The Progress of Super Tau-Charm Facility (STCF) in China

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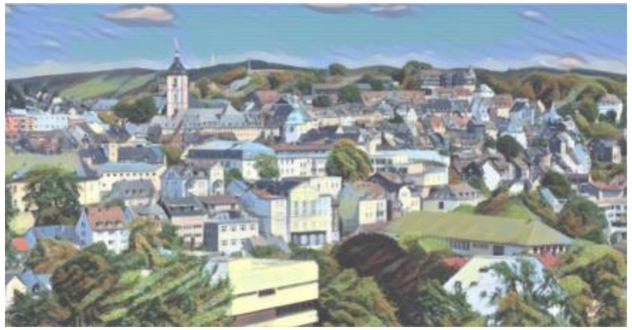
(on behalf of the STCF working group)

University of Chinese Academy of Sciences

The international CHARM 2023, Siegen, Germany from July 17 to July 21





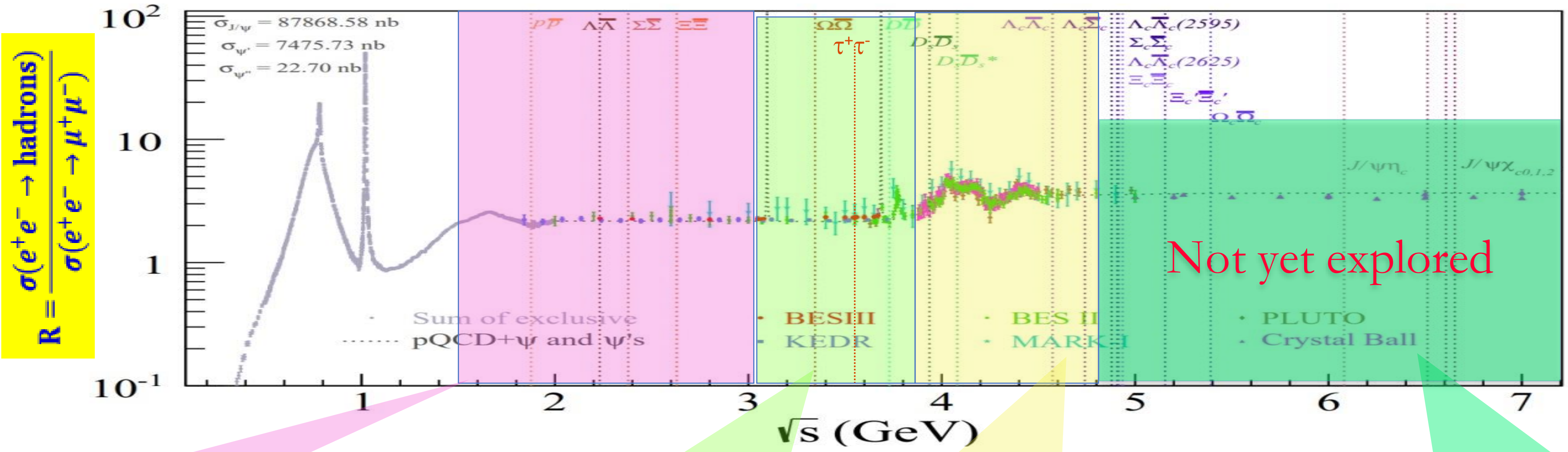


Outline

- Introduction to STCF project
- Physics programs & Simulation studies
  - QCD and Hadron Physics
  - Flavor Physics and CP Violation
  - Search for New Physics Beyond SM
- R&D Status of Key Technologies
- Status of Project Promotion in China
- Summary

Features and Physics Program @tau-charm Energy

- **Transition between smooth and resonance regions, perturbative and non-perturbative QCD**
- **Rich resonance structures, huge production X-sec. 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_{Ds}**
- **D_0-$\bar{D}_0$ mixing**
- **Charm baryons**

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

Features and Physics Program @tau-charm Energy

- **Transition** between smooth and resonance regions, perturbative and non-perturbative QCD
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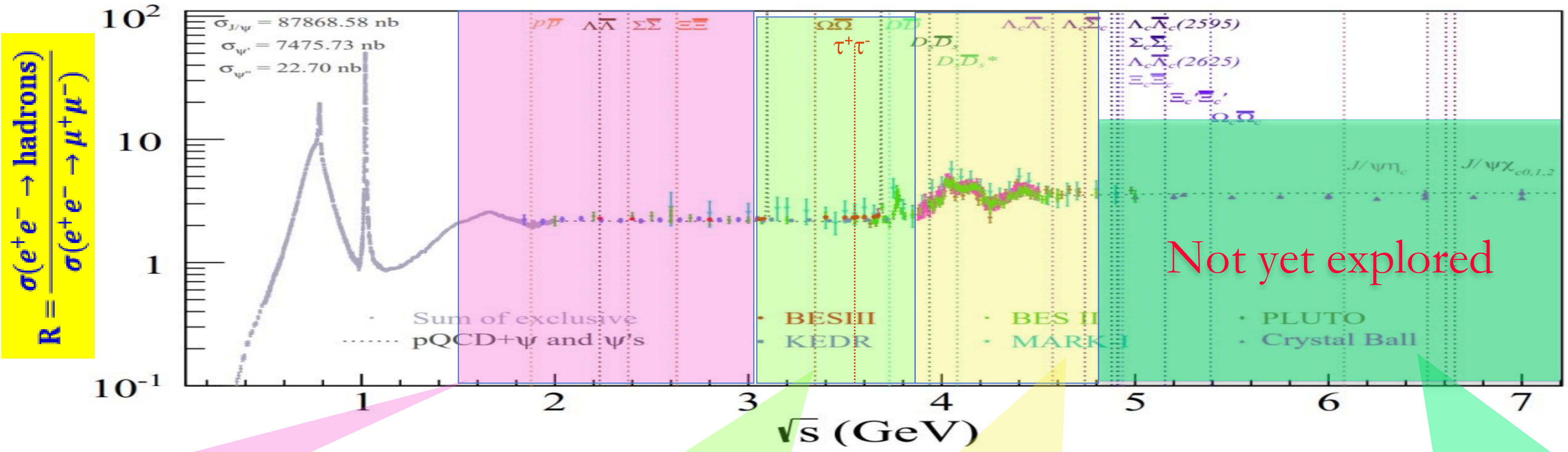

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- XYZ particles
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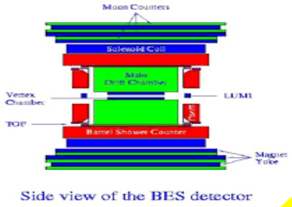
- New XYZ particle
- Hidden-charm pentaquark
- Multiquark state

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

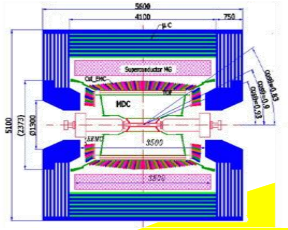
Tau-Charm Factories in China

BEPCI/BESI-II

($10^{31}cm^{-2}s^{-1}$)



BEPCII/BESIII($10^{33}cm^{-2}s^{-1}$)



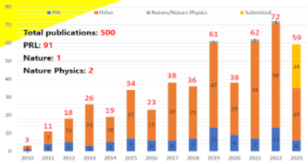
Super Tau-Charm Facility

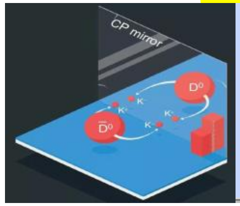
($10^{35}cm^{-2}s^{-1}$)?

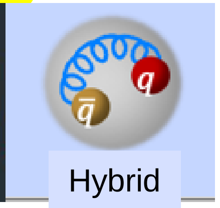
203?

2010

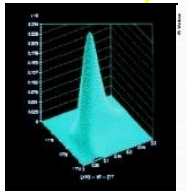
BESIII publications (May 9, 2023)

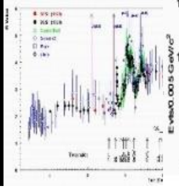


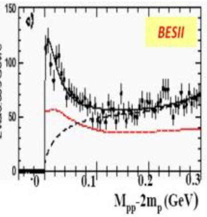




1990

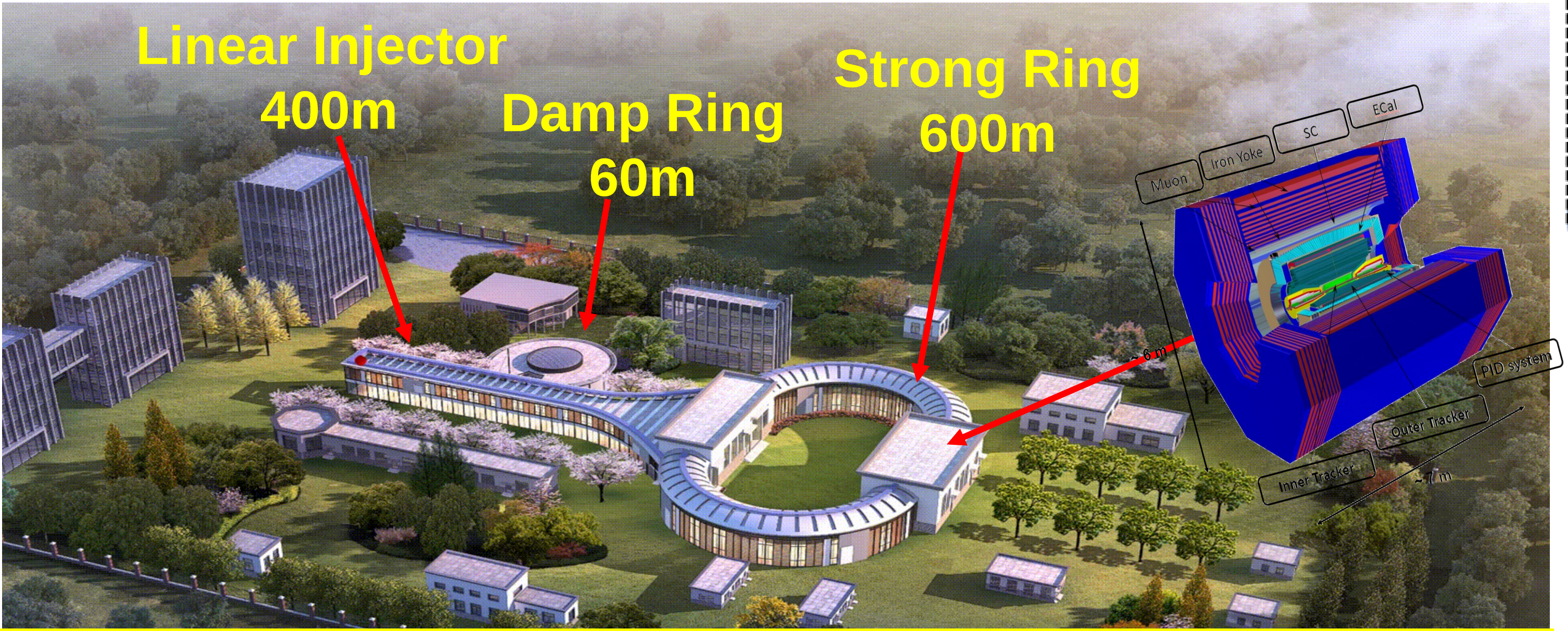


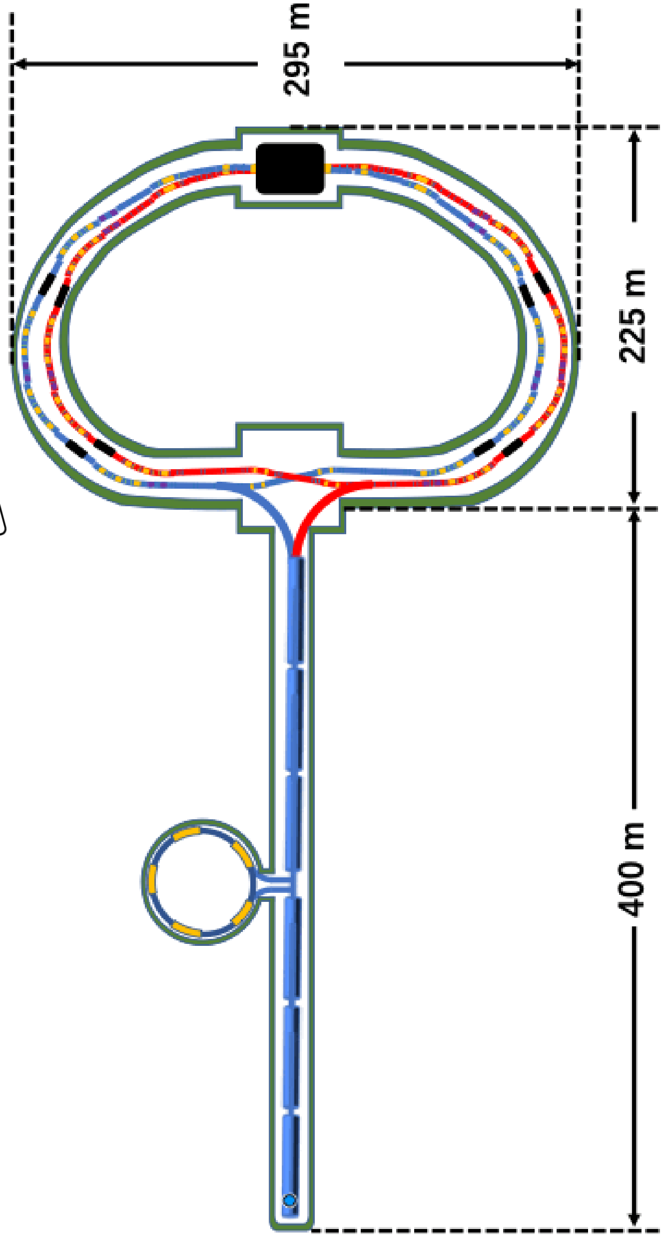




- **BEPCII/BESIII has made great achievements, but operated for 15 years.**
- **Limited by the site and tunnel, no room for further significant upgrade.**
- **However, the more data BESIII has, the more interesting and important physics topics appeared, e.g. nucleon inner structure, exotic states, CPV in hyperons….., and they are closely related to key science questions.**

Super Tau-Charm Facility





- E_{cm}=2-7GeV， L=0.5×10^{35} cm^{-2} s^{-1}
- Potential for upgrade to increase L and realize polarized beam
- Site area: 1 km^2

- 14^{th} 5-year plan (2021-2025): Key technology R&D, 0.42 B CNY.
- 15^{th} 5-year plan (2026-2030): Construction, 7 years, 4.5 B CNY.
- Operating for 10 years, upgrade for 3 years, operating for another 8 years.

