



DIRC-like Time-of-flight Detector (DTOF) for the experiment at the Super Tau-Charm Facility (STCF)

Yutong Feng

Some plots are repeated by **O**ffline Software of **S**uper Tau-**C**harm Facility (OSCAR).

Reference:

[JINST 16, P08021 \(2021\)](https://iopscience.iop.org/article/10.1088/1748-0221/16/08/P08021) <https://iopscience.iop.org/article/10.1088/1748-0221/16/08/P08021>

[Nucl. Instrum. Meth. A 1049, 168090 \(2023\)](https://linkinghub.elsevier.com/retrieve/pii/S0168900223000803) <https://linkinghub.elsevier.com/retrieve/pii/S0168900223000803>

OutLine

- Super Tau-Charm Facility Introduction
- DTOF Geometry Configuration
- Single Timing uncertainty
- Likelihood Method for PID
 - Timing method
 - Imaging method
- Summary

Super Tau-Charm Facility

Parameters of STCF:

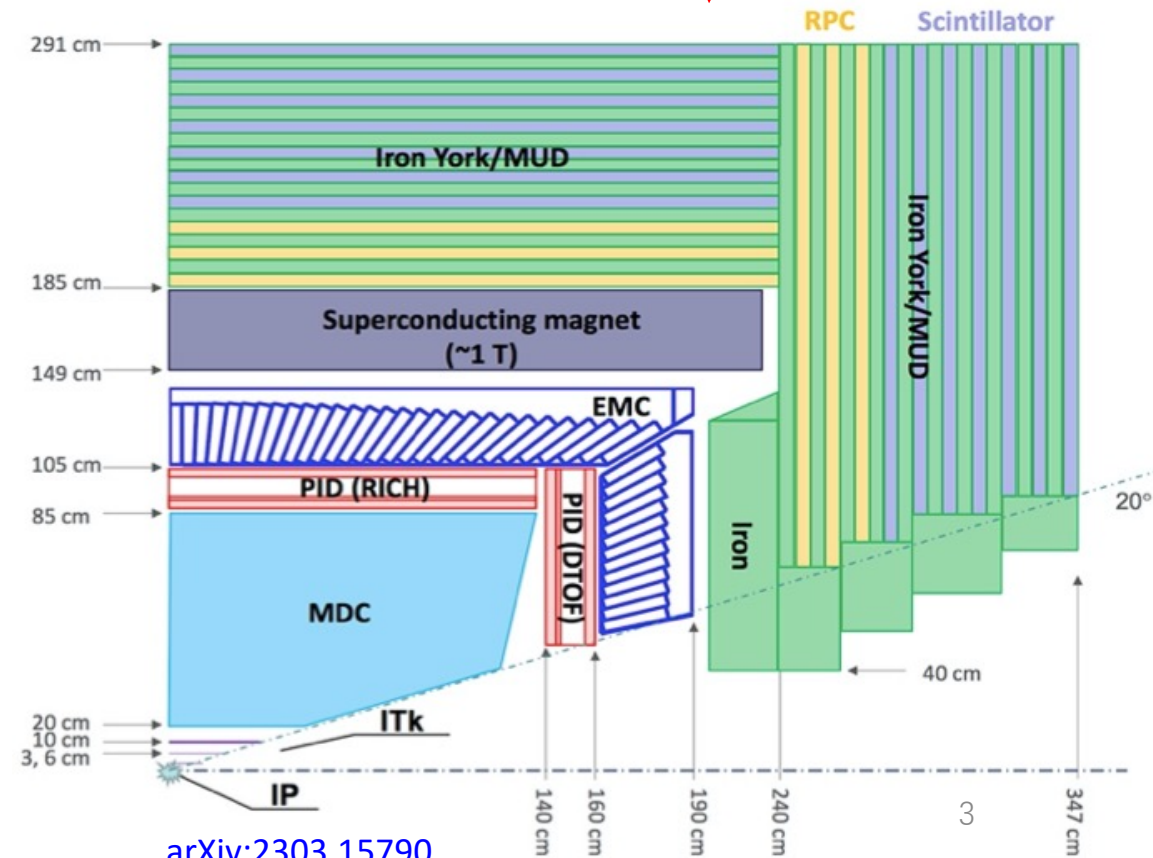
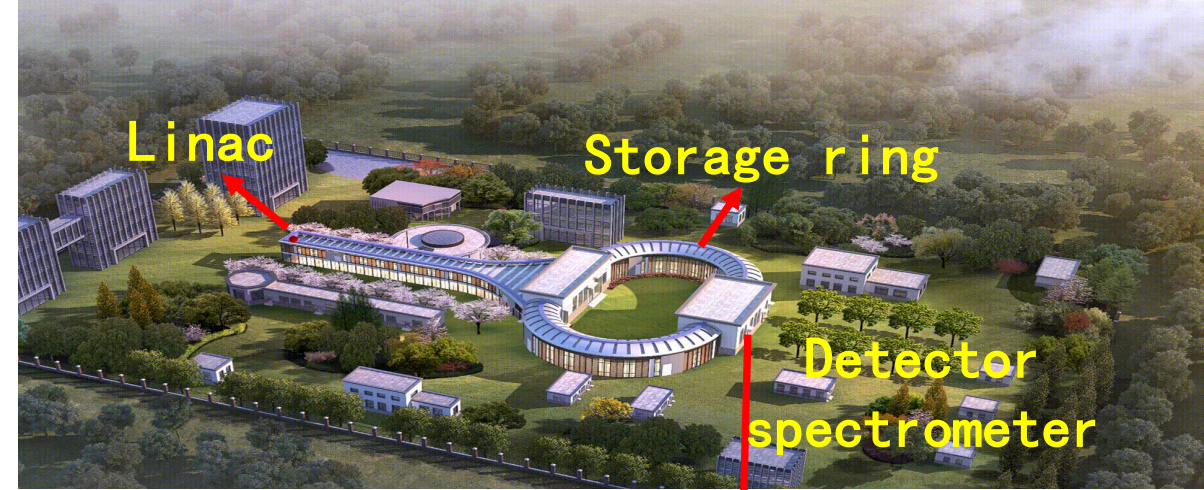
- Center-of-mass energy: 2 – 7 GeV
- Peak luminosity: $0.5 \sim 1 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$
- Circumference: $\sim 600 \text{ m}$
- Crossing angle: $2 \times 30 \text{ mrad}$

