Experimental Program for Super Tau-Charm Facility

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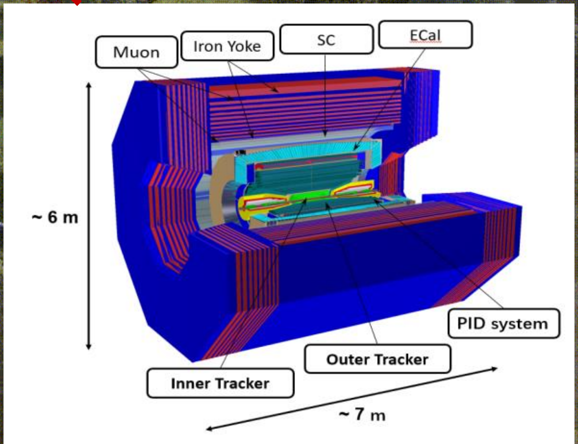
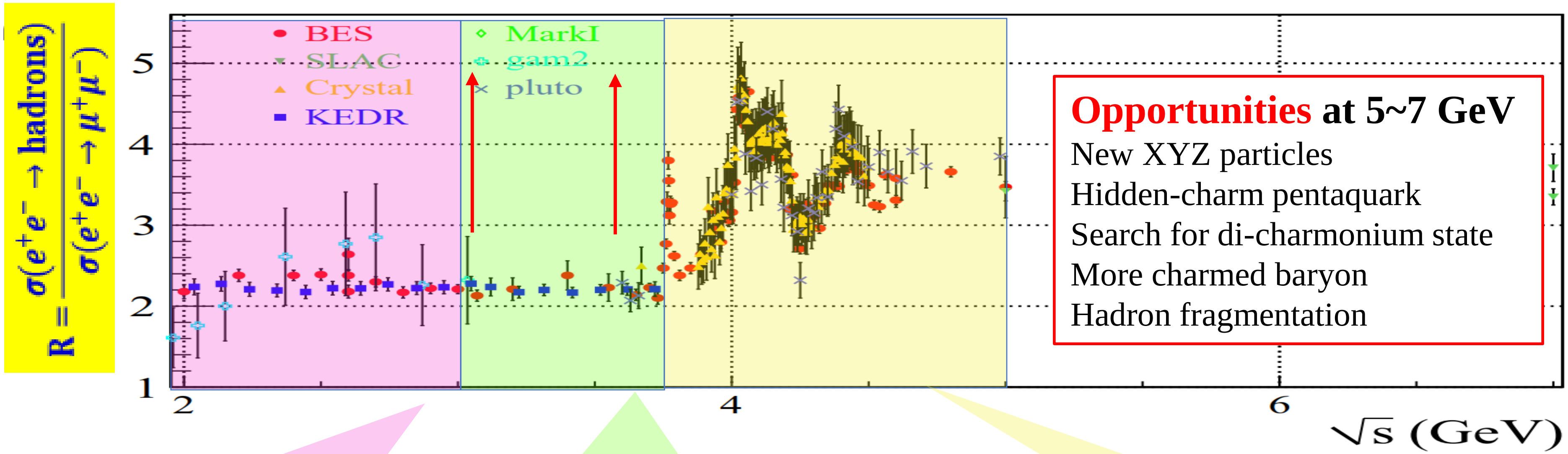
Super tau-Charm Facility in China

- 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



- 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

Expected data samples 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			

A 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}

A 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}

A 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}

- **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**

Highlighted physics at STCF

☐QCD and Hadronic Physics

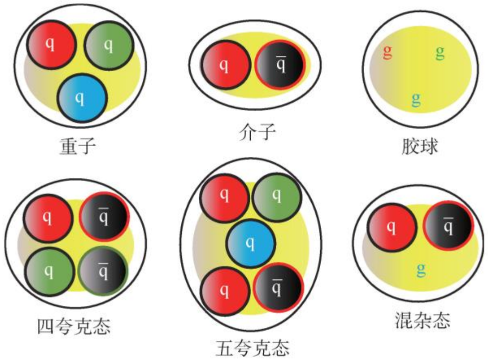
- ➢ Exotic states and hadron spectroscopy
- ➢ Hadron structures
- ➢ Precision test of SM parameters

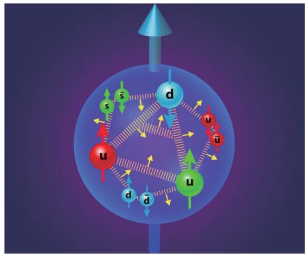
☐Flavor Physics and CP violation

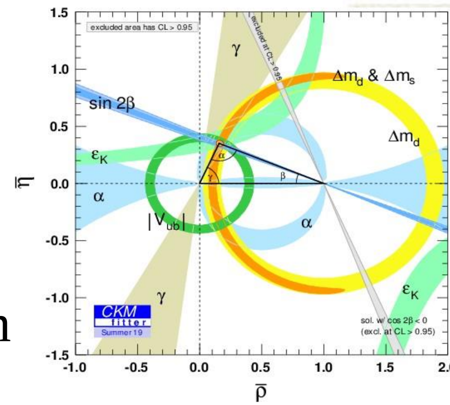
- ➢ CKM matrix, $D^0 - \overline{D}^0$ mixing
- ➢ CP violation in lepton, hyperon, charm

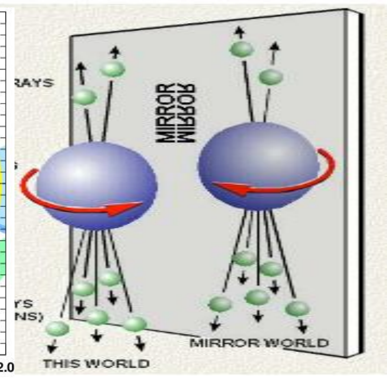
☐New Physics Search

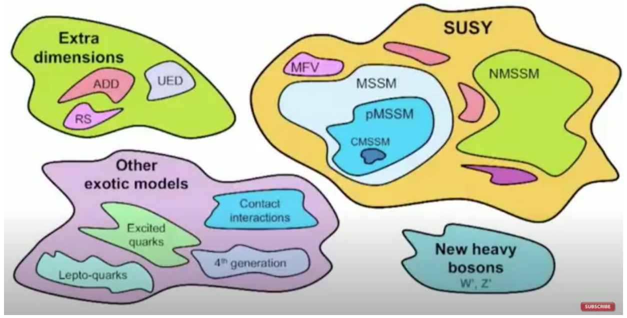
- ➢ Rare/Forbidden
- ➢ Dark particle search











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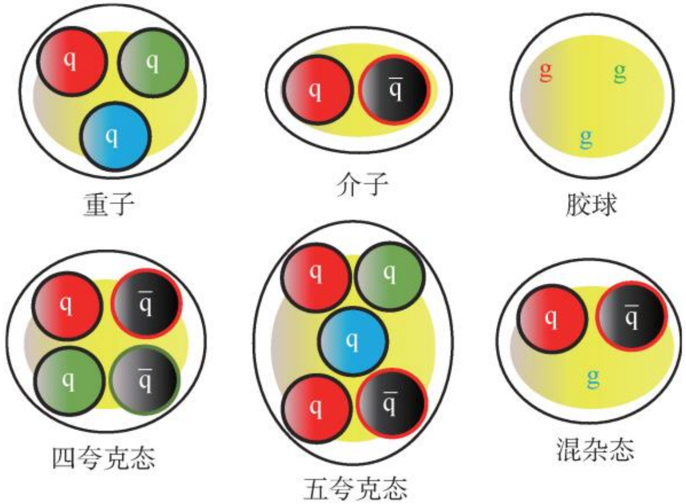
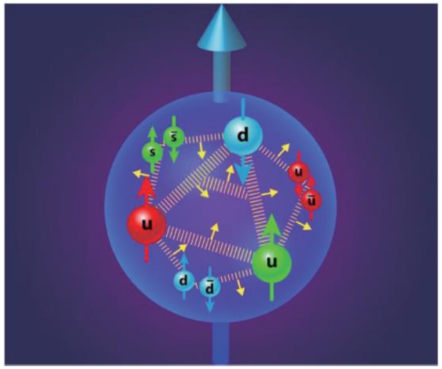
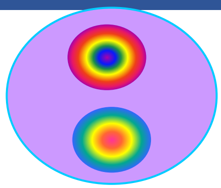




