Progress of the Future Super Tau-Charm Facility

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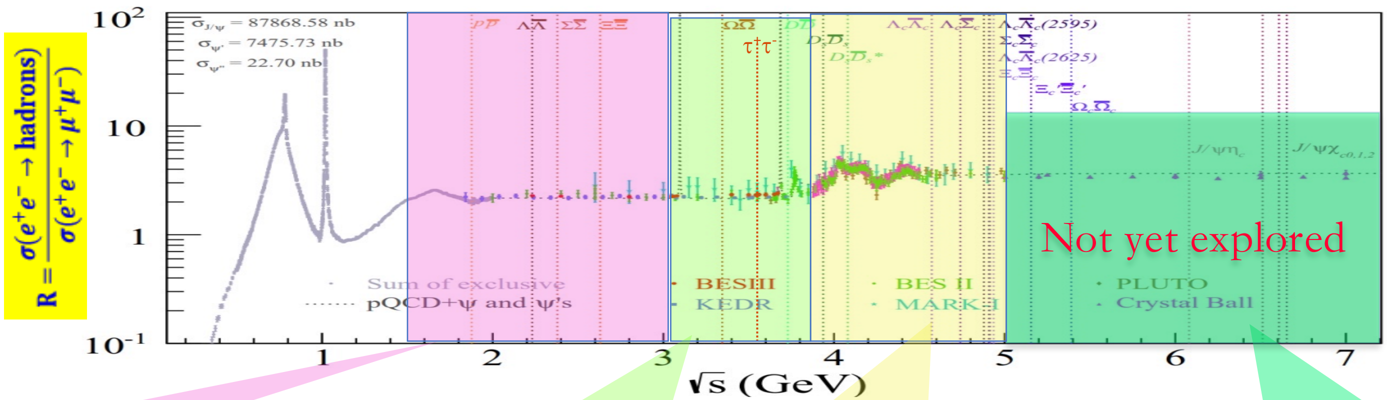
(On behalf of the STCF working group)

Features and Physics Program @ τ-charm Energy

- **Transition** region between smooth and resonance, perturbative and non-perturbative QCD.
- Rich resonance structures, **huge production cross section** for charmonium states.
- **Threshold effect** of pair production of hadrons and τ.
- **Exotic hadrons** (gluonic matter, hybrid, multiquarks etc)



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

- LH spectroscopy
- Gluonic and exotic
- LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- Physics with D mesons
- f_D and f_{D_s}
- D_0-$\overline{D_0}$ mixing
- Charm baryons

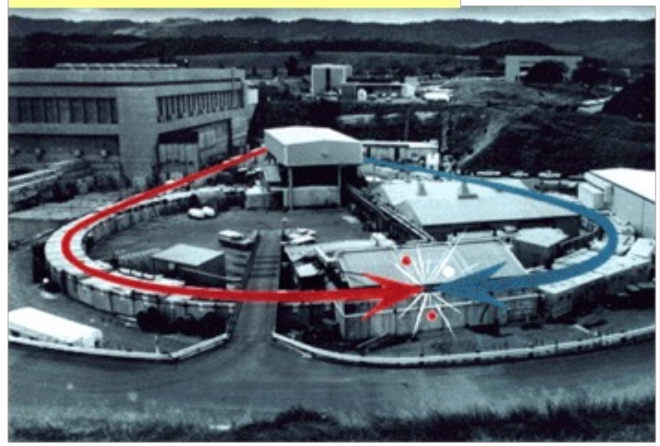
- New XYZ particle
- Hidden-charm pentaquark
- Multiquark state
- Di-charmonium state
- Charm baryons
- Hadron fragmentation

τ-Charm is a unique energy region that bridges the perturbative and non-perturbative QCD, for high precision measurements to meet the remining big challenge to the SM.

Dedicated τ-Charm Factories

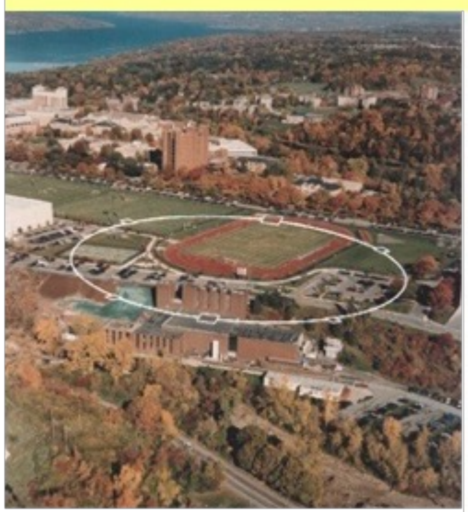
ADONE, FRASCATI
'69-'93

SPEAR, SLAC, '72-'90
6×10^{29} $cm^{-2}.s^{-1}$

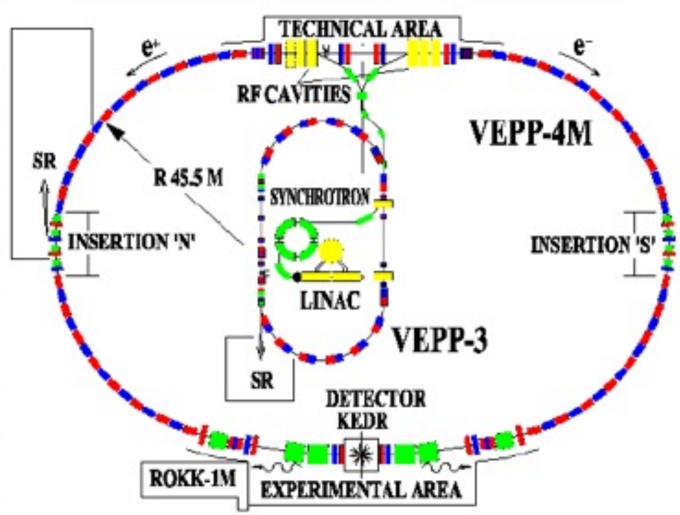


BEPC, IHEP, '90-'04
5×10^{30} $cm^{-2}.s^{-1}$

CESRc, Cornell, '04-'08
7×10^{31} $cm^{-2}.s^{-1}$

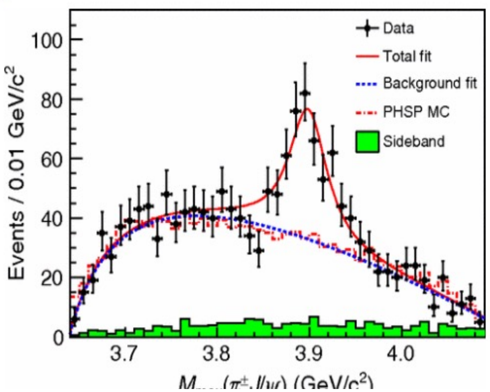


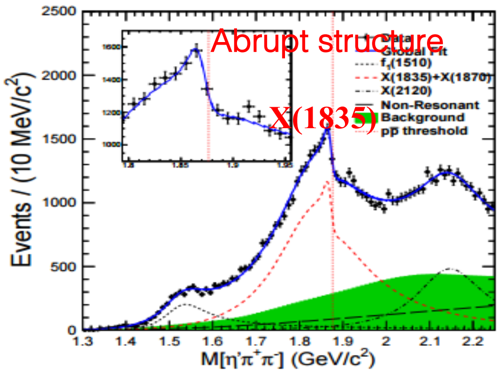
VEPP-4M, Novosibisk, '02-'12
1×10^{30} $cm^{-2}.s^{-1}$

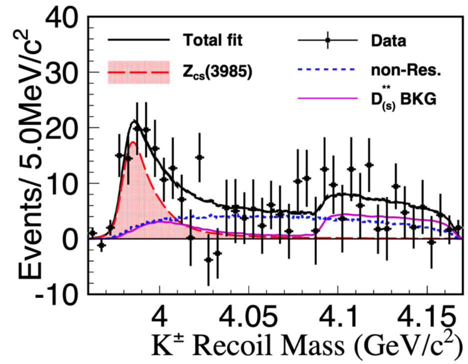


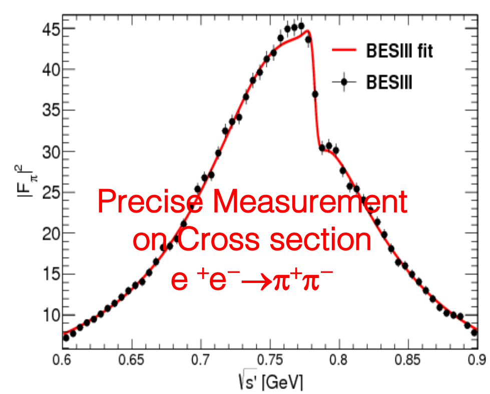
BEPCII, IHEP, '08-'2X(?)
1×10^{33} $cm^{-2}.s^{-1}$

