Likelihood analysis methods for the PID system of STCF experiment

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Abstract – The Super Tau-Charm Facility (STCF) is a proposed electron-positron collider in China, with a peak luminosity above 0.5×10^{35} $cm^{-2}s^{-1}$ and a center-of-mass energy range of 2 to 7 GeV. Effective particle identification (PID) is crucial for STCF experiments, requiring a separation power better than 4σ for charged hadrons ($\pi^{\pm}$, $K^{\pm}$, and $p/\bar{p}$) up to 2 GeV/c. To achieve this, a dedicated PID system is proposed, consisting of a Ring Imaging Cherenkov (RICH) detector for the barrel region and a time-of-flight detector (DTOF) using detection of internally reflected Cherenkov light technique for the endcap region. This work presents likelihood analysis methods to evaluate the PID performance of both PID detectors within the Offline Software of Super Tau-Charm Facility (OSCAR), featuring tailored analytical approaches for the fast extraction of photon hit maps.

Introduction

The baseline design of the STCF[1] PID system includes a RICH detector in the barrel and a DTOF in the endcap, achieving over 97% π/K identification efficiency up to 2 GeV/c, with a misidentification rate below 2%. The RICH detector[2] features a 10 mm liquid C_6F_{14} radiator, optical transparent quartz, working gas, and photon detectors with CsI-coated THGEM for photocathode and Micromegas (MM) for amplification. The DTOF detector[3-4] uses a fused silica plate as Cherenkov radiator and light guide, with MCP-PMTs for photon detection.

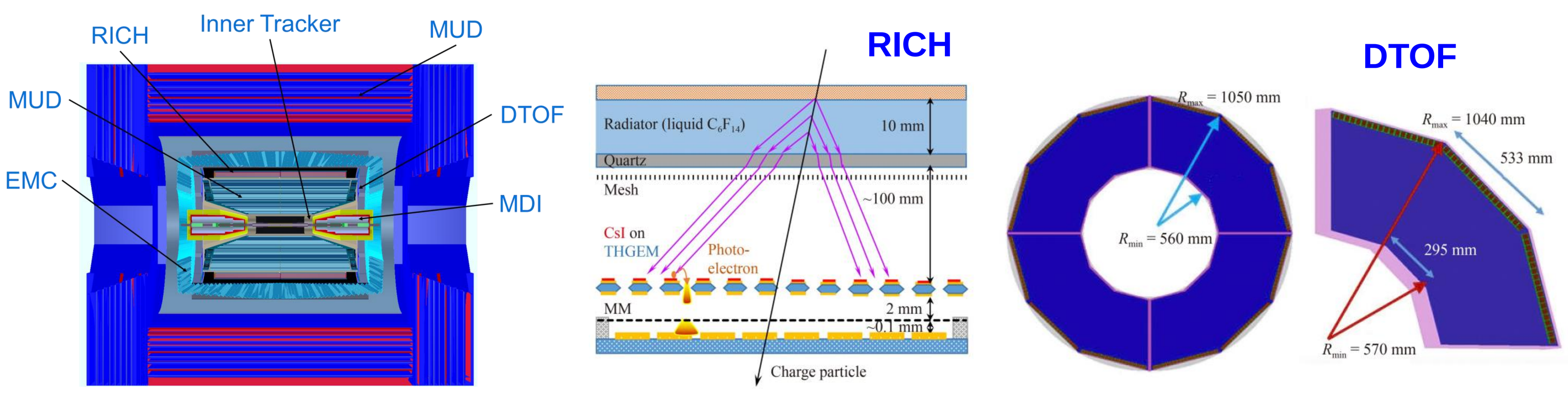

Figure 1. Layout of STCF detectors (left), and the structure of RICH (middle) and DTOF detectors (right)

