Experimental Program for Super Tau-Charm Facility

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The 13th International Workshop on e+e- collisions from Phi to Psi

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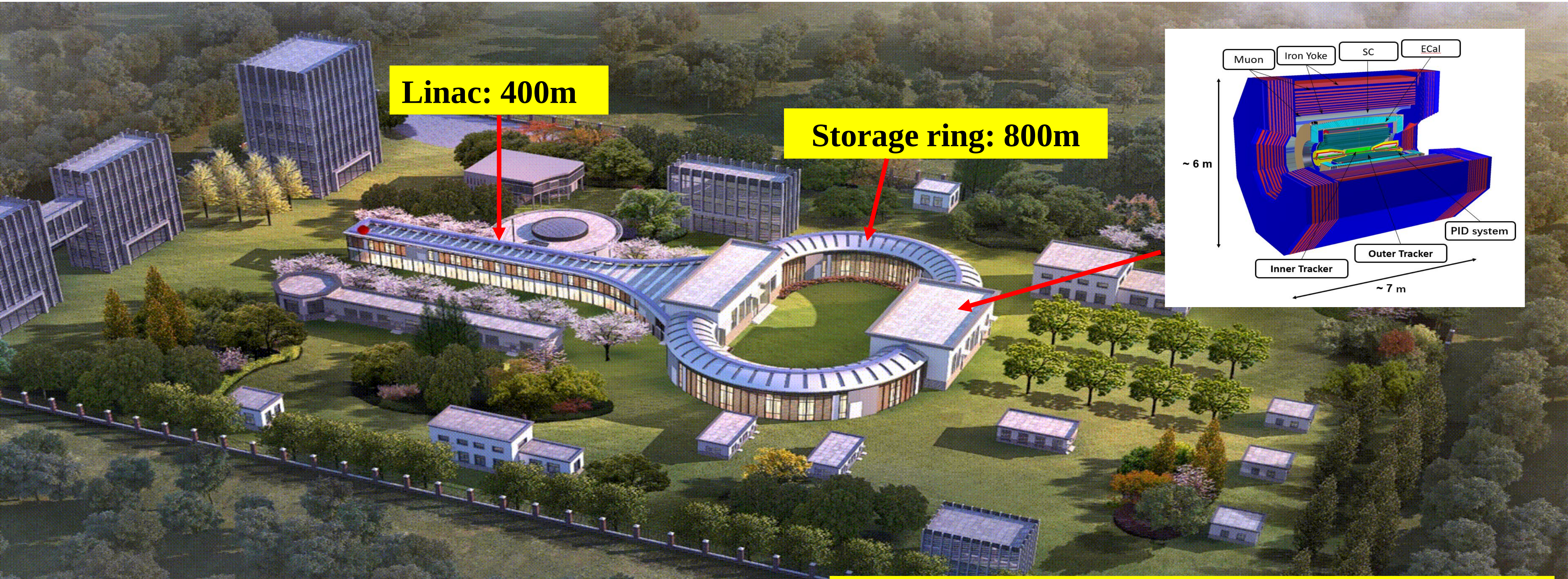
Super Tau-Charm Facility in China



- 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 of 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.

Expected Data Samples at STCF

Data sample 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

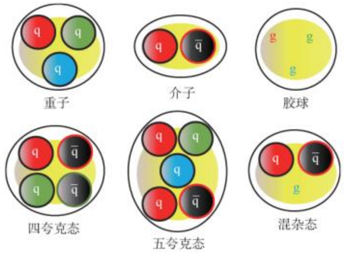
Decay Mode	$\mathcal{B}$ ($\times10^{-4}$) [2]	η/η' events
$J/\psi\to\gamma\eta'$	52.1 ± 1.7	1.8×10^{10}
$J/\psi\to\gamma\eta$	11.08 ± 0.27	3.7×10^{9}
$J/\psi\to\phi\eta'$	7.4 ± 0.8	2.5×10^{9}
$J/\psi\to\phi\eta$	4.6 ± 0.5	1.6×10^{9}

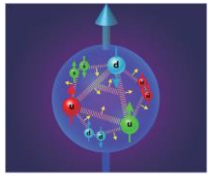
XYZ Factory

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

- 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 which is experimentally blank before

Physics Program at STCF

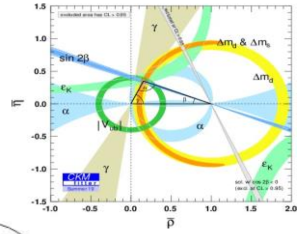


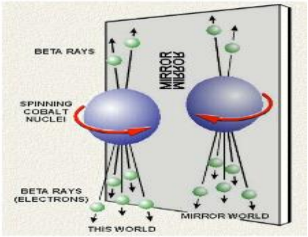


Physics at STCF

QCD and hadronic physics

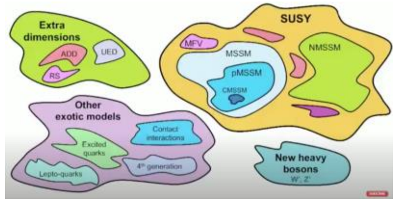
- **XYZ Properties:** e+e-→Y→γX,ηX,ϕX; e+e-→Y→πZc, KZcs
- **Hadron Spectroscopy:** Excited ccbar and their transition, Charmed hadron spectroscopy, Light hadron spectroscopy
- **R value:** e+e-→inclusive; τ mass: e+e-→τ+τ-
- **Nucleon Form Factors:** e+e-→BBbar from threshold
- **Pentaquarks:** e+e-→J/ψppbar, 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+ν, D→P l+ ν
- **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 πν, EDM of τ, τ→π/K π0 ν 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+ ν_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…

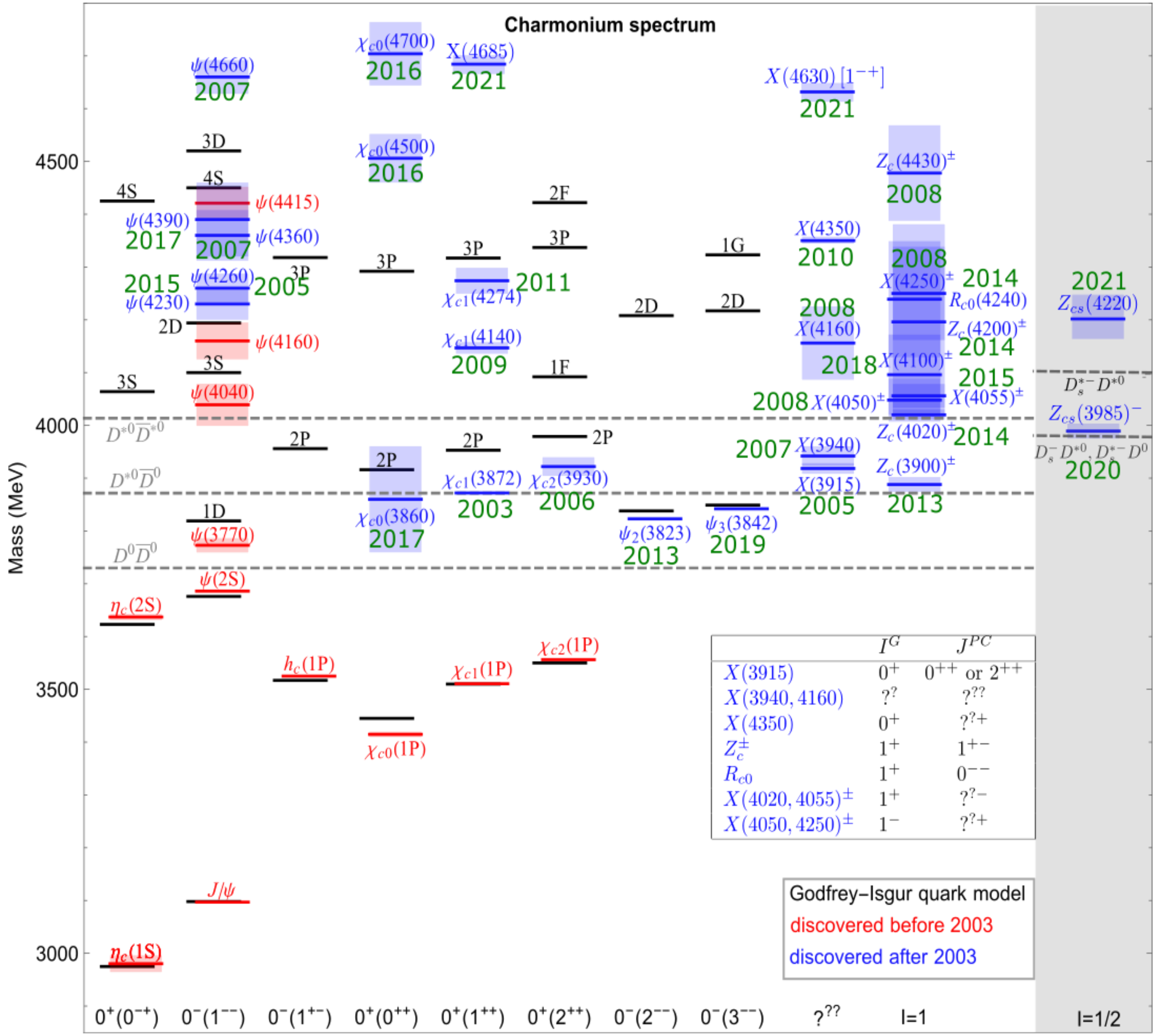
- Leading role
- In Competition with Belle II/LHCb
- Synergy with BelleII/LHCb/Eic/EicC

