HB Tracking by AI

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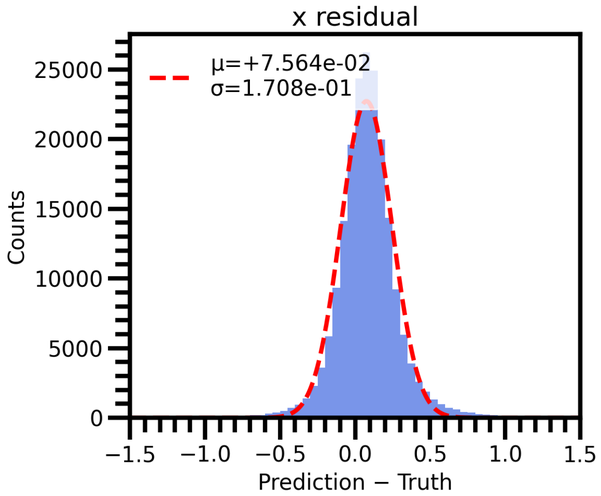
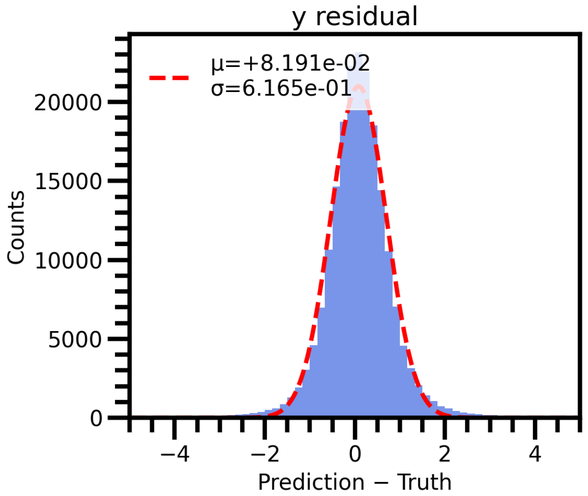
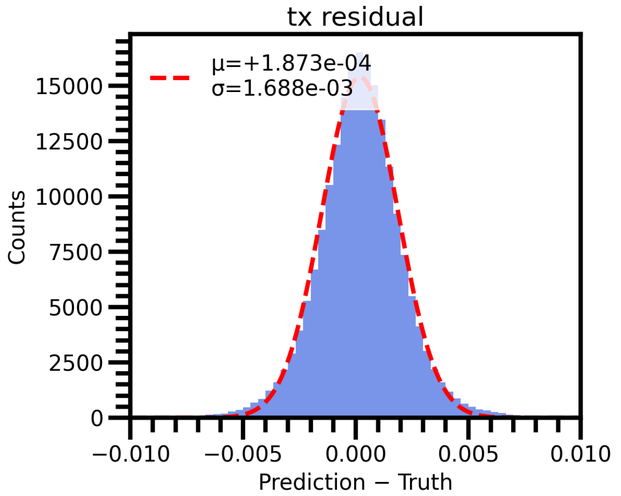
AI Model

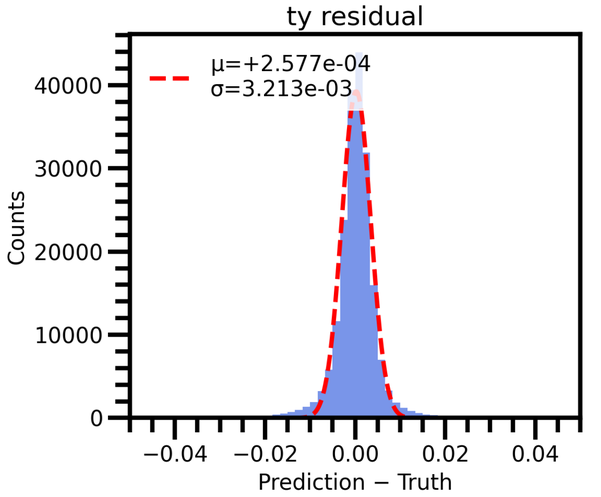
- The model builds a map from hit pattern to track state based on the transformer technique.
  - Input: HB hits on a track; features of hits include doca, xm, xr, yr, z in the tilted sector coordinates
  - Output: track state (x, y, tx, ty, Q) at z = 229 cm in the tilted sector coordinates
- Training samples:
  - Track states of TB tracks
  - Hits on corresponding HB tracks

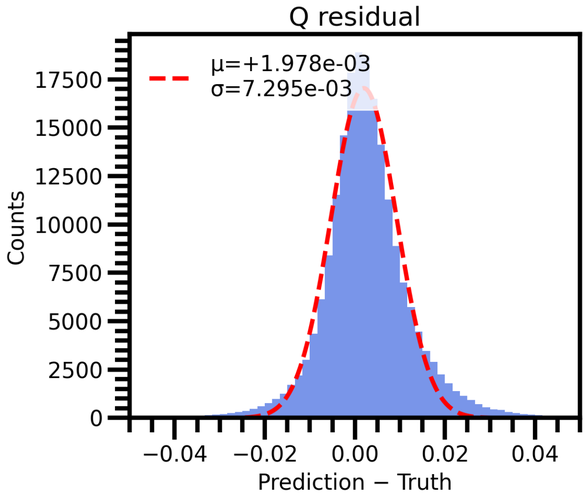
Validation for Model Trained by Inbending Run 5342



