Research Progress of the Super Tau-Charm Facility (STCF)

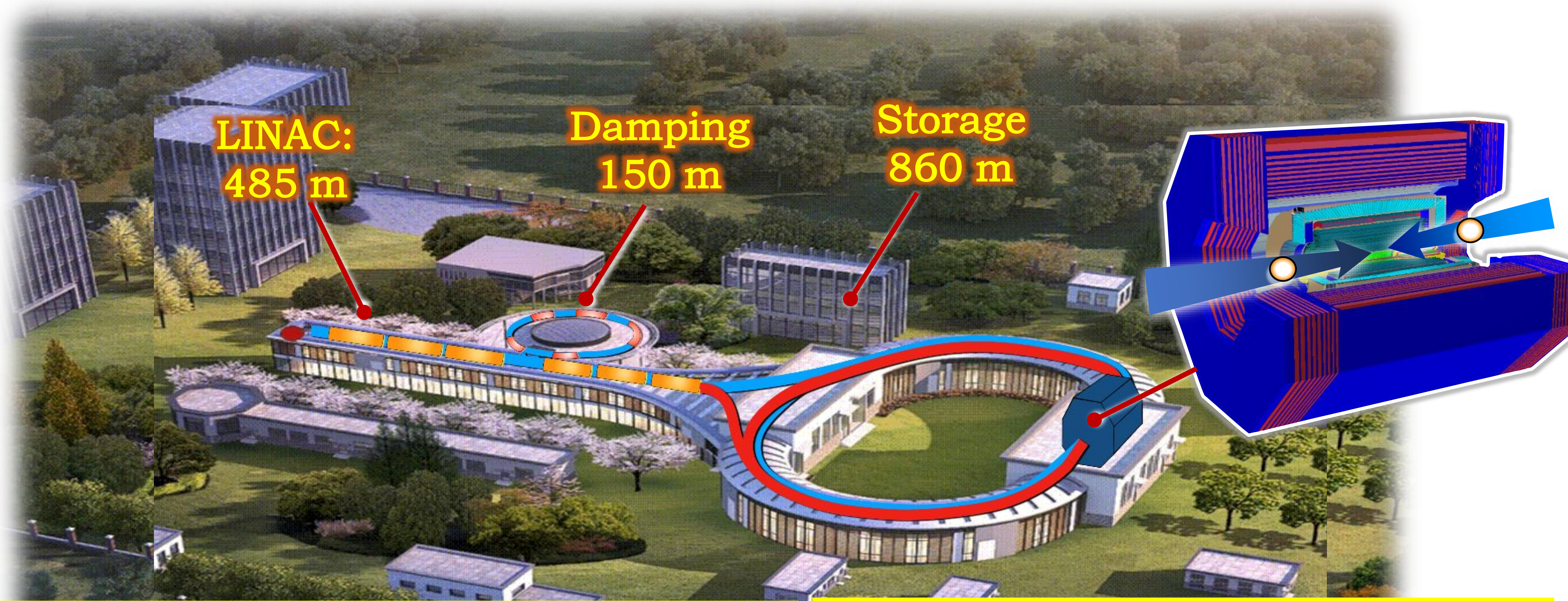
Qian LIU （on be half of the STCF team）
University of Chinese Academy of Sciences

2025/08/27 22nd Lomonosov Conference on Elementary Particle Physics

Outline

- ■ STCF project in China
- ■ Physics in STCF
- ■ Offline Software-OSCAR
- ■ Detector conceptual design and R&D
- ■ Summary and outlook

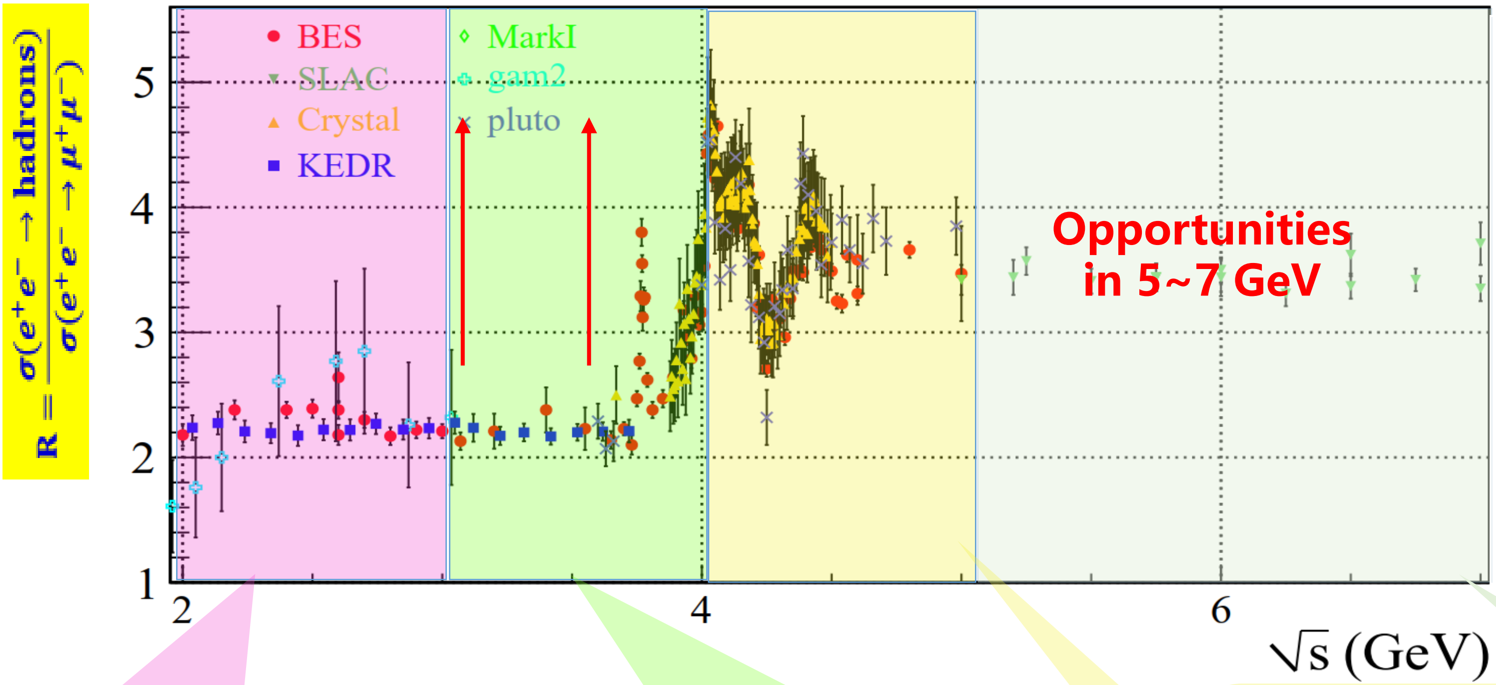
Super Tau-Charm Facility (STCF)



- Peak luminosity >0.5×10^{35} $cm^{-2}s^{-1}$ at 4 GeV
- Energy range E_{cm} = 2-7 GeV
- Potential to increase luminosity & realize beam polarization
- Total cost: 4.5B RMB

- 1 ab^{-1} data expected per year
- Rich of physics program, unique for physics with *c* quark and τ leptons,
- Important playground for study of QCD, exotic hadrons, flavor physics and search for new physics.

Physics in the Tau-Charm Energy Region



Unique Features in tau-charm region:

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

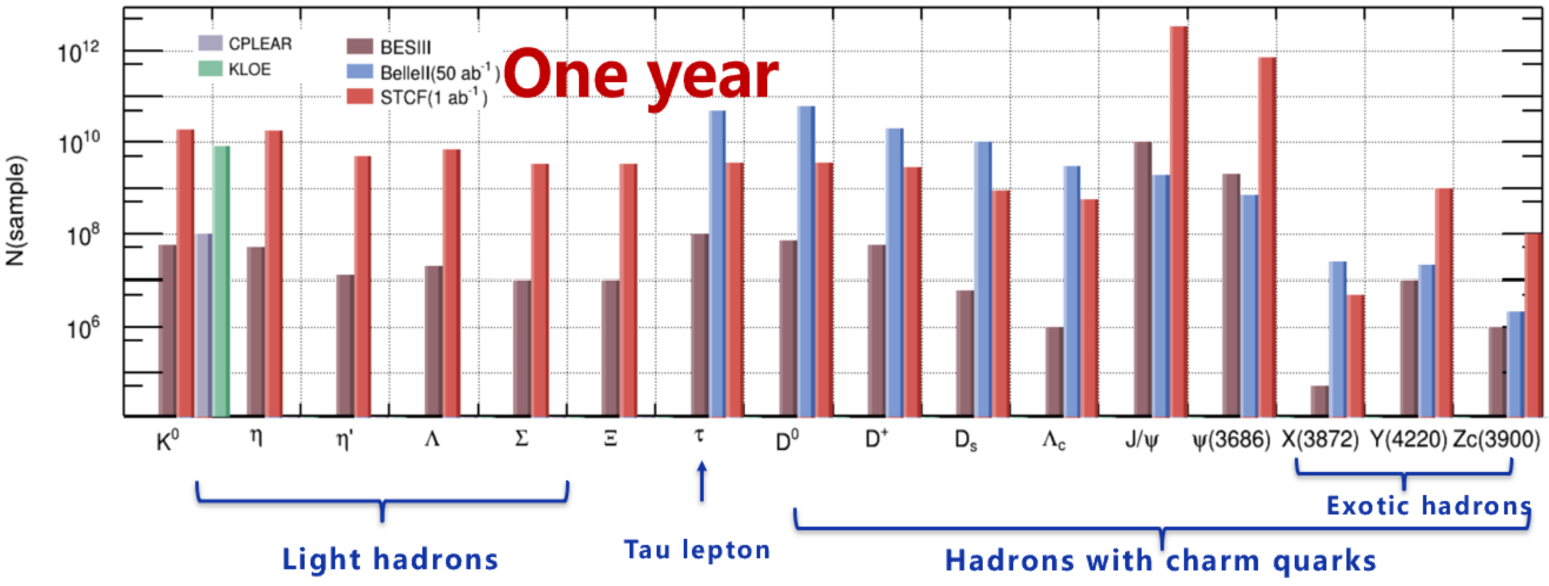
- Hadron form factors
- $Y(2170)$ resonance
- Mutltiquark states with s quark
- R value / g-2 related

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

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

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

Expected Data Production at STCF

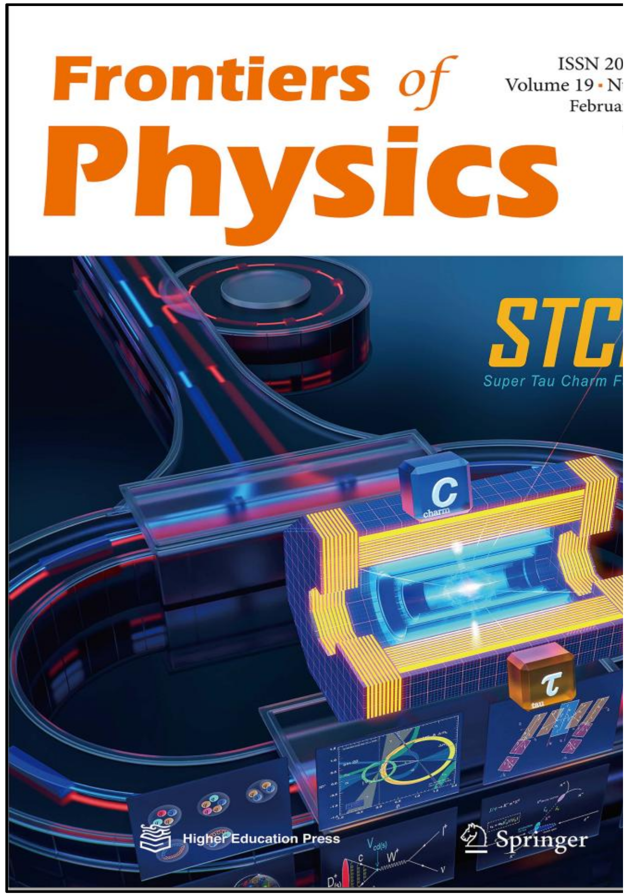


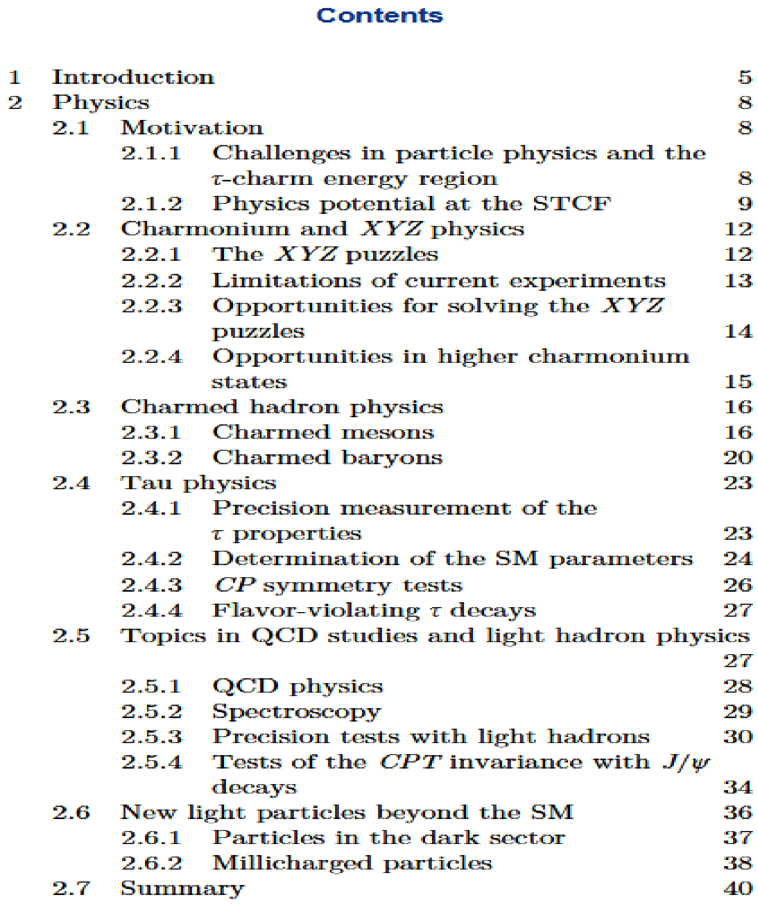
- About **1 ab^{-1}** integrated luminosity at STCF per year
- STCF shows superior **statistics and purity** compared to other experiments
- The **physics sensitivity** studies are based on, **but not limited to**, data samples of these size

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

Physics Program at STCF

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




Contents

Rich physics potential beyond the CDR content

Spin 3/2 polarization
Near-threshold resonance
Millicharged particles
Triangle singularity
J/psi seimileptonic decay
Belle locality
D_s^* radiative decay
FCNC
Light-cone distribution amplitudes
cLFV
baryogenesis
EMFFs
K0-K0bar
X(6200)
Neutral meson mixing
QCD sum rules
Two-pole
Muon g-2 and $\alpha(M_Z^2)$
$\Lambda-\bar{\Lambda}$ oscillation
Axion-like particle
Chiral theory
Fully charm tetraquarks
Tau EDM
SU(2)$_L$-signlet vector-like fermion partners
Hyperon EDM
X(4014)
Excited baryon
$\Delta S=2$ Nonleptonic hyperon decay
Axions
CPT
Coupled-channel effect
Hyperon-Nucleus Scattering
Proton charge radius
Invisible decay of J/psi
Phi meson photoproduction
$a_0(1710)$

Three-fold Physics Flagships at STCF

- Write STCF proposal for **scientific objectives** and **further refine** the physics flagships
- The main considerations for selecting physics flagships:
  - **Unique advantages** over Belle II/LHCb
  - Clear **public appeal**
  - **Strong synergies** with complementary experiments
- Three-fold physics flagships:

July 2024, Proposal writing Kick-off meeting

Nov. 2024, Further refine scientific objectives

1.Tests of fundamental Symmetries	**2.Exploring QCD nature and confinement**	**3.Precision Measurement of Fundamental Physical Parameters**
• CP : Hyperons, tau, EDM • CPV : $K^0-\bar{K}^0$ system • CLFV : Tau, meson decays	• Hadron Spectroscopy • Nuclear Structure • Fragmentation function	• R-Value, Tau mass • Running of fine structure constant $\Delta\alpha_{em}$ • CKM elements

1.Tests of Fundamental Symmetries

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

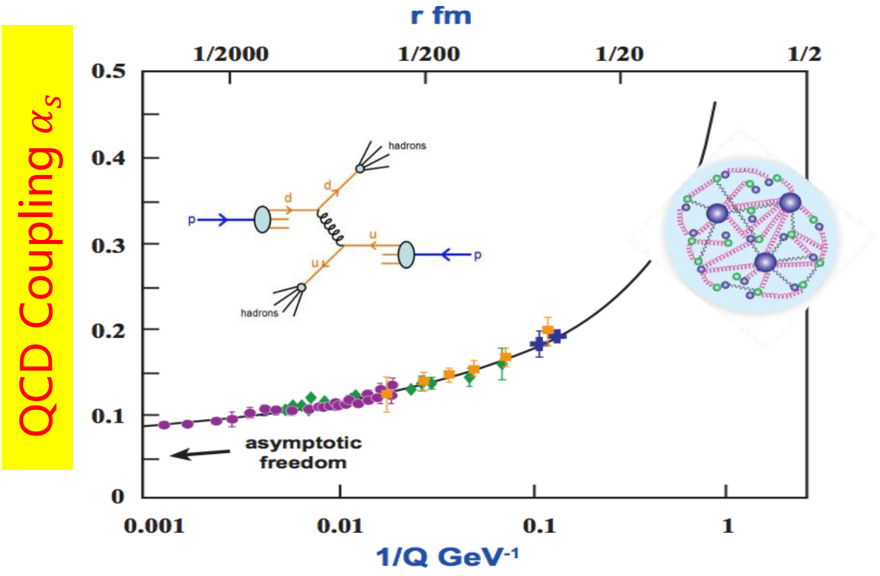
Current Status of CPV Research at the Quark Level

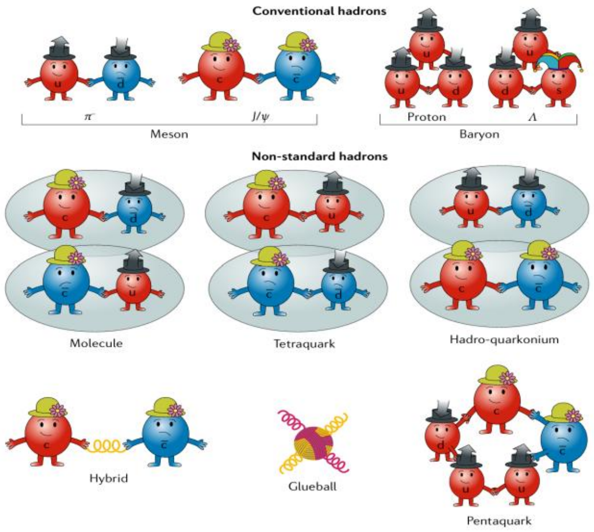
First Generation	Second Generation	Third Generation
Up/Down	Charm	Top
CPV in first generation is predicted to be far below current experimental sensitivity	**Charm mesons**: In 2009, LHCb discovered CPV at $\mathcal{O}(10^{-3})$, within SM predictions	Lifetime too short to form hadrons; decays before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

