超级陶粲装置上的物理模拟进展

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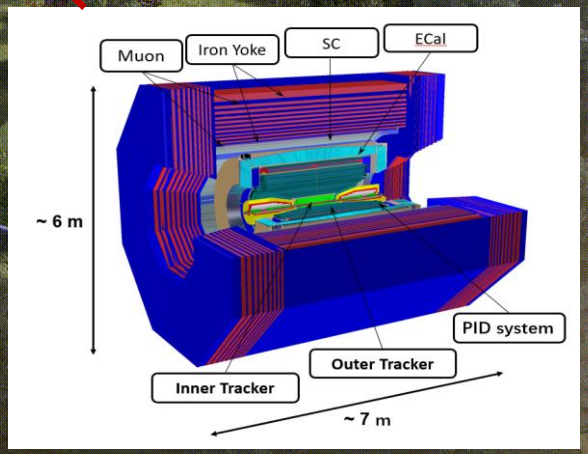
中国物理学会高能物理分会第十三届全国粒子物理学术

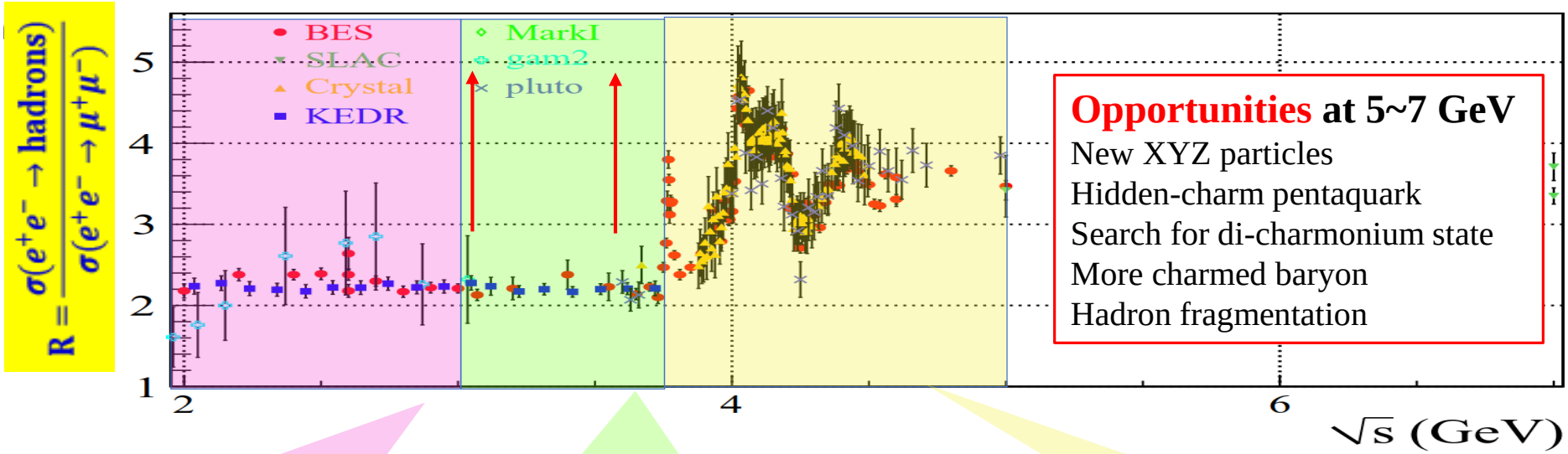
2021.8.16-19

Super tau-Charm Facility in China



- Peaking luminosity >0.5×10^{35} $cm^{-2}s^{-1}$ at 4 GeV
- Energy range E_{cm} = 2-7 GeV
- Potential to increase luminosity and realize beam polarization
- A nature extension and a viable option for China accelerator project in the post BEPCII/BESIII era

Physics in tau-Charm Region



Opportunities at 5~7 GeV

New XYZ particles
Hidden-charm pentaquark
Search for di-charmonium state
More charmed baryon
Hadron fragmentation

- 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.**

Expected Data Samples at STCF

不同能量点上一年产生的事例样本

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}	$CP_{D^0\bar{D}^0}=+1$
		$\pi^0D^0\bar{D}^0$	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工厂

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

超子工厂

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}

轻介子工厂

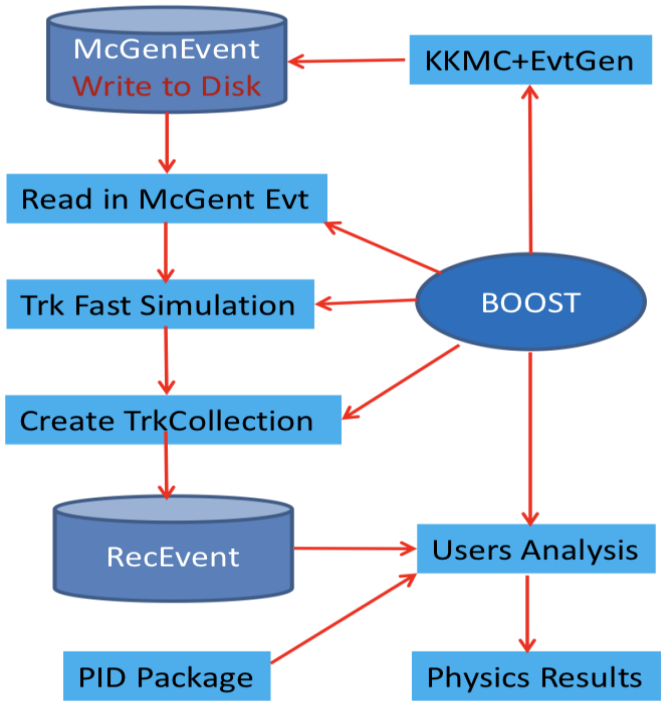
Decay Mode	$\mathcal{B}$ ($\times10^{-4}$) [2]	η/η' events
$J/\psi\to\gamma\eta'$	52.1 ± 1.7	1.8×10^{10}
$J/\psi\to\gamma\eta$	11.08 ± 0.27	3.7×10^{9}
$J/\psi\to\phi\eta'$	7.4 ± 0.8	2.5×10^{9}
$J/\psi\to\phi\eta$	4.6 ± 0.5	1.6×10^{9}

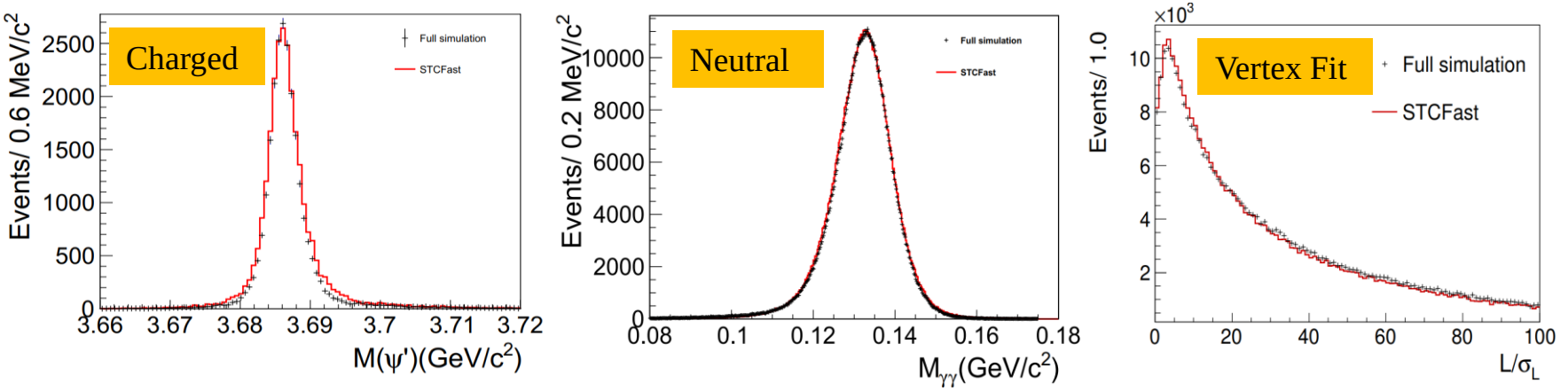
- **Belle-II (50/ab) has more statistics**
- **LHCb have much more statistics，but huge background**
- **STCF is expected to have higher detection efficiency and low bkgs for productions at threshold**
- **Additionally, STCF excellent resolution, kinematic constraining**

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



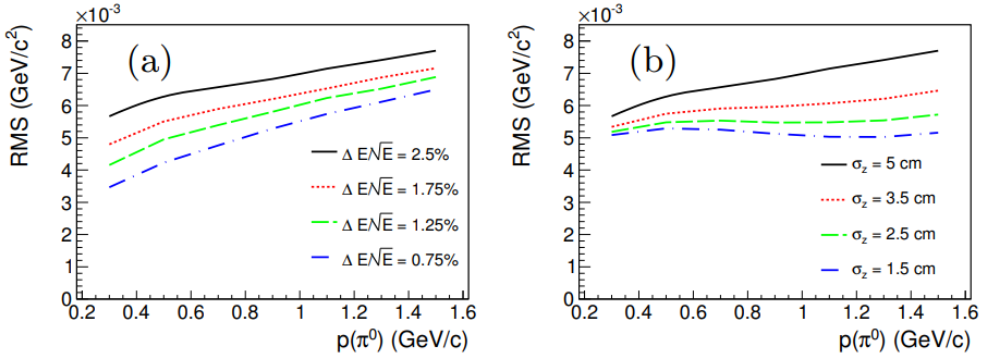


Fast Simulation Package

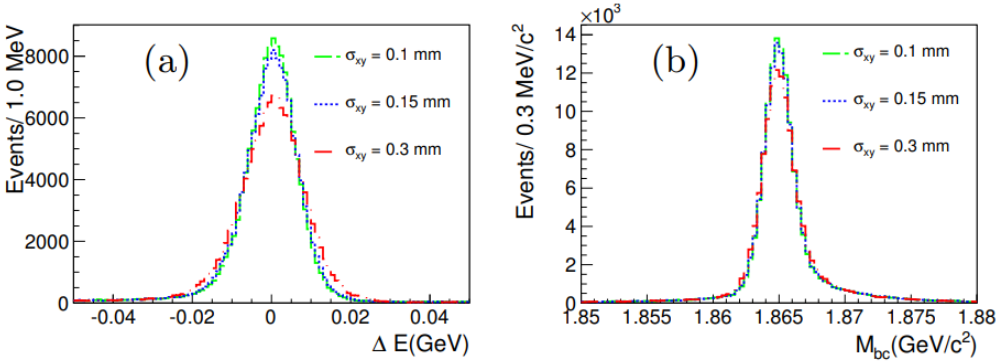
X. D. Shi *et al.*, JINST, 16, P03029 (2021)

