# Super Tau Charm Facility (STCF)

## Physics and Challenges

Zhengguo Zhao

University of Science and Technology of China

8/2/2024

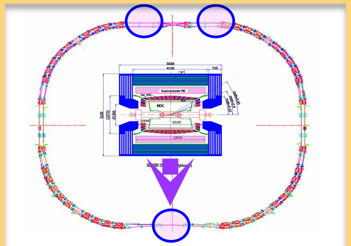
# Outline

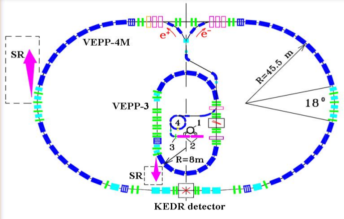
1. Introduction
2. The Super Tau Charm Facility
3. Conceptual Design and R&D for Key Technologies
4. Site selection and  future plans
5. Summary

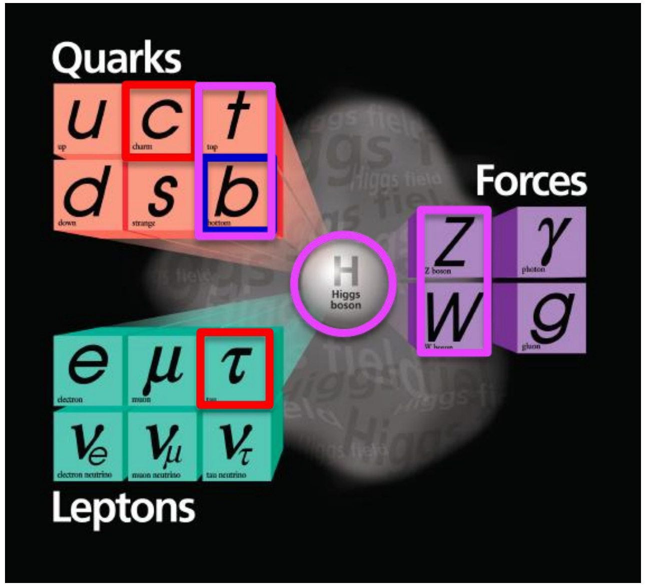
# Outline

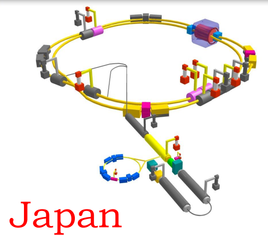
1. Introduction
2. The Super Tau Charm Facility
3. Conceptual Design and R&D for Key Technologies
4. Site selection and  future plans
5. Summary

# Particle Physics At Accelerators

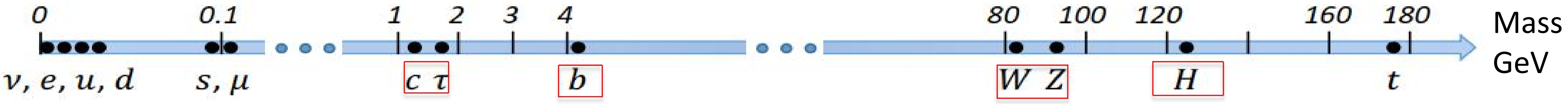







Increase luminosity ~50-100

China BEPCII Japan KEKB, US PEPII

China STCF Japan SKEKB

CERN LEP → LHC US Tevatron

CERN FCC China CEPC

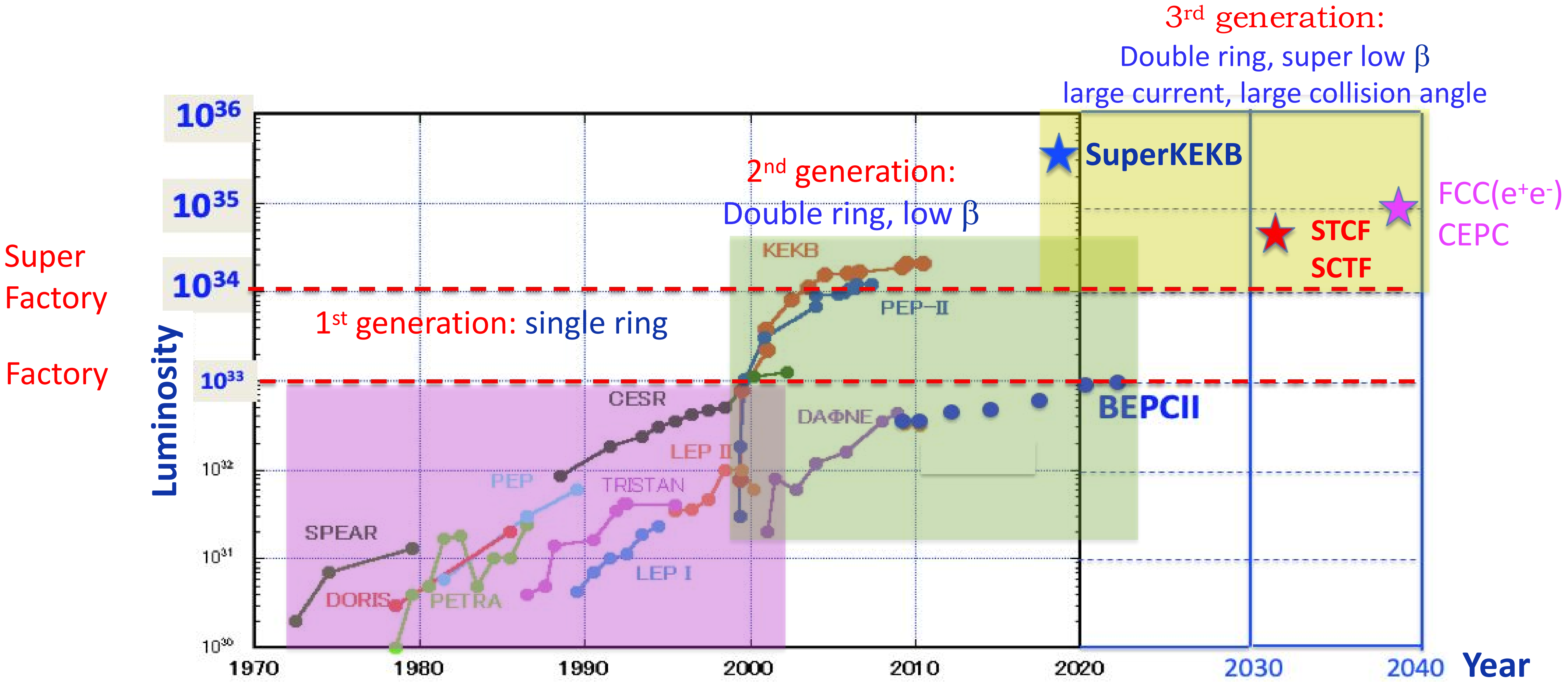
Increase energy ~10

High luminosity/precision frontier: Hadron structure, exotic matter, nature of strong interaction, search for new physics using c/b quarks and τ leptons as media.

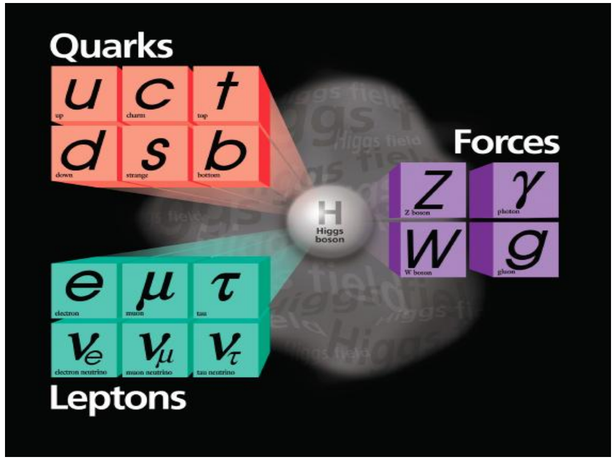
High energy frontier: origin of mass, nature of electroweak interaction, search for new physics through Higgs particle, precise study of third generation quarks.

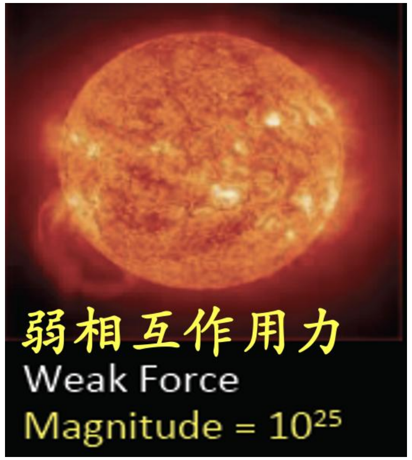
# History Of Electron Positron Colliders

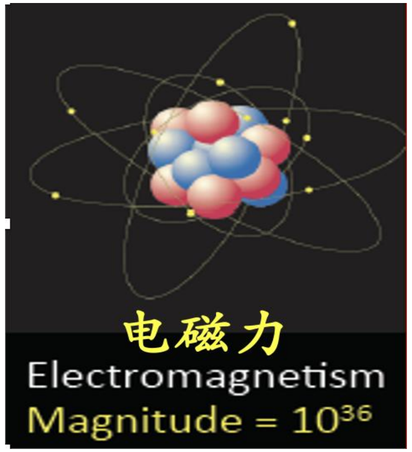
Challenge: Super high luminosity, high quality particle beam collision



# The Challenges To The Standard Model





New physics
beyond
The SM
?
Where is
the new physics?

In the energy region where hadron produced
Hadron production and decay
Hadron structure
Hadron spectrum
Exotic hadron

Any possible means of searches
New energy territory → Energy frontier

Higher precision measurement
→ Precision frontier

Key energy region
for the study of strong interaction

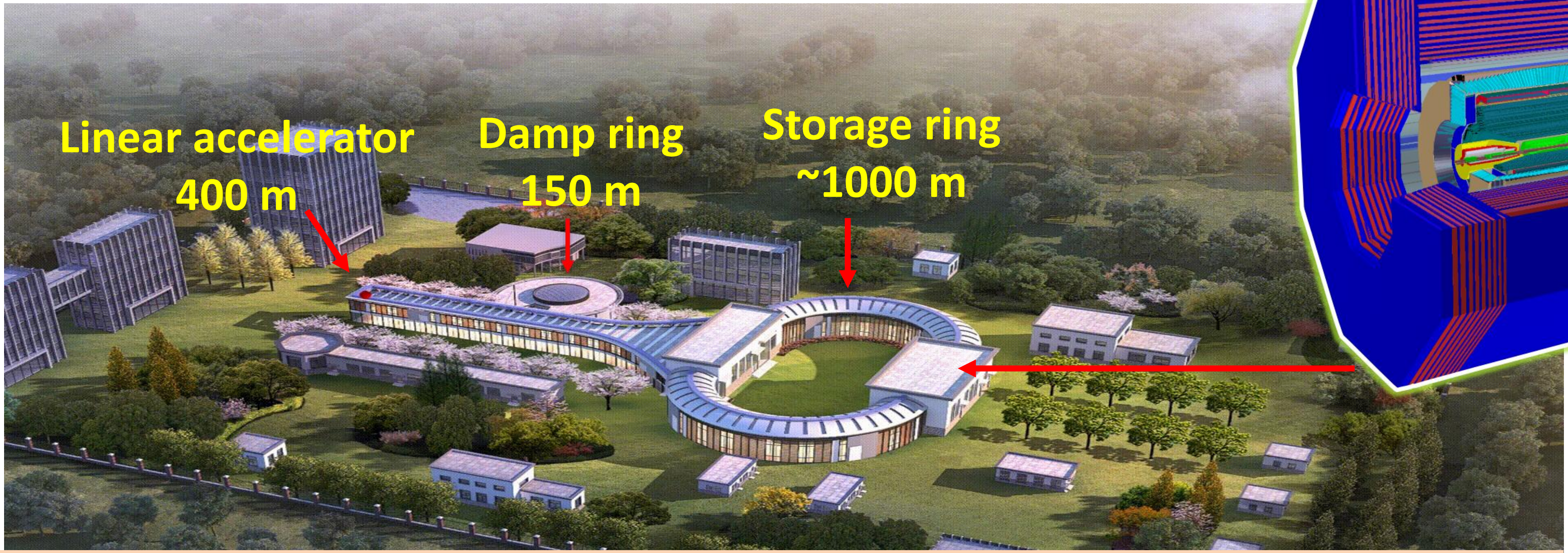
Unprecedented
Large data sample with high precision

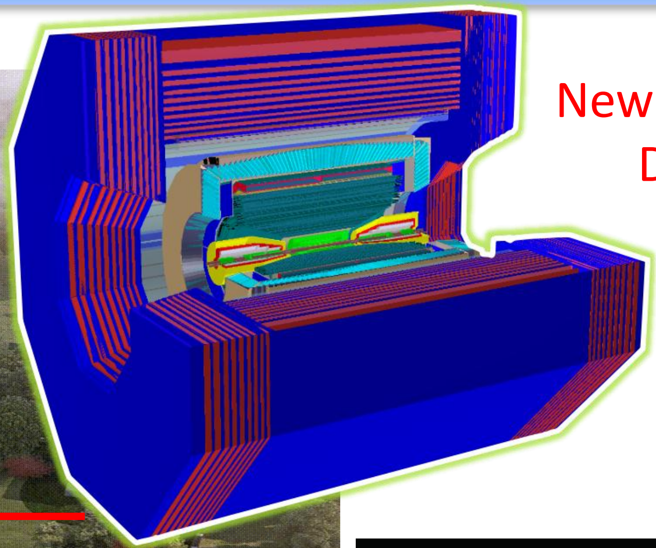
**STCF**

# Outline

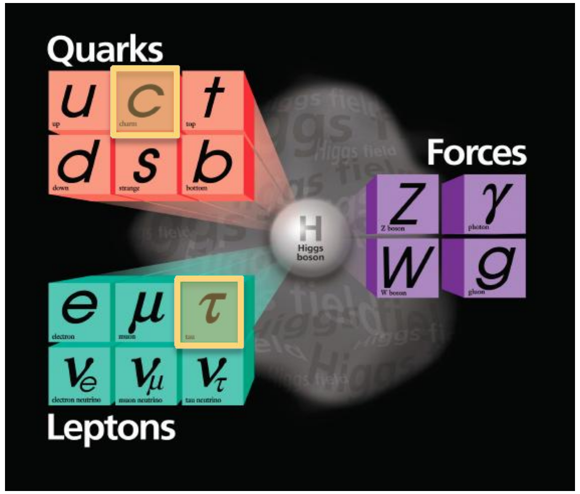
1. Introduction
2. The Super Tau Charm Facility
3. Conceptual Design and R&D for Key Technologies
4. Site selection and future plans
5. Summary

# Super Tau Charm Facility (STCF)



New Generation Detector

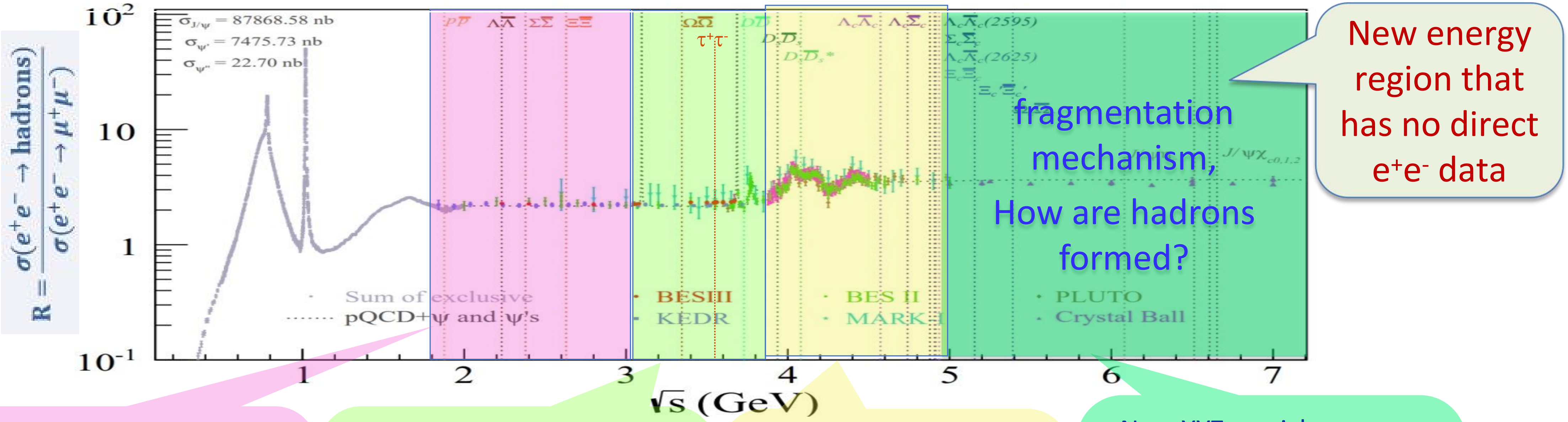



- $E_{cm}$=2-7GeV， L=0.5×$10^{35}$ $cm^{-2}$ $s^{-1}$
- Potential for an upgrade to increase L and realize polarized beam

Generate unprecedented large number of τ leptons, particles with c quarks, and hadrons to study the deep structure of matter and basic interactions

# Unique Features And Rich Physics Programs

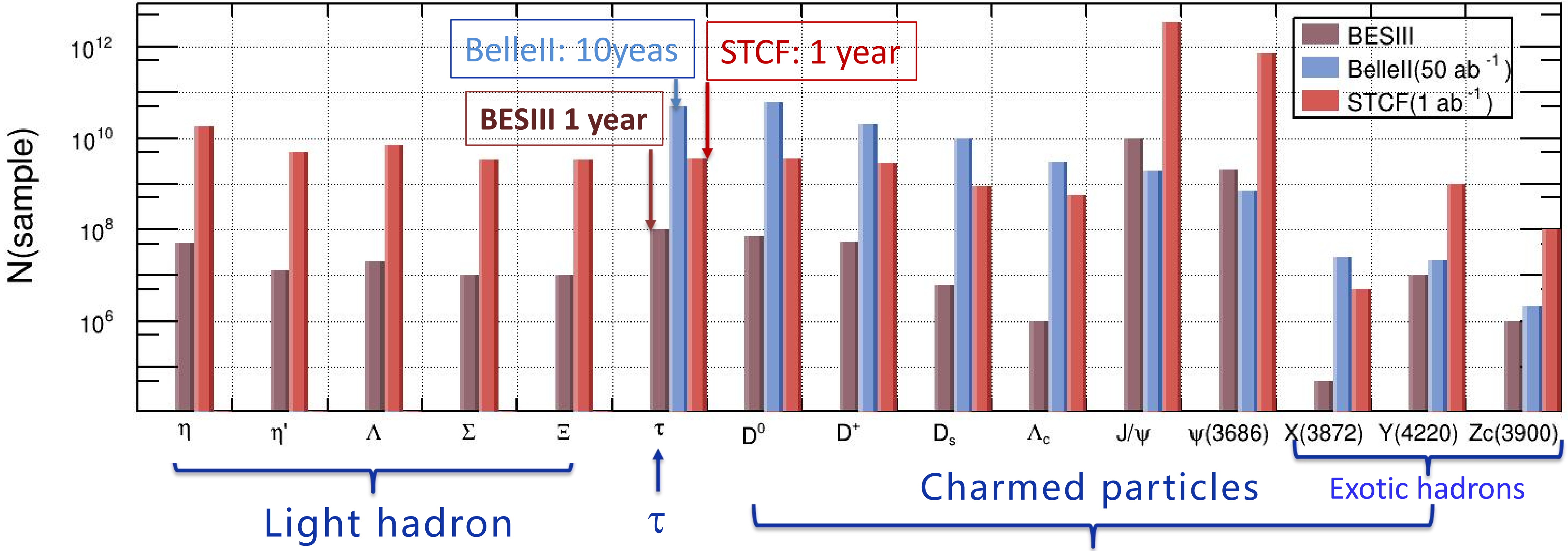
- Energy region bridges perturbative and non-perturbative QCD.
- Abundant resonance structures, huge production cross-sections for charmonium states.
- Threshold effect of pair production of hadron and $\tau$.
- Copious production of exotic hadrons (multi-quark, and hybrid states).




STCF will have unpreceded high statistical data, in 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,
and to the searches for new physics

# Unique Super Large Data Samples

The world's unique super large data sample with high resolution and low background
➜ high-precision measurement, and potential for discoveries

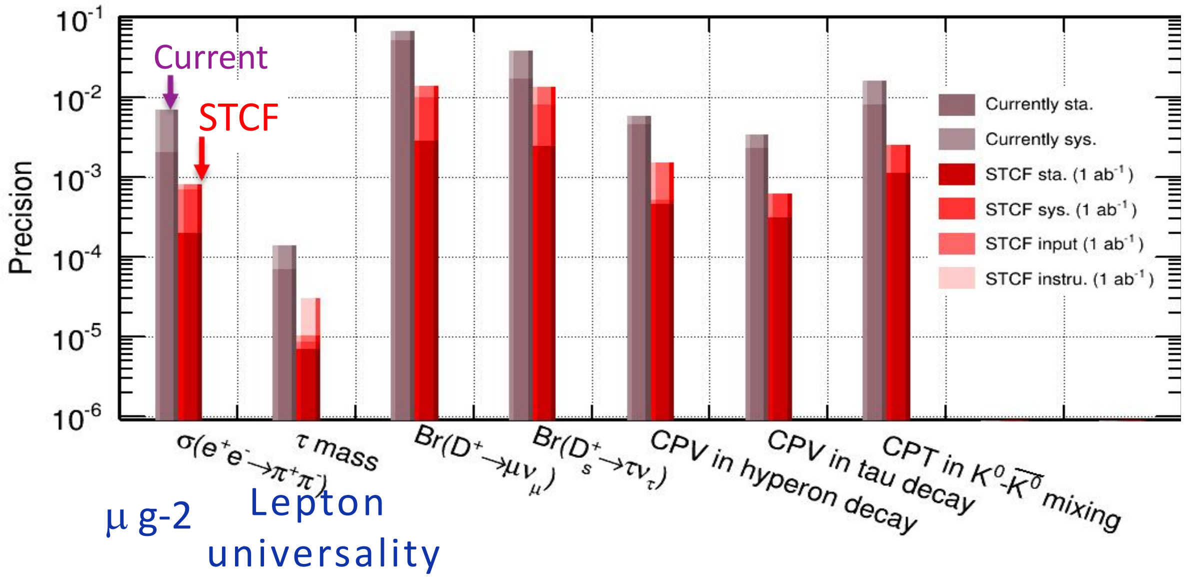



Not only a STCF, but also a factory of light hadrons, hyperons, and XYZ particles

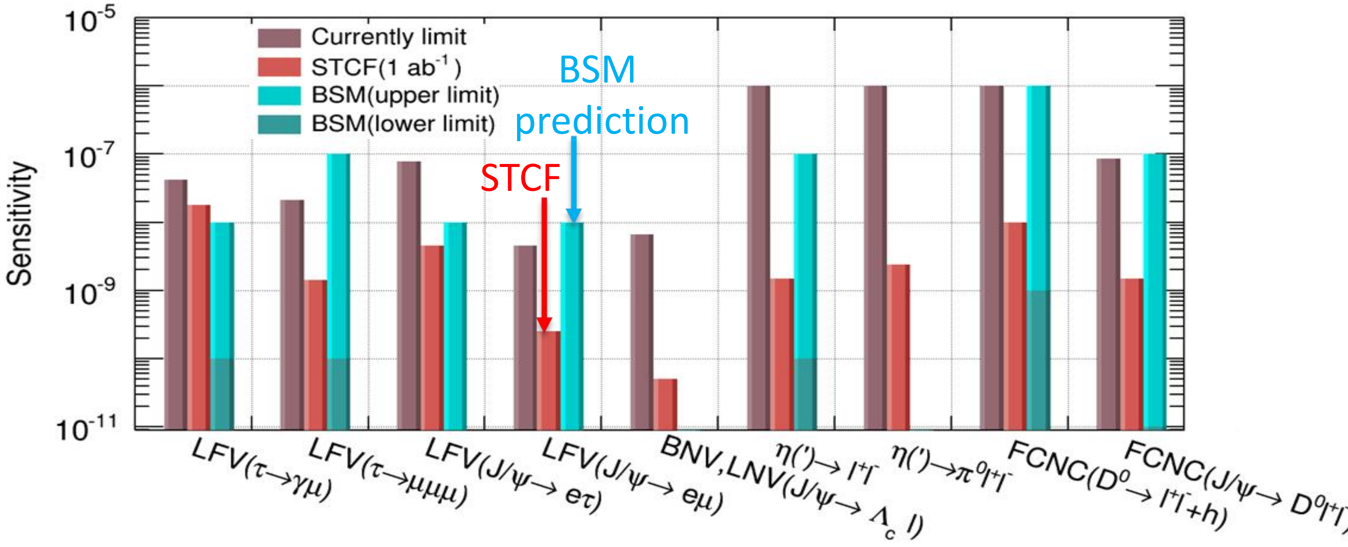
# Important High Precision Measurements and New Physics Searches

STCF can improve the current precisions of many important measurements, and sensitivities of many new physics searches by 1-2 orders of magnitude.

