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

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On behalf of the STCF Working Group

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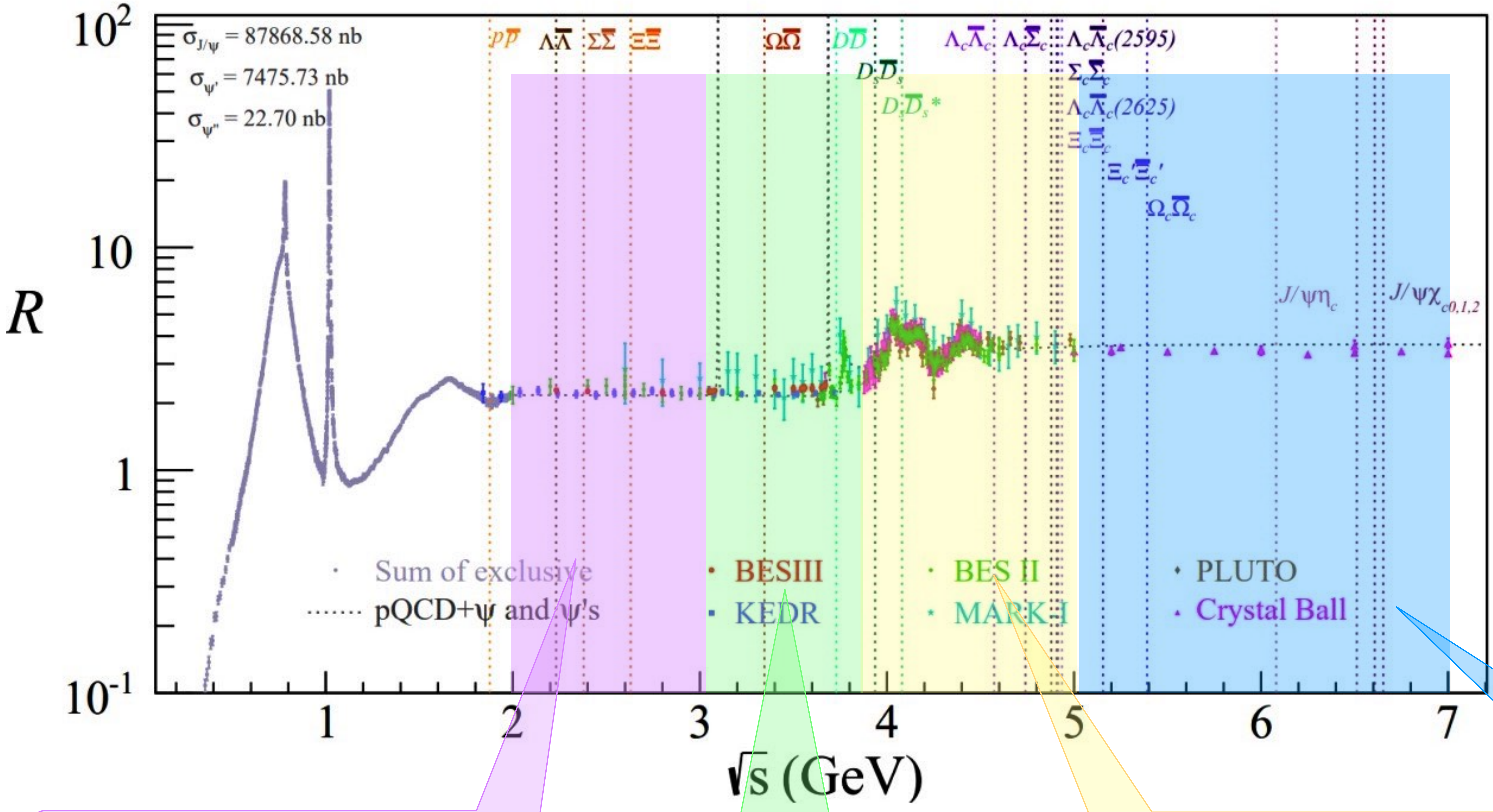
Chulalongkorn University, Bangkok, Thailand

Physics at the Tau-Charm Energy Region



Tau-charm energy region

2-7 GeV at e^+e^- collider

- Transition region between perturbative and non-perturbative QCD
- Pair production of hadrons and τ's at threshold
- Rich resonant structures, large production cross-sections for charmonium states and charmonium-like exotics

- Nucleon/Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark
- MLLA/LPHD and QCD sum rule predictions

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

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

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

History of Tau-Charm Colliders*

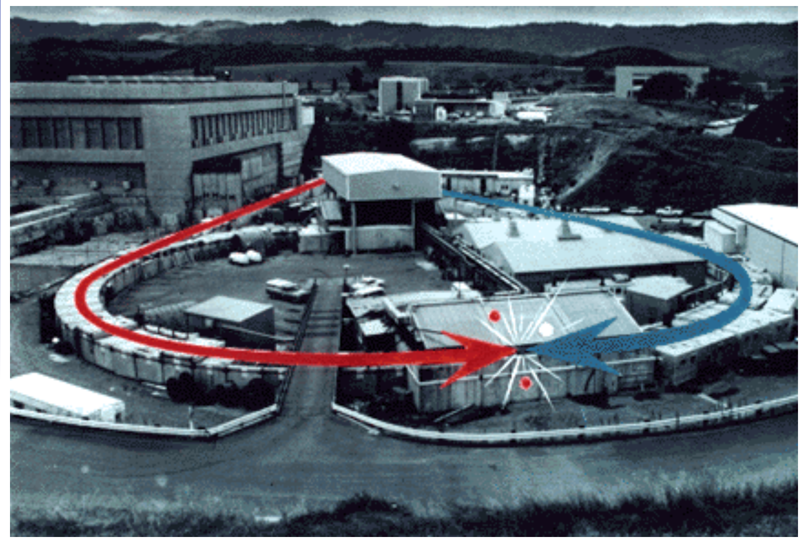
ADONE, Fracscati
’69 - ’93

BEPC, IHEP, ’90 - ’04
$5 \times 10^{30}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

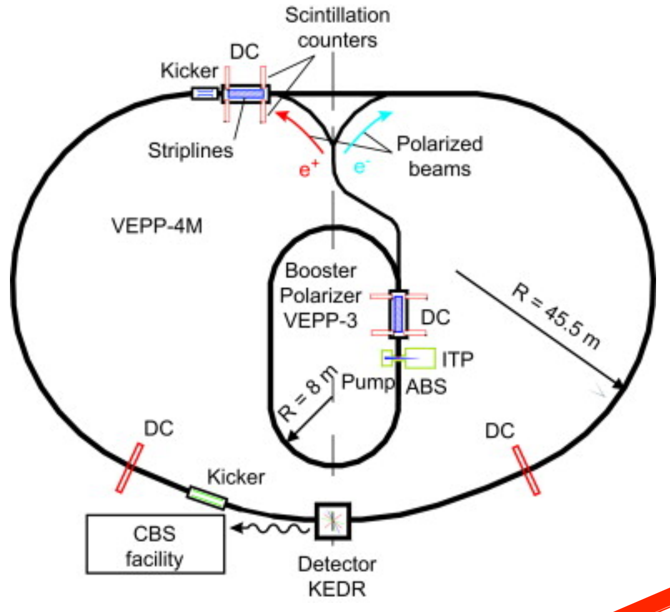
CESRc, Cornell, ’04 - ’08
$7 \times 10^{30}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

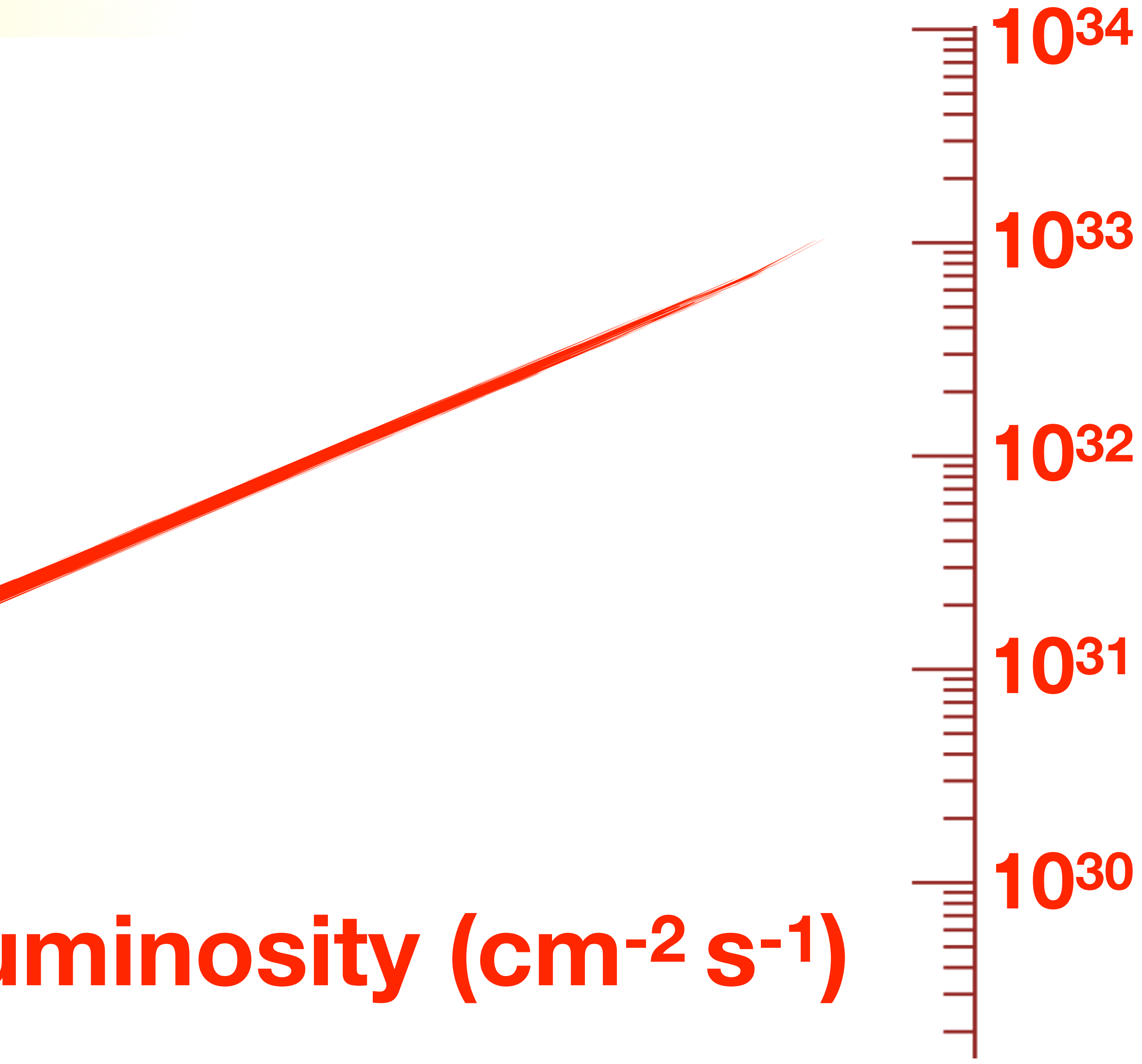
BEPCII, IHEP, ’08 - now
$1 \times 10^{33}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

SPEAR, SLAC, ’72 - ’90
$6 \times 10^{29}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$



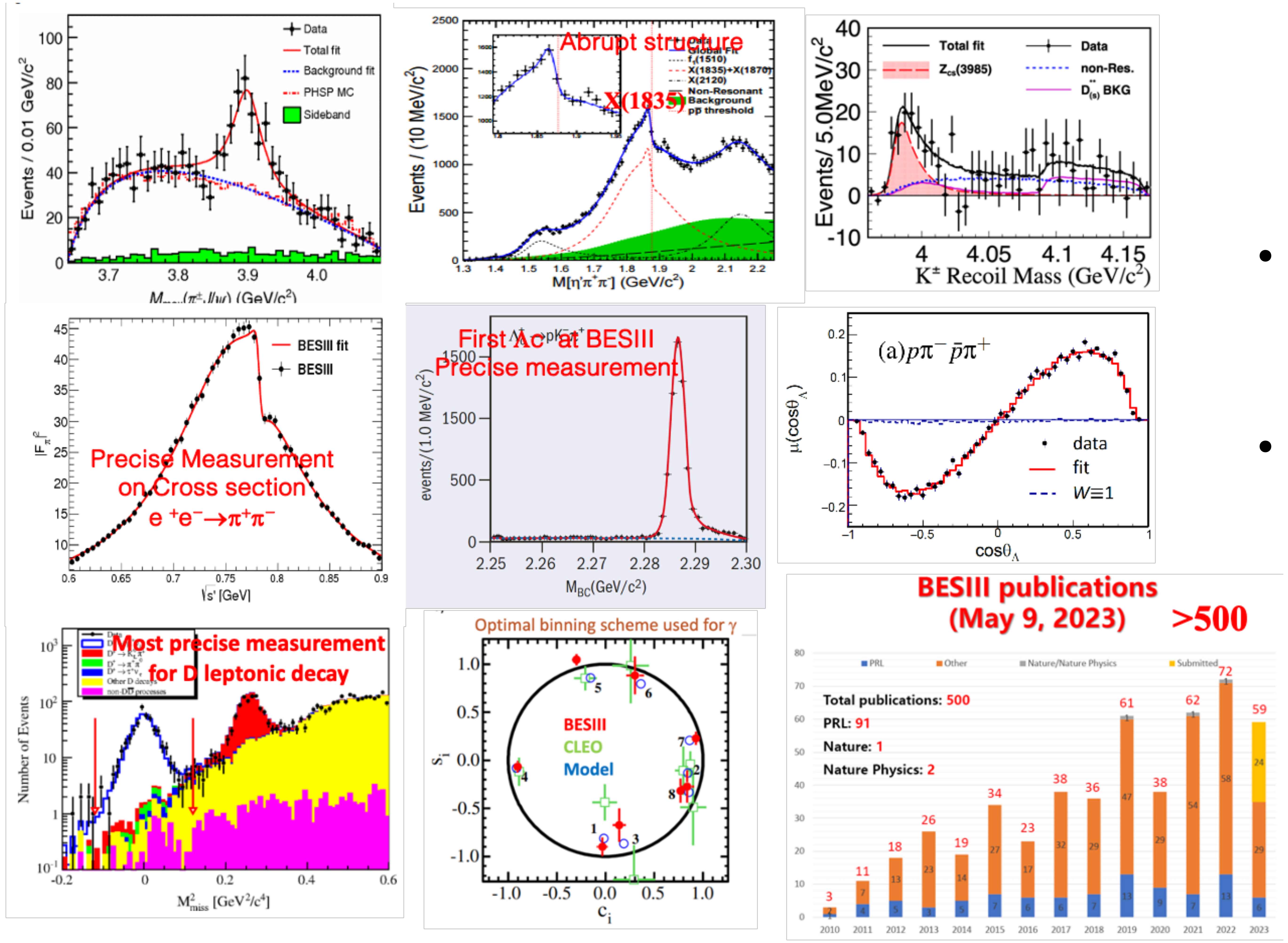
VEPP-4M, BINP, ’02 - ’12
$1 \times 10^{30}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$





