STCF Detector and Physics Program

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(On behalf of the STCF working groups)

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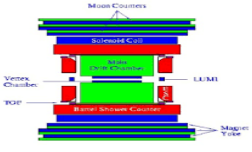
Outline

- The STCF project
- The STCF detector
- The STCF physics program
- Summary

The Beijing Electron-Positron Collider (BEPC)

Tau-charm energy region : 2-5 GeV

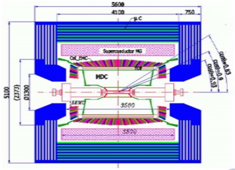


Side view of the BES detector

BEPCI /BESI-II

($10^{31}cm^{-2}s^{-1}$)

1990



BEPCII/BESIII

($10^{33}cm^{-2}s^{-1}$)

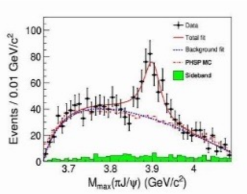
2010

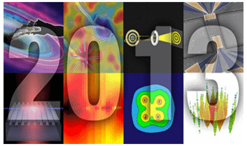
No room at BEPCII for significant upgrade

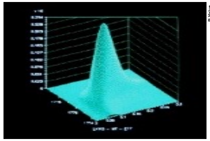
2030

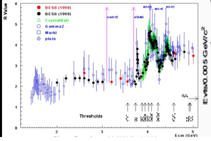
A completely new e^+e^- collider: a super tau-charm facility ?

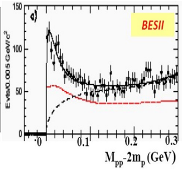
~ 10^{35} $cm^{-2}s^{-1}$

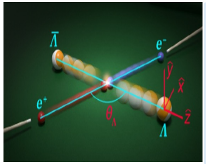


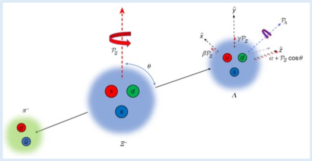






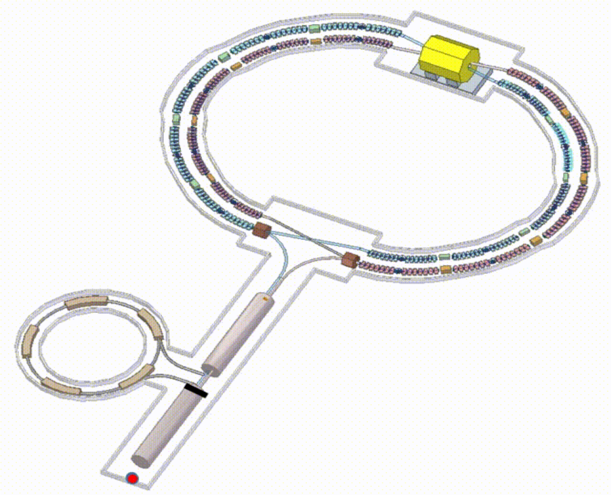






The Super Tau-Charm Facility in China (STCF)

❖ **STCF: a natural extension of the Beijing Electron-Positron Collider (BEPC II) and a viable option for a post-BEPCII HEP project in China.**



- **Extended energy region: E_{cm} = 2-7 GeV**
- **Super high luminosity: L >0.5×10^{35} $cm^{-2}s^{-1}$@4 GeV**
- Linac injector: ~300 m, storage ring: ~600 m
- Large Piwinski angle & Crab waist
- Potential for luminosity upgrade and a polarized electron beam

An super τ-c machine far beyond BEPCII

STCF Project Activities

■ **Working groups and routine group meetings**

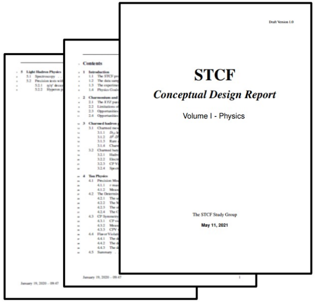
STCF Accelerator	154 events
STCF Physics	24 events
STCF Detector	523 events
STCF Accelerator-Detector Joint meetings	18 events
STCF International Conference	15 events

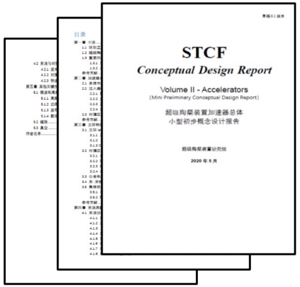
■ **International workshops on Future Tau-Charm Factories**

- 2015 USTC
- 2018 UCAS (March), Novosibirsk (May), Orsay (December)
- 2019 Moscow (September)
- 2020 Online (November)
- 2021 Online (November)

STCF Project Timeline (ideal)

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031-2040	2041-2042
CDR															
TDR															
Construction															
Data taking															
Upgrade															

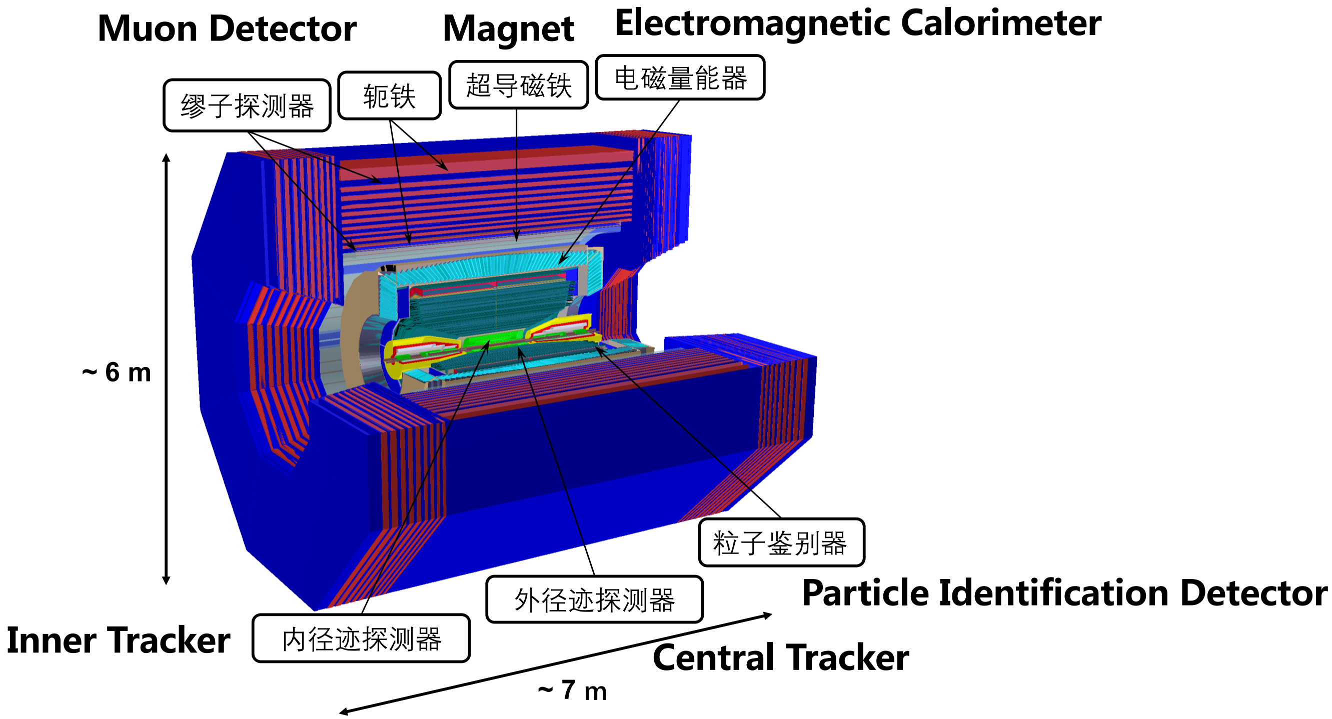




- Conceptual design studies have been largely finished. Three volumes of CDRs are being under review and will be released soon.

- Moving to the TDR stage with strong support from USTC and local governments.
  - Anhui province, Hefei city and USTC have agreed in principle to jointly fund a full R&D program for the STCF project. Details are being worked out.

