCb MC

- Trajectory function and its derivate may be found using states ar vertex and SciFi

$$f(\bar{z}_{ovtx}, \vec{s}_{scifi}) = (x^{ovtx} - x^{sf} - t_x^{sf}\bar{z})\left(\frac{q}{p}\right)^{-1}$$

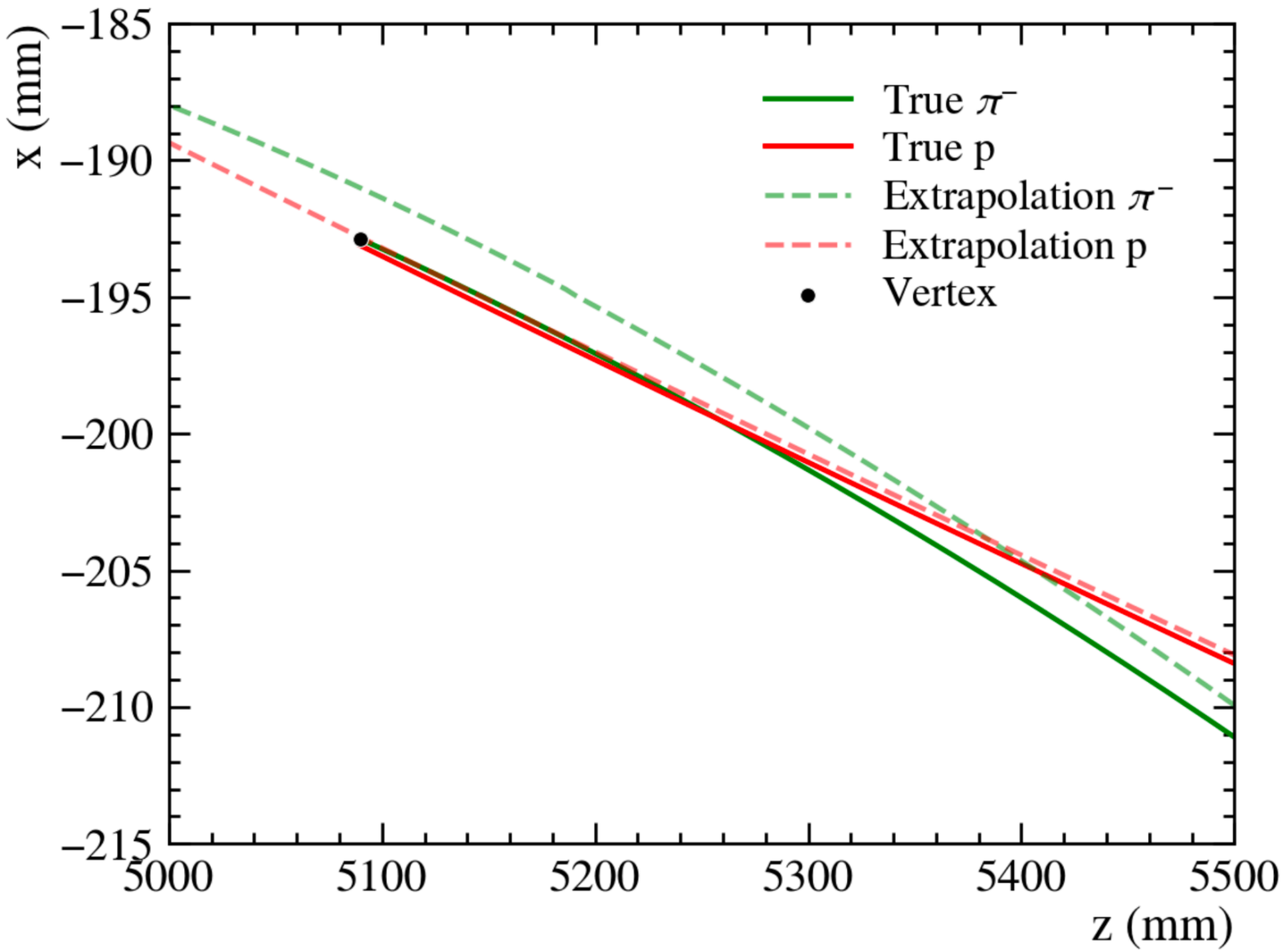
$$\left.\frac{\partial f(\bar{z}, \vec{s}_{scifi})}{\partial \bar{z}}\right|_{\bar{z}=\bar{z}_{ovtx}} = \left(t_x^{ovtx} - t_x^{sf}\right)\left(\frac{q}{p}\right)^{-1}$$

- But this gives only one point per track, which is affected by material interactions, hit position approximation



$f(z, \ldots)$ with standard LHCb MC

- The standard MC approach doesn't take into account magnet inhomogeneity along x and y axes, which leads to extrapolation errors

