HIEPA: Super Tau-Charm Factory in China

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Future opportunities in hadron physics

Introduction

- e^+e^- collider in the τ-charm region: long history in China, 30 years BEPC (1988-2005)
- most recent incarnation: BEPCII / BESIII,
  $\mathcal{L} = 1 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at $\sqrt{s} = 3.77\,\mathrm{GeV}$
- collaboration with international partners from the start,
- Super-τ-charm facility far beyond BEPCII is natural extension and viable options for a post-BEPCII project in China

These slides based on Peng Haiping's talk at Charm 2018 international workshops on HIEPA in 2015 (Hefei) and 2018 (Beijing / Huairou)

BEPCII: τ-charm facility

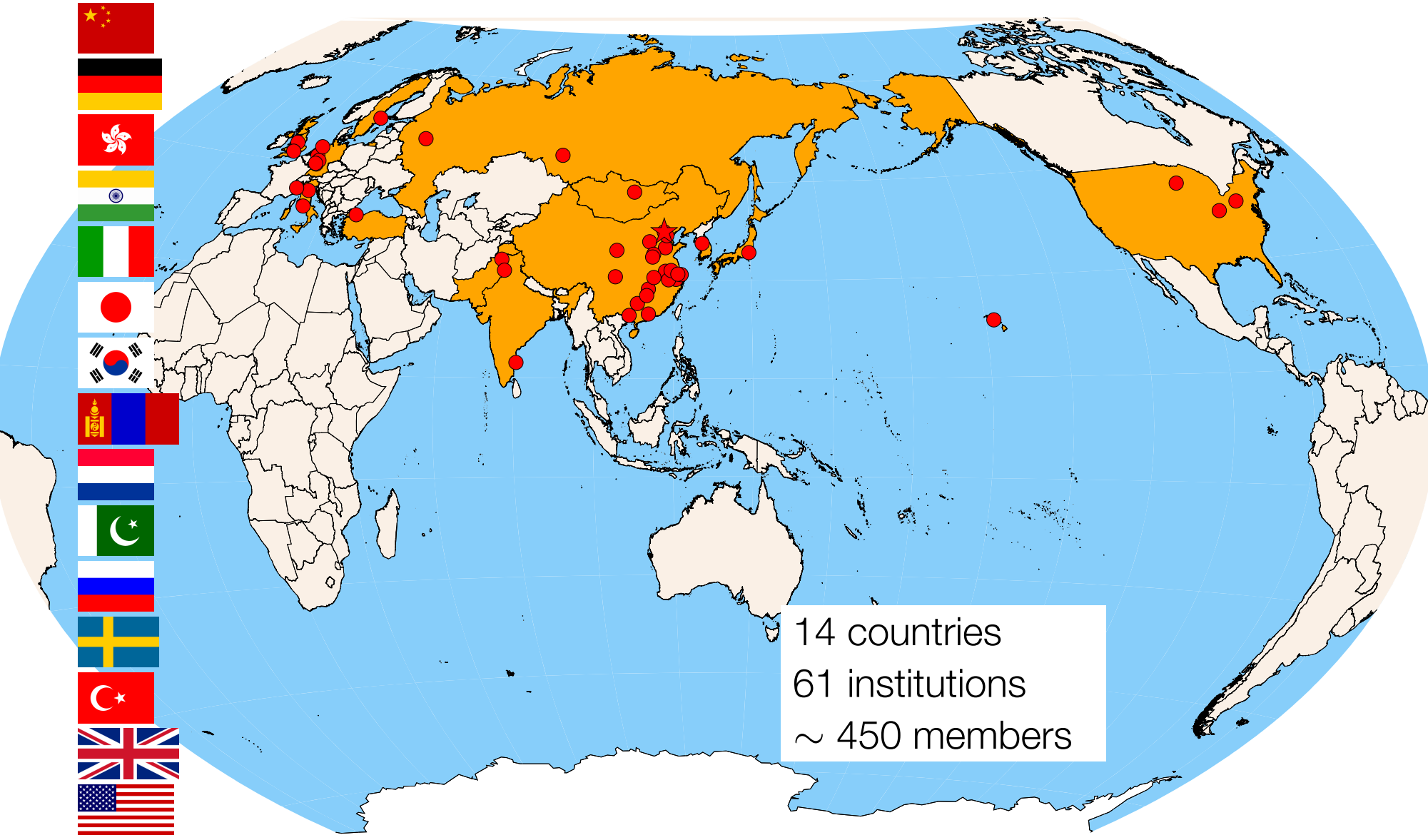
Features of dedicated τ-charm facility:

- threshold production
- clean signals, low backgrounds
- double-tag method
- high efficiency and resolution
- …

Limitations of BEPCII/BESIII

- limited range in E_{cm}: $2 \cdots 4.6\,\text{GeV}$
- luminosity $1 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$
- small-ish upgrades planned:
  increase E_{cm} by 300 MeV, implement top-up injection (gain of 30% in $\mathcal{L}_{\text{int}}$)

