Progress of the Super Tau Charm Facility project in China

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Nstar2026, Seville

07-11 Sep , 2026

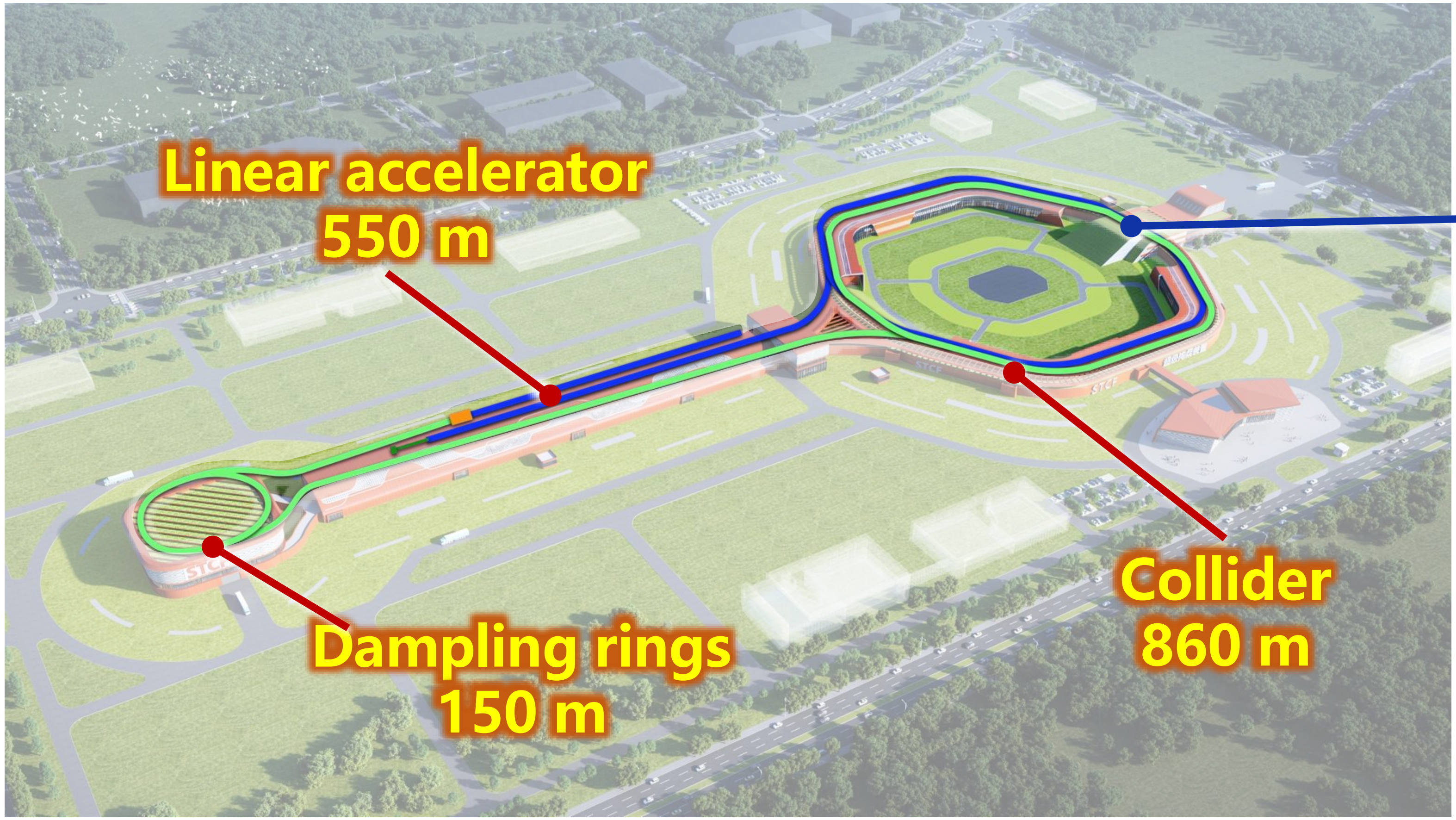
Content

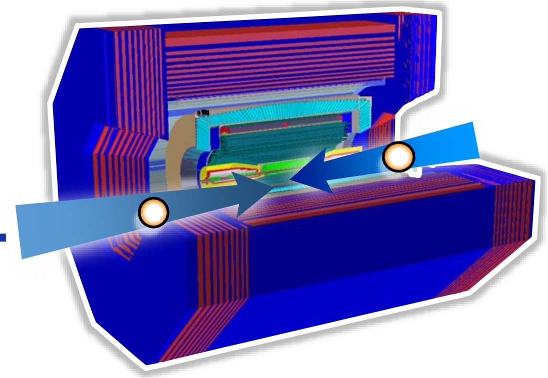
- STCF Overview
- Physics Objectives
- Key Technology R&D Progress
- Summary and outlook

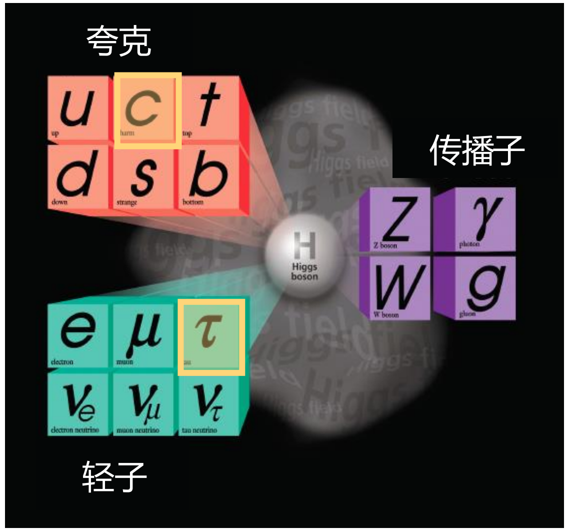
Content

The Super Tau Charm Facility

- **Third generation** e^+e^- collider. A factory producing massive **tau lepton** and **charm hadrons**, to unravel the mystery of **how quarks form matter** and the symmetries of **fundamental interactions**







