DIRC-like Time-of-flight Detector (DTOF) under the Offline Software of Super Tau-Charm Facility

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On behalf of the STCF DTOF-software working group

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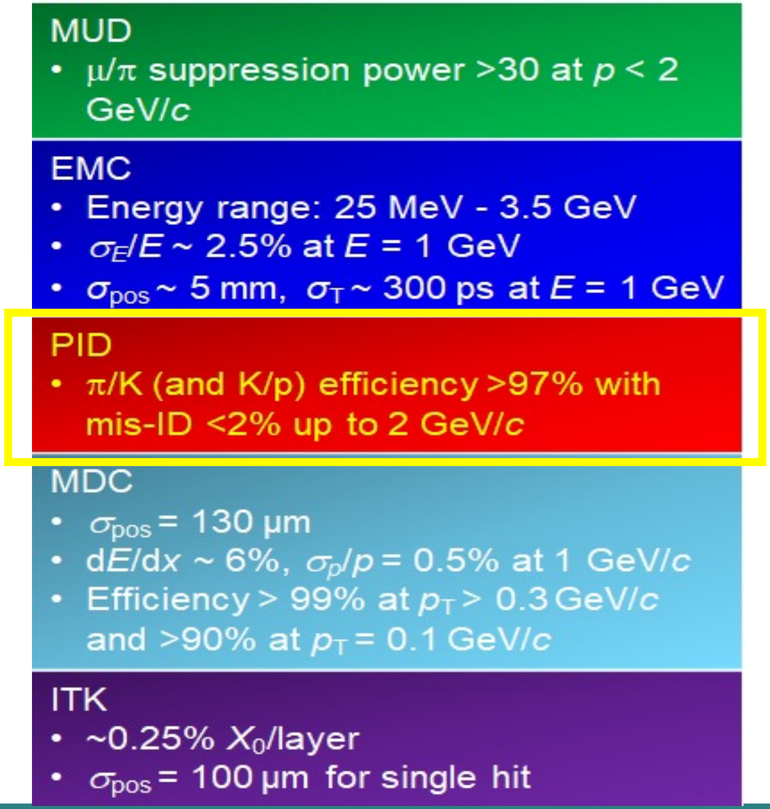
Super Tau-Charm Facility

Parameters of STCF:

- Center-of-mass energy: $2-7\text{GeV}$
- Peak luminosity: $0.5\sim1\times10^{35}\text{cm}^{-2}\text{s}^{-1}$
- Circumference: ~600m
- Crossing angle: 2×30mrad



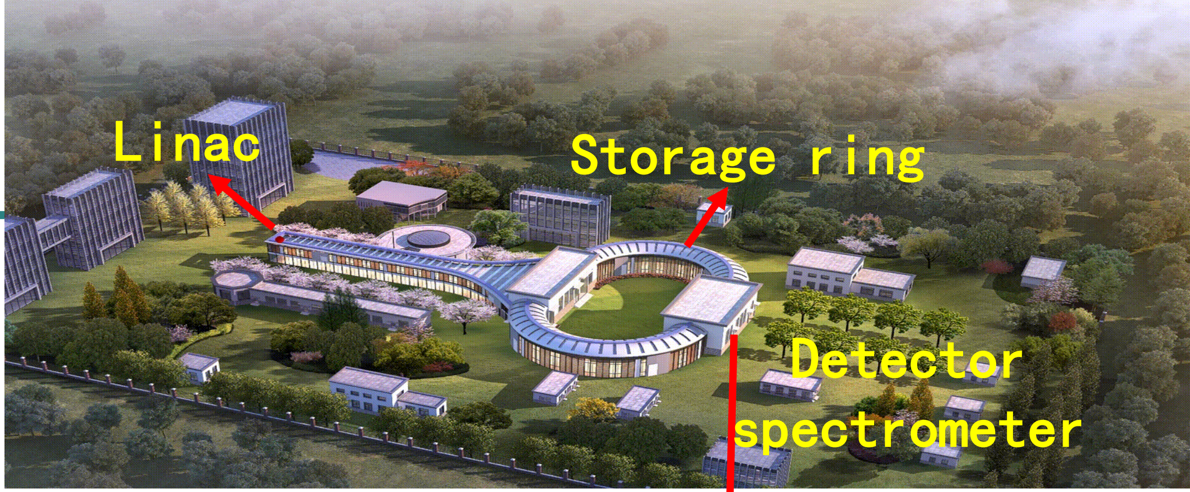
MUD
- μ/π suppression power >30 at $p < 2$ GeV/c

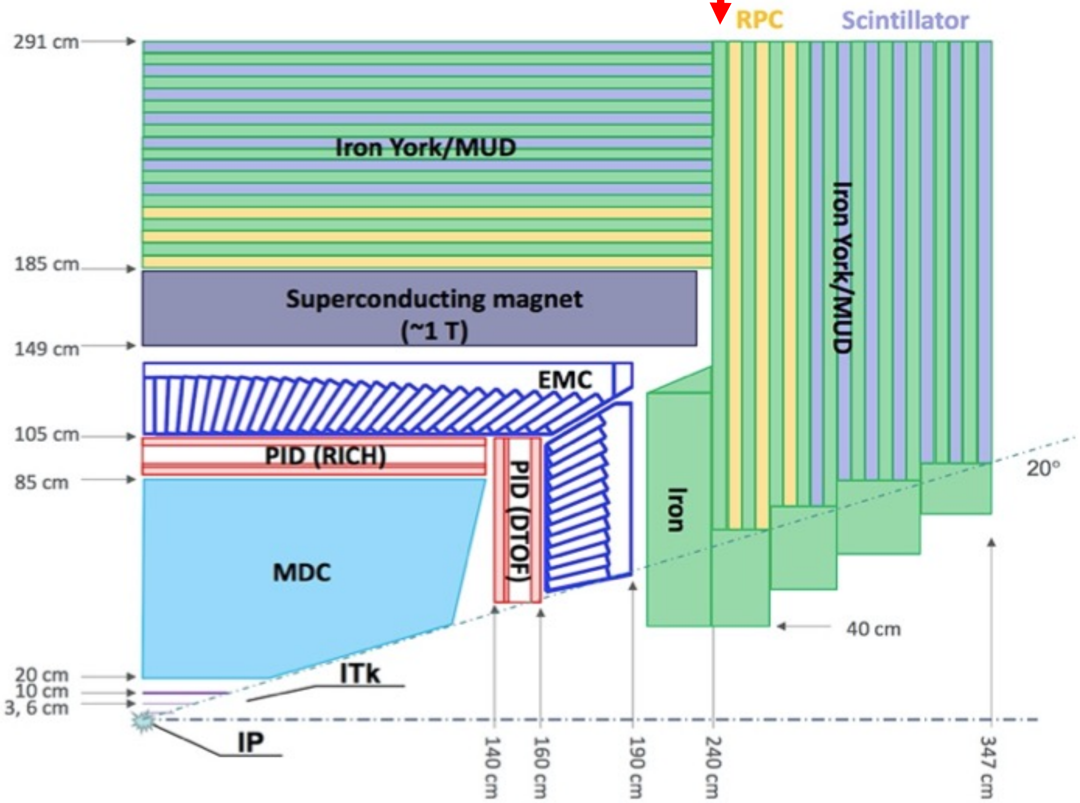
EMC
- Energy range: 25 MeV - 3.5 GeV
- $\sigma_E/E\sim2.5\%$ at $E = 1$ GeV
- $\sigma_{pos}\sim5$ mm, $\sigma_T\sim300$ ps at $E = 1$ GeV

PID
- π/K (and K/p) efficiency >97% with mis-ID <2% up to 2 GeV/c

MDC
- $\sigma_{pos} = 130$ μm
- dE/dx ~ 6%, $\sigma_p/p = 0.5\%$ at 1 GeV/c
- Efficiency > 99% at $p_T > 0.3$ GeV/c and >90% at $p_T = 0.1$ GeV/c