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

J/ψ 10^{12}

D pair 10^9

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

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		400	3.4×10^{12}	
3.670	1		2.4	2.4×10^9	
3.686	1	$\psi(3686)$ $\tau^+\tau^-$ $\psi(3686) \to \tau^+\tau^-$	640 2.5	6.4×10^{11} 2.5×10^9 2.0×10^9	
3.770	1	 $D^+\bar{D}^-$ $\tau^+\tau^-$	3.6 2.8 2.9	3.6×10^9 2.8×10^9 7.9×10^8 5.5×10^8 2.9×10^9	 Single Tag Single Tag
4.009	1	$D^{*0}\bar{D}^0$ + c.c	4.0 4.0 0.20 3.5	1.4×10^9 2.6×10^9 2.0×10^8 3.5×10^9	$\mathrm{CP}_{D^0\bar{D}^0} = +$ $\mathrm{CP}_{D^0\bar{D}^0} = -$
4.180	1	$D_s^{+*}D_s^-$+c.c. $D_s^{+*}D_s^-$+c.c. $\tau^+\tau^-$	0.90 3.6	9.0×10^8 1.3×10^8 3.6×10^9	Single Tag
4.230	1	$J/\psi\pi^+\pi^-$ $\tau^+\tau^-$ $\gamma X(3872)$	0.085 3.6	8.5×10^7 3.6×10^9	
4.360	1	$\psi(3686)\pi^+\pi^-$ $\tau^+\tau^-$	0.058 3.5	5.8×10^7 3.5×10^9	
4.420	1	$\psi(3686)\pi^+\pi^-$ $\tau^+\tau^-$	0.040 3.5	4.0×10^7 3.5×10^9	
4.630	1	$\psi(3686)\pi^+\pi^-$ $\Lambda_c\bar{\Lambda}_c$ $\Lambda_c\bar{\Lambda}_c$ $\tau^+\tau^-$	0.033 0.56 3.4	3.3×10^7 5.6×10^8 6.4×10^7 3.4×10^9	Single Tag
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			

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

Hyperon factory ($10^{8\text{-}9}$)

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($10^{9\text{-}10}$)

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 ($10^{6\text{-}10}$)

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

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

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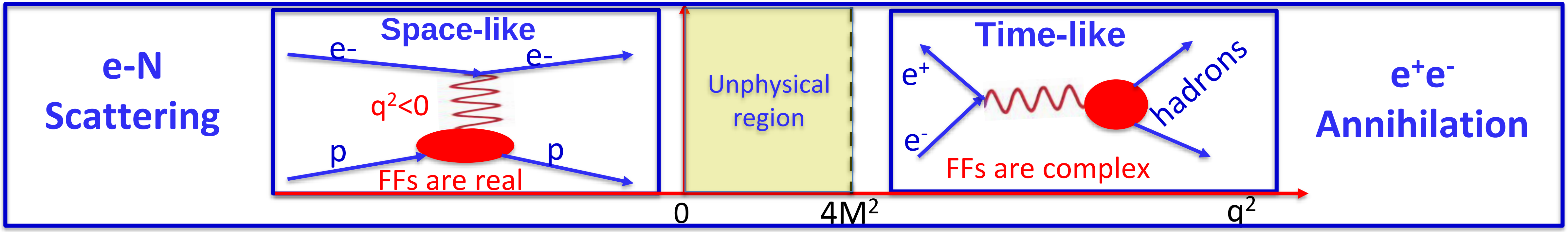
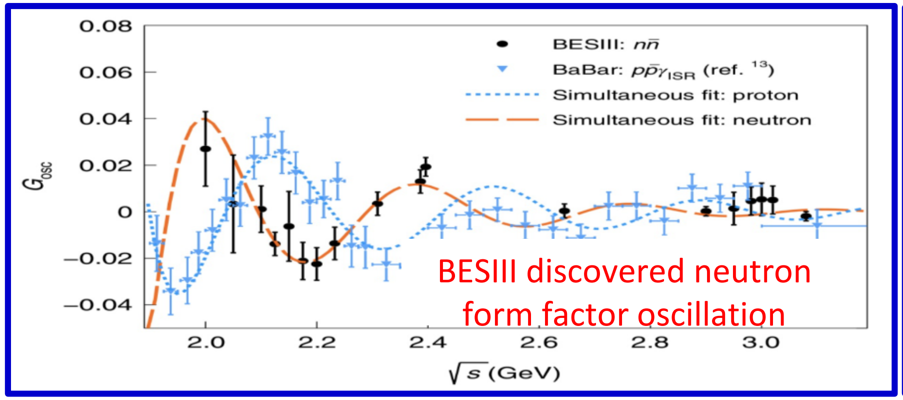
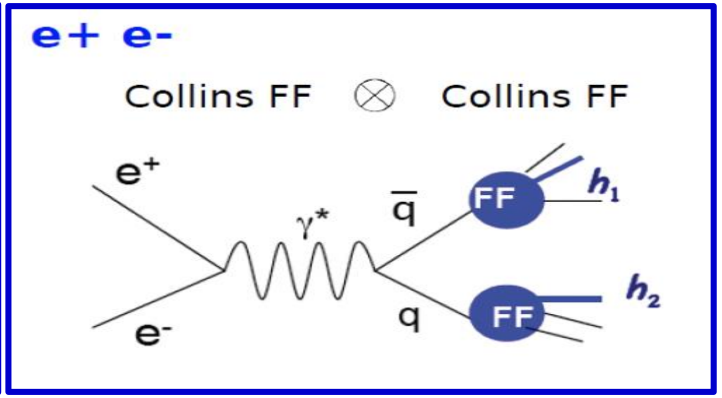
QCD and Hadron Physics

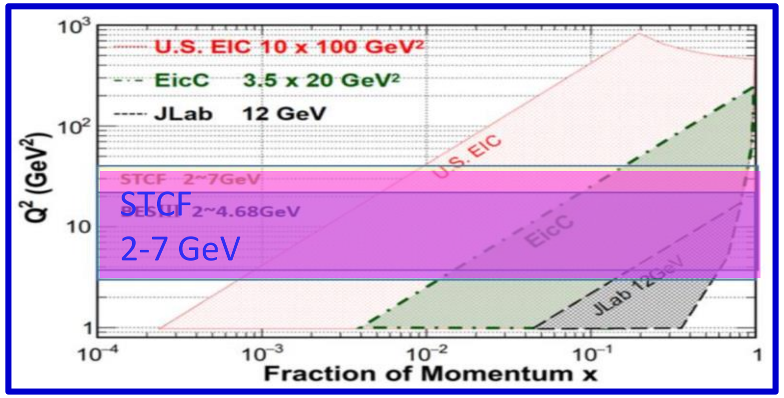
Hadron Production and Hadron Structure

- **Electron magnetic form factors (FFs): fundamental observables reflect the inner structure of nucleon.**
- **Fragmentation function: understanding QCD dynamics, hadron structure and production mechanism.**





