SUN YAT-SEN UNIVERSITY

超级陶粲装置 Super Tau-Charm Facility

Study of the DTOF Detector Simulation Performance for STCF

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On behalf of the STCF DTOF-software working group

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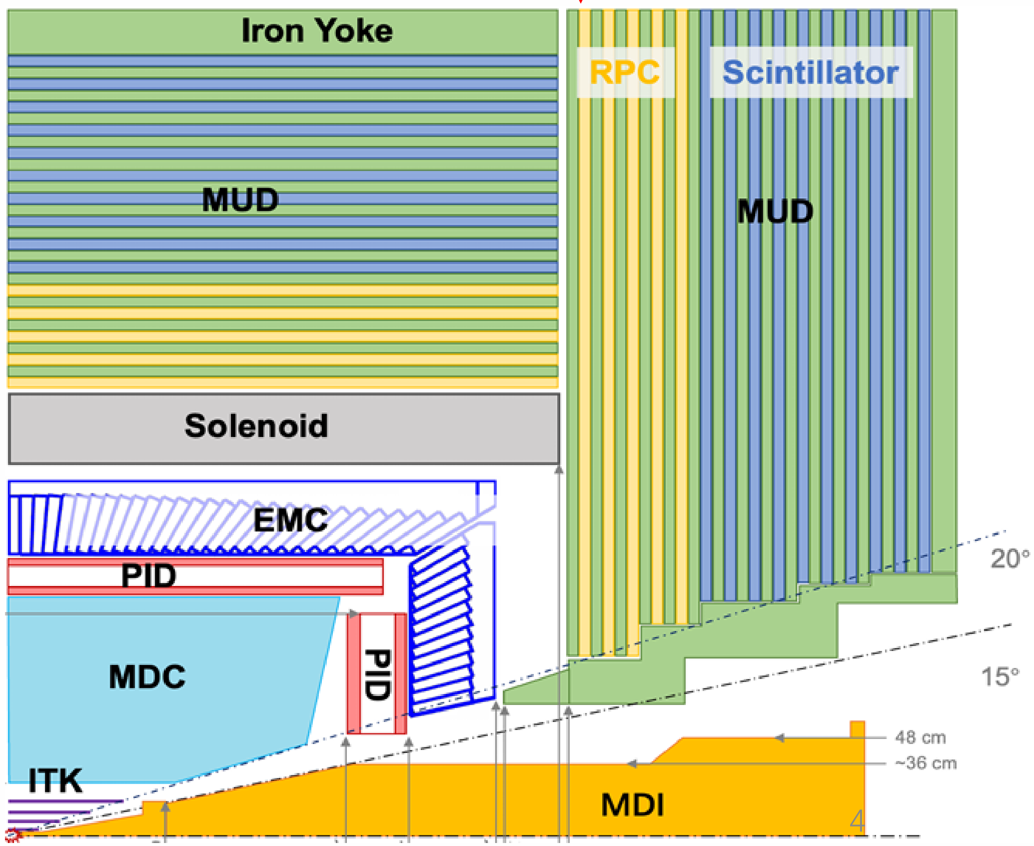
Outline

1. Introduction
2. Simulation
3. Digitization
4. Reconstruction --Timing method & Imaging method
5. Performance -- Single-Track & Multi-Track & Physics Processes
6. Summary

Introduction

Super Tau-Charm Facility

- Electron-positron collider experiment
- High luminosity: beyond **0.5×10^{35}** $cm^{-2} \cdot s^{-1}$ @ 4GeV
- Wide energy region: center-of-mass energy range of **2~7 GeV**



ITK

<0.25%X0 / layer

σ_{xy}< 100 μm

MDC

σ_{xy}< 130 μm

$\sigma p/p$ ~ 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

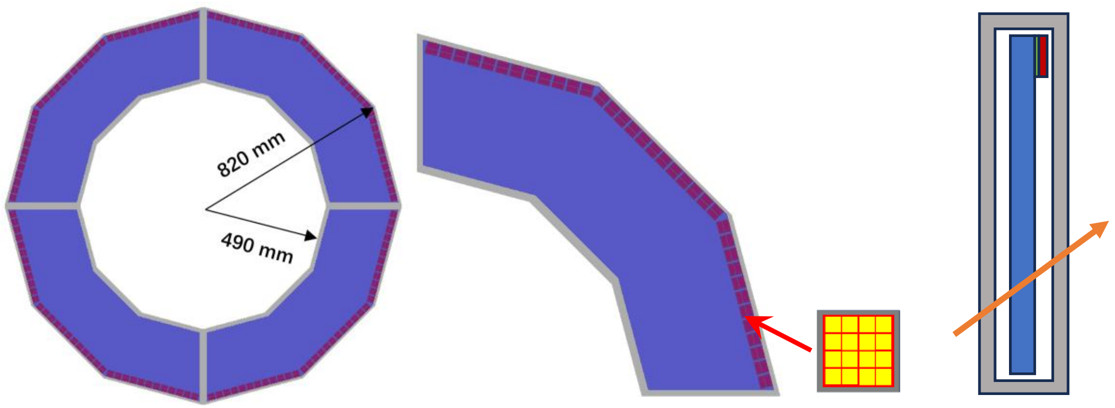
0.4 - 1.8 GeV

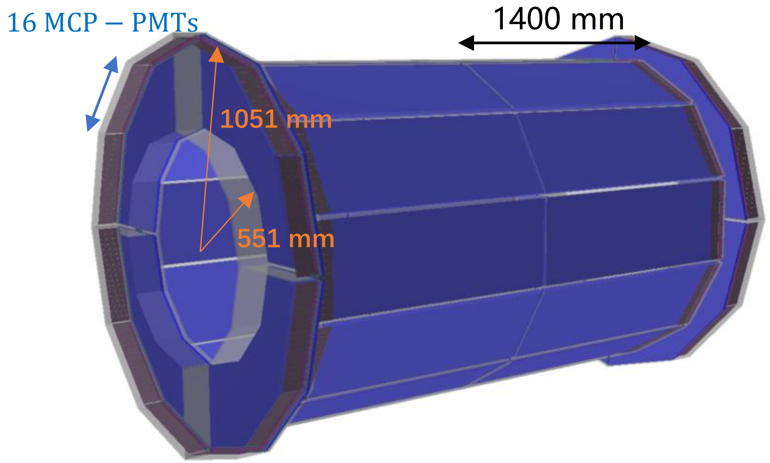
π suppression >30

DTOF Geometry

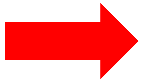
- **DTOF**: DIRC-like Time-Of-Flight Detector
- **2 discs**, each with **4 sectors**
- 15mm quartz radiator
- Side coupled to **MCP-PMT** with **Silicone Grease**
- **Aluminum** Honeycomb Panel **Shield**

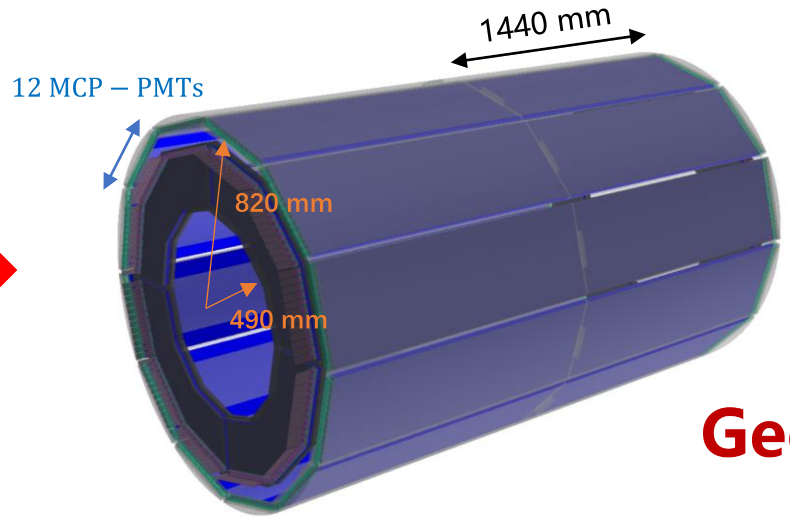
Detection of Internally Reflected Cherenkov Light





$\boldsymbol{\theta} \in (\mathbf{20°} - \mathbf{34°})$

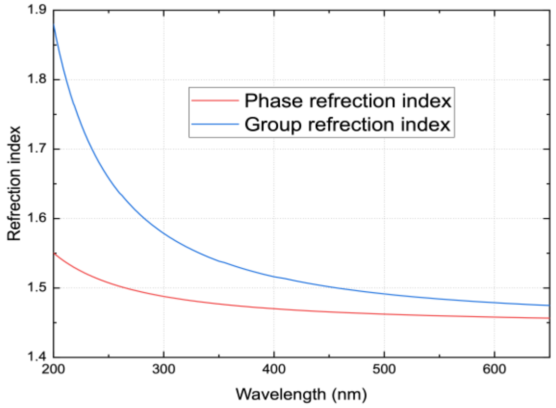


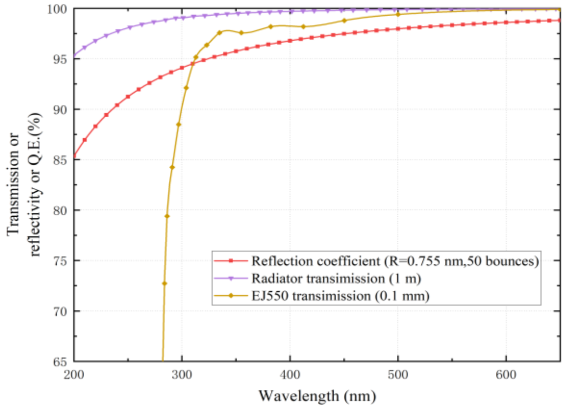


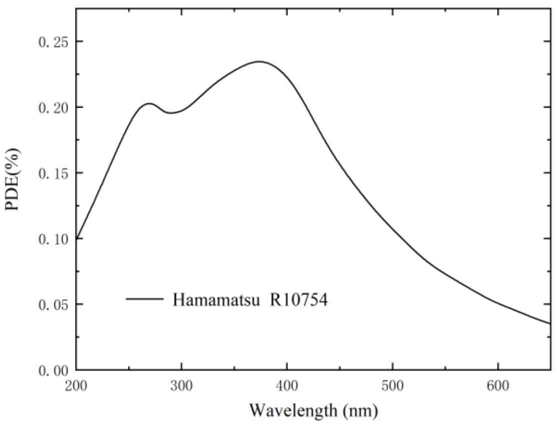
$\boldsymbol{\theta} \in (\mathbf{20°} - \mathbf{28°})$

