First look at updated HLT2 forward tracking parameterisations

Martin Tat

Heidelberg University

14th May 2025

UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

Outline

1. Introduction

2. Overview of forward tracking algorithm

3. Current tracking performance

4. Tracking performance with new parameterisation

5. Conclusion

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)

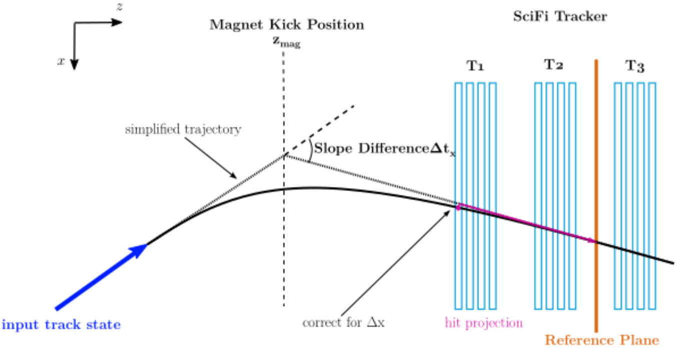
Introduction

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

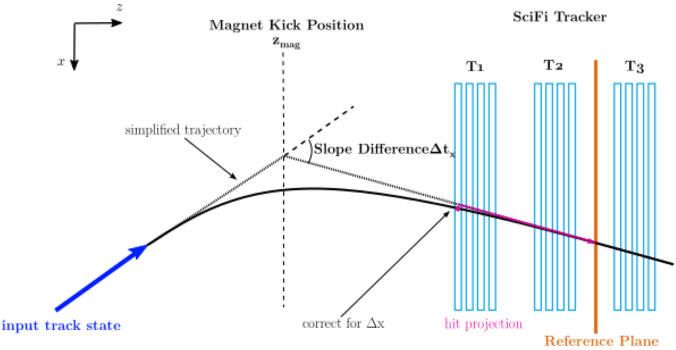


From CERN-THESIS-2023-097

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

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

Overview of forward tracking algorithm

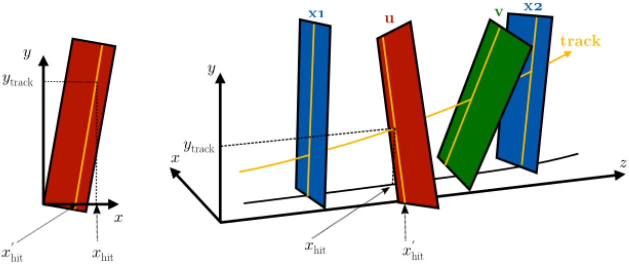


From CERN-THESIS-2023-097

- 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

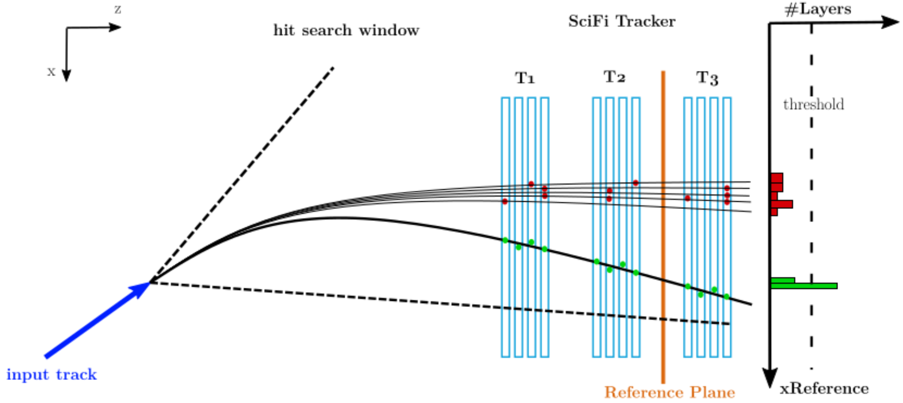


From CERN-THESIS-2023-097

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

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

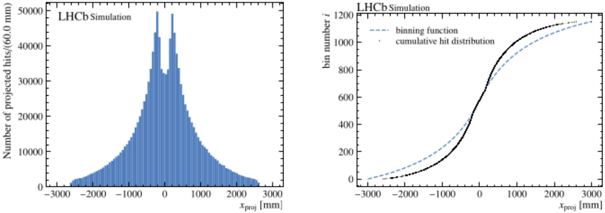
Overview of forward tracking algorithm



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.