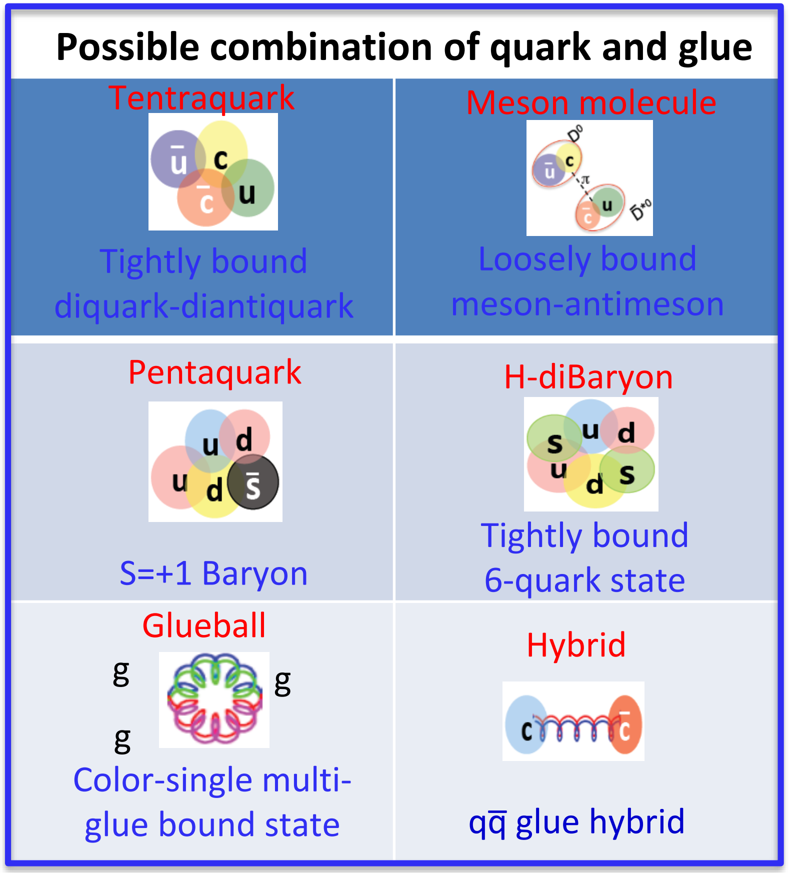


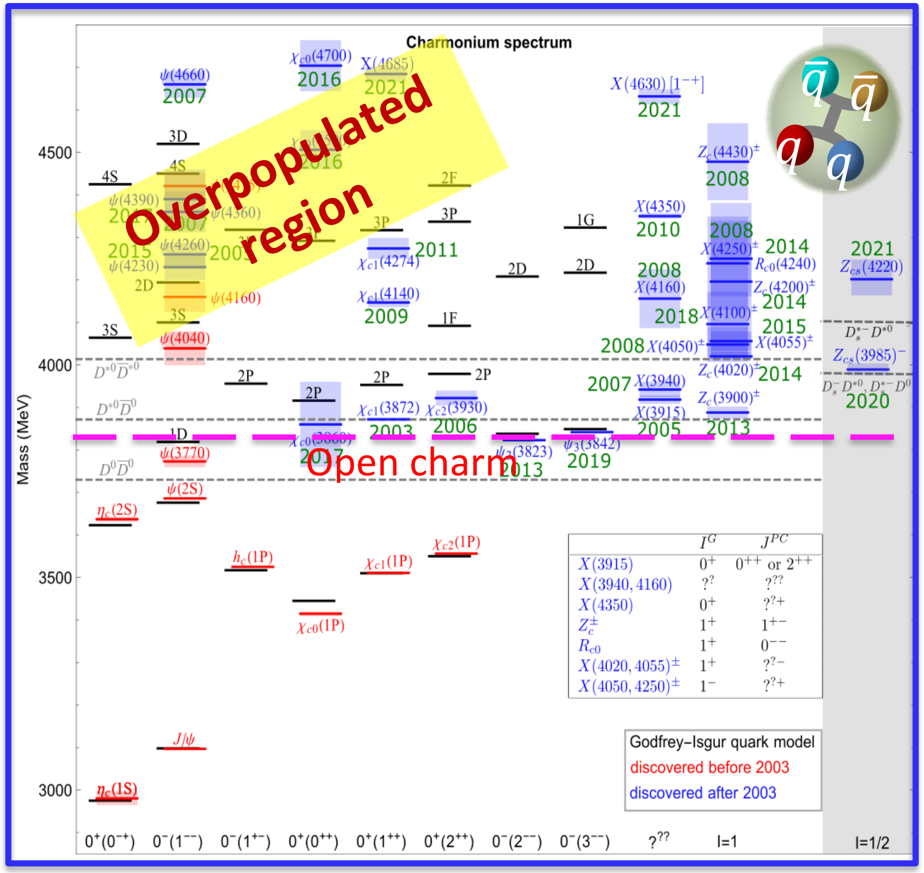


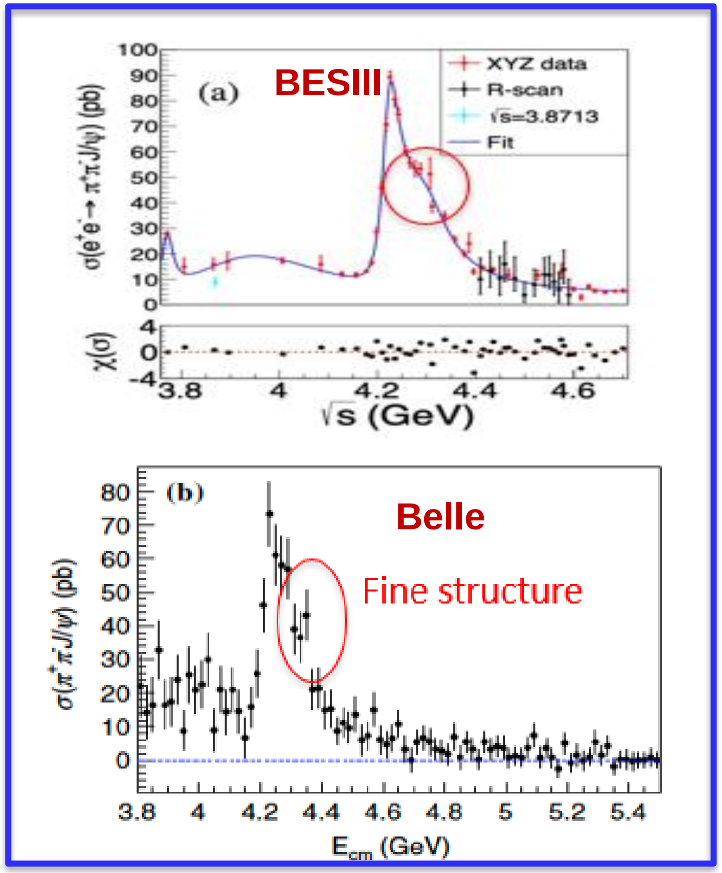
- **Hadron production: from 0.6 to 7 GeV exclusively and inclusively (+ making use of ISR).**
- **Nucleon form factors: complementary to e-N elastic scattering experiments in similar q^2 region.**
- **Fragmentation function: new data from e^+e^- to compare with ep data and to verify its universality.**

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 on searching for exotic hadrons.





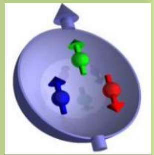


Flavor Physics and CP Violation

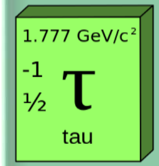
Flavor Physics and CP Violation

- **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 sensitivity.

Hyperon pairs from J/ψ decay,
clean topology, background free
Transversely polarized, spin correlation
Sensitivity: $A_{CP}\sim 10^{-4}$, $\xi\sim 0.05^{\circ}$



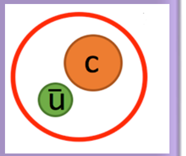
Hyperon decay



Tau lepton production&decay

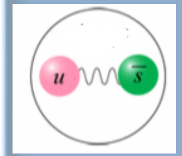
Peak cross section in $\sqrt{s}$ =4-5 GeV,
$\sigma_{\tau\tau}\approx 3.5$ nb, 10 ab^{-1} data in total
of τ decay with 1ab^{-1} @ 4.26 GeV
Sensitivity $\sim 10^{-3}$

Charm mixing



$D^0\bar{D}^0$ pairs produced at threshold
quantum coherence with
$(D^0\bar{D}^0)_{CP=-}$ or $(D^0\bar{D}^0)_{CP=+}$
Sensitivity: $x\sim 0.035\%$, $y\sim 0.023\%$,
$r_{CP}\sim 0.017$, $\alpha_{CP}\sim 1.3^{\circ}$

kaon mixing



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:
$\eta_{\pm}\sim 10^{-3}$, $\Delta\phi_{\pm}\sim 0.05^{\circ}$

CPV in Hyperons from J/ψ Decays

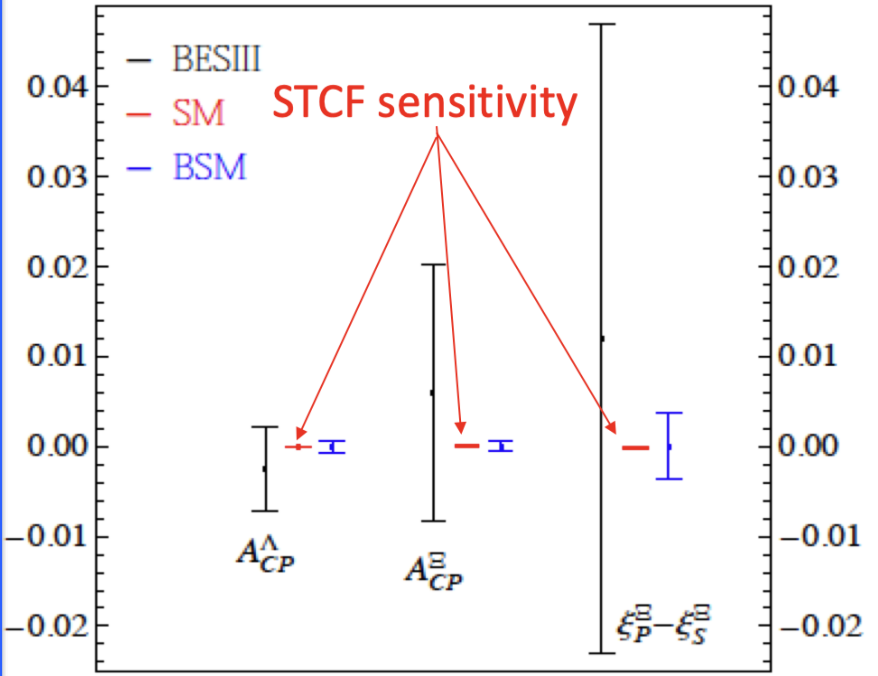
STCF: a Tera- J/ψ (10^{12}) factory → $10^{8\text{-}9}$ hyperons reconstructed

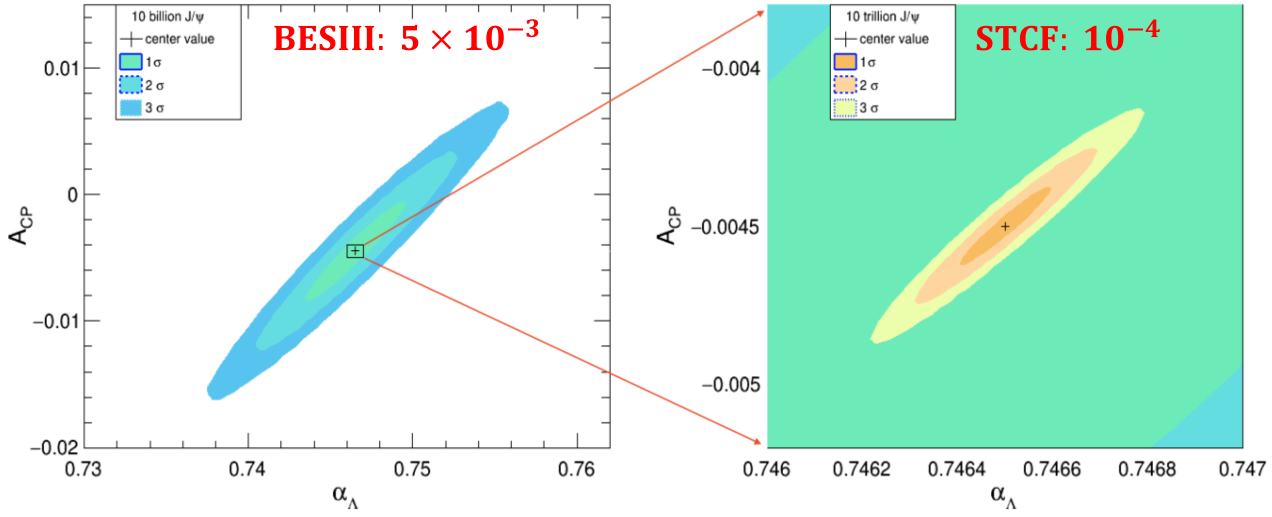
BESIII 10^{10} J/ψ → 4×10^{6} hyperons

STCF: Monochromatic collision, 10^{13} J/ψ
→ $10^{9\text{-}10}$ hyperons reconstructed

STCF CPV sensitivity: $10^{-4} - 10^{-5}$
Challenge to the SM!

X.G. He et al. Sci.Bull. 67 (2022) 1840-1843:

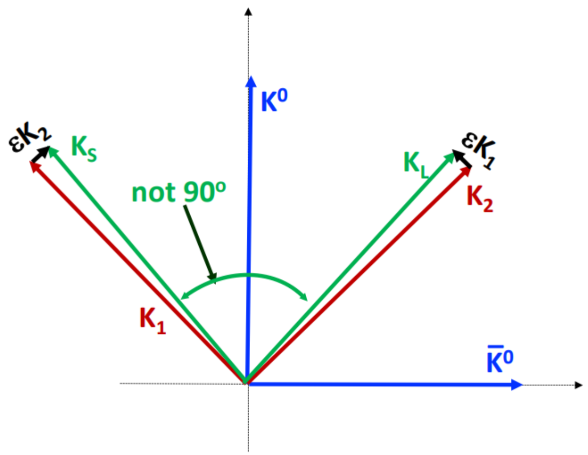


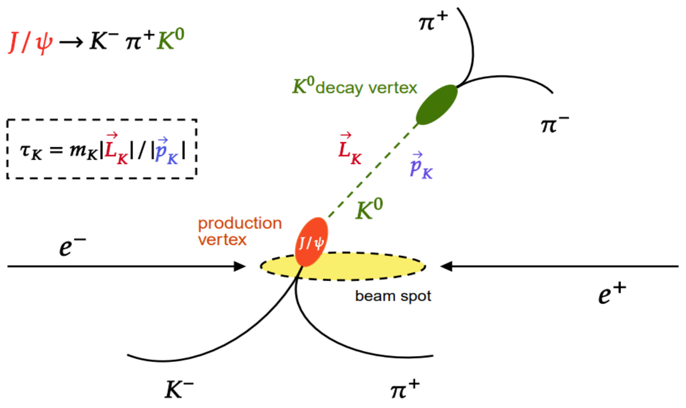


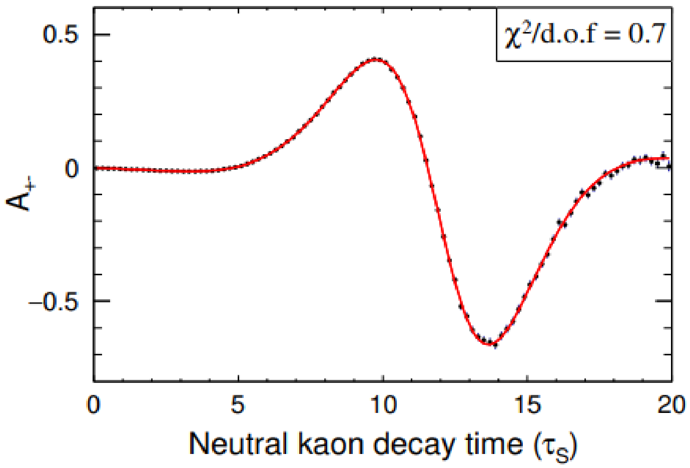
Testing CPT with Neutral Kaons

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 a 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

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

- **4×10^9 pairs of $D^{\pm,0}$ and 10^8 D_s pairs per year**
- **Mixing parameters and CPV parameters with 1 ab^{-1} data at 4009 MeV via coherent (C-even and C-odd) and incoherent process**
- **Time-integrated decay rate of D^0-$\bar{D}^0$ system**

$$\int_0^\infty dt_1 dt_2\ R(D^0\bar{D}^0 \to f_1 f_2; t_1, t_2)$$

$$= \frac{1}{4\Gamma}\Big(K_i K_{-j} + K_{-i}K_j + 2\mathbb{C}\sqrt{K_i K_{-j} K_{-i} K_j}(c_i c_j + s_i s_j) + 2(1+\mathbb{C})\Big(K_i\sqrt{K_j K_{-j}}\, r_{CP}^{-1}(c_j' y + s_j' x) + K_j\sqrt{K_i K_{-i}}\, r_{CP}^{-1}(c_i' y$$

$$K_{-i}\sqrt{K_j K_{-j}}\, r_{CP}(c_j' y - s_j' x) + K_{-j}\sqrt{K_i K_{-i}}\, r_{CP}(c_i' y - s_i' x)\Big)\Big)$$

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

STCF with 1 ab^{-1} data， sensitivities comparable 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 Measurement

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°

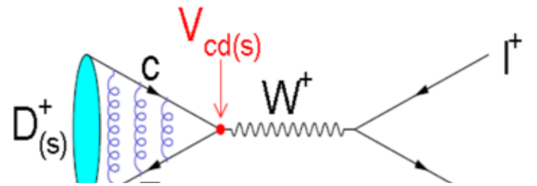
STCF is needed!

