Update on forward tracking parameterisation update

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Introduction

I previously presented an update on the HLT2 forward tracking parameterisations

- Link to Indico here
- 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
- Parameterisations updated using new MC samples
  - New magnetic field map (presented here)
  - Initially worked with a private MC production
  - Moved to centrally produced samples here

Reminder: Parameterisations in HLT2 forward tracking

Last time I presented these parameterisations:

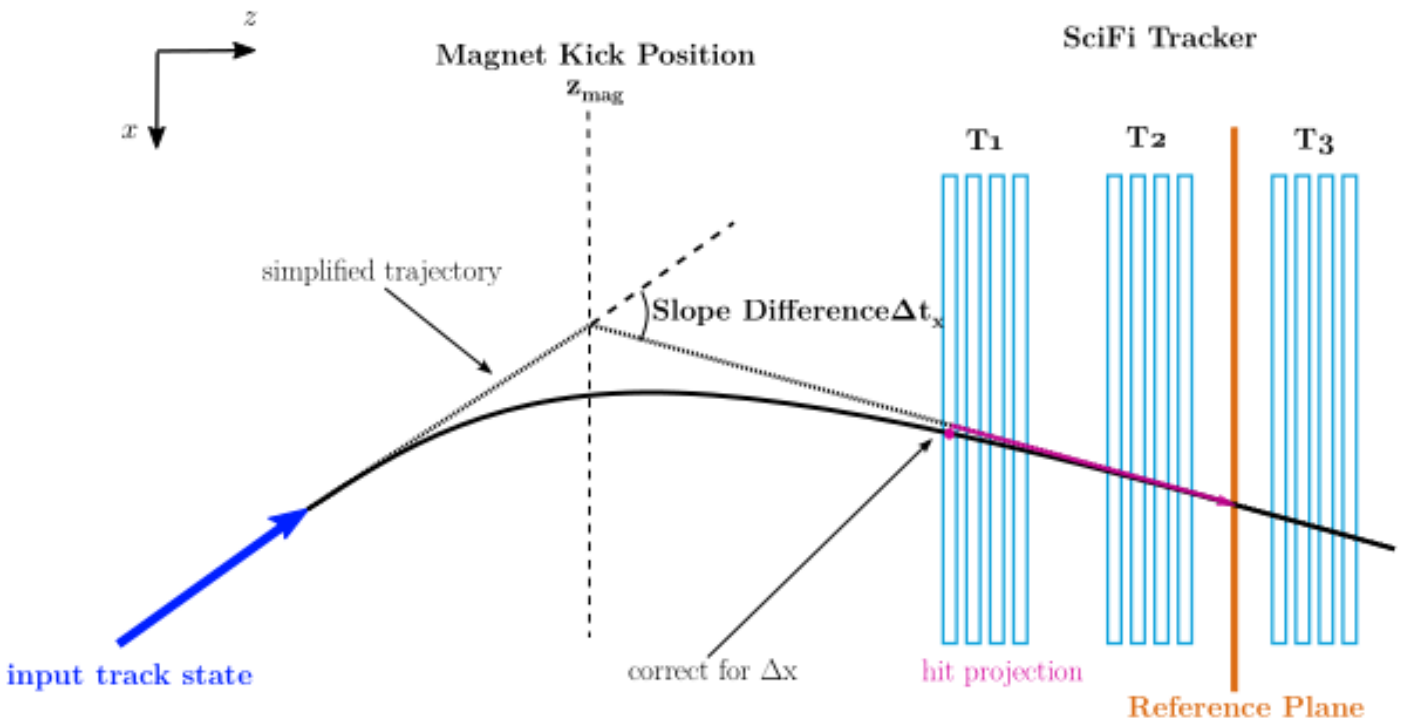
1. z magnet kick position
2. x fringe field correction
3. Stereo angle y correction
4. Hough histogram binning
5. z hit correction with SciFi yz tilt
6. Magnetic field integral

Reminder: Parameterisations in HLT2 forward tracking

Last time I presented these parameterisations:

1. z magnet kick position $\leftarrow$ Caused some issues
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