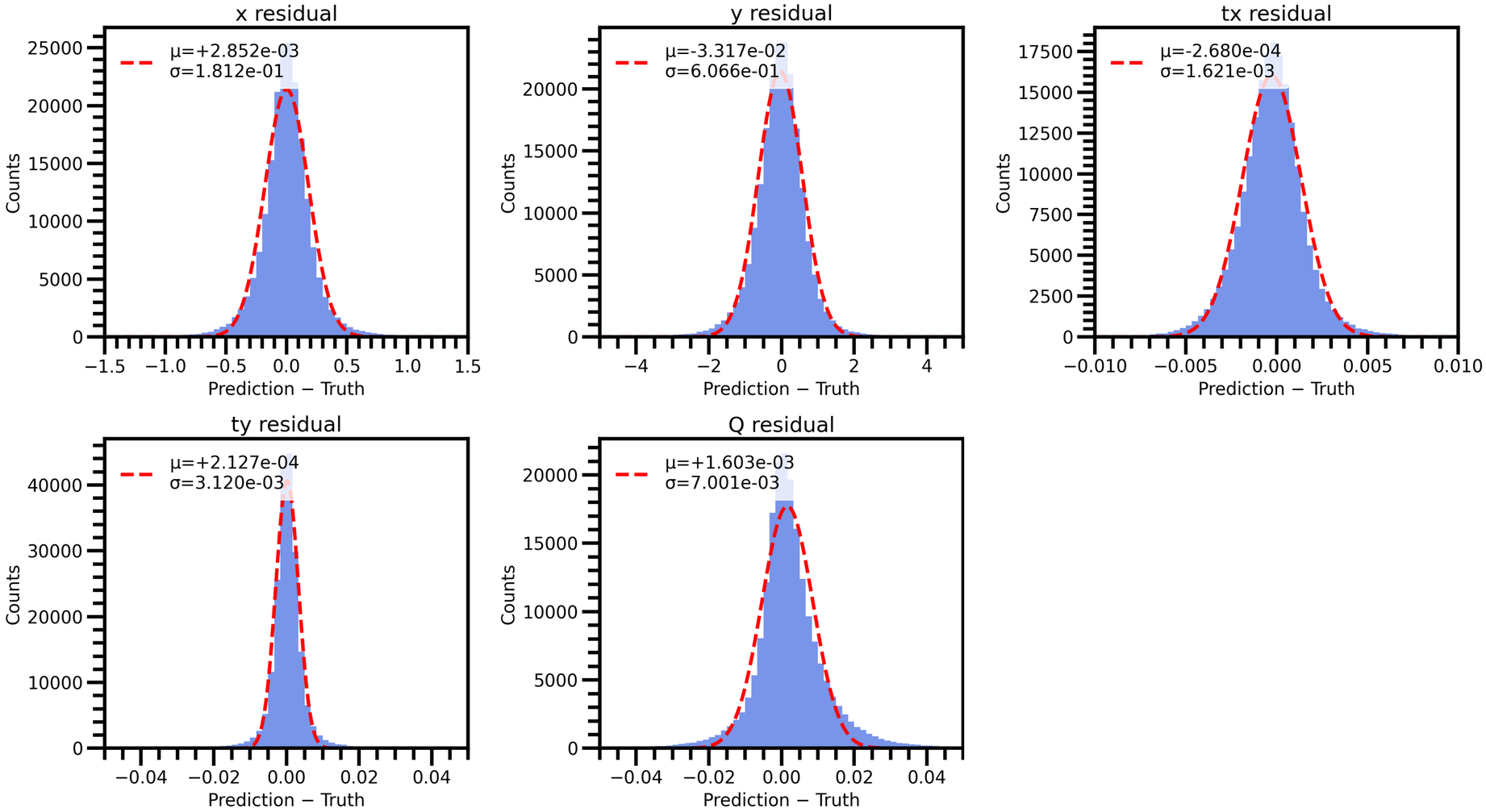




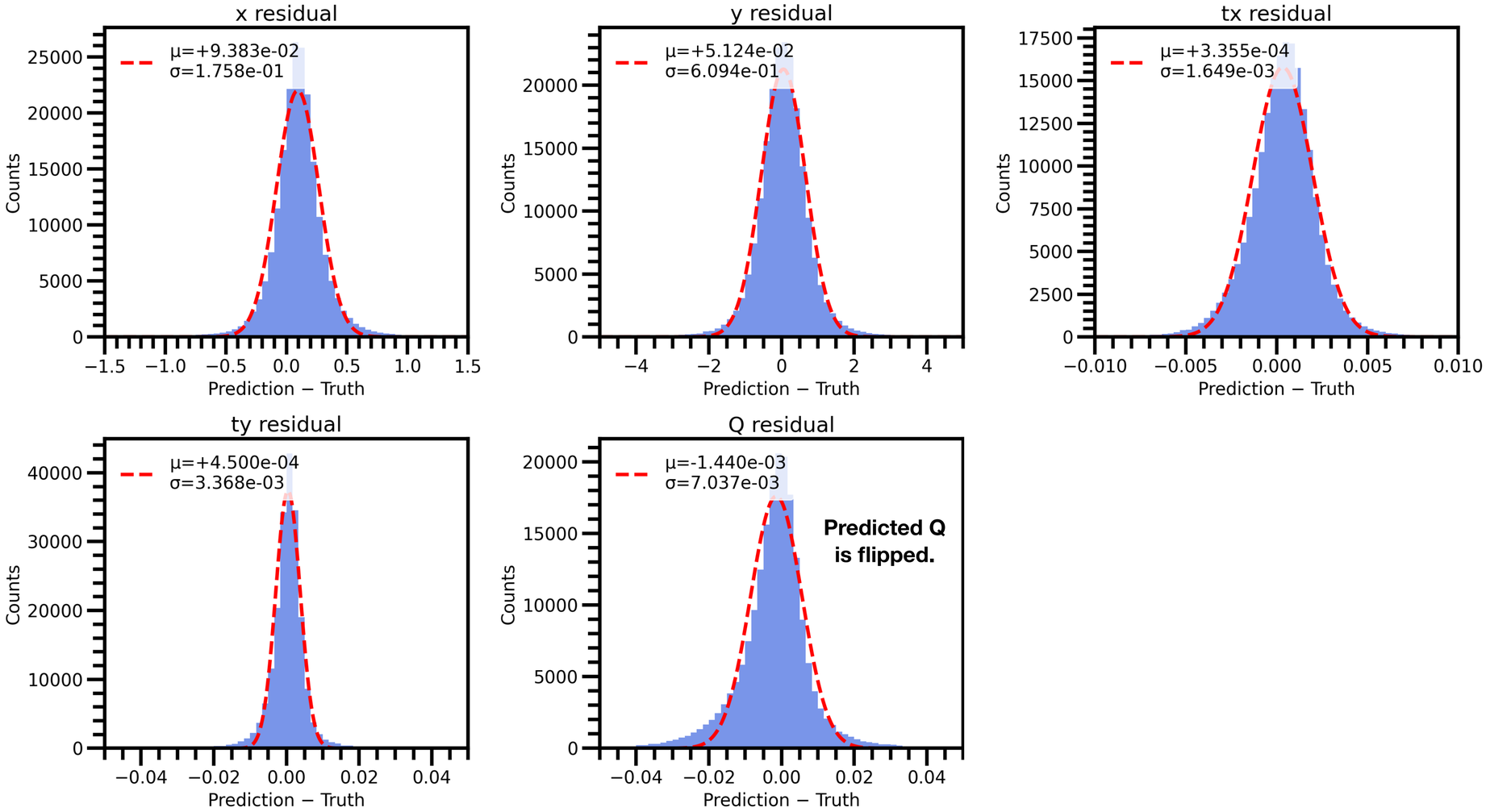




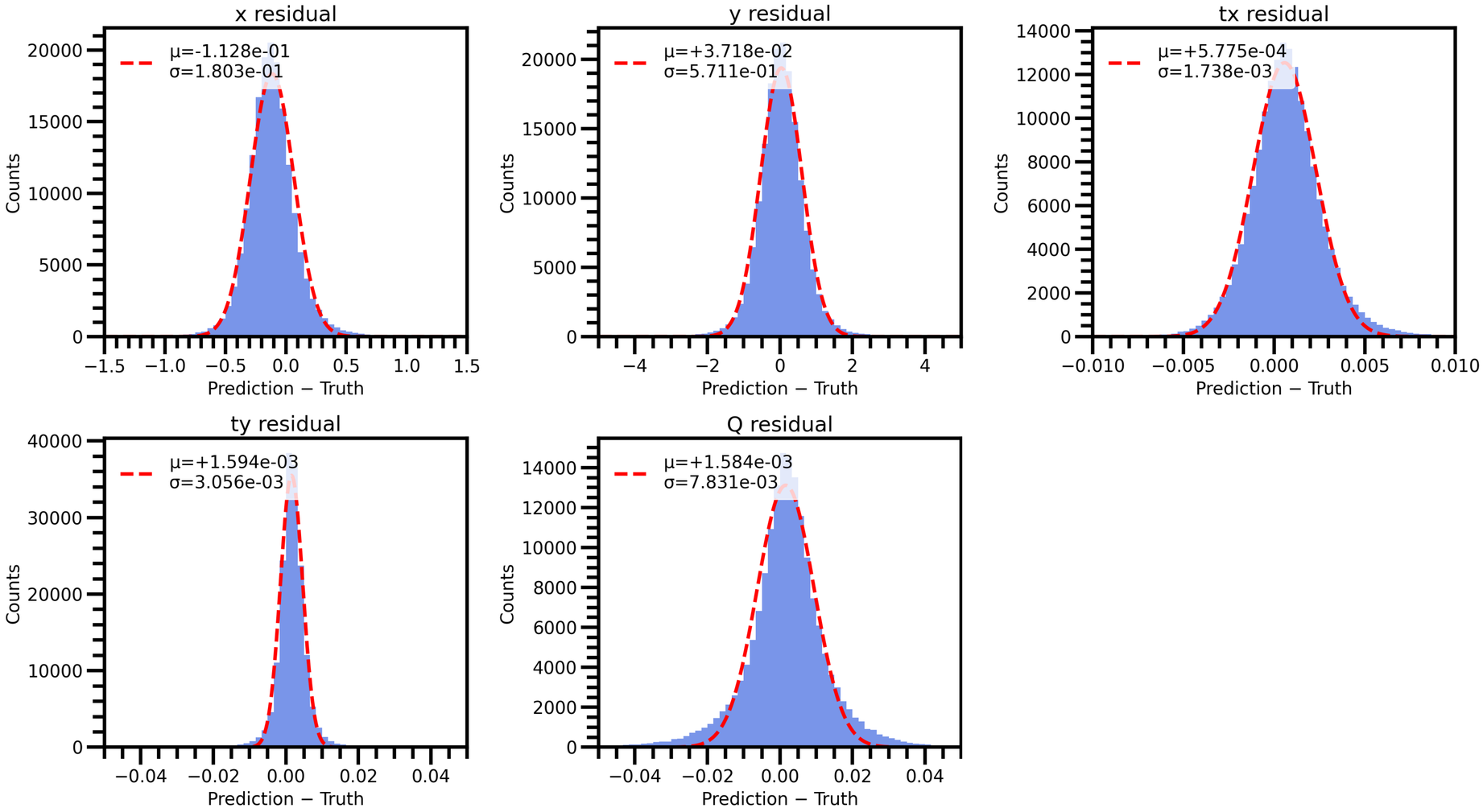
Validation for Model Trained by Outbending Run 5543