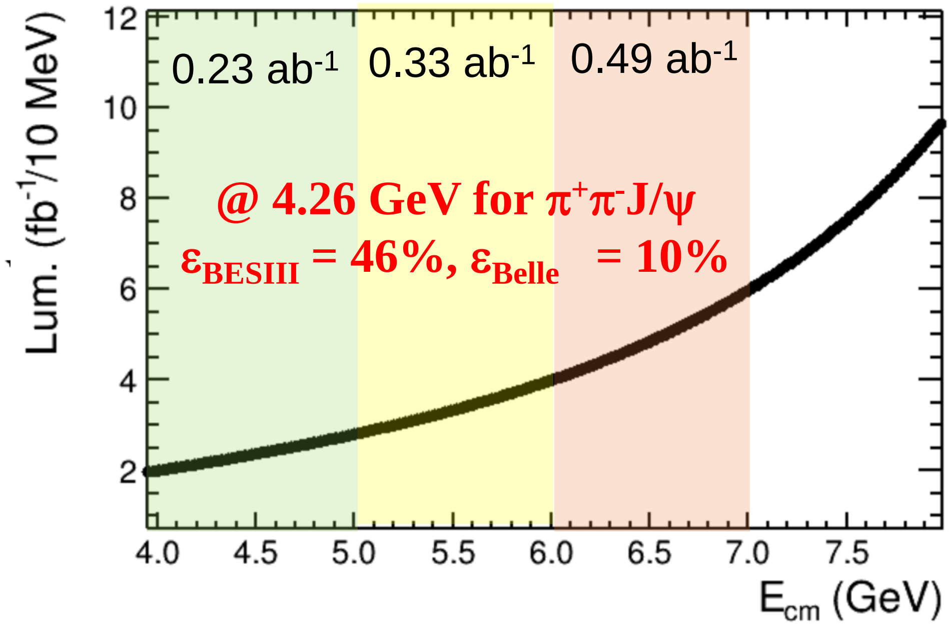
Expected Sensitivities

Physics at STCF	Benchmark Processes	Key Parameters*	Physics at STCF	Benchmark Processes	Key Parameters*
XYZ properties	$e^+e^- \to Y \to \gamma X, \eta X, \phi X$ $e^+e^- \to Y \to \pi Z_c, K Z_{cs}$	$N_{Y(4260)/Z_c/X(3872)} \sim 10^{10}/10^9/10^6$	**CKM matrix**	$D^+_{(s)} \to l^+ \nu_l, D \to P l^+ \nu_l$	$\delta V_{cd/cs} \sim 0.15\%$; $\delta f_{D/D_s} \sim 0.15\%$
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**	$D^0 \to K_s \pi^+\pi^-, K_s K^+ K^-$ ...	$\Delta(\cos\delta_{K\pi}) \sim 0.007$; $\Delta(\delta_{K\pi}) \sim 2°$
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	$e^+e^- \to (\pi, K, p, \Lambda, D) + X$ $e^+e^- \to (\pi\pi, KK, \pi K) + X$	$\Delta A^{\mathrm{Collins}} < 0.002$	**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	$\tau \to \gamma l, lll, l P_1 P_2$ $J/\psi \to l l', D^0 \to l l' (l' \neq l)$...	$\mathcal{B}(\tau \to \gamma\mu/\mu\mu\mu)$<12/1.5× 10^{-9}; $\mathcal{B}(J/\psi \to e\tau)$<0.71× 10^{-9}	**CPV in Charm**	$D^0 \to K^+K^-/\pi^+\pi^-$, $\Lambda_c \to p K^- \pi^+ \pi^0$ ...	$\Delta A_D \sim 10^{-3}$; $\Delta A_{\Lambda_c} \sim 10^{-3}$
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**	$D \to \gamma V, D^0 \to l^+ l^-, e^+e^- \to D^*$, $\Sigma^+ \to p l^+ l^-$...	$\mathcal{B}(D^0 \to e^+e^- X) < 10^{-8}$
Symmetry violation	$\eta^{(\prime)} \to l l \pi^0, \eta' \to \eta l l$...	$\mathcal{B}(\eta' \to ll/\pi^0 ll) < 1.5/2.4 \times 10^{-10}$	**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 $\mathcal{L} = 1\ \mathrm{ab}^{-1}$

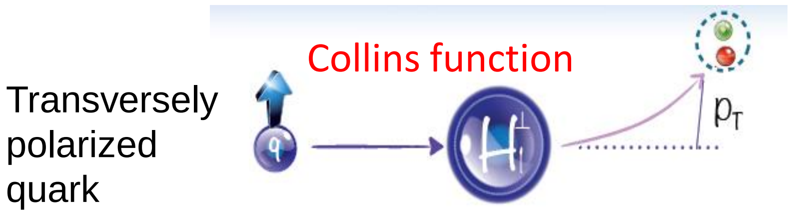
Charmonium (Like) Spectroscopy





- **Belle II :** ISR approach; B meson decay ($m_R <$ 4.8 GeV)
- **LHCb:** B/Λ_b decay; Prompt production
- **STCF:** Scan with 10 MeV/step, every point has 10 fb^{-1}/year, 3 ab^{-1} in 4-7 GeV

Collins Fragmentation Function (FF)

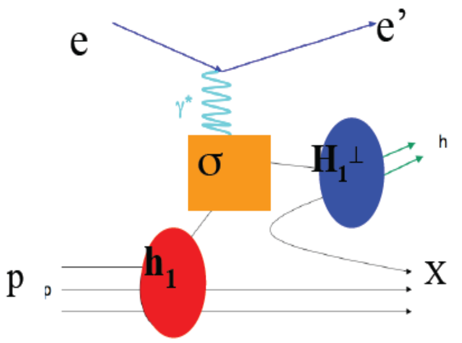


J. C. Collins, Nucl. Phys. B396, 161 (1993)

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

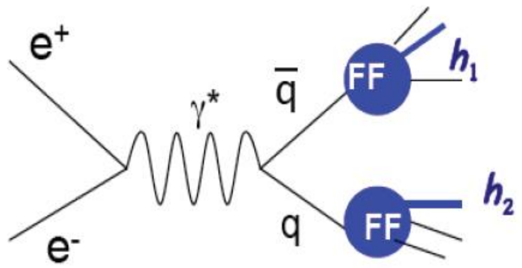
SIDIS

Transversity ⊗ Collins FF



e+ e-

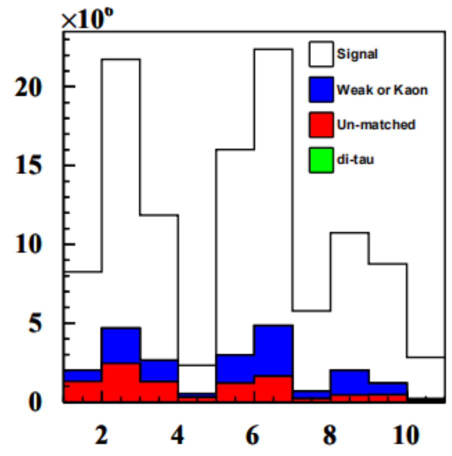
Collins FF ⊗ Collins FF

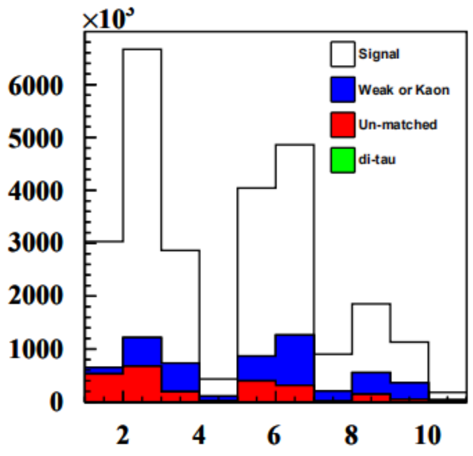


H_1: Collins FF

→ 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 1ab^{-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*

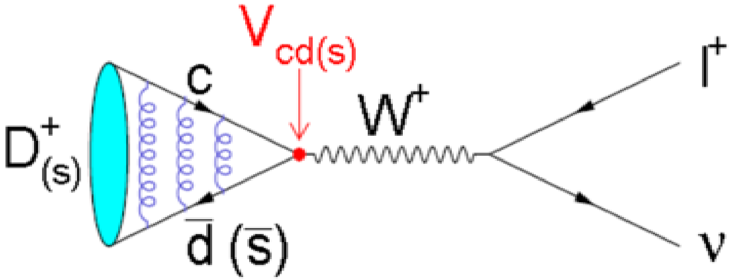
Facilities for Charm Study

- LHCb: huge x-sec, boost, 9 fb^{-1} now (x40 current B-factories)
- B-factories (Belle (II), BaBar): more kinematic constrains, clean environment, ~100% trigger efficiency
- τ-charm factory : Low backgrounds and high efficiency; missing technique; Quantum correlations and CP-tagging are unique;
  - Super τ-Charm Factory (STCF): 4×10^9 pairs of $D^{\pm,0}$, 10^8 Ds and Λ_c pairs per year
  - Highlighted Physics programs
    - Precise measurement of (semi-)leptonic decay (f_D, f_{Ds}, CKM matrix…)
    - $D^0-\bar{D}^0$ mixing, CPV
    - Rare decay (FCNC, LFV, LNV….)
    - Charmed baryons (J^{PC}, Decay modes, absolute BF)
    - Excited charmed meson and baryon states: like D_J, D_{sJ} , Λ_c^* (mass, width, J^{PC}, decay modes)
    - Light meson and hyperon spectroscopy studied in charmed hadron decays

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

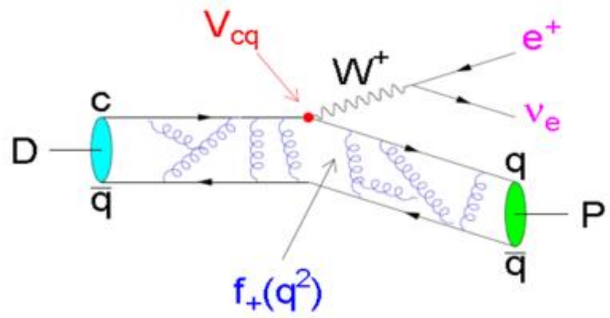
Purely Leptonic:

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



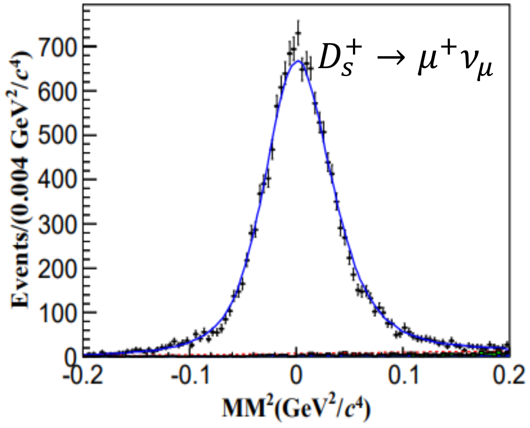
Semi-Leptonic:

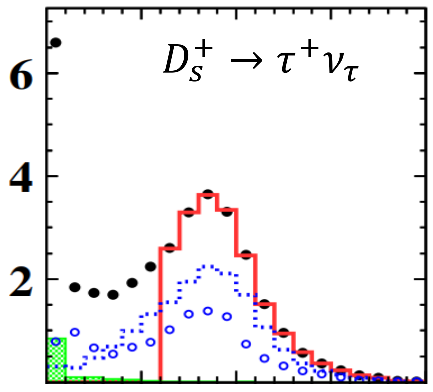
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{cs(d)}|^2 p^3_{K(\pi)} |f_+^{K(\pi)}(q^2)|^2$$



Directly 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	
$\mathcal{B}_{D_s^+\to\tau^+\nu_\tau}$	$1.6\%_{stat.}$	$2.4\%_{syst.}$	$0.6\%_{stat.}$	$2.7\%_{syst.}$	$0.3\%_{stat.}$	$1.0\%_{syst.}$
$f_{D_s^+}$ (MeV)	$0.9\%_{stat.}$	$1.4\%_{syst.}$	–	–	$0.2\%_{stat.}$	$0.6\%_{syst.}$
$\|V_{cs}\|$	$0.9\%_{stat.}$	$1.4\%_{syst.}$	–	–	$0.3\%_{stat.}$	$0.7\%_{syst.}$
$\frac{\mathcal{B}_{D_s^+\to\tau^+\nu_\tau}}{\mathcal{B}_{D_s^+\to\mu^+\nu_\mu}}$	$2.6\%_{stat.}$	$2.8\%_{syst.}$	$0.9\%_{stat.}$	$3.2\%_{syst.}$	$0.5\%_{stat.}$	$1.4\%_{syst.}$

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

Photon Polarization in $b \to s\gamma$

- In $b \to s\gamma$, the photon is left-handed under SM prediction. Many NP models have predicted a significant right-handed component of photon.
- A novel method is proposed by combine $B \to K_{res}(\to K\pi\pi)\gamma$ and $D^0 \to K_{res} e \nu_e$ to obtain the photon polarization model-independently (*W. Wang et al., PRL. 125, 051802 (2020)*).