Some have exceeded theoretical expectations→ Great potential to discover new physics!




Violation of symmetries(CP, CPT)

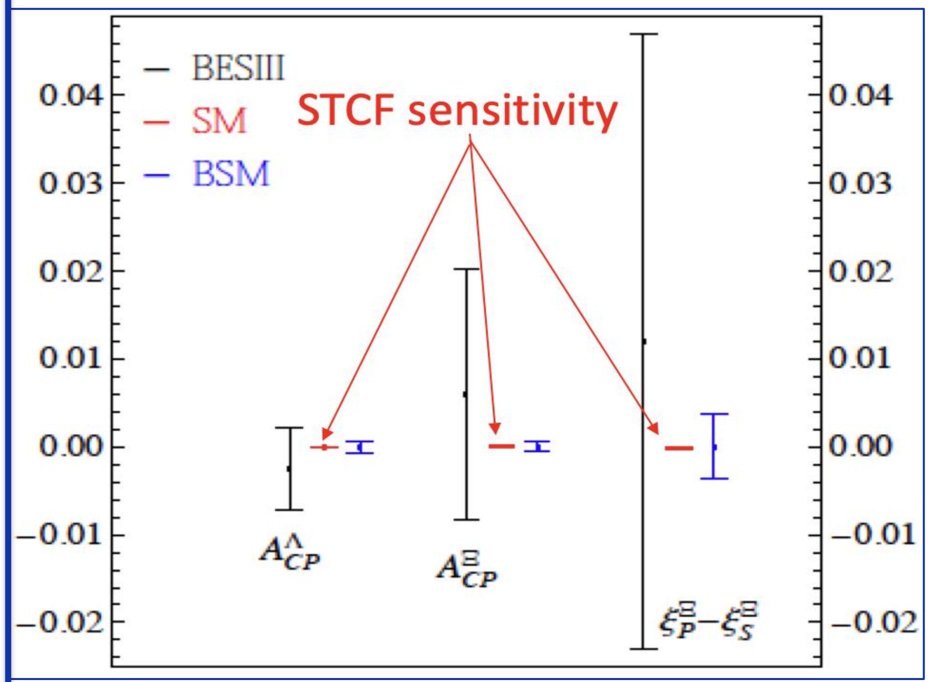


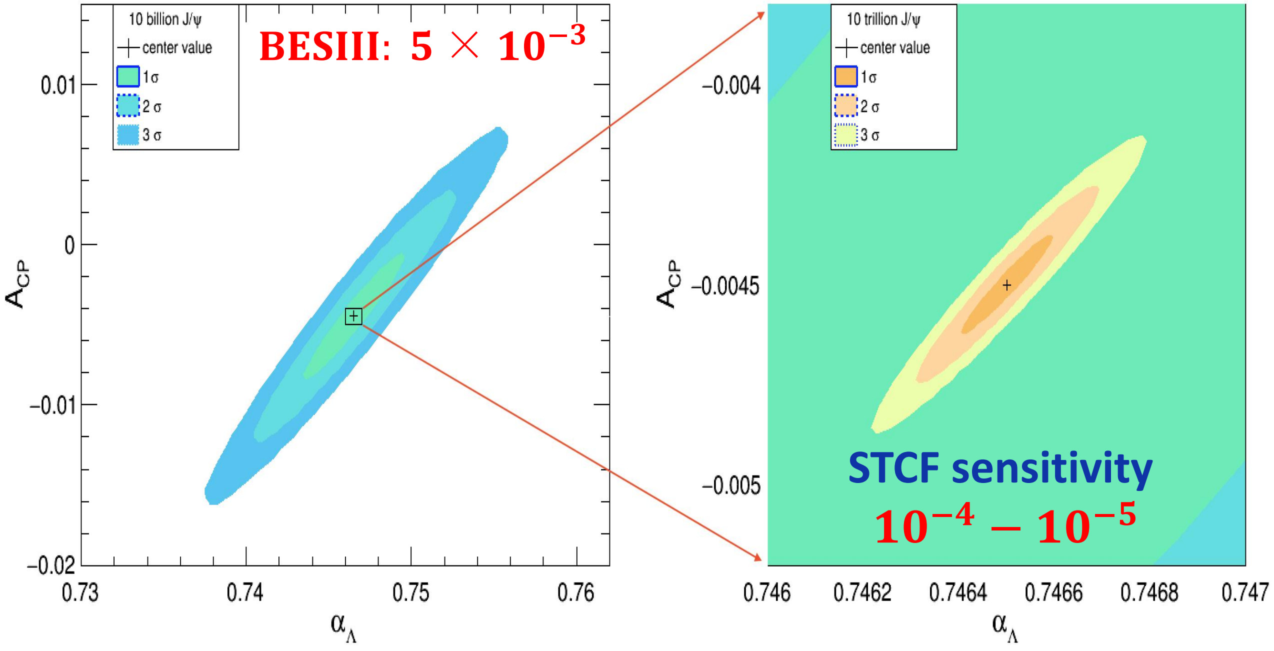

Violation of lepton flavor, baryon number, flavor-changing neutral current processes (LFV, BNV, FCNC)

# CPV of Hyperons from J/ψ Decays

**BESIII: $10^{10}$ $J/\psi \rightarrow 4\times10^{6}$ hyperons; STCF: $10^{12}$ $J/\psi \rightarrow 10^{8\text{-}9}$ hyperons**

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




**The first measurement of CPV from the baryon system!**

**Challenge to the SM for the discovery of new physics!**

# Outline

1. Introduction
2. The Super Tau Charm Facility
3. **Conceptual Design and R&D for Key Technologies**
4. Site selection and  future plans
5. Summary

# Conceptual Design Report

arXiv > hep-ex > arXiv:2303.15790

Search... Help | Advanced

High Energy Physics – Experiment

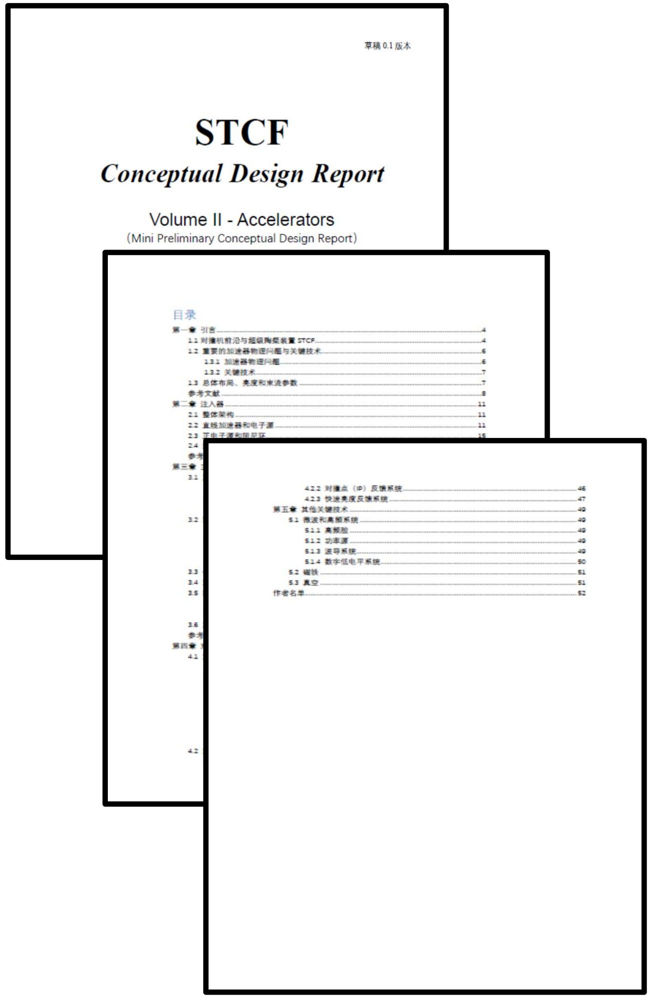
*[Submitted on 28 Mar 2023 (v1), last revised 30 Mar 2023 (this version, v2)]*

## 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 -- the BEPCII, providing a unique platform for exploring the asymmetry of matter-antimatter (charge-parity violation), in-depth studies of the internal structure of hadrons and the nature of non-perturbative strong interactions, as well as searching for exotic hadrons and physics beyond the Standard Model. The STCF project in China is under development with an extensive R\&D program. This document presents the physics opportunities at the STCF, describes conceptual designs of the STCF detector system, and discusses future plans for detector R\&D and physics case studies.


453 authors of 82 institutions from 9 countries



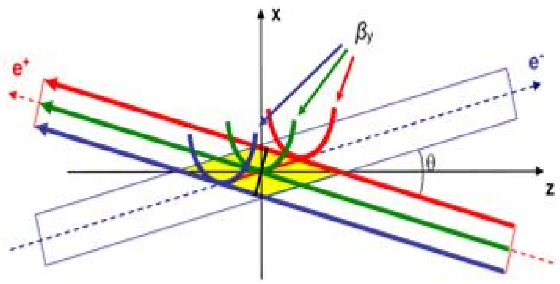
# Challenges and Key Technologies to Accelerator

The big challenge: super-high luminosity 0.5x10$^{35}$, wide energy range in 2-7 GeV

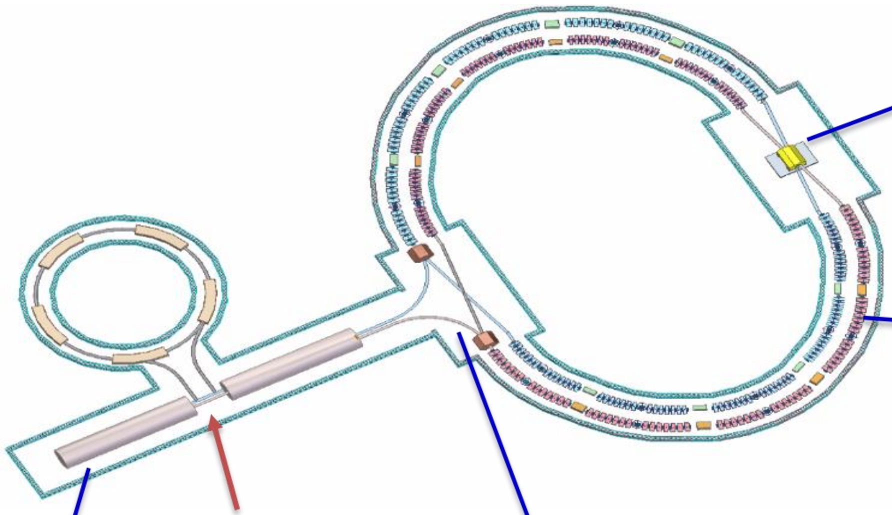
→ High currents, low emittance, super small β*, large Piwinski angle, crab-Waist

- IR strong nonlinearity and collective to strong current and small emittance
- Complex superconducting magnet in IR to have super small bunch size

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




Large Piwinski Angle+Crab Waist



**Storage Ring and Interaction Region**
Machine-detector interface
IP beam size (Y) nm scale, Crab-Waist, nonlinear compensation

**Precision Measurement and Control**
Stable operation of beam collision, Beam control (monitoring, diagnosing, measurement, tuning)

**Beam sources**
High beam intensity
High frequency
Low emittance

**Other Key Technologies**
Beam injection, magnet, RF cavity, precision collimation and alignment, Ultra-high vacuum

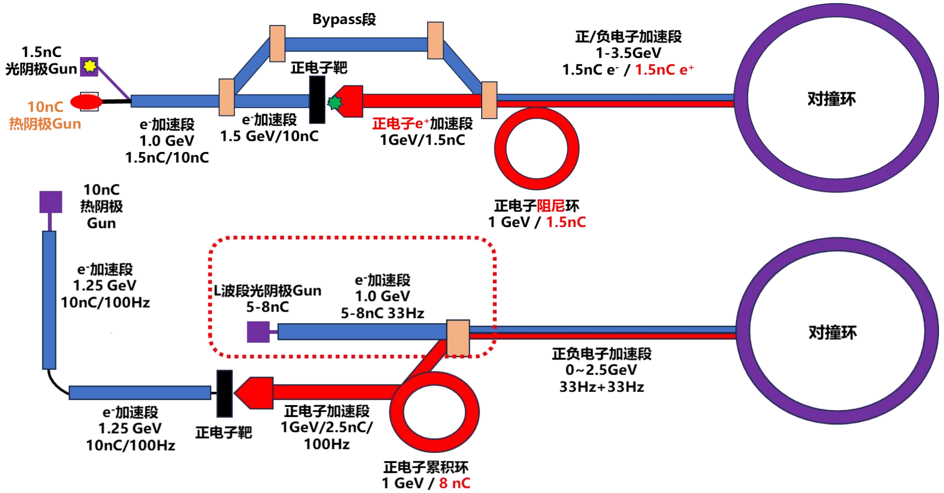
# Accelerator Conceptual Design in Course

## Two different CR injection schemes

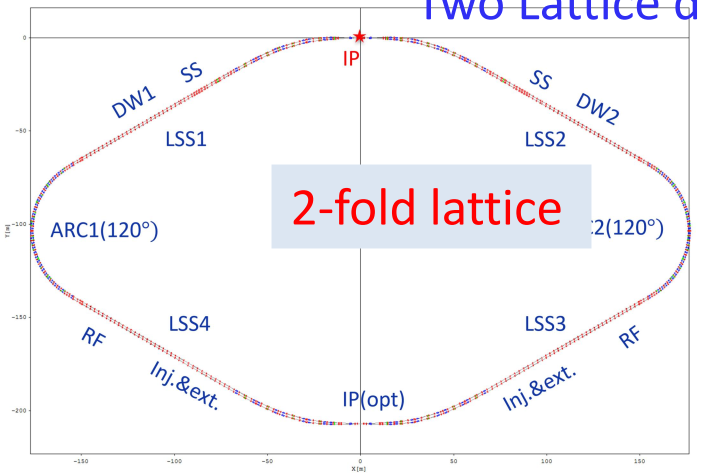
## Total length: ~400 m (+100 m beam transp.)

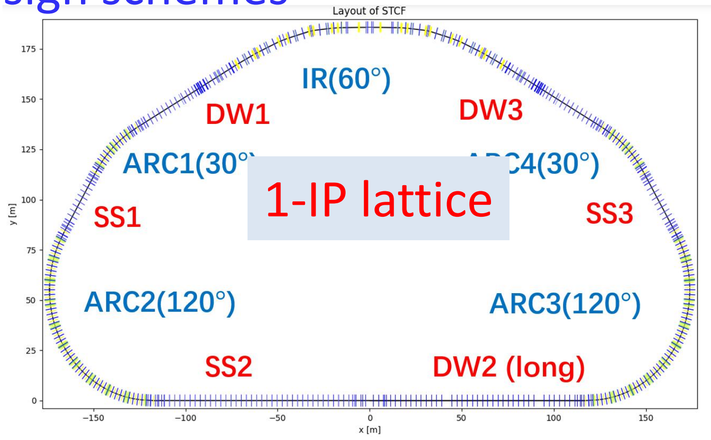
Off-axis injection

Swap-out injection




## Two Lattice design schemes

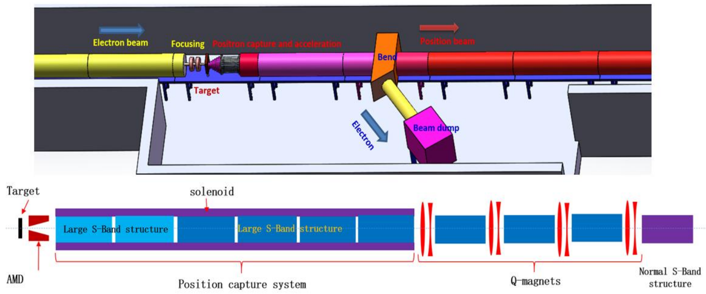


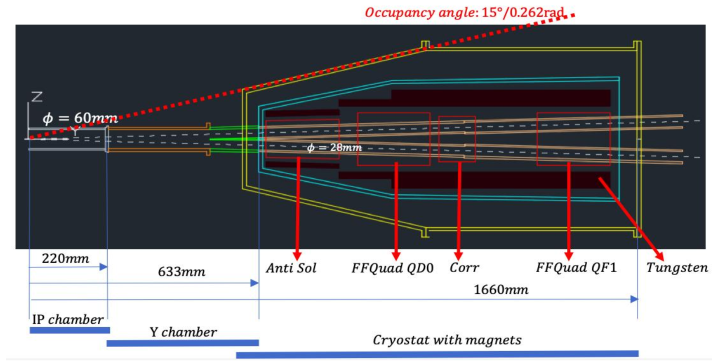

| Parameters | Units | STCF |
|---|---|---|
| Optimal beam energy, E | GeV | 2 |
| Circumference, C | m | 871.76 |
| Crossing angle, $2\theta$ | mrad | 60 |
| Revolution period, $T$ | $\mu$s | 2.908 |
| Horizontal emittance, $\varepsilon_x/\varepsilon_y$ | nm | 6.857/0.034 |
| Coupling, k | | 0.50% |
| Beta functions at IP, $\beta_x/\beta_y$ | mm | 40/0.6 |
| Beam size at IP, $\sigma_x/\sigma_y$ | $\mu$m | 16.56/0.143 |
| Betatron tune, $\nu_x/\nu_y$ | | 32.55/29.57 |
| Momentum compaction factor, $\alpha_p$ | $10^{-4}$ | 12.322 |
| Energy spread, $\sigma_e$ | $10^{-4}$ | 8.986 |
| Beam current, I | A | 2 |
| Number of bunches, $n_b$ | | 726 |
| Particles per bunch, $N_b$ | $10^{10}$ | 5.00 |
| Single-bunch charge | nC | 8.01 |
| Energy loss per turn, $U_0$ | keV | 406.8 |
| Damping time, $\tau_x/\tau_y/\tau_z$ | ms | 28.4/28.6/14.4 |
| RF frequency, $f_{RF}$ | MHz | 499.333 |
| Harmonic number, h | | 1452 |
| RF voltage, $V_{RF}$ | MV | 1.8 |
| Synchrotron tune, $\nu_z$ | | 0.0158 |
| Bunch length, $\sigma_z$ | mm | 9.72 |
| RF bucket height, $\delta_{RF}$ | % | 1.47 |
| Piwinski angle, $\phi_{pwi}$ | rad | 17.61 |
| Beam-beam parameter, $\xi_x/\xi_y$ | | 0.0027/0.082 |
| Hour-glass factor, $F_h$ | | 0.87 |
| Luminosity, L | $cm^{-2}s^{-1}$ | $1.0 \times 10^{35}$ |

# Progresses of Key Component Design

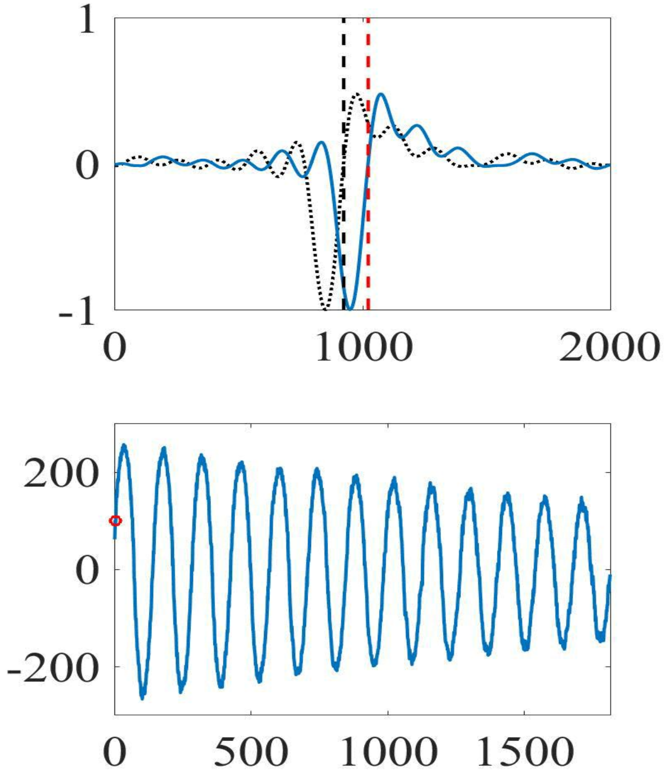
## Positron source




## Interaction region

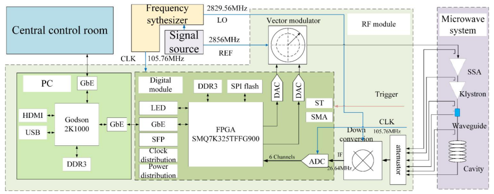



## Three-dimensional position and charge measurement system



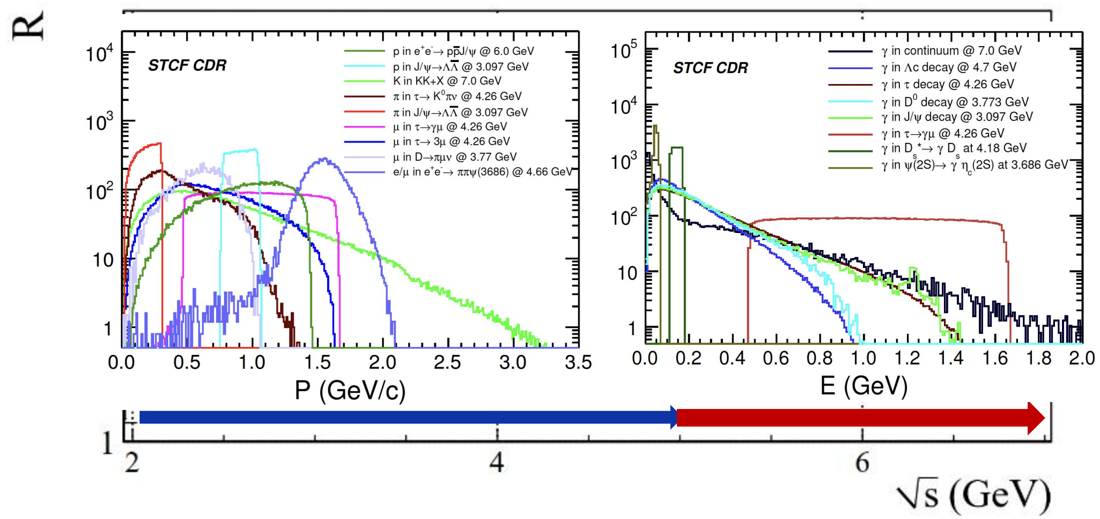

## Photocathode microwave electron gun

## Digital low level RF system



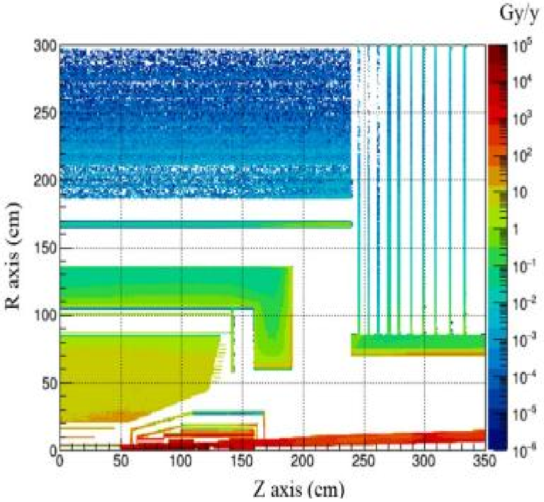

# Spectrometer Design Requirements And Challenges

**Wide energy region $E_{cm}$ : 2-7 GeV**




High efficient event triggering, acquisition, and reconstruction for super high events rate.
➜ Good particle identification, and accurately measure the position, energy, momentum, charge, and time of flight of the particles.