Charmonium (Like) Spectroscopy

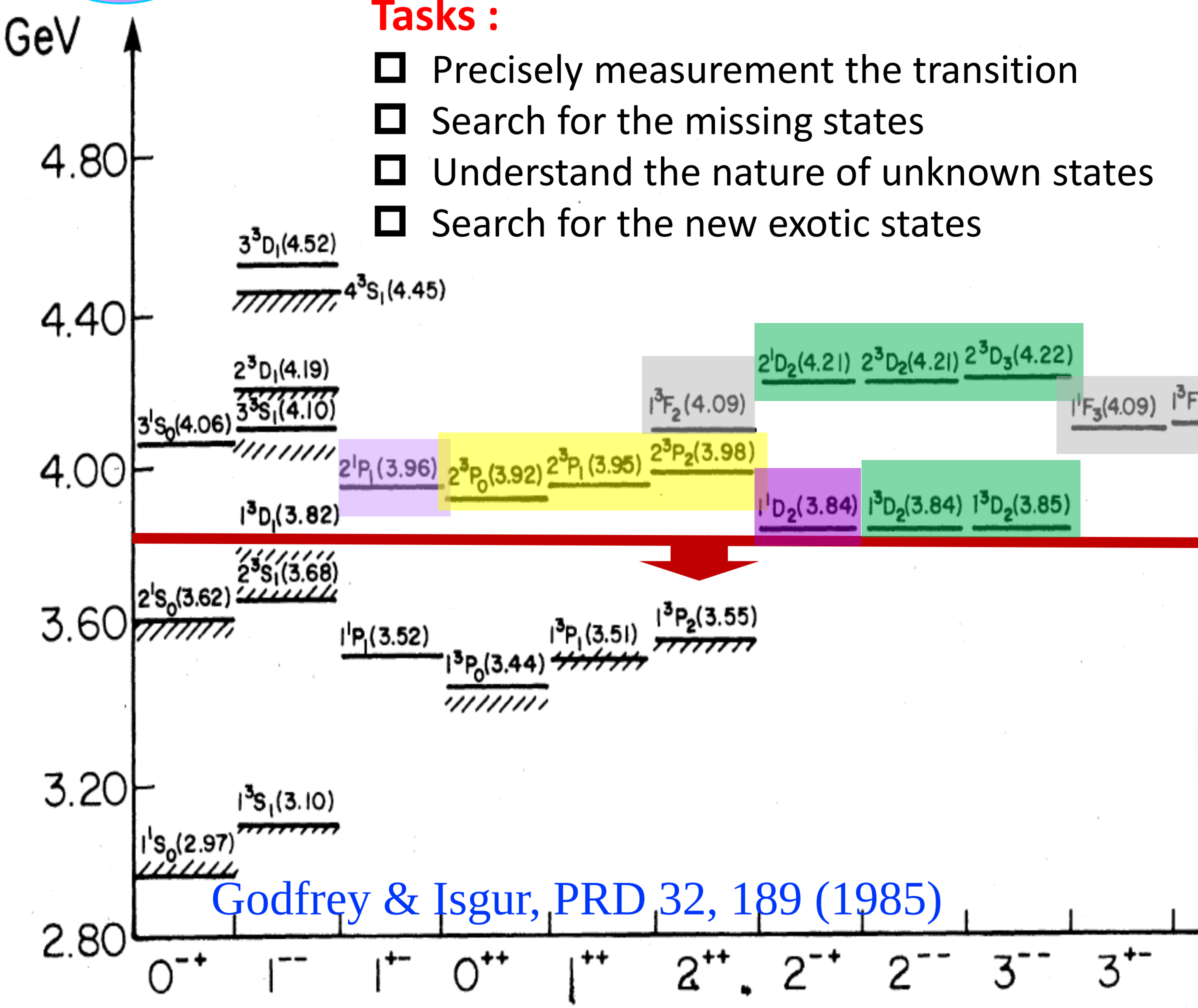


Excellent platform to explore the QCD

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

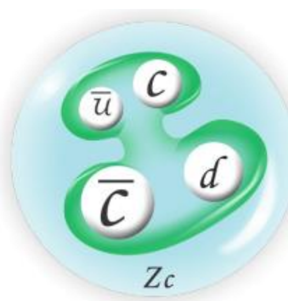
Tasks :

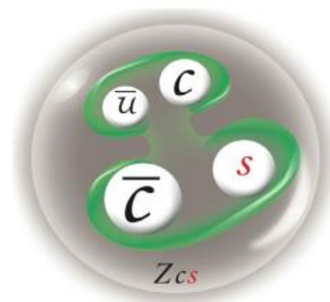
- ☐ Precisely measurement the transition
- ☐ Search for the missing states
- ☐ Understand the nature of unknown states
- ☐ Search for the new exotic states



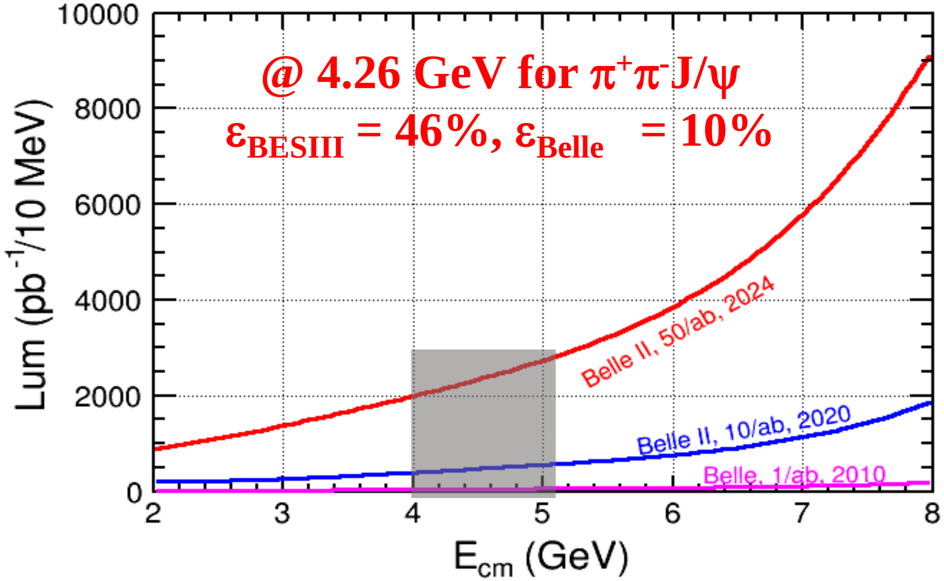
Godfrey & Isgur, PRD 32, 189 (1985)

X	Y	Z
X(3872)	Y(3940)	$Z_c(3900)$
X(3940)	Y(4008)	$Z_c(4020)$
X(4160)	Y(4260)	$Z_c(4050)$
X(4350)	Y(4360)	$Z_c(4200)$
	Y(4660)	$Z_c(4250)$
		$Z_c(4430)$
		$Z_{cs}(3985)$
		$Z_{cs}(4000)$
		$Z_{cs}(4220)$

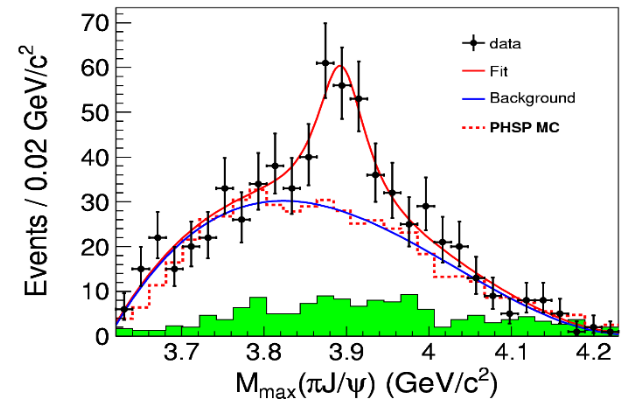




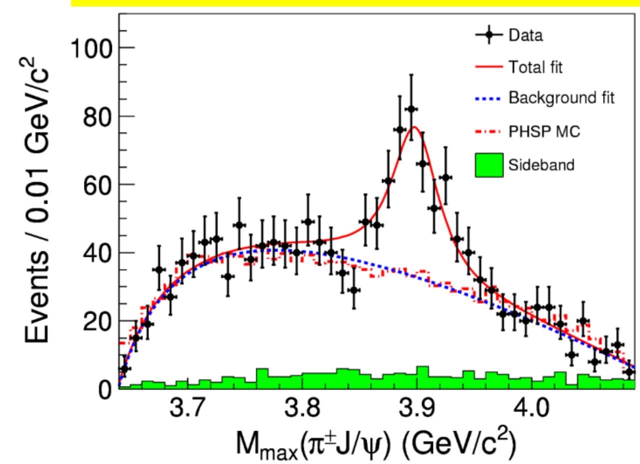
Charmonium(Like) Spectroscopy at STCF



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

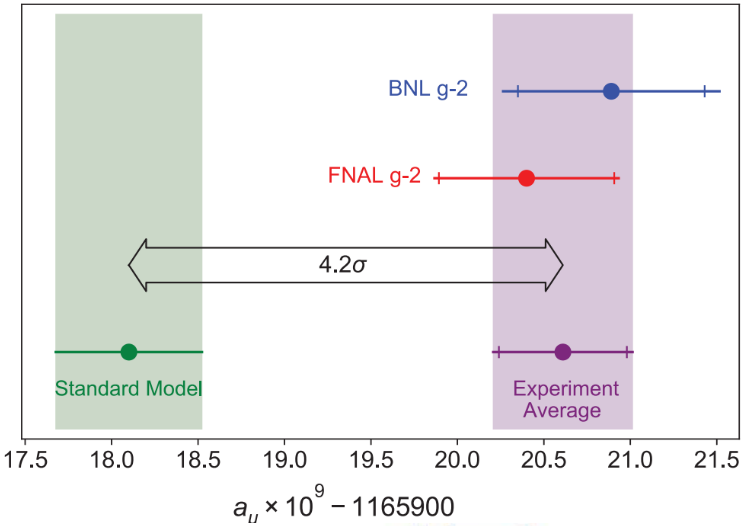


BESIII at 4.260 GeV: PRL110, 252001
0.525 fb^{-1} in one month running time

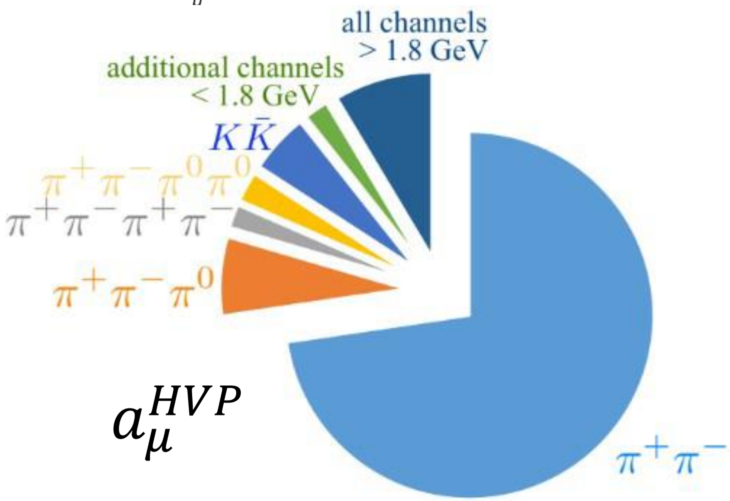


- B factory : Total integrate effective luminosity between 4-5 GeV is 0.23 ab^{-1} for 50 ab^{-1} data
- τ-C factory : scan in 4-5 GeV, 10 MeV/step, every point have 10 fb^{-1}/year, 5 time of Belle II for 50 ab^{-1} data
- τ-C factory have much higher efficiency and low background than B Factory