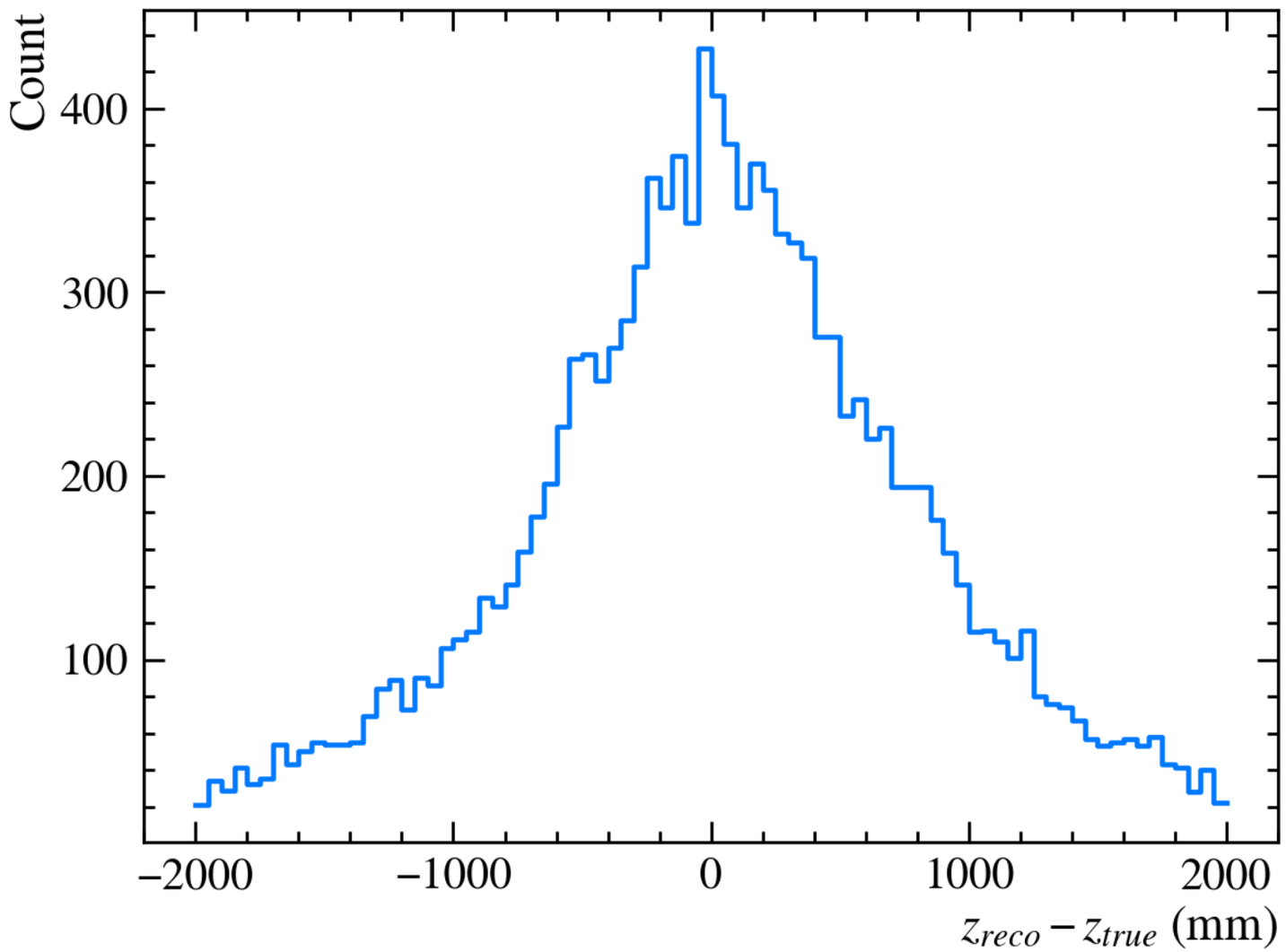


Vertex reconstruction

- Vertex position is found by numerical minimization of the distance of the closest approach between two tracks (DOCA):

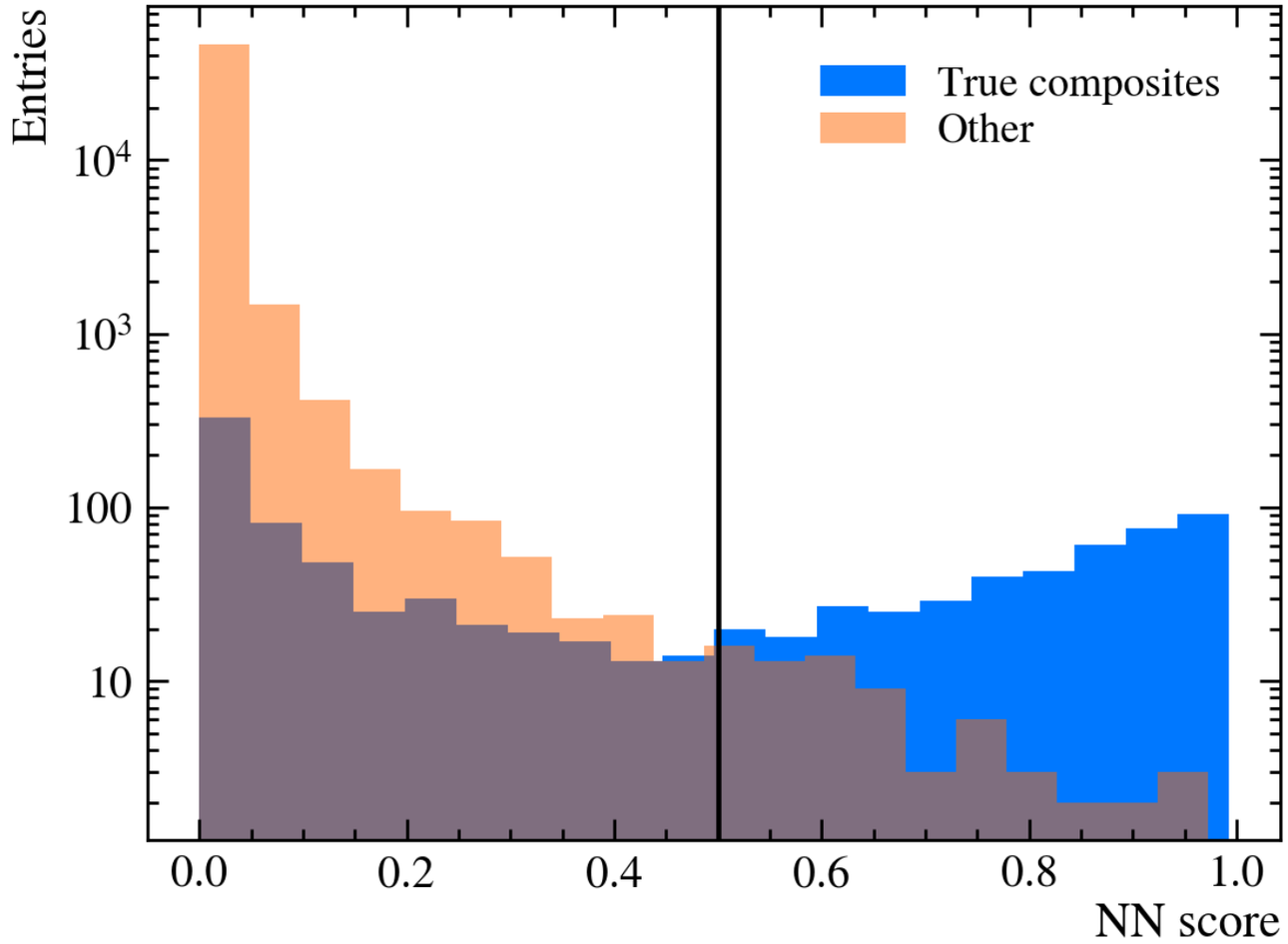
$$D(z) = (x_A(z) - x_B(z))^2 + (y_A(z) - y_B(z))^2$$

