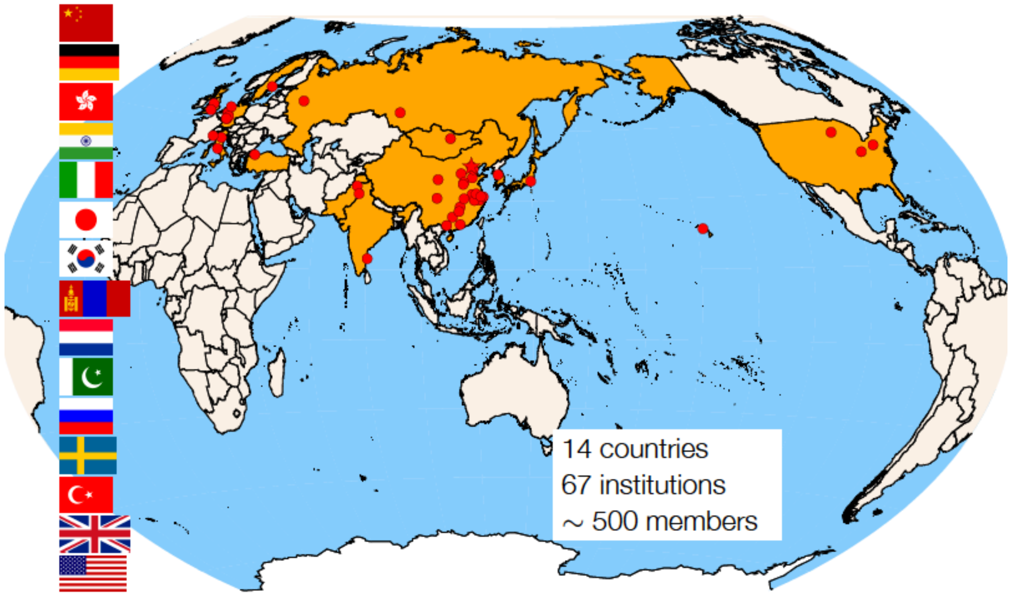
Precision hyperon physics at BESIII



The BESIII Collaboration 2019

Hai-Bo Li (李 海 波）

Institute of High Energy Physics, CAS

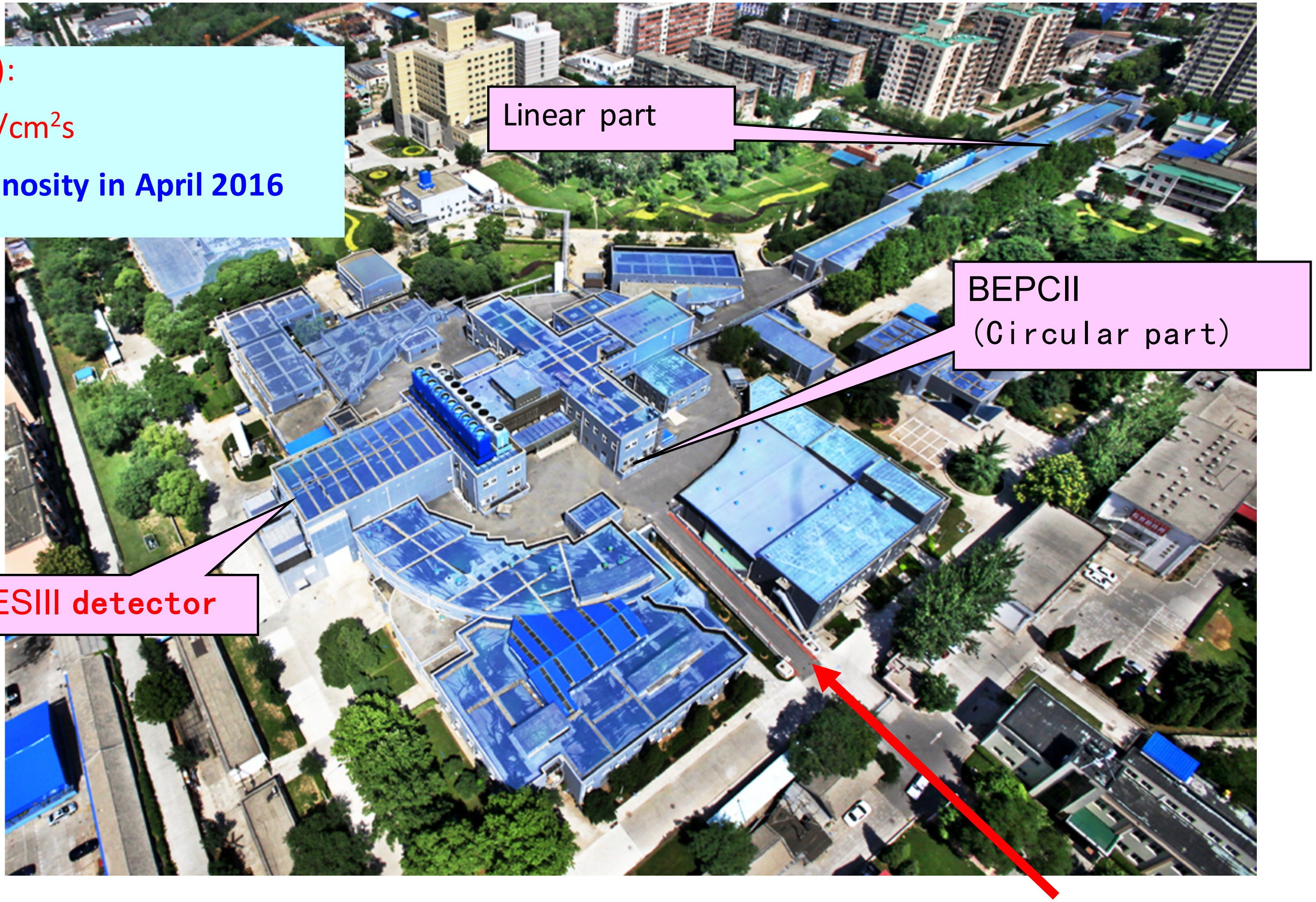
强子物理新发展研讨会，**2020**年**4**月**24-25**日

Beijing Electron-Positron Collider II (BEPCII)

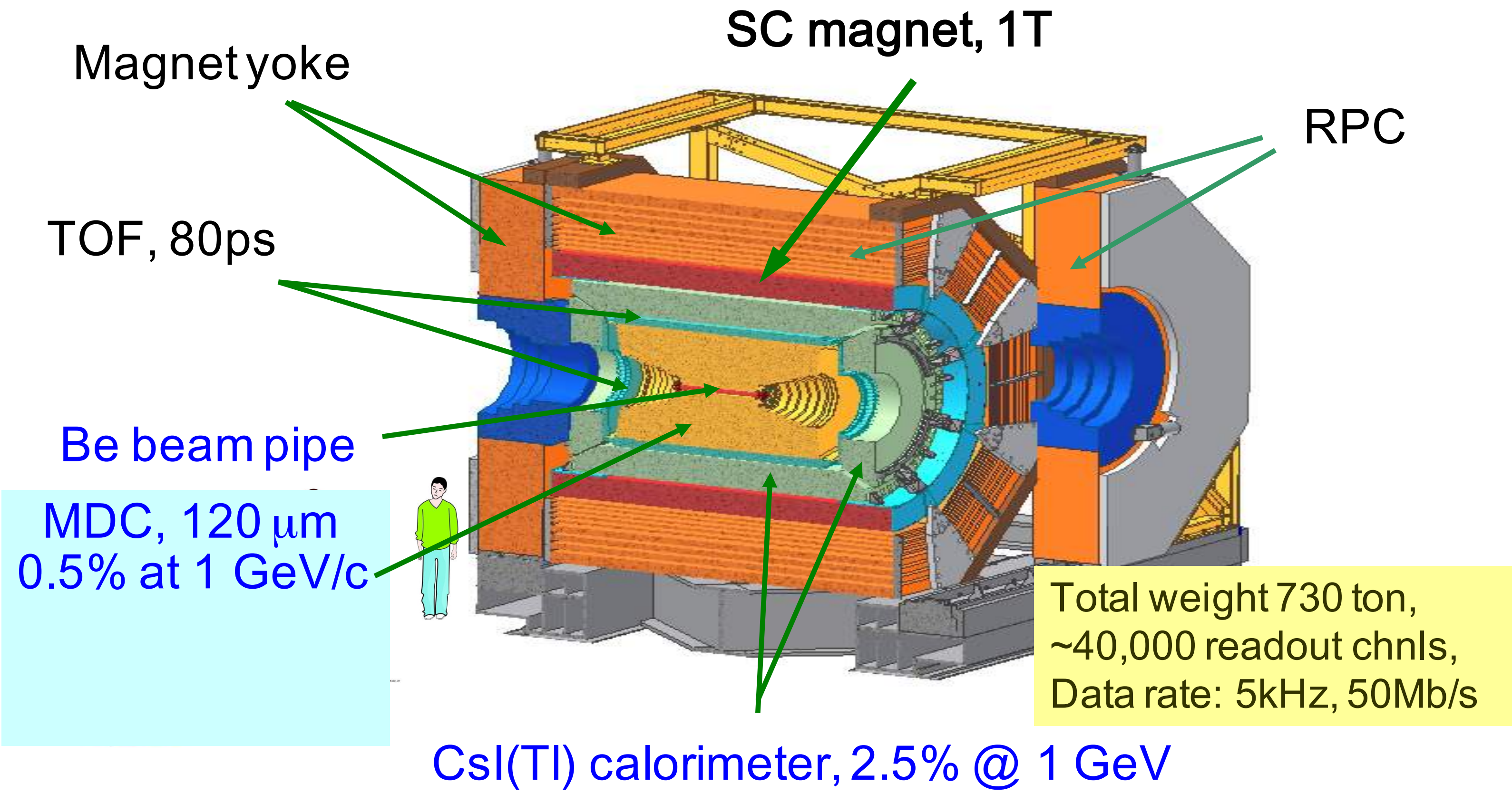
2008- **Now** (BEPCII):

L_{peak}=1.0x10^{33}/cm^{2}s

Reached peak luminosity in April 2016

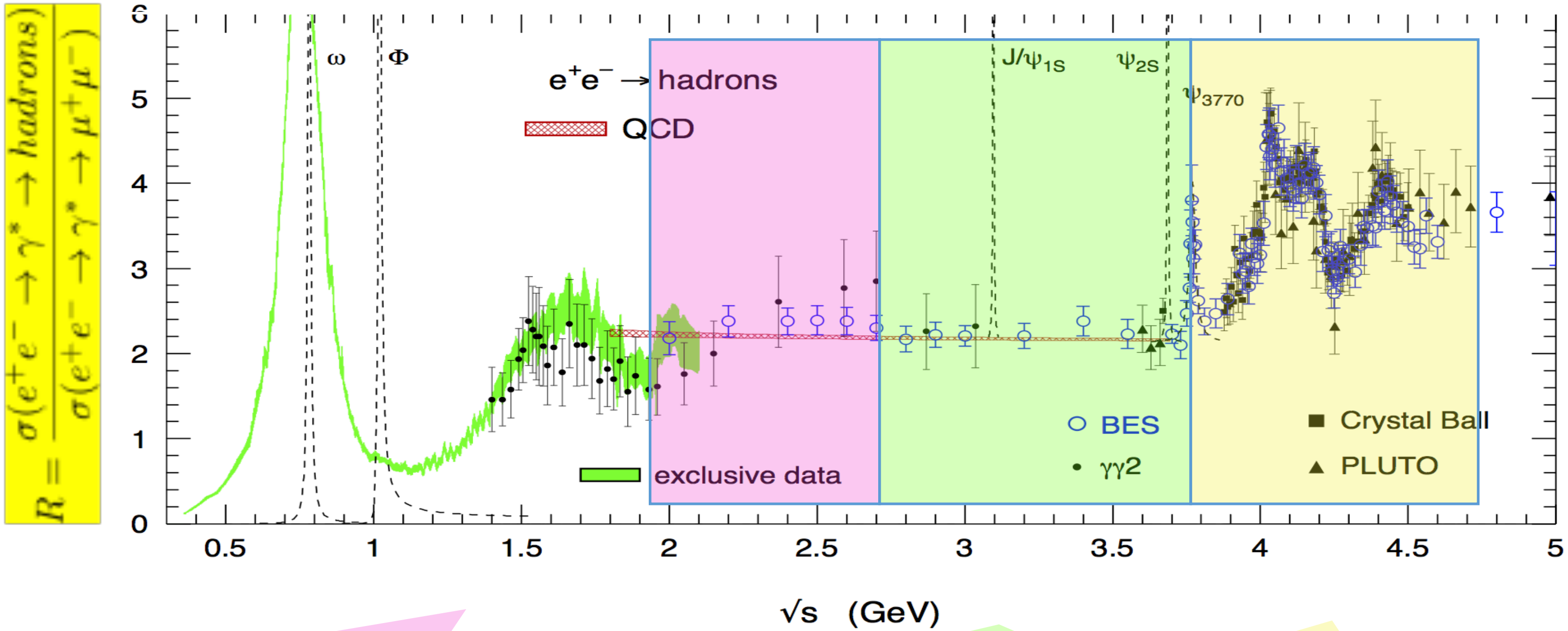


BESIII Detector



Has been in full operation since 2008,
all subdetectors are in very good status!

Physics at τ-charm Energy Region



- Hadron form factors
- R values and QCD

- Light hadron spectroscopy
- Gluonic and exotic states
- Physics with τ lepton

- XYZ particles
- Charm mesons
- Charm baryons

BESIII Collaboration

15 countries, 72 institutions
~500 members

10 years data taking at BESIII

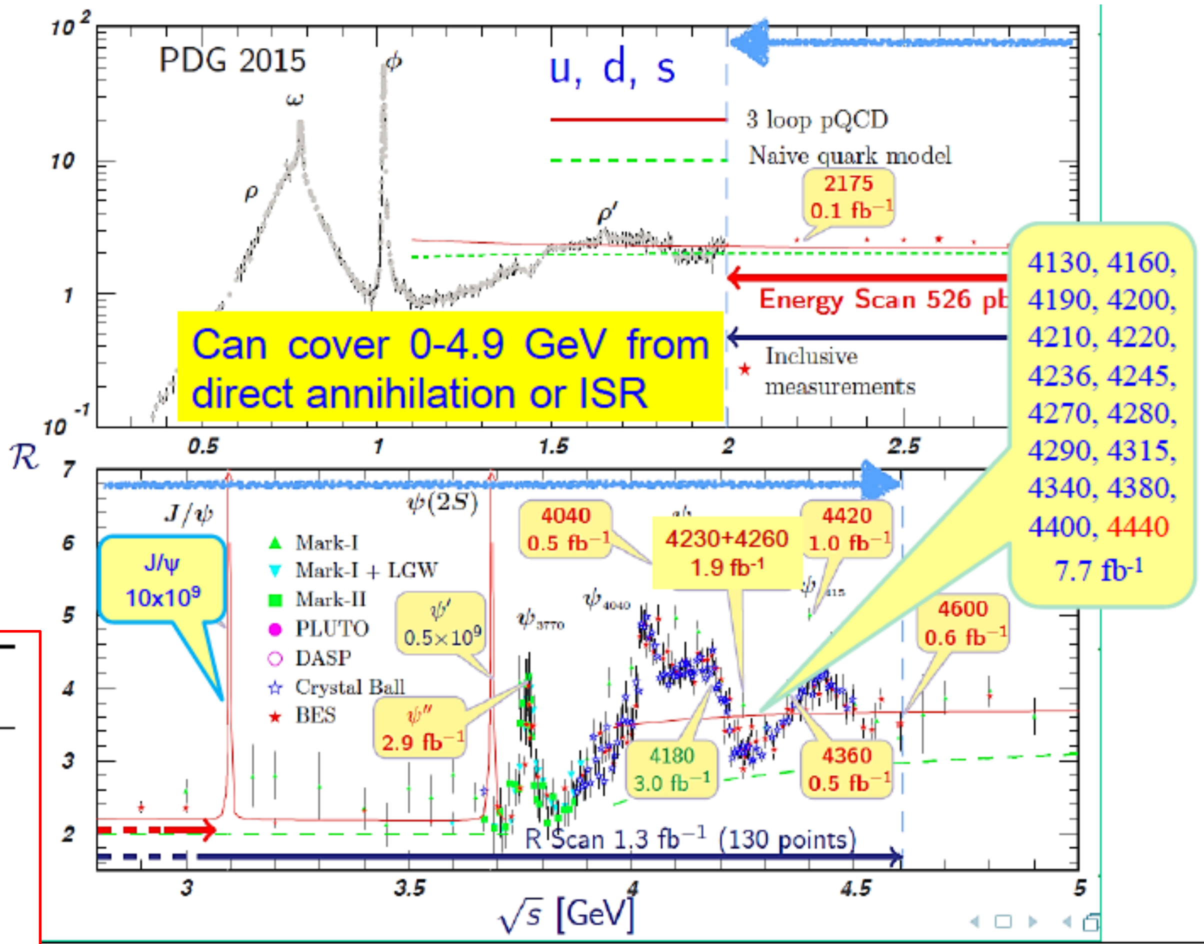
Data sets collected so far include,

- **10×10^9 J/ψ events**
- 0.5×10^9 ψ' 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 16 fb^{-1}