Three methods for exploiting interference (choice of D^0 decay modes):

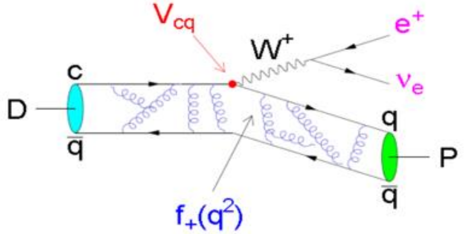
- Gronau, London, Wyler (GLW): Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \to K_S\pi^0$, $D^0 \to \pi^+\pi^-$
- Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+\pi^-$
  - With 1 ab^{-1} @ STCF : $\sigma(\cos\delta_{K\pi})$ ~0.007; $\sigma(\delta_{K\pi})$ ~2° ➔ **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.

Measurement of CKM Matrix Elements

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%$_{\rm syst}$ [120]	0.28%$_{\rm stat}$	2.8%$_{\rm stat}$ [66]
$f^\mu_{D^+}$ (MeV)	2.6%$_{\rm stat}$ 0.9%$_{\rm syst}$ [120]	0.15%$_{\rm stat}$	
$\lvert V_{cd}\rvert$	2.6%$_{\rm stat}$ 1.0%$^*_{\rm syst}$ [120]	0.15%$_{\rm stat}$	–
$\mathcal{B}(D^+ \to \tau^+\nu_\tau)$	20%$_{\rm stat}$ 10%$_{\rm syst}$ [121]	0.41%$_{\rm stat}$	–
$\frac{\mathcal{B}(D^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D^+ \to \mu^+\nu_\mu)}$	21%$_{\rm stat}$ 13%$_{\rm syst}$ [121]	0.50%$_{\rm stat}$	–
Luminosity	6.3 fb^{-1} at (4.178, 4.226) GeV	1 ab^{-1} at 4.009 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$	2.4%$_{\rm stat}$ 3.0%$_{\rm syst}$ [122]	0.30%$_{\rm stat}$	0.8%$_{\rm stat}$ 1.8%$_{\rm syst}$
$f^\mu_{D_s^+}$ (MeV)	1.2%$_{\rm stat}$ 1.5%$_{\rm syst}$ [122]	0.15%$_{\rm stat}$	
$\lvert V_{cs}\rvert$	1.2%$_{\rm stat}$ 1.5%$_{\rm syst}$ [122]	0.15%$_{\rm stat}$	–
$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	1.7%$_{\rm stat}$ 2.1%$_{\rm syst}$ [123]	0.24%$_{\rm stat}$	0.6%$_{\rm stat}$ 2.7%$_{\rm syst}$
$f^\tau_{D_s^+}$ (MeV)	0.8%$_{\rm stat}$ 1.1%$_{\rm syst}$ [123]	0.11%$_{\rm stat}$	–
$\lvert V_{cs}\rvert$	0.8%$_{\rm stat}$ 1.1%$_{\rm syst}$ [123]	0.11%$_{\rm stat}$	–
$\overline{f}^{\mu\&\tau}_{D_s^+}$ (MeV)	0.7%$_{\rm stat}$ 0.9%$_{\rm syst}$	0.09%$_{\rm stat}$	0.3%$_{\rm stat}$ 1.0%$_{\rm syst}$
$\lvert \overline{V}^{\mu\&\tau}_{cs}\rvert$	0.7%$_{\rm stat}$ 0.9%$_{\rm syst}$	0.09%$_{\rm stat}$	–
$f_{D_s^+}/f_{D^+}$	1.4%$_{\rm stat}$ 1.7%$_{\rm syst}$ [124]	0.21%$_{\rm stat}$	–
$\frac{\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)}$	2.9%$_{\rm stat}$ 3.5%$_{\rm syst}$	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

Search for New Physics Beyond SM

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

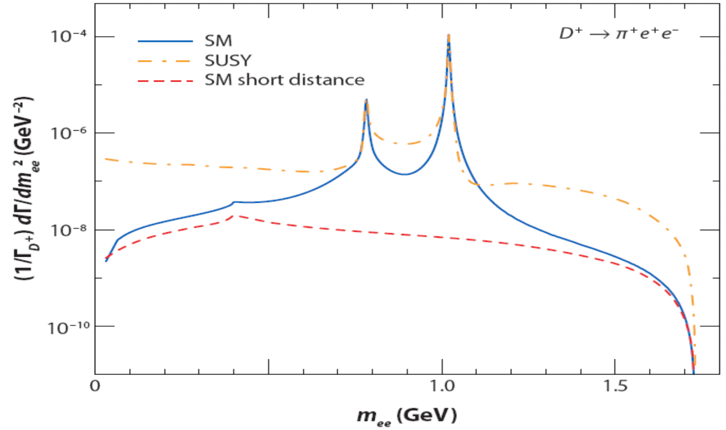
	STCF	Belle II	LHCb
Production yields	★★	★★★★	★★★★★
Background level	★★★★★	★★★	★★
Systematic error	★★★★★	★★★	★★
Completeness	★★★★★	★★★	★
(Semi)-Leptonic mode	★★★★★	★★★★	★★
Neutron/K_L mode	★★★★★	★★★	☆
Photon-involved	★★★★★	★★★★	★
Absolute measurement	★★★★★	★★★	☆

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

Charm rare decays

- **FCNC suppressed by GIM mechanism in SM:**
  - Short distance: interested, computable by pQCD, directly test SM $\mathcal{B}_{D^0\to X_u^0 e^+e^-} \simeq 8\cdot 10^{-9}$

    $\mathcal{B}_{D^+\to X_u^+ e^+e^-} \simeq 2\cdot 10^{-8}$
  - Long distance effect can enhance the rate to 10^{-6} ~10^{-7}, dominantly.
  - Allow with sizeable decay rate in NP



  - $1ab^{-1}$ @ STCF can achieve the sensitivity to 10^{-8}~10^{-9}, tested SM strictly
  - Can discriminate NP from SM by measuring :
    - $D\to Vl^+l^-$: AFB asymmetry
    - $D\to Pl^+l^-$: line shape of dilepton mass, to reveal the interference effect between long-distance and FCNC weak amplitude (NP amplitude);

➢ LFV, LNV and BNV decays are forbidden in the SM. However, NP models can allow at sizable levels.
  - STCF: 10^{-8}~10^{-9} ➔ stringent constrains to NP models

More detail MC simulation are necessary!

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
(Mini Preliminary Conceptual Design Report)
超级陶粲装置（STCF）加速器总体
小型初步概念设计报告

STCF
Conceptual Design Report
Volume III - Detector

The STCF Study Group
September 23, 2021

2022.4.24

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

"超级陶-粲装置关键技术攻关"项目论证意见

Endorsed 420 M CYN for R&D

2022.9.24

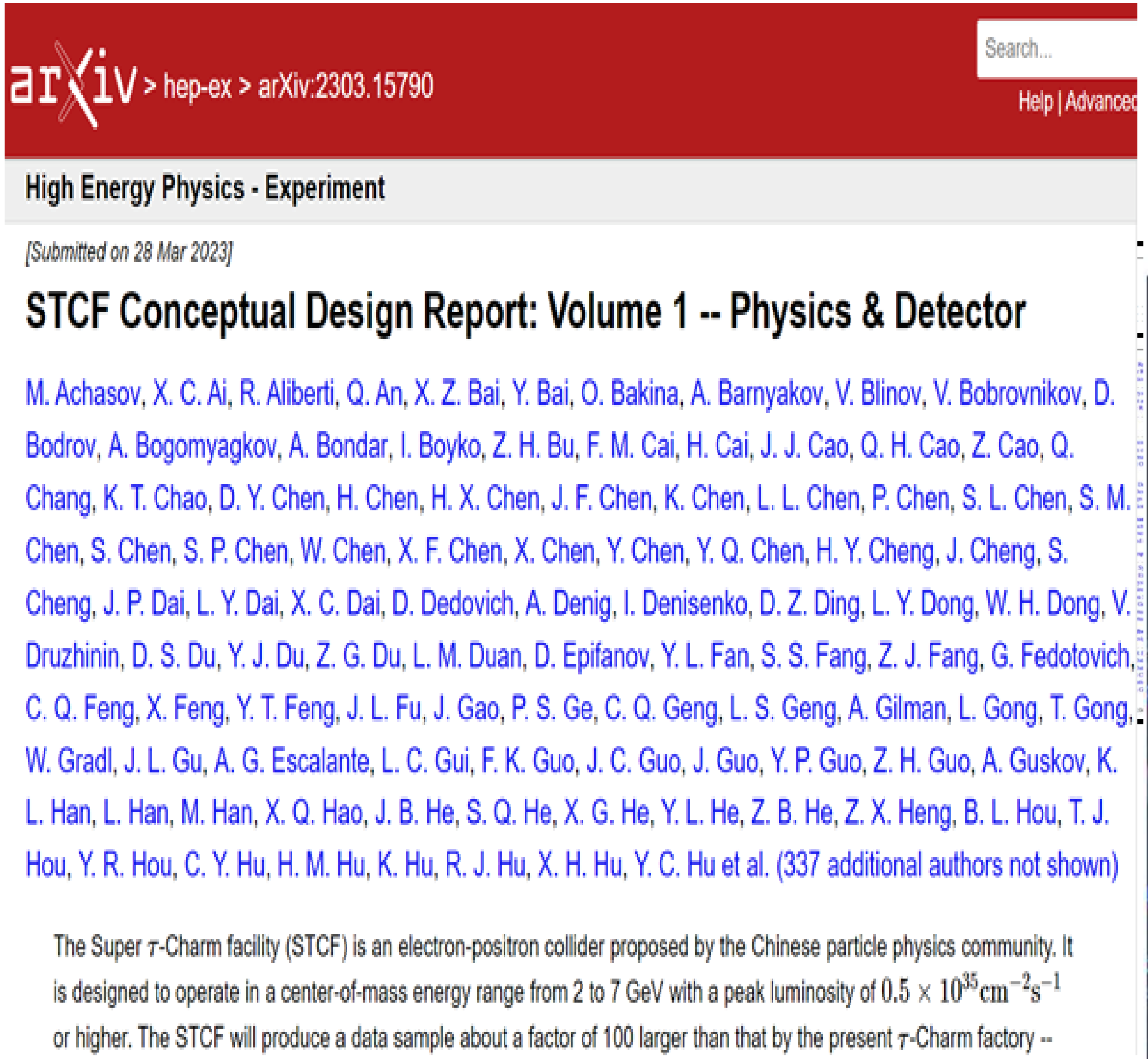
USTC formed project leadership team headed by USTC president

中国科学技术大学文件

校科字〔2022〕190 号

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

Conceptual Design Report


arXiv > hep-ex > arXiv:2303.15790

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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. Bakina, A. Barnyakov, V. Blinov, V. Bobrovnikov, D. Bodrov, A. Bogomyagkov, A. Bondar, I. Boyko, Z. H. Bu, F. M. Cai, H. Cai, J. J. Cao, Q. H. Cao, Z. Cao, Q. Chang, K. T. Chao, D. Y. Chen, H. Chen, H. X. Chen, J. F. Chen, K. Chen, L. L. Chen, P. Chen, S. L. Chen, S. M. Chen, S. Chen, S. P. Chen, W. Chen, X. F. Chen, X. Chen, Y. Chen, Y. Q. Chen, H. Y. Cheng, J. Cheng, S. Cheng, J. P. Dai, L. Y. Dai, X. C. Dai, D. Dedovich, A. Denig, I. Denisenko, D. Z. Ding, L. Y. Dong, W. H. Dong, V. Druzhinin, D. S. Du, Y. J. Du, Z. G. Du, L. M. Duan, D. Epifanov, Y. L. Fan, S. S. Fang, Z. J. Fang, G. Fedotovich, C. Q. Feng, X. Feng, Y. T. Feng, J. L. Fu, J. Gao, P. S. Ge, C. Q. Geng, L. S. Geng, A. Gilman, L. Gong, T. Gong, W. Gradl, J. L. Gu, A. G. Escalante, L. C. Gui, F. K. Guo, J. C. Guo, J. Guo, Y. P. Guo, Z. H. Guo, A. Guskov, K. L. Han, L. Han, M. Han, X. Q. Hao, J. B. He, S. Q. He, X. G. He, Y. L. He, Z. B. He, Z. X. Heng, B. L. Hou, T. J. Hou, Y. R. Hou, C. Y. Hu, H. M. Hu, K. Hu, R. J. Hu, X. H. Hu, Y. C. Hu et al. (337 additional authors not shown)