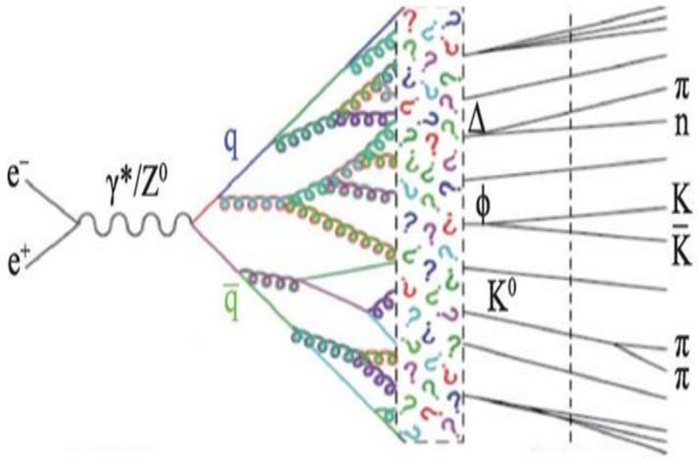
STCF prospects:

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

2.Quark Confinement



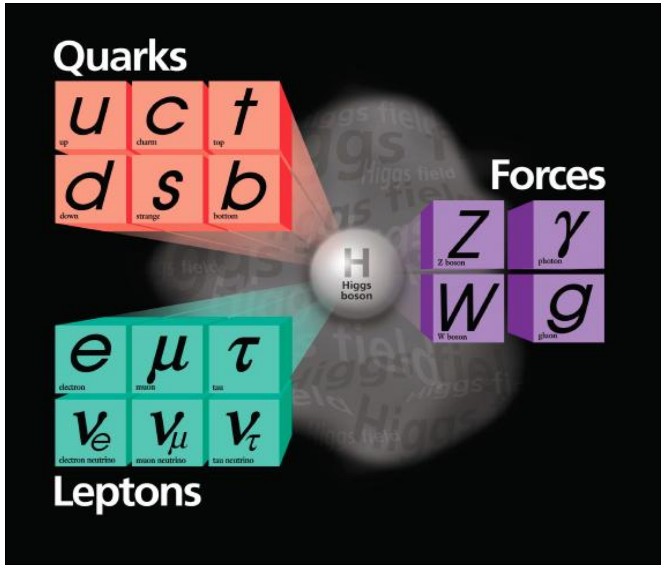




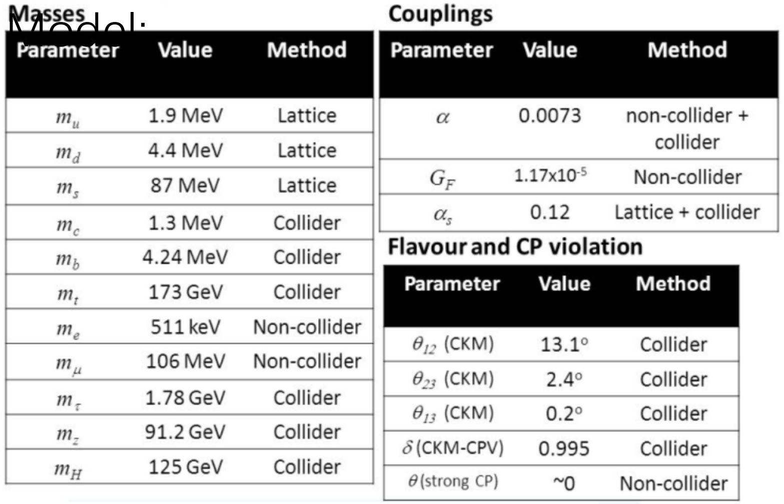
- Unraveling the physical mechanism of quark confinement requires summarizing **the laws of hadron spectra**, **production**, **decay**, and understanding **how quarks and gluons are distributed inside hadrons**.
- The STCF will produce vast quantities of **charmed hadrons** and **light flavor hadrons**,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

3.Fundamental Physics Parameters

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



Parameters of the Standard Model:



Masses

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

Couplings

Parameter	Value	Method
α	0.0073	non-collider + collider
G_F	1.17x10^{-5}	Non-collider
α_s	0.12	Lattice + collider

Flavour and CP violation

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

R value：

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

LFU test:

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

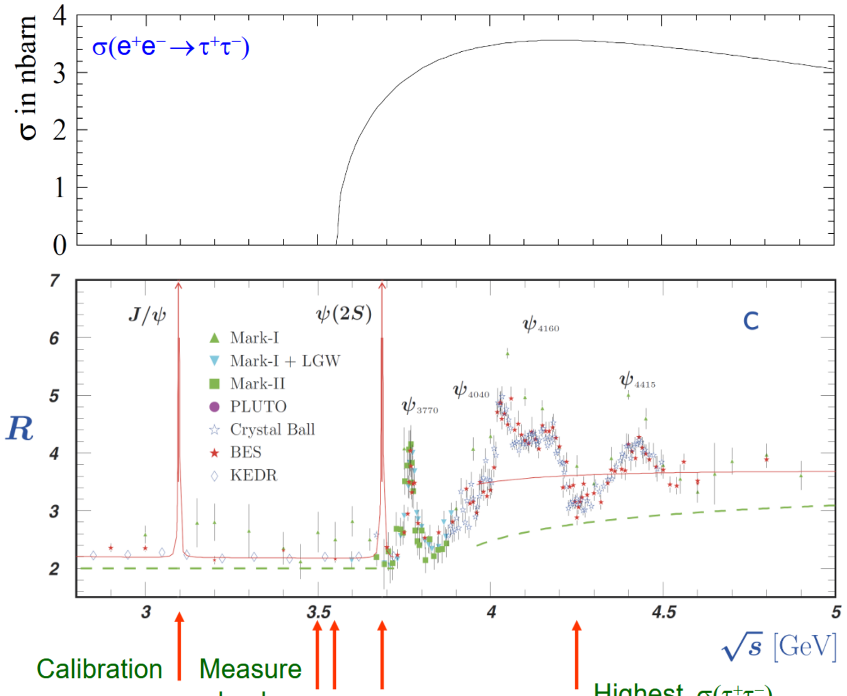
CKM matrix:

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

Tau physics potential at STCF

- Tau pairs in e^+e^- collider produced back-to-back in center-of-mass system
- At **tau-charm factory**: different energy region, different potential, runs near the tau pair threshold

Exp.	**Lum.**	$\sqrt{q}$	**Number of tau pairs**
ALEPH	200 pb^{-1}	91.2 GeV	3.3×10^5 reconstructed
BaBar	467 fb^{-1}	~10.58 GeV	4.3×10^8
Belle	988 fb^{-1}	~10.58 GeV	9.12×10^8
Belle II (prospect)	50 ab^{-1}	~10.58 GeV	4.6×10^{10}
BESIII	~35 fb^{-1}	From threshold to 4.95 GeV	$\sim 1.2 \times 10^8$
STCF (prospect)	**1 ab^{-1} per year**	**From threshold to 7 GeV**	$\sim 3.5 \times 10^9$



Calibration

Measure τ backgr.

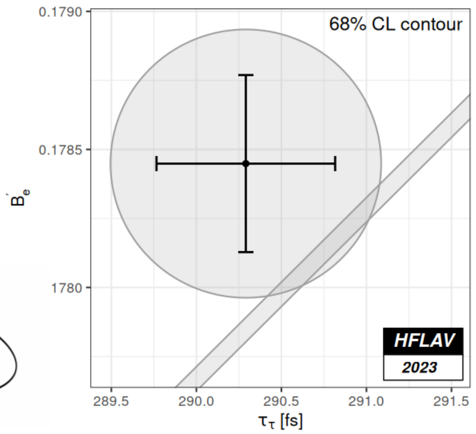
$\tau^+\tau^-$ Thr.

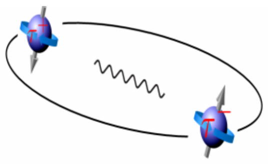
Highest $\sigma(\tau^+\tau^-)$ below open c

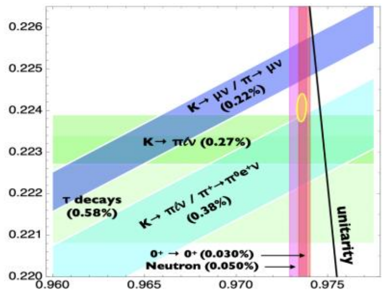
Highest $\sigma(\tau^+\tau^-)$

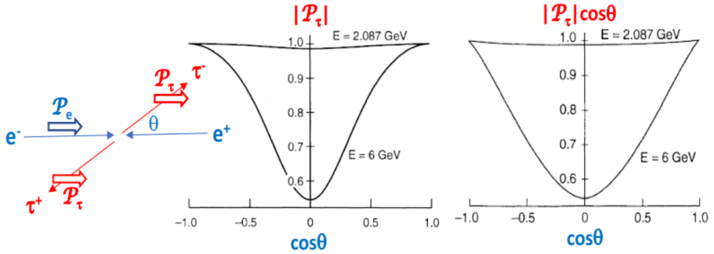
Tau physics potential at STCF

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



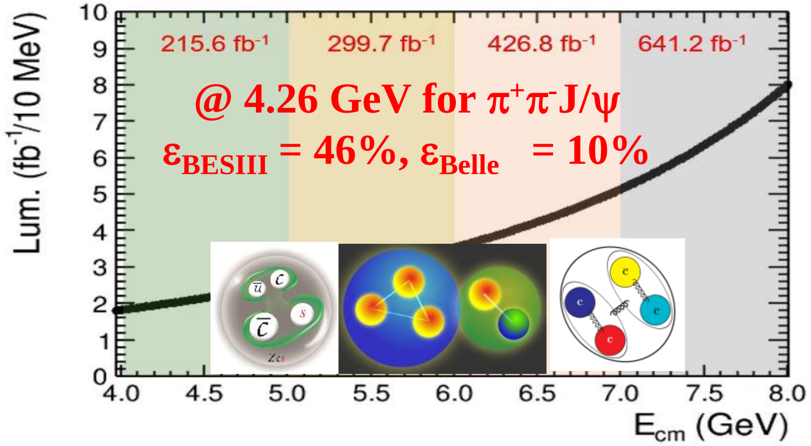




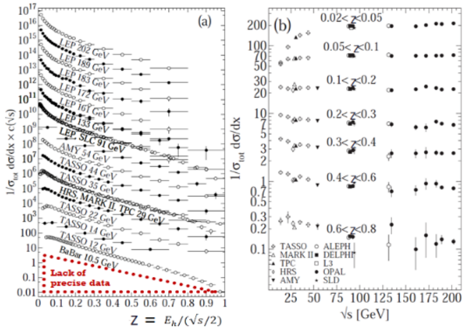


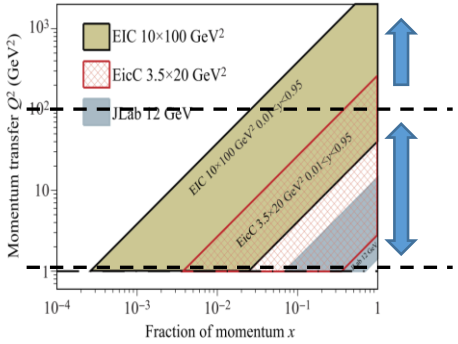
5-7 GeV physics potential at STCF

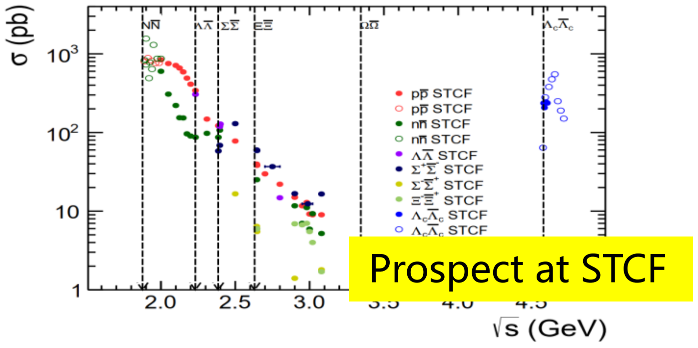
- **Hadron spectroscopy**
  - Many threshold opens in 5-7 GeV which yield more potentials for hadron studies
  - Structures in more channels for **XYZ physics**, with larger production rates above 5 GeV
  - **P_c pentaquarks** in $e^+e^- \to J/\psi h\bar{h}$ **for** hidden-charm and $e^+e^- \to \Lambda_c\bar{D}^*\bar{p},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



@ 4.26 GeV for $\pi^+\pi^- J/\psi$
$\varepsilon_{BESIII} = 46\%$, $\varepsilon_{Belle} = 10\%$

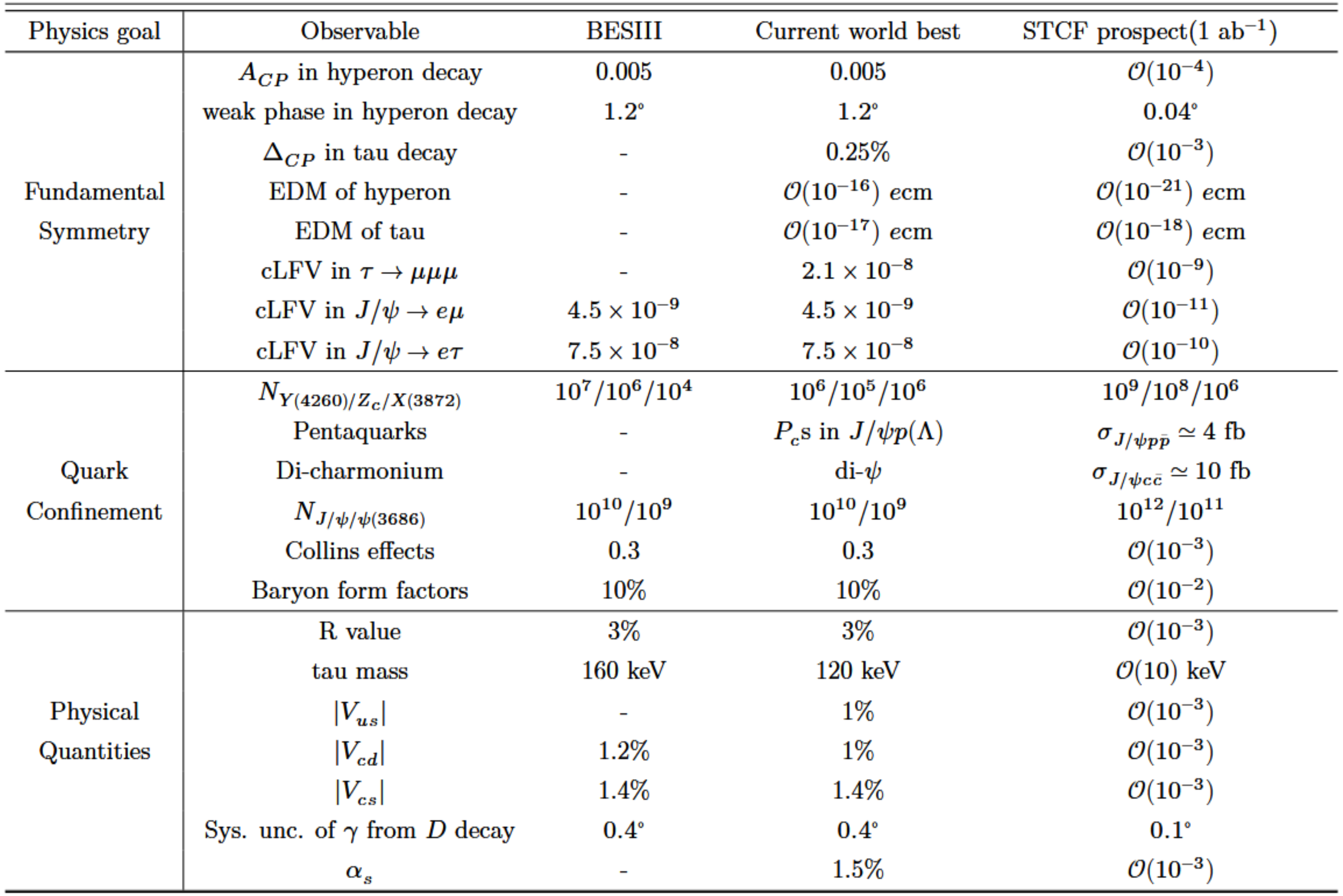






Expected Sensitivities

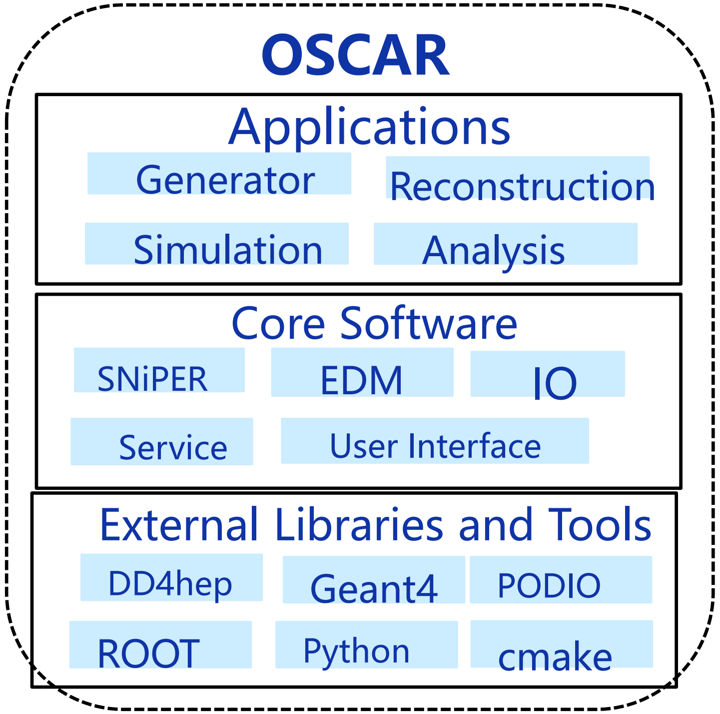
- Expected sensitivities at STCF by performing fast simulation are compared with other experiments