Simulation and reconstruction

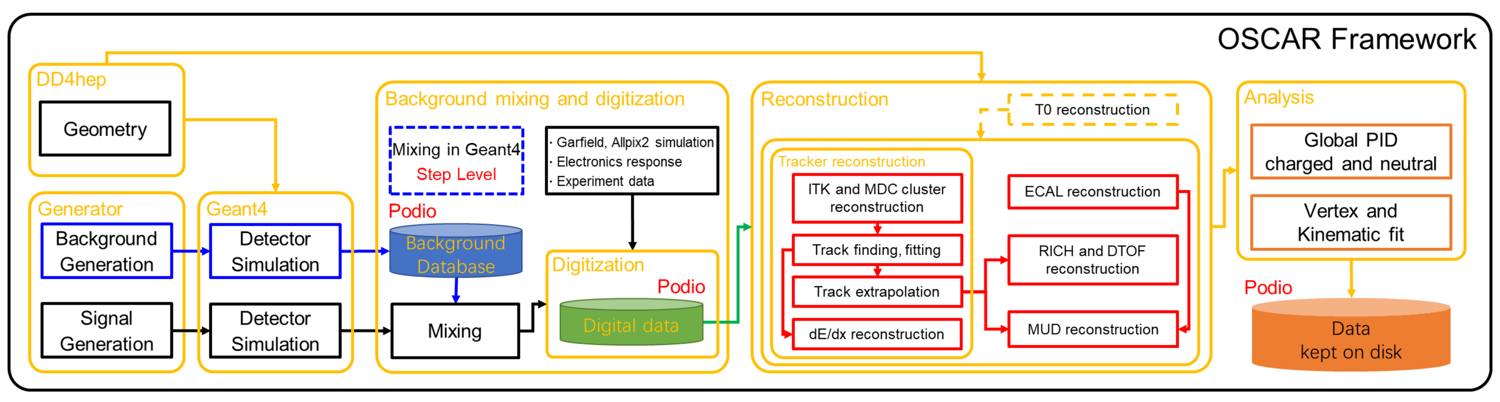

Figure 2. Simulation and reconstruction of STCF detectors in OSCAR framework.

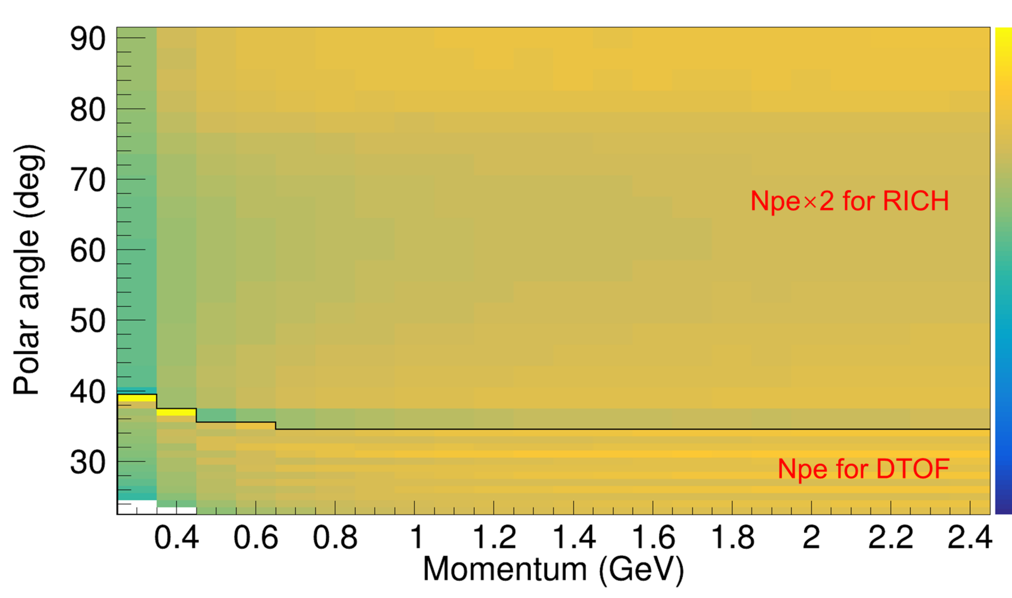

Figure 3. The number of photoelectrons (N_{pe}) for the DTOF (lower region) and RICH (upper region) detectors. For the DTOF, the N_{pe} is approximately 30, while for the RICH, it is approximately 15, with the values doubled ($N_{pe}\times 2$) to align with the scale used for comparison.

