超级τ-Charm装置上的物理研究及装置预研进展

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Outline

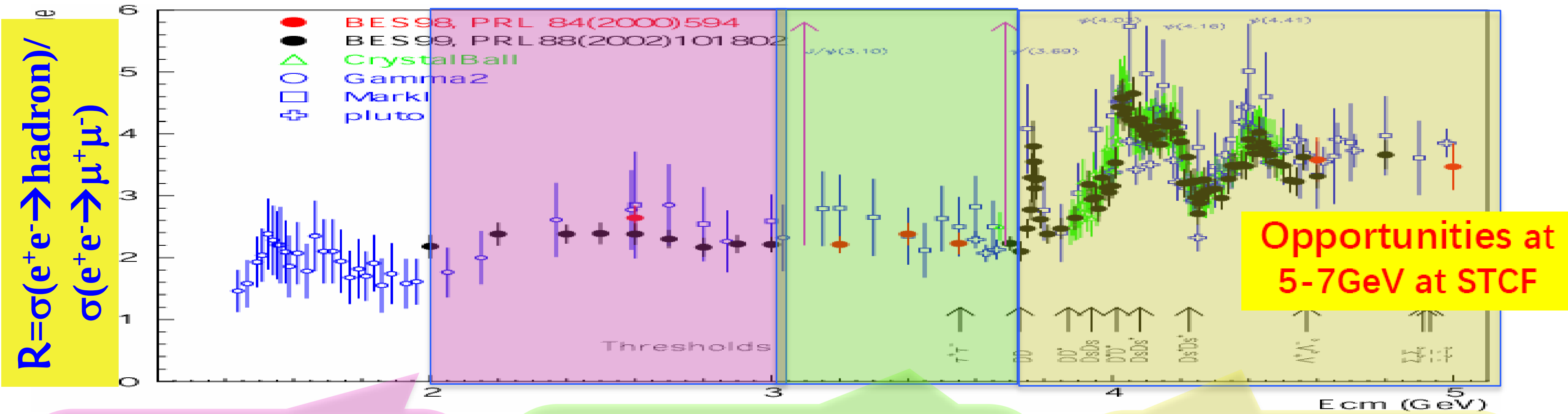
超级τ-Charm装置

Super Tau Charm Facility (STCF)

- Some Highlight Physics topics
- Conceptual Design status
- Funding Status & Potential sites
- Strategy & Prospect of Science-Technology Review
- Summary

Broad Physics at τ-c Energy Region

- **Unique features**：**Rich of resonance, Threshold characteristics, Quantum Correlation**
- **Abundant physics**

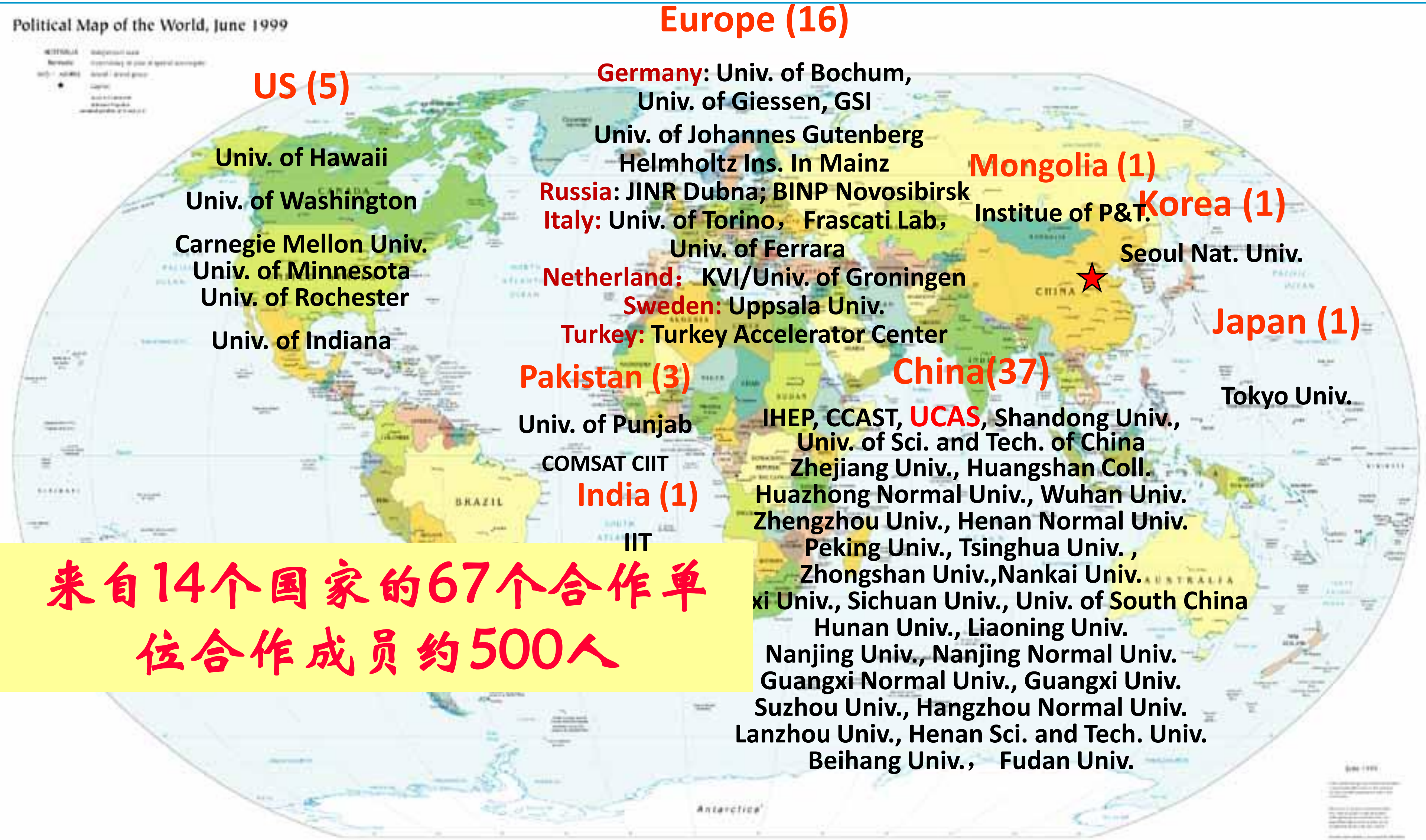


- **Hadron form factors**
- **Y(2175) resonance**
- **Mutltiquark states with s quark, Zs**
- **MLLA/LPHD and QCD sum rule predictions**

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

- **XYZ particles**
- **f_D and f_{Ds}**
- **D_0-D_0 mixing**
- **coherent D mesons decays**
- **Charm baryons**

BESIII国际合作组



Europe (16)

Germany: Univ. of Bochum, Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino，Frascati Lab，Univ. of Ferrara
Netherland: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

US (5)

Univ. of Hawaii
Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Mongolia (1)

Institue of P&T.

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (3)

Univ. of Punjab
COMSAT CIIT

India (1)

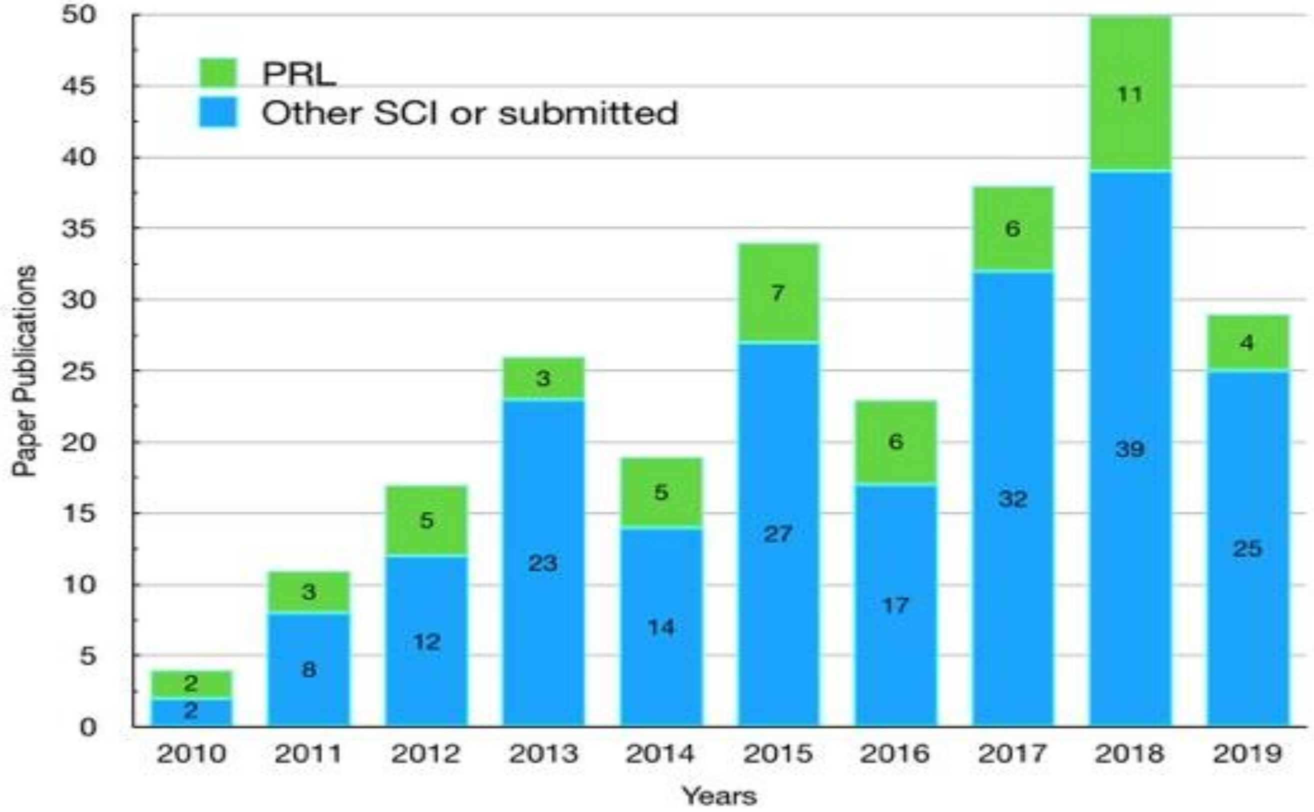
IIT

China(37)

IHEP, CCAST, UCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
xi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Beihang Univ.， Fudan Univ.

来自14个国家的67个合作单位合作成员约500人

Publication of BESIII



Up to May, 2019: 254 publications, 52 PRL,

Excellent in both number and quality

http://bes3.ihep.ac.cn/pub/physics.htm

~20 PhD / year

Physics output on the Λ_c^+

- One month data taking ⇒ Published 12 papers (7 PRLs)
- … more will be coming

Very productive!

Hadronic decay

$\Lambda_c^+ \to pK^-\pi^+$ + 11 CF hadronic modes	PRL 116, 052001 (2016)
$\Lambda_c^+ \to pK^+K^-$, $p\pi^+\pi^-$	PRL 117, 232002 (2016)
$\Lambda_c^+ \to nK_S\pi^+$	PRL 118, 12001 (2017)
$\Lambda_c^+ \to p\eta$, $p\pi^0$	PRD 95, 111102(R) (2017)
$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$	PLB 772, 388 (2017)
$\Lambda_c^+ \to \Xi^{0(*)}K^+$	PLB783, 200 (2018)

Semi-leptonic decay

$\Lambda_c^+ \to \Lambda e^+\nu_e$	PRL 115, 221805(2015)
$\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$	PLB 767, 42 (2017)

Inclusive decay

$\Lambda_c^+ \to \Lambda X$	PRL121, 062003 (2018)
$\Lambda_c^+ \to e^+X$	PRL 121 251801(2018)

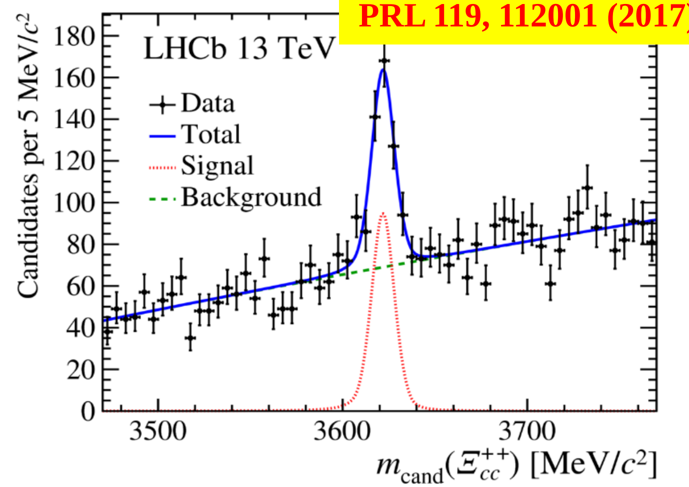
Production

$\Lambda_c^+\Lambda_c^-$ cross section	PRL 120,132001(2018)

Contributions to Ξ_{cc}^{++} observation

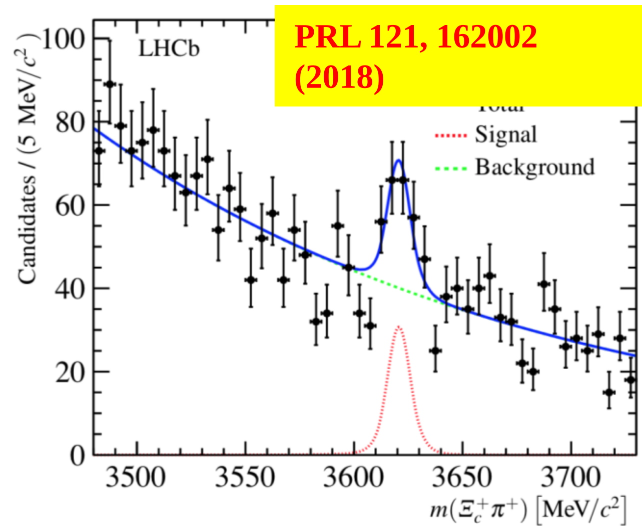
- **LHCb observed Ξ_{cc}^{++} from $\Xi_{cc}^{++} \to \Lambda_c^{+} K^{-} \pi^{+} \pi^{+}$ and $\Xi_c^{+} \pi^{+}$ decays**

PRL 119, 112001 (2017)



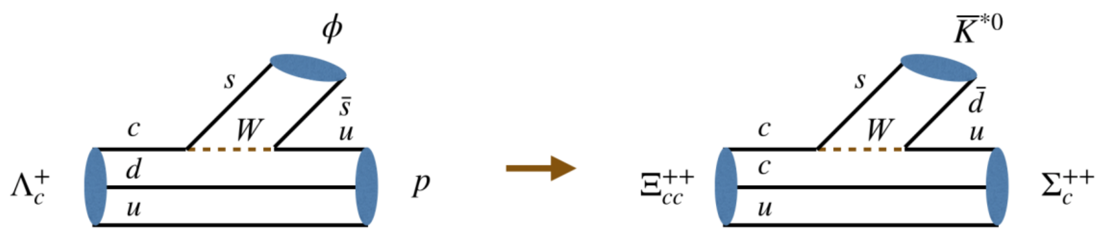
- **Credits from theorists**
  - **$\tau(\Xi_{cc}^{++}) \approx 3\,\tau(\Xi_{cc}^{+})$ (Chang, Li, Wang, Karliner, et al.)**
  - **"Discovery channels of $\Xi_{cc}^{++} \to \Lambda_c^{+} K^{-} \pi^{+} \pi^{+}$ and $\Xi_c^{+} \pi^{+}$ was predicted benefited from BESIII Λ_c^{+} measurements" (Fu-Sheng Yu, et al, '17)**

PRL 121, 162002 (2018)



A theoretical Framework for Charmed Hadrons

- **Topological diagrams + Symmetries + Experimental inputs ⇒ to understand the decaying dynamics, predicting double-charm baryon decays, CPV, etc. (predictive power)**
  - Λ_c^+ branching fractions used for global analysis
    ⇒ $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^+ \pi^+$ are large enough for observation.



