The Super Tau-Charm Facility in China

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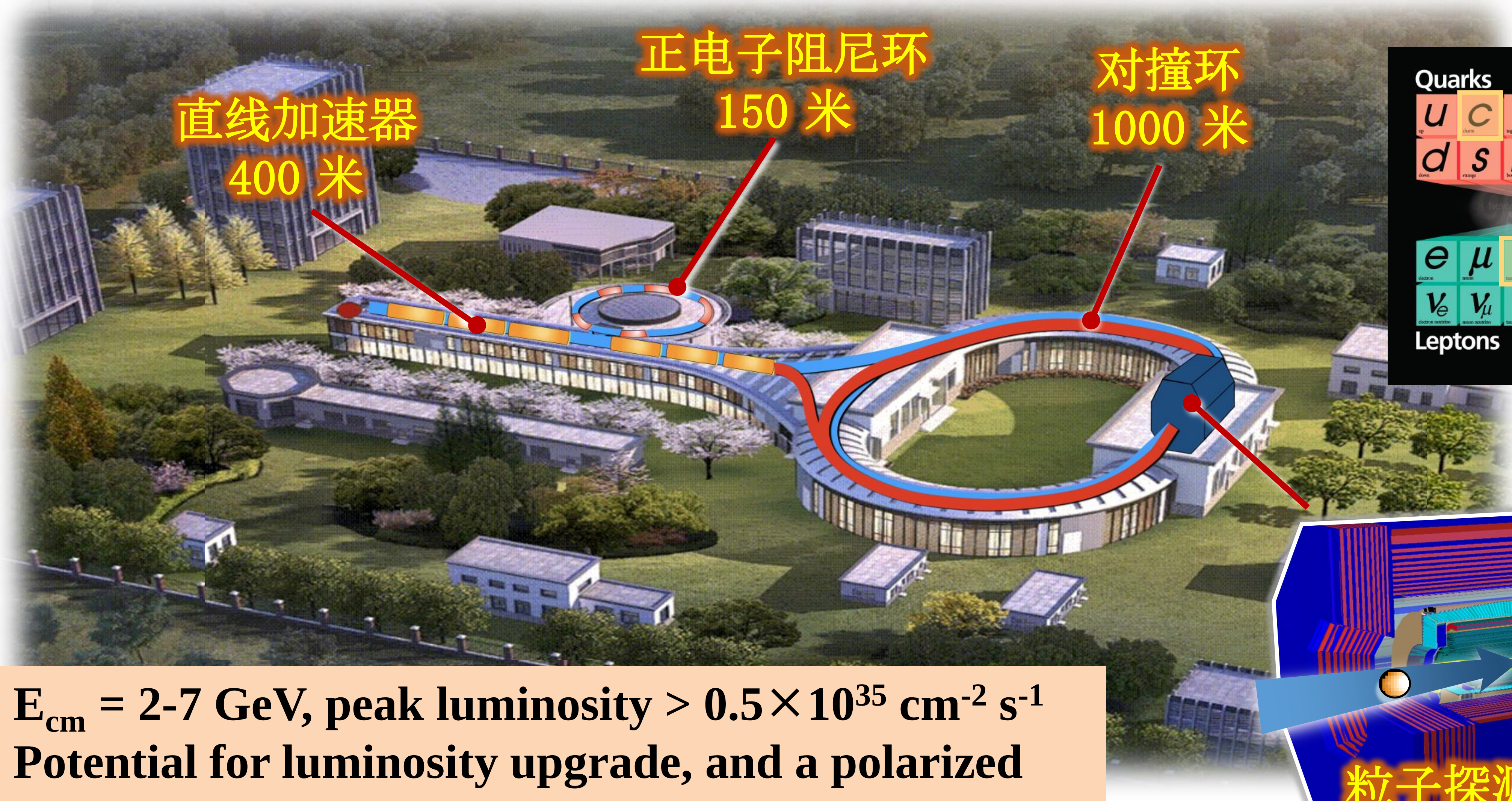
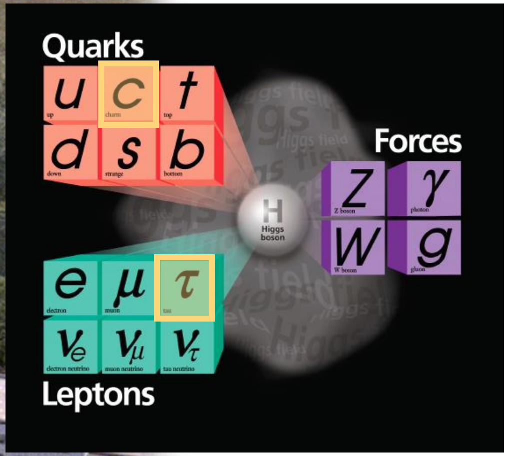
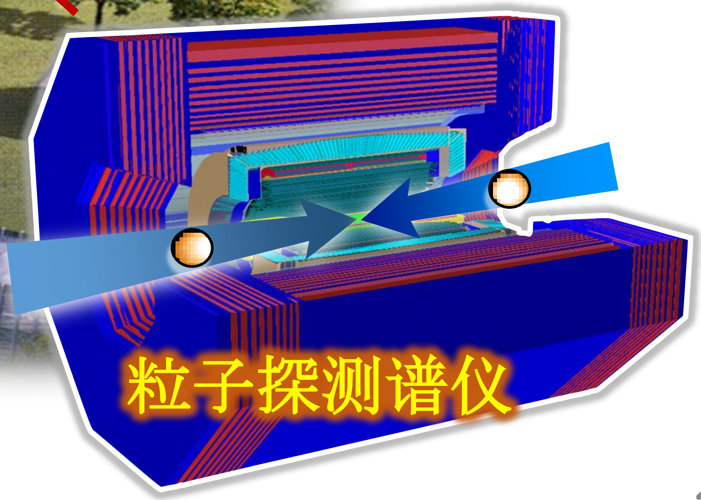
第六届粒子物理天问论坛，2024.11.8-12，洛阳

Super Tau-Charm Facility (STCF)



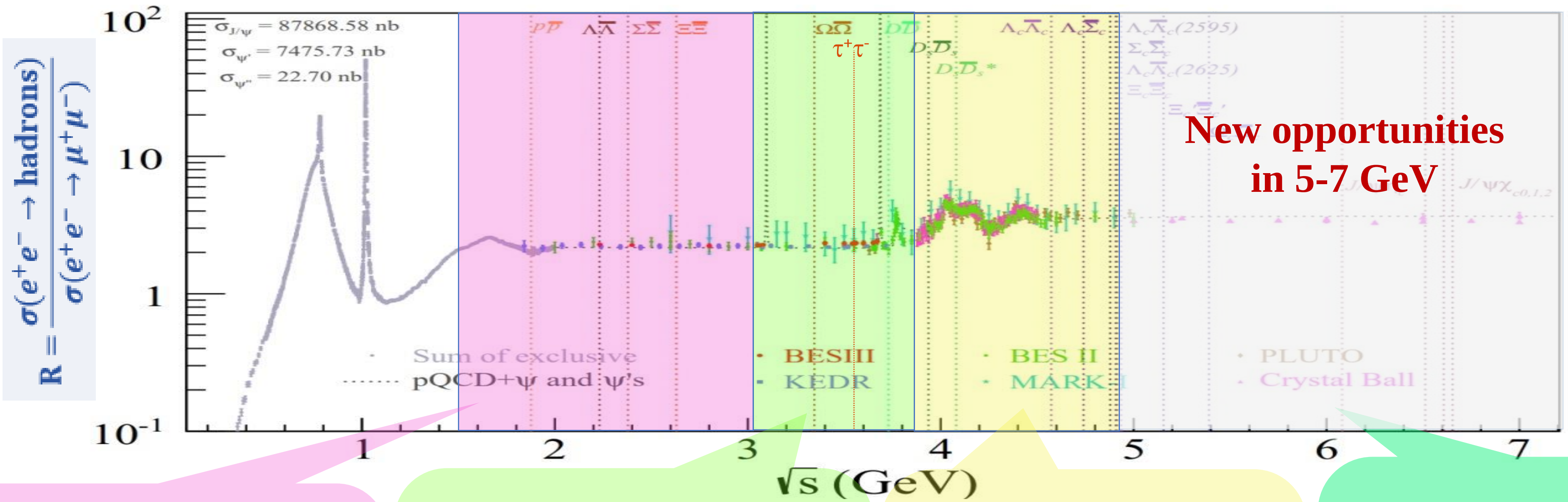




- **E_{cm} = 2-7 GeV, peak luminosity > 0.5×10^{35} cm^{-2} s^{-1}**
- **Potential for luminosity upgrade, and a polarized electron beam**
- **Site: Suburban “Future Big Science City” in Hefei**

2-7 GeV: Unique Features, Broad Physics Spectrum

- **Transition region** between perturbative and non-perturbative QCD
- **Rich** resonant structures, **large production cross-sections** for charmonium states
- **Pair production** of hadrons and tau leptons **at threshold**
- **Copious production of exotic hadrons** (multi-quark, gluonic and hybrid states)



- Nucleon/Hadron form factors
- ϕ(2170) resonance
- Mutltiquark states with s quark
- MLLA/LPHD and QCD sum rule predictions

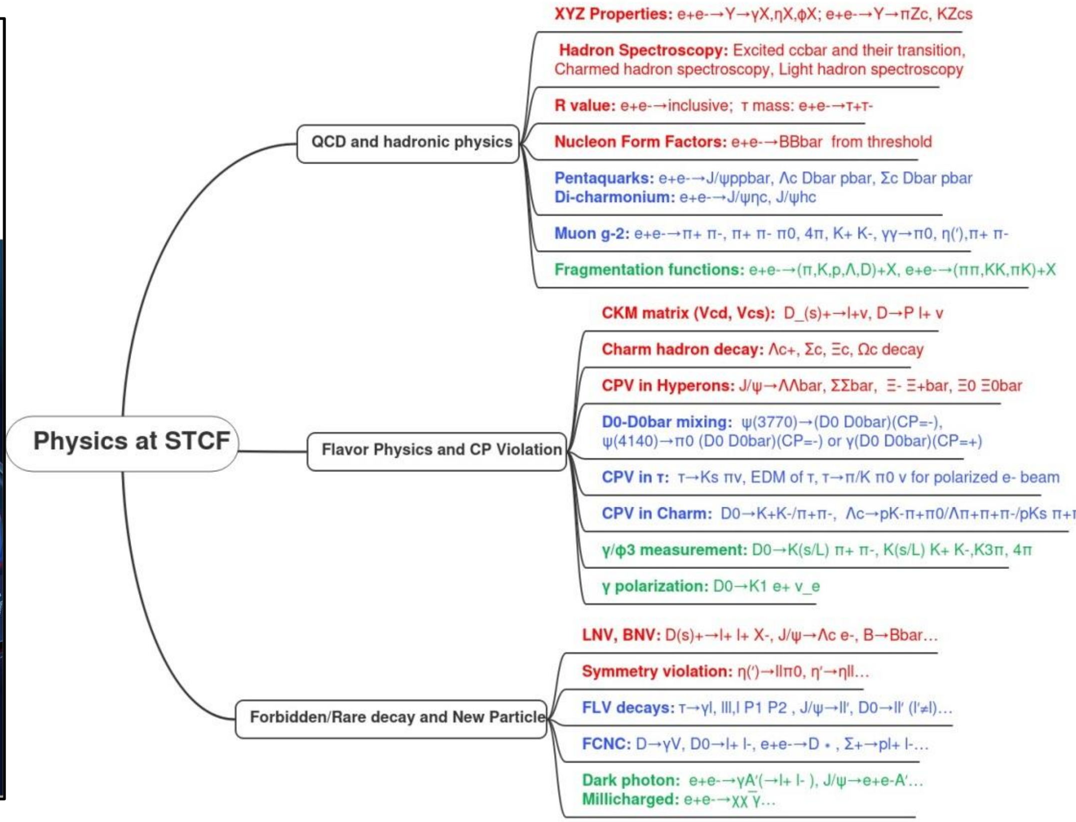
- Light hadron spectroscopy
- Gluonic and exotic
- LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

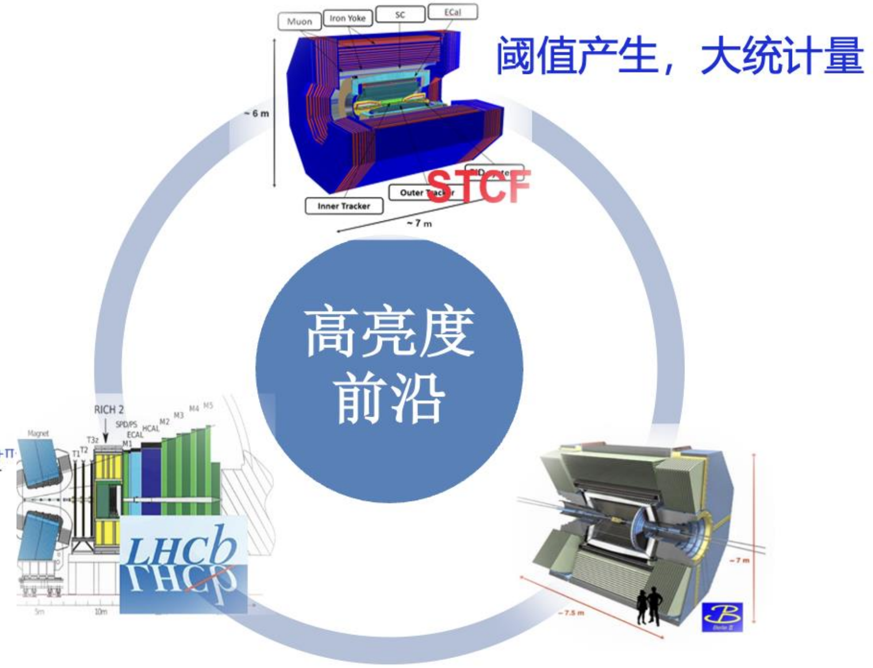
- XYZ particles
- Physics with D mesons
- f_D and f_{Ds}
- D_0-$\bar{D}_0$ mixing
- Charm baryons

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

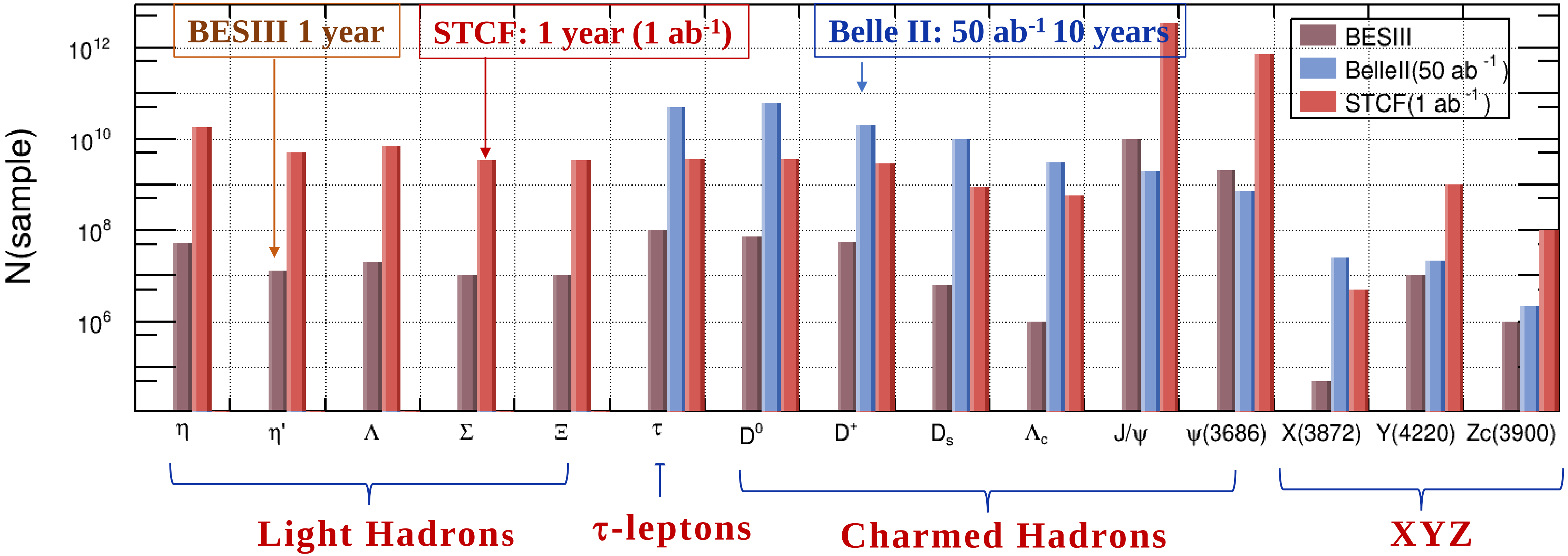
Physics Program at STCF

- **STCF conceptual design report: Physics & detector, Front. Phys. 19, 14701 (2024)**
  - ✓ **Leading role**
  - ✓ **In synergy with Belle II/LHCb/Eic/EicC**



