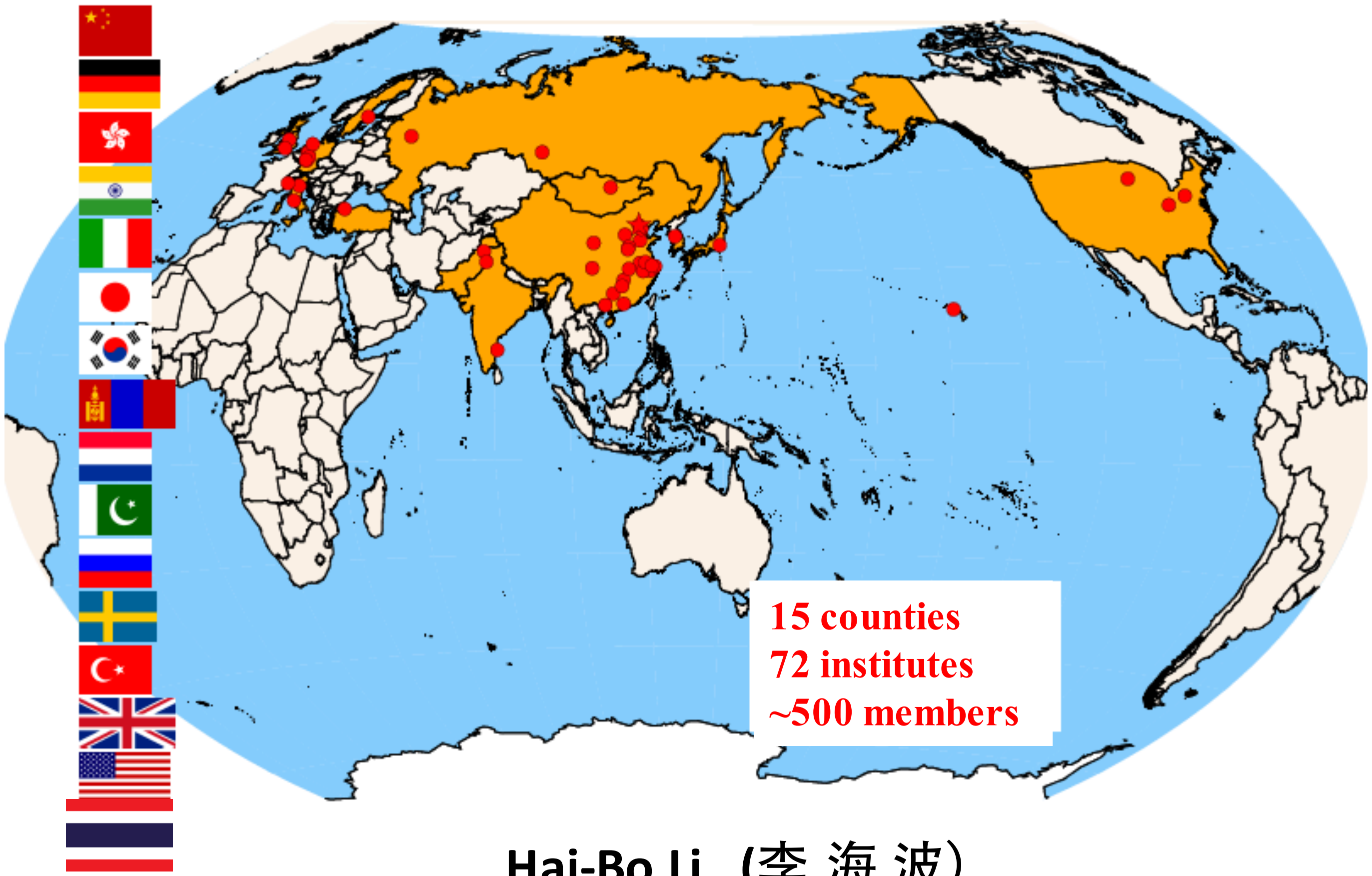
# BESIII future

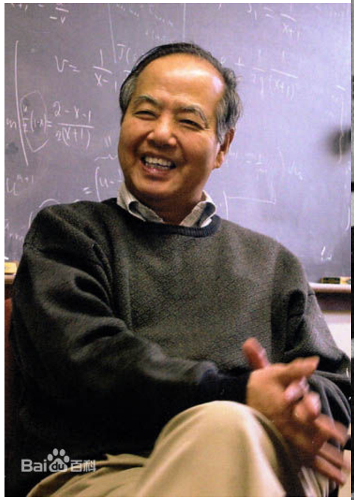



Hai-Bo Li （李 海 波）

(IHEP , September 5th-6th 2019, Beijing)

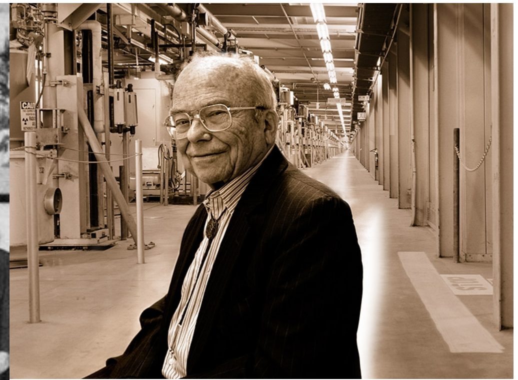
the Symposium on 30 years of BES Physics

# BES history: two important men



**Prof. T. D. Lee**

**The first meeting of the Sino-US committee on HEP, June 10-13, 1979, Beijing, China**

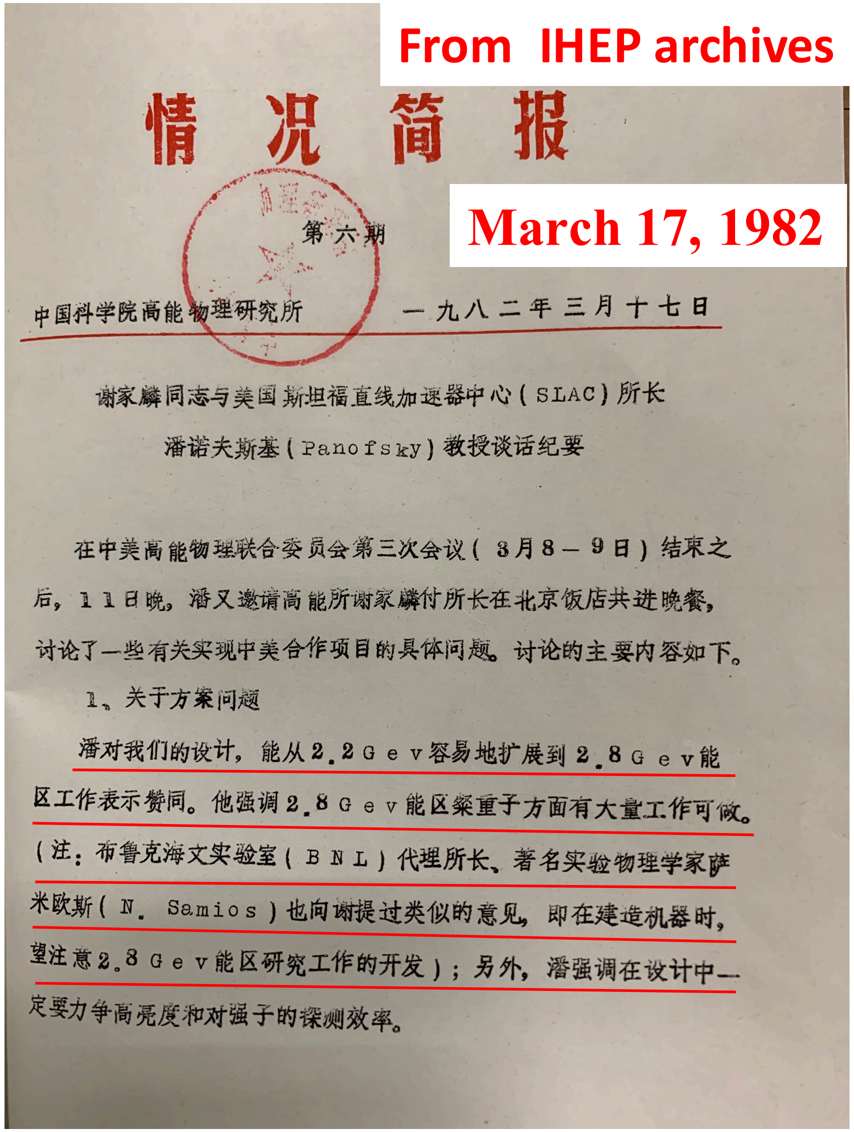


**Prof. W. (Pief) K. H. Panofsky**
**1919-2007**

**This is why we have BEPC/BES in China, and the reason we are here today!**

# BES history: Charmed baryon

From IHEP archives



情 况 简 报

第六期

March 17, 1982

中国科学院高能物理研究所　　一九八二年三月十七日

谢家麟同志与美国斯坦福直线加速器中心（SLAC）所长

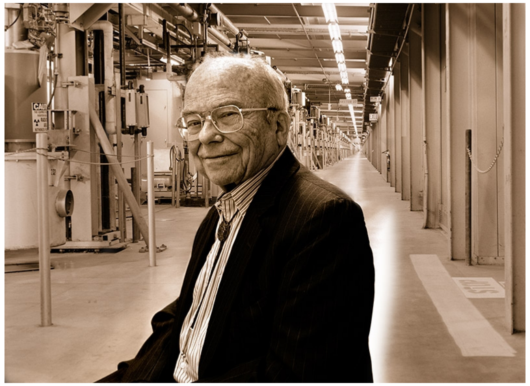
潘诺夫斯基（Panofsky）教授谈话纪要

在中美高能物理联合委员会第三次会议（3月8－9日）结束之后，11日晚，潘又邀请高能所谢家麟付所长在北京饭店共进晚餐，讨论了一些有关实现中美合作项目的具体问题。讨论的主要内容如下。

1、关于方案问题

潘对我们的设计，能从2.2Gev容易地扩展到2.8Gev能区工作表示赞同。他强调2.8Gev能区粲重子方面有大量工作可做。（注：布鲁克海文实验室（BNL）代理所长、著名实验物理学家萨米欧斯（N. Samios）也向谢提过类似的意见，即在建造机器时，望注意2.8Gev能区研究工作的开发）；另外，潘强调在设计中一定要力争高亮度和对强子的探测效率。

Prof. Jia-Lin Xie
1920-2016



Prof. W. K. H. Panofsky
1919-2007

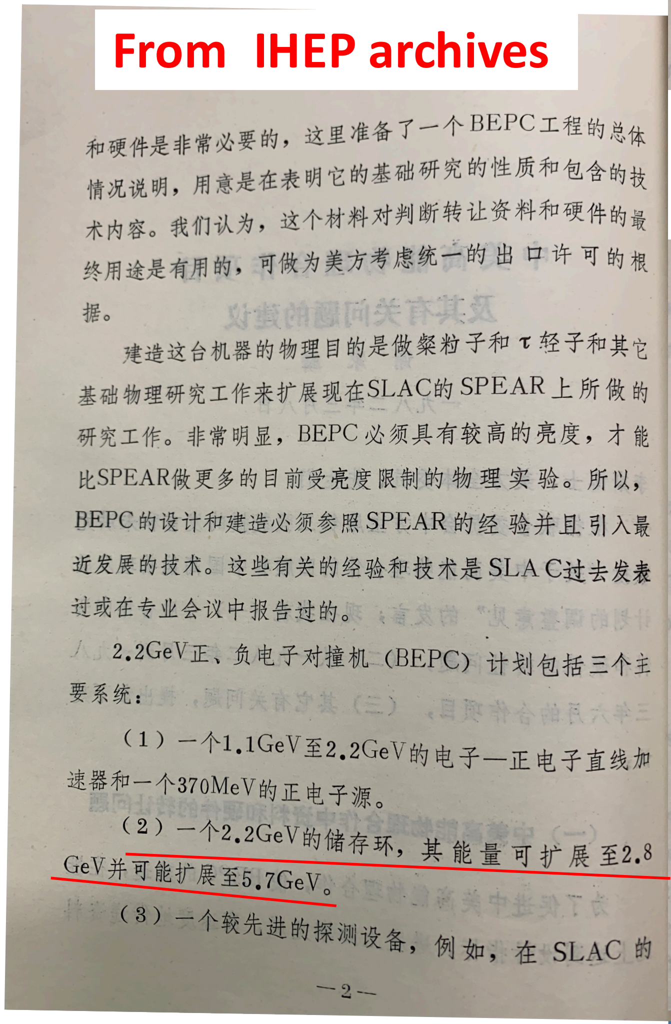
During the 3rd meeting of the Sino-US joint committee on HEP, March 8 – 9 , 1982, in Beijing. **Pief invited Prof. Xie a dinner in Beijing Hotel, Pief emphasized the importance to extend the beam energy from 2.2 to 2.8 GeV, so that the charmed baryons can be studied.**

BESI & BESII have not done it, since the low luminosities?

