26th International
Symposium on Spin Physics
A Century of Spin

The progress of Super Tau-Charm Facility in China

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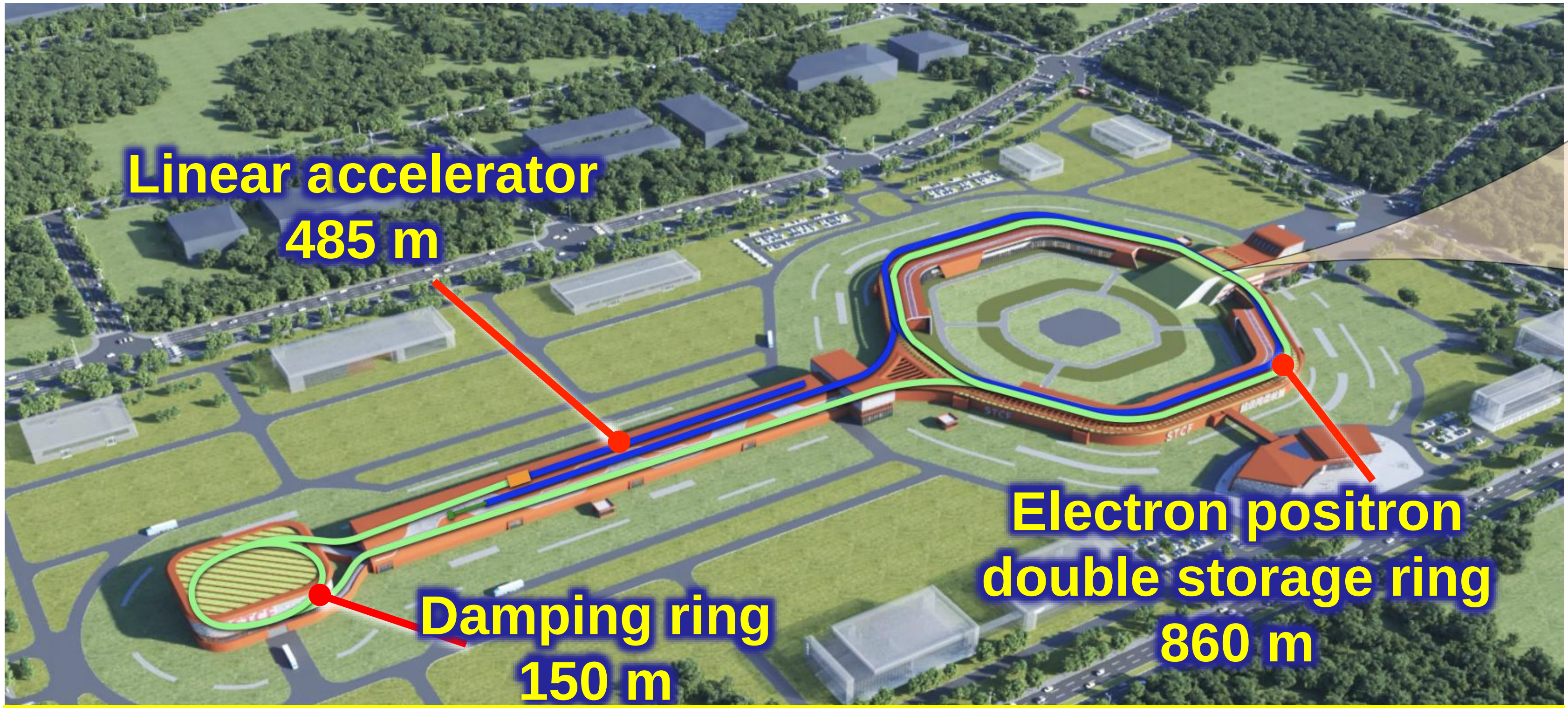
On behalf of the STCF working group
24/09/2025

STCF
超级陶粲装置
Super Tau-Charm Facility

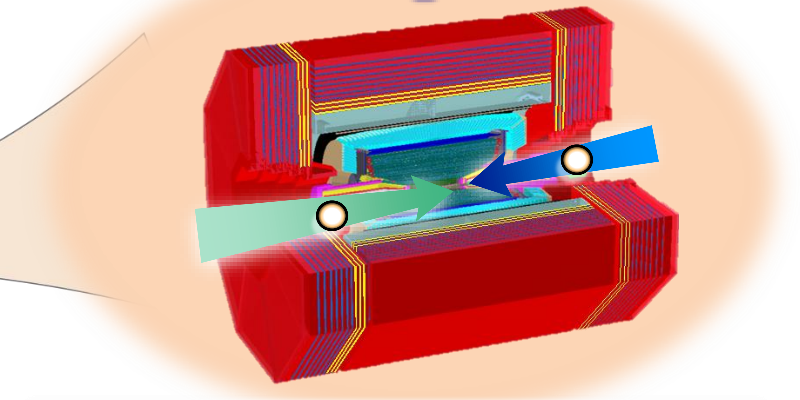
Outline

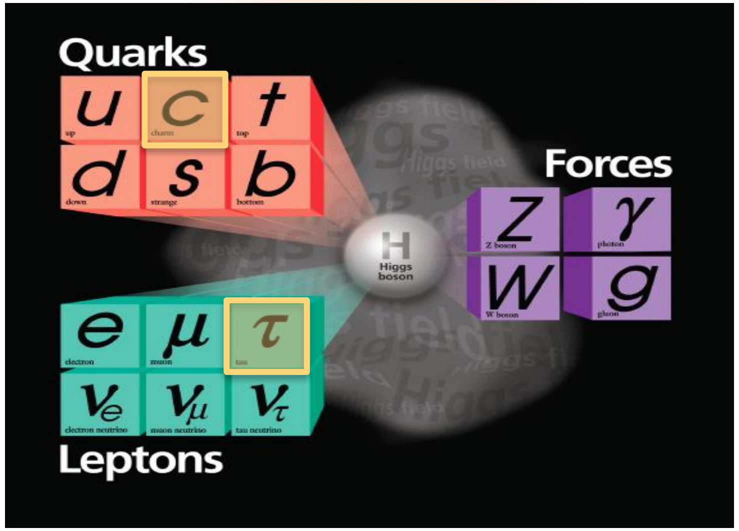
1. **Physics motivation**
2. Accelerator progress
3. Detector progress
4. Simulation studies
5. Summary

The Super Tau Charm Facility



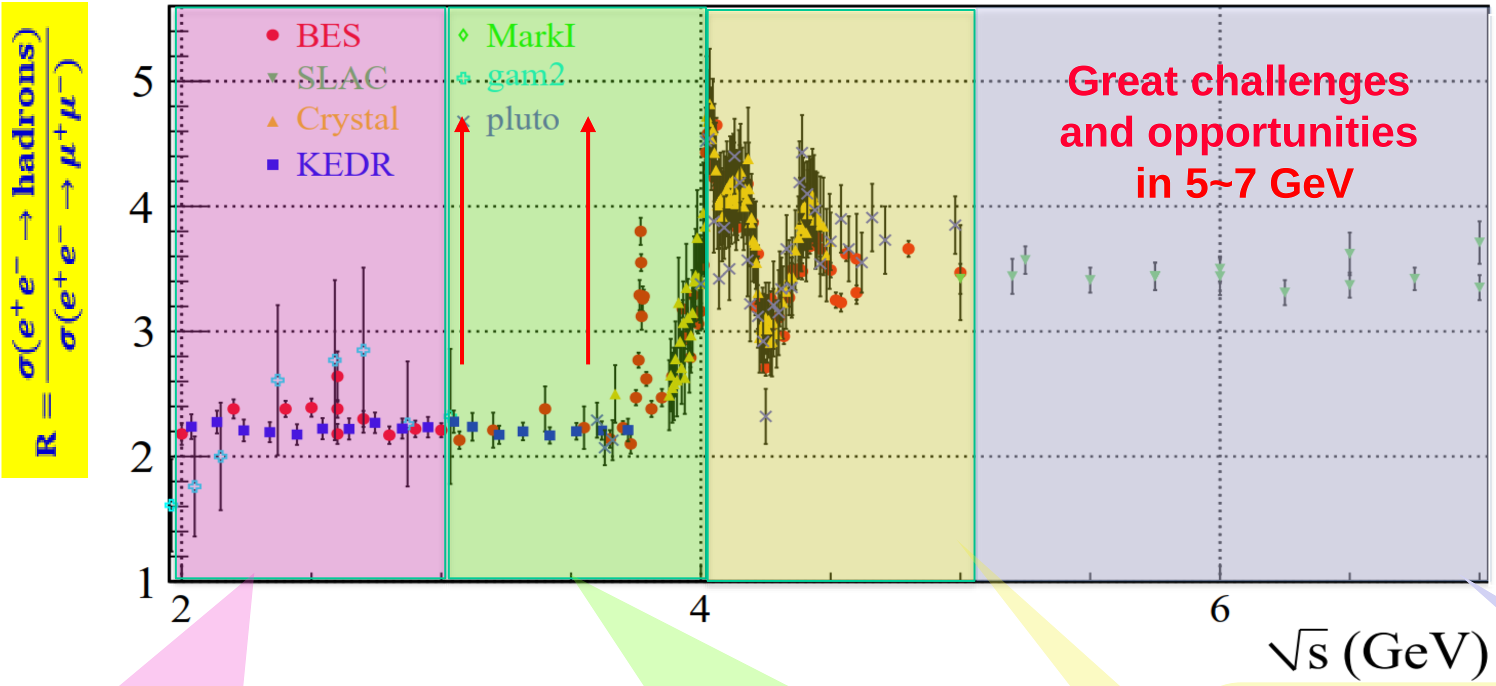
Detector spectrometer





- E_{CM} = 2-7GeV, luminosity over $0.5\times10^{35}cm^{-2}s^{-1}$
- Event rate within 2 days ≈ 1 year of current facility

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

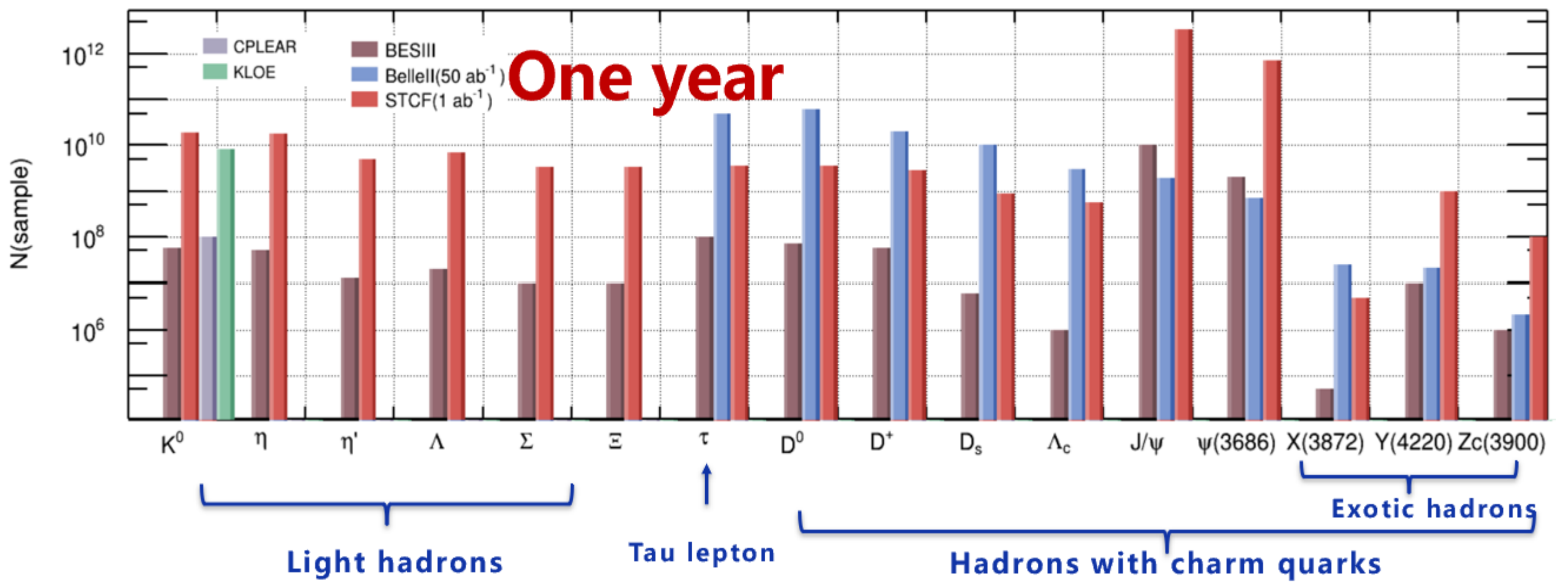
- XYZ particles
- Physics with D mesons
- f_D and f_{D_s}
- $D^0 - \bar{D}^0$ mixing
- Charm baryons

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

Physics Flagships & Expected Data Production

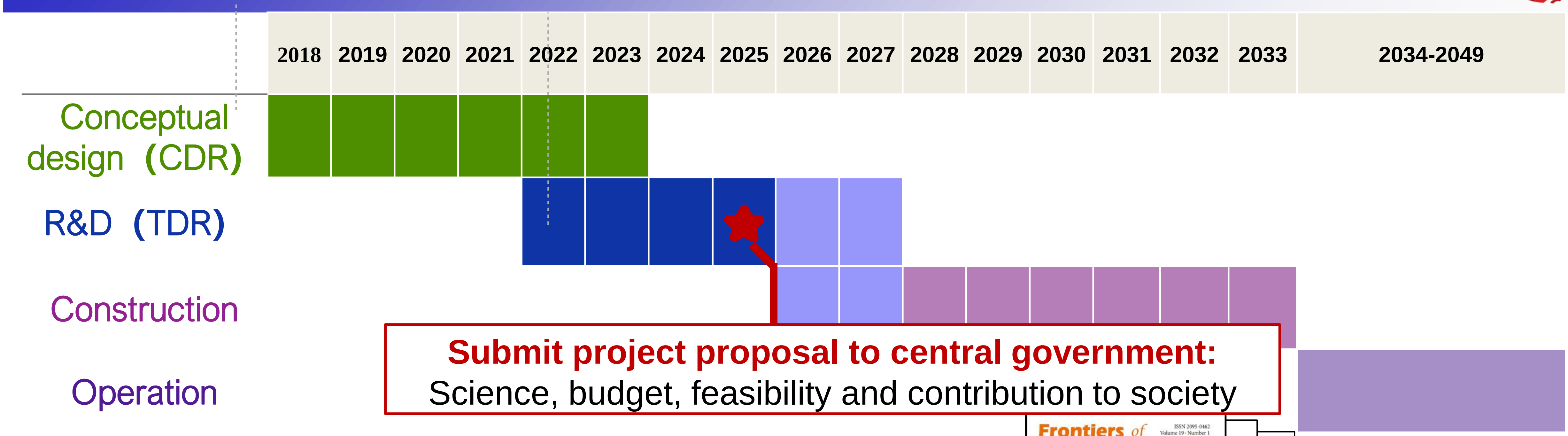
Three-fold physics flagships:

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



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

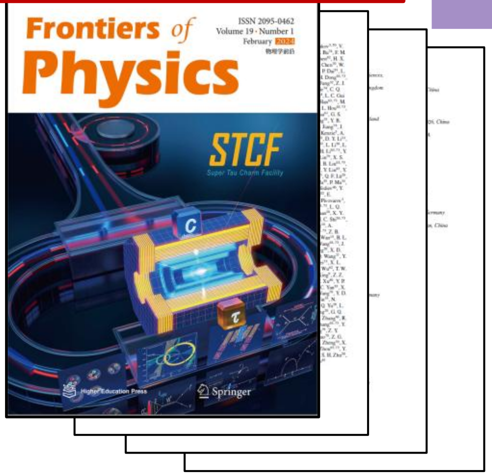
Timeline



- CDR Volume I - Physics & Detector：

  M. Achasov, et al., STCF conceptual design report

  (Volume 1): Physics & detector. Front. Phys. 19, 14701 (2024).

