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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Outline

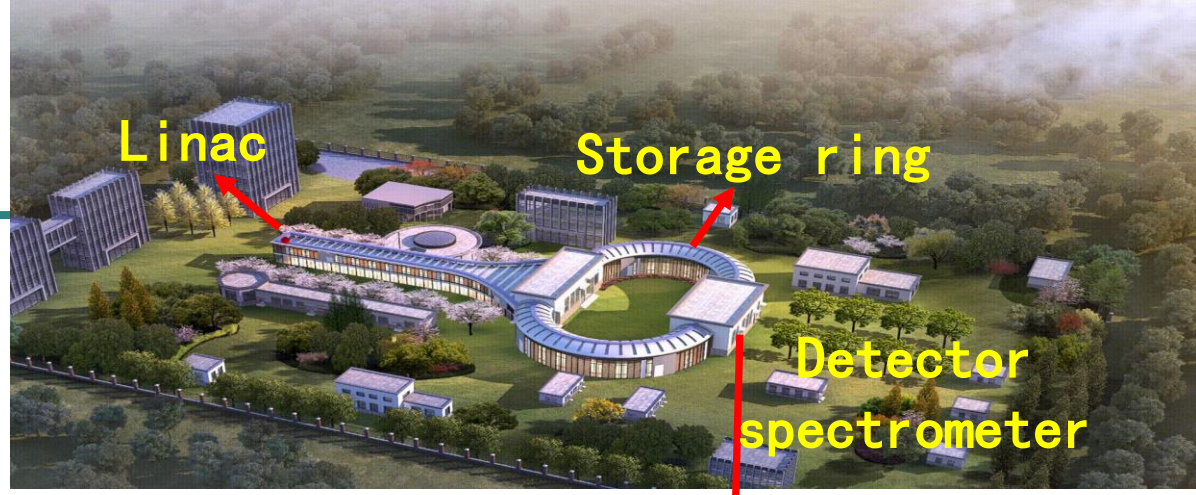
Overview of STCF;

DTOF:

- Geometry Configuration;
- Simulation;
- Reconstruction:
    - Likelihood Method for PID – Timing Method
    - Likelihood Method for PID – Imaging Method
- Multi-track Simulation setup and Efficiency

Summary

Super Tau-Charm Facility



Parameters of STCF:

- Center-of-mass energy: $2-7\mathrm{GeV}$
- Peak luminosity: $0.5\sim1\times10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Circumference: ~900 m
- Crossing angle: 2×30 mrad

more comprehensive physical study of particle composition and deep structure of matter.

ITK

<0.25%X0 / layer

σ_{xy}< 100 μm

MDC

σ_{xy}< 130 μm

σp/p ~ 0.5% @ 1 GeV

dE/dx~6%

PID

π/K efficiency > 97% with mis-ID < 2% up to 2GeV/c

EMC

E range: 0.025-3.5 GeV

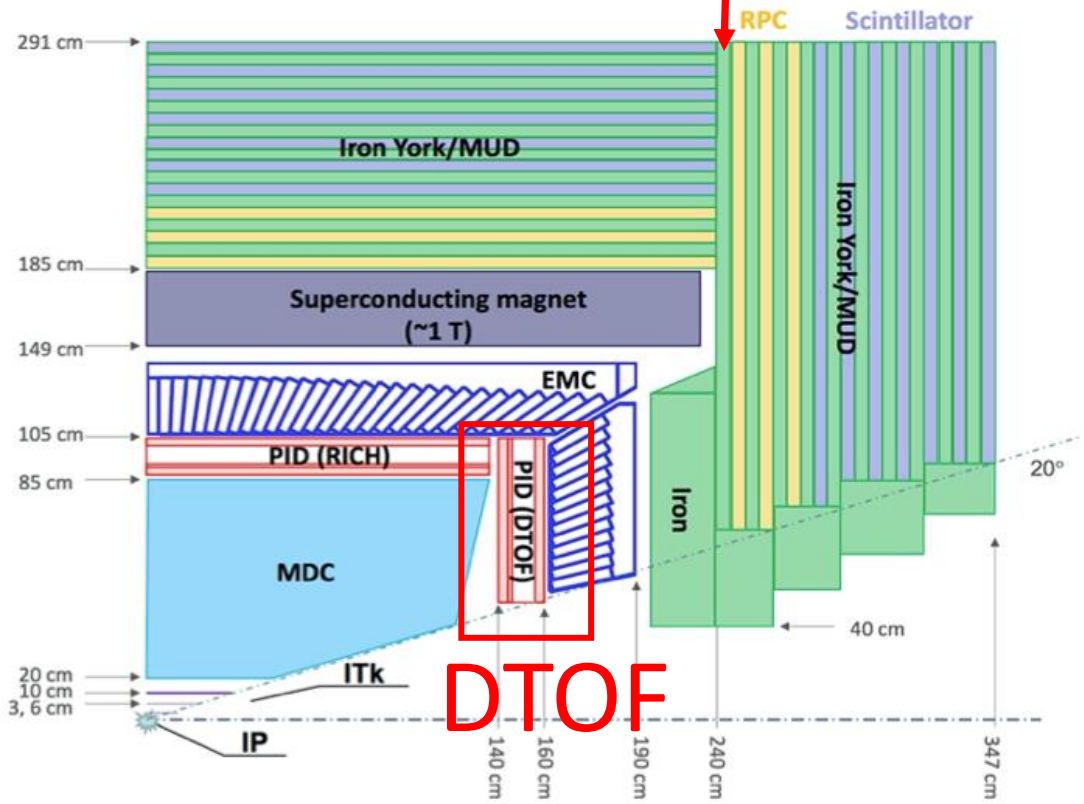
σ_E @ 1 GeV: 2 .5% in barrel, 4% at endcaps

Pos. Res. : ~ 4 mm

MUD

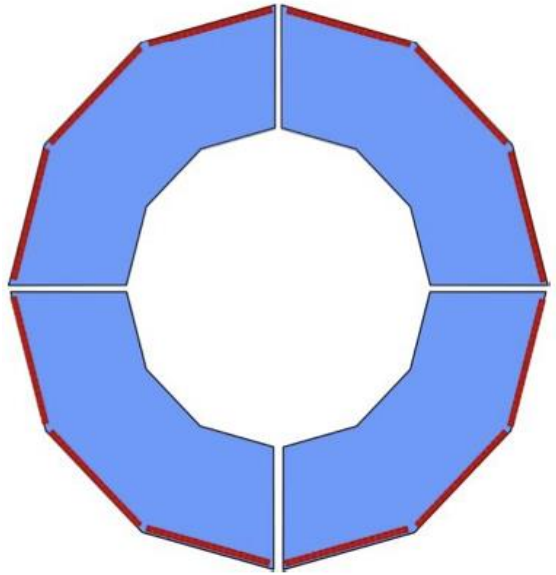
0.4 - 1.8 GeV

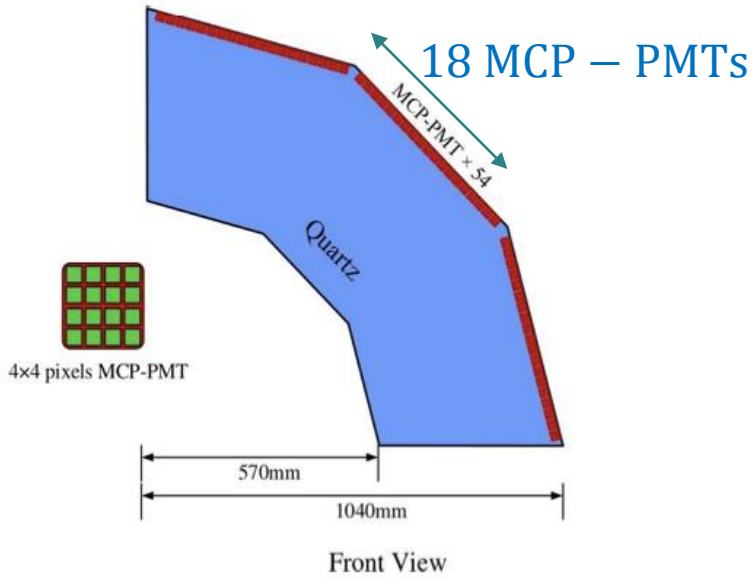
π suppression >30

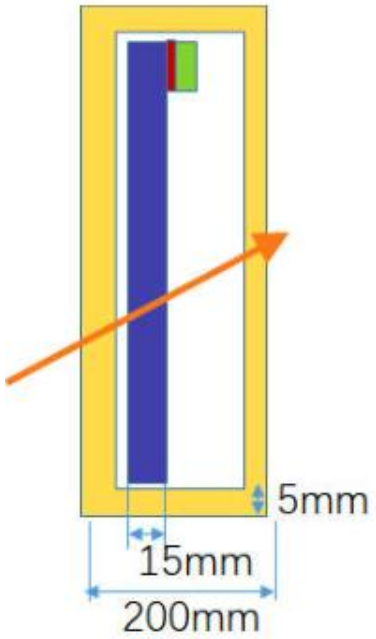


DTOF Geometry Configuration

- DTOF: DIRC technique to measure Time-Of-Flight; → Detection of Internally Reflected Cherenkov Light;
- Two identical endcap discs, $\sim \pm 1400$ 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 $\theta \in (22° - 36°)$.

