T-TRACK EXTRAPOLATION MODEL AND PROSPECTS FOR RECONSTRUCTION AT HLT1

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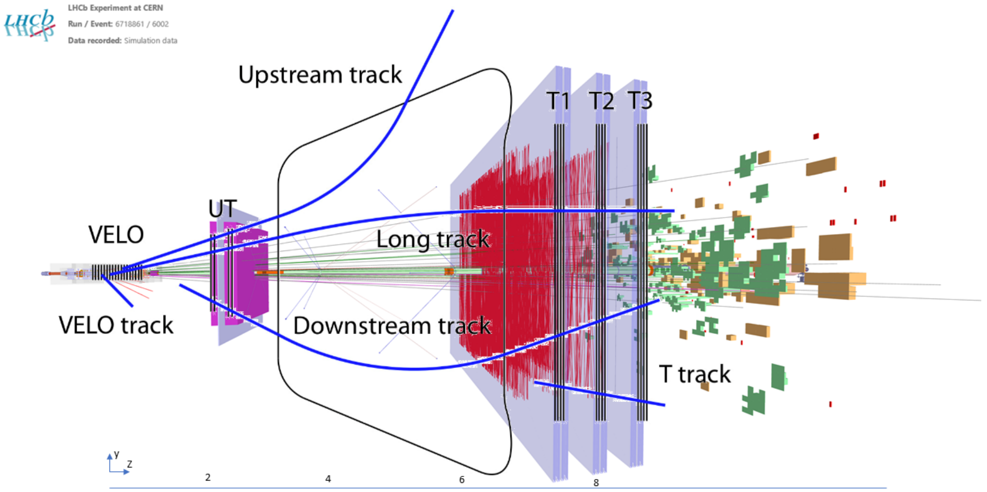


01

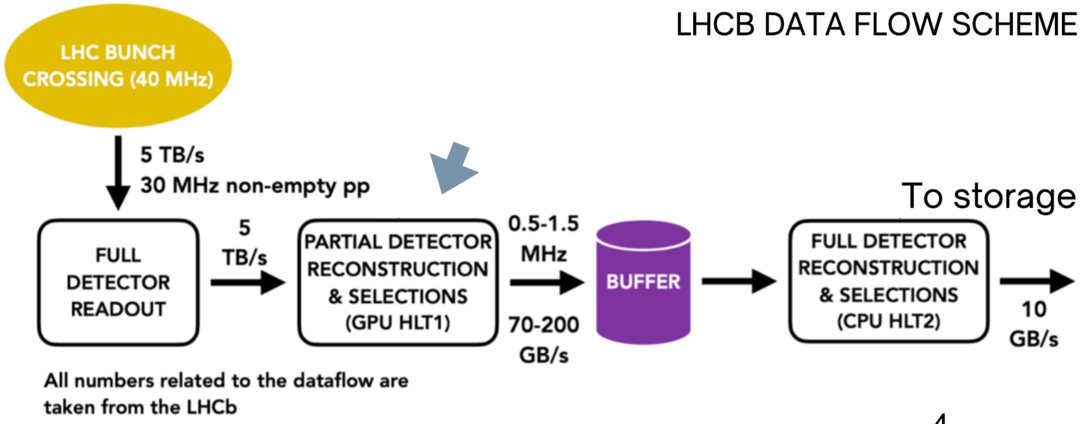
Introduction

LHCb High-level trigger system

HIGH-LEVEL TRIGGER SYSTEM

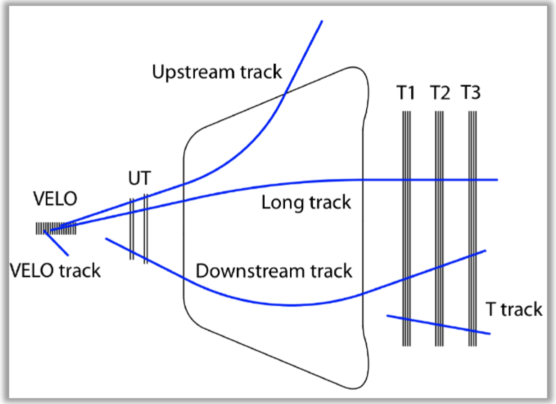
- LHC provides 40 million pp collisions per second (approx 5 TB/s of data)
- We're unable to save all the data from an economic point of view
- One needs to "select" only interesting events - done with high-level trigger system
- HLT1 & HLT2 - software triggers, able to reduce data flow down to 10GB/s

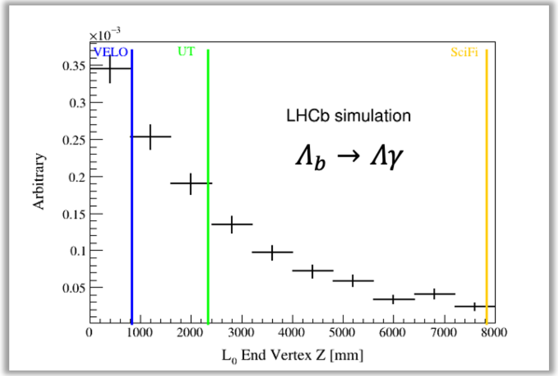
LHCB DATA FLOW SCHEME



Long-Lived particles

- Large fraction decays outside of VELO:
  For $\Lambda b \rightarrow \Lambda\gamma$ channel, the distribution of Λ decay vertices z leads to:
    - 51% - daughter hits UT & SciFi (downstream tracks)
    - 37% - daughter hits SciFi only (t-tracks)
- To reconstruct most of the Λ (as well as other LLPs), one needs downstream & t-track reconstruction and vertexing algorithms