Geometry Optimization

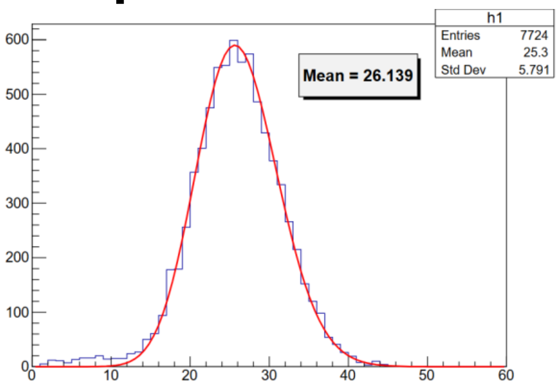
Simulation

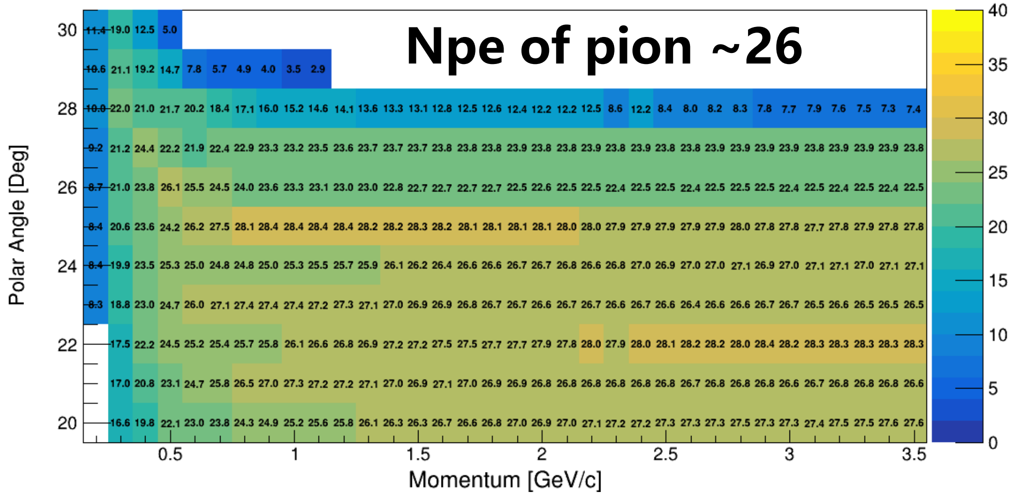






Npe distribution





The simulation models photon propagation, incorporating dispersion, radiator bulk loss, interface losses, grease attenuation, and Photon detection efficiency of MCP-PMT.

Digitization

■ The digitization process encompasses

➢ MCP-PMT transit time spread (TTS).

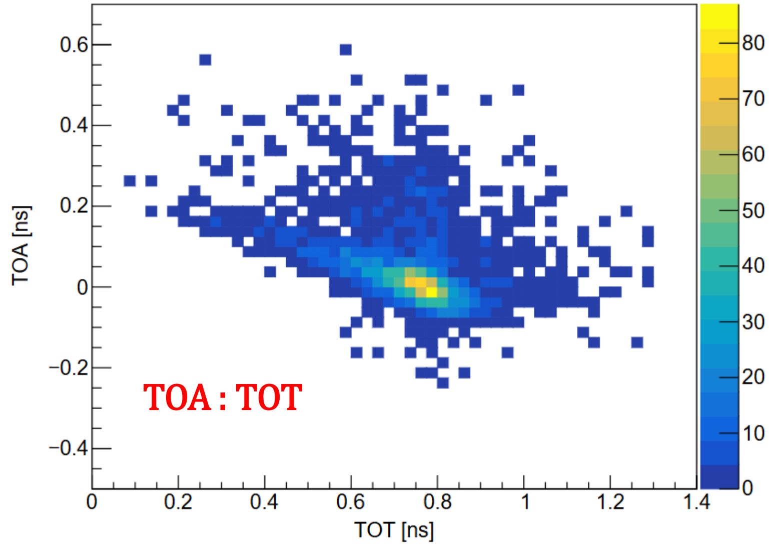
➢ Time-walk effect .

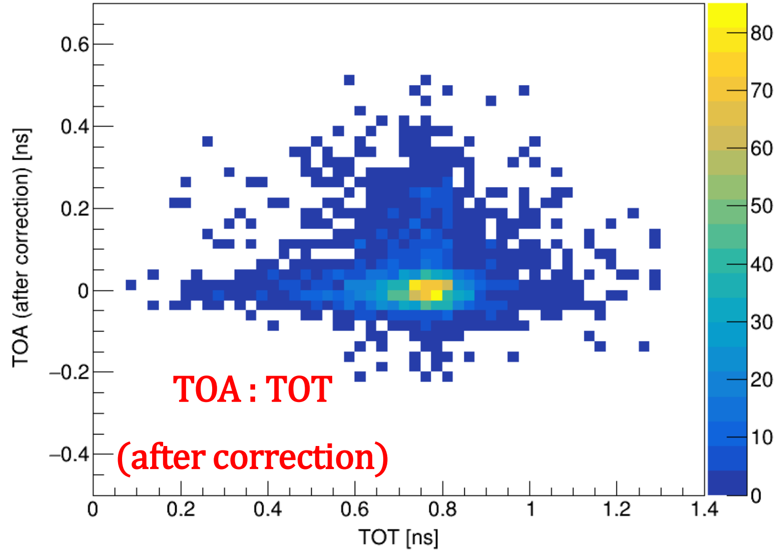
➢ Electronic dead time (200ns).

■ Output

channelID, TOA, TOT as input for reconstruction algorithm.

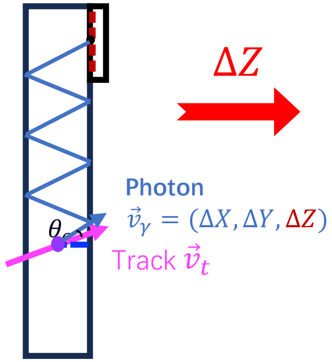
MCP-PMT : [R10754-07-M16]()

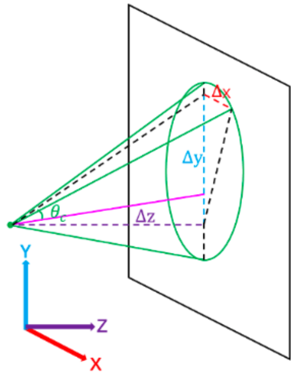


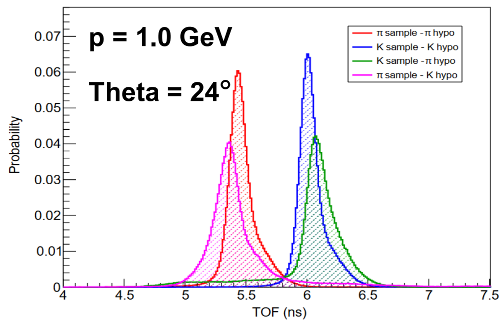


Reconstruction -- Timing Method (1D)

TOF reconstruction





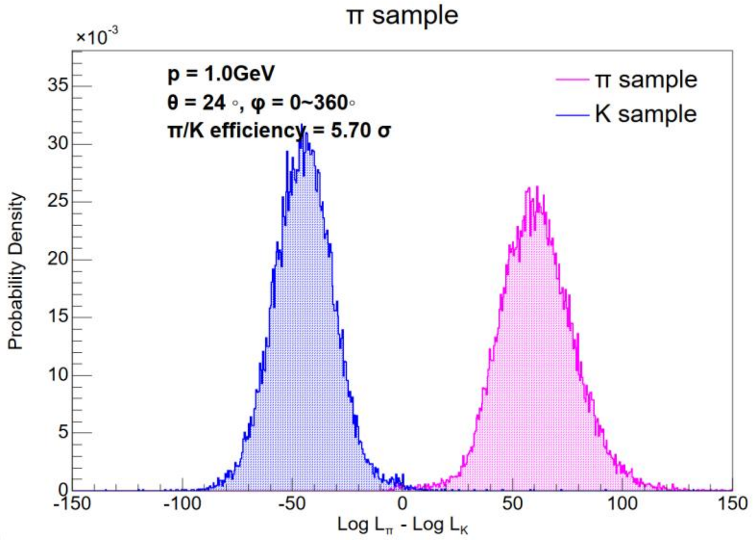


Particle Hypothesis β_h → **Photon Hit** $Channel, TOA$ / **CherenKov Angle θ_c** / **Track** $Position, Momentum$ → **Photon Path** → TOP → TOF_{rec}

Likelihood construction

$$L_h = e^{-N_h} \prod_{i=1}^{N_{p.e.}} [N_h f(\Delta t_i; p_h) + bkg]$$

N_h: $expected\ N_{p.e.}$; Δt_i: $TOF_{rec} - TOF_{hypo}$



Reconstruction -- Imaging Method (2D)