- **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:



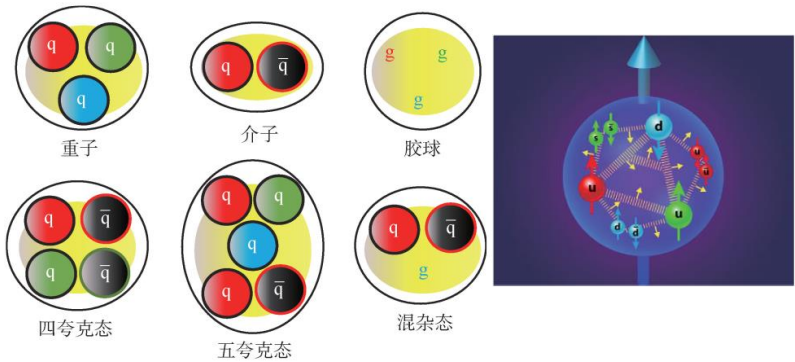
  - D tag with different track resolution:



Highlighted physics at STCF

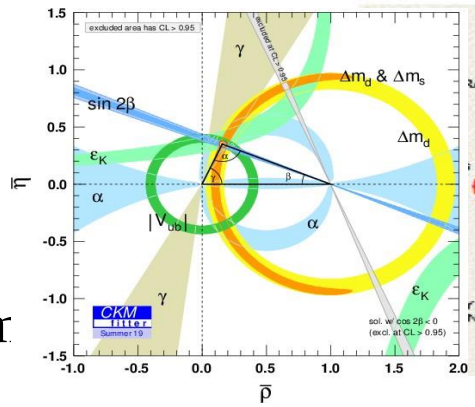
☐QCD and Hadronic Physics

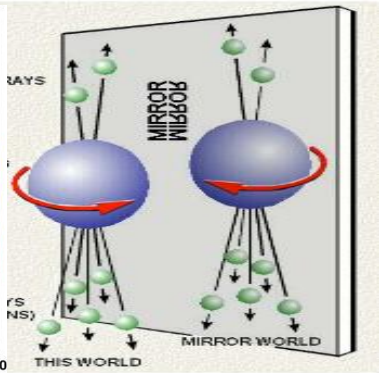
- ➢Exotic states and hadron spectroscopy
- ➢Hadron structures
- ➢Precision test of SM parameters



☐Flavor Physics and CP violation

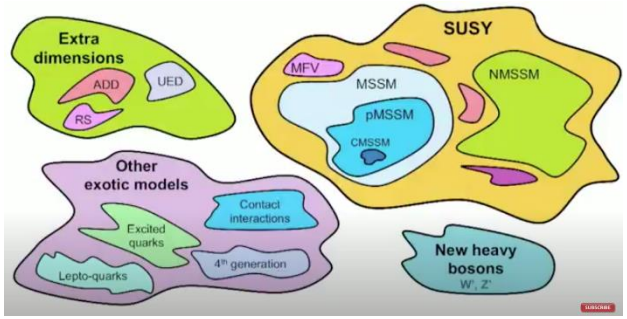
- ➢CKM matrix, $D^0 - \bar{D}^0$ mixing
- ➢CP violation in lepton, hyperon, charm





☐New Physics Search

- ➢Rare/Forbidden
- ➢Dark particle search



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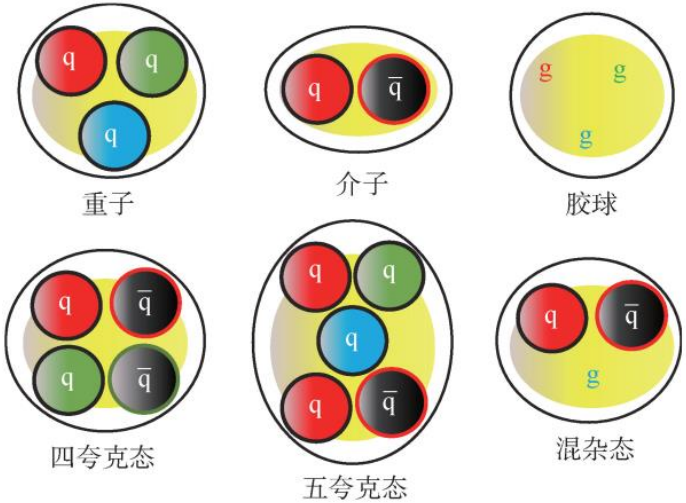

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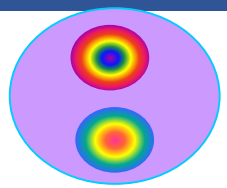
Charmonium (Like) Spectroscopy



Excellent platform to explore the QCD

Fruitful results in past decade, a new territory to study exotic hadrons

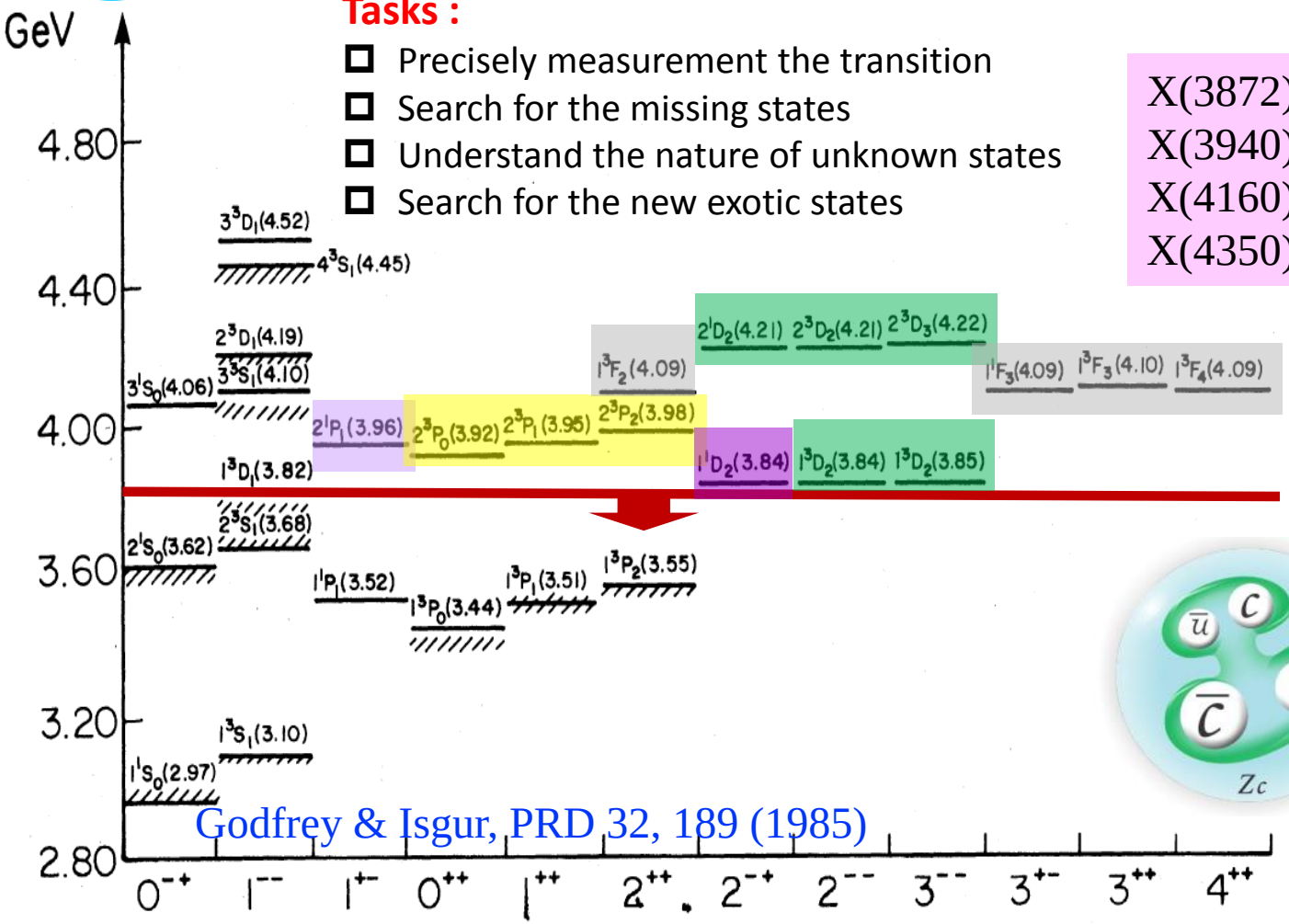
Tasks :

- Precisely measurement the transition
- Search for the missing states
- Understand the nature of unknown states
- Search for the new exotic states

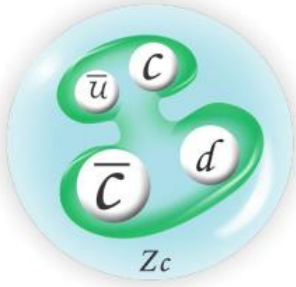
X(3872)
X(3940)
X(4160)
X(4350)

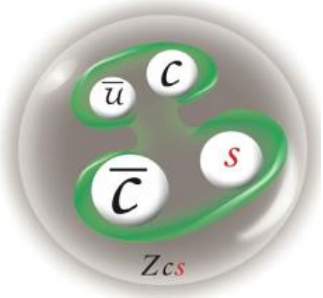
Y(3940)
Y(4008)
Y(4260)
Y(4360)
Y(4660)

$Z_c(3900)$
$Z_c(4020)$
$Z_c(4050)$
$Z_c(4200)$
$Z_c(4250)$
$Z_c(4430)$
$Z_{cs}(3985)$
$Z_{cs}(4000)$
$Z_{cs}(4220)$