Physical targets of STCF:

- Rich physics with c quark and τ leptons
- Non-perturbed strong interaction and hadron structure
- New physics searching

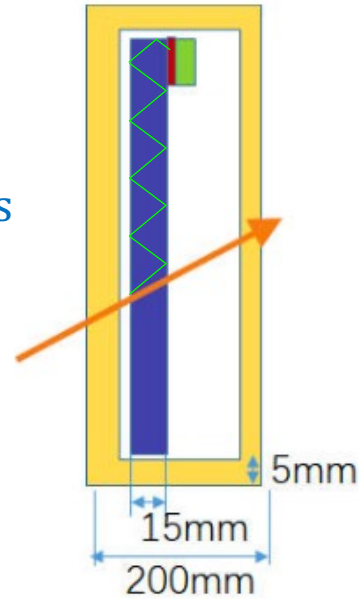
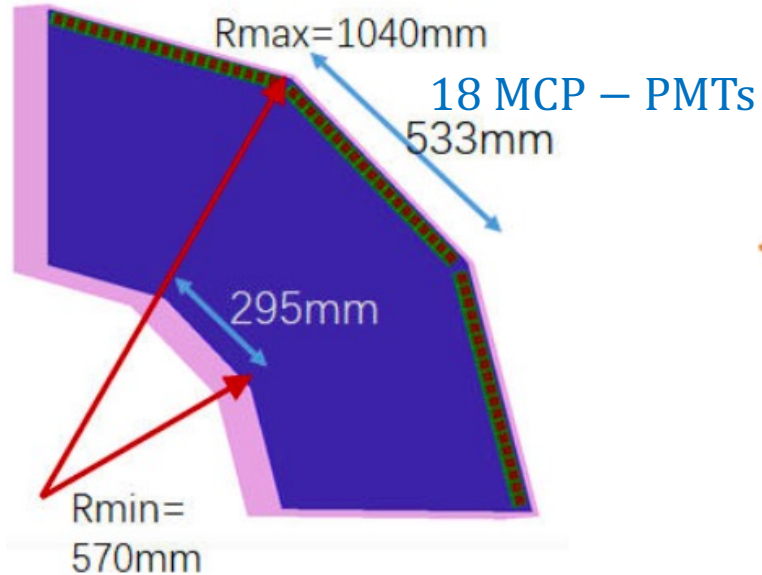
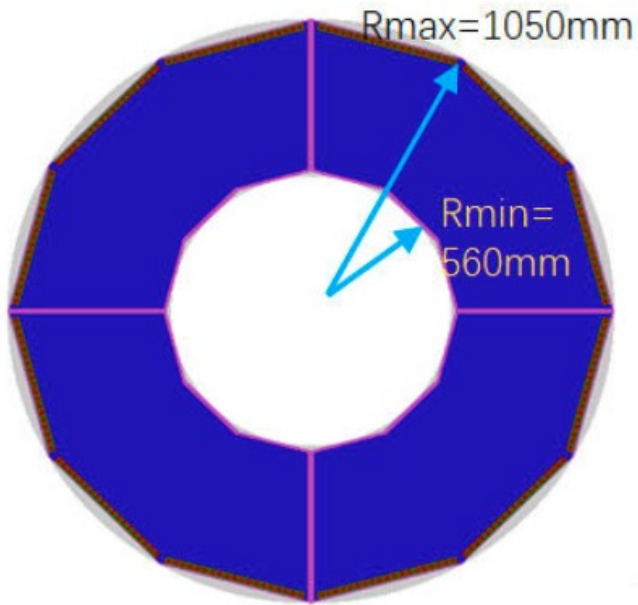
For DTOF:

- $4\sigma \pi/K$ separation at $p = 2 \text{ GeV}/c$
- Time resolution $\sim 50 \text{ ps}$

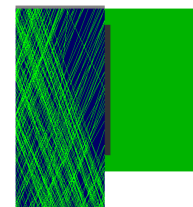


DTOF Geometry Configuration

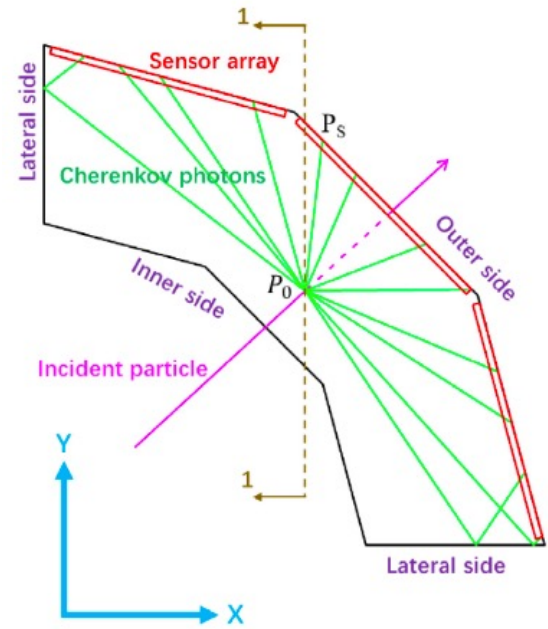
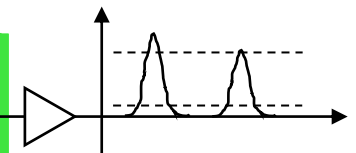
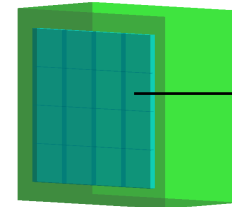
- Two identical endcap discs at $\sim \pm 1400$ mm away from the collision point along the beam direction.
- Each disc is made up of 4 quadrantal sectors, with $R_{min} = 560$ mm , $R_{max} = 1050$ mm.
- Covering in polar angles of $\sim 22^\circ - 36^\circ$.