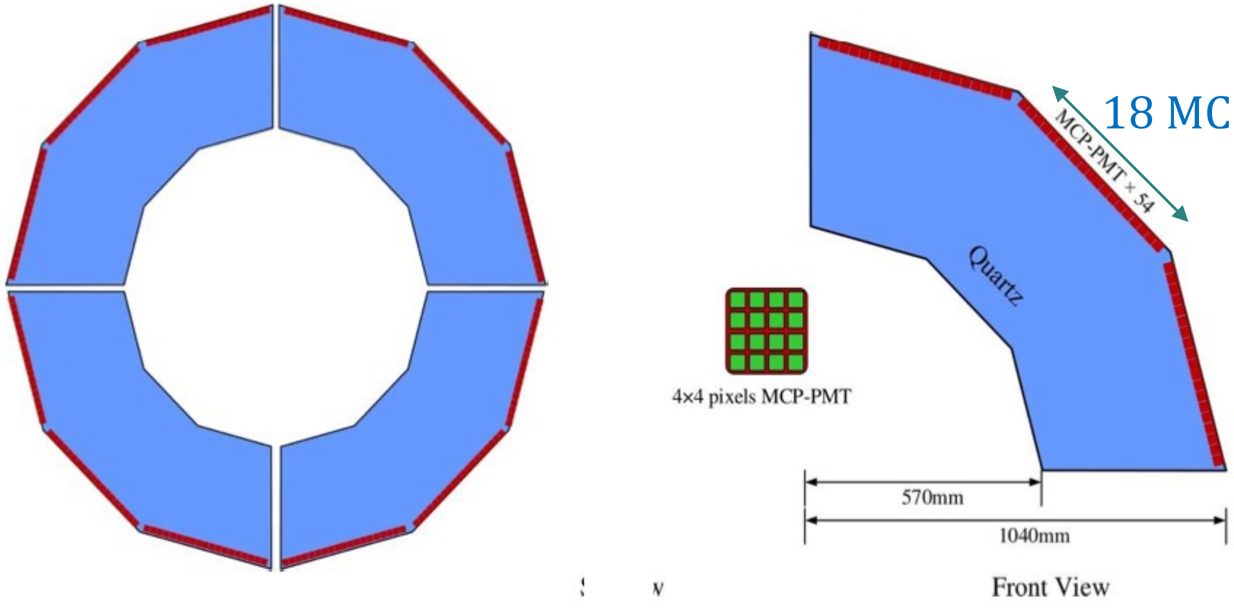
ITK
- ~0.25% X_0/layer
- $\sigma_{pos} = 100$ μm for single hit



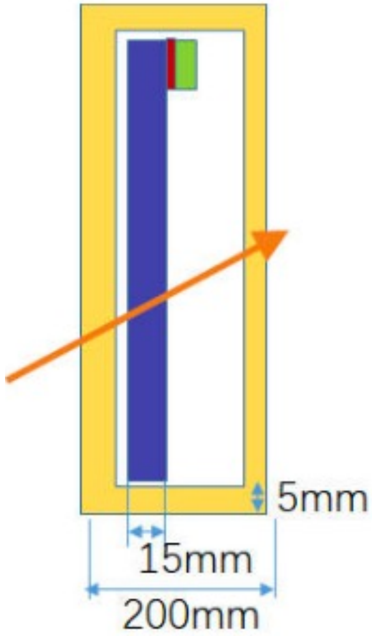


DTOF Geometry Configuration

- Two identical endcap discs, ~ ±1400 mm away from the collision point along the beam direction.
- Each disc: 4 sectors, $R_{min} = 570$ mm , $R_{max} = 1050$ mm.
- Covering polar angles $\theta \in (22° - 36°)$.

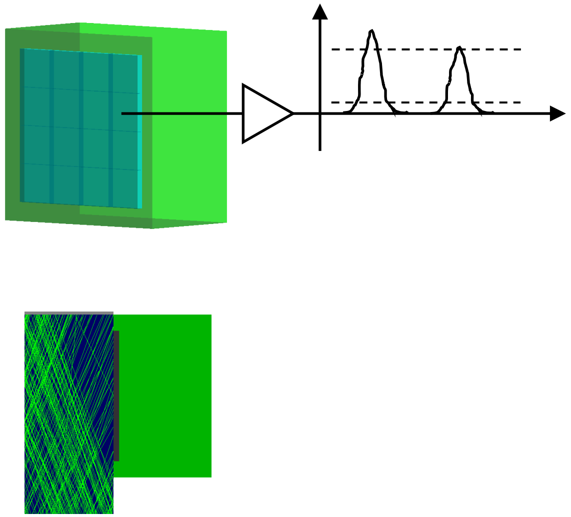


18 MCP – PMTs



4×4 anodes

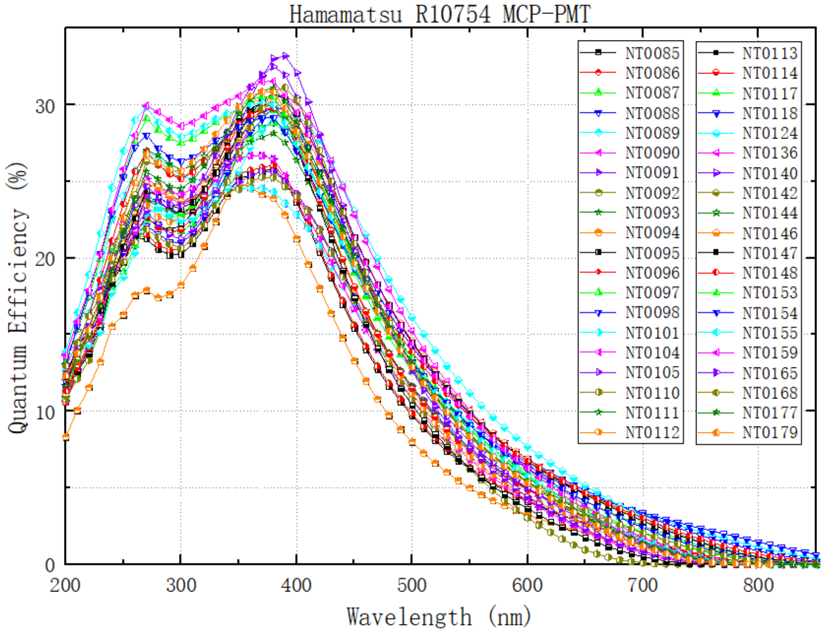
$5.5 \times 5.5\ mm^2$

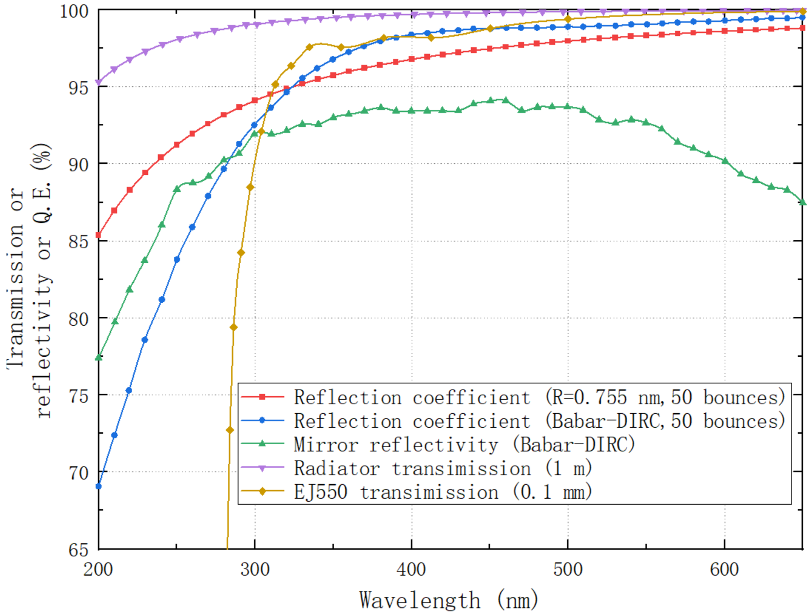


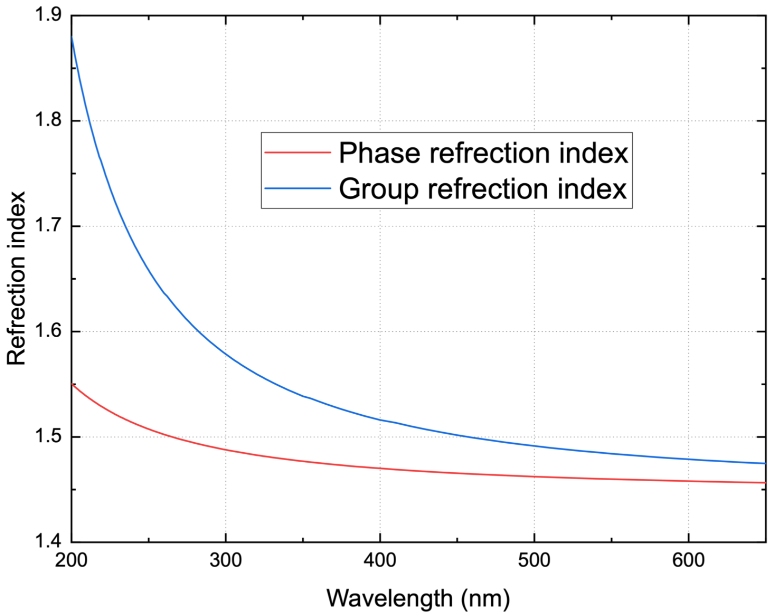
DTOF Simulation

Optical Parameters

- Optical parameters used in DTOF simulation.