Totally about 29 fb^{-1} in 10 year running

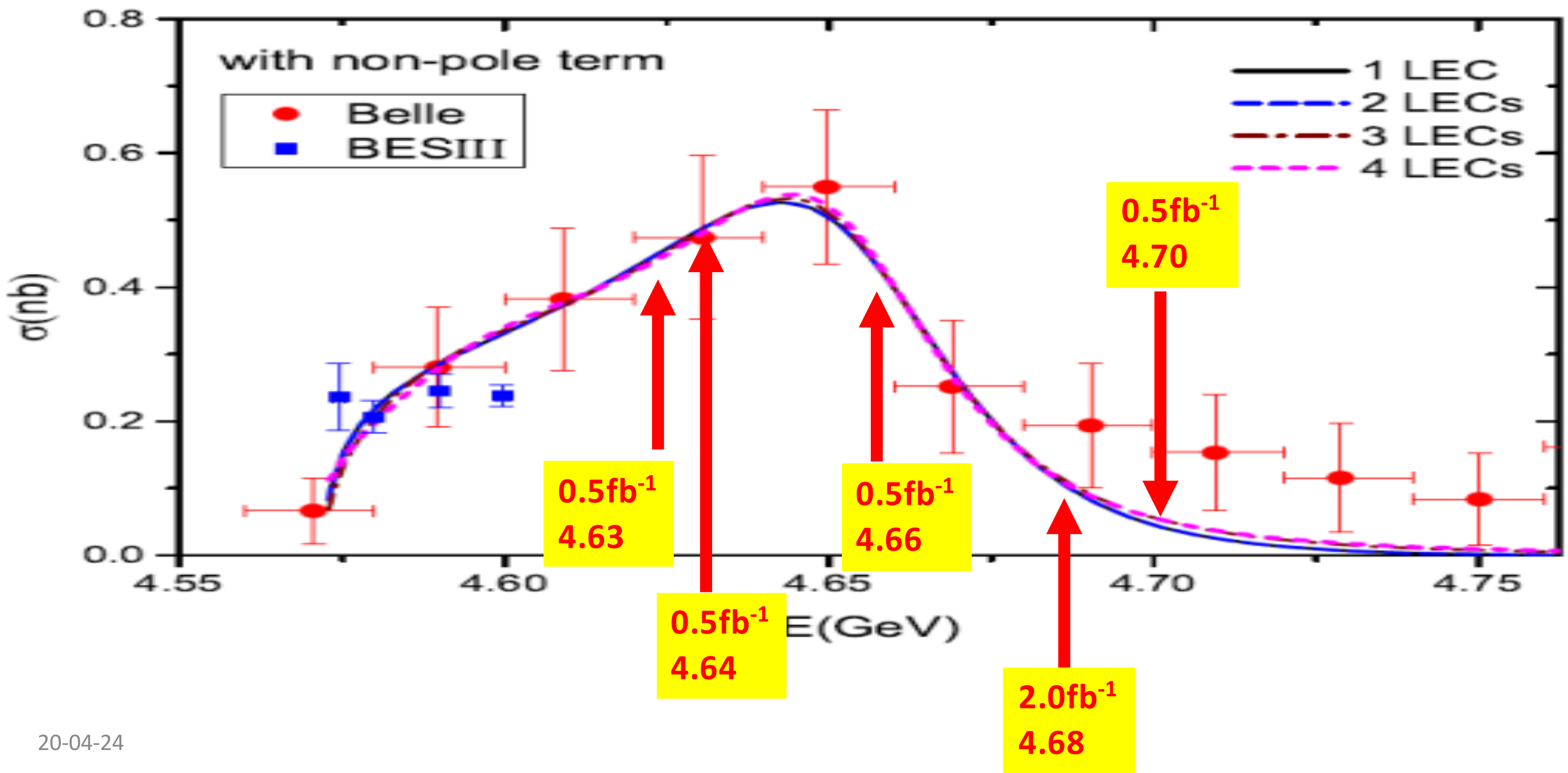


Unique data sets at open charm thresholds

$\sqrt{s}$ / 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	$\Lambda_c^+\bar{\Lambda}_c^-$

New data will be ready soon in 2020

$$e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^-$$



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}, with 10^{8} reconstructed D mesons (LHCb)
- All are consistent with CKM theory in the Standard model
- But no evidence was found in baryon system?

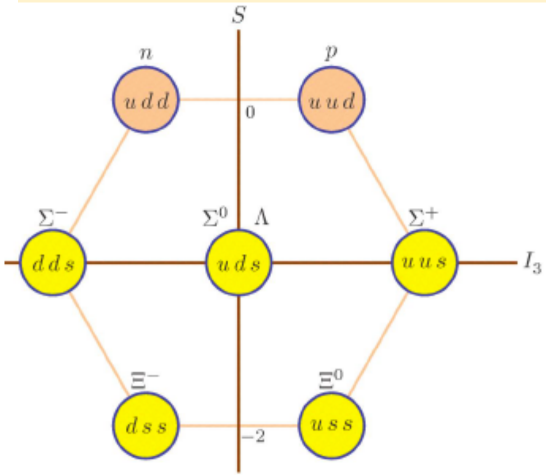
Baryon asymmetry of the Universe means that there must be non-SM CPV source.

CPV in hyperon decays, # events we need?

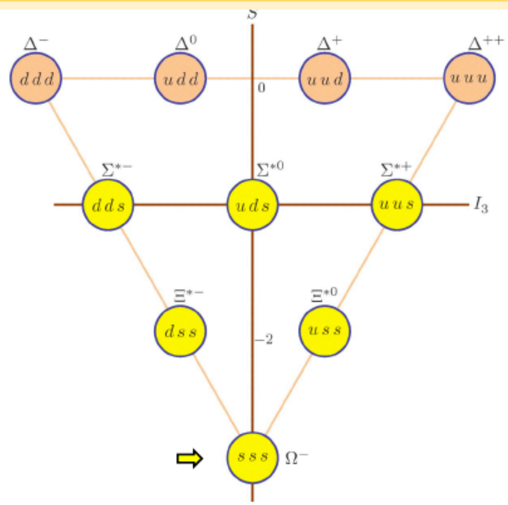
CPV in SM is small :			# events	Experiments
B meson :	$O(1)$	discovered (2001)	10^3	***B factory***
K meson :	$O(10^{-3})$	discovered (1964)	10^6	***Fix targets***
D meson :	$O(10^{-4})$	discovered(2019)	10^8	LHCb
Hyperon :	$O(10^{-4})$	no evidence (10^{-2})	$O(10^8)$	

Fix targets

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/ψ decays
- Quantum entangled pair productions
- Background free

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

Decay mode	$\mathcal{B}(\times 10^{-3})$	$N_B\ (\times 10^6)$	Detection Efficiency	Number of reconstructed
$J/\psi \to \Lambda\bar{\Lambda}$	1.61 ± 0.15	16.1 ± 1.5	40%	4500 X 10^3
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.29 ± 0.09	12.9 ± 0.9	25%	600 X 10^3
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.50 ± 0.24	15.0 ± 2.4	24%	640 X 10^3
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}^+$ (or c.c.)	0.31 ± 0.05	3.1 ± 0.5		
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.)	1.10 ± 0.12	11.0 ± 1.2		
$J/\psi \to \Xi^0\bar{\Xi}^0$	1.20 ± 0.24	12.0 ± 2.4	14%	670 X 10^3
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.86 ± 0.11	8.6 ± 1.0	19%	810 X 10^3
$J/\psi \to \Xi(1530)^0\bar{\Xi}^0$	0.32 ± 0.14	3.2 ± 1.4		
$J/\psi \to \Xi(1530)^-\bar{\Xi}^+$	0.59 ± 0.15	5.9 ± 1.5		
$\psi(2S) \to \Omega^-\bar{\Omega}^+$	0.05 ± 0.01	0.15 ± 0.03		

Advantage at e^+e^- machine

Known initial 4-momentum

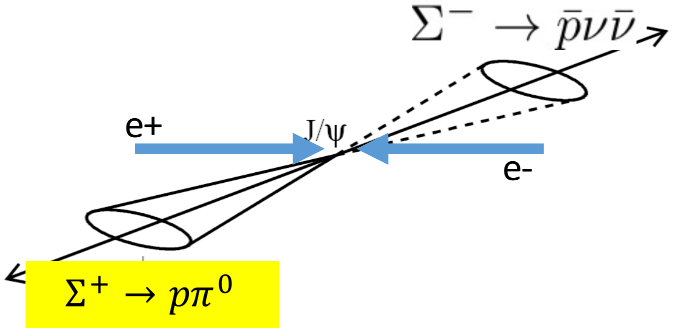
Strongly boosted

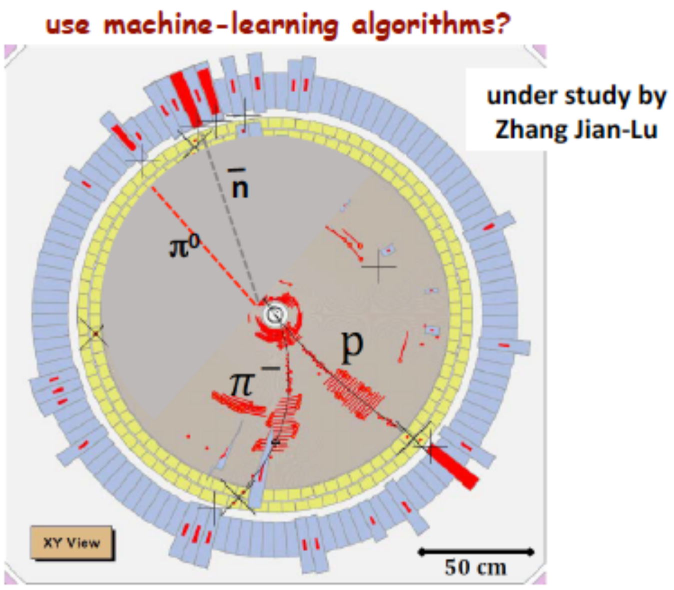
Substantial polarization

Decay with neutron & π^0

Decay with invisibles

Single tag

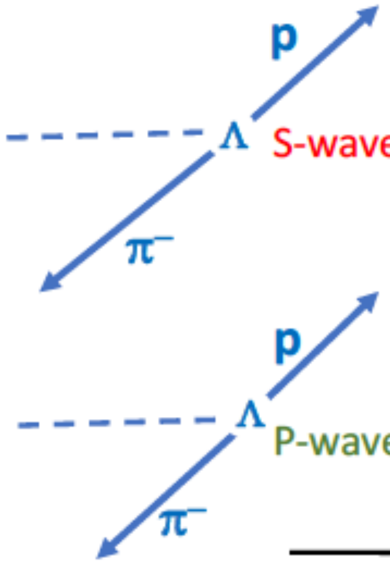




Both hyperons can be reconstructed, and the systematic uncertainties are under control.

Example CPV in $\Lambda \rightarrow p\pi^-$ ($\bar{\Lambda} \rightarrow p\pi^+$)

-- assume CPV is in P-wave --



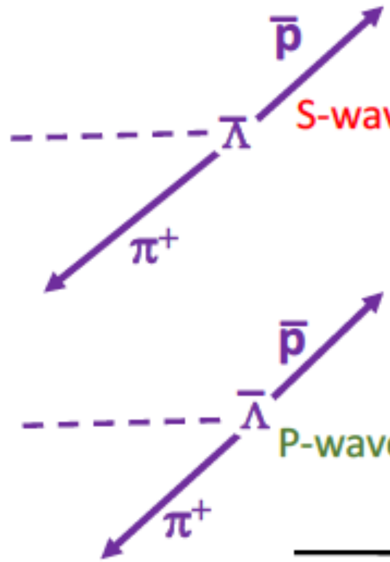
S-wave: $S\, e^{i\delta^S}$

P-wave: $P\, e^{i\delta^P + i\phi_{CP}}$

$$e^{-i\delta^S}\,(S + P\, e^{i(\delta^P - \delta^S) + i\phi_{CP}})$$

or $(\Delta_s = \delta^P - \delta^S)$

$$e^{-i\delta^S}\,(S + P\, e^{i\Delta_s + i\phi_{CP}})$$



S-wave: $S\, e^{i\delta^S}$

P-wave: $P\, e^{i\delta^P - i\phi_{CP}}$

$$e^{-i\delta^S}\,(S + P\, e^{i\Delta_s - i\phi_{CP}})$$

α, β *and* γ parameters for hyperon decays

1957

Chen Ning Yang Tsung-Dao Lee

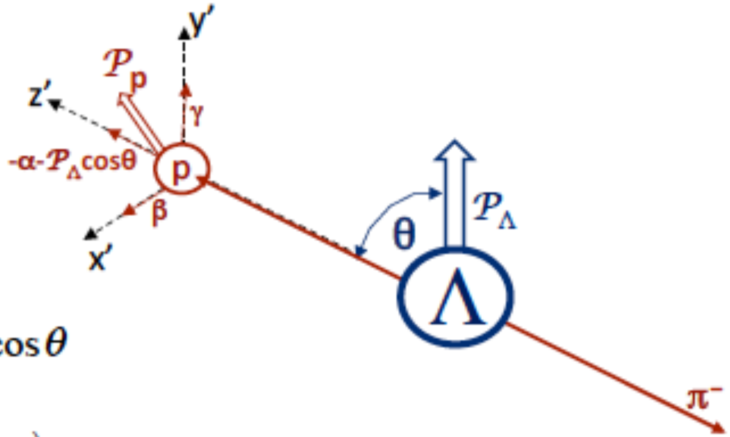
Phys. Rev. 108 1645 (1957)

General Partial Wave Analysis of the Decay of a Hyperon of Spin $\frac{1}{2}$

T. D. LEE* AND C. N. YANG

Institute for Advanced Study, Princeton, New Jersey

(Received October 22, 1957)



$$\frac{d\Gamma}{d\cos\theta} \propto 1 + \alpha P_\Lambda \cos\theta$$

$$P_p = \frac{(\alpha + P_\Lambda \cos\theta)\vec{z}' + \beta P_\Lambda \vec{x}' + \gamma P_\Lambda \vec{y}'}{1 + \alpha P_\Lambda \cos\theta}$$

$$\Lambda \to p\pi^-, \quad \Sigma^+ \to p\pi^0$$

$$\bar{S} = -\sum_i S_i e^{i(\delta_i^S - \phi_i^S)},$$

$$\bar{P} = \sum_i P_i e^{i(\delta_i^P - \phi_i^P)}.$$

$$\alpha = \frac{2\,\mathrm{Re}(S^* P)}{|S|^2 + |P|^2}$$

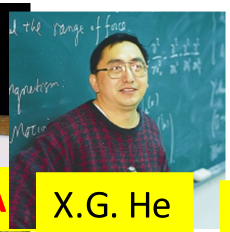
$$\beta = \frac{2\,\mathrm{Im}(S^* P)}{|S|^2 + |P|^2}$$

$$\gamma = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}$$

$$\alpha^2 + \beta^2 + \gamma^2 = 1$$

CP asymmetry $A = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}}, \quad B = \frac{\beta + \bar{\beta}}{\beta - \bar{\beta}}.$

CPV observables



PRD 34,833 1986
hep-ph/991023v1
hep-ph/0002210

PHYSICAL REVIEW D VOLUME 34, NUMBER 3 1 AUGUST 1986

Hyperon decays and *CP* nonconservation

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

Xiao-Gang He and Sandip Pakvasa
Department of Physics and Astronomy, University of Hawaii at Manoa, Honolulu, Hawaii 96822
(Received 7 March 1986)

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

CPV observables


Sandip PAKVASA


X.G. He


John Donoghue

PRD 34,833 1986
hep-ph/991023v1
hep-ph/0002210

decay rate difference

$$\Delta\Gamma = \frac{\Gamma_{\bar{p}\pi^+} - \Gamma_{p\pi^-}}{\Gamma} \approx \sqrt{2}\left(T_{3/2} \big/ T_{1/2}\right)\sin\Delta_S \sin\phi_{CP}$$

← $T_{3/2(1/2)}$: Ispin=3/2 (1/2) ampl & $\Delta_s = \delta_{3/2} - \delta_{1/2}$

decay asymmetry difference

$$\alpha_{\mp} = \pm\frac{2\mathrm{Re}(S^*P)}{|S|^2+|P|^2} = \pm\frac{2|S||P|\cos(\Delta_S \pm \phi_{CP})}{|S|^2+|P|^2}$$

$$\Delta\alpha = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+} = \frac{\sin\Delta_S \sin\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\Delta_S \tan\phi_{CP}$$

← for $\Lambda \to p\pi$, need measurement of $\Delta_s = \delta_S - \delta_P$

final-state polarization difference

$$\beta_{\mp} = \pm\frac{2\mathrm{Im}(S^*P)}{|S|^2+|P|^2} = \pm\frac{2|S||P|\sin(\Delta_S \pm \phi_{CP})}{|S|^2+|P|^2}$$

$$\Delta\beta = \frac{\beta_- + \beta_+}{\alpha_- - \alpha_+} = \frac{\cos\Delta_S \sin\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\phi_{CP}$$

← strong phase cancels out

$$\frac{\beta_- - \beta_+}{\alpha_- - \alpha_+} = \frac{\sin\Delta_S \cos\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\Delta_S$$

