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

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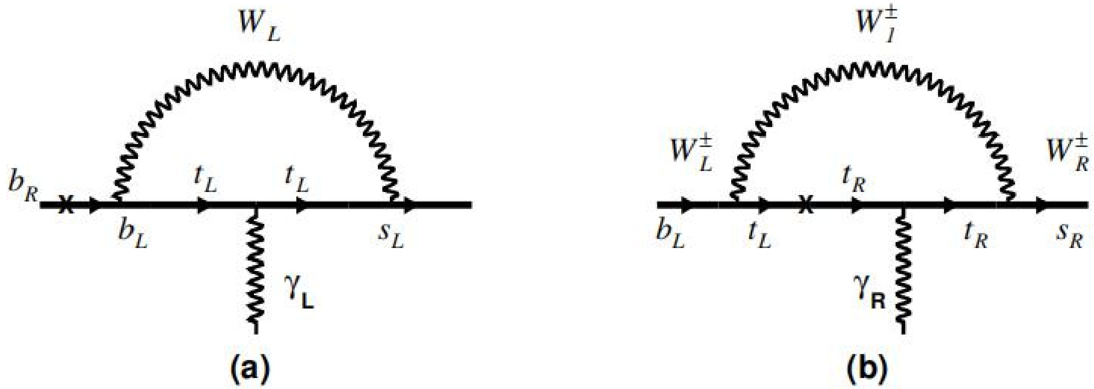
Outline

- Motivation
- MC Sample
- Event Selection and Analysis
- Optimization of Detector Response
- Statistical Analysis
- Summary

Photon Polarization In $b \to s\gamma$

- **Sensitivity to BSM**
  - In SM, right-handed vs. left-handed $\sim \dfrac{m_s}{m_b}$
  - In LRSM, right-handed vs. left-handed $\sim \dfrac{m_t}{m_b}$

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

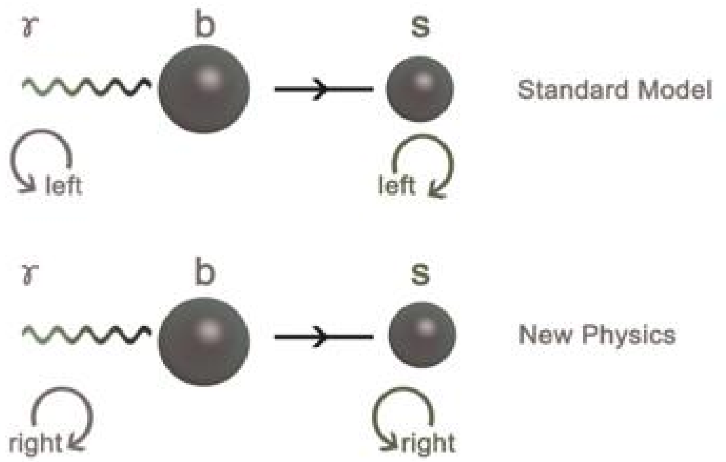


- Picture taken from report of Fu-Sheng Yu

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

for B decay : $|C_{7L}|^2 \ll |C_{7R}|^2$

for $\bar{B}$ decays : $|C_{7L}|^2 \gg |C_{7R}|^2$



- Picture taken from report of Fu-Sheng Yu

Photon Polarization In $b \to s\gamma$

➢ Have never been measured at a high precision

- CP asymmetry in time dependent decays $B(t) \to X_{s/d}^{CP}\gamma$ [1]
- $b \to sl^+l^-$ transition [2] (l^+l^-come from a virtual photon)
- $\Lambda_b \to \Lambda\gamma$ [3] (forward-upward asymmetry)

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

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

In SM, $\lambda_\gamma \simeq -1$ for $b \to s\gamma$ and $\lambda_\gamma \simeq +1$ for $\bar{b} \to \bar{s}\gamma$.

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

$M_{K\pi\pi}$ in (1.1,1.3) GeV, $A_{UD} = (6.9 \pm 1.7) \times 10^{-2}$

Observation of photon polarization !

