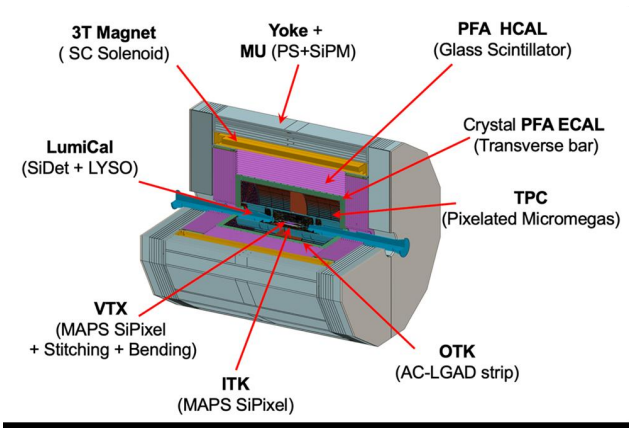
Flavor-physics impact of RICH at AGORA

Ziqiu Yang (IHEP)

2026 CEPC workshop
24 October 2026

AGORA detector: a quick reminder



AGORA reference detector

Z-pole physics

Tera-Z data provide abundant *b*- and *c*-hadron decays.

Detector performance

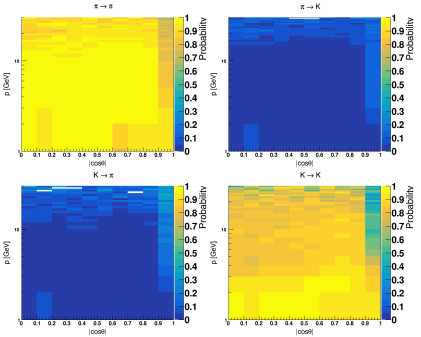
- Precision tracking and vertexing for impact-parameter and decay-time measurements.
- PFA-oriented ECAL/HCAL and dedicated muon identification for final-state reconstruction.

Flavor-physics opportunities

Precision measurements of heavy-hadron lifetimes, mixing and CP violation, together with searches for rare decays.

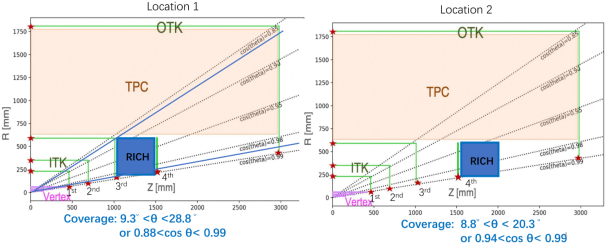
Physical motivation

Baseline π/K PID



Baseline PID becomes inefficient near $|\cos\theta| \to 1$.

Two proposed RICH locations

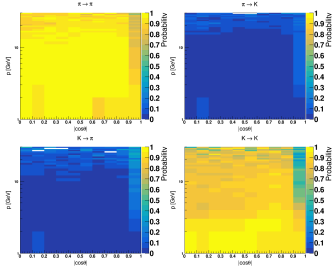


Two RICH locations are proposed to extend PID coverage in the forward region.

More PID coverage may improve flavor-physics sensitivity.

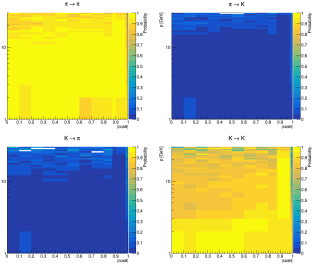
Assumed RICH extension of π/K PID

Baseline PID



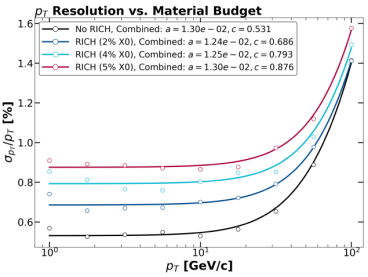
CEPCSW π/K PID

Assumed RICH PID



97% **correct π/K identification in the RICH**

Momentum resolution



Analysis assumption: 2%X_0 RICH material

Baseline PID is retained outside the RICH acceptance.