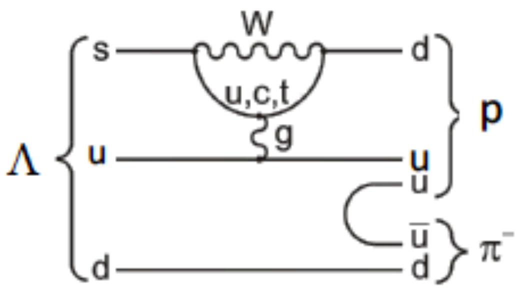
← measures the strong phase

} only practical in BESIII for $\Xi \to \Lambda\pi$ or $\Omega^- \to \Lambda K$

From Sandip

Constraints from Kaon decays

He & Valencia PRD 52, 5257

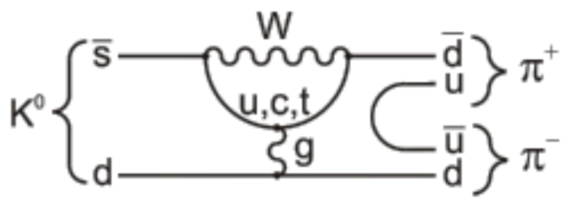


S- and P-waves
(parity violating
& conserving)

$\Lambda \to p\pi^-$	A_{NP}	
S-wave	$<6\times10^{-5}$	parity violating
P-wave	$<3\times10^{-4}$	parity conserving

$A_{SM} \sim 10^{-5}$

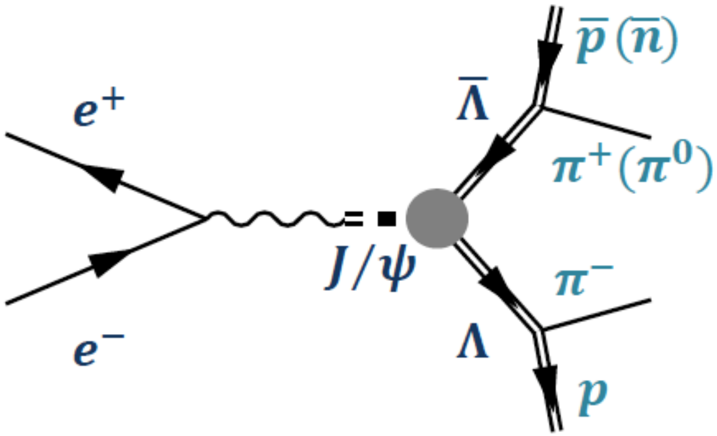
$Re(\varepsilon'/\varepsilon)=(1.6+0.3)\times10^{-3}$



S-wave only
(parity violating)

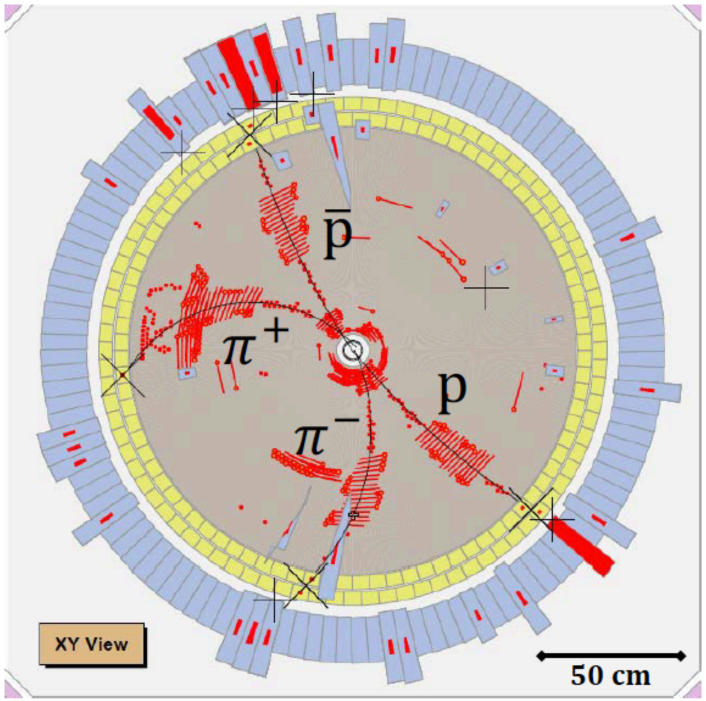
CPV measurement in Kaon system strongly constrains NP in S-waves, but no P-waves. Thus, searches of CPV in hyperon are complementary to those with Kaons.

Entangled hyperon pairs



Kang, Li, Lu, Phys.Rev. D81 (2010) 051901

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



To determine parameters:

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

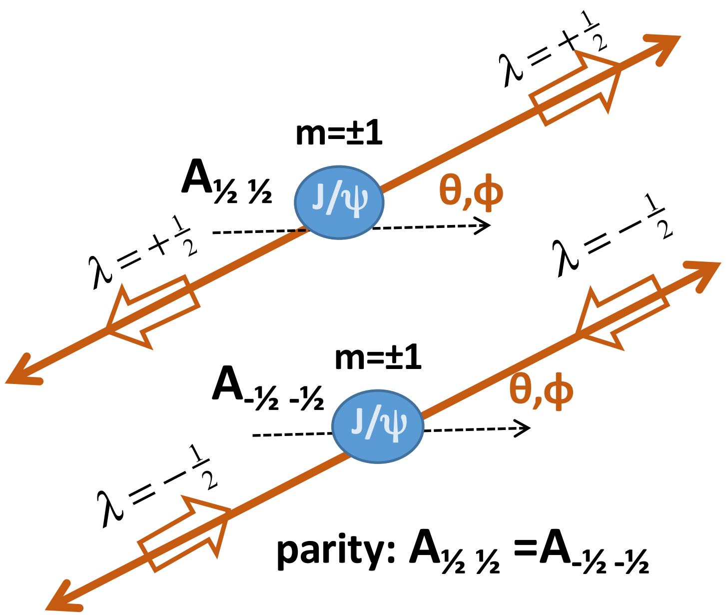
$$\alpha(\bar{\Lambda} \to \bar{p}\pi^+) = \alpha_+$$

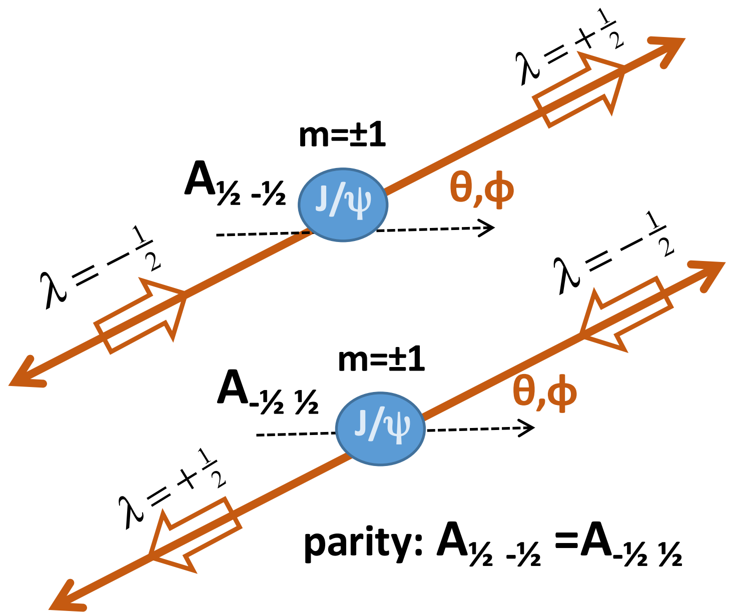
$$\alpha(\bar{\Lambda} \to \bar{n}\pi^0) = \bar{\alpha}_0$$

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

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

Production: 2 independent helicity amplitudes: $A_{½ ½}$, $A_{½ -½}$

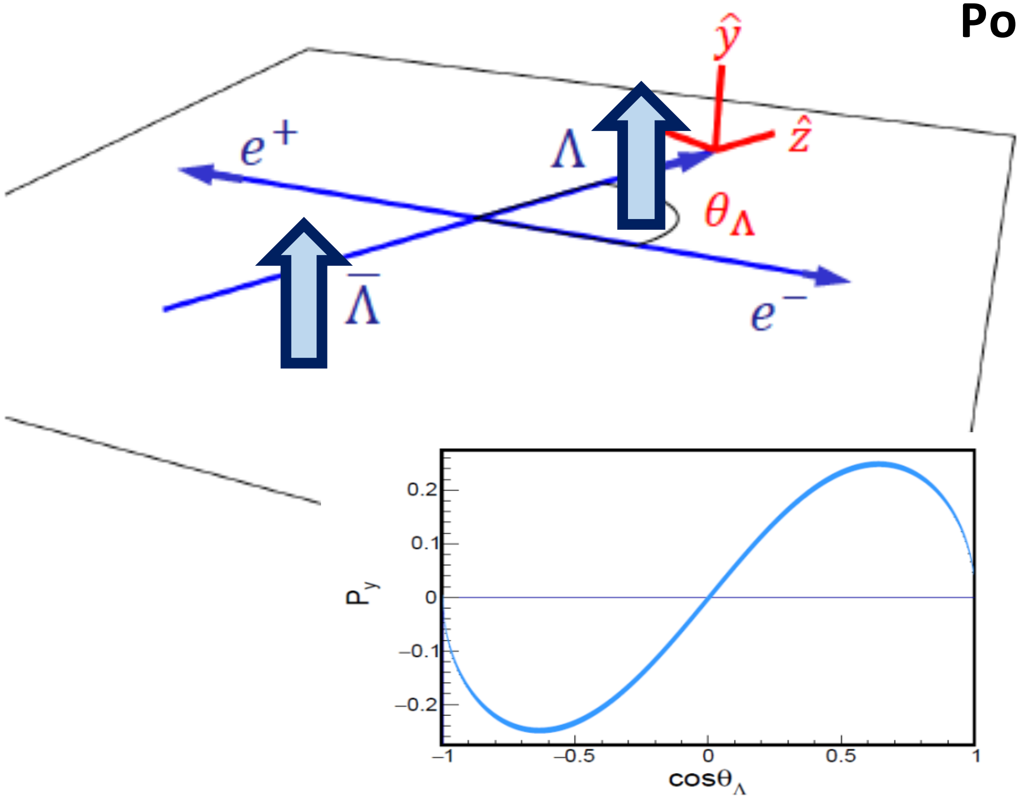




ΔΦ= complex phase between $A_{½ ½}$ and $A_{½ -½}$

$$\frac{d|\mathcal{M}|^2}{d\cos\theta} \propto (1+\alpha_{J/\psi}\cos^2\theta), \quad \text{with} \quad \alpha_{J/\psi} = \frac{|A_{1/2,-1/2}|^2 - 2|A_{1/2,1/2}|^2}{|A_{1/2,-1/2}|^2 + 2|A_{1/2,1/2}|^2}$$

If $\Delta\Phi \neq 0$, Λ and $\bar{\Lambda}$ are transversely polarized



Polarization is:

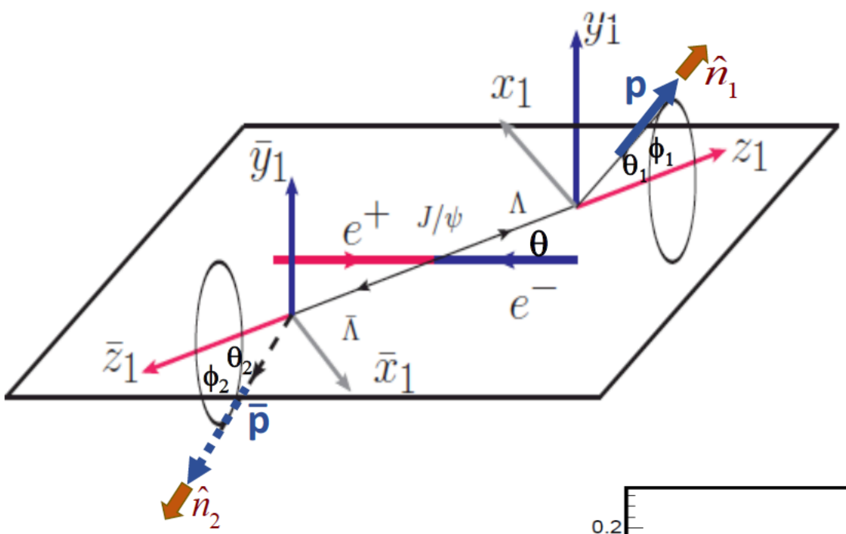
perpendicular to the production plane

θ_Λ-dependent

Same direction for Λ and $\bar{\Lambda}$

Correlated 5-dim. angular distribution

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



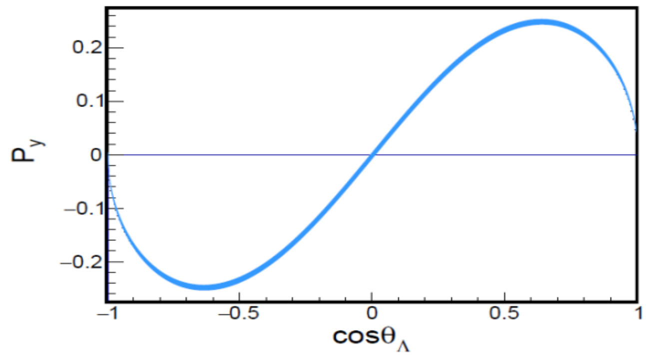
$$+\alpha_-\alpha_+\left[\sin^2\theta_\Lambda\left(n_{1,x}n_{2,x}-\alpha_\psi n_{1,y}n_{2,y}\right)+\left(\cos^2\theta_\Lambda+\alpha_\psi\right)n_{1,z}n_{2,z}\right]$$

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

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

polarization-term

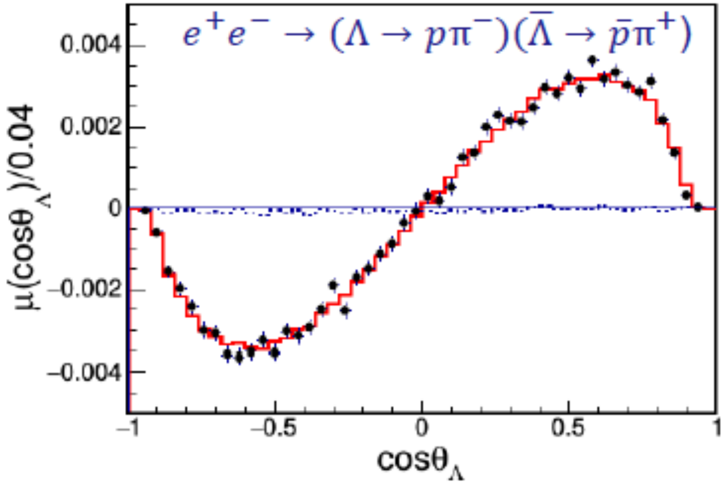
independent α_- and α_+ dependence

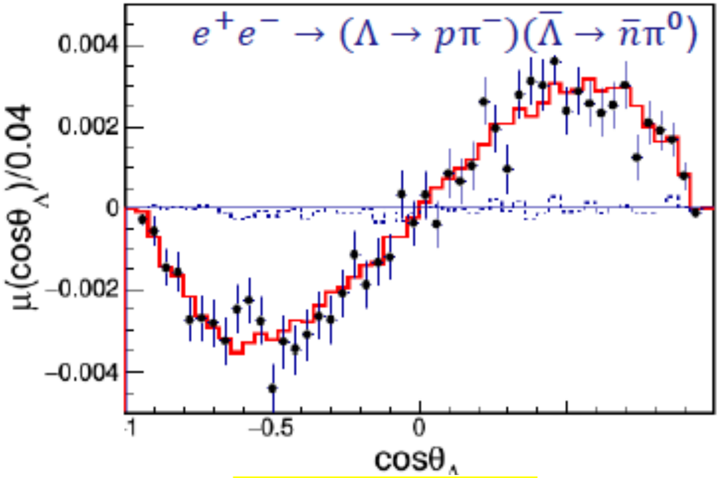


$$P_y(\cos\theta_\Lambda)=\frac{\sqrt{1-\alpha_\psi^2}\,\sin(\Delta\Phi)\cos\theta_\Lambda\sin\theta_\Lambda}{1+\alpha_\psi\cos^2\theta_\Lambda}$$

Fit results

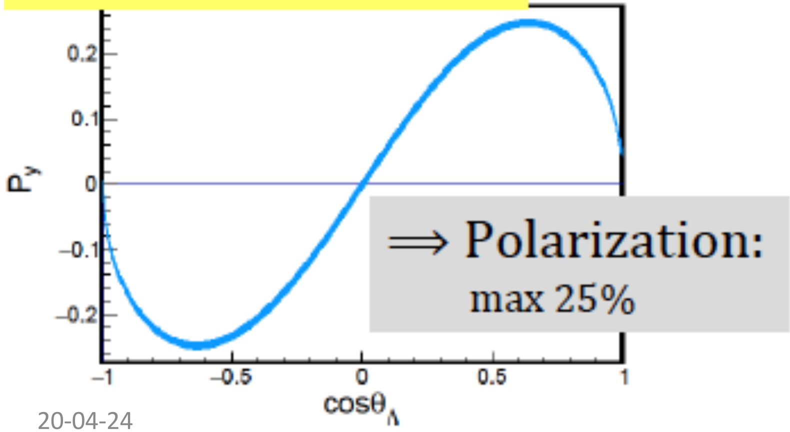
$\Delta\Phi$=42.3°±0.6°±0.5°

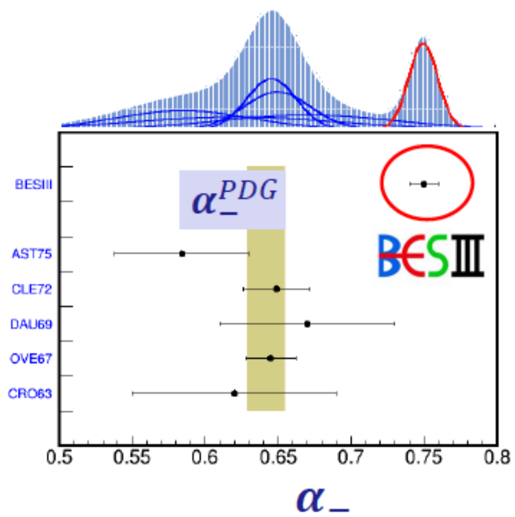




$\Lambda \to p\pi^-$: α_-=0.750±0.009±0.004

$\Delta\Phi$=42.3°±0.6°±0.5°





BESIII results with 1.3 billion J/ψ

Nature Physics 15,631-634 2019
arXiv:1808.08917
Only one-tenth of the data used

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [14]
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)°$	–
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]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

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

← 2) ~7σ upward shift from all previous measurements

← 3) ~3σ difference from 1.

