Track reconstruction at BESIII & HL-LHC

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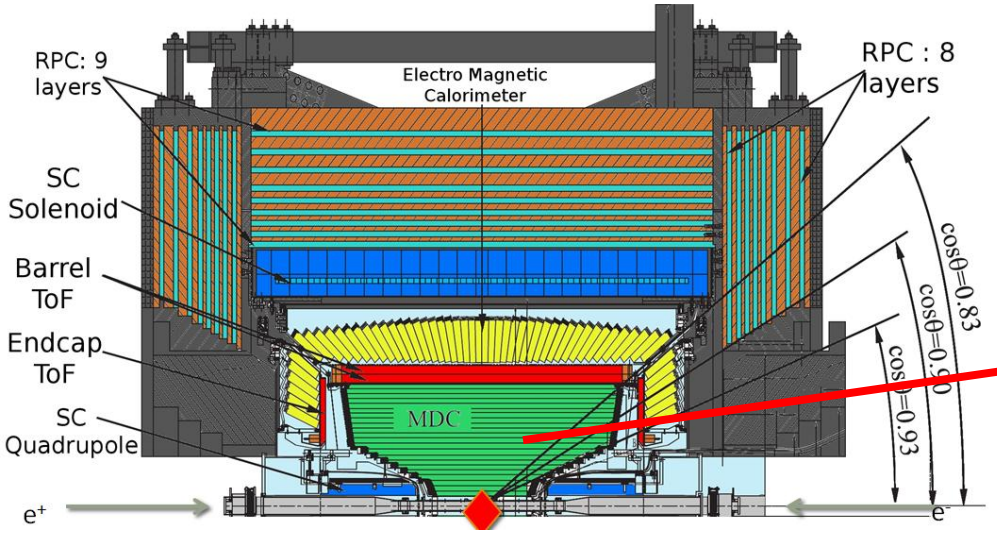
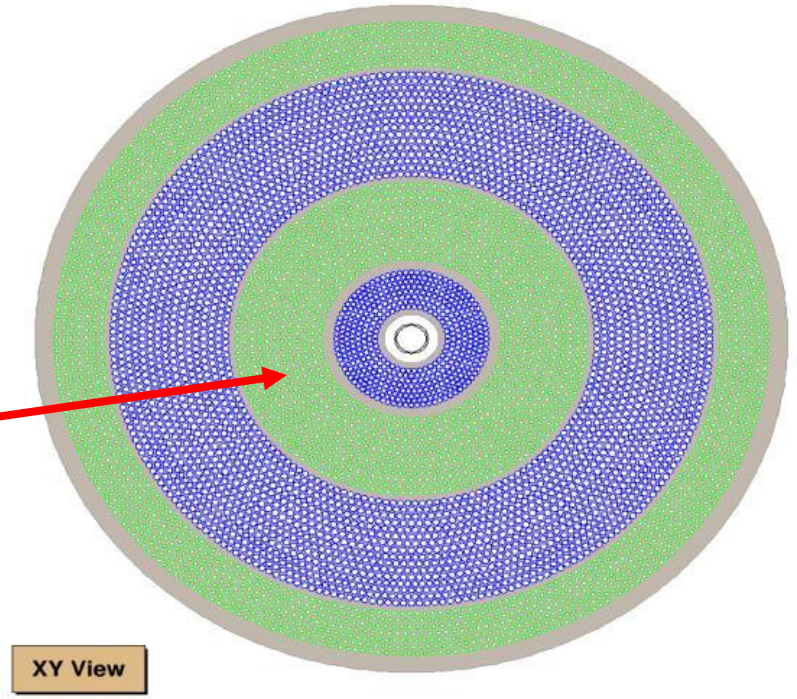
BESIII introduction



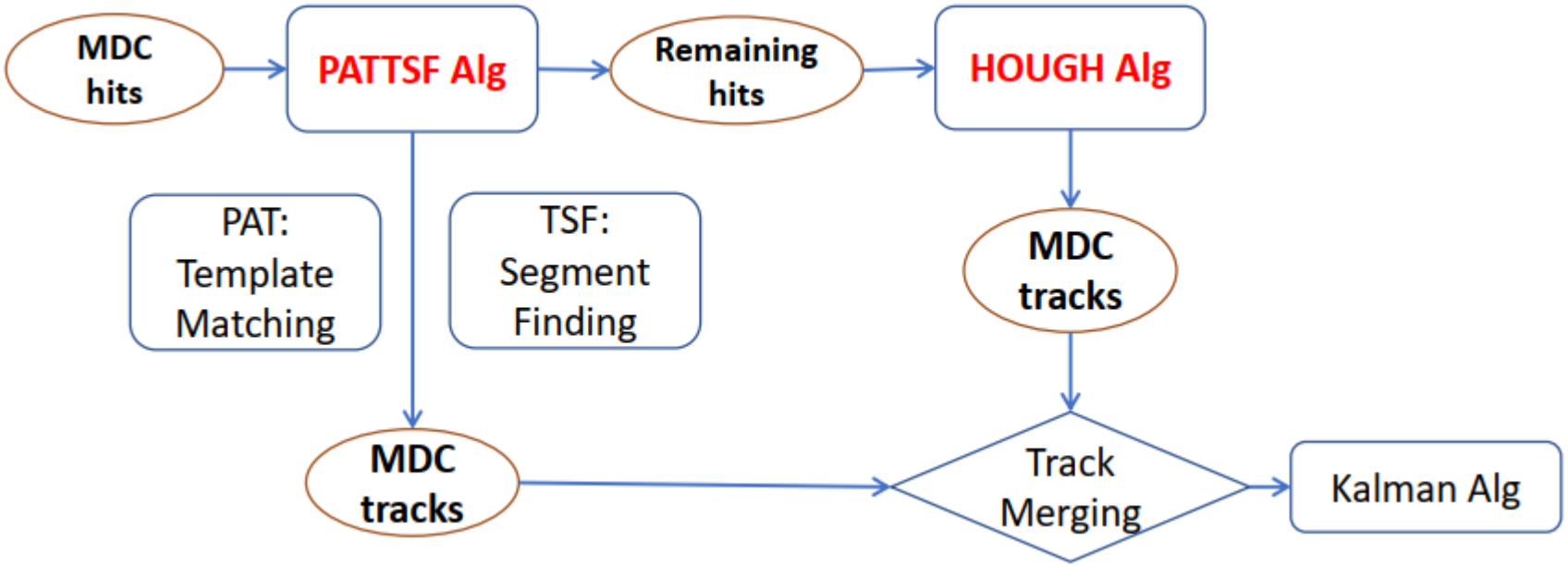


MDC, TOF, EMC, SC, MUC

Green: Axial layers (19)