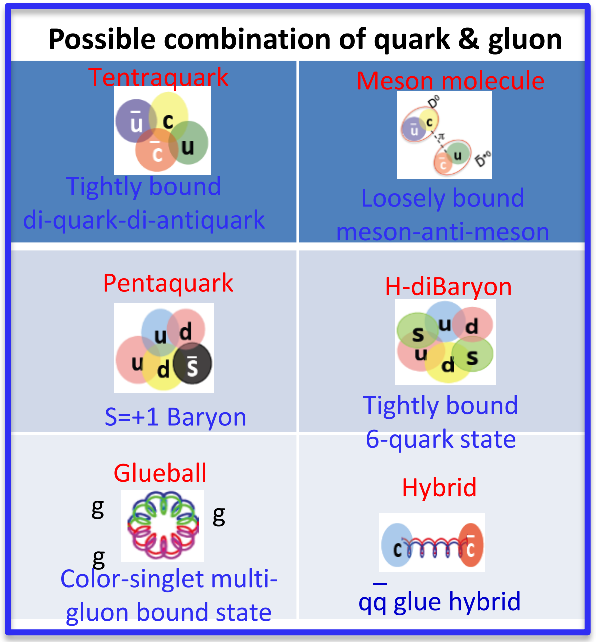


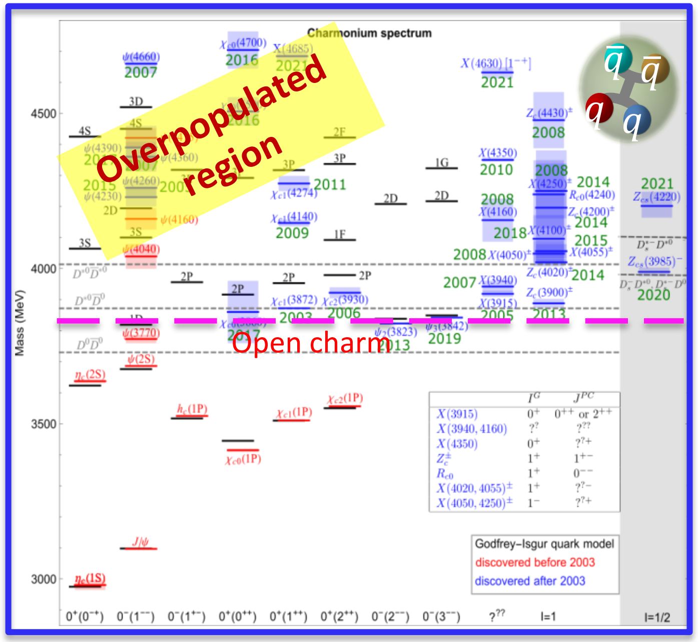
A Super Factory of Various Particles

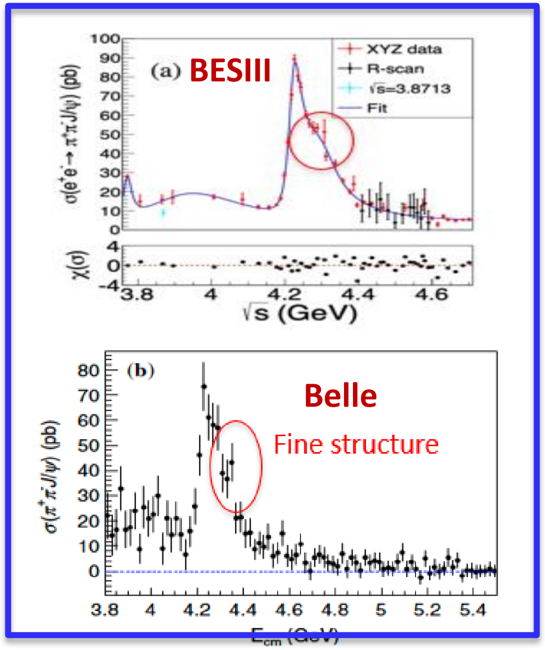


- Not only a τ-charm factory, but also a factory of XYZ, hyperons and light hadrons
  - ✓ Rich QCD and Hadron Physics
  - ✓ Flavor Physics and CPV
  - ✓ New Physics Beyond SM?

Hadron spectroscopy and exotic hadrons



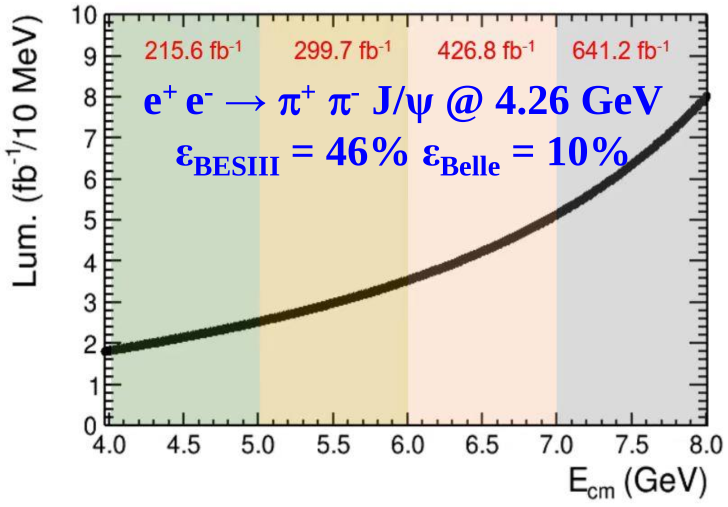




1 ab^{-1}/year at STCF

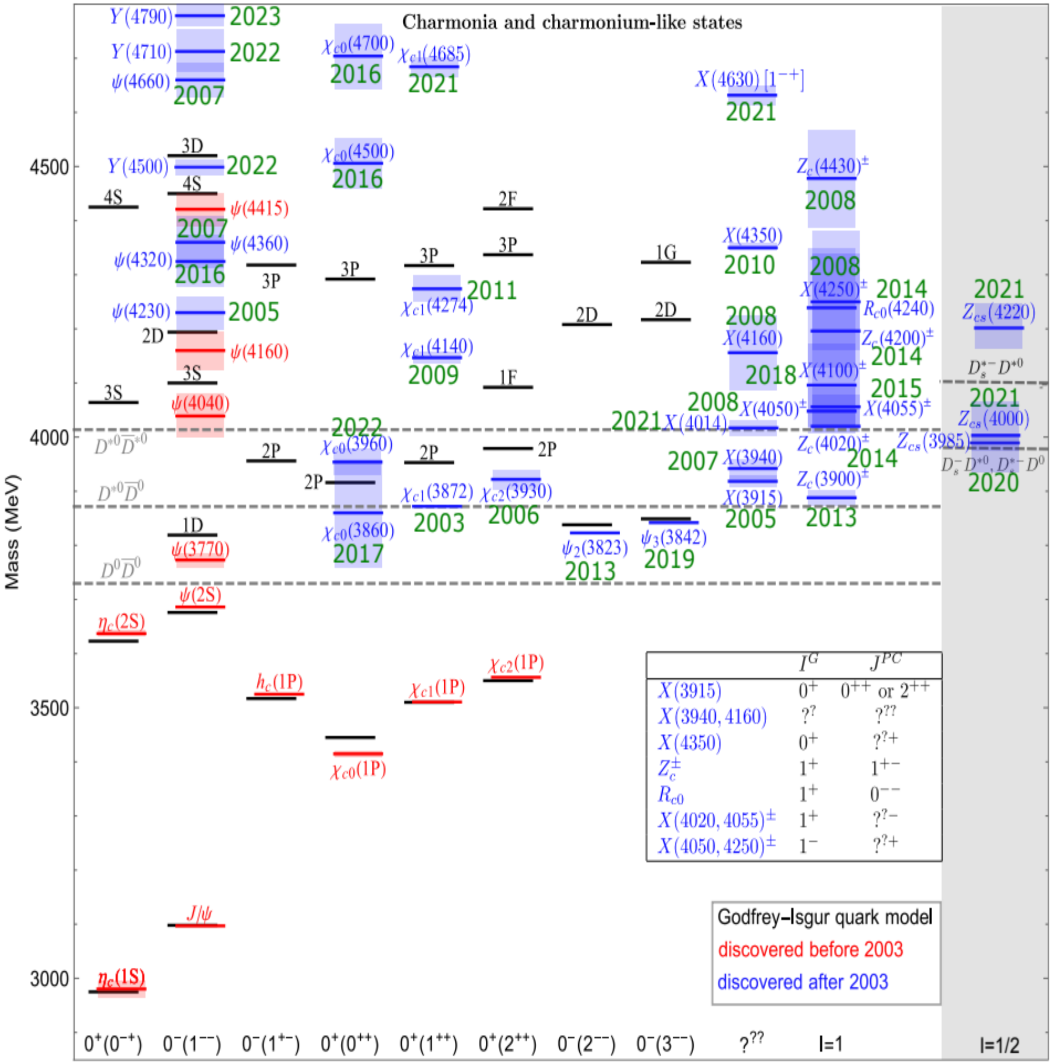
- 1B Y(4230)
- 100M $Z_c(3900)$
- 5M X(3872)

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



Charmonium(-like) states: so-called XYZ

The overpopulated charmonium spectrum is a unique territory to study exotic hadrons.



The XYZ puzzles:

- **Masses away from quark model predictions, *e.g.* X(3872), Y(4230) and Y(4260)**
- **Many seen in final states of charmonium, instead of open-cham channels (Not all)**
- **Charged structures like $Z_{c(s)}$ must contain at least four quarks. Their connections to Y and X are of interest**
- **An overall classification is still lacking**

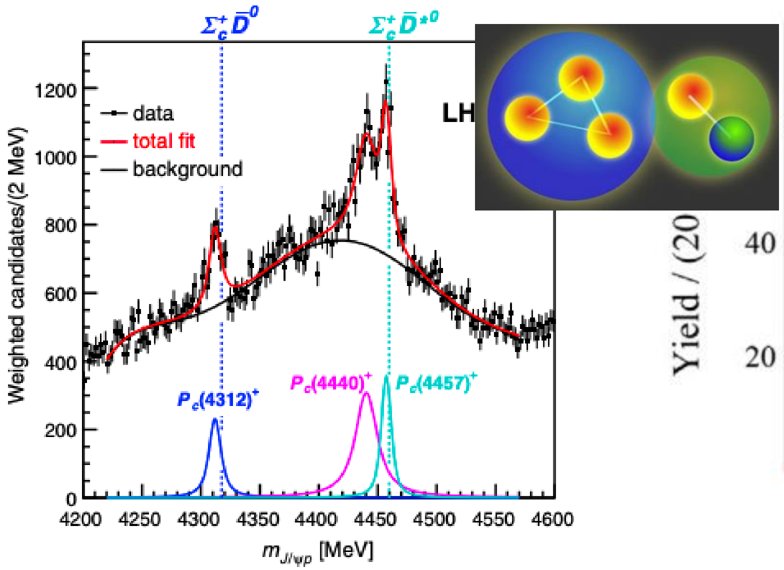
STCF advantage and opportunities :

- **Large data sample**
- **High efficiency and precision.**
- **Unique fine scan of exotic hadron states**

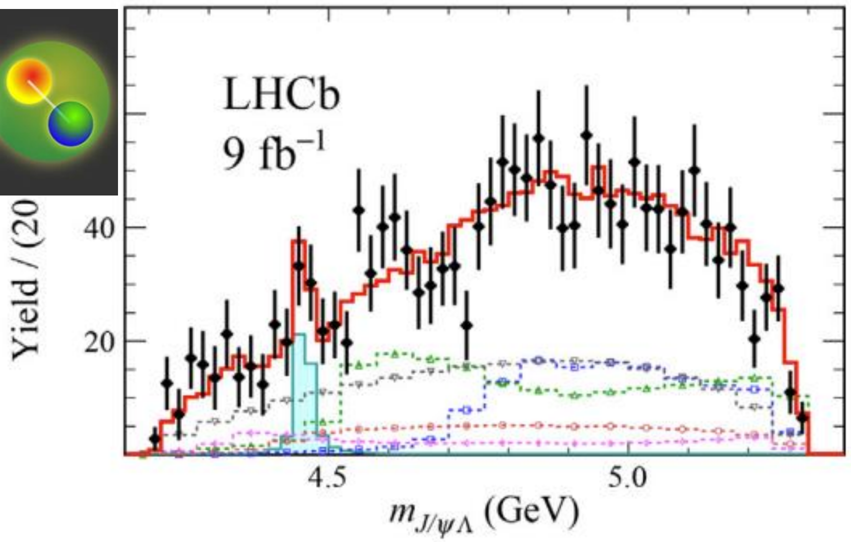
XYZ	$Y(4260)$	$Z_c(3900)$	$Z_c(4020)$	$X(3872)$
No. of events	10^{10}	10^9	10^9	5×10^6

The Penta-quark and Doubly Charmonium

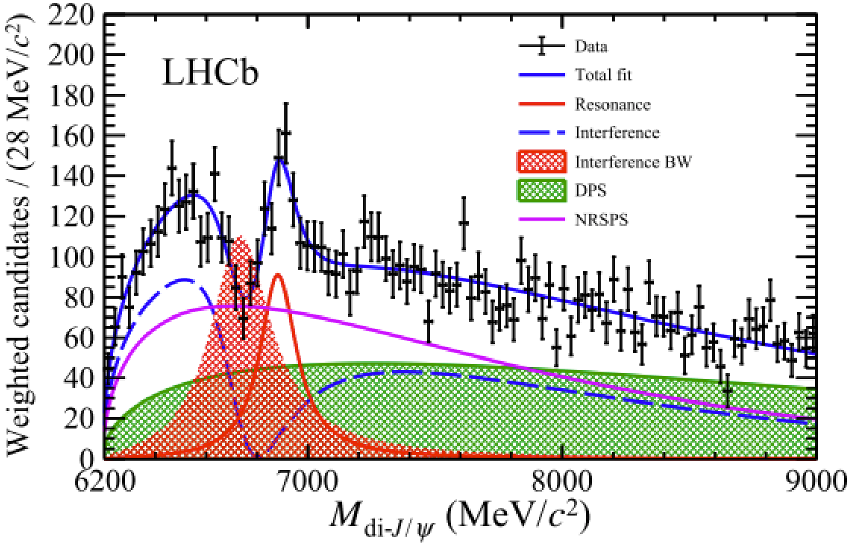
PRL 122, 222001 (2019)



Sci.Bull. 66 (2021) 1278



Sci.Bull. 65 (2020) 1983



- **P$_c$ pentaquarks are good hadronic molecule candidates**
- **More pentaquark states? Cross-section line shape?...**
- $e^+e^- \to J/\psi h\bar{h}$ **are possible processes for studying hidden-charm pentaquarks (**$J/\psi p\bar{p}$ **event level** ~10^3**)**
- **More likely decay to open-charm final states:**

$$e^+e^- \to \Lambda_c \bar{D}^* \bar{p}, \Sigma_c^* \bar{D}^{(*)} \bar{p}$$

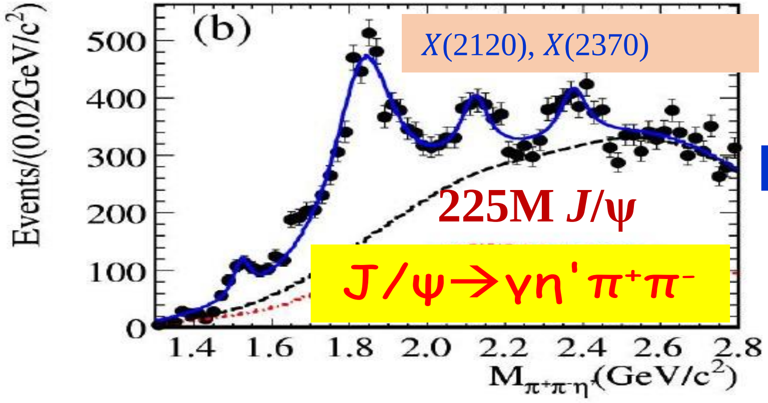
- $e^+e^- \to J/\psi c\bar{c}$ **has a production cross-section on the order of tens of fb**

STCF advantage and opportunities :

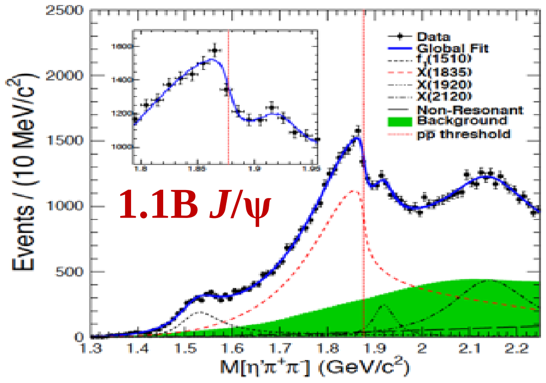
- **CM Energy region above 6 GeV is ideal for fully charmed multi-quark states**
- **Low background and high efficiency**

Glueball from J/ψ radiative decays?