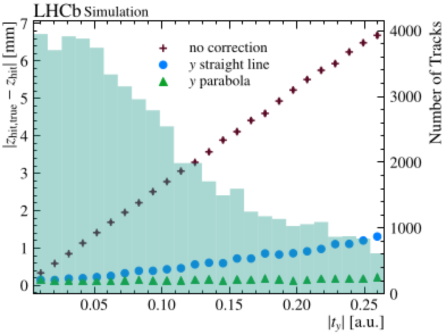
Figure 5.13: Distributions used to determine the binning scheme of the Hough histogram.

From CERN-THESIS-2023-097

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

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

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:

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

Overview of forward tracking algorithm

Finally, obtain momentum from change in track slope Δt_x:

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

The field integral B_{int} is parameterised as:

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

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:

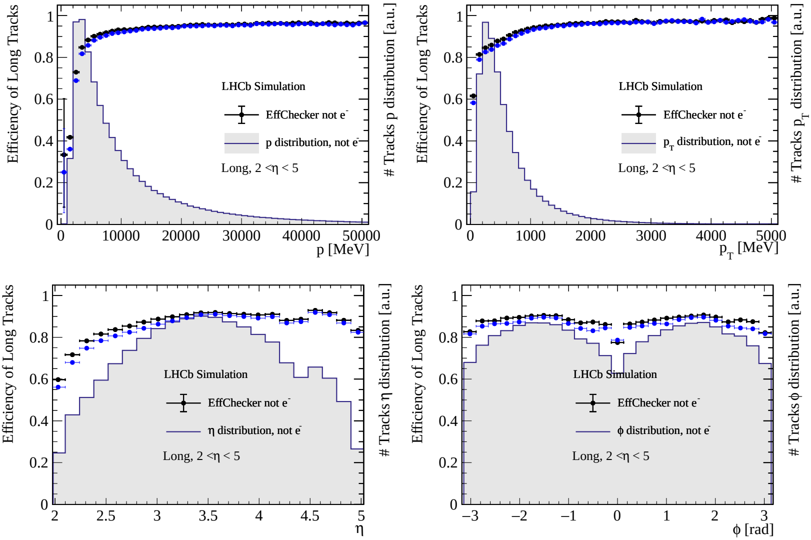
- Tracking efficiency vs p, p_T, η, $\texttt{nPVs}$, ϕ
    - Reconstructed / Reconstructible
    - Most important metric
- Momentum resolution vs p, η
    - Width of momentum residual distribution
    - Less important since track momentum is determined by Kalman fit

Current tracking performance

MC samples:

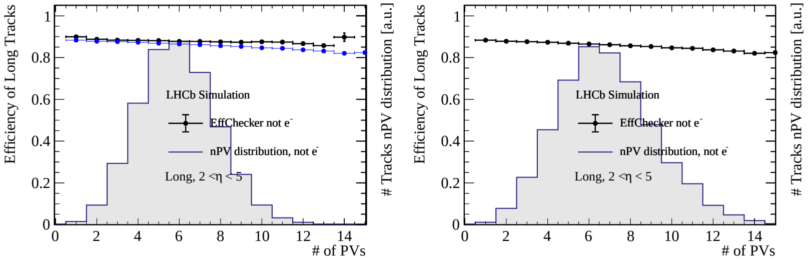
- DC19: Cross check with Andre's work
  - Found on Heidelberg cluster
  - Cocktail of $B_s^0 \to J/\psi\phi$, $B_s^0 \to \phi\phi$, $D^+ \to K_S^0\pi^+$, $Z^0 \to \mu^+\mu^-$, $D^{*+} \to [K^-\pi^+]_{D^0}\pi^+$, 50k MagUp/MagDown
- v8.1 field map: Private production
  - Many thanks to Jiahui and Alessandro 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
  - Production of official MC with new field map recently finished