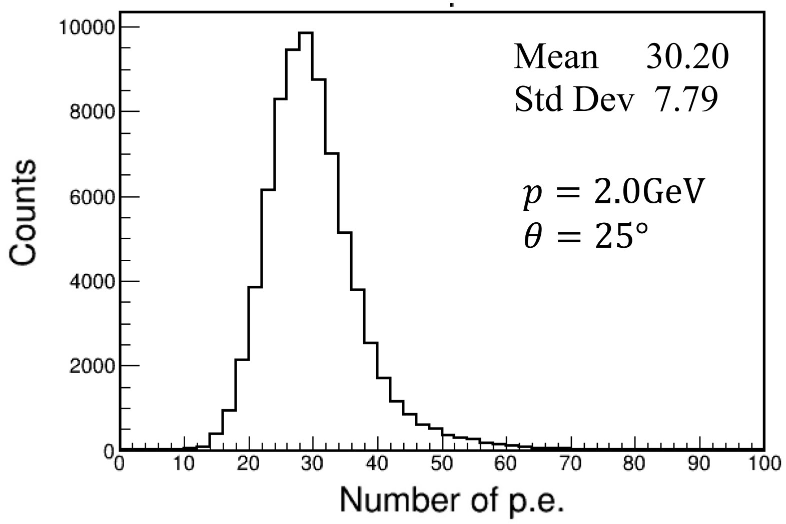


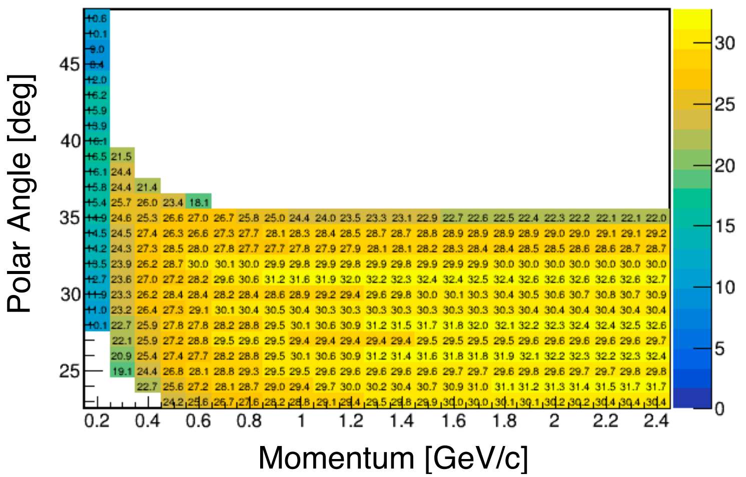


DTOF Simulation

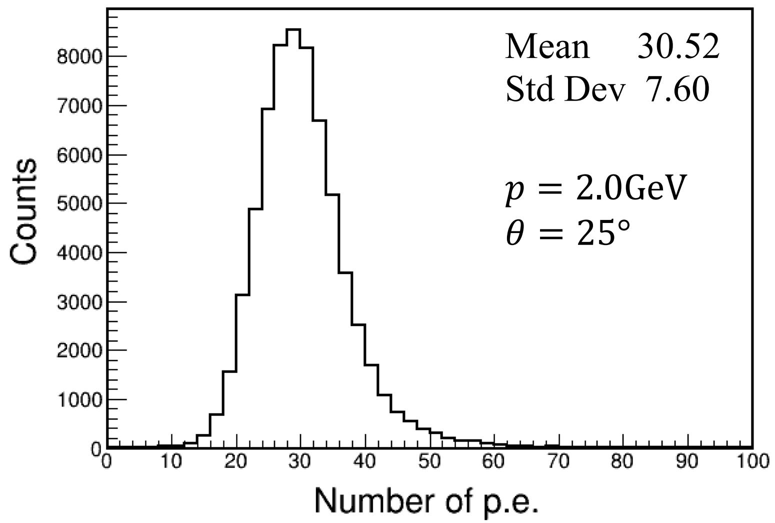
Photon Yield

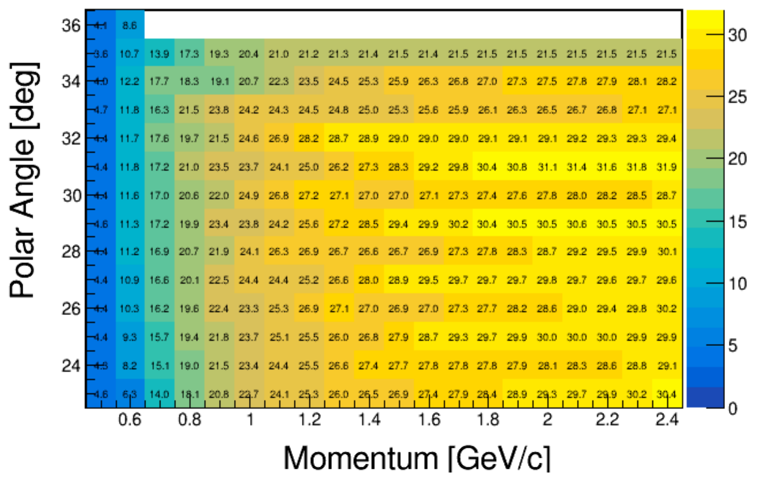
π Sample





K Sample

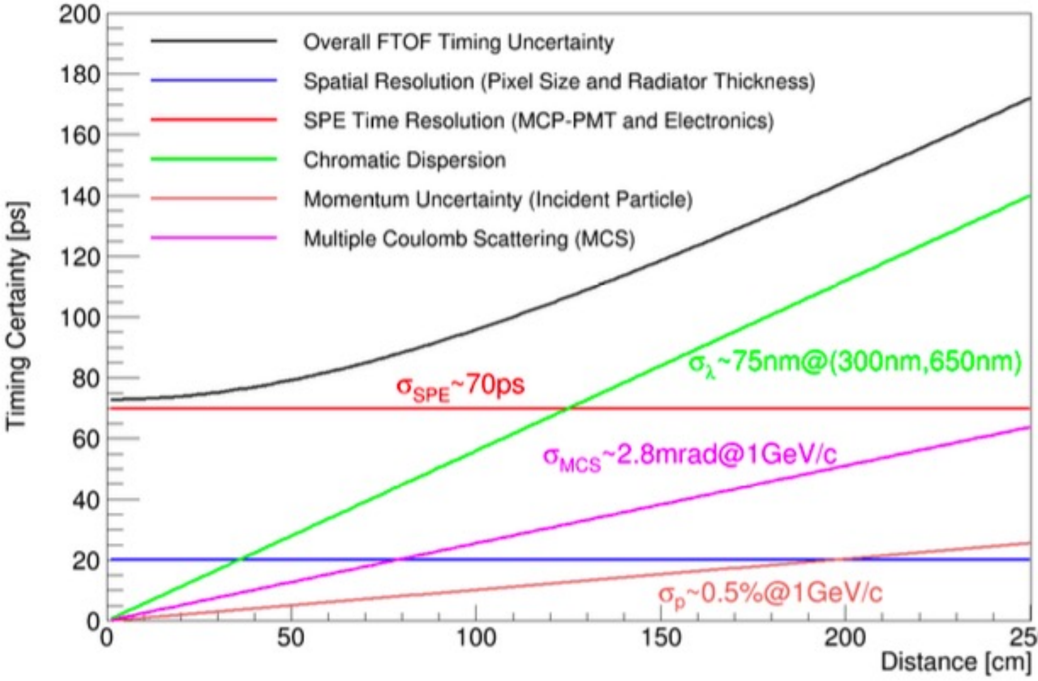




DTOF Reconstruction

Single Timing Uncertainties

$$\sigma_t = \sigma_{T_0} \oplus \sigma_{t_{MCS}} \oplus \sigma_{t_{ext(\vec{r},\vec{p})}} \oplus \frac{\sigma_{t_\lambda}}{\sqrt{N_{p.e.}}} \oplus \frac{\sigma_{t_D}}{\sqrt{N_{p.e.}}} \oplus \frac{\sigma_{TTS}}{\sqrt{N_{p.e.}}}$$