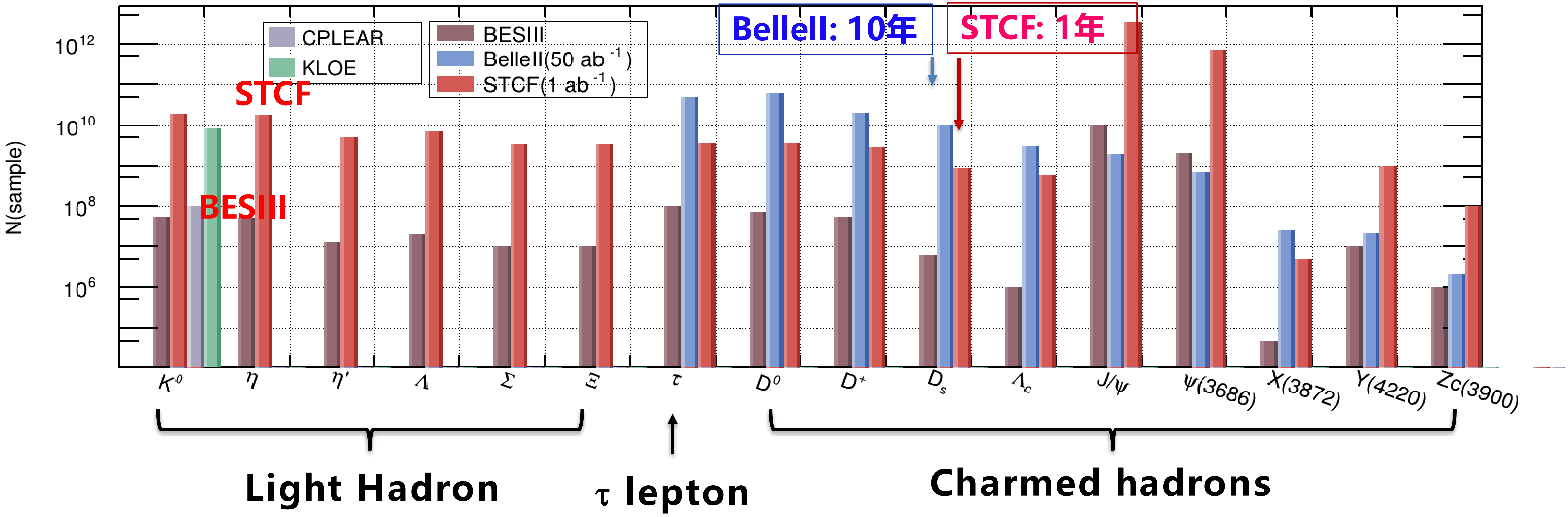
E_{cm}：2~7 GeV

Luminosity：0.5×10^{35} cm^{-2}s^{-1} @ 4 GeV

Expected Data Production at STCF

Huge statistics data sample + High Resolution + Low background

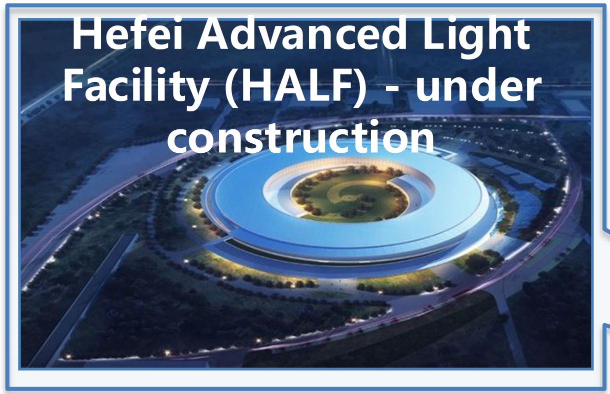
High precision measurement → Discovery

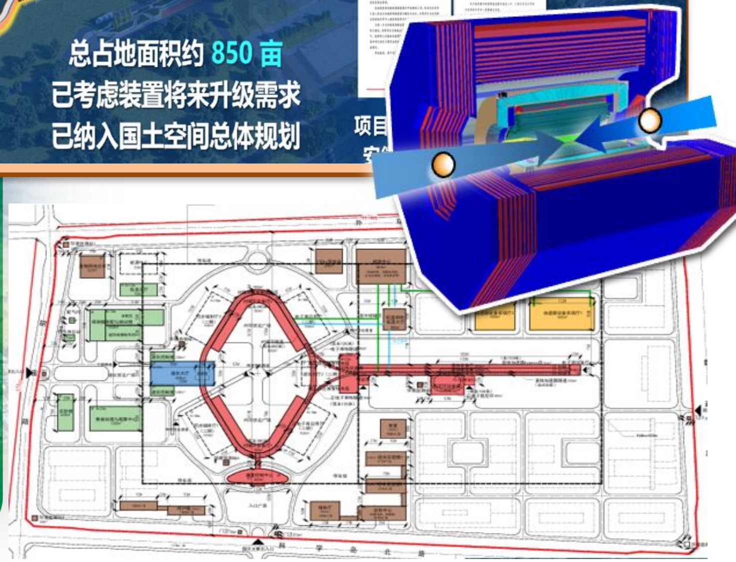


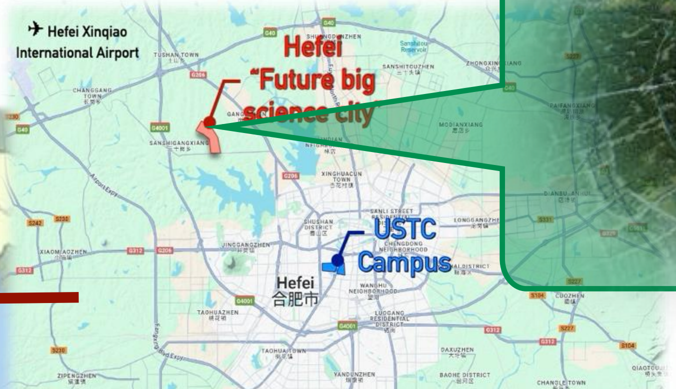
not only a τ-charm factory, but also a factory for XYZ exotics, hyperons, light hadrons

Site : Hefei, Anhui Province

Hefei Comprehensive National Science Center
"Future Big Science City", Hefei, Anhui Province







- Funded R&D : 0.4 Billion CNY by the Anhui government
- Construction budget : 4.96 Billion CNY

Promotion of the program

2011.12

Proposed at "workshop for acc. Based high energy physics development strategy"

2015.8

Fragrant Hills Science Forum

Demonstrated its importance and necessity. Urging to launch feasibility study and R&D

2018.6

USTC "double first-class" key project

Launch the conceptual design study and feasibility study

2021.9

Conceptual design report

Publish the CDR of physics and detector

2022.4

Governments of Anhui Province and Hefei City

Launch the STCF Key Technology R&D project

2023.8

Launch Meeting for Key Technology R&D Projects

2024.1

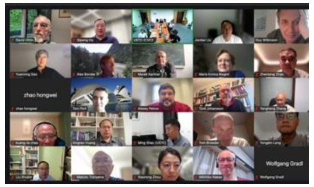
First STCF International Advisory Committee Meeting

2024.5

First Meeting of the Science and Tech. Committee

2024.10

Second STCF International Advisory Committee Meeting



2025.6

Third STCF IAC meeting

International review of collider conceptual design

2026.3

Project application for the "15th Five-Year Plan"

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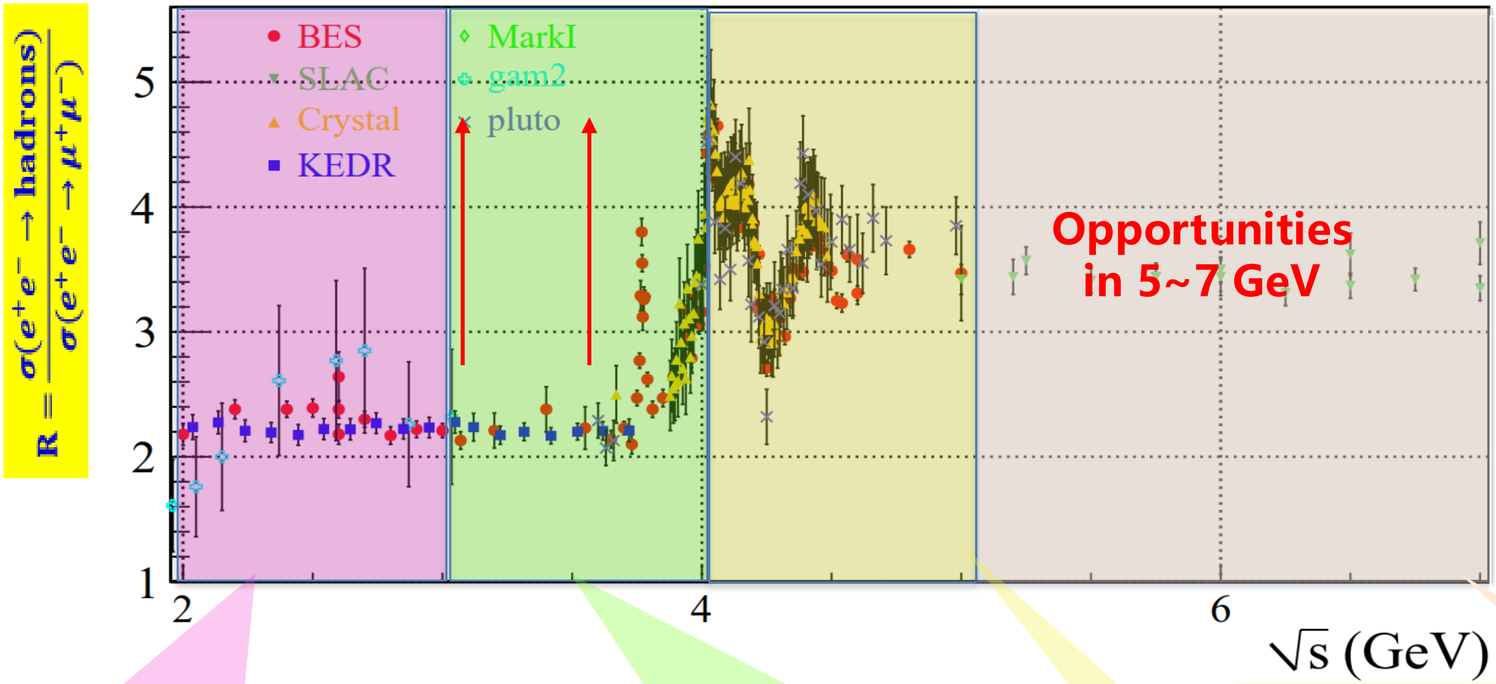
Physics in the Tau-Charm Energy Region



