



GNN-Based Track Finding for the STCF Main Drift Chamber High-Level Trigger

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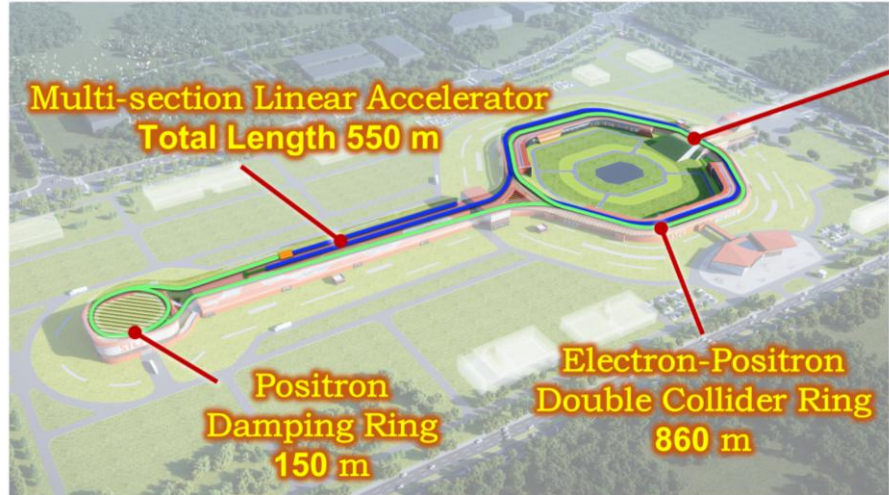
University of Science and Technology of China

On behalf of the STCF TRIG working group

2026.10.14

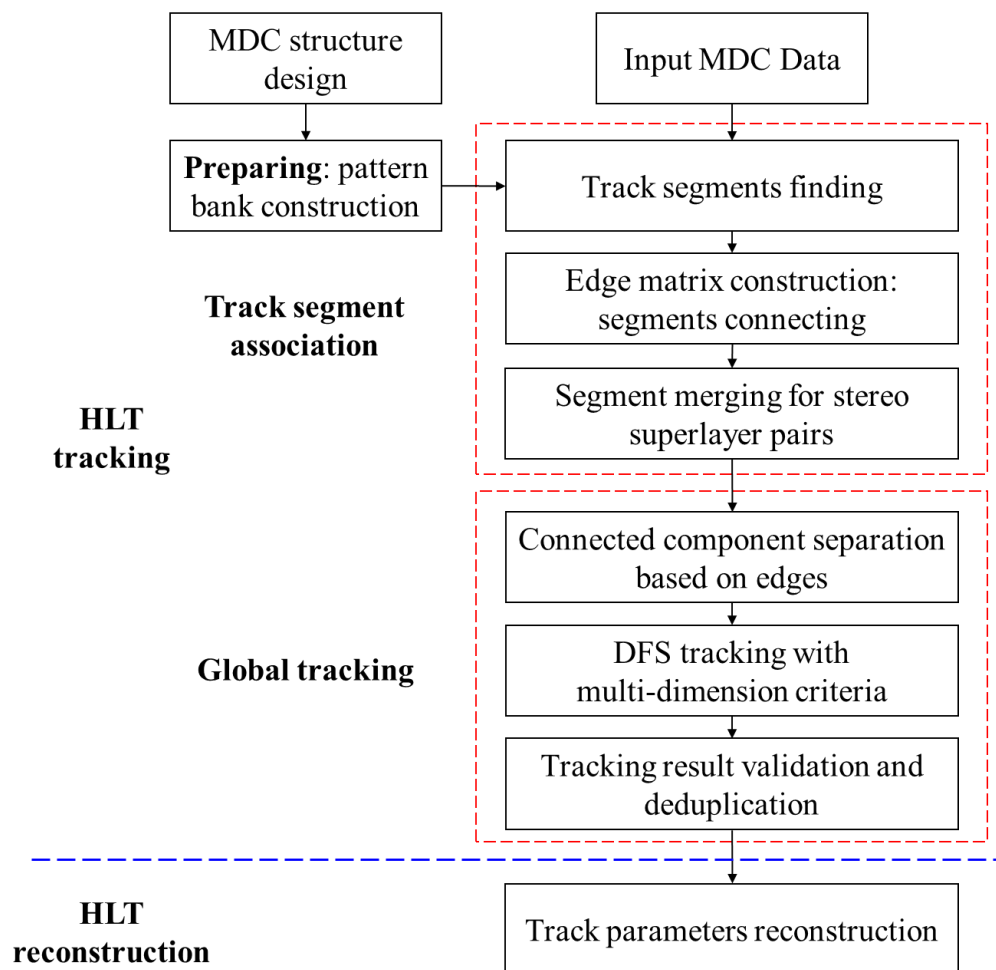
- Background and Motivation
- Algorithm Design
- GNN Training and Working Point Selection
- Performance Evaluation
- Summary and Outlook

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Main Drift Chamber (MDC): core of tracking

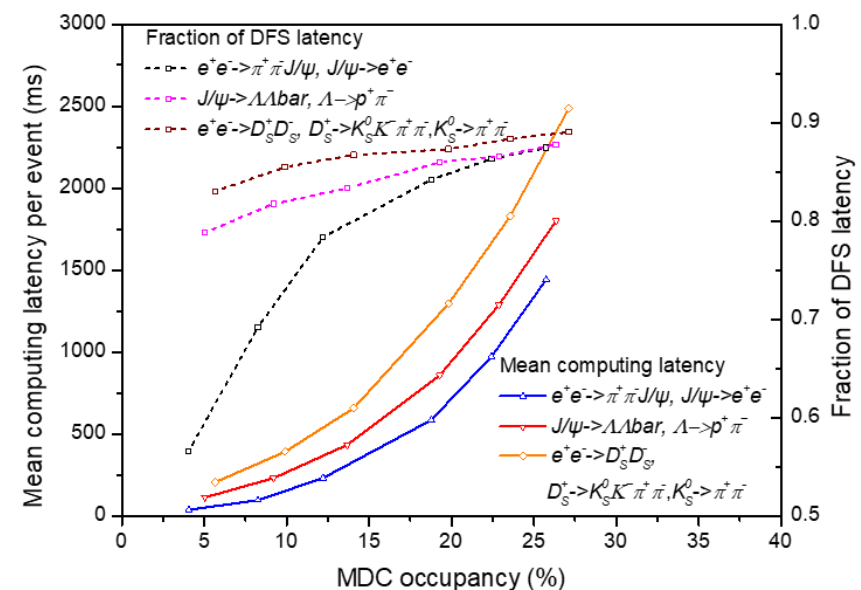
- ## MDC HLT Objectives:
- Compress the data volume without affecting offline analysis
 - Latency: 50 ms at 8% occupancy



HLT algorithm based on track segments and DFS:

- Track segment extraction using a pattern bank
- Depth-First Search-Based global tracking

Major Challenge: **High Latency**



□ Background and Motivation

□ **Algorithm Design**

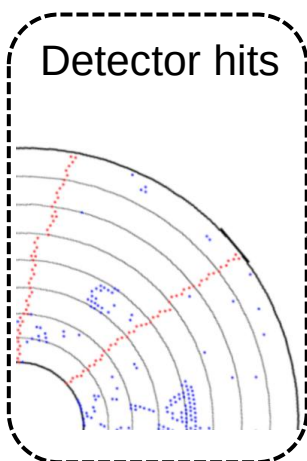
□ GNN Training and Working Point Selection

□ Performance Evaluation

□ Summary and Outlook

Overview of the GNN-Based Pipeline

Pre-processing stage



Input matrices

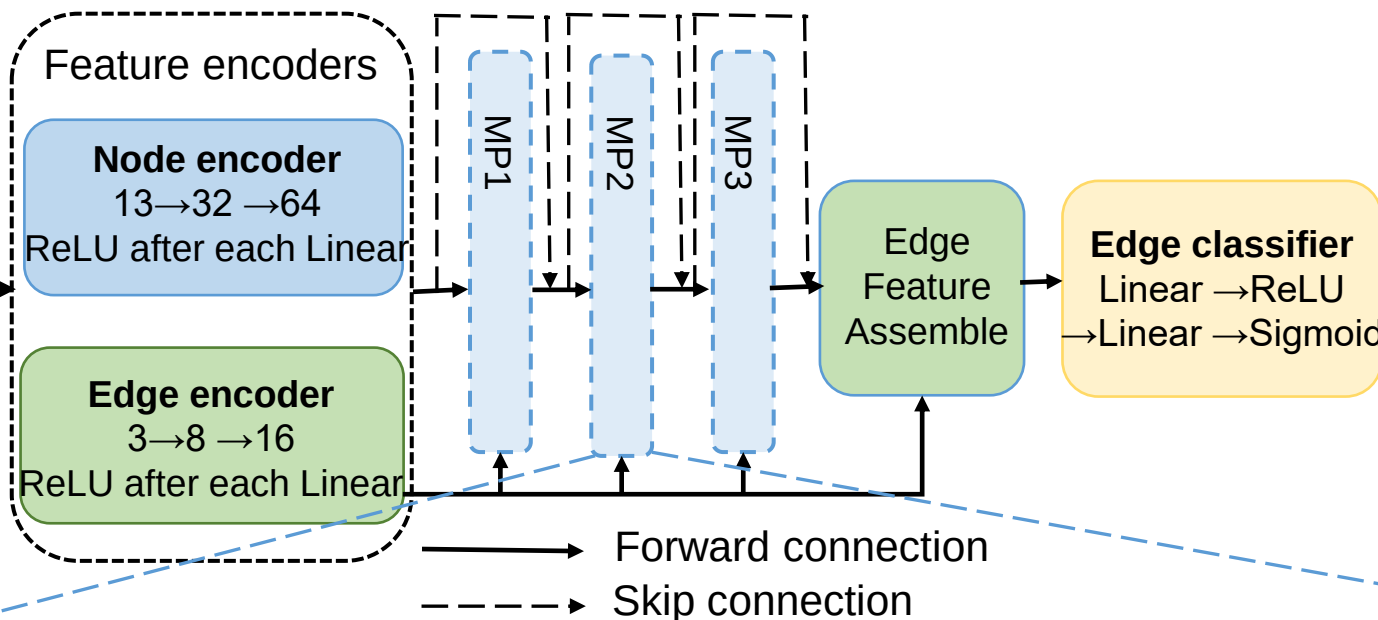
Nodes

SL_1	TAG_1	...	s_{t1}
SL_2	TAG_2	...	s_{t2}
...	...	...	...
SL_n	TAG_n	...	s_{tn}

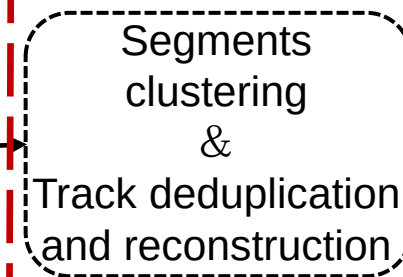
Edges

$Node_{11}$	$Node_{12}$	...	$\Delta\alpha_1$
$Node_{21}$	$Node_{22}$	...	$\Delta\alpha_2$
...	...	...	...
$Node_{n1}$	$Node_{n2}$	...	$\Delta\alpha_n$

