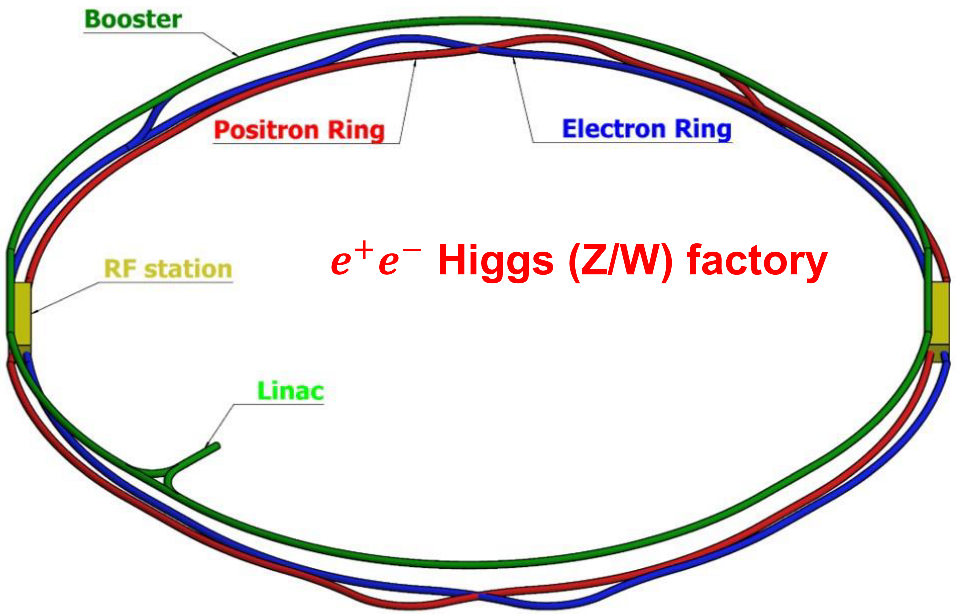
Progresses of future colliders

--- STCF & CEPC



Gang Li for the STCF and CEPC working groups

中国物理学会高能物理分会第十一届全国会员代表大会暨学术年会
2022.08.08-11, 大连

Many thanks to Haiping, Haijun , and other colleges

After the Higgs discovery in 2012, lots of achievements, still many fundamental questions remain unanswered

Higgs itself

Dark matter

Matter - anti-matter asymmetry

Mass hierarchy

Neutrinos

QCD confinement and exotic particles

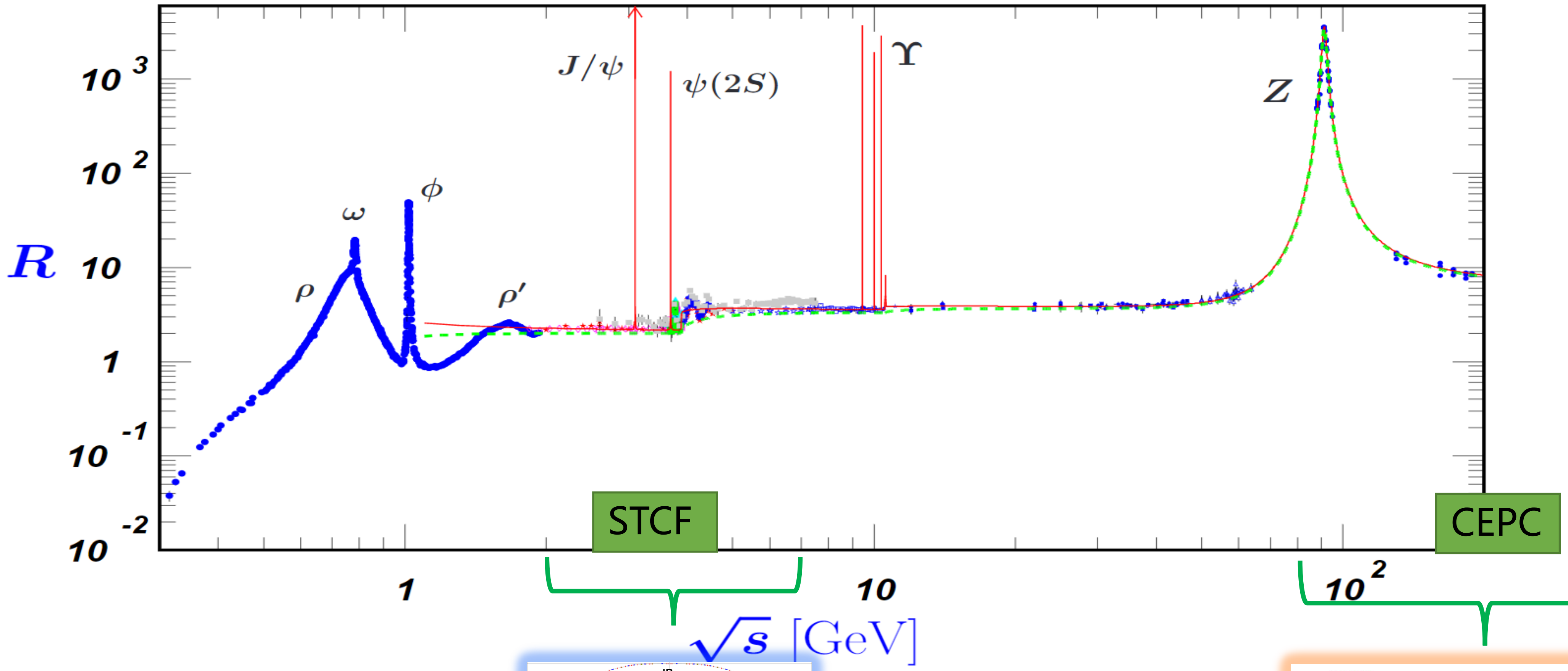
Dark energy

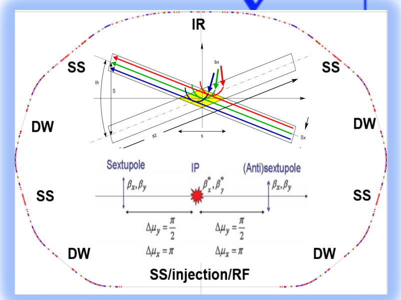
Gravity

… …

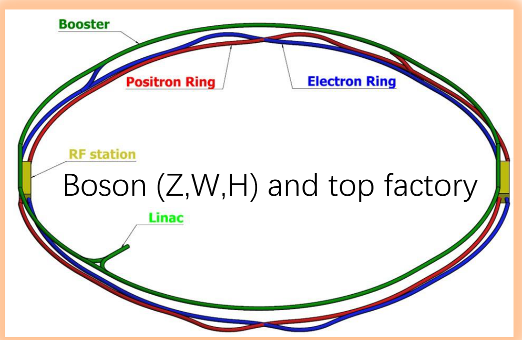
New data is much more important than ever !

Two circular e⁺e⁻ colliders proposed by Chinese scientists



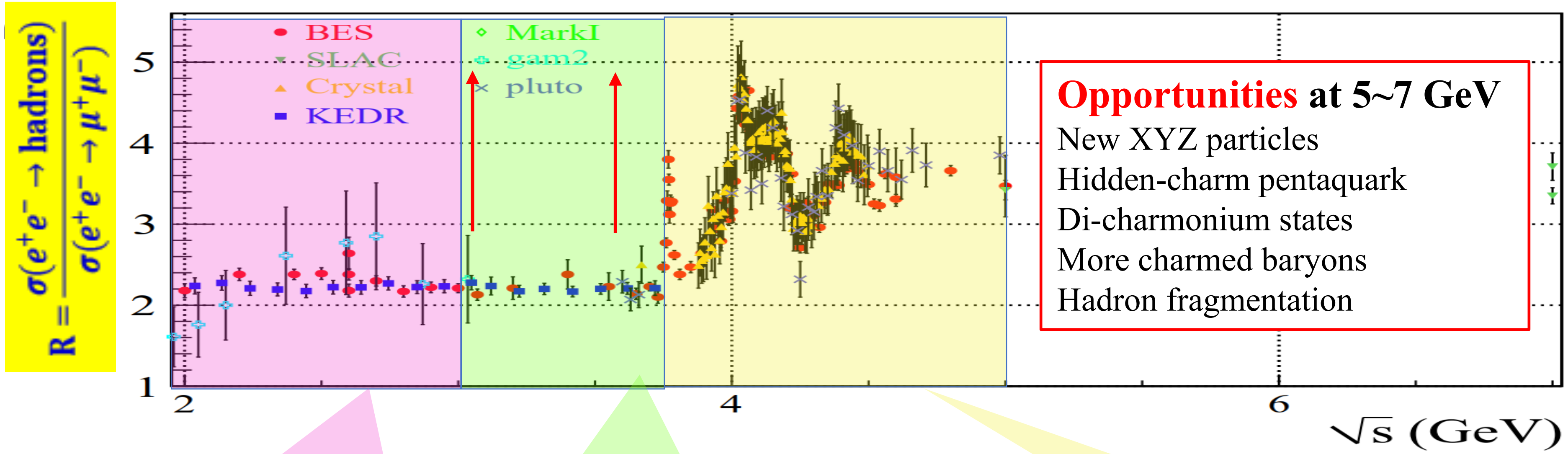


τ – charm factory



Super Tau-Charm

Physics at τ-Charm Region



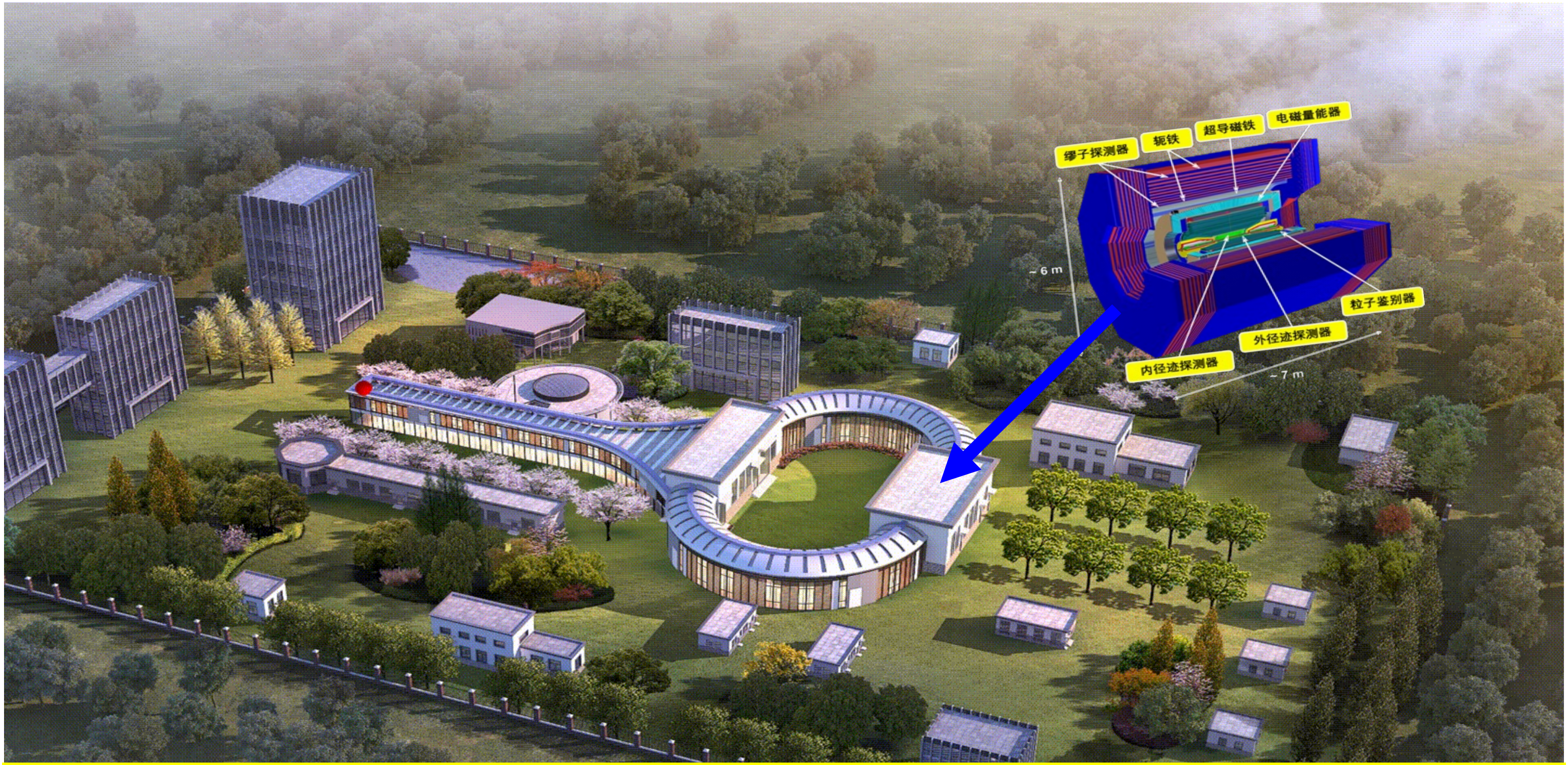
- Hadron form factors
- Y(2175)
- Mutltiquark states with *s* quark
- … …

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

- XYZ particles
- Physics with D mesons
- fD and fDs
- D0-D0 mixing
- Charm baryons

- **Rich of physics, unique for physics with *c* quark and τ lepton**
- **important playground for study of nature of non-pQCD, exotics, flavor physics, and search for new physics.**

STCF in China



- **CME :** **2-7** **GeV**
- **Peaking** $\mathcal{L}$ **:** **$>5\times10^{34}$** **$cm^{-2}\ s^{-1}$**
- **Potential** **to further improve the lumi and realize polarized beam**
- **Double storage ring** **: ~800 m ,** **injection** **: ~ 300m**
- **BESIII-Like** **detector**
- **Cost** **4.5B RMB**

Project progress and plan

Workshop for acc. based high energy physics development strategy

Super Charm-tau Factory

Zhengguo Zhao

On behalf of ???

2011/12 Sanya

2011

First proposed

2015

Xiangshan Science Conference

2018

USTC double first-class key projects

Several domestic and international workshop

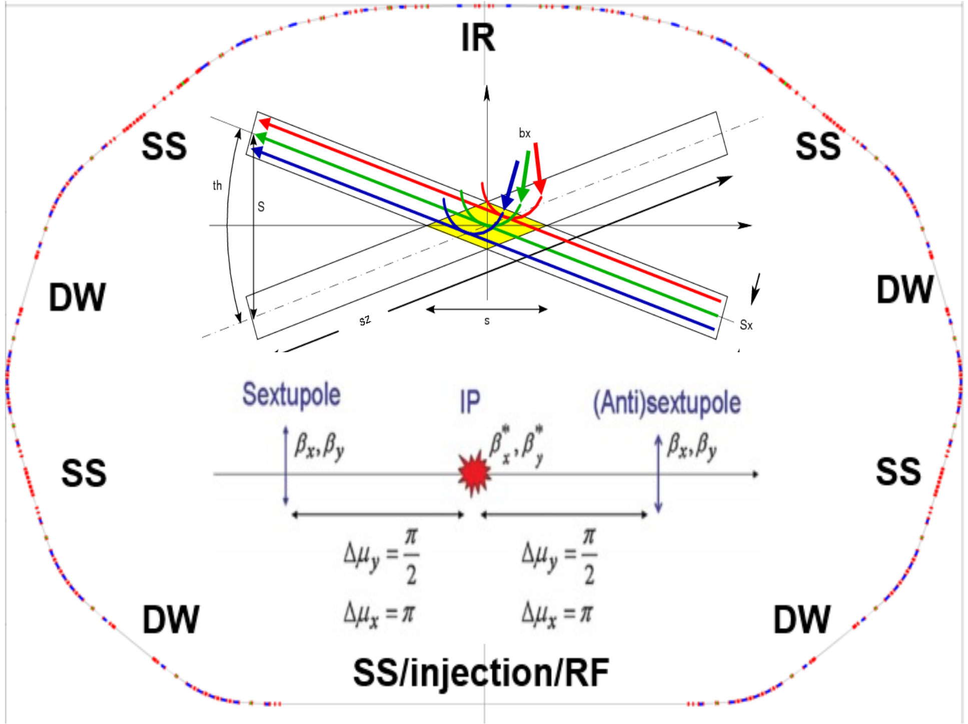
2021

Conceptual design report

Key technology R&D

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031-40	2041-43
CDR	■	■	■	■											
TDR	■	■	■	■	■	■	■	■							
Construction									■	■	■	■	■		
Commission														■	
Upgrade															■

Accelerator Conceptual Design



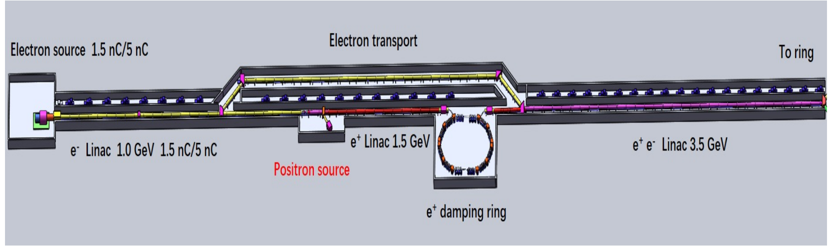
Parameters	Unit	Value
Circumference	m	574.78
Distance from final defocusing quadrupole to IP	m	0.9
Optimized energy	GeV	2.0
Total beam current	A	2
Horizontal/Vertical beta @ IP	m	0.09/0.0006
Total crossing angle (2θ)	mrad	60
Piwinski angle (ϕ)	rad	18.9
Beam-beam tune shift (ξ_x/ξ_y)	—	0.0038/0.0835
Coupling 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	MV	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	s	35

Interaction region :

- Large Piwinski-Angle Collision + Crabbed Waist

Linac Injector:

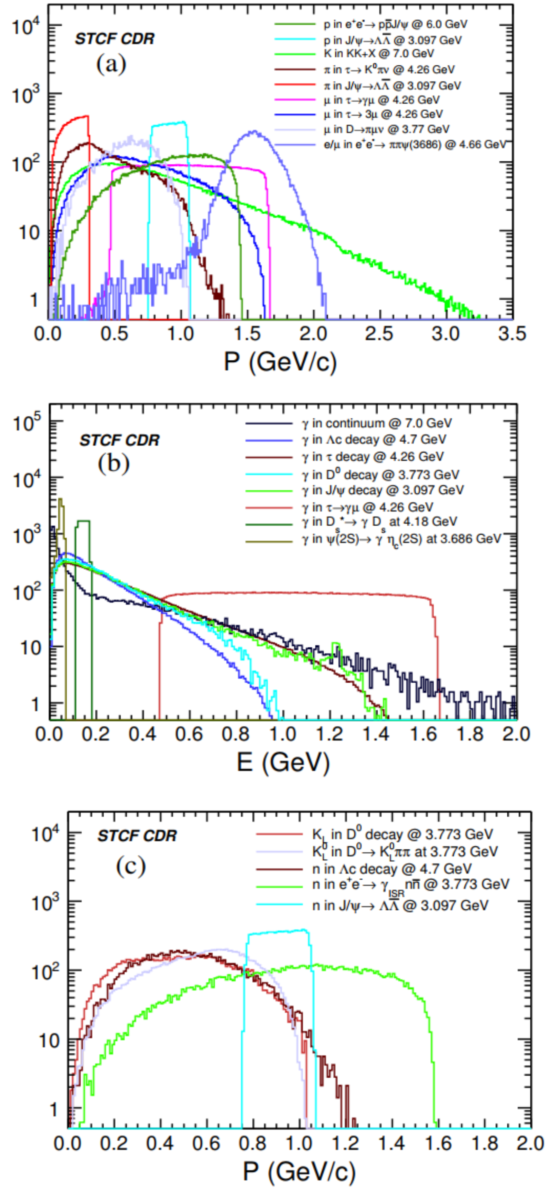
- No booster, full energy injection (1-3.5 GeV)
- Possible polarized e^- beam



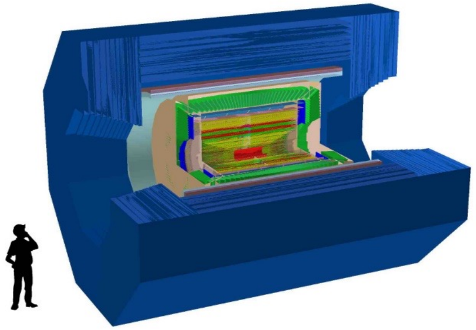
STCF Detector

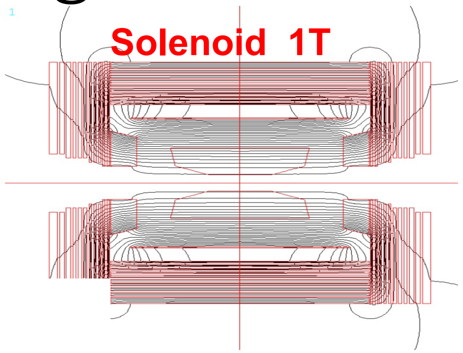
A BESIII-like detector but better than BESIII

- **Inner Tracker**
  - ~0.15% X_0 / layer
  - σ_{xy} ~ 50 μm
- **Out Tracker**
  - σ_{xy}~130 μm, σ_p/p~0.5%@1 GeV/c
  - dE/dx ~ 6%
- **PID system**
  - π/K (K/p) 3-4σ separation up to 2 GeV/c
- **Electromagnetic Calorimeter**
  - Range: 0.02 – 3 GeV
  - Resolution (1 GeV): 2.5% (barrel) and 4% (endcap)
- **Muon system**
  - π suppression power: >10 and lower to 0.4 GeV/c

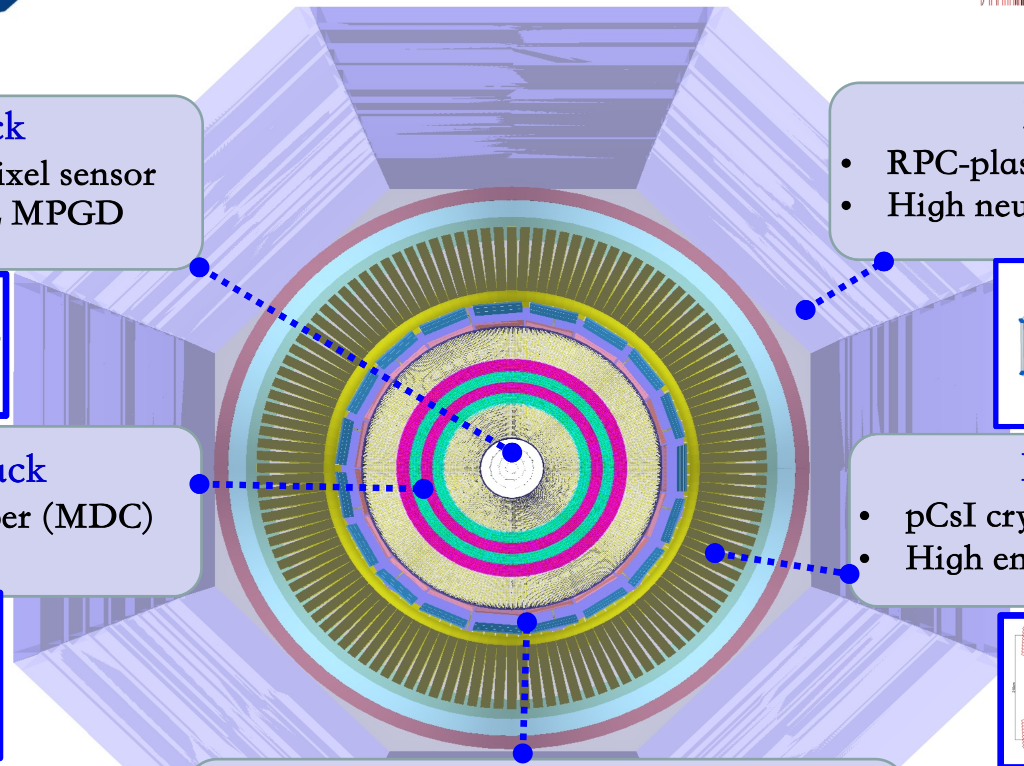


Detector Conceptual Design

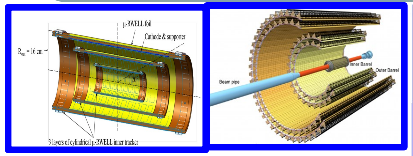




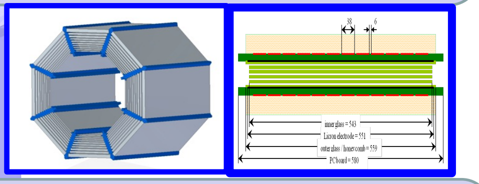
Micro/Fast Readout Electronics
High capability of Trigger, DAQ, Storage



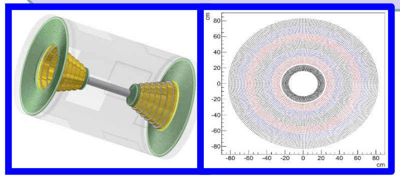
Inner Track
- Monolithic active Pixel sensor
- Low mass μRWELL MPGD