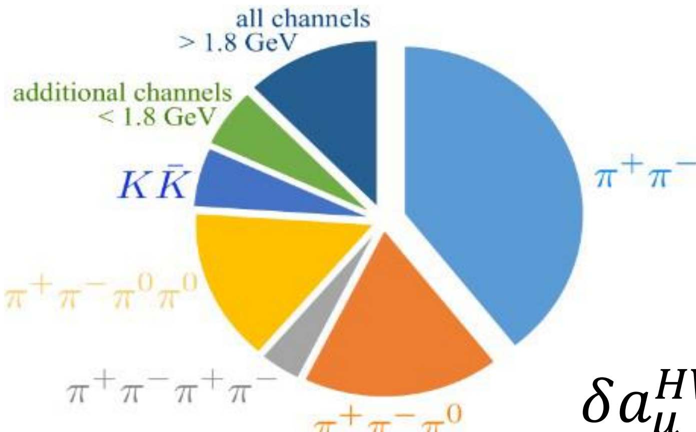
HVP Contribution to $(g-2)_\mu$



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



a_μ^{HVP}

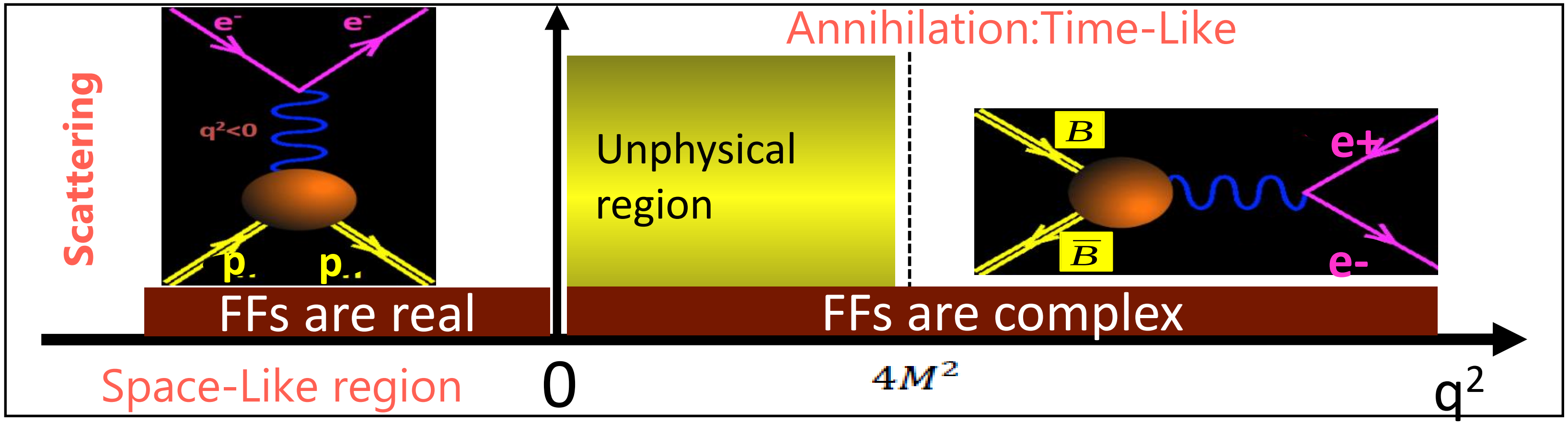


δa_μ^{HVP}

High Luminosity of STCF will largely improve the SM precisions !

Electromagnetic Form Factors

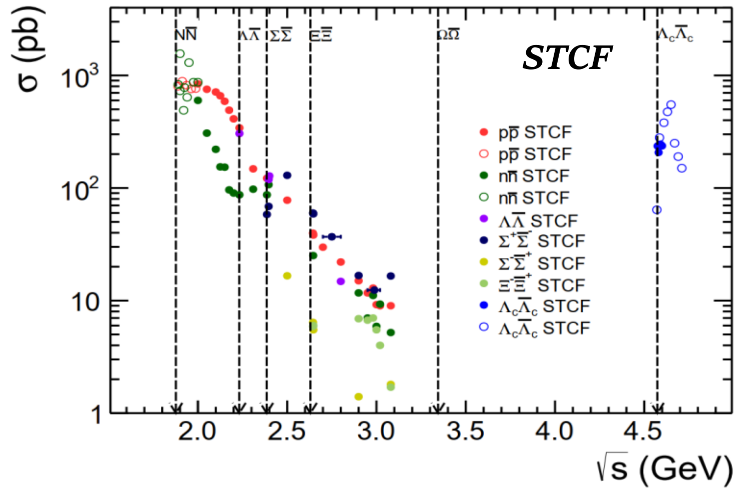
- **Fundamental properties of the nucleon**
  - **Connected to charge, magnetization distribution**
  - **Crucial testing ground for models of the nucleon internal structure**



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

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

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



QCD and Hadronic Physics

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

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

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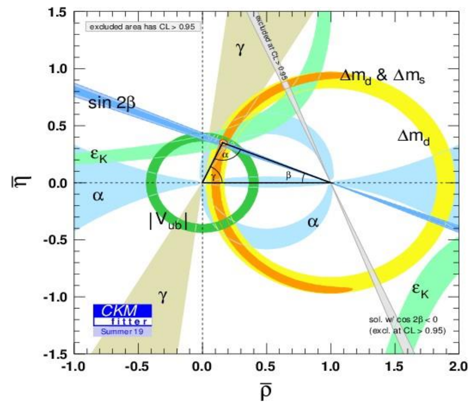
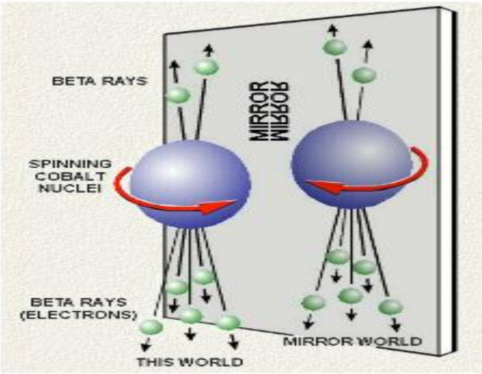
- **QCD and Hadronic Physics**
  - Exotic states and hadron spectroscopy
  - Hadron structures
  - Precision test of SM parameters
- **Flavor Physics and CP violation**
  - CKM matrix, $D^0 - \overline{D}^0$ mixing
  - CP violation in lepton, hyperon, charm
- **New Physics Search**
  - Rare/Forbidden
  - 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 γ/ϕ3 angle)
    - $D^0-\bar{D}^0$ 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)

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

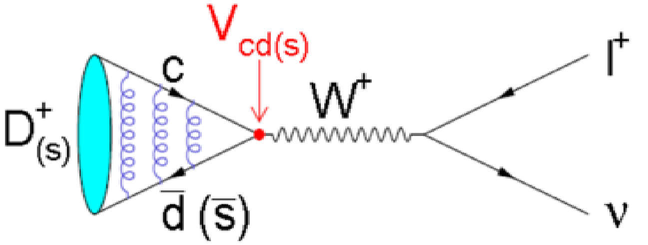
BESIII + B factories + LHCb + LQCD

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

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

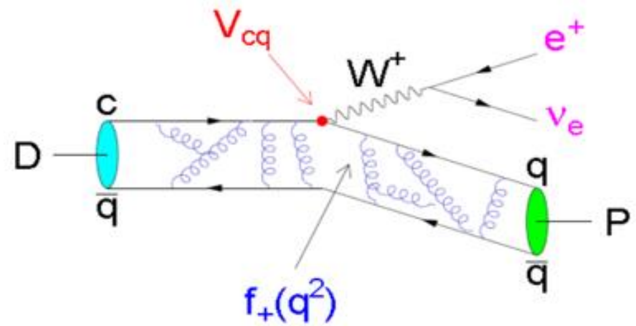
Purely Leptonic:

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



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

Theory : 0.2%(0.1% expected)

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* assuming Belle II improved systematics by a factor 2

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

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

- **STCF provide a unique place for the study of D^0 -$\bar{D}^0$ mixing and CPV by means of quantum coherence of D^0 and $\bar{D}^0$ produced through**

$$\psi(3770) \to (D^0\bar{D}^0)_{\text{CP}=-} \text{ or } \psi(4140) \to D^0\bar{D}^{*0} \to \pi^0(D^0\bar{D}^0)_{\text{CP}=-} \text{ or } \gamma(D^0\bar{D}^0)_{\text{CP}=+}$$

- The QC+incoherent results contains $D^0 \to K_S\pi\pi, D^0 \to K^-\pi^+\pi^0$ and general CP tag decay channels, The BelleII and LHCb only contain incoherent $D^0 \to K_S\pi\pi$ channel

