STCF 和其粲物理研究的前景

STCF and prospects of charm physics

秦小帅

Shandong University

For Super Tau-Charm Facility working group

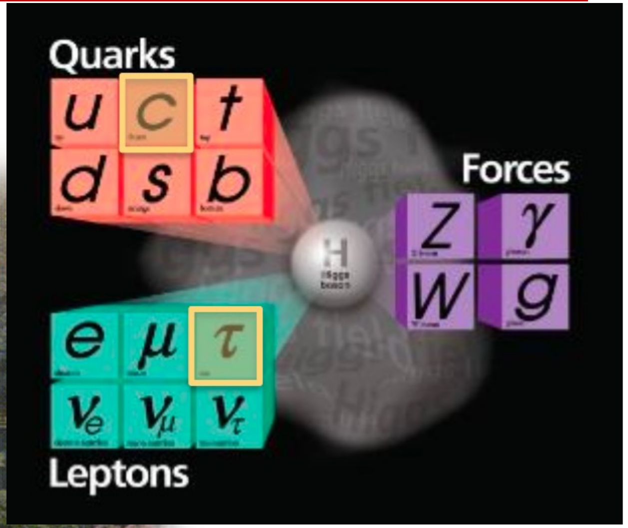
超级陶粲装置工作组

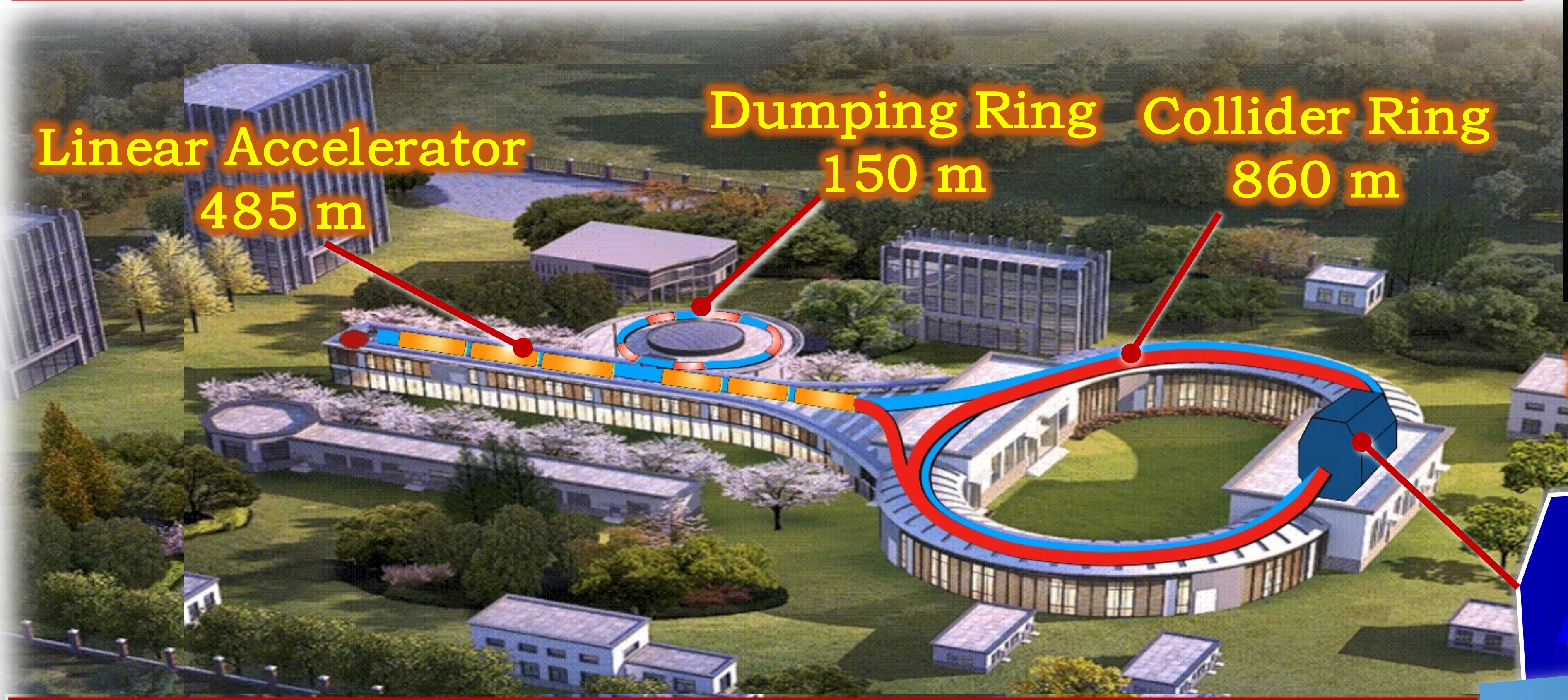
Charm Workshop

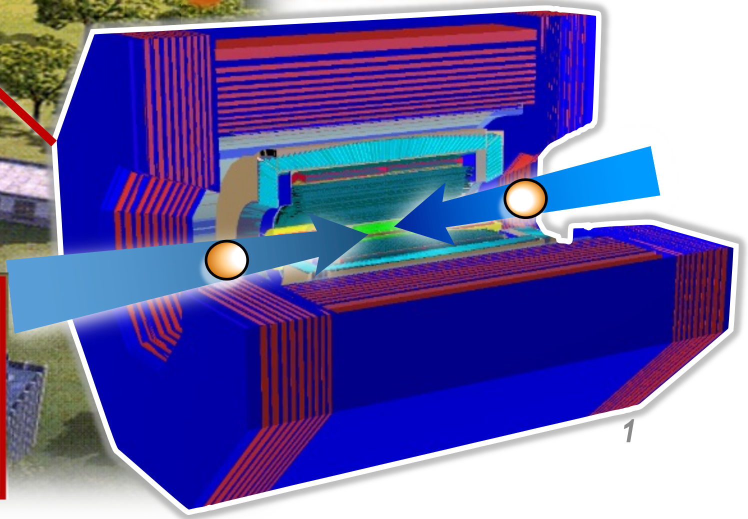
2025-06-30

STCF Project

A factory producing massive **tau lepton** and **hadrons**, to unravel the mystery of **how quarks form matter** and the **symmetries** of fundamental interactions





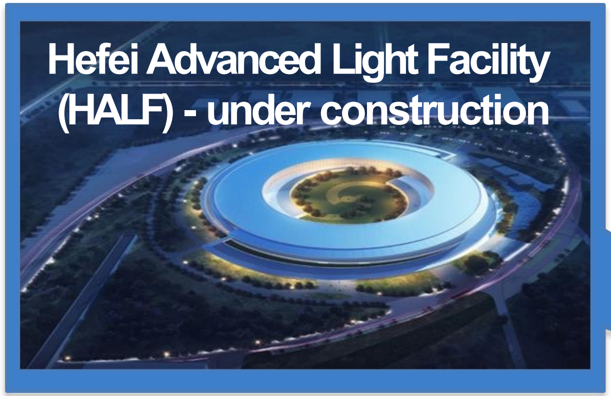


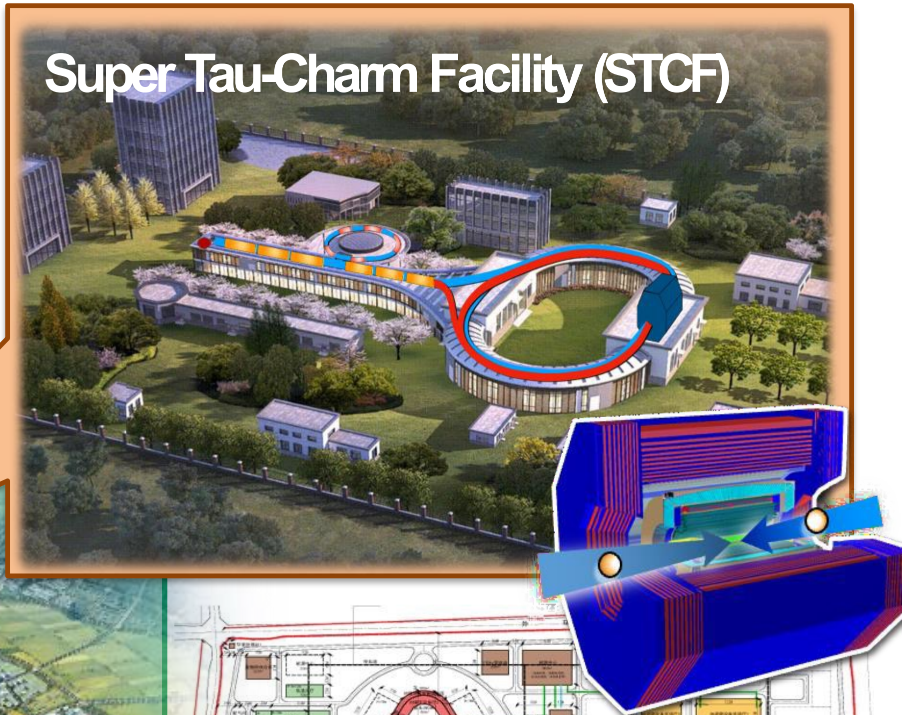
- E_{cm} = **2-7** GeV, $\mathcal{L} > 0.5\times10^{35}$ cm^{-2} s^{-1}
- Potential for upgrade to **increase luminosity** and realize **polarized beam**
- Site: 1 km^2, Hefei's suburban **"Future Big Science City"**

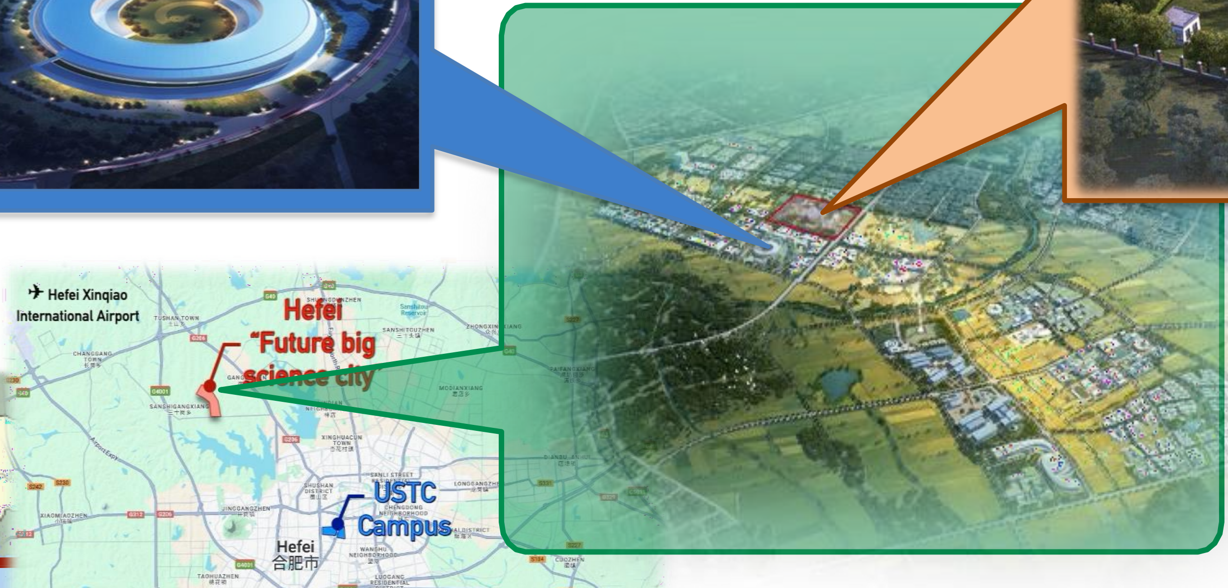
Site : Hefei, Anhui Province

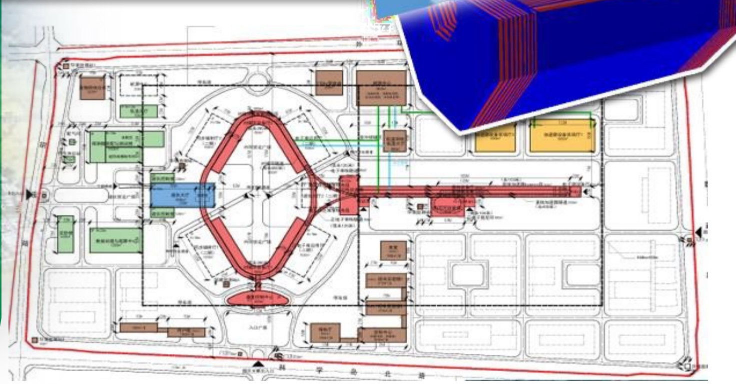
Hefei Comprehensive National Science Center