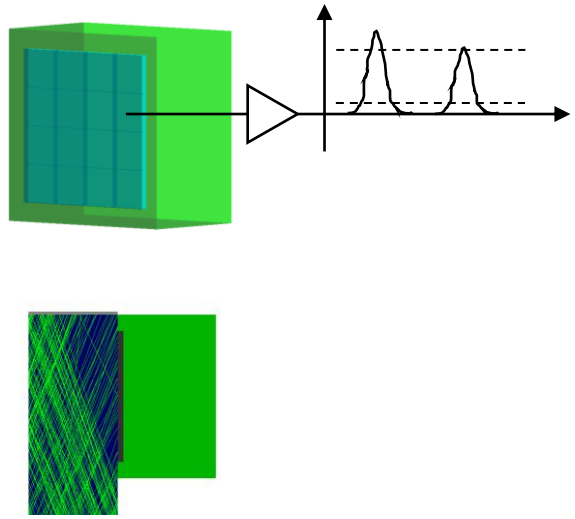






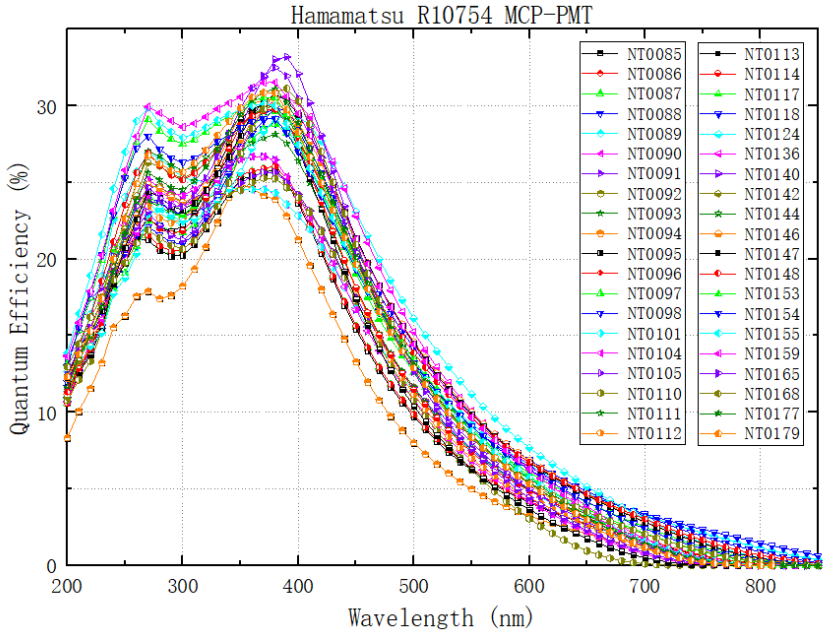
4×4 anodes

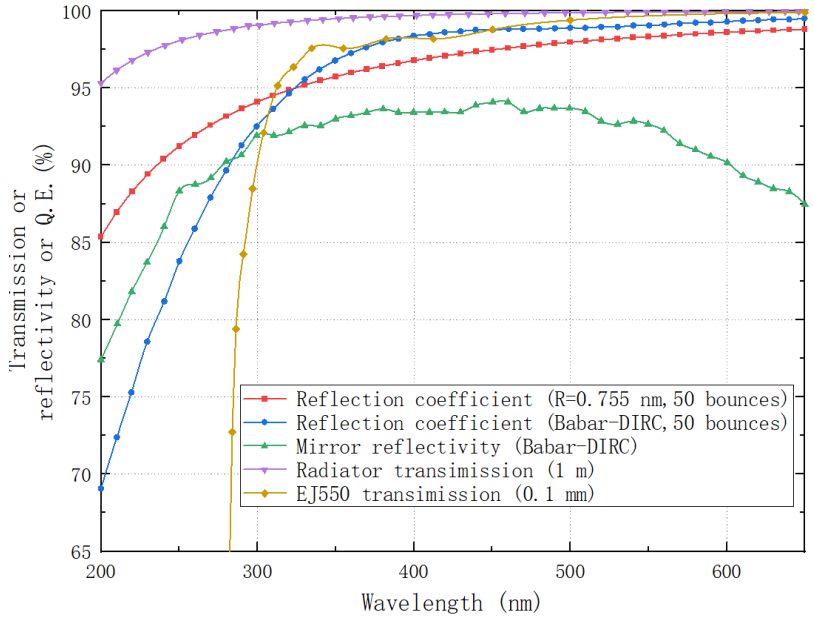
$5.5 \times 5.5\ mm^2$

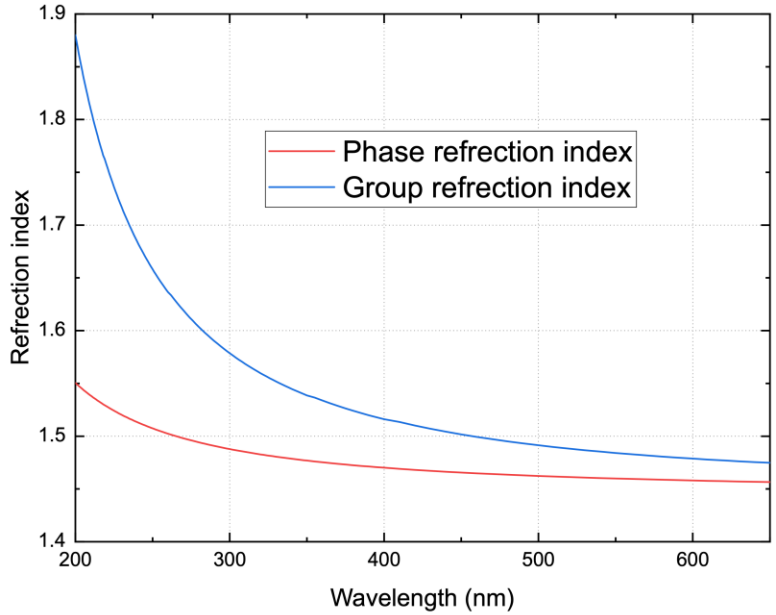


DTOF Simulation -- Optical Parameters

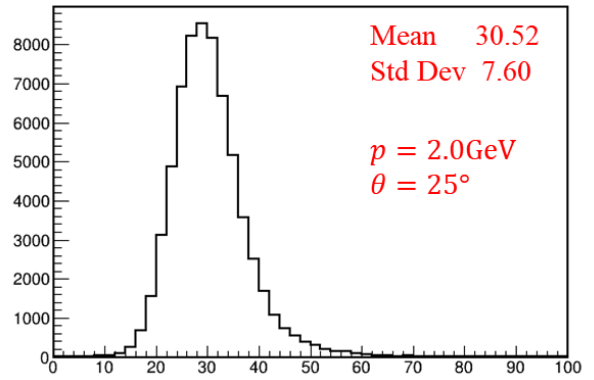
- Optical parameters used in DTOF simulation.