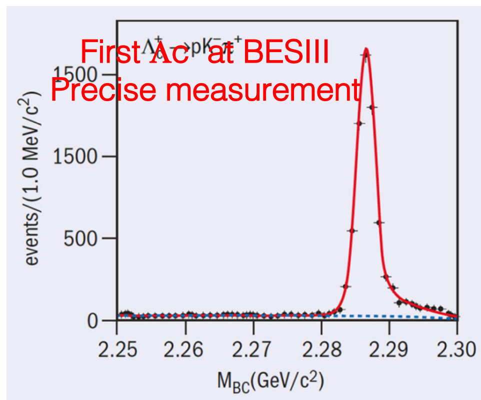
Fruitful BEPCII/BESIII Results

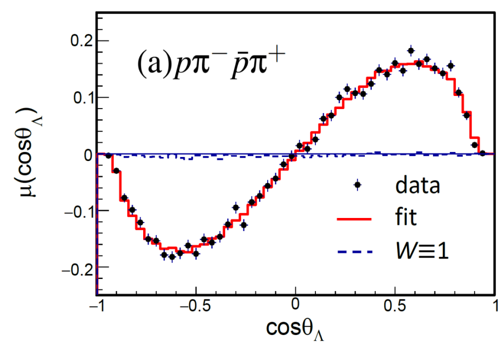


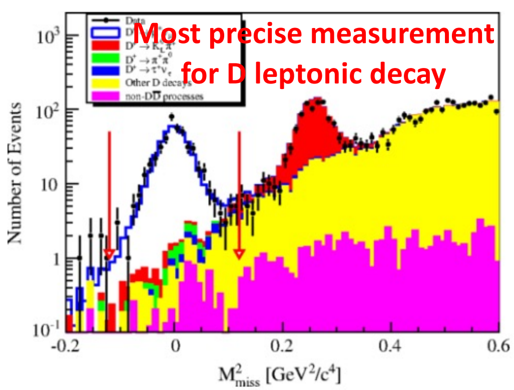


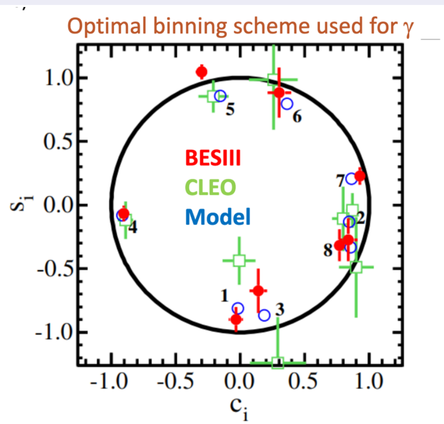




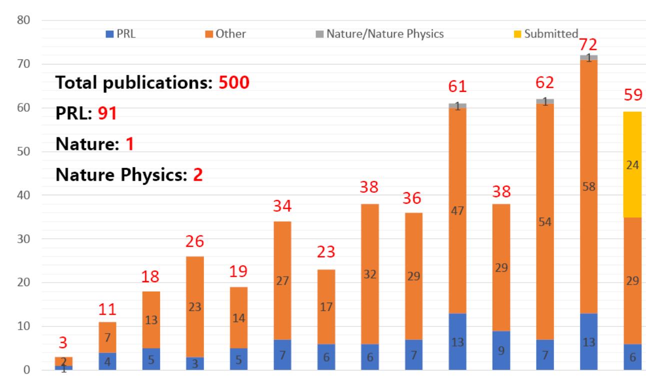








BESIII publications
(May 9, 2023) **>500**

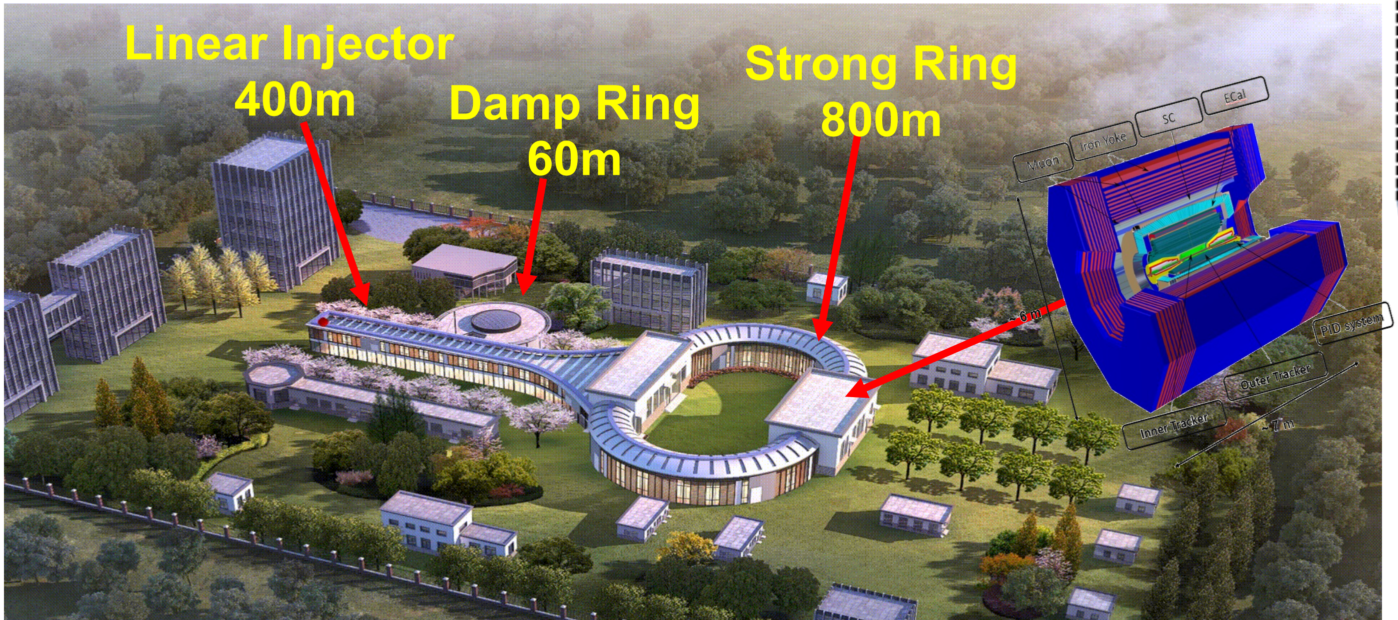


τ-c facility in China

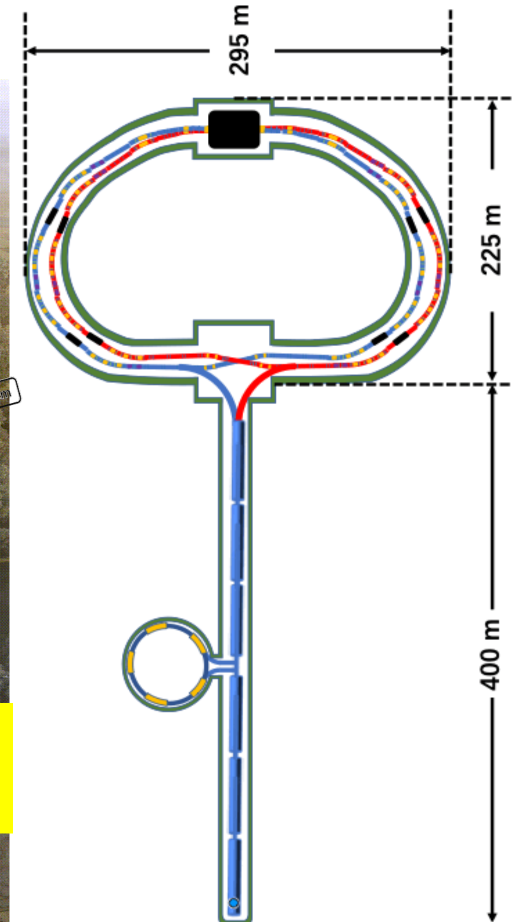
- BEPCII/BESIII have run 10 years, and are playing a leading role in tau-charm physics area.
- Limited by length of storage ring, no space and potential for major upgrade.
- Physics study limited by the Statistics (luminosity), collision energy up to 4.9 (5.6) GeV ……
- Many of the physics can be covered by ISR at Belle II
- BEPCII/BESIII will end her mission in 5 - 8(?) years

A Super Tau-Charm Facility (STCF) is the nature extension and a viable option for a post-BEPCII HEP project in China

Super τ-Charm Facility



- E_{cm}=2-7GeV, peaking Luminosity =5×10^{34} cm^{-2} s^{-1} @ 4GeV
- Potential for upgrade to increase L and realize polarized beam



- 14^{th} 5-year plan (2021-2025): Key technology R&D, 0.42 B CNY.
- 15^{th} 5-year plan (2026-2030): Construction, 6 years, 4.5 B CNY.
- Operating for 10 years, upgrade for 3 years, operating for another 7 years.

High Statistical Data : > 1 ab^{-1}/year

Table 1: The expected numbers of events per year at different STCF energy points.

CME (GeV)	Lumi (ab^{-1})		nb)	No. of Events	remark
3.097	1		00	3.4×10^{12}	
3.670	1		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		6	3.6×10^{9}	
			8	2.8×10^{9}	
				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}	$CP_{D^0\bar{D}^0} = +$
			4.0	2.6×10^{9}	$CP_{D^0\bar{D}^0} = -$
			0.20	2.0×10^{8}	
			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			

J/ψ 10^{12}

D pair 10^9

$\tau^+\tau^-$ 10^9

Millions to billions of Hyperons, light hadrons from J/ψ decays and XYZ's

Hyperon factory (10^{8-9})

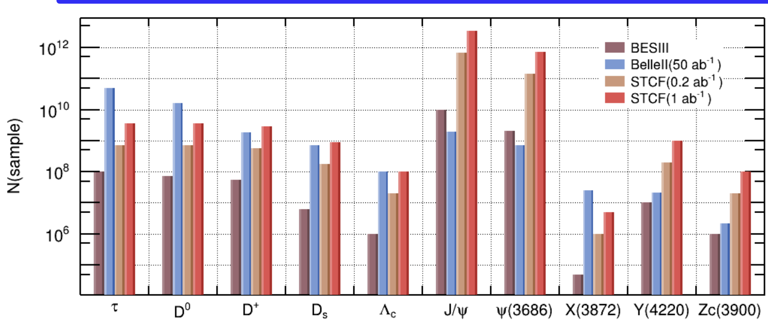
Decay mode	$\mathcal{B}$(units 10^{-4})	Angular distribution parameter α_ψ	Detection efficiency	No. events expected at STCF
$J/\psi \to \Lambda\bar{\Lambda}$	$19.43 \pm 0.03 \pm 0.33$	0.469 ± 0.026	40%	1100×10^6
$\psi(2S) \to \Lambda\bar{\Lambda}$	$3.97 \pm 0.02 \pm 0.12$	0.824 ± 0.074	40%	130×10^6
$J/\psi \to \Xi^0\bar{\Xi}^0$	11.65 ± 0.04	0.66 ± 0.03	14%	230×10^6
$\psi(2S) \to \Xi^0\bar{\Xi}^0$	2.73 ± 0.03	0.65 ± 0.09	14%	32×10^6
$J/\psi \to \Xi^-\bar{\Xi}^+$	10.40 ± 0.06	0.58 ± 0.04	19%	270×10^6
$\psi(2S) \to \Xi^-\bar{\Xi}^+$	2.78 ± 0.05	0.91 ± 0.13	19%	42×10^6

Light hadron (η/η') factory(10^{9-10})

Decay Mode	$\mathcal{B}$ ($\times 10^{-4}$) [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}

XYZ factory (10^{6-10})

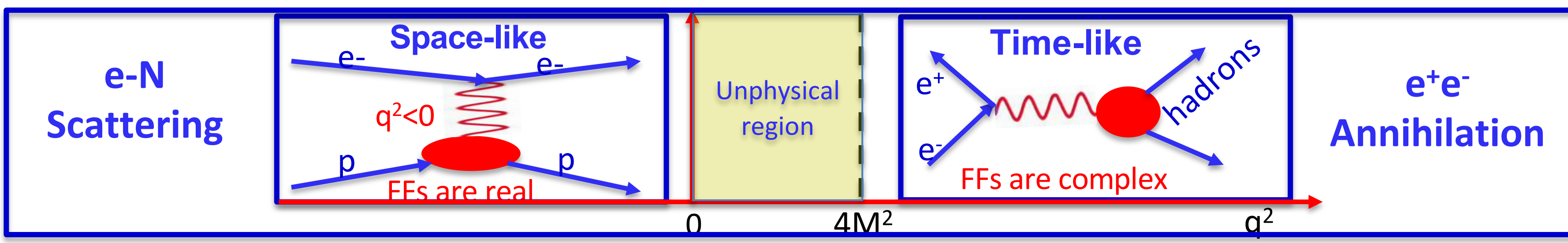
XYZ	Y(4260)	Z_c(3900)	Z_c(4020)	X(3872)
No. of events	10^{10}	10^{9}	10^{9}	5×10^{6}

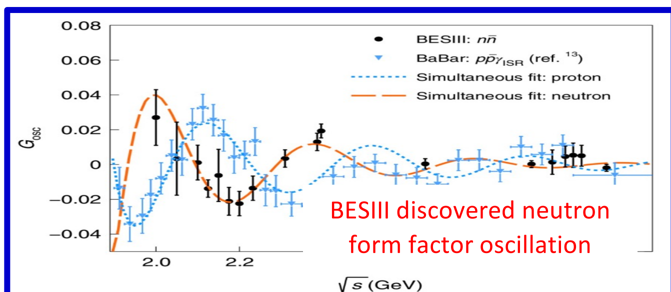


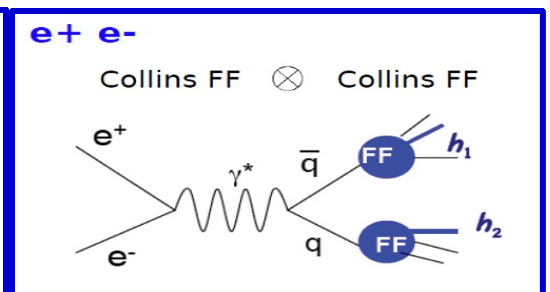
- **QCD and Hadron Physics**
- **Flavor Physics and CPV**
- **Search for New Physics Beyond SM**

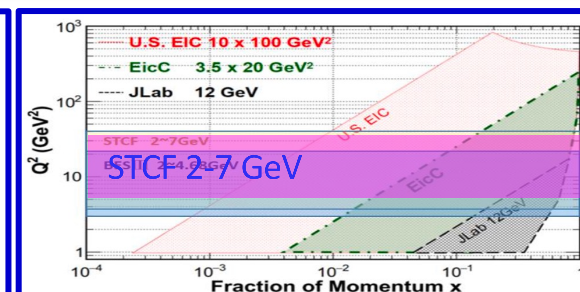
Hadron Production and Hadron Structure

- **Hadron production:**
  - ✓ from 0.6 to 7 GeV exclusively and inclusively (+ making use of ISR)
- **Nucleon electromagnetic form factors:**
  - ✓ fundamental observables reflect the inner structure of nucleon
  - ✓ complementary to e-N elastic scattering experiments in similar q^2 region.
- **Fragmentation function (FF):**
  - ✓ understanding QCD dynamics, hadron structure and production mechanism
  - ✓ new data from e^+e^- to compare with ep data and to verify its universality