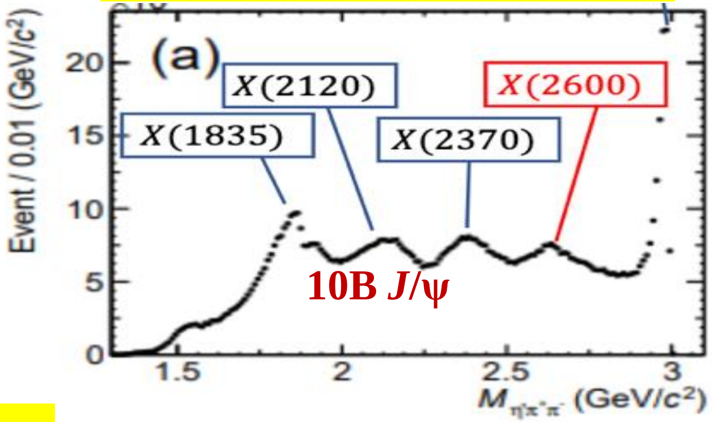
$J/\psi \to \gamma\eta'\pi^+\pi^-$

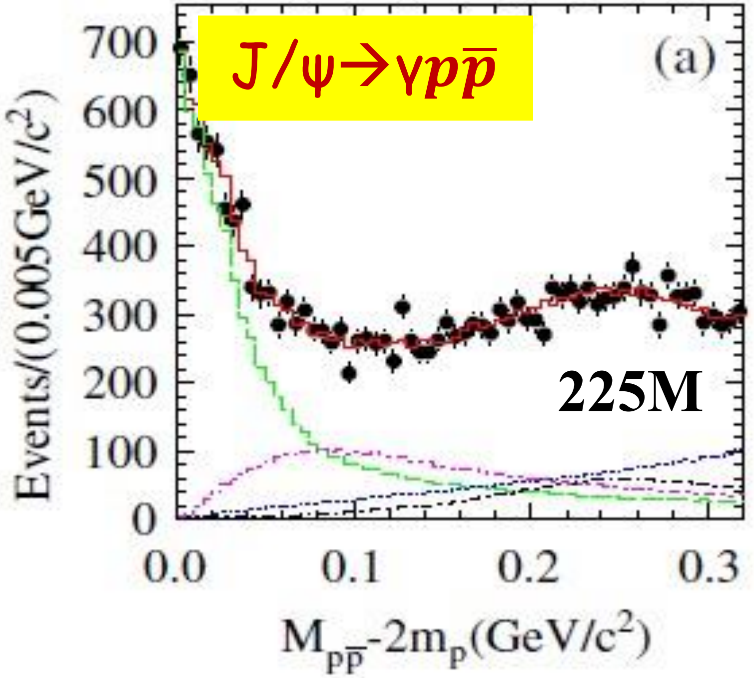


PRL117, 042002 (2016)

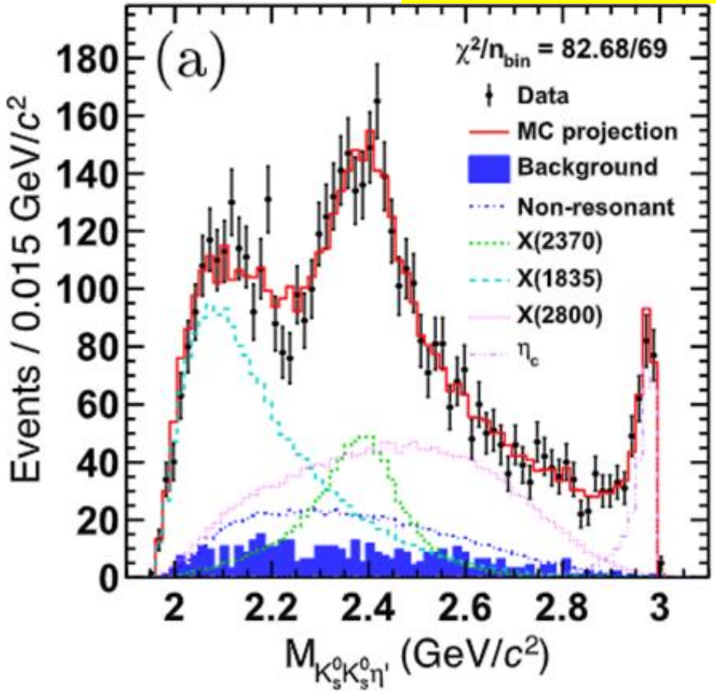


PRL129, 042001 (2022)



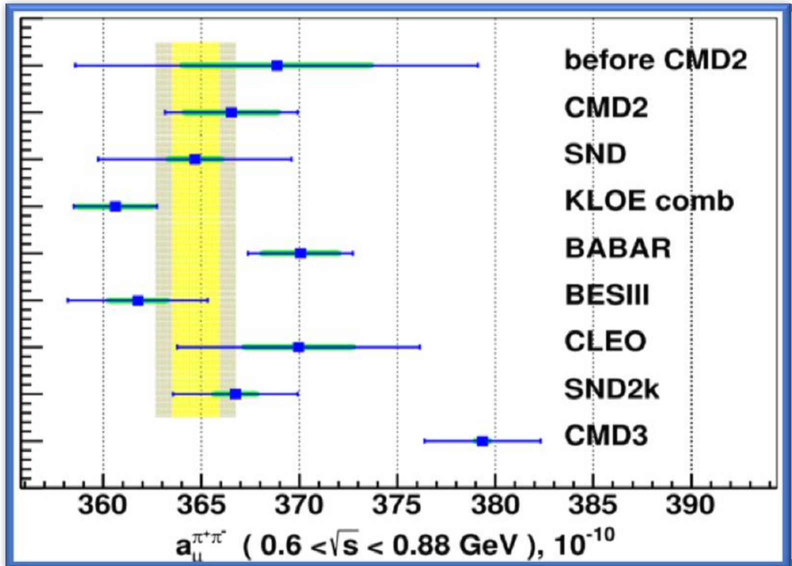


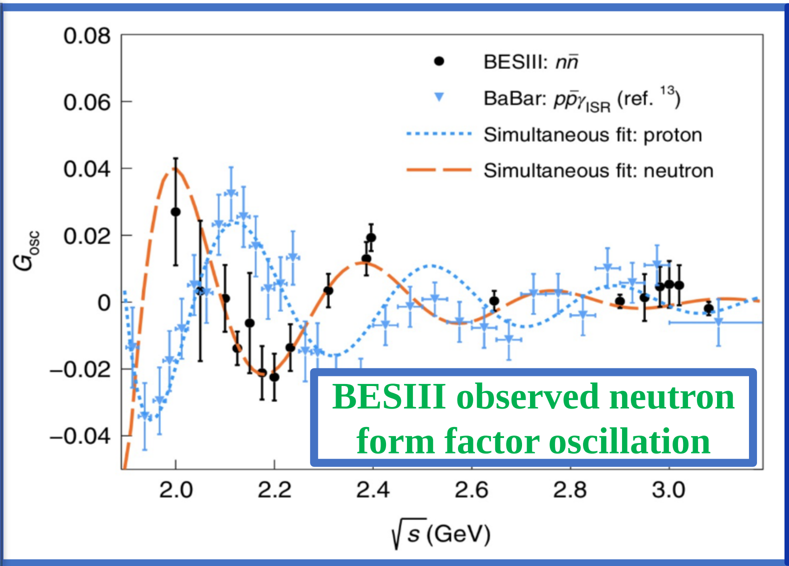
$J/\psi \to \gamma K_S K_S \eta'$ PRL 132.181901 (2024)

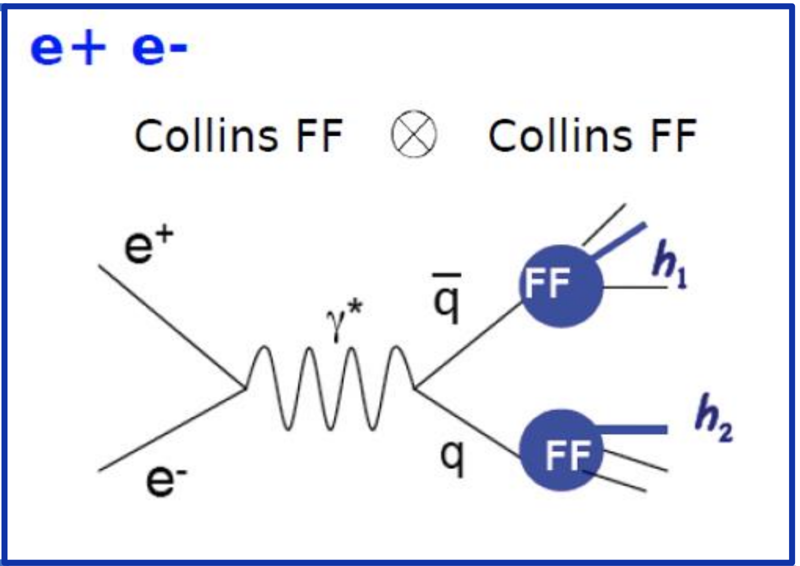


- Partial wave analysis $J/\psi \to \gamma K_S K_S \eta'$ in 10B J/ψ decays
- X(2370) $\to K_S K_S \eta'$ significance more than 14σ
- mass $2395 \pm 11^{+26}_{-94}$ MeV$/c^2$
- width $188^{+18}_{-17}{}^{+124}_{-33}$ MeV
- spin-parity is determined to be 0^{-+}
- candidate for lightest pseudoscalar glueball predicted by LQCD
- **Can STCF be the final judge?**

Hadron Production and hadron Structure







Hadron Production

- A key approach to understand hadron production mechanism & input for precise theory prediction
- Covering range (0.7-7 GeV), important input for hadron exp.

Nuclear EM FFs

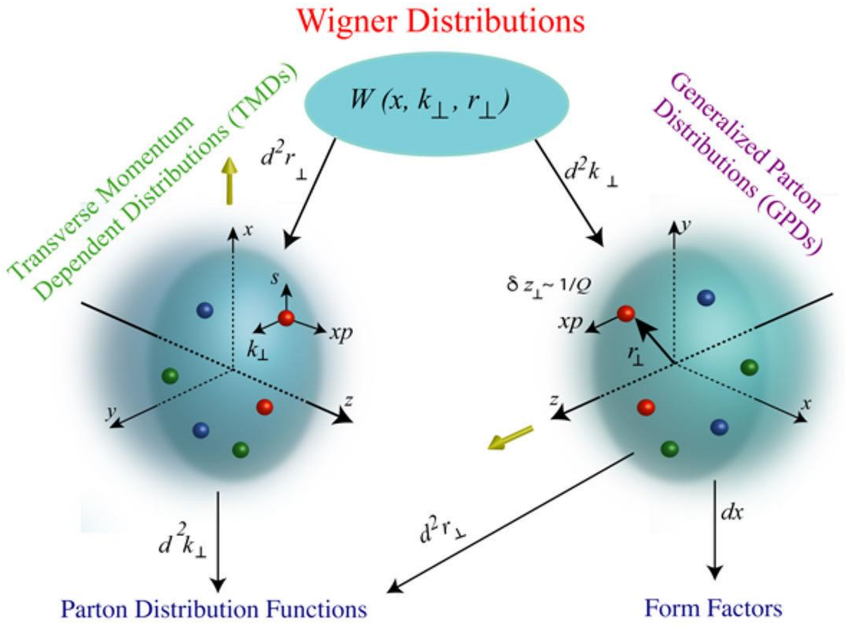
- Fundamental observable, reflects the inner structure of nucleon
- Complementarity to the e-N elastic scattering experiments in similar q^2 region

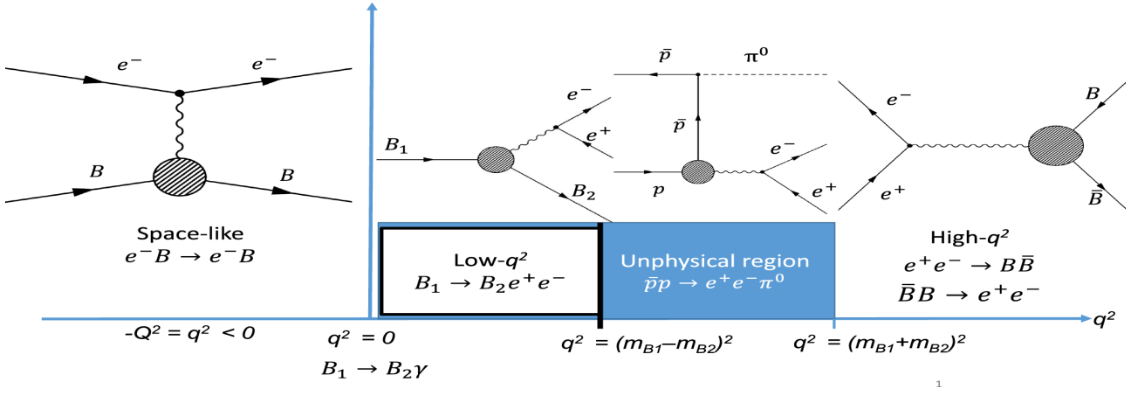
Fragmentation Function

- Understanding QCD dynamics, hadron structure & production mechanism.
- Comparing with ep data to verify universality of fragmentation.

- **Advantage @ STCF: Transition region between non-perturbative QCD and pQCD**

Nucleon structure: electromagnetic form factor





- **$e^+e^- \to B\bar{B}$ @one-photon exchange approximation**
  - ✓ $\frac{d\sigma}{dcos\theta_B} = \frac{\pi\alpha^2\beta C}{2s}[|G_M|^2(1+cos^2\theta_B) + \frac{1}{\tau}|G_E|^2 sin^2\theta_B]$
  - ✓ **velocity** $\beta = (1-4m_B^2/s)^{0.5}$

pQCD predicts continuous transition at high q^2, with the scaling behavior: $F_1 \propto q^{-4}, F_2 \propto q^{-6}$

→

Modified scaling expression in **non-perturbative** region: $\frac{q^2 F_2}{F_1} \propto \ln(\frac{q^2}{\Lambda^2})$, with $\Lambda \approx 0.3$ GeV

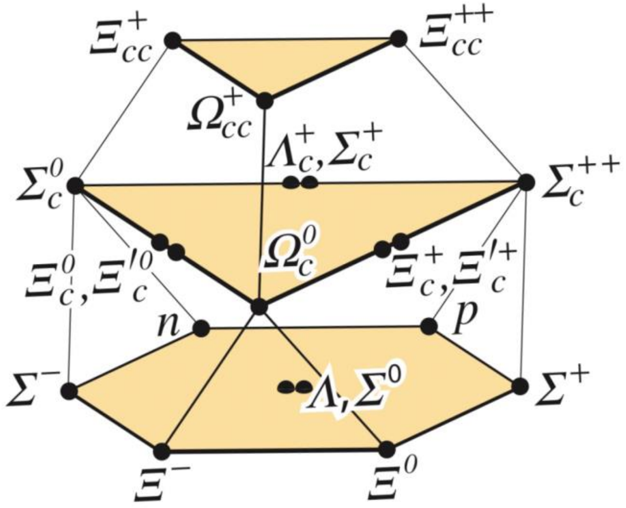
→

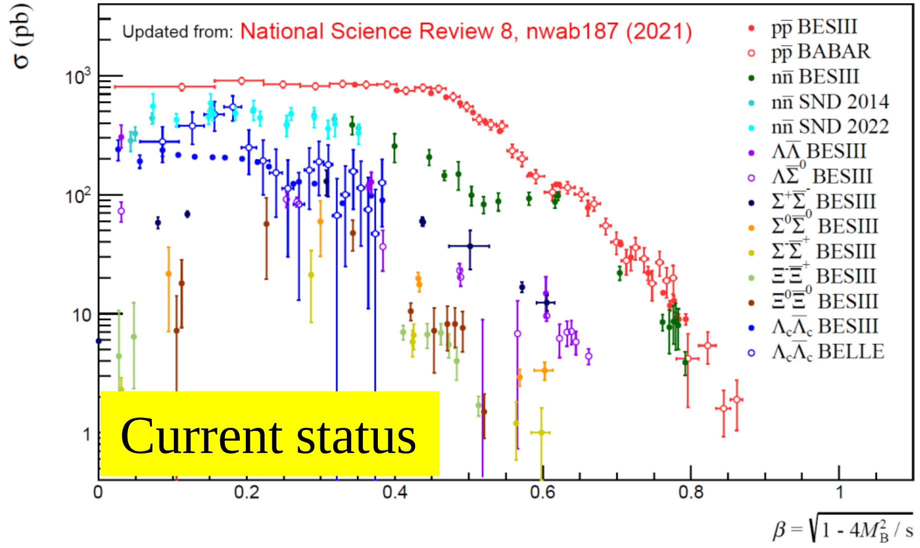
VMD model described the effect of meson cloud $|G_{eff}| = \frac{\mathcal{A}}{(1+\frac{q^2}{m_a^2})[1-q^2/q_0^2]^2}$

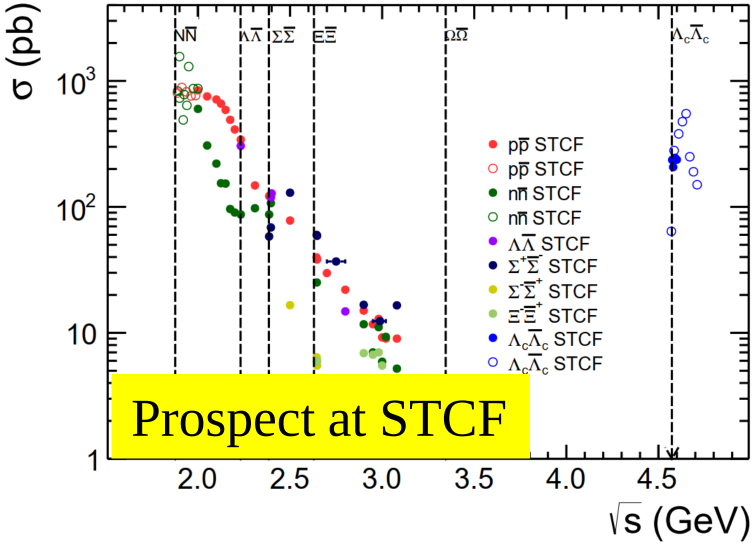
- **Various theory models for TL form factors**
- **Dispersion theoretical analysis: joint interpretation of SL and TL**