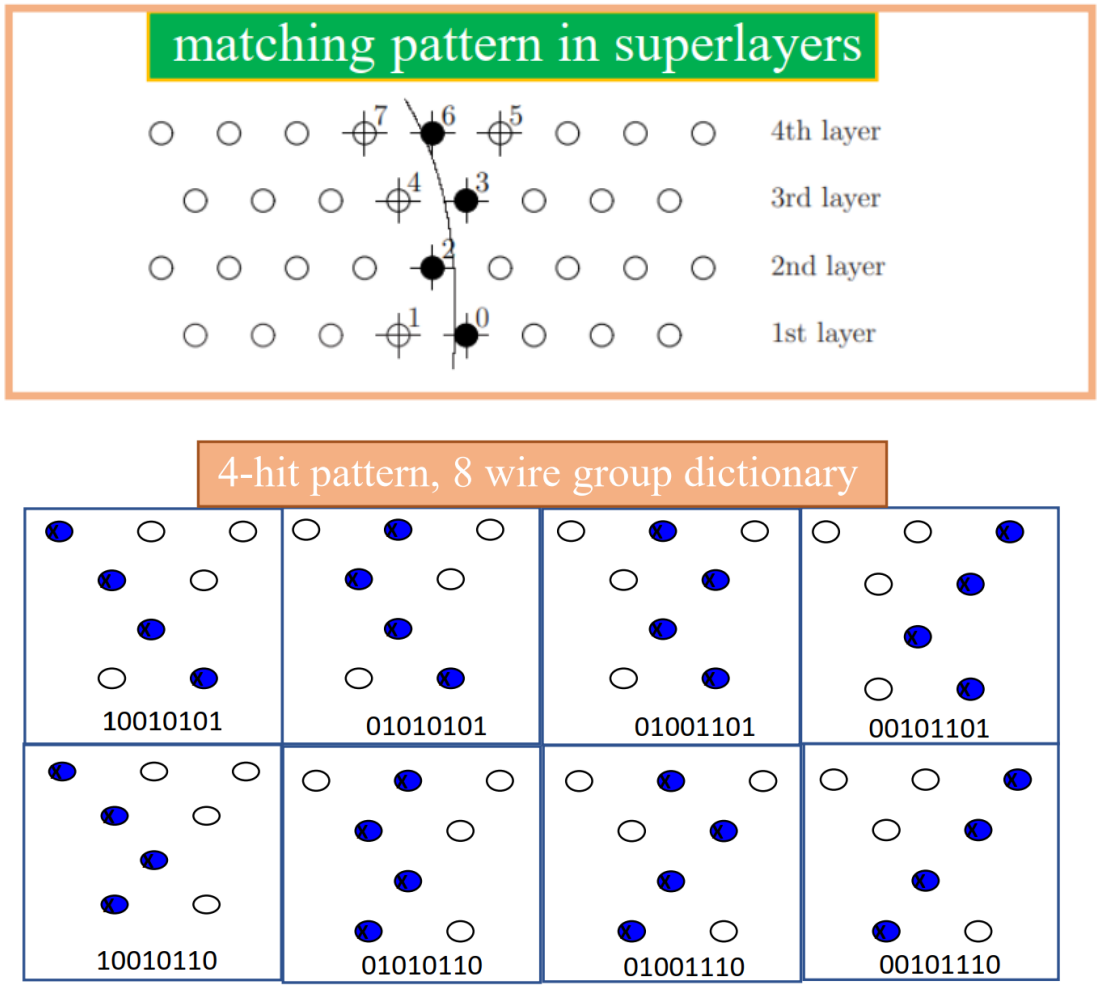
Blue: Stereo layers (24)

Offline track reconstrution



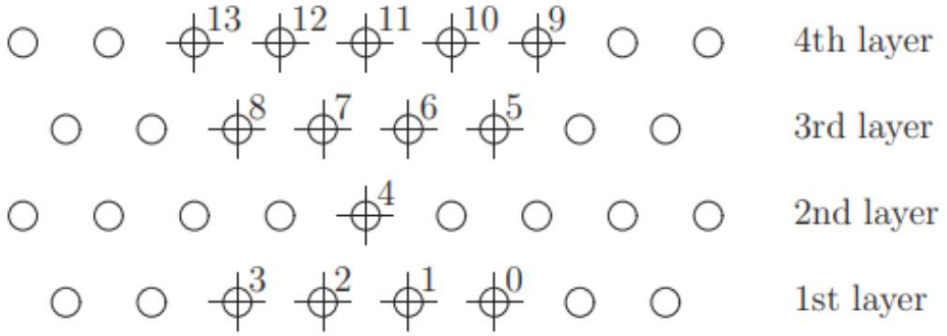
- Local: PAT & TSF
- Global / low p_t: Hough Alg