- Resolution ≈ 1 m leads to significant errors in $\vec{p}$ direction at vertex



Composite particle selection

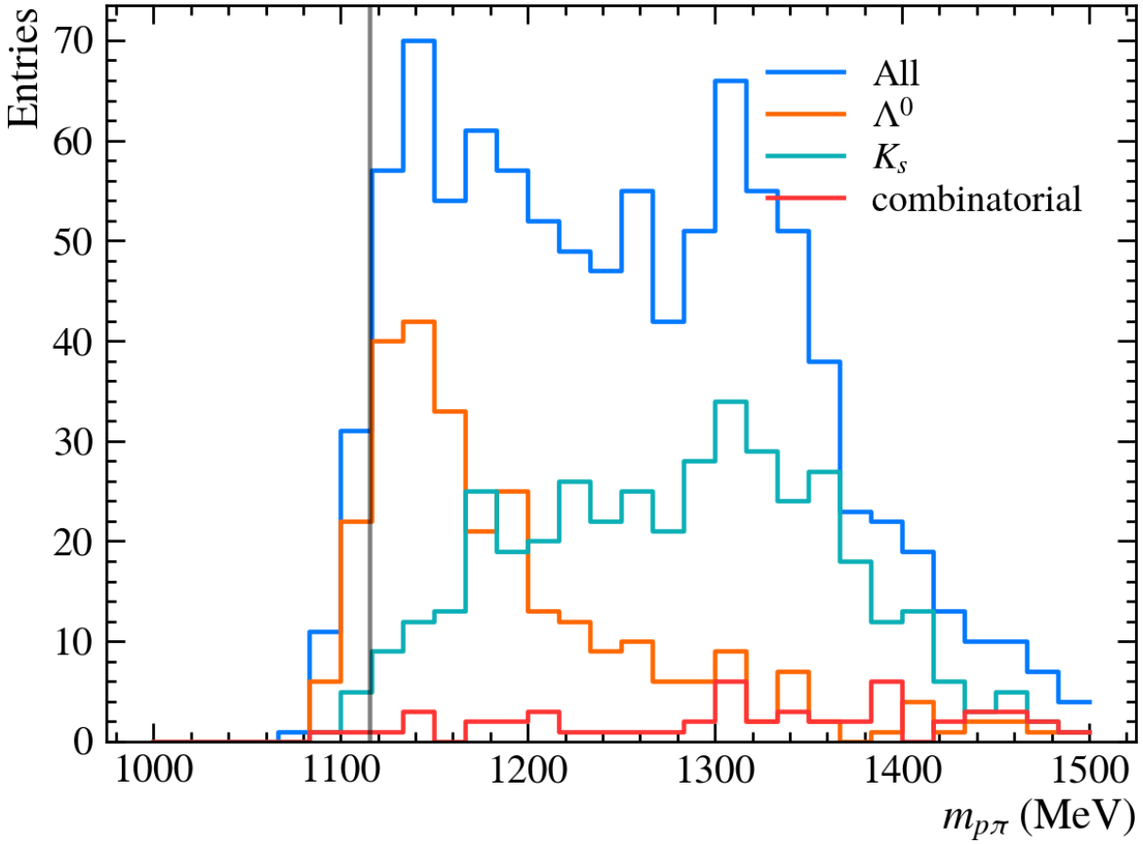
- Faraway composite particle selection is done in two steps:
  - Ghost killer with single-layer NN (common)
  - Rectangular cuts to select signal candidates