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

- [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)

A'_{UD} of D semipleptonic decay

- **To extract λ_γ**

  a ratio of Up-Down Asymmetry in semi-leptonic decay $D \to K_1 l^+ \vartheta_l \sim A'_{UD}$

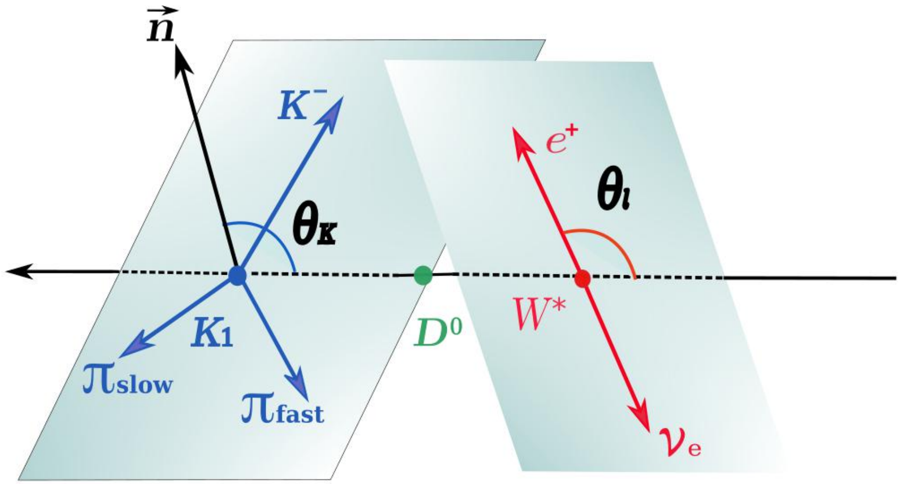
- **Combining $B \to K_{res}(\to K\pi\pi)\gamma$ and $D \to K_{res}(\to K\pi\pi)l\nu_l$**

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

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

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

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



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

Statistically limited to measure the A'_{UD}

M. Ablikim et al. (BESIII Collaboration), Phys. Rev. Lett 127,131801,(2021)

MC Simulation

➢ Fast simulation tool for STCF [1]

- 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

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

- **1ab^{-1} @$\sqrt{s}$ = 3.773 GeV**
  $$e^+e^- \sim D\bar{D},\ non-D\bar{D},\ \gamma_{ISR}J/\psi,\ \gamma_{ISR}\psi(3686)$$

- $D^0 \to K_1(1270)^- e^+ \nu_e$
  ISGW2 [2] , BF[3]
  The mass , width[3,4]
  and ratio of subdecays of $K_1(1270)$[4] (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

[1]. X.-D. Shi *et al.* JINST 16 P03029 (2021)
[2]. D. Scora and N. Isgur, Phys. Rev. D 52 2783 (1995).
[3]. P.A.Zylaetal.(ParticleDataGroup),Prog.Theor.Exp. Phys. 2020 083C01 (2020)
[4]. H. Guler et al. (Belle Collaboration), Phys. Rev. D 83 032005 (2011).

Event Selection

- **Single tags (ST)** $\overline{D}^0 \to K^+\pi^-,\ K^+\pi^-\pi^0,\ K^+\pi^-\pi^+\pi^-$
- **Good charged tracks** |cosθ| < 0.93 , |dr|<1cm , |dz|<10cm
- **Particle identification of charged tracks**

  Kaon: $CL_K > 0.001, CL_K > CL_\pi$ Pion: $CL_\pi > 0.001, CL_\pi > CL_K$

  electron: $\frac{E}{p} > 0.8, \frac{CL_e}{CL_e + CL_K + CL_\pi} > 0.8, CL_e > 0.001$
- **Neutral pion**