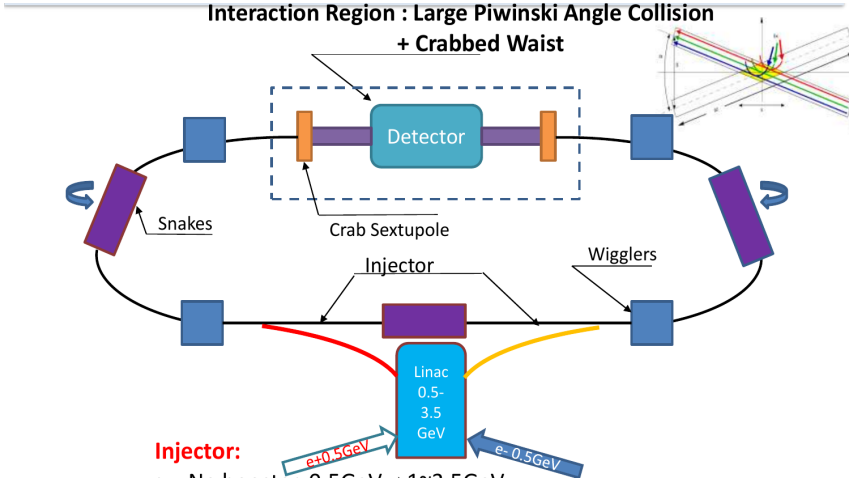
BEPCII/BESIII set to run for 8–10 more years
whitebook to be published. Then what?



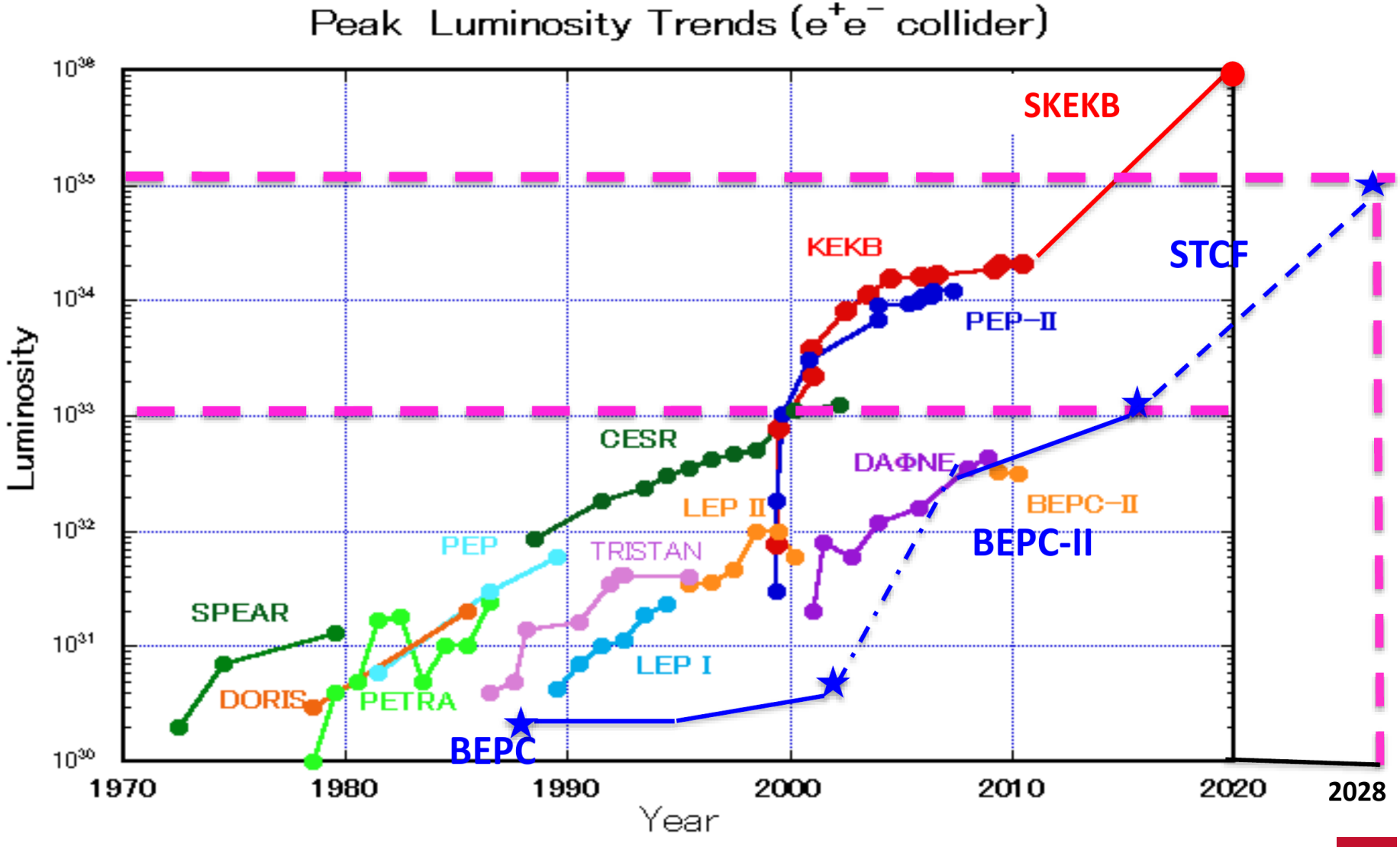
The BESIII Collaboration 2018

Super-Tau-Charm Facility

- Peak luminosity $1 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at $\sqrt{s} = 4\,\mathrm{GeV}$
- Energy range $E_{\mathrm{cm}} = 2 \cdots 7\,\mathrm{GeV}$
- Polarisation on e^- beam (Phase II)
- Basic features:
  - Symmetric machine, dual-ring storage rings
  - Large Piwinski angle + crabbed waist
  - Siberian snake
  - Total cost 4×10^9 RMB $\approx 500 \times 10^6$ EUR