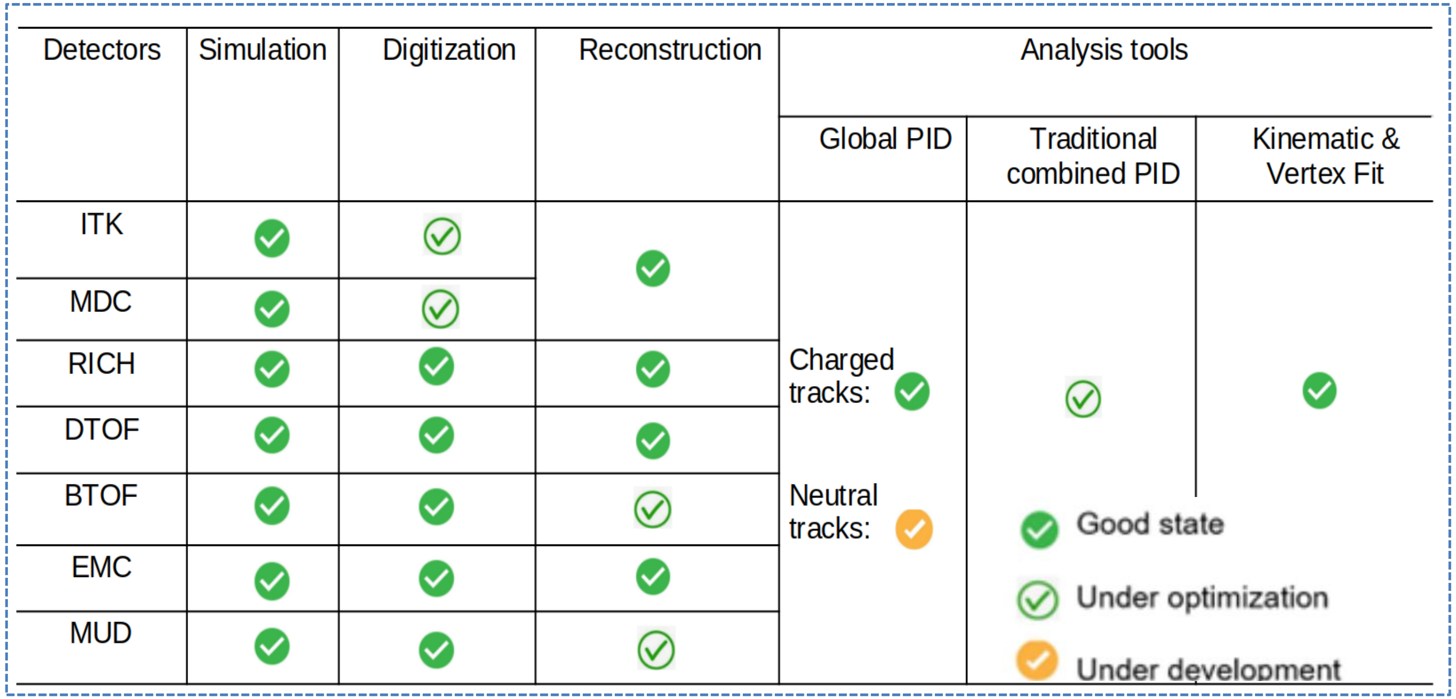


Physics goal	Observable	BESIII	Current world best	STCF prospect(1 ab^{-1})
Fundamental Symmetry	A_{CP} in hyperon decay	0.005	0.005	$\mathcal{O}(10^{-4})$
	weak phase in hyperon decay	1.2°	1.2°	0.04°
	Δ_{CP} in tau decay	-	0.25%	$\mathcal{O}(10^{-3})$
	EDM of hyperon	-	$\mathcal{O}(10^{-16})$ ecm	$\mathcal{O}(10^{-21})$ ecm
	EDM of tau	-	$\mathcal{O}(10^{-17})$ ecm	$\mathcal{O}(10^{-18})$ ecm
	cLFV in $\tau \to \mu\mu\mu$	-	2.1×10^{-8}	$\mathcal{O}(10^{-9})$
	cLFV in $J/\psi \to e\mu$	4.5×10^{-9}	4.5×10^{-9}	$\mathcal{O}(10^{-11})$
	cLFV in $J/\psi \to e\tau$	7.5×10^{-8}	7.5×10^{-8}	$\mathcal{O}(10^{-10})$
Quark Confinement	$N_{Y(4260)/Z_c/X(3872)}$	$10^7/10^6/10^4$	$10^6/10^5/10^6$	$10^9/10^8/10^6$
	Pentaquarks	-	P_cs in $J/\psi p(\Lambda)$	$\sigma_{J/\psi p\bar{p}} \simeq 4$ fb
	Di-charmonium	-	di-ψ	$\sigma_{J/\psi c\bar{c}} \simeq 10$ fb
	$N_{J/\psi/\psi(3686)}$	$10^{10}/10^9$	$10^{10}/10^9$	$10^{12}/10^{11}$
	Collins effects	0.3	0.3	$\mathcal{O}(10^{-3})$
	Baryon form factors	10%	10%	$\mathcal{O}(10^{-2})$
Physical Quantities	R value	3%	3%	$\mathcal{O}(10^{-3})$
	tau mass	160 keV	120 keV	$\mathcal{O}(10)$ keV
	$\|V_{us}\|$	-	1%	$\mathcal{O}(10^{-3})$
	$\|V_{cd}\|$	1.2%	1%	$\mathcal{O}(10^{-3})$
	$\|V_{cs}\|$	1.4%	1.4%	$\mathcal{O}(10^{-3})$
	Sys. unc. of γ from D decay	0.4°	0.4°	0.1°
	α_s	-	1.5%	$\mathcal{O}(10^{-3})$

Offline Software: OSCAR

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





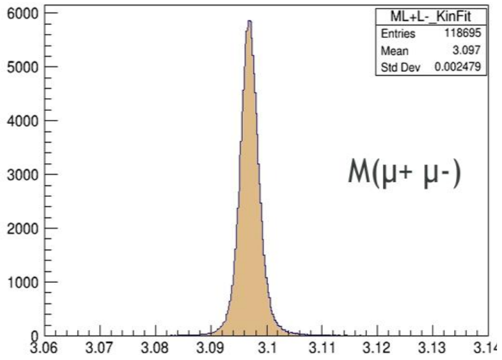
Detectors	Simulation	Digitization	Reconstruction	Analysis tools		
				Global PID	Traditional combined PID	Kinematic & Vertex Fit
ITK	✅	✓	✅	Charged tracks: ✅ Neutral tracks: 🟠	✓	✅
MDC	✅	✓				
RICH	✅	✅	✅			
DTOF	✅	✅	✅			
BTOF	✅	✅	✓			
EMC	✅	✅	✅			
MUD	✅	✅	✓			

✅ Good state
✓ Under optimization
🟠 Under development

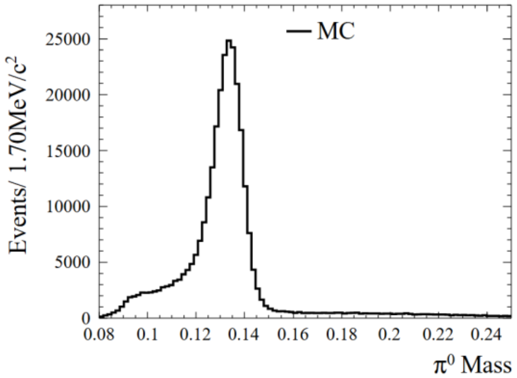
W.H. Huang et al 2023 JINST 18 P03004

Physics Full-simulation Activities

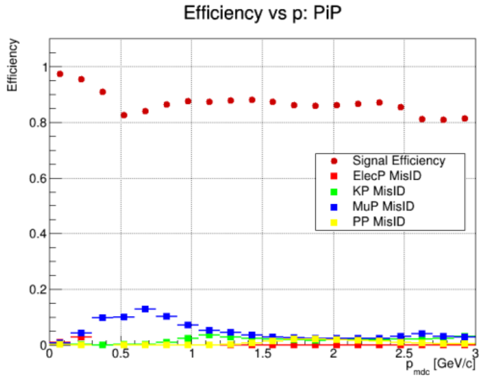
- **Testing of OSCAR full-simulation chain**



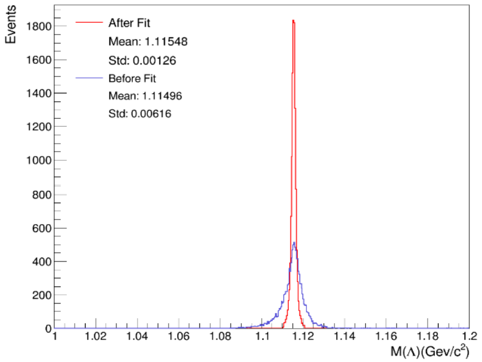
✓ **Tracking**



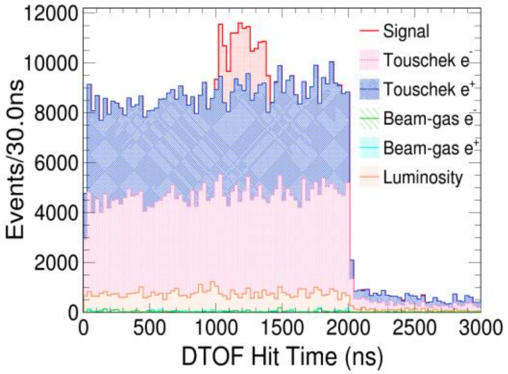
✓ **Neutral**



✓ **Global PID**



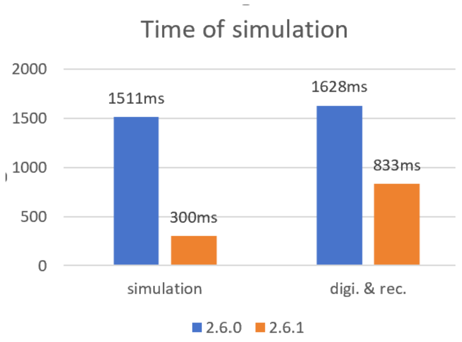
✓ **Kinematic fit**

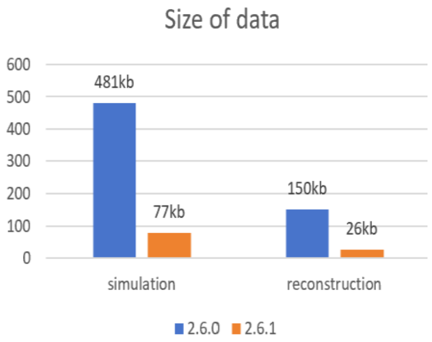


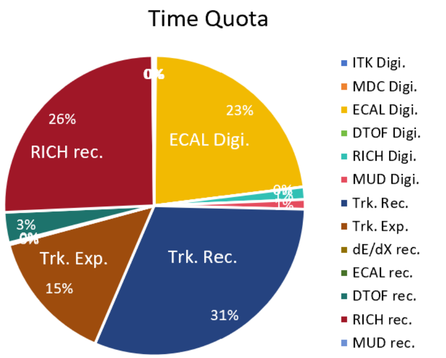
✓ **Background**

- **Generators in OSCAR**
  - Babayaga (bhabha, dimu, digam), Phokhara, Conexc (ISR)
  - Madgraph + Pythia (ditau)
  - Ekhara, Diag36, Gluga (two-photon)
  - KKMC + EvtGen (charmonium decay)
  - LundArlw, Pythia (qqbar)

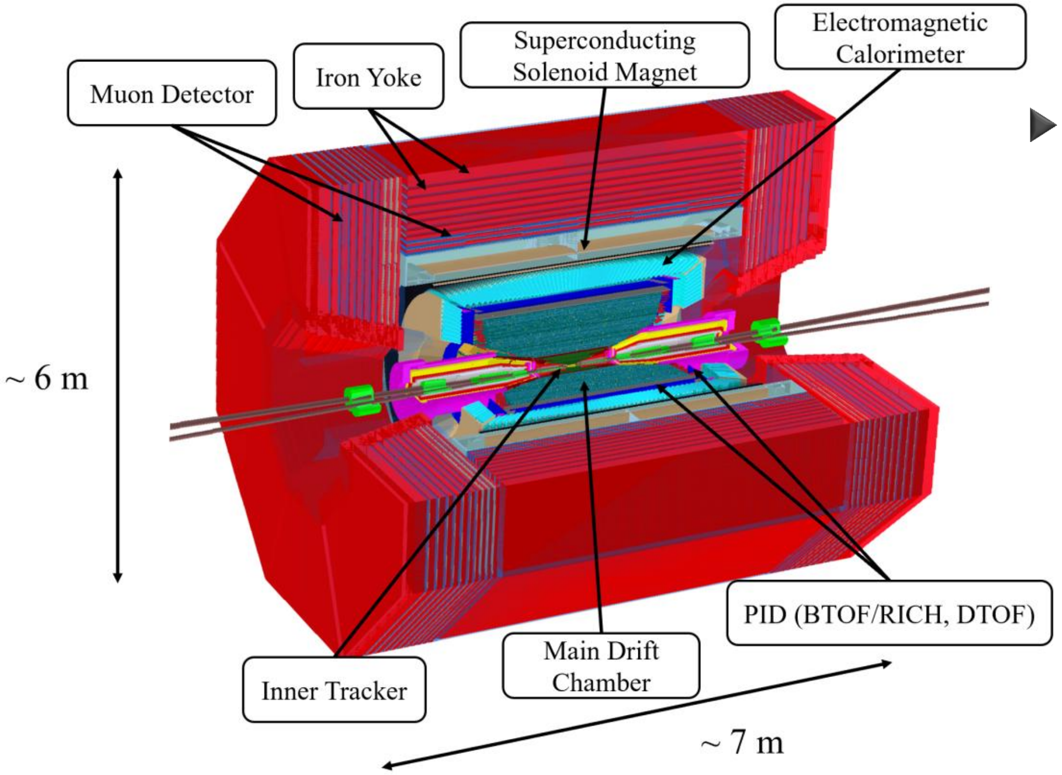
- **Computing optimization**



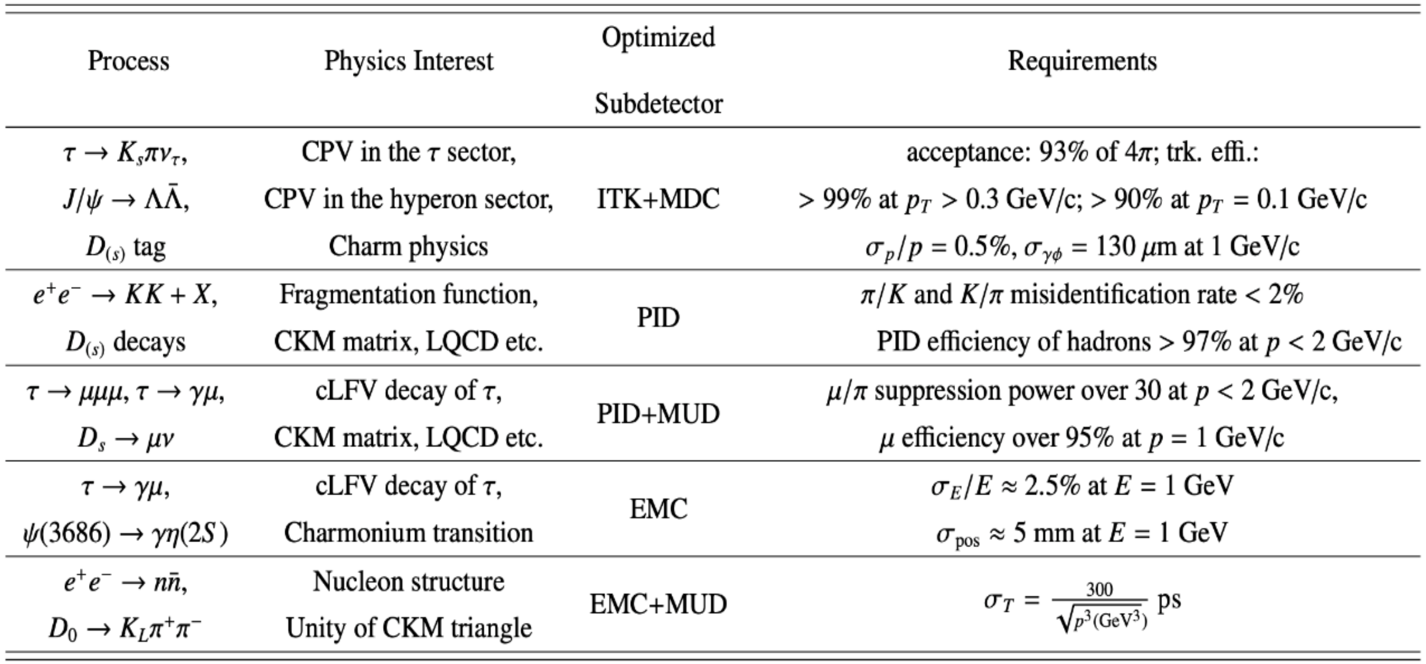




Physics Requirements for STCF Detector

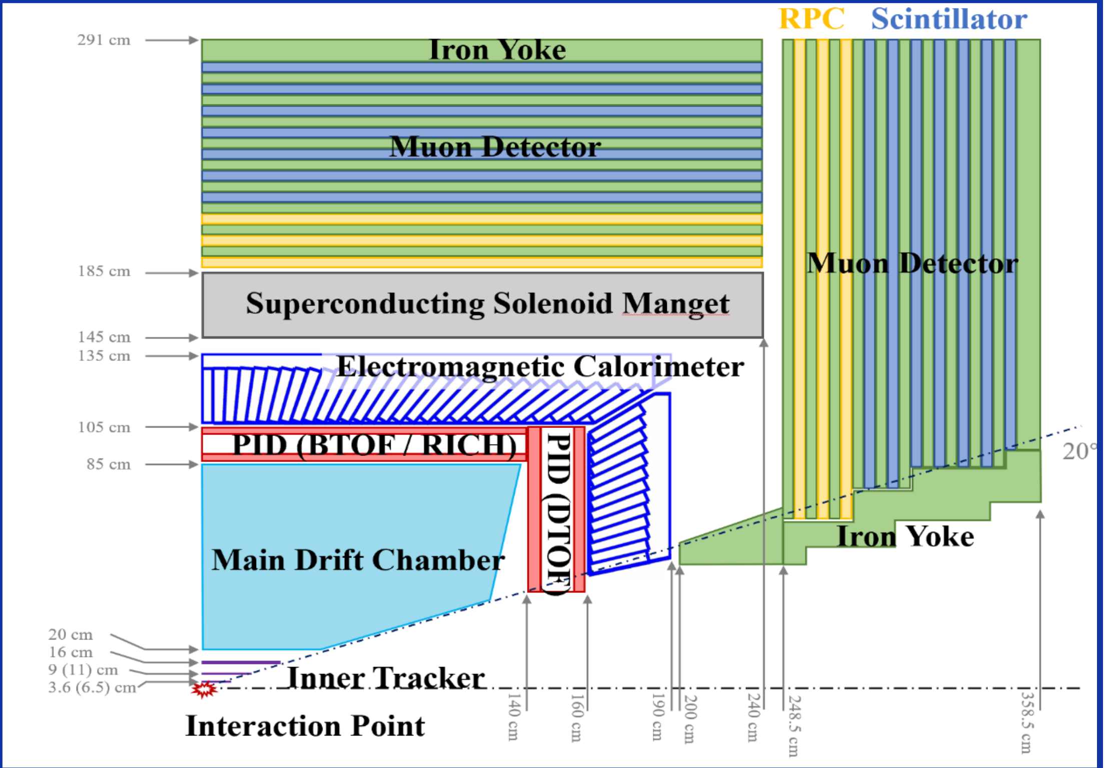


- **Highly efficient and precise reconstruction of exclusive final states produced in 2-7 GeV e^+e^- collisions**
  - Precise measurement of low-p (~>1GeV/c) particles
→ low mass tracking and PID detectors
  - Excellent PID: π/K and μ/π separation up to 2 GeV and beyond



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

Detector Design and Key Technologies



Major Performance Requirements

Acceptance: 94%×4π

Momentum res.: σ_p/p ~ 0.5% @ 1 GeV

Energy res. : σ_E/E ~ 2.5% @ 1 GeV

Hadron ID: π/K ~4σ @ 2 GeV

Muon ID: eff. >95%, mis-rate <3% @1 GeV

- Inner Tracker
  - MPGD: cylindrical uRGroove, σ_x ~100 μm
  - Silicon: low-mass MAPS, <0.3%X_0/layer
- Central Tracker (σ_p/p~0.5% @ 1GeV)
  - Drift chamber with super-small cells, σ_x <130 μm
- PID System (π/K ~4σ @ 2GeV)
  - Endcap: DIRC-like TOF - DTOF (σ_t~30 ps)
  - Barrel: RICH (<4mrad) or DTOF (σ_t~30 ps)
- EMC
  - pCsI + APD: (σ_E/E~2.5%, σ_x~5 mm, σ_t~300 ps @ 1GeV)
- Solenoid： 1 T
- Muon Detector (eff. >95%, mis-rate <3% @1GeV)
  - inner layers : glass RPC， > 300 Hz/cm^2
  - outer layers : scintillator strip + SiPM, ~ 2.4 m
- Trigger, DAQ, Clock and Data Transmission

