21st Conference on Flavor Physics and CP Violation (FPCP 2023)

Super Tau-Charm Facility

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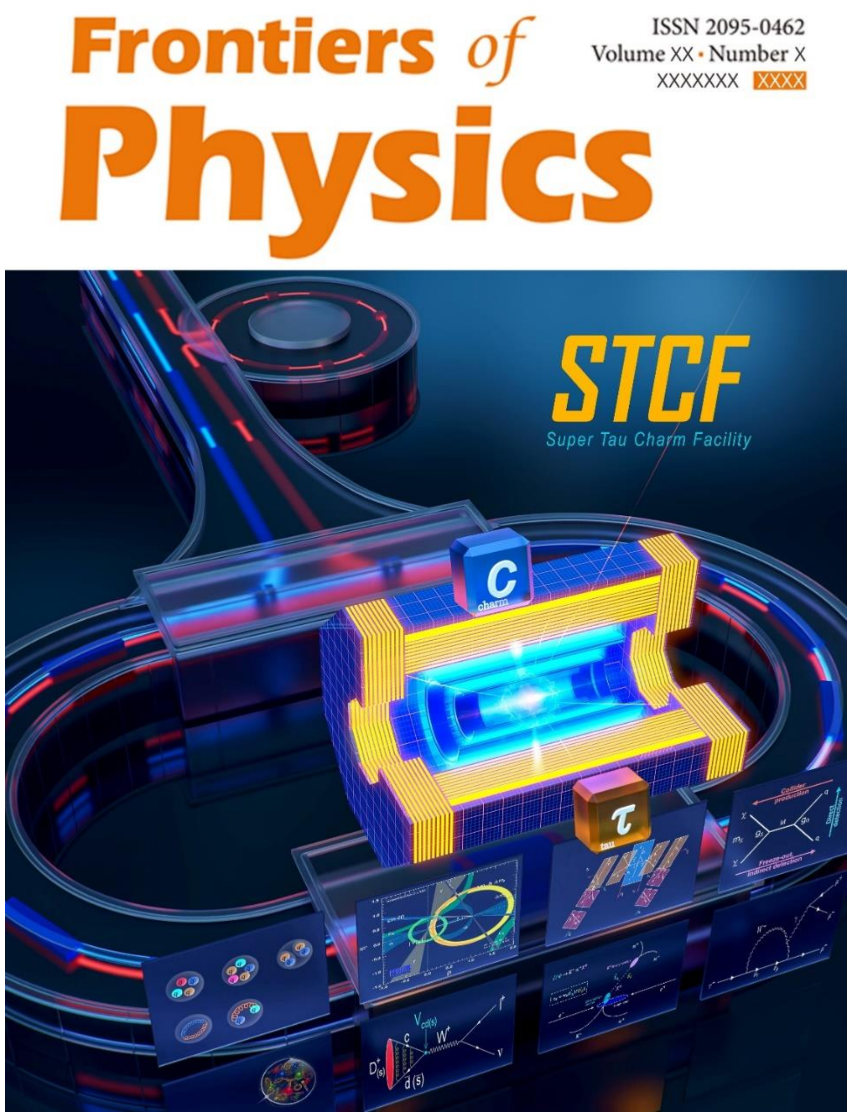
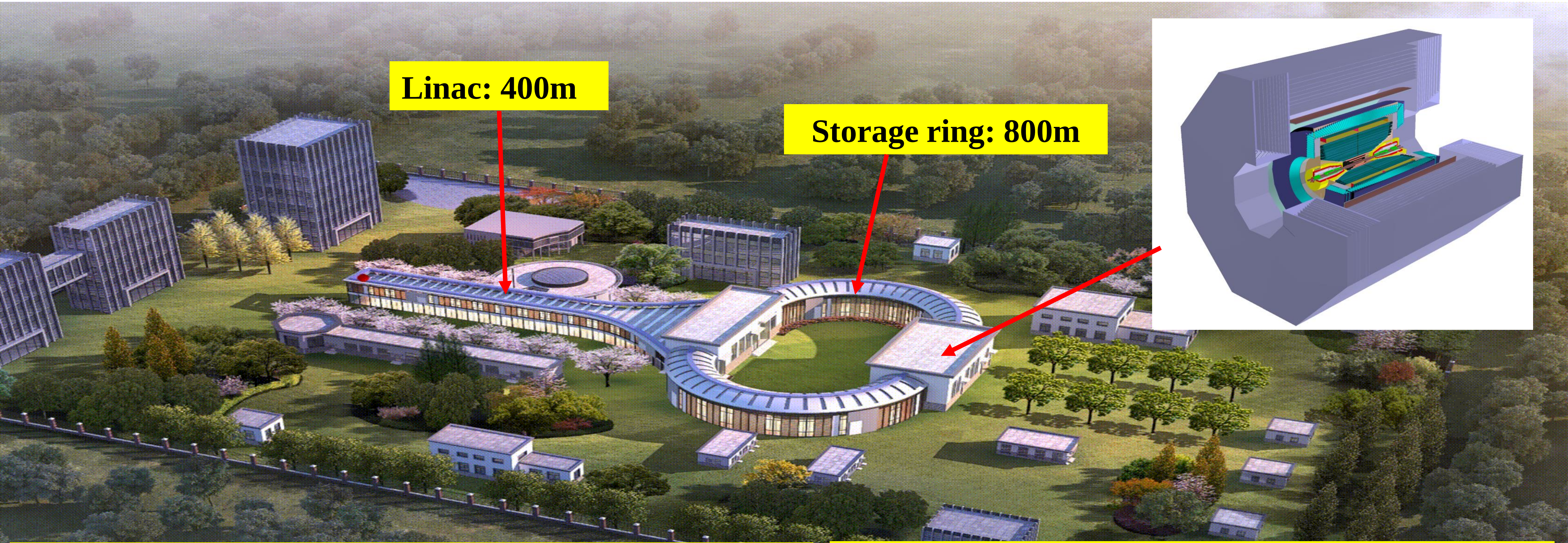
On behalf of the STCF working group

FPCP2023, Lyon, June 1 2023



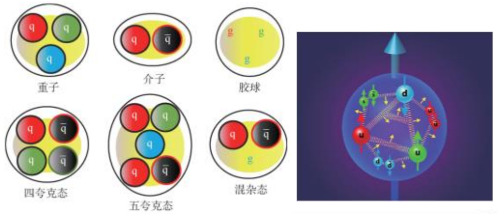
Super Tau Charm Facility (STCF) in China



- Peak luminosity $>0.5\times10^{35}$ $cm^{-2}s^{-1}$ 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 physics program, unique for physics with *c* quark and τ leptons
- Important playground for study of QCD, exotic hadrons, flavor and search for new physics.

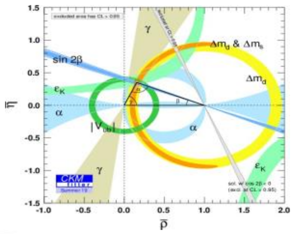
Physics programs at STCF

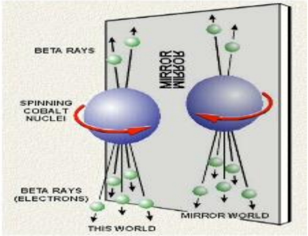


Physics at STCF

QCD and hadronic physics

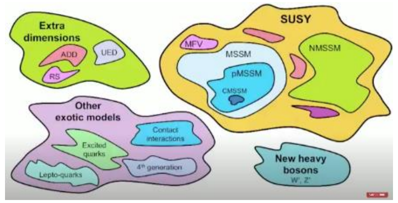
- **XYZ Properties:** $e^+e^- \to Y \to \gamma X, \eta X, \phi X$; $e^+e^- \to Y \to \pi Z_c$, KZ_{cs}
- **Hadron Spectroscopy:** Excited ccbar and their transition, Charmed hadron spectroscopy, Light hadron spectroscopy
- **R value:** $e^+e^- \to$ inclusive; τ mass: $e^+e^- \to \tau^+\tau^-$
- **Nucleon Form Factors:** $e^+e^- \to B\bar{B}$ from threshold
- **Pentaquarks:** $e^+e^- \to J/\psi p\bar{p}$, $\Lambda_c \bar{D} \bar{p}$, $\Sigma_c \bar{D} \bar{p}$
  Di-charmonium: $e^+e^- \to J/\psi \eta_c$, $J/\psi h_c$
- **Muon g-2:** $e^+e^- \to \pi^+\pi^-$, $\pi^+\pi^-\pi^0$, 4π, K^+K^-, $\gamma\gamma \to \pi^0$, $\eta^{(\prime)}$, $\pi^+\pi^-$
- **Fragmentation functions:** $e^+e^- \to (\pi, K, p, \Lambda, D)+X$, $e^+e^- \to (\pi\pi, KK, \pi K)+X$





Flavor Physics and CP Violation

- **CKM matrix (V_{cd}, V_{cs}):** $D_{(s)}^+ \to l^+\nu$, $D \to P l^+ \nu$
- **Charm hadron decay:** Λ_c^+, Σ_c, Ξ_c, Ω_c decay
- **CPV in Hyperons:** $J/\psi \to \Lambda\bar{\Lambda}$, $\Sigma\bar{\Sigma}$, $\Xi^-\bar{\Xi}^+$, $\Xi^0\bar{\Xi}^0$
- **D0-D0bar mixing:** $\psi(3770) \to (D^0\bar{D}^0)(CP=-)$, $\psi(4140) \to \pi^0 (D^0\bar{D}^0)(CP=-)$ or $\gamma(D^0\bar{D}^0)(CP=+)$
- **CPV in τ:** $\tau \to K_s \pi\nu$, EDM of τ, $\tau \to \pi/K\, \pi^0 \nu$ for polarized e- beam
- **CPV in Charm:** $D^0 \to K^+K^-/\pi^+\pi^-$, $\Lambda_c \to pK^-\pi^+\pi^0/\Lambda\pi^+\pi^+\pi^-/pK_s\pi^+\pi^-$
- **γ/ϕ3 measurement:** $D^0 \to K_{(S/L)}\pi^+\pi^-$, $K_{(S/L)}K^+K^-$, $K3\pi$, 4π
- **γ polarization:** $D^0 \to K_1 e^+ \nu_e$



Forbidden/Rare decay and New Particle

- **LNV, BNV:** $D_{(s)}^+ \to l^+ l^+ X^-$, $J/\psi \to \Lambda_c e^-$, $B \to \bar{B}$…
- **Symmetry violation:** $\eta^{(\prime)} \to ll\pi^0$, $\eta' \to \eta ll$…
- **FLV decays:** $\tau \to \gamma l$, lll, $l P_1 P_2$, $J/\psi \to ll'$, $D^0 \to ll'$ $(l' \neq l)$…
- **FCNC:** $D \to \gamma V$, $D^0 \to l^+l^-$, $e^+e^- \to D^*$, $\Sigma^+ \to p l^+ l^-$…
- **Dark photon:** $e^+e^- \to \gamma A'(\to l^+l^-)$, $J/\psi \to e^+e^- A'$…
  Millicharged: $e^+e^- \to \chi\bar{\chi}\gamma$…

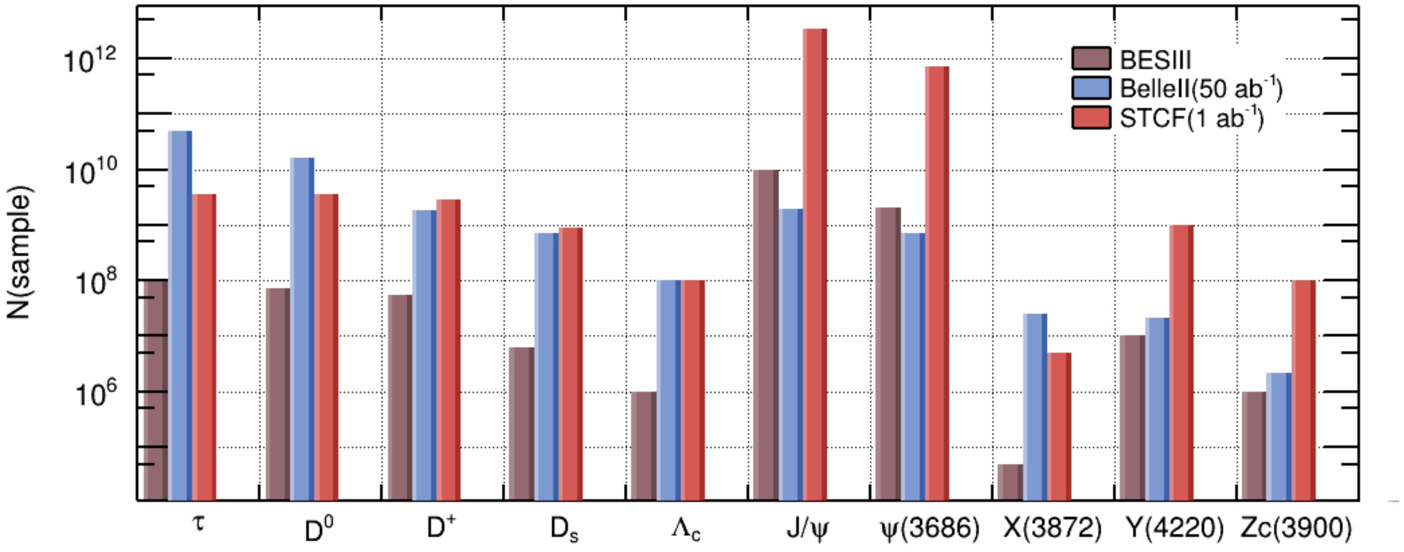
Expected data samples at STCF

Data sample produced per year

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

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			

A factory of hyperon, light meson, XYZ…



- STCF is expected to have higher detection efficiency and low bkg. for productions at threshold
- STCF has excellent resolution, kinematic constraining
- Opportunities at 5-7 GeV (less explored)