Luminosity evolution



Goal for integrated luminosity

Assumptions:

- 9 months / year running time (exclusive use of storage rings!)
- $\mathcal{L} = 1 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- average data taking efficiency 90%

… translate into

$$\mathcal{L} = 2\,\mathrm{ab}^{-1}\,/\mathrm{year}$$

with 10 years of data taking: $10\,\mathrm{ab}^{-1}$ to $20\,\mathrm{ab}^{-1}$

Competition with Belle II (eventually, $50\,\mathrm{ab}^{-1}$)

Data samples

	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	$3.6 \times 10^{4*}$

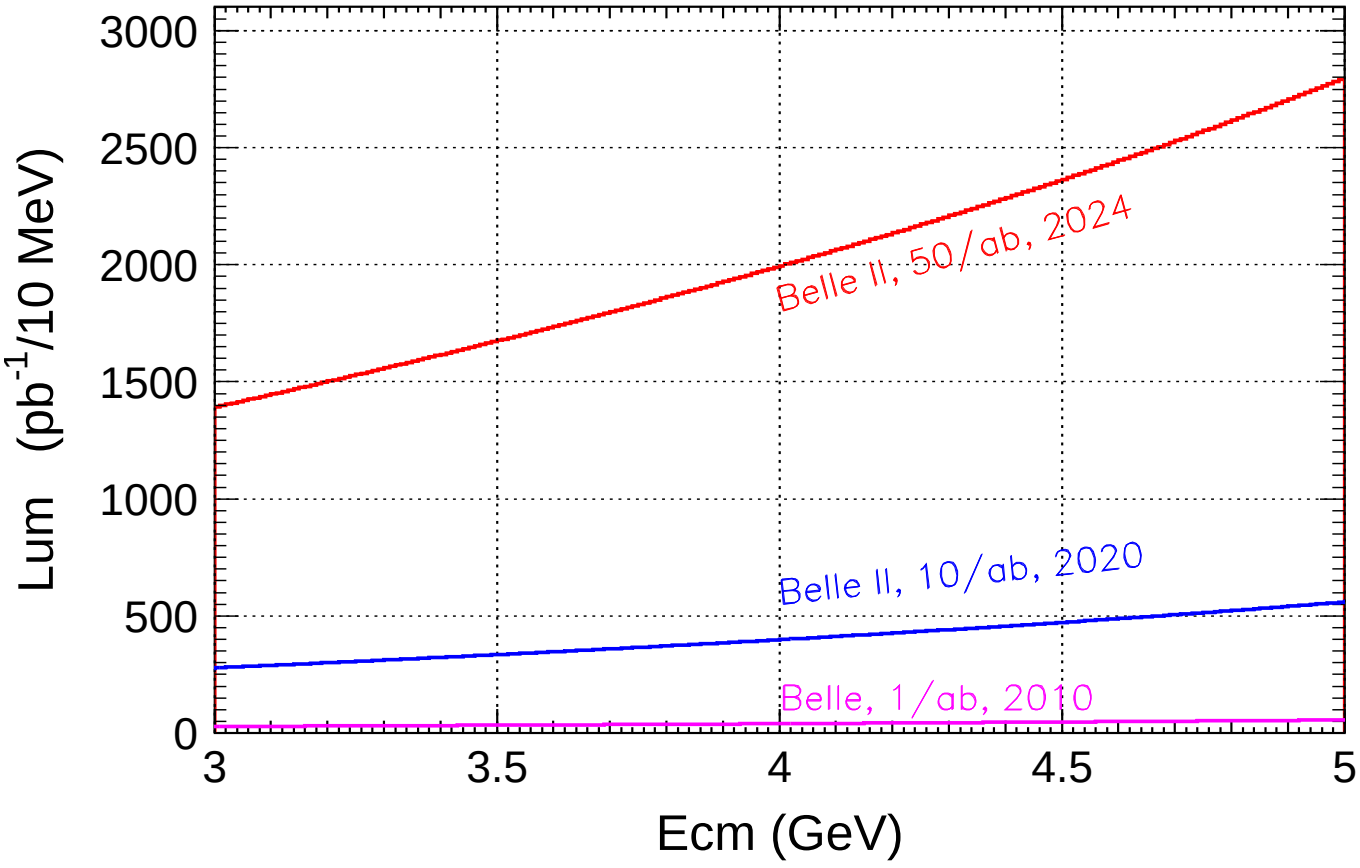
* process $e^+e^- \to D^{(*)-}\bar{p}\pi^+\Lambda_c^+$.