Unique Features in tau-charm region:

- **Transition** region between perturbative and non-perturbative QCD
- **Threshold effects and quantum correlation** of pair production of hadrons and tau leptons
- **Rich resonance** structures, **large production cross section** for charmonium(-like) states and exotics

- Hadron form factors
- $Y(2170)$ 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

Tests of Fundamental Symmetries

- The **discrete symmetries** play a crucial role in understanding natural laws.
- **Experimental evidence** of parity (P), time reversal (T), charge conjugation (C), and combined CP **violation**.
- STCF will enable **more precise tests** of **symmetry-breaking properties** with huge numbers of K, τ, hyperons and charmed hadrons.

Current Status of CPV Research at the Quark Level

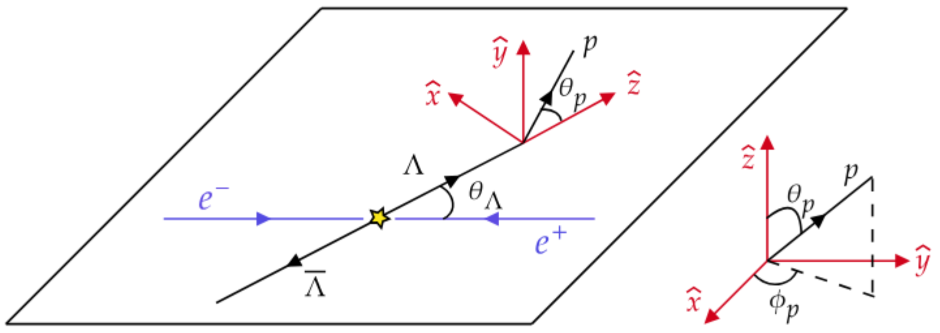
First Generation	Second Generation	Third Generation
Up/Down	Charm	Top
CPV in first generation is predicted to be far below current experimental sensitivity	**Charm mesons**: In 2009, LHCb discovered CPV at $\mathcal{O}(10^{-3})$, within SM predictions	Lifetime too short to form hadrons; decays before hadronization→ no "top hadron" CPV
	Charm baryons: **No CPV observed yet**. SM predicts $\mathcal{O}(10^{-4})$; new physics could reach $\mathcal{O}(10^{-3})$	
	Strange	Bottom
	Strange mesons: Discovered in 1964, CPV at level $\mathcal{O}(10^{-3})$, within SM predictions	**Bottom mesons**: Discovered in 2001 (BaBar/Belle), CPV at $\mathcal{O}(0.1)$, within SM predictions
	Strange baryons: **No CPV observed yet**. SM predicts $\mathcal{O}(10^{-4}$–$10^{-5})$; new physics could reach $\mathcal{O}(10^{-3})$	**Bottom baryons**: Discovered by LHCb in 2025, CPV at $\mathcal{O}(0.1)$, within SM predictions
Only strange baryons and charm baryons remain unexplored for CP violation—a final frontier for new physics in hadronic physics.		

STCF prospects:

- CPV of hyperons and charmed hadrons
- EDM of hyperons and tau
- CPT in neutral Kaon system
- Rare and forbidden process

Search for CPV and d_Λ in $J/\psi \to \Lambda\bar{\Lambda}$ decay

- **Angular distribution of hyperon production**



- Described by EM form factors $G_{1,2}$

$$\alpha_\psi = \frac{s^2|G_1|^2 - 4m^2|G_2|^2}{s^2|G_1|^2 + 4m^2|G_2|^2}, \quad \frac{G_1}{G_2} = \left|\frac{G_1}{G_2}\right| e^{-i\Delta\Phi}$$

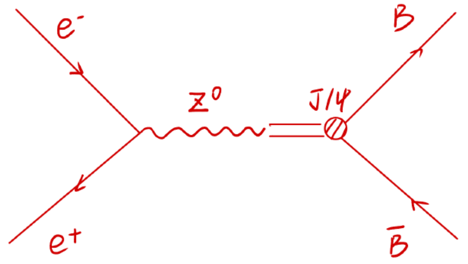
$$\boxed{\frac{d\Gamma}{d\Omega} \propto 1 + \alpha_\psi \cos^2\theta}$$

- Non-zero $\sin(\mathbf{\Delta\Phi})$ signatures hyperon polarization

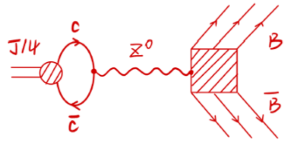
$$\boxed{P_y(\cos\boldsymbol{\theta}) = \frac{\sqrt{1-\alpha_\psi^2}\,\sin(\Delta\Phi)\cos\theta\sin\theta}{1+\alpha_\psi\cos^2\theta}}$$

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

- **P, CP violating terms in J/ψ production and decay**
  - P_L: J/ψ longitudinal polarization induced by Z boson
  - F_A: P violating form factors
  - H_T: CP violating form factors associated with EDM

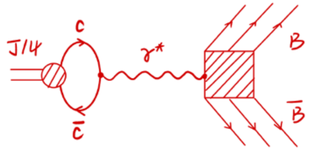


$$P_L = \frac{\rho_{++} - \rho_{--}}{\rho_{++} + \rho_{--}}$$



F_A : P violation term

Complex form factor, $F_A \neq 0$ indicate P violation



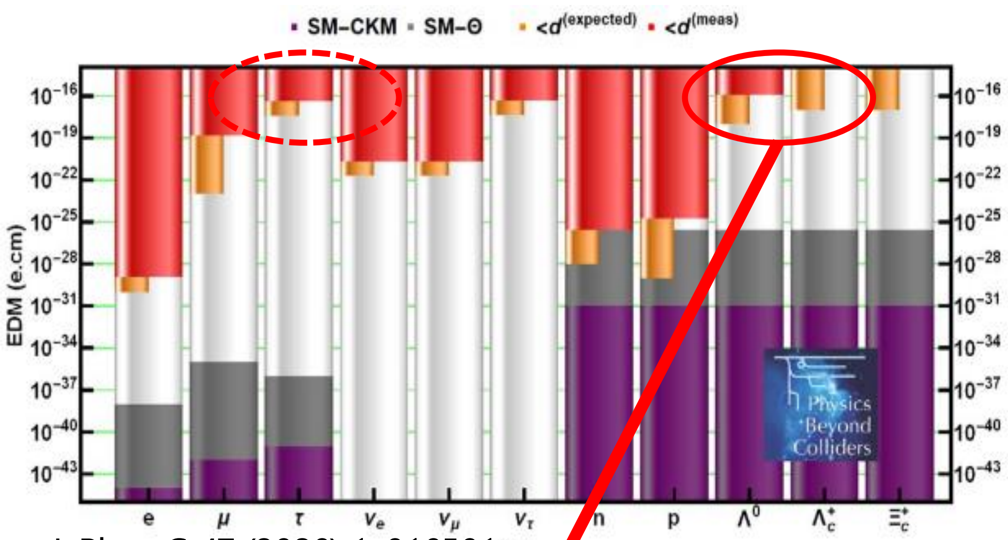
H_T: CP violation term

$$H_T(q^2) = \frac{2e}{3m_{J/\psi}^2} g_V d_B(q^2)$$

Assuming $d_B(q^2) \equiv d_B(0)$

$d_B(q^2)$: electric dipole form factor
$d_B(0)$: electric dipole moment
Physics Letters B 551 (2003) 16–26