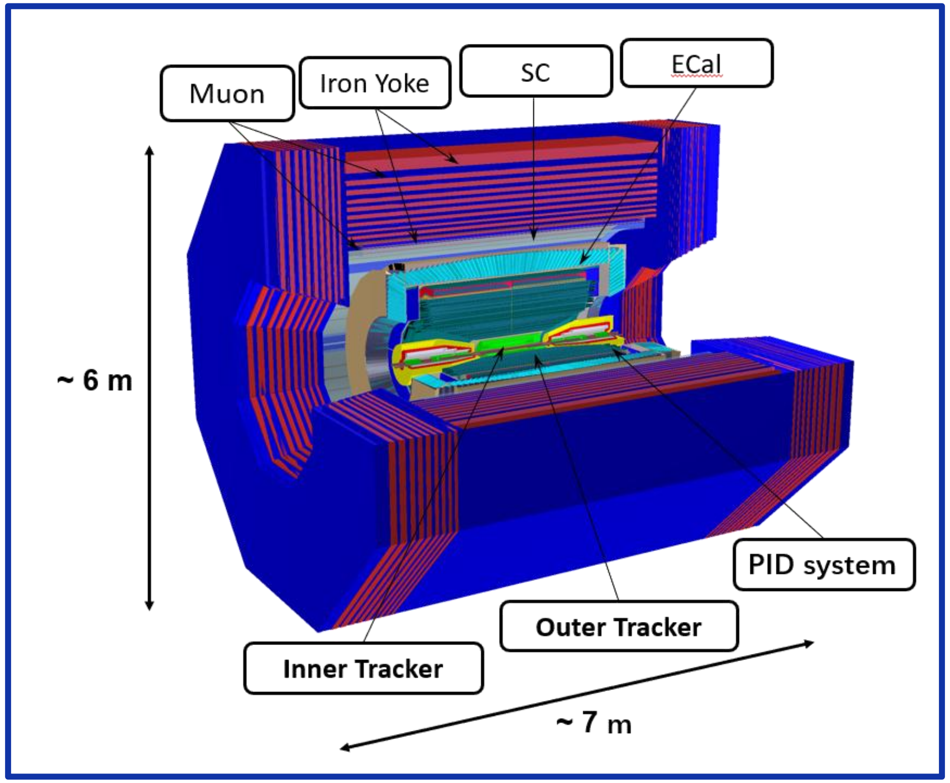
**Super high luminosity 5 × $10^{34}$ $cm^{-2}s^{-1}$**

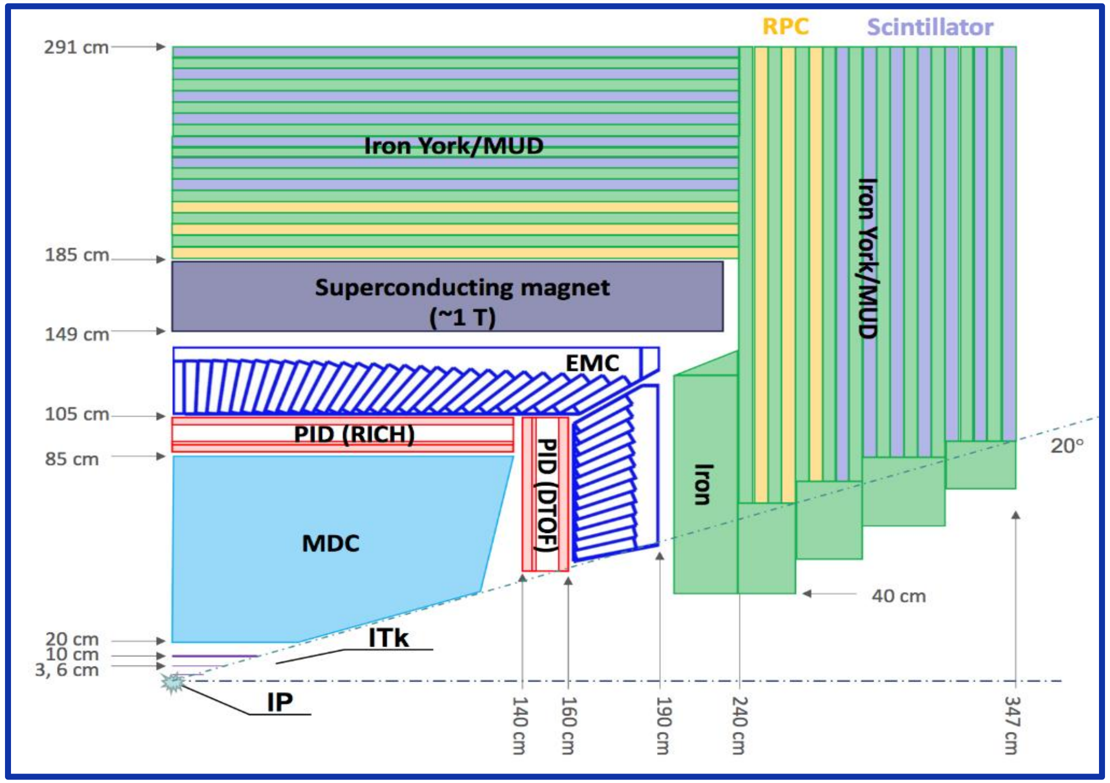



High events
~400 kHz
High counting rate
~1 MHz/$cm^2$
High data flow
~300 GB/s
High radiation and bkg
~4 kGy/y, ~2×$10^{11}$ $n_{eq}$/$cm^2$/y

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

# Spectrometer Layout and Its Expected Performance




**ITK**
- <0.3%$X_0$/layer
- $\sigma_{xy}$<100μm

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

**EMC (pure CsI + APD)**
- E range : 0.025~3.5 GeV
- $\sigma_E$ (%) @ 1GeV
  - Barrel 2.5
  - Endcap 4.0
- Pos. res. : 5 mm

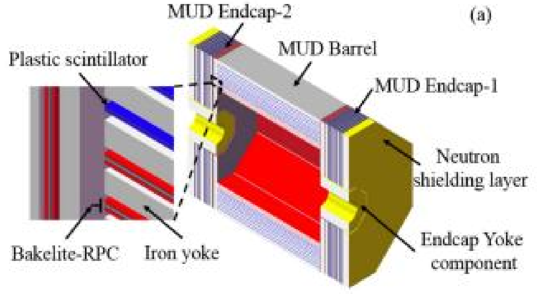
**PID**
Barrel: RICH with CsI-MPGD
Endcaps: DIRC-like TOF(DTOF)
- π/K (K/p) 3~4σ sepa. up to 2 GeV/c

**MUD (RPC + scintillator strip)**
- 0.4 ~ 2.0 GeV
- π suppression > 30

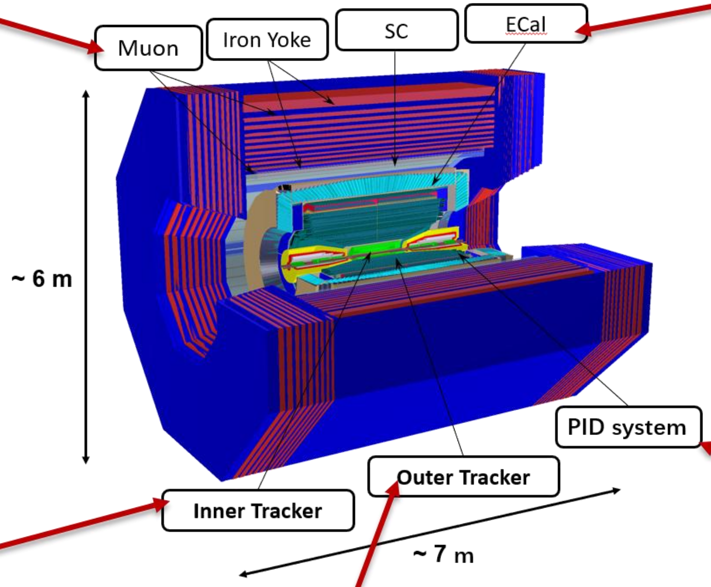
**Others :**
- Solid angle coverage: 94%·4π
- Radiative hardness at the most inner layer :~3.5kGy/y，~2×10$^{11}$ 1MeV n-eq/cm$^2$/y, ~1 MHz/cm$^2$
- Event rate： 400 KHz @ J/ψ

# Proposed Detector Technologies

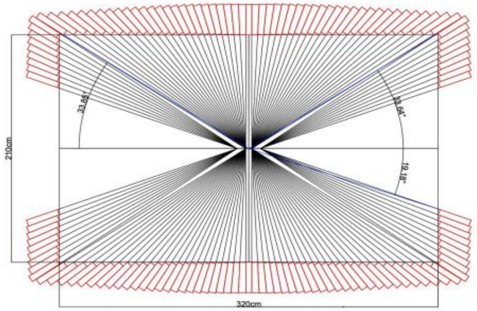
## Muon detector: RPC + scintillator




10 layers, Total area=1237 m2, solid angle=94%4π



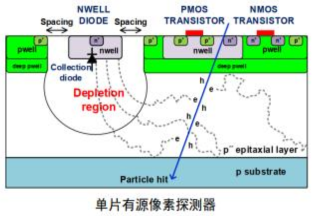

## ECAL: pCsI+APD



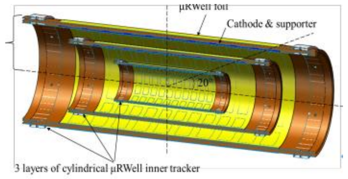
- ~8670 crystals
- Crystal size
  28cm ($15X_0$)
  5×5 $cm^2$
- 4 APDs (1×1$cm^2$)
  to enhance light yield

## Inner tracking

Si: CMOS MAPS

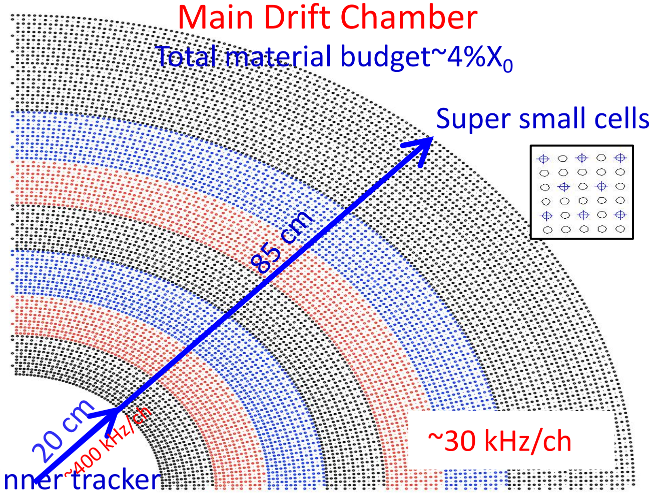



MPGD: μRWELL



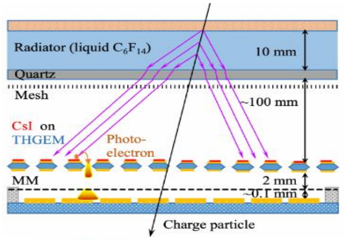

## Main Drift Chamber

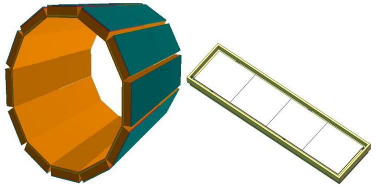
Total material budget~4%$X_0$




## Particle Identification Detectors

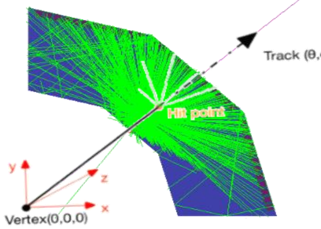
Barrel: RICH

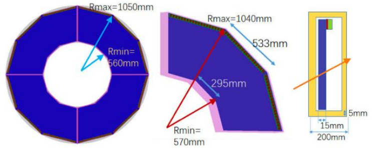


Material budget < $0.3X_0$

Endcap: DIRC-Like TOF(30ps)

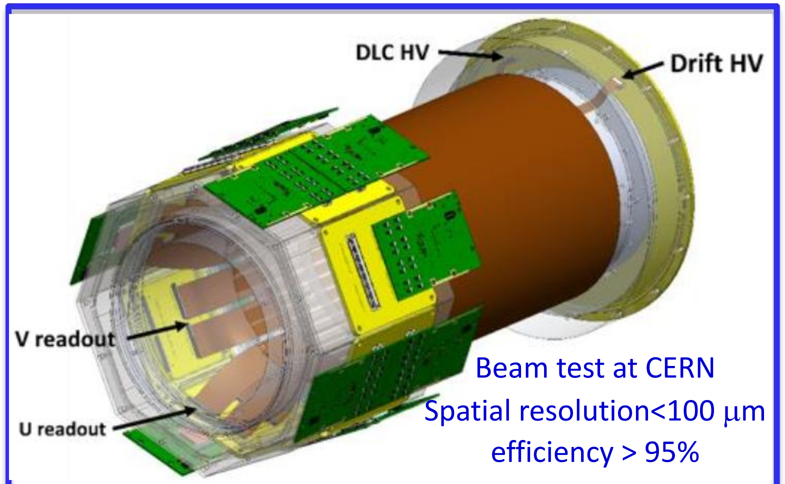


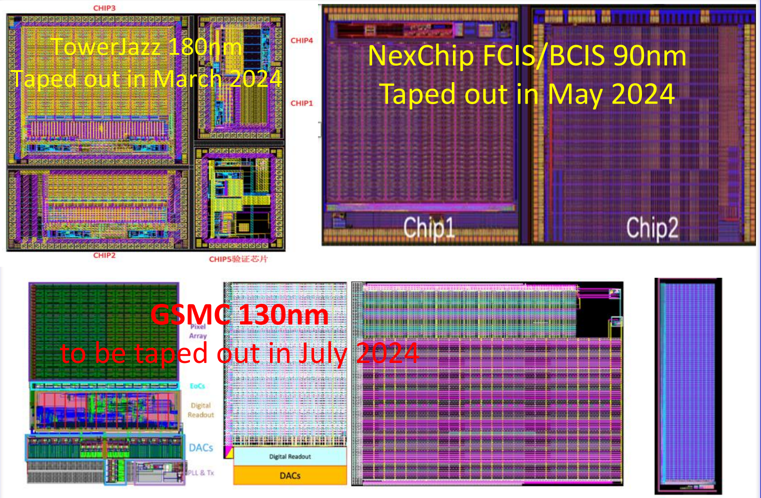




quartz plate + MCP-maPMT

# Detector R&D Progress

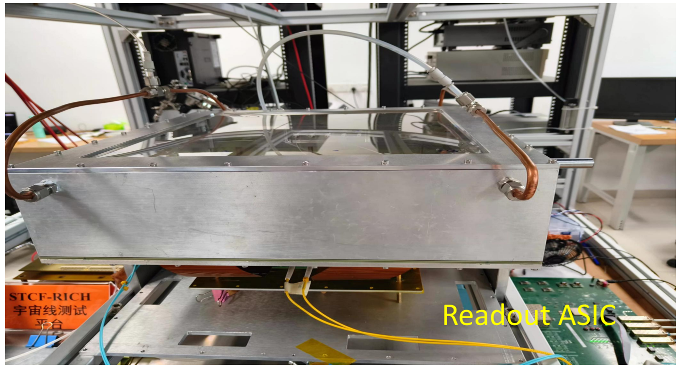
## Inner Tracker



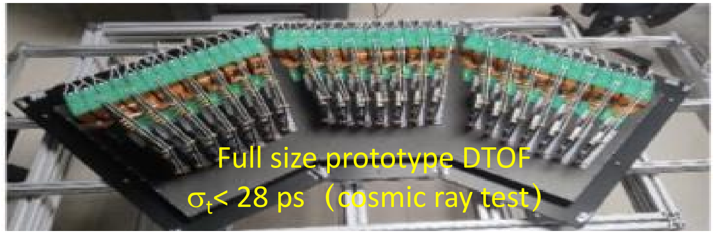

## Particle Identifier

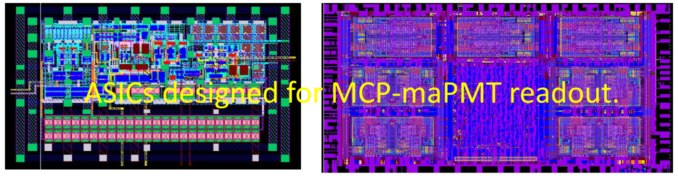
### RICH




30*30 cm² prototype RICH

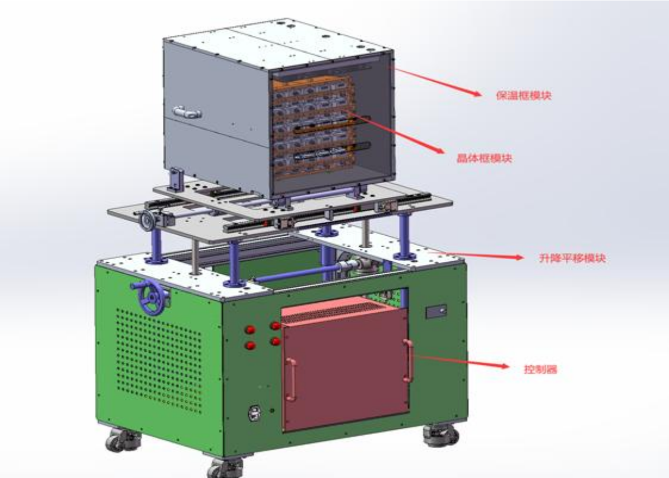
### DTOF




## Electromagnetic calorimeter

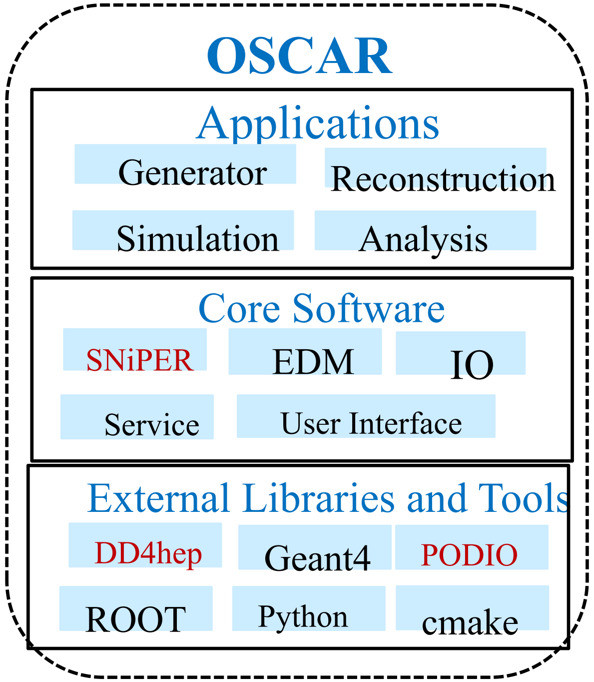




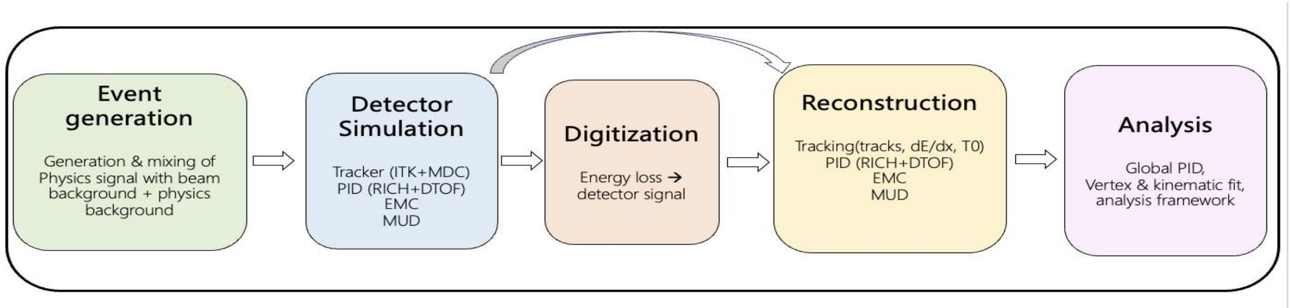

5×5 pCsI EMC Prototype

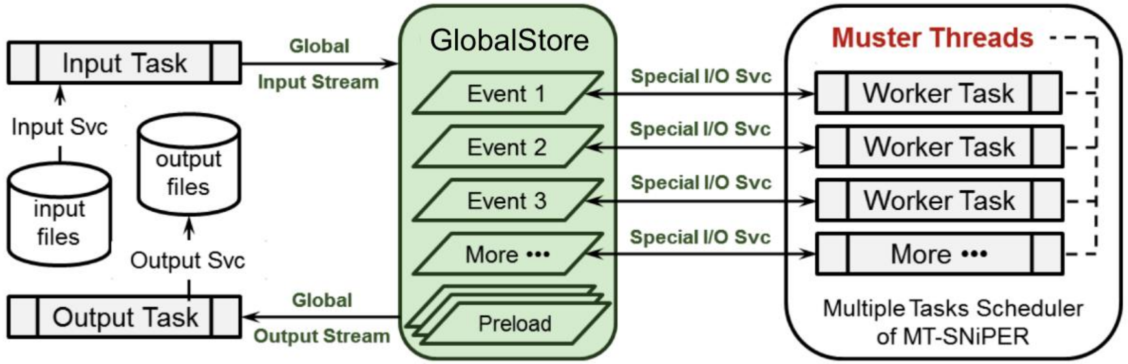
# Offline Software System

- Developed the offline data processing software framework OSCAR (Offline Software of STCF)
- Complete flow of data processing and physical analysis for simulation, reconstruction and physical analysis
- Developed parallel computing technology to optimize and accelerate offline data processing and physical analysis