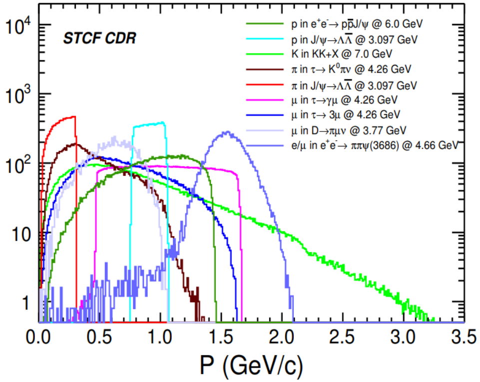
STCF Detector Concept

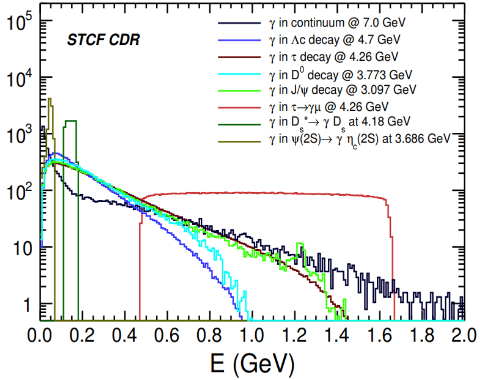


Physics Requirements

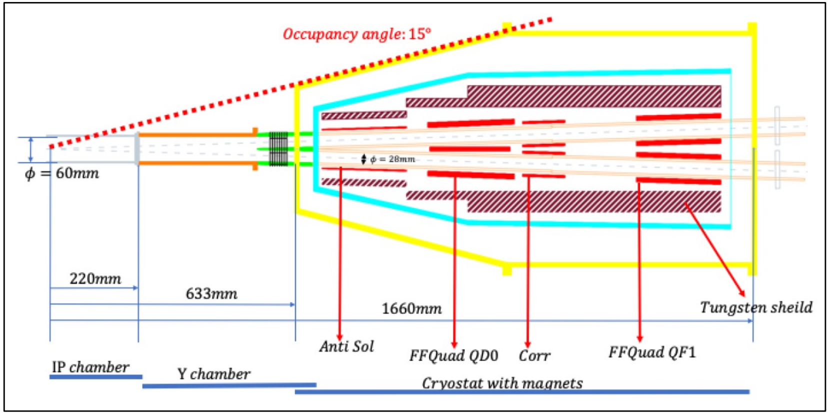
- ❖ **Highly efficient and precise reconstruction of exclusive final states produced in 2-7 GeV e+e- collisions**
  - Precise measurement of low-p particles → low mass
  - Excellent PID : π/K and μ/π separation up to 2 GeV

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 $\sigma_{\rm pos} \approx 5$ 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	$\sigma_T = \frac{300}{\sqrt{p^3(\mathrm{GeV}^3)}}$ ps





Experimental Conditions

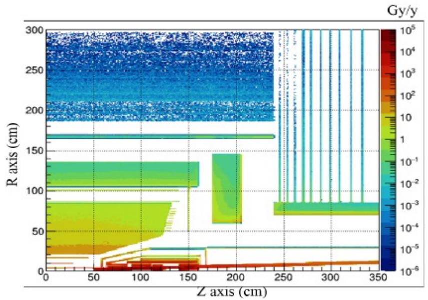


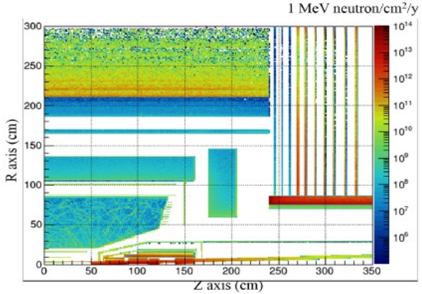
- ❖ **Interaction region and machine detector interface**
  - Boundaries defined for the detector system: beam pipe diameter of 6 cm, opening angle of 30^0 ...

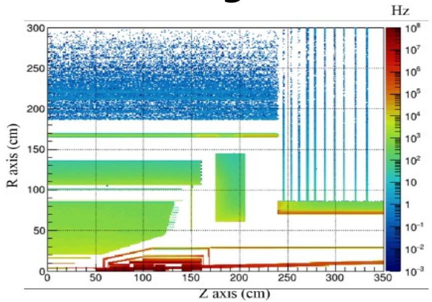
- ❖ **Beam-induced backgrounds have to be fully simulated and carefully evaluated.**
  - Luminosity backgrounds: radiative BhaBha scattering, two-photon process
  - Single-beam backgrounds: Thouschek scattering, beam-gas interaction, synchrotron radiation, injection background

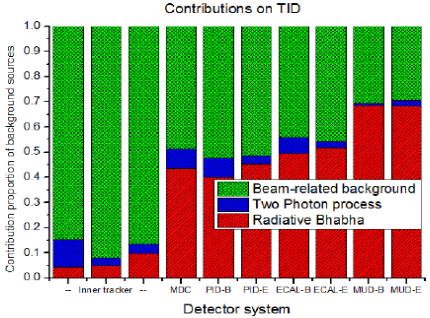
Beam-induced Backgrounds

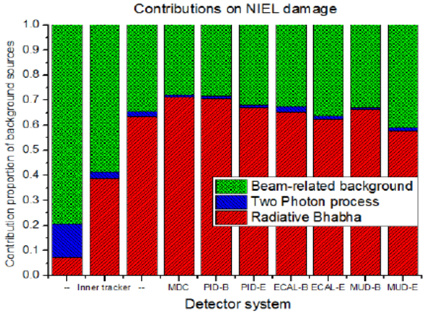
TID	NIEL	Counting rate

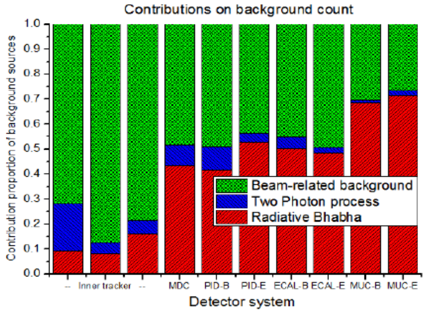








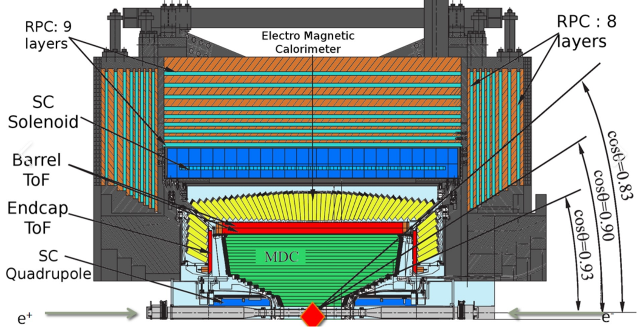


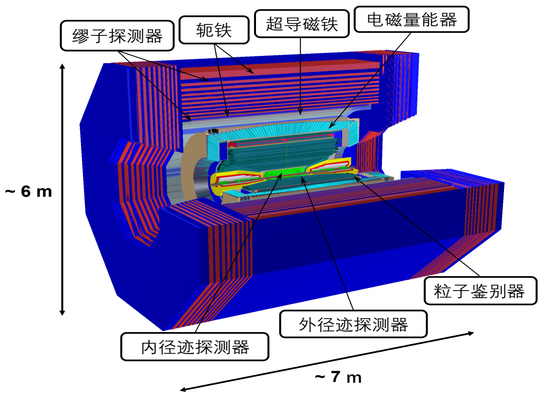


Inner most detector layer： ~3.5 kGy/y, ~10^{12} 1MeV n-eq/cm^2/y, ~1 MHz/cm^2

General Considerations for the Detector Design

BESIII Detector

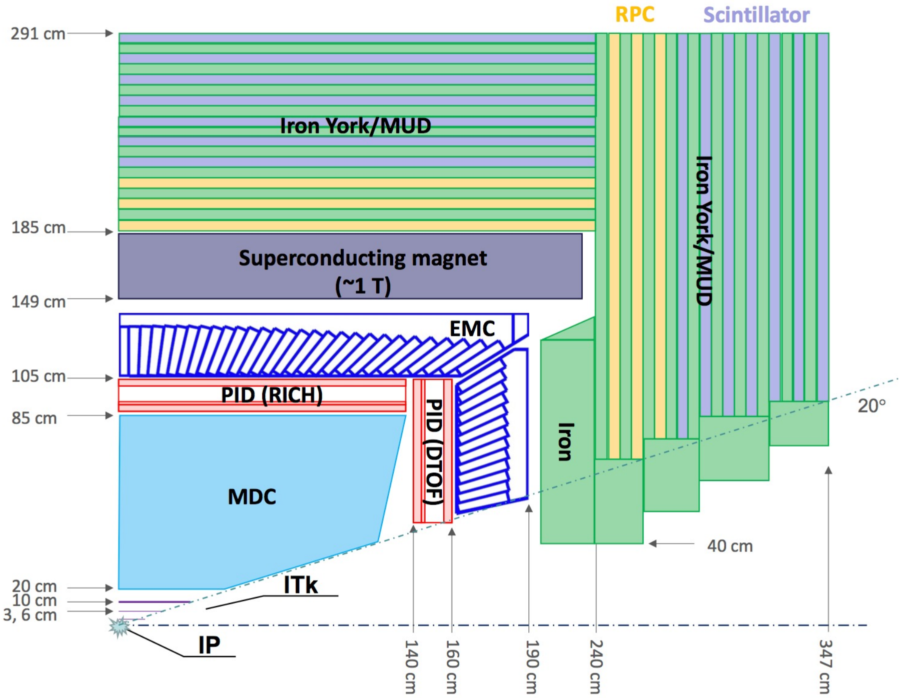




STCF Detector

- **Highest energy available 5 → 7 GeV : pushing up PID momentum range.**
  - Plastic scintillator/MRPC TOF detectors → Cherenkov detectors
  - Thicker iron yoke is needed
- **Peak luminosity $10^{33} \rightarrow 10^{35}$ $cm^{-2}s^{-1}$: significantly pushing up radiation background level.**
  - Inner tracker : wire chamber → high-rate tracking detector options
  - EMC: CsI(Tl) → fast crystal (pure CsI)
  - Streamer-mode RPC → avalanche-mode RPC + scintillator strips

