First look at updated HLT2 forward tracking parameterisations

Martin Tat

Heidelberg University

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UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

Outline

Introduction

I've had a look at the HLT2 forward tracking algorithm

- Relevant code lives in `Rec/Pr/PrAlgorithms/src/`
  - `PrForwardTracking.cpp`
  - `PrTrackModel.cpp`
- Tracking algorithm described in three steps:
  1. Trajectories based on equations of motion and detector geometry
  2. Parameterise complex calculations using polynomials
  3. Determine coefficients by fits to MC
- I plan to update these parameterisations
  - Previous work based on MC from 2019 (`DC19`)
  - New magnetic field map (presented here)

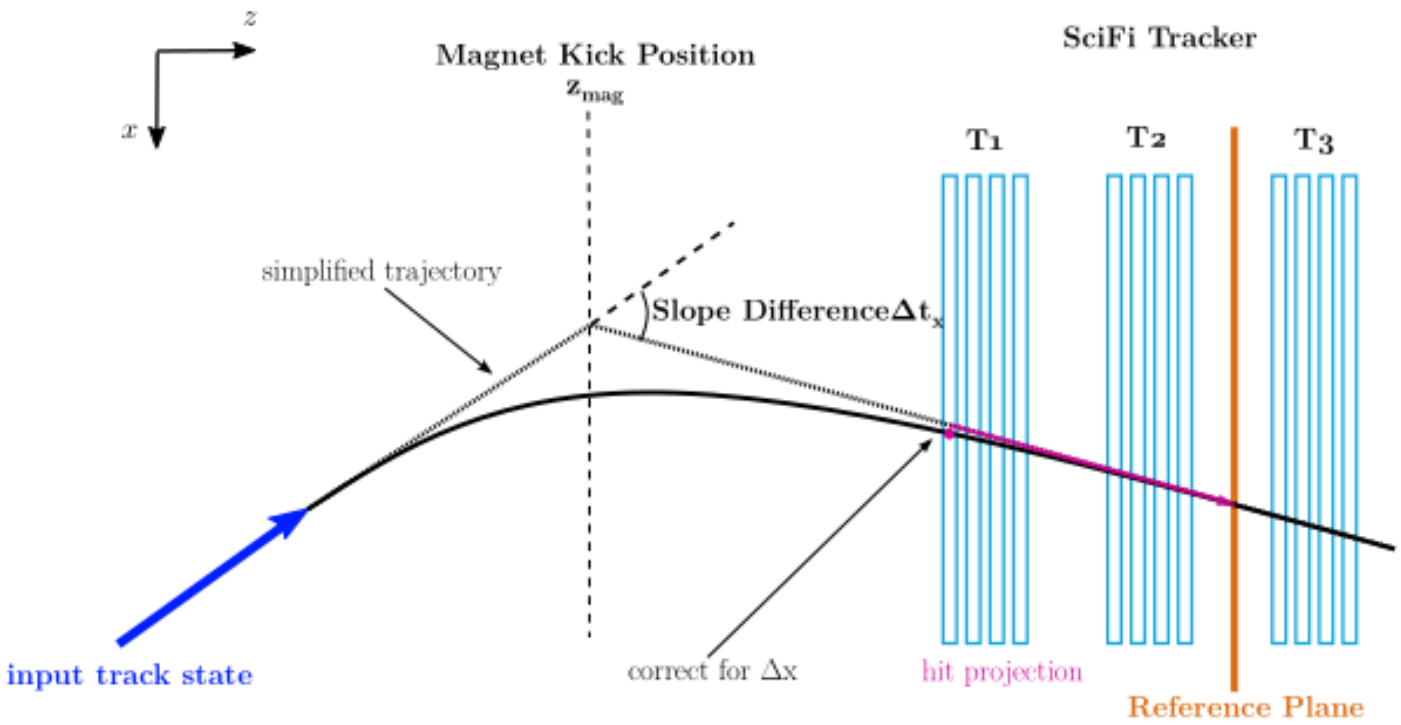
Introduction

Based on work by Andre Günther

Many thanks to Andre for the extensive documentation!

- Algorithm described in his thesis: CERN-THESIS-2023-097
  - All parameterisations are explained thoroughly
  - Numerical results all agree with what is in Rec
- Code available in: Reco-Parameterisation-Tuner
  - Only minor changes required to get code running with latest environment
  - All parameterisations can be reproduced with files found on Heidelberg computing cluster
  - Moore scripts provided for rerunning with new MC (must be XDIGI)