Scope of this study

Samples

CEPCSW full simulation at the Z pole

$$e^+e^- \to Z \to b\bar{b},$$
$$e^+e^- \to Z \to c\bar{c}.$$

eecc: 1,597,828 events

eebb: 1,596,648 events

Truth information

Particle species, decay chains and kinematics

Physics studies

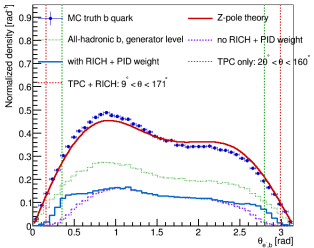
- Inclusive heavy-flavor yields
- Charm ΔA_{CP} precision
- CKM γ sensitivity

Baseline PID and assumed RICH PID

Possible gains from additional small-angle PID

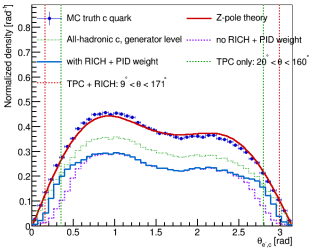
RICH increases inclusive heavy-flavor yields

b **sample:** +19.72%



$b \to B^{0,\pm}, B_s^0, B_c^{\pm}, \Lambda_b^0, \Xi_b^{0,\pm}, \Omega_b^{\pm}$
$\to p/\bar{p}, K^{\pm}, \pi^{\pm}$

c **sample:** +10.71%



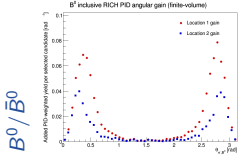
$c \to D^{0,\pm}, D_s^{\pm}, \Lambda_c^{\pm}, \Xi_c^{0,\pm}, \Omega_c^0$
$\to p/\bar{p}, K^{\pm}, \pi^{\pm}$

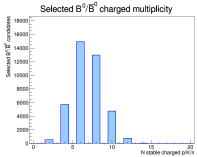
	b sample			*c* sample		
	baseline	RICH	relative PID gain	baseline	RICH	relative PID gain
hadronic events PID efficiency	28.04%	**33.57%**	**19.72%**	57.67%	**63.84%**	**10.71%**

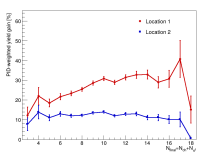
Location 1 provides larger PID gains

Modes with charged $p/K/\pi$ and π^0 candidates are evaluated assuming $\epsilon_{\pi^0} = 0.8$.

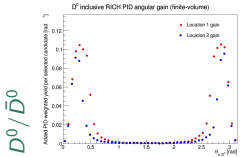
$B^0/\bar{B}^0$

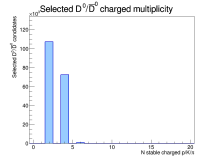


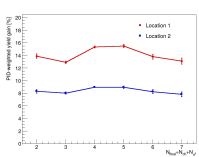




$D^0/\bar{D}^0$







PID gain

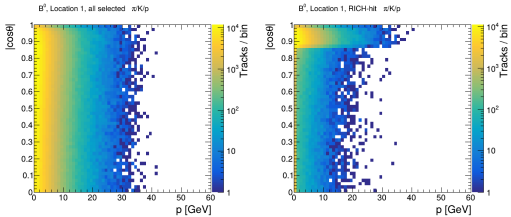
Location	$B^0/\bar{B}^0$	$D^0/\bar{D}^0$
Location 1	**27.5%**	**14.5%**
Location 2	12.7%	8.6%

Key observations

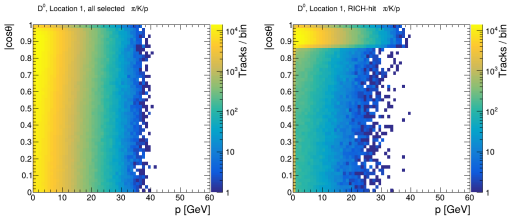
- Location 1 provides larger gains for both B^0 and D^0.
- Generally the gain increases with final-state multiplicity.

RICH-hit tracks occupy the forward low-momentum region

$B^0/\bar{B}^0$, **Location 1**



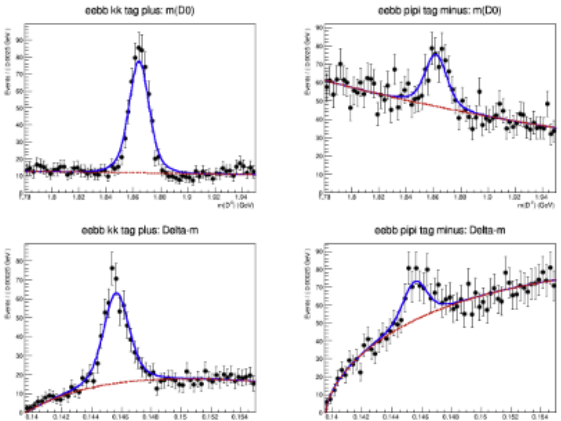
$D^0/\bar{D}^0$, **Location 1**



Scenario	B^0 RICH-hit fraction	D^0 RICH-hit fraction	RICH hits below 20 GeV, B^0/D^0
Location 1	**16.6%**	**17.0%**	99.67% / 98.15%
Location 2	8.6%	8.5%	99.71% / 98.16%