The STCF Detector Conceptual Design



Solid Angle Coverage : 94%•4π (θ~20⁰)

❖ Inner tracker
- MPGD: cylindrical μRWELL
- Silicon: CMOS MAPS

❖ Central tracker
- Drift chamber

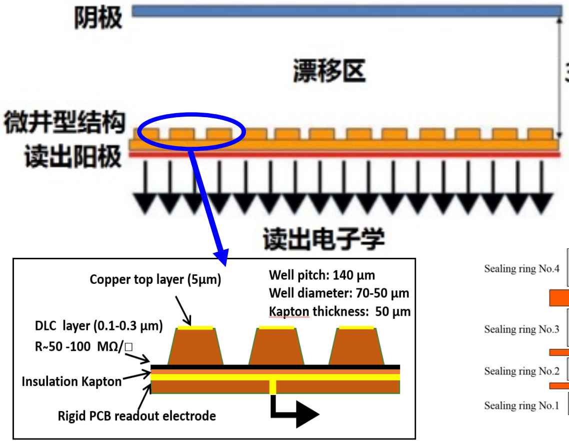
❖ PID
- Barrel: RICH
- Endcaps: DIRC-like TOF (DTOF)

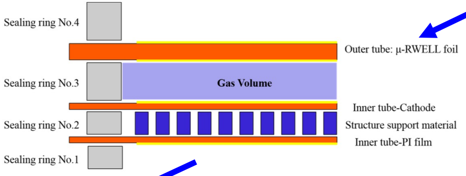
❖ EMC
- pure CsI + APD

❖ Muon detector
- Bakelite RPC + scintillator strips

Inner Tracker - μRWELL Option

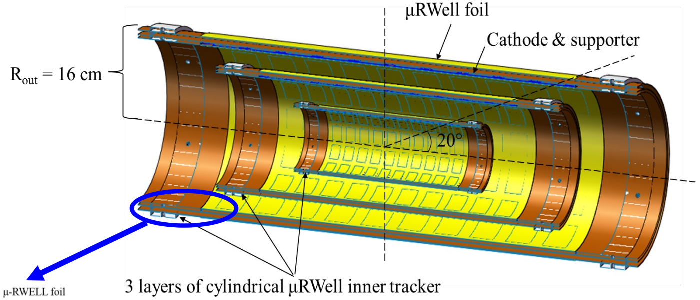
μRWELL: micro resistive WELL detector





Structure	Material	Thickness (cm)	Material budget (X/X_0)
Inner tube	Aluminum (X_0=8.897 cm)	0.001	0.011%
	Polyimide (X_0=28.57 cm)	0.01	0.035%
	Aramid honeycomb/Rohacell ($X_0\simeq$267 cm)	0.2	0.075%
Gas Volume	Helium-based gas mixture (X_0=56710 cm)	0.3	0.00053%
Outer tube (μRWELL foil)	Alumium (X_0=8.897 cm)	0.0015	0.017%
	Polyimide (X_0=28.57 cm)	0.03	0.106%
	DLC (X_0=12.13 cm)	0.0001	0.00082%
Total			0.245%

Cylindrical μRWELL tracking chamber

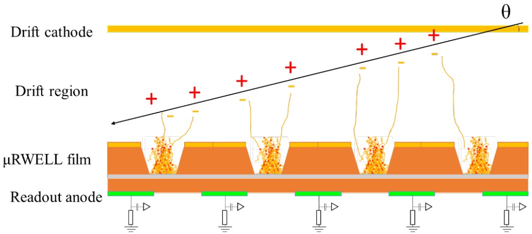


❖ Three cylindrical layers

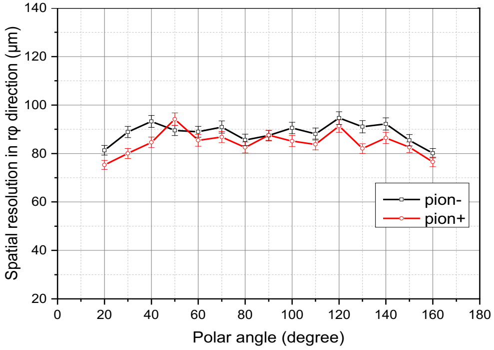
- Located at 6cm, 11cm, 16 cm
- Material budget / layer: 0.25% X_0
- 2D XV strip readout, 0.4mm pitch
- Hit rate up to 1 MHz/cm^2

Performance Simulation and Design Optimization

Position reconstruction algorithm charge centroid + micro-TPC

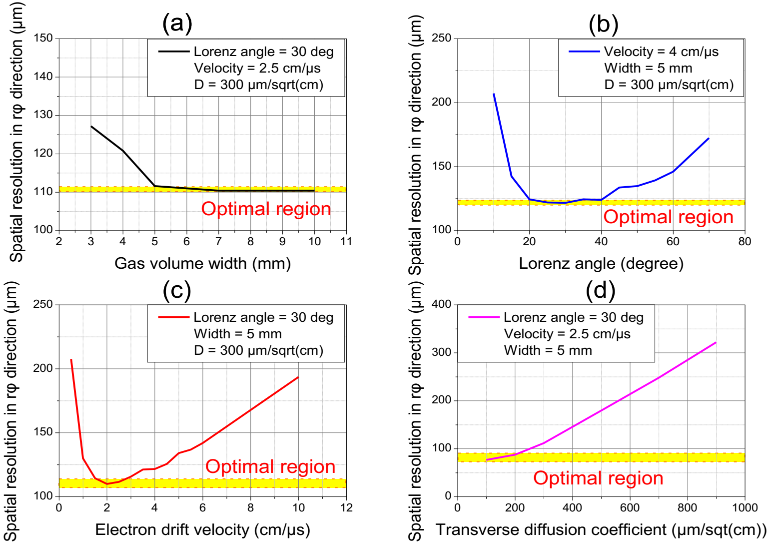


Position resolution



Occupancy with strip readout needs to be further examined.

Parameters Optimization



Optimized configuration

- **Working gas: Ar:CO_2 = 85:15**
- **Drift field: 500 V/cm**
- **Drift gap: 5 mm**