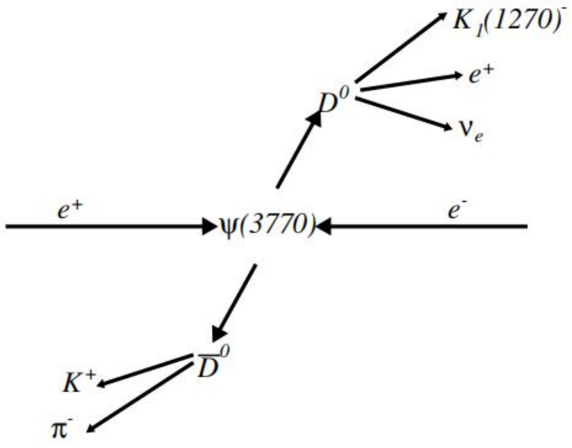
  $M_{\gamma\gamma}$ (0.115, 0.150)GeV/c^2

  1-C mass kinematic fit on $\pi^0 \to \gamma\gamma$, $\chi^2_{KMFIT} < 200$
- **ST D mesons**

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

  $M_{BC} = \sqrt{E^2_{beam} - |\vec{P}_{Kn\pi}|^2}$ ~ (1.858, 1.874) GeV/c^2

- **Charge conjugation, Double tag (DT) method**



- **Singal candidates** $D^0 \to K_1(1270)^- e^+ \nu_e$

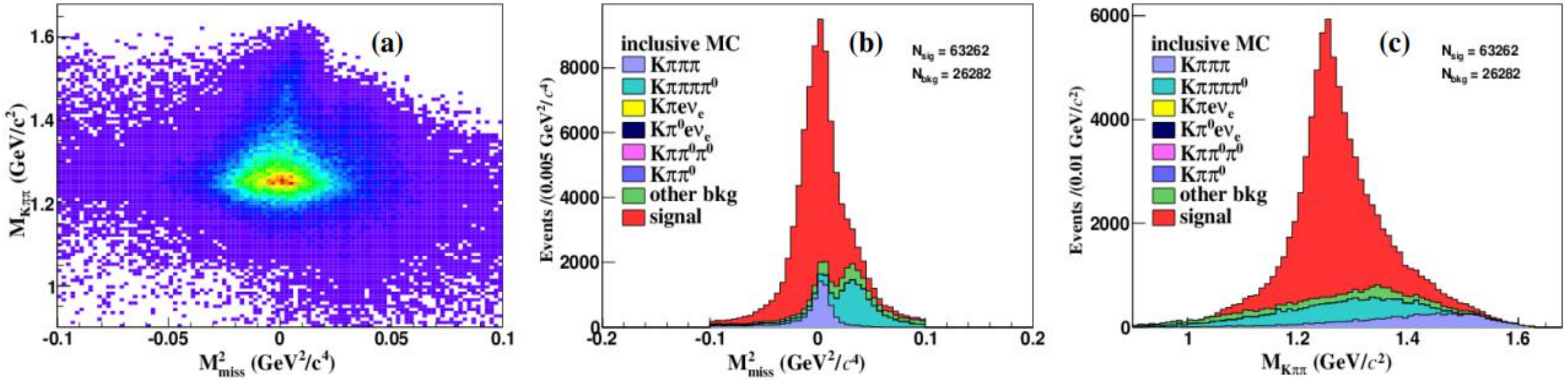
  $K_1(1270)^- \to K^-\pi^+\pi^-$

• 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)

DT Candidates

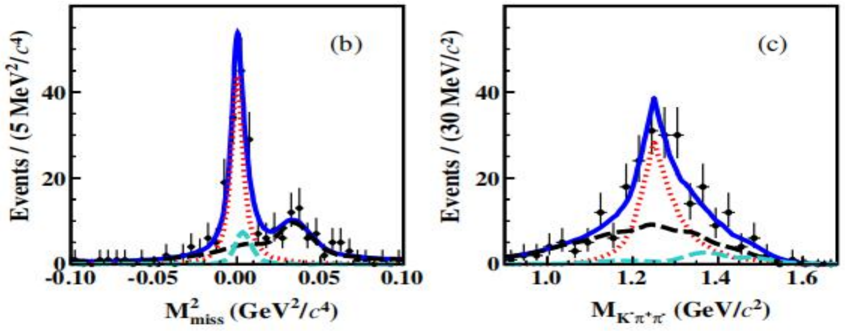
- **Main peaking backgrounds** e↔π,
  most criteria are same as **M. Ablikim et al. (BESIII Collaboration), Phys. Rev. Lett 127,131801,(2021)**