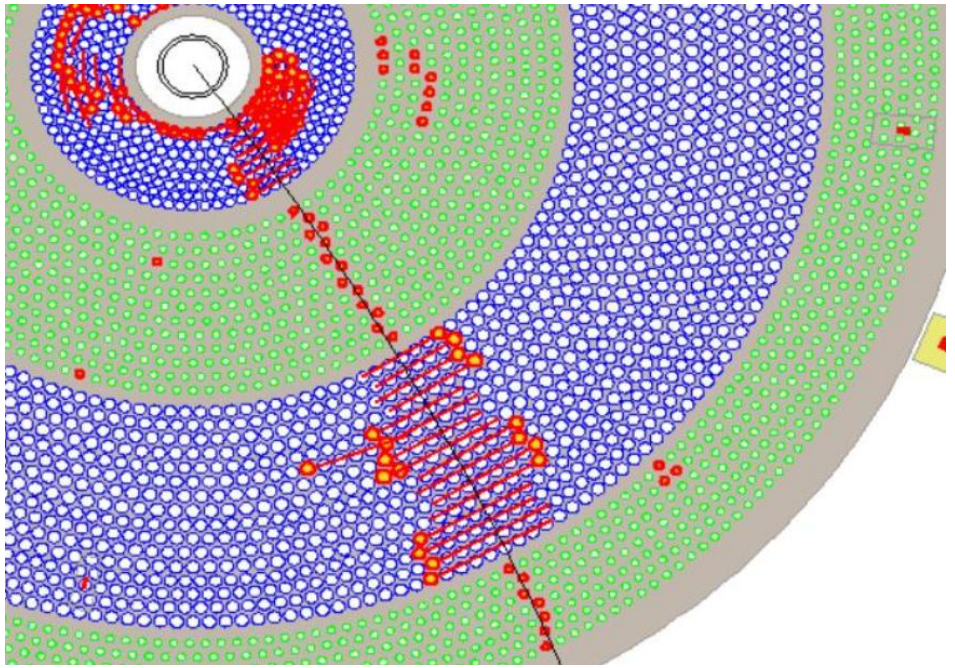
Local: Pattern matching finding (PAT)



- Particularly suitable for cell-based MDC geometry:
  - Superlayer structure
  - Symmetrical along ϕ

Local: Pattern matching finding (PAT)



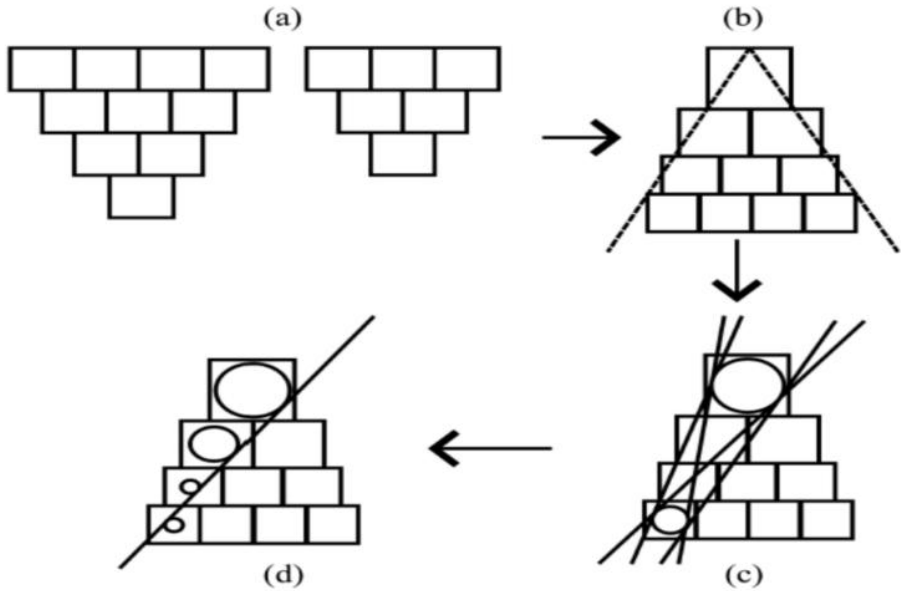


- It's actually 14-wire patterns at BESIII

- A solid example with large p_t

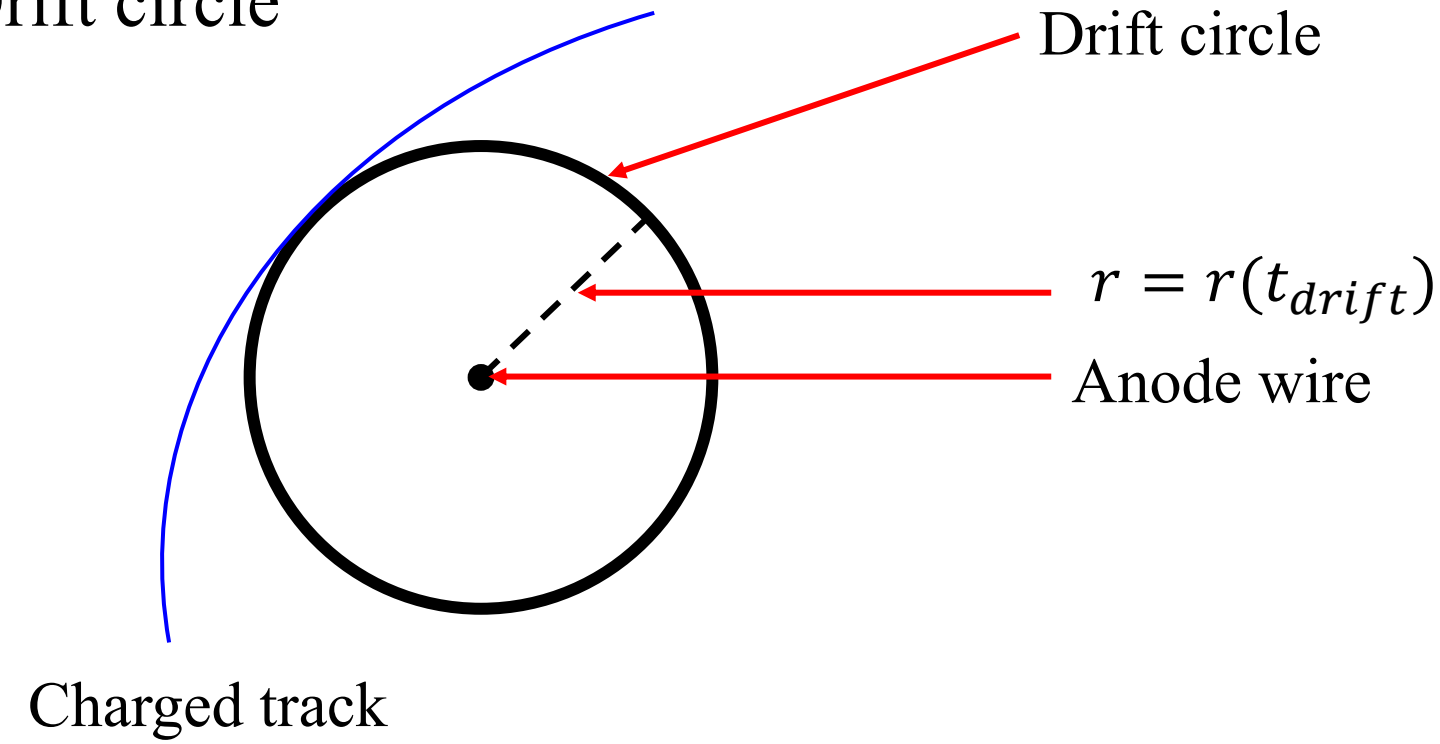
Local: Track segment finder (TSF)