Search for CPV and d_Λ in $J/\psi \to \Lambda\bar{\Lambda}$ decay



J. Phys. G 47 (2020) 1, 010501 PID

- EDM measurement only performed for Λ hyperon
- **d_Λ can be improved 10,000 in STCF**
- Search for EDM of the other strange and charmed baryons

- Based on OSCAR simulation, **statistical precision** improved by more than one order comparing to BESIII
- **Systematic uncertainty** dominated by **detector resolution effects**, could be improved by correcting resolution effect in MC with control samples, which is under study

Parameter	**Stat.**	BESIII Stat.	BESIII Sys.
$\alpha_{J/\psi}$	$\mathbf{1.4 \times 10^{-4}}$	2.2×10^{-3}	1.7×10^{-3}
$\Delta\Phi$	$\mathbf{2.7 \times 10^{-4}}$	4.2×10^{-3}	1.3×10^{-3}
A_{cp}	$\mathbf{3.0 \times 10^{-4}}$	4.6×10^{-3}	1.1×10^{-3}
$\sin W^2$	$\mathbf{6.4 \times 10^{-4}}$	1.2×10^{-3}	2.6×10^{-3}
$Re(d_\Lambda)$	$\mathbf{2.1 \times 10^{-20}}$	3.2×10^{-19}	0.5×10^{-19}
$Im(d_\Lambda)$	$\mathbf{1.6 \times 10^{-20}}$	2.6×10^{-19}	0.6×10^{-19}

CPV Program at STCF

Special issue for CP violation studies at STCF


CP violation studies at Super tau-charm facility

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Abstract

Charge-parity (CP) violation in the tau-charm energy region is one of the promising areas to search for. The future tau-charm facility of next generation is designed to operate in a center-of-mass energy from 2.0 to 7.0 GeV with a peak luminosity of 0.5×10^{35} cm^{-2}s^{-1}. Huge amount of hadrons and tau (τ) leptons will be collected with good kinematic constraint and low-background environment. In this report, possibilities of CP violation studies in tau-charm energy region and at the future tau-charm facility are discussed from various aspects, *i.e.* in the production and decay of hyperons and τ lepton; in the decay of charmed hadrons. The CPT invariance test in $K^0 - \bar{K}^0$ mixing is also presented.

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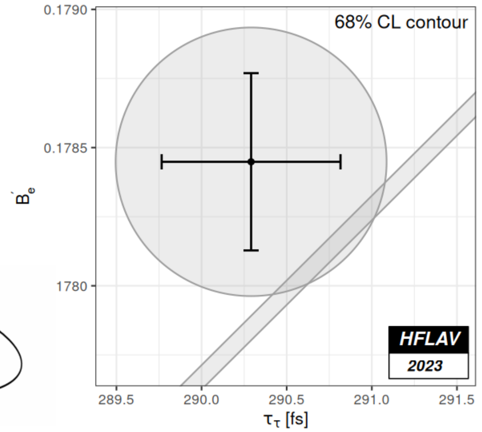
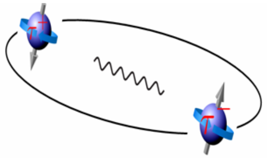
Contents

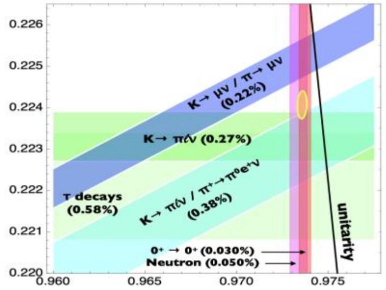
arXiv:2502.08907, submitted to Physics Reports

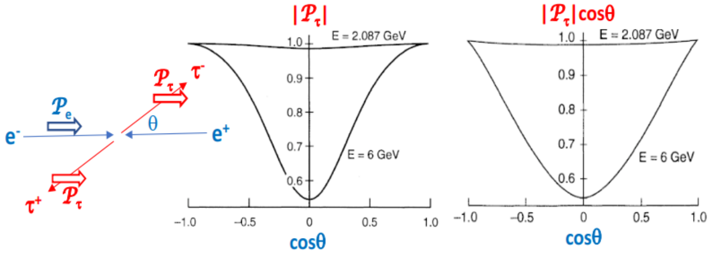
Tau physics potential at STCF

- **Properties of tau lepton**
  - **τ-lepton mass (Challenge from uncertainties in energy calibration and spread)**
  - **Tauonium** Enhanced significance with improved energy spread
  - **EDM** evolution of EDM form factors with energy
  - **Quantum entanglement**
- **Tau decay**
  - **cLFV** systematically studies via leptonic decays
  - **Cabibbo angle anomaly, CPV** studies via hadronic decays
  - **Amplitude/form factor** studies via many-body decays
  - **α_s and muon g-2**