- STCF: comparable (or even higher) production rates per ab^{-1}
- STCF: higher efficiency, (much) larger tagged samples
- STCF: will not run exclusively on one fixed E_{cm}
- Belle II: larger integrated luminosity

So: competition / coexistence with Belle II ?

Luminosity expectation BelleII (ISR) vs BESIII (direct)

B2TiP WG7



Luminosity expectation BelleII (ISR) vs BESIII (direct)

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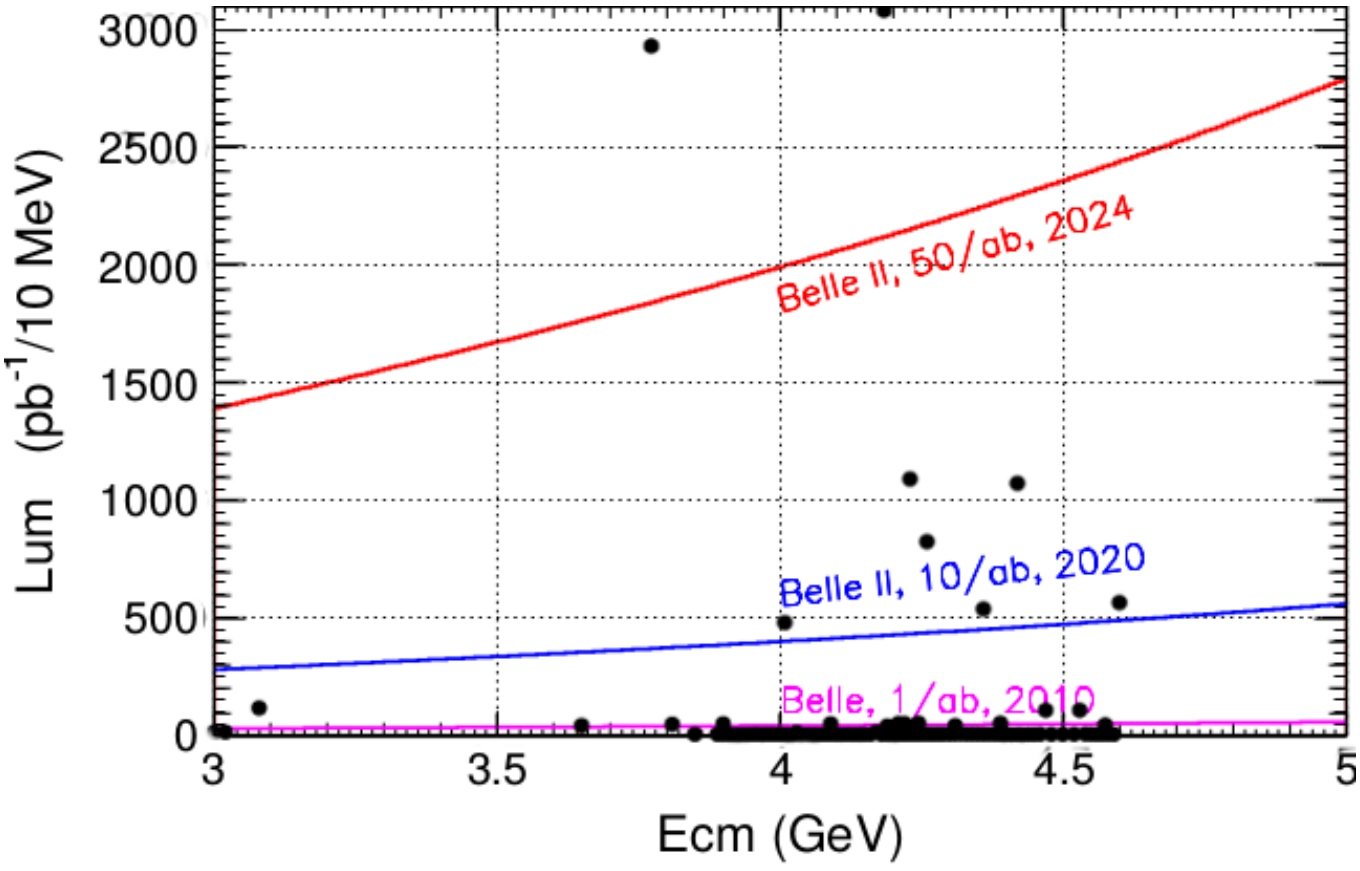
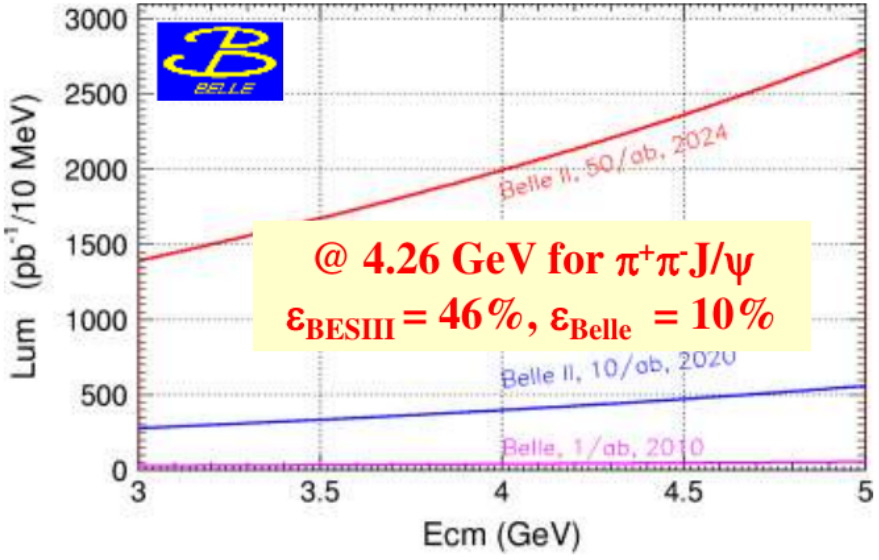