4x4 anodes



5.5x5.5 mm²



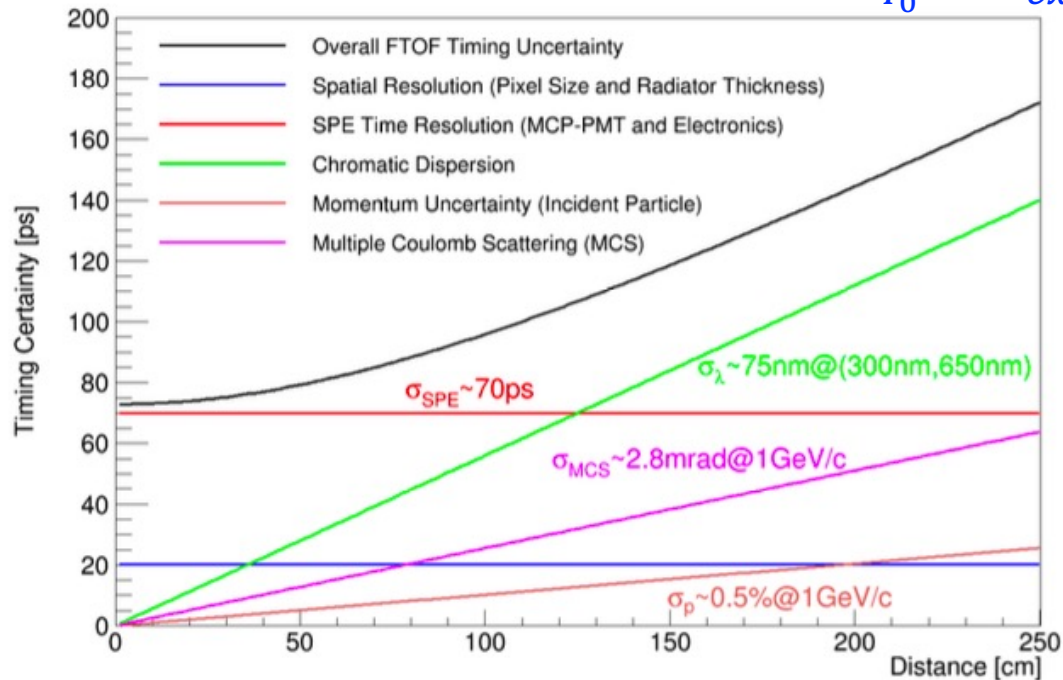
Single Timing uncertainty

$$a \oplus b = \sqrt{a^2 + b^2}$$

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

$$\text{Distance} = \sqrt{\Delta X^2 + \Delta Y^2} = 63.5 \text{ cm} \sim 83 \text{ ps}$$

$$\oplus \sigma_{T_0} \oplus \sigma_{ext} \sim 94 \text{ ps}$$



B. Qi et al 2021 JINST 16 P08021

OSCAR $\sim 95.7 \text{ ps}$

π	/ps
$\sigma_{t_{MCS}}$	9.8
σ_{t_λ}	40.7
σ_{t_D}	14.36
$\sigma_{t_{ext}}$	16.5
σ_{T_0}	40
σ_{TTS}	70

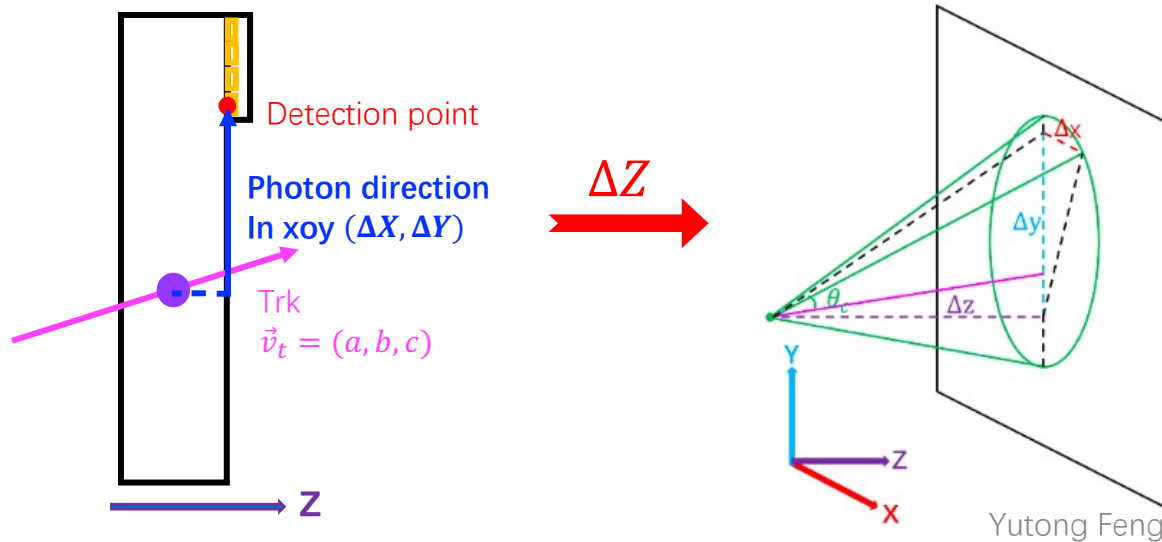
Likelihood Method for PID

● Timing Method JINST 16, P08021 (2021)

➤ TOF Reconstruction

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

$$LOP = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2} \Rightarrow TOF_{rec} = T - \frac{LOP \cdot \bar{n}_g}{c} - T_0$$



