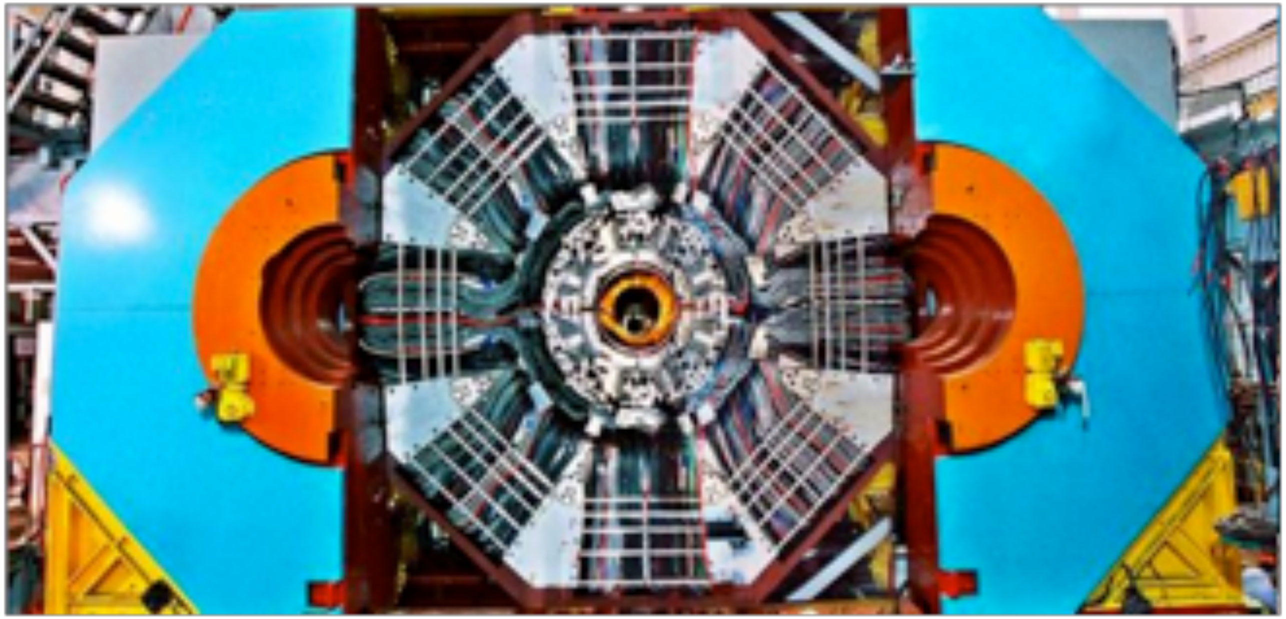
Precision hyperon physics at BESIII



李 海 波

中国科学院高能物理研究所

量子色动力学的未来，机遇与挑战，**2019年11月9-10**

北京大学

恭祝赵老师80华诞生日快乐！

祝您身体健康长寿！

赵老师一直以来关心、支持我国高能物理实验的发展，他最关心高能实验物理的规划和发展方向，亲力亲为。

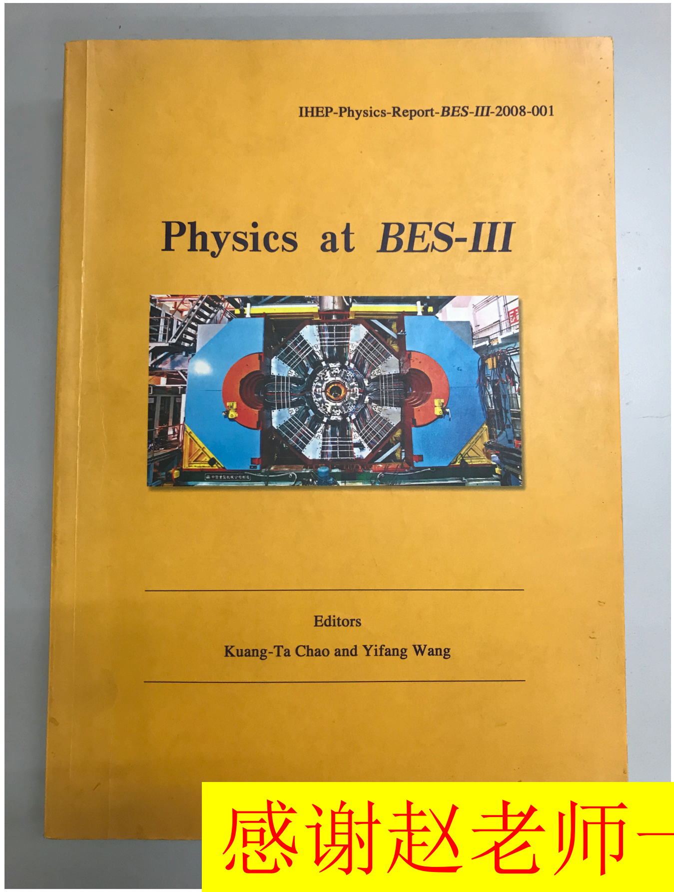
赵老师对物理求真、求实、孜孜不倦。

2006年3月16—20日在厦门，BESIII黄皮书启动会。


2006年3月16—20日在厦门，BESIII黄皮书启动会。
欢迎北京正负电子对撞机物理研讨会专家
祝赵老师生日快乐，身体健康！

From BESIII physics (yellow) book to BESIII white book

2009发表



2019即将发表

White Paper on the Future Physics Programme of BESIII

The BESIII collaboration[¶]

and

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S. Descotes-Genon[f], F.-K. Guo[c,i],
A. A. Petrov[j], J. L. Rosner[h], Z.-Q. Zhang[e]

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

感谢赵老师一直以来对BES实验的支持！

and Fields

Zeitschrift für Physik C Particles and Fields
December 1981, Volume 7, Issue 4, pp 317–320 |

1) Survey of Physics at STCF
质心系能量 6-7.5 GeV
2) CEPC @ Z pole

The (cc)–$(\overline{cc})$ (Diquark-Antidiquark) States in e^+e^- Annihilation

Kuang-Ta Chao
Fermi National Accelerator Laboratory, Batavia, Il 60510, USA, and Department of Physics, Peking University, Beijing, China

Received 10 September 1980

Abstract. The mass spectrum and decay modes of the (cc)–$(\overline{cc})$ states are estimated in a quark-gluon model. We argue that the peculiar resonance-like structures of $R(e^+e^- \to \text{hadrons})$ for $\sqrt{s}=6$–7 GeV may be due to production of the P-wave (cc)–$(\overline{cc})$ states. They are predicted to lie in the range 6.4–6.8 GeV and mainly decay into charmed mesons.

Charmonium molecules or $c\bar{c}q\bar{q}$ states [1] have been proposed to interpret some of the structures in e^+e^- annihilation cross section above 4 GeV. In a recent paper [2] we have studied various $c\bar{c}q\bar{q}$ states in a quark-gluon model. A rough estimate of the spectrum of the P-wave $b\bar{b}q\bar{q}$ states [3] has also been made in anticipation of the experimental possibilities opened up by the CESR machine. In this paper we shall focus

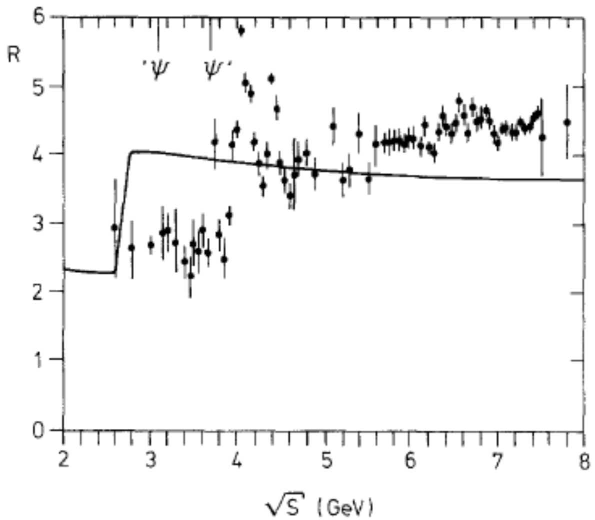


Fig. 1. Data for R from the SLAC-LBL collaboration. The curve is the QCD prediction for R [4]

1) **The** ccbarqqbar states
NPB **169 (1980) 281-306**
2) **The S wave Qqbarqqbar states** in the Adiabatic Approximation
Nucl.Phys. B183 (1981) 435-444
3) ZPC 4, (1981) 317-320

最近一次文章题目含BES

Title:Search for $C = +$ charmonium states in $e^+e^- \to \gamma + X$ at BEPCII/BESIII

Authors:Kuang-Ta Chao, Zhi-Guo He, Dan Li, Ce Meng
(Submitted on 31 Oct 2013)

Abstract: We extend our original study in Ref. [1] on the production of $C = +$ charmonium states $X = \eta_c(1S/2S)$ and $\chi_{cJ}(1P/2P)$ in $e^+e^- \to \gamma + X$ at B factories to the BEPCII/BESIII energy region with $\sqrt{s} = 4.0$-5.0 GeV. In the framework of nonrelativistic QCD factorization, the cross sections are estimated to be as large as 0.1-0.9 pb. The results could be used to search for the missing $2P$ charmonium states or to estimate the continuum backgrounds in the resonance region.

Comments: 10 pages, 2 figures
Subjects: High Energy Physics - Phenomenology (hep-ph)
Cite as: arXiv:1310.8597 [hep-ph]
(or arXiv:1310.8597v1 [hep-ph] for this version)

关于超子物理

PHYSICAL REVIEW D VOLUME 23, NUMBER 1 1 JANUARY 1981

Strangeness −2 and −3 baryons in a quark model with chromodynamics

Kuang-Ta Chao
Rutherford High Energy Laboratory, Chilton, Didcot, Oxon OX11 0QX, England
and Department of Physics, Peking University, Peking, China

Nathan Isgur
Department of Physics, University of Toronto, Toronto M5S 1A7, Canada

Gabriel Karl
Department of Physics, University of Guelph, Guelph N1G 2W1, Canada

(Received 11 June 1980)

We employ a quark model with ingredients suggested by quantum chromodynamics to study strangeness −2 and −3 resonances. Predictions of the spectrum and decay couplings of such states are made based on previous studies of the nonstrange and strangeness −1 sectors.

PHYSICAL REVIEW D VOLUME 41, NUMBER 3 1 FEBRUARY 1990

Baryon magnetic moments with confined quarks

Kuang-Ta Chao
Chinese Center of Advanced Science and Technology (World Laboratory), Beijing, China
and Department of Ph
(Recei

Within a rather general framework for
pression for the effective quark masses a
model with the spin-flavor SU(6) wave fu
to a good agreement between theory and

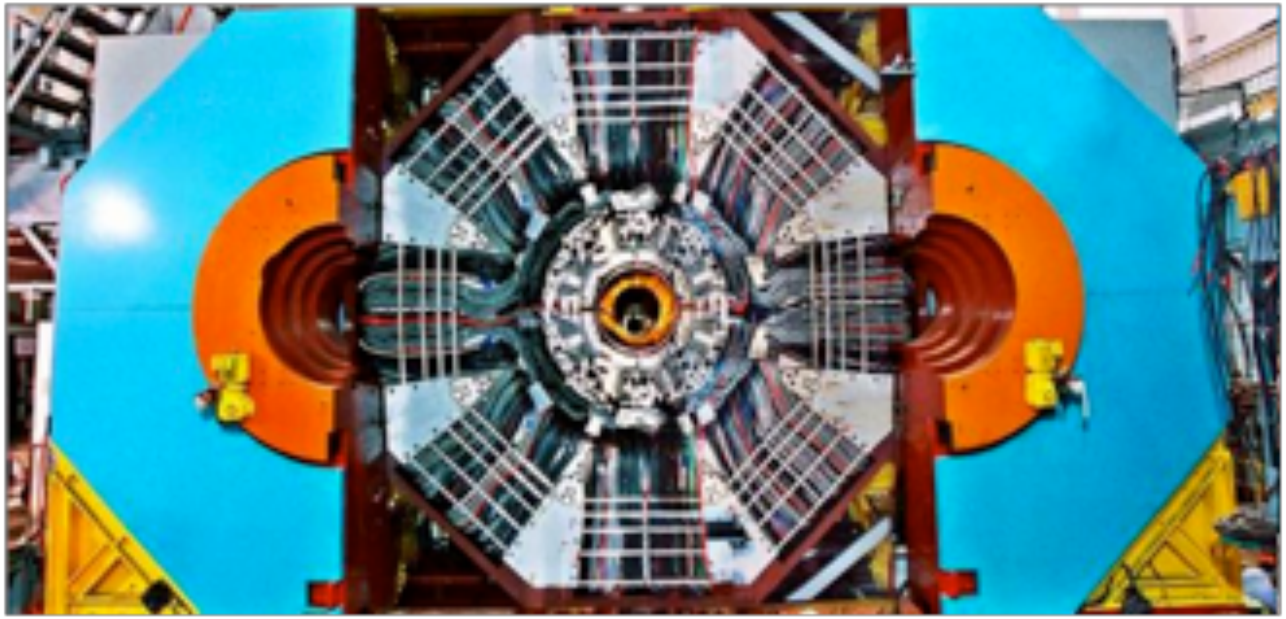
2 *98. Baryon magnetic moments*

References:

1. See, for example, D.H. Perkins, *Introduction to High Energy Physics* (Addison-Wesley, Reading, MA, 1987), or D. Griffiths, *Introduction to Elementary Particles* (Harper & Row, New York, 1987).
2. See, for example, J. Franklin, Phys. Rev. **D29**, 2648 (1984);
H.J. Lipkin, Nucl. Phys. **B241**, 477 (1984);
K. Suzuki, H. Kumagai, and Y. Tanaka, Europhys. Lett. **2**, 109 (1986);
S.K. Gupta and S.B. Khadkikar, Phys. Rev. **D36**, 307 (1987);
M.I. Krivoruchenko, Sov. J. Nucl. Phys. **45**, 109 (1987);
L. Brekke and J.L. Rosner, Comm. Nucl. Part. Phys. **18**, 83 (1988);
K.-T. Chao, Phys. Rev. **D41**, 920 (1990) and references cited therein; Also, see references cited in discussions of results in the experimental papers..