$Br(\Lambda_c^+ \to p\phi)/|V_{us}|^2$ = 2 % ➡ $Br\left(\Xi_{cc}^{++} \to \Sigma_c^{++} \bar{K}^{*0}\right)$ = O(%)

⬇

$\Xi_{cc}^{++} \to \Lambda_c^+ \pi^+ K^- \pi^+$

Large enough for observation

Λ_c^+ BFs from BESIII ⇒ Stronger predictive power

Some limitations for BEPCII/BESIII

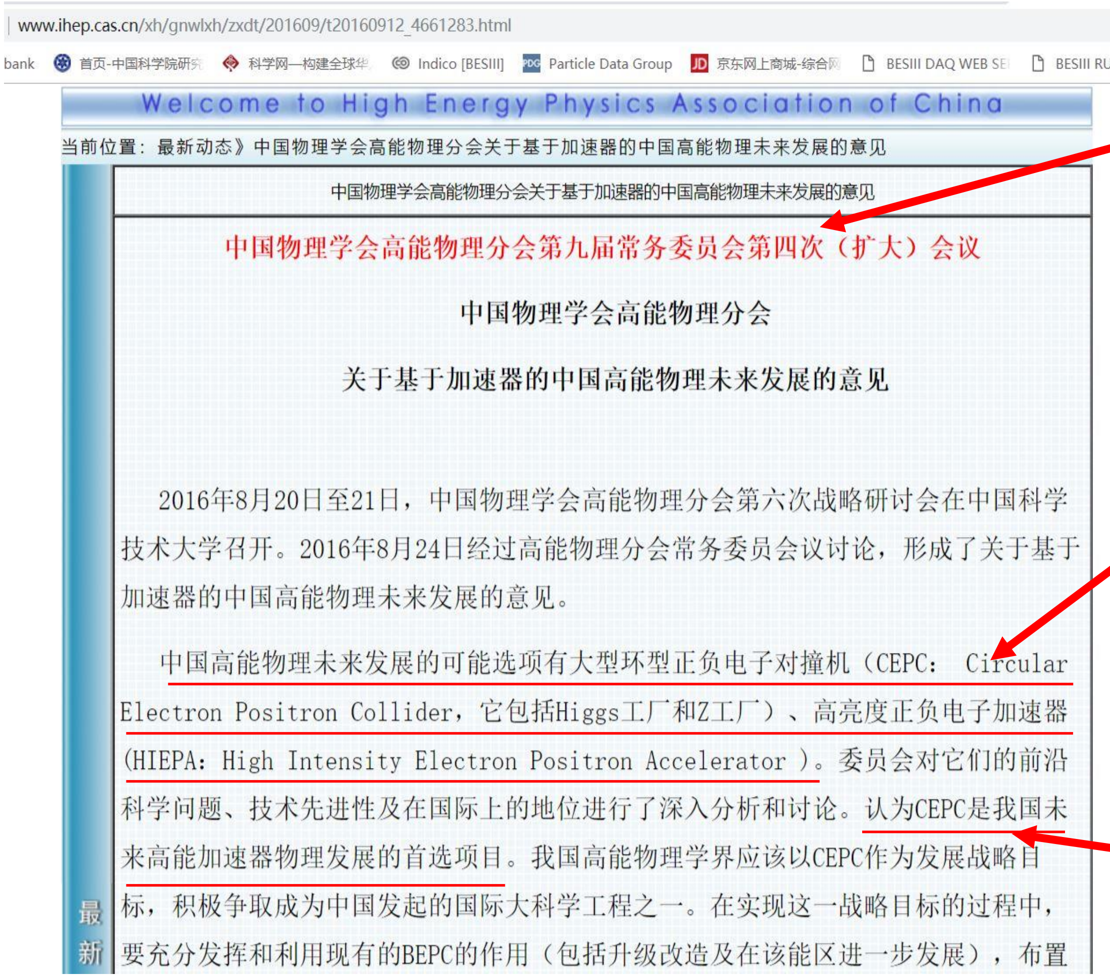
- BEPCII/BESIII have run 9 years, and are playing a leading role in tau-charm physics area.
- Limited by length of storage ring, no space and potential for the upgrade.
- Physics study limited by the Statistics (luminosity), CME ……
- Challenged by Belle II
- BEPCII/BESIII will end her mission in 5 - 7 years (?)

A Super τ-charm Facility is the nature extension and a viable option for a post-BEPCII HEP project in China

Accelerator based project in China

Consensus in HEP community (about on accelerator based particle physics project)

http://www.ihep.cas.cn/xh/gnwlxh/zxdt/201609/t20160912_4661283.html


www.ihep.cas.cn/xh/gnwlxh/zxdt/201609/t20160912_4661283.html

Welcome to High Energy Physics Association of China

当前位置：最新动态》中国物理学会高能物理分会关于基于加速器的中国高能物理未来发展的意见

中国物理学会高能物理分会关于基于加速器的中国高能物理未来发展的意见

中国物理学会高能物理分会第九届常务委员会第四次（扩大）会议

中国物理学会高能物理分会

关于基于加速器的中国高能物理未来发展的意见

2016年8月20日至21日，中国物理学会高能物理分会第六次战略研讨会在中国科学技术大学召开。2016年8月24日经过高能物理分会常务委员会议讨论，形成了关于基于加速器的中国高能物理未来发展的意见。

中国高能物理未来发展的可能选项有大型环型正负电子对撞机（CEPC： Circular Electron Positron Collider，它包括Higgs工厂和Z工厂）、高亮度正负电子加速器（HIEPA：High Intensity Electron Positron Accelerator ）。委员会对它们的前沿科学问题、技术先进性及在国际上的地位进行了深入分析和讨论。认为CEPC是我国未来高能加速器物理发展的首选项目。我国高能物理学界应该以CEPC作为发展战略目标，积极争取成为中国发起的国际大科学工程之一。在实现这一战略目标的过程中，要充分发挥和利用现有的BEPC的作用（包括升级改造及在该能区进一步发展），布置

Division of High Energy Physics, Chinese Physics Society,

There are viable options for China's next big project in High Energy Physics :CEPC (includes a Higgs factory and a Z factory) and HIEPA.

the CEPC project is the top choice for future development in High-energy Accelerator Physics in China.

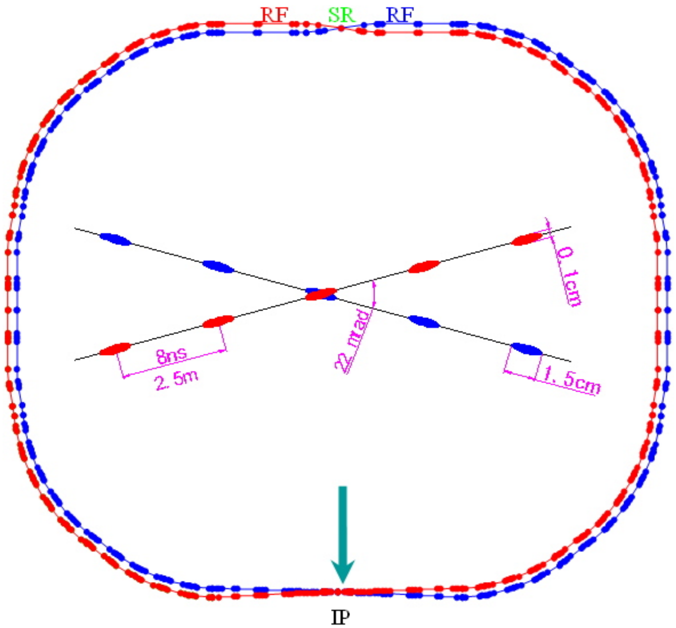
BEPCII vs STCF

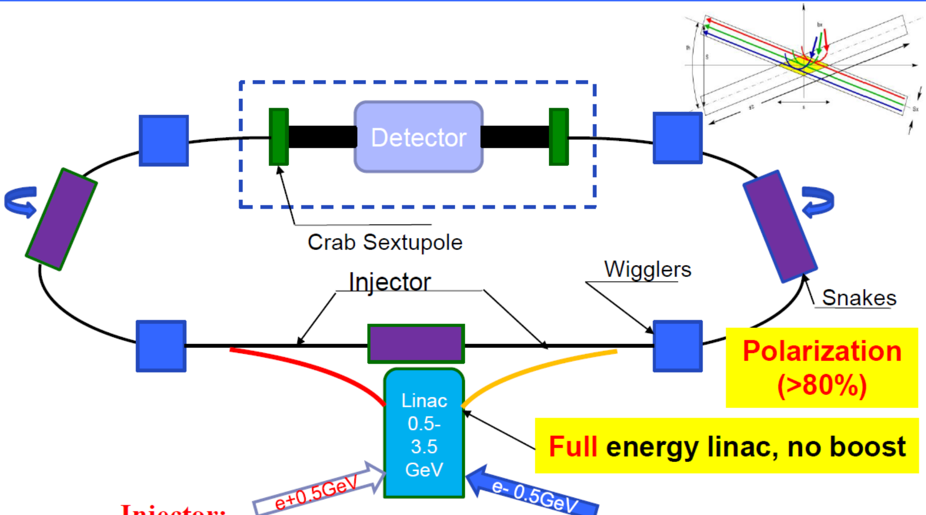
BEPCII

- 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

Designed STCF

- Peak luminosity 0.5-1×10^{35} $cm^{-2}s^{-1}$ at 4 GeV
- Energy range E_{cm} = 2–7 GeV
- Single Beam Polarization (Phase II)





Injector:

- e+, a convertor, a linac and a damping ring, 0.5GeV
- e-, a polarized e- source, accelerated to 0.5GeV

Highlight 1:Matter-Antimatter Asymmetry

CPV in K, B meson system ⇒ 1980, 2008 Nobel Prizes

2019 LHCb: CPV in D meson system!

What about CPV in Baryon & Lepton system?

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: $10^{-4} \sim 10^{-5}$**
- **One example: Phys. Rev. D34, 833 (1986).**

PHYSICAL REVIEW D VOLUME 34, NUMBER 3 1 AUGUST 1986

Hyperon decays and *CP* nonconservation

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Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003

Xiao-Gang He and Sandip Pakvasa
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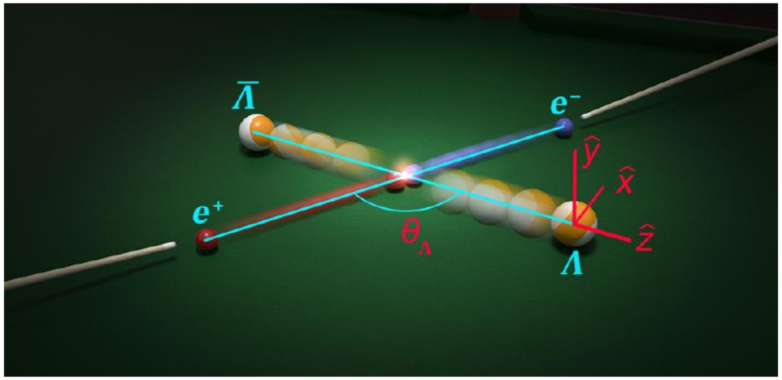
(Received 7 March 1986)

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.

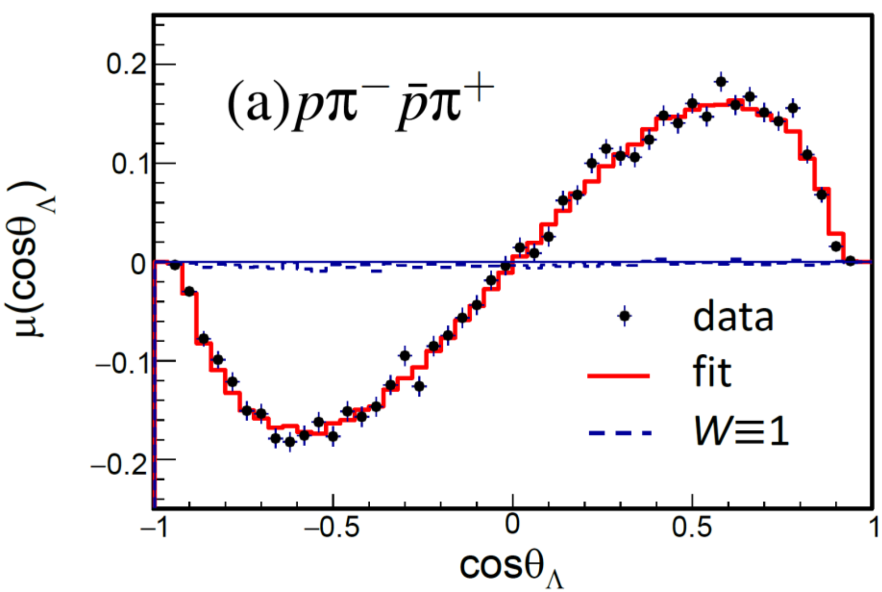
Spin polarization of Λ in $J/\psi \to \Lambda\bar{\Lambda}$



BESIII **Nature Physics**
arXiv:1808.08917

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

CP test

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

A_{CP} Sensitivities in STCF

- 4 trillion J/ψ events ⇒ $\Delta A_{CP} \sim 10^{-4}$
  - Luminosity optimized at J/ψ resonance
  - Luminosity of STCF: × 100
  - 2 – 3 years data taking
  - No polarization beams are needed
- Beam energy trick ⇒ small beam energy spread ⇒ J/ψ cross-section: × 10 ⇒ $\Delta A_{CP} \sim 10^{-5}$?
- Challenge: Systematics control
- Full simulation results are necessary!