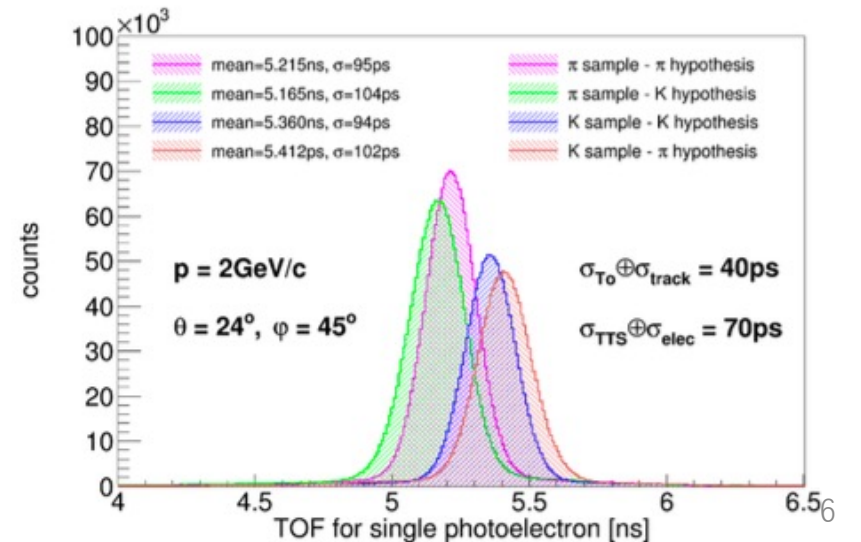
➤ Likelihood construction

$$\mathcal{L}_h = \prod_{i=0}^{N_{p.e.}} f_h(TOF_i)$$

$$f_h(t) = \text{Gaus}(TOF_{rec} | TOF_{hypo}, \sigma) + 0.05$$

signal bkg

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



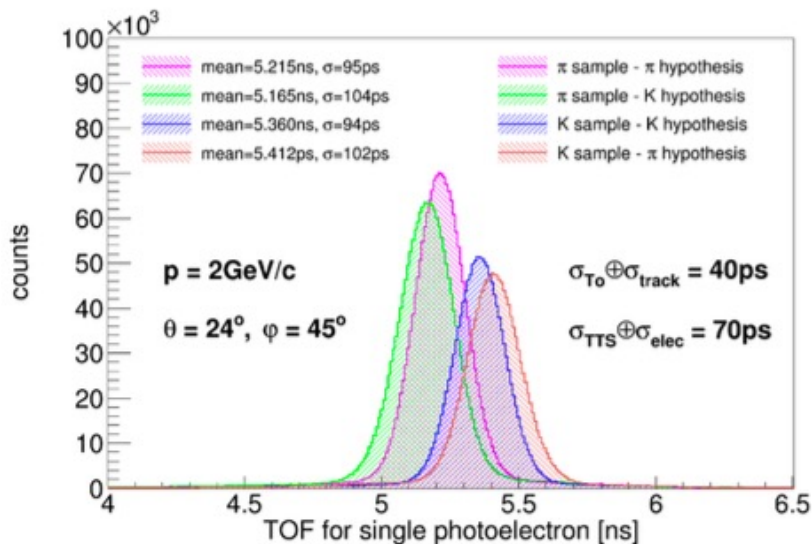
Likelihood Method for PID

- Timing Method

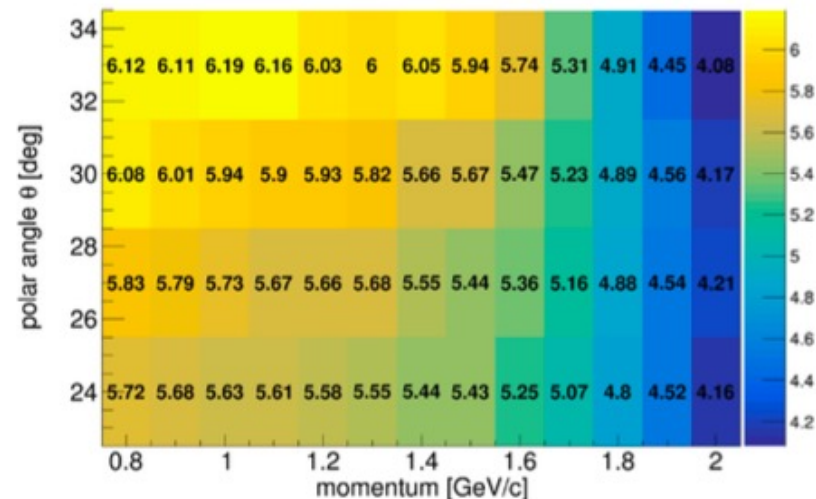
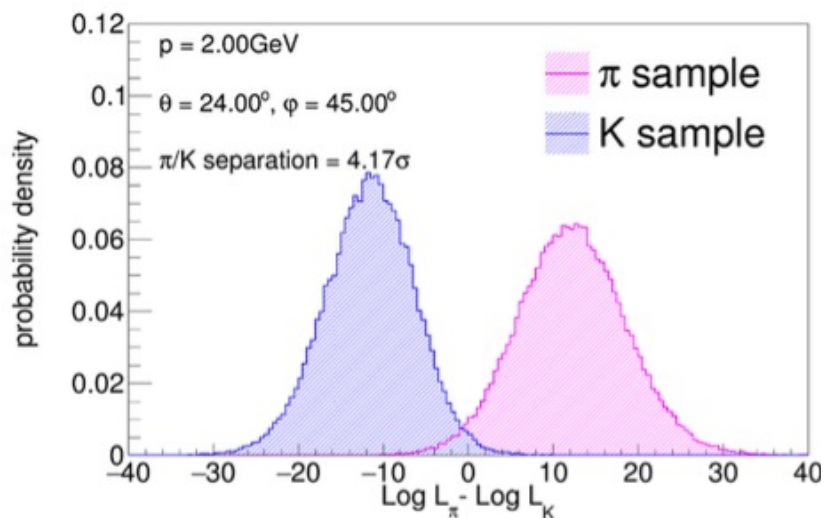
$$\mathcal{L}_h = \prod_{i=0}^{N_{p.e.}} f_h(TOF_i)$$

$$f_h(t) = Gaus(TOF_{rec} | TOF_{hypo}, \sigma) + 0.05_{bkg}$$

- $\sigma_t \sim 95 \text{ ps}$ by single photon-electron under right hypothesis
- $\sigma_t \sim 45 - 50 \text{ ps}$ by multi-photon-electrons
- 4.17σ π/K separation at $p = 2.0 \text{ GeV}/c$