"Future Big Science City", Hefei, Anhui Province





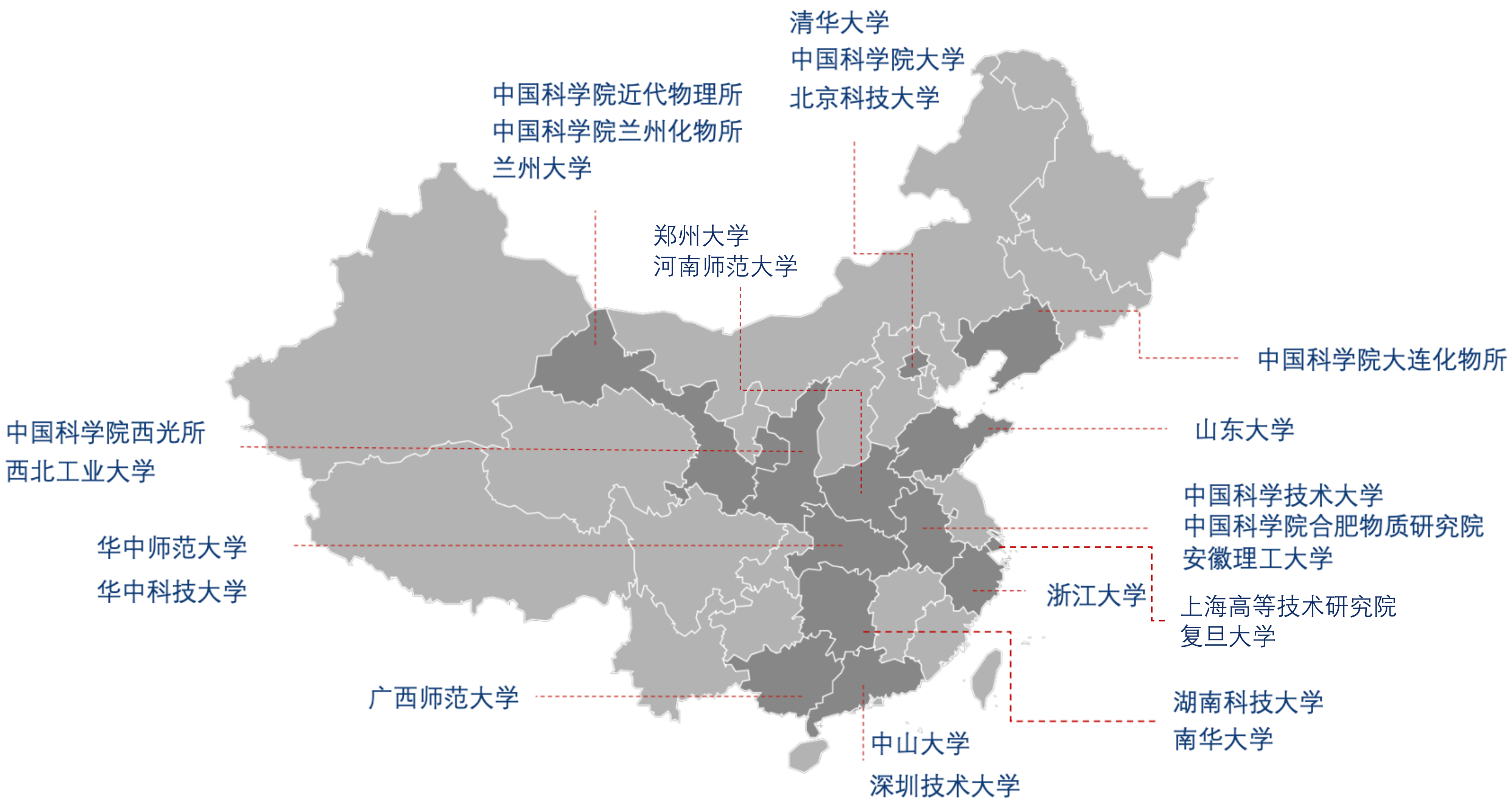




- **Funded R&D : 364 Million CNY by the Anhui government**
- **Construction budget : 4.5 Billion CNY**
- **Geological prospecting, civil engineering design are ongoing**

Current research team

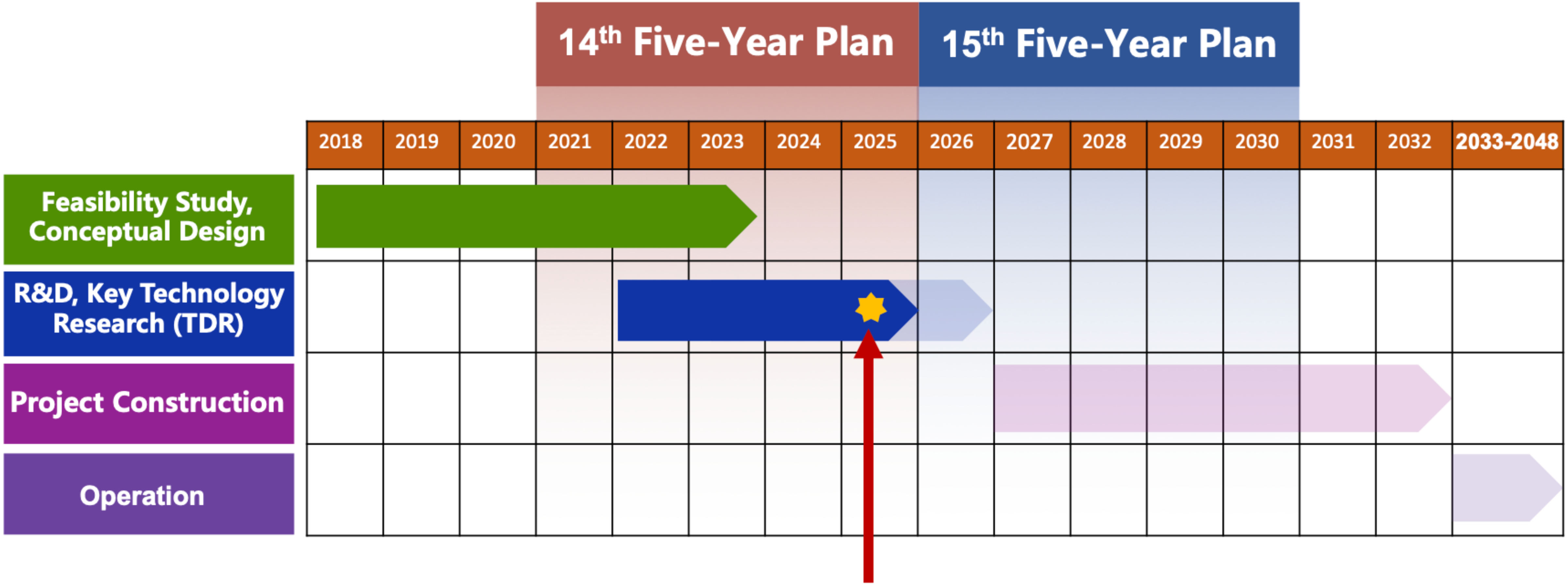
Key technology R&D : 25 Institutions, more than 170 researchers and 140 graduate students



其他参与物理研究单位:

- 北京大学
- 中科院高能所
- 中科院理论所
- 上海交通大学
- 北京师范大学
- 武汉大学
- 中国地质大学
- 辽宁大学
- 南京师范大学
- 南京大学
- 河北师范大学
- 南开大学
- 华南师范大学

Timetable

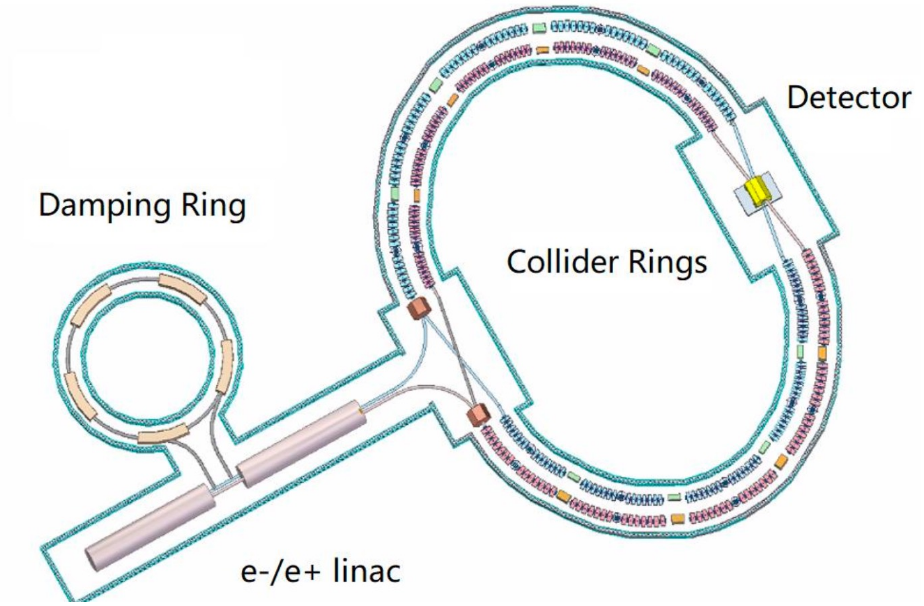


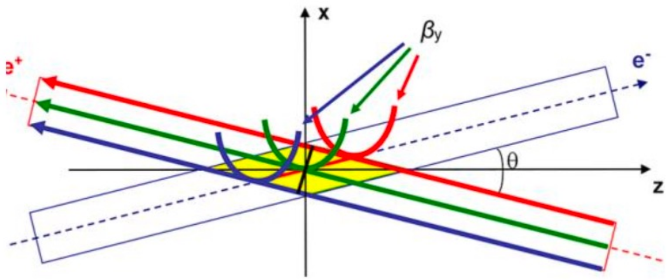
Submit project proposal to central government:
Science, budget, feasibility and contribution to society

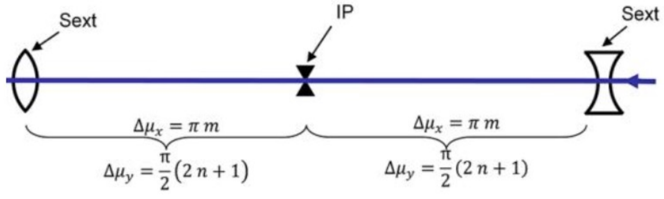
Accelerator

- Core design goal:
  - CMS energy: 2-7 GeV
  - Luminosity: $> 5\times10^{34} cm^{-2}s^{-1}@4GeV$
  - Upgrading potential: polarized beam, higher luminosity