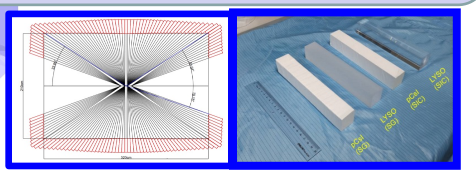
Muon detector
- RPC-plastic scintillator mixture
- High neutral hadron ID efficiency



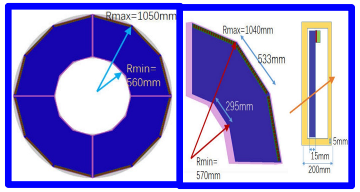
Outer Track
- Main Drift Chamber (MDC)
- Ultra-low mass

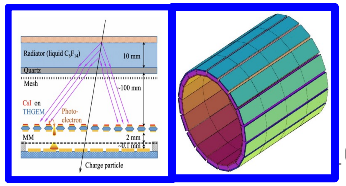


EM Calorimeter
- pCsI crystal based : fast
- High energy and timing resolution



Particle Identification
- MPGD-based RICH (barrel)
- High-precision timing DIRC (Endcap)





Data Samples

1 ab^{-1} data expected 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			

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

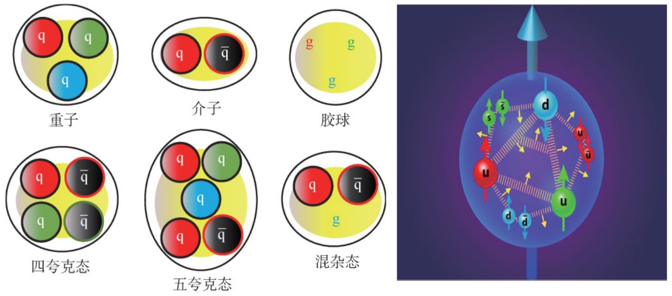
XYZ	$Y(4260)$	$Z_c(3900)$	$Z_c(4020)$	$X(3872)$
No. of events	10^{10}	10^9	10^9	5×10^6

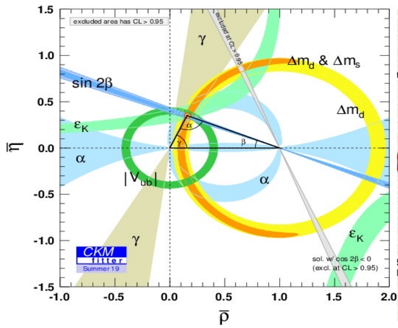
- **Belle-II : more statistics (50/ab)**
- **LHCb: much more statistics, huge bkg**

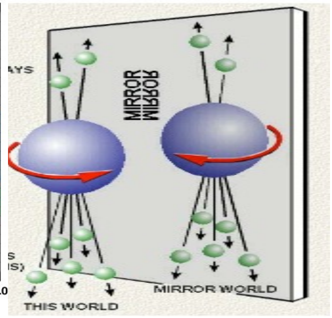
- **STCF : high detection efficiency, excellent resolution, kinematic constraining, low background, threshold production**

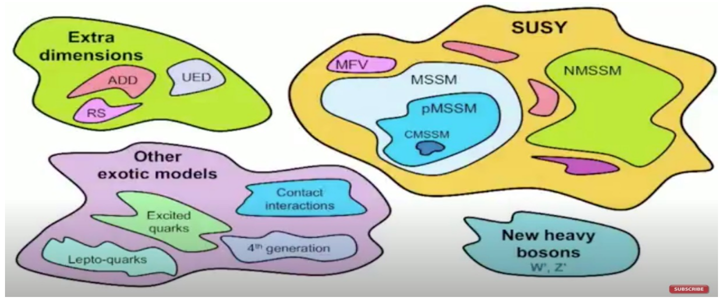
Highlighted physics

- **QCD and Hadronic Physics**
  - Exotic states and hadron spectroscopy
  - Hadron structures
  - Precision test of SM parameters
- **Flavor Physics and CP violation**
  - CKM matrix, $D^0 - \overline{D}^0$ mixing
  - CP violation in lepton, hyperon, charm
- **New Physics Search**
  - Rare/Forbidden
  - Universality test
  - Dark particle search







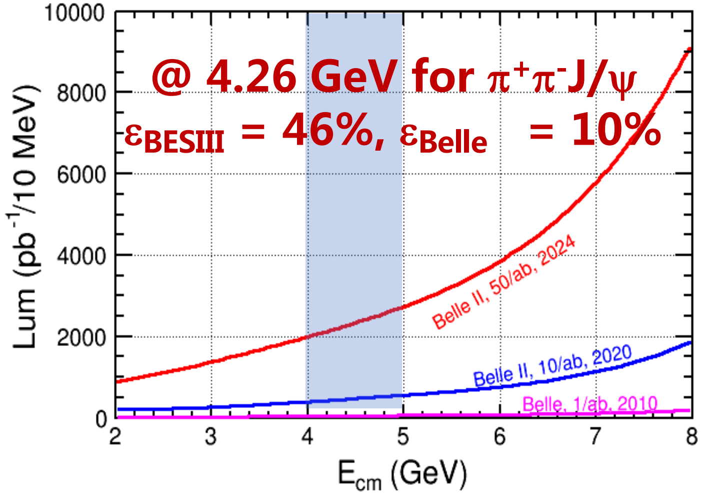


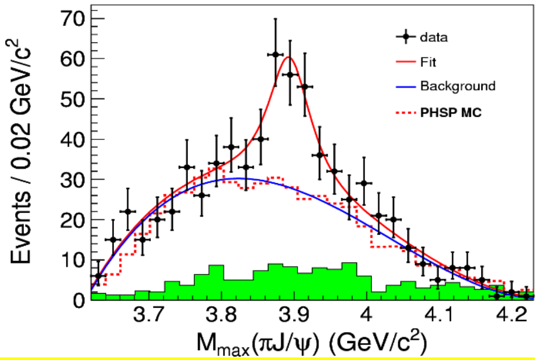
Several benchmark processes analyses performed to

optimize the detector design, and the physics potential

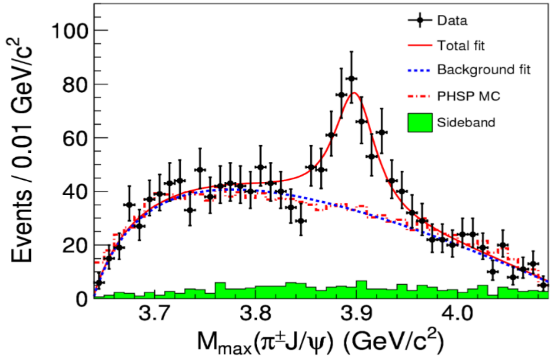
Charmonium(Like) Spectroscopy

platform to explore non-pQCD, Fruitful results in past decade,
a new territory to study exotic hadrons, but controversy





Belle with ISR: PRL110, 252002
967/fb in 10 years running



BESIII at 4.260 GeV: PRL110, 252001
0.525/fb in three month running

- **Belle-II : integrate eff. Lumi. between 4-5 GeV is 0.23 ab^{-1} for 50 ab^{-1} data**
- **STCF : scan in 4-5 GeV, 10 MeV/step, 10 fb^{-1}/point/year, 5 × Belle-II (50 ab^{-1})**
- **STCF : much higher efficiency and low background than Belle-II**

STCF : 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

Large statistics and much wider CME data provide opportunity to perform precise study and to pin down the nature of Charmomium-like states

See Fengkun Guo’ s Snowmass talk

QCD and Hadronic Physics

Physics at STCF	Benchmark Processes	Key Parameters*
XYZ properties	$e^+e^- \to Y \to \gamma X, \eta X, \phi X$ $e^+e^- \to Y \to \pi Z_c, KZ_{cs}$	$N_{Y(4260)/Z_c/X(3872)} \sim$ $10^{10}\ /10^9/10^6$
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)
Hadron Spectroscopy	Excited $c\bar{c}$ and their transition, Charmed hadron spectroscopy, Light hadron spectroscopy	$N_{J/\psi/\psi(3686)/\Lambda_c} \sim$ $10^{12}\ /10^{11}/10^8$
Muon g-2	$e^+e^- \to \pi^+\pi^-, \pi^+\pi^-\pi^0, K^+K^-$ $\gamma\gamma \to \pi^0, \eta^{(\prime)}, \pi^+\pi^-$	$\Delta a_\mu^{HVP} \ll 40\times10^{-11}$
R value, $\boldsymbol{\tau}$ mass	$e^+e^- \to inclusive$ $e^+e^- \to \tau^+\tau^-$	$\Delta m_\tau \sim 0.012\ \mathrm{MeV}$ (with 1 month scan)
Fragmentation functions	$e^+e^- \to (\pi, K, p, \Lambda, D) + X$ $e^+e^- \to (\pi\pi, KK, \pi K) + X$	$\Delta \mathrm{A}^{\mathrm{Collins}} < 0.002$
Nucleon Form Factors	$e^+e^- \to B\bar{B}$ from threshold	$\delta R_{EM} \sim 1\%$

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

A unique Charm factory

Low backgrounds and high efficiency; missing technique and absolute measurement; Quantum correlations and CP-tagging

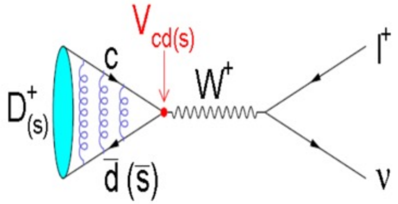
STCF data/year : 4×10^{9} pairs of $D^{\pm,0}$, 10^{8} D_s and Λ_c pairs

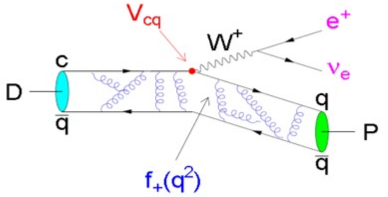
Highlighted Physics programs

- **Precise measurement of (semi-)leptonic decay (f_D, f_{Ds}, CKM)**
- **$D^0-\bar{D}^0$ mixing, CPV**
- **Strong phase, decay parameters…**
- **Rear 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**

See Xiaorui`s Snowmass talk

Charm meson leptonic Decays





Excellent platform for CKM elements and decay constants and universality test

	BESIII	STCF	Belle II
Luminosity	2.93 fb^{-1} at 3.773 GeV	1 ab^{-1} at 3.773 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D^+ \to \mu^+\nu_\mu)$	$5.1\%_{\text{stat}}\ 1.6\%_{\text{syst}}$ [6]	$0.28\%_{\text{stat}}$	–
f_{D^+} (MeV)	$2.6\%_{\text{stat}}\ 0.9\%_{\text{syst}}$ [6]	$0.15\%_{\text{stat}}$	–
$\lvert V_{cd}\rvert$	$2.6\%_{\text{stat}}\ 1.0\%^{*}_{\text{syst}}$ [6]	$0.15\%_{\text{stat}}$	–
$\mathcal{B}(D^+ \to \tau^+\nu_\tau)$	$20\%_{\text{stat}}\ 10\%_{\text{syst}}$ [7]	$0.41\%_{\text{stat}}$	–
$\frac{\mathcal{B}(D^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D^+ \to \mu^+\nu_\mu)}$	$21\%_{\text{stat}}\ 13\%_{\text{syst}}$ [7]	$0.50\%_{\text{stat}}$	–
Luminosity	3.2 fb^{-1} at 4.178 GeV	1 ab^{-1} at 4.009 GeV	50 ab^{-1} at $\Upsilon(nS)$
$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$	$2.8\%_{\text{stat}}\ 2.7\%_{\text{syst}}$ [8]	$0.30\%_{\text{stat}}$	$0.8\%_{\text{stat}}\ 1.8\%_{\text{syst}}$
$f_{D_s^+}$ (MeV)	$1.5\%_{\text{stat}}\ 1.6\%_{\text{syst}}$ [8]	$0.15\%_{\text{stat}}$	–
$\lvert V_{cs}\rvert$	$1.5\%_{\text{stat}}\ 1.6\%_{\text{syst}}$ [8]	$0.15\%_{\text{stat}}$	–
$f_{D_s^+}/f_{D^+}$	$3.0\%_{\text{stat}}\ 1.5\%_{\text{syst}}$ [8]	$0.21\%_{\text{stat}}$	–
$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	$2.2\%_{\text{stat}}\ 2.6\%^{\dagger}_{\text{syst}}$	$0.24\%_{\text{stat}}$	$0.6\%_{\text{stat}}\ 2.7\%_{\text{syst}}$
$f_{D_s^+}$ (MeV)	$1.1\%_{\text{stat}}\ 1.5\%^{\dagger}_{\text{syst}}$	$0.11\%_{\text{stat}}$	–
$\lvert V_{cs}\rvert$	$1.1\%_{\text{stat}}\ 1.5\%^{\dagger}_{\text{syst}}$	$0.11\%_{\text{stat}}$	–
$\bar{f}^{\mu\&\tau}_{D_s^+}$ (MeV)	$0.9\%_{\text{stat}}\ 1.0\%^{\dagger}_{\text{syst}}$	$0.09\%_{\text{stat}}$	$0.3\%_{\text{stat}}\ 1.0\%_{\text{syst}}$
$\lvert \bar{V}^{\mu\&\tau}_{cs}\rvert$	$0.9\%_{\text{stat}}\ 1.0\%_{\text{syst}}{}^{\dagger}$	$0.09\%_{\text{stat}}$	–
$\frac{\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)}{\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)}$	$3.6\%_{\text{stat}}\ 3.0\%^{\dagger}_{\text{syst}}$	$0.38\%_{\text{stat}}$	$0.9\%_{\text{stat}}\ 3.2\%_{\text{syst}}$

LQCD : 0.2%
(0.1% expected)

LQCD : 0.2%
(0.1% expected)

LQCD : 0.2%
(0.1% expected)

* assuming Belle II improved systematics by a factor 2

Statistical uncertainties comparable with theory precision
Systematic uncertainties are challenging

D^0-$\bar{D}^0$ mixing and CPV

STCF provide an unique place for the study of D^0-$\bar{D}^0$ mixing and CPV by means of quantum coherence of D^0 and $\bar{D}^0$ produced through

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

as well as incoherent flavor specific D^0 samples: $D^{*+} \to D^0\pi^+$

- **Mixing rate $R_M = \frac{x^2+y^2}{2} \sim 10^{-5}$ with 1 ab⁻¹ data at 3.773 GeV via same charged final states $(K^\pm\pi^\mp)(K^\pm\pi^\mp)$ or $(K^\pm l^\mp v)(K^\pm l^\mp v)$**
- **$\Delta A_{CP} \sim 10^{-3}$ for KK and ππ channels**

	1/ab @4009 MeV (only QC | QC+incoherent) (very preliminary estimation)		BELLEII(50/ab) [PTEP2019,123C01]	LHCb(50/fb) (SL | Prompt) [arXiv:1808.08865]	
$x(\%)$	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

- The only QC results: contains $D^0 \to K_S\pi\pi, D^0 \to K^-\pi^+\pi^0$ and general CP tag decay channels; needs to be tuned
- The QC+incoherent results: combines coherent and incoherent D^0 meson samples
- The BELLE II and LHCb results only contain incoherent $D^0 \to K_S\pi\pi$ channel

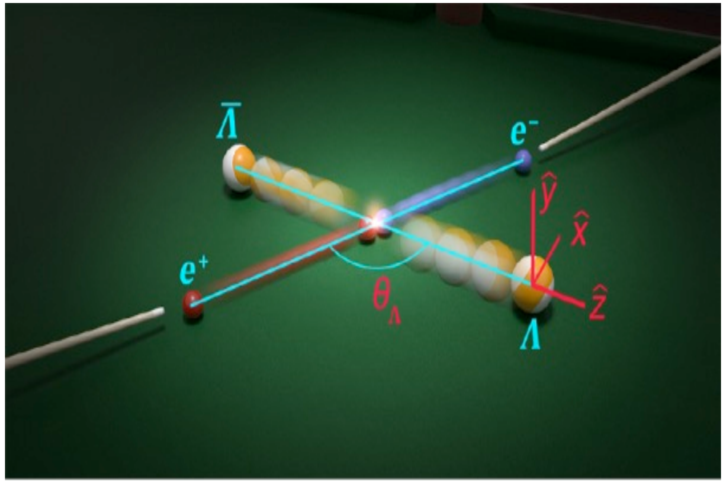
Precision Study of Charm Baryon

Era of precision study of the charmed baryon (Λ_c, Ξ_c and Ω_c) decays
to help developing more reliable QCD-derived models in charm sector

- **Hadronic decays:**
  to explore as-yet-unmeasured channels and understand full picture of intermediate structures in B_c decays, esp., those with neutron/Σ/Ξ
- **Semi-leptonic decays:**
  to test LQCD calculations and LFU
- **CPV in charmed baryon:**
  BP and BV two-body decay asymmetry, charge-dependent rate of SCS
- **Charm-flavor-conserving nonleptonic decays:** $\Xi_c \to \Lambda_c^+\pi$, $\Omega_c^0 \to \Xi_c\ \pi$
- **Electro-weak radiative decays :** $\Sigma_c^+ \to \Lambda_c^+\gamma$, $\Lambda_c^+ \to \Sigma\gamma, p\gamma$, $\Xi_c^{+/0} \to \Sigma^{+/0}\gamma$
- **Rare decays:** LFV, BNV, FCNC

STCF will provide very precise measurements of their overall decays, up to the unprecedented level of $10^{-6} \sim 10^{-7}$

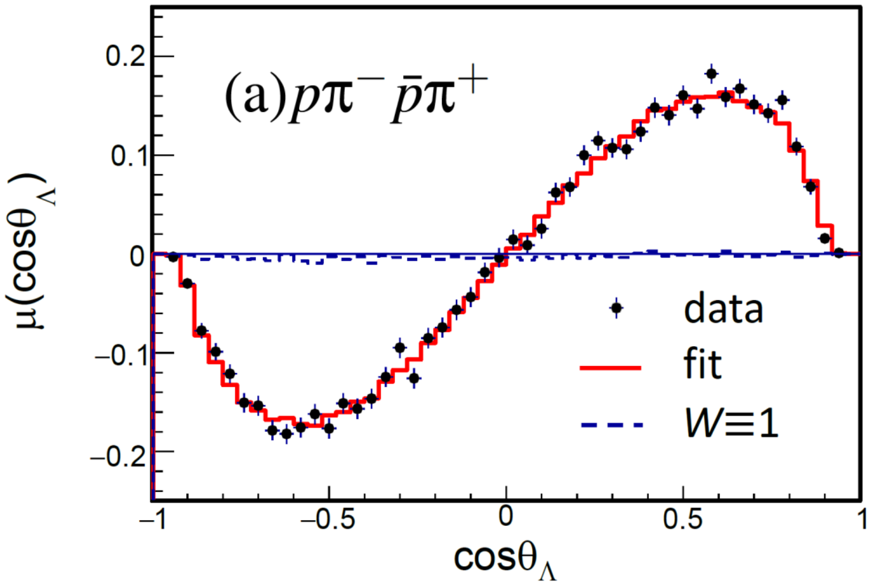
Polarization of hyperons and CPV



Nature Phys. 15, 631–634 (2019) BESIII

1.31 B J/ψ events
Quantum correlation in Λ pair

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [14]
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)^\circ$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [16]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [16]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [16]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–



2% level sensitivity for CPV test
SM prediction: 10^{-4}~10^{-5}

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

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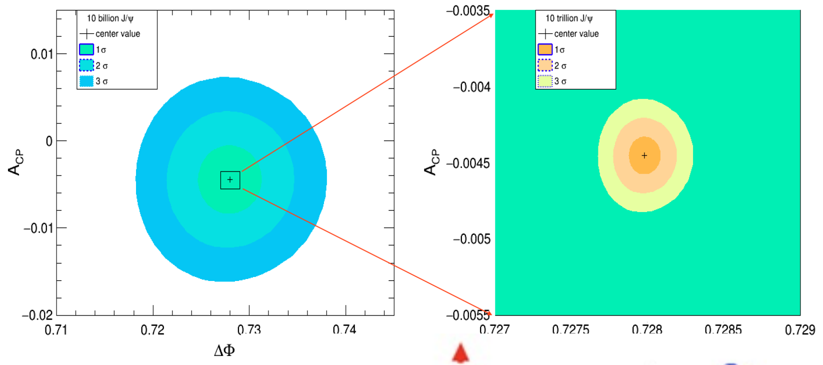
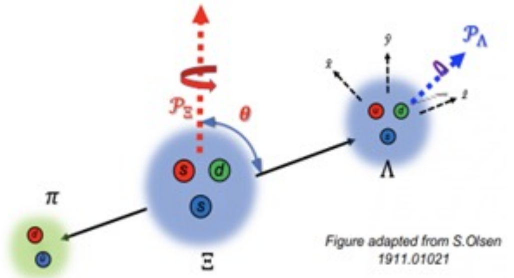
Polarization of hyperons and CPV

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

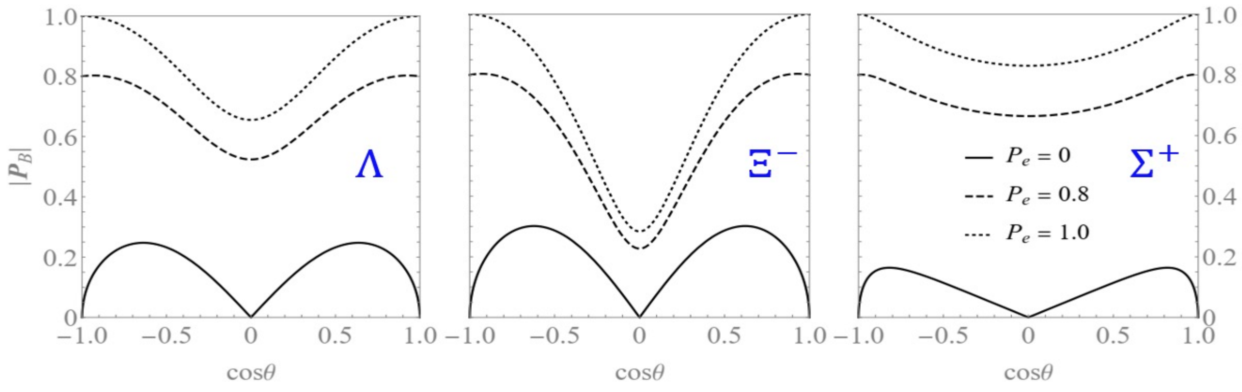
- Luminosity of STCF: × 100
- No polarized beams needed
- Systematic is challenging



	$\sigma(A_{CP}^{[\Lambda p]})$	$\sigma(A_{CP}^{[\Xi^-]})$	$\sigma(B_{CP}^{[\Xi^-]})$	Comment
BESIII	1.0×10^{-2} [a]	1.3×10^{-2}	3.5×10^{-2}	1.3×10^{9} J/ψ [28, 29]
BESIII	3.6×10^{-3}	4.8×10^{-3}	1.3×10^{-2}	1.0×10^{10} J/ψ (projection)
SCTF	2.0×10^{-4}	2.6×10^{-4}	6.8×10^{-4}	3.4×10^{12} J/ψ (projection)



$$A_{CP}^{D} := \frac{\alpha_D + \overline{\alpha}_D}{\alpha_D - \overline{\alpha}_D} \quad \text{and} \quad B_{CP}^{D} := \frac{\beta_D + \overline{\beta}_D}{\alpha_D - \overline{\alpha}_D},$$



- Magnitudes of the hyperon polarization versus e^- polarization

Flavor Physics and CPV

Physics at STCF	Benchmark Processes	Key Parameters*
CKM matrix	$D_{(s)}^{+} \to l^{+}\nu_{l}, D \to Pl^{+}\nu_{l}$	$\delta V_{cd/cs}$~0.15%; $\delta f_{D/D_s}$~0.15%
γ/ϕ_3 measurement	$D^0 \to K_s\pi^+\pi^-, K_sK^+K^-$ ...	$\Delta(\cos\delta_{K\pi})$ ~0.007; $\Delta(\delta_{K\pi})$ ~2^{o}
$D^0-\bar{D}^0$ mixing	$\psi(3770) \to (D^0\bar{D}^0)_{CP=-}$, $\psi(4140) \to \gamma(D^0\bar{D}^0)_{CP=+}$	Δx~0.035%; Δy~0.023%
Charm hadron decay	$D_{(s)}, \Lambda_c^+, \Sigma_c, \Xi_c, \Omega_c$ decay	$N_{D/D_s/\Lambda_c}$~$10^9/10^8/10^8$
γ polarization	$D^0 \to K_1 e^+\nu_e$	$\Delta A'_{UD}$~0.015
CPV in Hyperons	$J/\psi \to \Lambda\bar{\Lambda}$, $\Sigma\bar{\Sigma}$, $\Xi^-\bar{\Xi}^-$, $\Xi^0\bar{\Xi}^0$	ΔA_{Λ}~10^{-4}
CPV in τ	$\tau \to K_s\pi\nu$, EDM of τ, $\tau \to \pi/K\pi^0\nu$ for polarized e^-	$\Delta A_{\tau\to K_s\pi\nu}$~$10^{-3}$; Δd_τ~5×10^{-19} (e cm)
CPV in Charm	$D^0 \to K^+K^-/\pi^+\pi^-$, $\Lambda_c \to pK^-\pi^+\pi^0$ ...	ΔA_D~10^{-3}; ΔA_{Λ_c}~10^{-3}

