Experimental program for Super Tau-Charm Facility

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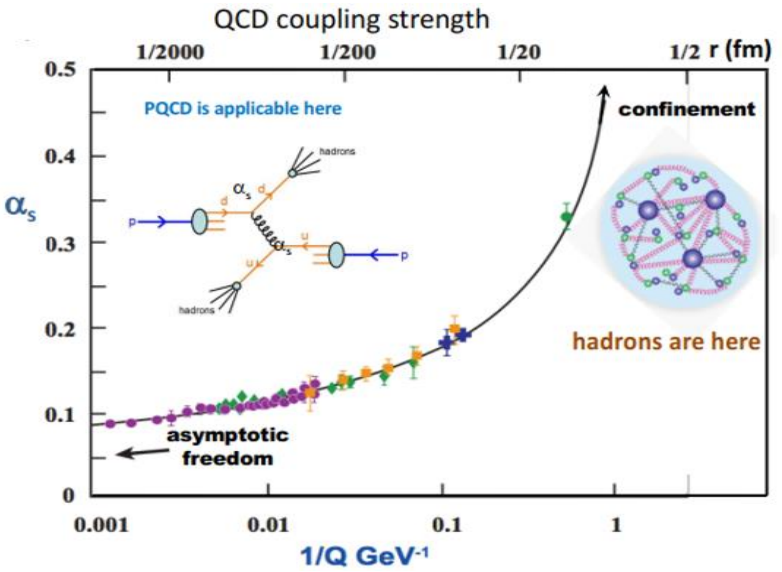
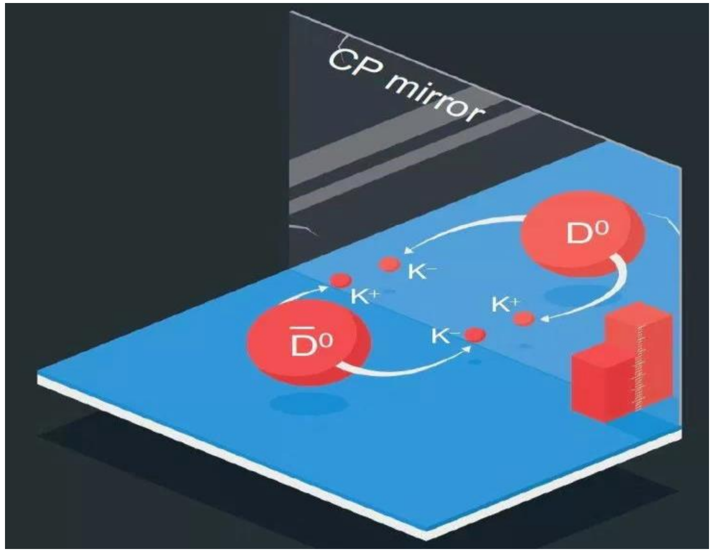
Challenges of the SM model

The SM of particle physics is a well-tested theoretical framework

However, the SM has a number of unresolved questions that require further investigations:

- **Confinement: formation of colorless bound states —— “hadrons”**
- **Matter-antimatter asymmetry of the Universe; dark matter, numbers of flavors, etc.**





Masses

Parameter	Value	Method
m_u	1.9 MeV	Lattice
m_d	4.4 MeV	Lattice
m_s	87 MeV	Lattice
m_c	1.3 MeV	Collider
m_b	4.24 MeV	Collider
m_t	173 GeV	Collider
m_e	511 keV	Non-collider
m_μ	106 MeV	Non-collider
m_τ	1.78 GeV	Collider
m_z	91.2 GeV	Collider
m_H	125 GeV	Collider

Couplings

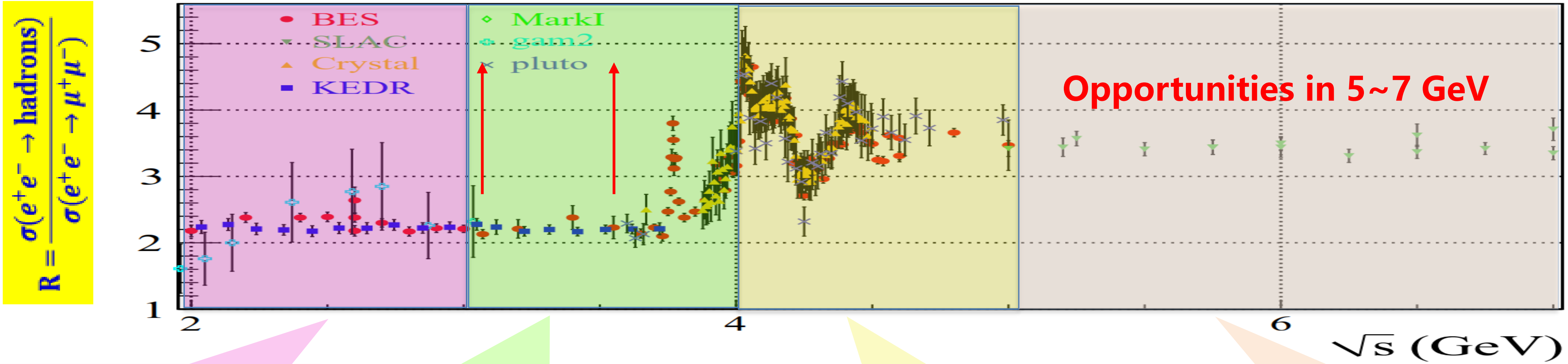
Parameter	Value	Method
α	0.0073	non-collider + collider
G_F	1.17×10^{-5}	Non-collider
α_s	0.12	Lattice + collider

Flavour and CP violation

Parameter	Value	Method
θ_{12} (CKM)	13.1°	Collider
θ_{23} (CKM)	2.4°	Collider
θ_{13} (CKM)	0.2°	Collider
δ (CKM-CPV)	0.995	Collider
θ (strong CP)	~0	Non-collider

Rich Physics in the Tau-Charm Energy Region

- **The tau-charm energy region covers a unique transition region between perturbative and non-perturbative QCD, with unique and rich physics programs**



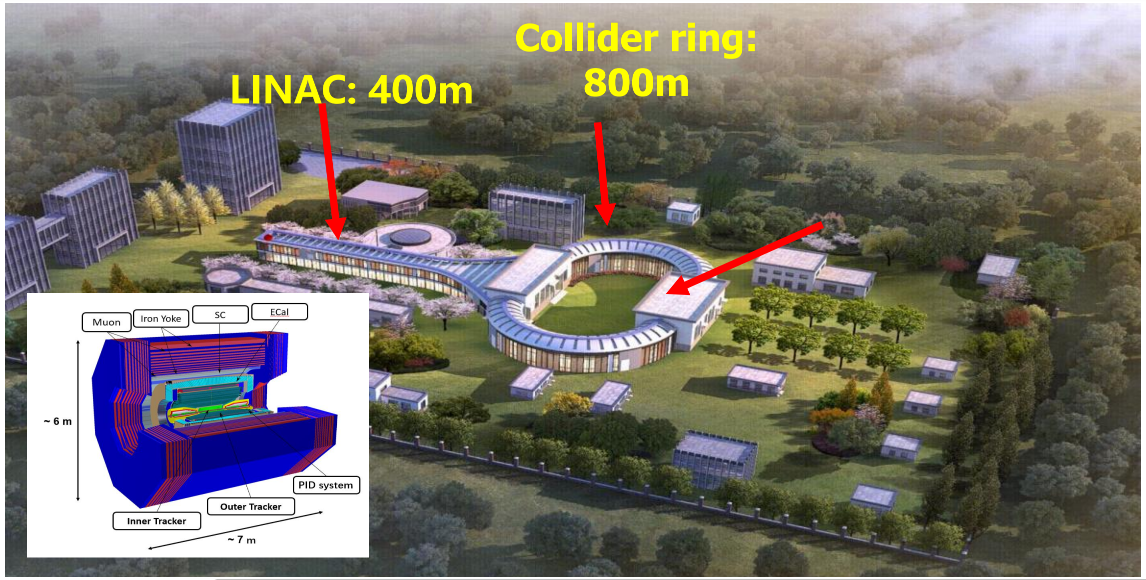
- Hadron form factors
- $Y(2175)$ resonance
- Mutltiquark states with s quark
- R value / g-2 related

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

- XYZ particles
- Physics with D mesons
- f_D and f_{D_s}
- $D^0 - \bar{D}^0$ mixing
- Charm baryons

- Complete XYZ family
- Hidden-charm pentaquarks
- Search for di-charmonium states
- More charmed baryons
- Hadron fragmentation