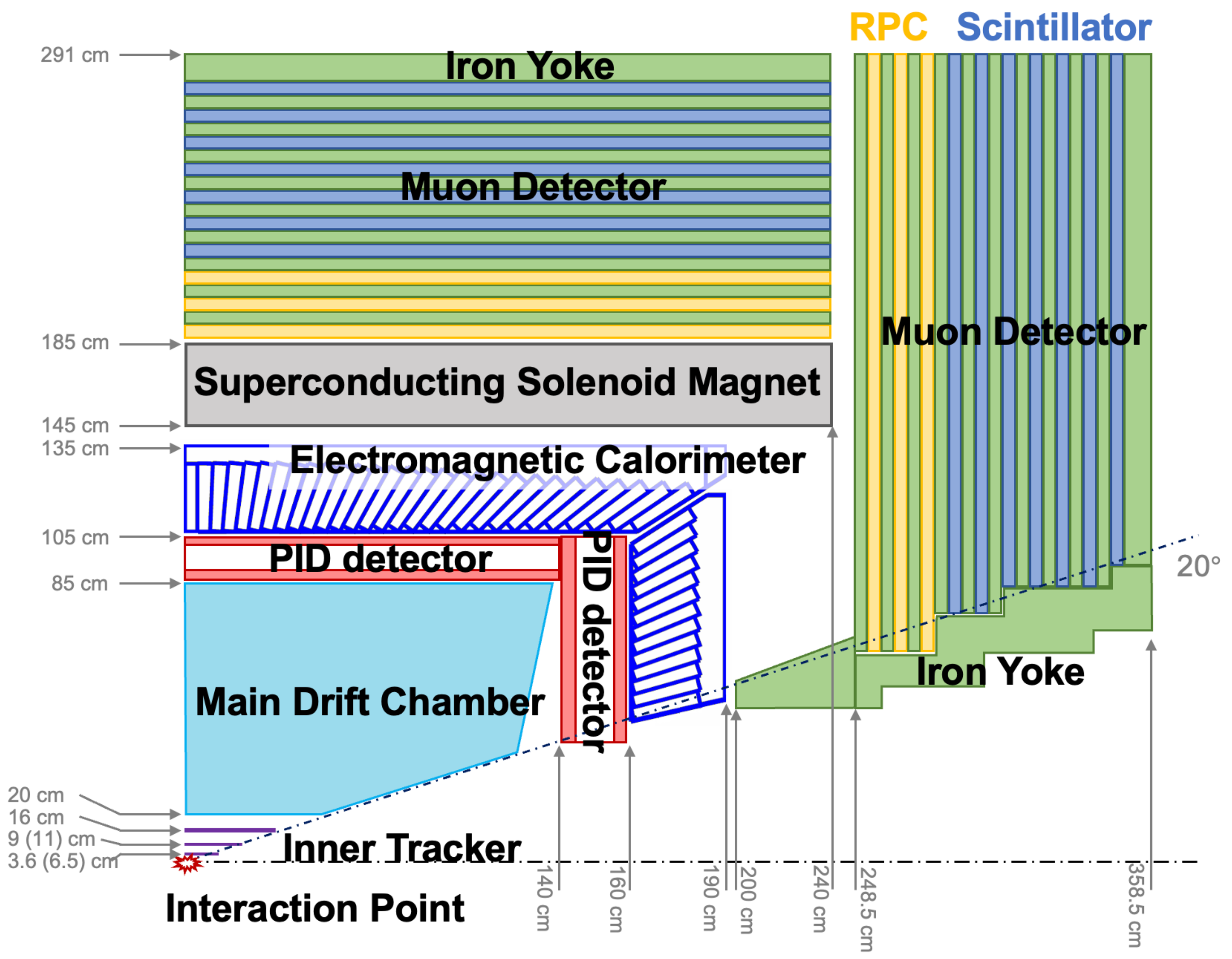
- Accelerator structure
  - Double-ring collider: low emittance, high current, large Piwinski angle
  - Injector: full-energy linac, e+ damping ring or accumulator, beam transport







Detector



Performance requirements

- ITK:
  - Material < $0.01X_0$, σ_{xy} < 100 μm
- MDC:
  - Material < $0.05X_0$
  - σ_{xy} < 130 μm, σ_p/p < 0.5% at 1 GeV/c
  - dE/dx resolution < 6%
- PID:
  - 3σ π/K separation, PID efficiency > 97% up to 2GeV
- EMC:
  - σ_E < 2.5%, σ_{pos} ~ 4 mm, σ_t ~ 300 ps at 1 GeV
- MUD:
  - μ efficiency > 95% above 0.7 GeV with $\pi \to \mu$ misidentification rate <3%

Detector performance

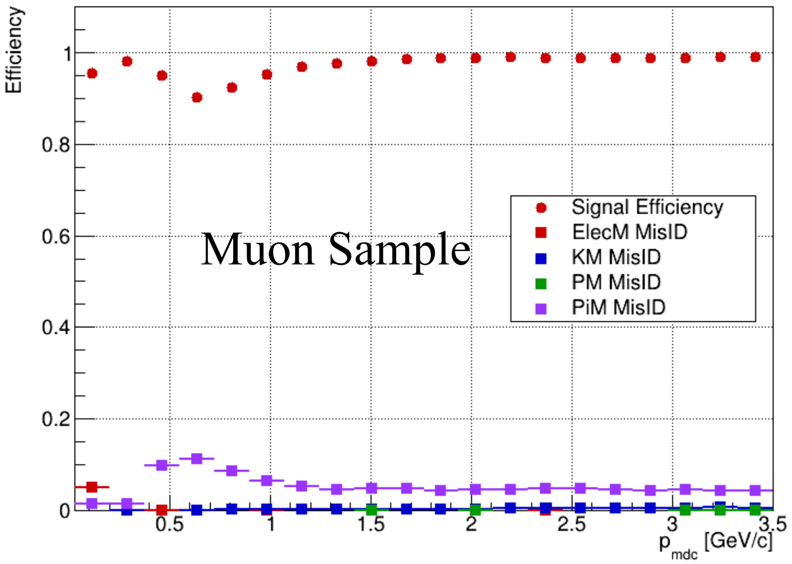
◆ Advanced accelerator、detector and software techniques R&D ongoing.

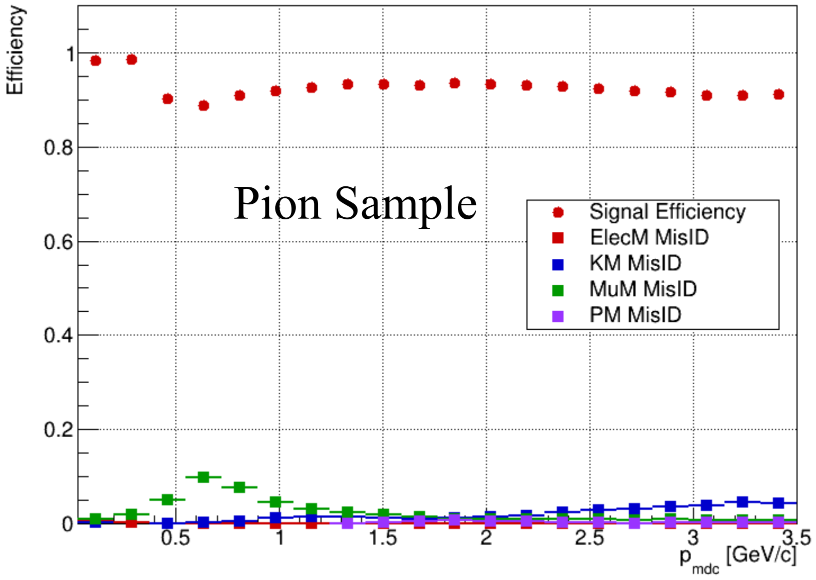
◆ Tracking

- helix parameter: better σ_z
- ϵ >90% for p_T > 75 MeV (except edge)
- long lived particle
  - ϵ >80% with decay length up to 200 mm
  - combined vertex/kinematic fit, better resolution

◆ PID

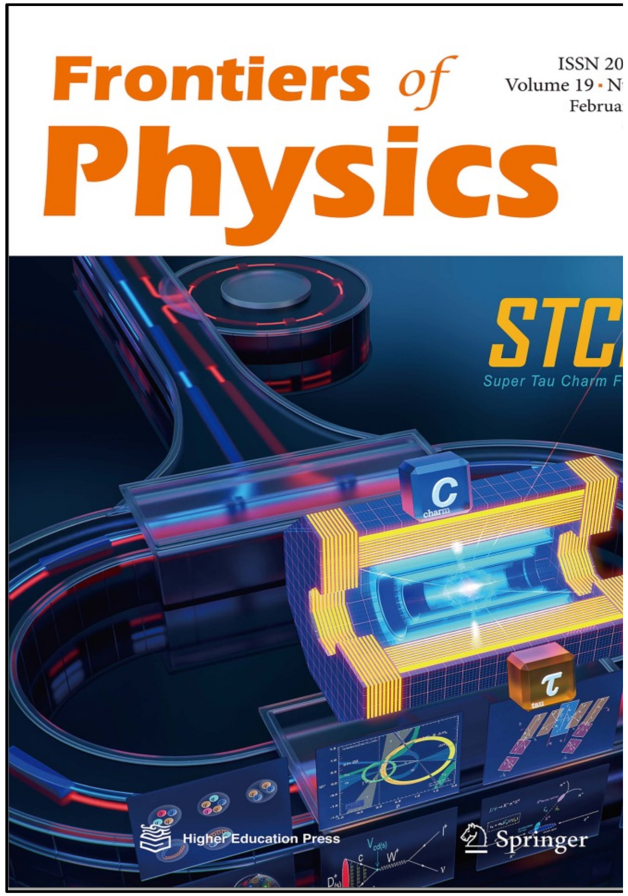
- π/K PID：
  - separation power > 3σ
  - p<2GeV: separation power > 4σ
- μ/π PID:
  - p>1 GeV， separation power > 3σ
  - p>1.5 GeV， separation power > 3.5σ





Physics Program at STCF

M. Achasov, et al., STCF conceptual design report (Volume 1): Physics & detector, Front. Phys. 19(1), 14701 (2024)

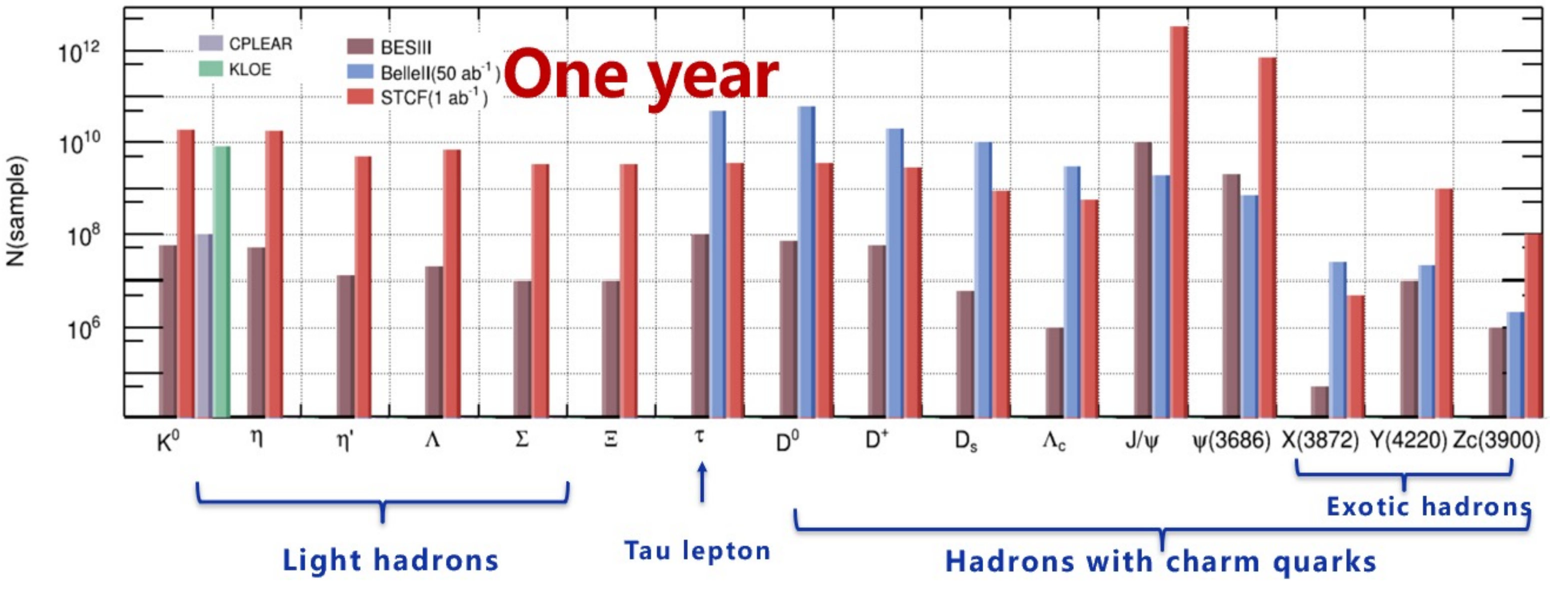


Contents

Rich physics potential beyond the CDR content

Spin 3/2 polarization
Near-threshold resonance
Millicharged particles
Triangle singularity
J/psi seimileptonic decay
Belle locality
D_s^* radiative decay
FCNC
Light-cone distribution amplitudes
cLFV
baryogenesis
EMFFs
K0-K0bar
Two-pole
X(6200)
Neutral meson mixing
QCD sum rules
Muon g-2 and $\alpha(M_Z^2)$
$\Lambda-\bar{\Lambda}$ oscillation
Axion-like particle
Chiral theory
Fully charm tetraquarks
Tau EDM
$SU(2)_L$-signlet vector-like fermion partners
$\Delta S=2$ Nonleptonic hyperon decay
Hyperon EDM
X(4014)
Excited baryon
Axions
CPT
Proton charge radius
Coupled-channel effect
Hyperon-Nucleus Scattering
$a_0(1710)$
Invisible decay of J/psi
Phi meson photoproduction