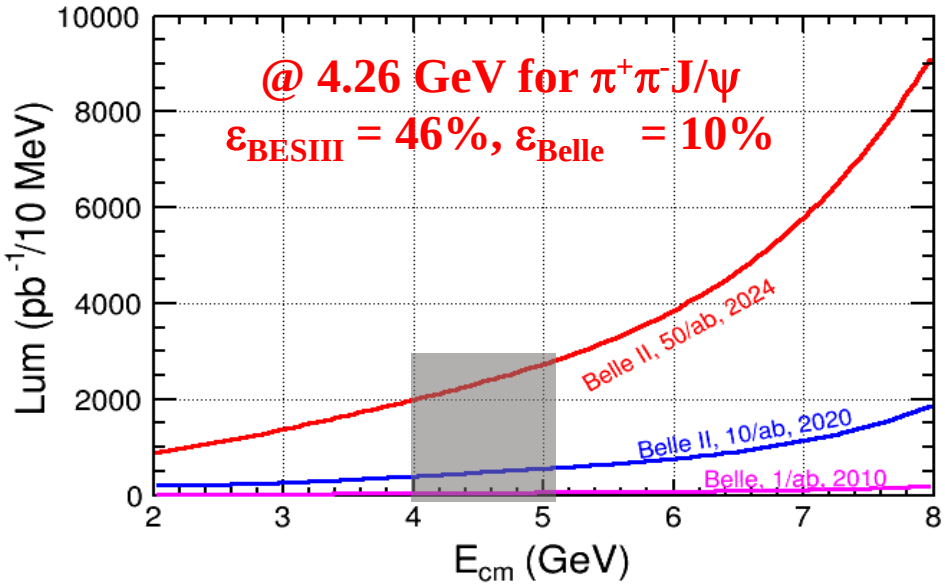


Godfrey & Isgur, PRD 32, 189 (1985)

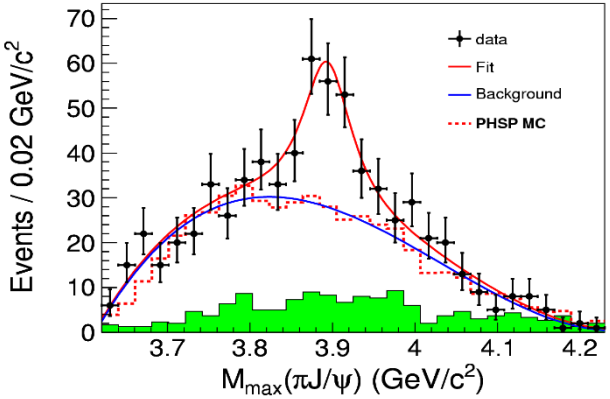




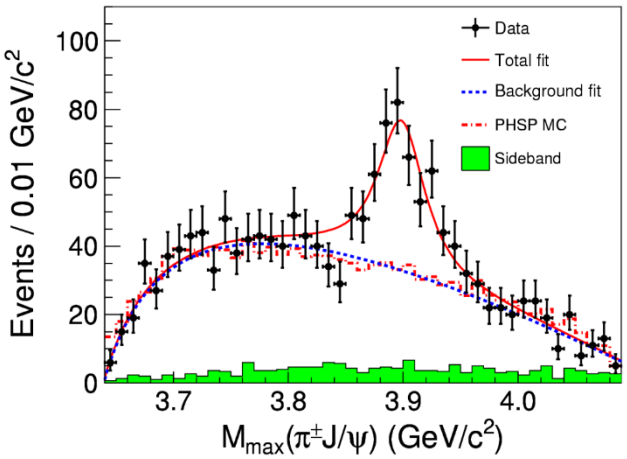
Charmonium(Like) Spectroscopy at STCF



Belle with ISR: PRL110, 252002
967 fb-1 in 10 years running time

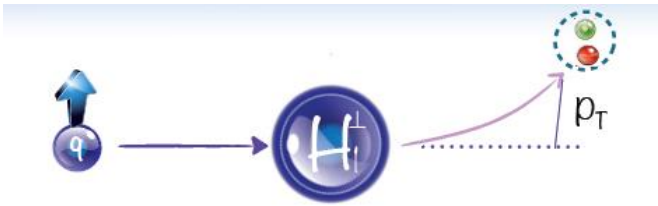


BESIII at 4.260 GeV: PRL110, 252001
0.525 fb^{-1} in one month running time



- B factory : Total integrate effective luminosity between 4-5 GeV is 0.23 ab^{-1} for 50 ab^{-1} data
- τ-C factory : scan in 4-5 GeV, 10 MeV/step, every point have 10 fb^{-1}/year, 5 time of Belle II for 50 ab^{-1} data
- τ-C factory have much higher efficiency and low background than B Factory

Collins Fragmentation Function (FF)

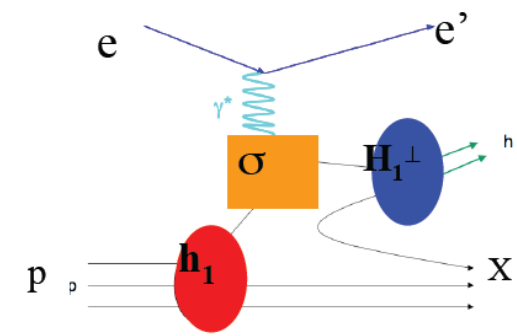


J. C. Collins, Nucl. Phys. B396, 161 (1993)

$$D_{hq^\uparrow}(z, P_{h\perp}) = D_1^q(z, P_{h\perp}^2) + H_1^{\perp q}(z, P_{h\perp}^2)\frac{(\hat{\mathbf{k}} \times \mathbf{P}_{h\perp}) \cdot \mathbf{S}_q}{zM_h},$$

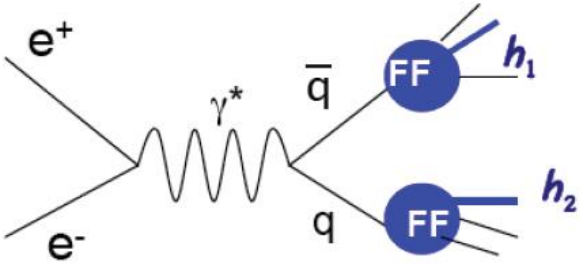
SIDIS

Transversity ⊗ Collins FF



e+ e-

Collins FF ⊗ Collins FF

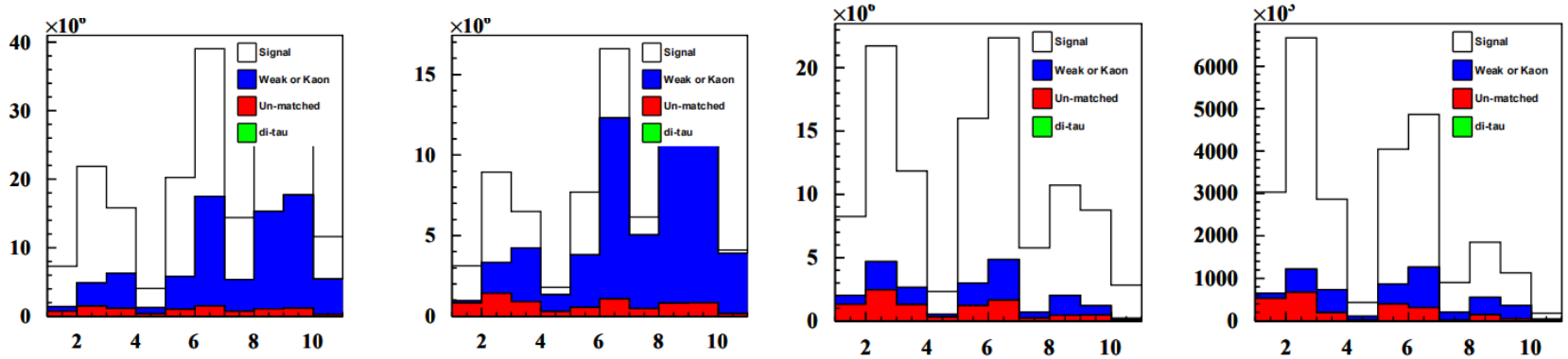


D_1: the un-polarized FF
H_1: Collins FF
→ describes the fragmentation of a transversely polarized quark into a spin-less hadron *h*.
→ depends on $z = 2E_h/\sqrt{s}$,
→ leads to an azimuthal modulation of hadrons around the quark momentum.

Collins FF at STCF

B. L. Wang *et al.*, Journal of University of Chinese Academy of Sciences, 2021, 38(4):433-441

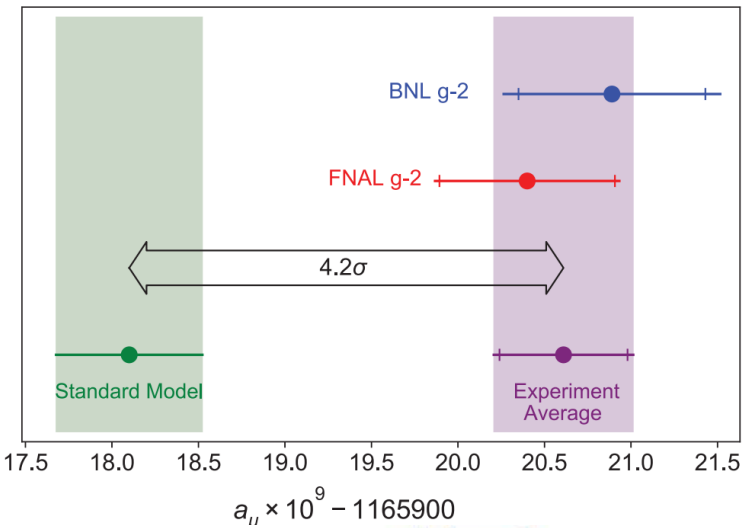
- STCF is a perfect machine for studying Collins effect
- Poor performance for the traditional dE/dx & TOF PID system for tracks > 0.8GeV
- This measurement suffer from systematic uncertain from $K-\pi$ mis-PID.
- The mis-PID is even worse in the case of KK Collins measurement.
- With 2.5 fb^{-1} 7GeV $q\bar{q}$ MC ($\sigma \approx 5\mathrm{nb}$ LundArlw), we study Collins effect at STCF.



