

Feasibility study of measuring $b \rightarrow s\gamma$ photon polarization in $D^0 \rightarrow K_1(1270)^- e^+ \nu_e$ at STCF

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Outline

- **Motivation**
- **Super Tau Charm Facility (STCF) and simulation**
- **Event selection and analysis**
- **Optimization of detector response**
- **Statistical analysis**
- **Summary**

Photon Polarization In $b \rightarrow s\gamma$

➤ Sensitivity to BSM

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* (C_{7L}\mathcal{O}_{7L} + C_{7R}\mathcal{O}_{7R})$$

$$|C_{7L}|^2 \gg |C_{7R}|^2 \quad (|C_{7L}|^2 \ll |C_{7R}|^2).$$

- In SM, left-(right-)handed photon predominate in $\bar{B}(B)$ decays.

➤ Have never been measured at a high precision

- Time dependent asymmetry decays $B(t) \rightarrow X_{s/d}^{CP} \gamma$ [1]
- $b \rightarrow sl^+l^-$ transition [2]
- $\Lambda_b \rightarrow \Lambda\gamma$ [3]

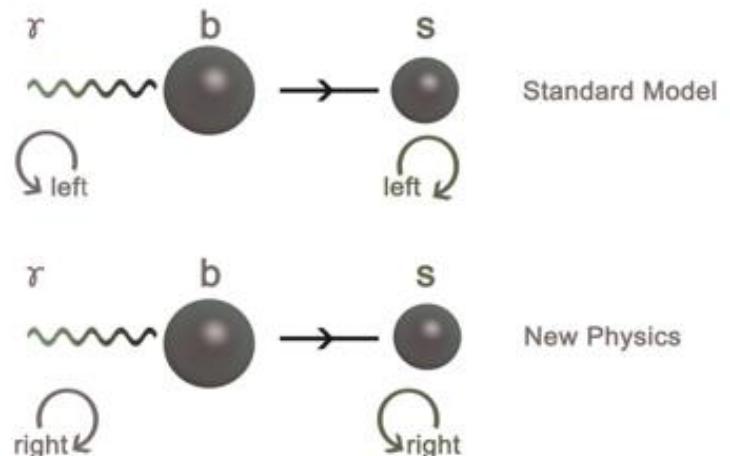
➤ Hadronic state helicity in $B \rightarrow K_{res} (\rightarrow K\pi\pi)\gamma$ [4]

$$\lambda_\gamma = \frac{|C_{7R}|^2 - |C_{7L}|^2}{|C_{7R}|^2 + |C_{7L}|^2}$$

$$\begin{aligned} A_{UD} &= \frac{\Gamma_{K_{res}}\gamma[\cos \theta_K > 0] - \Gamma_{K_{res}}\gamma[\cos \theta_K < 0]}{\Gamma_{K_{res}}\gamma[\cos \theta_K > 0] + \Gamma_{K_{res}}\gamma[\cos \theta_K < 0]} \\ &= \lambda_\gamma \frac{3 \operatorname{Im}[\vec{n} \cdot (\vec{J} \times \vec{J}^*)]}{4 |\vec{J}|^2}. \end{aligned}$$

$\lambda_\gamma \simeq -1$ for $b \rightarrow s\gamma$ and $\lambda_\gamma \simeq +1$ for $\bar{b} \rightarrow \bar{s}\gamma$.

R. Aaij et al. (LHCb Collaboration), Phys. Rev. Lett. 112, 161801 (2014).



● Picture taken from report of Fu-Sheng Yu

- [1]. F. Muheim, Y. Xie and R. Zwicky, Phys. Lett. B 664 174 (2008). [2]. F. Kruger and J. Matias, Phys. Rev. D 71 094009 (2005).
- [3]. T. Mannel and S. Recksiegel, Acta Phys. Pol. B 28, 2489 (1997); G. Hiller and A. Kagan, Phys. Rev. D 65, 074038 (2002)
- [4]. M. Gronau, Y. Grossman, D. Pirjol, and A. Ryd, Phys. Rev. Lett. 88, 051802 (2002); Gronau, Michael and Pirjol, Dan, Phys. Rev. D 66, 054008 (2002)