JINST 16, P08021 (2021)



Likelihood Method for PID

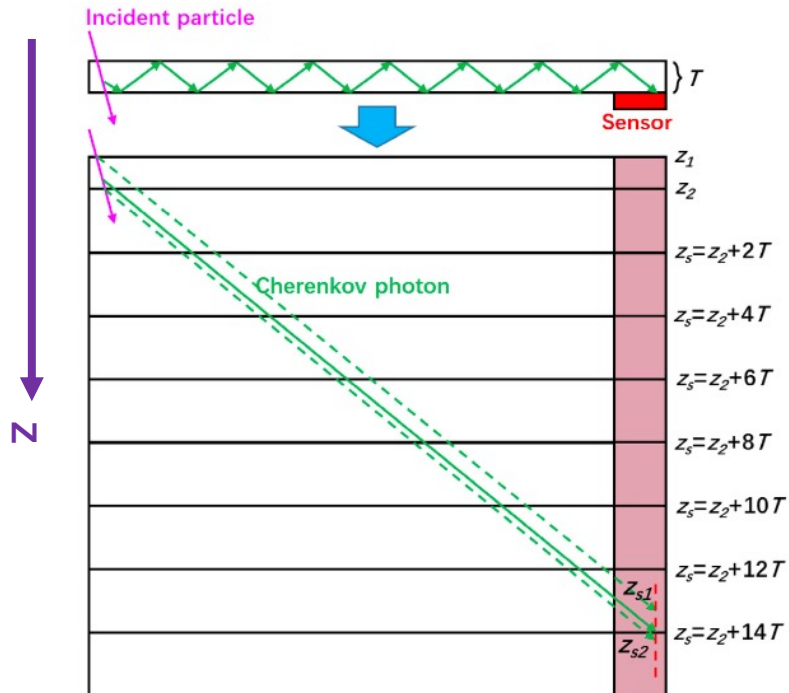
- **Imaging Method** [Nucl. Instrum. Meth. A 1049, 168090 \(2023\)](#)

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

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

$$z_s = z_2 + 2mT$$

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



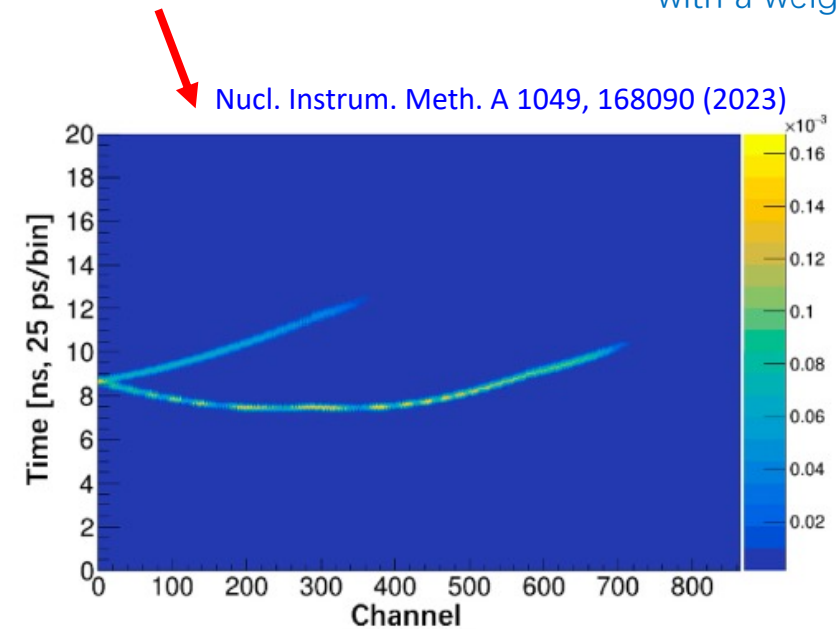
- **Likelihood construction**

$$\mathcal{L}_h = p_h(N_{p.e.}) \prod_{i=0}^{N_{p.e.}} f_h(x_i, t_i)$$

$$p_h(N_{p.e.}) = \sum_{n=0}^N \text{Poisson}_h(n, N_e) \times F_{bkg}(N - n)$$

$$f_h(x, t) = S_h(x, t) + \text{const}_{bkg}$$

$S_h(x, t)$ is the signal P.D.F. with a weight of $N_{p.e.}$



Likelihood Method for PID

- Imaging Method [Nucl. Instrum. Meth. A 1049, 168090 \(2023\)](#)