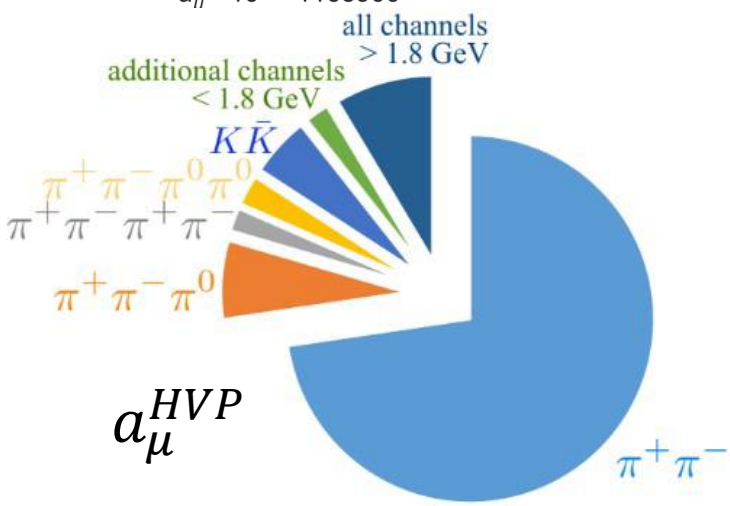
Blue: π/K mis-PID in KK Collins measurement.
Left) de/dx&TOF. Right) a 1% mis-PID set in FastSim

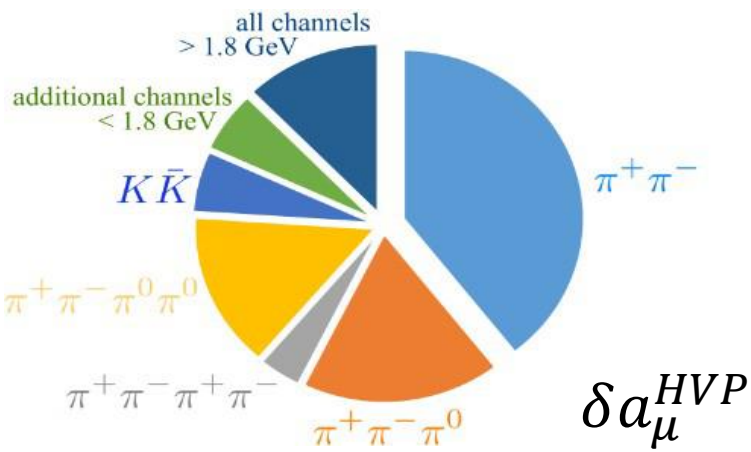
- By setting the K/π mis-PID at 1%, we obtain:
  - The statistical uncertainty for $25\mathrm{fb}^{-1}$ MC is ~10^{-3} to 10^{-2}
  - The statistical uncertainty for $1\mathrm{ab}^{-1}$ MC is ~10^{-4} to 10^{-3}

HVP Contribution to $(g-2)_\mu$



- **4.2σ discrepancy => Strong indication for physics beyond the SM?**
- **Dominant uncertainty of SM prediction comes from Hadronic vacuum polarization (HVP)**

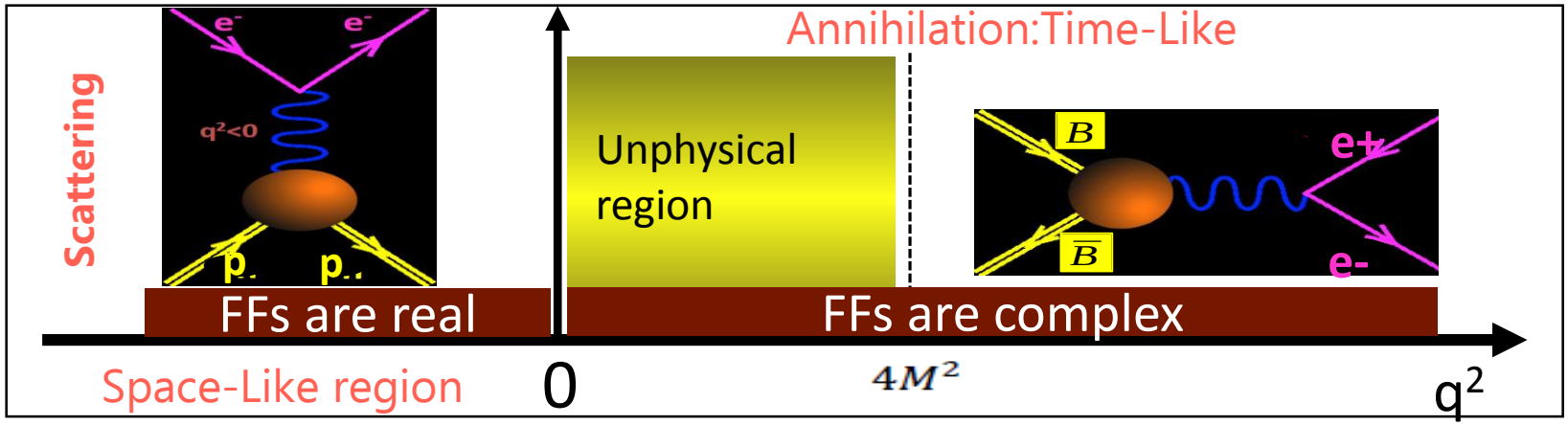




High Luminosity of STCF will largely improve the SM precisions !

Electromagnetic Form Factors

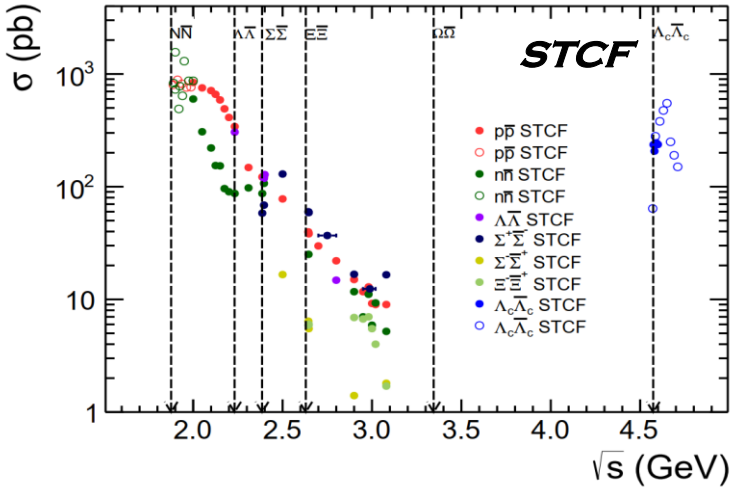
- **Fundamental properties of the nucleon**
  - **Connected to charge, magnetization distribution**
  - **Crucial testing ground for models of the nucleon internal structure**



$$\Gamma_\mu(p',p) = \gamma_\mu F_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2m_p} F_2(q^2)$$

$$G_E(q^2) = F_1(q^2) + \tau\kappa_p F_2(q^2),$$

$$G_M(q^2) = F_1(q^2) + \kappa_p F_2(q^2)$$



QCD and Hadronic Physics

Physics at STCF	Benchmark Processes	Key Parameters*	Remarks
XYZ properties	$e^+e^- \to Y \to \gamma X, \eta X, \phi X$ $e^+e^- \to Y \to \pi Z_c, KZ_{cs}$	$N_{Y(4260)/Z_c/X(3872)} \sim$ $10^{10}/10^9/10^6$	**Leading role**
Pentaquarks, Di-charmonium	$e^+e^- \to J/\psi p\bar{p}, \Lambda_c\bar{D}\bar{p}, \Sigma_c\bar{D}\bar{p}$ $e^+e^- \to J/\psi\eta_c, J/\psi h_c$	$\sigma(e^+e^- \to J/\psi p\bar{p})$~4 fb; $\sigma(e^+e^- \to J/\psi c\bar{c})$~10 fb (prediction)	In Competition with BelleII/LHCb
Hadron Spectroscopy	Excited $c\bar{c}$ and their transition, Charmed hadron spectroscopy, Light hadron spectroscopy	$N_{J/\psi/\psi(3686)/\Lambda_c} \sim$ $10^{12}/10^{11}/10^8$	**Leading role**
Muon g-2	$e^+e^- \to \pi^+\pi^-, \pi^+\pi^-\pi^0, K^+K^-$ $\gamma\gamma \to \pi^0, \eta^{(\prime)}, \pi^+\pi^-$	$\Delta a_\mu^{HVP} \ll 40 \times 10^{-11}$	In Competition with BelleII
R value, τ mass	$e^+e^- \to inclusive$ $e^+e^- \to \tau^+\tau^-$	Δm_τ~0.012 MeV (with 1 month scan)	**Leading role**
Fragmentation functions	$e^+e^- \to (\pi, K, p, \Lambda, D) + X$ $e^+e^- \to (\pi\pi, KK, \pi K) + X$	$\Delta A^{\mathrm{Collins}} < 0.002$	**Synergy with Eic/EicC**
Nucleon Form Factors	$e^+e^- \to B\bar{B}$ from threshold	δR_{EM}~1%	**Leading role**

*Sensitivity estimated based on $\mathcal{L} = 1\ \mathrm{ab}^{-1}$

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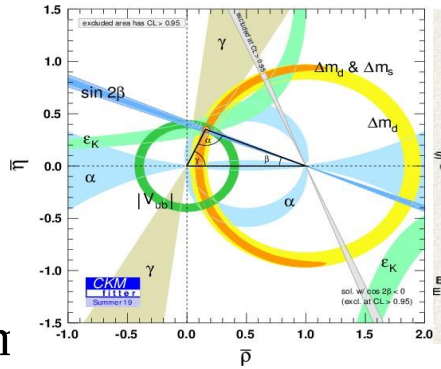
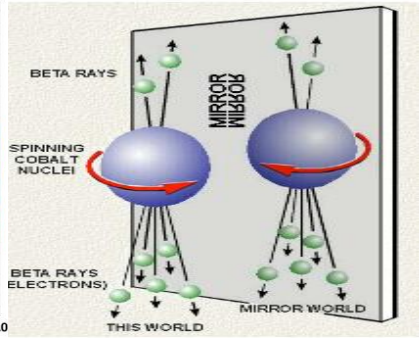