W.H. Huang et al 2023 JINST 18 P03004



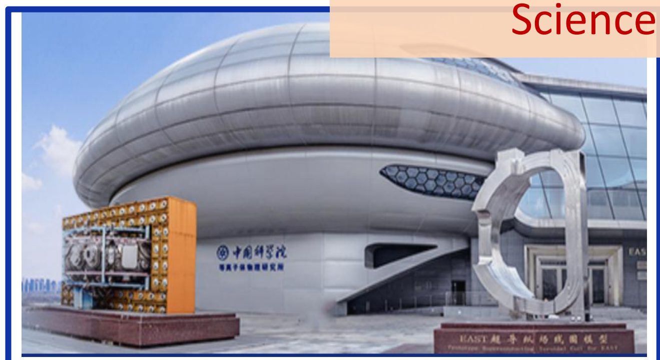
# Major Participating Laboratories


Hefei National Synchrotron Radiation Laboratory

State Key Laboratory of Nuclear Detection and Nuclear Electronics

Shanghai Institute of Advanced Technology, CAS

Hefei National Comprehensive Science Center



Institute of Plasma, CAS

High Magnetic Field Laboratory, CAS

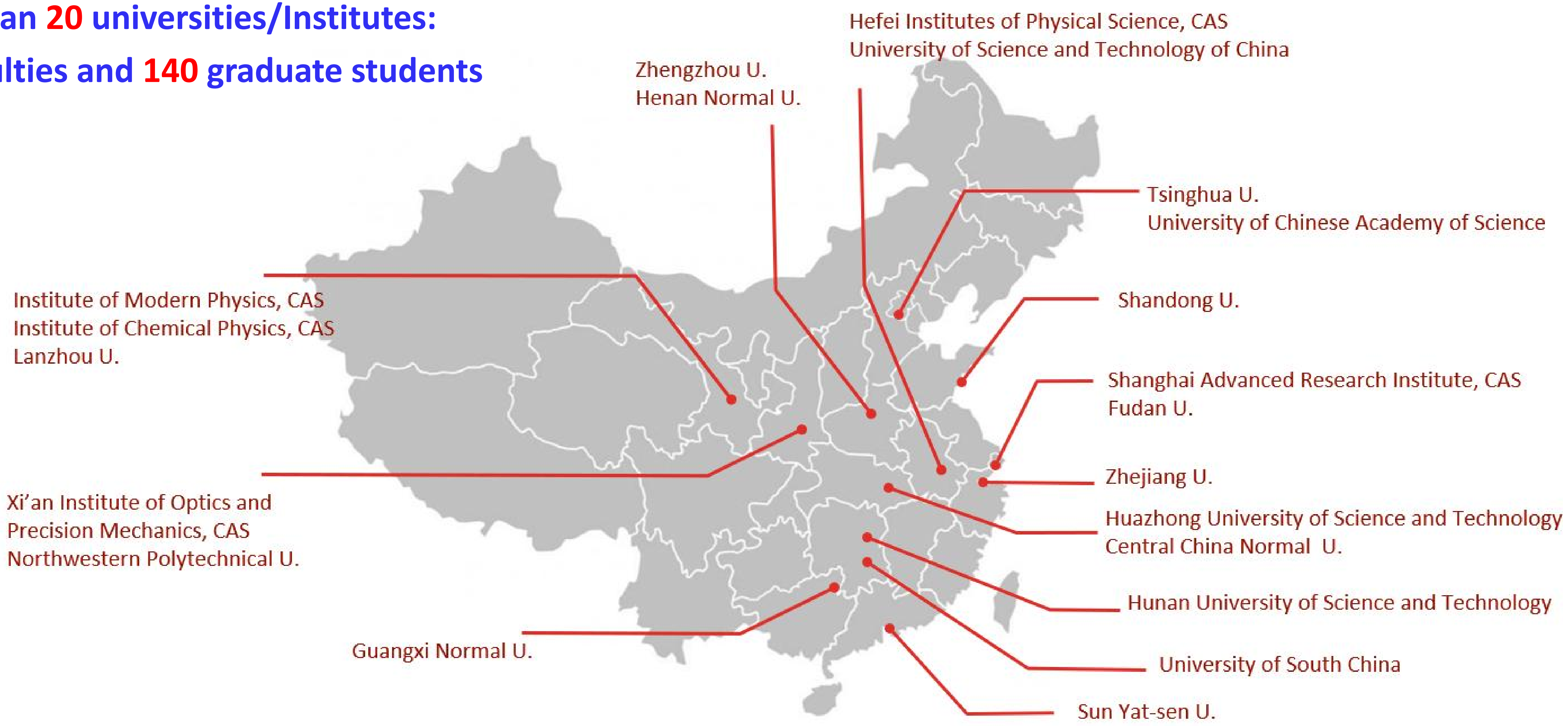
Institute of Modern Physics, CAS

# Institutions Participating to the R&D

**Began from year 2023**

**More than 20 universities/Institutes:**

**170 faculties and 140 graduate students**



# Institutions Interested in Joining STCF

## 107 Institutions interested in participating
## China: 70 Foreign countries: 37

- 中国科学技术大学
- 中国科学院大学
- 清华大学
- 北京大学
- 上海交通大学
- 复旦大学
- 山东大学
- 浙江大学
- 南京大学
- 南京师范大学
- 南开大学
- 中山大学
- 郑州大学
- 兰州大学
- 高能物理研究所
- 近代物理研究所
- 合肥物质科学院
- 上海高等研究院
- 西安光学精密机械研究所
- 合肥国家同步辐射实验室
- 北京航空航天大学
- 南华大学
- 湖南大学
- 湖南师范大学
- 湖南科技大学
- 四川大学
- 河南师范大学
- 河南科技大学
- 辽宁大学
- 广西大学
- 广西师范大学
- 香港大学
- 香港中文大学
- 武汉大学
- 华中科技大学
- 华中师范大学
- 黄山学院
- 惠州学院
- 福建工程学院
- 中科院理论所
- 中国科学院上海硅酸盐所
- 深圳综合粒子设施研究院
- 中央研究院物理研究所
- 杭州高等研究院
- 安徽大学
- 合肥工业大学
- 中南大学
- 中国地质大学
- 中国矿业大学
- 河北师范大学
- 河北大学
- 河南大学
- 湖北汽车工业学院
- 内蒙古大学
- 吉林大学
- 济南大学
- 辽宁师范大学
- 南阳师范学院
- 中国人民大学
- 华北电力大学
- 西北工业大学
- 曲阜师范大学
- 苏州大学
- 华南师范大学
- 东南大学
- 暨南大学
- 上海理工大学
- 烟台大学
- 云南大学
- 中国科学院兰州化物所

# Institutions Interested in Participating of STCF

## 107 Institutions interested in participating
## China: 70   Foreign countries: 37

- Institute for Basic Science, Daejeon, Korea
- Chung-Ang University, Korea
- Jozef Stefan Institute Ljubljana, Slovenia
- T. Shevchenko National University of Kyiv, Ukraine
- University Ljubljana and Jozef Institute Ljubljana, Slovenia
- University of Silesia, Katowice, PoStefanland
- Dubna, Russia
- BINP, Russia
- Novosibirsk State Technical University, Russia
- Novosibirsk State University, Russia
- Higher School of Economy 11 Pokrovsky Bulvar, Russia
- P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Russia
- Stanford University, USA
- Wayne State University, USA
- Carnegie Mellon University, USA
- Indiana University, USA
- Thomas Jefferson National Accelerator Facility, USA
- University of Wisconsin-Madison, USA
- GSI Darmstadt, Germany
- Goethe University Frankfurt, Germany
- Johannes Gutenberg University Mainz, Germany
- Helmholtz Institute Mainz, Germany
- University Münster, Germany
- IJCLab (The Irene Joliot-Curie Physics Laboratory of 2 Infinities), France
- Sezione di Ferrara, Italy L'Istituto di Fisica Nucleare di Torino, Italy
- L'Istituto di Fisica Nucleare di Firenze, Italy
- Scuola Normale Superiore, Pisa, Italy
- Laboratori Nazionali di Frascati, Italy
- INFN, Padova, Italy
- University of Pavia, Pavia, Italy
- University of Parma, Italy
- University of Oxford, UK
- University of Manchester, UK
- University of Cambridge, UK
- University of Bristol, UK
- EPFL, Switzerland
- Universitat de València, Spain

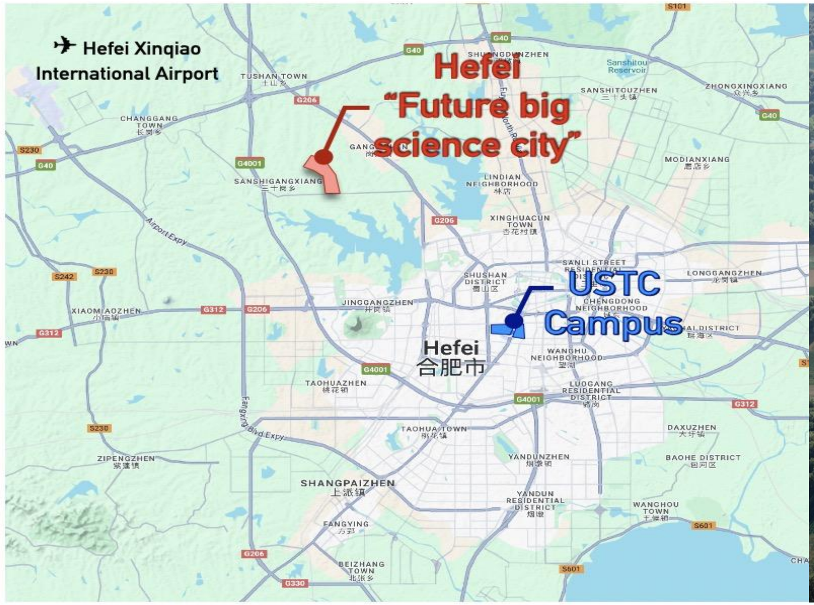
# Outline

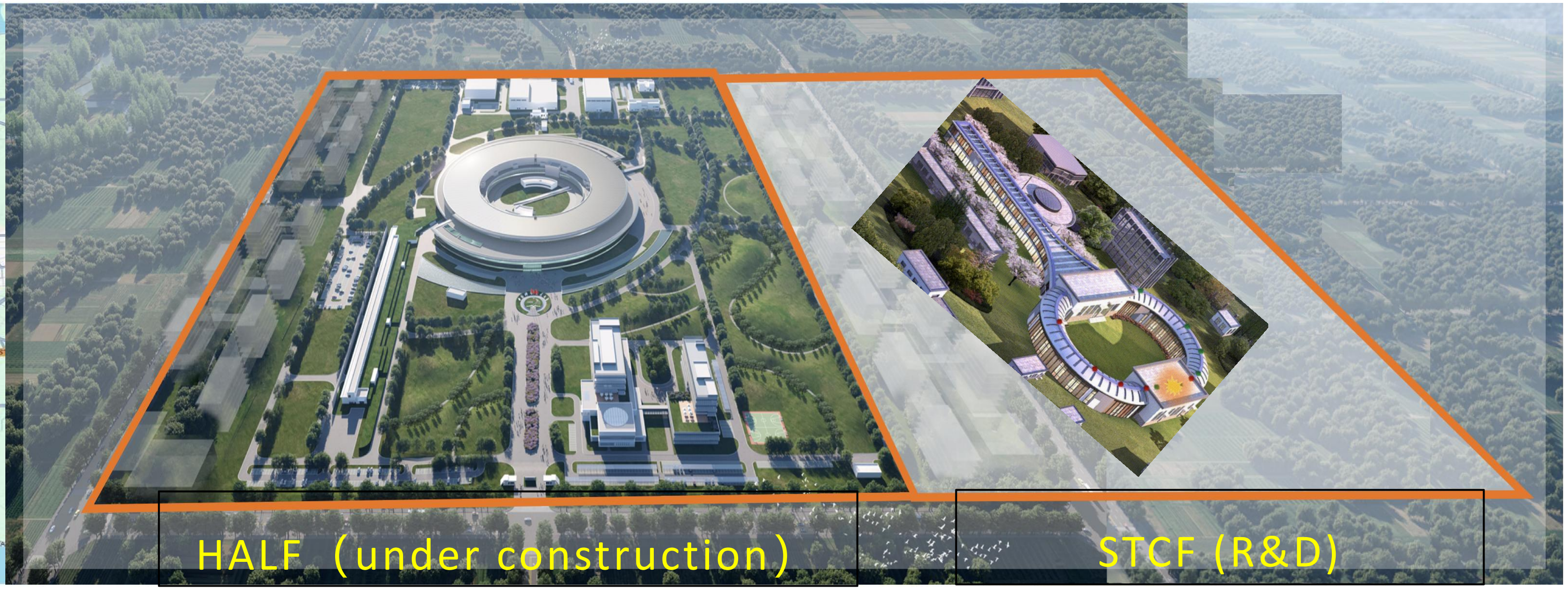
1. Introduction
2. The Super Tau Charm Facility
3. Conceptual Design and R&D for Key Technologies
4. **Site selection and  future plans**
5. Summary

# Site Selection – Future Big Science City

**A beautiful Big Science City in Hefei that is under construction**

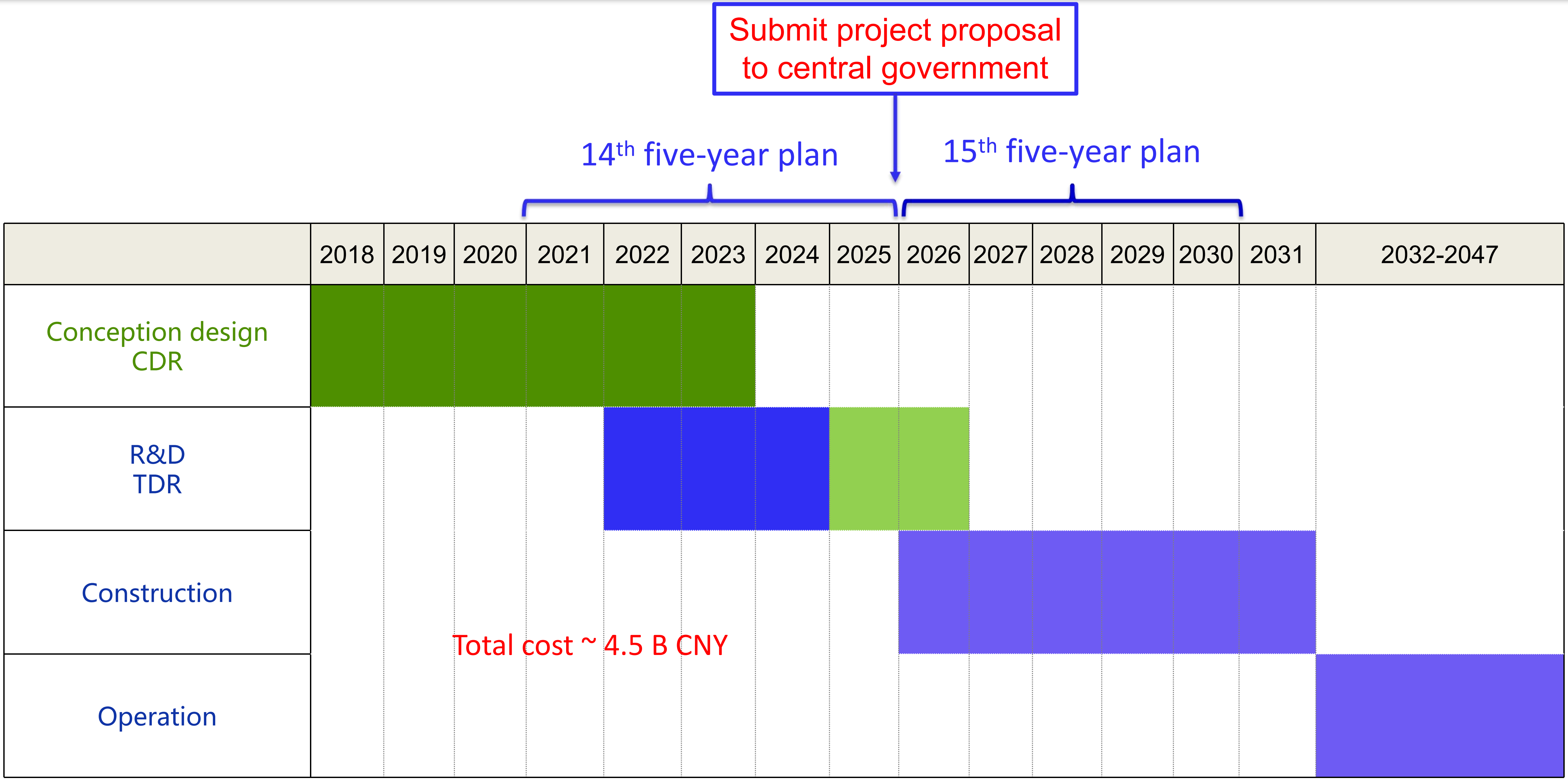
- **6 big facilities for sci. & tech., with a total land of 17155 acres.**
- **Plus 11815 acres of Ecological green space and modern agricultural land.**




- **Funded R&D for STCF : 364 Million CNY by the Anhui government**
- **Geological prospecting, civil engineering design are ongoing**

# Proposed Timeline



# Summary

- **STCF is a facility with unique features and rich in physics. It has great potential for discovery.**

- **STCF belongs to the high-luminosity/high-precision frontier: it is extremely challenging in terms of accelerators, particle detection, data acquisition and processing, computing, and network technologies.**

- **China is internationally recognized as the best place to construct STCF and has received wide support and recognition from the international community.**

- **We have been making Impressive progress for the R&D, and aiming to submit a proposal to the central government in 2025 for the 15th five-year plan (2026-2030)**

# A Super Tau Charm Facility: Physics and Challenges

**Abstract**

**STCF is an electron-positron collider with a luminosity of about 5x10$^{-34}$ cm$^{-1}$s$^{-1}$ and covers the center of mass energy from 2 to 7 GeV. The prominent features of the STCF are that its energy range bridges the perturbative and non-perturbative QCD; many different kinds of hadron pairs, as well as tau pairs, can be produced right at the production thresholds; and many predicted exotic states, such as glueballs, hybrids, and multiquark states may exit in the mass region.**

Having the power of providing unprecedented high statistical data and high-precision measurements, STCF will be a unique facility to systematically study the hadron production mechanism and the hadron structure, as well as the non-perturbative effect of the QCD that is the remaining big challenge to the SM. In addition, STCF has the discovery potential for new physics beyond the SM, such as the searches for CP violation process in the hyperons. **This presentation will report on the physics motivation, the challenges to the collider and the detector, as well as the current status of the STCF project.**

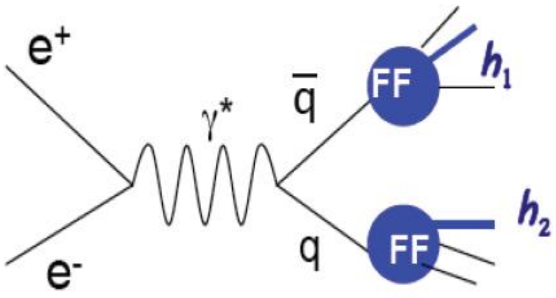
Dr. Zhengguo Zhao, an experimental particle physicist, obtained his Ph.D. at the University of Science and Technology of China (USTC) in 1988. He is now a distinguished professor at the USTC. He worked at the Swiss Federal Institute of Technology in Zurich(ETHZ) as a post-doctor, Institute of High Energy Physics of the Chinese Academy of Sciences (CAS) as physics division leader, and at the University of Michigan as a research scientist and visiting professor. He has been engaged in a few experiments of nuclear and particle physics: experiments to measure the strong energy shift and broadening of the ground state of pionic hydrogen and deuterium. Beijing Spectrometer (BES I-III) experiment at the Beijing Electron Positron Collider; The D0 experiment at Tevatron and the ATLAS experiment at the Large Hadron Collider. He is an academician of the CAS and is the vice president of the Chinese Physical Society.

# Collins Fragmentation Function

STCF will provide precise Collins FF input for TMD extraction at EIC/EicC

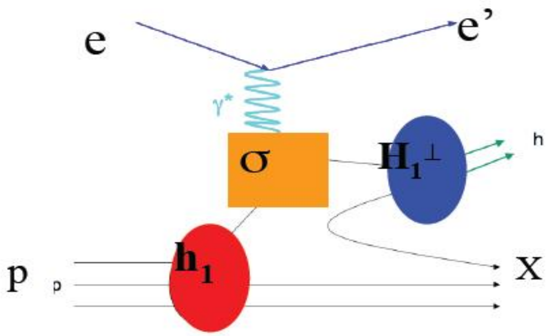
Journal of UCAS 38 (2021) 433.

Collins FF ⊗ Collins FF




Crucial input to TMD extraction in SIDIS

Transversity ⊗ Collins FF



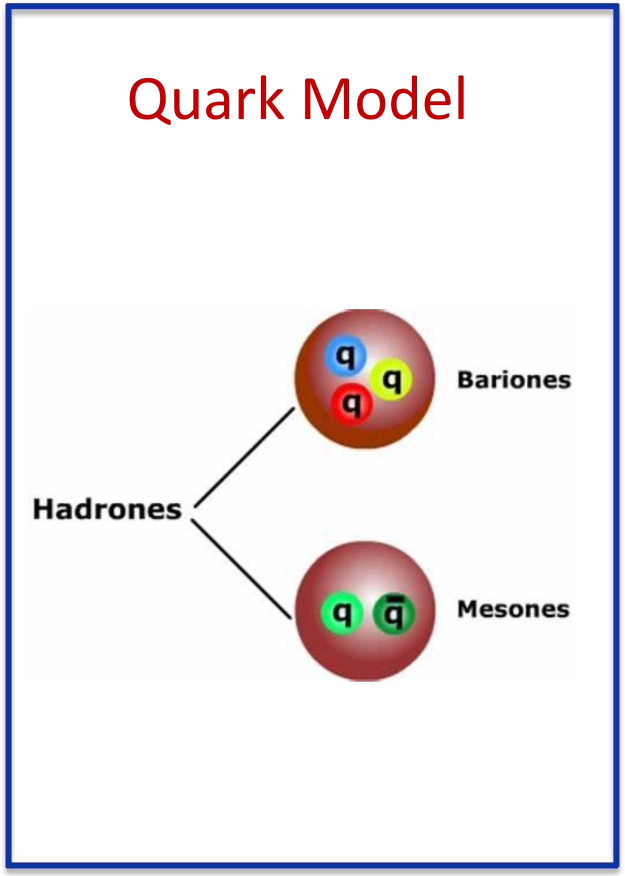

The statistical uncertainty on asymmetry $A^{UL}$ with $1ab^{-1}$ at 7 GeV:

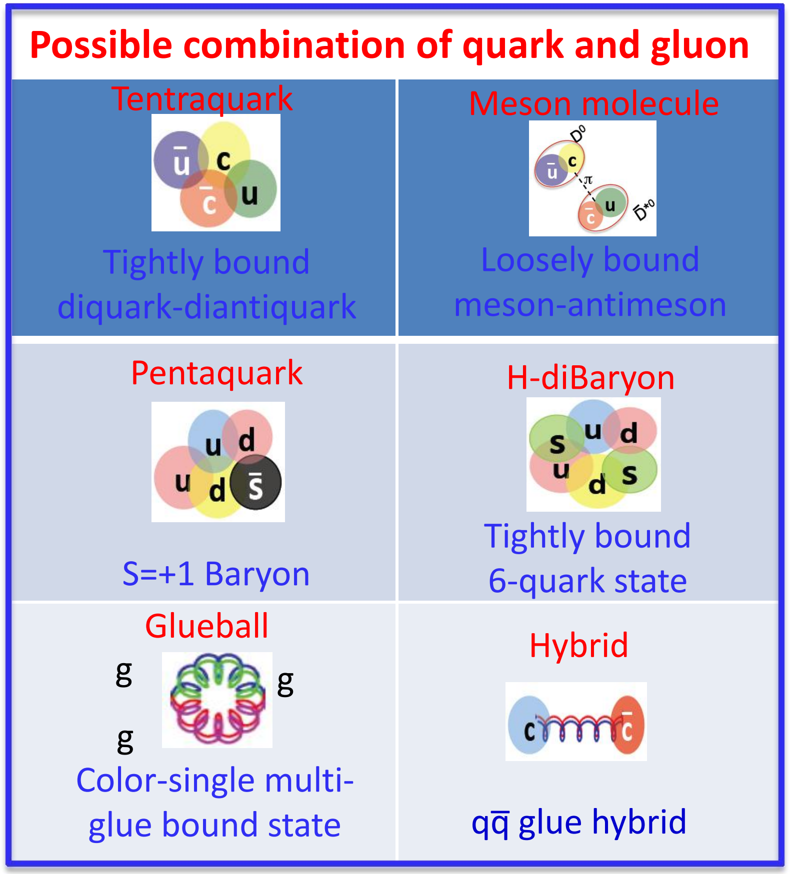
1.4~4.2× $10^{-4}$ for $\pi\pi X$, 3.5~20 × $10^{-3}$ for $KKX$

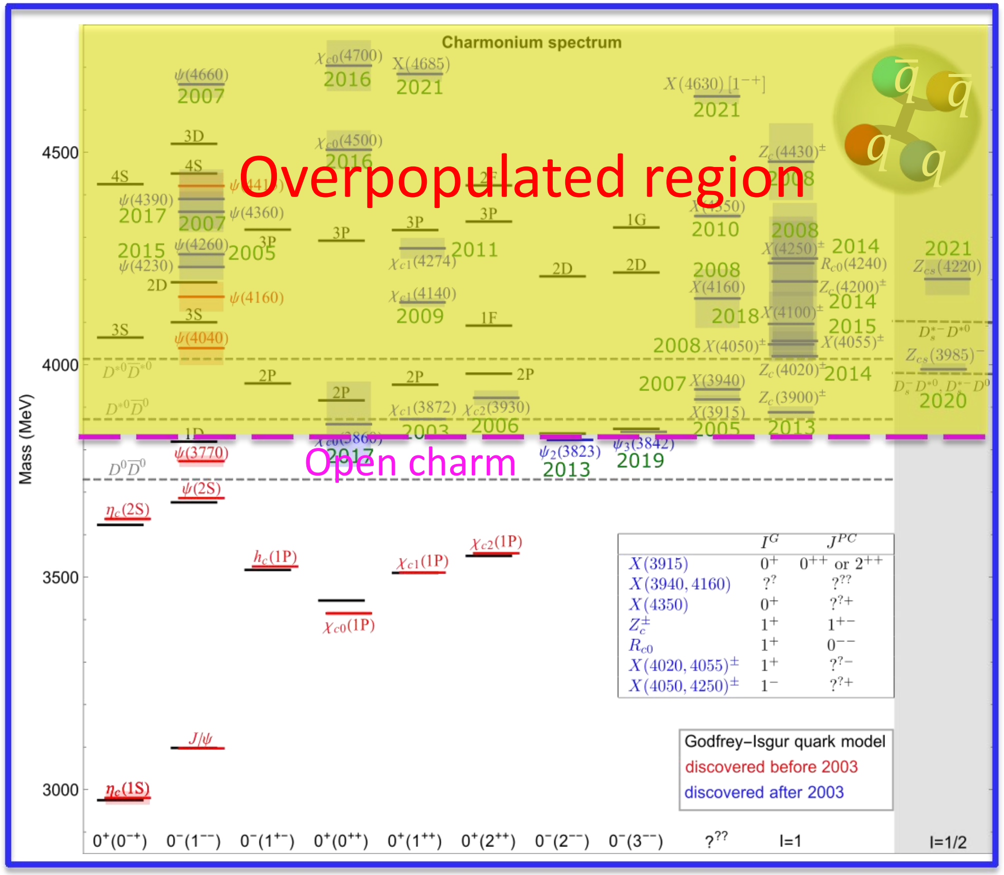
*They provide unique insight into the internal momentum and spin structure of hadron,*
*and are a key ingredient in the description of many cross sections*

# Hadron Spectron and Exotic hadrons

- Hadron spectroscopy is a crucial way to explore the QCD and its properties.
- State of mass above open charm is much overpopulated → many exotic states?
- STCF has unique advantages for searching and studying exotic hadrons.



