Progress of Super Tau Charm Facility (STCF) in China

Haiping Peng

penghp@ustc.edu.cn

Department of Modern Physics (MPHY)

State Key Laboratory of Particle Detection and Electronics

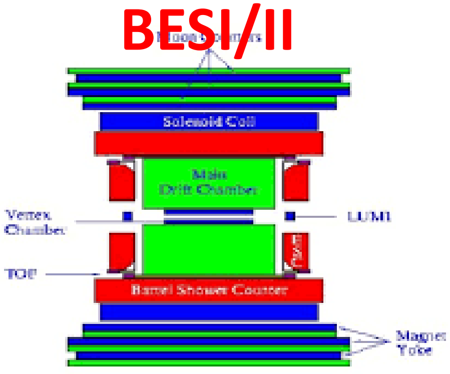
University of Science and Technology, China (USTC)

30 Years of τ-c facility in China

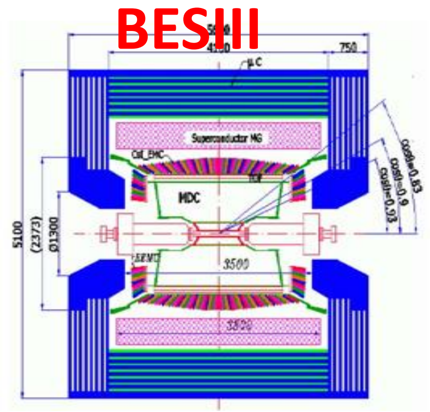
BEPCI (1988–2005)

$10^{31}cm^{-2}s^{-1} \Rightarrow 10^{33}cm^{-2}s^{-1}$

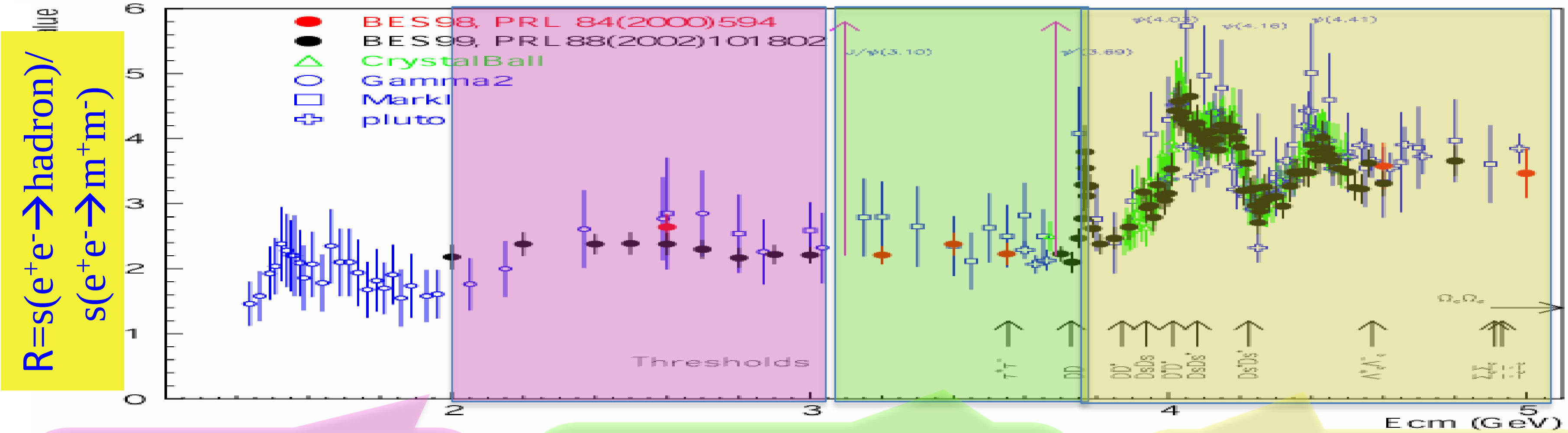
BEPCII (2006–now)



Side view of the BES detector



Broad Physics at τ-c Energy Region



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- 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
- f_D and f_{Ds}
- D_0-D_0 mixing
- Charm baryons

R scan

- **Precision $\Delta\alpha_{QED}$, a_μ, charm quark mass extraction.**
- **Hadron form factor(nucleon, Λ, p).**

Complementary and irreplaceable with other high-precision platforms

Status of BEPCII/BESIII

- BEPCII/BESIII have run 9 years, successful and excellent production, are playing a leading role in tau-charm physics
- Limited by length of storage ring, no space and potential for the upgrade
- Physics study limited by the statistics (luminosity), CME ……
- Challenged by Belle II
- BEPCII/BESIII will end her mission in 5-10 years

A STCF far beyond BEPCII, is nature extension and a viable option for a post-BEPCII HEP project in China

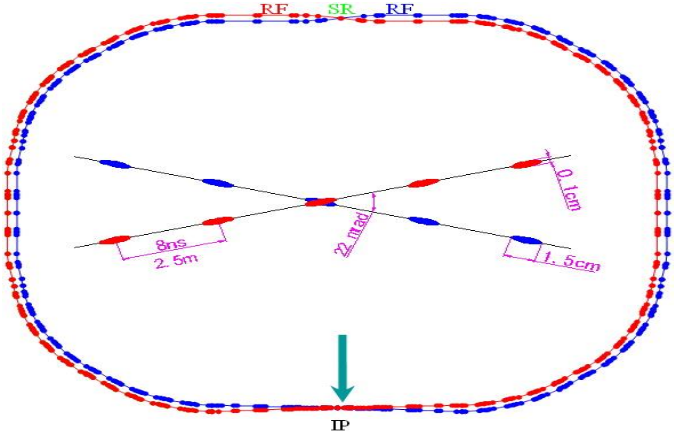
BEPCII vs STCF

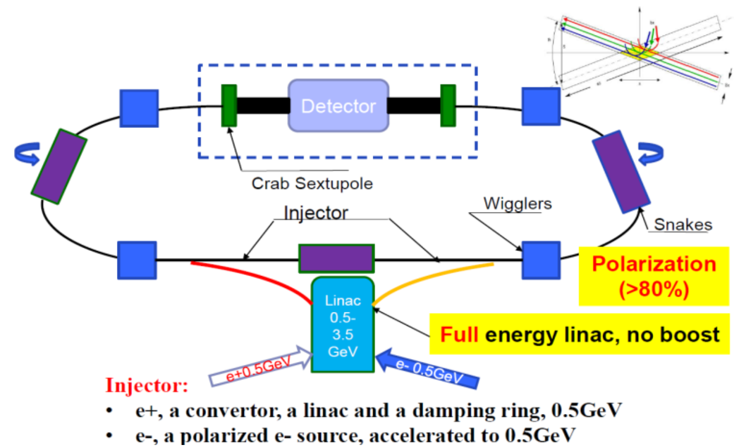
BEPCII

- Peak luminosity 0.6-1×10^{33} cm^{-2}s^{-1} at 3.773 GeV
- Energy range E_{cm} = 2 – 4.6 GeV
- No Polarization

Designing STCF

- Peak luminosity 1×10^{35} cm^{-2}s^{-1} at 4 GeV
- Energy range E_{cm} = 2–7 GeV
- Single/double Beam Polarization (Phase II)





Rich of physics program, unique for physics with c quark and τ leptons, important playground for study of QCD, exotic hadrons and search for new physics.

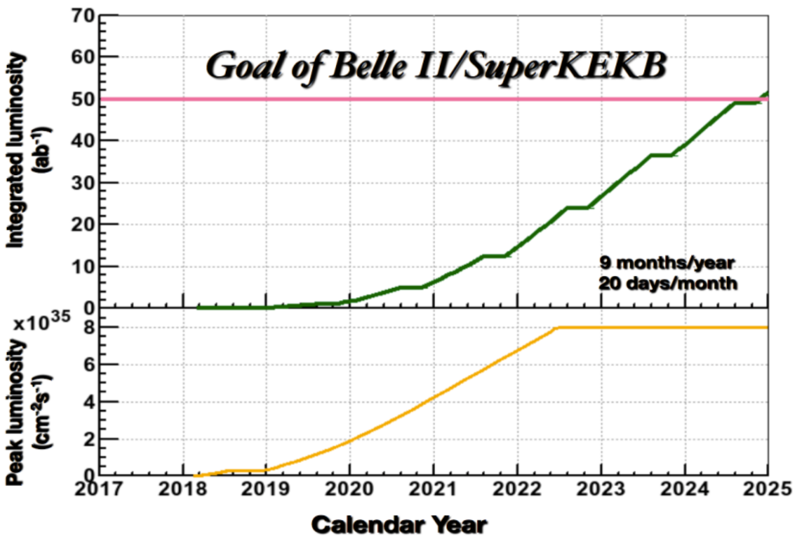
Integral Luminosity of STCF

- No Synchrotron radiation mode, assume running time 9 months/year
- Assume data taking efficiency 90%

$$10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1} \times 86400\mathrm{s} \times 270\mathrm{days} \times 90\% \sim \mathbf{2.0ab^{-1}/year}$$

10 years data taking, total 20 ab^{-1} conservatively

Excellent opportunities for the τ-charm physics

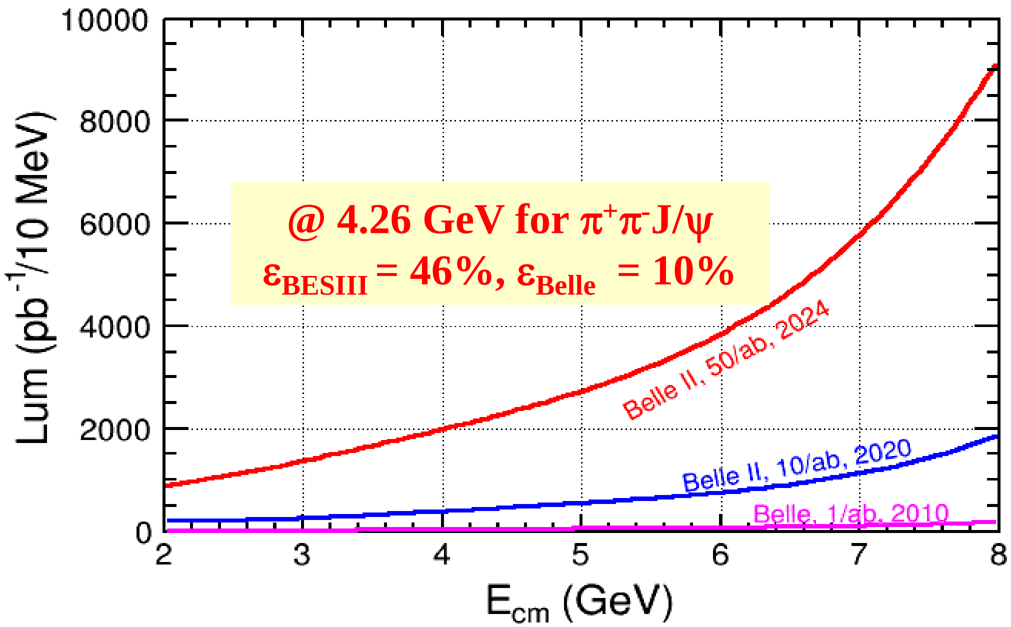


BELLEII

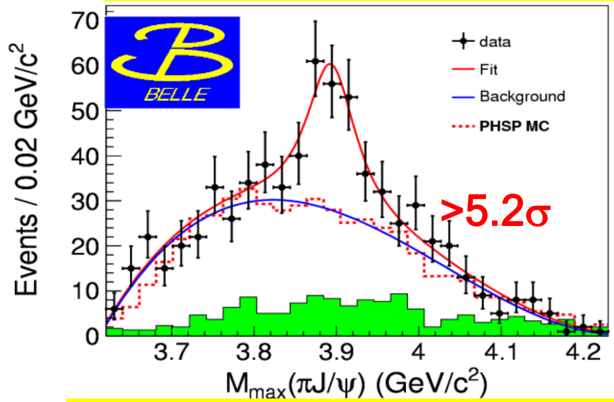
- each 1 ab^{-1} dataset provides
  - $\sim 1.1 \times 10^9$ $B\bar{B} \Rightarrow$ a B-factory;
  - $\sim 1.3 \times 10^9$ $c\bar{c} \Rightarrow$ a charm factory;
  - $\sim 0.9 \times 10^9$ $\tau^+\tau^- \Rightarrow$ a τ factory;
  - wide $E^{\mathrm{eff.}}_{\mathrm{CM}}$=[0.5-10] GeV via ISR.

Native question : Compete between STCF and BELLE II ?

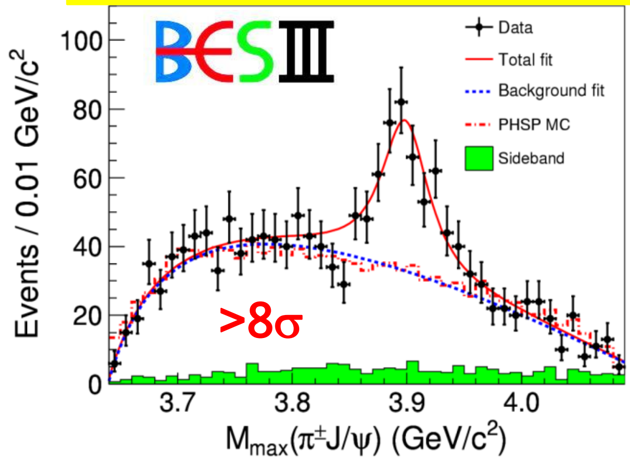
Charmonium-(Like) Physics



Belle with ISR: PRL110, 252002
967 fb^{-1} in 10 years running time



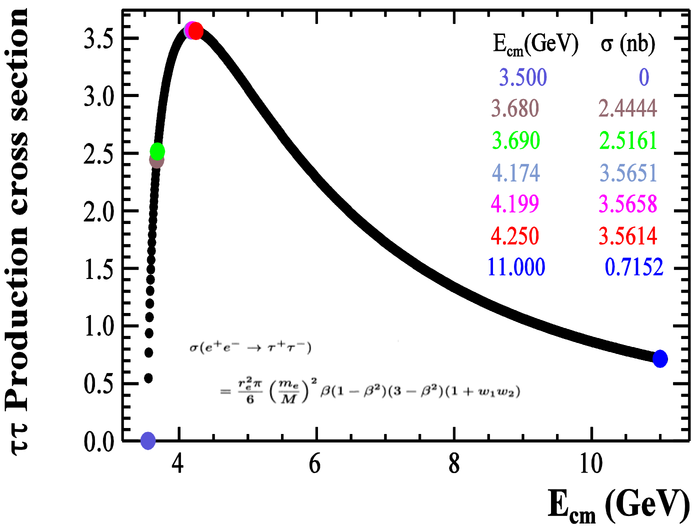
BESIII at 4.260 GeV: PRL110, 252001
0.525 fb^{-1} in one month running time



- **B factory :** Total integrate effective luminosity between 4-7 GeV is 1.5 ab^{-1} for 50 ab^{-1} data
- **τ-C factory** : scan in region 4-6 GeV, 10 MeV/step, every point have 10 fb^{-1}/year, 10 time of Belle II for 50 ab^{-1} data
- **τ-C factory** have much higher efficiency than B Factory
- **τ-C factory** have low bkgs for production at threshold

τ Lepton Physics

- X sec grows from 0.1nb near threshold to 3.5nb at 4.25GeV
  - 2×10^8 tau pairs/year at threshold (x-sec = 0.1nb)
  - 7×10^9 tau pairs/year at 4.25GeV (x-sec = 3.5nb)
  - 10^{10} tau pairs per year for Belle II (x-sec = 1nb)
- Physics Highlighted Physics program
  - Precision measurements of α_s, m_s, V_{us}
  - Lepton universality : m_τ, $\tau\to\pi^+\nu_\tau$ and $\tau\to K^+\nu_\tau$
  - Lorentz structure of the amplitude for $\tau\to\ell\nu_\ell\nu_\tau$
  - Search for LFV processes : $\tau\to\ell\gamma$, $\ell\ell\ell$, ℓh
  - Search for CPV
  - V-A Structure of the weak current in leptonic decays
  - Rare hadronic decays
- Competition to Belle II
  - Threshold effect is important for controlling and understanding background
  - Longitudinal polarization of the initial beams will significantly increase sensitivity in searches for CPV in lepton decays.