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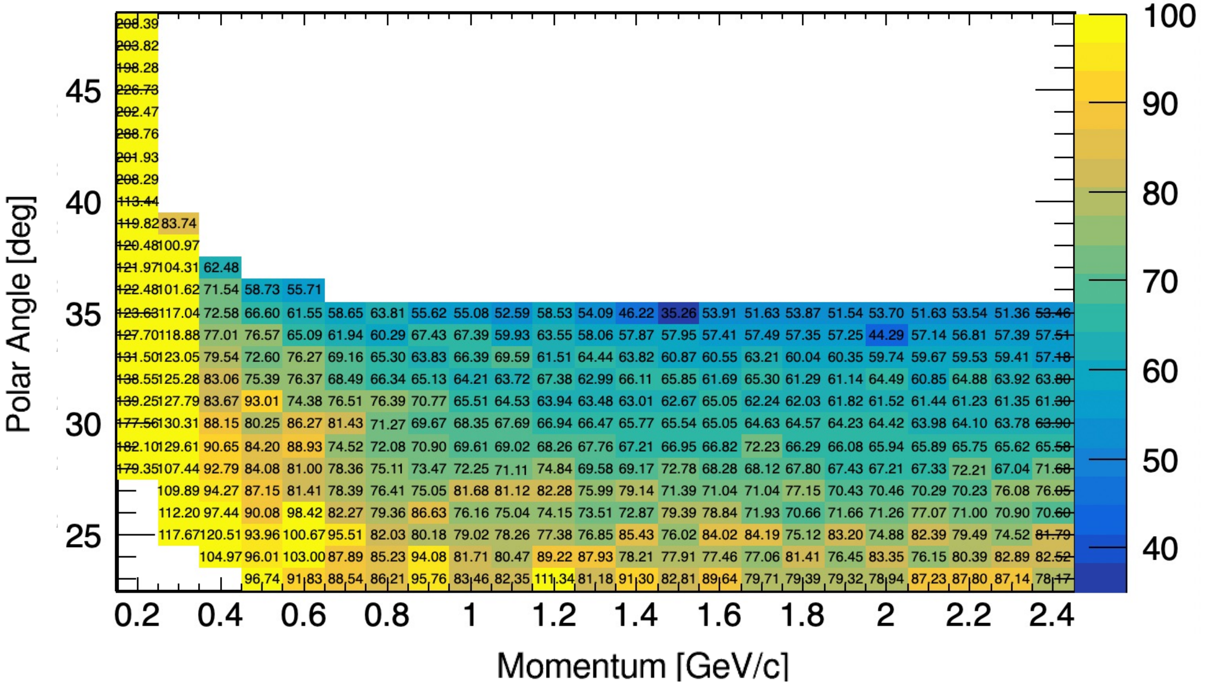
- Single photon timing uncertainty:

@2GeV

Overall σ_t ~50 ps

π	σ_{T_0}	$\sigma_{t_{MCS}}$	$\sigma_{t_{ext}}$	σ_{t_λ}	σ_{t_D}	σ_{TTS}	Total
/ps	40	9.8	16.5	40.7	14.4	30	68.8



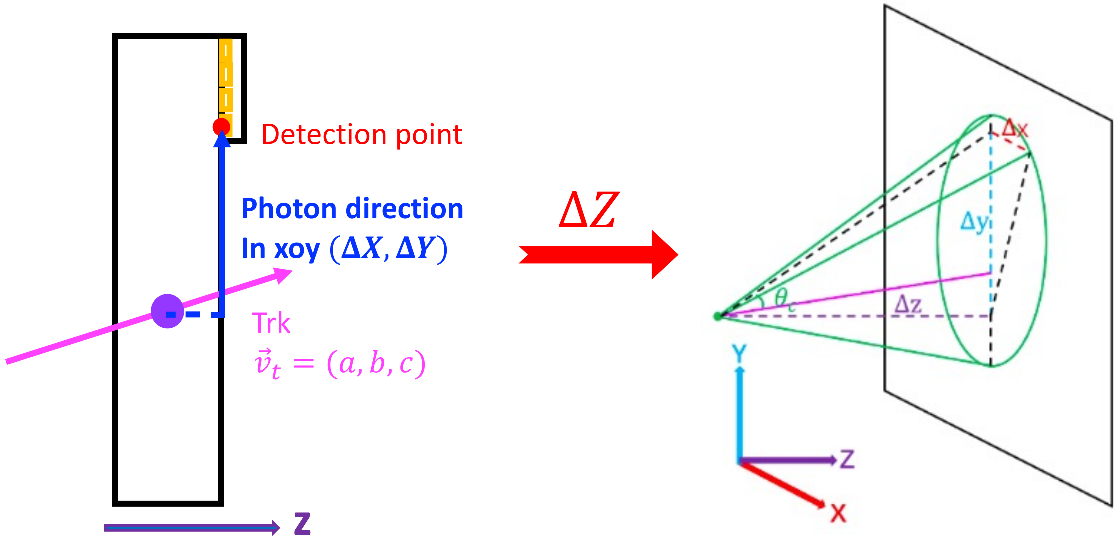
DTOF Reconstruction

Likelihood Method for PID – Timing Method

- **TOF Reconstruction**

$$cos\theta_c = \frac{1}{n\beta} = \frac{\vec{v}_t \cdot \vec{v}_p}{|\vec{v}_t| \cdot |\vec{v}_p|} \qquad \begin{cases} \vec{v}_t = (a, b, c) \\ \vec{v}_p = (\Delta X, \Delta Y, \Delta Z) \end{cases}$$

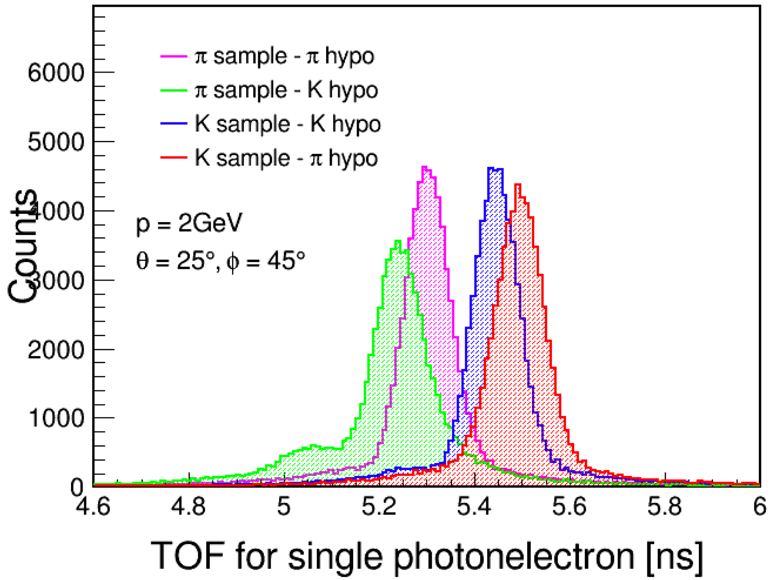
$$LOP = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2} \implies TOF_{rec} = T - \frac{LOP \cdot \overline{n_g}}{c} - T_0$$



- **Likelihood construction**

$$\mathcal{L}_h = \prod_{i=1}^{N_{p.e.}} \overset{\text{signal}}{N_h S_h\left(TOF_{rec} | \, TOF_{hypo}\right)} + \overset{\text{bkg}}{0.05}$$

where $TOF_{hypo} = \frac{LOF}{c\beta_{hypo}}$



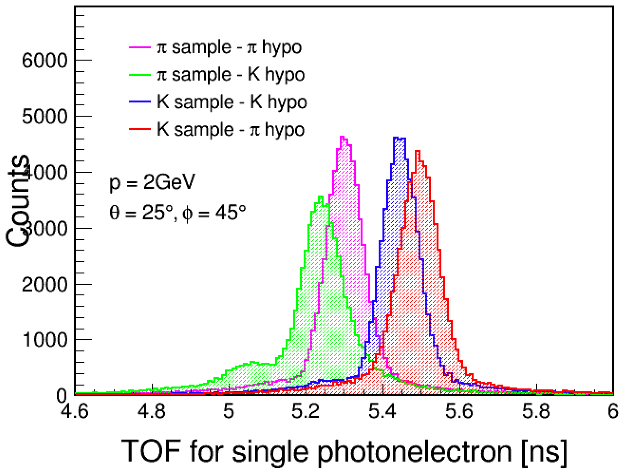
DTOF Reconstruction

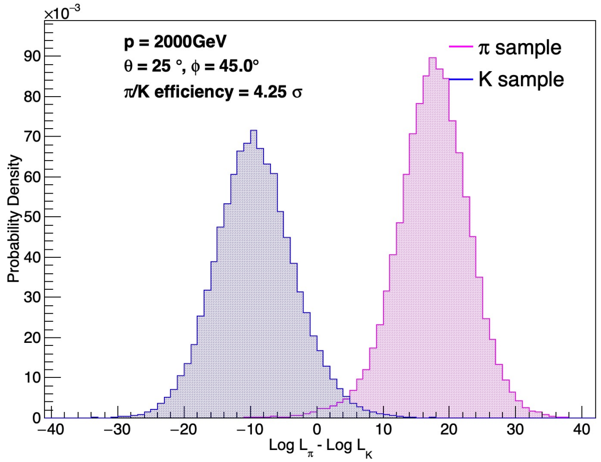
Likelihood Method for PID – Timing Method