The Super Tau Charm Facility



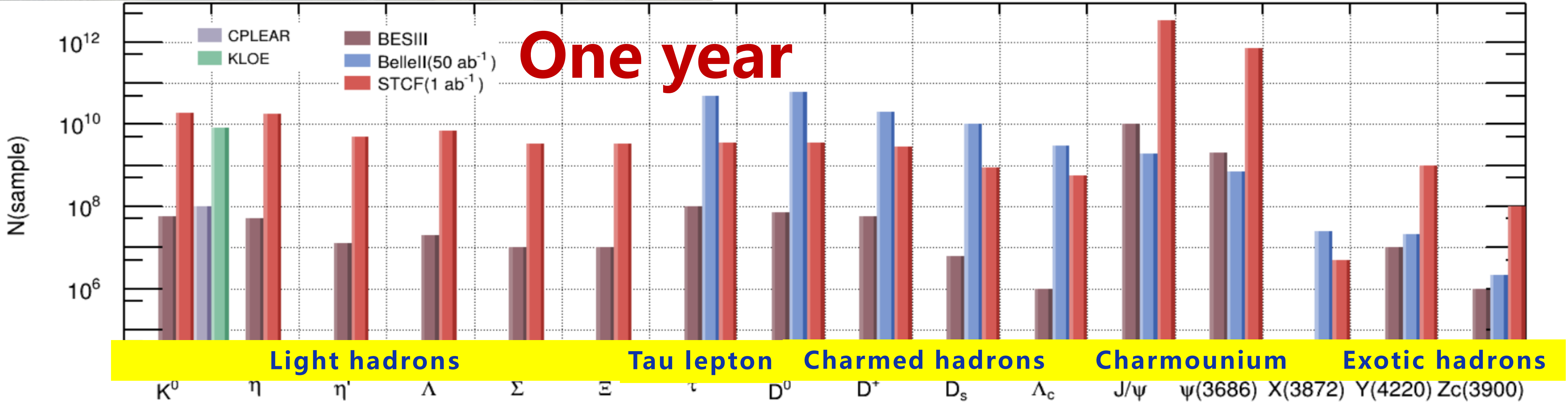
Energy range E_{cm} = 2-7 GeV

Peak luminosity >0.5×10^{35} $cm^{-2}s^{-1}$ at 4 GeV

1 ab^{-1} data expected per year

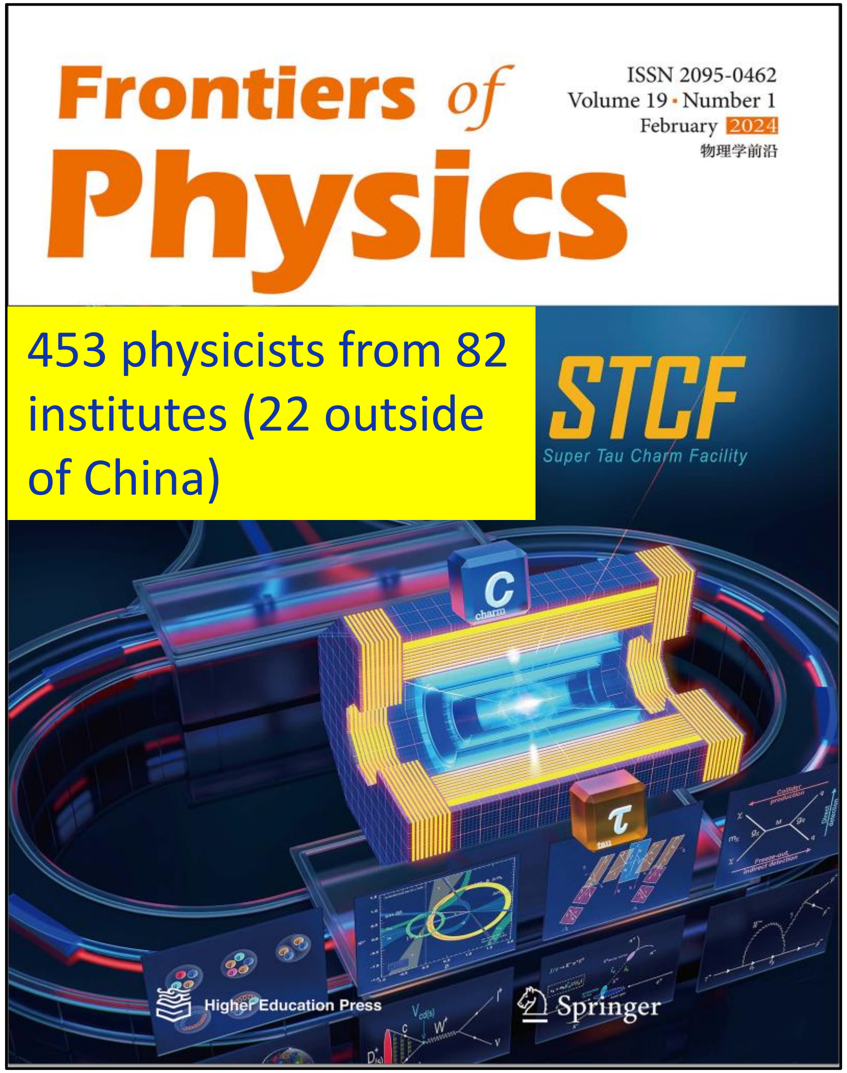
Potential to increase luminosity & realize beam polarization

