Update on forward tracking parameterisation update

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Introduction

I previously presented an update on the HLT2 forward tracking parameterisations

- 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:

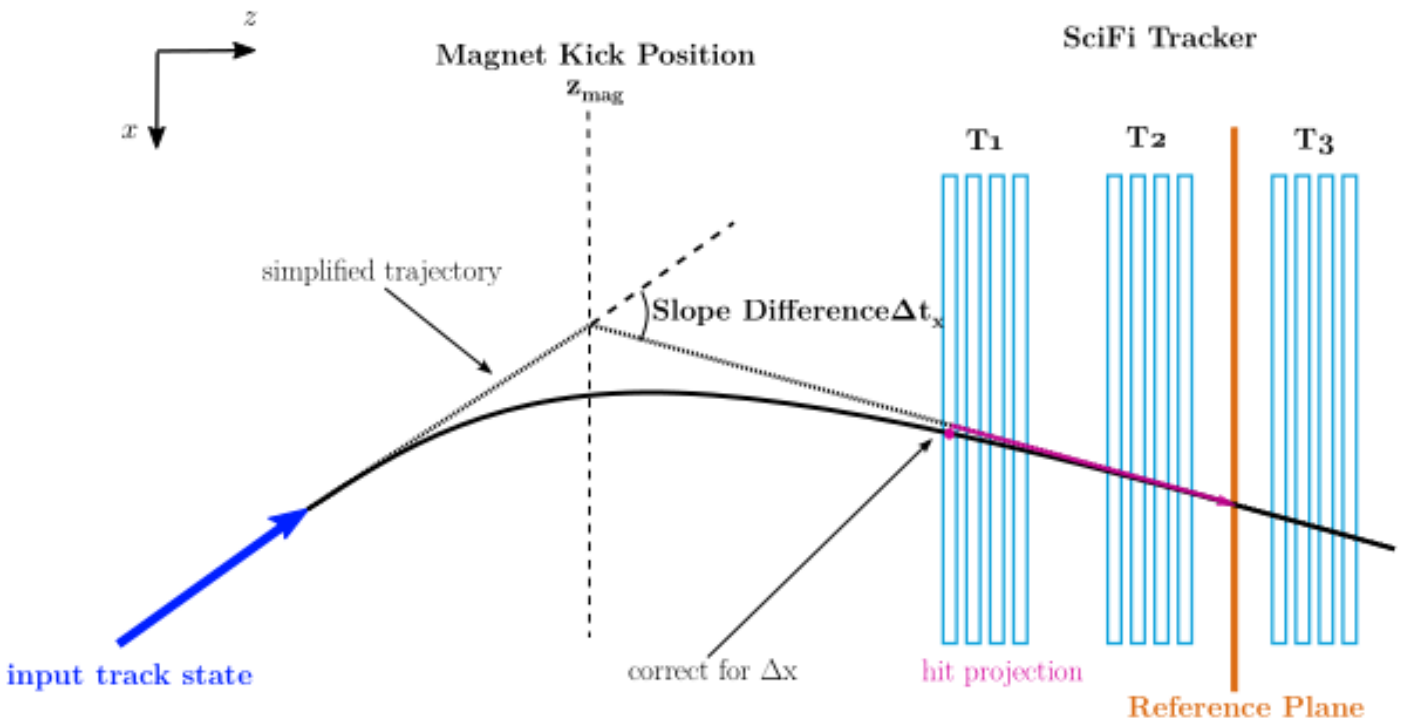
1. z magnet kick position
2. x fringe field correction
3. Stereo angle y correction
4. Hough histogram binning
5. z hit correction with SciFi yz tilt
6. Magnetic field integral