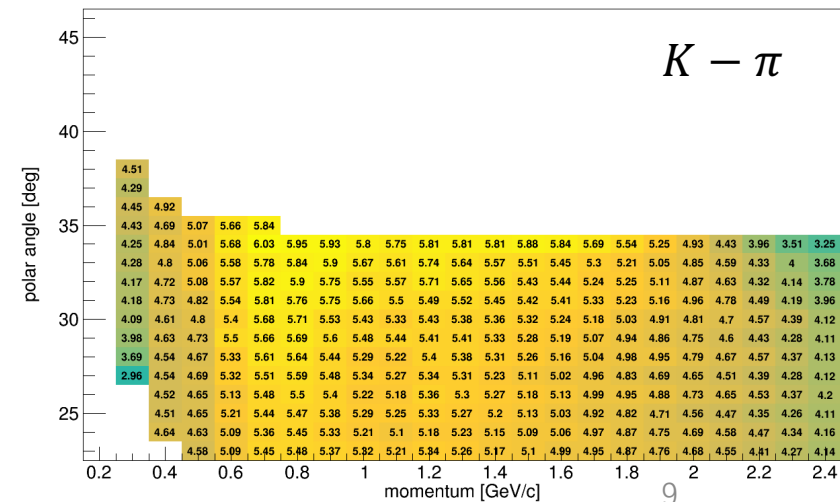
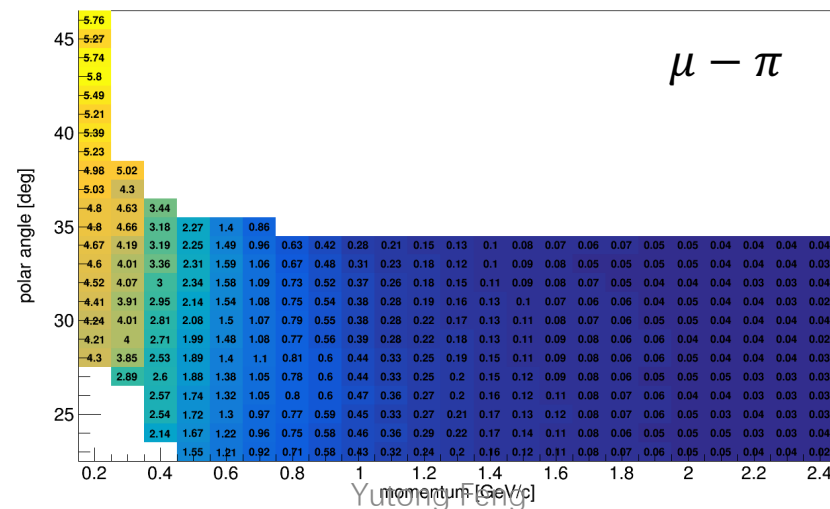
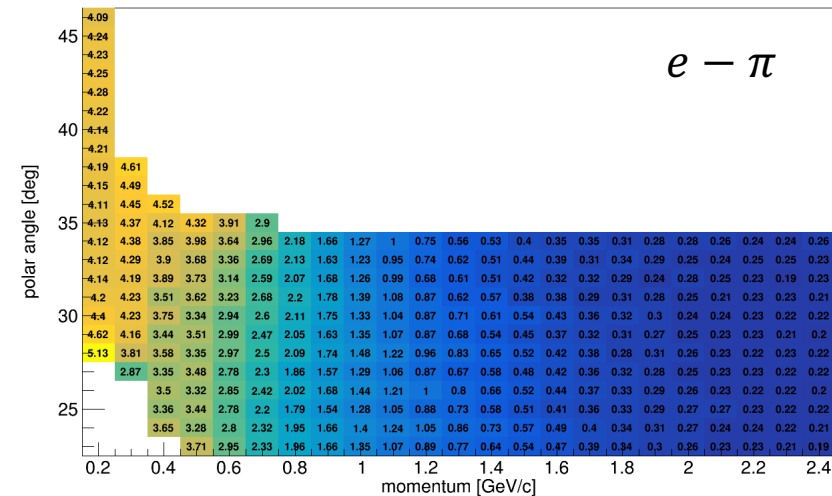
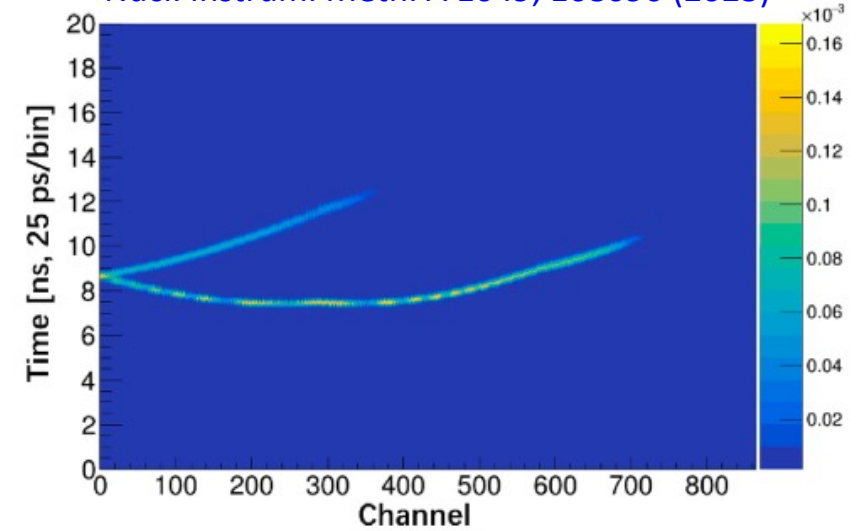
$$\mathcal{L}_h = p_h(N_{p.e.}) \prod_{i=0}^{N_{p.e.}} f_h(x_i, t_i)$$

$$p_h(N_{p.e.}) = \sum_{n=0}^N \text{Poisson}_h(n, N_e) \times F_{bkg}(N - n)$$

$$f_h(x, t) = S_h(x, t) + \text{const}_{bkg}$$

Improve π/K separation $\sim 4.7\sigma$, at $p = 2.0 \text{ GeV}/c$

[Nucl. Instrum. Meth. A 1049, 168090 \(2023\)](#)





Summary

- **Timing method**

Using transmission characteristic of Cherenkov photon to calculate its arrival time.

Construct the probability density function of TOF & realize the identification of particles.

- Overall reconstructed TOF time resolution $\sim 45 - 50$ ps
- π/K separation $\sim 4.17\sigma$, at $p = 2.0$ GeV/c

- **Imaging method**

Using emission & transmission characteristic of Cherenkov photon to evaluate its arrival (\vec{r}, t) .