Overview of forward tracking algorithm

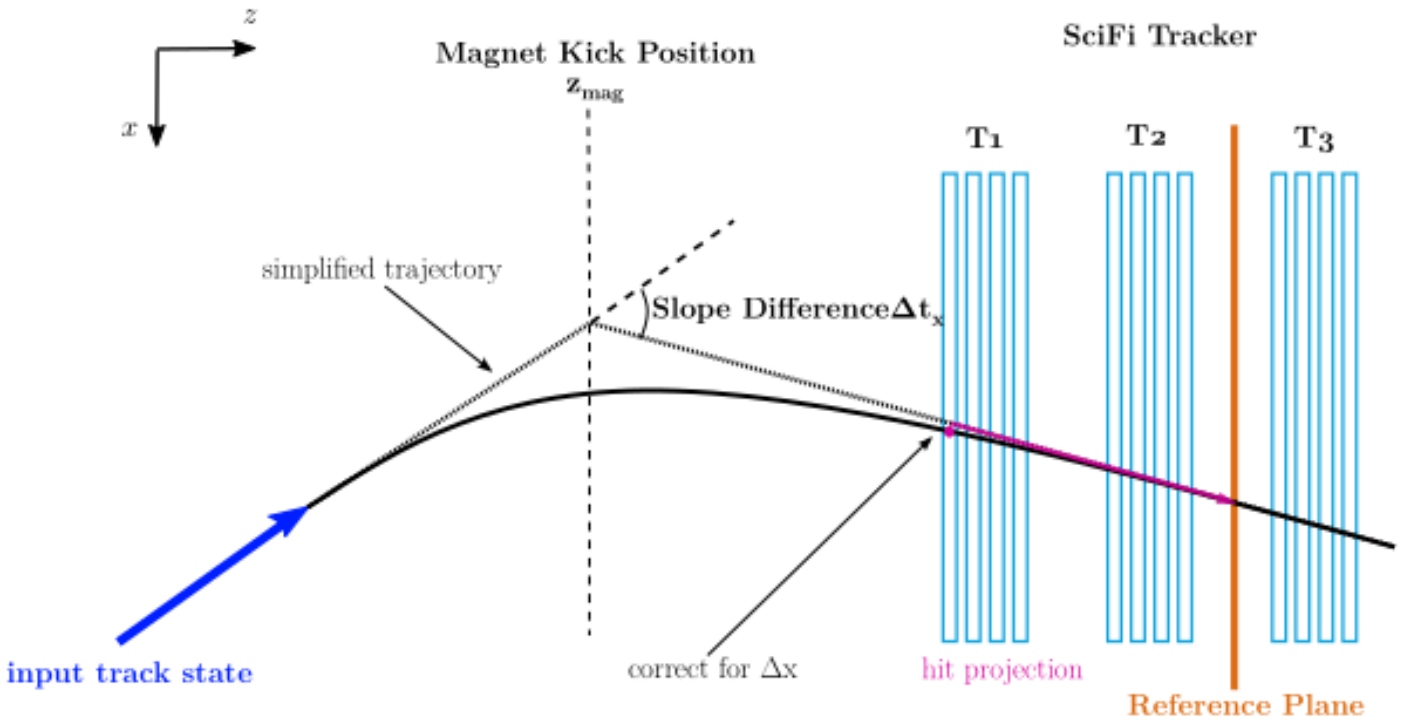


From CERN-THESIS-2023-097

- Simplified track model: Assume magnet "kicks" particle at $z = z_{\mathrm{mag}}$
- Parameterise z_{mag} as:

$$z_{\mathrm{mag}} = c_0 + c_1 t_x^2 + c_3 t_y^2 + \Delta t_x' (c_2 t_x + c_4 \Delta t_x')$$

Overview of forward tracking algorithm

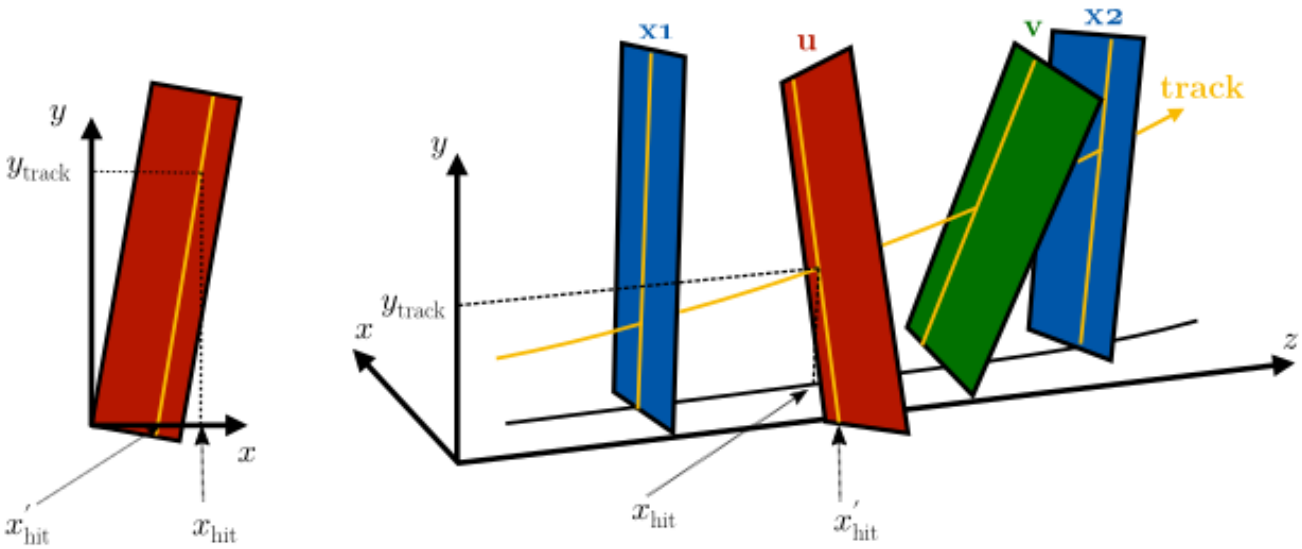


From CERN-THESIS-2023-097

- True path in xz plane deviates due to the SciFi fringe field
- Parameterise trajectory as:

$$x(z) = a_x + b_x(z - z_{\text{ref}}) + c_x(z - z_{\text{ref}})^2 + d_x(z - z_{\text{ref}})^3$$

Overview of forward tracking algorithm

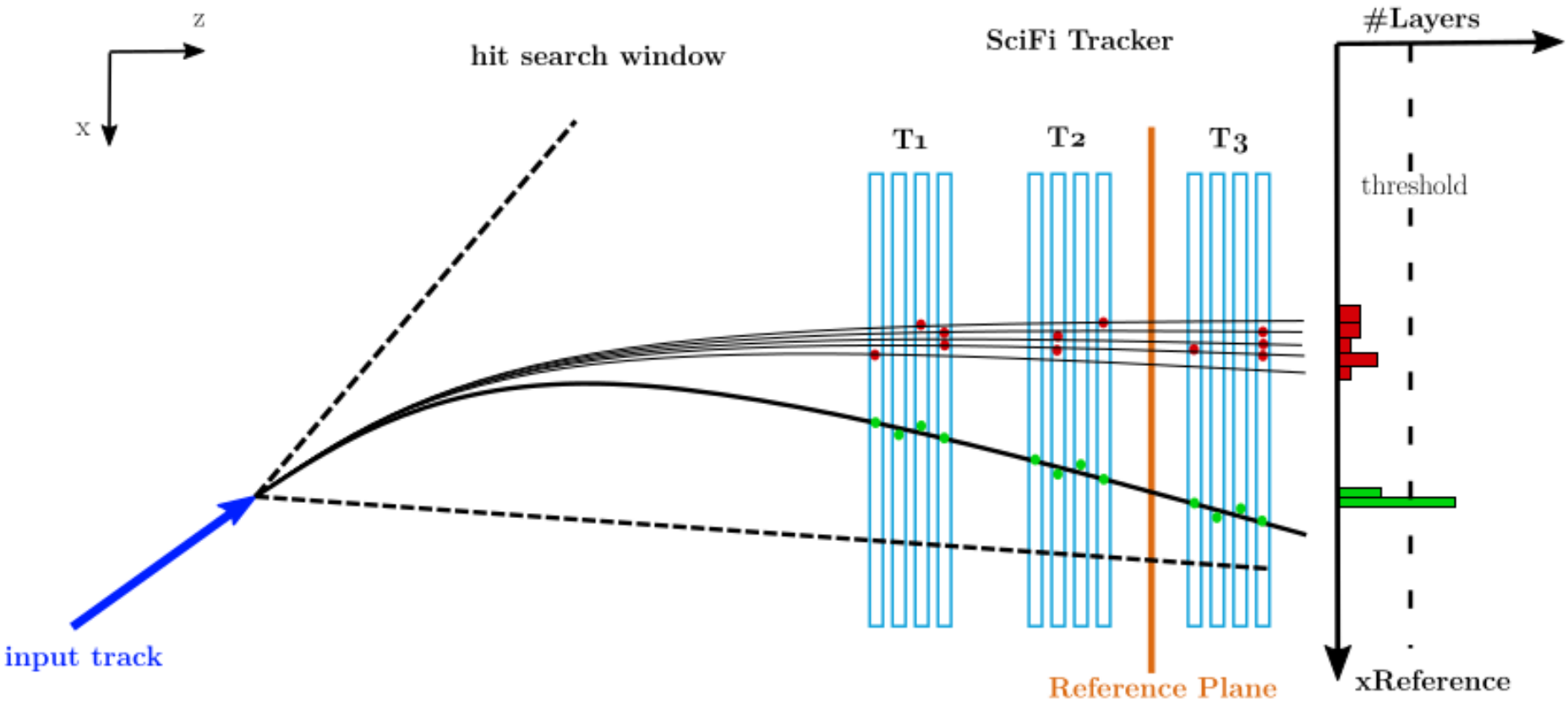


From CERN-THESIS-2023-097

- Hits in stereo layers must be "rotated", which requires y-position
- Account for small track curvature in yz plane:

$$\begin{aligned} y^L_{\text{corr}} =& \Delta t_x (c^L_0 + c^L_2 t_x t_y + c^L_5 t_x t_y^3 + c^L_6 t_x^3 t_y) \\ &+ t_x (c^L_1 + c^L_3 t_x t_y + c^L_4 t_x t_y^3 + c^L_7 t_x^3 t_y) \end{aligned}$$

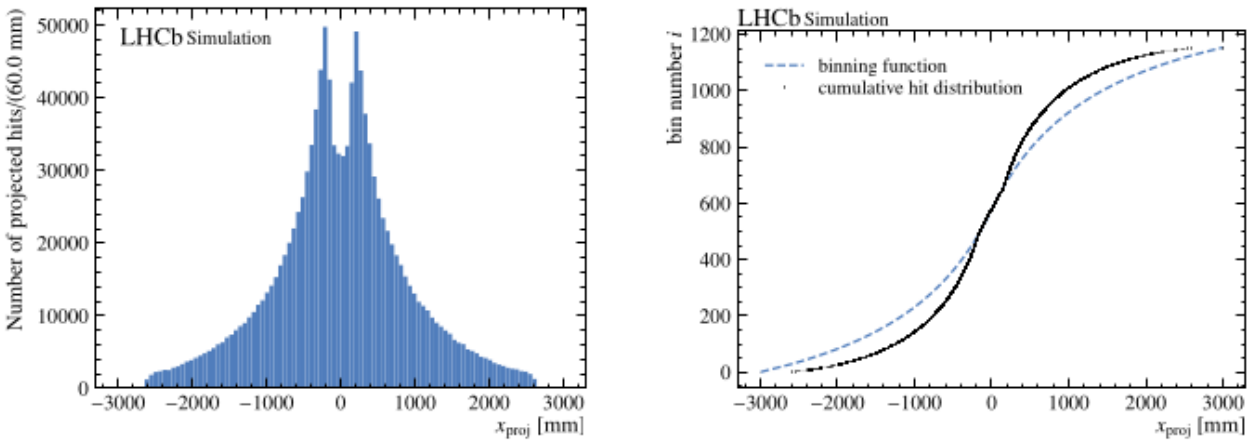
Overview of forward tracking algorithm



From CERN-THESIS-2023-097

- Once all SciFi hits are parameterised, map hits to reference plane
- Hits from real tracks show peaks in "Hough histogram"

Overview of forward tracking algorithm



a: Distribution of projected hits positions from several tracks.

b: Cumulative distribution of projected hits.

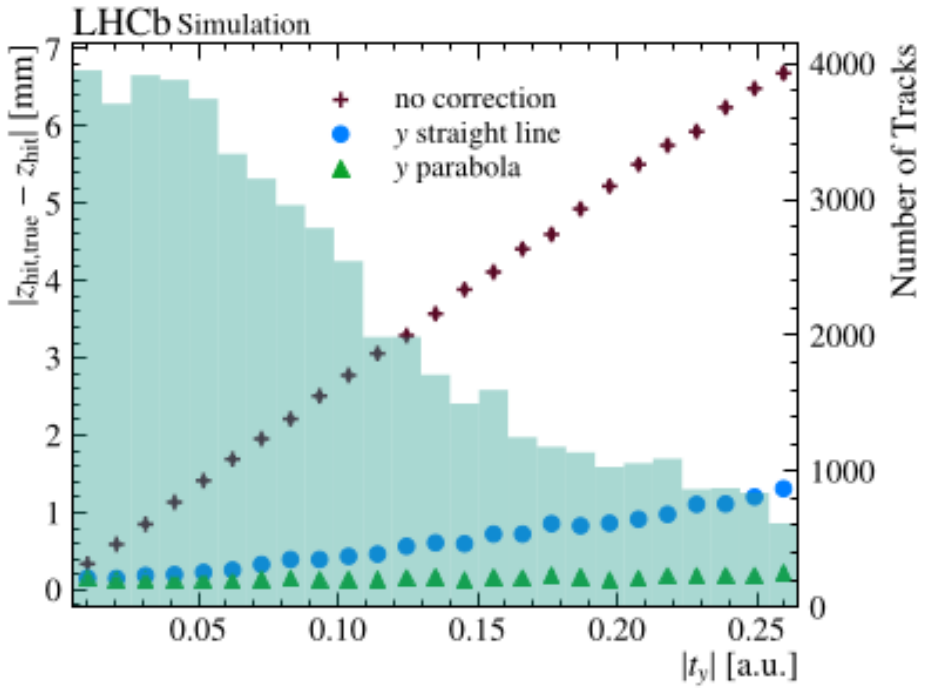
Figure 5.13: Distributions used to determine the binning scheme of the Hough histogram.

From CERN-THESIS-2023-097

- Hits (in reference plane) are not uniform along x-axis
- Transform x by sigmoid function before binning:

$$p_0 + \frac{p_1 x_{\text{proj}}}{1 + p_2 |x_{\text{proj}}|}$$

Overview of forward tracking algorithm



From CERN-THESIS-2023-097

- z-position must then be corrected for small tilt in yz plane
- Assume trajectory in yz plane is a parabola:

$$y(z) = a_y + b_y(z - z_{\text{ref}}) + c_y(z - z_{\text{ref}})^2$$
$$z'_{\text{hit}} = z_{\text{hit}} + \tan(0.21^\circ)y(z)$$

Overview of forward tracking algorithm

Finally, obtain momentum from change in track slope Δt_x:

$$\frac{q}{p} = \frac{\Delta t_x}{r_l B_{\text{int}}}$$

The field integral B_{int} is parameterised as:

$$\begin{aligned} B_{\text{int}} =& c_0 + t_y^2(c_1 + c_5 t_y^2 + c_6 t_x^2) + t_x b_x(c_{10} t_x + c_3 + c_7 t_y^2) \\ &+ c_{11} b_x^4 + c_2 t_x^2 + b_x^2(c_4 + c_8 t_y^2) + c_9 t_x^4 \end{aligned}$$