**But we did it at BESIII with 0.5 $fb^{-1}$ at 4.6 GeV**

# $E_{beam}$= 5.7 GeV was a dream

From IHEP archives



和硬件是非常必要的，这里准备了一个BEPC工程的总体情况说明，用意是在表明它的基础研究的性质和包含的技术内容。我们认为，这个材料对判断转让资料和硬件的最终用途是有用的，可做为美方考虑统一的出口许可的根据。

建造这台机器的物理目的是做粲粒子和τ轻子和其它基础物理研究工作来扩展现在SLAC的SPEAR上所做的研究工作。非常明显，BEPC必须具有较高的亮度，才能比SPEAR做更多的目前受亮度限制的物理实验。所以，BEPC的设计和建造必须参照SPEAR的经验并且引入最近发展的技术。这些有关的经验和技术是SLAC过去发表过或在专业会议中报告过的。

2.2GeV正、负电子对撞机（BEPC）计划包括三个主要系统：

（1）一个1.1GeV至2.2GeV的电子—正电子直线加速器和一个370MeV的正电子源。

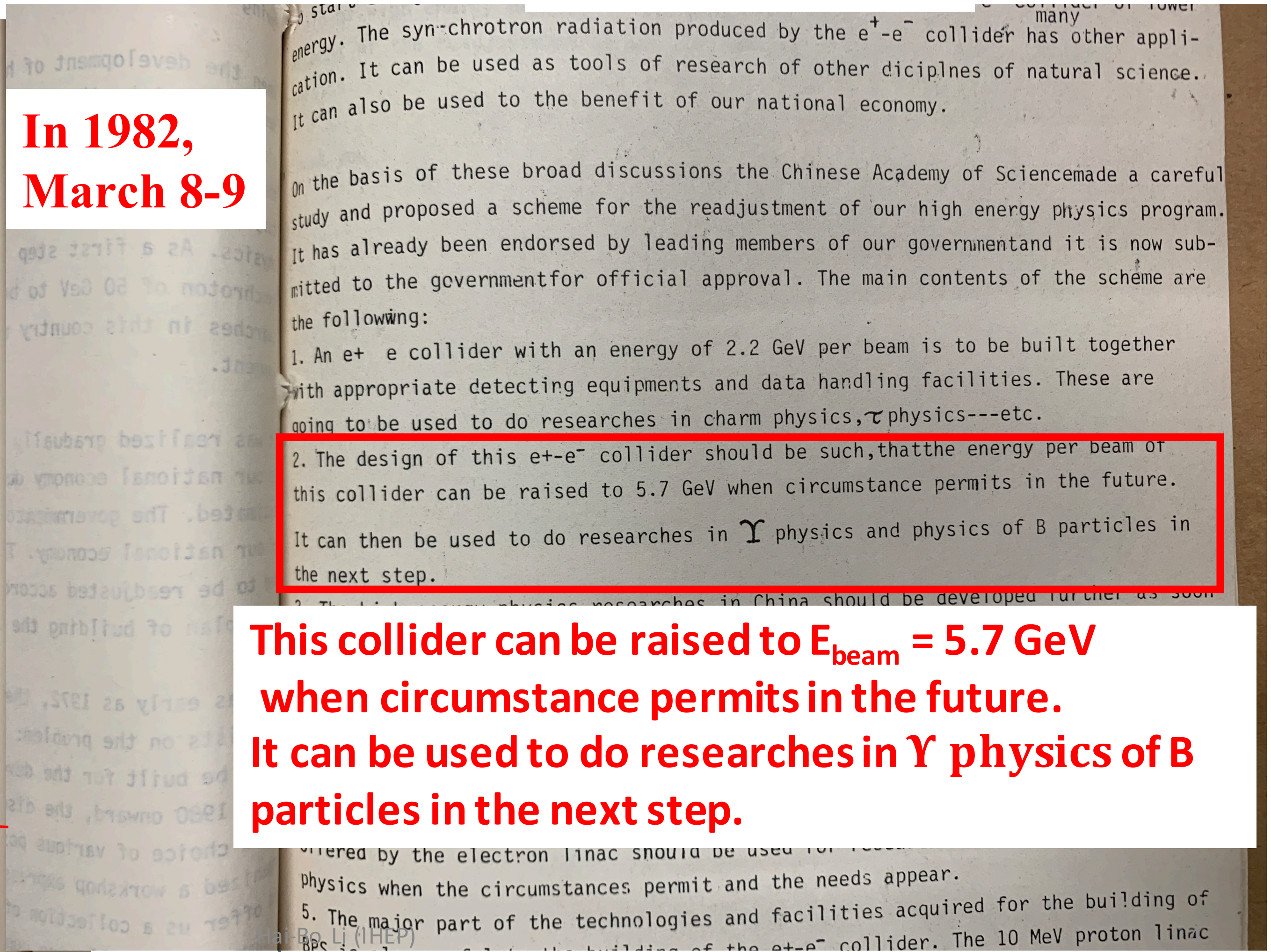
（2）一个2.2GeV的储存环，其能量可扩展至2.8GeV并可能扩展至5.7GeV。

（3）一个较先进的探测设备，例如，在SLAC的

—2—

From IHEP archives

**In 1982, March 8-9**



energy. The syn-chrotron radiation produced by the $e^+$-$e^-$ collider has other application. It can be used as tools of research of other diciplnes of natural science. It can also be used to the benefit of our national economy.

On the basis of these broad discussions the Chinese Academy of Sciencemade a careful study and proposed a scheme for the readjustment of our high energy physics program. It has already been endorsed by leading members of our governmentand it is now submitted to the governmentfor official approval. The main contents of the scheme are the following:

1. An e+ e collider with an energy of 2.2 GeV per beam is to be built together with appropriate detecting equipments and data handling facilities. These are going to be used to do researches in charm physics, τ physics---etc.

2. The design of this e+-e⁻ collider should be such, thatthe energy per beam of this collider can be raised to 5.7 GeV when circumstance permits in the future. It can then be used to do researches in $\Upsilon$ physics and physics of B particles in the next step.

...offered by the electron linac should be used for ... physics when the circumstances permit and the needs appear.

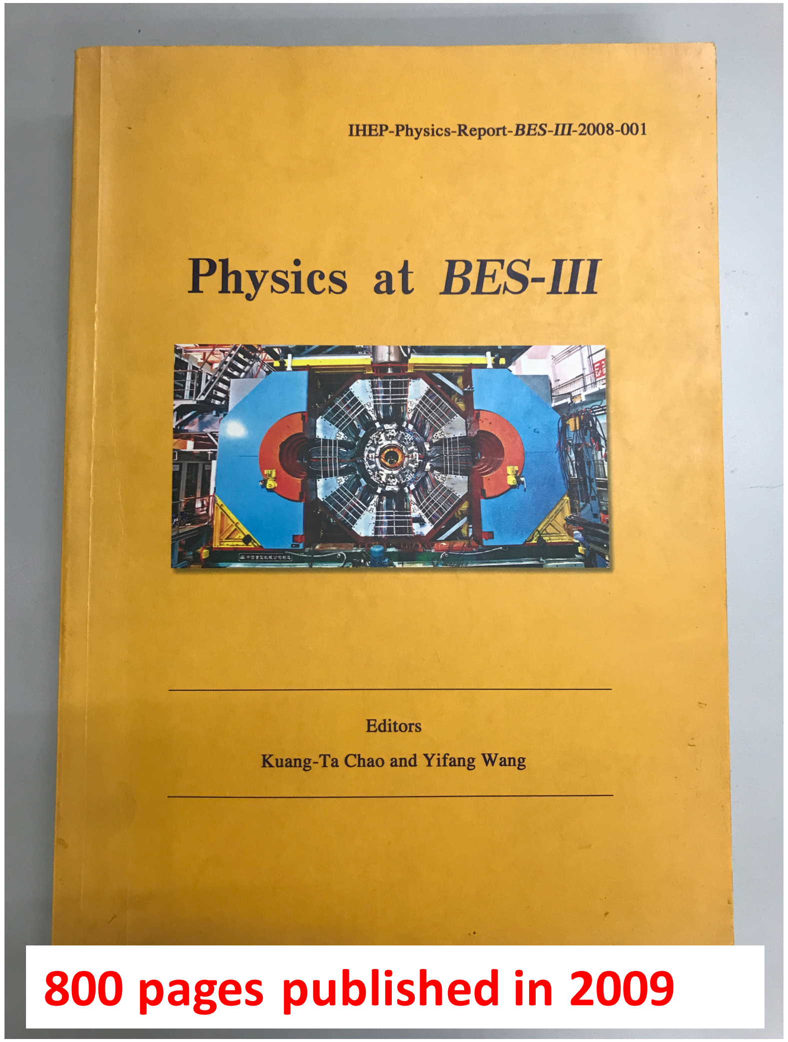
5. The major part of the technologies and facilities acquired for the building of the e+-e⁻ collider. The 10 MeV proton linac

**This collider can be raised to $E_{beam}$ = 5.7 GeV when circumstance permits in the future.**
**It can be used to do researches in $\Upsilon$ physics of B particles in the next step.**

Hai-Bo Li (IHEP)

# Planed physics programme

- Light hadron spectroscopy
  Meson, exotics, baryons …
- Charmonium physics
  Spectroscopy and transitions
  New states above open charm
  Decays
- Charmed meson & baryon physics:
  Decay, Mixing, CP violation
  CKM …
- $\tau$ physics, R values
- Searches of rare and forbidden processes




800 pages published in 2009

# 10 years data taking at BESIII

Data sets collected so far include,

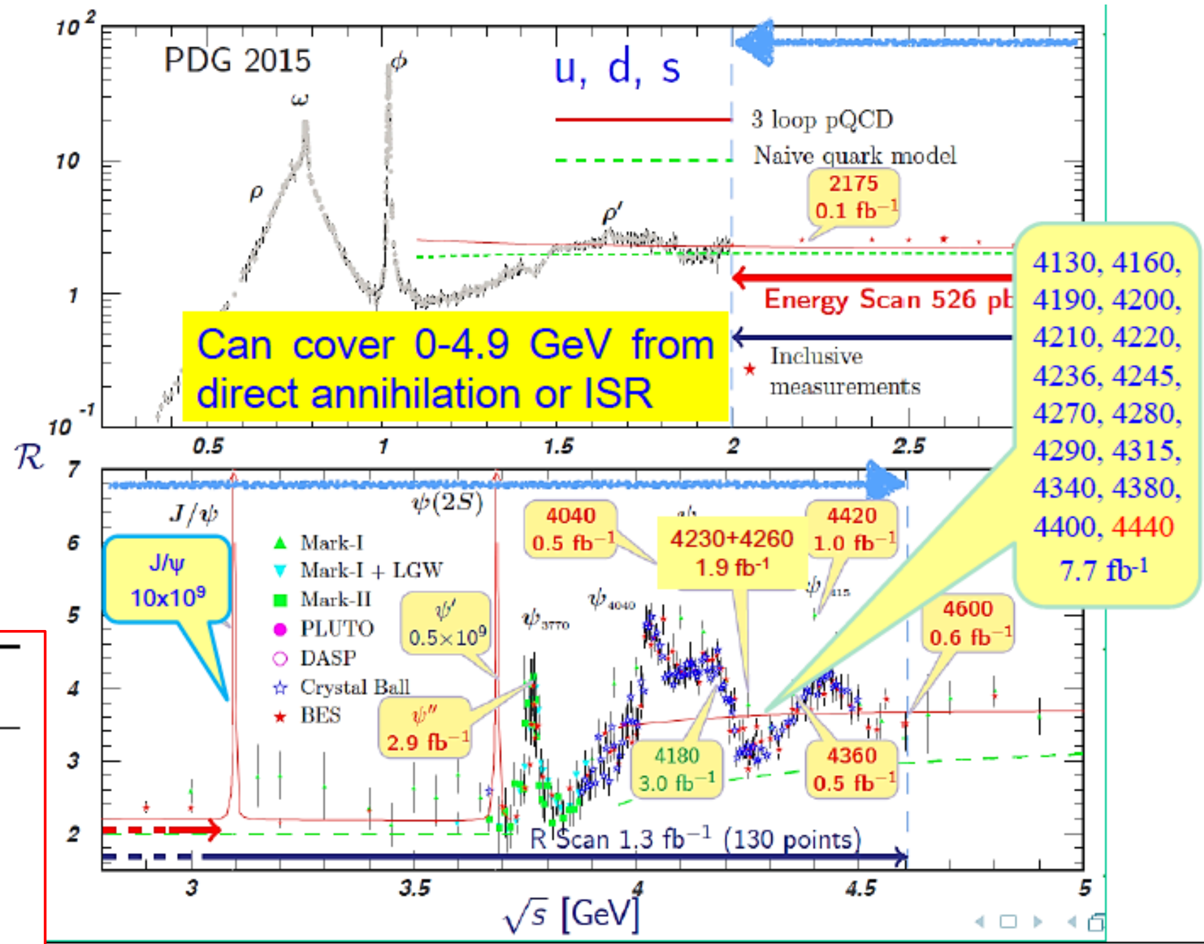
- **$10\times10^9$ $J/\psi$ events**
- $0.5\times10^9$ $\psi'$ events
- Scan data [2.0, 3.08] GeV; [3.735, 4.600] GeV

  130 energy points, about 2.0 $fb^{-1}$
- Large data sets for XYZ study above 4.0 GeV

  about 12 $fb^{-1}$

Unique data sets at open charm thresholds

| $\sqrt{s}$ / GeV | $\mathcal{L}$ / $fb^{-1}$ | |
|---|---|---|
| 3.77 | 2.93 | $D\bar{D}$ |
| 4.008 | 0.48 | $DD^*$, $\psi(4040)$, $D_s^+D_s^-$ |
| 4.18 | 3.2 | $D_sD_s^*$ |
| 4.6 | 0.59 | $\Lambda_c^+\bar{\Lambda}_c^-$ |



# Achievements

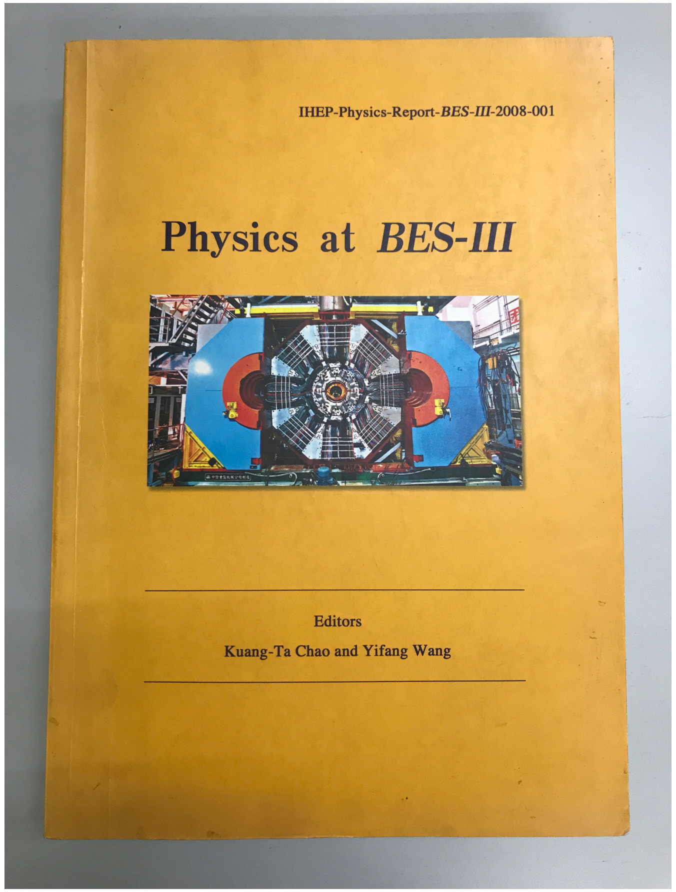
**More than 250 papers published or submitted so far**

**Highlights:**

- **Precision tau mass from BESIII**
- **Charmonium and *XYZ* spectroscopy： Zc(3900), X(3872) …**
- **Light hadron & searches of exotics: X(1835), X(ppbar)…**
- **Precision charm physics: decay constant, form factors, |Vcs|, |Vcd|**
- **Access to amplitudes of quantum-correlated $D^0$ decays: relative strong phases**
- **Charmed baryon production at threshold: $\Lambda_c$ production and decay**
- **Probe EM structures of baryons: $G_E, \ G_M$ of proton, neutron and hyperons**
- **Hyperon-anti-hyperon pairs from J/ψ and ψ′ decays: asymmetry parameters, *CP Violation,* and polarizations of hyperons**

# From BESIII physics (yellow) book to BESIII white paper

2008




2019

White Paper on the Future Physics Programme of BESIII

The BESIII collaboration¶

and

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IHEP-Physics-Report-BESIII-2019-8-3 for international review

¶Author list shown on the following pages

# BESIII future physics programme after 10 year running

**Since 2017, we started to discuss BESIII further physics programme :**

- **Potential physics topics**
- **Competition from other experiments**
- **The lifetime of BESIII experiment : detector upgrades ?**
- **Necessary of BEPCII/BESIII upgrades**

**190 pages white paper has been done, and has been reviewed by international committee (September 3-4, 2019)**

# Competition and complementary

- **Super-KEKB/Belle-II (50 $ab^{-1}$ ccbar cross-secion = 1.0 nb@Y(4S))**

  arXiv: 1808.10567 (Belle-II physics book)