Finite Element Computational Pattern

Particle Hypothesis
m, β_h, TOF

Track
$Position, Momentum$

→

Wavelength bin

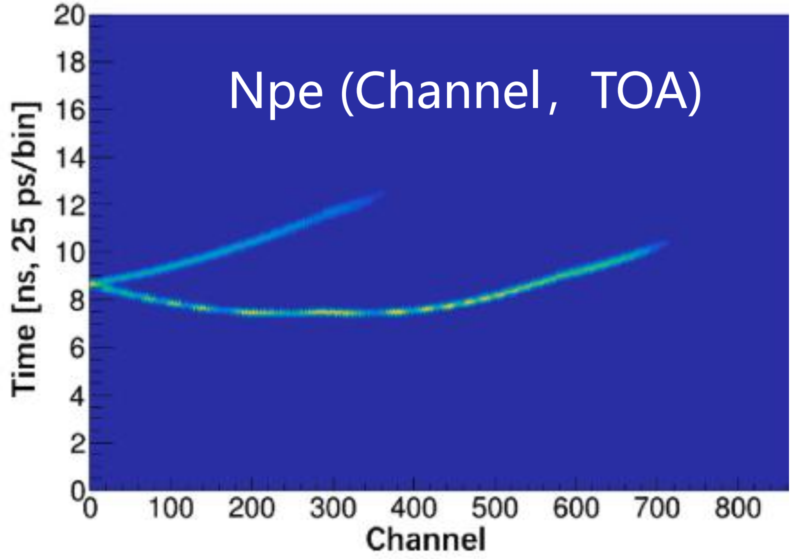
Pixel bin (Channel)

→

TOA

Npe

→



Likelihood construction

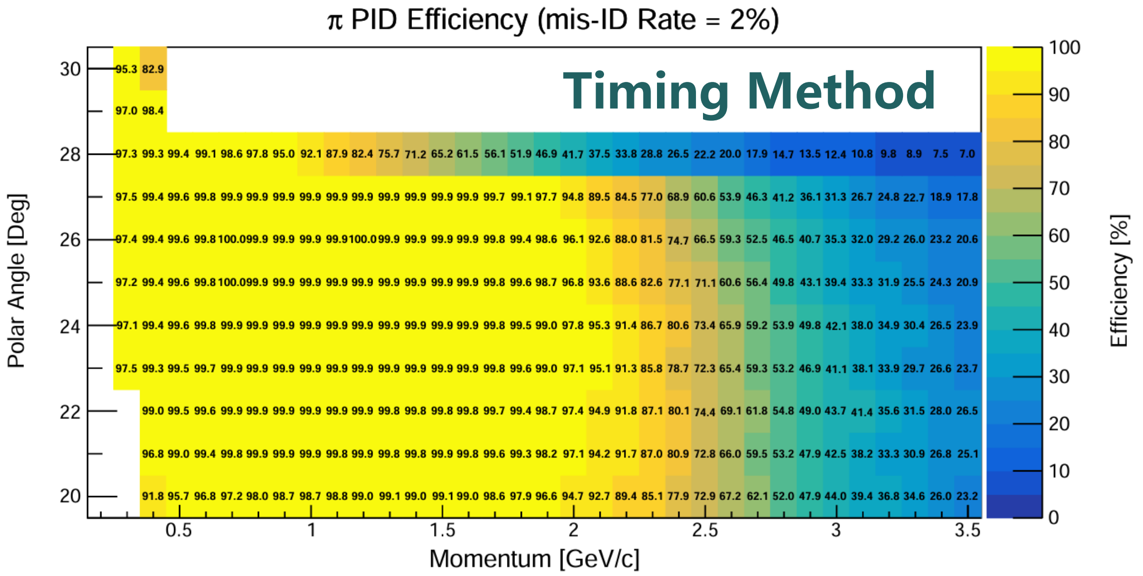
Photon Hit
$Channel, TOA$

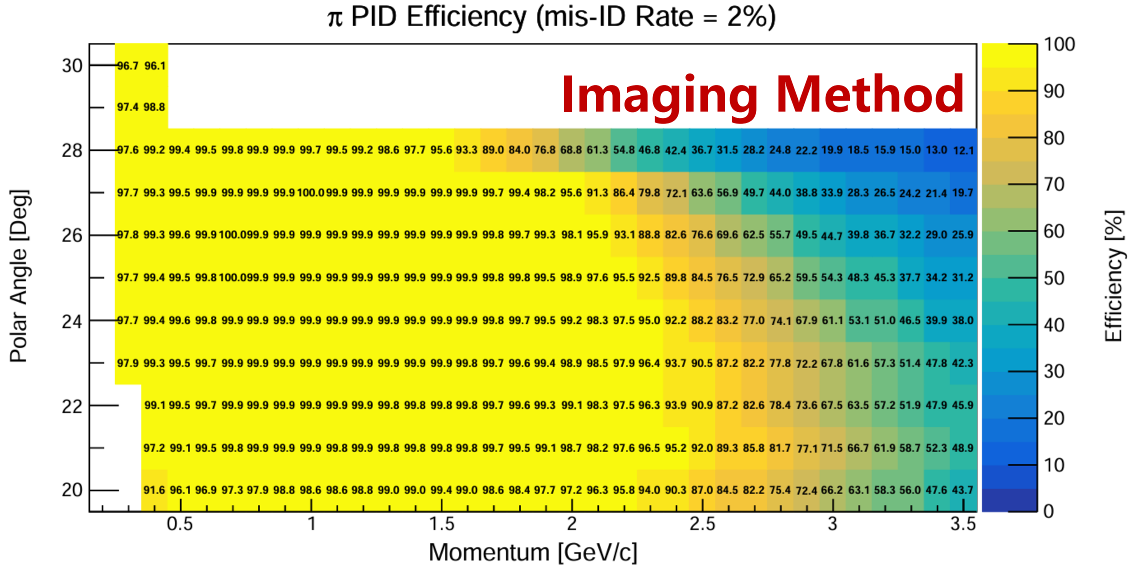
→

Get PDF
$f_h(ch_i, t_i)$

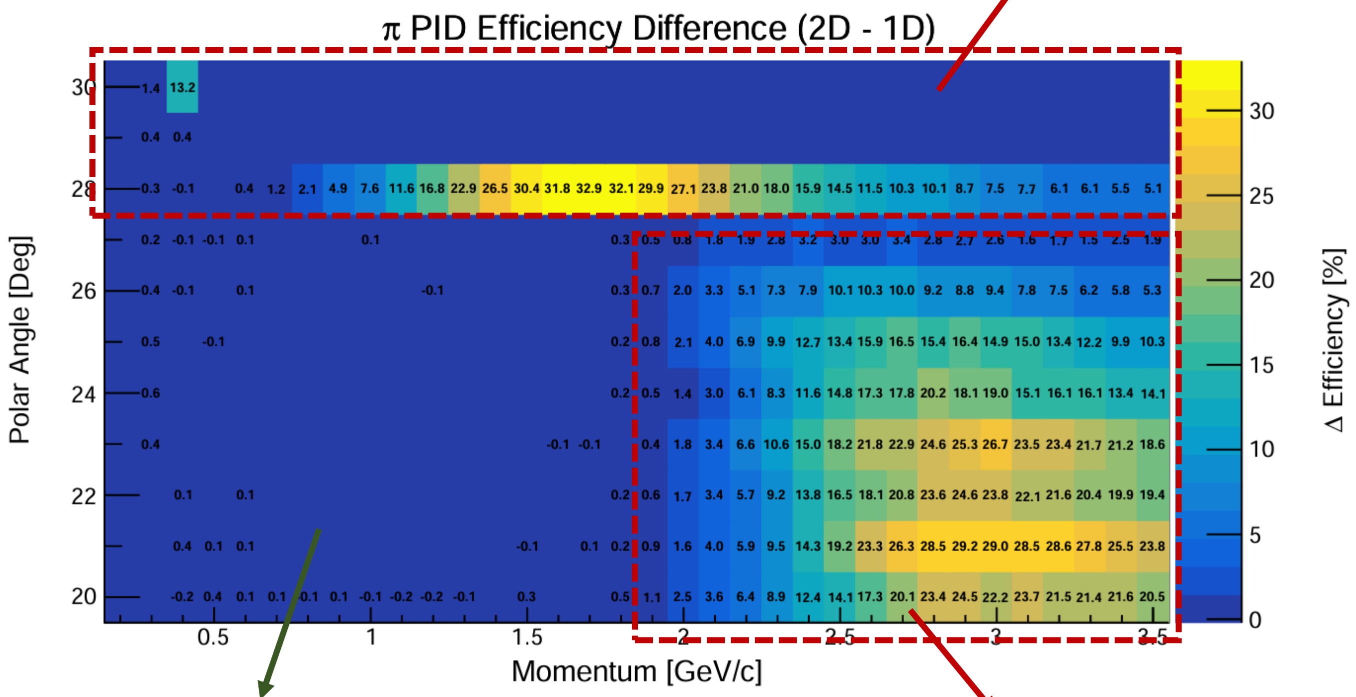
$$\mathcal{L}_h = e^{-\bar{N}_h} \prod_{i=1}^{N_{p.e.}} [\bar{N}_h S_h(ch_i, t_i) + B]$$

