SnowMass RF Townhall Meeting : Hadron Spectroscopy

Physics Potential of a Super Tau-Charm Facility (STCF)

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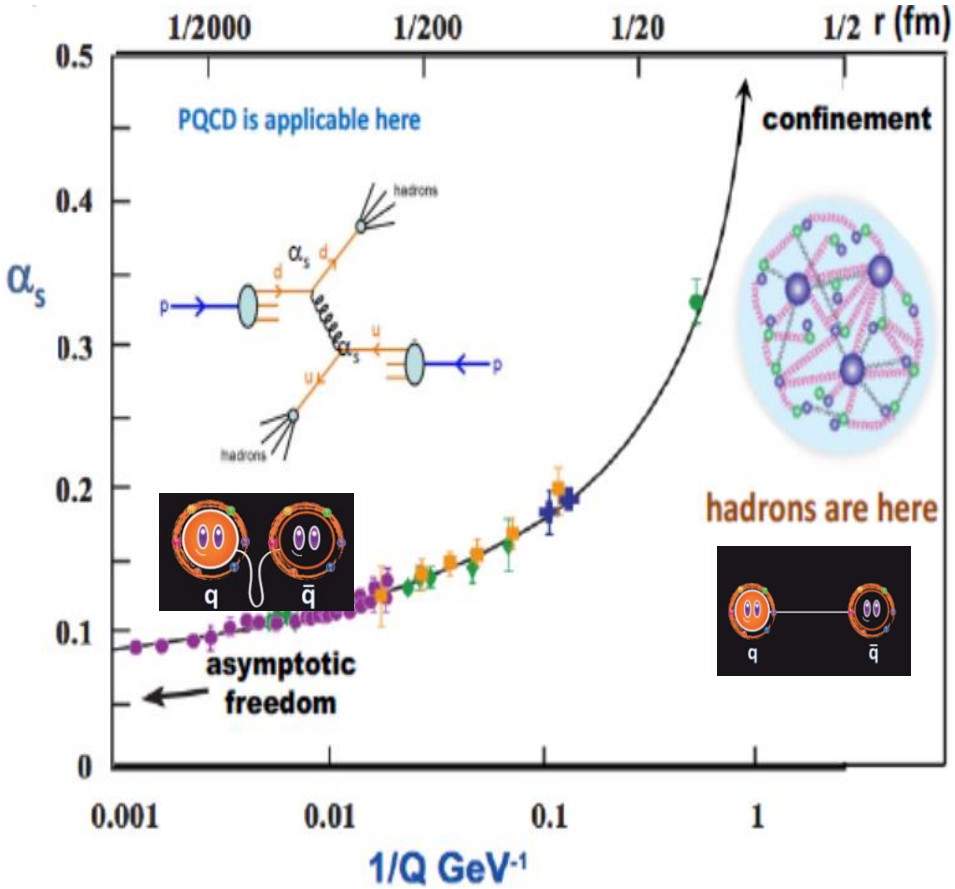
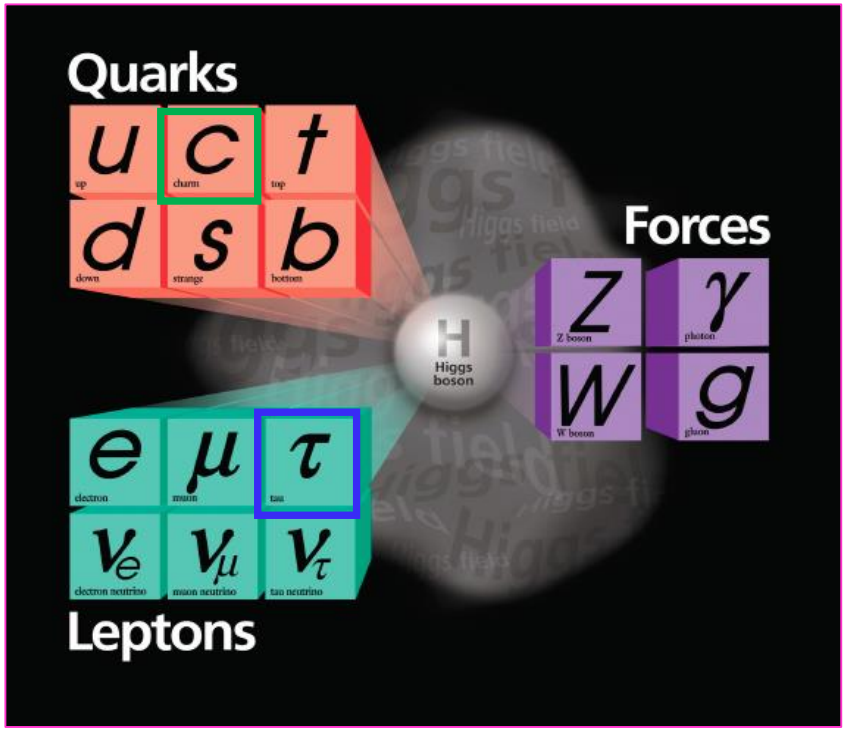
SM & QCD

- The asymptotic freedom of QCD in high energy region is precisely test
- But need more experimental inputs in the low energy region, color confinement
- τ Lepton and charmed quark provide excellent platform to study the QCD



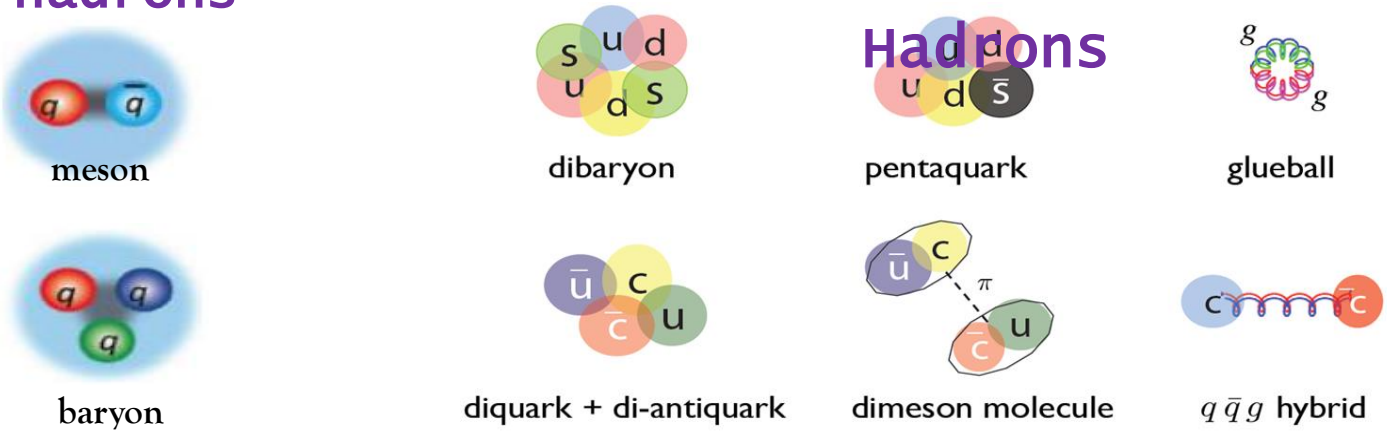


QM & Spectroscopy

Quark Model (QM) successfully describes the structure of sub-atom

Conventional hadrons

Exotic Hadrons



In last two decades, a series of new states (Tetraquark, Pentaquarks) are found,
however, their internal compositions are not identified yet :

- Main reason : imperfect on the perturbative QCD
- Incorporating theory with experimental observation, to improve power of prediction

Comprehensively establish the hadron spectrum and intensively study the exotic hadrons properties experimentally are essential !