Reminder: z_{mag} parameterisation

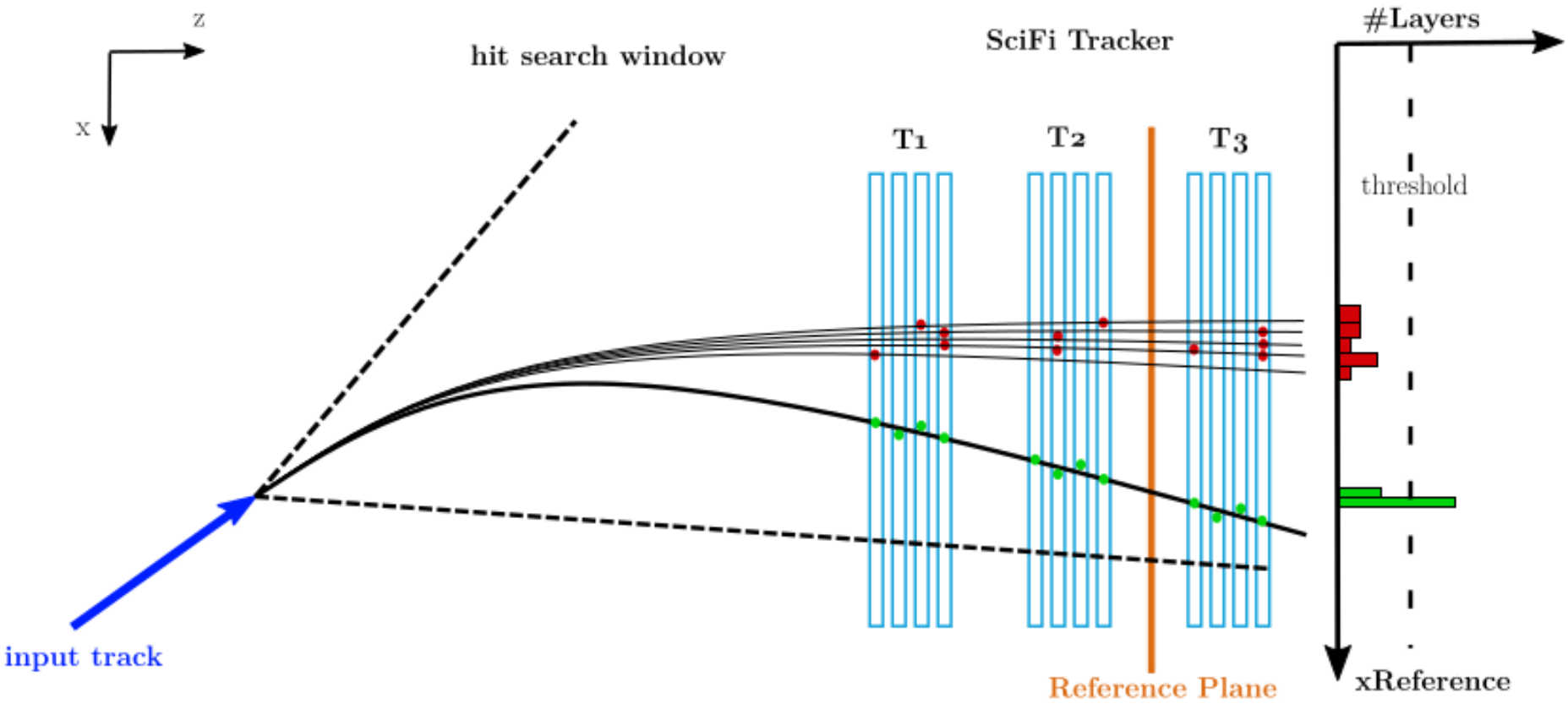


From CERN-THESIS-2023-097

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

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

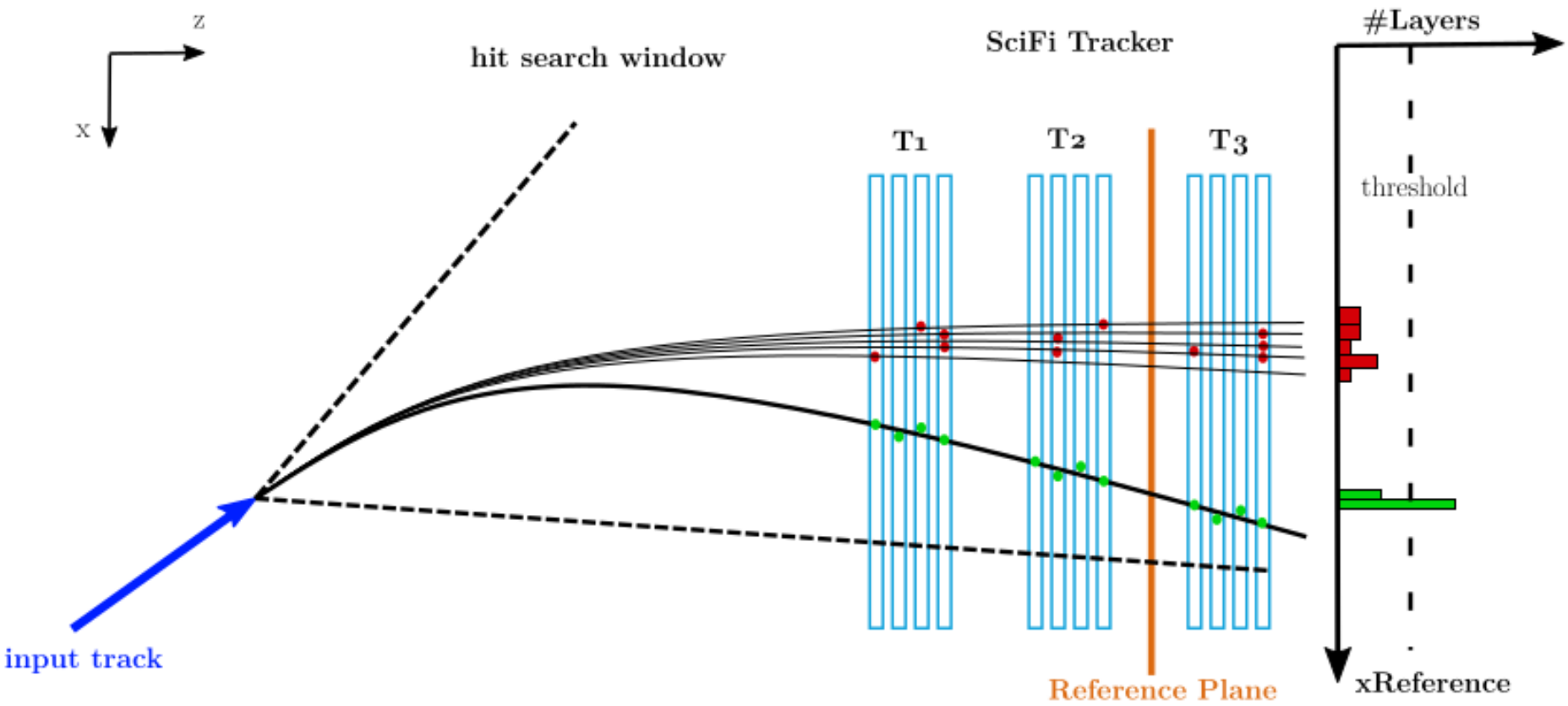
Reminder: Hit mapping to reference plane



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"

Reminder: Hit mapping to reference plane



From CERN-THESIS-2023-097

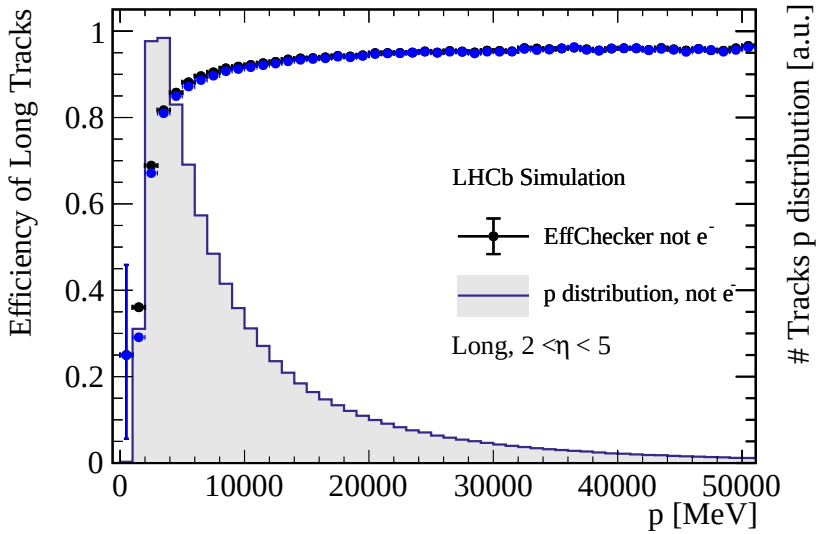
- Mapping depends on momentum, as low momentum tracks bend more
- Define a search window by assuming $p = p_{\text{min}} = 1500$ MeV/c

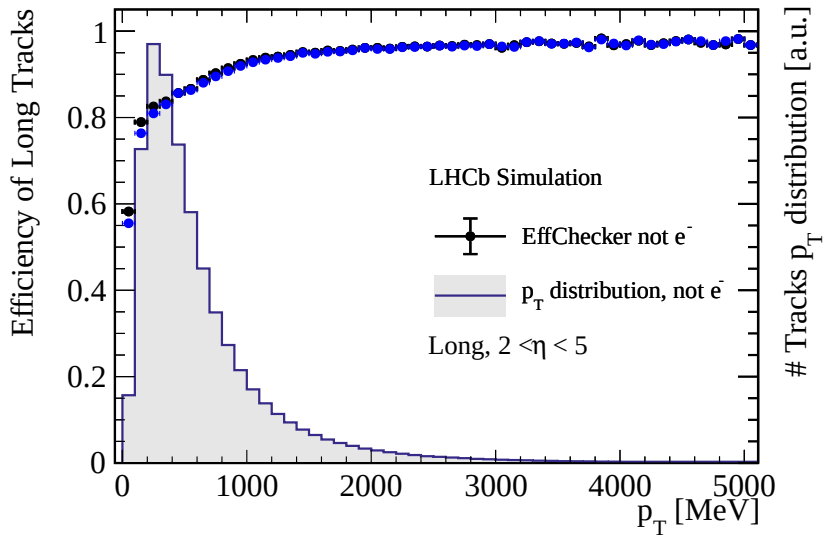
Reminder: Tracking efficiencies with new parameterisation

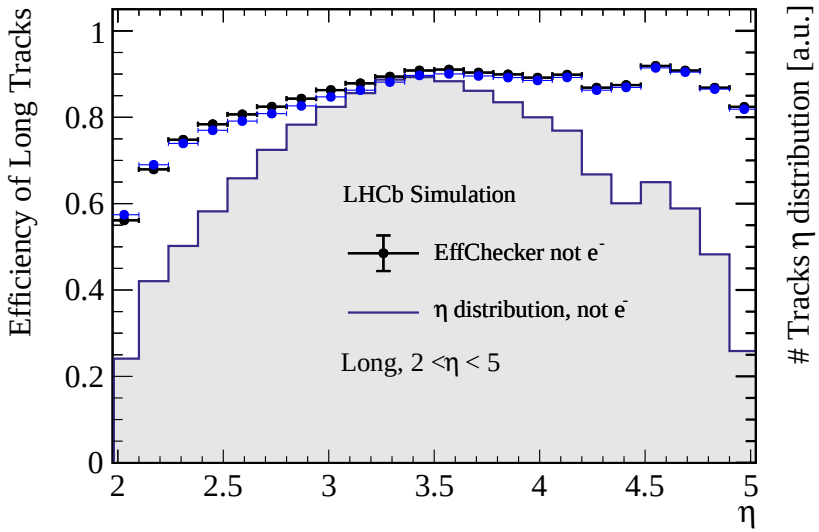
Previously: Performance found to be worse after update

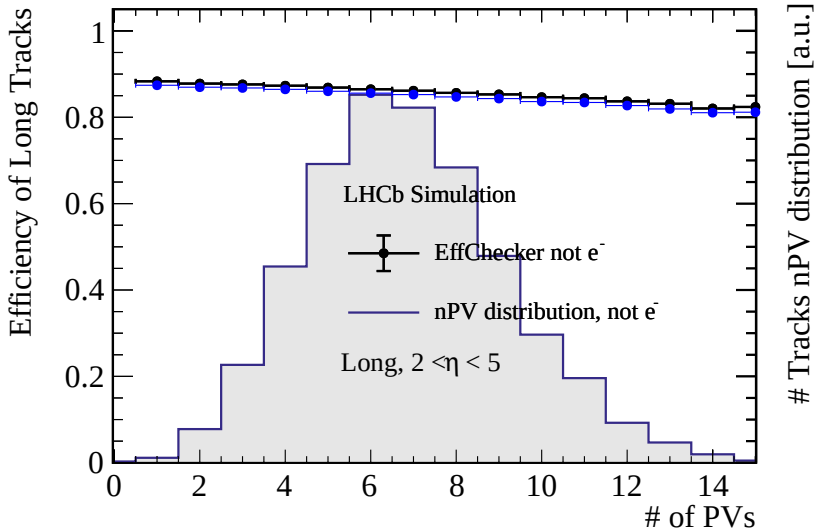
- Traced back to the z_{mag} parameterisation
- Reverting back to old z_{mag} parameterisation
  - Negligible change in performance compared to `2025-patches`
- Possible explanation: Biases in z_{mag} are larger with new MC