Global Objective

Create an effective selection with TT at HLT1

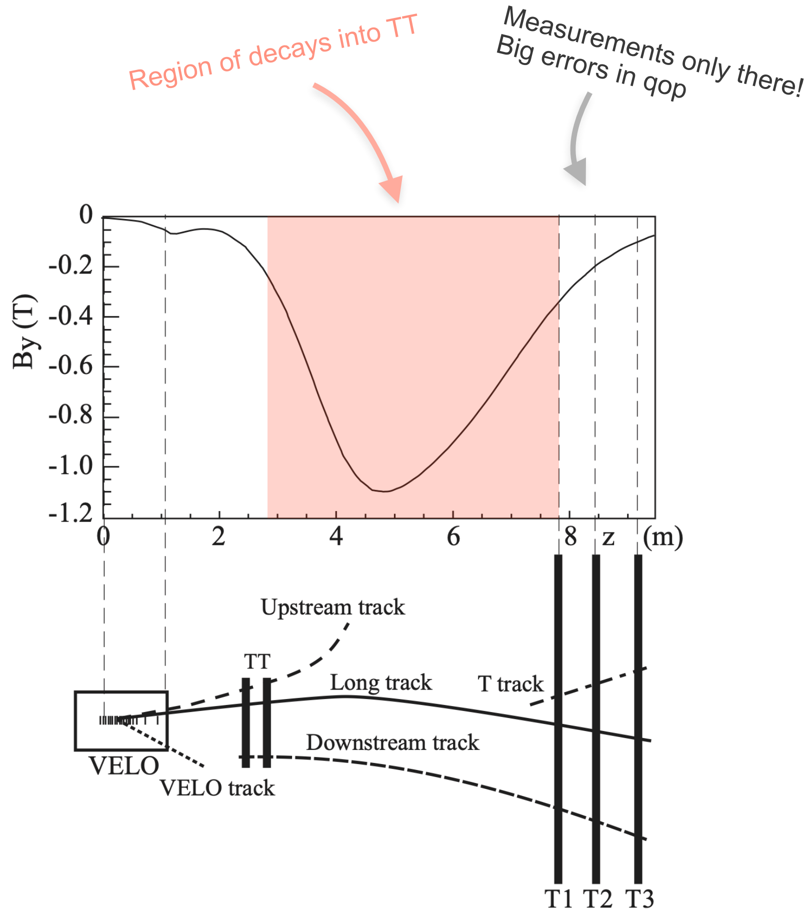
What's the problem?

A complex magnet field doesn't allow simple polynomial T-track extrapolation

Significant track momentum errors

Any existing solutions?

HLT2 uses RK for track extrapolation, which is completely unfeasible for HLT1 (timing constraint)



02

T-Track Extrapolation model

And why it's so tricky

T-Track Extrapolation model

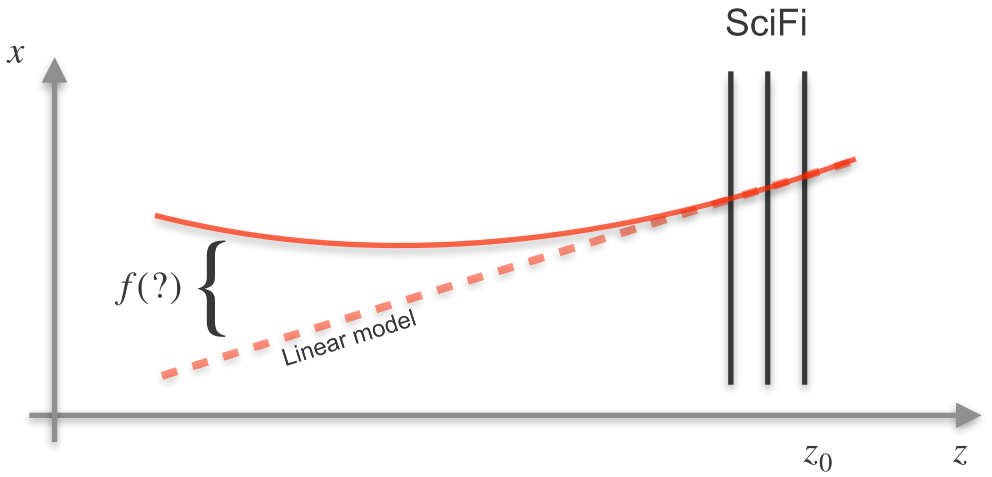
T-Track tracking model may be written as:

$$\begin{cases} x(z) = x_0 + tx(z - z_0) + f(?) \\ y(z) = y_0 + ty(z - z_0) \end{cases}$$

Obviously, f should satisfy:

$$f(\frac{q}{p} = 0) = 0$$

$$f(z = z_0) = 0$$



T-Track model with constraints

T-Track tracking model may be written as:

$$\begin{cases} x(z) = x_0 + tx(z - z_0) + f(?) \\ y(z) = y_0 + ty(z - z_0) \end{cases}$$

Obviously, f should satisfy:

$$f(\frac{q}{p} = 0) = 0$$

$$f(z = z_0) = 0$$

The unknown function f may be redefined as:

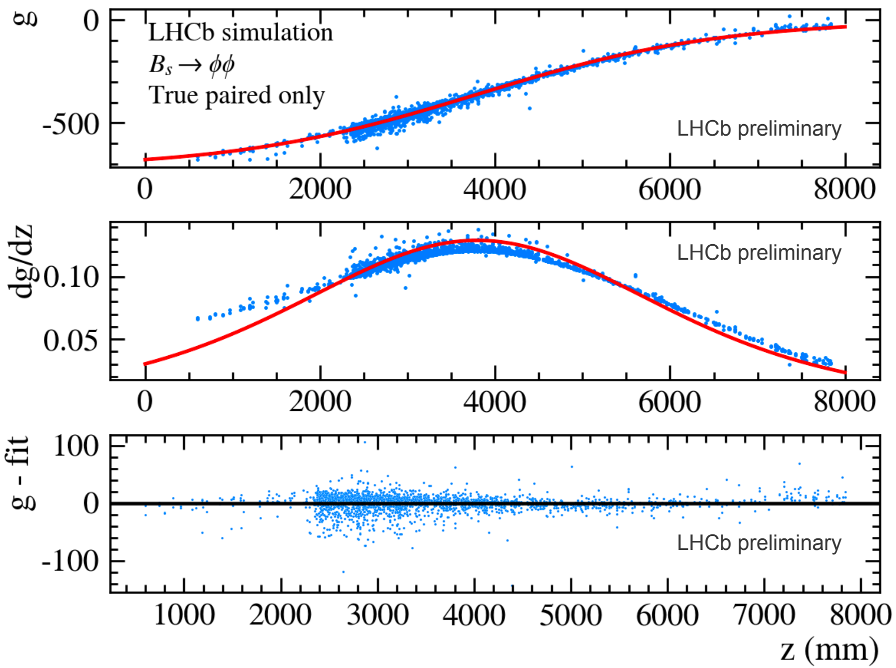
$$f(?) = \frac{q}{p}(z - z_0)g(?)$$

What is $g(z, \frac{q}{p}, \ldots)$?

g and its derivative may be found from MC data:

$$g = \frac{x_{ov} - x_{sf} - tx_{sf}(z_{ov} - z_{sf})}{\frac{q}{p}(z_{ov} - z_{sf})} \qquad \frac{dg}{dz} = \frac{tx_{ov} - tx_{sf} - \frac{q}{p}g}{\frac{q}{p}(z_{ov} - z_{sf})}$$

T-Track model for true paired only



Fitted with mirrored sigmoid:

$$g = \frac{a}{1 + e^{b(z-c)}}$$

$$\lim_{z\to+\infty} g(z) = 0 \qquad \lim_{z\to-\infty} g(z) = a$$

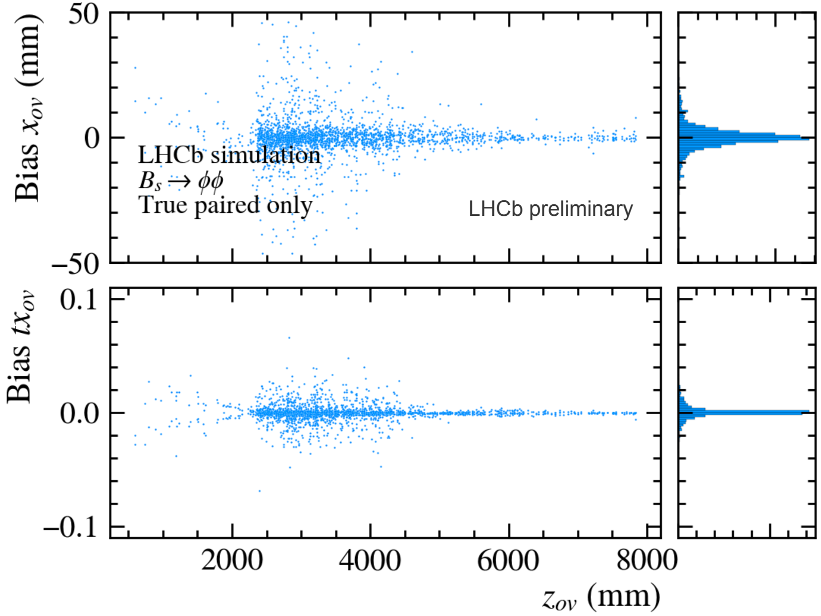
Constant slope before magnet

Still, some deviations exist, try correction

$$g = g_z(z) \cdot g_{qop}\left(\frac{q}{p}\right) \cdot g_{x_0}(x_0)$$

Should be near 1

T-Track model global fit



The fitting procedure was repeated, but this time over all variables at once:

$$g = \frac{a}{1 + e^{b(z-c)}}(e^{d(x_0-e)} + e^{-d(x_0+e)})(e^{k(qop-l)} + e^{-k(qop+l)})$$

Bias was estimated using true sf variables

Final track model:

$$x(z) = x_0 + tx(z - z_0) + \frac{q}{p}(z - z_0)g$$

$$y(z) = y_0 + ty(z - z_0)$$

03

Model applications

We have a model. What's now?