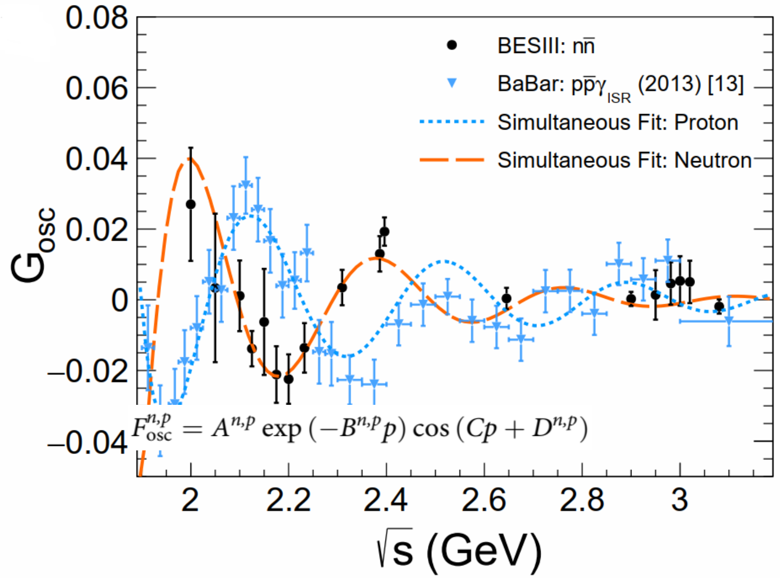
Prospect of TL form factor at STCF

- **Remaining questions of TL electromagnetic form factors**
  - ✓ **Step-like behavior of production cross section, indication of near-threshold singularity**
  - ✓ **Damped oscillation distribution after subtracting modified dipole in effective FF**
  - ✓ **Damped oscillation distribution of $|G_E/G_M|$ ratio**
  - ✓ **Evolution of the phase between G_E and G_M.**
  - ✓ **The asymptotic behavior of TL-EMFFs**

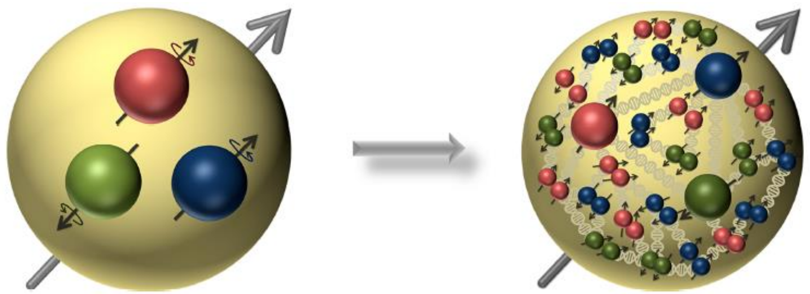


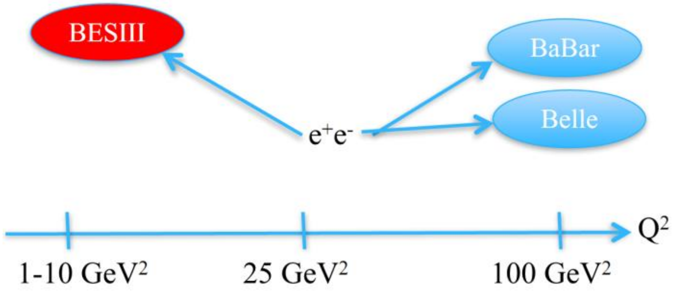


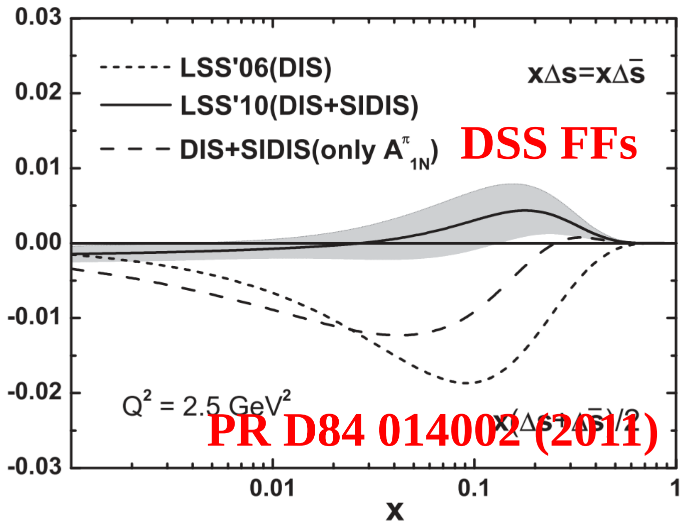


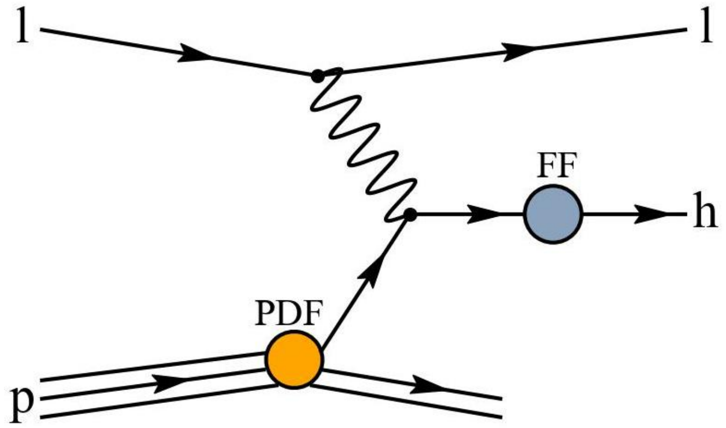


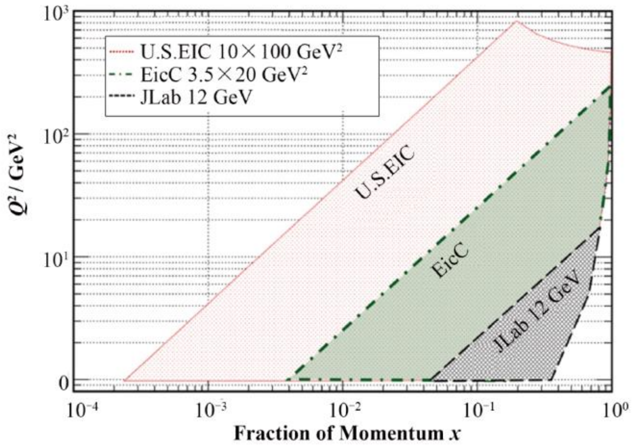
Fragmentation functions (FFs) for EIC & EicC









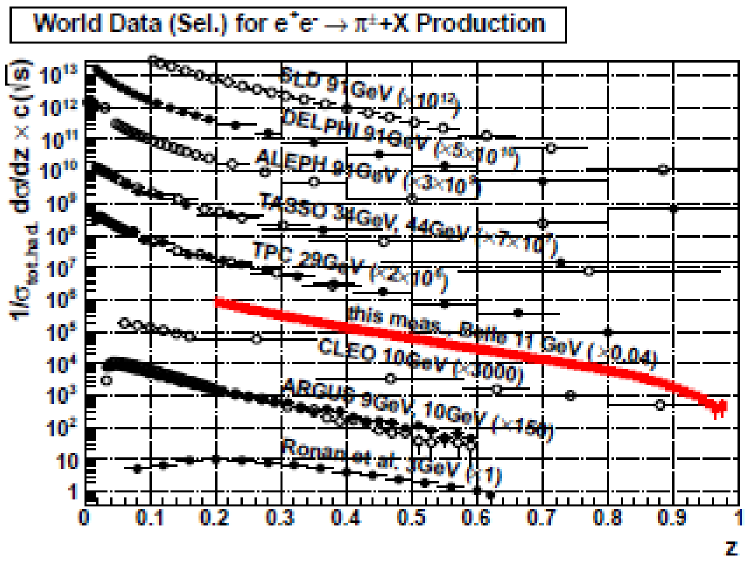


- Strange quark density function: $\Delta s(x)+\Delta\bar{s}(x)$
  - ✓ Inclusive DIS: only proton PDF
    - a. negative for all values of x
  - ✓ Semi-inclusive DIS: proton PDF & kaon FF
    - a. DSS FFs: positive for most of measured x
    - b. HKNS FF & JAM FF: negative
- SIA @ e^+e^-: the cleanest input for FFs fitting

Precise knowledge of FFs will be crucial

FFs with quark/hadron polarization

Hadron polarization	Quark polarizatiom @ PPNP 91 136 (2016)		
	Unpolarized	Longitudinally	Transversely
Unpolarized	D_1^h		$H_1^{\perp h}$
Longitudinally		G_1^h	$H_{1L}^{\perp h}$
Transversely	$D_{1T}^{\perp h}$	G_{1T}^h	H_1^h $H_{1T}^{\perp h}$



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M. Anselmino, P. Kroll E. leader, Z.Phys.C 18,307 1983
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"model estimates consistent with data"

LO groundbreaking

P. Chiappetta et al. , Nucl.Phys.B 412, 3 1994
J. Binneweis. B. Kniehl, G. Kramer, Z.Phys.C 65, 471 1995
J. Binneweis. B. Kniehl, G. Kramer, Phys.Rev.D 52, 4947 1995
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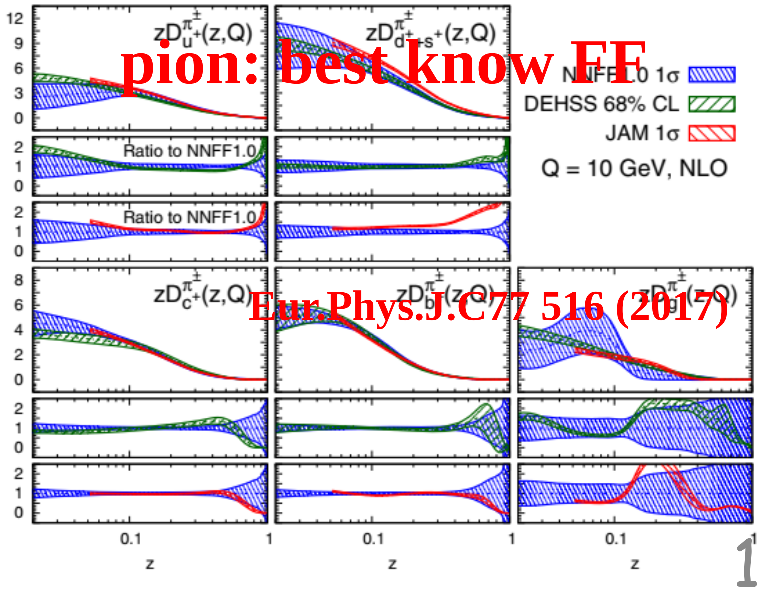
L. Bourhis et al. Eur.Phys.J.C 19, 89 2001
B. Kniehl G. Kramer, B. Potter, Nucl.Phys.B 582, 514 2000
S. Kretzer, Phys.Rev.D 62, 054001 2000
S. Albino, B. Kniehl, G. Kramer, Nucl.Phys.B 725 2005
M. Hirai et al., Phys.Rev.D 75, 094009 2007
… heavy flavors, hadron mass effects, resummations, …

π^0	CGGRW94
$\pi^\pm, K^\pm$	BKK95
$\pi^\pm, K^\pm$ LEP	
K^0	
Λ	DSV97
$h^\pm$	BFGW00
$\pi^\pm, K^\pm, p/\bar{p}$	KKP00
Flavor tagging	KRE00
OPAL tagging	AKK95
uncertainties	HKNS07

NLO e^+e^- paradigm

D. de Florian, R.S., M. Stratmann , Phys.Rev.D 75, 114010 2007	$e^+e^-, pp, SIDIS$	DSS07
S. Albino, B. Kniehl, G. Kramer, Nucl.Phys.B 803, 42 2008	e^+e^-, pp	AKK08
R.S., M. Stratmann, P. Zurita, Phys.Rev.D 81, 054001 2010	nFFs	SSZ10
C. Aidala, et al. Phys.Rev.D 83, 034002 2011	η	AESS11
E. Leader, A.V. Sidorov, D. Stamenov, arXiv:1312.5200	$SIDIS$ only	LSS13
M. Soleymaninia et al., Phys.Rev.D 88, 054019 2013	$e^+e^-, pSIDIS$	SKMNA13
D. de Florian et al. , Phys.Rev.D 91, 4035 2015, D 95 094019 2017	$\pi^\pm, K^\pm$ update	DSS14/17
E. Leader, A.V. Sidorov, D. Stamenov, Phys.Rev.D 94, 096001 2016	$SIDIS$ only	LSS15
V. Bertone, et al., EPJC 77,516 2017	$h^\pm, e^+e^-$ only	NNFF1.0
N. Sato, et al., Phys.Rev.D 101, 074020 2020	$e^+e^-, SIDIS$	JAM19
R. A. Khalek, et al., Phys.Lett.B 834, 137456 2022	$e^+e^-, SIDIS$	MAPFF1.0

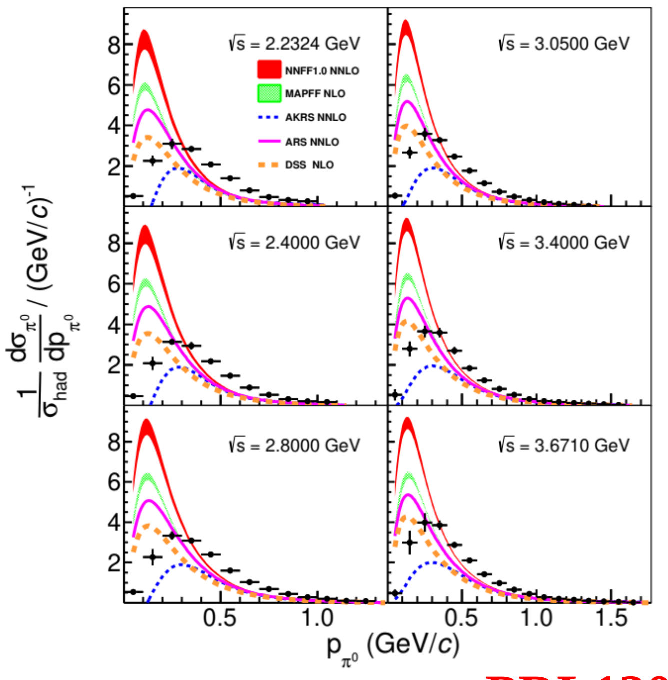
Global paradigm

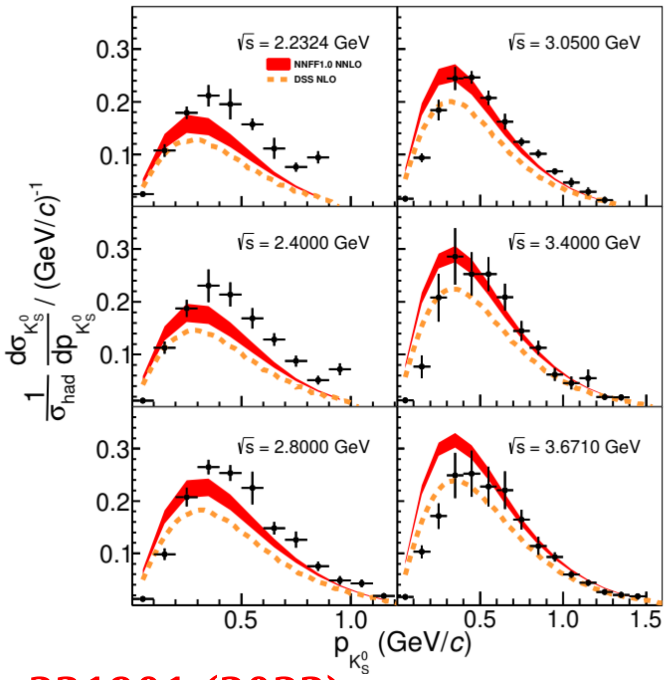


pion: best know FF

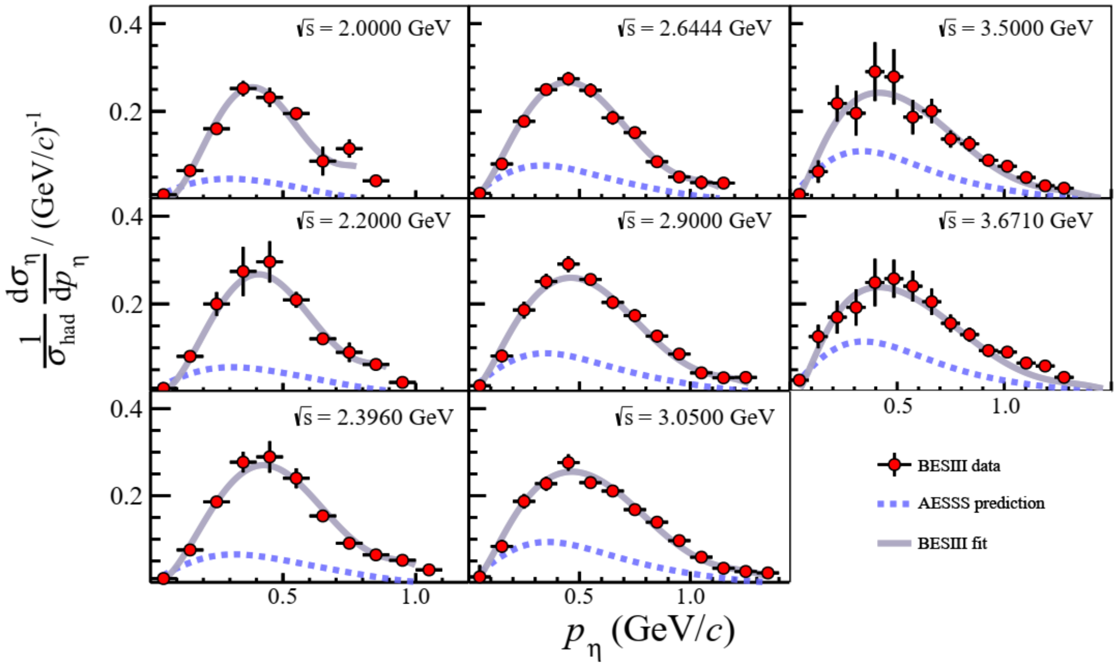
Eur.Phys.J.C77 516 (2017)