Expected Data Production at STCF



- About **1 ab^{-1}** integrated luminosity at STCF per year
- STCF shows **superior statistics** and **purity** compare to other experiments
- The physics **sensitivity** studies are based on these sizes of data samples

CME (GeV)	Lumi (ab^{-1})	Samples	σ(nb)	No. of Events	Remarks
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}	
4.009	1	$D^{*0}\bar{D}^0+c.c$	4.0	1.4×10^{9}	$CP_{D^0\bar{D}^0}=+$
		$D^{*0}\bar{D}^0+c.c$	4.0	2.6×10^{9}	$CP_{D^0\bar{D}^0}=-$
		$D_s^+D_s^-$	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-point scan with 10 MeV steps, 1 fb^{-1}/point			
> 5	2–7	Several ab^{-1} of high-energy data, details dependent on scan results			

Prospects of charm physics at STCF

- Charmed meson
  - leptonic and semi-leptonic decay
  - rare and radiative decay
  - $D - \overline{D}$ mixing and CP violation
- Charmed baryon
  - leptonic and semi-leptonic decay
  - hadronic decay
  - radiative decay
  - charmed baryon spectroscopy
  - CP violation
- XYZ,P_c,double-charmonium

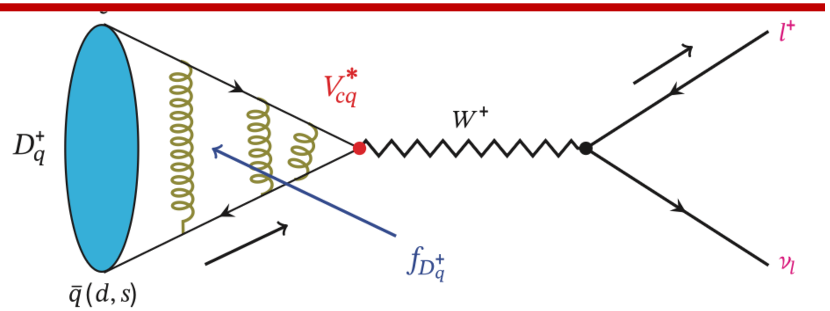
Charmed meson statistics

- Sample:
  - Comparison:
    - BESIII 20fb^{-1} at 3.773GeV
    - 7.33 fb^{-1} at E$_{cm}$ 4.128 - 4.226 GeV: $e^+e^- \to D_s D_s^*$

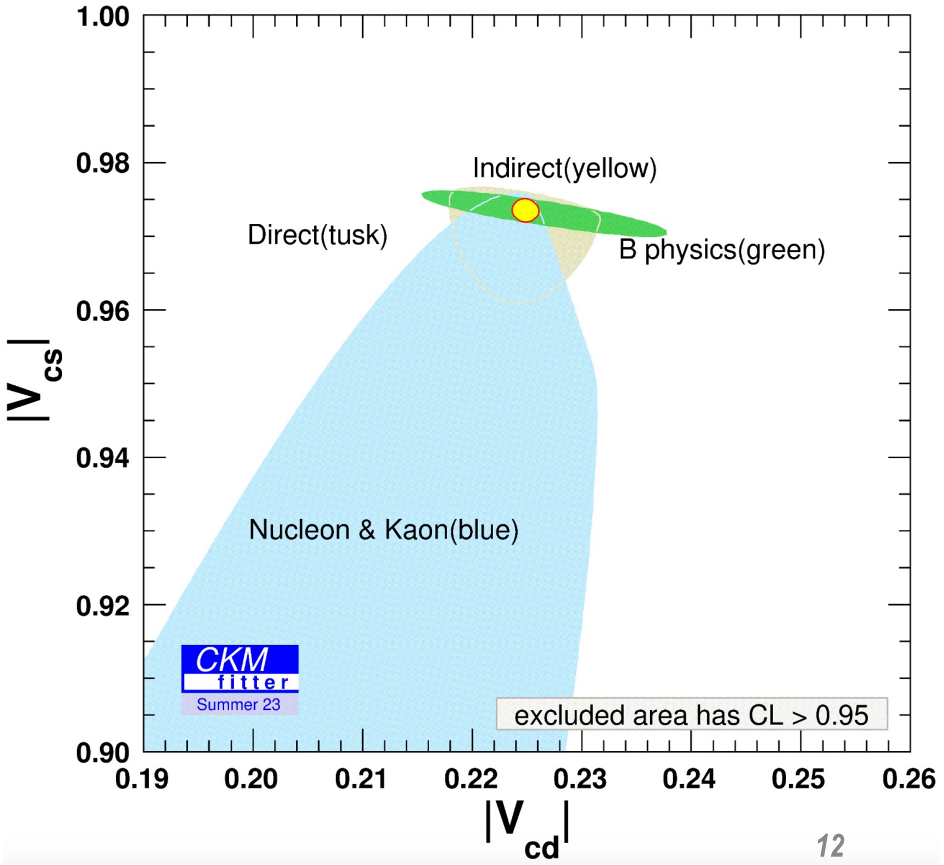
E$_{cms}$(GeV)	Process	Cross Section(nb)	STCF (1ab^{-1})	
3.770	$D^0\bar{D}^0$	3.6	3.6×10^9	
	D^+D^-	2.8	2.8×10^9	
	$D^0\bar{D}^0$		7.9×10^8	Single Tag
	D^+D^-		5.5×10^8	Single Tag
4.080	$D^{*0}\bar{D}^0+c.c.$	4.0	1.4×10^9	$CP_{D^0\bar{D}^0}=+$
	$D^{*0}\bar{D}^0+c.c.$	4.0	2.6×10^9	$CP_{D^0\bar{D}^0}=-$
	$D_s^+D_s^-+c.c.$	0.20	2.0×10^8	
4.180	$D_s^{+*}D_s^-+c.c.$	0.90	9.0×10^8	
	$D_s^{+*}D_s^-+c.c.$		1.3×10^8	Single Tag

$D^+ \to \mu^+\nu_\mu, D^+ \to \tau^+\nu_\tau$

- Decay constant f_D, f_{D_s}, LFU
- CKM matrix
  - unitarity and triangle
  - violations could hint at a fourth quark generation



Measurements	BESIII 20 fb^{-1} (or scaling *) at 3.773 GeV	STCF (1ab^{-1}) at 3.773 GeV	Belle II (50 ab^{-1}) at $\Upsilon(nS)$
$\mathcal{B}(D^+ \to \mu^+\nu_\mu)$	$2.0\%_{stat}$ $1.0\%_{sys}$	$0.28\%_{stat}$	-
$f^{\mu}_{D^+}(MeV)$	$1.0\%_{stat}$ $0.6\%_{sys}$	$0.15\%_{stat}$	-
$\lvert V_{cd}\rvert$	$1.0\%_{stat}$ $0.6\%_{sys}$	$0.15\%_{stat}$	-
$\mathcal{B}(D^+ \to \tau^+\nu_\tau)$	$7.0\%^*_{stat}$ $4.0\%^*_{sys}$	$0.41\%_{stat}$	-
$\frac{\mathcal{B}(D^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D^+ \to \mu^+\nu_\mu)}$	$7.3\%^*_{stat}$ $4.1\%^*_{sys}$	$0.50\%_{stat}$	-



arXiv:2410.07626 JHEP 01 (2025) 089
Chin.Phys.Lett. 42, 010201(2025)

$D_s^+ \to \mu^+\nu_\mu$, $D_s^+ \to \tau^+\nu_\tau$

- Decay constant f_D, f_{D_s}, LFU
- CKM matrix

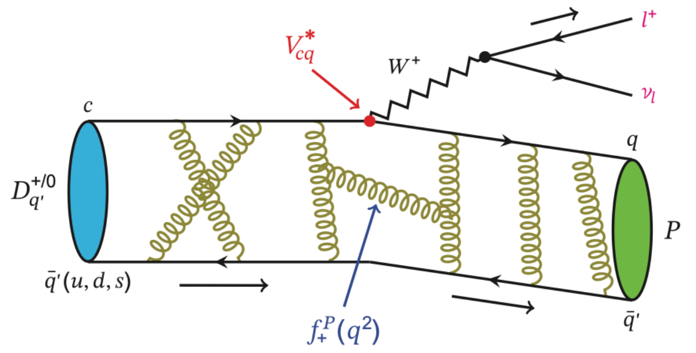
	Measurements	BESIII 7.3 fb^{-1} around 4.178 GeV	STCF (1ab^{-1}) at 4.009GeV	Belle II (50 ab^{-1}) at $\Upsilon(nS)$
$D_s^+ \to \mu^+\nu_\mu$	$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$	$2.0\%_{stat}$ $1.6\%_{sys}$	$0.30\%_{stat}$	$0.8\%_{stat}$ $1.8\%_{sys}$
	$f_{D_s^+}^{\mu}(MeV)$	$1.0\%_{stat}$ $0.9\%_{sys}$	$0.15\%_{stat}$	-
	$\lvert V_{cs}\rvert$	$1.0\%_{stat}$ $0.9\%_{sys}$	$0.15\%_{stat}$	-
$D_s^+ \to \tau^+\nu_\tau$	$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	$1.3\%_{stat}$ $1.5\%_{sys}$	$0.24\%_{stat}$	$0.6\%_{stat}$ $2.7\%_{sys}$
	$f_{D_s^+}^{\mu}(MeV)$	$0.7\%_{stat}$ $0.8\%_{sys}$	$0.11\%_{stat}$	-
	$\lvert V_{cs}\rvert$	$0.7\%_{stat}$ $0.8\%_{sys}$	$0.11\%_{stat}$	-
	$\bar{f}_{D_s^+}^{\mu\&\tau}(MeV)$	$0.6\%_{stat}$ $0.7\%_{sys}$	$0.09\%_{stat}$	$0.3\%_{stat}$ $1.0\%_{sys}$
	$\lvert \bar{V}_{cs}^{\mu\&\tau}\rvert$	$0.6\%_{stat}$ $0.7\%_{sys}$	$0.09\%_{stat}$	-
	$\frac{\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)}$	$2.4\%_{stat}$ $2.2\%_{sys}$	$0.38\%_{stat}$	$0.9\%_{stat}$ $3.2\%_{sys}$

PRD 108, 112001 (2023)
JHEP 09, 124 (2023),
PRD 108, 092014 (2023)