Better slopes with the model

T-Track tracking model allows better slope computation:

$$tx(z_{ov}) = tx_{sf} + \frac{q}{p}g(z_{ov}, x_{sf}, \frac{q}{p}) + \frac{q}{p}(z_{ov} - z_{sf})\frac{dg}{dz}(z_{ov}, x_{sf}, \frac{q}{p})$$

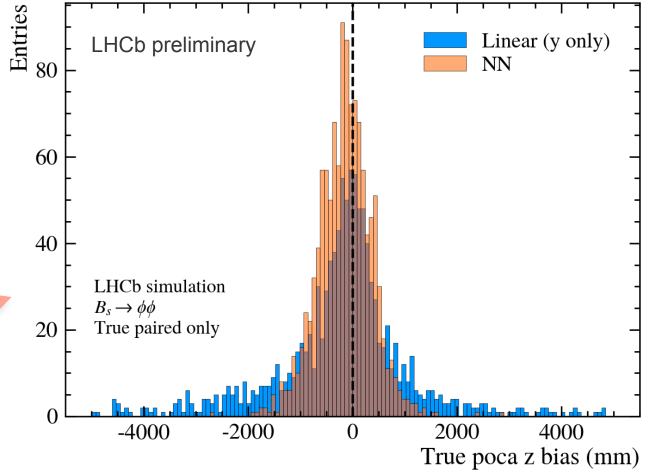
No z_{ov}

Numerical $DOCA(z_{ov})$ minimization fails because of bad SciFi qop accuracy

Poca z may be estimated from two-layer NN with inputs:

- $y^A_{sf} - y^B_{sf}$
- $ty^A_{sf} - ty^B_{sf}$
- $x^A_{sf} - x^B_{sf}$
- $tx^A_{sf} - tx^B_{sf}$
- qop^A
- qop^B

The size of hidden layers - 14; 5

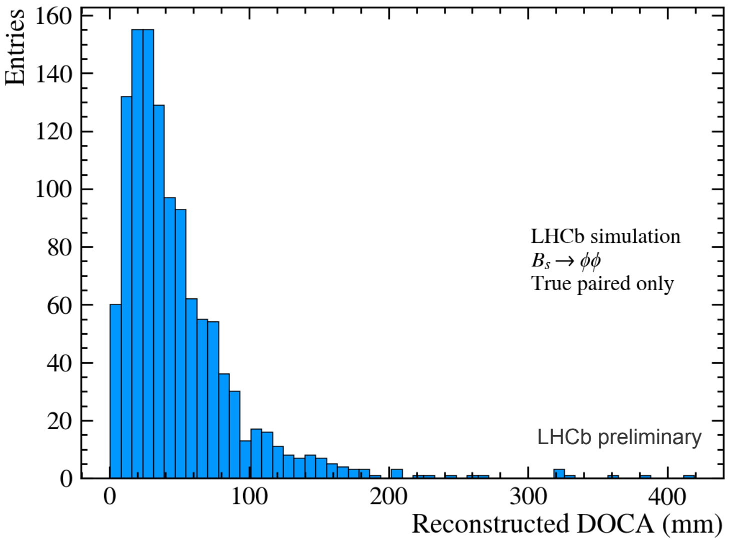


MAY WE USE IT FOR SELECTION?

Unlikely

- The track model allows better DOCA computation, but otherwise, it doesn't add any new variables
- With existing ones, there is no way to make an effective selection, at least with NN classification

However, the track model allows vertex fit - an effective tool in ghost reduction

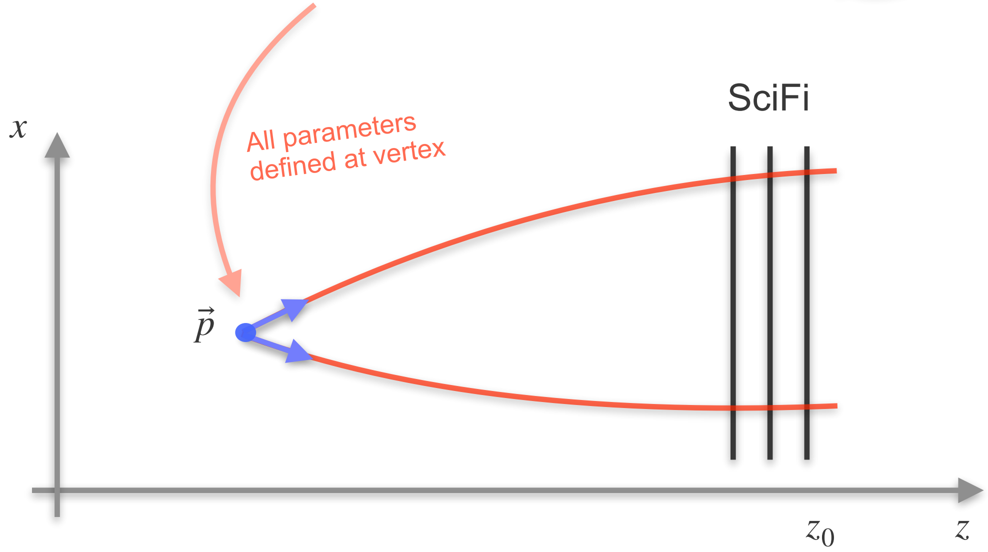


Mathematics of fitting – Part 1

Generally, there are 9 unknown parameters for a two-track vertex:

$$\vec{p} = (\underbrace{x_{ov}, y_{ov}, z_{ov}}_{\text{Vertex}}, \underbrace{tx^A_{ov}, ty^A_{ov}, qop^A}_{\text{Track A}}, \underbrace{tx^B_{ov}, ty^B_{ov}, qop^B}_{\text{Track B}})$$