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

Forbidden/Rare decay and NP

Physics at STCF	Benchmark Processes	Key Parameters* (U.L. at 90% C.L.)
LFV decays	$\tau \to \gamma l, lll, lP_1P_2$ $J/\psi \to ll', D^0 \to ll'(l' \neq l)\ldots$	$\mathcal{B}(\tau \to \gamma\mu/\mu\mu\mu)$<$12/1.5\times10^{-9}$; $\mathcal{B}(J/\psi \to e\tau)$<$0.71\times10^{-9}$
LNV, BNV	$D^+_{(s)} \to l^+l^+X^-, J/\psi \to \Lambda_c e^-$, $B \to \bar{B}\ldots$	$\mathcal{B}(J/\psi \to \Lambda_c e^-)< 10^{-11}$
Symmetry violation	$\eta^{(\prime)} \to ll\pi^0, \eta' \to \eta ll\ldots$	$\mathcal{B}(\eta' \to ll/\pi^0 ll)< 1.5/2.4\times 10^{-10}$
FCNC	$D \to \gamma V, D^0 \to l^+l^-, e^+e^- \to D^*, \Sigma^+ \to pl^+l^-\ldots$	$\mathcal{B}(D^0 \to e^+e^-X)< 10^{-8}$
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 $\Delta\epsilon_{A'}\sim10^{-4}$; $\Delta\epsilon_{\chi}\sim10^{-4}$

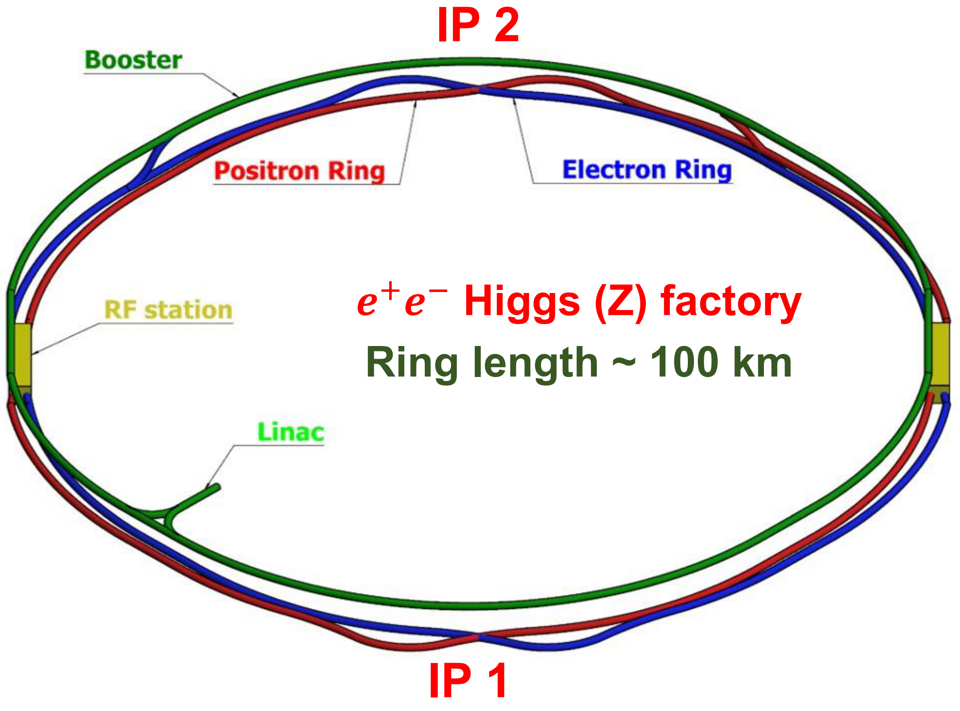
*Sensitivity estimated based on $\mathcal{L} = 1\ \mathrm{ab}^{-1}$

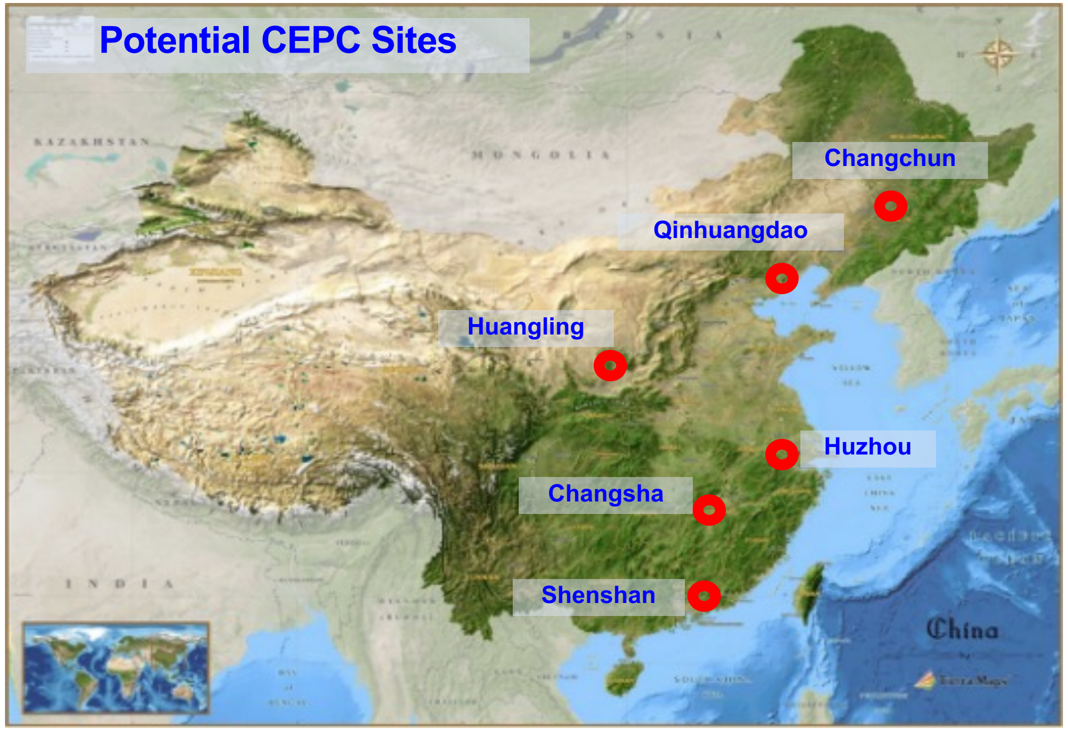
Please find more details in backup slides

CEPC

Circular Electron Positron Collider (CEPC)

- The CEPC aims to start operation in 2030’ s, as a Higgs (Z/W) factory
- To run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for 4 M Higgs; Tera Z @ 91 GeV, 100M **W** pair, and possible $t\bar{t}$ pair threshold upgrade
- Higgs, EW, flavor physics & QCD, BSM physics (eg. dark matter, EW phase transition, SUSY, LLP, ⋯.)
- Possible Super *pp* Collider (SppC) of $\sqrt{s}$ ~ 50–100 TeV in the future.

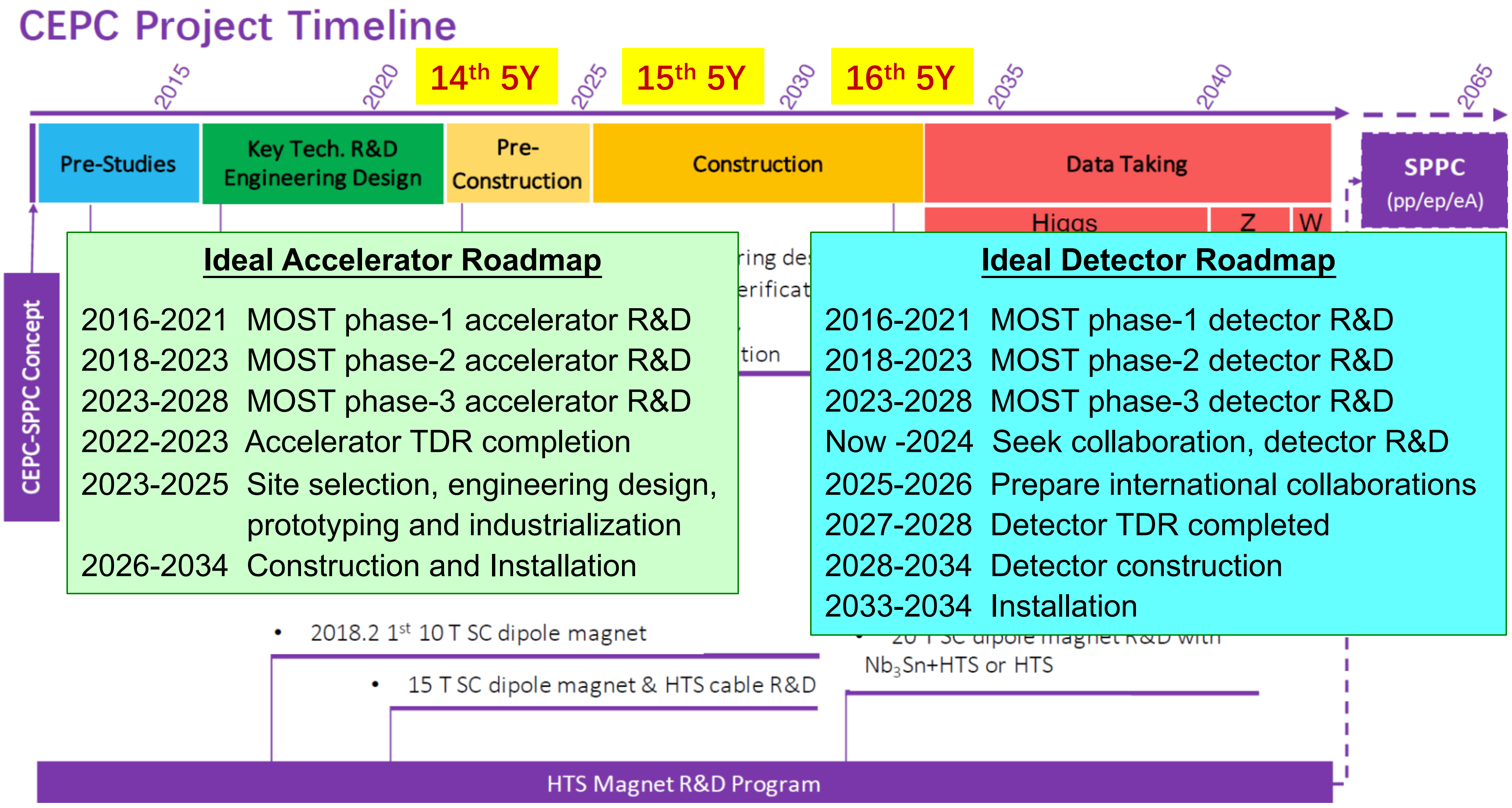




http://cepc.ihep.ac.cn/

CEPC Roadmap and Schedule (ideal)

- 2013-2025：Key technology R&D，from CDR to TDR, Site selection, Intl. Collab. etc.
- rs)



Ideal Accelerator Roadmap

2016-2021 MOST phase-1 accelerator R&D
2018-2023 MOST phase-2 accelerator R&D
2023-2028 MOST phase-3 accelerator R&D
2022-2023 Accelerator TDR completion
2023-2025 Site selection, engineering design, prototyping and industrialization
2026-2034 Construction and Installation

Ideal Detector Roadmap

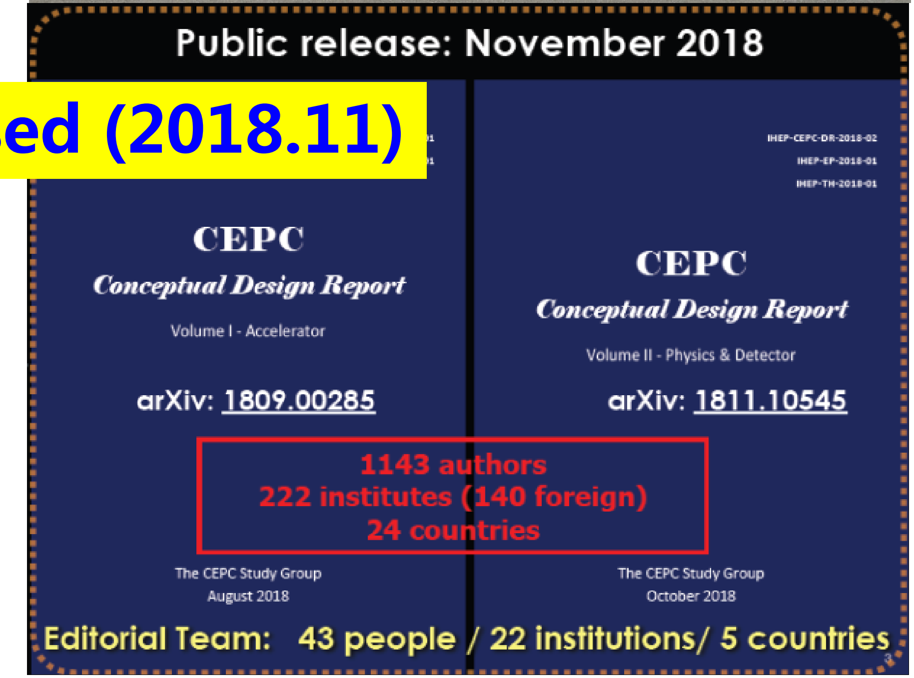
2016-2021 MOST phase-1 detector R&D
2018-2023 MOST phase-2 detector R&D
2023-2028 MOST phase-3 detector R&D
Now -2024 Seek collaboration, detector R&D
2025-2026 Prepare international collaborations
2027-2028 Detector TDR completed
2028-2034 Detector construction
2033-2034 Installation

CEPC Major Milestones

CEPC-SPPC Kickoff (2013.9)

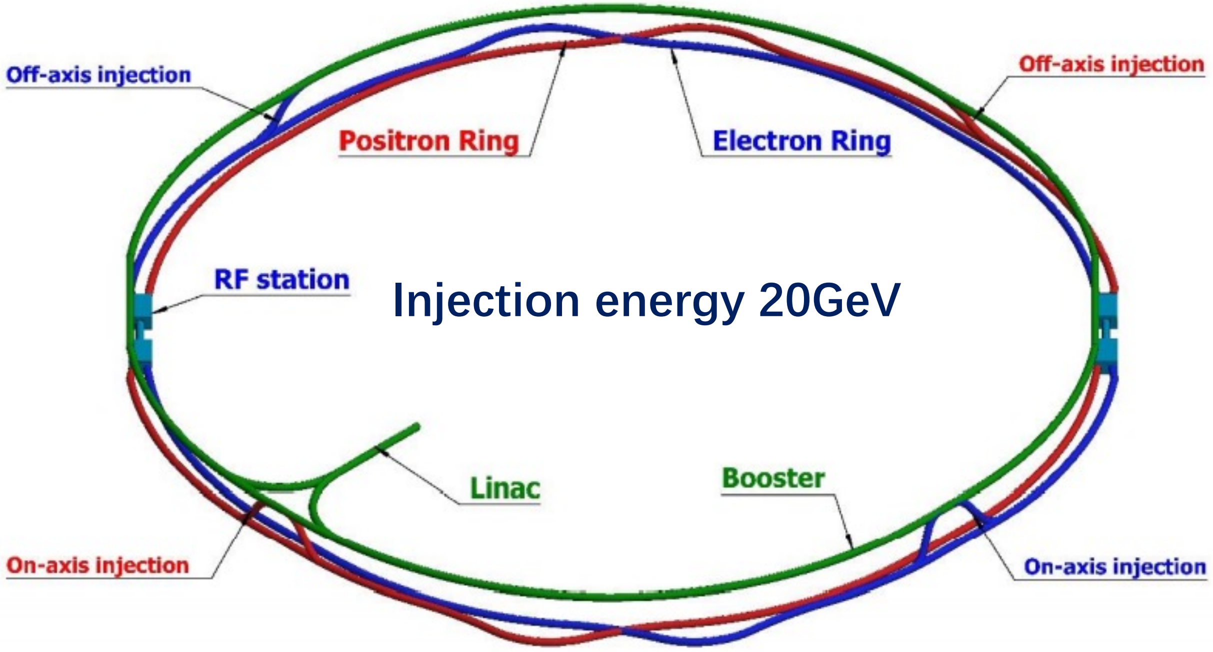
CEPC IAC Meeting (2015)

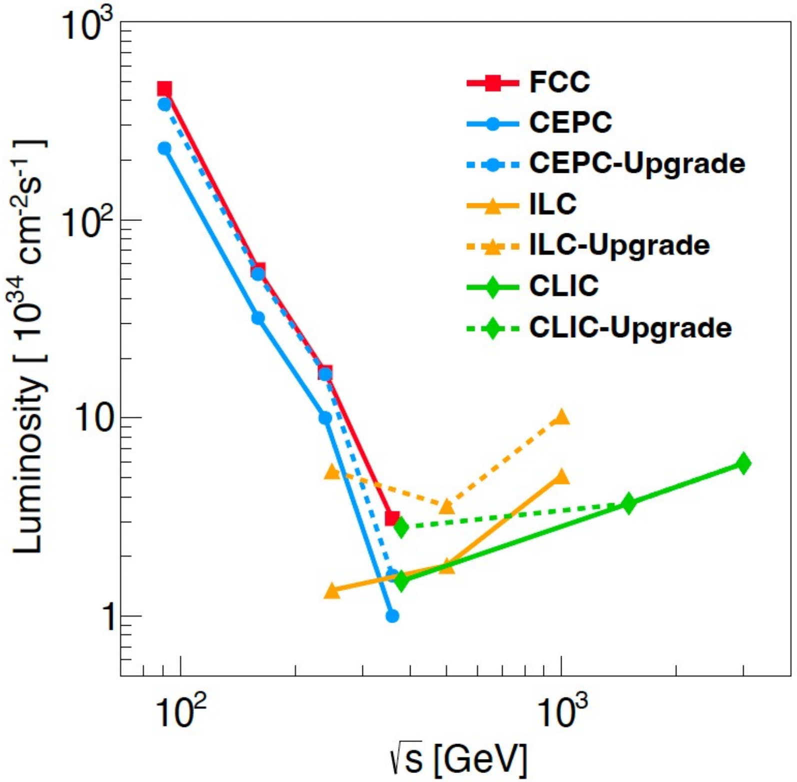
CEPC CDR Released (2018.11)



CEPC Accelerator Design Improvement & TDR

- 100 km double ring design (30 MW SR power, upgradable to 50MW).
- Switchable between H & Z, W modes without hardware change (magnet switch).
- New baseline for Linac (C-band, 20GeV) .



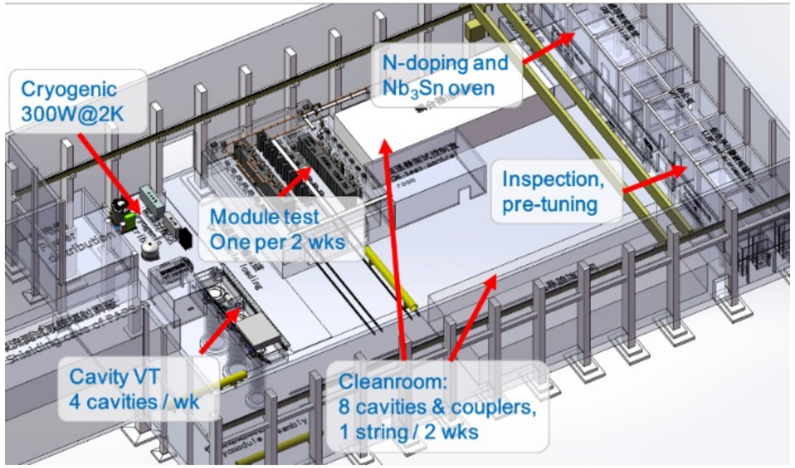


➔ Details at Yuhui Li`s talk

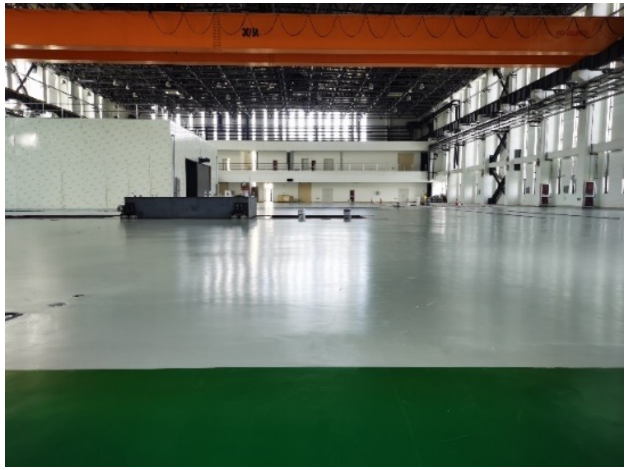
CEPC SCRF Test Facility

CEPC SCRF Test Facility is available : Beijing Huairou (4500m²)

New SC Lab Design (4500m²)



SC New Lab is available in 2021



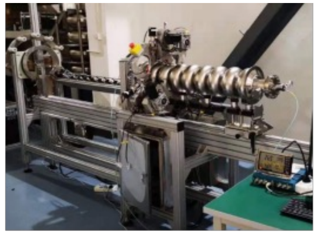
Crygenic system hall

Vacuum furnace (doping & annealing)