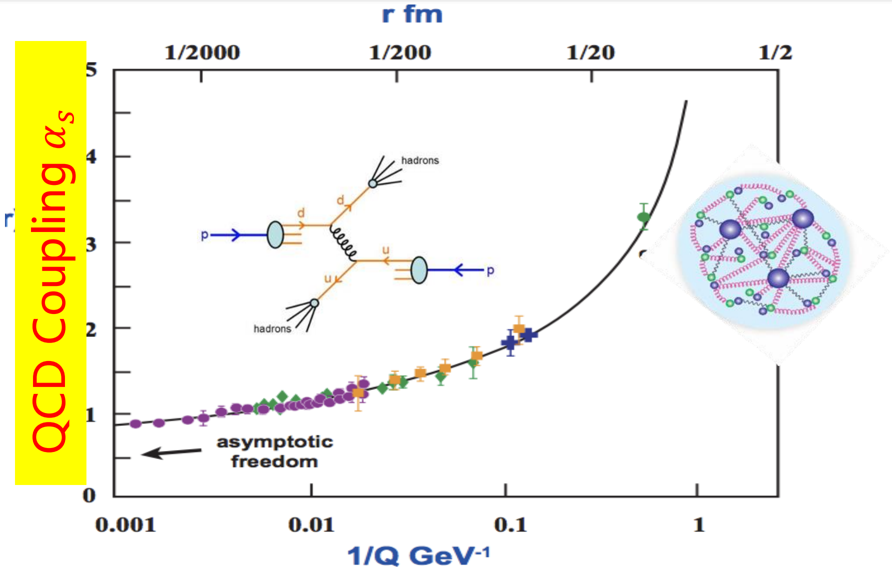


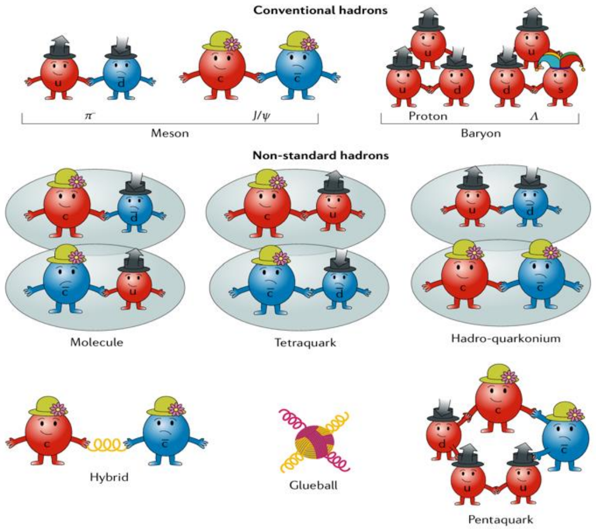


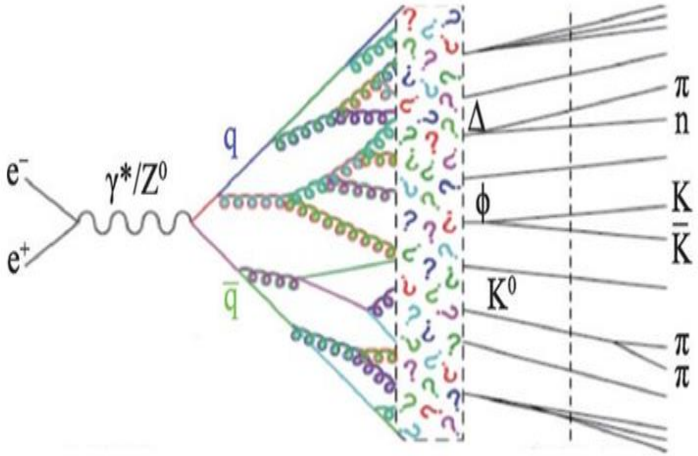




Quark Confinement



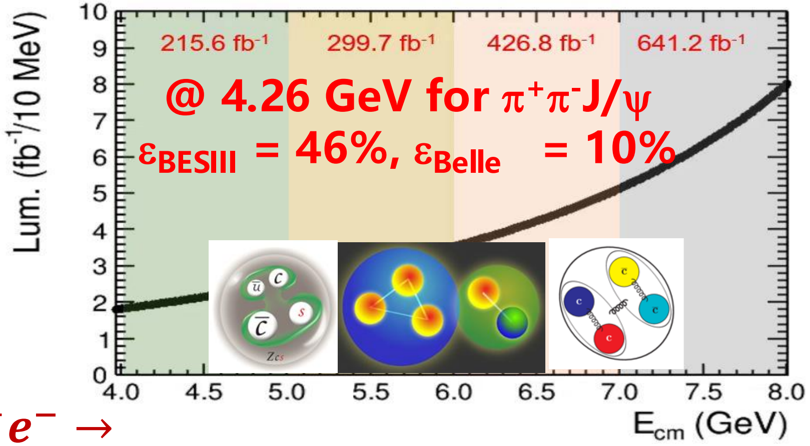


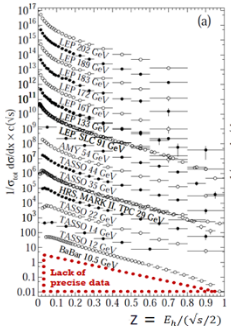


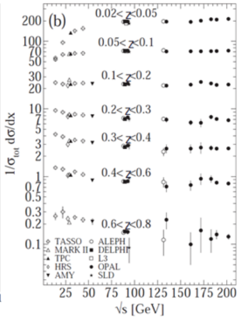
- Unraveling the physical mechanism of quark confinement requires summarizing **the laws of hadron spectra**, **production**, **decay**, and understanding **how quarks and gluons are distributed inside hadrons**.
- The STCF will produce vast quantities of **charmed hadrons** and **light flavor hadrons**, enabling studies on how quarks and gluons form hadrons and how color confinement shapes their internal structures.

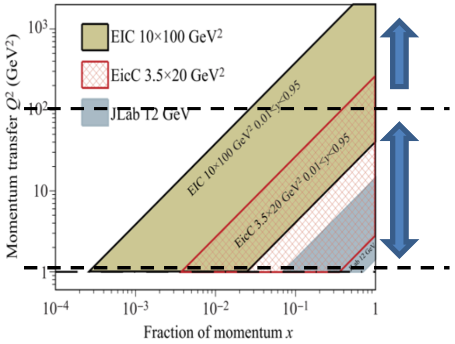
5-7 GeV physics potential at STCF

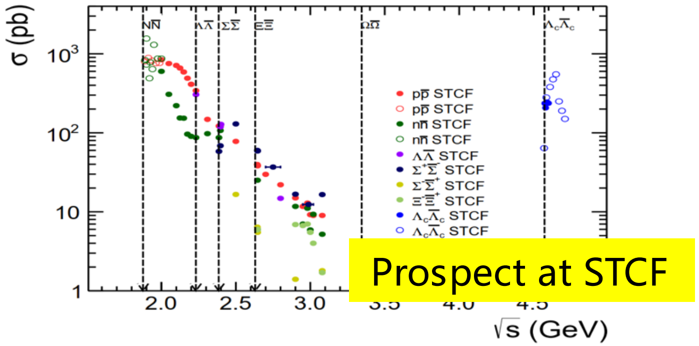
- **Hadron spectroscopy**
  - Many threshold opens in 5-7 GeV which yield more potentials for hadron studies
  - Structures in more channels for **XYZ physics**, with larger production rates above 5 GeV
  - **$\mathbf{P_c}$ pentaquarks** in $e^+e^- \to J/\psi h\bar{h}$ **for** hidden-charm and $e^+e^- \to \Lambda_c\bar{D}^*\bar{p}, \Sigma_c^*\bar{D}^{(*)}\bar{p}$ for open-charmed pentaquarks
  - Energy region above 6 GeV is ideal for **fully charmed tetraquark states** via $e^+e^- \to J/\psi c\bar{c}$ etc.
- **Hadronization and hadron structure**
  - **Fragmentation functions** for charmed quark is avaliable
  - Synergy with Eic(C) facilities for FF studies
  - A non-zero Pauli **Form factors** provides evidence for the existence of higher Fock states, that require higher energies





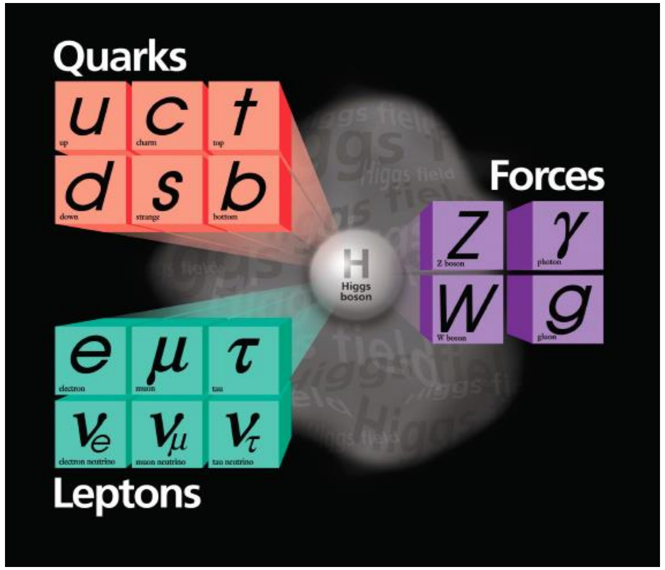






Fundamental Physics Parameters

- **Essential for rigorous SM tests and new physics searches.** STCF enables high-precision measurements:
  - **R-value**: A fundamental quantity reflecting quark flavors/colors, with implications for new particle searches and theoretical inputs (e.g., fine-structure constant, muon g-2)
  - **Tau lepton mass**: Critical for testing lepton universality
  - **CKM matrix unitarity and triangle** : Violations could hint at a fourth quark generation
  - **Strong coupling constant (α_s)** : Directly impacts Higgs/EW/top quark predictions and vacuum stability studies



Parameters of the Standard Model:

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

R value:

$$R \equiv \frac{\sigma^0(e^+e^- \to \text{hadrons})}{\sigma^0(e^+e^- \to \mu^+\mu^-)} \equiv \frac{\sigma^0_{\text{had}}}{\sigma^0_{\mu\mu}} \approx N_c \sum_f Q_f^2$$

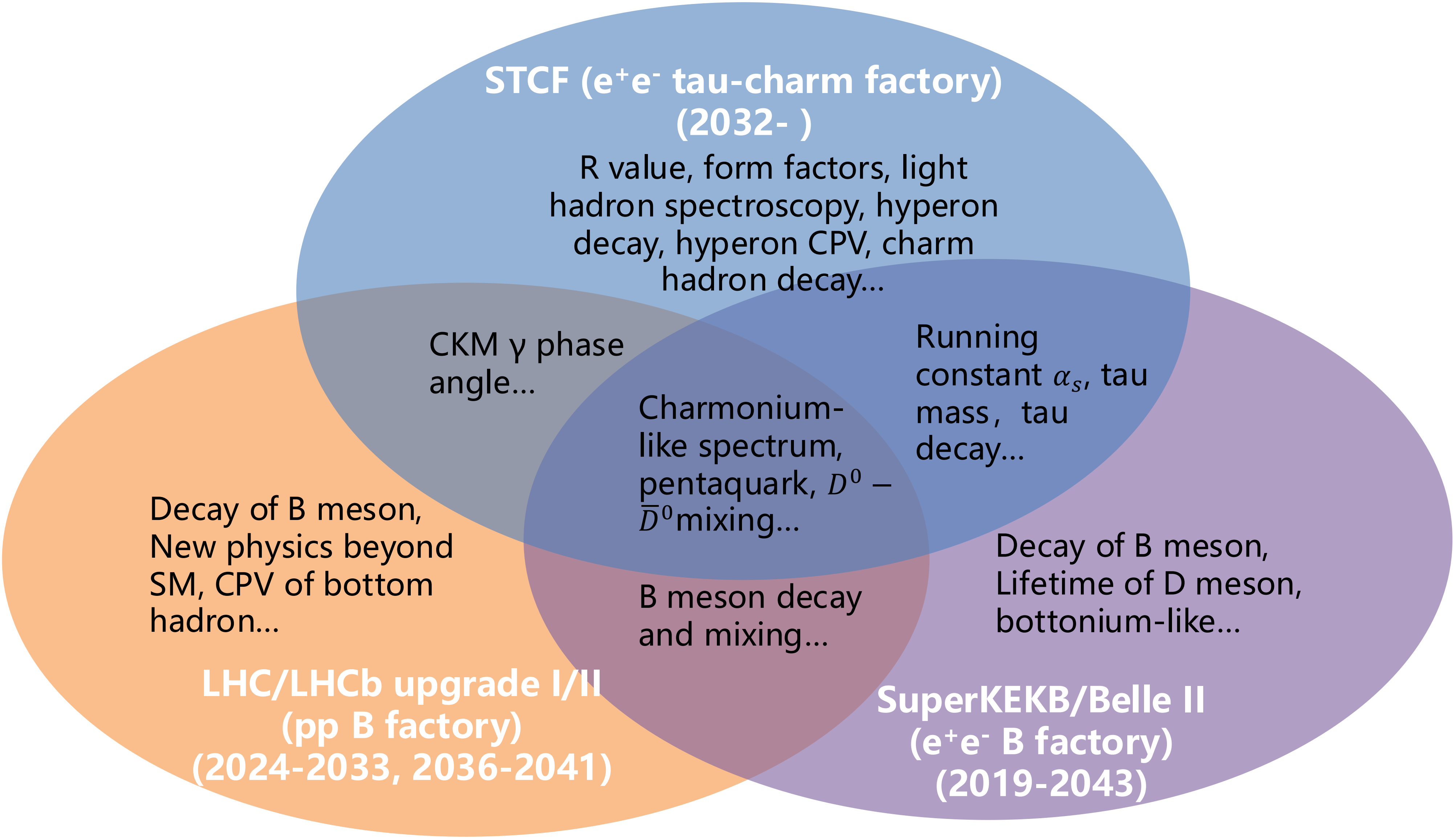
LFU test:

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{\tau_\mu}{\tau_\tau}\left(\frac{m_\mu}{m_\tau}\right)^5 \frac{B(\tau \to e\nu\bar{\nu})}{B(\mu \to e\nu\bar{\nu})}(1+F_W)(1+F_\gamma)$$

CKM matrix:

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

Complementary and Synergy of STCF, Belle II, and LHCb



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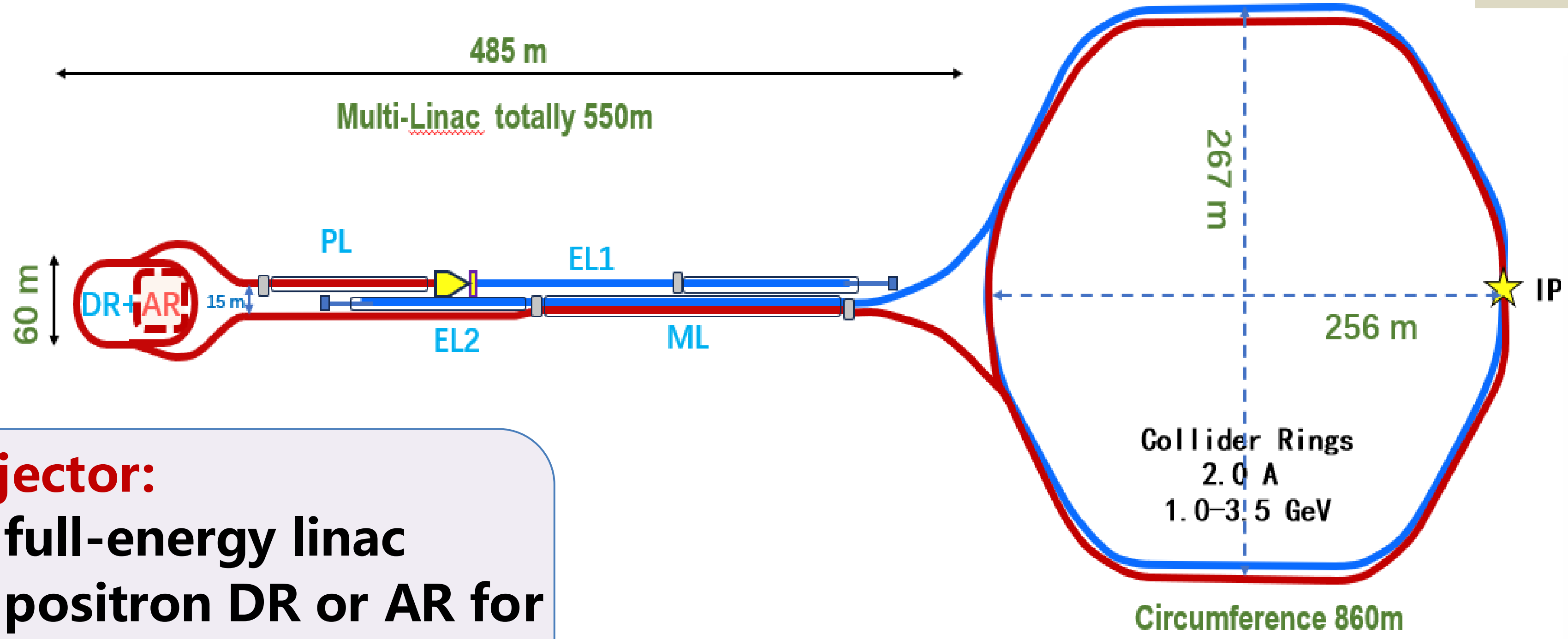
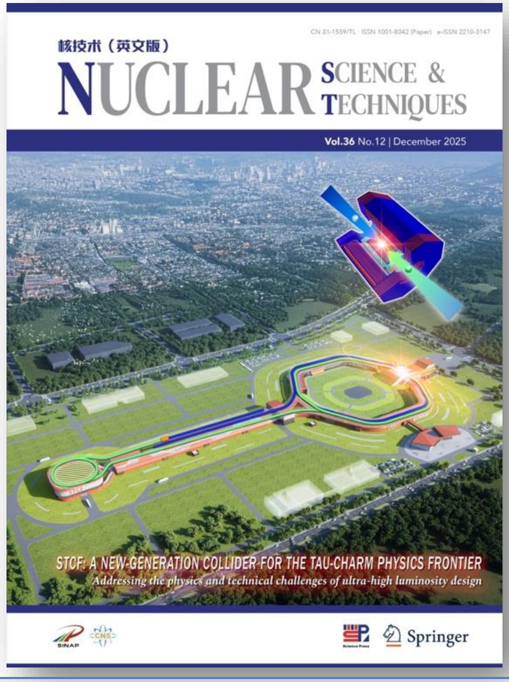
Accelerator Design