超子和重味重子的磁矩测量很多实验现在还在考虑
赵老师这篇文章被PDG引用

Precision hyperon physics at BESIII



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北京大学

Roadmap of CP violation in flavored hadrons

1980

2008

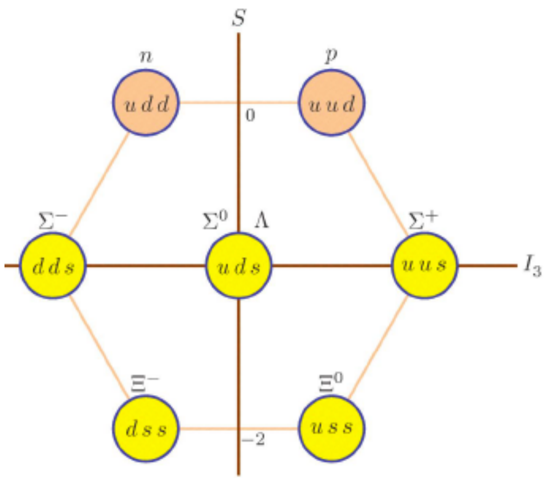
- In 1964, the first CPV was discovered in Kaon ;
- In 2001, CPV in B was established by two B-factories;
- In 2019, CPV discovered in D meson: 10^{-4}, 10^{8} reconstructed D mesons (LHCb)
- All are consistent with CKM theory in the Standard model
- But no evidence was found in baryon system?

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

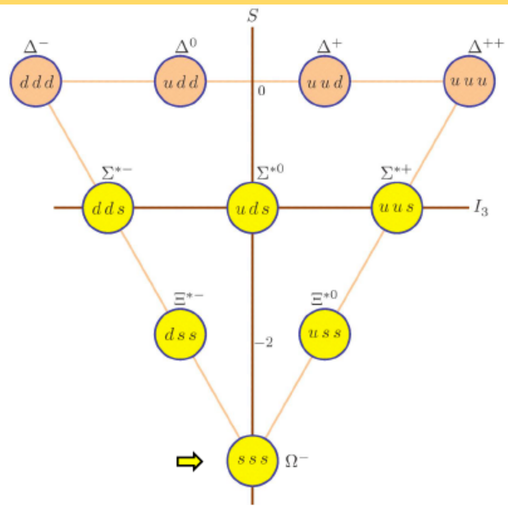
CPV in hyperon decays, # we need?

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 :	$O(10^{-4})$	evidence(2019)	10^8	LHCb
Hyperon :	$O(10^{-4})$	no evidence	$O(10^8)$	***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/ψ decays
- Quantum correlated 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%	3200 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

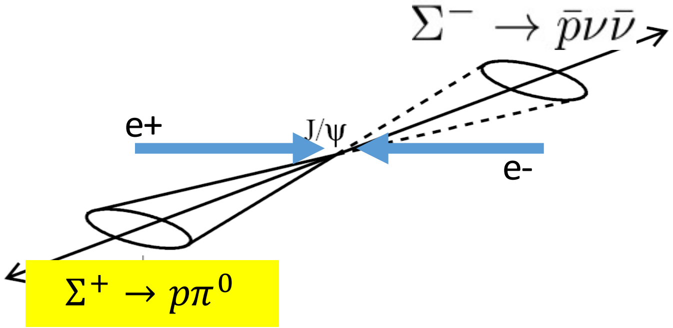
Strongly boosted

Substantial polarization

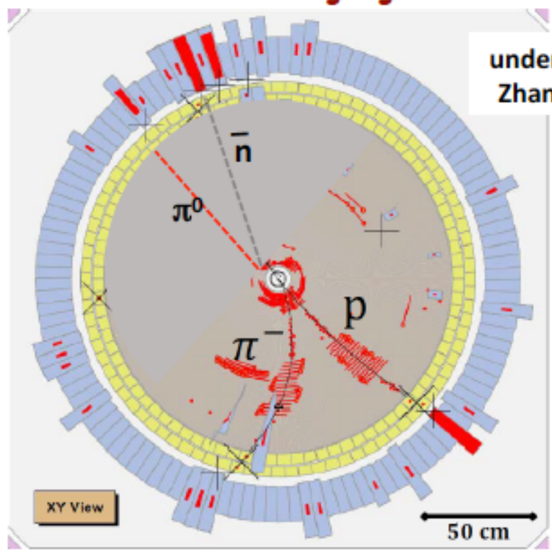
Decay with neutron & π^0

Decay with invisibles

Single tag



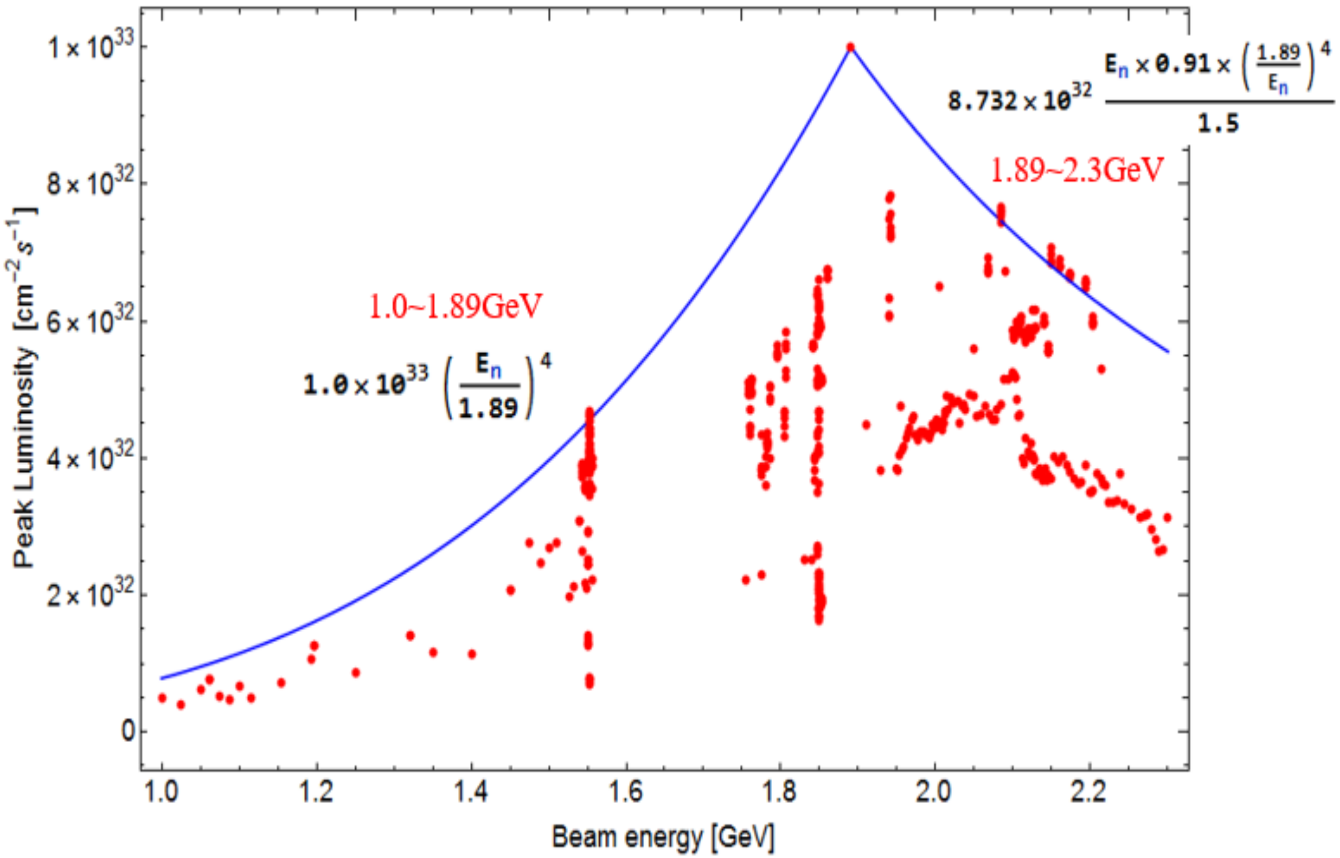
use machine-learning algorithms?



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

BEPCII luminosity optimized for ψ(3770) running

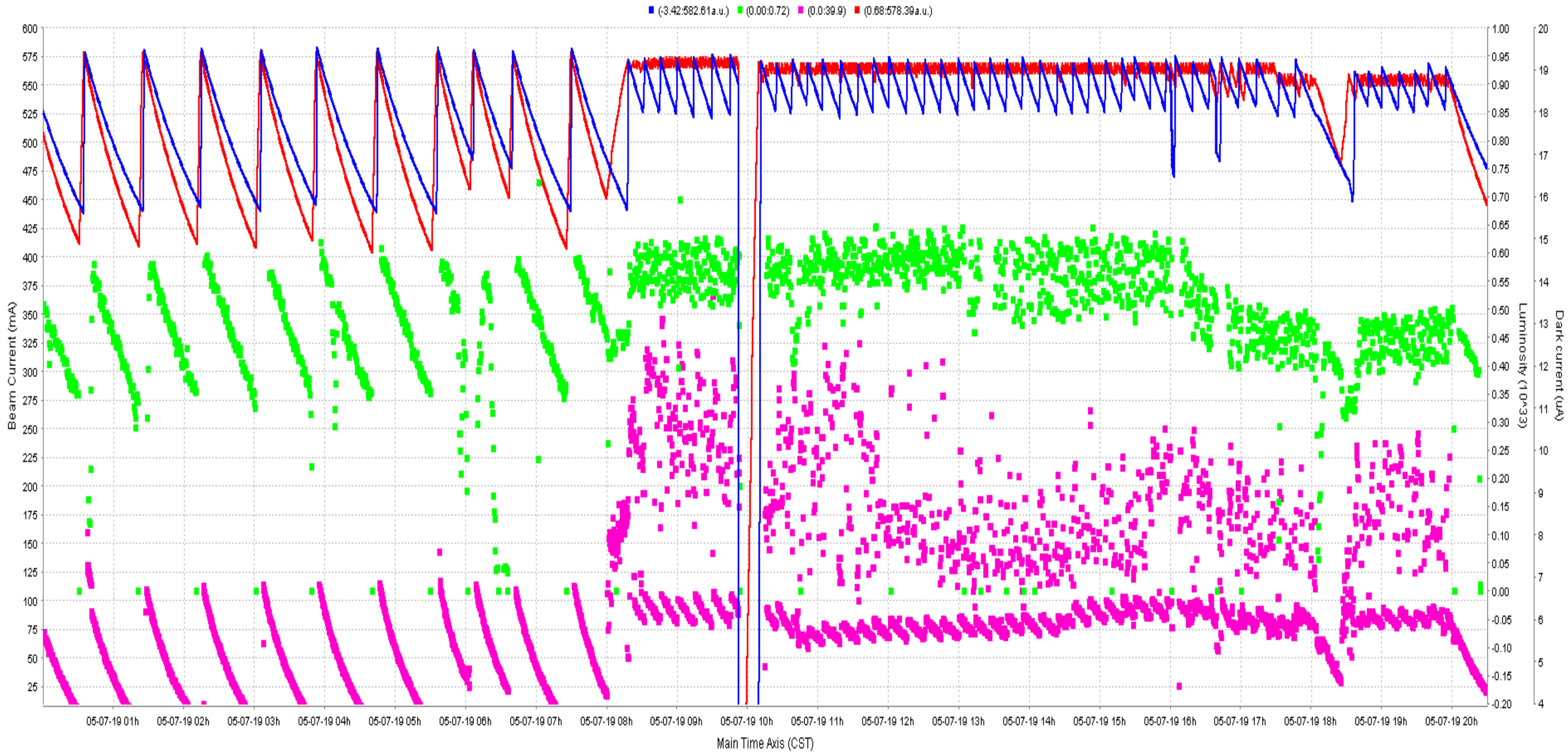
A factor of 2 gain for lattice optimized at J/ψ running