	1/ab @4.009 GeV (only QC | QC+incoherent)		BelleII(50/ab)	LHCb(50/fb) (SL | Prompt)	
$x(\%)$	0.036	0.035	0.03	0.024	0.012
$y(\%)$	0.023	0.023	0.02	0.019	0.013
r_{CP}	0.017	0.013	0.022	0.024	0.011
$\alpha_{CP}(^\circ)$	1.3	1.0	1.5	1.7	0.48

- **Mixing parameter (x, y)~0.05% with 1 ab^{-1} data at 4.040 by $e^+e^- \to \gamma D^0\bar{D}^0$**
- **ΔA_{CP}~10^{-3} for KK and ππ channels**

CPV in τ decay

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

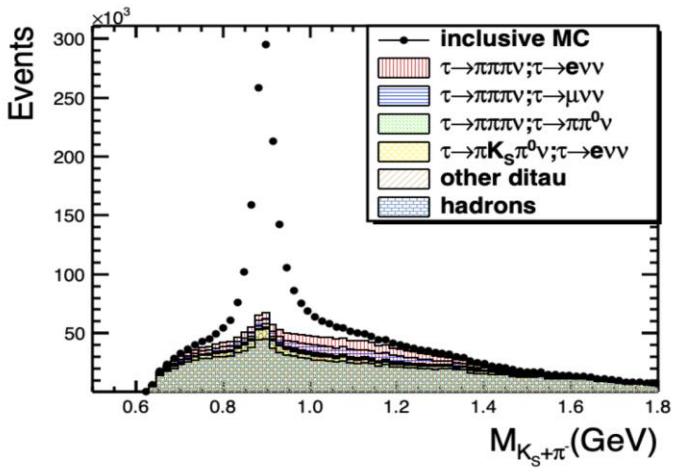
- The CPV source in $K^0-\bar{K}^0$ **mixing** produces a difference in tau decay rate

In Theory : $A_Q = \frac{B(\tau^+\to K_S^0\pi^+\bar{\nu}_\tau) - B(\tau^-\to K_S^0\pi^-\nu_\tau)}{B(\tau^+\to K_S^0\pi^+\bar{\nu}_\tau) + B(\tau^-\to K_S^0\pi^-\nu_\tau)} = (+0.36\pm0.01)\%$

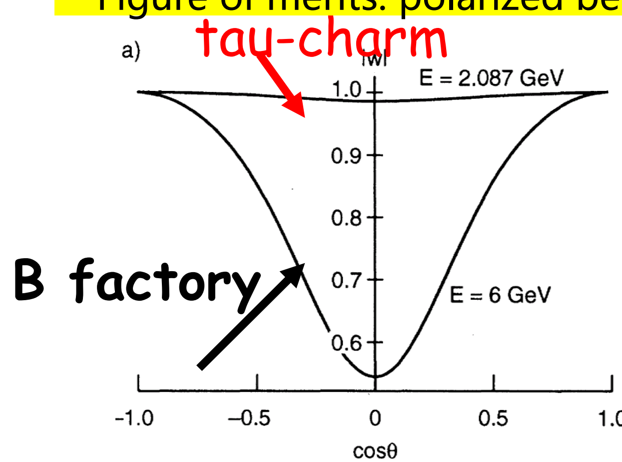
BaBar experiments : $A_{CP}(\tau^-\to K_S\pi^-\nu[\geq 0\pi^0]) = (-0.36\pm0.23\pm0.11)\%$

2.8σ away from the SM prediction

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



Possible choice to increase the Figure of merits: polarized beam



The CPV sensitivity with 1ab⁻¹ @ 4.26 GeV[1]:

$A_{STCF}\sim 9.7\times10^{-4}$

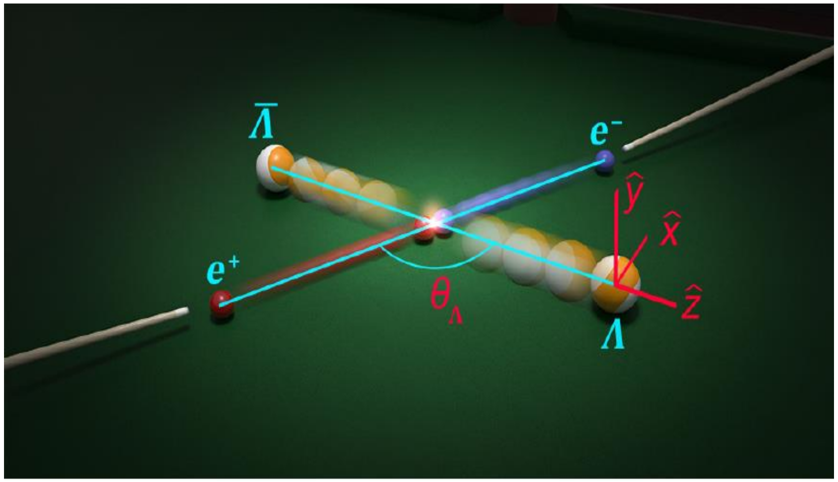
With 10 ab⁻¹ data:

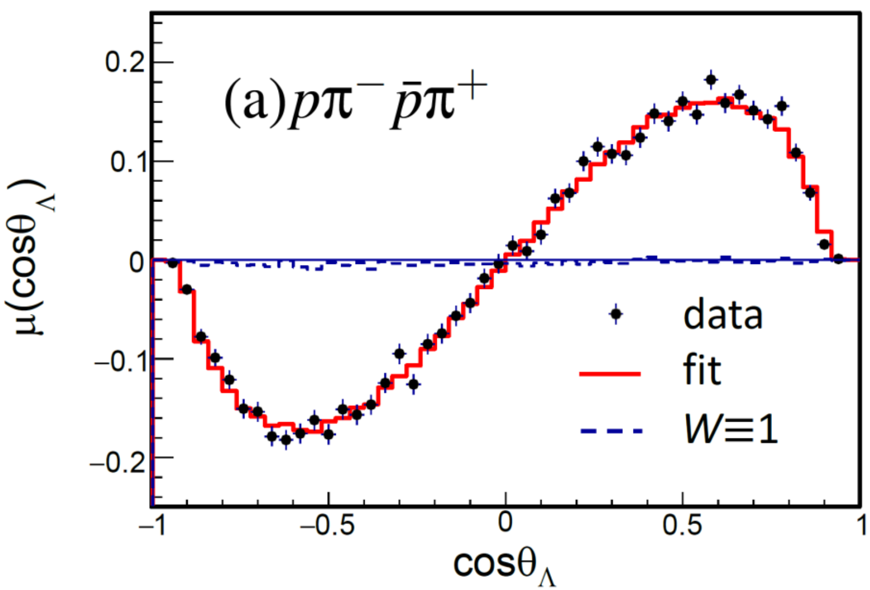
$A_{STCF}\sim 3.1\times10^{-4}$

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

Polarization of Λ hyperons and CPV

Nature Phys. **15**, 631–634 (2019)





1.31 B J/ψ events
Quantum correlation in Λ pair

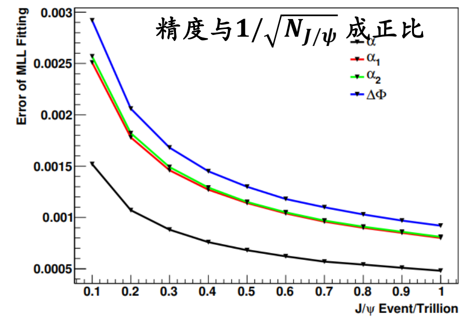
Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [14]
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)^\circ$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [16]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [16]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm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

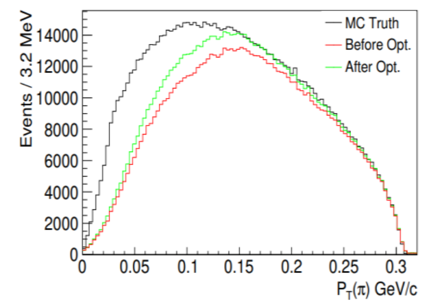
2% level sensitivity for CPV test
SM prediction: 10^{-4}~10^{-5}

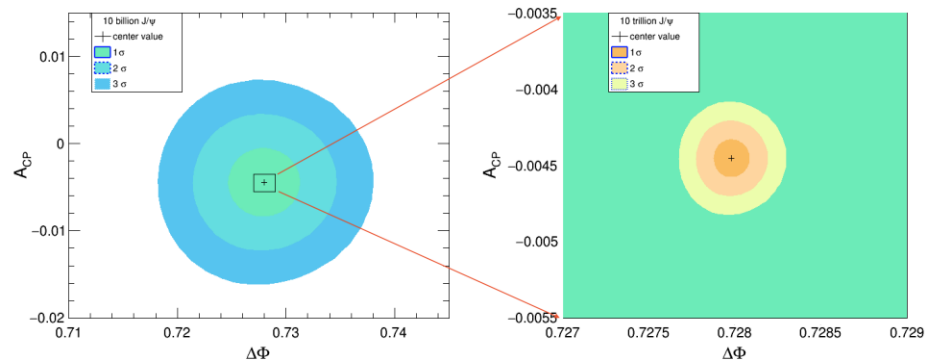
CP test $A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$

CPV in Hyperon Decays at STCF

- 4 trillion J/ψ events ⇒ A_{CP}~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}~10^{-5}?
- Challenge: Systematics control, spin procession effect in magnet