Validation for Model Trained by Inbending Run Applied into Outbending Run



Validation for Model Trained by Data Applied into RGA + Background MC



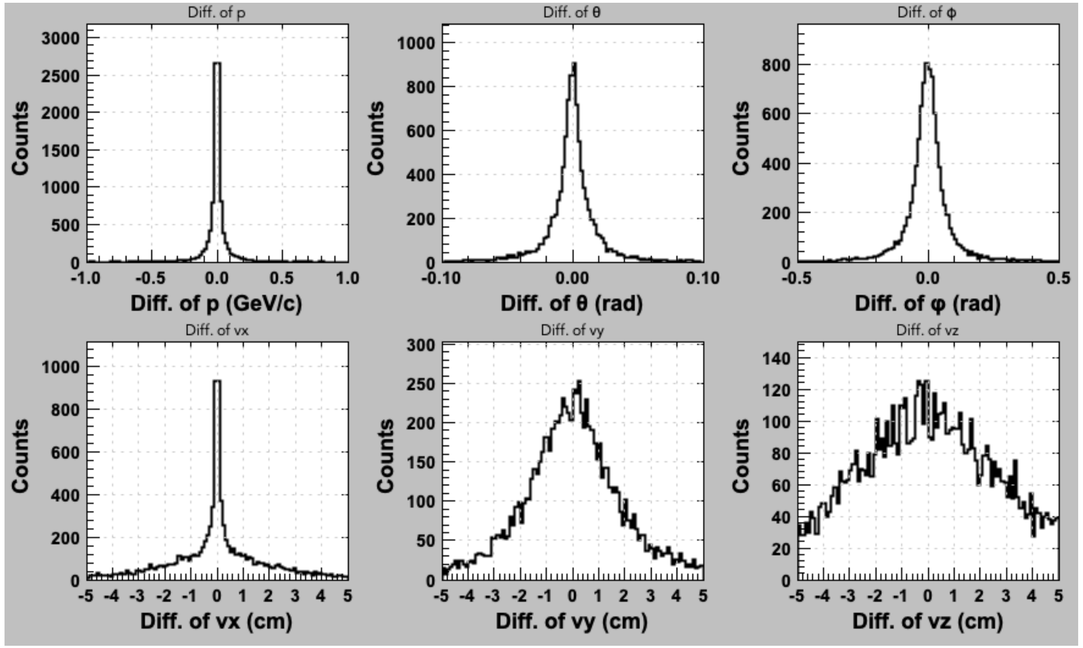
New Engine for HB Tracking by AI in coatjava

- The new engine with application of the AI model for estimation of HB track state, called as DCHBTrackingAI, is developed.

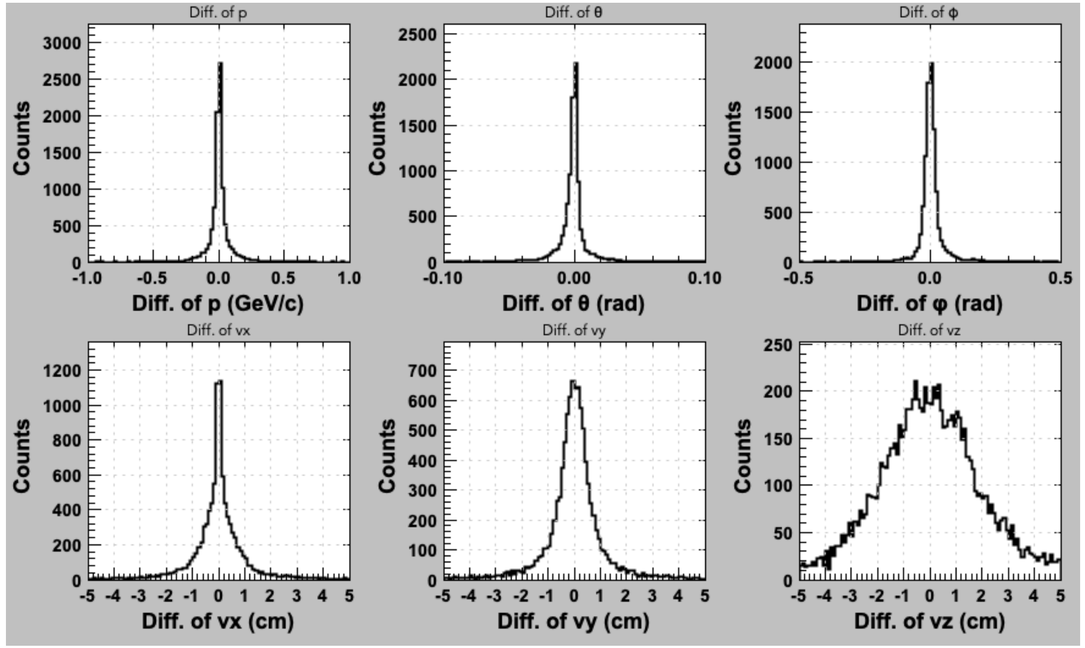
- The new engine is parallel to old engines: DCHBPostClusterConv for conventional HB tracking, and DCHBPostClusterAI for AI-assisted HB tracking.