# 加速器：核心技术与参数指标

## 各项核心技术要求均达到或超过世界先进水平！

| 核心技术 | STCF设计指标或要求 | 国内外现状 |
|---|---|---|
| 对撞环物理设计 | 大交叉角+Crab Waist对撞<br>大流强/低发射度：2A / 5 nm·rad<br>超高亮度 > 5 x $10^{34}$，束流寿命很短 < 300 s | 国内：BEPCII：小交叉角；0.9 A /150 nm·rad; 亮度$10^{33}$；寿命2小时<br>国际：SuperKEKB：设计(2.6A/3.6A)目前(1.1A/1.4A)，设计亮度6 x $10^{35}$目前 5 x $10^{34}$；寿命 > 600 s |
| 对撞区磁铁技术 | 对撞区双孔径超导四极铁<br>磁场梯度高 > 50 T/m | 国内：BEPCII单孔径超导磁铁，25 T/m<br>国际：SuperKEKB和BINP都研制了对撞区双孔径超导四极铁 |
| 环高频系统 | 耦合器功率 > 300 kW<br>高次模深度抑制常温腔 | 国内：耦合器功率 ~ 150 kW，无HOM抑制常温腔<br>国际：SuperKEKB耦合器功率 > 500 kW |
| 超快脉冲冲击磁铁 | 上升/下降时间 < 2 ns | 国内：HEPS: ~ 6 ns<br>国际：KEK-ATF：2~3 ns |
| 对撞环束流精确测量和反馈控制 | 逐束团横向位置分辨率好于 5 μm；纵向相位分辨率好于 0.2 ps；快速反馈阻尼时间 0.1 ms、纵向阻尼时间 0.5 ms | 国内：BEPCII：位置分辨率好于 5 μm；反馈 0.7 ms<br>国际：SuperKEKB: 逐圈横向位置分辨 50-100 μm，逐圈纵向相位分辨 0.033 ps |
| 正电子源 | 1.5 GeV 电子束能量驱动条件下，<br>单束团电荷量 1.5 nC | 国内：BEPCII 采用 150 MeV，仅满足上一代装置要求；CEPC 采用 4 GeV<br>国际：SuperKEKB 采用 3.3 GeV（目标 4 nC，当前 1.5 nC） |

# 探测谱仪：核心技术与参数指标

**各项核心技术均达到或超过世界先进水平!**

| 核心技术 | 超级陶粲装置要求 | 国内外现状 |
|---|---|---|
| MAPS 内径迹探测器 | 时间分辨 < 30 ns<br>位置分辨 < 20 μm<br>有能量测量，单层物质量 < 0.3% $X/X_0$ | 国内：无<br>国际：ALICE ITS2：时间分辨 10 μs，位置分辨 5 μm，无能量测量，单层物质量 ~ 0.35% $X/X_0$ |
| MPGD 内径迹探测器 | 时间分辨 < 10 ns<br>位置分辨 < 100 μm<br>计数率能力 > 1 MHz/cm²<br>圆柱形，单层物质量 < 0.3% $X/X_0$ | 国内：无<br>国际：KLOE CGEM：位置分辨 ~ 200 μm，单层物质量 ~ 0.5% $X/X_0$ |
| DIRC 粒子鉴别探测器 | 单元面积 ~ 0.6 m², 本底计数率 ~ 100 MHz条件下<br>时间分辨 < 30 ps | 国内：无<br>国际：研发中 |
| pCsI 晶体量能器 | 在 ~ 1MHz ( ≥ 0.5MeV) 本底计数率条件下<br>能量分辨：~5% @ 100 MeV，2.5% @ 1 GeV<br>时间分辨：300 ps @ 1GeV | 国内：BESIII 在平均 ~ 20 kHz ( > 0.5 MeV) 本底计数率条件下，能量分辨：~5% @ 100 MeV，2.5% @ 1 GeV, 无时间分辨<br>国际：Belle II 在平均 ~ 250 Hz ( > 100 MeV) 本底计数率条件下，能量分辨：~8% @ 100 MeV，2.2% @ 1 GeV, 无时间分辨 |
| 电子学读出 ASIC 芯片 | 全波形输出，64通道，<br>电荷分辨 < 0.5 fC @ 48 fC & 20 pF，<br>时间分辨 < 1.0 ns @ 20 fC & 20 pF，事例率 > 100kHz | 国内：无<br>国际：AGET芯片 事例率 < 1 kHz |
| | 64通道，时间分辨<10 ns@5fC，事例率 >4 MHz | 国内：无<br>国际：VMM芯片 事例率 < 1 MHz |

# 经费支持

| 执行年份 | 基金部门 | 基金类型 | 金额（万元） |
|---|---|---|---|
| 2018-2021 | 中科大 | 双一流重点项目 | 1500 |
| 2021-2026 | 中国科学院 | 国际伙伴项目 | 505 |
| 2022-2027 | 科技部 | 重点研发项目 | 1750 |
| 2023-2025 | 安徽省/合肥市/中科大 | 关键技术攻关项目 | 36400 |
| 2023-2027 | 基金委 | 重点项目群 | 1400 |
| 总和 | | | 41555 |

# 国际顾问委员会第一次会议


**国际顾问委员会(IAC)：共22位加速器、粒子物理专家**

**主　席：Guy Wilkinson (Oxford)**

**副主席：Frank Zimmermann (CERN)**

- **14位成员线下，8位线上**
- **听取项目组织、物理目标、关键技术、未来规划等汇报、实验室实地考察并做专题讨论**

# 国际顾问委员会第一次会议

- IAC 对项目的组织、进展和规划高度评价，对科学问题、加速器和探测器设计和关键技术、R&D 项目、国际合作等都提出建设性意见和建议

## Report of first meeting of International Advisory Committee for the Super Tau Charm Facility

Maria Enrica Biagini[*1], Ikaros Bigi[*2], Alex Bondar[*3], Tom Browder[4], Kuang-Ta Chao[*5], Yuanning Gao[5], Wolfgang Gradl[6], David Hitlin[*7], Tord Johansson[*8], Marek Karliner[*9], Eugeny Levichev[3], Yugang Ma[*10], Mikihiko Nakao[*11], Stephen Olsen[*12], Alexey Petrov[*13], Antonio Pich[*14], Makoto Tobiyama[*11], Guy Wilkinson[†*15] Hongwei Zhao[16], Zhentang Zhao[*17], Frank Zimmermann[†*18], Bingsong Zou[*19]

[1] INFN - Frascati National Laboratories, [2] University of Notre Dame, [3] Budker Institute of Nuclear Physics (BINP), [4] University of Hawaii, [5] Peking University, [6] Johannes Gutenberg University Mainz, [7] California Institute of Technology, [8] Uppsala University, [9] Tel Aviv University, [10] Fudan University, [11] High Energy Accelerator Research Organization (KEK), [12] Chung Ang University, [13] University of South Carolina, [14] University of Valencia, IFIC, [15] University of Oxford, [16] Institute of Modern Physics, CAS, [17] Shanghai Advanced Research Institute, CAS, [18] European Organization for Nuclear Research (CERN), [19] Institute of Theoretical Physics, CAS.

[†] Co-chairs.
[*] Attended meeting.

1. Introduction
2. Exclusive Summary
3. Physics and detector
   - Comments
   - Recommendations
4. Accelerator
   - Comments
   - Recommendations

# IAC专家具体意见

**2 Executive summary**

STCF will be unique facility with a broad and impressive physics reach. It will allow for results of world-leading precision in many important topics, and has significant discovery potential. It will ideally complement the other facilities that are currently operational or are foreseen for the 2030s and 2040s, and will be of great interest to the international particle physics community. The principal challenge of the project lies in the accelerator. Here the intended luminosity will exceed by two orders of magnitude that previously achieved in the same energy regime. The IAC is pleased to recognise the significant progress on the STCF accelerator design that has occurred since the establishment of a dedicated Accelerator Division led by Prof. J.Y. Tang. The demands on the detector are less formidable, but should not be underestimated given the extreme event rate and size of data samples foreseen.

**STCF将是一个具有丰富物理潜能的独特装置。它将在多个重要课题上获得世界领先的精确结果，并具有重大的发现的潜力。它将完美地补充目前正在运行或预计在2030年代和2040年代运行的其他设施，受到国际粒子物理学界的极大关注。项目的主要挑战在于加速器。其预期的亮度将比现有相同能量范围内实验的亮度高出两个数量级。IAC 十分认可自专门的加速器部门成立以来，在唐靖宇教授领导下，STCF 加速器设计取得的显著进展。虽然对探测器的要求没有那么严峻，但考虑到预期的极高事件率和数据样本的规模，这些要求也不容低估。**

- **未来会议计划：2024/10 线上；2025/05 线上；2025/10 线下**

# International Future Tau-Charm Facility Workshops

| Time | Place | Content |
|---|---|---|
| 2015.01 | Hefei, China | International Workshop focused on STC in China |
| 2018.03 | Beijing, China | International Workshop focused on STC in China |
| 2018.05 | Novosibirsk, Russia | International Workshop focused on SCTF in Russia |
| 2018.12 | Paris, France | 1st FTCF (Joint International Workshop) |
| 2019.08 | Moscow, Russia | 2nd FTCF |
| 2020.11 | Online, China | 3rd FTCF |
| 2021.11 | Online, Russia | 4th FTCF |
| 2024.01 | Hefei, China | 5th FTCF |
| 2024.11 | Guangzhou, China | 6th FTCF (Scheduled) |

**The 2024 International Workshop on Future Tau Charm Facilities(FTCF2024)**

Jan.14-18, 2024 Hefei·China

2018年2-7吉电子伏高亮度正负电子对撞机国际研讨会(HIEPA2018)


FTCF 2018, Paris

# Conferences/Workshops for STCF

## (Domestic) STCF Workshops

| Time | Place | Content |
|---|---|---|
| 2018.10 | Hengyang (USC) | STCF |
| 2019.03 | Beijing (UCAS) | STCF: Physics |
| 2019.07 | Hefei (USTC) | STCF: Accelerator |
| 2019.08 | Hefei (USTC) | STCF: Phys. & simulations |
| 2019.11 | Beijing (UCAS) | STCF: CDR |
| 2020.08 | Hefei (USTC) | STCF: From CDR to TDR |
| 2022.12 | Guangzhou (SYSU) | STCF: R&D kick-off |
| 2023.07 | Zhengzhou (ZZU) | STCF: Collaboration |
| 2024.07 | Lanzhou (LZU) | (scheduled) |

2022, online

2023, Zhengzhou

STCF Key Technology R&D Project Kick-off Meeting, Hefei, 2023

## STCF Project Development Meetings

| Time | Place | Meetings |
|---|---|---|
| 2022.04 | Hefei (USTC) | STCF Key Technology R&D Project Demonstration Meeting |
| 2023.08 | Hefei (USTC) | STCF Key Technology R&D Project Kick-off Meeting |
| 2023.12 | Hefei (USTC) | STCF Key Technology R&D Project Budget Review Meeting |
| 2024.01 | Hefei (USTC) | STCF 1st International Advisory Committee Meeting |
| 2024.05 | Hefei (USTC) | STCF 1st Consultative Committee Meeting (scheduled) |

STCF 1st IAC meeting (Hefei, 2024)

# 项目组织与管理

## 项目建设校领导小组

**组长：** 包信和（校长）
**副组长：** 傅尧
**成员：** 蒋一、王晓平、杨金龙、邓建松、薛天

## 项目总体保障组

**组长：** 中国科大校长
**成员：** 项目各参与单位的行政领导、项目首席科学家

## 学术秘书组

**组长：** 杨振伟
**成员：** 吕晓睿、周小蓉、鄢文标、何吉波
郭奉坤、张艾霖、郭志辉、胡启鹏
**职责：** 项目宣传、学术会议、学术文档

## 项目建设校工作小组

**组长：** 傅尧
**副组长：** 孙方稳、查正军、赵钢、封东来、陈宇翱
**成员：** 赵国飞、赵政国、姚子龙、龚流柱
梁宏飞、彭海平、薛永泉、瞿昆

## 项目顾问委员会

## 项目咨询委员会

## 项目总体/领导小组

## 项目办公室

**主任：** 邵明
**成员：** 曾晖、刘建党、胡东栋、李嫒嫒
王颖颖、王丽、鄢文标、张艾霖
胡启鹏、周小蓉、汪小庆
**职责：** 进度、质量、经费管理；绩效考核，
文档与信息管理，采购与设备管理

## 项目总体

**首席科学家：** 赵政国
**项目经理：** 赵政国
**项目副经理：** 彭海平、冷用斌、郑阳恒
**总工程师：** 唐靖宇
**副总工程师：** 殷立新、刘树彬、刘建北
**总工艺师：**

## 加速器分总体

共含11个系统

**主任：** 唐靖宇（代）
**副主任：** 罗箐

## 探测器分总体

共含11个系统

**主任：** 刘建北
**副主任：** 刘倩、赵雷、千奕

## 技术支持组

选址、场地、公共设施、通用技术

## 物理与软件组

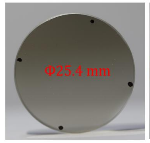
**组长：** 黄性涛
**副组长：** 周小蓉、艾小聪

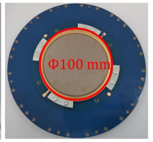
# 高新技术合作与推动

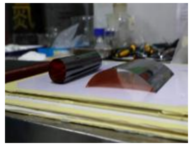
STCF探测谱仪的研发和建设涉及与**诸多研究单位和产业界的深度合作**，有力推动高新技术的发展和产业技术水平，**催生**一系列新的技术原理和方法，如：精确辐射探测与成像、抗辐照集成电路芯片、先进快电子学，基于人工智能的大数据处理和网格计算等。

这些高新技术将有力推动相关产业**发展和升级换代**。

**中国科学院兰州化学物理研究所**

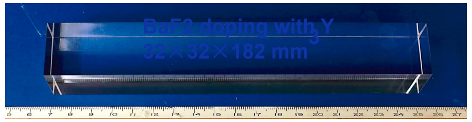


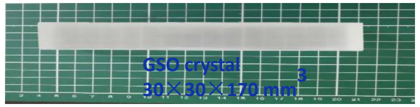


高性能碳基阻性电极研发及其在辐射探测中的应用

**中科院上海硅酸盐所**






新一代闪烁晶体的研发与应用

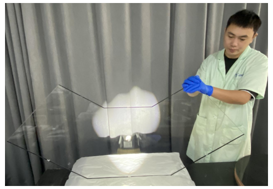
**合肥晶合集成电路股份有限公司**

单片有源硅像素芯片的研发

**中国科学院西安光学和精密机械研究所**

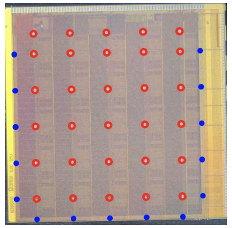
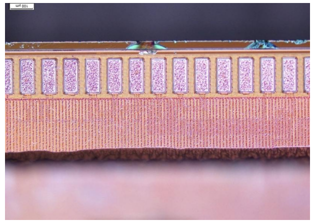

超快位敏多阳极微通道板光电倍增管的研发

**北京石英谷玻璃有限责任公司**

高纯石英的生产和超精细加工

**中国科学院苏州纳米技术与纳米仿生研究所**

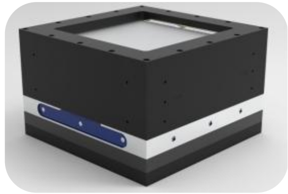



芯片键合与像素探测器集成

# 高新技术应用与转化

- STCF探测谱仪攻关中发展和衍生出的各种高新技术在专用集成电路设计 、射线成像 、束流诊断、无损检测、医疗仪器 、高端核仪器领、海洋资源与环境探测装备 、辐射探测与电信号测量核心部件等多个领域都有着极为重要的应用价值和潜力。
- 进行技术研发**成果转化，已成功孵化出两个高新技术公司**：
  - 见微科仪（安徽）技术有限公司
  - 合肥中科采象科技有限公司


## 见微科仪（安徽）技术有限公司




超低本底α/β检测仪、无损检测和透射成像设备、束流检测仪、放疗辐射检测设备、无损检测设备 …

## 合肥中科采象科技有限公司

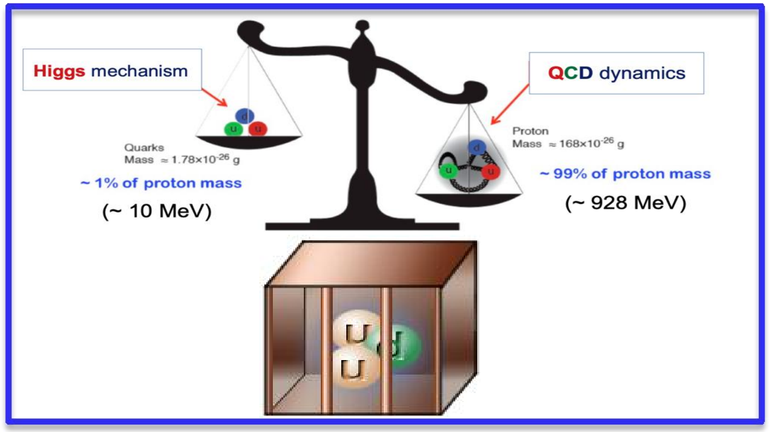


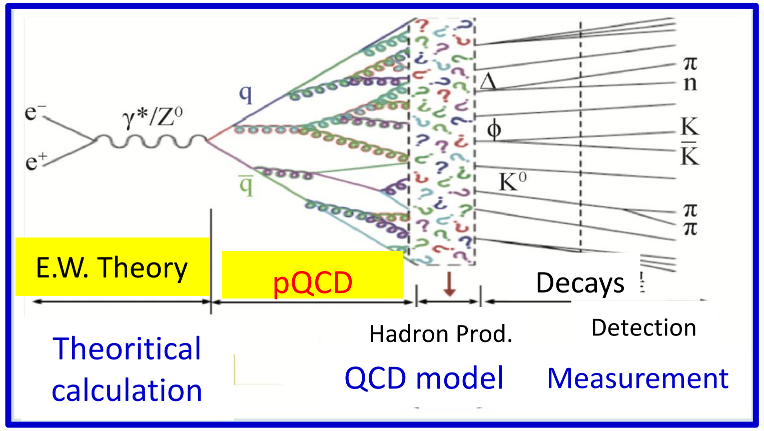
标准化、模块化核仪器与高端测量仪器，高端海洋物探采集装备，地质勘探和地震专用仪器，环境监测专用仪器仪表 …

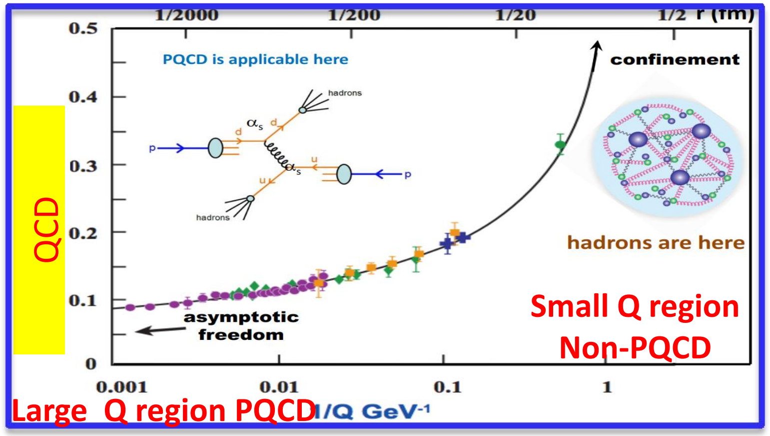
# Key Science Questions To The Strong Interaction

**The key questions to the strong interaction**

- **What is the origin of observable mass (mass of hadrons)?**
- **How are hadrons formed, and what is the hadron structure?**
- **What is the essence of asymptotic freedom and color confinement?**

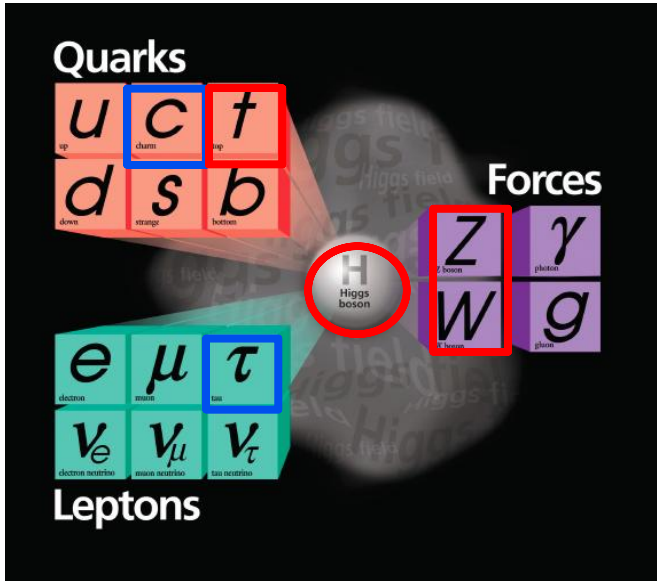


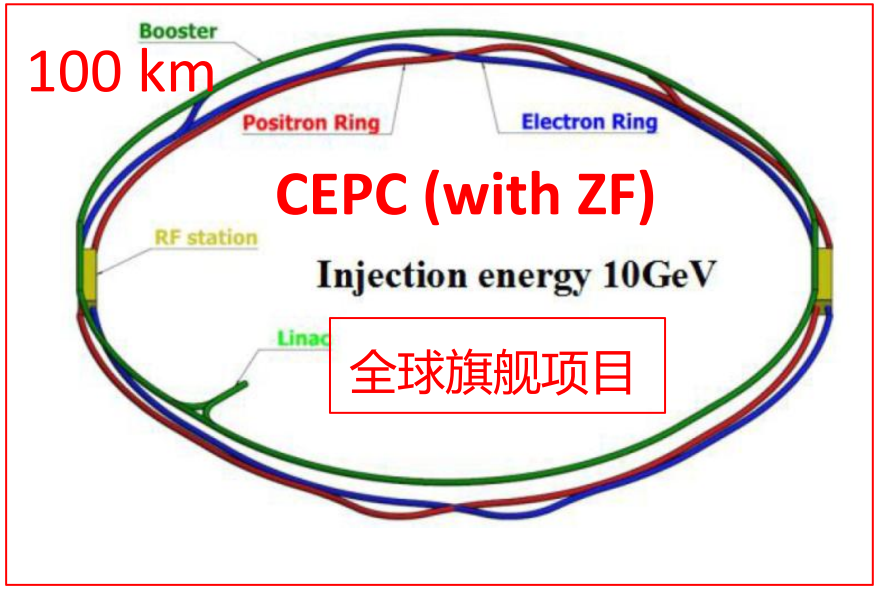




**The primary task of particle physics: develop understanding of the laws of nature at a more fundamental level.**
**→ Requires a coordinated multi-dimensional program: precise theoretical predictions for observation, experimental measurements with state-of-the-art sensitivities and well-controlled systematic errors.**
**→ STCF can play unique role to this primary task!**

# 工程建设指标对比：STCF 和 CEPC


- 质心系能量: 2-7 GeV
- 峰值亮度: 5 × $10^{34}$ cm$^{-2}$s$^{-1}$
- 对撞环周长： 800米

- 建造周期：5年
- 造价：45亿元
- 运行费用：1-2亿元/年

不同的：

- 物理目标
- 研究对象
- 规模和尺度

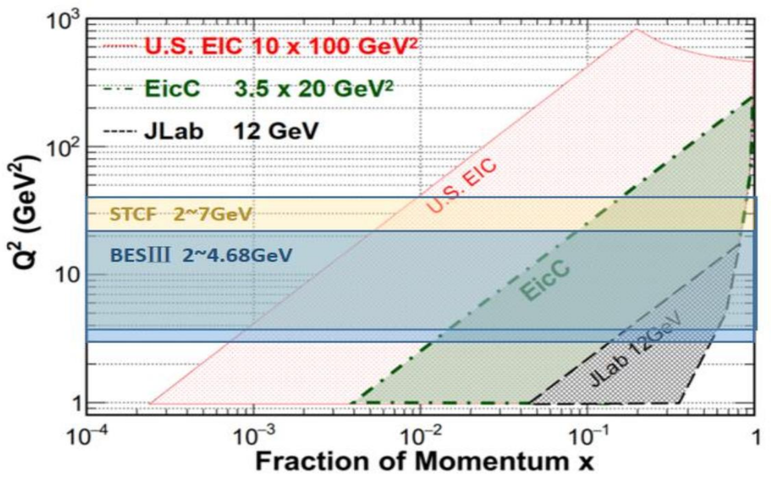
不可以相互替代!!