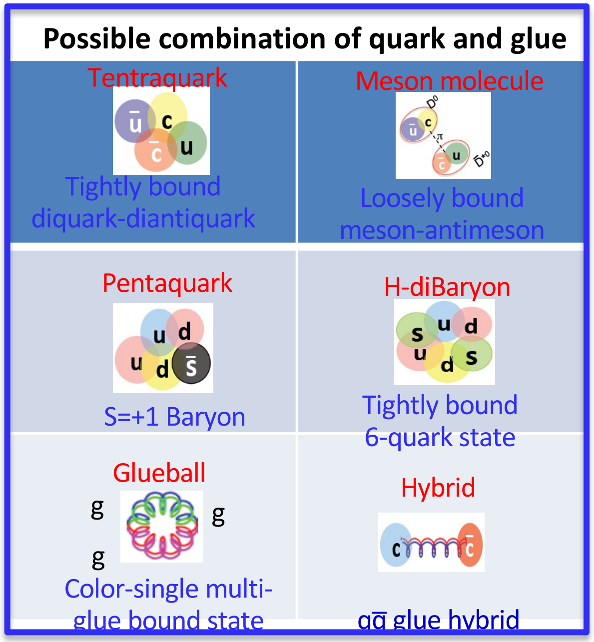


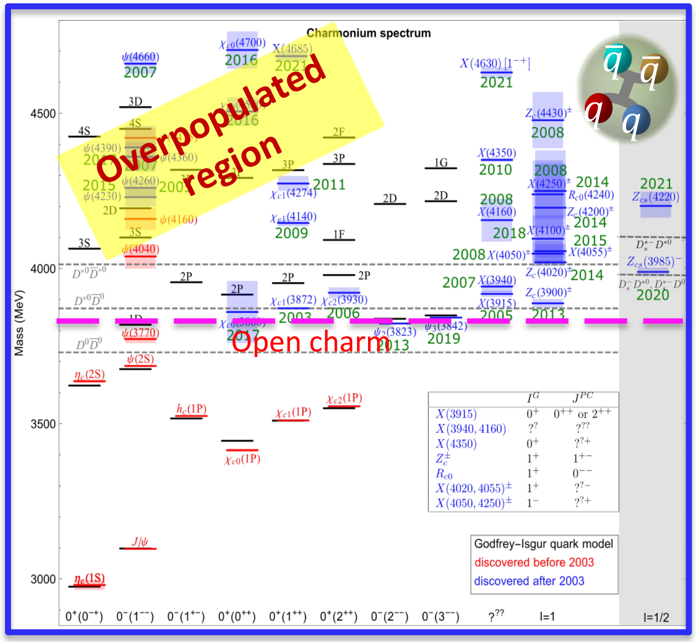


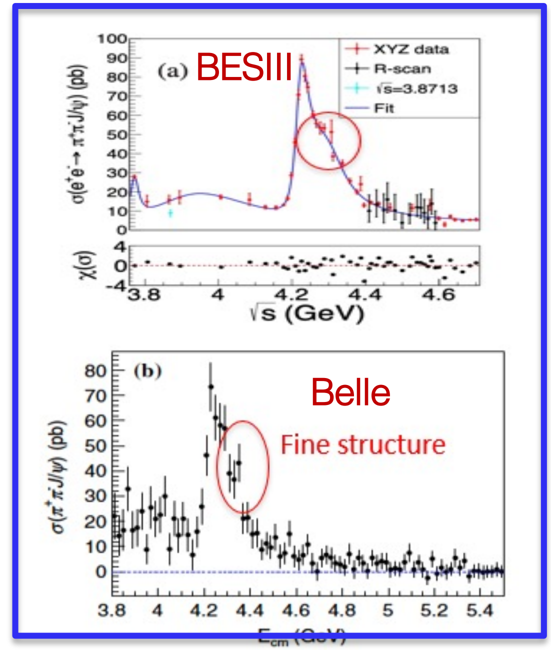




Hadron Spectroscopy and Exotic Hadrons







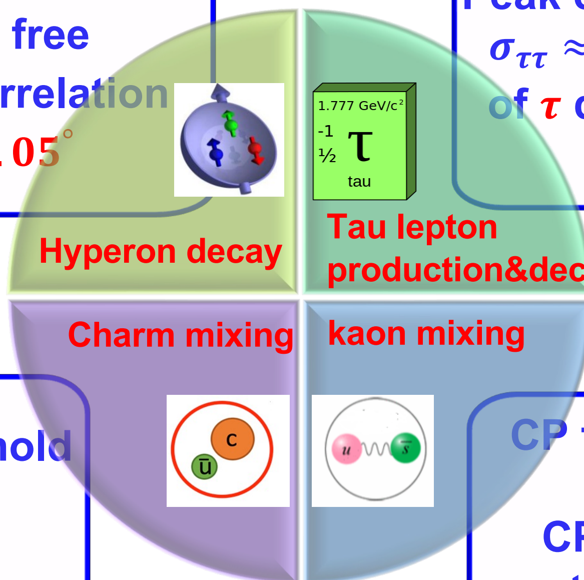
- Hadron **spectroscopy** is a crucial way to explore the QCD and its properties.
- QCD allows combinations of **multi-quarks and gluons**.
- Spectrum above open charm is much **overpopulated** → many exotic states?
- STCF has unique **advantages** for searching exotic hadrons (large effective luminosity, efficiency)

Flavor Physics and CP Violation

- **Large statistical** data samples from STCF offer the great opportunity to study **CP violation** in the Hyperon, Tau lepton, Charmed meson and Kaon
- **Polarized beam** is expected to improve the prob sensitivity.

Hyperon pairs from J/ψ decay,
clean topology, background free
Transversely polarized, spin correlation
Sensitivity: $A_{CP}\sim10^{-4}$, $\xi\sim0.05^{\circ}$

Peak cross section in $\sqrt{s}$ =4-5 GeV,
$\sigma_{\tau\tau}\approx3.5$ nb, 10 ab^{-1} data in total
of τ decay with 1ab^{-1} @ 4.26 GeV
Sensitivity $\sim10^{-3}$

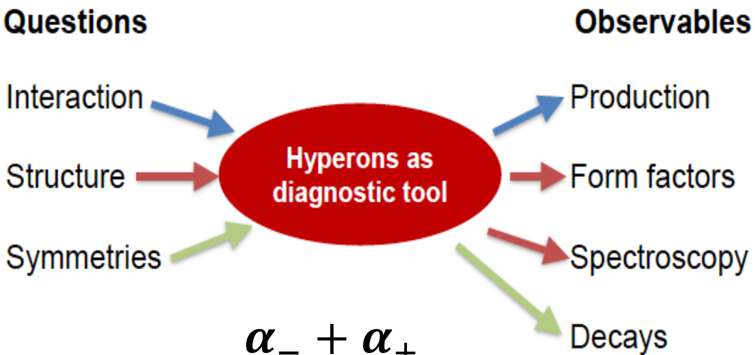


$D^0\bar{D}^0$ pairs produced at threshold
quantum coherence with
$(D^0\bar{D}^0)_{CP=-}$ or $(D^0\bar{D}^0)_{CP=+}$
Sensitivity: $x\sim0.035\%$,
$y\sim0.023\%$, $r_{CP}\sim0.017$, $\alpha_{CP}\sim1.3^{\circ}$

CP tagging and flavor tagging of
$K^0/\bar{K}^0$ from J/ψ decay
CP variables determined with
time-dependent decay rate
CP, CPT sensitivity:
$\eta_{\pm}\sim10^{-3}$, $\Delta\phi_{\pm}\sim0.05^{\circ}$

Hyperon diagnostic tool

The transversely polarized Λ in J/ψ decay offers an unique platform to study the nature of pQCD and test the EW model



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

Hyperon factory ($10^{8\text{-}9}$) **10^{12} J/ψ**

Decay mode	$\mathcal{B}$(units 10^{-4})	Angular distribution parameter α_ψ	Detection efficiency	No. events expected at STCF
$J/\psi \to \Lambda\bar{\Lambda}$	$19.43 \pm 0.03 \pm 0.33$	0.469 ± 0.026	40%	1100×10^6
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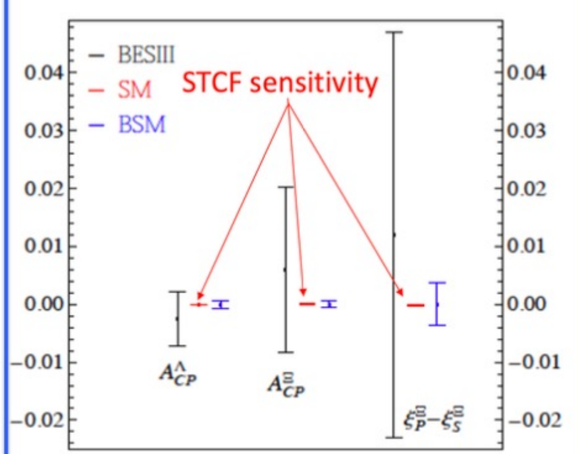
X.G. He et al. Sci.Bull. 67 (2022) 1840-1843:

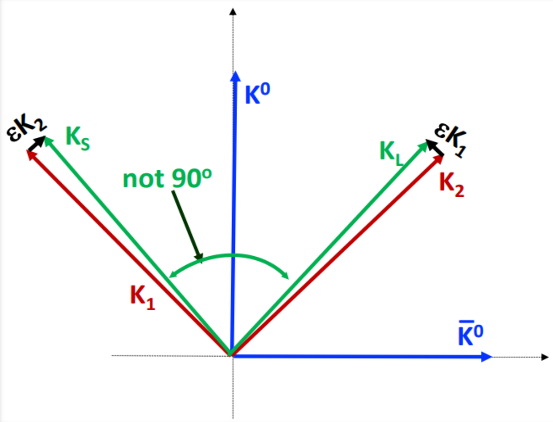


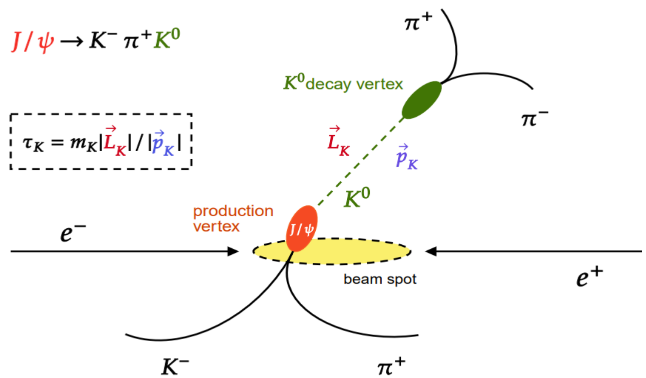
- **With one year data, STCF can reach CPV sensitivity of Λ to 1.2×10^{-4}, same level as SM prediction (10^{-4}~10^{-5}).**
- **Optimizing the reconstruction efficiency of low-momentum pion can greatly improve sensitivity.**
- **Using polarized beams, or "monochromatic" collision modes, can improve sensitivity to 10^{-5}.**
- **Systematic uncertainty is a challenge.**

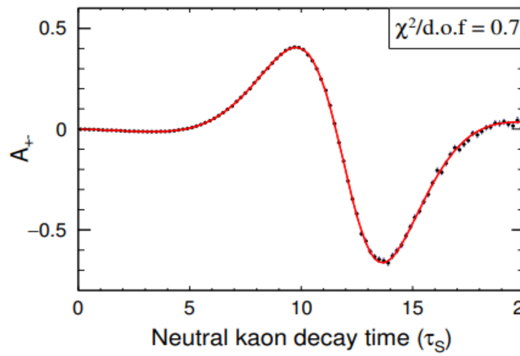
Testing CPT with Neutral Kaons

CPV parameters $|\eta_{+-}|$, ϕ_{+-} can be determined from time-dependent decay rates of K^0 and $\bar{K}^0$ to $\pi^+\pi^-$

$$A_{CP}^{+-}(\tau) = \frac{\bar{R}_f(\tau) - R_f(\tau)}{\bar{R}_f(\tau) + R_f(\tau)} \propto \frac{|\eta_{+-}| e^{\frac{1}{2}\Delta\Gamma\tau} \cos(\Delta m\tau - \phi_{+-})}{1 + |\eta_{+-}|^2 e^{\Delta\Gamma\tau}}$$







$K^0 - \bar{K}^0$ studies at STCF:

- $K^0 - \bar{K}^0$ flavor tagging via $J/\psi \to K^0 K^- \pi^+ / \bar{K}^0 K^+ \pi^-$
- $K_1 - K_2$ CP tagging by reconstructing $\pi^+\pi^-$ or $\pi^+\pi^-\pi^0$
- Precise determination of K^0 decay vertex ⇒ essential for time-distribution

- $|\eta_{+-}|$ reveals direct CPV in kaon meson
- ϕ_{+-} used to set limits on CPT violation.
- With >10^{10} $K^0/\bar{K}^0$ events from J/ψ decay,
- the sensitivity of $|\eta_{+-}|$, ϕ_{+-} are $\mathcal{O}(10^{-3})$

  ⇒ one magnitude better than PDG average.