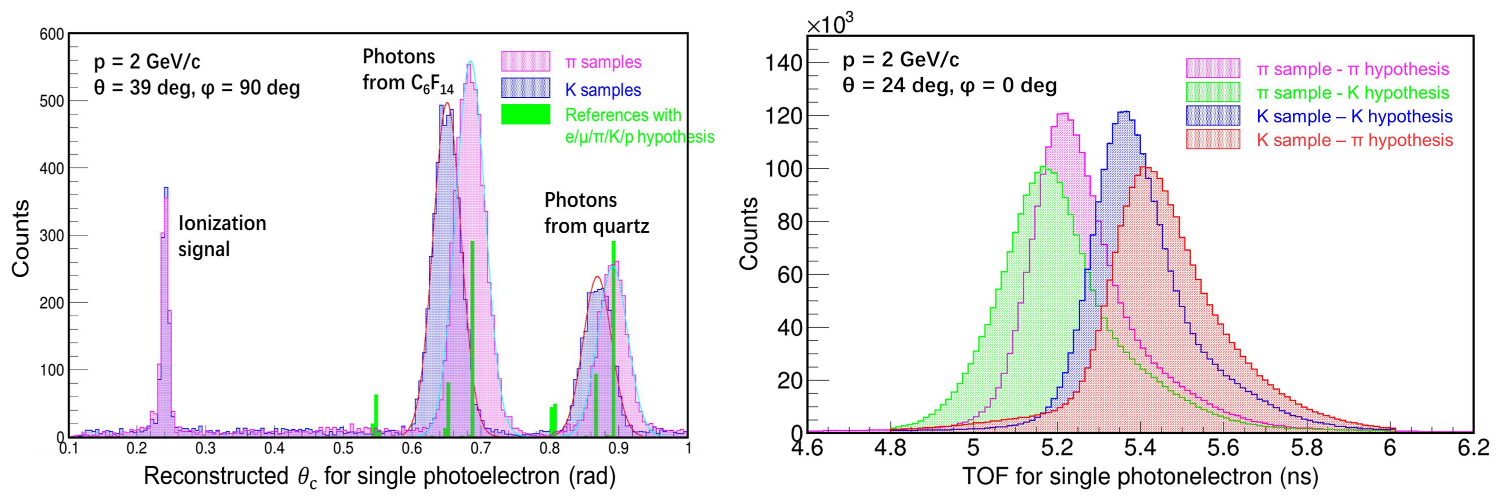

Figure 4. The reconstructed Cherenkov angle for RICH detector (left) and TOF reconstruction for DTOF (right).

PID performance

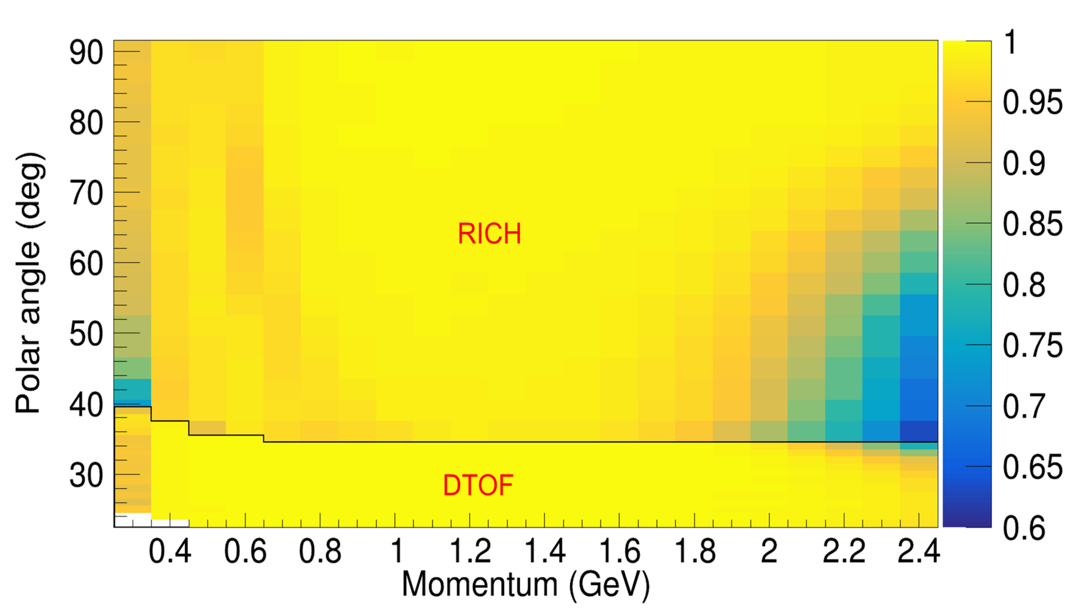

Figure 7. π ID-efficiency of the RICH (left) and DTOF (right) detectors at different directions momenta, where K mis-ID rate is 2%.