The Super τ-Charm facility (STCF) is an electron-positron collider proposed by the Chinese particle physics community. It is designed to operate in a center-of-mass energy range from 2 to 7 GeV with a peak luminosity of $0.5 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ or higher. The STCF will produce a data sample about a factor of 100 larger than that by the present τ-Charm factory --

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

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

Identified 31 items for R&D

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

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

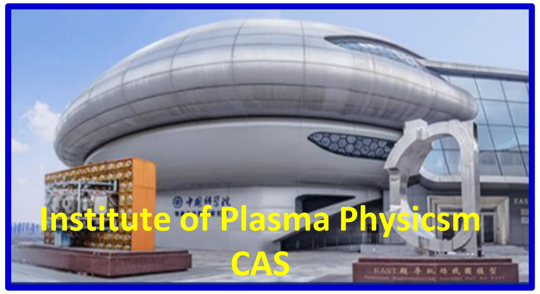
Major Laboratories and Institutions for project

State Key Laboratory of Particle Detection and Electronics

National Synchrotron Radiation Laboratory

Institute of Modern Physics CAS

Shanghai Advanced Research Institute, CAS



Institute of Plasma Physicsm CAS

High Magnetic Field Laboratory, CAS

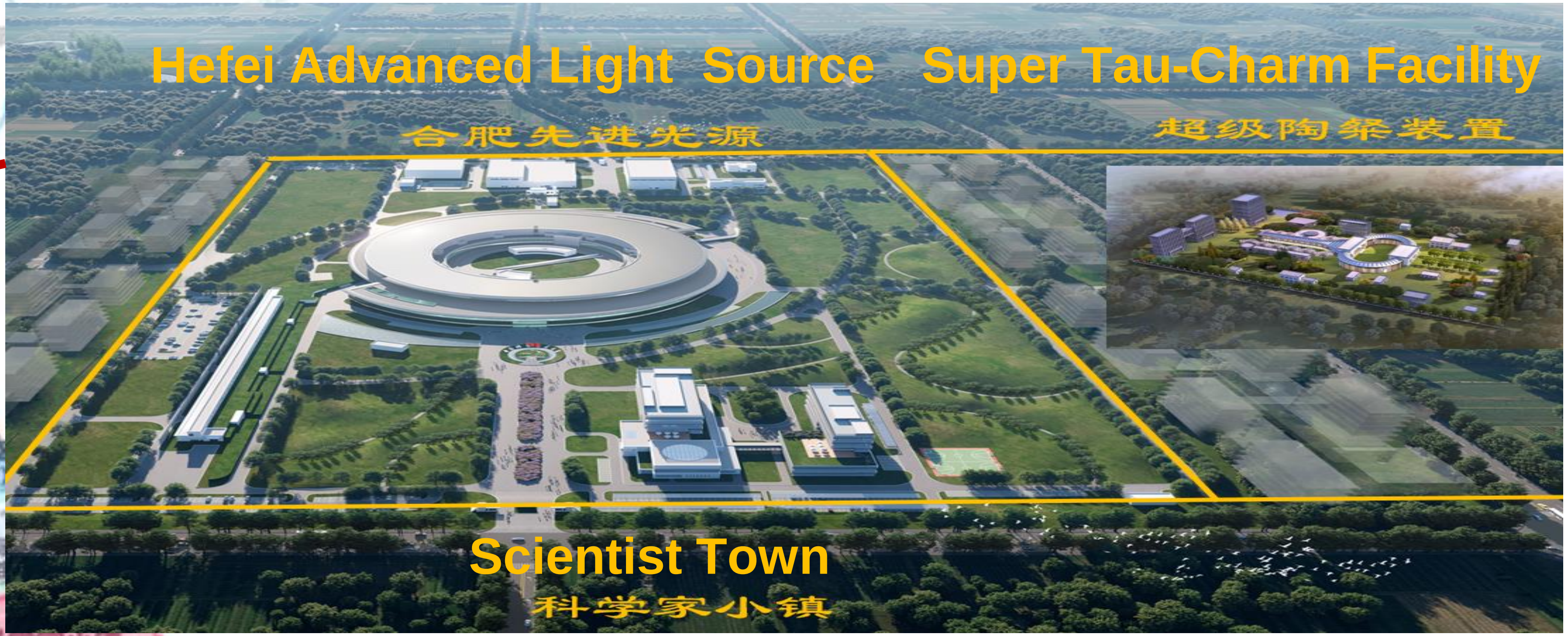
- Institute of High Energy Physics, Chinese Academy of Science (CAS)
- Hefei Institutes of Physical Science, CAS
- State Key Laboratory of Nuclear Physics and Technology, Peking University
- Key Laboratory for Particle Astrophysics and Cosmology, Ministry of Education(SJTU)
- Key Laboratory of Particle Physics and Particle Irradiation, Ministry of Education(SDU)
- Key Laboratory of Particle Physics and Cosmology of Shanghai (SJTU)
- TSUNG-DAO LEE INSTITUTE

Platform for Organizations

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

Site – Hefei, Anhui

A very attractive Science City, has one of three comprehensive national science centers for ‘Mega-science’ facilities

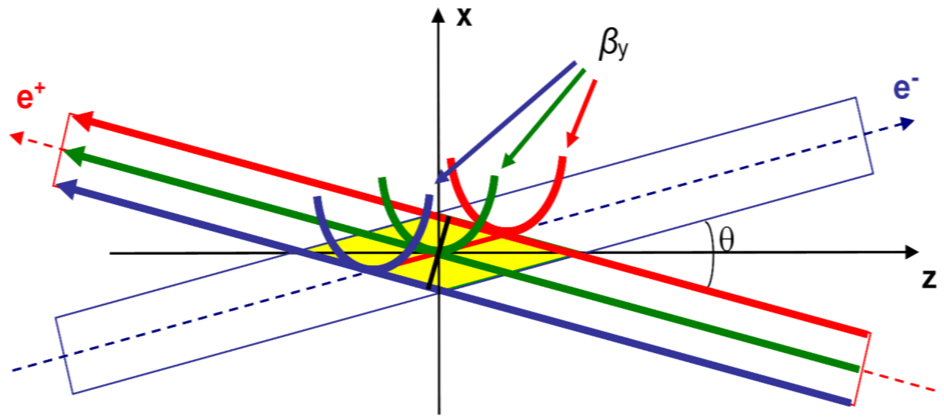


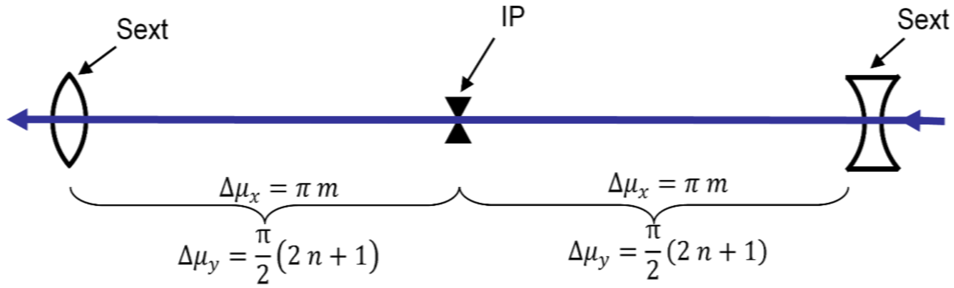
- 6 big facilities for science and technologies (17155 acres).
- Ecological green space and modern agricultural (11815 acres)
- HALF (4th generation light source) was approved by central government, and just began construction
- STCF site is preliminarily decided by local government in Apr. 2023, geological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

Challenges and Key Technologies of Accelerator

Large Piwinski Angle + Crab Waist

(P. Raimondi 2006)



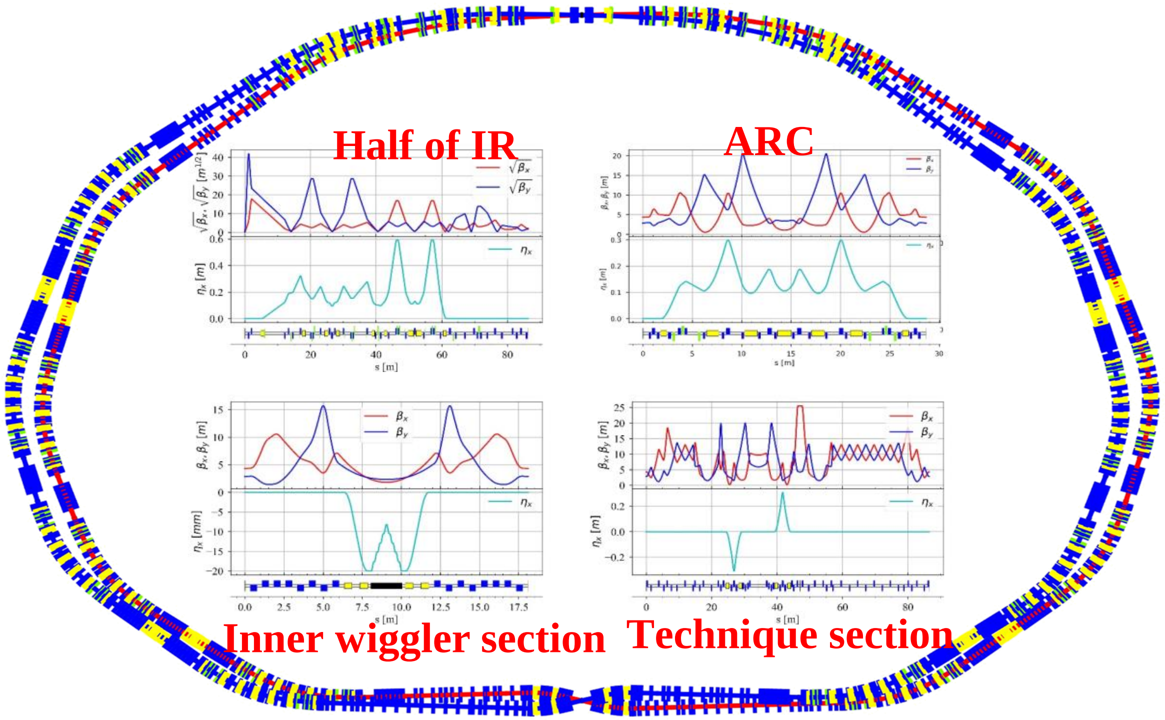


K. Hirata PRL 1995, 74, 2228

Test of "Crab-Waist" Collisions at the DAΦNE Φ Factory, PRL 2010, 104, 174801

- **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

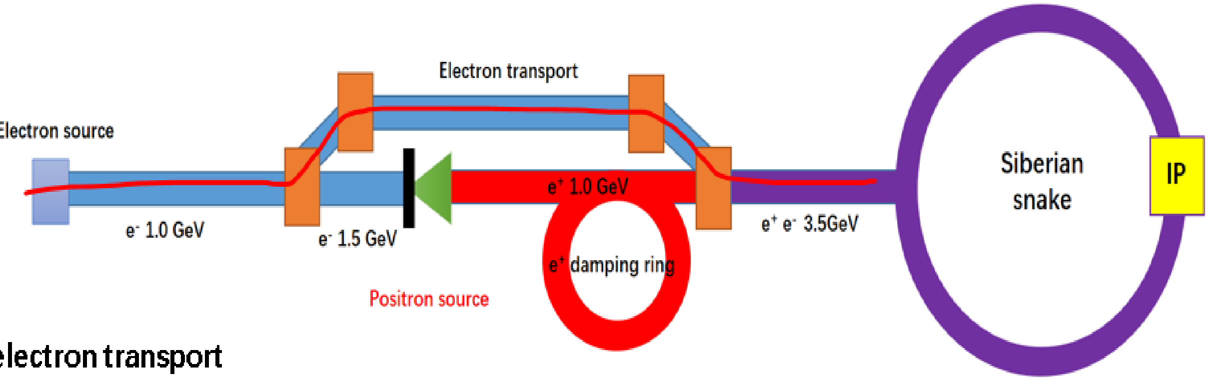
Status of Accelerator Design



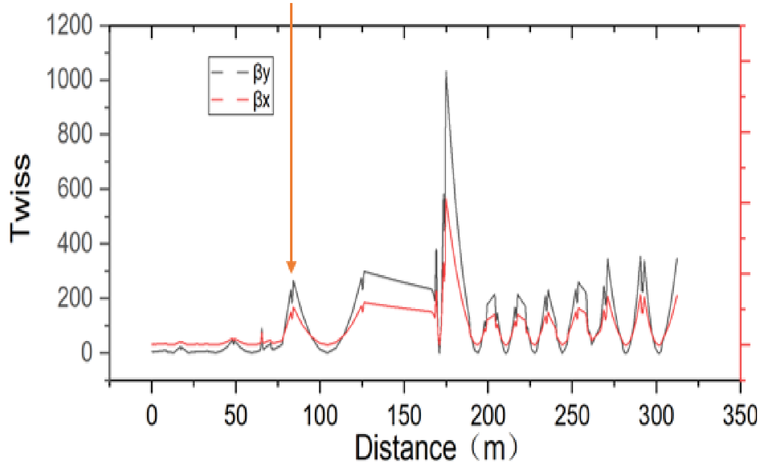
- Beam-beam simulation, collective effective simulation are ongoing
- Touschek Lifetime ~100s
- $\sigma_z = 8.04$ mm (w/o IBS), $\xi_x = 0.0040 \rightarrow \upsilon_z = 2.5\,\xi_x$
- $\sigma_z = 8.94$ mm (wi IBS), $\xi_x = 0.0032 \rightarrow \upsilon_z = 3.1\,\xi_x$
- w/o IBS: $\xi_y = 0.148$, $L = 1.98 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$
- wi IBS: $\xi_y = 0.111$, $L = 1.45 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$