Current tracking performance



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

Current tracking performance



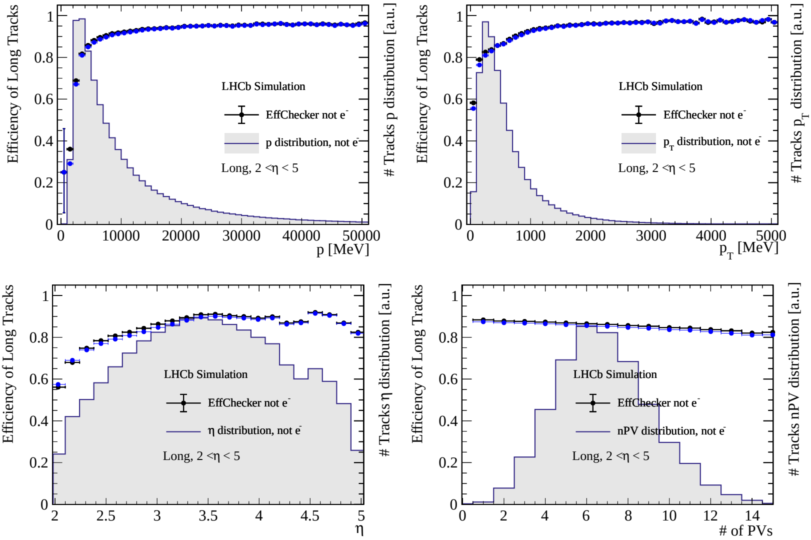
Left: DC19 in black and recent MC in blue. Right: Results with recent MC.

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

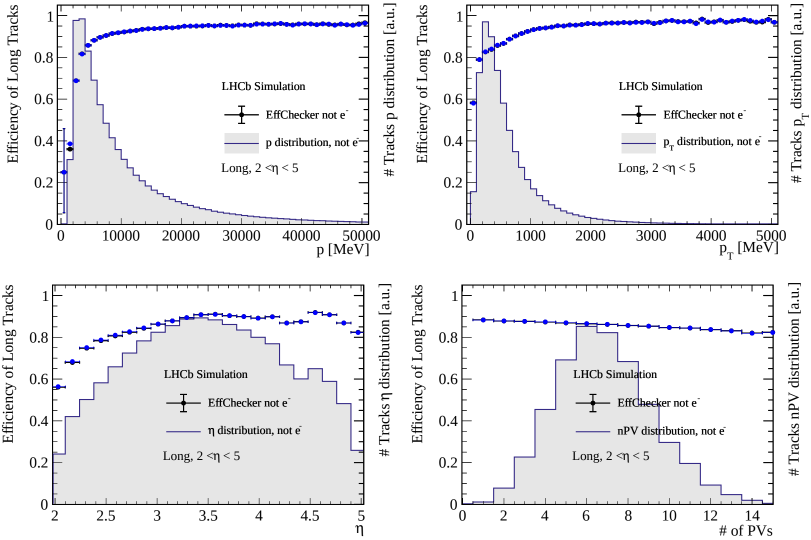
Observations with new parameterisation:

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

What went wrong?

- 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 → Use old parameterisation for now!