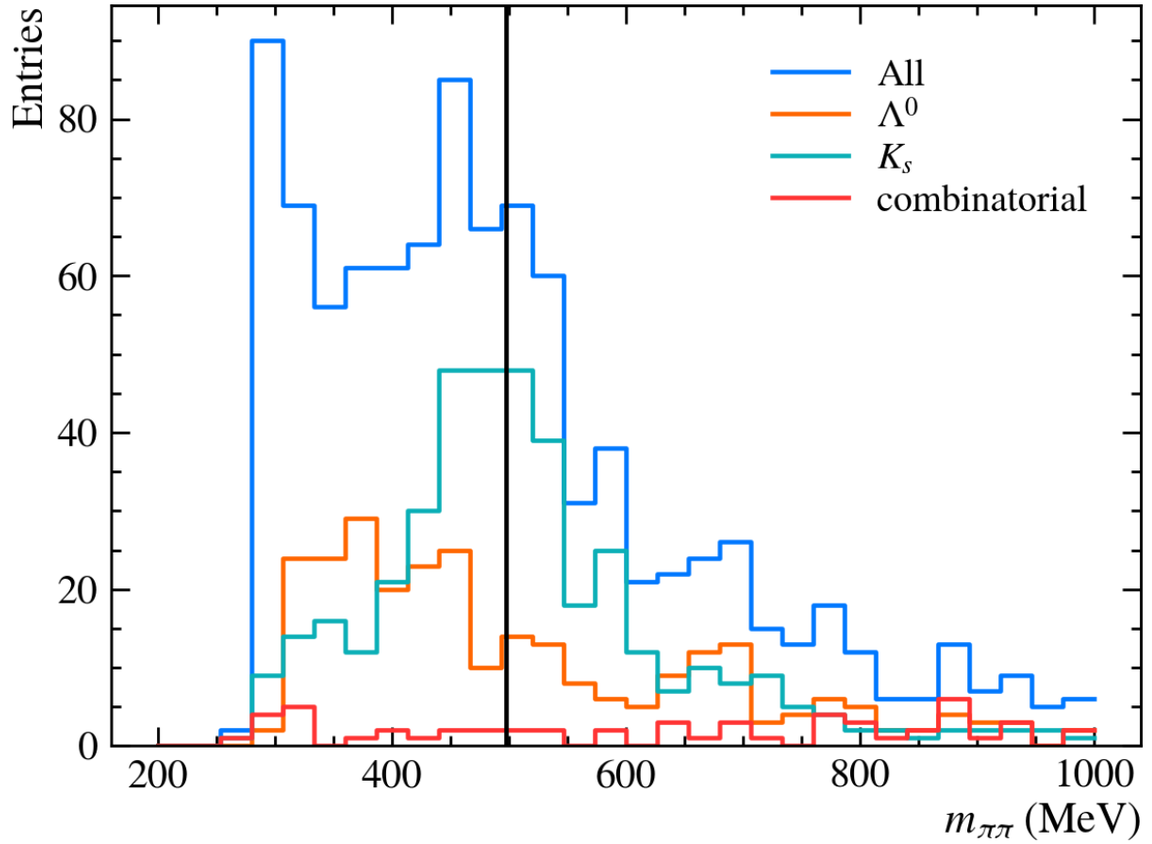


Fake track killer

- Most of the fake tracks ($\approx 99\,\%$) can be removed only if a preselection cut is applied $z_{ovtx} > 5000$ mm due to extrapolation errors