HB Track Resolution with TB Tracks as Reference

HB tracking by KF



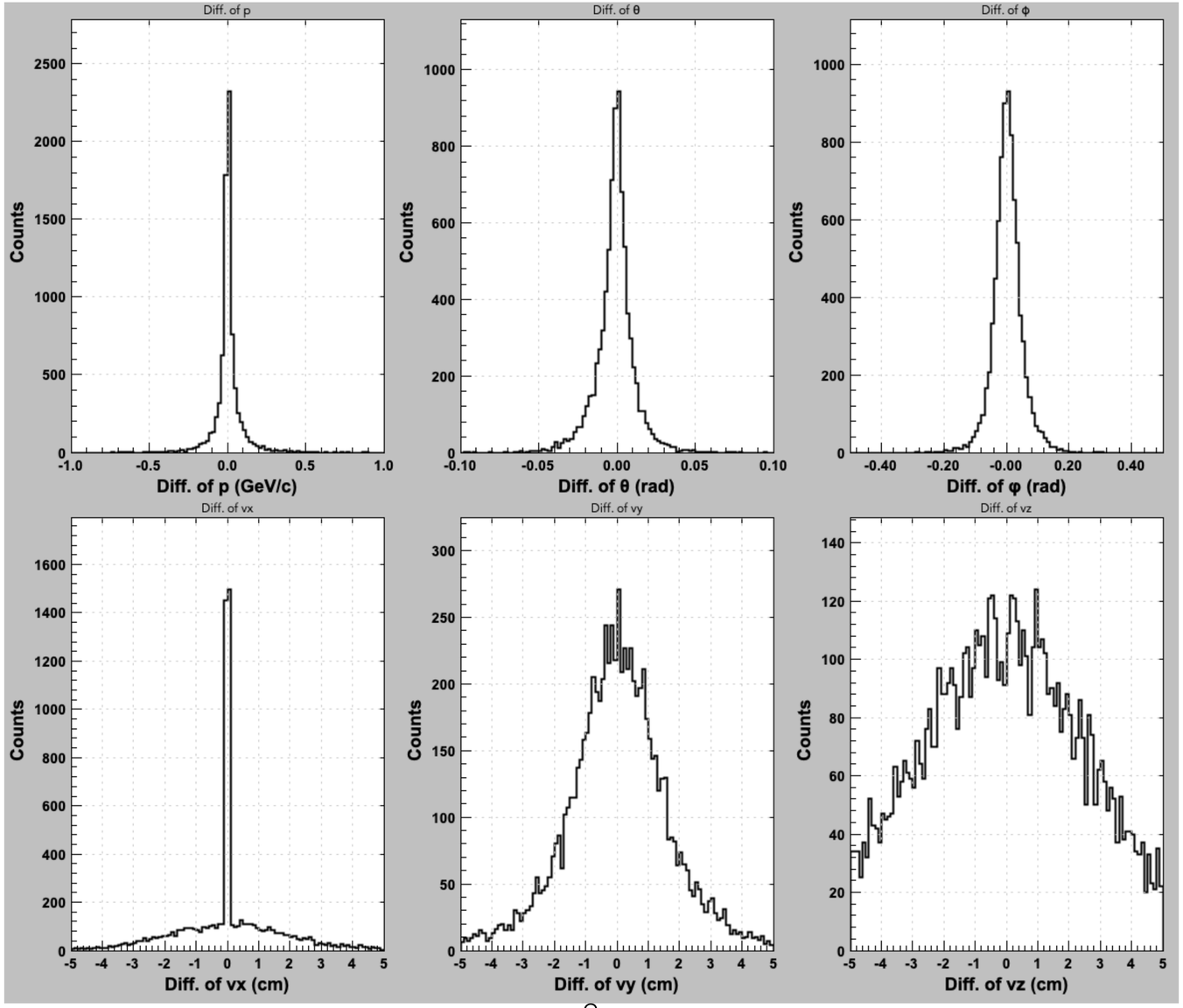
HB tracking by AI estimator



Difference between HB and TB tracks

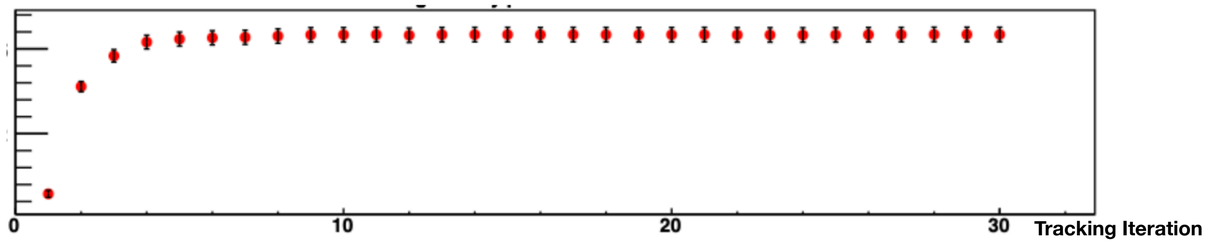
- Resolution for tracks by AI estimator is much better than HB tracking by KF.
- It will change quality for the following HB reconstruction based on HB tracks, and further affect TB reconstruction.

Difference between HB Tracks

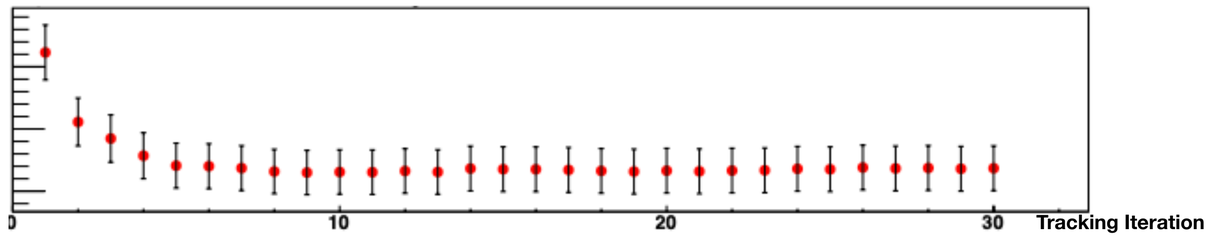


If Track State by AI as Initial State for HB KF Tracking

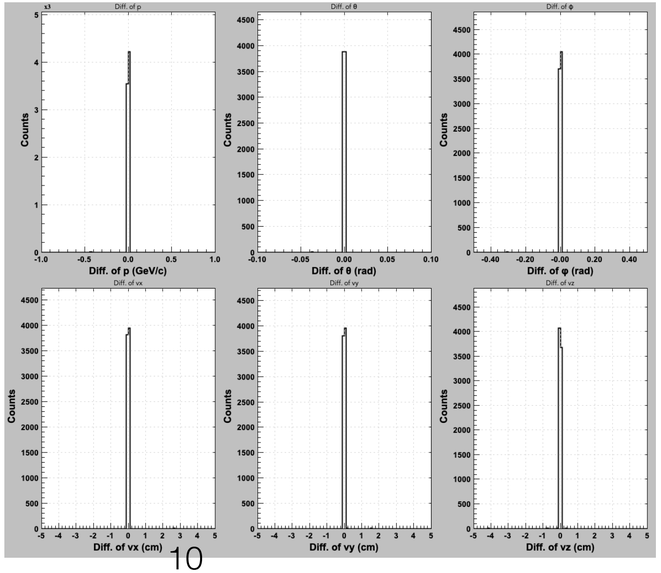
- If track state by AI is applied into HB KF tracking as initial state, track resolution becomes worse along iterations, until stable, like:



- For current HB KF tracking with initial state, roughly determined by 3 crosses, track resolution becomes better along iterations, until stable, like:



- Finally, tracking results are close. Plots show difference of HB tracks with two different initial state as input for KF.



Discussion for AI and KF Tracking

- KF processes hits sequentially and locally. Since large uncertainty of HB measurements, KF fits trajectories through thick tubes.

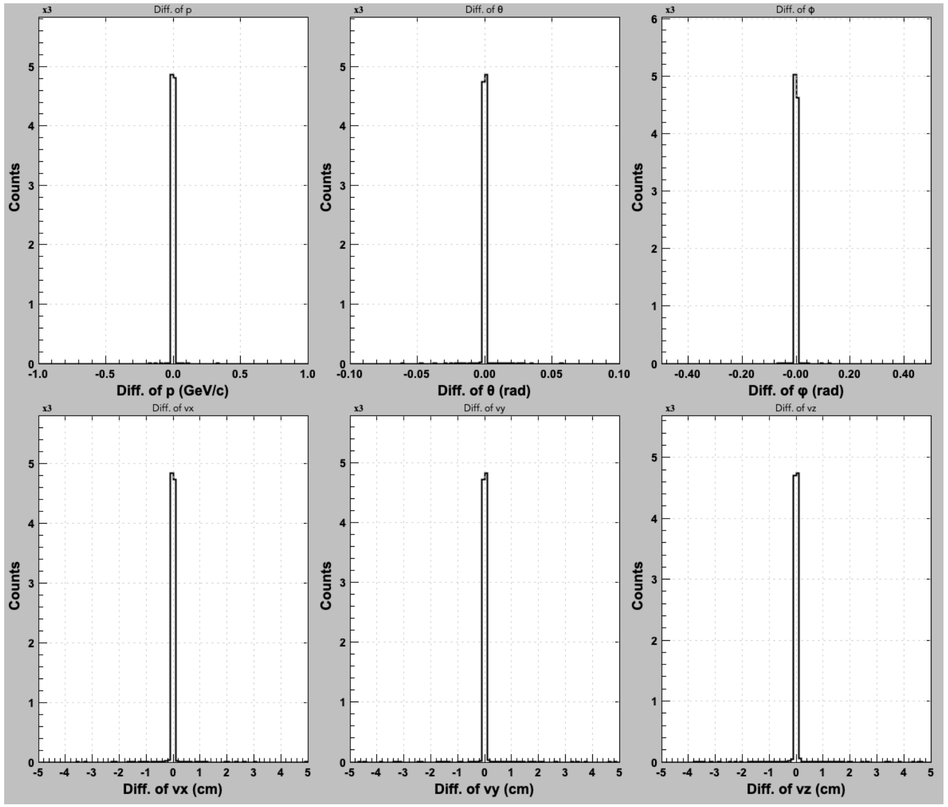
- Instead of propagating a track step by step, AI learns a direct mapping from hit pattern to track state. It absorbs left–right ambiguity, magnetic field inhomogeneity, cell geometry effects, etc.