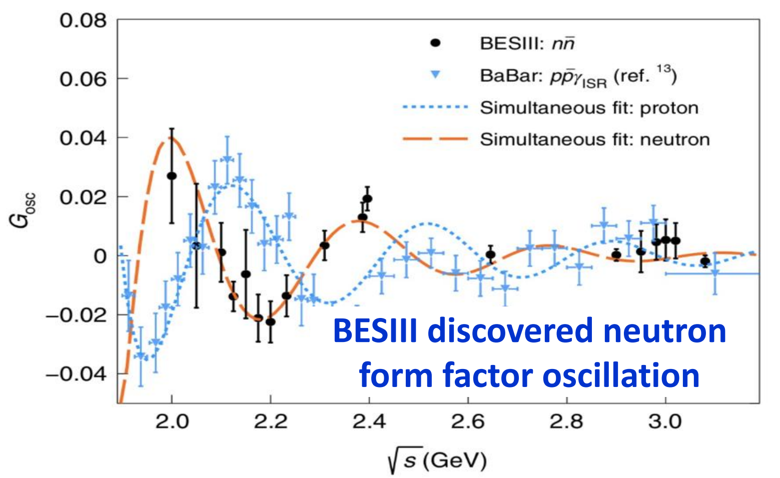
- 质心系能量： 91/240 GeV
- 峰值亮度: 115/5 × $10^{34}$ cm$^{-2}$s$^{-1}$
- 对撞环周长： 100千米

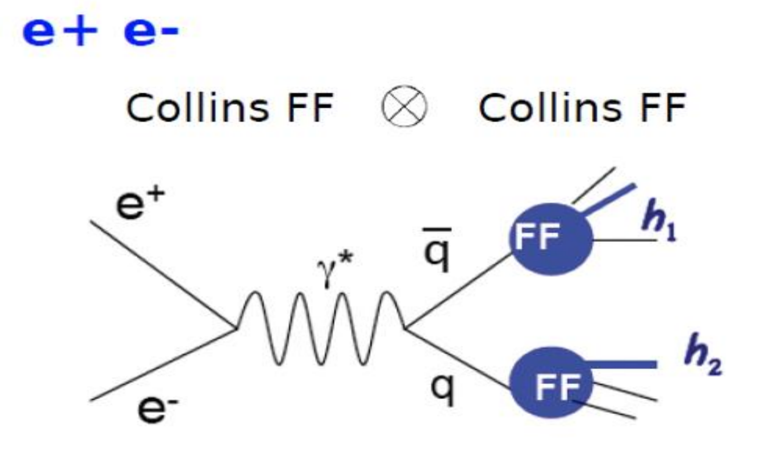
- 建造周期：10年
- 造价：364亿元
- 运行费用：16-20亿元/年

# Hadron Production and Hadron Structure

**Unique facility to study strong interactions**




## Hadron production and hadron spectrum

- Key pathway to understand hadron production mechanism and structure
- Cover energy region 0.6-7 GeV

## Inner structure of nucleons

- The most basic observables reflecting deep structure of mater
- Complementary to next generation e-N scattering experiments

## Fragmentation function

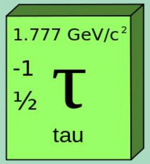
- Key to understanding the strong interaction mechanism, hadron production and hadron structure
- Together with ep data to test for universality of fragmentation mechanism

# Flavor Physics and CP Violation

- **Baryon asymmetry of the Universe indicates that there must be non-SM CPV source.**
- **CPV observed in K, B, D mesons, all are consistent with CKM theory in the SM.**
- **STCF can search for CPV with high sensitivity in hyperon, charm, τ and K.**

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

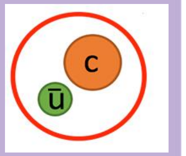
CP in Hyperon decay



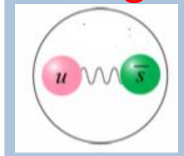

CP in τ production and decay

**Peak cross section in $\sqrt{s}$ =4-5 GeV,**
**$\sigma_{\tau\tau}\approx3.5$ nb, 10 ab$^{-1}$ data in total**
**of $\tau$ decay with 1ab$^{-1}$ @ 4.26 GeV**
**Sensitivity $\sim9.7\times10^{-4}$**

CP in charm mixing




CP, CPT in kaon 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: $x\sim0.035\%$, $y\sim0.023\%$,**
**$r_{CP}\sim0.017, \alpha_{CP}\sim1.3^{\circ}$**

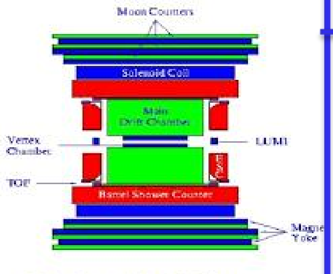
**CP tagging and flavor tagging of $K^0/\bar{K}^0$ from J/ψ decay**
**CP variables determined with**
**time-dependent decay rate**
**CP, CPT sensitivity:**
**$\eta_{\pm}\sim10^{-3}, \Delta\phi_{\pm}\sim0.05^{\circ}$**

# Challenges And Opportunities

**BEPC/BES, BESII**

$E_{cm}$: 2-4.8 GeV

L: $10^{31}$ $cm^{-2}s^{-1}$



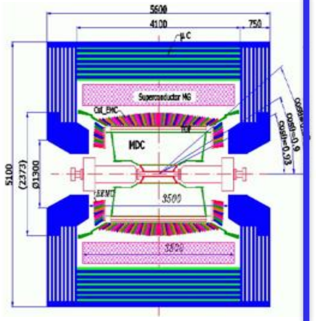

Side view of the BES detector

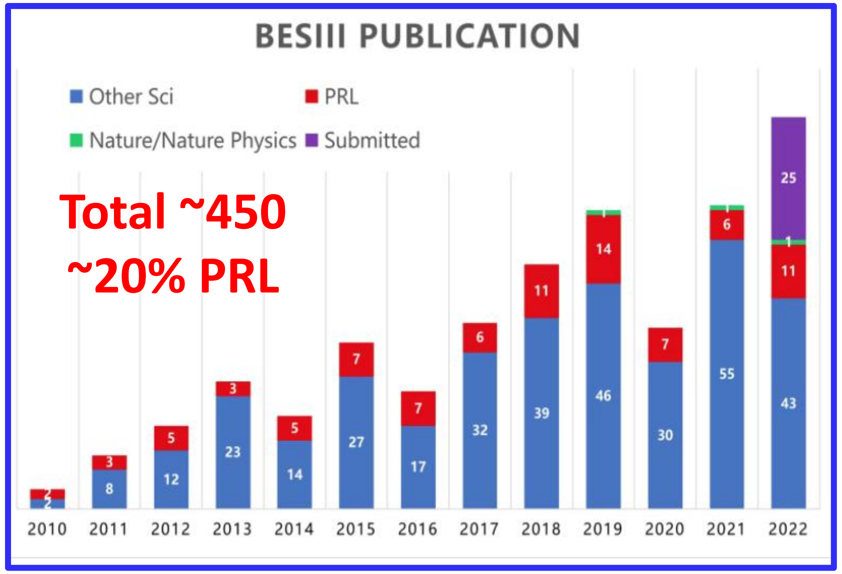
**Upgrade**

**BEPCII/BESIII**

$E_{cm}$: 2-4.8 GeV

L: $10^{33}$ $cm^{-2}s^{-1}$






- BEPCII/BESIII has made great contribution to HEP, but operated for over 15 years.
- Limited by the site and tunnel, no room for further significant upgrades.
- The more data BESIII has, the more interesting and important physics topics open, e.g. nucleon inner structure, exotic states, CPV in hyperons….., and these are closely related to the key science questions.

# CPV in Tau Leptons

- In SM, no direct CPV in tau decays at the tree level. However, due to $K^0 - \bar{K}^0$ mixing, CPV appears in $\tau \to K_s \pi \bar{\nu}$, to be

$$A_{cp} = \frac{\Gamma(\tau^+) - \Gamma(\tau^-)}{\Gamma(\tau^+) + \Gamma(\tau^+)} = (0.33 + 0.01)\%$$

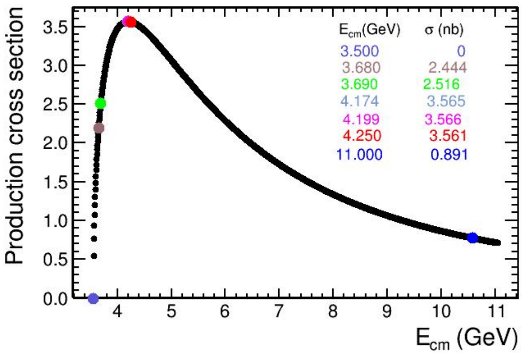
- Experimentally, BaBar found evidence of CPV in $\tau \to K_s \pi \bar{\nu}$ decays, to

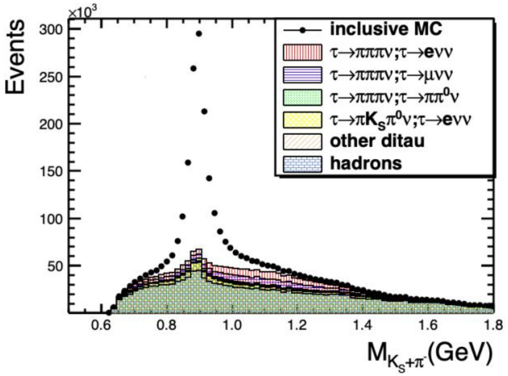
$$A_{cp} = (-0.36 \pm 0.23 \pm 0.11)\%$$

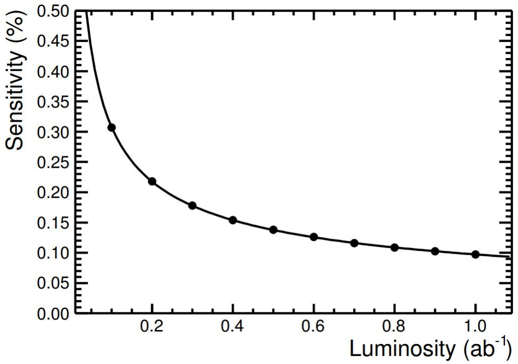
→ 2.8$\sigma$ deviation from SM prediction!

Tau studies at STCF:

- At 4.26 GeV, $N_{\tau\tau} \sim$ 1.0 ab$^{-1}$ ×3.5 nb=3.5× $10^9$
- Using 1ab$^{-1}$ @ 4.26 GeV, sensitivity of CPV is determined with decay-rate difference between $\tau^+ \to K_s \pi^+ \nu_\tau$ and $\tau^- \to K_s \pi^- \bar{\nu}_\tau$, to be $\Delta\ A_{\mathrm{CP}} \sim 0.097\%$
- With 10 ab$^{-1}$ data in $\sqrt{s} = 4 - 5$ GeV: $\Delta A_{\mathrm{cp}} \sim 0.031\%$



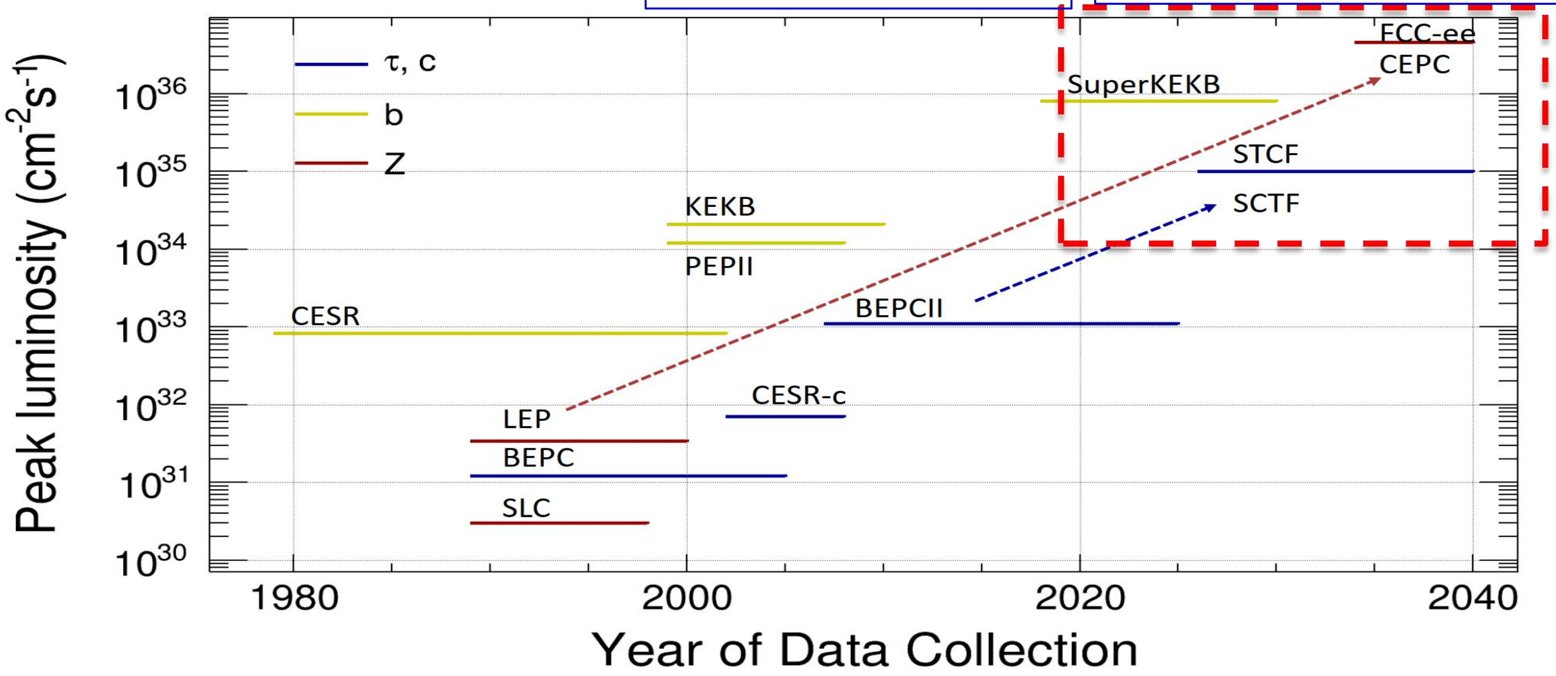




**With the data from $e^+ e^-$(polarized) collision, more CP parameters can be measured.**

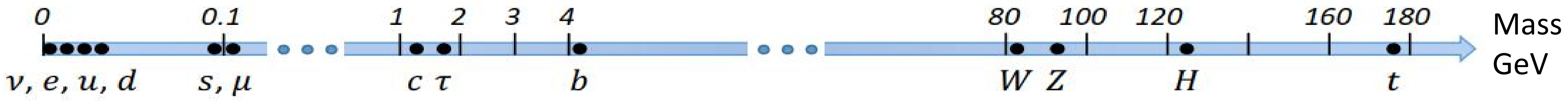
*H.Y. Sang et al., Chin. Phys. C 45, 053003 (2021)*

# High Luminosity $e^+e^-$ Colliders

| 1st generation<br>Single ring | 2nd generation<br>Double ring<br>More bunch, low β | 3rd generation<br>Double ring<br>Large current, large Piwinski angle+crab waist, super low β |
|---|---|---|




| Today | | Future | |
|---|---|---|---|
| Exp. | Data ($fb^{-1}$) | Exp. | Data ($ab^{-1}$) |
| BESIII | 100 | STCF | 10 |
| BELLE | 1000 | BELLE II | 50 |
| LHCb | 5 | LHCb | 0.3 |




High luminosity frontier: STCF SKEKB
Using flavor physics as tool for discovery

Energy frontier: LHC FCC CEPC
Using Higgs boson as a tool, and entering in to the new energy territory for the discovery

# XYZ states at STCF

**Collaborative inputs from experiments, theory and lattice QCD provide answers to the XY Z puzzles and a deeper understanding of how color confinement organizes the QCD spectrum.**

## The Y(4230) state (1B/year)

- Too many vector states
- Precisely determine their **resonance parameters**, **partial widths** of decay modes

| Partial decay width of Y(4230) | Expected precision |
|---|---|
| $\mathcal{B}_{\omega\chi_{c0}} \times \Gamma_{ee}$ | $0.8\%_{\text{stat.}}$ |
| $\mathcal{B}_{\pi^+\pi^- h_c} \times \Gamma_{ee}$ | $2.0\%_{\text{stat.}}$ |
| $\mathcal{B}_{\pi^+\pi^- J/\psi} \times \Gamma_{ee}$ | $0.7\%_{\text{stat.}}$ |
| $\mathcal{B}_{D^0 D^{*-}\pi^+ + c.c} \times \Gamma_{ee}$ | $0.8\%_{\text{stat.}}$ |
| $\mathcal{B}_{\pi^+\pi^-\psi(3686)} \times \Gamma_{ee}$ | $3.5\%_{\text{stat.}}$ |
| $\mathcal{B}_{\pi^+\pi^-\psi(3686)} \times \Gamma_{ee}$ | $0.7\%_{\text{stat.}}$ |

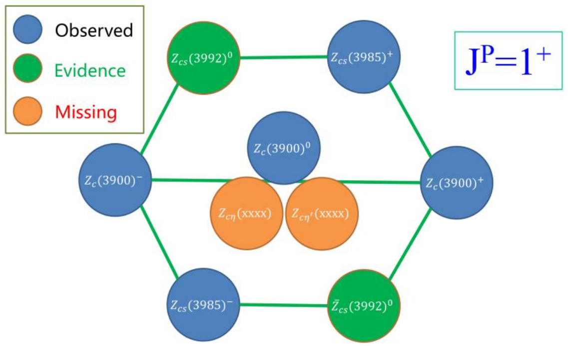
**Search for $1^{--}$ hybrids**

$\sigma(e^+e^- \to Y_{ccg}) \sim \mathcal{O}(10-100)$ pb

$\boldsymbol{\mathcal{O}(6-60)}$ in $\gamma\eta_c/\gamma\chi_{c0}$ expected

## The Zc(3900) state (100M/year)

- Establish $Z_c$ tetraquark family




| State | Signif. | JP | Mass (MeV) | Width (MeV) |
|---|---|---|---|---|
| $Z_{cs}(3985)$ | 5.3σ | ?? | $3982.5^{+1.8}_{-2.6} \pm 2.1$ | $12.8^{+5.3}_{-4.4} \pm 3.0$ |
| $Z_{cs}(4000)$ | 15σ | 1+ | $4003 \pm 6^{+4}_{-14}$ | 131±15±26 |
| $Z_{cs}(4220)$ | 5.9σ | 1+ | $4216 \pm 24^{+43}_{-30}$ | $233 \pm 52^{+97}_{-73}$ |

Are $Z_{cs}(3985)$ and $Z_{cs}(4000)$ the same or different states?

## The X(3872) state (5M/year)

- **STCF** can Precisely determine the **BF** of X(3872) decays → **proportion of $D\bar{D}^*$**
- Search for its partners

| Decay channel | Expected precision |
|---|---|
| $X(3872) \to \pi^+\pi^- J/\psi$ | $4.5\%_{\text{stat.}}$ |
| $X(3872) \to D^{*0}\bar{D}^0 + c.c$ | $5.0\%_{\text{stat.}}$ |
| $X(3872) \to \gamma J/\psi$ | $5.5\%_{\text{stat.}}$ |
| $X(3872) \to \gamma\psi(3686)$ | $5.0\%_{\text{stat.}}$ |
| $X(3872) \to \pi^0\chi_{c1}$ | $6.0\%_{\text{stat.}}$ |
| $X(3872) \to \omega J/\psi$ | $5.5\%_{\text{stat.}}$ |

**X(3872) in direct $e^+e^-$ collisions**

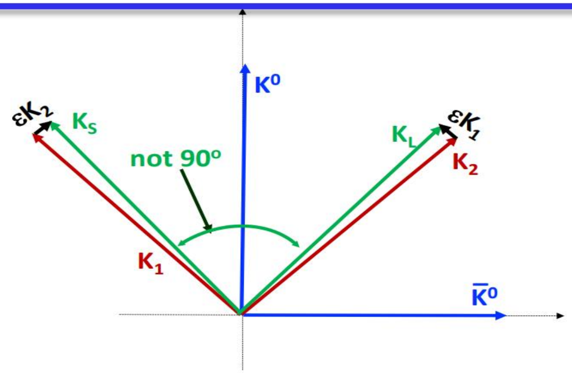
$\Gamma(X \to e^+e^-) \geq 0.03$ eV (VMD)

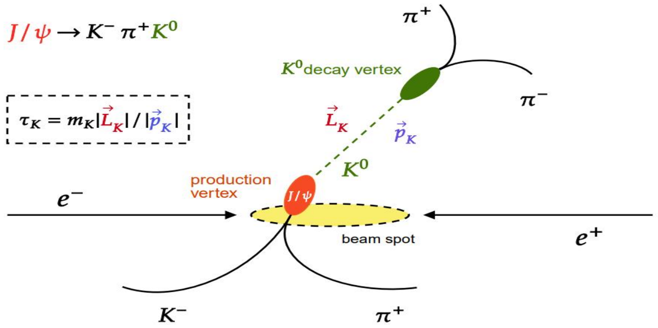
$\boldsymbol{\mathcal{O}(60)}$ in $\pi^+\pi^- J/\psi$ expected

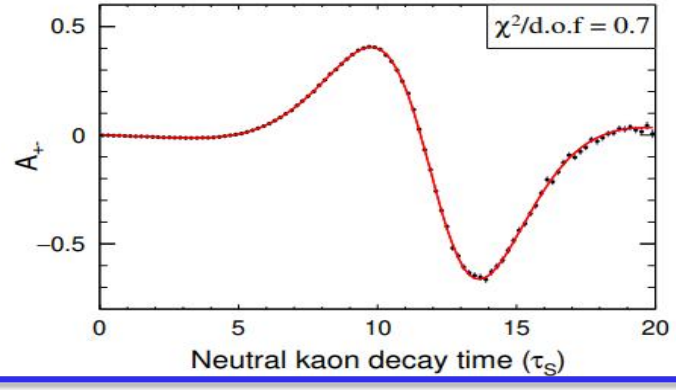
# CPT Violation from Neutral K Decays

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

$K^0 - \bar{K}^0$ at STCF: $$A_{CP}^{+-}(\tau) = \frac{\bar{R}_f(\tau) - R_f(\tau)}{\bar{R}_f(\tau) + R_f(\tau)} \propto \frac{|\eta_{+-}| e^{\frac{1}{2}\Delta\Gamma\tau} \cos(\Delta m\tau - \phi_{+-})}{1 + |\eta_{+-}|^2 e^{\Delta\Gamma\tau}}$$




$K^0 - \bar{K}^0$ flavor tagging via $J/\psi \to K^0K^-\pi^+/\bar{K}^0K^+\pi^-$

$K_1 - K_2$ 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

$\phi_{+-}$ used to set limits on CPT violation. With >$10^{10}$ $K^0/\bar{K}^0$ events from $J/\psi$ decay, he sensitivity of $|\eta_{+-}|$, $\phi_{+-}$ are $\mathcal{O}(10^{-3})$ ⇒ one order of magnitude better than PDG average.

**Break through the scope of quantum field theory and test new physics**

# Summary

- STCF has rich physics program, and has potential for breakingthrough to the understanding of strong interaction, and to the new physics searches.
- STCF will be one of the major centers for high energy physics in the world that focus at the precision frontier: advanced technologies of acclerator, particle detection and data treatment, computing and network…
- With over 10 years continious effort, we have finished feasibility study and the pre-conception design (CDR), and have started R&D for some key techologies.
- Anhui provice and USTC have officially committed the support to STCF R&D.
- STCF is not a project of USTC, but one of the entire high energy physics community. We are fully open to welcome international participation.