$e^+e^- \to \pi^0/K_S^0/\eta + X$ @ BESIII





PRL130, 231901 (2023)



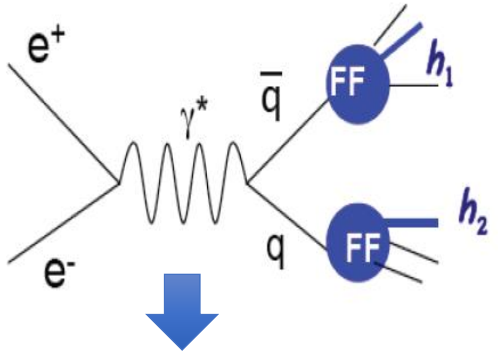
PRL133, 021901 (2024)

- **Inclusive π^0 production: surprise**
- **Inclusive K_S^0 production: not so bad**
- **Inclusive η: good fit achieved, detail arXiv:2404.11527**
  - ✓ $\sqrt{s}$ > 10GeV e^+e^- data + BESIII data
  - ✓ NNLO accuracy, hadron mass correction & higher twist contributions

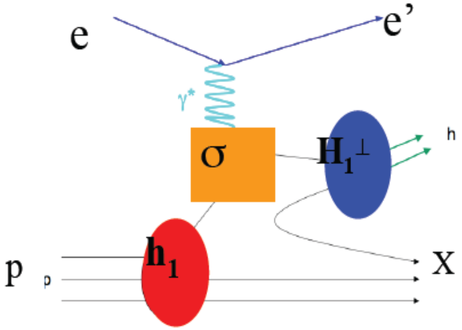
Collins Fragmentation Function

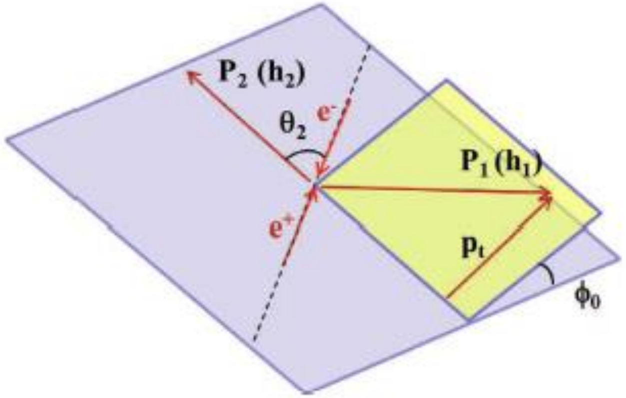
$$D_{hq^\uparrow}(z, P_{h\perp}) = D_1^q(z, P_{h\perp}^2) + H_1^{\perp q}(z, P_{h\perp}^2)\frac{(\hat{\mathbf{k}} \times \mathbf{P}_{h\perp}) \cdot \mathbf{S}_q}{z M_h}$$

Collins FF ⊗ Collins FF



Transversity ⊗ Collins FF





- Normalized ratio $R = N(2\phi_0)/\langle N_0\rangle$
  - ✓ $N(2\phi_0)$: di-pion yield in each $2\phi_0$ bin
  - ✓ $\langle N_0\rangle$: averaged bin content
  - ✓ R^U: unlike sign ($\pi^\pm\pi^\mp$);
  - ✓ R^L: like sign ($\pi^\pm\pi^\pm$)
  - ✓ R^C: all pion pair

- Double ratio: reduce acceptance and radiation effect

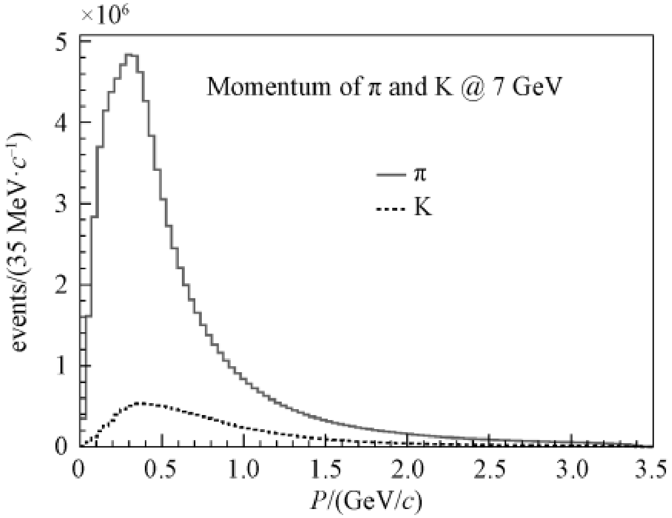
$$\frac{R^U}{R^{L(C)}} = 1 + \cos(2\phi_0) \cdot \frac{\sin^2\theta_2}{1+\cos^2\theta_2} \frac{\mathcal{F}(H_1^\perp(z_1)\bar{H}_1^\perp(z_2)/M_1M_2)}{D_1(z_1)\bar{D}_1(z_2)} = 1 + \cos(2\phi_0) \cdot A^{UL(UC)}$$

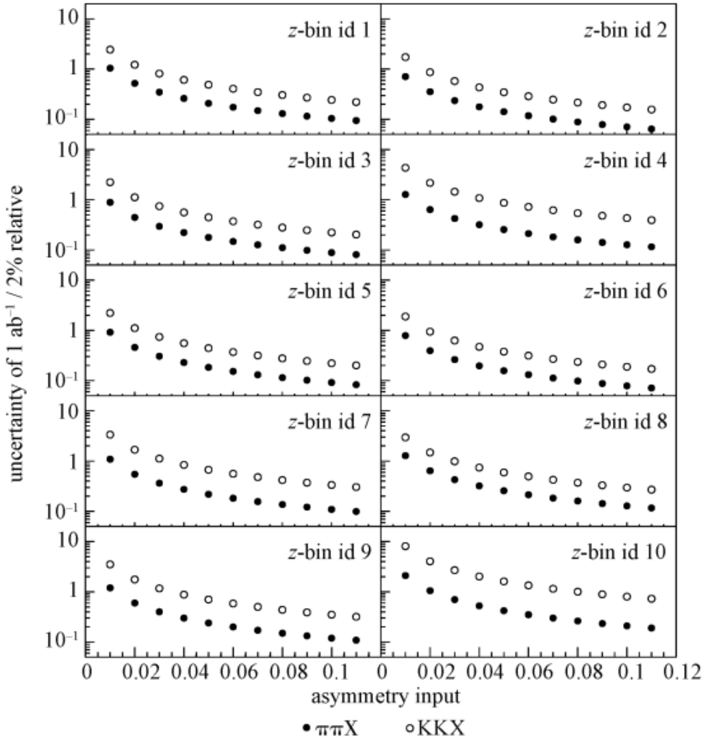
Fit function $\frac{R^U}{R^{L(C)}} = A\cos(2\phi_0) + B$

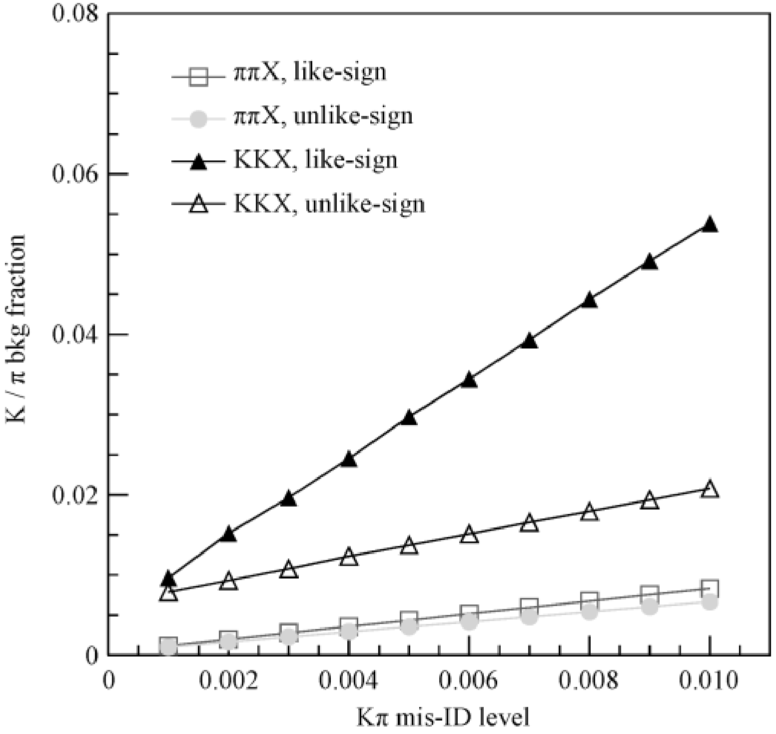
$A^{UL/UC}$ mainly contains Collins effect
B should be consistent with unity

Collins Fragmentation Function

Id	z_1z_2 范围	Id	z_1z_2 范围
1	[0.15,0.2),[0.15,0.2)	6	[0.2,0.3),[0.3,0.5)
2	[0.15,0.2),[0.2,0.3)	7	[0.2,0.3),[0.5,0.9]
3	[0.15,0.2),[0.3,0.5)	8	[0.3,0.5),[0.3,0.5)
4	[0.15,0.2),[0.5,0.9]	9	[0.3,0.5),[0.5,0.9]
5	[0.2,0.3),[0.2,0.3)	10	[0.5,0.9],[0.5,0.9]



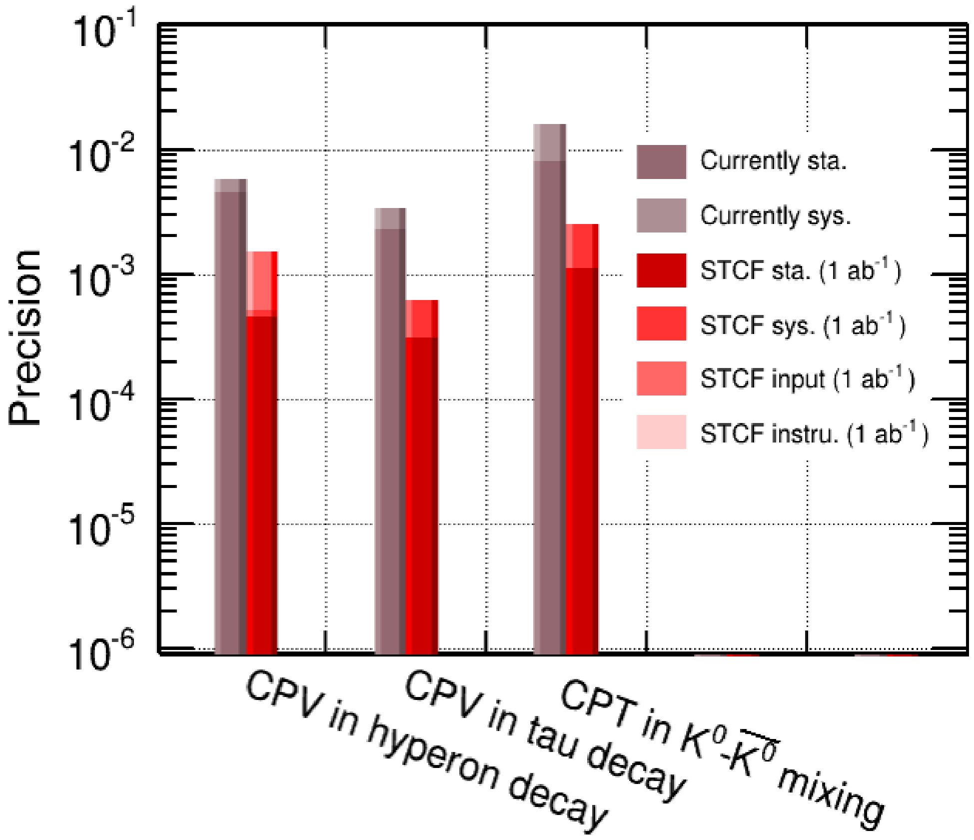




- **The statistical uncertainty on asymmetry A^{UL} with $1ab^{-1}$ @ 7 GeV**
  - ✓ **$(1.4, 4.2)\times10^{-4}$ for $e^+e^- \to \pi\,\pi + X$**
  - ✓ **$(3.5, 20)\times10^{-3}$ for $e^+e^- \to K\,K + X$**
- **Key process for PID of STCF**

CP Violation

- **CPV observed in K, B and D mesons, but all consistent with CKM theory in SM;**
- **Baryon asymmetry of the universe indicates the existence of non-SM CPV sources;**
- **STCF is capable of searching for CPV in hyperons and τ lepton, as well as CPT violation in Kaon with high sensitivity.**



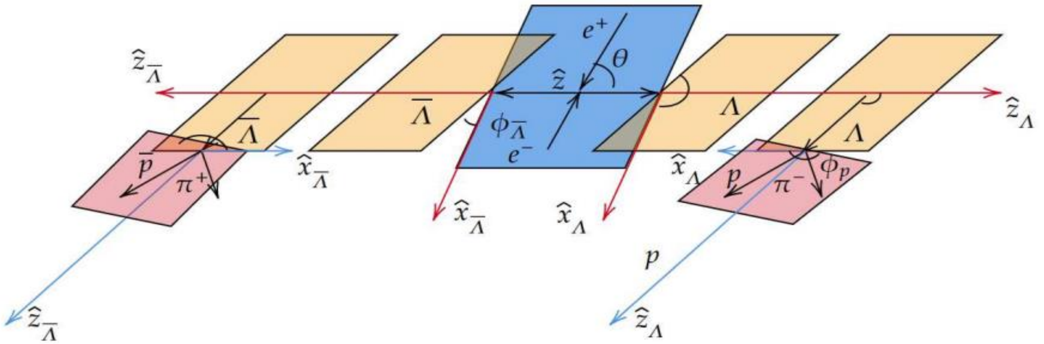
Unique advantages :

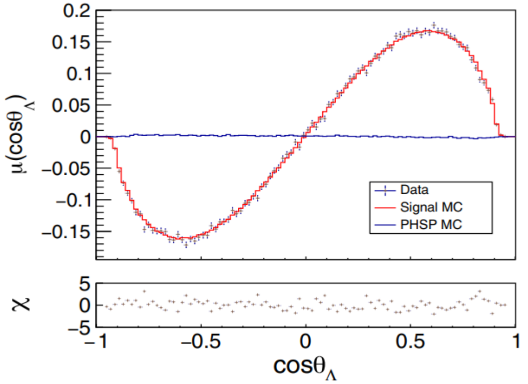
- **Quantum correlation, huge statistics, clean background**

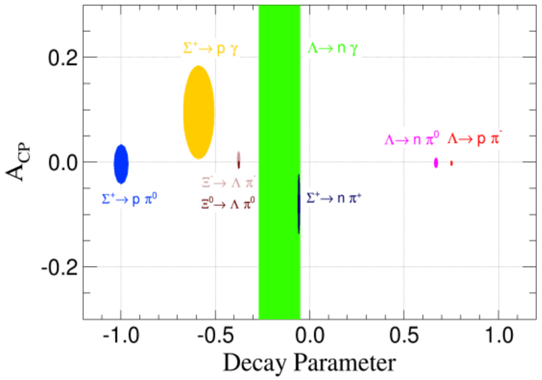
CPV in hyperon decay

- BESIII has observed the polarization of hyperon in the J/ψ decay, and carried out CPV measurement by performing the jointly angle distribution analysis.
- The sensitivity to test CPV in the J/ψ decay is found to be much improved due to the quantum correlation between hyperon pair, and the polarization of hyperon.