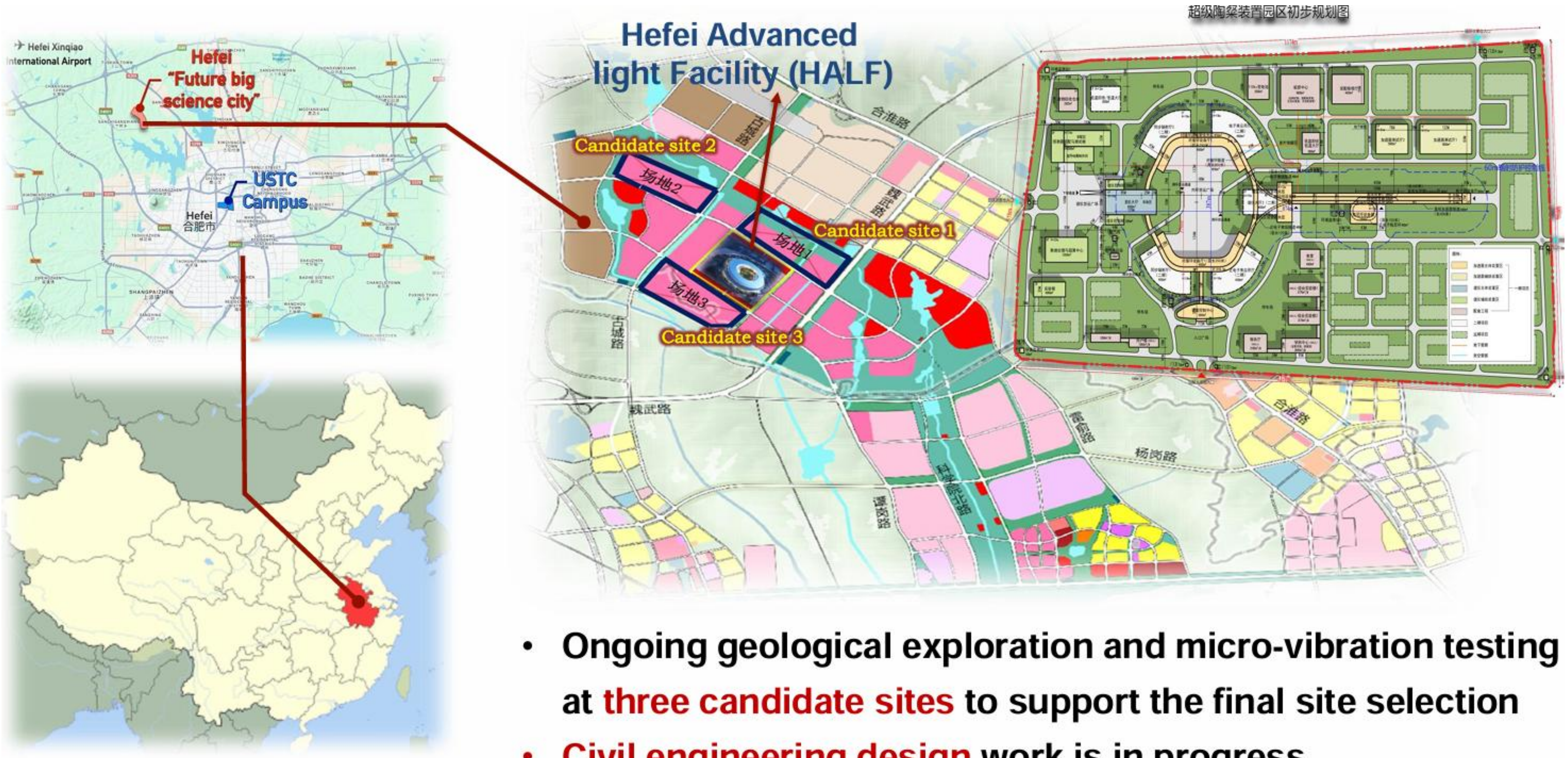


- CDR Volume II – Accelerator:

  Preparing publication: arxiv.org/abs/2509.11522

- **Funding**: **0.42 billion RMB** on the **R&D projects** from local government, MOST, NSFC and USTC (**2018-2027**)

Location: Hefei Future Big Science City



- Ongoing geological exploration and micro-vibration testing at **three candidate sites** to support the final site selection
- **Civil engineering design** work is in progress

Outline

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Lattice Design

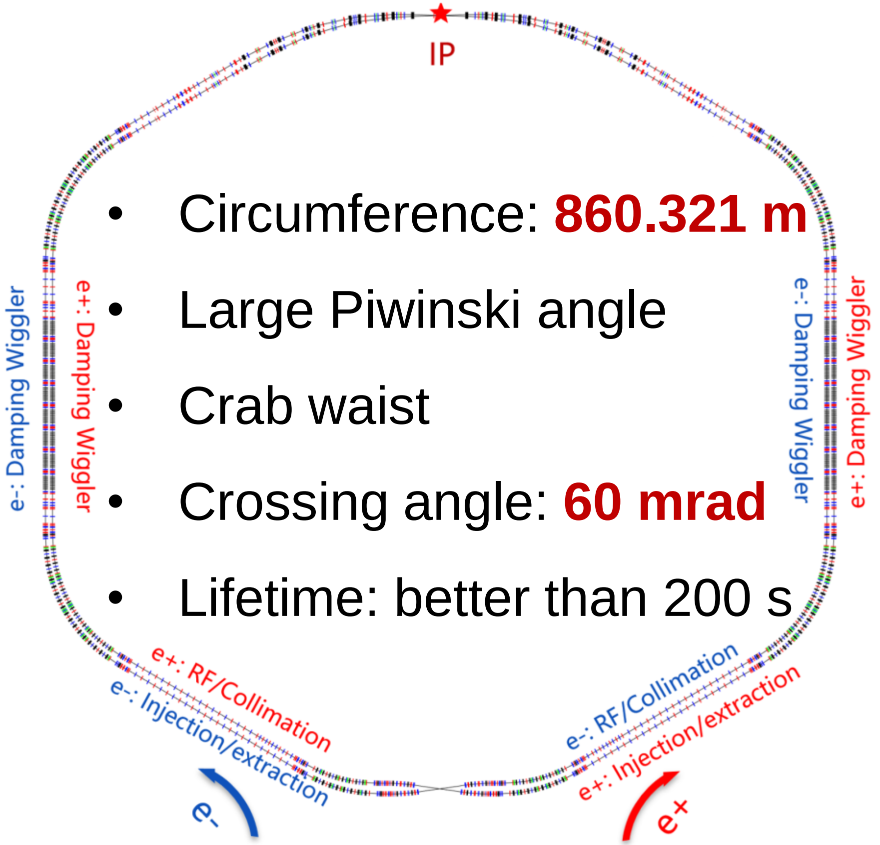
Relativistic energy

Bunch number & intensity

Beam-beam parameter

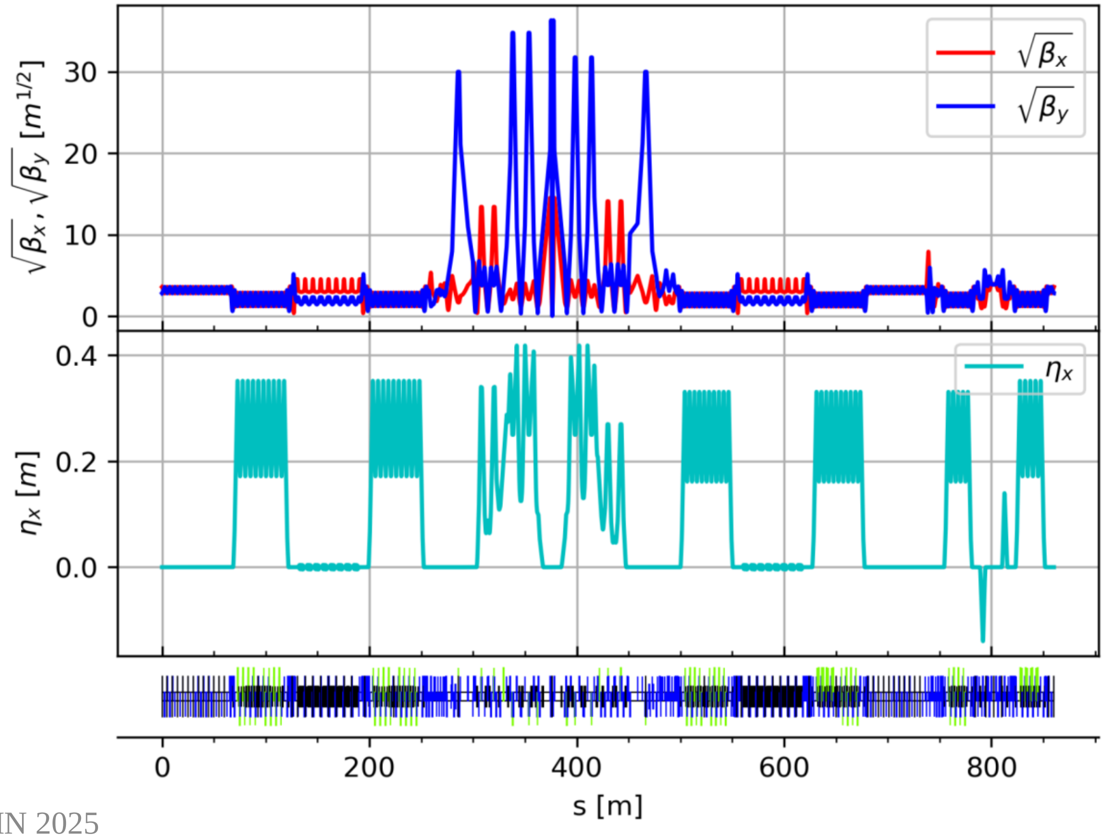
Hourglass effect

$$\mathcal{L}^* = \frac{N_1 N_2 f N_{bunch}}{2\pi \Sigma_x^* \Sigma_y^*} \Rightarrow L = \frac{\gamma n_b I_b}{2 e r_e \beta_y^*} \xi_y H$$



- Circumference: **860.321 m**
- Large Piwinski angle
- Crab waist
- Crossing angle: **60 mrad**
- Lifetime: better than 200 s

Beta function along lattice



Lattice Design

Parameters	Units	**2 GeV**	1 GeV	1.5 GeV	3.5 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**	30.555/34.57		
Beam current, I	A	**2**	1.1	1.7	2
Hor. Emittance (SR/DW+IBS)	nm	**8.79/4.63**	2.2/5.42	4.94/3.82	26.9/26.91
Ver. Emittance (SR/DW+IBS)	pm	**87.9/46.3**	330/813	494/382	134.5/134.55
Ratio, $\varepsilon_y/\varepsilon_x$	%	**1**	15	10	0.5
Momentum compaction factor, α_p	10^{-3}	**1.35**	1.26	1.32	1.37
Energy spread (DW+IBS)	10^{-4}	**7.8**	6.18	6.93	10.02
Energy loss per turn (SR+DW), U_0	keV	**543**	106	267	1494
SR power per beam (SR+DW), P	MW	**1.086**	0.117	0.453	2.988
RF voltage	MV	**2.5**	0.75	1.2	6
Synchrotron tune, ν_s		**0.0194**	0.0146	0.0154	0.0228
δ_{RF}	%	**1.68**	1.44	1.35	1.88
Bunch length (Nature/0.1Ω+IBS)	mm	**7.21/8.70**	6.62/9.79	7.89/8.56	8.26/8.89
Hor./Ver. beam-beam parameter, ξ_x/ξ_y		**0.005/0.095**	0.005/0.023	0.004/0.033	0.003/0.032
Luminosity	$cm^{-2}s^{-1}$	**9.4E+34**	6.19E+33	2.09E+34	4.48E+34