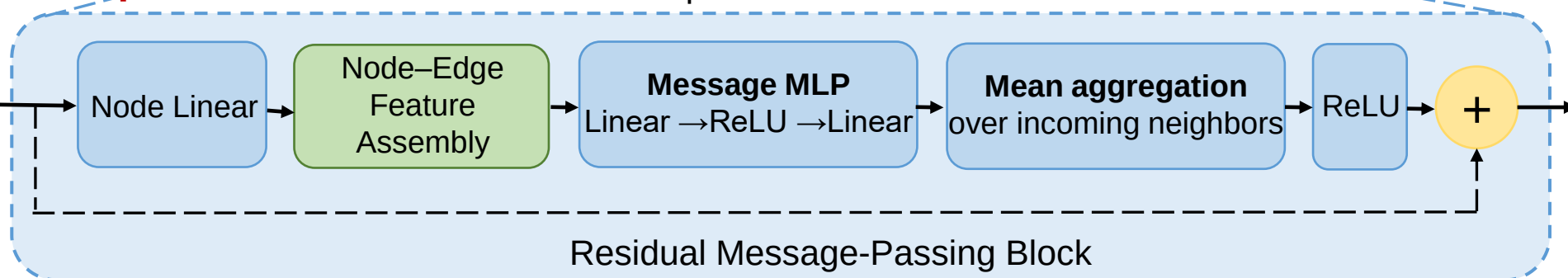
Edge classifier GNN



Post-processing stage



- Parameters: **47K**
- Weighted binary cross-entropy (BCE) loss

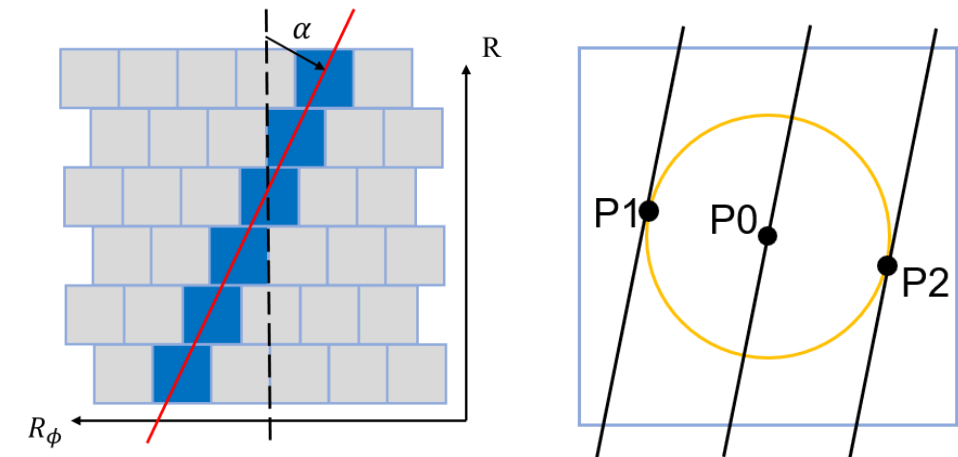
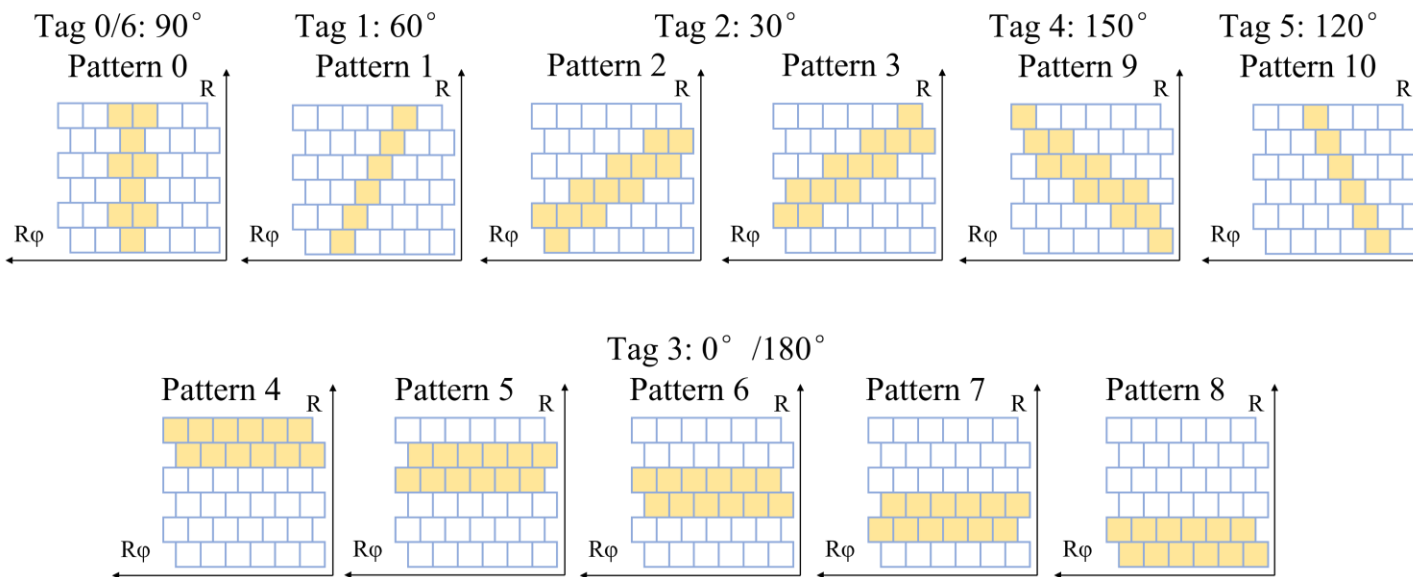


Pattern-Based Track Segments Finding

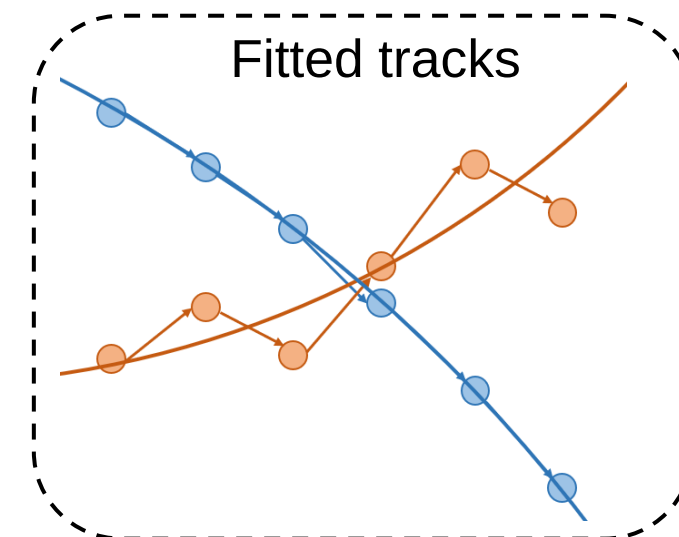
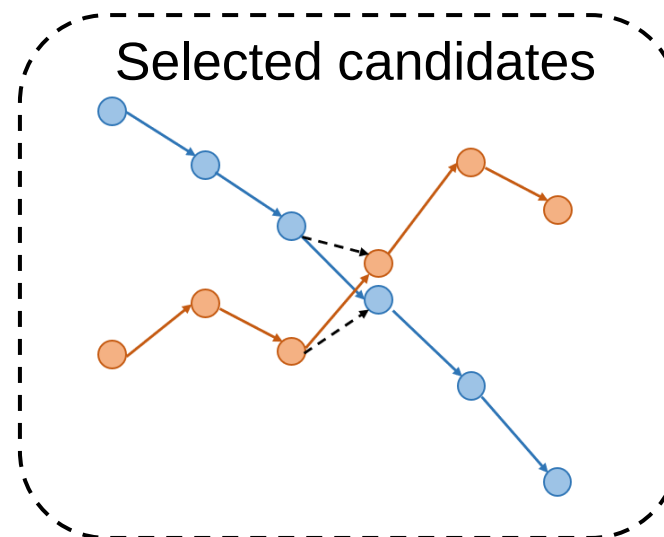
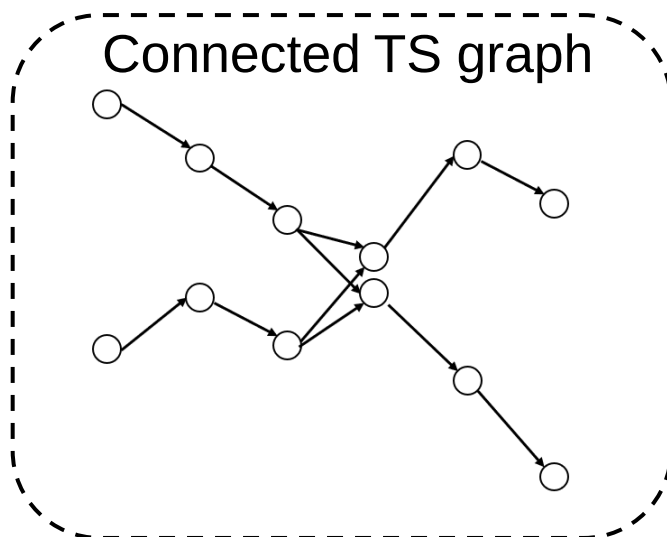
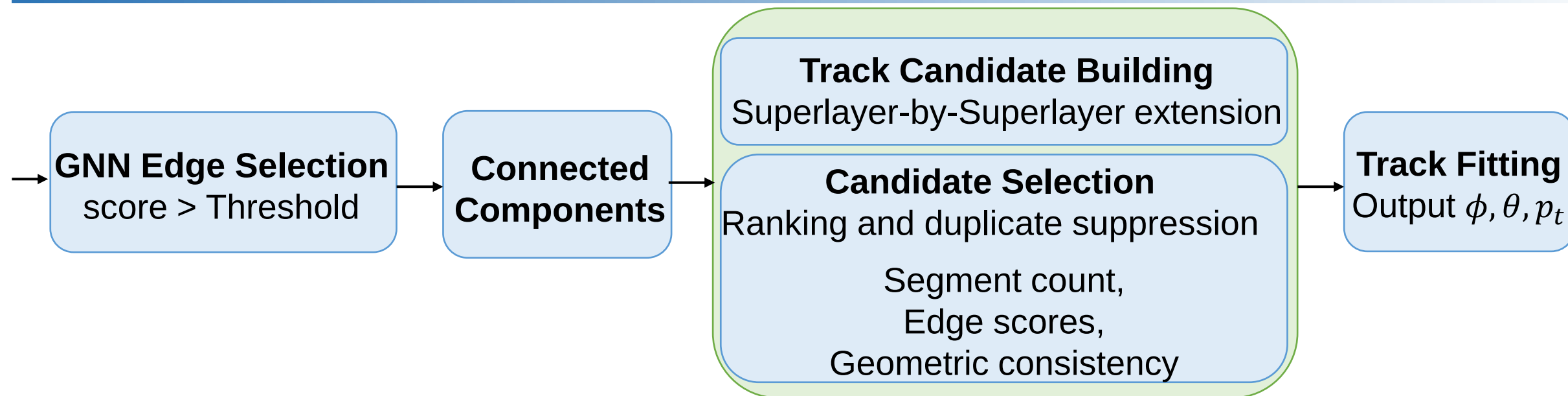
- Extract using an 11-pattern bank
- Bitwise operation accelerated pattern matching

