HENAN NORMAL UNIVERSITY

Experimental Program at STCF

Huijing Li（李惠静）

Henan Normal University

On behalf of the STCF working group

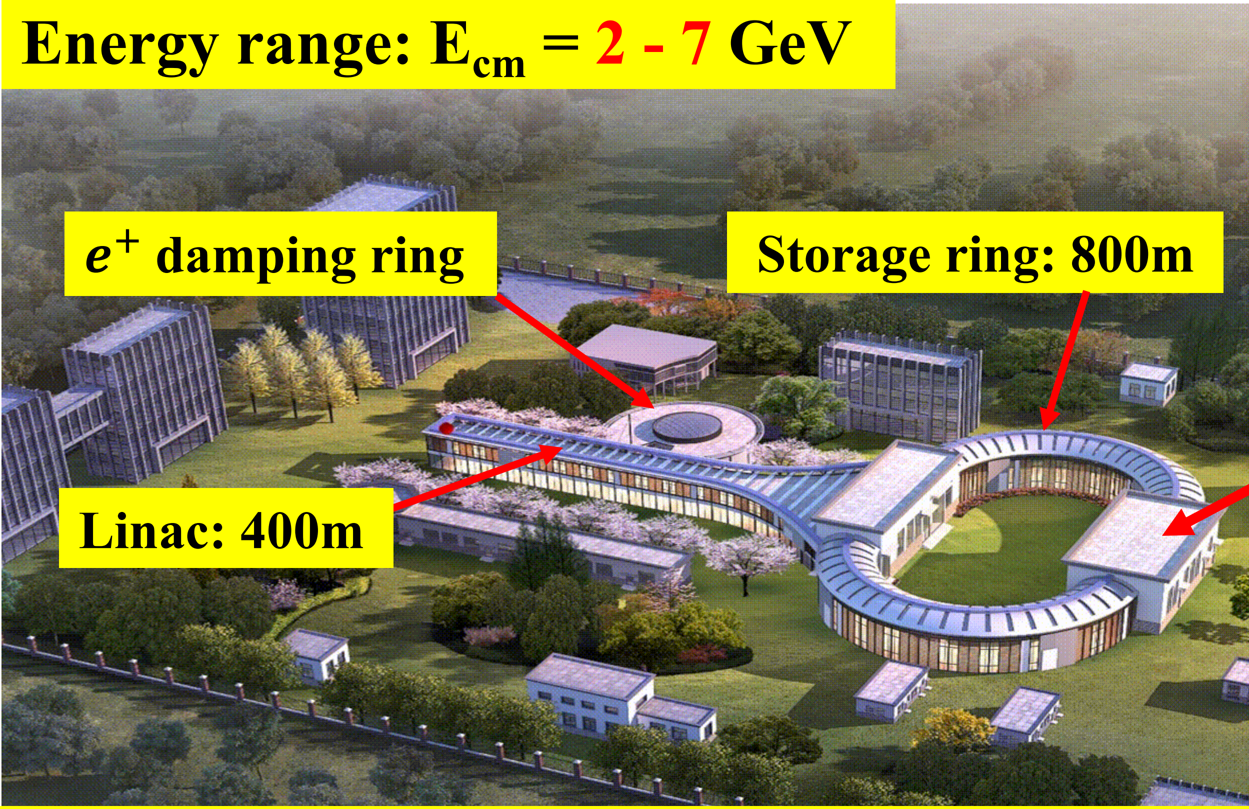
Aug. 11, 2022

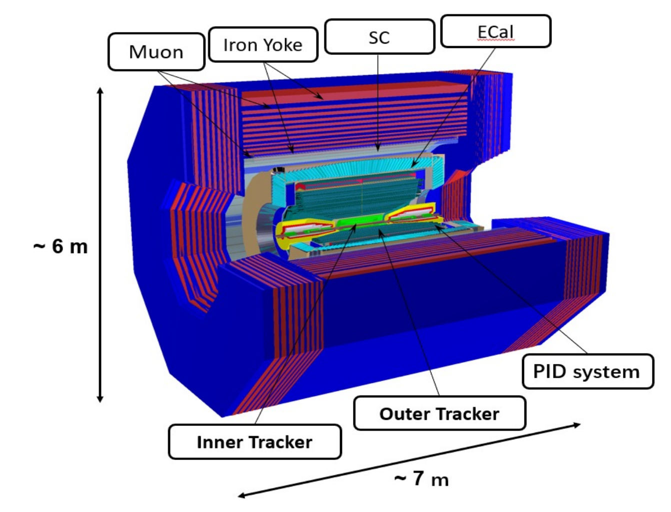
Liaoning Normal University

中国物理学会高能物理分会
第十一届全国会员代表大会暨学术年会
2022年8月8日-11日，辽宁大连(线上)

Super Tau-Charm Facility (STCF) in China

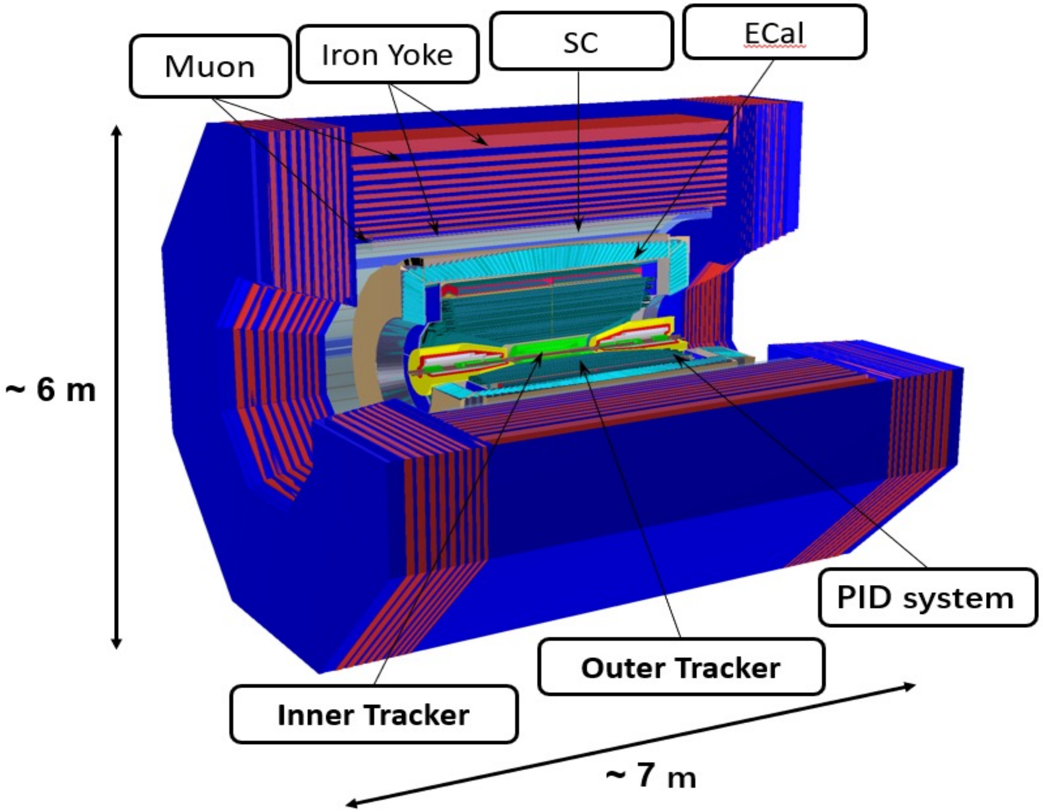
Energy range: E_{cm} = 2 - 7 GeV





- **Peaking luminosity: > 0.5×10^{35} cm^{-2} s^{-1} @ 4 GeV**
- **Potential to increase luminosity & realize beam polarization**
- **Total cost: 4.5B RMB**

STCF Detector



ITK
<0.25%X0 / layer
σ_{xy}< 100 mm

MDC
σ_{xy}< 130 mm
σp/p ~ 0.5% @ 1 GeV
dE/dx~6%

PID
π/K (and K/p) 3-4σ separation up to 2GeV/c

EMC
E range: 0.025-2GeV
σ_E @ 1 GeV: 2 .5% in barrel, 4% at endcaps
Pos. Res. : ~ 4 mm

MUD
0.4 - 1.8 GeV
π suppression >30

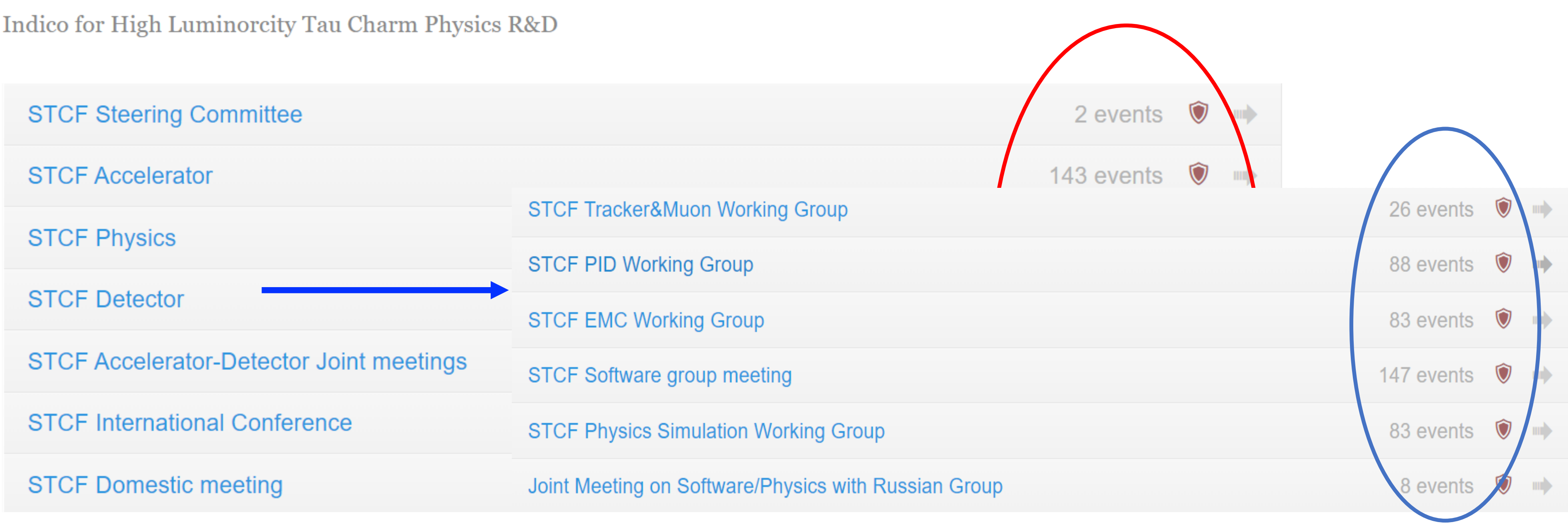
Requirement:

- High detection efficiency and good resolution
- Superior PID capability
- Tolerance to high rate/background environment

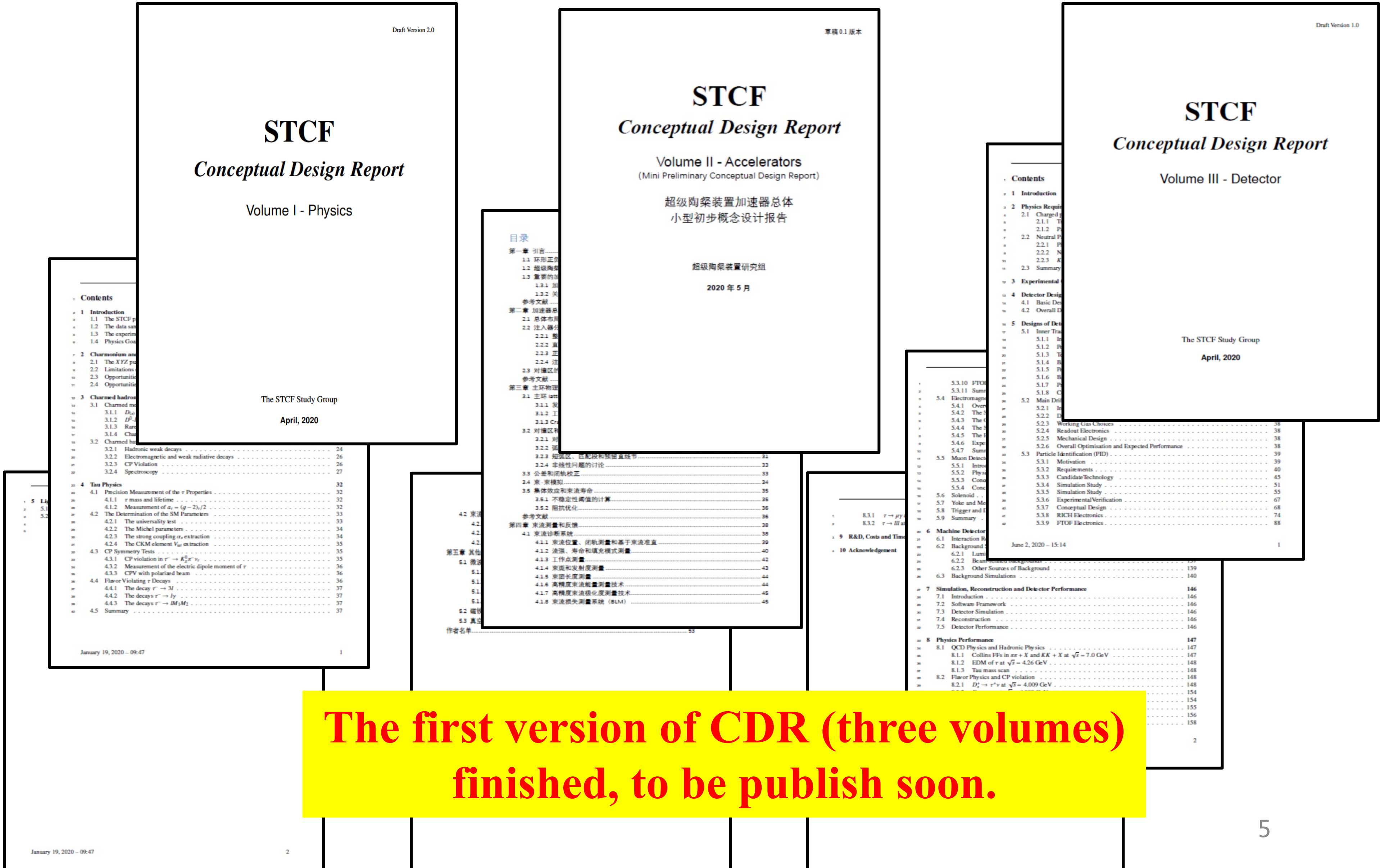
Tentative Plan

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031-2040	2041-2043
CDR															
TDR															
Construction															
Commission															
Upgrade															

Activities: http://cicpi.ustc.edu.cn/indico/categoryDisplay.py?categId=2



Conceptual design report (CDR)



The first version of CDR (three volumes) finished, to be publish soon.