← Is this reasonable?

← Indicates $\Delta I = \frac{3}{2}$ contribution?

$$\frac{\alpha_+}{\bar{\alpha}_0} = \frac{1+\frac{1}{\sqrt{2}}\left(T_{3/2}/T_{1/2}\right)}{1-\sqrt{2}\left(T_{3/2}/T_{1/2}\right)} \approx 1+\left(\frac{1}{\sqrt{2}}+\sqrt{2}\right)\left(T_{3/2}/T_{1/2}\right) = 1+\frac{3}{\sqrt{2}}\left(T_{3/2}/T_{1/2}\right)$$

$$\frac{\alpha_+}{\bar{\alpha}_0} - 1 = 0.087 \pm 0.030 = \frac{3}{\sqrt{2}}\left(T_{3/2}/T_{1/2}\right) \quad \Rightarrow \left(T_{3/2}/T_{1/2}\right) = 0.041 \pm 0.014$$

Help to understand $\Delta I = \frac{1}{2}$ ***puzzle***?

$$\frac{|T_{\Delta I=3/2}|}{|T_{\Delta I=1/2}|} \sim \frac{1}{22}$$

$\alpha_+/\bar{\alpha}_0 \neq 1$: ΔI=1/2 law violation

lifetime=12 ns

ΔI=1/2 law: $K^+ \rightarrow \pi^+\pi^0$ (ΔI=3/2 transition) : $\Gamma(K^+ \rightarrow \pi^+\pi^0) = |T_{3/2}|^2 \approx Bf(K^+ \rightarrow \pi^+\pi^0)/\tau_{K+}$

$K_S \rightarrow \pi^+\pi^-$ (ΔI=1/2 transition) : $\Gamma(K_S \rightarrow \pi^+\pi^-) = |T_{1/2}|^2 \approx Bf(K_S \rightarrow \pi^+\pi^-)/\tau_{KS}$

lifetime=0.21 ns

$$\frac{|T_{3/2}|}{|T_{1/2}|} \approx \frac{\sqrt{Bf(K^+ \rightarrow \pi^+\pi^0)\tau_{KS}}}{\sqrt{Bf(K_S \rightarrow \pi^+\pi^-)\tau_{K+}}} = \sqrt{\frac{0.21 \times 0.1\text{ns}}{0.69 \times 12\text{ns}}} \simeq \frac{1}{22}$$

$$\langle \bar{\Lambda} | \bar{p}\pi^+ \rangle = T_{1/2}\left(1 + \tfrac{1}{\sqrt{2}}\left(T_{3/2}/T_{1/2}\right)\right) \Rightarrow \alpha_+ = \alpha_{\Delta I=1/2}\left(1 + \tfrac{1}{\sqrt{2}}\left(T_{3/2}/T_{1/2}\right)\right)$$

$$\langle \bar{\Lambda} | \bar{n}\pi^0 \rangle = T_{1/2}\left(1 - \sqrt{2}\left(T_{3/2}/T_{1/2}\right)\right) \Rightarrow \bar{\alpha}_0 = \alpha_{\Delta I=1/2}\left(1 - \sqrt{2}\left(T_{3/2}/T_{1/2}\right)\right)$$

$$\frac{\alpha_+}{\bar{\alpha}_0} = \frac{1 + \frac{1}{\sqrt{2}}\left(T_{3/2}/T_{1/2}\right)}{1 - \sqrt{2}\left(T_{3/2}/T_{1/2}\right)} \approx 1 + \left(\tfrac{1}{\sqrt{2}} + \sqrt{2}\right)\left(T_{3/2}/T_{1/2}\right) = 1 + \tfrac{3}{\sqrt{2}}\left(T_{3/2}/T_{1/2}\right)$$

$$\frac{\alpha_+}{\bar{\alpha}_0} - 1 = 0.087 \pm 0.030 = \tfrac{3}{\sqrt{2}}\left(T_{3/2}/T_{1/2}\right) \quad \Rightarrow \left(T_{3/2}/T_{1/2}\right) = 0.041 \pm 0.014$$

good agreement

α_- FOR $\Lambda \rightarrow p\pi^-$

INSPIRE search

PDG2019 updates

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.750 \pm 0.009 \pm 0.004$	420k	ABLIKIM	2018AG	BES3	J/ψ to $\Lambda\overline{\Lambda}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.584 ± 0.046	8500	ASTBURY	1975	SPEC	
0.649 ± 0.023	10325	CLELAND	1972	OSPK	
0.67 ± 0.06	3520	DAUBER	1969	HBC	From Ξ decay
0.645 ± 0.017	10130	OVERSETH	1967	OSPK	Λ from $\pi^- p$
0.62 ± 0.07	1156	CRONIN	1963	CNTR	Λ from $\pi^- p$

References:

ABLIKIM	2018AG	arXiv:1808.08917	
ASTBURY	1975	NP B99 30	Measurement of the Differential Cross Section and the Spin Correlation Parameters P, A, and R in the Backward Peak of $\pi^- p \rightarrow K^0\Lambda$ at 5 GeV/c
CLELAND	1972	NP B40 221	A Measurement of the β-Parameter in the Charged Nonleptonic Decay of the Λ^0 Hyperon
DAUBER	1969	PR 179 1262	Production and Decay of Cascade Hyperons
OVERSETH	1967	PRL 19 391	Time Reversal Invariance in Λ Decay

α_+ FOR $\overline{\Lambda} \rightarrow \overline{p}\pi^+$

INSPIRE search

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-0.758 \pm 0.010 \pm 0.007$	420k	ABLIKIM	2018AG	BES3	J/ψ to $\Lambda\overline{\Lambda}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$-0.755 \pm 0.083 \pm 0.063$	$\approx$ 8.7k	ABLIKIM	2010	BES	$J/\psi \rightarrow \Lambda\overline{\Lambda}$
-0.63 ± 0.13	770	TIXIER	1988	DM2	$J/\psi \rightarrow \Lambda\overline{\Lambda}$

References:

ABLIKIM	2018AG	arXiv:1808.08917	
ABLIKIM	2010	PR D81 012003	Measurement of the Asymmetry Parameter for the Decay $\overline{\Lambda} \rightarrow \overline{p}\pi^+$
TIXIER	1988	PL B212 523	Looking at CP Invariance and Quantum Mechanics in $J/\psi \rightarrow \Lambda\overline{\Lambda}$ Decay

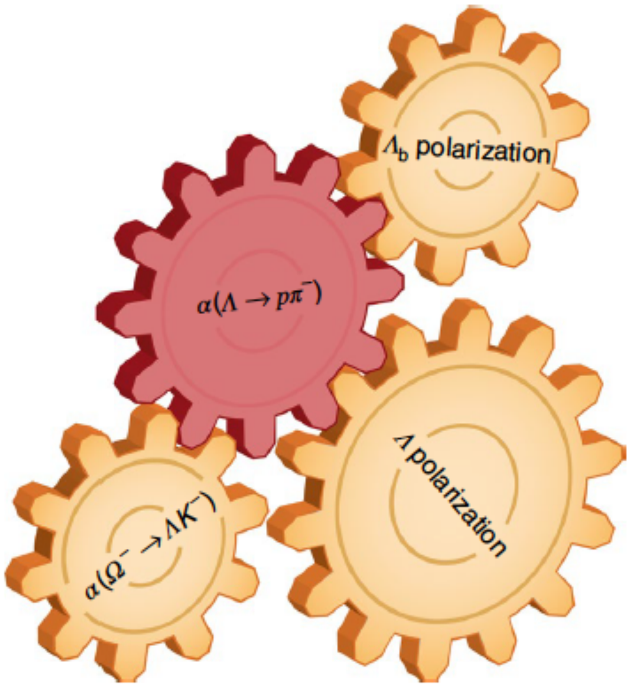
news & views

PARTICLE PHYSICS

Anomalous asymmetry

A measurement based on quantum entanglement of the parameter describing the asymmetry of the Λ hyperon decay is inconsistent with the current world average. This shows that relying on previous measurements can be hazardous.

Ulrik Egede



New input for many other measurements：

1) polarization

2) Asymmetry of the Λ_b and Λ_c

3) CPV in Λ_b and Λ_c decays

4) Decays of other charmed and beauty baryons

$J/\psi \rightarrow \Sigma^+(\rightarrow p\pi^0)\ \bar{\Sigma}^-(\rightarrow \bar{p}\pi^0)$

50 year-old measurements

α_0 FOR $\Sigma^+ \rightarrow p\pi^0$

VALUE	EVTS	DOCUMENT ID	
$-0.980^{+0.017}_{-0.015}$ OUR FIT			
$-0.980^{+0.017}_{-0.013}$ OUR AVERAGE			
$-0.945^{+0.055}_{-0.042}$	1259	[15] LIPMAN	73
-0.940 ± 0.045	16k	BELLAMY	72
$-0.98^{+0.05}_{-0.02}$	1335	[16] HARRIS	70
-0.999 ± 0.022	32k	BANGERTER	69

$\alpha_0 \approx 1$ ➔ S-wave ≈ P-wave

interference is maximum

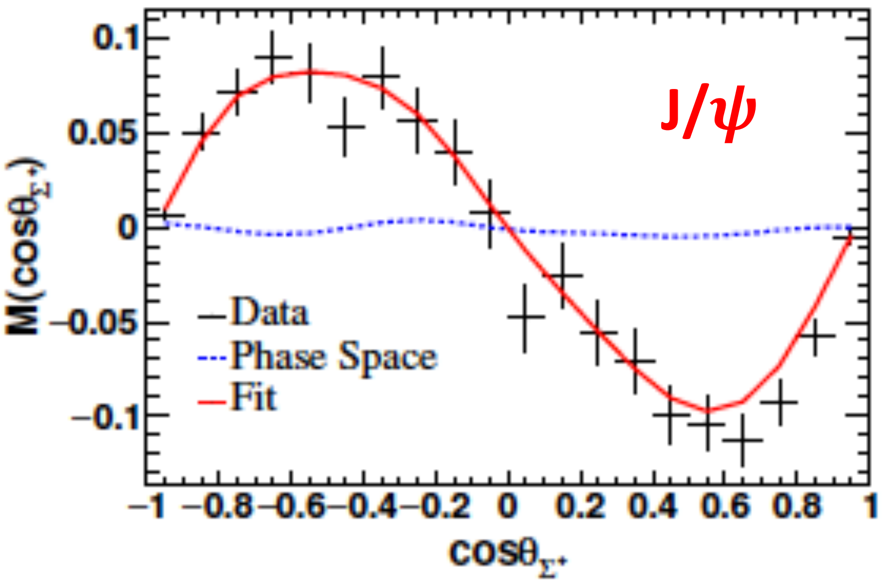
well suited for $\alpha_0+\bar{\alpha}_0/\alpha_0-\bar{\alpha}_0$

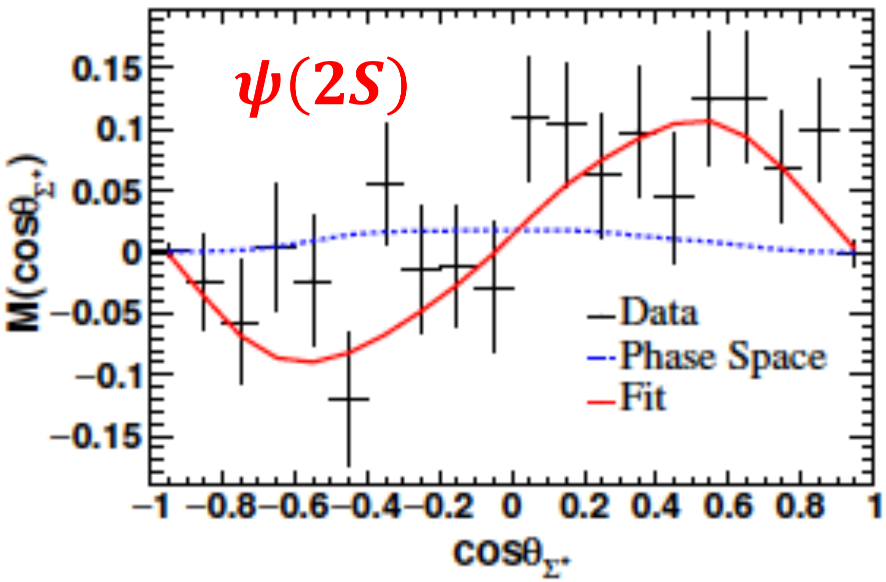
if the Σ^+s are polarized

J/ψ and $\psi(2S) \to \Sigma^+\bar{\Sigma}^-$ $(\Sigma^+ \to p\pi^0, \bar{\Sigma}^- \to \bar{p}\pi^0)$

arXiv:2004.07701 to be submitted to PRL

Both J/ψ and $\psi(2S)$ are polarized





Preliminary $\Sigma^+ \to p\pi^0$ results

arXiv:2004.07701 -- based on 1.3B J/ψ events --

Only one-tenth of the data used.

Parameter	Measured value
$\alpha_{J/\psi}$	$-0.508 \pm 0.006 \pm 0.004$
$\Delta\Phi_{J/\psi}$	$-0.270 \pm 0.012 \pm 0.009$
$\alpha_{\psi'}$	$0.682 \pm 0.03 \pm 0.011$
$\Delta\Phi_{\psi'}$	$0.379 \pm 0.07 \pm 0.014$
α_0	$-0.998 \pm 0.037 \pm 0.009$
$\bar{\alpha}_0$	$0.990 \pm 0.037 \pm 0.011$

Fred was correct!

To be submitted to PRL

PDG values

α_0 FOR $\Sigma^+ \to p\pi^0$

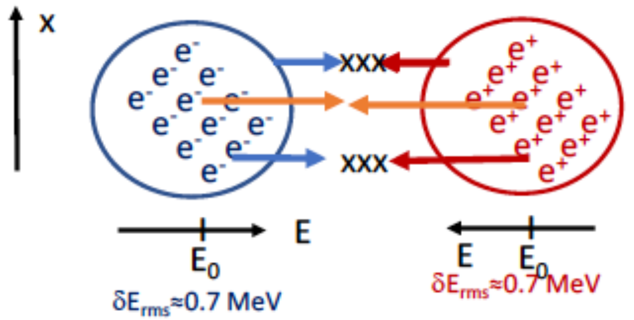
VALUE	EVTS	DOCUMENT ID	
$-0.980^{+0.017}_{-0.015}$ OUR FIT			
$-0.980^{+0.017}_{-0.013}$ OUR AVERAGE			
$-0.945^{+0.055}_{-0.042}$	1259	[15] LIPMAN	73
-0.940 ± 0.045	16k	BELLAMY	72
$-0.98\ ^{+0.05}_{-0.02}$	1335	[16] HARRIS	70
-0.999 ± 0.022	32k	BANGERTER	69

1st measurements

$$A_{CP,\Sigma} = (\alpha_0 + \bar{\alpha}_0)/(\alpha_0 - \bar{\alpha}_0) = -0.004 \pm 0.037 \pm 0.010$$

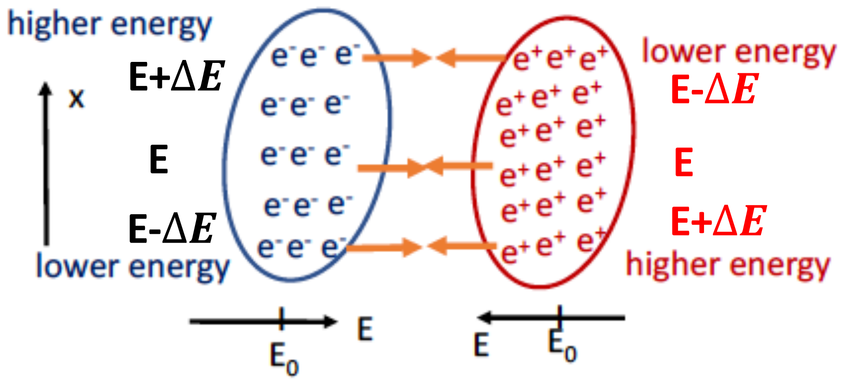
should reach 1% level with the full BESIII J/ψ event sample