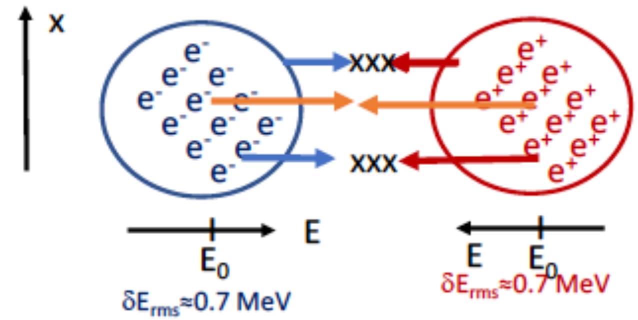
Gain on integrated luminosity from “Topup” injection

12 injections every 12 hours

20% gain on the integrated luminosity

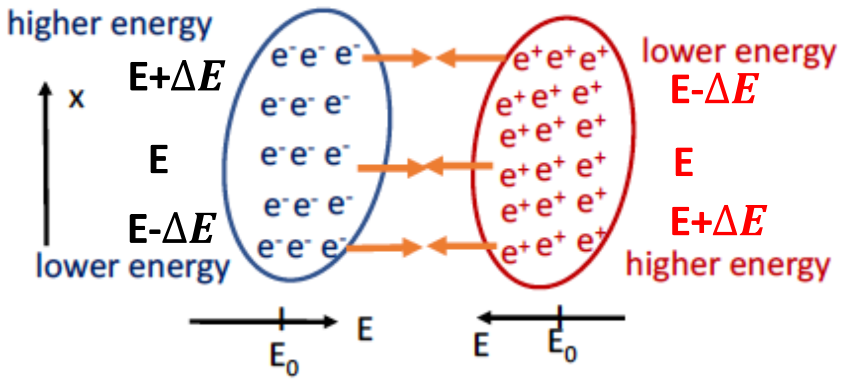


Monochromatic collision: factor of 10 from reduction of e^+e^- CM spread



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

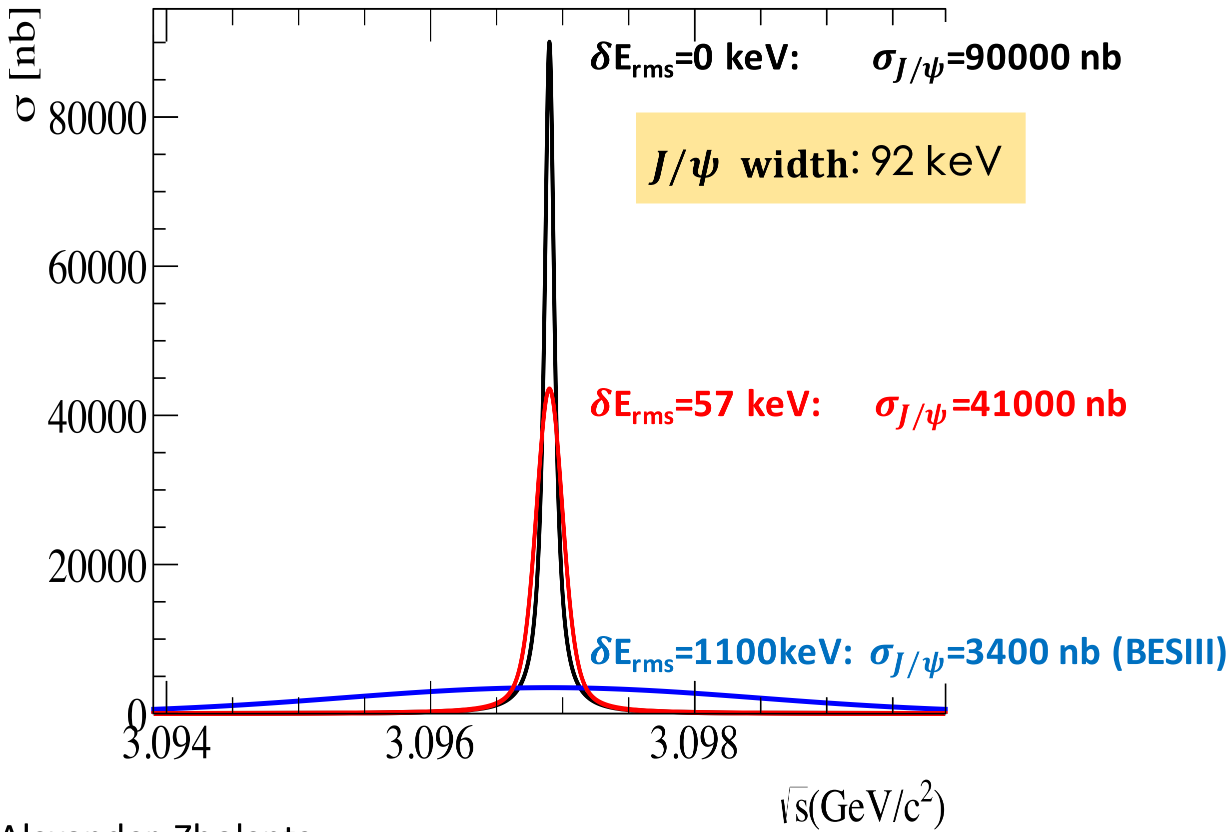
introduce dispersion



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

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

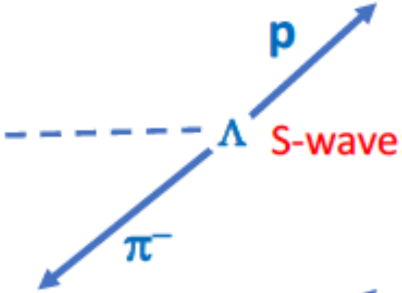
Billion of hyperon pairs reconstructed

CPV： $10^{-4} - 10^{-5}$

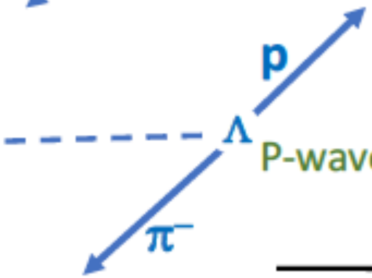
Challenge the SM

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

-- assume CPV is in P-wave --



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

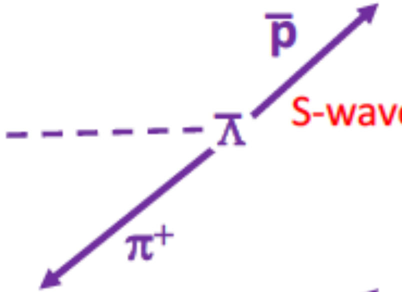


P-wave: $P\, e^{i\delta^P + i\phi_{CP}}$

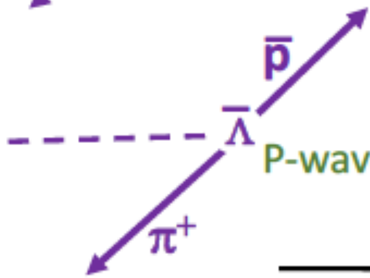
$$e^{-i\delta^S}\left(S + P\, e^{i(\delta^P - \delta^S) + i\phi_{CP}} \right)$$

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

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



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



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

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

α, β *and* γ parameters for hyperon decays

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

1957

Chen Ning Yang

Tsung-Dao Lee

Phys. Rev. 108 1645 (1957)

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

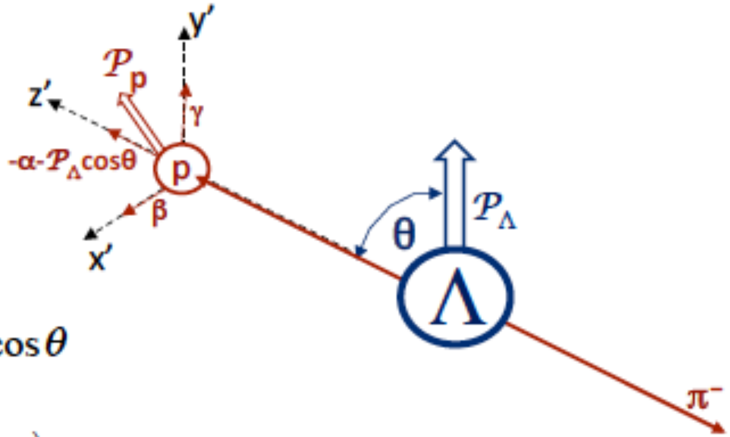
T. D. Lee* and C. N. Yang

Institute for Advanced Study, Princeton, New Jersey

(Received October 22, 1957)

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

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



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

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

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

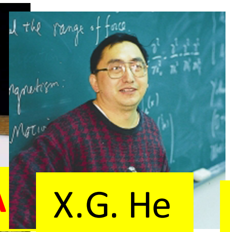
$$\beta = \frac{2\,\mathrm{Im}(S^* P)}{|S|^2 + |P|^2}$$

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

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

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

decay rate difference

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

← $T_{3/2(1/2)}$: 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

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

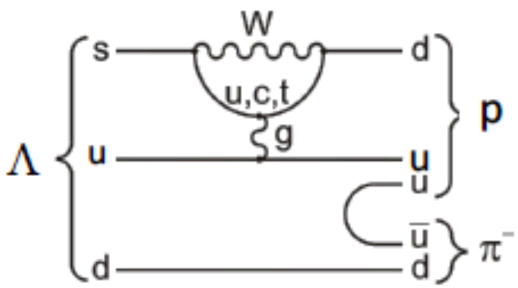
← measures the strong phase

} 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

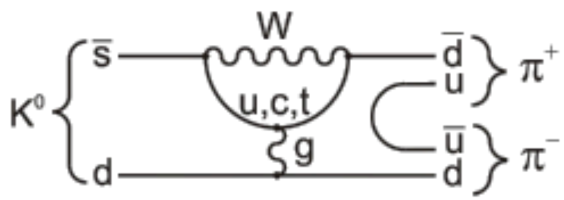


S- and P-waves
(parity violating
& conserving)

$\Lambda \to p\pi^-$	A_{NP}	
S-wave	$<6x10^{-5}$	parity violating
P-wave	$<3x10^{-4}$	parity conserving

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

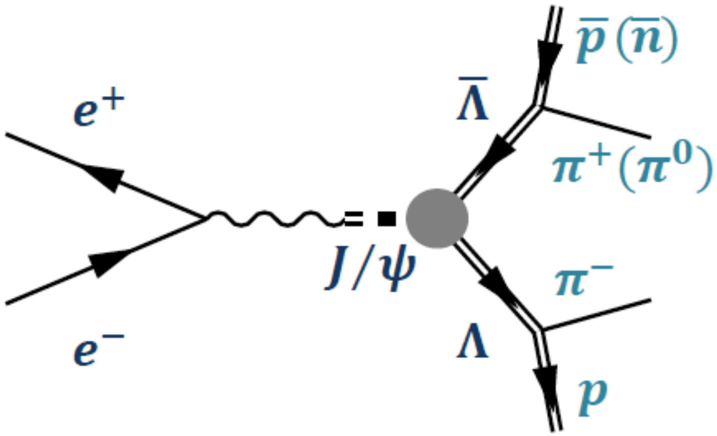
$Re(\varepsilon'/\varepsilon)=(1.6+0.3)x10^{-3}$



S-wave only
(parity violating)

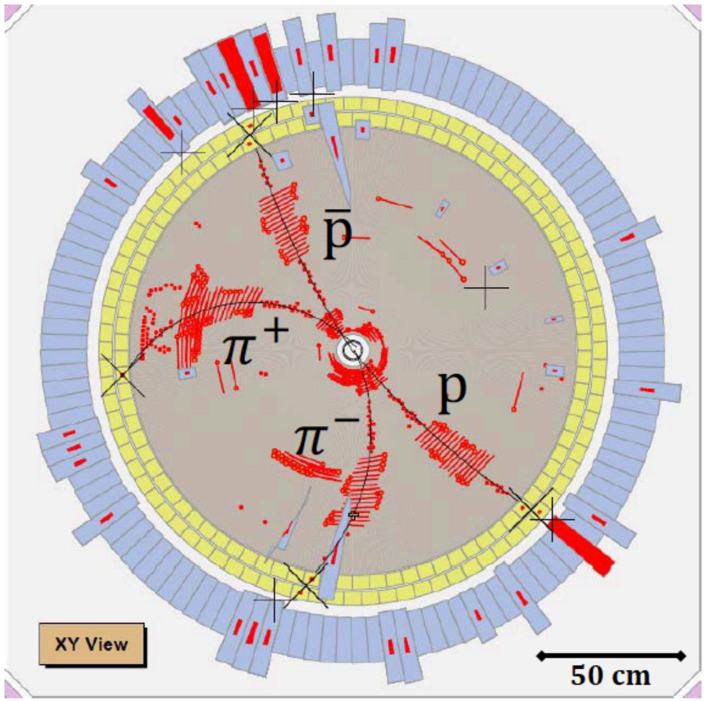
CPV measurement in Kaon system strongly constrains NP in S-waves, but no P-waves. Thus, searches of CPV in hyperon are complementary to those with Kaons.