Reminder: Tracking efficiencies with new parameterisation



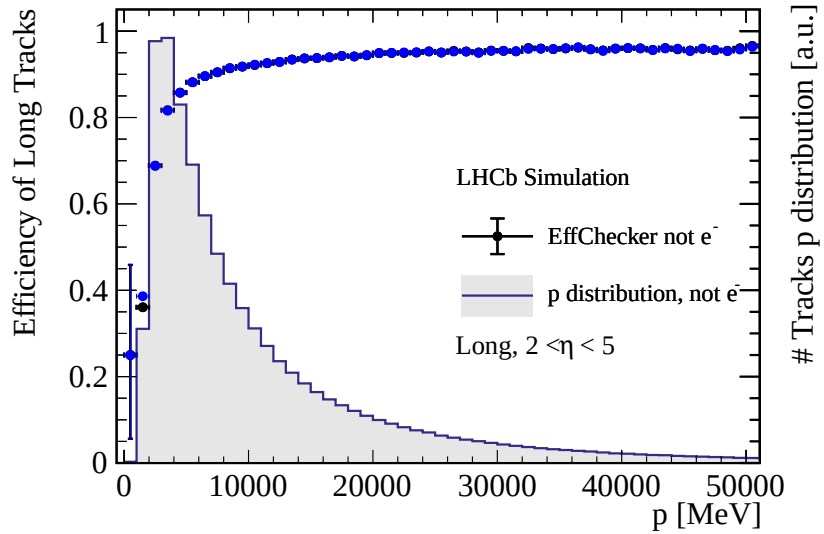


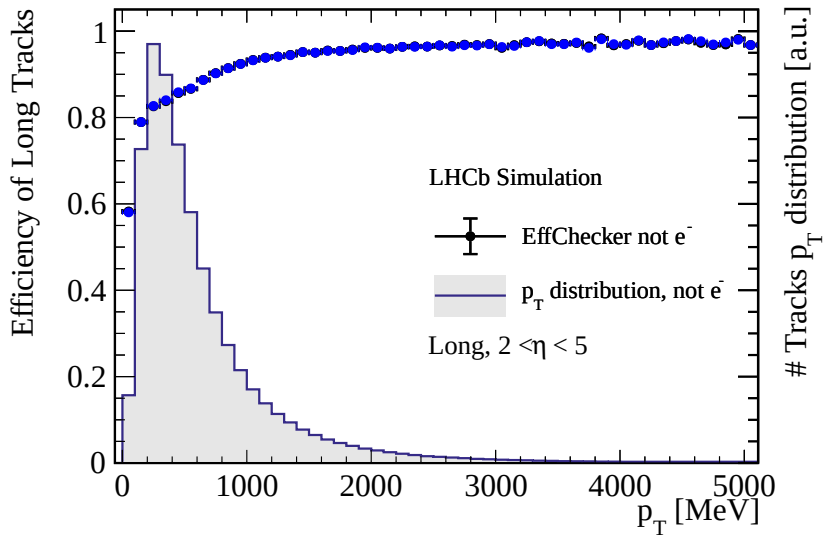


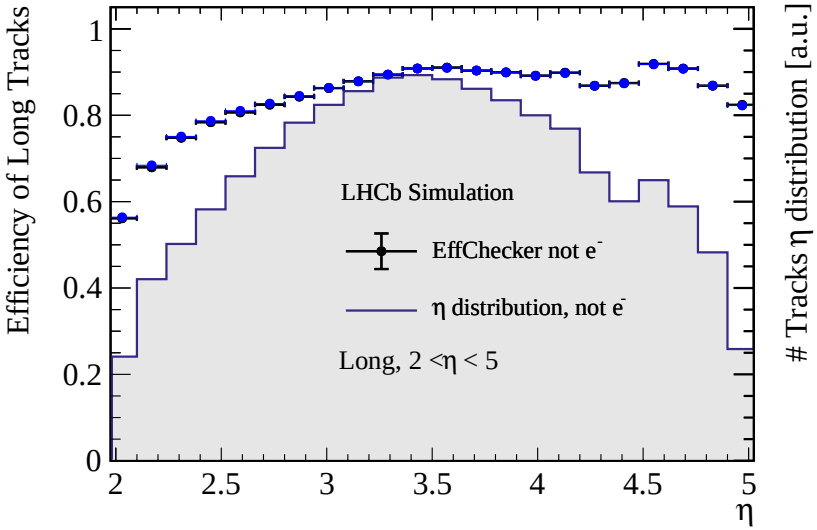


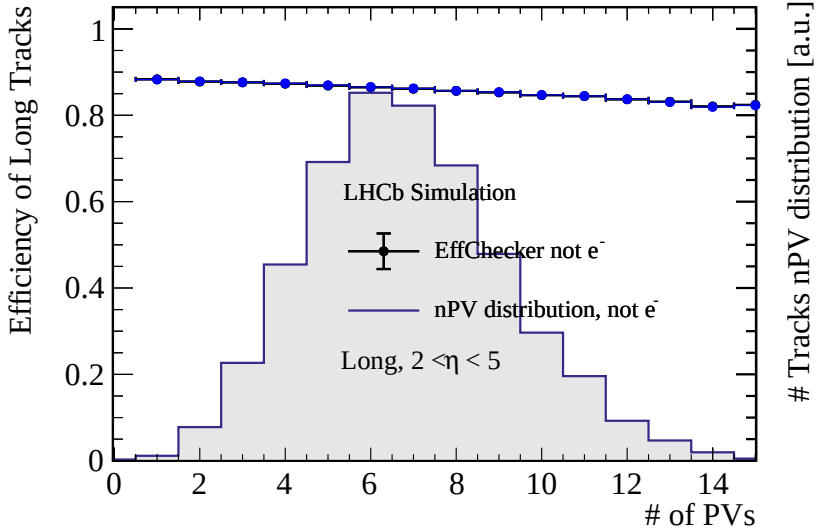
Black: Old parameterisation. Blue: Updated parameterisation.

Reminder: Tracking efficiencies with new parameterisation





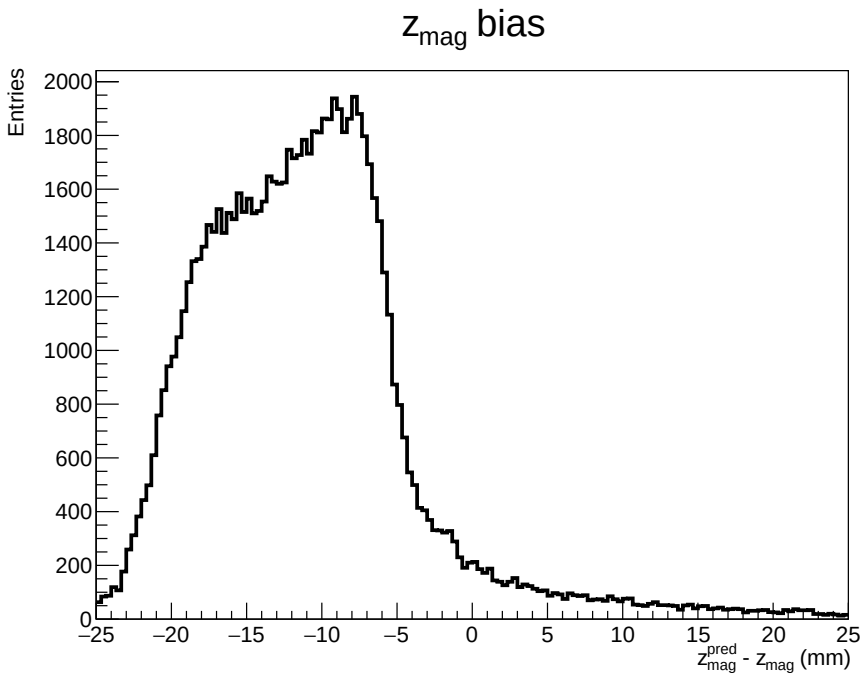


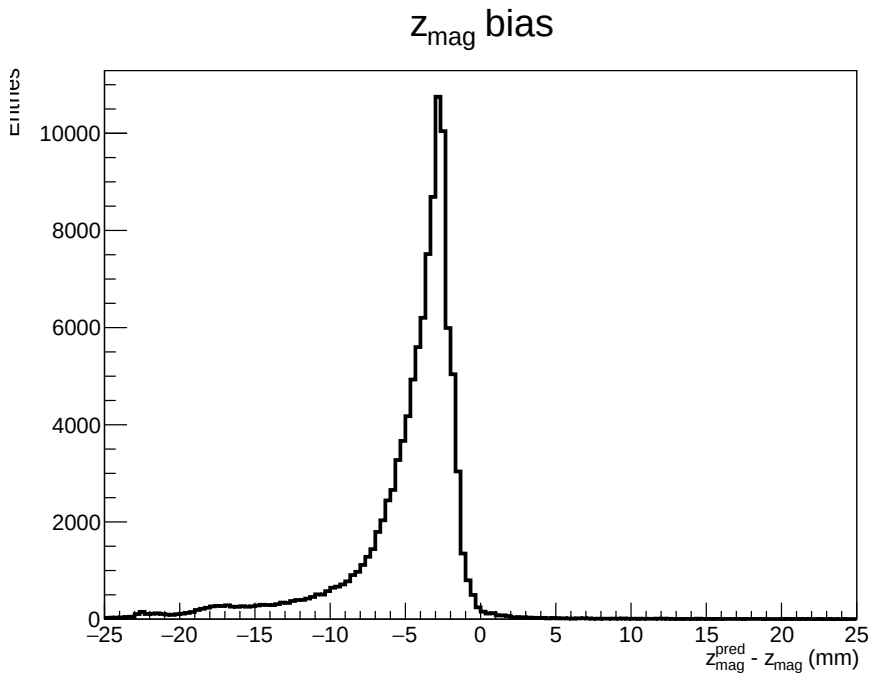


Black: Old parameterisation. Blue: Updated parameterisation with old z_{mag}.