Machine Parameters

Parameters	Phase1	Phase2
Circumference/m	600~800	600~800
Optimized Beam Energy/GeV	2.0	2.0
Beam Energy Range/GeV	1-3.5	1-3.5
Current/A	1.5	2.0
Emittance $(\varepsilon_x/\varepsilon_y)$/nm·rad	6/0.06	5/0.05
β Function @IP (β_x^*/β_y^*)/mm	60/0.6	50/0.5(estimated)
Full Collision Angle 2θ/mrad	60	60
Tune Shift ξy	0.06	0.08
Hourglass Factor	0.8	0.8
Aperture and Lifetime	15σ, 1000s	15σ, 1000s
Luminosity @Optimized Energy/ $\times 10^{35}cm^{-2}s^{-1}$	~0.5	~1.0

Expected Data Samples at STCF

Data sample produced per year

CME (GeV)	Lumi (ab^{-1})	samples	σ(nb)	No. of Events	remark
3.097	1	J/ψ	3400	3.4×10^{12}	
3.670	1	$\tau^+\tau^-$	2.4	2.4×10^{9}	
3.686	1	$\psi(3686)$	640	6.4×10^{11}	
		$\tau^+\tau^-$	2.5	2.5×10^{9}	
		$\psi(3686)\to\tau^+\tau^-$		2.0×10^{9}	
3.770	1	$D^0\bar{D}^0$	3.6	3.6×10^{9}	
		$D^+\bar{D}^-$	2.8	2.8×10^{9}	
		$D^0\bar{D}^0$		7.9×10^{8}	Single Tag
		$D^+\bar{D}^-$		5.5×10^{8}	Single Tag
		$\tau^+\tau^-$	2.9	2.9×10^{9}	
4.040	1	$\gamma D^0\bar{D}^0$	0.40	4.0×10^{6}	$CP_{D^0\bar{D}^0}=+1$
		$\pi^0 D^0\bar{D}^0$	0.40	4.0×10^{6}	$CP_{D^0\bar{D}^0}=-1$
		$D_s^+D_s^-$	0.20	2.0×10^{8}	
		$\tau^+\tau^-$	3.5	3.5×10^{9}	
4.180	1	$D_s^{+*}D_s^-$+c.c.	0.90	9.0×10^{8}	
		$D_s^{+*}D_s^-$+c.c.		1.3×10^{8}	Single Tag
		$\tau^+\tau^-$	3.6	3.6×10^{9}	
4.230	1	$J/\psi\pi^+\pi^-$	0.085	8.5×10^{7}	
		$\tau^+\tau^-$	3.6	3.6×10^{9}	
		$\gamma X(3872)$			
4.360	1	$\psi(3686)\pi^+\pi^-$	0.058	5.8×10^{7}	
		$\tau^+\tau^-$	3.5	3.5×10^{9}	
4.420	1	$\psi(3686)\pi^+\pi^-$	0.040	4.0×10^{7}	
		$\tau^+\tau^-$	3.5	3.5×10^{9}	
4.630	1	$\psi(3686)\pi^+\pi^-$	0.033	3.3×10^{7}	
		$\Lambda_c\bar{\Lambda}_c$	0.56	5.6×10^{8}	
		$\Lambda_c\bar{\Lambda}_c$		6.4×10^{7}	Single Tag
		$\tau^+\tau^-$	3.4	3.4×10^{9}	
4.0-7.0	3	300 points scan with 10 MeV step, 1 fb^{-1}/point			
> 5	2-7	several ab^{-1} high energy data, details dependent on scan results			

XYZ Factory

XYZ	$Y(4260)$	$Z_c(3900)$	$Z_c(4020)$	$X(3872)$
No. of events	10^{10}	10^9	10^9	5×10^6

Hyperon Factory

Decay mode	$\mathcal{B}$(units 10^{-4})	Angular distribution parameter α_ψ	Detection efficiency	No. events expected at STCF
$J/\psi\to\Lambda\bar{\Lambda}$	$19.43\pm0.03\pm0.33$	0.469 ± 0.026	40%	1100×10^6
$\psi(2S)\to\Lambda\bar{\Lambda}$	$3.97\pm0.02\pm0.12$	0.824 ± 0.074	40%	130×10^6
$J/\psi\to\Xi^0\bar{\Xi}^0$	11.65 ± 0.04	0.66 ± 0.03	14%	230×10^6
$\psi(2S)\to\Xi^0\bar{\Xi}^0$	2.73 ± 0.03	0.65 ± 0.09	14%	32×10^6
$J/\psi\to\Xi^-\bar{\Xi}^+$	10.40 ± 0.06	0.58 ± 0.04	19%	270×10^6
$\psi(2S)\to\Xi^-\bar{\Xi}^+$	2.78 ± 0.05	0.91 ± 0.13	19%	42×10^6

Light meson Factory

Decay Mode	$\mathcal{B}$ ($\times10^{-4}$) [2]	η/η' events
$J/\psi\to\gamma\eta'$	52.1 ± 1.7	1.8×10^{10}
$J/\psi\to\gamma\eta$	11.08 ± 0.27	3.7×10^{9}
$J/\psi\to\phi\eta'$	7.4 ± 0.8	2.5×10^{9}
$J/\psi\to\phi\eta$	4.6 ± 0.5	1.6×10^{9}

- **BelleII (50/ab) has more statistics**
- **LHCb have much more statistics, but huge background**
- **STCF is expected to have higher detection efficiency and low bkgs for productions at threshold**
- **Additionally, STCF has excellent resolution, kinematic constraining**

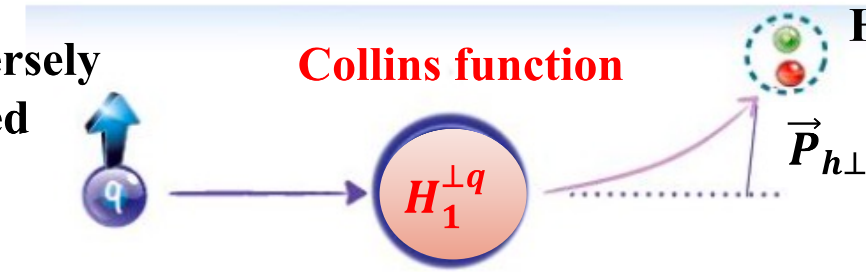
Outline

- ✍ **Collins effect** B. L. Wang *et al*., Journal of UCAS **38** (2021) 433
- ✍ **$b \to s\,\gamma$ photon polarization** Y.L. Fan *et al*., EPJC **81** (2021) 1068
- ✍ **$D_s^+ \to \ell^+ \nu_\ell$**
  - $\ell = \tau$ H.J. Li *et al*., EPJC **82** (2022) 310
  - $\ell = \mu$ J. J. Liu *et al*., EPJC **82** (2022) 337
- ✍ ***CP* violation**
  - **Λ decay**
    - **with non-polarized beam** Y. Xu *et al*., submitted
    - **with polarized e^- beam** S. Zeng *et al*., ongoing
  - **$K^0 - \bar{K}^0$ system**
    - **in J/ψ decay** J. Y. Zhang *et al*., draft ready
    - **in τ^- decay** H. Y. Sang *et al*., CPC **45** (2021) 053003

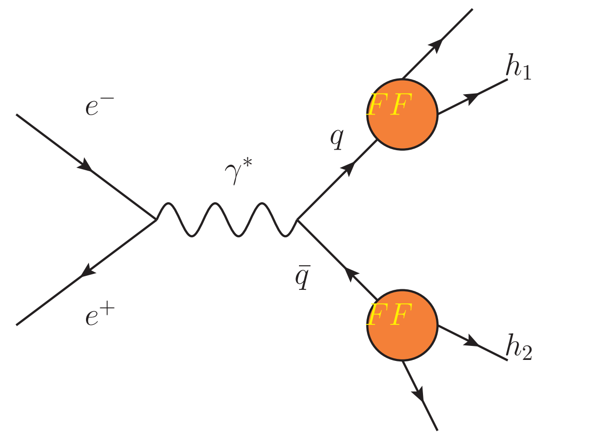
Collins effect

$e^+e^- \to q\bar{q}$ $(\sigma \approx 5$ nb, Lundarlw$)$@ $\sqrt{s} = 7$ GeV with a MC of 1 ab^{-1}

B. L. Wang *et al.*, Journal of UCAS **38** (2021) 433



e^+e^- : Collins FF ⊗ Collins FF



- The number density [1,2]:

unpolarized

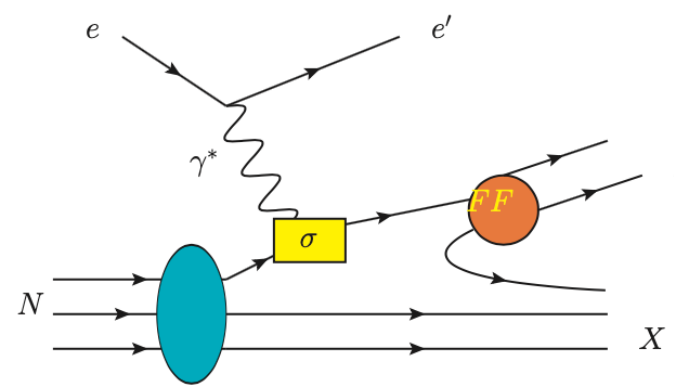
$$D_{h,q\uparrow}(z, P_{h\perp}^2) = D_1^q(z, P_{h\perp}^2)$$

spin

$$+H_1^{\perp q}(z, P_{h\perp}^2)\frac{(\hat{\vec{k}} \times \vec{P}_{h\perp}) \cdot \vec{S}_q}{z\, M_h}$$

$z = \frac{E_h}{\sqrt{s}/2}$: fractional energy of hadron (h)

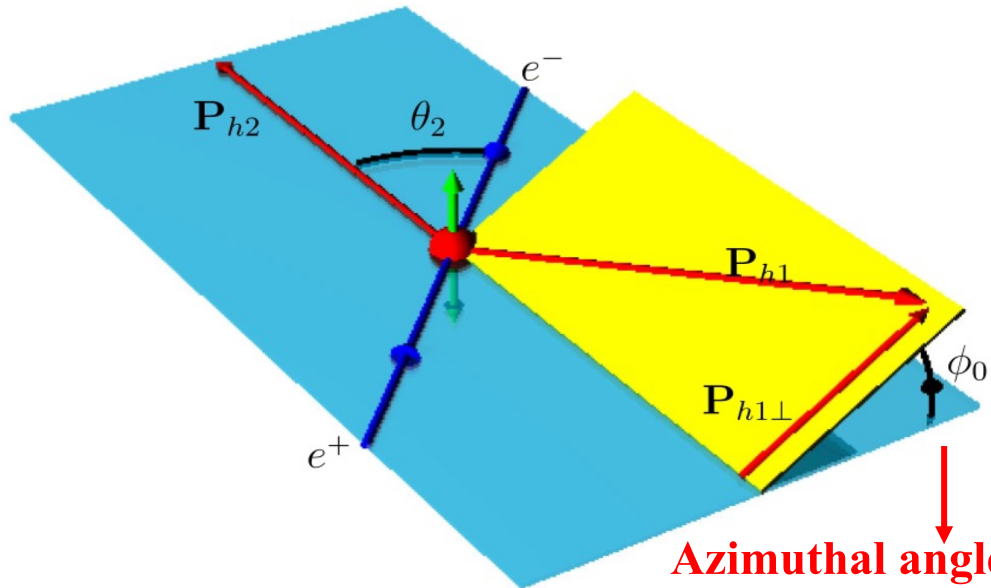
SIDIS: Transversity ⊗ Collins FF



[1] J. C. Collins, Nucl. Phys. B 396, 161 (1993).
[2] R. Seidl *et al.* (Belle Collaboration), Phys. Rev. D 78, 032011 (2008).