Flavor Physics and CP violation

Physics at STCF	Benchmark Processes	Key Parameters*
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%
γ/ϕ_3 measurement	$D^0 \to K_s\pi^+\pi^-, K_sK^+K^-$ ...	Δ(cosδ$_{K\pi}$) ~0.007; Δ(δ$_{K\pi}$) ~2°
$D^0 - \bar{D}^0$ 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%
Charm hadron decay	$D_{(s)}, \Lambda_c^+, \Sigma_c, \Xi_c, \Omega_c$ decay	$N_{D/D_s/\Lambda_c}$~$10^9/10^8/10^8$
γ polarization	$D^0 \to K_1 e^+\nu_e$	$\Delta A'_{UD}$~0.015
CPV in Hyperons	$J/\psi \to \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi^-\bar{\Xi}^-, \Xi^0\bar{\Xi}^0$	ΔA_{Λ}~10^{-4}
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)
CPV in Charm	$D^0 \to K^+K^-/\pi^+\pi^-$, $\Lambda_c \to pK^-\pi^+\pi^0$ ...	ΔA_D~10^{-3}; ΔA_{Λ_c}~10^{-3}

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

Highlighted physics at STCF

□QCD and Hadronic Physics

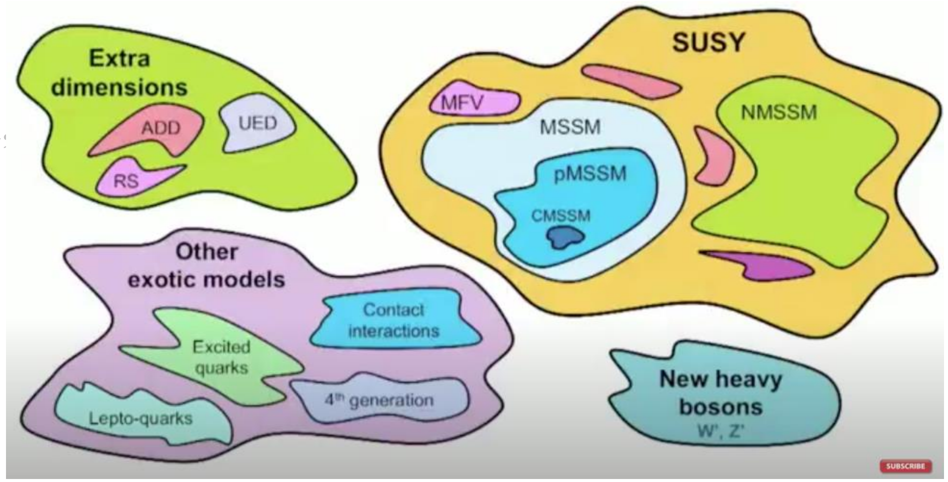
- ➢ Exotic states and hadron spectroscopy
- ➢ Hadron structures
- ➢ Precision test of SM parameters

□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



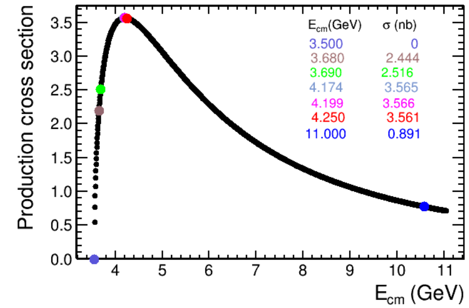
Studies of τ at STCF

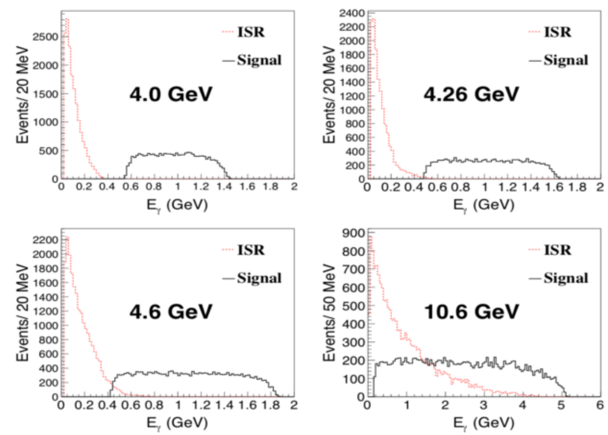
Advantage:

- Threshold production
- Peaking cross section in 4-5 GeV
- At 4.26 GeV, number of tau pairs per year:

$$N_{\tau\tau} \sim 1.0\ \mathrm{ab}^{-1} \times 3.5\ \mathrm{nb} = 3.5\times 10^{9}$$

- $e^+e^- \to \gamma\tau^+\tau^-$ is not the main background
- Improved π/μ misid rate at STCF



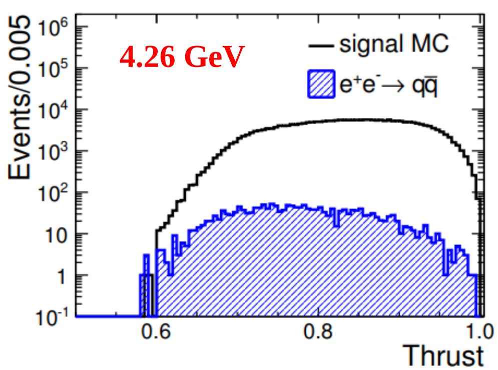


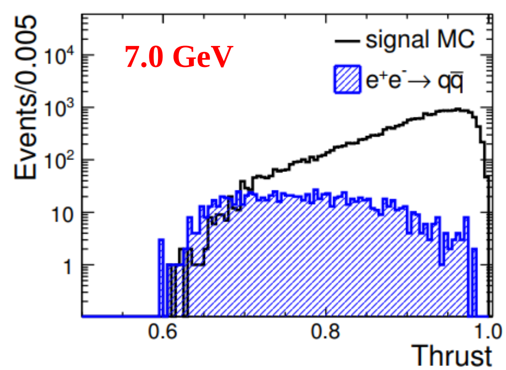
Disadvantage:

– Entangled topology of $e^+e^- \to \tau^+\tau^-$

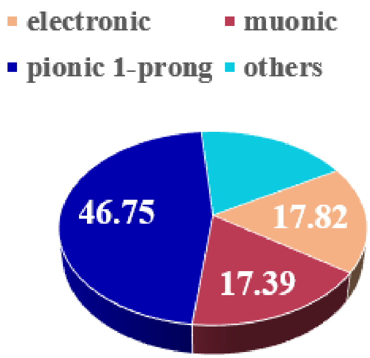
– Large $e^+e^- \to q\bar{q}$ background at low c.m.e

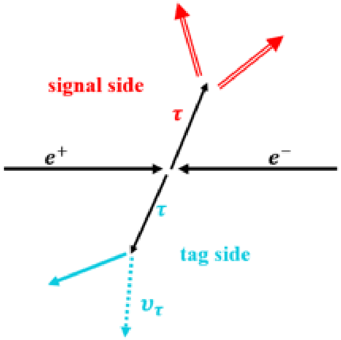
$$T \equiv max_{\vec{n}} \frac{\sum_i |\vec{n}\cdot\vec{p}_i|}{\sum_i |\vec{p}_i|}$$



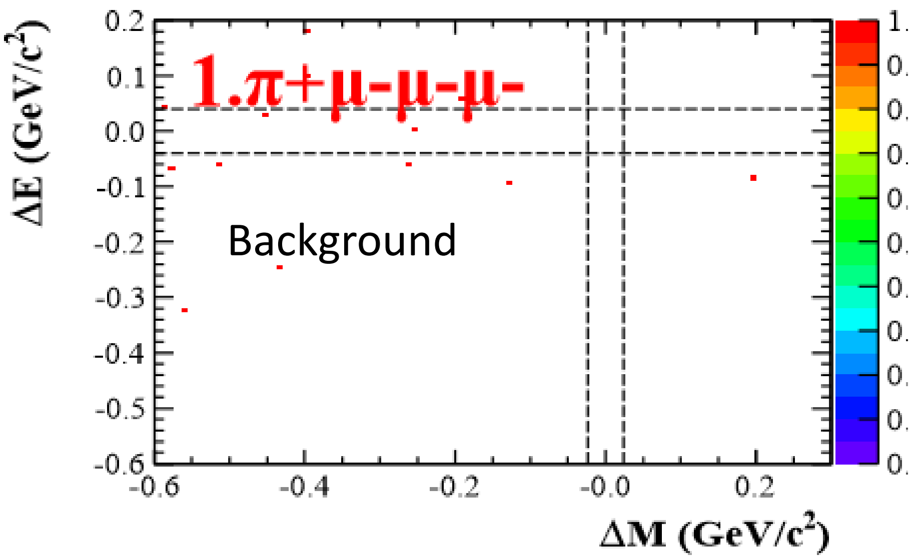


LFV decay of $\tau \to lll$ at STCF





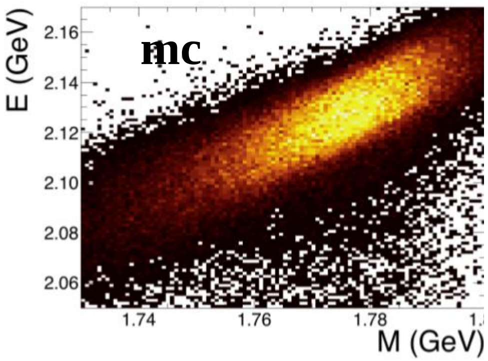
- Signal side: $\tau \to 3leptons$
- Tag side: $\tau \to e\upsilon\bar{\upsilon},\ \mu\upsilon\bar{\upsilon}\ ,\ \pi\upsilon + n\pi^0$ ($\mathcal{B}r =$ 82%)
- Almost background free, **the sensitivity : $\mathcal{B}_{UL}^{90}(\tau \to \mu\mu\mu) \sim 1/\mathcal{L}$**
- Best efficiency ($\tau \to \mu\mu\mu$):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