Measuring Photon Polarization In $b \rightarrow s\gamma$ Model-independently

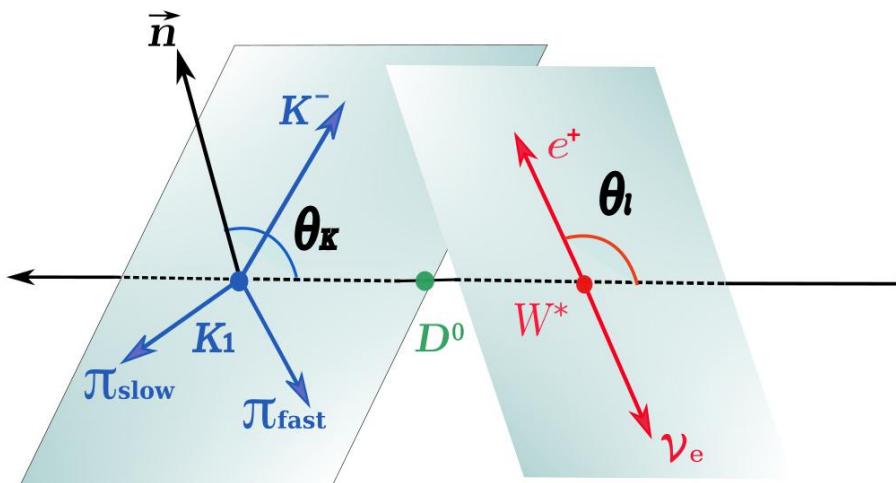
- Combining $B \rightarrow K_{res}(\rightarrow K\pi\pi)\gamma$ and $D \rightarrow K_{res}(\rightarrow K\pi\pi)l\nu_l$

$$A'_{UD} = \frac{\Gamma_{K_1^- e^+ \nu_e} [\cos \theta_K > 0] - \Gamma_{K_1^- e^+ \nu_e} [\cos \theta_K < 0]}{\Gamma_{K_1^- e^+ \nu_e} [\cos \theta_l > 0] - \Gamma_{K_1^- e^+ \nu_e} [\cos \theta_l < 0]} \\ = \frac{\text{Im}[\vec{n} \cdot (\vec{J} \times \vec{J}^*)]}{|\vec{J}|^2}.$$

$$\lambda_\gamma = \frac{4}{3} \frac{A_{UD}}{A'_{UD}}$$

W. Wang, F. S. Yu, and Z. X. Zhao,
Phys. Rev. Lett. 125, 051802 (2020).

- Kinematics for $D^0 \rightarrow K_1(1270)^- e^+ \nu_e \rightarrow K^- \pi^+ \pi^- e^+ \nu_e$



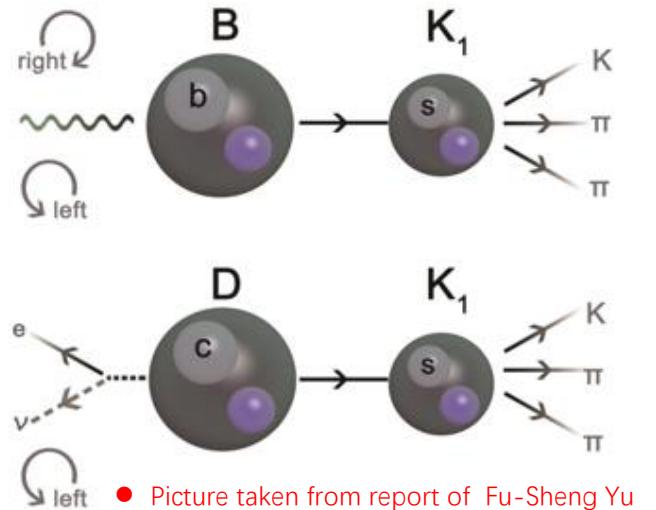
L. Bian, L. Sun and W. Wang, arXiv:2105.06207

- Observation of $D^0 \rightarrow K_1(1270)^- e^+ \nu_e \rightarrow K^- \pi^+ \pi^- e^+ \nu_e$

$$B(D^0 \rightarrow K_1(1270)^- e^+ \nu_e) = (1.09 \pm 0.13^{+0.09}_{-0.16} \pm 0.12) \times 10^{-3}$$