- **Performance**

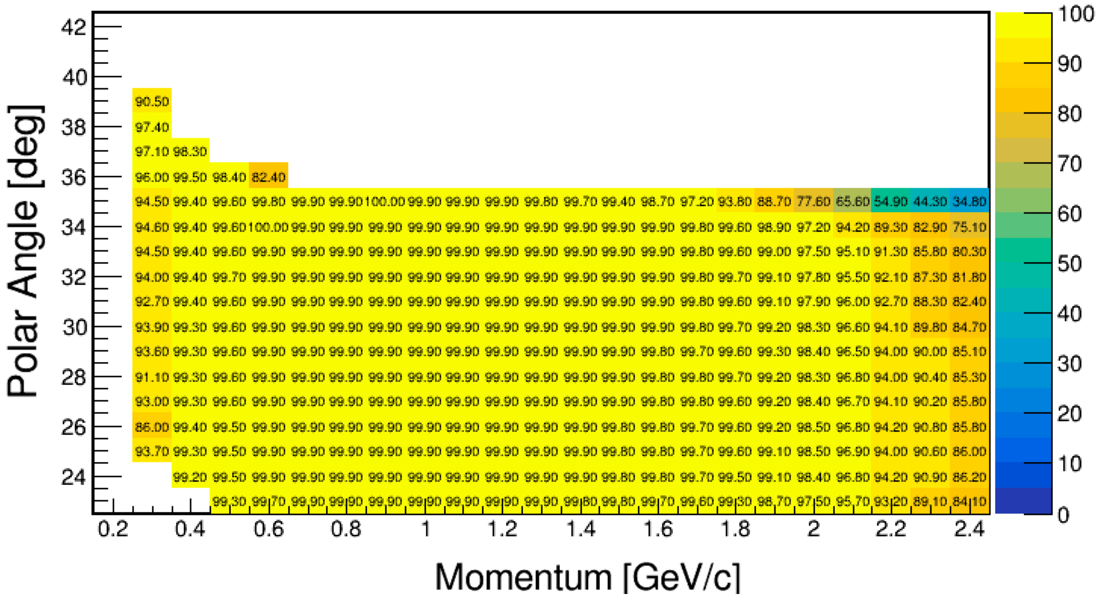
$$\mathcal{L}_h = \prod_{i=1}^{N_{p.e.}} N_h S_h\left(TOF_{rec} \middle| TOF_{hypo}\right) + 0.05$$

- $\sigma_t \sim 69\ ps$ by single photon-electron
- $\sigma_t \sim 50\ ps$ by multi-photon-electrons
- π efficiency $\sim 98\%$ at $p = 2.0$ GeV/c
  $(K \text{ mis} - \text{ID} = 2\%)$





π efficiency after mixing BKG in different $(|\vec{p}|, \theta)$:
$(K \text{ mis} - \text{ID} = 2\%)$



90.50																					
97.40																					
97.10	98.30																				
96.00	99.50	98.40	82.40																		
94.50	99.40	99.60	99.80	99.90	99.90	100.00	99.90	99.90	99.90	99.80	99.70	99.40	98.70	97.20	93.80	88.70	77.60	65.60	54.90	44.30	34.80
94.60	99.40	99.60	100.00	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.60	98.90	97.20	94.20	89.30	82.90	75.10
94.50	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.60	99.00	97.50	95.10	91.30	85.80	80.30
94.00	99.40	99.70	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.70	99.10	97.80	95.50	92.10	87.30	81.80
92.70	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.60	99.10	97.90	96.00	92.70	88.30	82.40
93.90	99.30	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.70	99.20	98.30	96.60	94.10	89.80	84.70
93.60	99.30	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.70	99.60	99.30	98.40	96.50	94.00	90.00	85.10
91.10	99.30	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.20	98.30	96.80	94.00	90.40	85.30
93.00	99.30	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.60	99.20	98.40	96.70	94.10	90.20	85.80
86.00	99.40	99.50	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.60	99.20	98.50	96.80	94.20	90.80	85.80
93.70	99.30	99.50	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.60	99.10	98.50	96.90	94.00	90.60	86.00
	99.20	99.50	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.50	99.10	98.40	96.80	94.20	90.90	86.20
		99.30	99.70	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.60	99.30	98.70	97.50	95.70	93.20	89.10	84.10

DTOF Reconstruction

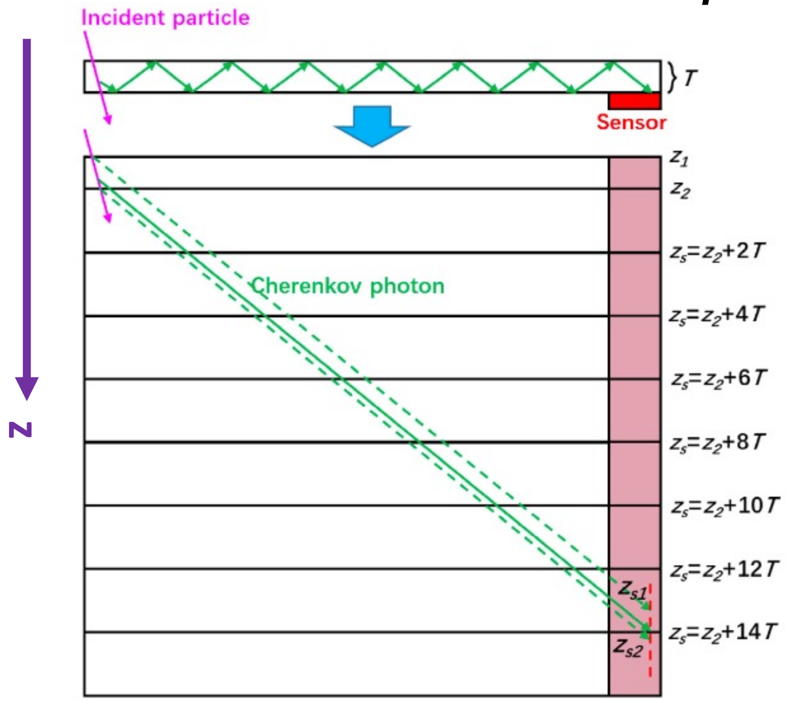
Likelihood Method for PID – Imaging Method

- **Photon TOA v.s. (x_s, y_s) Reconstruction**

$$cos\theta_c = \frac{1}{n\beta} = \frac{\vec{v}_t \cdot \vec{v}_p}{|\vec{v}_t| \cdot |\vec{v}_p|} \qquad \begin{cases} \vec{v}_t = (a,b,c) \\ \vec{v}_p = (x_s - x_0, y_s - y_0, z_s - z_0) \end{cases}$$

$$z_s = z_2 + 2mT$$

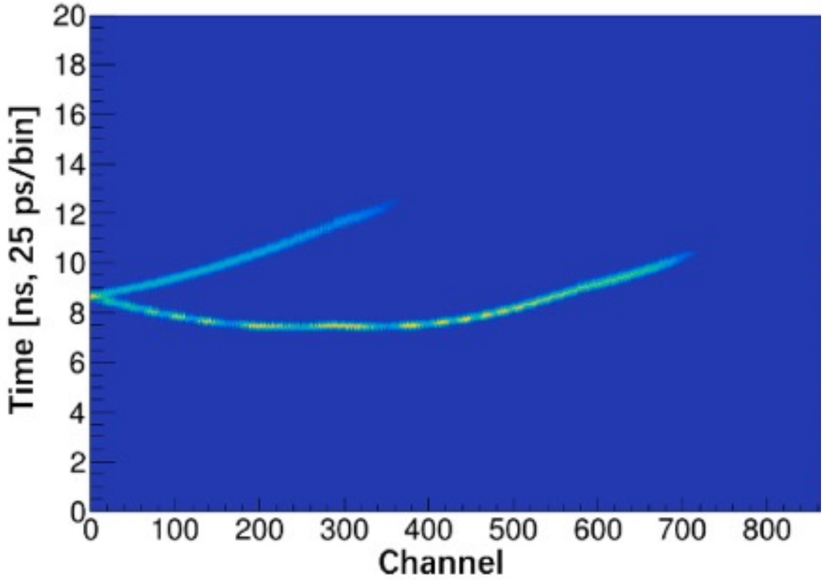
$$(\boldsymbol{x_s}, \boldsymbol{y_s}) \Longrightarrow \boldsymbol{z_e}, \boldsymbol{\phi_c} \Longrightarrow \boldsymbol{TOA} = \boldsymbol{TOF} + \frac{\mathbf{\Delta LOF_e}}{\boldsymbol{\beta c}} + \boldsymbol{TOP}$$