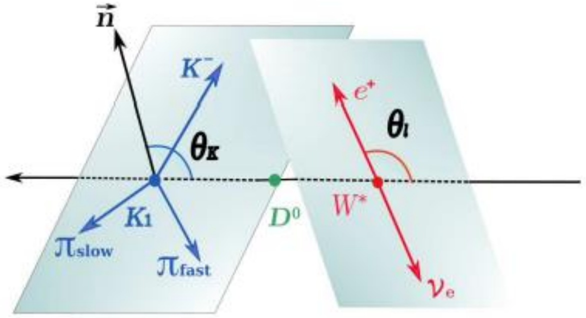
A_{UD} in $B \to K_{res}\gamma$ proportional to λ_γ

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

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

Determination of λ_γ model independent by combining with D $\to K_1 l^+ \nu_\tau$

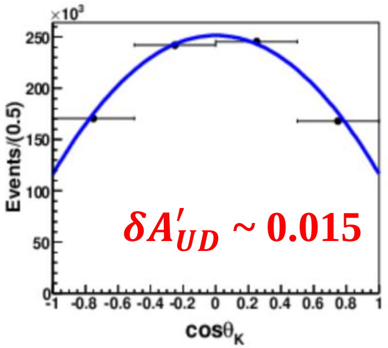
$$A'_{\rm UD} = \frac{\Gamma_{K_1^- e^+ \nu_e}[\cos\theta_K > 0] - \Gamma_{K_1^- e^+ \nu_e}[\cos\theta_K < 0]}{\Gamma_{K_1^- e^+ \nu_e}[\cos\theta_l > 0] - \Gamma_{K_1^- e^+ \nu_e}[\cos\theta_l < 0]} = \frac{{\rm Im}[\vec{n}\cdot(\vec{J}\times\vec{J}^*)]}{|\vec{J}|^2}.$$

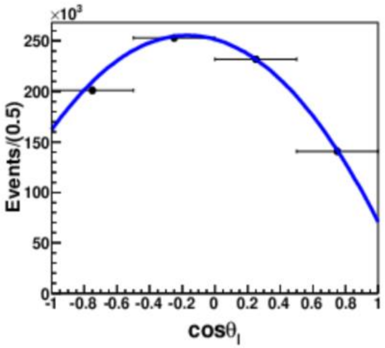


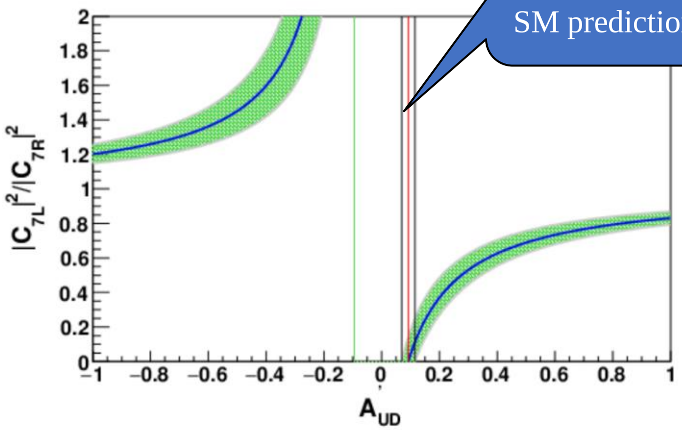
At STCF, over 30k signal events of $D^0 \to K_1(1270)^- e^+ \nu_e$ can be reconstructed

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

The dependence of Wilson coefficient on A'_{UD} (using A_{UD} as input):







$A'_{UD} \cong (9.2 \pm 2.3)\times10{-}2$ in SM prediction

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

CP violation

1980

2008

- In 1964, the first CPV was discovered in Kaon;
- In 2001, CPV in B was established by two B-factories;
- In 2019, CPV discovered in D meson (LHCb)
- All are consistent with CKM theory in the Standard model
- Baryon asymmetry of the Universe means that there must be non-SM CPV source.

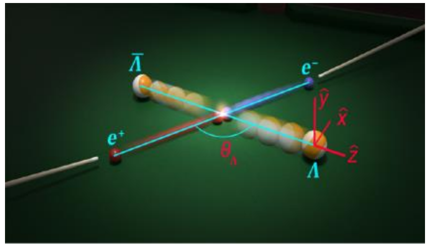
Probe CP violation

- **In Hyperon Decay**

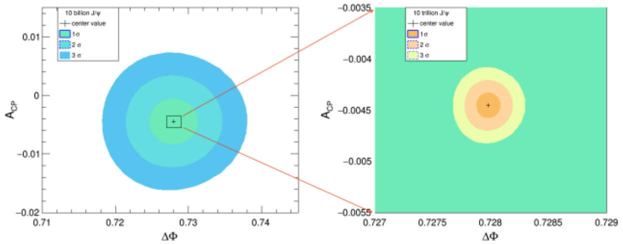
Λ is transversely polarized

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

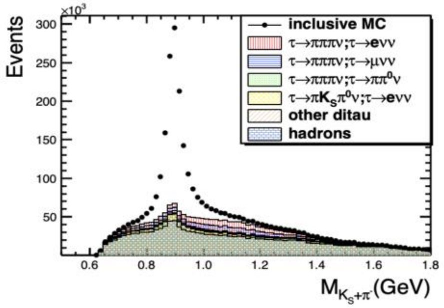


- **In tau Decay**

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 $\bar{D}^0$

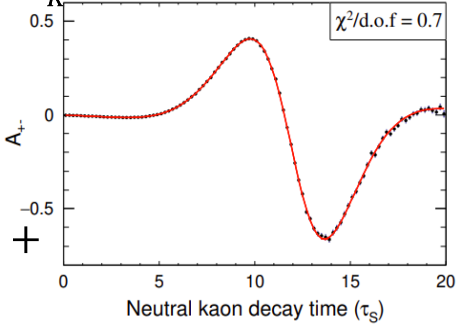
$\psi(3770) \to (D^0\bar{D}^0)_{CP=-}$ or $\psi(4140) \to D^0\bar{D}^{*0} \to \pi^0(D^0\bar{D}^0)_{CP=-}$ or $\gamma(D^0\bar{D}^0)_{CP=+}$

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

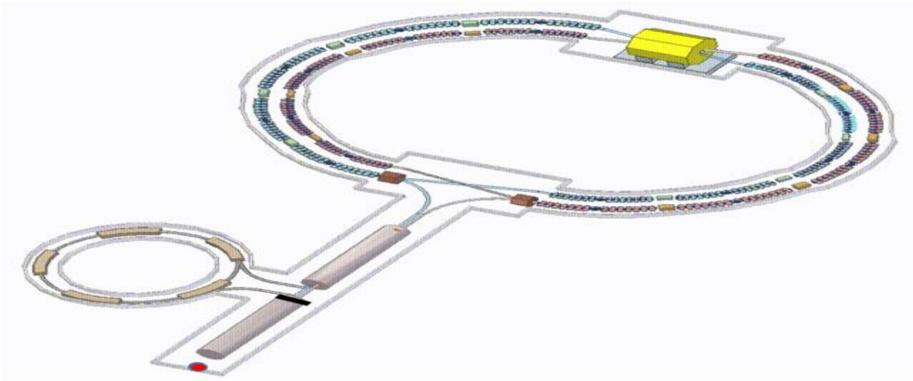
$$A_{+-}(\tau) = \frac{\bar{N}(\tau) - kN(\tau)}{\bar{N}(\tau) + kN(\tau)} = -2\frac{|\eta_f|\, e^{(1/2)(\Gamma_S-\Gamma_L)\tau}\cos(\Delta m\tau - \phi_f)}{1+|\eta_f|^2 e^{(\Gamma_S-\Gamma_L)\tau}}$$



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

See Jianyu's poster for detail

STCF Accelerator

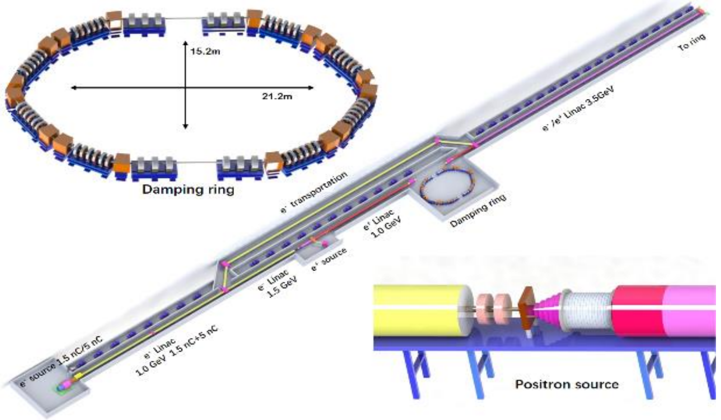


Challenge： realize luminosity of >0.5x10^{35} cm^{-2} s^{-1}

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

Interaction Region: Large Piwinski Angle Collision + Crabbed Waist

Parameters	Phase1	Phase2
Circumference/m	600~800	600~800
Optimized Beam Energy/GeV	2.0	2.0
Beam Energy Range/GeV	1-3.5	1-3.5
Current/A	1.5	2.0
Emittance $(\varepsilon_x/\varepsilon_y)$/nm·rad	6/0.06	5/0.05
β Function @IP (β_x^*/β_y^*)/mm	60/0.6	50/0.5(estimated)
Full Collision Angle 2θ/mrad	60	60
Tune Shift ξy	0.06	0.08
Hourglass Factor	0.8	0.8
Aperture and Lifetime	15σ, 1000s	15σ, 1000s
Luminosity @Optimized Energy/×10^{35}cm^{-2}s^{-1}	~0.5	~1.0



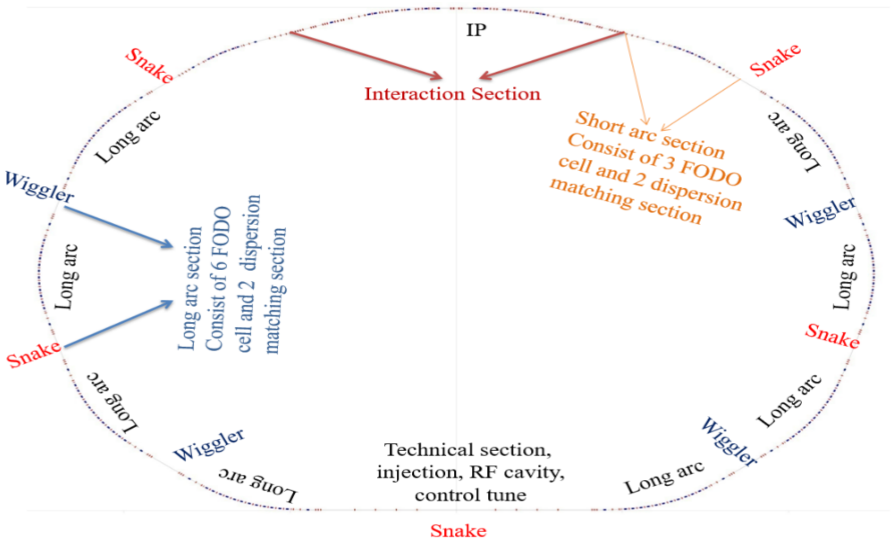
Injector:

- Length: 400m
- e$^+$, a convertor, a linac and a damping ring, 0.5 GeV
- e$^-$, a polarized e- source, accelerated to 0.5 GeV
- No booster, 0.5 GeV→1~3.5 GeV