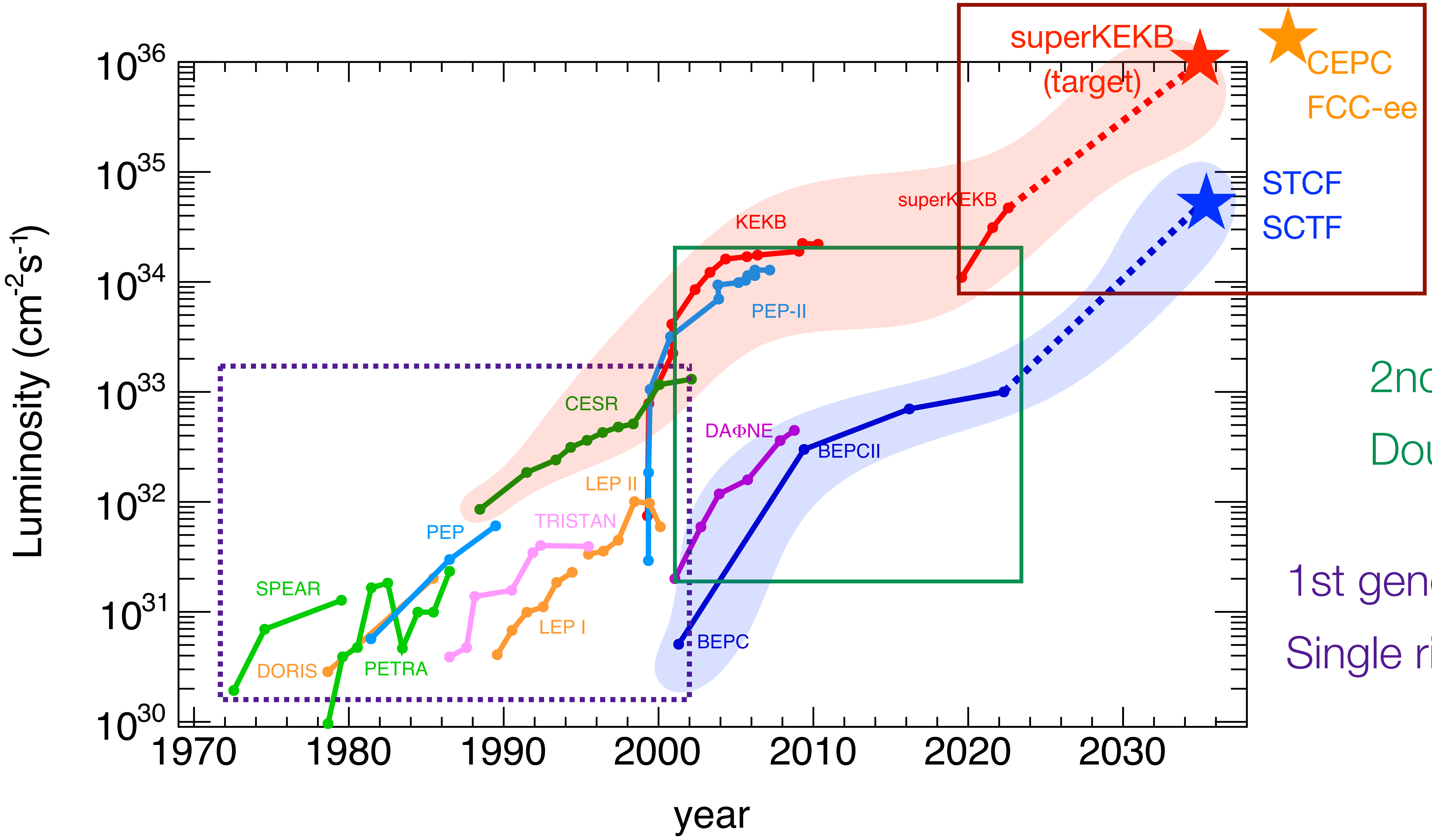
*not a inclusive list of all colliders

Fruitful BEPCII/BESIII Results



- Only current machine running in the Tau-Charm energy region: **BEPCII / BESIII**, playing a leading role in tau-charm physics
- BEPCII/BESIII have run over 15 years. Limited by length of storage ring and tunnel space, no potential for another major upgrade

The Three Generations of e^+e^- Colliders



3rd generation:
Double ring, low β, high current, large Piwinski angle + Crab Waist

2nd generation:
Double ring, low β

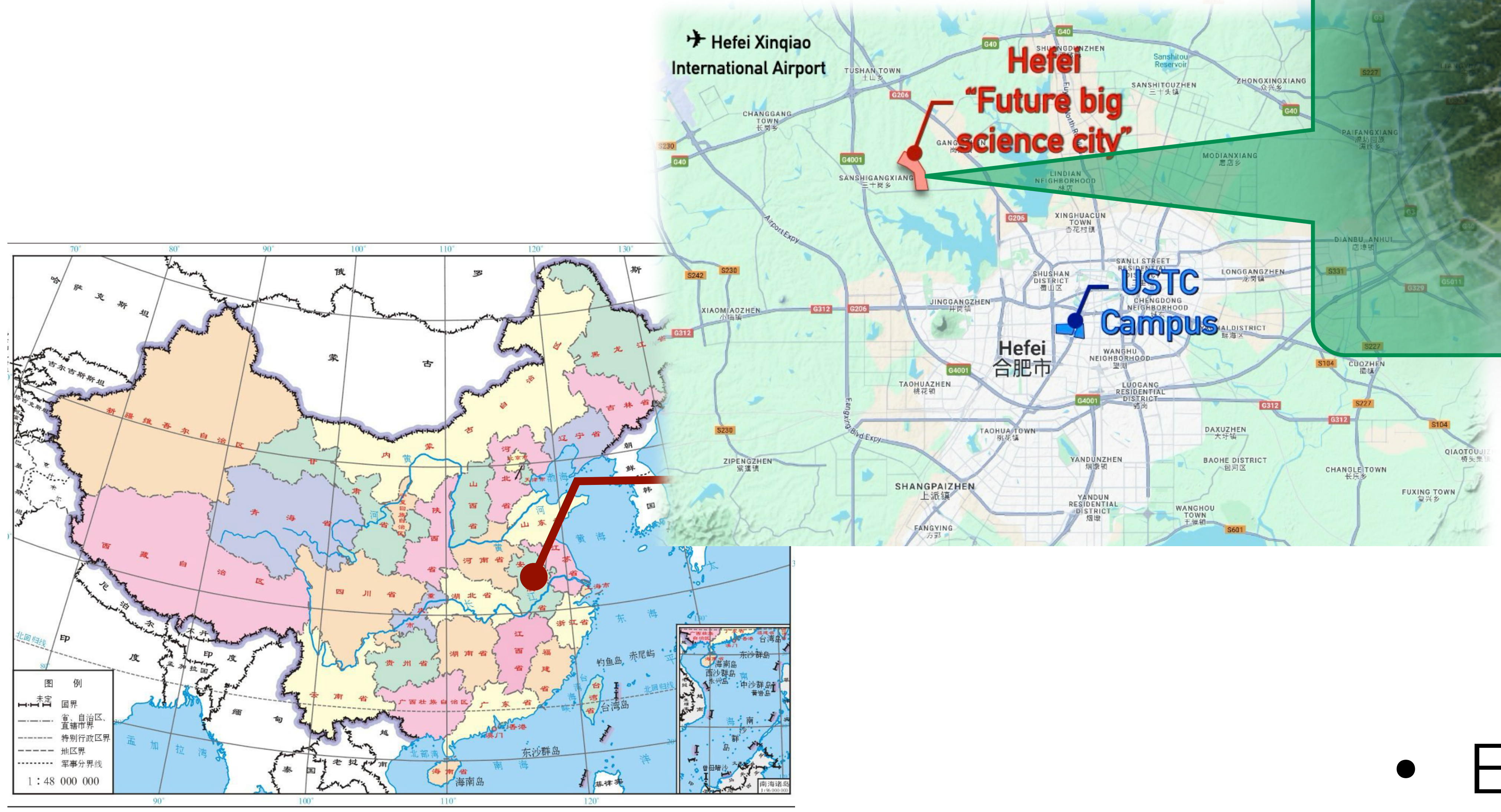
1st generation:
Single ring

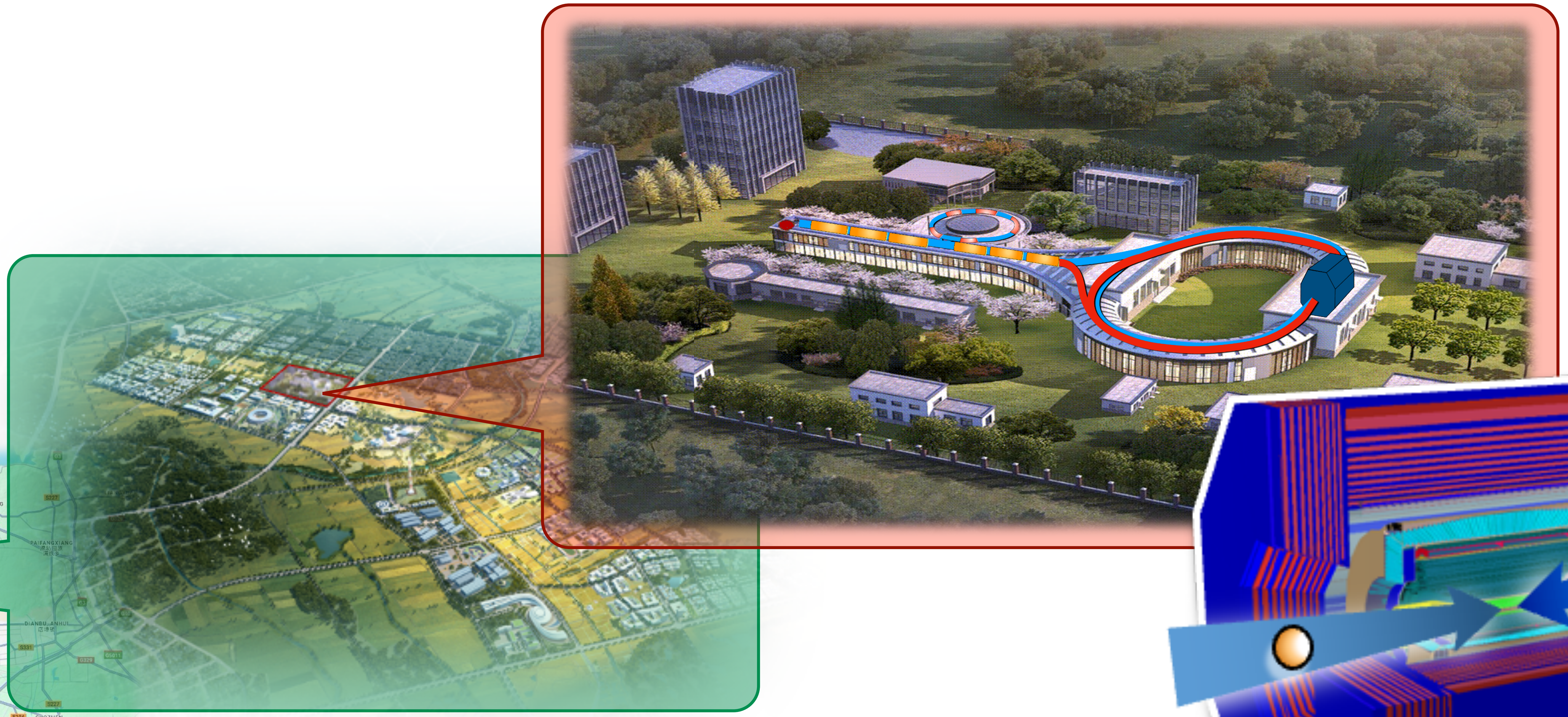
- Chinese proposal for 3rd generation **tau-charm factory** — **Super Tau-Charm Facility (STCF)**
  — a natural extension and a viable option for a post-BEPCII HEP project

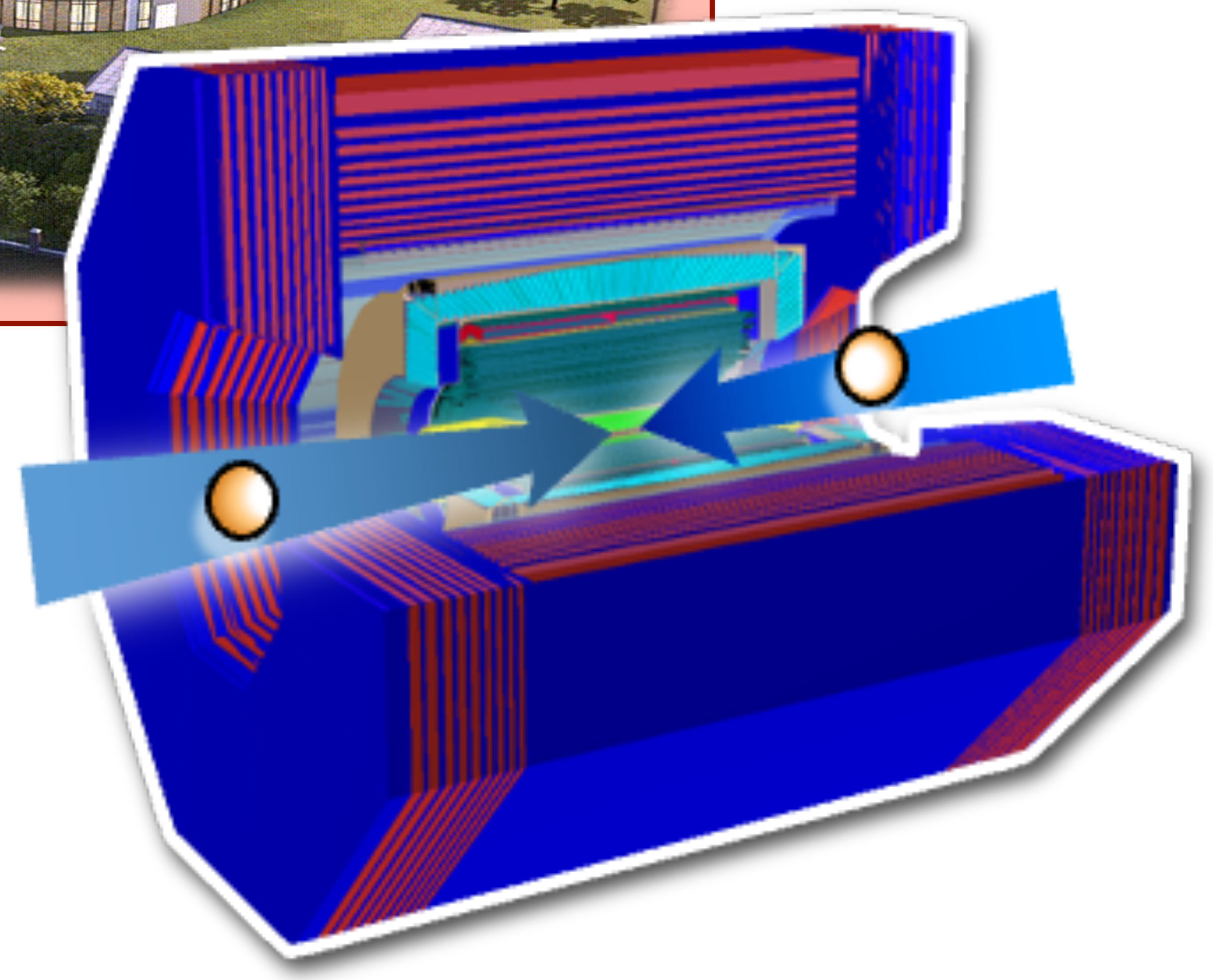
Super Tau-Charm Facility (STCF) in China

Site: "Future Big Science City"

Hefei, Anhui Province, China







- E_{cm}= **2 - 7 GeV**, L > **0.5 x 10^{35} cm^{-2} s^{-1}**
- Funded R&D: 0.4 Billion CNY funded by the Anhui government
- Construction budget: 4.5 Billion CNY

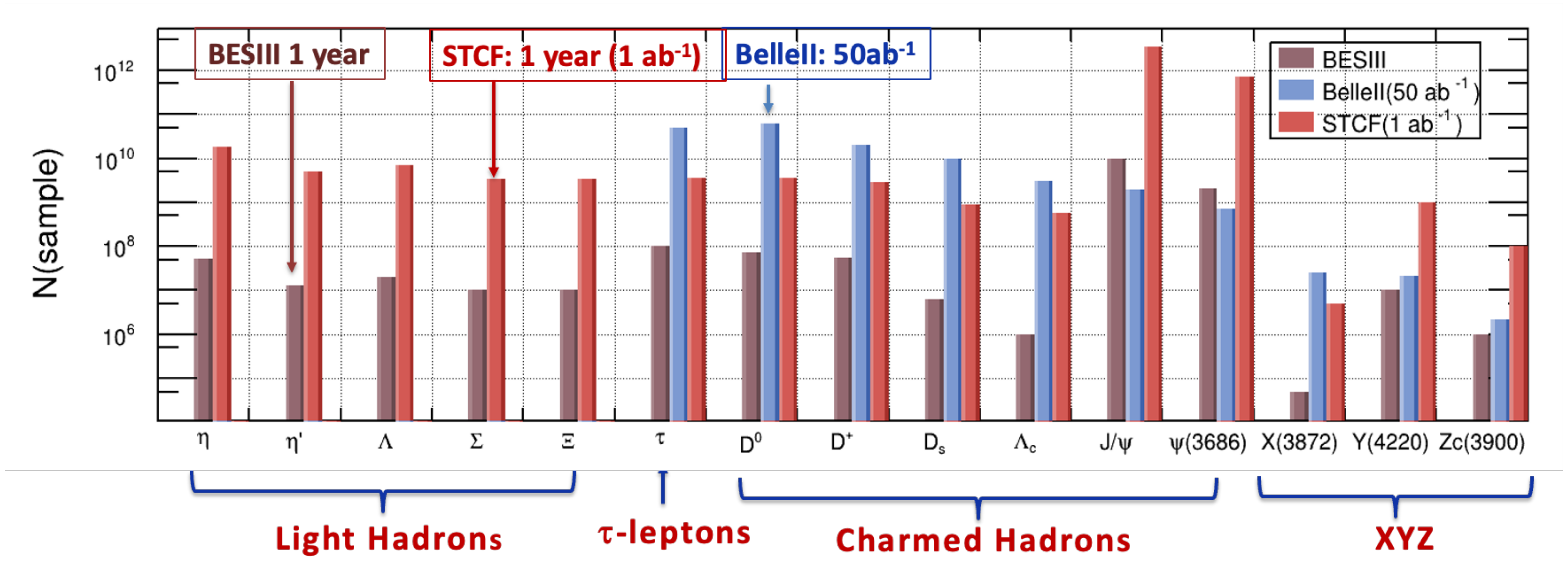
High Statistical Data Samples at STCF

Expected sample size per year

Table 1: The expected numbers of events per year at different STCF energy points.