- As test, HB tracking resolution by AI is better than by KF.

- The AI model is a pattern-based estimator without consideration of track propagation in the magnetic field, multiple scattering and energy loss.

- Therefore, with accurate TB measurements, KF tracking performs better than AI. HB track state by AI is input into TB KF tracking as initial state.

Comparison of TB Tracks between Different HB Tracks as Initial State of TB Tracking



- Although different HB track state are input into TB tracking as initial state, results of TB tracking through KF process are close.
- Therefore, effects of tracking resolution is slight with the same definition of hit resolution.
- However, change of HB tracks will affect resolution of TB hits. So TB tracking results will be affected with new TB hit resolution.

Overview from Observation of Event-by-Event Comparison

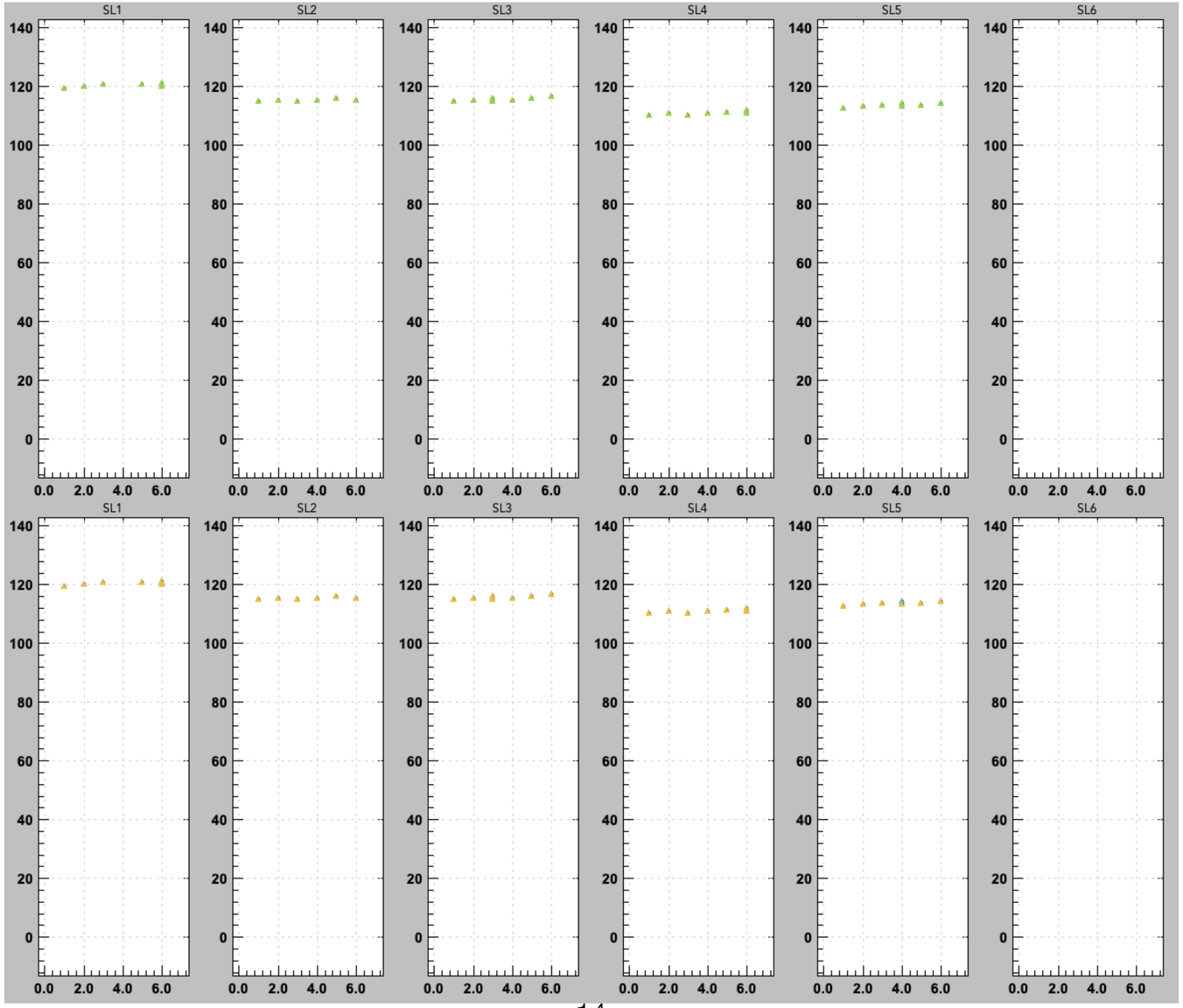
- Some missed tracks by the old HB tracking are saved by the new way.
- For those missed tracks, some of them are lost at the HB level, while some of them are lost at the TB level.
- The occupancy of the saved tracks is small compared to the total number of tracks. Therefore, the impact on the tracking efficiency is not significant.

Example 1

Failed for HB tracking

The reason could be that KF explodes due to rough initial state.

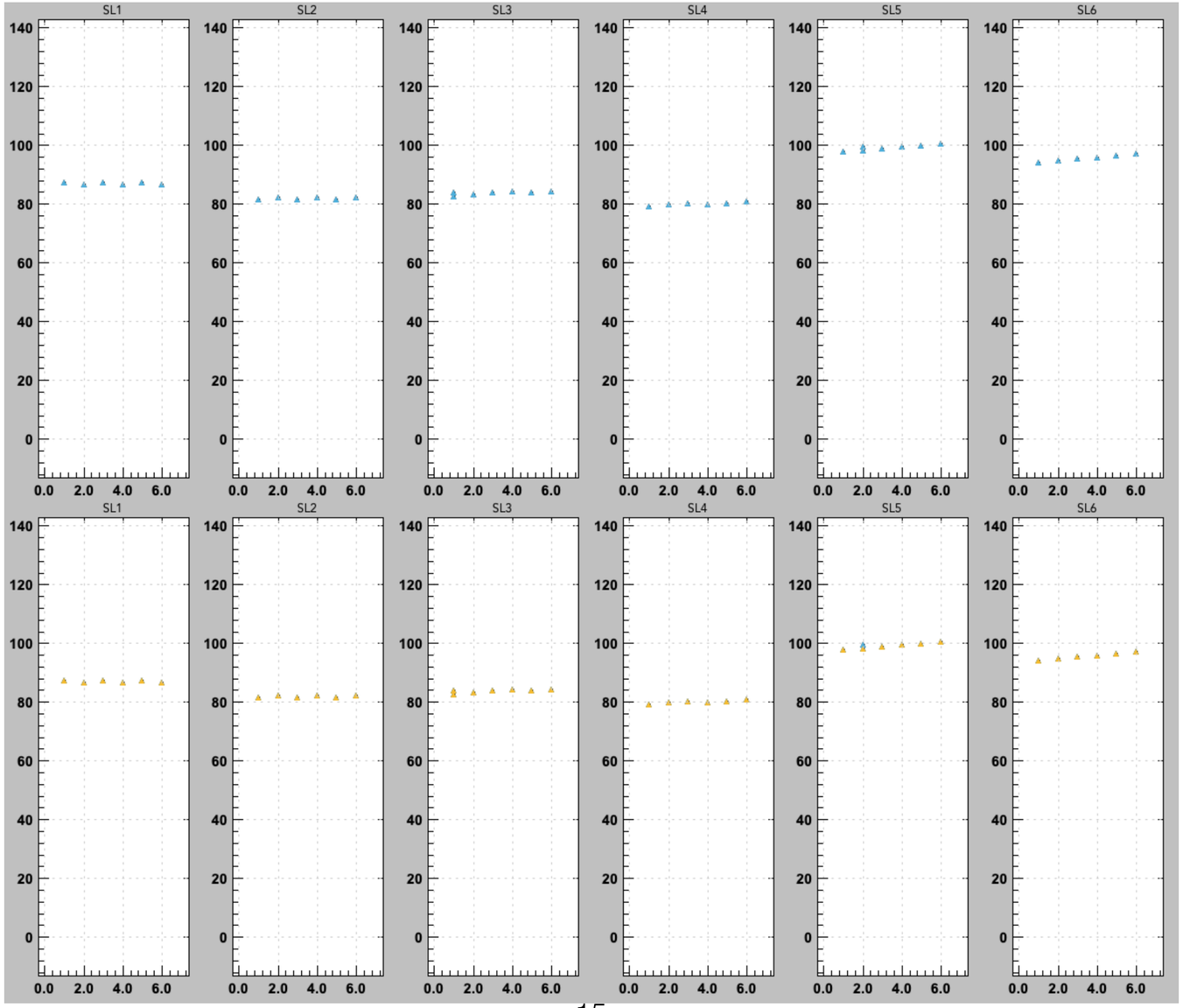
Passed for TB tracking with HB track estimated by AI