- Lower p_t ⇒ larger curvature, PAT struggles
  - Use drift circles
  - Fit with conformal transformation



Local: Track segment finder (TSF)

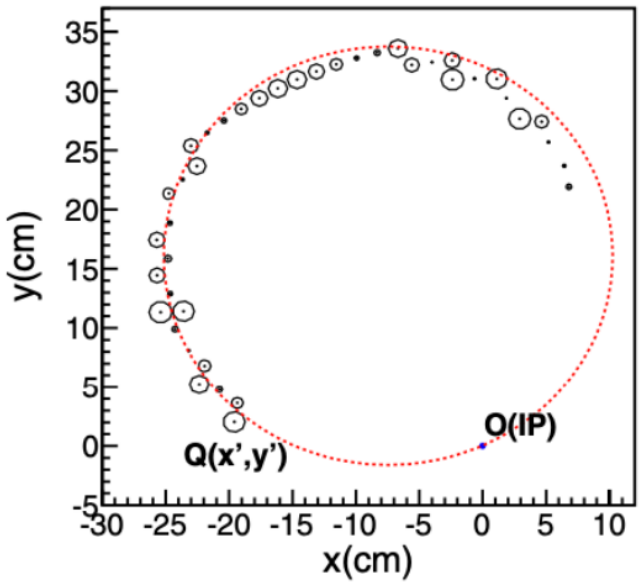
- Drift circle



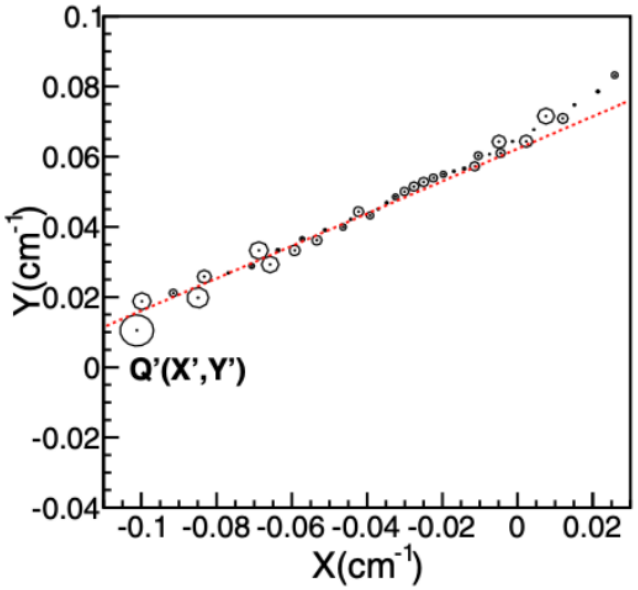
Local: Track segment finder (TSF)