CP Violation in τ Decay

- CP violation is observed in B, D and K sectors to date , but not observed in lepton sector yet.
- The discovery of CPV in the tau sector would be a clean signature of NP
- One of the most promising CPV channels is $\tau^- \to K_S \pi^- \nu$
  - SM CP asymmetry from K_S-K_L mixing is expected to be :
    [Bigi & Sanda, PLB 625, 2005, Grossman &Nir JHEP 1204 (2012) 002]

$$\frac{\Gamma(K_L \to \pi^- l^+ \nu) - \Gamma(K_L \to \pi^+ l^- \overline{\nu})}{\Gamma(K_L \to \pi^- l^+ \nu) + \Gamma(K_L \to \pi^+ l^- \overline{\nu})} = |p|^2 - |q|^2 \simeq (3.27 \pm 0.12) \times 10^{-3}$$

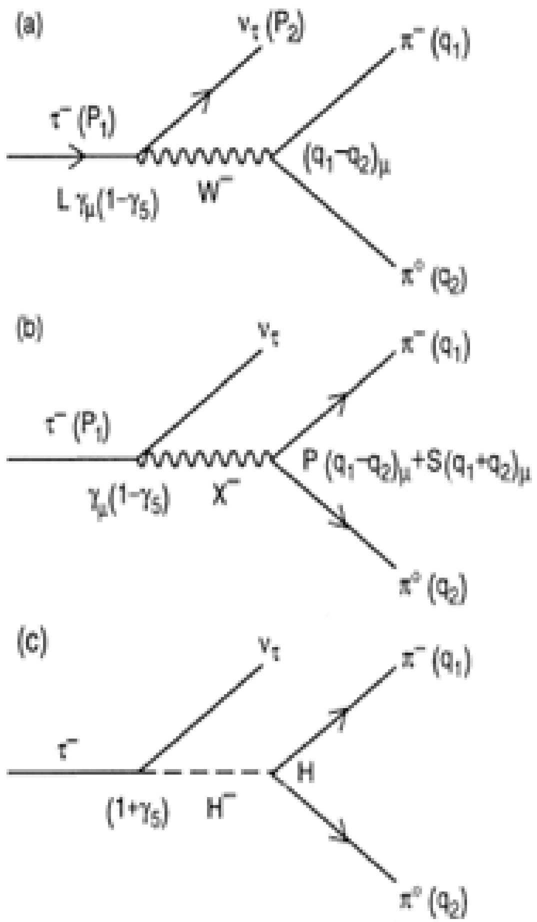
  - BaBar measurement [PRD 85, 031102]

$$A_\tau \equiv \frac{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S \nu_\tau)} = (-4.5 \pm 2.4 \pm 1.1) \times 10^{-3}.$$

  - Belle measurement [PRL 107, 131801]

$$|\mathrm{Im}(\eta_S)| < 0.026 \text{ or better}$$

$A_{cp} = (1.8 \pm 2.1 \pm 1.4) \times 10^{-3}$ @ W ~ [0.89-1.11] GeV



Charge Higgs, new Scalar, W_L-W_R Mixings, LeptonQuarks?

τ CPV in Angle Distribution

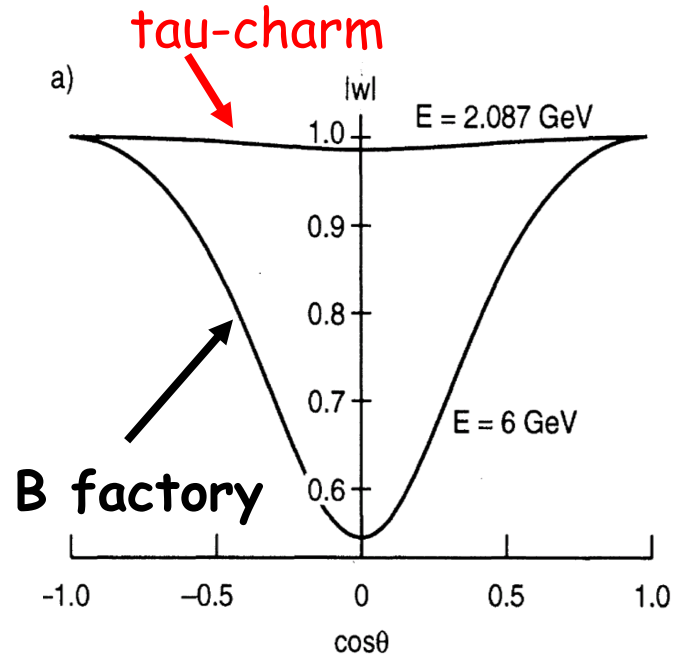
- Measurement on the angular CPV asymmetry is desirable
- Use T-odd rotationally invariant products in >=2 hadrons, such as

$\tau^- \to \pi^-\pi^0\nu_\tau / k^-\pi^0\nu_\tau$, $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau / K^-\pi^+\pi^-\nu_\tau$: $P_2^T \cdot (\vec{P}_{\pi^+} \times \vec{P}_{\pi^0})$

- Polarized of τ and beam are necessary
- Figure of Merits

$$\begin{aligned} \text{merit} &= \text{luminosity} \times \bar{w}_Z \times \text{ total cross section} \\ &\propto \text{luminosity} \times (w_1 + w_2) \\ &\quad \times \sqrt{1-a^2}a^2(1+2a) \;, \end{aligned}$$

Y. S. TSAI, PRD 51 (1995) 3172



BESIII @ 4.25 (10^{33}cm^{-2}s^{-1}) FOM=1

STCF @ 4.25 (10^{35}cm^{-2}s^{-1}) FOM=100

SuperKEKB @ (8×10^{35}cm^{-2}s^{-1}) FOM=52

CPV in Hyperon Decays

- In 1958, Okubo: CPV in hyperon-antihyperon allows ⇒ "Okubo effect"(Direct CPV) Phys. Rev. 109, 984 (1958).
- In 1959, Pais: extended Okubo's proposal to asymmetry parameters in Λ and $\underline{\Lambda}$ decays. Phys. Rev. Lett. 3, 242 (1959).
- In the '80s, a number of calculations were made. CKM predictions, CPV in Λ: $10^{-4} \sim 10^{-5}$

PHYSICAL REVIEW D VOLUME 34, NUMBER 3 1 AUGUST 1986

Hyperon decays and *CP* nonconservation

John F. Donoghue
Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003

Xiao-Gang He and Sandip Pakvasa
Department of Physics and Astronomy, University of Hawaii at Manoa, Honolulu, Hawaii 96822

(Received 7 March 1986)

We study all modes of hyperon nonleptonic decay and consider the *CP*-odd observables which result. Explicit calculations are provided in the Kobayashi-Maskawa, Weinberg-Higgs, and left-right-symmetric models of *CP* nonconservation.

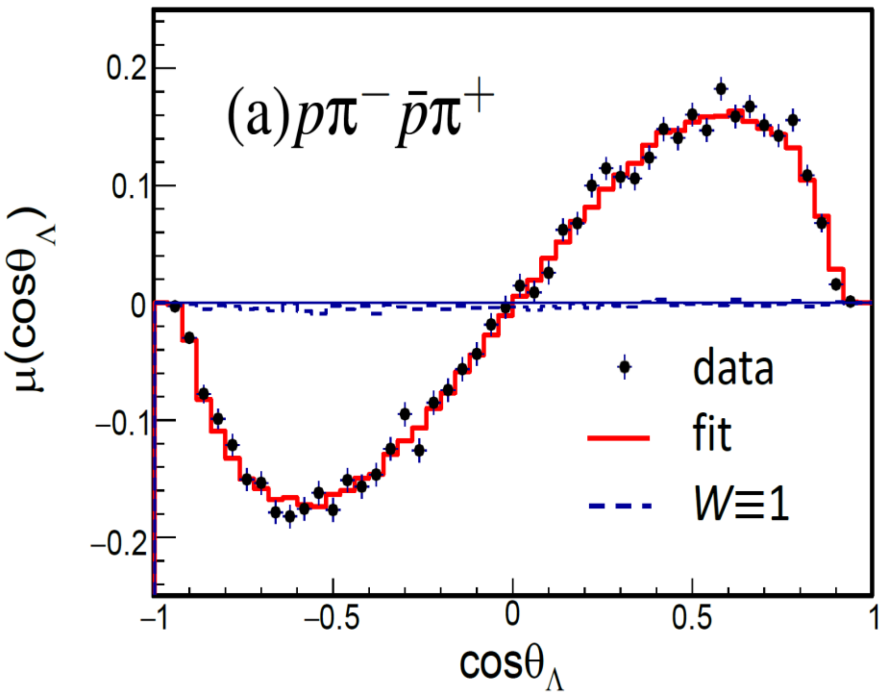
CPV in Hyperon Decays

arXiv:1808.08917

1.31 billion J/ψ events

Quantum correlation in Λ pair

First observation of Spin polarization of Λ in $J/\psi \to \Lambda\bar{\Lambda}$



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]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	

CP test

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

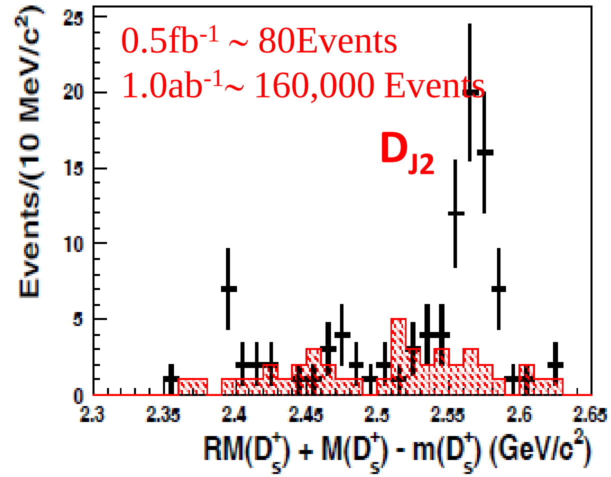
CPV in Hyperon Decays

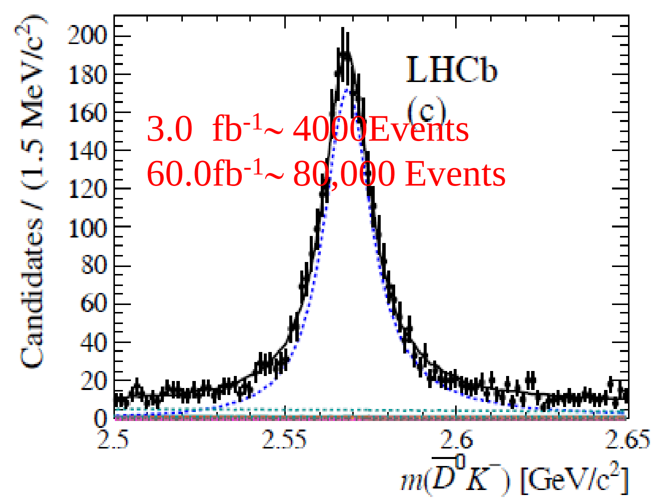
- 40 trillion J/ψ events $\Rightarrow \Delta A_{CP} \sim 10^{-4} - 10^{-5}$
  - Luminosity optimized at J/ψ resonance?
  - Luminosity of STCF: $\times$ 100
  - Beam energy trick $\Rightarrow$ small beam energy spread

    $\Rightarrow$ J/ψ cross-section: $\times$ 10 ??
  - one years data taking
  - No polarization beams are needed
- Challenge: Systematics control
- Full simulation results are necessary!

Charm Physics

- 4×10^9 pairs of $D^{\pm,0}$ and 10^7~$10^8 D_s$ pairs/year
  - 10^{10} charm from Belle II/year
- Competition to Belle II
  - The multiplicity of final state is lower by a factor of 2
  - Threshold effect, clean, double tagging
  - QM coherent state, $J^{PC}=1^{--}$ for DD, $J^{PC}=0^{++}$ for γDD
- Highlighted Physics programs
  - Precise measurement of leptonic, semi-leptonic decay (f_D, f_{Ds}, CKM matrix···)
  - D^0-D^0 bar mixing, CPV
  - Rare Decay (FCNC, LFV, LNV···.)
  - Excite Charm meson D_J, D_{sJ} (mass, width, J^{PC}, decay modes)
  - Charmed Baryons (J^{PC}, Decay modes, Br)
- Some sensitivities @ 1 ab^{-1} data at threshold
  - Direct CPV in $D\rightarrow hh$ sensitivity : 10^{-3}~10^{-4}
  - Probe y : $\Delta(y_{CP})$~0.1%
  - $RM=(x^2+y^2)/2$~10^{-5} in $K\pi$ and $Ke\nu$ channels
  - $\Delta(\cos\delta_{K\pi})$~0.007; $\Delta(\delta_{K\pi})$ ~ 2°





Features in Studying charmed hadron decays

	STCF	Belle(-II)	LHCb
Production yields	★★	★★★★	★★★★★
Background level	★★★★★	★★	★★
Systematic error	★★★★★	★★★	★★
Completeness	★★★★★	★★★	★
(Semi)-Leptonic mode	★★★★★	★★★	★
Neutron/K_L mode	★★★★★	★★	☆
Photon-involved	★★★★★	★★★★★	☆
Absolute measurement	★★★★★	★★★	☆

- Most are precision measurements, which are mostly dominant by the systematic uncertainty
- STCF has overall advantage

Precision measurement of CKM elements

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ \boxed{V_{cd} \; V_{cs}} & & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM matrix

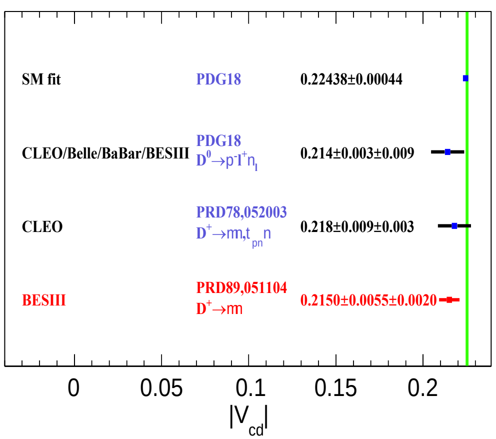
BESIII + B factories + LQCD

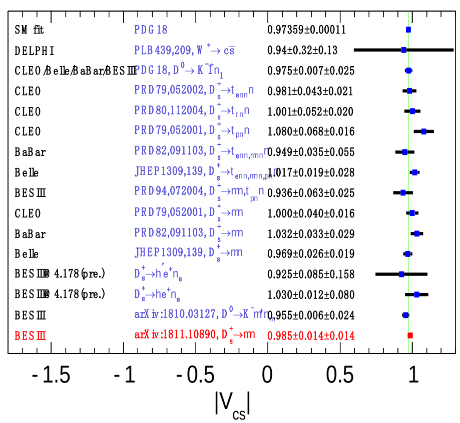
Three generations of quark?

Unitary matrix?