- Flat combinatorial background

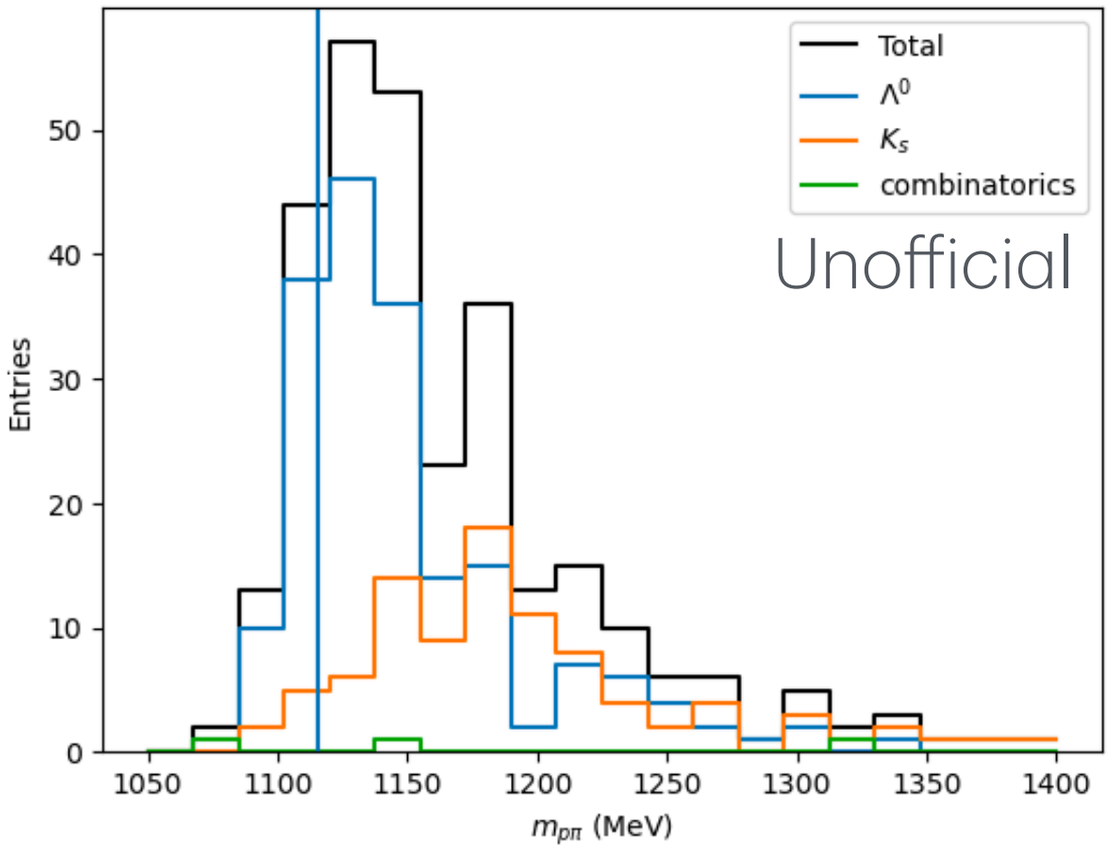




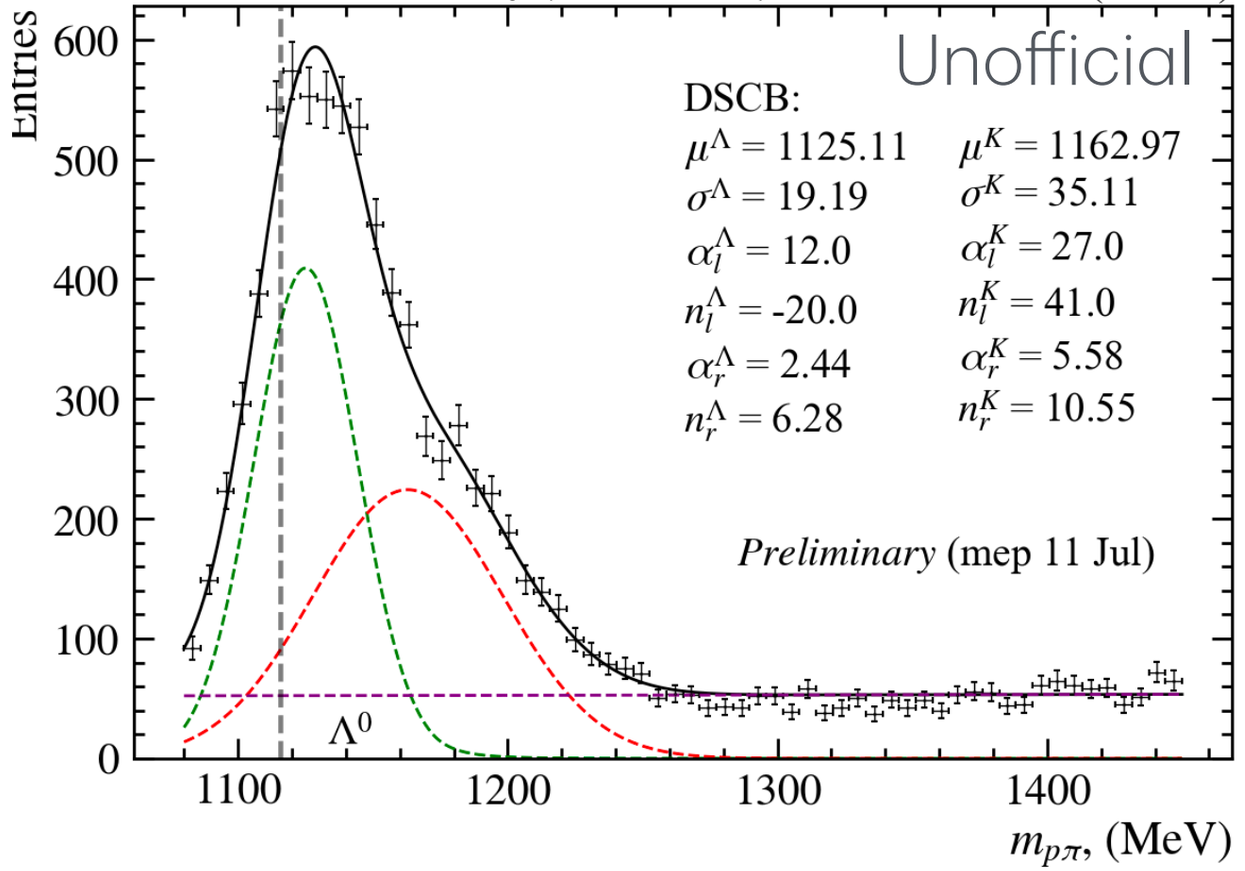
Selection

- Rectangular cuts only
- Two versions, for K_s^0 and Λ^0
- Bias in Λ^0 mass, big contamination from K_s^0

Minbias 2024 expected condition



July 2023 Data (mep dump)