- **LHCb and its upgrades (50 $fb^{-1}$ → $10^{11}$ reconstructed charm mesons)**

  **arXiv:1808.08865 (LHCb upgrade-II)**

- **proton-antiproton collisions (PANDA…)**
- **e-p/gamma-p collisions (Glue-X…)**
- **SHiP experiment at CERN: ($10^{18}$ D mesons, $10^{16}$ $\tau$, $10^{20}$ $\gamma$)**

**arXiv:1504.04855 ; arXiv:1807.02746**

# Physics programmes for future data taking

From the white paper

- **10-17 fb$^{-1}$ on $\psi$( 3770)**
- **6 fb$^{-1}$ at 4.18 GeV → Ds meson**
- **5 fb$^{-1}$ at 4.64 GeV for the charmed baryon**
- **Scan at the highest energy?**
- **Continue XYZ scan (500 fb$^{-1}$ /point between 4.0 and 4.6 GeV)**
- **Large Zc samples: 5 fb$^{-1}$ each at 4.23, 4.42 GeV**
- **High-statistics data samples around 2.2, 2.4 GeV**
- **3 billion $\psi$( 3686)**
- **…**

**…wishlist comprises about 40 fb$^{-1}$**

**BESIII has to run another 8 - 10 years to collect these data sets with current luminosity!**

# Upgrades to detectors: past and future

**Detector has running smoothly, performance generally excellence.**

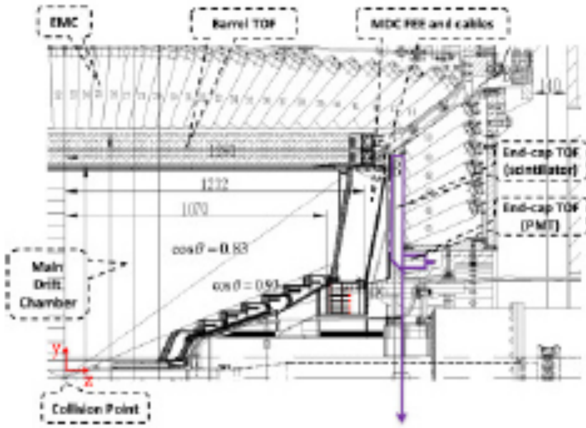
- ✓ **Endcap TOF upgrade （2015）**

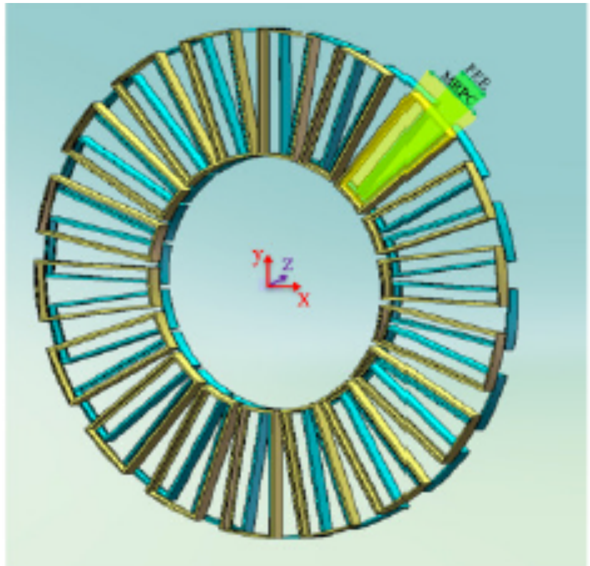
  **single layer plastic scintillator**

  **was replaced with multi-gap RPC.**

  **Time resolution: 110 ps → 60 ps**

  **95% $\pi/K$ separation up to 1.4 GeV**



- ✓ **Inner most part of the drift chamber:**

  **1) New inner drift chamber is ready**

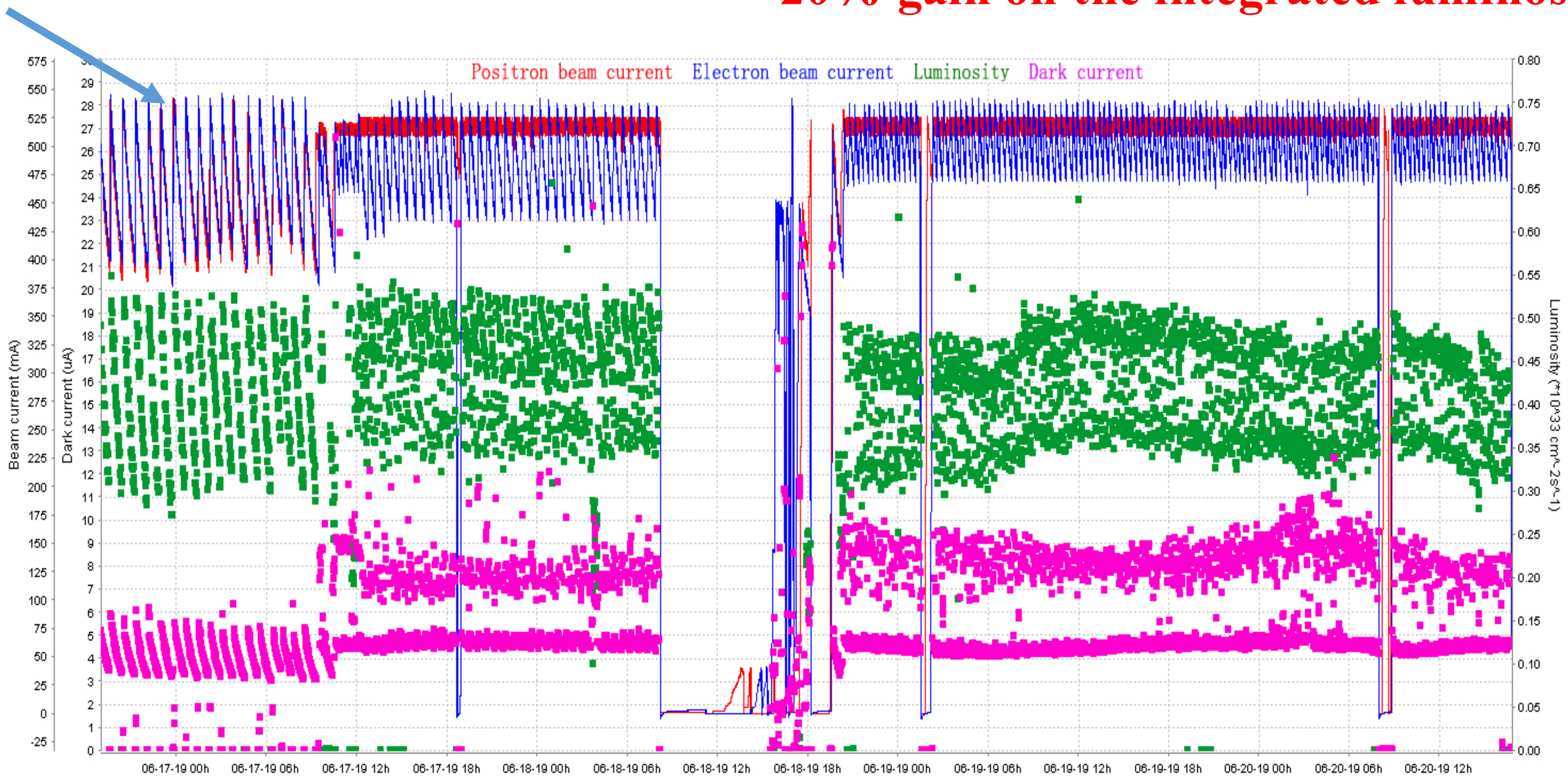
  **2) CGEM is in progress**

- ✓ **Super Conduct magnet : new valve box**

# Gain on integrated luminosity from "Topup" injection

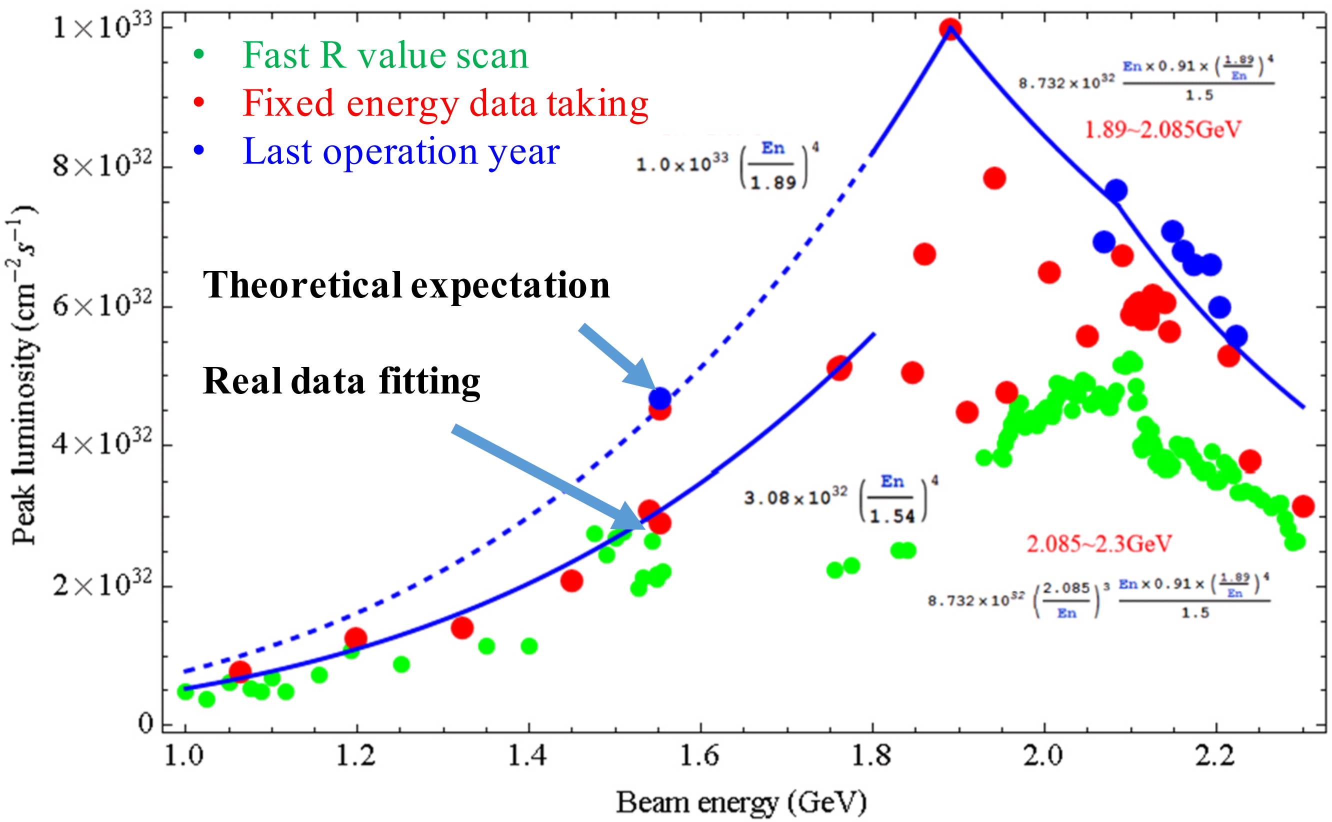
12 injections every 12 hours

**20% gain on the integrated luminosity**

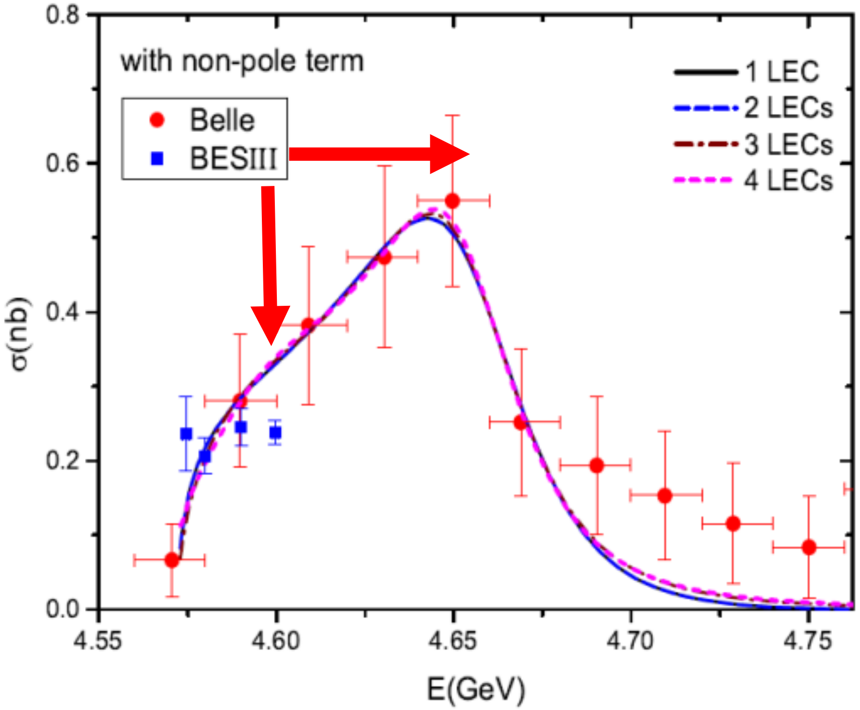


# BEPCII luminosity optimized for ψ(3770) running

## A factor of 2 gain for lattice optimized at J/ψ running



# Lineshape of $e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$




Belle: PRL101, 172001 (2008)
BESIII: PRL120,132001(2018)

**Machine upgrades:**

- ✓ **Energy upgrades**
- ✓ **Lumi improvement @ higher energy**
- ✓ **"Topup" injections**

**Some tensions between Belle and BESIII data on $e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$**
**BESIII future data above 4.6 GeV will follow a sharp rise of the Y(4660) or a flat cross section near threshold?**