Expected precision < 2% at BESIII

BESIII + B factories + LHCb + LQCD





Future BESIII:

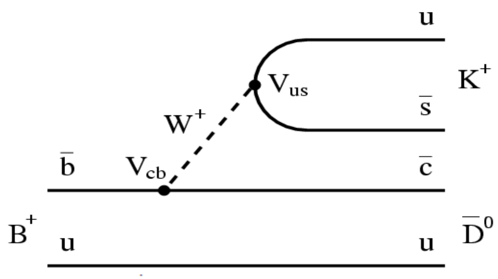
Vcd: ~1.5% (stat. dominant)

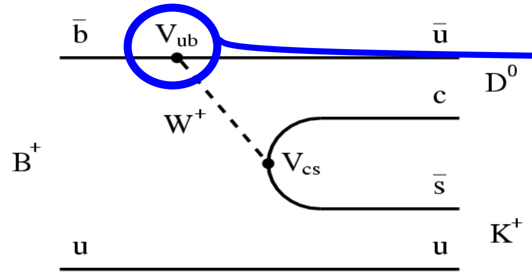
Vcs: ~1.5% (syst. dominant)

STCF: <0.2% (syst. dominant)

systematic control is challenging

γ/ϕ_3 from $B^- \to D^0 K^-$





$$\frac{A(B^+ \to D^0 K^+)}{A(B^+ \to \overline{D^0} K^+)} \equiv r_B e^{i(\delta_B + \phi_3)}$$

Runs	Collected / Expected integrated luminosity	Year attained	γ/ϕ_3 sensitivity
LHCb Run-1 [7, 8 TeV]	3 fb^{-1}	2012	8°
LHCb Run-2 [13 TeV]	5 fb^{-1}	2018	4°
Belle II Run	50 ab^{-1}	2025	1.5°
LHCb upgrade I [14 TeV]	50 fb^{-1}	2030	$< 1°$
LHCb upgrade II [14 TeV]	300 fb^{-1}	(>)2035	$< 0.4°$

BESIII 20/fb:
$\sigma(\gamma) \sim 0.4^o$

→ **STCF is needed!**

Three methods for exploiting interference (choice of D^0 decay modes):

- Gronau, London, Wyler (GLW): Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \to K_s\pi^0$, $D^0 \to \pi^+\pi^-$
- Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+\pi^-$
  - With 1 ab^{-1} @ STCF : $\sigma(\cos\delta_{K\pi}) \sim 0.007$; $\sigma(\delta_{K\pi}) \sim 2^o$ → $\sigma(\gamma) < 0.5^o$
- Giri, Grossman, Soffer, Zupan (GGSZ): Use Dalitz plot analysis of 3-body D^0 decays, e.g. $K_s\pi^+\pi^-$; high statistics; need precise Dalitz model
  - STCF reduces the contribution of *D* Dalitz model to a level of $\sim 0.1^o$

Precision study of the B_c decay

- Era of precision study of the charmed baryon (Λ_c, Ξ_c and Ω_c) decays at STCF
  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 particles
  - 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
  - Rare decays: LFV, BNV, FCNC

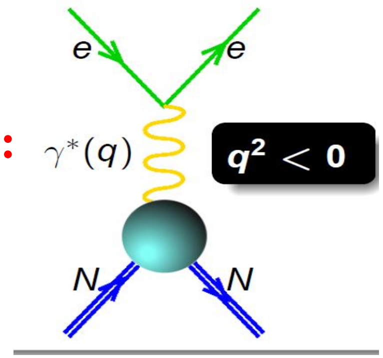
STCF will provide very precise measurements of their overall decays, up to the unprecedented level of 10^{-6} ~10^{-7}

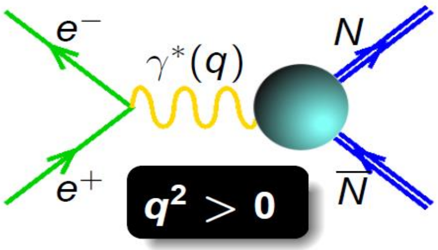
Nucleon Electromagnetic Form Factors (NEFFs)

Spatial distributions of electric charge and current inside the nucleon

$eN \rightarrow eN$ $\qquad$ $e^+e^- \leftrightarrow N\bar{N}, \Lambda\bar{\Lambda}$

Space-like:
FF real

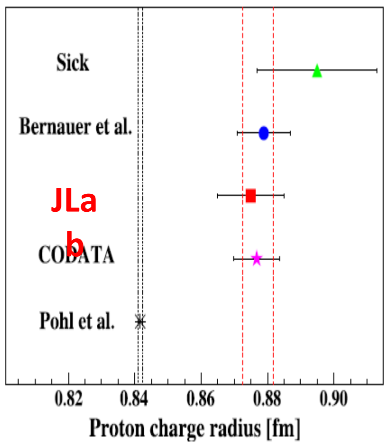




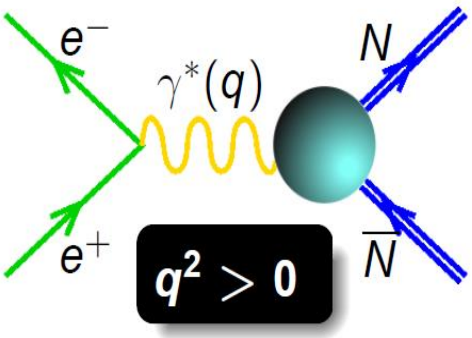
Time-like:
FF complex

Complete picture of nucleon structure requires space-like and time-like FF

- ✦ QCD predictions:
  - ✦ at large q^2, absolute value of $FF(q^2)=FF(-q^2)$
  - ✦ Experiment: time-like FF much larger than space-like FF
- ✦ Squared ratio of n/p form factors ≈ 0.25
  - ✦ Problem: only very poor data for neutron form factor
- ✦ Space-Like (1%) Vs Time-Like (10% BESIII expected)



Time Like FF



$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta\, C}{4 m_{B\bar{B}}^2}\left[\left(1+\cos^2\theta\right)\left|G_M(m_{B\bar{B}})\right|^2 + \frac{1}{\tau}\sin^2\theta \left|G_E(m_{B\bar{B}})\right|^2\right]$$

$$\tau = \frac{m_{B\bar{B}}^2}{4M_B^2} \qquad \beta = \sqrt{1-\frac{1}{\tau}}$$

Coulomb enhancement factor

$$C_{\text{charged}} = \frac{\pi\alpha/\beta}{1-\exp(-\pi\alpha/\beta)} \xrightarrow{(\beta\to 0)} \pi\alpha/\beta$$

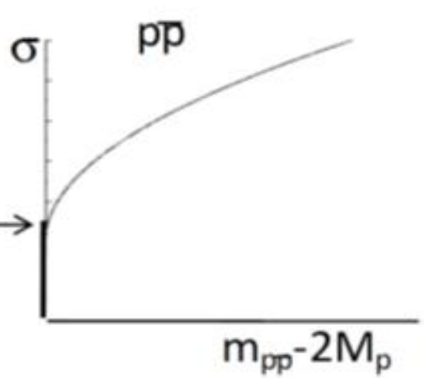
$$C_{\text{neutral}} = 1$$

in point-like approx

in point-like approx:

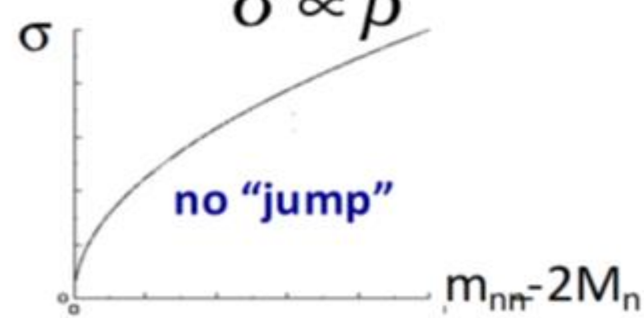
$$\sigma_0 = \frac{\pi^2\alpha^3}{2M_p^2}\left|G_{eff}(2M_p)\right|^2$$

$$\approx 0.85\text{nb}\left|G_{eff}(2M_p)\right|^2$$

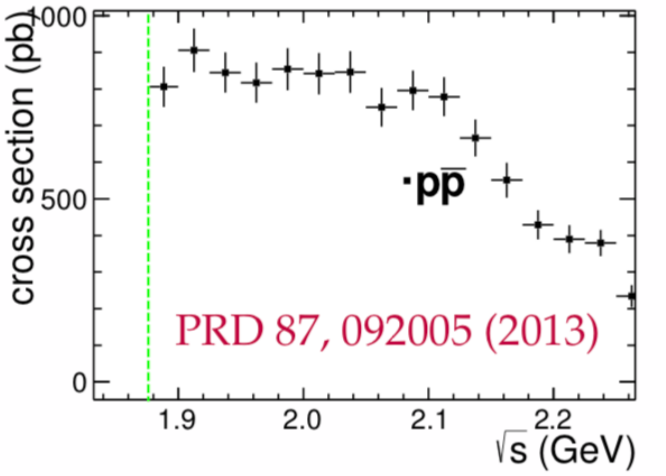


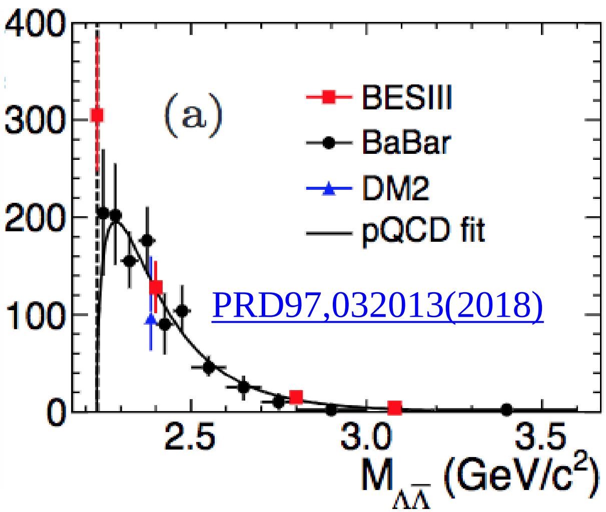
for $n\bar{n}$ ($\Lambda\bar{\Lambda}$): C=1

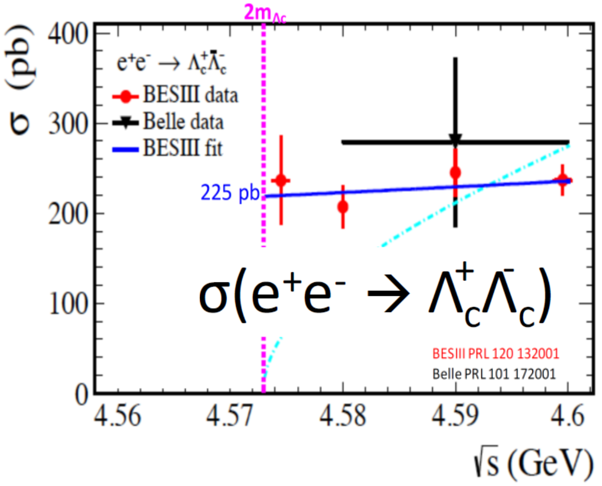
$\sigma \propto \beta$



Threshold production of baryon pair



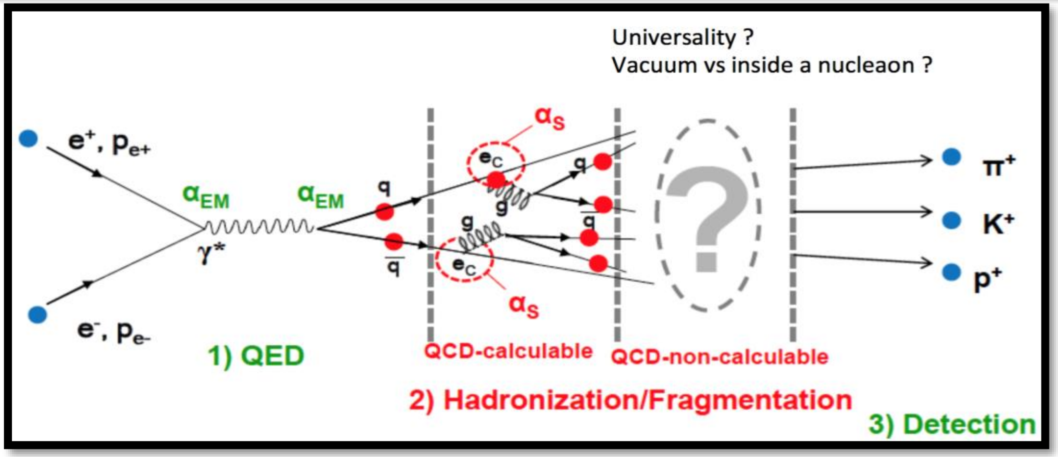


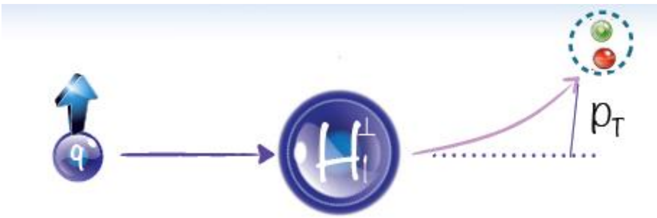


STCF: 100x more statistics will much enhance the understandings of these 'unexpected' threshold enhancement!

e^+e^- $\rightarrow p\bar{p}, n\bar{n}, \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi\bar{\Xi}, \Omega\bar{\Omega}, \Lambda_c\overline{\Lambda_c}, \Sigma_c\overline{\Sigma_c}, \Xi_c\overline{\Xi_c}, \Omega_c\overline{\Omega_c}$ ... @threshold

Collins Fragmentation Function





Collins Fragmentation Function :
considers the spin-dependent effects in fragmentation process

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

D_1: the unpolarized FF

H_1: Collins FF

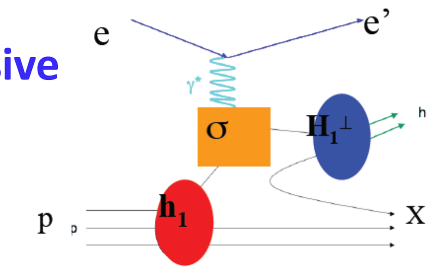
→ describes the fragmentation of a transversely polarized quark into a spinless hadron *h*.

→ depends on $z = 2E_h/\sqrt{s}\ \mathbf{P}_{h\perp}$

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

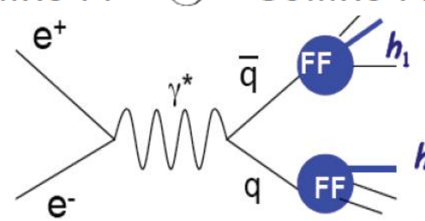
Transversity ⊗ Collins FF

Semi-inclusive DIS



Collins FF ⊗ Collins FF

e+ e-



Collins FF @ BESIII

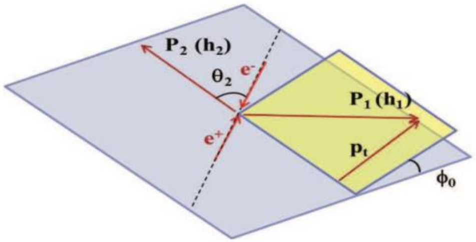
P. Sun, F. Yuan, PRD 88. 034016 (2013)

Predicted Collins asymmetries for BESIII :

$$e^+ e^- \rightarrow q\bar{q} \rightarrow \pi_1{}^{\pm}\pi_2{}^{\mp}X$$

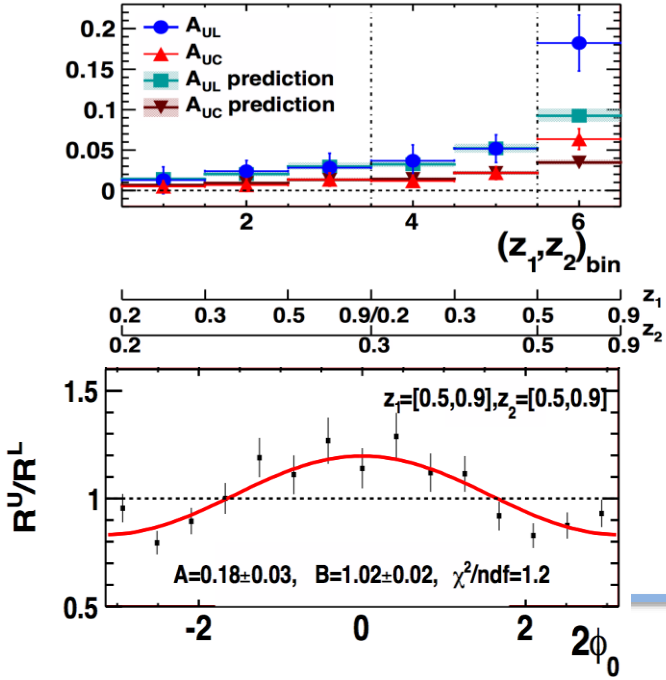
- **Double Ratio to cancel detection effects**
  - **Unlike-sign** $(\pi^{\pm}\pi^{\mp})$; **Like-sign:** $(\pi^{\pm}\pi^{\pm})$
  - **Charged:** $(\pi\pi)$

✦**Experimentally**



$$A_{UL(C)} = \frac{R^U}{R^{L(C)}} = A\cos(2\phi) + B$$

First time measurement in Low Q²~13GeV² at e+e- collision



- ~62 pb $^{-1}$ @3.65GeV
  - Continuum region
- Nonzero Collins effect at BESIII
- Basically consistent with predictions from PRD 88. 034016 (2013) .
- important inputs for understanding the spin structure of the nucleon
- valuable to explore the energy evolution of the spin-dependent fragmentation function.