Unlike-sign (U) $e^+e^- \to q\bar{q} \to h_1^{\pm}h_2^{\mp}X$ $(h_1 = h_2 = \pi, K)$

Like-sign (L): $e^+e^- \to q\bar{q} \to h_1^{\pm}h_2^{\pm}X$



- **Double ratio (DR):**

$$\mathrm{DR}(2\phi_0) = \frac{R^U}{R^L} = 1 + A^{UL}\cos(2\phi_0)$$

Collins asymmetry

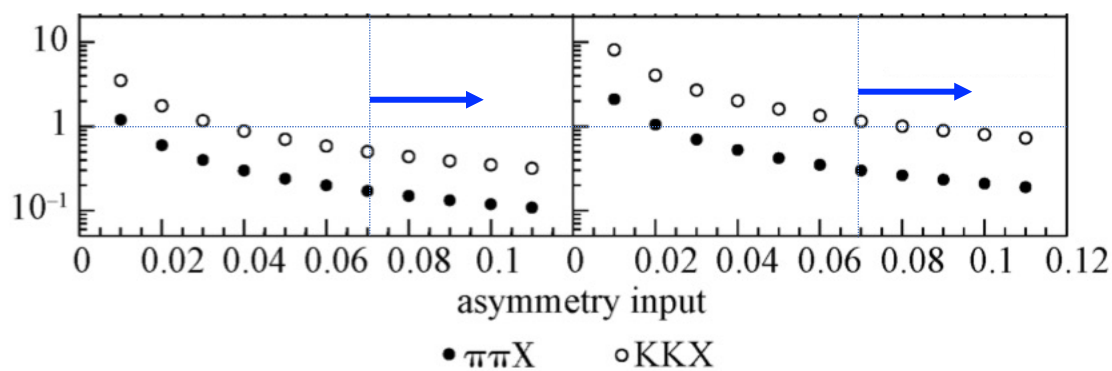
$$R^{U(L)} = \frac{N(2\phi_0)}{<N_0>}$$

$N(2\phi_0)$: Yield of h_1h_2 pair in a $2\phi_0$ range

$<N_0>$: Average yield

- The ratio of the relative statistical uncertainty of A^{UL}_{output} with 1 ab^{-1} over the precision of 2% required by EicC.

When $A^{UL}_{\mathrm{input}} > 0.07$, the relative statistical uncertainty of A^{UL}_{output} with 1 ab^{-1} is better than 2%.



$b \to s\,\gamma$ photon polarization

$D^0 \to K_1(1270)^- e^+ \nu_e\ @\sqrt{s} = 3.773$ GeV with a MC of 1 ab^{-1}

Y.L. Fan *et al.*, EPJC **81** (2021) 1068

In SM, $b \to s\,\gamma$: predominantly left-handed.

New physics: a right-handed photon polarization.

- **The photon helicity (λ_γ) in $B \to K_1\,\gamma$ [1]**

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

C: Wilson coefficients

- **In Ref.[2]**

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

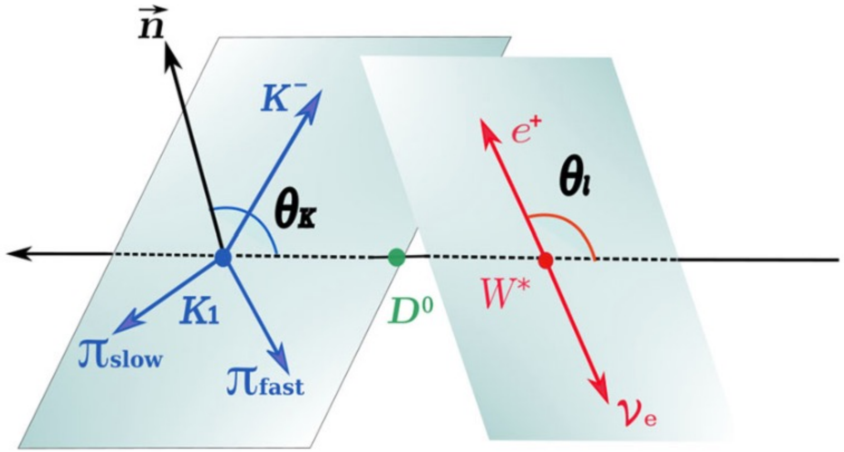
$A_{\rm UD}$ → in $B^+ \to K_1^+\,\gamma$

$A'_{\rm UD}$ → in $D^0 \to K_1^- e^+ \nu_e$

- **The ratio of up-down asymmetry:**

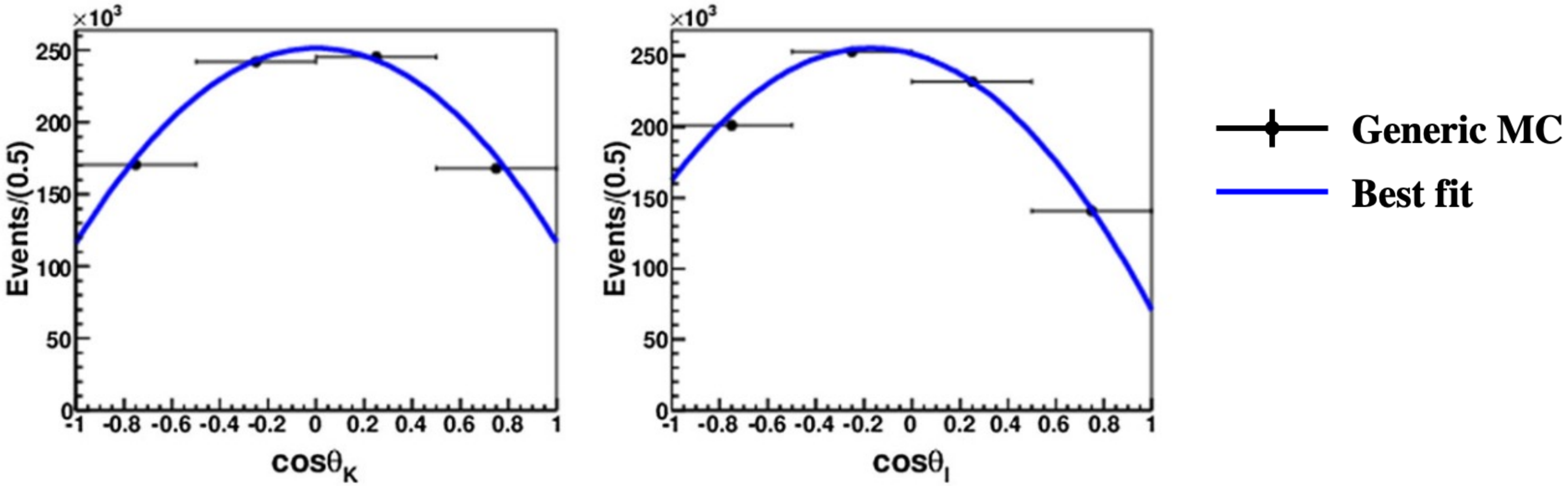
$$D^0 \to K_1(1270)^-(\to K^-\pi^+\pi^-)e^+\nu_e$$

$$A'_{\rm UD} = \frac{\Gamma(\cos\theta_K > 0) - \Gamma(\cos\theta_K < 0)}{\Gamma(\cos\theta_l > 0) - \Gamma(\cos\theta_l < 0)}$$



[1] M. Gronau and D. Pirjol, Phys. Rev. D 66, 054008 (2002).
[2] W. Wang, F. S. Yu, and Z. X. Zhao, Phys. Rev. Lett. 125, 051802 (2020).

Efficiency corrected signal yields



Optimization parameters for the STCF detector

- Reconstructed efficiencies for tracks are improved by 10%;
- π/e mis-identification rate: 3.2% @ 0.2 GeV/c.

Results

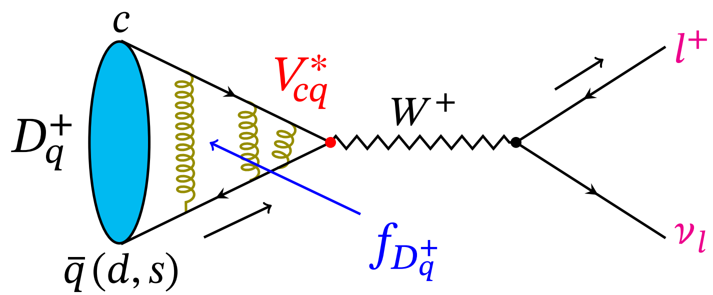
1 ab^{-1}	The statistical uncertainty of A'_{UD}	
Default	1.8×10^{-2}	
With optimizations	1.5×10^{-2}	Improved by 17%

Pure leptonic D_s^+ decays

- **Axial current (nonperturbative)**

$$< 0|\bar{s}\,\gamma_\mu\,\gamma_5\,c\,|D_s^+> = i\,p_\mu\,f_{D_s^+}.$$

$f_{D_s^+}$: D_s^+ **decay constant**



- V_{cs}: **CKM matrix element, fundamental SM parameter, measured by experiments.**

- **Decay width:** $\Gamma = \frac{G_F^2}{8\pi} f_{D_s^+}^2 \, |V_{cs}|^2 \, m_l^2 \, m_{D_s^+} \left(1 - \frac{m_l^2}{m_{D_s^+}^2}\right)^2$

- **Branching fraction:** $Br(D_s^+ \to l^+\nu_l) = \Gamma \cdot \tau_{D_s^+}$ **(lifetime)**

$$Br(D_s^+ \to l^+\nu_l) \propto \left[f_{D_s^+} \cdot |V_{cs}|\right]^2$$

Direct measurement

- ☐ $f_{D_s^+}$ **: calibrate the Lattice QCD calculations**
- ☐ τ^+/μ^+ **: test lepton flavor universality**
- ☐ $|V_{cs}|$ **: test the unitarity of the CKM matrix**

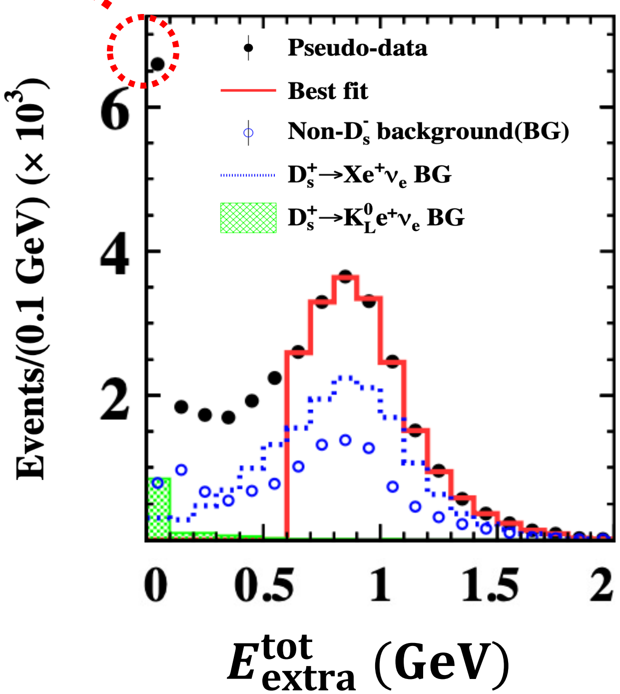
$D_s^+ \to \ell^+\nu_\ell(\ell = \tau, \mu) + c.c.$

$e^+e^- \to D_s^+ D_s^-$ @ 4.009 GeV with a generic MC of 0.1 ab^{-1}

- $D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$

Signal peak

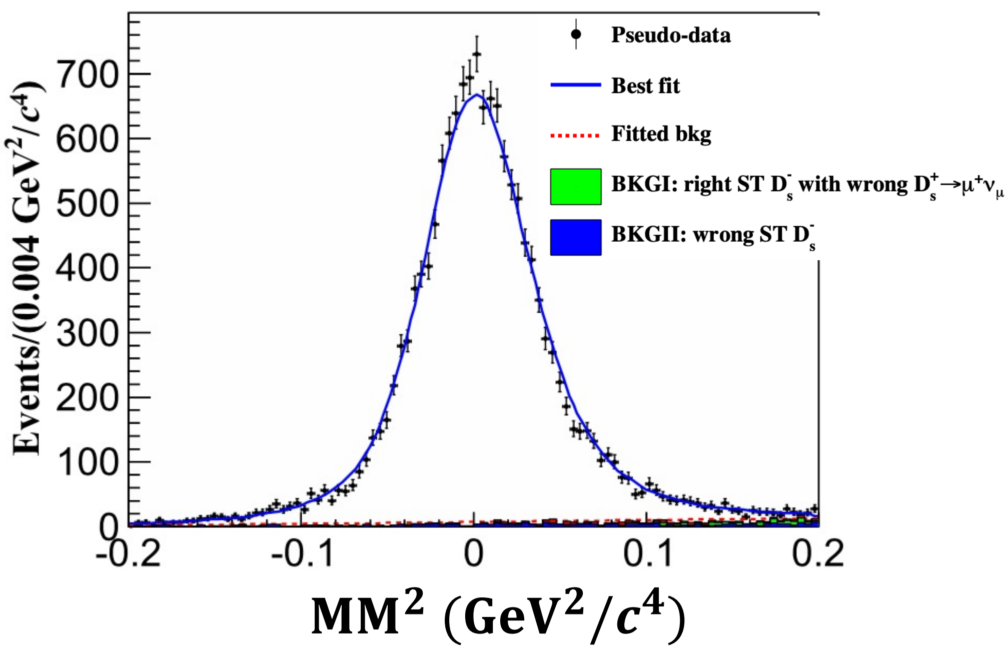
H.J. Li *et al.*, EPJC **82**(2022)310



E_{extra}^{tot}: the total energy of the extra good EMC showers.