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

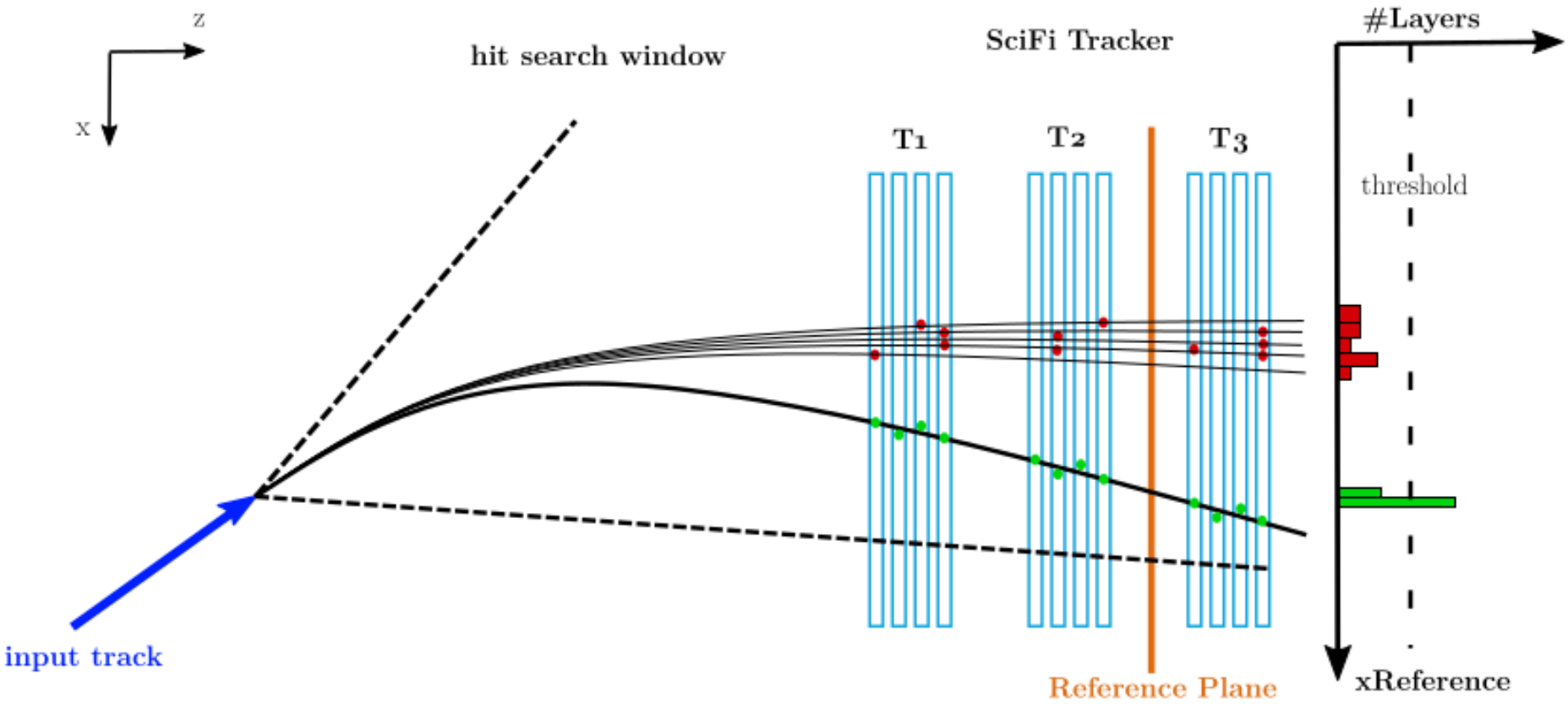


From CERN-THESIS-2023-097

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

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

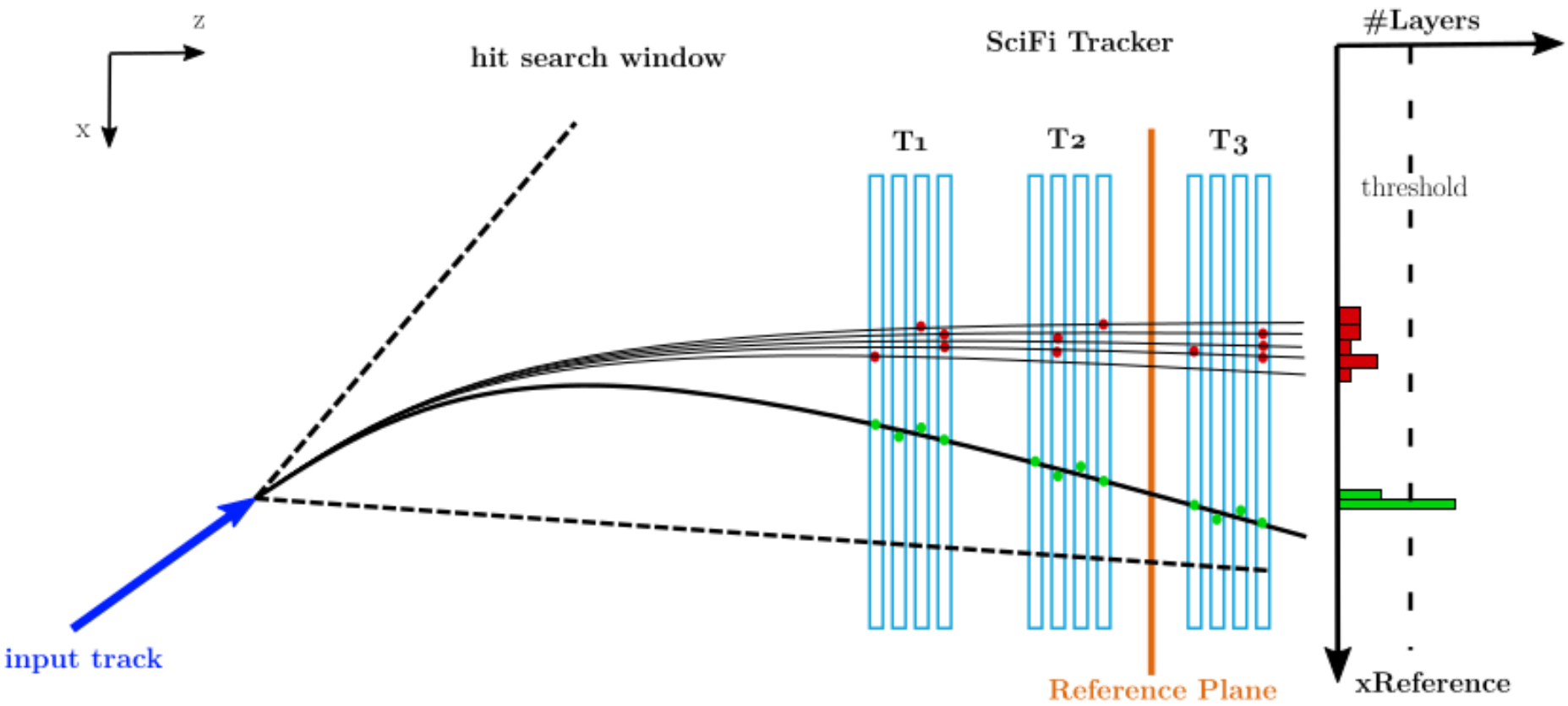
Reminder: Hit mapping to reference plane



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

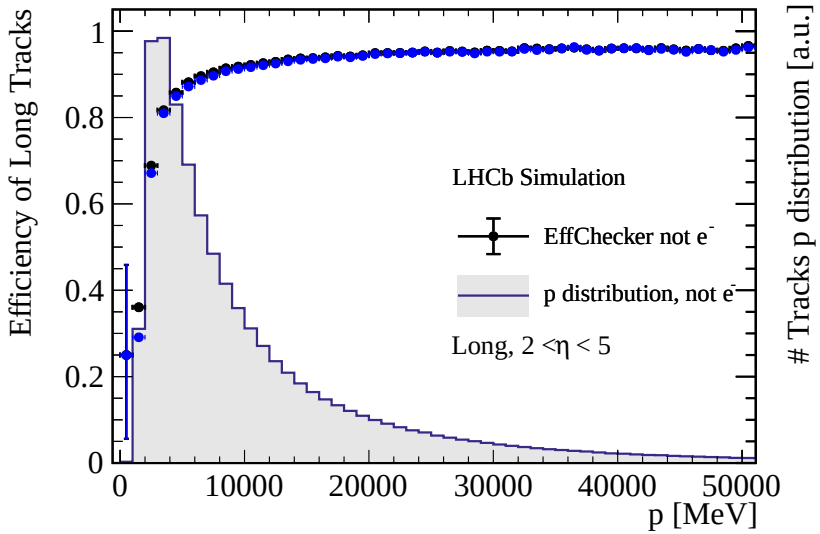
- Mapping depends on momentum, as low momentum tracks bend more
- Define a search window by assuming $p = p_{\text{min}} = 1500$ MeV/c

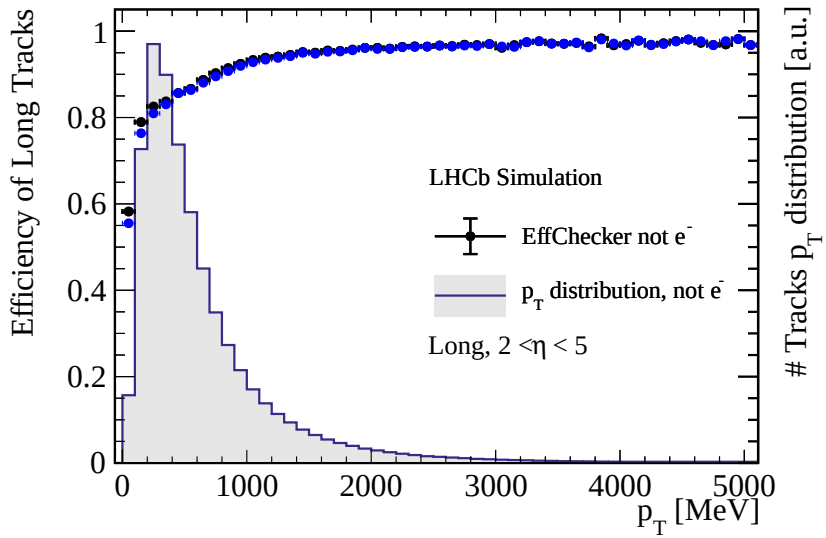
Reminder: Tracking efficiencies with new parameterisation

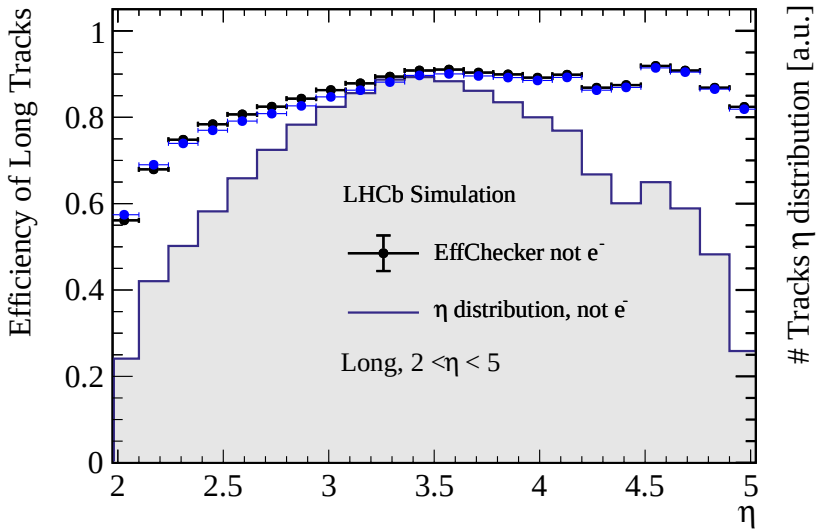
Previously: Performance found to be worse after update