Improve SciFi estimation of qop

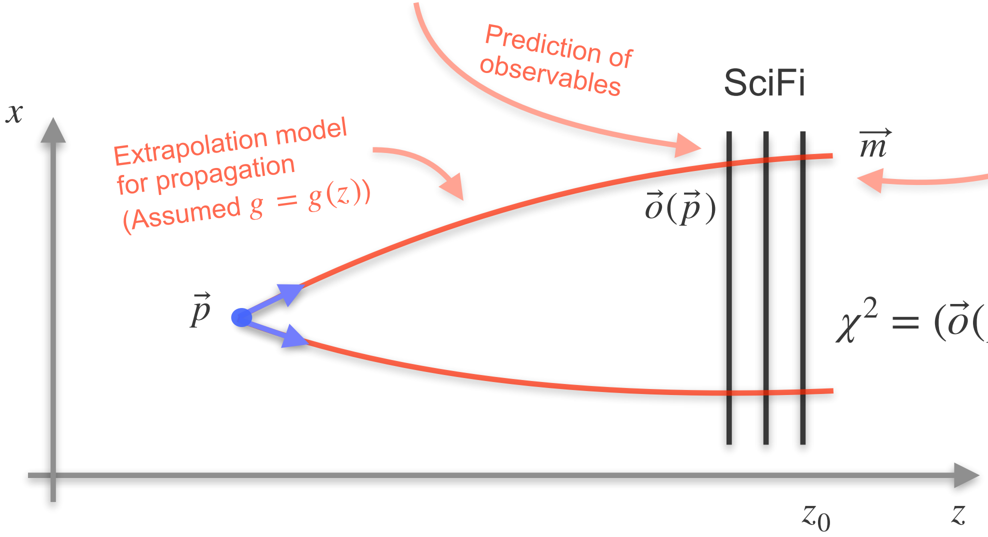


Mathematics of fitting - part 2

Using the parameter vector $\vec{p}$ one may construct the vector of 10 predicted observables:

$$\vec{o}(\vec{p}) = (\underbrace{x^A_{sf}, tx^A_{sf}, y^A_{sf}, ty^A_{sf}, qop^A_{sf}}_{\text{SciFi track A}}, \underbrace{x^B_{sf}, tx^B_{sf}, y^B_{sf}, ty^B_{sf}, qop^B_{sf}}_{\text{SciFi track B}})$$

Observables are measured ($\vec{m}$) with SciFi



The χ^2 may be constructed as:

$$\chi^2 = (\vec{o}(\vec{p}) - \vec{m}) \cdot cov^{-1} \cdot (\vec{o}(\vec{p}) - \vec{m})^T$$

Covariance matrix construction

Elements of the covariance matrix were estimated by definition:

$$cov_{ij} = (x_i - x_i^{true})(x_j - x_j^{true})$$

… and mapped versus some convenient reconstructible variable (e.g. $cov_{00} = cov_{00}(x_0)$)

Some elements were zeroed because of extremely small values ($10^{-10} - 10^{-12}$), and others because of independence in x and y axis, and assumption that qop is independent from y

The resulting covariance matrix:

$$covA = \begin{pmatrix} c00 & 0 & \boxed{0} & 0 & c40 \\ 0 & c11 & 0 & c31 & 0 \\ \boxed{0} & 0 & c22 & 0 & \boxed{0} \\ 0 & c31 & 0 & c33 & 0 \\ c40 & 0 & \boxed{0} & 0 & c44 \end{pmatrix} \begin{matrix} \text{X} \\ \text{Y} \\ \text{Tx} \\ \text{Ty} \\ \text{qop} \end{matrix}$$

$$cov = \begin{pmatrix} covA & 0 \\ 0 & covB \end{pmatrix}$$

Mathematics of fitting - part 3

The minimization with Newton–Raphson method:

$$\vec{p}^{\,i+1} = \vec{p}^{\,i} - H^{-1}\nabla\chi^2$$

where:

$$\nabla\chi_i^2 = 2(\nabla_i d_j \cdot cov_{jk}^{-1} \cdot d_k)$$

$$H_{ij} = 2(\nabla_i d_k \cdot cov_{kl}^{-1} \cdot \nabla_j d_l) + 2(\nabla_j \nabla_i d_k \cdot cov_{kl}^{-1} \cdot d_l)$$

$$\nabla_i = \frac{\partial}{\partial p_i}$$

Here the summation over the same indexes is assumed

To simplify equations, g in the extrapolation model is assumed to be $g = g(z_{ov})$

Turns out, that fit is numerically unstable and slow…

04

Simpler fit

Will it be accurate?

How to make fit faster & simpler

The simplest way to improve stability is to reduce the number of parameters:

Do we need y-z fit?

$$\vec{p} = (\underbrace{x_{ov}, y_{ov}, z_{ov}}_{\text{Vertex}}, \underbrace{tx^A_{ov}, ty^A_{ov}, qop^A}_{\text{Track A}}, \underbrace{tx^B_{ov}, ty^B_{ov}, qop^B}_{\text{Track B}})$$