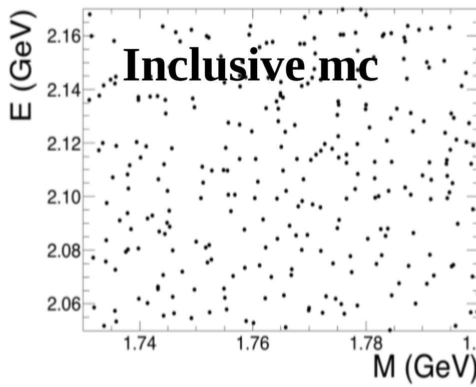


- **STCF with 1ab^{-1}:**

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

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

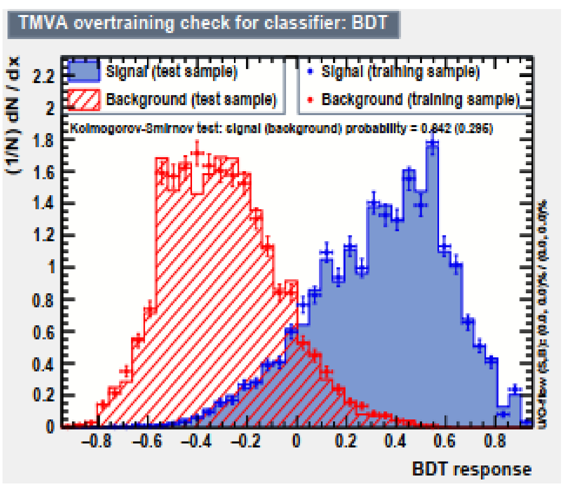


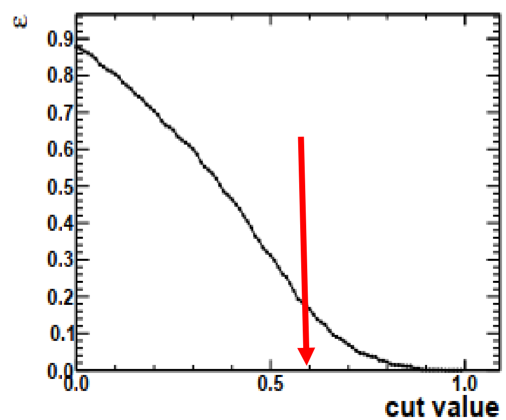


- Signal side $\tau\to\gamma\mu$
- Tag side: $\tau\to e\upsilon\bar{\upsilon},\ \pi\upsilon,\ \pi\pi^0\upsilon(\mathcal{B}r=54\%)$
- **Dominant background**: $e^+e^-\to\mu^+\mu^-$ and $e^+e^-\to\tau^+\tau^-, \tau^+\to\pi\pi^0\upsilon, \tau^-\to\mu\upsilon\bar{\upsilon}$

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



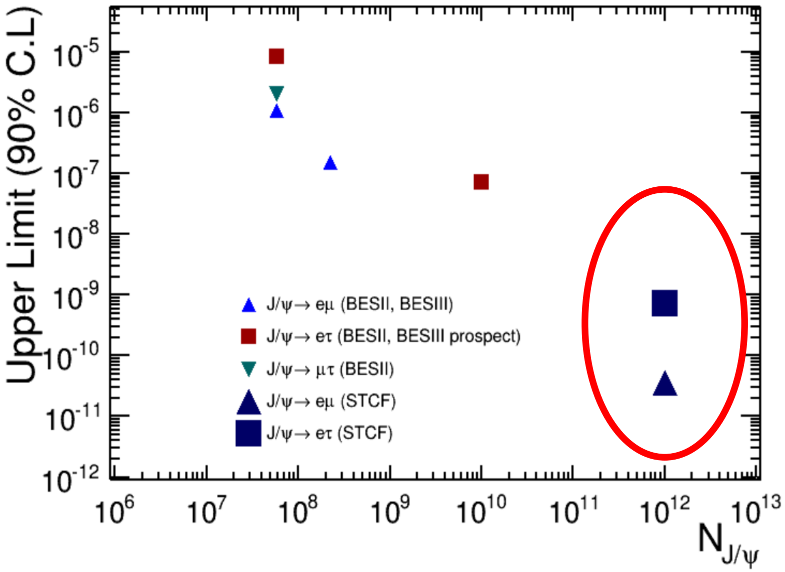


- **STCF with 1ab^{-1}:**

$$\mathcal{B}_{UL}^{90}(\tau\to\gamma\mu)<\frac{N_{UL}^{90}}{2\varepsilon N_{\tau\tau}}\sim1.2\times10^{-8}$$

LFV decay of $J/\psi \to e\tau$ at STCF

- The cLFV decays of vector mesons $\boldsymbol{V \to l_i l_j}$ are also predicted **in various of extension models** of SM:
  - $\mathcal{B}_{UL}^{90}(J/\psi \to e\mu) < 10^{-13}$
  - $\mathcal{B}_{UL}^{90}(J/\psi \to e(\mu)\tau)) < 10^{-9}$
- At **STCF**, **1 trillion** $\boldsymbol{J/\psi}$ can be obtained per year, taken efficiency from BESIII, the upper limit can be predicted to be:
  - $\mathcal{B}_{UL}^{90}(J/\psi \to e\mu) < 3.6 \times 10^{-11}$
  - $\mathcal{B}_{UL}^{90}(J/\psi \to e\tau)) < 7.1 \times 10^{-10}$
- The $\boldsymbol{\mathcal{B}_{UL}^{90}(J/\psi \to e\tau))}$ can be further **optimized** with better PID.

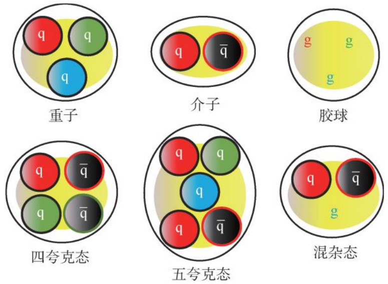


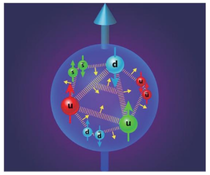
Forbidden/Rare decay and New Particle Search

Physics at STCF	Benchmark Processes	Key Parameters* (U.L. at 90% C.L.)
LFV 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}
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}
Symmetry violation	$\eta^{(\prime)} \to ll\pi^0, \eta' \to \eta ll\ldots$	$\mathcal{B}(\eta' \to ll/\pi^0 ll)$< $1.5/2.4 \times 10^{-10}$
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}
Dark photon, millicharged	$e^+e^- \to (J/\psi) \to \gamma A'(\to l^+l^-)\ldots$ $e^+e^- \to \chi\bar{\chi}\gamma\ldots$	Mixing strength $\Delta\epsilon_{A'}$~10^{-4}; $\Delta\epsilon_{\chi}$~10^{-4}

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

Summary of physics program at STCF

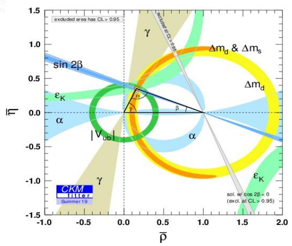


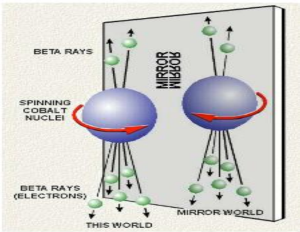


Physics at STCF

QCD and hadronic physics

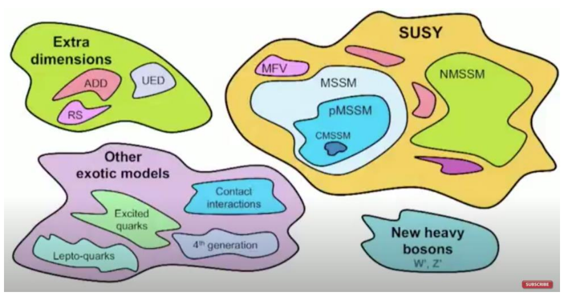
- **XYZ Properties:** e+e-→Y→γX,ηX,ϕX; e+e-→Y→πZc, KZcs
- **Hadron Spectroscopy:** Excited ccbar and their transition, Charmed hadron spectroscopy, Light hadron spectroscopy
- **R value:** e+e-→inclusive; τ mass: e+e-→τ+τ-
- **Nucleon Form Factors:** e+e-→BBbar from threshold
- **Pentaquarks:** e+e-→J/ψppbar, 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+v, D→P l+ v
- **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 πv, EDM of τ, τ→π/K π0 v 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+ v_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**