Preliminary Design of Lattice

Parameters	Unit	Value
Circumference	m	574.78
Distance from final defocusing quadrupole to IP	m	0.9
Optimized energy	GeV	2.0
Total beam current	A	2
Horizontal/Vertical beta @ IP	m	0.09/0.0006
Total crossing angle (2θ)	mrad	60
Piwinski angle (ϕ)	rad	18.9
Beam-beam tune shift (ξ_x/ξ_y)	—	0.0038/0.0835
Coupling ratio	—	0.5%
Natural chromaticities (C_x/C_y)	—	-87/-513
Horizontal emittance (ϵ_x) without/with IBS	nmrad	2.76/4.17
Horizontal beam size @ IP without/with IBS	μm	15.77/19.37
Vertical beam size @ IP without/with IBS	μm	0.091/0.117
Energy spread ($\frac{\sigma_{\Delta E}}{E}$) without/with IBS	$\times 10^{-4}$	5.3/7.2
Momentum compaction factor	—	7.2×10^{-4}
RF frequency	MHz	499.67268
RF voltage	KV	1.2
Harmonic number	—	958
Bunch length (σ_z)	mm	12.2
Particle number per bunch (N_b)	—	5.0×10^{10}
Energy loss per turn	MeV	0.1315
Synchrotron tune (ν_s)	—	0.00388
Damping times ($\tau_x/\tau_y/\tau_s$)	ms	58.51/58.33/29.12
Peak luminosity	$cm^{-2}s^{-1}$	1.2×10^{35}
Touschek lifetime	second	35

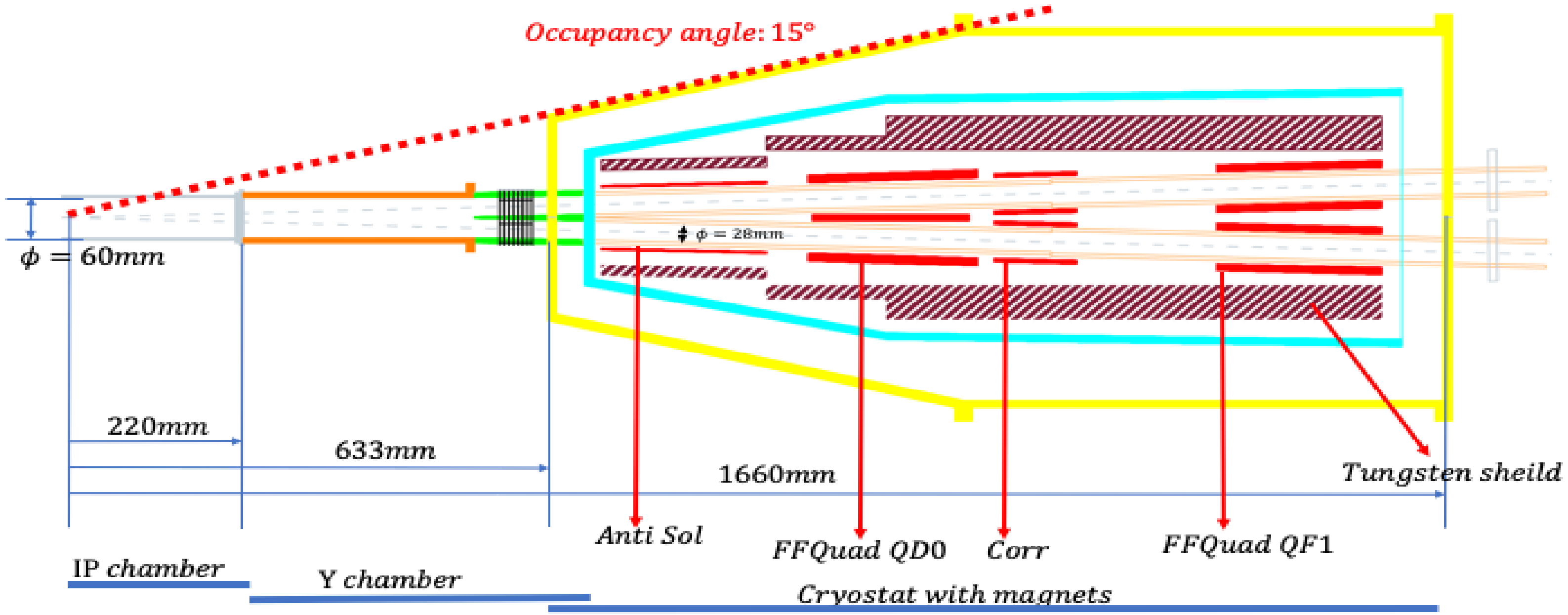
Linear lattice is designed with considering many factors and high precision to meet the high luminosity



- Total ring composed of 8 bending arc periods (4 super-periods), one interaction region, one technical region and 5 Siberian snakes.
- Beam-beam simulation: luminosity stable after 10,000 turns => $L=7.2\times10^{34}$ $cm^{-2}s^{-1}$

*J.Q. Lan, et al., Design of beam optics for a Super Tau-Charm Factory, 2021 JINST 16 T07001

Machine-Detector Interface



Beam pipe

- Inner radius: 30mm
- Thickness: 3mm
- Beam crossing angle: 2×30mrad

Magnet:

- De-focus magnet: 0.9 m from IP
- Focus magnet: 1.4 m from IP
- anti-solenoid and a correcting magnet: cancel magnetic field from detector

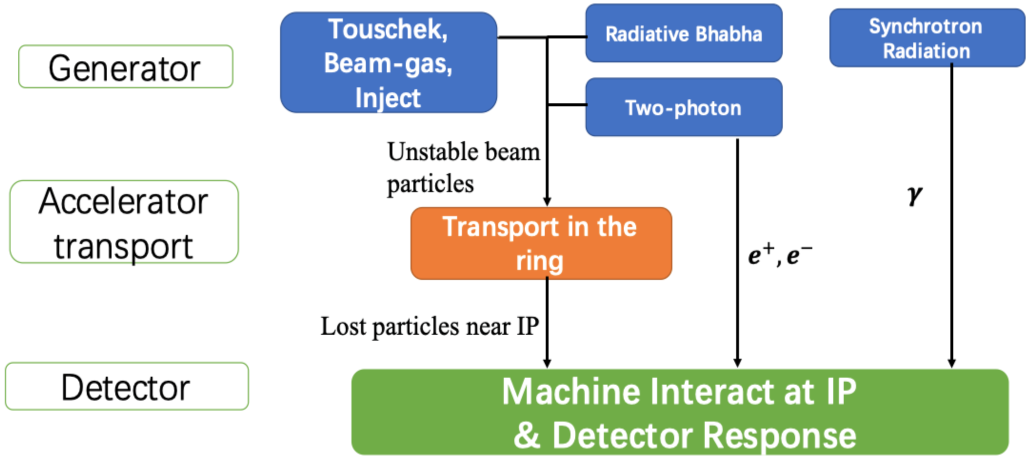
Helium channel:

- Cool down magnet
- Angle between MDI structure and mid-line of two beams is 15^{o}
- Tungsten shield to suppress bkg.

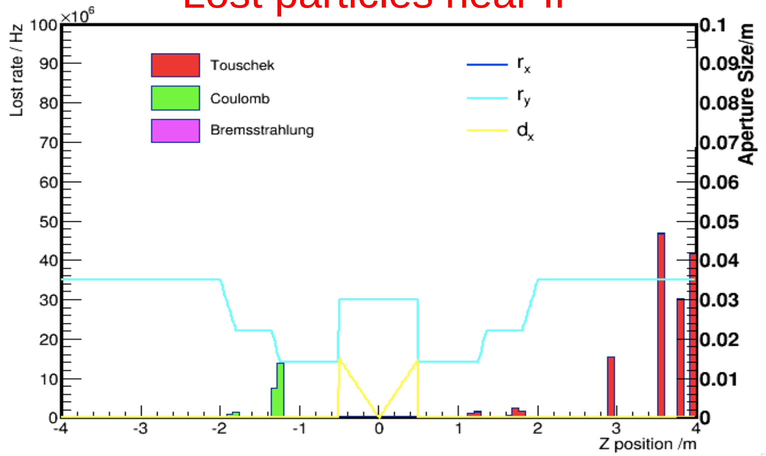
See Tao Liu's poster for more details

Beam Background Study

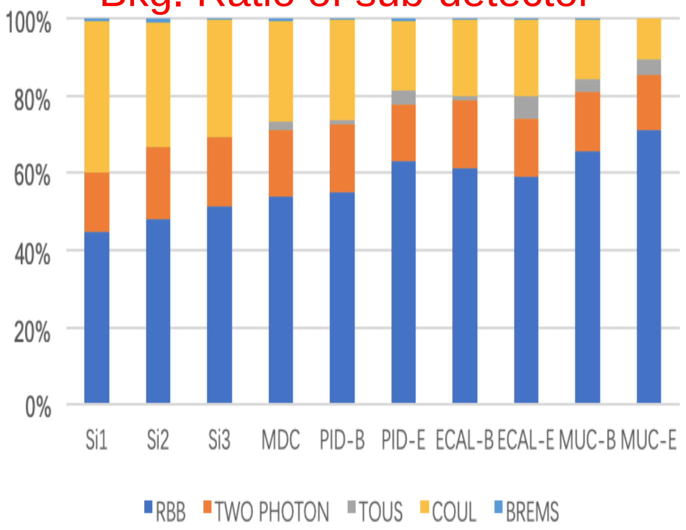
- Sources of background:
  - Luminosity-related background: radiative Bhabha, two-photon
  - Beam-related background: Touschek effect, beam-gas effects