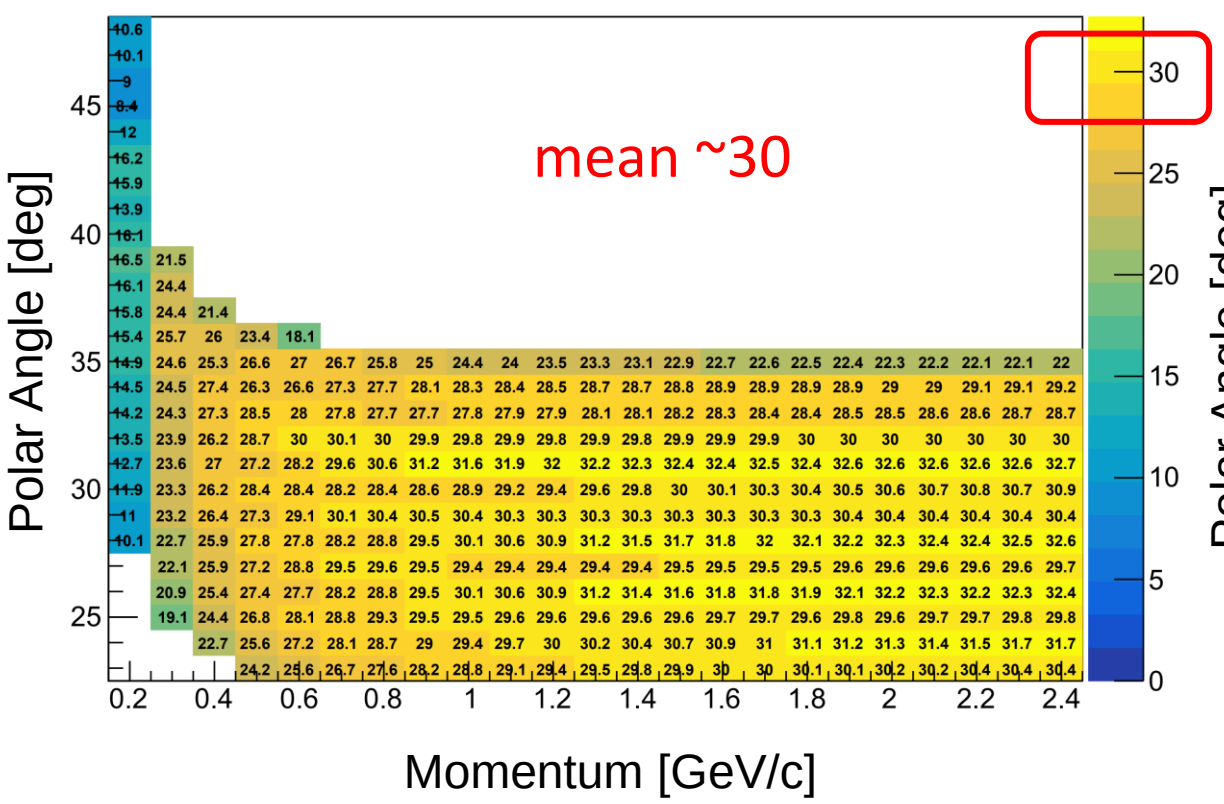




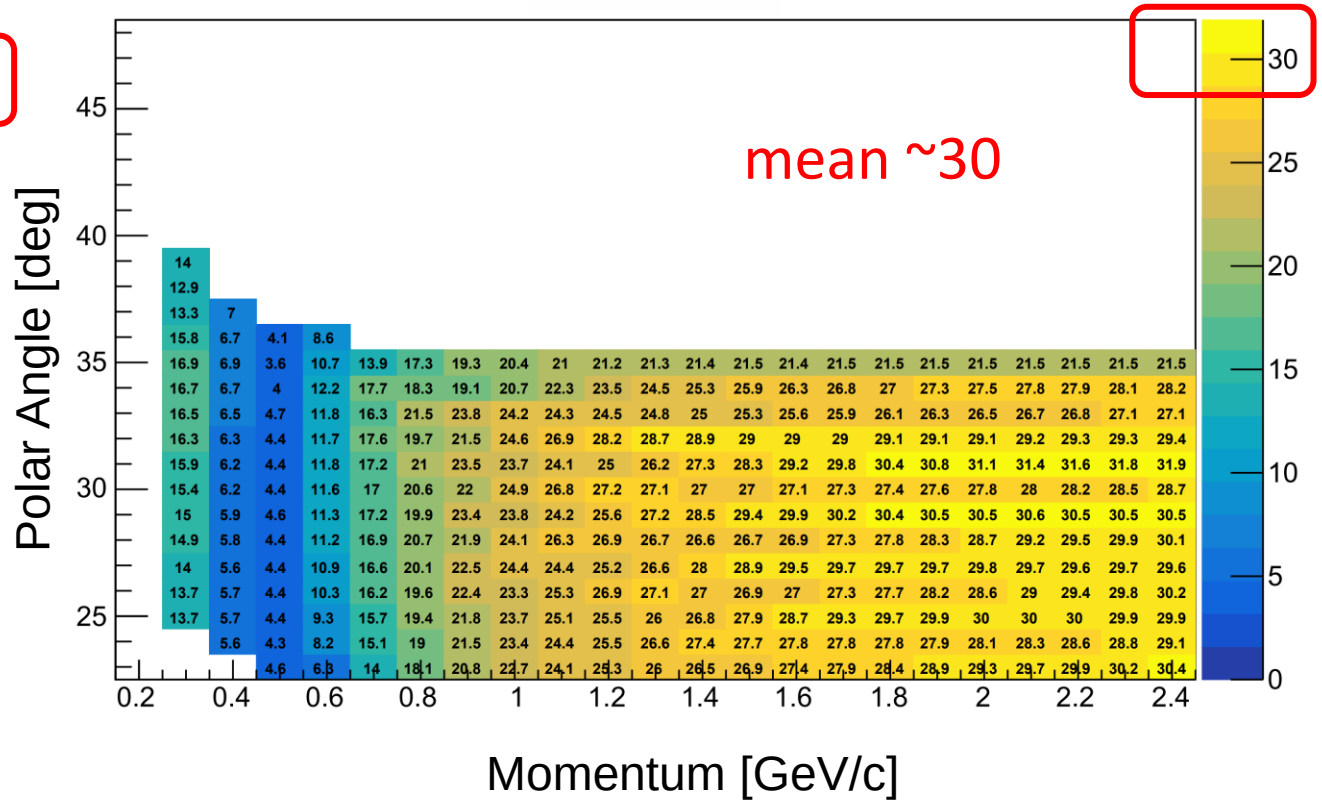
DTOF Simulation --Photon Yield



π Sample



K Sample



Reconstruction:

Likelihood Method for PID – Timing Method

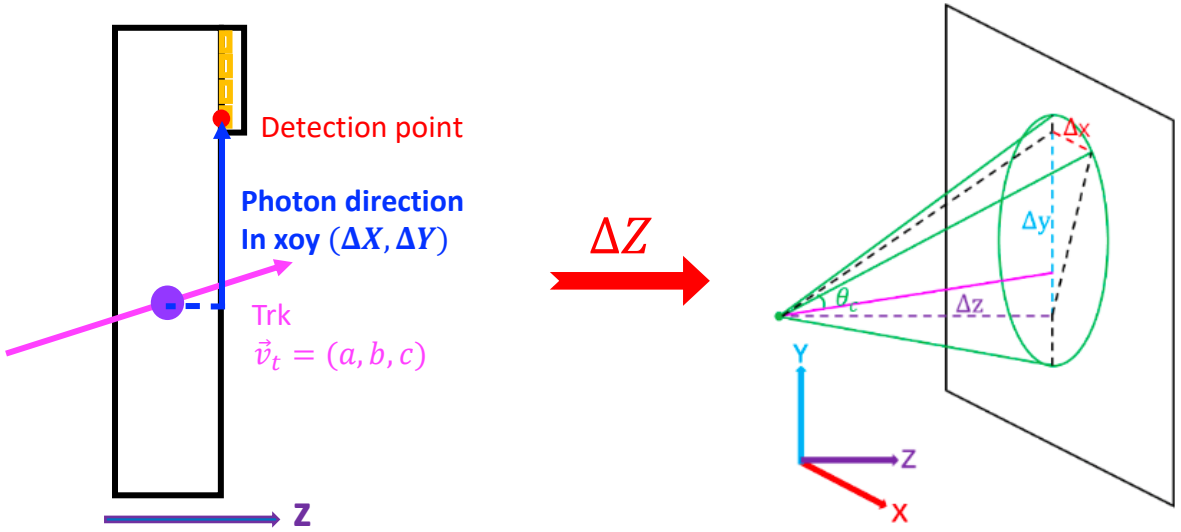
TOF Reconstruction--Timing Method

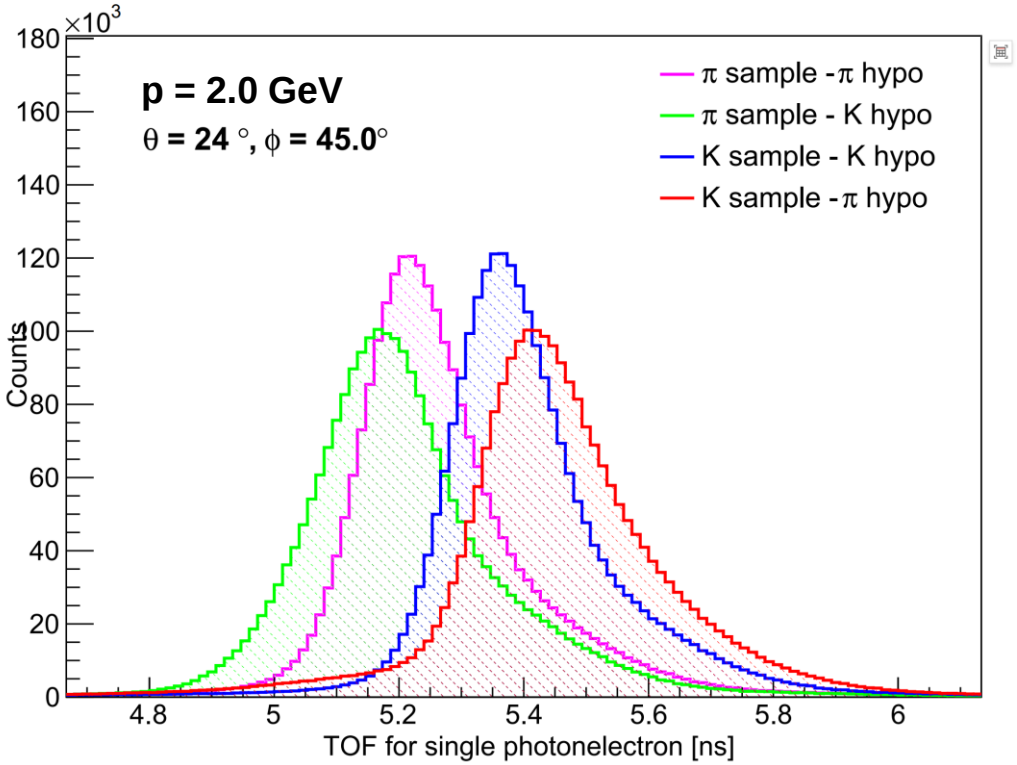
Reconstruct light path, including the length of propagation along different direction, i.e.ΔX, ΔY and ΔZ;

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

Length of propagation $$LOP = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2} \qquad (2)$$

Time of flight $$TOF_{rec} = T - \frac{LOP \cdot \overline{n_g}}{c} - T_0 \qquad (3)$$





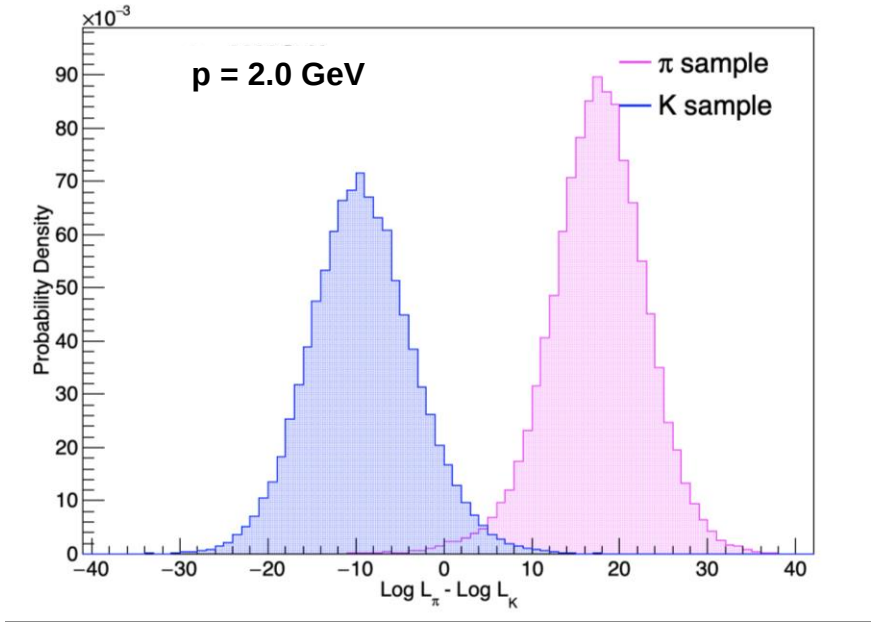
Singal track Performance -- Timing Method