QCD and hadron spectroscopy

Physics at STCF	Benchmark Processes	Key Parameters	
		BESIII	STCF
XYZ properties	$e^+e^- \to Y \to \gamma X, \eta X, \phi X$ $e^+e^- \to Y \to \pi Z_c, K Z_{cs}$	$N_{Y(4260)/Z_c/X(3872)}$ $\sim 10^6/10^6/10^4$	$N_{Y(4260)/Z_c/X(3872)}$ $\sim 10^{10}/10^9/10^6$
Pentaquarks **Di-charmonium**	$e^+e^- \to J/\psi p\bar{p}, \Lambda_c \bar{D} \bar{p}, \Sigma_c \bar{D} \bar{p}$ $e^+e^- \to J/\psi \eta_c, J/\psi h_c$	N/A	$\sigma(e^+e^- \to J/\psi p\bar{p})$~4 fb $\sigma(e^+e^- \to J/\psi c\bar{c})$~10 fb (prediction)
Hadron **Spectroscopy**	Excited $c\bar{c}$ and their transition, Charmed hadron spectroscopy, Light hadron spectroscopy	$N_{J/\psi/\psi(3686)/\Lambda_c}$ $\sim 10^{10}/10^9/10^6$	$N_{J/\psi/\psi(3686)/\Lambda_c}$ $\sim 10^{12}/10^{11}/10^8$
Hadron production **(<2GeV)** **(Muon g-2)**	$e^+e^- \to \pi^+\pi^-, \pi^+\pi^-\pi^0, K^+K^-$ $\gamma\gamma \to \pi^0, \eta^{(\prime)}, \pi^+\pi^-$	$\Delta a_\mu^{HVP} \sim 30 \times 10^{-11}$	$\Delta a_\mu^{HVP} < 10 \times 10^{-11}$
R value **τ mass**	$e^+e^- \to inclusive$ $e^+e^- \to \tau^+\tau^-$	$\delta R \sim 3\%$ $\Delta m_\tau \sim 0.12$ MeV	$\delta R \sim 1\%$ $\Delta m_\tau \sim 0.012$ MeV(1 month scan)
Fragmentation **functions**	$e^+e^- \to (\pi, K, p, \Lambda, D) + X$ $e^+e^- \to (\pi\pi, KK, \pi K) + X$	$\Delta A^{Collins} \sim 0.02$	$\Delta A^{Collins} < 0.002$
Nucleon FFs	$e^+e^- \to B\bar{B}$ from threshold	$\delta R_{EM} \sim 3\% - 20\%$	$\delta R_{EM} \sim 1\% - 3\%$

Flavor physics and CPV

Physics at STCF	Benchmark Processes	Key Parameters	
		BESIII	STCF
CKM matrix	$D^+_{(s)} \to l^+\nu_l, D \to Pl^+\nu_l$	$\delta V_{cd/cs}\sim1.5\%$ $\delta f_{D/D_s}\sim1.5\%$	$\delta V_{cd/cs}\sim0.15\%$ $\delta f_{D/D_s}\sim0.15\%$
γ/ϕ_3 measurement	$D^0 \to K_s\pi^+\pi^-, K_sK^+K^-$ ...	$\Delta(\cos\delta_{K\pi})\sim0.05$ $\Delta(\delta_{K\pi})\sim10^o$	$\Delta(\cos\delta_{K\pi})\sim0.007$ $\Delta(\delta_{K\pi})\sim2^o$
$D^0 - \bar{D}^0$ mixing	$\psi(3770) \to (D^0\bar{D}^0)_{CP=-}$, $\psi(4140) \to \gamma(D^0\bar{D}^0)_{CP=+}$	$\Delta x\sim0.2\%$ $\Delta y\sim0.2\%$	$\Delta x\sim0.035\%$ $\Delta y\sim0.023\%$
Charm hadron decay	$D_{(s)}, \Lambda_c^+, \Sigma_c, \Xi_c, \Omega_c$ decay	$N_{D/D_s/\Lambda_c}\sim10^7/10^7/10^6$	$N_{D/D_s/\Lambda_c}\sim10^9/10^8/10^8$
γ polarization	$D^0 \to K_1e^+\nu_e$	$\Delta A'_{UD}\sim0.2$??	$\Delta A'_{UD}\sim0.015$
CPV in Hyperons	$J/\psi \to \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi^-\bar{\Xi}^-, \Xi^0\bar{\Xi}^0$	$\Delta A_\Lambda\sim10^{-3}$	$\Delta A_\Lambda\sim10^{-4}$
CPV in τ	$\tau \to K_s\pi\nu$, EDM of τ $\tau \to \pi/K\pi^0\nu$ for polarized e^-	N/A	$\Delta A_{\tau\to K_s\pi\nu}\sim10^{-3}$ $\Delta d_\tau\sim5\times10^{-19}$ (e cm)
CPV in Charm	$D^0 \to K^+K^-/\pi^+\pi^-$, $\Lambda_c \to pK^-\pi^+\pi^0$ ...	$\Delta A_D\sim10^{-2}$ $\Delta A_{\Lambda_c}\sim10^{-2}$	$\Delta A_D\sim10^{-3}$ $\Delta A_{\Lambda_c}\sim10^{-3}$
CPV, CPT in $K^0 - \bar{K}^0$ mixing	$J/\psi \to K^0K^-\pi^+$		$\eta_\pm\sim10^{-3}, \Delta\phi_\pm\sim0.05^\circ$

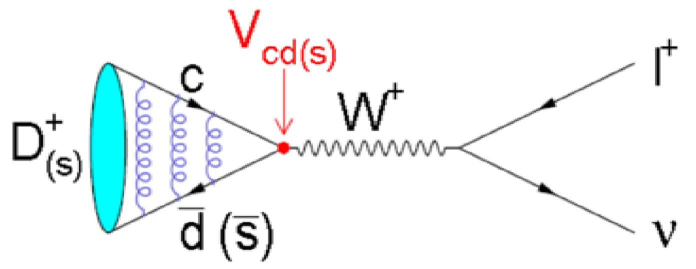
Exotic decays and BSM

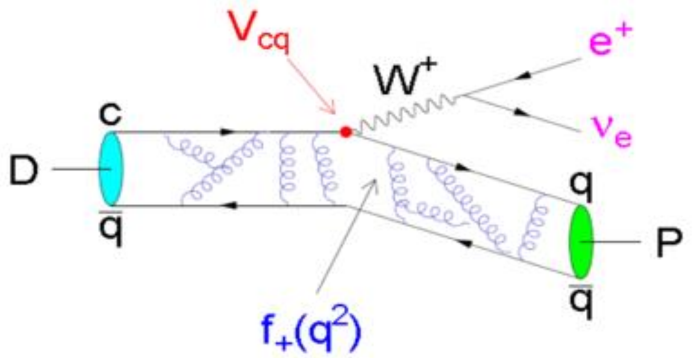
Physics at STCF	Benchmark Processes	BESIII (U.L. at 90% C.L.)	STCF (U.L. at 90% C.L.)
LFV decays	$\tau \to \gamma l, lll, lP_1P_2$ $J/\psi \to ll', D^0 \to ll' (l' \neq l) \ldots$	N/A $\mathcal{B}(J/\psi \to e\tau) < 1 \times 10^{-8}$	$\mathcal{B}(\tau \to \gamma\mu/\mu\mu\mu) < 12/1.5 \times 10^{-9}$ $\mathcal{B}(J/\psi \to e\tau) < 0.71 \times 10^{-9}$
LNV, BNV	$D^+_{(s)} \to l^+l^+X^-, J/\psi \to \Lambda_c e^-$, $B \to \bar{B} \ldots$	$\mathcal{B}(J/\psi \to \Lambda_c e^-) < 10^{-8}$	$\mathcal{B}(J/\psi \to \Lambda_c e^-) < 10^{-11}$
Charge Symmetry Violation	$\eta' \to ll\pi^0, \eta' \to \eta ll \ldots$	$\mathcal{B}(\eta' \to ll/\pi^0 ll) < 1 \times 10^{-6}$	$\mathcal{B}(\eta' \to ll/\pi^0 ll) < 1.5/2.4 \times 10^{-9}$
FCNC	$D \to \gamma V, D^0 \to l^+l^-, e^+e^- \to D^*, \Sigma^+ \to pl^+l^- \ldots$	$\mathcal{B}(D^0 \to e^+e^-X) < 10^{-6}$	$\mathcal{B}(D^0 \to e^+e^-X) < 10^{-8}$
Dark photon millicharged	$e^+e^- \to (J/\psi) \to \gamma A' (\to l^+l^-) \ldots$ $e^+e^- \to \chi\bar{\chi}\gamma \ldots$	Mixing strength $\Delta\epsilon_{A'} \sim 10^{-2}$; $\Delta\epsilon_{\chi} \sim 10^{-2}$	Mixing strength $\Delta\epsilon_{A'} \sim 10^{-4}$; $\Delta\epsilon_{\chi} \sim 10^{-4}$

$D_{(s)}$ (semi-)leptonic decay

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

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 : $|V_{cd(s)}| \times f_{D(s)}$

- 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 $f_{D(s)}$ and provide constraints of CKM-unitarity

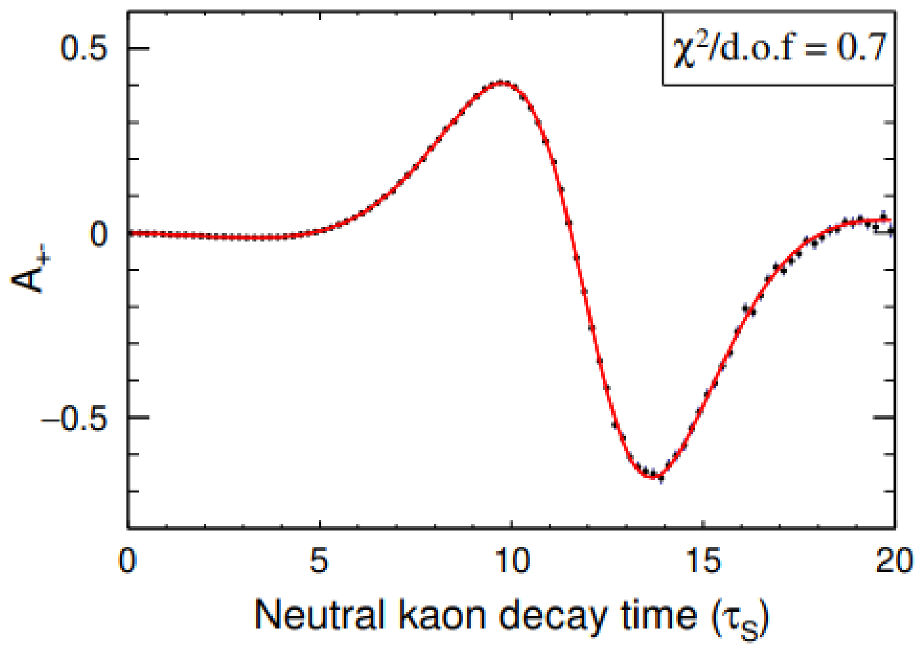
Source	BESIII [57]		BelleII [57]		This work at STCF	
	6 fb^{-1} at 4.178 GeV		50 ab^{-1} at $\Upsilon(nS)$		1 ab^{-1} at 4.009 GeV	
$\mathcal{B}_{D_s^+\to\tau^+\nu_\tau}$	$1.6\%_{\text{stat.}}$	$2.4\%_{\text{syst.}}$	$0.6\%_{\text{stat.}}$	$2.7\%_{\text{syst.}}$	$0.3\%_{\text{stat.}}$	$1.0\%_{\text{syst.}}$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

H.J. Li, J. J. Liu et al., Eur.Phys.J.C 82 (2022) 310
J.J. Liu, X. D. Shi et al. Eur.Phys.J.C 82 (2022) 337

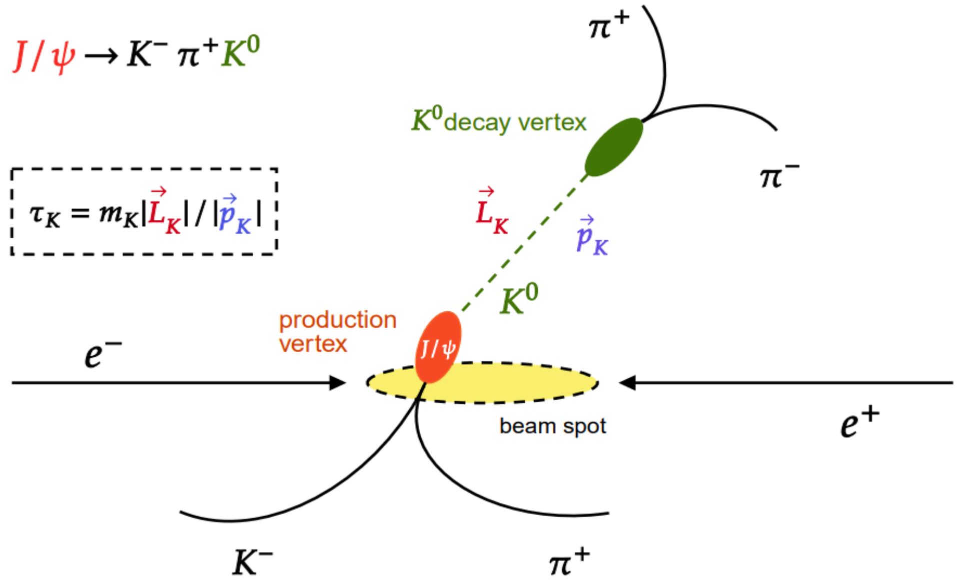
Testing CPT with neutral kaons

CPV parameters $|\eta_{+-}|$, ϕ_{+-} can be determined from difference of time-dependent decay rates of K^0 and $\bar{K}^0$ to $\pi^+\pi^-$:

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



- Precise determination of K^0 decay vertex is crucial to time-dependence measurement



- $|\eta_{+-}|$ reveals direct CPV in kaon meson
- ϕ_{+-} will be used to set limits on CPT violation
- With over 10 billion $K^0/\bar{K}^0$ events from J/ψ decay, the sensitivity of $|\eta_{+-}|$, ϕ_{+-} are $\mathcal{O}(10^{-3})$ ⇒ one magnitude better than PDG average

J. Y. Zhang et al., arXiv:2209.12551

Accelerator design

Relativistic factor

Bunch number

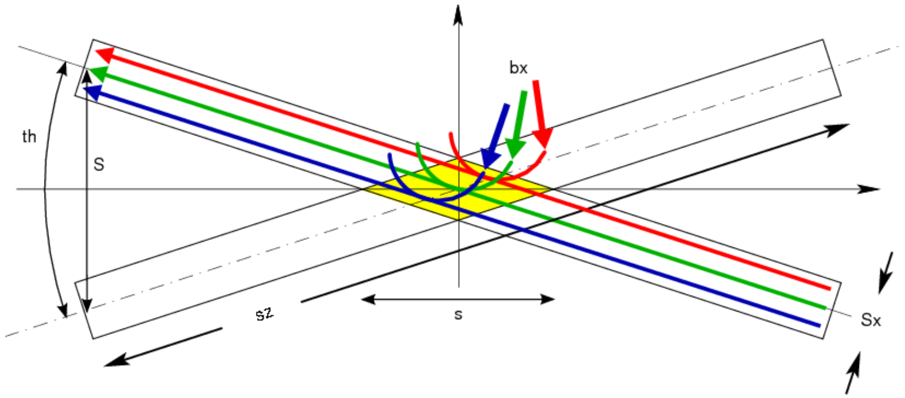
Bunch intensity

Vertical beam-beam parameter

$$L(\mathrm{cm}^{-2}\mathrm{s}^{-1}) = \frac{\gamma n_b I_b}{2 e r_e \beta_y^*} \xi_y H$$

→ Hourglass effect (difficulty of reducing σ_z to $\sigma_z \sim \beta_y^*$ with small β_y^*) $\Rightarrow$ L is decreased

Vertical betatron function

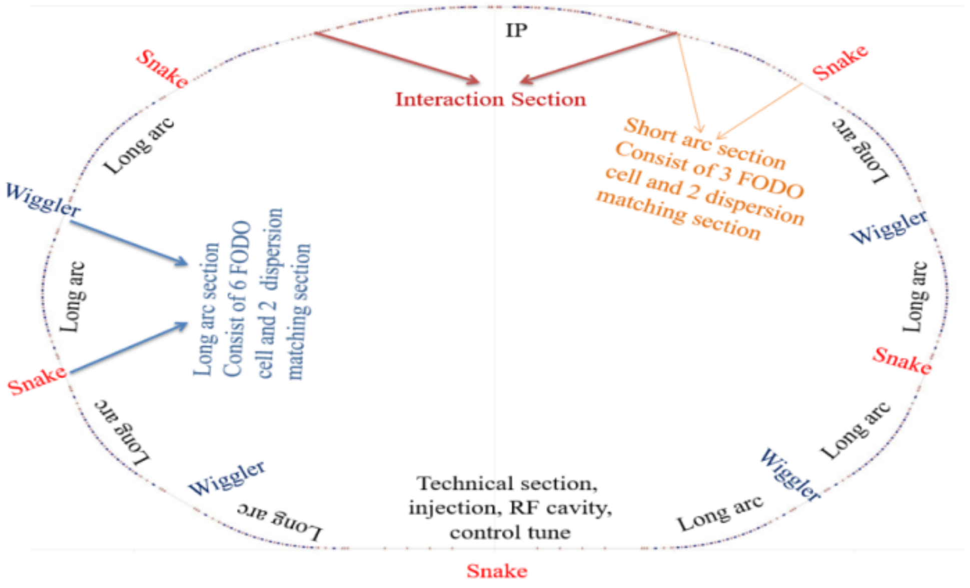


- Crabbed-waist beam-crossing with large Piwinski Angle ($\phi = \tan\theta \frac{\sigma_z}{\sigma_x}$)
  - When ϕ >10, $\sigma_{zeff} \sim \frac{\sigma_x}{\theta} \sim \beta_y^*$ ($\ll \sigma_z$), no need of $\beta_y^* \geq \sigma_z$
  - Beam-beam coupling resonances are suppressed by crab waist (proof-of-principle by DAFNE Φ-factory)
  - Deployed by BINP and SuperKEKB

Parameter	Value
Circumference (m)	600
Beam energy range (GeV)	1 ~ 3.5
Optimized beam energy (GeV)	2
Current (A)	2
Crossing angle 2θ (mrad)	60
Natural energy spread	4.0×10^{-4}
Bunch length (mm)	12
Luminosity ($\times 10^{35}$ cm^{-2}s^{-1})	> 0.5

Preliminary design of Lattice

- Preliminary accelerator physics design is finished
- Linear lattice and parameters can meet lumi requirements ⇒ 7.3×10^{34} $cm^{-2}s^{-1}$
- Key technologies (positron beam, beam stability, beam measurement, Low Level RF system) are being studied



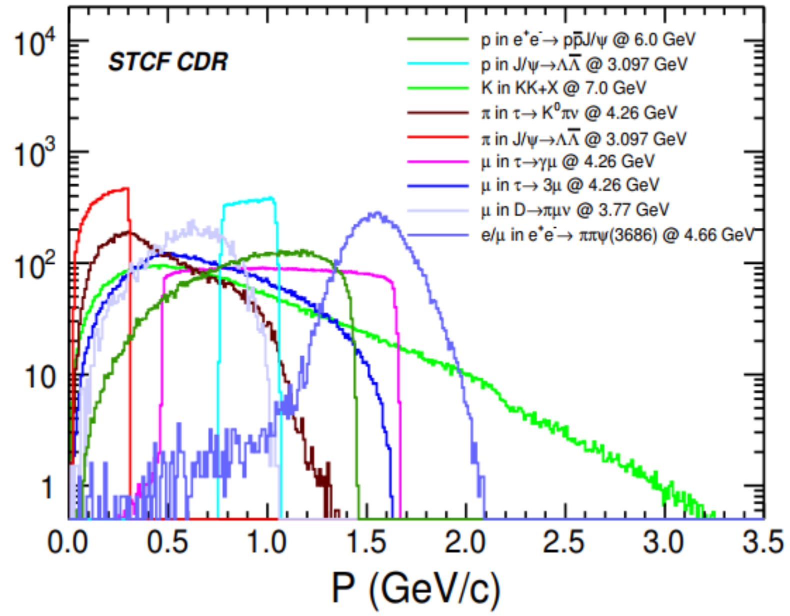
Total ring composed of 8 bending arc periods (4 super-periods), one interaction region, one technical region and 5 Siberian snakes

Parameters	**Value**	**Unit**
Optimize energy E	2.0	GeV
Circumference Π	617.06	m
f_{RF}	497.5	MHz
2θ	60	mrad
$\varepsilon_y/\varepsilon_x$	0.5	%
I	2.0	A
V_{RF}	3.0	MV
σ_z (w.o/w IBS)	7.3/10	mm
ε_x (w.o/w IBS)	2.84/4.29	nm
L_{HG}	$\geq 0.5\times 10^{35}$	$cm^{-2}s^{-1}$
ξ_x/ξ_y	0.004/0.10	-
$\tau_{Touschek}$	180~200	s

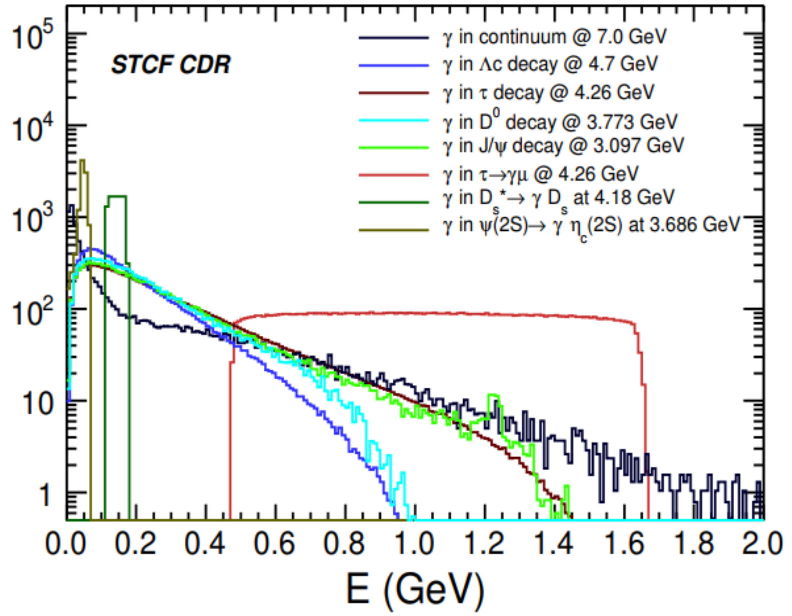
Particles to detect and identify at STCF

- Charged particles
  - e, μ, K, π, proton (p up to 3.5 GeV, most with p < 2 GeV, lots of particles with p < 400 MeV)
- Neutral particles:
  - γ (energy coverage from 25 MeV to 3.5 GeV)
  - K_L, neutron (up to 1.6 GeV)

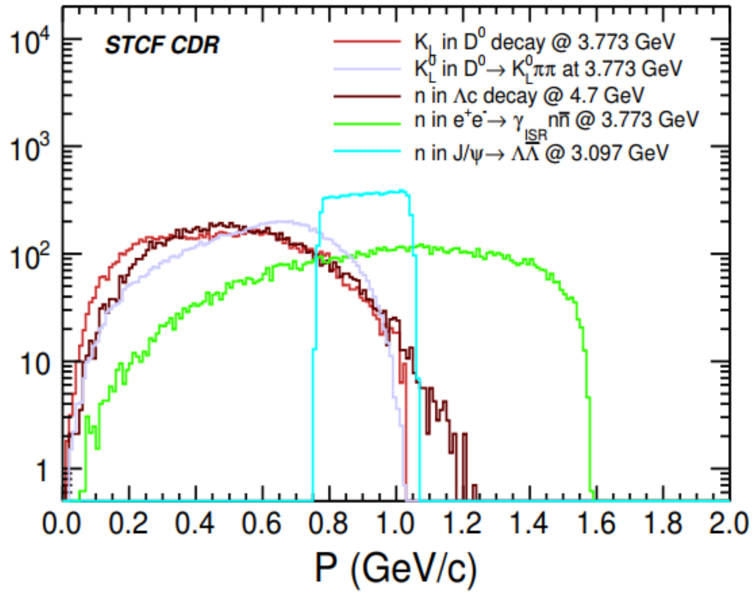
Charged particle momentum



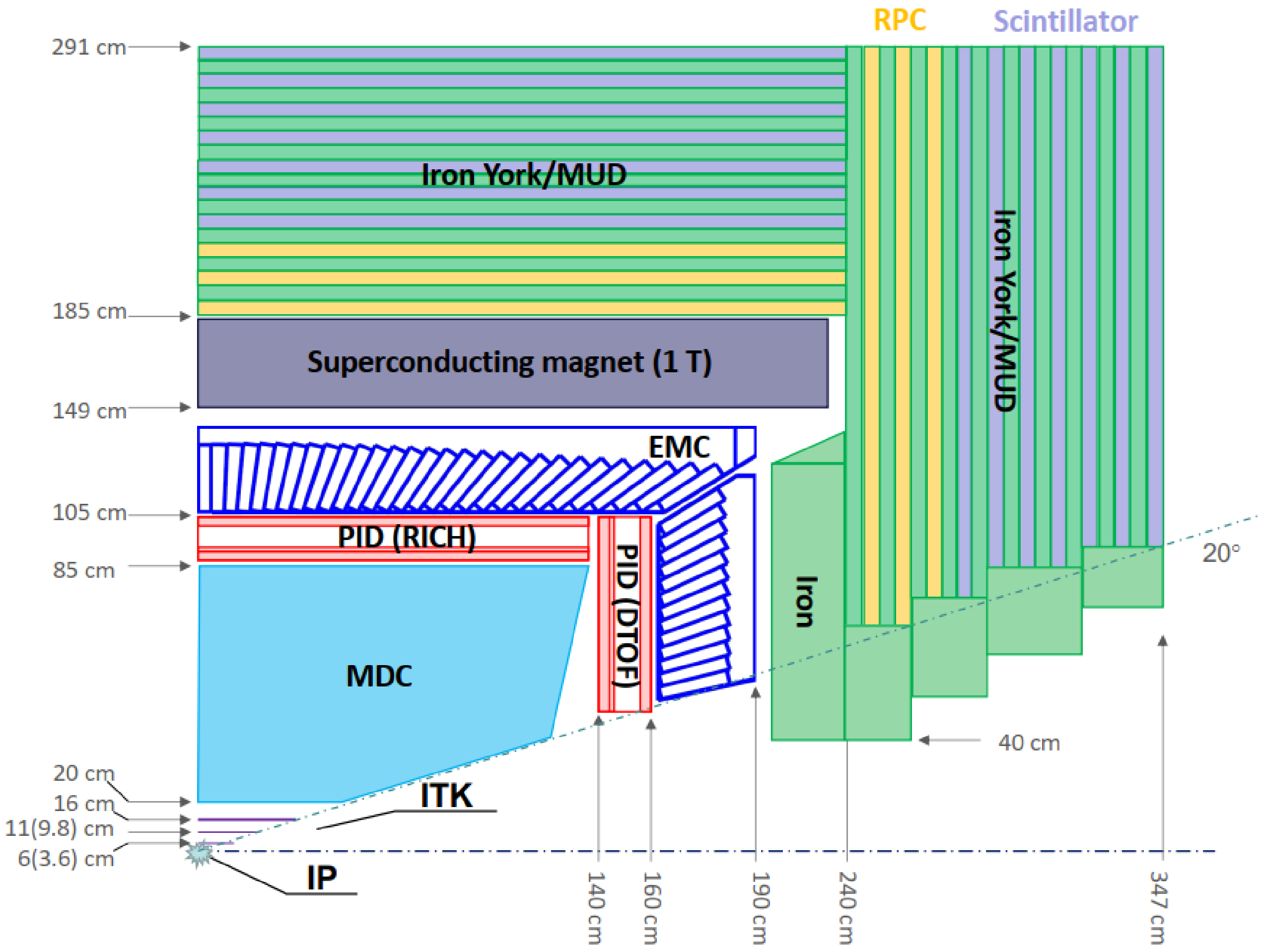
Photon energy



K_L and neutron momentum



STCF detector



Performance requirements

- ITK:
  - Material < $0.01X_0$, σ_{xy} < 100 μm

- MDC:
  - Material < 0.05 X_0
  - σ_{xy} < 130 μm, $\sigma(p)/p$ < 0.5% at 1 GeV/c
  - dE/dx resolution < 6%