Statistically limited to measure the A'_{UD}

M. Ablikim et al. (BESIII Collaboration),
arXiv:2102.10850 [hep-ex]

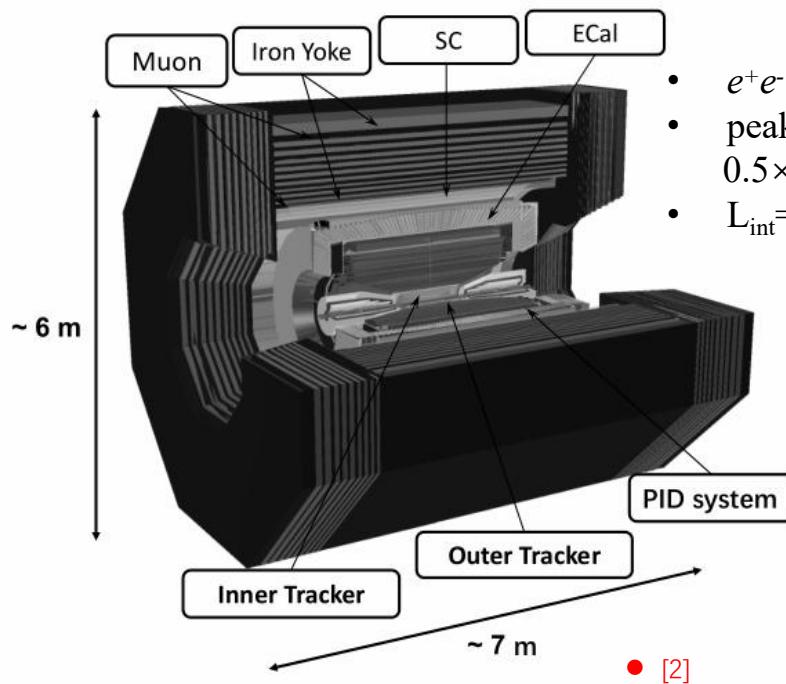


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- [1]. F. Muheim, Y. Xie and R. Zwicky, Phys. Lett. B 664 174 (2008). [2]. F. Kruger and J. Matias, Phys. Rev. D 71 094009 (2005).
- [3]. T. Mannel and S. Recksiegel, Acta Phys. Pol. B 28, 2489 (1997); G. Hiller and A. Kagan, Phys. Rev. D 65, 074038 (2002)
- [4]. M. Gronau, Y. Grossman, D. Pirjol, and A. Ryd, Phys. Rev. Lett. 88, 051802 (2002); Gronau, Michael and Pirjol, Dan, Phys. Rev. D 66, 054008 (2002)

STCF and MC Simulation

➤ Concept design of STCF [1]



- e^+e^- @ $\sqrt{s} = 2.0\text{--}7.0$ GeV
- peaking luminosity $0.5 \times 10^{35}\text{cm}^{-2}\text{s}^{-1}$ @ $\sqrt{s} = 4.0$ GeV
- $L_{\text{int}} = 1\text{ab}^{-1}$ per year

charmed hadron pairs near the charm threshold
allow for measuring A'_{UD} in with very low background level

[1]. H. P. Peng, High Intensity Electron Positron Accelerator (HIEPA), Super Tau Charm Facility (STCF) in China, talk at Charm2018, Novosibirsk, Russia, May 21-25, 2018.

[2]. X.-D. Shi *et al.* JINST 16 P03029 (2021)

[3]. D. Scora and N. Isgur, Phys. Rev. D 52 2783 (1995).

[4]. P.A.Zyla et al.(ParticleDataGroup),Prog.Theor.Exp. Phys. 2020 083C01 (2020)

[5]. H. Guler *et al.* (Belle Collaboration), Phys. Rev. D 83 032005 (2011).

➤ Fast simulation tool for STCF [2]

- Resolution and efficiency responses for tracking of final state particles, PID system ; kinematic fit related to variables.
- Functions for adjust performance of each sub-system.

➤ MC simulated samples 1ab^{-1} @ $\sqrt{s} = 3.773$ GeV

- Beam-energy spread , ISR in the e^+e^- annihilations, ISR production of J/Ψ and Ψ states, other continuum process
- $D^0 \rightarrow K_1(1270)^- e^+ \nu_e$ ISGW2 [3] , BF[4]
- The mass , width[4] and ratio of subdecays of $K_1(1270)$ [5](fit2)

Mass (GeV/c^2)	1.253 ± 0.007
Width (MeV)	90 ± 20
Decay mode	Decay ratio (%)
$K\rho$	54.8 ± 4.3
$K_0^*(1430)\pi$	2.01 ± 0.64
$K^*(892)\pi$	17.1 ± 2.3
$K\omega$	22.5 ± 5.2