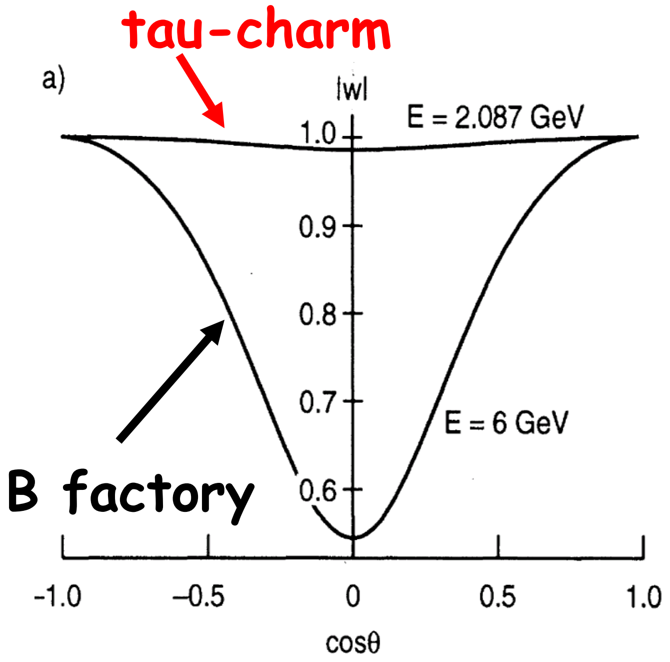
CPV in τ decays

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

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

- 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 @ ($8x10^{35}cm^{-2}s^{-1}$) FOM=52

Experimental challenge:
reconstruction of τ (No secondary vertices)

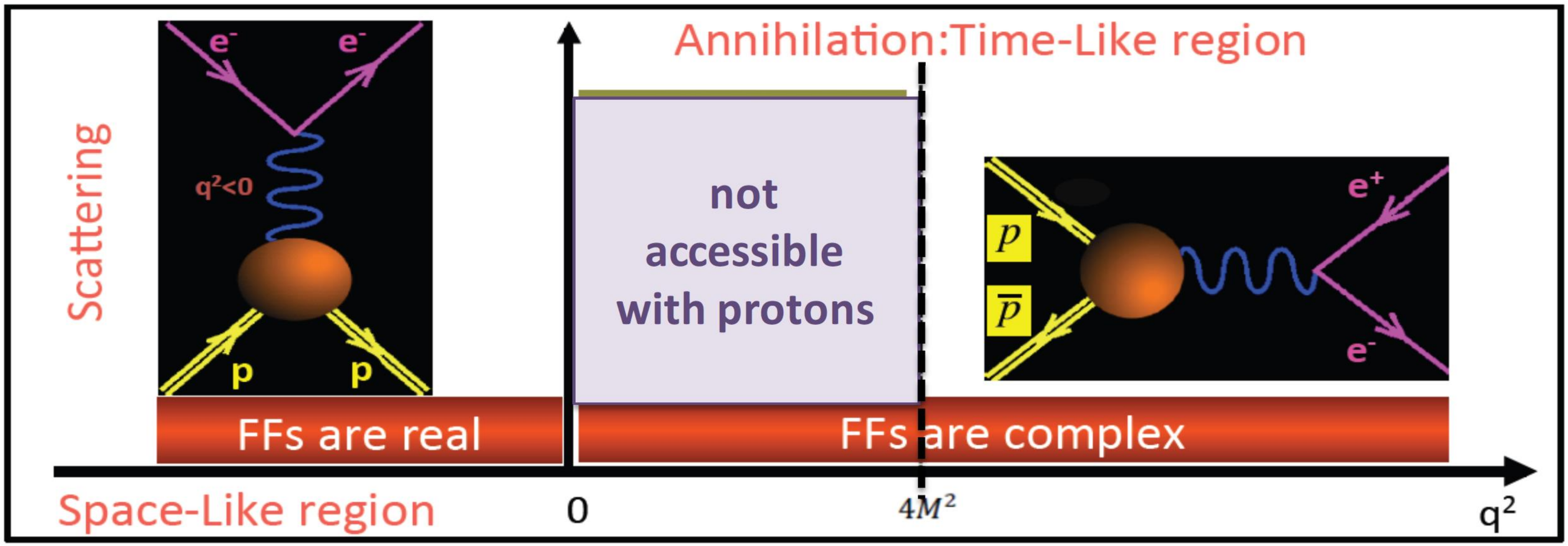
R/QCD Highlights

Baryon Form Factors

✦ **for B=p: JLAB & e^+e^- are complementary**

Crossing symmetry:

$$\langle N(p')|j^\mu|N(p)\rangle \rightarrow \langle \overline{N}(p')N(p)|j^\mu|0\rangle$$



$$J^\mu = \langle N(p')|j^\mu|N(p)\rangle = e\bar{u}(p')\left[\gamma^\mu F_1(q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2M}F_2(q^2)\right]u(p)$$

Fermi & Dirac form factors

$e^+e^- \to p\bar{p}, n\bar{n}, \Lambda\bar{\Lambda}$ threshold

Integrated cross section:

$$\sigma_{p\bar{p}} = \frac{4\pi\alpha^2\beta C}{3m^2}\left|G_{eff}(m_{p\bar{p}})\right|^2(1+1/2\tau)$$

$$\text{for } p\bar{p}\text{: } C = \frac{\pi\alpha/\beta}{1-\exp(-\pi\alpha/\beta)} \to \frac{\pi\alpha}{\beta}$$

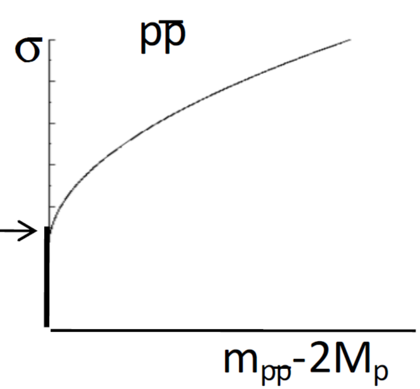
Sommerfeld resummation factor

in point-like approx:

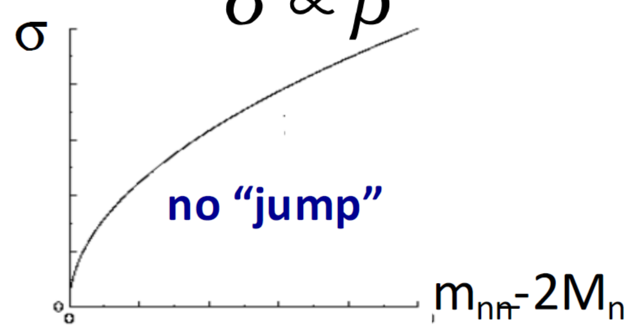
for $n\bar{n}$ $(\Lambda\bar{\Lambda})$: $C=1$

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

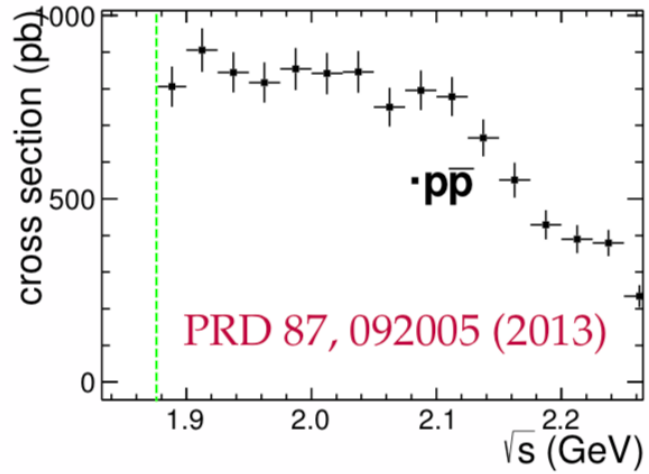
$$\approx 0.85\text{nb}\left|G_{eff}(2M_p)\right|^2 \to$$

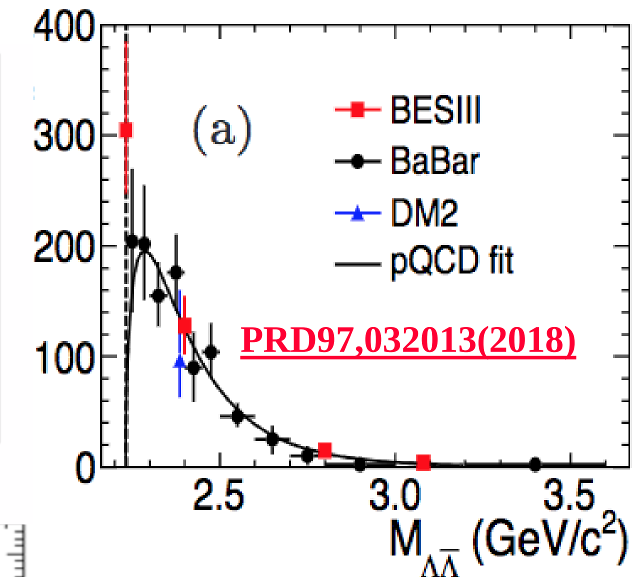


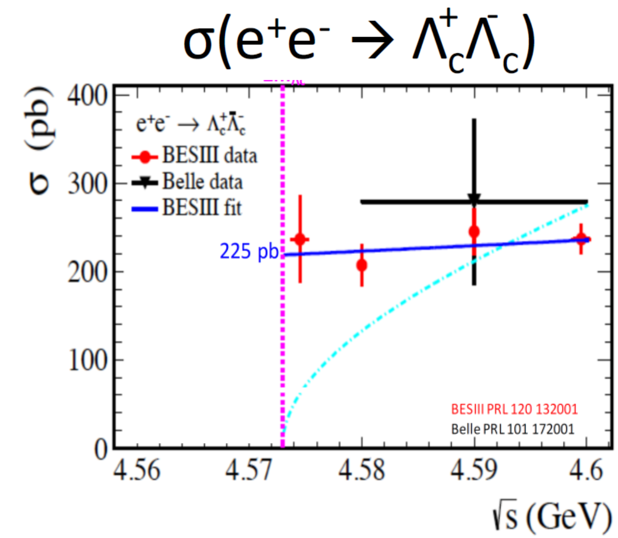
$$\sigma \propto \beta$$

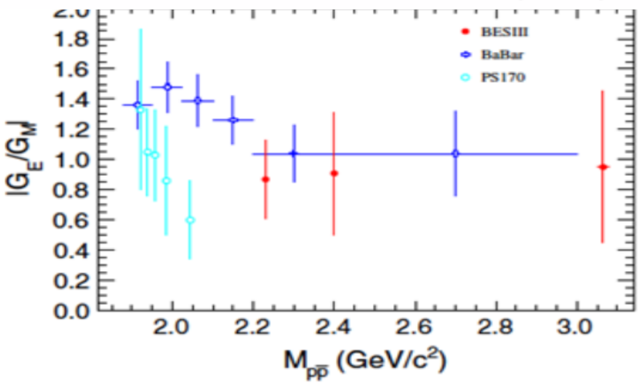


The threshold production of baryon pair





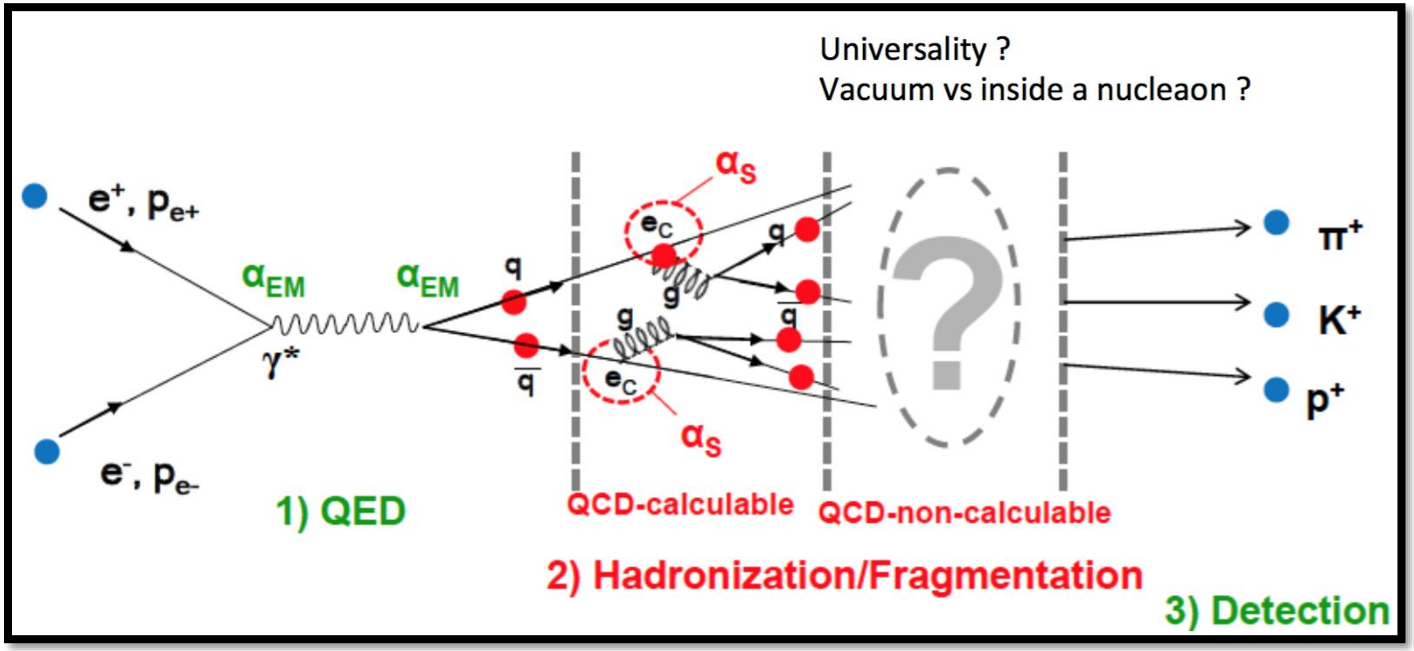


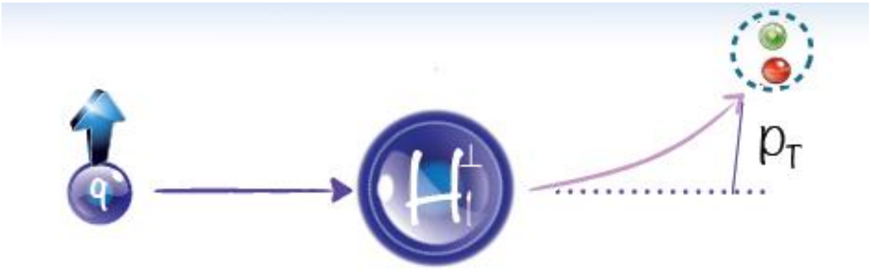


Form factor reflects spatial distributions of electric charge and current inside the nucleon

STCF: 100× more statistics will much enhance the understandings of these 'unexpected' threshold enhancement! (Study $e^+e^- \to p\bar{p}, n\bar{n}, \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi\bar{\Xi}, \Omega\bar{\Omega}, \Lambda_c\overline{\Lambda_c}, \Sigma_c\overline{\Sigma_c}, \Xi_c\overline{\Xi_c}, \Omega_c\overline{\Omega_c}$ … @threshold)

极化依赖的Collins碎裂函数测量





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

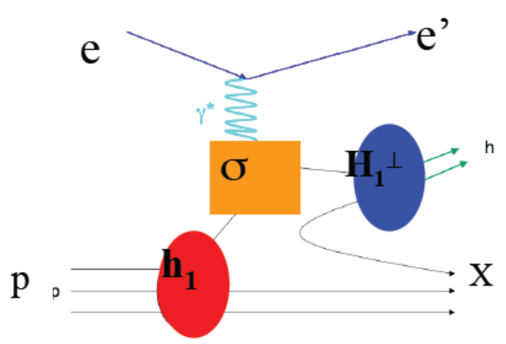
Collins Fragmentation Function (FF)

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

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.