- **Likelihood construction --Timing Method**

signal bkg

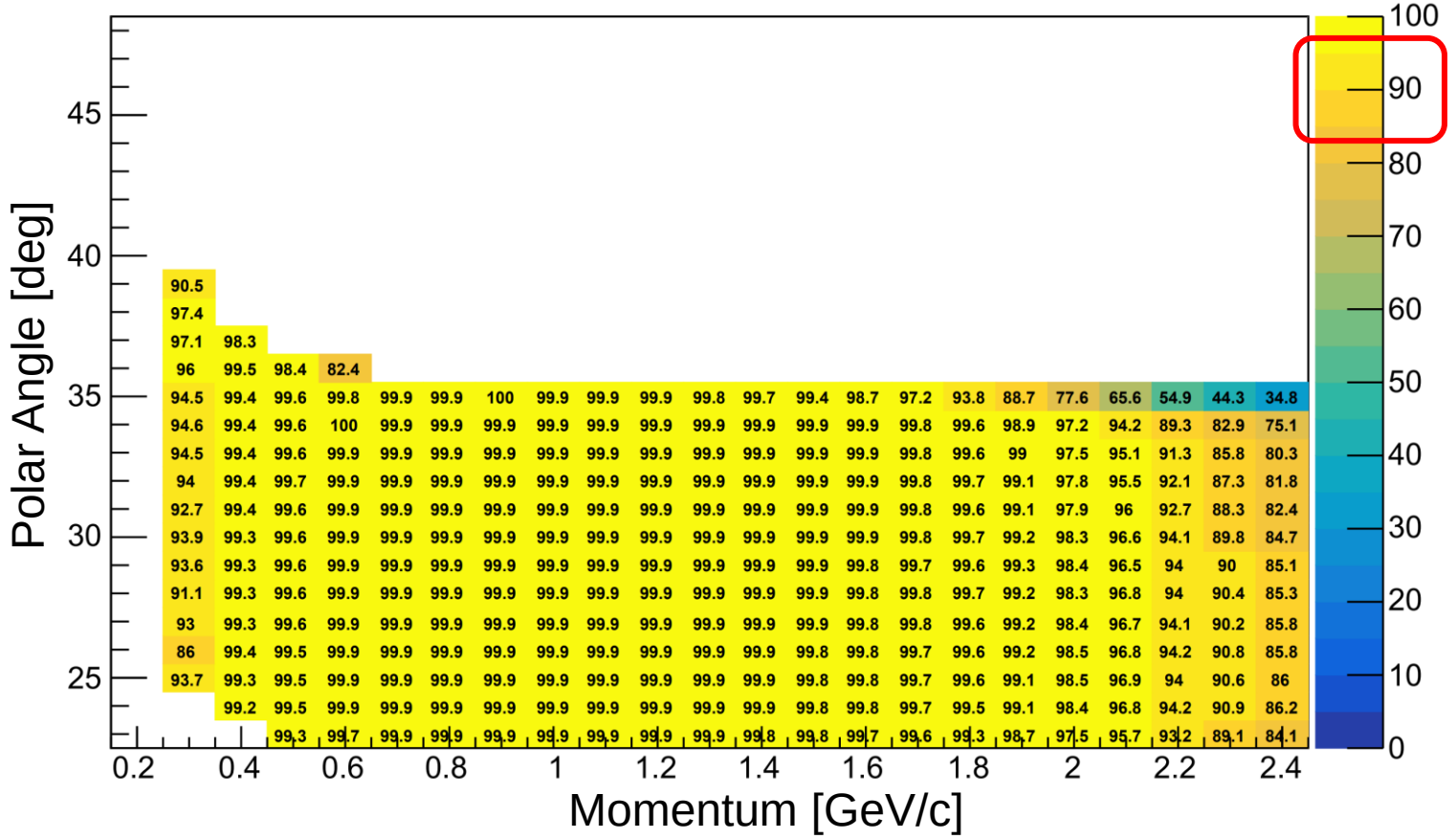
$$\mathcal{L}_h = \prod_{i=1}^{N_{p.e.}} N_h S_h\left(TOF_{rec} | \, TOF_{hypo}\right) + Contant$$

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



- π efficiency $\sim 98\%$ at $p = 2.0$ GeV/c

$(K$ mis $-$ ID $= 2\%)$



DTOF Timing Uncertainties

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

σ_{T_0} : the starting time of an event.

$\sigma_{t_{MCS}}$: the Mutiple Compton Scattering of the charged tracks.

$\sigma_{t_{ext(\vec{r},\vec{p})}}$: the extrapolation algorithm of the charged tracks.

σ_{t_λ}: chromatic dispersion effect.

σ_{t_D}: the position resolution owing to finite photon sensor size

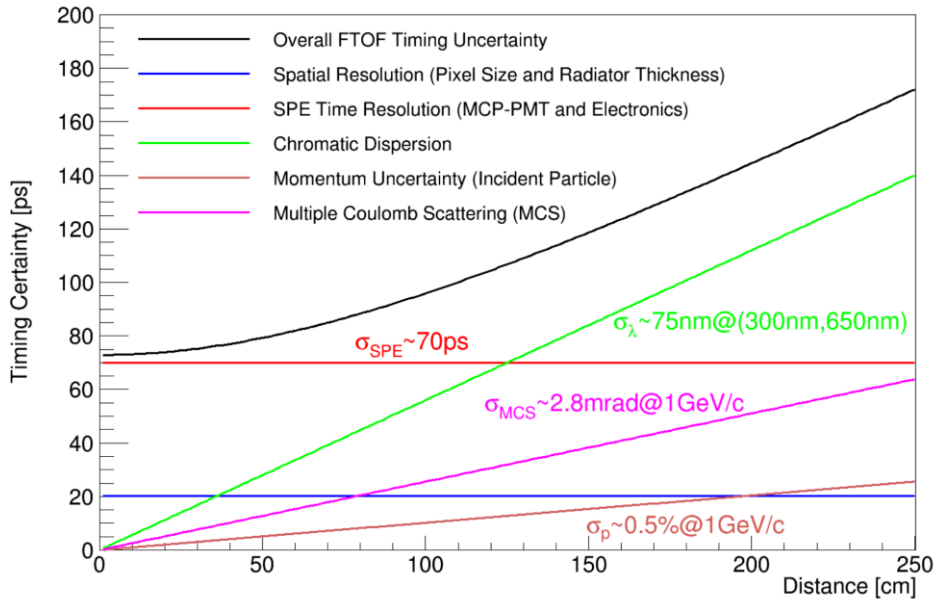
σ_{TTS} : the transit time spread of the MCP-PMT.

- $\sigma_t < 70\ ps$ by single photon-electron
- $\sigma_t < 50\ ps$ by multi-photon-electrons

@ 2GeV

- Single photon timing uncertainty:

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



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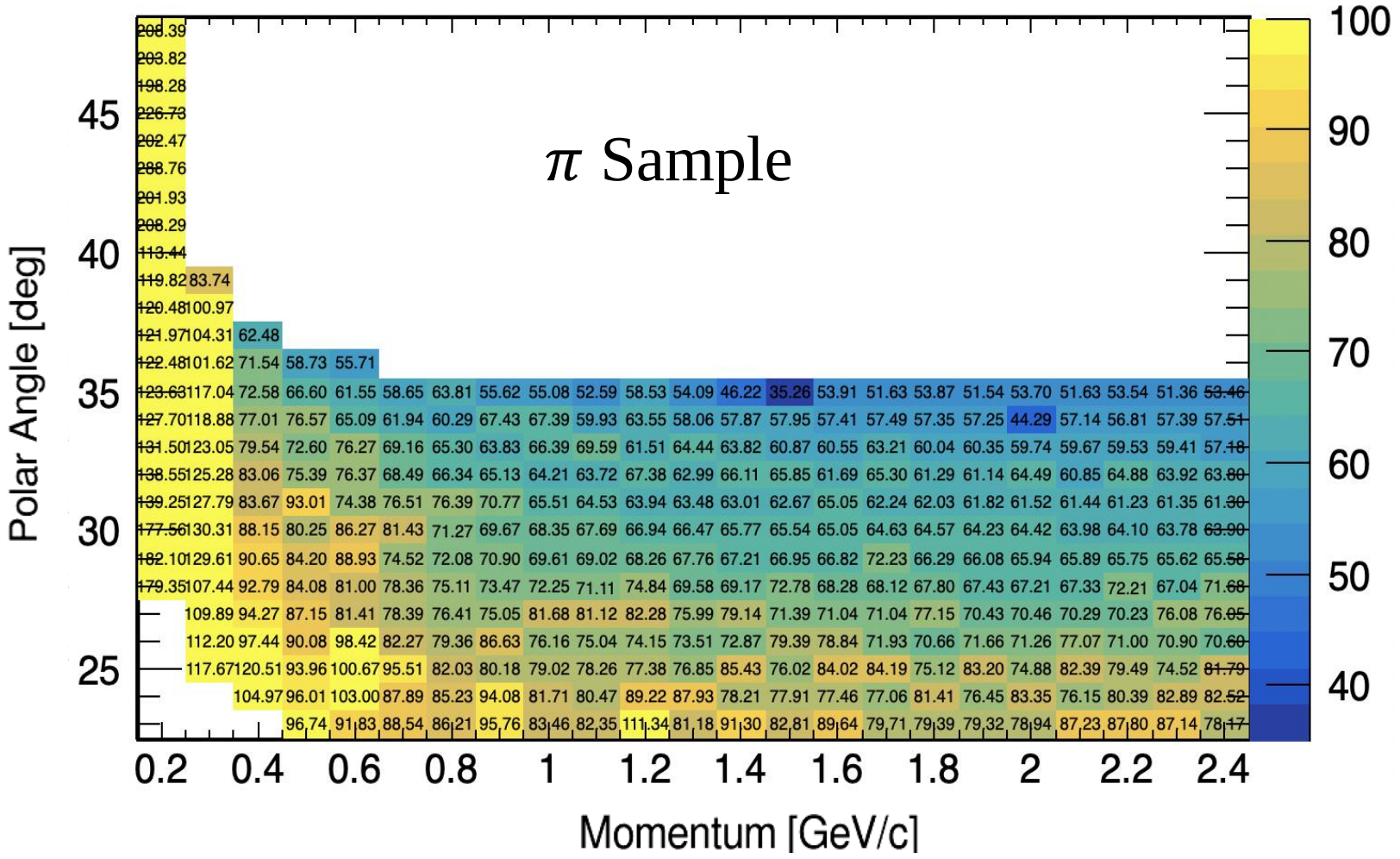
Single Timing Uncertainties