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

STCF is an **unique** platform 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

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

- 4×10^9 pairs of $D^{\pm,0}$ and 10^8 D_s pairs per year
- $\Delta A_{CP} \sim 10^{-3}$ for KK and $\pi\pi$ channels with 1 ab^{-1} data at 3.773 GeV
- Mixing rate $R_M = \frac{x^2+y^2}{2} \sim 10^{-5}$ with 1 ab^{-1} data at 3.773 GeV via same charged final states $(K^\pm\pi^\mp)(K^\pm\pi^\mp)$ or $(K^\pm l^\mp v)(K^\pm l^\mp v)$
- Mixing and CPV parameters can be performed with data at 4009 MeV via coherent (C-even and C-odd) and incoherent process

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

STCF is of comparable sensitivities with 1 ab^{-1} data with Belle II and LHCb

	1/ab @4009 MEV (only QC | QC+incoherent) (preliminary estimation)		BELLEII(50/ab) [PTEP2019, 123C01]	LHCb(50/fb) (SL | Prompt) [arXiv:1808.08865]	
$x(\%)$	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

- The only QC : contains $D^0 \to K_S\pi\pi,\ K^-\pi^+\pi^0$ and general CP tag decay channels
- The QC + incoherent : combines coherent and incoherent D^0 meson samples
- The BELLE II and LHCb results only contain incoherent $D^0 \to K_S\pi\pi$ channel

D^0 strong phase difference in γ/ϕ_3 angle

B→DK decays with interference is the cleanest way and promising process to measure γ/ϕ_3 angle, and the strong phase difference of $D^0\bar{D}^0$ is needed

Runs	Collected / Expected integrated luminosity	Year attained	γ/ϕ_3 sensitivity
LHCb Run-1 [7, 8 TeV]	3 fb^{-1}	2012	8°
LHCb Run-2 [13 TeV]	5 fb^{-1}	2018	4°
Belle II Run	50 ab^{-1}	2025	1.5°
LHCb upgrade I [14 TeV]	50 fb^{-1}	2030	< 1°
LHCb upgrade II [14 TeV]	300 fb^{-1}	(>)2035	< 0.4°

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

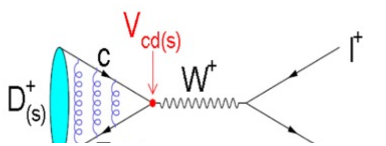
BESIII 20 fb^{-1}: σ(γ) ~0.4°

STCF is needed!

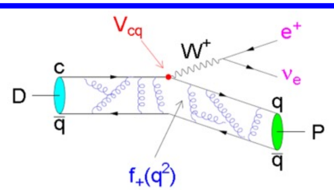
- **Gronau, London, Wyler (GLW): Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \to K_s\pi^0$, $D^0 \to \pi^+\pi^-$**
- **Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+\pi^-$**
  - **With 1 ab^{-1} @ STCF : $\sigma(\cos\delta_{K\pi})$ ~0.007; $\sigma(\delta_{K\pi})$ ~2° → σ(γ) <0.5°**
- **Giri, Grossman, Soffer, Zupan (GGSZ): Use Dalitz plot analysis of 3-body D^0 decays, e.g. $K_s\pi^+\pi^-$;**
  - **STCF reduces the contribution of *D* Dalitz model to a level of ~0.1°, and allow detailed comparisons of the results from different decay modes.**

CKM elements measurement

CKM elements are the fundamental SM parameters that describe the mixing of quark fields due to weak interaction. Charmed meson leptonic decays are the best way to measure $|V_{cd}|$ and $|V_{cs}|$



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



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

	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%$_{\rm stat}$ 1.6%$_{\rm syst}$ [8]	0.28%$_{\rm stat}$	–
f_{D^+} (MeV)	2.6%$_{\rm stat}$ 0.9%$_{\rm syst}$ [8]	0.15%$_{\rm stat}$	–
$\lvert V_{cd}\rvert$	2.6%$_{\rm stat}$ 1.0%$^*_{\rm syst}$ [8]	0.15%$_{\rm stat}$	–
$\mathcal{B}(D^+ \to \tau^+\nu_\tau)$	20%$_{\rm stat}$ 10%$_{\rm syst}$ [9]	0.41%$_{\rm stat}$	–
$\frac{\mathcal{B}(D^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D^+ \to \mu^+\nu_\mu)}$	21%$_{\rm stat}$ 13%$_{\rm syst}$ [9]	0.50%$_{\rm stat}$	–
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%$_{\rm stat}$ 2.7%$_{\rm syst}$ [10]	0.30%$_{\rm stat}$	0.8%$_{\rm stat}$ 1.8%$_{\rm syst}$
$f_{D_s^+}$ (MeV)	1.5%$_{\rm stat}$ 1.6%$_{\rm syst}$ [10]	0.15%$_{\rm stat}$	–
$\lvert V_{cs}\rvert$	1.5%$_{\rm stat}$ 1.6%$_{\rm syst}$ [10]	0.15%$_{\rm stat}$	–
$f_{D_s^+}/f_{D^+}$	3.0%$_{\rm stat}$ 1.5%$_{\rm syst}$ [10]	0.21%$_{\rm stat}$	–
$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	2.2%$_{\rm stat}$ 2.6%$^\dagger_{\rm syst}$	0.24%$_{\rm stat}$	0.6%$_{\rm stat}$ 2.7%$_{\rm syst}$
$f_{D_s^+}$ (MeV)	1.1%$_{\rm stat}$ 1.5%$^\dagger_{\rm syst}$	0.11%$_{\rm stat}$	–
$\lvert V_{cs}\rvert$	1.1%$_{\rm stat}$ 1.5%$^\dagger_{\rm syst}$	0.11%$_{\rm stat}$	–
$f^{\mu\&\tau}_{D_s^+}$ (MeV)	0.9%$_{\rm stat}$ 1.0%$^\dagger_{\rm syst}$	0.09%$_{\rm stat}$	0.3%$_{\rm stat}$ 1.0%$_{\rm syst}$
$\lvert V^{\mu\&\tau}_{cs}\rvert$	0.9%$_{\rm stat}$ 1.0%$_{\rm syst}$†	0.09%$_{\rm stat}$	–
$\frac{\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)}$	3.6%$_{\rm stat}$ 3.0%$^\dagger_{\rm syst}$	0.38%$_{\rm stat}$	0.9%$_{\rm stat}$ 3.2%$_{\rm syst}$

Theory : 0.2%(0.1% expected)

Theory : 0.2%(0.1% expected)

Theory : 0.2%(0.1% expected)

Stat. uncertainty is close to theory precision, Sys. is challenging

Lepton Flavor Universality

LFU is critical to test the SM and search for new physics beyond

Purely Leptonic:

$$R_{D^+_{(s)}} = \frac{\Gamma(D^+_{(s)} \to \tau^+\nu_\tau)}{\Gamma(D^+_{(s)} \to \mu^+\nu_\mu)} = \frac{m^2_{\tau^+}\left(1-\frac{m^2_{\tau^+}}{m^2_{D^+_{(s)}}}\right)^2}{m^2_{\mu^+}\left(1-\frac{m^2_{\mu^+}}{m^2_{D^+_{(s)}}}\right)^2}.$$

Semi-Leptonic:

$$R_{\mu/e} = \frac{\Gamma_{D\to h\mu\nu_\mu}}{\Gamma_{D\to he\nu_e}}$$

	$R(D_s^+)$	$R(D^+)$	$R(K^-)$	$R(\bar{K}^0)$	$R(\pi^-)$	$R(\pi^0)$
SM	9.74(1)	2.66(1)	0.975(1)	0.975(1)	0.985(2)	0.985(2)
BESIII	10.19(52)	3.21(64)	0.974(14)	1.013(29)	0.922(37)	0.964(45)

BESIII 1σ difference

BESIII ~2σ difference

- **Large uncertainty from BESIII, dominant by statistically limited**
- **STCF would improve them significantly**

Comparison of Facilities for Charm Studies

- **LHCb :** huge x-sec, boost, 9 fb^{-1} now (300 fb^{-1} Run III)
- **Belle-II** : more kinematic constrains, clean environment, ~100% trigger efficiency
- **STCF** : Low backgrounds and high efficiency, Quantum correlations and CP-tagging are unique

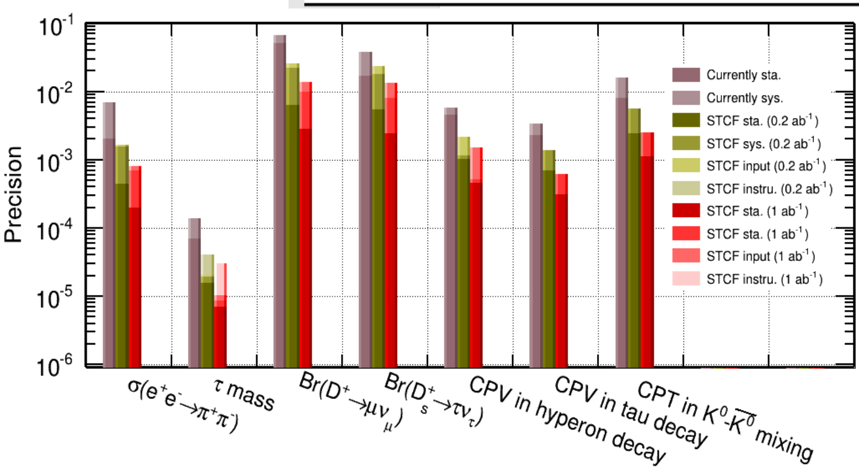
	STCF	Belle II	LHCb
Production yields	★★	★★★★	★★★★★
Background level	★★★★★	★★★	★★
Systematic error	★★★★★	★★★	★★
Completeness	★★★★★	★★★	★
(Semi)-Leptonic mode	★★★★★	★★★☆☆	★★☆
Neutron/K_L mode	★★★★★	★★★☆	☆
Photon-involved	★★★★★	★★★★	★☆☆
Absolute measurement	★★★★★	★★★☆	☆☆