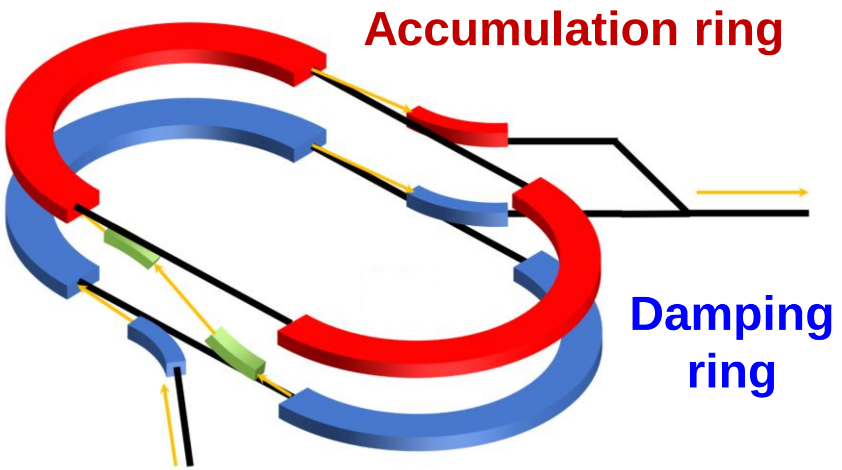
Injector Research

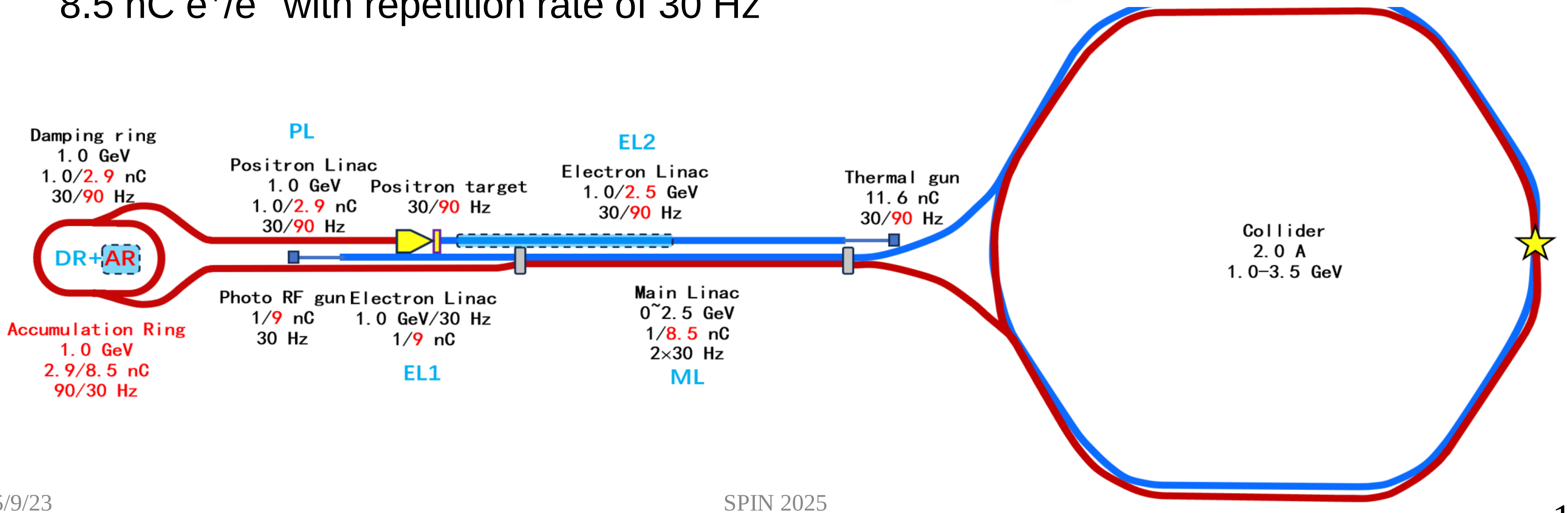
- **First stage:** **Off-Axis Injection**

1.0 nC e^+/e^- with repetition rate of 30 Hz

- **Future upgrade:** **Swap-Out Injection**

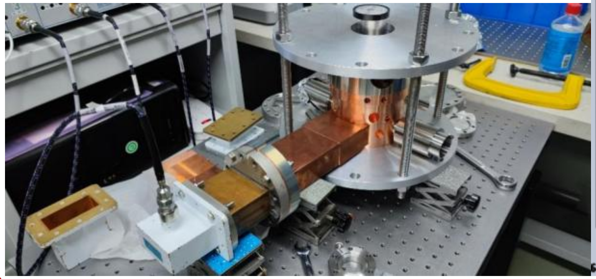
8.5 nC e^+/e^- with repetition rate of 30 Hz

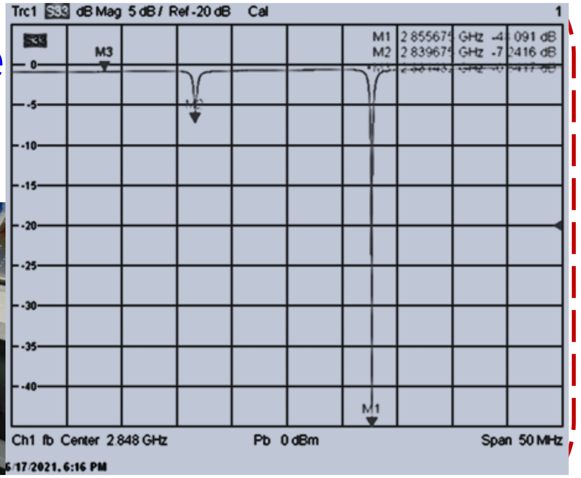




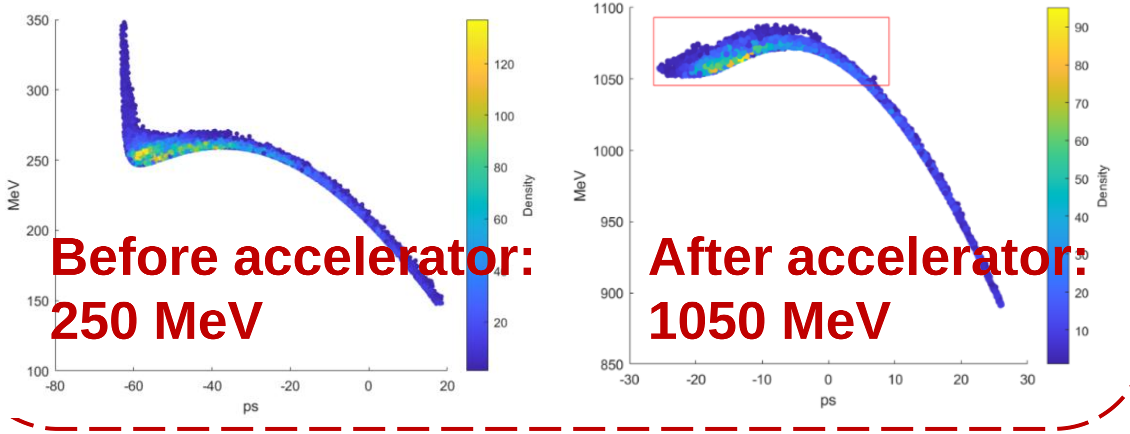
e^+ e^- Source and Damping Ring

Microwave photocathode electron source cold test





Positron beam Phase Space Distribution

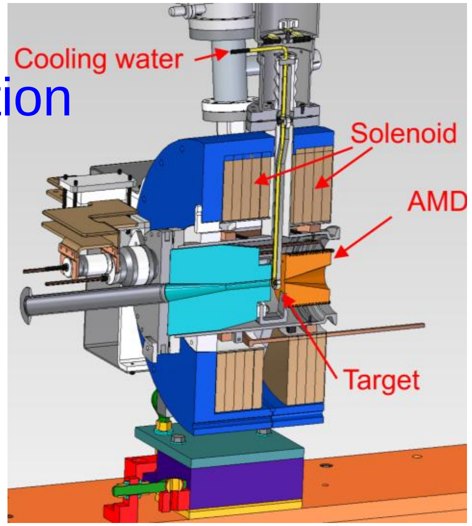


Before accelerator: 250 MeV

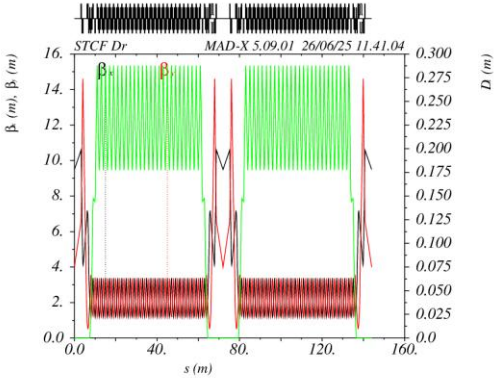
After accelerator: 1050 MeV

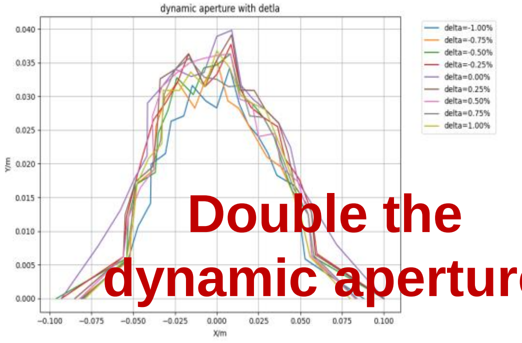
Positron target optimization

Charge: 11.6 nC
Energy: 1.0 GeV
Repetition rate: 30 Hz



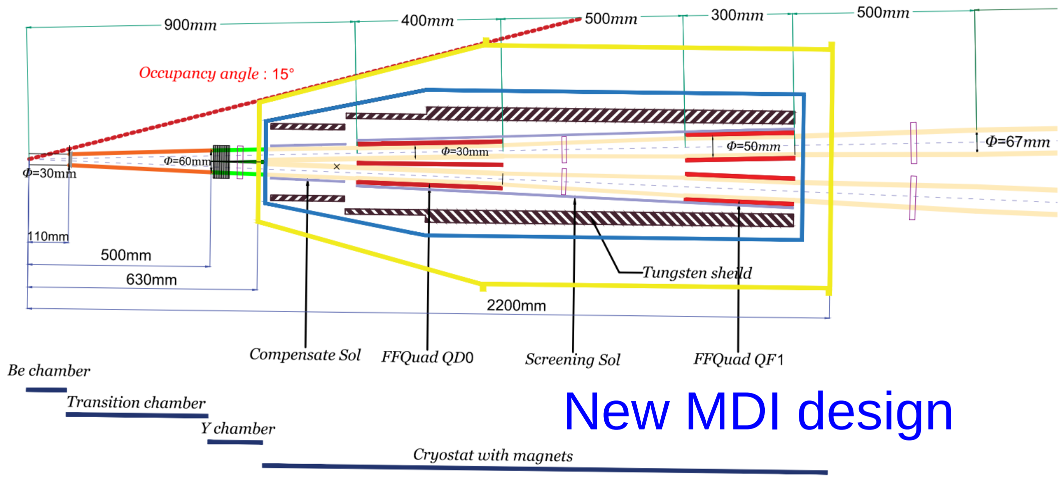
Damping ring design based on FODO structure





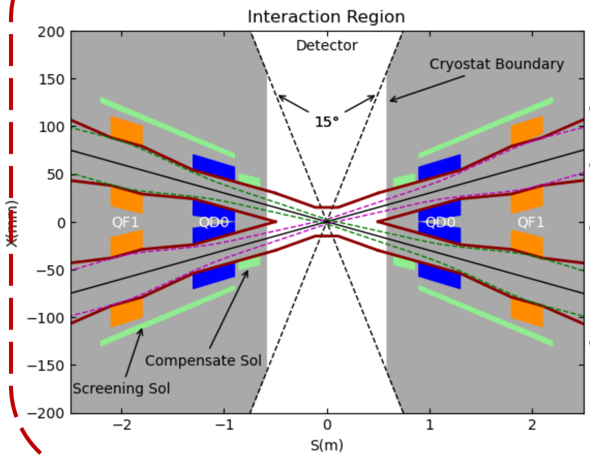
Double the dynamic aperture

MDI Design



New MDI design

MDI beam stay clear



- Beam stay clear @ 2GeV:
- ε_x ~ 5nm
- ε_y: ~ 5% coupling
- Hori. BSC: $22\sigma_x$+2 mm ($\sim 24\sigma_x$)
- Vert. BSC : $22\sigma_y$+2 mm ($\sim 26\sigma_y$)