- **Likelihood construction**

$$\mathcal{L}_h = \prod_{i=1}^{N_{p.e.}} f_h(ch_i, t_i) = \prod_{i=1}^{N_{p.e.}} \bar{N}_h S_h(ch_i, t_i) + B$$

$$\sum_{ch_i, t_i} \bar{N}_h S_h(ch_i, t_i) = \bar{N}_h$$



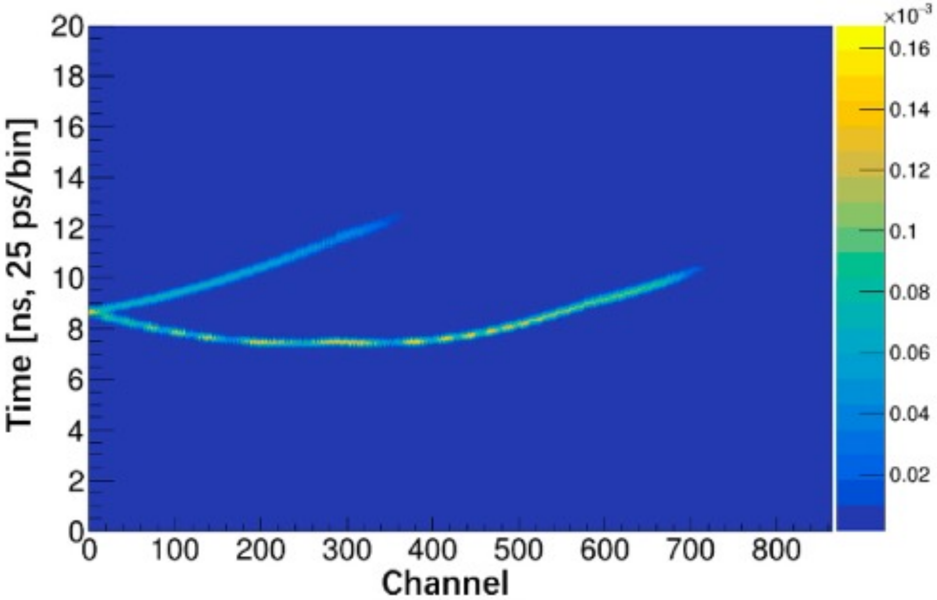
DTOF Reconstruction

Likelihood Method for PID – Imaging Method

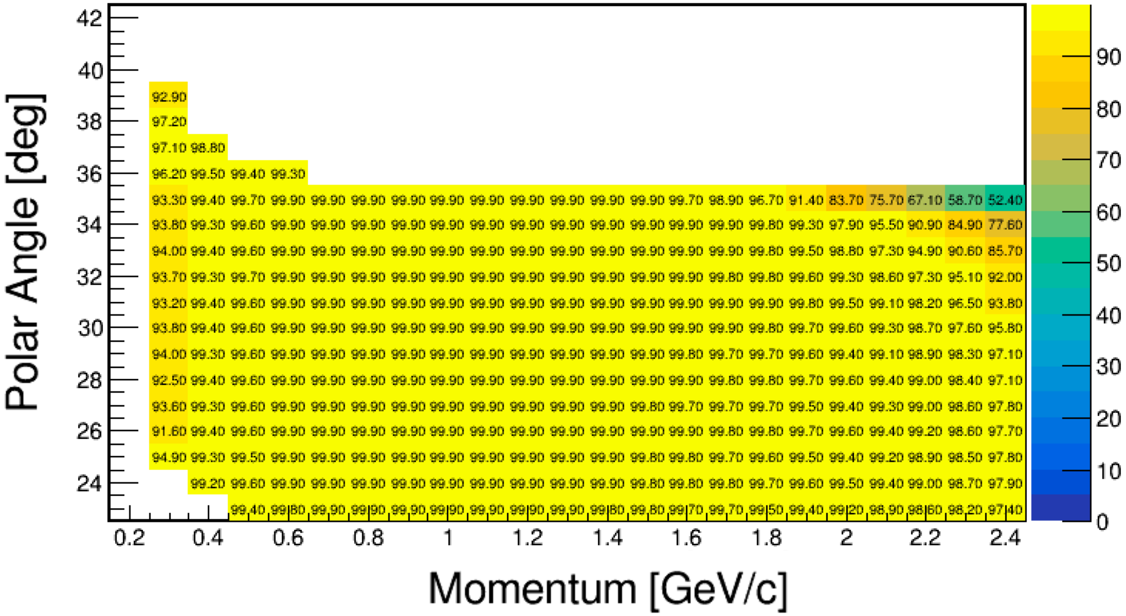
- **Performance**

$$\mathcal{L}_h = \prod_{i=1}^{N_{p.e.}} f_h(ch_i, t_i) = \prod_{i=1}^{N_{p.e.}} \bar{N}_h S_h(ch_i, t_i) + B$$

- π efficiency ~ 99%, at $p = 2.0\ \mathrm{GeV/c}$ (K mis − ID = 2%)
- Imaging method performed better at $p > 2\ \mathrm{GeV/c}$



π efficiency after mixing BKG in different $(|\vec{p}|, \theta)$:
(K mis − ID = 2%)



92.90																					
97.20																					
97.10	98.80																				
96.20	99.50	99.40	99.30																		
93.30	99.40	99.70	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.70	98.90	96.70	91.40	83.70	75.70	67.10	58.70	52.40
93.80	99.30	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.30	97.90	95.50	90.90	84.90	77.60
94.00	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.50	98.80	97.30	94.90	90.60	85.70
93.70	99.30	99.70	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.60	99.30	98.60	97.30	95.10	92.00
93.20	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.50	99.10	98.20	96.50	93.80
93.80	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.70	99.60	99.30	98.70	97.60	95.80
94.00	99.30	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.70	99.70	99.60	99.40	99.10	98.90	98.30	97.10
92.50	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.60	99.40	99.00	98.40	97.10
93.60	99.30	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.70	99.70	99.70	99.50	99.40	99.30	99.00	98.60	97.80
91.60	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.60	99.40	99.20	98.60	97.70
94.90	99.30	99.50	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.60	99.50	99.40	99.20	98.90	98.50	97.80
	99.20	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.70	99.60	99.50	99.40	99.00	98.70	97.90
		99.40	99.80	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.70	99.50	99.40	99.20	98.90	98.60	98.20	97.40

Summary

The Simulation & Reconstruction software of DTOF has been established based on OSCAR:

Simulation

- ✓ Geometry simulation has been constructed.

Reconstruction

- ✓ Both two Algorithm can satisfy 97% π efficiency at $\mathrm{p} \leq 2.0\ \mathrm{GeV/c}$

Timing method

- π efficiency $\sim 98\%$, at $\mathrm{p} = 2.0\ \mathrm{GeV/c}$.
- Overall reconstructed TOF time resolution ~ 50 ps.

Imaging method

- π efficiency $\sim 99\%$, at $p = 2.0\ \mathrm{GeV/c}$.

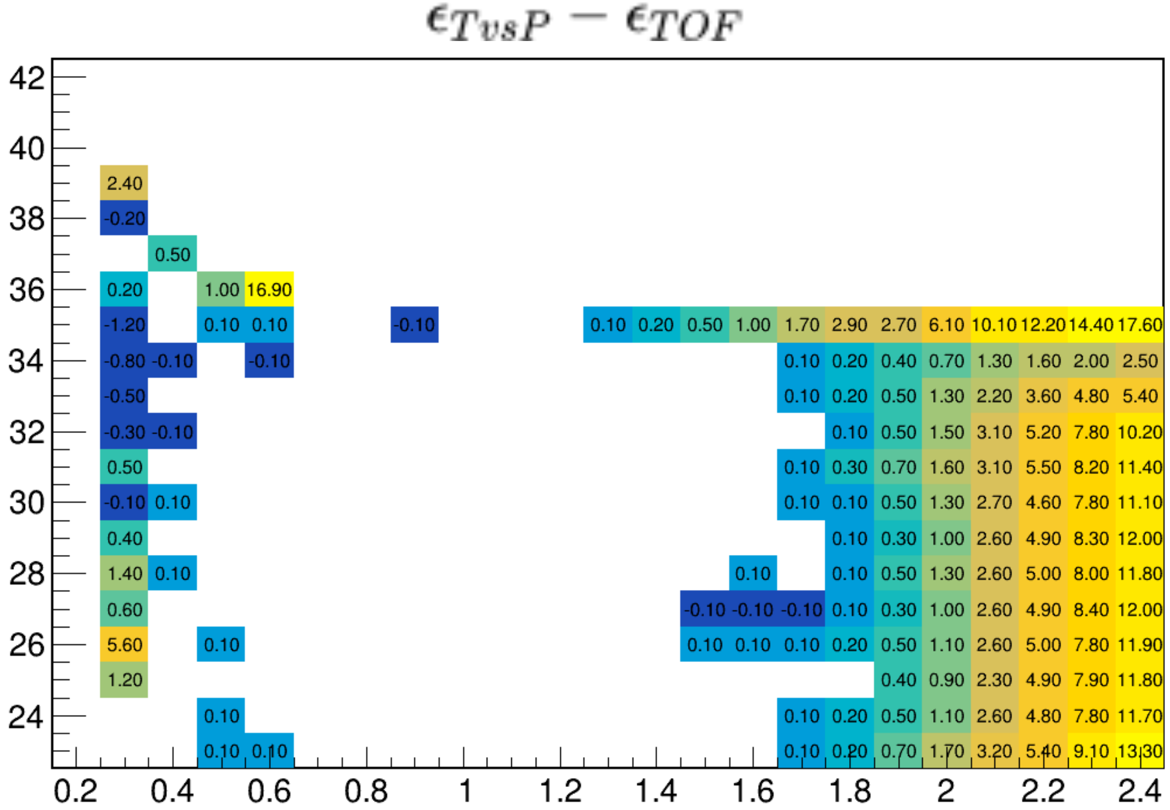
Improve the efficiency of Global PID. $\theta \in (22°, 36°)$, $\mathrm{p} \in (0.2, 2.4)\ \mathrm{GeV/c}$.