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:

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

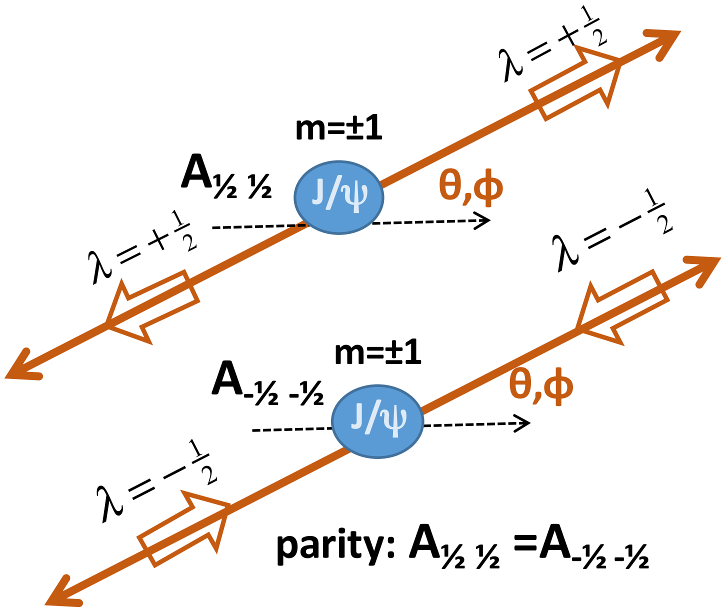
$$\alpha(\bar{\Lambda} \to \bar{p}\pi^+) = \alpha_+$$

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

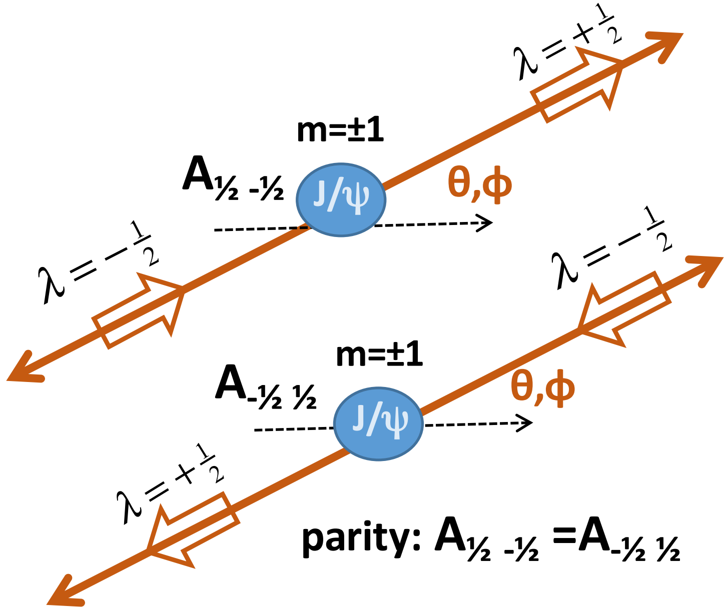
$$\alpha(\Lambda \to n\pi^0) = \alpha_0$$

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

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



parity: $A_{½\,½} = A_{-½\,-½}$

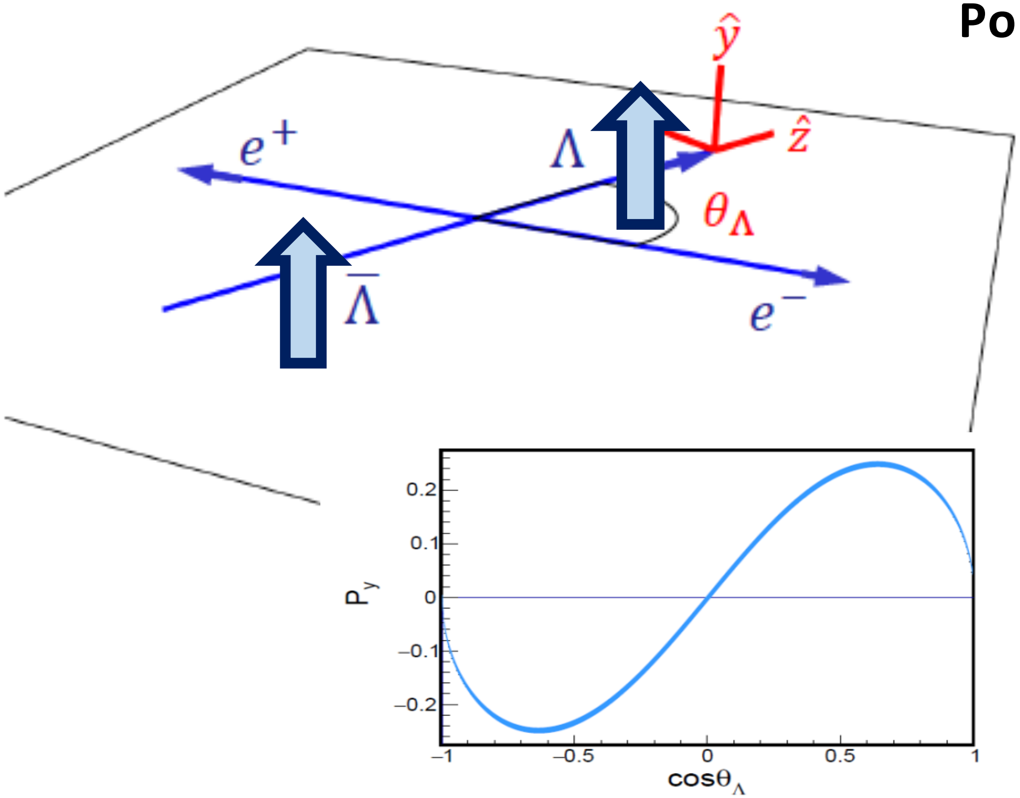


parity: $A_{½\,-½} = A_{-½\,½}$

Δ= 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 $\Delta \neq 0$, Λ and $\bar{\Lambda}$ are transversely polarized



Polarization is:

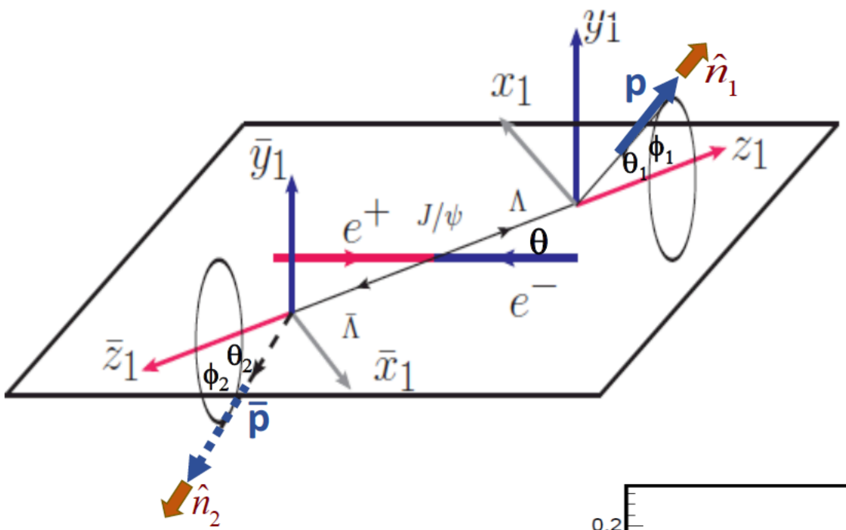
perpendicular to the production plane

θ_Λ-dependent

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

Correlated 5-dim. angular distribution

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



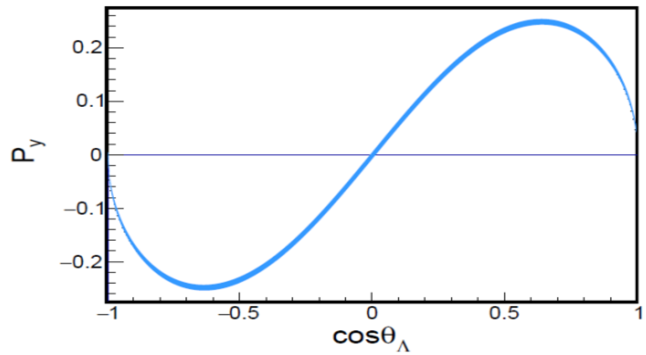
$$+\alpha_-\alpha_+\left[\sin^2\theta_\Lambda\left(n_{1,x}n_{2,x}-\alpha_\psi n_{1,y}n_{2,y}\right)+\left(\cos^2\theta_\Lambda+\alpha_\psi\right)n_{1,z}n_{2,z}\right]$$

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

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

polarization-term

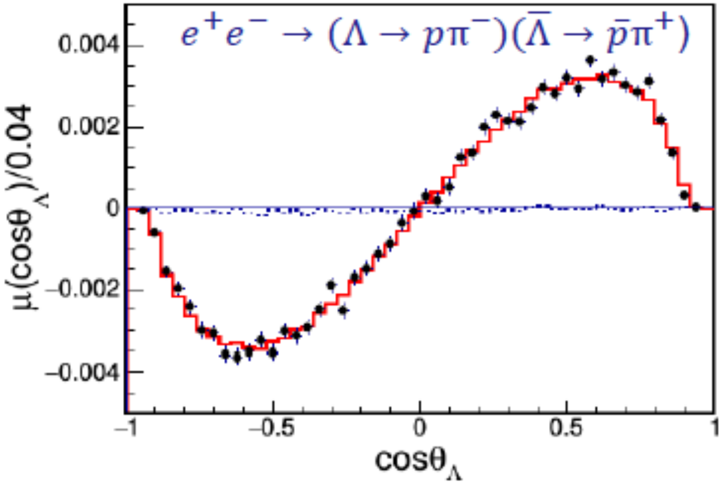
independent α_- and α_+ dependence

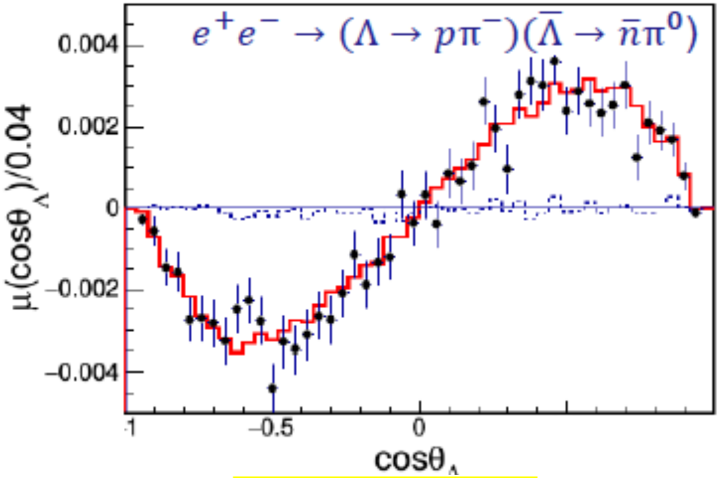


$$P_y(\cos\theta_\Lambda)=\frac{\sqrt{1-\alpha_\psi^2}\,\sin(\Delta\Phi)\cos\theta_\Lambda\sin\theta_\Lambda}{1+\alpha_\psi\cos^2\theta_\Lambda}$$

Fit results

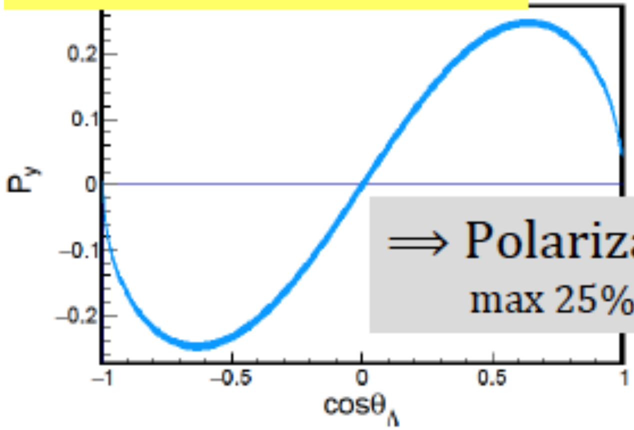
$\Delta\Phi=42.3°\pm0.6°\pm0.5°$



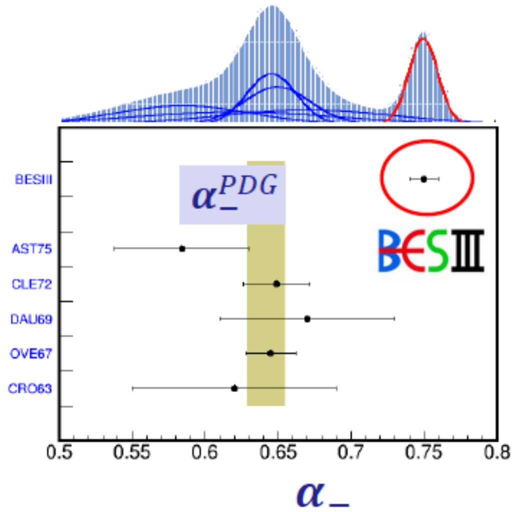


$\Lambda \to p\pi^-$: $\alpha_-=0.750\pm0.009\pm0.004$

$\Delta\Phi=42.3°\pm0.6°\pm0.5°$



$\Longrightarrow$ Polarization:
max 25%



BESIII results with 1.3 billion J/ψ

Nature Physics 15,631-634 2019

arXiv:1808.08917

实验结果用了八分之一的数据

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) 3x precision improvement -same data sample-

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

← 3) ~3σ difference from 1. Is this reasonable?