- $D_s^+ \to \mu^+\nu_\mu$

J. J. Liu *et al.*, EPJC **82**(2022)337



$$\mathrm{MM}^2 = \sqrt{\left(E_{\mathrm{beam}} - E_{\mu^+}\right)^2 - \left|-\vec{p}_{D_s^-} - \vec{p}_{\mu^+}\right|^2}$$

Missing mass squared.

Optimization of detector response

- Reconstructed efficiencies for tracks are improved by 10%;
- π/K mis-identification rates: 1.0% @ 1 GeV/*c*.
- π/μ mis-identification rates: 3.0% @ 1 GeV/*c*.

Results

Source (1 ab^{-1})	$Br_{D_s^+\to\tau^+\nu_\tau}$	$Br_{D_s^+\to\mu^+\nu_\mu}$	$\frac{Br_{D_s^+\to\tau^+\nu_\tau}}{Br_{D_s^+\to\mu^+\nu_\mu}}$	Combined τ and μ (STCF)	
				$f_{D_s^+}$ (MeV)	$\lvert V_{cs}\rvert$
Relative stat.	0.3%	0.2%	0.5%	0.1%	0.2%

Comparable to uncertainty (0.2%) of the LQCD calculation (249.9 ± 0.5) MeV.

Syst.: limited by the uncertainty (0.8%) of the D_s^+ lifetime $\tau_{D_s^+} = (504 \pm 4)\times 10^{-15}$ s.

CP violation (CPV)

- **Sakharov conditions for the observed matter-antimatter asymmetry :**
  - **Baryon number violation**
  - **C and CP violation**
  - **Out of thermal equilibrium**

- **CPV in SM is too small:**

Source	CPV magnitude	Experiments
K **meson**	$\mathcal{O}(10^{-3})$	**Discovered in 1964 at Fix targets**
B **meson**	$\mathcal{O}(1)$	**Discovered in 2001 at BaBar and Belle**
D **meson**	$\mathcal{O}(10^{-4})$	**Discovered in 2019 at LHCb**

CPV has yet to be established in baryonic decay and lepton sector.

CP violation of Λ decay

$e^+e^- \to J/\psi \to \Lambda(\to p\pi^-)\,\bar{\Lambda}(\to \bar{n}\pi^0, \bar{p}\pi^+)$ with a MC of J/ψ events @ 3.097 GeV

- **Λ polarizaiton**

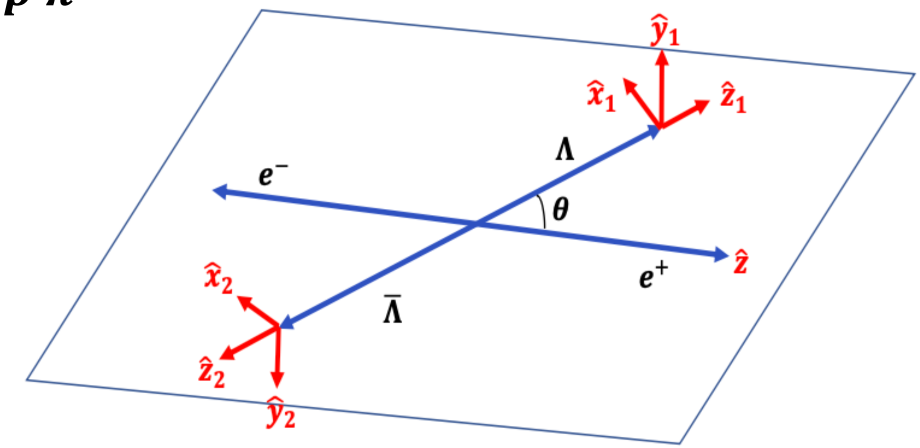
  $\Delta\Phi \neq 0$, the phase difference between helicity conserving and helicity flip amplitudes of $e^+e^- \to \Lambda\bar{\Lambda}$.

- **The angular distribution of proton in $\Lambda \to p\,\pi^-$**

$$\frac{1}{4\pi}(1 + \alpha_1 \vec{P}_\Lambda \cdot \hat{n})$$

α_1 → asymmetry parameter

$\vec{P}_\Lambda$ → Λ polarization



- **The joint angular distribution**

Polarized e^- beam case [1] = Non-polarized beam case

$$+\alpha_1 T_6 + \alpha_2 T_7 - \alpha_1\alpha_2 T_8$$

→ $\propto$ polarizability P_z of the e^- beam

θ: angle(Λ, e^+)

Or

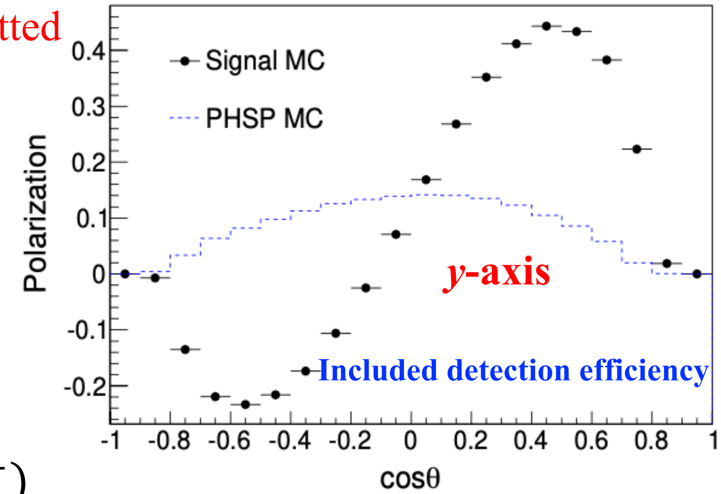
θ: angle(Λ, e^-)

[1] N. Salone *et al.*, Phys. Rev. D 105, 116022 (2022).

- **The polarization of Λ in the y-axis with non-polarized beam:** θ: angle(Λ, e^-)

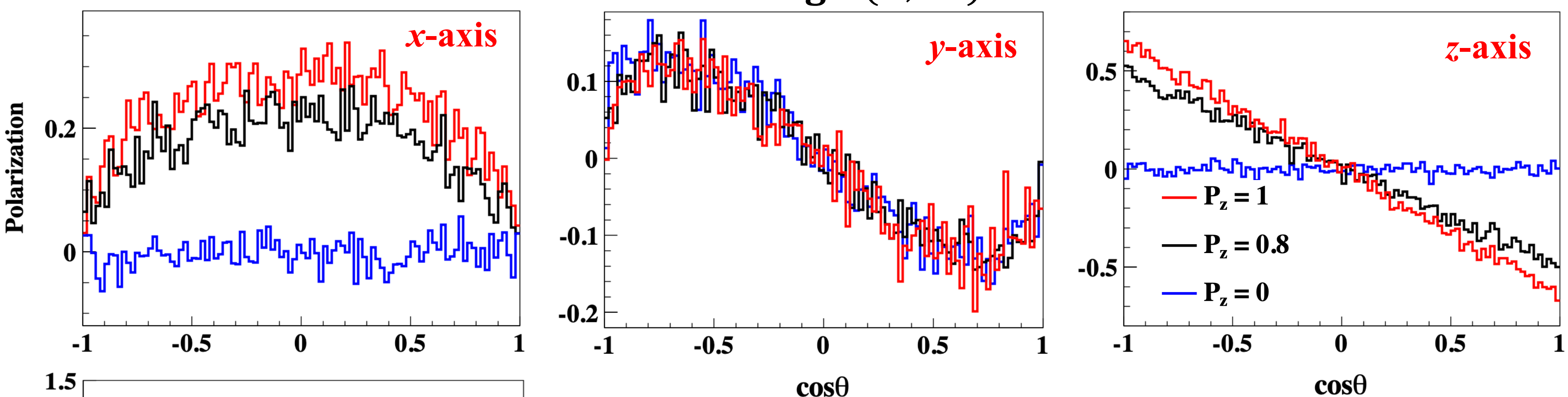
Y. Xu *et al.*, submitted

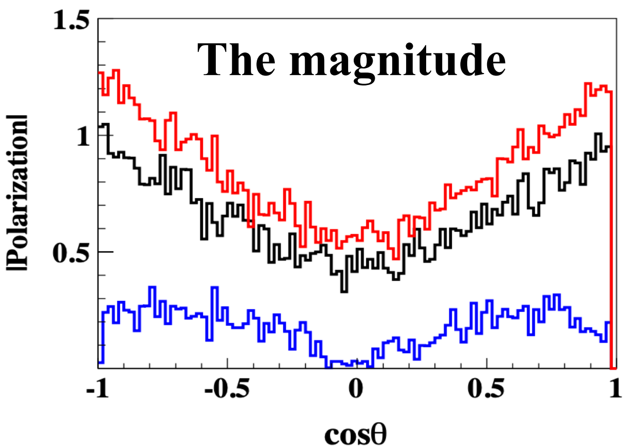
$$P_{\Lambda \text{ in } y} = \frac{\sqrt{1-\alpha^2}\,\sin\theta\,\cos\theta}{1+\alpha\cos^2\theta}\,\sin(\Delta\Phi)$$



- **The polarization of Λ with polarized e^- beam:**

θ: angle(Λ, e^+)





P_z : e^- beam polarizability

S. Zeng *et al.*, ongoing

- $P_z = 1$
- $P_z = 0.8$
- $P_z = 0$

$P_z = 1$ and $P_z = 0.8$: **The magnitudes are higher.**

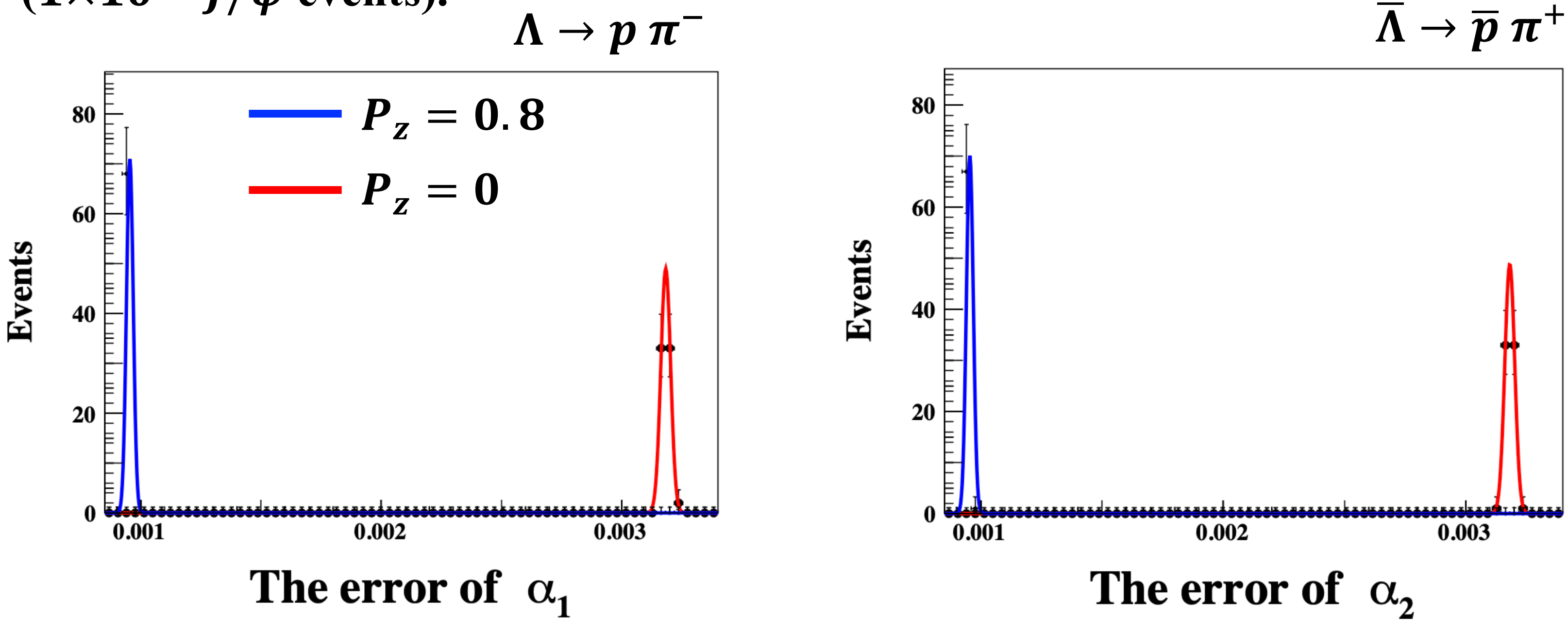
- The statistical sensitivity for CP violation in Λ decays with 1×10^{12} J/ψ events in the **non-polarized beam** case.

$$A_{CP}=\frac{\alpha_1+\alpha_2}{\alpha_1-\alpha_2}\sim\mathcal{O}(10^{-4})$$

Theoretical prediction $A_{CP}\approx10^{-4}$ [1,2].

(If CP is conserved, $\alpha_1=-\alpha_2$, $A_{CP}=0$)

- The precision of each parameter with different **polarizability P_z of the e^- beam** (1×10^{12} J/ψ events).



- **The sensitivity of A_{CP} is expected to be smaller in the polarized beam case.**

[1] J. F. Donoghue, X. G. He, and S. Pakvasa, Phys. Rev. D 34, 833 (1986).
[2] I. I. Bigi, X. W. Kang, and H. B. Li, Chin. Phys. C 42, 013101 (2018).