Thank you!

BackUp

BackUp

π efficiency after mixing BKG in different $(|\vec{p}|, \theta)$:

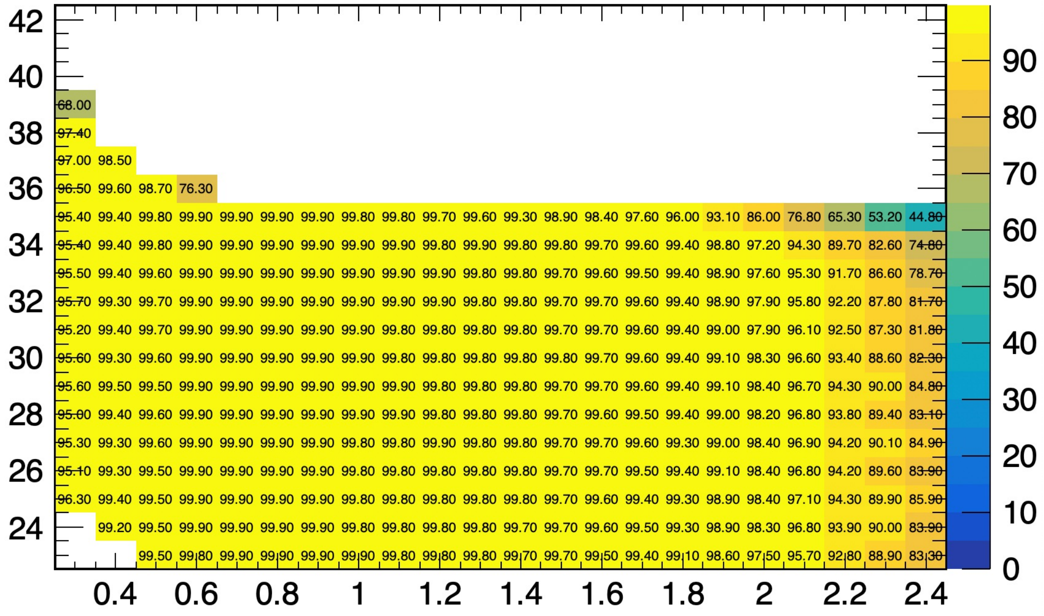


TOF method: shorter reconstruct time

BackUp

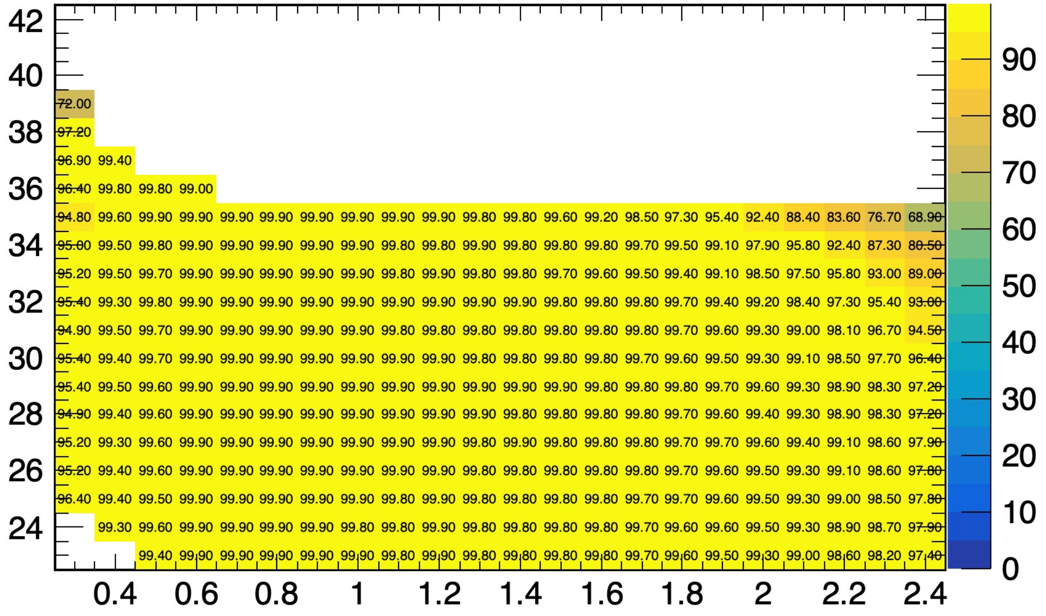
K efficiency $(\pi \text{ mis} - \text{ID} = 2\%)$

TOF Method



68.00																					
97.40																					
97.00	98.50																				
96.50	99.60	98.70	76.30																		
95.40	99.40	99.80	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.60	99.30	98.90	98.40	97.60	96.00	93.10	86.00	76.80	65.30	53.20	44.80
95.40	99.40	99.80	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.90	99.80	99.80	99.70	99.60	99.40	98.80	97.20	94.30	89.70	82.60	74.80
95.50	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.60	99.50	99.40	98.90	97.60	95.30	91.70	86.60	78.70
95.70	99.30	99.70	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.70	99.70	99.60	99.40	98.90	97.90	95.80	92.20	87.80	81.70
95.20	99.40	99.70	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.80	99.70	99.70	99.60	99.40	99.00	97.90	96.10	92.50	87.30	81.80
95.60	99.30	99.60	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.80	99.80	99.70	99.60	99.40	99.10	98.30	96.60	93.40	88.60	82.30
95.60	99.50	99.50	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.70	99.70	99.60	99.40	99.10	98.40	96.70	94.30	90.00	84.80
95.00	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.70	99.60	99.50	99.40	99.00	98.20	96.80	93.80	89.40	83.10
95.30	99.30	99.60	99.90	99.90	99.90	99.90	99.80	99.80	99.90	99.80	99.80	99.70	99.70	99.60	99.30	99.00	98.40	96.90	94.20	90.10	84.90
95.10	99.30	99.50	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.80	99.80	99.70	99.70	99.50	99.40	99.10	98.40	96.80	94.20	89.60	83.90
96.30	99.40	99.50	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.80	99.80	99.70	99.60	99.40	99.30	98.90	98.40	97.10	94.30	89.90	85.90
	99.20	99.50	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.80	99.70	99.70	99.60	99.50	99.30	98.90	98.30	96.80	93.90	90.00	83.90
		99.50	99.80	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.70	99.70	99.50	99.40	99.10	98.60	97.50	95.70	92.80	88.90	83.30