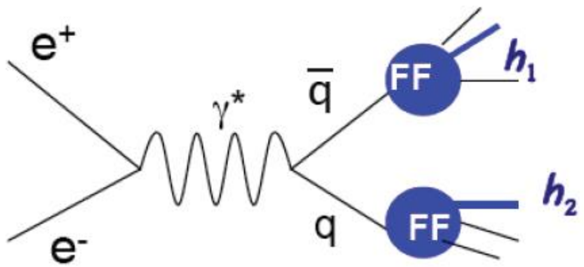
SIDIS

Transversity ⊗ Collins FF



e+ e-

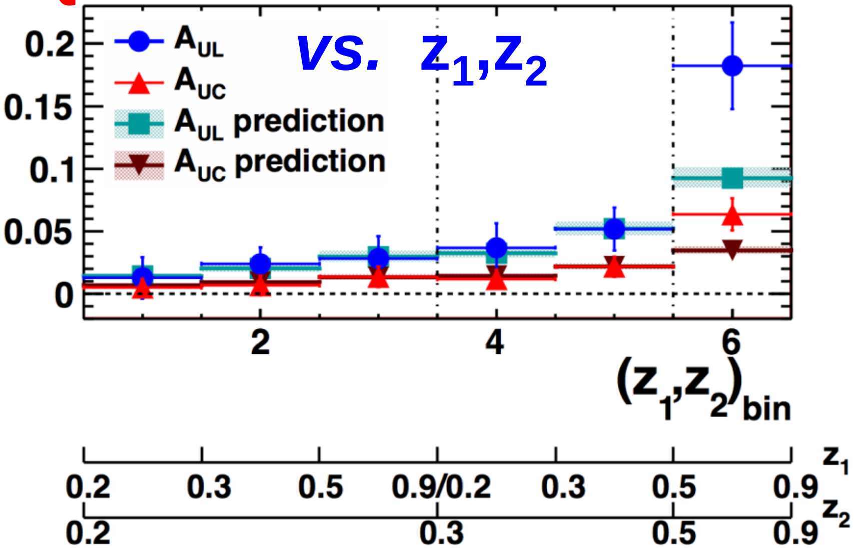
Collins FF ⊗ Collins FF

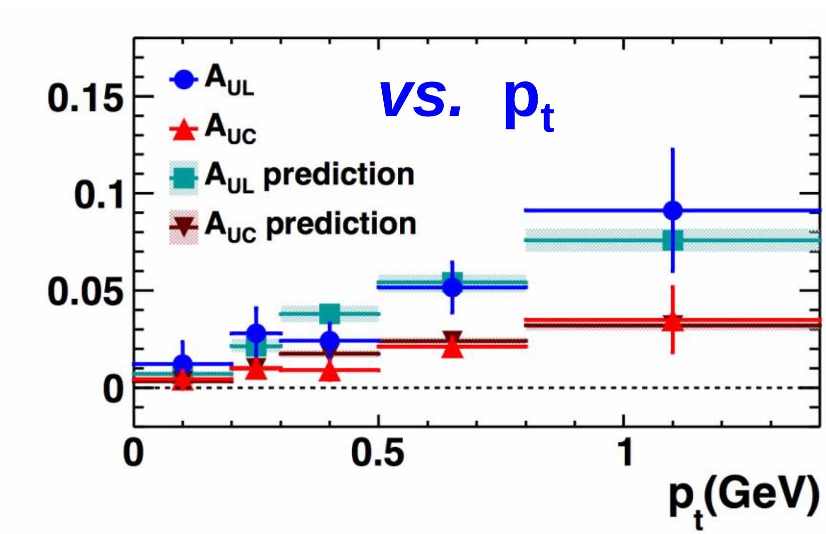


Collins effect at BESIII

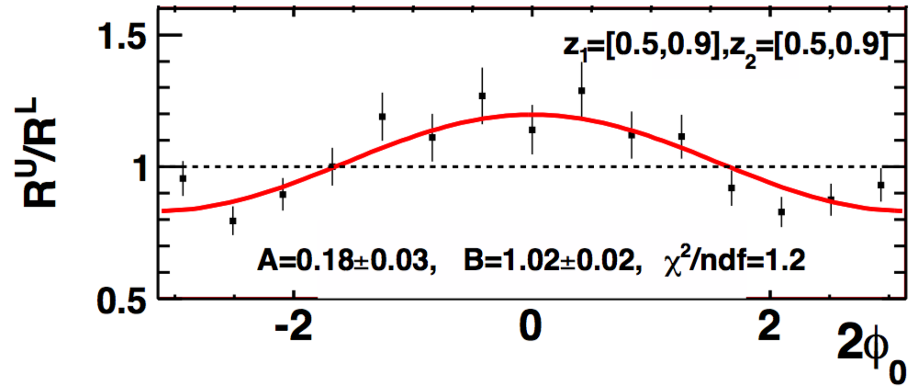
PRL 116, 042001 (2016)

First time measurement in Low Q^2~13GeV^2 at e+e- collision





- A_{UL}, A_{UC} enote asymmetries for UL and UC ratios, respectively



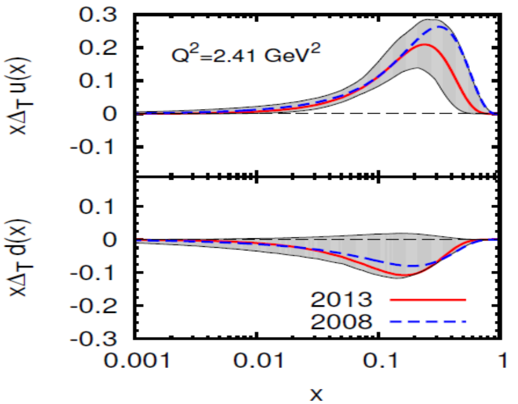
- ~62 pb $^{-1}$ @3.65GeV
  - Continuum region
- Nonzero Collins effect at BESIII
- Basically consistent with predictions from PRD 88. 034016 (2013) .
- important inputs for understanding the spin structure of the nucleon
- valuable to explore the energy evolution of the spin-dependent fragmentation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

Global Analysis on Collins FF

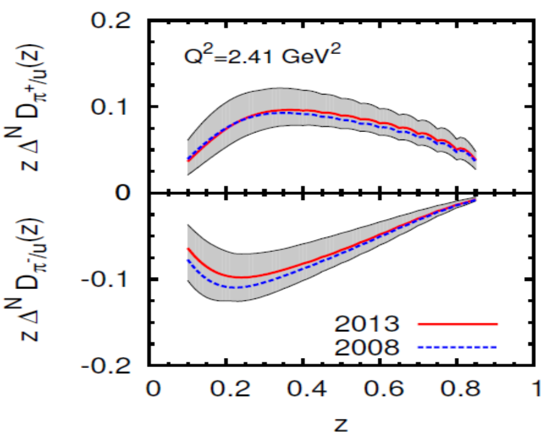
Anselmino et al., PRD 87, 094019 (2013)

Using data from HERMES, COMPASS, Belle

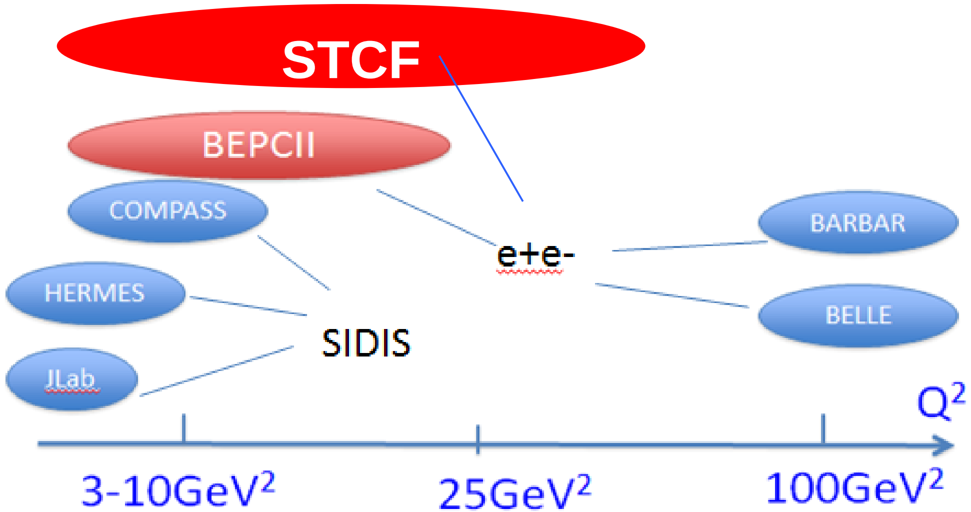
Transversity



Collins pion



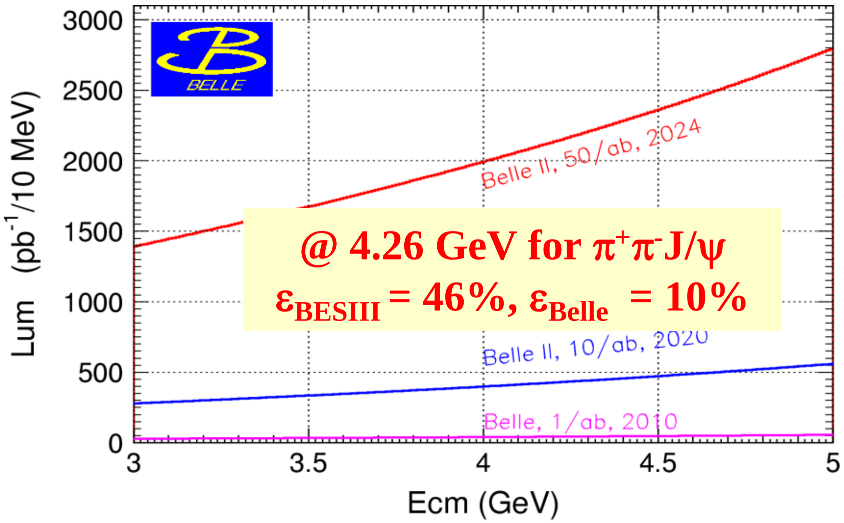
- **The Q^2 evolution of Collins FFs was assumed following the extrapolation in the unpolarized FF, and this has not been validated.**
- **Low Q^2 data from e^+e^- collider is useful.**
- **BEPCII / STCF**
  - **Similar Q^2 coverage with SIDIS in EicC**



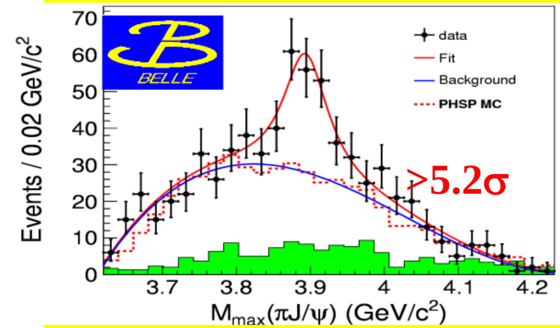
Charmonium-Like Physics (XYZ)

No challenge from Super KEKb/Belle II

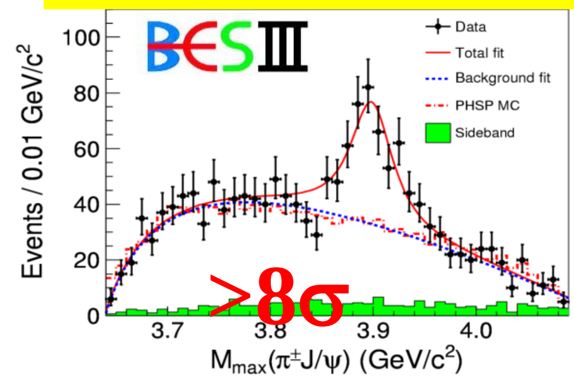
- **τ-C Factory : $e^+e^- \to Y/\psi \to Z_c + X$**
- **B Factory : ISR, B decay**



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 4-5 GeV is 0.23ab^{-1} for 50 ab^{-1} data**
- **τ-C factory : scan in region 4-5 GeV, 10 MeV/step, every point have 20 fb^{-1}/year, 10 time of Belle II for 50 ab^{-1} data**
- **τ-C factory have much higher efficiency than B Factory**

STCF CDR status

Parameters and Plan of STCF

Parameters	Phase 1	Phase 2
Circumference/m	600-800	600-800
Optimized Beam Energy/GeV	2	2
Energy Range/GeV	1-3.5	1-3.5
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
Dynamic Aperture	15σ	15σ
Total Lifetime	~1800s	~1800s

Basic Features:

- **Large Piwinski angle collision + crabbed waist**
- **Siberia snake for polarization**

Strategy :

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

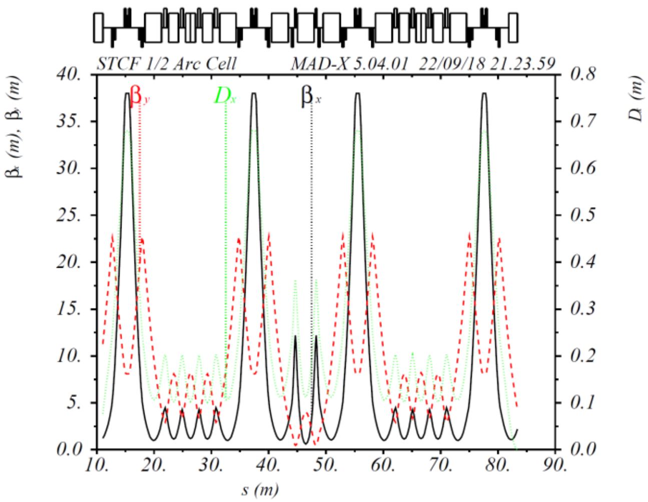
Final:

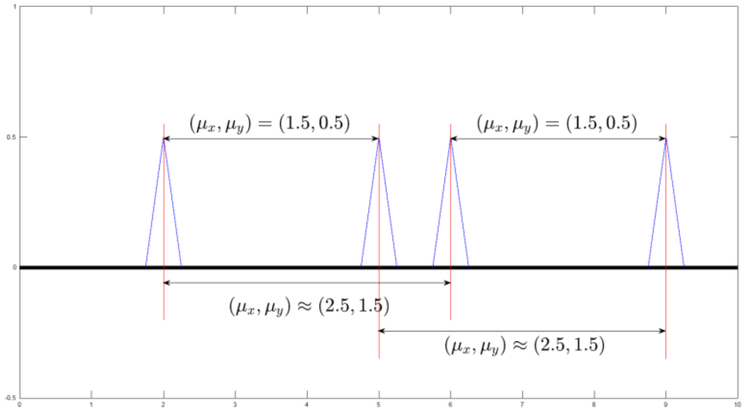
- **90% Polarization e- injection, 80% Polarization @IP**