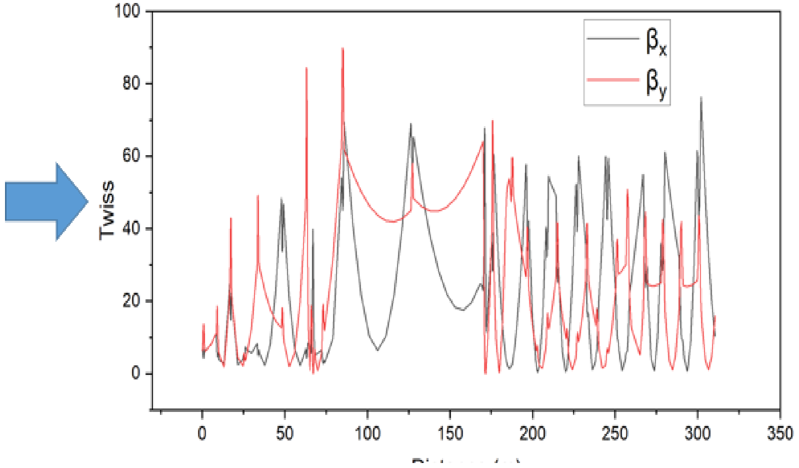
Parameters	Units	STCF-v2	STCF-v3 (no wiggler)	STCF-v3 (wiggler)	STCF-v3 (wiggler+IBS)
Optimal beam energy, E	GeV	2	2	2	2
Circumference, C	m	617.06	616.76	616.76	616.76
Crossing angle, 2θ	mrad	60	60	60	60
Relative gamma		3913.9	3913.9	3913.9	3913.9
Revolution period, T_0	ms	2.058	2.057	2.057	2.057
Revolution 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	$\mathrm{cm^{-2}s^{-1}}$	6.21E+35	2.23E+35	1.98E+35	1.45E+35

Status of Accelerator Design



By pass electron transport



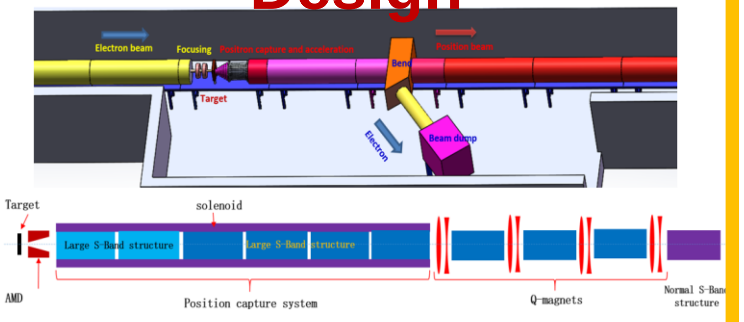


Parameter	Value
Energy	1.0 GeV
Perimeter	~58 mm
Repetition frequency	50 Hz
Bending radius	2.7 m
Dipole magnets, B_0	1.4 T
Momentum compression factor, α_c	0.076
U_0	35.8 keV
Damping time x/y/z	12/12/6 ms
δ_0	0.05%
ε_0	287.4 mm·mrad
Bunch length	7 mm
ε_{inj}	2500 mm·mrad
$\varepsilon_{ext\ x/y}$	704/471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

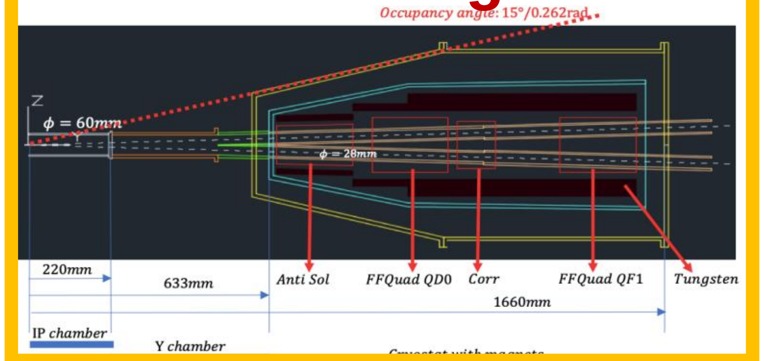
By optimizing the layout of the focusing units in the bypass drift section, the Twiss parameters have been successfully reduced to an acceptable range.

Status of Accelerator Key Technology R&D

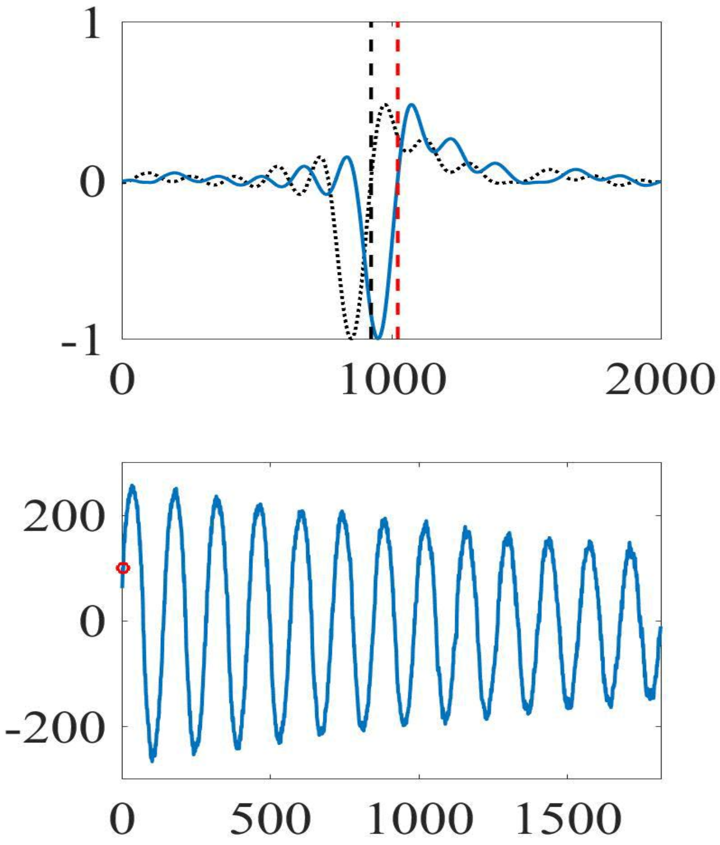
Positron Source Design



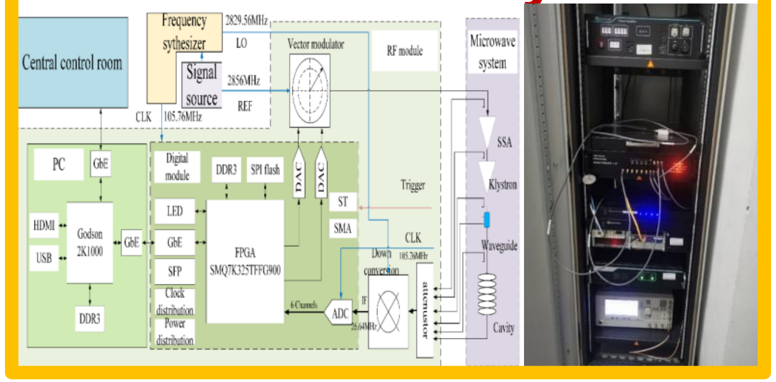
MDI Design



3D Position measurement technique for each beam bunch



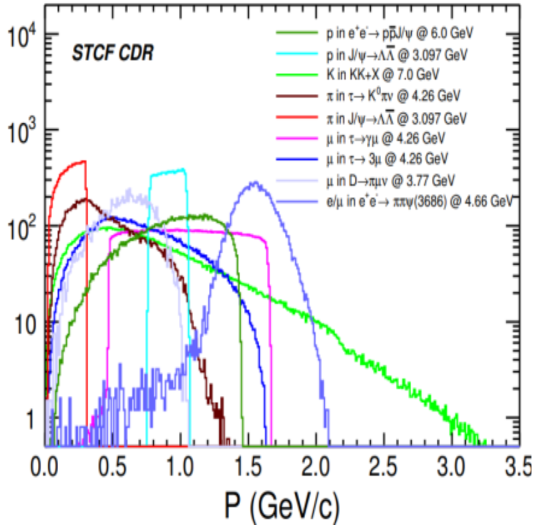
Low level RF system

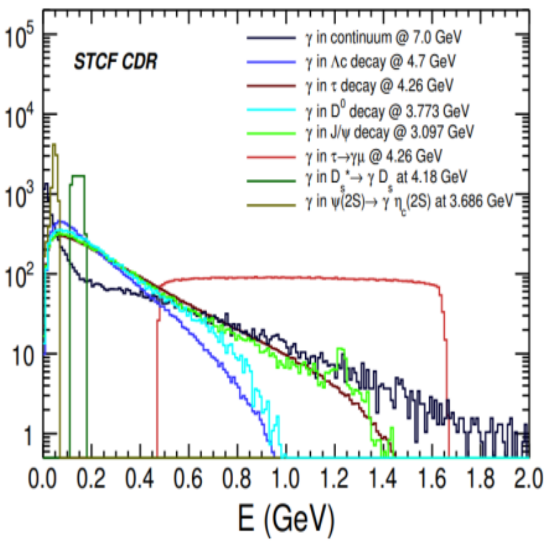


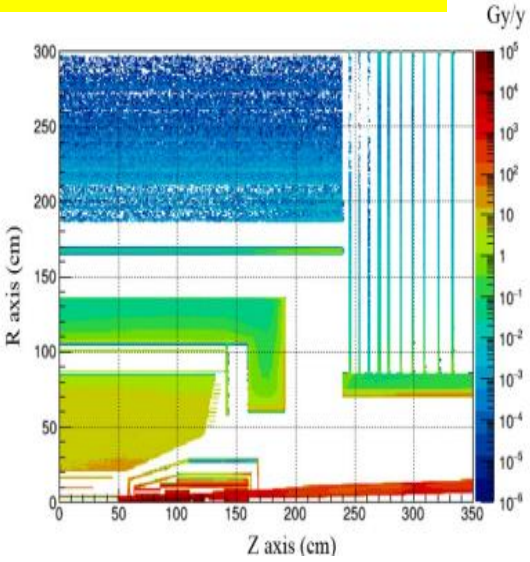
photocathode microwave electron gun

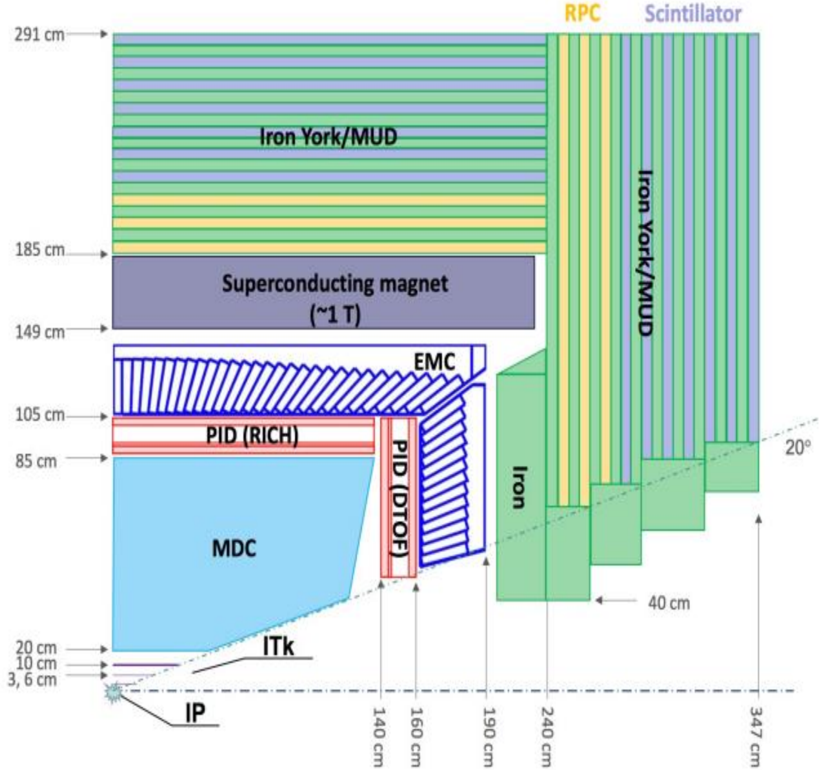
Challenges for Technologies of Spectrometer