# Energy and luminosity upgrades

**Energy upgrades**

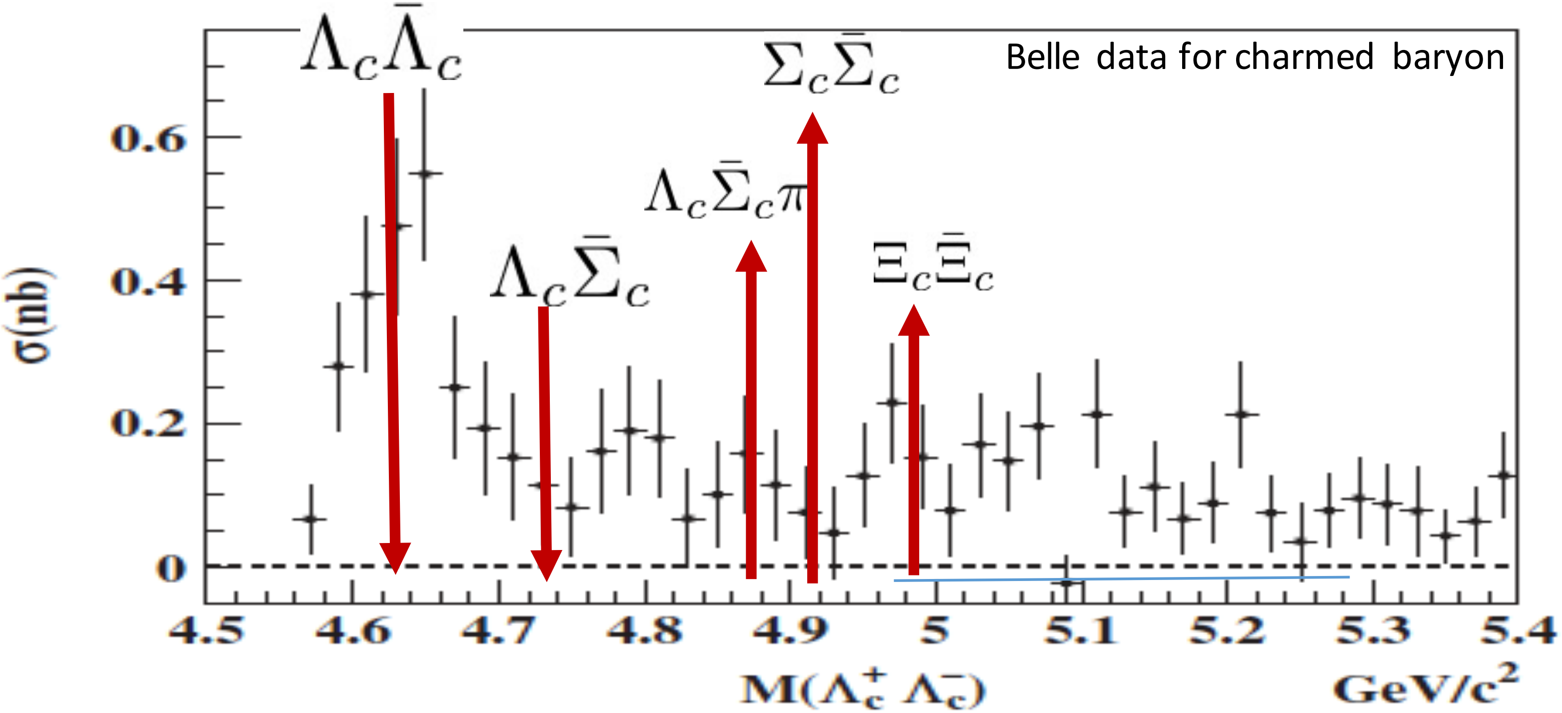
- **currently, $E_{beam}^{max}$=2.3 GeV limited by power supply, cooling of magnets**
- **upgrade I: $E_{beam}^{max}$=2.35 GeV , done in summer shutdown in 2019**
- **upgrade II: $E_{beam}^{max}$=2.45 GeV, need to rebuild SePtum magnets (2020)**

**access to the** $e^+e^- \to \Lambda_c\bar{\Lambda}_c,\ \Lambda_c\bar{\Sigma}_c,\ \Sigma_c\bar{\Sigma}_c,\ \Xi_c\bar{\Xi}_c?$

**Future luminosity upgrades**

- **improvement of beam power: more bunches with stable running → a factor of 2 or 3**
- **try crab-waist : a factor of 10 times gain on the luminosity?**

# Access to the heavier charmed baryons




Energy thresholds

- ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ 4.74 GeV
- ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c\ \pi$ 4.88 GeV
- ✓ $e^+e^- \to \Sigma_c\ \bar{\Sigma}_c$ 4.91 GeV (10MeV above current limit)
- ✓ $e^+e^- \to \Xi_c\ \bar{\Xi}_c$ 4.95 GeV (50 MeV above current limit)

# Charmed baryons productions

Marek Karliner

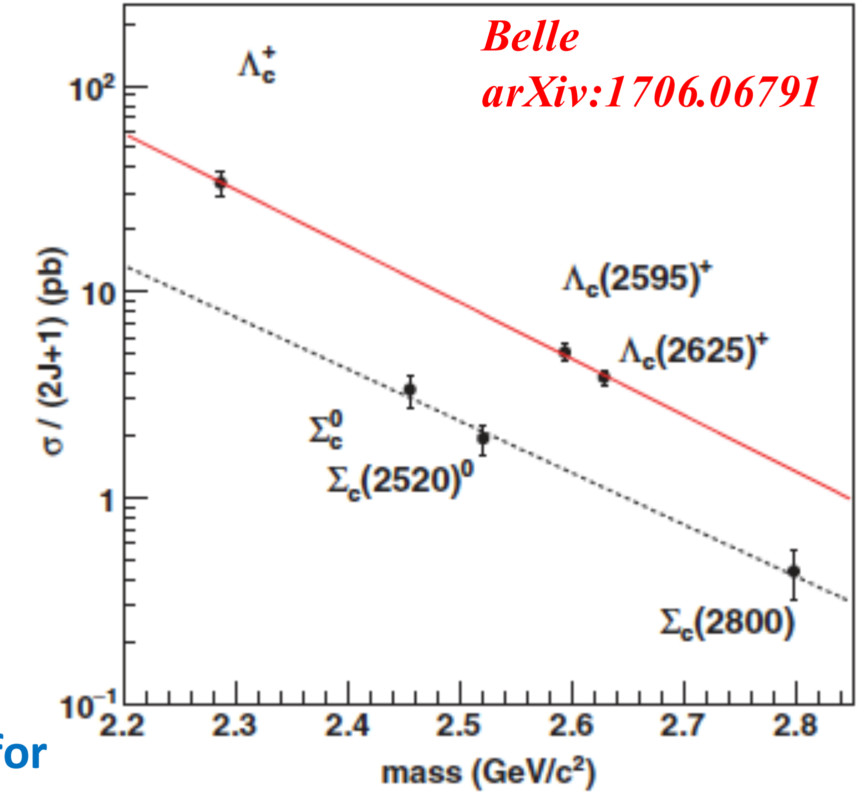
In the charmed baryon system, the light quarks are more like di-quarks

$$\Lambda_c^+(c[ud]_{spin=0}),\ \Sigma_c(c[ud]_{spin=1})$$

The spin-0 diquarks: "good" diquarks

The spin-1 one : "bad" diquarks.

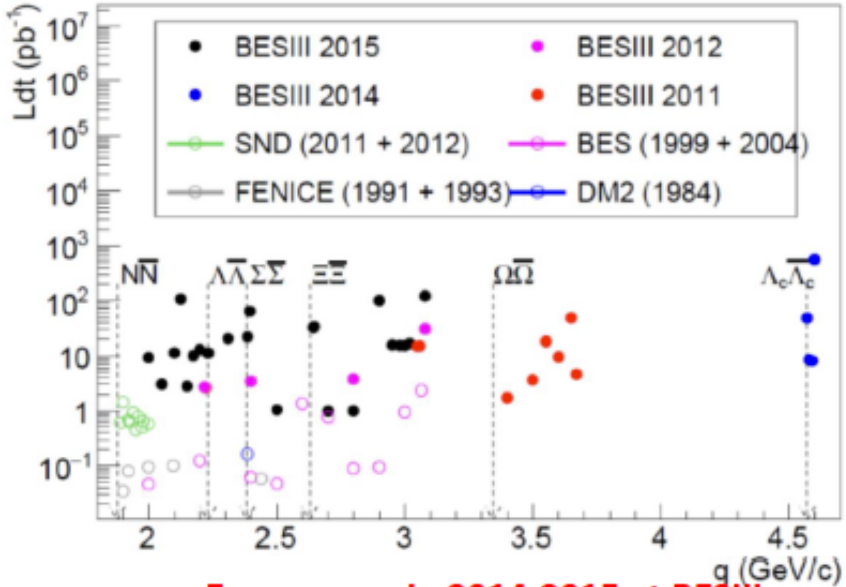
The bad diquarks are heavier. So if the hadronization from the initial (ccbar) proceeds in one step, by attaching diquarks, it will provide a simple and natural explanation for the fact that the $\Lambda_c$ cross section is much bigger than that of $\Sigma_c$.



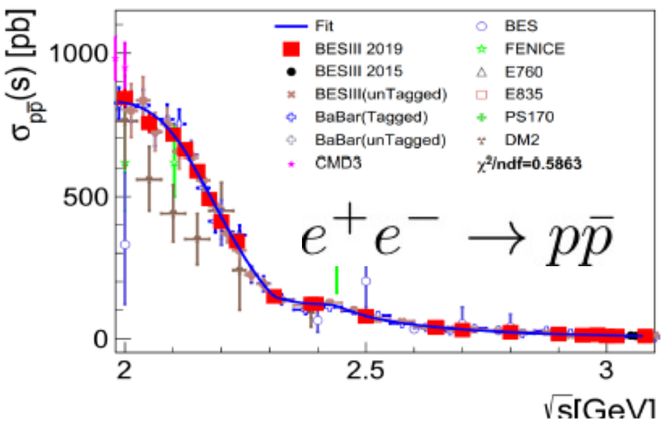

***Then how about the behaves at the threshold, and to test it at BESIII will be very interesting!***

# Advantage: unique data near to the thresholds

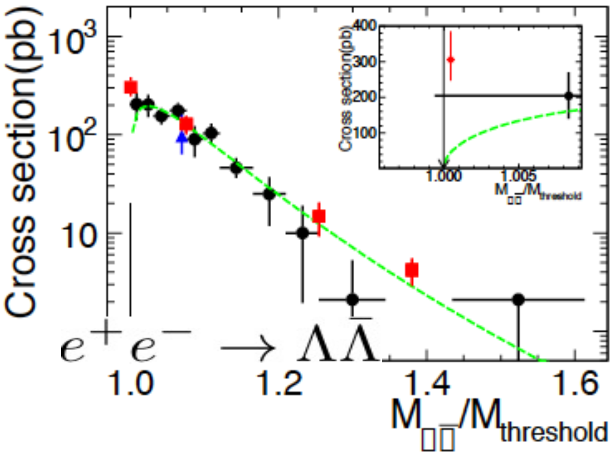
- **D/Ds/$\Lambda_c$ hadrons near thresholds:**
  **precision branching fractions, unique access to the relative phase, test of SM**
- **Hyperon and charmed baryon Spin polarization in QC**
- **Form-factors in the time-like production**
- **CP violation with quantum-correlated pair productions of hyperons and charmed baryon**

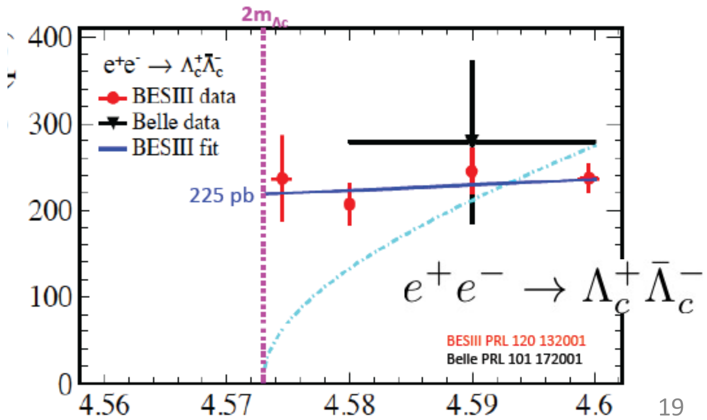



Energy scan in 2014-2015 at BESIII

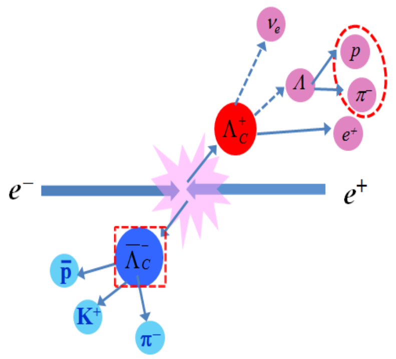



Best precision on $\sigma$: 3% (systematic dominant)



# The First Charmed baryon near to the thresholds



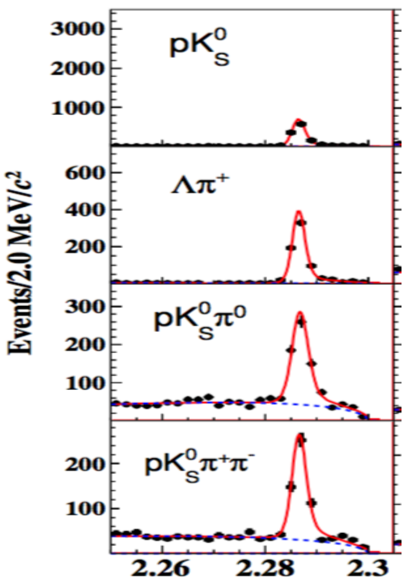

*Signal Tag Variable :* $M_{\mathrm{BC}} = \sqrt{E_{\mathrm{beam}}^2 - |\vec{p}_{\bar{\Lambda}_c^-}|^2}$

**590 pb$^{-1}$ @ 4.6 GeV**

$U_{\mathrm{miss}} = E_{\mathrm{miss}} - c|\vec{p}_{\mathrm{miss}}|$

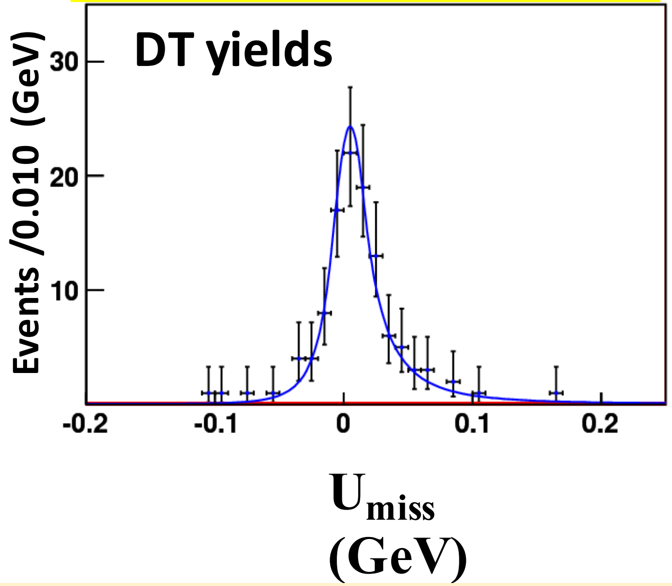
***PRL 116, 052001 (2016)***

**ST yields**




| modes | $N_i^{ST}$ |
|---|---|
| $pK_S$ | $1243 \pm 37$ |
| $pK^-\pi^+$ | $6308 \pm 88$ |
| $pK_S\pi^0$ | $558 \pm 33$ |
| $pK_S\pi^+\pi^-$ | $454 \pm 28$ |
| $pK^-\pi^+\pi^0$ | $1849 \pm 71$ |
| $\Lambda\pi^+$ | $706 \pm 27$ |
| $\Lambda\pi^+\pi^0$ | $1497 \pm 52$ |
| $\Lambda\pi^+\pi^-\pi^+$ | $609 \pm 31$ |
| $\Sigma^0\pi^+$ | $586 \pm 32$ |
| $\Sigma^+\pi^0$ | $271 \pm 25$ |
| $\Sigma^+\pi^+\pi^-$ | $836 \pm 43$ |
| $\Sigma^+\omega$ | $157 \pm 22$ |