Example 2

Passed for HB tracking, while failed for TB tracking

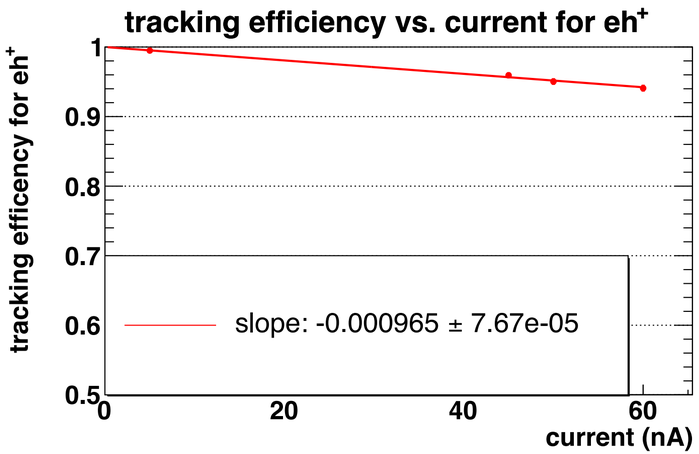
Passed for TB tracking with HB track estimated by AI

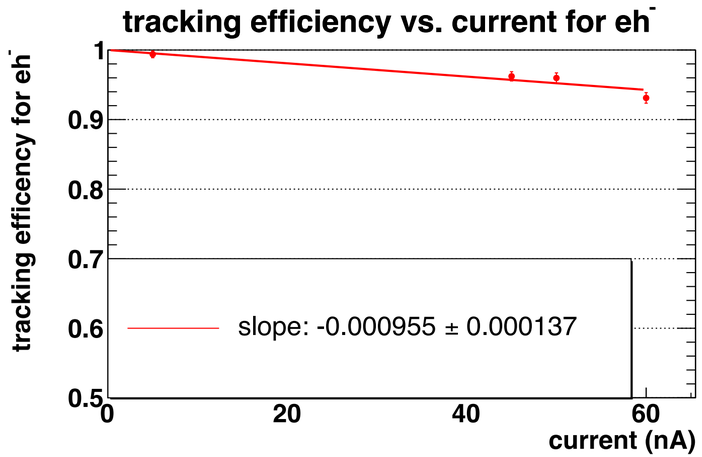


RGA

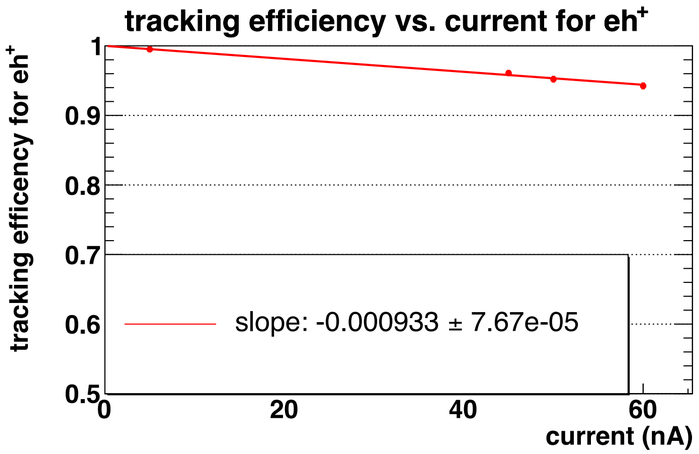
Tracking Efficiency

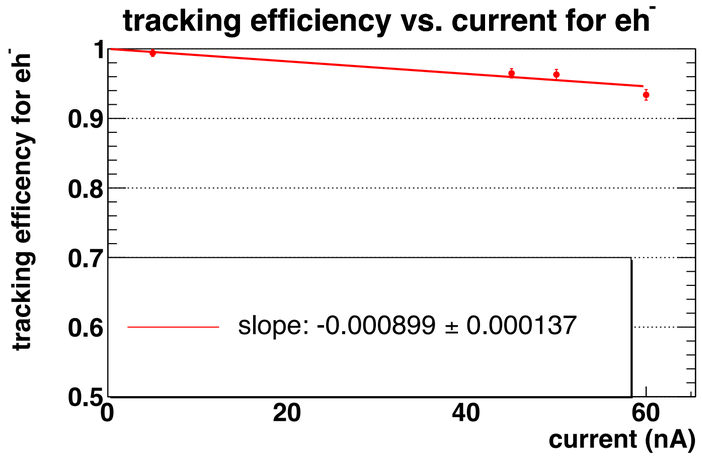
AI-assisted HB tracking





HB tracking by AI estimator

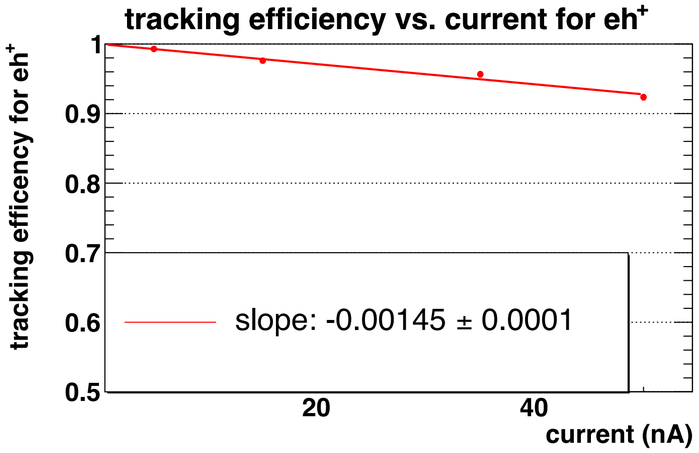


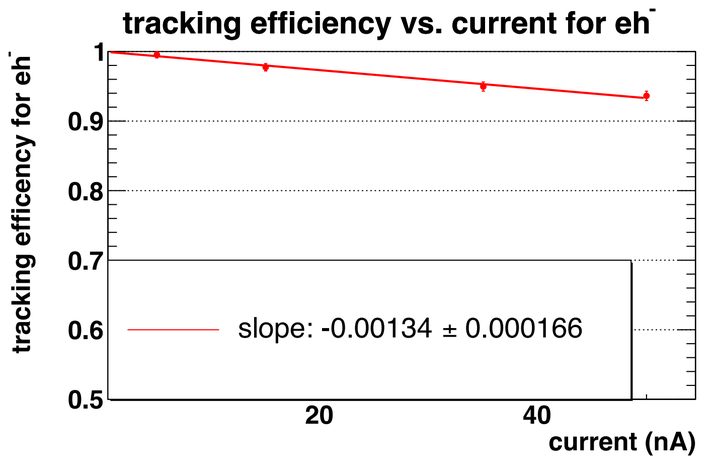


RGB

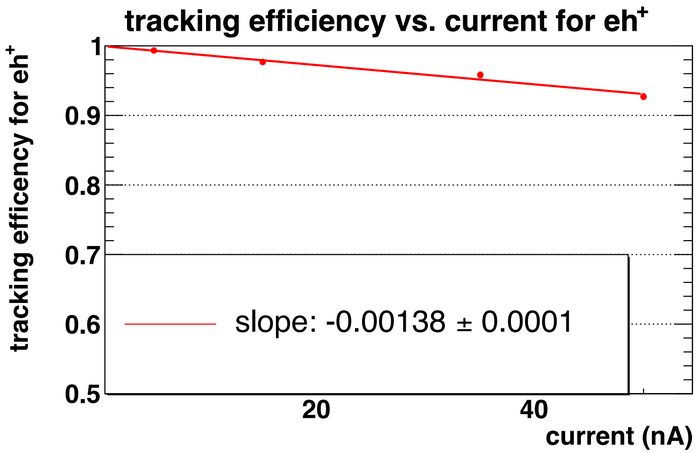
Tracking Efficiency

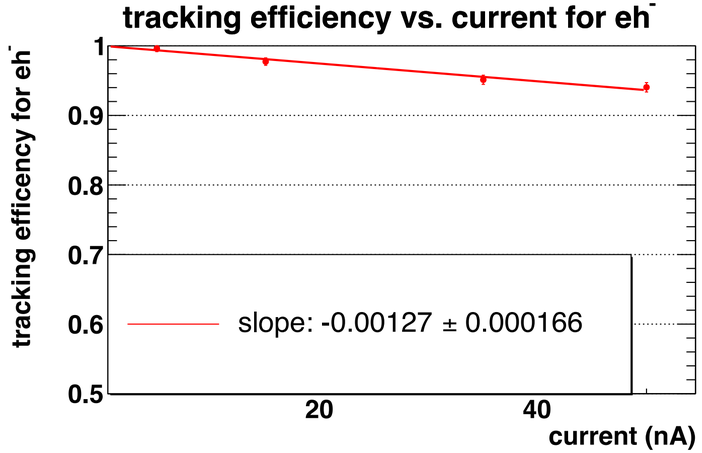
AI-assisted HB tracking





HB tracking by AI estimator

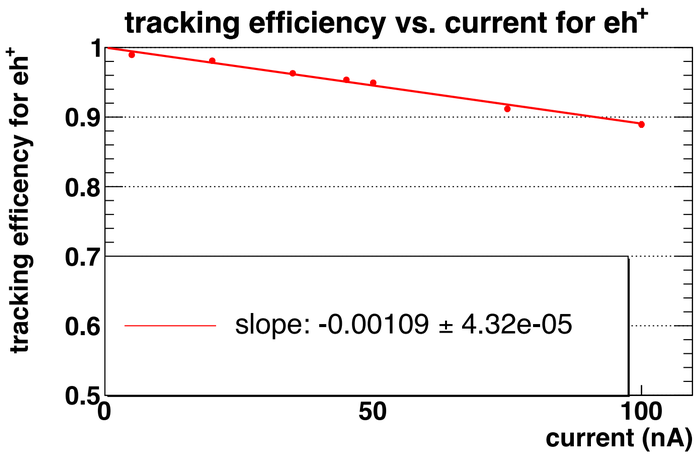


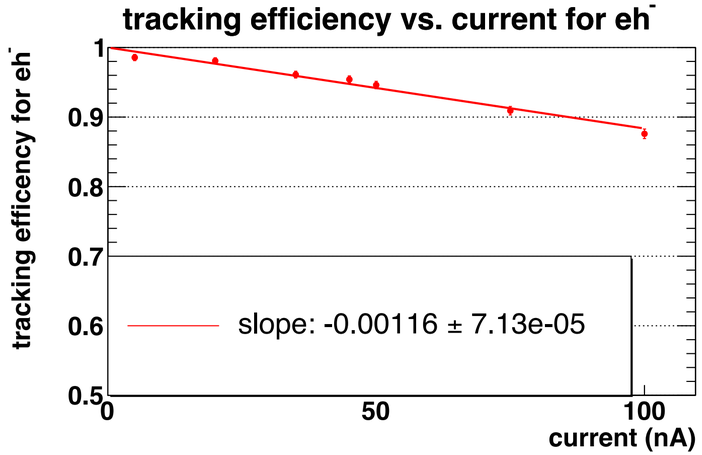


RGD

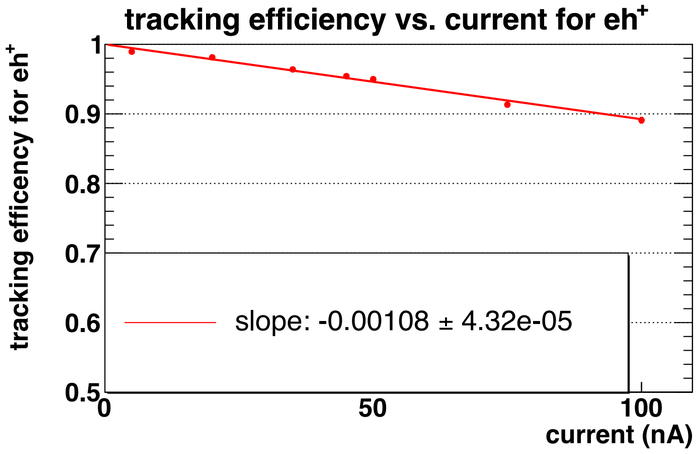
Tracking Efficiency

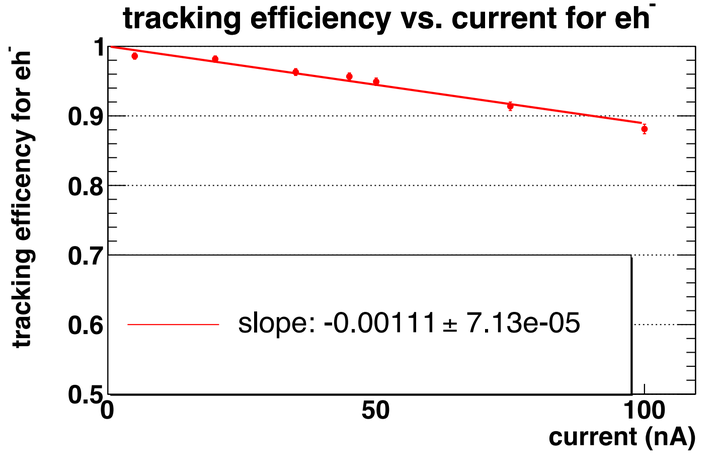
AI-assisted HB tracking





HB tracking by AI estimator

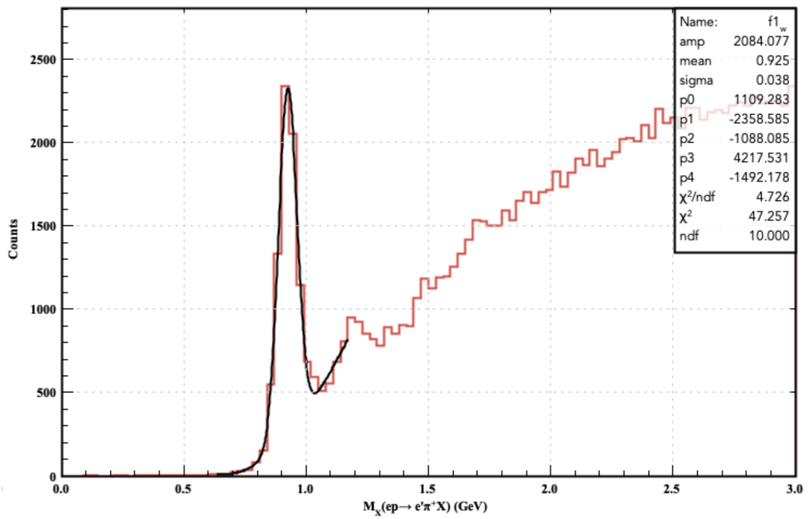


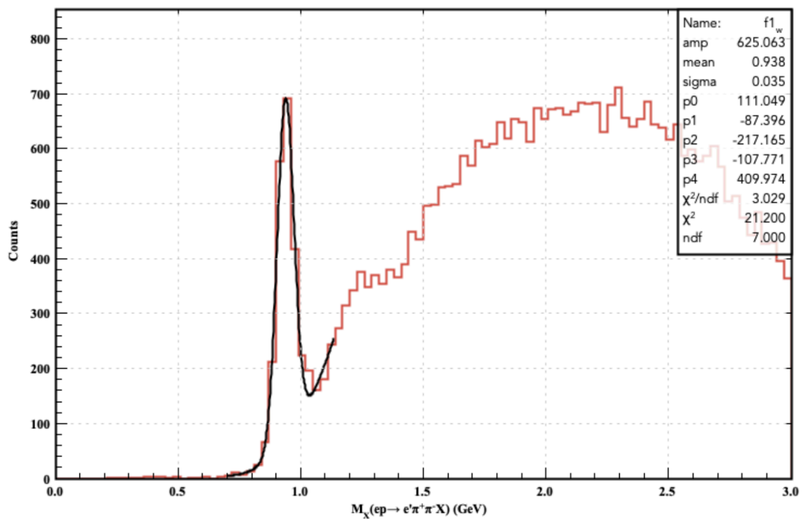


RGA Run 5418

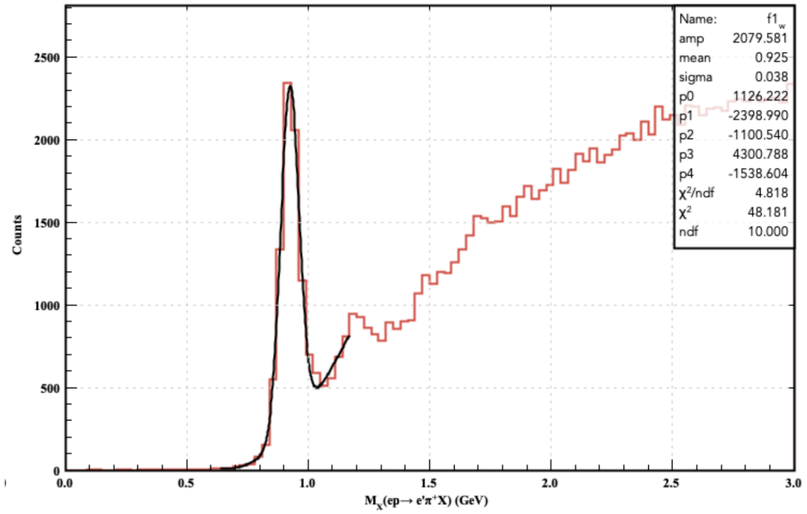
Resolution

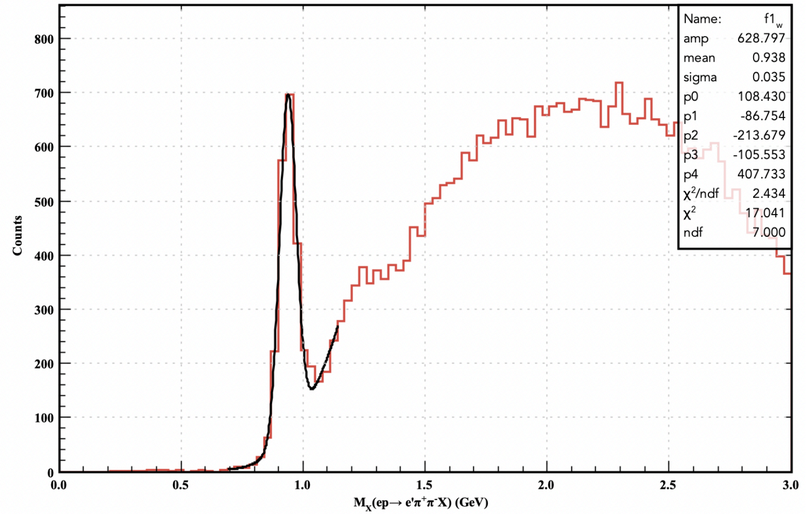
AI-assisted HB tracking





HB tracking by AI estimator





CPU Time

AI-assisted HB tracking

```
==================================
      BAND:     0.03 ms  0.01%