Semi-leptonic decay

◆CKM matrix, form factors

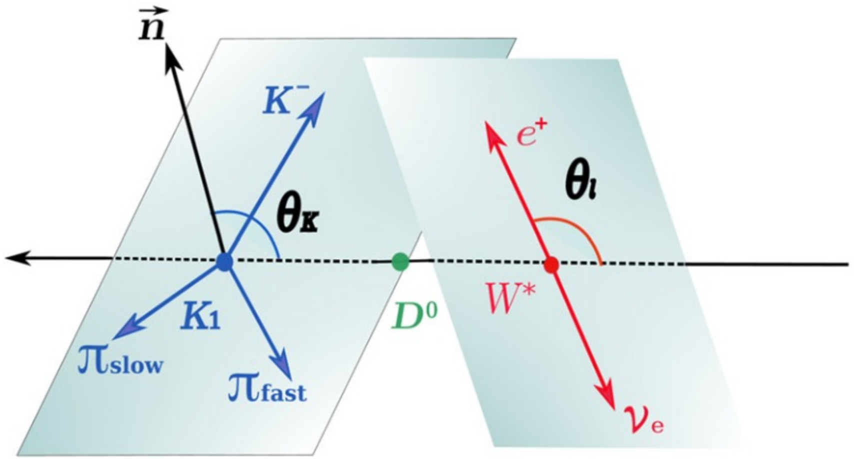
◆inclusive semi-leptonic decay: isospin symmetry test



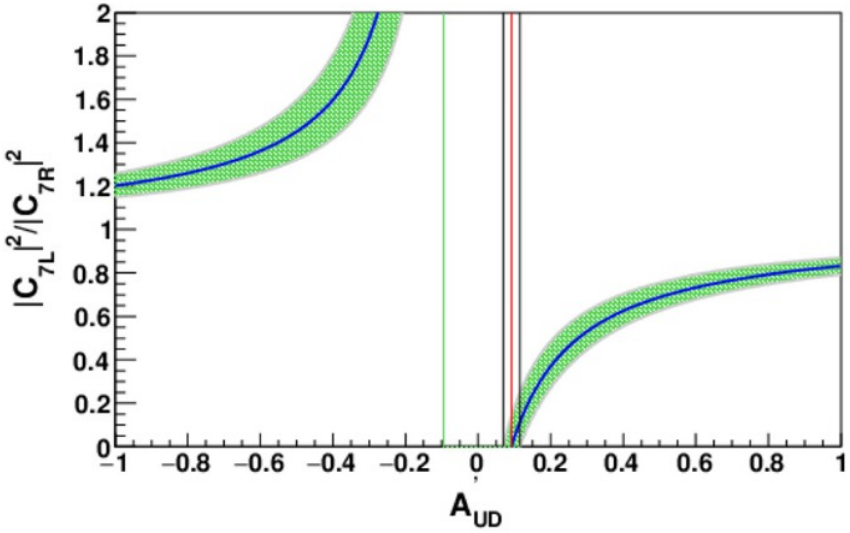
◆$D^0 \to K_1(1270)^- e^+ \nu_e$ sensitivity study:

- determine photon polarization in $b \to s\gamma$ model independently
- right-handed photon helicity for BSM
- $\mathcal{B} = (10.9 \pm 1.3^{+0.9}_{-1.6} \pm 1.2) \times 10^{-4}$ (19%) 2.93 fb^{-1} at 3.773 GeV
- $1ab^{-1}$ sensitivity of $\mathcal{B}$: $1.1\%_{stat}$, A_{UD} 1.5×10^{-2}

PRL 127, 131801(2021)
EPJC (2021) 81:1068



Wilson coefficient vs A_{UD}



CP violation

Special issue for CP violation studies at STCF

CP violation studies at Super tau-charm facility

Hai-Yang Cheng[a], Zhi-Hui Guo[b], Xiao-Gang He[c], Yingrui Hou[d], Xian-Wei Kang[e], Andrzej Kupsc[f,g], Ying-Ying Li[h], Liang Liu[h], Xiao-Rui Lyu[d], Jian-Ping Ma[i], Stephen Lars Olsen[j,k], Haiping Peng[h], Qin Qin[q], Pablo Roig[m,n], Zhi-Zhong Xing[o], Fu-Sheng Yu[p], Yu Zhang[q], Jianyu Zhang[d], Xiaorong Zhou[h]

[a]*Institute of Physics, Academia Sinica, Taipei, 11529, China*
[b]*Hebei Normal University, Shijiazhuang, 050024, China*
[c]*Shanghai Jiao Tong University, Shanghai, 200250, China*
[d]*University of Chinese Academy of Sciences, Beijing, 100049, China*
[e]*Beijing Normal University, Beijing, 100875, China*
[f]*National Centre for Nuclear Research, Warsaw, 02-093, Poland*
[g]*Uppsala University, Uppsala, SE-75120, Sweden*
[h]*University of Science and Technology of China, Address One, 230026, China*
[i]*Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing, 100190, China*
[j]*High Energy Physics Center, Chung-Ang University, Seoul, 06974, Korea*
[k]*Particle and Nuclear Physics Institute, Institute for Basic Science, Daejeon, 34126, Korea*
[l]*Huazhong University of Science and Technology, Wuhan, 430074, China*
[m]*Departamento de Física, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, Mexico City, AP 14740, CP 07000, Mexico*
[n]*IFIC, Universitat de València – CSIC, Paterna, E-46980, Spain*
[o]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, 100049, China*
[p]*Lanzhou University, Lanzhou, 730000, China*
[q]*University of South China, Hengyang, 421001, China*

Abstract

Charge-parity (CP) violation in the tau-charm energy region is one of the promising areas to search for. The future tau-charm facility of next generation is designed to operate in a center-of-mass energy from 2.0 to 7.0 GeV with a peak luminosity of 0.5×10^{35} cm^{-2}s^{-1}. Huge amount of hadrons and tau (τ) leptons will be collected with good kinematic constraint and low-background environment. In this report, possibilities of CP violation studies in tau-charm energy region and at the future tau-charm facility are discussed from various aspects, *i.e.* in the production and decay of hyperons and τ lepton; in the decay of charmed hadrons. The CPT invariance test in $K^0 - \bar{K}^0$ mixing is also presented.

Preprint submitted to PHYSICS REPORTS *September 25, 2024*

Contents

arXiv:2502.08907, submitted to Physics Reports

CP violation

- No observation of CPV in charmed and strange baryons yet.

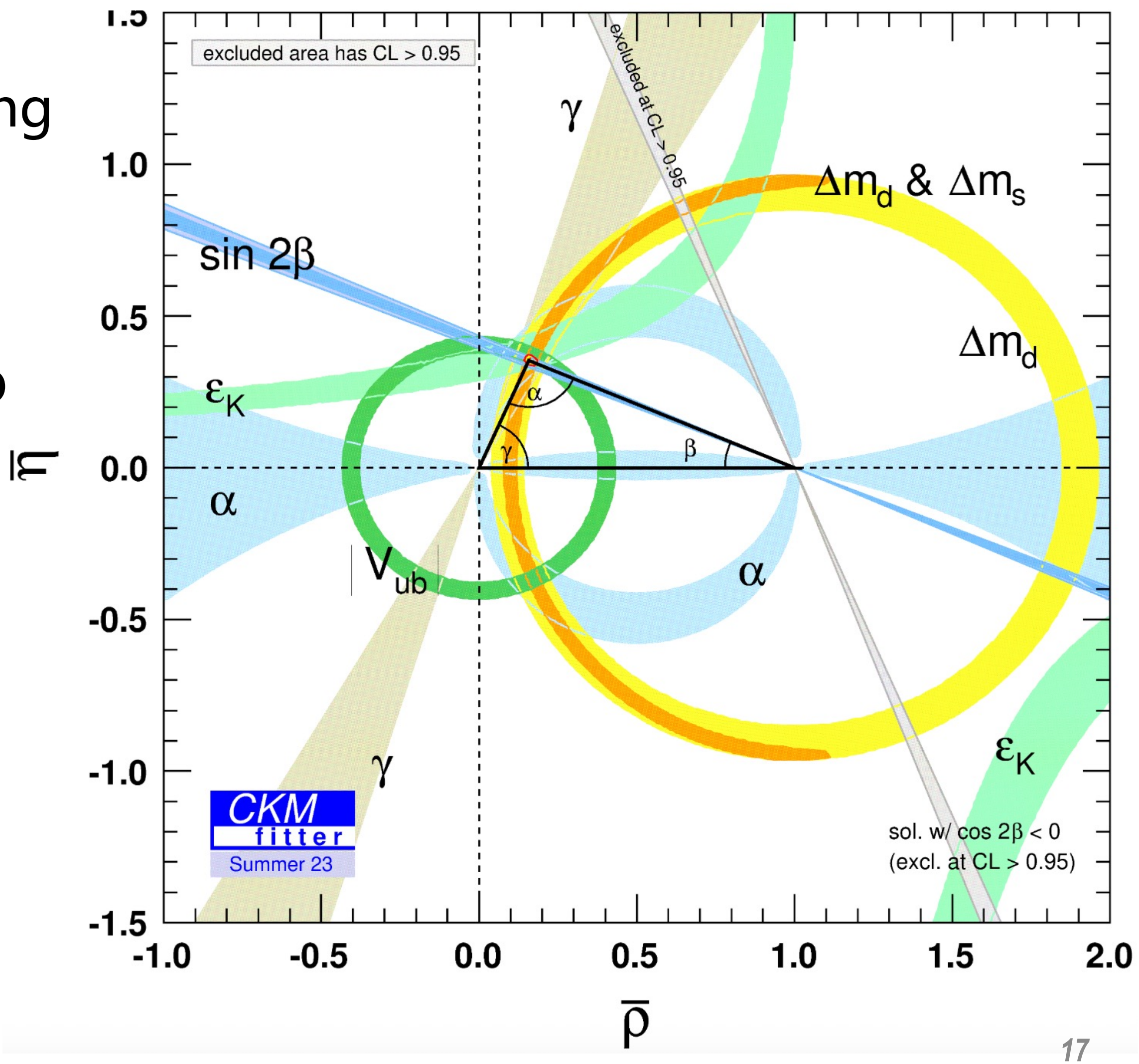
<table>
<tr><th colspan="3">Current Status of CPV Research at the Quark Level</th></tr>
<tr><th>First Generation</th><th>Second Generation</th><th>Third Generation</th></tr>
<tr><td>Up/Down</td><td>Charm</td><td>Top</td></tr>
<tr><td rowspan="6">CPV in first generation is predicted to be far below current experimental sensitivity</td><td>Charm mesons: In 2009, LHCb discovered CPV at $\mathcal{O}(10^{-3})$, within SM predictions</td><td rowspan="2">Lifetime too short to form hadrons; decays before hadronization→ no "top hadron" CPV</td></tr>
<tr><td>Charm baryons: No CPV observed yet. SM predicts $\mathcal{O}(10^{-4})$; new physics could reach $\mathcal{O}(10^{-3})$</td></tr>
<tr><td>Strange</td><td>Bottom</td></tr>
<tr><td>Strange mesons: Discovered in 1964, CPV at level $\mathcal{O}(10^{-3})$, within SM predictions</td><td>Bottom mesons: Discovered in 2001 (BaBar/Belle), CPV at $\mathcal{O}(0.1)$, within SM predictions</td></tr>
<tr><td>Strange baryons: No CPV observed yet. SM predicts $\mathcal{O}(10^{-4}–10^{-5})$; new physics could reach $\mathcal{O}(10^{-3})$</td><td>Bottom baryons: Discovered by LHCb in 2025, CPV at $\mathcal{O}(0.1)$, within SM predictions</td></tr>
<tr><td colspan="2">Only strange baryons and charm baryons remain unexplored for CP violation—a final frontier for new physics in hadronic physics.</td></tr>
</table>