Beam background at the inner most layer

~1 Mrad/y, ~1×10^{11} 1MeV n-eq/cm^2/y, ~1 MHz/cm^2

R&D Status Overview

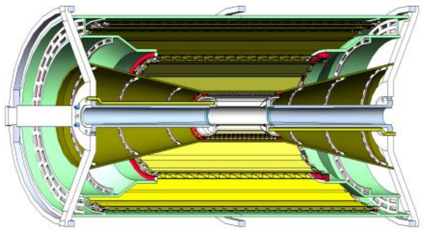
- **A complete R&D program covering every aspect of the STCF detector is in place and being vigorously implemented. Many systems are on track to achieve the primary R&D goals by the end of this year or early next year. Some systems have reached the large-scale prototype level.**

- **Inner tracker – MPGD : a cylindrical MPGD prototype, readout ASIC prototype with full function**
- **Inner tracker – MAPS : MAPS designed with different CMOS processes, chips with TJ180 returned**
- **Main Drift Chamber : a full-length drift chamber prototype with super-small cells under construction**
- **Barrel PID : a 32×32cm^2 RICH prototype, 3 iterations in readout ASIC design already.**
- **Endcap PID : a full-size DTOF prototype, readout ASIC prototypes**
- **EM Calorimeter : a 5×5 pCsI calorimeter prototype, pileup real-time removal algorithm and implementation**
- **Muon Detector : large-size glass RPC and scintillator units, readout ASIC prototypes**
- **Clock and Data Transmission : key ASIC modules for clock management and high-speed link**
- **Trigger : L1 and HLT trigger algorithms, firmware programing and hardware development**
- **DAQ : architecture design, software and hardware development almost finished**
- **Detector Magnet : conceptual design optimized, moved to technical design**
- **Detector Mechanical Design : engineering design for each sub-system, designs for detector assembly and installation**
- **MDI and Forward detectors : luminosity detectors ad zero-degree detectors, beam background**
- **Detector Control System : system design and technical demonstrators**
- **Combined beam test : first such a test performed of EMC + DTOF + DAQ at CERN PS**

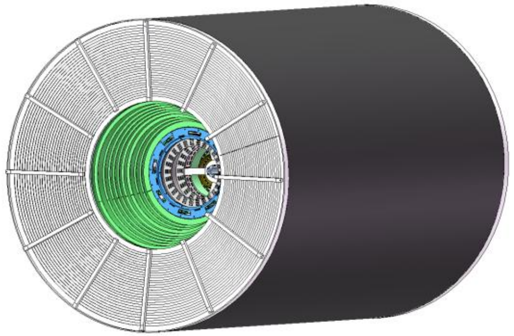
Detector Mechanical Design

- Detector conceptual design has been transferred into engineering drawings
- Engineering design available for each sub-detector or system
- Design studies on detector assembly and installation

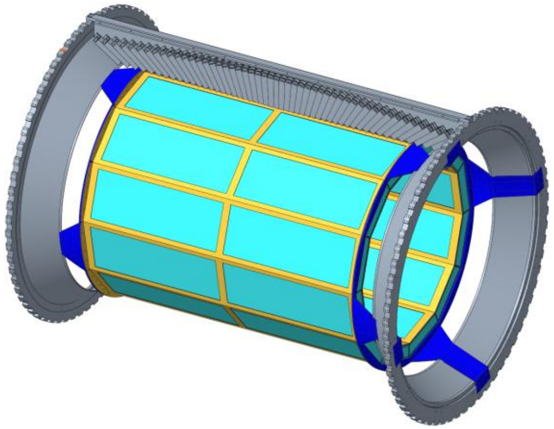
ITK-MAPS



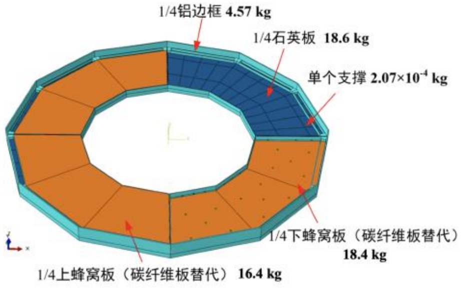
MDC



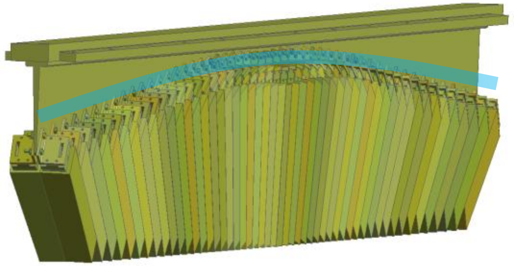
RICH

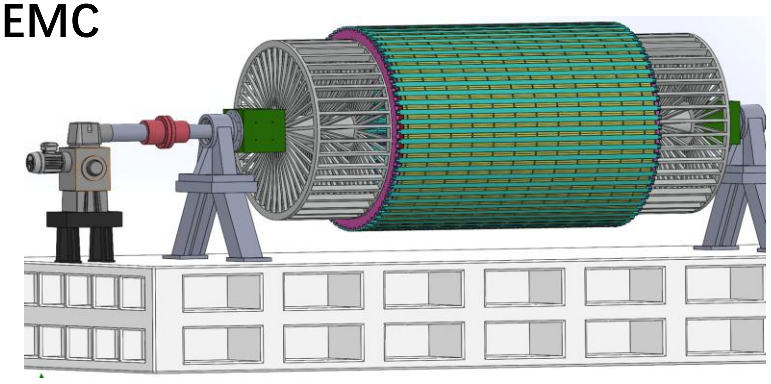


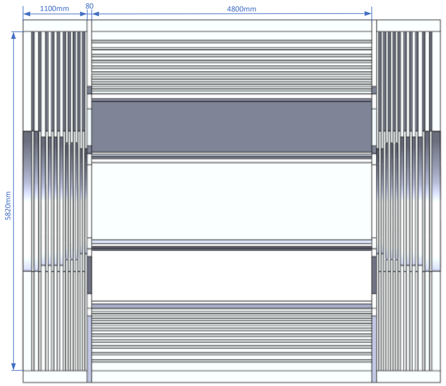
DTOF



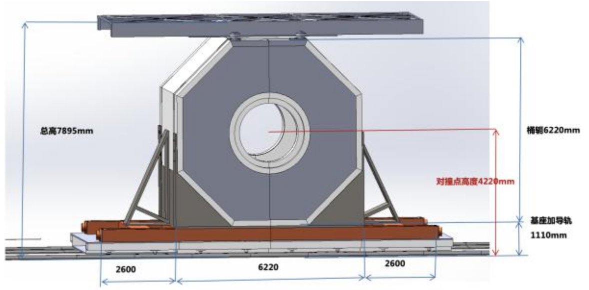
EMC





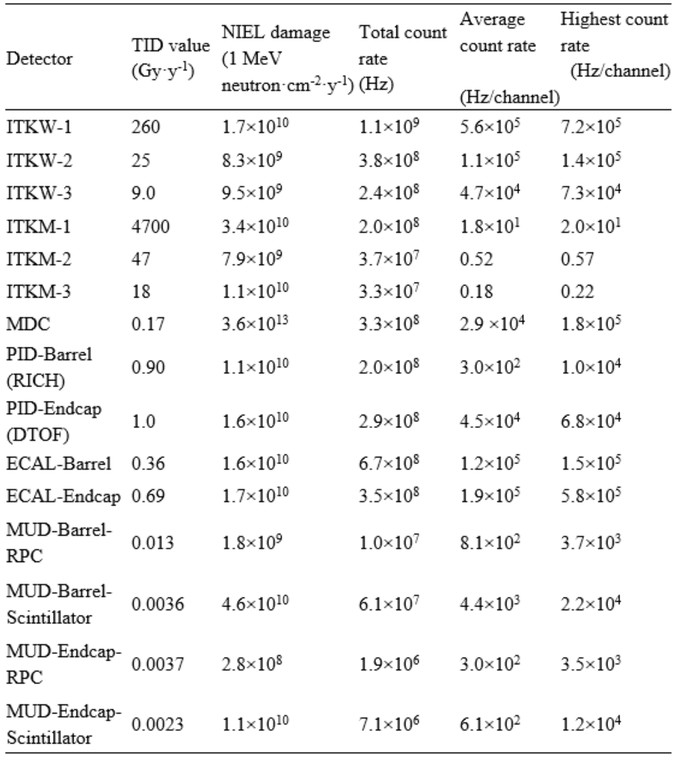


Iron Yoke

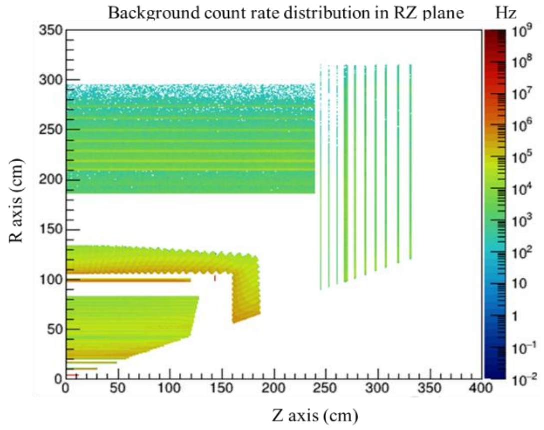


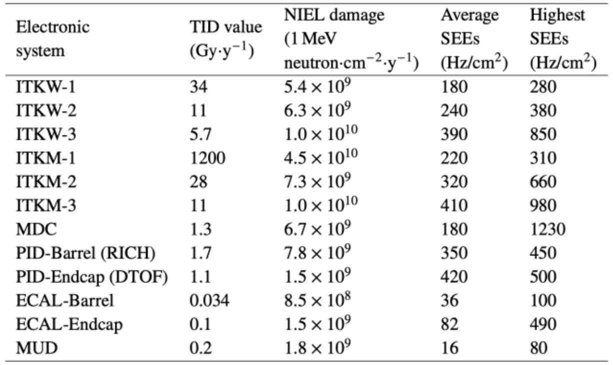
Beam Background and Forward Detectors

- ❖ **Keeping up with accelerator design evolution for beam background estimation. Working closely with MDI people to optimize the detector geometry and radiation shielding design in MDI region.**
- ❖ **Simulation studies on luminosity detectors (radiative Bhabha) and zero-degree detectors (ISR, two-photon process). Preliminary determination of the sites of these detectors at STCF from these studies.**

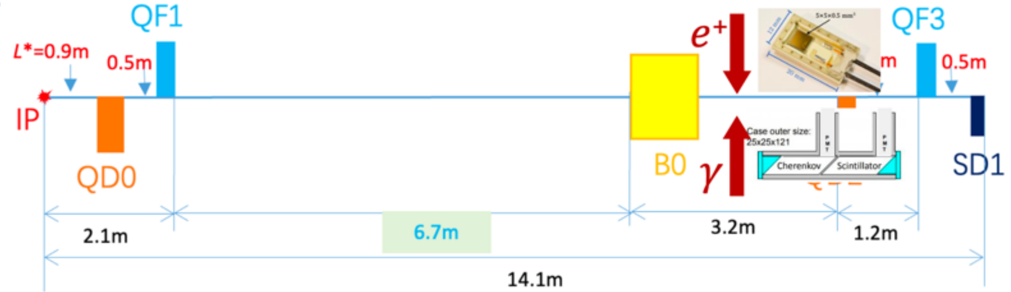


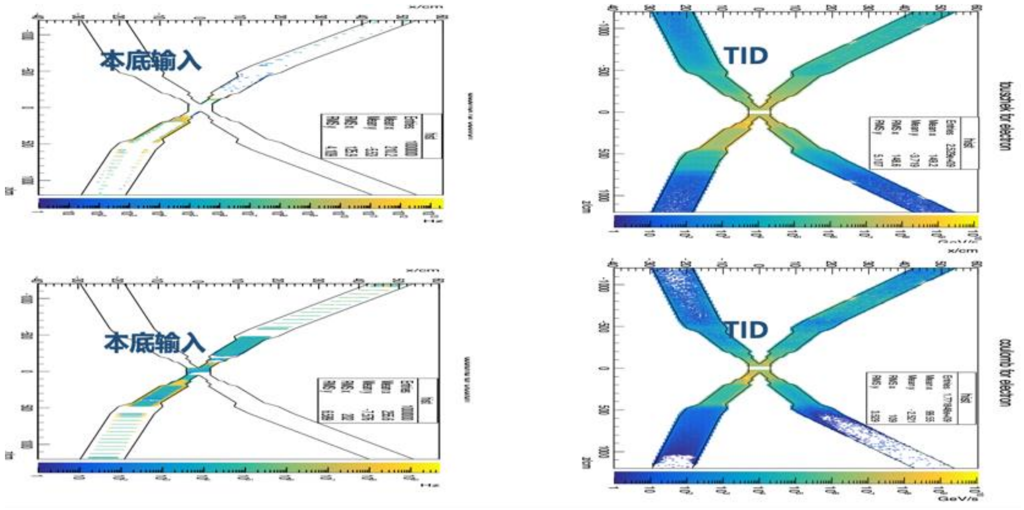
Detector	TID value (Gy·y^{-1})	NIEL damage (1 MeV neutron·cm^{-2}·y^{-1})	Total count rate (Hz)	Average count rate (Hz/channel)	Highest count rate (Hz/channel)
ITKW-1	260	1.7×10^{10}	1.1×10^{9}	5.6×10^{5}	7.2×10^{5}
ITKW-2	25	8.3×10^{9}	3.8×10^{8}	1.1×10^{5}	1.4×10^{5}
ITKW-3	9.0	9.5×10^{9}	2.4×10^{8}	4.7×10^{4}	7.3×10^{4}
ITKM-1	4700	3.4×10^{10}	2.0×10^{8}	1.8×10^{1}	2.0×10^{1}
ITKM-2	47	7.9×10^{9}	3.7×10^{7}	0.52	0.57
ITKM-3	18	1.1×10^{10}	3.3×10^{7}	0.18	0.22
MDC	0.17	3.6×10^{13}	3.3×10^{8}	2.9×10^{4}	1.8×10^{5}
PID-Barrel (RICH)	0.90	1.1×10^{10}	2.0×10^{8}	3.0×10^{2}	1.0×10^{4}
PID-Endcap (DTOF)	1.0	1.6×10^{10}	2.9×10^{8}	4.5×10^{4}	6.8×10^{4}
ECAL-Barrel	0.36	1.6×10^{10}	6.7×10^{8}	1.2×10^{5}	1.5×10^{5}
ECAL-Endcap	0.69	1.7×10^{10}	3.5×10^{8}	1.9×10^{5}	5.8×10^{5}
MUD-Barrel-RPC	0.013	1.8×10^{9}	1.0×10^{7}	8.1×10^{2}	3.7×10^{3}
MUD-Barrel-Scintillator	0.0036	4.6×10^{10}	6.1×10^{7}	4.4×10^{3}	2.2×10^{4}
MUD-Endcap-RPC	0.0037	2.8×10^{8}	1.9×10^{6}	3.0×10^{2}	3.5×10^{3}
MUD-Endcap-Scintillator	0.0023	1.1×10^{10}	7.1×10^{6}	6.1×10^{2}	1.2×10^{4}





Electronic system	TID value (Gy·y^{-1})	NIEL damage (1 MeV neutron·cm^{-2}·y^{-1})	Average SEEs (Hz/cm^{2})	Highest SEEs (Hz/cm^{2})
ITKW-1	34	5.4×10^{9}	180	280
ITKW-2	11	6.3×10^{9}	240	380
ITKW-3	5.7	1.0×10^{10}	390	850
ITKM-1	1200	4.5×10^{10}	220	310
ITKM-2	28	7.3×10^{9}	320	660
ITKM-3	11	1.0×10^{10}	410	980
MDC	1.3	6.7×10^{9}	180	1230
PID-Barrel (RICH)	1.7	7.8×10^{9}	350	450
PID-Endcap (DTOF)	1.1	1.5×10^{9}	420	500
ECAL-Barrel	0.034	8.5×10^{8}	36	100
ECAL-Endcap	0.1	1.5×10^{9}	82	490
MUD	0.2	1.8×10^{9}	16	80

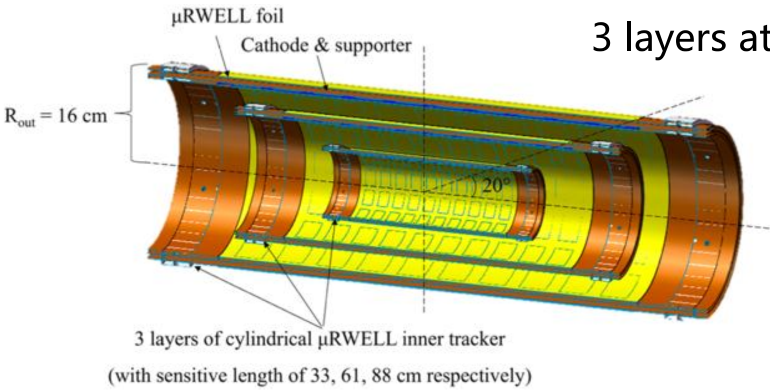


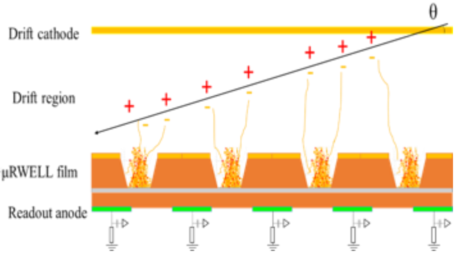


Tracking System : ITK + MDC

ITK Gaseous option : MPGD

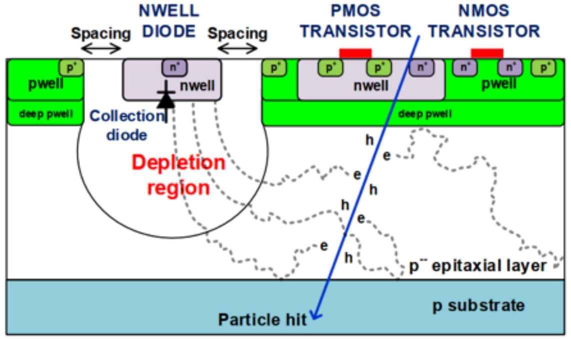
3 layers at 6cm, 11cm and 16 cm





Material budget ~ 0.3%X_0/layer

ITK Silicon option: CMOS MAPS

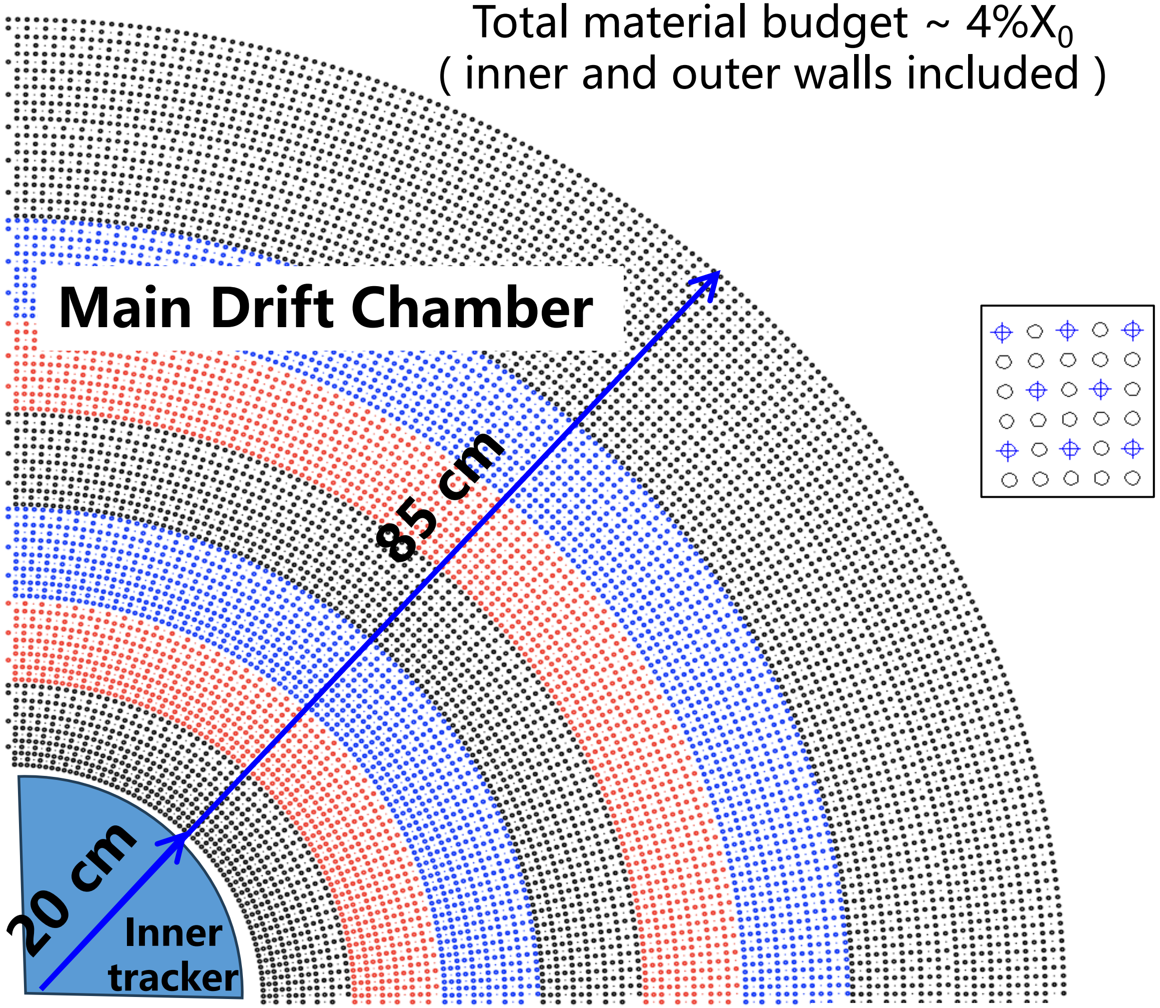


3 layers at

3.6cm, 9.8cm and 16 cm

Total material budget ~ 4%X_0

(inner and outer walls included)