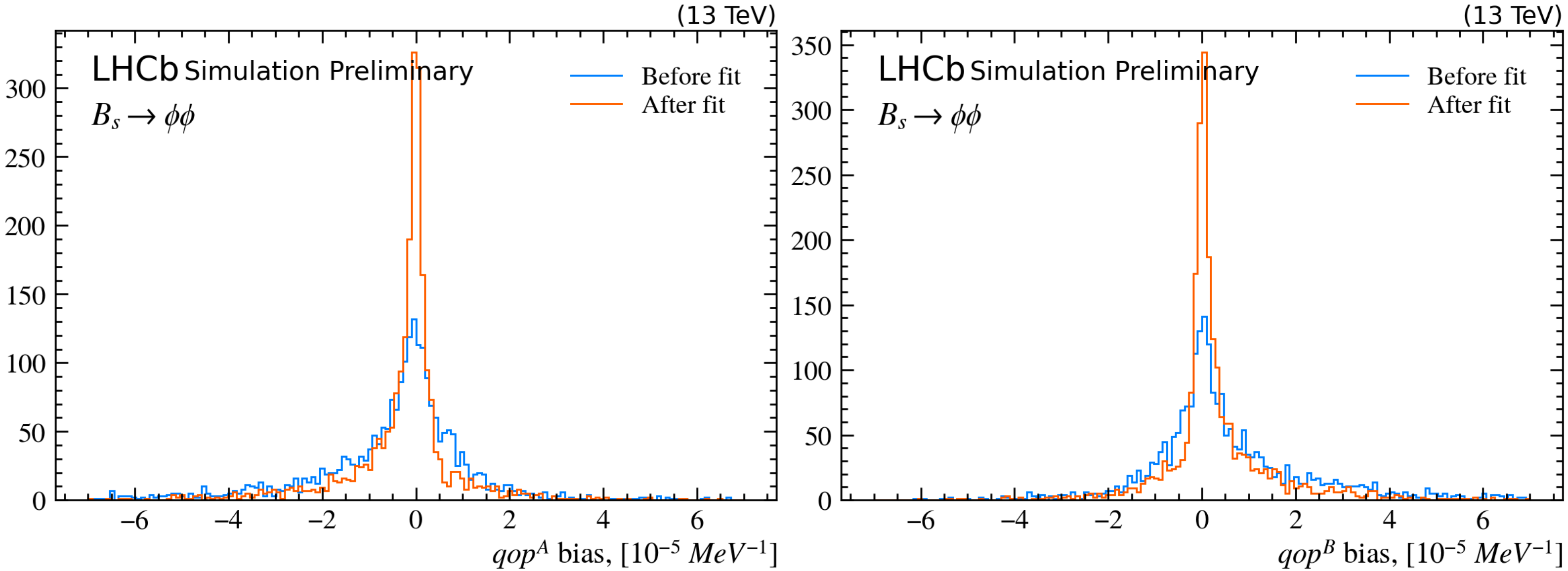
By removing z_{ov} we remove non-linearity from equations

Only 5 iterations enough in Python tests…

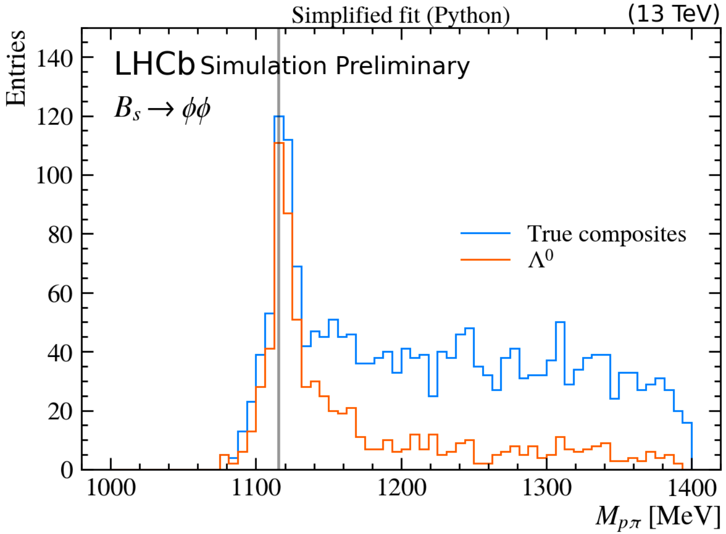
This leads to the following parameter vector:

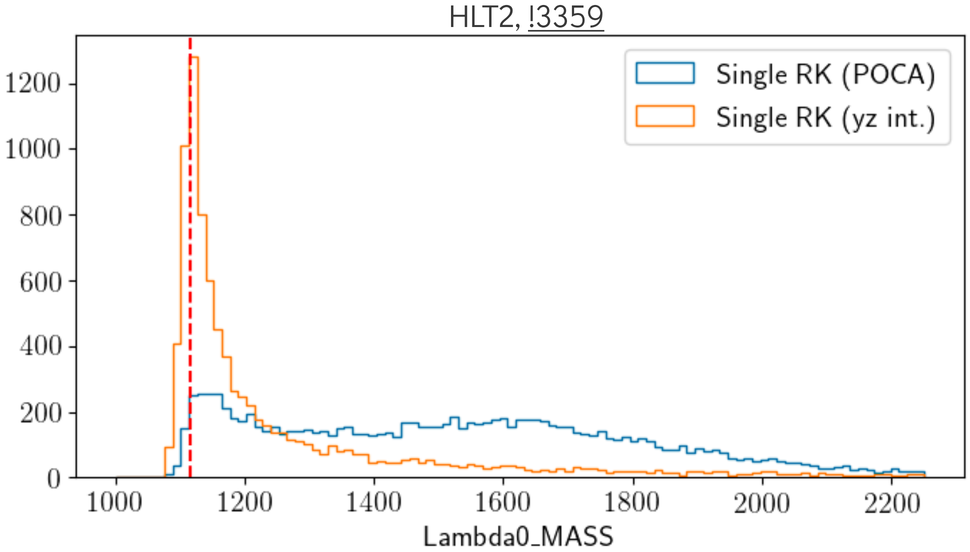
$$\vec{p} = (x_{ov}, \underbrace{tx^A_{ov}, qop^A}_{\text{Track A}}, \underbrace{tx^B_{ov}, qop^B}_{\text{Track B}})$$

Faster Fitting results



Final mass resolution





Thanks for your attention!