µRWELL Detector R&D

Major challenges: high rate, cylindrical shape

Step1: Gluing

Step2:Patterning, Etching

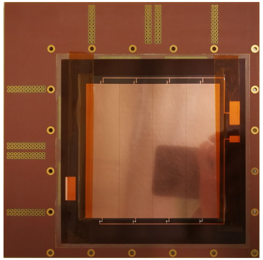
Step3: Drilling

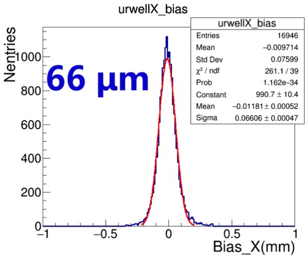
Step4: Plating

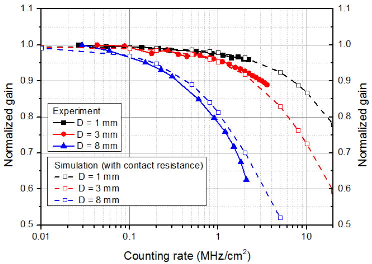
Step5: Etching

A fast-grounding layout for large area fabrication

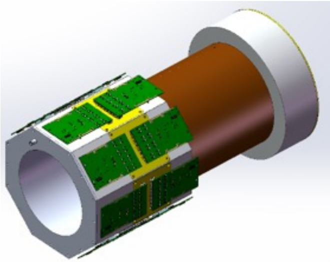
High-rate µRWELL prototype development

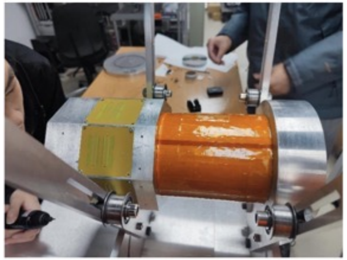


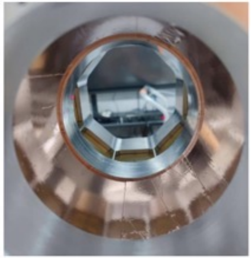




cylindrical µRWELL structure design and engineering

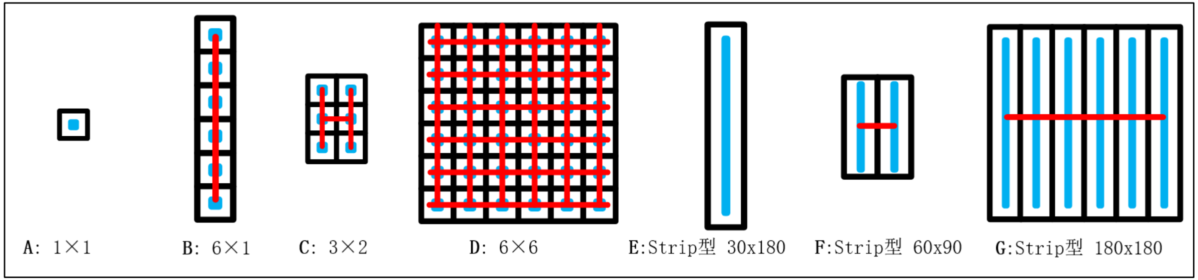


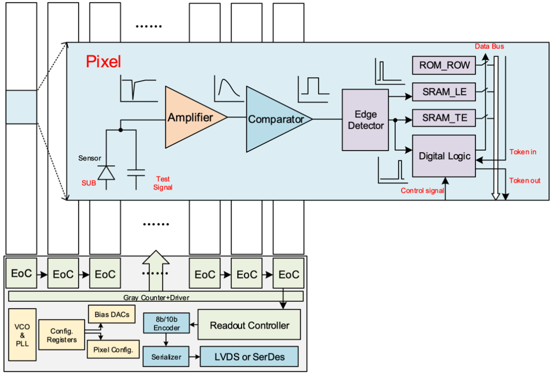


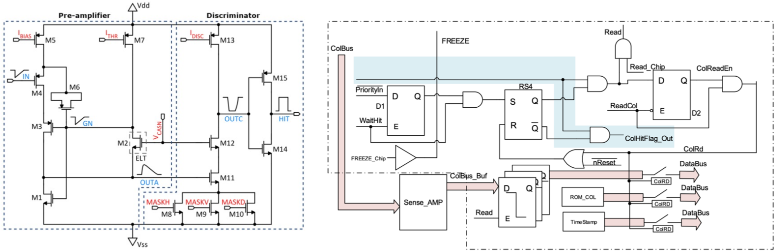


Inner Tracker – CMOS MAPS Option

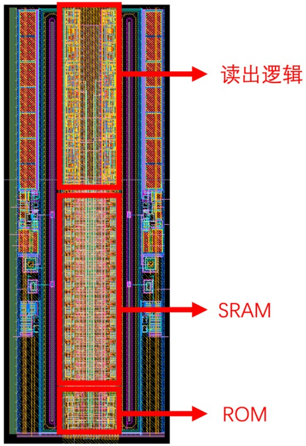
Aiming for a low-power chip design (required for a low-mass system) with timing capability



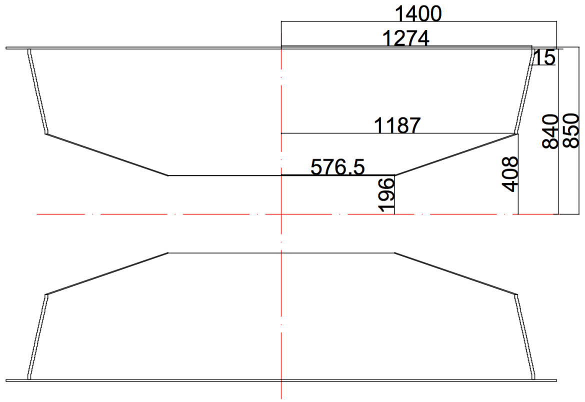


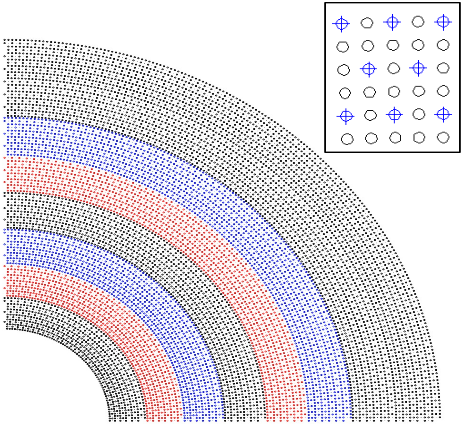


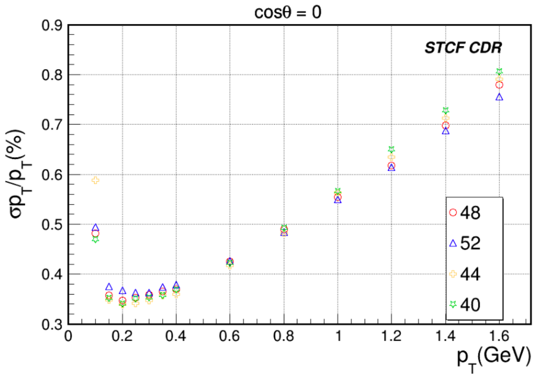
TJ 180nm CIS



Central Tracker – Main Drift Chamber





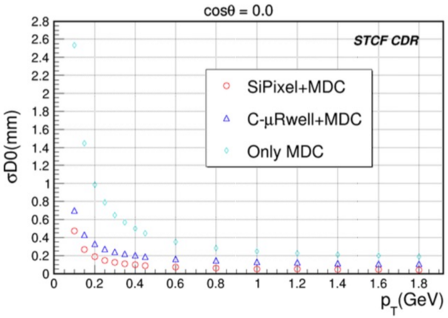


Superlayer	Radius (mm)	Num. of Layers	Inclination (mrad)	Num. of Cells	Cell size (mm)
A	200.0	6	0	128	9.8 to 12.5
U	271.6	6	39.3 to 47.6	160	10.7 to 12.9
V	342.2	6	-41.2 to -48.4	192	11.2 to 13.2
A	419.2	6	0	224	11.7 to 13.5
U	499.8	6	50.0 to 56.4	256	12.3 to 13.8
V	578.1	6	-51.3 to -57.2	288	12.6 to 14.0
A	662.0	6	0	320	13.0 to 14.3
A	744.0	6	0	352	13.3 to 14.5
total	200 to 827.3	48		11520	

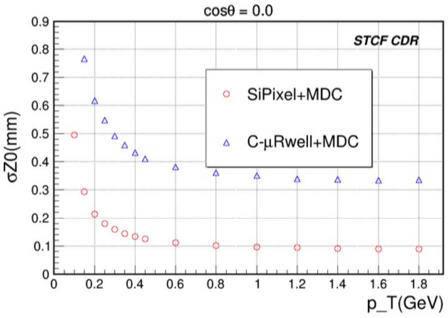
Hit rate at the inner most layer ~ 400 kHz/channel
→ a big challenge for readout electronics

- **A lot of simulation performed to optimize the drift chamber design :**
  - Square cell：9.8～14.5 mm
  - 48 wire layers arranged in 8 super layers
  - Sense (field) wire：W(Al), 20(100)μm in diameter
  - Working gas：He/C3H8 (60/40)
  - Total material budget: 4% (walls included)

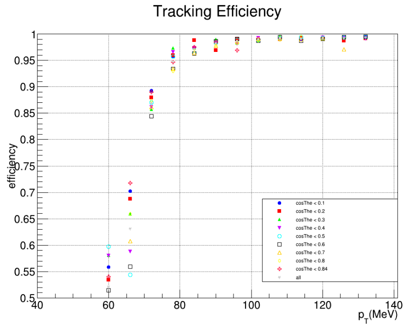
Expected Performance of the tracking system

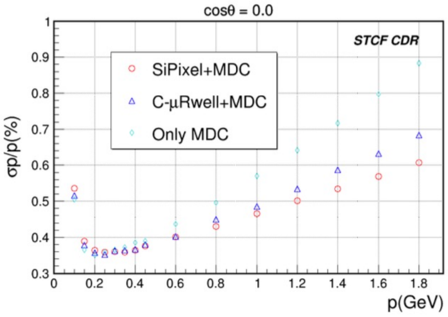


(a)



(b)





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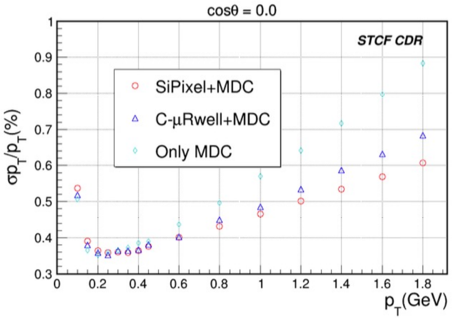
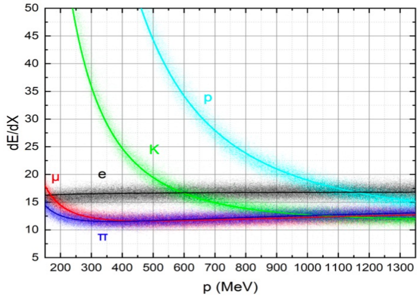
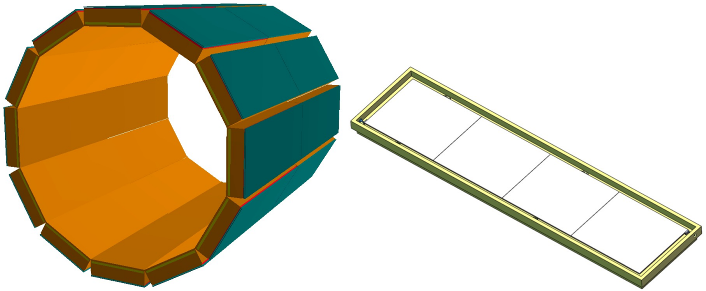