~400 kHz/ch

~30 kHz/ch

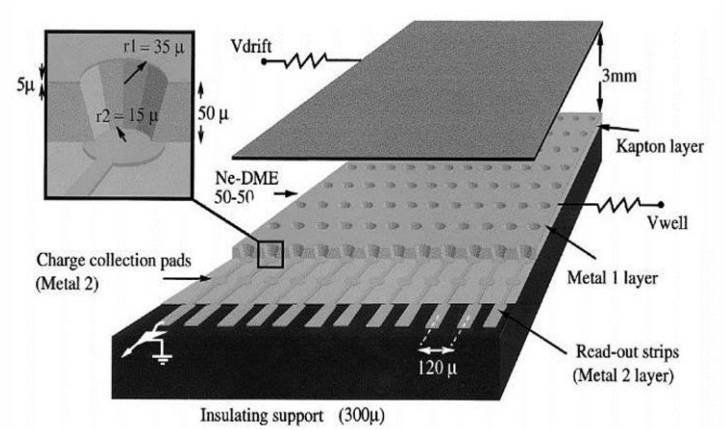
Inner-outer separate designs to accommodate different levels of radiation background

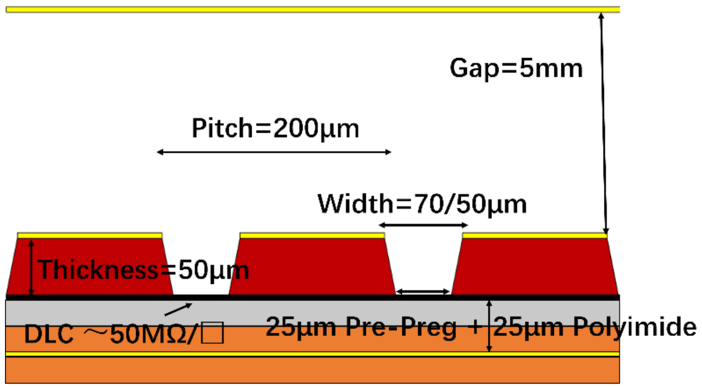
MPGD ITK : μRGroove

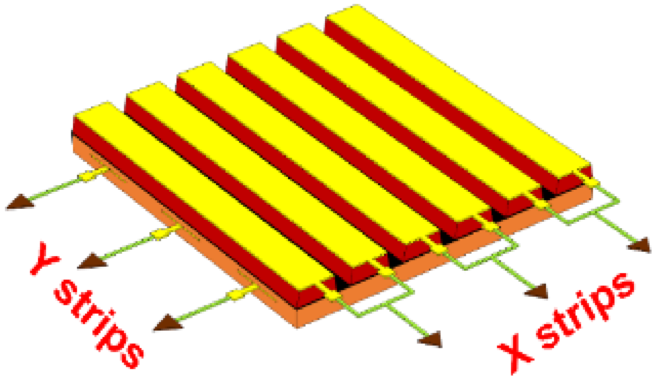
Features: Low material budget, low cost, radiation resistance

Challenges: Low-material-budget substrate √, cylindrical structure √…

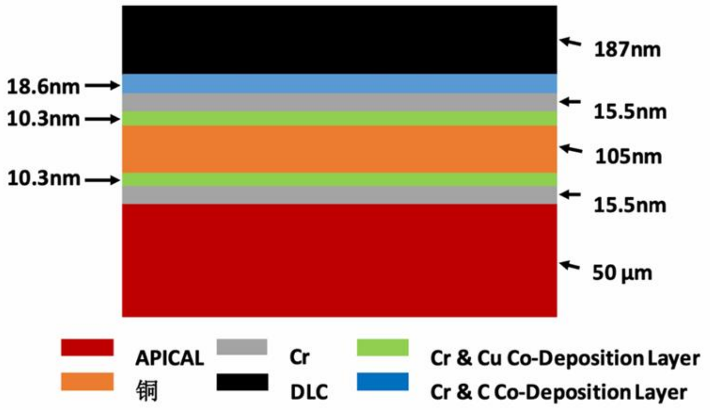
WELL detector

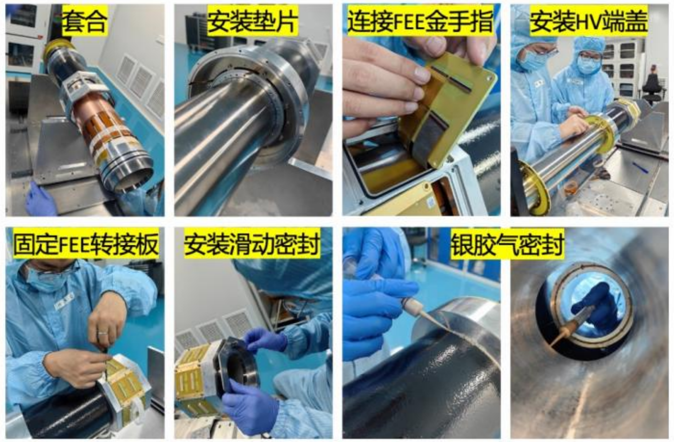


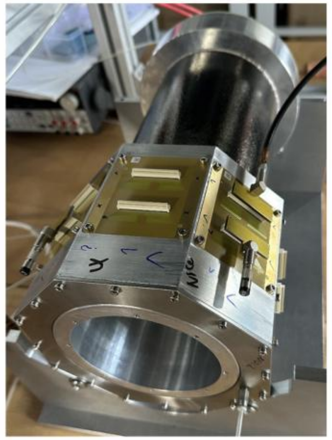




μRGroove provides larger signals and easier production compared to μRWELL.







Fabriacating the low-mass c-μRGroove prototype: material budget ~ 0.23%X0/layer

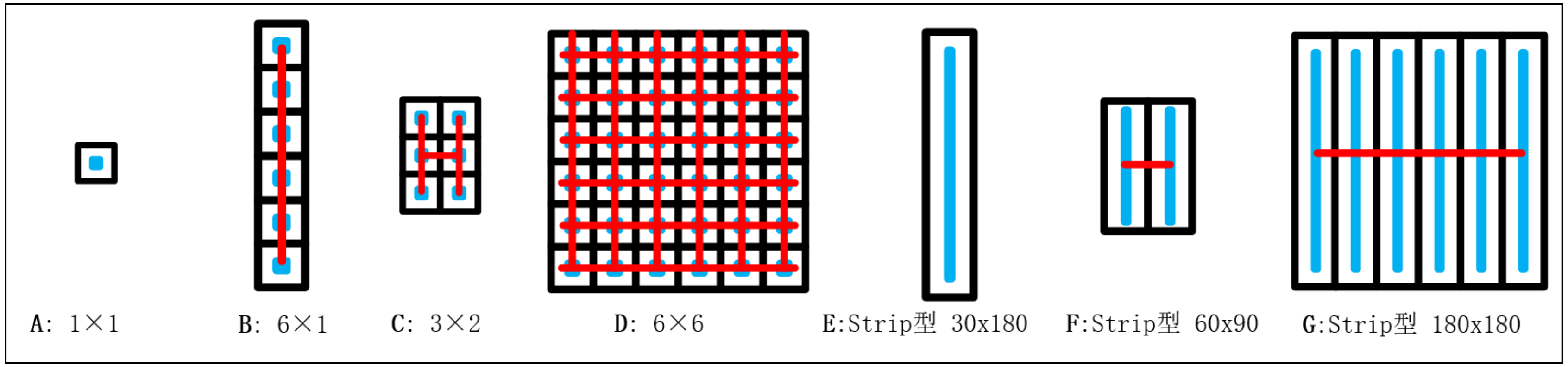
MAPS ITK : MAPS Designs

Features: High radiation resistance, high position resolution

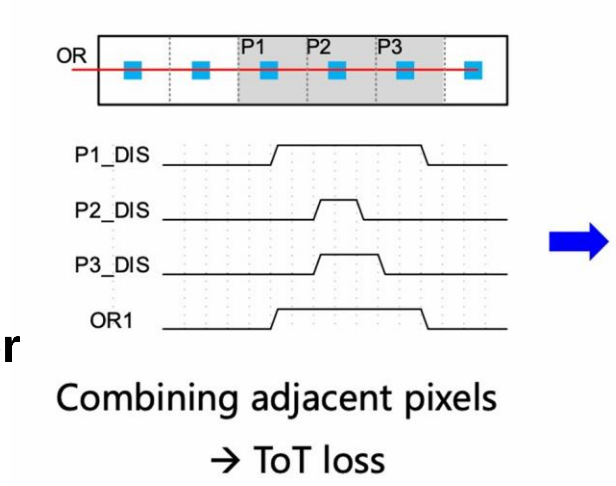
Challenges: MAPS, low power consumption, timing, etc.

Aiming for a low-power chip design (required for a low-mass system) with timing and charge measurement capability

Use larger pixel size to reduce the power consumption density

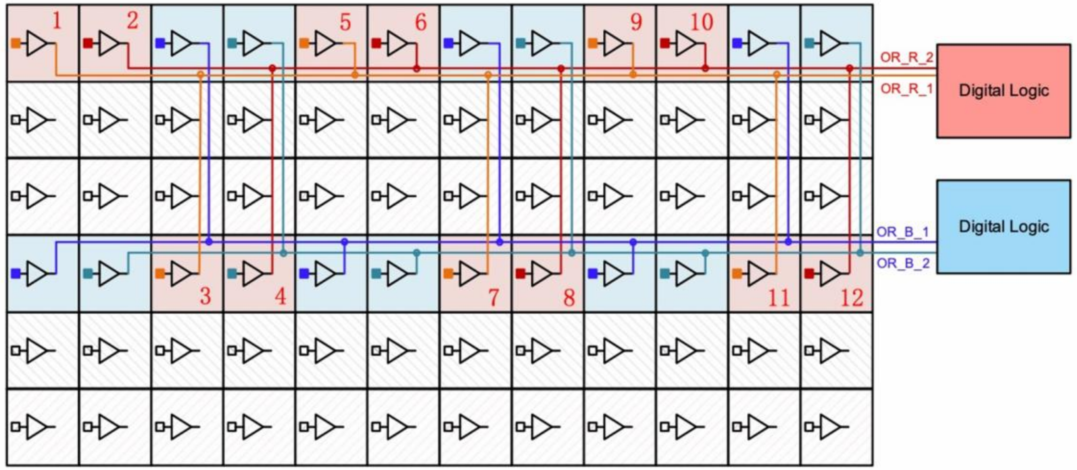


Combining non-adjacent pixels and designing a super-pixel design that can provide both high position and high time resolutions for low power consumption.



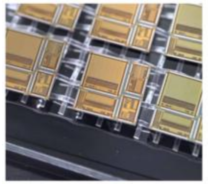
Combining adjacent pixels

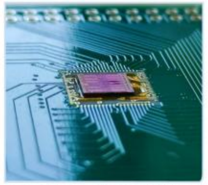
→ ToT loss

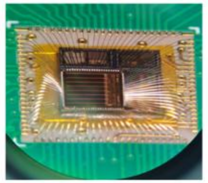


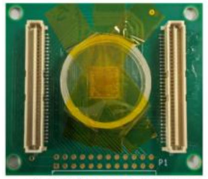
MAPS ITK : MAPS Testing

- Characterized the TJ chips for threshold, noise, fake hit rate and capacitance. Tested the chips with laser and radioactive sources (Fe55 and Sr90) for detection efficiency, charge collection efficiency and time resolution.

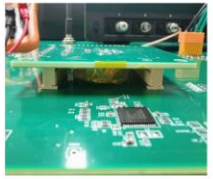

TJ芯片


同尺寸芯片试粘接在绝缘胶上

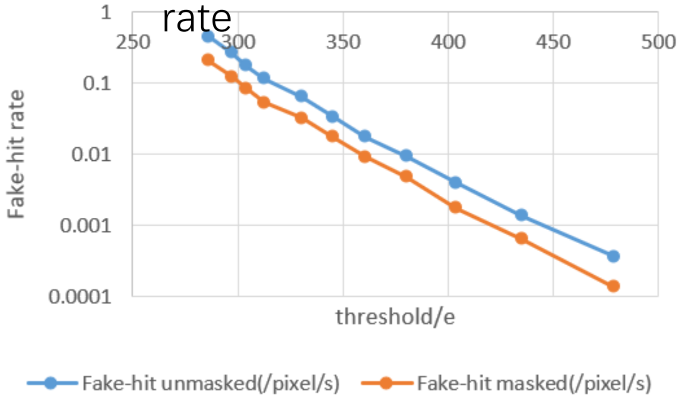

未划片直接打线

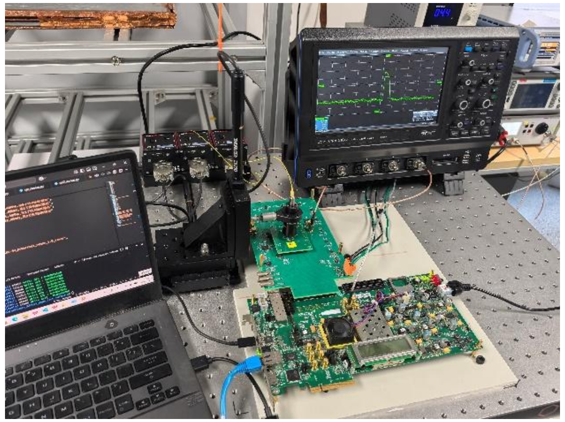

子板背面(芯片+保护壳)

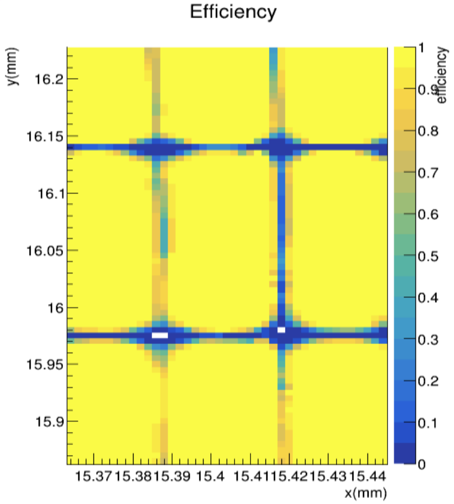

子板正面(绝缘胶挖洞)

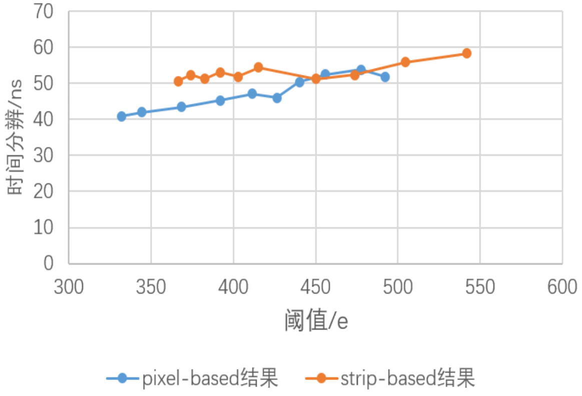

子板安装在测试转接板上

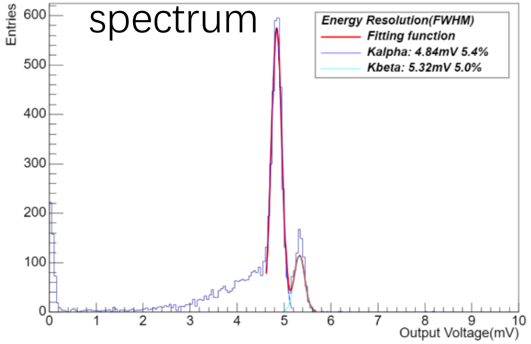
偏压/V	Threshold/e	FPN/e	TN/e	A_{OUT}/mV	基线RMS/mV
-2	268.2	7.15	16.1	523	7.8
-3	234.7	2.75	15.3	477	9.2
-4	212.2	0.82	15.4	417	7.06
-5	178.1	5.32	11.3	348	5.92
-6	182.1	7.11	12.1	292	5.88