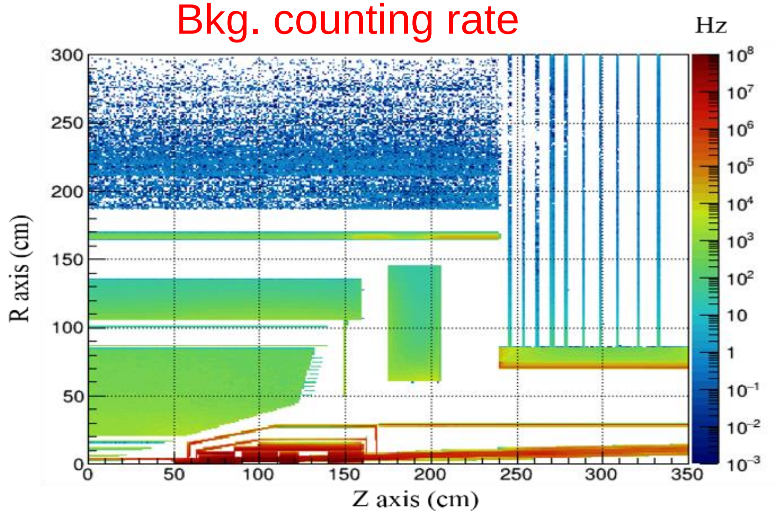
Lost particles near IP



Bkg. Ratio of sub-detector

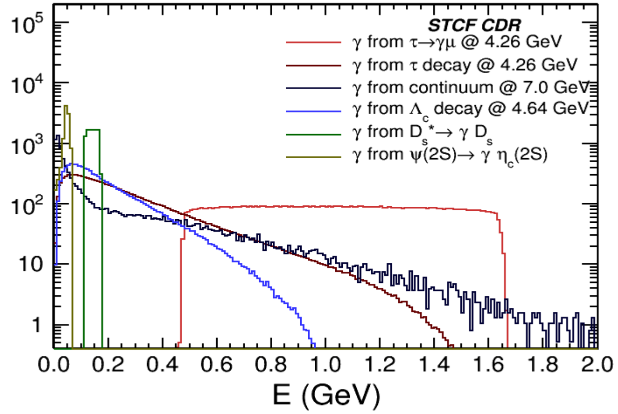


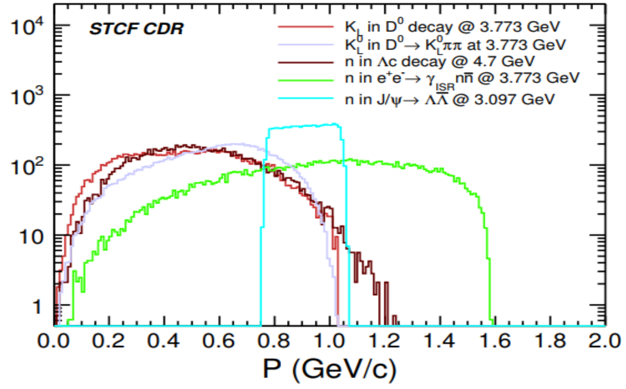
Bkg. counting rate

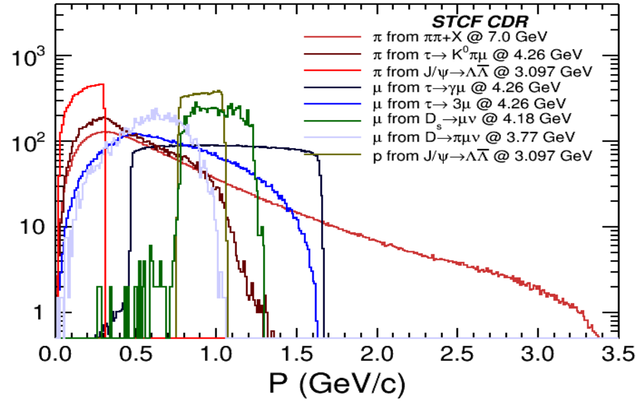


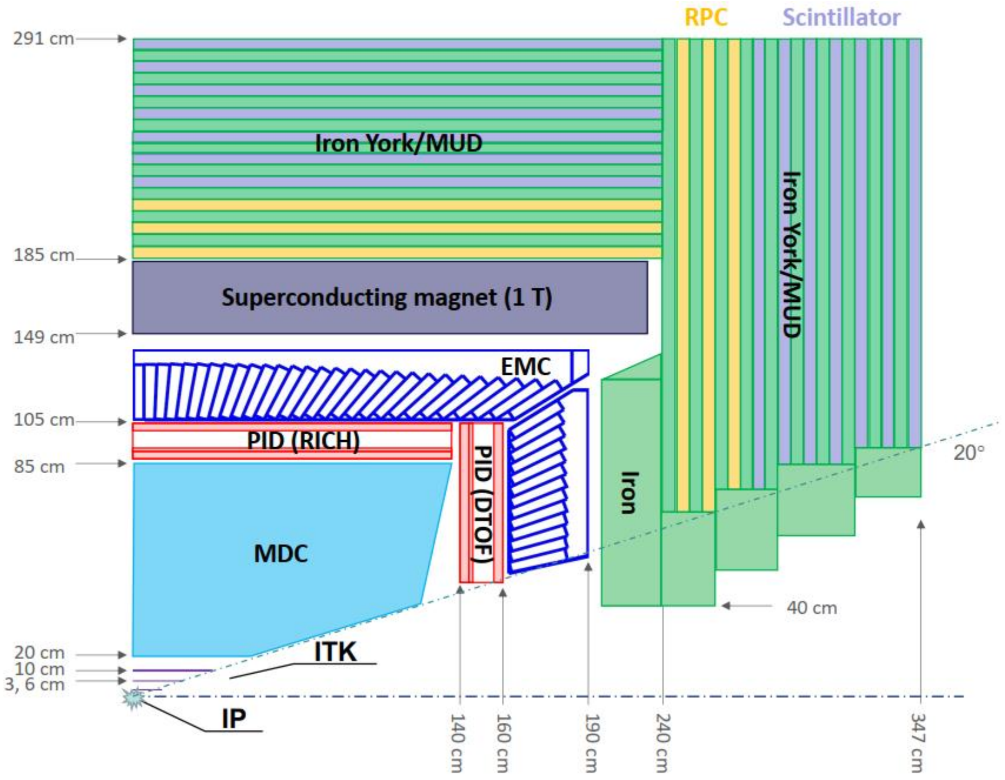
A beam-test have been carried out at BEPCII/BESIII to verify the simulations.

STCF Detector









Requirement:

- High detection efficiency and good resolution
- Superior PID ability
- Tolerance to high rate/background environment

ITK

<0.25%X0 / layer

σ_{xy}< 100 μm

MDC

σ_{xy}< 130 μm

σp/p ~ 0.5% @ 1 GeV

PID

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

EMC

E range: 0.025-3.5 GeV

σ_E @ 1 GeV: 2 .5% in barrel, 4% at endcaps

Pos. Res. : ~ 4 mm

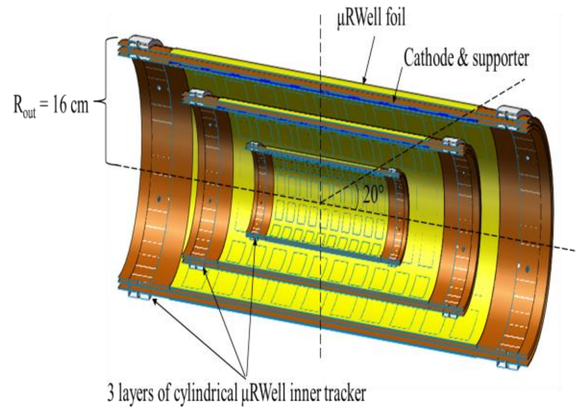
MUD

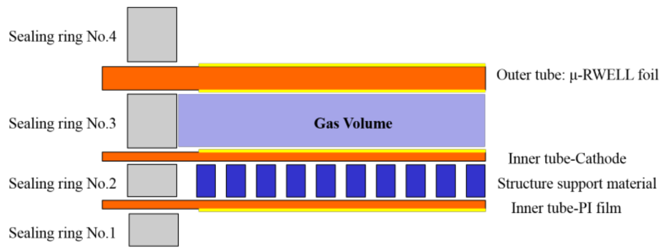
0.4 - 1.8 GeV

π suppression >30

Inner tracker

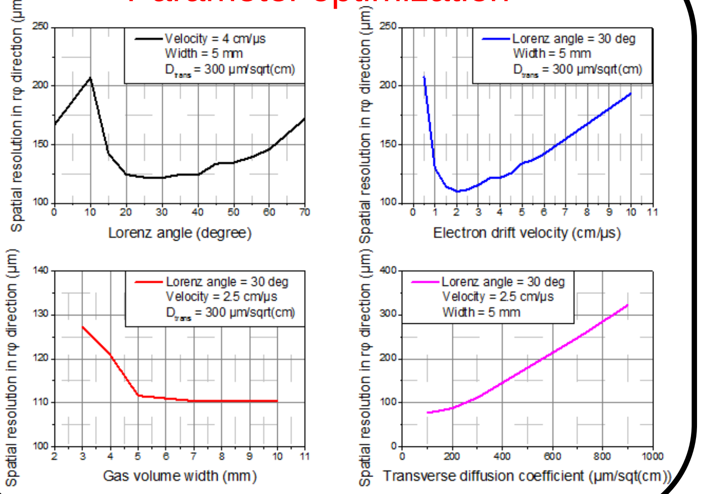
μRWELL-based



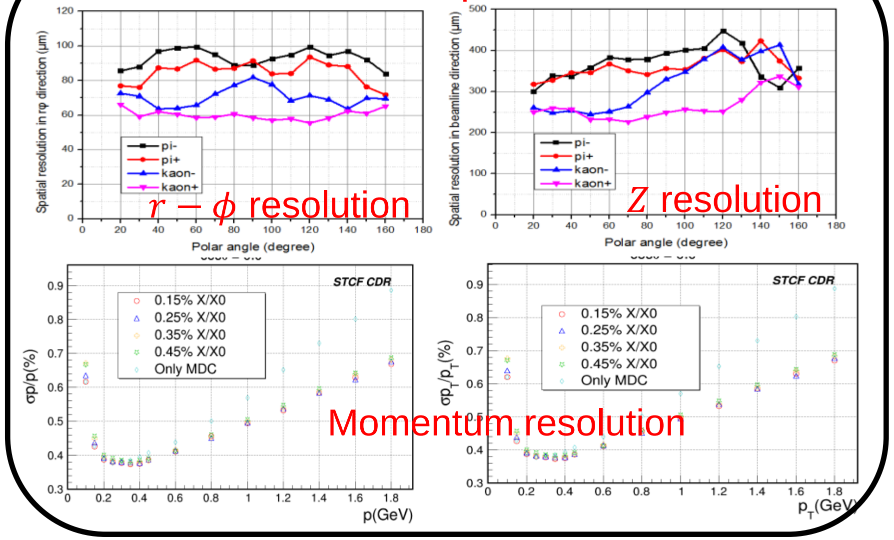


- ☐ 3-layer cylindrical-μRWell
- ☐ Inner radii 6 , 11 , 16 cm
- ☐ Material budget/layer ~0.25%X_0
- ☐ 2D readout，maximum counting rate: 112 kHz/cm^2。
- ☐ Working gas： $Ar:CO_2$=85:15

Parameter optimization

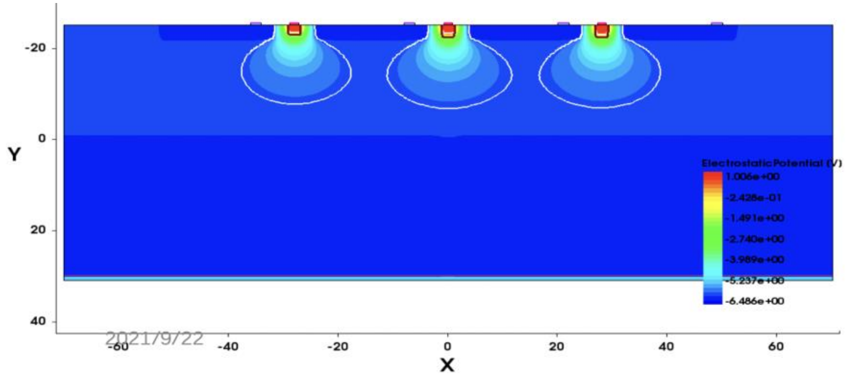


Detector performance



Silicon-based

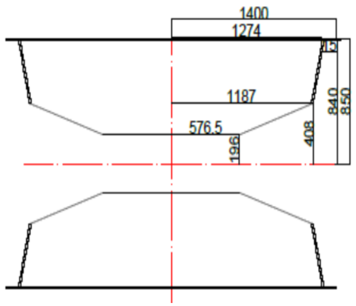
- Excellent radiation resistance and better vertex resolution
- Three layers of silicon pixel detector with radii 3.6, 9.8, 16 cm
- CMOS silicon pixel is considered

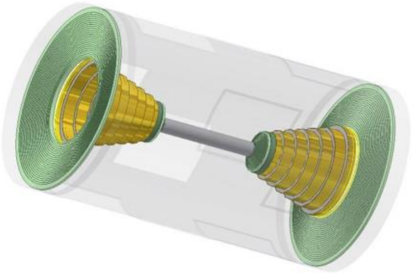


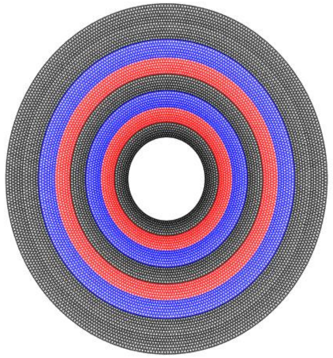
- ☐ Further optimization of detector structure, manufacturing of detector prototype and performance test

Main Drift Chamber (MDC)