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

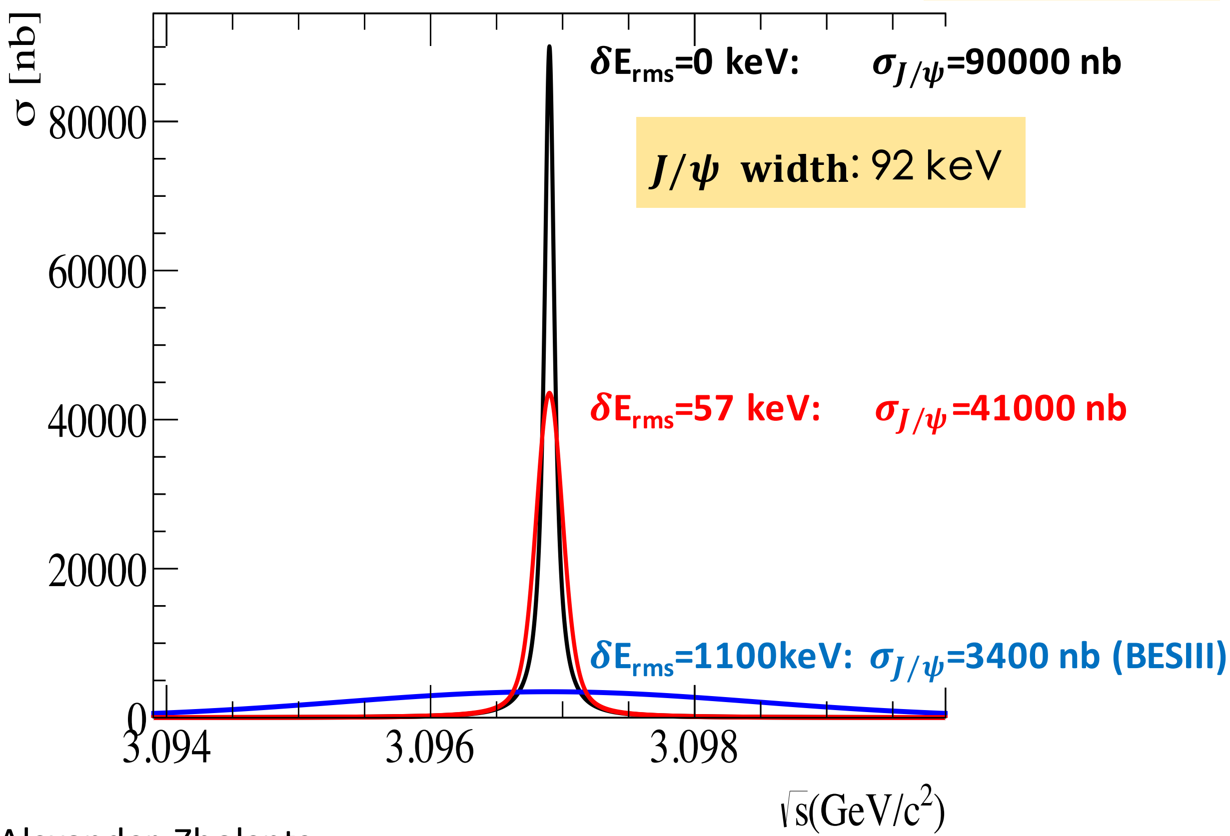
introduce dispersion



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

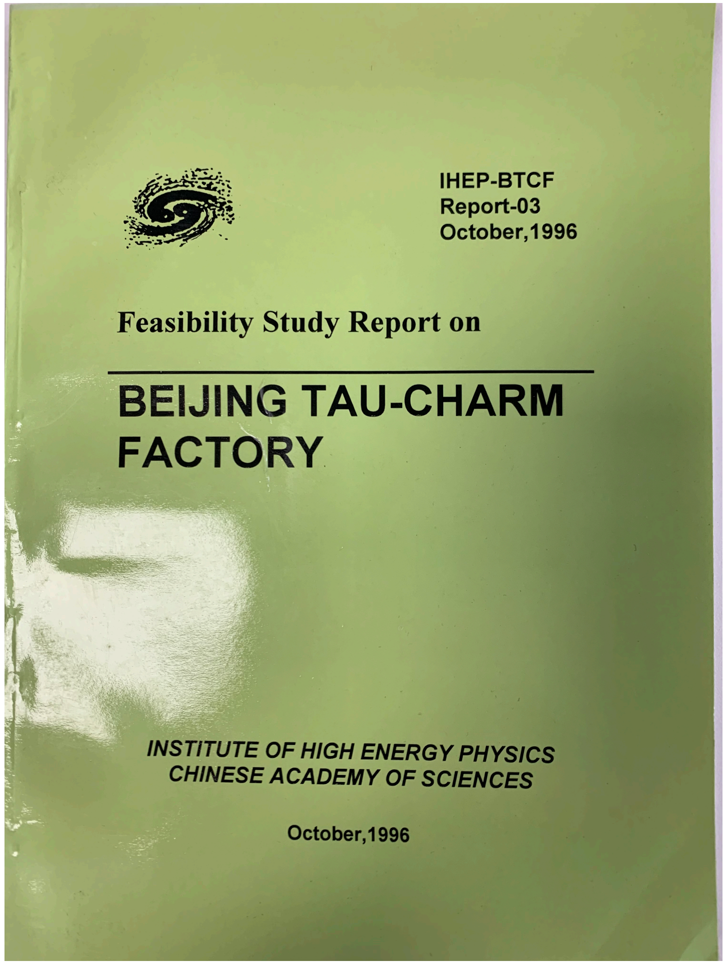
J/ψ production cross-section

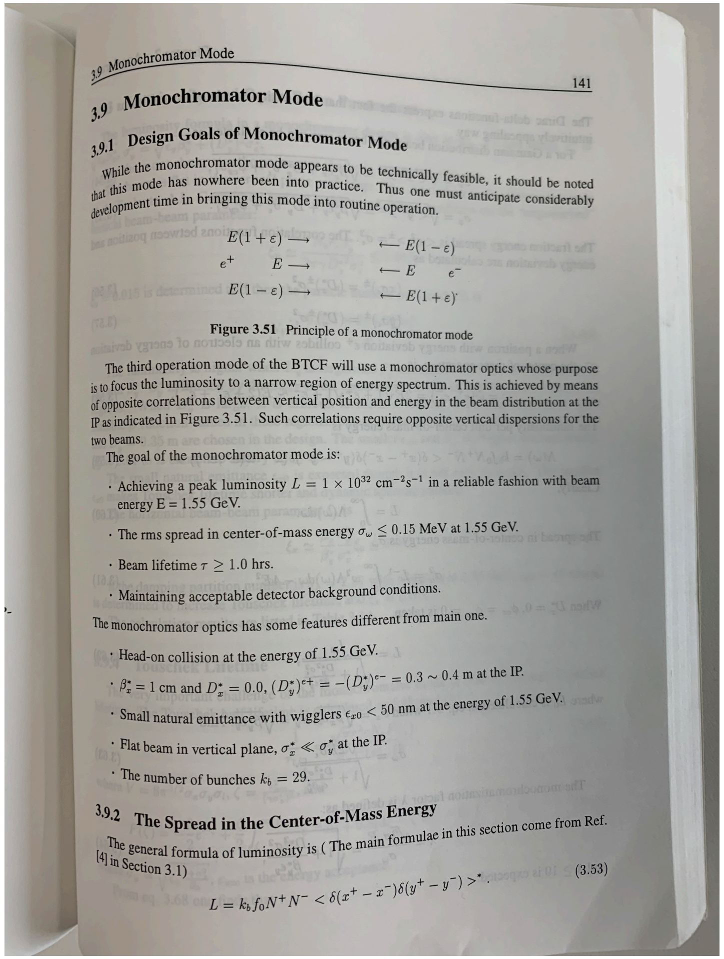
Xiaoshuai Qin



Alexander Zholents
CERN SL/92-27/AP

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.

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

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)

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

Future J/ψ factory

BESIII collected
10 billion J/ψ

Current technology "Topup" $\times 2$ +
"improved technology "monochromatic collision" $\times 10$ +
Someday with new facility (J/ψ factory) $\times 100$

10^{13} J/ψ per year at a super J/ψ factory

10 Billions of hyperon pairs produced

Billion of hyperon pairs reconstructed

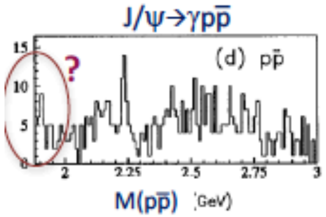
CPV： $10^{-4} - 10^{-5}$

Challenge the SM

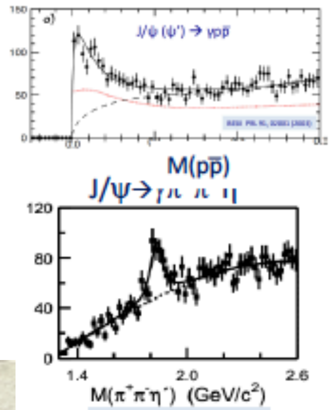
What did I learn during 30 yrs at BES?

you never have enough J/ψ events

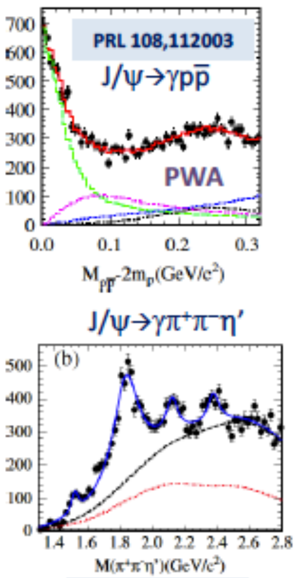
1996: 8 M J/ψ's	2002: 58 M J/ψ's	2011: 225 M J/ψ's	2016: 1.3 B J/ψ's	2019: 10 B J/ψ's



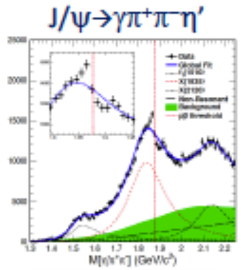
PRL 76, 3502



PRL 95,262001



PRL 106,072002



PRL 117,042002

???

Steve Olsen

BESII: 58 million

BESIII collected 10 billion J/ψ

$10^{13} J/\psi$ per year at a super J/ψ factory

10 Billions of hyperon pairs produced

Billion of hyperon pairs reconstructed

CPV： $10^{-4} - 10^{-5}$

Challenge the SM

CP violation with 10 billion J/ψ, and future facilities

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

$A_\Lambda = -0.006 \pm 0.012 \pm 0.007$

BESIII

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

	Events	Error A_Λ	
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 L=$0.47 \cdot 10^{33}$ $\Delta E = 0.9$ MeV
SuperTauCharm	$6 \cdot 10^8$	$3 \cdot 10^{-4}$	L=10^{35} cm^{-2}s^{-1} $2 \cdot 10^{12}$ J/ψ $\Delta E = 0.9$ MeV
SuperTauCharm + reduced ΔE	$3 \cdot 10^9$	$1.4 \cdot 10^{-4}$	L=10^{35} cm^{-2}s^{-1} 10^{13} J/ψ $\Delta E < 0.9$ MeV??

a guess

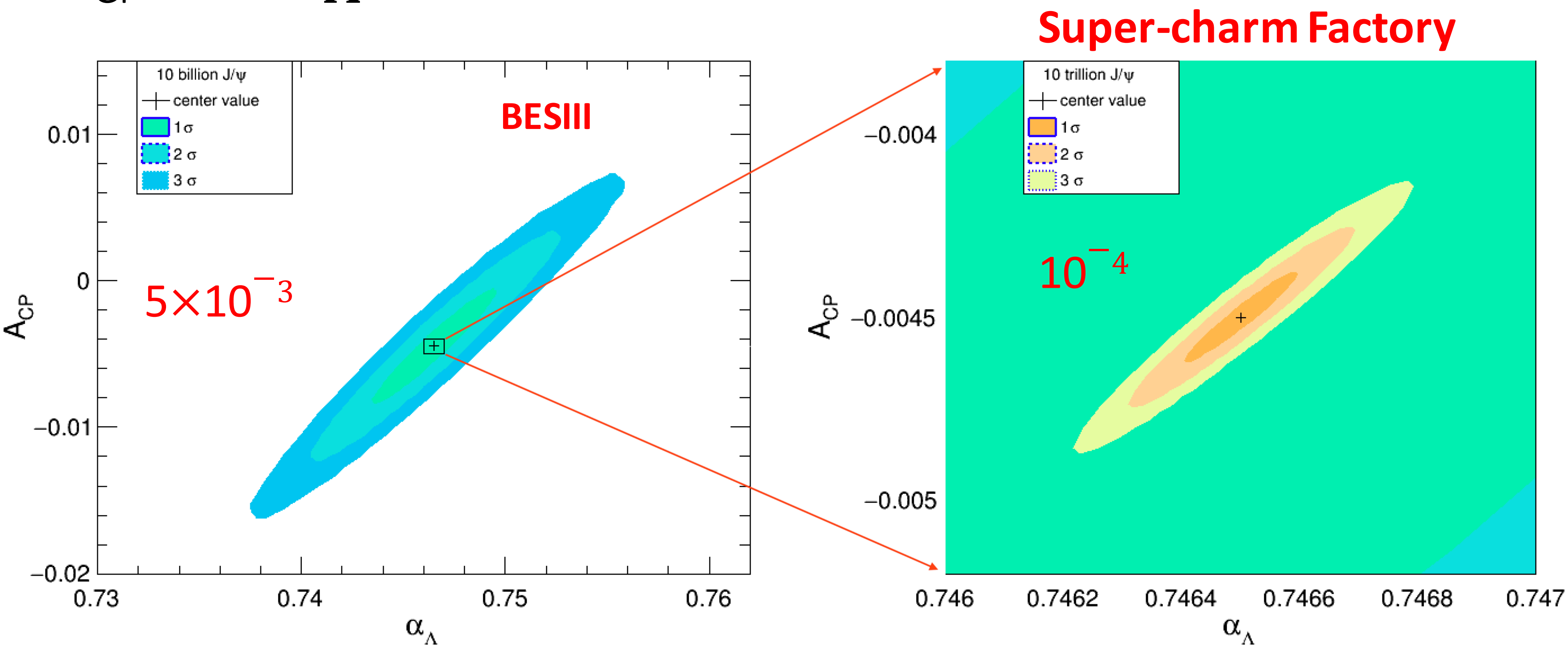
$-3 \times 10^{-5} \leq A_\Lambda \leq 4 \times 10^{-5}$
$-2 \times 10^{-5} \leq A_\Xi \leq 1 \times 10^{-5}$
$-5 \times 10^{-5} \leq A_{\Xi\Lambda} \leq 5 \times 10^{-5}$

CKM

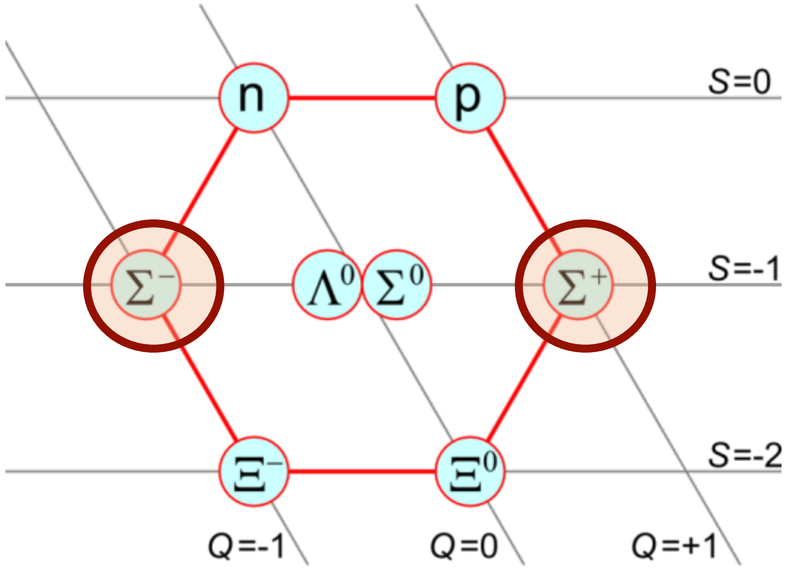
Tandean,Valencia PRD67, 056001

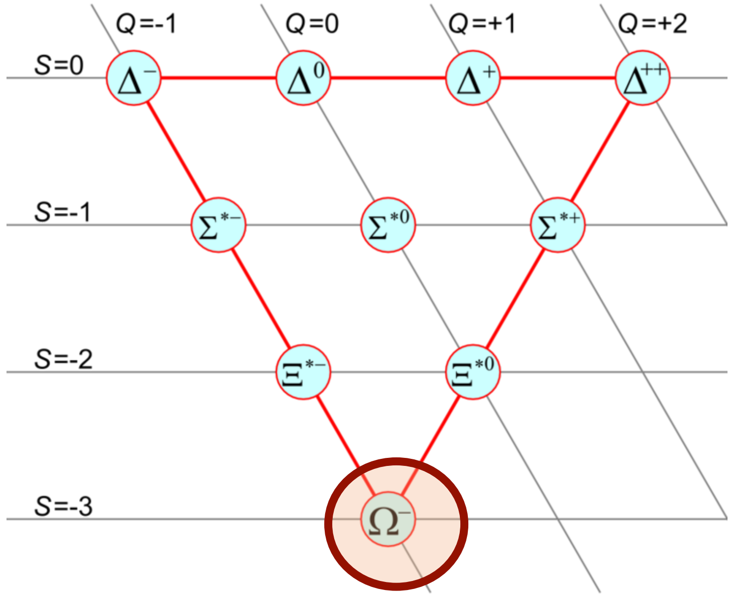
$$\sigma(A_\Lambda) = \frac{\sqrt{1+\varrho}}{\sqrt{2}\alpha_\Lambda}\sigma(\alpha_\Lambda)$$

A_{CP} VS. α_Λ



How about other weakly decaying hyperons?