Comparison of Timing & Imaging Method





Use Imaging Method

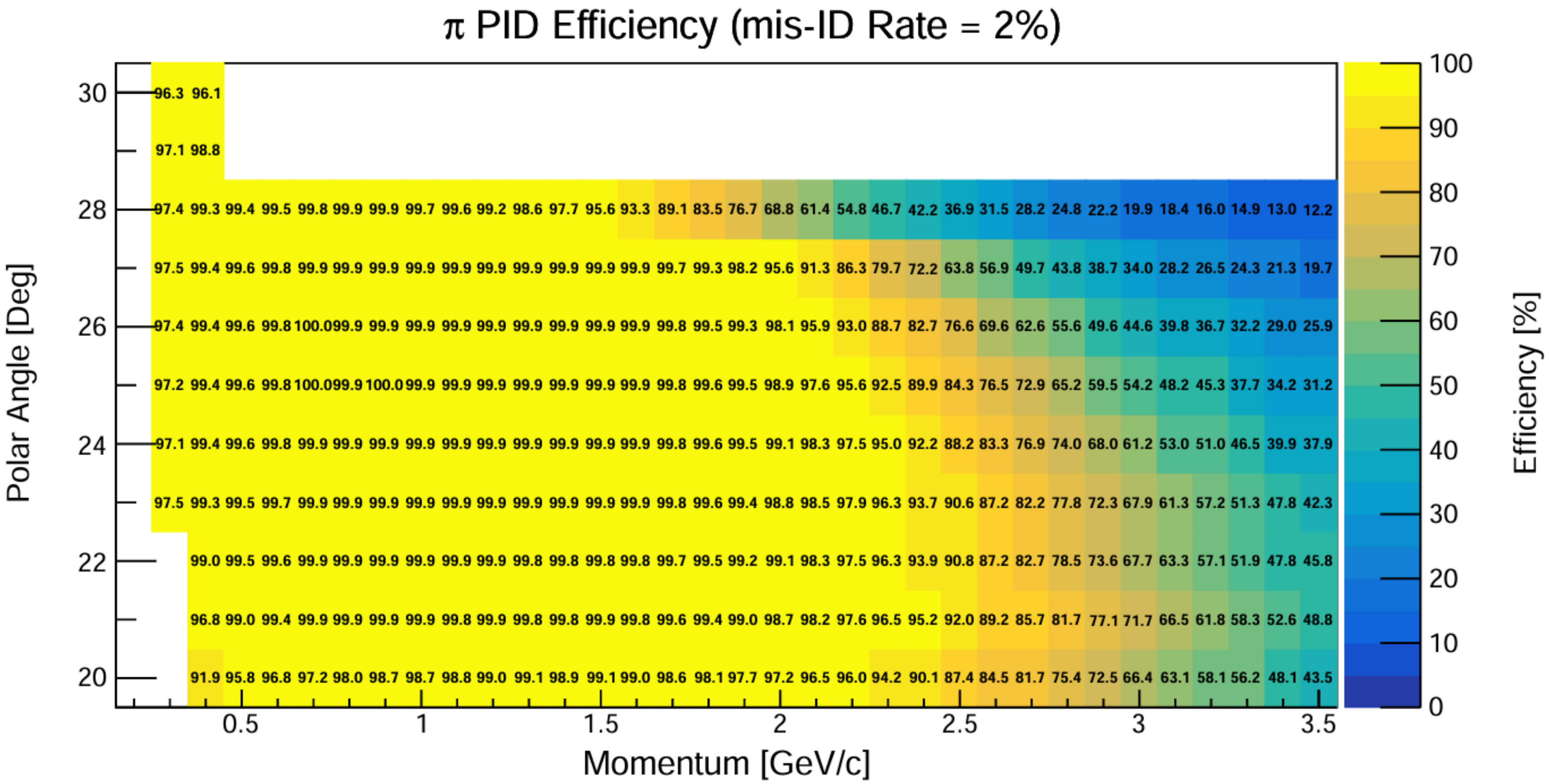


Use Timing Method

Use Imaging Method

Hybrid single-track reconstruction

Performance -- Single-Track



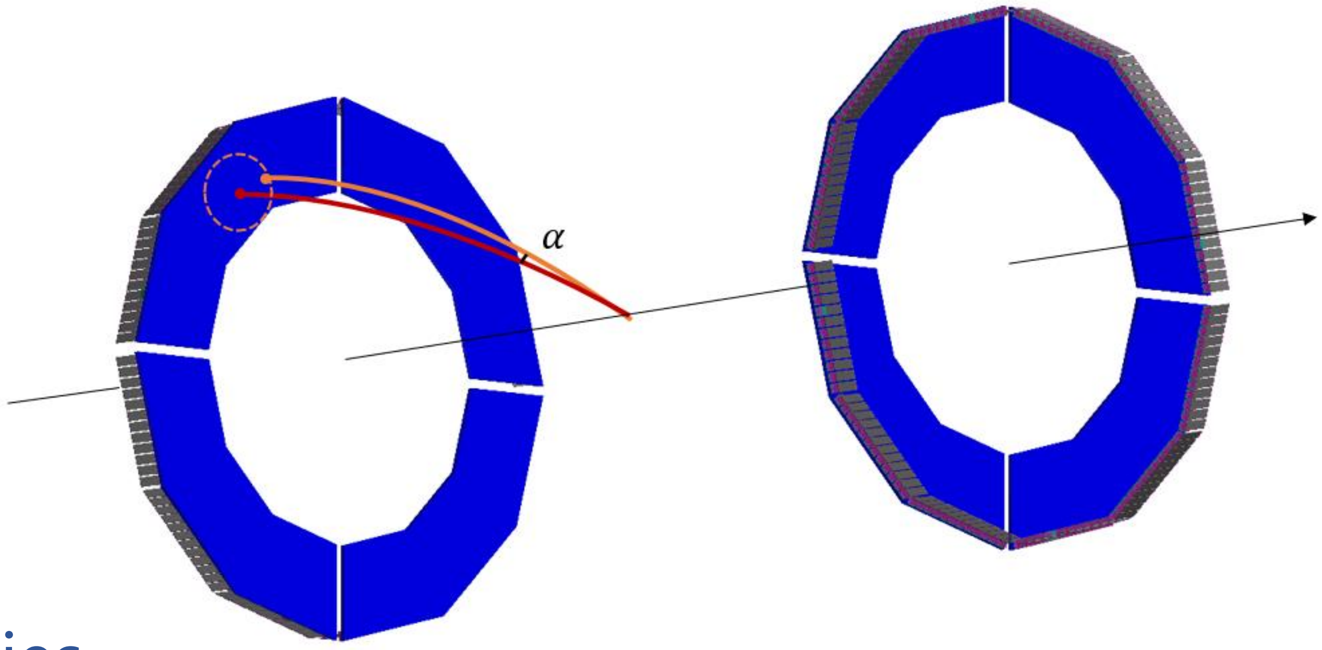
Track Selection:

- No primary decay
- Primary hit on DTOF
- Reconstructed track = 1
- Track extrapolation to DTOF

✓ π/K identification efficiency >97% at 2GeV (mis-ID rate =2%)

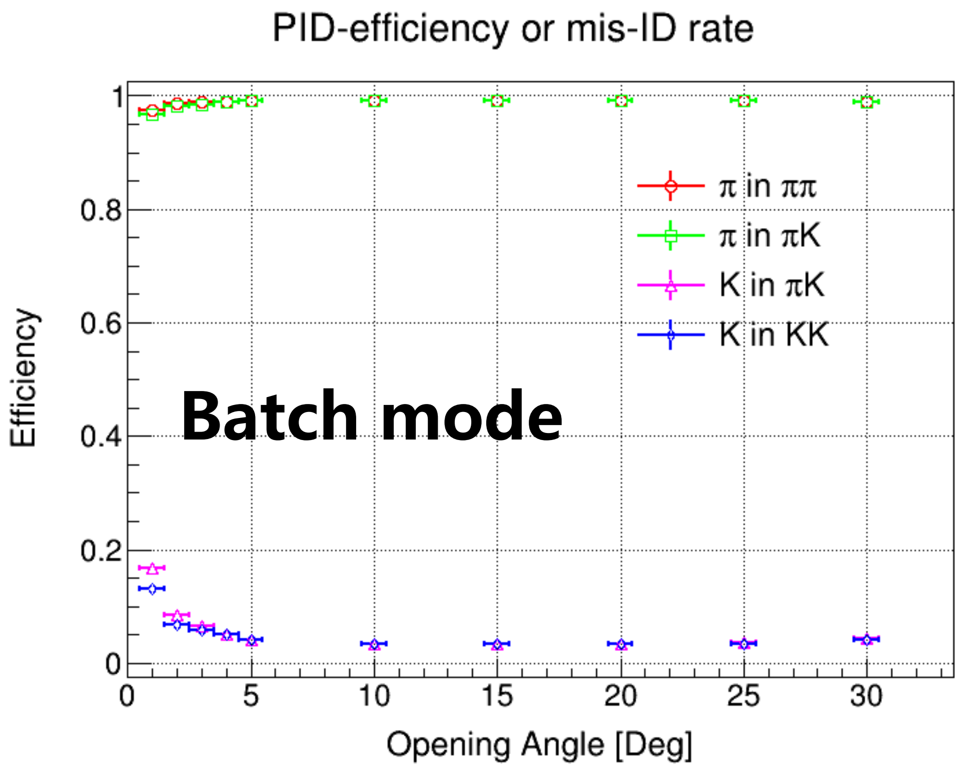
Multi-Track simulation

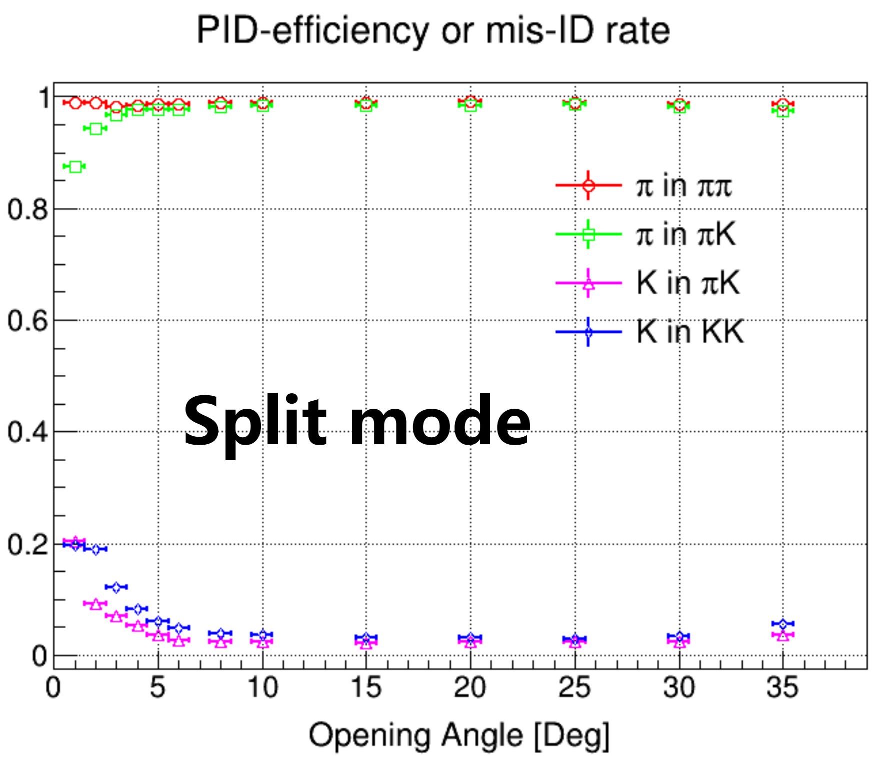
- 2 tracks hit the same sector;
- $p = 2.0\ \mathrm{GeV}$, both
- θ~Uniform , φ~Uniform
- Fix Opening Angle α : 1°~ 35°