Background trigger rate




Efficiency

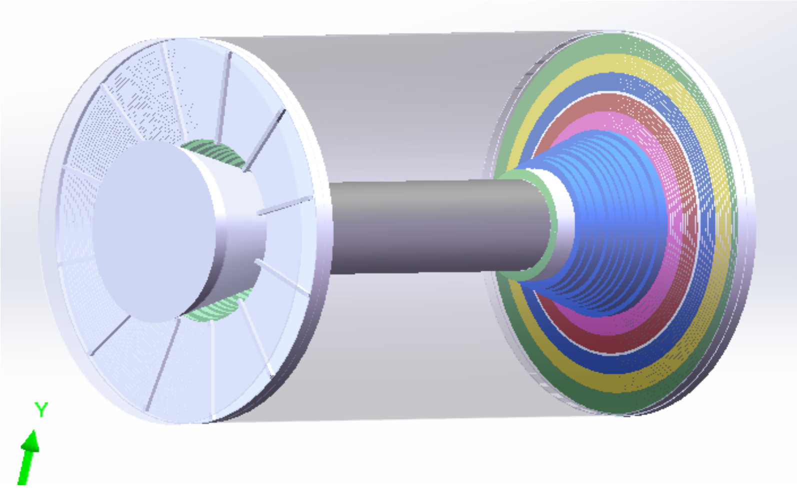

Time resolution

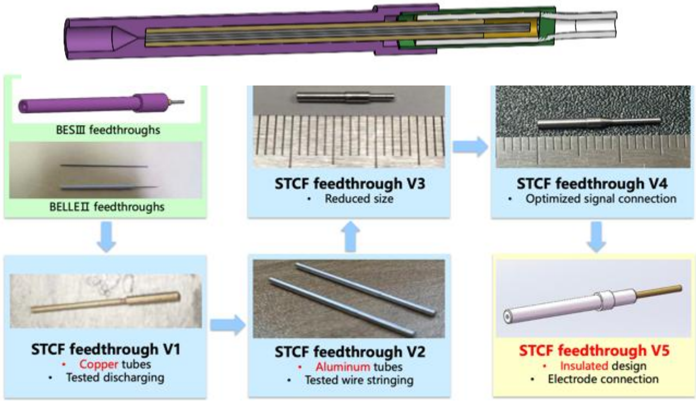

Fe55 energy spectrum

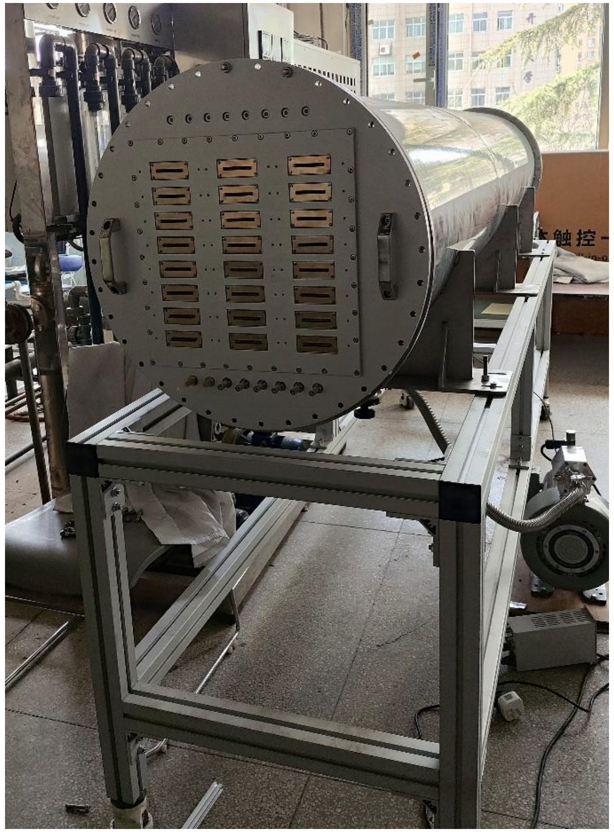
Main Drift Chamber : Detector

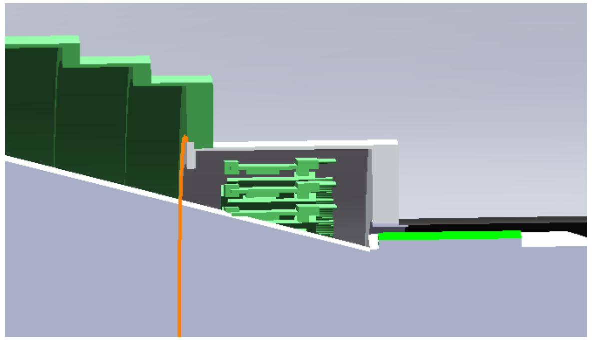
•**Challenges**: Low material budget, high count rate, small unit..

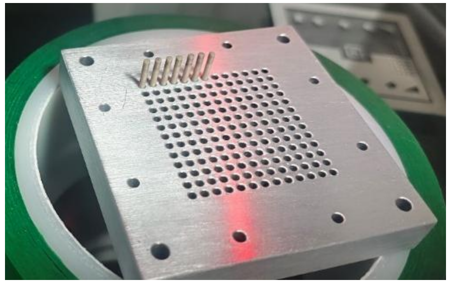
- ❖ **Endplate structure optimized to simplify the assembly process**
- ❖ **Intensive ongoing R&D effort on feedthrough for super-small cells (~5 mm)**
- ❖ **A full-length super-small cell drift chamber prototype is under construction.**

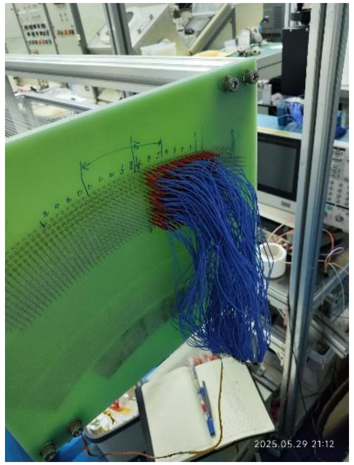








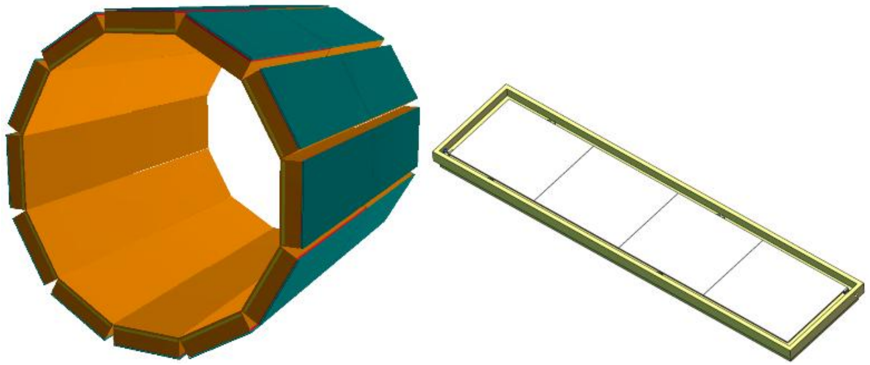




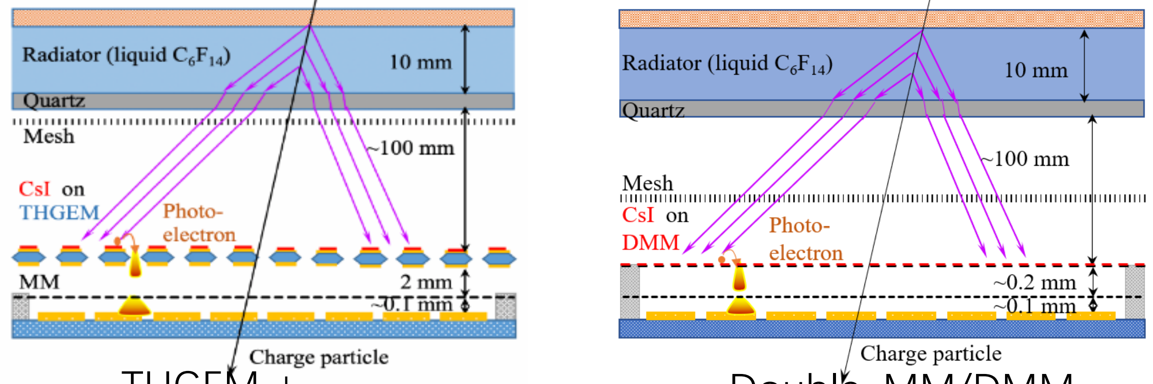
PID System

- PID system: thickness < 20cm, material budget < $0.3X_0$, π/K ~4σ @ 2GeV

❖ Barrel PID: A RICH detector using MPGD with CsI for photon detection, σ_θ ~ 4 mrad



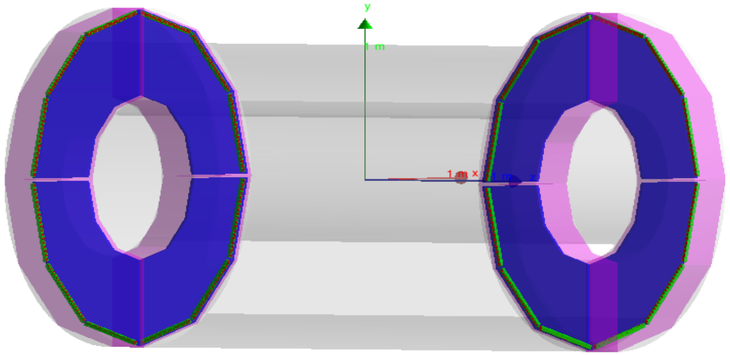
Two MPGD-based photo detector options

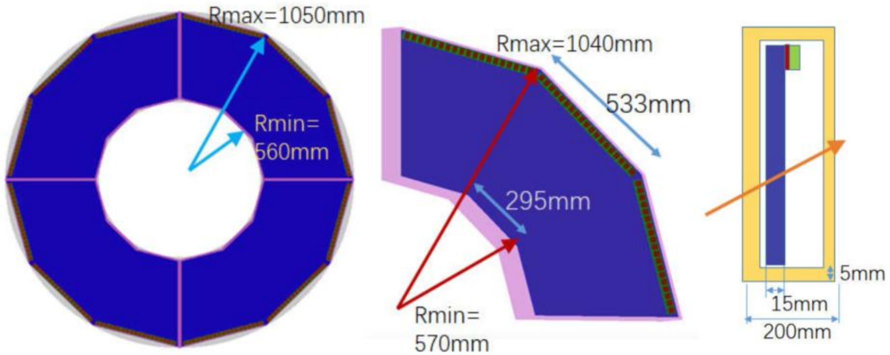


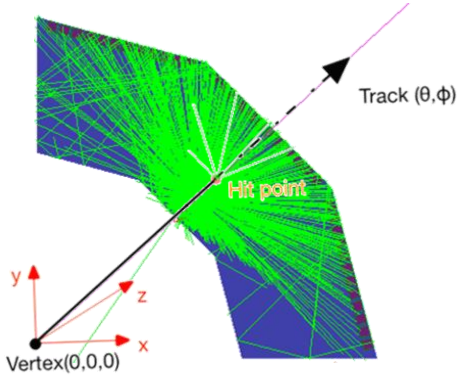
THGEM + MM

Double-MM/DMM

- Endcap PID: A DIRC-like TOF detector, DTOF, quartz plate + MCP-maPMT , σ_t ~ 30ps



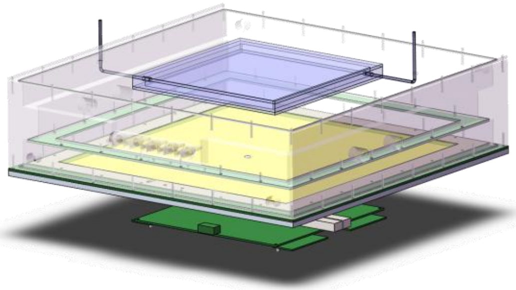


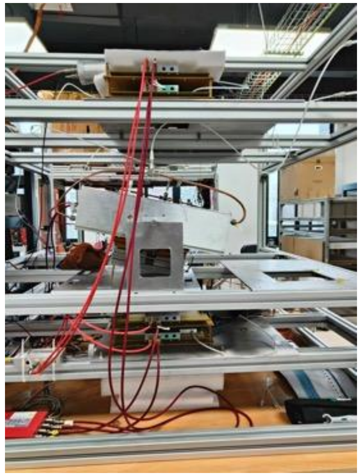


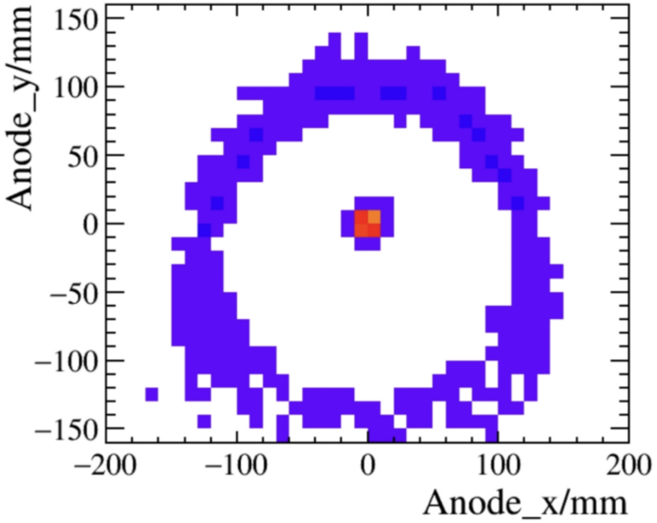
PID Barrel : RICH

- **Features**: Large-area s.p.e. detection
- **Challenges**: Large-area gas detector, UV s.p.e. detection, readout, etc.

Cosmic-ray test of a 32×32 cm^2 RICH prototype with THGEM + MM

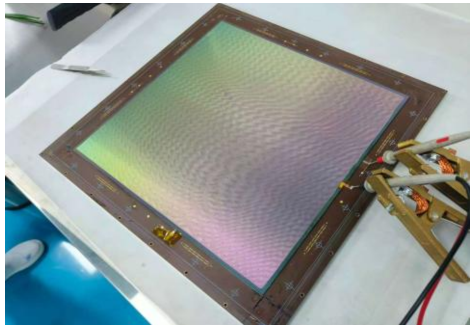






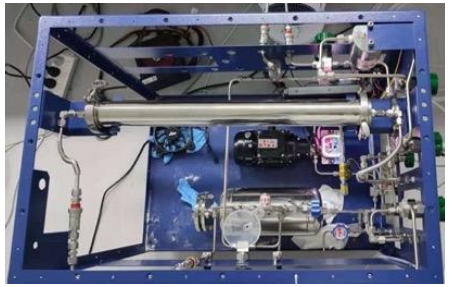
Moved to DMM option : DMM-RICH

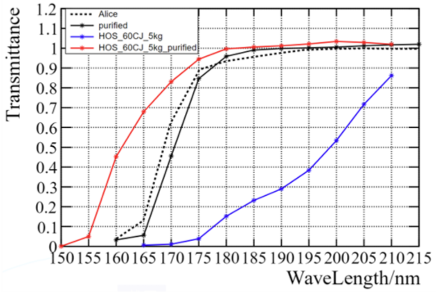
- Compact structure
- High gain & good time resolution
- High electron collection efficiency & low ion backflow



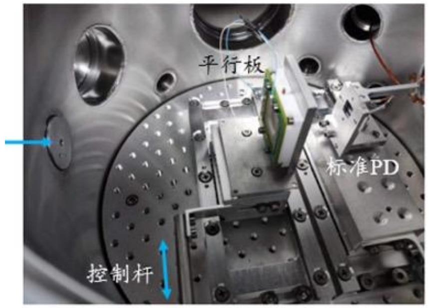
Ongoing test of a DMM-RICH prototype

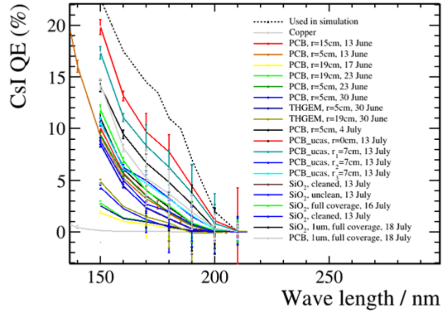
Ongoing efforts to bring up the photoelectron yield





Enhancing radiator transparency by purifying C_6F_{14}





Improving QE: CsI coating and QE measurement

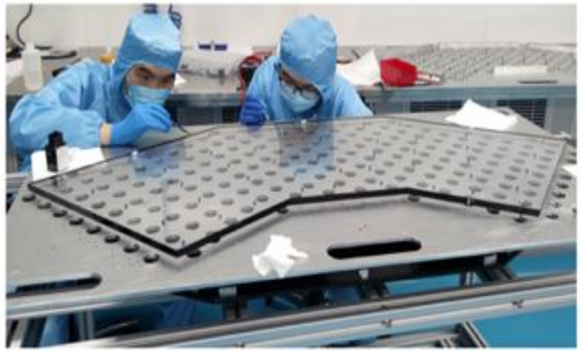
PID Endcap: DTOF

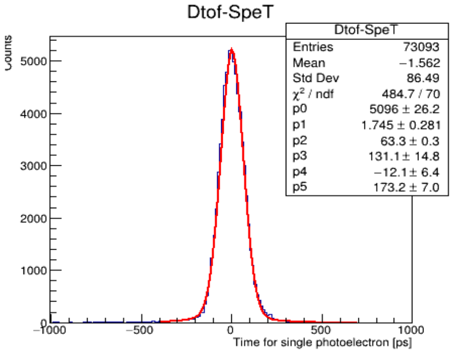
•**Features**: High-precision time resolution

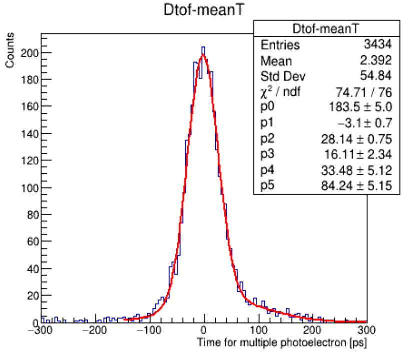
•**Challenges**: Fabrication of large-area quartz radiators, MAPMT, etc.

- A full-size DTOF prototype (a quadrant of STCF DTOF at one endcap) was built and tested with cosmic-rays to demonstrate the DTOF concept and technology on the full scale.