- **Accepted $D^0 \to K^-\pi^+\pi^-e^+\upsilon_e$ candidate events**



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

- **2-D fit of BESIII results ~ 109±12.5**



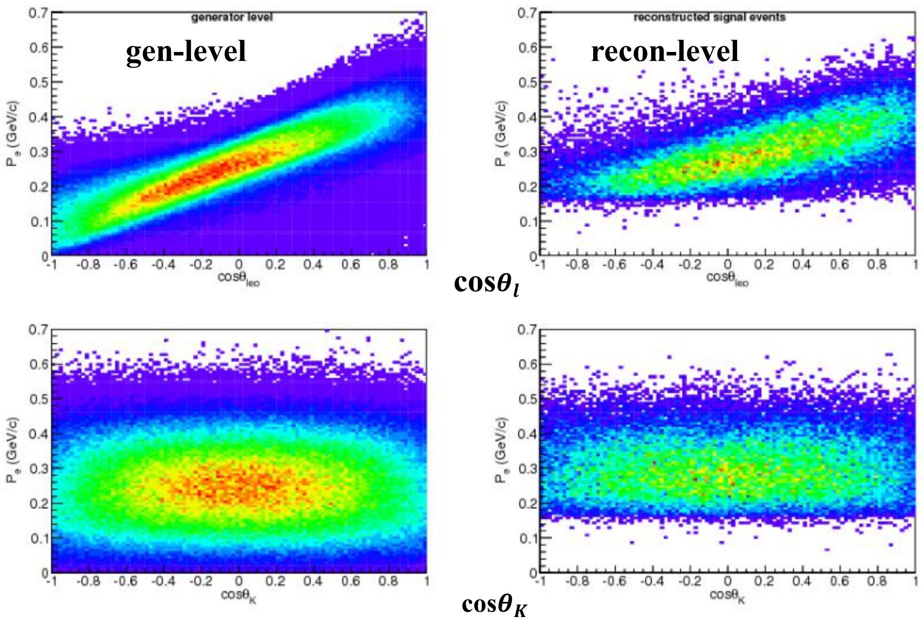
- **Selection efficiencies**

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

Dependence of DT Efficiency on $cos\theta_l$

Electron Momentum Dependence

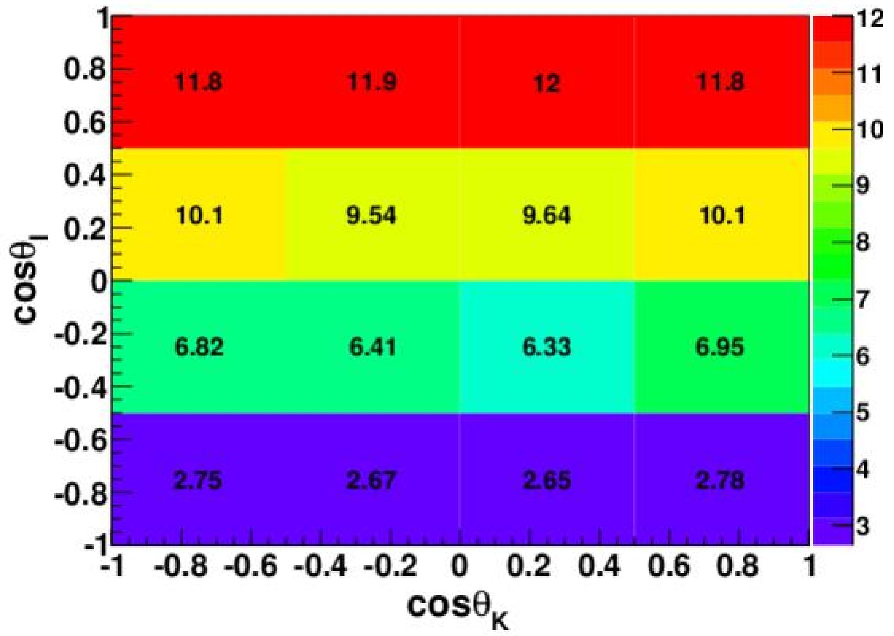
$\cos\theta_l$
~ low momentum electron
~ tracking & PID efficiencies