α Estimation

- Local segment direction
- Drift-time-assisted Hough transform



Online Tracking and Reconstruction



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Impact of **background composition**, **α –related features**, and **process diversity**

Evaluation metrics

- edge level: ROC/AUC, FPR/TPR
vs threshold
- hit level: signal hit efficiency,
background hit rejection

$$\text{Signal hit efficiency} = \frac{N_{sig}^{pass}}{N_{sig}^{input}}$$

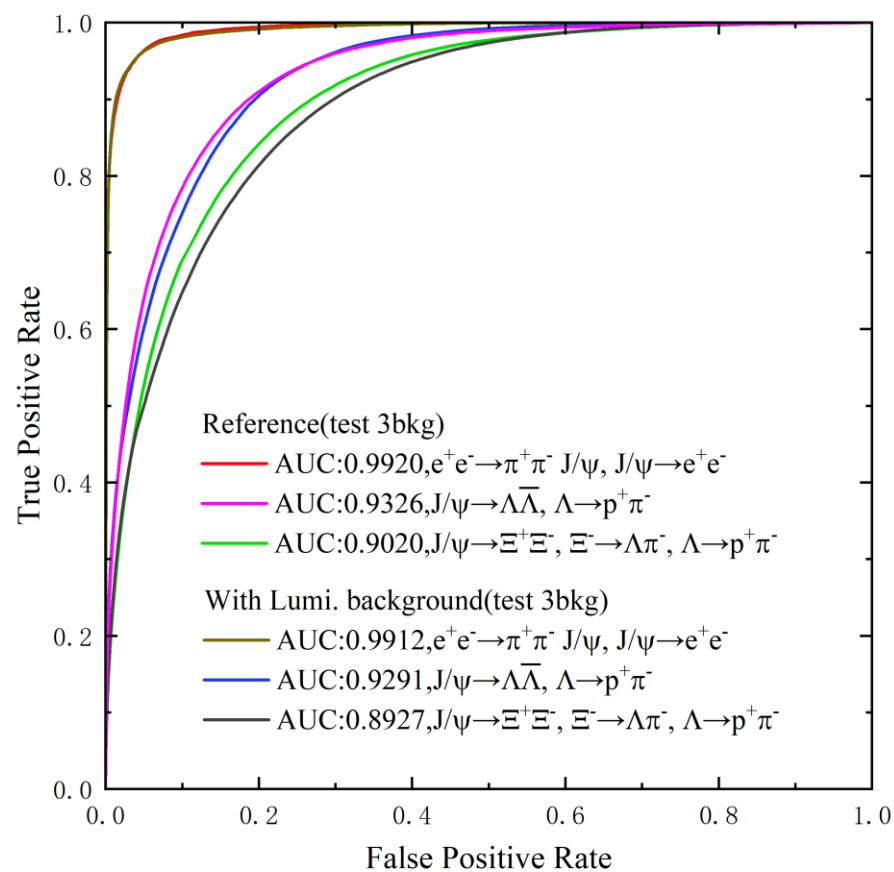
$$\text{Background hit rejection} = \frac{N_{bkg}^{rej}}{N_{bkg}^{input}}$$

Model	Luminosity background	α -related features	Training processes
Reference	No	Yes	$e^+e^- \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow e^+e^-$
With Lumi. background	Yes	Yes	$e^+e^- \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow e^+e^-$
Without α features	No	No	$e^+e^- \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow e^+e^-$
Mixed processes	No	Yes	$e^+e^- \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow e^+e^-$ $J/\psi \rightarrow \Lambda\bar{\Lambda}$, $\Lambda \rightarrow p^+\pi^-$ $J/\psi \rightarrow \Xi^+\Xi^-$, $\Xi^- \rightarrow \Lambda\pi^-$, $\Lambda \rightarrow p^+\pi^-$ (4:1:1)

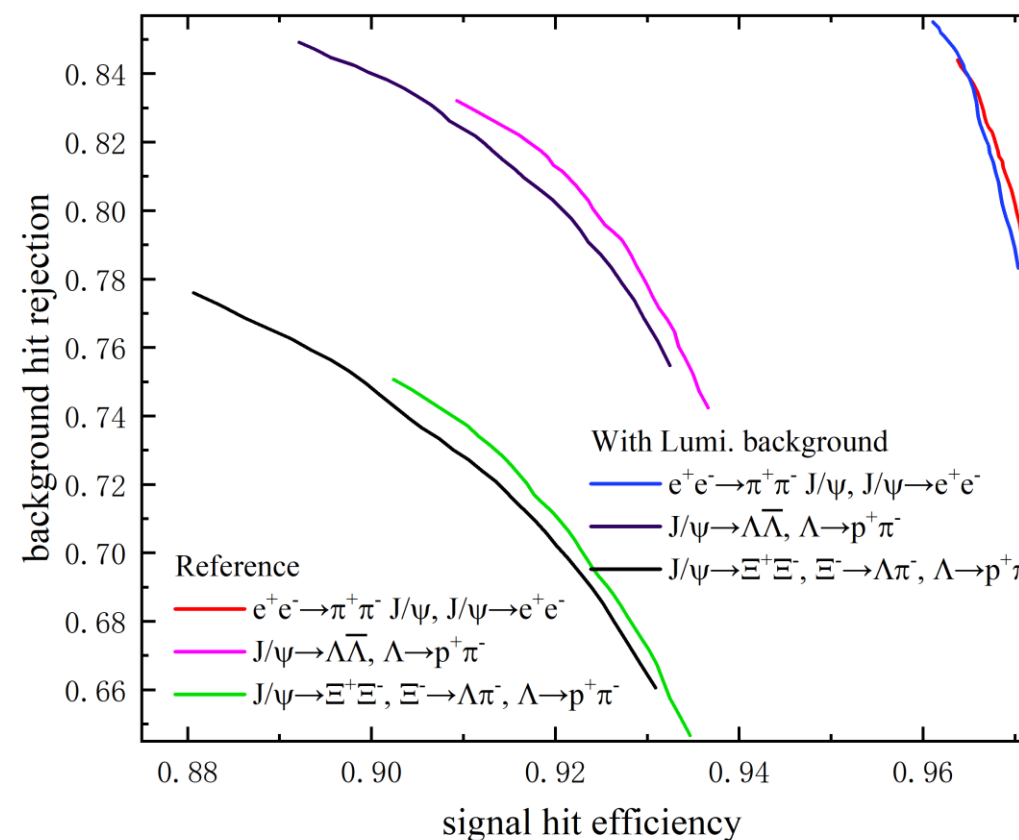
All models are evaluated on common,
independent test samples.