Event Selection

- **Single tags (ST)** $\bar{D}^0 \rightarrow K^+ \pi^-$, $K^+ \pi^- \pi^0$, $K^+ \pi^- \pi^+ \pi^-$
- **Good charged tracks** $|\cos\theta| < 0.93$, $|dr| < 1\text{cm}$, $|dz| < 10\text{cm}$
- **Particle identification of charged Kaon and pion**

Kaon: $CL_K > 0, CL_K > CL_\pi$ Pion: $CL_\pi > 0, CL_\pi > CL_K$

electron: $\frac{E}{p} > 0.8, \frac{CL_e}{CL_e + CL_K + CL_\pi} > 0.8$

- **Neutral pion**

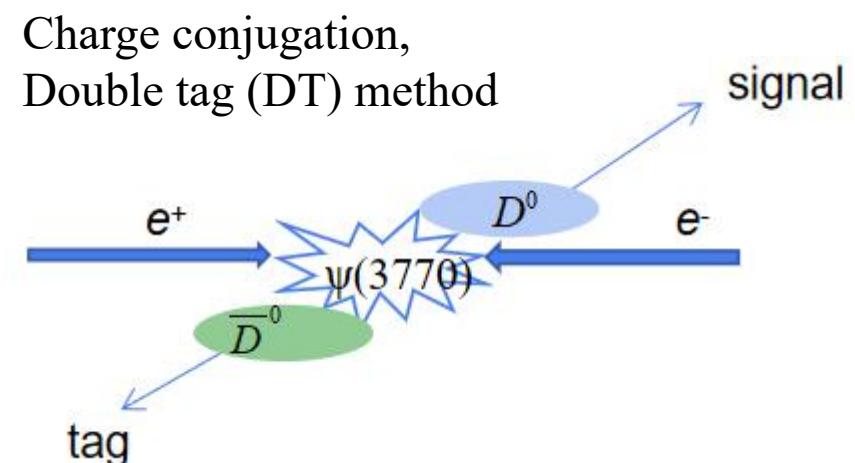
$M_{\gamma\gamma}(0.115, 0.150)\text{GeV}/c^2$

1-C mass kinematic fit on $\pi^0 \rightarrow \gamma\gamma$, $\chi^2_{\text{KMFIT}} < 200$

- **ST D mesons**

$$M_{BC} = \sqrt{E_{beam}^2 - |\vec{P}_{Kn\pi}|^2}$$

$$\Delta E = E_{Kn\pi} - E_{beam} \quad (29, 27), (-69, 38), (-31, 28) \text{ MeV}$$



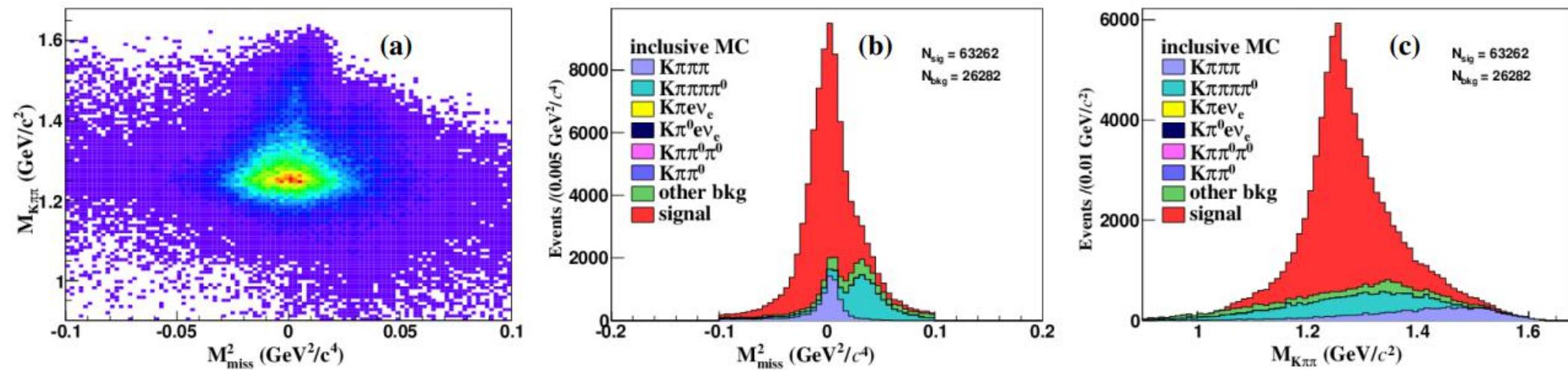
- **Singal candidates** $D^0 \rightarrow K_1(1270)^- e^+ \nu_e$
 - $K_1(1270)^- \rightarrow K^- \pi^+ \pi^-$
 - only four good unused charged tracks
 - charge(lepton) = charge(Kaon in tag side)
 - other three charged tracks are identified as a Kaon and two pions.
 - charge(Kaon) = -charge(lepton)
- **Main peaking backgrounds** $e \leftrightarrow \pi$, criterial are same as
M. Ablikim et al. (BESIII Collaboration), arXiv:2102.10850 [hep-ex]