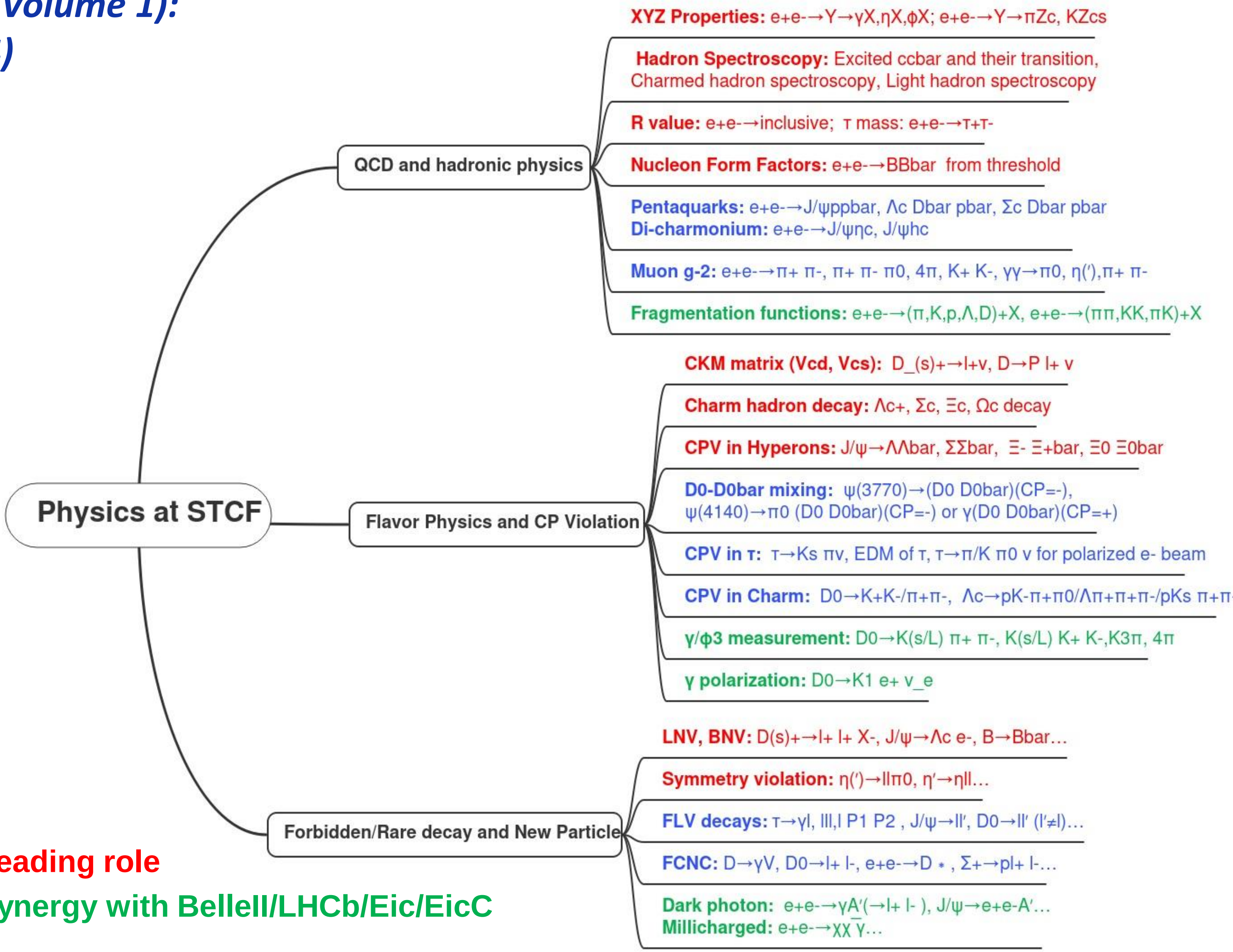
Total cost: 4.5B RMB



Physics Program at STCF

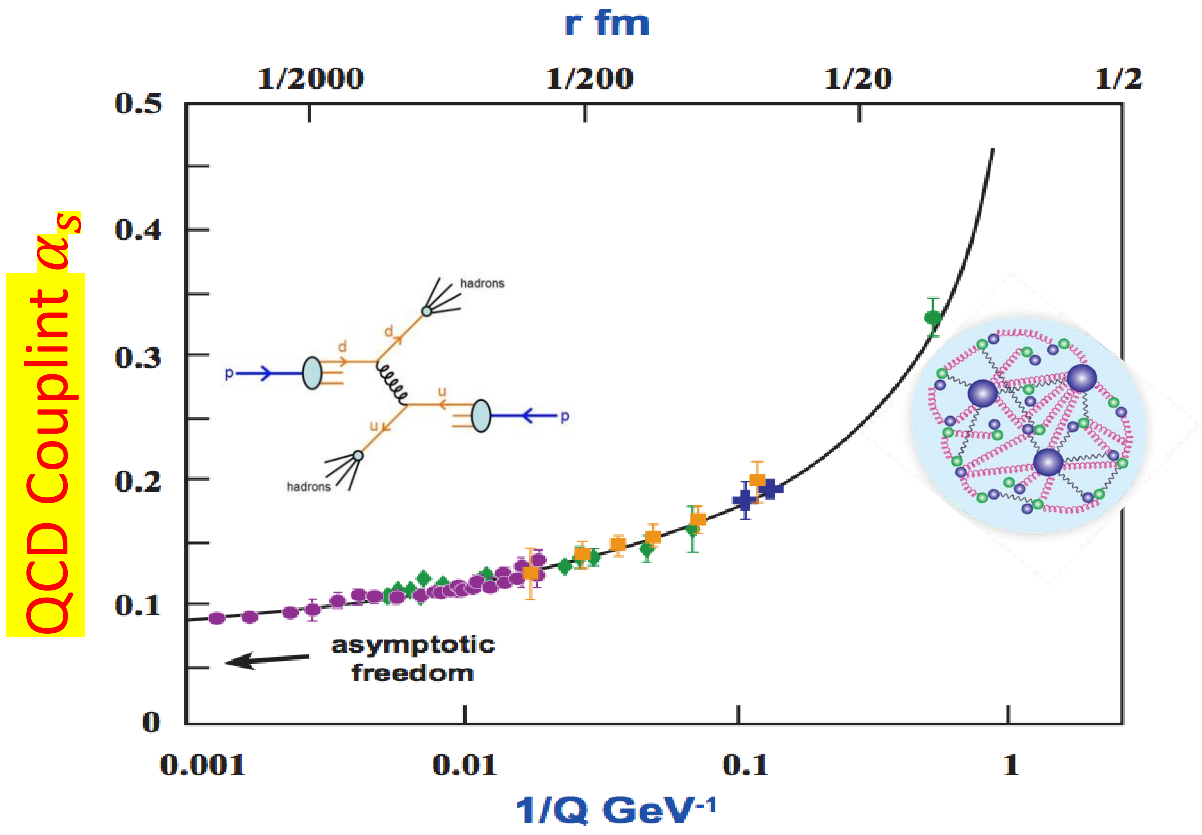
M. Achasov, et al., STCF conceptual design report (Volume 1): Physics & detector, Front. Phys. 19(1), 14701 (2024)

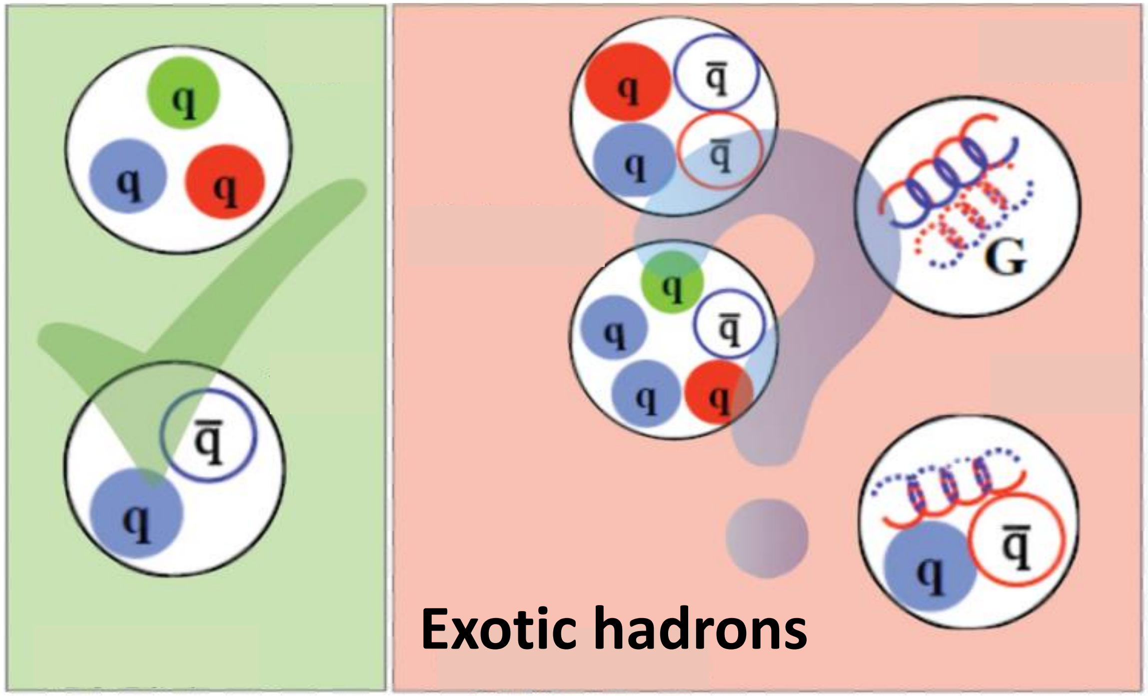




- **Leading role**
- **Synergy with BelleII/LHCb/Eic/EicC**

Key Question: Inner structure of hadrons

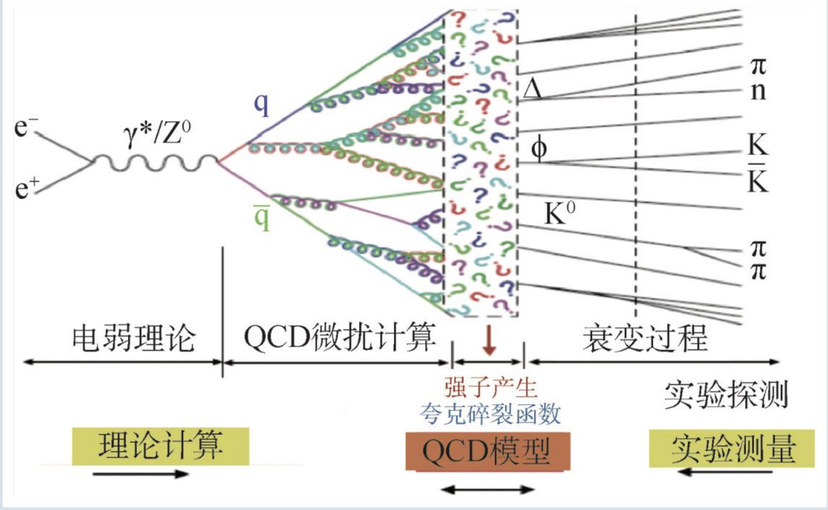


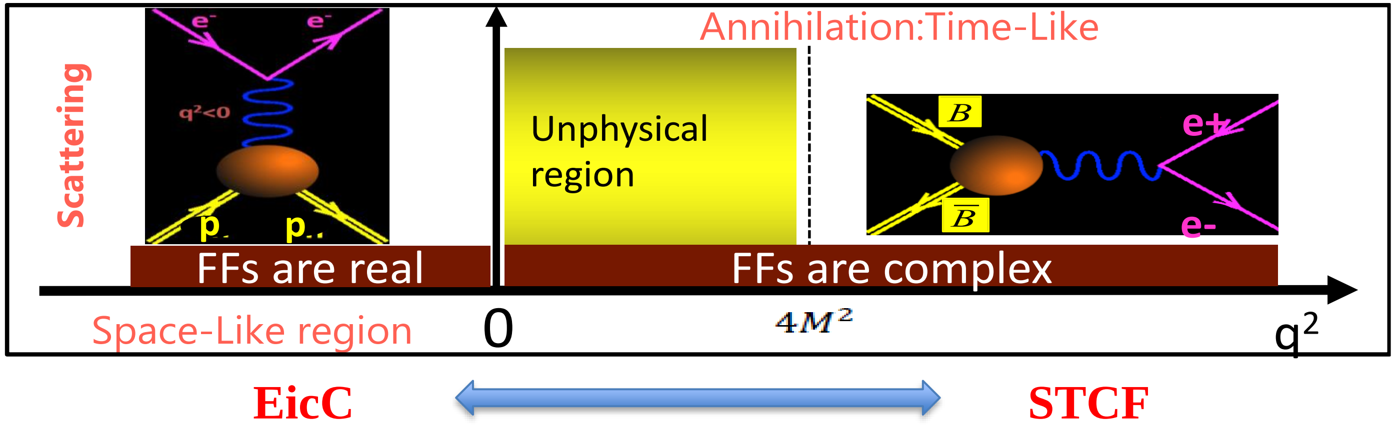


Hadron structure/spectroscopy is a crucial way to explore the QCD theory and confinement

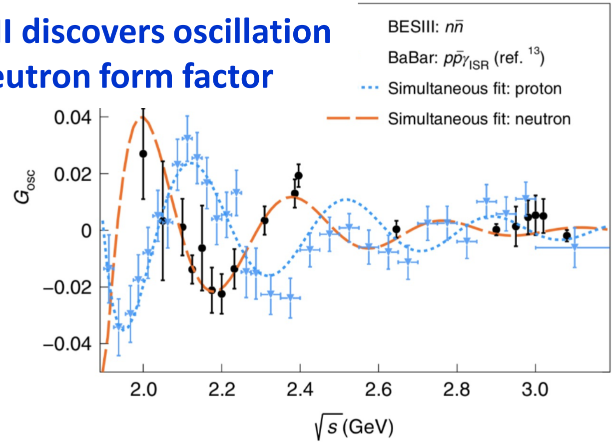
QCD and hadron structure

- Remaining big challenge in SM：non-perturbative effect in QCD theory
- The largest uncertainty is from the low-energy non-perturbative energy region
- STCF fine (ISR) scan from 0.6–7 GeV to study production of hadrons inclusively and exclusively