# High Precision Measurement of EDM of Hyperons

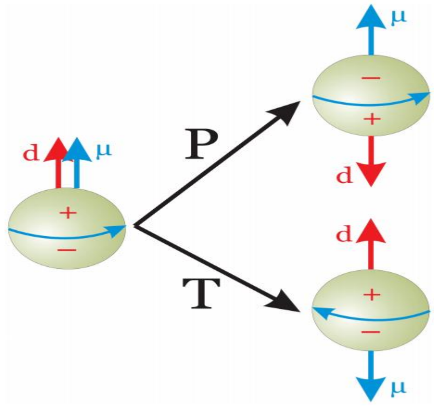
**A new method for measuring hyperon EDM, can improve by 2 orders of magnitude compared with existing limitations!**

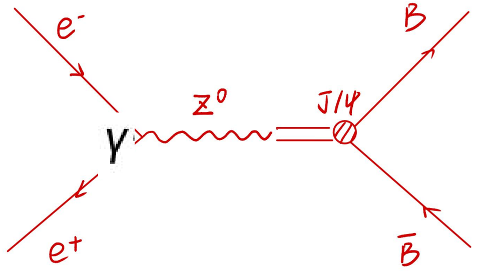
X.G.He, J.P. Ma, PLB 839(2023)137834

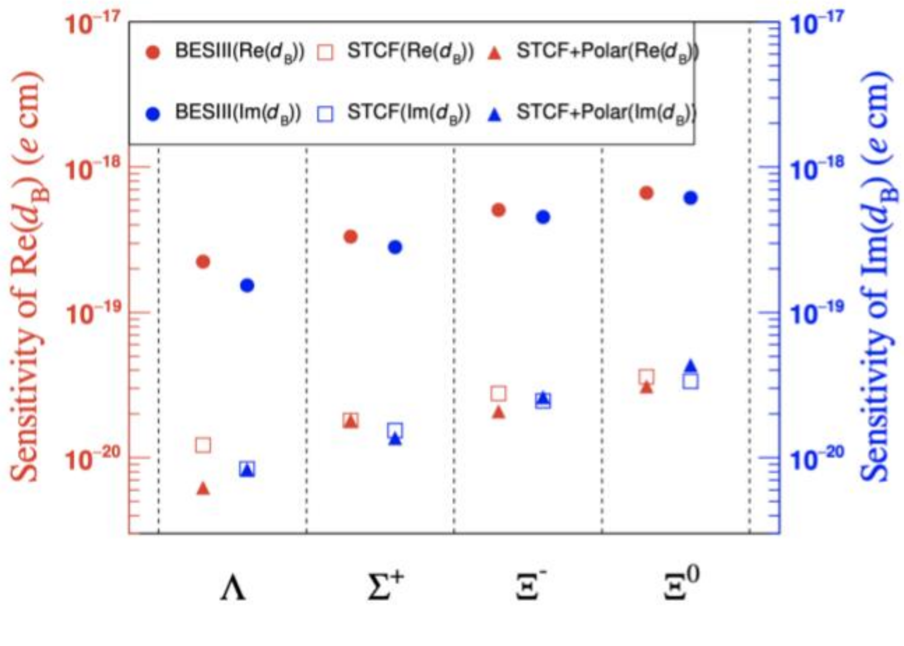
SM: $\sim 10^{-26}$ e cm

BESIII: milestone for hyperon EDM measurement
$\Lambda$ $10^{-19}$e cm ( FermiLab $10^{-16}$ e cm)
first achievement for $\Sigma^+$,$\Xi^-$ and $\Xi^0$ at level of $10^{-19}$e cm
a litmus test for new physics

STCF: improved by 2 order of magnitude




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

Several CPV sources contributed to $H_T$ Take hyperon EDM as the major source for $H_T$

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

Neglect q dependence, $d_B$ for hyperon EDM

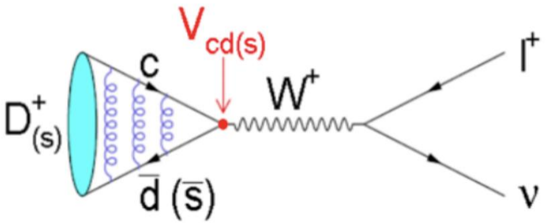
Detailed dynamics in $J/\psi$ decay to hyperon pair, have been studied:

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

# CKM Matrix and Universality of Lepton Interaction

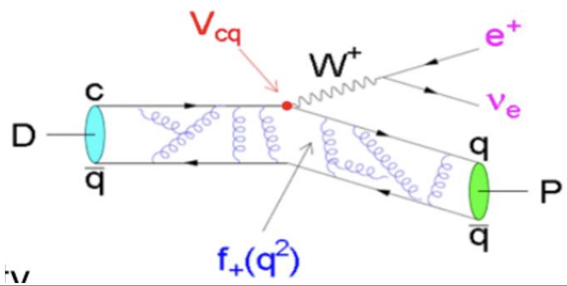
## Pure leptonic decay

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




## Semi-leptonic decay

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




## Direct measurement

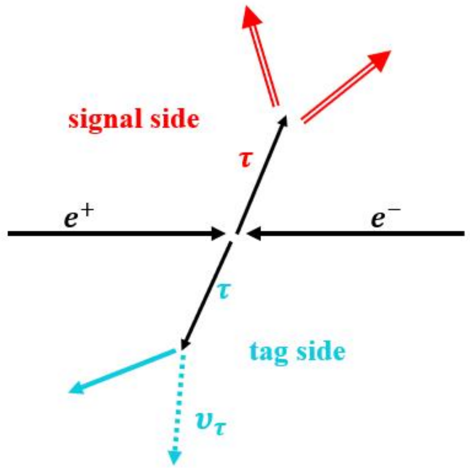
$|V_{cd(s)}|$ x $f_{D(s)}$ or $|V_{cd(s)}|$ x FF

- Input $f_{D(s)}$ or $f^{K(\pi)}(0)$ from LQCD => $|V_{cd(s)}|$
- Input $|V_{cd(s)}|$ from a global fit => $f_{D(s)}$ or $f^{K(\pi)}(0)$
- Validate LQCD calculation of input $f_{B(s)}$ and provide constraints of CKM-unitarity

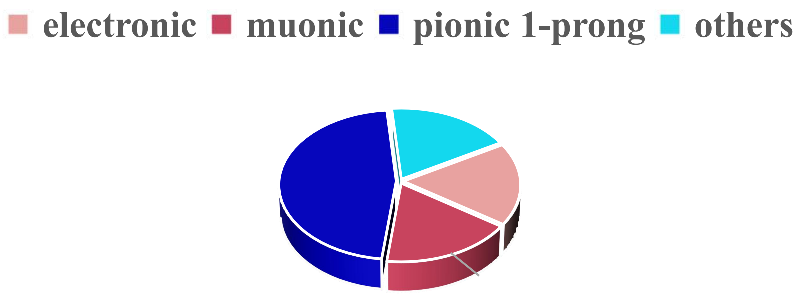
| Source | BESIII [57] | | BelleII [57] | | This work at STCF | |
|---|---|---|---|---|---|---|
| | 6 $fb^{-1}$ at 4.178 GeV | | 50 $ab^{-1}$ at $\Upsilon(nS)$ | | 1 $ab^{-1}$ at 4.009 GeV | |
| $\mathcal{B}_{D_s^+\to\tau^+\nu_\tau}$ | $1.6\%_{\text{stat.}}$ | $2.4\%_{\text{syst.}}$ | $0.6\%_{\text{stat.}}$ | $2.7\%_{\text{syst.}}$ | $0.3\%_{\text{stat.}}$ | $1.0\%_{\text{syst.}}$ |
| $f_{D_s^+}$ (MeV) | $0.9\%_{\text{stat.}}$ | $1.4\%_{\text{syst.}}$ | – | – | $0.2\%_{\text{stat.}}$ | $0.6\%_{\text{syst.}}$ |
| $\|V_{cs}\|$ | $0.9\%_{\text{stat.}}$ | $1.4\%_{\text{syst.}}$ | – | – | $0.3\%_{\text{stat.}}$ | $0.7\%_{\text{syst.}}$ |
| $\frac{\mathcal{B}_{D_s^+\to\tau^+\nu_\tau}}{\mathcal{B}_{D_s^+\to\mu^+\nu_\mu}}$ | $2.6\%_{\text{stat.}}$ | $2.8\%_{\text{syst.}}$ | $0.9\%_{\text{stat.}}$ | $3.2\%_{\text{syst.}}$ | $0.5\%_{\text{stat.}}$ | $1.4\%_{\text{syst.}}$ |

**The experimental accuracy reaches the calculation accuracy of grid point QCD!**

# Physics of Flavor Change of the Tau

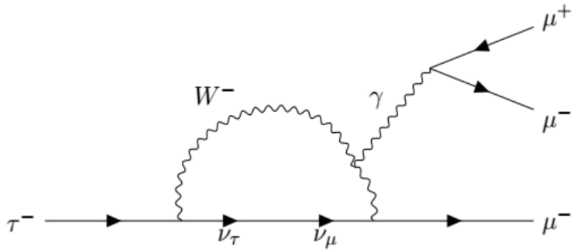



- Precisely known kinematics of initial state
- Full reconstruction of signal side
- Neutrino in tag side is missing




**Channel 1:** $\tau \to \gamma\mu$

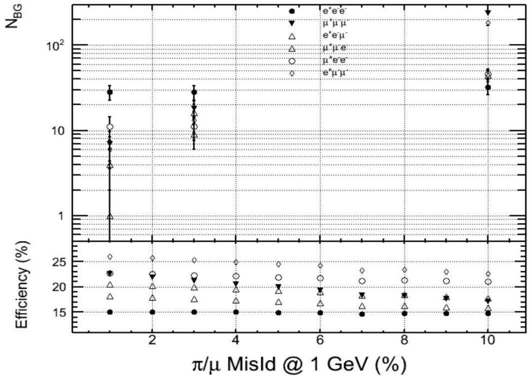
**Channel 2:** $\tau \to lll \; (l = e, \mu \quad)$

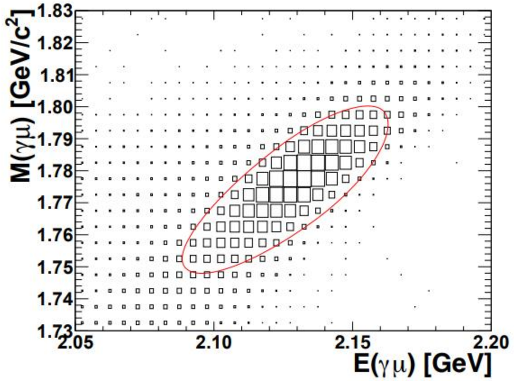


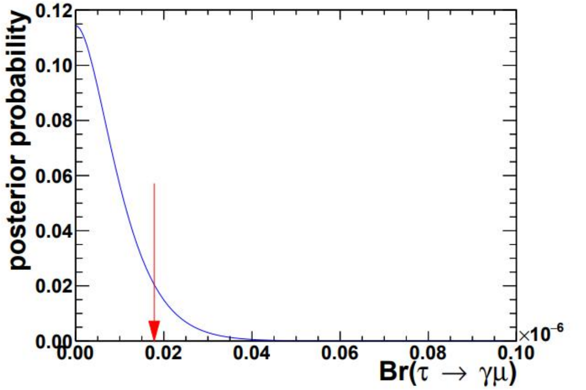

Br ~$(\Delta M_{ij}/M_W)^4$ <$10^{-40}$

At STCF, $3.5 \times 10^9$ $\tau^-\tau^+$ per year, the upper limit is predicted to be:

$$\mathcal{B}_{UL}^{90}(\tau \to 3l) < 1.4 \times 10^{-9}, \quad \mathcal{B}_{UL}^{90}(\tau \to \gamma\mu) < 1.8 \times 10^{-8}$$



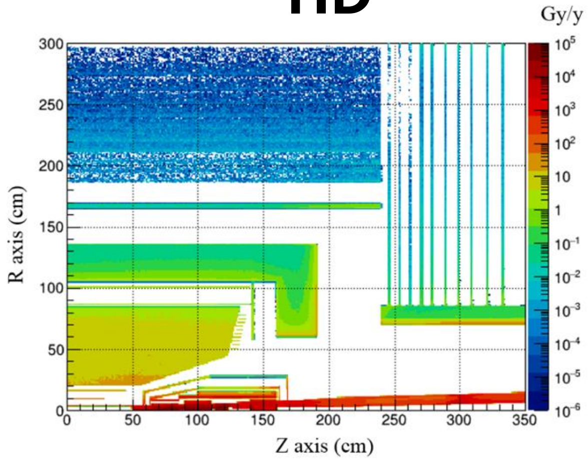



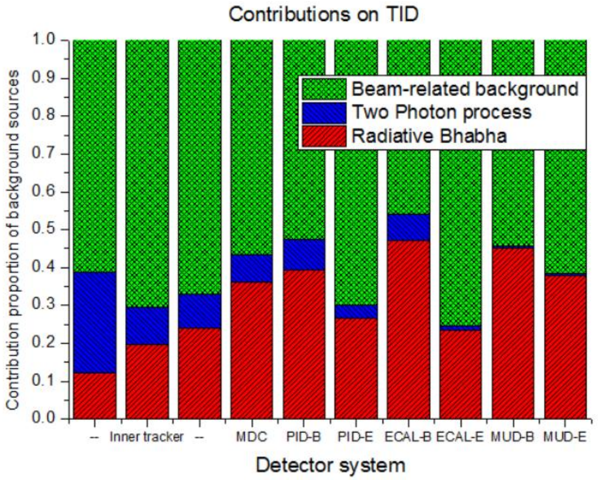




*T. Xiang et al., arXiv: 2305.00483*

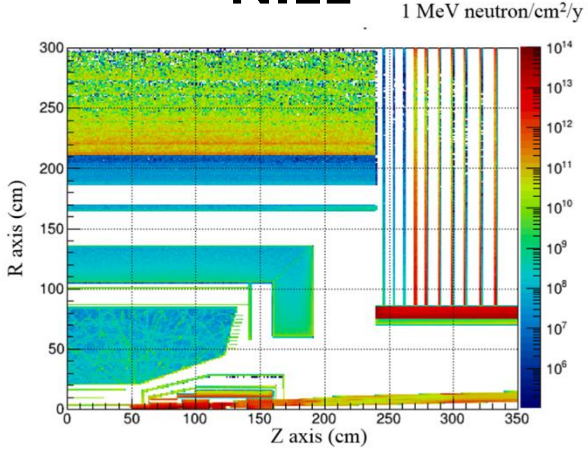
# Beam-induced Backgrounds

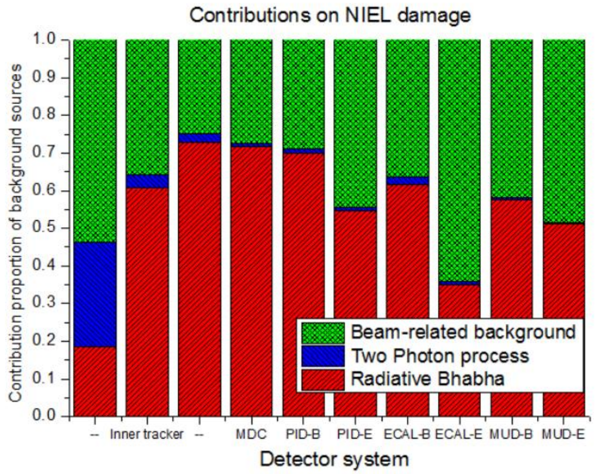
**TID**



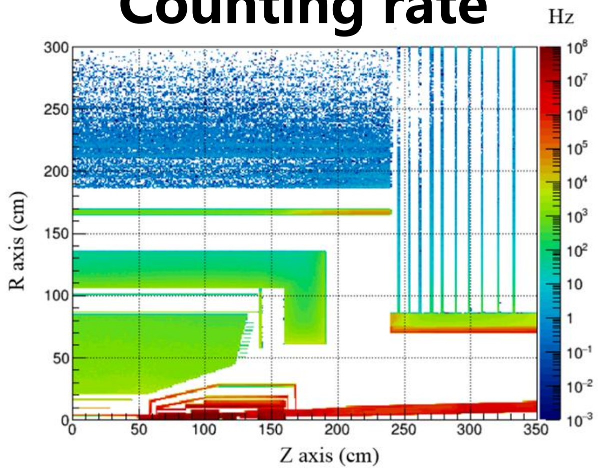



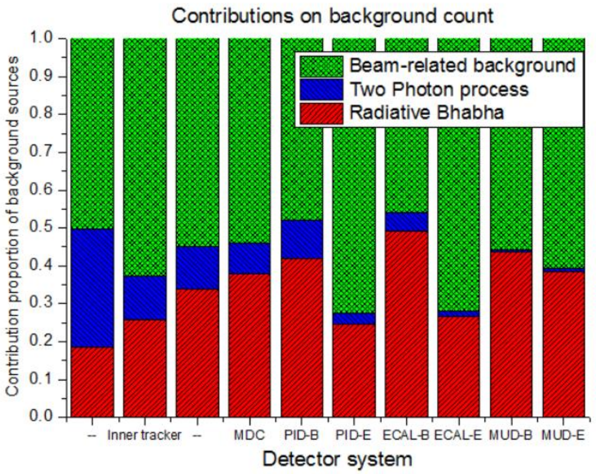

**NIEL**




**Counting rate**




**Inner most detector layer**: ~3.5 kGy/y, ~$2\times10^{11}$ 1MeV n-eq/$cm^2$/y, ~1 MHz/$cm^2$

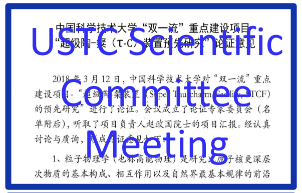
The major challenge is to maintain or even enhance the state of the art performance of **$\tau$-c** detectors in much harsher experimental conditions.

# Project Promotion: History and Present Status

China High Energy Physics Branch discussion on development strategy of accelerator-based high energy physics


**2011**
First proposed


**2015**
Urging to launch feasibility study and R&D




**2018**
USTC support 20 M CYN for feasibility study


**2021**
Conceptional Design Report

3.5 M CYN from CAS International Partner Program


**2022**
420 M CYN from Anhui for R&D

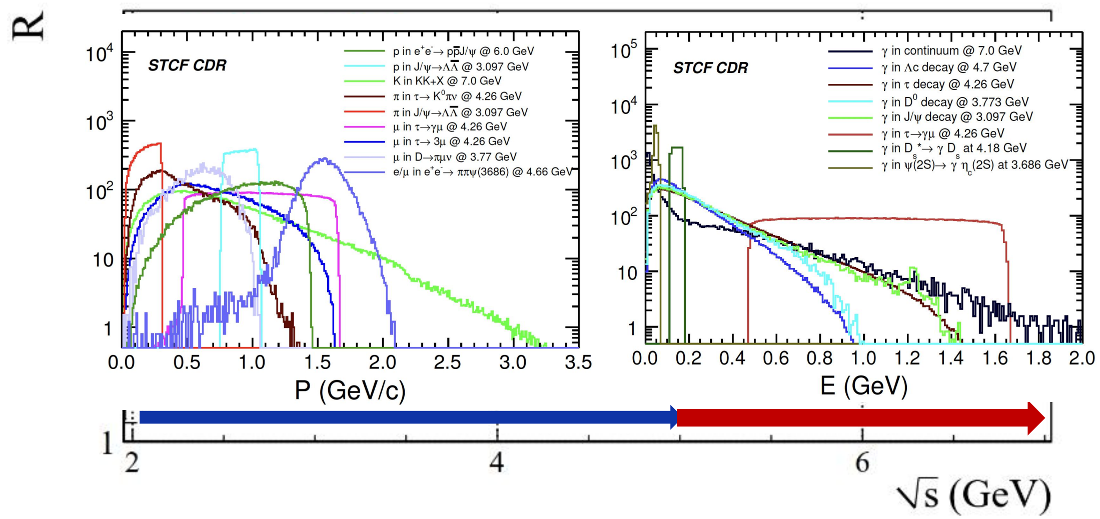
18 M CYN from MOST


**2023**
Kickoff

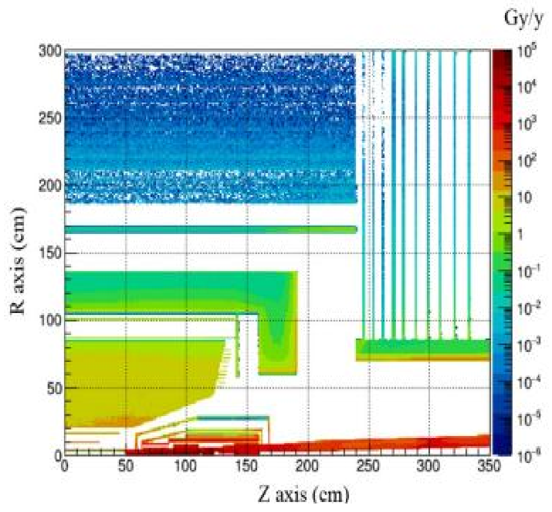
14 M CYN From NSFC (in application)

# Spectrometer Design Requirements and Challenges

## Wide energy region $E_{cm}$ : 2-7 GeV




## Super high luminosity $5 \times 10^{34}$ $cm^{-2}s^{-1}$




**High events**
~400 kHz

**High counting rate**
~1 MHz/$cm^2$

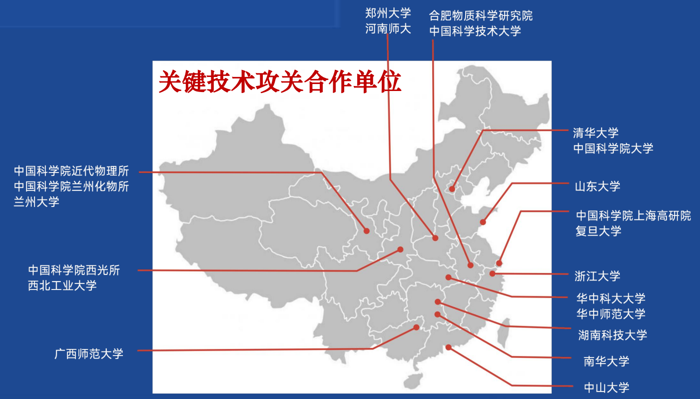
**High data flow**
~300 GB/s

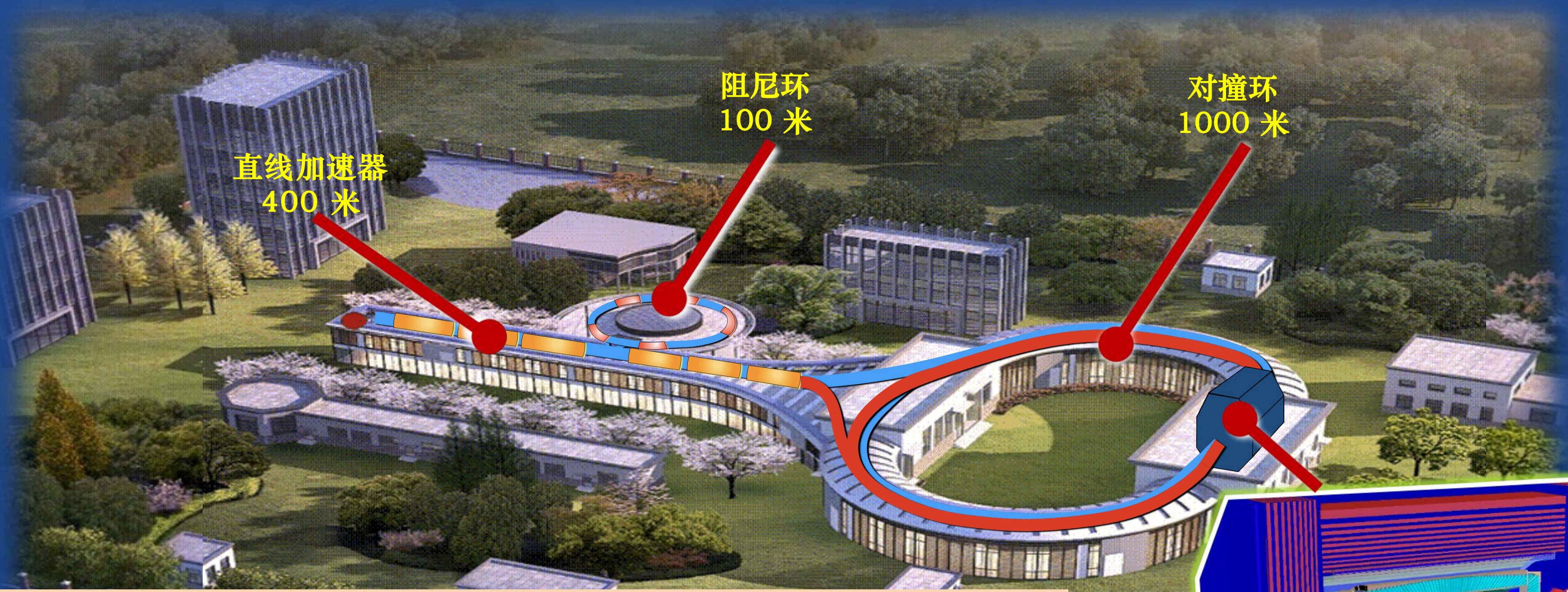
**High radiation and bkg**
~4 kGy/y,~$2 \times 10^{11} n_{eq}/cm^2/y$