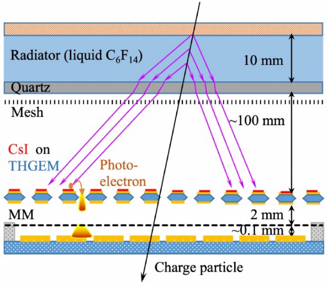
(d)



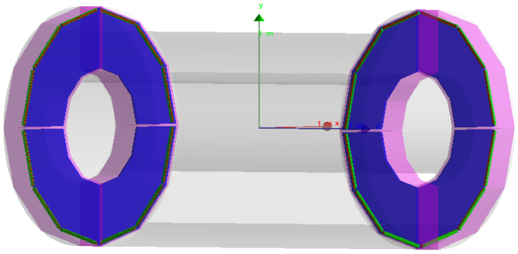
Particle Identification

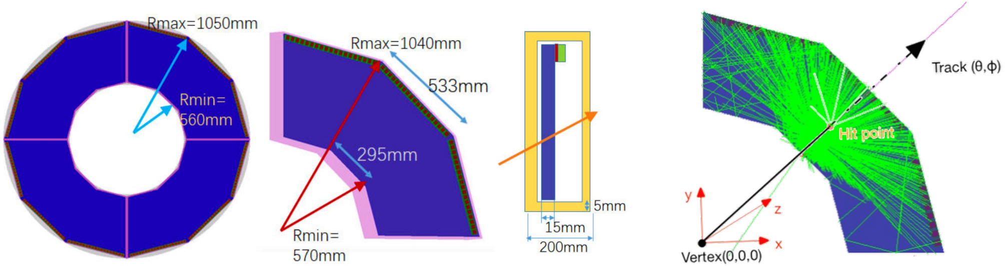
❖ **Barrel : A RICH detector using MPGD for photon detection (TOF technology no longer feasible for PID up to 2 GeV due to short distance of flight)**





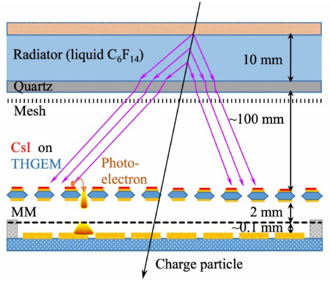
❖ **Endcaps : A DIRC-like high-resolution TOF detector is proposed (TOF option is possible thanks to the longer distance of flight) .**



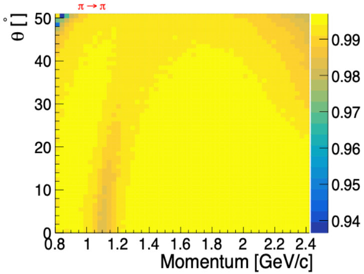


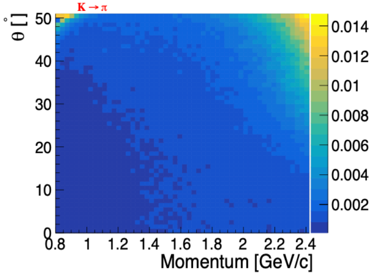
The RICH Detector

- Radiator: liquid C6F14 with n ~ 1.3
- THGEM+MM with CsI photo cathode
- Simulated number of photon electrons ~ 10
- Total material budget < $0.3X_0$

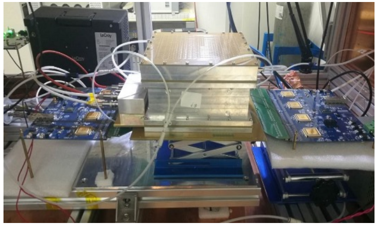


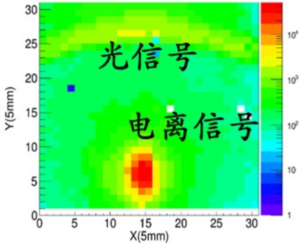
- $\boldsymbol{K/\pi}$ > 4 $\boldsymbol{\sigma}$ @2.0GeV/c
- $\boldsymbol{K/p}$ > 4 $\boldsymbol{\sigma}$ @ 2.0GeV/c
- potential for $\boldsymbol{\pi}/\mu$ in 0.3-0.5GeV/c



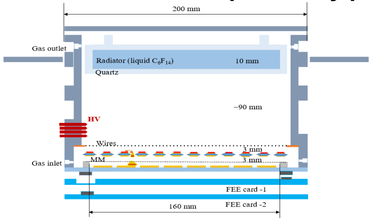


A RICH prototype with quartz radiator

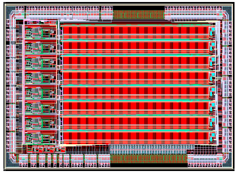




A RICH prototype with C6F14

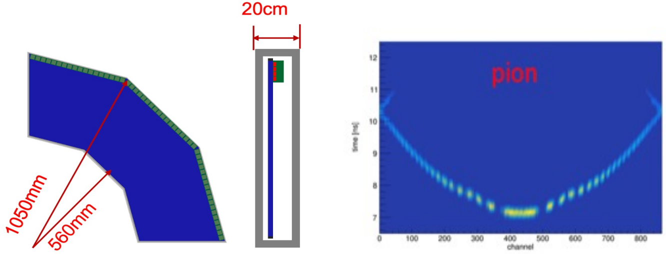


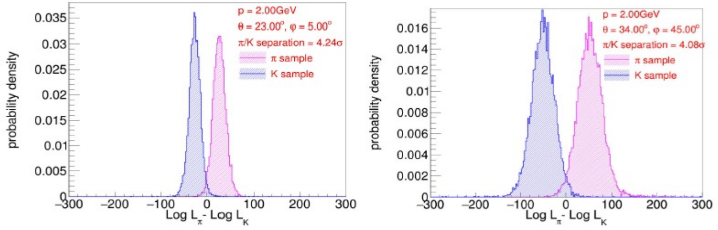
Development of readout chip and electronics



The DTOF Detector

- **Detector design has been deeply optimized**
  - quartz plate size and thickness, surface treatment, MCP-PMT coupling

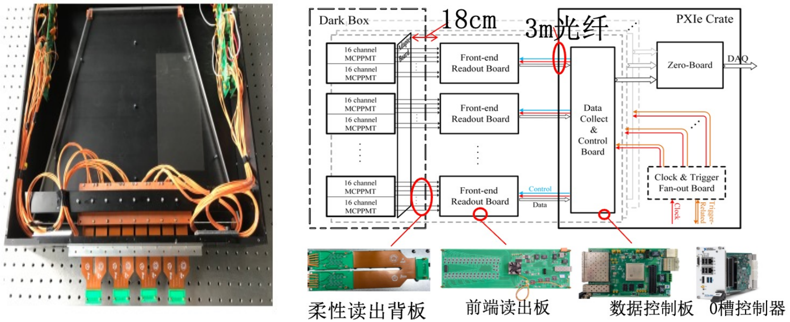


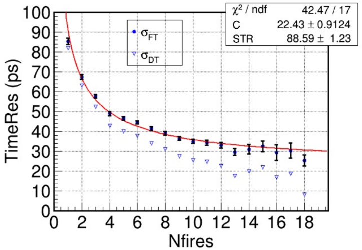


π/K ~ 4 σ @2GeV

The PID performance can be further enhanced by combining timing and spatial pattern of photon hits

Length of propagation is calculated for each detected photon. TOF is then reconstructed from arrival times measured of all detected photons.

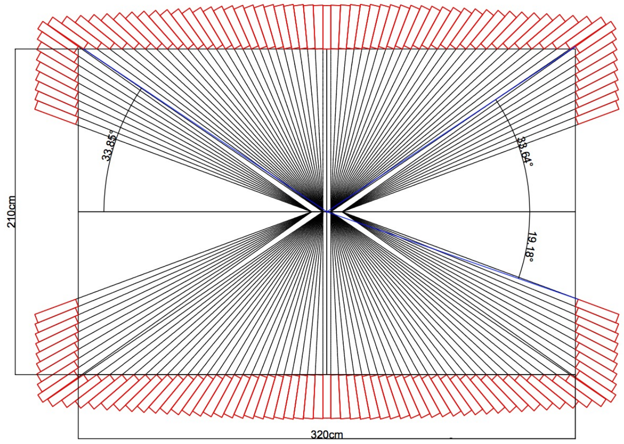




- A DTOF prototype and readout electronics were developed and tested with cosmic rays.
- Time resolution < 30 ps