New Physics Search

- Rare/Forbidden
- Dark particle search

Facilities for Charm Study

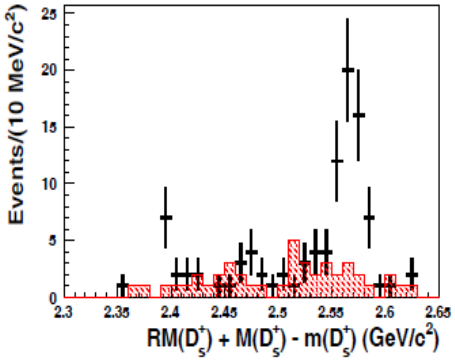
- LHCb: huge x-sec, boost, 9 fb^{-1} now (×40 current B factories)
- B-factories (Belle(-II), BaBar): more kinematic constrains, clean environment, ~100% trigger efficiency
- τ-charm factory : Low backgrounds and high efficiency, Quantum correlations and CP-tagging are unique
- STCF :

- 4×10^9 pairs of $D^{\pm,0}$ and 10^8 D_s pairs per year
  - 10^{10} charm from Belle II/year
- Highlighted Physics programs
  - Precise measurement of (semi-)leptonic decay (f_D, f_{Ds}, CKM matrix…)
  - D decay strong phase (Determination of $\gamma/\phi3$ angle)
  - $D^0 - \overline{D}^0$ mixing, CPV
  - Rare decay (FCNC, LFV, LNV….)
  - Excite charm meson states D_J, D_{sJ} (mass, width, J^{PC}, decay modes)
  - Charmed baryons (J^{PC}, Decay modes, absolute BF)

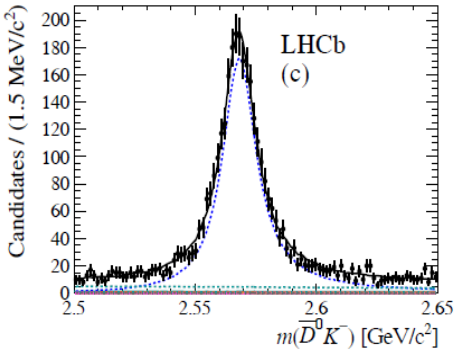
Features in Charm Hadron Decays

	STCF	Belle II	LHCb
Production yields	★★	★★★★	★★★★★
Background level	★★★★★	★★★	★★
Systematic error	★★★★★	★★★	★★
Completeness	★★★★★	★★★	★
(Semi)-Leptonic mode	★★★★★	★★★★	★★
Neutron/K_L mode	★★★★★	★★★	☆
Photon-involved	★★★★★	★★★★	★
Absolute measurement	★★★★★	★★★	☆

0.5 fb^{-1} ~ 80 Events
1.0 ab^{-1}~ 160000 Events



3.0 fb^{-1}~ 4000 Events
60 fb^{-1}~ 80000 Events



- Most are precision measurements, which are mostly dominant by the systematic uncertainty
- STCF has overall advantages in several studies

Precision Measurements of CKM Elements

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

- A precise test of EW theory
- New physics beyond SM?

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

BESIII + B factories + LQCD

Three generations of quark?

Unitary matrix?

Expected precision < 2% at BESIII

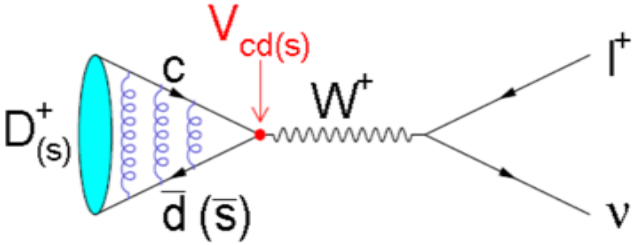
BESIII + B factories + LHCb + LQCD

A direct measurement of $V_{cd(s)}$ is one of the most important task in charm physics

$D_{(s)}$ (Semi-)Leptonic decay

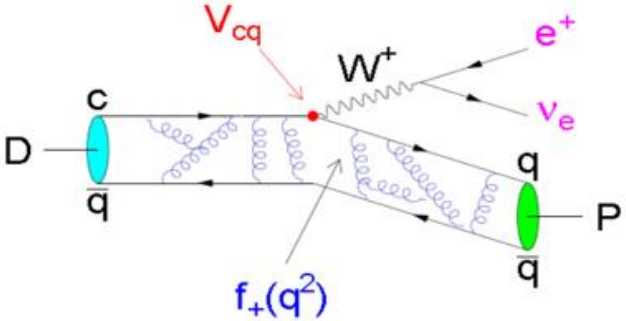
Purely Leptonic:

$$\Gamma(D^+_{(s)} \to \ell^+ \nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi} \mid V_{cd(s)} \mid^2 m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$



Semi-Leptonic:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{cs(d)}|^2 p^3_{K(\pi)} |f_+^{K(\pi)}(q^2)|^2$$



Directly measurement : $|V_{cd(s)}|$ x $f_{D(s)}$ or $|V_{cd(s)}|$ x FF

- Input $f_{D(s)}$ or $f^{k(\pi)}(0)$ from LQCD $\Rightarrow$ $|V_{cd(s)}|$
- Input $|V_{cd(s)}|$ from a global fit $\Rightarrow$ $f_{D(s)}$ or $f^{k(\pi)}(0)$
- Validate LQCD calculation of Input $f_{B(s)}$ and provide constrain of CKM-unitarity

$D_{(s)}$ (Semi-)Leptonic decay

	BESIII	STCF	Belle II
Luminosity	2.93 fb^{-1} at 3.773 GeV	1 ab^{-1} at 3.773 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D^+ \to \mu^+\nu_\mu)$	$5.1\%_{stat}$ $1.6\%_{syst}$ [8]	$0.28\%_{stat}$	–
f_{D^+} (MeV)	$2.6\%_{stat}$ $0.9\%_{syst}$ [8]	$0.15\%_{stat}$	–
$\lvert V_{cd}\rvert$	$2.6\%_{stat}$ $1.0\%^{*}_{syst}$ [8]	$0.15\%_{stat}$	–
$\mathcal{B}(D^+ \to \tau^+\nu_\tau)$	$20\%_{stat}$ $10\%_{syst}$ [9]	$0.41\%_{stat}$	–
$\frac{\mathcal{B}(D^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D^+ \to \mu^+\nu_\mu)}$	$21\%_{stat}$ $13\%_{syst}$ [9]	$0.50\%_{stat}$	–
Luminosity	3.2 fb^{-1} at 4.178 GeV	1 ab^{-1} at 4.009 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$	$2.8\%_{stat}$ $2.7\%_{syst}$ [10]	$0.30\%_{stat}$	$0.8\%_{stat}$ $1.8\%_{syst}$
$f_{D_s^+}$ (MeV)	$1.5\%_{stat}$ $1.6\%_{syst}$ [10]	$0.15\%_{stat}$	–
$\lvert V_{cs}\rvert$	$1.5\%_{stat}$ $1.6\%_{syst}$ [10]	$0.15\%_{stat}$	–
$f_{D_s^+}/f_{D^+}$	$3.0\%_{stat}$ $1.5\%_{syst}$ [10]	$0.21\%_{stat}$	–
$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	$1.9\%_{stat}$ $2.3\%^{\dagger}_{syst}$	$0.24\%_{stat}$	$0.6\%_{stat}$ $2.7\%_{syst}$
$f_{D_s^+}$ (MeV)	$0.9\%_{stat}$ $1.2\%^{\dagger}_{syst}$	$0.11\%_{stat}$	–
$\lvert V_{cs}\rvert$	$0.9\%_{stat}$ $1.2\%^{\dagger}_{syst}$	$0.11\%_{stat}$	–
$\overline{f}^{\mu\&\tau}_{D_s^+}$ (MeV)	$0.9\%_{stat}$ $1.0\%^{\dagger}_{syst}$	$0.09\%_{stat}$	$0.3\%_{stat}$ $1.0\%_{syst}$
$\lvert \overline{V}^{\mu\&\tau}_{cs}\rvert$	$0.9\%_{stat}$ $1.0\%_{syst}{}^{\dagger}$	$0.09\%_{stat}$	–
$\frac{\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)}$	$3.6\%_{stat}$ $3.0\%^{\dagger}_{syst}$	$0.38\%_{stat}$	$0.9\%_{stat}$ $3.2\%_{syst}$

Theory : 0.2%(0.1% expected)

Theory : 0.2%(0.1% expected)

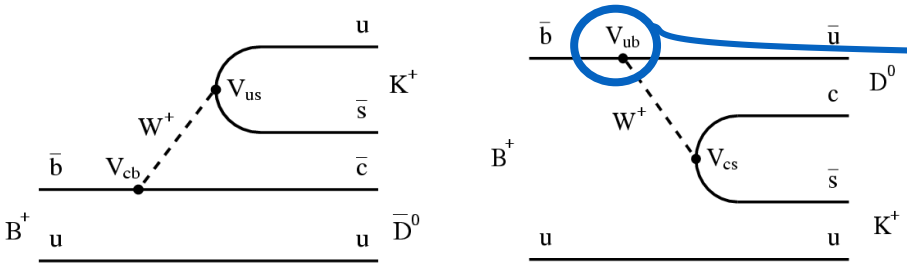
Theory : 0.2%(0.1% expected)

* assuming Belle II improved systematics by a factor 2

Stat. uncertainty is closed to theory precision
Sys. is challenging

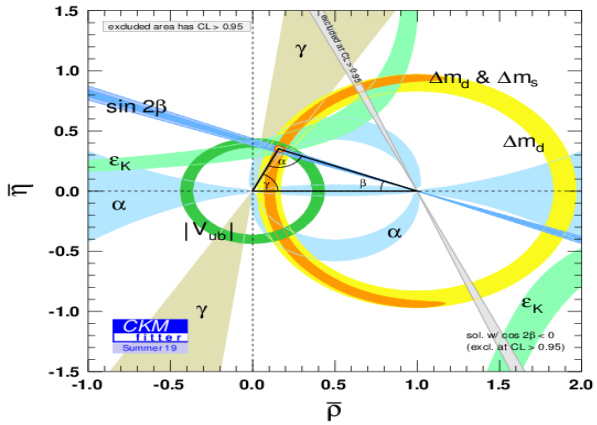
Determination of γ/ϕ_3 angle

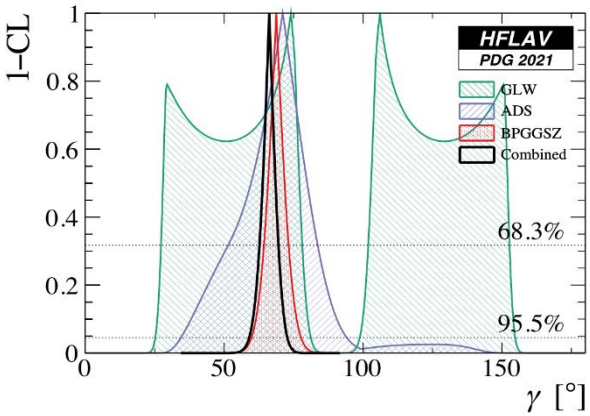
- The cleanest way to extract γ is from B→DK decays:



$$\frac{A(B^+ \to D^0 K^+)}{A(B^+ \to \overline{D^0} K^+)} \equiv r_B e^{i(\delta_B + \phi_3)}$$