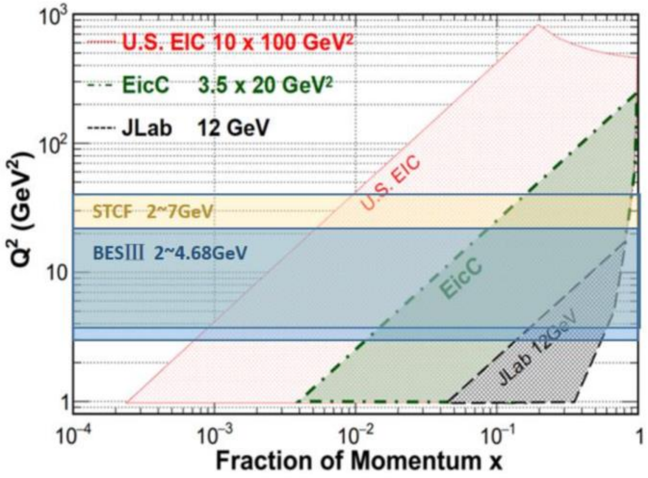


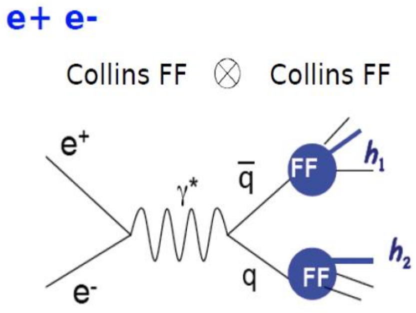


BESIII discovers oscillation of neutron form factor

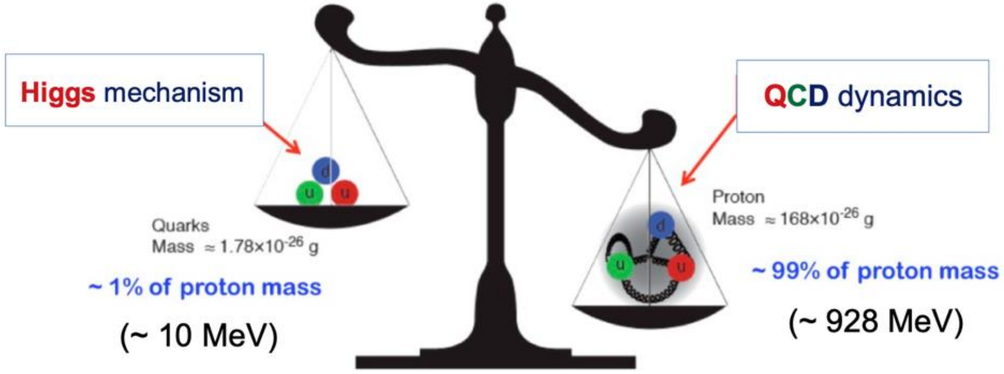


Hadron form factor and fragmentation function:
complementary measurements between deep inelastic experiments and STCF in similar Q^2 region

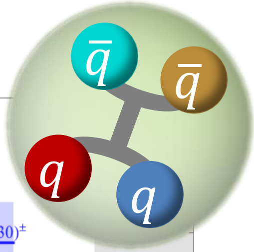




Strong interaction and exotic hadrons

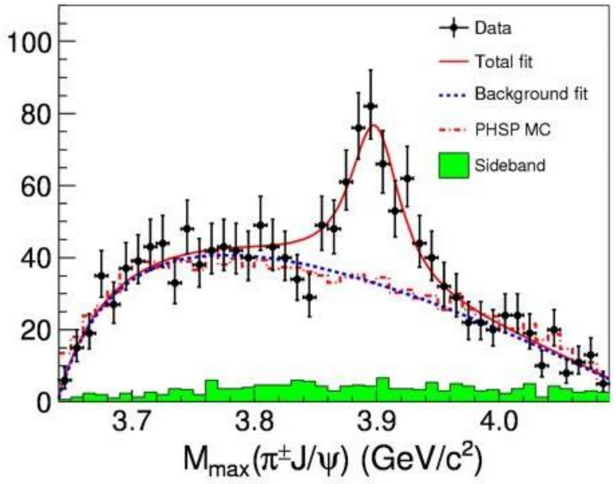


- Overpopulated charmonium spectrum is a unique territory to study exotic hadrons
- STCF provides unique fine scan of the exotic hadron states

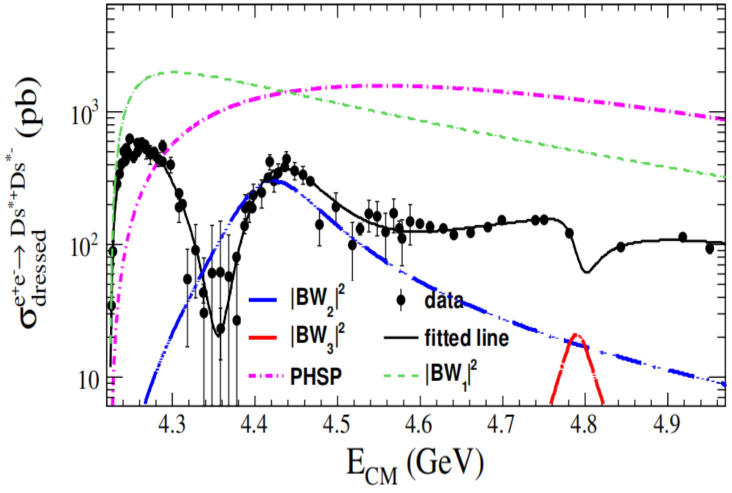


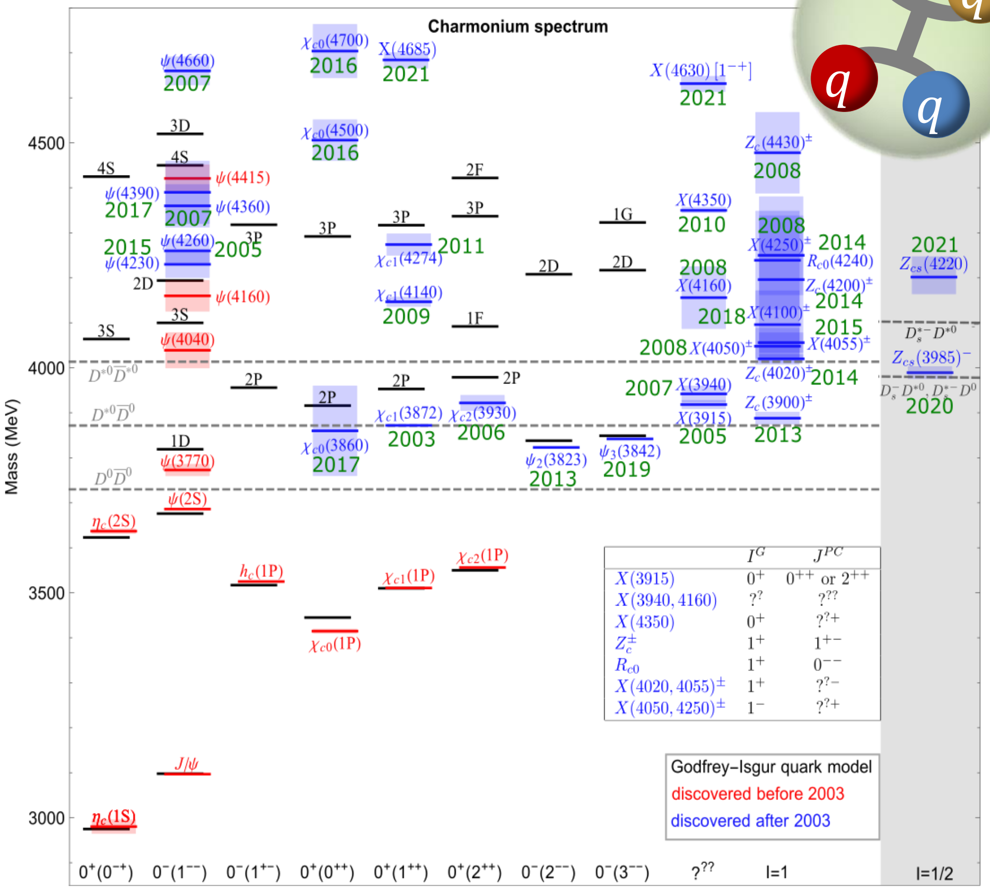
- Hadron spectroscopy is a crucial way to explore the QCD theory and confinement

BESIII, PRL110, 252001 (2013)



BESIII, PRL131, 151903 (2023)





Light Hadron Opportunity at STCF

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

CME (GeV)	Lumi (ab^{-1})	Samples	σ(nb)	No. of Events	Remarks
3.097	1	J/ψ	3400	3.4×10^{12}	
3.670	1	$\tau^+\tau^-$	2.4	2.4×10^{9}	
3.686	1	$\psi(3686)$	640	6.4×10^{11}	
		$\tau^+\tau^-$	2.5	2.5×10^{9}	
		$\psi(3686) \to \tau^+\tau^-$		2.0×10^{9}	
3.770	1	$D^0\bar{D}^0$	3.6	3.6×10^{9}	
		$D^+\bar{D}^-$	2.8	2.8×10^{9}	
		$D^0\bar{D}^0$		7.9×10^{8}	Single tag
		$D^+\bar{D}^-$		5.5×10^{8}	Single tag
		$\tau^+\tau^-$	2.9	2.9×10^{9}	
4.009	1	$D^{*0}\bar{D}^0 + c.c$	4.0	1.4×10^{9}	$CP_{D^0\bar{D}^0} = +$
		$D^{*0}\bar{D}^0 + c.c$	4.0	2.6×10^{9}	$CP_{D^0\bar{D}^0} = -$
		$D_s^+D_s^-$	0.20	2.0×10^{8}	
		$\tau^+\tau^-$	3.5	3.5×10^{9}	
4.180	1	$D_s^{+*}D_s^-$+c.c.	0.90	9.0×10^{8}	
		$D_s^{+*}D_s^-$+c.c.		1.3×10^{8}	Single tag
		$\tau^+\tau^-$	3.6	3.6×10^{9}	
4.230	1	$J/\psi\pi^+\pi^-$	0.085	8.5×10^{7}	
		$\tau^+\tau^-$	3.6	3.6×10^{9}	
		$\gamma X(3872)$			
4.360	1	$\psi(3686)\pi^+\pi^-$	0.058	5.8×10^{7}	
		$\tau^+\tau^-$	3.5	3.5×10^{9}	
4.420	1	$\psi(3686)\pi^+\pi^-$	0.040	4.0×10^{7}	
		$\tau^+\tau^-$	3.5	3.5×10^{9}	
4.630	1	$\psi(3686)\pi^+\pi^-$	0.033	3.3×10^{7}	
		$\Lambda_c\bar{\Lambda}_c$	0.56	5.6×10^{8}	
		$\Lambda_c\bar{\Lambda}_c$		6.4×10^{7}	Single tag
		$\tau^+\tau^-$	3.4	3.4×10^{9}	
4.0–7.0	3	300-point scan with 10 MeV steps, 1 fb^{-1}/point			
> 5	2–7	Several ab^{-1} of high-energy data, details dependent on scan results			