Study of z_{mag} bias

Study bias $z_{\mathrm{mag}}^{\mathrm{pred}} - z_{\mathrm{mag}}$ of original parameterisation:



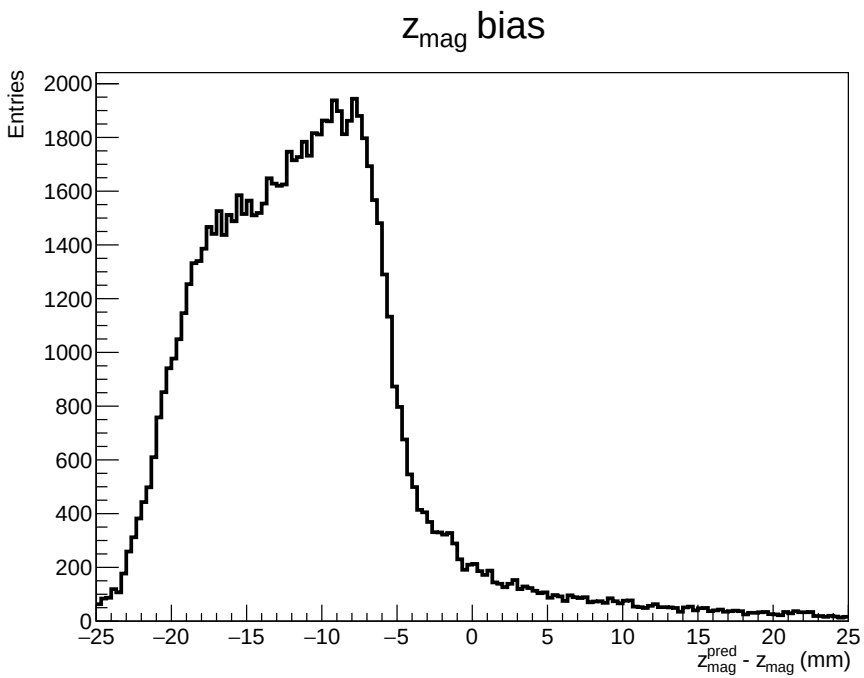


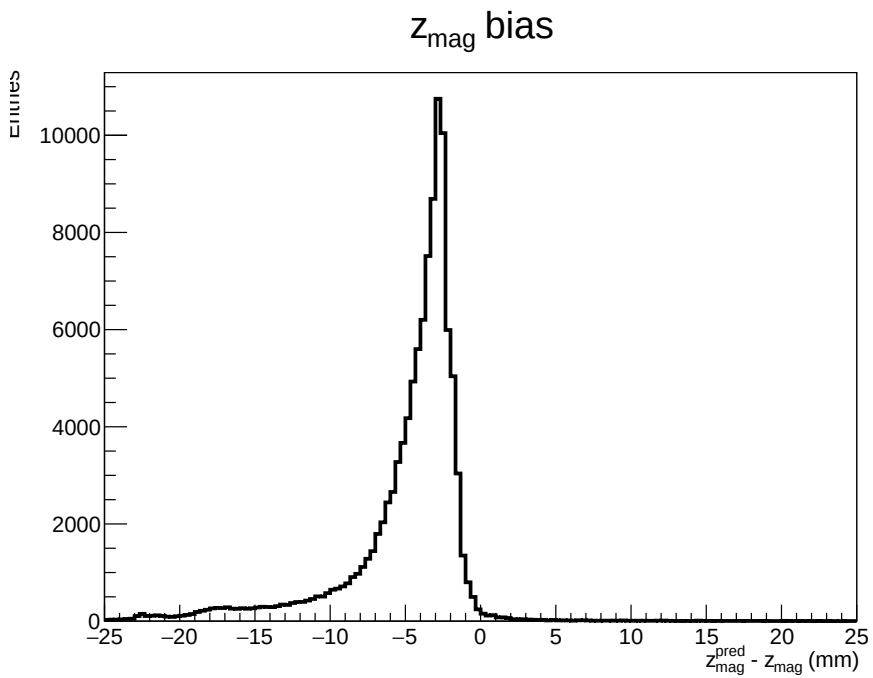
Left: $p < 7$ GeV. Right: $p > 7$ GeV.

- Parameterisation struggles a low momentum
  - Large negative bias
  - Very wide distribution

Study of z_{mag} bias

Study bias $z_{\mathrm{mag}}^{\mathrm{pred}} - z_{\mathrm{mag}}$ of original parameterisation:



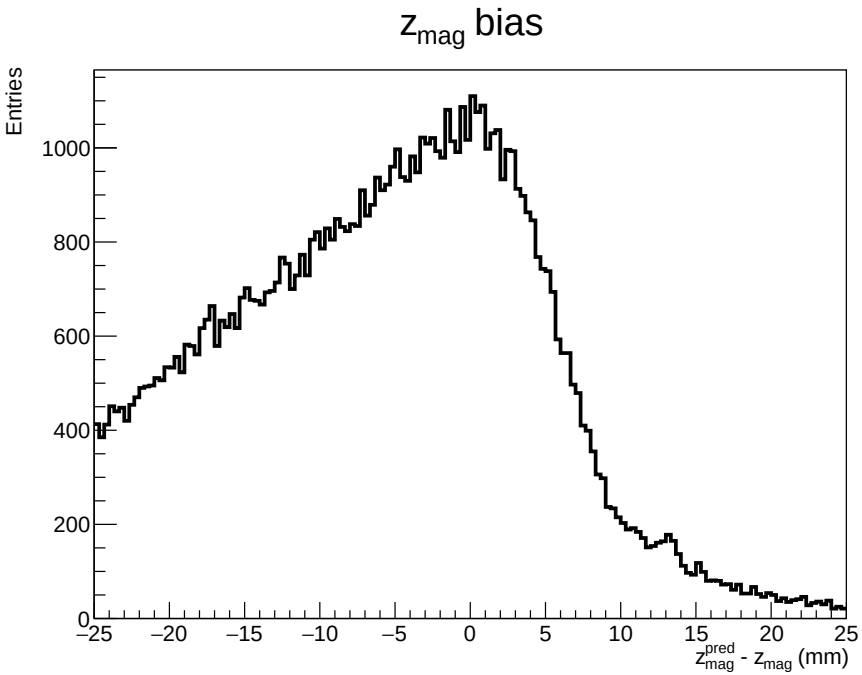


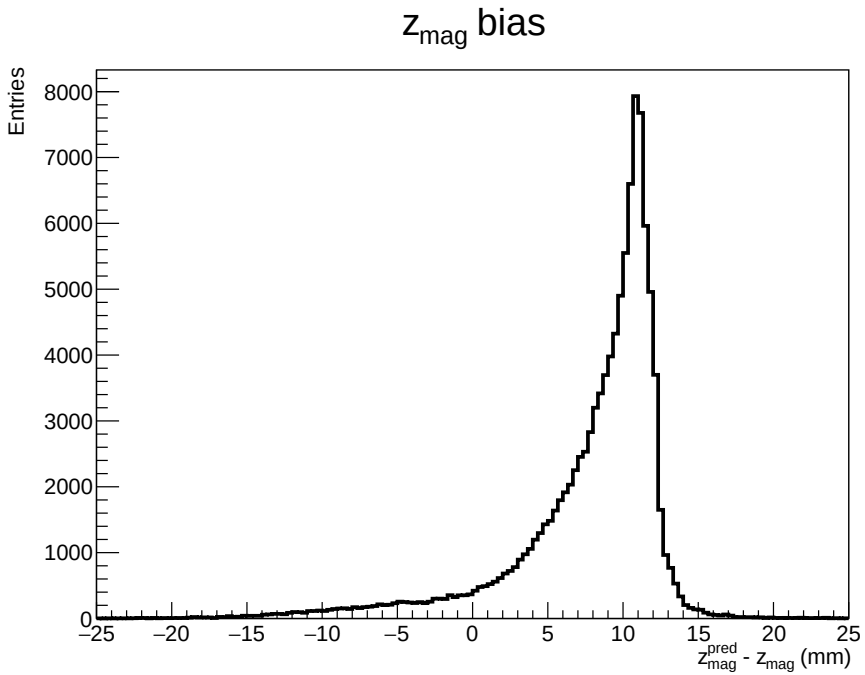
Left: $p < 7$ GeV. Right: $p > 7$ GeV.