       CND:     0.64 ms  0.11%
      CTOF:     1.69 ms  0.29%
     CVTFP:    61.91 ms 10.76%
     CVTSP:    25.92 ms  4.51%
      DCCR:     9.29 ms  1.62%
     DCHAI:    52.15 ms  9.07%
      DCHB:    71.77 ms 12.47%
     DCTAI:   156.37 ms 27.18%
      DCTB:   151.86 ms 26.40%
     EBHAI:     0.76 ms  0.13%
      EBHB:     0.79 ms  0.14%
     EBTAI:     0.92 ms  0.16%
      EBTB:     0.98 ms  0.17%
        EC:     1.60 ms  0.28%
       FMT:     0.04 ms  0.01%
    FTOFHB:     2.02 ms  0.35%
    FTOFTB:     2.02 ms  0.35%
      HTCC:     0.06 ms  0.01%
      LTCC:     0.04 ms  0.01%
 MAGFIELDS:     0.02 ms  0.00%
      MLTD:    26.86 ms  4.67%
    RASTER:     0.02 ms  0.00%
    READER:     0.09 ms  0.02%
      RICH:     2.29 ms  0.40%
      RTPC:     0.04 ms  0.01%
     SWAPS:     0.25 ms  0.04%
    WRITER:     4.89 ms  0.85%
==================================
      TOTAL:   575.30 ms
```

HB tracking by AI estimator

```
==================================
      BAND:     0.03 ms  0.01%
       CND:     0.61 ms  0.10%
      CTOF:     1.56 ms  0.26%
     CVTFP:    65.67 ms 10.85%
     CVTSP:    27.62 ms  4.56%
      DCCR:    10.22 ms  1.69%
      DCHB:    76.67 ms 12.66%
    DCHTAI:    45.63 ms  7.54%