Overview of forward tracking algorithm

In summary, these are the parameterisations used in forward tracking:

1. z magnet kick position
2. x fringe field correction
3. Stereo angle y correction
4. Hough histogram binning
5. z hit correction with SciFi yz tilt
6. Magnetic field integral

Current tracking performance

Metrics for tracking performance:

- Tracking efficiency vs p, p_T, η, nPVs, ϕ
  - Reconstructed / Reconstructible
  - Most important metric
- Momentum resolution vs p, η
  - Width of momentum residual distribution
  - Less important since track momentum is determined by Kalman fit

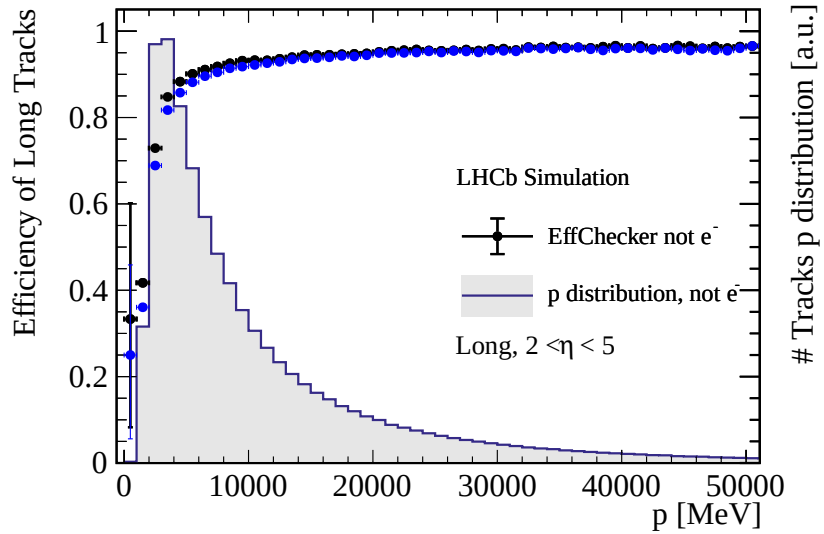
Current tracking performance

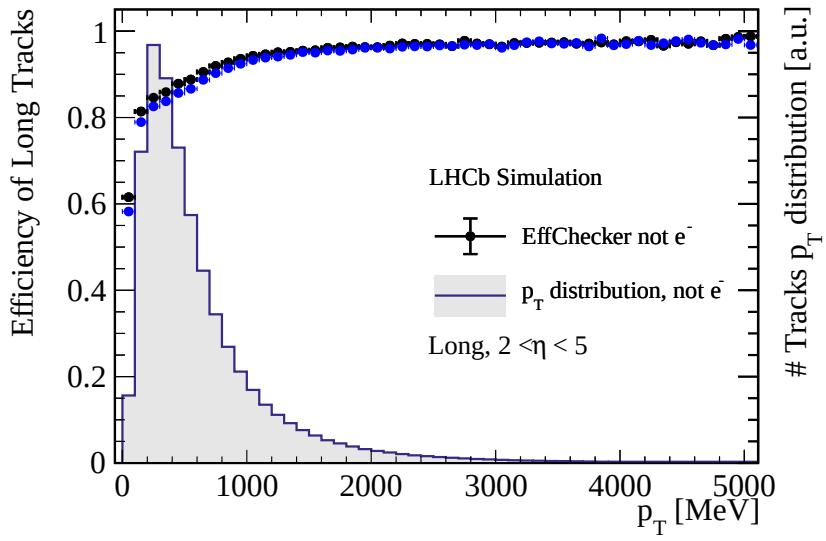
MC samples:

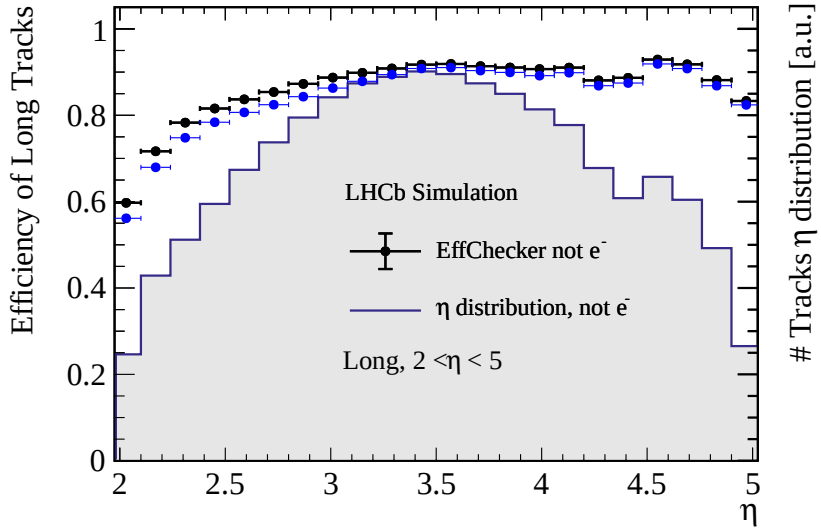
- `DC19`: Cross check with Andre's work
  - Found on Heidelberg cluster
  - Cocktail of $B_s^0 \to J/\psi\phi$, $B_s^0 \to \phi\phi$, $D^+ \to K_S^0\pi^+$, $Z^0 \to \mu^+\mu^-$, $D^{*+} \to [K^-\pi^+]_{D^0}\pi^+$, 50k MagUp/MagDown

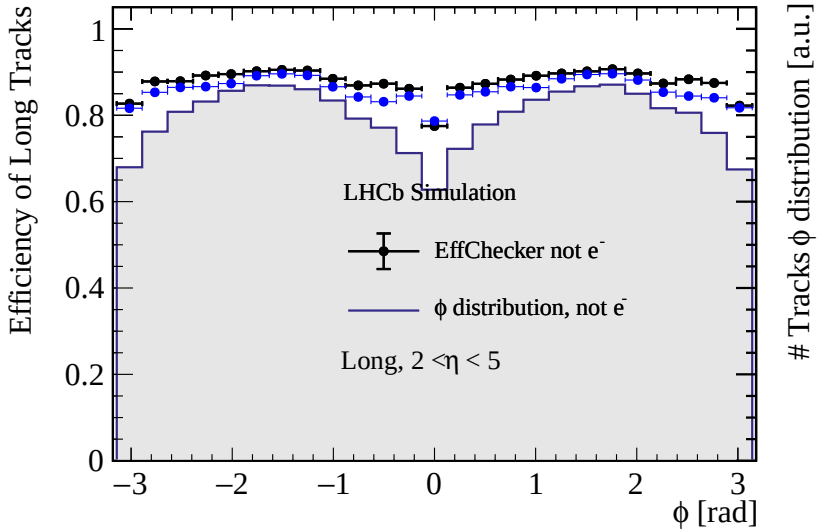
- `v8.1` field map: Private production
  - Many thanks to Jiahui and Alessandro for your help producing this!
  - Cocktail of $B_s^0 \to J/\psi\phi$, $B_s^0 \to \phi\phi$, $D^+ \to K_S^0\pi^+$, 10k MagDown