- Conformal transformation

$$\begin{cases} X = \dfrac{x}{x^2+y^2} \\ Y = \dfrac{y}{x^2+y^2} \end{cases}$$



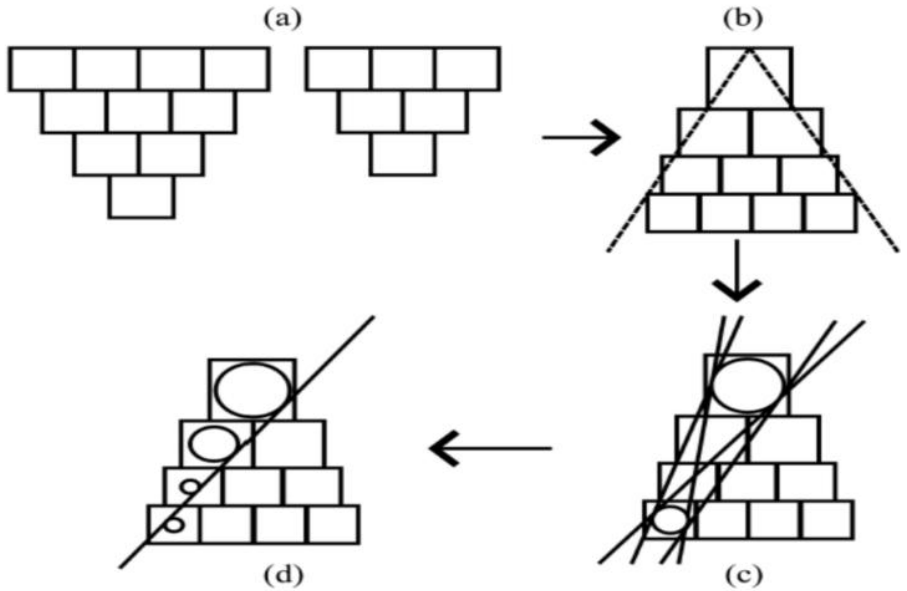
(a) x-y plane



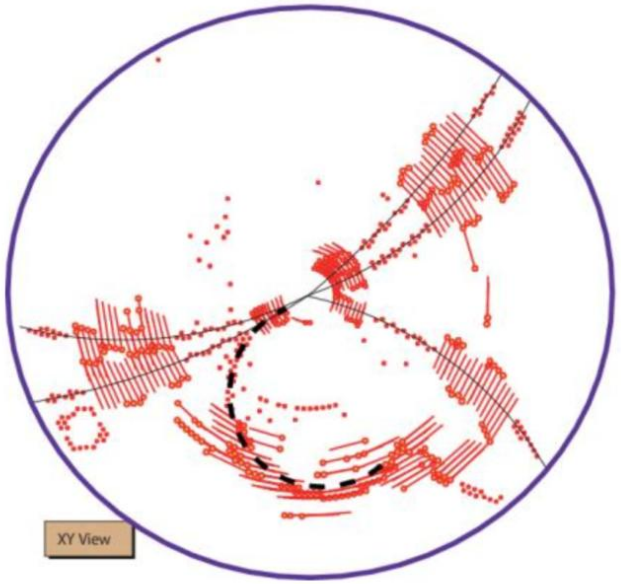
(b) comformal plane

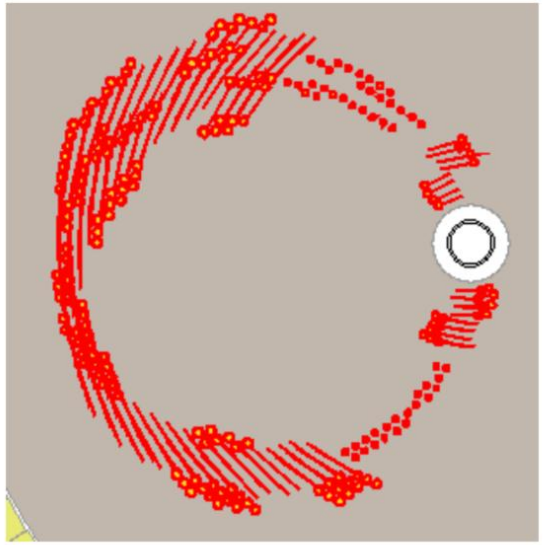
Local: Track segment finder (TSF)

- Lower p_t ⇒ larger curvature, PAT struggles
  - Use drift circles
  - Fit with conformal transformation



Global: Hough algorithm

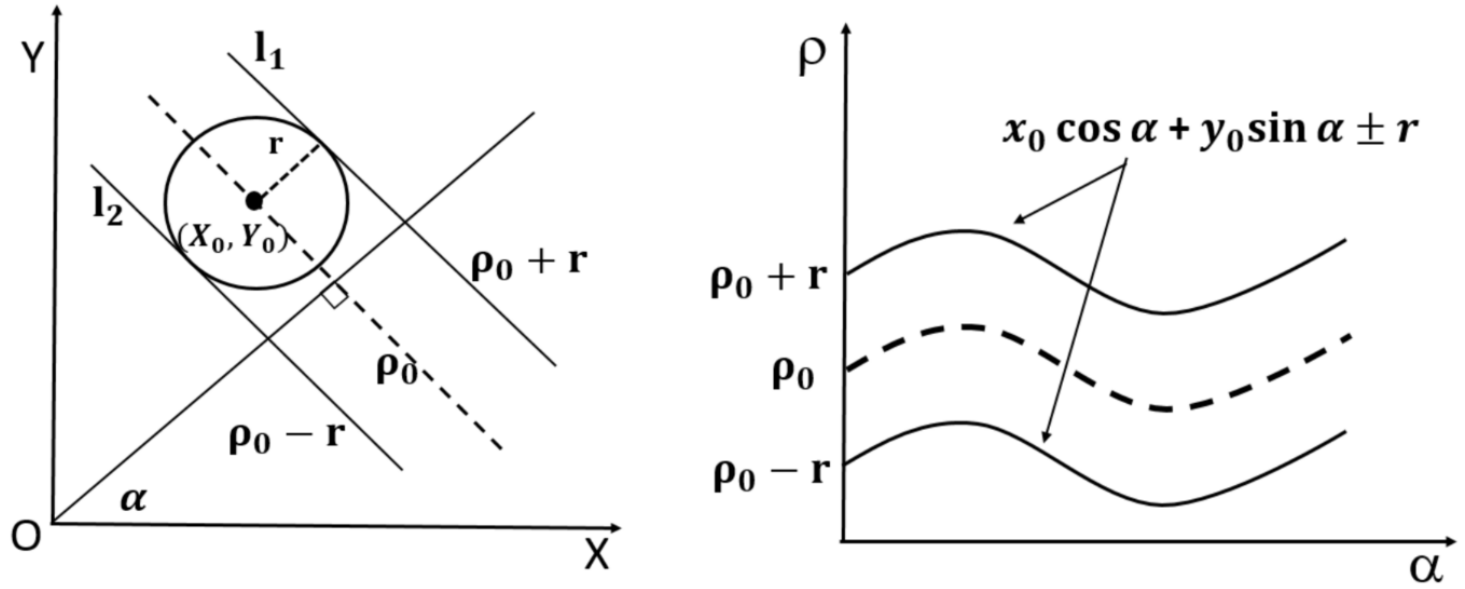




- $p_t < 120\ \mathrm{MeV}/c$
  - With large p_z ⇒ short tracks
  - With small p_z ⇒ multiturn reacks