$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$




**We will accumulate at least 10~20x more $\Lambda_c$ pairs**

***Almost background free***

# High precision charm physics @thresholds: D/Ds

| Observables | Exp. measure | BESIII | Belle-II | LHCb |
|---|---|---|---|---|
| $B(D^+ \to l\nu)$ | $f_D\|V_{cd}\|$ | 1.1% | 1.4% | N/A |
| $B(D_S^+ \to l\nu)$ | $f_{Ds}\|V_{cs}\|$ | 1.0% | 1.0% | N/A |
| $\frac{B(D^+ \to l\nu)}{B(D_S^+ \to l\nu)}$ | $\frac{f_D\|V_{cd}\|}{f_{Ds}\|V_{cs}\|}$ | 1.0% | 1.4% | N/A |
| $d\Gamma(D \to \pi l\nu)/dq^2$ | $f_{D\to\pi}(0)\|V_{cd}\|$ | 0.6% | 1.0% | N/A |
| $d\Gamma(D \to K l\nu)/dq^2$ | $f_{D\to K}(0)\|V_{cs}\|$ | 0.5% | 0.9% | N/A |
| $d\Gamma(D_S \to K l\nu)/dq^2$ | $f_{Ds\to K}(0)\|V_{cd}\|$ | 1.3% | N/A | N/A |
| $d\Gamma(D_S \to \phi l\nu)dq^2$ | $f_{Ds\to\phi}(0)\|V_{cs}\|$ | 1.0% | N/A | N/A |

Belle: 2.5%

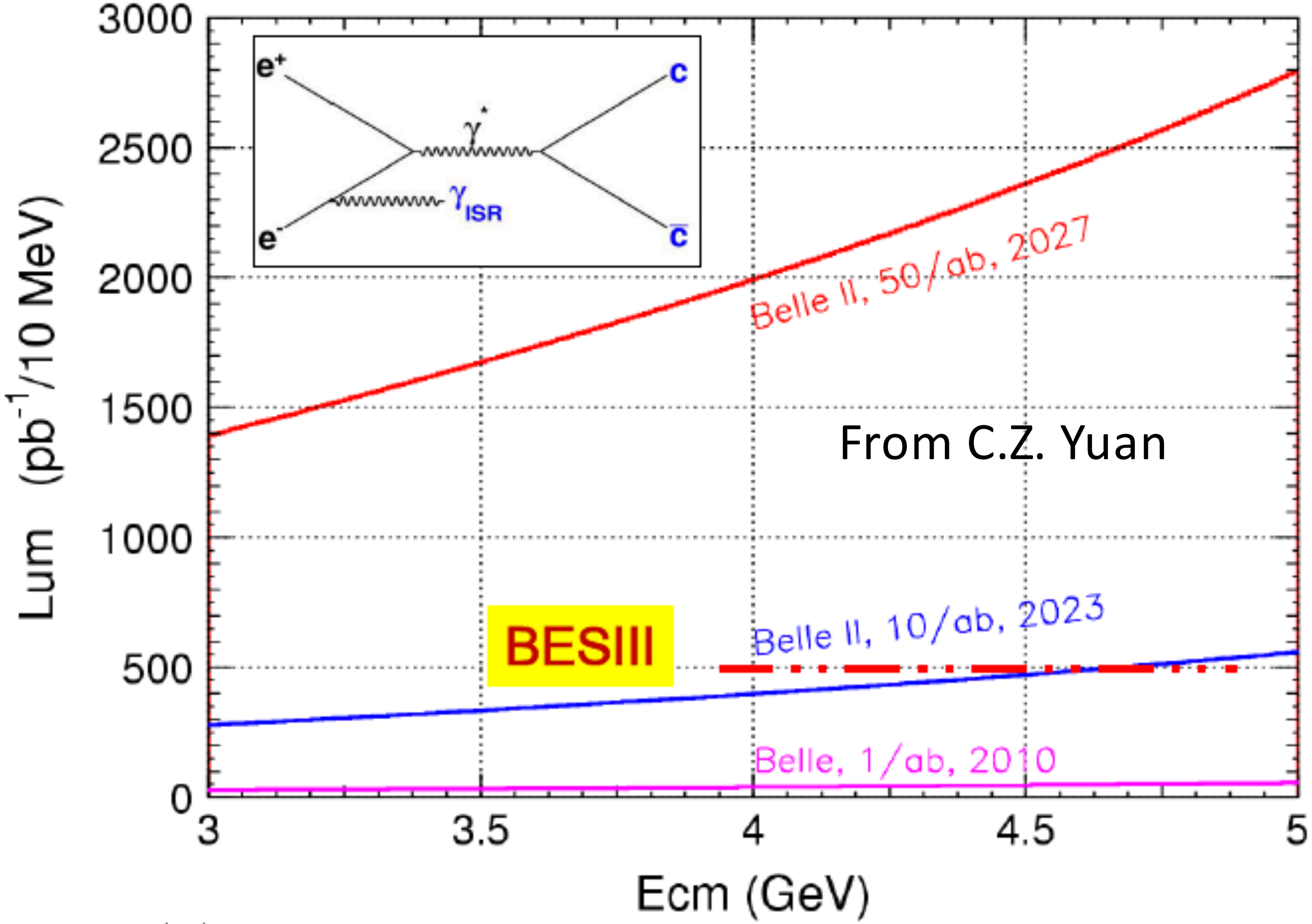
BESIII: 20fb$^{-1}$ @ 3770 MeV, 6fb$^{-1}$ @ 4180 MeV, arXiv: 0809.1869 (BESIII physics book)

Belle-II: 50 ab$^{-1}$ @ Y(4S) arXiv: 1808.10567 (Belle-II physics book)

LHCb: : **arXiv:1808.08865 for upgrade-II**

# Belle II vs. BESIII

ISR produces events at all CM energies BESIII can reach




BelleII schedule:
2022: 20/ab :
2025: 50/ab:

At 4.26 GeV for $\pi^+\pi^- J/\psi$
$\varepsilon_{BESIII}$ = 46%
$\varepsilon_{Belle}$ = 10%

BESIII: high efficiency for open-charm

BelleII: very low efficiency for open charm

# Belle II vs. BESIII on XYZ study

Full Belle II data sample (50 $ab^{-1}$ at 10.58 GeV, ISR events in 10 MeV) compared with 0.5 $fb^{-1}$ at BESIII

| ISR mode | $L_{BESIII}/L_{Belle\ II}$ | $\varepsilon_{BESIII}/\varepsilon_{Belle\ II}$ | $N_{BESIII}/N_{Belle\ II}$ |
|---|---|---|---|
| $\pi^+\pi^- J/\psi$ @ 4.26 GeV | 0.5 $fb^{-1}$ / 2.2 $fb^{-1}$ | 46% / 10% | 1.07 |
| $\pi^+\pi^- \psi'$ @ 4.36 GeV | 0.5 $fb^{-1}$ / 2.3 $fb^{-1}$ | 41% / 5% | 1.82 |
| @ 4.66 GeV | 0.5 $fb^{-1}$ / 2.5 $fb^{-1}$ | 35% / 6% | 1.19 |
| $\pi^+\pi^- h_c$ @ 4.26 GeV<br>@ 4.36 GeV | 0.5 $fb^{-1}$ / 2.2 $fb^{-1}$ | 2.7% / — | > 5 |
| $K^+K^- J/\psi$ @ 4.6 GeV | 0.5 $fb^{-1}$ / 2.4 $fb^{-1}$ | 29% / 7.5% | 0.81 |
| @ 4.9 GeV | 0.5 $fb^{-1}$ / 2.7 $fb^{-1}$ | ~29% / 10% | 0.54 |
| $\Lambda^+_c \Lambda^-_c$ @ 4.6 GeV | 0.5 $fb^{-1}$ / 2.4 $fb^{-1}$ | 51% / 7.5% | 1.42 |
| @ 4.9 GeV | 0.5 $fb^{-1}$ / 2.7 $fb^{-1}$ | ~37% / 7.5% | 0.91 |

# Roadmap of CP violation in flavored hadrons

1980


2008

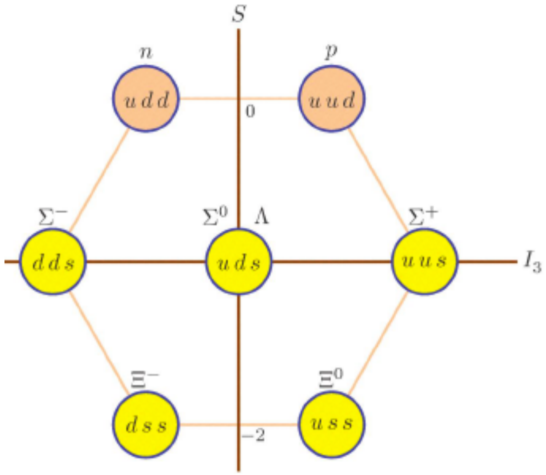
- **In 1964, the first CPV was discovered in Kaon ；**
- **In 2001, CPV in B was established by two B-factories;**
- **In 2019, CPV discovered in D meson: $10^{-4}$, $10^{8}$ reconstructed D mesons (LHCb)**
- **All are consistent with CKM theory in the Standard model**
- **But no evidence was found in strange baryons?**

**Baryon asymmetry of the Universe means that there must be non-SM CPV source.**

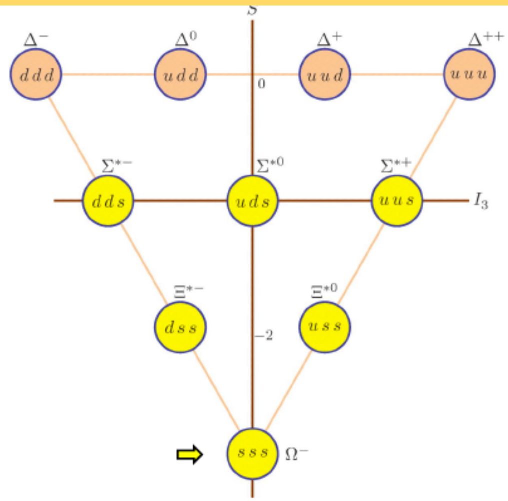
# CPV in hyperon decays and New physics

| CPV in SM is small : | | | # events | Experiments |
|---|---|---|---|---|
| B meson : | O(1) | discovered (2001) | $10^3$ | B factory |
| K meson : | $O(10^{-3})$ | discovered (1964) | $10^6$ | Fix targets |
| D meson : | $O(10^{-4})$ | discovered (2019) | $10^8$ | LHCb |
| Hyperon : | $O(10^{-4})$ | $10^{-2}$ | $O(10^8)$ | Fix targets |
| | | | | → BESIII ? |

**Flavor-SU(3) Octet of spin ½**




**Flavor-SU(3) Decuplet of spin 3/2**



# Why Hyperon physics at BESIII？

**10 billion J/psi events collected**

- **Large BRs in J/psi decays**
- **Quantum correlated pair productions**
- **Easy to reconstruct**
- **Background free**

| Decay mode | $\mathcal{B}(\times 10^{-3})$ | $N_B\ (\times 10^6)$ |
|---|---|---|
| $J/\psi \to \Lambda\bar{\Lambda}$ | $1.61 \pm 0.15$ | $16.1 \pm 1.5$ |
| $J/\psi \to \Sigma^0\bar{\Sigma}^0$ | $1.29 \pm 0.09$ | $12.9 \pm 0.9$ |
| $J/\psi \to \Sigma^+\bar{\Sigma}^-$ | $1.50 \pm 0.24$ | $15.0 \pm 2.4$ |
| $J/\psi \to \Sigma(1385)^-\bar{\Sigma}^+$ (or c.c.) | $0.31 \pm 0.05$ | $3.1 \pm 0.5$ |
| $J/\psi \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.) | $1.10 \pm 0.12$ | $11.0 \pm 1.2$ |
| $J/\psi \to \Xi^0\bar{\Xi}^0$ | $1.20 \pm 0.24$ | $12.0 \pm 2.4$ |
| $J/\psi \to \Xi^-\bar{\Xi}^+$ | $0.86 \pm 0.11$ | $8.6 \pm 1.0$ |
| $J/\psi \to \Xi(1530)^0\bar{\Xi}^0$ | $0.32 \pm 0.14$ | $3.2 \pm 1.4$ |
| $J/\psi \to \Xi(1530)^-\bar{\Xi}^+$ | $0.59 \pm 0.15$ | $5.9 \pm 1.5$ |
| $\psi(2S) \to \Omega^-\bar{\Omega}^+$ | $0.05 \pm 0.01$ | $0.15 \pm 0.03$ |


Hai-Bo Li, arXiv:1612.01775
A. Adlarson, A. Kupsc, arXiv:1908.03102


**The number of reconstructed hyperon-anti-hyperon pairs will be a few millions.**

# Advantage at $e^+e^-$ machine

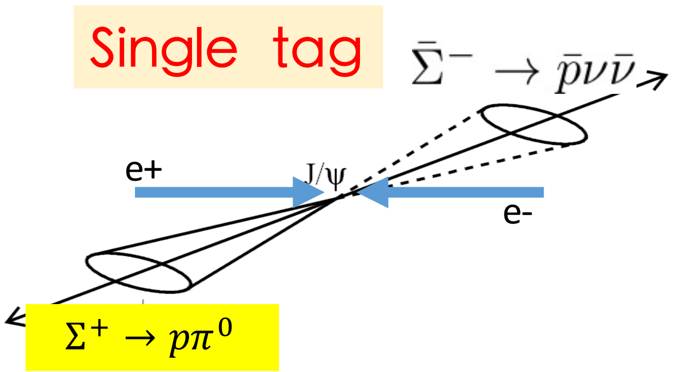
**Known initial 4-momentum**

**Strongly boosted**

**Substantial polarization**

**Decay with neutron & $\pi^0$**

**Decay with invisibles**



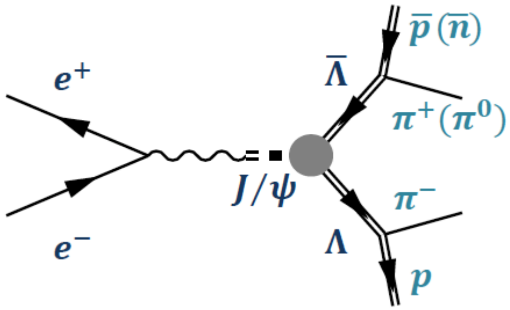

$$|\Lambda\bar{\Lambda}\rangle^{C=-1} = \chi_1 \frac{1}{\sqrt{2}}[|\Lambda\rangle|\bar{\Lambda}\rangle - |\bar{\Lambda}\rangle|\Lambda\rangle],$$