$J/\psi \sim 10^{12}$

$\psi(3686) \sim 10^{11}$

- Large number of J/ψ and $\psi(3686)$ events for exploring light hadron physics
- Traces of glueballs and hybrid states may be found in more ways
- Search for more production and decay modes of hybrid candidates and glueball candidates
- Electromagnetic couplings to glueball candidates:
  - radiative transition rates
  - transition form factors in the time-like region
  - couplings to $\gamma\gamma$

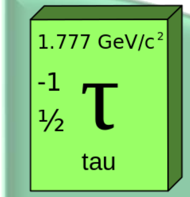
Probe CP violation

- CPV has been observed in K, B, D mesons, all are consistent with CKM theory in the Standard Model
- Baryon asymmetry of the Universe indicates that there must be non-SM CPV source

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

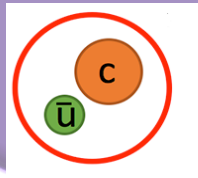
CP in hyperon decay

CP in tau decay/production



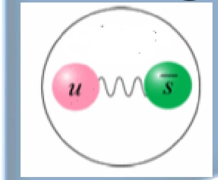
Peak cross section in $\sqrt{s}$ =4-5 GeV,
$\sigma_{\tau\tau}\approx$ 3.5 nb, 10 ab^{-1} data in total
Sensitivity of τ decay with 1ab^{-1} @ 4.26 GeV $\sim9.7\times10^{-4}$

CP in charm mixing



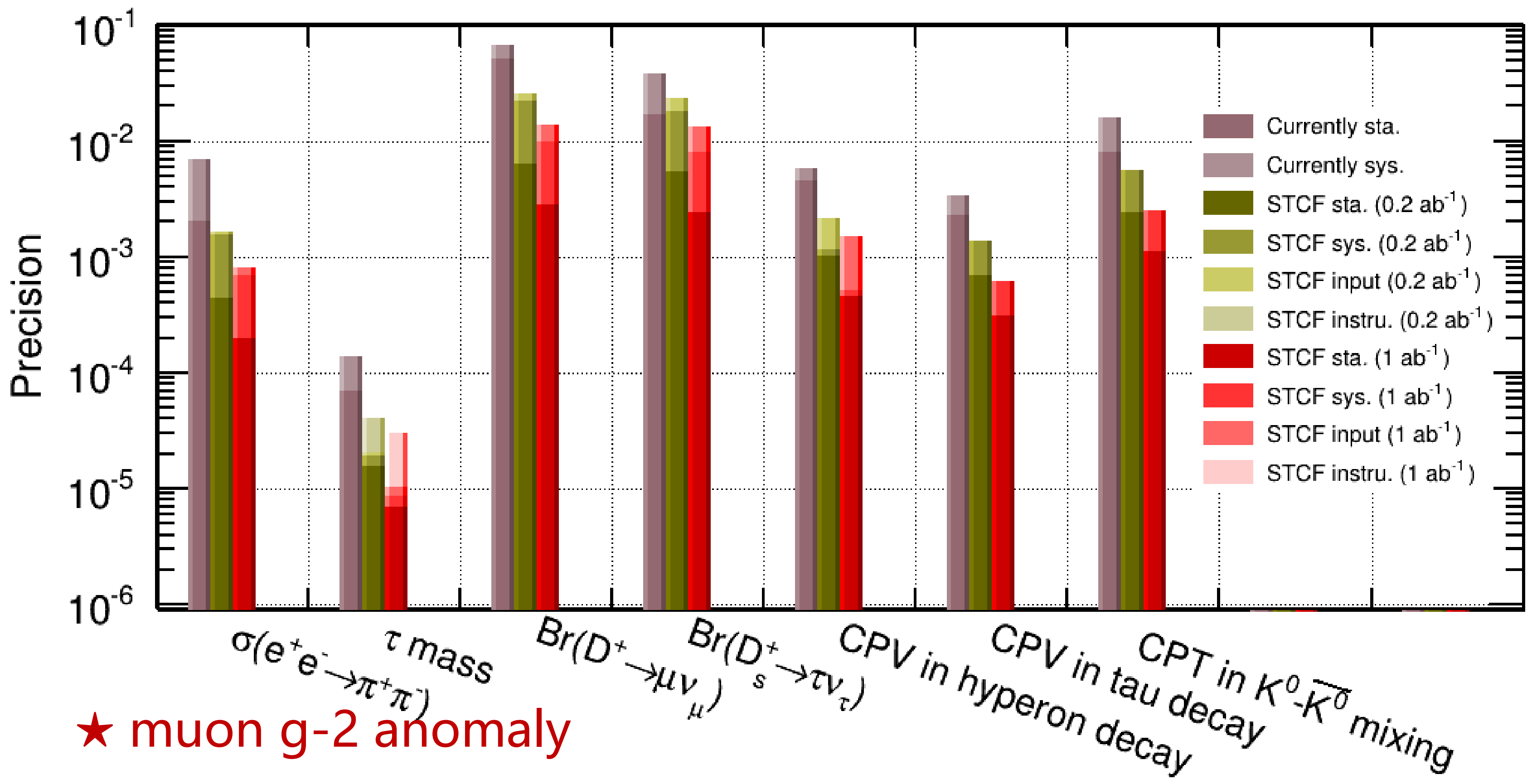
Billions $D^0/\bar{D}^0$, threshold production,
quantum coherence with $(D^0\bar{D}^0)_{\mathrm{CP}=-}$ or $(D^0\bar{D}^0)_{\mathrm{CP}=+}$
Sensitivity: $x\sim0.035\%$, y$\sim0.023\%$,
$r_{CP}\sim0.017$, $\alpha_{CP}\sim1.3^{\circ}$

CPT in kaon mixing



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

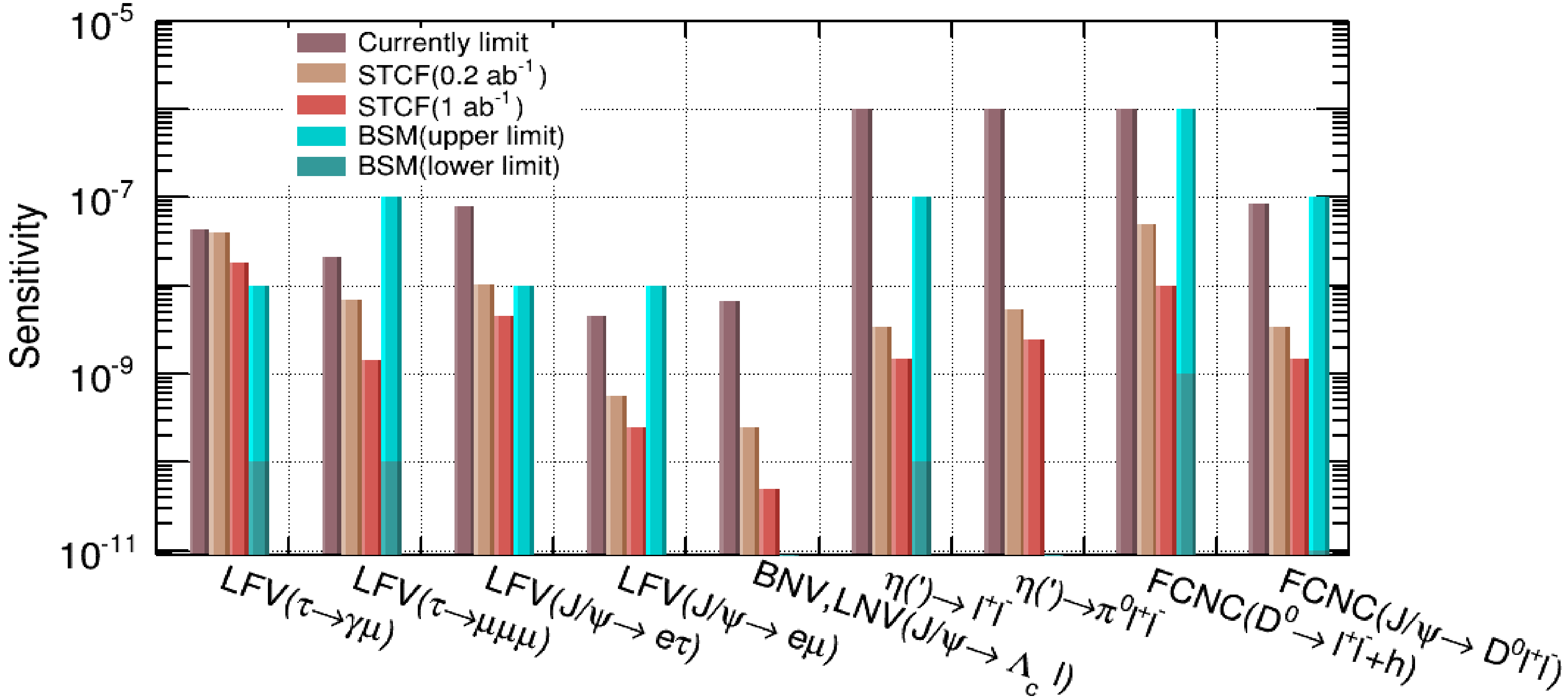
Sensitivity of Precision Measurements



★ muon g-2 anomaly

- **The precision frontier for testing of SM parameters**
- **Uncertainties from reducible (selection-based), and irreducible sources (theoretical input, instrument effect)**