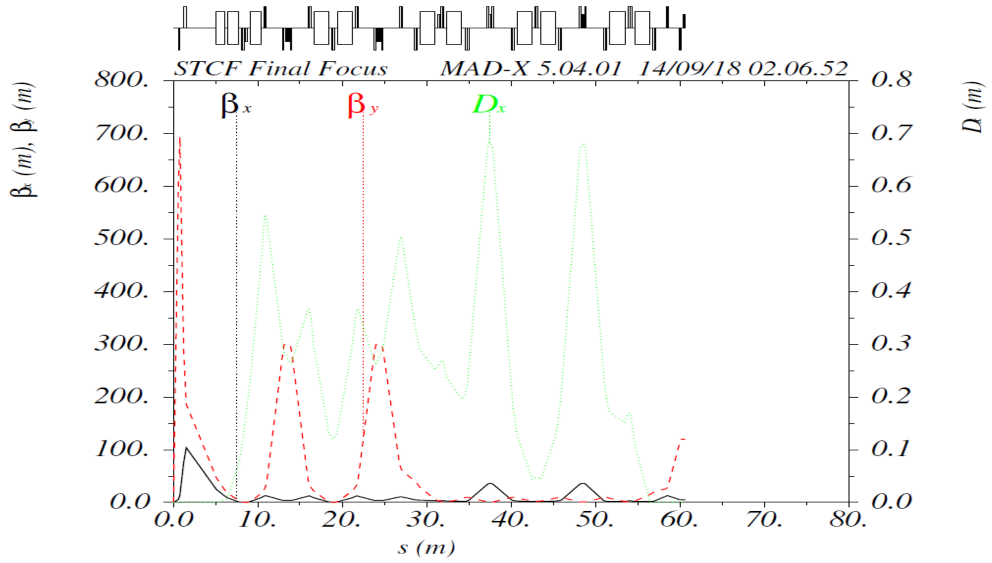
Upgrade: Polarized e+

A quasi-7BA-arc Lattice

- More nonlinear cancellation in IR







Achieved Parameters

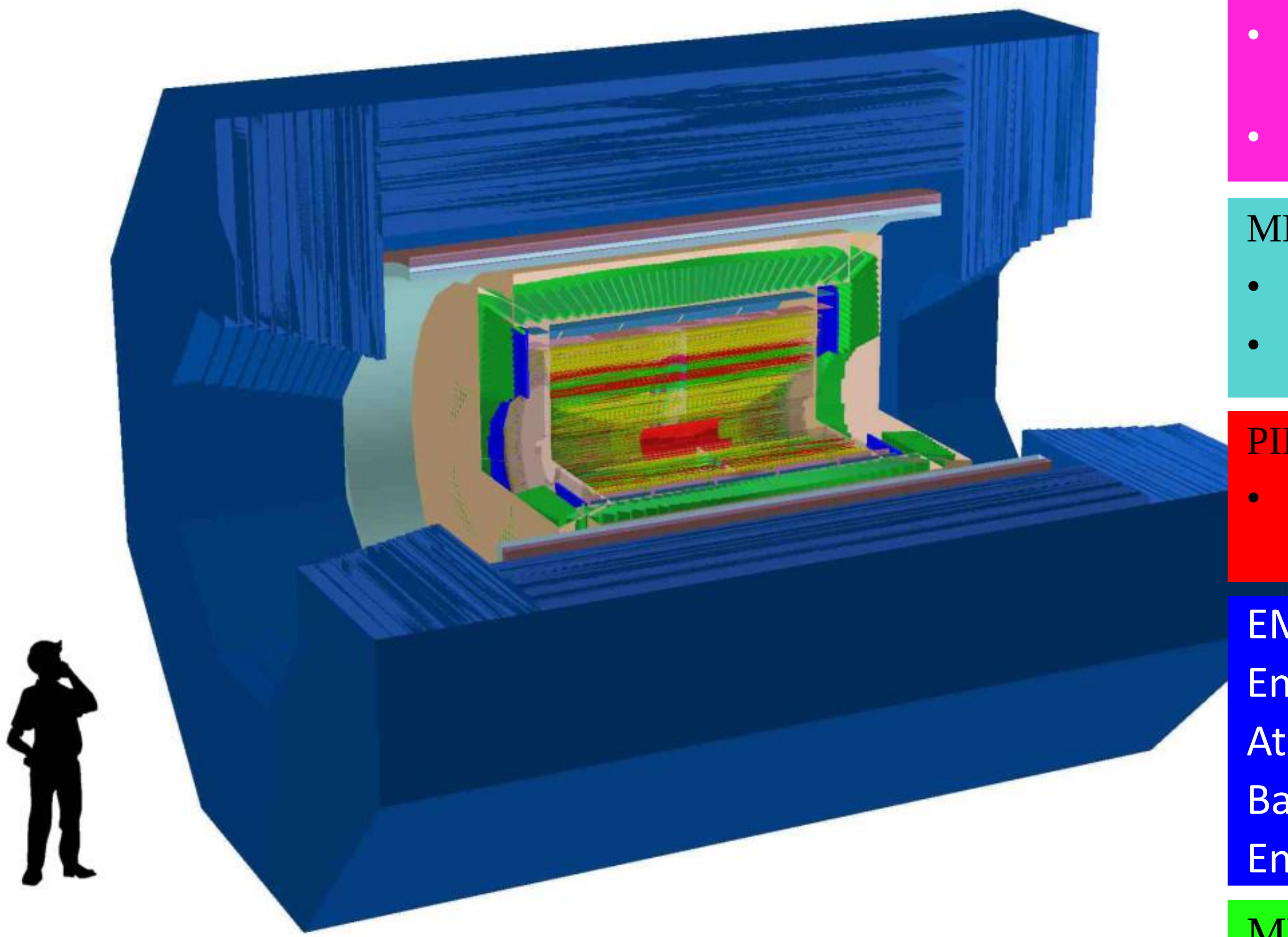
✦Collider with 7BA-based Arc

✦Parameters now

Parameters	Phase 1
Circumference/m	~400
Beam Energy/GeV	2
Current/A	1.5
Emittance$(\varepsilon_x/\varepsilon_y)$/nm·rad	2.4/0.03
β Function @ IP (β_x^*/β_y^*)/mm	66.5/0.55
ν_x /υ_y	17.2/10.7
Collision Angle(full θ)/mrad	60
Tune Shift ξ_y	0.06 (goal)
Hour-glass Factor	0.8 (goal)
Luminosity/×10^{35}cm^{-2}s^{-1}	~0.8 estimated

- **Raw results, needs more work**
- **Interaction region, tunes and tune shift should be optimized**
- **Consider much longer rings (600-800m), may achieve much better performance of emittance and allow enough space for 5 Siberian snakes or more (if really needed), high polarization may be available.**

Detector Layout



PXD

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

MDC

- σ_{xy}=100 μm
- dE/dx<7%, σ_p/p =0.5% at 1 GeV

PID

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

EMC

Energy range: 0.02-2GeV

At 1 GeV	σ_E (%)
Barrel(Cs(I):	2
Endcap (Cs):	4

MUD

- μ/π suppression power >10

General Consideration of Detector

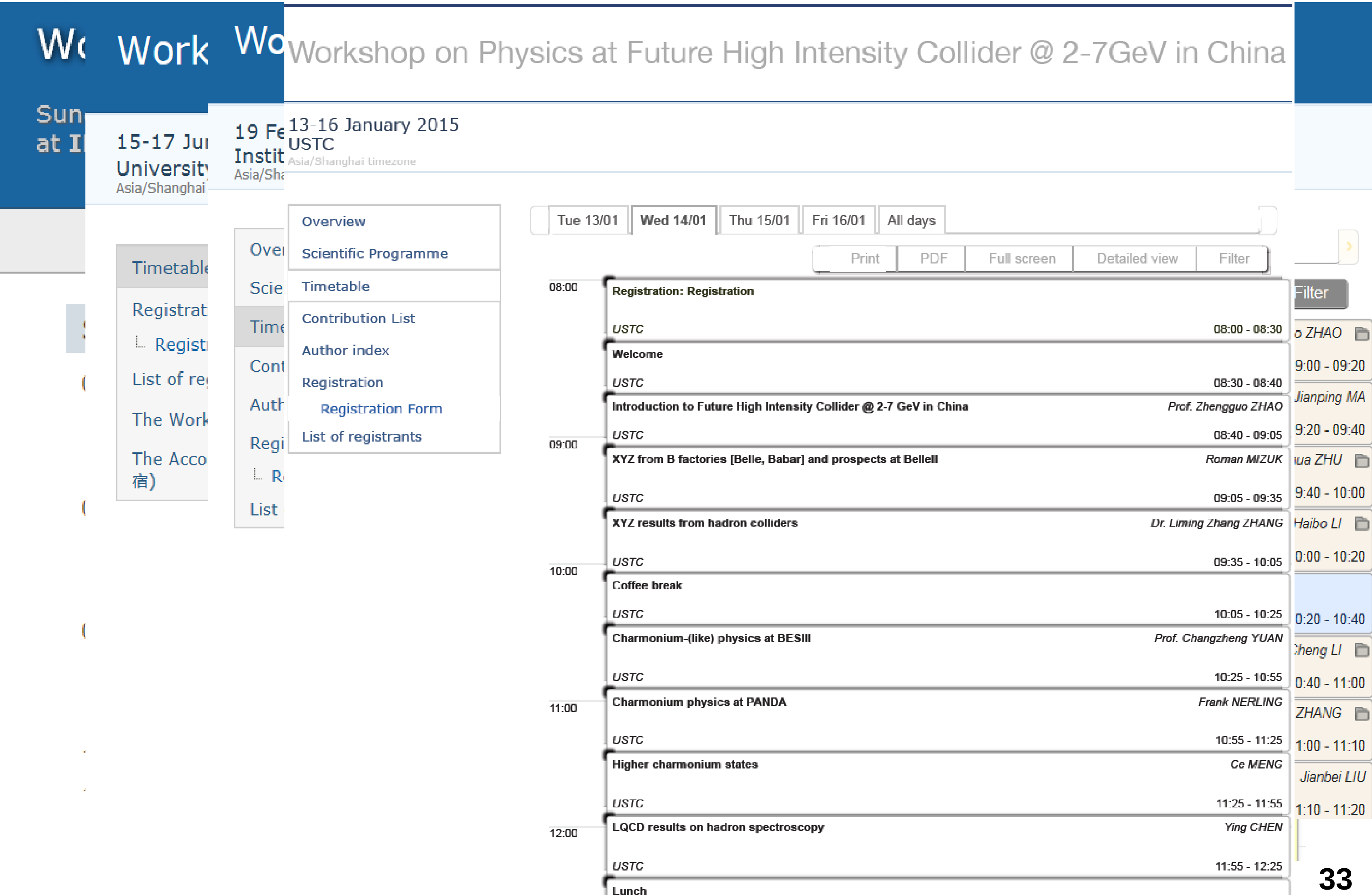
- Much larger radiation tolerance, especially at IP and forward regions
- Efficient event triggering, exclusive state reconstruction and tagging
- The Systematic uncertainty control
- Reasonable cost
- STCF Detector team has been formed. (Currently, USTC team is playing the leading role.)
- Lots of progress 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)

Strategy & 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.
- Webpage: http://wcm.ustc.edu.cn/pub/CICPI2011/futureplans/
- Domestic Workshops (2011, 12, 13, 14, 16)
- International Workshops (2015, 18)
- Report to USTC Scientific Committee and USTC presidents
- Report to Hefei High-tech Development Zone
- Report to Anhui Development Planning Commission
- Form the Organization for the project
- Regular weekly meetings for Accelerator/Detector Design!

Activities


Workshop on Physics at Future High Intensity Collider @ 2-7GeV in China
13-16 January 2015
USTC
Asia/Shanghai timezone
Overview
Scientific Programme
Timetable
Contribution List
Author index
Registration
Registration Form
List of registrants
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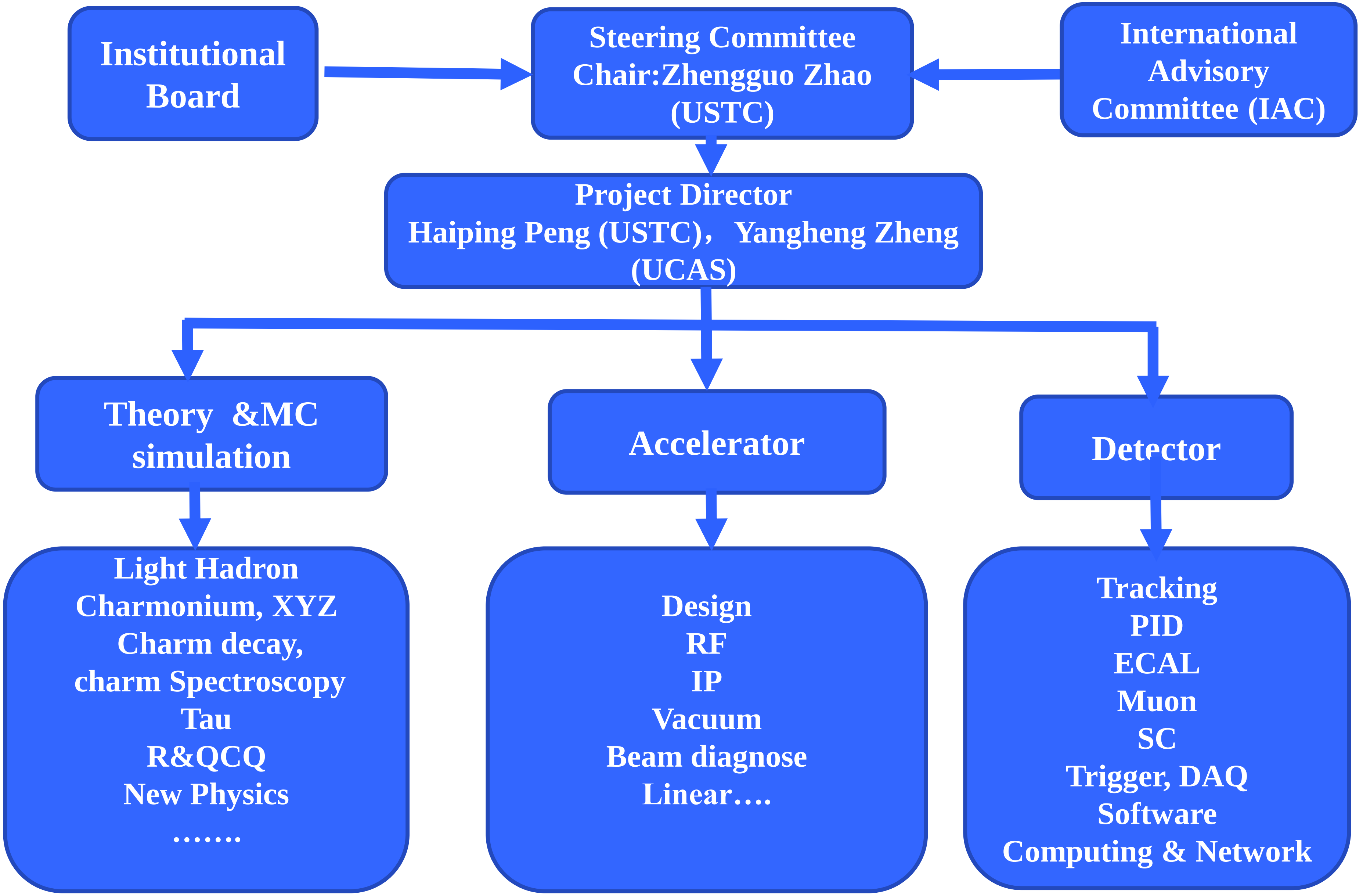
Registration: Registration
USTC
08:00 - 08:30
Welcome
USTC
08:30 - 08:40
Introduction to Future High Intensity Collider @ 2-7 GeV in China
Prof. Zhengguo ZHAO
USTC
08:40 - 09:05
09:00
XYZ from B factories [Belle, Babar] and prospects at BelleII
Roman MIZUK
USTC
09:05 - 09:35
XYZ results from hadron colliders
Dr. Liming Zhang ZHANG
USTC
09:35 - 10:05
10:00
Coffee break
USTC
10:05 - 10:25
Charmonium-(like) physics at BESIII
Prof. Changzheng YUAN
USTC
10:25 - 10:55
11:00
Charmonium physics at PANDA
Frank NERLING
USTC
10:55 - 11:25
Higher charmonium states
Ce MENG
USTC
11:25 - 11:55
12:00
LQCD results on hadron spectroscopy
Ying CHEN
USTC
11:55 - 12:25
Lunch