Optimized central beam pipe

Min. radius: 30 mm → 15 mm

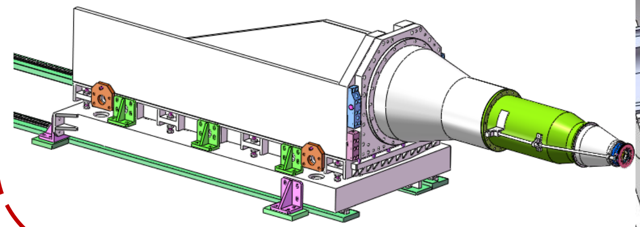
Cross section optimization

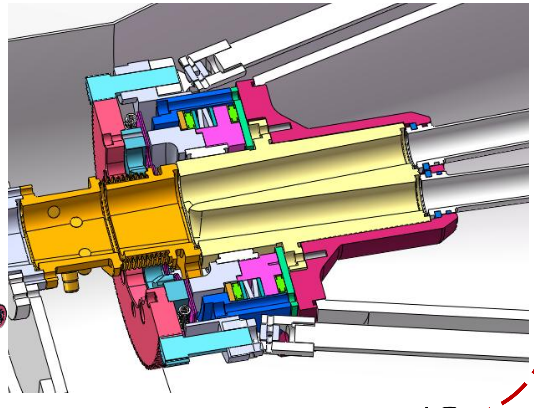
Cooling simulation and design

MDI support and RVC flange optimization

Remote control

Smaller space requirements

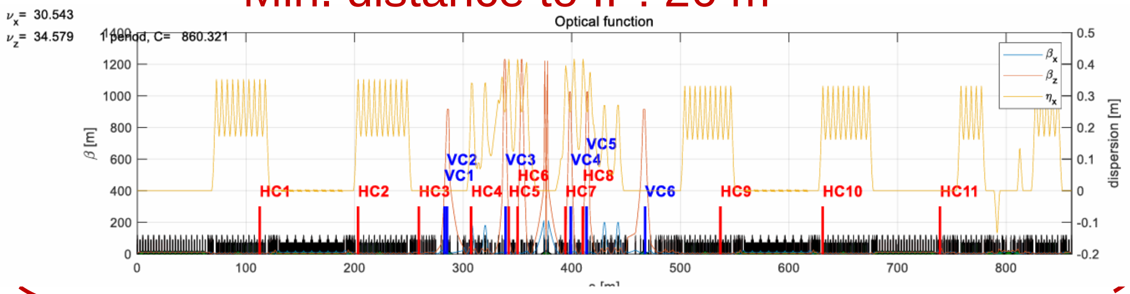




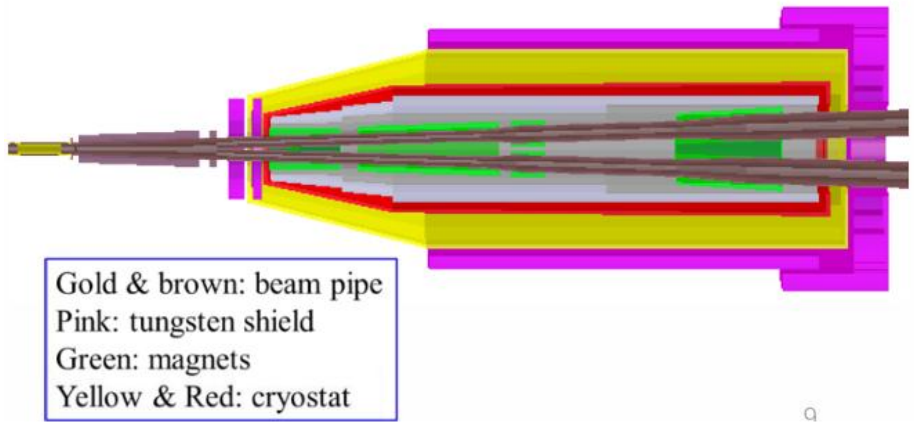
Background Simulation and Suppression

New collimator system for lattice V12_c

11 hor., 6 ver. Collimators
Min. Radius: 8 mm
Min. distance to IP: 26 m

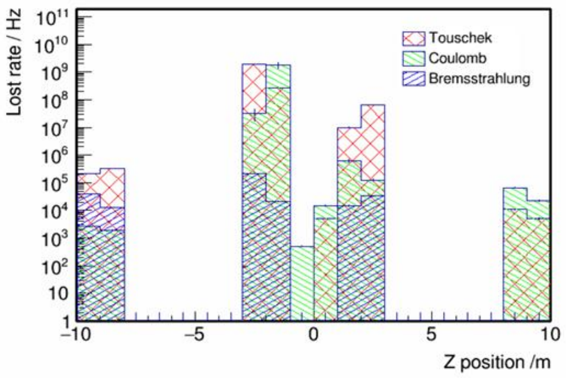


Additional shield in MDI



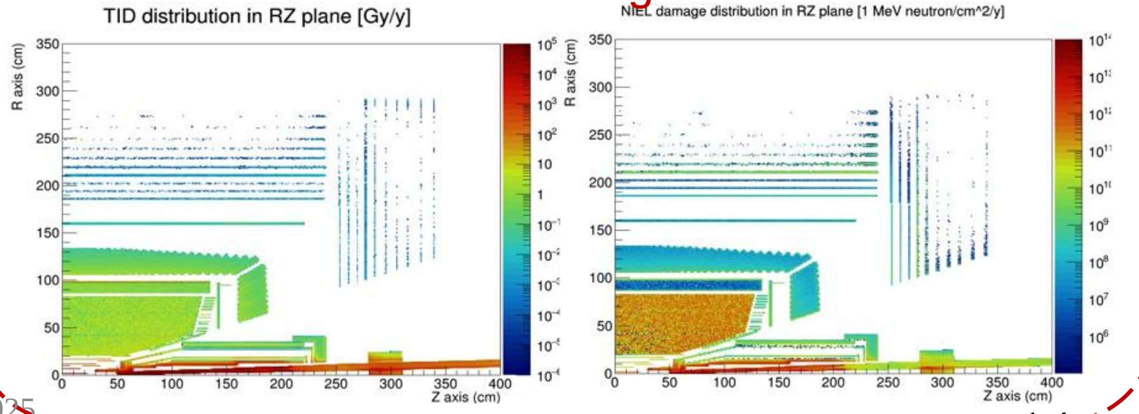
Beam loss in IR

- Tous. rate in IR: 2.3×10^9 Hz
- Beam-gas rate in IR: 1.9×10^9 Hz
- Beam lifetime: 843.6 s



Background simulation result

several times higher than the CDR level



Outline

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STCF Detector Spectrometer

High physics event:

400 kHz@ peak

High background:

Hundreds of kHz ~ MHz /channel

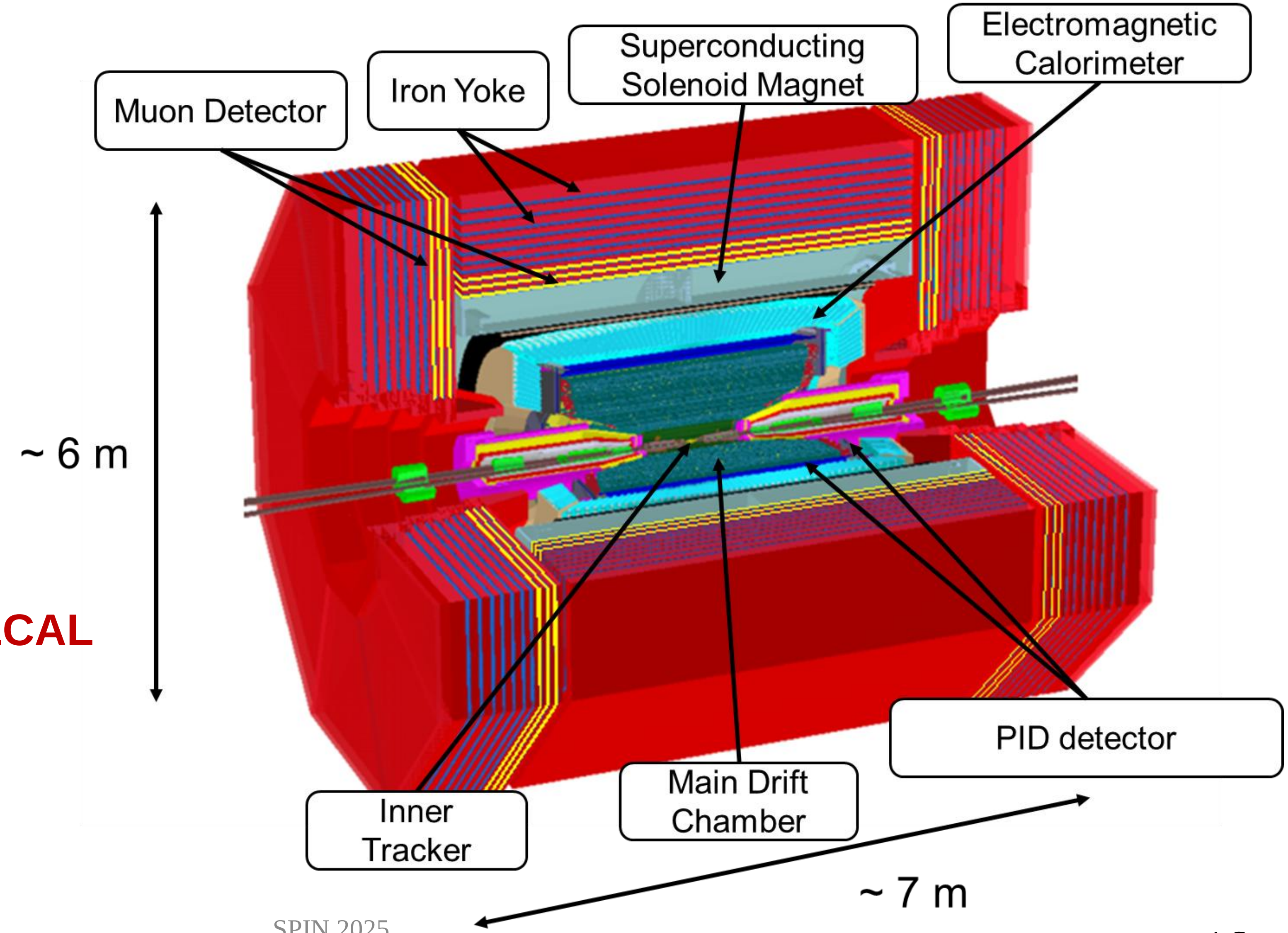
High accuracy

Pos: ~130 μm@tracker, 5 mm@ECAL

Erg: 2.5%@1GeV photon

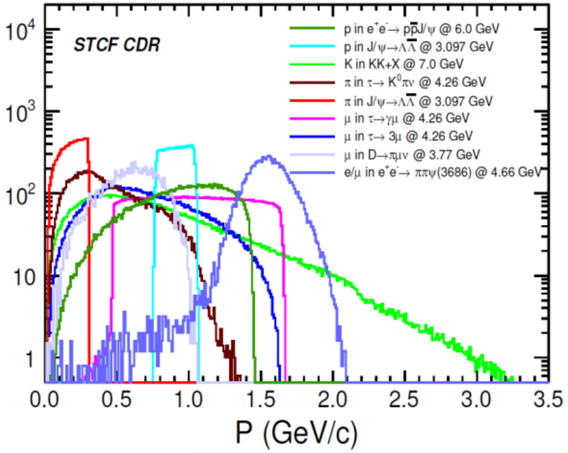
PID: 4σ for K/π

…

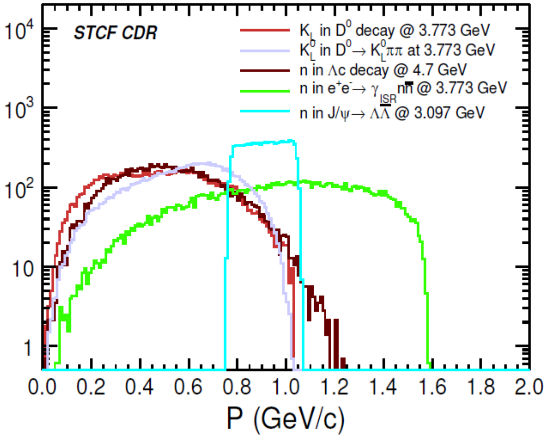


Physics requirements

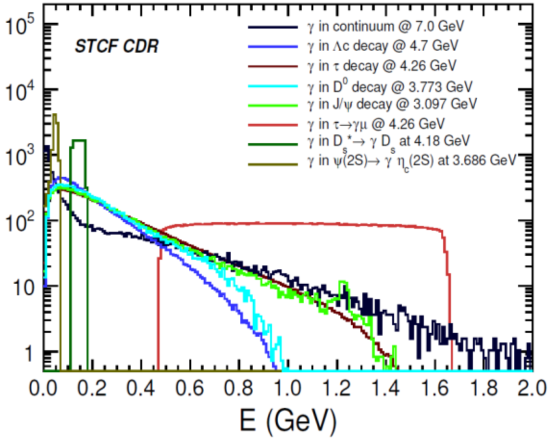
Charged particle



Neutron/K_L



Photon

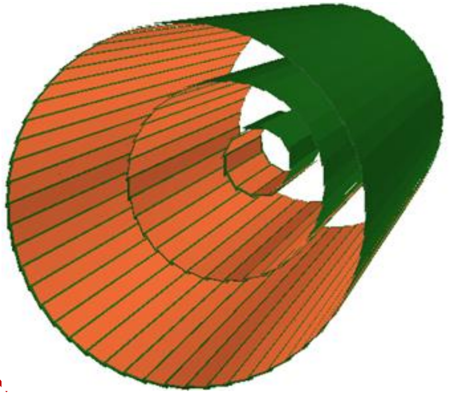


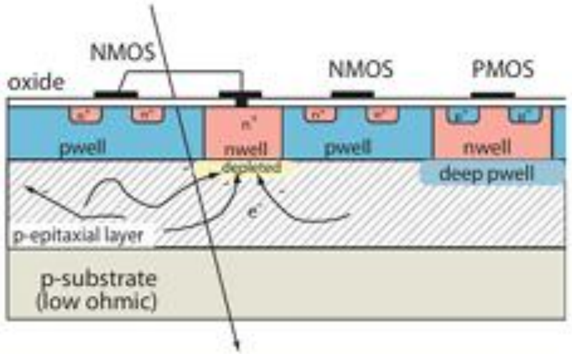
Process	Physics Interest	Optimized Subdetector	Requirements
$\tau \to K_s\pi\nu_\tau$, $J/\psi \to \Lambda\bar{\Lambda}$, $D_{(s)}$ tag	CPV in the τ sector, CPV in the hyperon sector, Charm physics	ITK+MDC	acceptance: 93% of 4π; trk. effi.: $> 99\%$ at $p_T > 0.3$ GeV/c; $> 90\%$ at $p_T = 0.1$ GeV/c $\sigma_p/p = 0.5\%$, $\sigma_{\gamma\phi} = 130\ \mu$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