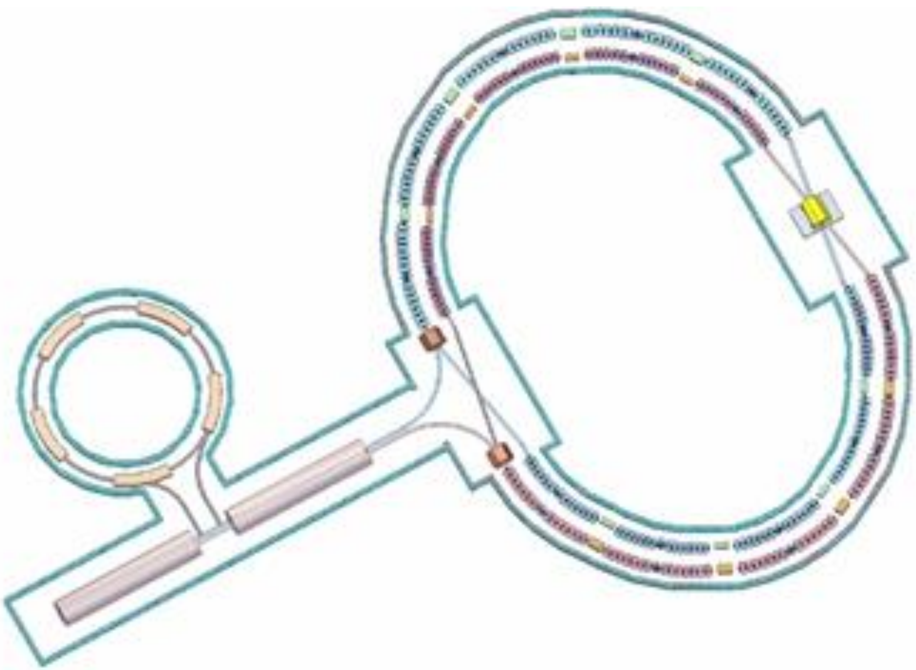
Tentative Plan

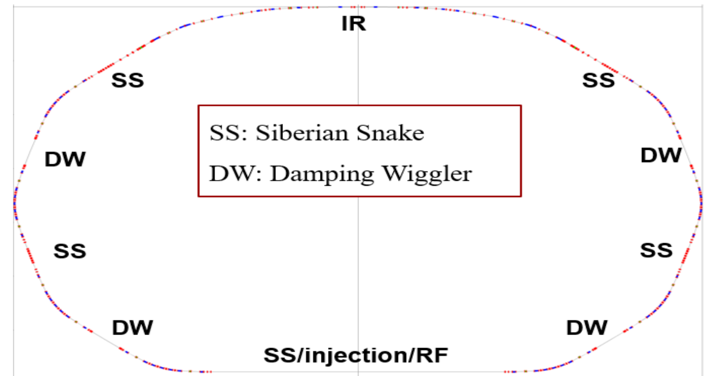
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031-2040	2041-2042
Form Group	■	■	■	■											
CDR	■	■	■	■											
TDR	■	■	■	■	■	■	■								
Construction							■	■	■	■	■	■	■		
In operation														■	
Upgrade															■

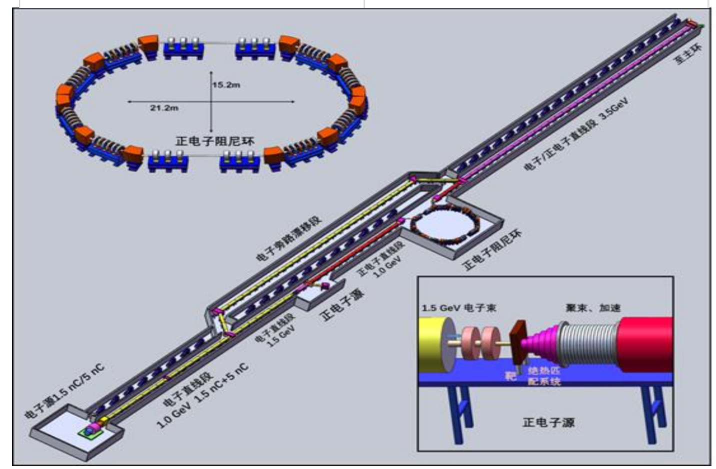
The first version of CDR (three volumes) has finished

STCF Accelerator

Interaction Region : Large Piwinski Angle Collision + Crabbed Waist







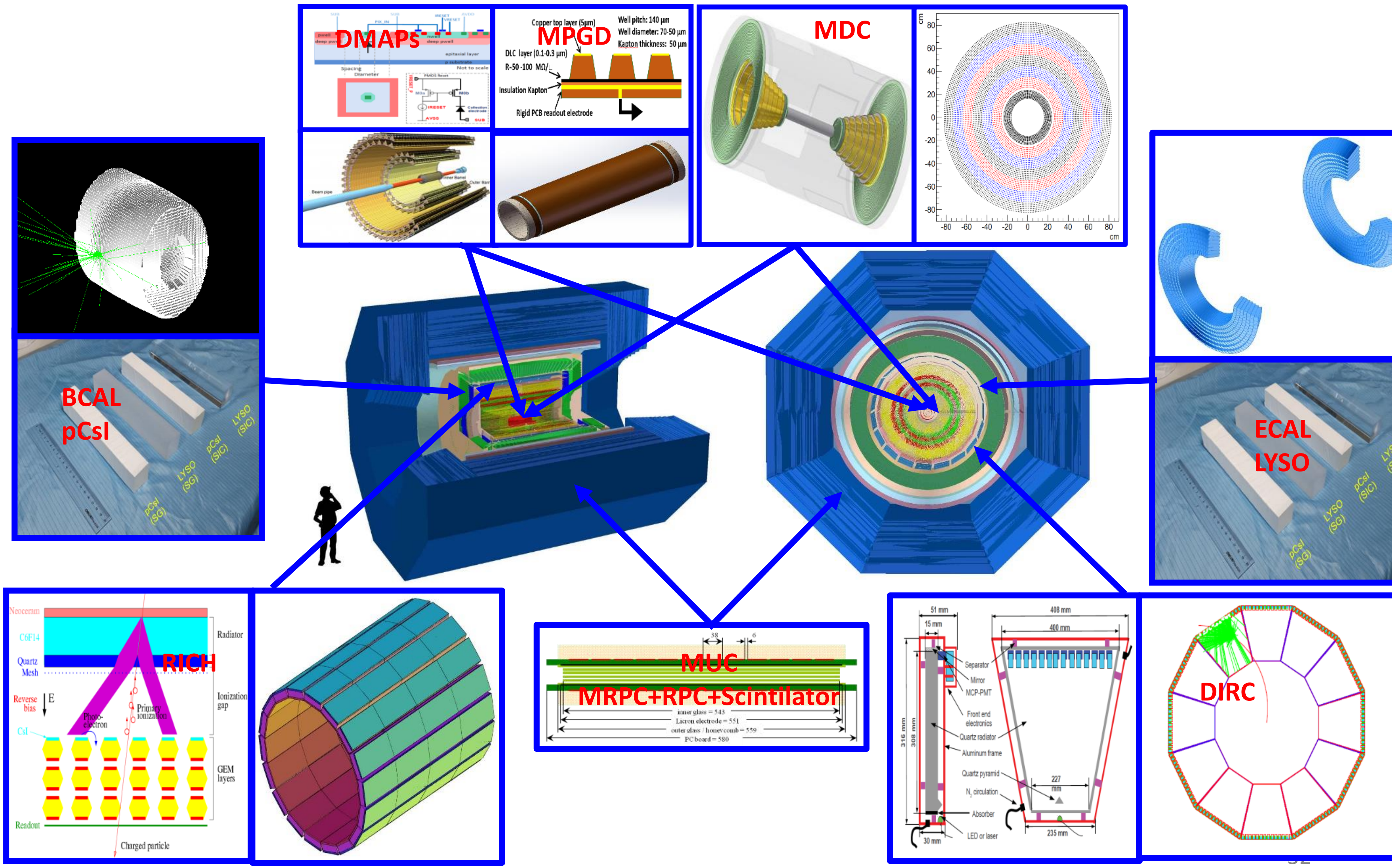
Injector:

- No booster, 0.5 GeV→1~3.5 GeV
- e+, a convertor, a linac and a damping ring, 0.5 GeV
- e-, a polarized e- source, accelerated to 0.5 GeV

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

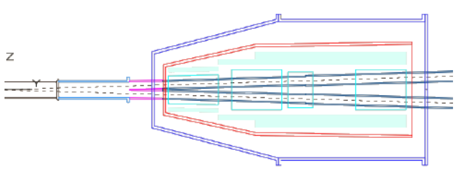
STCF detector

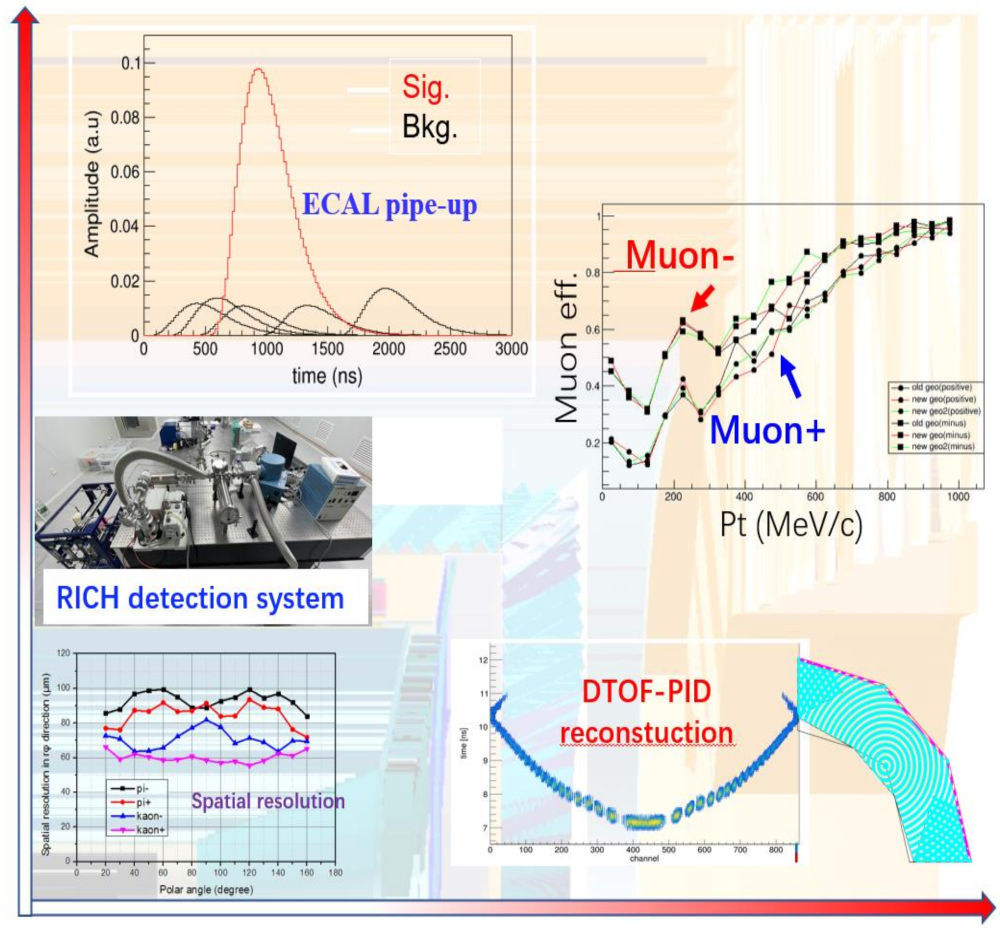


STCF detector

- **MDI**： CDR finished; beam/physics background estimation;
- **Inner Tracker**： MPGD CDR finished, in optimizing; Silicon tracker ongoing
- **MDC**： CDR finished
- **PID**： CDR finished; Prototyle of RICH (2nd version) and DTOF
- **ECAL**： CDR finished; optimizing crystal and electronics
- **MUC**： CDR finished; optimizing

