Introduction, orientation of the workshop

Hai-Bo LI
Institute of High Energy Physics
July 7th-8th , Fudan University, Shanghai

Roadmap of CPV

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

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 ± 0.15	16.1 ± 1.5
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.29 ± 0.09	12.9 ± 0.9
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.50 ± 0.24	15.0 ± 2.4
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}^+$ (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
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.86 ± 0.11	8.6 ± 1.0
$J/\psi \to \Xi(1530)^0\bar{\Xi}^0$	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

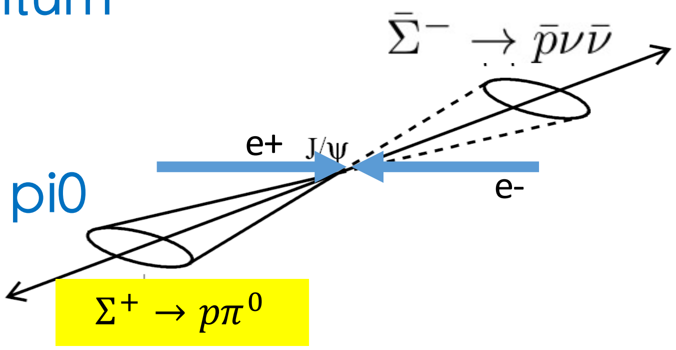
Double tag

Known initial 4-momentum

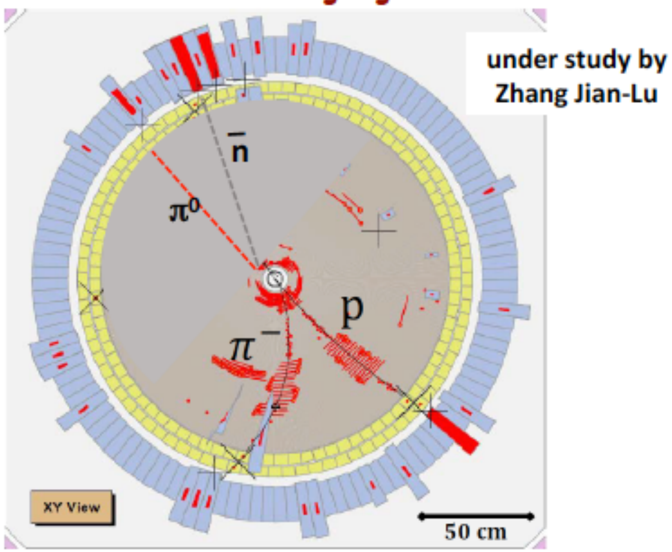
Strongly boosted

Decay with neutron & pi0

Decay with invisibles



use machine-learning algorithms?

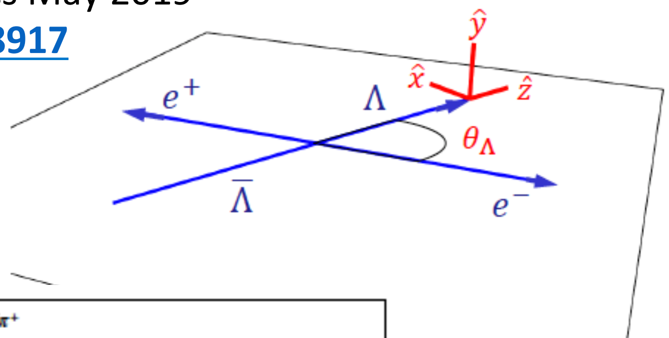


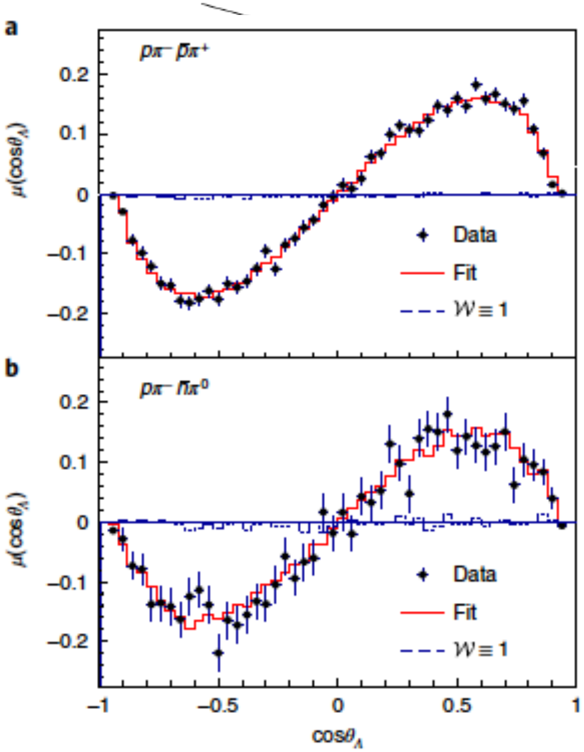
Both hyperons can be reconstructed
and large control sample, and systematic
uncertainties are under control.