$\Sigma^+ \rightarrow p\pi^0$

$\rightarrow n\pi^+$

$\Sigma^- \rightarrow n\pi^-$

final state baryon polarization measurements impractical with BESIII

$\Omega^- \rightarrow \Lambda K^-$

$\rightarrow \Xi^0\pi^-$

$\rightarrow \Xi^-\pi^0$

need $\psi' \rightarrow \Omega^-\overline{\Omega}^+$ data rates are low

CPV observables in $\Xi^- \to \Lambda\pi$ decay

decay rate difference

$$\frac{\Gamma_{\bar{\Lambda}\pi^+} - \Gamma_{\Lambda\pi^-}}{\Gamma} \equiv 0$$

← $\Lambda\pi$ final states are purely Ispin=1, only $\Delta I=1/2$ transitions allowed, no $\Delta I=3/2$ transition possible

decay asymmetry difference

$$\alpha_{\mp} = \pm \frac{2\,\mathrm{Re}(S^*P)}{|S|^2+|P|^2} = \pm \frac{2|S||P|\cos\left(\Delta_S \pm \phi_{CP}\right)}{|S|^2+|P|^2}$$

$$\frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+} = \frac{\sin\Delta_S \sin\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\Delta_S \tan\phi_{CP}$$

← in this case, the strong phase ($\Delta_s = \delta_S - \delta_P$) is measureable (see below)

final-state polarization difference

$$\beta_{\mp} = \pm \frac{2\,\mathrm{Im}(S^*P)}{|S|^2+|P|^2} = \pm \frac{2|S||P|\sin\left(\Delta_S \pm \phi_{CP}\right)}{|S|^2+|P|^2}$$

$$\frac{\beta_- + \beta_+}{\alpha_- - \alpha_+} = \frac{\cos\Delta_S \sin\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\phi_{CP}$$

← Strong phase cancels out

$$\frac{\beta_- - \beta_+}{\alpha_- - \alpha_+} = \frac{\sin\Delta_S \cos\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\Delta_S$$

← measures the strong phase

} big advantage for Ξ over Λ

Σ^-?

From S.L. Olsen

α_- FOR $\Sigma^- \rightarrow n\pi^-$

VALUE	*EVTS*	*DOCUMENT ID*	
-0.068 ± 0.008 OUR AVERAGE			
-0.062 ± 0.024	28k	HANSL	78
-0.067 ± 0.011	60k	BOGERT	70
-0.071 ± 0.012	51k	BANGERTER	69

Σ^- DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$n\pi^-$	(99.848 ± 0.005) %

40~50 year-old measurements,

probably wrong for the same reason the Λ measurements were wrong

$\alpha\_\approx0$ ➔ 1 partial wave dominates

interference is small not well suited for $\alpha_-+\alpha_+/\alpha_- - \alpha_+$ measurements

no measurements of $\bar{\alpha}_+$ for $\bar{\Sigma}^+$

single dominant decay mode

no suitable for $\Delta\Gamma$ measurements

Ω^-?

α FOR $\Omega^- \rightarrow \Lambda K^-$

Some early results have been omitted.

VALUE	EVTS	DOCUMENT ID	
0.0180±0.0024 OUR AVERAGE			
+0.0207±0.0051±0.0081	960k	[7] CHEN	05
+0.0178±0.0019±0.0016	4.5M	[7] LU	05A

α FOR $\Omega^- \rightarrow \Xi^0 \pi^-$

VALUE	EVTS	DOCUMENT ID	
+0.09±0.14	1630	BOURQUIN	84

α FOR $\Omega^- \rightarrow \Xi^- \pi^0$

VALUE	EVTS	DOCUMENT ID	
+0.05±0.21	614	BOURQUIN	84

Ω^- DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	ΛK^-	(67.8±0.7) %
Γ_2	$\Xi^0 \pi^-$	(23.6±0.7) %
Γ_3	$\Xi^- \pi^0$	(8.6±0.4) %

$\alpha \approx 0$ ➔ 1 partial wave dominates all modes

interference is small, not well suited for $\alpha + \bar{\alpha}/\alpha - \bar{\alpha}$ measurements

$\Gamma(\Xi^0\pi^-) \approx 3x\ \Gamma(\Xi^-\pi^0)$ ⇐ $T_{3/2} \approx T_{1/2}$

$\Delta\Gamma$ will be enhanced

Hyperon decays

Rare and forbidden decays

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

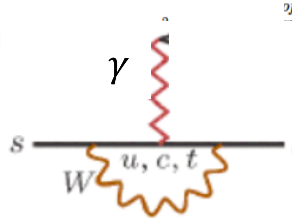
PERSPECTIVE

Prospects for rare and forbidden hyperon decays at BESIII

Hai-Bo Li[1,2,†]
of High Energy Physics, Beijing 100049, China
ademy of Sciences, Beijing 100049, China
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., Λ, Σ, Ξ, and Ω,
h the proposed data samples at BESIII. Based o
branching fractions of the hyperon decays is in th
ie", rare

SM



$B_i \to B_f\gamma$	$\mathcal{B}$ ($\times 10^{-3}$)	α_γ
$\Lambda \to n\gamma$	1.75 ± 0.15	–
$\Sigma^+ \to p\gamma$	1.23 ± 0.05	-0.76 ± 0.08
$\Sigma^0 \to n\gamma$	–	–
$\Xi^0 \to \Lambda\gamma$	1.17 ± 0.07	-0.70 ± 0.07
$\Xi^0 \to \Sigma^0\gamma$	3.33 ± 0.10	-0.69 ± 0.06
$\Xi^- \to \Sigma^-\gamma$	0.127 ± 0.023	1.0 ± 1.3
$\Omega^- \to \Xi^-\gamma$	< 0.46 (90% C.L.)	–

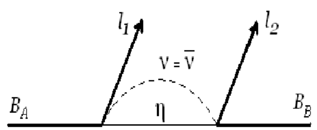
FCNC: radiative decays

Decay mode	Current data $\mathcal{B}(\times 10^{-6})$	Sensitivity $\mathcal{B}$(90%C.L.) $(\times 10^{-6})$	Type
$\Lambda \to ne^+e^-$	-	< 0.8	
$\Sigma^+ \to pe^+e^-$	< 7	< 0.4	
$\Xi^0 \to \Lambda e^+e^-$	7.6 ± 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

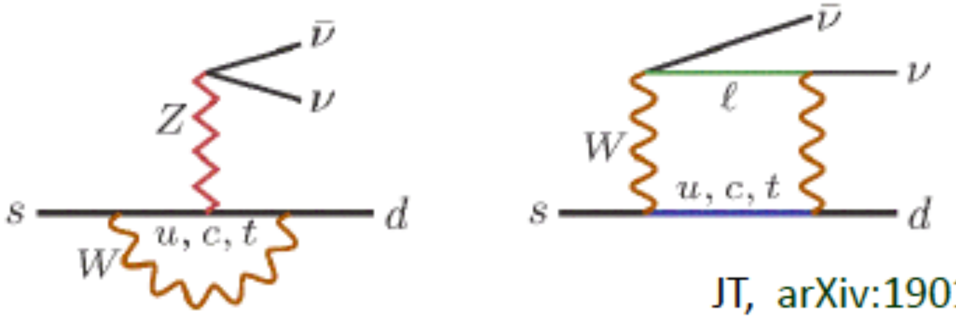
Neutrinoless double beta decays



Most of them never studied.

Search for rare decay and New physics

SM



JT, arXiv:1901.10447 [JHEP 04 (2019) 104]
G Li, JY Su, JT, arXiv:1905.08759

SM predictions:

$\Lambda \to n\nu\bar{\nu}$	$\Sigma^+ \to p\nu\bar{\nu}$	$\Xi^0 \to \Lambda\nu\bar{\nu}$	$\Xi^0 \to \Sigma^0\nu\bar{\nu}$	$\Xi^- \to \Sigma^-\nu\bar{\nu}$	$\Omega^- \to \Xi^-\nu\bar{\nu}$
7.1×10^{-13}	4.3×10^{-13}	6.3×10^{-13}	1.0×10^{-13}	1.3×10^{-13}	4.9×10^{-12}

$$\mathcal{B}(\Lambda \to nN_2\bar{N}_3) < 1.3 \times 10^{-5}, \quad \mathcal{B}(\Sigma^+ \to pN_2\bar{N}_3) < 3.5 \times 10^{-6},$$
$$\mathcal{B}(\Xi^0 \to \Lambda N_2\bar{N}_3) < 1.9 \times 10^{-6}, \quad \mathcal{B}(\Xi^0 \to \Sigma^0 N_2\bar{N}_3) < 2.6 \times 10^{-6},$$
$$\mathcal{B}(\Xi^- \to \Sigma^- N_2\bar{N}_3) < 3.2 \times 10^{-6}, \quad \mathcal{B}(\Omega^- \to \Xi^- N_2\bar{N}_3) < 1.5 \times 10^{-4}.$$

arXiv:1912.13507
JY Su, Jusak Tandean

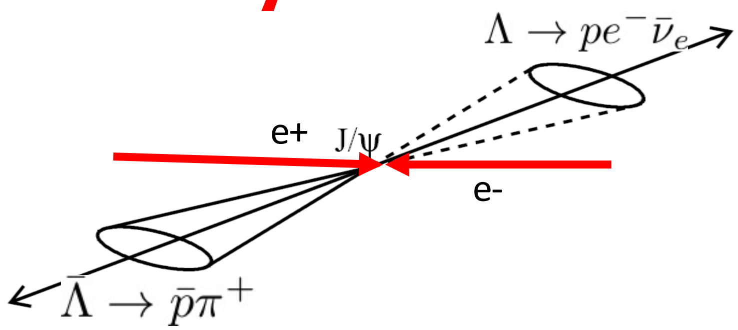
Sensitivities from BESIII 10 billion J/ψ

$\Lambda \to n\nu\bar{\nu}$	$\Sigma^+ \to p\nu\bar{\nu}$	$\Xi^0 \to \Lambda\nu\bar{\nu}$	$\Xi^0 \to \Sigma^0\nu\bar{\nu}$	$\Omega^- \to \Xi^-\nu\bar{\nu}$
3×10^{-7}	4×10^{-7}	8×10^{-7}	9×10^{-7}	2.6×10^{-5}

Semileptonic decays

Fully reconstruct one of the hyperons, then the momentum of the other hyperon will be known, which provides hyperon beam, so we can look for invisible final states:

– neutrino ; other invisible particles



Decay mode	$\mathcal{B}$ ($\times 10^{-4}$)	$\lvert\Delta S\rvert$	$g_1(0)/f_1(0)$
$\Lambda \to pe^- \bar{\nu}_e$	8.32 ± 0.14	1	0.718 ± 0.015
$\Sigma^+ \to \Lambda e^+ \nu_e$	0.20 ± 0.05	0	–
$\Sigma^- \to ne^- \bar{\nu}_e$	10.17 ± 0.34	1	-0.340 ± 0.017
$\Sigma^- \to \Lambda e^- \bar{\nu}_e$	0.573 ± 0.027	0	–
$\Sigma^- \to \Sigma^0 e^- \bar{\nu}_e$	–	0	–
$\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$	2.52 ± 0.08	1	1.210 ± 0.050
$\Xi^- \to \Lambda e^- \bar{\nu}_e$	5.63 ± 0.31	1	0.250 ± 0.050
$\Xi^- \to \Sigma^0 e^- \bar{\nu}_e$	0.87 ± 0.17	1	–
$\Xi^- \to \Xi^0 e^- \bar{\nu}_e$	< 23 (90% C.L.)	0	–
$\Omega^- \to \Xi^0 e^- \bar{\nu}_e$	56 ± 28	1	–

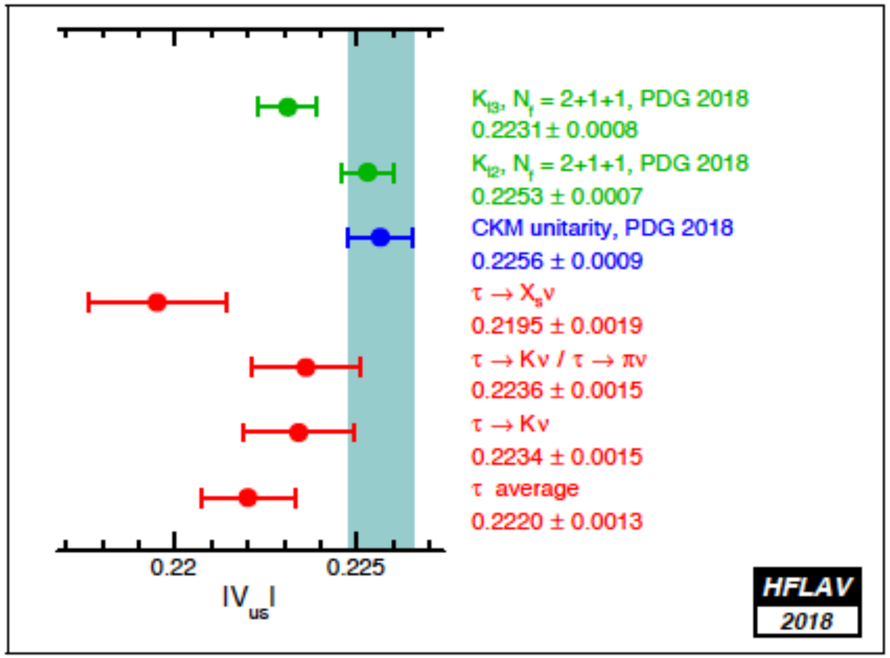
$$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$$

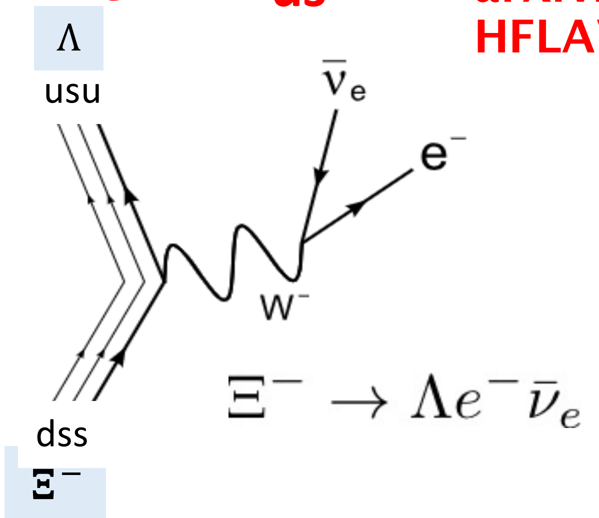
$$\to \bar{p}\pi^+$$

$$\to pe^- \bar{\nu}_e$$

Semileptonic decays: V_{us}

arXiv:1909.12524
HFLAV group 2018





V_{us} measurements are inconsistent:

between Kl3 and Kl2 decays and tau decays.