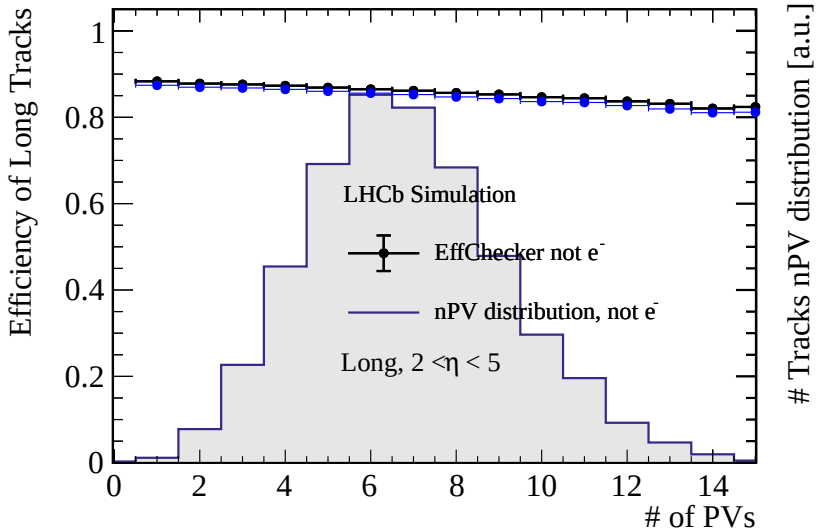
- Traced back to the z_{mag} parameterisation
- Reverting back to old z_{mag} parameterisation
  - Negligible change in performance compared to `2025-patches`
- Possible explanation: Biases in z_{mag} are larger with new MC

Reminder: Tracking efficiencies with new parameterisation



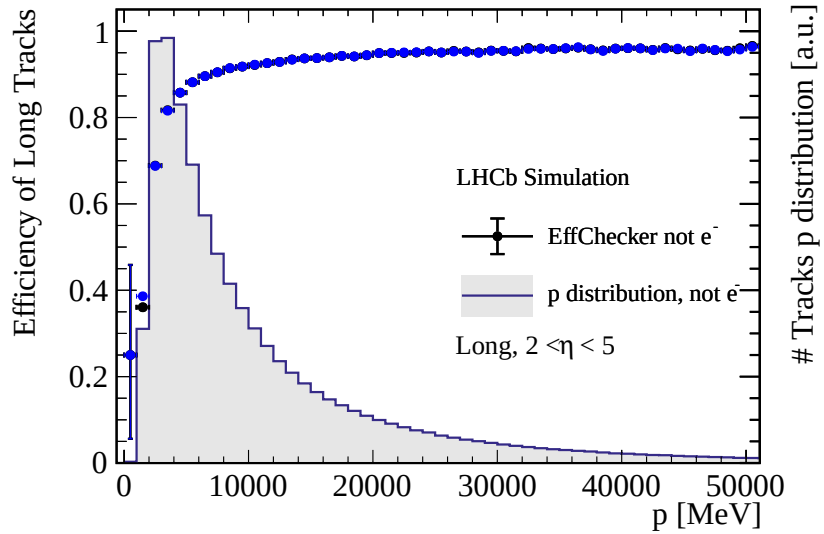


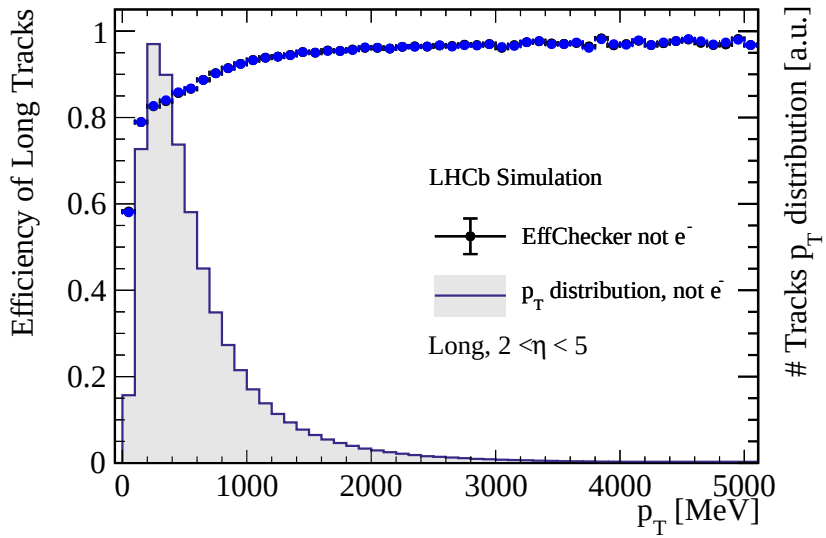


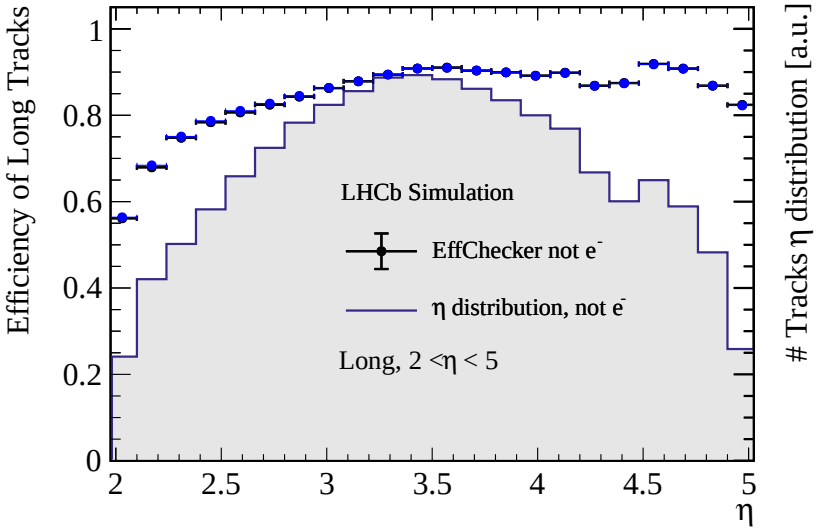


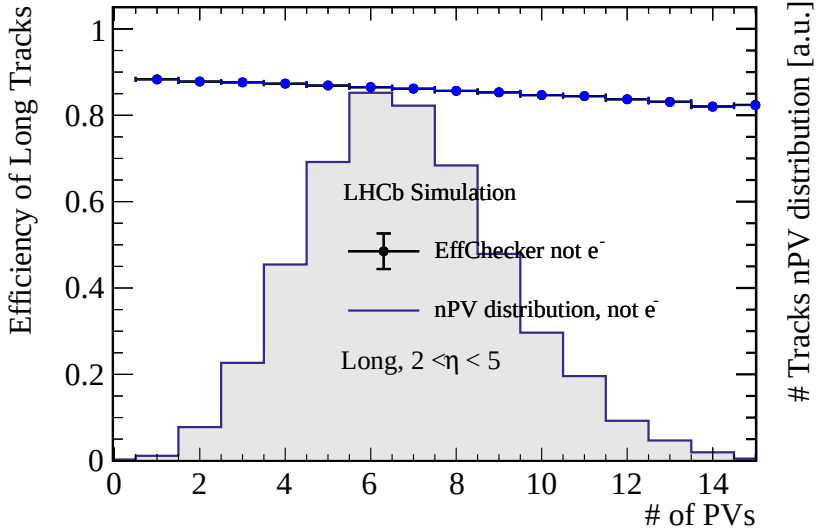
Black: Old parameterisation. Blue: Updated parameterisation.