High efficient event triggering, acquisition, and reconstruction for super high events rate.
➜ Good particle identification, and accurately measure the position, energy, momentum, charge, and time of flight of the particles.

| 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 $\tau$ sector, CPV in the hyperon sector, Charm physics | ITK+MDC | acceptance: 93% of $4\pi$; 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 | $\pi/K$ and $K/\pi$ 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 $\tau$, CKM matrix, LQCD etc. | PID+MUD | $\mu/\pi$ suppression power over 30 at $p < 2$ GeV/c, $\mu$ efficiency over 95% at $p = 1$ GeV/c |
| $\tau \to \gamma\mu$, $\psi(3686) \to \gamma\eta(2S)$ | cLFV decay of $\tau$, Charmonium transition | EMC | $\sigma_E/E \approx 2.5\%$ at $E = 1$ GeV $\sigma_{pos} \approx 5$ 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 | $\sigma_T = \frac{300}{\sqrt{p^3(GeV^3)}}$ ps |

# 新一代大科学装置
# 超级陶粲装置关键技术攻关



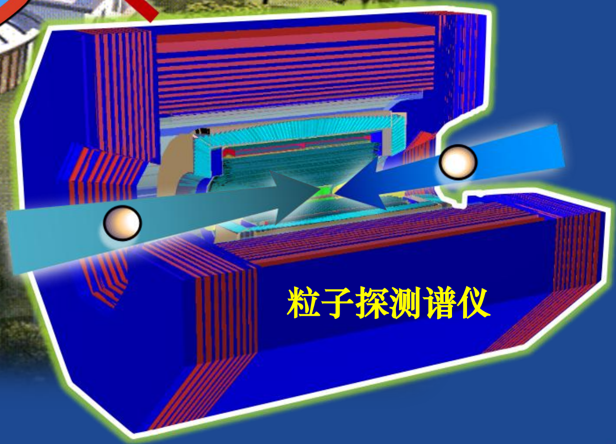




**新宽能区:** 2-7GeV，超高亮度: > 0.5 ×$10^{35}$ $cm^{-2}$ $s^{-1}$

**高精度前沿:** 重大科学问题，引领世界陶粲物理研究，大科学国际合作基地

**尖端技术前沿:** 加速器，粒子探测，快电子学，大数据

**科技人才高地:** 有国际竞争力，掌握尖端科技，催生和推动高新技术

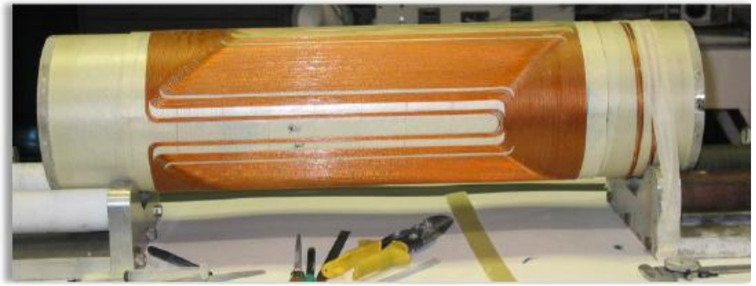


# Key challenges on AP and technologies

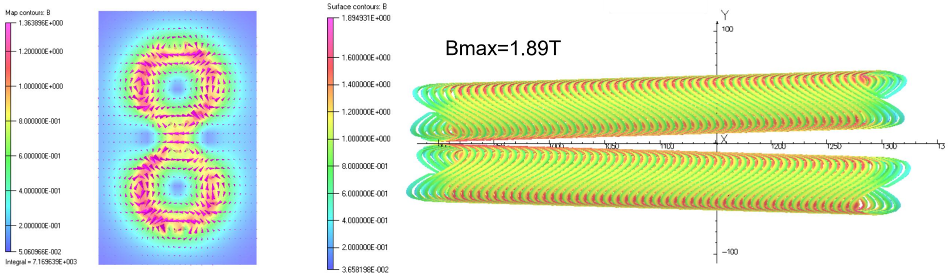
| No | Key design or tech | Prio. | Comments |
|---|---|---|---|
| 1 | Collider ring AP design | A+ | Espec. IR, key to realize high-lumi |
| 2 | IR SC magnets | A+ | Complex structure, high-field, tight space, less exp. |
| 3 | Collider ring RF | A+ | High-power, deep-damped HOM, less exp. |
| 4 | Injector AP design | A | Prov. high-qual. beams to CR, 2 injection schemes |
| 5 | MDI | A | Very tight space and complex mech. (acc. and det.) |
| 6 | Collider beam instrum. | A | High-prec. and fast bunch meas., fast feedbacks |
| 7 | Collider ring injection | A | ns-scale kickers for bunch swap-out injection |
| 8 | Positron source | A | Low e- energy to generate e+ beam |
| 9 | Collider ring vacuum | A- | High-current circ. beams, ultra-high vacuum for IR |
| 10 | Electron source | A- | High-bunch charge photocathode e-gun |
| 11 | Linac microwave | A- | Large-aper. S-band acc. struct., less exp, LLRF |
| 12 | Linac power source | A- | High-power solid-state modulator |

# Key challenges (3) – IR SC magnets

- IR SC magnets
  - Technically very challenging, very few labs have experience
  - Very tight space, complex and combined coils
  - 3rd-Gen e+/e- colliders even more difficult: twin-aperture, higher field gradient (~50 T/m)
  - In China: IHEP built the first IR magnet for BEPC-II; some experience in other SC magnets
  - STCF R&D: developing prototypes by steps, different technologies under consider. (BEPCII serpentine, CCT✓, cos2θ/DCT)



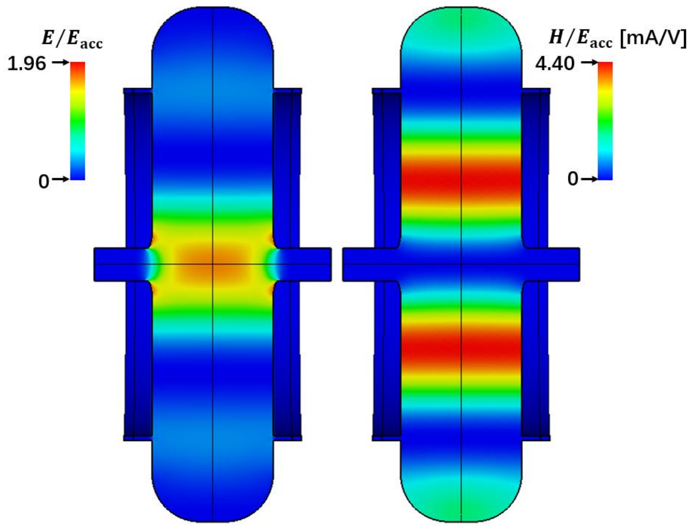
IHEP BEPCII-U (Serpentine)




A CCT type prototype just started
(60 mrad, 54 mm separation, 50 T/m)

# Key challenges (4) – Ring RF

- RF for Collider rings
  - High synchrotron radiation (2 Amperes): RF power and couplers
  - HOM deep-damped: instabilities
  - Large energy range (1-3.5 GeV): high $V_{RF}$
  - Beam loading: at bunch swap-out injection
  - Stability: more powerful LLRF
  - Selected for R&D: TM020 RT cavity, 500 MHz;  200 kW coupler

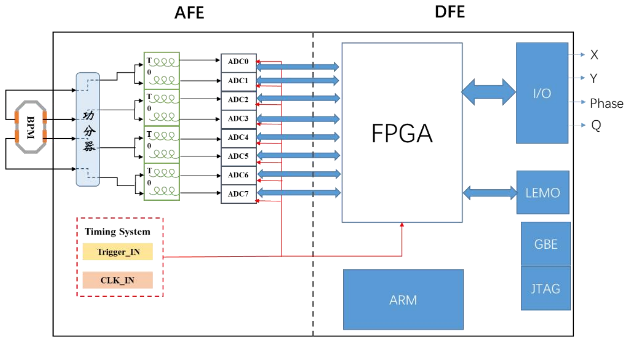



TM020 cavity in prototyping

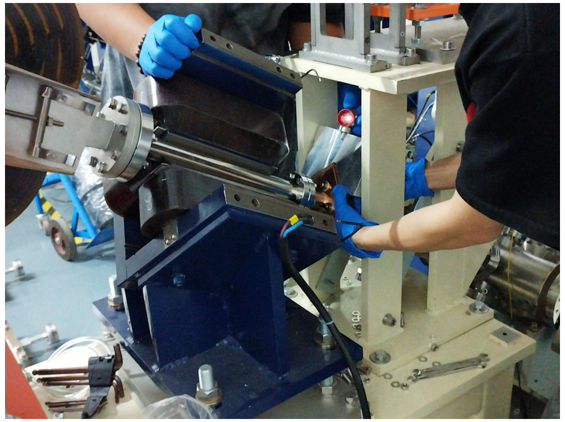
| RF parameters | |
|---|---|
| Working mode | TM020 |
| Frequency [MHz] | 499.7 |
| R/Q [Ω] | 84.4 |
| Unloaded quality factor | 62828 |
| $E_p/E_{acc}$ | 1.92 |
| $B_p/E_{acc}$ [mA/V] | 2.64 |
| Vcav (inpot: 100 kW) [kV] | 728.2 |

# Key challenges (5) – Beam instrumentation

- Requirements for beam instrum.
  - CR precise bunch meas.: bunch-by-bunch 3D meas., trans. position res. <5 μm, long. phase res.<0.2 ps
  - CR B-by-B fast feedback: coupled bunch inst.
  - IP: orbit feedback
  - Injector: bunch length and charge meas.
- R&D efforts
  - Bunch 3D meas.: probe, signal treat, electronics, S/N, integration
  - B-by-B fast feedback: raising bandwidth, avoiding interference to single bunch
  - Injector bunch length and charge meas.: cavity-based
  - Prototypes: beam tests in different machines

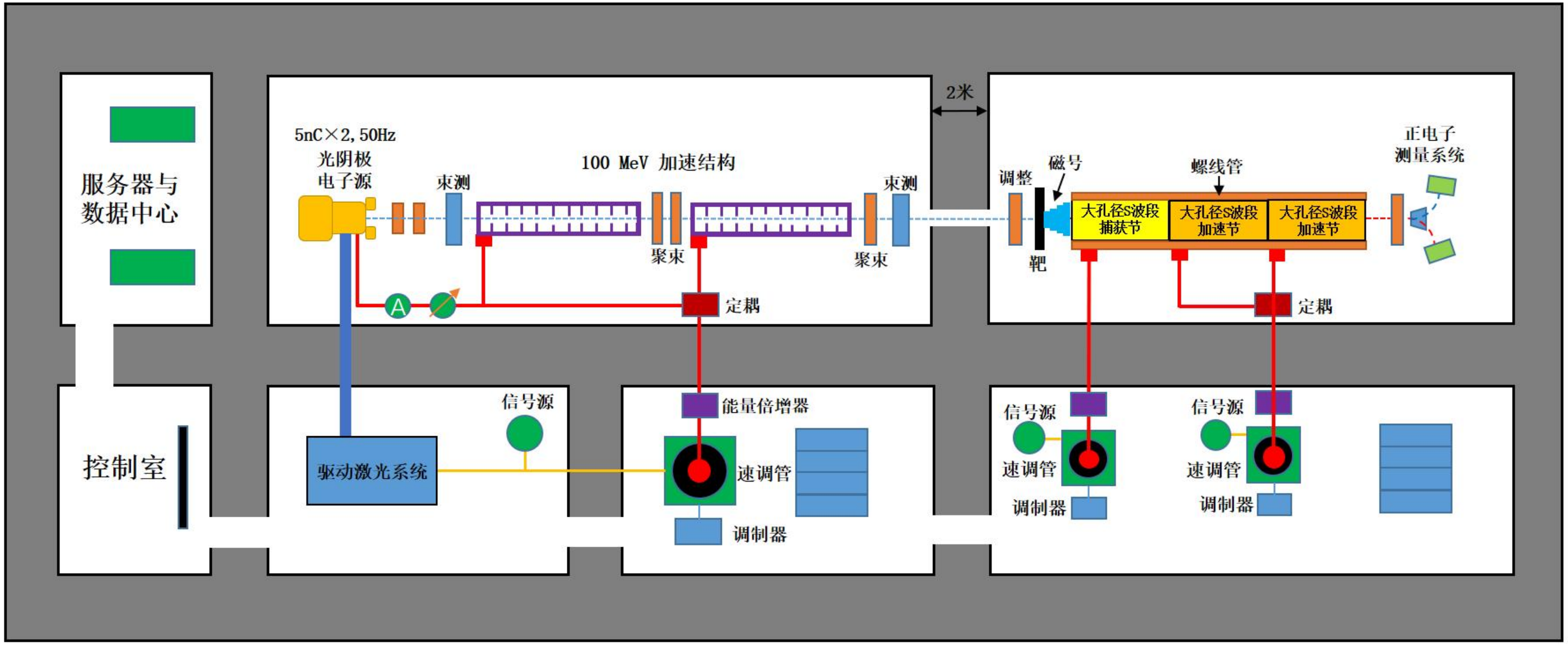



Integrated board for B-by-B 3D meas.



Cavity-based: bunch length, charge and profile meas.

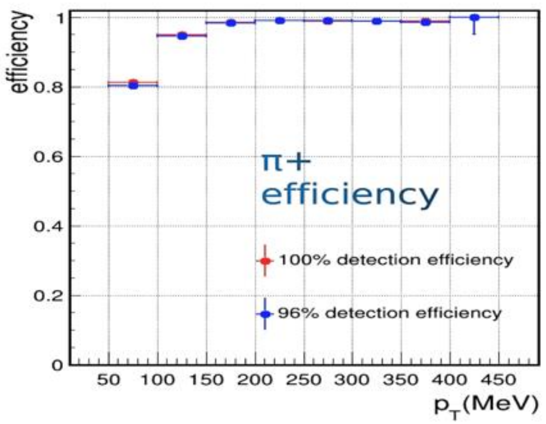
e- linac: 2* 6-m sections; e+ linac: 3 large-aper. accel. tubes



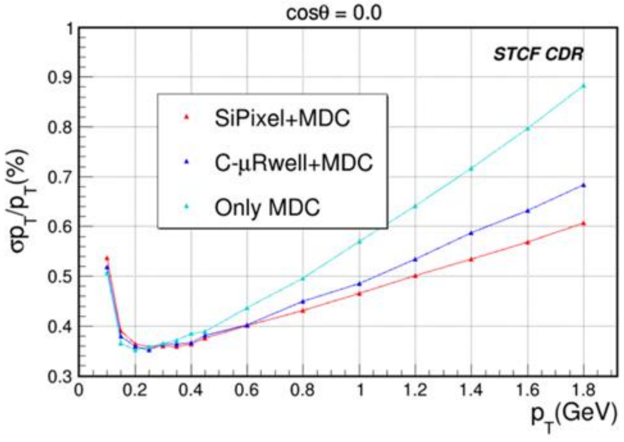

# Located in the accelerator test hall of HALF (Hefei Advanced Light Facility under construction)

# Expected Performance

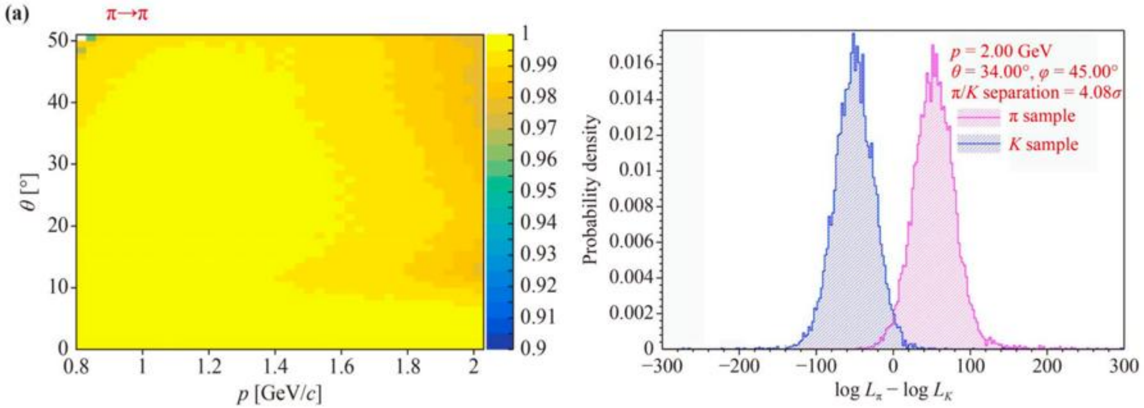
## Tracking efficiency



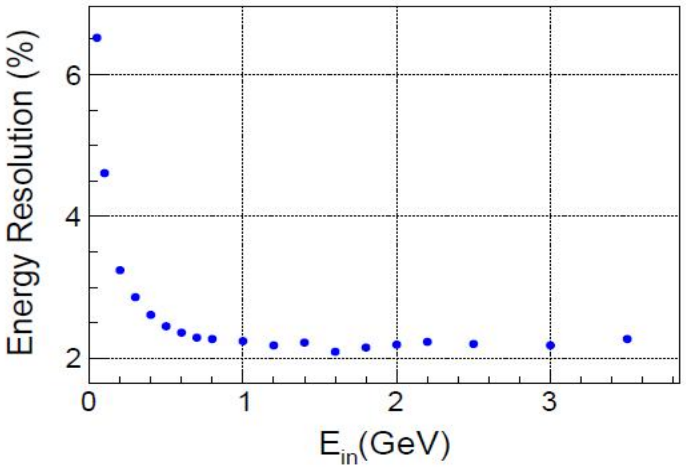

## Momentum resolution



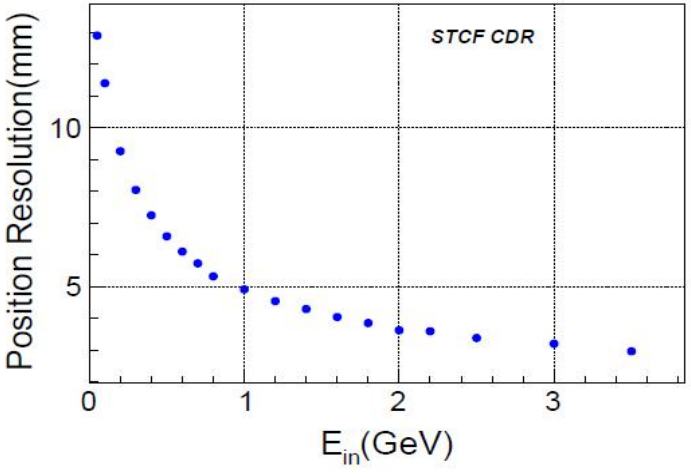

## Pion/K separation capability



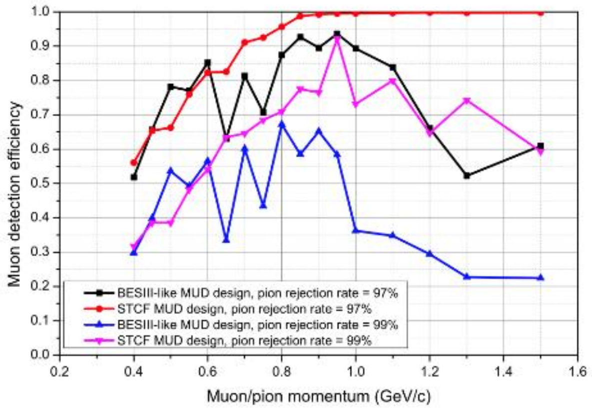

## Photon energy resolution



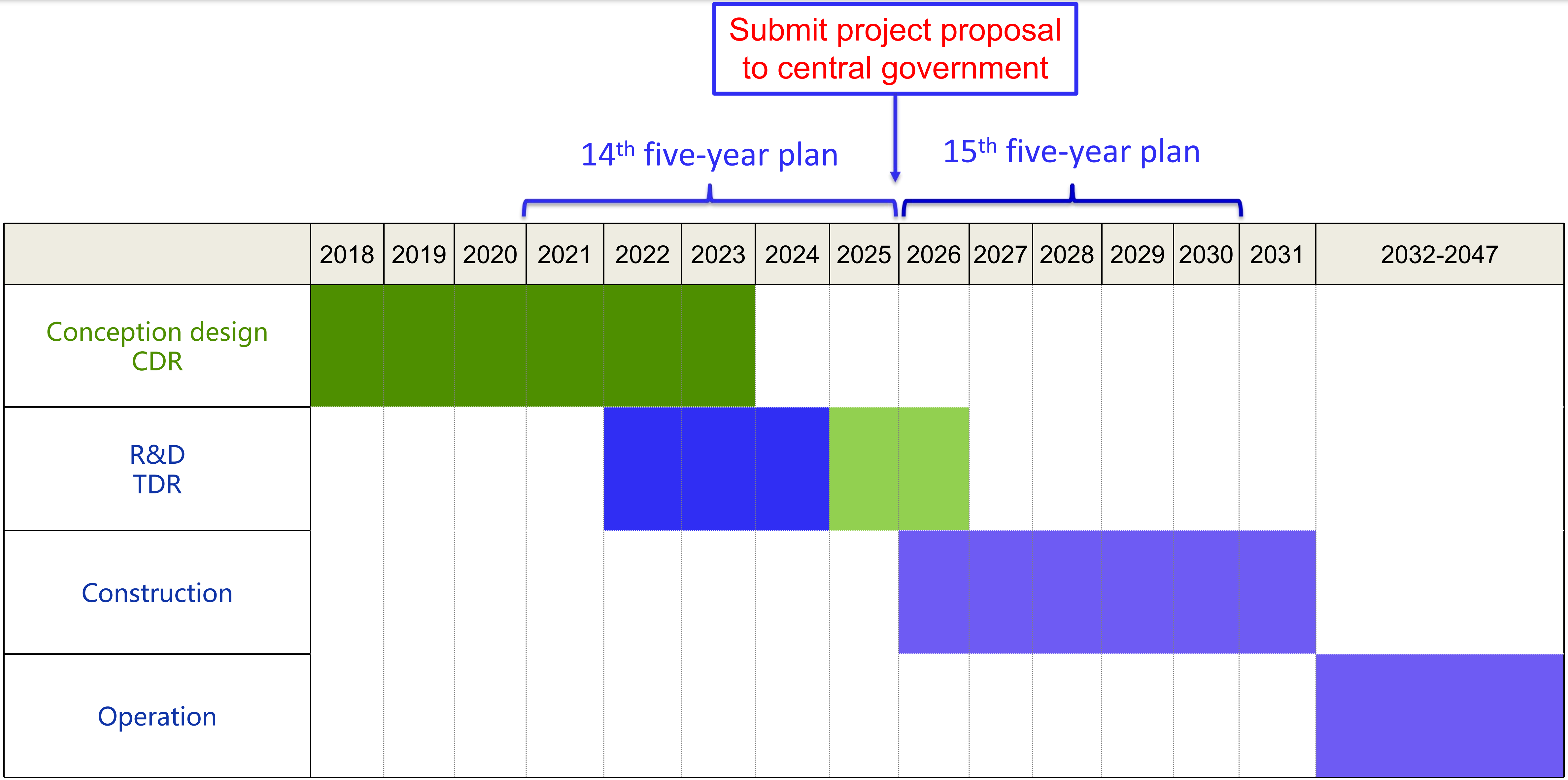

## Photon position resolution




## Muon identification efficiency



# Proposed Timeline



# 目前攻关项目参加和合作单位

## 加速器 (7)

中国科学技术大学

中国科学院上海高研院

中国科学院近代物理所

合肥物质科学研究院

清华大学

华中科技大学

中国科学院大连化物所

## 探测器研发单位 (14)

中国科学技术大学

中国科学院大学

中国科学院近物所

华中师范大学

中国科学院西光所

山东大学

兰州大学

郑州大学

西北工业大学

中国科学院兰州化物所

湖南科技大学

浙江大学

广西师范大学

复旦大学

## 软件研发高校 (10)

山东大学

郑州大学

中国科学院大学

中山大学

复旦大学

兰州大学

南华大学

河南师大

湖南科技大学

中国科学技术大学