Drift chamber: robustness, low cost and low material budget



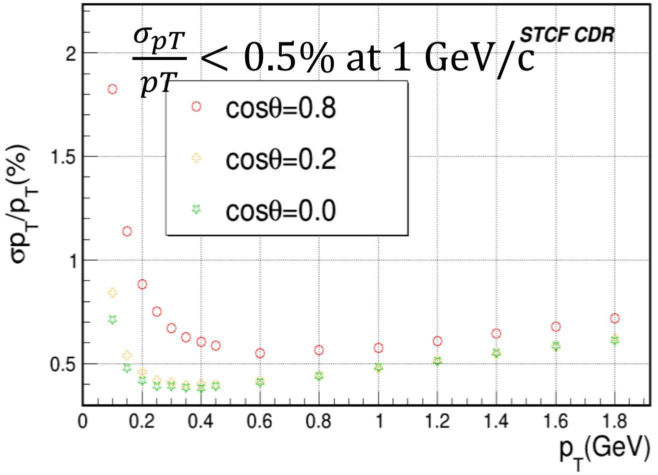


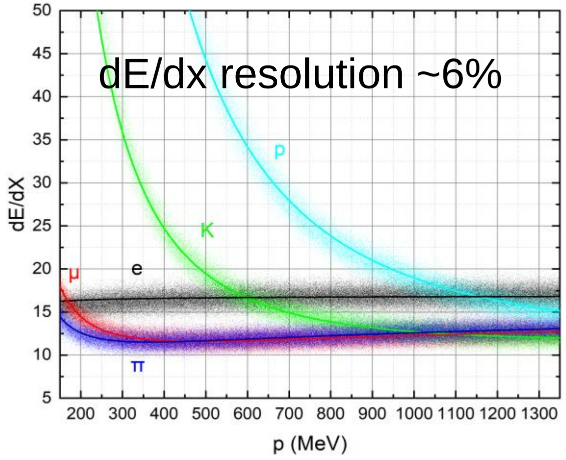


MDC optimization:

- 8 superlayers，six layers in each superlayer
- Square-shape cell structure
- sense(field)wire：20(100)μm-diameter gold-coated tungsten (aluminum)wire
- Working gas：He/C_3H_8 (60/40)
- Material budget：4.0%X_0

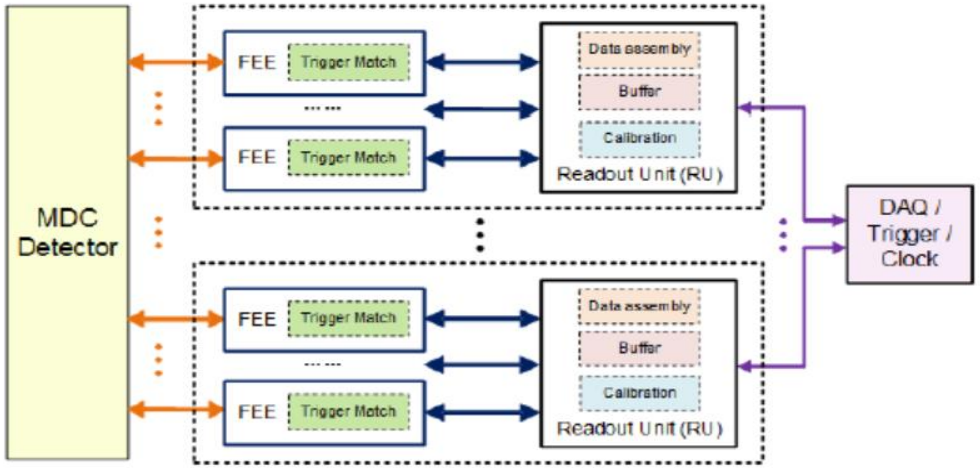
MDC expected performance





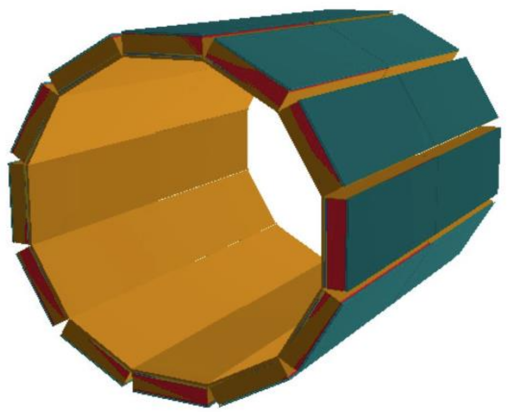
Readout Electronics

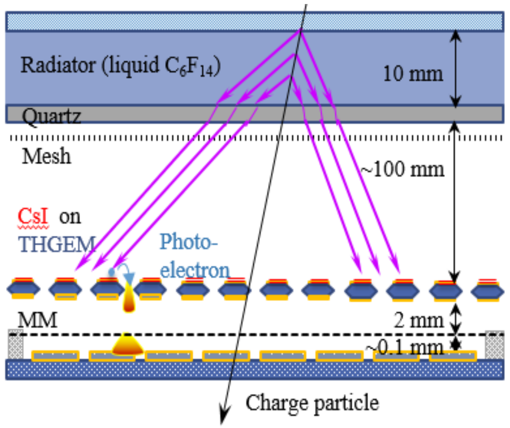
11520 readout electronic channels, compose of FEE modules and Readout Units



Particle Identification System - RICH

Micro-pattern gas detector (MPGD) based Ring Imaging Cherenkov detector (RICH)

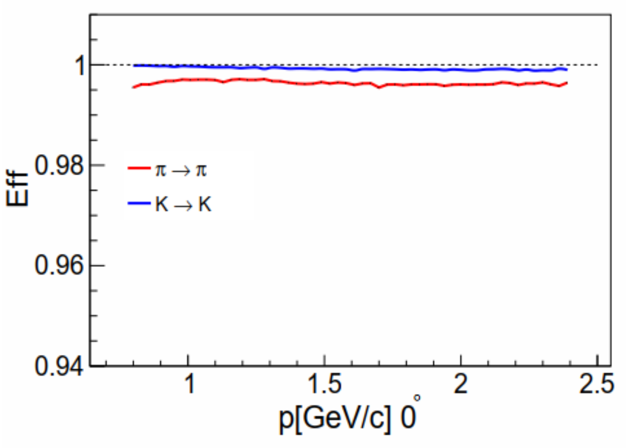


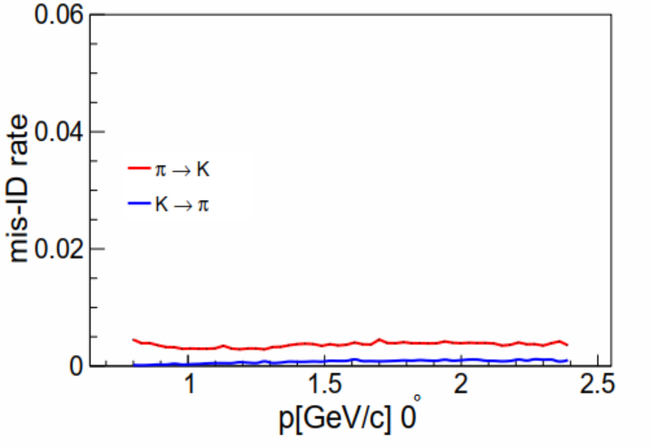


RICH optimization:

- Polar coverage: $|\cos\theta| < 0.83$
- Radial position: $0.85 < r < 1.05$ m
- Material budget $<0.3X_0$
- fast time response to cope high luminosity environment
- Radiator: C_6F_{14} in Quartz box / Quartz, n~1.3
- Np.e ~ 10
- Photoelectron drifted to the MM with a gain $>10^5$

RICH Expected Performance



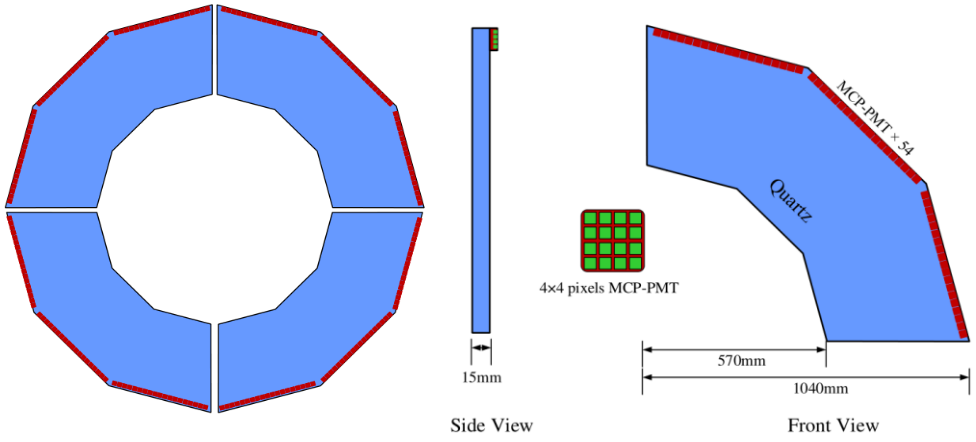


2019@DESY principle prototype beam test

- Quartz radiator+C_SI photocathode +MPGD photoelectric detector+AGET circuit

- Second round beam test to be carried out

Particle Identification System - DTOF



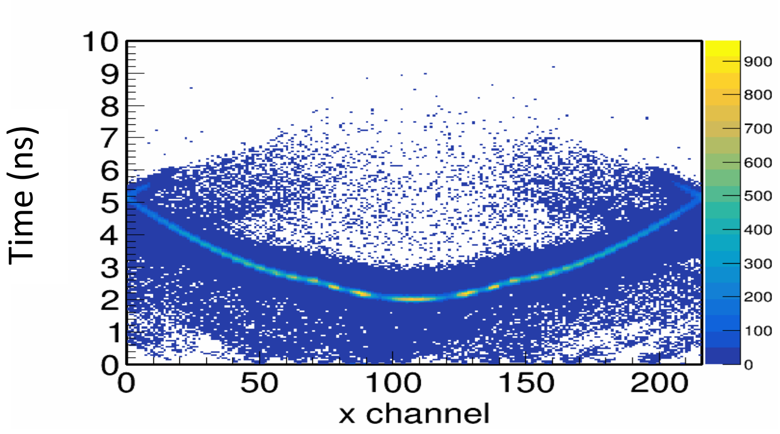
Detection of Internal total-Reflected Cherenkov light (DIRC)

DTOF optimization:

- Polar coverage: 0.81<|cosθ| < 0.93
- Fused silica radiator, fan shaped, 15mm thick
- Array of 3X(15-16) MCP-PMT directly coupled to radiator

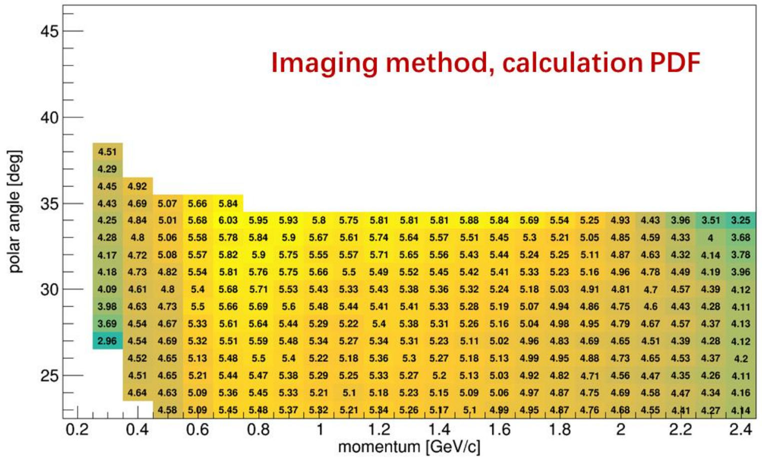
Time resolution: $\sigma_{tot}^2 \sim \sigma_{trk}^2 + \sigma_{T0}^2 + \sigma_{DT}^2$