Luminosity background: **slightly degrade performance**

edge level ROC curves

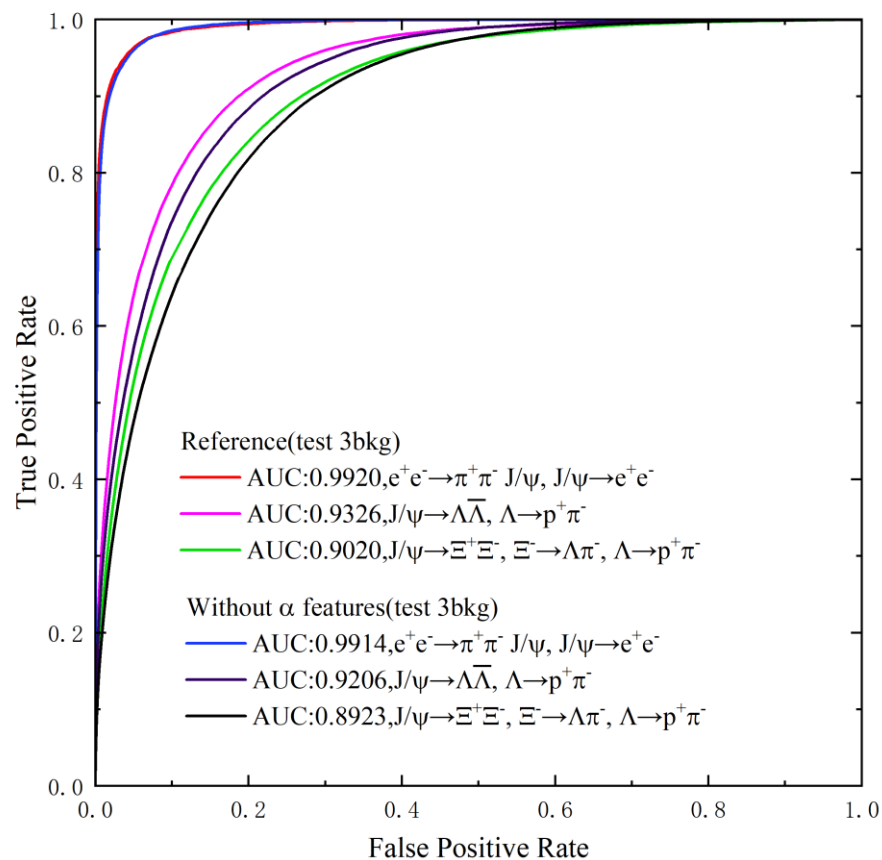


hit level curves

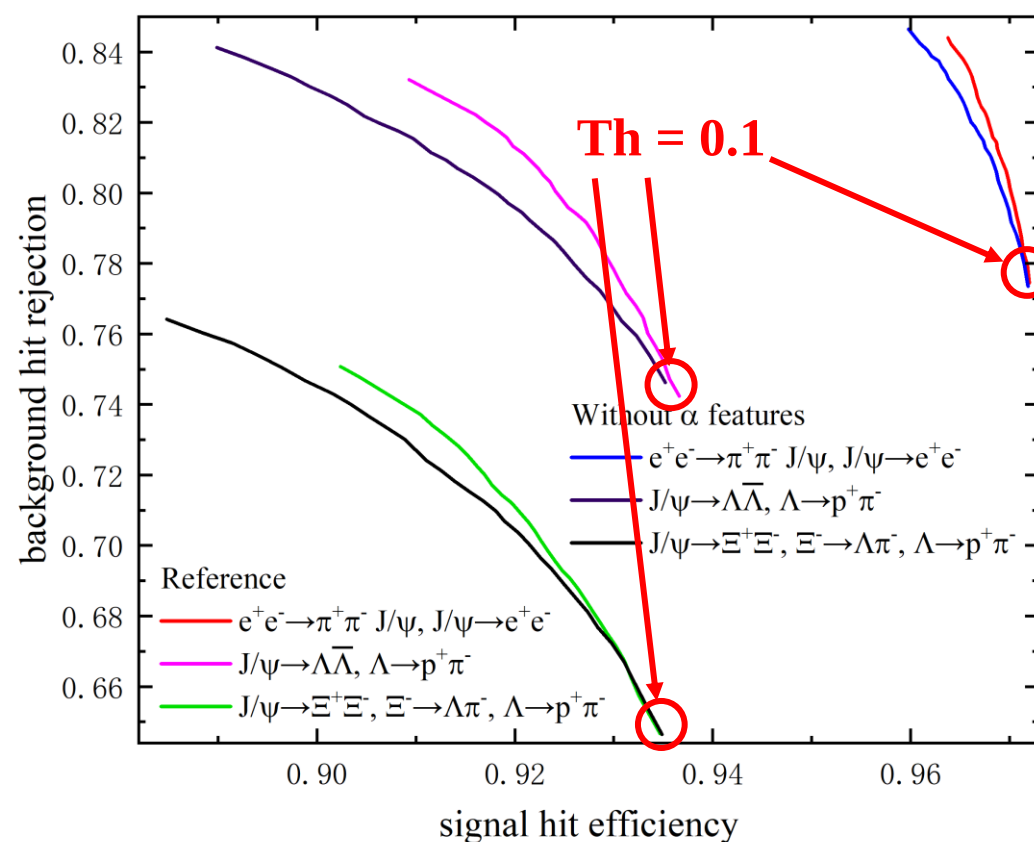


α -related features: provide a improvement

edge level ROC curves

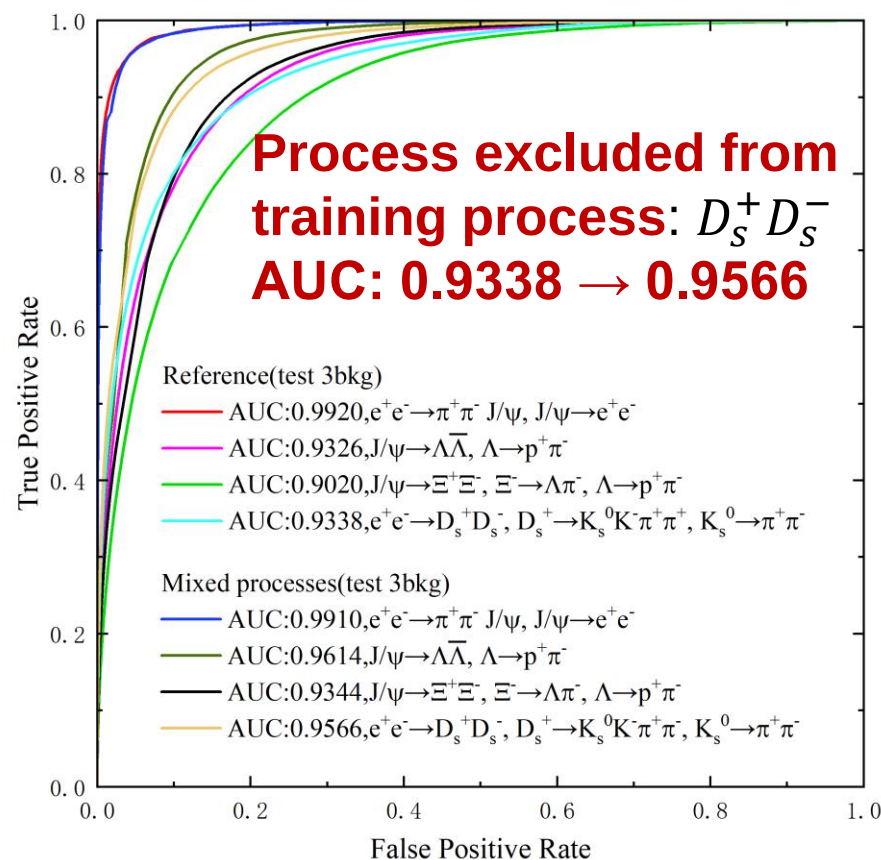


hit level curves

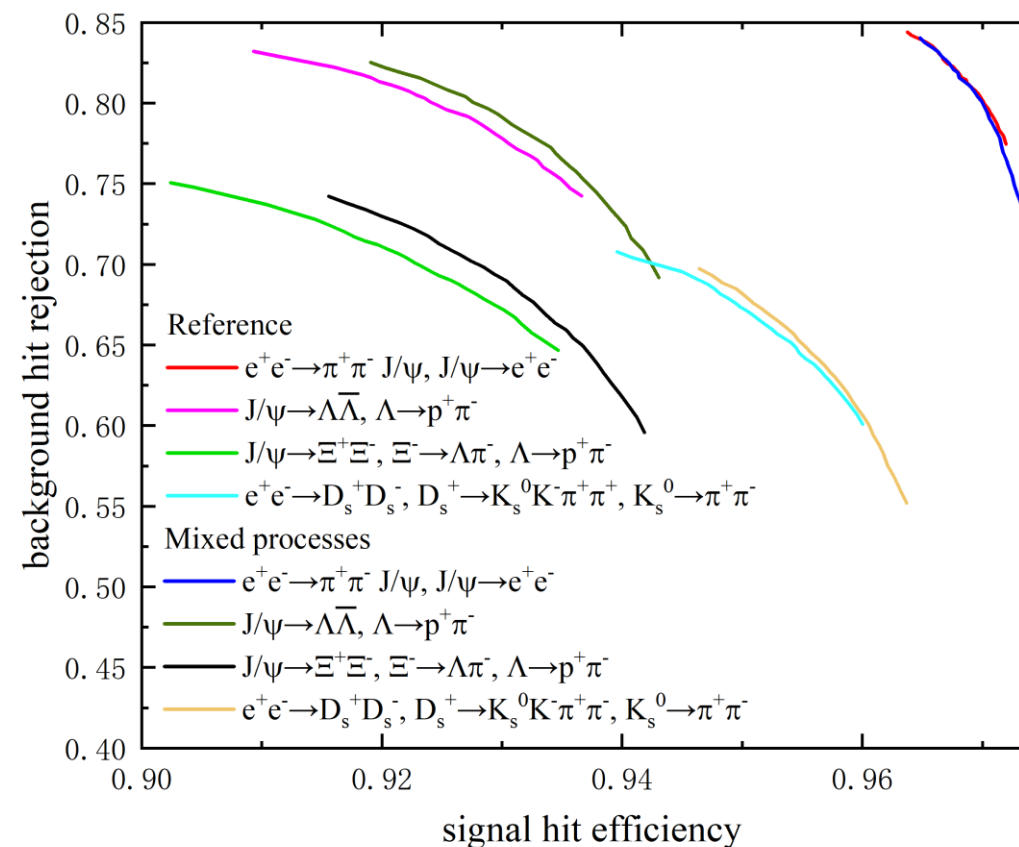


Mixed processes: **improve generalization**

edge level ROC curves

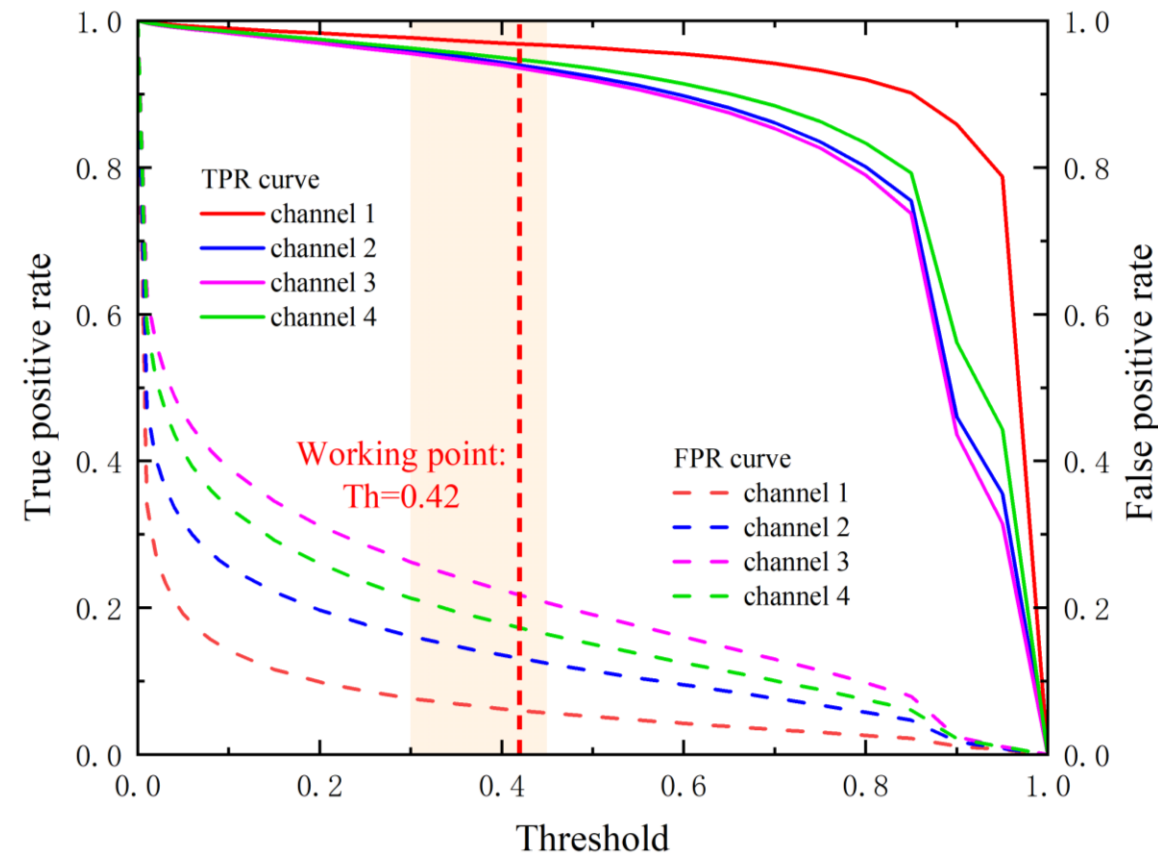
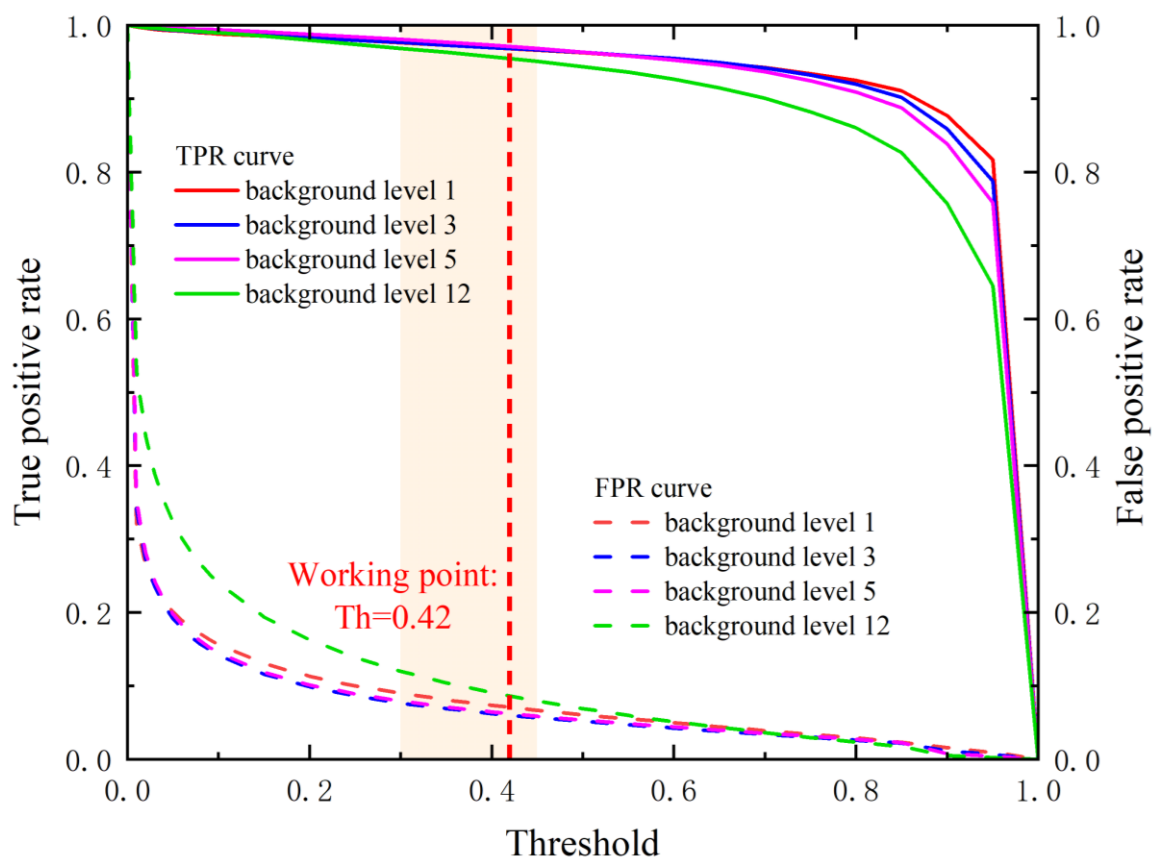