DT Candidates

- Accepted $D^0 \rightarrow K^-\pi^+\pi^-e^+\nu_e$ candidate events

$$M_{miss}^2 = E_{miss}^2 - p_{miss}^2, \quad E_{miss} = E_{beam} - E_{K\pi\pi e}$$

$$p_{miss} = |\vec{p}_{tag} - \vec{p}_{K\pi\pi e}|, \quad \vec{p}_{tag} = \frac{\vec{p}_{tag}}{|\vec{p}_{tag}|} \sqrt{E_{beam}^2 - m_{D^0}^2}$$

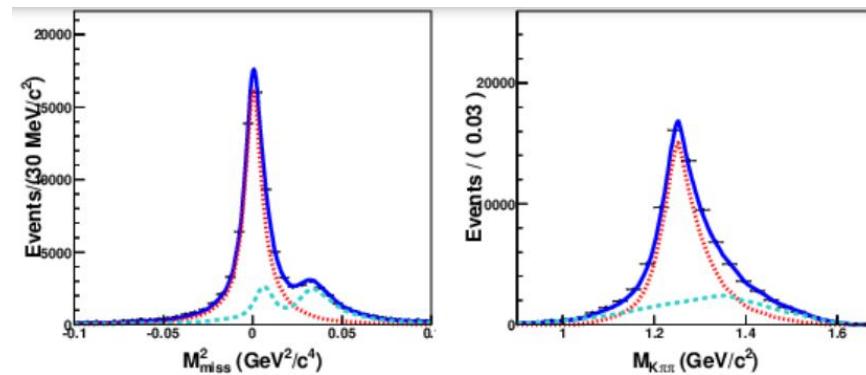


- Selection efficiencies

12.11%, 6.93%, 6.25% for $\bar{D}^0 \rightarrow K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^-\pi^+$

Signal Yields

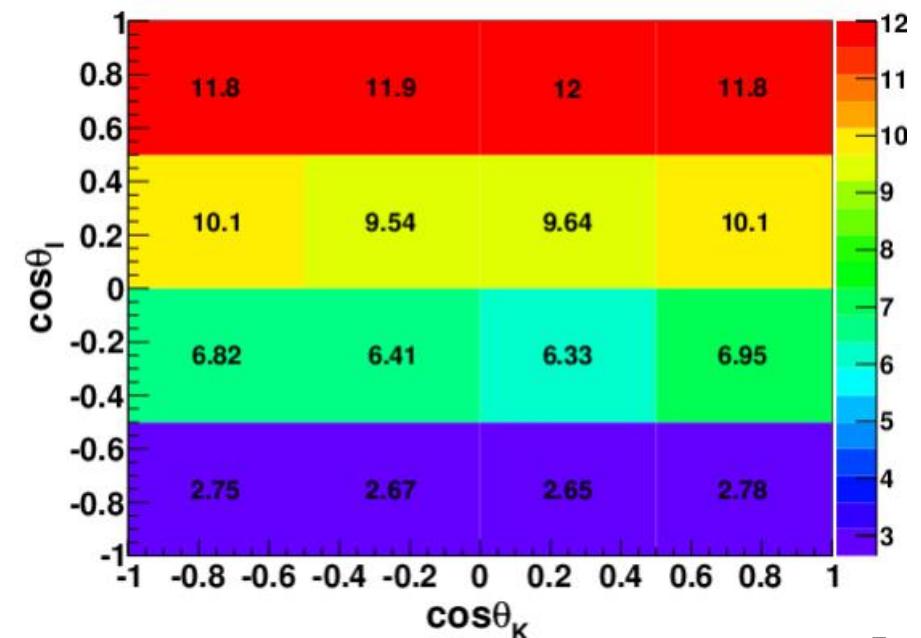
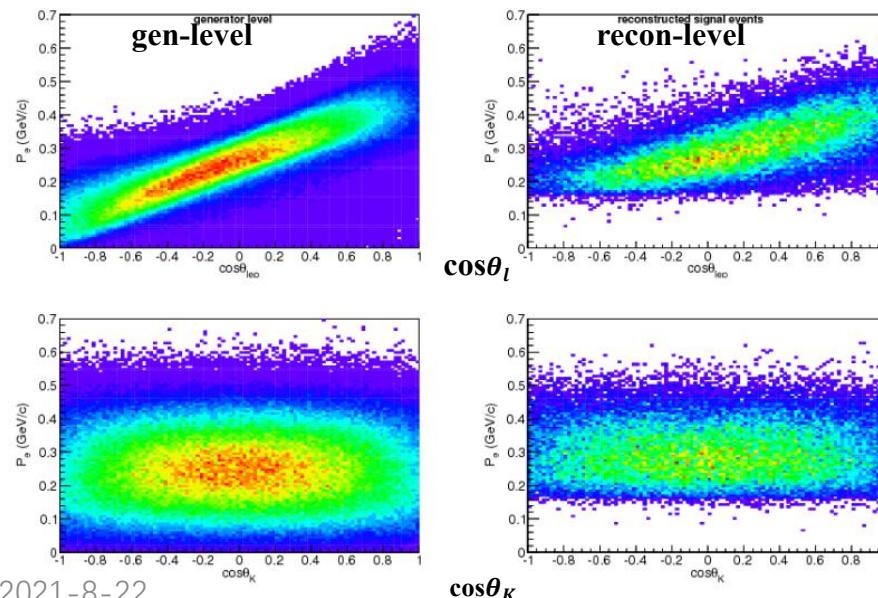
- Fit to M_{miss}^2 and $M_{K\pi\pi}$ to obtain signal yields