Current tracking performance



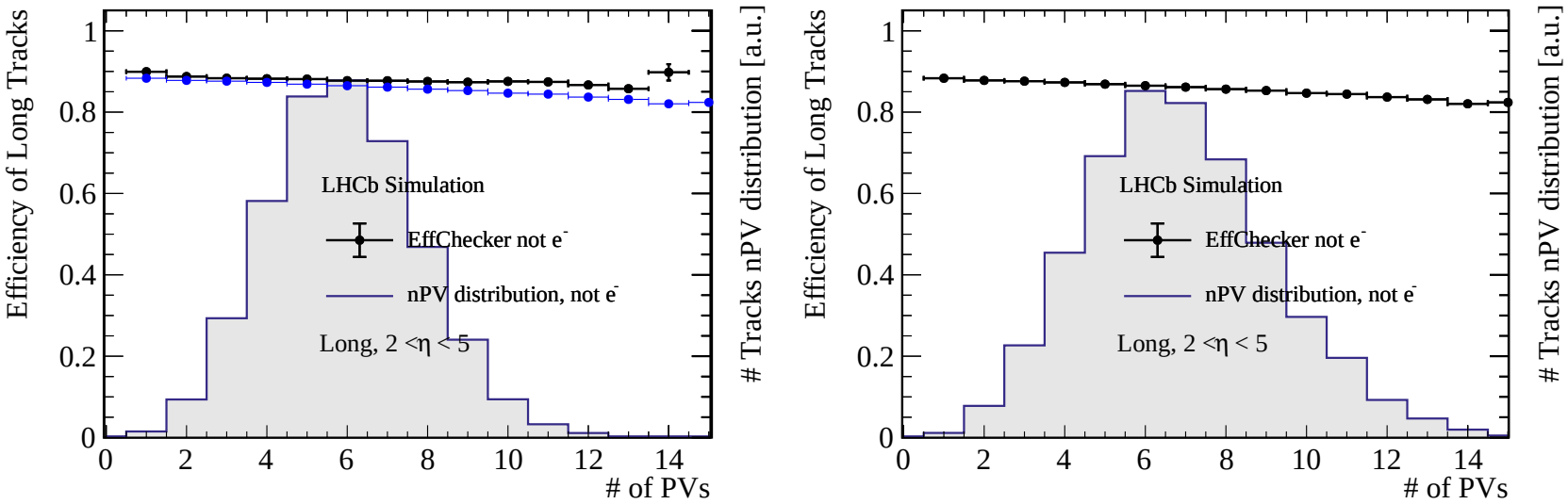






Black: Results with DC19. Blue: Results with recent MC.

Current tracking performance



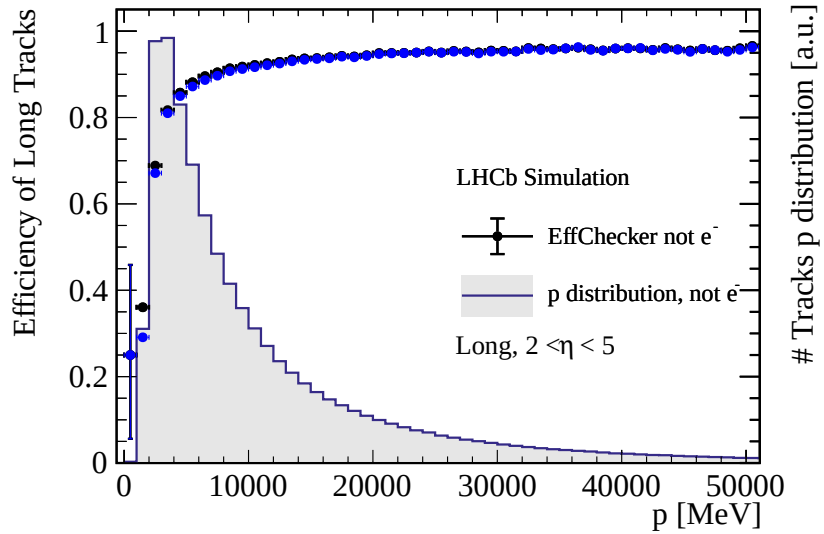
Left: DC19 in black and recent MC in blue. Right: Results with recent MC.

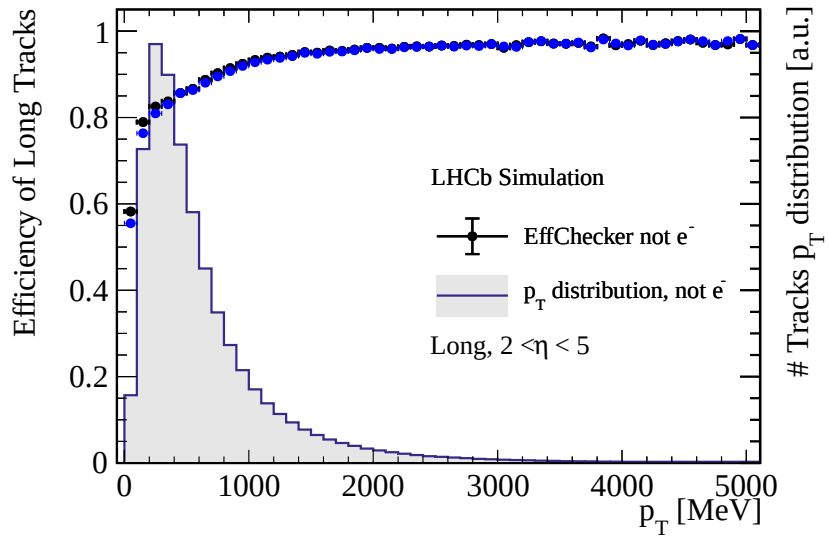
Tracking performance with new parameterisation