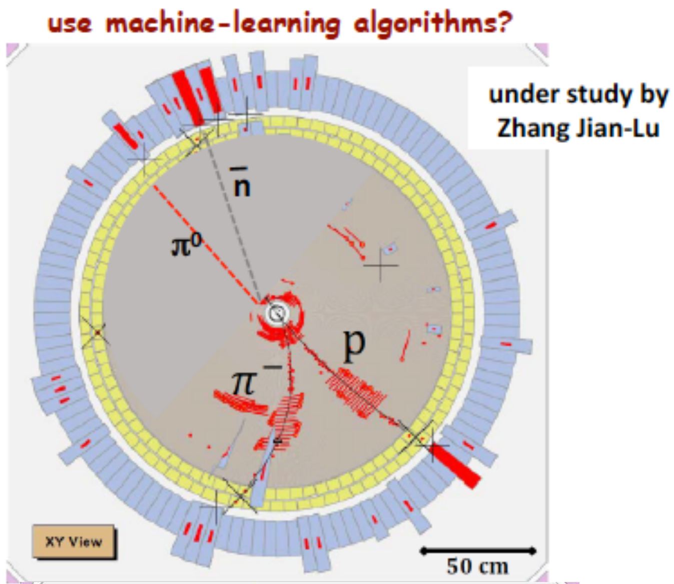
$$\alpha(\Lambda \to p\pi^-) = \alpha_-$$

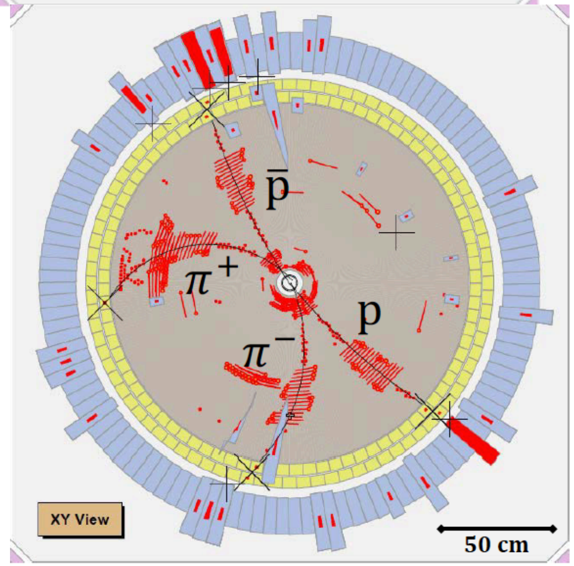
$$\alpha(\bar{\Lambda} \to \bar{p}\pi^+) = \alpha_+$$

$$\alpha(\bar{\Lambda} \to \bar{n}\pi^0) = \bar{\alpha}_0$$

$$\alpha(\Lambda \to n\pi^0) = \alpha_0$$

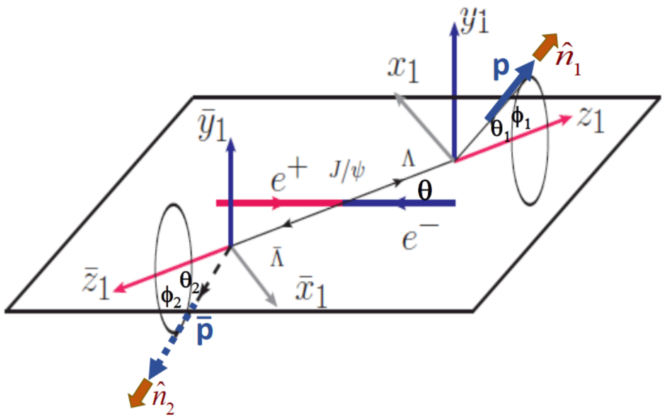


# Correlated 5-dim. angular distribution

$$\mathcal{W}(\xi;\alpha_\psi,\Delta\Phi,\alpha_-,\alpha_+) = 1+\alpha_\psi\cos^2\theta_\Lambda$$




$$+\alpha_-\alpha_+\left[\sin^2\theta_\Lambda\left(n_{1,x}n_{2,x}-\alpha_\psi n_{1,y}n_{2,y}\right)+\left(\cos^2\theta_\Lambda+\alpha_\psi\right)n_{1,z}n_{2,z}\right]$$

$$+\alpha_-\alpha_+\sqrt{1-\alpha_\psi{}^2}\cos(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\left(n_{1,x}n_{2,z}+n_{1,z}n_{2,x}\right)$$

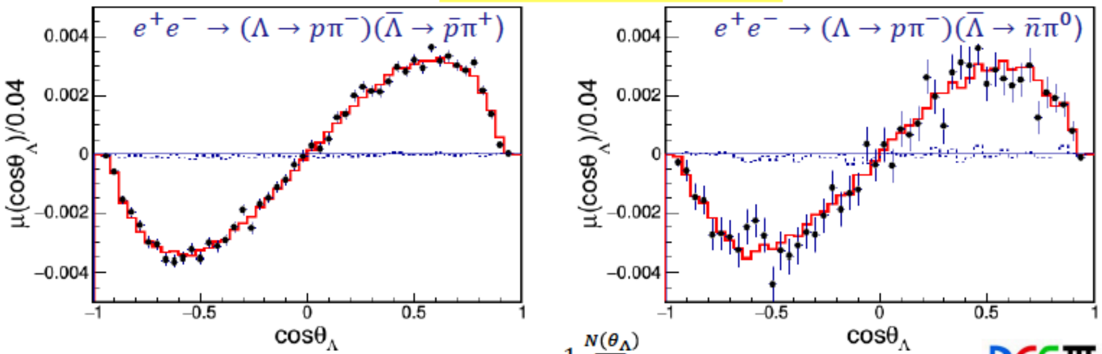
$$+\sqrt{1-\alpha_\psi{}^2}\sin(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda\left(\alpha_-n_{1,y}+\alpha_+n_{2,y}\right),$$

**If Λ is polarized, both a$_-$ and a$_+$ can be measured simultaneously, which allow us to search for CPV**

$$P_y(\cos\theta_\Lambda)=\frac{\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\cos\theta_\Lambda\sin\theta_\Lambda}{1+\alpha_\psi\cos^2\theta_\Lambda}$$

**Fit results**

$\Delta\Phi=42.3^\circ\pm0.6^\circ\pm0.5^\circ$




BESIII

**moment:** $\mu(\cos\theta_\Lambda)=\frac{1}{N}\sum_{i=1}^{N(\theta_\Lambda)}\left(n_{1,y}^{(i)}-n_{2,y}^{(i)}\right)$

**(uncorrected for acceptance)**

# BESIII results with 1.3 billion $J/\psi$

Nature Physics May 2019
arXiv:1808.08917

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

comments on these 3 items:

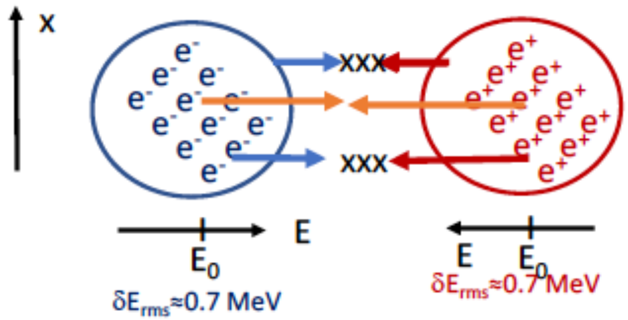
← 1) 3x precision improvement -same data sample-

← 2) ~$7\sigma$ upward shift from all previous measurements

← 3) ~$3\sigma$ difference from 1. Is this reasonable?

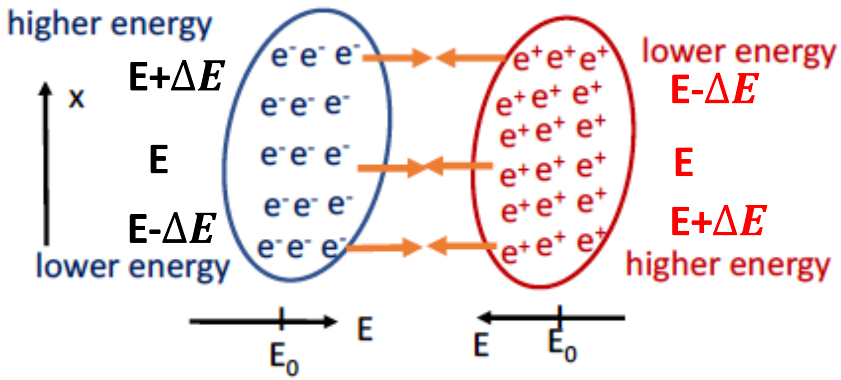
$|\Delta I| = ½$ rule in Kaon decay

# Monochromatic collision: factor of 10 from reduction of $e^+e^-$ CM spread




only $e^+e^-$ pairs with $E_{cm}$=3096 ± 0.14 MeV can produce a J/ψ, ~1/30th of the total

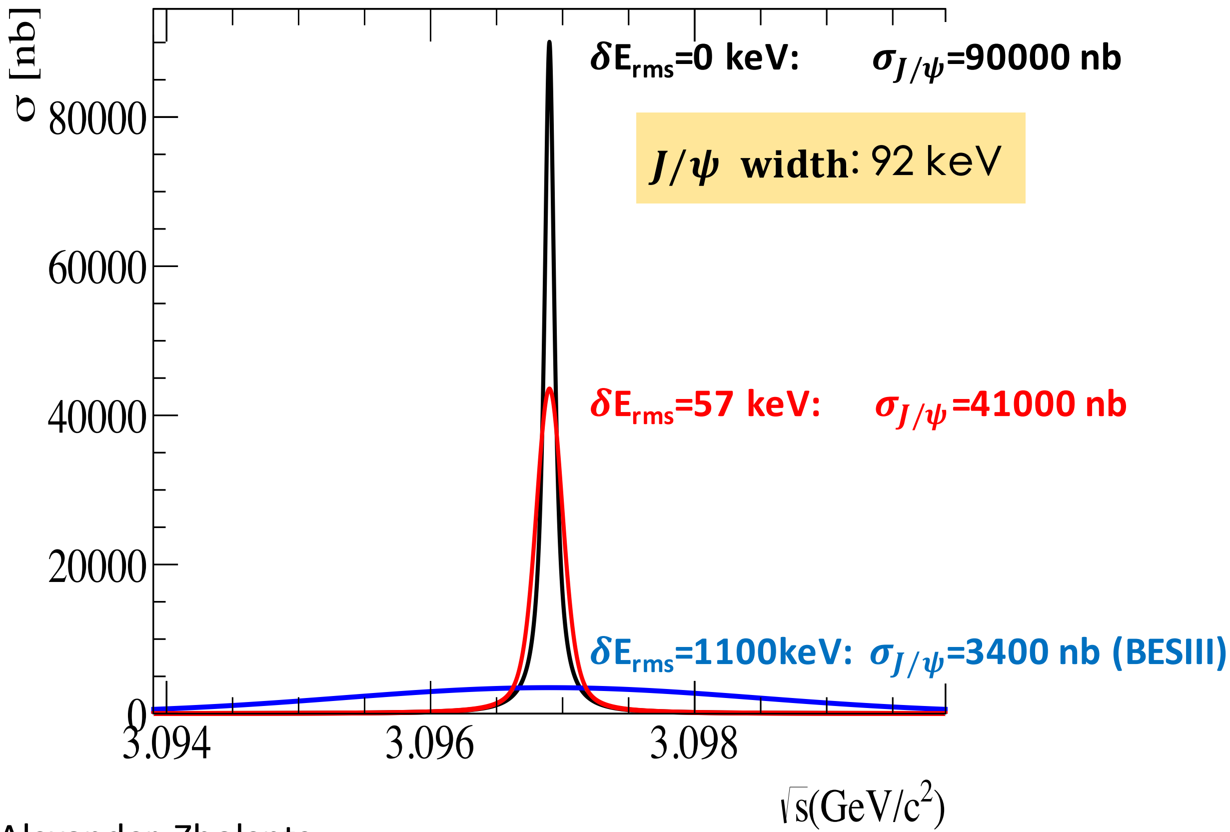
introduce dispersion




more $e^+e^-$ pairs with $E_{cm}$=3096 ± 0.14 MeV

$J/\psi$ production cross-section

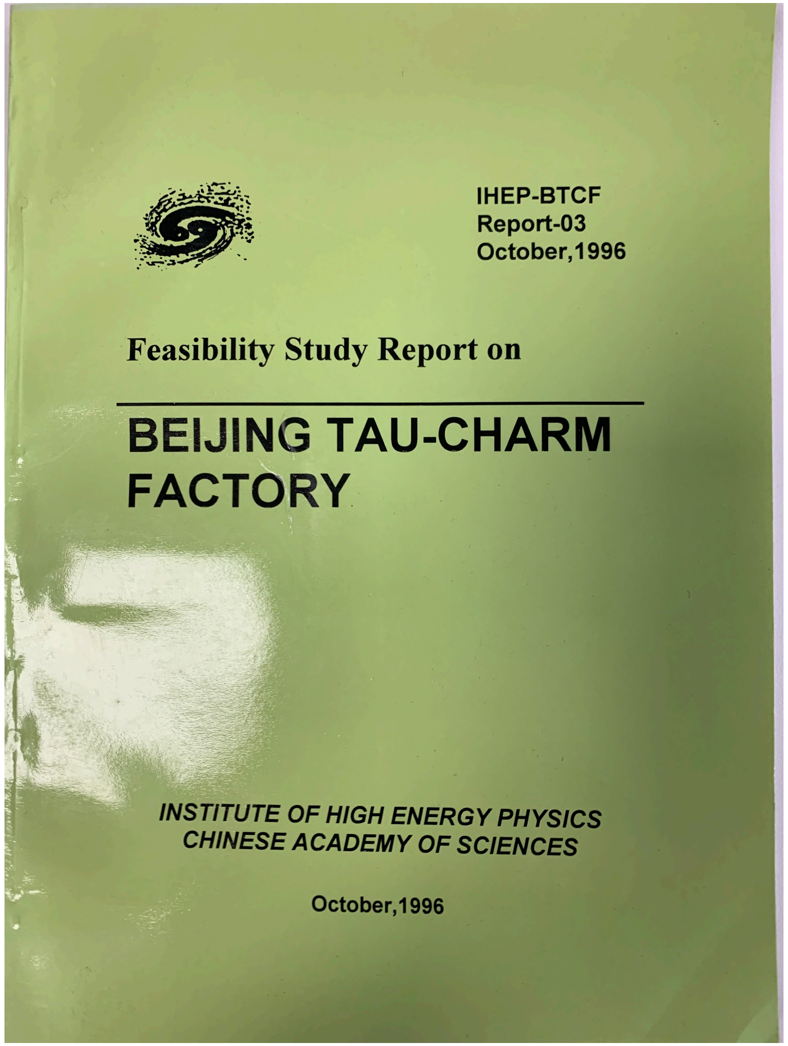
Xiaoshuai Qin

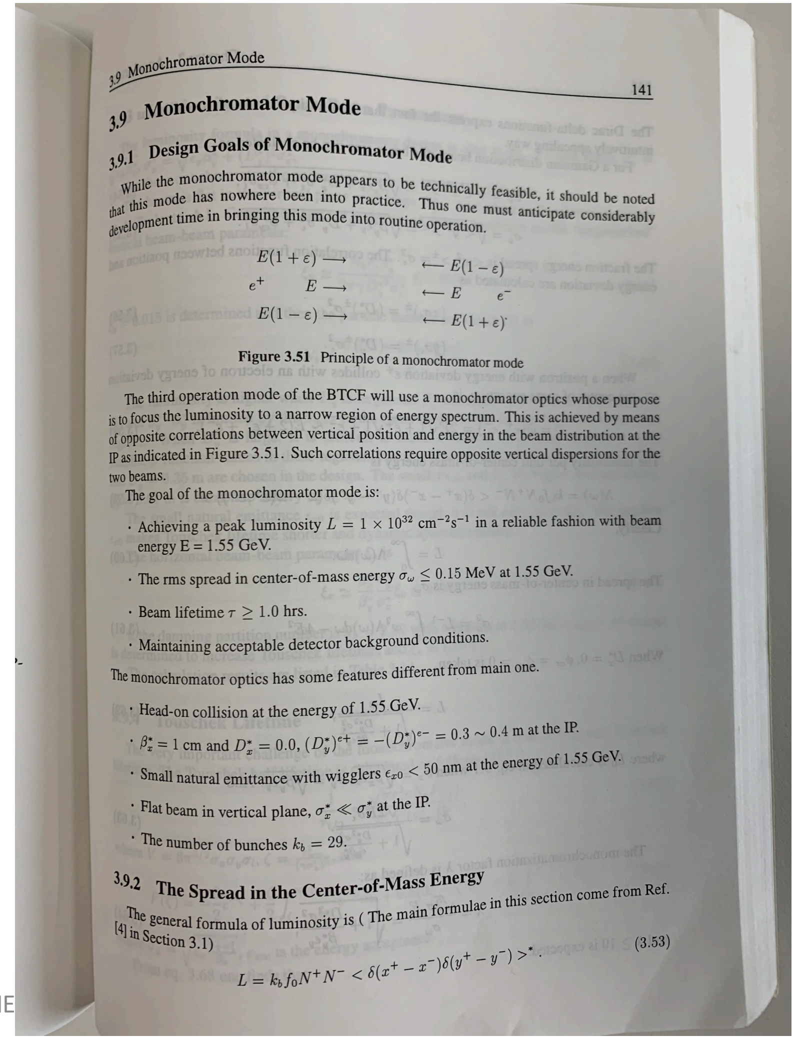



Alexander Zholents
CERN SL/92-27/AP

BESIII may get trillion $J/\psi$ per year!
A dream （Steve Olsen)?