Global: Hough algorithm

- Hough transform for drift circles

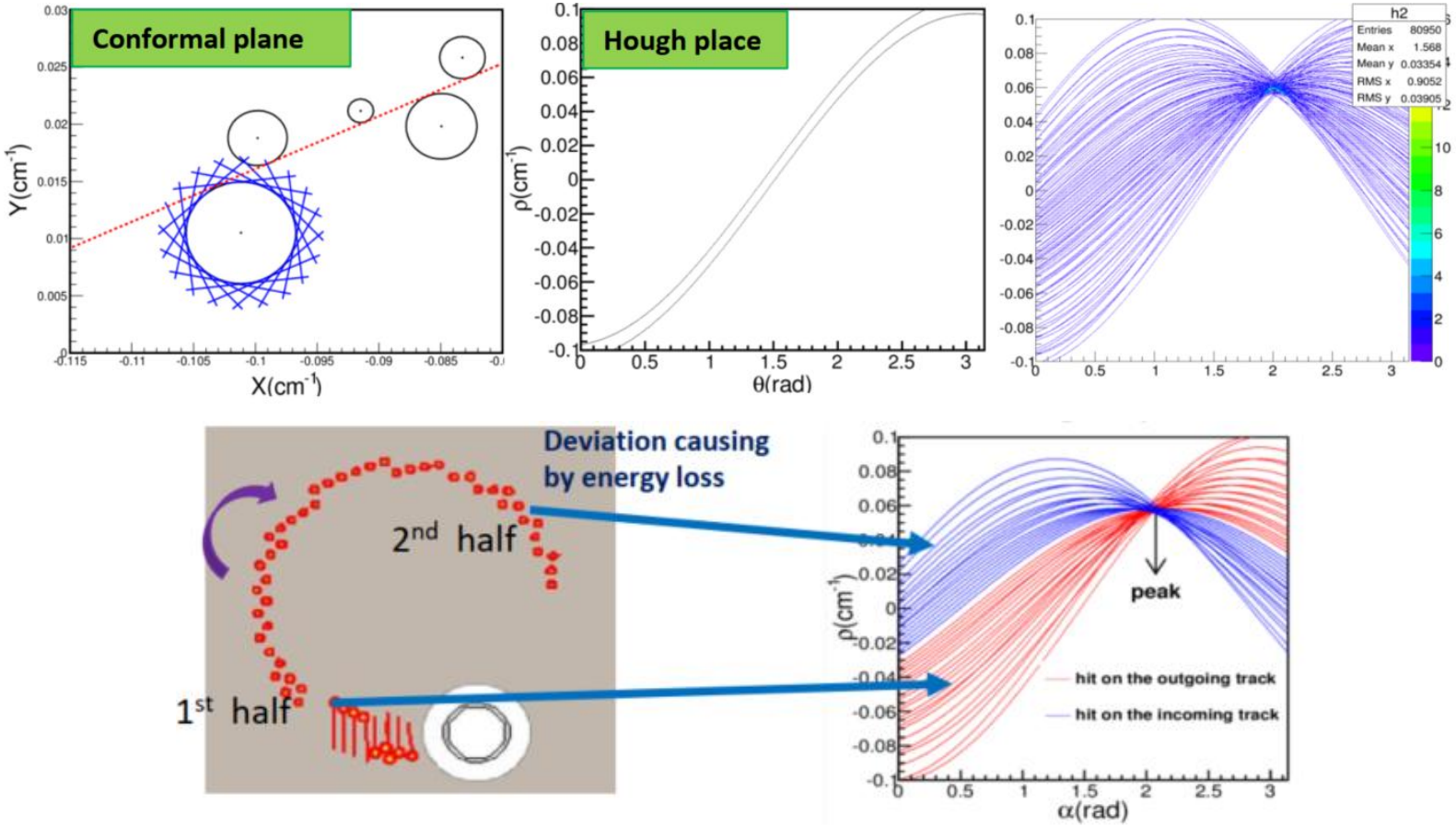


$$\rho = X\cos\alpha + Y\sin\alpha + r \text{ (upper half circle)}$$

$$\rho = X\cos\alpha + Y\sin\alpha - r \text{ (lower half circle)}$$

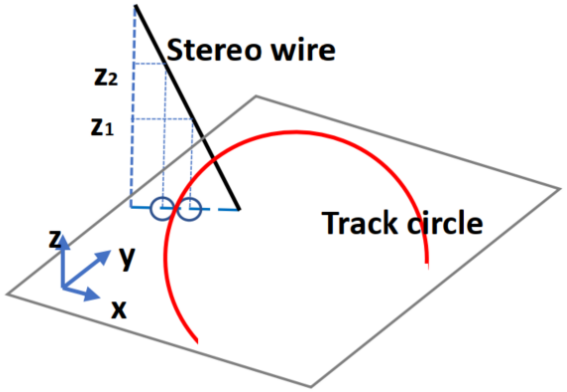
Global: Hough algorithm

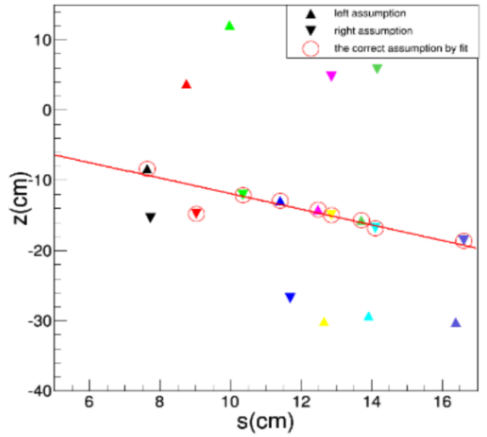
- Hough transform for drift circles



Kalman filter

- Z-coordinate info: Left/right ambiguity





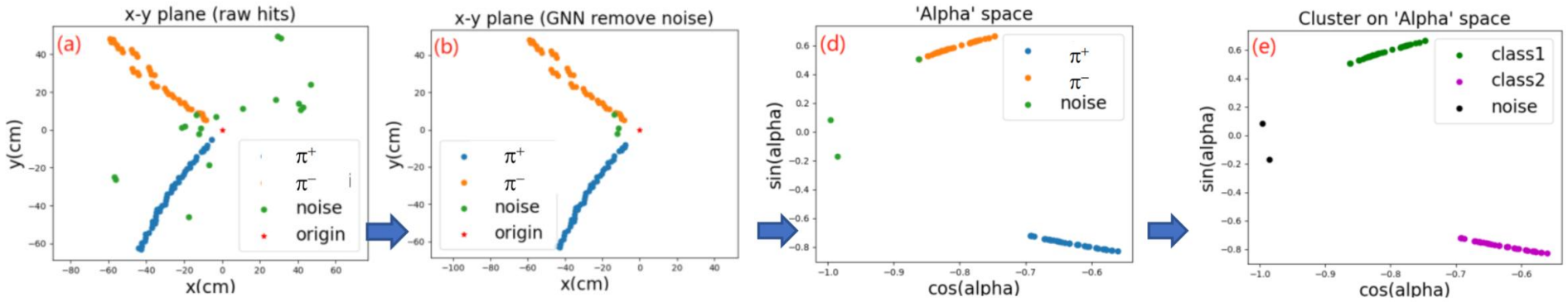
- Helix parameters: $(r_x, r_y, r_z, \kappa_p, \cot\lambda)$

$$\boldsymbol{q_{k|k}} = \boldsymbol{q_{k|k-1}} + K_k(\boldsymbol{m_k} - H_k\boldsymbol{q_{k|k-1}})$$