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







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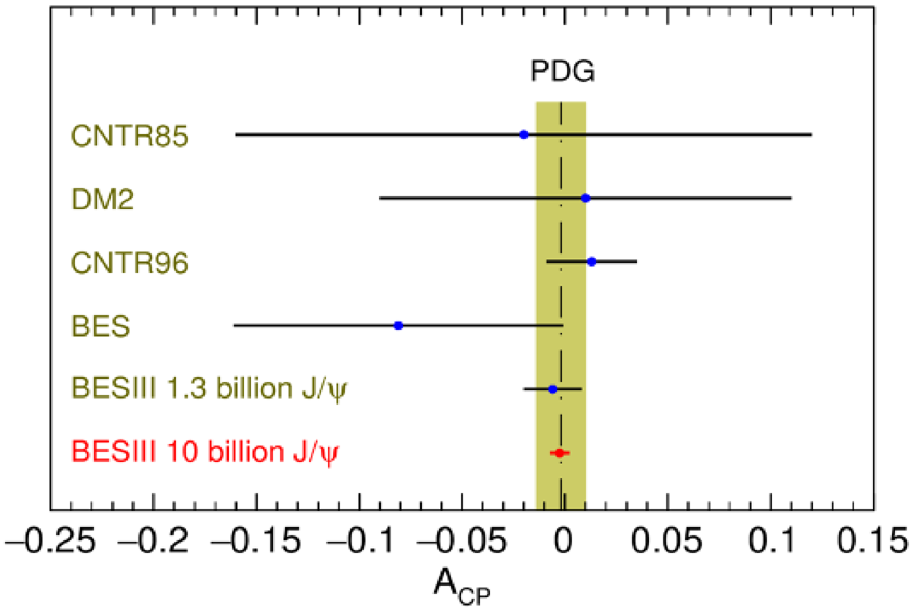


0.5% level sensitivity for CPV test

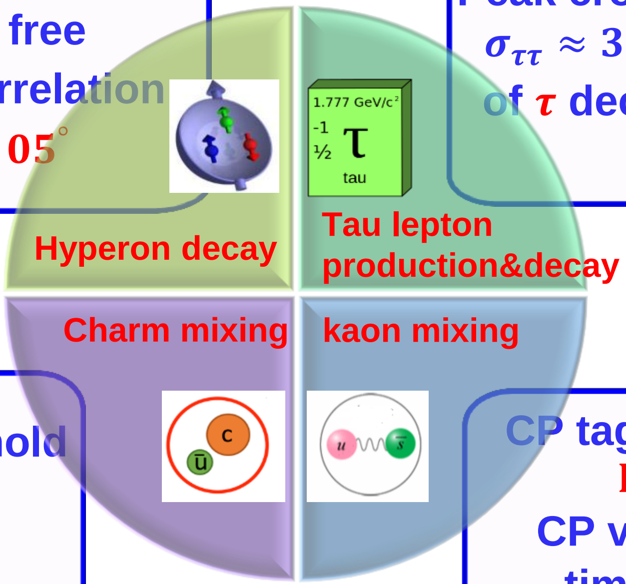
SM prediction: 10^{-4}~10^{-5}

CPV at STCF

- **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,
$\sigma_{\tau\tau}\approx 3.5$ nb, 10 ab^{-1} data in total
of τ decay with 1ab^{-1} @ 4.26 GeV
Sensitivity $\sim10^{-3}$

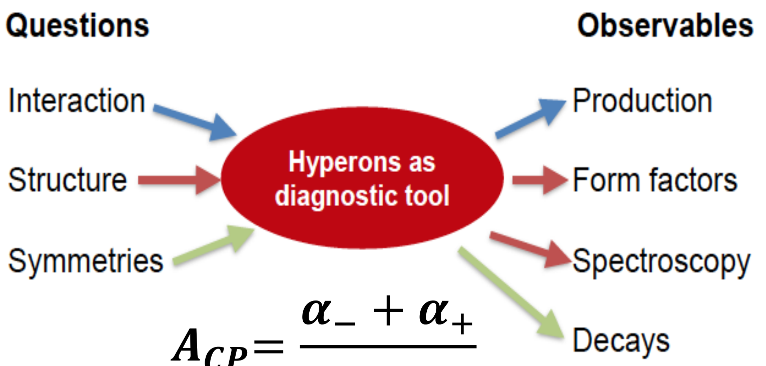


$D^0\bar{D}^0$pairs produced at threshold
quantum coherence with
$(D^0\bar{D}^0)_{CP=-}$ or $(D^0\bar{D}^0)_{CP=+}$
Sensitivity: $x\sim0.035\%$,
$y\sim0.023\%$, $r_{CP}\sim0.017$, $\alpha_{CP}\sim1.3^{\circ}$

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 CPV at STCF

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

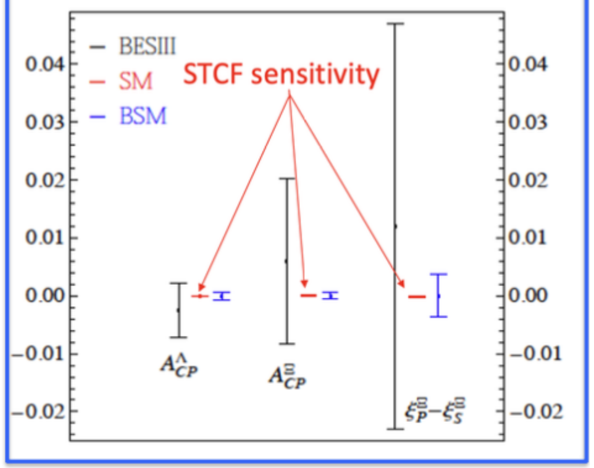


$$A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$$

10^{12} J/ψ → hyperon factory (10^9)

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

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

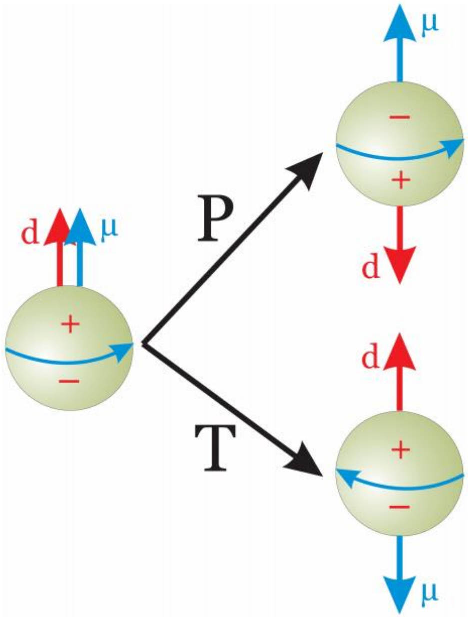


- **With one year data, STCF can reach CPV sensitivity of *Λ* to 1.2×10^{-4}, same level as SM prediction (10^{-4}~10^{-5}).**
- **Optimizing the reconstruction efficiency of low-momentum pion can greatly improve sensitivity.**
- **Using polarized beams, or "monochromatic" collision modes, can improve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

Searching for hyperon EDM

μ: magnetic dipole moment

d: electric dipole moment

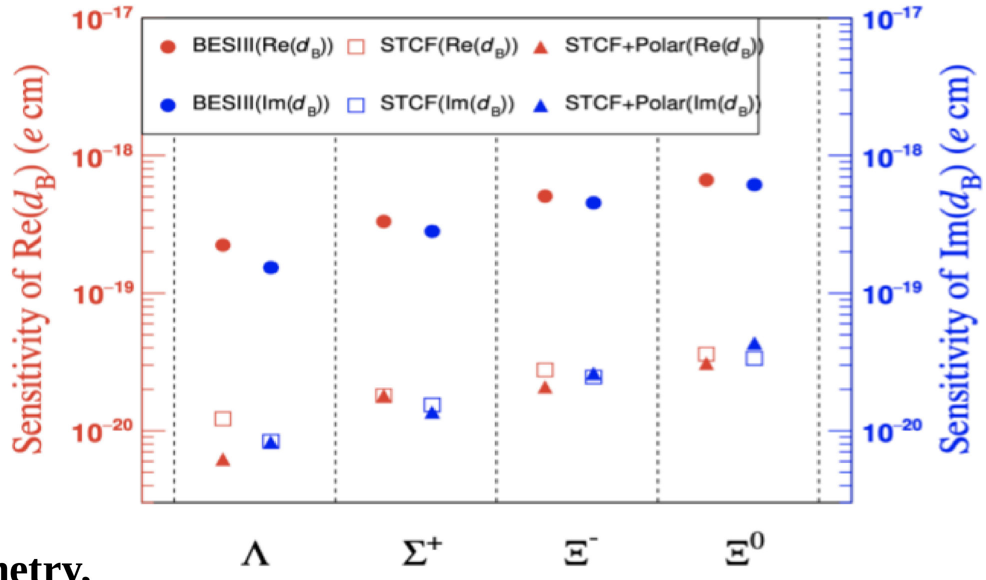


Non-zero EDM ⇒ violate P & T symmetry,
T violation ⇔ CP violation, if CPT holds

- **Detailed dynamics in J/ψ decay to hyperon pair**

$$\mathcal{A} = \epsilon_\mu(\lambda)\bar{u}(\lambda_1)\left(F_V\gamma^\mu + \frac{i}{2M_\Lambda}\sigma^{\mu\nu}q_\nu H_\sigma + \gamma^\mu\gamma^5 F_A + \sigma^{\mu\nu}\gamma^5 q_\nu H_T\right)v(\lambda_2)$$

Systematic measurement of EDMs of hyperon family



(a)Sensitivity of $Re(d_B)$ and $Im(d_B)$

X. G. He, J. P. Ma PLB 839, 137834

SM: $\sim 10^{-26}$ e cm

BESIII: milestone for hyperon EDM measurement
$\Lambda\ 10^{-19}$e cm (FermiLab 10^{-16} e cm)

first achievement for Σ^+,Ξ^- and Ξ^0 at level of 10^{-19}e cm

a litmus test for new physics

STCF: improved by 2 order of magnitude

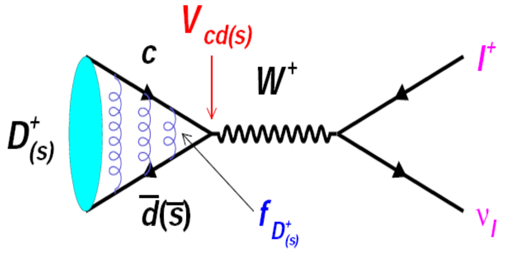
Precise measurement of CKM elements

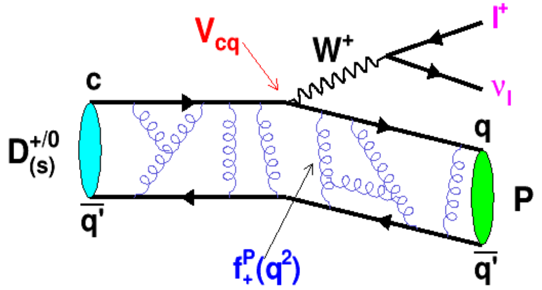
- **CKM elements are the fundamental SM parameters that describe the mixing of quark fields due to weak interaction. Charmed meson leptonic decays are the best way to measure $|V_{cd}|$ and $|V_{cs}|$**

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

Expected precision < 1% at BESIII

BESIII + B factories + 格点QCD





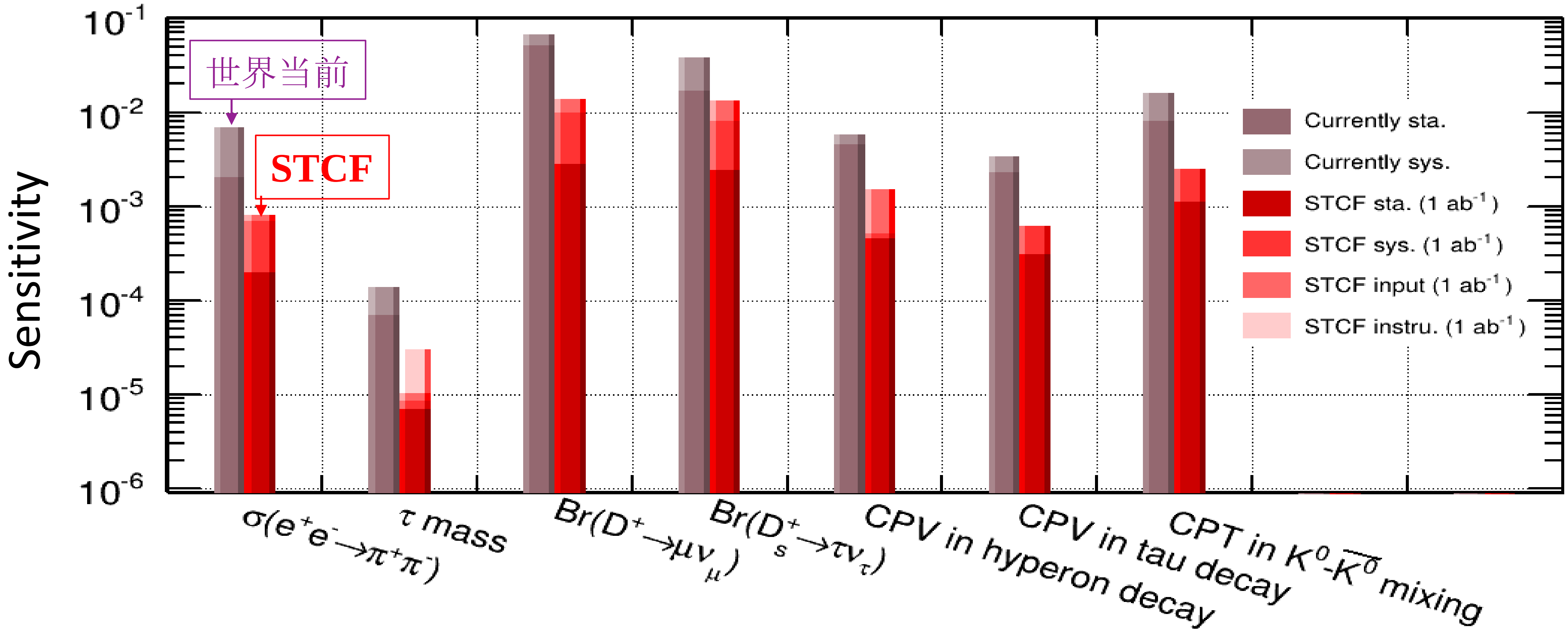
	BESIII	STCF	Belle II
Luminosity	2.93 fb^{-1} at 3.773 GeV	1 ab^{-1} at 3.773 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D^+\to\mu^+\nu_\mu)$	$5.1\%_{stat}$ $1.6\%_{syst}$ [8]	$0.28\%_{stat}$	–
f_{D^+} (MeV)	$2.6\%_{stat}$ $0.9\%_{syst}$ [8]	$0.15\%_{stat}$	–
$\lvert V_{cd}\rvert$	$2.6\%_{stat}$ $1.0\%^{*}_{syst}$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

Theory : 0.2% (0.1% expected)

Theory : 0.2% (0.1% expected)

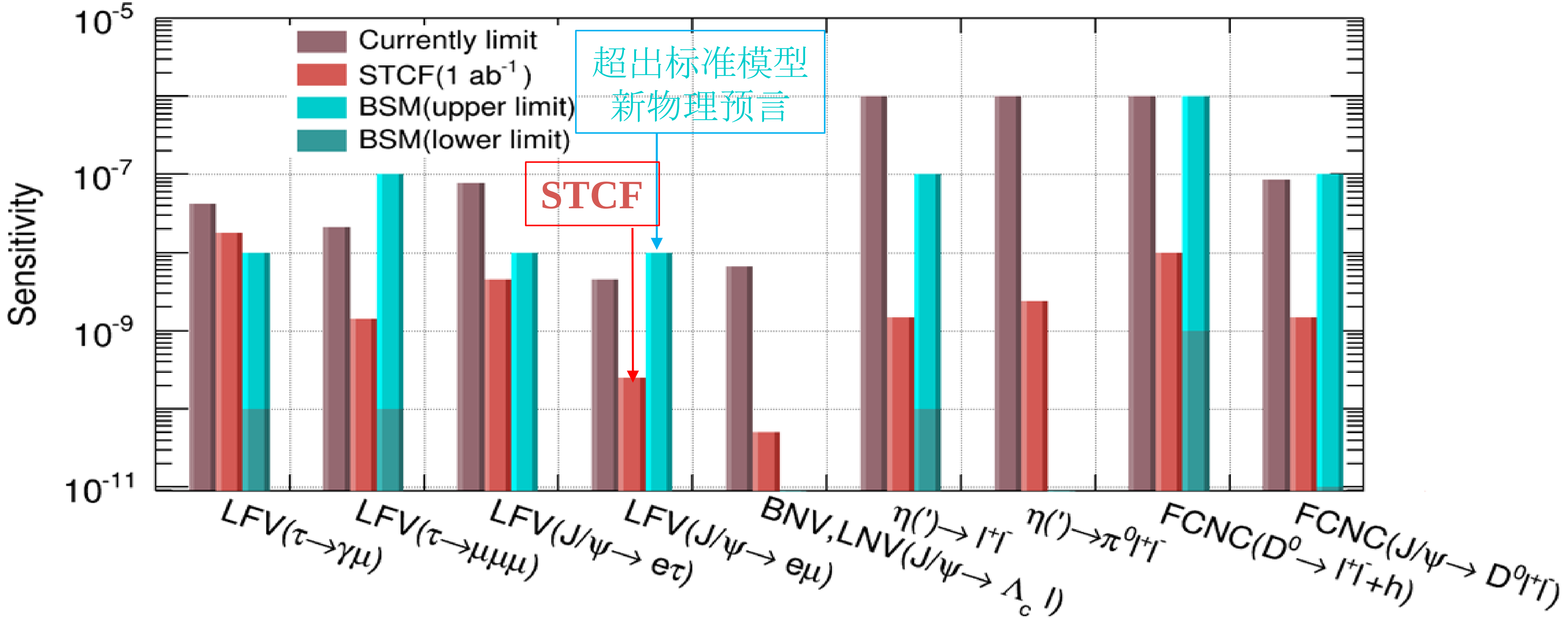
Theory : 0.2% (0.1% expected)

Sensitivity of precision measurements



- The precision frontier for testing of SM parameters
- Uncertainties from reducible (selection-based), and irreducible sources (theoretical input, instrument effect)
- About one order of magnitude improvement in sensitivities

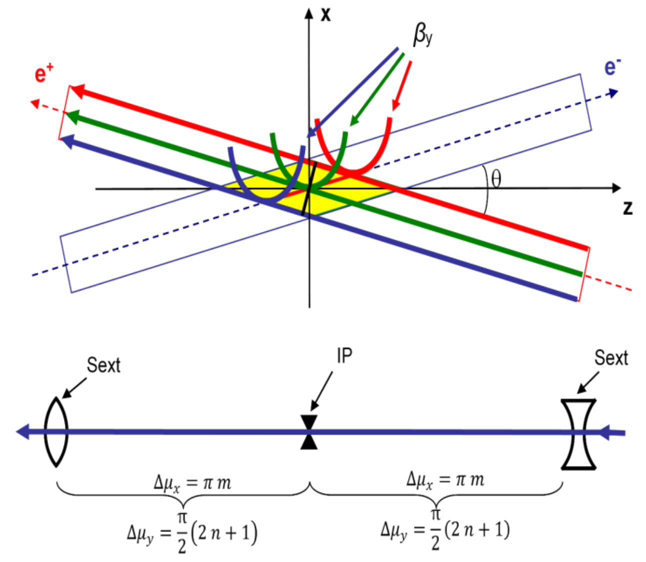
Sensitivity of rare or forbidden decays



- Sensitivity of **various rare/forbidden decays** measurements at STCF are compared with various **BSM models**
- The precision at STCF can be used to **distinguish between various BSM models**