Single Timing Uncertainties in different $(|\vec{p}|, \theta)$:



Reconstruction:

Likelihood Method for PID – Imaging Method

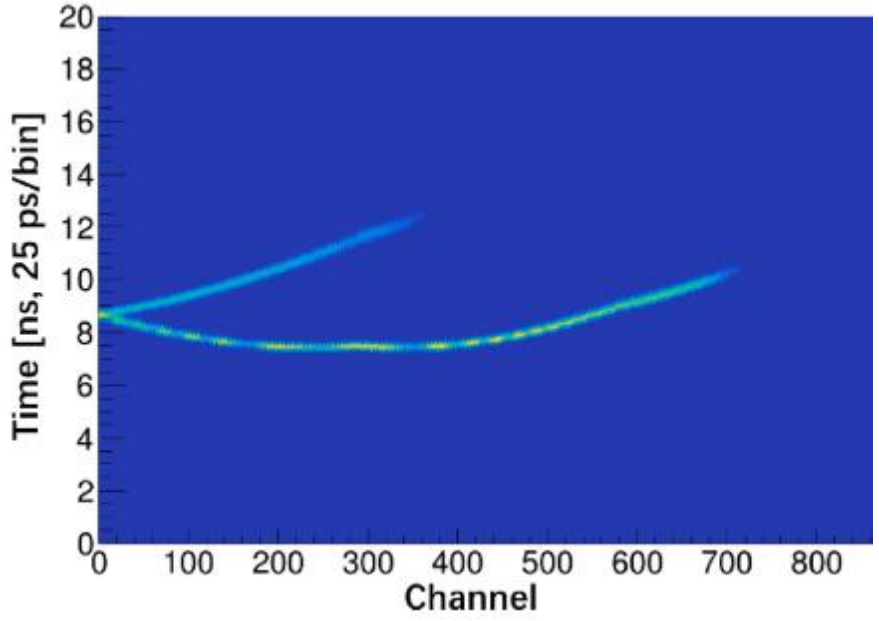
Imaging Method

- **Likelihood construction**

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

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

the simulated $f_h(ch_i, t_i)$ for DTOF detector:

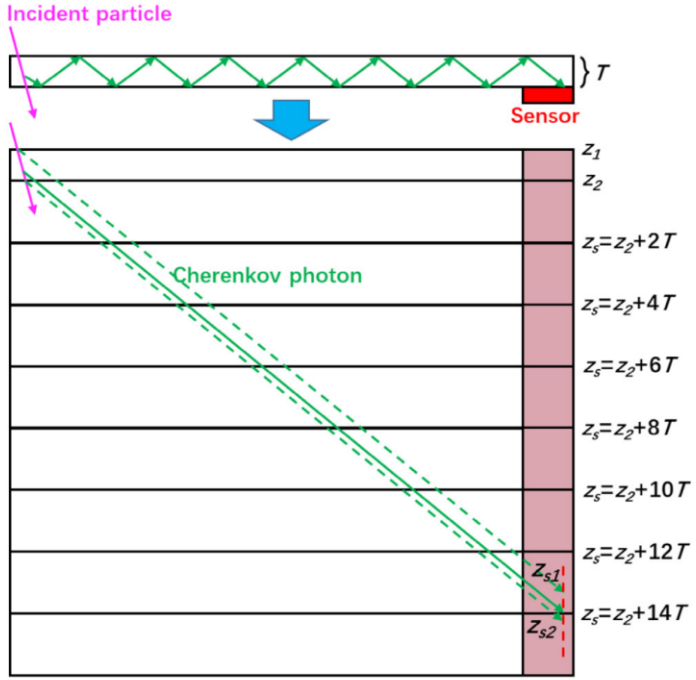


- **Photon TOA v.s. (x_s, y_s) Reconstruction**

$$cos\theta_c = \frac{1}{n\beta} = \frac{\vec{v}_t \cdot \vec{v}_p}{|\vec{v}_t| \cdot |\vec{v}_p|} \quad \begin{cases} \vec{v}_t = (a, b, c) \\ \vec{v}_p = (x_s - x_0, y_s - y_0, z_s - z_0) \end{cases} \quad (2)$$

$$z_s = z_2 + 2mT \quad (3)$$

$$(x_s, y_s) \Rightarrow z_e, \phi_c \Rightarrow \boldsymbol{TOA = TOF + \frac{\Delta LOF_e}{\beta c} + TOP} \quad (4)$$



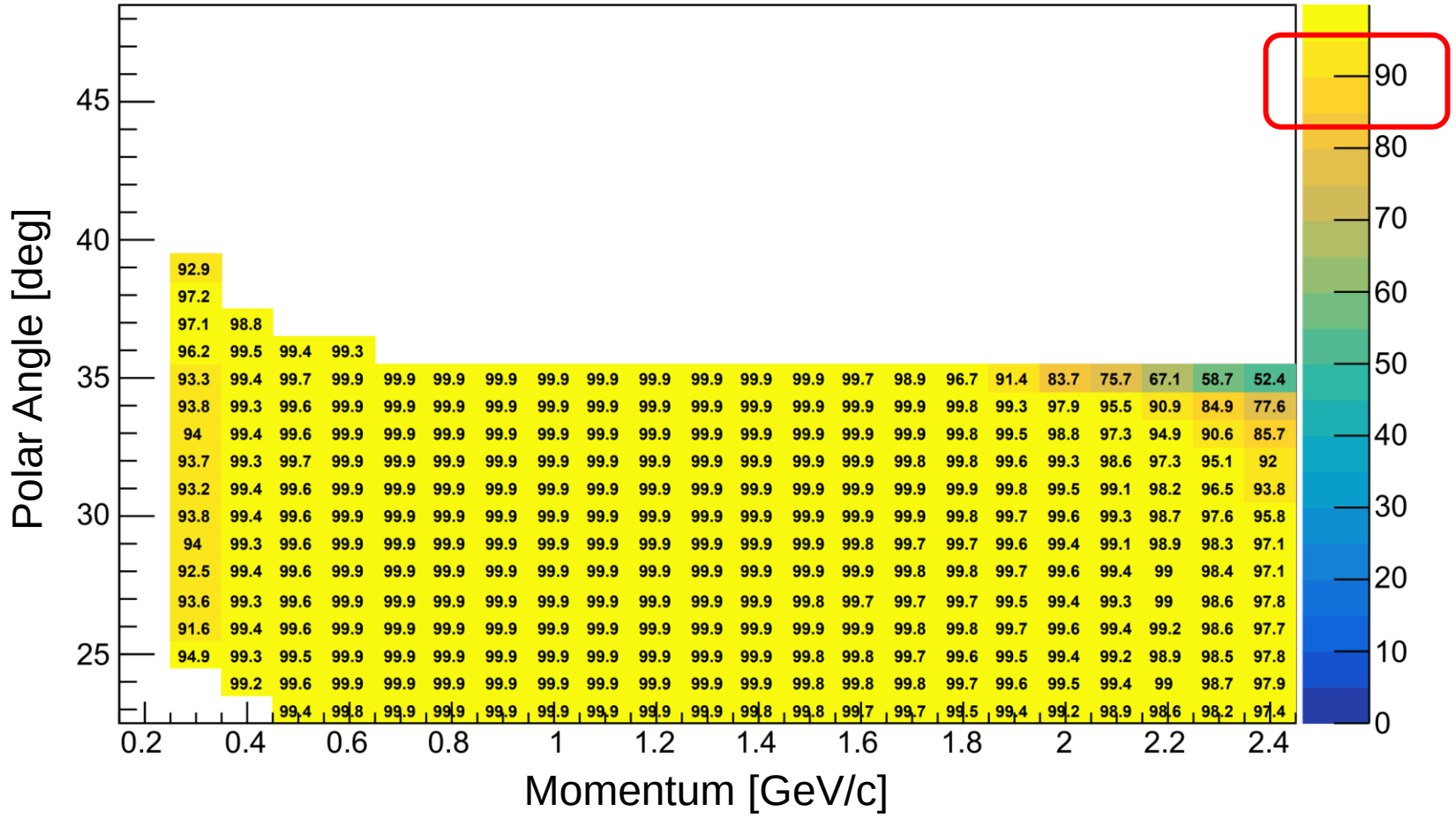
Expanded view of the path of Cherenkov light along the z-axis.

Singal track Performance--Imaging Method

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

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

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



Multi-track simulation setup and Efficiency

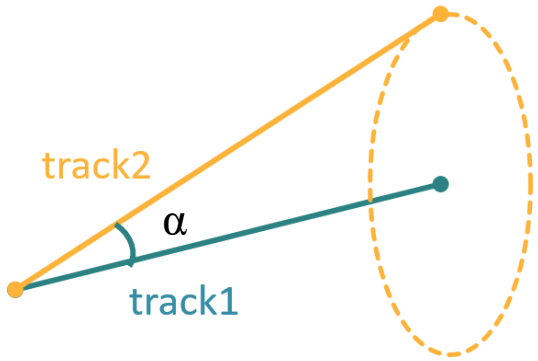
Multi-track simulation setup

- two tracks hit the same sector;
- $p1 = p2 = 2.0\ \mathrm{GeV}$
- Random:

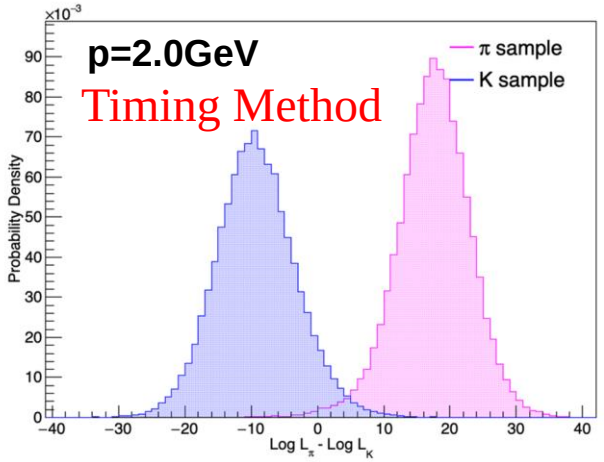
  track1: randomly hited at DTOF ;