What's next?

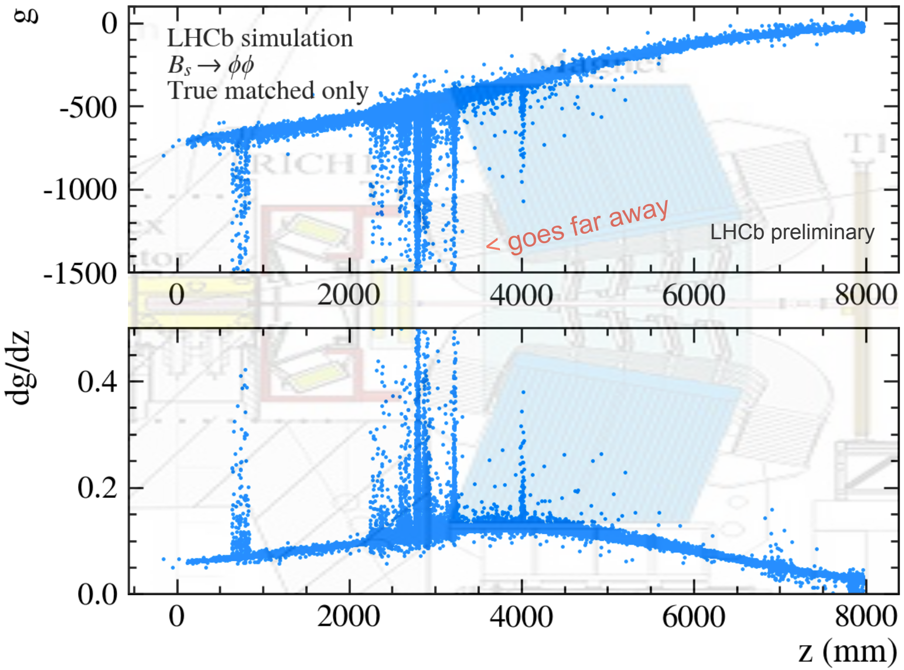
- Implementation & benchmarking in Allen
- Additional studies in order to simplify and/or improve fitting
- Development of selection lines

-01

Backup

Who's there?

T-Track Extrapolation model

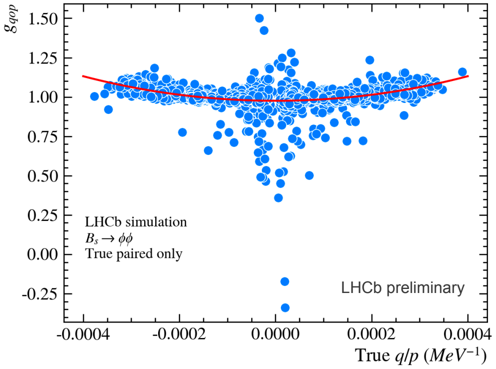


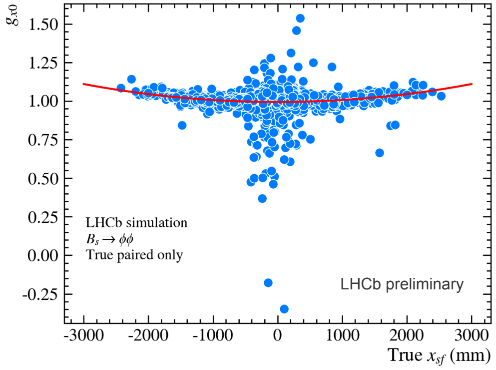
Spikes at specific z, that correspond to detector parts

Material interaction effect?

What if use only true T-Tracks, paired with any other T-Track by common mother id condition?

Corrections for T-Track model





$$g = g_z(z) \cdot g_{qop}(\frac{q}{p}) \cdot g_{x_{sf}}(x_0)$$

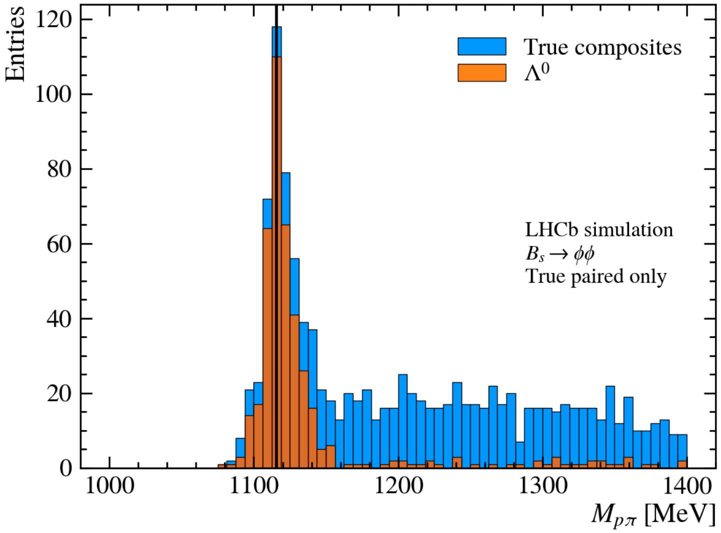
Corrections may be found in a sequential way:

$$g_{qop} = \frac{g}{g_z(z_{ov})} \qquad g_{x_0} = \frac{g}{g_z(z_{ov})g_{qop}(\frac{q}{p})}$$