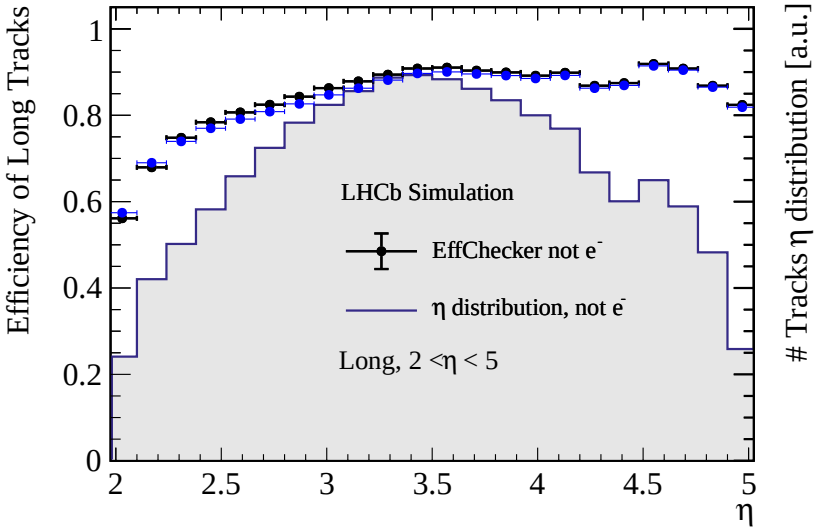
New parameterisation:

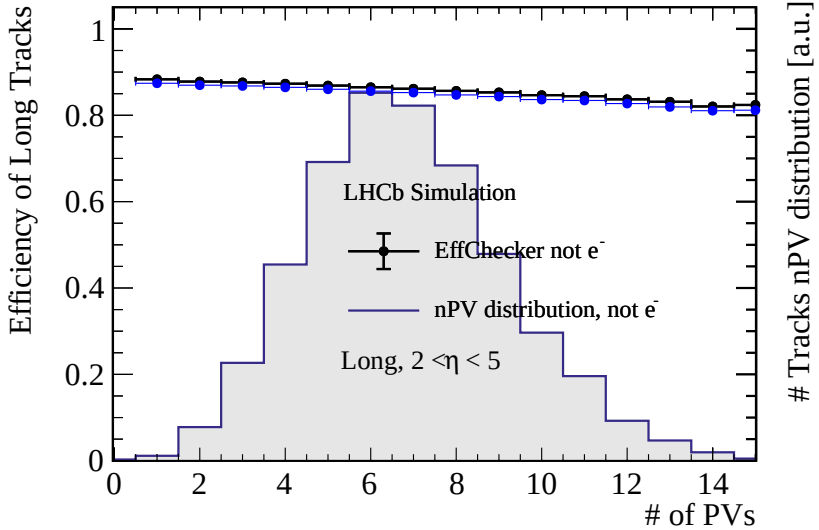
- Run Andre's code on recent MC samples
- No change in choice of parameterisation
- Exact numerical changes can be found in this MR: !4362

Tracking performance with new parameterisation









Black: Old parameterisation. Blue: Updated parameterisation.

Tracking performance with new parameterisation

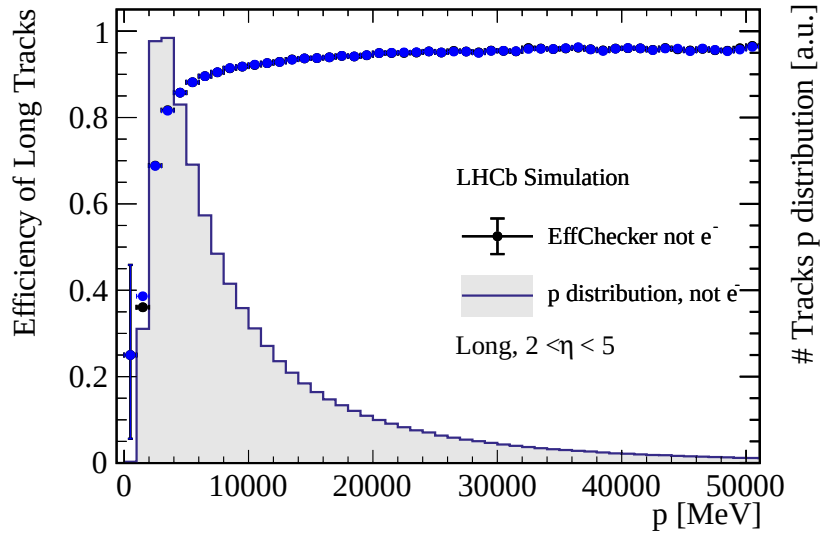
Observations with new parameterisation:

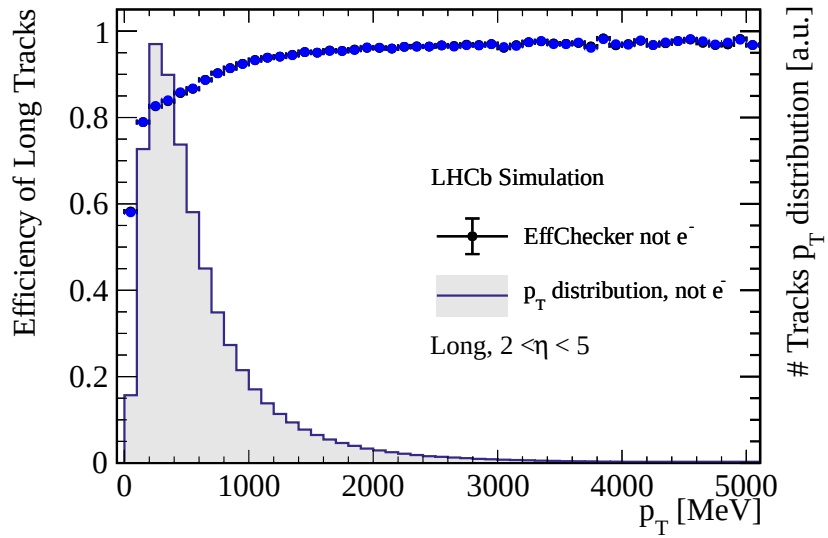
- Changes are generally small
- But it is worrying that performance is strictly worse

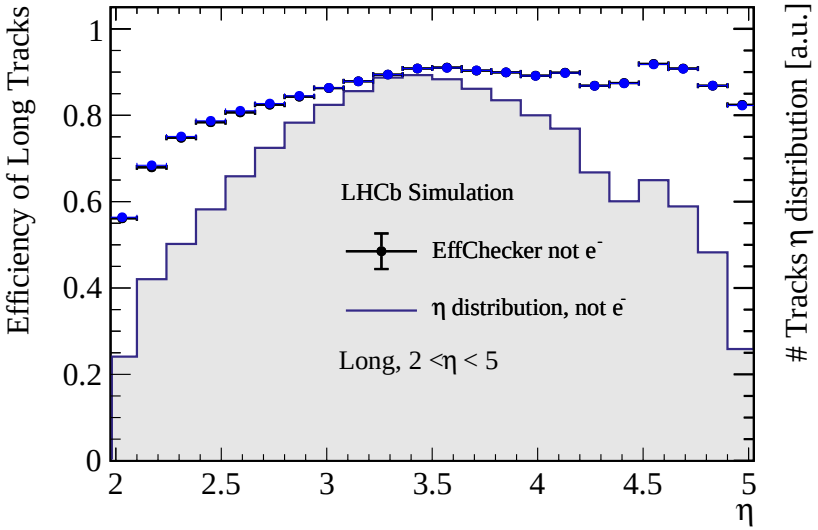
What went wrong?