- Parameterisation works well at high momentum
  - Small and almost negligible bias
  - Very small variance

Study of z_{mag} bias

If we only update coefficients of z_{mag} parameterisation:

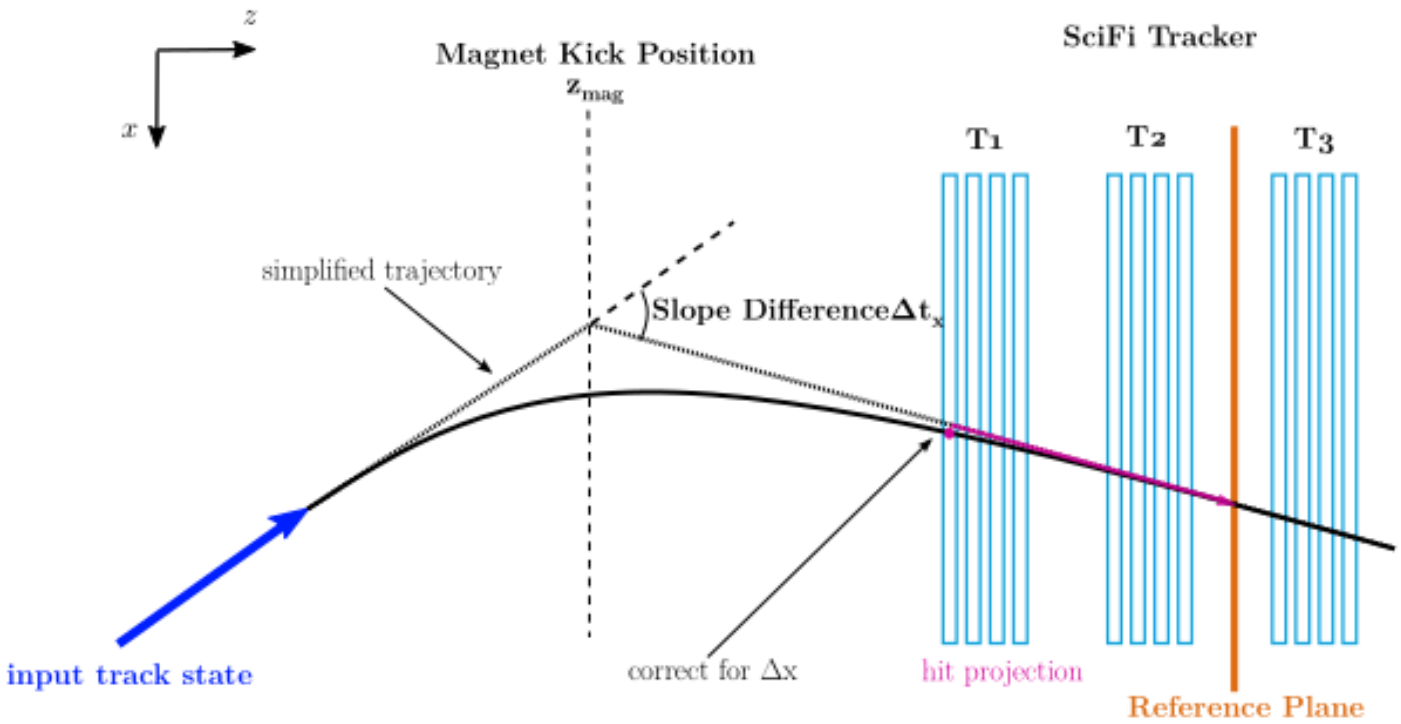




Left: $p < 7$ GeV. Right: $p > 7$ GeV.

- Potential explanation of worse performance with new coefficients:
  - Bias is generally worse
  - Parameterisation doesn't describe z_{mag} well

Reminder: z_{mag} parameterisation

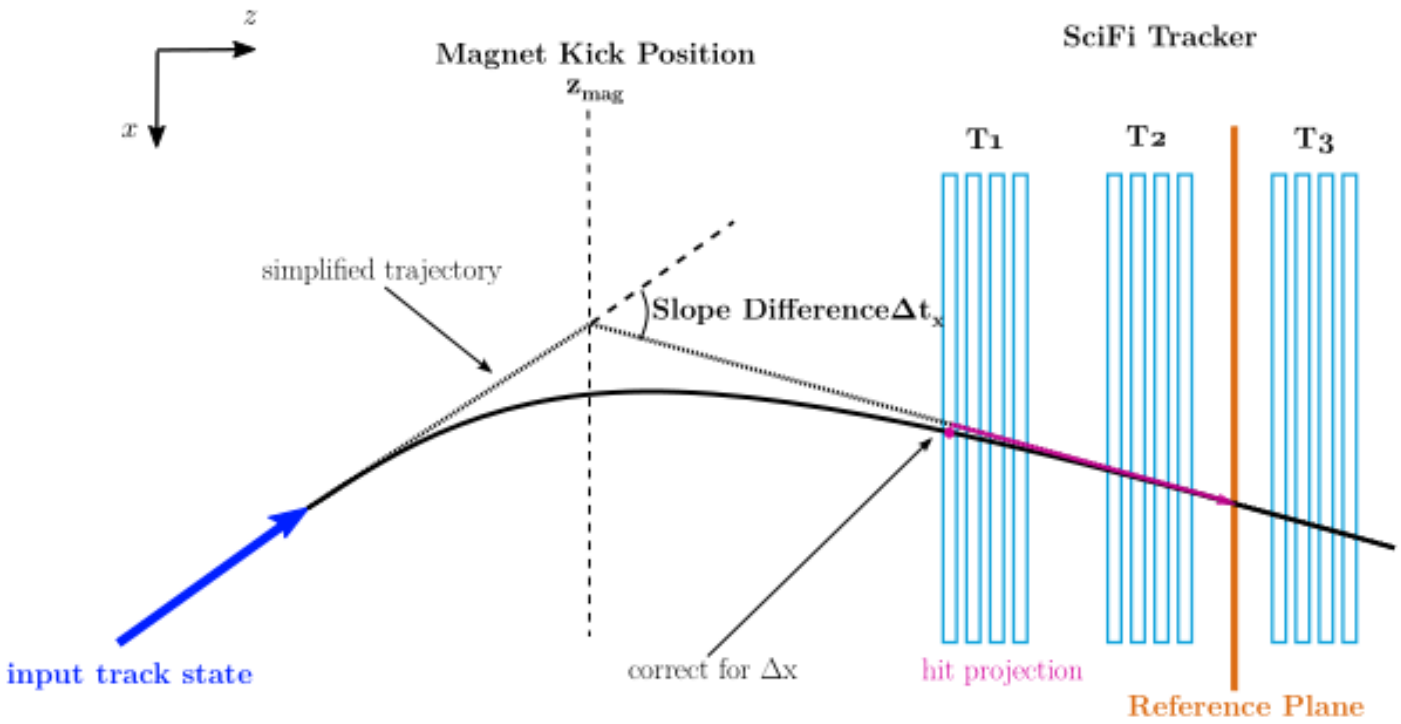


From CERN-THESIS-2023-097

- Original z_{mag} parameterisation:

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

Improved z_{mag} parameterisation



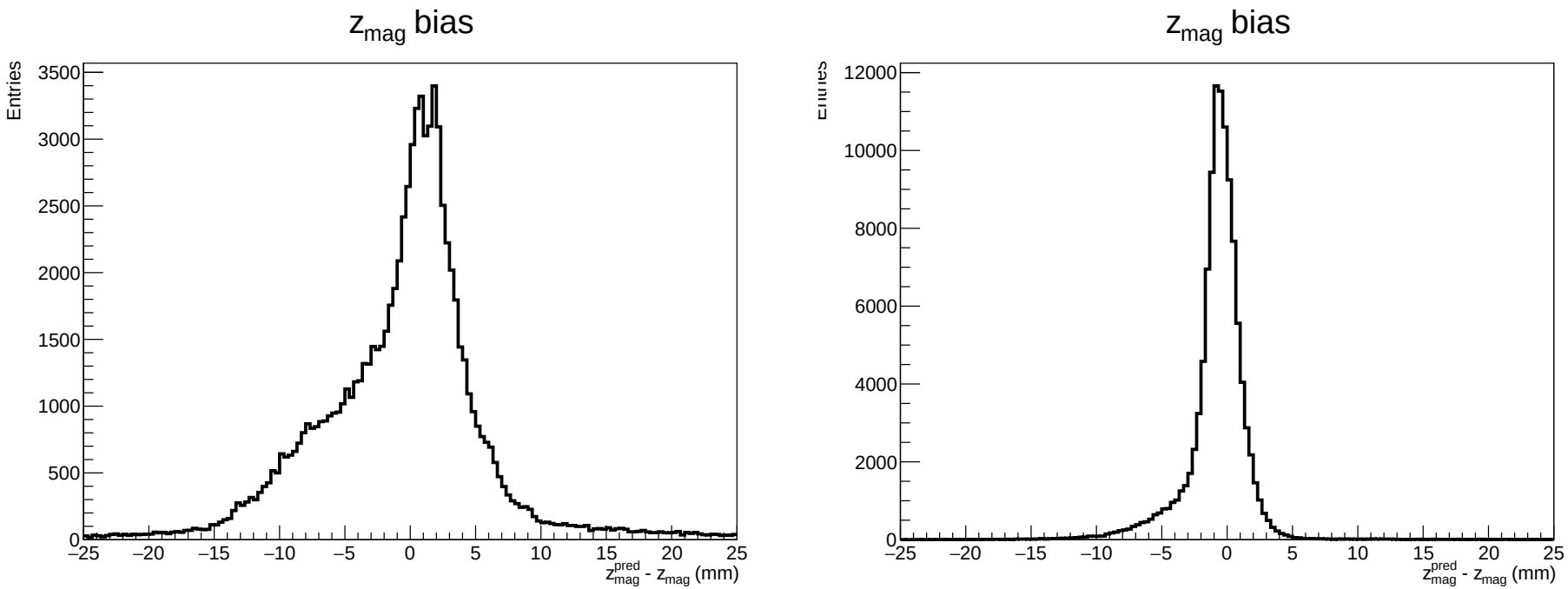
From CERN-THESIS-2023-097

- After trial and error, this parameterisation was obtained:

$$\begin{aligned} z_{\mathrm{mag}} =& c_0 + c_1 t_x^2 + c_3 t_y^2 + \Delta t_x' (c_2 t_x + c_4 \Delta t_x') \\ &+ (c_5 + c_6 t_x^2 + c_7 t_y^2 + c_8 |\Delta t_x'|^2) |\Delta t_x'| \end{aligned}$$

Study of z_{mag} bias

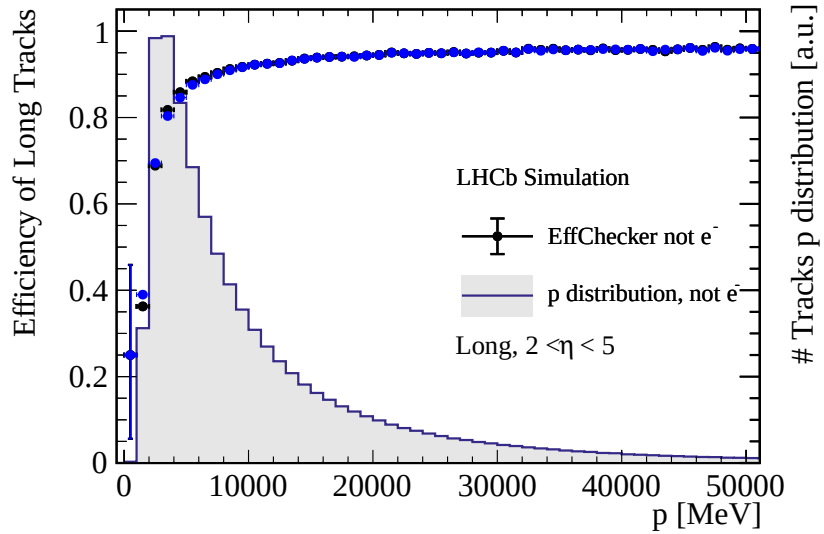
Check biases with new improved parameterisation:

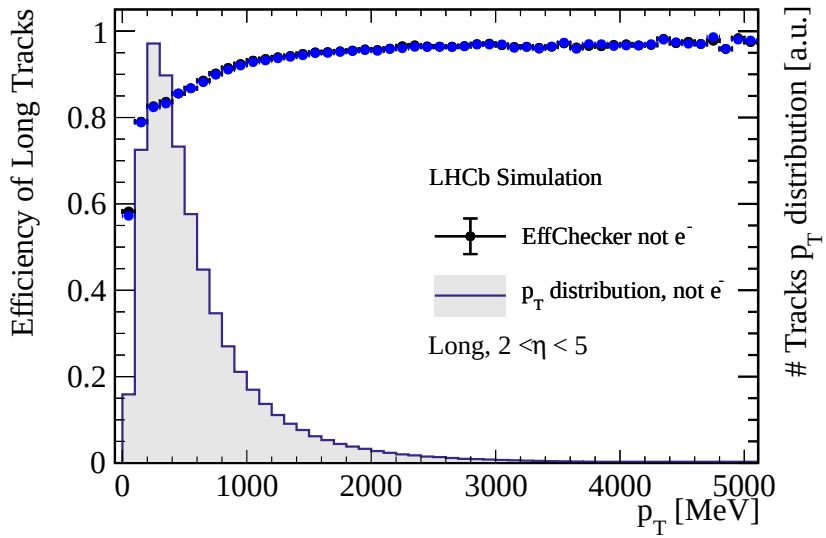


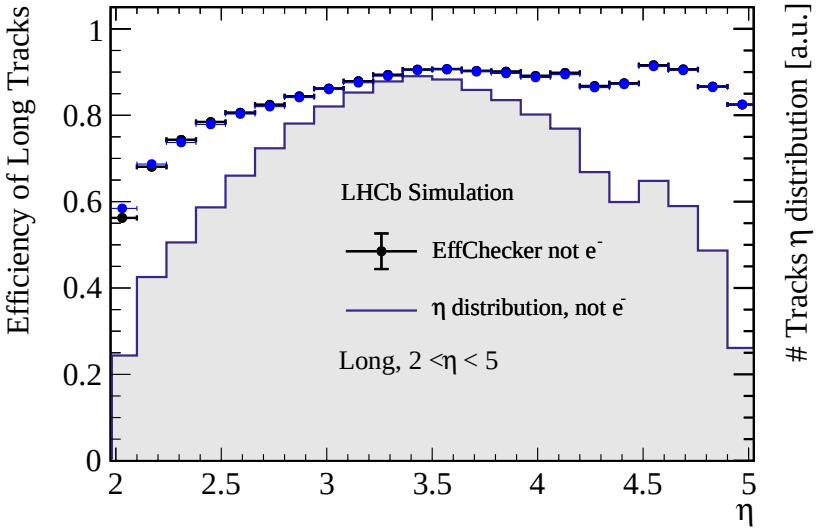
Left: $p < 7$ GeV. Right: $p > 7$ GeV.

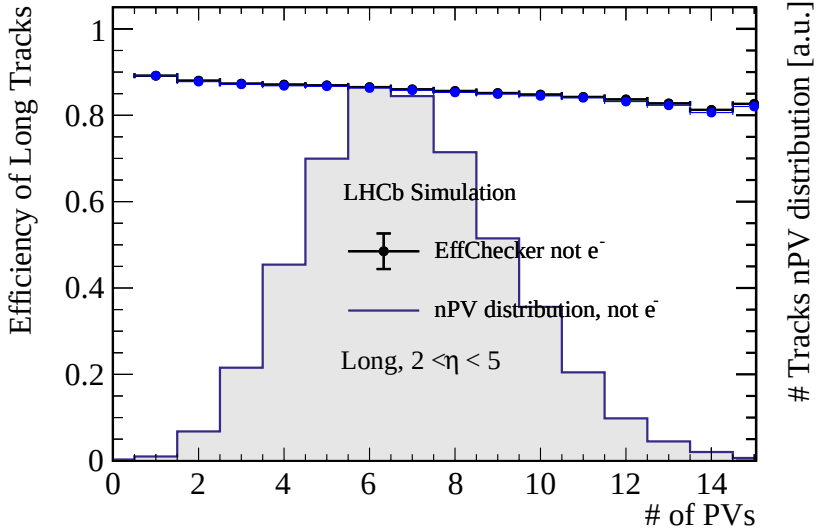
- Huge improvement in biases:
  - Almost symmetric and unbiased distribution at high momentum
  - Mostly unbiased at low momentum, with a left tail