$D^0 - \bar{D}^0$mixing and CPV

- CP violation in neutral D meson
  - CP violation in the direct decays
  - CP violation associated with $D^0 - \bar{D}^0$mixing
  - interplay between decay and mixing

refer to Yu Zhang's talk

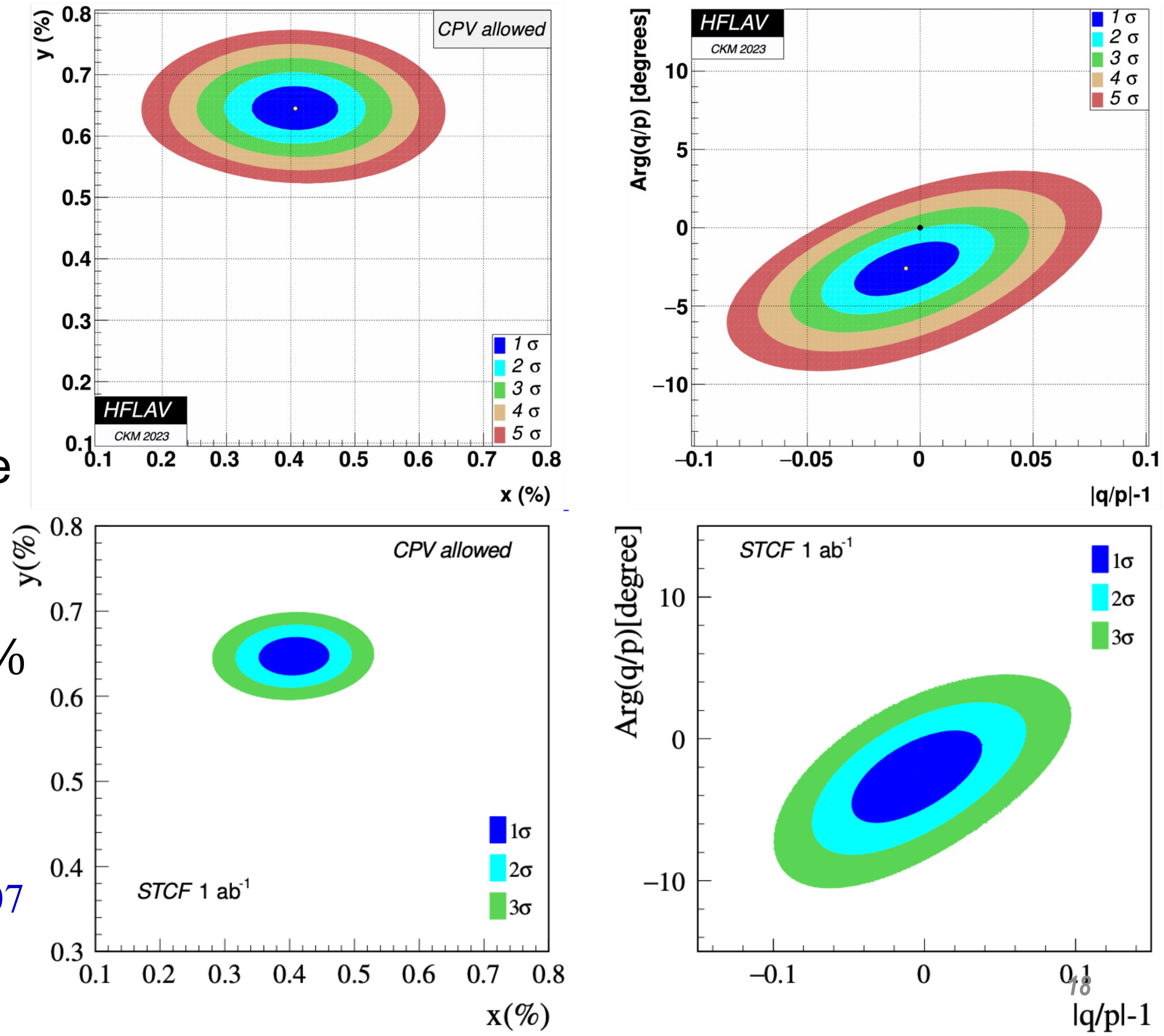
- Charm mixing and indirect CP violation parameters x, y hard to calculate due to large long-distance uncertainties
- HFAG gives (at $95\%\ CL$)
  - $\mathbf{3.2 \times 10^{-3} < x < 4.9 \times 10^{-3}}$
  - $\mathbf{6.0 \times 10^{-3} < y < 6.9 \times 10^{-3}}$
- Sensitivity of CKM angle γ:
  - BESIII ~$0.4°$, STCF ~$0.1°$



$D^0 - \bar{D}^0$ mixing and CPV

- ψ(4010)： neutral D pairs
  - $D\bar{D}^*$, C-even $D\bar{D}$ 1.2×10^9
  - $D^{*+}\bar{D}^-$, flavor specific D: 2.23×10^9
- $D \to K^-\pi^+\pi^+\pi^-, K_S^0\pi^+\pi^-, K^-\pi^+\pi^0$
  - tree-level decays
  - direct CP violation neglected
  - indirect charm CP violation can be studied at the 10^{-4} level in STCF
  - combined result:
    - $\sigma(x) = 0.036\%, \sigma(y) = 0.015\%$
    - $\sigma(r_{CP}) = 0.028, \sigma(\phi) = 2.14°$

arXiv:2502.08907



Rare decay and radiative decay

- FCNC: $D^{0(+)} \to \gamma V^{0(+)}$, $D^0 \to \gamma\gamma$, $D^0 \to \ell^+\ell^-$, $D^0 \to \ell^+\ell^- X$
- LFV, LNV:
  - LFV: $D \to \ell^+\ell^{-\prime}$,$D \to \ell^+\ell^{-\prime} X$
  - LNV: $D^+ \to \ell^+\ell^{+\prime} X^+$, $D_s^+ \to \ell^+\ell^{+\prime} X^+$, Majorana neutrino
  - sensitivities at STCF around $10^{-8}\sim 10^{-9}$ Chin.Phys.Lett. 42, 010201(2025)
- More processes refer to Liang Sun' s talk

- axion-like particles
  - $D_s \to$ meson + axion−like particles (ALP-HNL model, JHEP 01 (2025) 070, PRD111, 035010(2025))
  - $D^0 \to \bar{\Lambda}$ + missing particle (RPV-SUSY model, PRD99, 055039(2019))

Charmed baryon: Λ_c^+ decays study at STCF

- 1 ab^{-1} sample:

E_{cms}(GeV)	Process	Cross Section(nb)	STCF ($1ab^{-1}$)	
4.630	$\Lambda_c\bar{\Lambda}_c$	0.56	5.6×10^8	
			6.4×10^7	Single Tag

- Like BESIII, STCF have advantages of semi-leptonic, neutron/K_L^0, radiative and inclusive decays.

Decay	BESIII current BF results	Belle/LHCb BF results
$\Lambda_c^+ \to \Lambda e^+\nu_e$	$(3.56 \pm 0.11 \pm 0.07)\%$	no result
$\Lambda_c^+ \to n\pi^+$	$(6.6 \pm 1.2 \pm 0.4)\times10^{-4}$	no result
$\Lambda_c^+ \to \Sigma^+\gamma$	$< 4.4\times10^{-4}$	no result
$\Lambda_c^+ \to Xe^+\nu_e$	$(4.06 \pm 0.10 \pm 0.09)\%$	no result

Semi-leptonic decay

- CKM matrix, form factors et al.

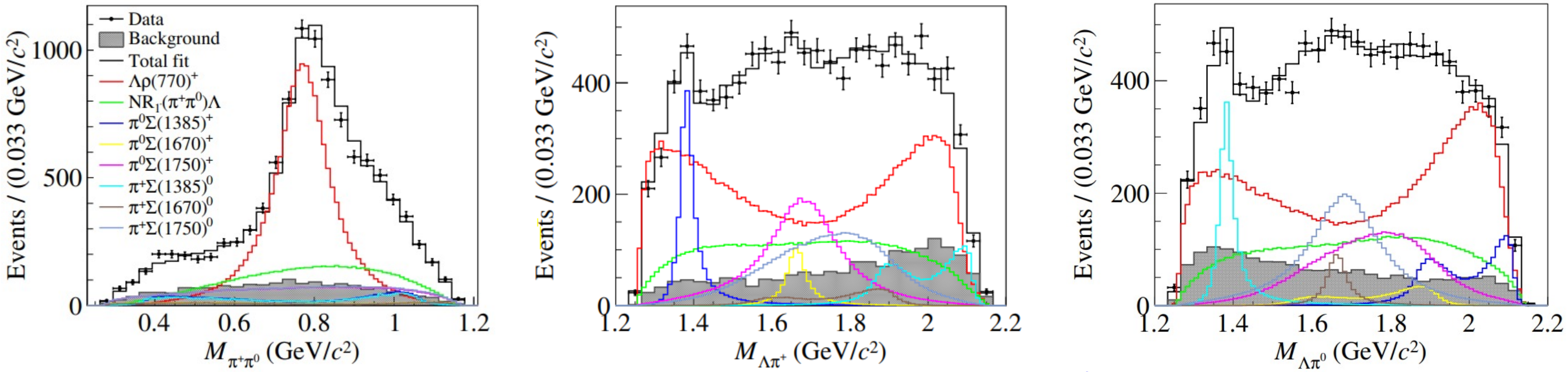
Decay	BESIII current BF results(10^{-3})	BESIII sensitivity	STCF 1 ab^{-1}
$\Lambda_c^+ \to \Lambda e^+ \nu_e$	35.6 ± 1.3	3.6%	0.2%
$\Lambda_c^+ \to pK^- e^+ \nu_e$	0.88 ± 0.18	20%	1.3%
$\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu$	34.8 ± 1.7	4.9%	0.3%
$\Lambda_c^+ \to n e^+ \nu_e$	3.57 ± 0.37	10%	0.6%

PRL 129, 231803 (2022)
PRD 106, 112010 (2022)
PRD 108 (2023) 3, L031105
Nat Commun. 16, 681 (2025)

Hadronic decays

◆Amplitude analysis

JHEP 12(2023) 033

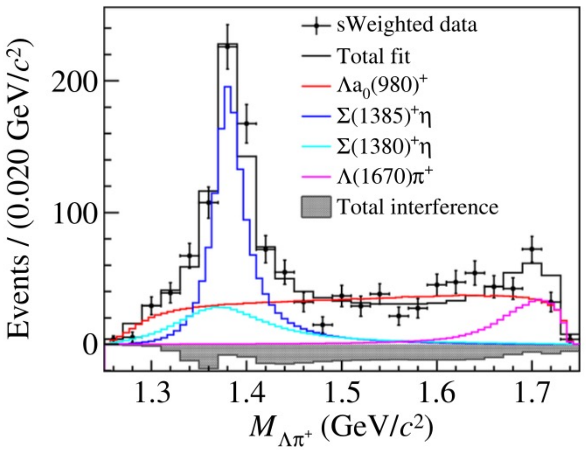


- First amplitude analysis on charmed baryon multi-hadron decay $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ using about 10K signal events.

$$\alpha_{\Lambda\rho(770)^+} = -0.763 \pm 0.053 \pm 0.045,$$
$$\alpha_{\Sigma(1385)^+\pi^0} = -0.917 \pm 0.069 \pm 0.056,$$
$$\alpha_{\Sigma(1385)^0\pi^+} = -0.789 \pm 0.098 \pm 0.056.$$

Process	FF (%)	$\mathcal{S}$	α
$\Lambda a_0(980)^+$	$54.0 \pm 8.4 \pm 2.6$	13.1σ	$-0.91^{+0.18}_{-0.09} \pm 0.08$
$\Sigma(1385)^+\eta$	$30.4 \pm 2.6 \pm 0.7$	22.5σ	$-0.61 \pm 0.15 \pm 0.04$
$\Lambda(1670)\pi^+$	$14.1 \pm 2.8 \pm 1.2$	11.7σ	$0.21 \pm 0.27 \pm 0.33$
ΛNR_{0^+}	15.4 ± 5.3	6.7σ	$\cdots$

PRL 134,021901(2025)



About 1.3K signal events are used for PWA of $\Lambda_c^+ \to \Lambda\pi^+\eta$.