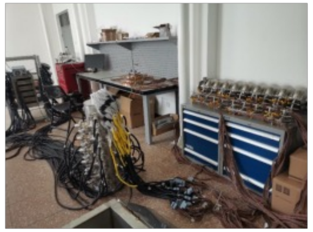
Nb3Sn furnace

Nb/Cu sputtering device

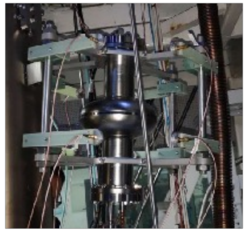
Cavity inspection camera and grinder



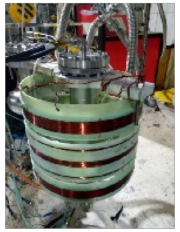
9-cell cavity pre-tuning machine



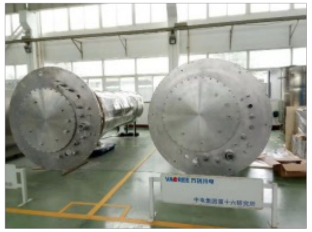
Temperature & X-ray mapping system



Second sound cavity quench detection system



Helmholtz coil for cavity vertical test

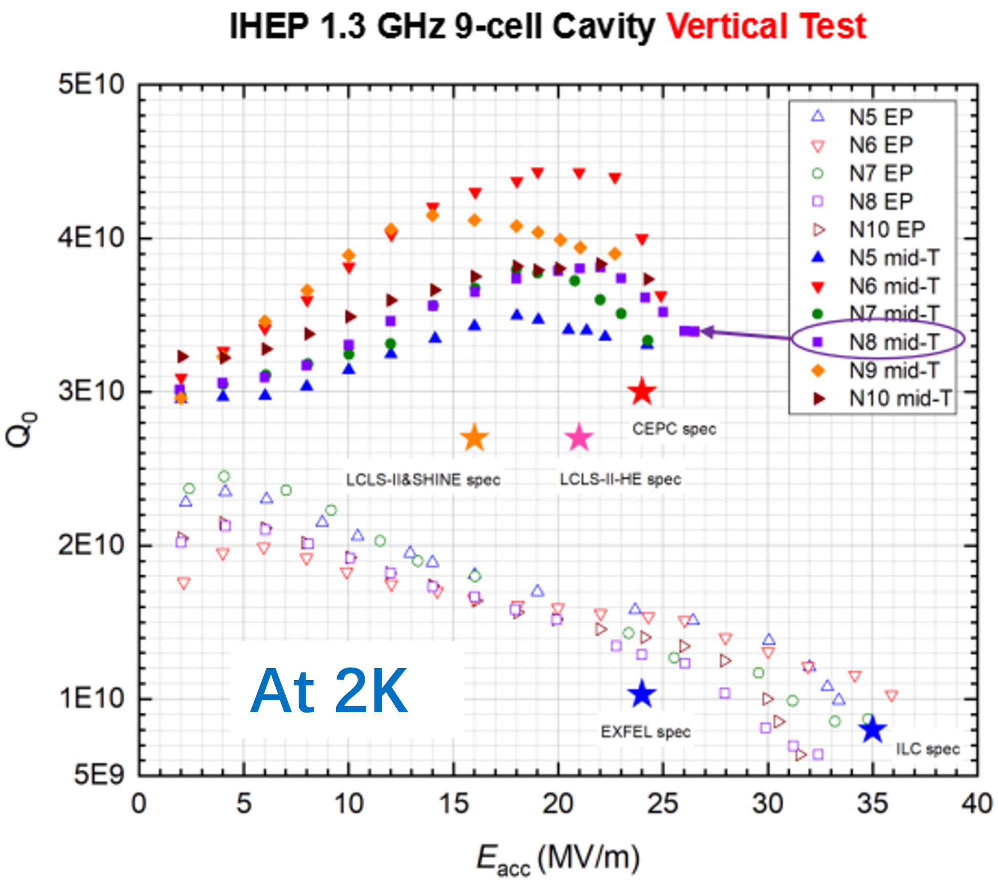


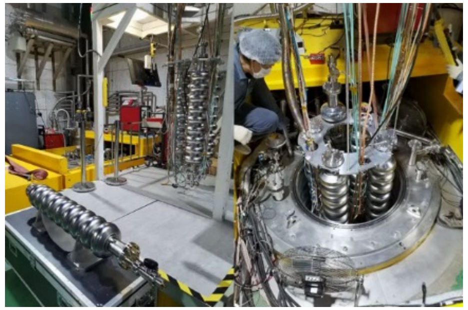
Vertical test dewars

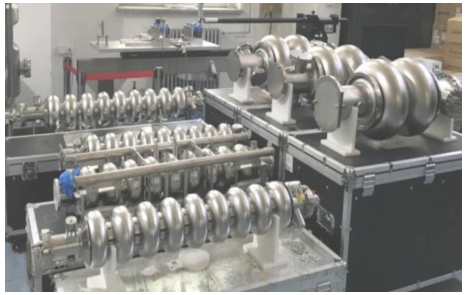
Horizontal test cryostat

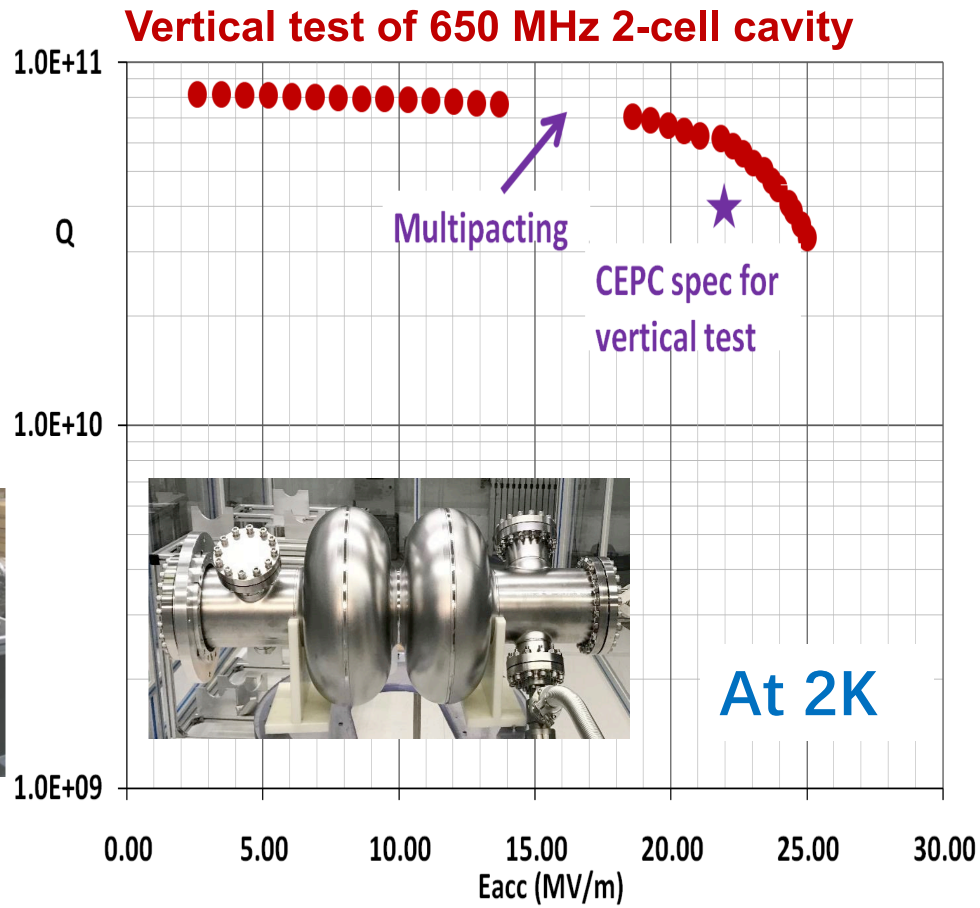
CEPC R&D: High Q SCRF Cavities

- 1.3 GHz 9-cell SCRF cavity for booster: Q_0 = 3.4E10 @ 26.5 MV/m
- 650 MHz 2-cell SCRF cavity for collider ring: Q_0 = 6.0E10 @ 22.0 MV/m
- SCRF cavities for both booster & collider ring reach CEPC design goal









Medium-temperature (Mid-T) annealing adopted to reach Q_0 = 3.4E10 @ 26.5 MV/m

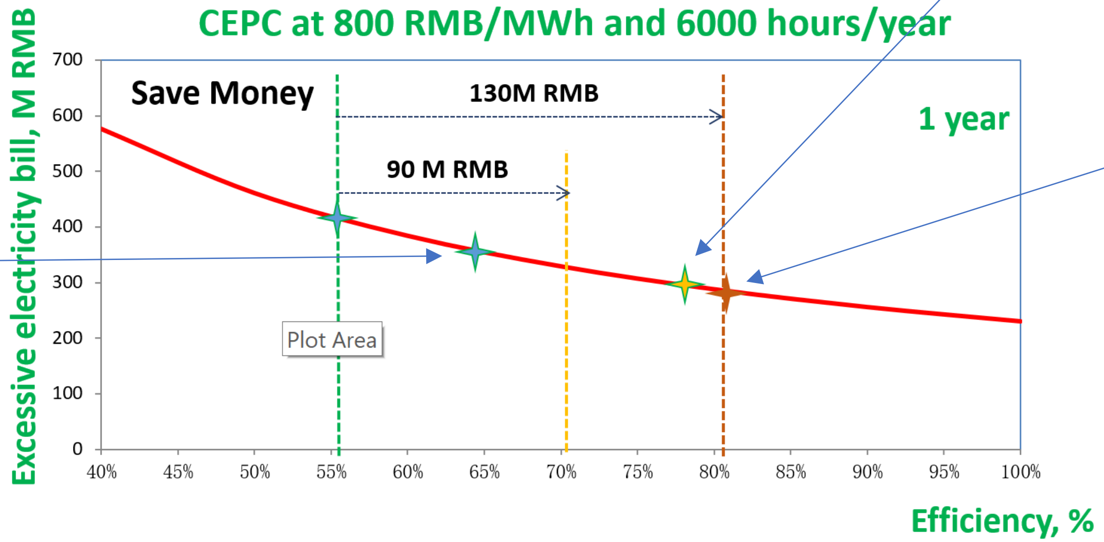
N-infusion adopted to reach Q_0 = 6.0E10 @ 22.0 MV/m

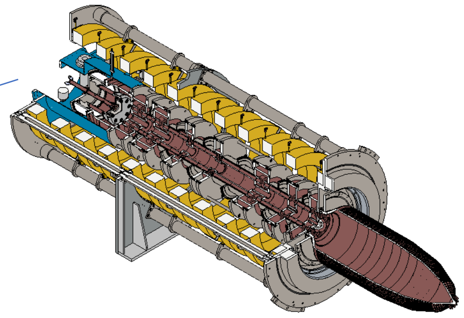
CEPC R&D: High Efficiency Klystrons

- The 1st prototype finished fabrication & passed the max. power test. Output power reaches 700 kW in CW mode, 800 kW in pulsed mode. Design efficiency is 65%, achieved efficiency ~ 62%.
- The 2nd klystron prototype is manufactured and under test at PAPS, design eff is ~ 77%, achieved efficiency ~70%.
- Multi-beam Klystron design is finished, design efficiency is ~ 80.5%.
- High efficiency Klystron helps to reduce electricity consumption.

The 2nd Klystron (under test)

The 1st Klystron (tested)

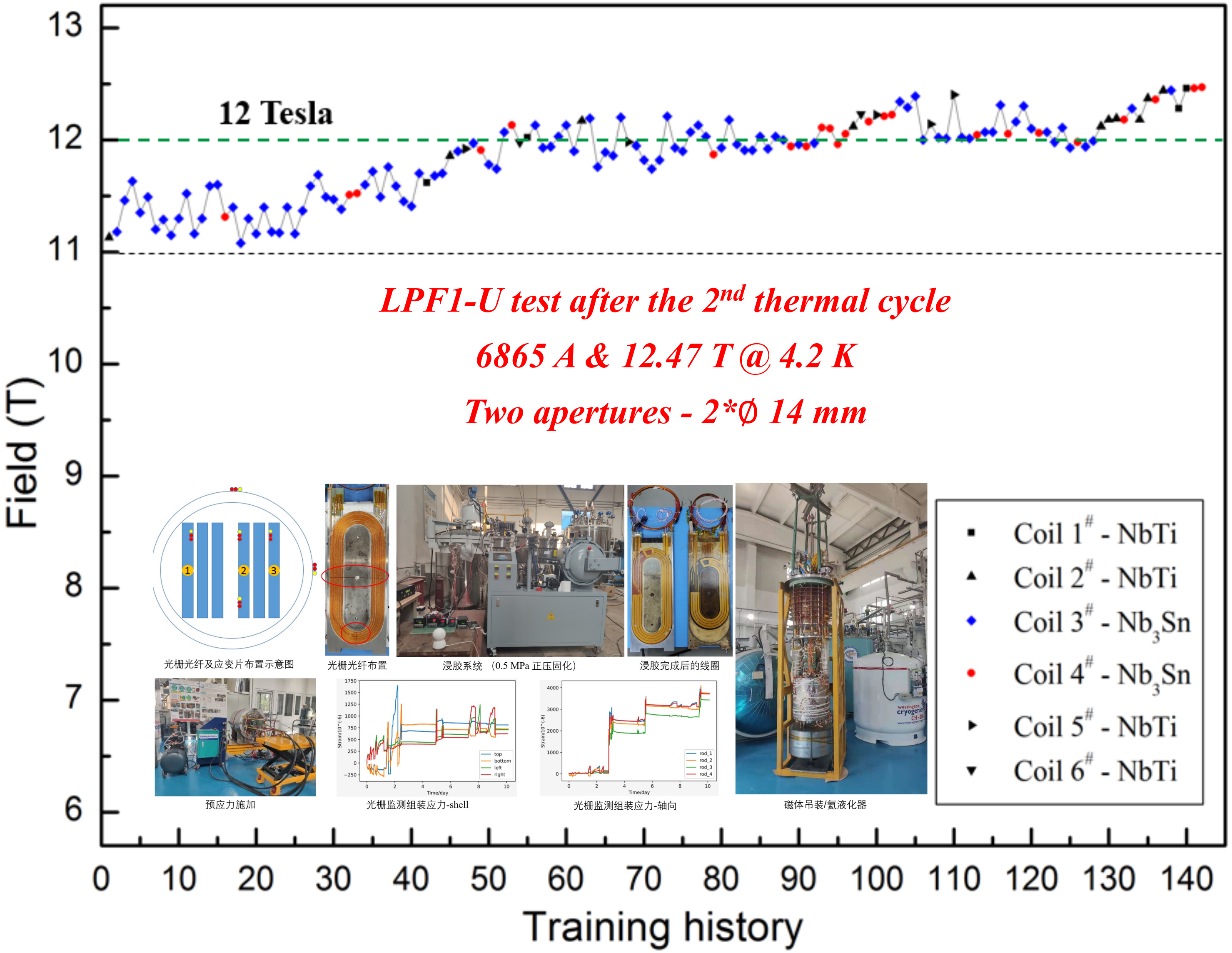


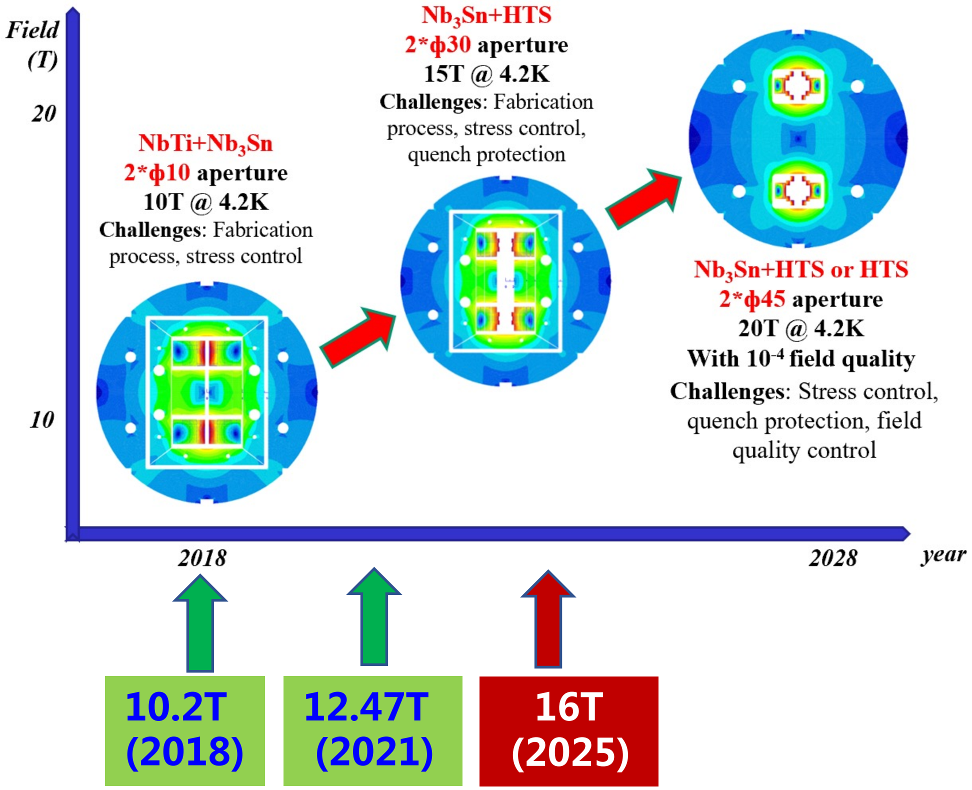


Multi-beam Klystron

HTS SC Magnet (>12T)

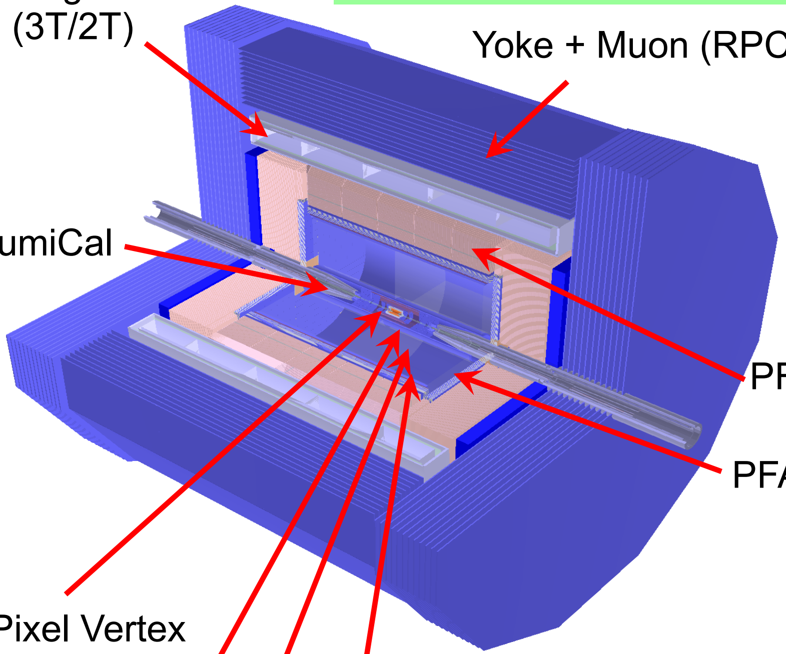
Domestic SC dipole magnet exceeded 12T (IHEP, June, 2021)



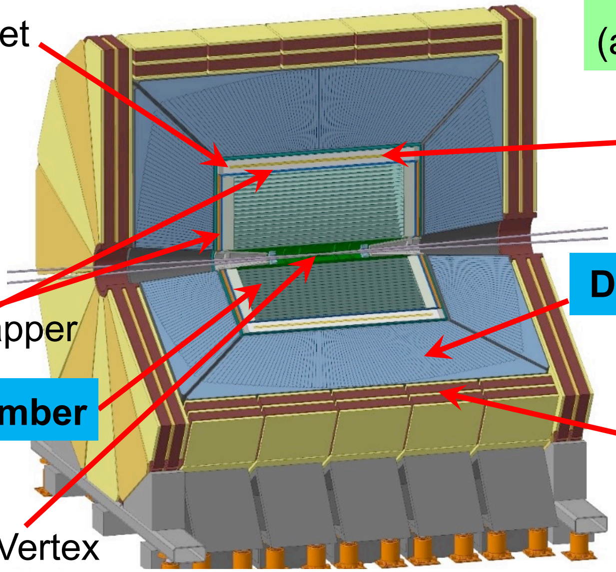


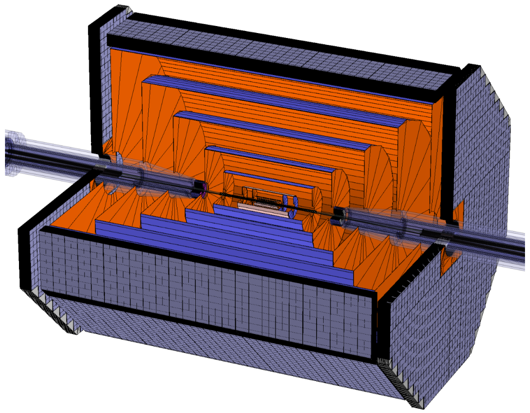
Conceptual Detector Designs

(Baseline Design)
Particle Flow Approach



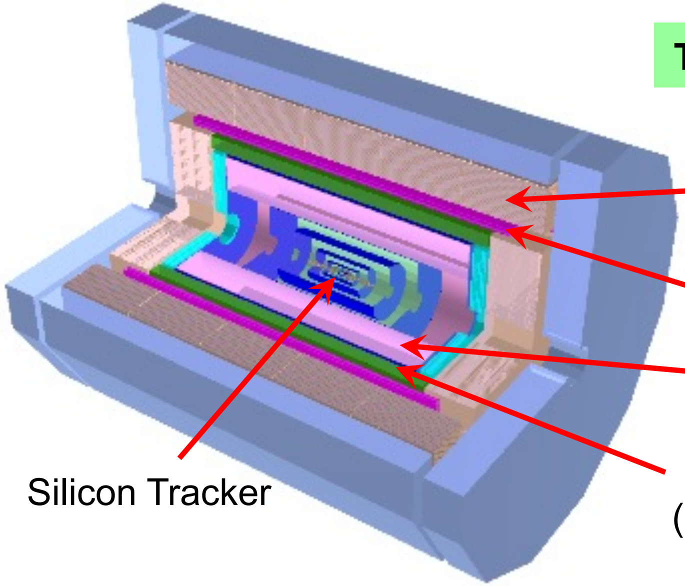
IDEA concept
(also proposed for FCC-ee)





FST concept
(Full Silicon Tracker)

The 4th Concept

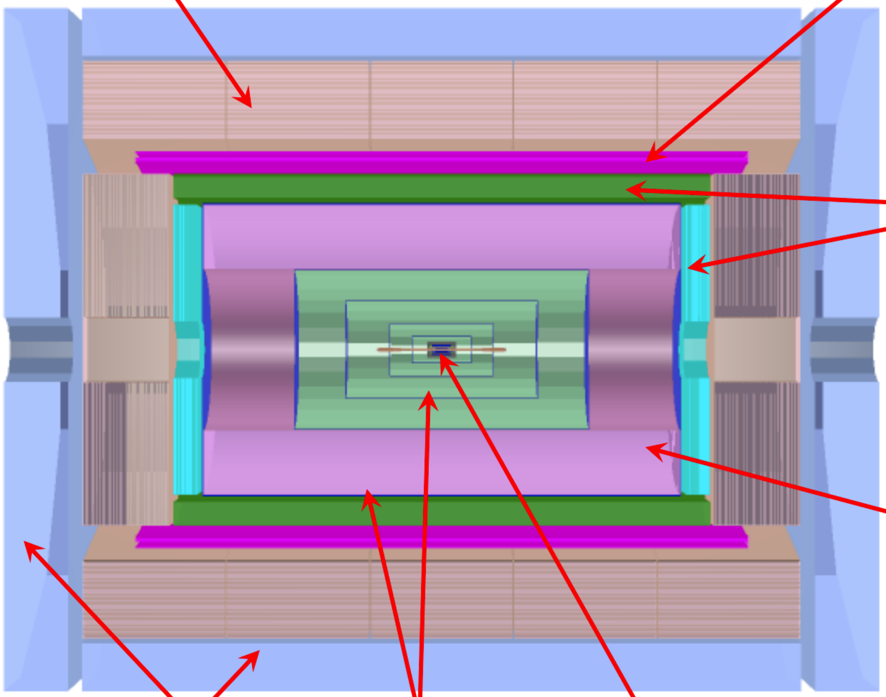


The 4th Conceptual Detector Design

Scint Glass PFA HCAL

Advantage: Cost efficient, high density

Challenges: Light yield, transparency, massive production.



Muon+Yoke **Si Tracker** **Si Vertex**

Solenoid Magnet (3T / 2T) Between HCAL & ECAL

Advantage: the HCAL absorbers act as part of the magnet return yoke.

Challenges: thin enough not to affect the jet resolution (e.g. BMR); stability.

Transverse Crystal bar ECAL

Advantage: better π^0/γ reconstruction.

Challenges: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

A Drift chamber that is optimized for PID

Advantage: Work at high luminosity Z runs

Challenges: sufficient PID power; thin enough not to affect the moment resolution.

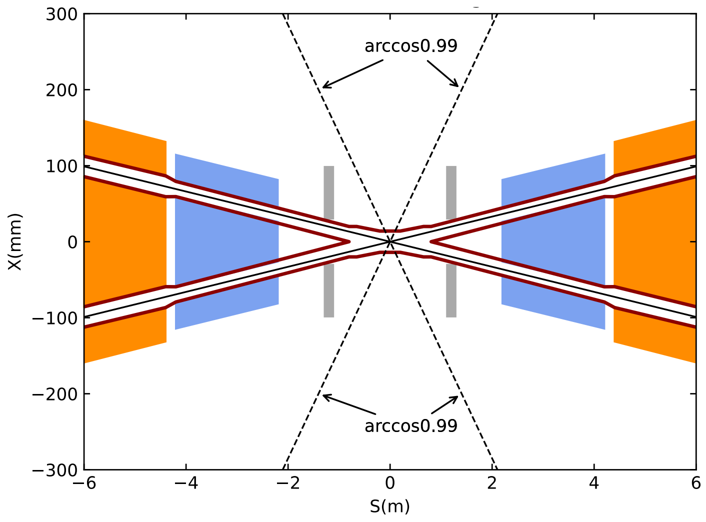
Det	Technology
Pixel Vertex	JadePix
	TaichuPix
	Arcadia
	CPV(SOI)
	Stiching
Tracker & PID	TPC
	CEPCPix
	Drift chamber
	PID DC
	LGAD
	Silicon Strip

Det	Technology
Calorimeter	Crystal ECAL
	Si+W ECAL
	Scint+W ECAL
	Scint AHCAL
	ScintGlass AHCAL
	RPC SDHCAL
	MPGD SDHCAL
	DR Calorimeter
Muon	Scintillation Bar
	RPC
	μ-Rwell
Lumi	SiTrk+Crystal ECAL
	SiTrk+SiW ECAL

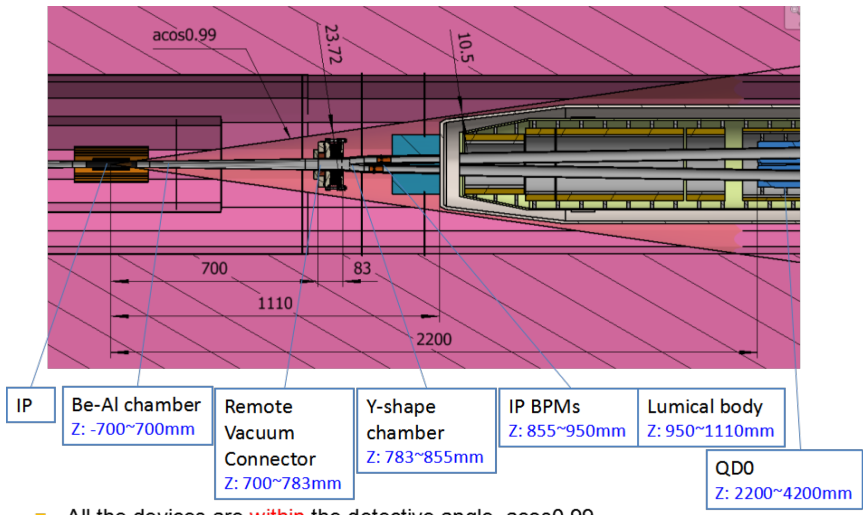
CEPC R&D: Machine Detector Interface (MDI)

Crossing angle: 33 mrad

Focal length: 2.2 m



Final focusing magnets (QD0, QF1) with Segmented Anti-Solenoidal Magnets

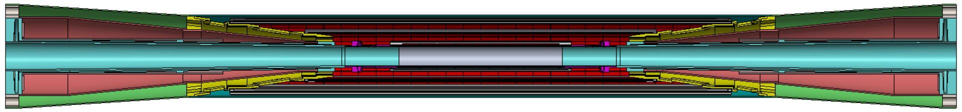


- All the devices are within the detective angle, acos0.99.