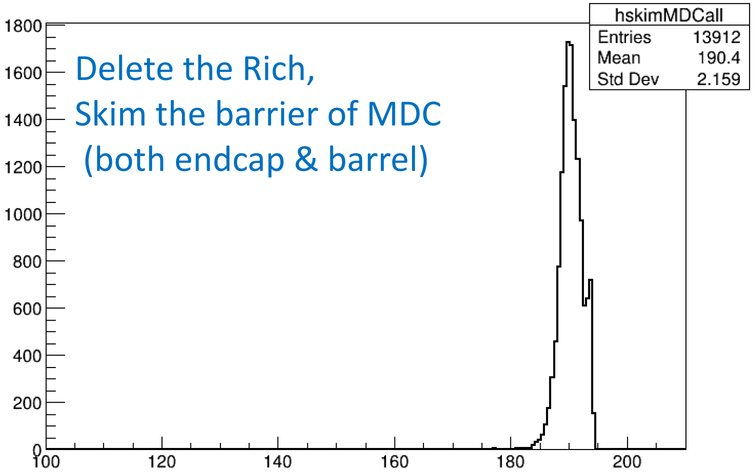
TvsP Method

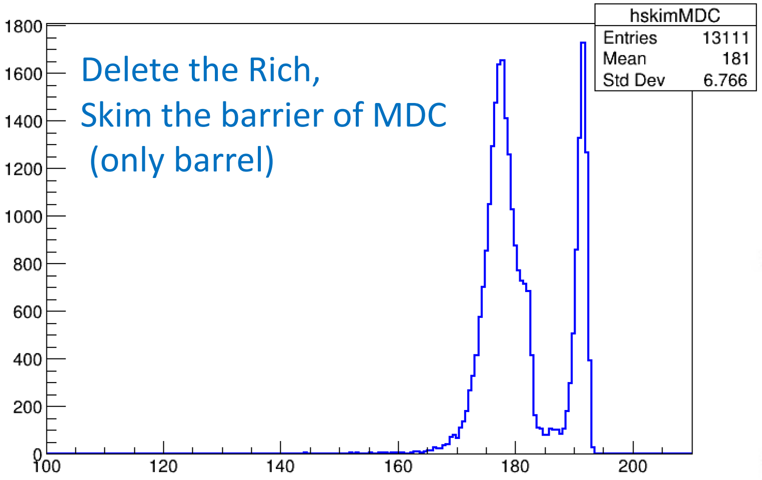


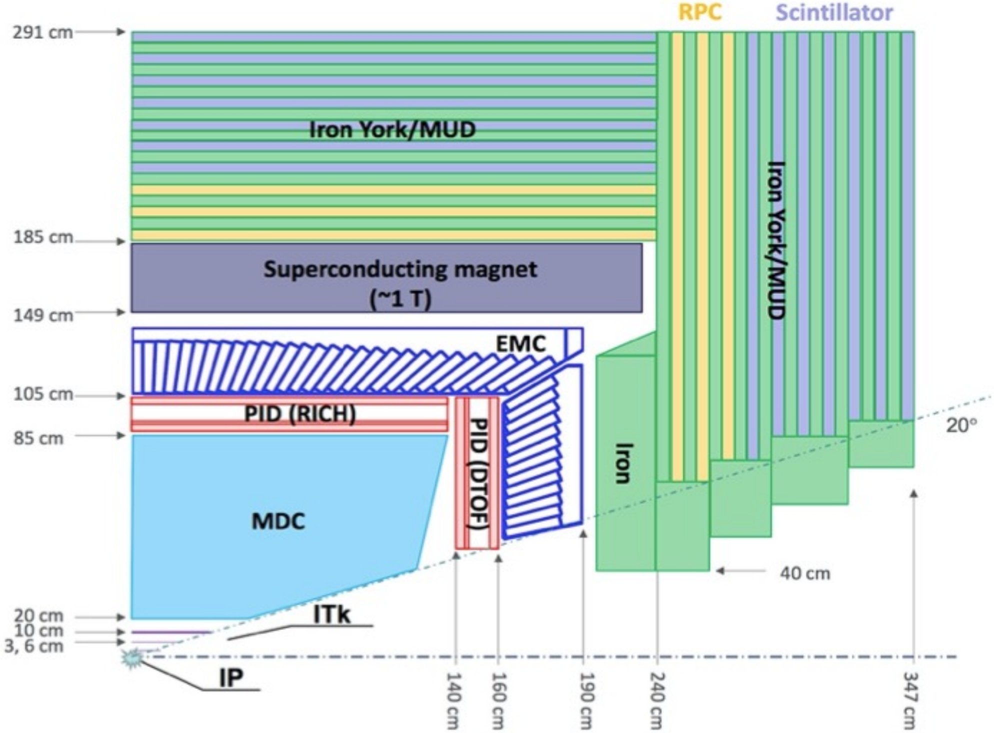
72.00																					
97.20																					
96.90	99.40																				
96.40	99.80	99.80	99.00																		
94.80	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.60	99.20	98.50	97.30	95.40	92.40	88.40	83.60	76.70	68.90
95.00	99.50	99.80	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.90	99.80	99.80	99.80	99.70	99.50	99.10	97.90	95.80	92.40	87.30	80.50
95.20	99.50	99.70	99.90	99.90	99.90	99.90	99.90	99.80	99.90	99.80	99.80	99.70	99.60	99.50	99.40	99.10	98.50	97.50	95.80	93.00	89.00
95.40	99.30	99.80	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.70	99.40	99.20	98.40	97.30	95.40	93.00
94.90	99.50	99.70	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.80	99.80	99.80	99.80	99.70	99.60	99.30	99.00	98.10	96.70	94.50
95.40	99.40	99.70	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.80	99.70	99.60	99.50	99.30	99.10	98.50	97.70	96.40
95.40	99.50	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.70	99.60	99.30	98.90	98.30	97.20
94.90	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.80	99.70	99.60	99.40	99.30	98.90	98.30	97.20
95.20	99.30	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.90	99.80	99.80	99.80	99.70	99.70	99.60	99.40	99.10	98.60	97.90
95.20	99.40	99.60	99.90	99.90	99.90	99.90	99.90	99.90	99.90	99.80	99.80	99.80	99.80	99.80	99.70	99.60	99.50	99.30	99.10	98.60	97.80
96.40	99.40	99.50	99.90	99.90	99.90	99.90	99.90	99.80	99.90	99.80	99.80	99.80	99.80	99.70	99.70	99.60	99.50	99.30	99.00	98.50	97.80
	99.30	99.60	99.90	99.90	99.90	99.90	99.80	99.80	99.90	99.80	99.80	99.80	99.80	99.70	99.60	99.60	99.50	99.30	98.90	98.70	97.90
		99.40	99.90	99.90	99.90	99.90	99.90	99.80	99.90	99.80	99.80	99.80	99.80	99.70	99.60	99.50	99.30	99.00	98.60	98.20	97.40

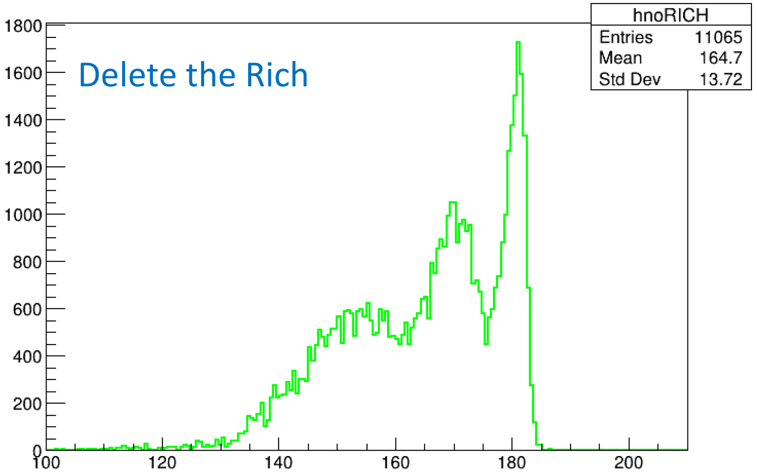
BackUp

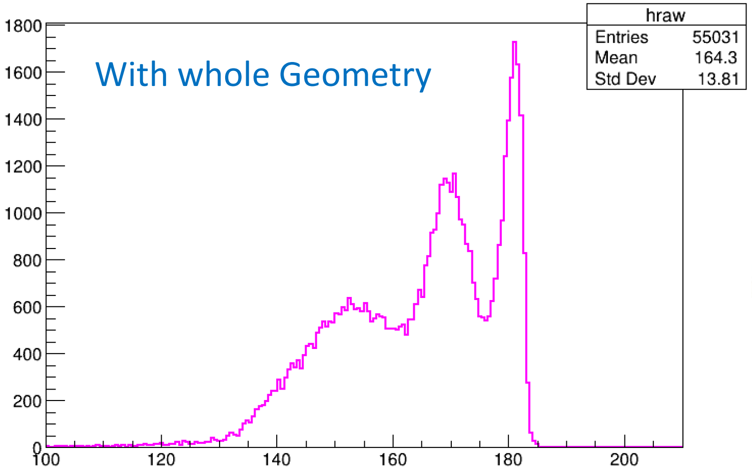
$@\ \theta = 41°, p = 0.2\ \text{GeV},\ \pi\ \text{Sample}$


Delete the Rich,
Skim the barrier of MDC
(both endcap & barrel)


Delete the Rich,
Skim the barrier of MDC
(only barrel)




Delete the Rich


With whole Geometry