# Monochromatic collision: in 1996



3.9 Monochromator Mode 141

### 3.9 Monochromator Mode

#### 3.9.1 Design Goals of Monochromator Mode

While the monochromator mode appears to be technically feasible, it should be noted that this mode has nowhere been into practice. Thus one must anticipate considerably development time in bringing this mode into routine operation.

$$\begin{array}{cccc} & E(1+\varepsilon)\longrightarrow & \longleftarrow E(1-\varepsilon) & \\ e^+ & E\longrightarrow & \longleftarrow E & e^- \\ & E(1-\varepsilon)\longrightarrow & \longleftarrow E(1+\varepsilon) & \end{array}$$

**Figure 3.51** Principle of a monochromator mode

The third operation mode of the BTCF will use a monochromator optics whose purpose is to focus the luminosity to a narrow region of energy spectrum. This is achieved by means of opposite correlations between vertical position and energy in the beam distribution at the IP as indicated in Figure 3.51. Such correlations require opposite vertical dispersions for the two beams.

The goal of the monochromator mode is:

- Achieving a peak luminosity $L = 1 \times 10^{32}$ cm$^{-2}$s$^{-1}$ in a reliable fashion with beam energy E = 1.55 GeV.
- The rms spread in center-of-mass energy $\sigma_\omega \leq 0.15$ MeV at 1.55 GeV.
- Beam lifetime $\tau \geq 1.0$ hrs.
- Maintaining acceptable detector background conditions.

The monochromator optics has some features different from main one.

- Head-on collision at the energy of 1.55 GeV.
- $\beta_x^* = 1$ cm and $D_x^* = 0.0$, $(D_y^*)^{e+} = -(D_y^*)^{e-} = 0.3 \sim 0.4$ m at the IP.
- Small natural emittance with wigglers $\epsilon_{x0} < 50$ nm at the energy of 1.55 GeV.
- Flat beam in vertical plane, $\sigma_x^* \ll \sigma_y^*$ at the IP.
- The number of bunches $k_b = 29$.

#### 3.9.2 The Spread in the Center-of-Mass Energy

The general formula of luminosity is ( The main formulae in this section come from Ref. [4] in Section 3.1)

$$L = k_b f_0 N^+ N^- < \delta(x^+ - x^-)\delta(y^+ - y^-) >^* . \quad (3.53)$$

# CP violation with 10 billion $J/\psi$, plus monochromator

From A. Kupcs
Adlarson and Kupsc,
arXiv:1908.03102
I.I. Bigi, X.W. Kang, HBL
arXiv:1704.04708

1.3 billion $J/\psi$

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

$A_\Lambda$ = -0.006 ± 0.012± 0.007

Previous result:

$A_\Lambda$ = 0.013 ± 0.021
PS185 PRC54(96)1877

BESIII

$J/\psi \to \Lambda\bar{\Lambda}$

$J/\psi \to \Xi^-\bar{\Xi}^+ (\Xi \to \Lambda\pi)$

| | Events | Error $A_\Lambda$ | |
|---|---|---|---|
| BESIII(2018) | $4.2 \cdot 10^5$ | $1.2 \cdot 10^{-2}$ | $1.31\ 10^9$ J/ψ |
| BESIII | $3 \cdot 10^6$ | $5 \cdot 10^{-3}$ | $10^{10}$ J/ψ<br>L=$0.47 \cdot 10^{33}$ $\Delta E = 0.9$ MeV |
| BESIII+ reduced $\Delta E$ | $6\times10^8$ | $10^{-4} - 10^{-5}$ | $10^{12}$ $J/\psi$<br>$\Delta E$ <100 keV |

$2\times10^{-3}$

$1\times10^{-5}$

$-3 \times 10^{-5} \le A_\Lambda \le 4 \times 10^{-5}$
$-2 \times 10^{-5} \le A_\Xi \le 1 \times 10^{-5}$
$-5 \times 10^{-5} \le A_{\Xi\Lambda} \le 5 \times 10^{-5}$

CKM

Tandean,Valencia PRD67, 056001

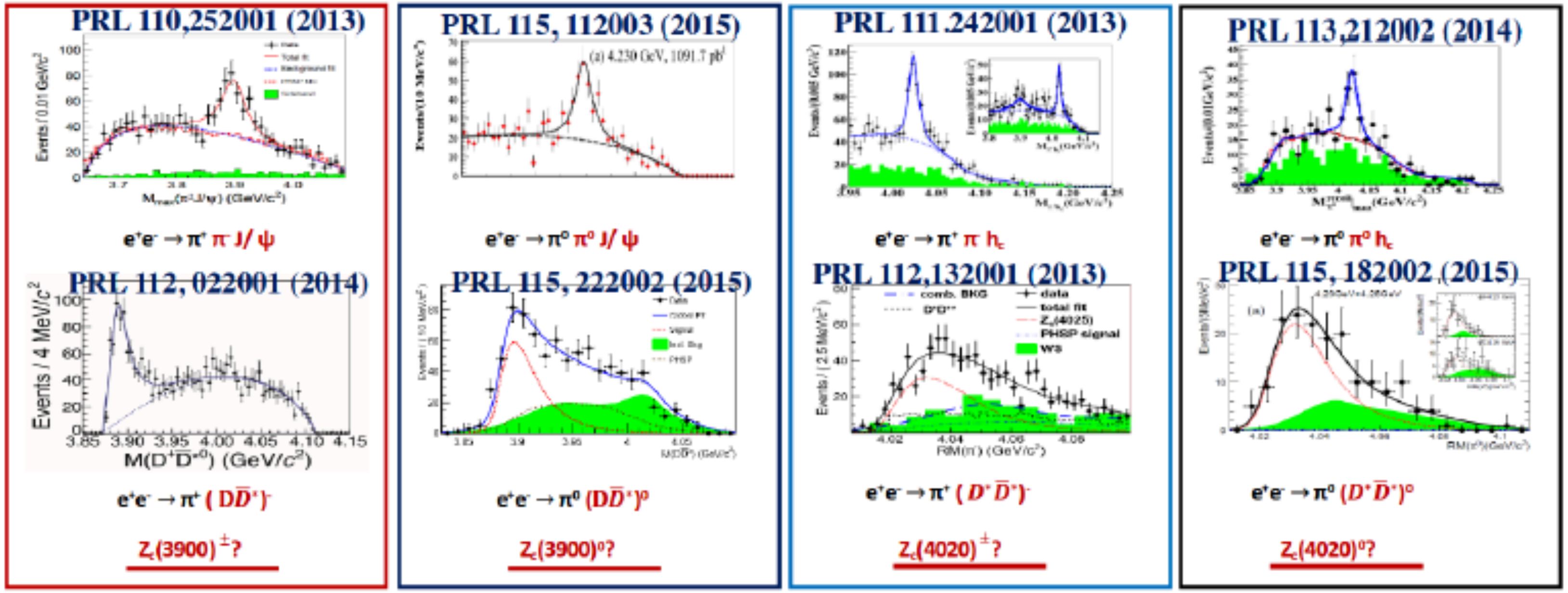
# Summary

- **Great achievements**
- **BESIII is uniquely well suited for a variety of study of pair productions at thresholds;**
- **BESIII provides unique access to strong phase and CPV in hyperons;**
- **Whitepaper with outline of physics programme for the next 6-10 years is ready for publication. International review has been finished in September (3-4), 2019;**
- **Higher energy, higher luminosity, and a lot of exciting physics ahead of us with BESIII.**

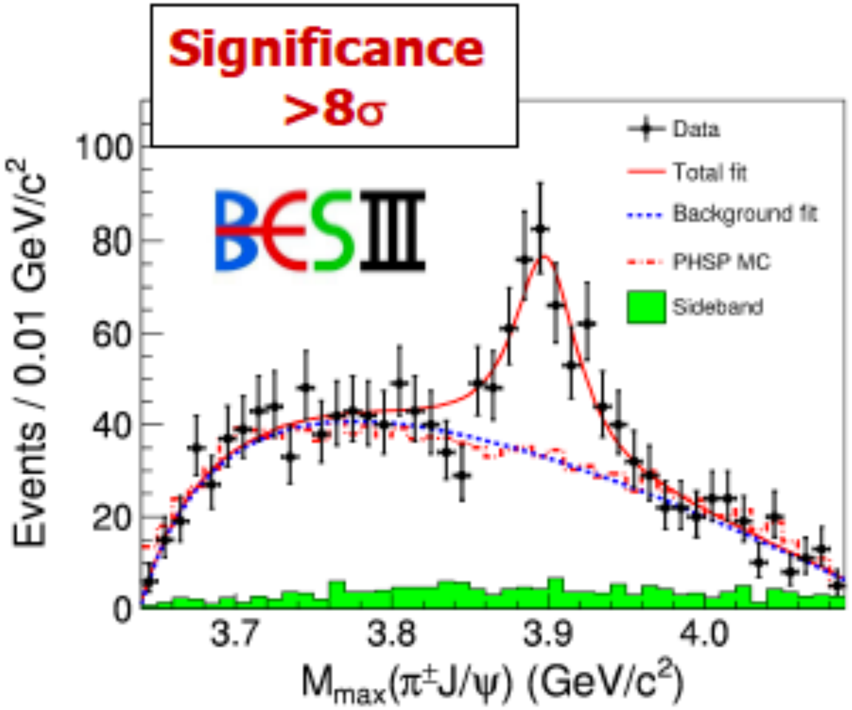
**Thank you!**

# Back-ups

# Discoveries of Zc at BESIII in 2013



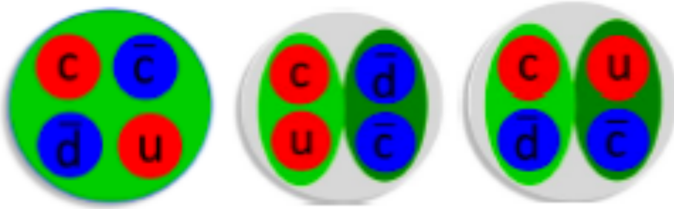
# Discoveries of Zc at BESIII in 2013




In $e^+e^- \to \pi^+\pi^- J/\psi$ events at 4.26 GeV, a particle decays into $\pi^{\pm}J/\psi$ is observed!

- Couples to $c\bar{c}$
- Has electric charge
- At least 4 quarks
- A tetraquark state?
  A $\bar{D}D^*$ molecule?

- Mass = (3899.0±3.6±4.9) MeV
- Width = (46±10±20) MeV
- Fraction = (21.5±3.3±7.5)%




PRL110, 252001 (2013) [16]

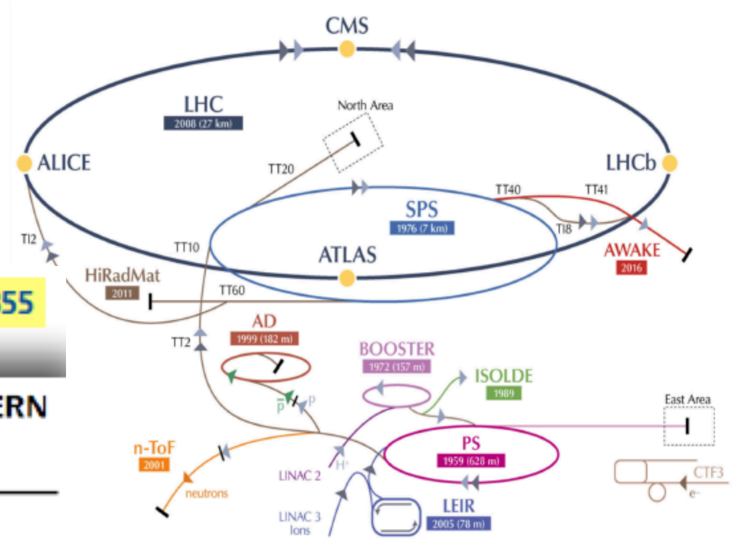
# What is SHiP ?