Construct a multidimensional likelihood function of hit-position and hit-time of photon $\mathcal{L}_h(\vec{r}, t)$ & realize the PID.

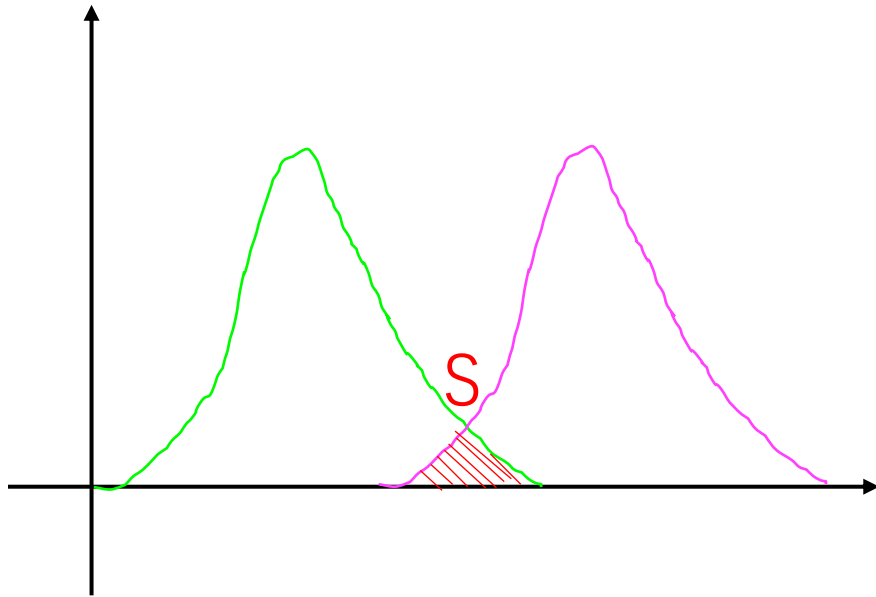
- π/K separation $\sim 5\sigma$, at $p = 2.0$ GeV/c

For STCF, it will improve the PID efficiency in $\theta \in (22^\circ, 36^\circ)$, $p \in (0.2, 2.4)$ GeV/c.

Thank you !

Appendix

Separation

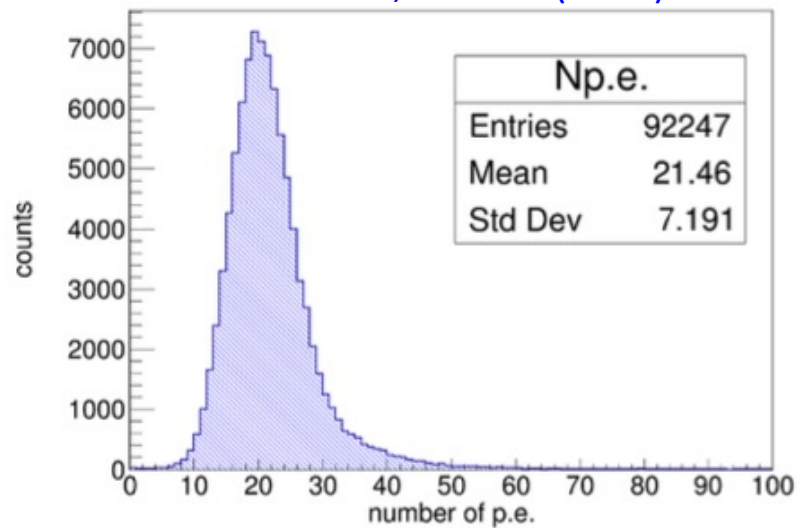


$$P(x) = \frac{1}{2} \operatorname{erf}\left(\frac{x}{\sqrt{2}\sigma}\right) = 1 - \mathbf{S}$$

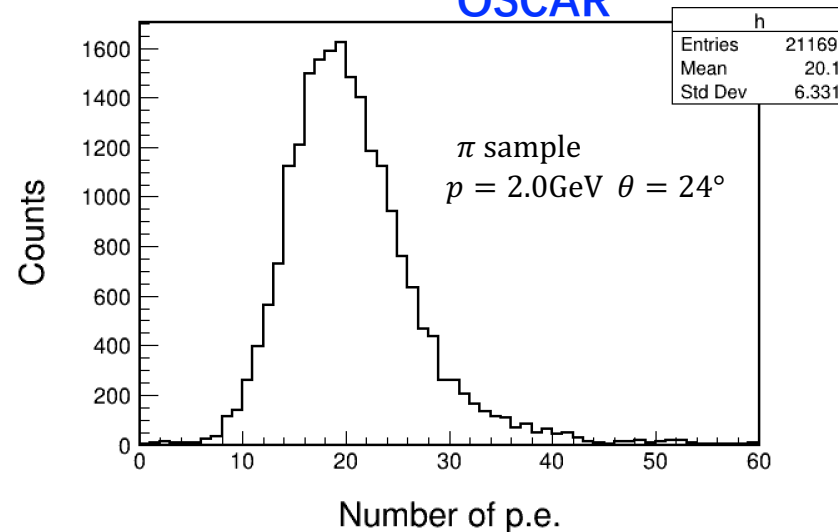
$$\text{Separation} = x\sigma$$

Photoelectron Yield

JINST 16, P08021 (2021)