Singnal reconstruction efficiencies in bins of cos θ_K vs. cos θ_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 to Extract A'_{UD}

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

- 2-D unbin-maximum likelihood fit
- extracted signal yields in each ($\cos\theta_K$ vs. $\cos\theta_l$) bin

➢ Bin migration

- full width at half maximum(FWHM) :
  $\sigma(\cos\theta_l) \sim 0.12$
  $\sigma(\cos\theta_K) \sim 0.05$
- bin width : 0.5
- expected bo be negligible

➢ Fit function [1]

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

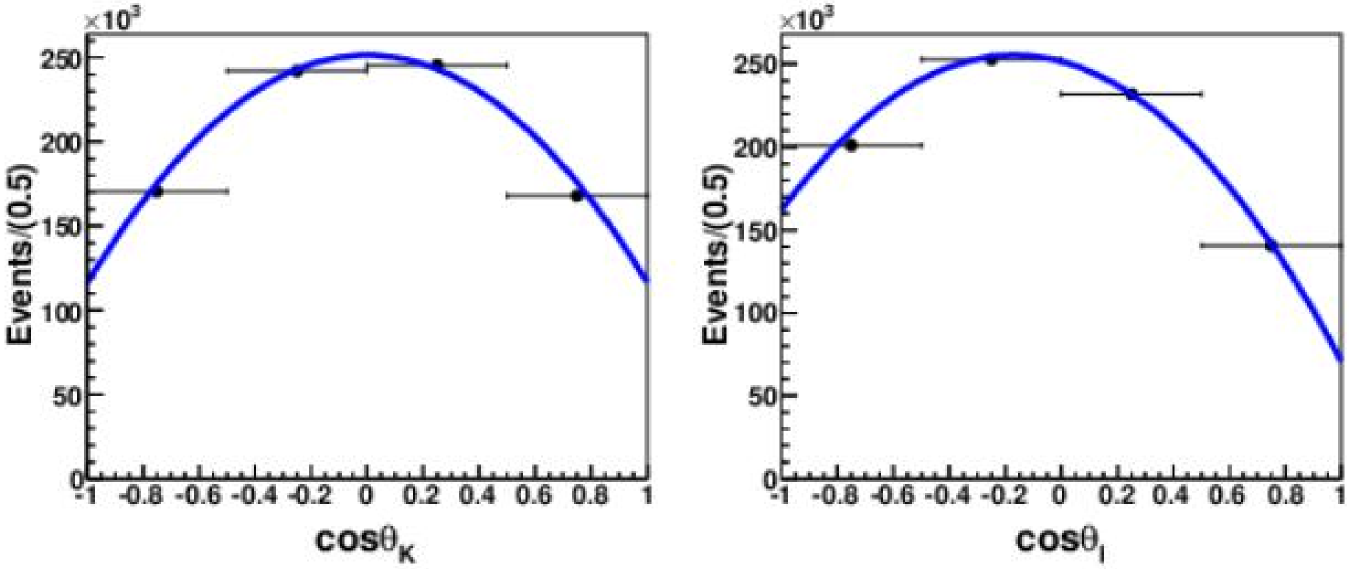
$$d_+ = \frac{|c_+|^2}{|c_0|^2}, d_- = \frac{|c_-|^2}{|c_0|^2}$$