← 暗示$\Delta I = \frac{3}{2}$的贡献?

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

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

帮助理解$\Delta I = 1/2$疑难

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

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

lifetime=12 ns

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

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

lifetime=0.21 ns

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

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

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

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

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

good agreement

α_- FOR $\Lambda \to p\pi^-$

INSPIRE search

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.750 ±0.009 ±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 $\pi^- p \to K^0\Lambda$ 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 $\overline{\Lambda} \to \overline{p}\pi^+$

INSPIRE search

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
−0.758 ±0.010 ±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 ±0.083 ±0.063	≈ 8.7k	ABLIKIM	2010	BES	$J/\psi \to \Lambda\overline{\Lambda}$
−0.63 ±0.13	770	TIXIER	1988	DM2	$J/\psi \to \Lambda\overline{\Lambda}$

References:

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

PDG2019 updates

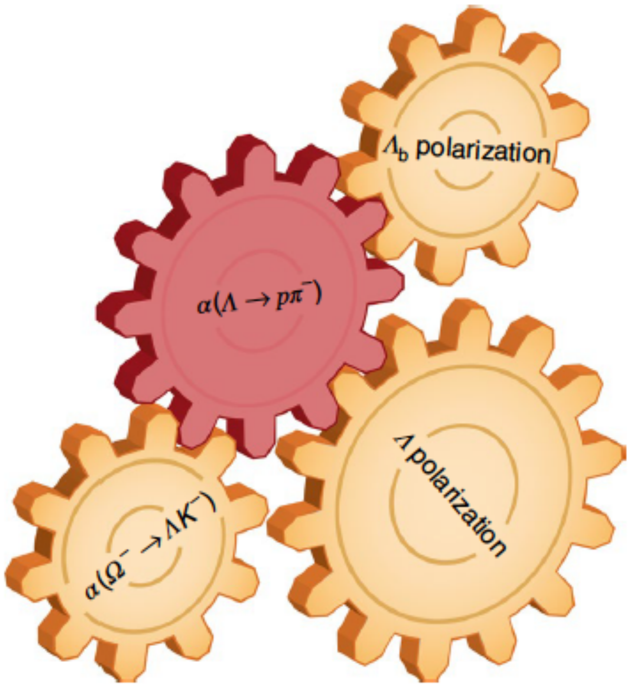
news & views

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

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

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

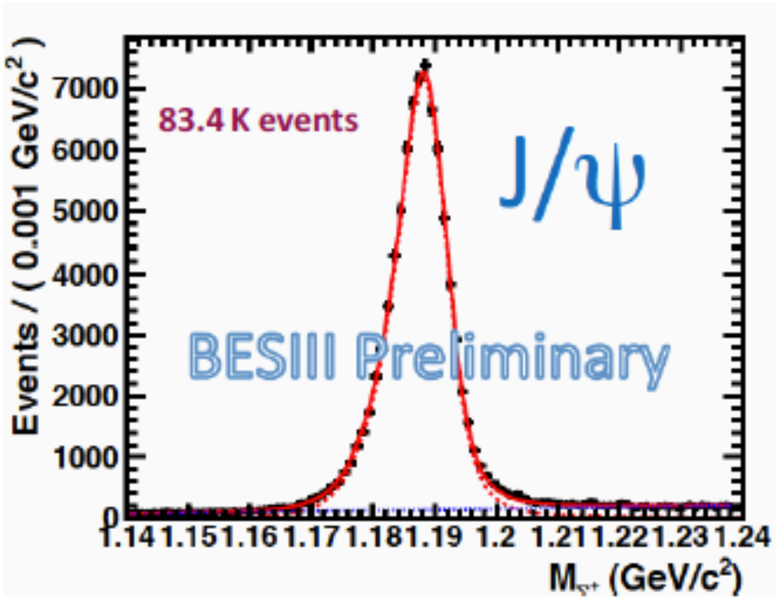
interference is maximum

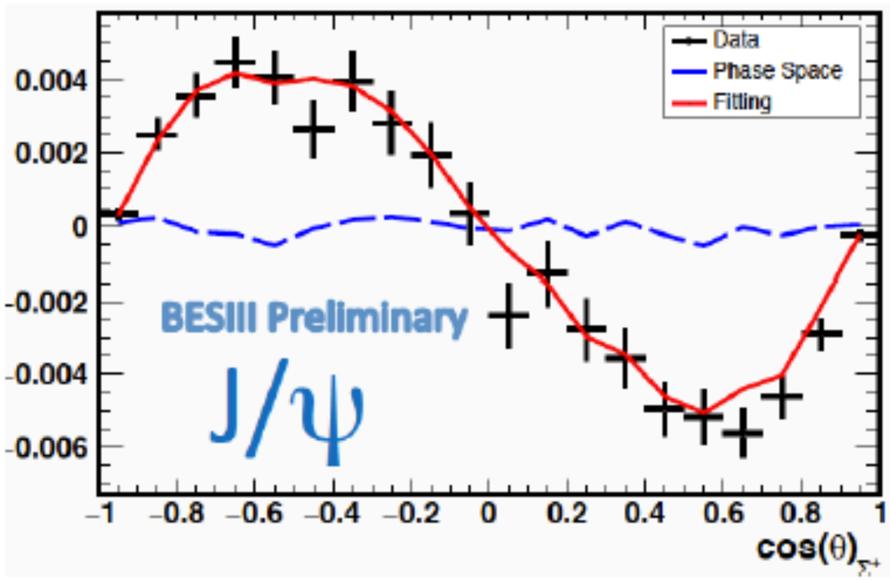
well suited for $\alpha_0+\bar{\alpha}_0/\alpha_0-\bar{\alpha}_0$

if the Σ^+s are polarized

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

the Σ^+s are polarized!





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

-- based on 1.3B J/ψ events --

实验结果用了八分之一的数据

Parameters		These measurements
$\alpha_{J/\psi}$		-0.507 ± 0.006 ± 0.002
$\Delta\Phi_{J/\psi}$		-0.269 ± 0.012 ± 0.006
$\alpha_{\psi(3686)}$		0.676 ± 0.03 ± 0.006
$\Delta\Phi_{\psi(3686)}$		0.376 ± 0.07 ± 0.009
α_0	Fred was right!	-0.999 ± 0.037 ± 0.010
$\bar{\alpha}_0$		0.992 ± 0.037 ± 0.008

BESIII Preliminary

1st measurements

$$A_{CP,\Sigma} = (\alpha_0 + \bar{\alpha}_0)/(\alpha_0 - \bar{\alpha}_0) = -0.015 \pm 0.037 \pm 0.008$$

BESIII Preliminary

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

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

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

From A. Kupas

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

Previous result:

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

BESIII

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

	Events	Error A_Λ	
BESIII(2018)	**$4.2 \cdot 10^5$**	**$1.2 \cdot 10^{-2}$**	**$1.31\ 10^9\ J/\psi$**
BESIII	$3 \cdot 10^6$	$5 \cdot 10^{-3}$	$10^{10}\ J/\psi$ $L=0.47 \cdot 10^{33}$ $\Delta E = 0.9$ MeV
SuperTauCharm	$6 \cdot 10^8$	$3 \cdot 10^{-4}$	$L=10^{35}\ cm^{-2}s^{-1}$ $2 \cdot 10^{12}\ J/\psi$ $\Delta E = 0.9$ MeV
SuperTauCharm + reduced ΔE	$3 \cdot 10^9$	$1.4 \cdot 10^{-4}$	$L=10^{35}\ cm^{-2}s^{-1}$ $10^{13}\ J/\psi$ $\Delta E < 0.9$ MeV??

a guess

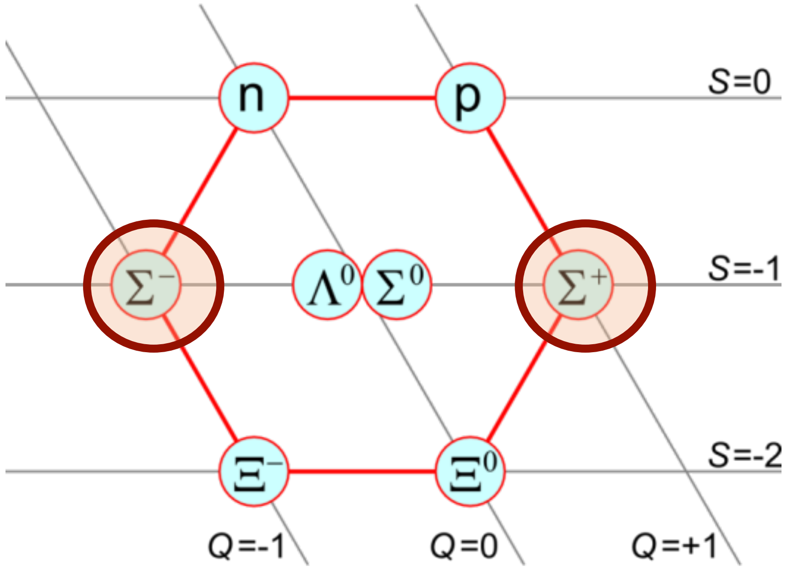
$-3 \times 10^{-5} \leq A_\Lambda \leq 4 \times 10^{-5}$
$-2 \times 10^{-5} \leq A_\Xi \leq 1 \times 10^{-5}$
$-5 \times 10^{-5} \leq A_{\Xi\Lambda} \leq 5 \times 10^{-5}$

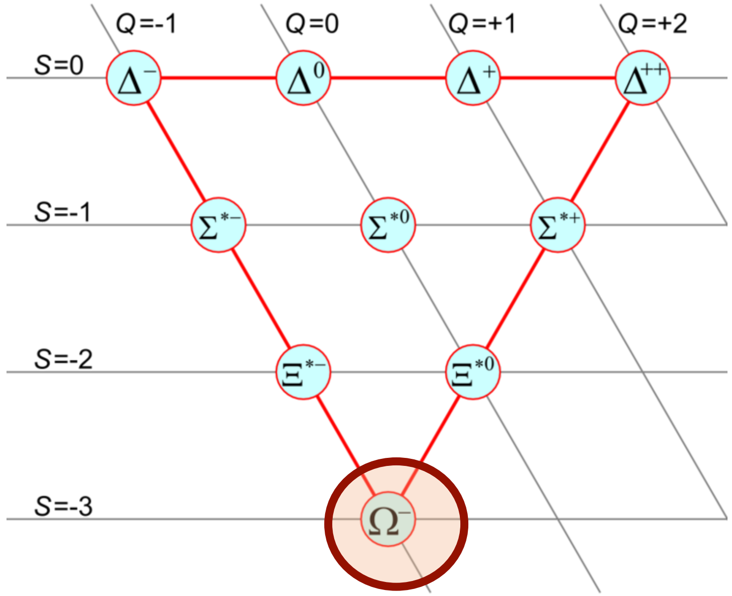
CKM

Tandean,Valencia PRD67, 056001

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

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

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

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

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

final-state polarization difference

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

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

← 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

$\alpha_{-} \approx 0$ ➔ 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 $\Omega^- \to \Lambda K^-$

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 $\Omega^- \to \Xi^0 \pi^-$

VALUE	EVTS	DOCUMENT ID	
+0.09±0.14	1630	BOURQUIN	84

α FOR $\Omega^- \to \Xi^- \pi^0$

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

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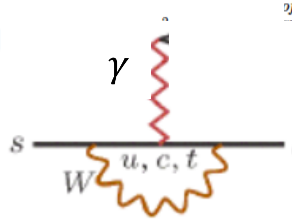
7, 2017; accepted May 8, 2017

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.)	–

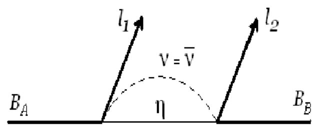
FCNC: radiative decays

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

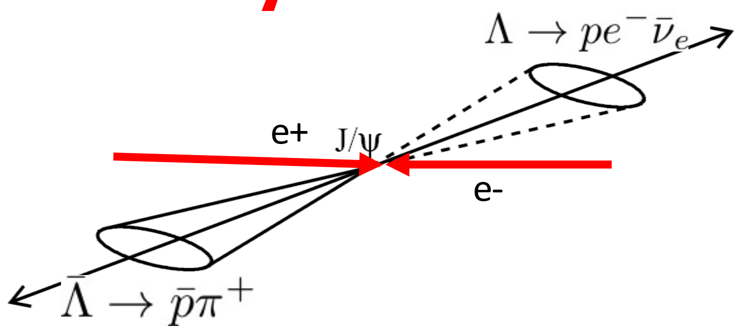
Neutrinoless double beta decays



Most of them never studied.