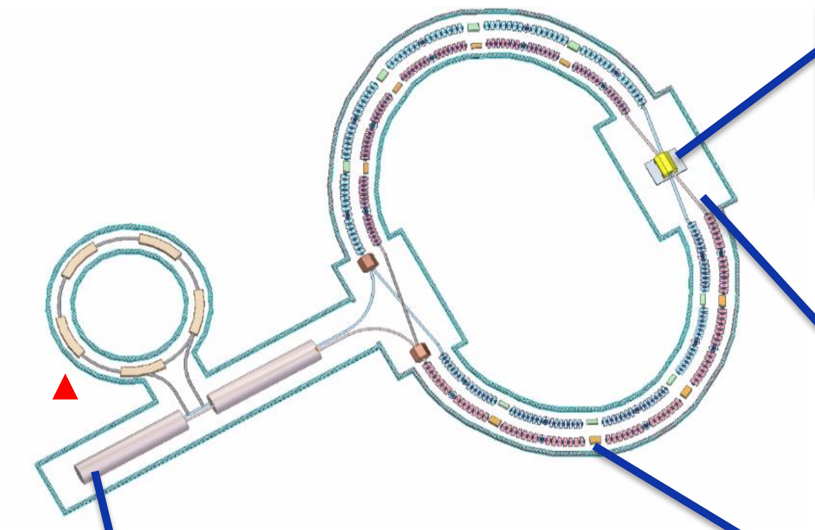
Challenges of STCF Accelerator

- Ultra-high luminosity in tau charm energy region (2-7 GeV), high-quality beam, stable operation
- Extremely small bunch size, high current intensity, strong nonlinearity and collective effect



$$L = \frac{\gamma n_b I_b}{2 e r_e \beta_y^*} \xi_y H$$

Large Piwinski angle + Crab Waist



Collider Ring and IR Physics Design
IP beam size (Y) nm scale, Crab-Waist, nonlinear compensation extremely difficult

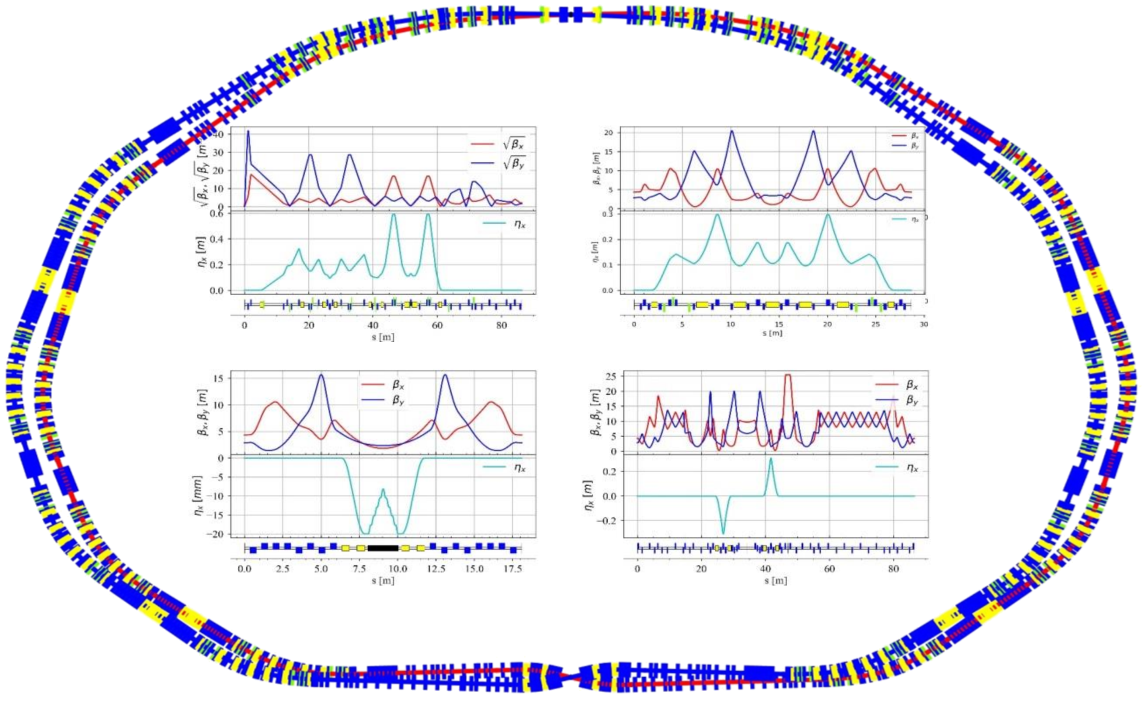
IR Technologies
SC magnets, MDI

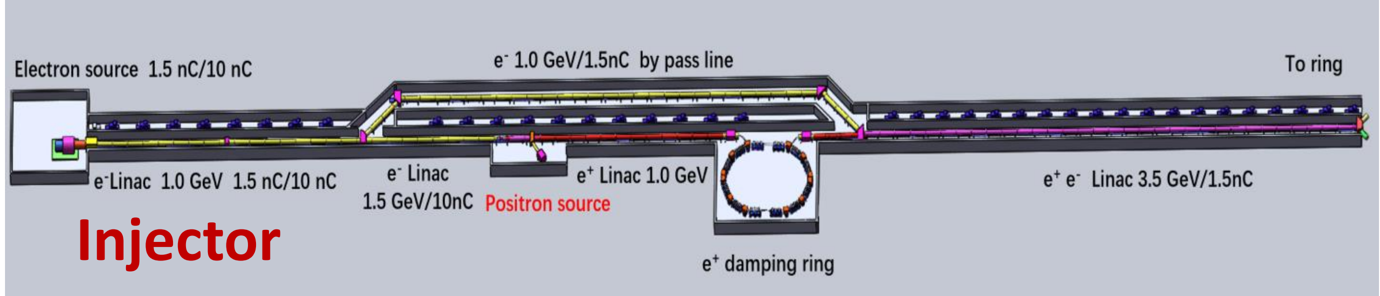
Other key technologies
Ring RF, beam instrumentation and control, beam injection...

Injection into CR (small DA)
high I_b and low ε e+/e- sources

STCF accelerator pre-conceptual design

Collider ring lattice



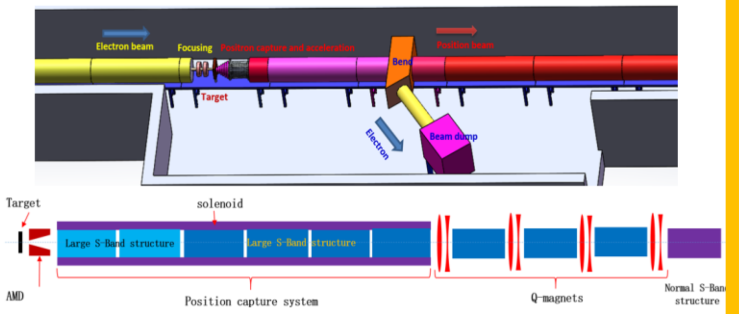


Working on a design with a larger collider ring (800-1000 m)

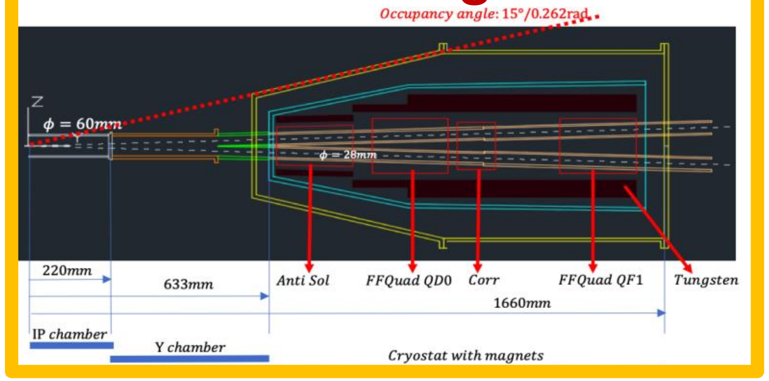
Parameters	Units	STCF
Optimal beam energy, E	GeV	2
Circumference, C	m	616.76
Crossing angle, 2θ	mrad	60
Revolution period, T_0	μs	2.057
Horizontal emittance, ε_x	nm	5.77
Vertical emittance, ε_y	pm	28.85
Beta function at IP, β_x/β_y	mm	40/0.6
Beam size at IP, σ_x/σ_y	μm	15.19 /0.132
Betatron tune, ν_x/ν_y		31.552/24.572
Momentum compaction factor, α_p	10^{-4}	9.71
Energy spread, σ_ε	10^{-4}	8.26
Beam current, I	A	2
Number of bunches, n_b		512
Single-bunch charge	nC	8.04
Energy loss per turn, U_0	keV	286
SR power per beam, P_{SR}	MW	0.572
Transvers damping time, $\tau_{x/y}$	ms	28.59
RF frequency, f_{RF}	MHz	499.7
RF voltage, V_{RF}	MV	1.2
Bunch length, σ_z	mm	8.2
Piwinski angle, ϕ_{Piw}	rad	16.19
Ver. beam-beam parameter, ξ_y		0.107
Luminosity, L	$cm^{-2}s^{-1}$	1.37E+35

STCF Accelerator R&D

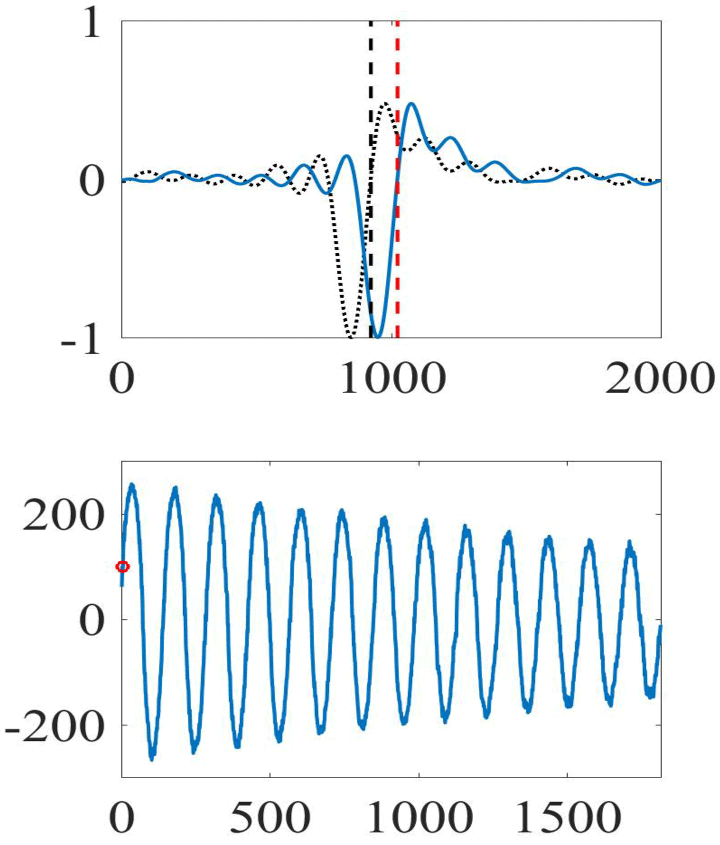
Positron Source Design



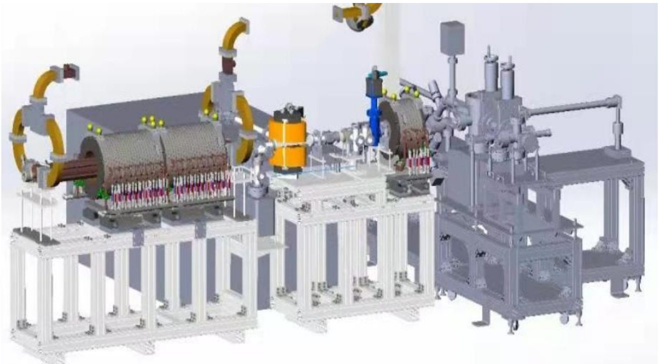
MDI Design



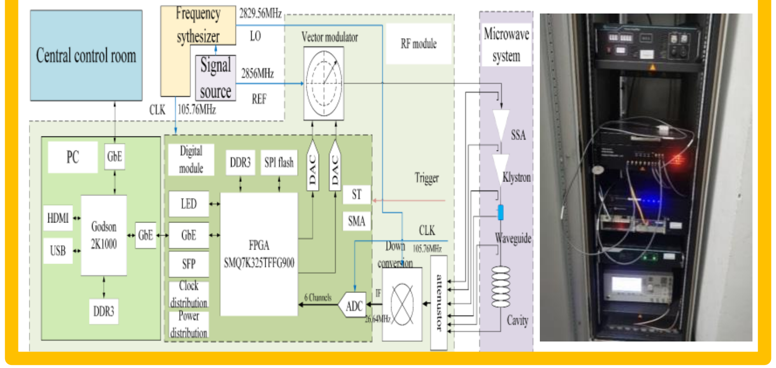
Bunch-by-Bunch 3D position measurement



Photocathode RF gun



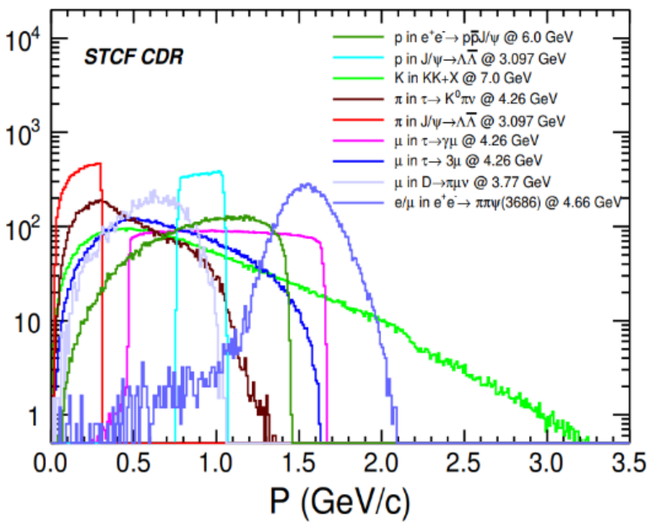
Low level RF system

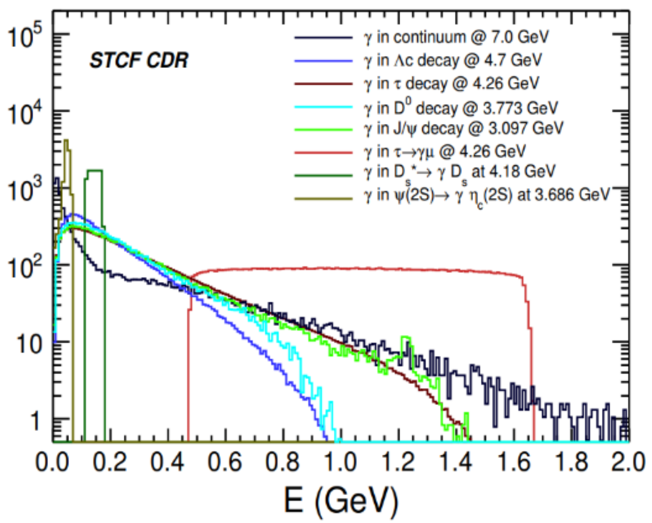


Detector requirements from physics

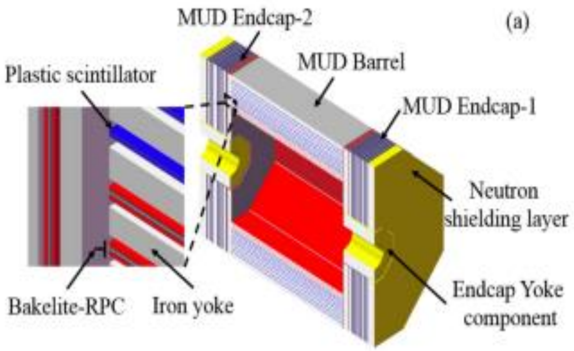
- **Highly efficient and precise reconstruction of exclusive final states produced in 2-7 GeV e^+e^- collisions**
  - ✓ **Precise measurement of low-p particles (< 1 GeV/c) → low mass**
  - ✓ **Excellent PID：π/K and μ/π separation up to 2 GeV**

Process	Physics Interest	Optimized Subdetector	Requirements
$\tau \to K_s \pi \nu_\tau$, $J/\psi \to \Lambda\bar{\Lambda}$, $D_{(s)}$ tag	CPV in the τ sector, CPV in the hyperon sector, Charm physics	ITK+MDC	acceptance: 93% of 4π; trk. effi.: $> 99\%$ at $p_T > 0.3$ GeV/c; $> 90\%$ at $p_T = 0.1$ GeV/c $\sigma_p/p = 0.5\%$, $\sigma_{\gamma\phi} = 130\ \mu$m at 1 GeV/c
$e^+e^- \to KK + X$, $D_{(s)}$ decays	Fragmentation function, CKM matrix, LQCD etc.	PID	π/K and K/π misidentification rate $< 2\%$ PID efficiency of hadrons $> 97\%$ at $p < 2$ GeV/c
$\tau \to \mu\mu\mu$, $\tau \to \gamma\mu$, $D_s \to \mu\nu$	cLFV decay of τ, CKM matrix, LQCD etc.	PID+MUD	μ/π suppression power over 30 at $p < 2$ GeV/c, μ efficiency over 95% at $p = 1$ GeV/c
$\tau \to \gamma\mu$, $\psi(3686) \to \gamma\eta(2S)$	cLFV decay of τ, Charmonium transition	EMC	$\sigma_E/E \approx 2.5\%$ at $E = 1$ GeV $\sigma_{\text{pos}} \approx 5$ mm at $E = 1$ GeV
$e^+e^- \to n\bar{n}$, $D_0 \to K_L \pi^+\pi^-$	Nucleon structure Unity of CKM triangle	EMC+MUD	$\sigma_T = \frac{300}{\sqrt{p^3(\text{GeV}^3)}}$ ps