Broad Physics at τ-c energy region

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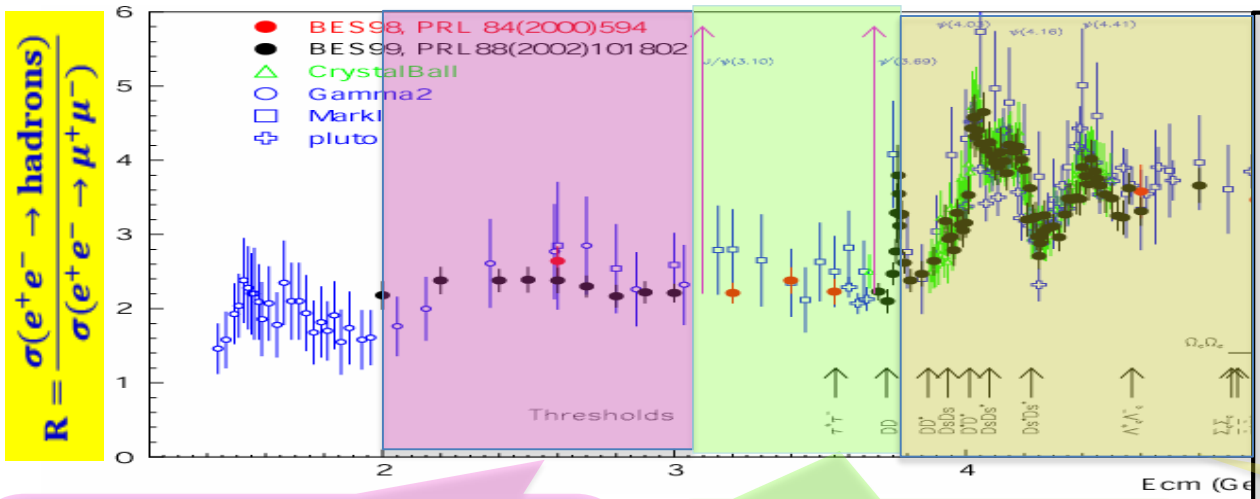

5-7GeV,
Blank in
e^+e^-directly
Opportunity
STCF

- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark
- 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
- fD and fDs
- D0-D0 mixing
- Charm baryons

Unique features :

- ☐ Transition region between QCD and pQCD
- ☐ Rich of resonance and exotics
- ☐ Threshold characteristics, Quantum Correlation…

τ-c Physics at China

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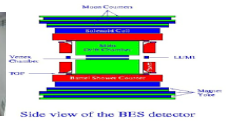
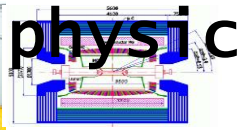
30 years history, leading role in tau-charm and hadrons physic area

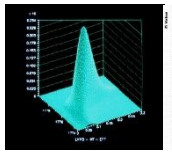
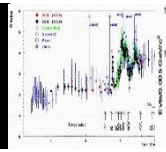
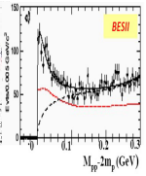



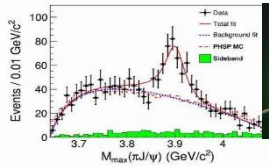
BEPCI /BESI-II ($10^{31}cm^{-2}s^{-1}$)

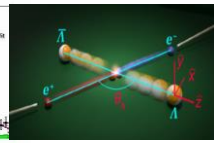
BEPCII/BESIII ($10^{33}cm^{-2}s^{-1}$)

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

1990 2000 2010 2020 2030

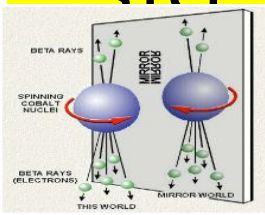


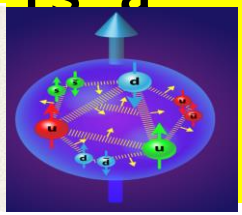


BEPCII/BESIII will end her mission in 5-10 years, STCF is a

Challenge of BEPCII/BESIII：

- Limited by length of storage ring, no large space and potential for the upgrade.
- Physics study limited by the Statistics (luminosity), CME ……
- Competition from Belle II and LHCb





STCF at China

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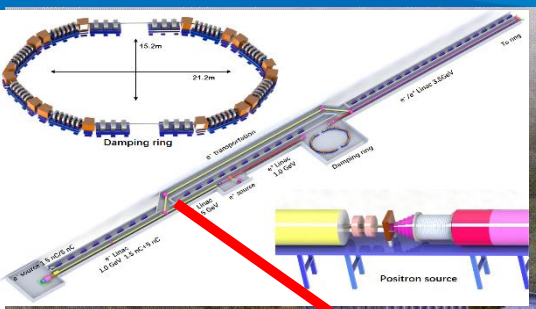
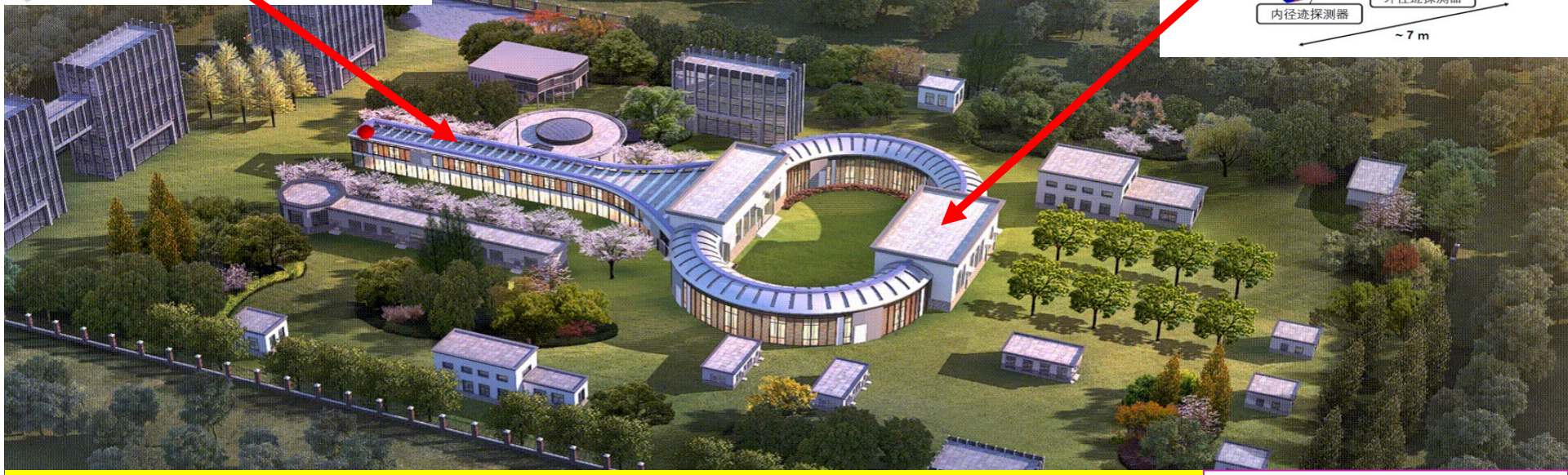
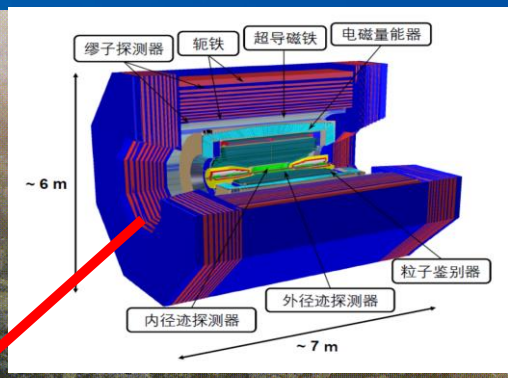