USTC Scientific Committee Review

- **USTC president agreed, and scientific committee endorsed supporting R&D → 10 M RMB**

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														■

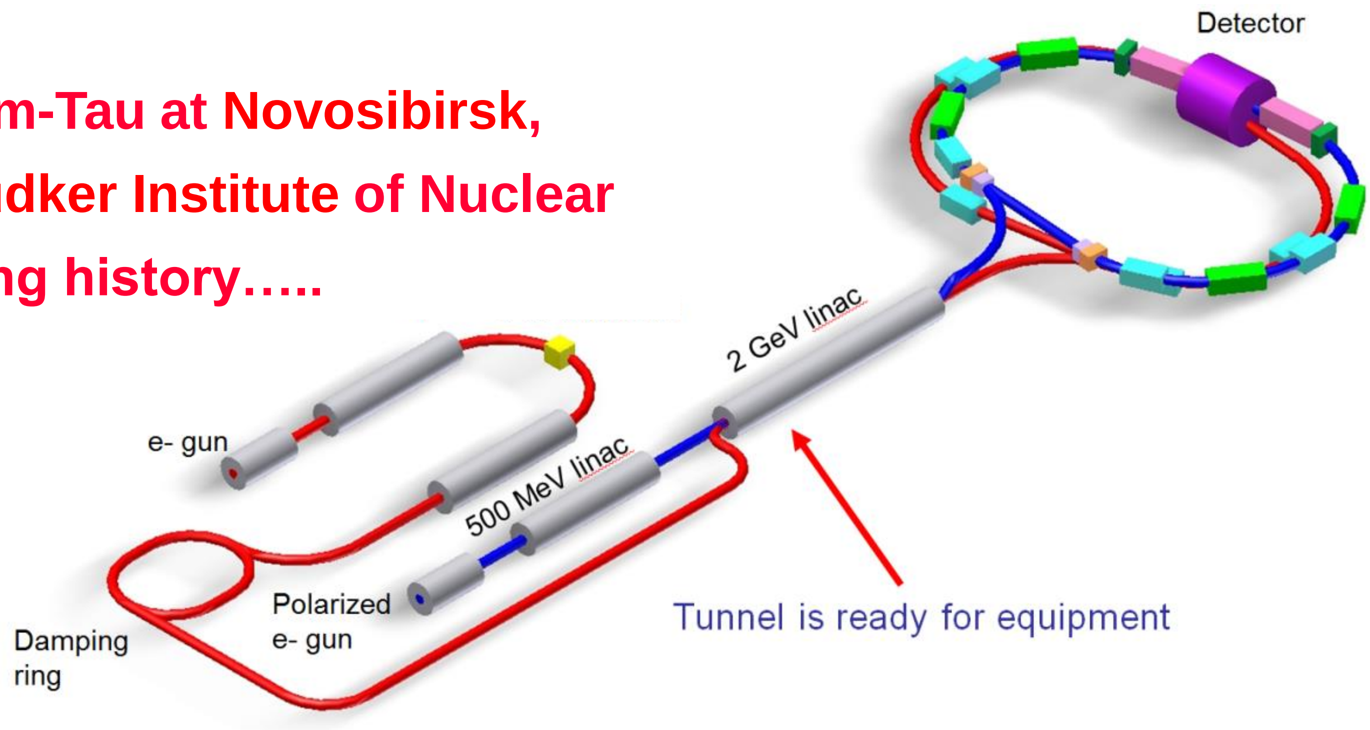
A unique precision frontier in the world for 30 years!

R&D budget: 200M RMB
Total budget: 4B RMB
(estimated in 2014)

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

International Collaboration

Super Charm-Tau at Novosibirsk, RUSSIA, Budker Institute of Nuclear Physics Long history…..



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

Science & Technology Review

Home

COMMITTEES

- Local Organising Committee
- Program Committee
- International Advisory Committee

PROGRAM

REGISTRATION

Home

The workshop will be dedicated to the discussion of the future tau-charm factory projects. The physics case will be revisited via joint theory and experiment contributions, together with detailed discussions on the required accelerator and detector design. The two existing proposals – the one in Novosibirsk and the one in Hefei – will give a base for discussions.

The first day of the workshop will be dedicated to expected physics reach, the second day to the accelerator discussions, while the third day to the detector for the future tau-charm factory.

PRACTICAL INFORMATION

- Travel
- Lodging
- Social events

Poster

CONTACT US

discuss the design and key technology of accelerator and detection

Institutions shown Interest

- University of Science and Technology of China
- Institute of High Energy Physics, CAS
- Institute of Theoretical Physics, CAS
- Tsinghua University
- University of Chinese Academy of Sciences
- **Shandong University**
- Shanghai Jiaotong University
- Peking University
- Zhejiang University
- Nanjing University
- Nankai University
- Wuhan University
- Central China Normal University Lanzhou University
- University of Southern China
- Beijing University of Aeronautics and Astronautics
- …….
- Institute for Basic Science, Daejeon, Korea
- Dubna, Russia
- Budker Institute and Novosibirsk University, Russia
- T. Shevchenko National University of Kyiv, Kyiv, Ukraine
- University Ljubljana and Jozef Stefan Institute Ljubljana, Slovenia
- Jozef Stefan Institute Ljubljana, Slovenia

- **Stanford University, USA**
- **Wayne State University, USA**
- **Carnegie Mellon University, USA**
- **GSI Darmstadt and Goethe University Frankfurt, Germany**
- **Goethe University Frankfurt, Germany**
- **GSI Darmstadt, Germany**
- **Johannes Gutenberg University Mainz, Germany**
- **Helmholtz Institute Mainz, Germany**
- **LAL (IN2P3/CNRS and Paris-Sud University), Orsay, France**
- **Sezione di Ferrara, Italy**
- **L'Istituto di Fisica Nucleare di Torino, Italy**
- **L'Istituto di Fisica Nucleare di Firenze, Italy**
- **Scuola Normale Superiore, Pisa, Italy**
- **University of Silesia, Katowice, Poland**
- **Laboratori Nazionali di Frascati, Italy**
- **INFN, Padova, Italy**
- **University of Pavia, Pavia, Italy**
- **University of Parma, Italy**

Conceptual Design Report

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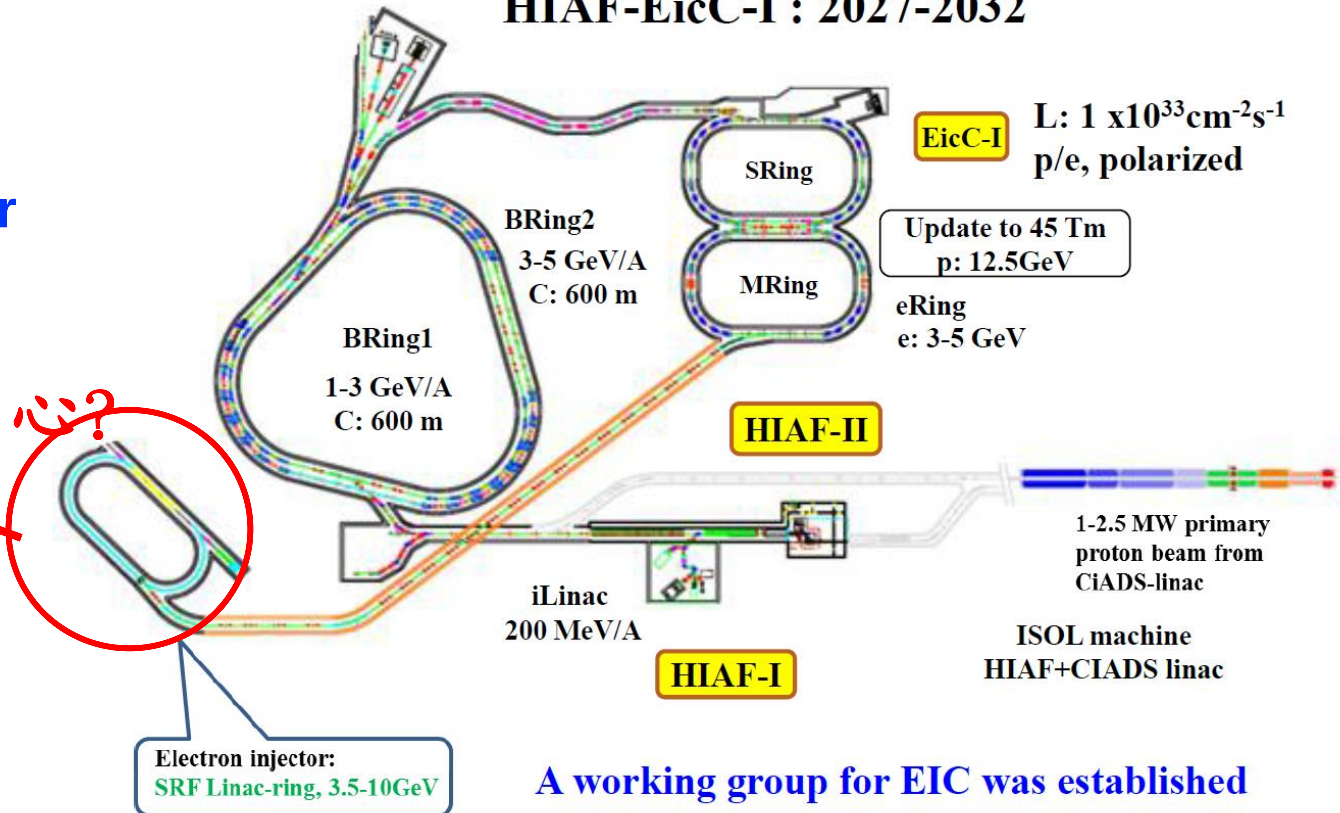
Candidate site 1: 广东

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

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

⇒ QCD 国家中心?

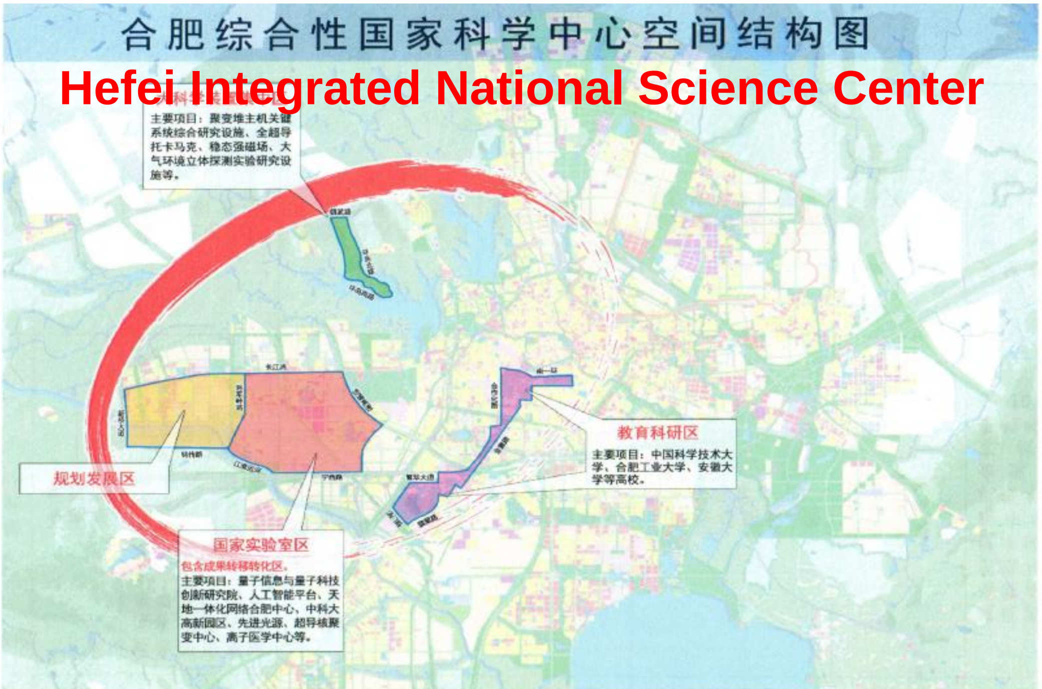


A working group for EIC was established at IMP led by Dr. Nu Xu and Jianping Chen.

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

Candidate site 2: 安徽合肥

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



- ✦ University of Science and Technology of China (USTC)
- ✦ National Synchrotron Radiation Lab and Hefei Light Source, operated by USTC
- ✦ The only National Lab operated by University in China. (Totally Four officially approved National Labs in China)

- Pay a lot of attention on accelerator facilities
- Hefei Advanced light source is under design
- STCF is listed in future plan

Summary

- Super τ-c Facility (STCF): nature extension and a viable option for a post-BEPCII project
- Status of STCF project in China:
  - Physics: Rich & unique for physics with c quark and τ leptons.
  - Detector & Electronics: Significant progress in R&D at USTC
  - 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
  - An international collaboration is under preparing
- Strategy & Plan
  - Complete CDR in 2 years, TDR in 6 years
  - Construction site: Currently open

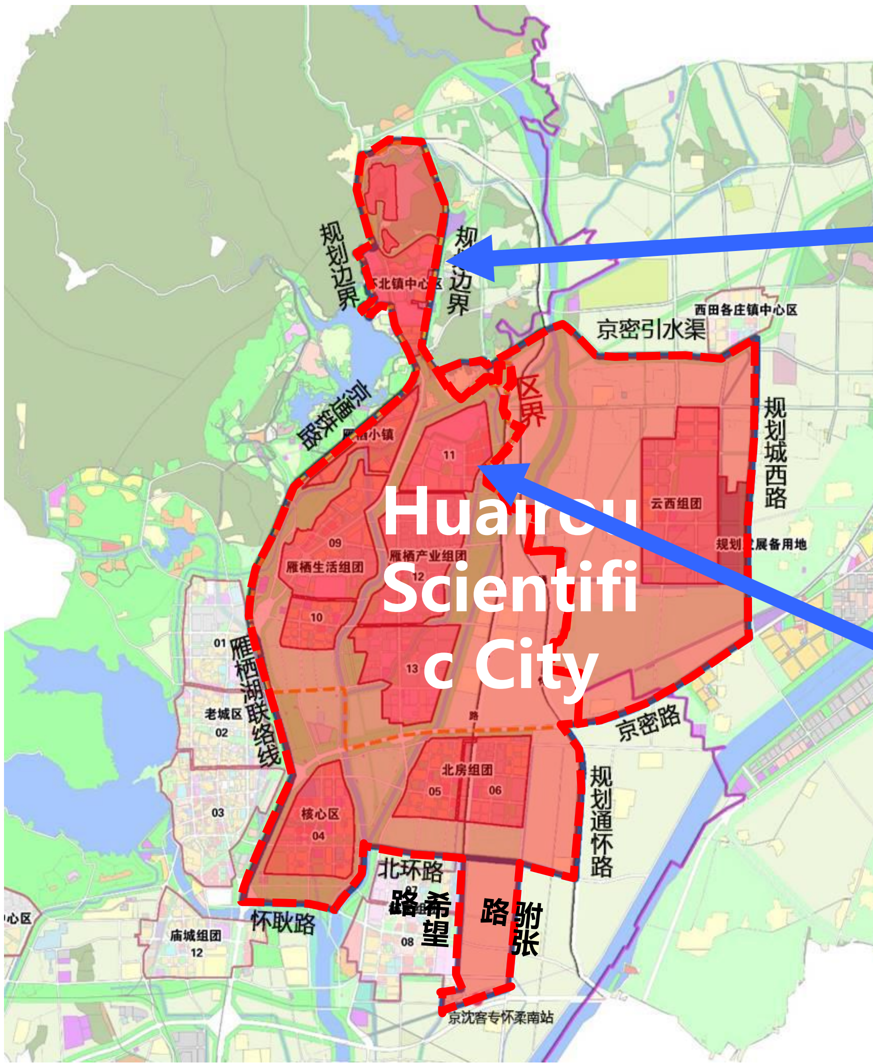
Welcome to join the effort

Thank you!