arXiv: 2303.15790

MAPS-based Inner Tracker

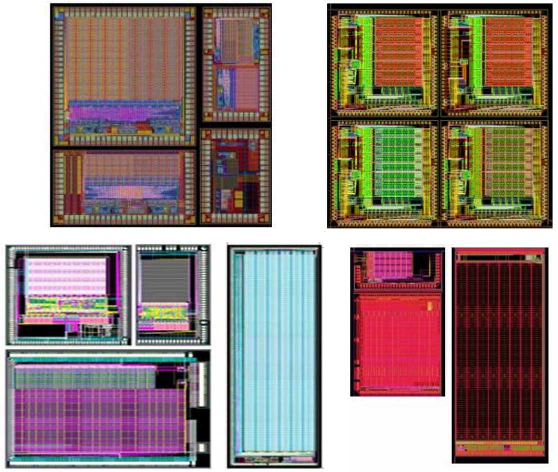
MAPS-based inner tracker design



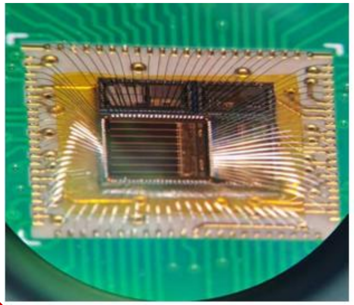


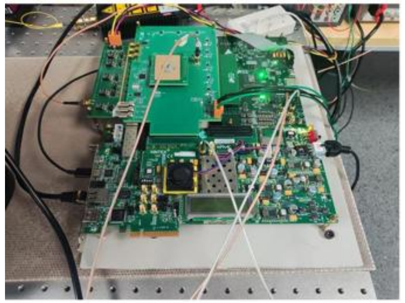
MAPS chip design & manufacturing

TJ 180nm
GSMC 130nm
BCIS 90nm
IRAY 180nm

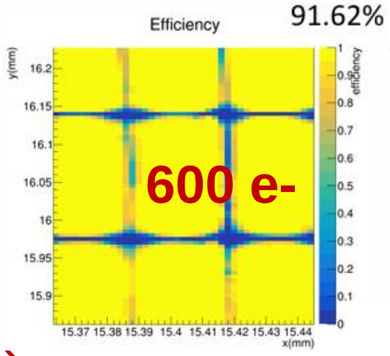


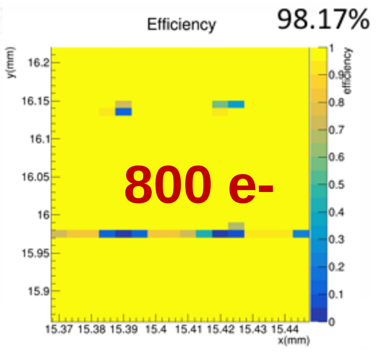
Laser and Sr90 test

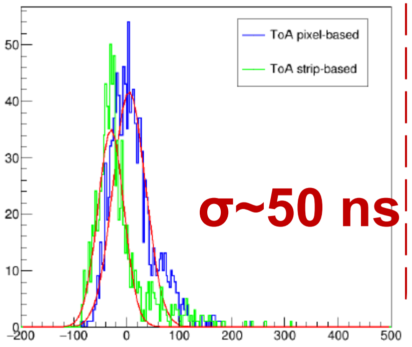




Efficiency and time resolution test result

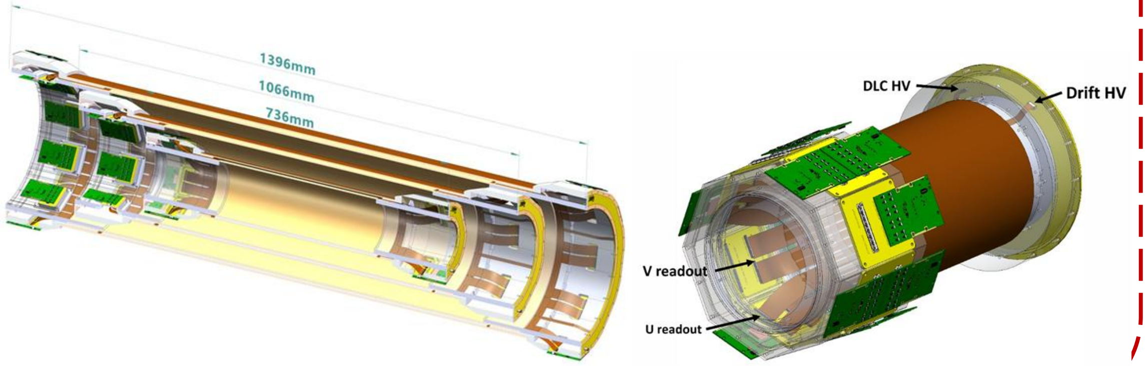




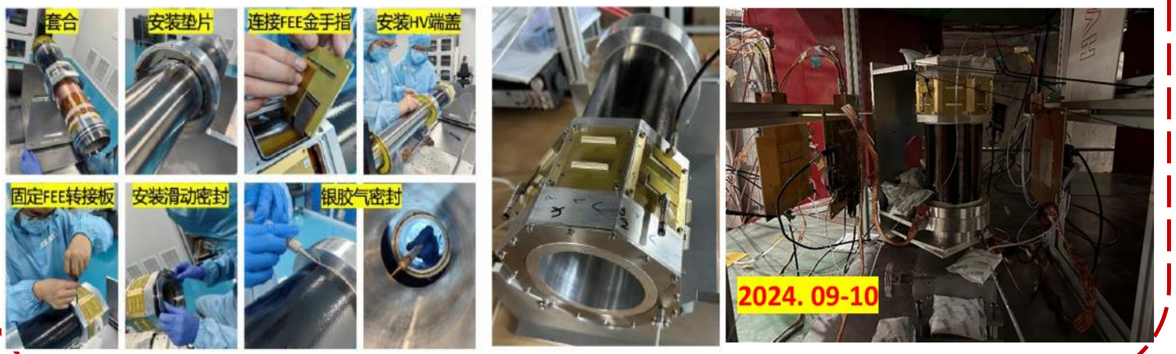


MPGD-based Inner Tracker

C-μRGroove inner tracker design

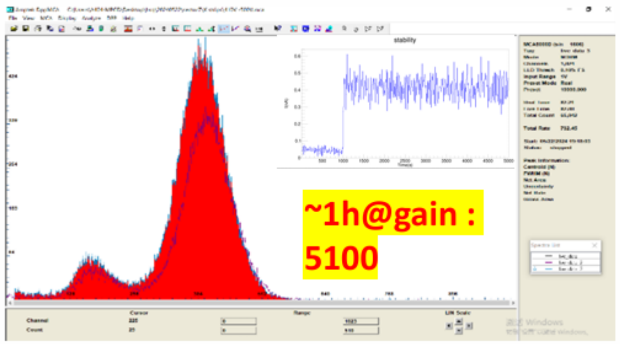


C-μRGroove prototype manufacturing & test

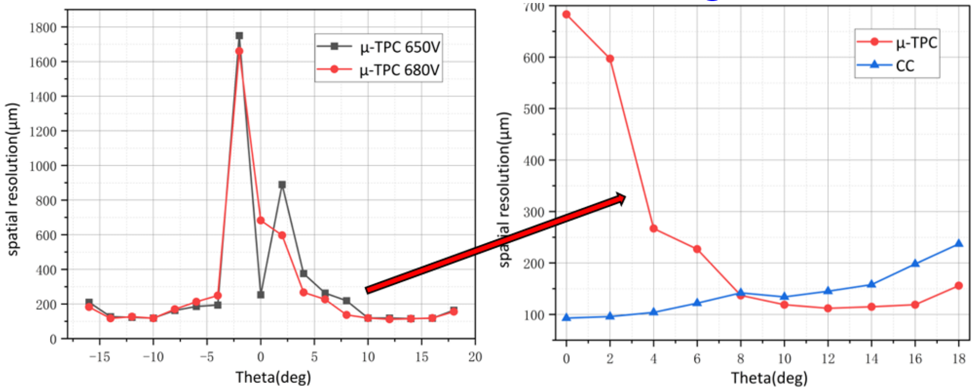


Material budget: **0.23% X_0**
Effective gain: **~ 5100**

Structure	Material	Thickness (cm)	Material budget (X0)
Drift electrode	LMB-GND	---	2*0.001138%
	Polyimide (X0=28.57cm)	0.0025*2	0.0175%
	Glue (X≈20cm)	0.001*2	0.01%
	Rohacell (X0≈689cm)	0.2	0.029%
Gas volume	Argon-based gas mixture (X0=11760cm)	0.5	0.00425%
Inner cylinder (μRGroove foil)	Cu (X0=1.43cm)	0.0015*65%	0.0682%
	Cr (X0=2.077cm)	0.000001*65%	0.0000313%
	Apical (X0=28.57cm)	0.005*70%	0.01225%
	Glue (X0≈20cm)	0.001*5	0.025%
	Kapton (X0=28.57cm)	0.0025*2	0.0175%
	Al (X0=8.892cm)	0.0012*(1*33.6%)	0.00453%
	DLC (X0=12.13cm)	0.0001	0.00082%
	Polyimide (X0=28.57cm)	0.0025	0.00875%
	Rohacell (X0≈689cm)	0.2	0.029%
	LMB-GND	---	0.001138%
Total			0.2302%

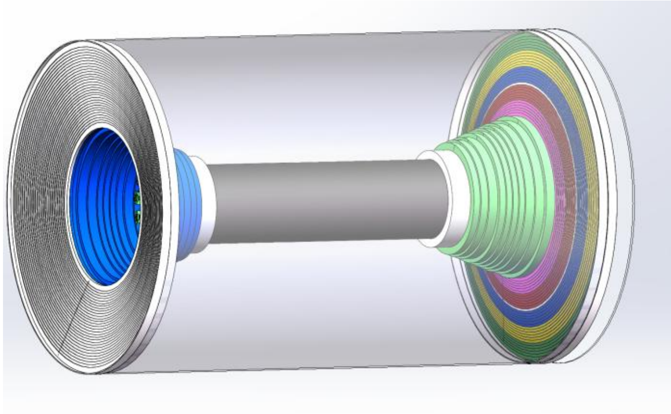


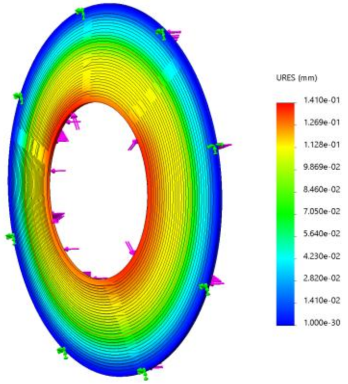
Spatial resolution: **100-200 μm**
Work well under 1 T magnetic field



Main Drift Chamber

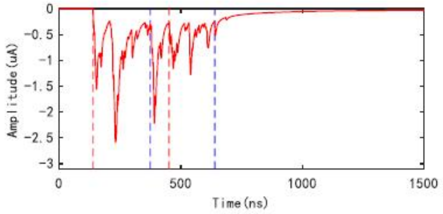
Super-small-cell drift chamber design & simulation

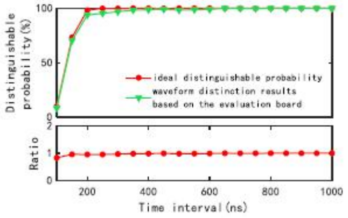


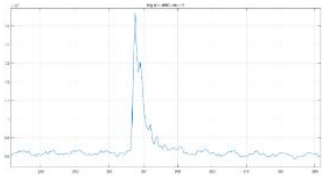


Full length prototype manufacturing

Electronics system development

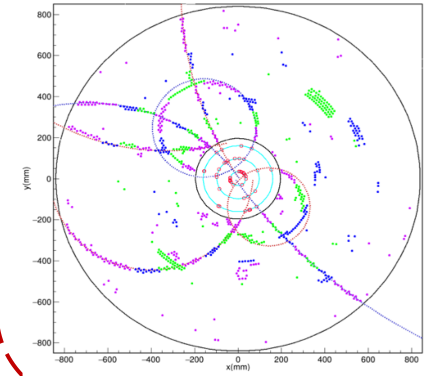


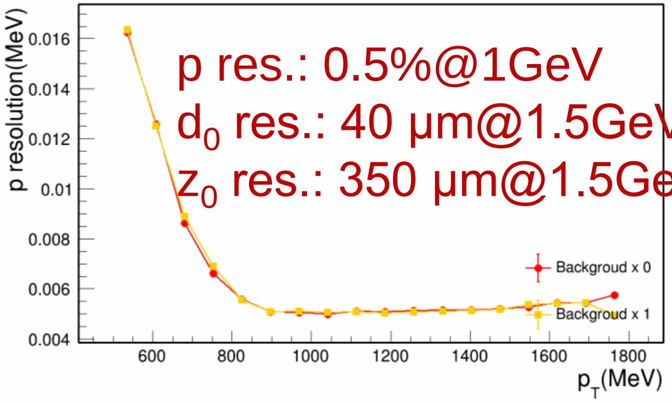




Tracker simulation performance

$J/\psi \to \Xi^-\bar{\Xi}^+ \to \Lambda\pi^-\bar{\Lambda}\pi^+ \to p\pi^-\pi^-\bar{p}\pi^+\pi^+$