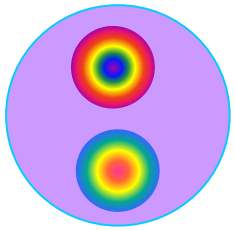


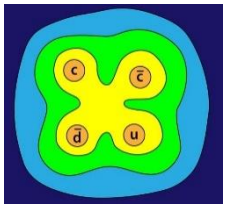


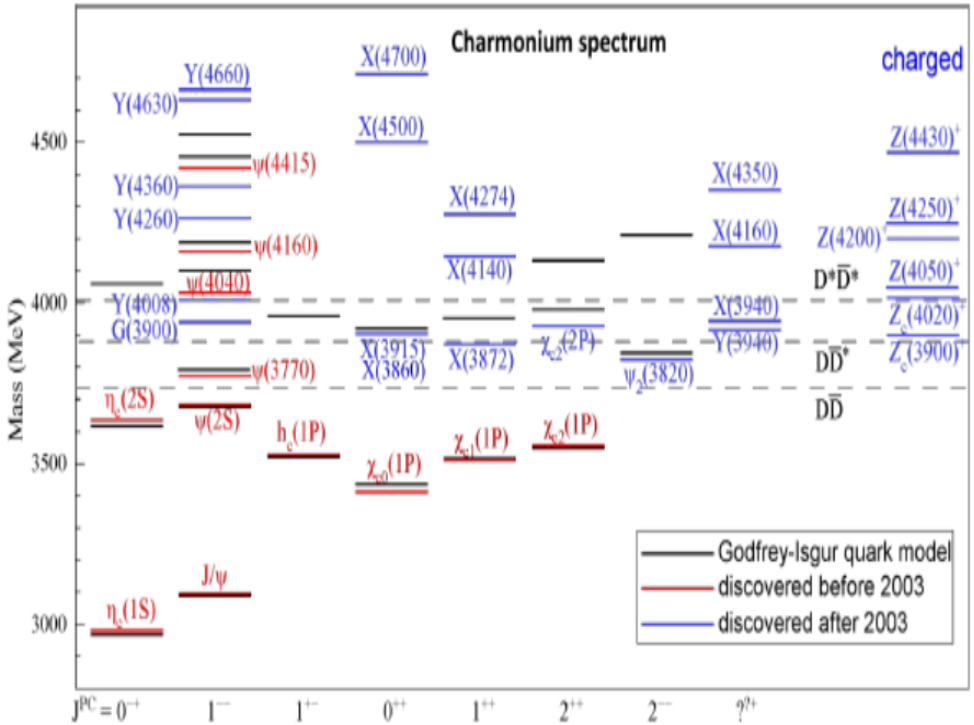
- Central mass energy : 2-7 GeV (BEPCII 2-4.7 GeV)
- Peaking Luminosity : > 0.5×10^{35} cm^{-2} s^{-1} at 4 GeV (two orders of BEPCII)
- Potential to increase luminosity and realize beam polarization

Deliver at least 1 ab^{-1}/year data

Charmonium(-like) Spectroscopy







Tasks :

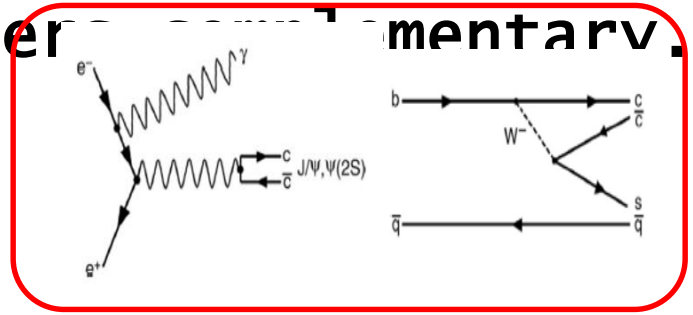
- Precisely measurement the transition
- Search for the missing states
- Understand the nature of unknown states
- Search for the new exotic states

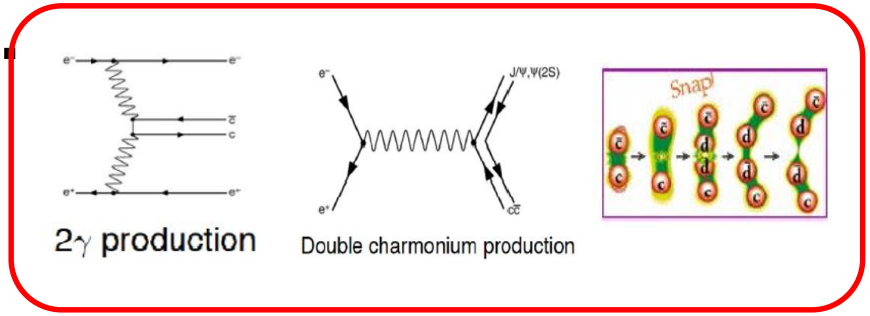
- Very activity and large progress in past decades, a new territory for exotic hadron
- Remarkable developments : the fail of hadron models to anticipate the rich charmonium spectrum of hidden-charm states

Charmonium(-Like) Production

- Prominently produced in the e^+e^- collision and decay,

other complementary,





- STCF : XYZ-Meson factory

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

Expected event number per year at STCF

- Opportunities :
  - Precision Argand plot analysis
  - Precise mass and width measurements
  - Rare decays and new states searching