  - Interference between tree-level decays; theoretically clean
  - current uncertainty $\sigma(\gamma) \sim 5^0$
  - however, theoretical relative error $\sim 10^{-7}$ (very small!)
- Information of *D decay strong phase* is needed
  - Best way is to employ quantum coherence of DD production at threshold

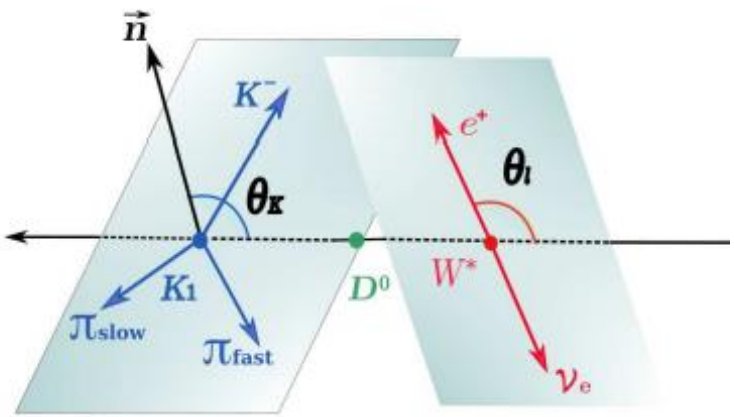




Photon polarization in $b \to s\gamma$

Y. L. Fan, *et al.*, arXiv:2107.06118

- In $b \to s\gamma$, the photon is left-handed under SM prediction. Many NP models have predicted a significant right-handed component of photon.
- A novel method is proposed by combine $B \to K_{res}(\to K\pi\pi)\gamma$ and $D^0 \to K_{res} e \upsilon_e$ to obtain the photon polarization model-independently (*W. Wang et al., PRL. 125, 051802 (2020)*).



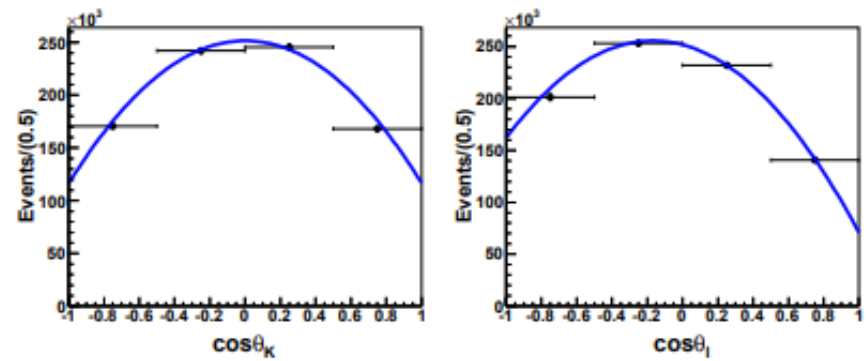
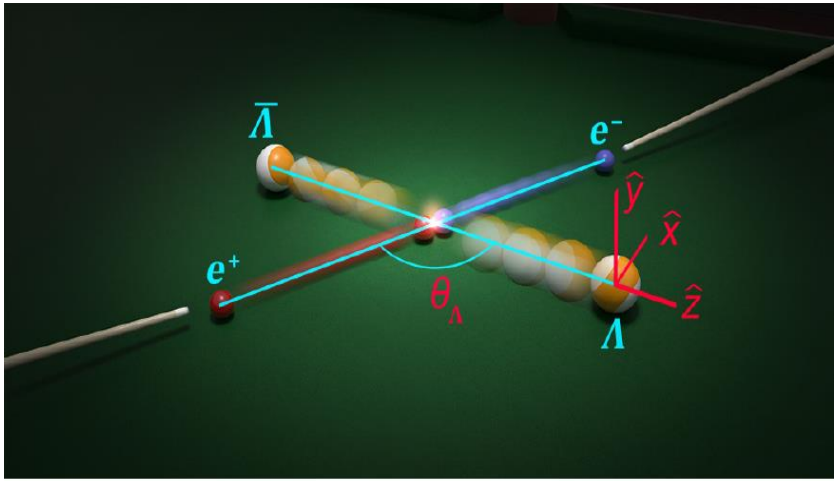


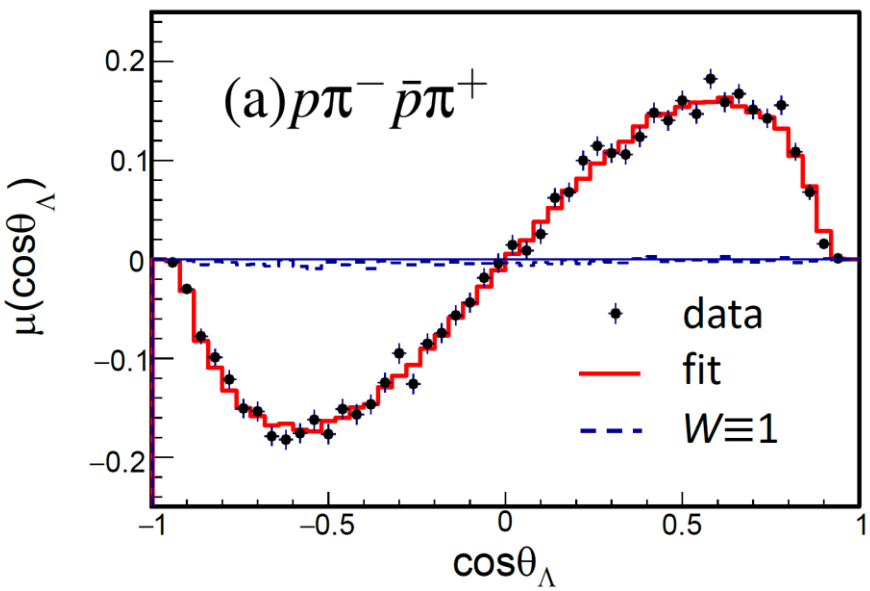
Fig. 5 Efficiency corrected signal yields in bins of $\cos\theta_K$(left) and $\cos\theta_l$(right). The curve is the result of fit using polynomial function.

$$\delta A'_{ud} = 1.5 \times 10^{-2}$$

For details, see the talk by Yulan Fan tomorrow:
https://indico.ihep.ac.cn/event/10906/session/5/contribution/343

Polarization of Λ hyperons and CPV





Nature Phys. **15**, 631–634 (2019)

1.31 B J/ψ events
Quantum correlation in Λ pair

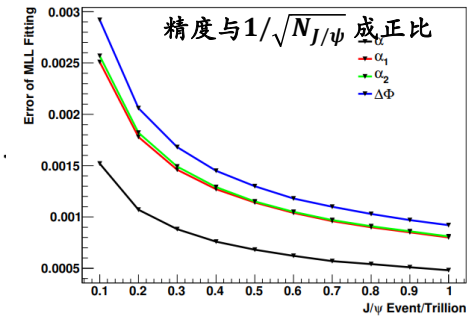
Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [14]
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)^\circ$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [16]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [16]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [16]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

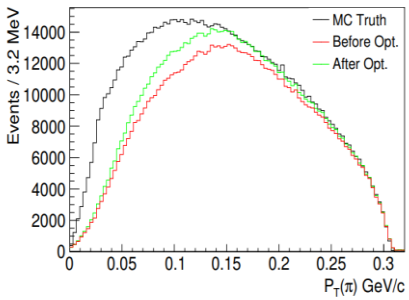
2% level sensitivity for CPV test
SM prediction: 10^{-4}~10^{-5}

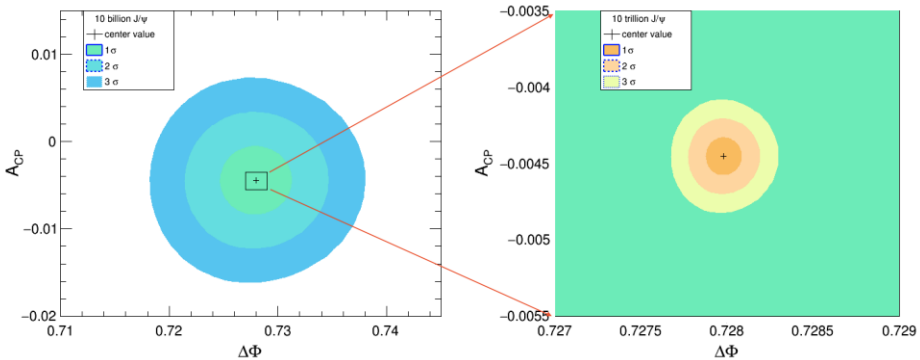
CP test $A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$

CPV in Hyperon Decays at STCF

- 4 trillion J/ψ events ⇒ $A_{CP}\sim 10^{-4}$
  - Luminosity optimized at J/ψ resonance
  - Luminosity of STCF: × 100
  - 2 – 3 years data taking
  - No polarization beams are needed







- Beam energy trick
  ⇒ small beam energy spread
  ⇒ J/ψ cross-section: × 10 ⇒ $A_{CP}\sim 10^{-5}$?
- Challenge: Systematics control, spin procession effect in magnet