- Typical mass resolution for charged final states in ISR physics: $\lesssim 5\,\mathrm{MeV}/c^2$
- Spacing of BESIII R-scan points: 5 MeV (beam-energy spread $\sim$ 1.3 MeV)

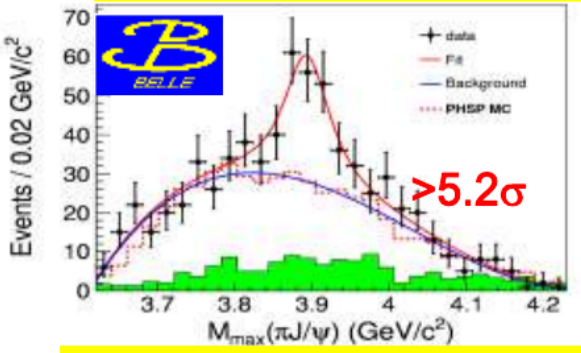
Charmonium-like states

- **τ-C Factory :** $e^+e^- \rightarrow Y/\psi \rightarrow Z_c + X$

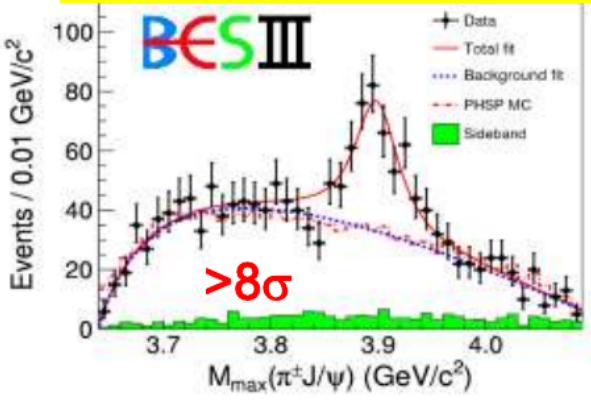


- **B Factor :** ISR, B decay

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

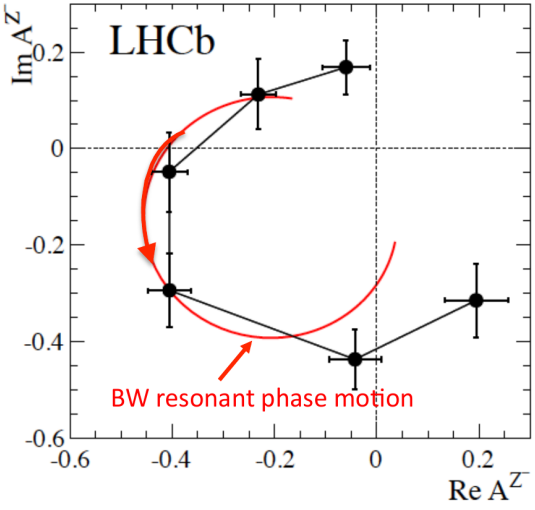
Physics opportunities

- **Precision tests of SM**
  - R scan
  - Hadron form factors (p, n, Λ, Λ_C, …)
  - Transition form factors
  - $\Delta\alpha_{\mathrm{QED}}$, a_μ
  - τ decays, lepton universality tests
  - CKM matrix $|V_{us}|$, $|V_{cs}|$
- **CP violation**
  - CPV in τ or charm decays
  - CPV in baryon / hyperon / charmed baryon decays
- **NP searches**
  - Rare / forbidden decays of charm, charmonium, τ FCNC, LFV, LNV, BNV, invisible …
  - Rare decays of light mesons ($\eta, \eta', \omega, \phi$)
- **Hadron physics**
  - spectroscopy of mesons, baryons, hyperons
  - threshold effects
  - glueball searches
  - multiquark, exotics, hybrids …
  - charmonium(-like) spectroscopy
  - charmed baryons
- **Exotic physics**
  - light dark matter
  - new interactions