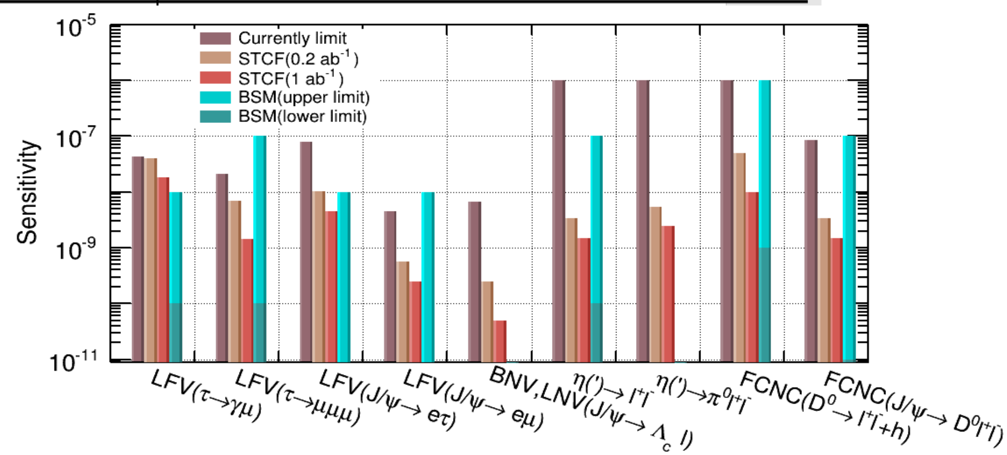
- Most are **precision** measurements, which are mostly dominant by the **systematic** uncertainty
- STCF has **advantages** in several studies

Benchmark processes simulation

$\mathcal{L} = 1\ \mathrm{ab}^{-1}$

Physics at STCF	Benchmark Processes	Key Parameters*	Physics at STCF	Benchmark Processes	Key Parameters*
XYZ properties	$e^+e^- \to Y \to \gamma X, \eta X, \phi X$ $e^+e^- \to Y \to \pi Z_c, KZ_{cs}$	$N_{Y(4260)/Z_c/X(3872)}$~ $10^{10}/10^9/10^6$	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%
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)	γ/ϕ_3 measurement	$D^0 \to K_s\pi^+\pi^-, K_sK^+K^-$ ...	$\Delta(\cos\delta_{K\pi})$ ~0.007; $\Delta(\delta_{K\pi})$ ~2°
Hadron Spectroscopy	Excited $c\bar{c}$ and their transition, Charmed hadron, Light hadron	$N_{J/\psi/\psi(3686)/\Lambda_c}$~ $10^{12}/10^{11}/10^8$	$D^0-\bar{D}^0$ 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%
Muon g-2	$\pi^+\pi^-, \pi^+\pi^-\pi^0, K^+K^-$ $\gamma\gamma \to \pi^0, \eta^{(\prime)}, \pi^+\pi^-$	$\Delta a_\mu^{HVP} \ll 40 \times 10^{-11}$	Charm hadron decay	$D_{(s)}, \Lambda_c^+, \Sigma_c, \Xi_c, \Omega_c$ decay	$N_{D/D_s/\Lambda_c}$~$10^9/10^8/10^8$
R value, τ mass	$e^+e^- \to inclusive$ $e^+e^- \to \tau^+\tau^-$	Δm_τ~0.012 MeV (with 1 month scan)	γ polarization	$D^0 \to K_1 e^+\nu_e$	$\Delta A'_{UD}$~0.015
Fragmentation functions	$e^+e^- \to (\pi, K, p, \Lambda, D) + X$ $e^+e^- \to (\pi\pi, KK, \pi K) + X$	$\Delta A^{\mathrm{Collins}} < 0.002$	CPV in Hyperons	$J/\psi \to \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi^-\bar{\Xi}^-, \Xi^0\bar{\Xi}^0$	ΔA_Λ~10^{-4}
Nucleon Form Factors	$e^+e^- \to B\bar{B}$ from threshold	δR_{EM}~1%	CPV in τ	$\tau \to K_s\pi\nu$, EDM of τ,	$\Delta A_{\tau\to K_s\pi\nu}$~$10^{-3}$; Δd_τ~5×10^{-19} (e cm)
FLV decays	$\tau \to \gamma l, lll, lP_1P_2$ $J/\psi \to ll', D^0 \to ll'(l' \neq l)$...	$\mathcal{B}(\tau \to \gamma\mu/\mu\mu\mu)$<12/1.5× 10^{-9}; $\mathcal{B}(J/\psi \to e\tau)$<0.71× 10^{-9}	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}
LNV, BNV	$D^+_{(s)} \to l^+l^+X^-, J/\psi \to \Lambda_c e^-$, $B \to \bar{B}$...	$\mathcal{B}(J/\psi \to \Lambda_c e^-)$< 10^{-11}	FCNC	$D \to \gamma V, D^0 \to l^+l^-, e^+e^- \to D^*$, $\Sigma^+ \to pl^+l^-$...	$\mathcal{B}(D^0 \to e^+e^-X)$< 10^{-8}
Symmetry violation	$\eta^{(\prime)} \to ll\pi^0, \eta' \to \eta ll$...	$\mathcal{B}(\eta' \to ll/\pi^0 ll)$< $1.5/2.4 \times 10^{-10}$	Dark photon, millicharged	$e^+e^- \to (J/\psi) \to \gamma A'(\to l^+l^-)$... $e^+e^- \to \chi\bar{\chi}\gamma$ ...	Mixing strength $\Delta\epsilon_{A'}$~10^{-4}; $\Delta\epsilon_\chi$~10^{-4}





Status of Project Promotion

2011

Proposed at "Workshop for acc. based high energy physics development strategy"

Super Charm-tau Factory

Zhengguo Zhao

On behalf of ???

2015

香山科学会议简报

Fragrant Hills Science Forum

11 academicians

Demonstrated importance and necessity of STCF, Urging to lauch fesibility study and R&D as soon as possible

2017

中共安徽省委文件

Notice of the People's Government of Anhui Province and the CAS on the Implementation Plan of Hefei Comprehensive National Science and Technology Center

STCF was listed as large scientific facility that about to promote. Proposed to start fesibility study, and R&D.

2018

USTC Scientific Committee Meeting

Demonstrated the significance of STCF. USTC President ratify 20 M CYN to support feasibility study

2021

Conceptual Design Report (CDR)

STCF Conceptual Design Report Volume I - Physics

STCF Conceptual Design Report Volume II - Accelerators

STCF Conceptual Design Report Volume III - Detector

2022.4.24

Project review for R&D of key technologies organized by Anhui Province.

Endorsed 420 M CYN for R&D

2022.9.24

USTC formed project leadership team headered by USTC president

中国科学技术大学文件

Implement funds; Coordinate with CAS and National Development and Reform Commission to promote projects

Conceptual Design Report

arXiv > hep-ex > arXiv:2303.15790

Search...

Help | Advanced

High Energy Physics - Experiment

[Submitted on 28 Mar 2023]

STCF Conceptual Design Report: Volume 1 -- Physics & Detector

M. Achasov, X. C. Ai, R. Aliberti, Q. An, X. Z. Bai, Y. Bai, O. Bal
Bodrov, A. Bogomyagkov, A. Bondar, I. Boyko, Z. H. Bu, F. M.
Chang, K. T. Chao, D. Y. Chen, H. Chen, H. X. Chen, J. F. Che
Chen, S. Chen, S. P. Chen, W. Chen, X. F. Chen, X. Chen, Y. C
Cheng, J. P. Dai, L. Y. Dai, X. C. Dai, D. Dedovich, A. Denig, I.
Druzhinin, D. S. Du, Y. J. Du, Z. G. Du, L. M. Duan, D. Epifano
C. Q. Feng, X. Feng, Y. T. Feng, J. L. Fu, J. Gao, P. S. Ge, C. C
W. Gradl, J. L. Gu, A. G. Escalante, L. C. Gui, F. K. Guo, J. C.
L. Han, L. Han, M. Han, X. Q. Hao, J. B. He, S. Q. He, X. G. He
Hou, Y. R. Hou, C. Y. Hu, H. M. Hu, K. Hu, R. J. Hu, X. H. Hu, Y

The Super τ-Charm facility (STCF) is an electron-positron collider prop
is designed to operate in a center-of-mass energy range from 2 to 7 G
or higher. The STCF will produce a data sample about a factor of 100

Key Technology R&D project

新一代正负电子对撞机——超级陶粲装置关键技术攻关项目

新一代正负电子对撞机——超级陶粲装置

关键技术攻关项目

A new generation of e^+e^- collider —STCF Key Technolgy R&D

April of 2022

Identified 31 items for R&D

Year	Budget (M CYN)
2022	40
2023	190
2024	120
2025	62
Total	420

超级陶粲装置项目组编制 1

新一代正负电子对撞机——超级陶粲装置关键技术攻关项目

目 录

新一代正负电子对撞机——超级陶粲装置关键技术攻关项目

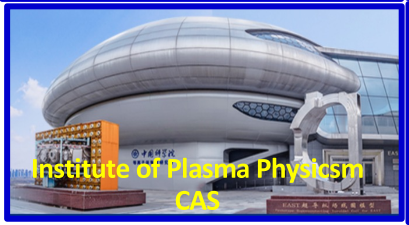
R&D project Review 2022.04.22

Total 120 pages
Chapter 1. Instroduction
Chapter 2. Background and necessity of STCF
Chapter 3. Physics opportunities and the key technologies
Chapter 4. Contents of the R&D
Chapter 5. Project management and implementation scheduling
Chapter 6. Project risks and countermeasures
Chapter 7. Conclusions
Chapter 8. Appendix

Major Laboratories and Institutions for the project

State Key Laboratory of Particle Detection and Electronics

National Synchrotron Radiation Laboratory



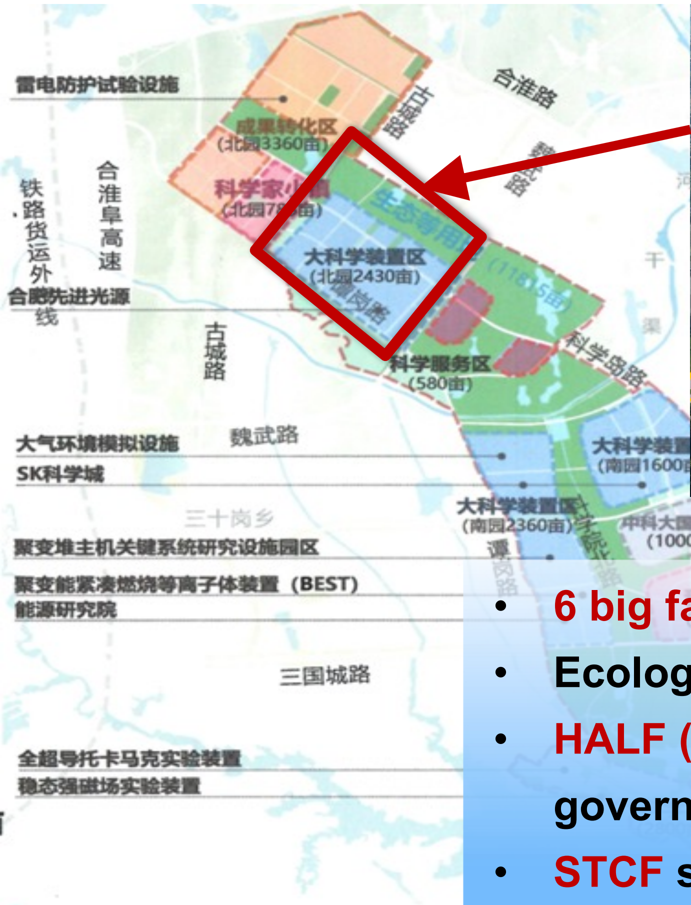
- Institute of High Energy Physics, Chinese Academy of Science (CAS)
- Hefei Institutes of Physical Science, CAS
- State Key Laboratory of Nuclear Physics and Technology, PKU
- Key Laboratory for Particle Astrophysics and Cosmology, Ministry of Education, SJTU
- Key Laboratory of Particle Physics and Particle Irradiation, Ministry of Education, SDU
- Key Laboratory of Particle Physics and Cosmology of Shanghai, SJTU
- Tsung-Dao Lee Institute, Shanghai