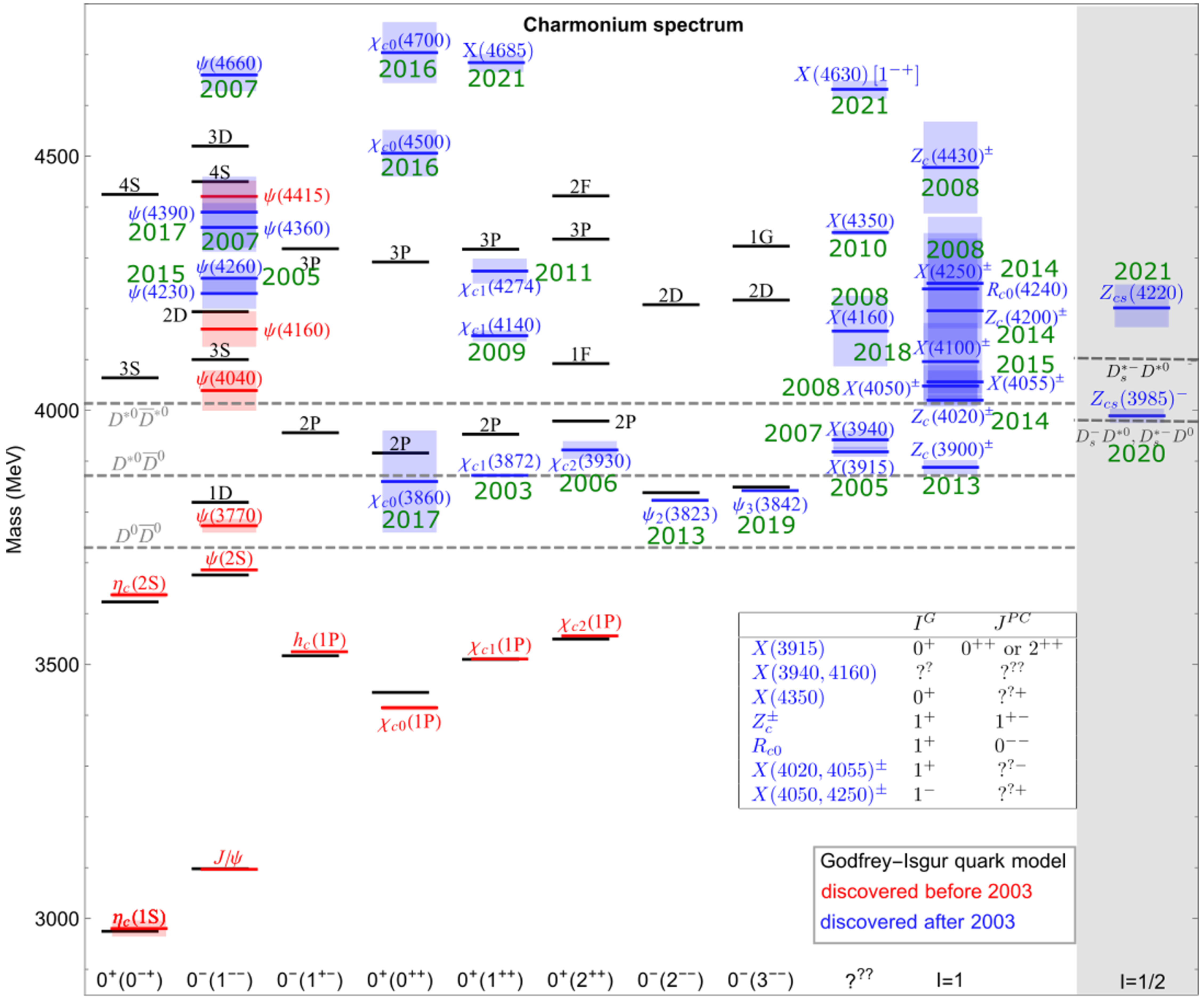
CME (GeV)	Lumi (ab^{-1})	samples	σ(nb)	No. of Events	remark
3.097	1	J/ψ	3400	3.4×10^{12}	
3.670	1	$\tau^+\tau^-$	2.4	2.4×10^{9}	
3.686	1	$\psi(3686)$	640	6.4×10^{11}	
		$\tau^+\tau^-$	2.5	2.5×10^{9}	
		$\psi(3686)\to\tau^+\tau^-$		2.0×10^{9}	
3.770	1	$D^0\bar{D}^0$	3.6	3.6×10^{9}	
		D^+D^-	2.8	2.8×10^{9}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

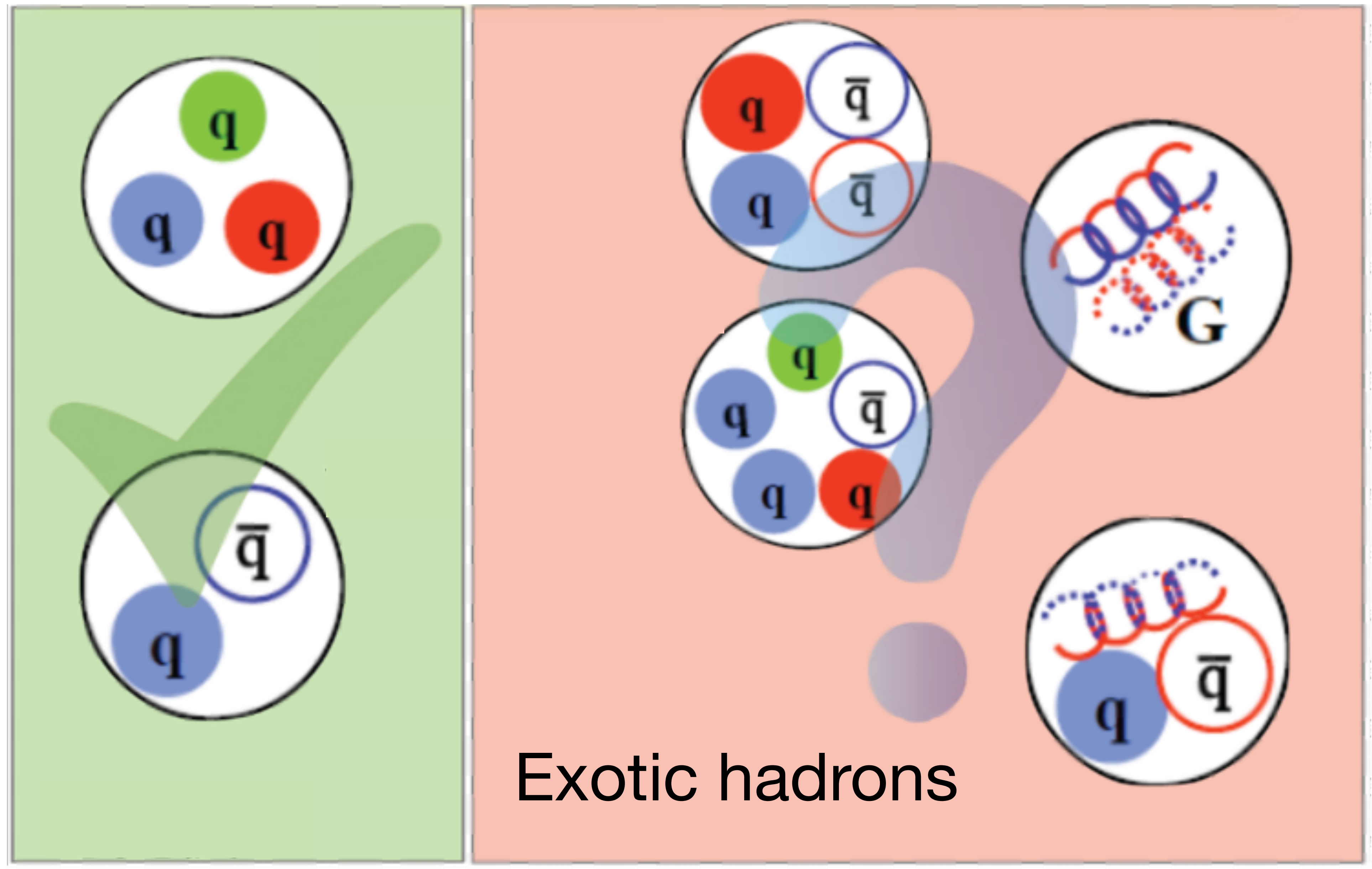
STCF (per year) vs. BEPCII (per year) vs. superKEKB (full)



- STCF is not only a tau-charm factory but also a super factory for XYZ particles, hyperons and light hadrons

Physics Opportunities: XYZ states





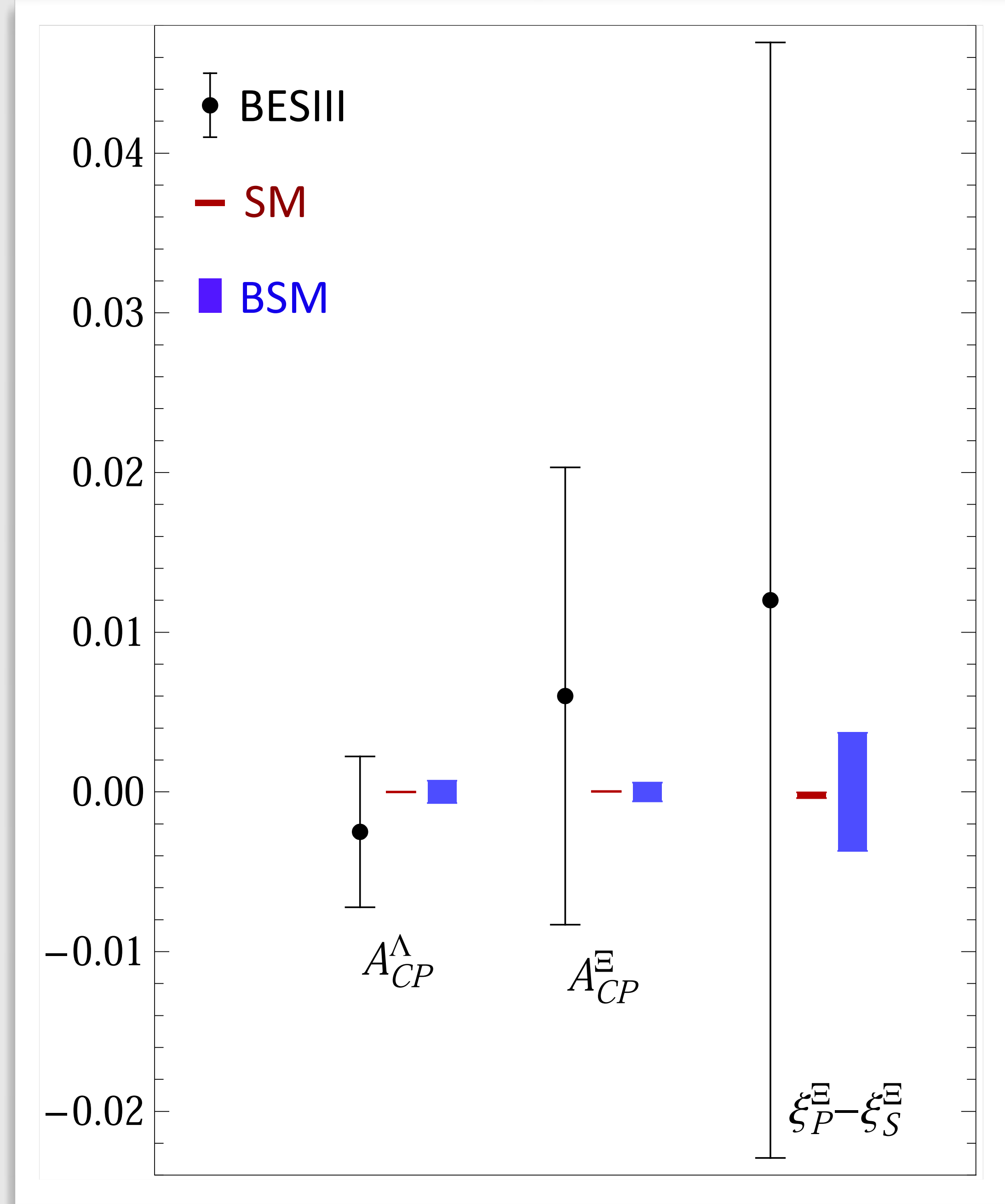
- QCD allows combinations of multi-quarks and gluons
- Spectrum above open charm is significantly overpopulated with exotic states
- STCF offers unique advantages for studying exotic hadrons and searching new ones (large luminosity and high efficiency)

Physics Opportunities: CP Violation

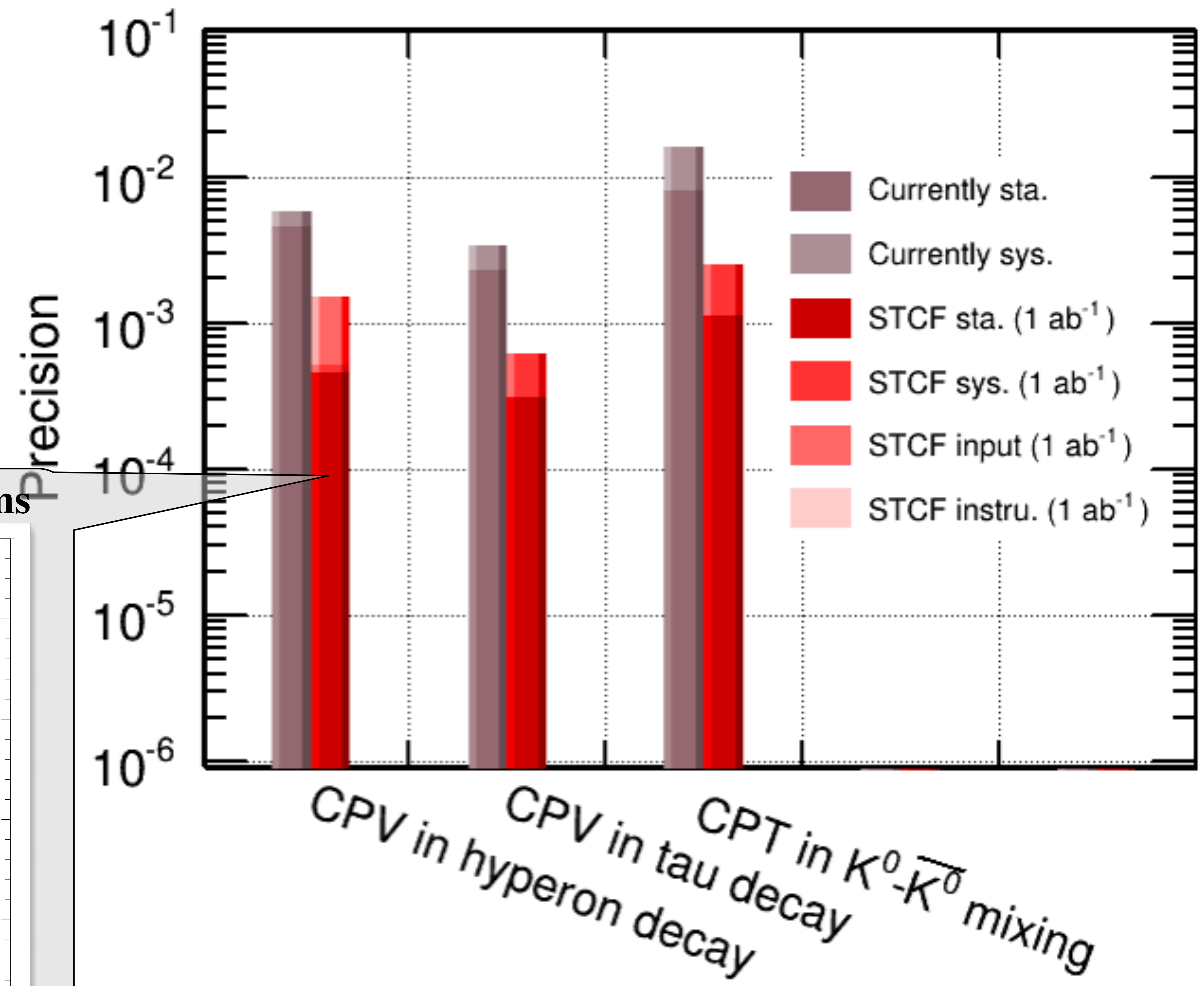
- CPV observed in K, B, D mesons, all are consistent with CKM theory in SM
- Baryon asymmetry of the Universe suggests the existence of non-SM CPV source(s)