CP violation of $K^0 - \overline{K}^0$ system

- **Strangeness is conserved in strong interaction**

$$K^0 = d\,\bar{s}, \qquad \overline{K}^0 = \bar{d}\,s$$

- **Strangeness can be changed in weak interaction**

e.g. $K^0 \to \pi^+\pi^-$ $\qquad$ $K^0 - \overline{K}^0$ **mixing or oscillation**

- **Assume CP is symmetric, the CP eigenstates:**

$CP = 1$:

$$|K_1> = \frac{1}{\sqrt{2}}\left[|K^0> \ + |\overline{K}^0>\right],$$

$CP = -1$:

$$|K_2> = \frac{1}{\sqrt{2}}\left[|K^0> \ - |\overline{K}^0>\right],$$

- **But CP is violated in weak interaction, the mass states:**

$$|K_S> = \frac{1}{\sqrt{1+|\epsilon_S|^2}}\left[|K_1> \ + \epsilon_S|K_2>\right]$$

$$|K_L> = \frac{1}{\sqrt{1+|\epsilon_L|^2}}\left[|K_2> \ + \epsilon_L|K_1>\right]$$

(If CP conservation: $\epsilon_S = \epsilon_L = 0$)

$J/\psi \to K^- \pi^+ K^0 + c.c.$

$e^+e^- \to J/\psi \to K^-\pi^+K^0(\to \pi^+\pi^-) + c.c.$ with 3.9×10^9 signal events.

- **Introduce the CP violation parameters:**

J. Y. Zhang *et al*., draft ready

$$\eta_{+-} = \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} = |\eta_{+-}|e^{\phi_{+-}}$$

Amplitude

- **The $K^0/\bar{K}^0$ can be tagged:**

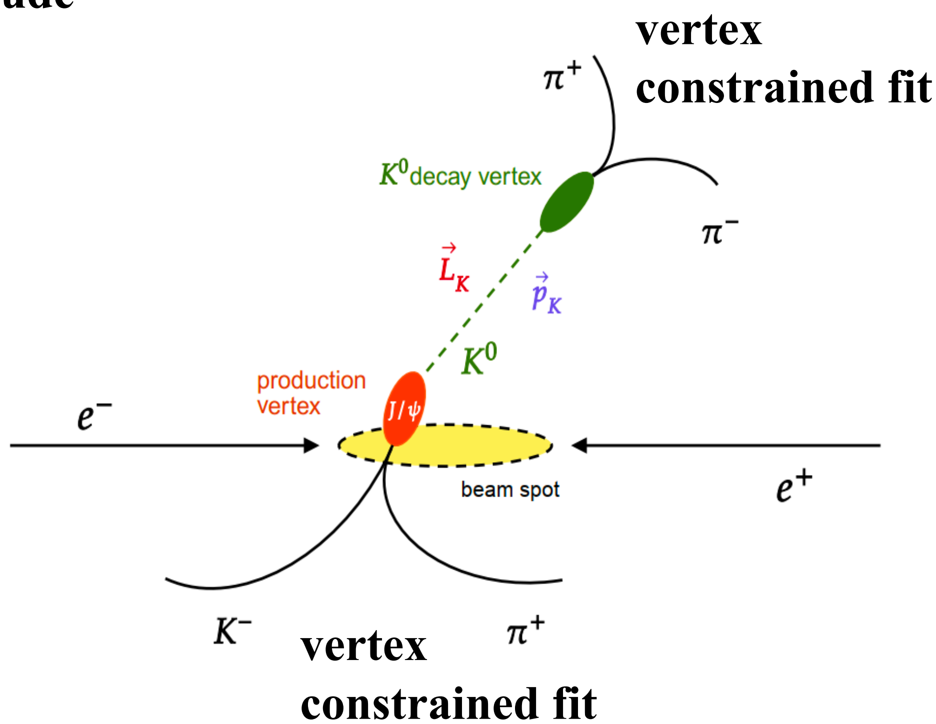
$$J/\psi \to K^-\pi^+K^0$$

$$J/\psi \to K^+\pi^-\bar{K}^0$$

- **The decay lifetime of K^0 ($\bar{K}^0$) at STCF:**

$$\tau_K = \frac{m_K \cdot |\vec{L}_K|}{|\vec{p}_K|}$$

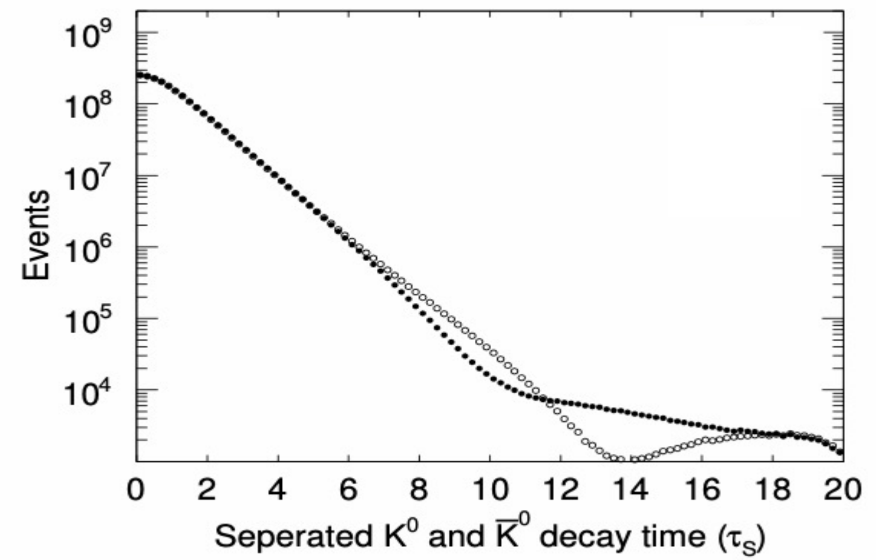
The position uncertainty of production vertex is taken as $\sigma_x = 13.6$ μm, $\sigma_y = 1.4$ μm, $\sigma_z = 50$ μm.



- **The number of time-dependent events**

  - **N(τ) for $K^0 \rightarrow \pi^+ \pi^-$**
  - **$\overline{N}(\tau)$ for $\overline{K}^0 \rightarrow \pi^+ \pi^-$**

→

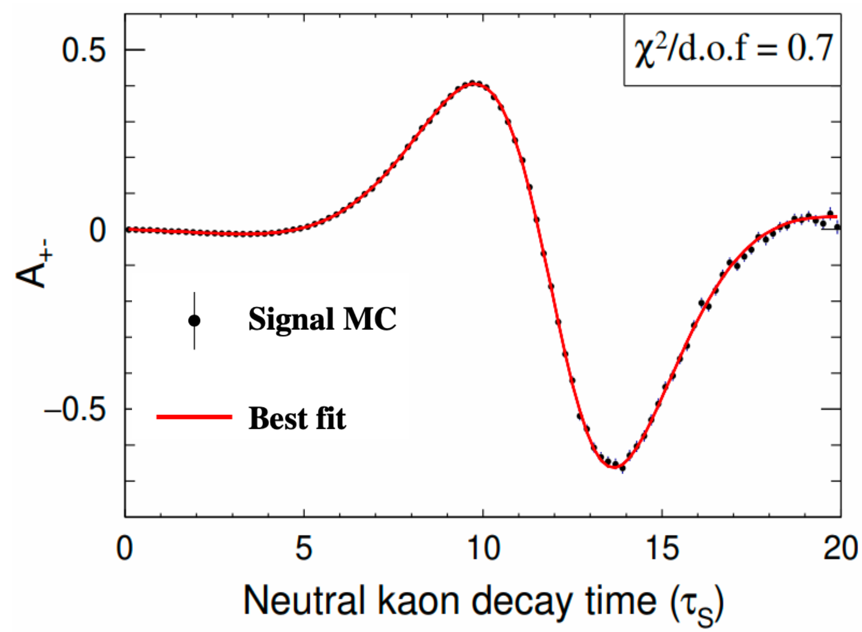


- **The time-dependent decay rate asymmetry**

$$A_{+-}(\tau) = \frac{\overline{N}(\tau) - kN(\tau)}{\overline{N}(\tau) + kN(\tau)}$$

$$= -2\frac{|\eta_f|e^{(\Gamma_S-\Gamma_L)\tau}\cos(\Delta m\,\tau - \phi_f)}{1+|\eta_f|^2 e^{(\Gamma_S-\Gamma_L)\tau}}$$

Par.	$\lvert\eta_{+-}\rvert(10^{-3})$	ϕ_{+-}(degree)
PDG	2.232 ± 0.011	43.4 ± 0.5
STCF	$2.2320 \pm 0.0025 \pm 0.0027$	$43.510 \pm 0.051 \pm 0.059$



The relative precisions of the CP violation parameters are 1×10^{-3}.

$\tau^- \to K_S^0 \pi^- \nu_\tau + c.c.$

$e^+e^- \to \tau^+\tau^- (\sigma \approx 3.5\ \text{nb})\ @\sqrt{s} = 4.26\ \text{GeV}$ **with a MC of 1** ab^{-1}

H. Y. Sang *et al.*, CPC **45** (2021) 053003

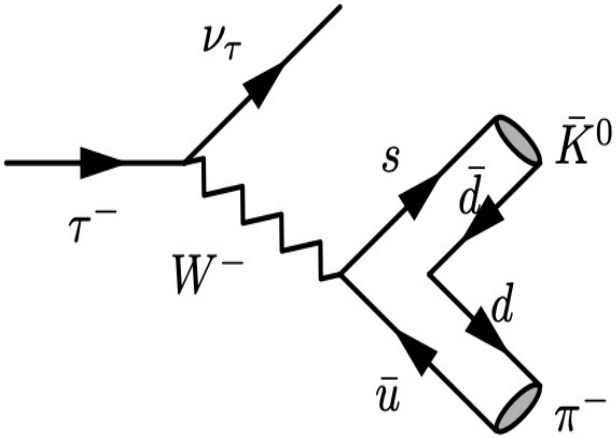
In the SM, the CPV of $\tau^- \to K_S^0 \pi^- \nu_\tau$ due to the $K^0 - \bar{K}^0$ oscillation [1, 2]:

$$A_{\text{CP}} = \frac{\Gamma(\tau^+ \to K_S^0 \pi^+ \bar{\nu}_\tau) - \Gamma(\tau^- \to K_S^0 \pi^- \nu_\tau)}{\Gamma(\tau^+ \to K_S^0 \pi^+ \bar{\nu}_\tau) + \Gamma(\tau^- \to K_S^0 \pi^- \nu_\tau)} = (0.33 \pm 0.01)\%$$

BaBar Collaboration [3]:

$$A_{\text{CP}}[\tau^- \to K_S^0 \pi^+ (\geq 0\pi^0) \bar{\nu}_\tau] = (-0.36 \pm 0.23 \pm 0.11)\%$$

$2.8\ \sigma$ away from the SM prediction after correction.



A higher-precision result of $\tau^- \to K_S^0 \pi^- \nu_\tau$ is required to

- **hunt for signals of New physics.**
- **Determine the intermediate resonances parameters.**
- **Determine the CKM matrix element $|V_{\text{us}}|$.**

[1] I. I. Bigi and A. I. Sanda, Phys. Lett. B 625, 47 (2005).
[2] Y. Grossman and Y. Nir, JHEP 1204, 002 (2012).
[3] J. P. Lees et al. (BaBar Collaboration), Phys. Rev. D 85, 031102 (2012).

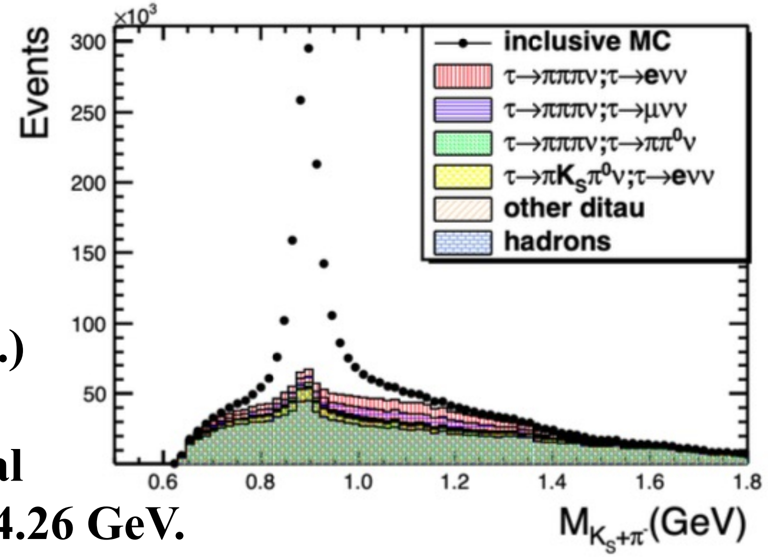
Decay chain:

$e^+e^- \rightarrow \tau^+\tau^-$

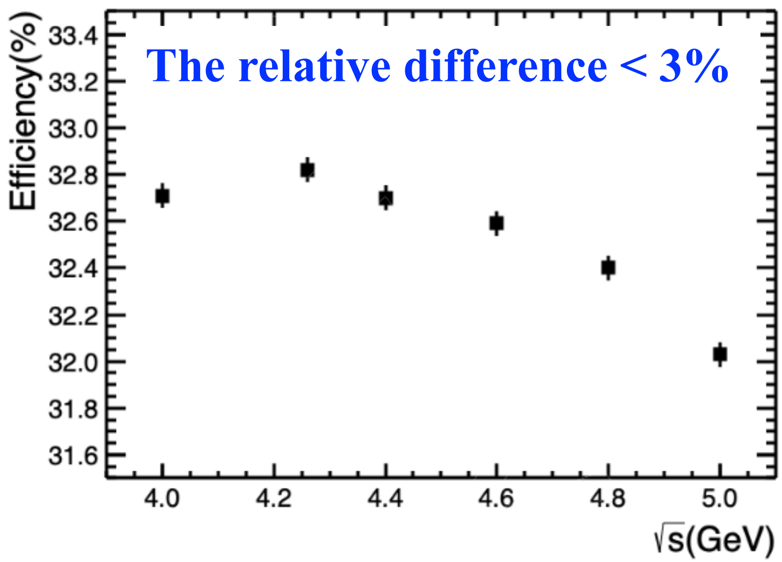
Tag side: $\tau^+ \rightarrow \ell^+\nu_\ell\nu_\tau\ (\ell = e, \mu)$