- PID:
  - $3\,\sigma\ \pi/K$ separation, PID efficiency > 97% up to 2 GeV

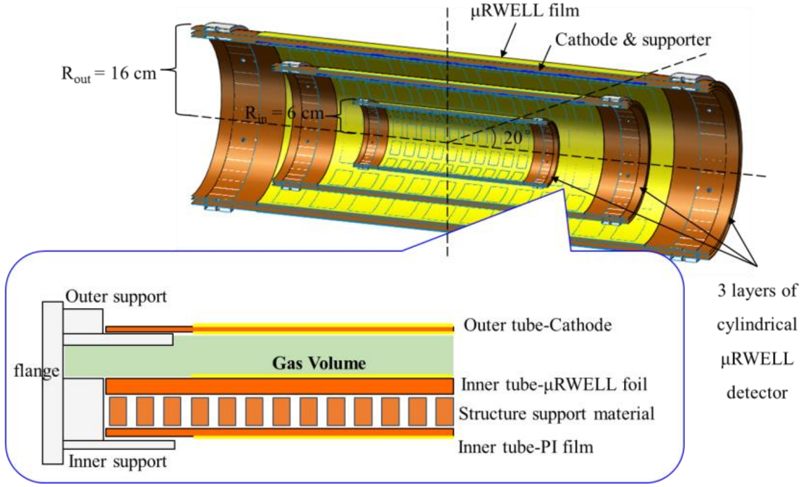
- EMC:
  - σ_E < 2.5%, σ_{pos} ~ 4 mm, σ_t ~ 300 ps at 1 GeV

- MUD:
  - μ efficiency > 95% above 0.7 GeV with $\pi \to \mu$ misidentification rate <3%

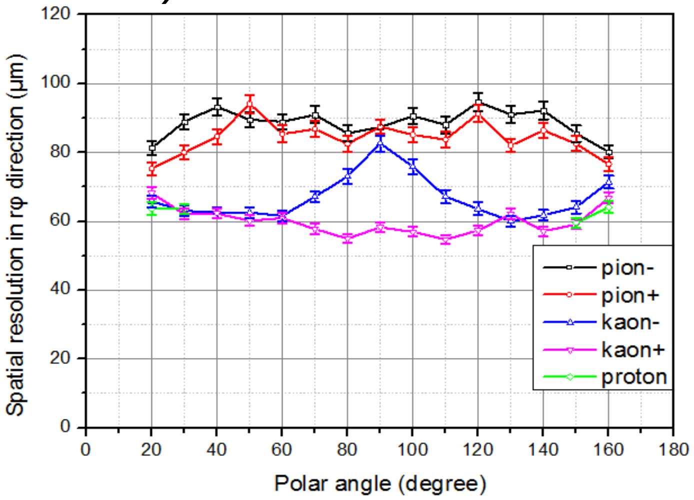
Tracking system

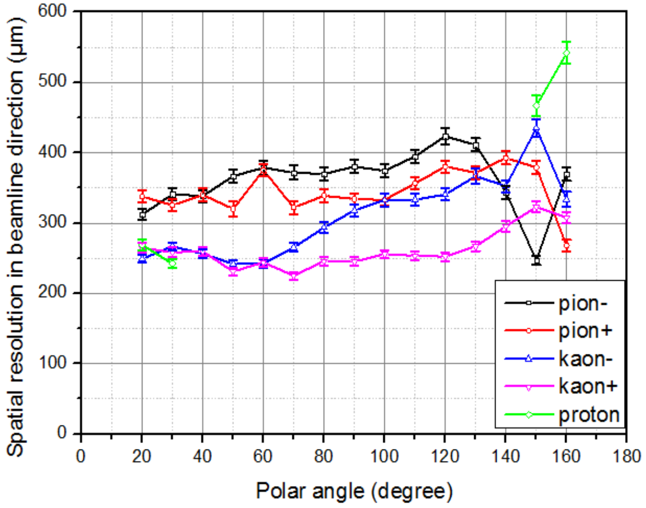
ITK + MDC (optimized working gas, MDC cell structure…)

Inner Tracker (ITK): 3 layers of uRWELL (alternative MAPS)

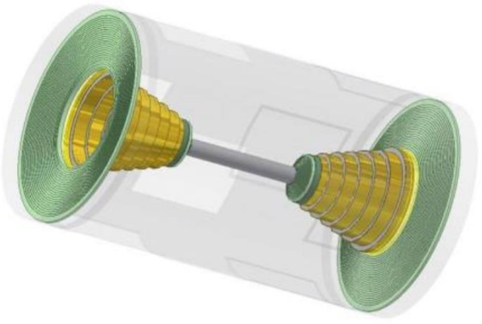


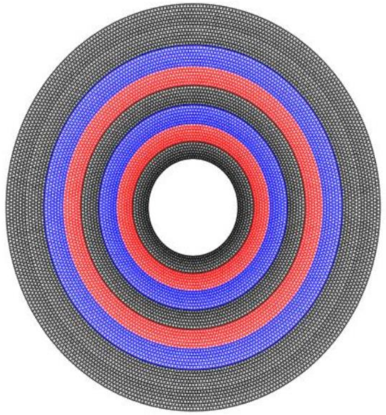
Expected $\sigma_{r\varphi}$ ~ 100 μm, σ_z ~ 400 μm



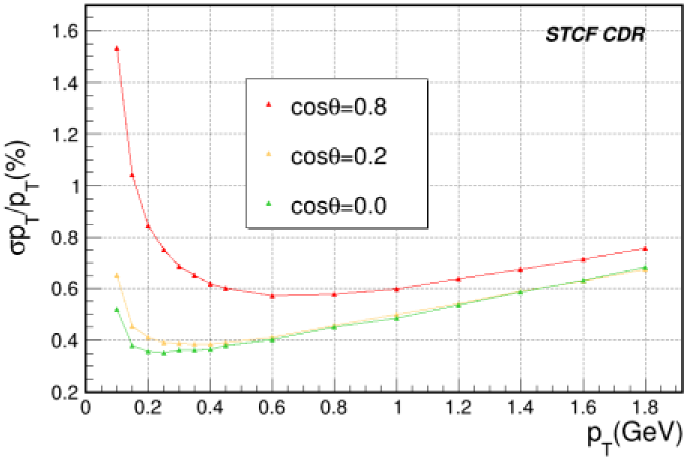


Main Drift Chamber (MDC): 48 Axial/Stereo drift layers

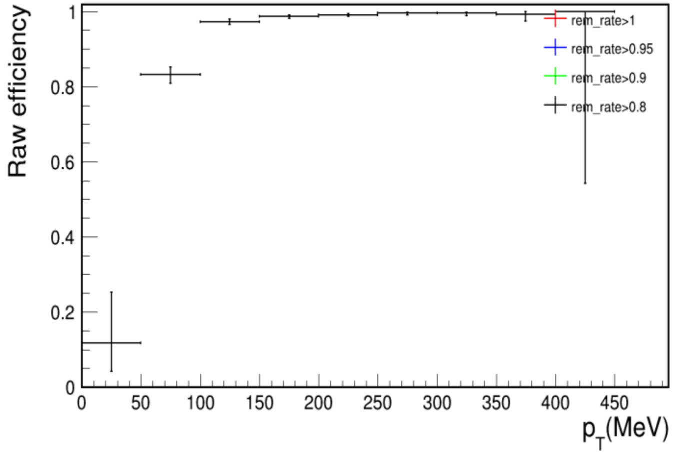




Expected $\sigma(p_T)/p_T$< 0.5% @1 GeV/c



Expected trk. Eff. > 85% above 50 MeV



Particle Identification Detectors

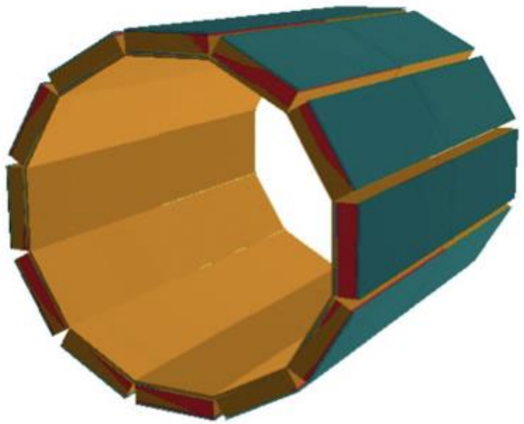
Two Cherenkov detectors: RICH in the barrel + DTOF in the endcap

RICH: Micro-Pattern Gas Detector(MPGD) based Ring Image Cherenkov Detector

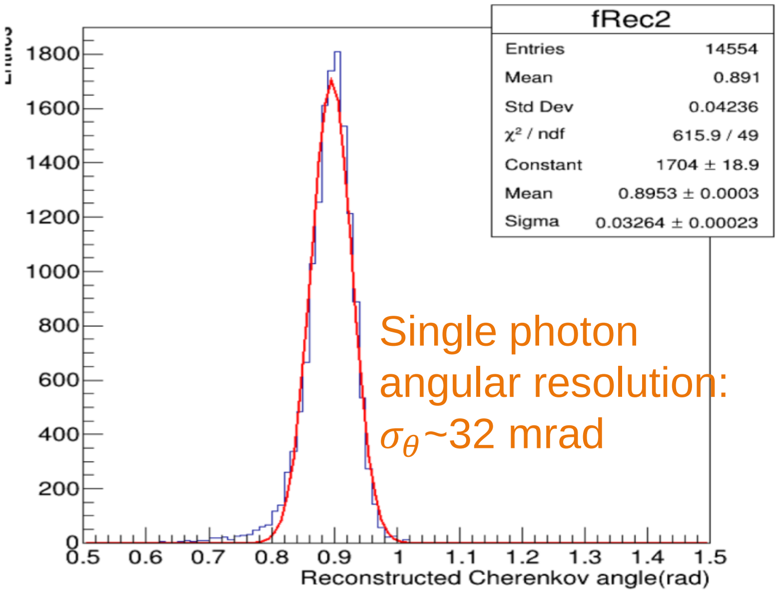
- Principle prototype is beam-tested:
  - Performance (e.g. photon angular resolution, light yield) meets expected requirements

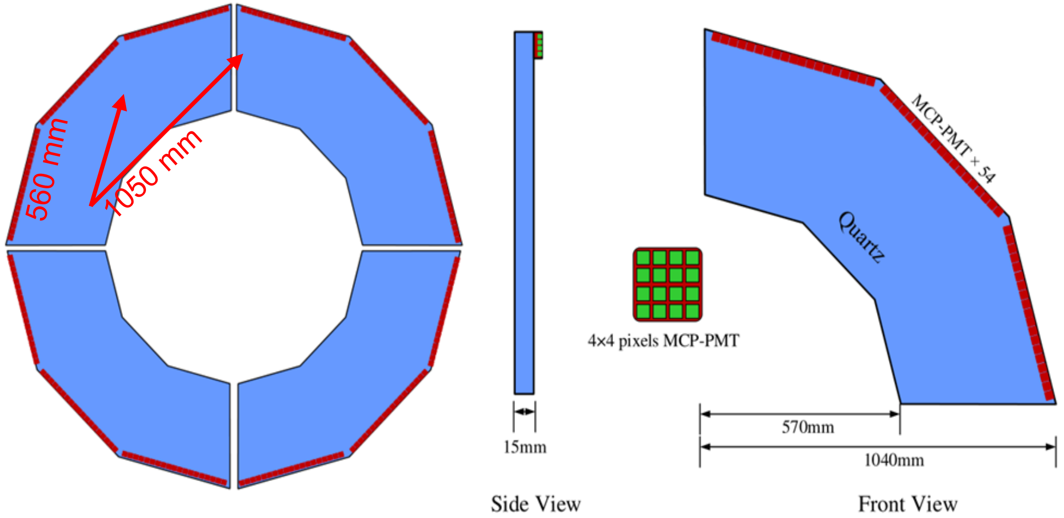
DTOF: DIRC-based Time-of-Flight

- Full-size prototype is tested:
  - ✓ Intrinsic time resolution < 25 ps
  - ✓ 4.2σ π/K separation at p = 2 GeV using position and time