Goal: E_{cm} 2-7 GeV, luminosity > 5×10^{34} cm^{-2}s^{-1} @ 4 GeV

arXiv: 2509.11522 [acc-ph]
Publshed on NST





Injector:
- full-energy linac
- positron DR or AR for different injection modes

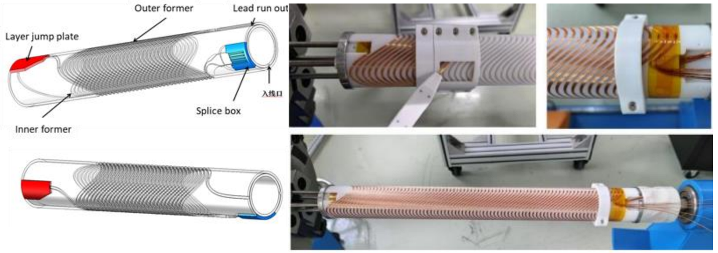
CM (GeV)	2.0	3.0	4.0	7.0
Simulated lumi. (cm^{-2} s^{-1})	6.2×10^{33}	2.1×10^{34}	9.4×10^{34}	4.5×10^{34}

Double-Ring Collider
- low emittance
- high current
- large Piwinski angle
- Crab-waist collision scheme

Accelerator R&D

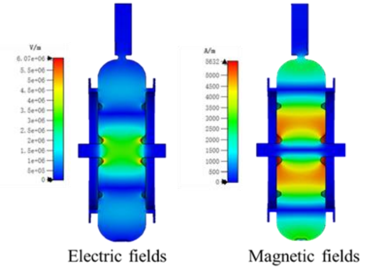
IR SC Magnets

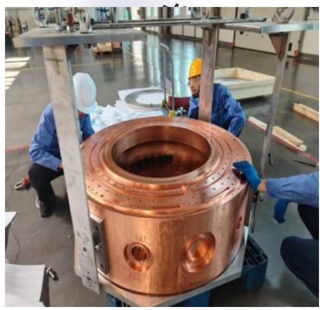
Focus on the QD0, CCT, Vertical test in early 2026



Room-Temperature RF Cavity

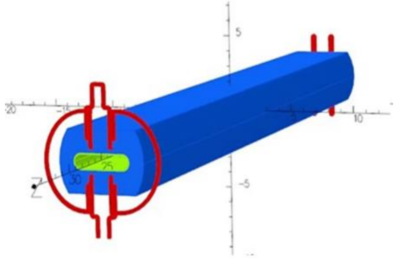
TM020-mode



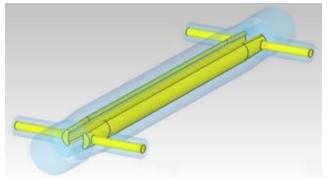


Kicker Magnets

Nonlinear kicker

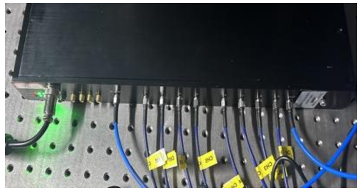


Ultrafast kicker



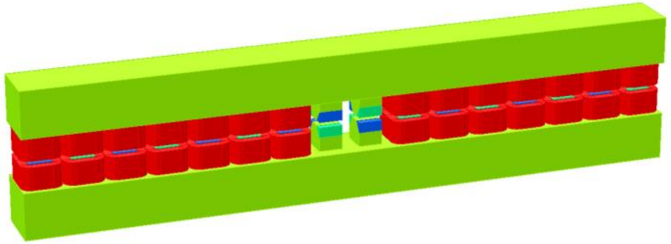
Bunch by Bunch Profile Monitor

Beam tests in different facilities (SSRF, HLS, DLS)



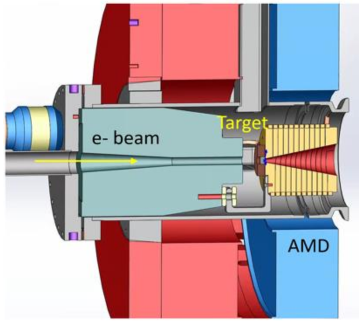
Damping Wigglers

RT electromagnetic wigglers, hybrid structure with permanent magnet blocks



Conventional Positron Source

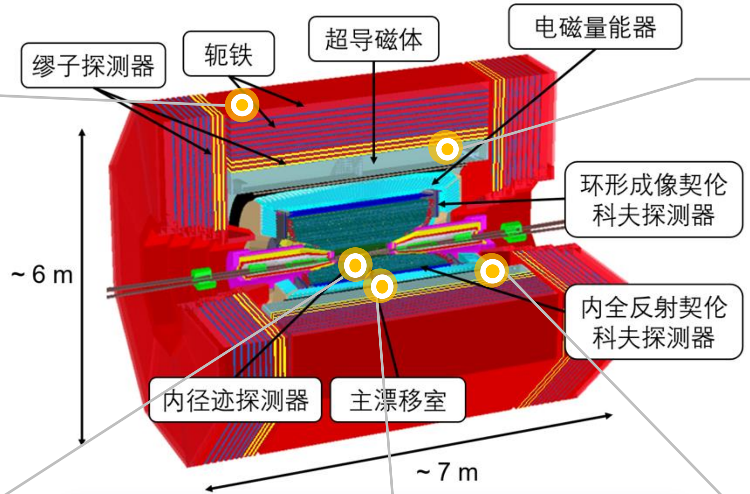
To be test in dedicated test beam platform



Detector Design

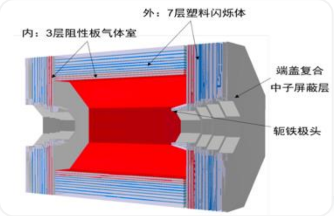
Goal: Ultra-high precision measurement and identification under strong irradiation, high background, high event rate, and large dynamic range.