Almost all tracks with RICH hits have momenta below $20\,\mathrm{GeV}/c$**.**

ΔA_{CP} benchmark



Representative $e^+e^- \to b\bar{b}$, $D^0 \to K^+K^-$ $D^0 \to \pi^+\pi^-$, baseline PID fit.

$$D^{*\pm} \to D^0\pi_s^\pm, \pi \text{ tag } D \text{ flavor}$$

$$D^0 \to K^+K^-,\ \pi^+\pi^-.$$

$$\Delta A_{CP} = A_{\rm raw}(KK) - A_{\rm raw}(\pi\pi).$$

The simultaneous fit uses $m(D^0)$, $\Delta m = m(D^*) - m(D^0)$, and

$$\mu = N_S S + N_P P + N_C C + N_X X,$$

with signal, real-D^0 plus random-π_s, combinatorial and cross-feed components.

Why RICH gives little gain for ΔA_{CP}

$D^0 \to h^+h^-$: two charged daughter tracks

Only a small fraction enters the Location 1 RICH:

	KK	$\pi\pi$
eecc	3.1%	2.8%
eebb	2.7%	3.9%

Few tracks receive additional PID information, so the precision gain is limited.

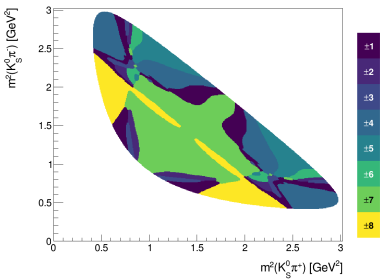
Extrapolation to $10^{12}Z$

$$\sigma^{(q)}_{10^{12}Z} = \sigma^{(q)}_{\mathrm{MC}} \sqrt{\frac{N^{(q)}_{\mathrm{MC}}}{10^{12}\,\mathcal{B}(Z \to q\bar{q})}}.$$

Sample	baseline	RICH	improvement
eecc	2.18×10^{-4}	2.18×10^{-4}	0.28%
eebb	2.69×10^{-4}	2.68×10^{-4}	0.53%
Combined	1.70×10^{-4}	1.69×10^{-4}	0.38%

Combined precision gain: $\sim 0.4\%$

Truth-level γ benchmark: GGSZ method



16 signed GGSZ bins ($i = \pm1, \ldots, \pm8$).

External charm inputs

- BESIII strong-phase measurements provide (F_i, c_i, s_i) and their covariance.

Signal channel: $B^\pm \to DK^\pm,\ D \to K^0_S\pi^+\pi^-$

Expected bin yields

$$S_i^\pm = h_B \Big[F_{\mp i} + r_B^2 F_{\pm i} + 2 r_B \sqrt{F_i F_{-i}} \left(c_i \cos(\delta_B \pm \gamma) \pm s_i \sin(\delta_B \pm \gamma) \right) \Big]$$

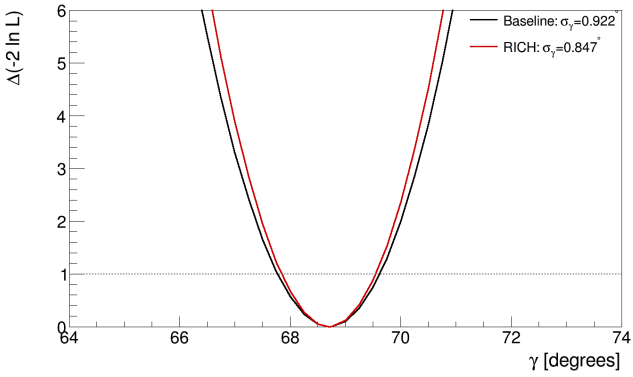
$$\mu_i^\pm = S_i^\pm + B_i^{D\pi,\pm}$$

Binned Poisson likelihood

$$-2 \ln \mathcal{L} = 2 \sum_{i,\pm} \left[\mu_i^\pm - n_i^\pm + n_i^\pm \ln \frac{n_i^\pm}{\mu_i^\pm} \right] + \Delta \mathbf{z}^T V_{c,s}^{-1} \Delta \mathbf{z}$$

- $n_i^\pm$: Asimov yields generated at the input $\gamma_{\rm in}$.
- $\mu_i^\pm$: Expected yields at the scanned γ.