- STCF is capable of searching for CPV in hyperon and τ, and CPTV in K with high sensitivity

Direct search for CPV in hyperons



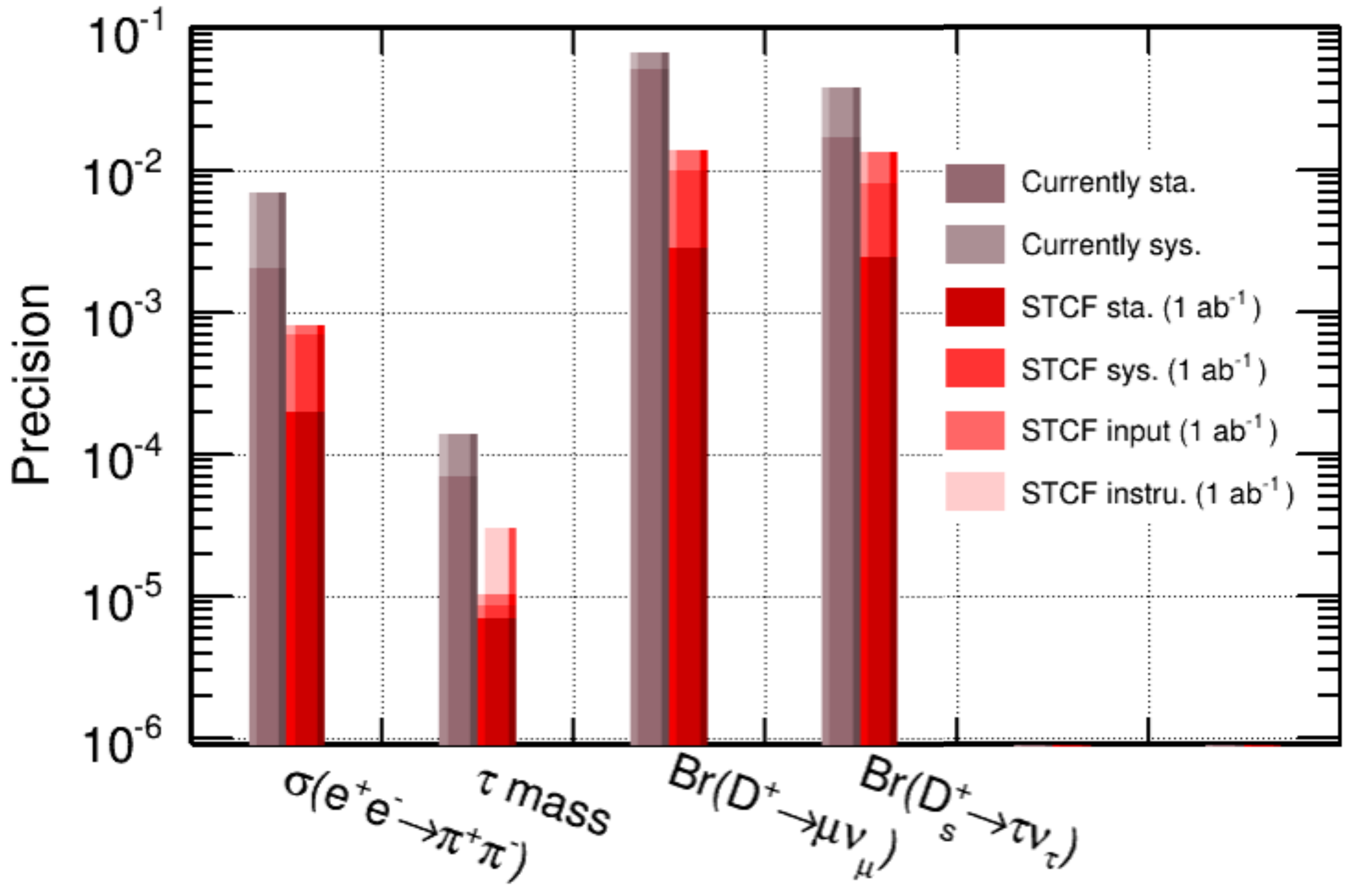
X.G. He et al. Sci. Bull. 67 (2022) 1840–1843

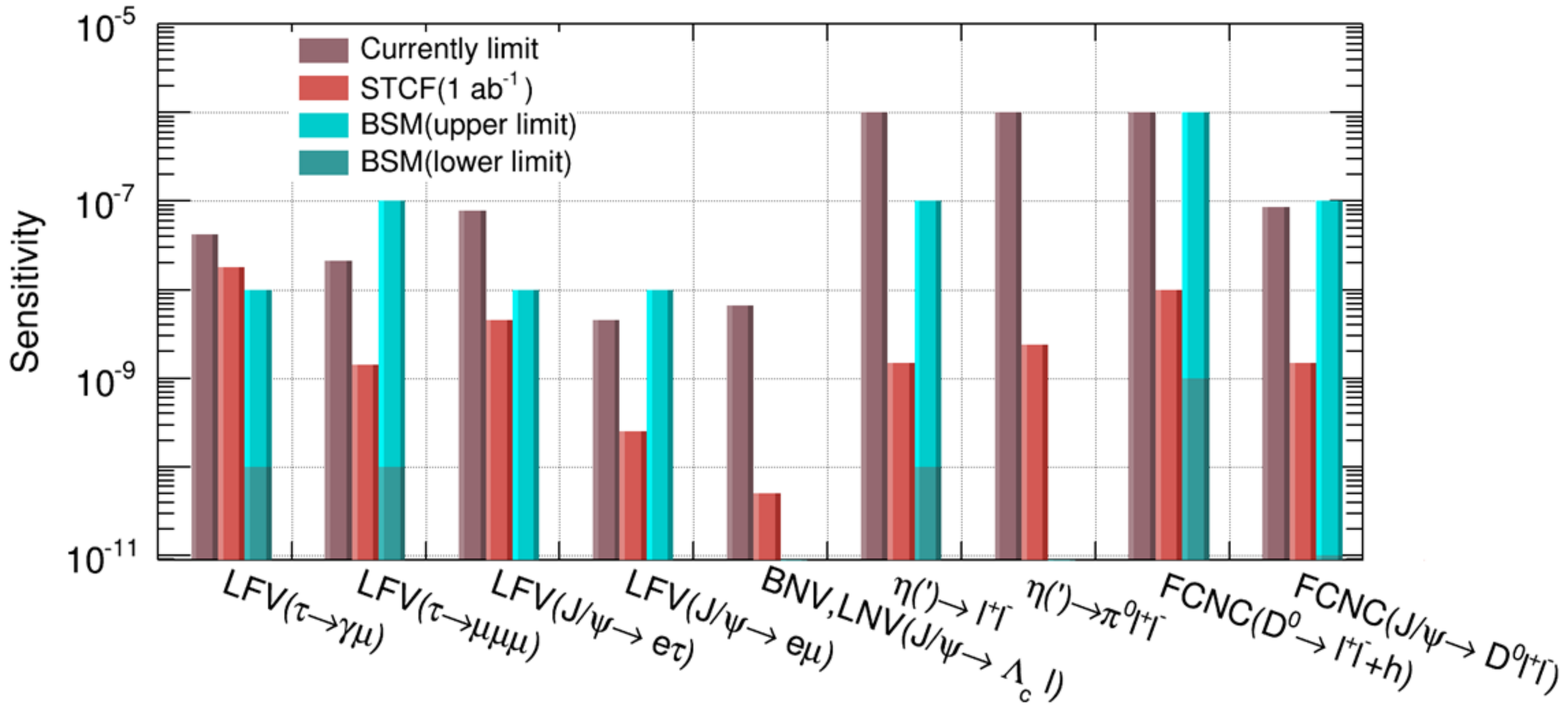


STCF: 10^{12} J/ψ → 10^{8} hyperons

Sensitivity comparable with SM predictions

Physics Opportunities: Precisions and Sensitivities



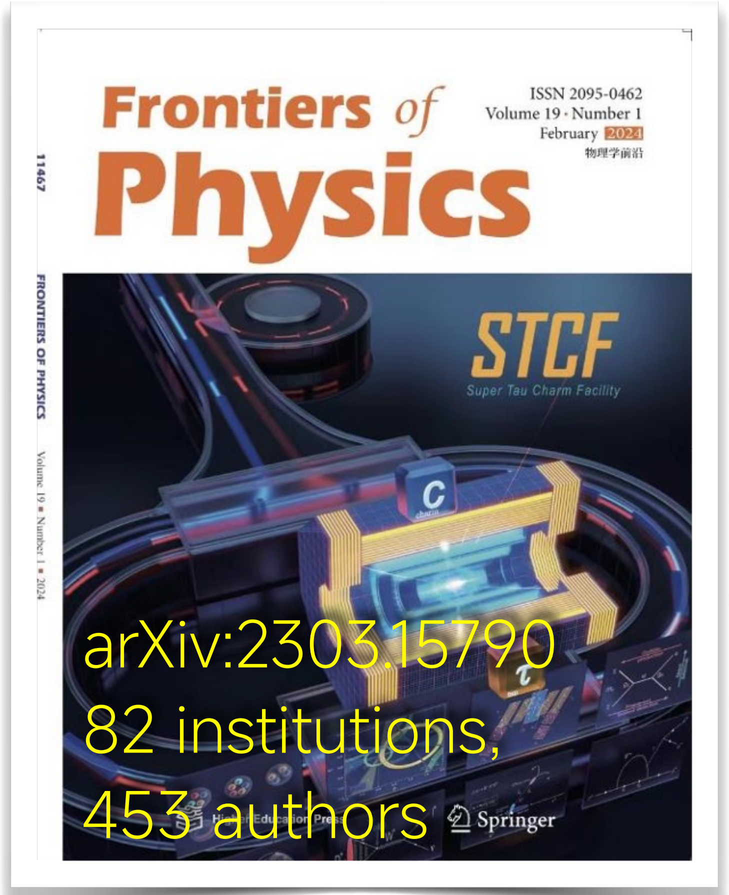


- STCF is expected to improve the current precisions of many important measurements by ~1 order of magnitude and enhance sensitivities to various rare or forbidden decays by ~2 orders of magnitude.

Physics Opportunities: Beyond What I Can Cover Here

- Nuclear EM form factors
- Fragmentation functions
- And more …

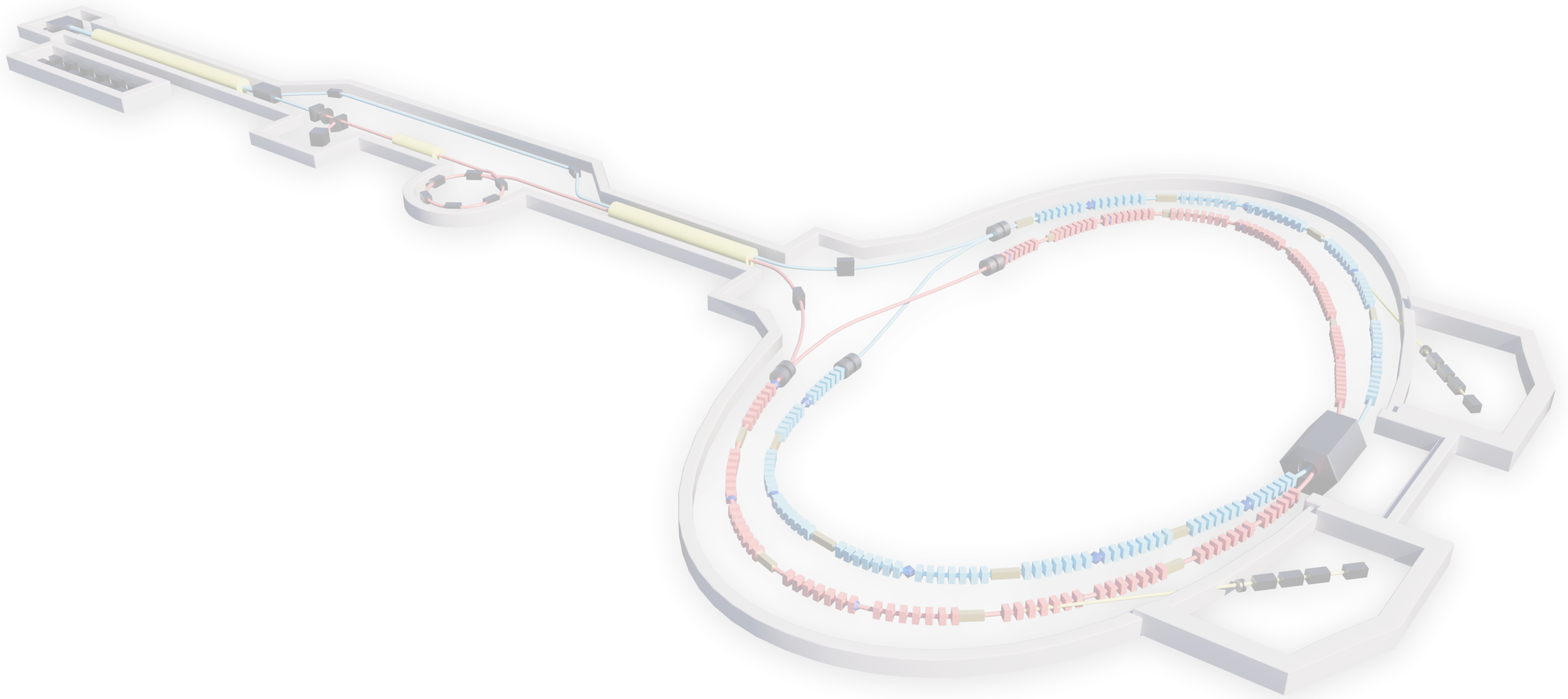
CP in charmed baryon
Near-threshold resonance
EMFFs
Triangle singularity
Tau EDM
D_s^* radiative decay
Hyperon-Nucleus Scattering
FCNC
Light-cone distribution amplitudes
Millicharged particles
K0-K0bar
Neutral meson mixing
Spin 3/2 polarization
QCD sum rules
Muon g-2 and $\alpha(M_Z^2)$
$\Lambda - \bar{\Lambda}$ oscillation
Axion-like particle
cLFV
Fully charm tetraquarks
$SU(2)_L$-singlet vector-like fermion partners
$\Delta S = 2$ Nonleptonic hyperon decay
Hyperon EDM
X(4014)
Proton charge radius
Coupled-channel effect
$a_0(1710)$
Invisible decay of J/psi