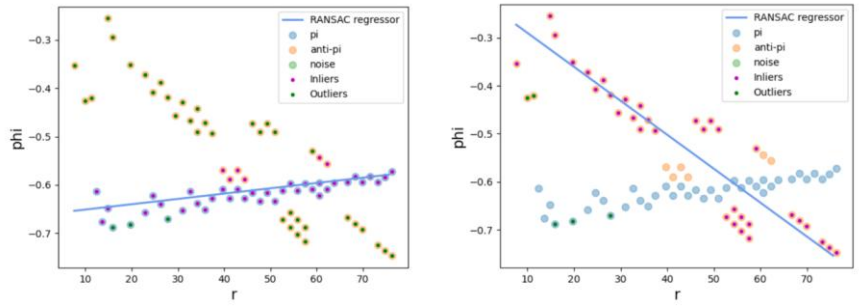
Considering inhomogeneous magnetic field, energy loss and multiple scattering with e, μ, π, K, p hypothesis.

Graph neural network

- Noise cancelling: Edge classification
- Clustering: Density-Based Spatial Clustering of Applications with Noise



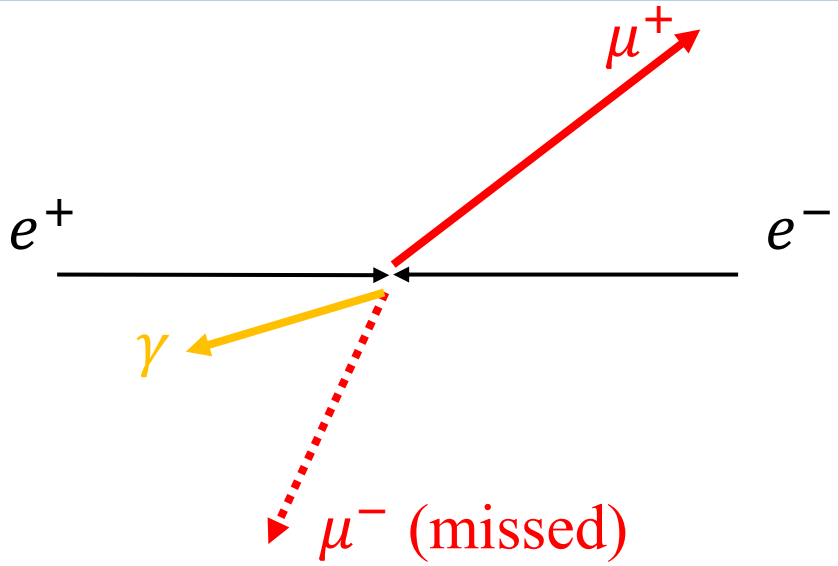
- Separation: Random Sample Consensus

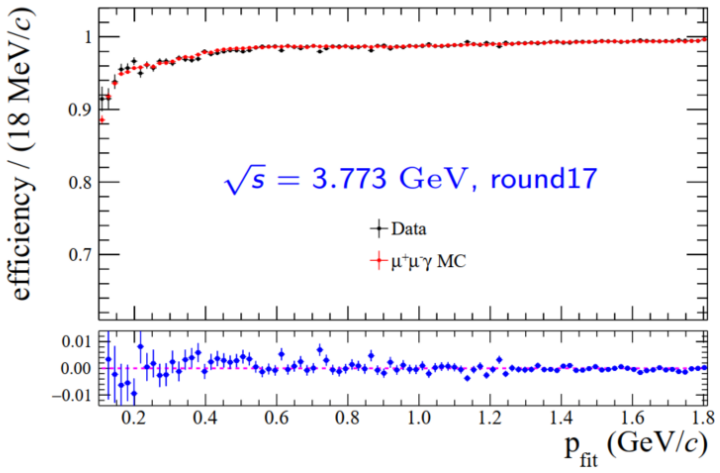


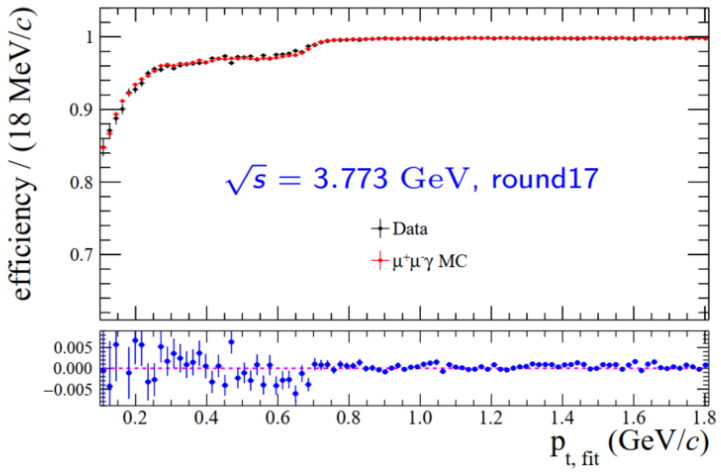
https://indico.cern.ch/event/1128328/

Tracking efficiency

- Control sample
  - E.g. $e^+e^- \to \gamma\mu^+\mu^-$
- $\varepsilon = \frac{N_{found}}{N_{total}}$