Example: charmonium-like state $Z(4430)^+ \to \psi(2S)\pi^+$

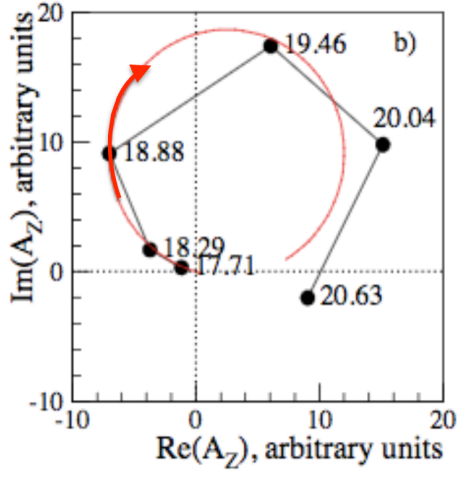
- Seen by Belle in $\bar{B}^0 \to \psi(2S)\pi^+K^-$ PRL **100**, 142001
- no significant signal in BABAR data ($\approx \frac{1}{2}$ Belle's statistics) PRD **79**, 112001
- Belle 4-dim amplitude analysis: clear signal PRD **88**, 074026
- LHCb: 10× Belle's statistics: confirms Belle and shows phase motion PRL **112**, 222002
  $J^P = 1^+$, Breit-Wigner-like phase motion

Model-ind. Argand plot



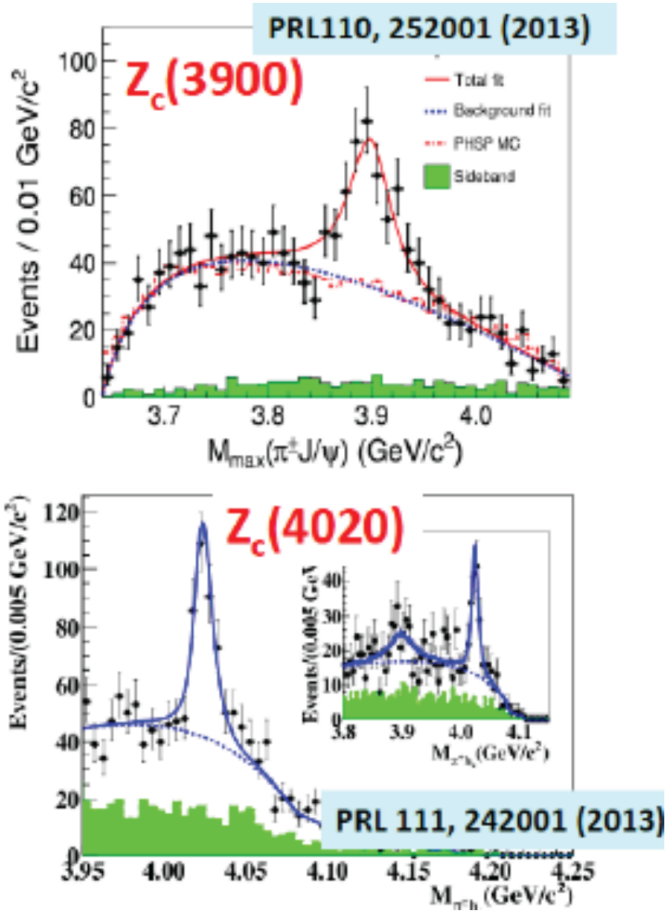
BW-like counter-clockwise phase motion is clearly established

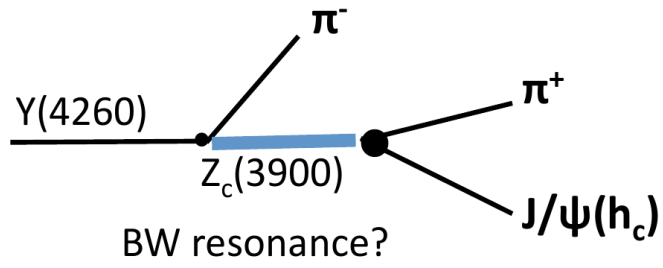
rescattering process predicts clockwise phase motion



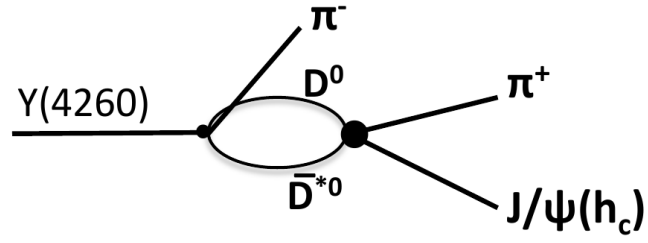
Pakhlov &Uglov, PLB 183 (2015)

Similarly for $Z_c(3900) \to J/\psi\,\pi^+$ and $Z_c(4020) \to h_c\pi^+$?





BW resonance?



Threshold cusp?