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

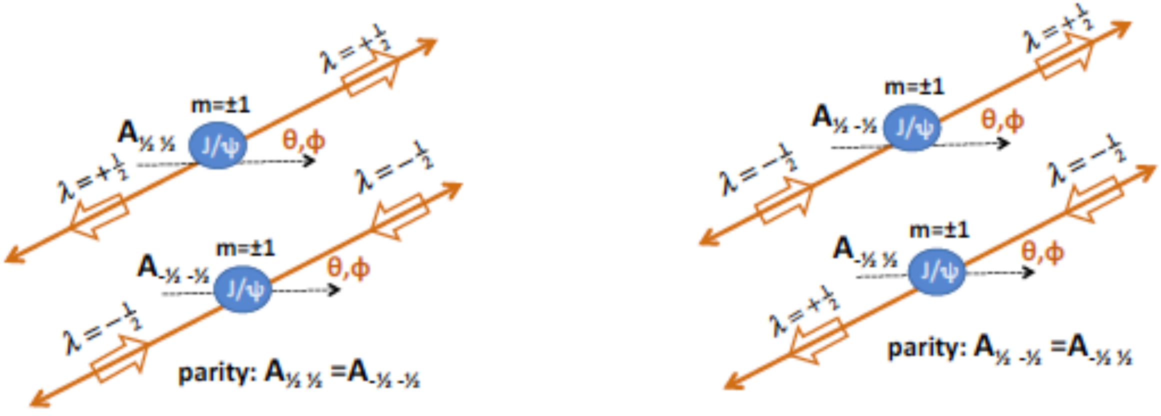
Nature Physics May 2019

arXiv:1808.08917





Transverse polarization was observed which perpendicular to the production plane, the polarizations for hyperon and anti-hyperon are equal and same direction, and modified by the production angle θ_Λ



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

Results from 10% of J/psi data

Nature Physics May 2019
arXiv:1808.08917

420,000 hyperon pairs reconstructed

From Steve Olsen

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

← 1) 3 times better

← 2) increased bt 17%, 7 σ deviation from previous.

← 3) ~3σ from 1.0.

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

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

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

帮助理解$\Delta I = 1/2$疑难

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

10 billion J/ψ – prospects

Nature Physics May 2019
arXiv:1808.08917

Parameters	This work
α_ψ	$0.461 \pm 0.006 \pm 0.007$
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)^\circ$
α_-	$0.750 \pm 0.009 \pm 0.004$
α_+	$-0.758 \pm 0.010 \pm 0.007$
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$

100亿J/ψ数据 – 预期结果

- ← 1） 精度达到 0.002
- ← 精度达到： 0.2 度
- ← 2) 精度达到 0.003
- ← 3) CP破坏的精度： 0.004
- ← 精度达到 0.01
  ~7σ偏离1.0.
  确立$\Delta I = \frac{3}{2}$的贡献

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

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

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

Rare and forbidden decays

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

PERSPECTIVE

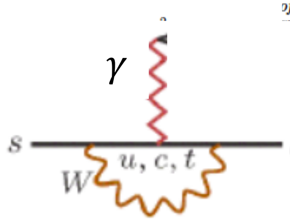
Prospects for rare and forbidden hyperon decays at BESIII

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

SM



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
e", rare

$B_i \to B_f\gamma$	$\mathcal{B}$ ($\times 10^{-3}$)	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.)	–