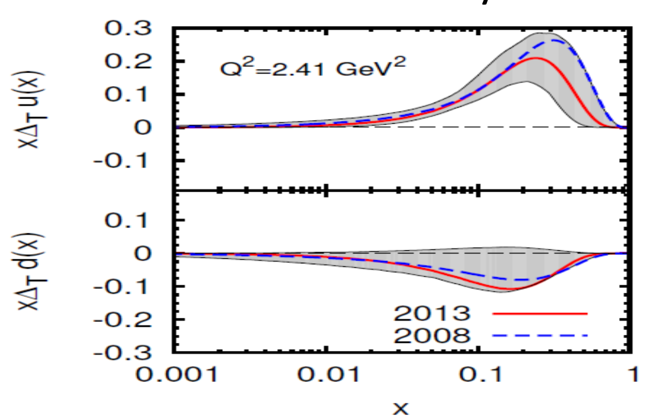
PRL 116, 042001 (2016)

Global Analysis on Collins FF

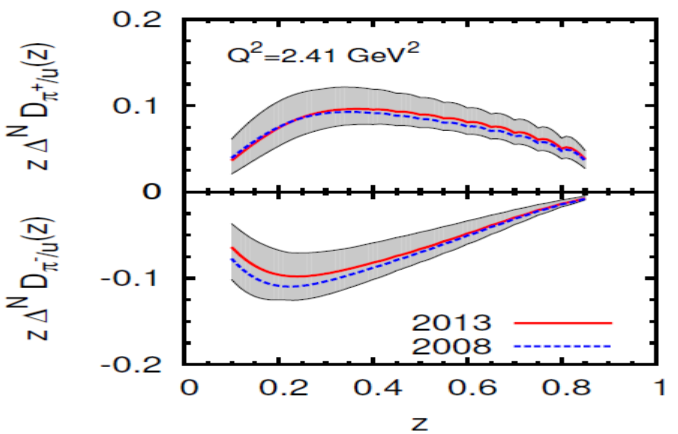
Anselmino et al., PRD 87, 094019 (2013)

Using data from HERMES, COMPASS, Belle

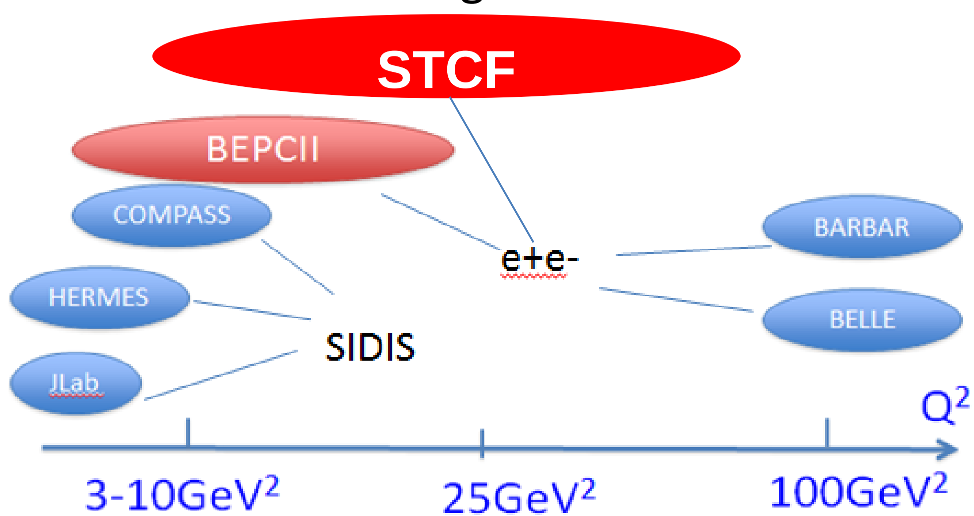
Transiversity



Collins pion FF

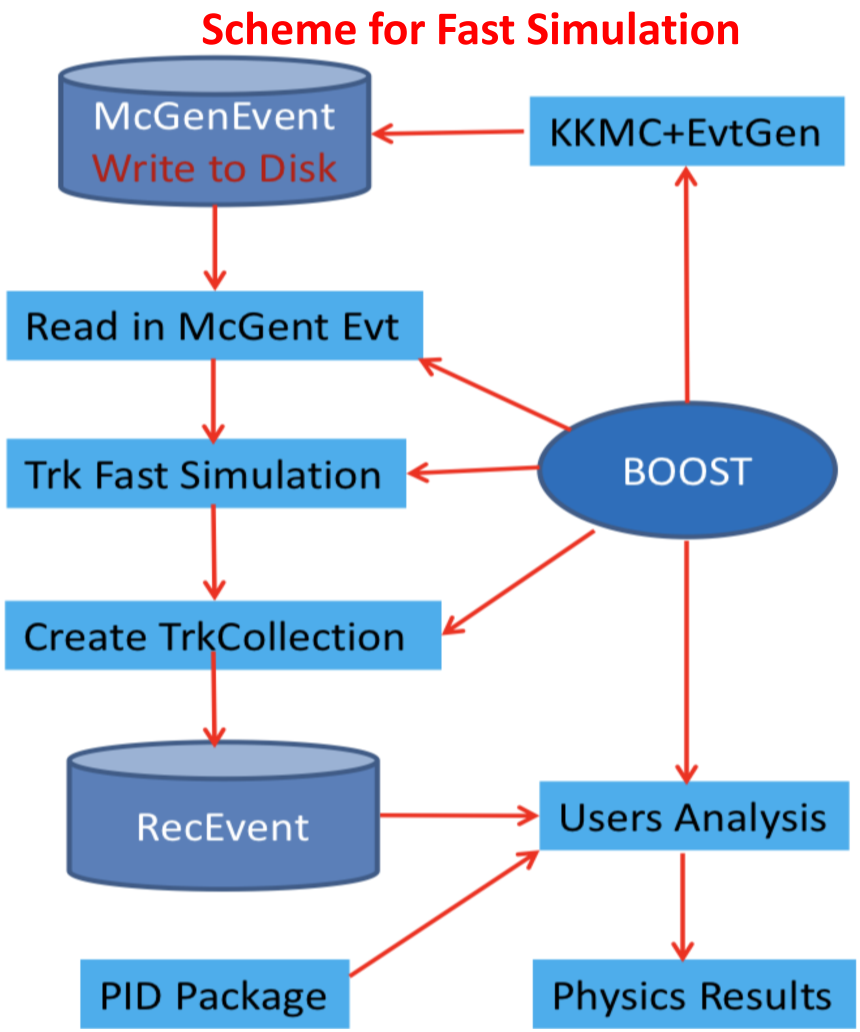


- The Q^2 evolution of Collins FFs was assumed following the extrapolation in the unpolarized FF, and this has not been validated.
- Low Q^2 data from e^+e^- collider is useful.
- BEPCII / STCF
  - Similar Q^2 coverage with SIDIS



Fast Simulation Software

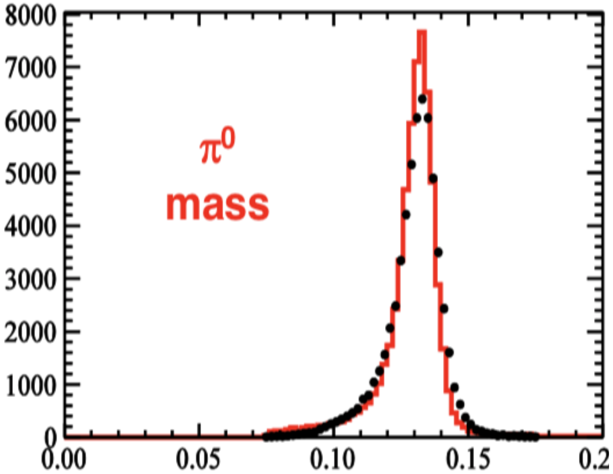
Optimize Detector design, study the physics sensitivity

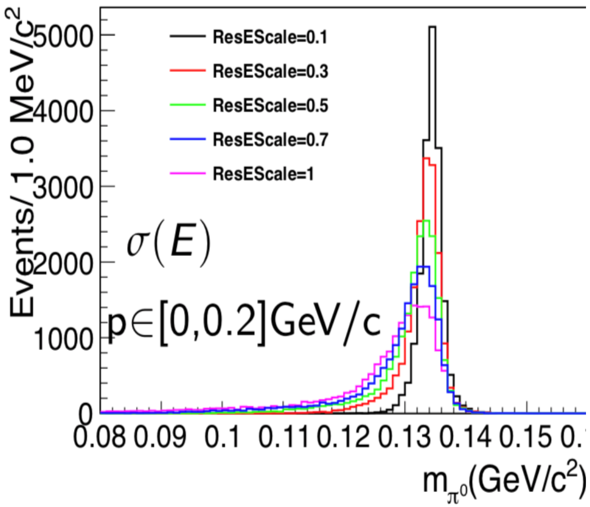


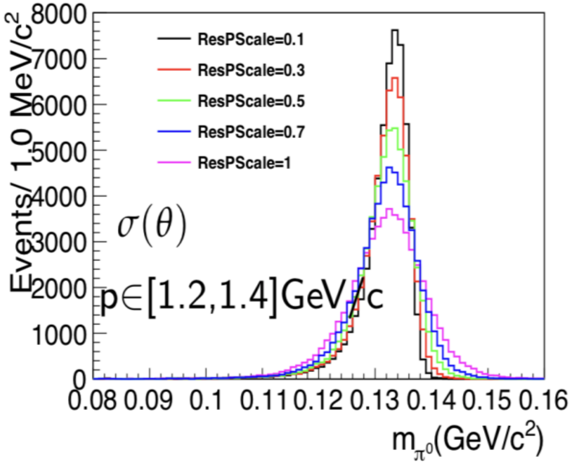
- **Same as BESIII for McGenEvt, and keep events in storage.**
- **Fast simulation for charge and neutral tracks(resolution, efficiency, error matrix etc.).**
- **Do not keep RecEvt information, fix random seed for repeating analysis.**
- **User analysis the same as BESIII jobs.**
- **Optimize STCF detector by scaling the response parameters**

Fast Simulation Software

BESIII detector is excellent reference to validate software $\psi(3686) \to \gamma\pi^0\pi^0$







—— **Full Simulation**

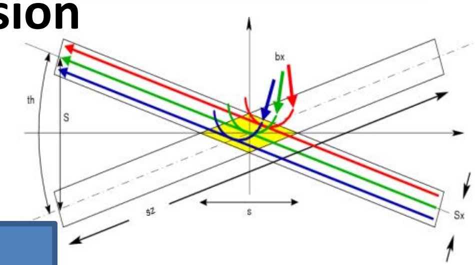
● **Fast simulation**

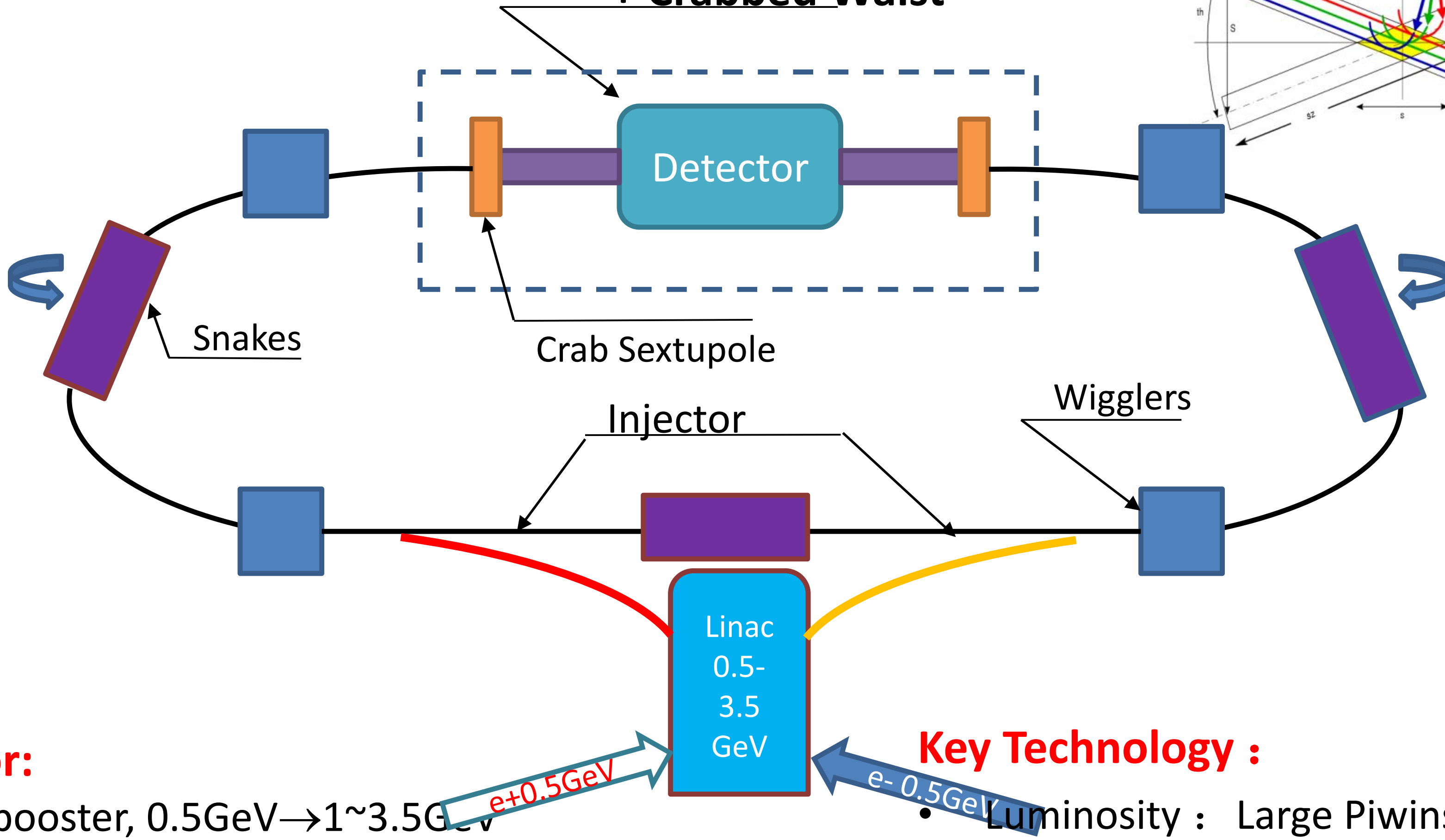
Good agreement between Fast and Full simulation for gamma Energy resolution

The resolution of π^0 can be improved with improvement of energy/position resolution