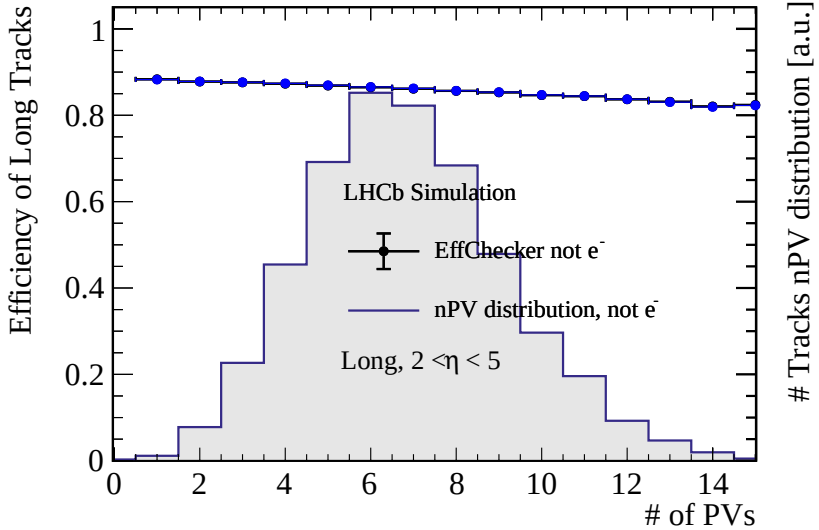
- Not enough time to investigate thoroughly, unfortunately...
- ... so do a simple process of elimination:
  1. Revert each parameterisation back to the old one
  2. Rerun reconstruction and check track efficiencies
  3. Figure out which parameterisation worsens the performance
- Culprit: z magnet kick position $\rightarrow$ Use old parameterisation for now!

Tracking performance with new parameterisation





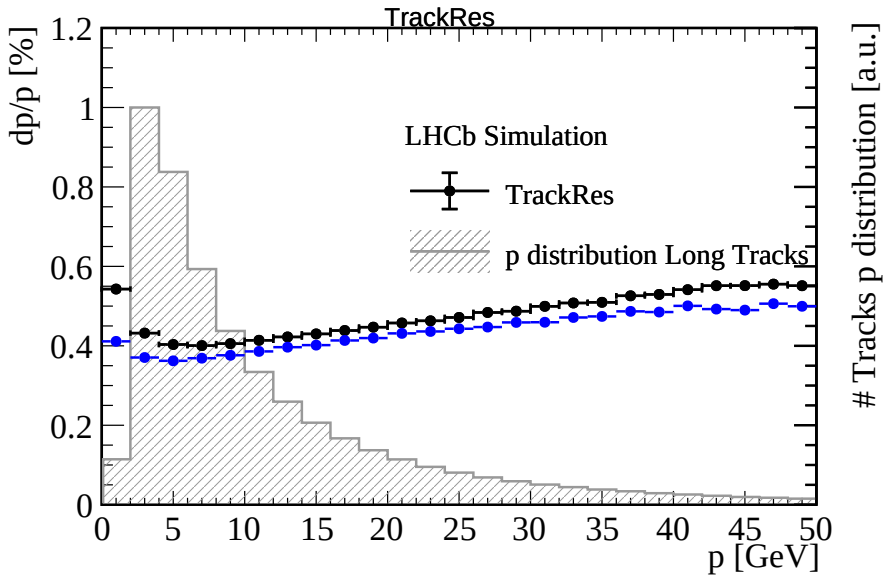


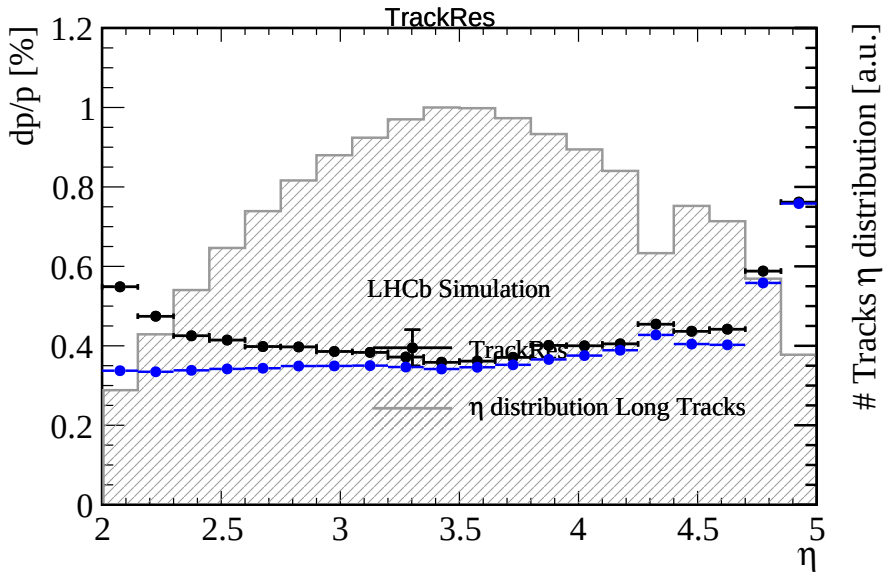


Black: Old parameterisation. Blue: Updated parameterisation with old z_{mag}.

Tracking performance with new parameterisation

What about momentum resolution?