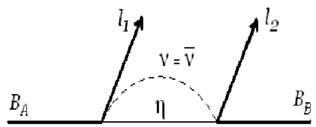
FCNC: radiative decays

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

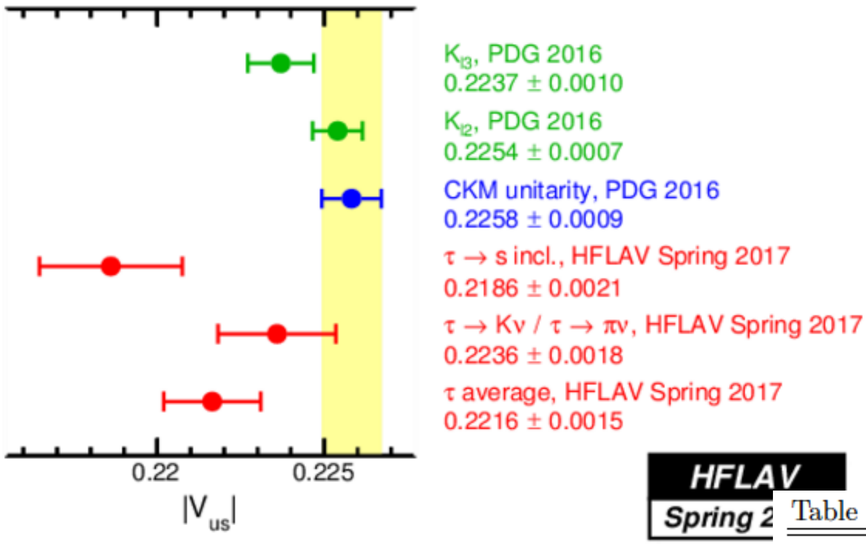
Weak penguin

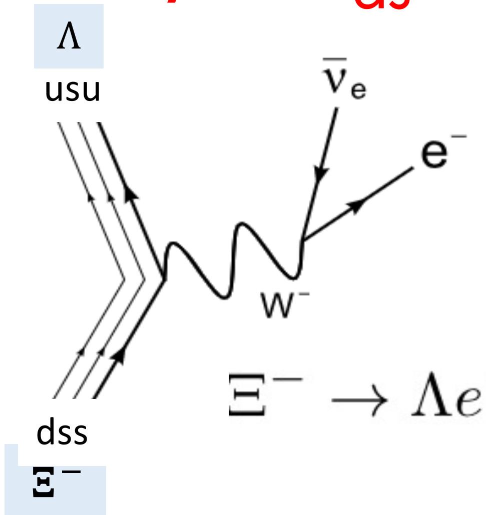
Neutrinoless double beta decays



Most of them never studied.

Semileptonic decays: V_{us}





$$\Xi^- \to \Lambda e^- \bar{\nu}_e$$

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

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

Can we do better ?

Future J/psi factory

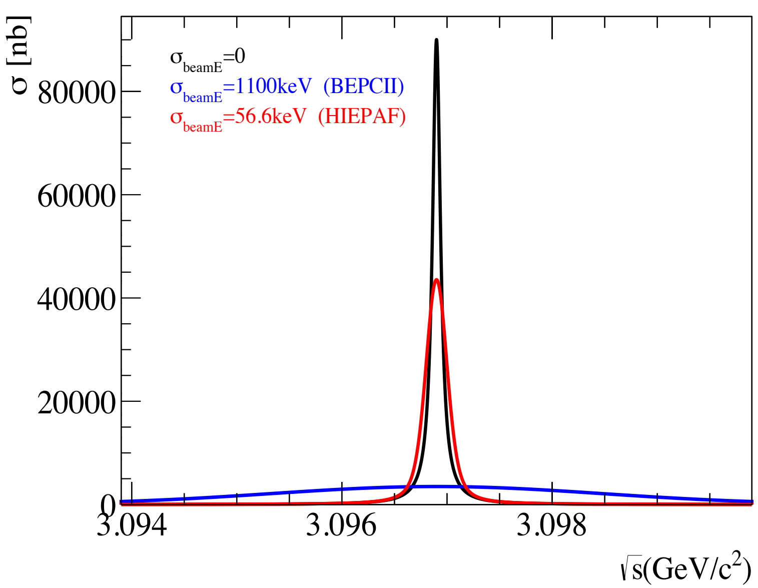
Width of J/ψ： 92 keV

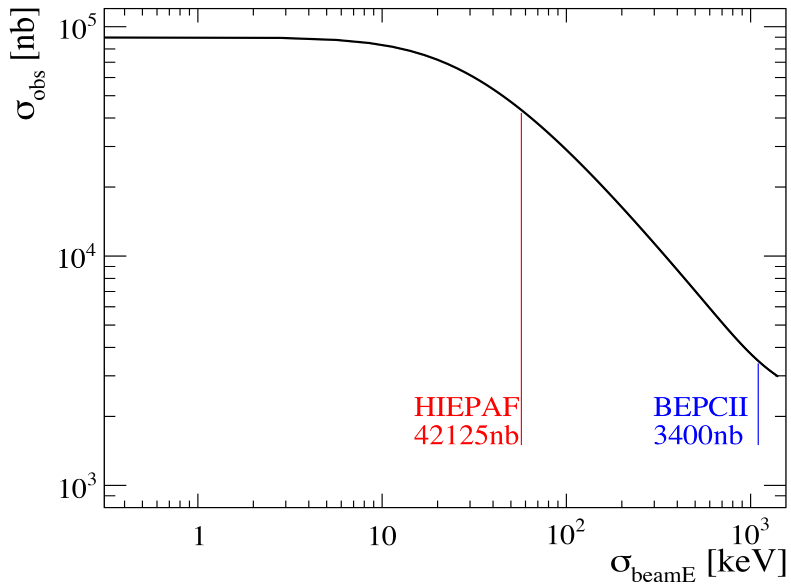
BEPCII: uncertainty of E_{CM} 1.2 MeV → observed cross-section J/ψ: 3400 nb ;

With monochromator optics, uncertainty on E_{CM} : 100 keV

→ observed cross-section of J/ψ : 41000 nb   excited !

The same data taking time, a factor of 1000 increase than that at BEPCII





Future J/psi factory

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

Billion of hyperon pairs produced

Billon of hyperon pairs reconstructed

CPV： $10^{-4} - 10^{-5}$

Challenge SM

In the workshop

- Polarization in various hyperon productions: strong interaction, inner structure?
- Measurements of CPV: observables
- Understand the decays of hyperons: $\Delta I = \frac{1}{2}$ rule
- Rare hyperon decays
- Semileptonic decays: from factors, and Vus

Thank you !