Reconstructed mean Cherenkov angle

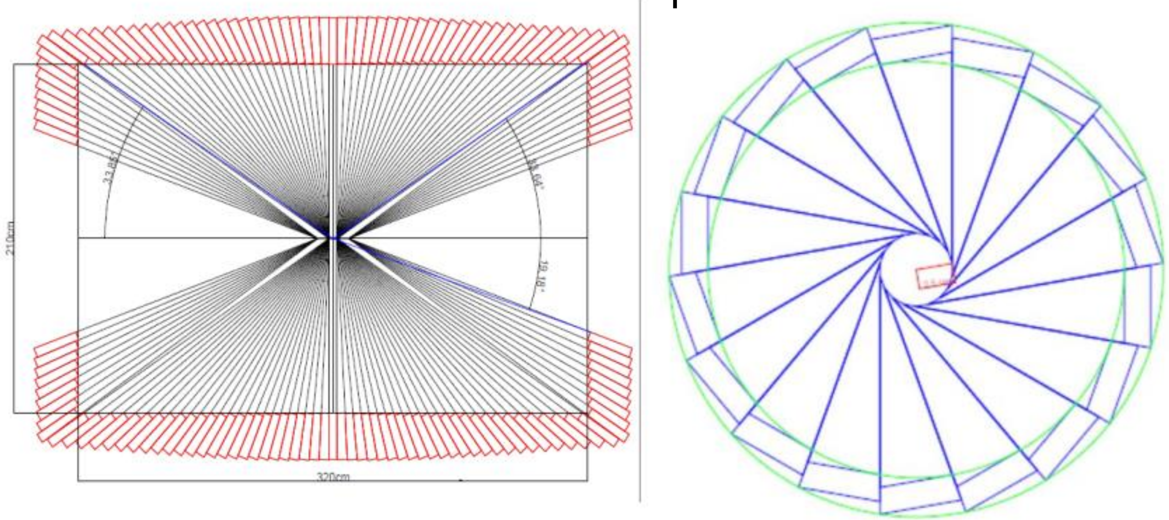




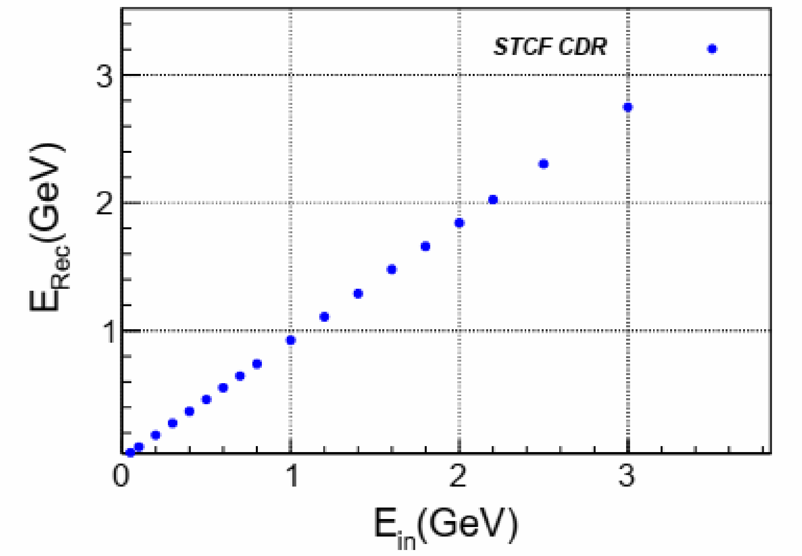
Electromagnetic Calorimeter

- Pure CsI crystal (pCsI) ⇒ short decay time & good radiation resistance
- Avalanche Photodiode (APD) for light collection ⇒ large gain
- Defocused design ⇒ improve acceptance

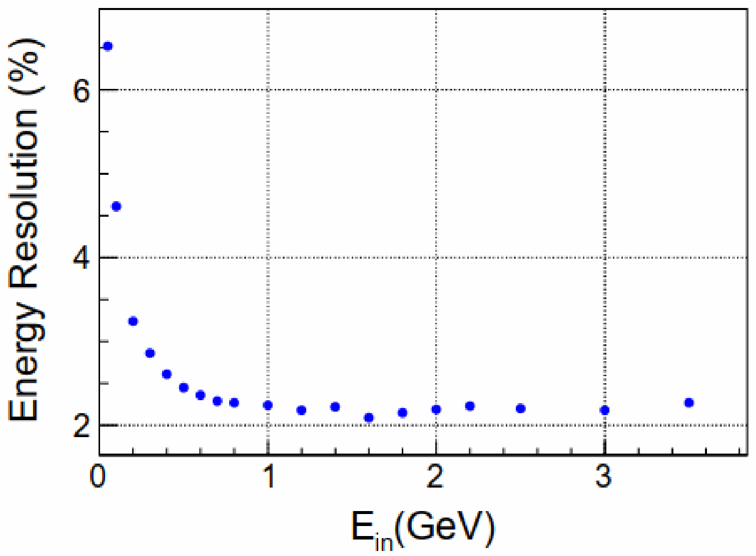
6732 crystals (51circles x 132 bars/circle) in barrel + 968 in each endcap



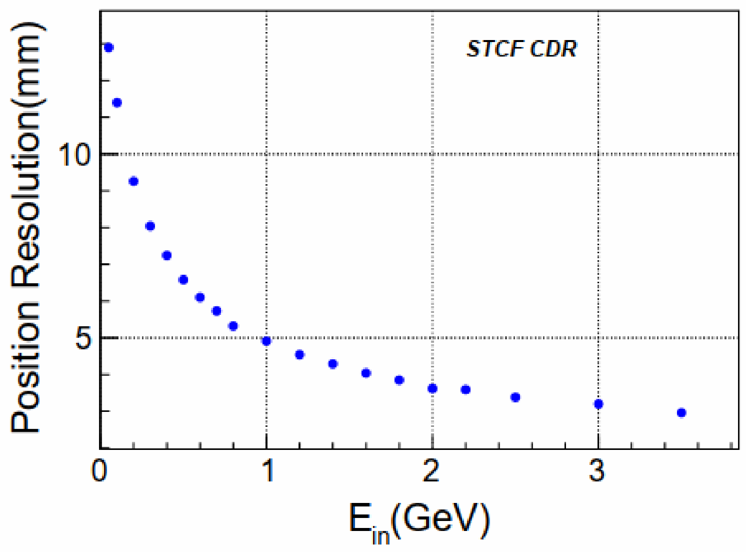
Expected energy linearity



Expected energy resolution

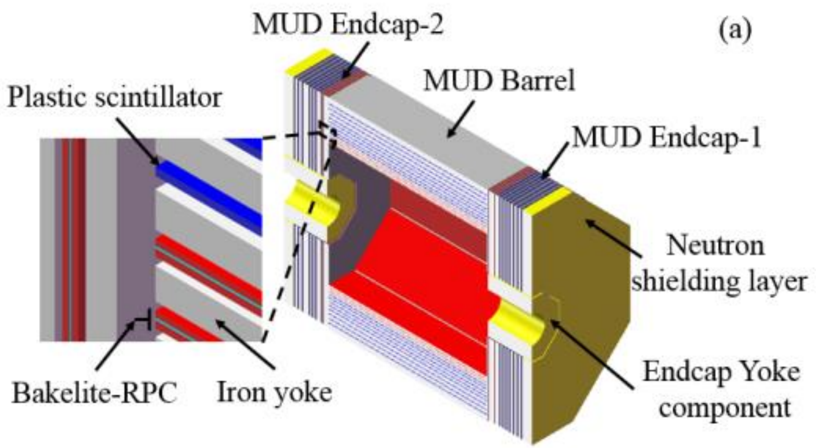


Expected position resolution

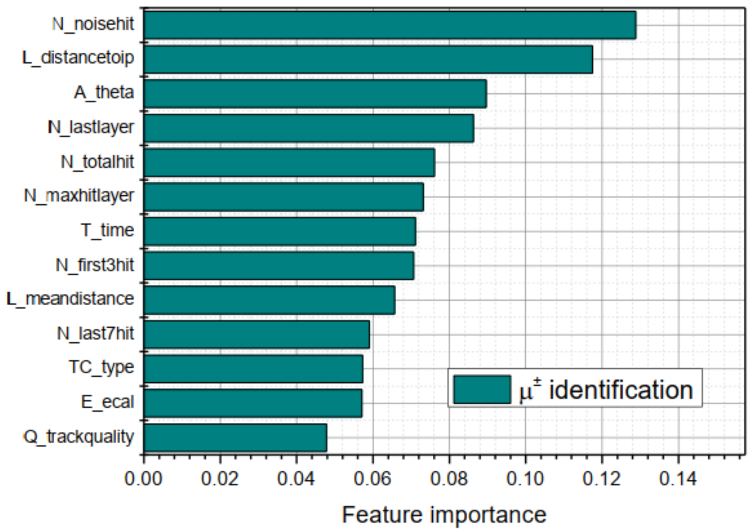


Muon Detector

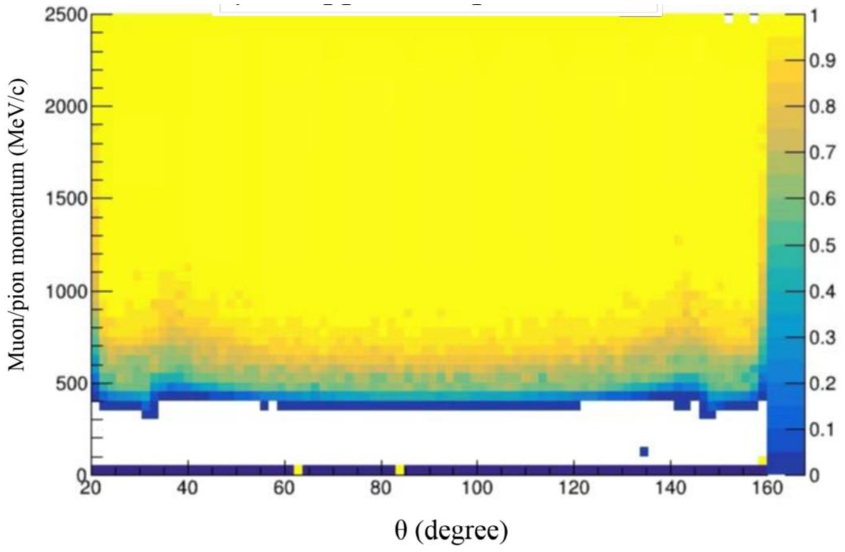
- Hybrid design: 3-layer Bakelite-RPC + 7-layer plastic scintillator
  - Resistive Plate Chamber: low bkg., high eff., robustness, low cost
  - Plastic scintillator: higher count rate, sensitive to neutral particles
- Test of scintillator strip, wavelength-shifting fiber and SiPM are ongoing



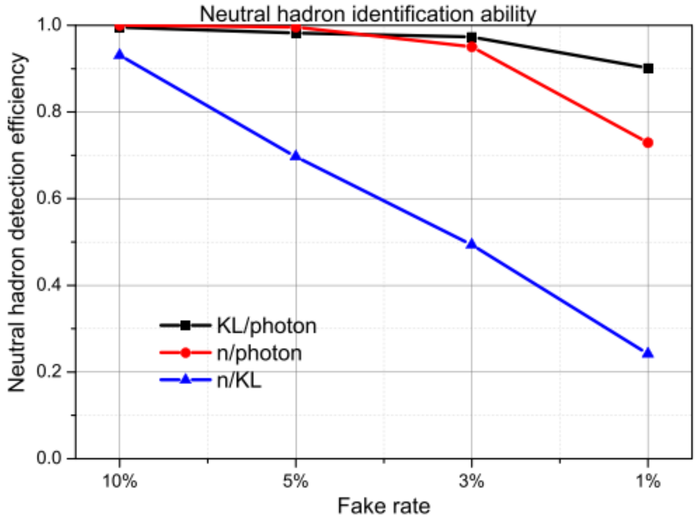
PID using BDT



Expected μ PID with π rejection rate at 97%



Expected neutral hadron detection efficiency

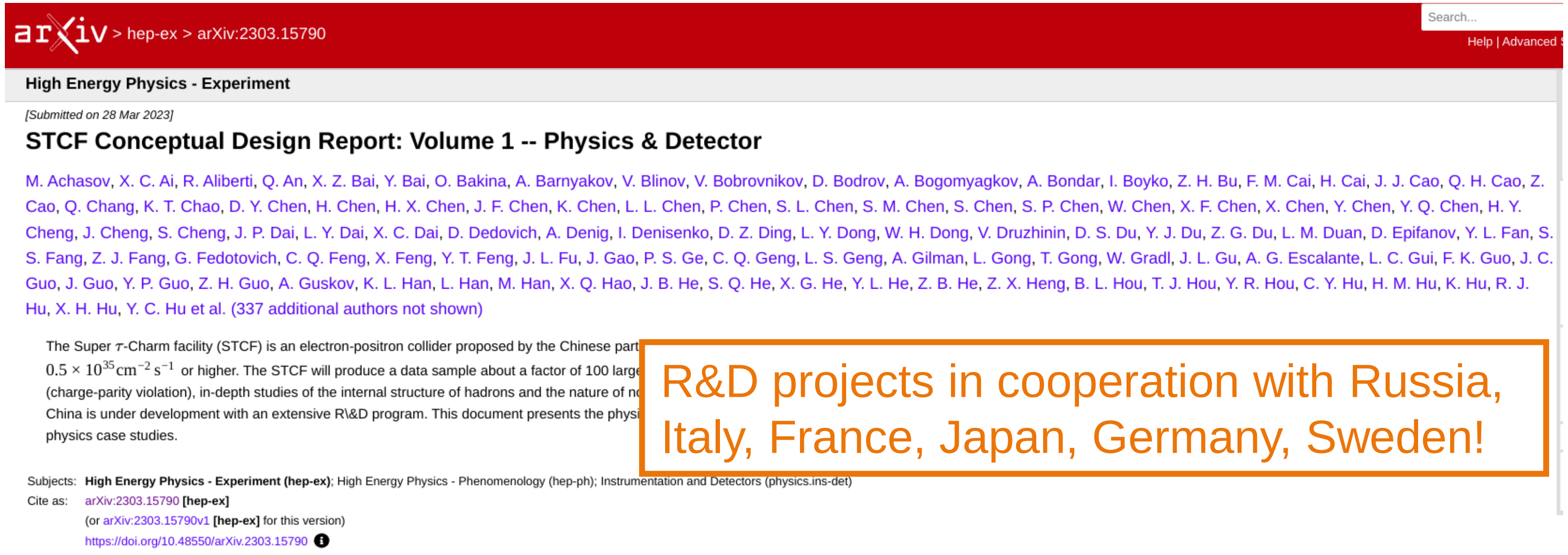


Timeline

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032-2042	2043-2046
Form collaboration																
Conception design CDR																
R&D (TDR)																
Construction																
Operation																
Upgrade																

