

Design and Performance of DIRC-like time of flight detector for the experiment at the Super Tau-Charm Facility



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Abstract: The Super Tau-Charm Facility (STCF) is a future electron-positron collider proposed in China with a peak luminosity of above $0.5 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ and center-of-mass energy ranging from 2 to 7 GeV. In physics research of STCF, excellent particle identification (PID) ability is one of the most important parts for the high energy particles experiment. The effective PID is required within the detector acceptance for charged hadrons (π^\pm , K^\pm , and p/\bar{p}), with a statistical separation power better than 3σ up to 2 GeV/c. A DIRC-like time-of-flight (DTOF) detector is proposed to realize the PID aim at the endcap. In this poster, the conceptual design of FTOF is presented. Its geometry optimization and performance is studied by a Geant4 simulation, and a π/K separation power of DTOF of $\sim 4\sigma$ or better at the momentum of 2 GeV/c is achieved over the full DTOF sensitive area.

Introduction

The Super Tau-Charm Facility (STCF) is a future high-luminosity electron-positron collider proposed in China, which would operate in a center-of-mass energy region ranging from 2 to 7 GeV with a peak luminosity of $>0.5 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$.

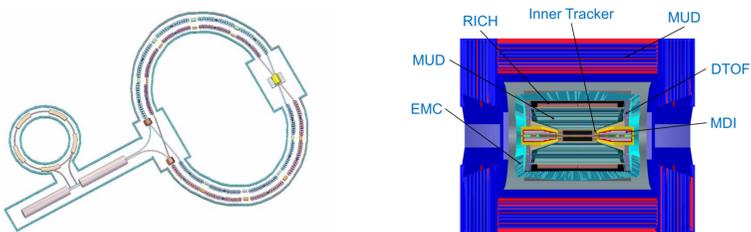


Figure 1. Layout of STCF accelerator (left) and detectors (right) A DIRC-like time of flight detector (DTOF) is proposed as the endcap PID detector at the STCF experiment, which use fused silica as Cherenkov radiator and provide a charged hadrons separation power better than 3σ up to 2 GeV/c.

DTOF geometry optimization

Table 1. Description of the different DTOF geometry configurations and their performances at $p=2\text{GeV}/c$, $\theta = 24^\circ$ and $\varphi = 45^\circ$

Configuration/Geometry ID	0	1	2	3	4	5	6
Radiator shapes (sector number)	4	12	24	4	4	4	4
Radiator thickness (mm)	15	15	15	10	20	15	15
Outer side surface	A	A	A	A	A	M	45° M
Inner side surface	A	A	A	A	A	A	A
Lateral side surface	M	M	M	M	M	M	M
Number of photoelectron for pions (except background)	21.8	21.9	17.0	15.5	25.7	33.2	38.7
Accumulated charge density on MCP-PMT anode (C/cm^2)	10.8	10.5	9.6	8.8	11.8	17.0	25.6
π/K separation power	4.17 σ	4.08 σ	3.66 σ	3.99 σ	4.27 σ	4.26 σ	4.19 σ

• "A" is absorber, "M" is mirror.

By comparing above geometries, an optimum geometry configuration of DTOF is obtained, i.e. Geometry 0. An array of 3×18 MCP-PMTs are optically coupled to its radiator along the outer side as photon sensors.

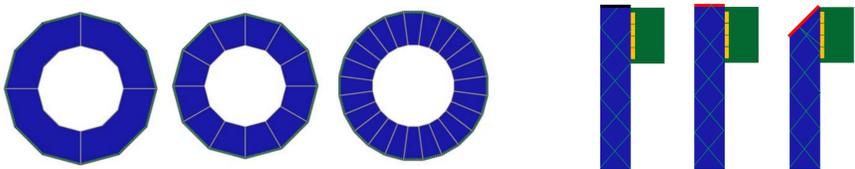


Figure 2. Three different radiator shapes (left) and three different mirror setups.

Simulation and reconstruction

Geant4 simulations are performed to study the expected performance of DTOF. The setups of simulation are listed below:

- **2 cm Aluminum plate:** before DTOF, simulate the tracker endcap material budget
- **Mirror reflection factor:** wavelength dependent, mean of $\sim 92\%$
- **Radiator surface roughness:** $\sigma_a = 0.1^\circ$, corresponding to an average reflection factor of $\sim 97\%$
- **Refraction index:** wavelength dependent, mean of ~ 1.47 , 300 nm – 650 nm
- **Photon sensors:** 4×4 anodes, directly coupled to the radiator surfaces with no air gap or other cookies, QE $\sim 25\%$ @ 380nm

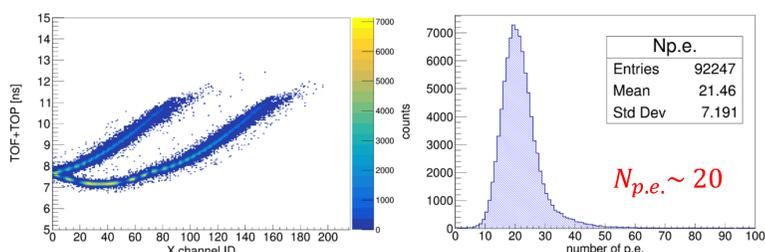


Figure 3. The simulated time of propagation vs. hit position pattern of DTOF, and the number of photoelectrons, for pions at $p=2\text{GeV}/c$.