Searching for 1^{--} Hybrid

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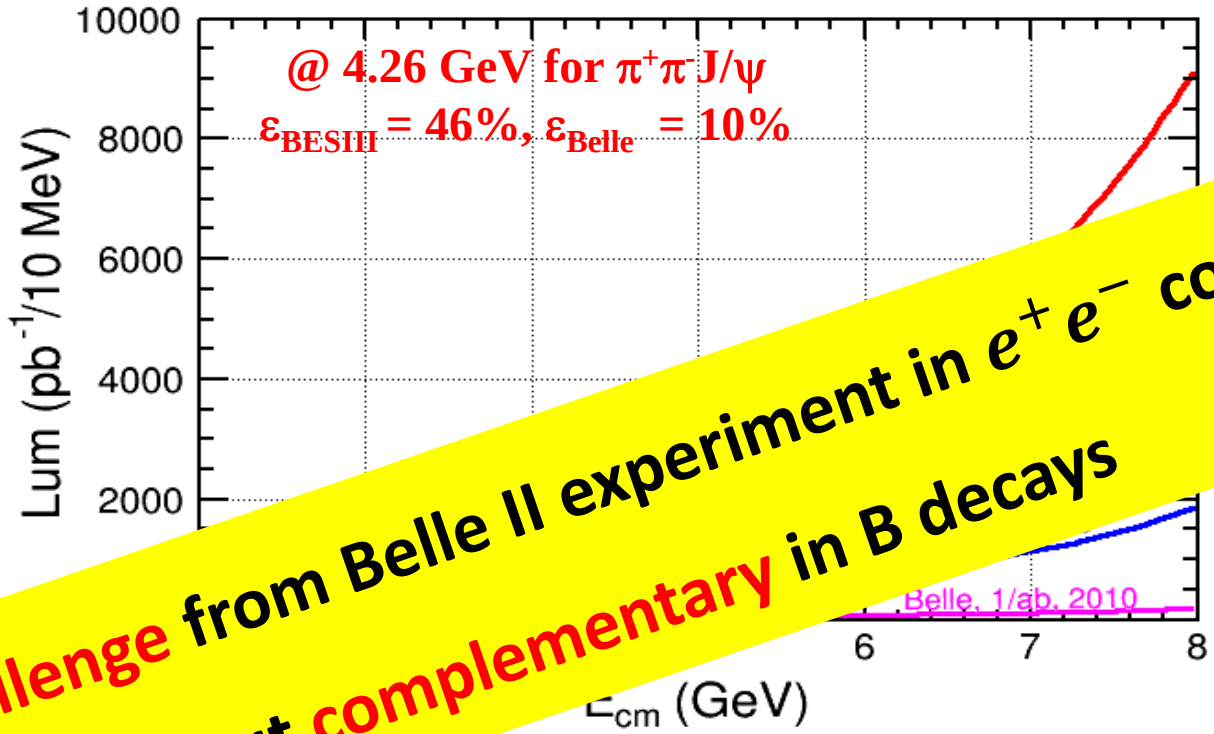
- 1^{--} Hybrid may produce directly in e^+e^- e^+e^- collision, and radiative decay to spin-zero charmonium states [in Hybrid, cc in spin-singlet, LQCD by Dudek'09]
  - Assume $\sigma(e^+e^-\to H_{ccg}) \sim O(10–100)$ pb [???]
  - $B(H_{ccg}\to\gamma\eta_c)\sim 2\times B(H_{ccg}\to\gamma\chi_{c0}) \sim 4\times10^{-4}$
- Scan between 4-5 GeV for 1 year (1 ab^{-1}), search for exotic structure in process $e^+e^-\to\gamma\eta_c$ and $\gamma\chi_{c0}$
  - Assume $\varepsilon B \sim 10\%$ for $\gamma\eta_c$ and $\gamma\chi_{c0}$ decay to γ+hadrons
- With 100 energy points between 4-5 GeV
  - $N^{obs}(\gamma\eta_c)$=O(4-40) events/point/year at peak
  - $N^{obs}(\gamma\chi_{c0})$=O(2-20) events/point/year at peak

Competition with Belle-II

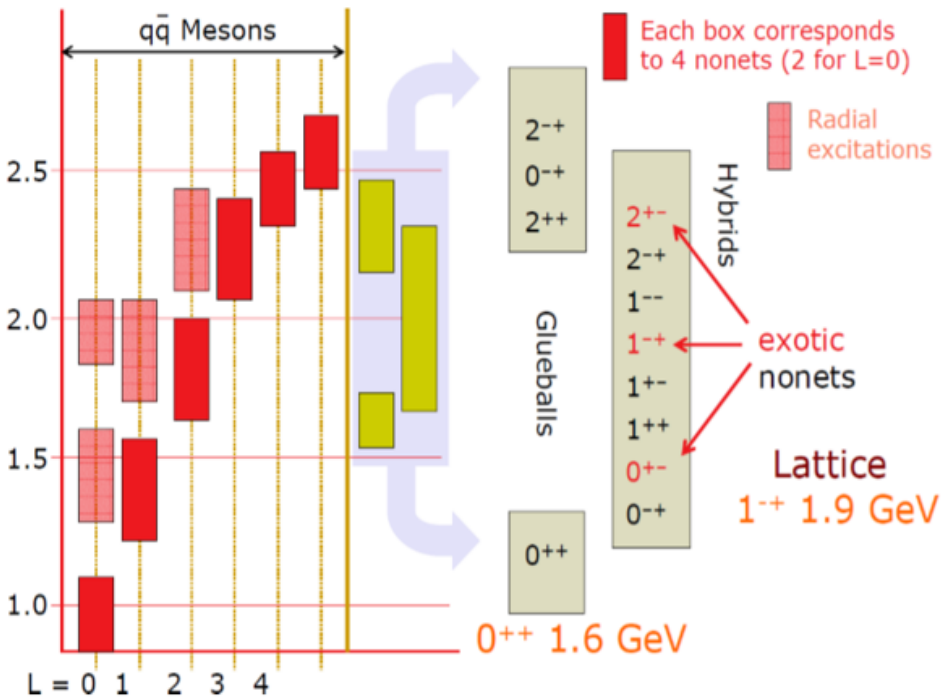


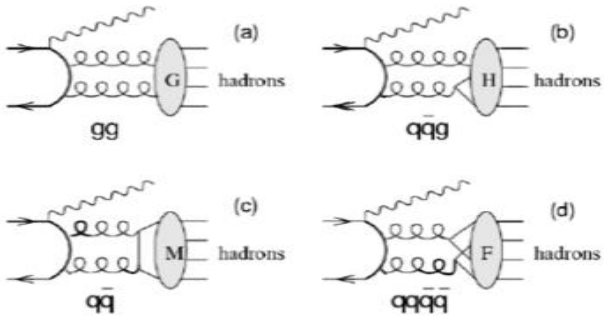
No challenge from Belle II experiment in e^+e^- collision, but complementary in B decays

- [illegible] integrate effective luminosity between 4-[illegible].23 ab^{-1} for 50 ab^{-1} data
- τ[illegible] factory : scan in 4-5 GeV, 10 MeV/step, every point have 10 fb^{-1}/year, 5 time of Belle II for 50 ab^{-1} data
- τ-C factory have higher efficiency and low background than B Factory

Light hadrons

- Glueballs, hybrids, exotic states searching are greatly motivated in light hadrons scope, but challenged obviously.
- Great progress on Lattie QCD, more experimental inputs are necessary





$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$

$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$

- Charmonium decays is an ideal hunting ground
  - "Glue-rich"process
  - Clean and high statistics sample
  - I (J^{PC}) filter in strong decays

STCF : ψ factory

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3T J/ψ or 500B ψ′/year

- Systematic study of glueball, hybrid and conventional spectroscopy
  - Precision multi-variable analysis
  - Comprehensive measurement of all possible decay modes, e.g. $J/\psi \to \gamma\eta\eta'$
  - …
- Light hadrons η/η′ factory : important role in low energy QCD

Decay Mode	$\mathcal{B}$ ($\times 10^{-4}$) [9]	η/η' events
$J/\psi \to \gamma\eta'$	52.1 ± 1.7	5.21×10^9
$J/\psi \to \gamma\eta$	11.08 ± 0.27	1.1×10^9
$J/\psi \to \phi\eta'$	7.4 ± 0.8	7.4×10^8
$J/\psi \to \phi\eta$	4.6 ± 0.5	4.6×10^8