Layout of Machine

Interaction Region : Large Piwinski Angle Collision + Crabbed Waist





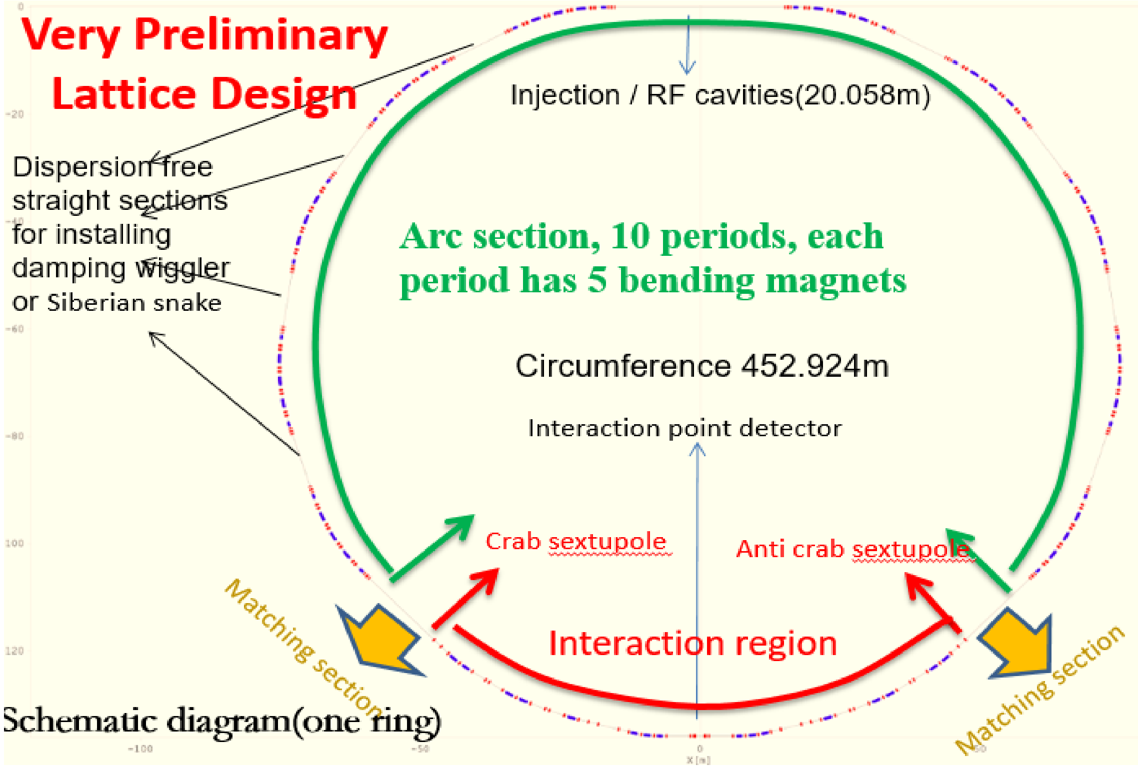
Injector:

- No booster, 0.5GeV→1~3.5GeV
- e+, a convertor, a linac and a damping ring, 0.5GeV
- e-, a polarized e- source, accelerated to 0.5GeV

Key Technology：

- Luminosity： Large Piwinski Angle Collision + Crabbed Waist
- Polarization： Siberlan Snake

Progress of Accelerator



- **Accelerator physics :** Beam-beam effects, impedance and collective effects, Injection, beam polarization ….
- **Instrumentation :** Energy/polarization Measurement, Feedback and control system …..
- **Key Technologies :** Vacuum, Magnets, RF ….

Parameters and Plan of the Machine

Parameters	1	2
Circumference/m	~600	~600
Beam Energy/GeV	2	2
Current/A	1.5	2
Emittance$(\varepsilon_x/\varepsilon_y)$/nm·rad	5/0.05	5/0.05
β Function @ IP (β_x^*/β_y^*)/mm	100/0.9	67/0.6
Collision Angle(full θ)/mrad	60	60
Tune Shift ξ_y	0.06	0.08
Hour-glass Factor	0.8	0.8
Luminosity/$\times 10^{35}$cm^{-2}s^{-1}	~0.5	~1.0

Luminosity :

$$L = \frac{\gamma n_b I_b}{2 e r_e \beta_y^*} \xi_y H$$

- Increase beam current
- Minimize β Function β_y^*
- Optimize ξ_y and H

Strategy :

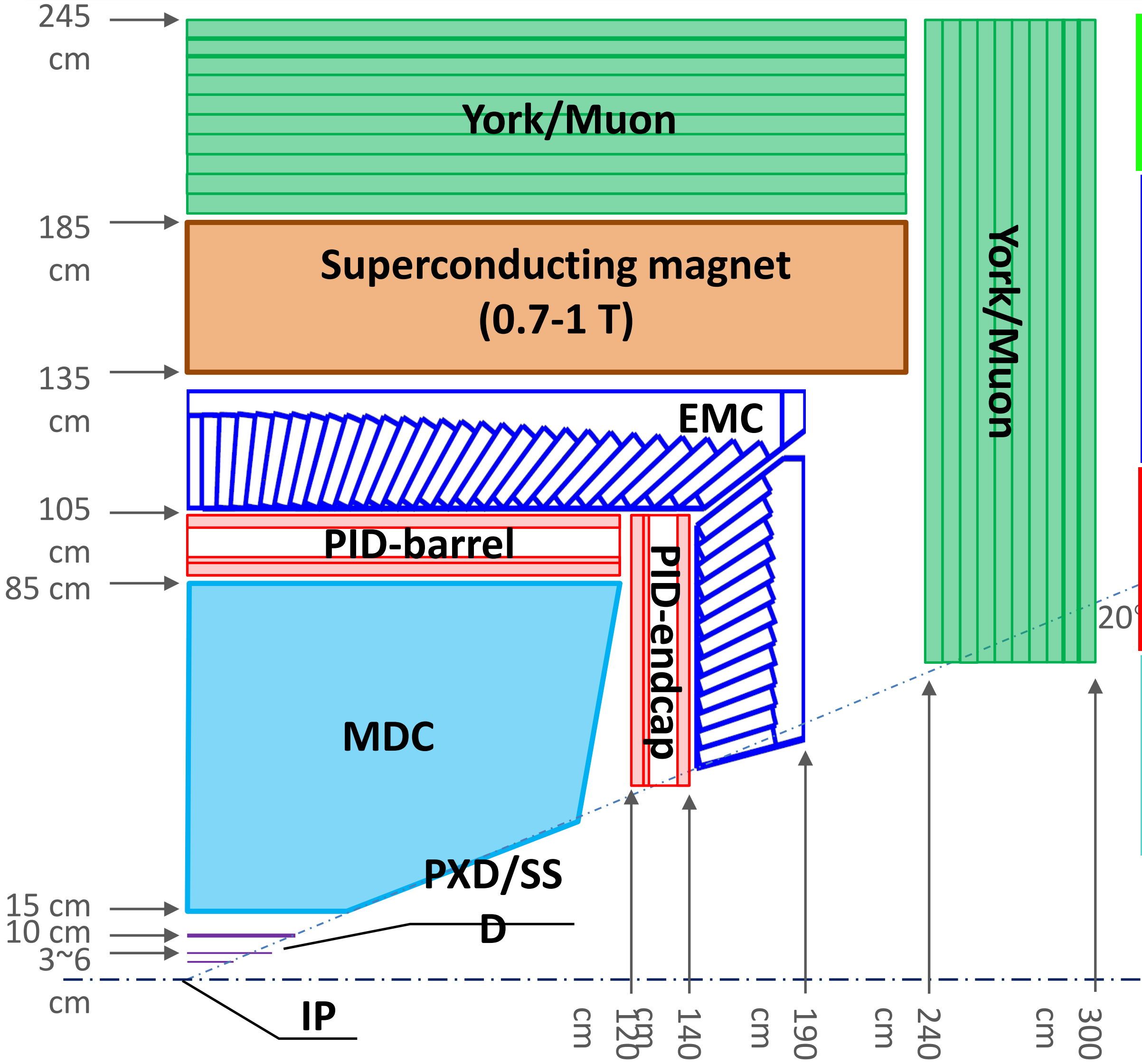
- (Phase 0) Pilot: 0.5×10^{35}
- (Phase I) Nominal: 1.0×10^{35}
- (Phase II) Polarized beam
- .....

Final:

90% Polarization e- and e+ injection,

80% Polarization @IP

Detector Layout



MUD

- μ/π suppression power >10/30

EMC

- Energy range: 0.02-2.5 GeV
- At 1 GeV σ_E (%)
  - Barrel(Cs(I): 2
  - Endcap (Cs): 4

PID

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

MDC (Low mass)

- σ_{xy}=130 mm
- dE/dx<7%, σ_p/p =0.5% at 1 GeV

PXD

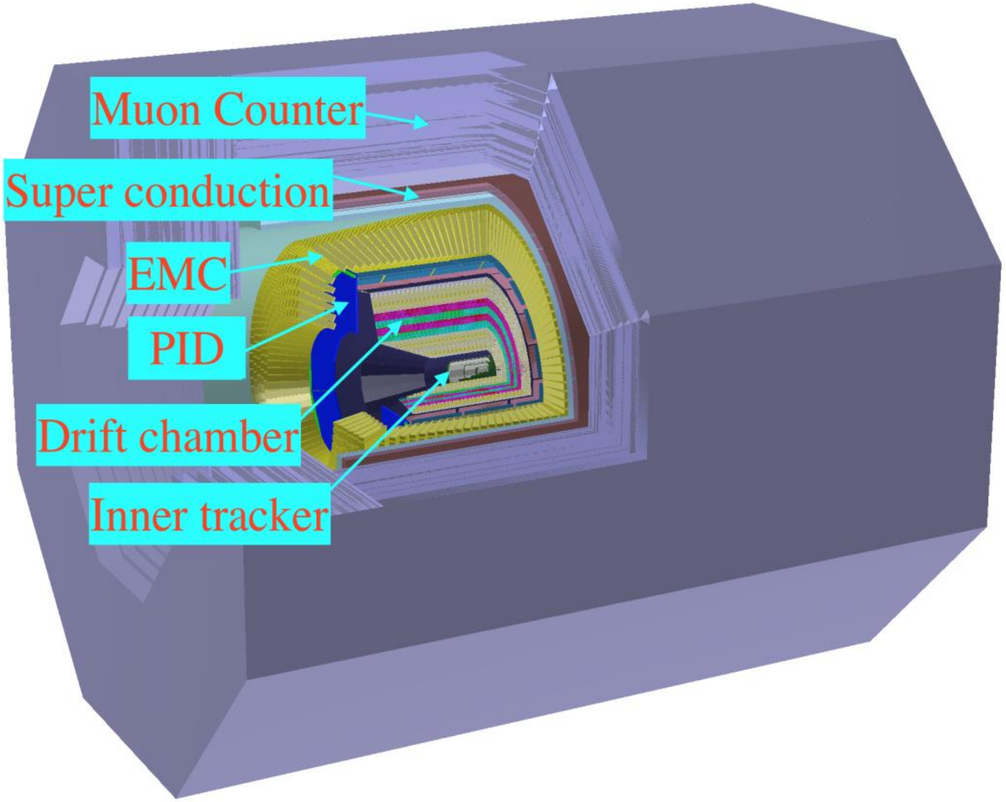
- Material budget ~0.15%X_0/layer
- σ_{xy}=50 mm

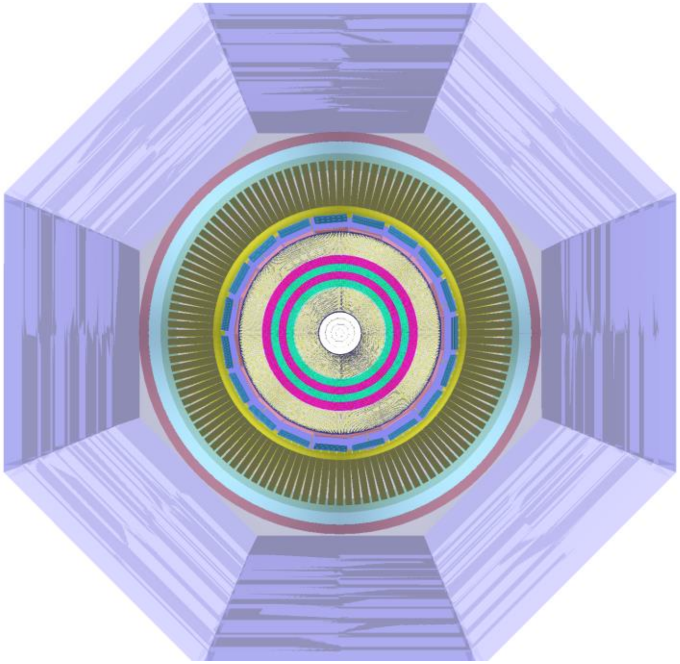
General Consideration of Detector

- Much larger radiation tolerance, especially at IP and forward regions
- Efficient event triggering, exclusive state reconstruction and tagging
- The Systematic uncertainty control
- Reasonable cost
- Lots of progress on Tracking, PID, EMC and Muon system R&D.
  - Tracking: Several Micro-Pattern Detector (DEPFET, MAPS, GEM/MicroMegas/ uRWELL) Technologies for inner tracking are testing.
  - PID: RICH/DIRC for Barrel and DIRC-like TOF for EndCap
  - EMC: CsI(Tl), CsI, BSO, PbWO4, LYSO
  - Muon Counter with precise timing (σ_T<80 ps, Space reolution~0.6 mm)

Detector View

- **OSCAR: Offline Software of Super Tau-Charm Facility.**
- **Detector geometry with DD4hep.**





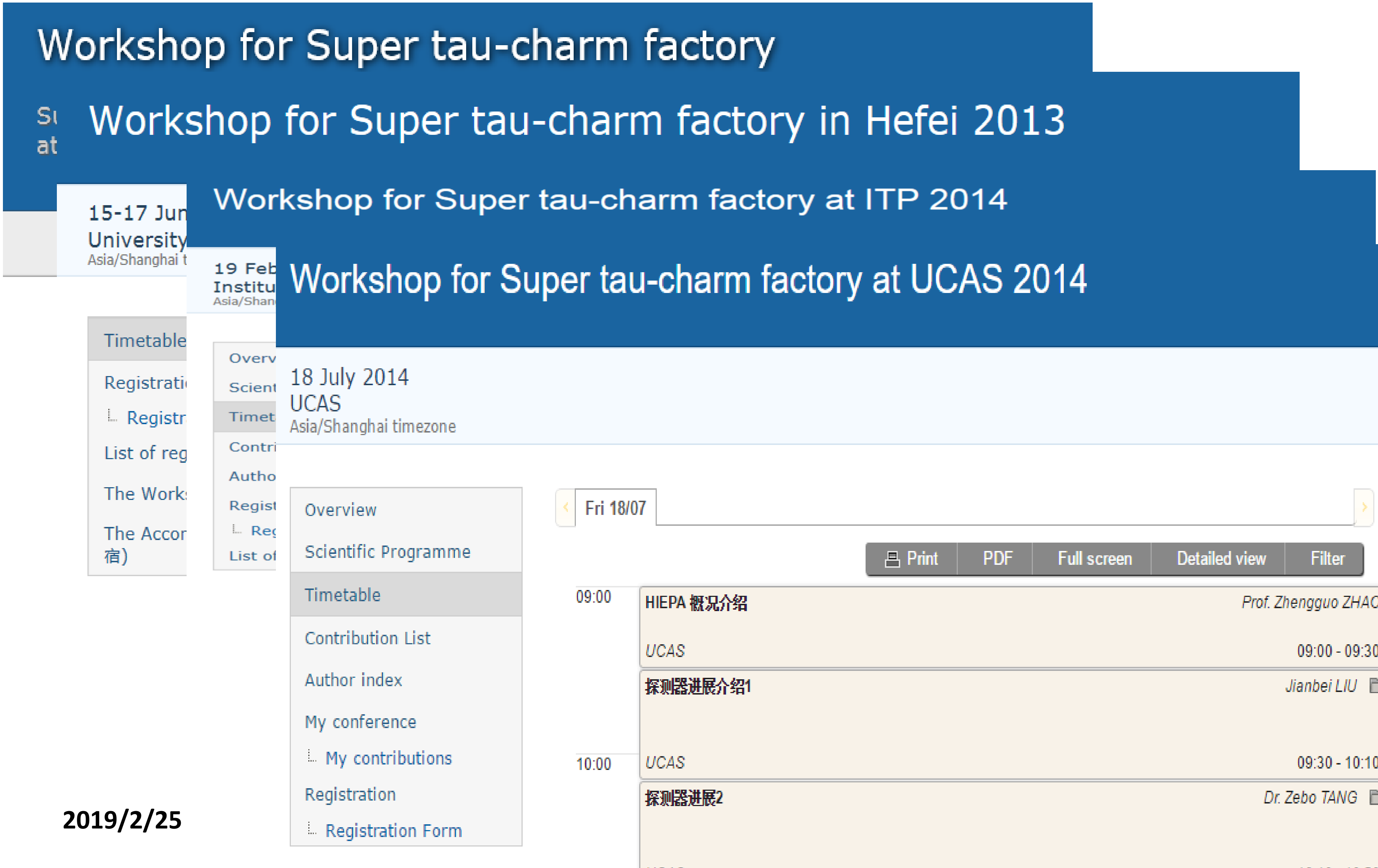
Strategy and Activities

CDR → TDR → project application → construction → commissioning

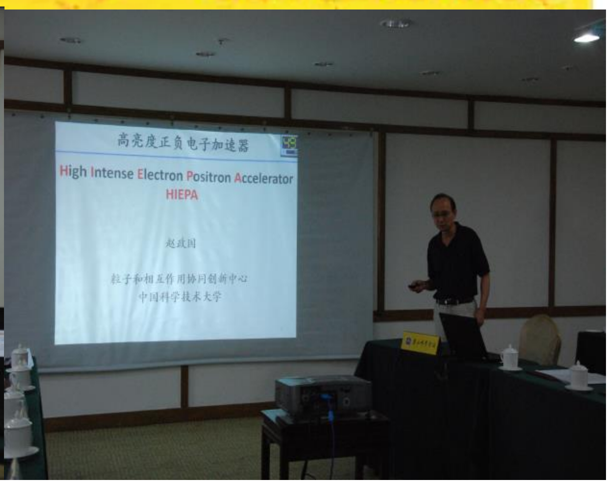
- **Strategy: focus on CDR (2 years) and TDR (6 years) depend on the available resources. Open to the construction site.**
- **Workshops : Domestic(2011, 12, 13, 14, 16), International(2015, 18)**
- **Report to :**
  - USTC Scientific Committee and USTC presidents
  - Hefei High-tech Development Zone
  - Anhui Development Planning Commission
  - CAS
- **Form the Organization for the project**
  - Regular weekly meetings for physics/Accelerator/Detector