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









ITk
- $< 0.25\% X_0$ / layer
- $\sigma_{xy} <\sim 100\ \mu m$

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

EMC

E range: 0.025-3.5GeV

σ_E (%) @ 1 GeV

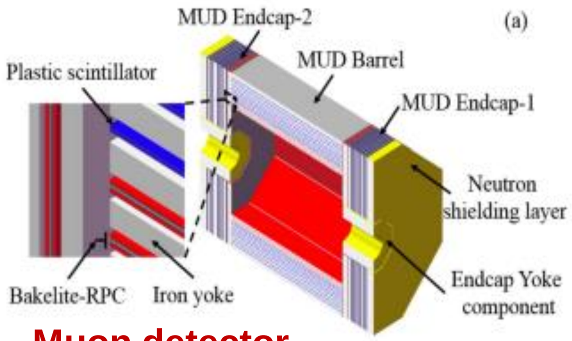
Barrel:	2.5
Endcap:	4
Pos. Res. :	5 mm

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

MUD
- 0.4 - 2 GeV
- π suppression >30

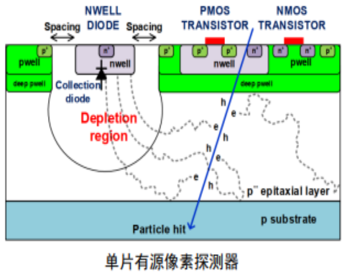
- **Radiative hardness at the most inner layer :~3.5kGy/y, ~2×10^{11} 1MeV n-eq/cm^2/y, ~1 MHz/cm^2**
- **Solid Angle Coverage : 94%·4π**
- **Event rate : 400KHz @J/ψ**

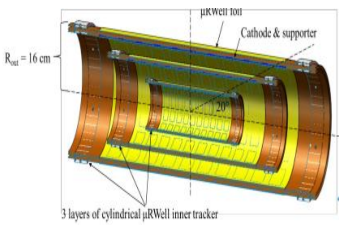
Detector options



Muon detector

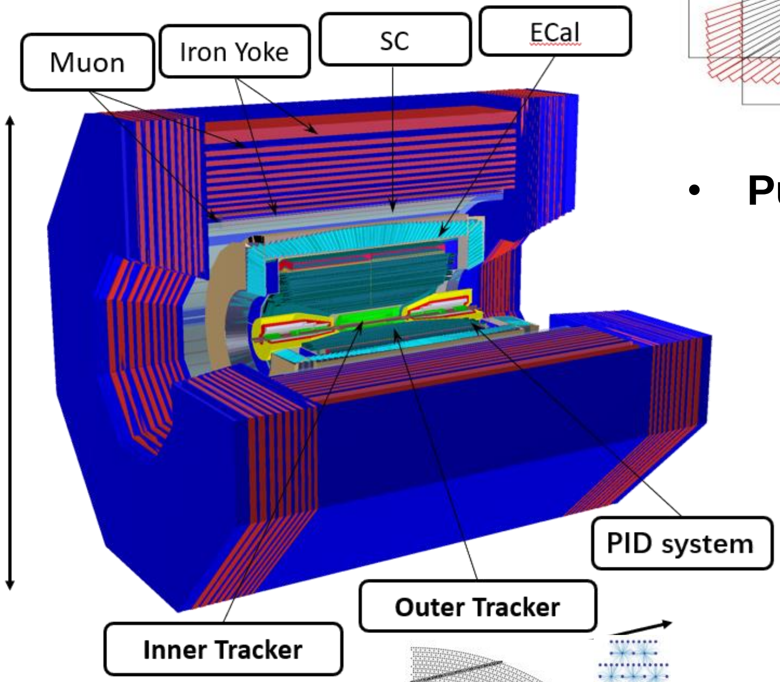
- Bakelite RPC + Scintillator strips

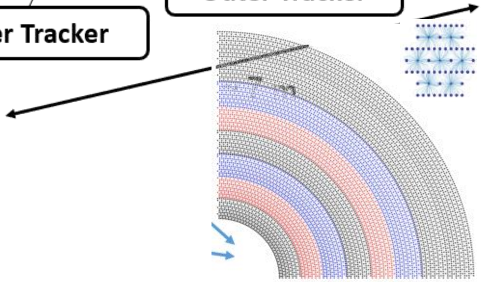




Inner Tracker

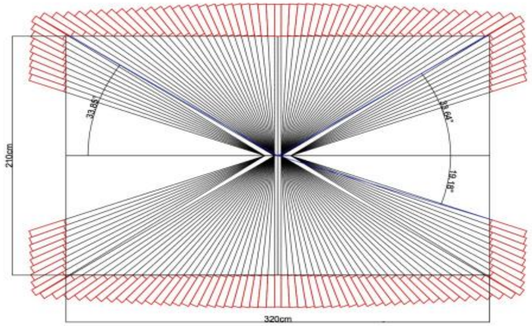
- MPGD: Cylindrical μRWELL
- Silicon: CMOS MAPS





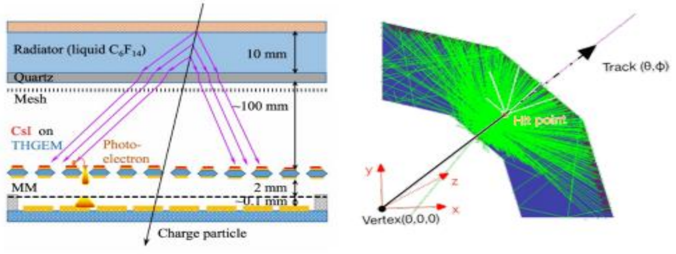
Central Tracker

- Drift Chamber with extra-low mass and small cell



EM calorimeter

- Pure CsI crystal + APD



Particle Identification

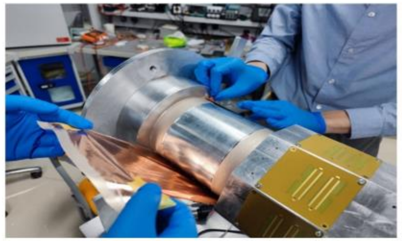
- Barrel: RICH
- EndCap: DIRC-Like TOF

Status of R&D (ITK)

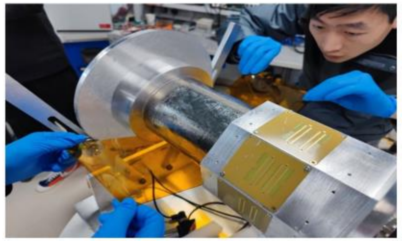
Challenge : high rate, low material and high radiation tolerance

MPDG : Cylindrical structure Design and engineering

1、粘接铜屏蔽层

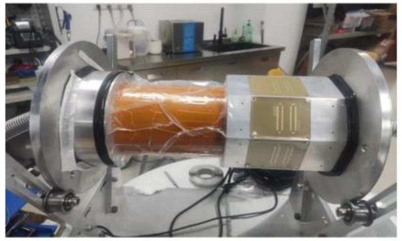


2、粘接kapton

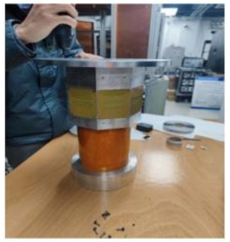


3、粘接PMI泡沫

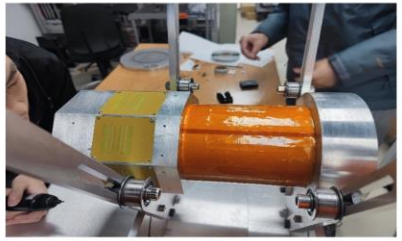
4、粘接封装kapton



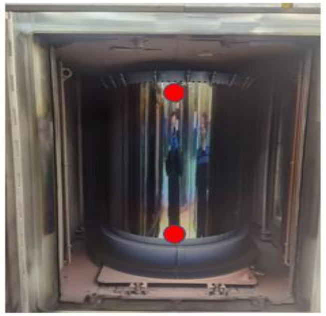
5、模具拆卸



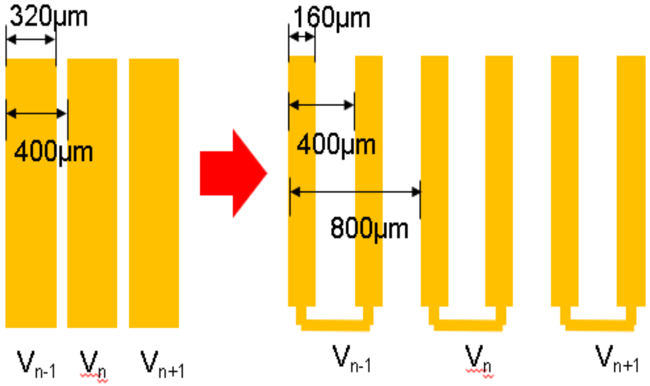
6、最终成品



MPDG : Low material electrodes R&D

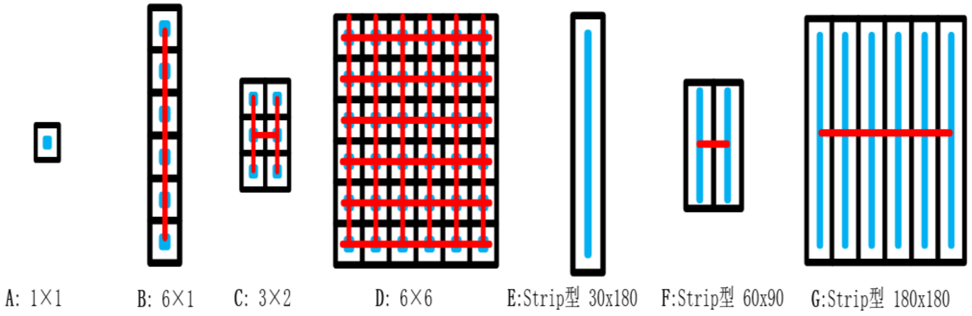


端点电阻测试： 22Ω

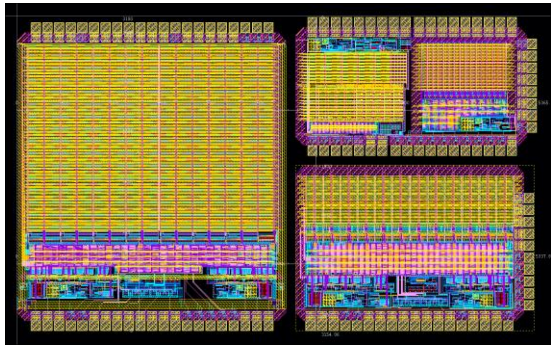


Silicon : Aiming for a low-power chip design with low mass and timing capability

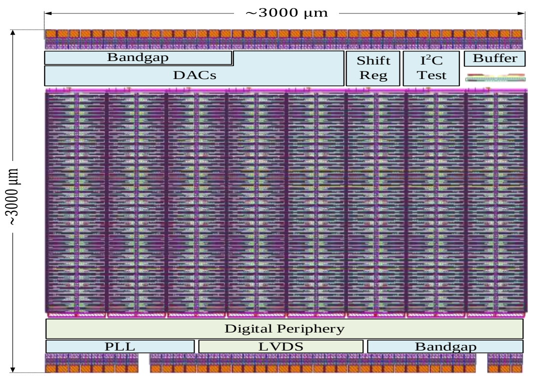
Pixel design



Chip design



TowerJazz 180 nm

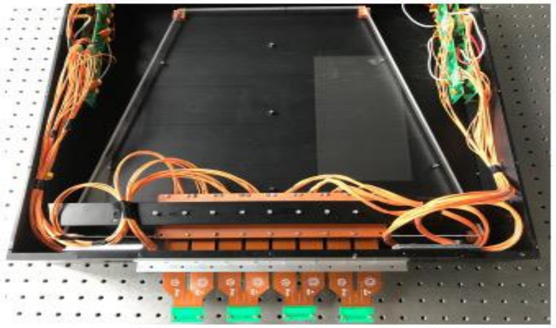


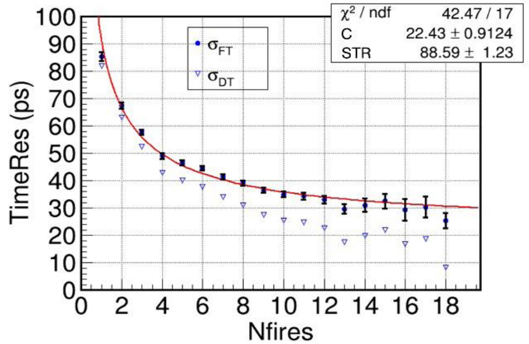
FCIS 90 nm

Status of R&D (PID)