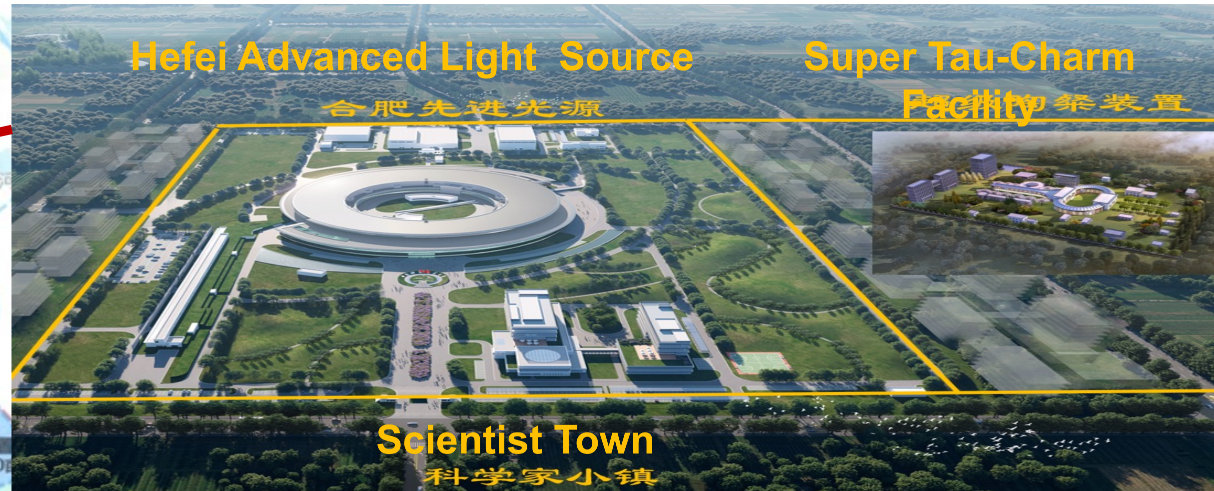
Platform for Organizations

1. Collaborative Innovation Center for Particles and Interactions
2. Particle Science and Technology Research Center of USTC

Construction Site: Hefei, Anhui

Heifei Science City: one of three **comprehensive national science** centers for **'Mega-science'** facilities in China

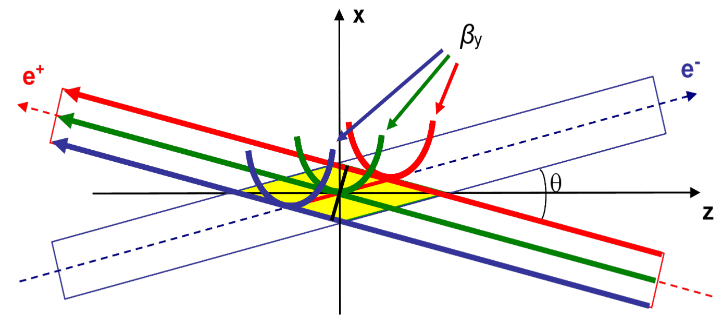


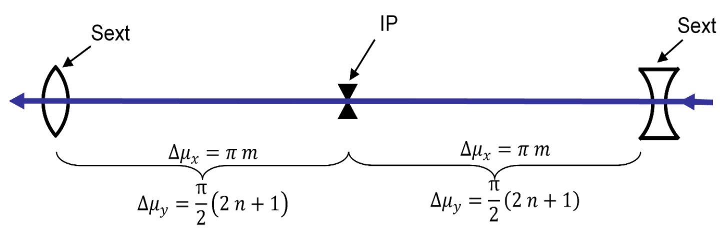


- **6 big facilities** for science and technologies (17155 acres).
- Ecological green space and modern agricultural (11815 acres)
- **HALF (4^{th} generation light source)** was **approved** by central government，and just began **construction**
- **STCF** site is **preliminarily decided** by local government in Apr. 2023, **geological exploration** and **engineering design** is ongoing

Challenges of Accelerator

Large Piwinski Angle + Crab Waist
(P. Raimondi 2006)



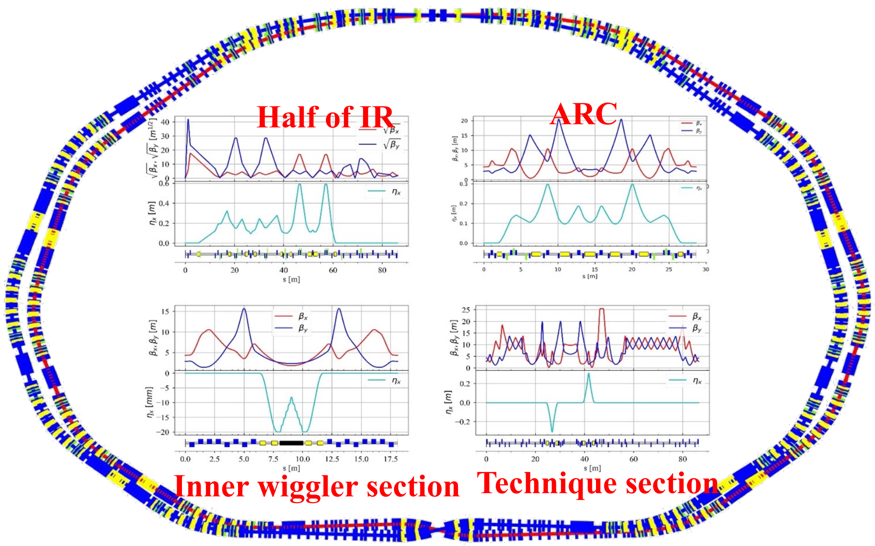


K. Hirata, PRL 74, 2228 (1995)

Test of "Crab-Waist" Collisions at the DAΦNE Φ Factory, PRL 2010

- **Accelerator physics**
  - **High current and small bunches at IP → Collective effects and Instability increased**
  - **Strong Focusing→Negative chromaticity → Chromatic correcting sextupoles + crab waist sextupoles → more non-linearity**
  - **Smaller dynamic aperture and energy aperture, also much shorter Touschek lifetime**
- **Key Technologies**
  - **high peak luminosity : Interaction Region Misc**
  - **high integrated luminosity : Beam instrumentations and so on**
  - **Beam sources and injection : high current and quality electron and positron source; on-axis injection may be necessary**

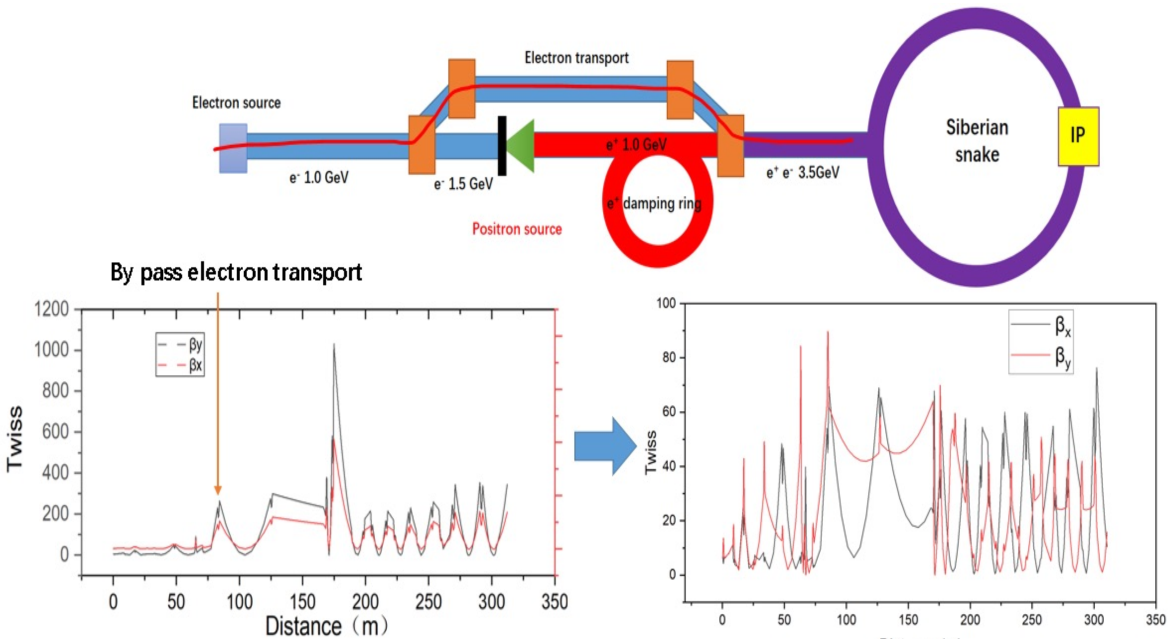
Status of Accelerator Design



- Beam-beam simulation, collective effective simulation are considered
- $\sigma_z = 8.04$ mm(w/o IBS), $\xi_x = 0.0040 \rightarrow \upsilon_z = 2.5\,\xi_x$
- $\sigma_z = 8.94$ mm(wi IBS), $\xi_x = 0.0032 \rightarrow \upsilon_z = 3.1\,\xi_x$
- w/o IBS: $\xi_y = 0.148,\ L = 1.98\times10^{35}\ cm^{-2}s^{-1}$
- w/ IBS: $\xi_y = 0.111,\ L = 1.45\times10^{35}\ cm^{-2}s^{-1}$
- Touschek Lifetime ~100s

Parameters	Units	STCF-v2	STCF-v3 (no wiggler)	STCF-v3 (wiggler)	STCF-v3 (wiggler+IBS)
Optimal beam energy, E	GeV	2	2	2	2
Circumference, C	m	617.06	616.76	616.76	616.76
Crossing angle, 2θ	mrad	60	60	60	60
Relative gamma		3913.9	3913.9	3913.9	3913.9
Revolution period, T_0	ms	2.058	2.057	2.057	2.057
Revolution frequency, f_0	kHz	485.84	486.08	486.08	486.08
Horizontal emittance, ε_x	nm	2.84	5.40	3.12	4.47
Coupling, k		0.50%	0.50%	0.50%	0.50%
Vertical emittance, ε_y	pm	14.2	27	15.6	22.35
Hor. beta function at IP, β_x	mm	90	40	40	40
Ver. beta function at IP, β_y	mm	0.6	0.6	0.6	0.6
Hor. beam size at IP, σ_x	mm	15.99	14.70	11.17	13.37
Ver. beam size at IP, σ_y	mm	0.092	0.127	0.097	0.116
Betatron tune, ν_x/ν_y		37.552/24.571	31.552/24.572	31.552/24.572	31.552/24.572
Momentum compaction factor, α_p	10^{-4}	5.26	10.29	10.27	10.27
Energy spread, σ_e	10^{-4}	5.6	5.17	7.88	8.77
Beam current, I	A	2	2	2	2
Number of bunches, n_b		512	512	512	512
Single-bunch current, I_b	mA	3.91	3.91	3.91	3.91
Particles per bunch, N_b	10^{10}	5.02	5.02	5.02	5.02
Single-bunch charge	nC	8.04	8.04	8.04	8.04
Energy loss per turn, U_0	keV	157.3	135.87	273	273
Hor. damping time, τ_x	ms	52.34	60.57	30.14	30.14
Ver. damping time, τ_y	ms	52.34	60.57	30.14	30.14
Long. damping time, τ_z	ms	26.17	30.28	15.07	15.07
RF frequency, f_{RF}	MHz	497.5	497.5	497.5	497.5
Harmonic number, h		1024	1024	1024	1024
RF voltage, V_{RF}	MV	3	1.2	1.2	1.2
Synchronous phase, f_s	deg	177	173	167	167
Synchrotron tune, ν_z		0.0113	0.0100	0.0099	0.0099
Natural bunch length, σ_z	mm	2.55	5.22	8.04	8.94
RF bucket height, $(\Delta E/E)_{max}$	%	4.04	1.73	1.56	1.56
Piwinski angle, ϕ_{Piw}	rad	4.78	10.66	21.58	20.06
Hor. beam-beam parameter, ξ_x		0.0884	0.0094	0.0040	0.0032
Ver. beam-beam parameter, ξ_y		0.489	0.173	0.148	0.111
Equivalent bunch length, σ_{z_e}	mm	0.53	0.49	0.37	0.45
Hour-glass factor, F_h		0.8801	0.8932	0.9287	0.9066
Luminosity, L	$cm^{-2}s^{-1}$	6.21E+35	2.23E+35	1.98E+35	1.45E+35