CPV in τ decay

H. Y. Sang, *et al.*, Chin. Phys. C 45, 053003 (2021)

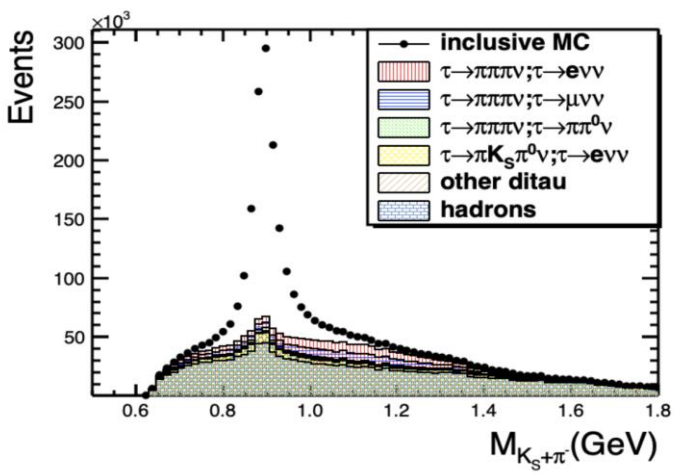
- The CPV source in $K^0 - \bar{K}^0$ **mixing** produces a difference in tau decay rate

In Theory : $$A_Q = \frac{B(\tau^+ \to K_S^0\pi^+\bar{\nu}_\tau) - B(\tau^- \to K_S^0\pi^-\nu_\tau)}{B(\tau^+ \to K_S^0\pi^+\bar{\nu}_\tau) + B(\tau^- \to K_S^0\pi^-\nu_\tau)} = (+0.36 \pm 0.01)\%$$

BaBar experiments : $$A_{CP}(\tau^- \to K_S\pi^-\nu[\geq 0\pi^0]) = (-0.36 \pm 0.23 \pm 0.11)\%$$

2.8σ away from the SM prediction

Theorist try to reconcile the deviation, but not coverage even NP included



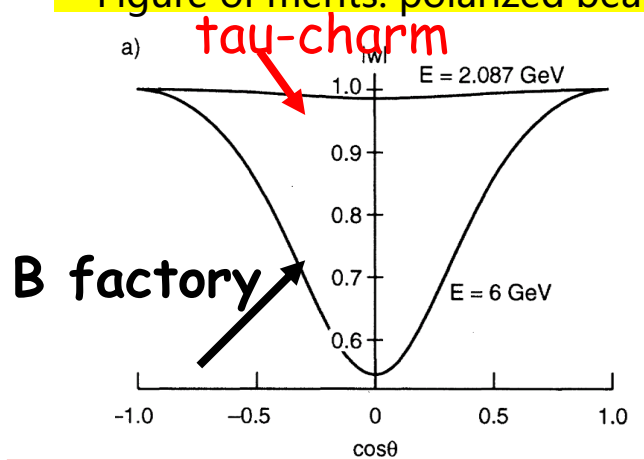
The CPV sensitivity with 1ab^{-1} @ 4.26 GeV[1]:

$A_{STCF} \sim 9.7 \times 10^{-4}$

With 10 ab^{-1} data:

$A_{STCF} \sim 3.1 \times 10^{-4}$

Possible choice to increase the Figure of merits: polarized beam



$$\begin{aligned} \text{merit} &= \text{luminosity} \times \bar{w}_Z \times \text{ total cross section} \\ &\propto \text{luminosity} \times (w_1 + w_2) \\ &\quad \times \sqrt{1-a^2}\,a^2(1+2a)\ , \end{aligned}$$

Flavor Physics and CP violation

Physics at STCF	Benchmark Processes	Key Parameters*	Remarks
CKM matrix	$D^+_{(s)} \to l^+\nu_l, D \to Pl^+\nu_l$	$\delta V_{cd/cs}$~0.15%; $\delta f_{D/D_s}$~0.15%	**Leading role**
γ/ϕ_3 measurement	$D^0 \to K_s\pi^+\pi^-, K_sK^+K^- \ldots$	$\Delta(\cos\delta_{K\pi})$ ~0.007; $\Delta(\delta_{K\pi})$ ~2°	**Synergy with BelleII/LHCb**
$D^0 - \bar{D}^0$ mixing	$\psi(3770) \to (D^0\bar{D}^0)_{CP=-}$, $\psi(4140) \to \gamma(D^0\bar{D}^0)_{CP=+}$	Δx~0.035%; Δy~0.023%	In Competition with BelleII/LHCb
Charm hadron decay	$D_{(s)}, \Lambda_c^+, \Sigma_c, \Xi_c, \Omega_c$ decay	$N_{D/D_s/\Lambda_c}$~$10^9/10^8/10^8$	**Leading role**
γ polarization	$D^0 \to K_1 e^+\nu_e$	$\Delta A'_{UD}$~0.015	**Synergy with BelleII/LHCb**
CPV in Hyperons	$J/\psi \to \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi^-\bar{\Xi}^-, \Xi^0\bar{\Xi}^0$	ΔA_Λ~10^{-4}	**Leading role**
CPV in τ	$\tau \to K_s\pi\nu$, EDM of τ, $\tau \to \pi/K\pi^0\nu$ for polarized e^-	$\Delta A_{\tau\to K_s\pi\nu}$~$10^{-3}$; Δd_τ~5×10^{-19} (e cm)	In Competition with BelleII
CPV in Charm	$D^0 \to K^+K^-/\pi^+\pi^-$, $\Lambda_c \to pK^-\pi^+\pi^0 \ldots$	ΔA_D~10^{-3}; ΔA_{Λ_c}~10^{-3}	In Competition with BelleII/LHCb

*Sensitivity estimated based on $\mathcal{L} = 1\ \mathrm{ab}^{-1}$

Highlighted physics at STCF

☐QCD and Hadronic Physics

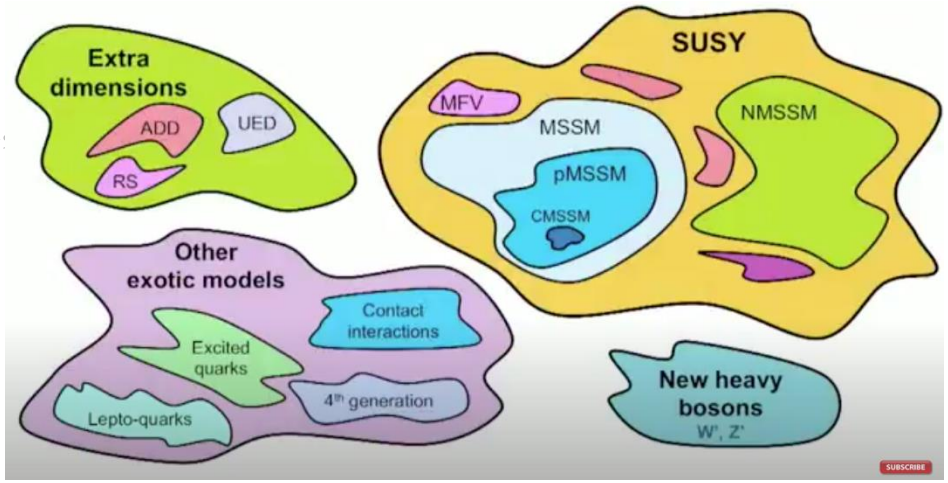
- ➢Exotic states and hadron spectroscopy
- ➢Hadron structures
- ➢Precision test of SM parameters

☐Flavor Physics and CP violation

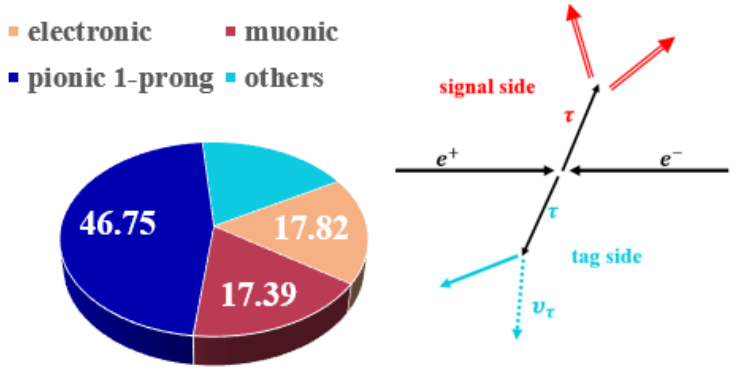
- ➢CKM matrix, $D^0 - \overline{D}^0$ mixing
- ➢CP violation in lepton, hyperon,

☐New Physics Search

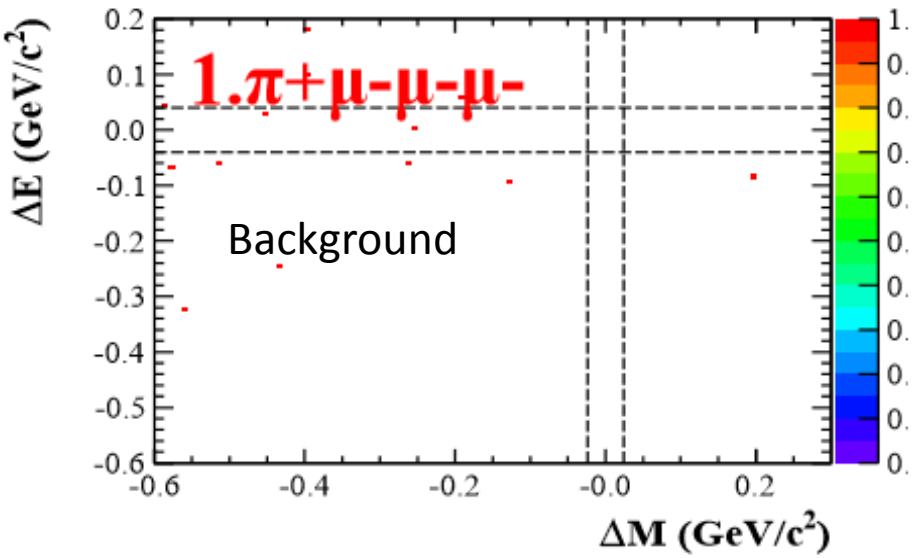
- ➢Rare/Forbidden
- ➢Dark particle search