CDR Volume 1 – Physics & Detector (arXiv: 2303.15790)

CDR Volume-II – Accelerator (in preparation)


arXiv > hep-ex > arXiv:2303.15790

Search...

Help | Advanced

High Energy Physics - Experiment

[Submitted on 28 Mar 2023]

STCF Conceptual Design Report: Volume 1 -- Physics & Detector

M. Achasov, X. C. Ai, R. Aliberti, Q. An, X. Z. Bai, Y. Bai, O. Bakina, A. Barnyakov, V. Blinov, V. Bobrovnikov, D. Bodrov, A. Bogomyagkov, A. Bondar, I. Boyko, Z. H. Bu, F. M. Cai, H. Cai, J. J. Cao, Q. H. Cao, Z. Cao, Q. Chang, K. T. Chao, D. Y. Chen, H. Chen, H. X. Chen, J. F. Chen, K. Chen, L. L. Chen, P. Chen, S. L. Chen, S. M. Chen, S. Chen, S. P. Chen, W. Chen, X. F. Chen, X. Chen, Y. Chen, Y. Q. Chen, H. Y. Cheng, J. Cheng, S. Cheng, J. P. Dai, L. Y. Dai, X. C. Dai, D. Dedovich, A. Denig, I. Denisenko, D. Z. Ding, L. Y. Dong, W. H. Dong, V. Druzhinin, D. S. Du, Y. J. Du, Z. G. Du, L. M. Duan, D. Epifanov, Y. L. Fan, S. S. Fang, Z. J. Fang, G. Fedotovich, C. Q. Feng, X. Feng, Y. T. Feng, J. L. Fu, J. Gao, P. S. Ge, C. Q. Geng, L. S. Geng, A. Gilman, L. Gong, T. Gong, W. Gradl, J. L. Gu, A. G. Escalante, L. C. Gui, F. K. Guo, J. C. Guo, J. Guo, Y. P. Guo, Z. H. Guo, A. Guskov, K. L. Han, L. Han, M. Han, X. Q. Hao, J. B. He, S. Q. He, X. G. He, Y. L. He, Z. B. He, Z. X. Heng, B. L. Hou, T. J. Hou, Y. R. Hou, C. Y. Hu, H. M. Hu, K. Hu, R. J. Hu, X. H. Hu, Y. C. Hu et al. (337 additional authors not shown)

The Super τ-Charm facility (STCF) is an electron-positron collider proposed by the Chinese part
$0.5 \times 10^{35} \mathrm{cm}^{-2} \mathrm{s}^{-1}$ or higher. The STCF will produce a data sample about a factor of 100 large
(charge-parity violation), in-depth studies of the internal structure of hadrons and the nature of n
China is under development with an extensive R\&D program. This document presents the physi
physics case studies.

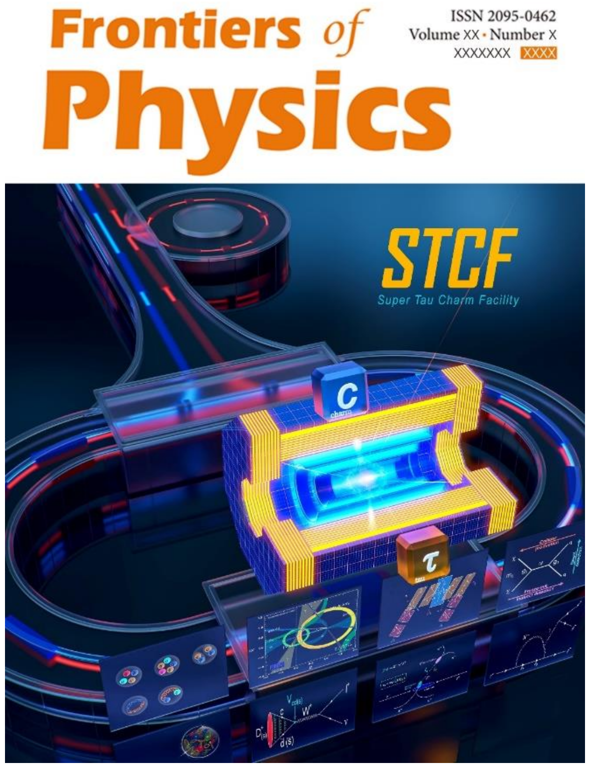
Subjects: **High Energy Physics - Experiment (hep-ex)**; High Energy Physics - Phenomenology (hep-ph); Instrumentation and Detectors (physics.ins-det)

Cite as: arXiv:2303.15790 **[hep-ex]**

(or arXiv:2303.15790v1 **[hep-ex]** for this version)

https://doi.org/10.48550/arXiv.2303.15790

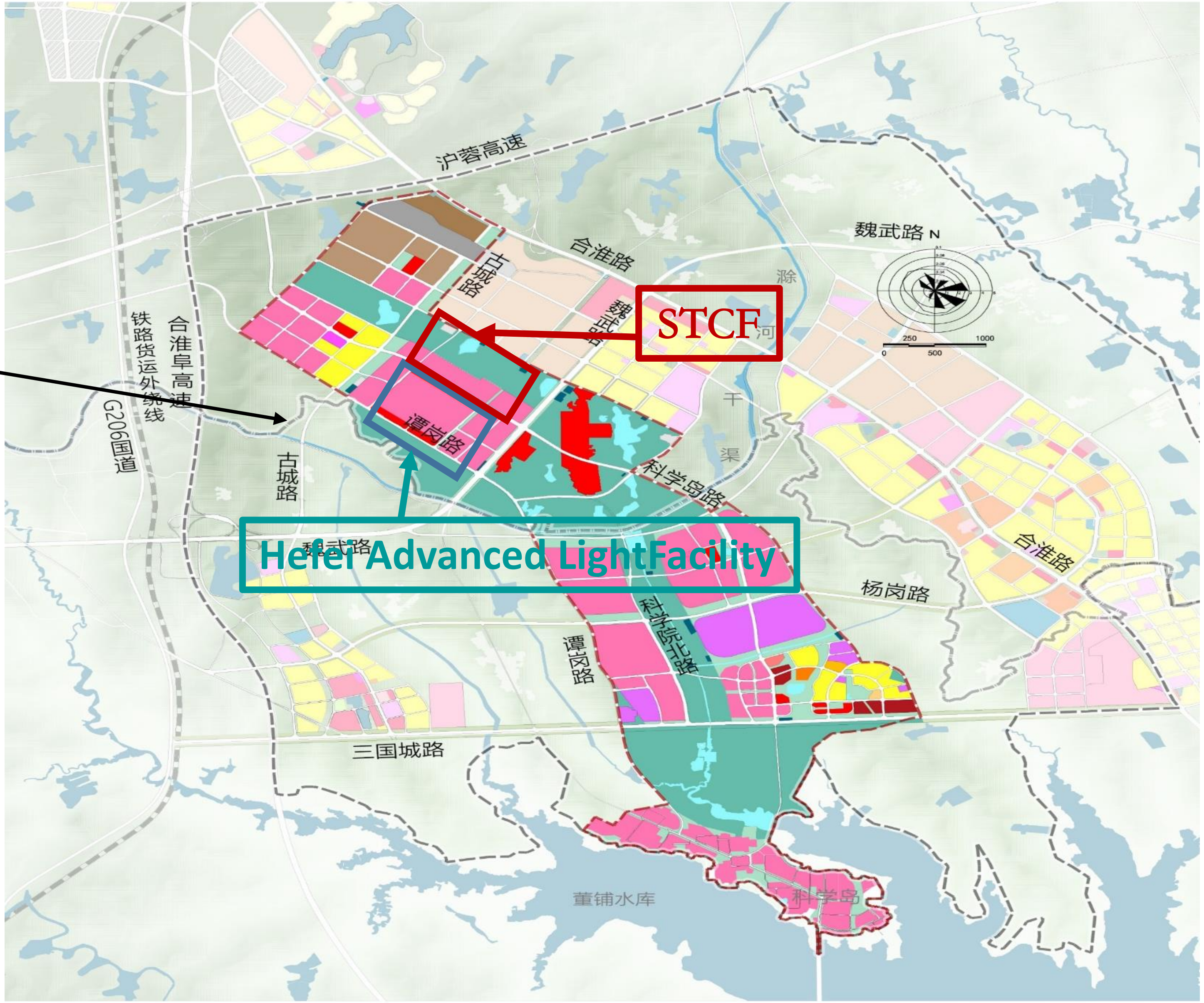
R&D projects in cooperation with Russia, Italy, France, Japan, Germany, Sweden!



Funding

- 0.42 billion RMB on the R&D projects from local government and USTC (year 2022-2025)
- In the past 5 years, about 24 Million RMB from foundation of USTC, CAS programs and NSFC…
  - Double First-Class university project foundation of USTC: 20 Million RMB (year 2018-2021)
  - International partnership program of CAS: 3.5 million RMB (year 2021-2023)
  - Over three NSFC projects for relevant technologies, and several general and youth programs
  - …

STCF Site



Located in Hefei Comprehensive National Science Center (6 large scale scientific facilities in total with area of 17155 acres)

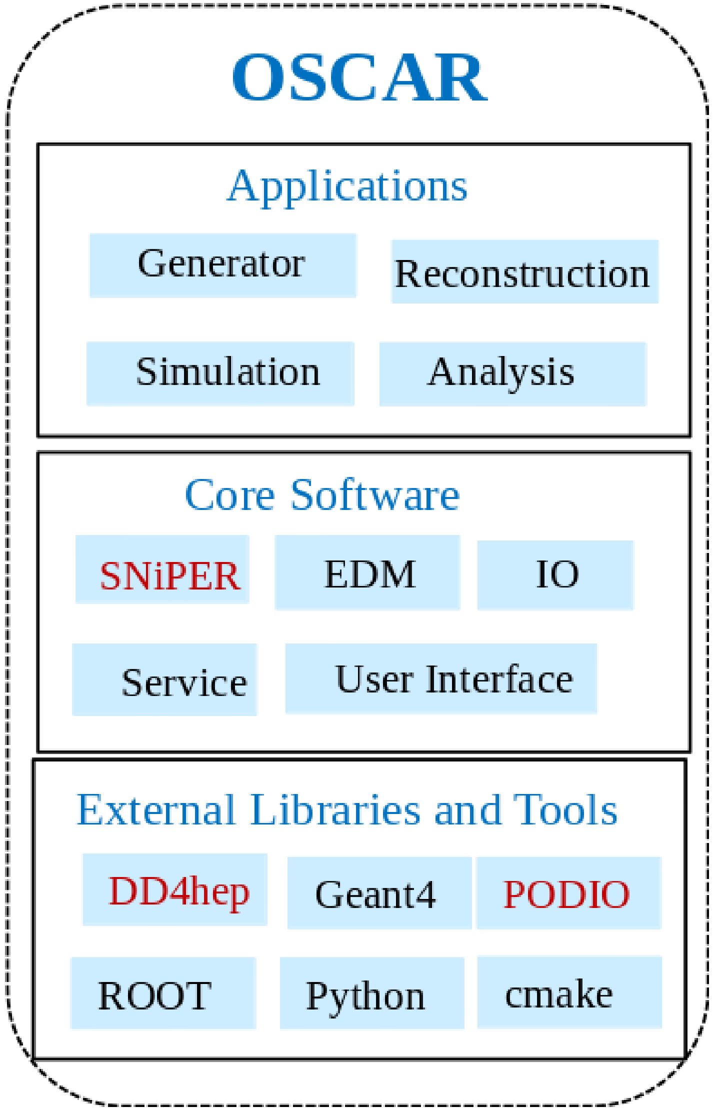
Summary

- STCF is an important and unique platform for probing physics at τ-charm sector
  - Funds of 0.42 billion RMB for R&D projects in year 2022-2025
  - Feasibility studies of accelerator, detector, software have been performed
    - CDR for physics and detector finished
    - CDR for accelerator in preparation
  - Key technology R&D projects are in progress
- Welcome to join STCF!