hit level curves



Offline crosschecks: threshold range of 0.3–0.45

Selected working point: **0.42** for high background rejection



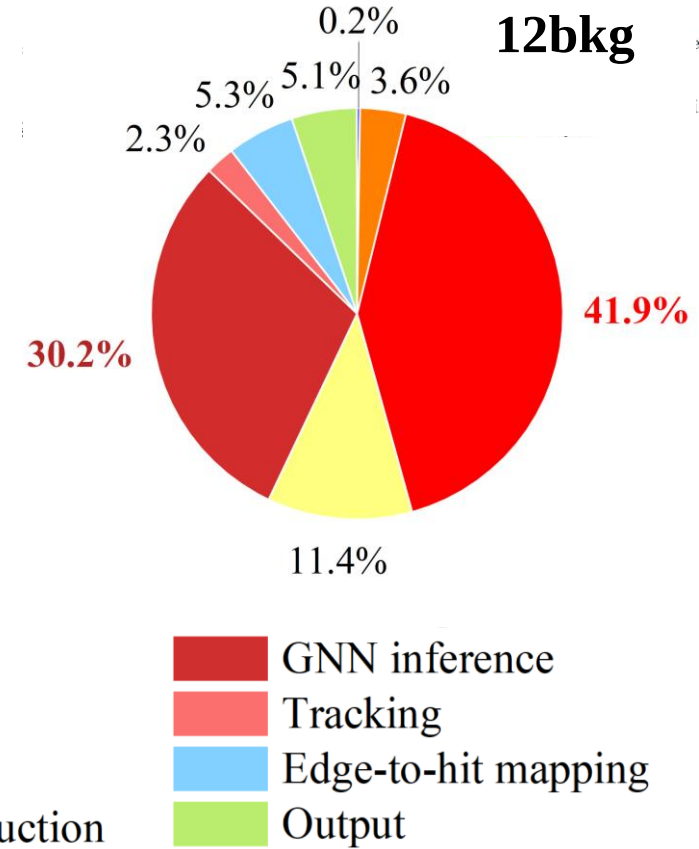
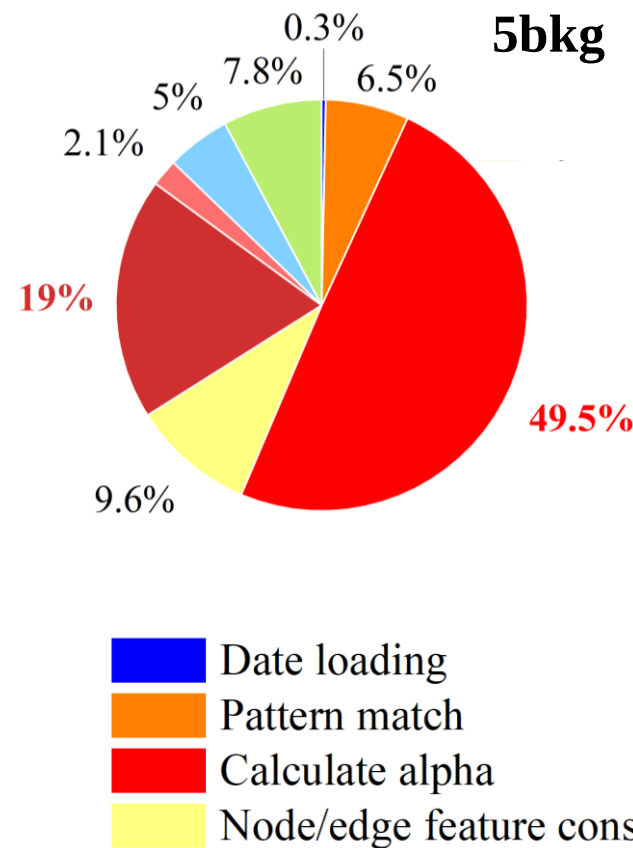
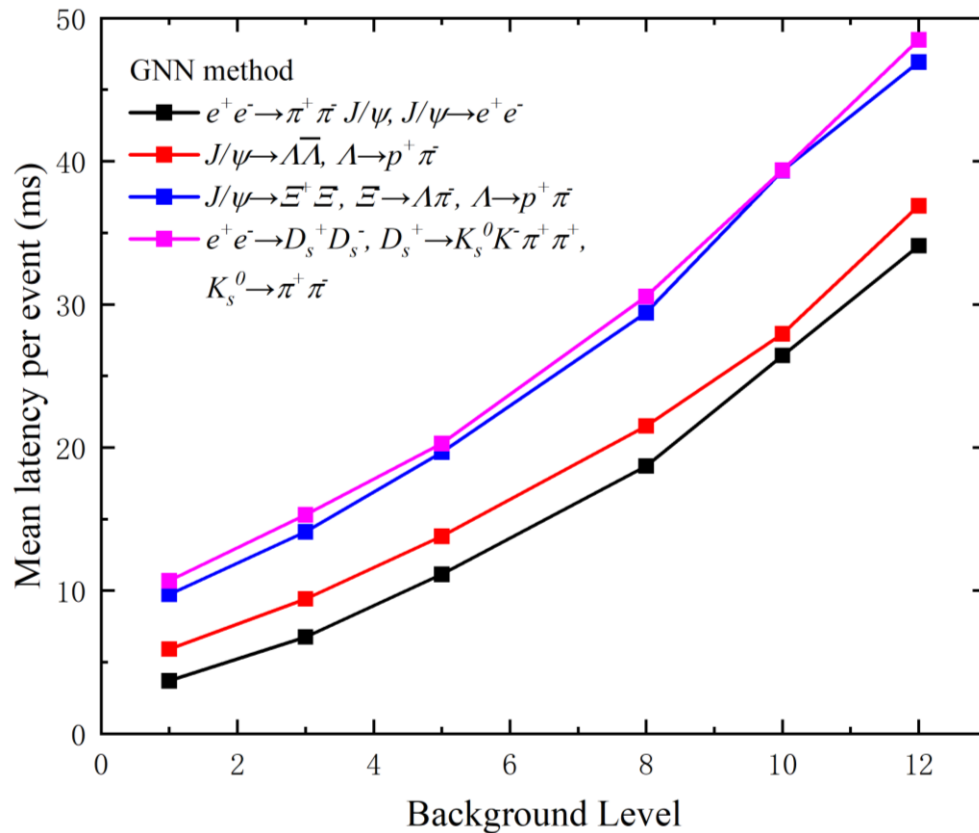
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Timing Performance

□ AMD EPYC 9654 CPU (3.7GHz frequency)