UNIVERSITÄT BONN

## A proton beam dump experiment proposed at CERN

- fixed target facility in the SPS North Area

HQL2018




arXiv:1504.04855

## A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case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Fedor Bezrukov,[6,7] Kyrylo Bondarenko,[8] Alexey Boyarsky*,[8] Nathaniel Craig,[9]
Ki-Young Choi,[10] Cristóbal Corral,[11] David Curtin,[12] Sacha Davidson,[13,14] André de Gouvêa,[15]
Stefano Dell'Oro,[16] Patrick deNiverville,[17] P. S. Bhupal Dev,[18] Herbi Dreiner,[19]
Marco Drewes,[20] Shintaro Eijima,[21] Rouven Essig,[22] Anthony Fradette,[17] Björn Garbrecht,[20]
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David McKeen,[43] Guenakh Mitselmakher ,[44] Sven-Olaf Moch,[45] Rabindra N. Mohapatra,[46]
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Maxim Pospelov§,[3,17] Mary Hall Reno,[49] Andreas Ringwald,[27] Adam Ritz,[17]
Leszek Roszkowski,[50] Valery Rubakov,[24] Oleg Ruchayskiy*,[21] Jessie Shelton,[51]
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Goran Senjanovic,[53,54] Osamu Seto,[55] Mikhail Shaposhnikov*,§,[21] Brian Shuve,[3]
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Daniel Stolarski,[5] Matt Strassler,[38] Vladimir Tello,[53] Francesco Tramontano§,[59,60]
Anurag Tripathi,[59] Sean Tulin,[61] Francesco Vissani,[16,62] Martin W. Winkler,[63]
Kathryn M. Zurek[64,65]

# What is SHiP ?

UNIVERSITÄT BONN

## A proton beam dump experiment proposed at CERN

- fixed target facility in the SPS North Area
- $E_p$ = 400 GeV, $N_{pot} = 2 \cdot 10^{20}$ (protons on target), t = 5 yrs
- aim to search for hidden, very weakly interacting new particles
- also good for $\nu_\tau$-physics

## It would make good use of the full SPS intensity

- which, apart from the ~2 fills/day of the LHC, is not exploited

## Data taking to start 2026 (after LS3)

## Anticipated yields

- $10^{18}$ D mesons
- $10^{16}$ $\tau$ leptons
- $10^{20}$ photons

# Rare and forbidden decays

Front. Phys. 12(5), 121301 (2017)
DOI 10.1007/s11467-017-0691-9

PERSPECTIVE

## Prospects for rare and forbidden hyperon decays at BESIII

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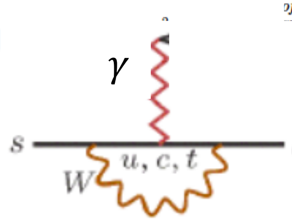
uthor. E-mail: †lihb@ihep.ac.cn

7, 2017; accepted May 8, 2017

Electron Spectrometer III (BESIII) is proposed t
pairs, which provide a pristine experimental envir
. About $10^6$–$10^8$ hyperons, i.e., $\Lambda$, $\Sigma$, $\Xi$, and $\Omega$,
h the proposed data samples at BESIII. Based o
branching fractions of the hyperon decays is in th
ie", rare

SM




| $B_i \to B_f\gamma$ | $\mathcal{B}$ ($\times10^{-3}$) | $\alpha_\gamma$ |
|---|---|---|
| $\Lambda \to n\gamma$ | $1.75 \pm 0.15$ | – |
| $\Sigma^+ \to p\gamma$ | $1.23 \pm 0.05$ | $-0.76 \pm 0.08$ |
| $\Sigma^0 \to n\gamma$ | – | – |
| $\Xi^0 \to \Lambda\gamma$ | $1.17 \pm 0.07$ | $-0.70 \pm 0.07$ |
| $\Xi^0 \to \Sigma^0\gamma$ | $3.33 \pm 0.10$ | $-0.69 \pm 0.06$ |
| $\Xi^- \to \Sigma^-\gamma$ | $0.127 \pm 0.023$ | $1.0 \pm 1.3$ |
| $\Omega^- \to \Xi^-\gamma$ | $< 0.46$ (90% C.L.) | – |

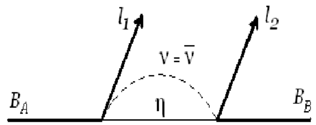
**FCNC: radiative decays**

| Decay mode | Current data $\mathcal{B}(\times10^{-6})$ | Sensitivity $\mathcal{B}$(90%C.L.) ($\times10^{-6}$) | Type |
|---|---|---|---|
| $\Lambda \to ne^+e^-$ | - | $< 0.8$ | |
| $\Sigma^+ \to pe^+e^-$ | $< 7$ | $< 0.4$ | |
| $\Xi^0 \to \Lambda e^+e^-$ | $7.6 \pm 0.6$ | $< 1.2$ | |
| $\Xi^0 \to \Sigma^0 e^+e^-$ | - | $< 1.3$ | |
| $\Xi^- \to \Sigma^- e^+e^-$ | - | $< 1.0$ | |
| $\Omega^- \to \Xi^- e^+e^-$ | - | $< 26.0$ | Type A |
| $\Sigma^+ \to p\mu^+\mu^-$ | $(0.09^{+0.09}_{-0.08})$ | $< 0.4$ | |
| $\Omega^- \to \Xi^-\mu^+\mu^-$ | - | $< 30.0$ | |
| $\Lambda \to n\nu\bar{\nu}$ | - | $< 0.3$ | |
| $\Sigma^+ \to p\nu\bar{\nu}$ | - | $< 0.4$ | |
| $\Xi^0 \to \Lambda\nu\bar{\nu}$ | - | $< 0.8$ | |
| $\Xi^0 \to \Sigma^0\nu\bar{\nu}$ | - | $< 0.9$ | Type B |
| $\Xi^- \to \Sigma^-\nu\bar{\nu}$ | - | -* | |
| $\Omega^- \to \Xi^-\nu\bar{\nu}$ | - | $< 26.0$ | |
| $\Sigma^- \to \Sigma^+e^-e^-$ | - | $< 1.0$ | |
| $\Sigma^- \to pe^-e^-$ | - | $< 0.6$ | |
| $\Xi^- \to pe^-e^-$ | - | $< 0.4$ | |
| $\Xi^- \to \Sigma^+e^-e^-$ | - | $< 0.7$ | |
| $\Omega^- \to \Sigma^+e^-e^-$ | - | $< 15.0$ | |
| $\Sigma^- \to p\mu^-\mu^-$ | - | $< 1.1$ | |
| $\Xi^- \to p\mu^-\mu^-$ | $< 0.04$ | $< 0.5$ | Type C |
| $\Omega^- \to \Sigma^+\mu^-\mu^-$ | - | $< 17.0$ | |
| $\Sigma^- \to pe^-\mu^-$ | - | $< 0.8$ | |
| $\Xi^- \to pe^-\mu^-$ | - | $< 0.5$ | |
| $\Xi^- \to \Sigma^+e^-\mu^-$ | - | $< 0.8$ | |
| $\Omega^- \to \Sigma^+e^-\mu^-$ | - | $< 17.0$ | |

**EM penguin**

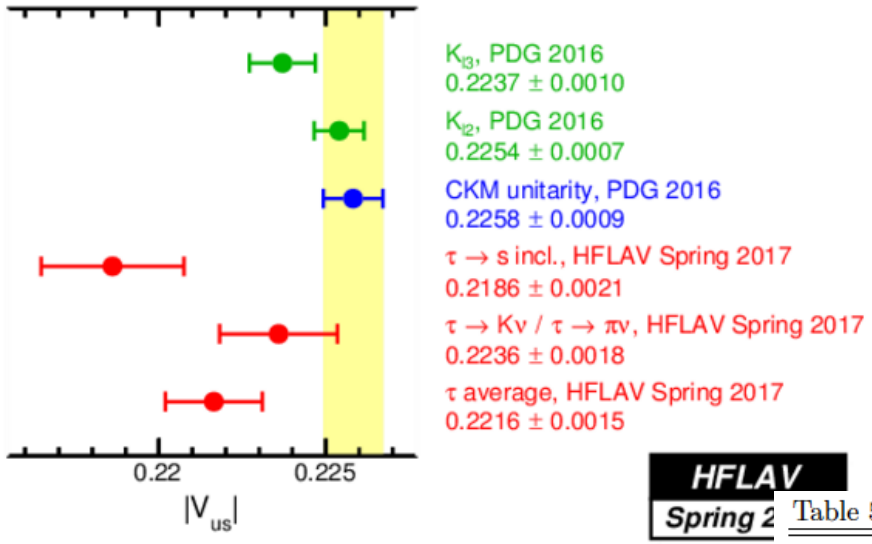
**Weak penguin**

**Neutrinoless double beta decays**




**Most of them never studied.**

# Semileptonic decays: $V_{us}$



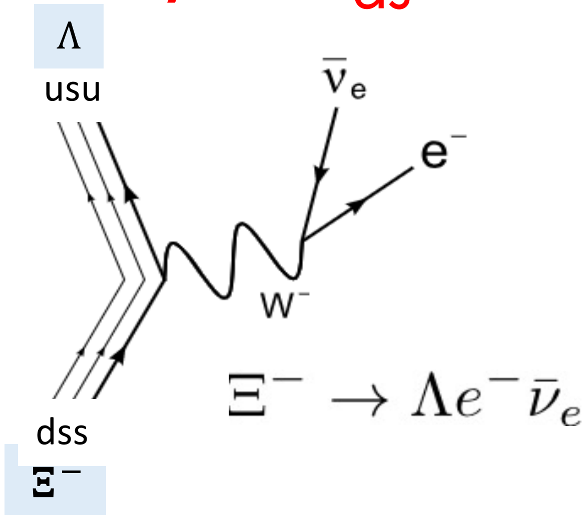



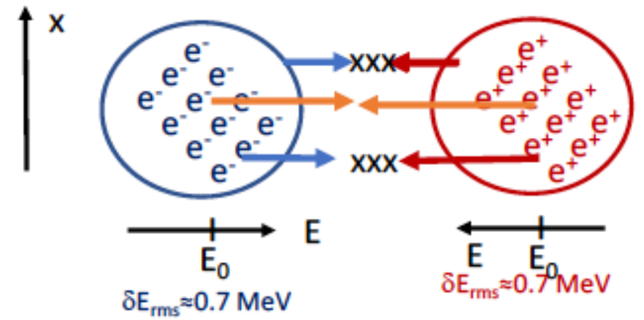

Table 5: Results from $V_{us}$ analysis using measured $g_1/f_1$ values

| Decay Process | Rate ($\mu sec^{-1}$) | $g_1/f_1$ | $V_{us}$ |
|---|---|---|---|
| $\Lambda \to p e^- \overline{\nu}$ | 3.161(58) | 0.718(15) | $0.2224 \pm 0.0034$ |
| $\Sigma^- \to n e^- \overline{\nu}$ | 6.88(24) | −0.340(17) | $0.2282 \pm 0.0049$ |
| $\Xi^- \to \Lambda e^- \overline{\nu}$ | 3.44(19) | 0.25(5) | $0.2367 \pm 0.0099$ |
| $\Xi^0 \to \Sigma^+ e^- \overline{\nu}$ | 0.876(71) | 1.32(+.22/ − .18) | $0.209 \pm 0.027$ |
| Combined | — | — | $0.2250 \pm 0.0027$ |

N. Cabibbo, E. Swallon, R. Winston
Ann.Rev.Nucl.Part.Sci. 53:39-75,2003

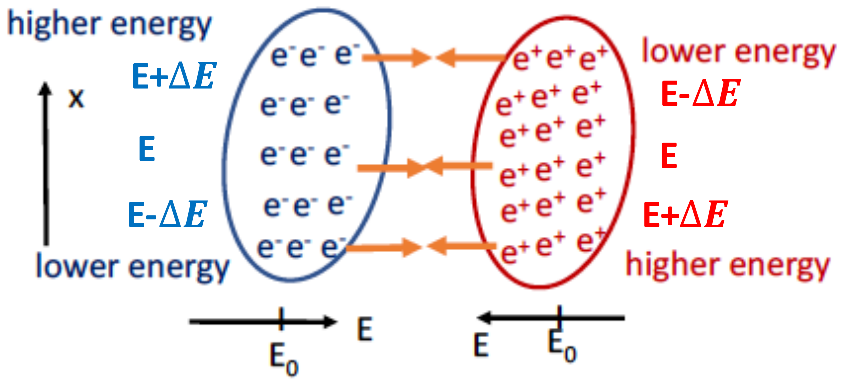
Can we do better ?

# Monochromatic collision: factor of 10 from reduction of $e^+e^-$ CM spread

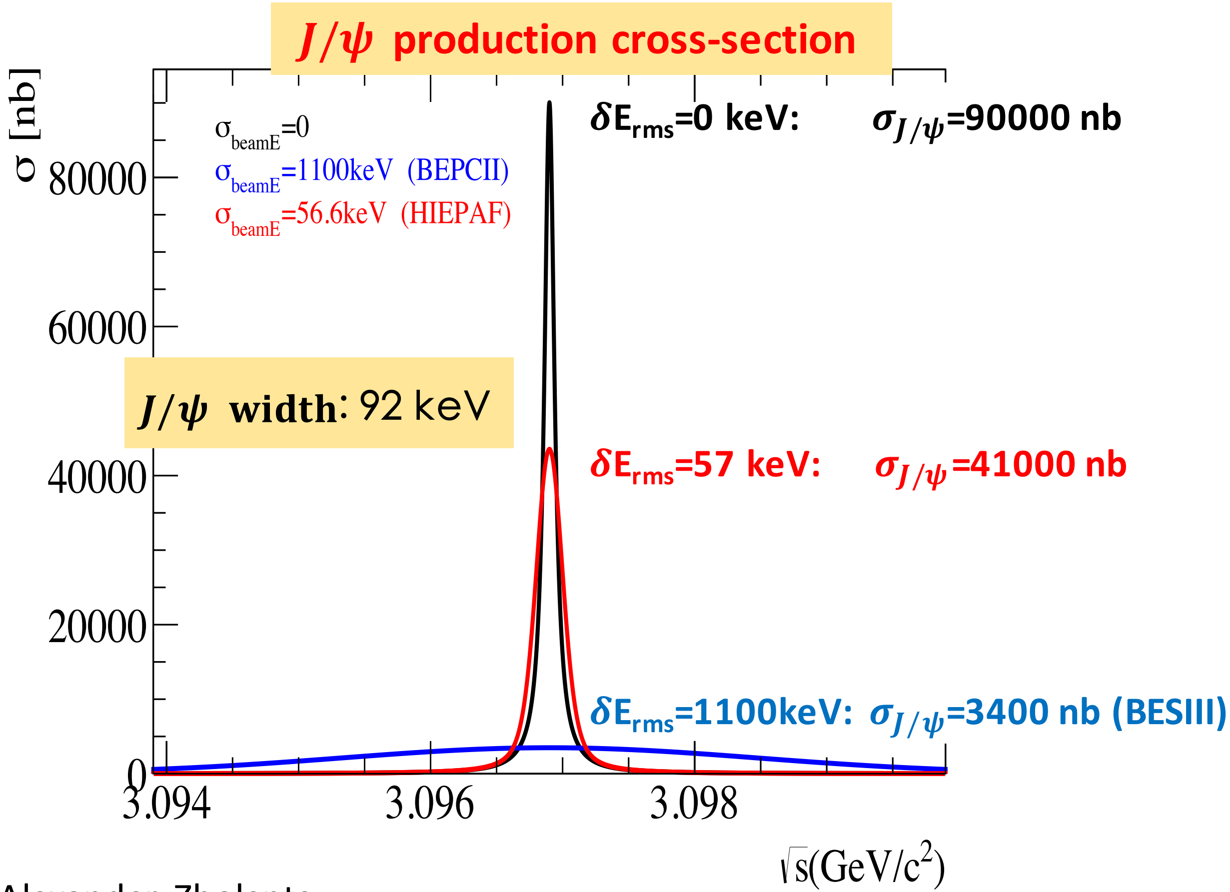



only $e^+e^-$ pairs with $E_{cm}$=3096 ± 0.14 MeV
can produce a J/ψ, ~1/30th of the total

introduce dispersion




more $e^+e^-$ pairs with $E_{cm}$=3096 ± 0.14 MeV

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