Truth-level γ profile: RICH gain in the current Z-pole dataset



Truth-level GGSZ fit

$B^{\pm} \to DK^{\pm}, \qquad D \to K^0_S \pi^+ \pi^-$

Physical $B^{\pm} \to D\pi^{\pm}$ cross-feed is included.

Profile likelihood

$$\Delta(-2\ln L)(\gamma) = -2\ln \frac{\mathcal{L}(\gamma, \hat{\hat{\boldsymbol{\theta}}}_\gamma)}{\mathcal{L}(\hat{\gamma}, \hat{\boldsymbol{\theta}})}$$

$$\hat{\hat{\boldsymbol{\theta}}}_\gamma = \arg\max_{\boldsymbol{\theta}} \mathcal{L}(\gamma, \boldsymbol{\theta})$$

$\Delta(-2\ln L) = 1 \quad \Rightarrow \quad 1\sigma$ precision on γ

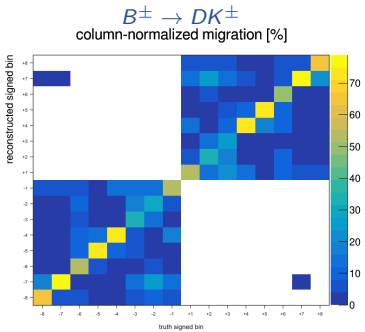
Current Z-pole dataset

$\sigma_\gamma^{\text{base}} \simeq 0.923^\circ, \qquad \sigma_\gamma^{\text{RICH}} \simeq 0.847^\circ$

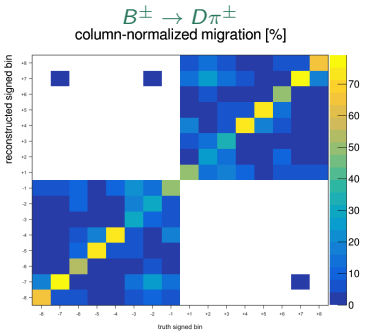
8.22% better precision

Baseline and nominal RICH use the same current Z-pole dataset.

Reco-level detector 0response: migration and $D\pi$ cross-feed



Signal-mode Dalitz-bin migration after reconstruction and selection.

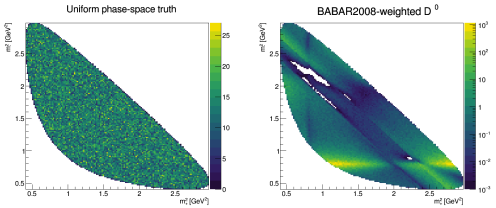


Potential cross-feed source, processed with the same selection.

$$M_{ji} = P(j_{\mathrm{reco}} \mid i_{\mathrm{truth}}, \mathrm{selected}), \qquad \sum_j M_{ji} = 1.$$

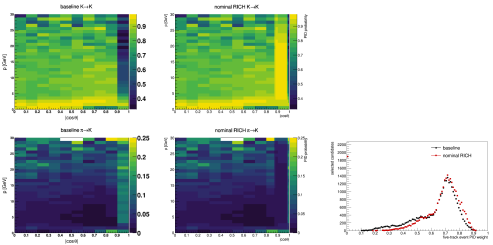
Off-diagonal entries describe Dalitz-bin migration.