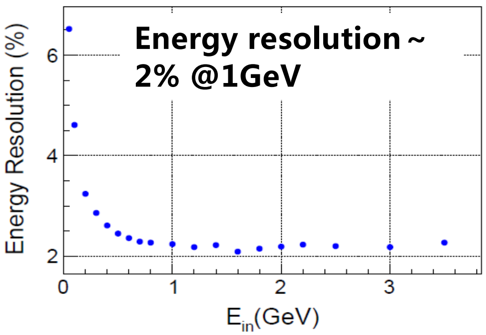
Electromagnetic Calorimeter

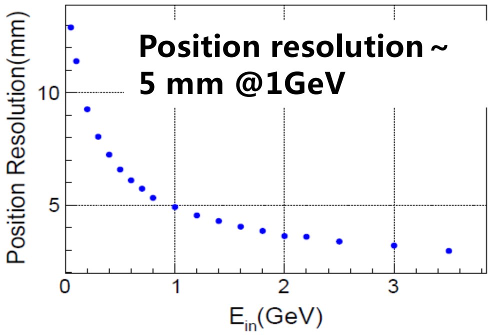
- A crystal calorimeter using pCsI (short decay time of 30ns) to tackle the high background rate (~ 1 MHz/crystal)
  - crystal size：28cm (15X_0), 5×5cm^2
  - defocused layout： 6732 crystals in barrel，1938 crystals in endcaps
  - 4 large area APDs to address low light yield: 4×(1×1cm^2)



pCsI has a very low light yield of 3.6% → a major R&D task : enhance light yield

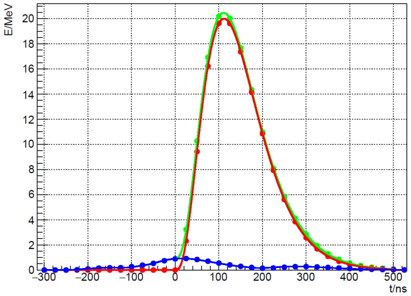
Simulation assuming a light yield of 100pe/MeV

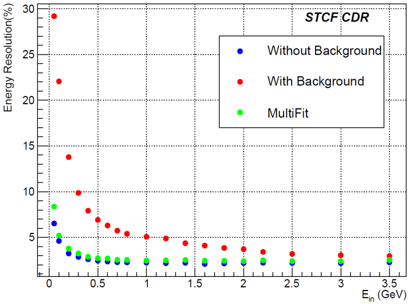




Pileup mitigation and detector R&D

- Waveform fitting with multiple templates

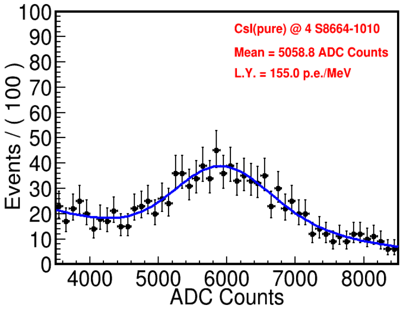




Very effective in mitigating the pileup effect

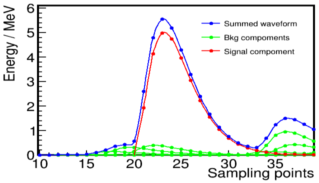
- Light yield studies

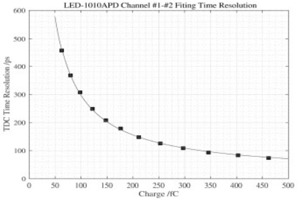
reflector : 225um thick Teflon



Light yield reached up to 155 p.e./MeV

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



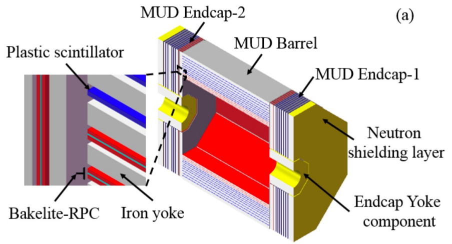


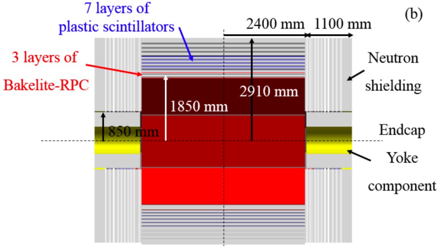
Dynamic range : 3 MeV ~ 3 GeV

ENE : ~ 1 MeV

Time resolution : < 200 ps@1GeV

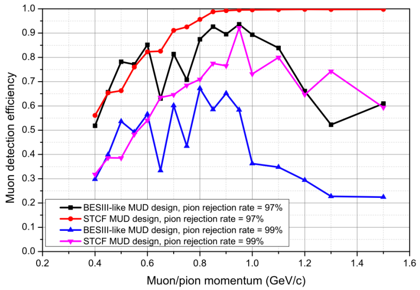
The Muon Detector

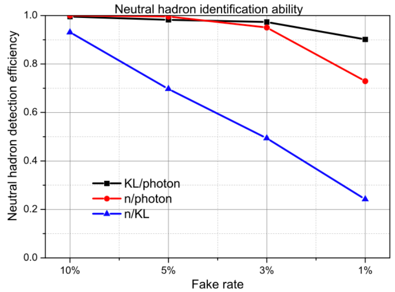




Parameter	Baseline design
R_{in} [cm]	185
R_{out} [cm]	291
R_e [cm]	85
L_{Barrel} [cm]	480
T_{Endcap} [cm]	107
Segmentation in ϕ	8
Number of detector layers	10
Iron yoke thickness [cm]	4/4/4.5/4.5/6/6/6/8/8 cm
(λ=16.77 cm)	Total: 51 cm, 3.04λ
Solid angle	79.2%×4π in barrel 14.8%×4π in endcap 94%×4π in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

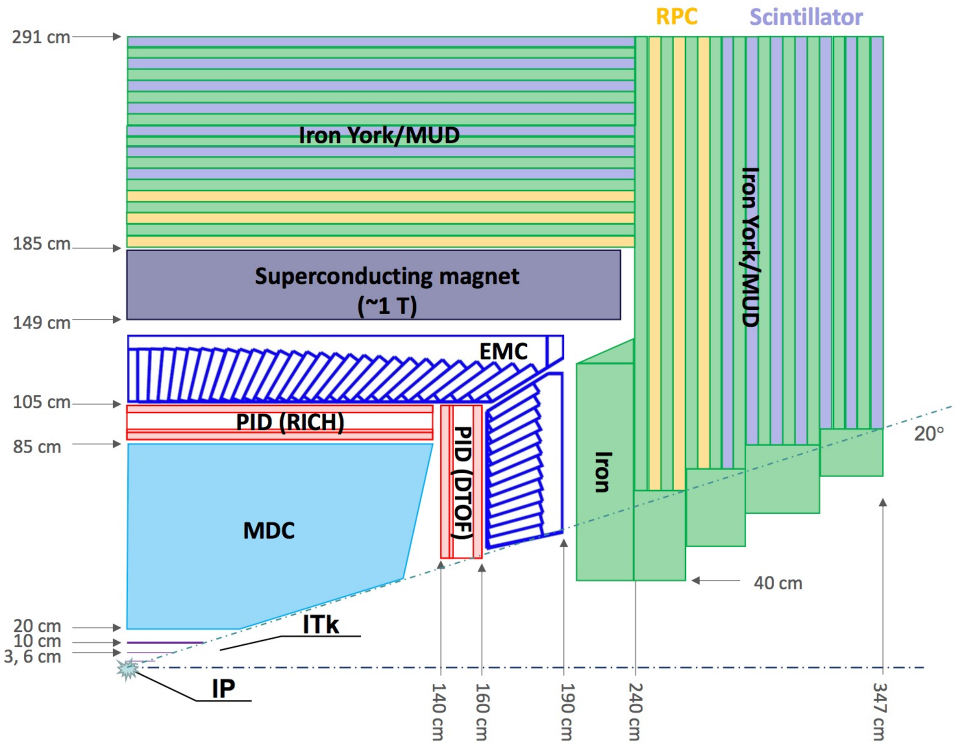
- A hybrid design with Bakelite RPC and scintillator strips for optimal overall performance
  - RPC for inner layers : not sensitive to background
  - Scintillator for outer layers: sensitive to hadrons
- Key design parameters have been optimized based on simulation of muon identification performance
  - Inner 3 RPC layers + outer 7 scintillator layers
  - Taking neutral hadron identification into account





Using BDT combining the muon detector and EMC

Detector Summary



ITk
- $< 0.25\% X_0$ / layer
- $\sigma_{xy} < 100\ \mu m$

Cylindrical μRWELL
CMOS MAPS

MDC
- $\sigma_{xy} < 130\ \mu m$
- $\sigma_p/p \sim 0.5\%$ @ 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