- Multi-track Processing Strategies
  - Batch mode (Joint Hypothesis)
  - Split mode (Independent Track-by-Track)

Performance -- Multi-Track





Track Selection:

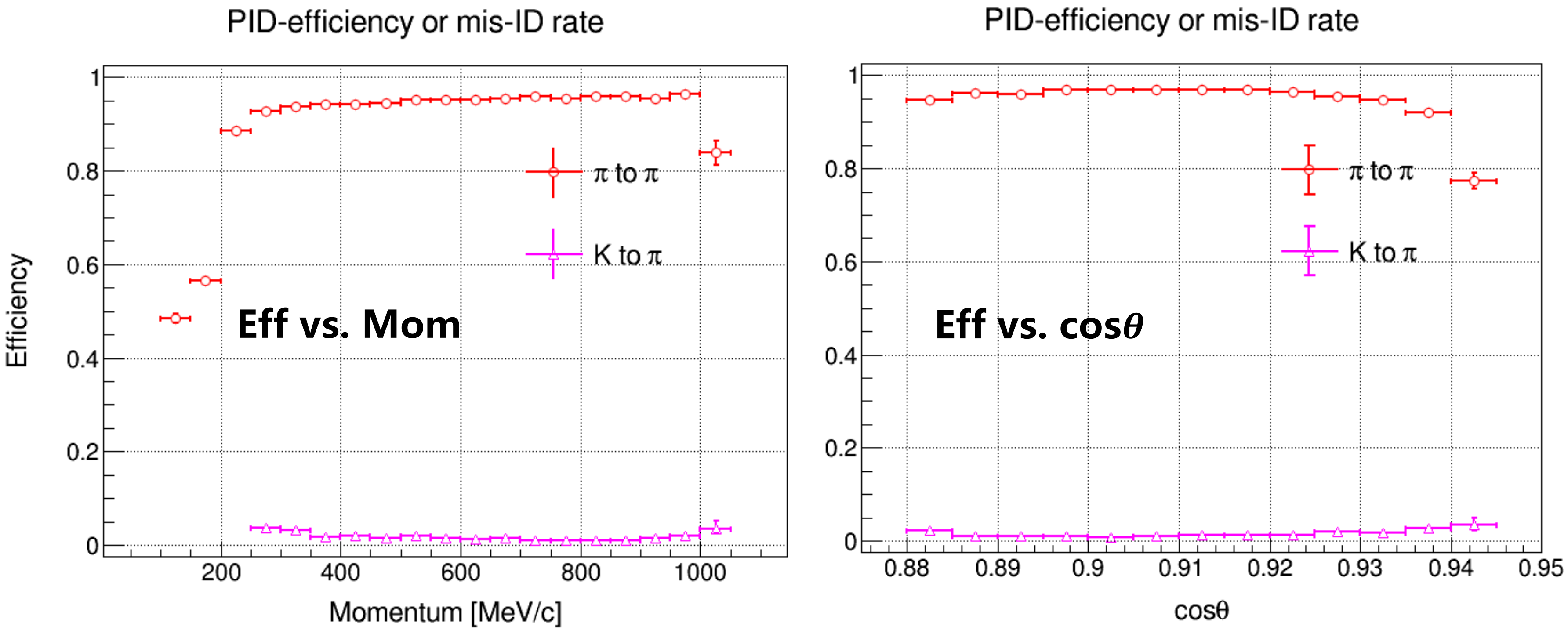
- No primary decay
- Primary both hit on DTOF
- Reconstructed track = 2
- Track extrapolation to DTOF

✓ Performance matches Single-track; <5° Degradation (Rec resolution)

✓ Comparable performance, Split mode is better for Global PID

Performance -- Physics Processes

Inclusive Hadronic D^0 Decay $\sqrt{s} = 3.773\ GeV$



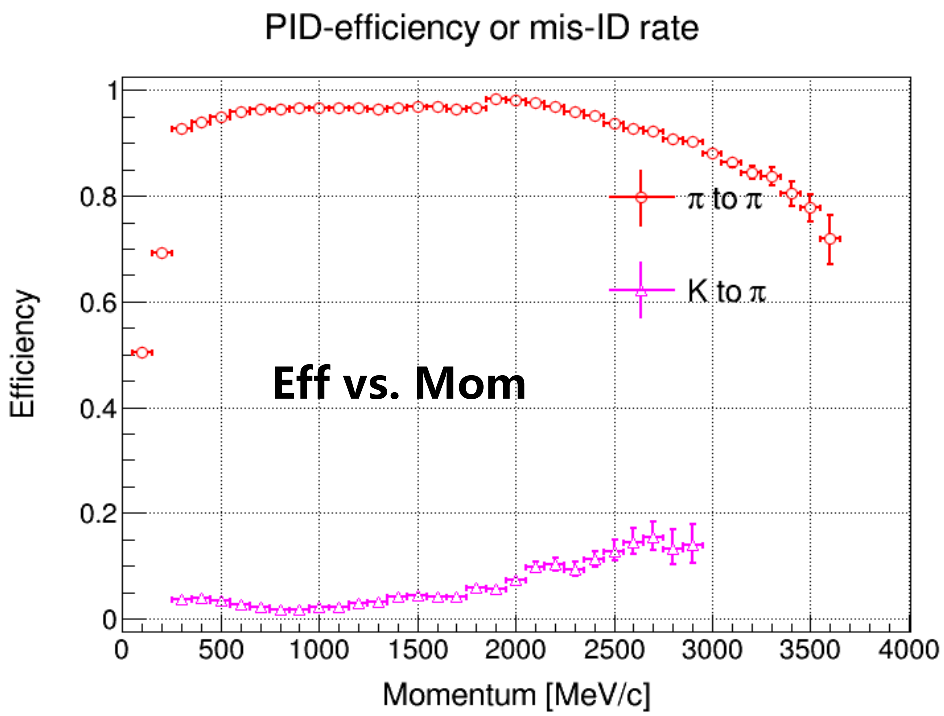
Track Selection:

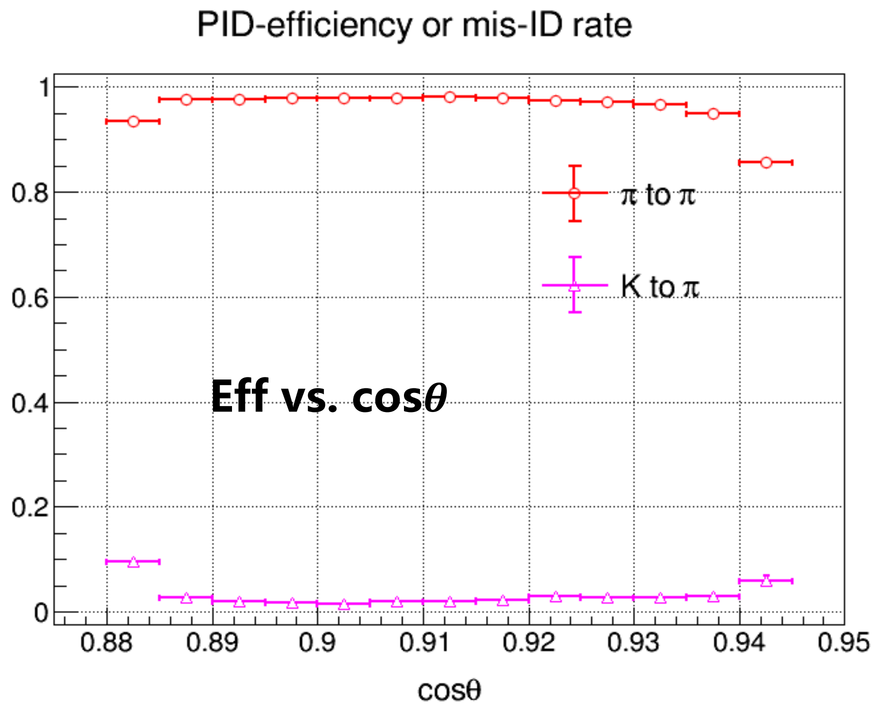
- Primary hit on DTOF
- Track extrapolation to DTOF

✓ π/K identification efficiency above 95% and K mis-ID rate < 2% for p < 1GeV/c.

Performance -- Physics Processes

Inclusive e⁺e⁻→J/psi→Hadrons $\sqrt{s} = 7GeV$





Track Selection:

- Primary hit on DTOF
- Track extrapolation to DTOF

✓ π/K identification efficiency above 95% and K mis-ID rate < 5% for p < 2GeV/c.