Likelihood analysis methods

- RICH likelihood function:

$$\mathcal{L}_h=\prod_{i=1}^{N_{p.e.}}[\bar{N}_{h,ch}+B]$$

- DTOF likelihood function:

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

Here, h represents different particle hypotheses, and $S_h(ch_i,t_i)$ is the probability density of photons in spatial and temporal domains for DTOF. The log-likelihood difference ($\Delta\mathrm{Log}\mathcal{L}$) is expressed as:

- RICH: $$\Delta\mathrm{Log}\,\mathcal{L}_{\pi-K}=\sum_{i=1}^{N_{p.e.}}\mathrm{Log}\,\frac{\bar{N}_{\pi,ch_i}+B}{\bar{N}_{K,ch_i}+B}$$
- DTOF: $$\Delta\mathrm{Log}\mathcal{L}_{\pi-K}=\sum_{i=1}^{N_{p.e.}}\mathrm{Log}\,\frac{\bar{N}_\pi S_\pi(ch_i,t_i)+B}{\bar{N}_K S_K(ch_i,t_i)+B}$$

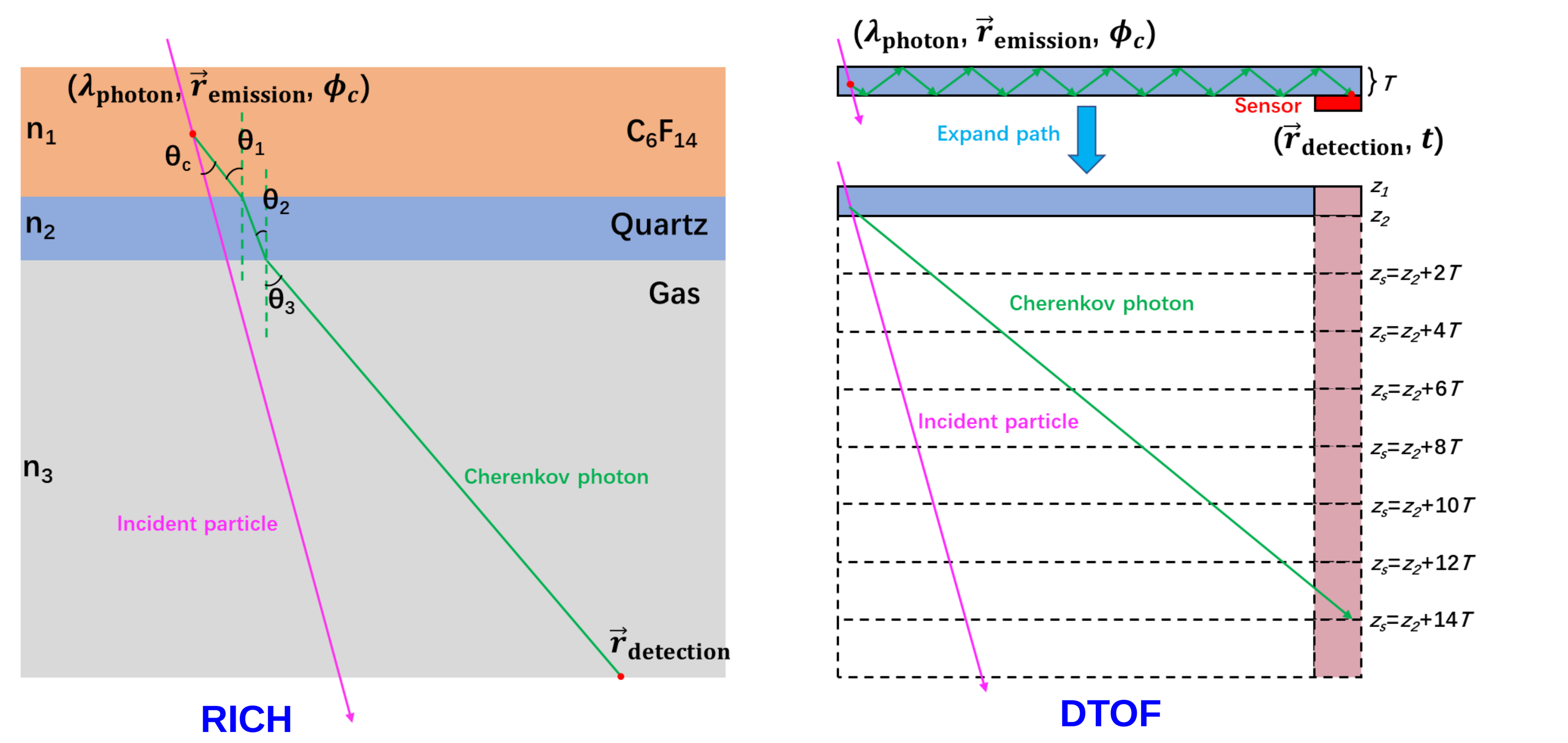

Figure 5. Analytical approaches for the fast extraction of photon hit maps. The Jacobian matrix, which transforms from the emission space ($\lambda_{\mathrm{photon}}$, $\vec{r}_{\mathrm{emission}}$, ϕ_c) to the detection space ($\vec{r}_{\mathrm{detection}}$, t), is obtained by summing over all possible photon paths. The emission space is divided into small intervals, with the light paths expanded to ensure accurate transformation.

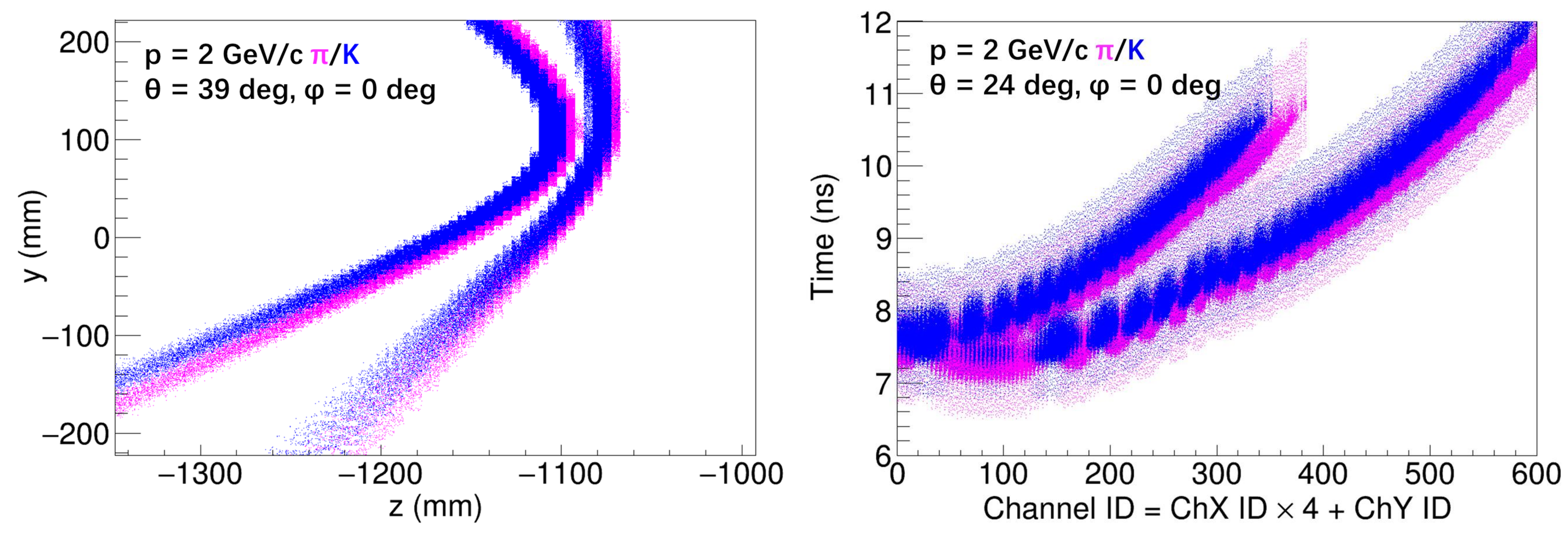

Figure 5. Examples of photon hit maps from the RICH (left) and DTOF (right) detectors. The RICH detector shows 2D spatial distributions of photon hits, while the DTOF detector presents time-position patterns.