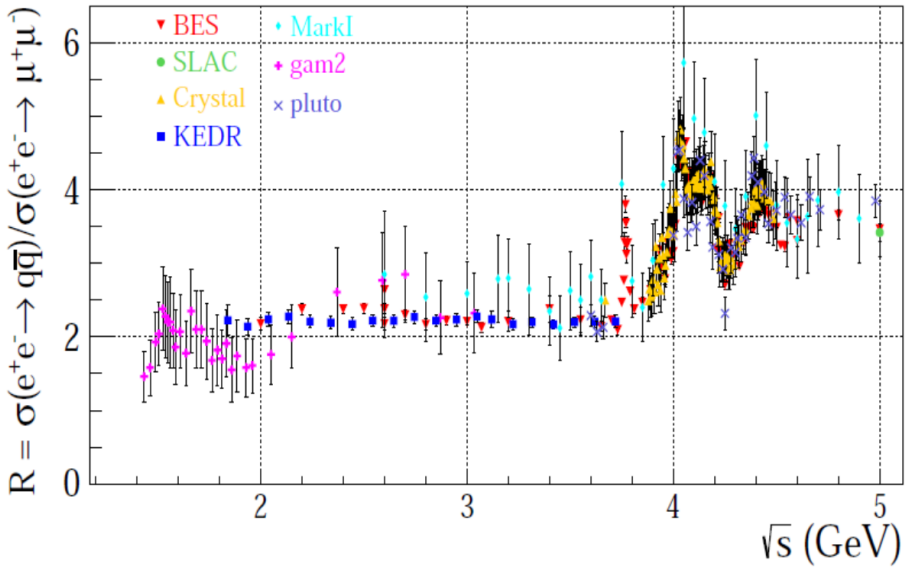
1T J/ψ

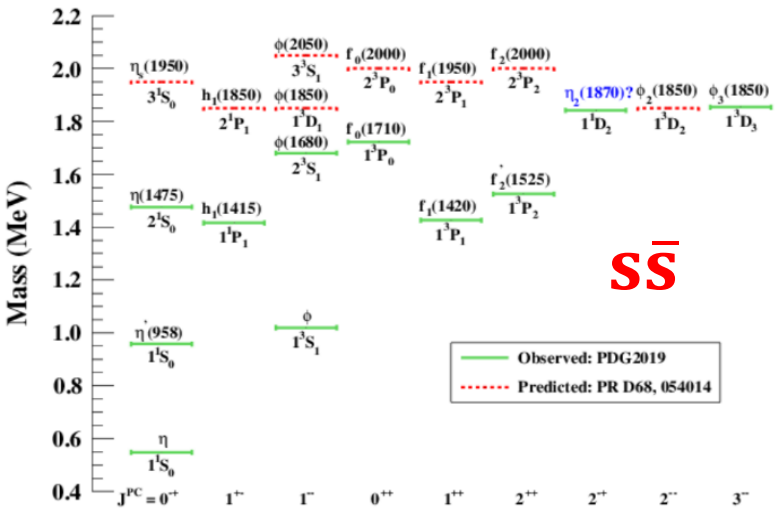
- Baryon spectroscopy
- Hyperon decays : CP asymmetry violation…

Decay mode	$\mathcal{B}$(units 10^{-4})	Angular distribution parameter α_ψ	Detection efficiency	No. events expected at STCF
$J/\psi \to \Lambda\bar{\Lambda}$	$19.43 \pm 0.03 \pm 0.33$	0.469 ± 0.026	40%	1100×10^6
$\psi(2S) \to \Lambda\bar{\Lambda}$	$3.97 \pm 0.02 \pm 0.12$	0.824 ± 0.074	40%	130×10^6
$J/\psi \to \Xi^0\bar{\Xi}^0$	11.65 ± 0.04	0.66 ± 0.03	14%	230×10^6
$\psi(2S) \to \Xi^0\bar{\Xi}^0$	2.73 ± 0.03	0.65 ± 0.09	14%	32×10^6
$J/\psi \to \Xi^-\bar{\Xi}^+$	10.40 ± 0.06	0.58 ± 0.04	19%	270×10^6
$\psi(2S) \to \Xi^-\bar{\Xi}^+$	2.78 ± 0.05	0.91 ± 0.13	19%	42×10^6

3T J/ψ

Vector Mesons

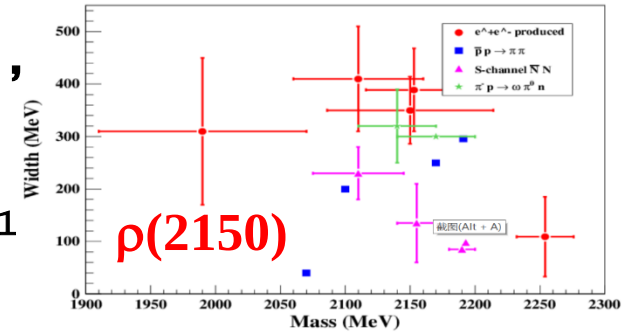


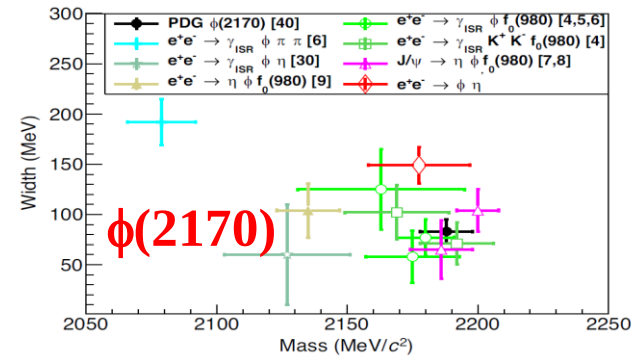


- $J^{PC}=1^{--}$ vectors can be produced directly
- PDG: ρ(2000), ρ(2270), ω(1900), ω(2205), ω(2290), wω(2330). more need
- $\sqrt{s} \in [2.0, 3.0]$GeV: study of ρ*, ω* and ϕ*
  - Unobserved $s\bar{s}$ mesons
  - Many"omitted"from summary table or "further states"in PDG2020

ρ(2150) and ϕ(2170)

- ρ(2150): inconsistent between e^+e^-, $\bar{p}p$, s-channel $\bar{N}N$ and p^-p experiments
- ϕ(2170): candidate for $s\bar{s}g$ hybrid, 2^3D_1 or 3^3S_1 $s\bar{s}$, tetraquark, molecular state $\Lambda\bar{\Lambda}$, $\phi f_0(980)$ resonance with FSI, three body system ϕKK





STCF :

- Based on isospin and OZI rule, precisely measure resonances parameters, and decay strength, e.g. ϕ(2170) @ $\phi\eta'$
- Comprehensive study of decays : e.g. $e^+e^- \to KK\pi\pi$, $KK\pi$
- Complicate intermediate states, large sample and PWA are necessary

Charmed hadrons

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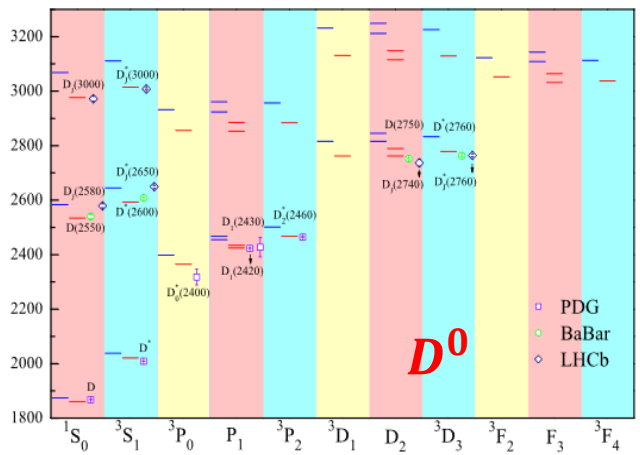
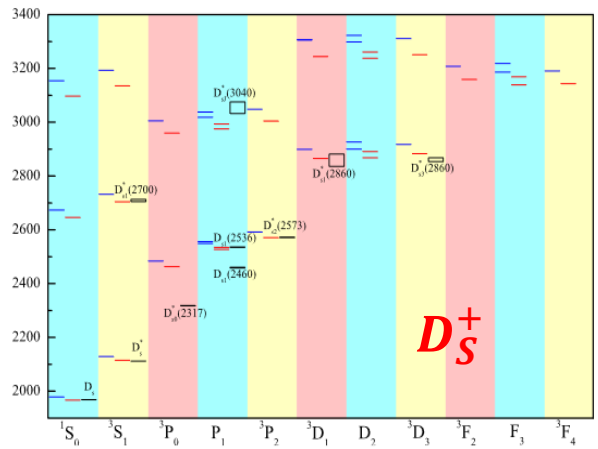
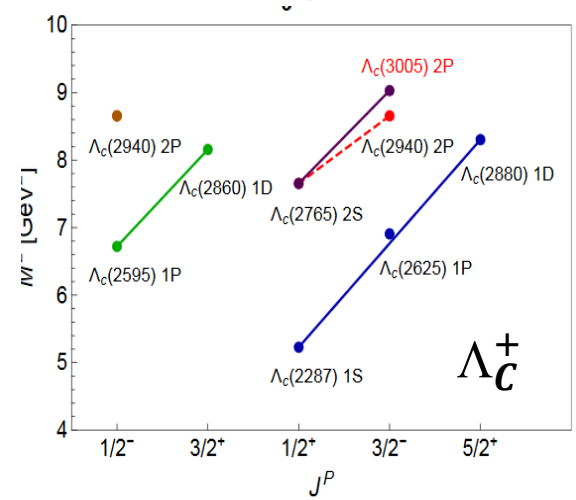
Charmed hadron Spectroscopy provide an ideal role in studying the dynamics of the light