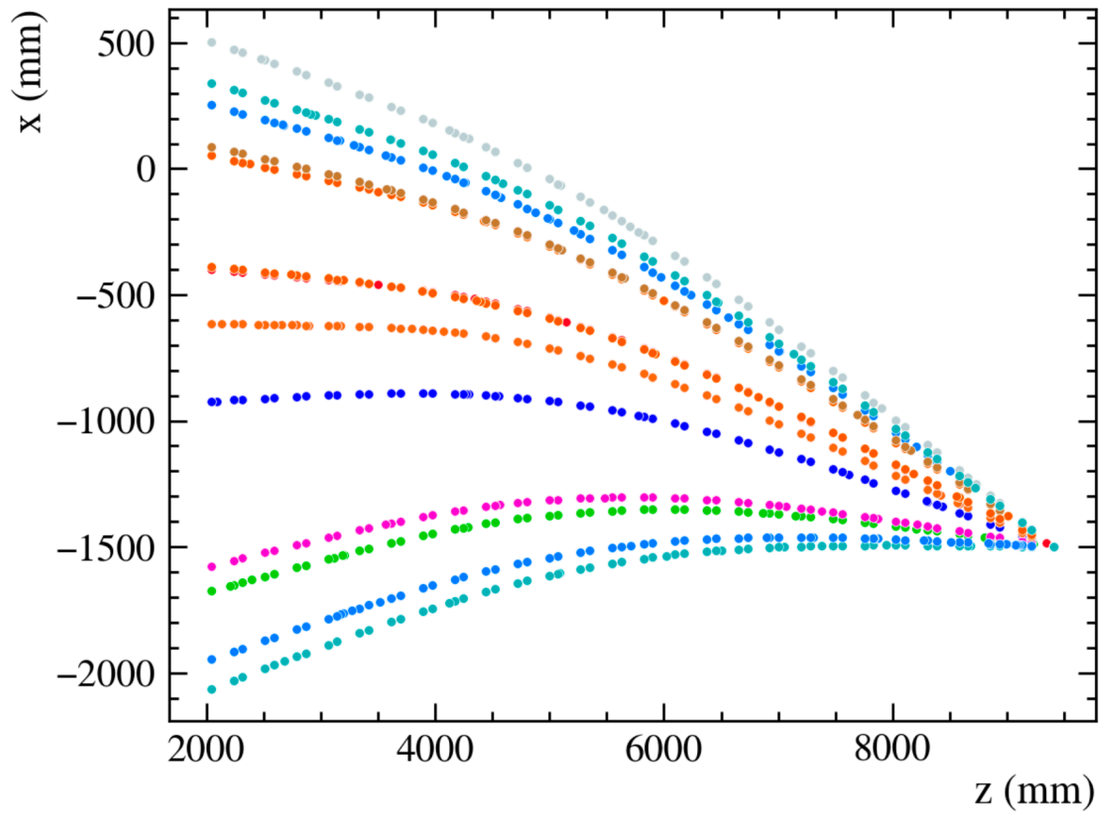


Can we do it better?

$f(z, \dots)$ with particle gun

Work in progress

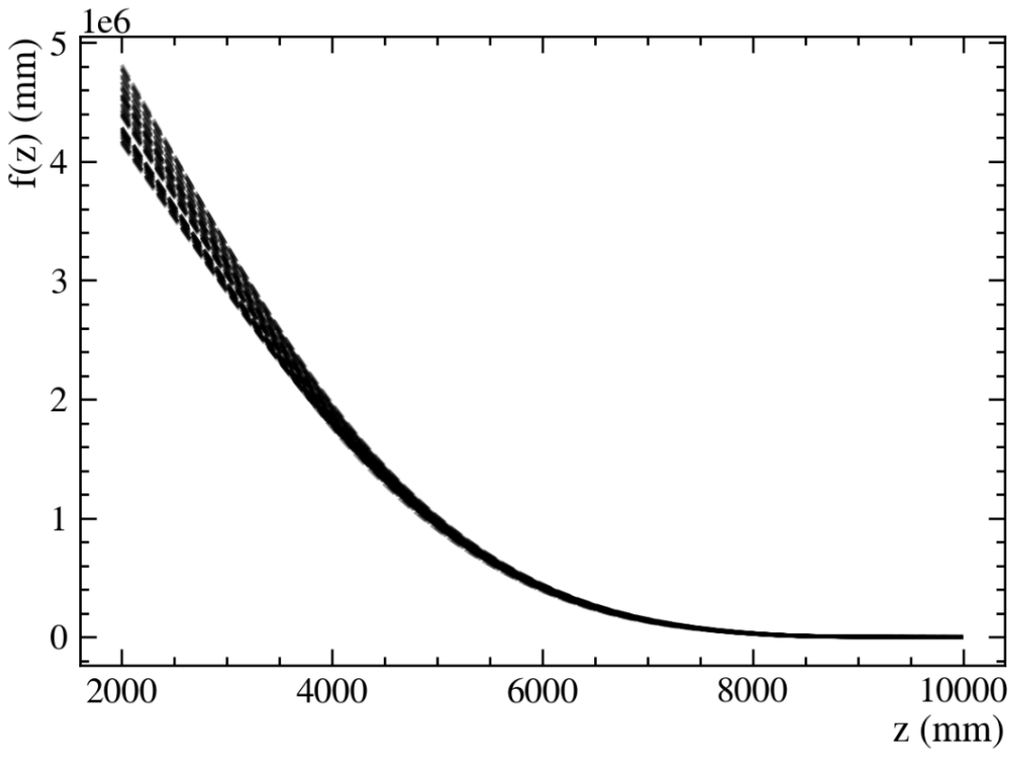
- Dedicated simulation with only SciFi and Magnet
- Particles ($\pi^{\pm}$) are shooted from SciFi plane in upstream directions
- Position and momentum vectors are stored every ≈ 100 mm in z axis
- Complete $f(z)$ and $\frac{\partial f(z, \dots)}{\partial \bar{z}}$ with each particle