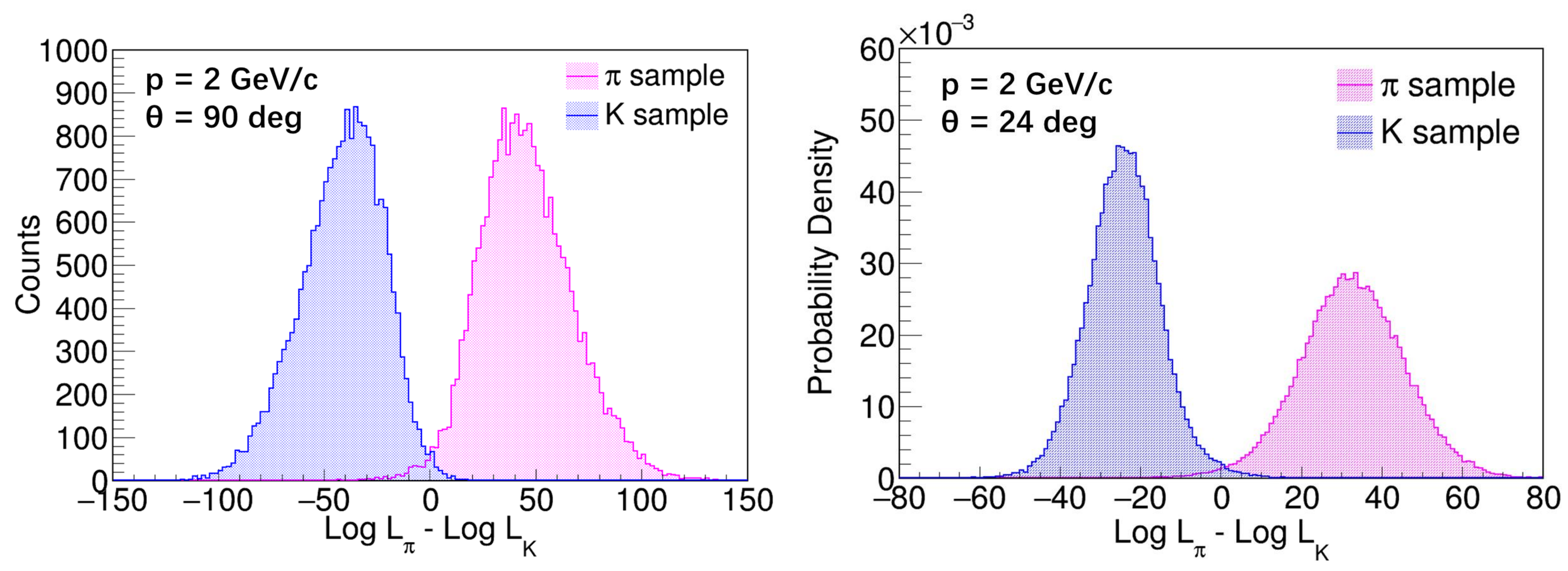

Figure 6. The log-likelihood difference of the RICH (left) and DTOF (right) detectors for π/K separation at 2 GeV/c.

[1] M. Achasov et al. STCF conceptual design report (Volume 1): Physics & detector. Frontiers of Physics, 2024, 19(1): 14701.

[2] Li P et al. Study of hybrid micropattern gaseous detector with CsI photocathode for Super Tau-Charm facility RICH. Journal of Instrumentation, 2023, 18(04): P04028.

[3] B. Qi et al. DIRC-like time-of-flight detector for the experiment at the Super Tau-Charm Facility, Journal of Instrumentation, 16 (2021) P0821.

[4] B. Qi et al. Imaging-based likelihood analysis for the STCF DTOF detector, Nuclear Instruments and Methods in Physics Research Section A, 2023, 1049: 168090.