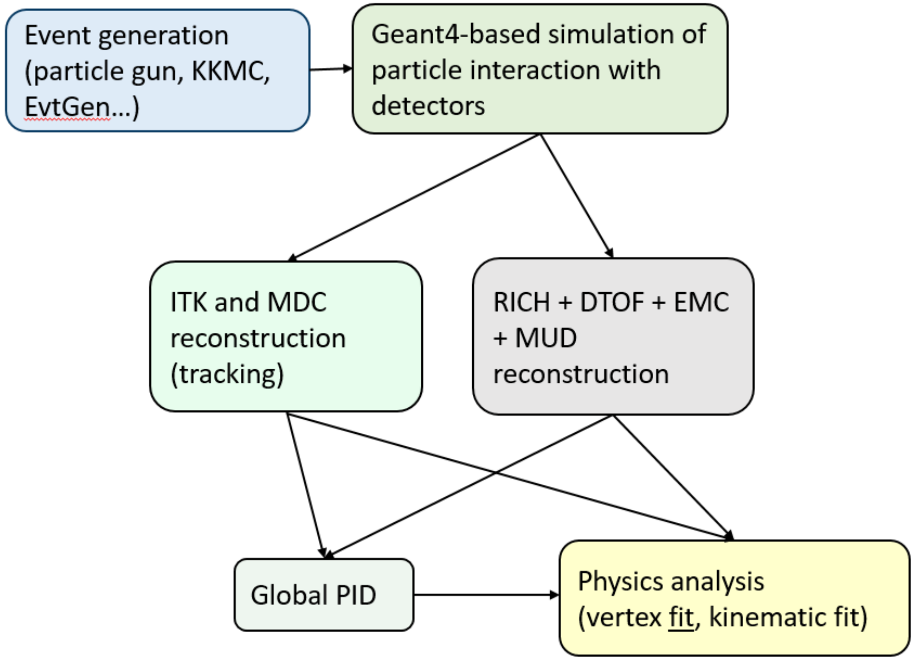
Thank you！

backup

OSCAR – Offline Software of Super Tau-Charm Facility



- Based on C++17, CMake, gitlab
- SNiPER (adopted by JUNO, LHAASO) based light-weight framework
- PODIO (used by FCC, CEPC …) based Event Data Model
- Supporting **a full event simulation and reconstruction workflow** to facilitate physics simulation and detector layout studies!



arXiv: 2211.03137

International Collaboration

- **Russia**: BINP and Novosibirsk State Technical University
  - Preliminarily agreement on R&D of some key technology and talent training
  - Joint monthly meeting (online)
- **France**(LAL)： Joint R&D on FTOF detector
- **Italy**(Frascati National Laboratory): Accelerator physics, R&D of detector
- **Japan**(KEK): Accelerator physics design and background study in IR region
- **Germany**, Mainz University; **Sweden**, Uppsala University: Physics studies

Joint China-Russia-Europe Conference

International Conferences

- International Workshop on Charm physics
- Conference on Flavor Physics and CP violation
- International workshop on Tau lepton Physics
- Gordon Research Conference
- …..

Researcher Exchange and Visiting

Institutions Intended to Participate STCF

About 60 institutions (24 from foreign countries), are willing to participate.
Most **these institutions** have long time experiences working at BES experiments, or the other collider experiments.

- 中国科学技术大学
- 清华大学
- 北京大学
- 上海交通大学
- 复旦大学
- 山东大学
- 浙江大学
- 南京大学
- 南京师大
- 南开大学
- 中山大学
- 高能物理研究所
- 兰州近代物理所
- 合肥物质研究院
- 合肥同步辐射国家实验室
- 西安光机所
- 中国科学院大学

- 南华大学
- 北京航天航空大学
- 湖南大学
- 湖南师大
- 四川大学
- 河南师大
- 河南科技大学
- 辽宁大学
- 广西大学
- 广西师大
- 兰州大学
- 香港大学
- 香港中文大学
- 黄山学院
- 武汉大学
- 华中师大
- 湖南科技大学

- Institute for Basic Science, Daejeon, Korea
- T. Shevchenko National University of Kyiv, Ukraine
- University Ljubljana and Jozef Stefan Institute Ljubljana, Slovenia
- Jozef Stefan Institute Ljubljana, Slovenia
- University of Silesia, Katowice, Poland
- Dubna, Russia
- Budker Institute and Novosibirsk University, Russia
- Stanford University, USA
- Wayne State University, USA
- Carnegie Mellon University, USA
- GSI Darmstadt and Goethe University Frankfurt, Germany
- Goethe University Frankfurt, Germany

- GSI Darmstadt, Germany
- Johannes Gutenberg University Mainz, Germany
- Helmholtz Institute Mainz, Germany
- LAL (IN2P3/CNRS and Paris-Sud University), Orsay, France
- Sezione di Ferrara, Italy
- L'Istituto di Fisica Nucleare di Torino, Italy
- L'Istituto di Fisica Nucleare di Firenze, Italy
- Scuola Normale Superiore, Pisa, Italy
- Laboratori Nazionali di Frascati, Italy
- INFN, Padova, Italy
- University of Pavia, Pavia, Italy
- University of Parma, Italy

Conferences For STCF

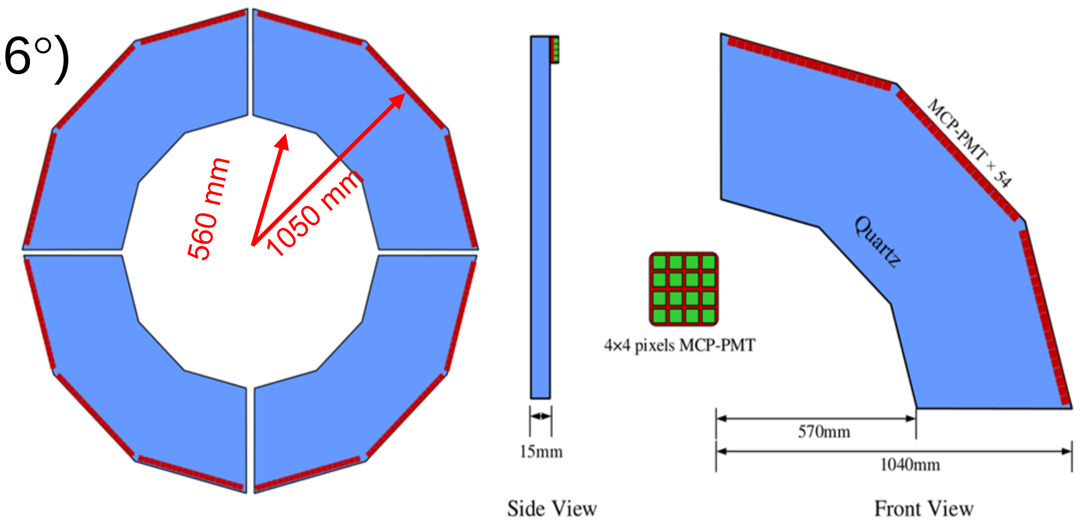
Time	Place	Content
2015.01	Hefei, China	First
2018.03	Beijing, China	Second
2018.05	Novosibirsk, Russia	Third
2018.12	Paris, France	Fourth
2019.08	Moscow, Russia	Fifth
2020.11	Online, China	Sixth
2021.11	Online, Russia	Seventh

Time	Place	Content
2018.10	Hengyang (USC)	Super Tau-Charm Facility
2019.03	Beijing (UCAS)	Physics at STCF
2019.07	Hefei (USTC)	STCF: accelerator measurement and control technology
2019.08	Hefei (USTC)	Physics and simulations at STCF
2019.11	Beijing (UCAS)	STCF CDR
2020.08	Hefei (USTC)	STCF: From CDR to TDR

Particle Identification Detector - DTOF

- DIRC-based Time-of-Flight Detector in the endcap (22°-36°)
- Large area quartz (0.56 m^2 sensitive area)
- 3D (x, y, t) measurement with 42 MCP-PMT (23x23 mm^2 sensitive area): σ_{xy} ~ 2mm, single photon σ_t ~ 70 ps

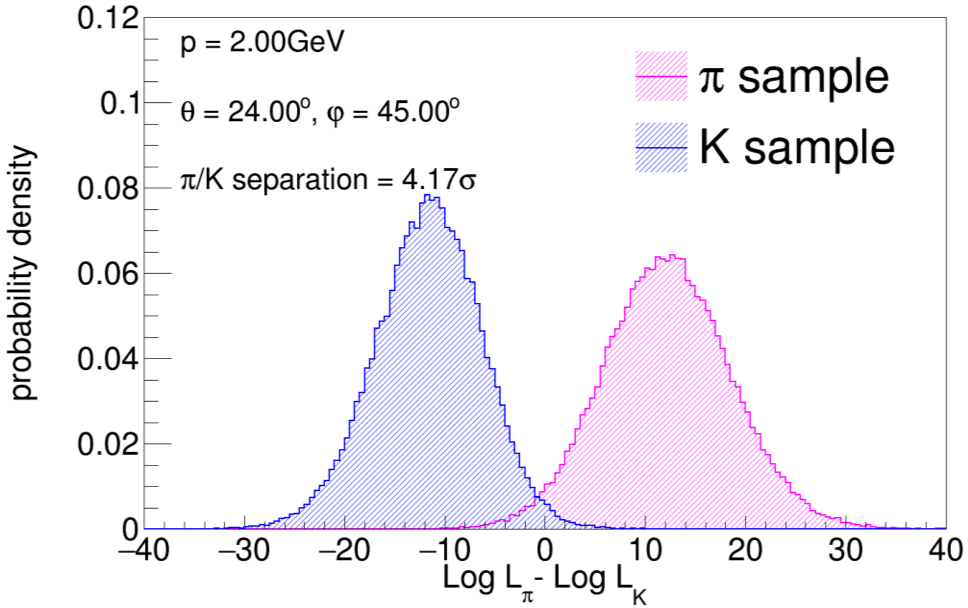
  => 30 ps of charged particle



Full size prototype！

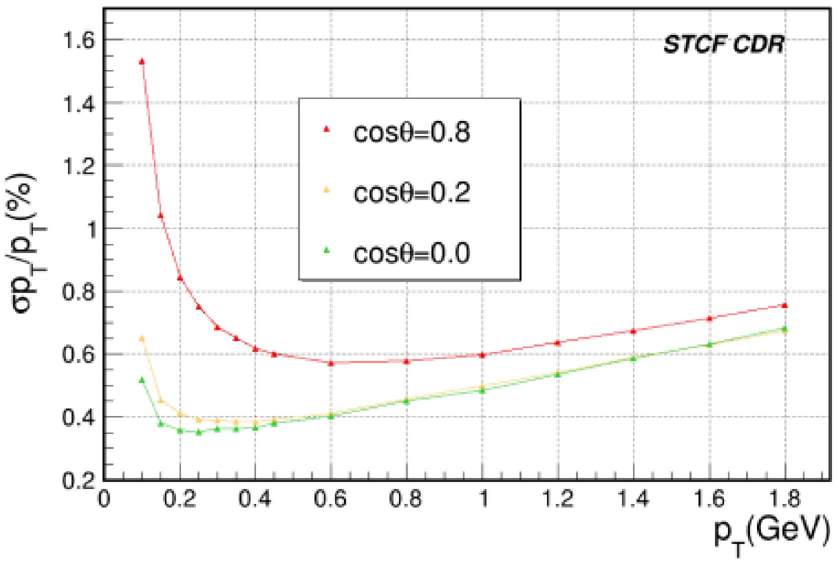
- ✓ Electronics for full size prototype ready
- ✓ Prototype is under cosmic ray test, preliminary results shows intrinsic time resolution <25ps
- ✓ Application of DTOF for barrel PID is under consideration

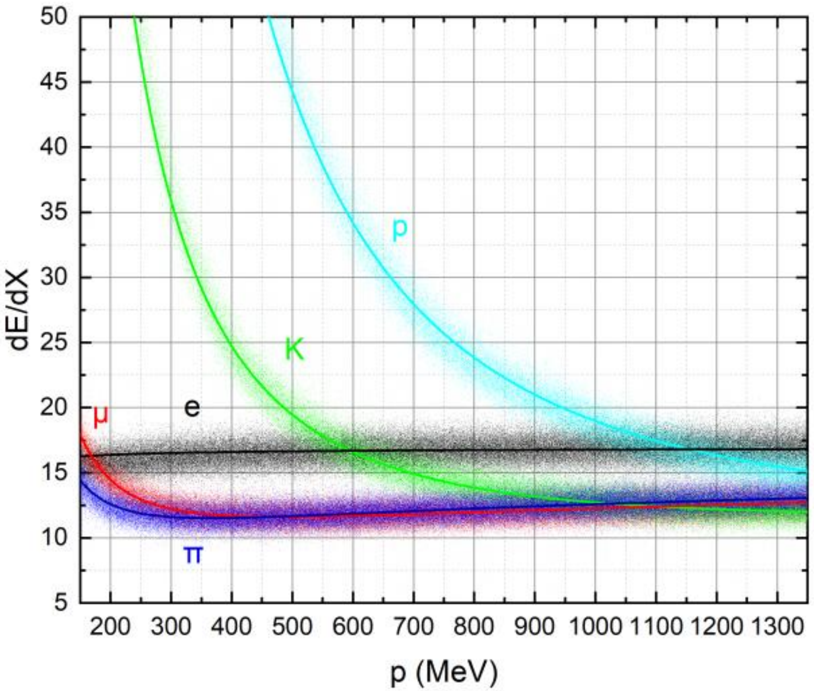
Expected likelihood-based π /K PID using position and time