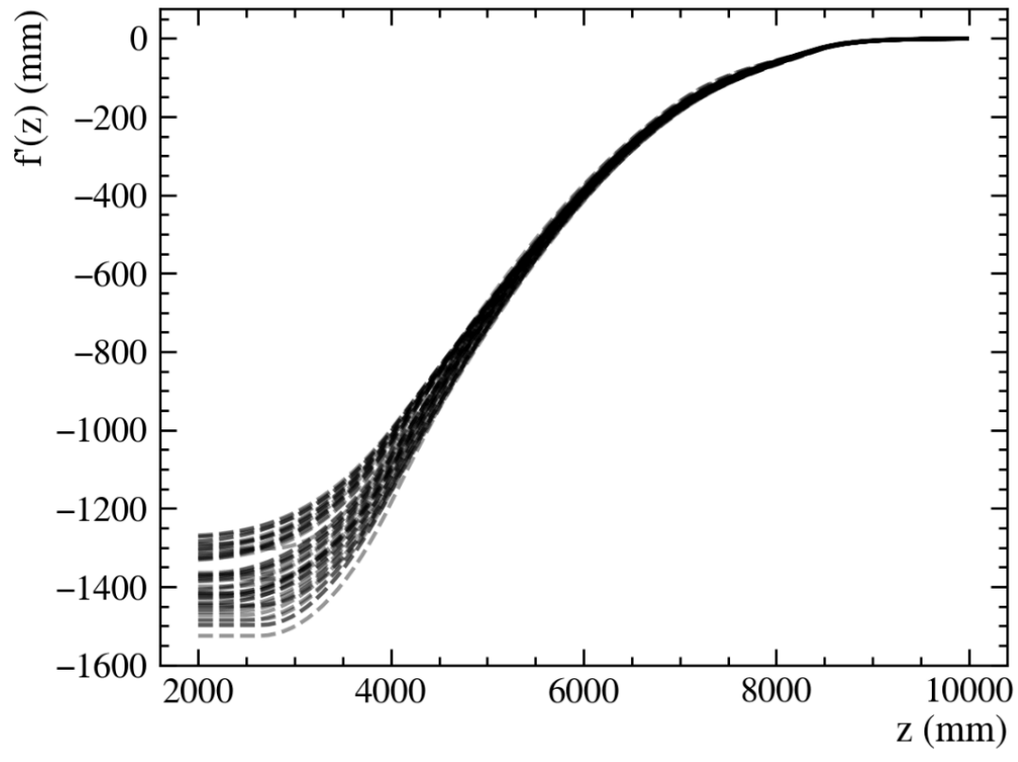


$f(z, \dots)$ with particle gun

Work in progress

- Precise measurements of particle trajectory
- Functions $f(z, \dots)$ and $\frac{\partial f(z, \dots)}{\partial \bar{z}}$ for different starting positions and $\vec{p}$:



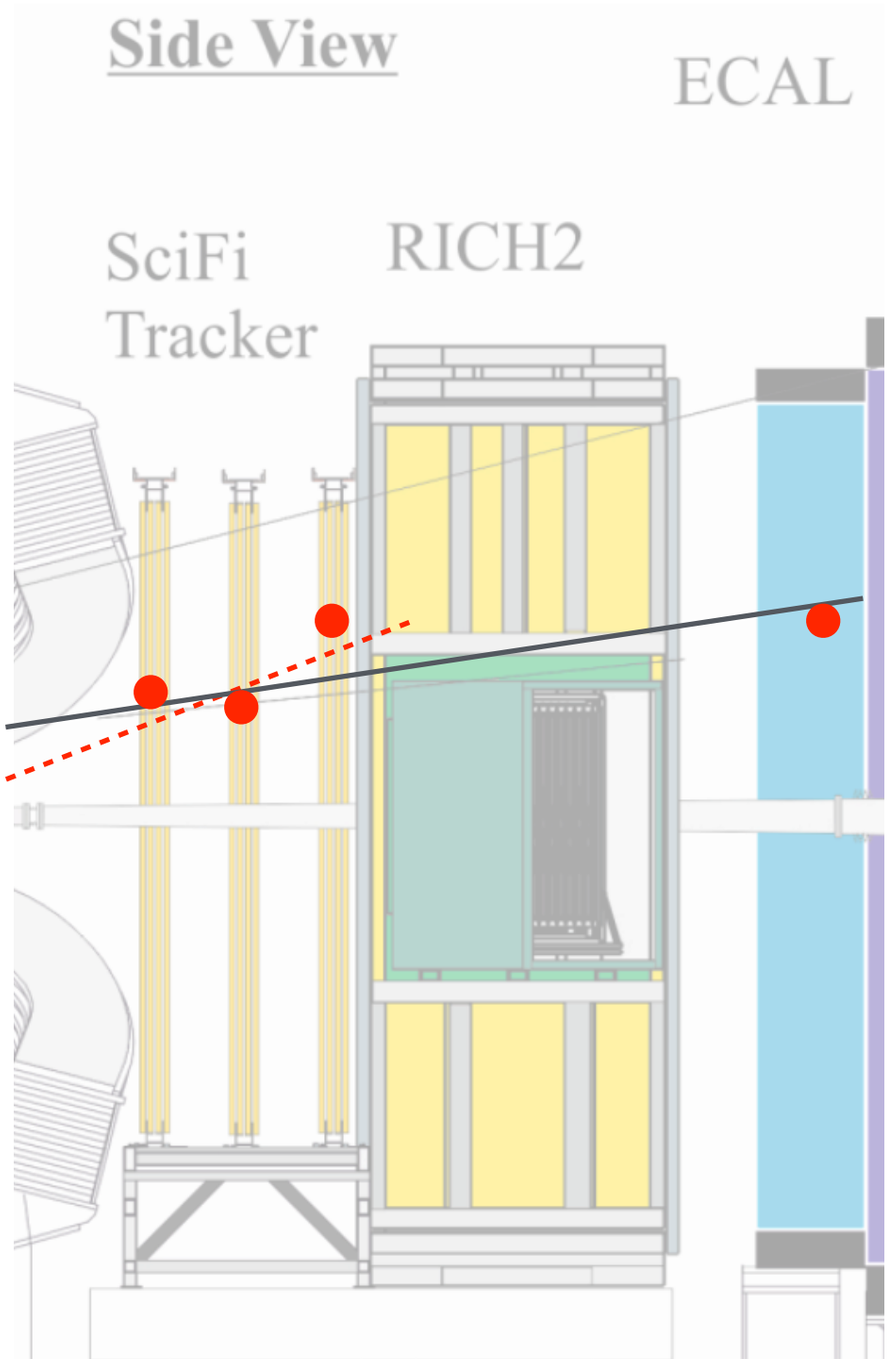


- Possibility to study the dependence of $f(z, \dots)$ on other variables

Improve SciFi y resolution

Work in progress

- SciFi y resolution doesn't allow vertex position estimation using only $y - z$ plane
- However, one may try to extrapolate SciFi track towards ECAL plane and search for clusters there
- The calo clusters may be used to improve track parameters in $y - z$ plane
- Will we be able to reconstruct vertices in that case?

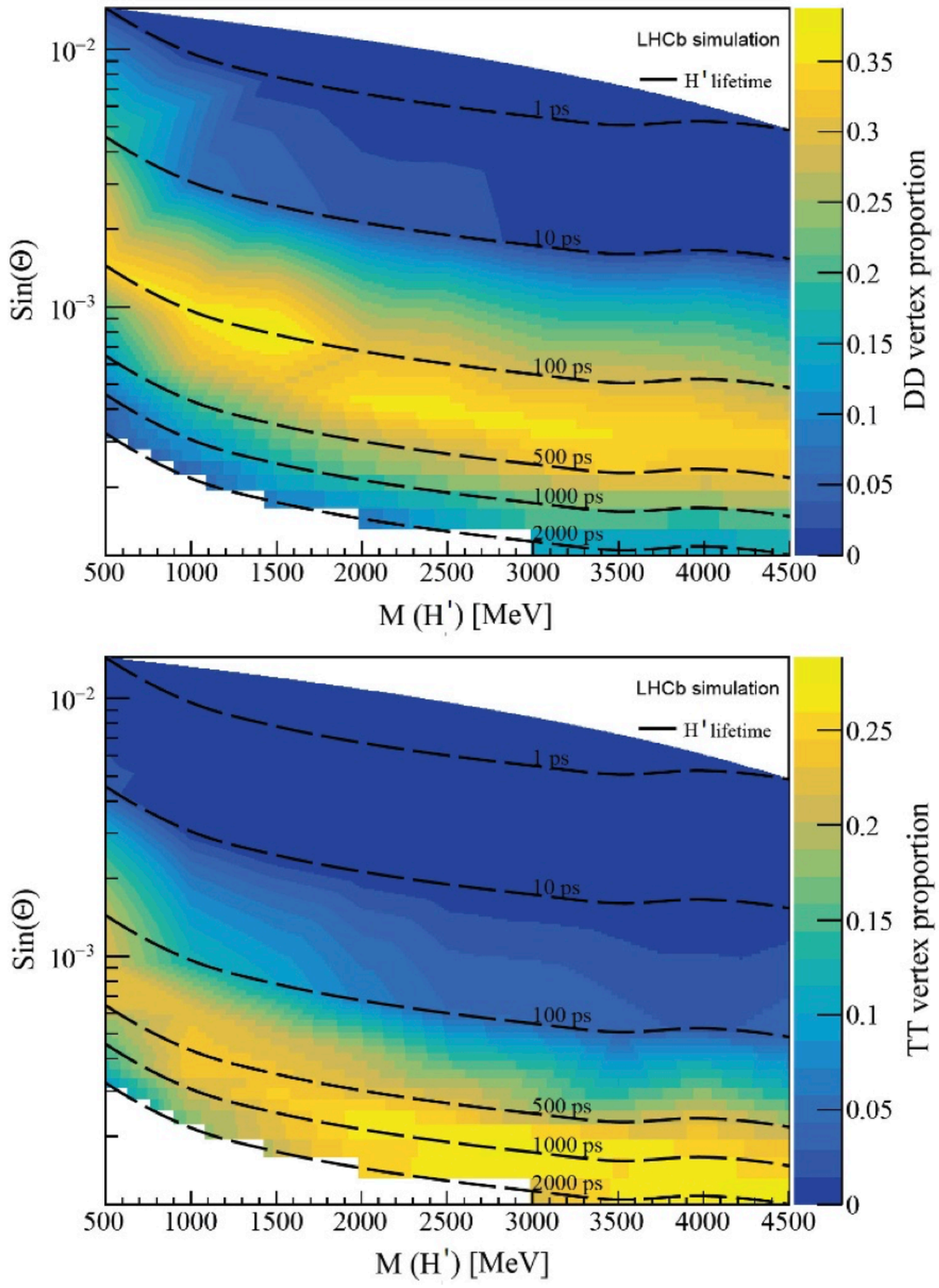


Summary

- Proposal to use “trajectory function” notation for Faraway track extrapolation
- Developed simulation setup for precise trajectory studies
- First implementation of Faraway track reconstruction at HLT1!
- Currently, $z > 5000$ mm cut is enforced, but studies are ongoing in order to remove that

Thank you for your attention!

BACKUP


LHCb simulation
H' lifetime
1 ps
10 ps
100 ps
500 ps
1000 ps
2000 ps
Sin(Θ)
M (H') [MeV]
DD vertex proportion
TT vertex proportion