Reminder: Tracking efficiencies with new parameterisation





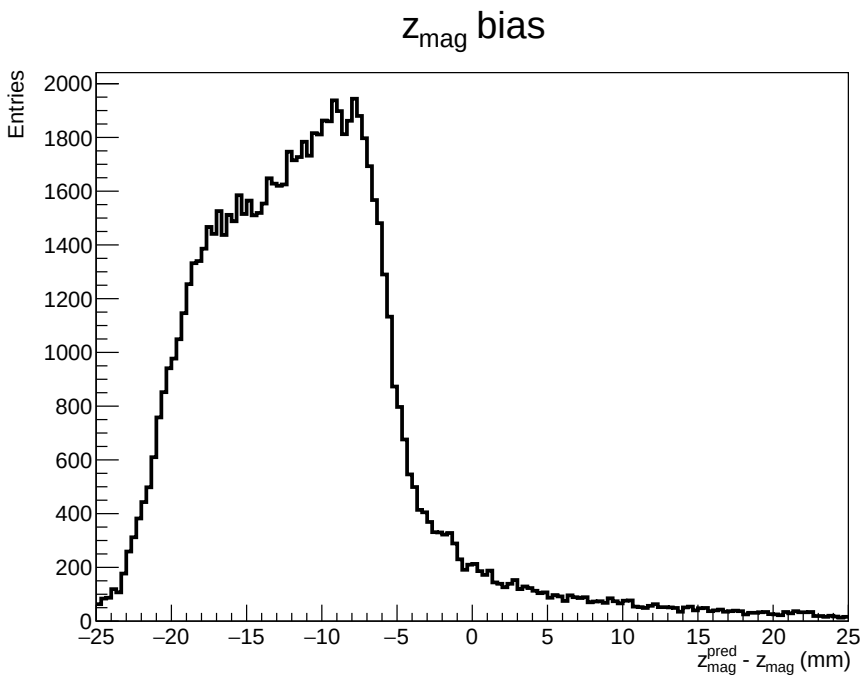


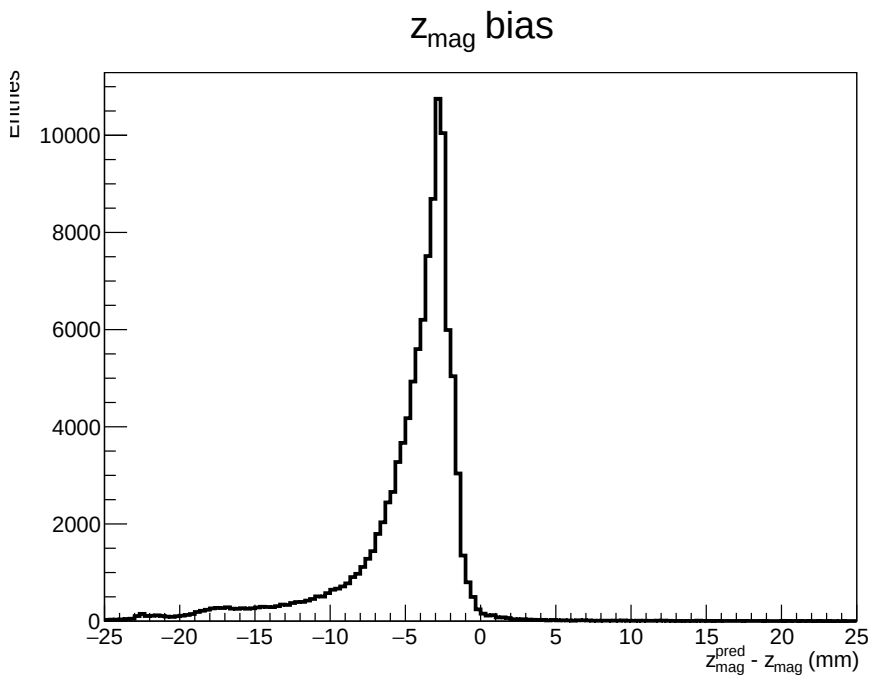


Black: Old parameterisation. Blue: Updated parameterisation with old z_{mag}.

Study of z_{mag} bias

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



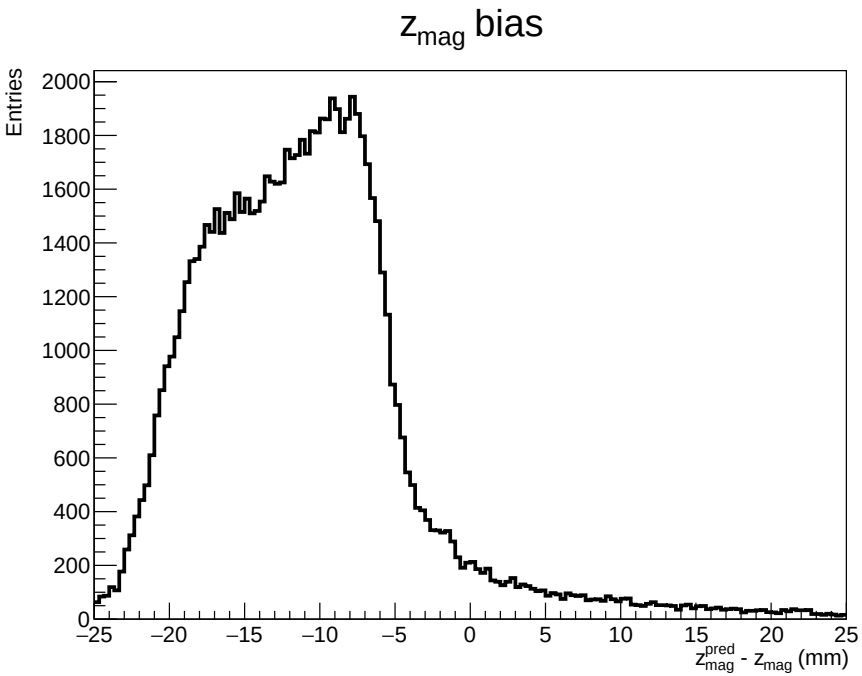


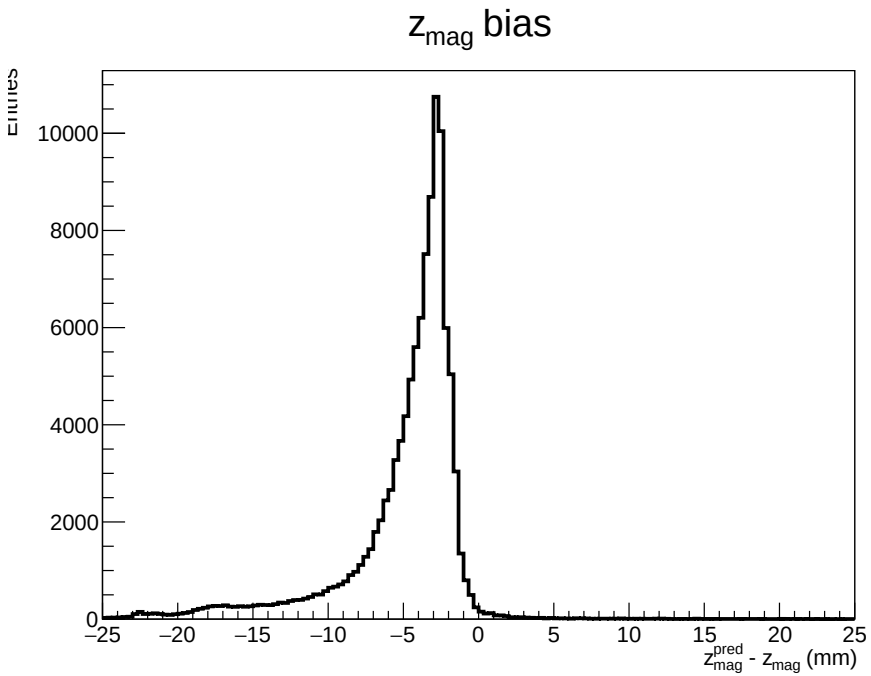
Left: $p < 7$ GeV. Right: $p > 7$ GeV.