- ✓ $\sigma_{trk} \sim 10ps$; $\sigma_{T0} \sim 40ps$
- ✓ $\sigma_{DT} = \frac{\sigma_{SPE} \oplus \sigma_{TOP}}{\sqrt{N}}$, $\sigma_{SPE} \sim 70ps$



Time image

Expected Performance of DTOF

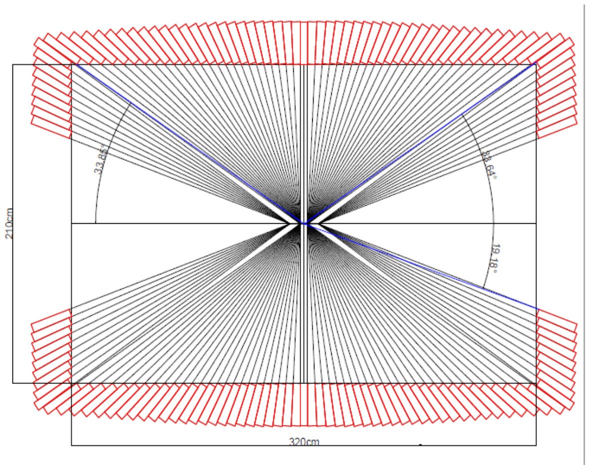


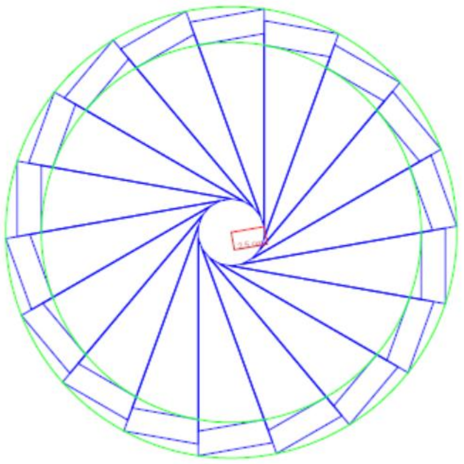
> 4σ π/K separation power with p<2.4GeV/c

Finished small-size prototype and cosmic-ray test

Large-size DTOF prototype will be assembled on Sep.2022.

Electromagnetic Calorimeter (EMC)



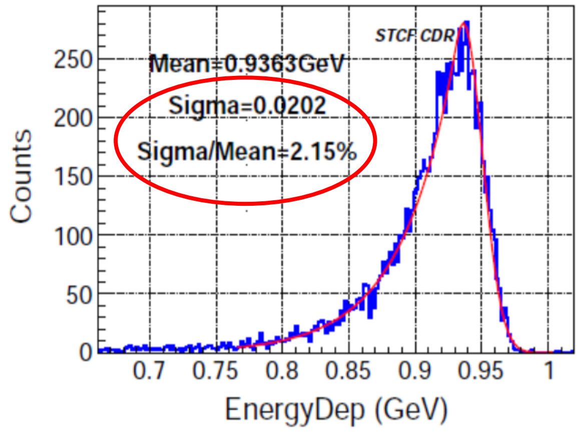


EMC optimization

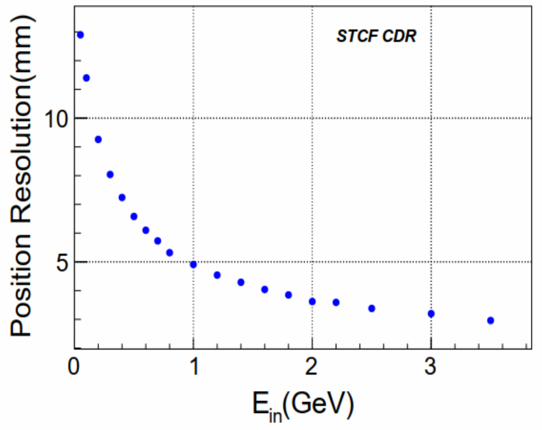
- Pure CsI crystal => short decay time & good radiation resistance
- Light collection： Avalanche Photodiode (APD), large gain
- Length： 28cm(15X_0), 5X5 cm^2
- Reflective Material: Teflon film
- 6732 crystals in barrel， 1938 at endcaps

Expected performance of EMC

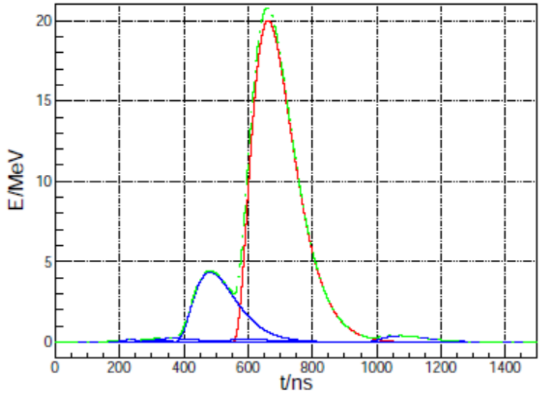
Ene. Res.



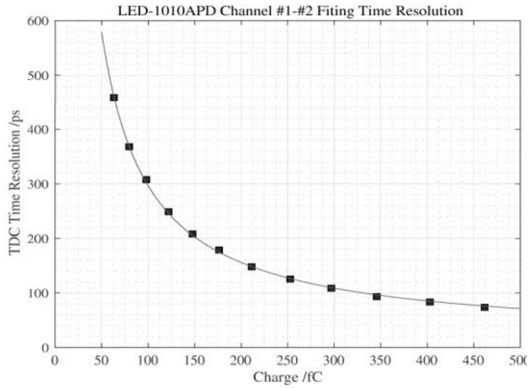
Pos. Res.



Pipeup mitigation:
multi-waveform fitting



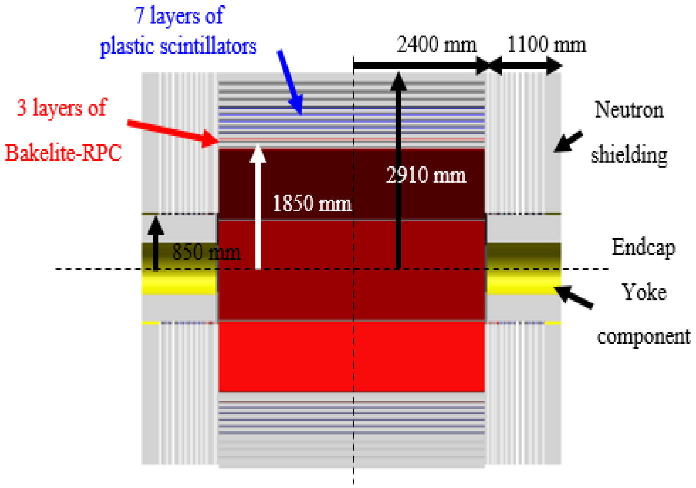
Electronics time res.
(including APD)



Muon Detector (MUD)

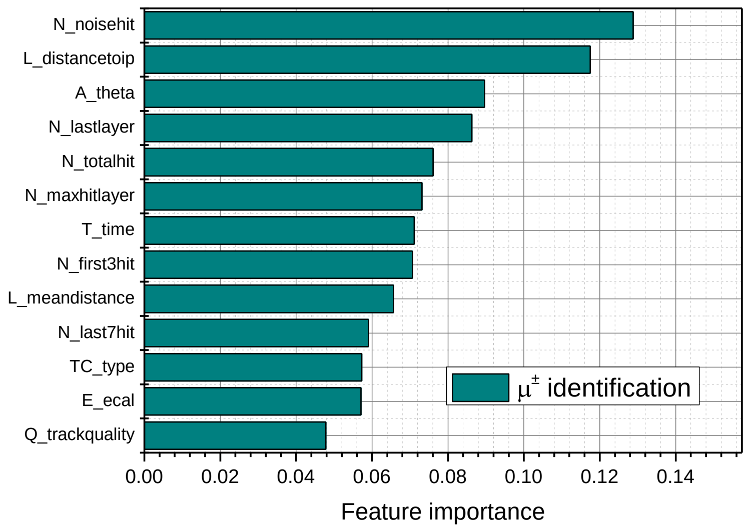
Optimization of MUD:

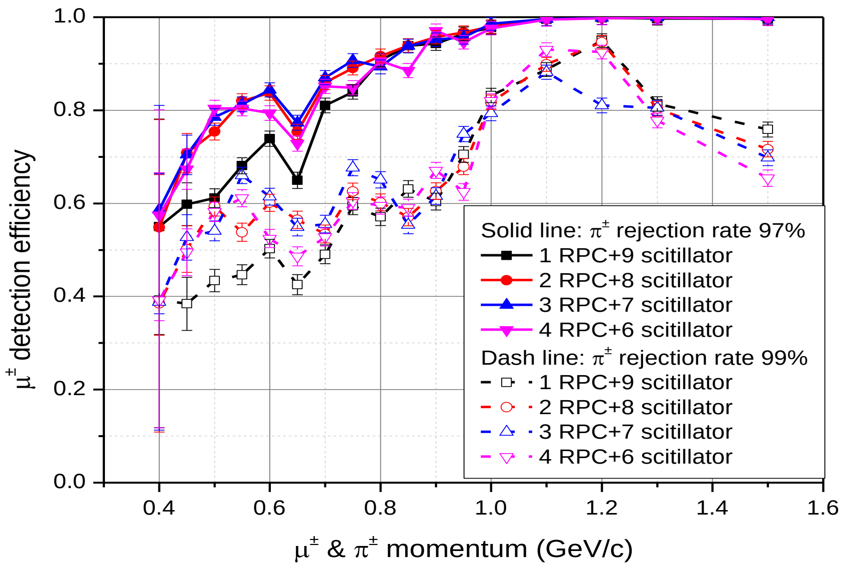
- Hybrid design of MUD: 3 layer Bakelite-RPC, 7 layers plastic scintillator
  - Resistive Plate Chamber: low bkg., high eff., robustness、low cost
  - Plastic scintillator： higher count rate, sensitive to neutral particles
- Thickness of iron yoke: 4, 4, 4.5, 4.5, 6, 6, 6, 8, 8 cm