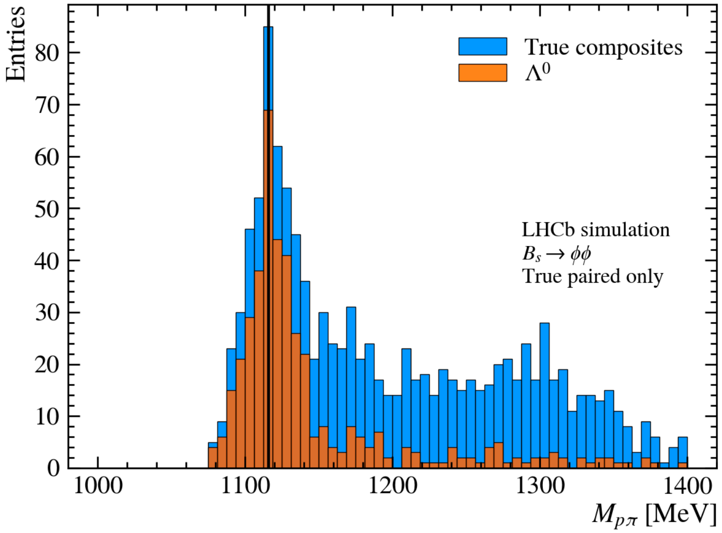
Both functions fitted with:

$$g_{qop/x_0} = a(e^{b(x-c)} + e^{-b(x+c)})$$

Mass resolution with better slope

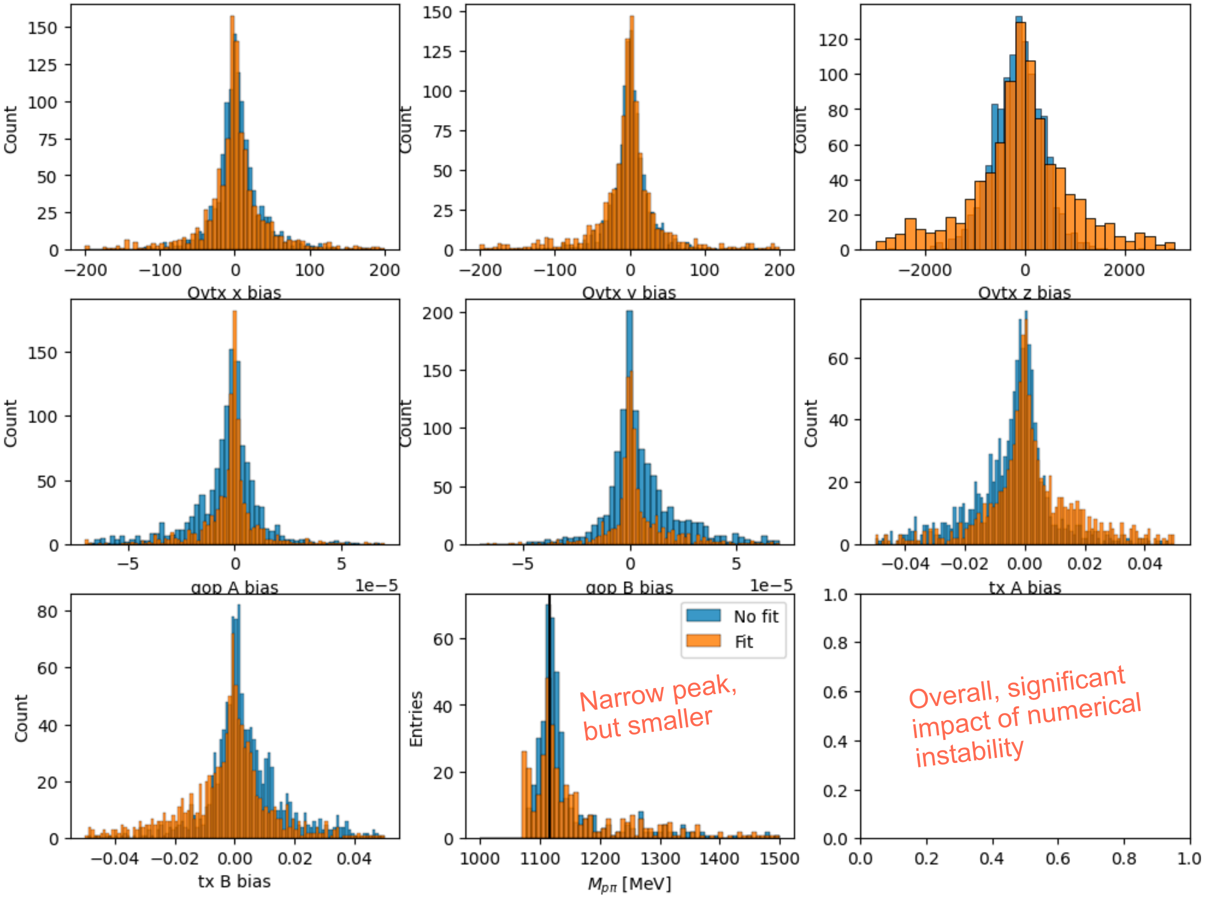


True variables



Reconstructed variables

Fitting results



Little to no improvement in vertex pos.

Significant improvement of qop

Little improvement tx