$\sigma_P/P \leq 0.5\%$ @ 1 GeV/c， $\sigma_E/E \leq 2.5\%$ @ 1 GeV， $K/\pi \geq 4\sigma$ @ 2 GeV/c



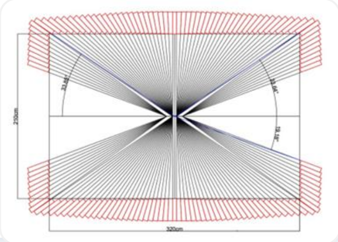
Muon Detector

Resistive Plate Chamber+ Plastic scintillator



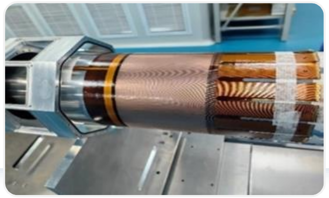
Electromagnetic Calorimeter

pCsI +APD



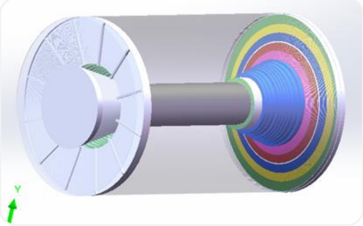
Inner tracker

µRGroove Detector
CMOS MAPS



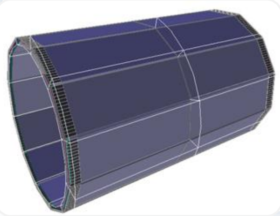
Central Tracker

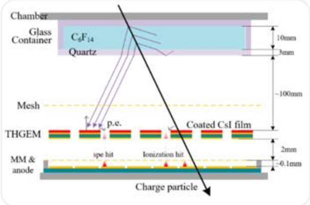
Low material-budget
Main Drift Chamber



Particle Identification System

DIRC-like　　环形成像





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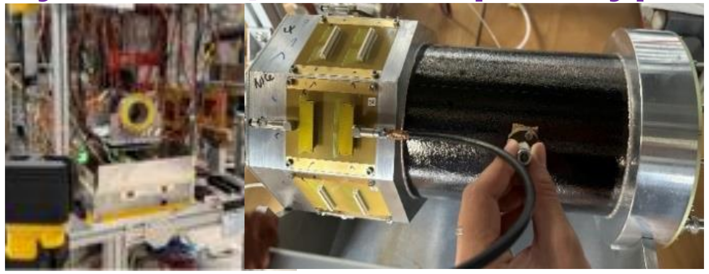
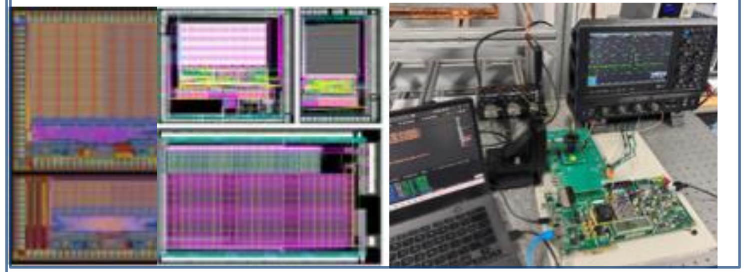
Detector R&D

- Completed the **prototypes** of all five sub-detectors, and met or exceeded the design specifications in **beam test** (7/31 – 8/14, 2024 & 10/15 – 10/29, 2025)

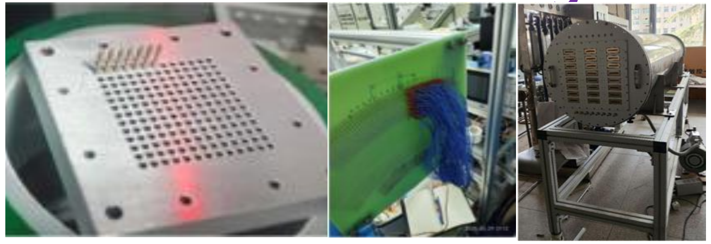
Cylindrical μRGroove prototype



ITK: CMOS prototype chips



Main tracker full length



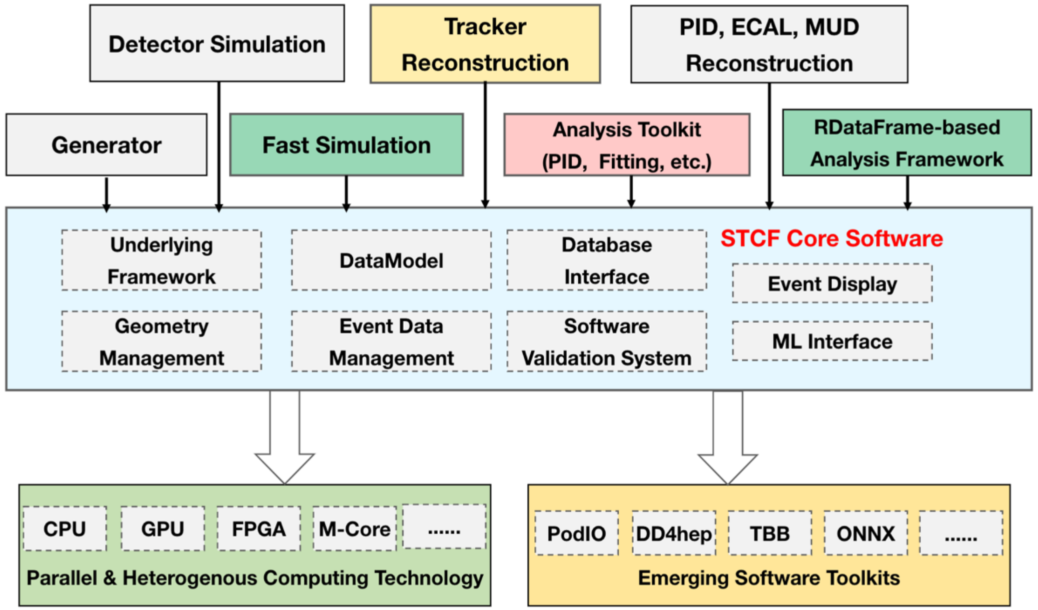
PID

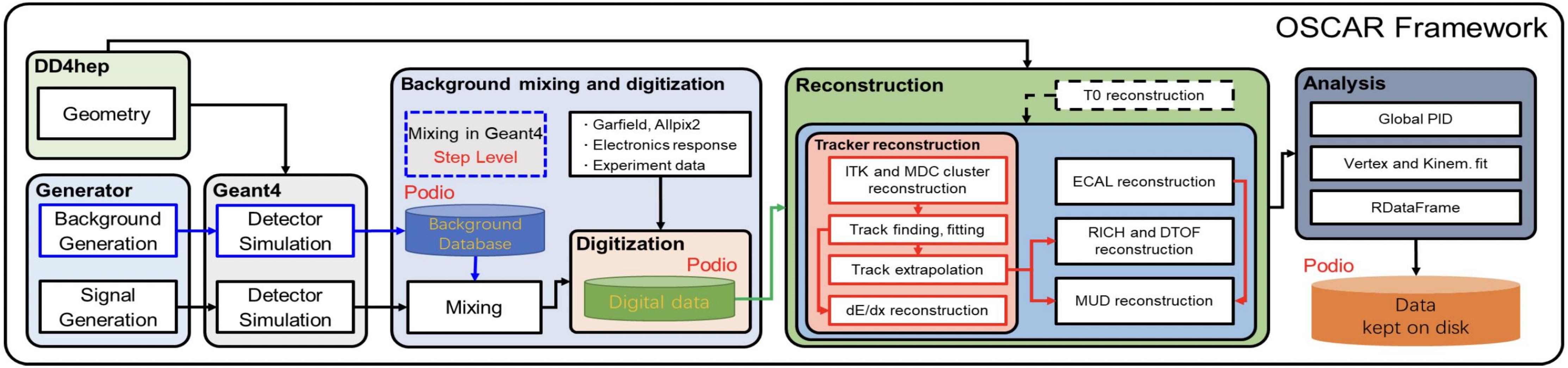
EMCal: 5 X 5 prototype

Muon: Plastic Scintillator+ RPC

Offline Analysis 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
- Over twenty physics analysis are undergoing with OSCAR full simulation





Content

- STCF Overview
- Physics Objectives
- Key Technology R&D Progress
- **Summary and outlook**

Summary and outlook

- 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 within 1-2 years
- STCF has submit a proposal to the central government in 2025 and defensed for inclusion in the 15th five-year plan (2026-2030)
- Expanding international collaboration and exploring synergies with other projects are crucial. All forms of collaboration are welcomed.

Thank you!