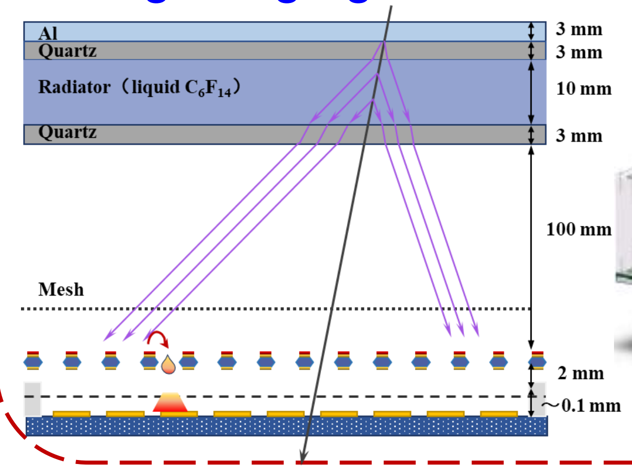


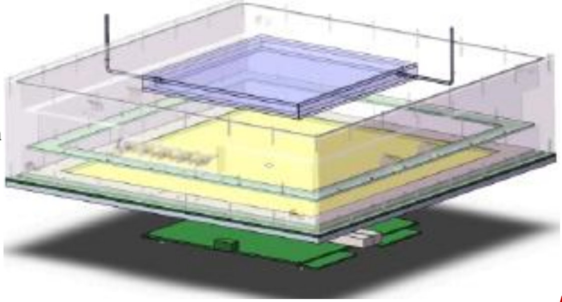


p res.: 0.5%@1GeV
d_0 res.: 40 μm@1.5GeV
z_0 res.: 350 μm@1.5GeV

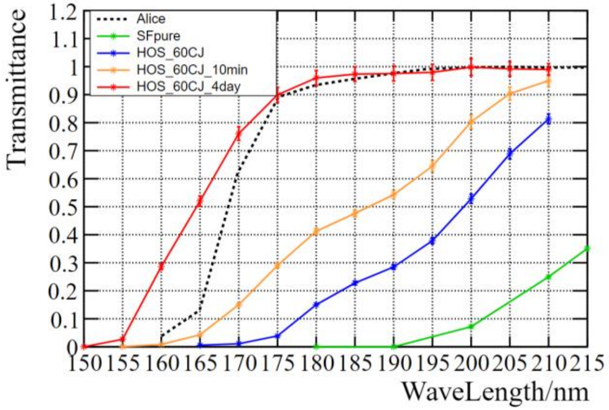
Particle Identification in Barrel

Ring imaging Cherenkov (RICH) detector

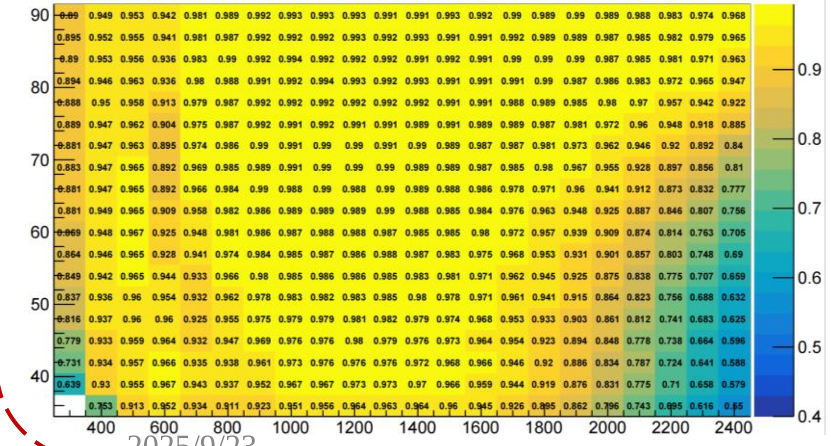




C_6F_{14} purification & transmission ratio promotion

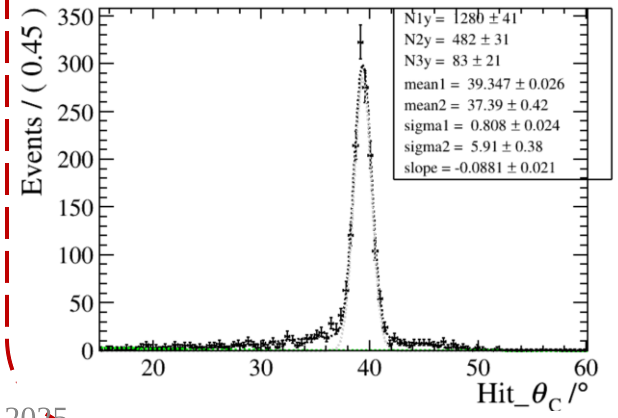


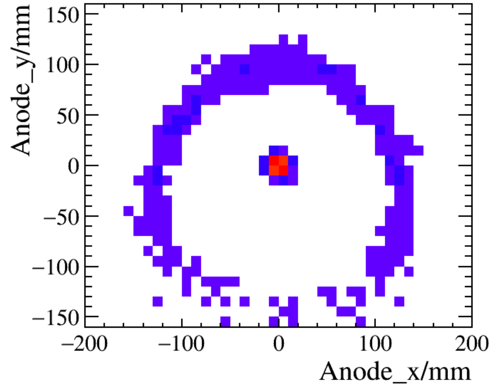
Simulated PID efficiency



>95% π efficiency with a 2% mis-PID rate

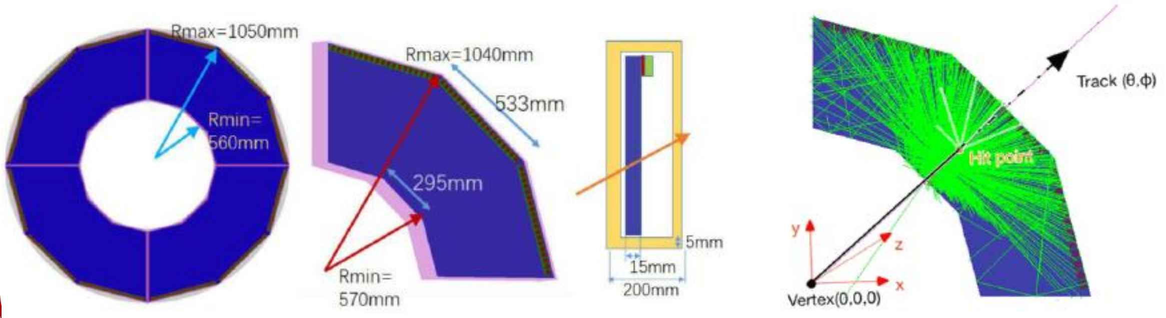
Cosmic ray test results



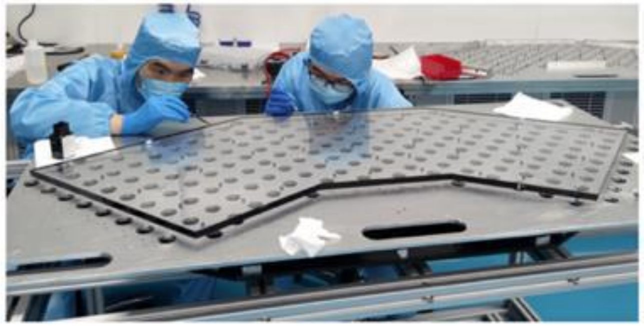


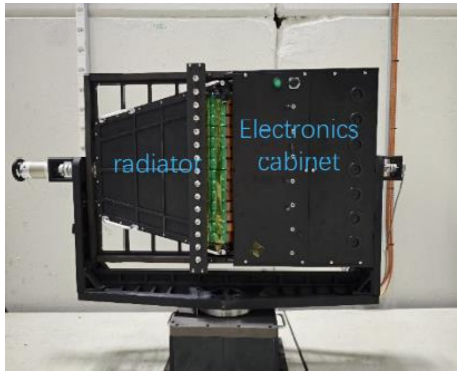
Particle Identification in Endcap

Detection of internal total-reflected Cherenkov light (DIRC)-like TOF

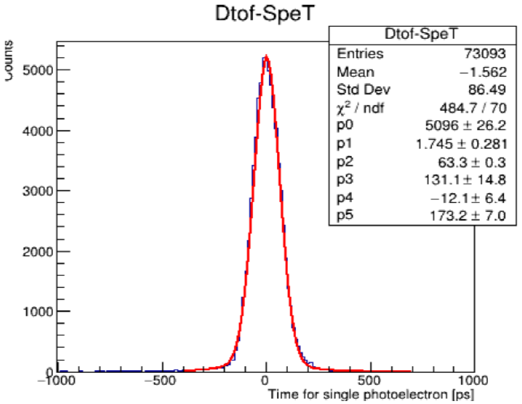


Prototypes optimization and manufacturing

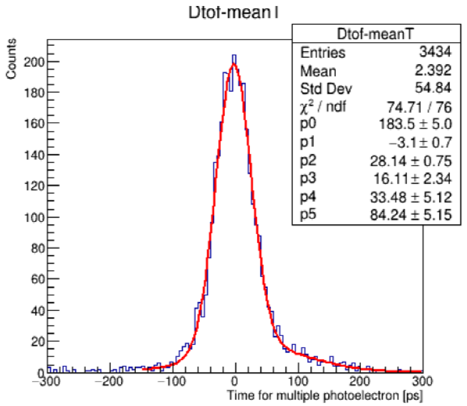




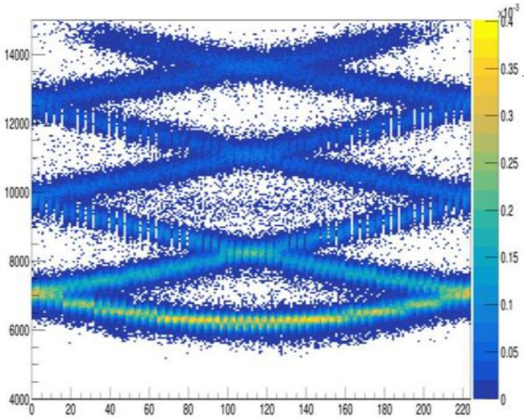
σ_{spe} = 59 ps

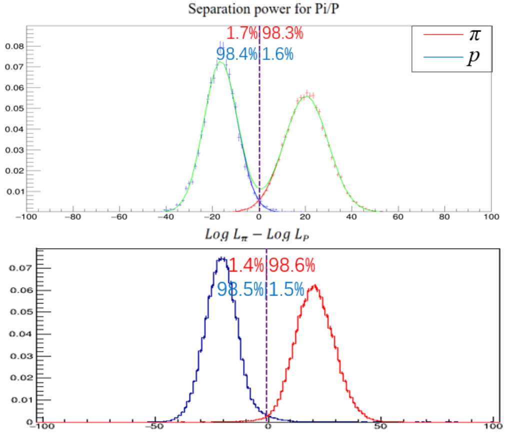


σ_{track} = 21 ps



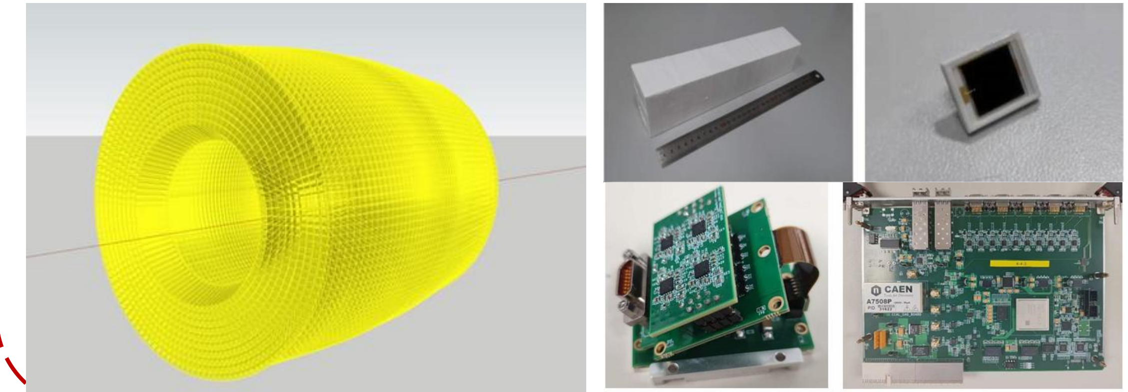
π/K separation > 4 σ for high pt particles