2021 Workshop on CEPC Detector & MDI Mechanical Design, Oct.22-23

Beam Pipe

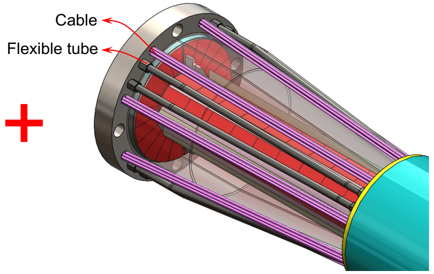
ϕ 28→20 mm, Be thickness: 0.85→0.35 mm

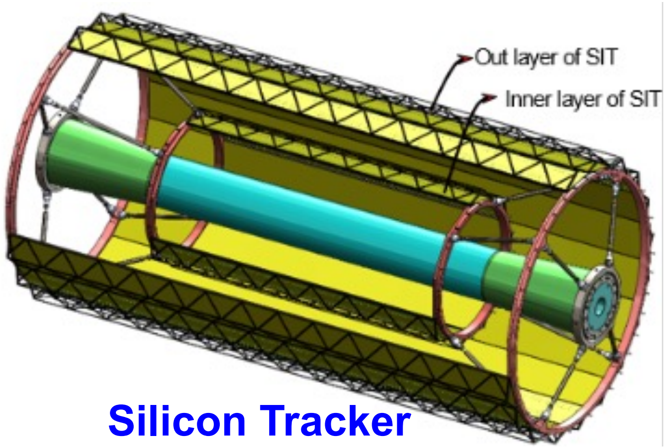


Vertex

+

LumiCal Tracker



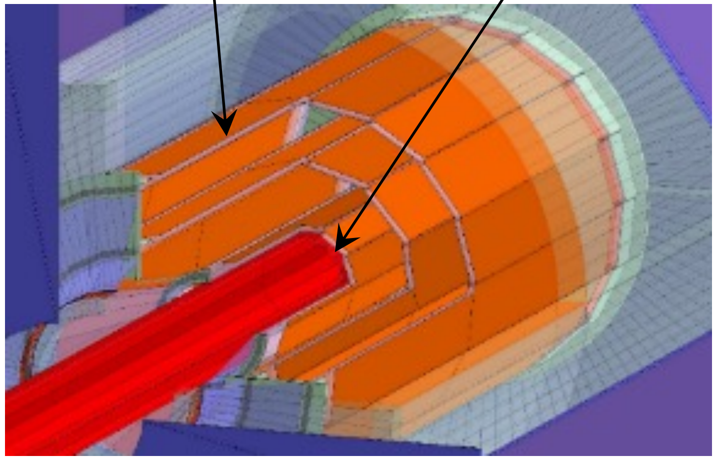


Silicon Tracker

Workshop on CEPC Central Beampipe and Beryllium Application May 6, 2022

CEPC R&D: Silicon Pixel Chips

2 layers / ladder R_{in}~16 mm



Goal: σ(IP) ~ 5 μm for high P track

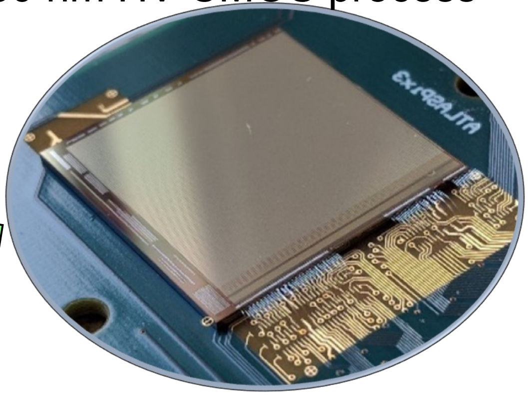
CDR design specifications

- Single point resolution ~ 3μm
- Low material (0.15% X_0 / layer)
- Low power (< 50 mW/cm^2)
- Radiation hard (1 Mrad/year)

Silicon pixel sensor develops in 5 series:
JadePix, TaichuPix, CPV, Arcadia, CEPCPix

Develop **CEPCPix** for a CEPC tracker basing on **ATLASPix3** **CN/IT/UK/DE**

TSI 180 nm HV-CMOS process

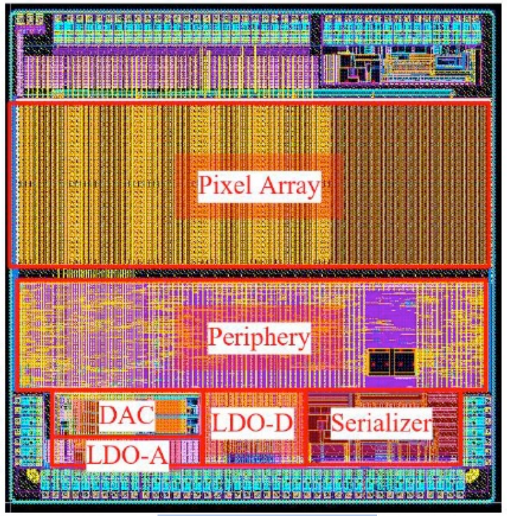


JadePix-3 Pixel size ~16×23 μm^2

Tower-Jazz 180nm CiS process
Resolution 5 microns, 53mW/cm^2

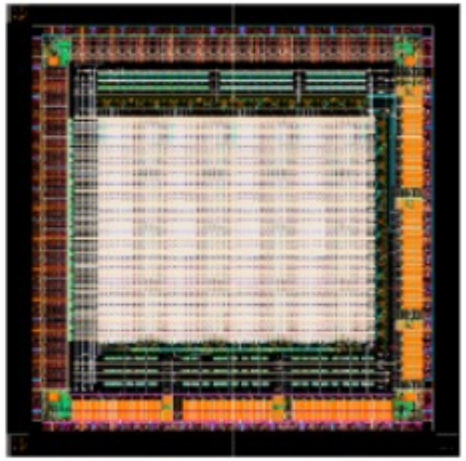
MOST 1

TaichuPix-2, 64×192 array
25×24 μm^2 pixel size

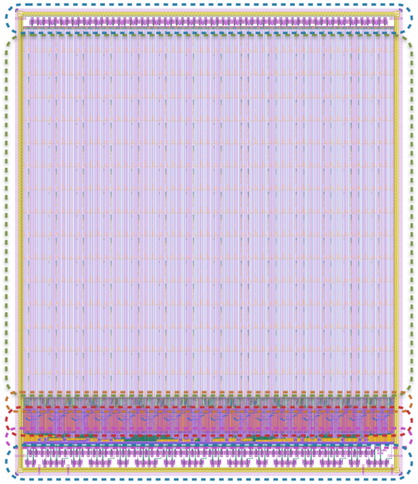


MOST 2

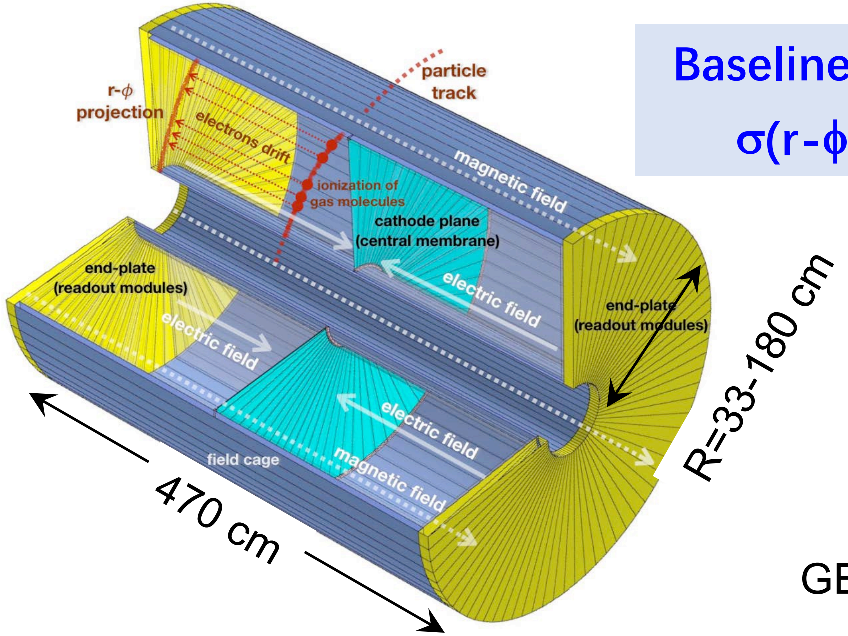
CPV4 (SOI-3D), 64×64 array
~21×17 μm^2 pixel size



Arcadia by Italian groups for IDEA vertex detector
LFoundry 110 nm CMOS

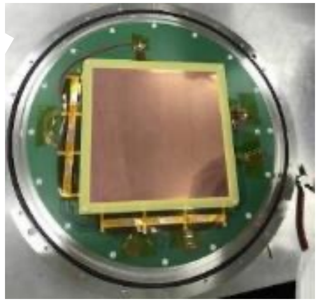


CEPC R&D: Time Projection Chamber

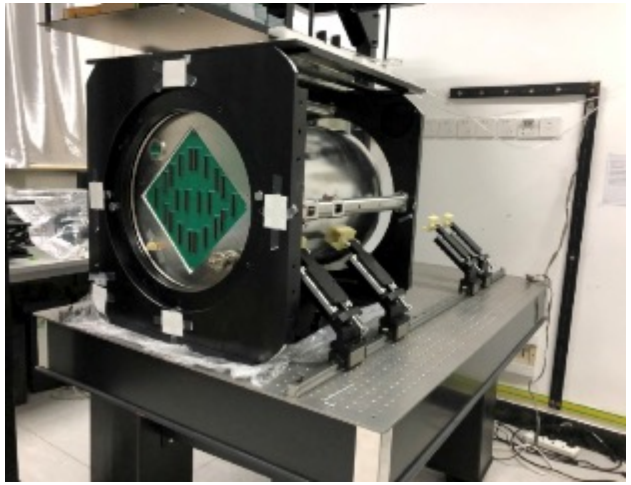


Baseline main tracker

$\sigma(r\text{-}\phi) \sim 100\ \mu m$



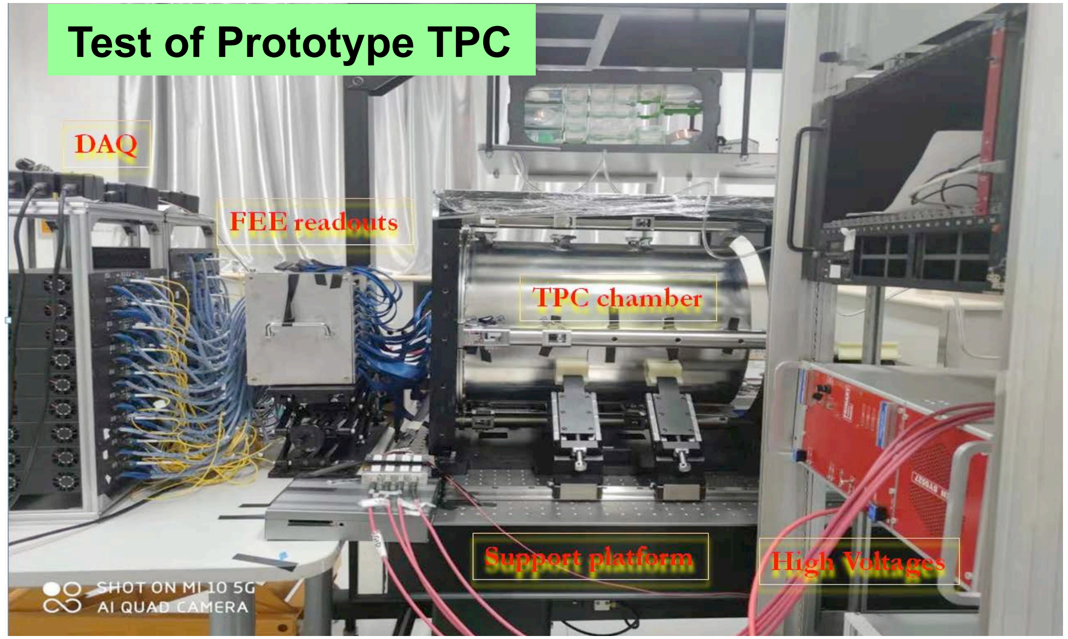
GEM-MM cathode



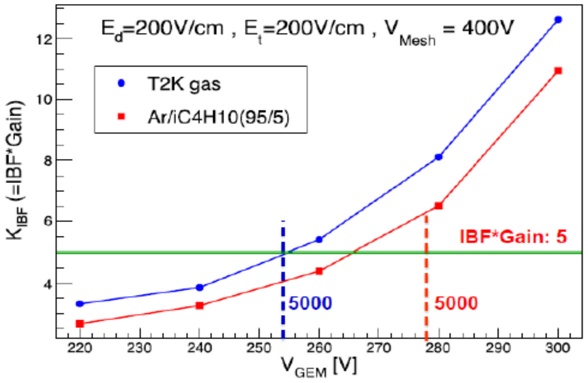
TPC Prototype + UV laser beams

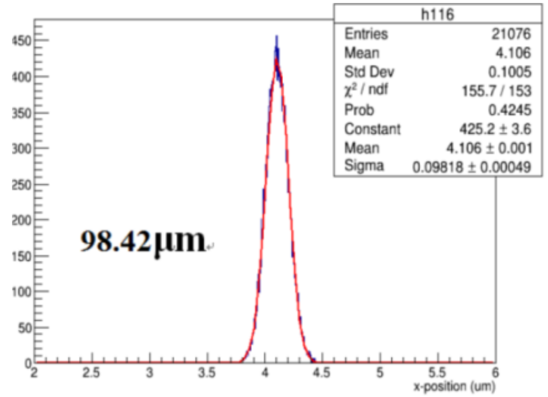
MOST 1 (IHEP+THU)

Low power FEE ASIC



Challenge: Ion backflow (IBF) affects the resolution. It can be corrected by a laser calibration at low luminosity, but difficult at high luminosity Z-pole.





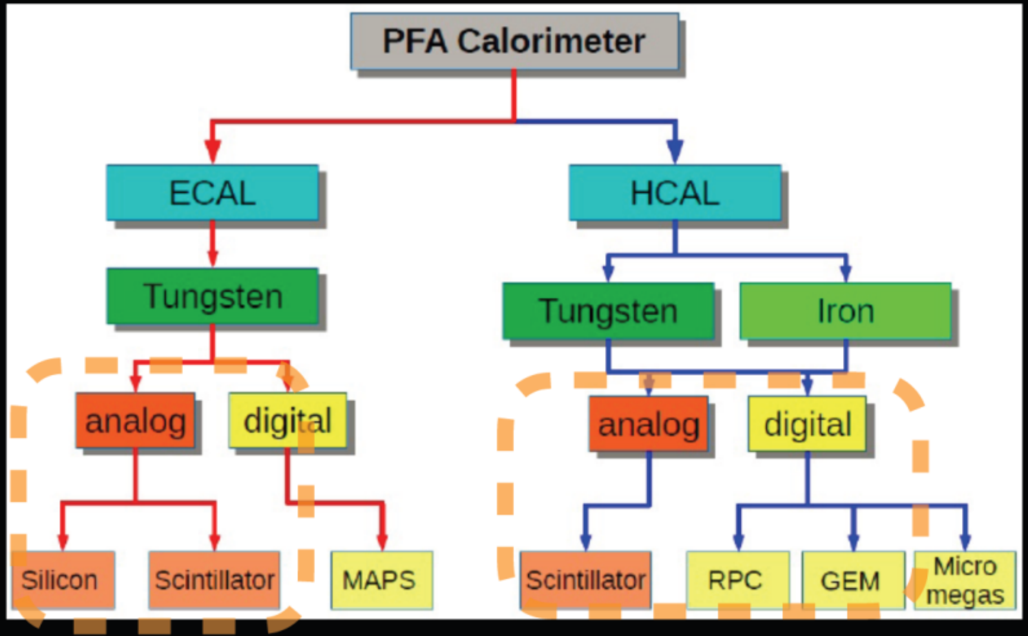
$\sigma_x < 100\ \mu m$ for drift length of 27cm

CEPC R&D: PFA Calorimeters

Calorimeter options

Chinese institutions have been focusing on Particle Flow calorimeters

R&D supported by MOST, NSFC and IHEP seed funding



High Granularity	Electromagnetic	ECAL with Silicon and Tungsten (LLR, France) ECAL with Scintillator+SiPM and Tungsten (IHEP + USTC)
	Hadronic	SDHCAL with RPC and Stainless Steel (SJTU + IPNL, France) SDHCAL with ThGEM/GEM and Stainless Steel (IHEP + UCAS + USTC) HCAL with Scintillator+SiPM and Stainless Steel (IHEP + USTC + SJTU)
Newer Options	Some longitudinal granularity	Crystal Calorimeter (LYSO:Ce + PbWO) Dual readout calorimeters (INFN, Italy + Iowa, USA) — RD52

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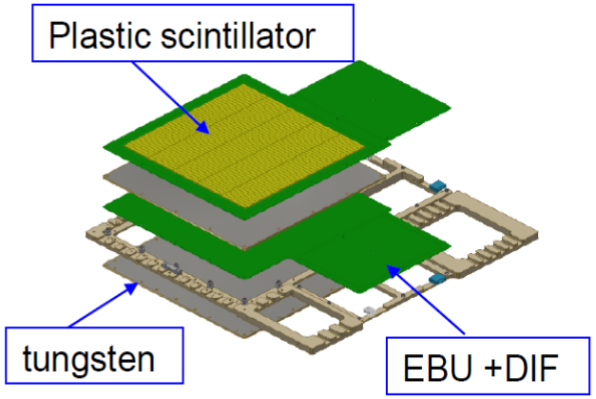
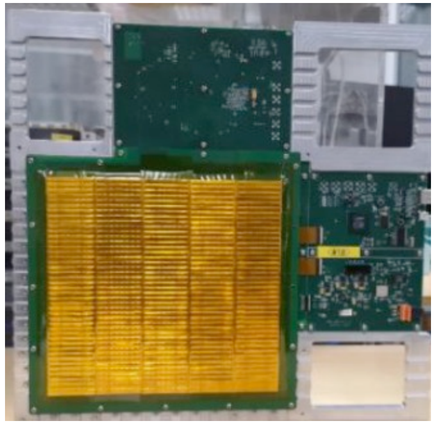
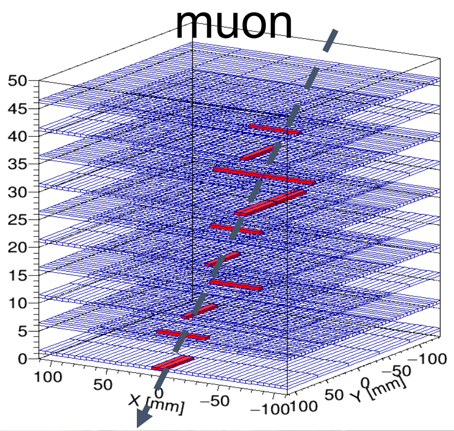
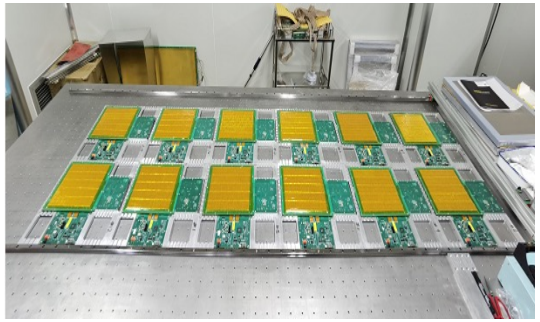
CEPC R&D: Calorimeters

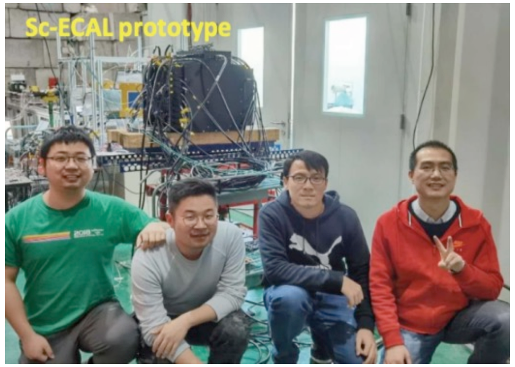
Scintillator-W ECAL Prototype



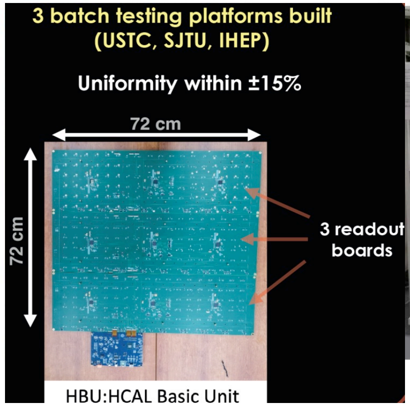


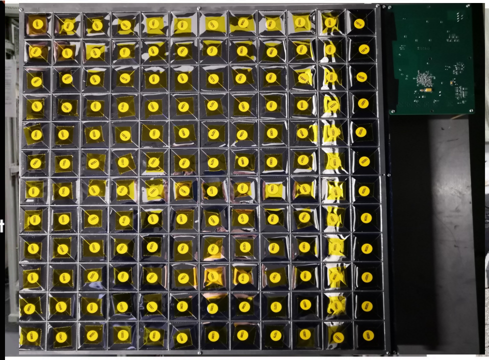






Scintillator + SiPM AHCAL Prototype

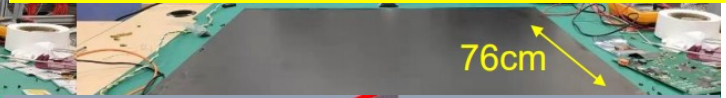


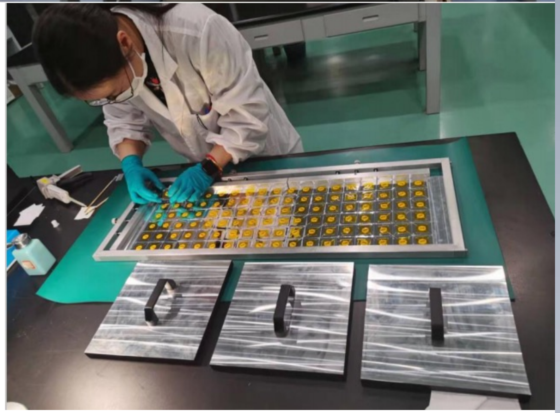


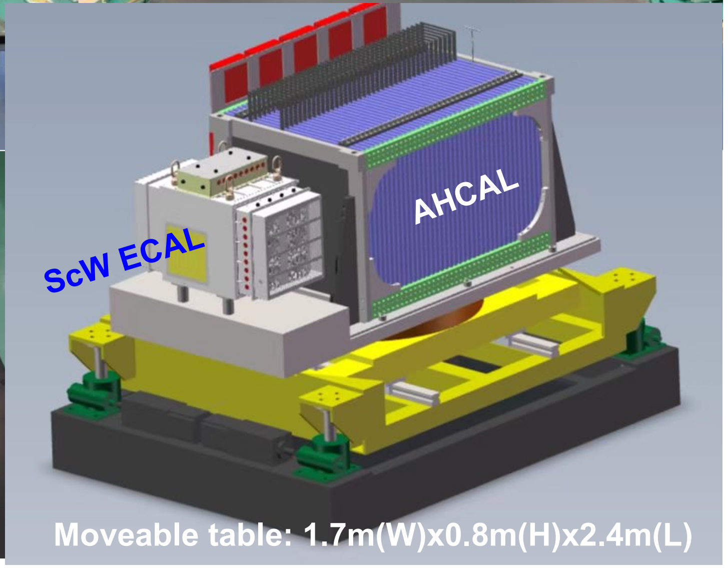
SJTU

IHEP

Combined: ScW-ECAL + AHCAL

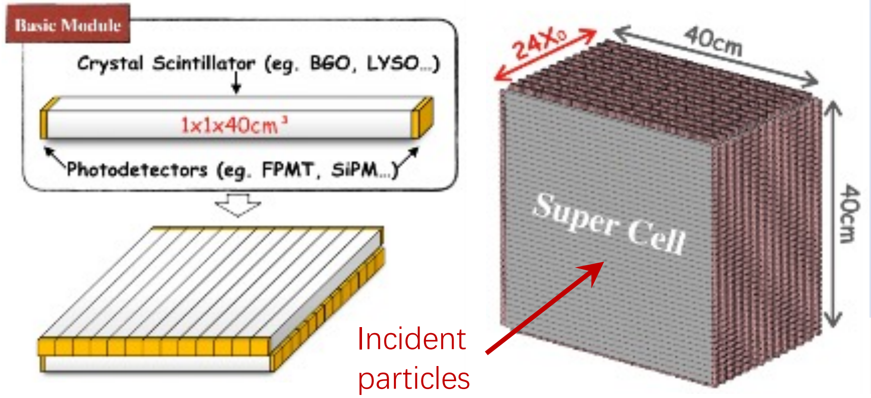






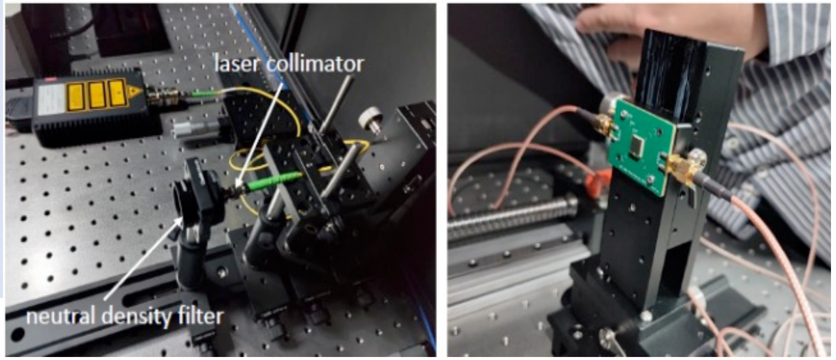
➔ Testbeam at CERN SPS for two prototypes in Oct. 2022

CEPC R&D: High Granularity Crystal ECAL



Goal

- Boson Mass Resolution < 4%
- Better BMR than ScW-ECAL
- Much better sensitivity to γ/e, especially at low energy.