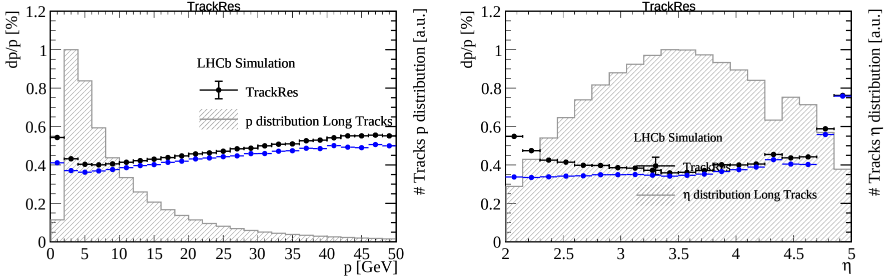
Tracking performance with new parameterisation



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

Tracking performance with new parameterisation

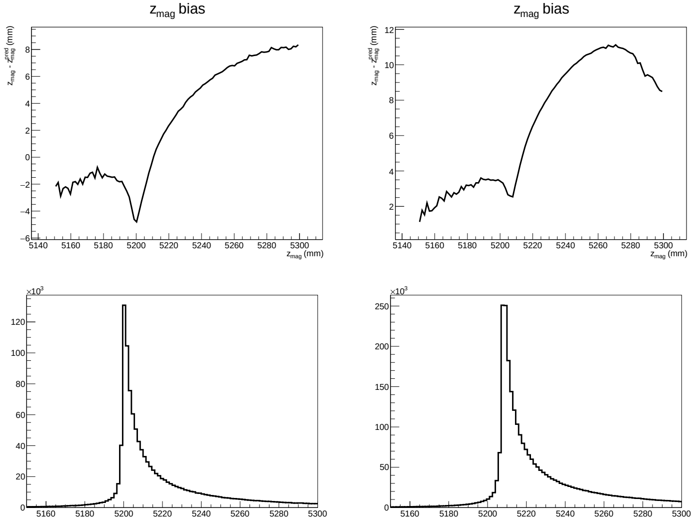
What about momentum resolution?



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

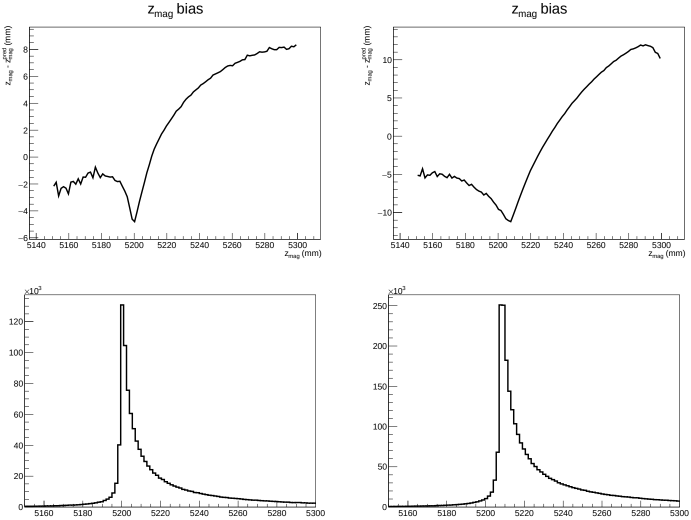
Clear improvement in momentum resolution!

Tracking performance with new parameterisation



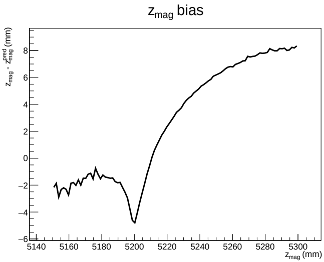
Left: Results with `DC19`. Right: Results with recent MC (old parameterisation).