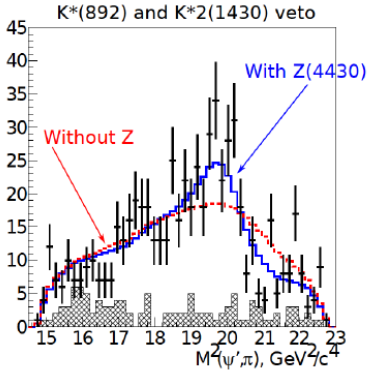
D. Bugg, Europhys. Lett. 96, 11002 (2011)

E. Swanson. PRD 91, 034009 (2015)

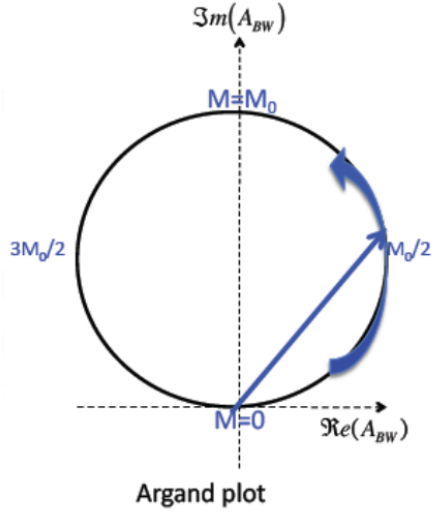
S. Olsen, talk at 2nd HIEPA workshop

Lesson for HIEPA

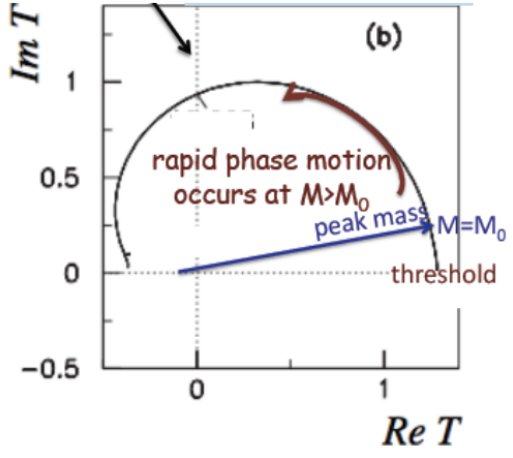
Bump hunting is out! multi-dimensional coupled-channel amplitude analyses are required.



High statistics phase-motion measurements are essential.