- **Mesons :**
  - only 1S and 1P states are found, almost of all others are missing
  - Many excited states are reported in experiment, but still controversial on the existence or their natures : $D_{sJ}^*(2632)$, $D_{s0}^*(2317)$, $D_{s1}(2460)$
- **Baryons :**
  - J^P s have not measured yet, except for the Λ_c^+
  - The spectroscopy need fill
- **STCF :** CME up to 7GeV, Clean, threshold production, e.g. $e^+e^- \to D^{(*)}D^{**}(\pi)$, $\Lambda_c\Lambda_c^*(\pi)$, …

Activities and Progress

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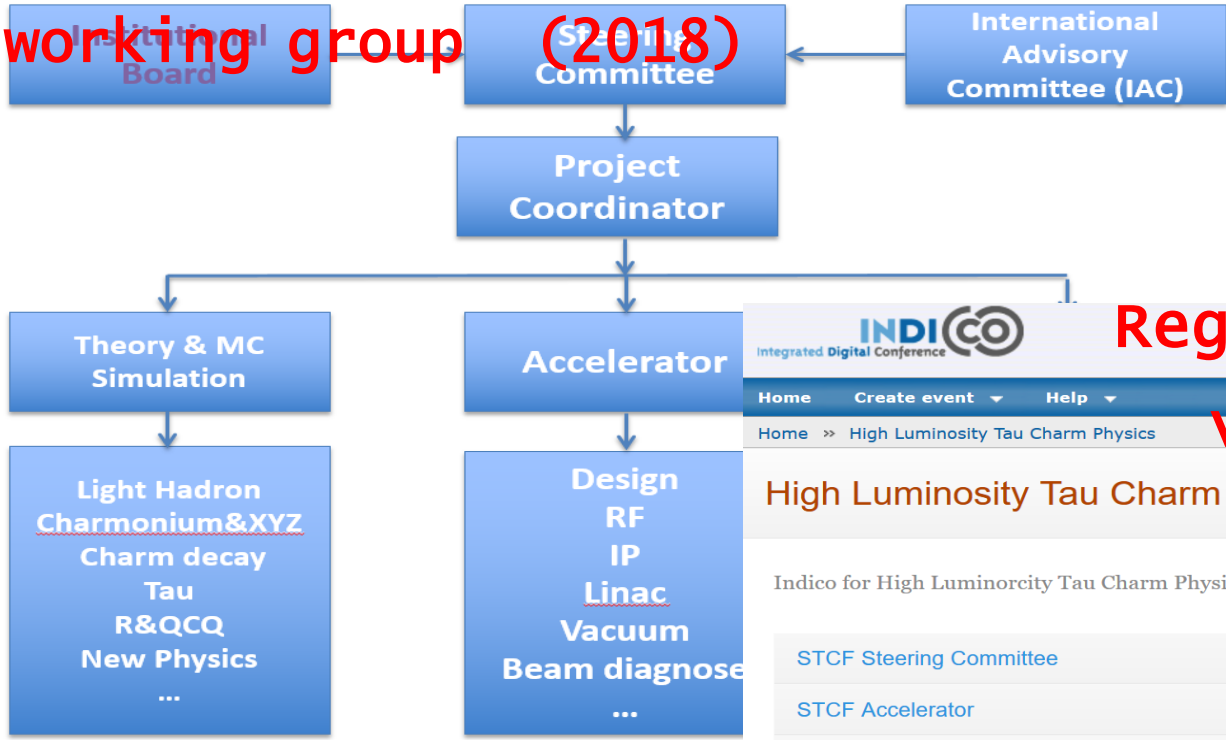
Form the organization, build up working group (2018)



Regular meeting, very active

Toward to have CDR and TDR in 5-7 years

Preliminary CDR

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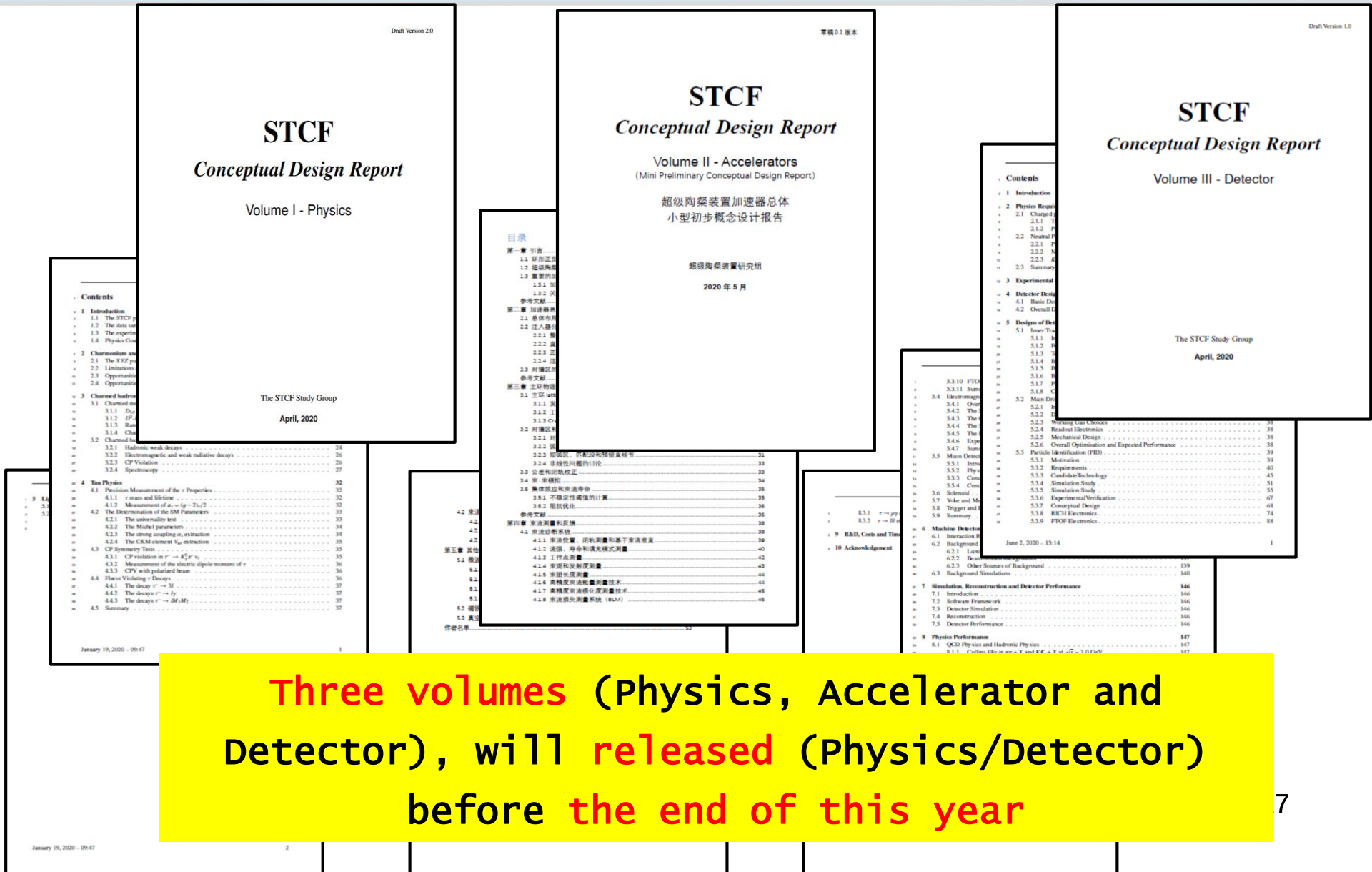