Key words / main topics of STCF physics CDR citations

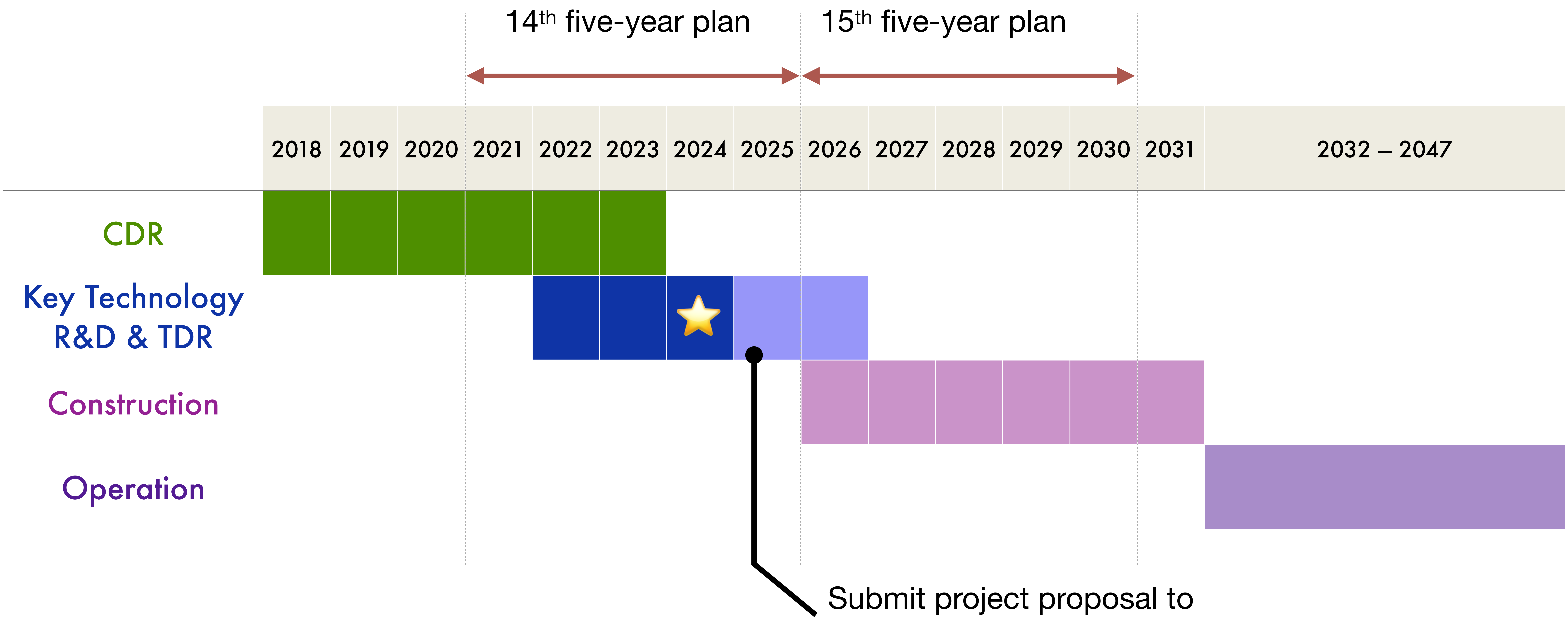
Status of STCF project

with a focus on progress since last FPCP



FPCP2023 STCF report

Tentative Project Schedule for STCF



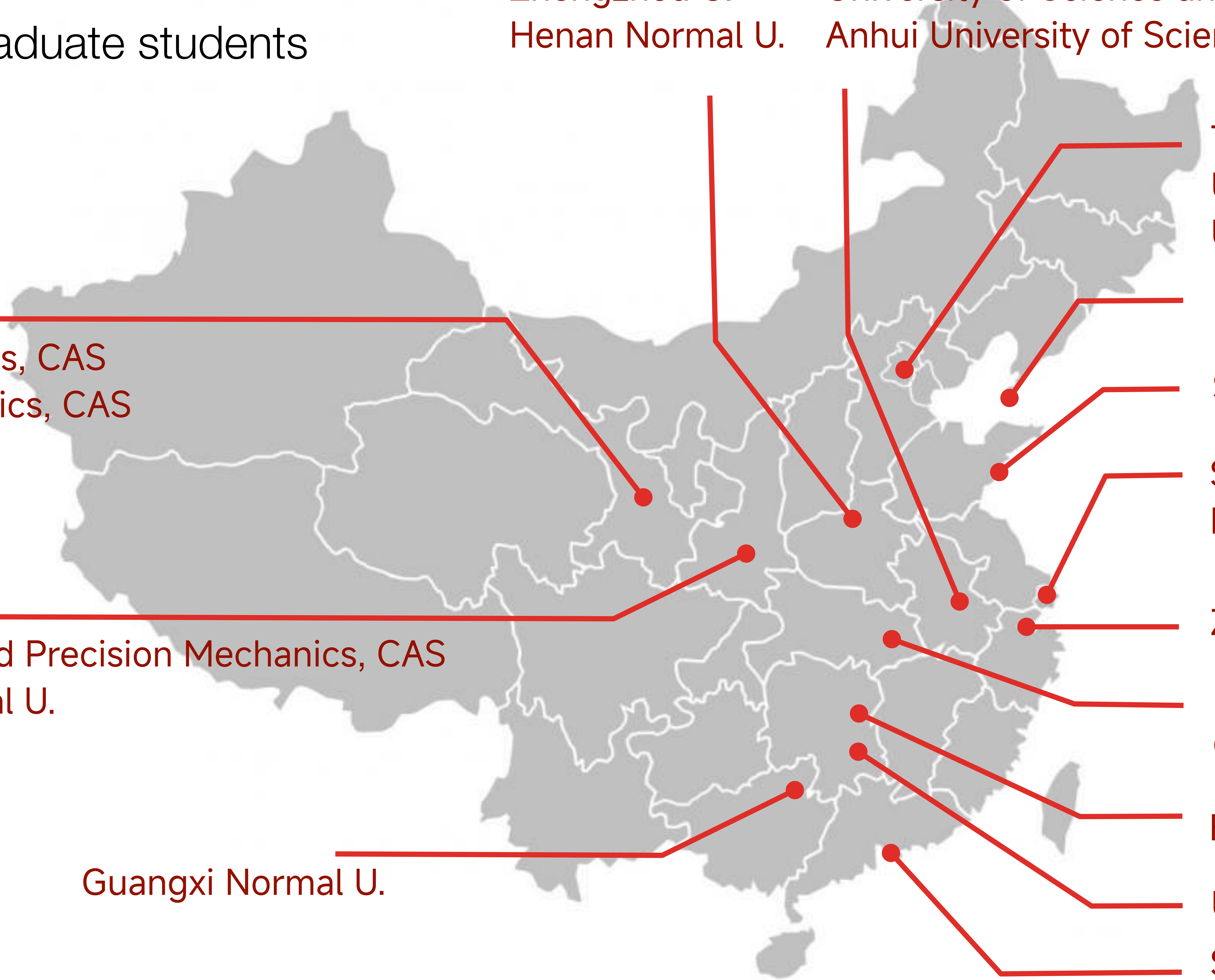
Submit project proposal to central government:

Science, budget, feasibility and contribution to society

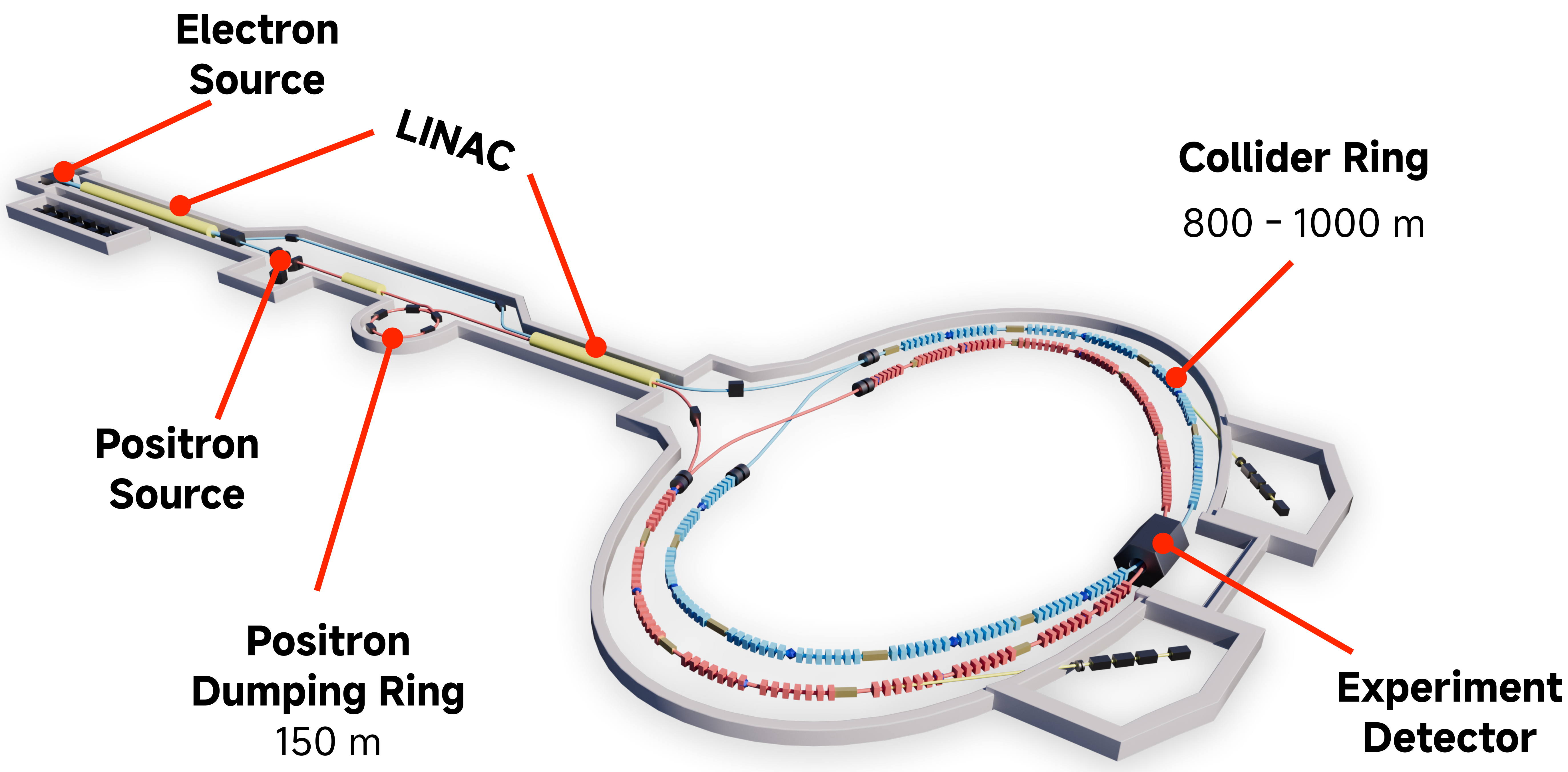
Key Technology R&D — Research Team

More than 20 universities/Institutes:

170 faculties and 140 graduate students

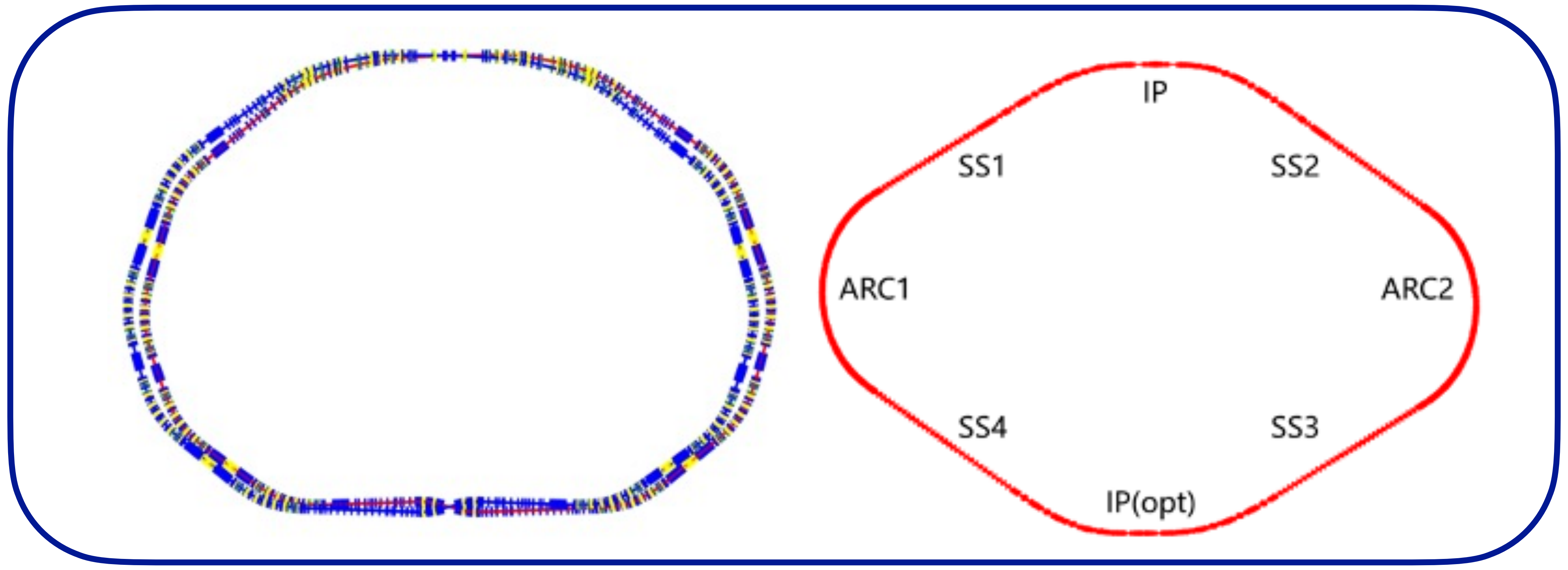


STCF Accelerator Design

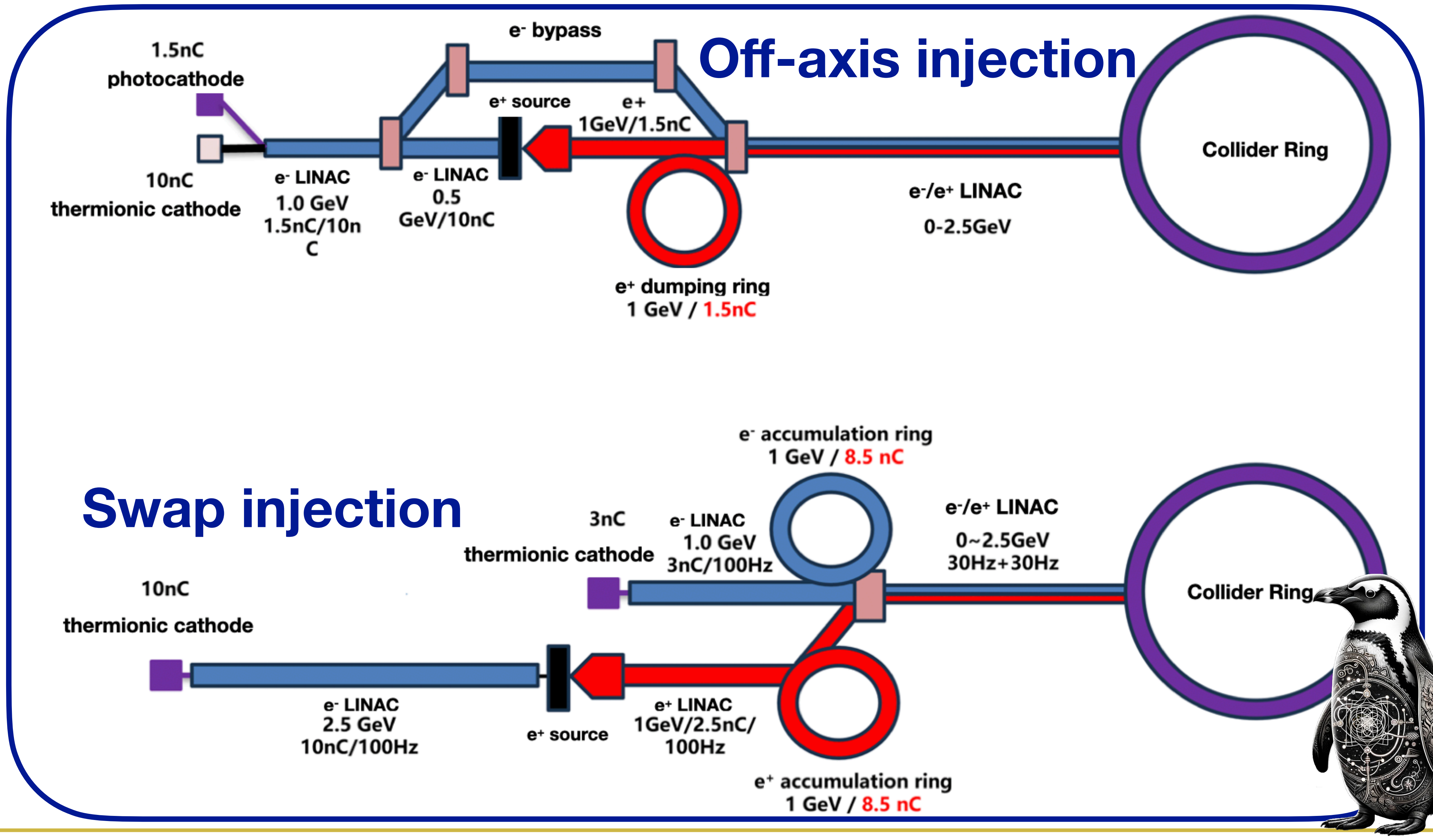


STCF schematic layout

Two collider ring lattice designs



Two injector designs



STCF Accelerator R&D — Machine Parameters

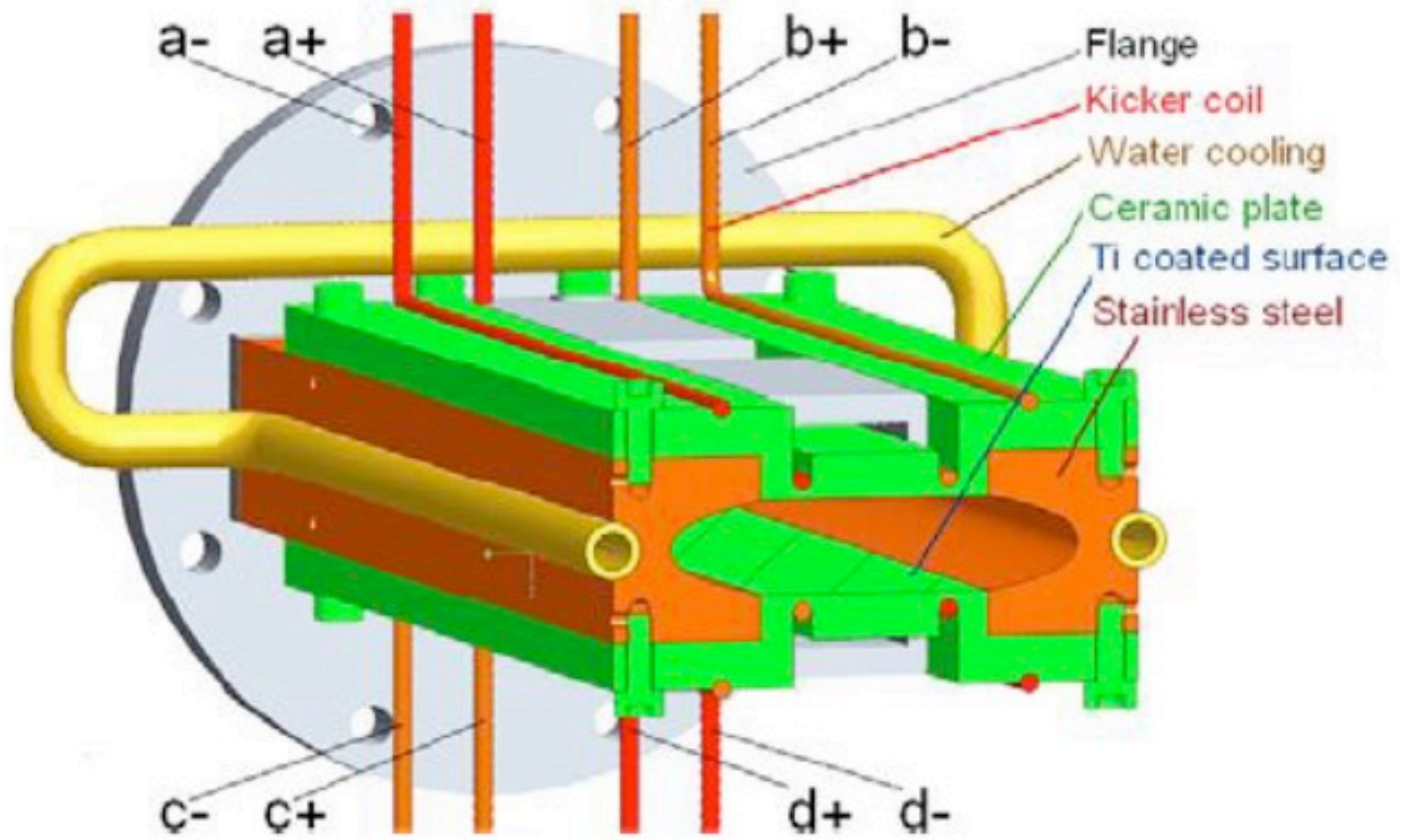
		Tau-Charm Factory		B Factory		Z Factory	
Parameters	Units	BINP-SCTF (2018)	**STCF (April. 2024)**	SuperKEKB LER(e+)	SuperKEKB HER(e-)	FCC-ee Z	CEPC Z (2022)
Optimal beam energy, ***E***	GeV	2	**2**	4	7.007	45.6	45.5
Circumference, ***C***	m	813.1	**848.4**	3016.3	3016.3	97756	100000
Crossing angle, ***2q***	mrad	60	**60**	83	83	30	33
Horizontal emittance, e_x	nm	8	**6.919**	3.2	4.6	0.27	0.27
Coupling, ***k***		0.50%	**0.50%**	0.27%	0.25%	0.37%	0.52%
Vertical emittance, e_y	pm	40	**34.595**	8.64	11.5	1.00	1.40
Ver. beta function at IP, β_y	mm	0.8	**0.6**	0.27	0.3	0.8	0.9
Ver. beam size at IP, s_y	mm	0.179	**0.144**	0.048	0.059	0.028	0.035
Beam current, ***I***	A	1.7	**2**	3.6	2.6	1.39	1.3392
Single-bunch charge	nC	11.36	**8.04**	14.49	10.46	27.24	22.43
SR power per beam, P_{SR}	MW	0.6137	**0.572**	6.732	6.37	50.04	49.5504
Bunch length, s_z	mm	10.00	**8.43**	6.00	5.00	12.12	8.70
Ver. beam-beam parameter, ξ_y		0.121	**0.094**	0.083	0.074	0.133	0.125
Luminosity, ***L***	10^{35} cm^{-2} s^{-1}	1.01	**1.19**	8.4	8.6	21.5	17.6

Preliminary machine parameters

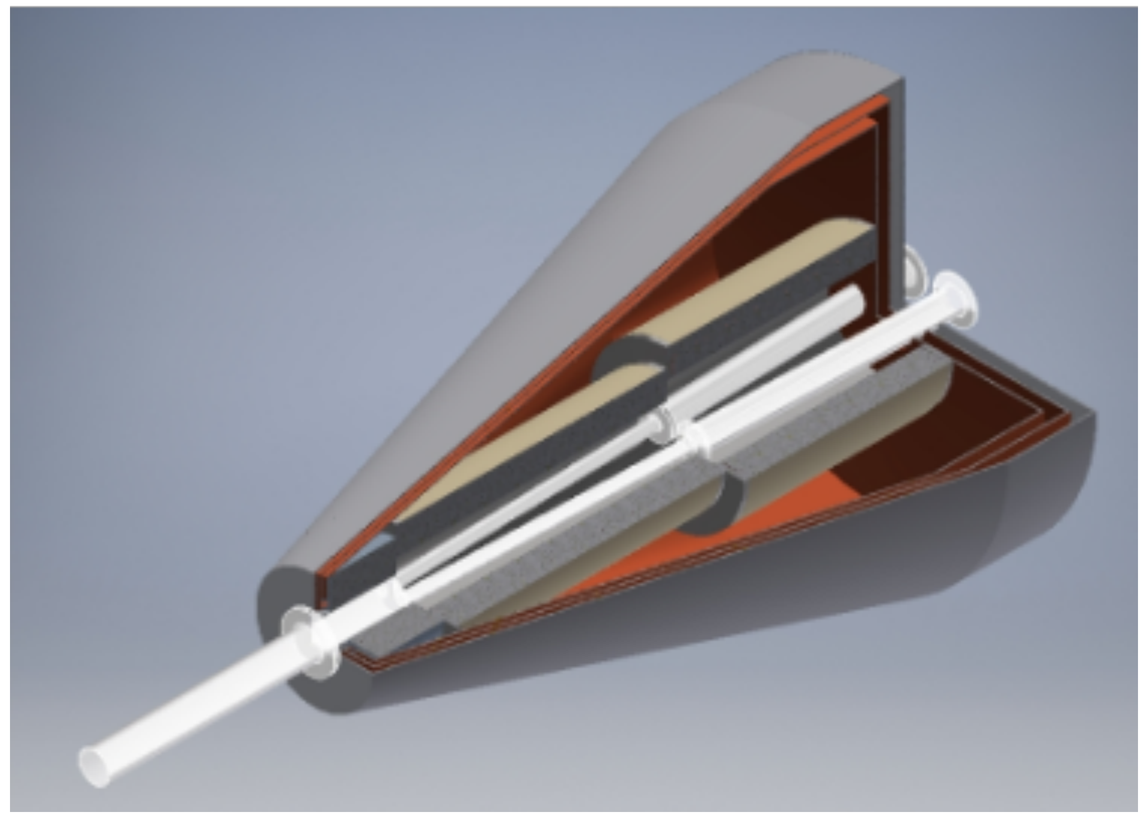
- Preliminary lattice for 850 m
- Simulated luminosity: 1.2 x 10^{35} cm^{-2} s^{-1}

STCF Accelerator R&D — Hardware

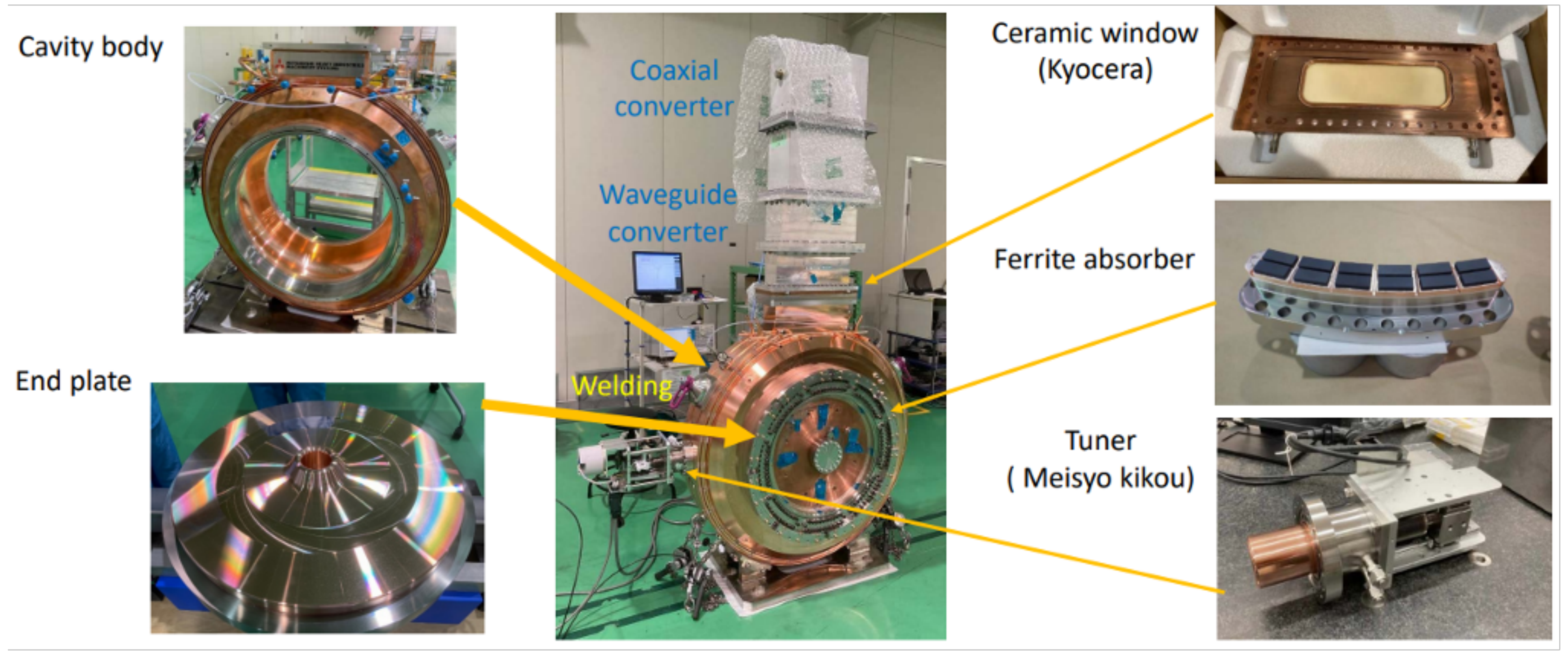
- **Collider Ring RF cavity:** Compared RT and SC cavities, now prefer RT cavity TM020 by Spring-8 (J-PAC), building prototype
- **IR SC magnet:** Comparing DCT, CCT and cos2θ, prototype to be built
- **Injector kicker:** High-rep (50 Hz), super fast kicker (bottom < 4 ns)
- …



Multi-wire nonlinear kicker



BINP/SCTF IR SC magnet prototype

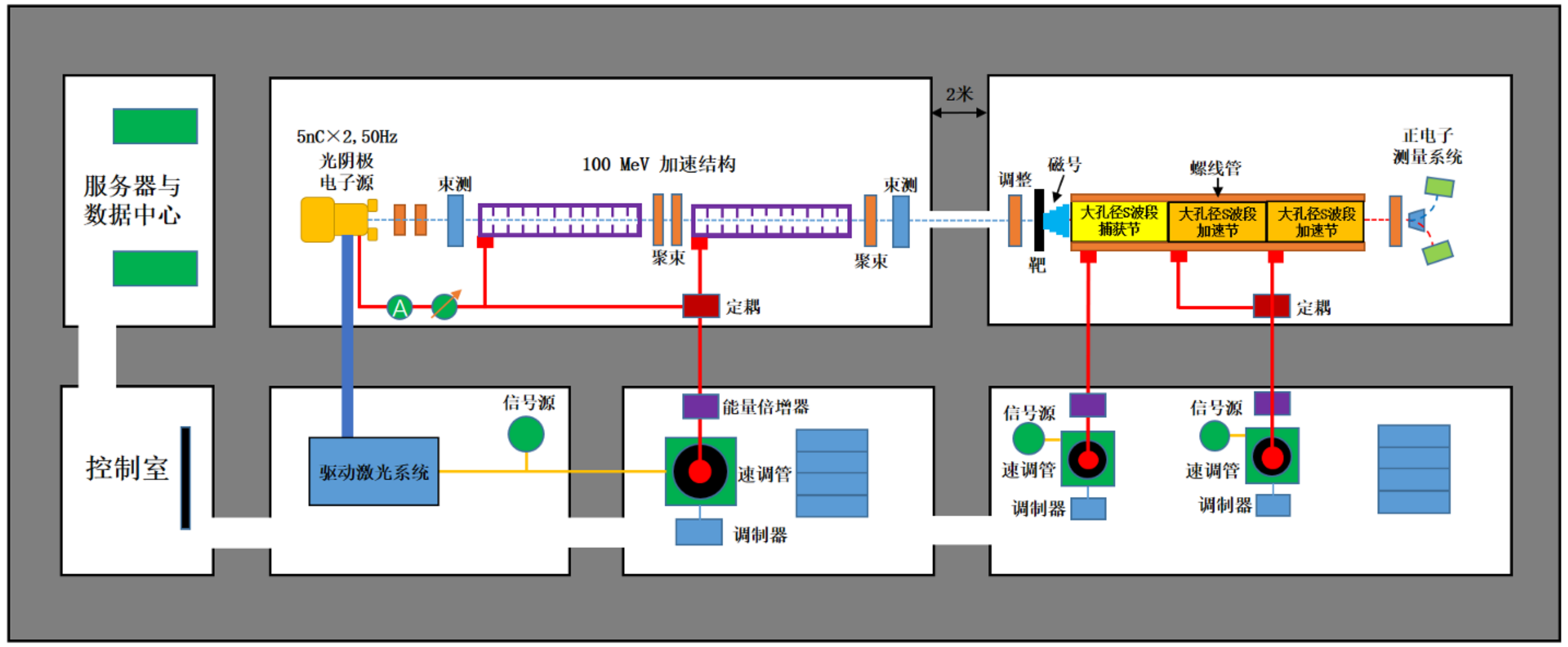


Spring-8 TH020 RT RF Cavity

STCF Accelerator R&D — Team and Plan

- Accelerator division established in 2023 receiving strong backing from the National Synchrotron Radiation Lab (NSRL)
- Manpower: ~ 90 persons, with 50% students, and continue to expand
- Pre-CDR to be released by the end of 2024, CDR by 2025

STCF test facility



NSRL-led STCF e^+ and e^- test facility construction

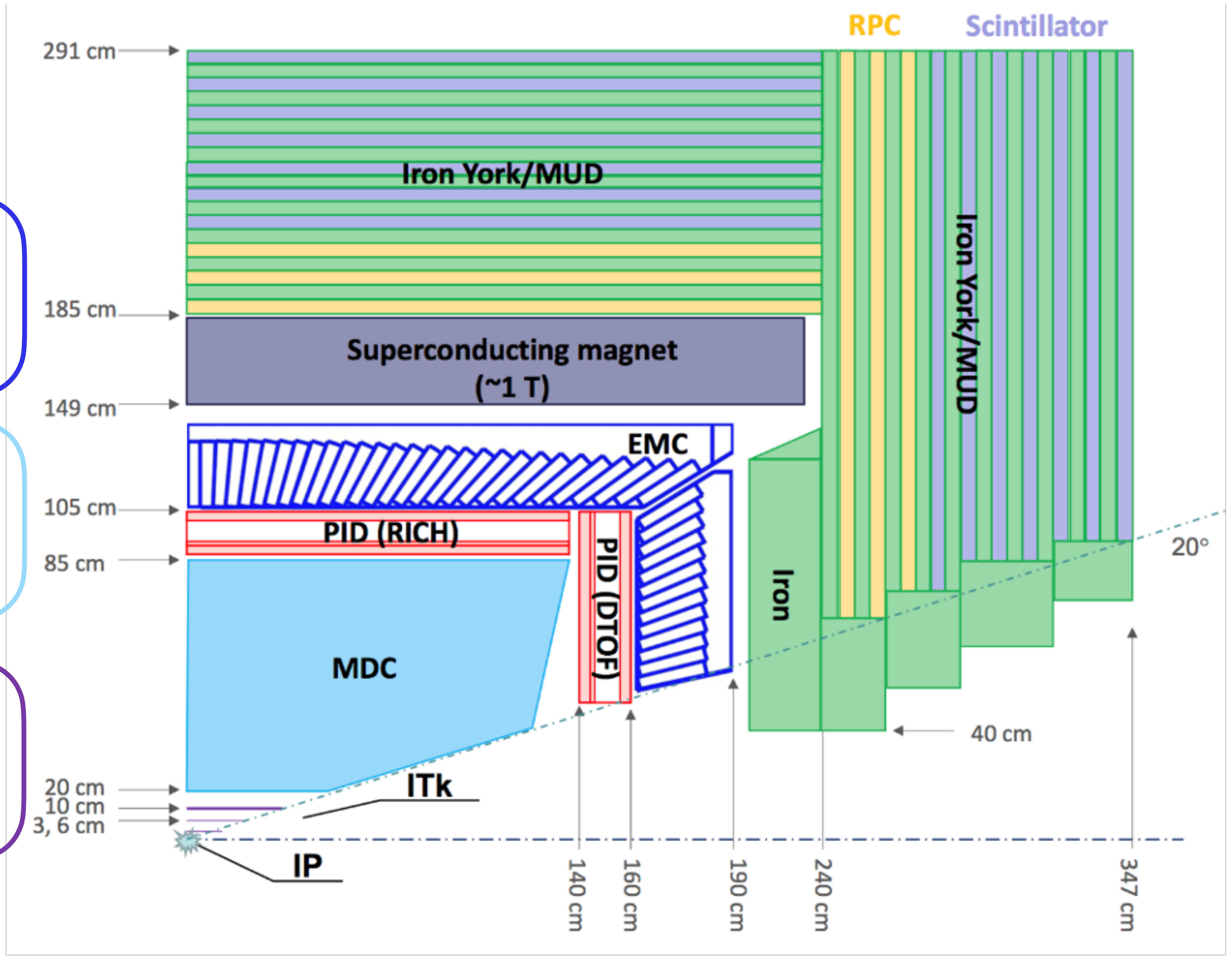
- Located in HALF site
- Begin operations in 2026
- Feature ~100 MeV e^- and e^+ beams