vs



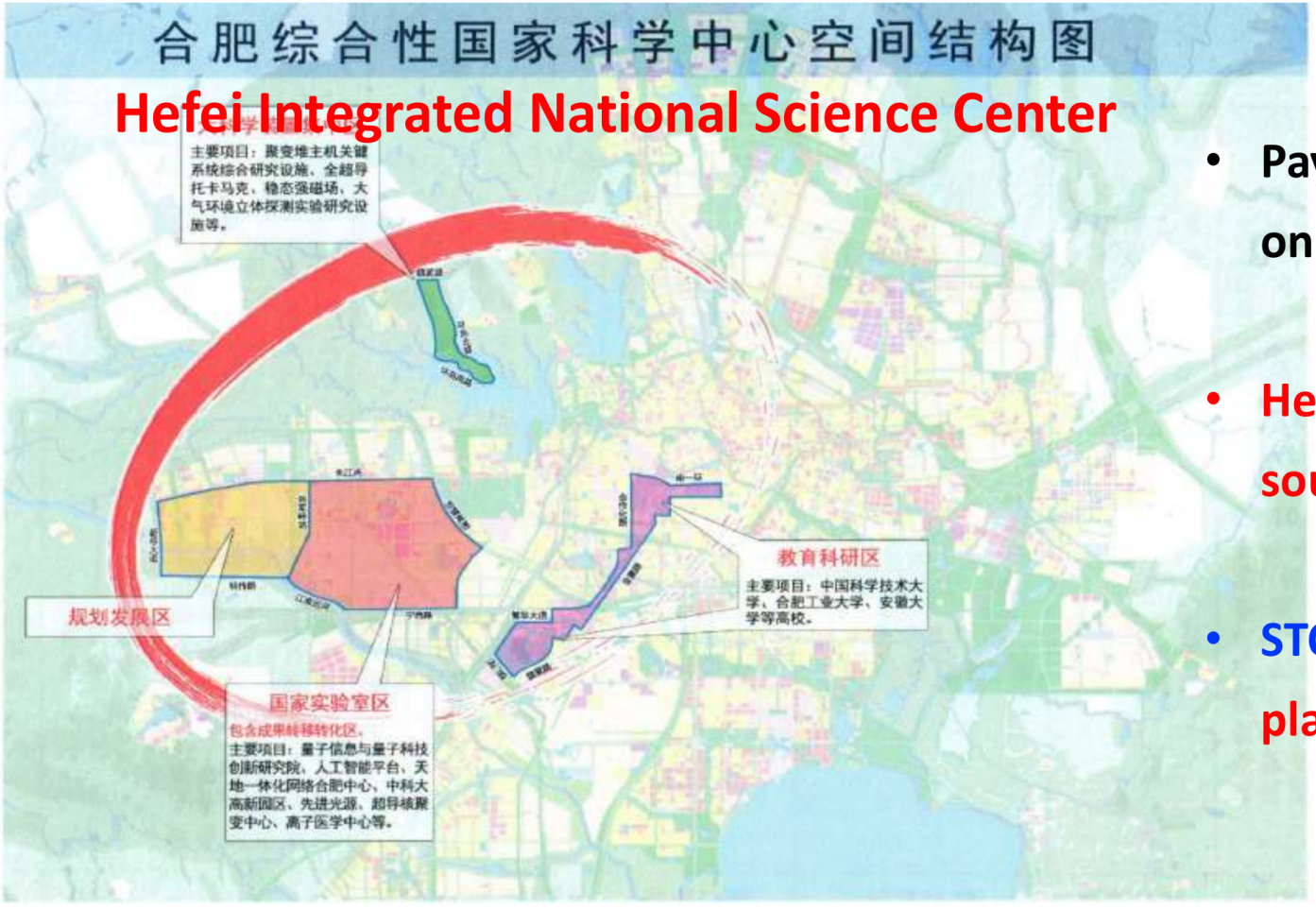
S. Olsen, talk at 2nd HIEPA workshop

Potential site for HIEPA: Hefei

About 2 hours by airplane from Beijing,
or 2.5 hours by high-speed train from Shanghai

Potential site for HIEPA: Hefei

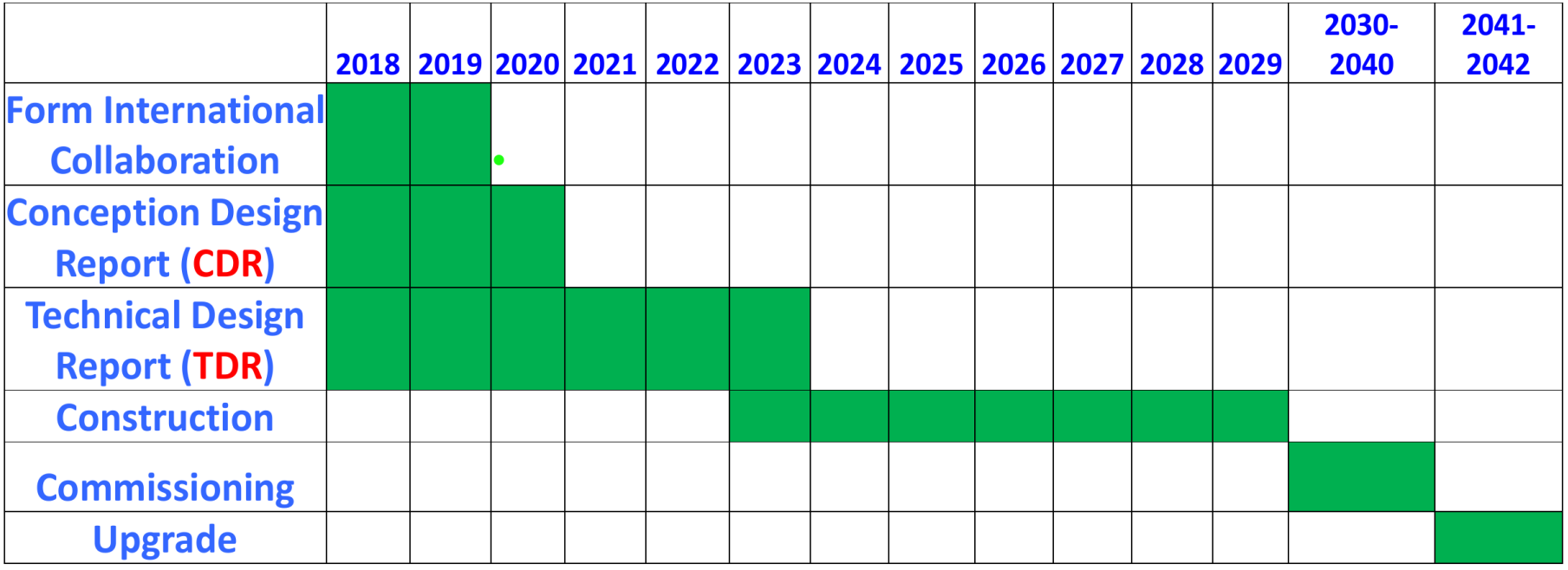
One of three integrated national science center, which will play important role in 'Megascience' of China in near future



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

Peng Hai-Ping, Charm 2018

Tentative timeline



Peng Hai-Ping, Charm 2018

Super-τ-charm facility in Russia

- Novosibirsk super-τ-charm project
  Under consideration since 2006
- Substantial documentation available
- SCTF approved by Russian Government, endorsed by ECFA
  funding by 2020 ?
- Accelerator design being adapted to recent developments
  e.g. increase of E_{cm} to 6 GeV, increased luminosity
- Common workshop with Chinese project, at LAL, Orsay, Dec 4–7, 2018:
  `http://workshop-tau-charm-factory.lal.in2p3.fr/`

Summary

- Super-τ-charm facility natural extension of very successful BES–BESII–BESIII
- At the precision frontier
  - Rich physics programme
  - Precision tests of SM, interplay with *B* physics programme (LHCb, Belle II)
  - Important for study of QCD, exotic hadrons, and searches for BSM
- STCF in China
  - Could come online 2030, after the end of BESIII operation
  - Appears favourably in reports to Ministry of Science and Technology, Chinese National Science Foundation, and Chinese Academy of Science
  - R&D funds allocated
  - International collaboration being formed now, essential for promoting the project
- Interplay with STCF in Novosibirsk?