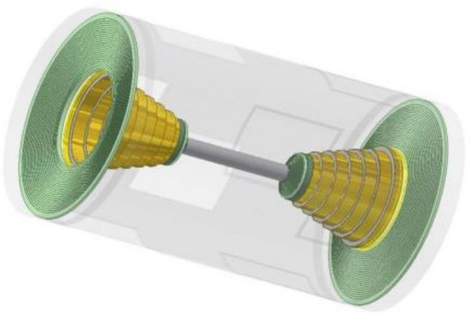


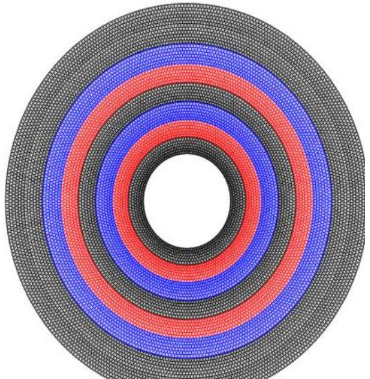
Main Drift Chamber

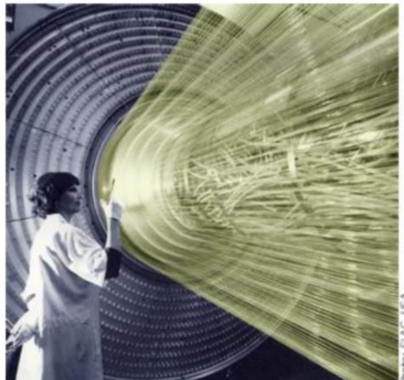
- 48 Axial/Stereo layers of drift wires arranged in 8 superlayers (AUVAUVAA)
- Square-shape cell structure (inner chamber: 6mm, outer chamber: 10-15 mm)
- Sense (field) wire: 20 (50) um-diameter goldcoated tungsten (aluminum) wire
- Working gas: He/C3H8 (60/40)
- Currently, stress analysis of wire board and analysis of electric field of cell on-going

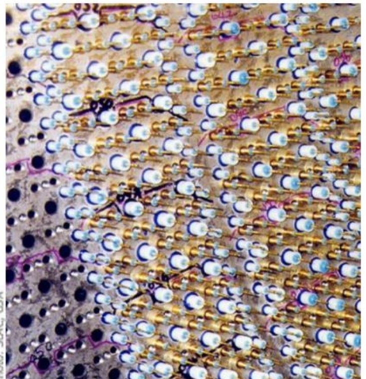










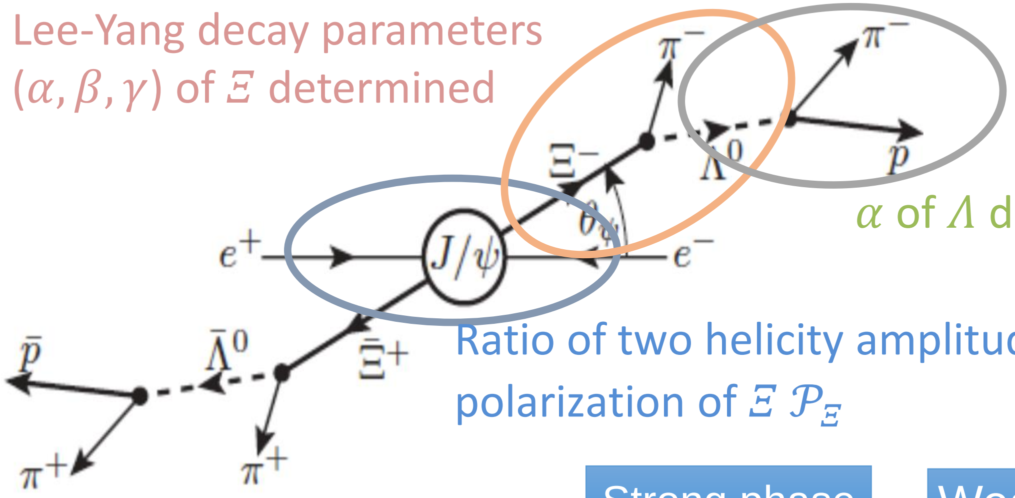


CP studies with quantum-correlated $\boldsymbol{Y\bar{Y}}$ pairs

- In Kaon sector, weak part from interference between $|\Delta I| = 1/2$ and $|\Delta I| = 3/2$ transition amplitudes in S-wave decays
- In Hyperon sector, weak part from interference between S-wave and P-wave decays

➢ **Typical reaction of $e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+$**

Lee-Yang decay parameters (α, β, γ) of Ξ determined



α of Λ determined

Ratio of two helicity amplitudes α_ψ
polarization of Ξ $\mathcal{P}_\Xi$

Strong phase

Weak phase

CP observables:

$$\mathcal{A}^Y_{CP} \equiv \frac{\alpha_Y + \alpha_{\bar{Y}}}{\alpha_Y - \alpha_{\bar{Y}}} = -\sin(\delta^P_{y\pi} - \delta^S_{y\pi})\sin(\xi^P_Y - \xi^S_Y)$$

$$\mathcal{B}^\Xi_{CP} \equiv \frac{\beta_\Xi + \beta_{\bar{\Xi}}}{\alpha_\Xi - \alpha_{\bar{\Xi}}} = \tan(\xi^P_\Xi - \xi^S_\Xi) \approx \xi^P_\Xi - \xi^S_\Xi$$

➢ 1.3 B J/ψ yields 73k $J/\psi \to \Xi^-\bar{\Xi}^+$ events at BESIII. First limit on weak phase of a P-wave amplitude!

$$\xi^P_\Xi - \xi^S_\Xi = 0.7^\circ \pm 2.0^\circ \quad \in \{-2.6^\circ, +4.0^\circ\} \ (90\% \text{ C.L.})$$
$$\delta^P_{\Lambda\pi} - \delta^S_{\Lambda\pi} = -2.3^\circ \pm 2.1^\circ \quad \in \{-5.8^\circ, +1.2^\circ\} \ (90\% \text{ C.L.})$$

➢ STCF will produce 3.4 trillion J/ψ, the sensitivity is expected to be $\Delta(\xi^P_\Xi - \xi^S_\Xi) \sim 0.04^\circ$

➢ SM prediction of $\xi^P_\Xi - \xi^S_\Xi$ to be $(-0.01 \pm 0.01)^\circ$

➢ Any significance deviation from zero will indicate new CPV beyond SM!

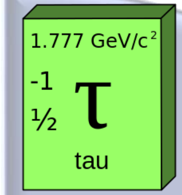
X. R. Zhou, S. Olsen, Int. J. Mod. Phys. A. 37, 2250169 (2022)

Probe CP violation

- CPV has been observed in K, B, D mesons, all are consistent with CKM theory in the Standard Model
- Baryon asymmetry of the Universe indicates that there must be non-SM CPV source

Billions hyperon pairs from J/ψ decay, clean topology, background free
Transversely polarized, spin correlation
Sensitivity: $A_{CP}\sim10^{-4}$, $\xi\sim0.05^{\circ}$

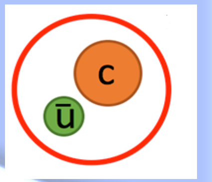
CP in hyperon decay



CP in tau decay/production

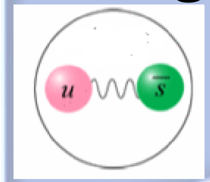
Peak cross section in $\sqrt{s}$ =4-5 GeV, $\sigma_{\tau\tau}\approx$ 3.5 nb, 10 ab^{-1} data in total
Sensitivity of τ decay with 1ab^{-1} @ 4.26 GeV $\sim9.7\times10^{-4}$

CP in charm mixing



Billions $D^0/\overline{D}^0$, threshold production, quantum coherence with $(D^0\overline{D}^0)_{\mathrm{CP}=-}$ or $(D^0\overline{D}^0)_{\mathrm{CP}=+}$
Sensitivity: $x\sim0.035\%$, y$\sim0.023\%$, $r_{CP}\sim0.017$, $\alpha_{CP}\sim1.3^{\circ}$

CPT in kaon mixing



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

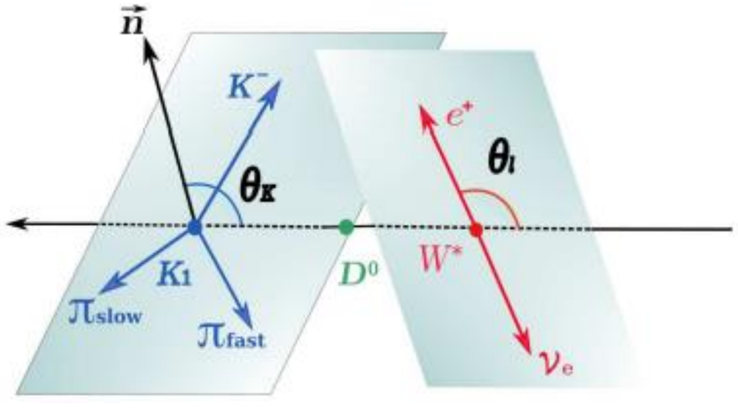
Photon Polarization in $\boldsymbol{b \to s\gamma}$

Y. L. Fan et al., Eur. Phys. J. C 81, 1068 (2021)

- Left-handed photon in $b \to s\gamma$ with SM. Many NP models have predicted a significant right-handed component:

  photon polarization is given as: $\lambda_\gamma = \dfrac{|C_{7R}|^2 - |C_{7L}|^2}{|C_{7R}|^2 + |C_{7L}|^2}$,

- A novel method proposed for model independent determination of λ_γ by combining $B \to K_{res}(\to K\pi\pi)\gamma$ and $D^0 \to K_{res} e \upsilon_e$ (*W. Wang et al., PRL. 125, 051802 (2020)*):



$$\lambda_\gamma = \frac{4\ A_{UD}}{3\ A'_{UD}}.$$

A_{UD} in $B \to K_{res}\gamma$ proportional to λ_γ

$$A_{UD} = \frac{\Gamma_{K_{res}\gamma}[\cos\theta_K > 0] - \Gamma_{K_{res}\gamma}[\cos\theta_K < 0]}{\Gamma_{K_{res}\gamma}[\cos\theta_K > 0] + \Gamma_{K_{res}\gamma}[\cos\theta_K < 0]} = \lambda_\gamma \frac{3\ \mathrm{Im}[\vec{n}\cdot(\vec{J}\times\vec{J}^*)]}{4\ |\vec{J}|^2}.$$

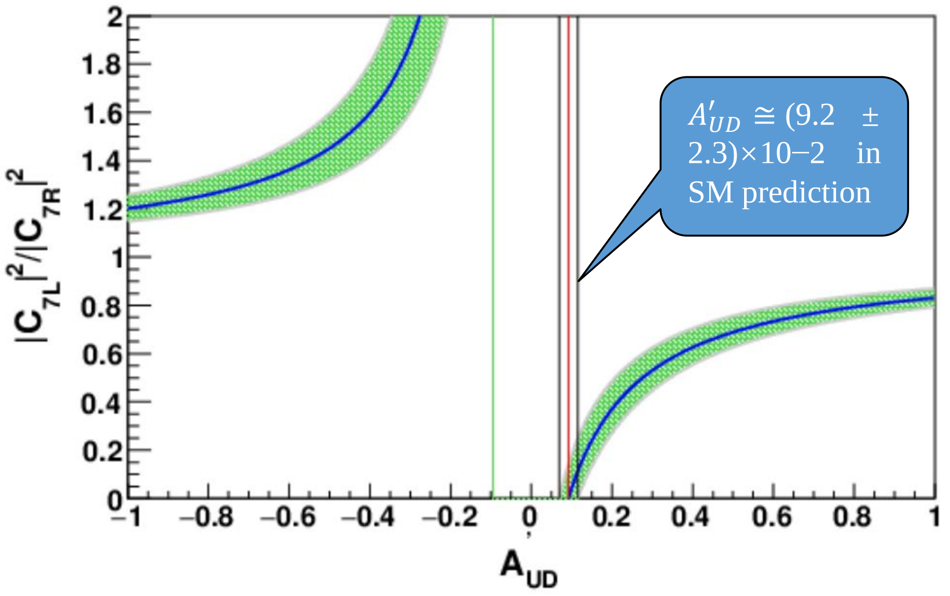
LHCb: $A_{UD} = (6.9 \pm 1.7) \times 10^{-2}$

A'_{UD} in $\mathrm{D} \to K_1 l^+ \nu_\tau$

$$A'_{UD} = \frac{\Gamma_{K_1^- e^+\nu_e}[\cos\theta_K > 0] - \Gamma_{K_1^- e^+\nu_e}[\cos\theta_K < 0]}{\Gamma_{K_1^- e^+\nu_e}[\cos\theta_l > 0] - \Gamma_{K_1^- e^+\nu_e}[\cos\theta_l < 0]} = \frac{\mathrm{Im}[\vec{n}\cdot(\vec{J}\times\vec{J}^*)]}{|\vec{J}|^2}.$$

At STCF, over 30k signal events of $D^0 \to K_1(1270)^- e^+ \nu_e$ can be reconstructed *=> a stat. uncertainty of 0.015 for A'_{UD} is achieved*

Extracted dependence of Wilson coefficient on A'_{UD}



Detector requirements

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 $\sigma_{pos} \approx 5$ 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