Activities

Several Domestic Workshops (2011, 12, 13, 14)



Science & Technology Review

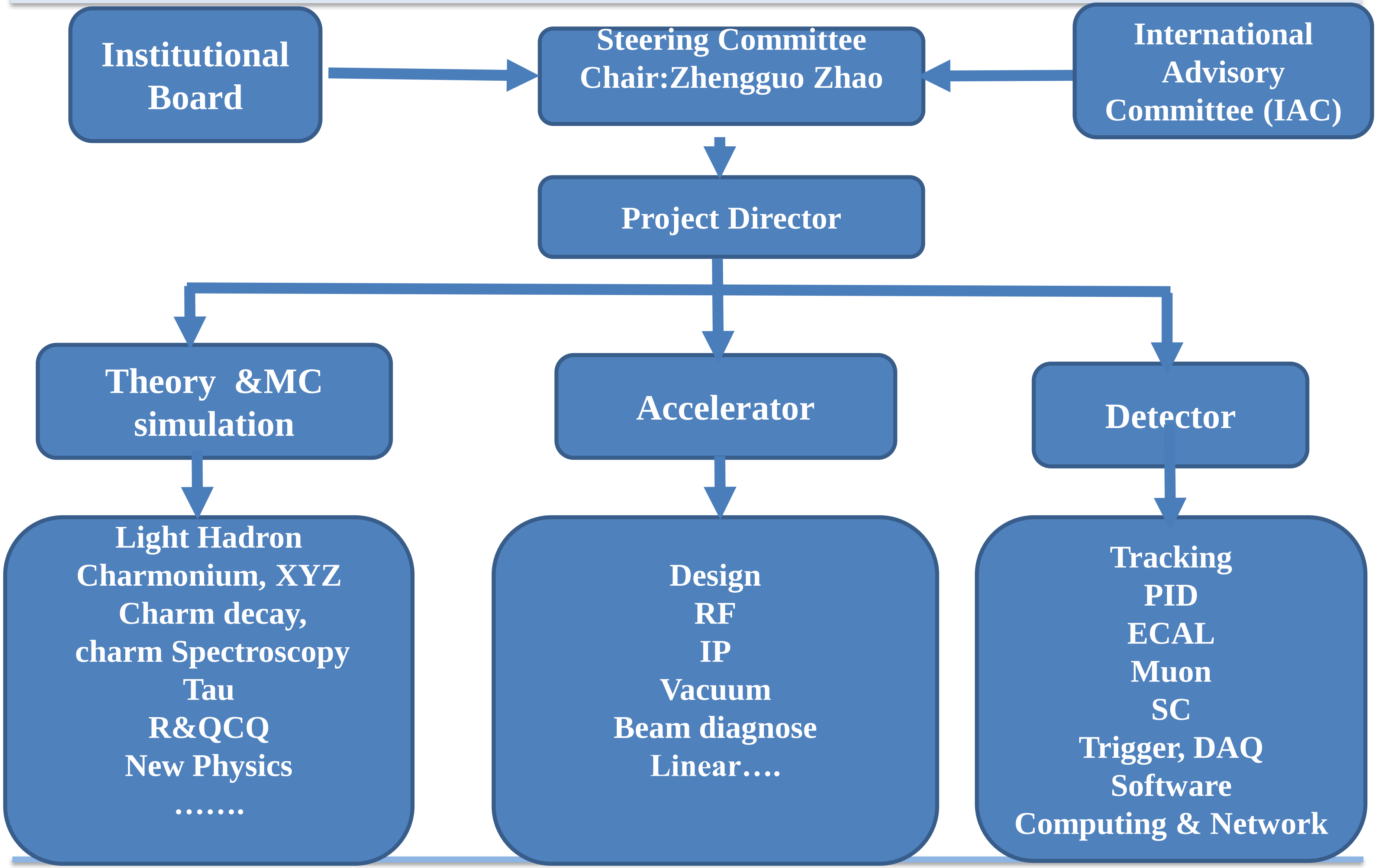


Fragrance Hill science Conference, June, 2015, ~40 scientists and officials joint

USTC Scientific Committee Review

- USTC president agreed
- Scientific committee endorsed supporting R&D

Organization



Tentative Plan & Estimated Budget

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030-2040	2041-2042
Form International Collaboration	■	■												
Conception Design Report (CDR)	■	■												
Technical Design Report (TDR)	■	■	■	■	■									
Construction						■	■	■	■	■	■	■		
Commissioning													■	
Upgrade														■

A unique precision frontier in the world for 30 years!

R&D budget 200M RMB

Total budget 4B RMB

单位：亿元	
eLinac	4.0+1.0 (阻尼环)
Electron ring	7.0
Positron ring	7.0
束线	1.2
实验谱仪	8.0
低温	1.0
配套设施	1.8
装置土建	6.0
不可预见	3.0
合计	40

Candidate site 1 : Hefei, Anhui province

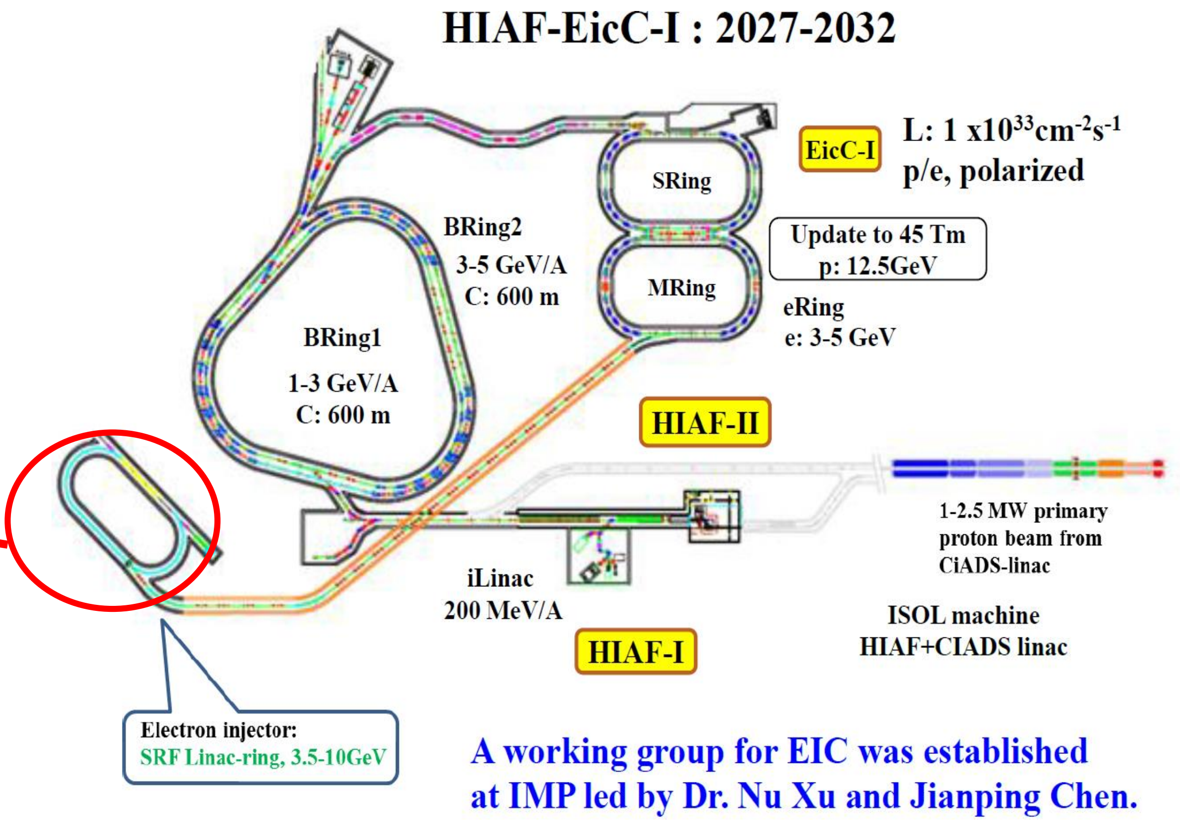
One of three integrated national science centers, which will play important role in 'Megascience' of China in near future

- Pay a lot of attention on **accelerator** facilities
- **Hefei Advanced light source** is under design
- STCF is listed in **future plan**
- **Reviewed** on Jan. 20, 2019

Candidate site 2： Canton Province

- **Institute of Modern Physics, CAS, proposed building HIAF-EicC in Huizhou, Canton**

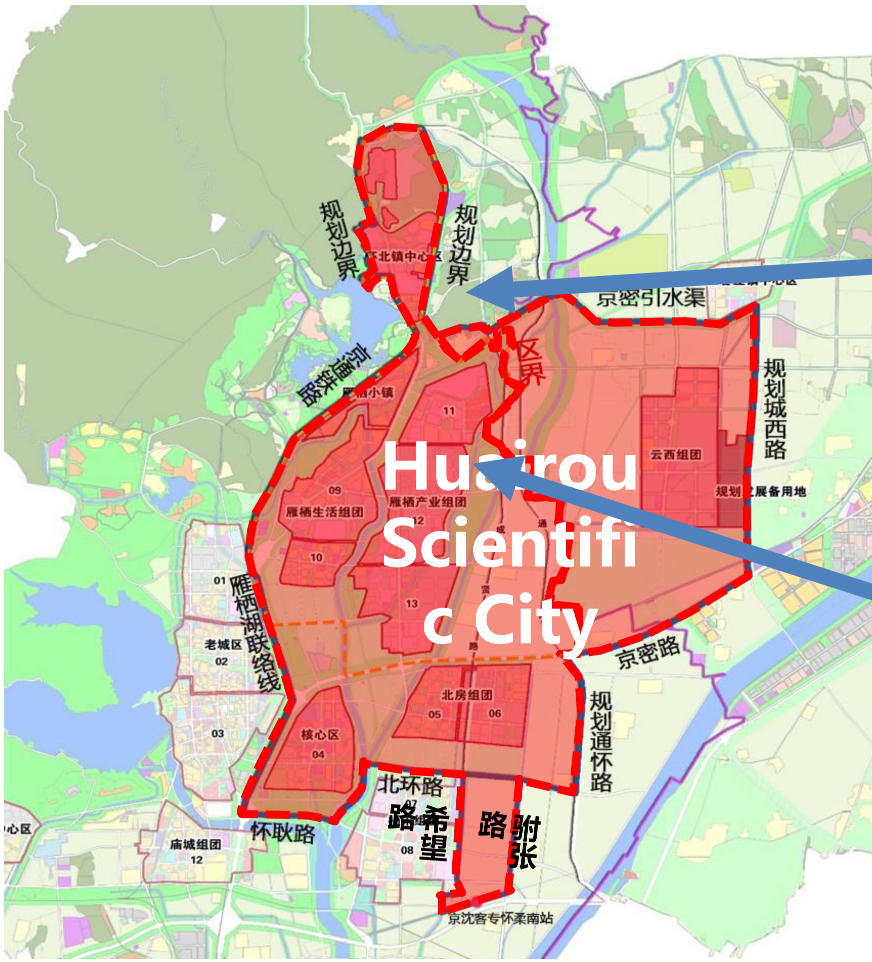
STCF Share the design effort of the electron accelerator of EicC?



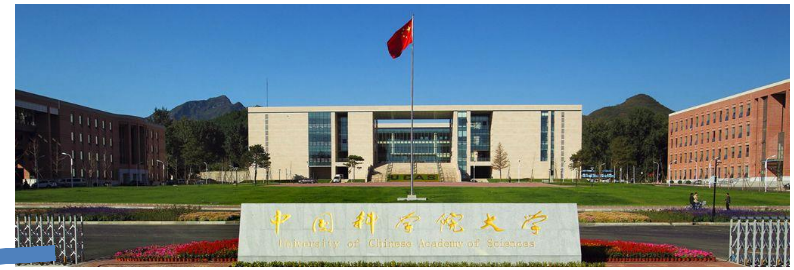
- **SUN YAT-SEN UNIVERSITY proposed building Southern Synchrotron Radiation light source in Canton**

Candidate Site : Huairou Beijing

- Planned Scientific City : 100.9 km^2 (One of three integrated national science centers)



UCAS



Synchrotron radiation light source

So far, no dedicated facility for particle physics yet!

Summary

- **Super τ-c Facility (STCF): nature extension and a viable option for a post-BEPCII HEP project**
  - Symmetric, double ring with circumference around 600~1000 m
  - $E_{cm} = 2 - 7$ GeV, $L = 1 \times 10^{35}\ cm^{-2}s^{-1}$, polarization beam (PhaseII)
- **STCF is one of the crucial precision frontier**
  - rich of physics program
  - unique for physics with c quark and τ leptons.
- **One of critical project for China HEP, realistically, practically, reasonably.**
- **Strategy and Plan**
  - Complete CDR in 2 years, TDR in 5-7 years
  - Construction site: Currently open

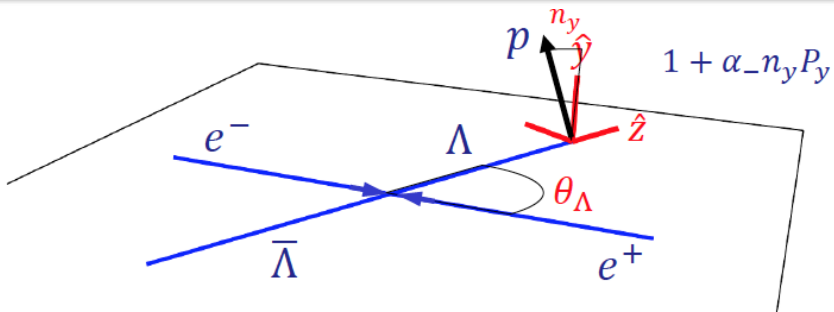
Summary

- Status of STCF project in China
  - Detector & Electronics: Significant progress in R&D
  - Accelerator: Design group is formed and working hard, progress are ongoing. More experts are needed.
  - Funding: 10M RMB for initial R&D from USTC; More communication to CAS and Local governments

Welcome to join the effort

谢谢
Thanks.