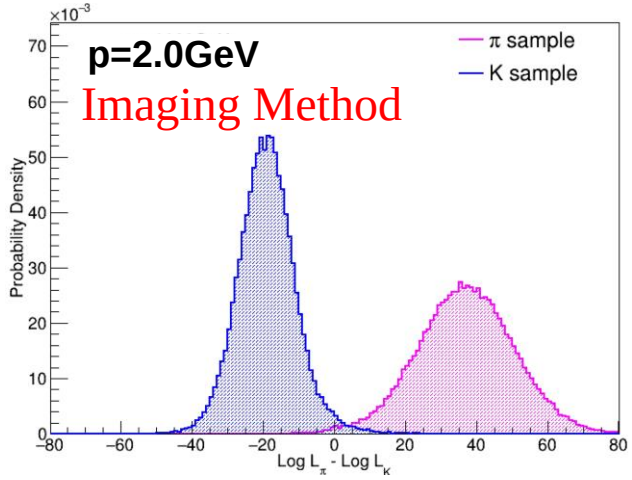
  track2: rotates around track 1;

Fix Angle α : the angle between track1 and track2； 2°~ 30° (+2;)



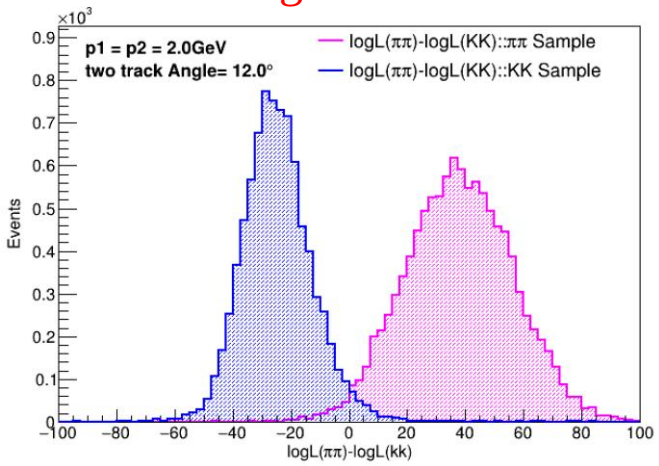
Single track:



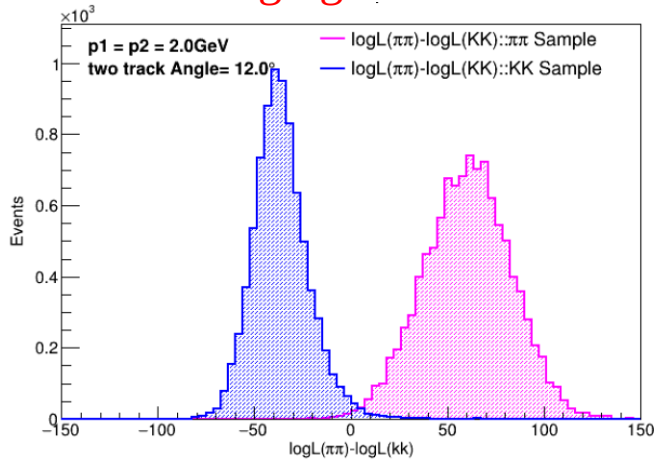


Multi track:

Timing Method



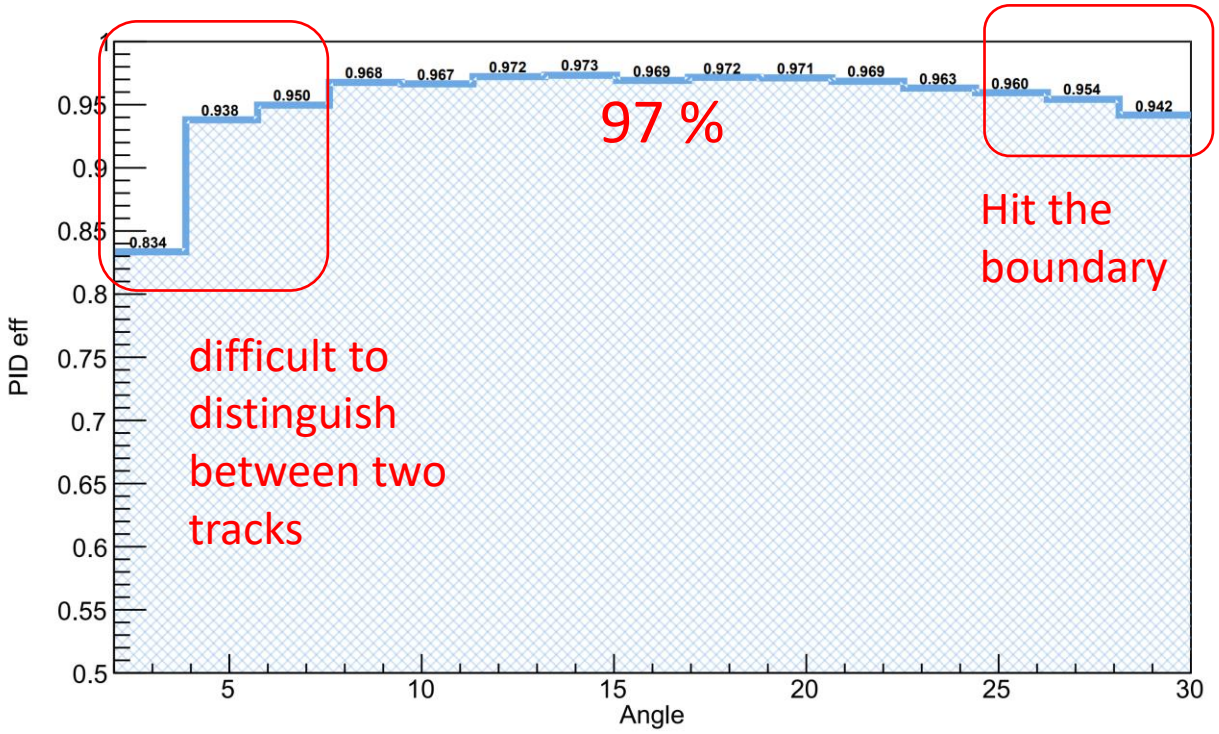
Imaging Method



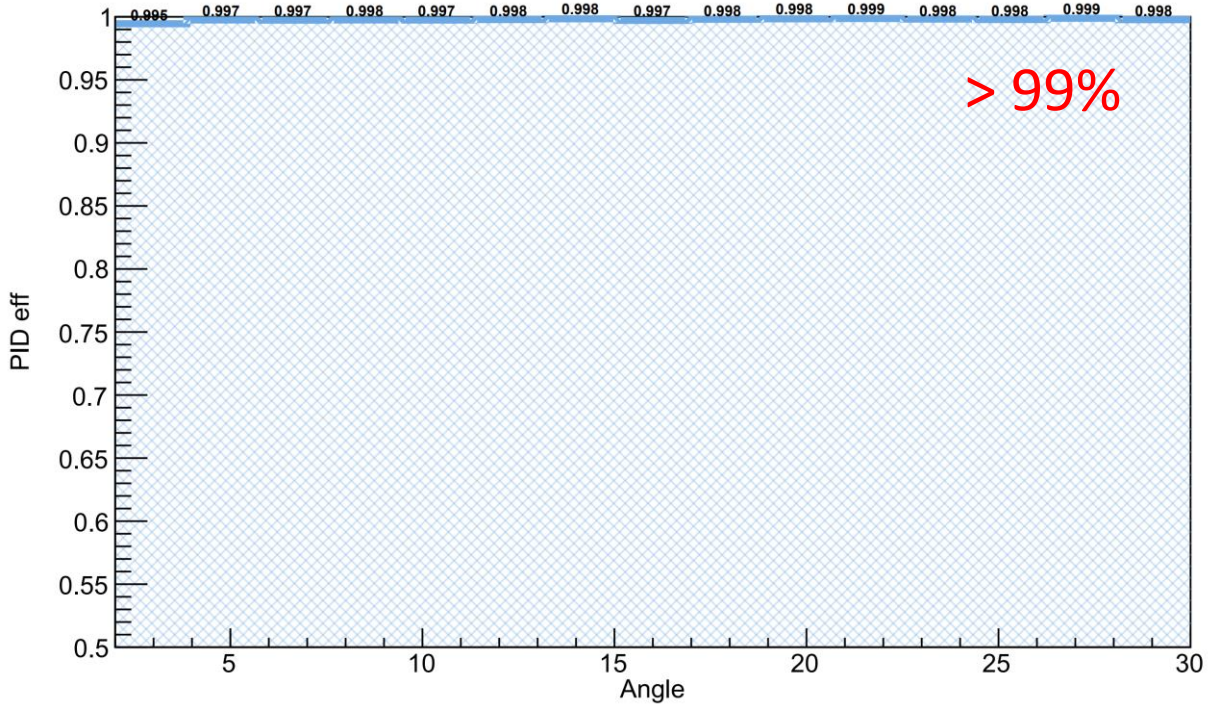
Multi-track Efficiency @ 2GeV

$\pi\pi$ efficiency (KK mis − ID = 2%)

Timing method:



Imaging Method:



Multi-track Efficiency @ 2GeV

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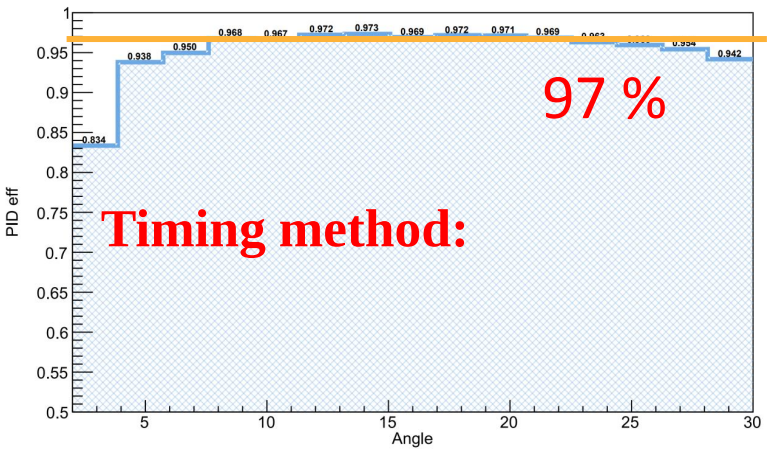
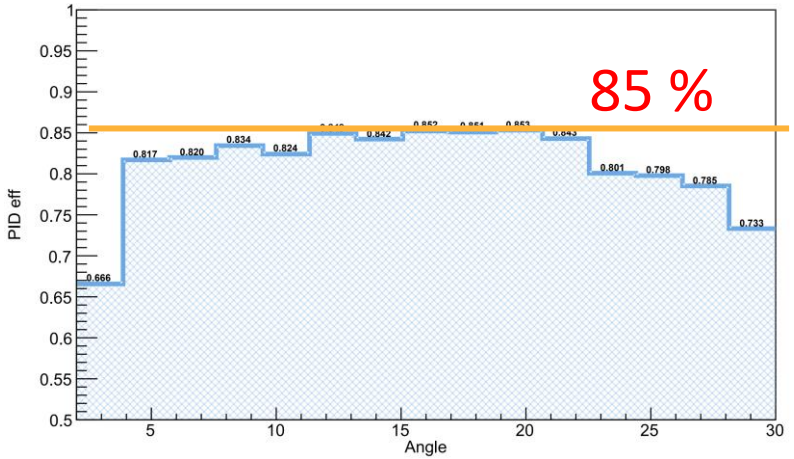
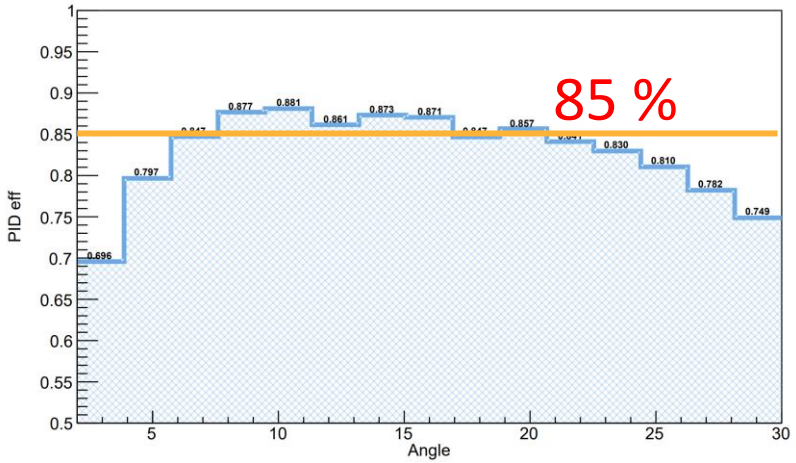


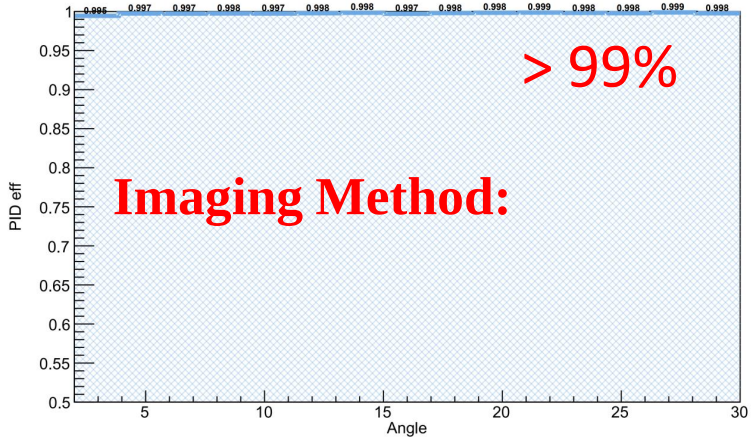
$\pi\pi$ efficiency($K\pi$ mis − ID = 2%)



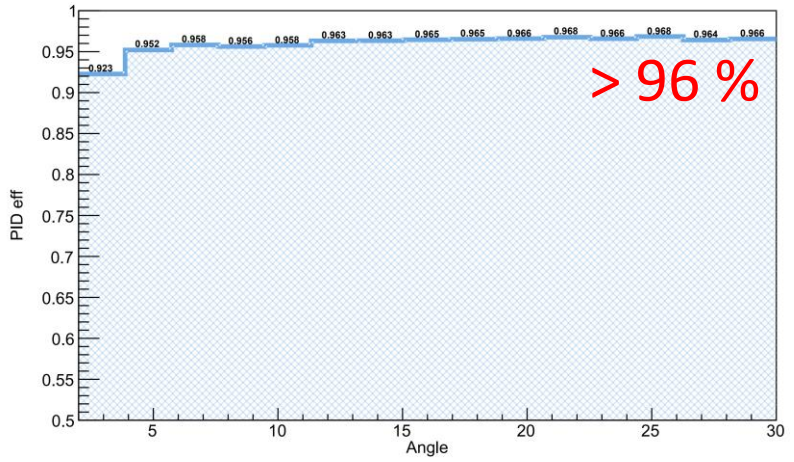
KK efficiency($K\pi$ mis − ID = 2%)



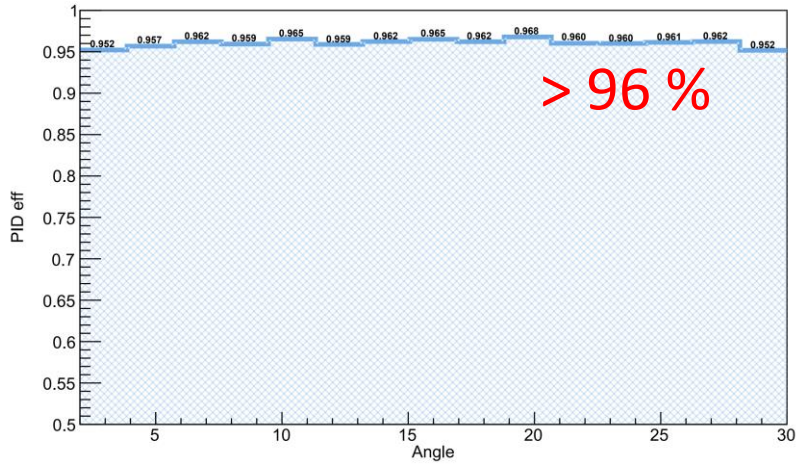
$\pi\pi$ efficiency (KK mis − ID = 2%)



$\pi\pi$ efficiency($K\pi$ mis − ID = 2%)



KK efficiency($K\pi$ mis − ID = 2%)



Summary

- Full channel Geometry, Simulation, Event Mixing and Digitization has been constructed.
- **Timing method:** π efficiency $\sim 98\%$, at $p = 2.0$ GeV/c.
- **Imaging method:** π efficiency $\sim 99\%$, at $p = 2.0$ GeV/c.
- **Multi-Track:** $\pi\pi$ efficiency ~ 97% satisfy the PID performance requirement.

DTOF improve the efficiency of Global PID. $\theta \in (22°, 36°)$, $p \in (0.2, 2.4)$ GeV/c.

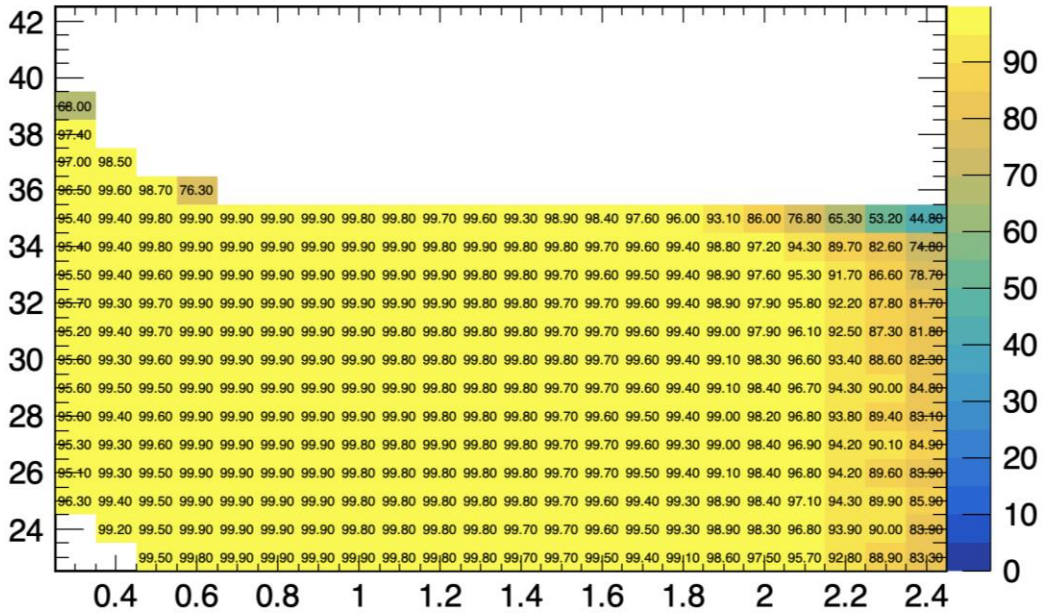
Thank you!