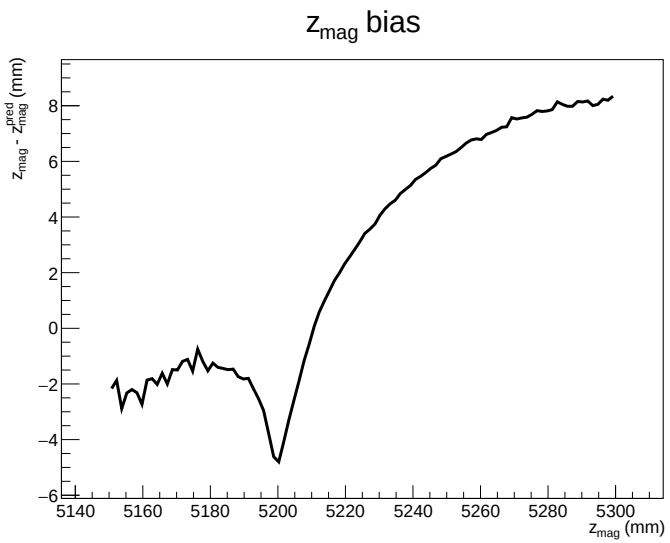


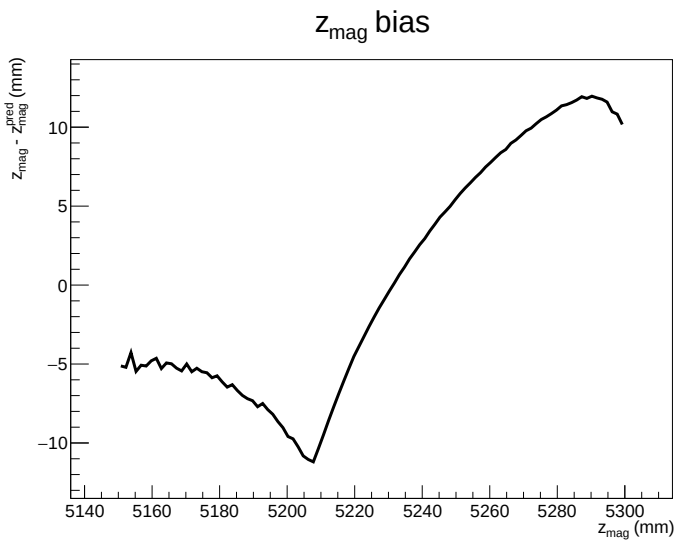


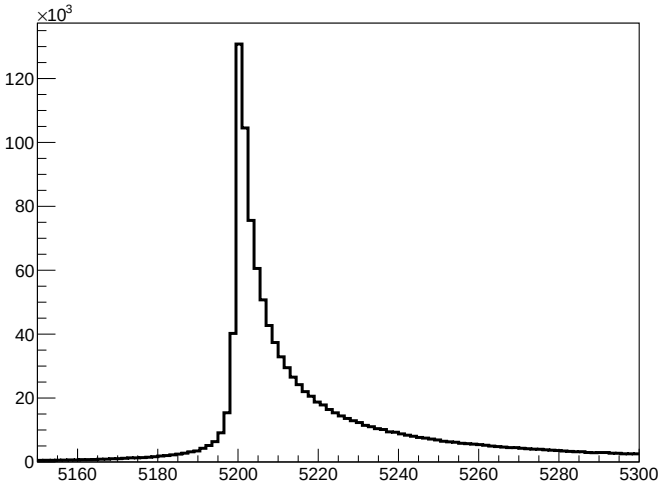
Black: Old parameterisation. Blue: Updated parameterisation with old z_{mag}.

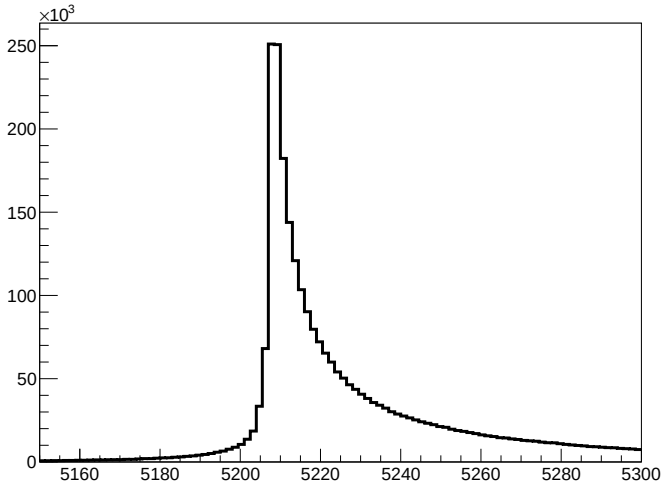
Clear improvement in momentum resolution!

Tracking performance with new parameterisation



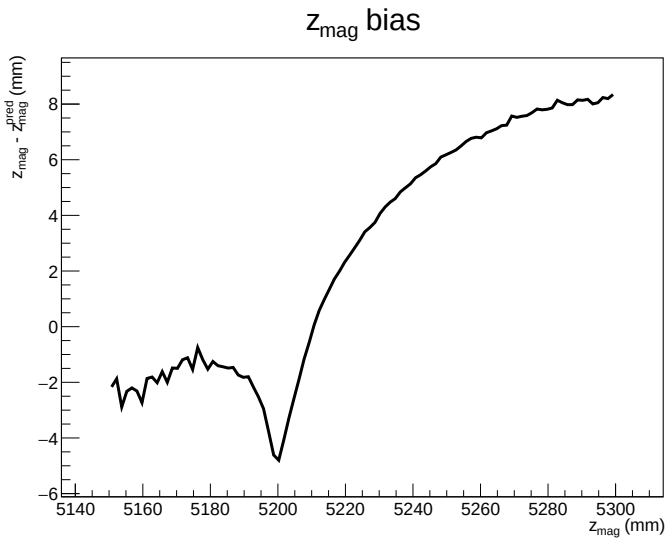


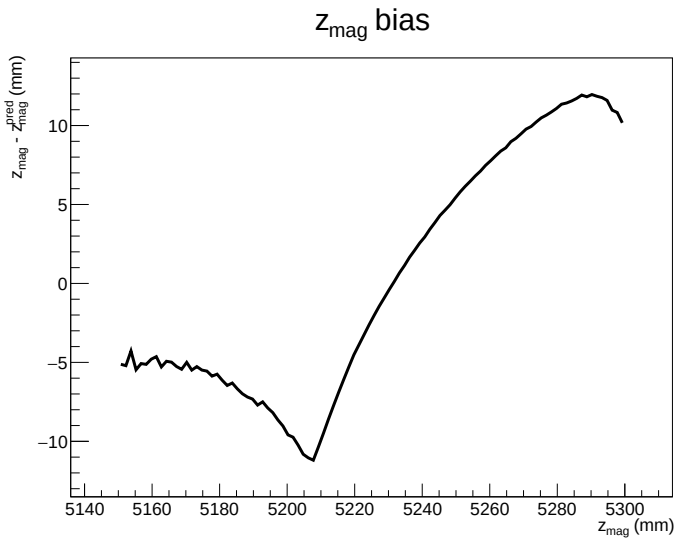




Left: Results with DC19. Right: Results with recent MC.

Tracking performance with new parameterisation





- In Andre's thesis, the bias in z_{mag} was found to be a few millimetres
  - Sufficient for this simple track model
- However, with the recent MC, this bias seems to be larger...
  - ... probably the choice of parameterisation is not ideal
  - I need to look into different parameterisations

Summary and next steps

- I have attempted to run the forward tracking parameterisations using Andre Günther's code "out of the box"
  1. Initial results showed a degradation in performance
  2. Traced the issue to the z_{mag} parameterisation
  3. Using the old z_{mag} parameterisation for now:
     - Very small improvement in track efficiencies
     - Noticeable improvement in momentum resolution

- Note: Results are very preliminary! Need to:
  1. Rerun studies with full set of MC samples
  2. Look into other parameterisations of z_{mag}

Thanks for listening!