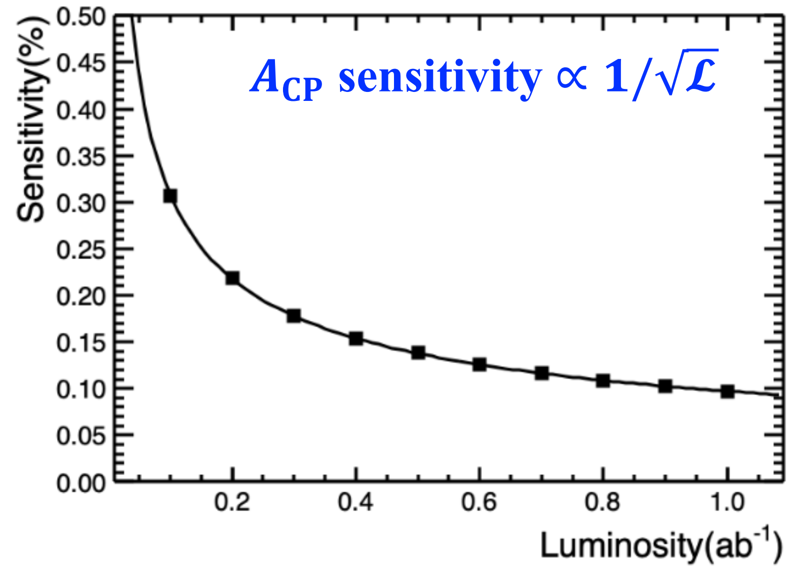
Signal side: $\tau^- \rightarrow K_S^0\pi^-\nu_\tau, K_S^0 \rightarrow \pi^+\pi^-$

(The charge conjugate decays are always implied.)



After fitting the $K_S^0\pi^-$ invariant mass, the statistical sensitivity of A_{CP} is 9.7×10^{-4} based on 1 ab^{-1} @4.26 GeV.





The statistical sensitivity of A_{CP} is 3.1×10^{-4} based on 10 ab^{-1} @4.0 - 5.0 GeV.

Comparable to uncertainty of the SM prediction of $(0.33 \pm 0.01)\%$.

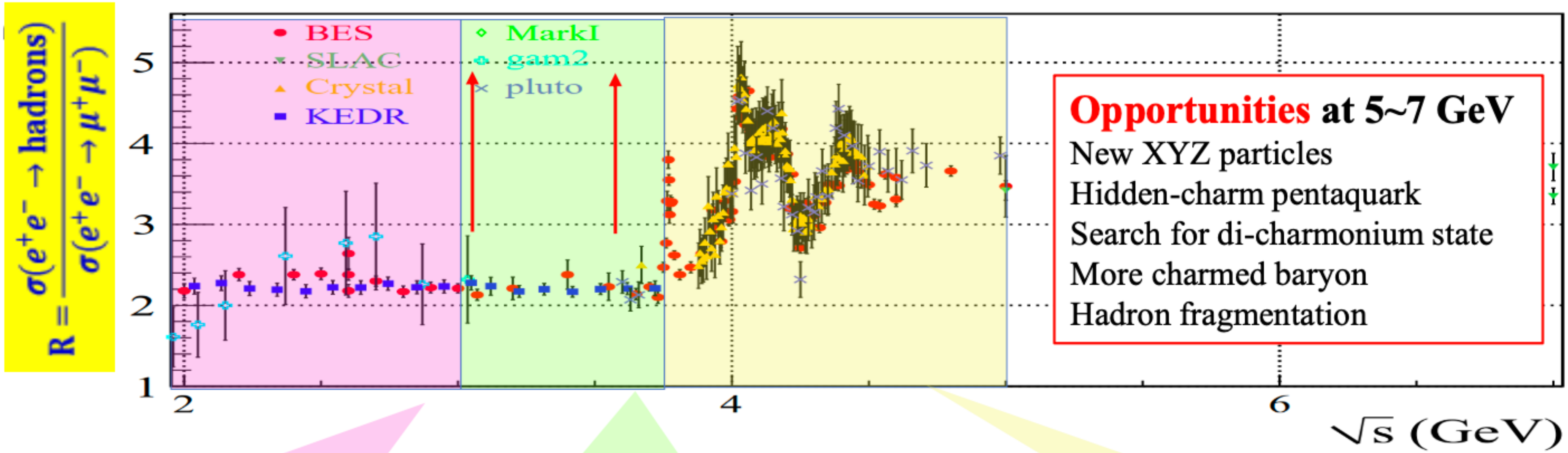
Summary

Channel (1 ab^{-1})	Summary
$e^+e^- \to q\bar{q}$ @7GeV	The Collins asymmetry (> 0.07) with 1 ab^{-1} can satisfy the precision of 2% required by EicC.
$D^0 \to K_1(1270)^- e^+ \nu_e$ @3.773 GeV	The stat. of ratio of up-down asymmetry is 1.5×10^{-2}.
$e^+e^- \to D_s^+ D_s^-$ @ 4.009 GeV	The relative stat. of $f_{D_s^+}$ is 0.1% with $D_s^+ \to \ell^+ \nu_\ell (\ell = \tau, \mu)$.
$J/\psi \to \Lambda\bar{\Lambda}$ @ 3.097 GeV	CP violation in Λ decays is 10^{-4} with non-polarized beam case; The magnitude of Λ polarization with polarized e^- beam is higher than that with non-polarized beam.
$J/\psi \to K^-\pi^+K^0 + c.c.$ @ 3.097 GeV	The relative stat. of the CP violation is 1×10^{-3}.
$e^+e^- \to \tau^+\tau^-$ @4.26 GeV	CP violation in $\tau^- \to K_S^0 \pi^- \nu_\tau$ decay is 9.7×10^{-4}, and will reach 3.1×10^{-4} based on 10 ab^{-1} @4.0 - 5.0 GeV.

Thanks for your attention!

Back up

Physics in tau-Charm Region



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark,
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- Physics with D mesons
- fD and fDs
- D0-D0 mixing
- Charm baryons

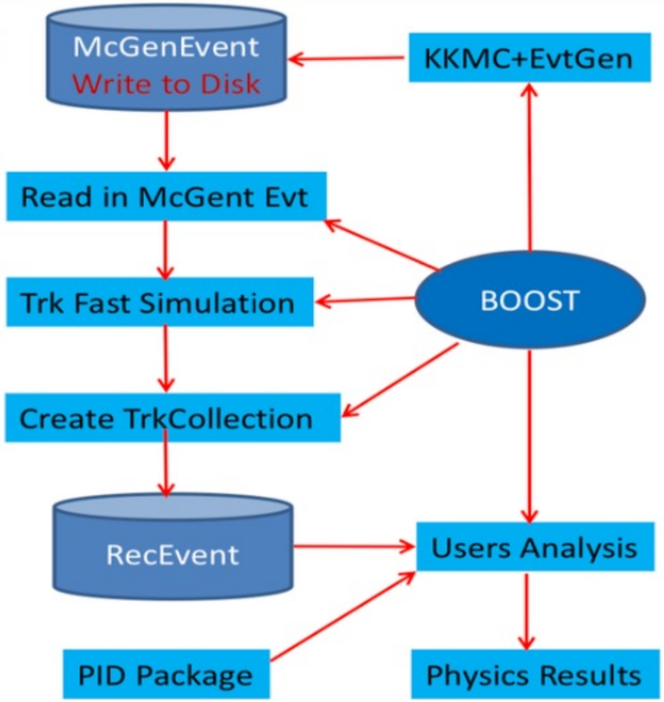
- **Rich of physics program, unique for physics with *c* quark and τ leptons,**
- **important playground for study of QCD, exotic hadrons, flavor and search for new physics.**

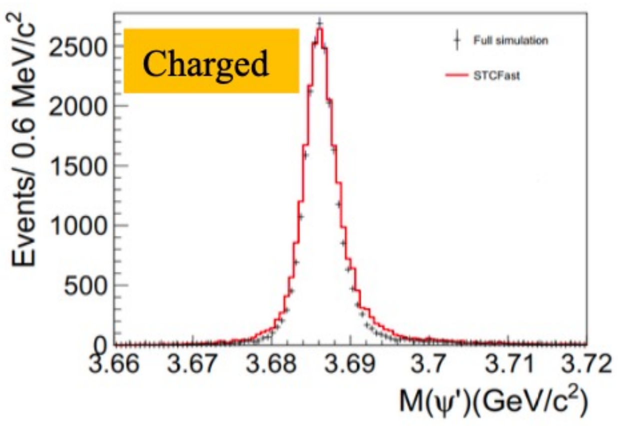
模拟样本的重建基于 STCF 项目组开发的快速重建包 STCFastSimAlg。它可以读取样本中的末态粒子四动量信息，基于不同粒子的动量分辨、探测效率、粒子类型判断效率以及粒子误判几率等信息对末态粒子进行效率舍选和动量改变。舍选后的事例可以被当成假数据应用到 STCF 的预研工作中。作为初次预研，STCFastSimAlg 采用 BESⅢ实验的径迹重建以及粒子鉴别的效率曲线。由于

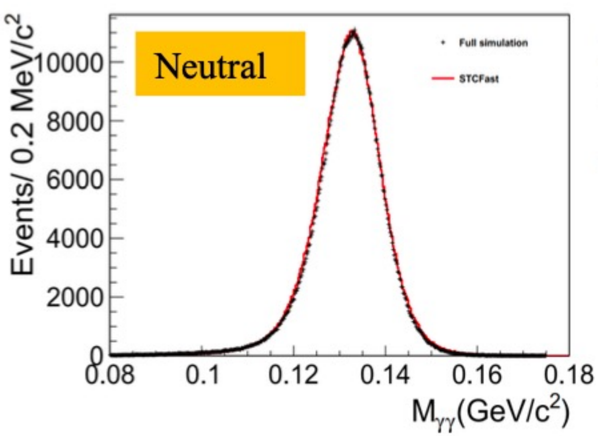
Fast Simulation Package

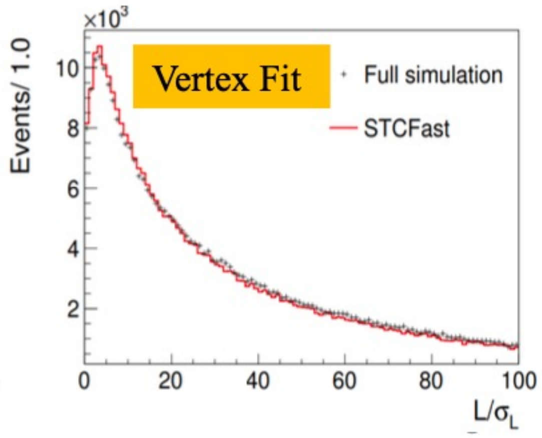
X. D. Shi *et al.*, JINST, 16, P03029 (2021)

- The FastSim can provide a critical tool for exploring physical potential;
- The FastSim takes the response of physical objects in each sub-detector: resolution, efficiency, helix, error matrix etc.
- Geant4 free, save time and space
- The package is validated well by comparing fast simulation and BESIII's result







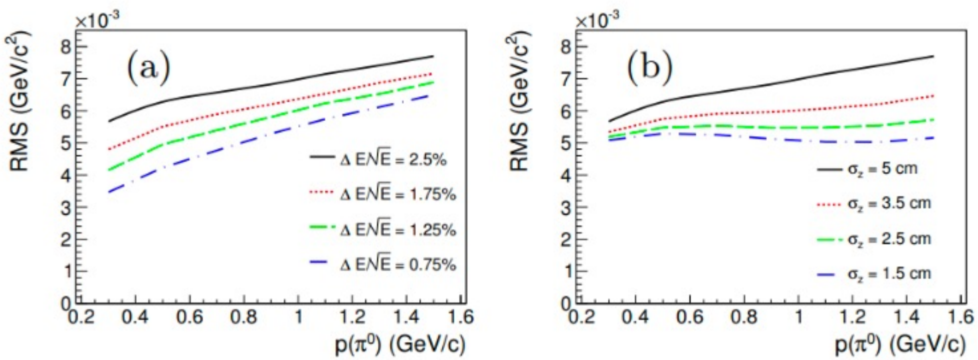


Fast Simulation Package

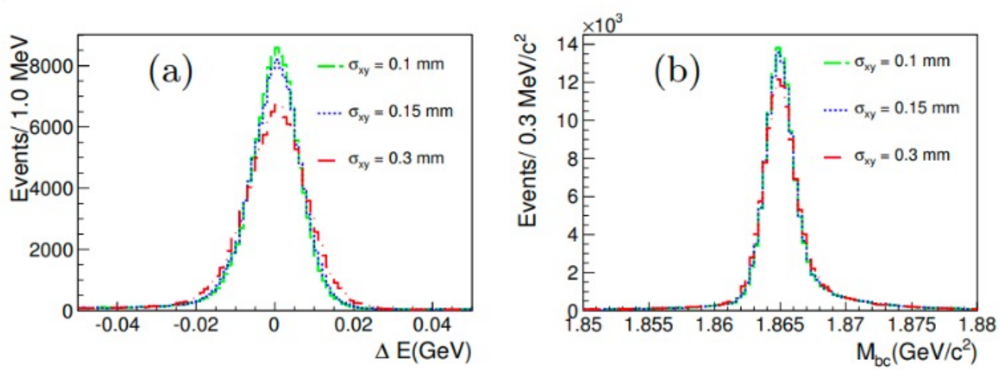
X. D. Shi *et al.*, JINST, 16, P03029 (2021)