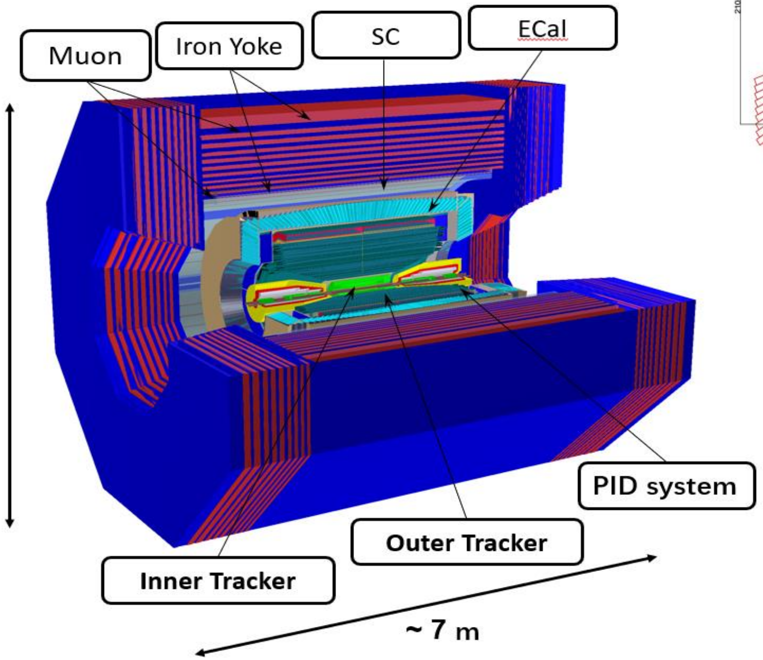
STCF detector conceptual design

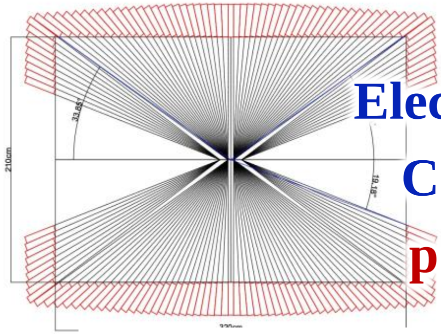


Muon Detector

Resistive Plate Chamber+

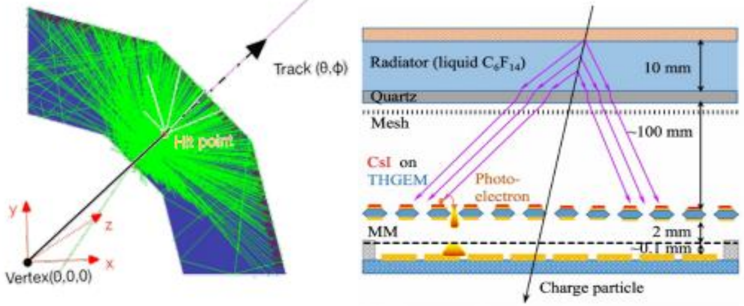
Plastic scintillator





Electromagnetic Calorimeter

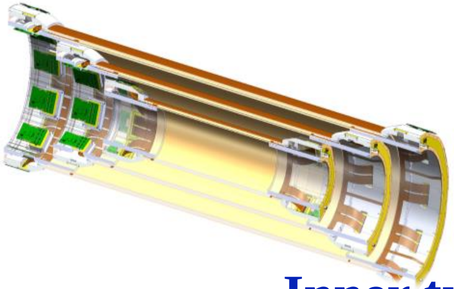
pCsI +APD

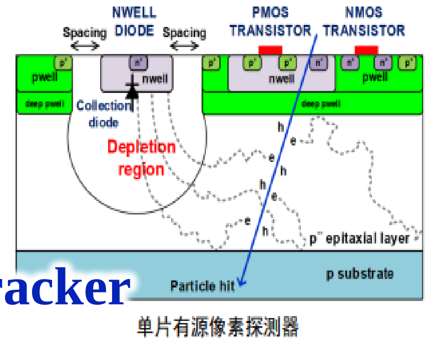


Particle Identification System

Barrel：RICH-like

Endcap：DIRC-like

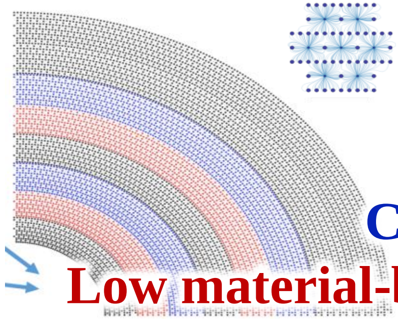




Inner tracker

μRWELL Detector

CMOS MAPS

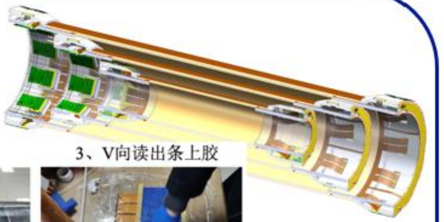


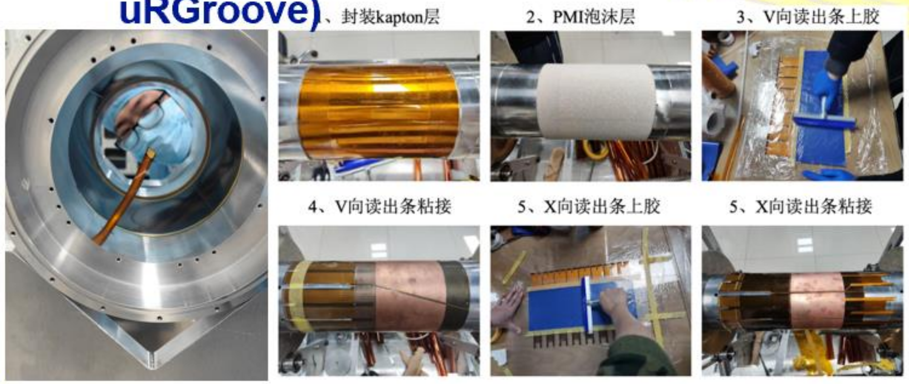
Central Tracker

Low material-budget Main Drift Chamber

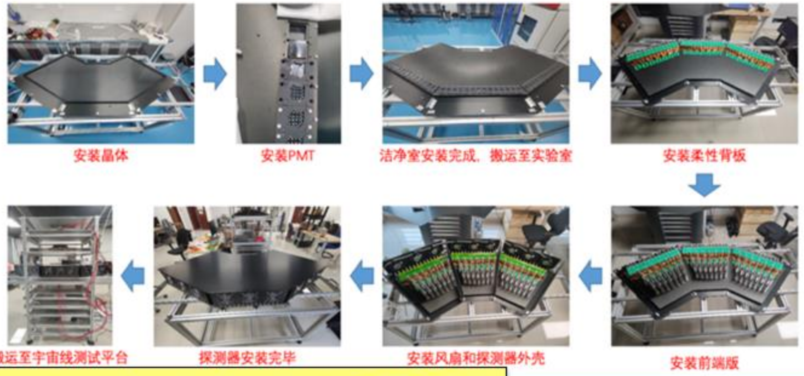
STCF detector R&D: detector prototypes

Cylindrical MPGD (uRWELL, uRGroove)



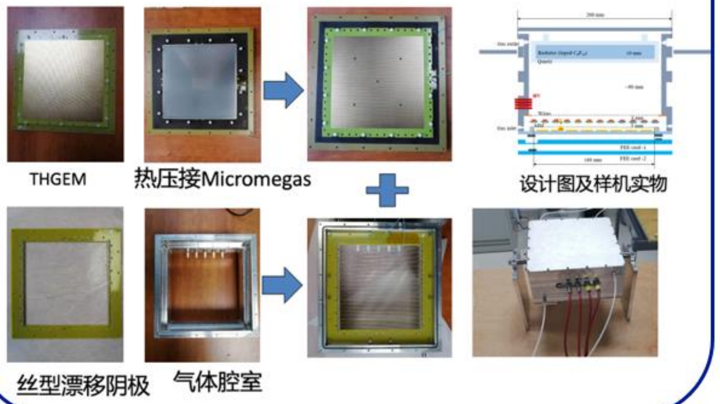


Full-sized DTOF sector prototype



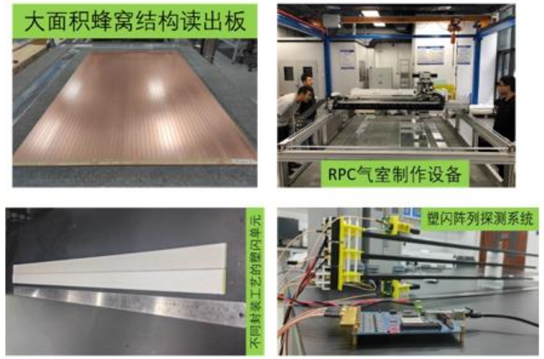
ECal, RICH, DTOF and DAQ beam test scheduled at CERN

30 cm × 30 cm RICH prototype



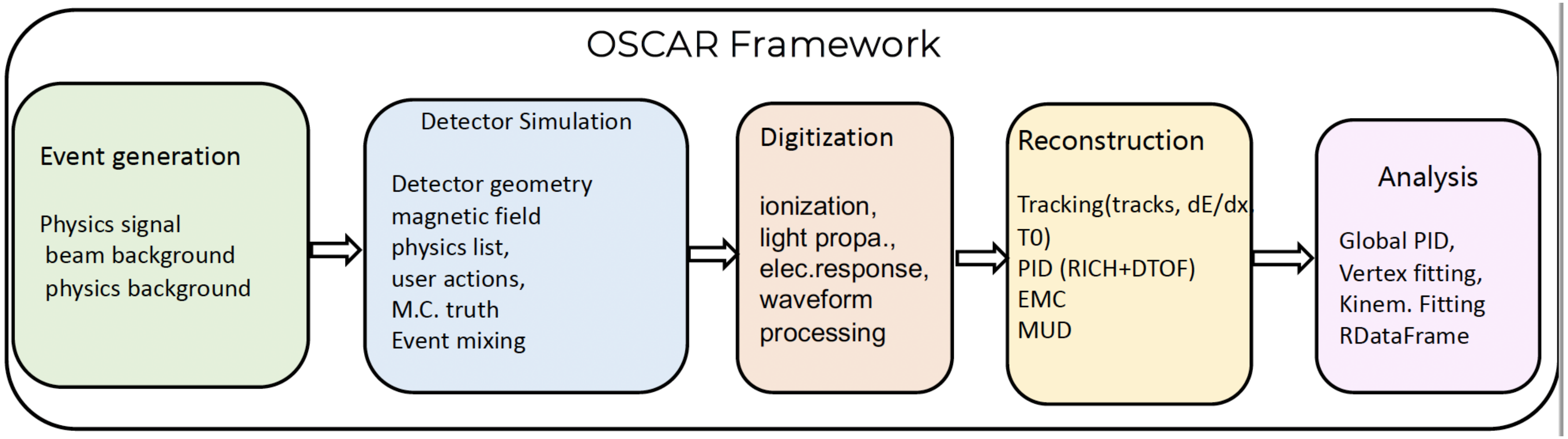
pCsI ECAL

Large sized RPC and scintillator strips

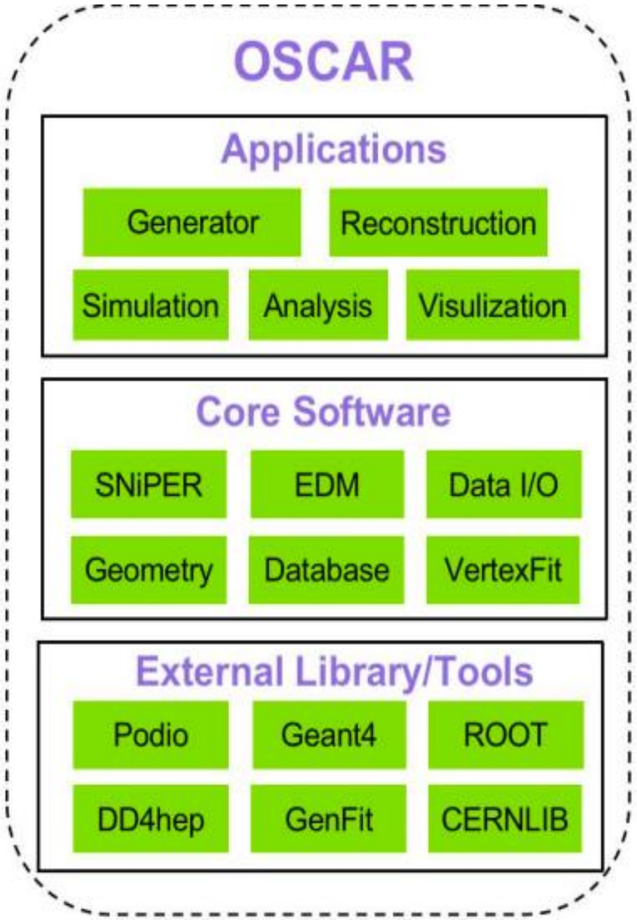


Offline software

- Developed based on light-weight and flexible SNiPER framework and adopted some state-of-the-art technologies
  - ✓ Podio for Event Data Model
  - ✓ DD4hep for detector description
  - ✓ TBB for multi-threading
  - ✓ ONNX for machine learning
- Full simulation under OSCAR is undergoing



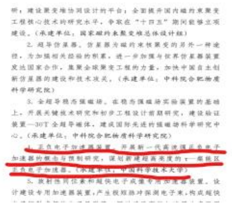
Architecture of OSCAR: three layers



STCF Project Development

Super Charm-tau Factory

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



Hefei Comprehensive National Science and Technology center, STCF listed as a big science facility to be promoted

Conceptual Design Report To publish CDR for the physics and Detector, formulate the preliminary CDR for accelerator

- **Chinese Academy of Sciences**, 2021-2026, International Partnership program, 5.0 M RMB
- **Ministry of Science and Technology**, 2022-2027, National Key R&D Program of China, 17.5 M RMB
- **National Natural Science Foundation of China**, 2024-2027, Group of Key Projects, 14.0 M RMB

2011 — 2015 — 2017 — 2018 — 2021 — 2022.4

Fragrant Hills Science Forum Demonstrated its importance and necessity, Urging to lauch fesibility study and R&D

USTC "double first-class" key project Launch the conceptual design study and feasibility study

Governments of Anhui Province and Hefei City Launch the STCF Key Technology R&D project

Kick-Off Meeting and R&D Project Review Meeting

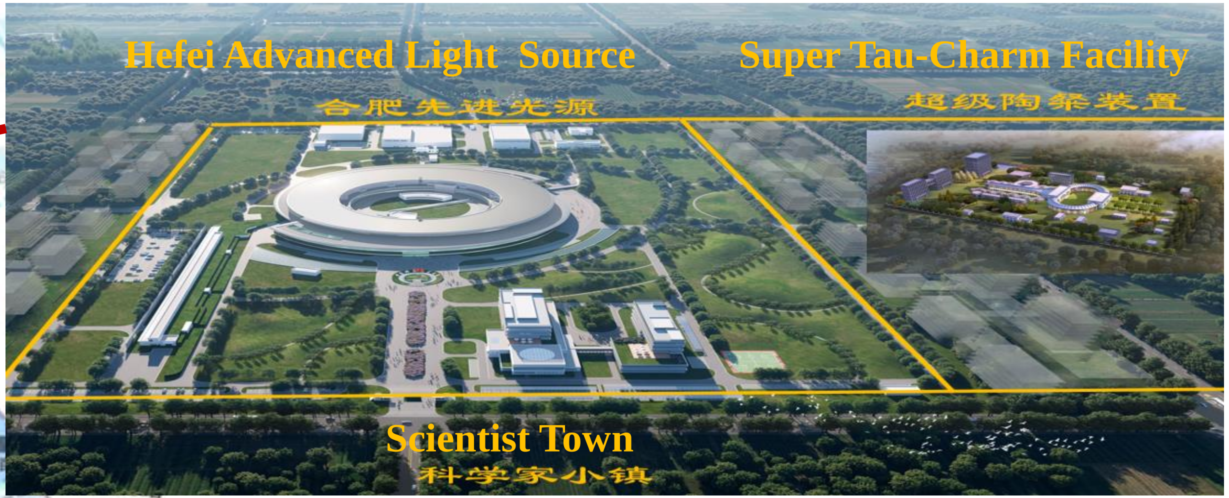
Kick-off Meeting, Aug. 2023, USTC

More than 30 academicians of CAS, as well as government officials of Anhui province and Hefei city, along with representatives from various domestic research institutions, totaling 170 attendees.

R&D Project Review, Dec. 2023, USTC

Organized by Development and Reform Commissions of Anhui province and Hefei city. The R&D project was approved for a budget of ~400M CNY and is jointly funded by Anhui, Hefei and USTC.

Site selection – future big science city



- **Six 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

Project Schedule in the ideal scenario

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032-2047
Conceptual design CDR															
Key Technology R&D TDR															
Construction															
Operation															15 years

Summary

- STCF covers a unique transition region between perturbative and non-perturbative QCD, providing precision measurements aimed at answering key questions in QCD and search for new physics BSM.
- STCF will utilize and challenge key technologies accelerator, particle detection and data processing, computing and networking.
- Anhui province and USTC have committed support, aiming for applying construction approval during the 15th five-year plan (2026-2030).
- International collaboration is crucial, with ongoing efforts to expand collaborations both domestically and internationally, so:

Welcome to join!