The reconstruction algorithm is based on the Cherenkov angle relation shown as

$$\cos(\theta_c) = \frac{1}{n_p \beta} = \frac{\vec{v}_t \cdot \vec{v}_p}{|\vec{v}_t| \cdot |\vec{v}_p|}$$

where \vec{v}_t is the velocity vector of incident particle when impinging the radiator, $\vec{v}_p = (\Delta X, \Delta Y, \Delta Z)$ is the 3D spatial difference between the photon sensor pixel and the particle incident position. The 2D (X and Y) difference can be readily obtained, while ΔZ can be deduced with a certain particle species hypothesis. Then the length of propagation (LOP) of photon inside the radiator is

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

and the time of flight (TOF) is

$$TOF = T - \frac{LOP \cdot \bar{n}_g}{c} - T_0$$

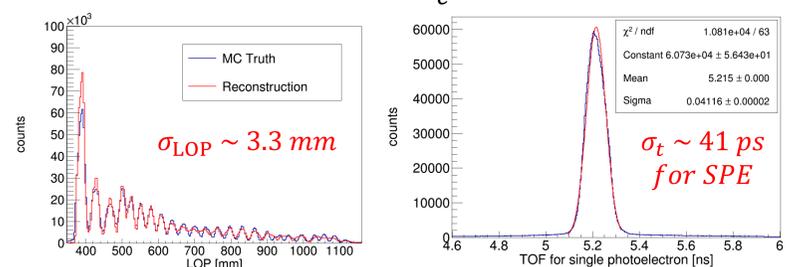


Figure 4. The uncertainty of LOP and the intrinsic TOF resolution from DTOF reconstruction for the single photoelectron (SPE), for pions at $p=2\text{GeV}/c$, $\theta = 24^\circ$ and $\varphi = 45^\circ$.

PID performance

When convoluting all contributing factors, the resolution of TOF measurement is $\sim 100 \text{ ps}$ for SPE and $\sim 50 \text{ ps}$ for combining all photons.

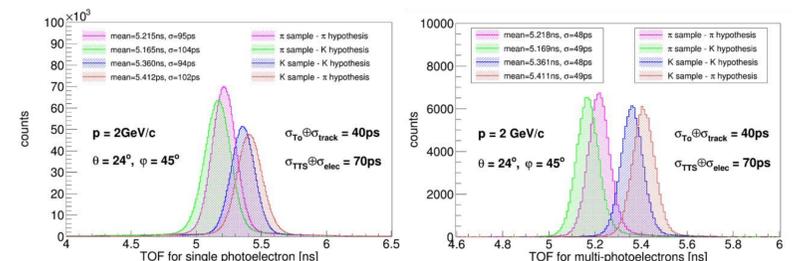


Figure 5. The TOF PID capability of the DTOF detector for π/K separation at $2\text{GeV}/c$, for the SPE (left) and combining all photons (right).

By apply a likelihood method, shown as

$$\mathcal{L}_h = \prod_{i=1}^n f_h(TOF_i^h) \text{ and } \Delta \ell = \text{Log } \mathcal{L}_\pi - \text{Log } \mathcal{L}_K$$

a π/K separation power of $\sim 4\sigma$ or better at the momentum of 2 GeV/c is achieved over the full DTOF sensitive area.

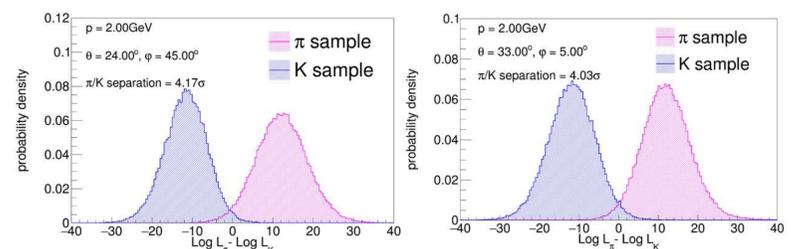


Figure 6. The likelihood PID capability of the DTOF detector for π/K separation at $2 \text{ GeV}/c$, emitted at different angles.

Conclusions

- A **15 mm thick quadrant shape** radiator covered with **absorber** on its outer side surface is the optimum geometry.
- A resolution of TOF measurement of $\sim 100 \text{ ps}$ for SPE and $\sim 50 \text{ ps}$ for combining all photons are obtained from simulation and reconstruction.
- By apply a likelihood method, a π/K separation power of $\sim 4\sigma$ or better at the momentum of 2 GeV/c is achieved over the full DTOF sensitive area.

References

- [1] Q. Luo and D. Xu, Progress on Preliminary Conceptual study of HIEPA, a super tau-charm factory in China, 9th International Particle Accelerator Conference (IPAC 2018), Vancouver, British Columbia, Canada (2018), <https://doi.org/10.18429/JACoW-IPAC2018-MOPML013>.
- [2] B. Qi, Z. Li, M. Shao, et al., A DIRC-like time-of-flight detector for the experiment at the Super Tau-Charm Facility. arXiv:2104.05297, 2021.