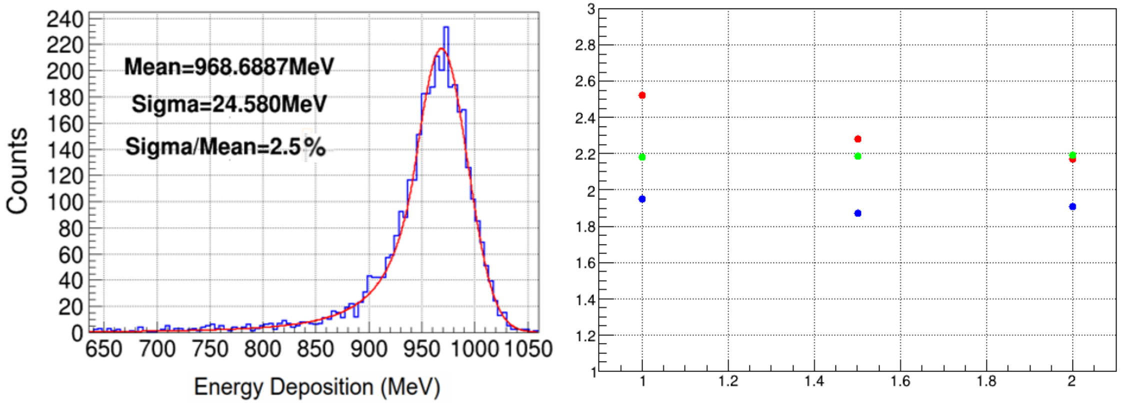


Electron Calorimeter

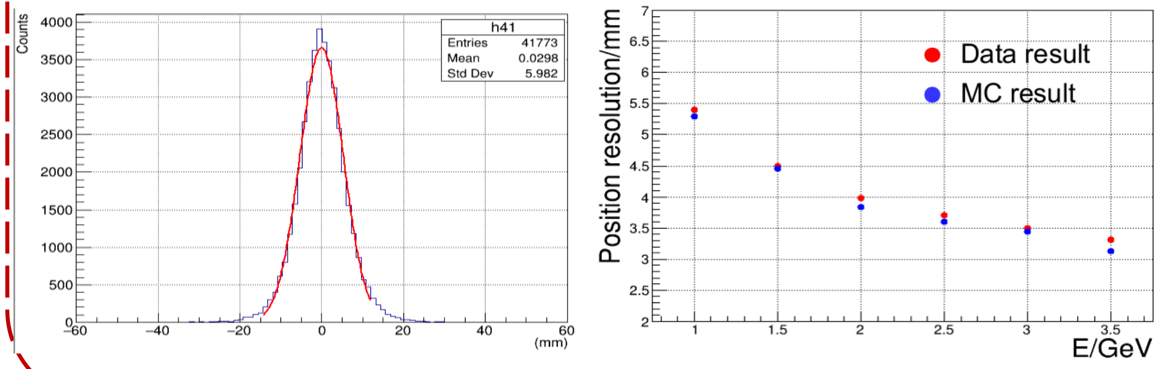
Pure CsI ECAL and electronic system



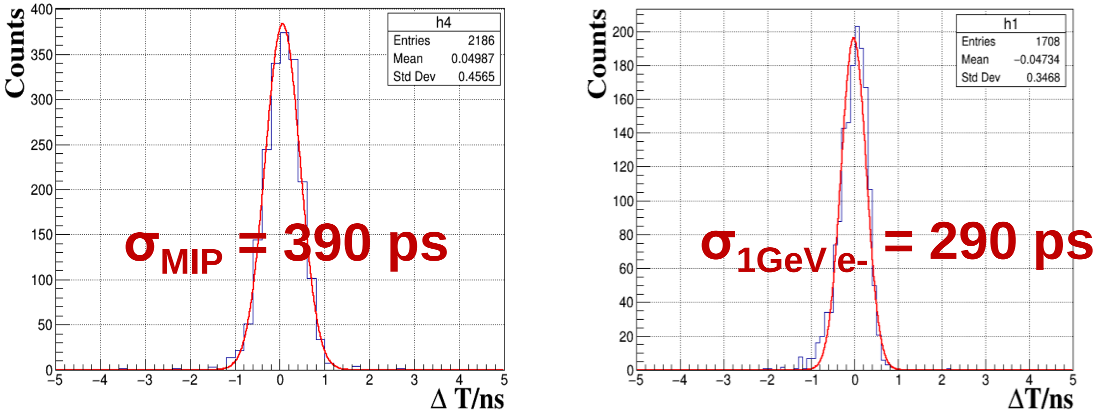
Energy resolution ~ 2.5% @ 1 GeV e⁻



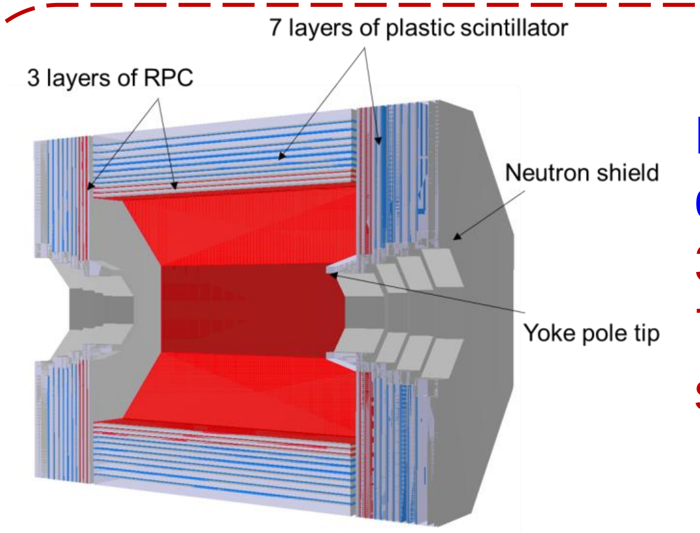
Position resolution ~ 5.3 mm @ 1 GeV e⁻



Time resolution

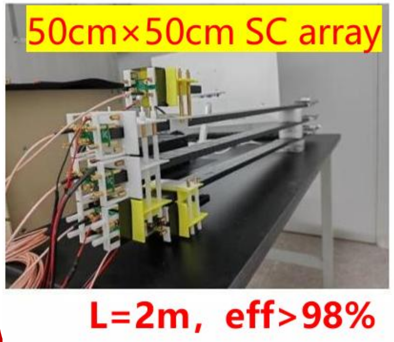


Muon Detector

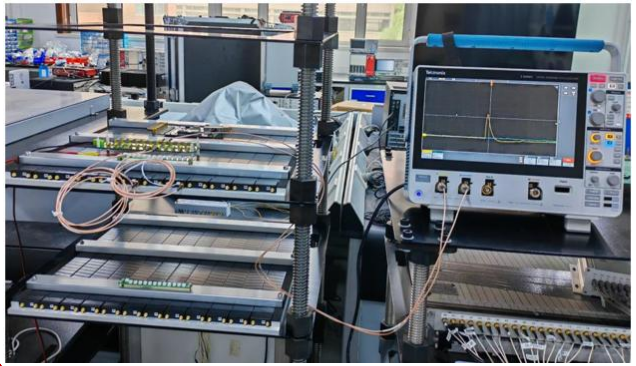


Hybrid muon detector:
3 layers of RPC
7 layers of plastic scintillator

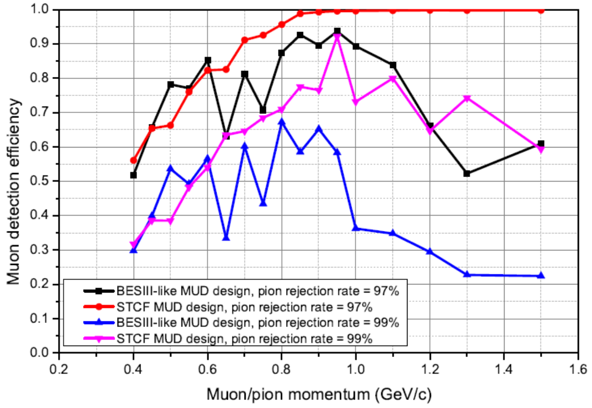
Detector and electronics research

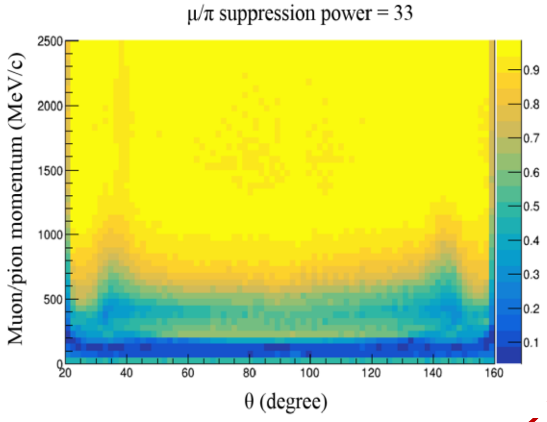


Prototype development

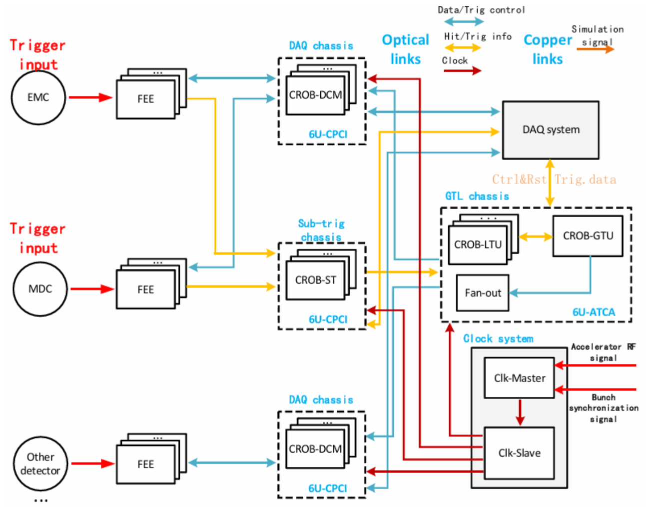


μ/π separation simulaiton

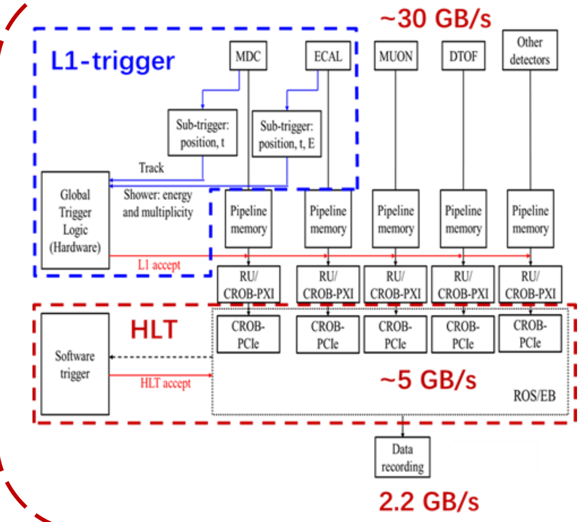




Trigger, DAQ and Clock



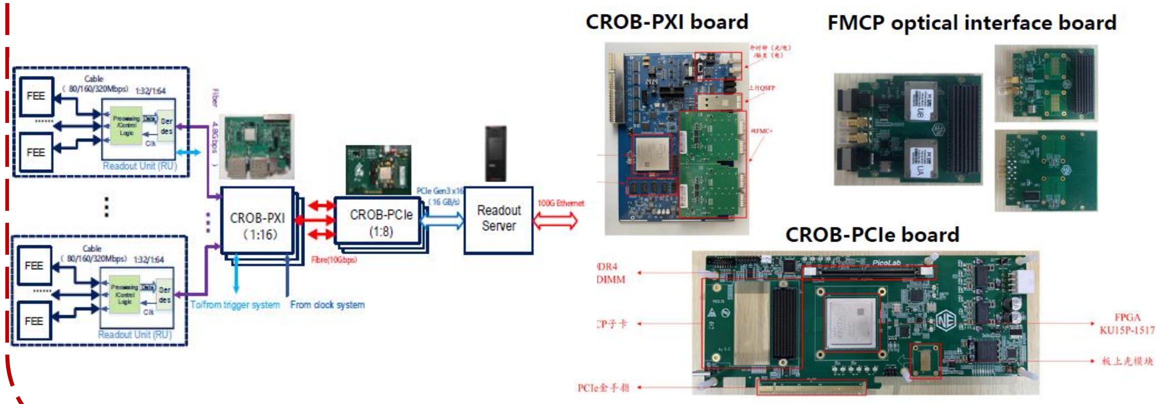
Data flow design
Upstream
Downstream



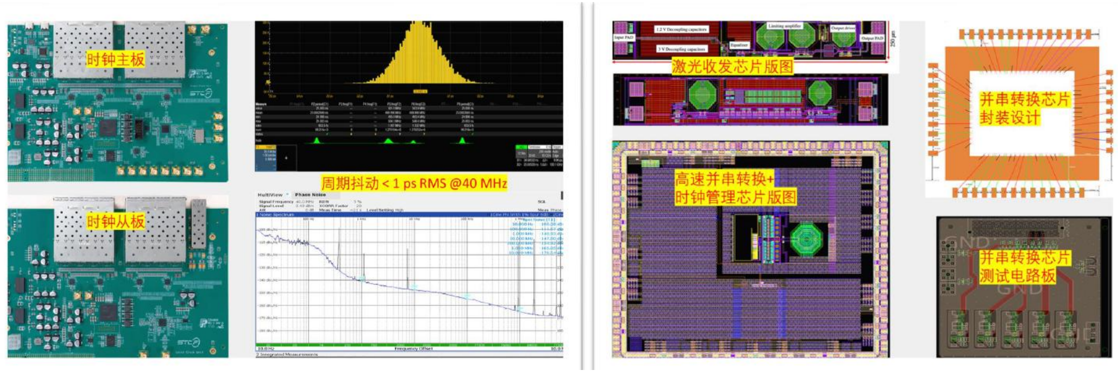
L1 trigger:
99% physics trigger eff.
30 kHz bkg. Trigger rate

HLT:
70% data compression ratio

DAQ: data transmission rate **6.43 GB/s/board**



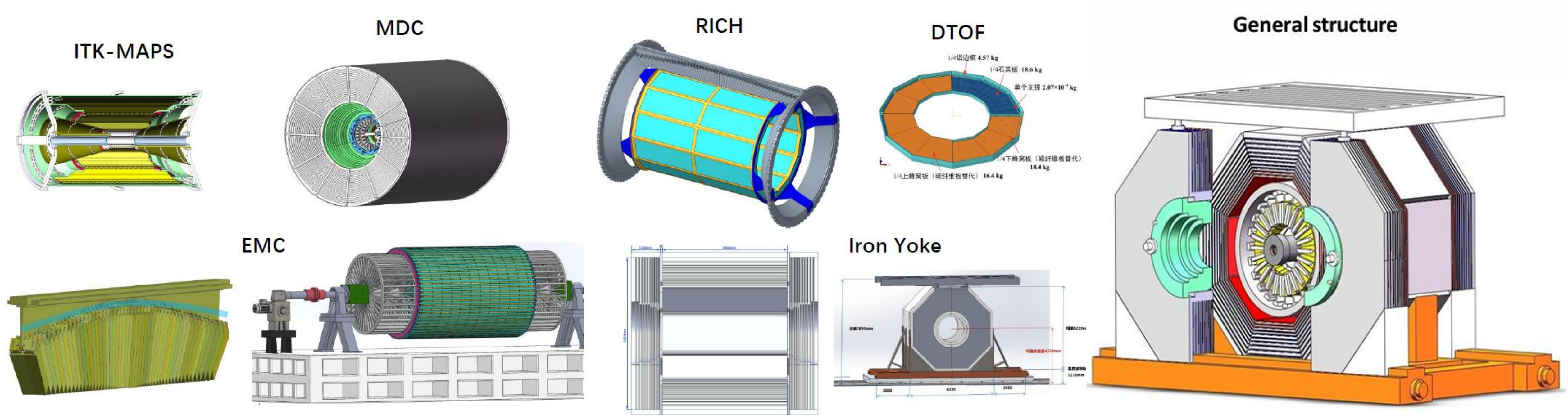
Clock: jitter RMS < **5 ps**



Detector Mechanical Design

Design mechanical for each detector system

Research the detector assembly and installation



Outline

1. Physics motivation
2. Accelerator progress
3. Detector progress
4. **Simulation studies**
5. Summary

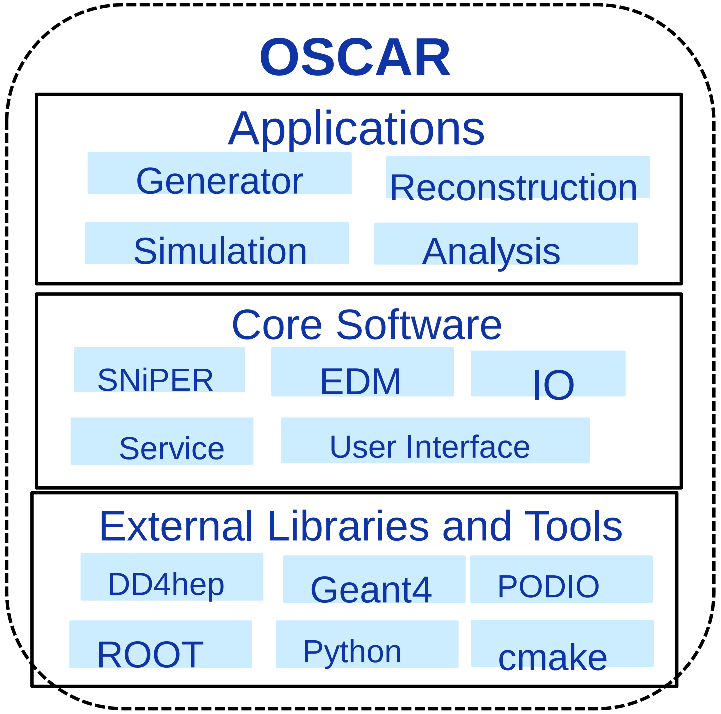
Full Software Chain for STCF

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	Analysis tools: Traditional combined PID	Analysis tools: Kinematic & Vertex Fit
ITK	Good state	Under optimization	Good state (ITK and MDC)	Charged tracks: Good state; Neutral tracks: Under development	Under optimization	Good state
MDC	Good state	Under optimization				
RICH	Good state	Good state	Good state			
DTOF	Good state	Good state	Good state			
BTOF	Good state	Good state	Under optimization			
EMC	Good state	Good state	Good state			
MUD	Good state	Good state	Under optimization			