Tracking efficiencies with new improved parameterisation







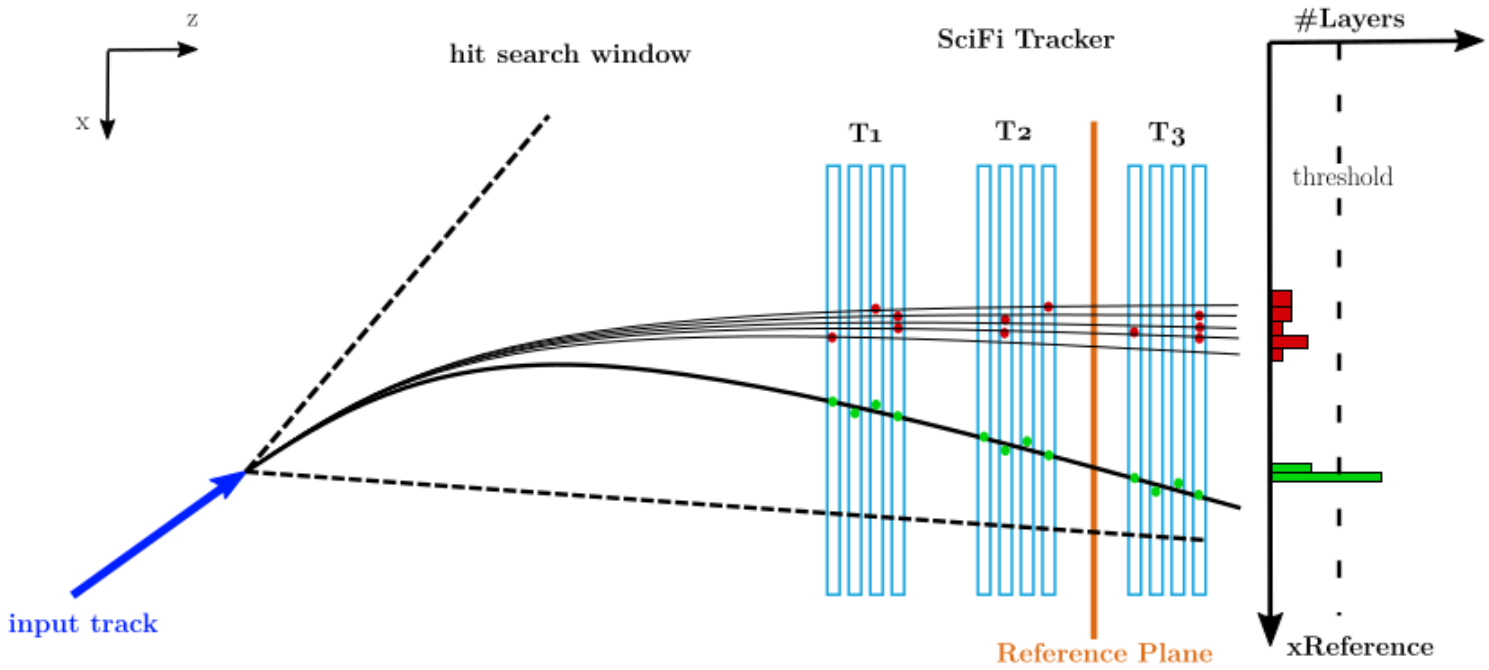


Black: Old parameterisation. Blue: Updated parameterisation of z_{mag}.

Tracking efficiencies with new improved parameterisation

- Perhaps we should keep the original z_{mag} parameterisation?
  - Determined by Andre Günther using DC19 MC
- Total tracking efficiency dropped from 86.01% to 85.75% with updated parameterisation
- Efficiencies get worse with more accurate parameterisation...
- ...but perhaps in this case doing the wrong thing is better
- Is there a straightforward explanation for this...?

Reminder: Hit mapping to reference plane

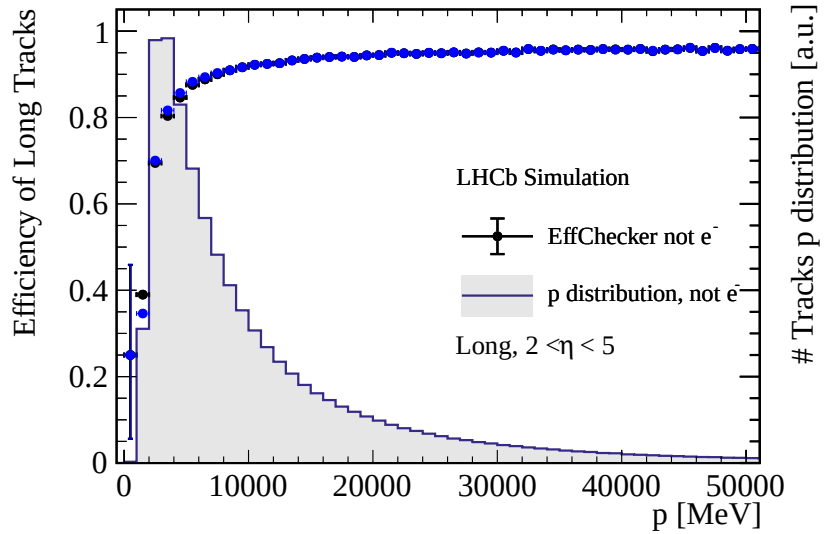


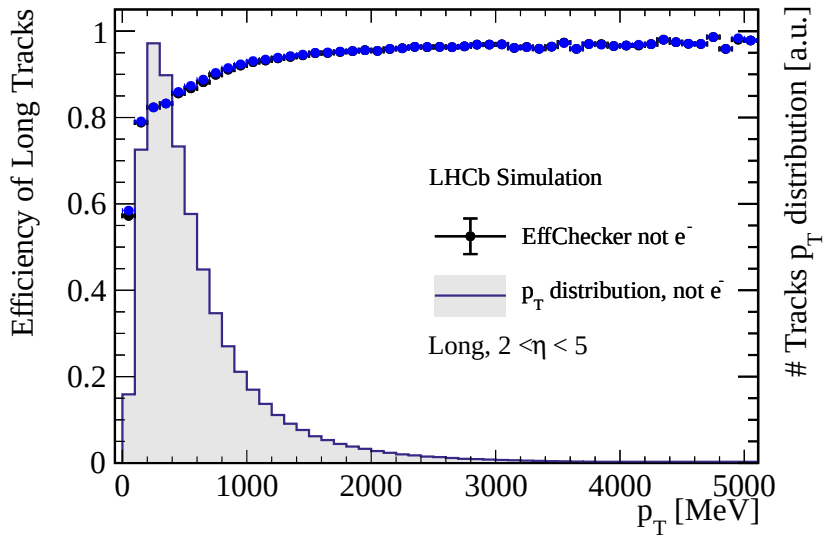
From CERN-THESIS-2023-097

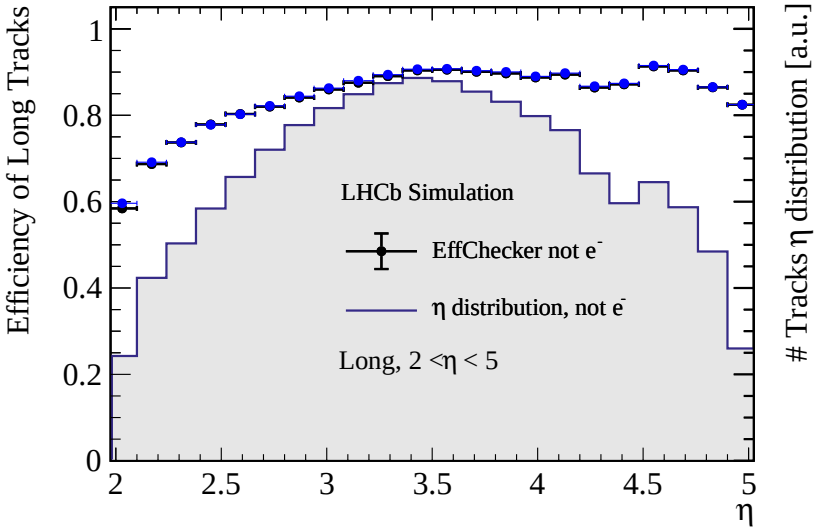
- Define a search window by assuming $p = p_{\text{min}} = 1500$ MeV/c
- My understanding is:
  - z_{mag} is underestimated $\rightarrow$ Search window becomes larger!

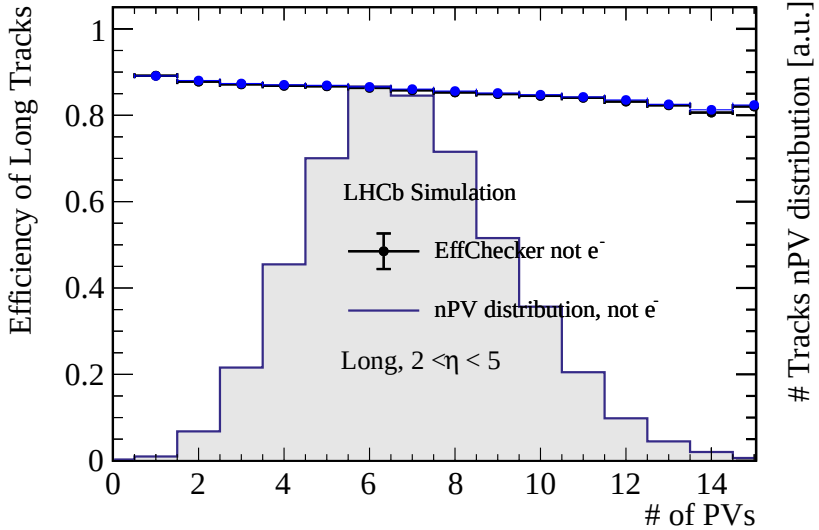
  $\rightarrow$ Add -9.5 mm bias at low momentum to improve performance