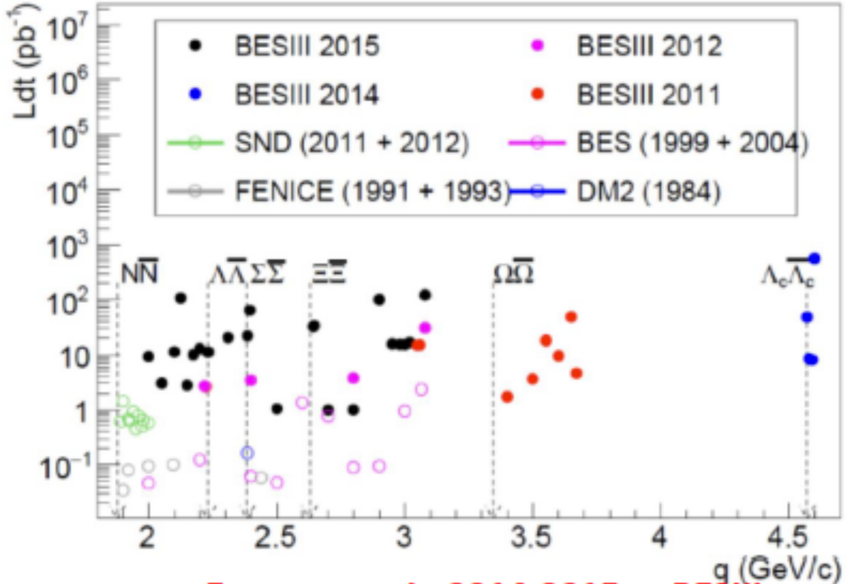
Table 5: Results from V_{us} analysis using measured g_1/f_1 values

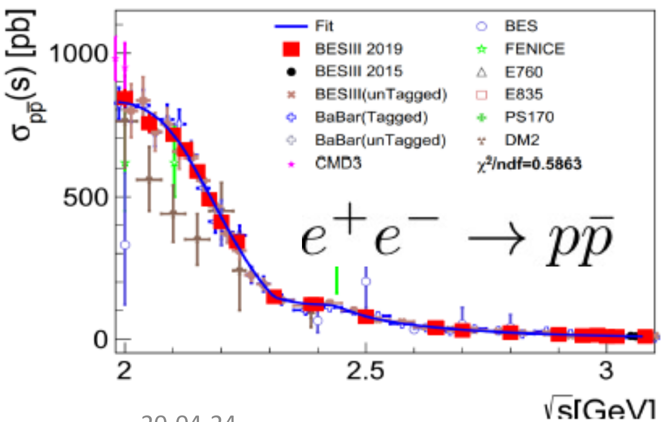
Decay Process	Rate (μsec^{-1})	g_1/f_1	V_{us}
$\Lambda \to p e^- \bar{\nu}$	3.161(58)	0.718(15)	0.2224 ± 0.0034
$\Sigma^- \to n e^- \bar{\nu}$	6.88(24)	−0.340(17)	0.2282 ± 0.0049
$\Xi^- \to \Lambda e^- \bar{\nu}$	3.44(19)	0.25(5)	0.2367 ± 0.0099
$\Xi^0 \to \Sigma^+ e^- \bar{\nu}$	0.876(71)	1.32(+.22/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

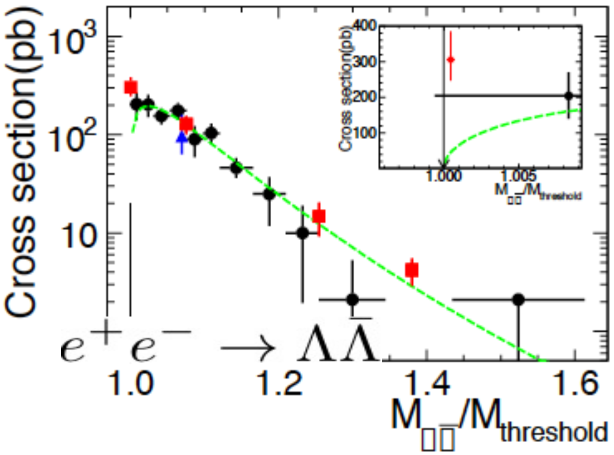
N. Cabibbo, E. Swallon, R. Winston
Ann.Rev.Nucl.Part.Sci. 53:39-75,2003

Advantage: data near to the thresholds

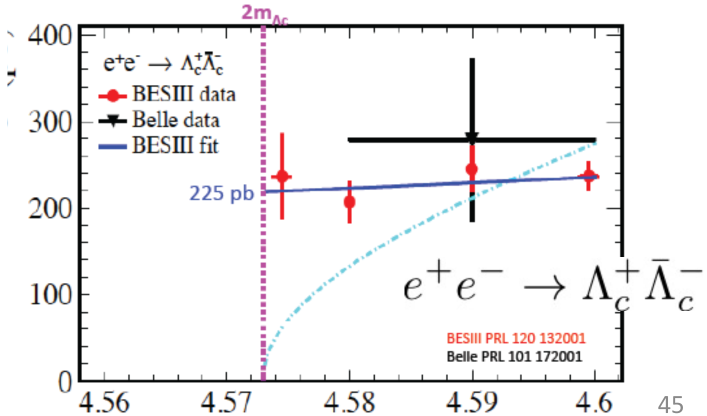
- **Baryon pair productions near thresholds: precision branching fractions, unique access to the relative phase, test of QCD;**
- **Hyperon and charmed baryon Spin polarization in quantum productions;**
- **Form-factors in the time-like production**
- **CP violation with quantum-correlated pair productions of hyperons and charmed baryon**





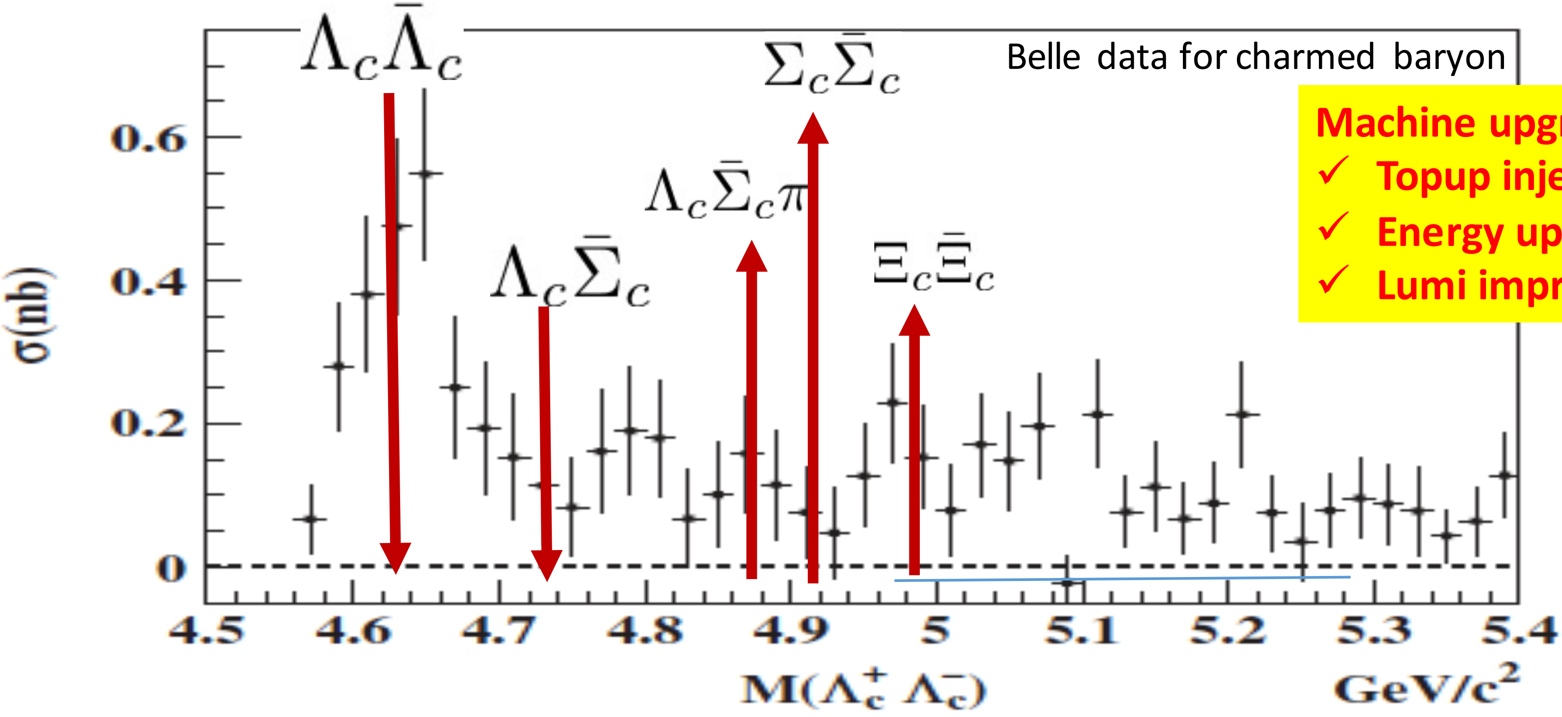


Energy scan in 2014-2015 at BESIII



Best precision on σ: 3% (systematic dominant)

Access to the heavier charmed baryons



Machine upgrades:

- ✓ **Topup injection (finished)**
- ✓ **Energy upgrades**
- ✓ **Lumi improvement *2-3**

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)

BESIII white paper: Future Physics Programme

arXiv:1912.05983 : Chin.Phys. C44 (2020) no.4, 040001

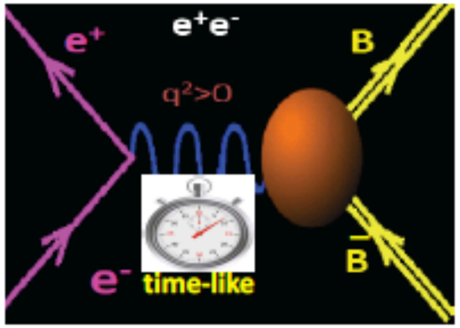
Table 7.1. List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program. The right-most column shows the number of required data taking days with the current (T_C) and upgraded (T_U) machine. The machine upgrades include top-up implementation and beam current increase.

Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^{\pm}$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

Another 5 to 8 years running to collect another 56 fb-1 data at different energies .

Time-like form-factors of nucleons and hyperons

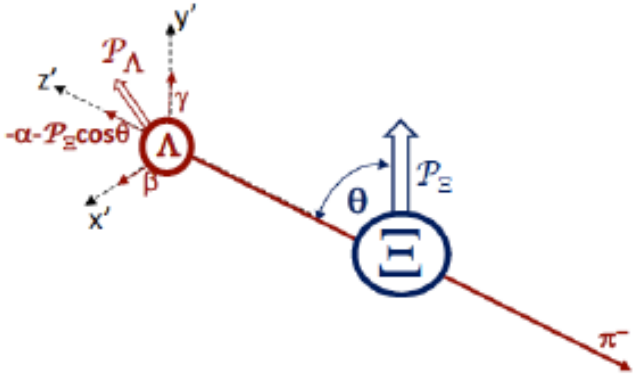
-- 21st century probes of the structure of baryons



World's most sensitive searches for CPV in hyperon decays

-- a new frontier for CPV studies

Steve Olsen



BESII: 58 million

BESIII collected 10 billion J/ψ

$10^{13} J/\psi$ per year at a super J/ψ factory

10 Billions of hyperon pairs produced

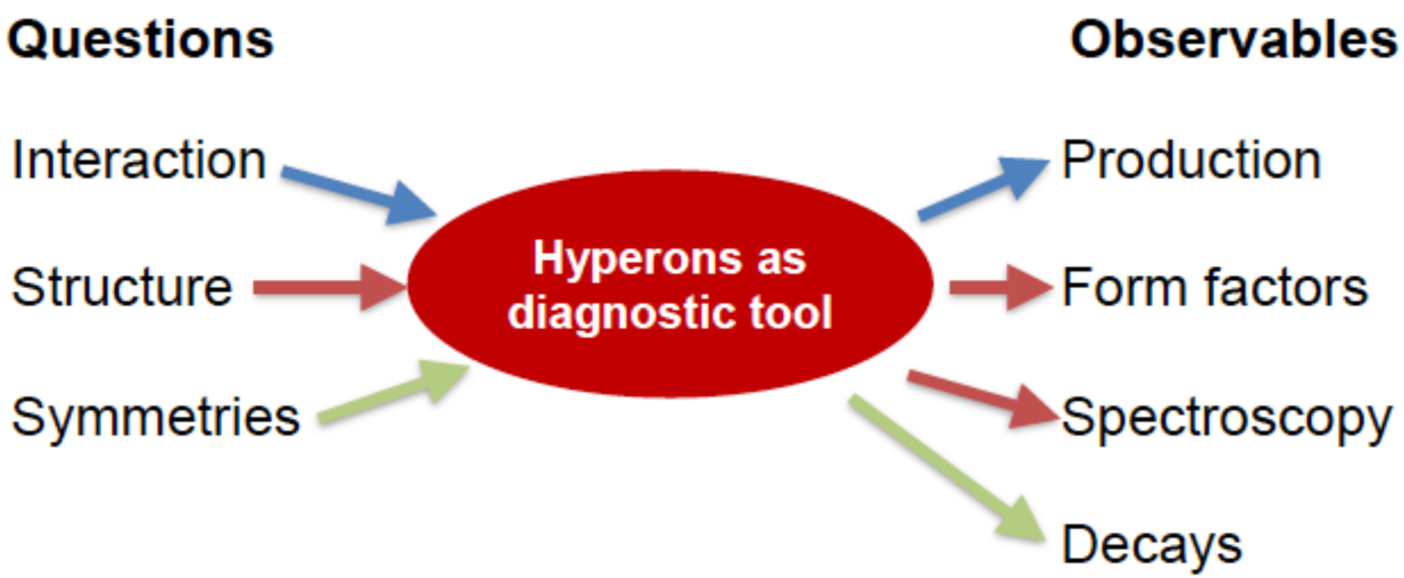
Billion of hyperon pairs reconstructed

CPV： $10^{-4} - 10^{-5}$

Challenge the SM

Summary

Hyperons are a laboratory for strong interaction, baryon structure and symmetry studies. BESIII provides huge amount quantum-correlated hyperon pairs!



Summary

Hyperon polarization in J/ψ (ψ') decays → new way to study CPV

→ complementary to CPV studies with Kaons

→ BESIII as already rewritten the PDG book for Λ decays

→ about to do the same for Ξ /Σ$^+$ decays

→ good opportunities for Δα measurements with Σ$^+$

→ Σ$^-$ and Ω CPV measurements are probably hard

Charmed baryon

CPV can be accessed via both decay parameters and T-odd observables

STCF will play an important role on the search for CPV in charmed baryon with quantum correlated data near the production threshold!

Hyperon physics at BESIII &STCF: next new frontier for CPV studies!

Some of my slides from Steve Olsen, Andrzej Kupscs, Sandip PAKVASA

2019年7月8-9日 复旦大学 Hyperon physics

https://indico.ihep.ac.cn/event/9834/overview

Thanks !

Thank you !

Beginners of CPV and rare decays of Hyperon physics at BESIII:

Andrzej Kupscs(Uppsala University), Jie Liu(IHEP),

Rong-Gang Ping (IHEP), Hai-Bo LI and Jian-Bin Jiao (SDU)

BESIII achievements

More than 280 papers published or submitted so far, 30% at PRL

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: Λ_c production and decay**
- **Probe EM structures of baryons: G_E, G_M of proton, neutron and hyperons**
- **Hyperon-anti-hyperon pairs: asymmetry parameters, *CP Violation,* and polarizations of hyperons**

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?**

CPV in charmed baryon

X.W. Kang, HBL, G.R. Lu and A. Datta Int.J.Mod.Phys. A26 (2011) 2523

CPV from asymmetry parameters:

$$\langle A_{\rm CP}^{(X)}\rangle = \frac{\alpha_Y^{(X)} + \alpha_{\bar{Y}}^{(\bar{X})}}{\alpha_Y^{(X)} - \alpha_{\bar{Y}}^{(\bar{X})}}$$

Triple product asymmetry:

$$\langle A_T\rangle = \frac{N(C_T>0) - N(C_T<0)}{N(C_T>0) + N(C_T<0)}$$

$$\langle \bar{A}_T\rangle = \frac{N(\bar{C}_T>0) - N(\bar{C}_T<0)}{N(\bar{C}_T>0) + N(\bar{C}_T<0)}$$

$$C_T = (\vec{p}_X \times \vec{p}_\pi)\cdot \vec{p}_{\bar{X}}$$

$\Lambda_c \to BV$	Br	Eff. (ϵ)	Expected errors at BES-III ($\times 10^{-2}$)
$\Lambda\rho^+ \to (p\pi^-)(\pi^+\pi^0)$	$3.2\times 10^{-2*}$	0.65	0.44
$\Sigma(1385)^+\rho^0 \to (\Lambda\pi^+)(\pi^+\pi^-)$	2.4×10^{-3}	0.69	1.55
$\Sigma^+\rho^0 \to (p\pi^0)(\pi^+\pi^-)$	$0.7\times 10^{-2*}$	0.62	0.96
$\Sigma^+\omega \to (p\pi^0)(\pi^+\pi^-\pi^0)$	1.4×10^{-2}	0.49	0.76
$\Sigma^+\phi \to (p\pi^0)(K^+K^-)$	0.8×10^{-3}	0.52	3.10
$\Sigma^+K^{*0} \to (p\pi^0)(K^-\pi^+)$	0.7×10^{-3}	0.57	3.17

$$\mathcal{A}_T = \frac{1}{2}\left[\langle A_T\rangle + \langle \bar{A}_T\rangle\right] = \langle A_T\rangle \neq 0$$

Sensitivities of CPV from triple products:

2.3 million Λ_c *pairs at BESIII*

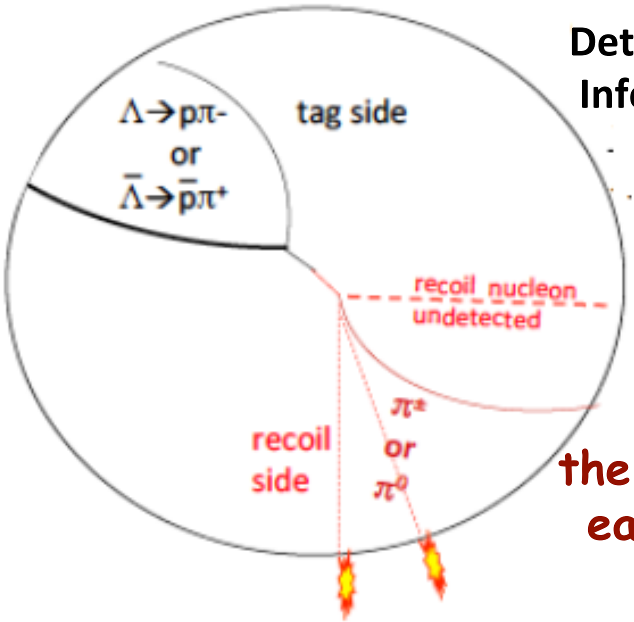
2.0 billion Λ_c *pairs* at STCF : $10^{-3} - 10^{-4}$

$T_{3/2} \neq 0$: decay rate asymmetry in BESIII?

use *partial* reconstruction of J/ψ→ΛΛ?