Amplitude model and event-level five-track PID



Uniform phase space; the realistic sample is reweighted event-by-event.

$$w_{D^0} = I_{\mathrm{LUT}}(m_-^2, m_+^2), \qquad w_{\bar{D}^0} = I_{\mathrm{LUT}}(m_+^2, m_-^2).$$



PID is evaluated per track from momentum, direction, charge/species and detector scenario, then combined over all five tracks.

$$w_{\mathrm{event}} = \prod_{k=1}^{5} w_{\mathrm{PID}}(p_k, \cos\theta_k, q_k, \mathrm{scenario}).$$

Reco-level GGSZ likelihood

Direct fit

- The current profile scan is performed directly in (γ, r_B, δ_B); the physical-parameter yield model is shown below:

$$
\begin{aligned}
N_i^- &\propto F_i + r_B^2 F_{-i} \\
&\quad + 2r_B\sqrt{F_i F_{-i}}\,[c_i\cos(\delta_B-\gamma) - s_i\sin(\delta_B-\gamma)], \\
N_i^+ &\propto F_{-i} + r_B^2 F_i \\
&\quad + 2r_B\sqrt{F_i F_{-i}}\,[c_i\cos(\delta_B+\gamma) + s_i\sin(\delta_B+\gamma)].
\end{aligned}
$$

Reco-bin expectation

$$
\mu_j^{\pm} = \sum_i R_{ji}^{DK} N_i^{\pm} + \sum_i R_{ji}^{D\pi} N_i^{D\pi,\pm}.
$$

$\mu_j^{\pm}$: expected mean candidates in reco bin j; $n_j^{\pm}$: observed (here Asimov) count in that bin.

$$
-2\ln\mathcal{L} = 2\sum_{j,\pm}\left[\mu_j^{\pm} - n_j^{\pm} + n_j^{\pm}\ln\frac{n_j^{\pm}}{\mu_j^{\pm}}\right] + \Delta\mathbf{z}^T V_{c,s}^{-1}\Delta\mathbf{z}.
$$

Fixed $D\pi/DK$ normalization assumption

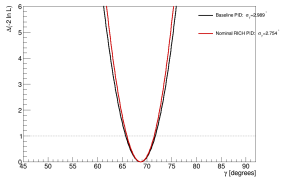
$$
\frac{\mathcal{B}(B\to D\pi)}{\mathcal{B}(B\to DK)} = 12.5
$$

$$
\begin{aligned}
N_{Dh}^{\mathrm{prod}} &= N_Z\,\mathcal{B}(Z\to b\bar{b})\,f_{B^\pm}\,\mathcal{B}(B^\pm\to Dh^\pm) \\
&\quad\times\mathcal{B}(D\to K_S^0\pi^+\pi^-) \\
&\quad\times\mathcal{B}(K_S^0\to\pi^+\pi^-), \qquad h = K,\pi.
\end{aligned}
$$

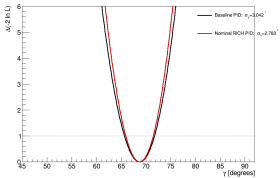
Fit inputs

- $R_{ji}^{DK,D\pi}$ include reconstruction, selection, migration and five-track PID;
- F_i are fixed to BESIII values and profiles the full BESIII c_i, s_i covariance.

Reco-level γ sensitivity: phase-space comparison



Uniform phase space



BABAR2008 amplitude model

Both curves are direct physical-parameter profiles with the full BESIII c_i, s_i covariance.

Result for the current Z-pole dataset

phase-space model	baseline	RICH
Uniform	2.989°	2.754°
BABAR2008	3.042°	2.783°

- RICH gain: 7.87% (uniform), 8.51% (BABAR2008);
- F_i fixed to BESIII; full c_i, s_i covariance profiled;
- response includes formal reconstruction, selection, migration and five-track PID;
- $D\pi/DK = 12.5$.

Summary

Gain in inclusive events with PID information

- Forward/backward PID increases the usable heavy-flavor yield.

b : $+\mathbf{19.72}\%$

c : $+\mathbf{10.71}\%$

for all hadronic final states.

Location comparison

	$B^0/\bar{B}^0$	$D^0/\bar{D}^0$
Loc. 1	$+\mathbf{27.5\%}$	$+\mathbf{14.5\%}$
Loc. 2	$+12.7\%$	$+8.6\%$

Location 1 overlaps more with the forward heavy-flavor track population and therefore gives the larger PID gain.

Physics benchmarks

Charm: $D^0 \to KK, \pi\pi$ ΔA_{CP}

$\sim \mathbf{0.4}\%$ precision gain

Truth-level γ in the current Z-pole dataset

σ_γ : $0.923^\circ \longrightarrow 0.847^\circ$

$\mathbf{8.22}\%$ gain

Reco-level γ

σ_γ : $3.042^\circ \longrightarrow 2.783^\circ$

$\mathbf{8.51}\%$ gain

RICH precision gain depends on the number of final-state particles.

Other RICH detector layouts and PID-performance scenarios are also possible.