Backup Slides

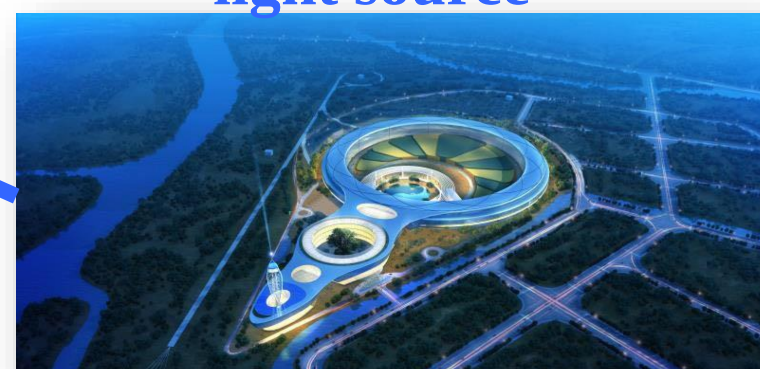
Candidate site 3: 北京怀柔

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



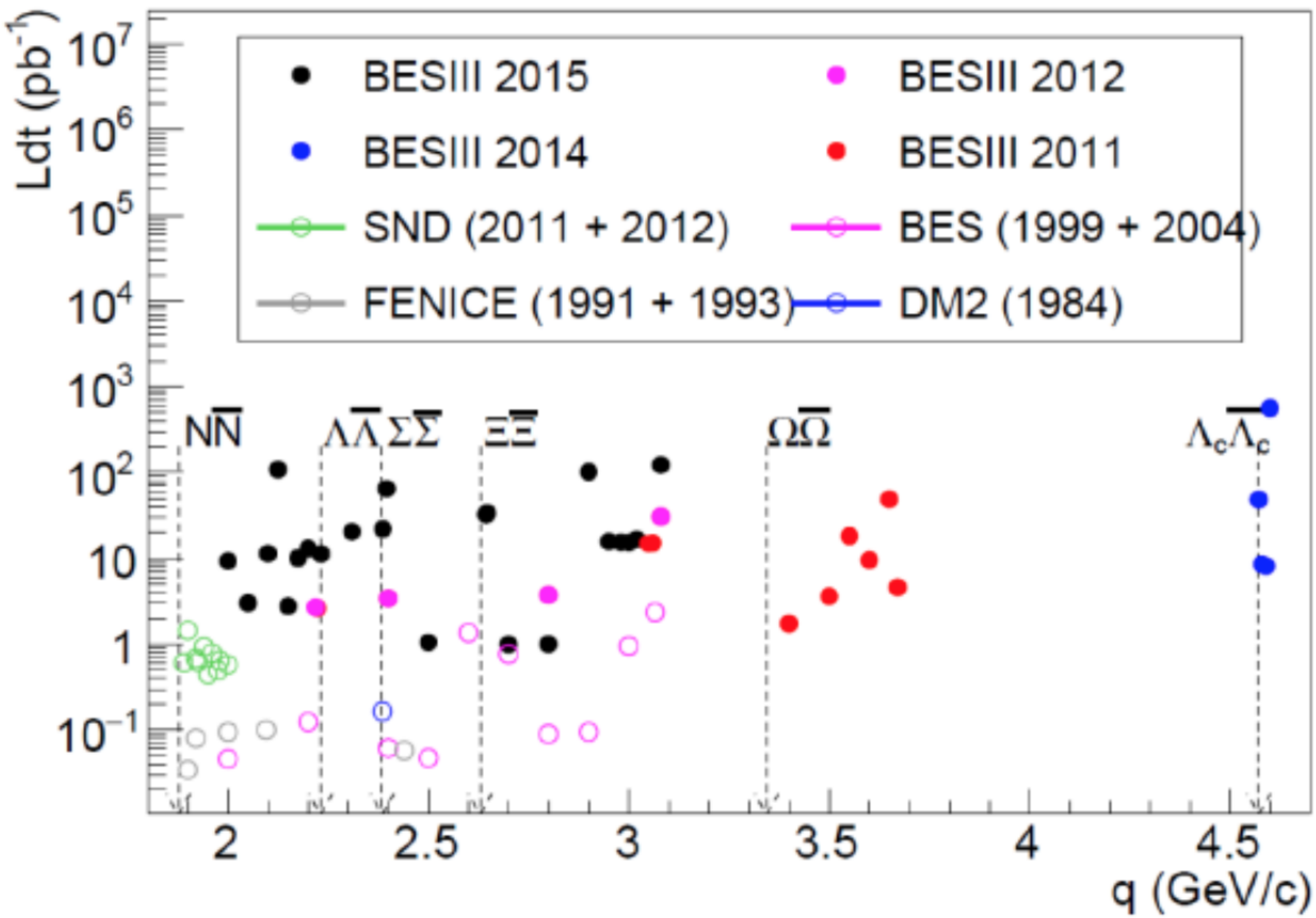
UCAS

Synchrotron radiation light source



So far, no dedicated facility for particle physics yet!

Energy scan 2014-2015 at BESIII



- ➢ World leading scan from 2.0 GeV – 3.08 GeV energy region
- ➢ Nucleon and Hyperon form-factor available

Rich Physics programs @ STCF

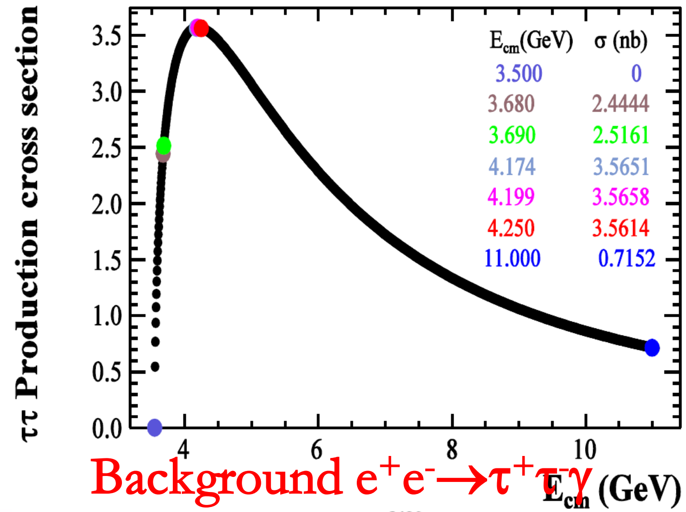
Unique for physics with c quark and τ leptons, important playground for study of QCD, exotic hadrons and search for new physics.

- **Charmonium & Chramonium-like XYZ (Luminosity & CME)**
- **Charmed hadrons (Luminosity & CME)**
- **τ Lepton CP (Luminosity & polarized beam)**
- **New physics (Luminosity)**
- **R / QCD (Luminosity & CME)**
- **…**

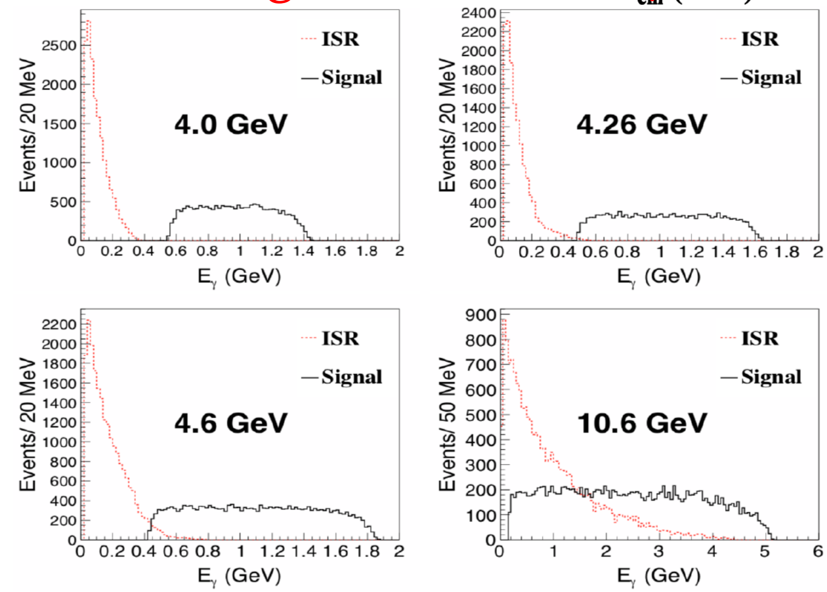
More information can be found in Bingsong Zou's "Physics Summary of STCF", presented at Joint Workshop of future tau-charm factory, December 2018.

cLFV Decay $\tau \to \mu\gamma$

- **Charge Lepton Flavor Violation $\tau \to \gamma\mu$**
  - **New physics beyond SM, constraint many modes.**
  - **Current limit: 4.4×10^{-8} at Babar with 0.9×10^{9} τ pairs**
- **Cross section grows from 0.1 nb near threshold to 3.5 nb to 4.25 GeV.**
  - **At BelleII:**
    - **10^{10} τ pairs/year**
    - **ISR background dominant: $e^+e^- \to \gamma\tau^+\tau^-$**
    - **Expected limit: 3×10^{-9}@50 ab^{-1}**
  - **At STCF:**
    - **7.0×10^{9} τ pairs/year at 4.25 GeV**
    - **$e^+e^- \to \gamma\tau^+\tau^-$ background not contribute at 4.25 GeV.**
    - **Dominant background: $\gamma\mu^+\mu^-$, $\tau \to \pi\upsilon$**
    - **4.4×10^{-8} @ 6.34 ab^{-1} estimated at BESIII**
    - **Much lower μ/π misID rate is needed**
    - **Fast simulation on this process is progressing**



Background $e^+e^- \to \tau^+\tau^-\gamma$



Does not contribute below $\sqrt{s} \approx 4m_\tau/\sqrt{3} \approx 4.1$ GeV.

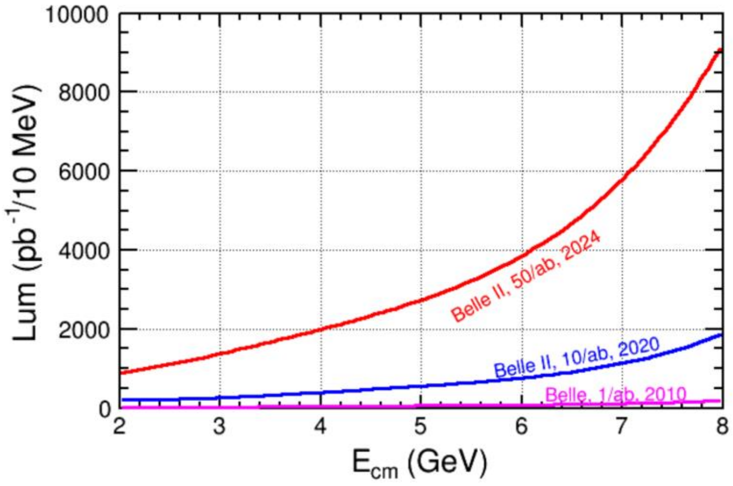
Integrated Luminosity of STCF

- Assume running time 9 months/year, data taking efficiency 90%

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

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

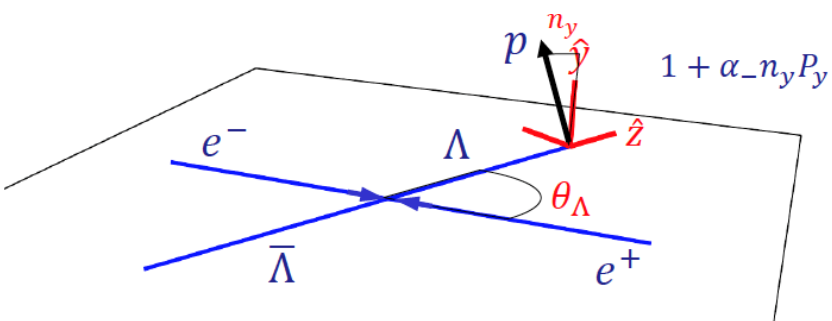
Excellent opportunities for the τ-charm physics



- **B factory**: Total integrated effective luminosity between 2-7 GeV is ~1.5ab^{-1} for 50 ab^{-1} data.
- **STCF** is expected to have higher detection efficiency
  - e.g. @4.26 GeV for $\pi^+\pi^-J/\psi$, $\varepsilon_{\text{BESIII}} = 46\%$, $\varepsilon_{\text{Belle}}$=10%
- **STCF** has low backgrounds for productions at threshold.