Can BESIII measure this with low systematic errors?

$$\frac{Bf\left(\Lambda \to n\pi^0\right)}{Bf\left(\Lambda \to p\pi^-\right)} - \frac{Bf\left(\bar{\Lambda} \to \bar{n}\pi^0\right)}{Bf\left(\bar{\Lambda} \to \bar{p}\pi^+\right)} = \frac{N\left(\bar{\Lambda}_{\text{tag}} + \pi^0\right)}{N\left(\bar{\Lambda}_{\text{tag}} + \pi^-\right)} - \frac{N\left(\Lambda_{\text{tag}} + \pi^0\right)}{N\left(\Lambda_{\text{tag}} + \pi^+\right)}$$



Detect a Λ→pπ⁻ or Λ→pπ⁺ accompanied by a π± or π⁰
Infer presence of the recoil nucleon by missing mass

the 10^{10} J/ψ data sample has >1M events in each category ➔ statistical precision ≈10^{-3}

Decay rate asymmetry in BESIII

using partially reconstructed J/ψ→ ΛΛ events --

this $\Delta_s=\delta_{3/2}-\delta_{1/2}$

$$\frac{Bf\left(\Lambda\to n\pi^0\right)}{Bf\left(\Lambda\to p\pi^-\right)}-\frac{Bf\left(\bar\Lambda\to \bar n\pi^0\right)}{Bf\left(\bar\Lambda\to \bar p\pi^+\right)}=\cdot\frac{\Gamma_{n\pi^0}}{\Gamma_{p\pi^-}}-\frac{\Gamma_{\bar n\pi^0}}{\Gamma_{\bar p\pi^+}}=\frac{\Gamma_{n\pi^0}\Gamma_{\bar p\pi^+}-\Gamma_{\bar n\pi^0}\Gamma_{p\pi^-}}{\Gamma_{p\pi^-}\Gamma_{\bar p\pi^+}}\approx 2\left(1+\sqrt{2}\right)\left(T_{3/2}\big/T_{1/2}\right)\sin\Delta_s\sin\phi_{CP}$$

sensitivity is nominally reduced by a factor of ~5

here I used:

$$\Gamma_{p\pi^-}\approx\left|T_{1/2}\right|^2+\sqrt{2}\left|T_{1/2}\right|\left|T_{3/2}\right|\cos(\Delta_s+\phi_{CP})$$

$$\Gamma_{n\pi^0}\approx\tfrac{1}{2}\left|T_{1/2}\right|^2-\left|T_{1/2}\right|\left|T_{3/2}\right|\cos(\Delta_s+\phi_{CP})$$

$$\Gamma_{\bar p\pi^-}\approx\left|T_{1/2}\right|^2+\sqrt{2}\left|T_{1/2}\right|\left|T_{3/2}\right|\cos(\Delta_s-\phi_{CP})$$

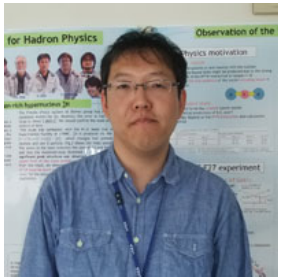
$$\Gamma_{\bar n\pi^0}\approx\tfrac{1}{2}\left|T_{1/2}\right|^2-\left|T_{1/2}\right|\left|T_{3/2}\right|\cos(\Delta_s+\phi_{CP})$$

same data would be useful for an $\alpha_0+\alpha_0/\alpha_0-\alpha_0$ measurement

2) Why the big change in α?

Why different?

from: Kiyoshi Tanida
JAEA Japan



- Multiple scattering:
  - E.g., at 95 MeV with 3 cm scatterer (target), θ_0 becomes as large as 1.5 degree.
    → 5 degree multiple scattering occurs with a probability of 1 % order and dominates over single scattering
  - Actual scatterer thickness is even larger
  - Of course, analyzing power for multiple Coulomb scattering is almost 0
    → Can explain the difference
- Note: effective A_N depends on target thickness
  - This is why target thickness is explicit in the new data.
  - We have to be careful!!

轻子数和重子数破坏的寻找

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

PERSPECTIVE

Prospects for rare and forbidden hyperon decays at BESIII

Hai-Bo Li[1,2,†]

[1] *Institute of High Energy Physics, Beijing 100049, China*
[2] *University of Chinese Academy of Sciences, Beijing 100049, China*
Corresponding author. E-mail: †*lihb@ihep.ac.cn*
Received April 17, 2017; accepted May 8, 2017

The study of hyperon decays at the Beijing Electron Spectrometer III (BES tigate the events of J/ψ decay into hyperon pairs, which provide a pristine e at the Beijing Electron–Positron Collider II. About 10^6–10^8 hyperons, i.e., produced in the J/ψ and $\psi(2S)$ decays with the proposed data samples at samples, the measurement sensitivity of the branching fractions of the hyper of 10^{-5}–10^{-8}. In addition, with the known center-of-mass energy and "tag and decays with invisible final states can be probed.

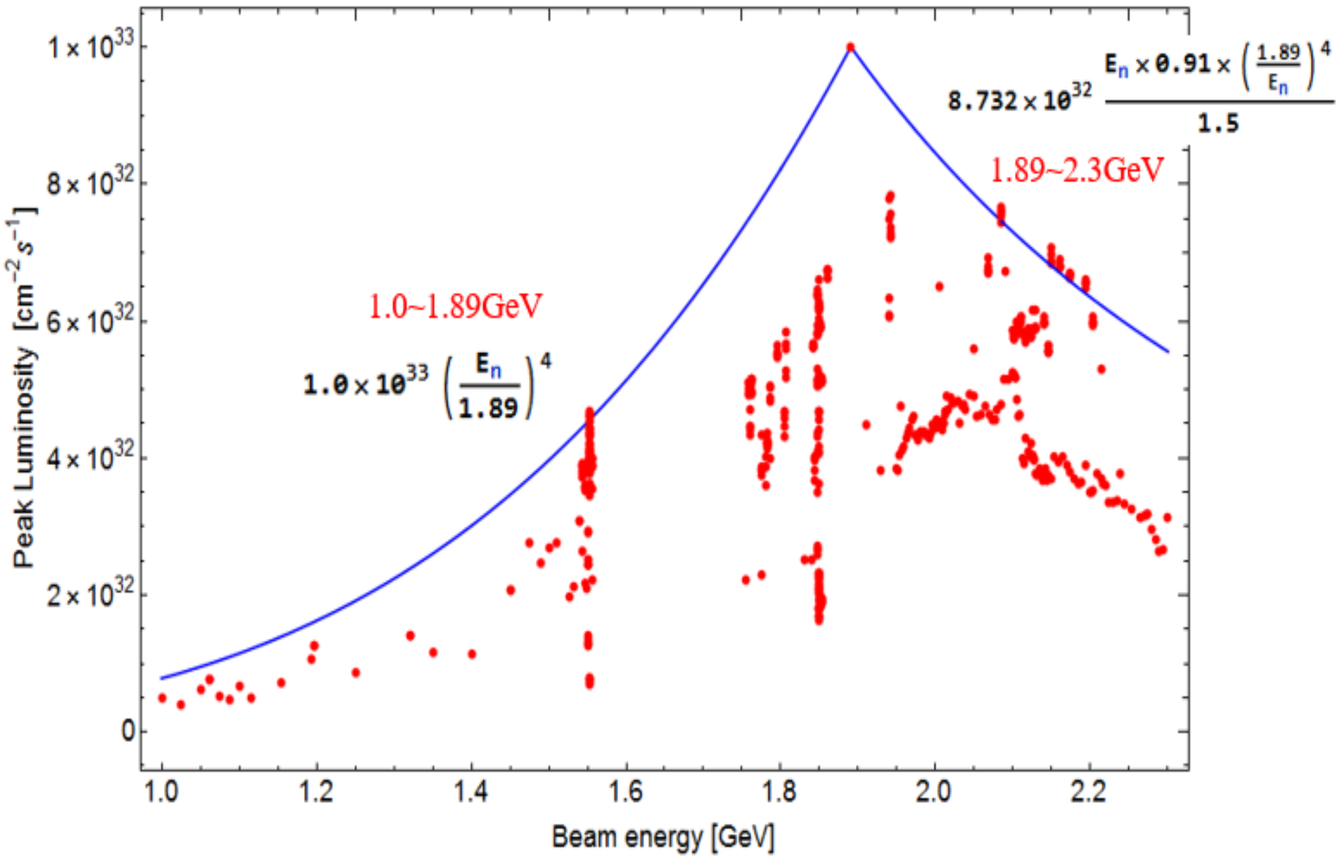
Keywords BESIII, J/ψ decay, hyperon, rare decay, FCNC, lepton flavor v

BESIII的敏感度

Decay mode	Current data $\mathcal{B}$ ($\times 10^{-6}$) (90% C.L.)	Sensitivity $\mathcal{B}$ ($\times 10^{-6}$)	ΔL	ΔB
$\Lambda \to M^+ l^-$	< 0.4–3.0 [68]	< 0.1	$+1$	-1
$\Lambda \to M^- l^+$	< 0.4–3.0 [68]	< 0.1	-1	-1
$\Lambda \to K_S \nu$	< 20 [68]	< 0.6	$+1$	-1
$\Sigma^+ \to K_S l^+$	–	< 0.2	-1	-1
$\Sigma^- \to K_S l^-$	–	< 1.0	$+1$	-1
$\Xi^- \to K_S l^-$	–	< 0.2	$+1$	-1
$\Xi^0 \to M^+ l^-$	–	< 0.1	$+1$	-1
$\Xi^0 \to M^- l^+$	–	< 0.1	-1	-1
$\Xi^0 \to K_S \nu$	–	< 2.0	$+1$	-1

BEPCII luminosity optimized for ψ(3770) running

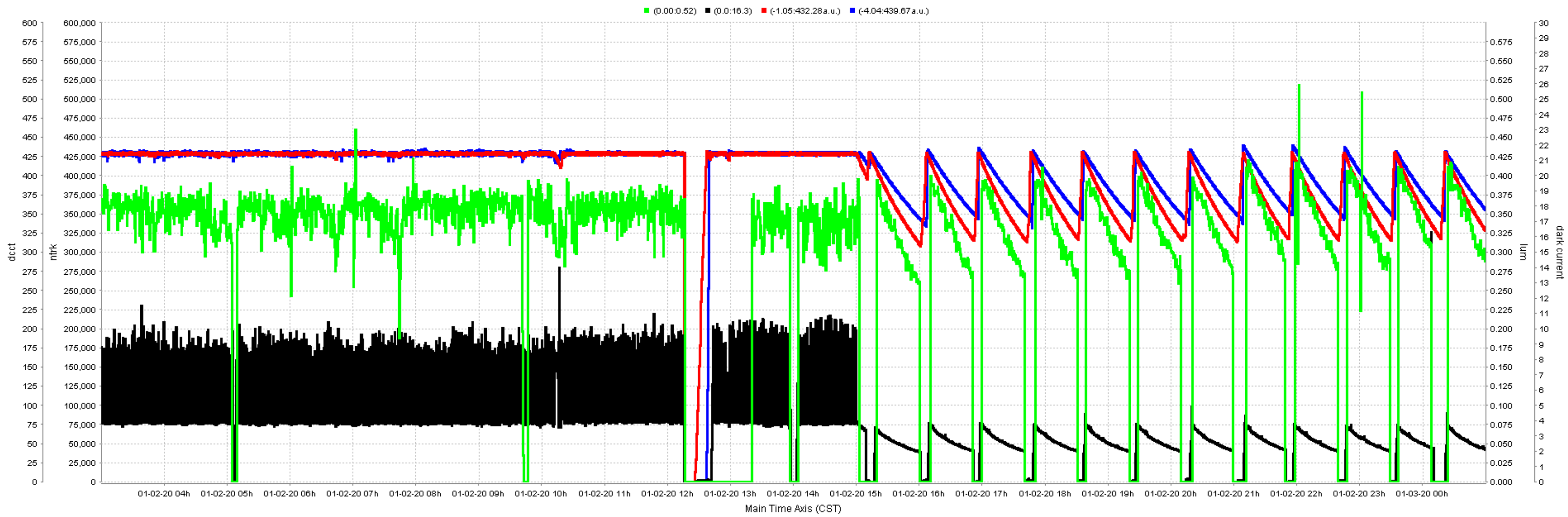
A factor of 2 gain for lattice optimized at J/ψ running



Gain on integrated luminosity from "Topup" injection

30% gain on the integrated luminosity

12 injections every 12 hours



单色对撞模式

单色模式概念，垂直位置的质心能量

上	高能量电子	E+ ε →← E - ε	低能量正电子
中	理想能量电子	E →← E	理想能量正电子
下	低能量电子	E - ε →← E + ε	高能量正电子

对撞质心能量：

$$E_{CM} = 2E_{e^-}E_{e^+} + 2m_e^2c^4 + 2\sqrt{E_{e^-}^2 - m_e^2c^4}\sqrt{E_{e^+}^2 - m_e^2c^4}cos(\theta)$$

头对头对撞时 $\boldsymbol{\theta = 0}$，$\boldsymbol{cos(\theta) = 1}$，$E_{e^-} = E(1+\epsilon_{e^-})$，$E_{e^+} = E(1+\epsilon_{e^+})$，

ϵ_{e^-}，ϵ_{e^+} 为两束流能量偏差的相对值，假设：$E_{e^-} \sim E_{e^+} \sim E$

$$E_{CM} = 2E\sqrt{1+\epsilon_{e^-}}\sqrt{1+\epsilon_{e^+}} \sim 2E\sqrt{1+\epsilon_{e^-}+\epsilon_{e^+}}$$

如果 $\epsilon_{e^-} = -\epsilon_{e^+}$ 束流质心能量散度为零.

单色对撞模式

实际情况下，对撞点处束流有一个分布（不是质点），不同粒子的位置（垂直方向）

$$y^*=\sigma_y{}^*+\sigma_\varepsilon\times D_y{}^*$$ （*：表示对撞点）

这里$\sigma_y{}^*$：垂直尺寸的分布（$=\sqrt{\beta_y^*\varepsilon_y}$），$\beta_y^*$为对撞点振幅函数，$\varepsilon_y$为垂直方向发射度。

σ_ε：能散的分布，$D_y{}^*$：垂直色散函数

束流的分布会使质心系能散增加，但束流尺寸越小，质心系能散也会越小。

这对J/ψ很窄的共振峰通道的事例率提高意义很大

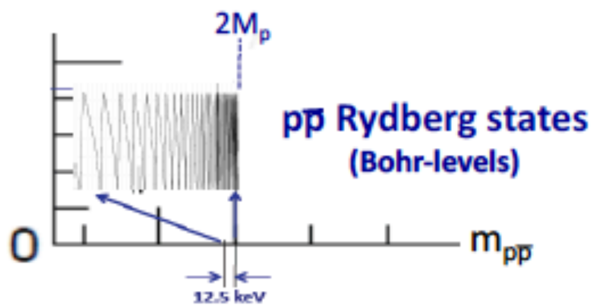
事例率提高因子是

$$\lambda=\sqrt{1+\frac{D_y^{*2}\sigma_\varepsilon^2}{\beta_y^*\varepsilon_y}}$$

λ通常可以设计到大于10

$e^+e^- \rightarrow p\bar{p}$ at threshold

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



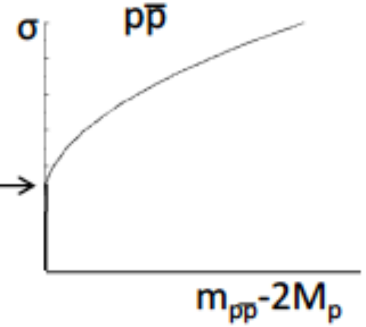
for $p\bar{p}$: $$C = \frac{\pi\alpha/\beta}{1-\exp(-\pi\alpha/\beta)} \rightarrow \frac{\pi\alpha}{\beta}$$

Sommerfeld resummation factor

in point-like approx:

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

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



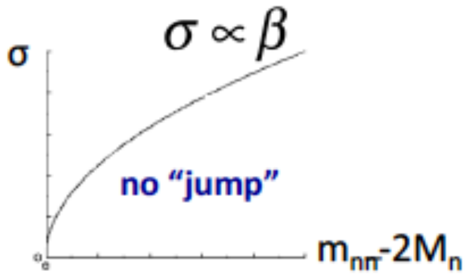
$e^+e^- \rightarrow n\bar{n}$ (or $\Lambda\bar{\Lambda}$) at threshold

Integrated cross section: $$\sigma_{n\bar{n}}(m_{n\bar{n}}) = \frac{4\pi\alpha^2\beta C}{3m_n^2}\left|G_{eff}(m_{n\bar{n}})\right|^2\left(1+1/2\tau\right)$$

no Rydberg states
(Bohr-levels)

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

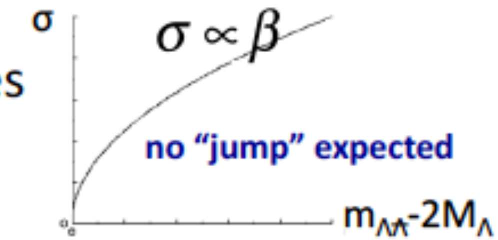
in point-like approx:



$e^+e^- \rightarrow \Lambda\bar{\Lambda}$

Electrically neutral → no Rydberg states

- no Coulomb enhancement



in point-like approx:

Isospin singlet, π-exchange not allowed

- Λ-$\bar{\Lambda}$ molecule is unlikely