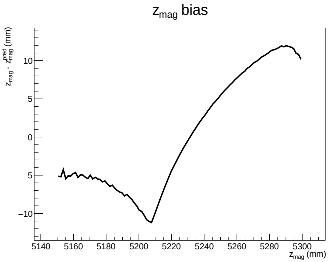
Tracking performance with new parameterisation



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

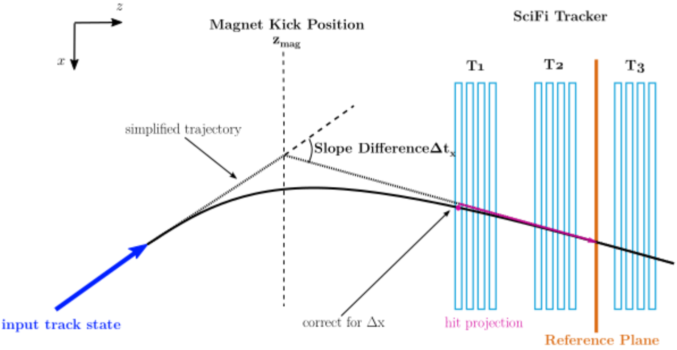
Tracking performance with new parameterisation





- 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

Back to overview of forward tracking algorithm

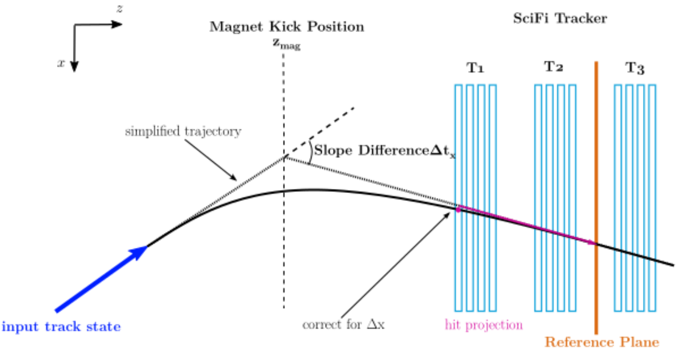


From CERN-THESIS-2023-097

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

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

Back to overview of forward tracking algorithm

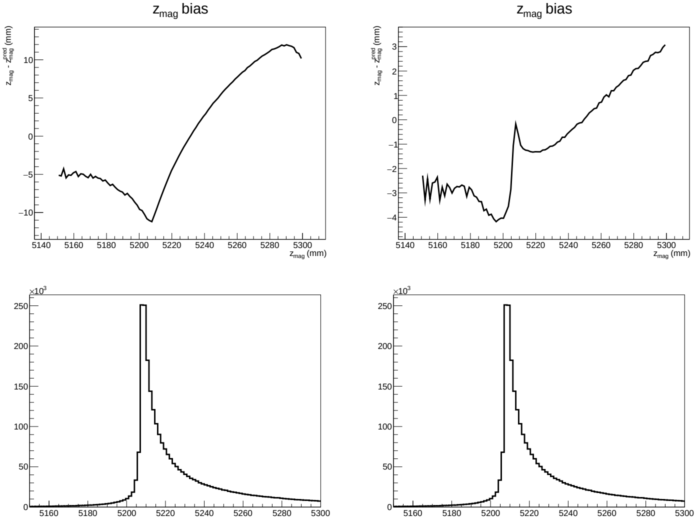


From CERN-THESIS-2023-097

- Try a more sophisticated parameterisation of z_{mag}:

$$\begin{aligned} z_{\mathrm{mag}} = & c_0 + c_1 t_x^2 + c_3 t_y^2 + \Delta t'_x (c_2 t_x + c_4 \Delta t'_x) \\ & + c_5 |\Delta t_x| + c_6 |\Delta t_x|^3 \end{aligned}$$

Tracking performance with improved parameterisation



Left: Andre's parameterisation. Right: My proposed parameterisation.

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. When using the old z_{mag} parameterisation:
     - Very small improvement in track efficiencies
     - Noticeable improvement in momentum resolution
- I have attempted to improve the z_{mag} model
  - Preliminary studies show reduced biases in z_{mag}

Thanks for listening!