Spin polarization of Λ in J/ψ→ΛΛ



$1+\alpha_- n_y P_y$

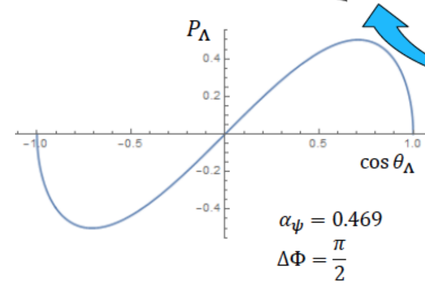
$$\frac{d\Gamma}{d\cos\theta_\Lambda d\Omega_1} \propto (1+\alpha_\psi \cos^2\theta_\Lambda)\{1+\alpha_1 P_\Lambda(\theta_\Lambda)\sin\theta_1 \sin\phi_1\}$$

$\Lambda \to p\pi^-$: $\Omega_1 = (\cos\theta_1, \phi_1)$: $\alpha_1 \to \alpha_-$

For unpolarized e+e- beams

$$\bar{P}_\Lambda(\theta_\Lambda) = \frac{\sqrt{1-\alpha_\psi}\cos\theta_\Lambda \sin\theta_\Lambda}{1+\alpha_\psi \cos^2\theta_\Lambda}\sin(\Delta\Phi)\hat{y}$$

$\Delta\Phi \neq 0$



$$e^+e^- \to (\Lambda \to p\pi^-)(\bar{\Lambda} \to \bar{p}\pi^+)$$

Göran Fäldt, AK
PLB772 (2017) 16

$$d\sigma \propto \mathcal{W}(\boldsymbol{\xi})\; d\cos\theta\; d\Omega_1 d\Omega_2$$

$\Lambda \to p\pi^-$: $\Omega_1 = (\cos\theta_1, \phi_1)$ $\qquad \alpha_- = \alpha_1$

$\bar{\Lambda} \to \bar{p}\pi^+$: $\Omega_2 = (\cos\theta_2, \phi_2)$ $\qquad \alpha_+ = \alpha_2$

$\boldsymbol{\xi}$: $(\cos\theta, \Omega_1, \Omega_2)$

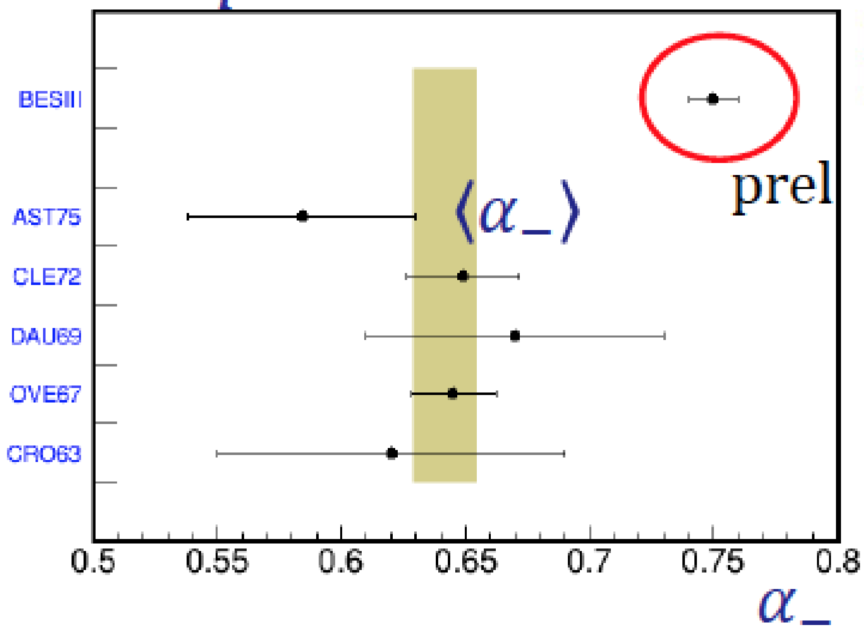
Spin correlations

$$\begin{aligned}\mathcal{W}(\boldsymbol{\xi}) =& 1+\alpha_\psi \cos^2\theta \\ &+\boxed{\alpha_1\alpha_2\left(\mathcal{T}_1(\boldsymbol{\xi})+\sqrt{1-\alpha_\psi{}^2}\cos(\Delta\Phi)\mathcal{T}_2(\boldsymbol{\xi})+\alpha_\psi\mathcal{T}_6(\boldsymbol{\xi})\right)} \\ &+\sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi)\sin\theta\cos\theta\,(\alpha_1\sin\theta_1\sin\phi_1+\alpha_2\sin\theta_2\sin\phi_2)\end{aligned}$$

Spin polarization of Λ in J/ψ→ΛΛ

Observation of the spin polarization of Λ hyperons in the $J/\psi \to \Lambda\bar{\Lambda}$ decay

$\Lambda \to p\pi^-$: α_-



BESIII

17% larger than PDG avg
> 5 σ difference

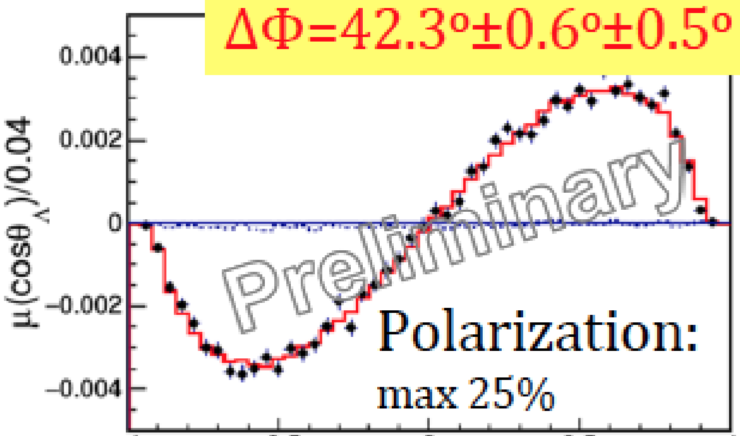
CP test

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

$\boxed{A_{CP} = -0.006 \pm 0.012 \pm 0.007}$ prel

$A_{CP} = 0.013 \pm 0.021$
PS185 PRC54(96)1877
CKM $A_{CP} \sim 10^{-4}$

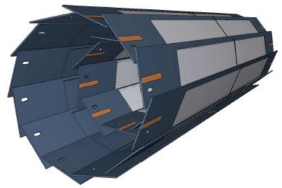
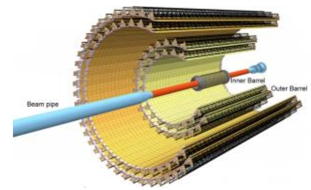
ΔΦ=42.3°±0.6°±0.5°

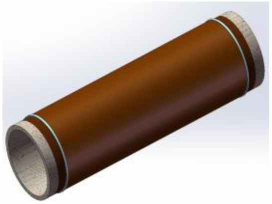


STCF: $\Delta A_{CP} = 10^{-4}$

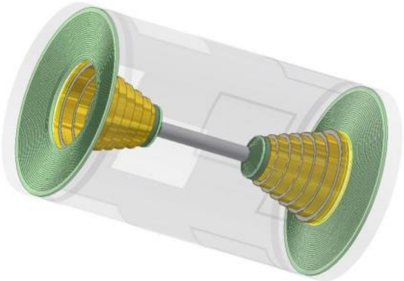
Detector requirements & Baseline

- **Vertexing :**

  - Not very critical
  - But to combine with a central tracker to improve the tracking efficiency for low momentum track and resolution
  - Special design to cope with the large radiation close to IP
  - Technologies options :
    - ✓ A Low mass silicon detectors : DEPFET, MAPS …
    - ✓ MPGD : Cylindrical GEM/MicroMegas/Urwell

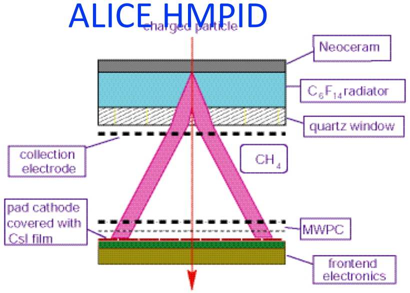


- **Central tracking :**
  - large acceptance, low mass, high efficiency and high resolution
  - A low mass drift chamber with smaller cell size and lighter working gas

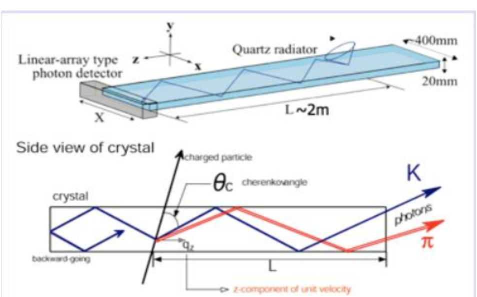
Detector requirements & Baseline

- **PID system :**
  - π/K separation up to 2GeV, compact (<20cm) and low mass (<0.5X_0)
  - Cherenkov-based technology is favorable for high momentum, and dE/dx for the low momentum tracks
  - Technology options : RICH, DIRC-Like
    - ✓ Baseline Design : Proximity RICH, similar to ALICE HMPID, but with CsI-coated MPGD readout
    - ✓ Alternative Design : Aerogel + Position Sensitive Photon Detector, similar to BELLE-II ARICH

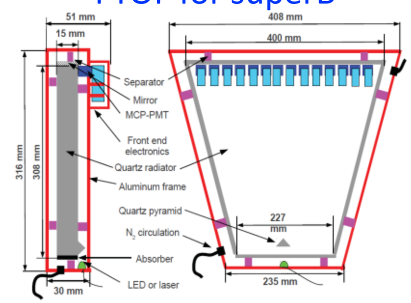
ALICE HMPID



iTOP for BELLE2

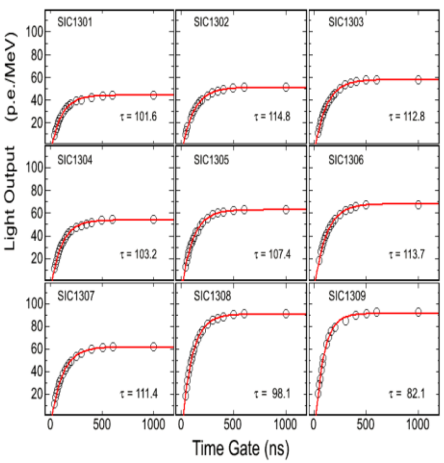


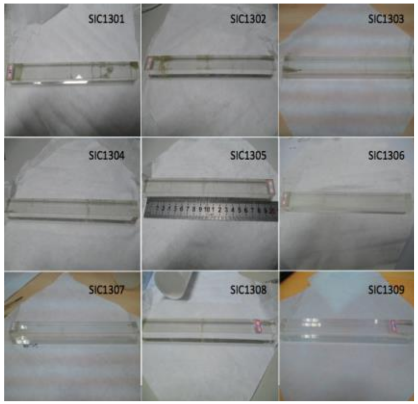
FTOF for superB

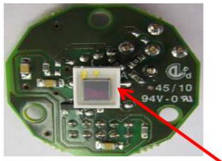


Detector requirements & Baseline

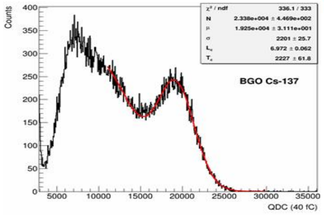
- **e/γ measurement :**
  - High efficiency for low energy γ
  - Good energy, position and time resolution
  - Fast response and Radiation hardened
  - Technology option : Crystal + novel photon detector (e.g. SiPM)
    - ✓ Crystal : pure CsI for barrel, LYSO for Endcap
    - ✓ Readout : Larger Area PD, APD and SiPM

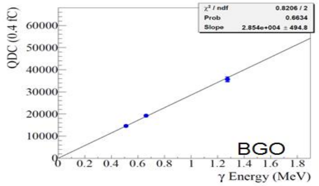






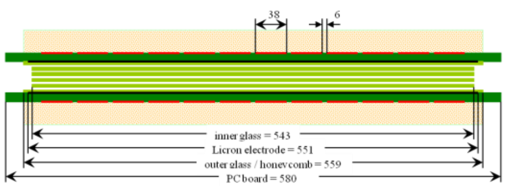
Hamamatsu S10362-33-050C, 3x3 mm^2



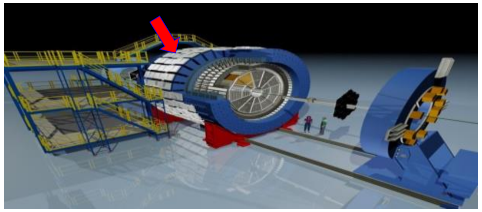


Detector requirements & Baseline

- **μ detection**
  - Low momentum threshold (p~0.4GeV)
  - high μ efficiency and μ/π suppression power>10 (30)
  - Technology option：
    - ✓ 2-3 inner layers with MRPC for precise timing
    - ✓ ~8 outer layers with RPC (Barrel : streamer, Endcap : avalanche)



MTD at STAR



Long-Strip MRPC Module at STAR

- Active area: 87 x 52 cm^2
- Read out strip: 87 cm x 3.8 cm
- Gas gaps: 0.25 mm x 5

Performance:

- Efficiency: > 98%
- Time resolution: < 80 ps
- Spatial resolution: 0.6 cm

- **Magnet**
  - Desirable to be adjustable from 0.5-1.0 T

Activities

中国科学技术大学
UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA
地址：中国安徽省合肥市金寨路 96 号 电话：0551－63603445，63606552

关于尽快启动“超级陶粲装置的加速器与探测器技术研究”
项目的请示

尊敬的各位领导：
根据中央十八届五中全会公报要点之-
目，组建一批国家实验室，提出并牵头组织国
年 3 月 14 日印发的国发[2018]5 号“积极
通知，我们建议由中国科学技术大学牵头在
加速器对撞机-超级陶粲装置（Super Tau-
1~3.5 GeV，亮度高于 $5\times10^{34}\ cm^{-2}s^{-1}$，未来升
建设 7 年，经费约 40 亿人民币。装置建成
STCF 建成后将成为基于加速器的粒子
合性国家科学中心的核心装置，为陶粲物理
引领该领域研究约二十年。STCF 的建设和运
力、发展和储备相关核心技术、培养高科技

1. STCF 运行在陶粲能区，处于微扰和非微
态结构、高产额、低本底等其他类似实
粒子物理领域关注的重点之一。STCF 具
子态（包括多夸克态，胶子球等）的寻找
寻找等重大前沿课题取得突破性成果。
2. 在国际上，针对新一代陶粲工厂的建设
核物理研究所也提议建设新一代的高亮
们的建议也得到了约五十个国内外大学
的积极响应。
3. STCF 项目将研发与运用不同领域的前沿
学科和产业的极大发展，带动发展的
展，服务于国家安全、能源、医疗、信
4. STCF 的建设、运行和维护将培养大批
学工程经验和国际视野的优秀综合性人
国其他大科学工程建设储备和输送高水

合肥综合性国家科学中心

超级陶-粲装置
Super Tau-Charm Facility (
预研究方案

（重大科技基础设施预研究）

（中国科学技术大学）

二〇一八年 六 月

国家重大科技基础设施“十四五”
项目建设需求建议

中文名称：	超级陶-粲装置（Super Tau-charm Facility（STCF））
学科领域	☐能源科学 ☐生命科学 ☐地球系
	☐材料科学 ☐空间和天文科学
	☑粒子物理和核物理 ☐工程技术科
设施类型：	☐ 多学科共用平台型装置
	☐ 服务国家发展需求的设施
	☑ 瞄准基础科学前沿的设施
研究所：	中国科学技术大学
联系人	姓名：赵政国
	地址：中国科学技术大学近代物理系
	电话：0551-63603445
	Email：Zhaozg@ustc.edu.cn

2018 年 月 日

国家重大科技基础设施中长期
项目建设需求建议

项目名称：	超级陶-粲装置（Super Tau-charm Facility（STCF））
学科领域	☐能源科学 ☐生命科学 ☐地球系统与环境科学
	☐材料科学 ☐空间和天文科学
	☑粒子物理和核物理 ☐工程技术科学
设施类型：	☐ 多学科共用平台型装置
	☐ 服务国家发展需求的设施
	☑ 瞄准基础科学前沿的设施
研究所：	中国科学技术大学
联系人	姓名：赵政国
	地址：中国科学技术大学近代物理系
	电话：0551-63603445
	Email：Zhaozg@ustc.edu.cn