Status of Accelerator Design

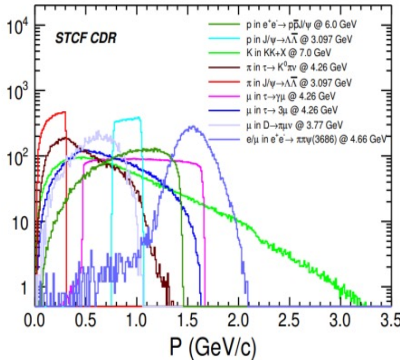


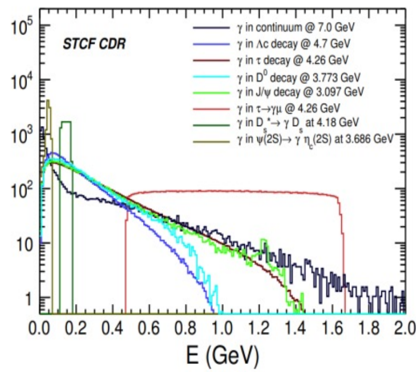
Parameter	Value
Energy	1.0 GeV
Perimeter	~58 mm
Repetition frequency	50 Hz
Bending radius	2.7 m
Dipole magnets， B_0	1.4 T
Momentum compression factor， α_c	0.076
U_0	35.8 keV
Damping time x/y/z	12/12/6 ms
δ_0	0.05%
ε_0	287.4 mm·mrad
Bunch length	7 mm
ε_{inj}	2500 mm·mrad
$\varepsilon_{ext\ x/y}$	704/471 mm·mrad
$\delta_{inj}/\delta_{ext}$	0.3/0.06
Divergence of energy	1%
f_{rf}	650 MHz
V_{rf}	1.8 MV

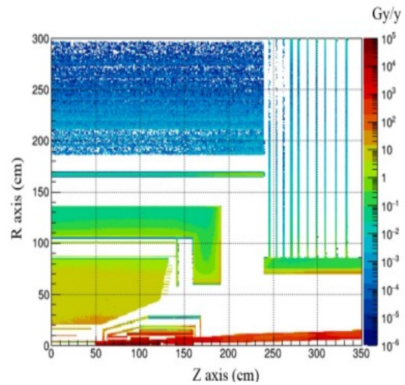
By optimizing the layout of the focusing units in the bypass drift section, the Twiss parameters have been successfully reduced to an acceptable range.

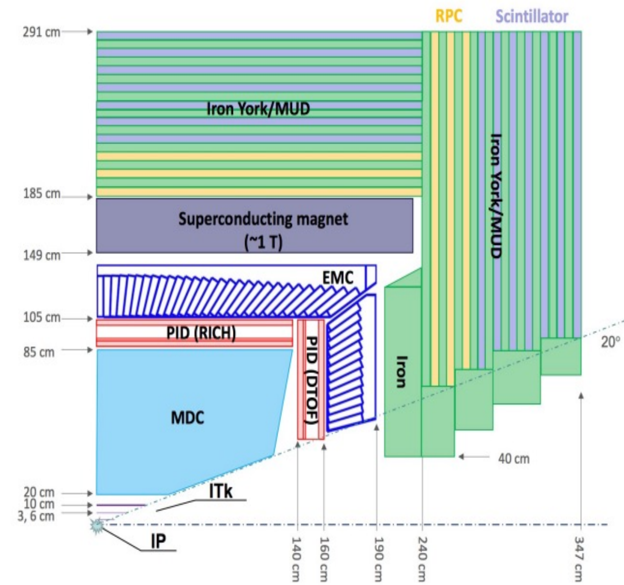
Challenges of Spectrometer

Highly efficient and precise reconstruction of exclusive final states under the extreme conditions of high event rate, dynamic range, and radiative hardness









ITK
- $<0.3\%X_0$/layer
- $\sigma_{xy}<100\mu m$

MDC
- $\sigma_{xy}<130\mu m$
- $\sigma_p/p\sim 0.5\%$ @ 1GeV
- dE/dx ~6%

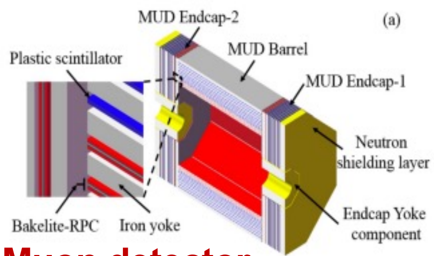
EMC
- E range : 0.025~3.5 GeV
- σ_E (%) @ 1GeV
  - Barrel 2.5
  - EndCap 4.0
- Pos. Res. : 5mm

PID
- π/K (K/p) 3~4σ Sepa. up to 2GeV/c

MUD
- 0.4~2.0 GeV
- π Suppression > 30

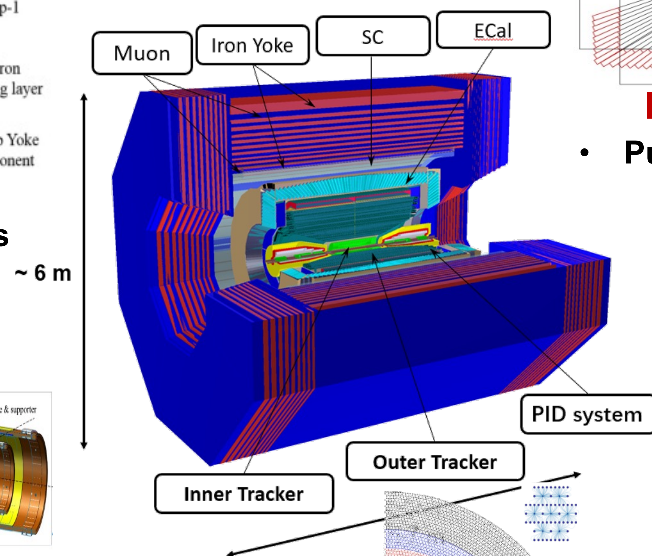
Others :
- Solid Angle Coverage : 94%·4π
- Radiative hardness at the most inner layer :~3.5kGy/y，~2×10^{11} 1MeV n-eq/cm^2/y, ~1 MHz/cm^2
- Event rate ： 400KHz @J/ψ

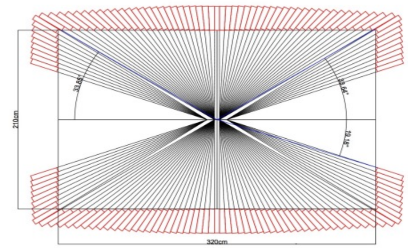
Detector options



Muon detector

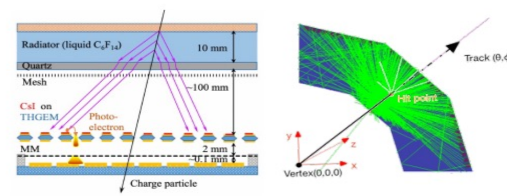
- Bakelite RPC + Scintillator strips





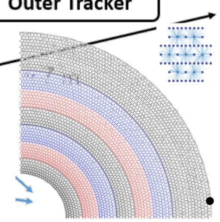
EM calorimeter

- Pure CsI crystal + APD



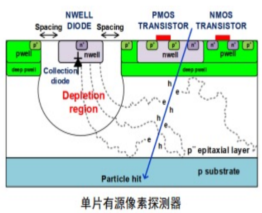
Particle Identification

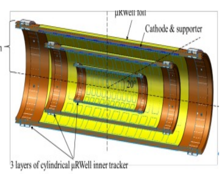
- Barrel : RICH
- EndCap : DIRC-Like TOF



Central Tracker

- Drift Chamber with extreme-low mass and small cell





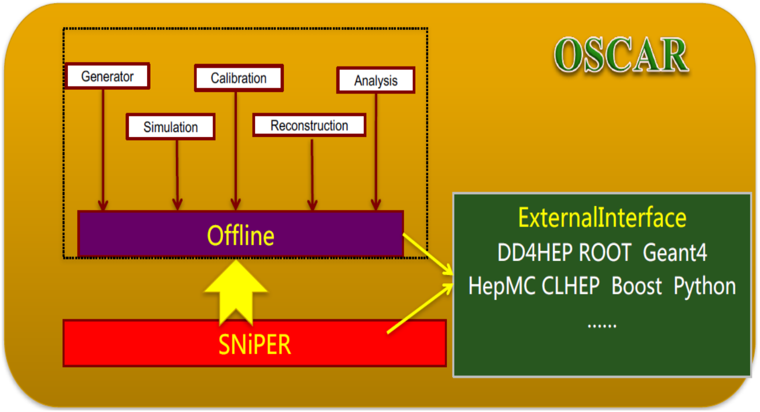
Inner Tracker

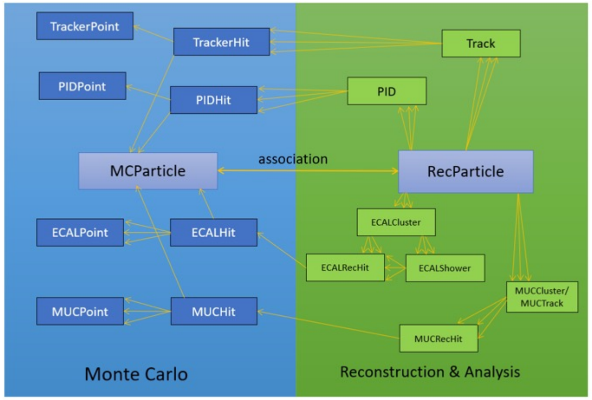
- MPGD: Cylindrical μRWELL
- Silicon : CMOS MAPS

The R&D of each sub-system are ongoing, include both detector and electronics

Offline Software

- Offline Software System of Super Tau-Charm Facility (OSCAR)
  - External Interface+ Framework +Offline
- SNiPER framework provides common functionalities for full data processing
- Offline including Generator, Simulation, Calibration, Reconstruction and Analysis





- Geometry management system, FullSim, FullRec, PodIO event data model are almost done
- Algorithm of reconstruction, calibration, analysis tool and performance test are under optimizations

Tentative Plan of STCF

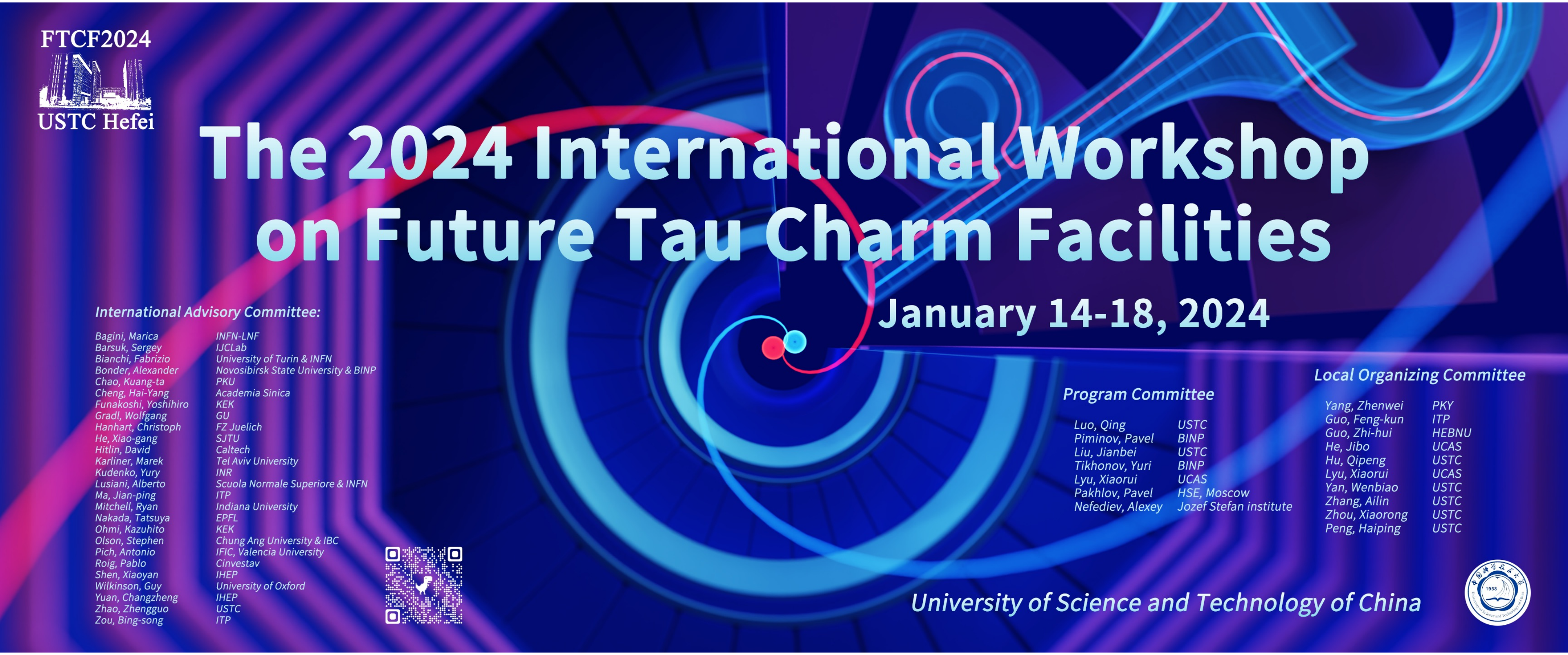
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032-2046	2046
Form collaboration																
Conception design CDR																
R&D (TDR)																
Construction																
Operation																