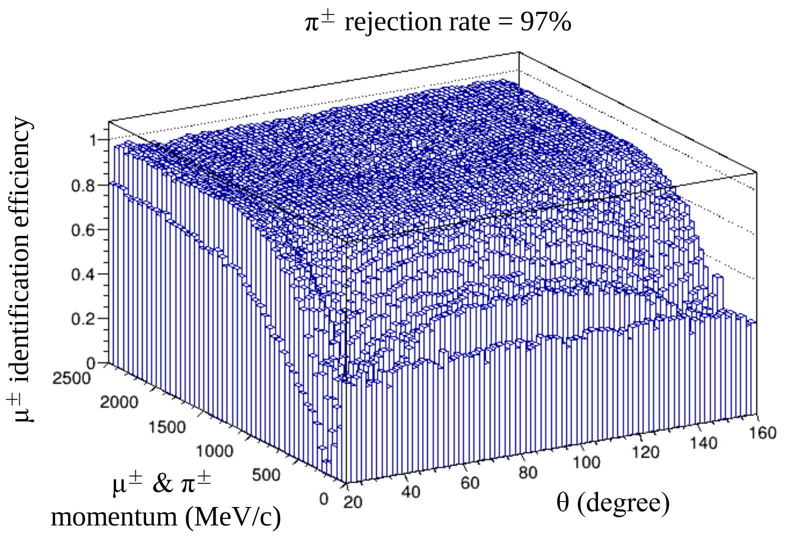


Performance of MUD

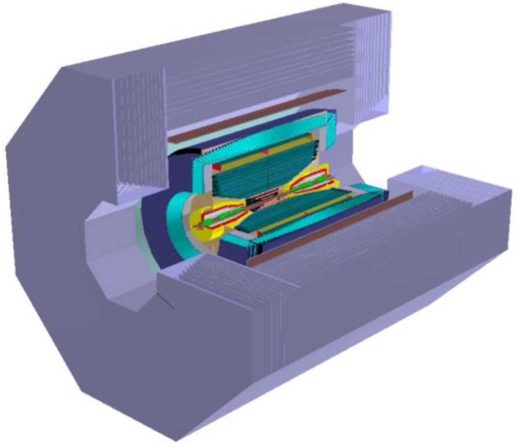
BDT performed to distinguish π/μ



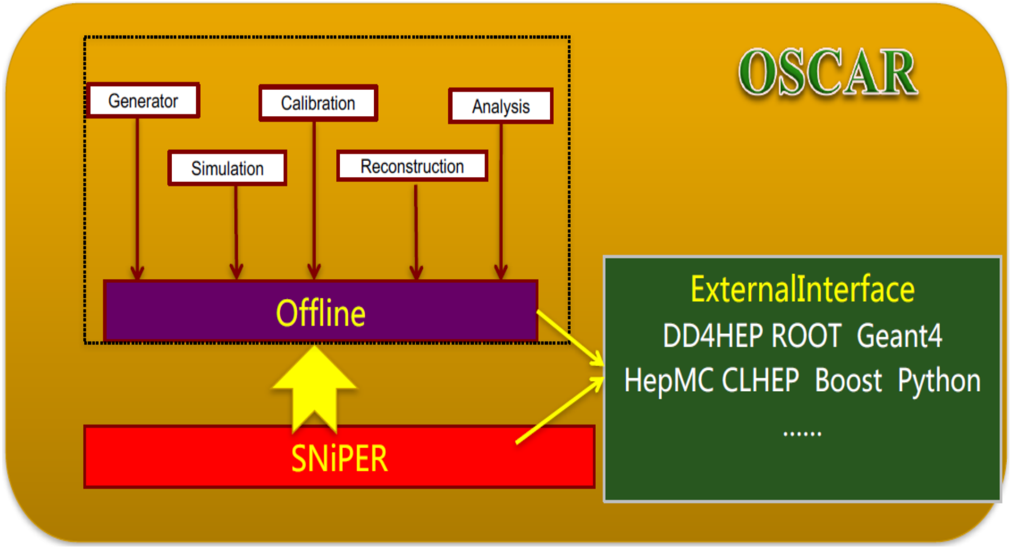


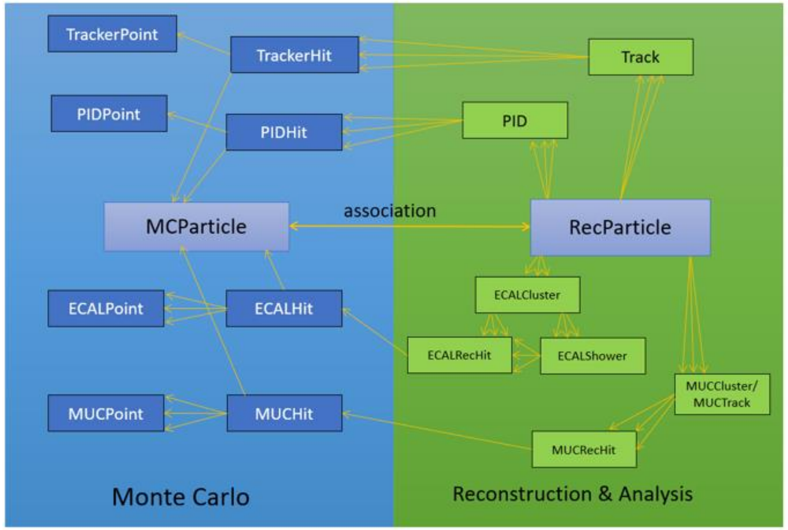


Offline Software



- 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



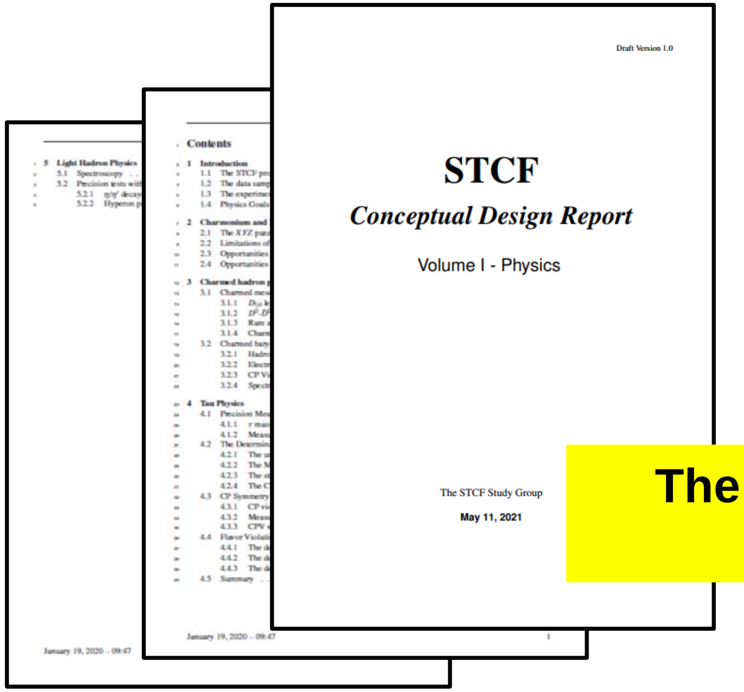


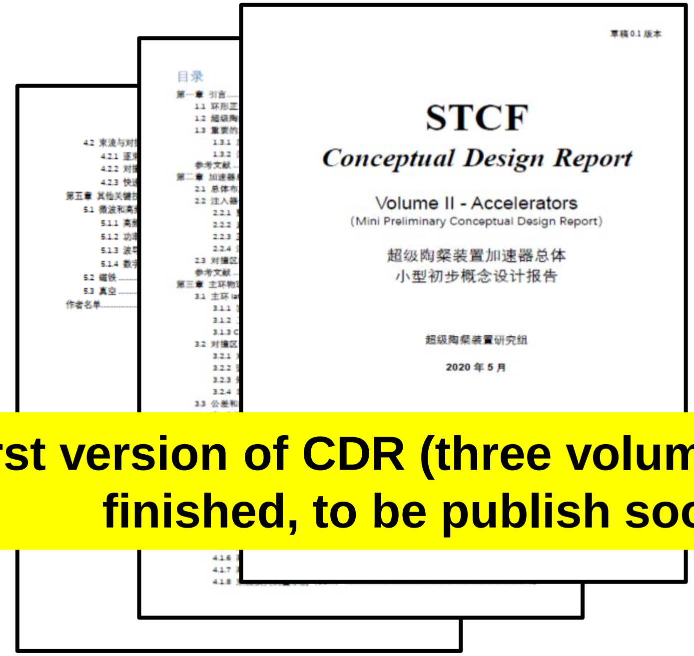
- Geometry management system, FullSim, FullRec, PodIO event data model are under developing
- Rec. Algorithm, calibration, analysis tool and performance test are under optimizations

Tentative Plan

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031-2040	2041-2042
Form Group															
CDR															
TDR															
Construction															
In operation															
Upgrade															

Activities: http://cicpi.ustc.edu.cn/indico/categoryDisplay.py?categId=2



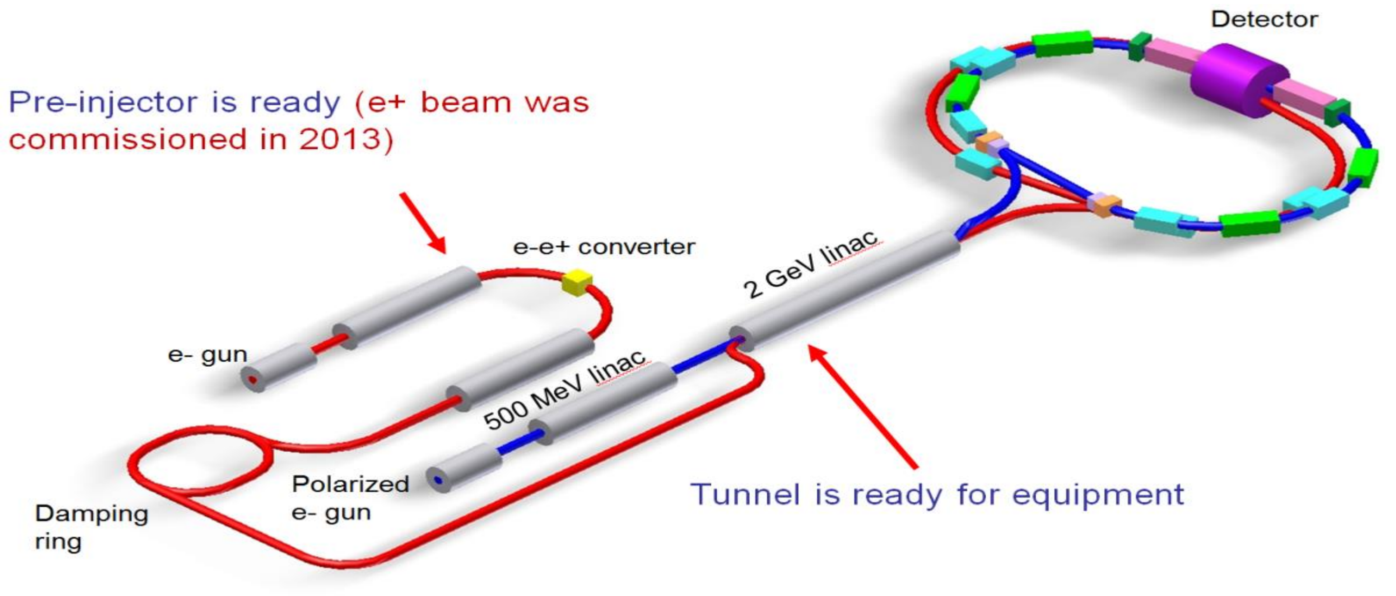


The first version of CDR (three volumes) has been finished, to be publish soon.

International Collaboration

Super Charm-Tau at Novosibirsk, RUSSIA,

Budker Institute of Nuclear Physics (BINP)



- Pre-Agreement of Joint effort on R&D, details are under negotiation
- Joint workshop between China, Russia, and Europe
  - 2018 UCAS (March), Novosibirsk (May), Orsay (December)
  - 2019 Moscow(September), 2020 Online (November), 2021 Online (Nov.)

Fund Support

- **Double First-Class university project foundation of USTC, 20 Million RMB (2018-2021)**
- **International partnership program of CAS, 3.5 million RMB (year 2021-2023)**
- **Three key NSFC projects for relevant technologies, and several general and youth programs …**
- **Now, Anhui Province, Hefei city and USTC have agree to jointly endorse the R&D project of STCF, and the process of support is under way.**

Summary

- **Super τ-c Facility (STCF): e^+e^- collision with E_{cm} = 2 – 7 GeV, L > 0.5 × 10^{35} $cm^{-2}s^{-1}$**
- **STCF is one of the crucial precision frontier aiming for understanding QCD, testing EW models and probing new physics**
- **Many activities on physics/detector/accelerator, three volumes CDR finished**
- **Key technology R&D project is being promoted**
- **An International collaboration is necessary to boost the construction of the project**

Thanks!