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



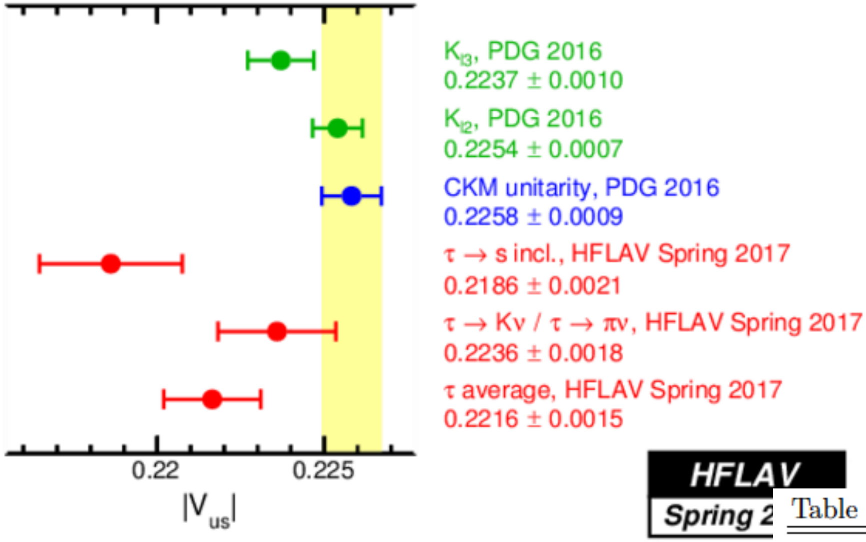
Decay mode	$\mathcal{B}$ ($\times 10^{-4}$)	$\lvert\Delta S\rvert$	$g_1(0)/f_1(0)$
$\Lambda \to pe^-\bar{\nu}_e$	8.32 ± 0.14	1	0.718 ± 0.015
$\Sigma^+ \to \Lambda e^+\nu_e$	0.20 ± 0.05	0	–
$\Sigma^- \to ne^-\bar{\nu}_e$	10.17 ± 0.34	1	-0.340 ± 0.017
$\Sigma^- \to \Lambda e^-\bar{\nu}_e$	0.573 ± 0.027	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}



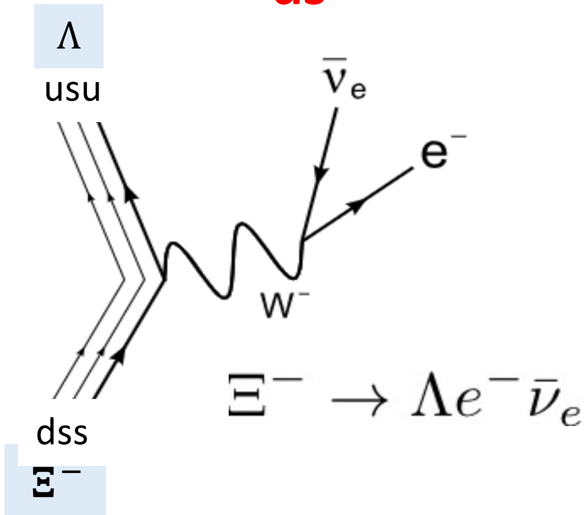


Table 5: Results from V_{us} analysis using measured g_1/f_1 values

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

V_{us} measurements are inconsistent:

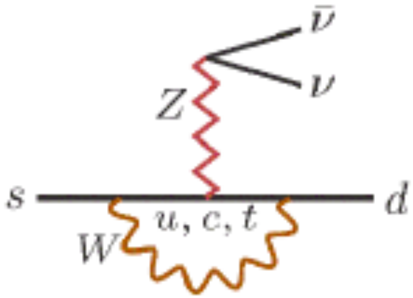
K semileptonic and leptonic decays

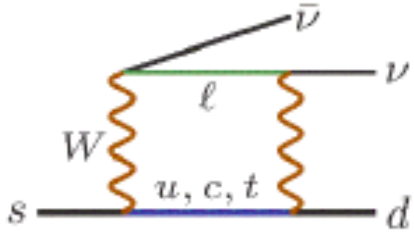
tau decays

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

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}

$\mathcal{B}(\Lambda \to n f \bar{f}) < 6.6 \times 10^{-6}$, $\mathcal{B}(\Sigma^+ \to p f \bar{f}) < 1.7 \times 10^{-6}$

$\mathcal{B}(\Xi^0 \to \Lambda f \bar{f}) < 9.4 \times 10^{-7}$, $\mathcal{B}(\Xi^0 \to \Sigma^0 f \bar{f}) < 1.3 \times 10^{-6}$

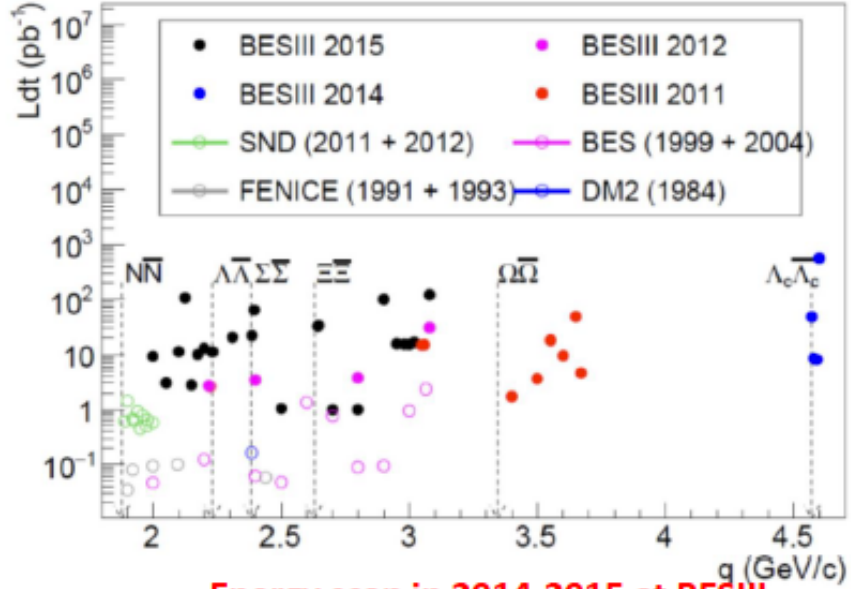
$\mathcal{B}(\Omega^- \to \Xi^- f \bar{f}) < 7.5 \times 10^{-5}$

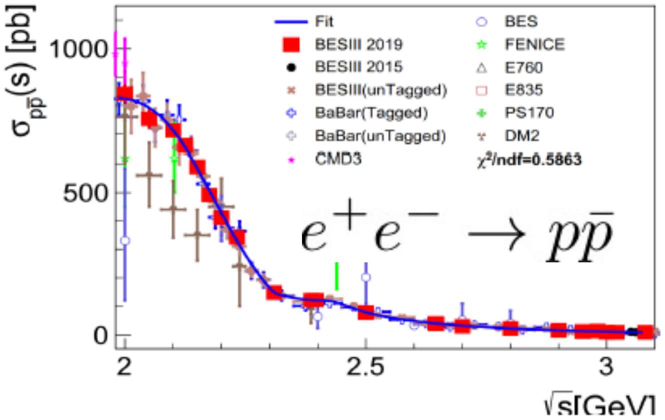
Sensitivities from BESIII 10 billion J/ ψ

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

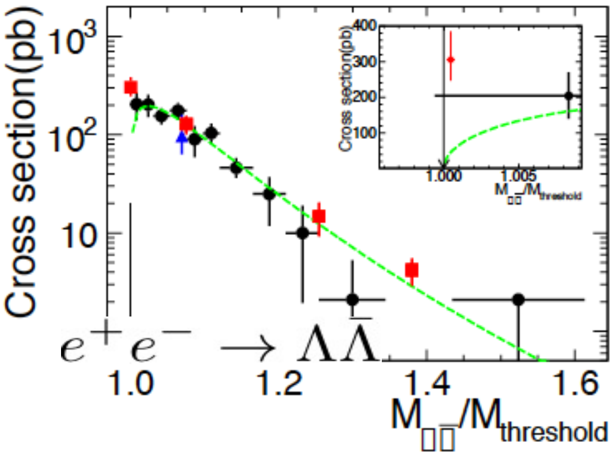
Advantage: data near to the thresholds

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

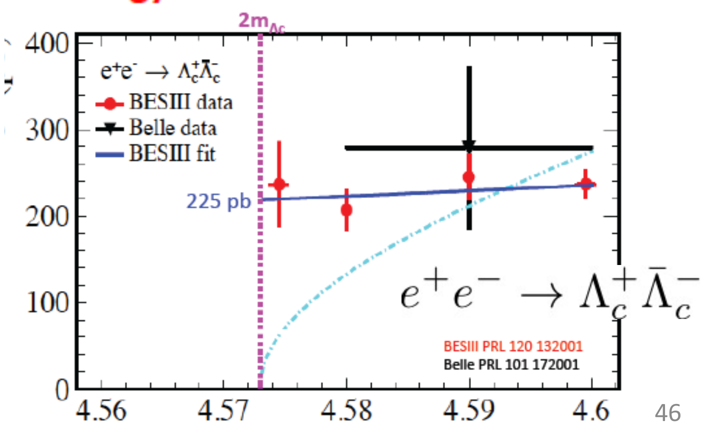




Best precision on σ: 3% (systematic dominant)



Energy scan in 2014-2015 at BESIII



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:

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

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

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

$\Lambda_c \to BP$	Br	Eff. (ϵ)	Expected errors at BES-III ($\times 10^{-2}$)
$\Lambda\pi^+ \to (p\pi^-)\pi^+$	6.8×10^{-3}	0.82	0.85
$\Lambda K^+ \to (p\pi^-)K^+$	3.2×10^{-4}	0.75	4.08
$\Lambda(1520)\pi^+ \to (pK^-)\pi^+$	8.1×10^{-3}	0.75	0.81
$\Sigma^0\pi^+ \to (\Lambda\gamma)\pi^+$	1.0×10^{-2}	0.62	0.80
$\Sigma^0 K^+ \to (\Lambda\gamma)K^+$	4.0×10^{-4}	0.56	4.23
$\Sigma^+\pi^0 \to (p\pi^0)\pi^0$	5.0×10^{-3}	0.60	1.15
$\Sigma^+\eta \to (p\pi^0)(\pi^+\pi^-\pi^0)$	8.2×10^{-4}	0.52	3.06
$\Xi^0 K^+ \to (\Lambda\pi^0)K^+$	2.6×10^{-4}	0.57	5.20

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

Sensitivities of CPV from triple products:

2.3 million Λ_c *pairs at BESIII*

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

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

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

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

$\Lambda_c \to BV$	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:

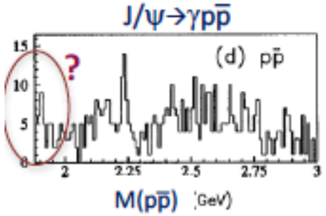
2.3 million Λ_c *pairs at BESIII*

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

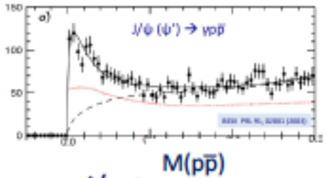
What did I learn during 30 yrs at BES?