E range: 0.025-3.5GeV

σ_E (%) @ 1 GeV

Barrel: 2 .5

Endcap: 4

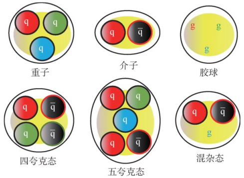
Pos. Res. : 5 mm

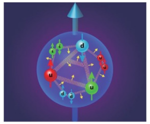
pCsI + APD

MUD
- 0.4 - 2 GeV
- π suppression >30

RPC + scintillator

STCF Physics Program

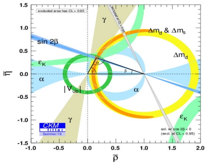


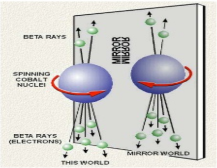


Physics at STCF

QCD and hadronic physics

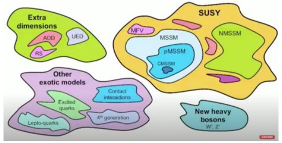
- **XYZ Properties:** e+e-→Y→γX,ηX,ϕX; e+e-→Y→πZc, KZcs
- **Hadron Spectroscopy:** Excited ccbar and their transition, Charmed hadron spectroscopy, Light hadron spectroscopy
- **R value:** e+e-→inclusive; τ mass: e+e-→τ+τ-
- **Nucleon Form Factors:** e+e-→BBbar from threshold
- **Pentaquarks:** e+e-→J/ψppbar, Λc Dbar pbar, Σc Dbar pbar
  Di-charmonium: e+e-→J/ψηc, J/ψhc
- **Muon g-2:** e+e-→π+ π-, π+ π- π0, 4π, K+ K-, γγ→π0, η('),π+ π-
- **Fragmentation functions:** e+e-→(π,K,p,Λ,D)+X, e+e-→(ππ,KK,πK)+X





Flavor Physics and CP Violation

- **CKM matrix (Vcd, Vcs):** D_(s)+→l+v, D→P l+ v
- **Charm hadron decay:** Λc+, Σc, Ξc, Ωc decay
- **CPV in Hyperons:** J/ψ→ΛΛbar, ΣΣbar, Ξ- Ξ+bar, Ξ0 Ξ0bar
- **D0-D0bar mixing:** ψ(3770)→(D0 D0bar)(CP=-), ψ(4140)→π0 (D0 D0bar)(CP=-) or γ(D0 D0bar)(CP=+)
- **CPV in τ:** τ→Ks πv, EDM of τ, τ→π/K π0 v for polarized e- beam
- **CPV in Charm:** D0→K+K-/π+π-, Λc→pK-π+π0/Λπ+π+π-/pKs π+π-
- **γ/ϕ3 measurement:** D0→K(s/L) π+ π-, K(s/L) K+ K-,K3π, 4π
- **γ polarization:** D0→K1 e+ v_e



Forbidden/Rare decay and New Particle

- **LNV, BNV:** D(s)+→l+ l+ X-, J/ψ→Λc e-, B→Bbar…
- **Symmetry violation:** η(')→llπ0, η'→ηll…
- **FLV decays:** τ→γl, lll,l P1 P2 , J/ψ→ll', D0→ll' (l'≠l)…
- **FCNC:** D→γV, D0→l+ l-, e+e-→D*, Σ+→pl+ l-…
- **Dark photon:** e+e-→γA'(→l+ l-), J/ψ→e+e-A'…
  Millicharged: e+e-→χχ̄γ…

- Leading role
- Competing with Belle II/LHCb
- Complementary to BelleII/LHCb/Eic/EicC

Expected Data Samples at STCF

Data samples produced per year

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}	
		$D^+\bar{D}^-$	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}	
4.040	1	$\gamma D^0\bar{D}^0$	0.40	4.0×10^{6}	$CP_{D^0\bar{D}^0}=+1$
		$\pi^0 D^0\bar{D}^0$	0.40	4.0×10^{6}	$CP_{D^0\bar{D}^0}=-1$
		$D_s^+D_s^-$	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			

Hyperon Factory

Decay mode	$\mathcal{B}$(units 10^{-4})	Angular distribution parameter α_ψ	Detection efficiency	No. events expected at STCF
$J/\psi\to\Lambda\bar{\Lambda}$	$19.43\pm0.03\pm0.33$	0.469 ± 0.026	40%	1100×10^6
$\psi(2S)\to\Lambda\bar{\Lambda}$	$3.97\pm0.02\pm0.12$	0.824 ± 0.074	40%	130×10^6
$J/\psi\to\Xi^0\bar{\Xi}^0$	11.65 ± 0.04	0.66 ± 0.03	14%	230×10^6
$\psi(2S)\to\Xi^0\bar{\Xi}^0$	2.73 ± 0.03	0.65 ± 0.09	14%	32×10^6
$J/\psi\to\Xi^-\bar{\Xi}^+$	10.40 ± 0.06	0.58 ± 0.04	19%	270×10^6
$\psi(2S)\to\Xi^-\bar{\Xi}^+$	2.78 ± 0.05	0.91 ± 0.13	19%	42×10^6

Light meson Factory

Decay Mode	$\mathcal{B}$ $(\times10^{-4})$ [2]	η/η' events
$J/\psi\to\gamma\eta'$	52.1 ± 1.7	1.8×10^{10}
$J/\psi\to\gamma\eta$	11.08 ± 0.27	3.7×10^{9}
$J/\psi\to\phi\eta'$	7.4 ± 0.8	2.5×10^{9}
$J/\psi\to\phi\eta$	4.6 ± 0.5	1.6×10^{9}

XYZ Factory

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

- High detection efficiency and low background for production at threshold
- High detection resolution, kinematic constraining
- Unexplored opportunities at 5-7 GeV

Expected Sensitivities

Physics at STCF	Benchmark Processes	Key Parameters*	Physics at STCF	Benchmark Processes	Key Parameters*
XYZ properties	$e^+e^- \to Y \to \gamma X, \eta X, \phi X$ $e^+e^- \to Y \to \pi Z_c, KZ_{cs}$	$N_{Y(4260)/Z_c/X(3872)} \sim$ $10^{10}/10^9/10^6$	**CKM matrix**	$D^+_{(s)} \to l^+\nu_l, D \to Pl^+\nu_l$	$\delta V_{cd/cs} \sim 0.15\%$; $\delta f_{D/D_s} \sim 0.15\%$
Pentaquarks, Di-charmonium	$e^+e^- \to J/\psi p\bar{p}, \Lambda_c\bar{D}\bar{p}, \Sigma_c\bar{D}\bar{p}$ $e^+e^- \to J/\psi\eta_c, J/\psi h_c$	$\sigma(e^+e^- \to J/\psi p\bar{p})$~4 fb; $\sigma(e^+e^- \to J/\psi c\bar{c})$~10 fb (prediction)	**γ/ϕ_3 measurement**	$D^0 \to K_s\pi^+\pi^-, K_sK^+K^-$ ...	$\Delta(\cos\delta_{K\pi}) \sim 0.007$; $\Delta(\delta_{K\pi}) \sim 2°$
Hadron Spectroscopy	Excited $c\bar{c}$ and their transition, Charmed hadron, Light hadron	$N_{J/\psi/\psi(3686)/\Lambda_c} \sim$ $10^{12}/10^{11}/10^8$	**$D^0 - \bar{D}^0$ mixing**	$\psi(3770) \to (D^0\bar{D}^0)_{CP=-}$, $\psi(4140) \to \gamma(D^0\bar{D}^0)_{CP=+}$	$\Delta x \sim 0.035\%$; $\Delta y \sim 0.023\%$
Muon g-2	$\pi^+\pi^-, \pi^+\pi^-\pi^0, K^+K^-$ $\gamma\gamma \to \pi^0, \eta^{(\prime)}, \pi^+\pi^-$	$\Delta a_\mu^{HVP} \ll 40 \times 10^{-11}$	**Charm hadron decay**	$D_{(s)}, \Lambda_c^+, \Sigma_c, \Xi_c, \Omega_c$ decay	$N_{D/D_s/\Lambda_c} \sim 10^9/10^8/10^8$
R value, τ mass	$e^+e^- \to inclusive$ $e^+e^- \to \tau^+\tau^-$	$\Delta m_\tau \sim 0.012$ MeV (with 1 month scan)	**γ polarization**	$D^0 \to K_1 e^+\nu_e$	$\Delta A'_{UD} \sim 0.015$
Fragmentation functions	$e^+e^- \to (\pi, K, p, \Lambda, D) + X$ $e^+e^- \to (\pi\pi, KK, \pi K) + X$	$\Delta A^{\text{Collins}} < 0.002$	**CPV in Hyperons**	$J/\psi \to \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi^-\bar{\Xi}^-, \Xi^0\bar{\Xi}^0$	$\Delta A_\Lambda \sim 10^{-4}$
Nucleon Form Factors	$e^+e^- \to B\bar{B}$ from threshold	$\delta R_{EM} \sim 1\%$	**CPV in τ**	$\tau \to K_s\pi\nu$, EDM of τ,	$\Delta A_{\tau\to K_s\pi\nu} \sim 10^{-3}$; $\Delta d_\tau \sim 5 \times 10^{-19}$ (e cm)
FLV decays	$\tau \to \gamma l, lll, lP_1P_2$ $J/\psi \to ll', D^0 \to ll'(l' \neq l)$...	$\mathcal{B}(\tau \to \gamma\mu/\mu\mu\mu)$<12/1.5× 10^{-9}; $\mathcal{B}(J/\psi \to e\tau)$<0.71× 10^{-9}	**CPV in Charm**	$D^0 \to K^+K^-/\pi^+\pi^-$, $\Lambda_c \to pK^-\pi^+\pi^0$ ...	$\Delta A_D \sim 10^{-3}$; $\Delta A_{\Lambda_c} \sim 10^{-3}$
LNV, BNV	$D^+_{(s)} \to l^+l^+X^-, J/\psi \to \Lambda_c e^-$, $B \to \bar{B}$...	$\mathcal{B}(J/\psi \to \Lambda_c e^-) < 10^{-11}$	**FCNC**	$D \to \gamma V, D^0 \to l^+l^-, e^+e^- \to D^*$, $\Sigma^+ \to pl^+l^-$...	$\mathcal{B}(D^0 \to e^+e^-X) < 10^{-8}$
Symmetry violation	$\eta^{(\prime)} \to ll\pi^0, \eta' \to \eta ll$...	$\mathcal{B}(\eta' \to ll/\pi^0 ll) < 1.5/2.4 \times 10^{-10}$	**Dark photon, millicharged**	$e^+e^- \to (J/\psi) \to \gamma A'(\to l^+l^-)$... $e^+e^- \to \chi\bar{\chi}\gamma$ ...	Mixing strength $\Delta\epsilon_{A'} \sim 10^{-4}$; $\Delta\epsilon_\chi \sim 10^{-4}$