STCF Detector Design

EMCal (EMC)
- Pure Cesium iodide (CsI) + APD

Main tracker (MDC)
- Drift chamber

Inner tracker (ITk)
- OPT1: MPGD: cylindrical MPGD
- OPT2: Silicon: CMOS MAPS

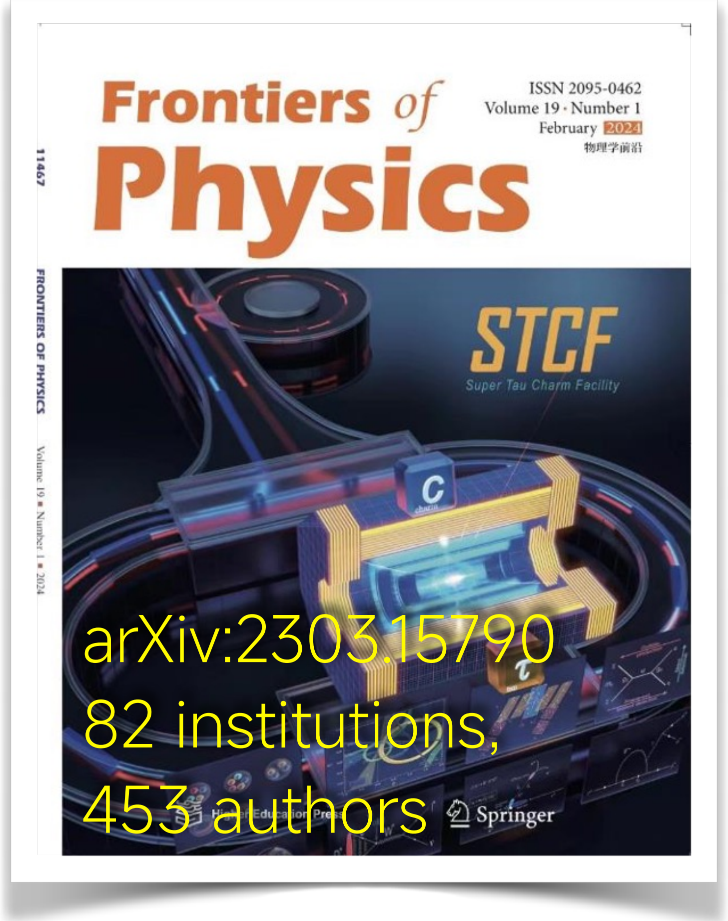


STCF detector cross-section

Muon detector (MUD)
- RPC + scintillator strips

SC Magnet
- Superconducting solenoid ~ 1T

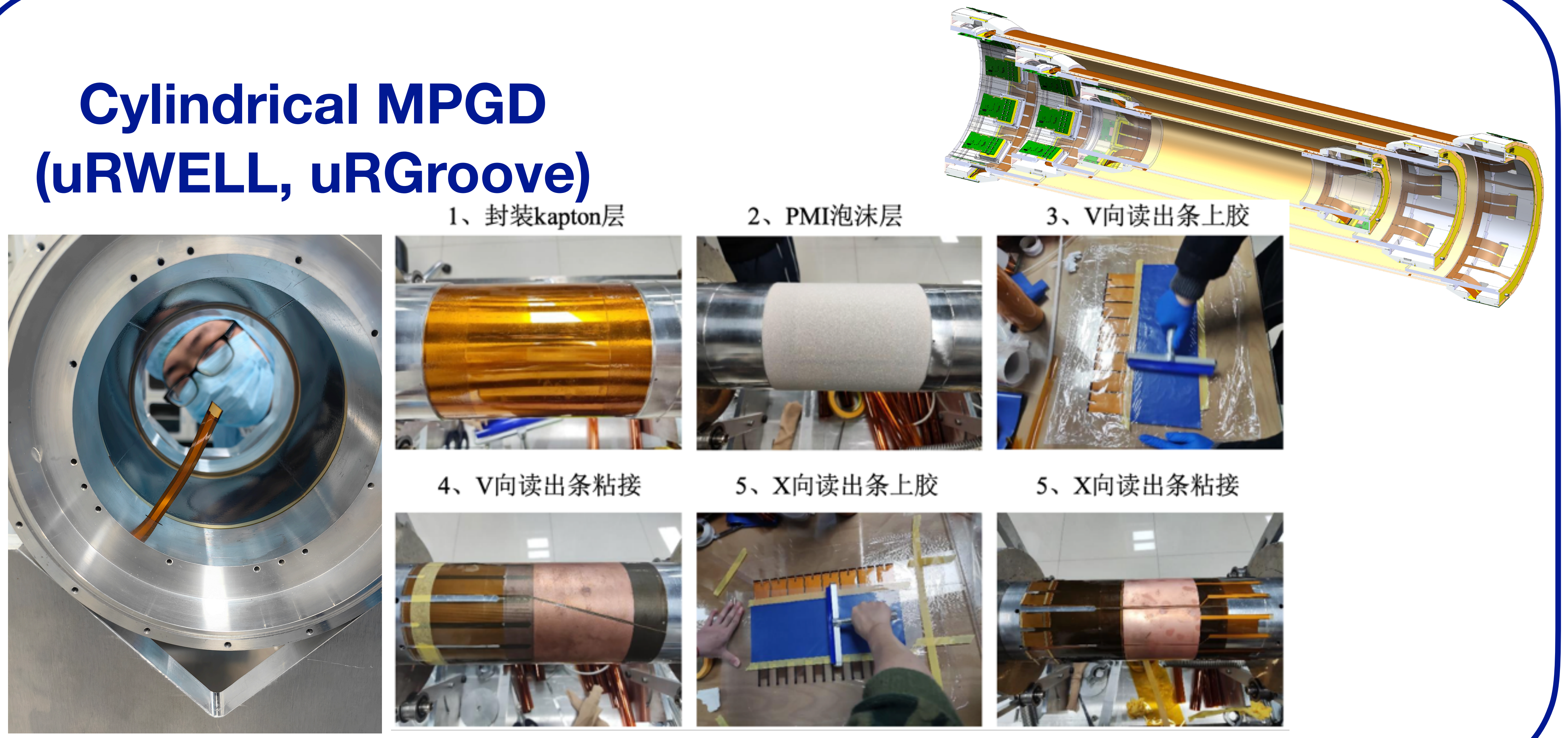
PID
- Barrel: **RICH** with CsI-MPGD
- Endcap: DIRC-like TOF (**DTOF**)



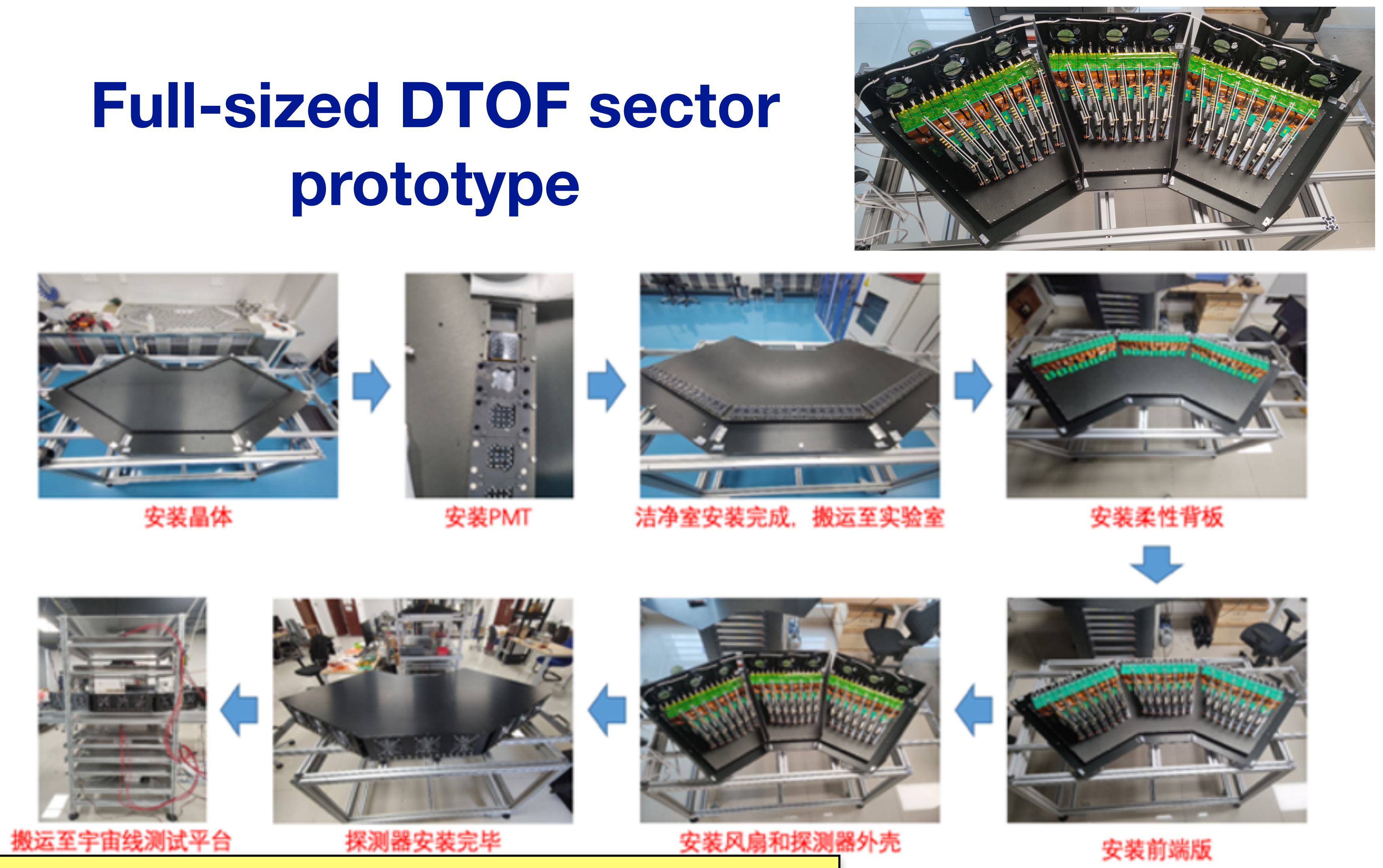
- Highly efficient and precise reconstruction of exclusive final states
- Precise measurement of low-p particles (< 1 GeV/c)
- Outstanding PID: π/K and μ/π separation up to 2 GeV

STCF Detector R&D — Detector Prototypes

Cylindrical MPGD (uRWELL, uRGroove)