Summary

- **STCF is an unique facility in precision frontier**
  - ✓ Ecm = 2-7GeV, peaking $\mathcal{L} > 0.5\times10^{35}$ $cm^{-2}s^{-1}$, polarized beam (Phase II)
  - ✓ Symmetric, double ring with circumference around 600~1000 m
- **STCF has rich physics program, and has potential for breakthrough to the understanding of strong interaction, and to the new physics searches, but it also challenge in both accelerator and spectrometer**
- **During the past few years, we have finished STCF feasibility study and the conception design (CDR).**
- **Anhui province and USTC have officially endorsed the STCF project: the R&D for the key technologies is launched and great progresses have been achieved; the project site is preliminarily decided, and geological exploration and engineering design is ongoing**
- **Project construction will be applied during the 15th five-year plan (2026-2030y) from central government**

Thanks for your attention!
Welcome to join!

https://indico.pnp.ustc.edu.cn/event/91/



sincerely welcome your attendance!

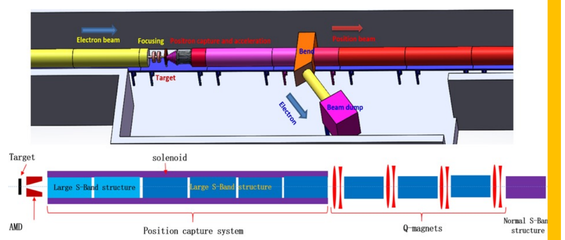
Backup Slides

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

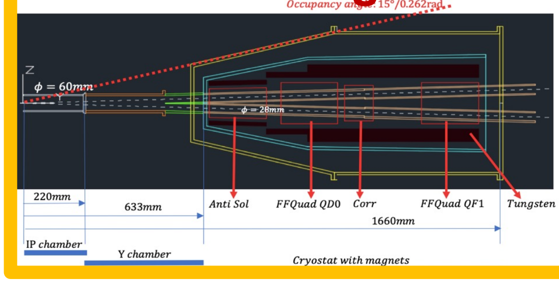
- **Three kinds of $D^0\overline{D}^0$ samples can be used @4009MeV**
  - **Quantum-incoherent flavor specific D^0 samples: $D^{*+} \to D^0\pi^+$**
    - Help to improve precision of strong-phase difference measurement
    - Be used to constrain the charm mixing and CPV parameters
  - **Quantum-coherent C-even $D^0\overline{D}^0$ samples: $D^{*0}\overline{D}^0 \to D^0\overline{D}^0\gamma$**
    - Be used to perform charm mixing and CPV parameters measurements
      - The interference effect, containing mixing and CPV, is doubled compare to incoherent case
    - Help to constrain the strong-phase difference and CP fraction measurements
  - **Quantum-coherent C-odd $D^0\overline{D}^0$ samples: $D^{*0}\overline{D}^0 \to D^0\overline{D}^0\pi^0$**
    - Same as $D^0\overline{D}^0$ samples @3770, improve precision of strong-phase difference measurements and CP fraction measurements

Status of Key Technology R&D

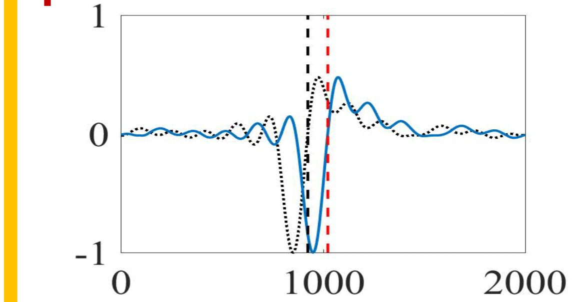
Positron Source Design

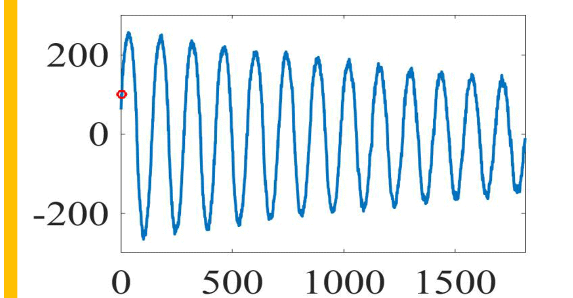


MDI Design



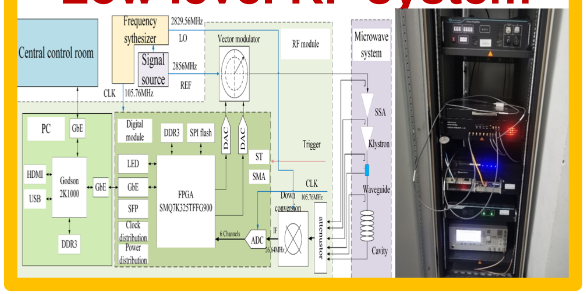
Bunch-by-Bunch 3D position measurement





Photocathode RF gun

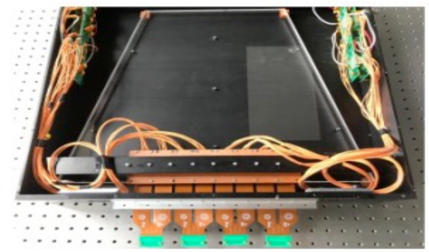
Low level RF system

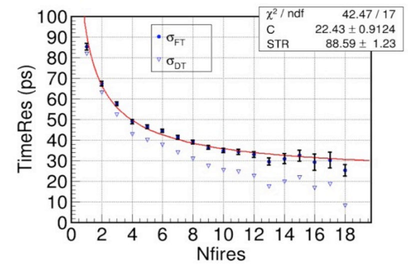


Status R&D (PID)

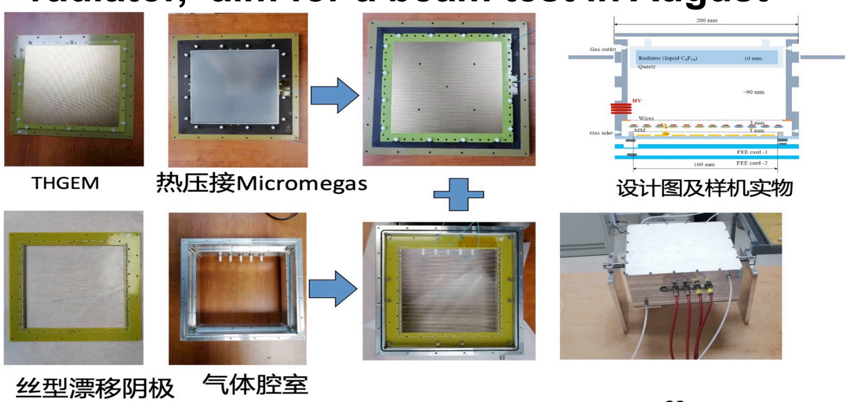
A RICH Prototype with quartz radiator,
A successful beam test (2019)

A small-sized DTOF prototype (2019),
with time resolution <30 ps by cosmic rays

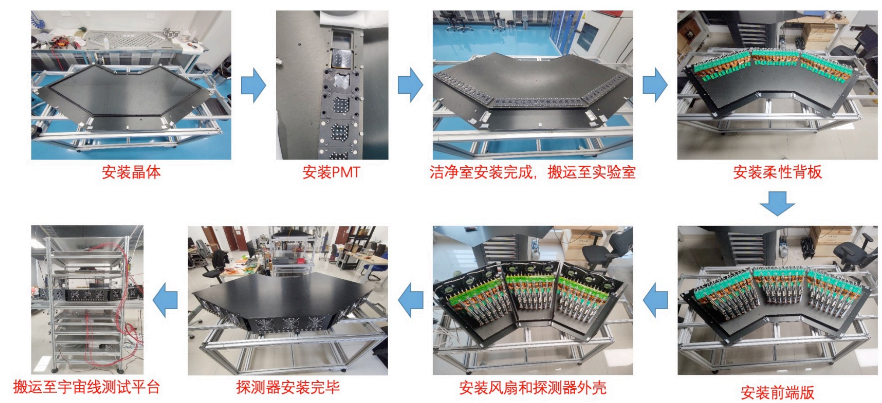




A RICH Prototype with liquid C6F14 (n~1.3)
radiator, aim for a beam test in August



A full-sized DTOF prototype,
with time resolution <28 ps by cosmic rays

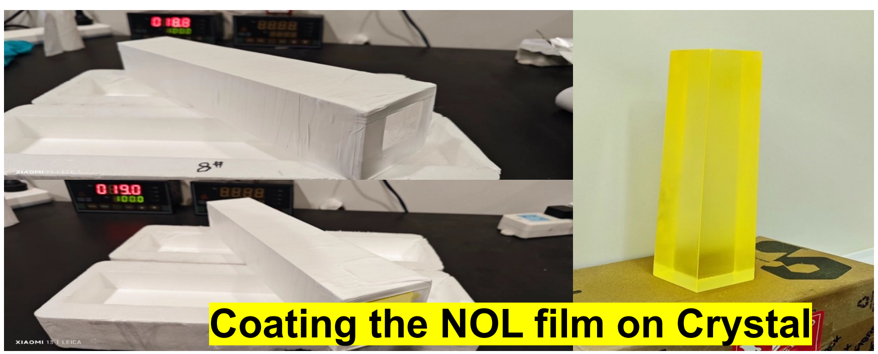


Status of R&D (EMC)

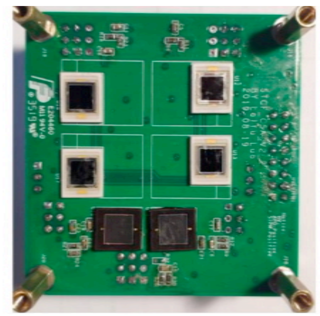
Increase light yields and reduce the pile up effects, time capability is expected

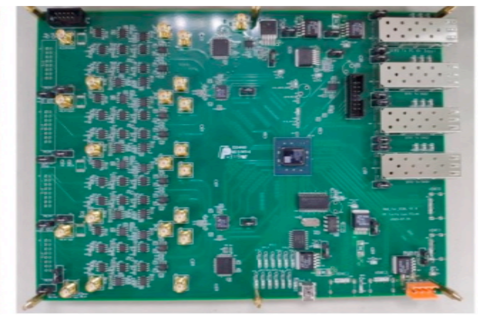
A **wavelength shifter in propagation** scheme to increase the **light yields** (3.5 times)

Coating the NOL film on Tyvek



A **waveform digitization electronics** (CSA + Shape + ADC) for the waveform and time resolution





A **waveform fitting** with multiple templates to effectively mitigate the **pileup** effect