- **The FastSimu provide flexibly adjusted responses in each sub-system, which is helpful for the optimization of detector design during R&D.**

  - RMS of pi0 with different energy/position resolution of photon:



  - D tag with different track resolution:



The polarization of weakly decaying particles, such as the Λ hyperons, can be inferred from the angular distribution of the daughter particles. In the case of decay $\Lambda \to p\pi^-$ and with the Λ hyperon polarization given by the vector $\mathbf{P}_\Lambda$, the angular distribution of the daughter protons is $\frac{1}{4\pi}(1+\alpha_{-}\mathbf{P}_\Lambda \cdot \mathbf{n})$, where $\mathbf{n}$ is the unit vector along the proton momentum in the Λ rest frame. The asymmetry parameter α_{-} of the decay is bounded by $-1 \leq \alpha_{-} \leq 1$ and characterizes the degree of mixing of parity-conserving and parity-violating amplitudes in the process[15]. The corresponding asymmetry param-

The relative expected precisions

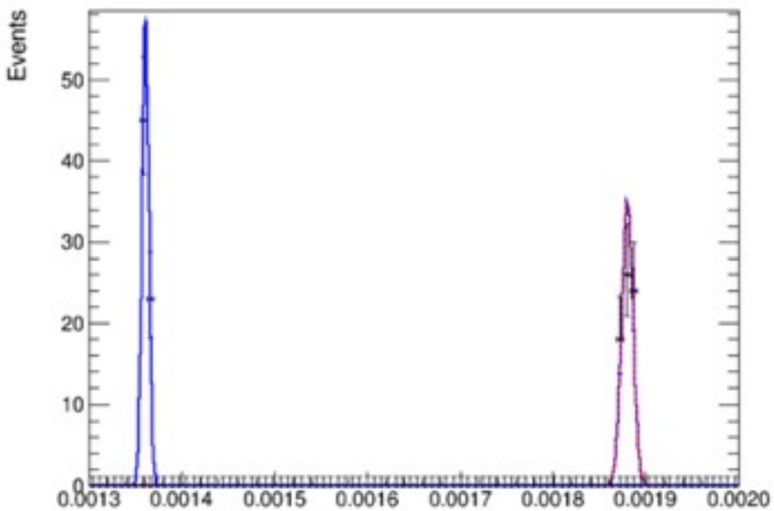
Source	BESIII [1] 6 fb^{-1} at 4.178 GeV		BelleII [1,2] 50 ab^{-1} at $\Upsilon(nS)$		This work at STCF 1 ab^{-1} at 4.009 GeV	
	Stat. (%)	Syst. (%)	Stat.(%)	Syst.(%)	Stat.(%)	Syst.(%)
$Br_{D_s^+\to\tau^+\nu_\tau}$	1.6	2.4	0.6	2.7	0.3	1.0
$f_{D_s^+}$ (MeV)	0.9	1.4	--	--	0.2	0.6
$\|V_{cs}\|$	0.9	1.4	--	--	0.3	0.7
$\frac{Br_{D_s^+\to\tau^+\nu_\tau}}{Br_{D_s^+\to\mu^+\nu_\mu}}$	2.6	2.8	0.9	3.2	0.5	1.1

The external input of D_s^+ lifetime [$\tau_{D_s^+} = (504 \pm 4)\times 10^{-15}$ s] introduces a relative uncertainty of 0.4%, need to be improved.

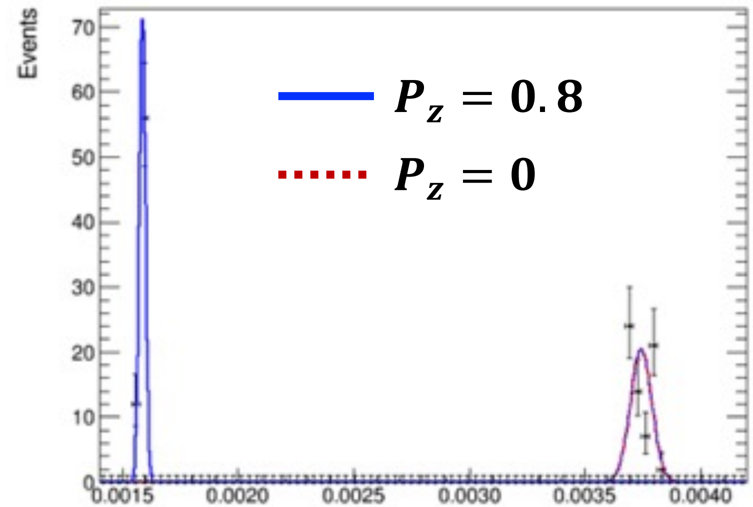
[1] M. Ablikim *et al.*, Chin. Phys. C 44, 040001 (2020).

[2] E. Kou *et al.* (Belle II Collaboration), PTEP 2019, 123C01 (2019); PTEP 2020, 029201 (2020) (erratum).

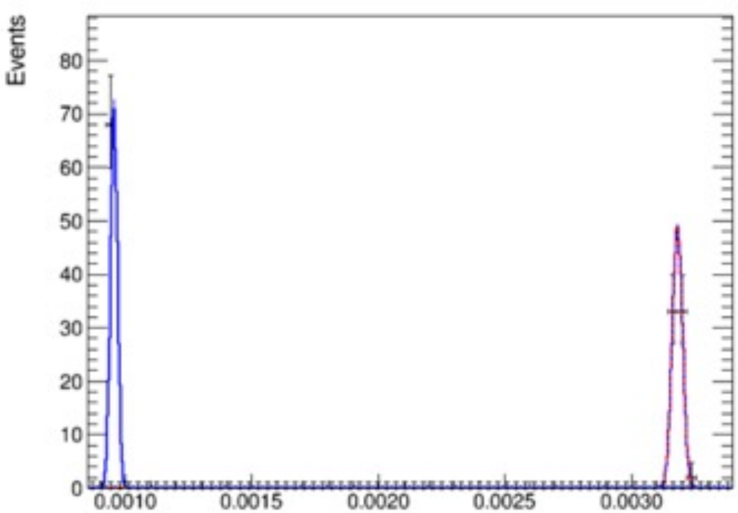
- **The precision of each parameter with different polarizability P_z of the e^- beam (normalized to 1 trillion J/ψ events).**



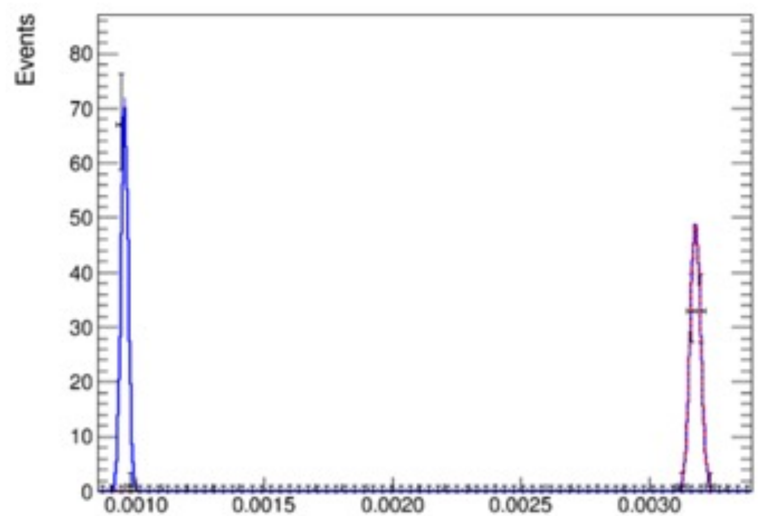
The error of α



The error of $\Delta\Phi$

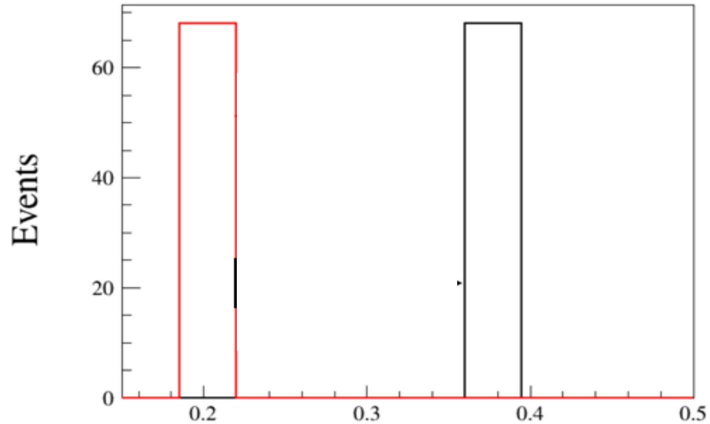


The error of α_1

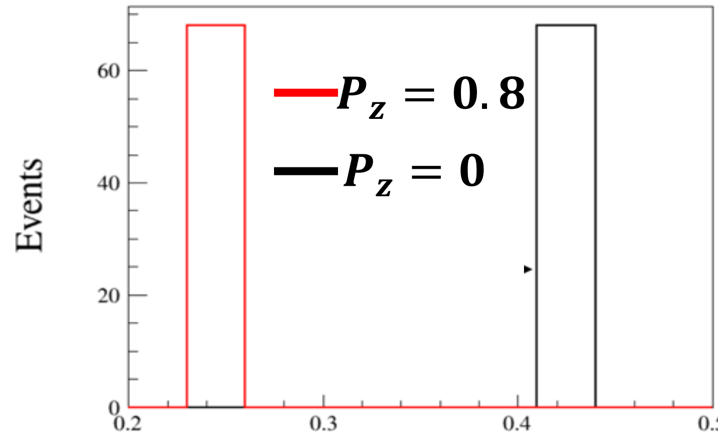


The error of α_2

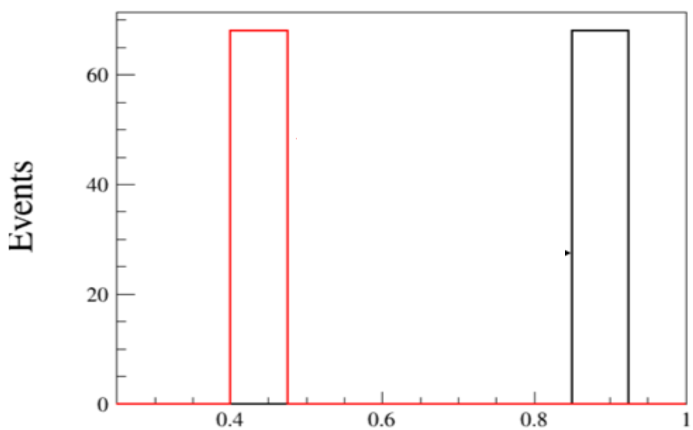
- **The reason for the much improved precision may come from the reduced global correlation factor.**



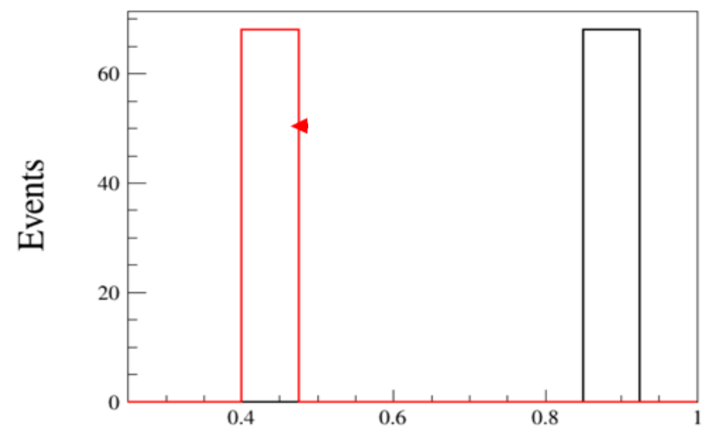
The global correlation of α



The global correlation of $\Delta\Phi$



The global correlation of α_1



The global correlation of α_2

CP violation of $K^0 - \bar{K}^0$ system

Neutral kaons have definite quark components and strangeness S when they are produced by strong interaction ($K^0 = d\,\bar{s}$, $\bar{K}^0 = \bar{d}\,s$).

J. Y. Zhang *et al.*, draft ready

But the strangeness can be changed via flavor changing process (weak interaction), namely $K^0 - \bar{K}^0$ mixing or oscillation.