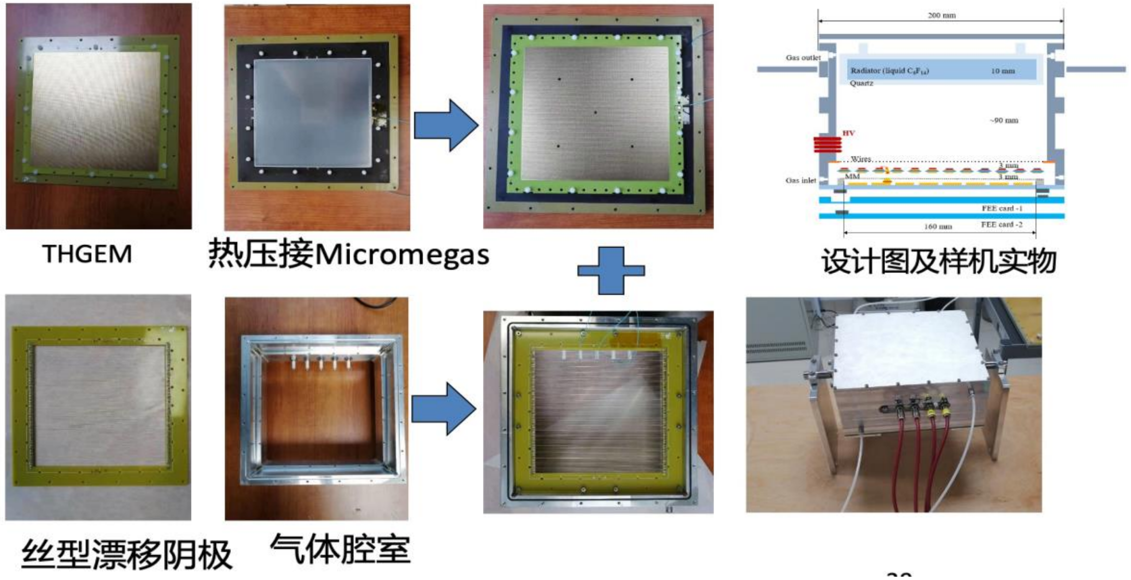
A RICH Prototype with quartz radiator,
A successful beam test (2019)

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

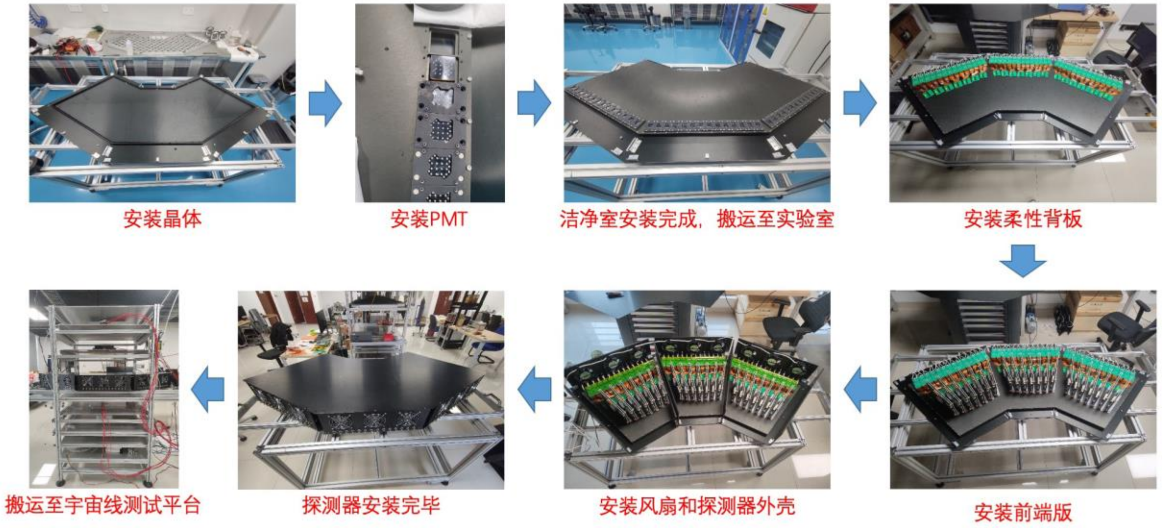




A RICH Prototype with liquid C_6F_{14} (n~1.3)
radiator, aim for a beam test in August



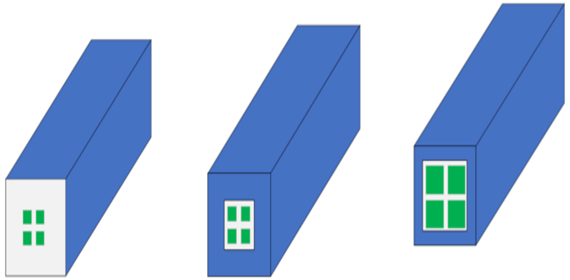
A full-sized DTOF prototype,
with time resolution <28 ps by cosmic rays



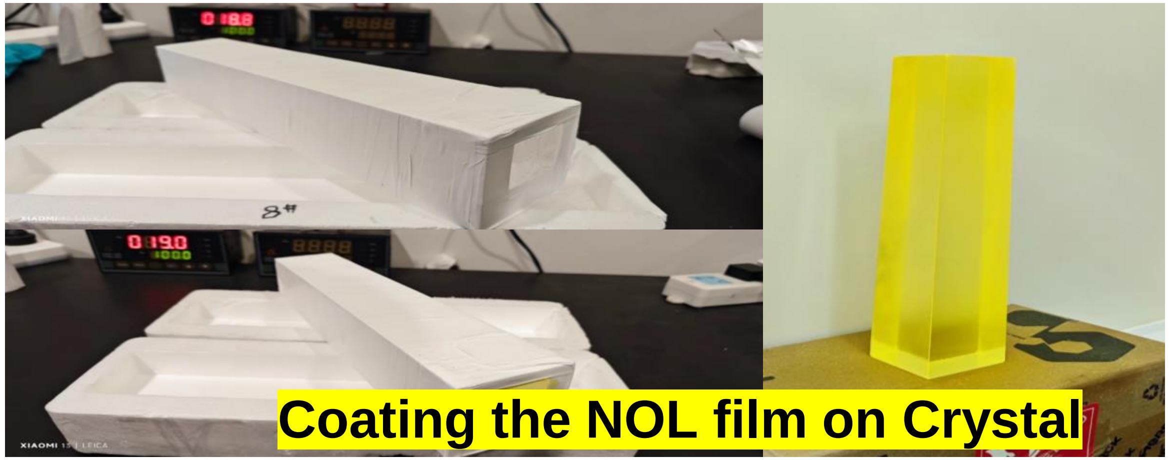
Status of R&D (EMC)

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)



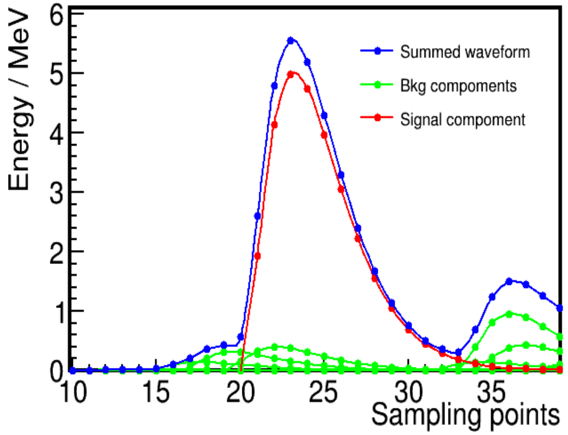
Coating the NOL film on Tyvek

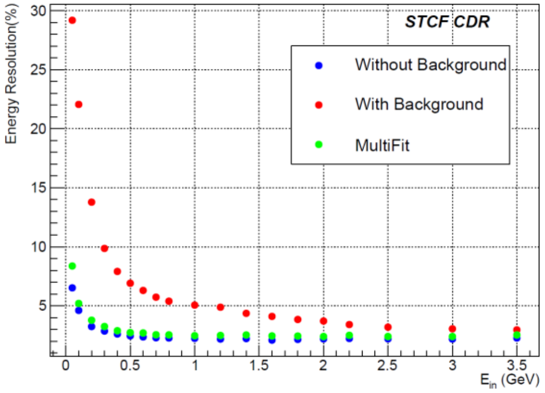


Coating the NOL film on Crystal

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





Tentative Plan of STCF

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032-2042	2043-2046
Form collaboration																
Conception design CDR																
R&D (TDR)																
Construction																
Operation																
Upgrade																

Summary

- STCF is a 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.
- With over 10 years continious efforts, we have finished STCF feasibility study and the conception design (CDR).
- Anhui provice and USTC have officially endorsed the support to STCF, the R&D for the key technologies was launched and great progress is achieved; the site is preliminarily decided, and geological exploration and engineering design is ongoing
- Will apply for the construction projection during the 15th five-year plan (2026-2030) from central government
- A STCF collaboration is expected to expend faster both domestically and internationally.


Thanks for your attention!
Welcome to join!

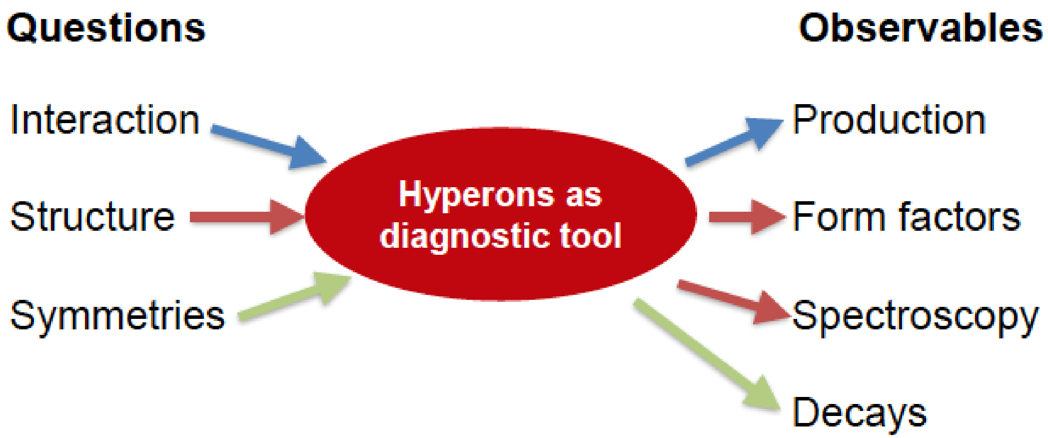
Backup Slides

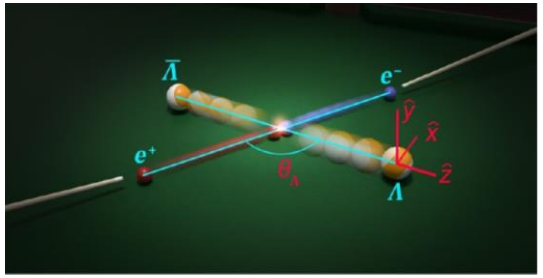
Hyperon Diagnostic Tool

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

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

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





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

- **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 statistics.**
- **Using polarized beams, or "monochromatic" collision modes, can increase sensitivity to 10^{-5}.**
- **Systematic uncertainty is a challenge.**

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

- **Three kinds of $D^0\bar{D}^0$ samples can be used @4009 MeV**
  - **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 $D^0\bar{D}^0$ samples: $D^{*0}\bar{D}^0 \to D^0\bar{D}^0\gamma$**
    - 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 $D^0\bar{D}^0$ samples: $D^{*0}\bar{D}^0 \to D^0\bar{D}^0\pi^0$**
    - Same as $D^0\bar{D}^0$ samples @3770, improve precision of strong-phase difference measurements and CP fraction measurements