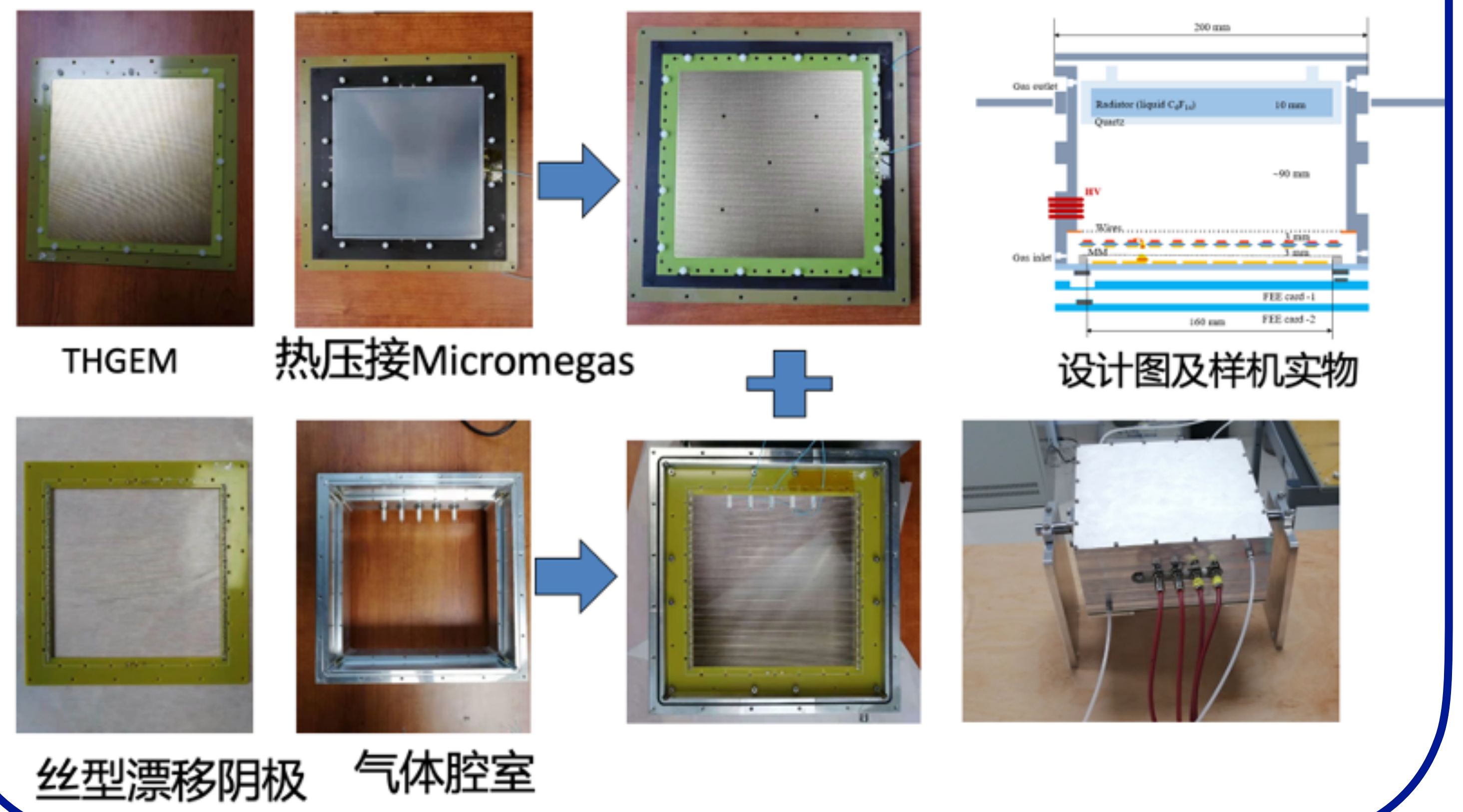


Full-sized DTOF sector prototype

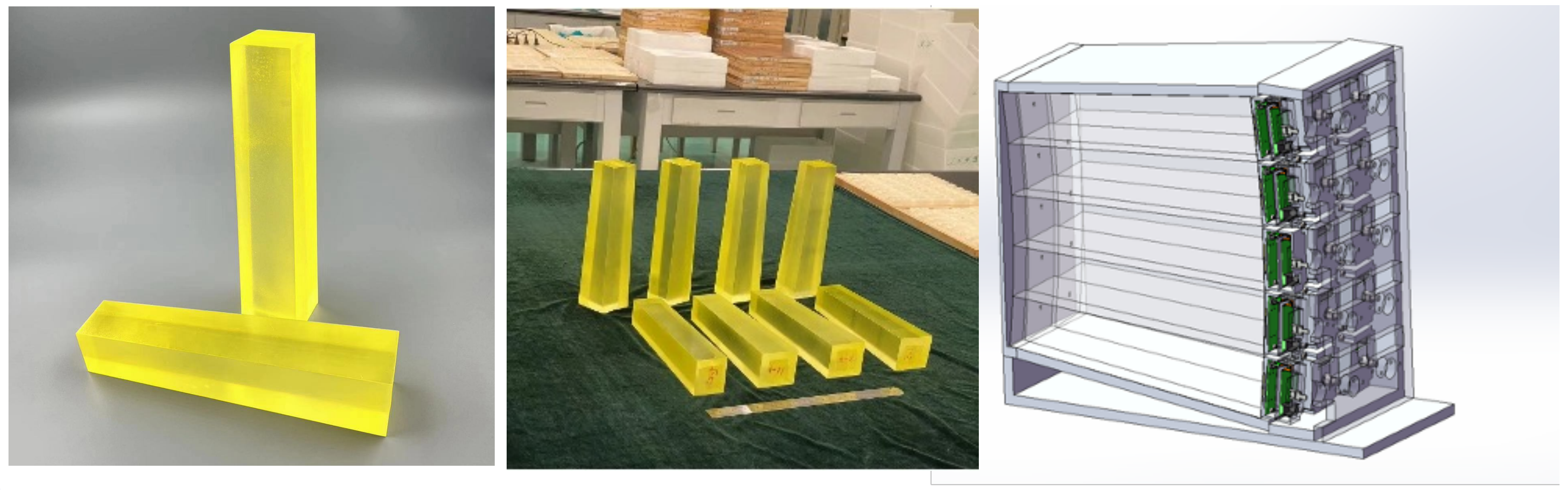


ECal, RICH, DTOF and DAQ beam test scheduled at CERN

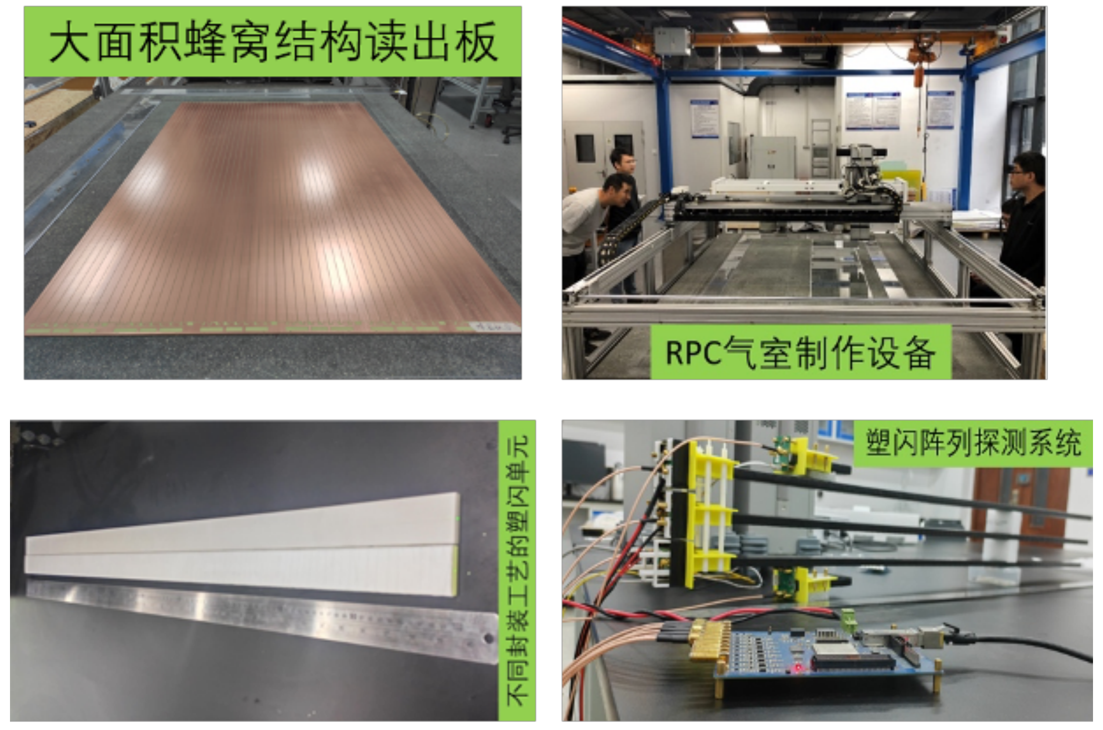
30 cm × 30 cm RICH prototype



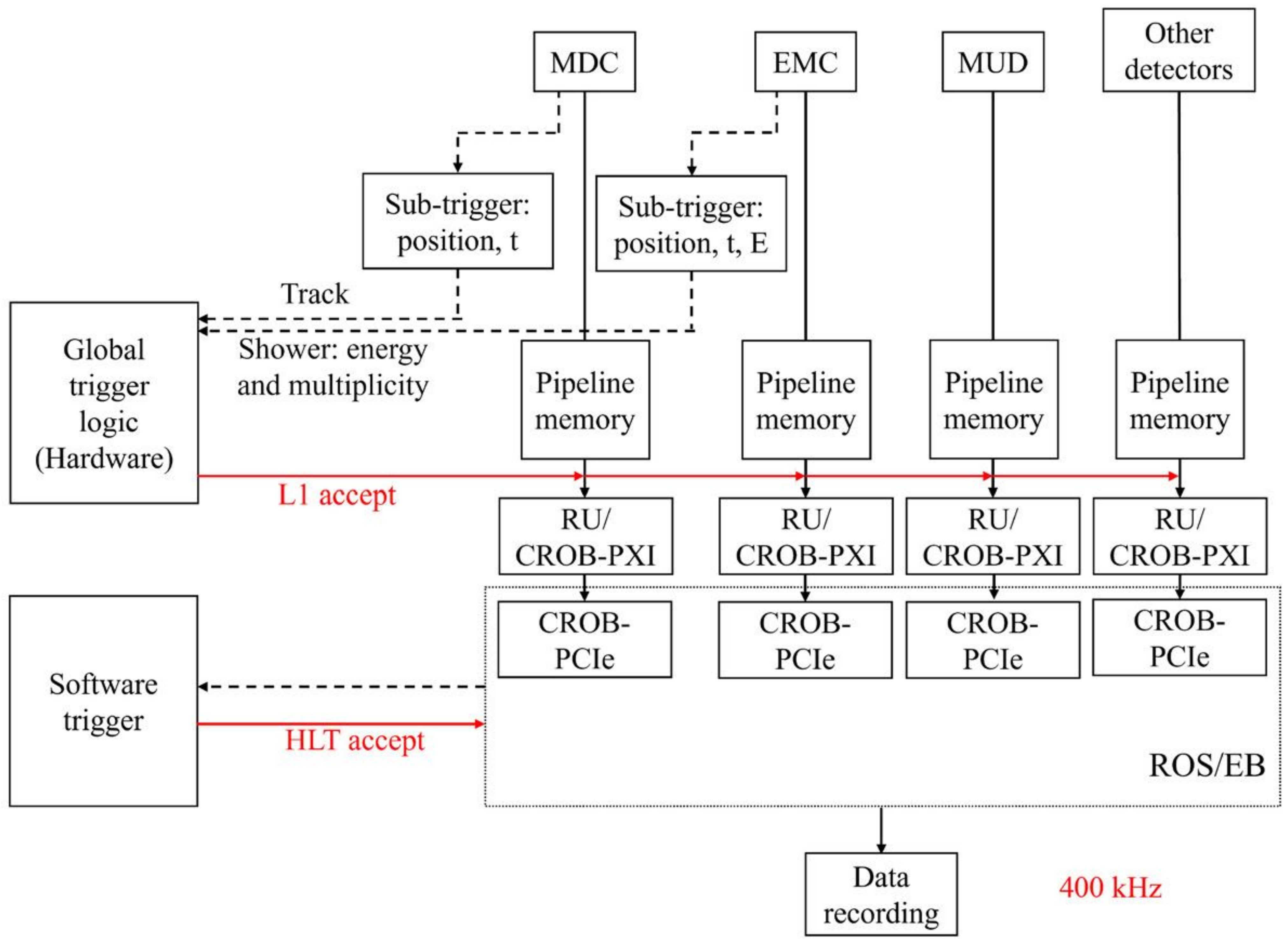
pCsI ECAL



Large sized RPC and scintillator strips

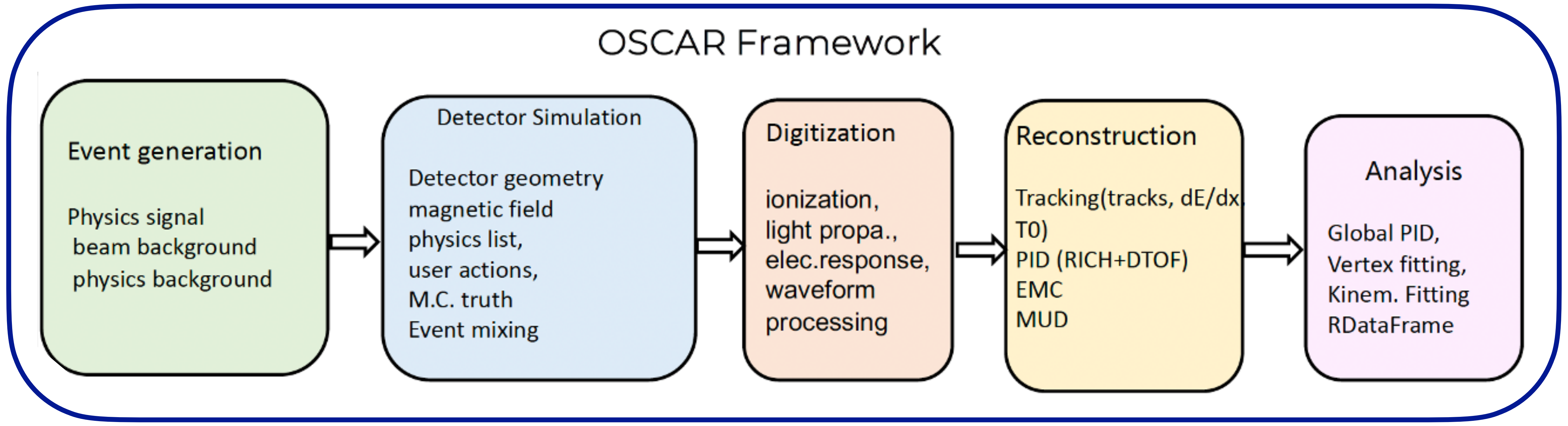


STCF Detector R&D — Trigger, DAQ and Software



Schematic STCF trigger systems

- STCF experiment core software: OSCAR
- Developed using the light-weight and flexible SNiPER framework and adopted some state-of-the-art technologies
- Full chain of STCF detector data processing is established



- Peak Lumi: event rate ~ 400 kHz, Raw data bandwidth > 200 GB/s
- Hardware trigger + software trigger
- Triggered data bandwidth ~ 30 GB/s

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)

STCF workshop 2022, online

STCF workshop 2023, Zhengzhou

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

STCF 1st IAC meeting (Hefei, 2024)

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 National Consultative Committee Meeting

International Future Tau-Charm Facility Workshops

Time	Place	Content
2015.01	Hefei, China	International Workshop focused on Super tau-Charm Facility in China
2018.03	Beijing, China	International Workshop focused on Super tau-Charm Facility in China
2018.05	Novosibirsk, Russia	International Workshop focused on Super tau-Charm Facility in Russia
2018.12	Paris, France	1^{st} FTCF (Joint International Workshop)
2019.08	Moscow, Russia	2^{nd} FTCF
2020.11	Online, China	3^{rd} FTCF
2021.11	Online, Russia	4^{th} FTCF
2024.01	Hefei, China	5^{th} FTCF


FTCF2024-Guangzhou

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

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

Summary

- STCF is a viable medium-term HEP project in China with excellent value-to-cost ratio and great physics potential for breakthroughs
- The STCF project is in the R&D stage with strong backing from local governments
- Aiming to submit a proposal to the central government in 2025 for inclusion in the 15th five-year plan (2026-2030)
- Expanding international collaboration and exploring synergies with other projects is crucial. We are open to all forms of collaboration

Thank you ขอบคุณ

Backup Slides

STCF Project Development

Super Charm-tau Factory

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

2011

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

2015

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

2017

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

2018

Conceptual Design report
Publish the CDR for the physics and Detector, formulate the preliminary CDR for accelerator

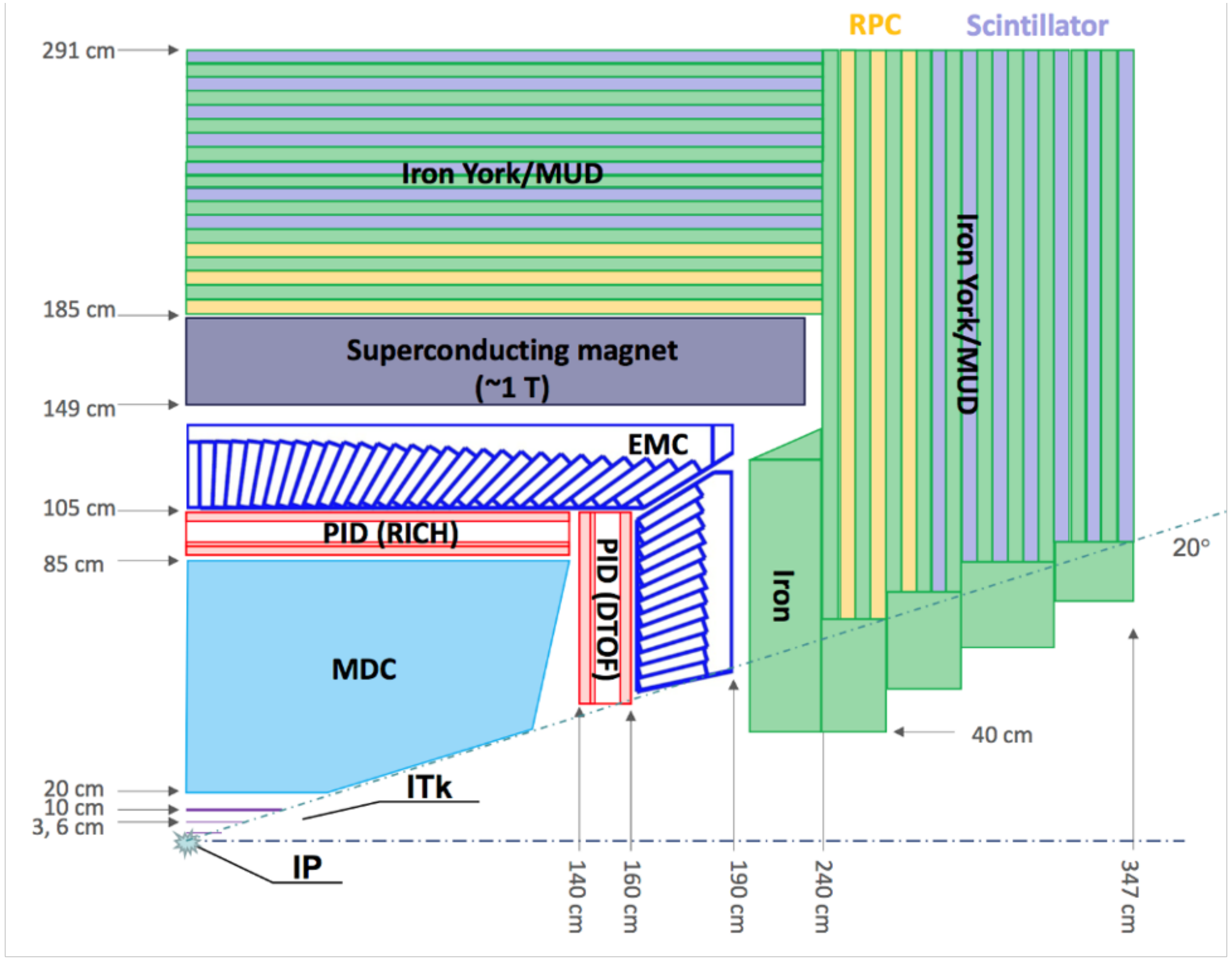
2021

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

2022.4

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

STCF Project Development



ITK
- <~ 0.3%X_0 / layer
- σ_{xy}<~ 100 μm

Cylindrical MPGD
CMOS MAPS

MDC
- σ_{xy}< 130 μm
- σ_p/p ~ 0.5% @ 1 GeV
- dE/dx~6%

Cylindrical
Drift chamber

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

RICH with MPGD
DIRC-like TOF

EMC
Energy range: 0.025-3.5GeV
σ_E (%) @ 1 GeV
Barrel: 2 .5
Endcap: 4
Pos. Res. : 5 mm

pCsI + APD

MUD
- 0.4 - 2 GeV
- π suppression >30

RPC + scintillator