Sensitivity of Rare or Forbidden Decays



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

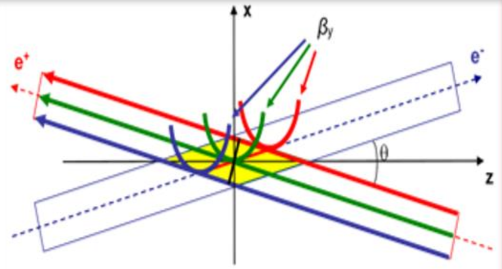
Challenges of STCF Accelerator

Goal: ultra-high luminosity in tau charm energy region (2-7 GeV), high-quality beam, stable operation

Characteristics: extremely small bunch size, high current intensity, strong nonlinearity and collective effect

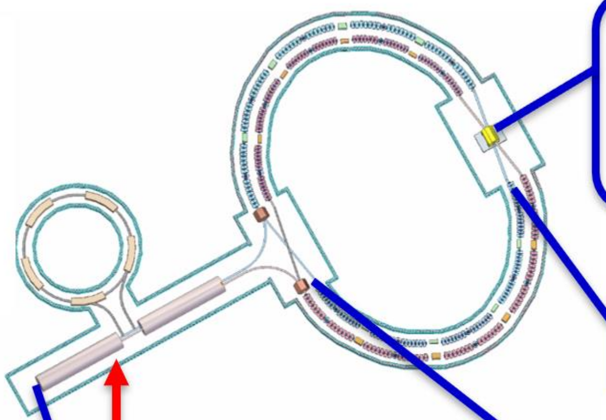
Preliminary machine parameters

Parameters	Units	STCF (April. 2024)
Optimal beam energy, ***E***	GeV	**2**
Circumference, ***C***	m	**848.4**
Crossing angle, ***2q***	mrad	**60**
Horizontal emittance, e_x	nm	**6.919**
Coupling, ***k***		**0.50%**
Vertical emittance, e_y	pm	**34.595**
Ver. beta function at IP, β_y	mm	**0.6**
Ver. beam size at IP, s_y	mm	**0.144**
Beam current, ***I***	A	**2**
Single-bunch charge	nC	**8.04**
SR power per beam, P_{SR}	MW	**0.572**
Bunch length, s_z	mm	**8.43**
Ver. beam-beam parameter, ξ_y		**0.094**
Luminosity, ***L***	10^{35} cm^{-2} s^{-1}	**1.19**



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

Big Piwinski angle + Crab Waist



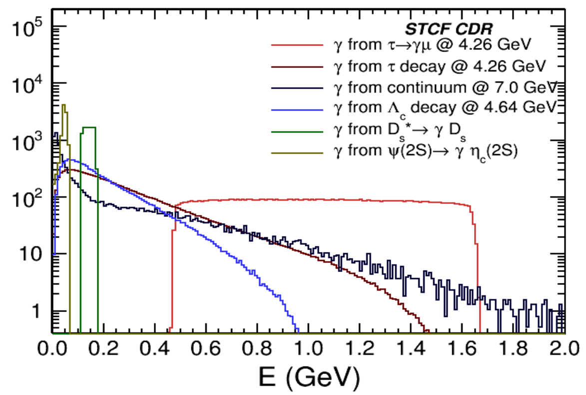
Injection into CR (small DA): high I_b and low ε e+/e- sources

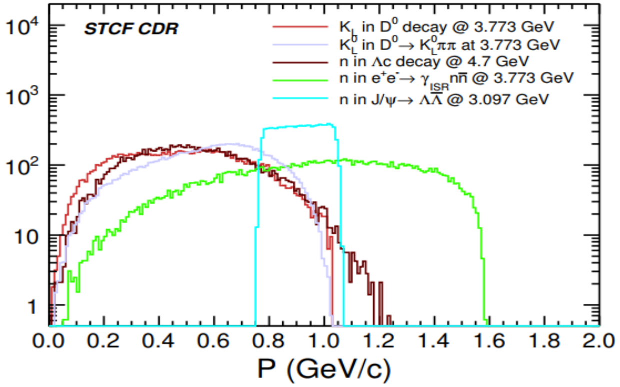
Collider Ring and IR AP design: IP beam size (Y) nm scale, Crab-Waist, nonlinear compensation extremely difficult

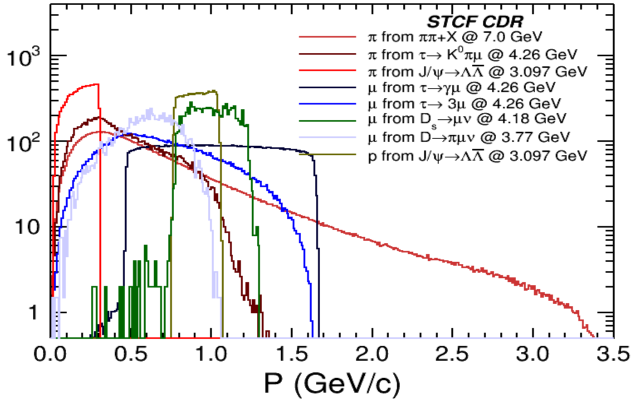
IR Technologies: SC magnets, MDI

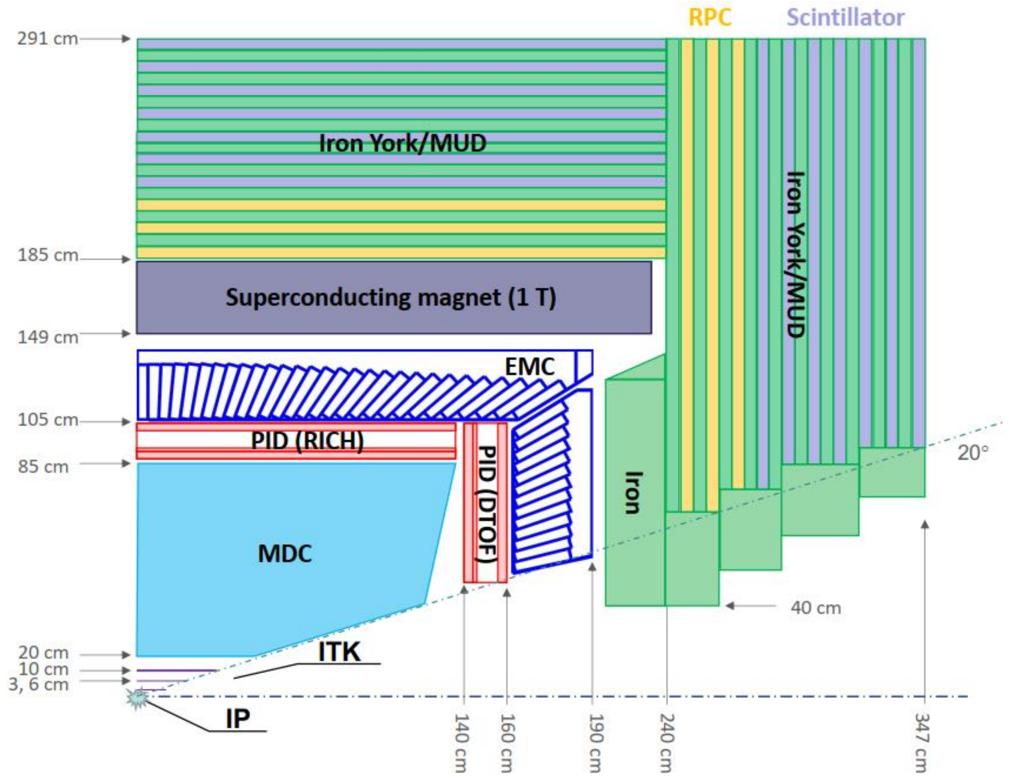
Other key technologies: Ring RF, beam instrum. and control, beam injection...