Summary

- **Evaluates the DTOF performance using the full-detector simulation framework of the OSCAR.**
- **Hybrid single-track reconstruction** :
  - ✓ π/K identification efficiency >97% at 2GeV/c (mis-ID rate =2%)
- **Multi-Track PID Performance** :
  - ✓ Performance is consistent with the single-track result
- **Physics Processes** :
  - ✓ π/K identification efficiency above 95% and K mis-ID rate<5% for p < 2GeV/c.

Thank you!

Backup

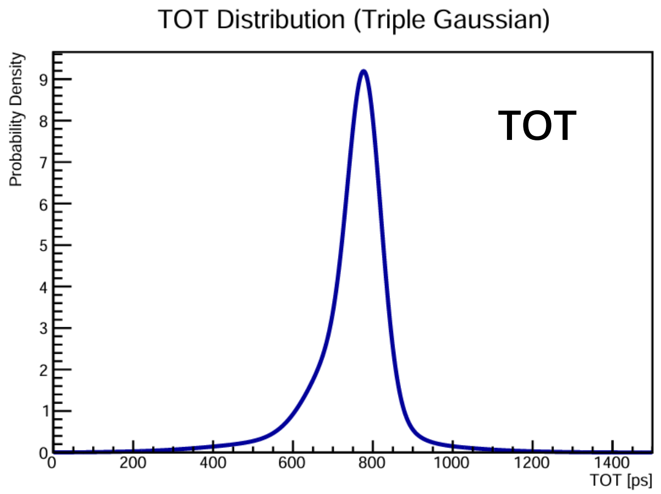
Digitization

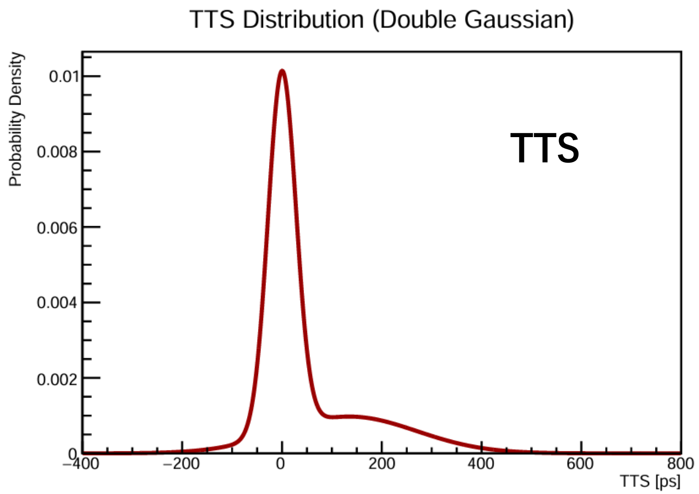
$$f_{\mathrm{TTS}}(t) = \frac{A_1}{\sqrt{2\pi}\sigma_1}\exp\left(-\frac{(t-\mu_1)^2}{2\sigma_1^2}\right) + \frac{A_2}{\sqrt{2\pi}\sigma_2}\exp\left(-\frac{(t-\mu_2)^2}{2\sigma_2^2}\right)$$

$A_1 = 0.67, \mu_1 = 0, \sigma_1 = 28$
$A_2 = 0.33, \mu_2 = 135, \sigma_2 = 135$

$$f_{\mathrm{TOT}}(t) = \frac{A_1}{\sqrt{2\pi}\sigma_1}\exp\left(-\frac{(t-\mu_1)^2}{2\sigma_1^2}\right) + \frac{A_2}{\sqrt{2\pi}\sigma_2}\exp\left(-\frac{(t-\mu_2)^2}{2\sigma_2^2}\right) + \frac{A_3}{\sqrt{2\pi}\sigma_3}\exp\left(-\frac{(t-\mu_3)^2}{2\sigma_3^2}\right)$$

$A_1 = 700, \mu_1 = 780, \sigma_1 = 40$
$A_2 = 450, \mu_2 = 730, \sigma_2 = 80$
$A_3 = 200, \mu_2 = 700, \sigma_2 = 220$





TOA = TTS + (TOTtru - TOTMEAN) * TOTCALIPAR

TOTMEAN = 0.78, TOTMAX = 0.9, TOTCALIPAR = -0.35; // ns

MCP-PMT : R10754-07-M16

Reconstruction -- Timing Method (1D)

TOF reconstruction

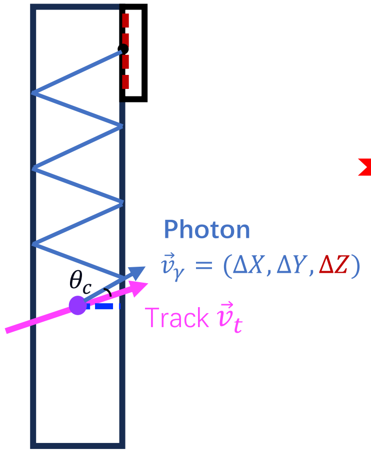
Particle Hypothesis β_h → $cos\theta_c = \frac{1}{n\beta_h}$ → **CherenKov Angle θ_c** → **ΔZ** → **$LOP\ \&TOP$** → **TOF_{rec}**

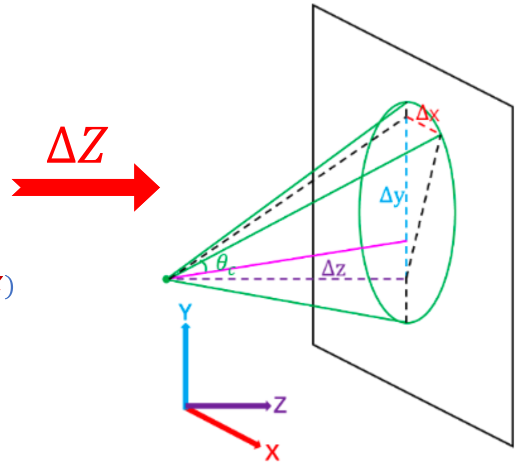
Track Pos, Mom $\vec{v}_t$ Photon Hit channel $\vec{v}_\gamma$ → $cos\theta_c = \frac{\vec{v}_t \cdot \vec{v}_\gamma}{|\vec{v}_t| \cdot |\vec{v}_\gamma|}$ → **CherenKov Angle θ_c**

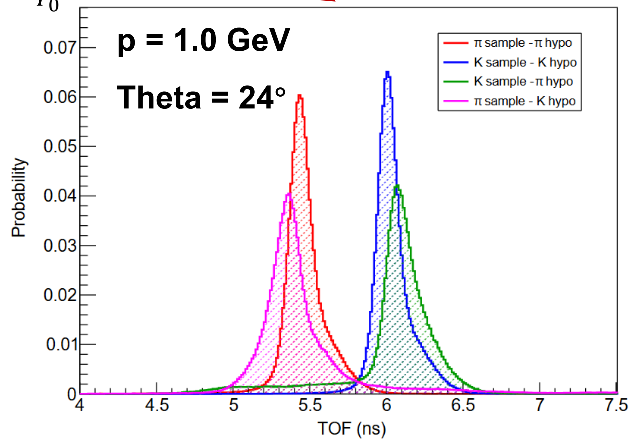
$TOP = LOP \cdot \overline{n_g}/c$

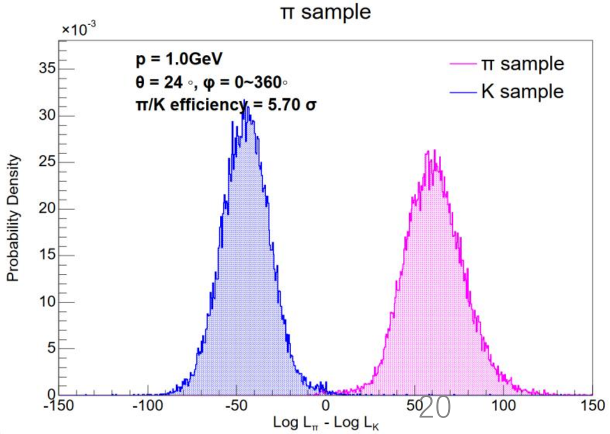
$LOP = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$