*Sensitivity estimated based on $\mathcal{L} = 1$ ab^{-1}

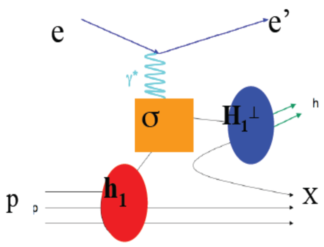
Collins Fragmentation Function (FF)

J. C. Collins, Nucl. Phys. B396, 161 (1993)

$$D_{hq^\uparrow}(z, P_{h\perp}) = D_1^q(z, P_{h\perp}^2) + \boxed{H_1^{\perp q}(z, P_{h\perp}^2)} \frac{(\hat{\mathbf{k}} \times \mathbf{P}_{h\perp}) \cdot \mathbf{S}_q}{zM_h},$$

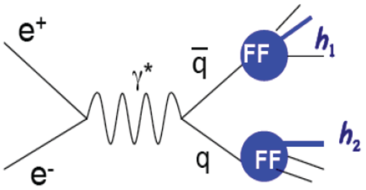
SIDIS

Transversity ⊗ Collins FF



e+ e-

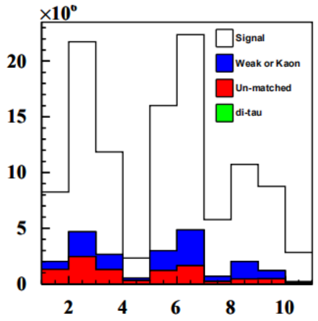
Collins FF ⊗ Collins FF

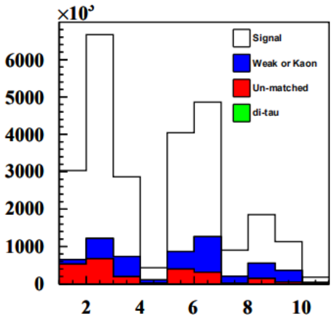


***H_1*: Collins FF**

→ describes the fragmentation of a transversely polarized quark into a spin-less hadron *h*.

→ leads to an azimuthal modulation of hadrons around the quark momentum.





- The statistical uncertainty asymmetry A^{UL} with $1\mathrm{ab}^{-1}$ at 7 GeV[1]:
  - (1.4~4.2)×10^{-4} for $\pi\pi X$
  - (3.5~20)×10^{-3} for KKX
- 2% precision required by EicC

[1] B. L. Wang et al., Journal of UCAS 38 (2021) 433

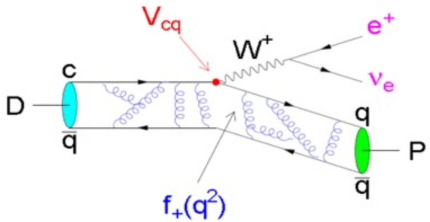
$D_{(s)}$ (Semi-)Leptonic decay

Purely Leptonic:

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

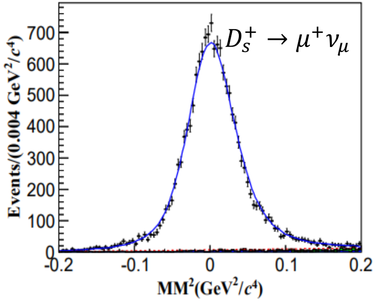
Semi-Leptonic:

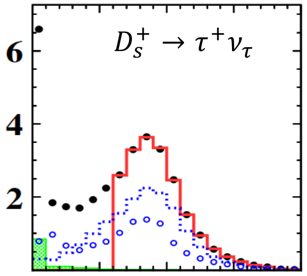
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{cs(d)}|^2 p^3_{K(\pi)} |f_+^{K(\pi)}(q^2)|^2$$



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

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





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

H.J. Li, J. J. Liu et al., Eur.Phys.J.C 82 (2022) 4, 310; 337

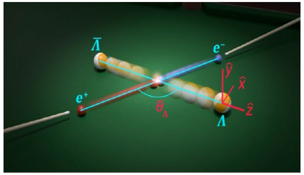
Probing CP Violation

❖ In Hyperon Decay

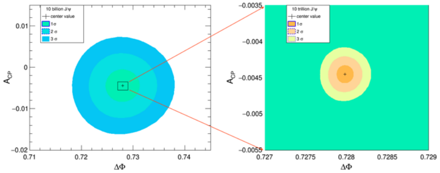
Λ is transversely polarized

CP test via $A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$

4 trillion J/ψ events ⇒ $A_{CP} \sim 10^{-4}$



Complementary to Kaon decay with P-wave transition

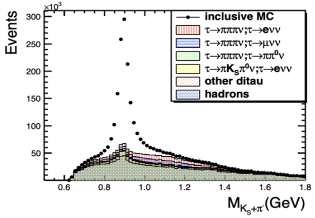


• In tau Decay

The CPV source in $K^0 - \bar{K}^0$ **mixing** produces a difference in $\tau \to K_S \pi \nu$ decay rate:

$$A_Q = \frac{B(\tau^+ \to K_S^0 \pi^+ \bar{\nu}_\tau) - B(\tau^- \to K_S^0 \pi^- \nu_\tau)}{B(\tau^+ \to K_S^0 \pi^+ \bar{\nu}_\tau) + B(\tau^- \to K_S^0 \pi^- \nu_\tau)} = (+0.36 \pm 0.01)\%$$

CPV sensitivity with 1ab^{-1} @ 4.26 GeV[1]: $A_{STCF} \sim 9.7 \times 10^{-4}$



[1] H. Y. Sang, et al., CPC 45, 053003 (2021)

• In Charm Decay

Quantum coherence of D^0 and $\bar{D}^0$

$$\psi(3770) \to (D^0\bar{D}^0)_{CP=-} \text{ or } \psi(4140) \to D^0\bar{D}^{*0} \to \pi^0(D^0\bar{D}^0)_{CP=-} \text{ or } \gamma(D^0\bar{D}^0)_{CP=+}$$

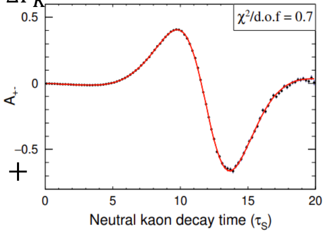
	1/ab @4.009 GeV (QC | QC+incoherent)		BelleII(50/ab)	LHCb(50/fb) (SL | Prompt)	
$x(\%)$	0.036	0.035	0.03	0.024	0.012
$y(\%)$	0.023	0.023	0.02	0.019	0.013
r_{CP}	0.017	0.013	0.022	0.024	0.011
$\alpha_{CP}(^\circ)$	1.3	1.0	1.5	1.7	0.48

• In $K^0 - \bar{K}^0$ Mixing

CPT test: $\phi_\pm = \phi_{00} = \phi_\varepsilon = \tan^{-1}\frac{2\Delta m_K}{\Delta\Gamma_K}$

$$A_{+-}(\tau) = \frac{\bar{N}(\tau) - kN(\tau)}{\bar{N}(\tau) + kN(\tau)}$$

$$= -2\frac{|\eta_f|\, e^{(1/2)(\Gamma_S - \Gamma_L)\tau} \cos(\Delta m\tau - \phi_f)}{1 + |\eta_f|^2 e^{(\Gamma_S - \Gamma_L)\tau}}$$



With 1 trillion J/ψ, $J/\psi \to K^-\pi^+K^0 +$ $c.c.$, $\Delta\phi_\pm \sim 0.05^\circ$ (PDG: 0.5°)

Summary

- **STCF is a super tau-charm factory 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 activities promoting the project at home and abroad, and conducting design studies and detector R&D.**
- **Intensive conceptual design studies in the past few years have resulted in 3 volumes of CDRs covering physics, detector and accelerator.**
- **The project is moving on to the TDR stage with strong support from local governments and USTC. International collaboration is essential for realizing the project.**