Three volumes (Physics, Accelerator and Detector), will released (Physics/Detector) before the end of this year

International Collaboration

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SCT at Novosibirsk, Russia

Budker Institute of Nuclear Physics Long history…..

Seeking intensive international Collaboration

- Carry out joint effo… …ology, joint meeting month…
- Joint w…
  - 201…
  - 2019…
  - 2020 …na) online
- Others efforts :
  - FTOF for PID (LAL)
  - uRwell for inner tracking (Frascati)
  - Accelerator Lattice (KEK)

Summary

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- Physics at τ-c energy region is abundant, and is unique for the hadron spectroscopy and test QCD
- A super τ-c facility (STCF) is nature extension of BEPCII/BESIII and a viable option for post-BEPCII era in China
- Great progress has achieved for feasibility study of STCF
- Strategy & Plan
  - Intend to have a CDR and TDR in five years
  - Construction site: Currently open

Tentative Schedule

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	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031-2040	2041-2042
Form International Collaboration															
Conception Design Report (CDR)															
Technical Design Report (TDR)															
Construction															
Commissioning															
Upgrade															

Funding Support

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USTC : Initial funds

15M CNY (2018-2020)

CAS : Program for cultivation of international big science program

6M CNY (2021-2025)

NSFC : Key technology R&D

3 Key programs + several general programs ~10 M CNY

Seeking for the funding support on R&D from MOST, CAS and local goverment

Budget Estimation

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R&D : 250M CNY, Construction : 4 B CNY

(Very Rough)

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 : Hefei

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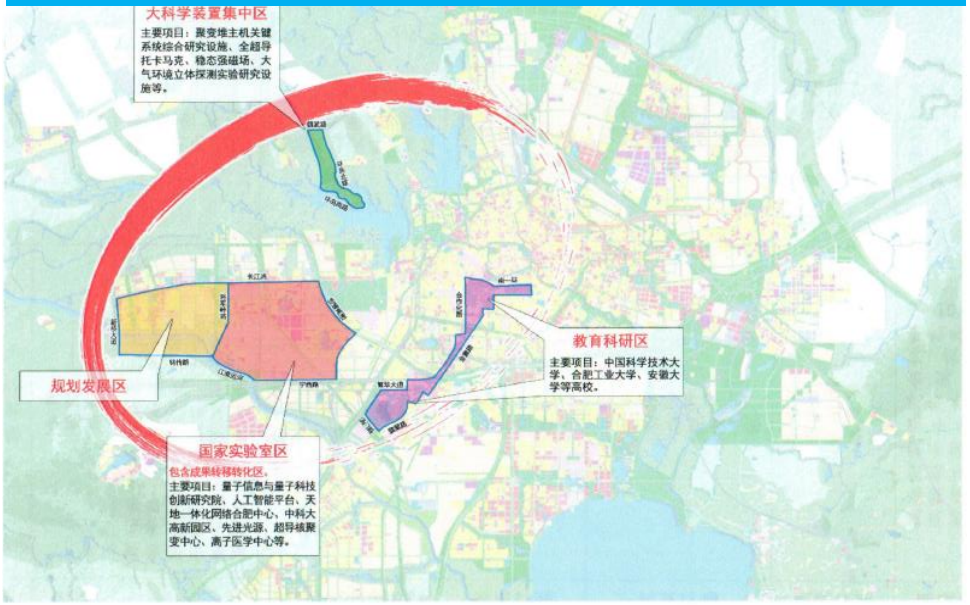
One of three integrated national science centers, which will play important role in 'Megascience' of China in near future

Hefei Integrated National Science Center



- 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**

Candidate Site : Canton

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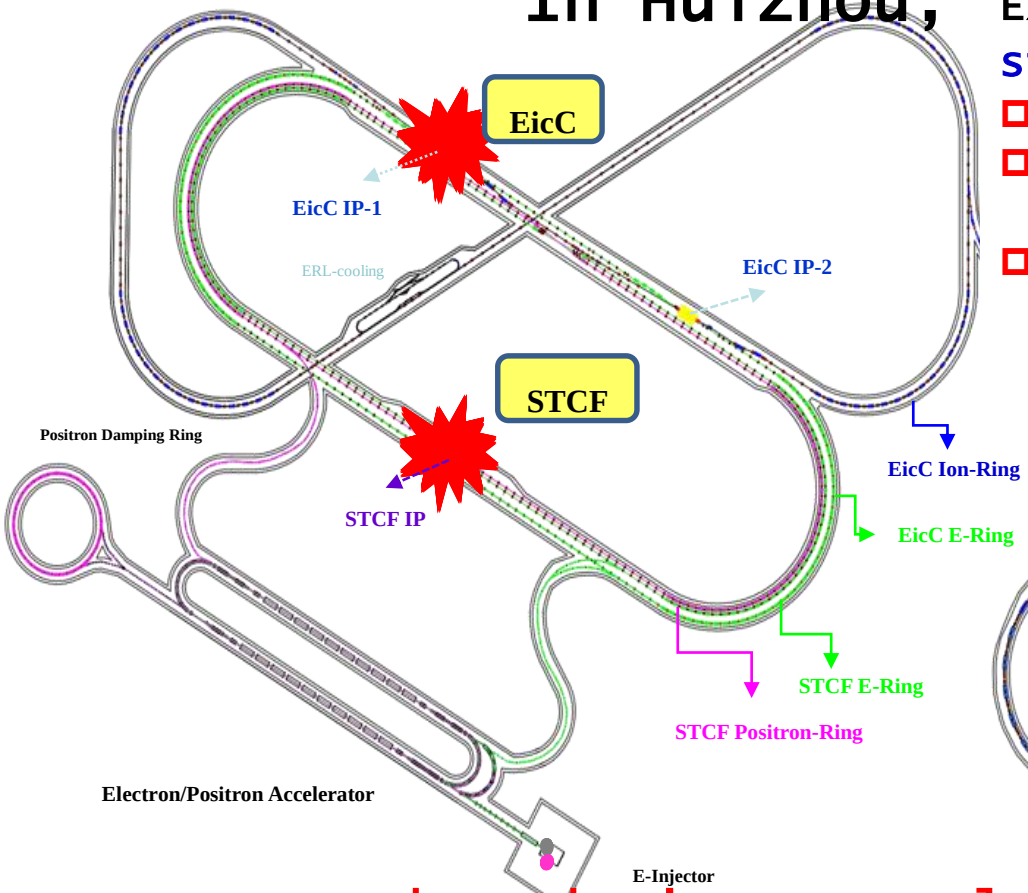
University of Science and Technology of China