- 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:



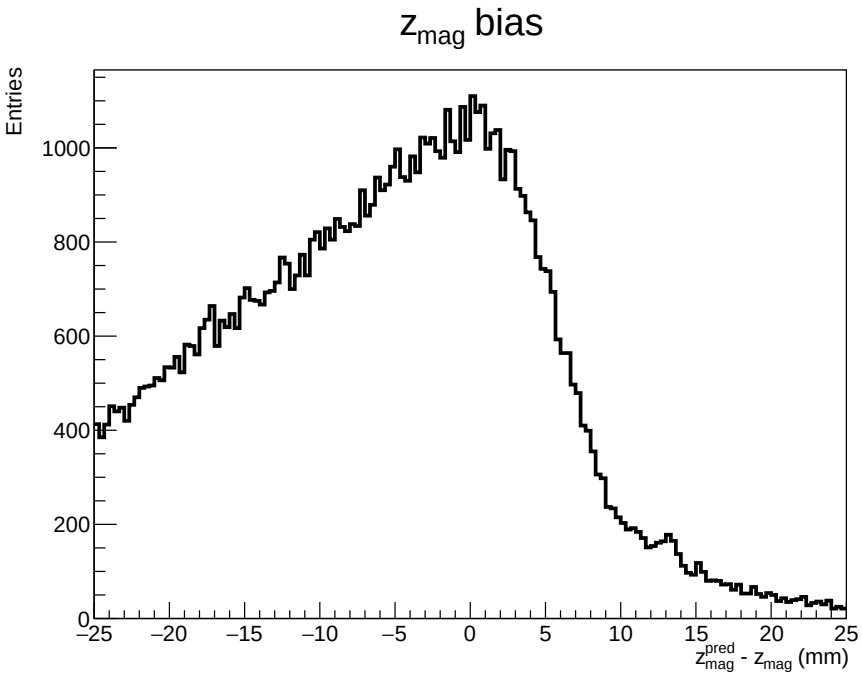


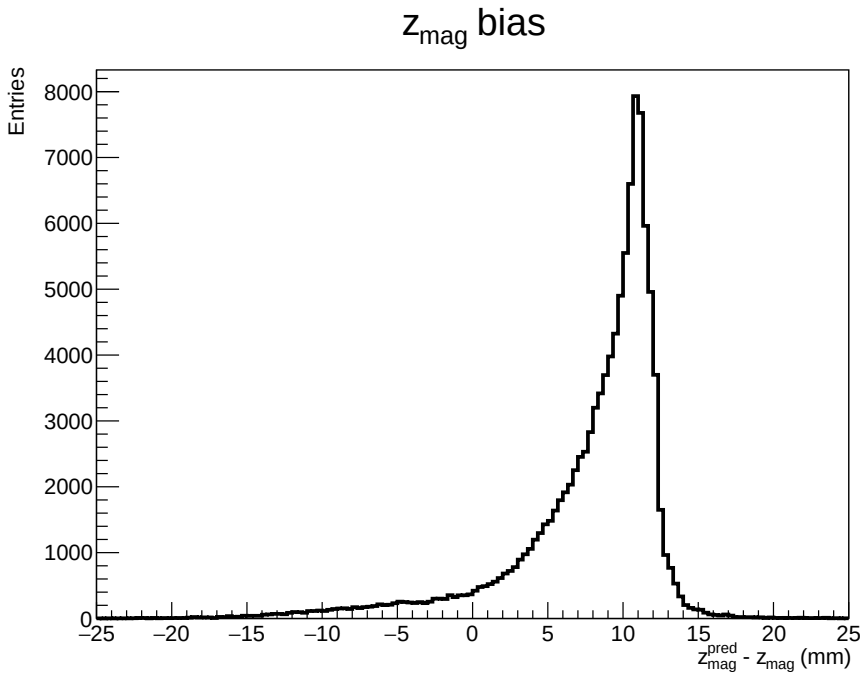
Left: $p < 7$ GeV. Right: $p > 7$ GeV.

- 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:

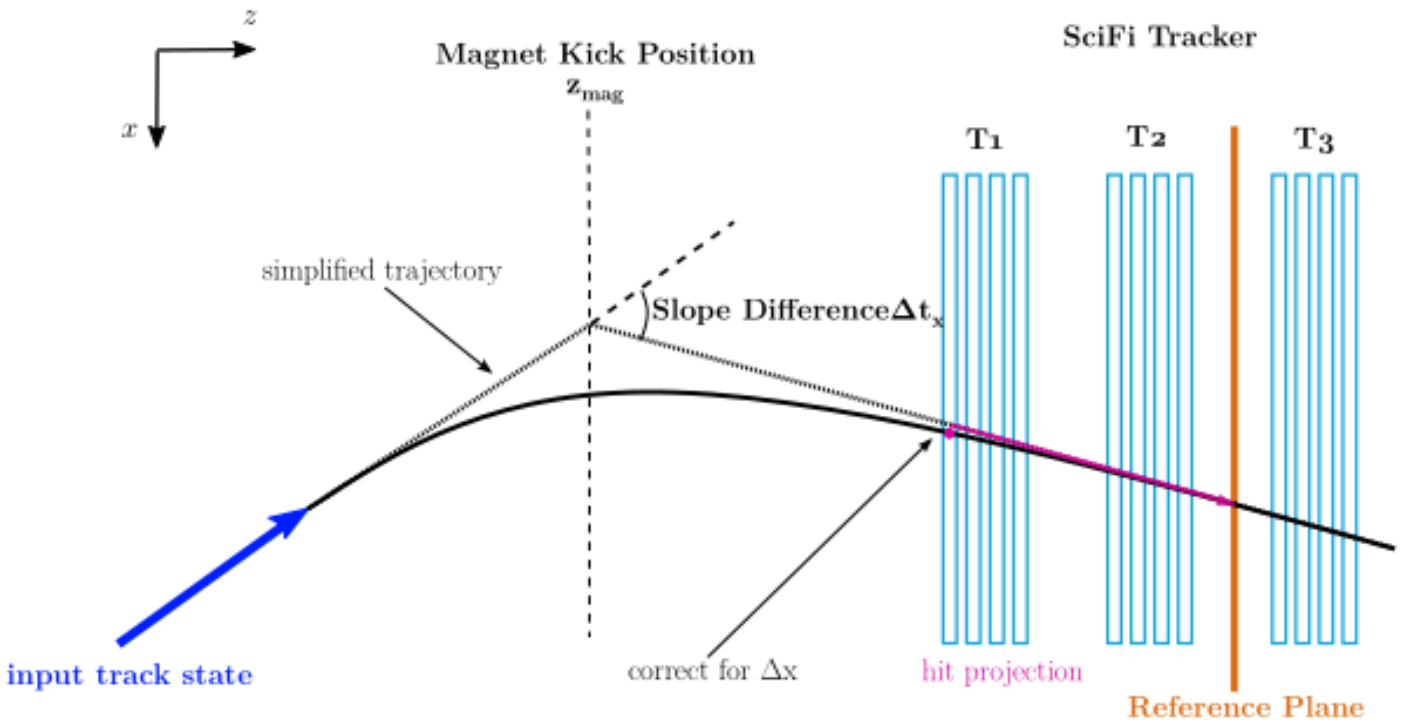




Left: $p < 7$ GeV. Right: $p > 7$ GeV.