σ_{spe}=59 ps , σ_{track}=21 ps

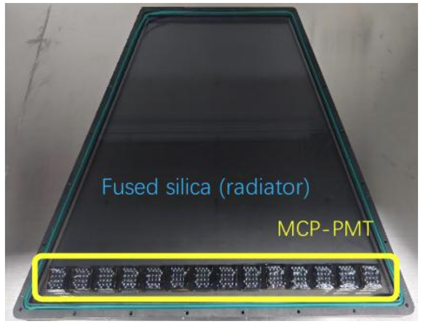


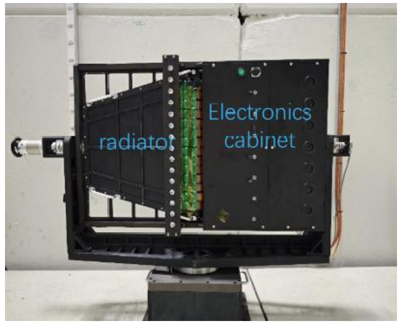


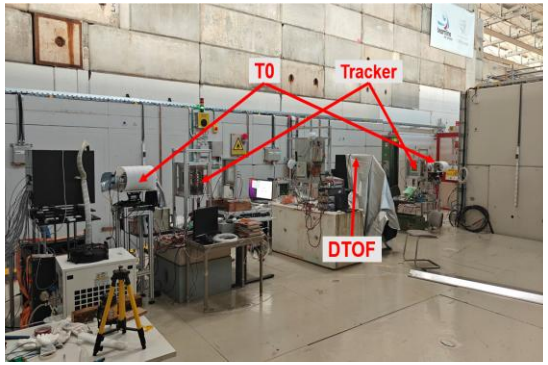


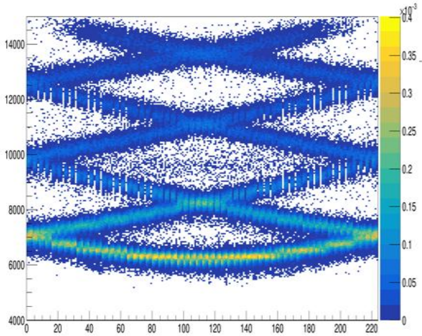
- A smaller DTOF prototype a third the size of the quadrant was built and tested with particle beams at CERN to demonstrate the PID capability of the DTOF detector

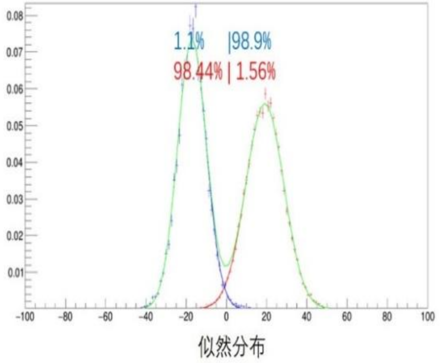
π/K separation >4σ @







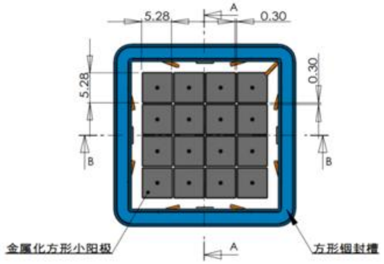


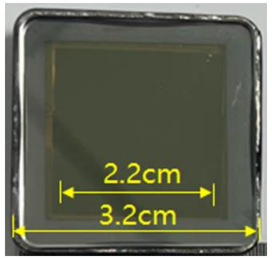


MCP-maPMT and Readout ASICs

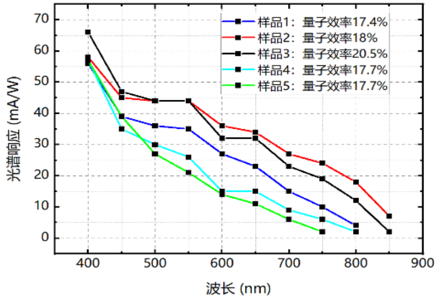
- MCP-maPMT: a critical component of the DTOF technology
- Intensive R&D on techniques (ALD and electron scrubbing) to produce long-life MCP-PMT (target Q > 10 C/cm^2).
- Designed and produced 1-inch MCP-maPMT prototypes with 16 annodes each.
- Carried out various tests of the MCP-maPMT prototypes
  - TTS<40 ps, QE>20%, G>10^6,
  - Aging : <10% gain drop when Q>11C/cm^2

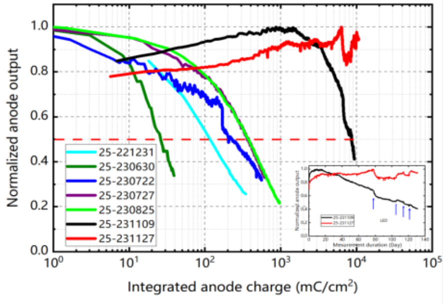
- Two ASICs designed for MCP-maPMT readout. Prototype chips produced and tested
  - FET: target ~ 15 ps, measured ~15 ps
  - TDC: target ~ 15 ps , measured ~10 ps

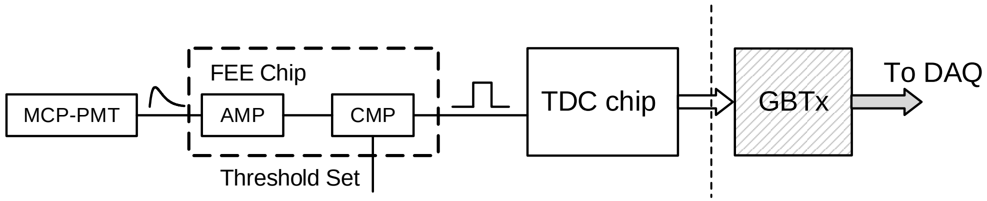


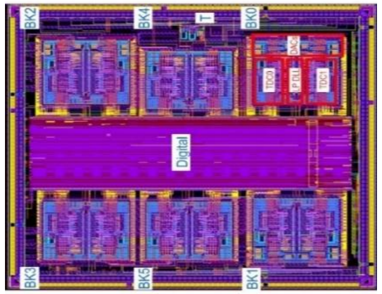


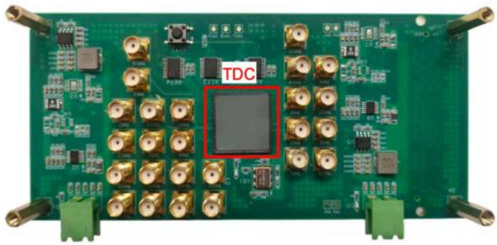
MCP-PMT编号	25-240507	25-240521	25-240605	25-240620
MCP类型	ALD-MCP，ALD镀膜厚度：D2			
MCP厂家	厂家1	厂家1	厂家2	厂家2
MCP电子清刷剂量	0.75 uA·h/cm²	0.87 uA·h/cm²	0.75 uA·h/cm²	0.87 uA·h/cm²

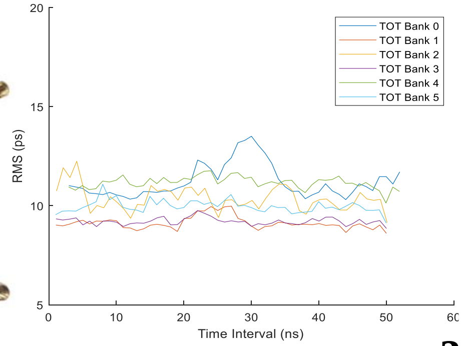










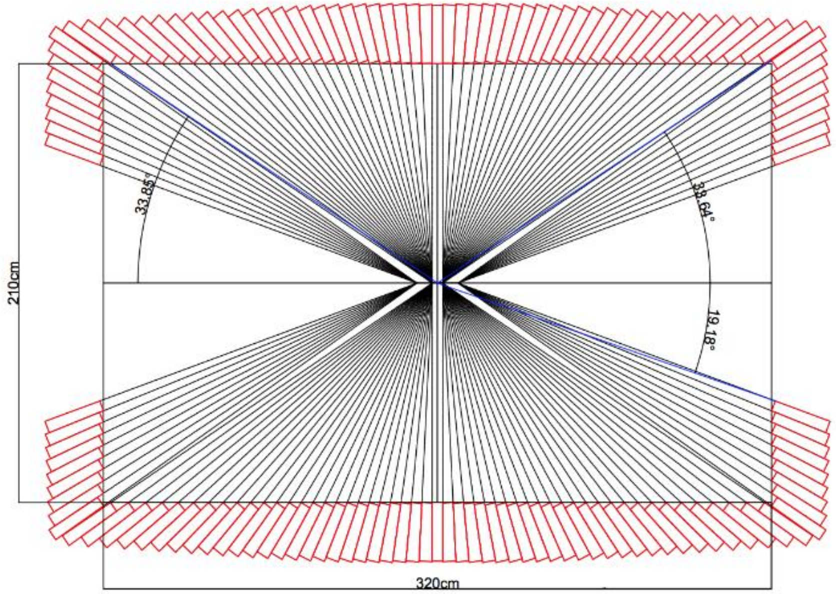


EMC

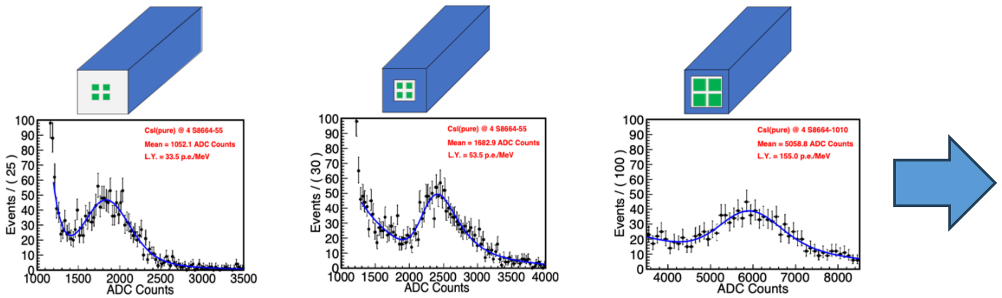
- **Features**: Fast time response, high energy resolution
- **Challenges**: CsI light yield, event pile-up and time extraction, etc.

A crystal calorimeter using pCsI (short decay time of 30ns) to tackle the high background rate (~1 MHz/crystal)

- Crystal size: 28cm ($15X_0$), $5\times5cm^2$
- Defocused layout: 6732 crystals in barrel, 1938 crystals in endcaps
- 4 large area APDs to address low light yield: $4\times(1\times1cm^2)$



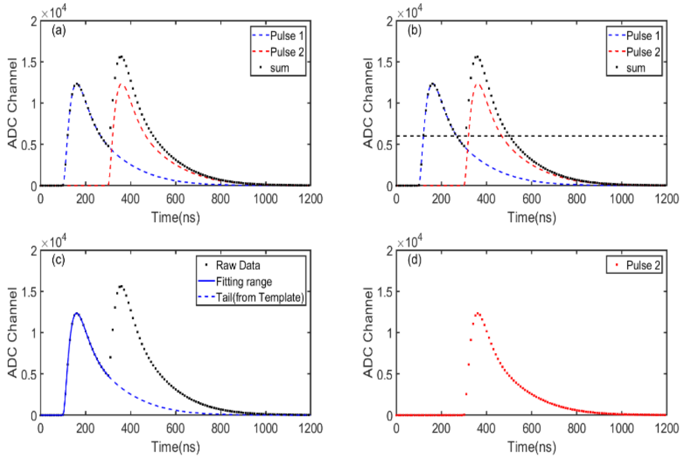
A very low light yield of 3.6% for pCsI → a major R&D task : enhance the light yield of a pCsI unit

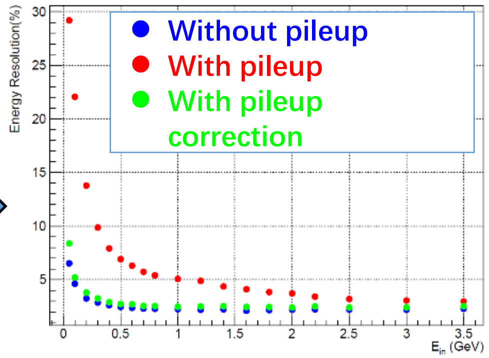


Light yield : 50 p.e./MeV → 300 p.e./MeV

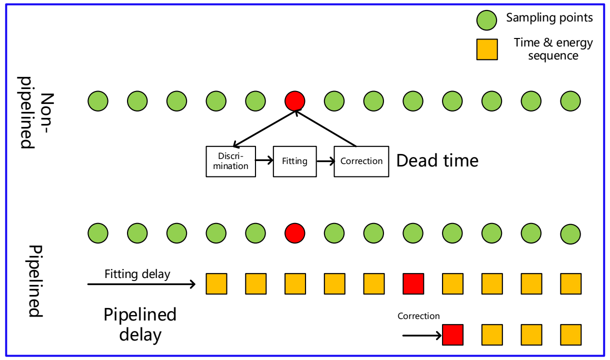
EMC : Pileup Mitigation and Electronics

- Significant pileup in EMC in the presence of beam background (~1 MHz/ch). A dead-time free pileup correction algorithm involving waveform fitting based on pipelined optimal filtering has been developed and implemented in FPGA

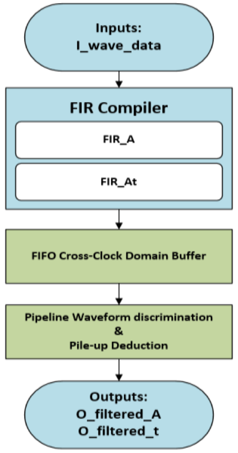




Very effective in mitigating the pileup effect

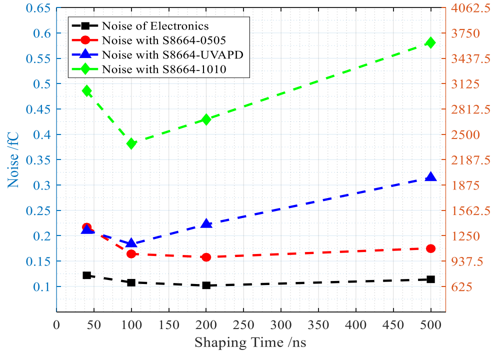


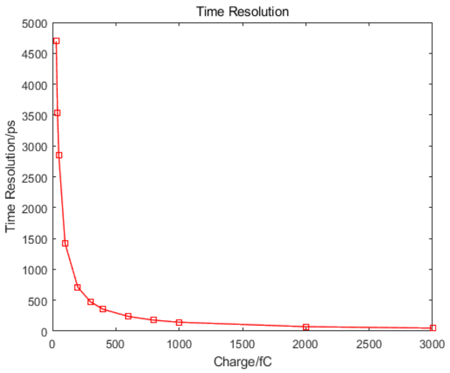
Pipelined correction algorithm



FPGA implementation

- Development of waveform digitization electronics (CSA + shaper + ADC)





Dynamic range
3 MeV ~ 3 GeV

ENE : ~ 0.5 MeV

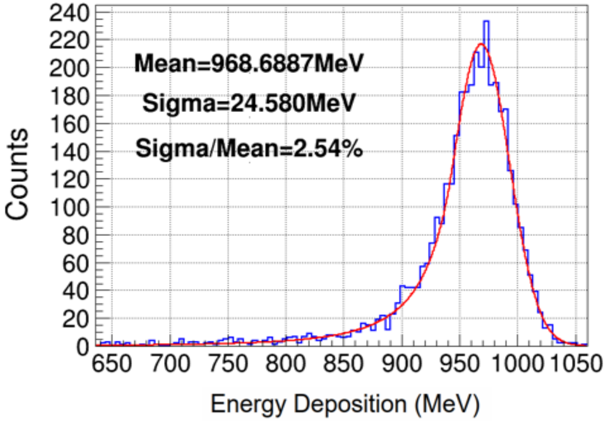
Time resolution
< 150 ps@1GeV

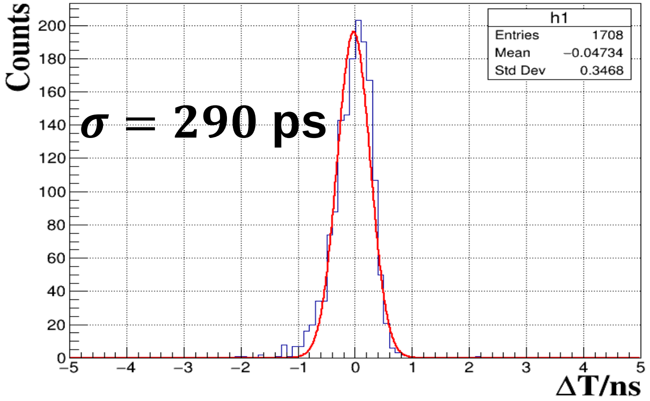
5×5 pCsI EMC Prototype

EMC prototype in the making

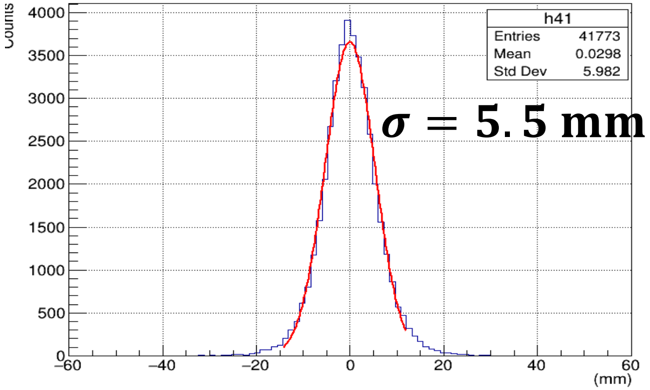
Beam test at CERN PS

Performance from the beam test with 1 GeV/c electrons





$\sigma = 290$ ps

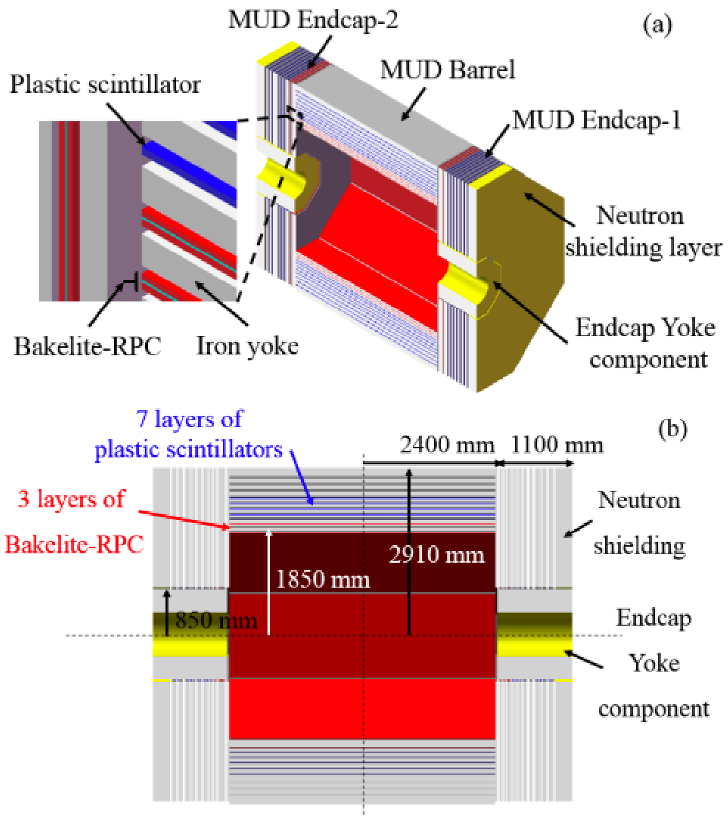


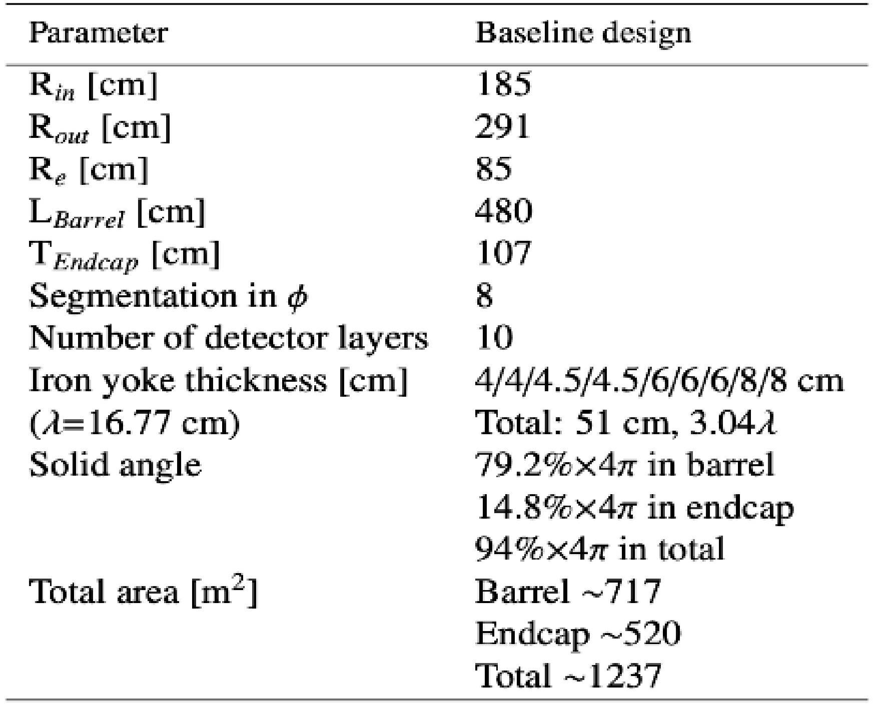
$\sigma = 5.5$ mm

Muon Detector

- **Features**: Enables muon and neutral hadron identification
- **Challenges**: R&D and optimization of the two types of detectors

- **A hybrid design with RPC and scintillator strips for optimal overall muon and neutral hadron identification performance**
  - **RPC for inner 3 layers : not sensitive to background**
  - **Scintillator for outer 7 layers: sensitive to hadrons**