2018 年 月 日

计划申请科学院的先导B项目

香山科学会议简报

第 534 期

香山科学会议办公室　　二〇一五年八月二十六日

2-7GeV 高亮度正负电子加速器上的物理、应用及其关键技术

--- 香山科学会议第 533 次学术讨论会

粒子物理学(也称高能物理学)是研究比原子核更深层次物质的基本构成、相互作用以及自然界最基本规律的学科。经过几十年的实验检验，粒子物理标准模型获得了巨大的成功，被认为是当今世界能够最好描述微观世界的理论模型。特别是随着 2012 年 Higgs 粒子的发现，人类对物质微观世界的认识达到了空前的高度。但是在标准模型框架中，仍有一系列最基本的问题，如暗物质是什么、CP 破坏的起源、为什么夸克和轻子只有三代等得不到合理的理论解释。物理学家们普遍认为自然界应该存在一个更基本的物理模型，而标准模型只是该模型在现有实验所能达到能标的有效近似。亟待更多的实验来揭开微观世界之谜。

加速器物理实验被认为是当今世界人类研究微观世界最有效的途径。当今的加速器物理实验可以分为两个前沿：一是高能量前沿(The Energy Frontier)，该类实验是在更高能量，更大范围检验标

四、小结与建议

与会的专家学者在充分交流和讨论的基础上，形成如下的基本共识和建议：

1. 加速器粒子物理实验的研究水平反映了一个国家甚至人类的经济、科学技术和教育的综合实力，推动了高新技术、方法和设备的发展。中国应有与大国地位相称的高能加速器和相关科学前沿的粒子物理实验，在两代北京正负电子对撞机研究的基础上，尽快推动下一代加速器物理大装置立项，对于我国基础科学与技术的长远发展，具有重要的战略意义。
2. 韬-粲能区有非常丰富的物理课题，有关键的科学问题和技术有待解决。综合考虑中国现有粒子物理的研究现状，国际地位，人才队伍，技术储备以及国家的经济实力和工业基础等，高亮度正负电子加速器(HIEPA)应该是目前我国粒子物理、大科学中心多学科研究和交叉研究的综合平台的最重要选项之一。
3. HIEPA 的建成将是世界上在高精度前沿进行粒子物理研究的几大中心之一，将使得中国在继 BEPCII/BESIII 后，继续引领世界韬-粲物理以及强相互作用的深入研究。同时 HIEPA 将与未来的高能量前沿的高能物理实验互补，在新物理的寻找中扮演关键性角色。
4. HIEPA 提供的新一代同步辐射 x 射线光源将与我国现有的或者将来的 x 射线光源互补，将为中国材料、物质结构、生物、化学、医

学、军事等领域的研究提供重要和独特研究平台。同时 HIEPA 还提供了我国未来进行其他高科技研究的潜力。但考虑到工程及技术的难点，应该在保证对撞机高亮度的前提下，合理协调同步辐射的运用，同时要充分考虑束流极化难度，合理安排工程建设步骤。

5. HIEPA 的建设将极大地推动中国相关高新技术的发展和高科技综合性人才的培养。将为中国高等院校和研究所输送大量的优秀人才，大幅度地提高中国高等院校从事大科学工程研究的能力，也为未来中国相关的大科学工程如环形正负电子对撞机（CEPC）等提供大量的技术和人才的储备。

6. BEPCII/BESIII 即将完成其使命，时间迫在眉睫，应立即组织队伍，凝练物理课题，开展方案设计，研究关键问题，探讨实现路径，尽快完成可行性研究报告以及及时开展预研究工作，争取 2025 年完成 HIEPA 项目的建设。

Data samples

Data samples with 1 ab^{-1} integral luminosity

	STCF					Belle II		
Data Set	process	σ/nb	N	ST eff./%	ST N	σ/nb	N	Tag N
J/ψ	–	–	1.0×10^{12}	–	–	–	–	–
$\psi(2S)$	–	–	3.0×10^{11}	–	–	–	–	–
D^0	$D^0\bar{D}^0(3.77)$	~ 3.6	3.6×10^9	10.8	0.78×10^9	–	1.4×10^9	–
D^+	$D^+D^-(3.77)$	~ 2.8	2.8×10^9	9.4	0.53×10^9	–	7.7×10^8	–
D_s	$D_sD_s^*(4.18)$	~ 0.9	0.9×10^9	6.0	0.11×10^9	–	2.5×10^8	–
τ^+	$\tau^+\tau^-(3.68)$	~ 2.4	2.4×10^9	–	–	0.9	0.9×10^9	–
	$\tau^+\tau^-(4.25)$	~ 3.6	3.5×10^9	–	–	–	–	–
Λ_c	$\Lambda_c\Lambda_c(4.64)$	~ 0.6	5.5×10^8	5.0	0.55×10^8	–	1.6×10^8	$3.6 \times 10^{4*}$

* process $e^+e^- \to D^{(*)-}\bar{p}\pi^+\Lambda_c^+$.

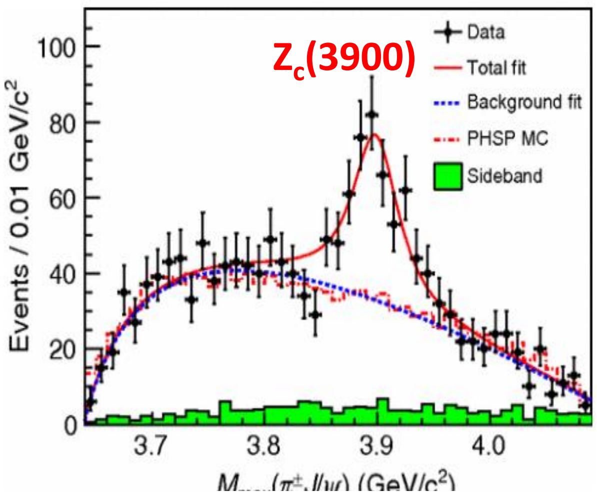
- STCF have more larger x-sec
- STCF is expected to have higher detection efficiency, low background
- Belle II can have larger integral luminosity

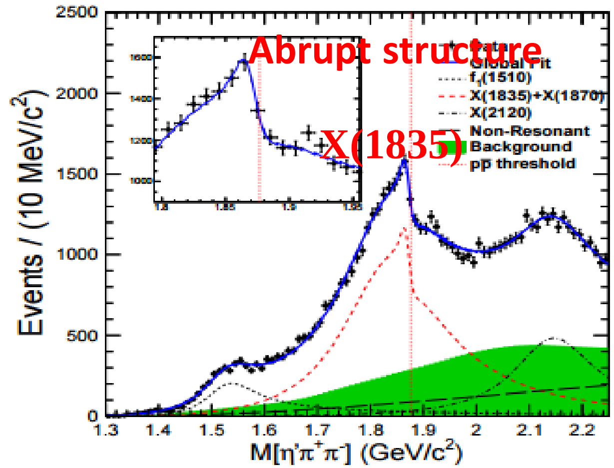
Detail simulations are ongoing to study the potential for the physics research

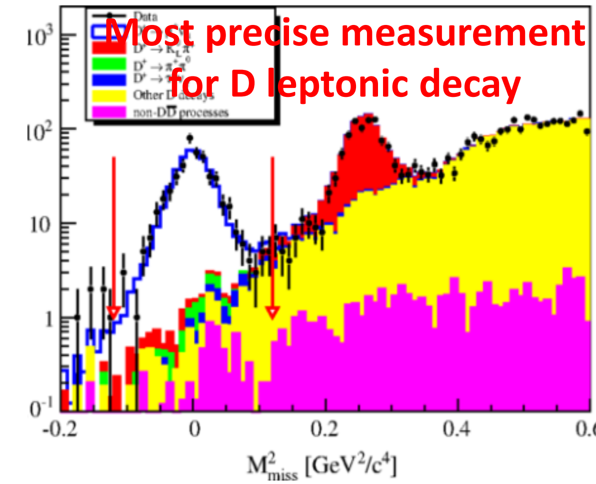
R and QCD Physics

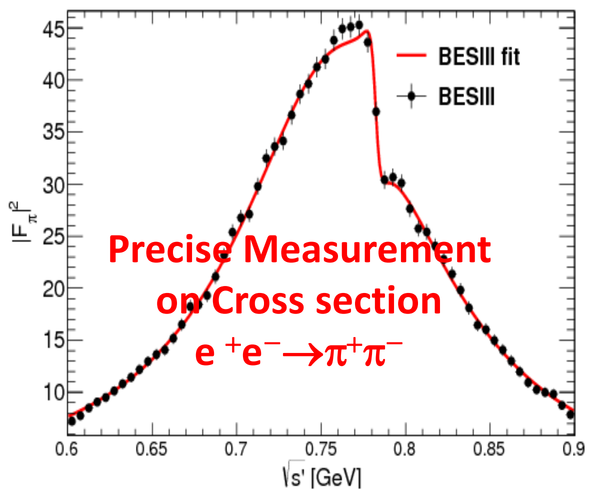
- Detailed study of exclusive processes $e^+ e^- \to (2\text{-}10)h$, $h=\pi, K, \eta, p\cdots$, Scan between 2-7GeV and ISR $\sqrt{s}<2$GeV
  - Meson Spectroscopy
  - Intermediate dynamics
  - Search for exotic states (tetraquarks, hybrids, glueballs)
  - Form factors
- High precision determination of $R=\sigma(e^+ e^- \to \text{hadrons})/\sigma(e^+ e^- \to \mu^+\mu^-)$ at low energies and fundamental quantities
  - $(g_\mu-2)/2$, 92% from < 2GeV, 7% from 2-5GeV
  - $\alpha(M_z)$, 19.0% from < 2GeV, 18.1% from 2-5GeV
  - QCD parameters (charm quark masses)
- Inclusive cross section $e^+ e^- \to h + X$
  - QCD parameters (α_s, quark and gluon condensates)
  - Fragmentation functions
  - Spin alignment of vector
  - MLLA/LPHP prediction

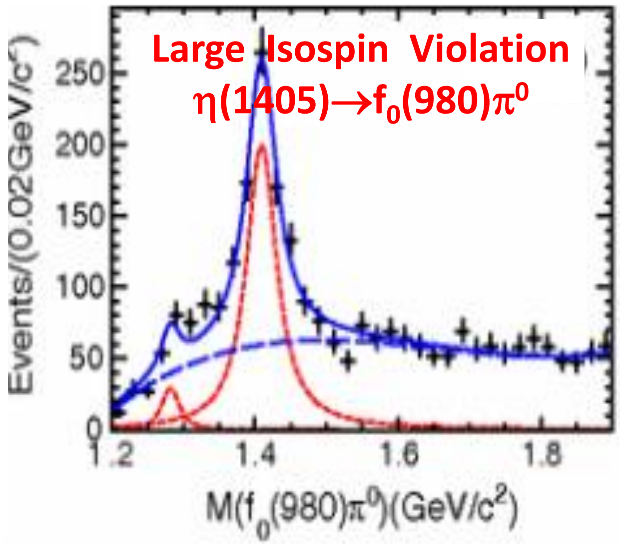
Fruitful BESIII Results

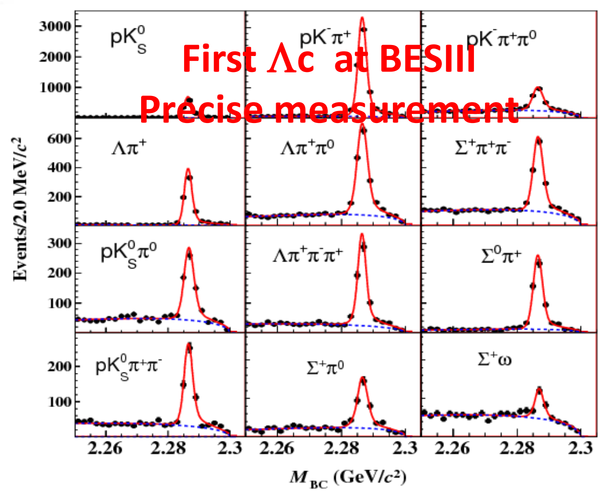




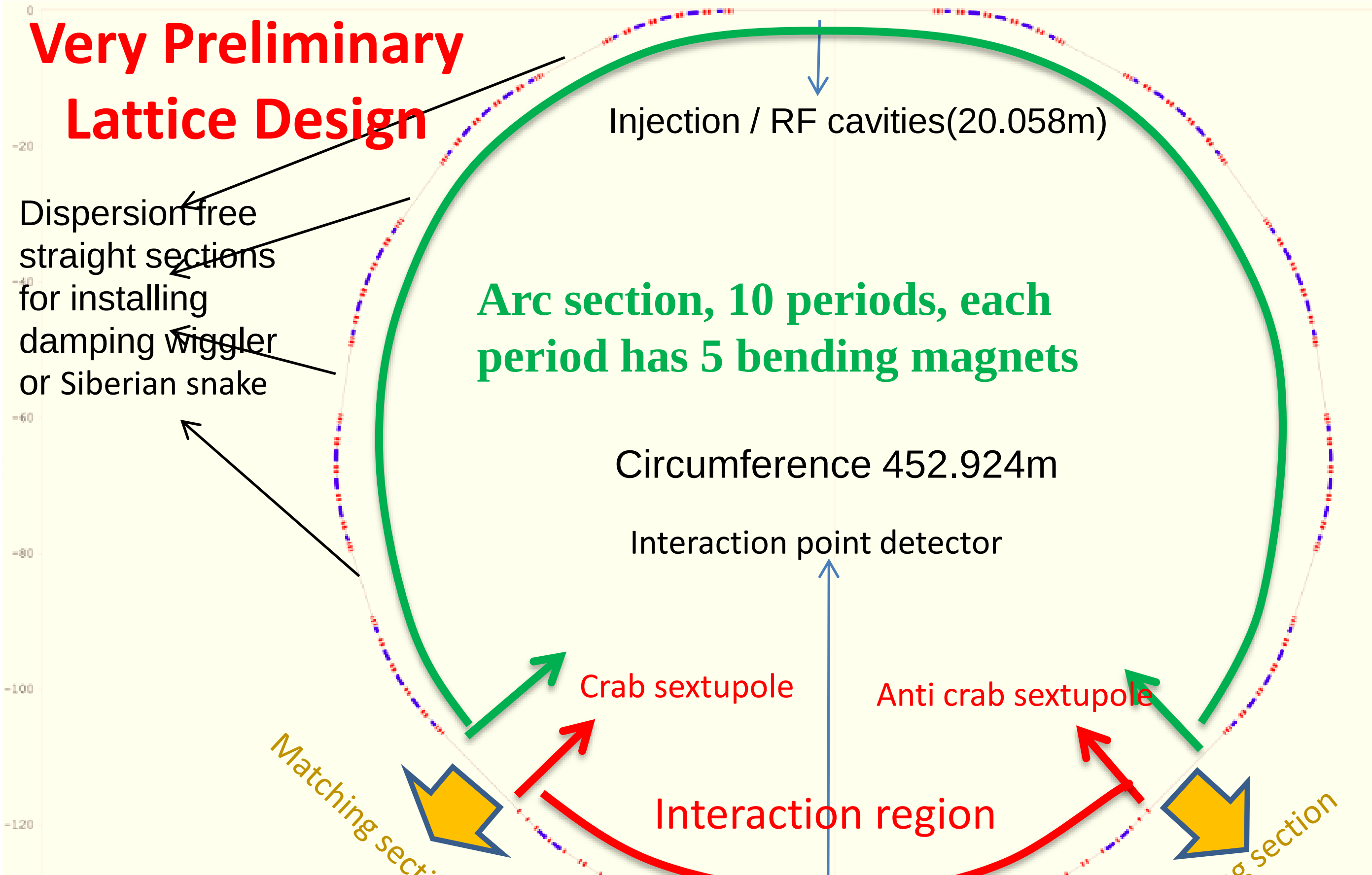








Lattice Design



Schematic diagram(one ring)