- Signal reconstruction efficiencies in bins of $\cos \theta_K$ and $\cos \theta_l$

$$\varepsilon_{DT}^j = \frac{\sum_i \mathcal{B}_{ST}^i \varepsilon_{DT}^{ij}}{\sum_i \mathcal{B}_{ST}^i}$$

tag mode i
angular bin j



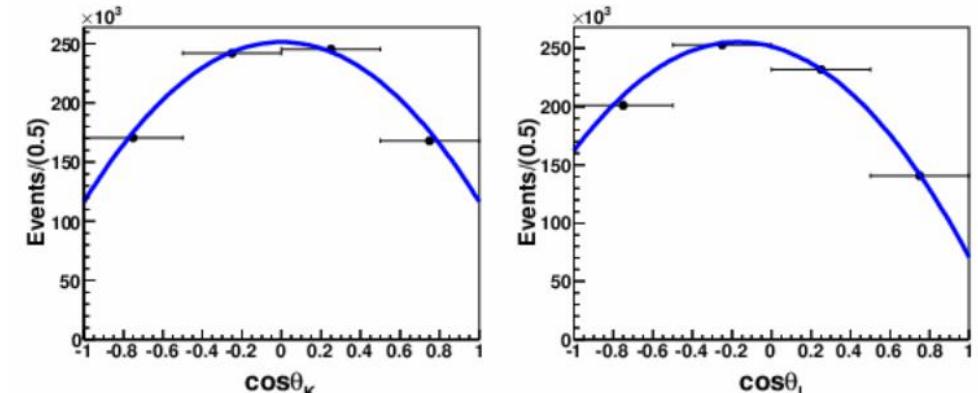
Angular Fit and Extract A'_{UD}

➤ Fit function

$$\begin{aligned} f(\cos \theta_K, \cos \theta_l; A'_{UD}, d_+, d_-) = & \\ & (4 + d_+ + d_-)[1 + \cos^2 \theta_K \cos^2 \theta_l] \\ & + 2(d_+ - d_-)[1 + \cos^2 \theta_K] \cos \theta_l \\ & + 2A'_{UD}(d_+ - d_-) \cos \theta_K [1 + \cos^2 \theta_l] \\ & + 4A'_{UD}(d_+ + d_-) \cos \theta_K \cos \theta_l \\ & - (4 - d_+ - d_-)[\cos^2 \theta_K + \cos^2 \theta_l]. \end{aligned}$$

$$d_+ = \frac{|c_+|^2}{|c_0|^2}, d_- = \frac{|c_-|^2}{|c_0|^2} \quad c_{\pm} \sim \text{transverse polarization} \quad c_0 \sim \text{longitudinal polarization}$$