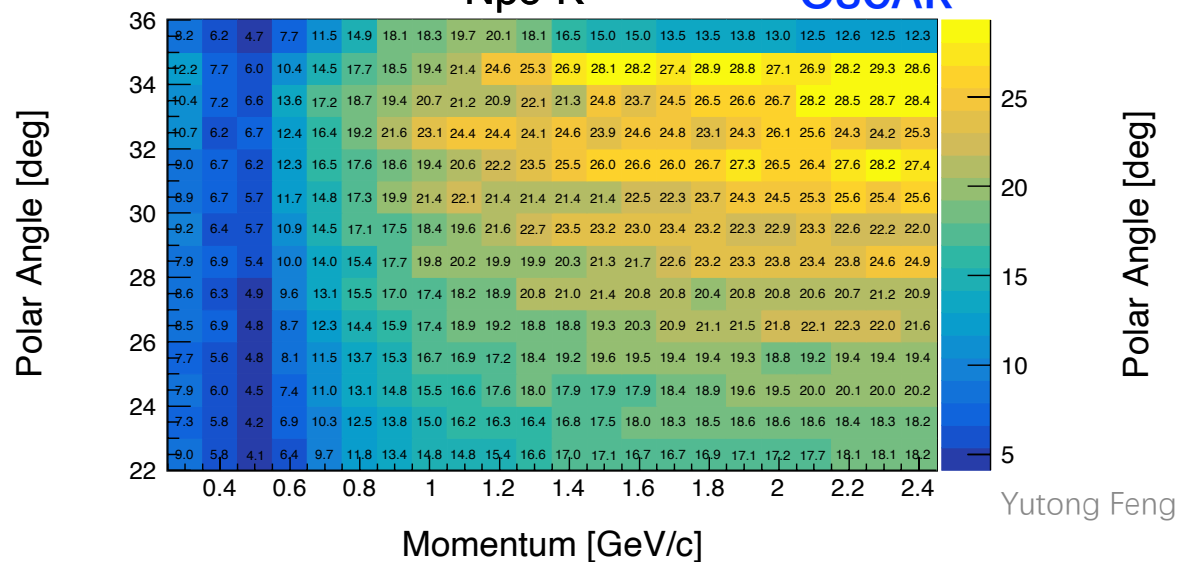


OSCAR



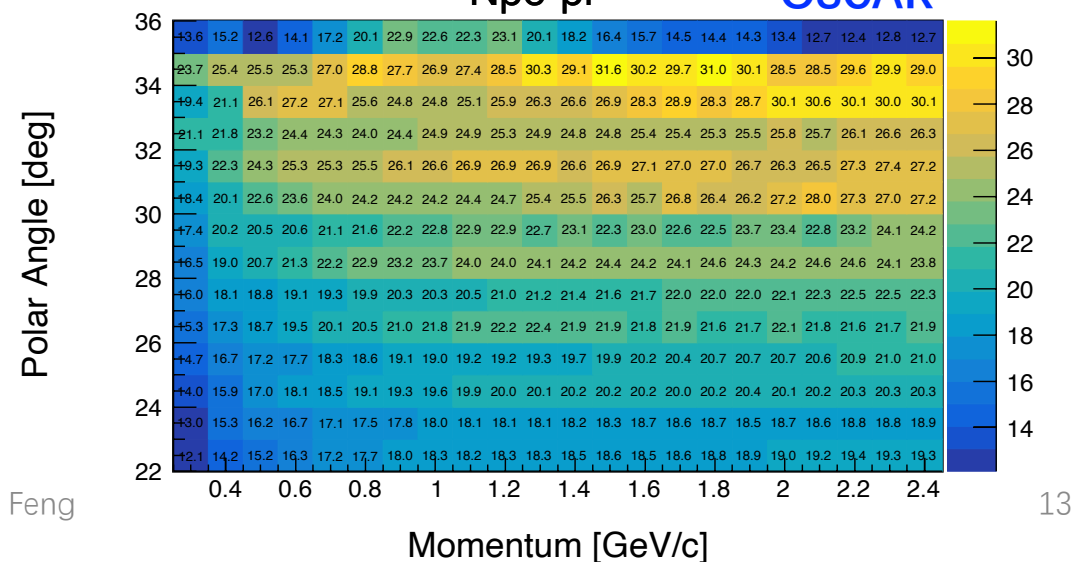
Npe-K

OSCAR



Npe-pi

OSCAR

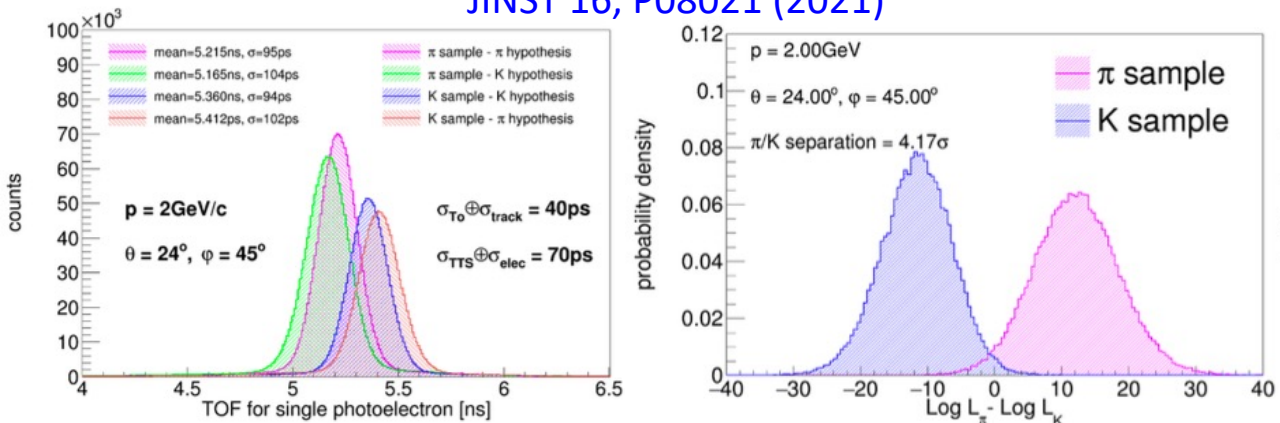


Likelihood Method for PID

- Timing Method

	JINST 16, P08021	OSCAR
σ_t by single p.e.	~ 95 ps	~ 95 ps
σ_t by multi p.e.	$\sim 45-50$ ps	~ 50 ps
π/K separation ($p = 2.0$ GeV/c)	4.17σ	3.95σ

JINST 16, P08021 (2021)



OSCAR