- Timing at two ends for positioning along bar.
- Significant reduction of number of channels.

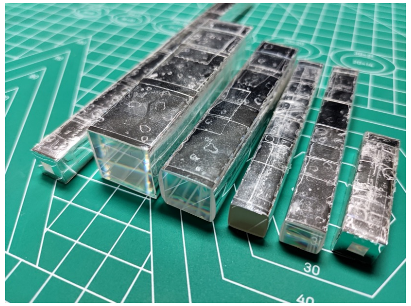
Conceptual Design

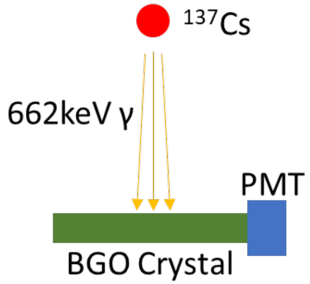
Bench Test

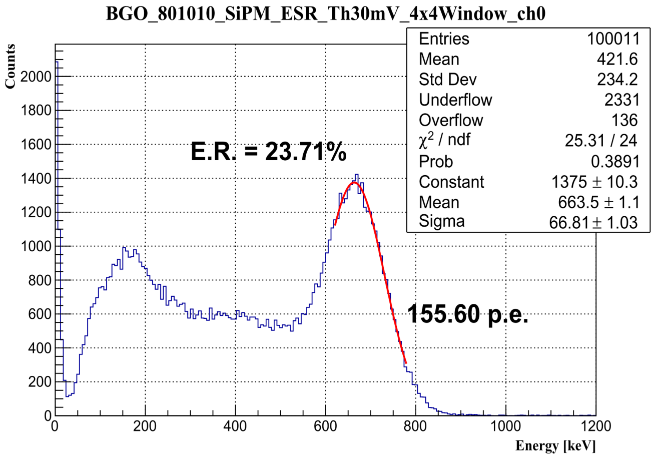
Full Simulation Studies

+ Optimizing PFA for crystals

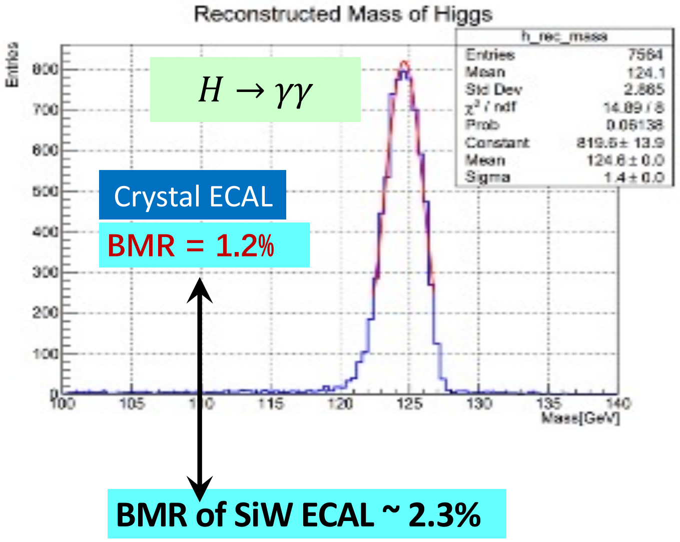
Performance Test



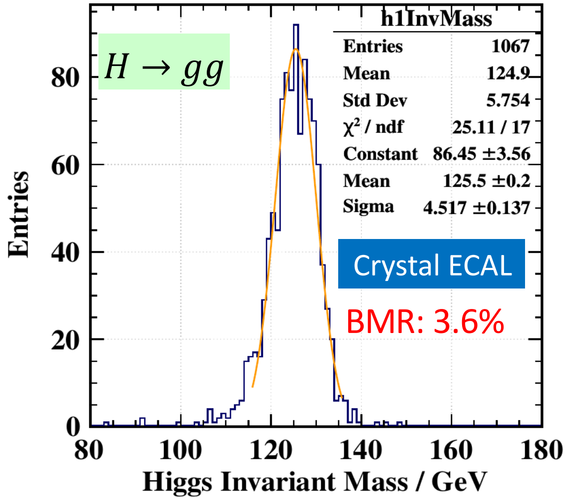




Performance with photons



Performance with jets



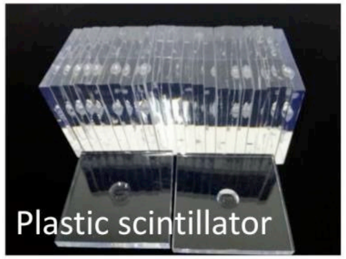
CEPC R&D: New HCAL with Scintillating Glass Tiles

Goal

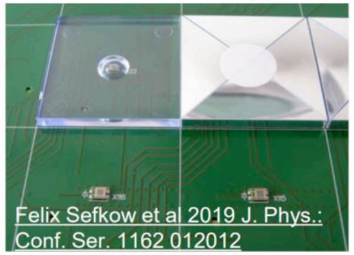
- Better hadronic energy resolution
- Further improve BMR

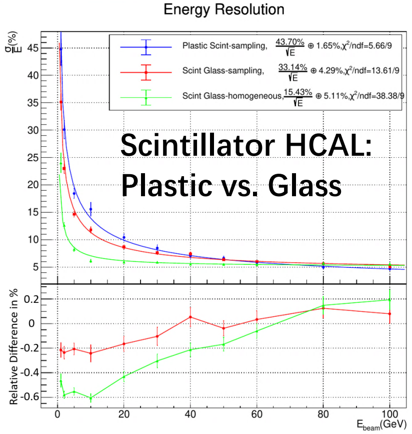
Full simulation studies

Tiles for AHCAL (30x30x3mm)

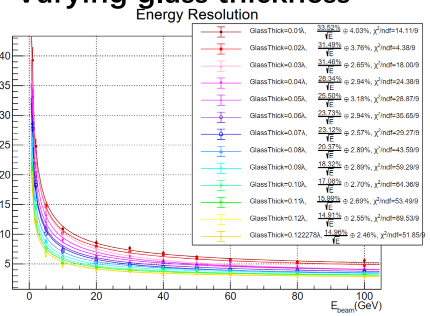


'SiPM-on-Tile" design for HCAL

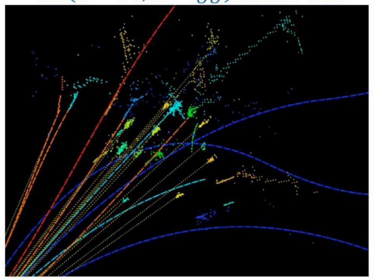




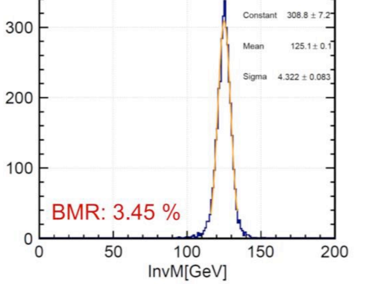
Varying glass thickness



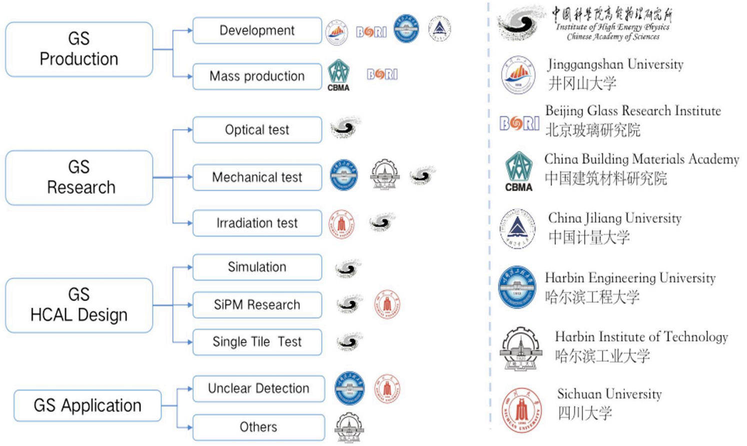
$ZH(Z \to \nu\nu, H \to gg)$ at 240 GeV

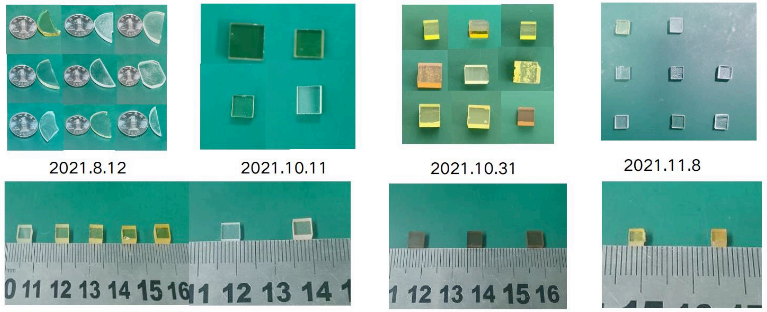


Performance study with jets



Scintillating Glass R&D

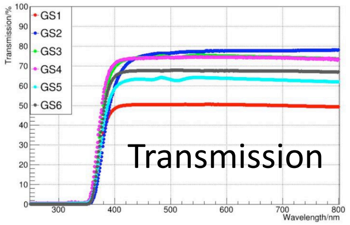


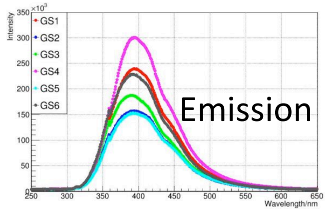


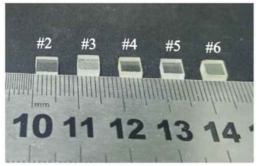
2021.8.12 2021.10.11 2021.10.31 2021.11.8

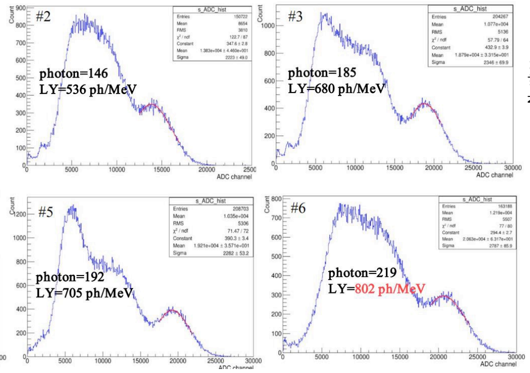
2021.11.13 2021.11.22 2021.11.23

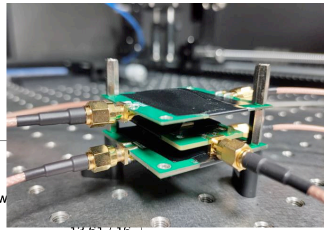
Testing Scintillating Glass Samples

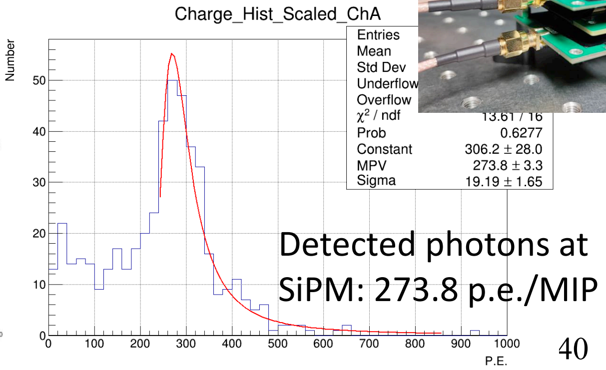






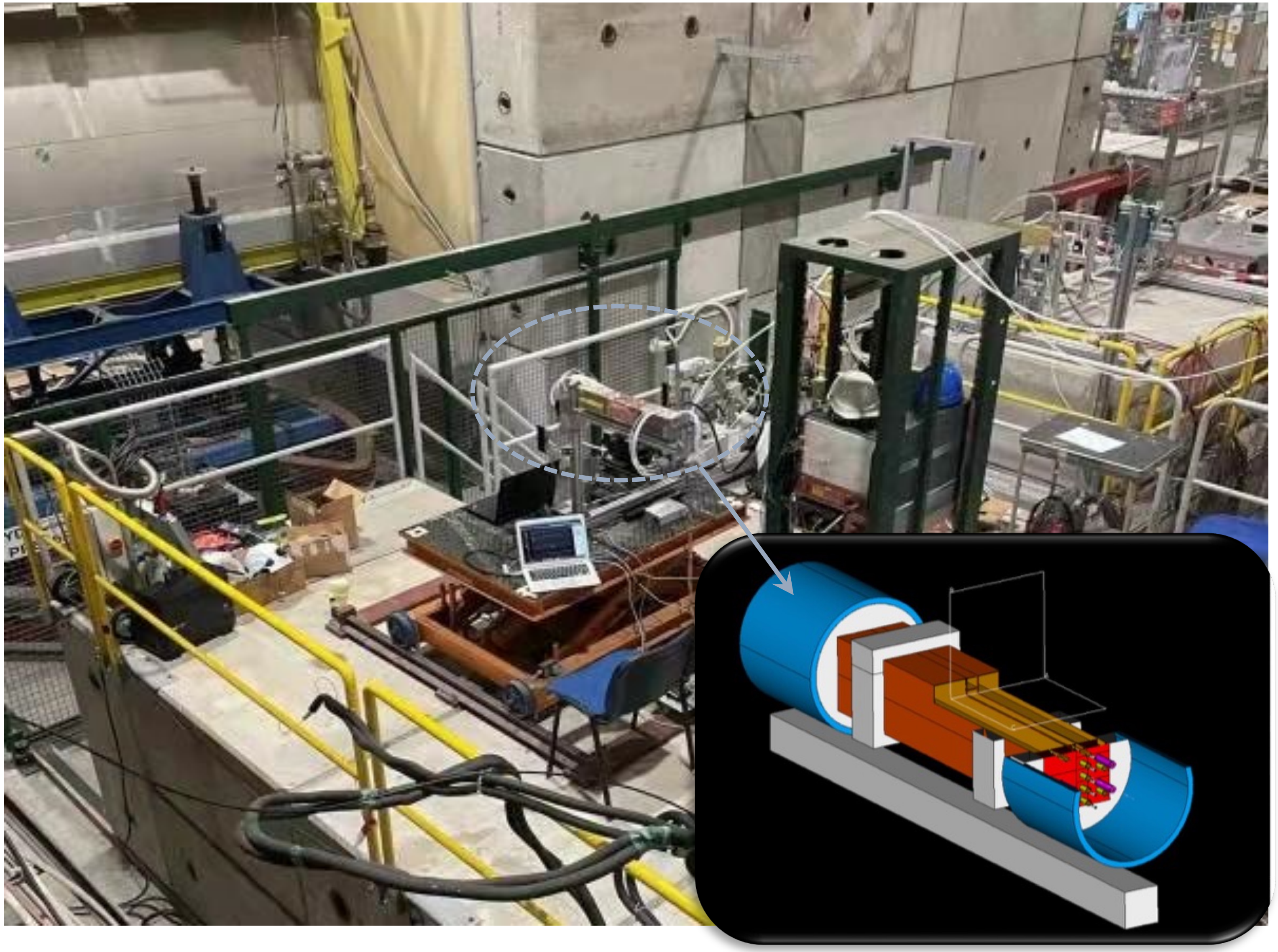


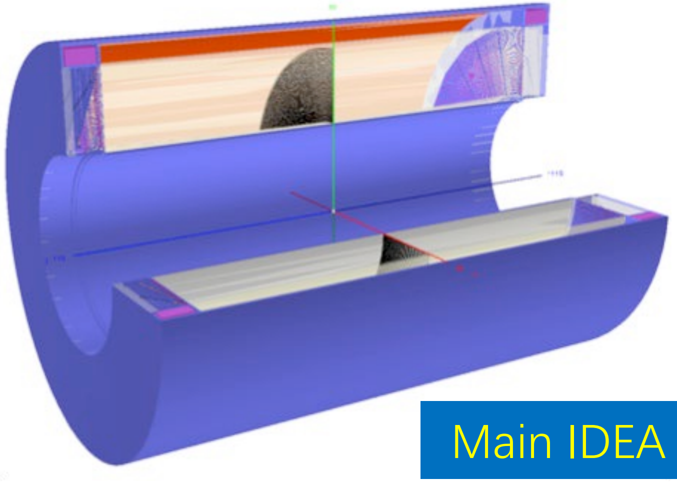




Detected photons at SiPM: 273.8 p.e./MIP

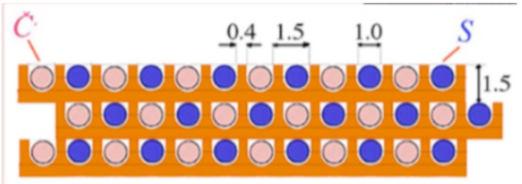
CEPC R&D: IDEA Tracker and Dual Readout Calorimeter

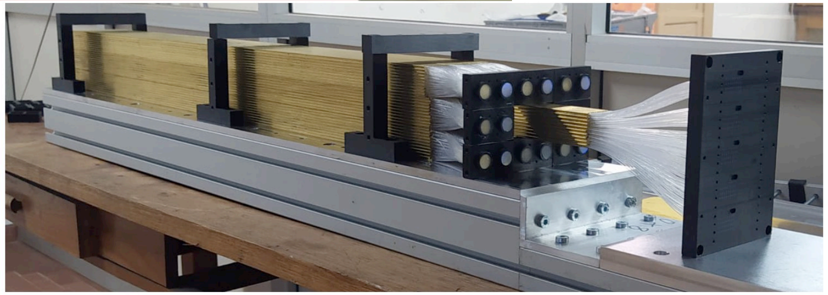




Main IDEA tracker

Dual Readout CAL





Italian groups and IHEP colleagues participated the test beam at CERN.

International Efforts

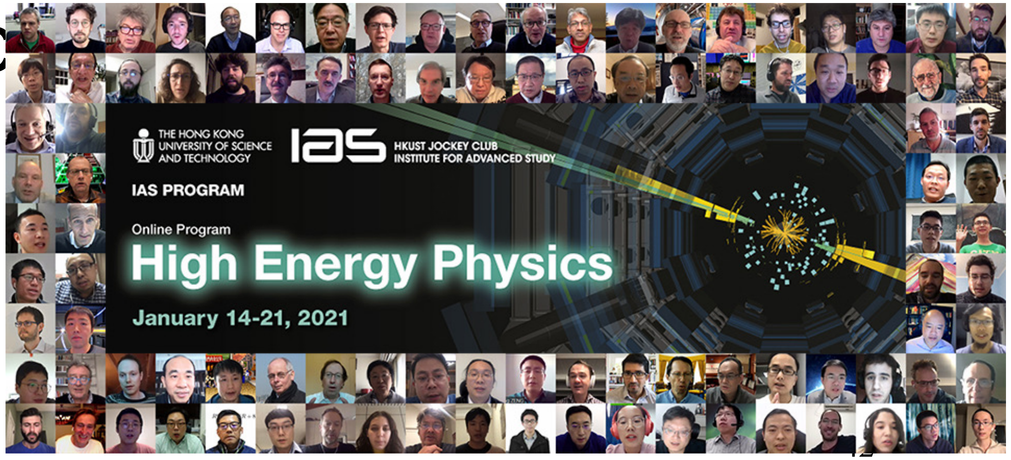
- **The 7th annual IAC meeting was held on Nov 1-5, 2021.**
- **International Accelerator Review Committee (IARC),** and **International Detector R&D Review Committee (IDRDRC)** started operating in 2019.
- Currently the CEPC study group consists of ~1/3 international members. **By year 2025-26, two international experiment collaborations should be formed.**
- International collaborating R&D through different channels, including CALICE, LCTPC, RD*, …
- The R&D research are supported by **MOST, NSFC, CAS, institutes, local government**, …

International workshops (with emphasis on CEPC

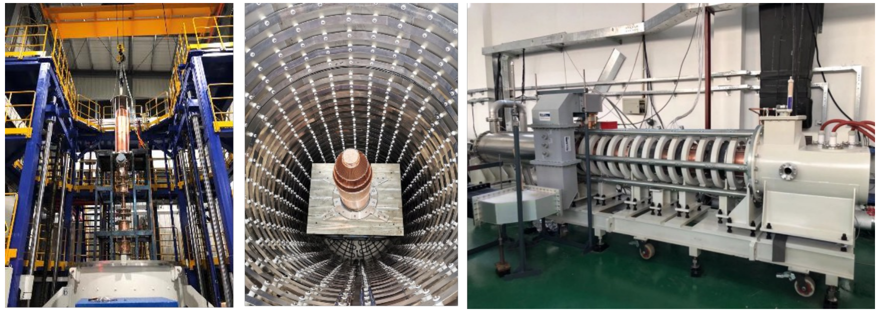
- **In China:** Beijing (2017-2019), Shanghai (2020.10),

  Nanjing (2021.11 online, 2022.10)

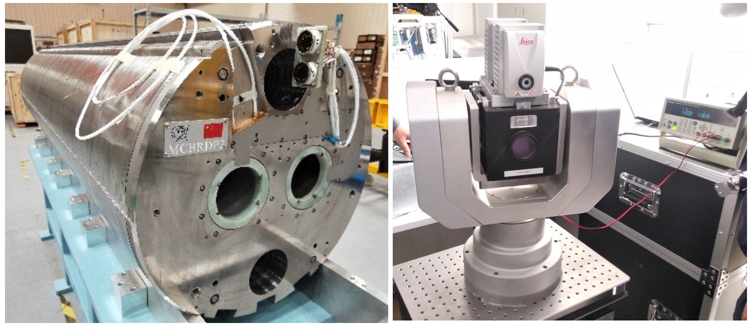
  Annual HKUST-IAS HEP program (since 2015)
- **In Europe:** Rome (2018.05), Oxford (2019.04), **Marseille**
- **In USA :** Chicago (2019.09), DC (2020.04 / online)



CEPC Collaboration with Industry (CIPC)



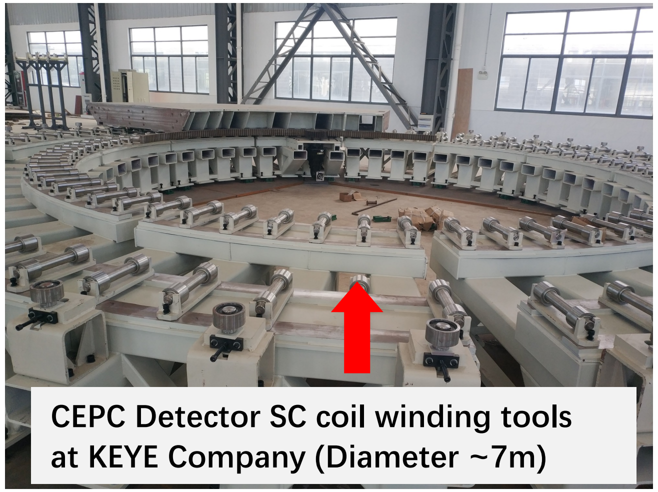
CEPC 650MHz Klystron at Kunshan Co.



CERN HL-LHC CCT SC magnet

CEPC SC QD0 coil winding at KEYE Co.

CIPC was established in Nov. 2017, there are 70+ companies join the CIPC so far.



CEPC Detector SC coil winding tools at KEYE Company (Diameter ~7m)

CEPC long magnet measurement coil

1) Superconduting materials (for cavity and for magnets)
2) Superconducting cavities
3) Cryomodules
4) Cryogenics
5) Klystrons
6) Magnet technology
7)Vacuum technologies
8) Mechanical technologies
9)Electronics
10) SRF
11) Power sources
12) Civil engineering
13) Precise machinery
.....