5

$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$



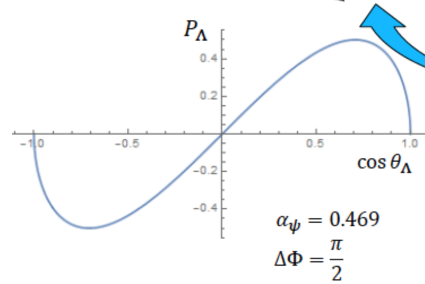
$$\frac{d\Gamma}{d\cos\theta_\Lambda d\Omega_1} \propto \left(1 + \alpha_\psi \cos^2\theta_\Lambda\right)\left\{1 + \alpha_1 P_\Lambda(\theta_\Lambda)\sin\theta_1 \sin\phi_1\right\}$$

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

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

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

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

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

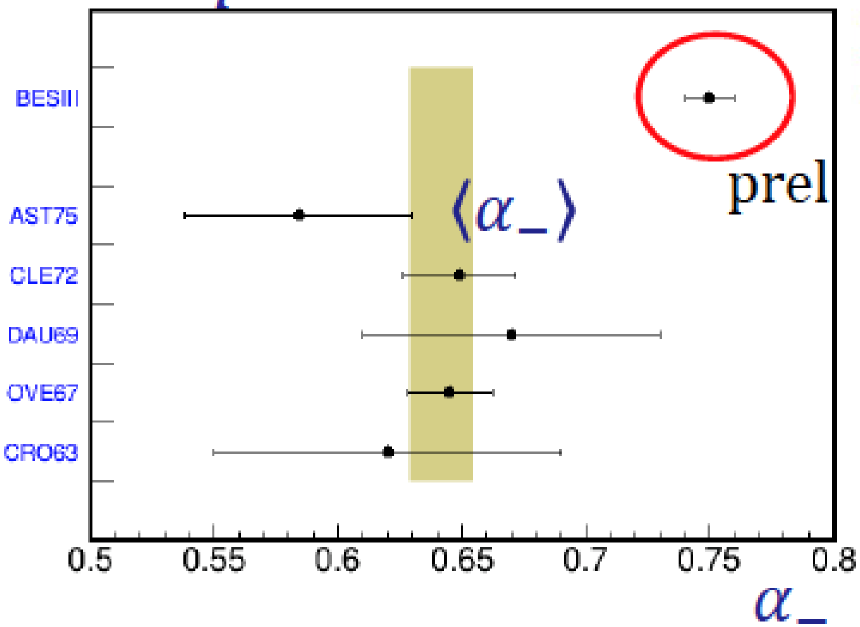
$\boldsymbol{\xi}$: $(\cos\theta, \Omega_1, \Omega_2)$

Spin correlations

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

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

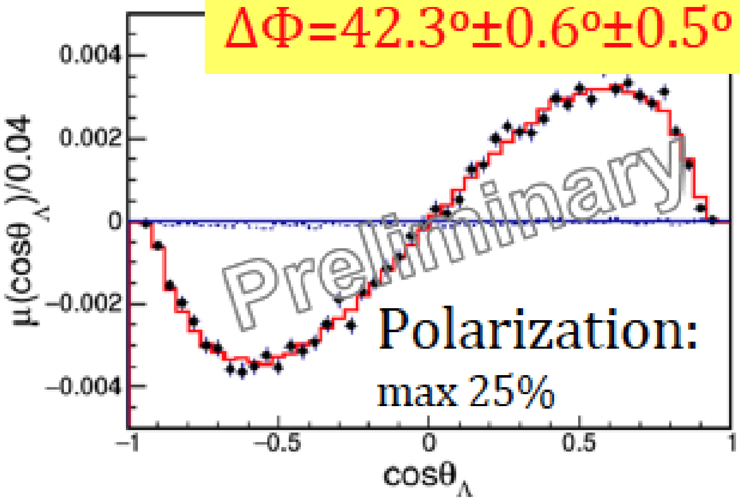
$$A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$$

A_{CP} = -0.006 ± 0.012± 0.007 prel

A_{CP}= 0.013 ± 0.021
PS185 PRC54(96)1877

CKM $A_{CP} \sim 10^{-4}$

$\Delta\Phi$=42.3°±0.6°±0.5°



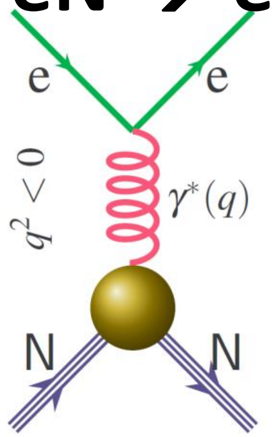
Polarization: max 25%

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

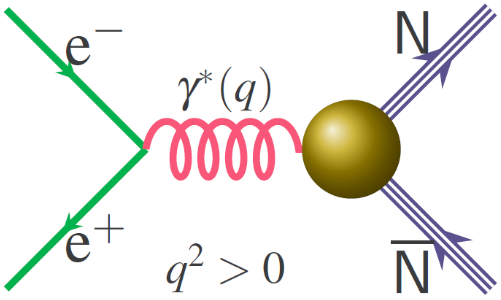
Time-Like Baryon Form Factors

Space-like:
FF real

eN → eN



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



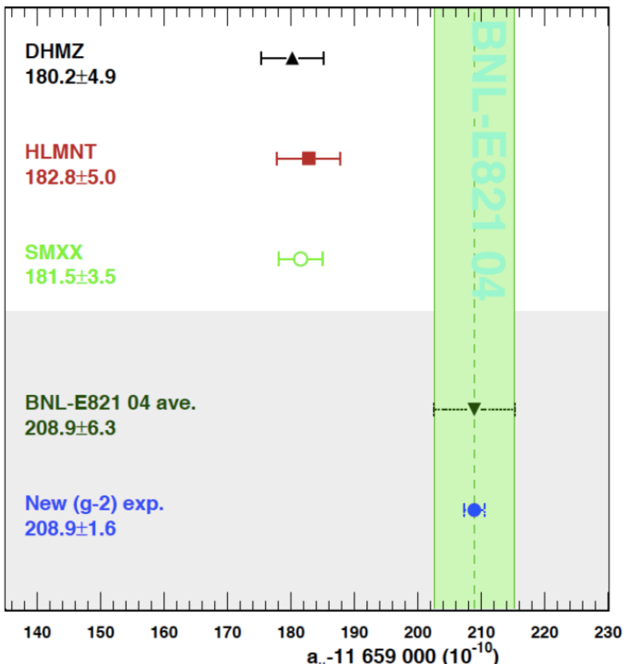
Time-like:
FF complex

- **Fundamental properties of the baryon**
- **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**

Impact on $(g_\mu-2)/2$

At present, the anomalous magnetic moment of the muon $a_\mu = (g-2)_\mu/2$ are known with an uncertainty of about one half per million!

$$a_\mu^{\rm SM} = (11\,659\,180.2 \pm 4.9)\cdot 10^{-10}\,,$$
$$a_\mu^{\rm exp} = (11\,659\,208.9 \pm 6.3)\cdot 10^{-10}\,.$$

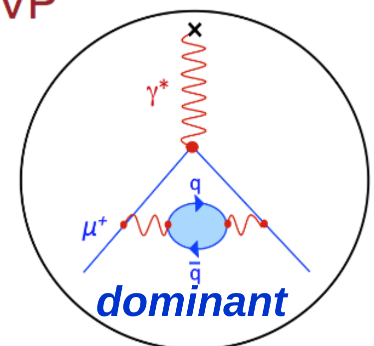


SM-Exp: 3.5σ difference

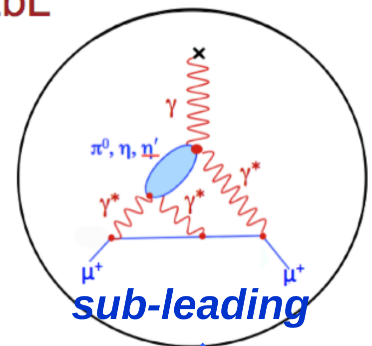
Sensitive to probe new physics.

Data-driven approach: reduce model uncertainty to 10-20%

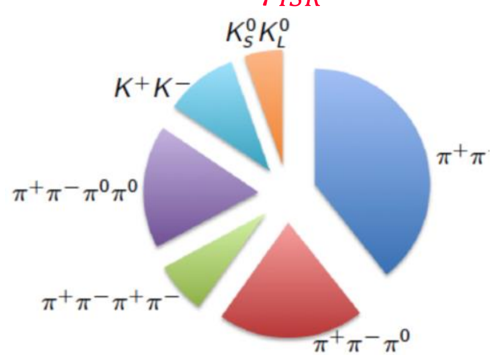
HVP



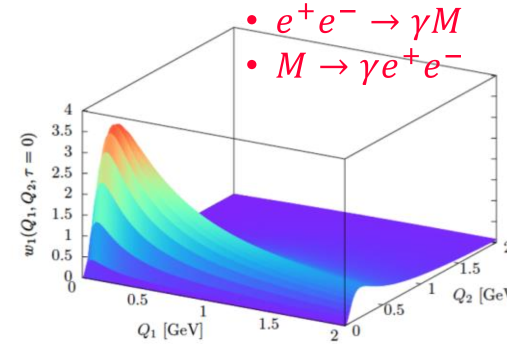
HLbL



- $e^+e^- \to \gamma_{ISR}\, hadrons$



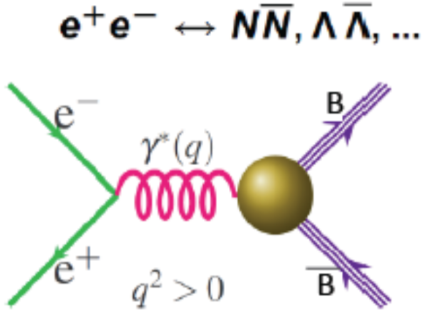
- $\gamma\gamma* \to$ M
- $e^+e^- \to \gamma M$
- $M \to \gamma e^+e^-$



High Luminosity of STCF will largely improve the SM precisions

$e^+e^- \to$ Baryon-Antibaryon Pair

Born cross section:



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

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

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

integrated cross section:

$$\sigma_{B\bar{B}}(m_{B\bar{B}}) = \frac{4\pi\alpha^2\beta C}{3m^2}\left[\left|G_M(m_{B\bar{B}})\right|^2 + \frac{1}{2\tau}\left|G_E(m_{B\bar{B}})\right|^2\right] = \frac{4\pi\alpha^2\beta C}{3m^2}\left|G_{eff}(m_{B\bar{B}})\right|^2\left(1+1/2\tau\right)$$

"effective" form factor

effective form factor:

$$\left|G_{eff}\right|^2 = \frac{\left|G_M\right|^2 + \frac{1}{2\tau}\left|G_E\right|^2}{1+\frac{1}{2\tau}}\sigma_{B\bar{B}}(m_{B\bar{B}}) \;\Rightarrow\; \left|G_{eff}\right| = \left(\frac{3m_{B\bar{B}}^2}{\pi\alpha^2\beta C\left(1+\frac{1}{2\tau}\right)}\right)^{\frac{1}{2}}\sqrt{\sigma_{B\bar{B}}}$$

analyticity:

$$G_M(4M_B^2) = G_E(4M_B^2) \;\Rightarrow\; G_{eff}(4M_B^2) = G_M(4M_B^2)$$

Selected Highlight topics

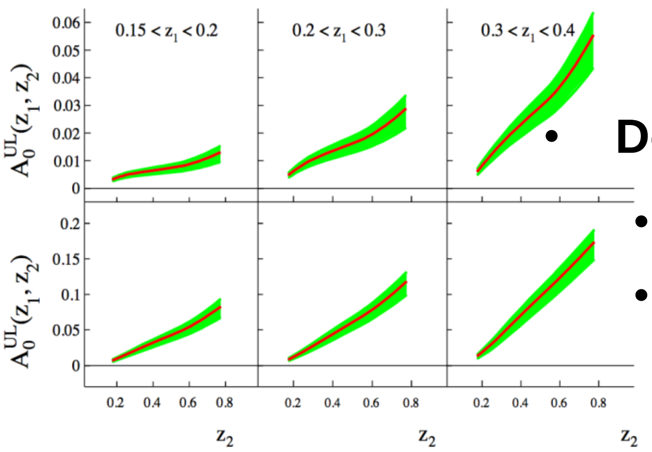
- Time-like Form factors of Baryon pair
- Collins Fragmentation functions; MLLA/LPHP prediction
- Polarization & CPV of Hyperon
- $(g_{\mu} - 2)/2$, 92% from < 2GeV, 7% from 2-5GeV

Collins Fragmentation Function(FF)

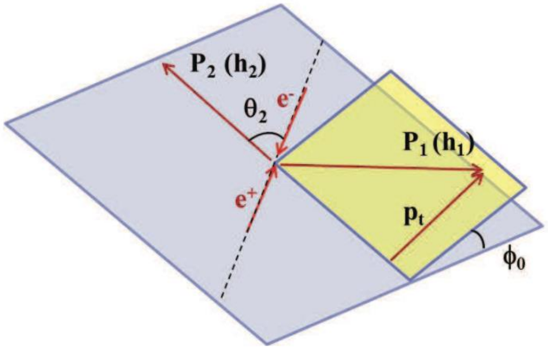
D. Boer Nucl.Phys.B806:23(2009):

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

P. Sun, F. Yuan, PRD 88. 034016 (2013)
Predicted Collins asymmetries for BESIII :



✦ Experimentally



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

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

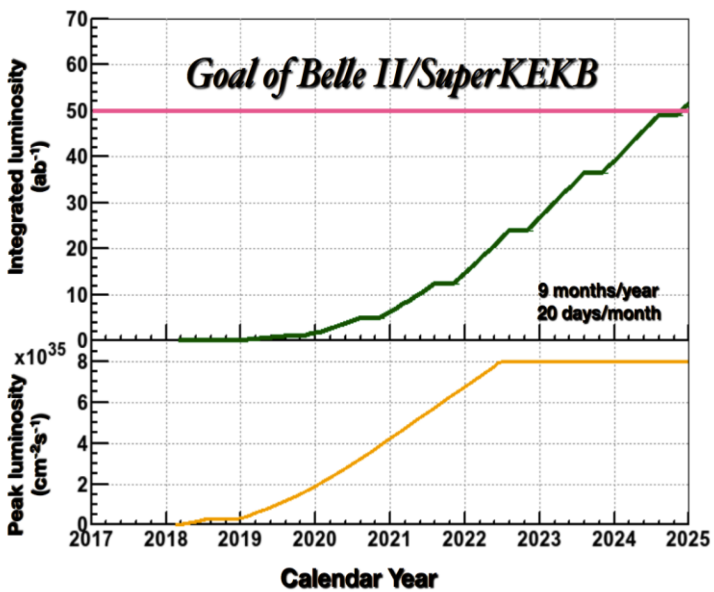
Integral Luminosity of STCF

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

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

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

Excellent opportunities for the τ-charm physics



BELLE-II

- 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 $E_{CM}^{eff.}$=[0.5-10] GeV via ISR.

Native question : Compete between STCF and BELLE-II ?

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 yields /per luminosity**
- **STCF is expected to have higher detection efficiency**
- **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 $e^+ e^- \to (2\text{-}10)h$, $h=\pi, K, \eta, p\ldots$
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; MLLA/LPHP prediction
- Spin alignment of vector

Two photon Physics

- Measurement of $\Gamma_{\gamma\gamma}$ for $J^{PC} = 0^{-+}, 0^{++}, 2^{-+}, 2^{++}$ states
- Study of $\gamma\gamma^* \to R$, $R = 1^{++}$
- Transition Form Factors in $\gamma^*\gamma^* \to R$
- Cross section of $\gamma\gamma \to \text{hadrons}$

Key Technologies

Polarization

- Spin Polarized Electron Source
- Polarization Rotation and Maintenance for Rings and Final Focus

RF

- Superconducting Cavities, Deflecting Cavities, Higher Harmonic Cavities, etc.

Magnets

- High Quality Magnets with high strength, Superconducting Magnets and Solenoids

Diagnostics and Control

- Low Emittance Measurement, Transverse and Longitudinal Feedback, etc.

Collaboration Needed

- **Accelerator Physics**
  - IR Design
  - Polarization: Spin Rotation and Maintenance
  - Collective Effects: Simulation and Bench Measurements
  - Advanced Computational Accelerator Physics
- **Accelerator Technologies**
  - Superconducting Cavities and Magnets
  - Polarized Beam Sources
  - Ultrahigh Vacuum Chamber with Small Aperture, Optimized Impedance and Low SEE