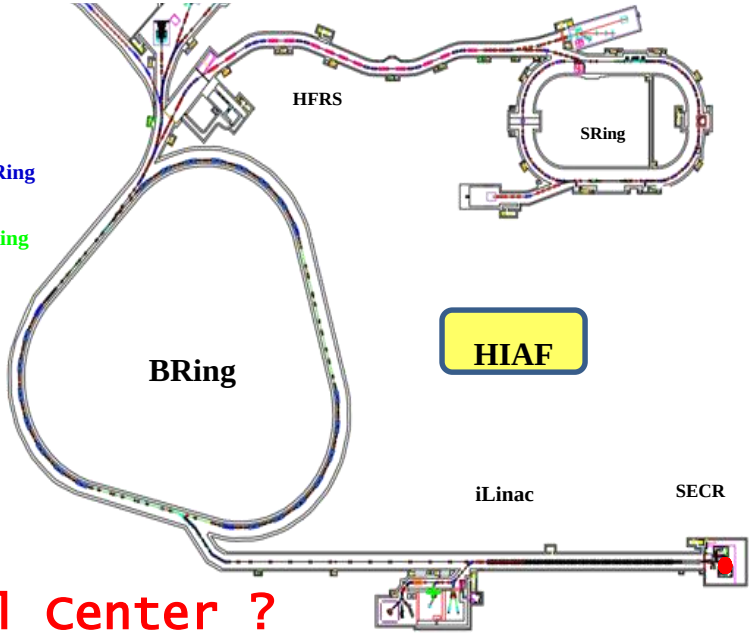
Institute of Modern Physics, CAS, proposed building HIAF-EicC

In Huizhou,



Exploring feasibility and strategy

- Complementarity in physics
- Sharing e-ring and infrastructure
- Joint R&D and Key technologies



A Hadron Physics Internal Center ?

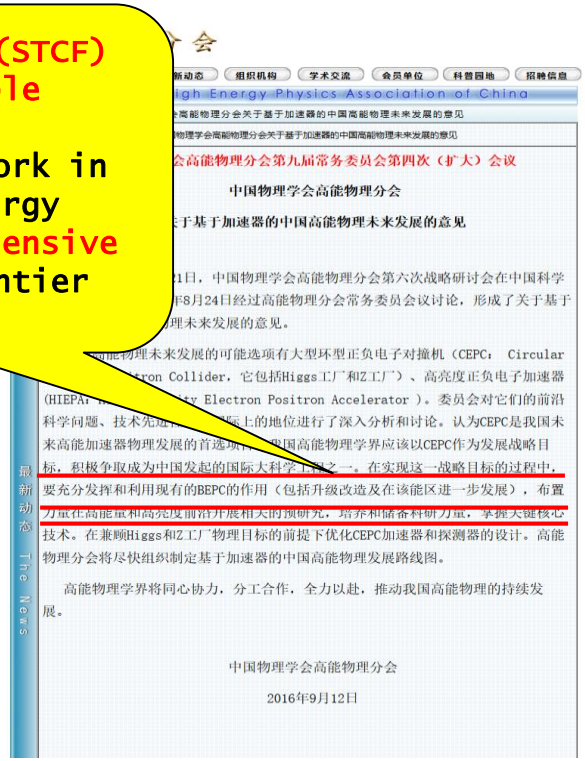
Accelerator based project in China

中国科学技术大学
University of Science and Technology of China

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

Web of Division of High energy physics, Chinese Physics Society http://www.ihep.cas.cn/xh/gnwlxh/zxdt/

CEPC and HIEPA (STCF) are the viable options …
Carry out the work in both high energy frontier and intensive luminosity frontier



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

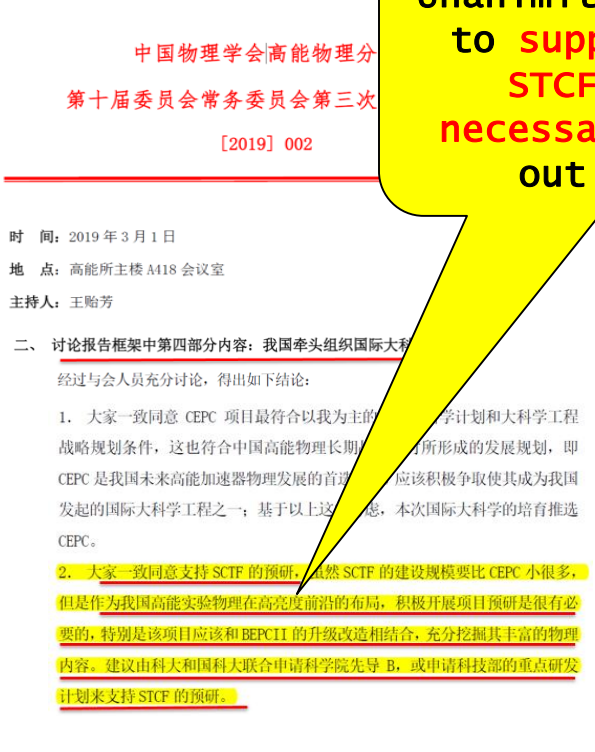
…1日，中国物理学会高能物理分会第六次战略研讨会在中国科学…年8月24日经过高能物理分会常务委员会议讨论，形成了关于基于…理未来发展的意见。

…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 …tron Collider，它包括Higgs工厂和Z工厂）、高亮度正负电子加速器（HIEPA: …ity Electron Positron Accelerator ）。委员会对它们的前沿科学问题、技术先进…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…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），布置力量在高能量和高亮度前沿开展相关的预研究，培养和储备科研力量，掌握关键核心技术。在兼顾Higgs和Z工厂物理目标的前提下优化CEPC加速器和探测器的设计。高能物理分会将尽快组织制定基于加速器的中国高能物理发展路线图。

高能物理学界将同心协力，分工合作，全力以赴，推动我国高能物理的持续发展。

中国物理学会高能物理分会

2016年9月12日



中国物理学会高能物理分…

第十届委员会常务委员会第三次…

[2019] 002

时　间：2019 年 3 月 1 日

地　点：高能所主楼 A418 会议室

主持人：王贻芳

二、 讨论报告框架中第四部分内容：我国牵头组织国际大科…

经过与会人员充分讨论，得出如下结论：

1. 大家一致同意 CEPC 项目最符合以我为主的…学计划和大科学工程战略规划条件，这也符合中国高能物理长期…所形成的发展规划，即 CEPC 是我国未来高能加速器物理发展的首选…应该积极争取使其成为我国发起的国际大科学工程之一；基于以上这…态，本次国际大科学的培育推选 CEPC。

2. 大家一致同意支持 SCTF 的预研。虽然 SCTF 的建设规模要比 CEPC 小很多，但是作为我国高能实验物理在高亮度前沿的布局，积极开展项目预研是很有必要的，特别是该项目应该和 BEPCII 的升级改造相结合，充分挖掘其丰富的物理内容。建议由科大和国科大联合申请科学院先导 B，或申请科技部的重点研发计划来支持 STCF 的预研。

Unanimity to consent to support R&D of STCF, …it is necessary to carry out the R&D