STCF detector









ITK

<0.25%X0 / layer

σ_{xy}< 100 μm

MDC

σ_{xy}< 130 μm

$\sigma p/p$ ~ 0.5% @ 1 GeV

PID

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

EMC

E range: 0.025-3.5 GeV

σ_E @ 1 GeV: 2 .5% in barrel, 4% at endcaps

Pos. Res. : ~ 4 mm

MUD

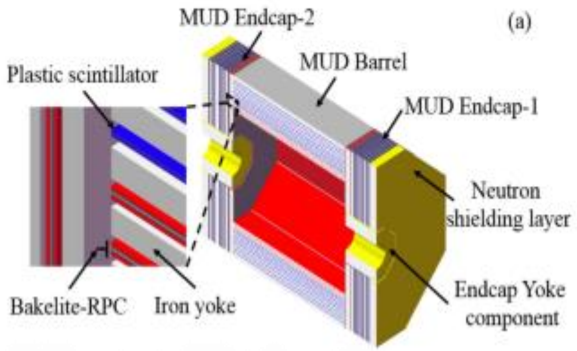
0.4 - 1.8 GeV

π suppression >30

Requirement:

- High detection efficiency and good resolution
- Superior PID ability
- Tolerance to high rate/background environment

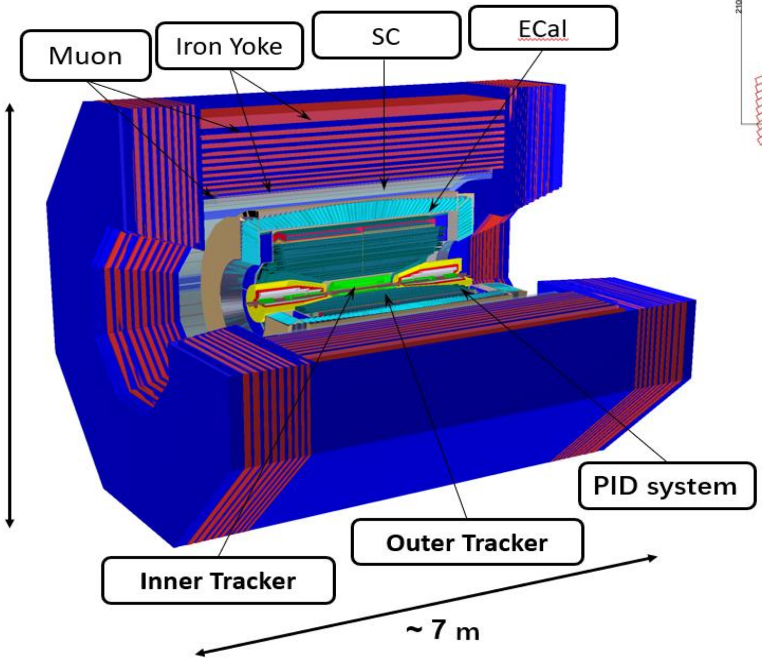
STCF Detector Conceptual Design

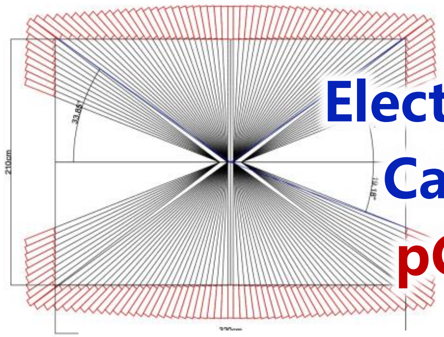


Muon Detector

Resistive Plate Chamber+

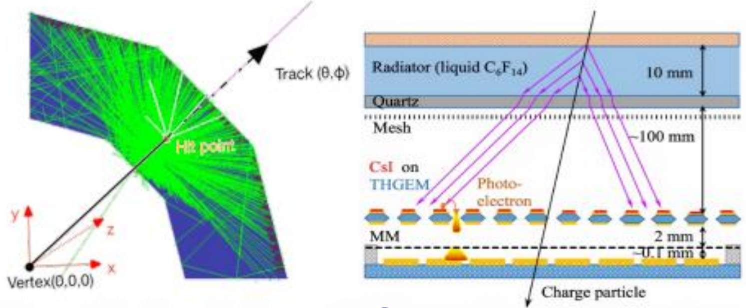
Plastic scintillator





Electromagnetic Calorimeter

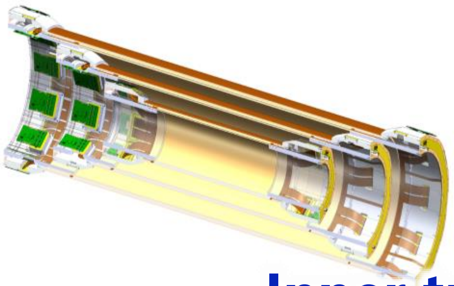
pCsI +APD

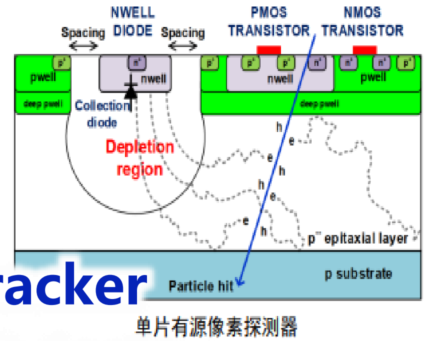


Particle Identification System

Barrel：RICH-like

Endcap：DIRC-like

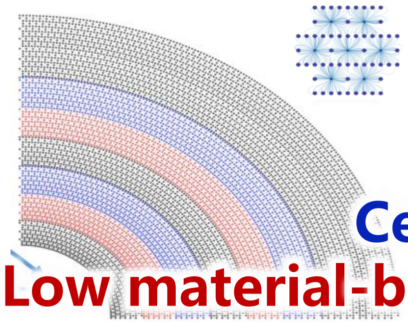




Inner tracker

μRWELL Detector

CMOS MAPS

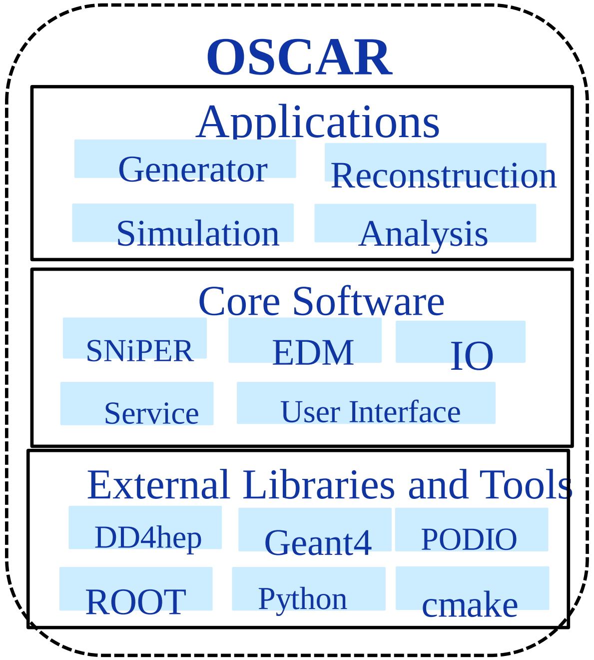


Central Tracker

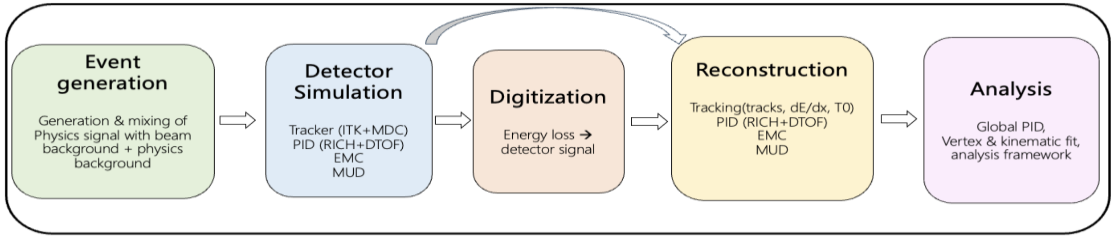