$c_\pm$ ~ transverse polarization of K_1
c_0 ~ longitudinal polarization of K_1

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

Angular Fit to Extract $A_{UD}^{'}$

- **2-D χ^2 fit to efficiency corrected signal yields in each (cos θ_K vs. cos θ_l)**



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

Optimization of Detector Responses

➢ Optimization factors for different sub-detector responses

- **charged tracking selection** (detection efficiency, momentum and position resolution)
  <1>. detection efficiency (p_T, cosθ) : increasing **from 10% to 50%** √
  <2>. σ_{xy} (resolution of tracking system in xy plane): **ranging from 150 μm to 30 μm.**
  <3>. σ_z (resolution of tracking system in z direction): **ranging from 2500 μm to 500 μm**.

- **neutral selection** (detection efficiency, energy and position resolution)
  <1>. detection efficiency : increasing **from 10% to 50%** √
  <2>. energy resoultion : increasing **from 10% to 50%**
  <3>. position resoultion : increasing **from 10% to 50%**

- **identification of electron at low momentum** (misidentify a pion as electron in p<0.6 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)

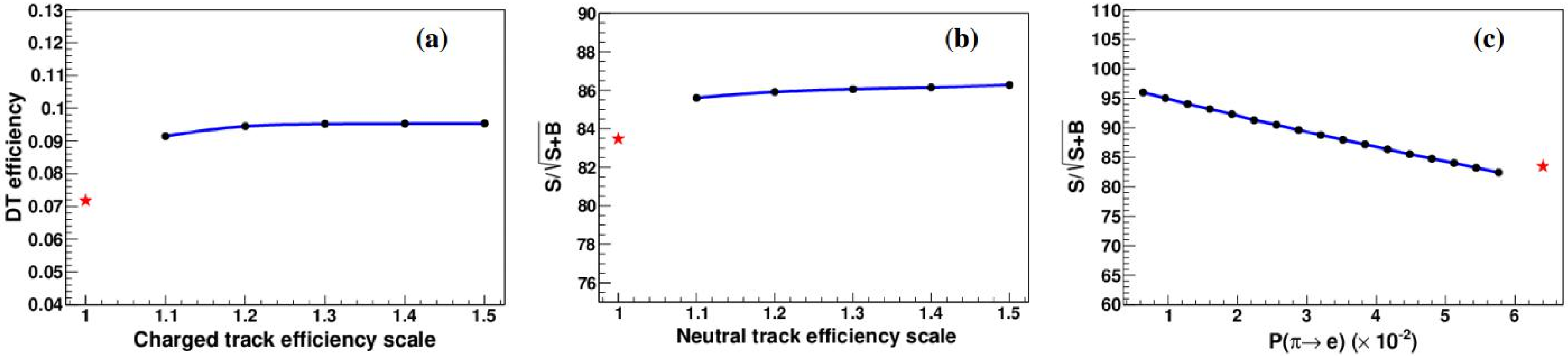
➢ Characterization of the detector performance

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

- DT efficiencies

Optimization of Detector Responses

➢ Optimization



- reconstrcution efficiency for charged track: in 1.1(10%) improved by 27%
- reconstrcution efficiency for meutral track: in 1.1(10%) improved by 4%
- misidentification rate of π/e： in 3.2% @ 0.2 GeV   improved by 7%

➢ Sensitivity

- signal selection efficiency ~ improved by 33%
- $\sigma_{stat}(A^{'}_{UD}) \sim 1.5\times10^{-2}$ (~improved by 17%)