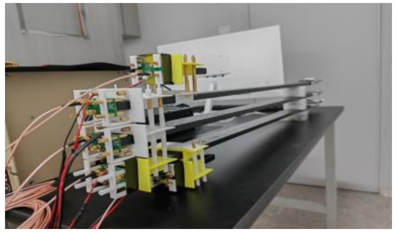


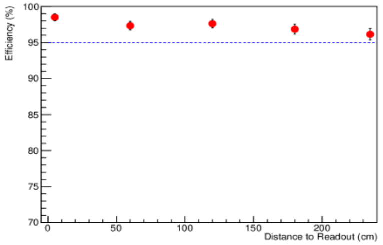
Parameter	Baseline design
R_{in} [cm]	185
R_{out} [cm]	291
R_e [cm]	85
L_{Barrel} [cm]	480
T_{Endcap} [cm]	107
Segmentation in ϕ	8
Number of detector layers	10
Iron yoke thickness [cm]	4/4/4.5/4.5/6/6/6/8/8 cm
(λ=16.77 cm)	Total: 51 cm, 3.04λ
Solid angle	79.2%×4π in barrel 14.8%×4π in endcap 94%×4π in total
Total area [m^2]	Barrel ~717 Endcap ~520 Total ~1237

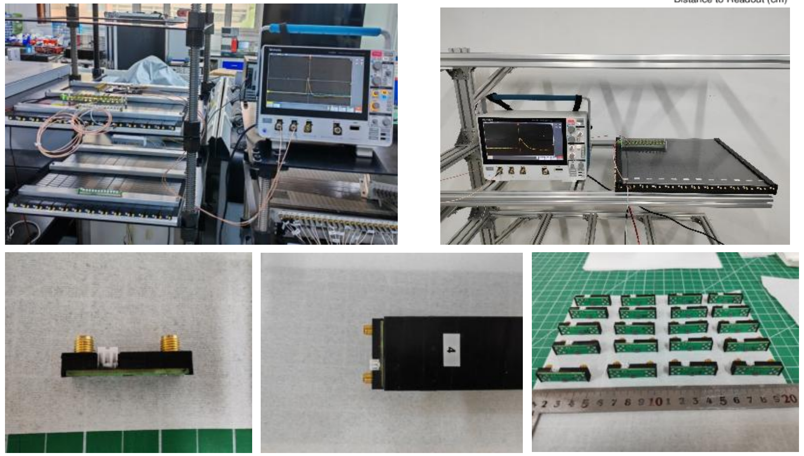
MUD R&D

Scintillator strip + WLS + SiPM

- Design and fabrication of the scintillator unit： reflector, fiber groove, optical coupling, surface processing.
- Fabricated 2.4 long scintillator units (efficiency>95%) and a 50×50 cm² scintillator strip array

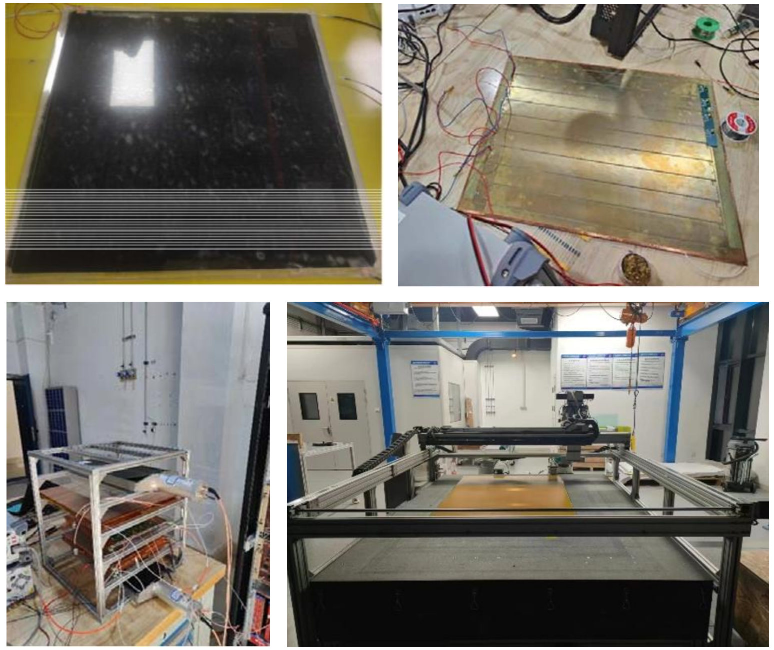






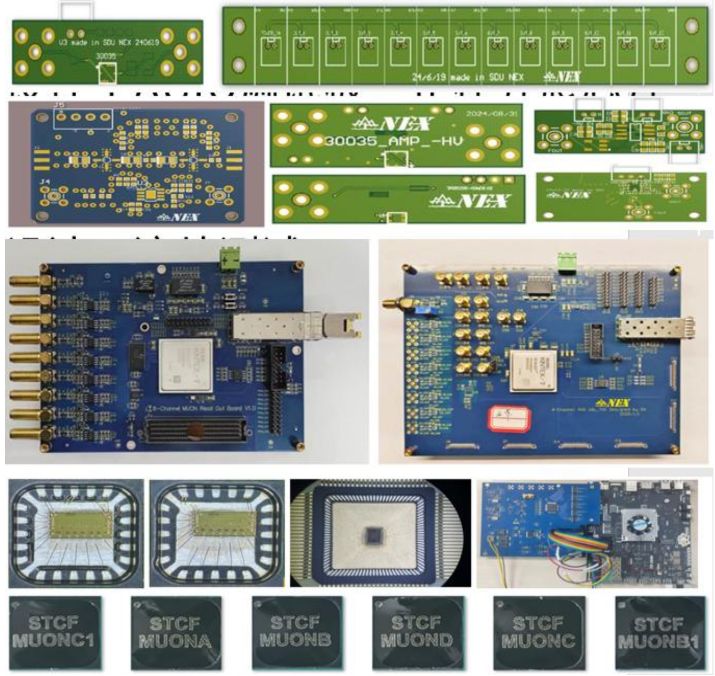
Glass RPC

- Developed glass RPC fabrication techniques and built a 40×40 cm² glass prototype.
- Focusing on low-resistivity glass RPC for high count rate capabilities. Built some small prototypes.



Readout Electronics

- Developed front-end amplifiers and readout boards. Tested with detector prototypes.
- Designed front-end ASICs for different input capacitance and gains. Prototype chips being tested



Summary & Outlook

FRONTIERS OF PHYSICS

REPORT
Volume 19 / Issue 1 / 14701 / 2024

STCF conceptual design report (Volume 1):
Physics & detector

M. Achasov[3], X. C. Ai[82], R. Aliberti[38], Q. An[63,72], X. Z. Bai[63,72], Y. Bai[62], O. Bakina[39], A. Barnyakov[3,50],
V. Blinov[3,50,51], V. Bobrovnikov[3,51], D. Bodrov[23,60], A. Bogomyagkov[3], A. Bondar[3], I. Boyko[39],
Z. H. Bu[73], F. M. Cai[20], H. Cai[77], J. J. Cao[20], Q. H. Cao[54], X. Cao[33], Z. Cao[63,72], Q. Chang[20],
K. T. Chao[54], D. Y. Chen[62], H. Chen[81], H. X. Chen[62], J. F. Chen[58], K. Chen[6], L. L. Chen[20],
P. Chen[78], S. L. Chen[6], S. M. Chen[66], S. Chen[69], S. P. Chen[69], W. Chen[64], X. Chen[74], X. F. Chen[58],
X. R. Chen[33], Y. Chen[32], Y. Q. Chen[36], H. Y. Cheng[34], J. Cheng[48], S. Cheng[28], T. G. Cheng[2],
J. P. Dai[80], L. Y. Dai[28], X. C. Dai[54], D. Dedovich[39], A. Denig[19,38], I. Denisenko[39], J. M. Dias[4],
D. Z. Ding[58], L. Y. Dong[32], W. H. Dong[63,72], V. Druzhinin[3], D. S. Du[63,72], Y. J. Du[77], Z. G. Du[41],
L. M. Duan[33], D. Epifanov[3], Y. L. Fan[77], S. S. Fang[32], Z. J. Fang[63,72], G. Fedotovich[3], C. Q. Feng[63,72],
X. Feng[54], Y. T. Feng[63,72], J. L. Fu[69], J. Gao[59], P. S. Ge[73], C. Q. Geng[15], L. S. Geng[2], A. Gilman[71],
L. Gong[43], T. Gong[21], B. Gou[33], W. Gradl[38], J. L. Gu[63,72], A. Guevara[4], L. C. Gui[26], A. Q. Guo[33],
F. K. Guo[4,69,2], J. C. Guo[63,72], J. Guo[59], Y. P. Guo[11], Z. H. Guo[16], A. Guskov[39], K. L. Han[69], L. Han[63,72],
M. Han[63,72], X. Q. Hao[20], J. B. He[69], S. Q. He[63,72], X. G. He[59], Y. L. He[20], Z. B. He[33], Z. X. Heng[20],
B. L. Hou[63,72], T. J. Hou[74], Y. R. Hou[69], C. Y. Hu[74], H. M. Hu[32], K. Hu[57], R. J. Hu[33], X. H. Hu[9], Y. C. Hu[49],
J. Hua[61], G. S. Huang[63,72], J. S. Huang[47], M. Huang[69], Q. Y. Huang[69], W. Q. Huang[69], X. T. Huang[57],
X. J. Huang[33], Y. B. Huang[14], Y. S. Huang[64], N. Hüsken[38], V. Ivanov[3], Q. P. Ji[20], J. J. Jia[77], S. Jia[62],
Z. K. Jia[63,72], H. B. Jiang[77], J. Jiang[57], S. Z. Jiang[14], J. B. Jiao[57], Z. Jiao[24], H. J. Jing[69], X. L. Kang[8],
X. S. Kang[43], B. C. Ke[82], M. Kenzie[5], A. Khoukaz[76], I. Koop[3,50,51], E. Kravchenko[3,51], A. Kuzmin[3],
Y. Lei[60], E. Levichev[3], C. H. Li[42], C. Li[55], D. Y. Li[33], F. Li[63,72], G. Li[55], G. Li[15], H. B. Li[32,69], H. Li[63,72],
H. N. Li[61], H. J. Li[20], H. L. Li[27], J. M. Li[63,72], J. Li[32], L. Li[56], L. Li[59], L. Y. Li[63,72], N. Li[64], P. R. Li[41],
R. H. Li[30], S. Li[59], T. Li[57], W. J. Li[20], X. Li[33], X. H. Li[74], X. Q. Li[6], X. H. Li[63,72], Y. Li[79], Y. Y. Li[72], Z. J. Li[33],
H. Liang[63,72], J. H. Liang[61], Y. T. Liang[33], G. R. Liao[13], L. Z. Liao[25], Y. Liao[61], C. X. Lin[69], D. X. Lin[33],
X. S. Lin[63,72], B. J. Liu[32], C. W. Liu[15], D. Liu[63,72], F. Liu[6], G. M. Liu[61], H. B. Liu[14], J. Liu[54], J. J. Liu[74],
J. B. Liu[63,72], K. Liu[41], K. Y. Liu[43], K. Liu[59], L. Liu[63,72], Q. Liu[69], S. B. Liu[63,72], T. Liu[11], X. Liu[41], Y. W. Liu[63,72],
Y. Liu[82], Y. L. Liu[63,72], Z. Q. Liu[57], Z. Y. Liu[41], Z. W. Liu[45], I. Logashenko[3], Y. Long[63,72], C. G. Lu[33],
J. X. Lu[2], N. Lu[63,72], Q. F. Lü[26], Y. Lu[7], Y. Lu[69], Z. Lu[62], P. Lukin[3], F. J. Luo[74], T. Luo[11], X. F. Luo[6],
H. J. Lyu[24], X. R. Lyu[69], J. P. Ma[35], P. Ma[33], Y. Ma[15], Y. M. Ma[33], F. Maas[19,38], S. Malde[71], D. Matvienko[3],
Z. X. Meng[70], R. Mitchell[29], A. Nefediev[40], Y. Nefedov[39], S. L. Olsen[22,53], Q. Ouyang[32,63], P. Pakhlov[23],
G. Pakhlova[23,52], X. Pan[60], Y. Pan[62], E. Passemar[29,65,67], Y. P. Pei[63,72], H. P. Peng[63,72], L. Peng[27],
X. Y. Peng[8], X. J. Peng[41], K. Peters[12], S. Pivovarov[3], E. Pyata[3], B. B. Qi[63,72], Y. Q. Qi[63,72], W. B. Qian[69],
Y. Qian[33], C. F. Qiao[69], J. J. Qin[74], J. J. Qin[63,72], L. Q. Qin[13], X. S. Qin[57], T. L. Qiu[33], J. Rademacker[68],
C. F. Redmer[38], H. Y. Sang[63,72], M. Saur[54], W. Shan[26], X. Y. Shan[63,72], L. L. Shang[20], M. Shao[63,72],
L. Shekhtman[3], C. P. Shen[11], J. M. Shen[28], Z. T. Shen[63,72], H. C. Shi[63,72], X. D. Shi[63,72], B. Shwartz[3],
A. Sokolov[3], J. J. Song[20], W. M. Song[36], Y. Song[63,72], Y. X. Song[10], A. Sukharev[3,51], J. F. Sun[20],
L. Sun[77], X. M. Sun[6], Y. J. Sun[63,72], Z. P. Sun[33], J. Tang[64], S. S. Tang[63,72], Z. B. Tang[63,72], C. H. Tian[63,72],
J. S. Tian[78], Y. Tian[33], Y. Tikhonov[3], K. Todyshev[3,51], T. Uglov[52], V. Vorobyev[3], B. D. Wan[15],
B. L. Wang[69], B. Wang[63,72], D. Y. Wang[54], G. Y. Wang[21], G. L. Wang[17], H. L. Wang[61], J. Wang[49],
J. H. Wang[63,72], J. C. Wang[63,72], M. L. Wang[32], R. Wang[63,72], R. Wang[33], S. B. Wang[59], W. Wang[59],
W. P. Wang[63,72], X. C. Wang[20], X. D. Wang[74], X. L. Wang[63,72], X. L. Wang[20], X. P. Wang[2], X. F. Wang[41],

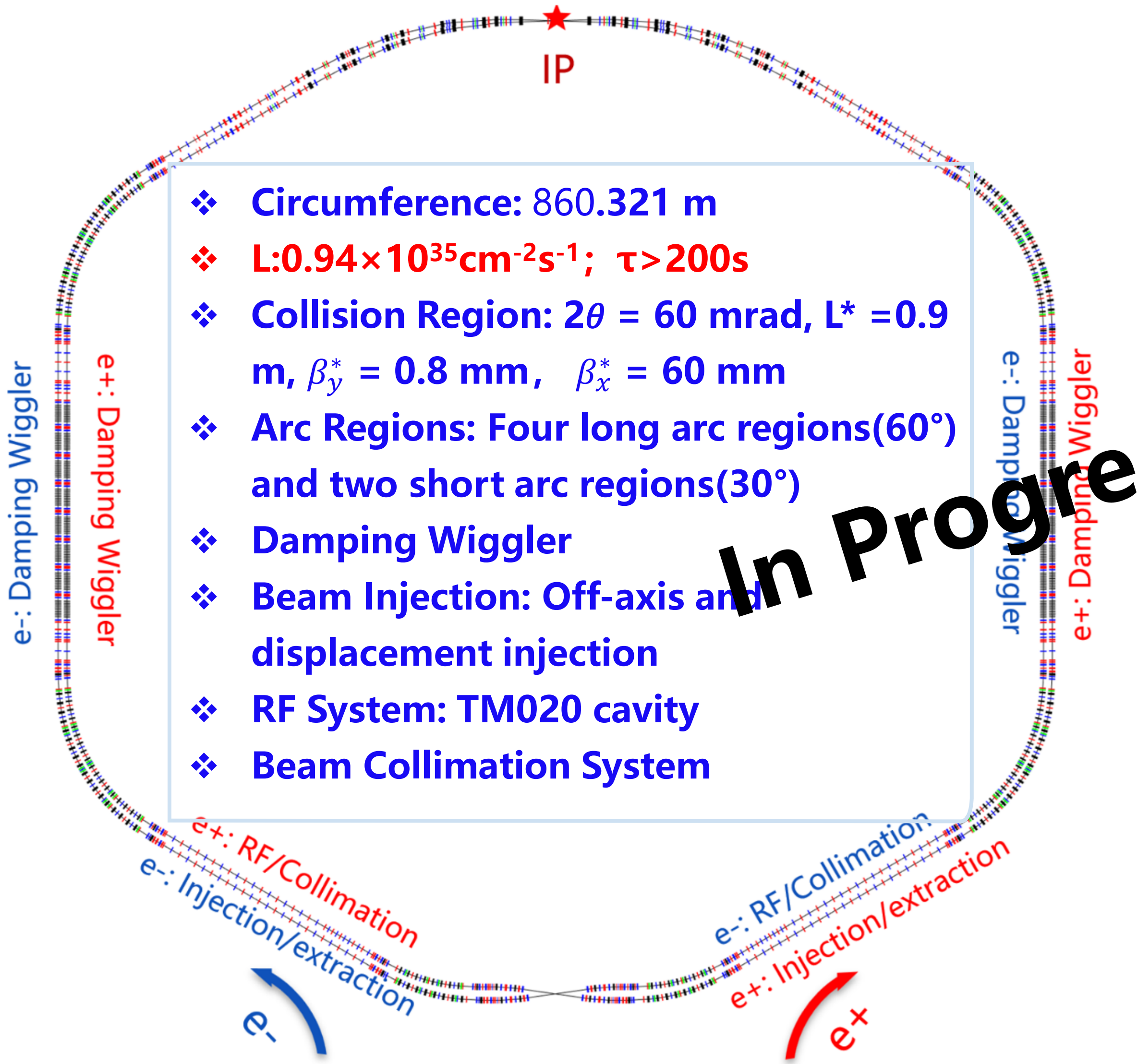
Higher Education Press

arXiv: 2303.15790
https://doi.org/10.1007/s11467-023-1333-z

- **STCF is a super tau-charm facility proposed by the Chinese HEP community as one of the post-BEPCII HEP projects in China.**
  - E_{cm} = 2 – 7 GeV, L > 0.5×10^{35} $cm^{-2}s^{-1}$@4 GeV
- **Many new R&D efforts have launched, the CDR for physics and detector was published recently.**
- **A full-scale R&D program funded by local governments and USTC**
- **Still lots of room for design optimization, particularly global optimization**

Thanks for your attention!

STCF accelerator



- **Circumference:** 860.321 m
- **L:0.94×10^{35}cm^{-2}s^{-1}; τ>200s**
- **Collision Region: 2θ = 60 mrad, L* =0.9 m, β_y^* = 0.8 mm, β_x^* = 60 mm**
- **Arc Regions: Four long arc regions(60°) and two short arc regions(30°)**
- **Damping Wiggler**
- **Beam Injection: Off-axis and displacement injection**
- **RF System: TM020 cavity**
- **Beam Collimation System**

Parameters	Units	2 GeV
Circumference, C	m	860.321
Crossing angle, 2θ	mrad	60
Hor. /Ver. beta function at IP, β_x^*/β_y^*	mm	60/0.8
Hor./Ver. betatron tune		30.543/34.58
Beam current, I	A	2
Hor. Emittance (SR/DW+IBS)	nm	8.79/4.63
Ver. Emittance (SR/DW+IBS)	pm	87.9/46.3
Ratio, $\varepsilon_y/\varepsilon_x$	%	1
Momentum compaction factor, α_p	10^{-3}	1.35
Energy spread (DW+IBS)	10^{-4}	7.8
Energy loss per turn (SR+DW), U_0	keV	543
SR power per beam (SR+DW), P	MW	1.086
RF voltage	MV	2.5
Synchrotron tune, ν_s		0.0194
δ_{RF}	%	1.68
Bunch length (Nature/0.1Ω+IBS)	mm	7.21/8.70
Hor./Ver. beam-beam parameter, ξ_x/ξ_y		0.005/0.095
Luminosity	cm^{-2}s^{-1}	9.4E+34

Qing LUO @ workshop on Super Tau Charm Facility,2025.07