More than 40 companies joined in first phase of CIPC，**and 70 companies now.**

CEPC Physics Program (White Papers)

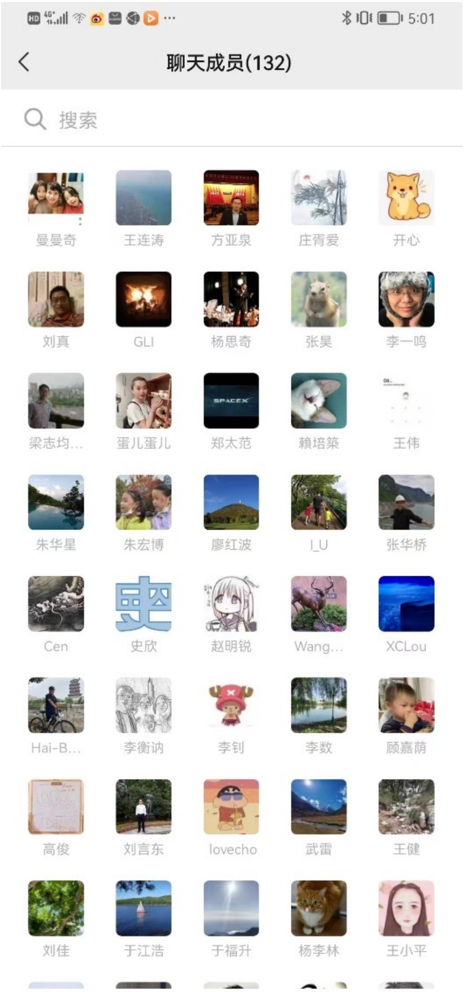
CEPC Operation mode		ZH	Z	W^+W^-	ttbar
$\sqrt{s}$ [GeV]		~ 240	~ 91.2	~ 160	~ 360
Run time [years]		7	2	1	-
CDR (30MW)	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	3	32	10	-
	$\int L\,dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	-
	Event yields [2 IPs]	1×10^6	7×10^{11}	$\sim10^8$	-
Run time [years]		10	2	1	5
Latest (50MW)	**L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]**	8.3	192	27	0.8
	$\int L\,dt$ [ab^{-1}, 2 IPs]	20	96	7	1
	Event yields [2 IPs]	4×10^6	4×10^{12}	$\sim10^8$	5×10^5

Physics similar to FCC-ee, ILC, CLIC

- 2019.3 **Higgs** White Paper published *(CPC V43, No. 4 (2019) 043002)*
- 2019.7 Workshop@PKU: **EW, Flavor, QCD** working groups formed
- 2020.1 Workshop@HKUST-IAS: Review progress, EW draft ready
- 2021.4 Workshop@Yangzhou: **BSM** working group formed

Yangzhou (2021)

CEPC Physics Program: Snowmass LoI



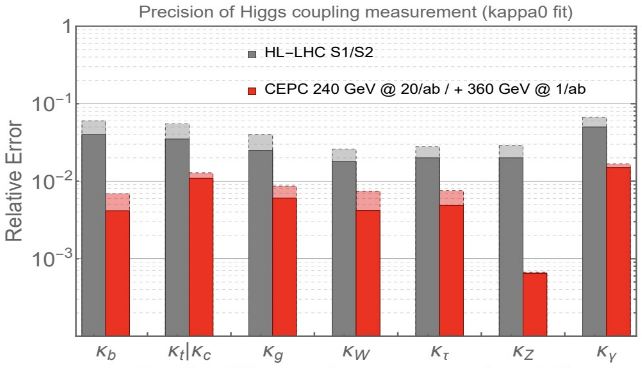
	Submitter	Title
1	Xin	EF01 Higgs boson CP properties at CEPC
2	Yanping	EF01 Measurement of branching fractions of Higgs hadronic decays
3	MJRM & Shu	EF02 Study of EWPT in Exotic Higgs decays with CEPC detector simulation
4	Mingrui Zhao	EF03 Feasibility study of CP violation phase Phi-s measurement via Bs->J/psi Phi at CEPC
5	Peiwen Wu	EF03 Probing top quark FCNC couplings at future electron positron collider
6	Lingfeng Li	EF03 Searching for Bs->Phivv and other b->svv processes at CEPC
7	Siqi Yang	EF04 Measurement of leptonic effective weak mixing angle at CEPC
8	Jiayin Gu	EF04 Probing new physics with measurement of ee->WW at CEPC with optimal observables
9	Bo Li	EF04 Measurement of Rb in hadronic Z decays at the CEPC
10	Zhao Li	EF04 NNLO electroweak correction to Higgs and Z associated production at future Higgs factory
11	Shuang-Yong Zhou	EF04 Positivity bounds on quartic-gauge-boson couplings
12	Qin qin	EF05 Exclusive Z decay
13	Zhao Li	EF05 NNLO EW correction to Higgs and Z associated production at future Higgs factory
14	Yang Zhang	EF08 SUSY Global fits with future colliders using GAMBIT
15	Tianjun li	EF08 Probing SUSY and DM at CEPC, FCC & ILC
16	Mengchao Zhang	EF09 Search for Asymmetric DM model at CEPC by displaced lepton jets
17	Peiwen Wu	EF09 Search for t+j+MET signals from DM models at future electron positron collider
18	Xin Shi & Weiming	EF09 DM via Higgs portal at CEPC
19	Kepan Xie	EF10 Lepton portal DM, Gravitational waves and collider phenomenology
20	Taifan Zheng	RF1 Exploring NP with Bc->Tauv

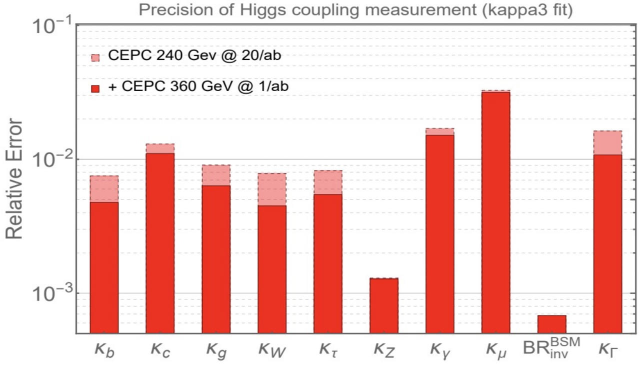
arXiv: 2205.08553

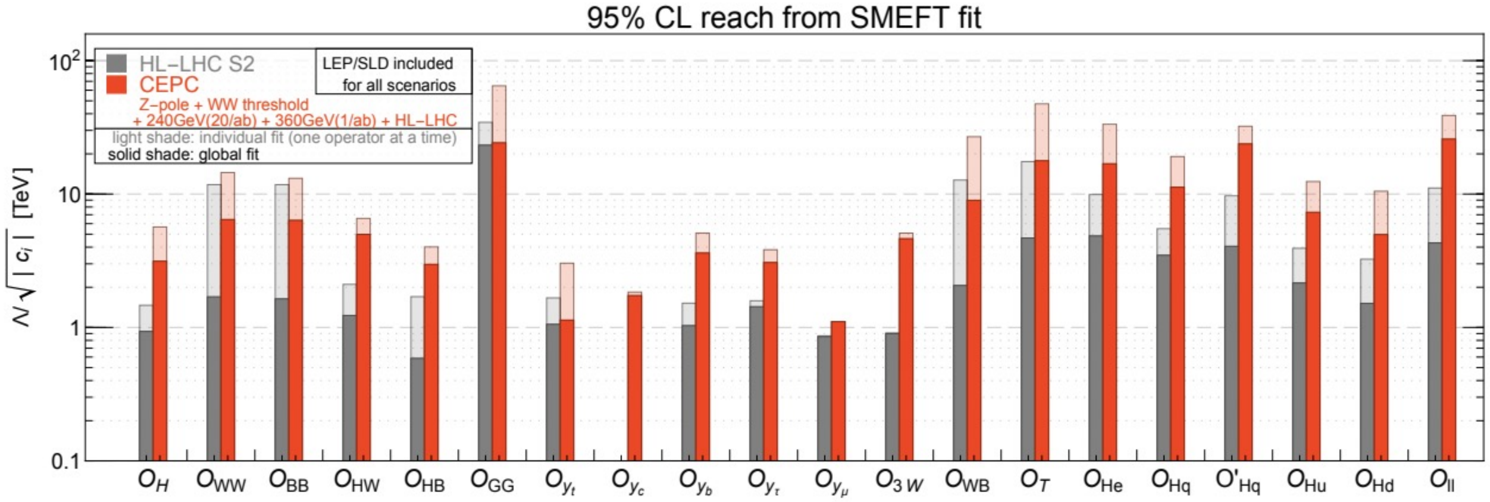
- ✓ Many talks presented at Snowmass meetings
- ✓ Many relevant performance studies, and extra physics analyses

CEPC Physics Program: Higgs and EW

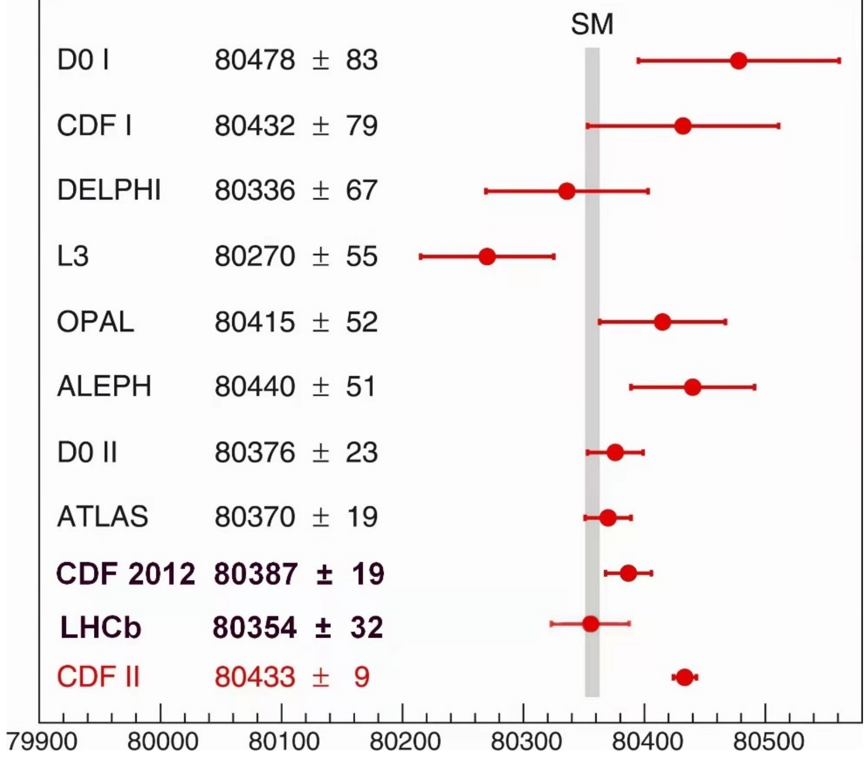
	240 GeV, 20 ab^{-1}		360 GeV, 1 ab^{-1}		
	ZH	vvH	ZH	vvH	eeH
inclusive	0.26%		1.40%	\	\
H→bb	0.14%	1.59%	0.90%	1.10%	4.30%
H→cc	2.02%		8.80%	16%	20%
H→gg	0.81%		3.40%	4.50%	12%
H→WW	0.53%		2.80%	4.40%	6.50%
H→ZZ	4.17%		20%	21%	
$H \to \tau\tau$	0.42%		2.10%	4.20%	7.50%
$H \to \gamma\gamma$	3.02%		11%	16%	
$H \to \mu\mu$	6.36%		41%	57%	
$H \to Z\gamma$	8.50%		35%		
$Br_{upper}(H \to inv.)$	0.07%				
Γ_H	1.65%		1.10%		





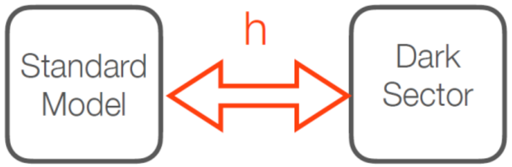


Observable	current precision	CEPC precision (Stat. Unc.)	CEPC runs	main systematic
Δm_Z	2.1 MeV [37–41]	0.1 MeV (0.005 MeV)	Z threshold	E_{beam}
$\Delta\Gamma_Z$	2.3 MeV [37–41]	0.025 MeV (0.005 MeV)	Z threshold	E_{beam}
Δm_W	9 MeV [42–46]	0.5 MeV (0.35 MeV)	WW threshold	E_{beam}
$\Delta\Gamma_W$	49 MeV [46–49]	2.0 MeV (1.8 MeV)	WW threshold	E_{beam}
Δm_t	0.76 GeV [50]	$\mathcal{O}(10)$ MeV[a]	$t\bar{t}$ threshold	
ΔA_e	4.9×10^{-3} [37, 51–55]	1.5×10^{-5} (1.5×10^{-5})	Z pole ($Z \to \tau\tau$)	Stat. Unc.
ΔA_μ	0.015 [37, 53]	3.5×10^{-5} (3.0×10^{-5})	Z pole ($Z \to \mu\mu$)	point-to-point Unc.
ΔA_τ	4.3×10^{-3} [37, 51–55]	7.0×10^{-5} (1.2×10^{-5})	Z pole ($Z \to \tau\tau$)	tau decay model

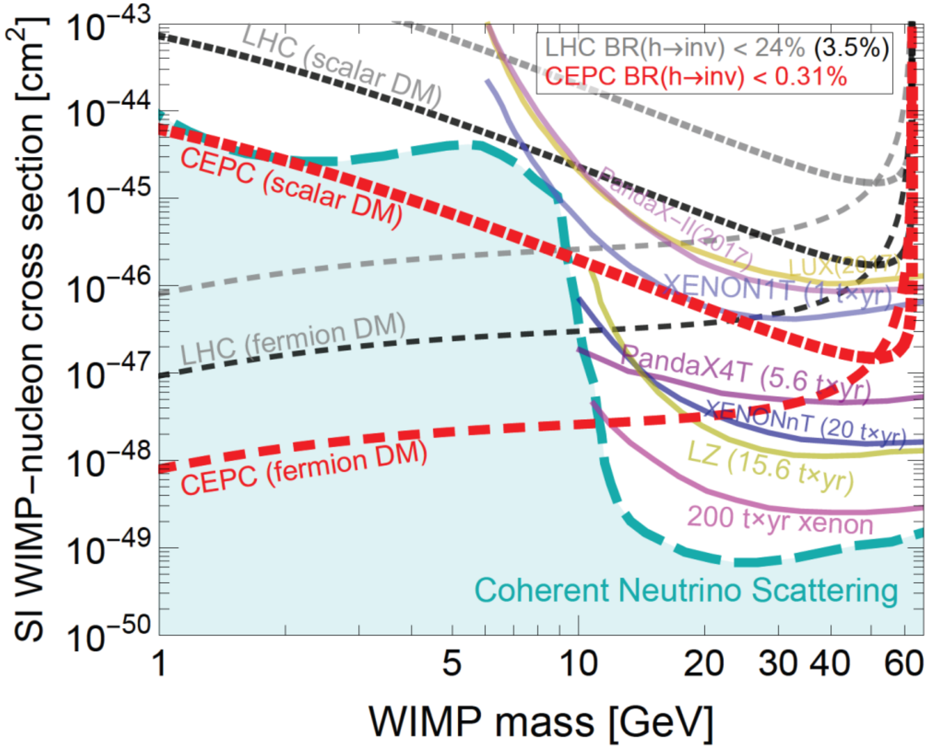


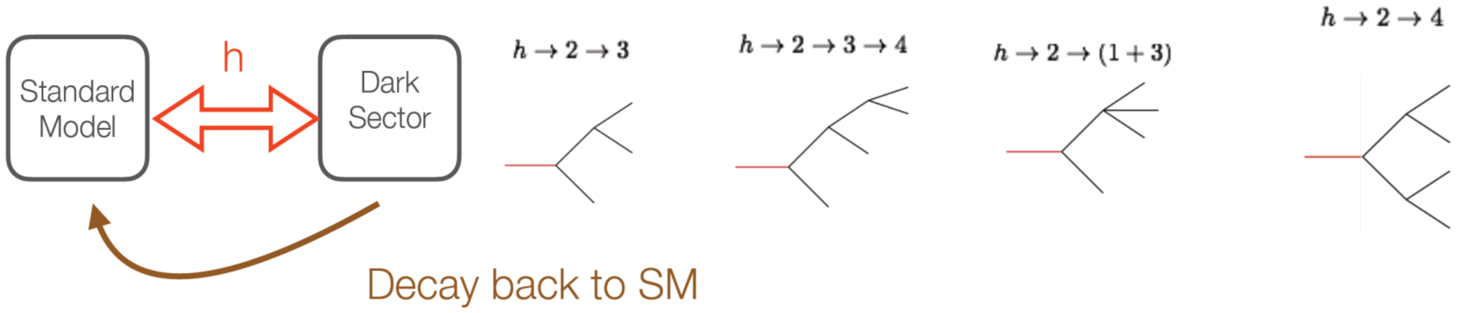
$BR(Z \to \mu e)$	$< 7.5\times10^{-7}$	$10^{-8}-10^{-10}$	$\mathcal{O}(10^{-9})$	PID limited
$BR(Z \to \pi^+\pi^-)$			$\mathcal{O}(10^{-10})$	$\sigma(\vec{p}_{track})$ limited, good PID
$BR(Z \to \pi^+\pi^-\pi^0)$			$\mathcal{O}(10^{-9})$	$\tau\tau$ bkg
$BR(Z \to J/\psi\gamma)$	$< 1.4\times10^{-6}$		$10^{-9}-10^{-10}$	$\ell\ell\gamma+\tau\tau\gamma$ bkg
$BR(Z \to \rho\gamma)$	$< 2.5\times10^{-5}$		$\mathcal{O}(10^{-9})$	$\tau\tau\gamma$ bkg, $\sigma(p_{track})$ limited

Discovery Potential for New Physics

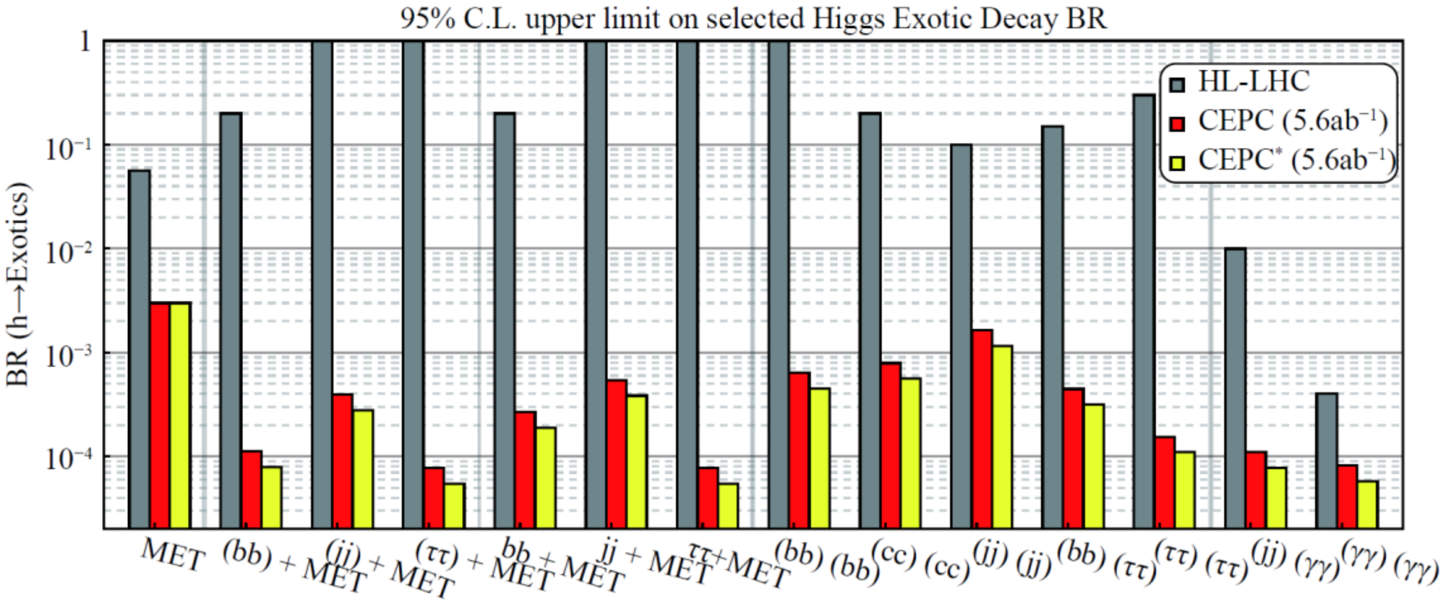


$$h \to X_{\rm dm} X_{\rm dm}$$





Higgs decays into BSM particles, H→ X_1X_2



Significantly better sensitivity for dark matter and selected Higgs exotic decays than HL-LHC

Summary

- **Two electron-positron colliders proposed by Chinese scientists**
  - **CEPC: Ecm = 90-360 GeV, peaking $\mathcal{L} >$ (5, 115)×1034 cm-2s-1 at (240, 91) GeV**
  - **STCF: Ecm = 2 - 7 GeV, peaking $\mathcal{L} >$ 5×1034 cm-2s-1**
  - **Both aim precision study of the SM, as well as the new physics searches**
  - **Milestones: CDRs released**
  - **Active R&D on machine, detector, physics, and MDI ongoing**
  - **Made major progress + breakthroughs in common technologies**
  - **Industrial involvements**
  - **International collaboration and engagement**
- **Efforts on "科学院大科学装置规划" to realize at least one of them**
- **The SM has been "normal science" for 50+ years, we need new paradigms in our field**
- **China should/could play a more important role in the future**

"The greater danger for most of us lies not in setting our aim too high and falling short; but in setting our aim too low, and achieving our mark" *(Michelangelo)*

Aim high or we will not realize the potential of our field, discovery will be stalled and we betray ourselves and the next generation.

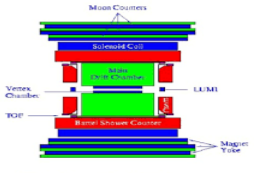
"取法于上，仅得为中，取法于中，故为其下" — 李世民《帝范》

Photo credit: Michael Hoch/CERN

Extras

Tau-Charm Factory in China

30 yields history , Successful and fruitful physics results

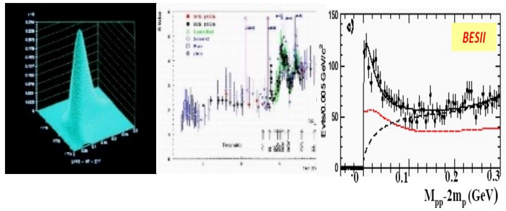


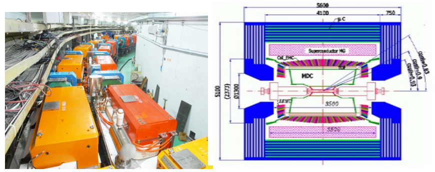
Side view of the BES detector

BEPCI /BESI-II

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

1990

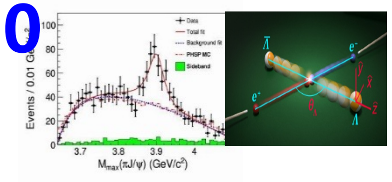




BEPCII/BESIII

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

2010



2030

STCF?

($10^{35}cm^{-2}s^{-1}$)?