Assume CP is symmetric, the CP eigenstates:

$$|K_1> = \frac{1}{\sqrt{2}}\left[|K^0> + |\bar{K}^0>\right], \text{with } CP = 1;$$

$$|K_2> = \frac{1}{\sqrt{2}}\left[|K^0> - |\bar{K}^0>\right], \text{with } CP = -1;$$

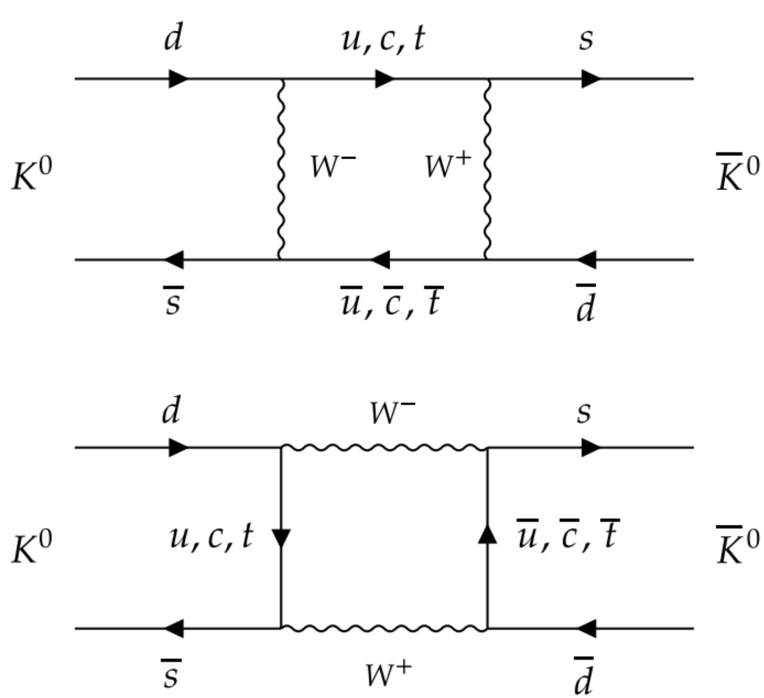
But CP is violated in weak interaction, the mass states:

$$|K_S> = \frac{1}{\sqrt{1+|\epsilon_S|^2}}\left[|K_1> + \epsilon_S|K_2>\right];$$

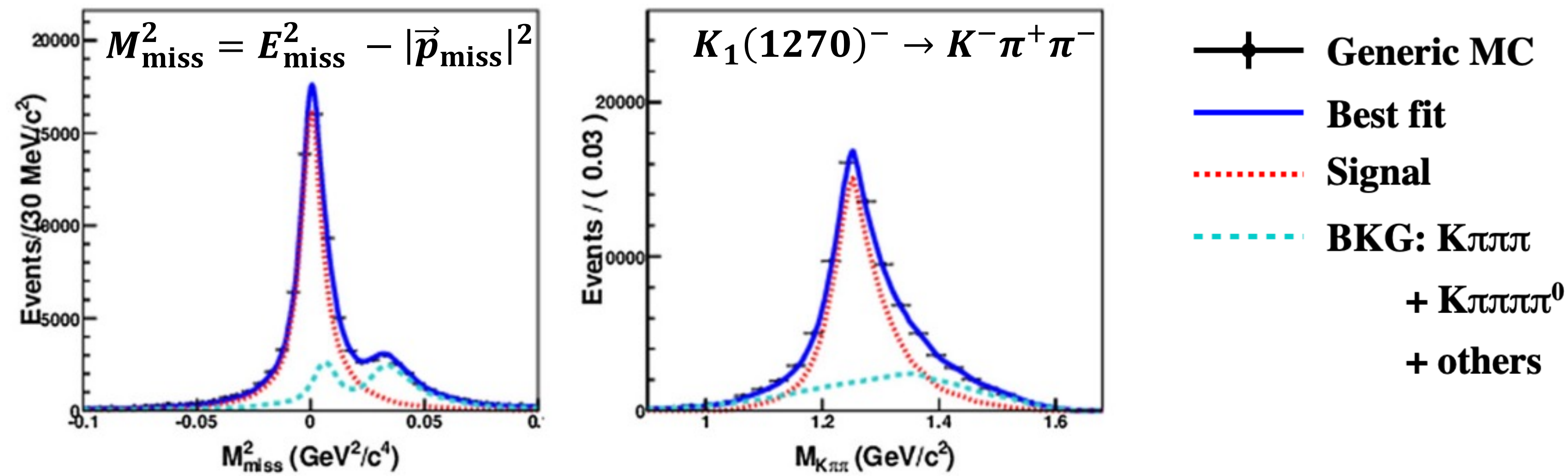
$$|K_L> = \frac{1}{\sqrt{1+|\epsilon_L|^2}}\left[|K_2> + \epsilon_L|K_1>\right];$$

If CP conservation: $\epsilon_S = \epsilon_L = 0$.

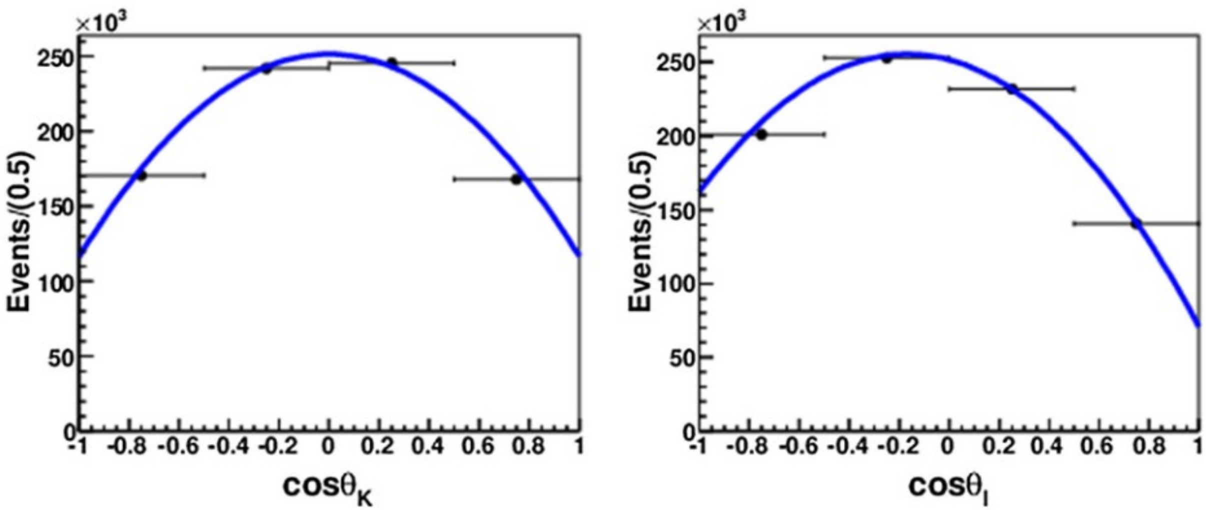
$K^0 - \bar{K}^0$ mixing

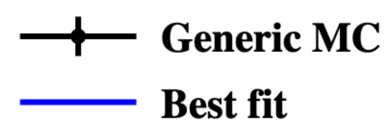


- **Two-dimensional (2-D) fit for $D^0 \to K_1(1270)^- e^+ \nu_e$**



- **Efficiency corrected signal yields**





The statistical uncertainty of $A'_{\rm UD}$ is 1.8×10^{-2}.

CP violation of Λ decay

$e^+e^- \to J/\psi \to \Lambda(\to p\pi^-)\,\bar{\Lambda}(\to \bar{n}\pi^0, \bar{p}\pi^+)$ with a MC of J/ψ events @ 3.097 GeV

- **The joint angular distribution with non-polarized beam:**

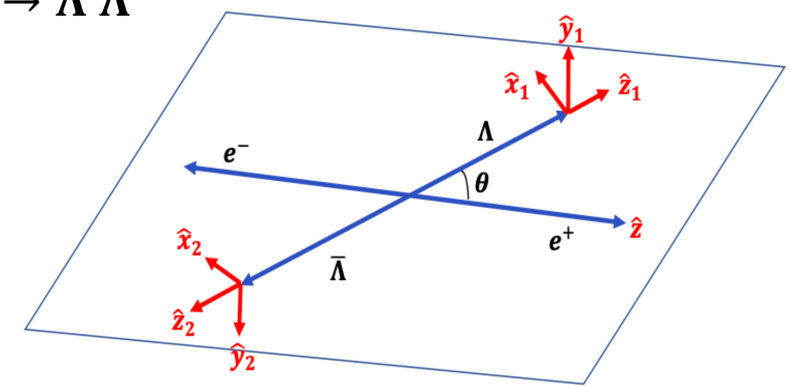
Y. Xu *et al.*, submitted

The angular distribution of $J/\psi \to \Lambda\,\bar{\Lambda}$

$$\mathcal{W}(\xi) = \mathcal{F}_0(\xi) + \alpha\mathcal{F}_5(\xi) + \alpha_1\alpha_2\left(\mathcal{F}_1(\xi) + \sqrt{1-\alpha^2}\cos(\Delta\Phi)\mathcal{F}_2(\xi) + \alpha\mathcal{F}_6(\xi)\right) + \sqrt{1-\alpha^2}\sin(\Delta\Phi)\left(-\alpha_1\mathcal{F}_3(\xi) + \alpha_2\mathcal{F}_4(\xi)\right),$$

the spin correlations between Λ and $\bar{\Lambda}$

the transverse polarization effects of Λ and $\bar{\Lambda}$



- **The joint angular distribution with polarized e^- beam [1]:**

S. Zeng *et al.*, ongoing

$$\mathcal{W}(\xi) = \mathcal{F}_0(\xi) + \alpha\mathcal{F}_5(\xi) + \alpha_1\alpha_2\left(\mathcal{F}_1(\xi) + \sqrt{1-\alpha^2}\cos(\Delta\Phi)\mathcal{F}_2(\xi) + \alpha\mathcal{F}_6(\xi)\right) + \sqrt{1-\alpha^2}\sin(\Delta\Phi)\left(-\alpha_1\mathcal{F}_3(\xi) + \alpha_2\mathcal{F}_4(\xi)\right), + \boxed{\alpha_1 T_6 + \alpha_2 T_7 - \alpha_1\alpha_2 T_8}$$

$\propto$ polarizability P_z of the e^- beam

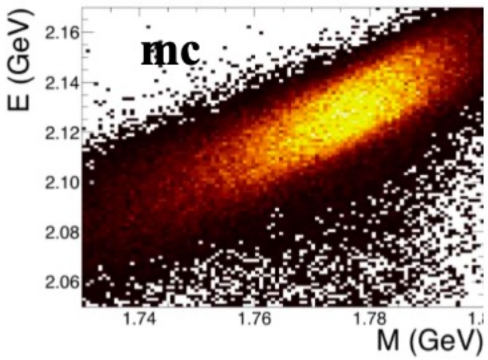
The angular distribution of proton in $\Lambda \to p\,\pi^-$ is $\frac{1}{4\pi}(1 + \alpha_1\,\vec{P}_\Lambda \cdot \hat{\vec{n}})$.

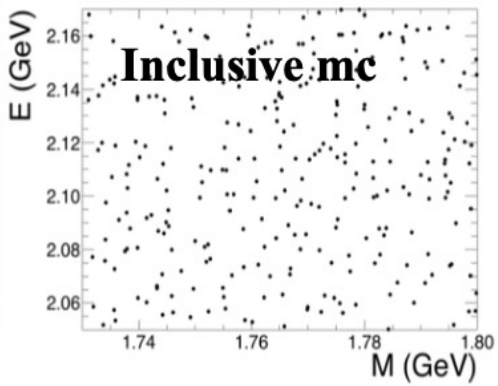
α_1: asymmetry parameter

$\vec{P}_\Lambda$: polarization

[1] N. Salone *et al.*, Phys. Rev. D 105, 116022 (2022).

LFV decay of $\tau\rightarrow\gamma\mu$ at STCF

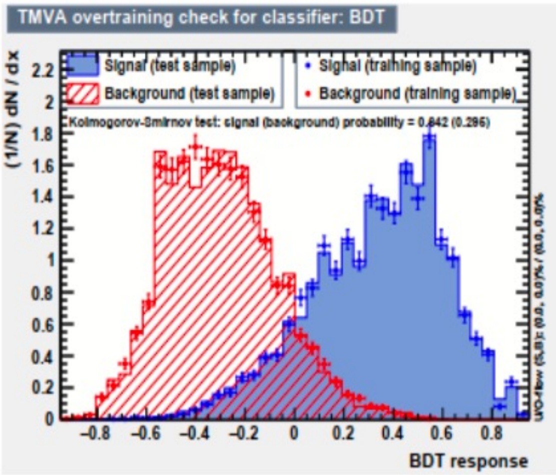


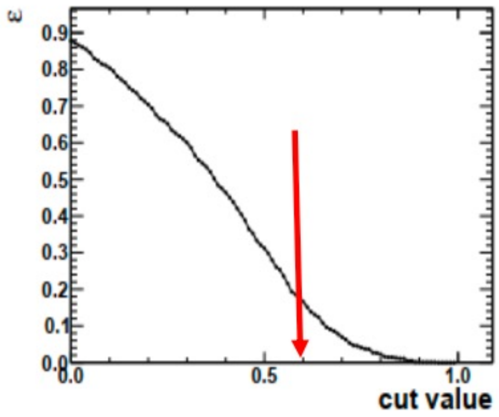


- Signal side $\tau \rightarrow \gamma\mu$
- Tag side: $\tau \rightarrow e\upsilon\bar{\upsilon},\ \pi\upsilon,\ \pi\pi^0\upsilon(\mathcal{B}r = 54\%)$
- **Dominant background**: $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-, \tau^+ \rightarrow \pi\pi^0\upsilon, \tau^- \rightarrow \mu\upsilon\bar{\upsilon}$

TABLE II. Optimization for pion/muon separation.

	μ eff. at 1 GeV	$UL(\mathcal{B}(\tau \rightarrow \gamma\mu))/10^{-8}$
3 %	96.7 %	1.2
1.7 %	92.6 %	1.5
1 %	87.3 %	1.8





- **STCF with 1ab^{-1}:**

$$\mathcal{B}_{UL}^{90}(\tau \rightarrow \gamma\mu) < \frac{N_{UL}^{90}}{2\varepsilon N_{\tau\tau}} \sim 1.2 \times 10^{-8}$$