$TOF_{rec} = T - TOP - T_0$







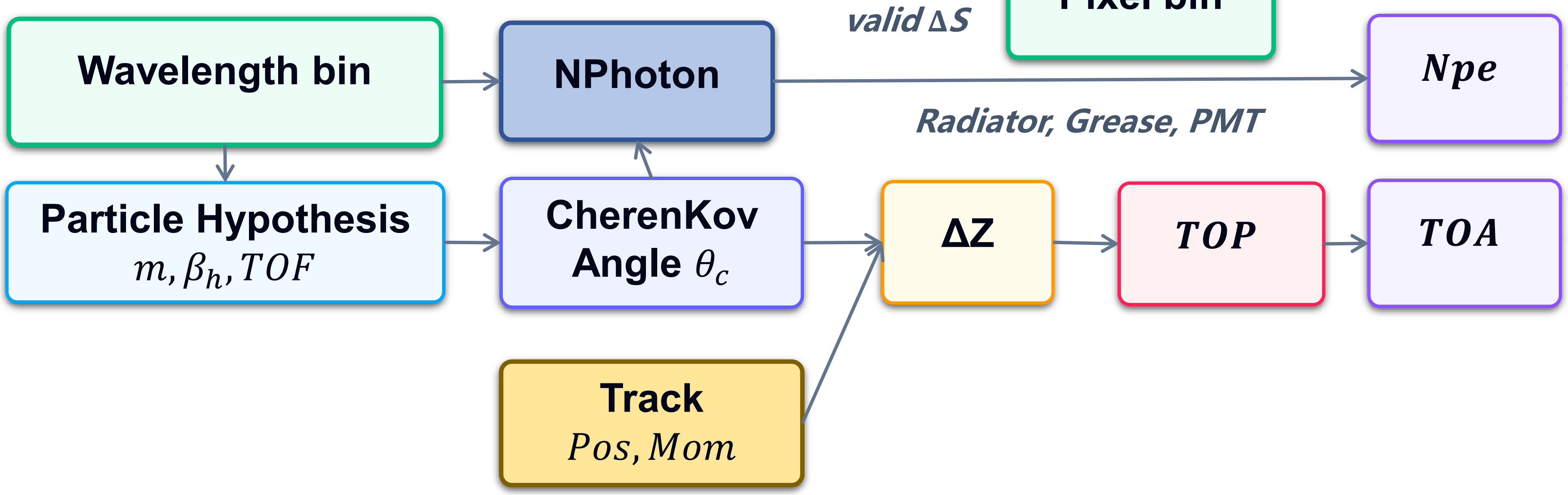


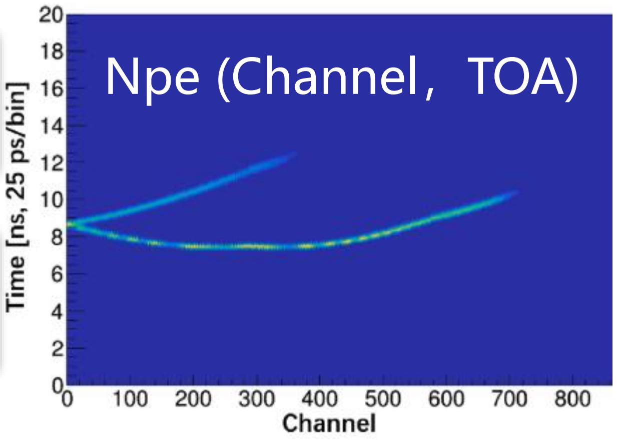
Likelihood construction

$$L_h = e^{-N_h} \prod_{i=1}^{N_{p.e.}} [N_h f(\Delta t_i; p_h) + bkg]$$

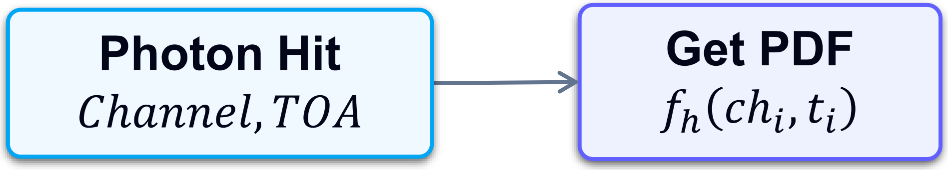
Reconstruction -- Imaging Method (2D)

Finite Element Computational Pattern



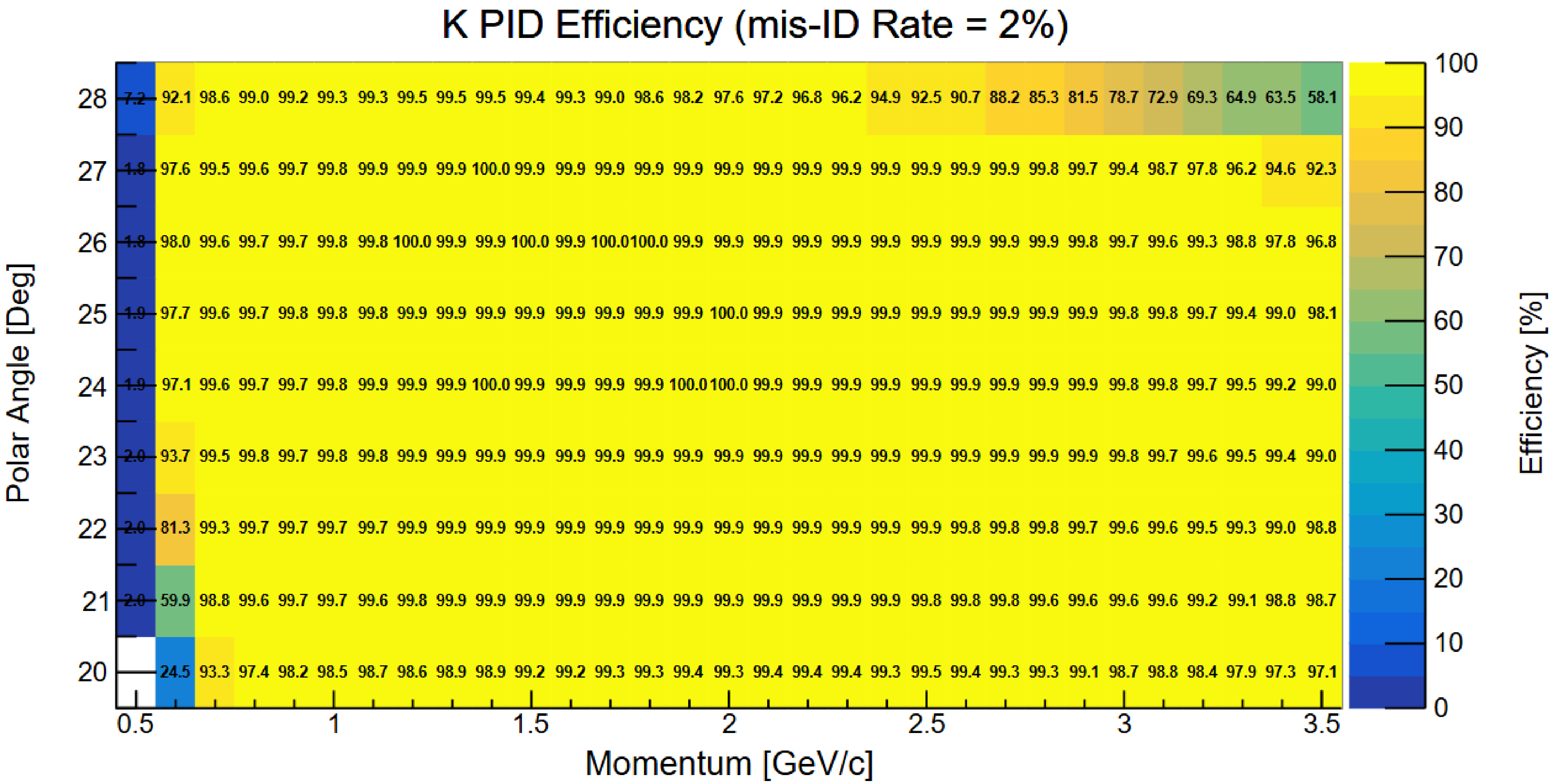


Likelihood construction



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

Hybrid mode


K PID Efficiency (mis-ID Rate = 2%)
28 7.2 92.1 98.6 99.0 99.2 99.3 99.3 99.5 99.5 99.5 99.4 99.3 99.0 98.6 98.2 97.6 97.2 96.8 96.2 94.9 92.5 90.7 88.2 85.3 81.5 78.7 72.9 69.3 64.9 63.5 58.1
27 1.8 97.6 99.5 99.6 99.7 99.8 99.9 99.9 99.9 100.0 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.8 99.7 99.4 98.7 97.8 96.2 94.6 92.3
26 1.8 98.0 99.6 99.7 99.7 99.8 99.8 100.0 99.9 99.9 100.0 99.9 100.0 100.0 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.8 99.7 99.6 99.3 98.8 97.8 96.8
25 1.9 97.7 99.6 99.7 99.8 99.8 99.8 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 100.0 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.8 99.8 99.7 99.4 99.0 98.1
24 1.9 97.1 99.6 99.7 99.7 99.8 99.9 99.9 99.9 100.0 99.9 99.9 99.9 99.9 100.0 100.0 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.8 99.8 99.7 99.5 99.2 99.0
23 2.0 93.7 99.5 99.8 99.7 99.8 99.8 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.8 99.7 99.6 99.5 99.4 99.0
22 2.0 81.3 99.3 99.7 99.7 99.7 99.7 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.8 99.8 99.8 99.7 99.6 99.6 99.5 99.3 99.0 98.8
21 2.0 59.9 98.8 99.6 99.7 99.7 99.6 99.8 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.9 99.8 99.8 99.8 99.6 99.6 99.6 99.6 99.2 99.1 98.8 98.7
20 24.5 93.3 97.4 98.2 98.5 98.7 98.6 98.9 98.9 99.2 99.2 99.3 99.3 99.4 99.3 99.4 99.4 99.4 99.3 99.5 99.4 99.3 99.3 99.1 98.7 98.8 98.4 97.9 97.3 97.1
Polar Angle [Deg]
0.5 1 1.5 2 2.5 3 3.5
Momentum [GeV/c]
100 90 80 70 60 50 40 30 20 10 0
Efficiency [%]

Timing Method -- Likelihood

$$\mathcal{L}_{\mathcal{TOF}} = N_{pe}^{\text{hypo}} \sum_{i=1}^{3} w_i(p)\text{Gaus}\big(\Delta t; \mu_i, \sigma_i(p)\big) + \ bkgped\_TOF$$

$$\text{with } w_1 = r(p), w_2 = \frac{1}{2}r(p), w_3 = 1 - \frac{3}{2}r(p); \sigma_1(p) \sim \mathcal{O}(1/p)$$