Tracking efficiencies with biased z_{mag} parameterisation









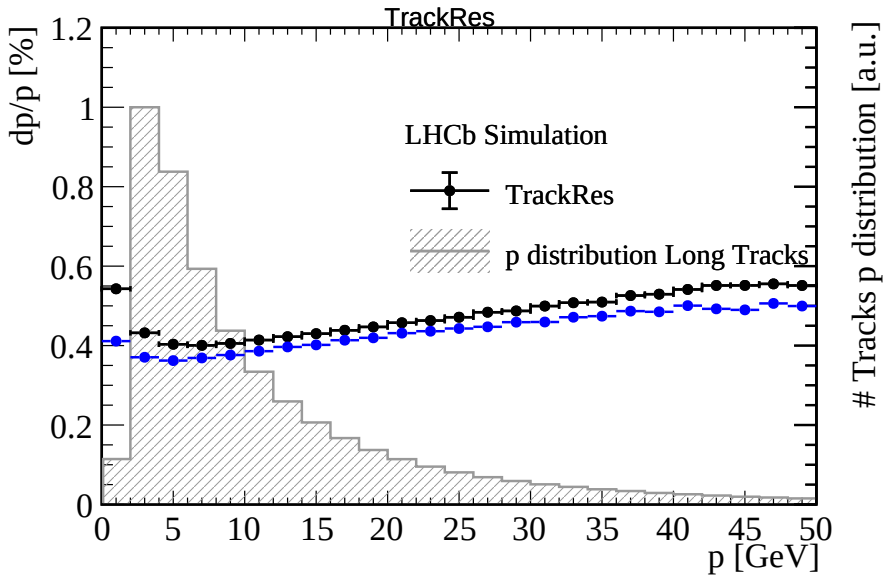
Black: Updated parameterisation. Blue: With bias in z_{mag}.

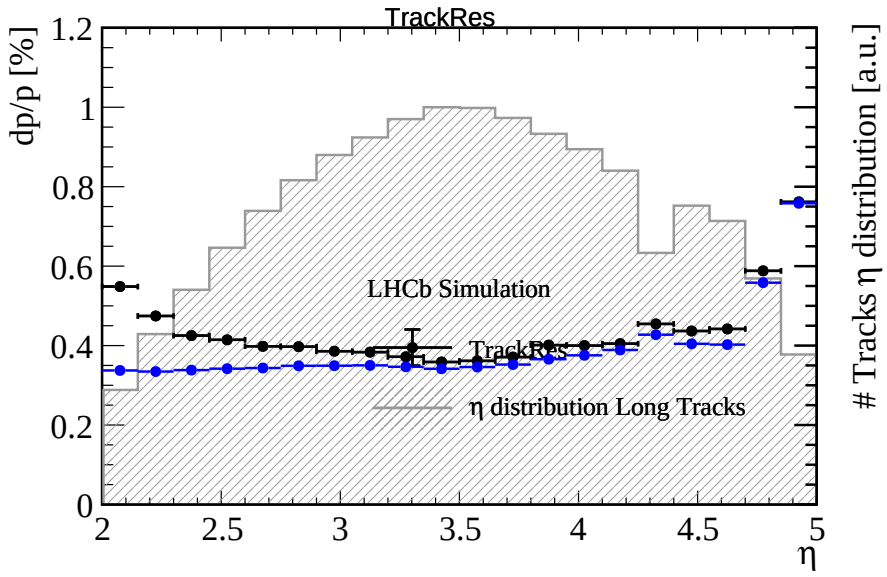
Conclusion of z_{mag} studies

- Indeed, the improvement in performance when introducing a bias confirms that it is the search window size that drive the tracking efficiencies at low momentum
- With a bias, efficiency improved from 85.75% to 86.02%
  - Note: With old parameterisation the efficiency was 86.01%
- This motivates us to keep the original z_{mag} parameterisation
- In fact, since there is no overall improvement, I propose we do not change the parameterisations for 2025 data taking

Reminder: Momentum resolution

Previously I showed a momentum resolution improvement:





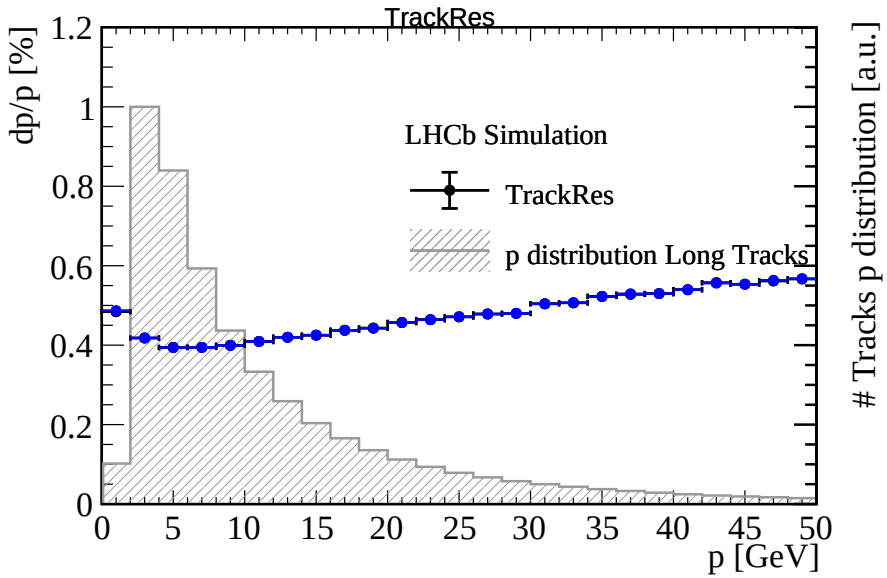
Black: Old parameterisation, old MC. Blue: New parameterisation, new MC.

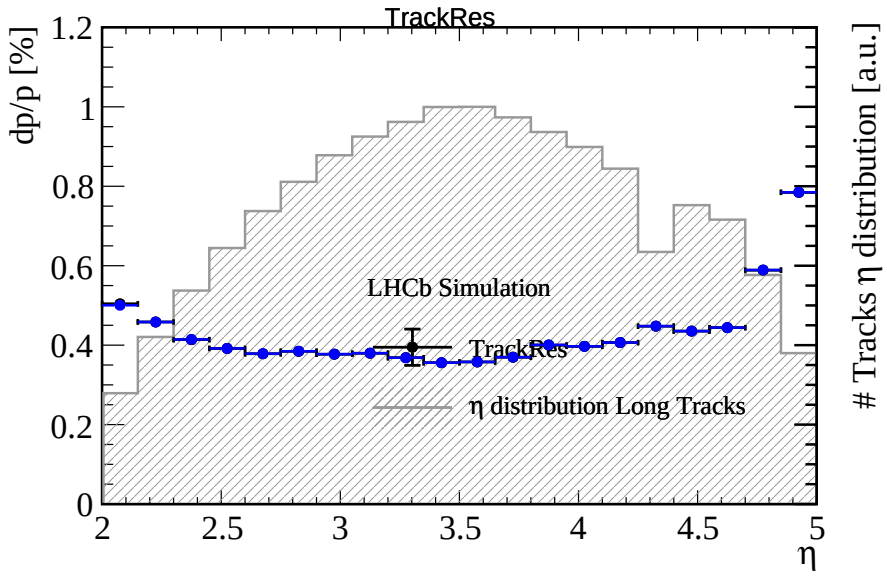
I must apologise, but this was a mistake on my part

This improvement was not due to the new parameterisation, but due to the different MC used by me and Andre.

Momentum resolution

Correct comparison, using the same MC sample:





Black: Old parameterisation. Blue: Proposed parameterisation.

No improvement in track resolution, even with new magnetic field parameterisation

Summary

- Parameterisations are re-evaluated using centrally produced MC
  1. Larger MC samples
  2. Both magnet polarities
  3. Larger selection of decay modes
- Possible improvements to z_{mag} parameterisation have been explored
  - Biases are reduced, but performance gets slightly worse
  - Reason for this unexpected behaviour:
    - Original parameterisation mostly underestimated z_{mag}

    $\rightarrow$ Overestimated search windows in the x-plane

    $\rightarrow$ More hits included in reconstruction

    $\rightarrow$ Higher tracking reconstruction
- Once it was understood, tracking efficiencies remain the same
- I propose: Keep current parameterisation

Next steps

1. Most urgent: Improve throughput
   - Code was already heavily optimised by Andre...
   - ...but I'll do some quick checks for obvious bottleknecks
2. After June TS: Document work in ParamScriptor
   - Mostly copy Andre's old code, with updated Moore scripts
   - I have already added new samples to TestDB in this MR
3. Long term: Some ideas for improvements to make code more generic
   - Plot residuals and ensure small bias/variance
   - Fit coefficients with orthogonal polynomial basis functions
   - Change loss function to something more robust against outliers

Thanks for listening!