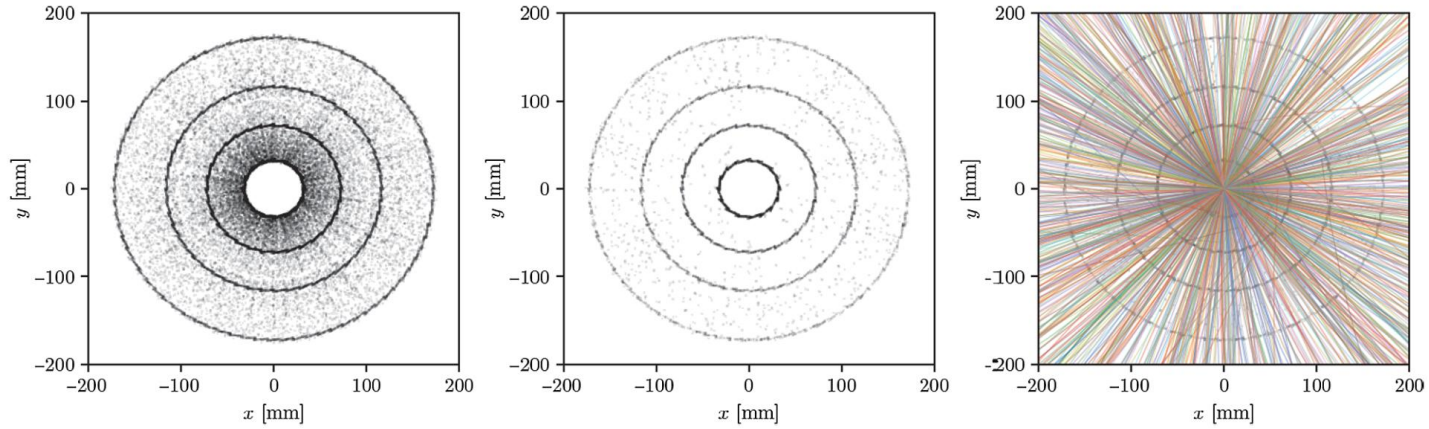


https://indico.ihep.ac.cn/event/24834/

HiLumi LHC

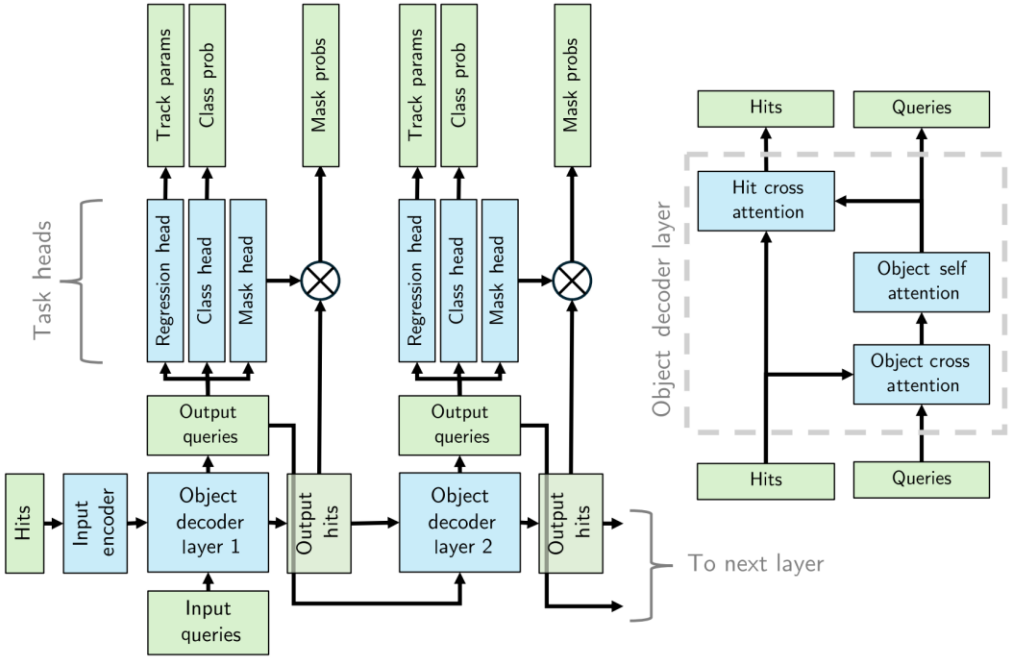
- $\mathcal{L} \sim 5 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Event rate ~ 40 MHz
- $\sim \mathcal{O}(10^5)$ hits per event

  $\Rightarrow$ Calls for algorithms with low complexity



Track reconstruction model

- Noise filter: Transformer classifier
  - Avoids graph construction as in GNN
- Track Rec.: MaskFormer
  - An encoder-decoder architechture
  - Sliding window attention in $\phi \Rightarrow \mathcal{O}(M \times w)$
  - End-to-end reconstruction



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Performance

- Tracking efficiency

Model	Initial purity ($\|\eta\| < \|\eta\|^{max}$)	Filter efficiency	Filter purity	Reconstructible
600 MeV	15.6% (34.0%)	99.5%	72.7%	99.7%
750 MeV	11.2% (24.3%)	99.5%	67.2%	99.6%
1 GeV	13.1% (14.8%)	99.4%	64.5%	98.8%

- Time complexity (on a single NVDIA A100 GPU)

	Tracking time (ms)	Filter + tracking time (ms)
600 MeV	100 ± 12	123 ± 14
750 MeV	74 ± 9	97 ± 11
1 GeV	76 ± 9	99 ± 11

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Summary

- PAT, TSF, Hough Alg., Kalman filter
- GNN, Tansformer/MaskFormer

Thank you!