LFV decay of $\tau \to lll$ at STCF



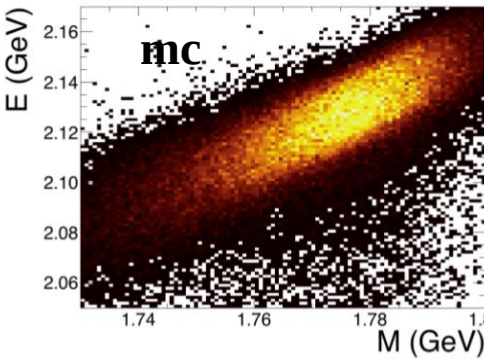
- Signal side: $\tau \to 3leptons$
- Tag side: $\tau \to e\upsilon\bar{\upsilon}$, $\mu\upsilon\bar{\upsilon}$, $\pi\upsilon + n\pi^0$ ($\mathcal{B}r = 82\%$)
- Almost background free, **the sensitivity : $\mathcal{B}_{UL}^{90}(\tau \to \mu\mu\mu) \sim 1/\mathcal{L}$**
- Best efficiency ($\tau \to \mu\mu\mu$): 22.5% **(including tag branching fraction)**

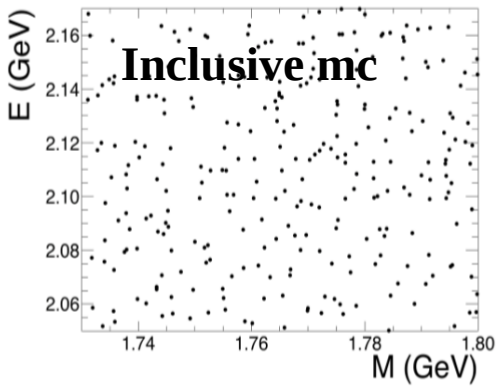


- **STCF with 1ab^{-1}:**

$$\mathcal{B}_{UL}^{90}(\tau \to \mu\mu\mu) < \frac{N_{UL}^{90}}{2\varepsilon N_{\tau\tau}} \sim 1.5 \times 10^{-9}$$

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

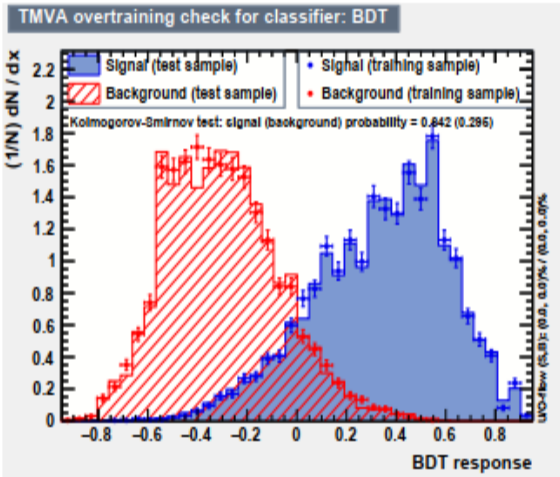


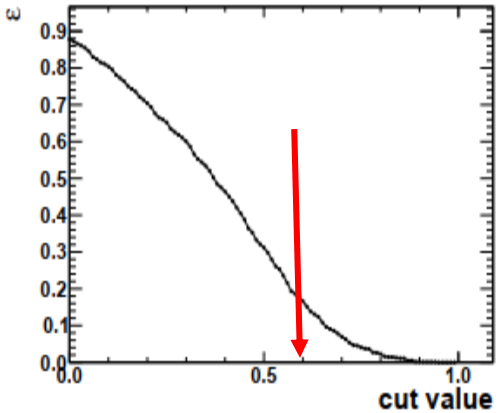


- Signal side $\tau \to \gamma\mu$
- Tag side: $\tau \to e\upsilon\bar{\upsilon},\ \pi\upsilon,\ \pi\pi^0\upsilon(\mathcal{B}r = 54\%)$
- **Dominant background**: $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \tau^+\tau^-, \tau^+ \to \pi\pi^0\upsilon, \tau^- \to \mu\upsilon\bar{\upsilon}$

TABLE II. Optimization for pion/muon separation.

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





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

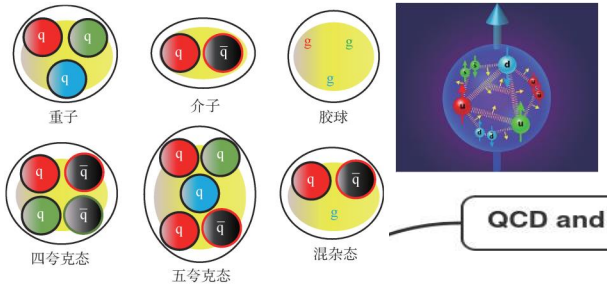
$$\mathcal{B}_{UL}^{90}(\tau \to \gamma\mu) < \frac{N_{UL}^{90}}{2\varepsilon N_{\tau\tau}} \sim 1.2 \times 10^{-8}$$

Forbidden/Rare decay and New Particle Search

Physics at STCF	Benchmark Processes	Key Parameters* (U.L. at 90% C.L.)	Remarks
FLV decays	$\tau \to \gamma l, lll, lP_1P_2$ $J/\psi \to ll', D^0 \to ll'(l' \neq l)\ldots$	$\mathcal{B}(\tau \to \gamma\mu/\mu\mu\mu)$<12/1.5× 10^{-9}; $\mathcal{B}(J/\psi \to e\tau)$<0.71× 10^{-9}	In Competition with BelleII
LNV, BNV	$D^+_{(s)} \to l^+l^+X^-, J/\psi \to \Lambda_c e^-$, $B \to \bar{B}\ldots$	$\mathcal{B}(J/\psi \to \Lambda_c e^-) < 10^{-11}$	**Leading role**
Symmetry violation	$\eta^{(\prime)} \to ll\pi^0, \eta' \to \eta ll\ldots$	$\mathcal{B}(\eta' \to ll/\pi^0 ll)<$ $1.5/2.4 \times 10^{-10}$	**Leading role**
FCNC	$D \to \gamma V, D^0 \to l^+l^-, e^+e^- \to D^*$, $\Sigma^+ \to pl^+l^-\ldots$	$\mathcal{B}(D^0 \to e^+e^-X) < 10^{-8}$	In Competition with BelleII
Dark photon, millicharged	$e^+e^- \to (J/\psi) \to \gamma A'(\to l^+l^-)\ldots$ $e^+e^- \to \chi\bar{\chi}\gamma$ ...	Mixing strength $\Delta\epsilon_{A'} \sim 10^{-4}$; $\Delta\epsilon_{\chi} \sim 10^{-4}$	**Synergy with BelleII/…**

*Sensitivity estimated based on $\mathcal{L} = 1\ \mathrm{ab}^{-1}$

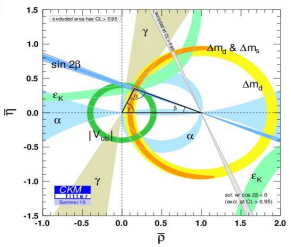
Summary of physics program at STCF

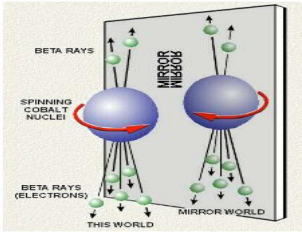


Physics at STCF

QCD and hadronic physics

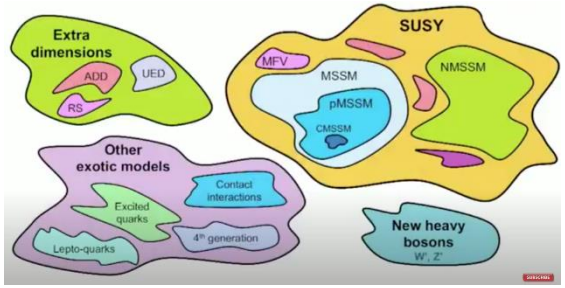
- **XYZ Properties:** e+e-→Y→γX,ηX,φX; e+e-→Y→πZc, KZcs
- **Hadron Spectroscopy:** Excited ccbar and their transition, Charmed hadron spectroscopy, Light hadron spectroscopy
- **R value:** e+e-→inclusive; τ mass: e+e-→τ+τ-
- **Nucleon Form Factors:** e+e-→BBbar from threshold
- **Pentaquarks:** e+e-→J/ψppbar, Λc Dbar pbar, Σc Dbar pbar
  Di-charmonium: e+e-→J/ψηc, J/ψhc
- **Muon g-2:** e+e-→π+ π-, π+ π- π0, 4π, K+ K-, γγ→π0, η(′),π+ π-
- **Fragmentation functions:** e+e-→(π,K,p,Λ,D)+X, e+e-→(ππ,KK,πK)+X





Flavor Physics and CP Violation

- **CKM matrix (Vcd, Vcs):** D_(s)+→l+ν, D→P l+ ν
- **Charm hadron decay:** Λc+, Σc, Ξc, Ωc decay
- **CPV in Hyperons:** J/ψ→ΛΛbar, ΣΣbar, Ξ- Ξ+bar, Ξ0 Ξ0bar
- **D0-D0bar mixing:** ψ(3770)→(D0 D0bar)(CP=-), ψ(4140)→π0 (D0 D0bar)(CP=-) or γ(D0 D0bar)(CP=+)
- **CPV in τ:** τ→Ks πν, EDM of τ, τ→π/K π0 ν for polarized e- beam
- **CPV in Charm:** D0→K+K-/π+π-, Λc→pK-π+π0/Λπ+π+π-/pKs π+
- **γ/φ3 measurement:** D0→K(s/L) π+ π-, K(s/L) K+ K-,K3π, 4π
- **γ polarization:** D0→K1 e+ ν_e



Forbidden/Rare decay and New Particle

- **LNV, BNV:** D(s)+→l+ l+ X-, J/ψ→Λc e-, B→Bbar…
- **Symmetry violation:** η(′)→llπ0, η′→ηll…
- **FLV decays:** τ→γl, lll,l P1 P2 , J/ψ→ll′, D0→ll′ (l′≠l)…
- **FCNC:** D→γV, D0→l+ l-, e+e-→D * , Σ+→pl+ l-…
- **Dark photon:** e+e-→γA′(→l+ l-), J/ψ→e+e-A′…
  Millicharged: e+e-→χχ̄γ…

- **Leading role**
- In Competition with BelleII/LHCb
- **Synergy with BelleII/LHCb/Eic/EicC**

2021年超级陶粲装置研究进展研讨会

- 时间：2021年12月9日至13日
- 地点：中山大学广州校区
- 会议注册网站：

http://cicpi.ustc.edu.cn/indico/conferenceDisplay.py?confId=3752

- 会议联系人:

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欢迎参加！

Thanks for your attention!

Welcome to join the effort!