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

Reminder: z_{mag} parameterisation

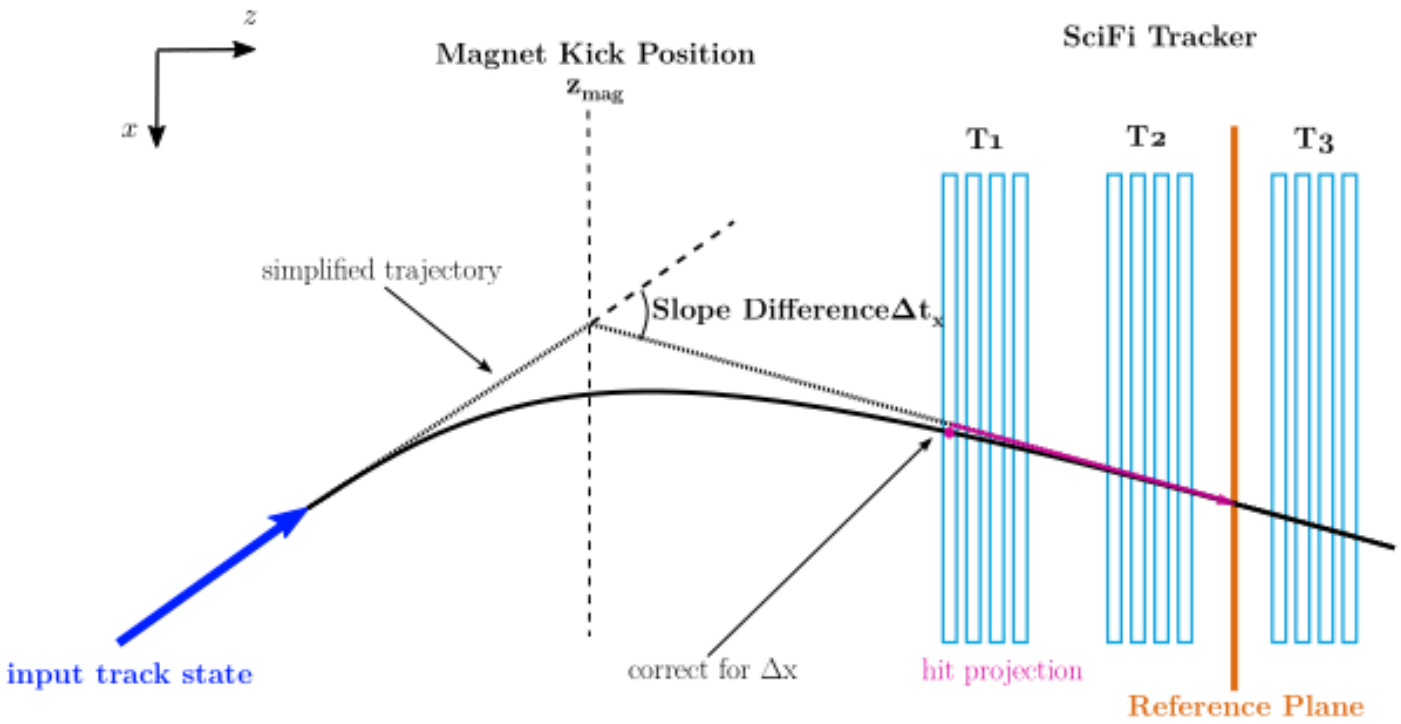


From CERN-THESIS-2023-097

- 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



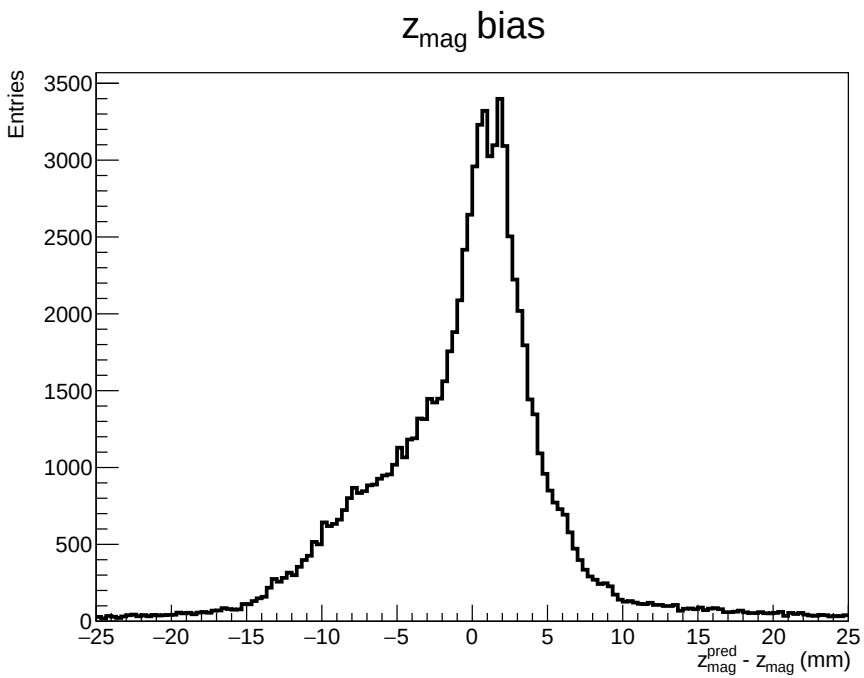
From CERN-THESIS-2023-097

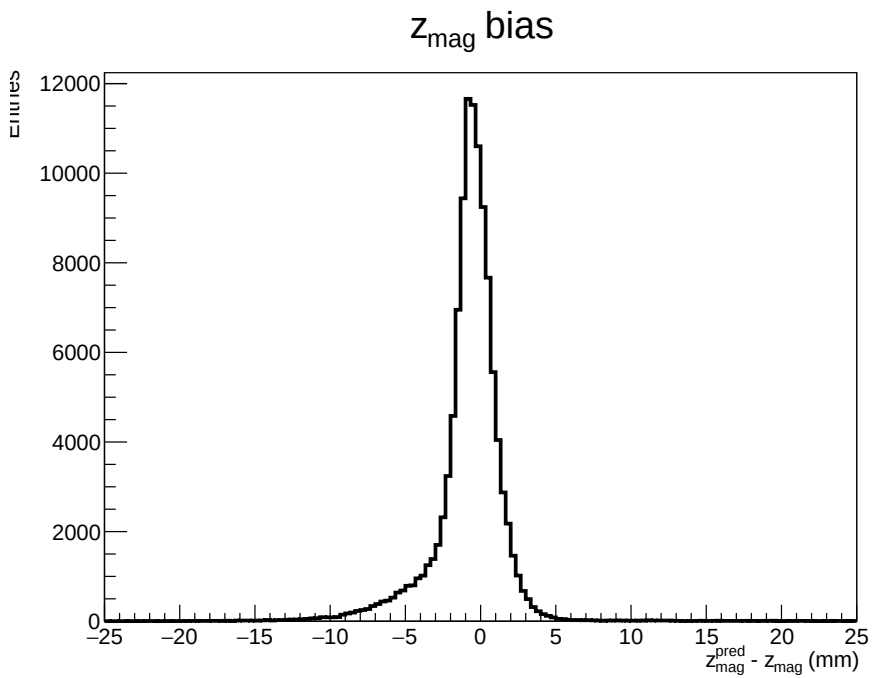
- After trial and error, this parameterisation was obtained:

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

Study of z_{mag} bias

Check biases with new improved parameterisation:

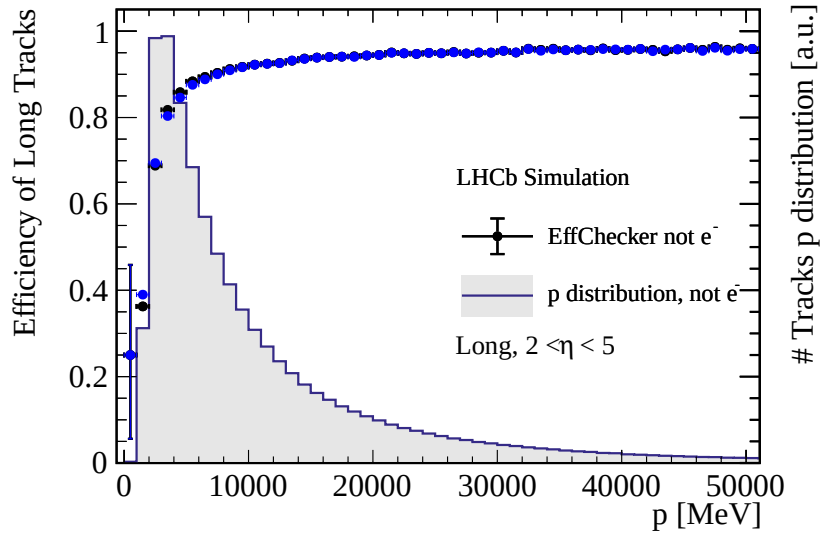


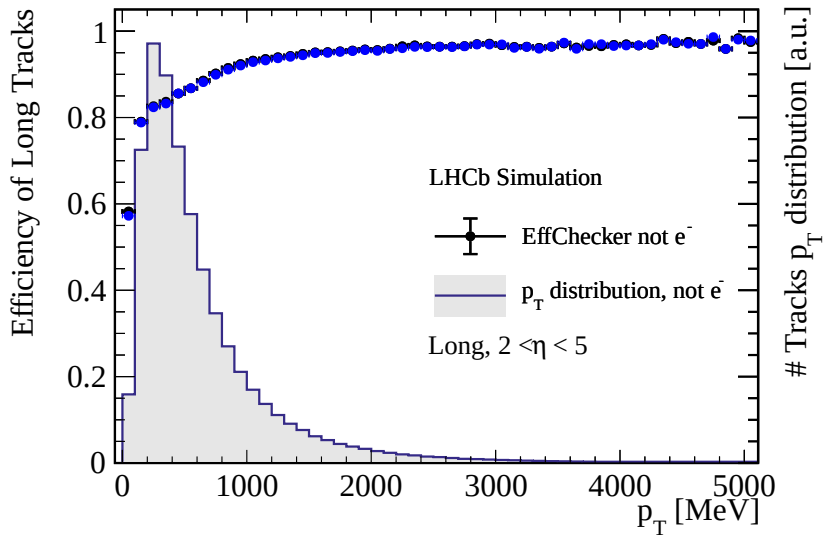


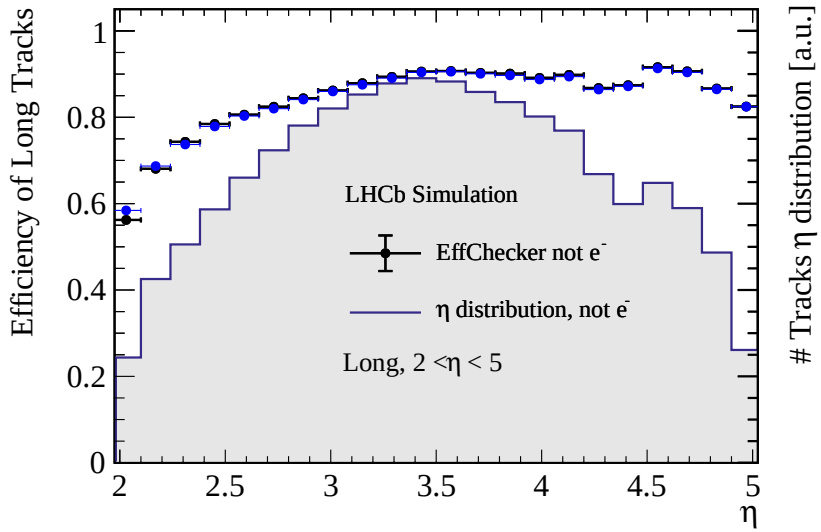
Left: $p < 7$ GeV. Right: $p > 7$ GeV.

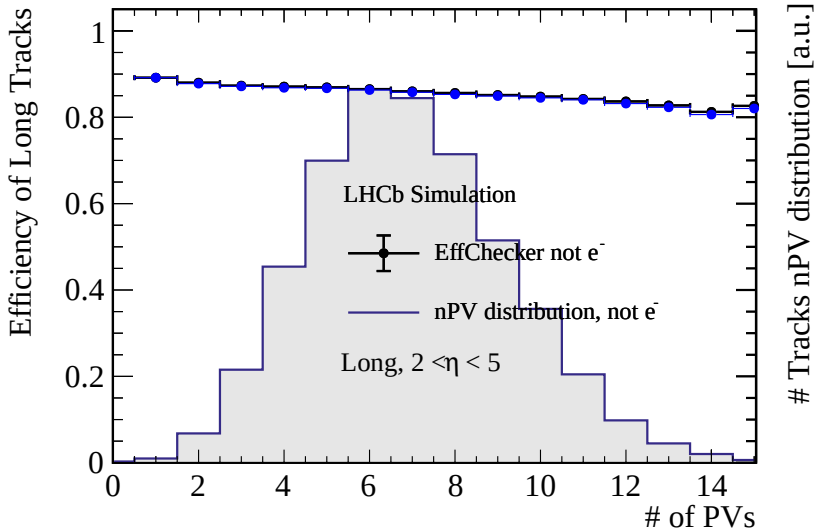
- Huge improvement in biases:
  - Almost symmetric and unbiased distribution at high momentum
  - Mostly unbiased at low momentum, with a left tail