More amplitude analysis need larger data set.

Potential of undiscovered decay channels

- BF of inclusive decay and sum of exclusive decay indicate undiscovered decay channels

Decay	Inclusive BF	Sum of exclusive BF	Ratio	Reference
$\Lambda_c^+ \to X e^+ \nu_e$	$(4.06 \pm 0.10 \pm 0.09)\%$	$(3.64 \pm 0.11 \pm 0.07)\%$	90%	PRD 107, 052005 (2023)
$\Lambda_c^+ \to \Lambda X$	$(38.2 \pm 2.5 \pm 0.9)\%$	$(31.3 \pm 1.2)\%$	82%	PRL 121, 062003 (2018)
$\Lambda_c^+ \to K_S^0 X$	$(10.9 \pm 0.2 \pm 0.1)\%$	$(7.9 \pm 0.3)\%$	72%	JHEP 2025, 194 (2025)
$\Lambda_c^+ \to \Sigma^+ X$		$(10.97 \pm 0.35)\%$		BESIII Ongoing
$\Lambda_c^+ \to \Sigma^0 X$		$(6.7 \pm 0.5)\%$		BESIII Ongoing
$\Lambda_c^+ \to p X$		$(48.7 \pm 1.0)\%$		BESIII Ongoing

Radiative decay

- EM transitions between two charmed baryons:
  - dynamics of these particles and underlying symmetrical structures.

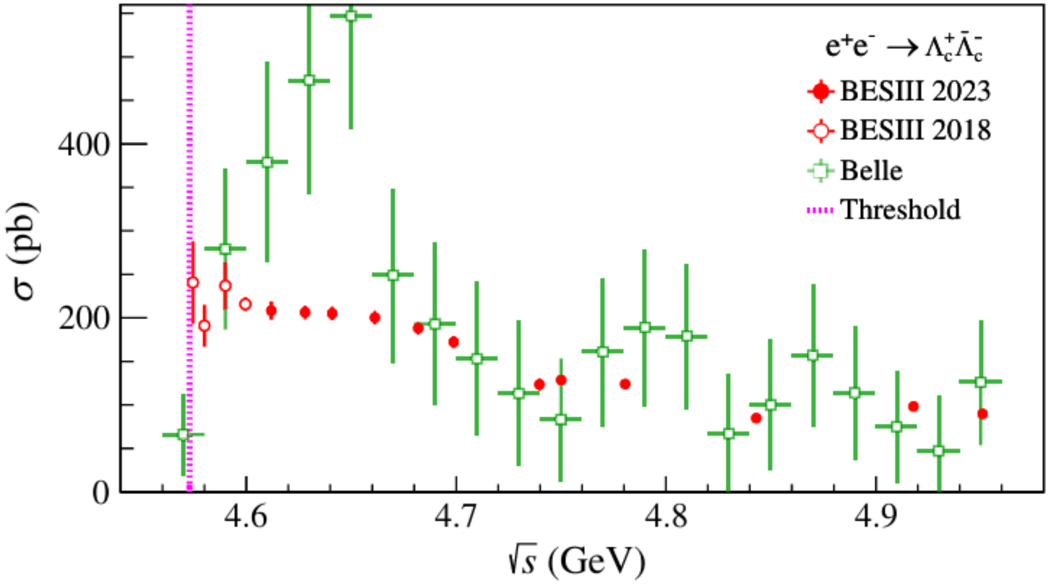
  - $\Sigma_c \to \Lambda_c\,\gamma, \Xi_c' \to \Xi_c\,\gamma$
  - $\Sigma_c^* \to \Lambda_c\,\gamma, \Xi_c^* \to \Xi_c\,\gamma$
  - $\Sigma_c^* \to \Sigma_c\,\gamma, \Xi_c^* \to \Xi_c'\,\gamma$
  - $\Omega_c^* \to \Omega_c\,\gamma$
  - $\Lambda_c(2595,2625) \to \Lambda_c\,\gamma$
  - $\Xi_c(2790,2815) \to \Xi_c\,\gamma$

Chin.Phys.Lett. 42, 010201(2025)

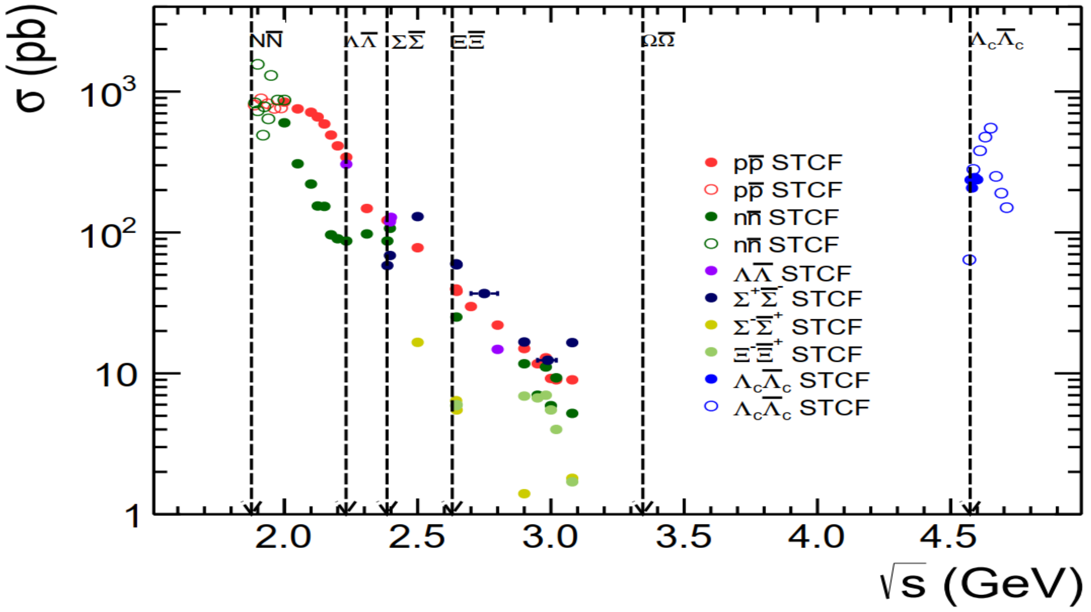
  - $\Lambda_c^+ \to \Sigma\,\gamma$ estimated to be 10^{-4}, $\mathcal{B}\,(\Lambda_c^+ \to \Sigma\,\gamma) < 2.5\times10^{-4}$ **Belle & BESIII**
  - $\Lambda_c^+ \to p\,\gamma$

Charmed baryons spectroscopy

- More Λ_C, $\Lambda_C^{(*)}$
- $\Lambda_C\overline{\Lambda}_C$, $\Sigma_C\bar{\Sigma}_C$, $\Xi_C\bar{\Xi}_C$, $\Omega_C\overline{\Omega}_C$
  - Some cross section not well known
  - Double tag, clean and quantum correlation.

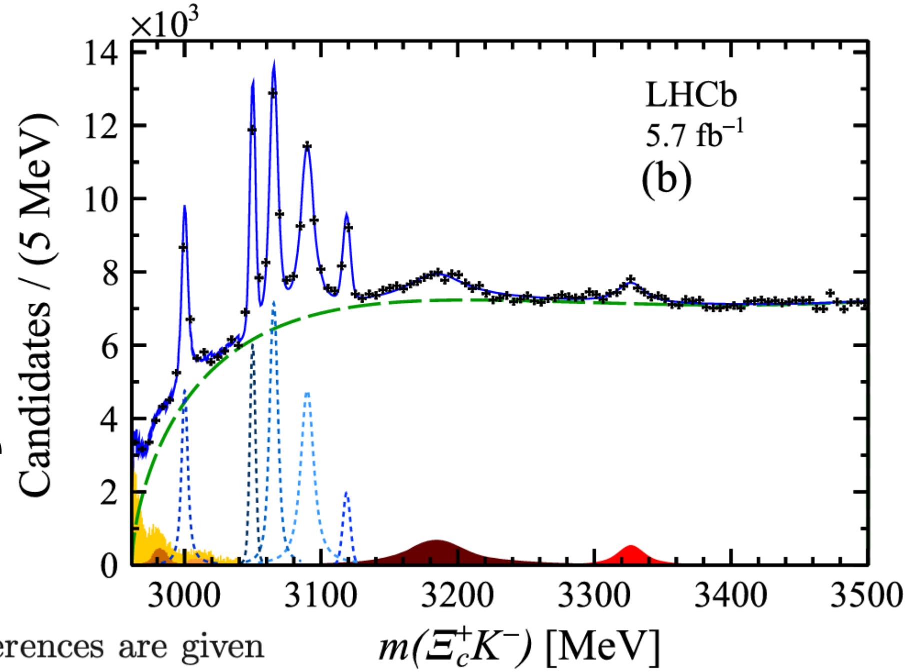


PRL 131, 191901 (2023)



Charmed baryons spectroscopy

- Identify spin-parity quantum numbers:
  - clarify J^P of $\Lambda_c(2940)^+$, $3/2^-$ or $1/2^-$
  - $\Omega_c(3000), \Omega_c(3050), \Omega_c(3066), \Omega_c(3090)$. via $\Xi_c^+ K^-$
  - $\Omega_c(3119), \Omega_c(3185), \Omega_c(3227)$. via $\Xi_c^+ K^-$
- Above 7.4GeV
  - doubly charmed baryon Ξ_c^{++} would be available



PRL 131,131902 (2023) **LHCb**
PRD 97, 051102(R) (2018) **Belle**

Table 5: Charmed baryon spectroscopy of antitriplet and sextet states. Mass differences are given as $\Delta m_{\Xi_c\Lambda_c} \equiv m_{\Xi_c} - m_{\Lambda_c}$, $\Delta m_{\Xi_c'\Sigma_c} \equiv m_{\Xi_c'} - m_{\Sigma_c}$, $\Delta m_{\Omega_c\Xi_c'} \equiv m_{\Omega_c} - m_{\Xi_c'}$ in units of MeV.

	$J^P(nL)$	States	Mass difference
$\bar{\mathbf{3}}$	$\frac{1}{2}^+(1S)$	$\Lambda_c(2287)^+$, $\Xi_c(2470)^+, \Xi_c(2470)^0$	$\Delta m_{\Xi_c\Lambda_c} = 183$
	$\frac{1}{2}^-(1P)$	$\Lambda_c(2595)^+$, $\Xi_c(2790)^+, \Xi_c(2790)^0$	$\Delta m_{\Xi_c\Lambda_c} = 198$
	$\frac{3}{2}^-(1P)$	$\Lambda_c(2625)^+$, $\Xi_c(2815)^+, \Xi_c(2815)^0$	$\Delta m_{\Xi_c\Lambda_c} = 190$
	$\frac{3}{2}^+(1D)$	$\Lambda_c(2860)^+$, $\Xi_c(3055)^+, \Xi_c(3055)^0$	$\Delta m_{\Xi_c\Lambda_c} = 201$
	$\frac{5}{2}^+(1D)$	$\Lambda_c(2880)^+$, $\Xi_c(3080)^+, \Xi_c(3080)^0$	$\Delta m_{\Xi_c\Lambda_c} = 196$
6	$\frac{1}{2}^+(1S)$	$\Omega_c(2695)^0$, $\Xi_c'(2575)^{+,0}, \Sigma_c(2455)^{++,+,0}$	$\Delta m_{\Omega_c\Xi_c'} = 119$, $\Delta m_{\Xi_c'\Sigma_c} = 124$
	$\frac{3}{2}^+(1S)$	$\Omega_c(2770)^0$, $\Xi_c'(2645)^{+,0}, \Sigma_c(2520)^{++,+,0}$	$\Delta m_{\Omega_c\Xi_c'} = 120$, $\Delta m_{\Xi_c'\Sigma_c} = 128$

Chin.Phys.Lett. 42, 010201(2025)

CPV in charmed baryons

- Decay rate asymmetry
- T-odd triple product
- Polarization based CP observables