BEPCII/BESIII

Natural extension

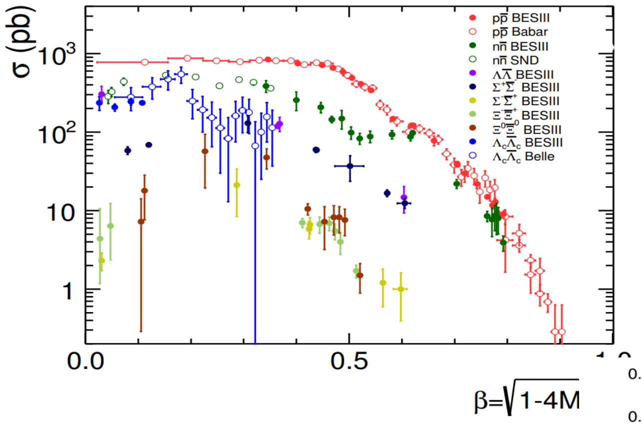
Challenge of BEPCII/BESIII experiment :

- **Successful operation for 13 years, but limited potential for further upgrade**
- **BEPCII/BESIII lifetime is less than 10 years。**
- **Some key scientific questions require higher luminosity and wider CME.**

Electromagnetic Form Factors

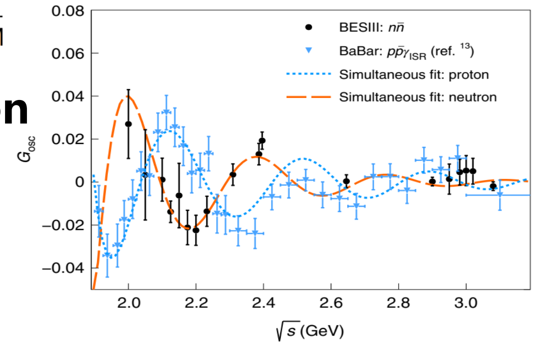
Fundamental properties of the nucleon, connected to charge and magnetization distributions, crucial testing ground for models of the nucleon internal structure

Several "Surprise" results from BESIII



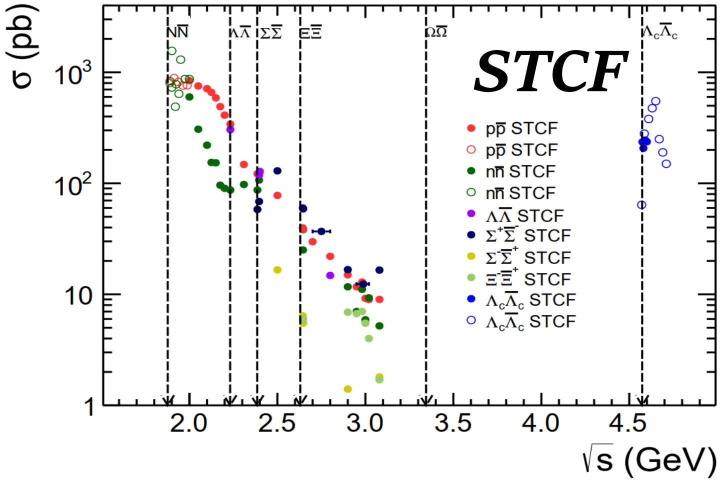
Abnormal X-sec at production threshold

Oscillation as function of CME
Orthogonal between neutron and proton



STCF unique features :

- **Threshold Production**
- **Low background**
- **Almost all baryons**
- **Incomparable precision**



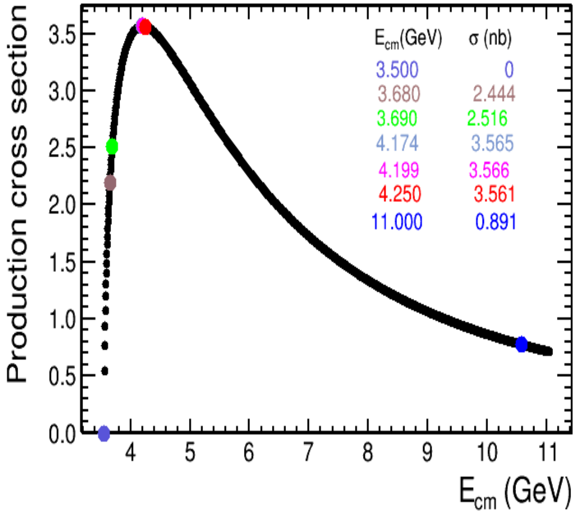
STCF provide opportunities for systematical and precise measurements, and to understand the nature the nucleons

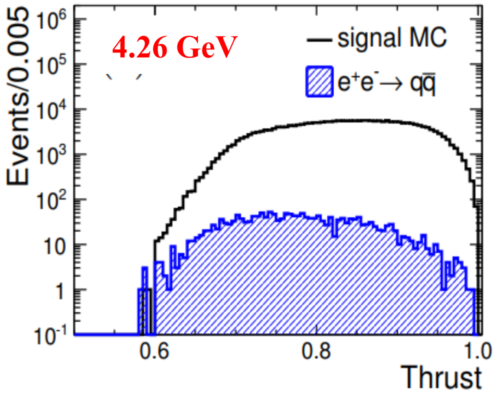
LFV in τ decays

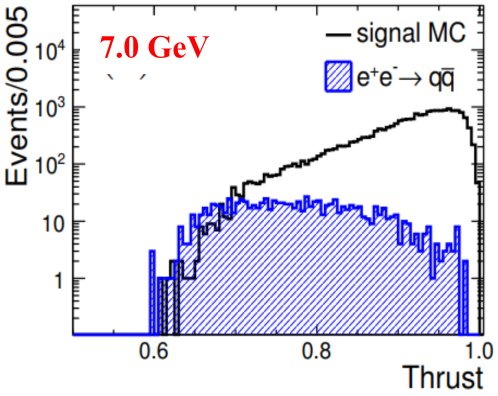
LFV is a sensitive probe for NP, τ decays are an ideal processes for LFV

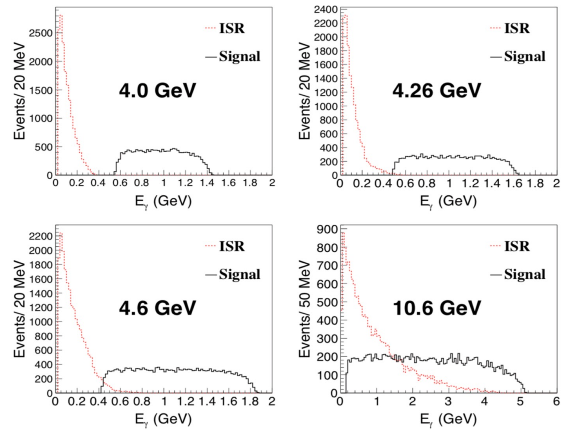
τ production at STCF :

- Peaking x-Sec in 4-5 GeV
- At 4.26 GeV, tau pair number/year: $3.5\times\mathbf{10^9}$
- $e^+e^- \to \gamma\tau^+\tau^-$ is not the main background
- Improved π/μ mis-id rate at STCF
- Entangled topology of $e^+e^- \to \tau^+\tau^-$
- Large $e^+e^- \to q\bar{q}$ background at low c.m.e

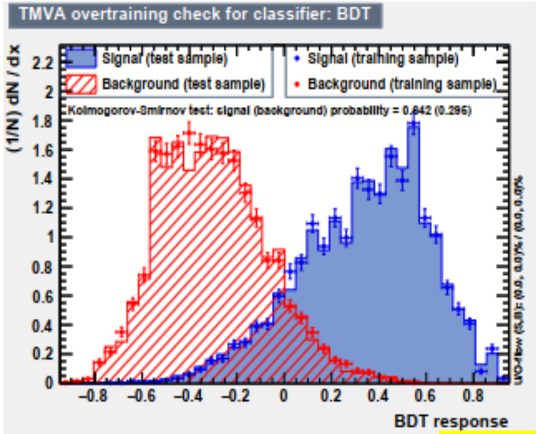


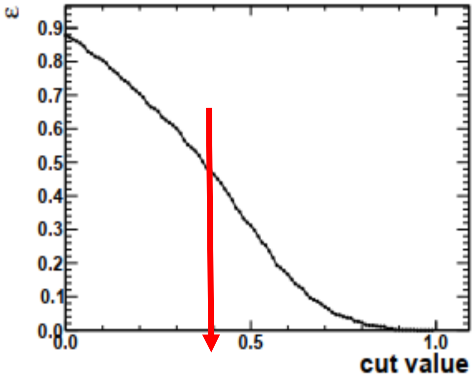






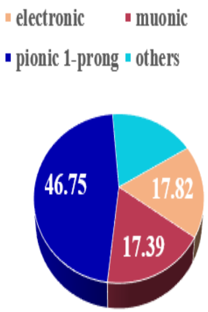
LFV decay of $\tau \to \gamma\mu / \boldsymbol{lll}$

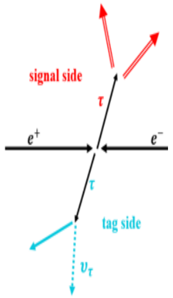


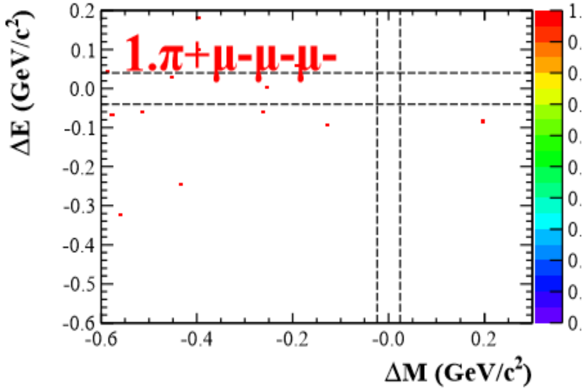


- **Tag side:** $\tau \to e\upsilon\bar{\upsilon},\ \pi\upsilon,\ \pi\pi^0\upsilon$ $(\mathcal{B}r = 54\%)$
- **Dominant background:** $e^+e^- \to \mu^+\mu^-$ **and** $e^+e^- \to \tau^+\tau^-$, $\tau^+ \to \pi\pi^0\upsilon, \tau^- \to \mu\upsilon\bar{\upsilon}$

$$\mathcal{B}_{UL}^{90}(\tau \to \gamma\mu) < \frac{N_{UL}^{90}}{2\varepsilon N_{\tau\tau}} \sim 1.2\times10^{-8}\ (1\text{ab}^{-1})$$







- **Tag side:** $\tau \to e\upsilon\bar{\upsilon},\ \mu\upsilon\bar{\upsilon},\ \pi\upsilon + n\pi^0$ $(\mathcal{B}r = 82\%)$
- **Almost background free, the sensitivity :** $\mathcal{B}_{UL}^{90}(\tau \to \mu\mu\mu) \sim 1/\mathcal{L}$
- **Best efficiency** $(\tau \to \mu\mu\mu)$**: 22.5% (including tag branching fraction)**

$$\mathcal{B}_{UL}^{90}(\tau \to \mu\mu\mu) < \frac{N_{UL}^{90}}{2\varepsilon N_{\tau\tau}} \sim 1.5\times10^{-9}(1\text{ab}^{-1})$$

LFV in J/ψ decays

- The cLFV decays of vector mesons $V \to l_i l_j$ are also predicted **in various of extension models** of SM:

$$\mathcal{B}^{90}_{UL}(J/\psi \to e\mu) < 10^{-13}$$

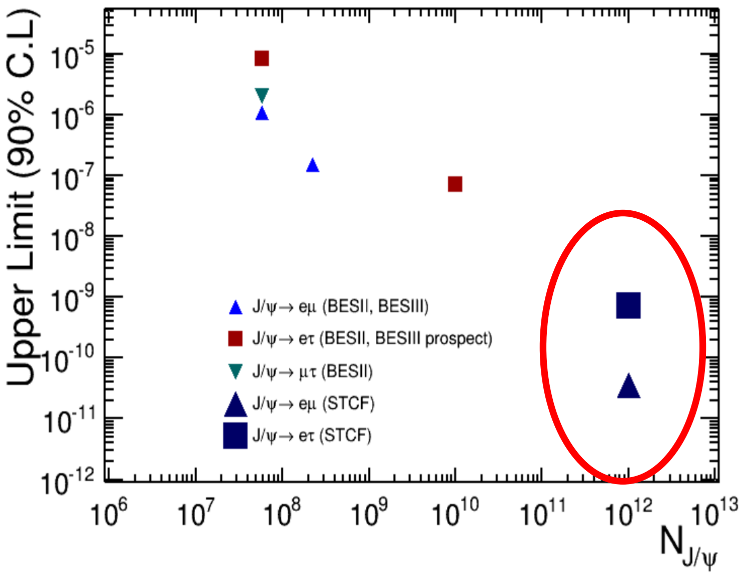
$$\mathcal{B}^{90}_{UL}(J/\psi \to e(\mu)\tau)\ ) < 10^{-9}$$

- Taking efficiency from BESIII, 1 **trillion J/ψ result** the upper limit to be:

$$\mathcal{B}^{90}_{UL}(J/\psi \to e\mu) < 3.6\times10^{-11}$$

$$\mathcal{B}^{90}_{UL}(J/\psi \to e\tau)\ ) < 7.1\times10^{-10}$$

- The $\mathcal{B}^{90}_{UL}(J/\psi \to e\tau)$) can be further **optimized** with better PID.



CEPC Financial Model

Funding Sources	Financial Model #1 （RMB）	Financial Model #2 (RMB)
Central Government	30B	6-10B
Local Government	Land, Infrastructure	25-18B Land, Infrastructure
International Partners	1-5B	1-5B
Companies & Donations	0-3B	0-3B
Total Budget	36B	36B

In Oct., 2021: Institute of Science and Technology Strategic Consulting, CAS is carrying out an independent assessment of Social Cost Benefit Analysis for the CEPC project, the report will be available in this year.

CEPC Accelerator TDR Design Improvement

2018 CDR Baseline Design

	Higgs	W	Z（3T）	Z（2T）
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5 × 2			
Piwinski angle	3.48	7.0	23.8	
Particles /bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number	242	1524	12000 (10% gap)	
Bunch spacing (ns)	680	210	25	
Beam current (mA)	17.4	87.9	461.0	
Synch. radiation power (MW)	30	30	16.5	
Bending radius (km)	10.7			
Momentum compaction (10^{-5})	1.11			
β function at IP β_x^*/β_y^* (m)	0.36/0.0015	0.36/0.0015	0.2/0.0015	0.2/0.001
Emittance x/y (nm)	1.21/0.0024	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.06	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.018/0.109	0.013/0.123	0.004/0.06	0.004/0.079
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz)	650			
Harmonic number	216816			
Natural bunch length σ_z (mm)	2.72	2.9[illegible]	[illegible]	
Bunch length σ_z (mm)	4.4	[illegible]	[illegible]	
Damping time $\tau_x/\tau_y/\tau_E$ (ms)	[illegible]	[illegible]	[illegible]849.5/849.5/425.0	
Natural Chromaticit[illegible]	[illegible]	[illegible]1161	-491/-1161	-513/-1594
Betat[illegible]	363.10 / 365.22			
S[illegible]	0.065	0.040	0.028	
H[illegible] (2 cell) (k[illegible]	0.46	0.75	1.94	
Natural energy spread (%)	0.100	0.066	0.038	
Energy spread (%)	0.134	0.098	0.080	
Energy acceptance requirement (%)	1.35	0.90	0.49	
Energy acceptance by RF (%)	2.06	1.47	1.70	
Photon number due to beamstrahlung	0.082	0.050	0.023	
Beamstruhlung lifetime /quantum lifetime[†] (min)	80/80	>400		
Lifetime (hour)	0.43	1.4	4.6	2.5
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP (10^{34} cm^{-2}s^{-1})	3	10	17	32

[†] include beam-beam simulation and real lattice

2021 Improved Design

	ttbar	Higgs	W	Z
Number of Ips		2		
Circumference [km]		100.0		
SR power per beam [MW]		30		
Half crossing angle at IP [mrad]		16.5		
Bending radius [km]		10.7		
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
Bunch population [10^10]	20	14	13.5	14
Beam current [mA]	3.3	16.7	84.1	803.5
Momentum compaction [10^-5]	0.71	0.71	1.43	1.43
Beta functions at IP (bx/by) [m/mm]	1.04/2.7	0.33/1	0.21/1	0.13/0.9
Emittance (ex/ey) [nm/pm]	1.4/4.7	0.64/1.3	0.87/1.7	[illegible]7/1.4
Beam size at IP (sigx/sigy) [um/nm]	39/113	15/36	[illegible]	[illegible]/35
Bunch length (SR/total) [mm]	2.2/2.9	2.3/[illegible]	[illegible]	2.5/8.7
Energy spread (SR/total) [%]	0.15/0.20	[illegible]	0.07/0.14	0.04/0.13
Energy acceptance (DA/RF) [%]	2.3[illegible]	[illegible]/2.2	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	0.071[illegible]	0.015/0.11	0.012/0.113	0.004/0.127
RF voltage [GV]	10	2.2	0.7	0.12
RF frequency [MHz]	650	650	650	650
HOM power per cavity (5/2/1cell)[kw]	0.4/0.2/0.1	1/0.4/0.2	-/1.8/0.9	-/-/5.8
Qx/Qy/Qs	0.12/0.22/0.078	0.12/0.22/0.049	0.12/0.22/	0.12/0.22/
Beam lifetime (bb/bs)[min]	81/23	39/18	60/717	80/182202
Beam lifetime [min]	18	12.3	55	80
Hour glass Factor	0.89	0.9	0.9	0.97
Luminosity per IP[1e34/cm^2/s]	0.5	5.0	16	115

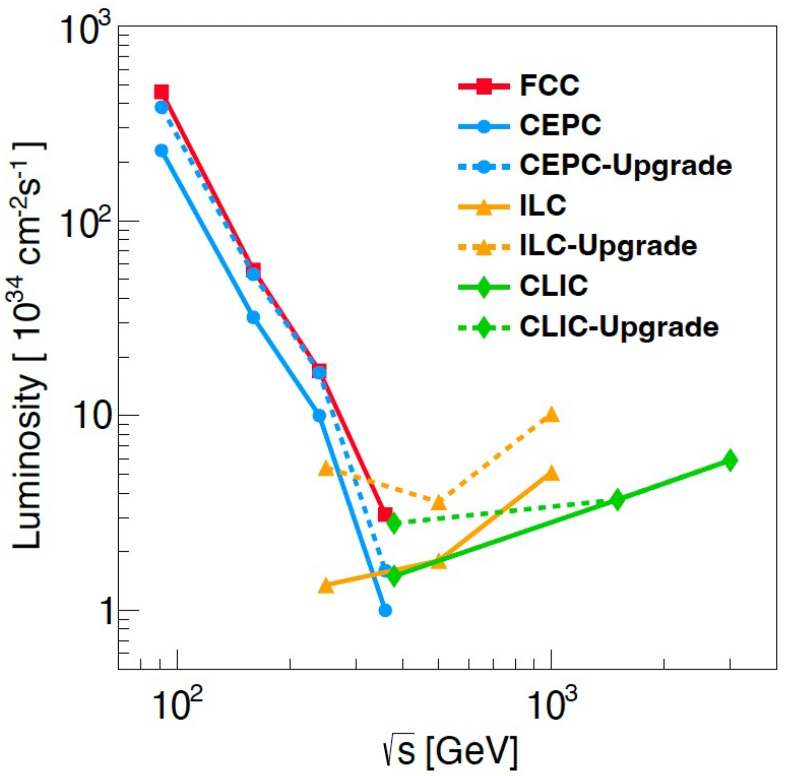
67%⇑

259%⇑

CEPC Accelerator TDR Design (Upgrade)

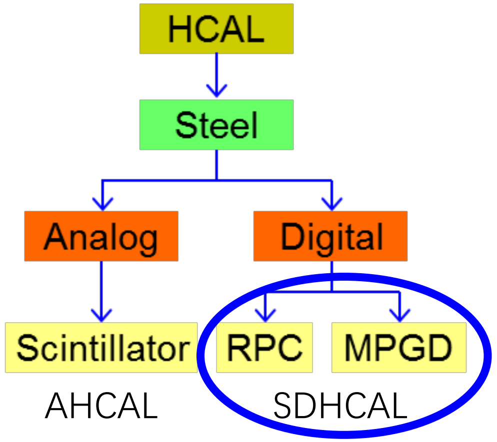
	Higgs	W	Z	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	50			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	120	80	45.5	180
Energy loss per turn [GeV]	1.8	0.357	0.037	9.1
Piwinski angle	5.94	6.08	24.68	1.21
Bunch number	415	2162	19918	58
Bunch spacing [ns]	385	154	15(10% gap)	2640
Bunch population [10^{10}]	14	13.5	14	20
Beam current [mA]	27.8	140.2	1339.2	5.5
Momentum compaction [10^{-5}]	0.71	1.43	1.43	0.71
Phase advance of arc FODOs [degree]	90	60	60	90
Beta functions at IP (bx/by) [m/mm]	0.33/1	0.21/1	0.13/0.9	1.04/2.7
Emittance (ex/ey) [nm/pm]	0.64/1.3	0.87/1.7	0.27/1.4	1.4/4.7
Beam size at IP (sx/sy) [um/nm]	15/36	13/42	6/35	39/113
Bunch length (SR/total) [mm]	2.3/3.9	2.5/4.9	2.5/8.7	2.2/2.9
Energy spread (SR/total) [%]	0.10/0.17	0.07/0.14	0.04/0.13	0.15/0.20
Energy acceptance (DA/RF) [%]	1.7/2.2	1.2/2.5	1.3/1.7	2.3/2.6
Beam-beam parameters (xx/xy)	0.015/0.11	0.012/0.113	0.004/0.127	0.071/0.1
RF voltage [GV]	2.2 (2cell)	0.7 (2cell)	0.12 (1cell)	10 (5cell)
RF frequency [MHz]	650			
Beam lifetime [min]	20	55	80	18
Luminosity per IP[10^{34}/cm^2/s]	8.3	26.6	191.7	0.8

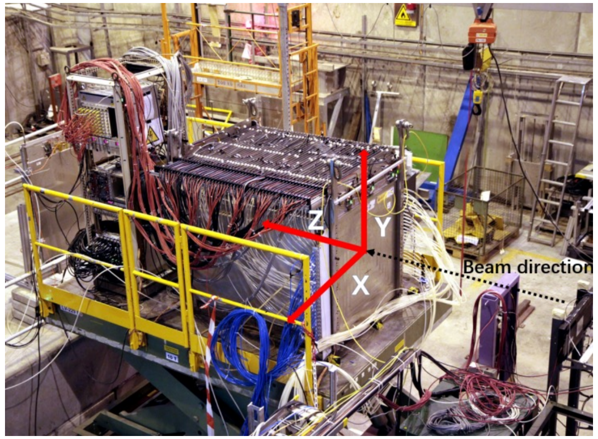
CEPC accelerator whitepaper for Snowmass21, arXiv:2203.09451



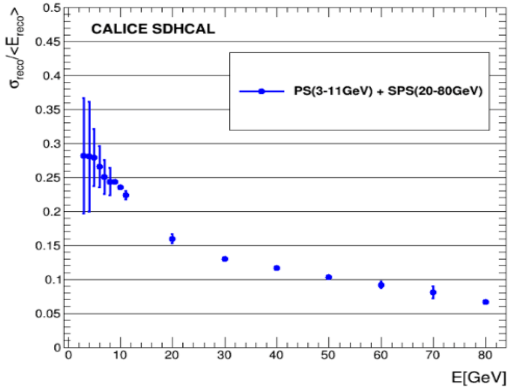
Higher SR power of 50MW, the Lumi. will increase ~66%.

CEPC R&D: SDHCAL

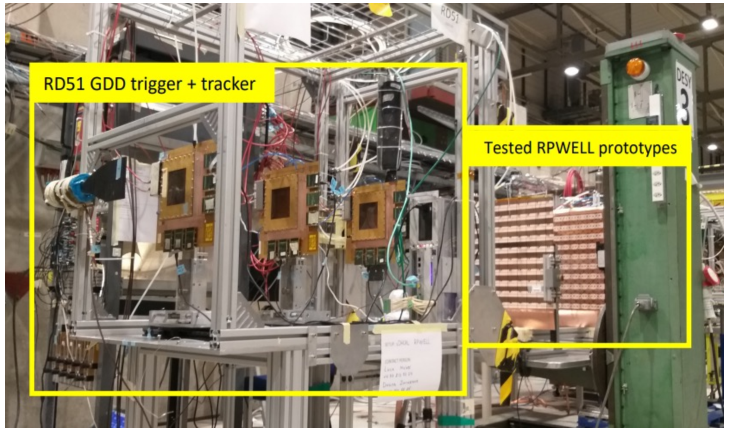




SDHCAL-GRPC (1.3 m^3, IPNL)



[JINST 15, P10009 (2020)](#)
[arXiv:2202.09684](#)



SDHCAL-RPWELL (50x50cm^2, WIS)

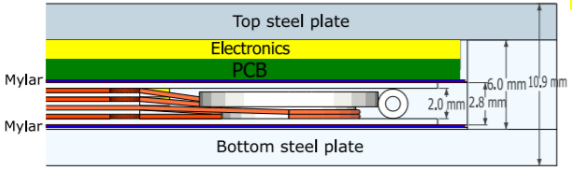
MOST 1: RPC and MPGD (RWELL) R&D, MIP Eff > 95%

GRPC 1m x 1m (SJTU)

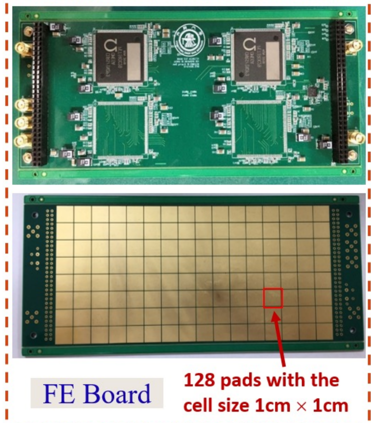
[JINST 16 (2021) P12022](#)

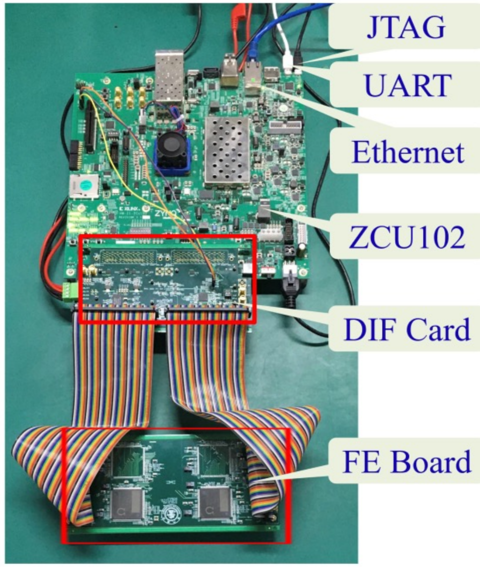
RWELL 0.5m x 1m (USTC+IHEP)

R&D Plan: 5-D SDHCAL (X, Y, Z, E, Time)
- MRPC + fast timing PETIROC ASIC (~40 ps)



IPNL
SJTU
IJCLab
OMEGA
CIEMAT





➢ Event classification with Graph neural network achieves an average accuracy of ~89%