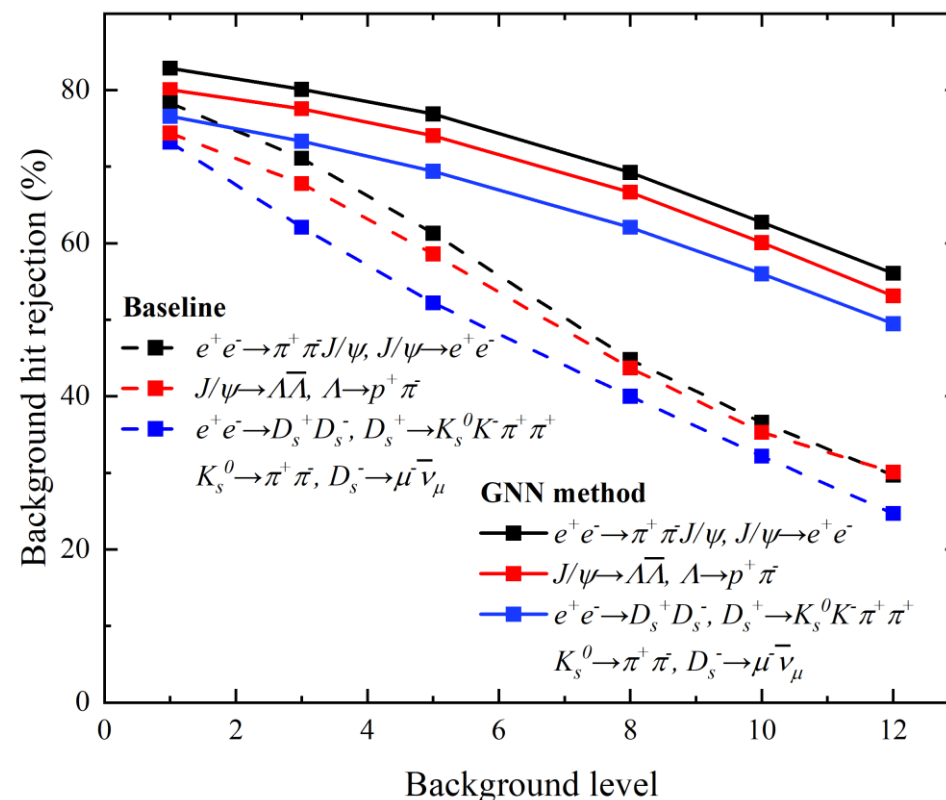
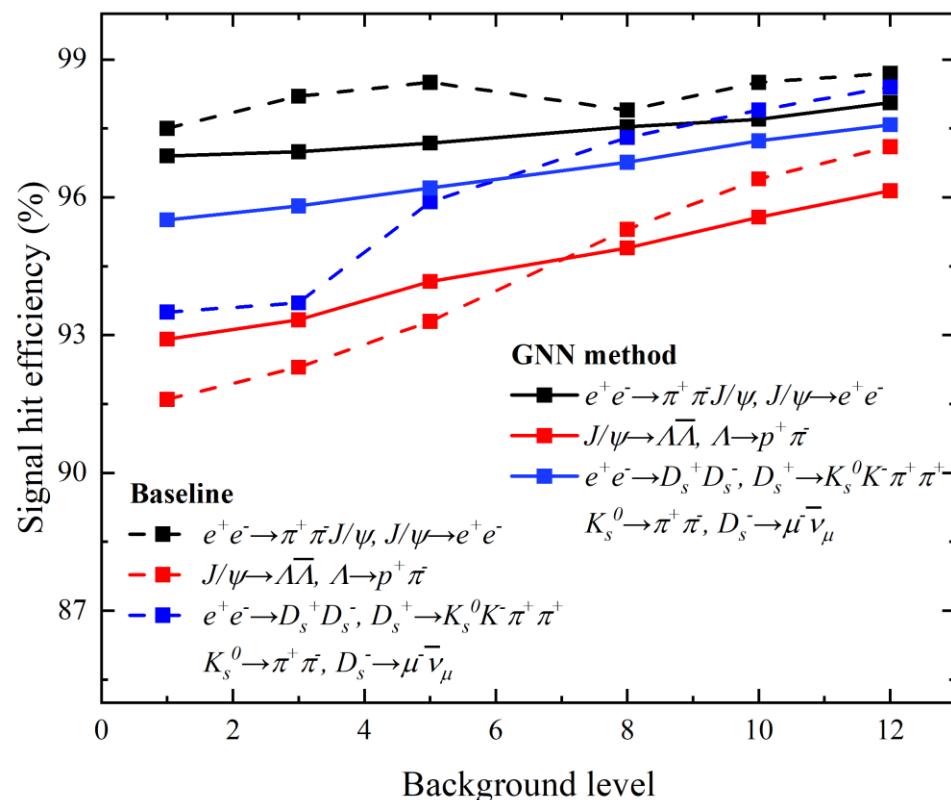
- Single-core Single-thread CPU
- Optimized compilation with ACLiC

➤ For $e^+e^- \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow e^+e^-$



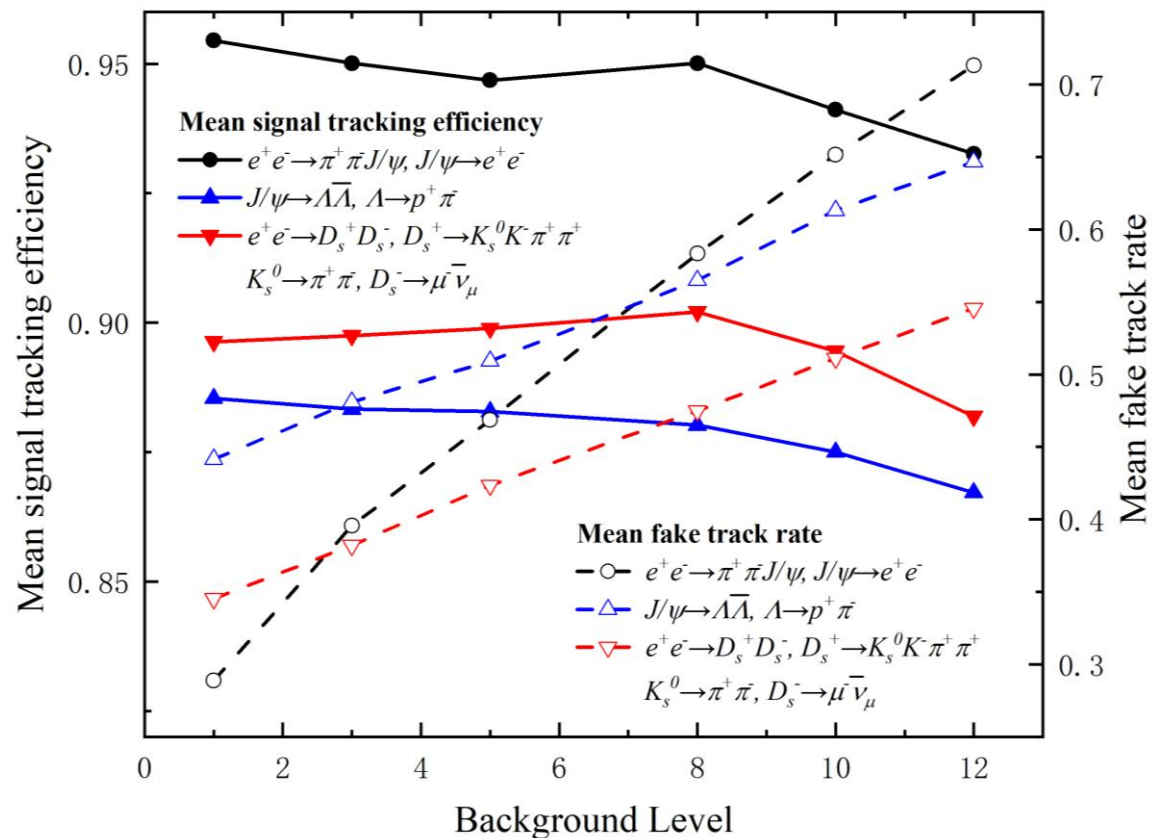
Approximately 93–98% of signal hits are retained

At 12bkg, approximately 50-56% of background hits are still rejected

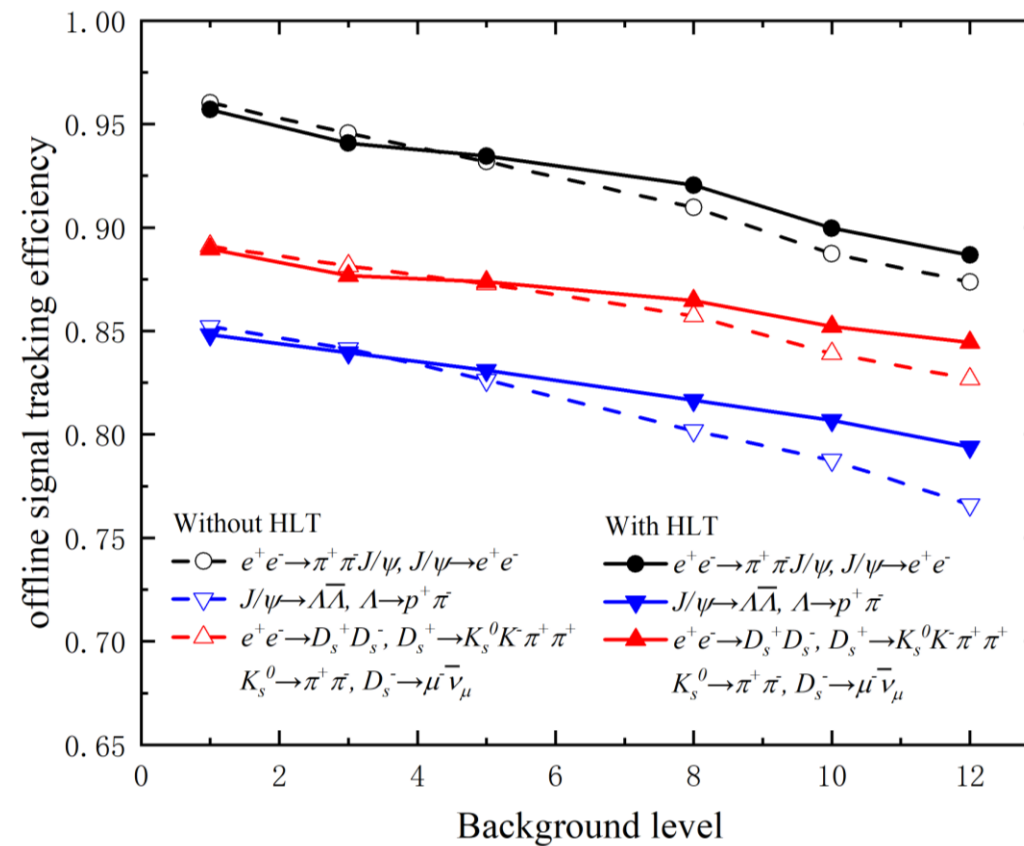


background hit rejection: **greatly improved**
 signal hit efficiency: **small changes**

Online tracking performance



Offline tracking with and without HLT



Online tracking: **room for improvement** in candidate selection and reconstruction

Offline tracking: **comparable signal tracking efficiency** with and without HLT

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Summary:

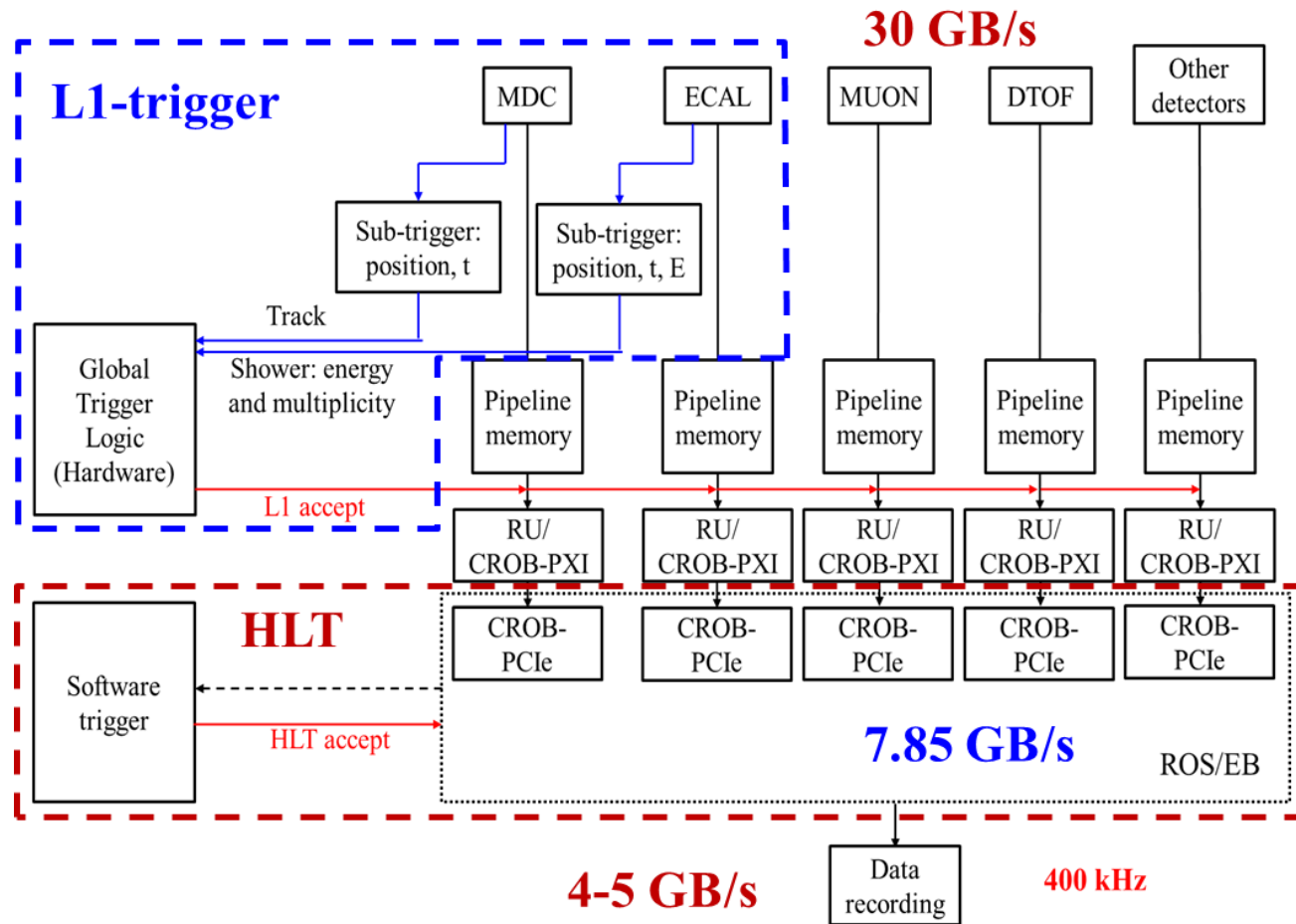
- Developed a **GNN-based** algorithm for the STCF MDC HLT.
- Studied **training-set composition** and its impact on performance.
- Achieved latency below **15ms@3bkg(8% occupancy), 50 ms@12bkg(25% occupancy)**.

Outlook:

- Replace alpha calculation with a simple MLP to reduce latency.
- Reduce fake tracks and improve online track reconstruction.
- Explore a segment-to-track GNN framework.

Thanks!

Back up——Trigger System

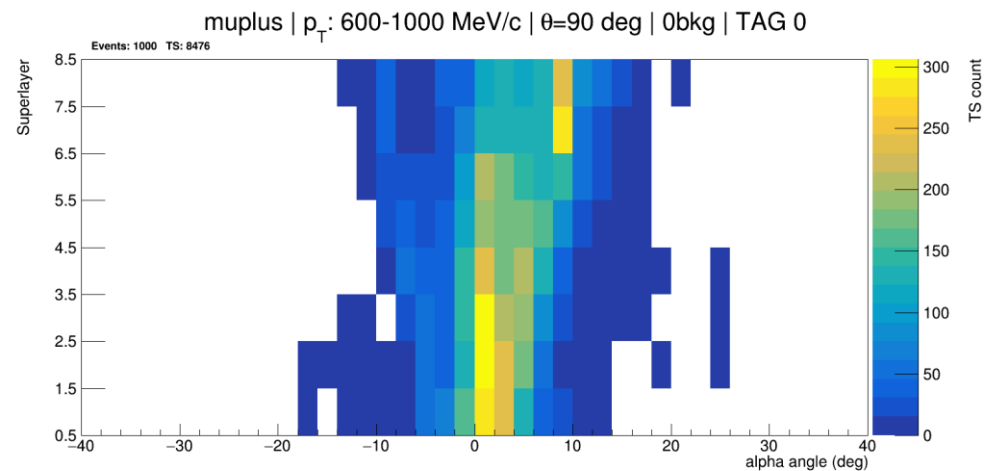
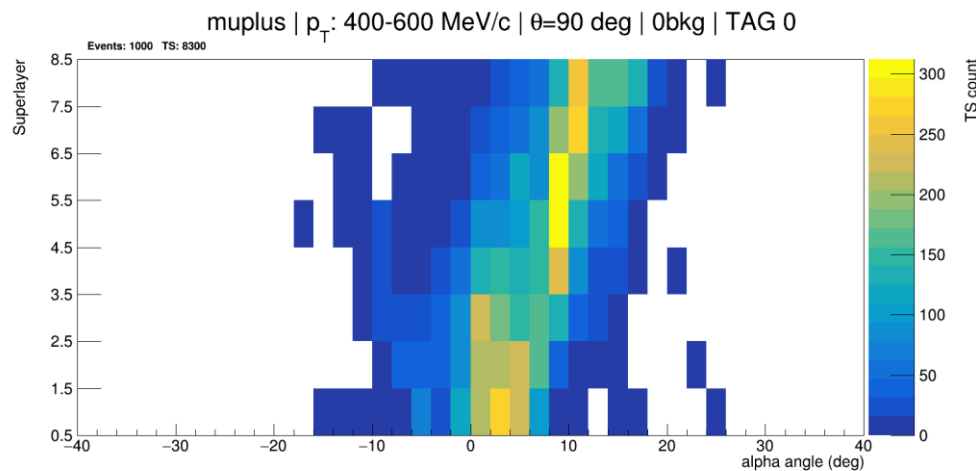
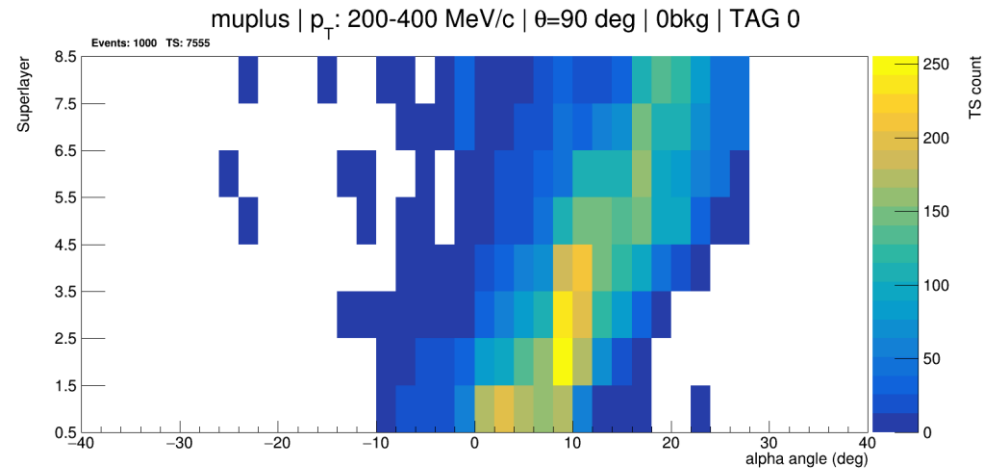
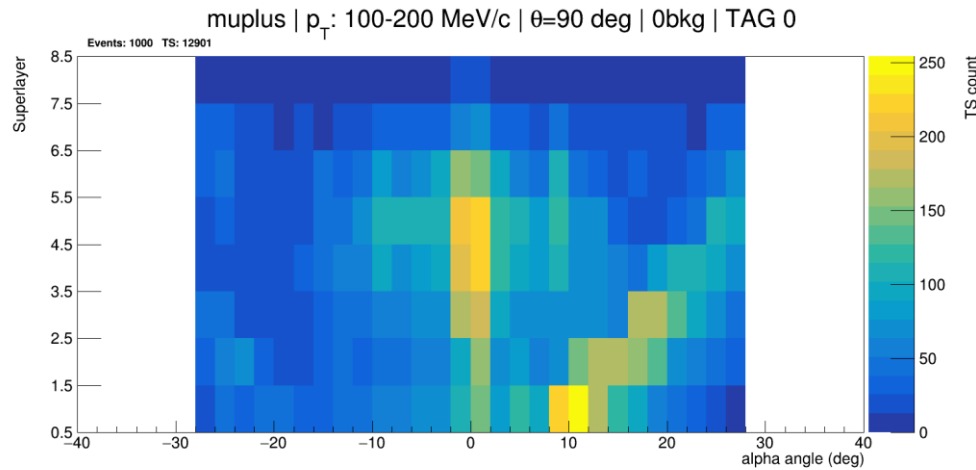


It stably operates at a peak physics event rate of **400 kHz** at the J/ψ energy point (and 60 kHz at other energy points), achieving efficient online data processing.

Back up— α distribution

For $\theta = 90^\circ$, TAG0

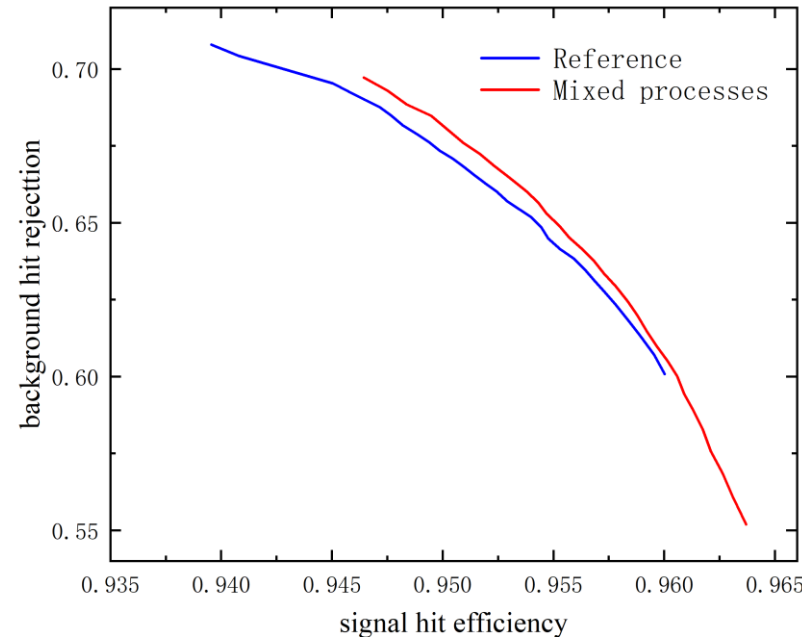
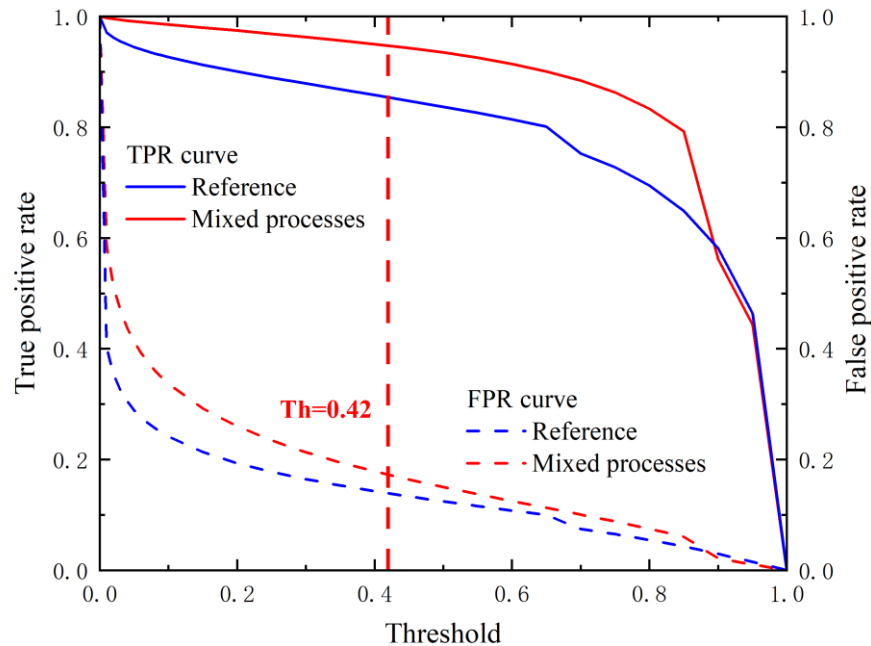
α retains track-bending information and exhibits a clear dependence on transverse momentum.