Backup

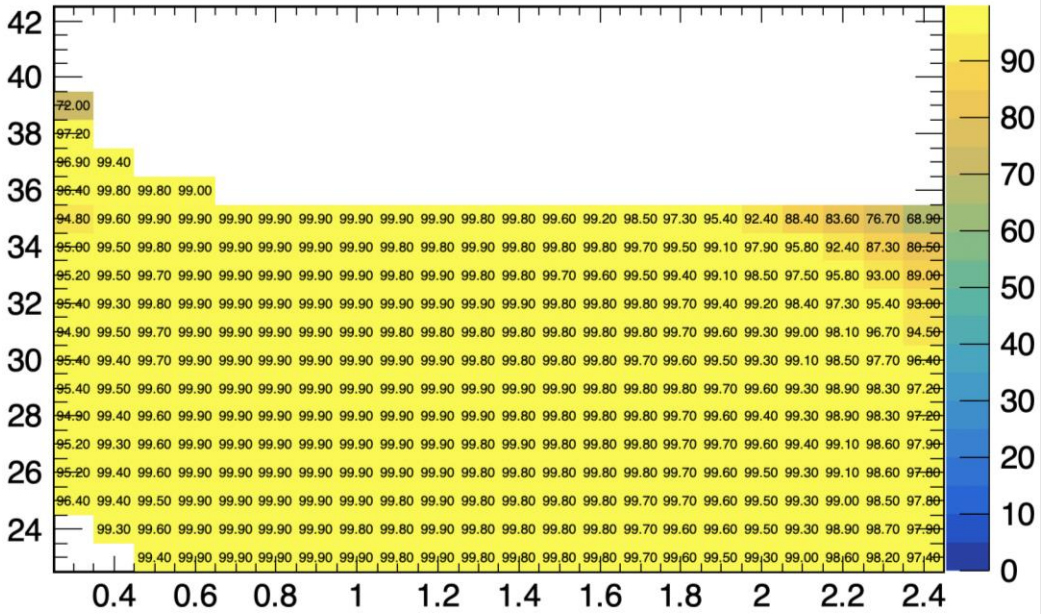
BackUp

K efficiency (π mis $-$ ID $= 2\%$)

TOF Method

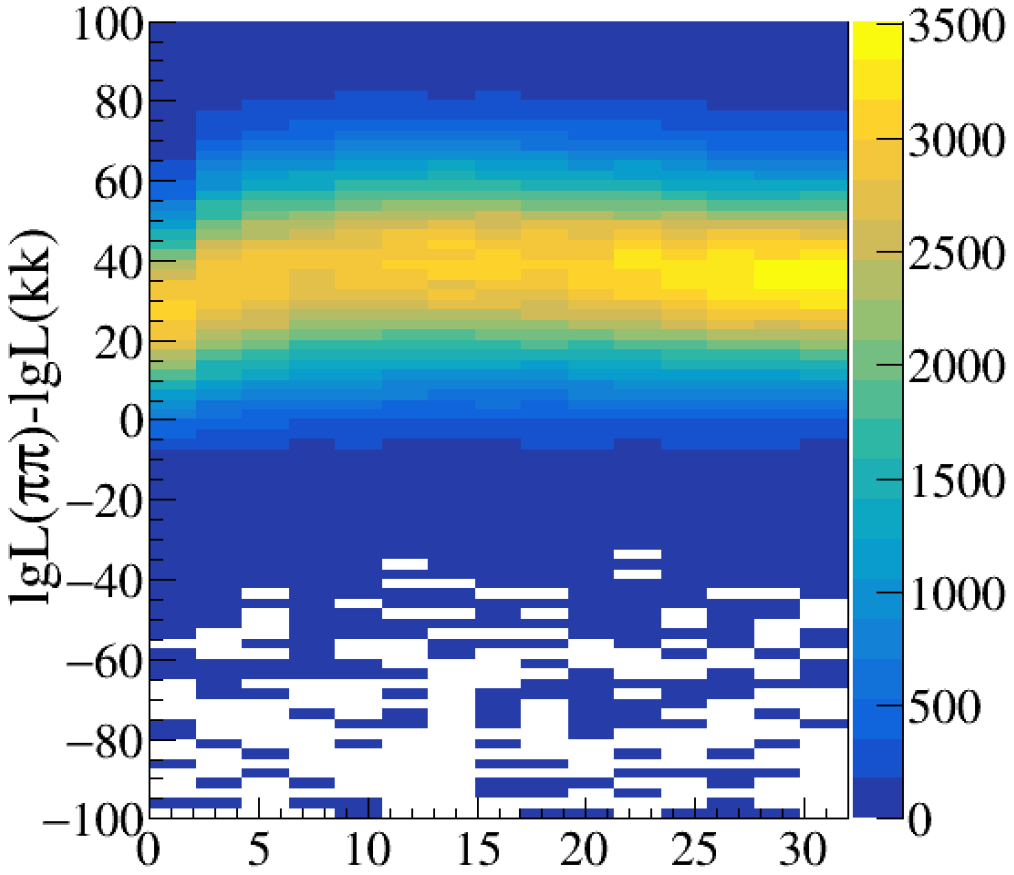


TvsP Method

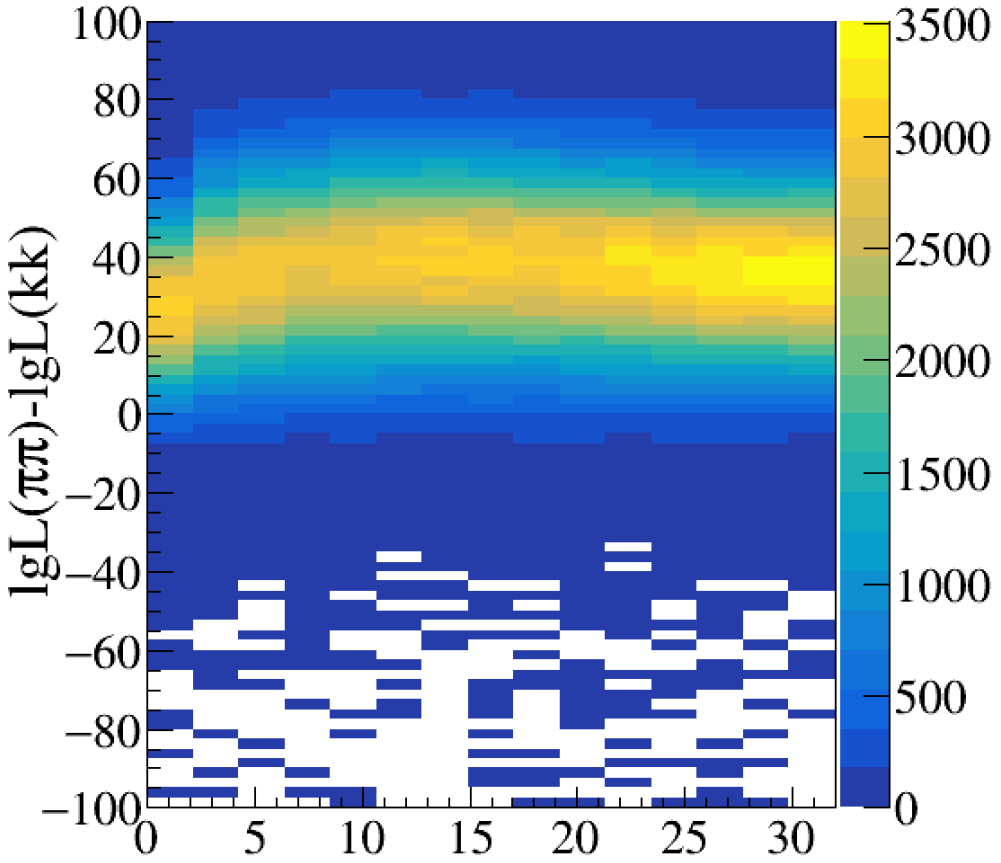


Multi-track

Timing Method



Imaging Method

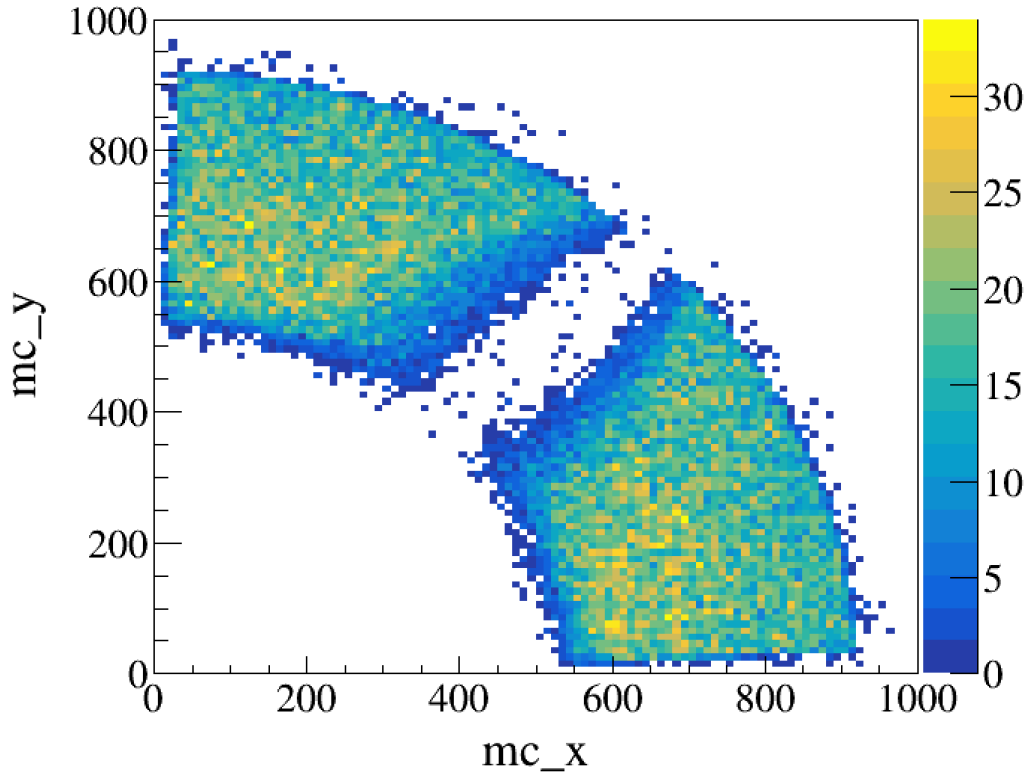


Multi-track

$\pi\pi$ Sample

Hit position of two tracks

Two tracks angle = 24°



Two tracks angle = 4°