➤ 2-D χ^2 fit to $\cos \theta_K$ and $\cos \theta_l$



statistical sensitivity 1.8×10^{-2} @ $1ab^{-1}$ MC sample

➤ Bin migration

full width at half maximum(FWHM) :

$$\cos \theta_l \sim 0.12$$

$$\cos \theta_K \sim 0.05$$

bin width : 0.5

expected to be negligible

➤ Counting method to calculate A'_{UD}

$$A'_{ud} = \frac{\frac{N_{KpLm}}{\epsilon_{KpLm}} + \frac{N_{KpLp}}{\epsilon_{KpLp}} - \frac{N_{KmLm}}{\epsilon_{KmLm}} - \frac{N_{KmLp}}{\epsilon_{KmLp}}}{\frac{N_{KpLp}}{\epsilon_{KpLp}} + \frac{N_{KmLp}}{\epsilon_{KmLp}} - \frac{N_{KmLm}}{\epsilon_{KmLm}} - \frac{N_{KpLm}}{\epsilon_{KpLm}}}$$

statistical sensitivity 5.2×10^{-2} @ $1ab^{-1}$ MC sample

Optimization of Detector Responses

➤ Optimized contents

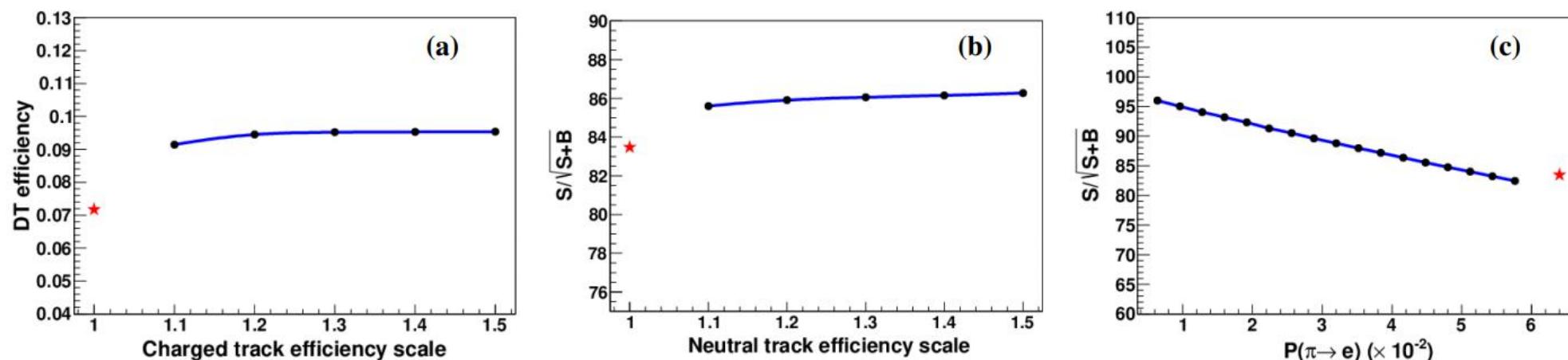
- charged tracking selection (detection efficiency, momentum and position resolution)
 - <1>. detection efficiency (p_T , $\cos\theta$) : increasing **from 10% to 50%**
 - <2>. σ_{xy} (resolution of tracking system in xy plane): **ranging from 30 um to 150 um.**
 - <3>. σ_z (resolution of tracking system in z direction): **ranging from 500 um to 2500 um.**
- neutral selection (detection efficiency, energy and position resolution)
 - <1>. detection efficiency : increasing **from 10% to 50%**
 - <2>. energy resolution : increasing **from 10% to 50%**
 - <3>. position resolution : increasing from 10% to 50%
- identification of electron at low momentum (misidentify a pion as electron in $p < 0.6 \text{ GeV}/c$)
 - <1>. misidentification rate for π/e ranging **from 5.7% to 0.64% @ 0.2GeV/c**
(can be reduced from 6.4% to 3.2% at 0.2GeV/c in STCF)

➤ Characterization of the detector performance

- figure-of-merit ($\frac{S}{\sqrt{S+B}}$)
- DT efficiencies

Optimization of Detector Responses

➤ Optimization



- reconstruction efficiency for charged track: in 1.1(10%) improved by 27%
- reconstruction efficiency for neutral track: in 1.1(10%) improved by 4%
- misidentification rate of π/e : in 3.2% @ 0.2 GeV