Back up——Mixed processes model

The improvement of hit level do not directly follow the size of the edge-level AUC improvements.

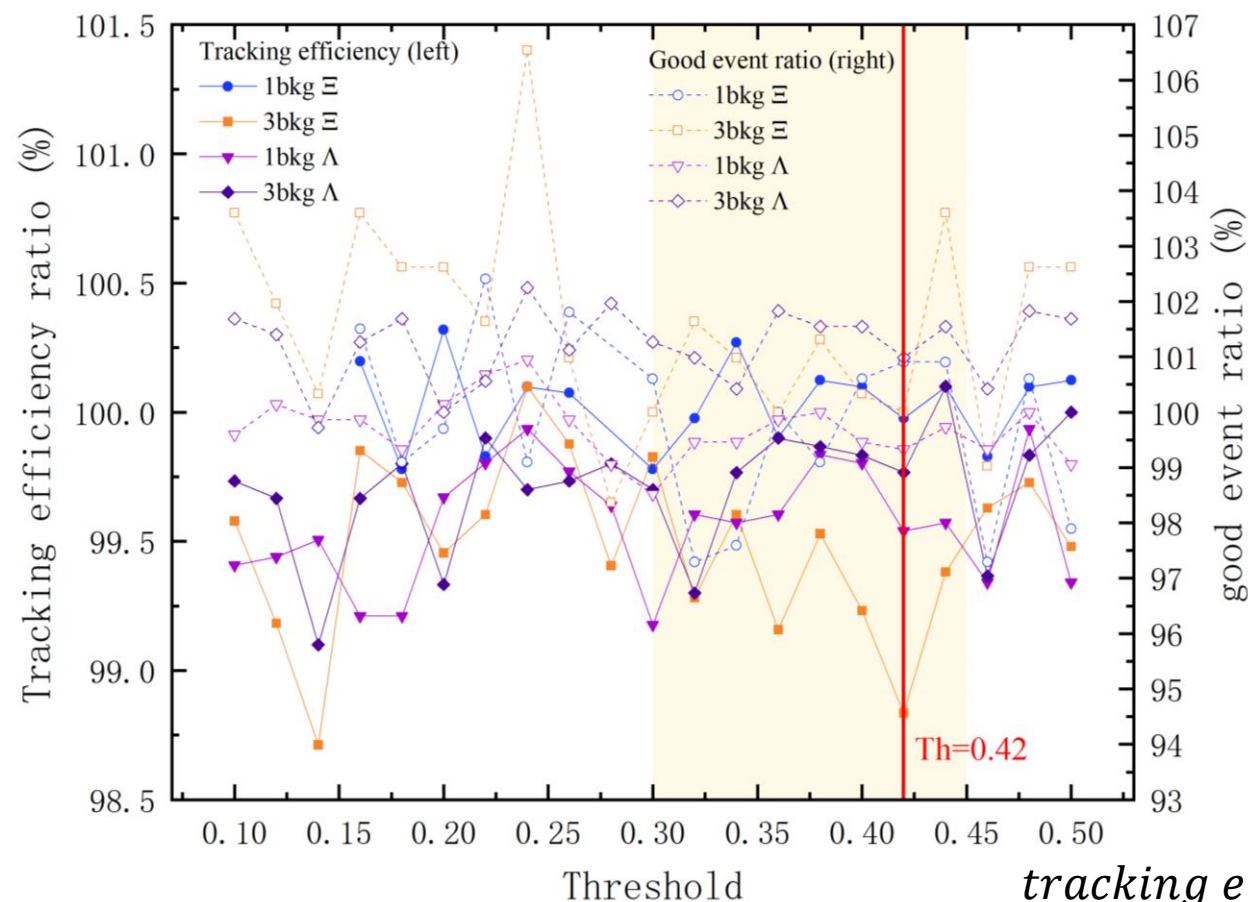
For $e^+e^- \rightarrow D_S^+ D_S^-$, $D_S^+ \rightarrow K_S^0 K^- \pi^+ \pi^+$, $K_S^0 \rightarrow \pi^+ \pi^-$



For the mixed-process model, it has a high FPR while also having a high TPR. This is why we consider both edge-level and hit-level performance when selecting the model.

Back up——Working point selection

For the samples tested here, the average good event ratio is closest to 100%, and tracking efficiency is also around 100%.

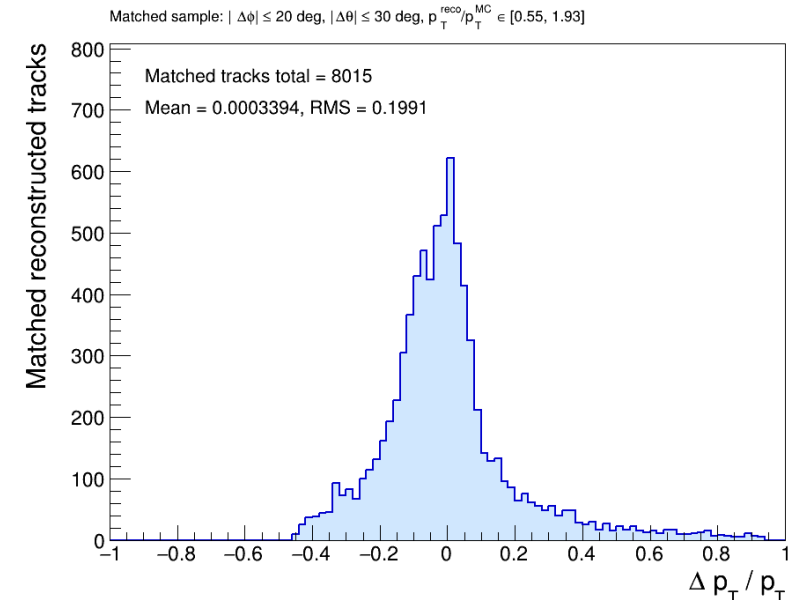
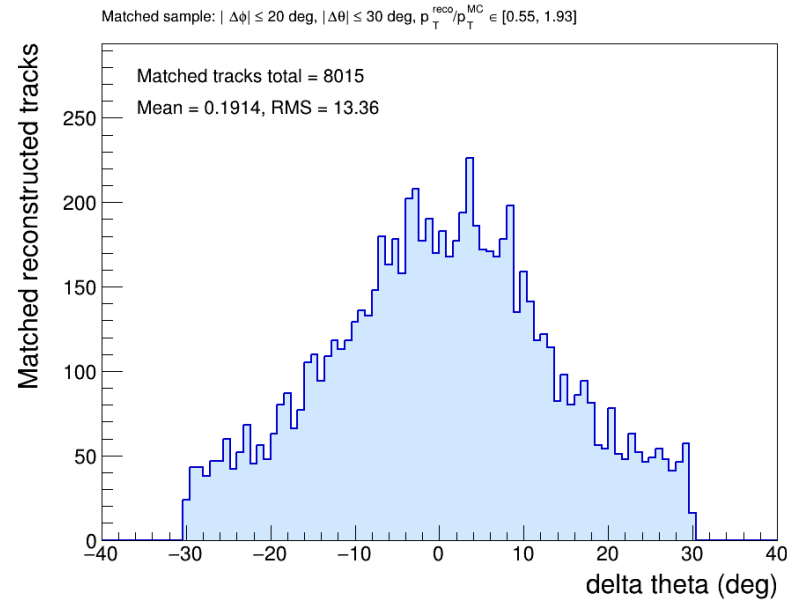
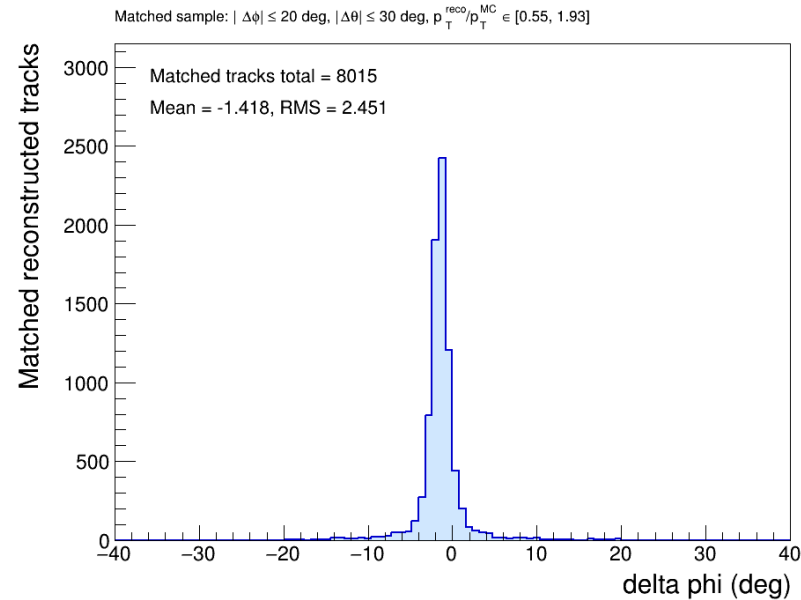


A good event is defined as an event with n final-state particles where at least $n-1$ reconstructed tracks match MC tracks.

$$\text{good event ratio} = \frac{\text{good event with HLT}}{\text{good event without HLT}}$$

$$\text{tracking efficiency ratio} = \frac{\text{tracking efficiency with HLT}}{\text{tracking efficiency without HLT}}$$

➤ For 3bkg $e^+e^- \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow e^+e^-$



Residual distributions between MC truth and tracks matched in the online reconstruction

- Further improvement of θ reconstruction.