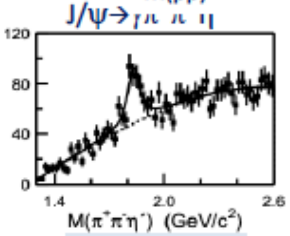
you never have enough J/ψ events

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

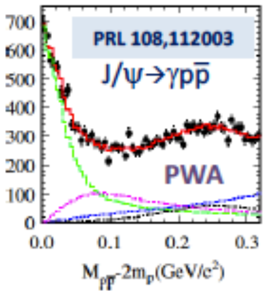


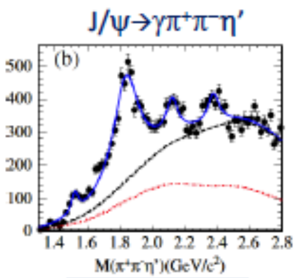
PRL 76, 3502



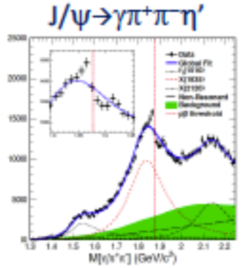


PRL 95,262001





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

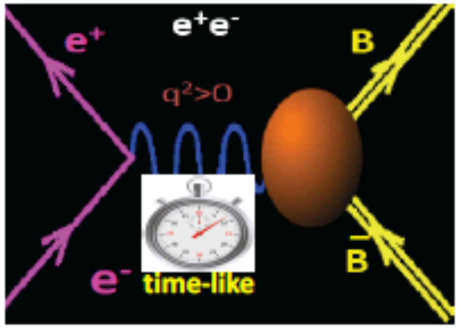
Billion of hyperon pairs reconstructed

CPV: $10^{-4} - 10^{-5}$

Challenge the SM

Time-like form-factors of nucleons and hyperons

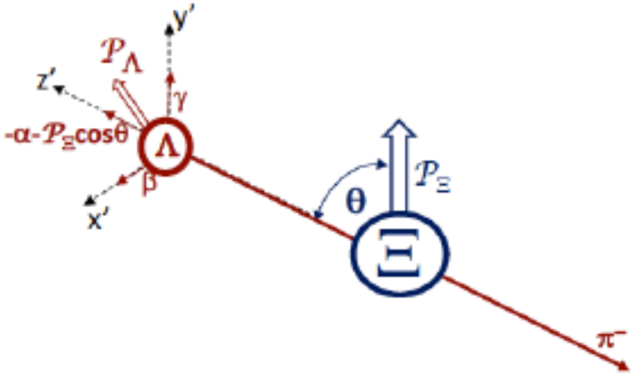
-- 21st century probes of the structure of baryons



World's most sensitive searches for CPV in hyperon decays

-- a new frontier for CPV studies

Steve Olsen



BESII: 58 million

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$10^{13} J/\psi$ 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

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 $\Delta\alpha$ 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 at charmed baryon 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

谢谢！

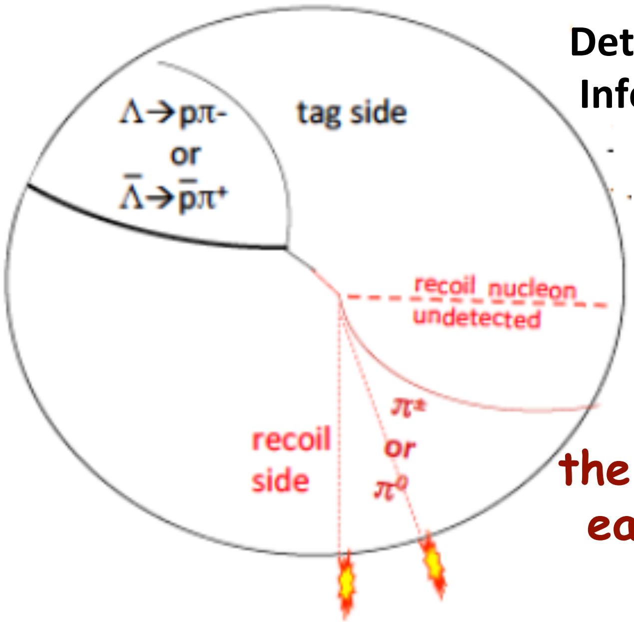
附件

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

use *partial* reconstruction of $J/\psi \to \Lambda\Lambda$?

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 $\Lambda\to p\pi^-$ or $\Lambda\to p\pi^+$ accompanied by a $\pi^\pm$ or π^0
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 $J/\psi \rightarrow \Lambda\Lambda$ events --

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

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

sensitivity is nominally reduced by a factor of ~5

here I used:

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

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

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

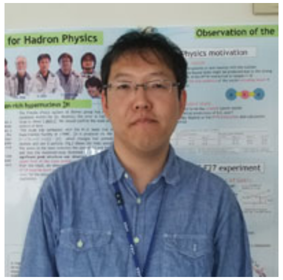
$$\Gamma_{\bar{n}\pi^0} \approx \tfrac{1}{2}\left|T_{1/2}\right|^2 - \left|T_{1/2}\right|\left|T_{3/2}\right|\cos(\Delta_s + \phi_{CP})$$

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

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Corresponding author. E-mail: †*lihb@ihep.ac.cn*

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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

对未来J/ψ工厂的影响

目前BEPCII的亮度，每年可以积累100亿J/ψ样本： $\mathbf{10^{10}}$

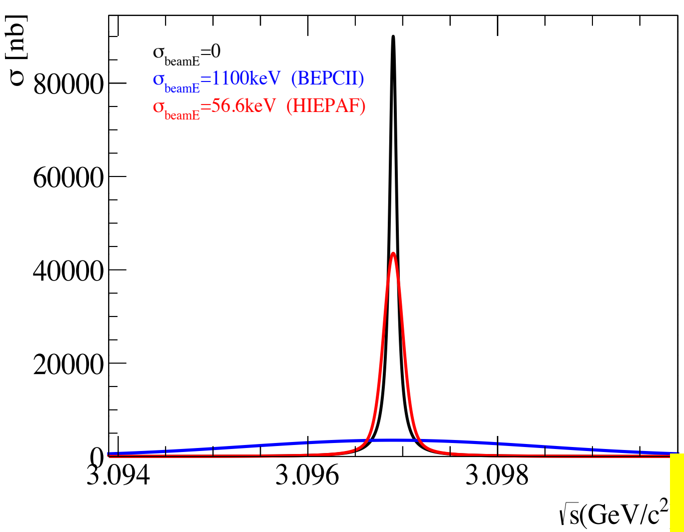
J/ψ 的物理宽度 92 keV

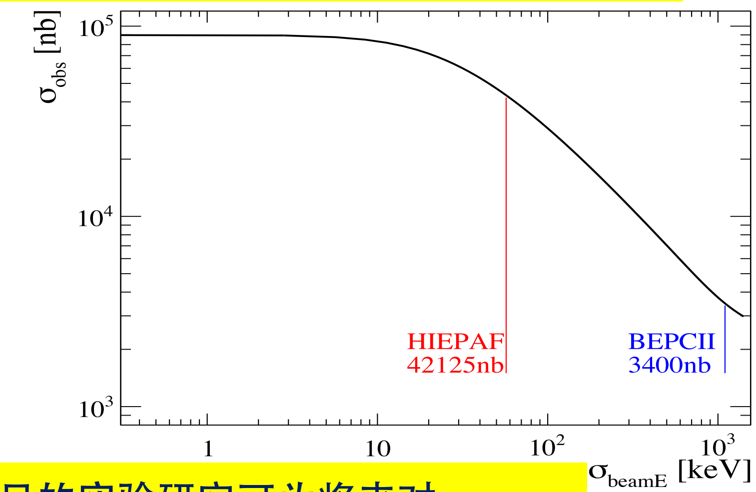
BEPCII上，质心能量的不确定性：1.2 MeV → J/ψ的有效观测截面：3400 nb；

升级后的BEPCII， 利用单色对撞模式，把质心能散降低到100 keV

→ J/ψ 的有效观测截面：41000 nb 这是激动人心的事情！

同样数据获取时间， 在超级J/ψ 工厂上将比BEPCII提高1000倍。





本项目的实验研究可为将来对撞机的设计提供极其有价值的参考，从而可以每年获取$\mathbf{10^{13}}\,J/\psi$

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 $\theta = 0$，$cos(\theta) = 1$， $E_{e^-} = E(1 + \epsilon_{e^-})$， $E_{e^+} = E(1 + \epsilon_{e^+})$，
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

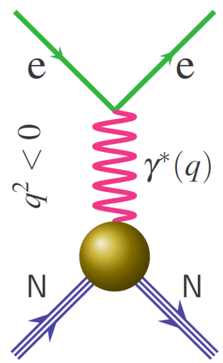
$$\lambda=\sqrt{1+\frac{D_y^{*2}\sigma_\varepsilon^2}{\beta_y^*\varepsilon_y}}$$

λ通常可以设计到大于10

Nucleon Form Factor

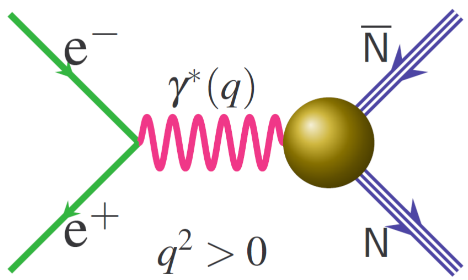
- **Fundamental properties of the nucleon**
  - **Connected to charge, magnetization distribution**
  - **Crucial testing ground for models of the nucleon internal structure**
- **Can be measured from space-like processes (eN) (precision 1%) or time-like process (e^+e^- annihilation) (precision 10%-30%)**

eN → eN



Space-like:
FF real

$e^+e^- \leftrightarrow N\bar{N}, \Lambda\bar{\Lambda}$



Time-like:
FF complex

$e^+e^- \to B\bar{B}$

-- formulae & definitions --

Sachs form factors

$G_E = F_1 + \frac{q^2}{4M^2} F_2$

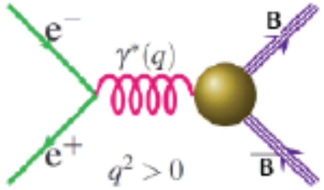
$G_M = F_1 + F_2$

$G_E(0) = Q_N$

$G_M(0) = \mu_N$

Born cross section:

$e^+e^- \leftrightarrow N\bar{N}, \Lambda\bar{\Lambda}, \ldots$



time-like "Sachs" form-factors

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta\, C}{4m_{B\bar{B}}^2}\left[\left(1+\cos^2\theta\right)\left|G_M(m_{B\bar{B}})\right|^2 + \frac{1}{\tau}\sin^2\theta \left|G_E(m_{B\bar{B}})\right|^2\right]$$

$$\tau = \frac{m_{B\bar{B}}^2}{4M_B^2} \qquad \beta = \sqrt{1-\frac{1}{\tau}}$$

Coulomb enhancement factor

$$C_{\text{charged}} = \frac{\pi\alpha/\beta}{1-\exp(-\pi\alpha/\beta)} \xrightarrow{(\beta\to 0)} \pi\alpha/\beta$$

$$C_{\text{neutral}} = 1$$

in point-like approx

integrated cross section:

$$\sigma_{B\bar{B}}(m_{B\bar{B}}) = \frac{4\pi\alpha^2\beta C}{3m_B^2}\left[\left|G_M(m_{B\bar{B}})\right|^2 + \frac{1}{2\tau}\left|G_E(m_{B\bar{B}})\right|^2\right] = \frac{4\pi\alpha^2\beta C}{3m_B^2}\left|G_{eff}(m_{B\bar{B}})\right|^2\left(1+1/2\tau\right)$$

"effective" form factor

effective form factor:

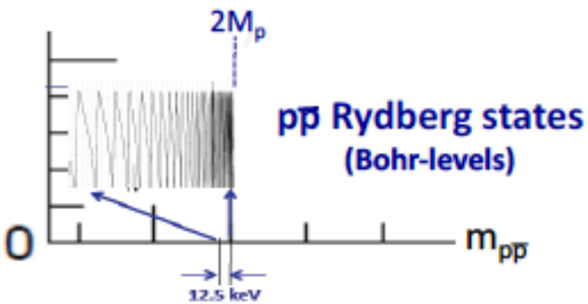
$$\left|G_{eff}\right|^2 = \frac{\left|G_M\right|^2 + \frac{1}{2\tau}\left|G_E\right|^2}{1+\frac{1}{2\tau}}\sigma_{B\bar{B}}(m_{B\bar{B}}) \;\Rightarrow\; \left|G_{eff}\right| = \left(\frac{3m_{B\bar{B}}^2}{\pi\alpha^2\beta C\left(1+\frac{1}{2\tau}\right)}\right)^{\frac{1}{2}}\sqrt{\sigma_{B\bar{B}}}$$

analyticity: $G_M(4M_B^2) = G_E(4M_B^2) \;\Rightarrow\; G_{eff}(4M_B^2) = G_M(4M_B^2)$

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

Integrated cross section:

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



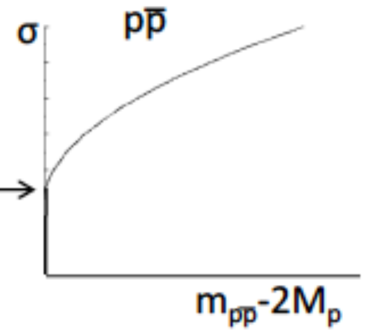
$$\text{for } p\bar{p}\text{: } C = \frac{\pi\alpha/\beta}{1-\exp(-\pi\alpha/\beta)} \to \frac{\pi\alpha}{\beta}$$

Sommerfeld resummation factor

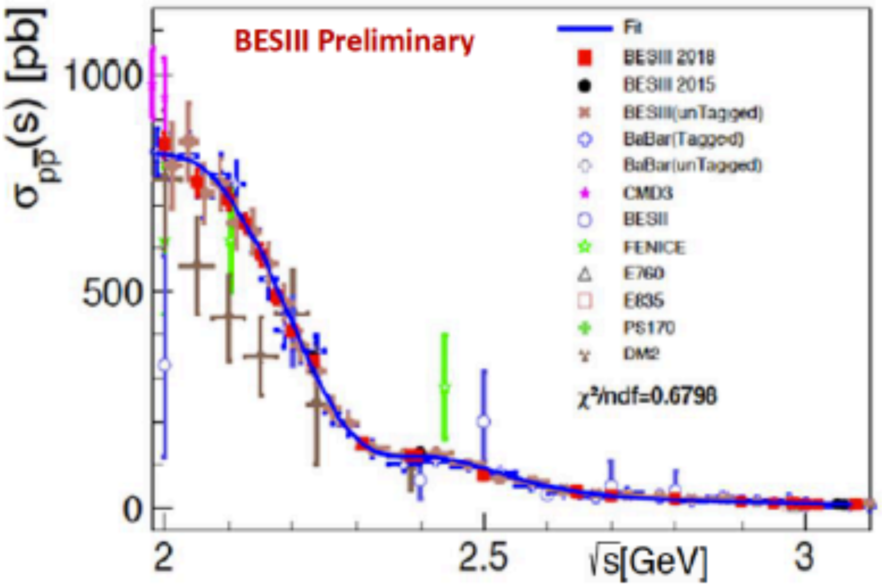
in point-like approx:

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

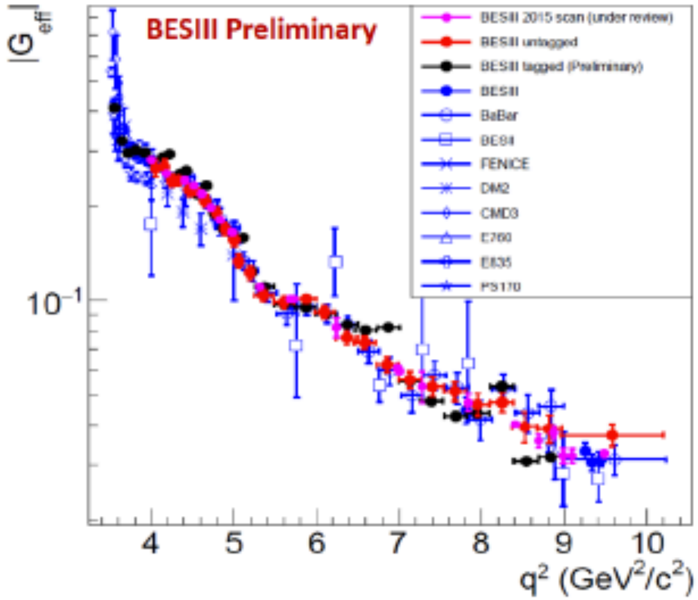
$$\approx 0.85\text{nb}\left|G_{eff}(2M_p)\right|^2 \longrightarrow$$



$G_{eff}(q^2)$



BESIII Preliminary
$\sigma_{p\bar{p}}(s)$ [pb]
1000
500
0
2
2.5
3
$\sqrt{s}$[GeV]
Fit
BESIII 2018
BESIII 2015
BESIII(unTagged)
BaBar(Tagged)
BaBar(unTagged)
CMD3
BESII
FENICE
E760
E835
PS170
DM2
χ^2/ndf=0.6798



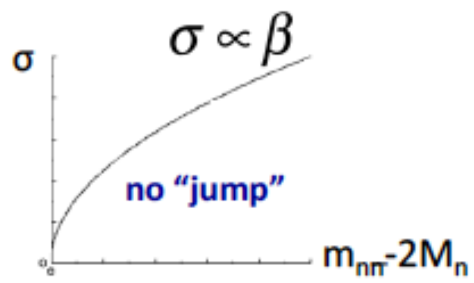
BESIII Preliminary
$|G_{eff}|$
10^{-1}
4
5
6
7
8
9
10
q^2 (GeV^2/c^2)
BESIII untagged
BESIII tagged (Preliminary)
BESIII
BaBar
BES
FENICE
DM2
CMD3
E760
E835
PS170

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

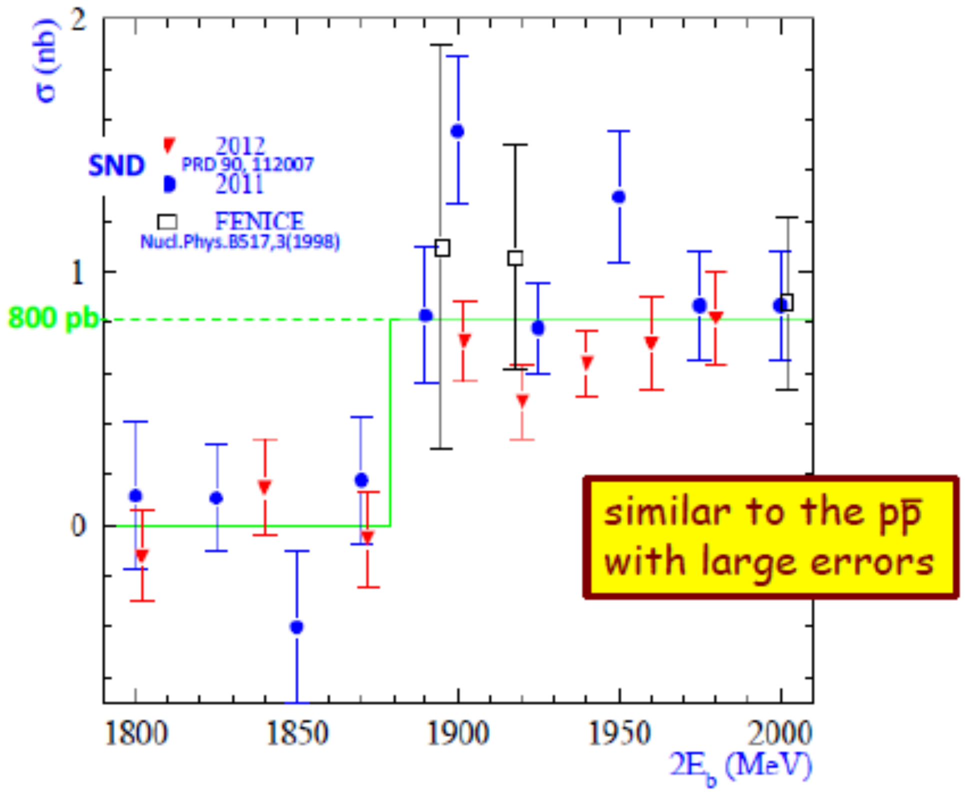
Integrated cross section: $$\sigma_{n\bar{n}}(m_{n\bar{n}}) = \frac{4\pi\alpha^2\beta C}{3m_n^2}\left|G_{eff}(m_{n\bar{n}})\right|^2(1+1/2\tau)$$

no Rydberg states
(Bohr-levels)

for $n\bar{n}$ ($\Lambda\bar{\Lambda}$): $C = 1$
in point-like approx:



indications of σ($e^+e^- \rightarrow n\bar{n}$) jump at $E_{cm}=2m_n$

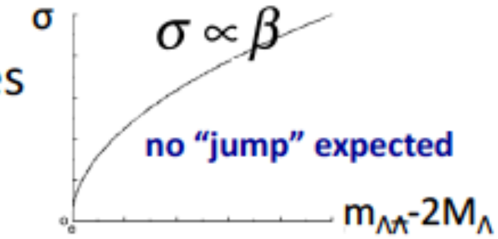


BESIII results will be reported soon

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

Electrically neutral → no Rydberg states

- no Coulomb enhancement



in point-like approx:

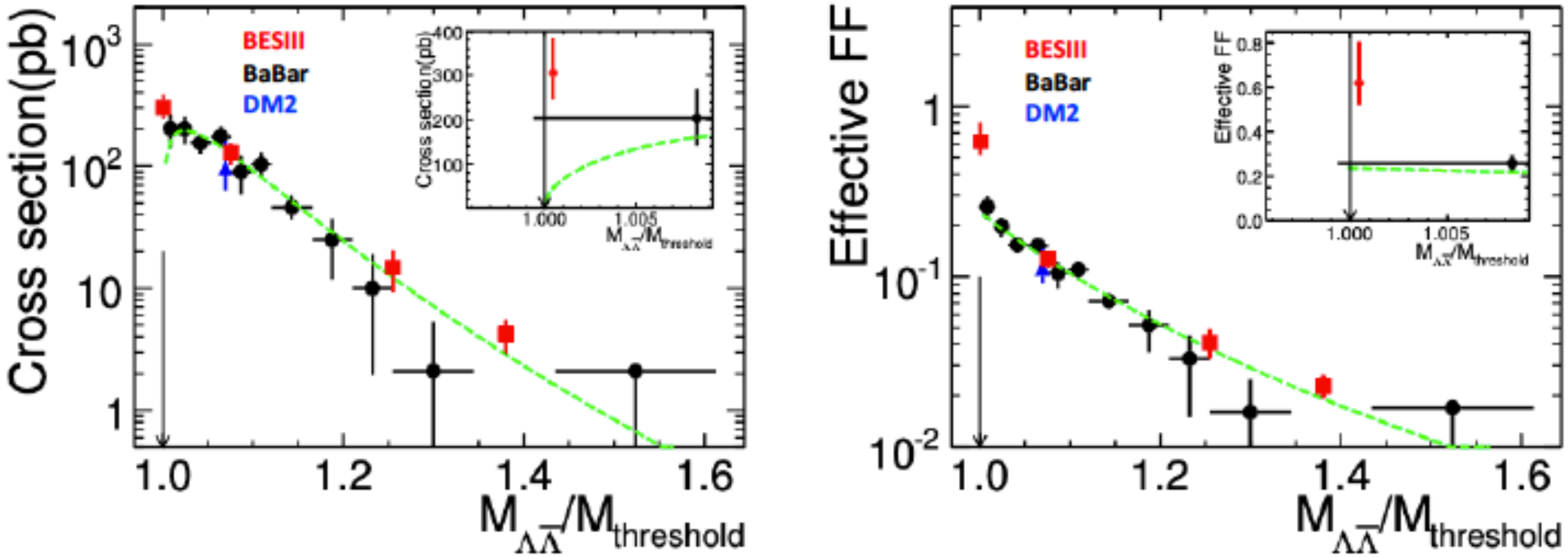
Isospin singlet, π-exchange not allowed

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

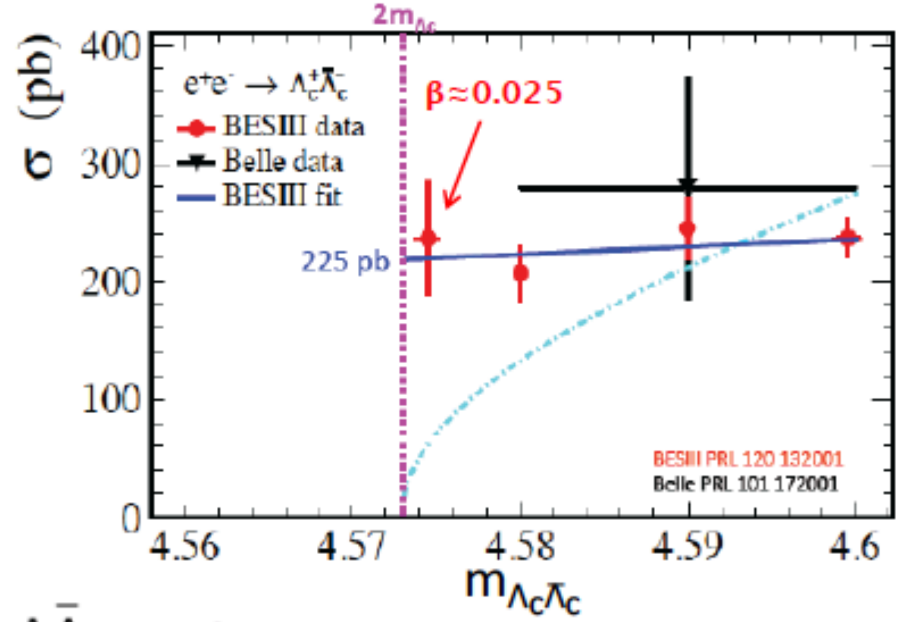
$\sigma(e^+e^- \to \Lambda\bar{\Lambda})$ & G_{eff} at threshold

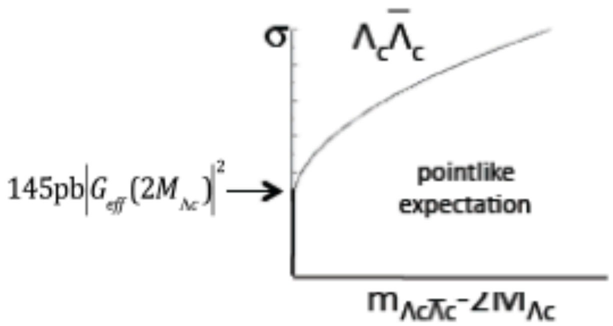
$$\sigma_{\Lambda\bar{\Lambda}}(m_{\Lambda\bar{\Lambda}}) = \frac{4\pi\alpha^2\beta}{3m_\Lambda^2}\left|G_{eff}(m_{\Lambda\bar{\Lambda}})\right|^2(1+1/2\tau)$$

no sign of $\sigma \propto \beta$ threshold behaviour



$\sigma(e^+e^- \rightarrow \Lambda_c^+\Lambda_c^-)$ @~threshold





≈225 pb "jump" at threshold

≈consistent with $\delta\sigma \approx$ 145 pb $|G_{eff}|$=1 pointlike jump

but ≈flat after that (like pp)