T-odd triple product

- Λ_c^+ four body decays:
  - $\Lambda_c^+ \to pK^-\pi^+\pi^0$, $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$, $\Lambda_c^+ \to pK_s\pi^+\pi^-$
- Direct CPV, T-odd triple product: $C_{\hat{T}} = \boldsymbol{p}_{p/\Lambda} \cdot (\boldsymbol{p}_{h_1} \times \boldsymbol{p}_{h_1})$

$$\mathrm{BR}(\Lambda_c^+ \to pK^-\pi^+\pi^0) \simeq 4.4\%$$

$$\mathrm{BR}(\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-) \simeq 3.6\%$$

$$\mathrm{BR}(\Lambda_c^+ \to pK_S\pi^+\pi^-) \simeq 1.6\%$$

$$A_{CP}^{(K_S^0)} = \frac{N(\Lambda_c^+ \to pK_S^0\pi^+\pi^-) - N(\bar{\Lambda}_c^- \to \bar{p}K_S^0\pi^-\pi^-)}{N(\Lambda_c^+ \to pK_S^0\pi^+\pi^-) + N(\bar{\Lambda}_c^- \to \bar{p}K_S^0\pi^-\pi^-)}$$

$$A_{\hat{T}}(C_{\hat{T}}) = \frac{N(C_{\hat{T}} > 0) - N(C_{\hat{T}} < 0)}{N(C_{\hat{T}} > 0) + N(C_{\hat{T}} < 0)}$$

$$\delta_{CP} \equiv \frac{1}{2}(A_{T\text{-odd}} - \bar{A}_{T\text{-odd}})$$

- SM predicts CPV for $\Lambda_c^+ \to pK_s\pi^+\pi^-$ at "around" $\mathbf{3.3\times10^{-3}}$ due to CPV in $K^0 - \overline{K}^0$ oscillation
- STCF sensitivity: **0.2%-0.5%**

Channel	Direct CPV	$(a_P + \bar{a}_P)/2$, δ_{CP}
$\Lambda_c^+ \to pK^-\pi^+\pi^0$	0.0025	0.0026
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	0.0052	0.0052
$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	0.0040	0.0041

PRD 100, 113002(2019)

Polarization based CP observables

- Λ_c^+ pair production in STCF @ 4.682 GeV

$$A_{CP}^{\alpha} = \frac{\alpha_f - \bar{\alpha}_{\bar{f}}}{\alpha_f + \bar{\alpha}_{\bar{f}}} \propto -\tan\phi \tan\delta$$

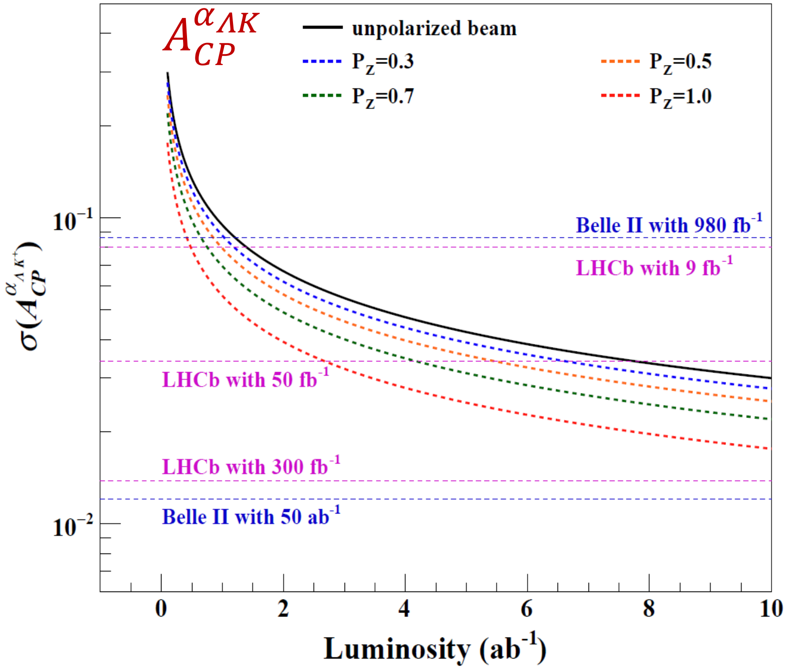
ϕ: CP-odd weak phase

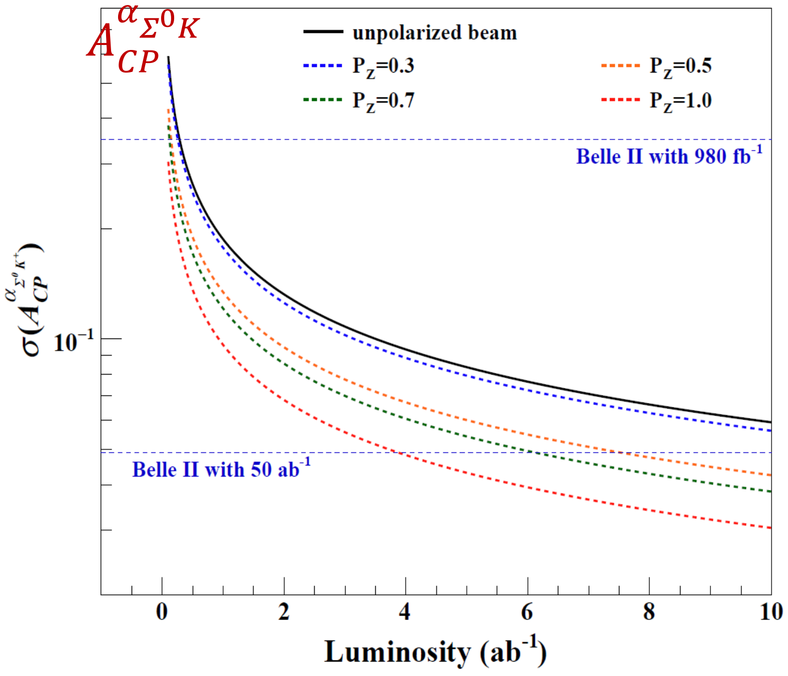
δ: CP-even strong phase

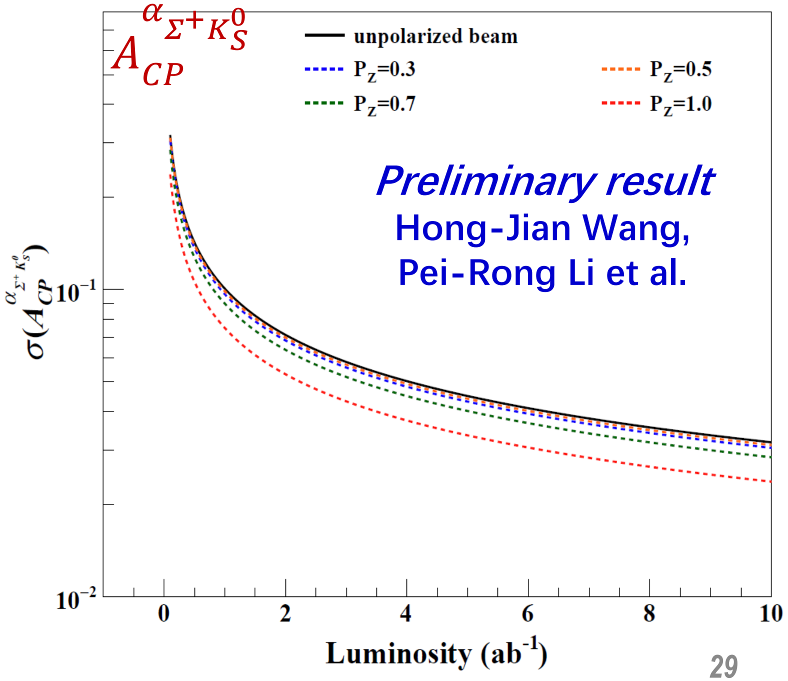
- Comparable sensitivities with Belle II for $\Sigma^0 K$ or better
- Sensitivities $\mathcal{O}(10^{-2})$ still far away from expectation $\mathcal{O}(10^{-4})$

He et al. arXiv:2404.19166

Cheng et al. arXiv:2505.07150



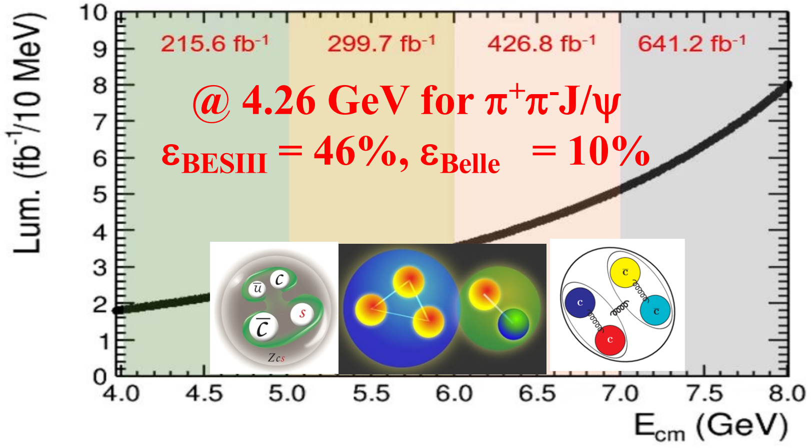




Potential research above 5GeV at STCF

Hadron spectroscopy

- Many threshold opens:
  more potentials for hadron studies
- Structures in more channels for **XYZ physics**
  with larger production rates above 5 GeV
  - eg. KKJ/ψ, $\omega\omega J/\psi$, $\phi\phi J/\psi$
- **P_c pentaquarks**
  - hidden-charm $J/\psi N$: $J/\psi p\bar{p}$, $J/\psi n\bar{n}$, ~4fb, statistic: $\mathcal{O}(10^3)$ events
    neutron is hard for LHCb
  - open-charmed P_c: $\Lambda_c \bar{D}^{(*)}\bar{p}, \Sigma_c^{(*)}\bar{D}^{(*)}\bar{p}$. $\mathcal{O}(10)$ fb, LHCb observation
- **fully charmed tetraquark states** via $e^+e^- \to J/\psi c\bar{c}$ etc above 6 GeV
  - $cc\bar{c}\bar{c}$ states, double- J/ψ , double- η_c , low lying $cc\bar{c}\bar{c}$.
  - $\mathcal{O}(10)$ fb, clean channels (LHCb, CMS measurement)



TDR related study – full simulation

- Detailed full simulation for sensitivity study.
- To be finished within this year.

Physics goal	Processes	Contributors
CKM matrix	$D \to \pi\mu\nu$	Qingyuan Huang (UCAS)
	$D \to \mu\nu$	Jiahui Qiao (HNU)
	$D \to$ inclusive	Jiayuan Su, Hongrui Liu (HUST)
	$\tau \to K\nu$	
Strong phase	$D^0 \to K^-\pi^+\pi^0$	Cheng Wang (LZU)
Charm mixing, strong phase	C-even correlated $D\bar{D}$	Yinghao Wang (LZU, UCAS) Qiang Lan (USC)
CPV in Λ_c^+ decays	$\Lambda K^+, \Sigma^0 K^+, \Sigma^+ K_S^0$	Hongjian Wang (LZU)

Summary

- The STCF is a next generation high luminosity τ-charm facility
  - R&D project is ongoing with strong backing from local governments
  - Aiming to submit a proposal to the central government this year for inclusion in the15th five-year plan (2026-2030)
  - All forms of collaboration are opened

- The STCF has great physics potential for breakthroughs
  - High statistics and advanced detector
  - Various valuable physics results can be foreseen.

Thank you!

2025年超级陶粲装置研讨会

- ◆2025年超级陶粲装置研讨会
- ◆湖南科技大学，湘潭，2025年7月2日至7月6日
- ◆https://indico.pnp.ustc.edu.cn/event/3672/
- ◆注册参会～300人
- ◆欢迎各位专家学者莅临指导交流