Good state
Under optimization
Under development

Expected Sensitivities

Tests of fundamental Symmetries

- CP : Hyperons, tau, EDM
- CPV : $K^0 - \bar{K}^0$ system
- CLFV : Tau, meson decays

Exploring QCD nature and confinement

- Hadron Spectroscopy
- Nucleon Structure
- Fragmentation function

Precision Measurement of Fundamental Physical Parameters

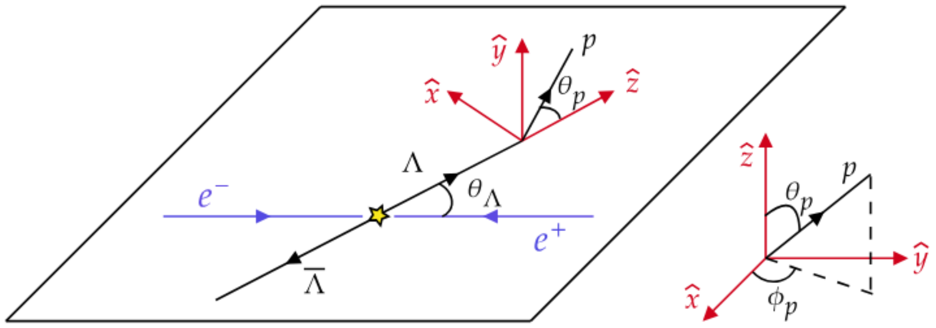
- R-Value, Tau mass
- Running of fine structure constant $\Delta\alpha_{em}$
- CKM elements

Expected sensitivities at STCF by fast simulation

Physics goal	Observable	BESIII	Current world best	STCF prospect($1\ \text{ab}^{-1}$)
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
	$\lvert V_{us}\rvert$	-	1%	$\mathcal{O}(10^{-3})$
	$\lvert V_{cd}\rvert$	1.2%	1%	$\mathcal{O}(10^{-3})$
	$\lvert V_{cs}\rvert$	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%	$\mathcal{O}(10^{-3})$

Hyperon Polarization and Spin Physics

$J/\psi \to \Lambda\bar{\Lambda}$, $\Lambda \to p\pi^-$



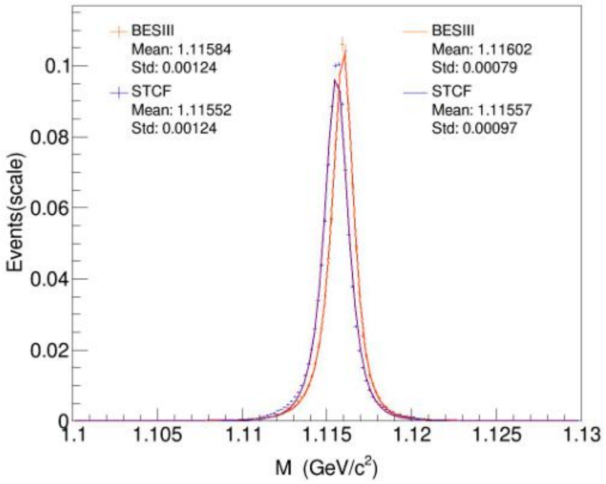
- Described by EM form factors $G_{1,2}$

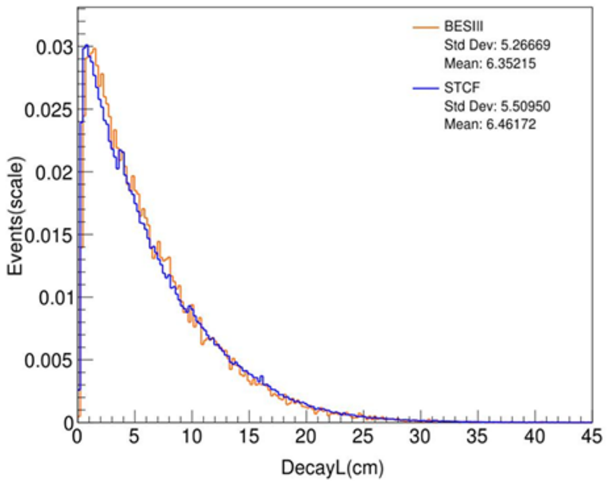
$$\alpha_\psi = \frac{s^2|G_1|^2 - 4m^2|G_2|^2}{s^2|G_1|^2 + 4m^2|G_2|^2}, \quad \frac{G_1}{G_2} = \left|\frac{G_1}{G_2}\right| e^{-i\Delta\Phi}$$

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

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

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



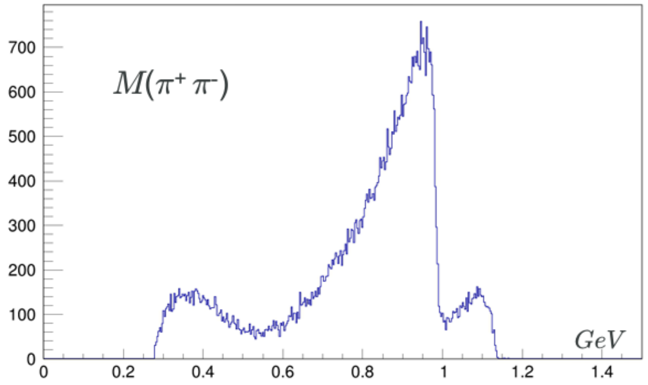


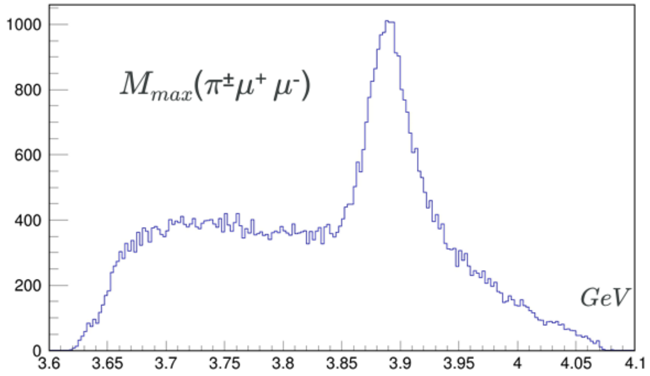
Parameter	Stat.	BESIII Stat.	BESIII Sys.
$\alpha_{J/\psi}$	1.4×10^{-4}	2.2×10^{-3}	1.7×10^{-3}
$\Delta\Phi$	2.7×10^{-4}	4.2×10^{-3}	1.3×10^{-3}
A_{cp}	3.0×10^{-4}	4.6×10^{-3}	1.1×10^{-3}
$\sin W^2$	6.4×10^{-4}	1.2×10^{-3}	2.6×10^{-3}
$Re(d_\Lambda)$	2.1×10^{-20}	3.2×10^{-19}	0.5×10^{-19}
$Im(d_\Lambda)$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

Charmonium-like, Tetra- and Penta-quarks

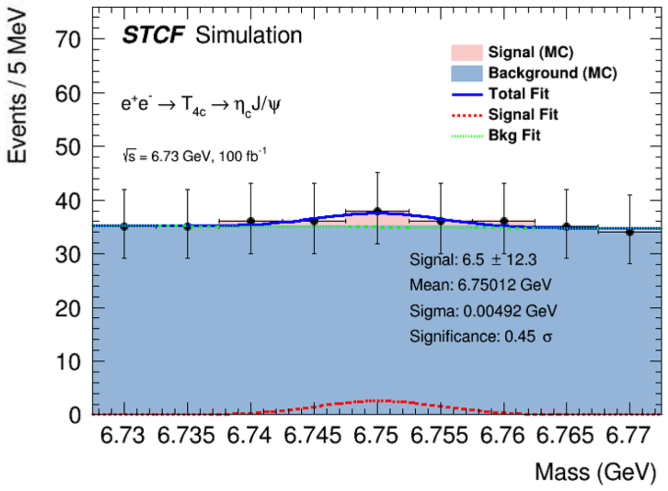
XYZ	$Y(4260)$	$Z_c(3900)$	$Z_c(4020)$	$X(3872)$
No. of events	10^{10}	10^9	10^9	5×10^6

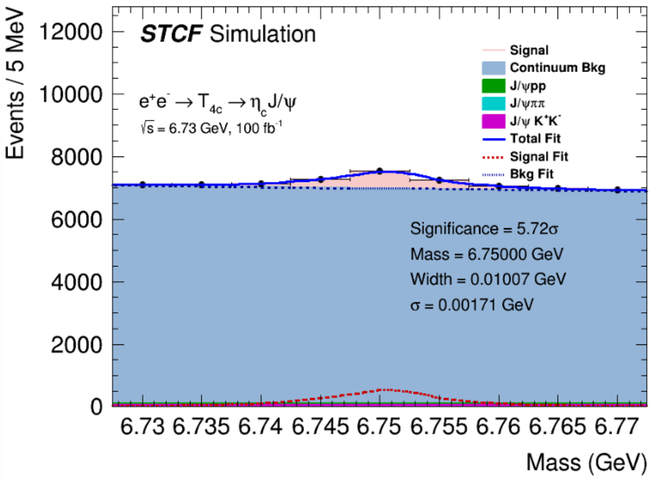
$e^+e^- \to \pi Z_c(3900)$

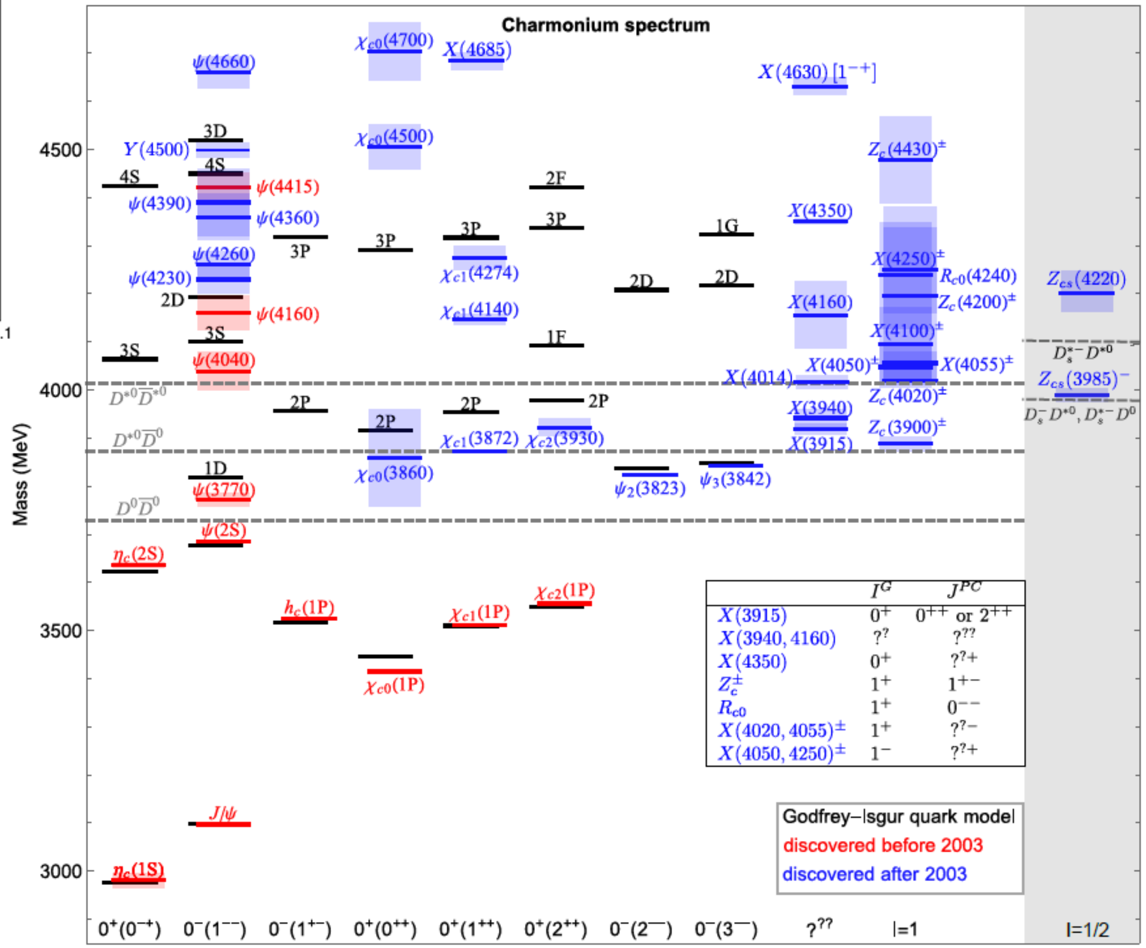




$e^+e^- \to \eta_c J/\psi$







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Summary

- STCF has a rich physics program with breakthrough potential in the studies of **how quarks form matter** and **symmetry of fundamental interactions**, and beyond.
- **Significant progress** has obtained during the **key technology R&D project** of accelerator and detector
- Aiming for **construction approval** from central government during the **15th Five-Year Plan** (2026-2030).
- Expanding **international collaboration** and exploring **synergies** with other projects are crucial. All forms of collaboration are welcome.

Thanks for your attention!