➤ Sensitivity

- signal selection efficiency ~ improved by 33%
- $A_{UD}' \sim 1.5 \times 10^{-2}$ (~improved by 17%)

Dependence of Wilson Coefficiency on A'_{UD}

➤ Dependence of Wilson coefficient on A'_{UD}

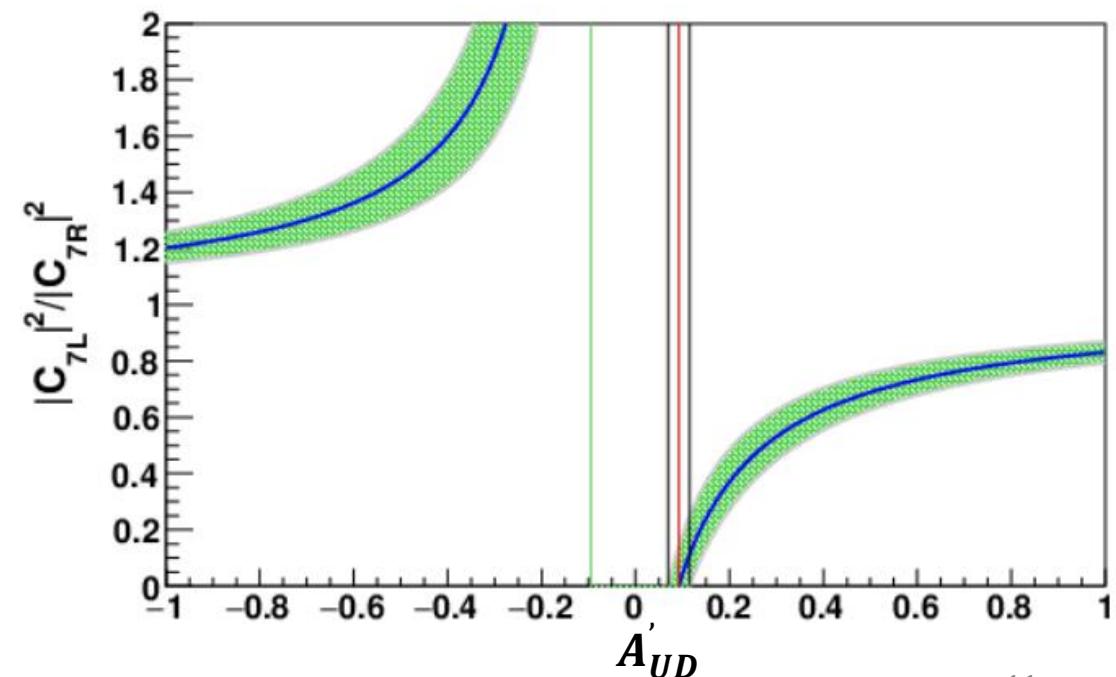
$$\frac{|C_{7L}|^2}{|C_{7R}|^2} = \frac{A'_{UD} - \frac{3}{4}A_{UD}}{A'_{UD} + \frac{3}{4}A_{UD}}$$

input of A_{UD} : $M_{K\pi\pi} \sim (1.1, 1.3) \text{ GeV}, (6.9 \pm 1.7) \times 10^{-2}$ (R. Aaij et al. (LHCb Collaboration). Phys. Rev. Lett. 112, 161801 (2014)).

In SM, $A'_{UD} = (9.2 \pm 2.3) \times 10^{-2}$

➤ Potential sources of systematic uncertainties

- electron tracking and PID efficiencies
- bin migration
- signal and background shape modeling



Summary

- **Statistical sensitivity of A'_{UD}**

$\mathcal{L} = 1 \text{ ab}^{-1}$ @ $\sqrt{s} = 3.773 \text{ GeV}$ + optimised efficiency with the fast simulation

statistical sensitivity of a ratio of up-down asymmetry A'_{UD} in $D^0 \rightarrow K_1(1270)^- e^+ \nu_e \sim 1.5 \times 10^{-2}$

- **New physics**

Combining the A_{UD} measured in $B^+ \rightarrow K_1^+ (\rightarrow K^+ \pi^- \pi^+) \gamma$

R. Aaij et al. (LHCb Collaboration). Phys. Rev. Lett. 112, 161801 (2014)
photon polarization in $b \rightarrow s \gamma$ can be measured model-independently.