Low material-budget Main Drift Chamber

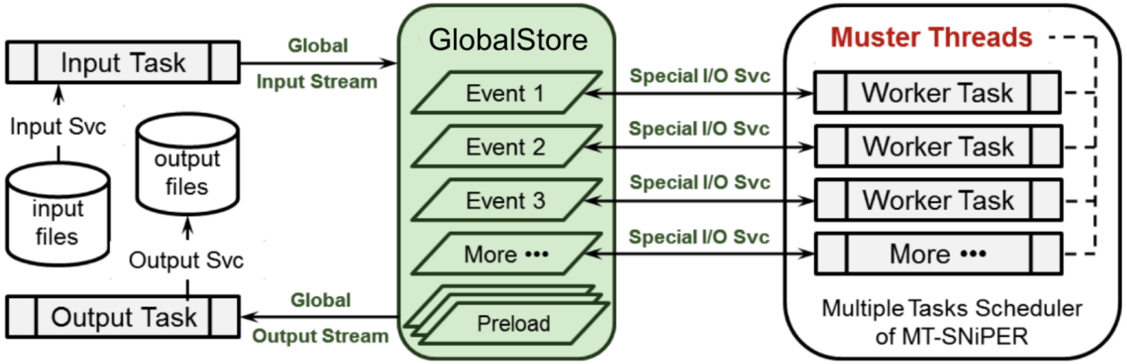
Offline Software

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



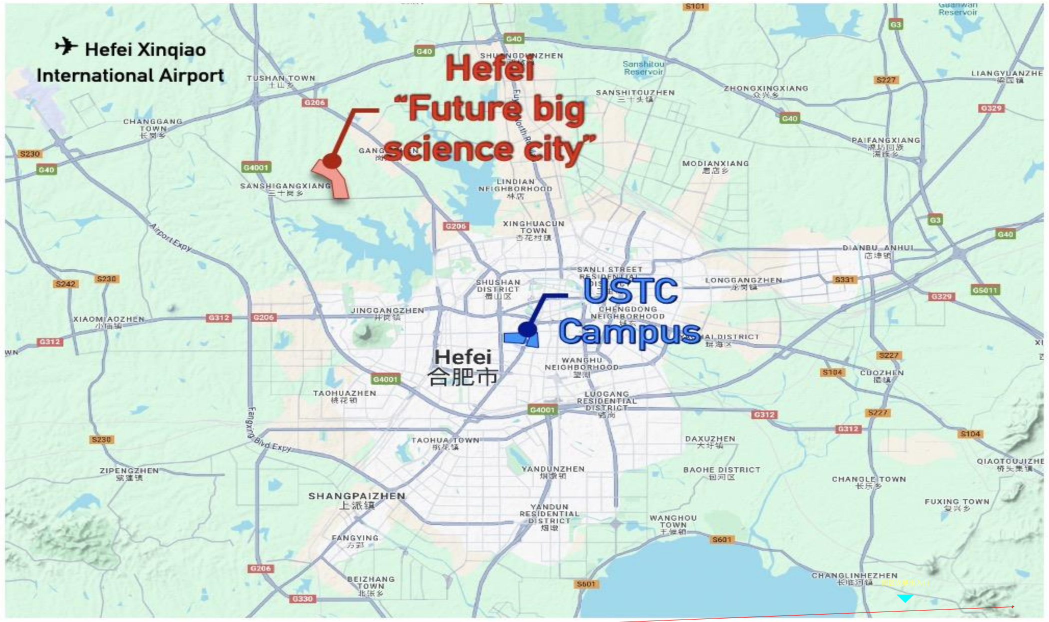
W.H. Huang et al 2023 JINST 18 P03004

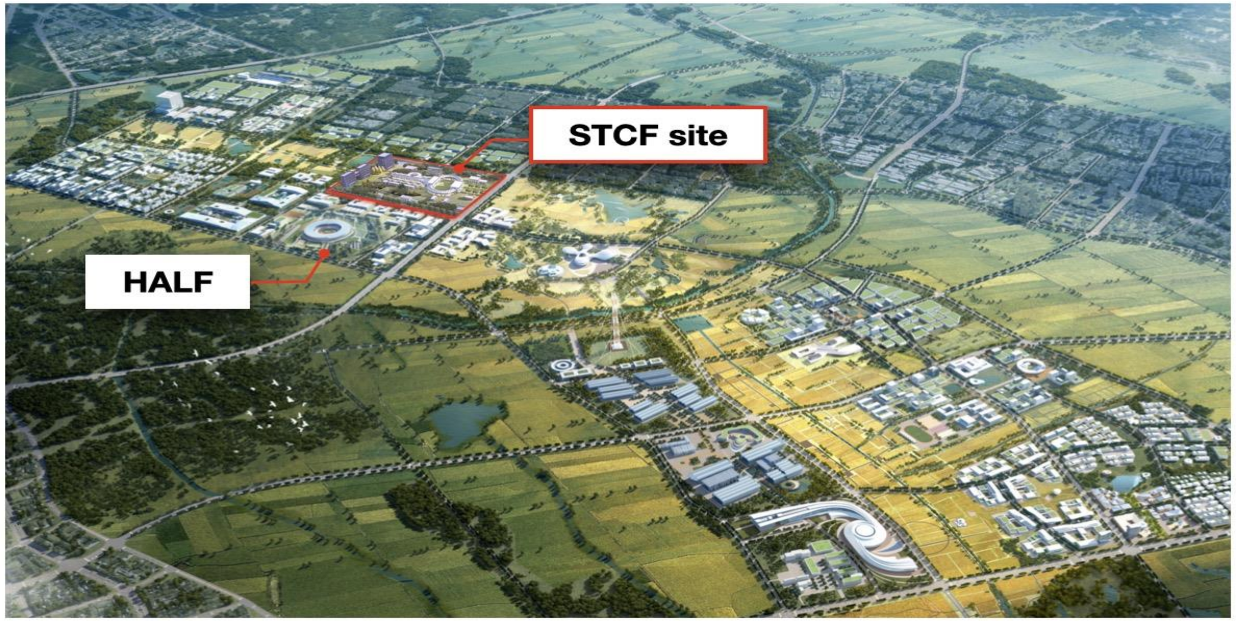


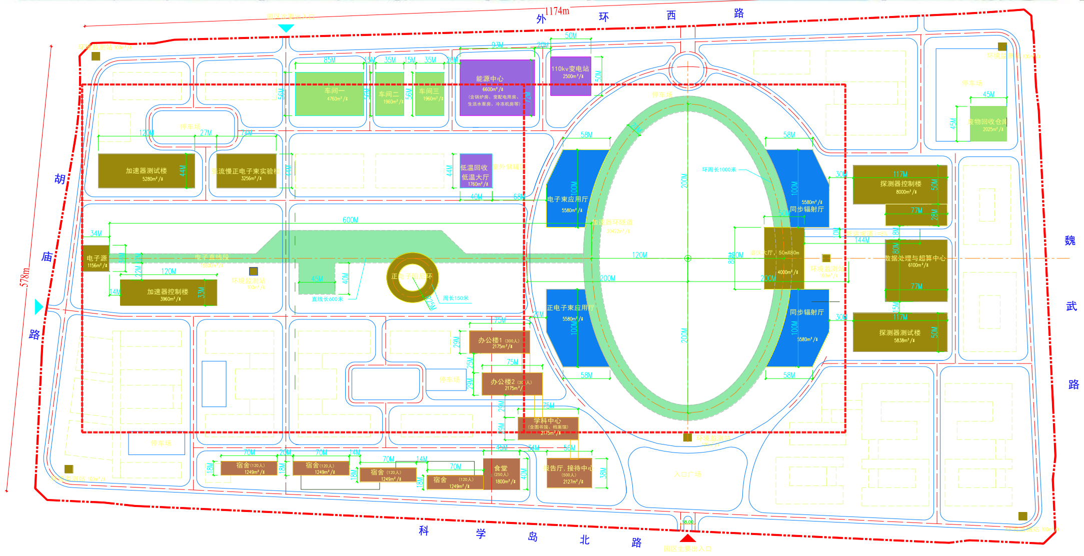


- Full simulation under OSCAR is undergoing: $e^+e^- \to \pi^+\pi^- J/\psi$, $\Lambda\bar{\Lambda}$, $\pi\pi/K\pi/KK+X$, $D^0\bar{D}^0$…

Site of STCF : Hefei

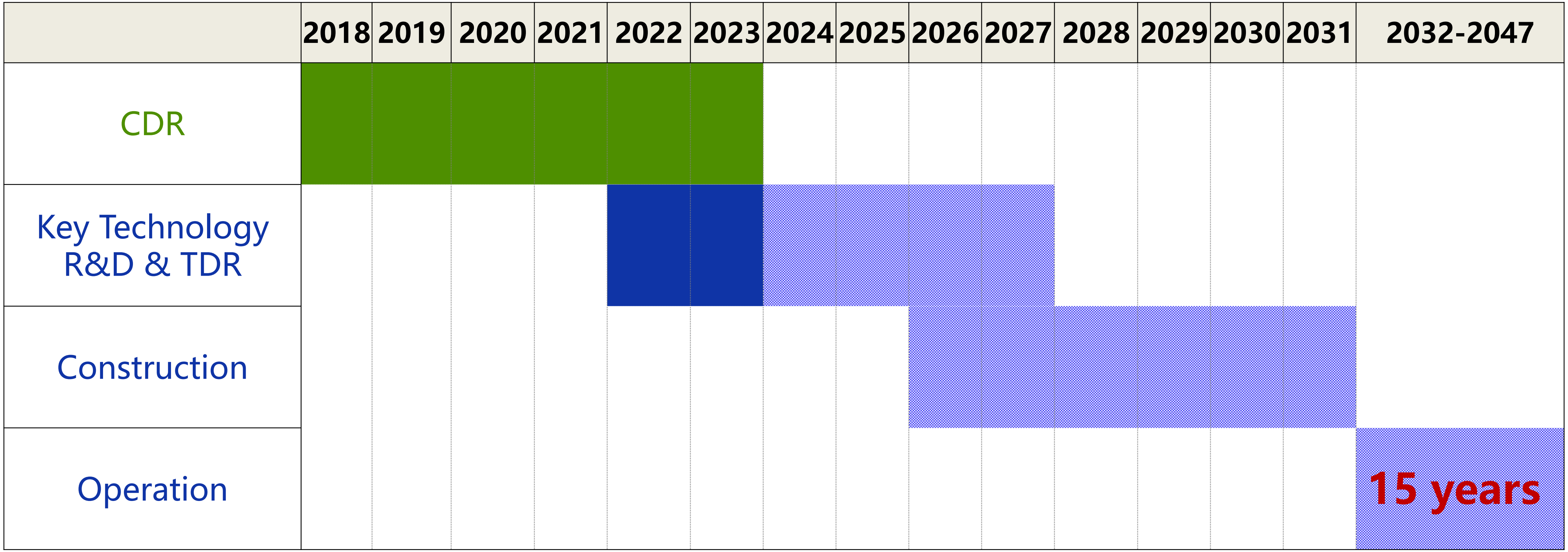






- **Funded R&D****: 0.4 Billion CNY funded by the Anhui government**
- **Construction budget: 4.5 Billion CNY**

Tentative Project Schedule for STCF



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 utilized 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

FTCF2024-Guangzhou

The 6th International Workshop on Future Tau-Charm Facilities (**FTCF2024-Guangzhou**) will be hosted by Sun Yat-Sen University (SYSU) in Guangzhou, China, **Nov. 17-21, 2024**.

https://indico.pnp.ustc.edu.cn/event/1948/

Thanks for your listening!