Tracking efficiencies with new improved parameterisation







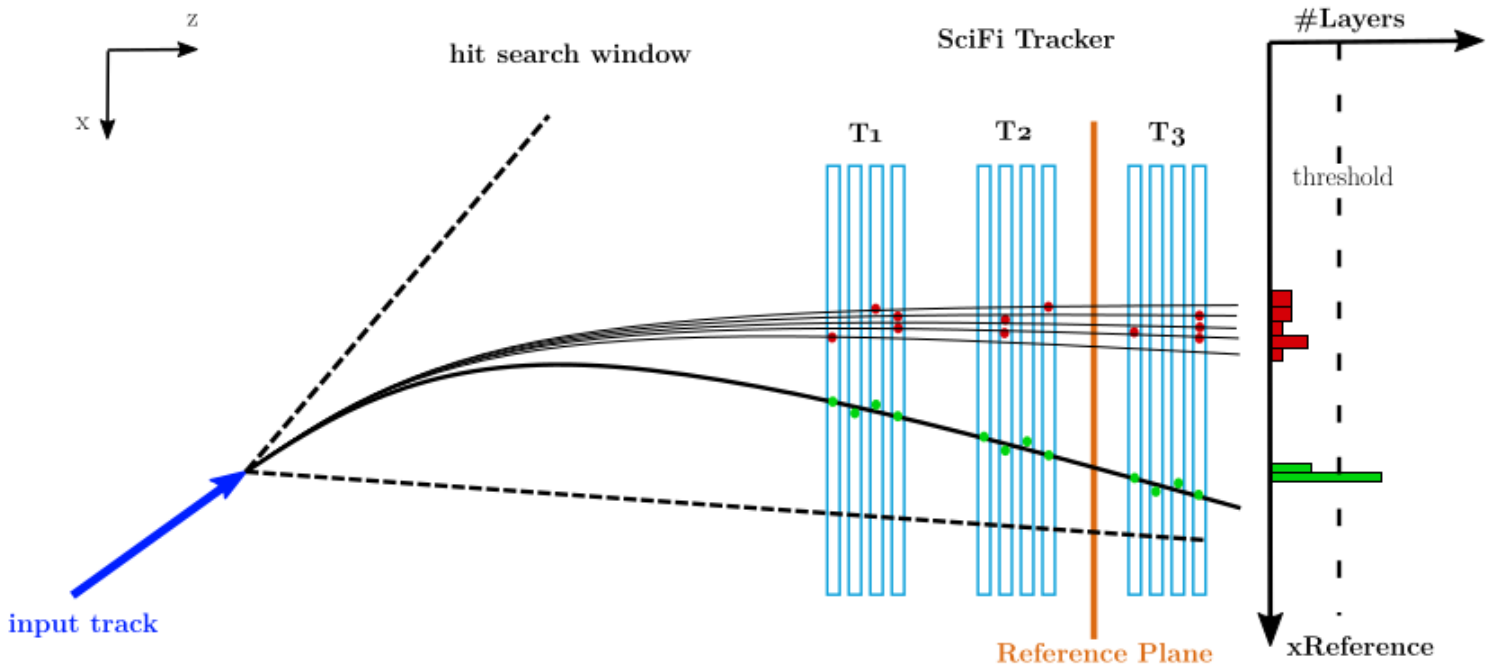


Black: Old parameterisation. Blue: Updated parameterisation of z_{mag}.

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

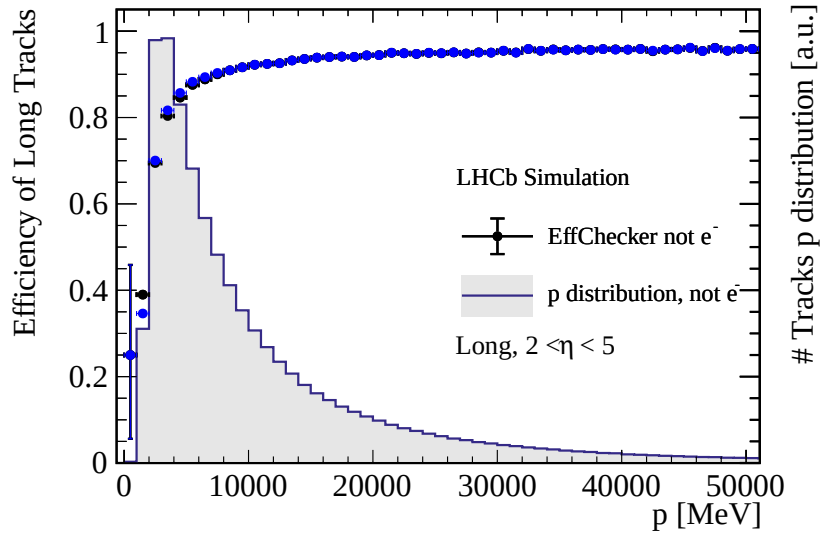


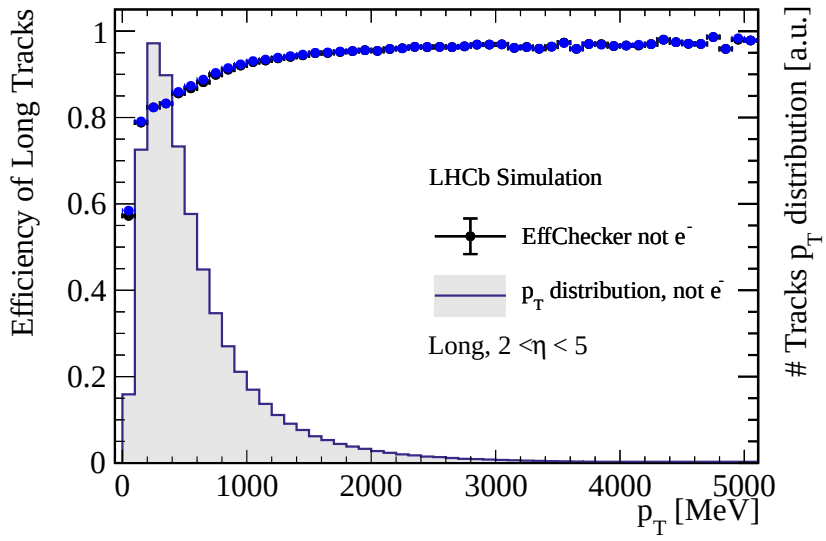
From CERN-THESIS-2023-097

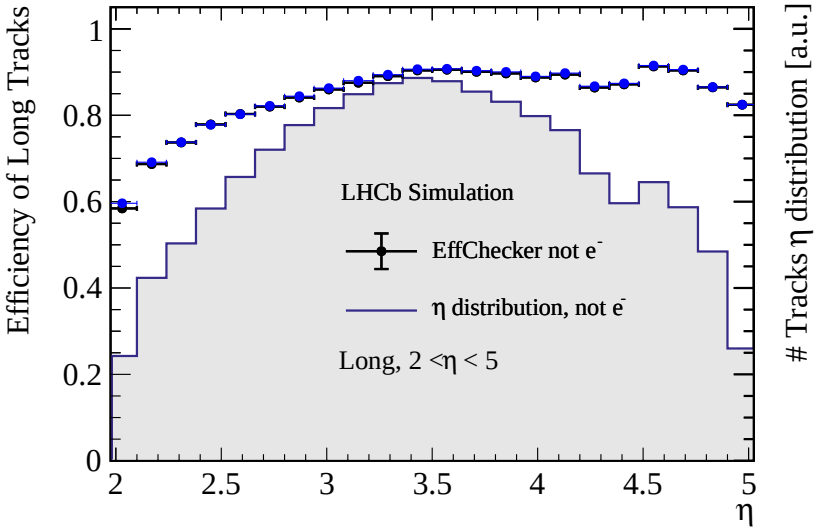
- Define a search window by assuming $p = p_{\text{min}} = 1500$ MeV/c
- My understanding is:
  - z_{mag} is underestimated $\rightarrow$ Search window becomes larger!

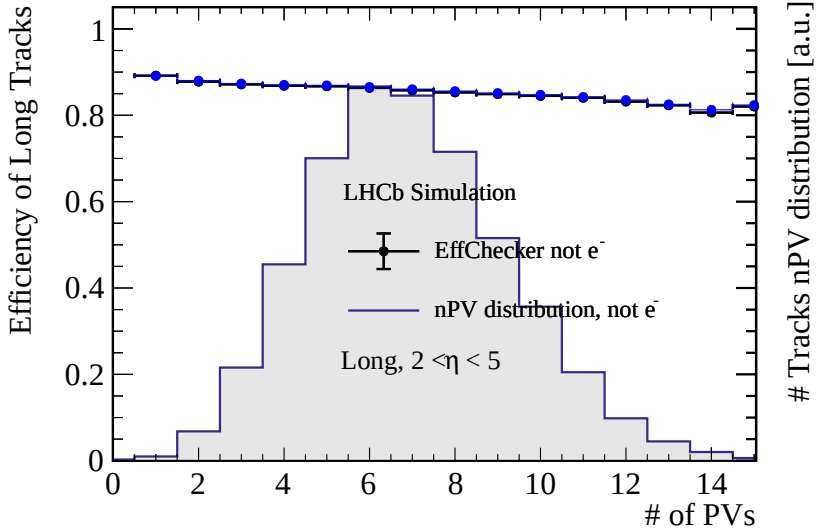
  $\rightarrow$ Add -9.5 mm bias at low momentum to improve performance

Tracking efficiencies with biased z_{mag} parameterisation









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

Conclusion

- 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, parameterisations will not change for 2025 data taking

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!