Dependence of Wilson Coefficiency on A'_{UD}

- **Dependance of Wilson coefficienct on A'_{UD}**

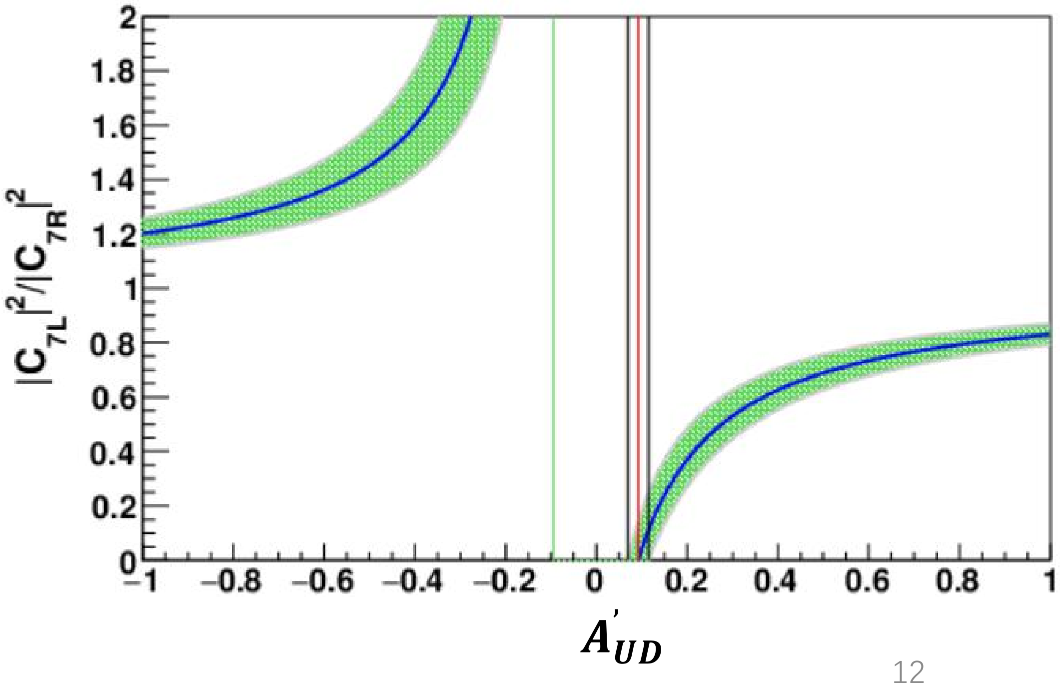
$$\frac{|C_{7L}|^2}{|C_{7R}|^2} = \frac{3A'_{UD} - 4A_{UD}}{3A'_{UD} + 4A_{UD}}$$

input of A_{UD}= $(6.9\pm1.7)\times10^{-2}$ $M_{K\pi\pi}\sim(1.1, 1.3)$ GeV
(R. Aaij et al. (LHCb Collaboration). Phys. Rev. Lett.112, 161801 (2014)).

In SM, $A'_{UD} = (9.2\pm2.3)\times10^{-2}$

- **Potential sources of systematic uncertainties**

  - electron tracking and PID efficiencies √
  - bin migration
  - signal and background shape modeling √
  - non-resonance contribution
  - $K_1(1400)$ contribution √



Summary

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

arXiv:2107.06118v3

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

statistical sensitivity of a ratio of up-down asymmetry $\boldsymbol{A'_{UD}}$ @ STCF in $D^0 \to K_1(1270)^- e^+ \nu_e$

$\sim\ 1.5\times10^{-2}$

- **Probing for new physics**

Combining the A'_{UD} in STCF and $\boldsymbol{A_{UD}}$ measured in $B^+ \to K_1^+(\to K^+\pi^-\pi^+)\gamma$ from B factories photon polarization in $b \to s\gamma$ can be measured model-independently with high precision.

Back Up

- **Counting method to calculate A'_{UD}**

$$A'_{UD} = \frac{N'(cos\theta_K > 0, cos\theta_l < 0) + N'(cos\theta_K > 0, cos\theta_l > 0) - N'(cos\theta_K < 0, cos\theta_l < 0) - N'(cos\theta_K < 0, cos\theta_l > 0)}{N'(cos\theta_K > 0, cos\theta_l > 0) + N'(cos\theta_K < 0, cos\theta_l > 0) - N'(cos\theta_K < 0, cos\theta_l < 0) - N'(cos\theta_K > 0, cos\theta_l > 0)}$$

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

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