MDI design





Strategy & Activities

CDR → TDR → project application → construction → commissioning

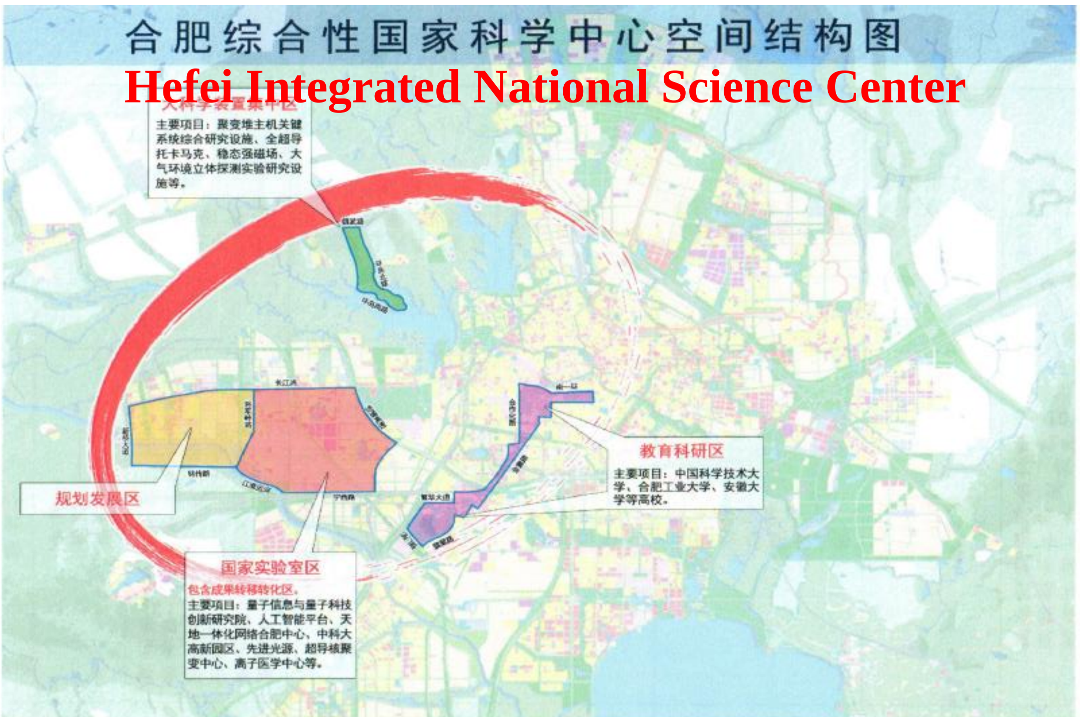
- Strategy: focus on CDR (4 years) and TDR (7 years) depend on the available resources. the construction site open.
- Domestic Workshops (2011, 12, 13, 14, 16, 20, 21)
- International Workshops (2015, 18, 19, 20, 21)

Funding support for R&D

- Double First-Class university project foundation of USTC
- CAS international cooperation and exchange project
- National Science Foundation of China (Key/General programs)
- The 14th five-year planning, National Key Basic Research Program of China

Candidate Site : Hefei

One of three integrated national science centers, which will play important role in 'Megascience' of China in near future



- **University of Science and Technology of China (USTC)**
- **National Synchrotron Radiation Lab and Hefei Light Source, operated by USTC**
- **The only National Lab operated by University in China. (Totally Four officially approved National Labs in China)**

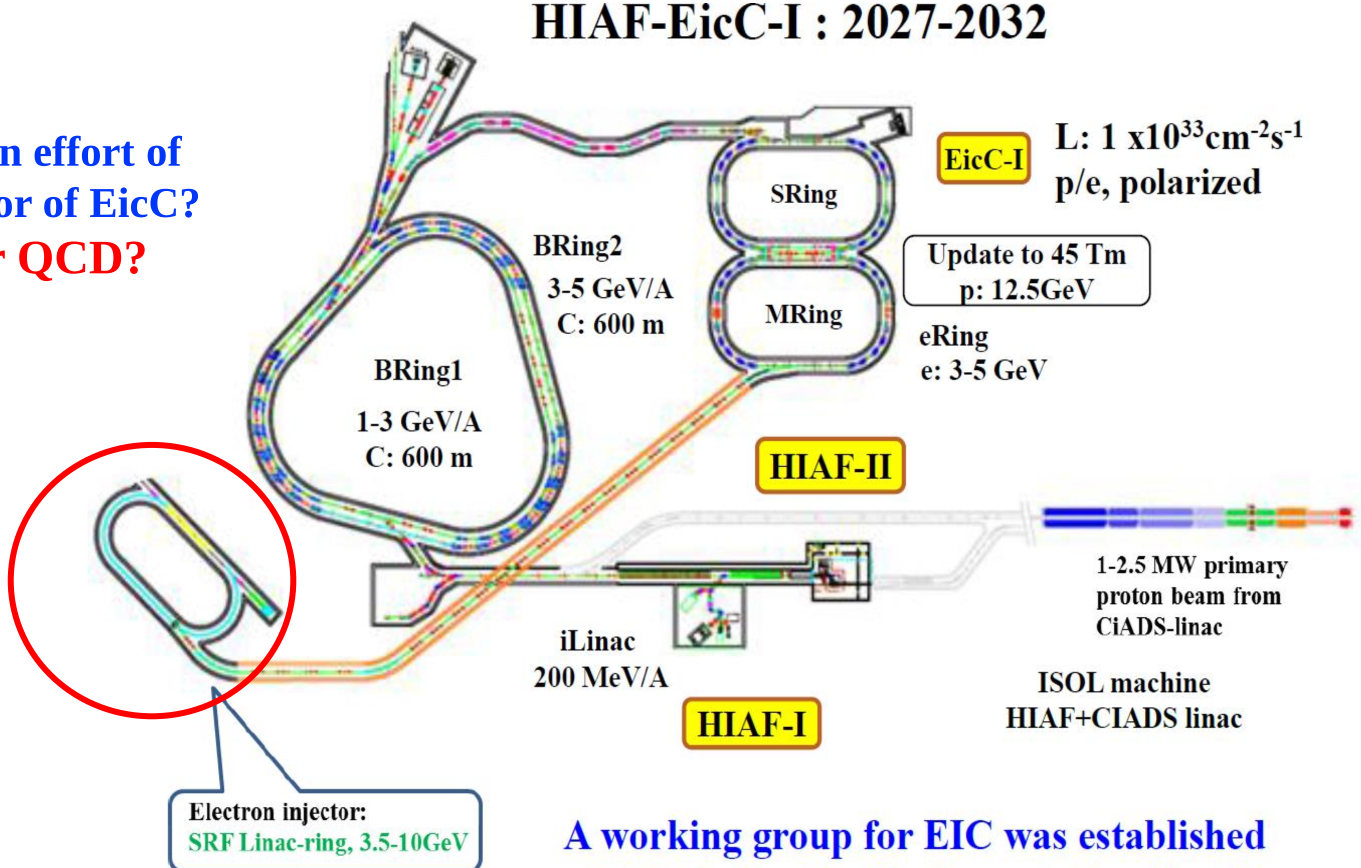
- **Pay a lot of attention on accelerator facilities**
- **Hefei Advanced light source is under design**
- **STCF is listed in future plan**

Candidate Site : Huizhou

Institute of Modern Physics, CAS, proposed building HIAF-EicC in Huizhou, Canton

STCF Share the design effort of the electron accelerator of EicC?

National Center for QCD?



A working group for EIC was established at IMP led by Dr. Nu Xu and Jianping Chen.

Summary

- **Super τ-c Facility** (STCF):
  - e^+e^- collision with $E_{cm} = 2 – 7$ GeV, $L > 0.5 \times 10^{35}$ $cm^{-2}s^{-1}$
- **STCF is one of the crucial precision frontier**
  - rich of physics program
  - unique for physics with c quark and τ leptons,
  - important playground for study of QCD, exotic hadrons and search for new physics.
- **Complementary to Belle-II and LHCb in understanding the QCD/EW models and searching for new physics**
- **Project organization is setup and a working group is toward for CDR/TDR**
- **An International collaboration is essential for promoting the project.**

Thanks for your attention!

Welcome to join the effort!