$r(p) = \ 0.65 \ - \ 6402./\,p\,/\,p;$

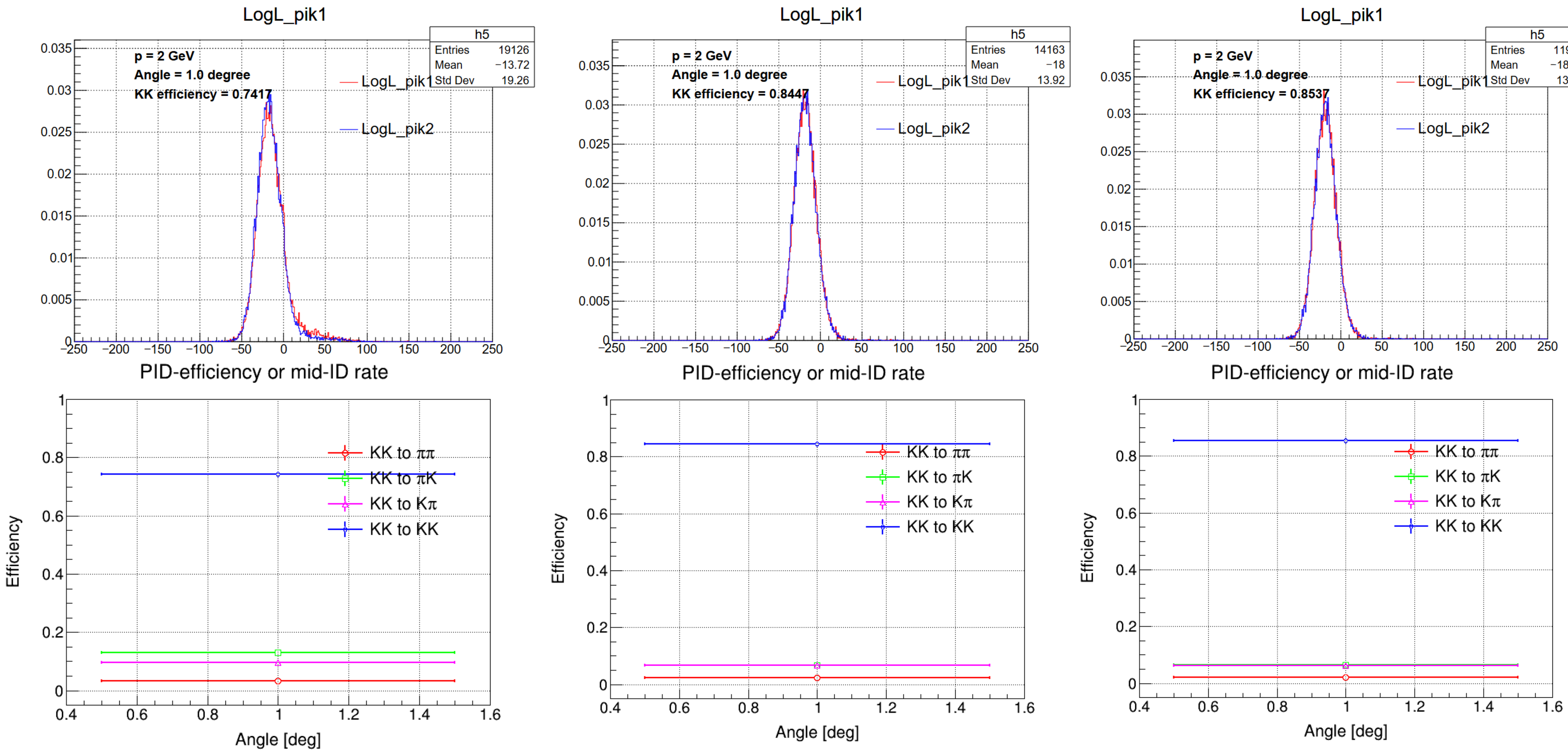
$\mu_1 = 0,$ $\sigma_1(p) = 0.06 \ + \ 5.645\,/\,p \ + \ 965.6\,/\,p\,/\,p$

$\mu_2 = 0.135,$ $\sigma_2 = 0.15$

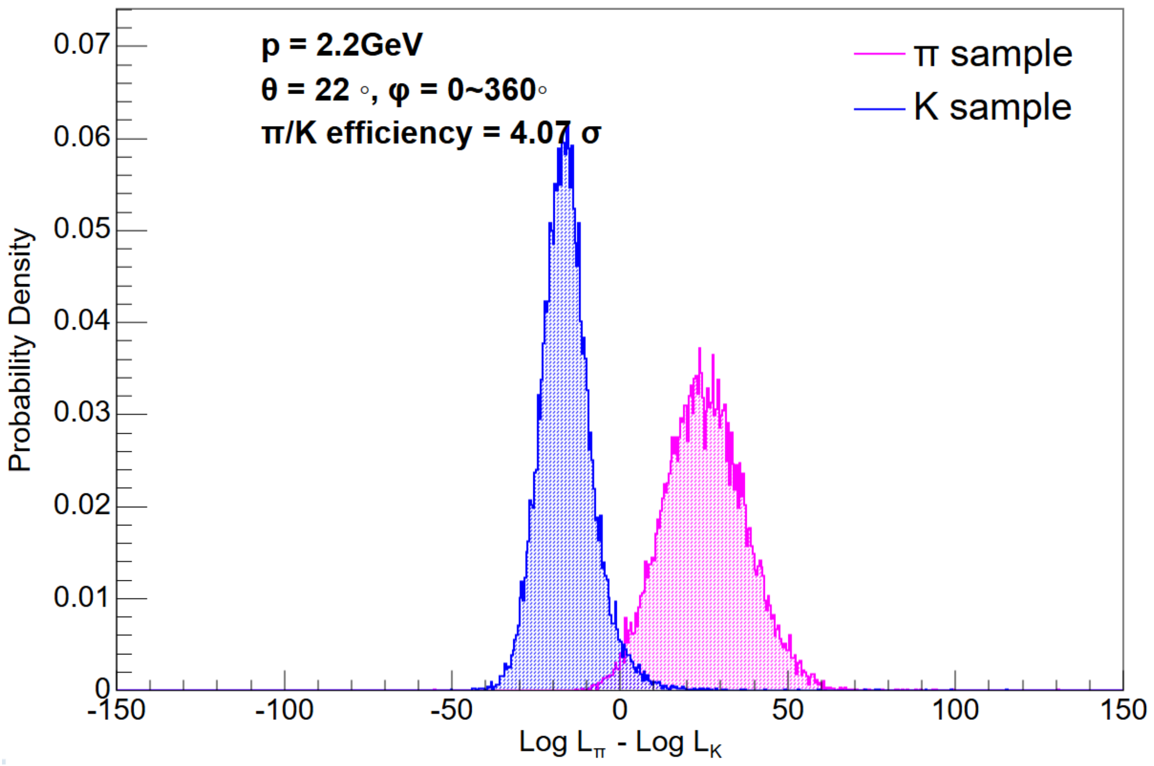
$\mu_3 = 0.05,$ $\sigma_3 = 0.33$

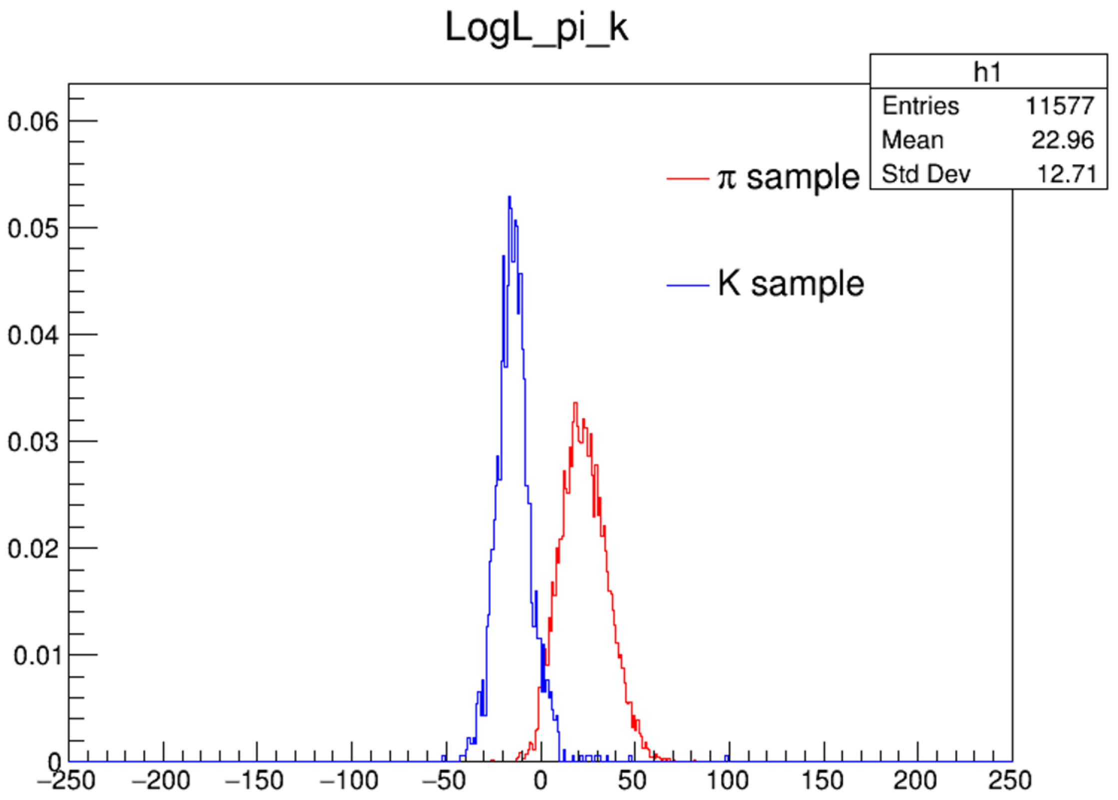
验证

recextMom-mcMom在100MeV以内 &&recextPos-mcPos在2mm以内



■ 两条径迹夹角比较小时，重建径迹误差比较大，从而会影响pik鉴别效率；对重建精度作要求后，效率明显提升


p = 2.2GeV
θ = 22 ◦, φ = 0~360◦
π/K efficiency = 4.07 σ
π sample
K sample
Probability Density
Log L_π - Log L_K


LogL_pi_k
h1
Entries 11577
Mean 22.96
Std Dev 12.71
π sample
K sample