     DCTAI:   167.37 ms 27.64%
      DCTB:   162.79 ms 26.89%
     EBHAI:     0.77 ms  0.13%
      EBHB:     0.81 ms  0.13%
     EBTAI:     0.95 ms  0.16%
      EBTB:     1.00 ms  0.17%
        EC:     1.56 ms  0.26%
       FMT:     0.04 ms  0.01%
    FTOFHB:     1.89 ms  0.31%
    FTOFTB:     1.91 ms  0.32%
      HTCC:     0.06 ms  0.01%
      LTCC:     0.04 ms  0.01%
 MAGFIELDS:     0.02 ms  0.00%
      MLTD:    30.31 ms  5.01%
    RASTER:     0.02 ms  0.00%
    READER:     0.10 ms  0.02%
      RICH:     2.37 ms  0.39%
      RTPC:     0.04 ms  0.01%
     SWAPS:     0.27 ms  0.05%
    WRITER:     5.10 ms  0.84%
==================================
      TOTAL:   605.43 ms
```

Summary

- The AI model for estimation of HB track state and the new engine with application of the model works well.
- Comparison to HB tracking by KF, tracking efficiency is a little bit improved, processing speed is ~12% faster, and resolution is close.
- Resolution for HB tracks by AI estimator is much better than HB tracking by KF. It will change quality for the following HB reconstruction based on HB tracks, and further affect TB reconstruction.
- New HB tracks by AI will affect resolution of TB hits.
- Any effects on calibrations?