BNV/LNV Searches in Charmonium Decays at BESIII

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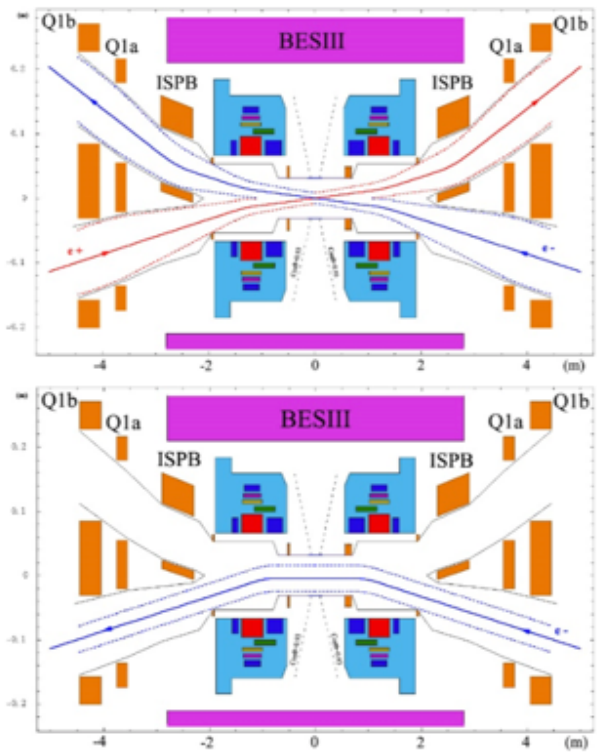
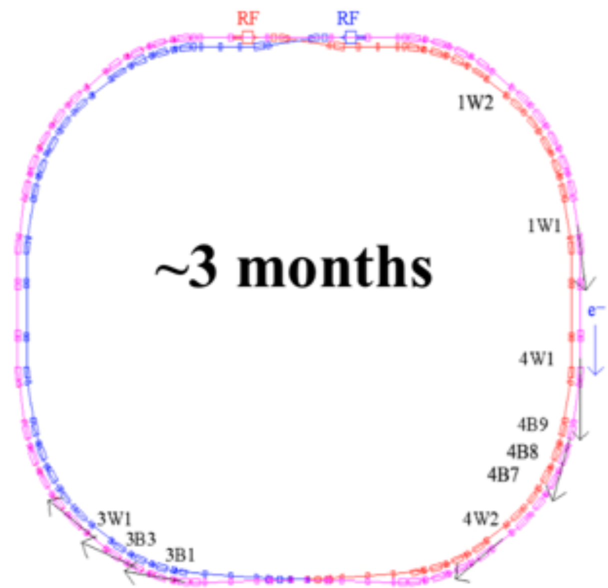
Outline

01 Introduction: BEPCII/BESIII experiment

01 Introduction: BEPCII Collider

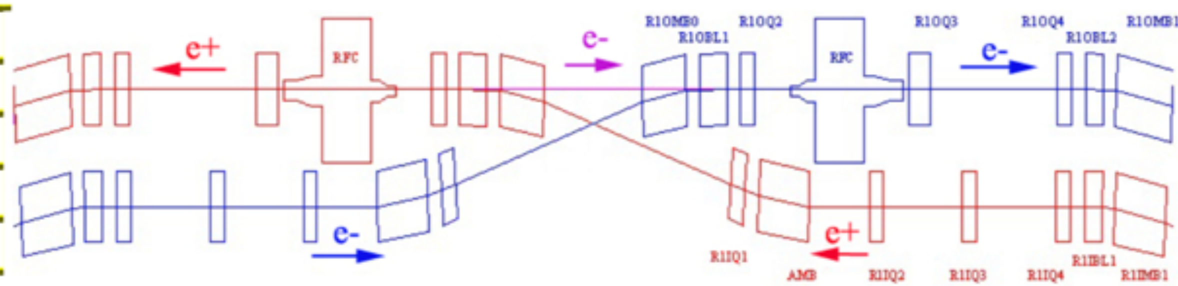
Collider





SR Facility

January 2004	Construction started
Mar.28, 2008	Installation of detector started
Jun. 22, 2008	BEPCII Commissioning started
May 13, 2009	Luminosity reached $3.3\times10^{32}cm^{-2}s^{-1}$
Apr. 5, 2016	Luminosity reached $1.0\times10^{33}cm^{-2}s^{-1}$

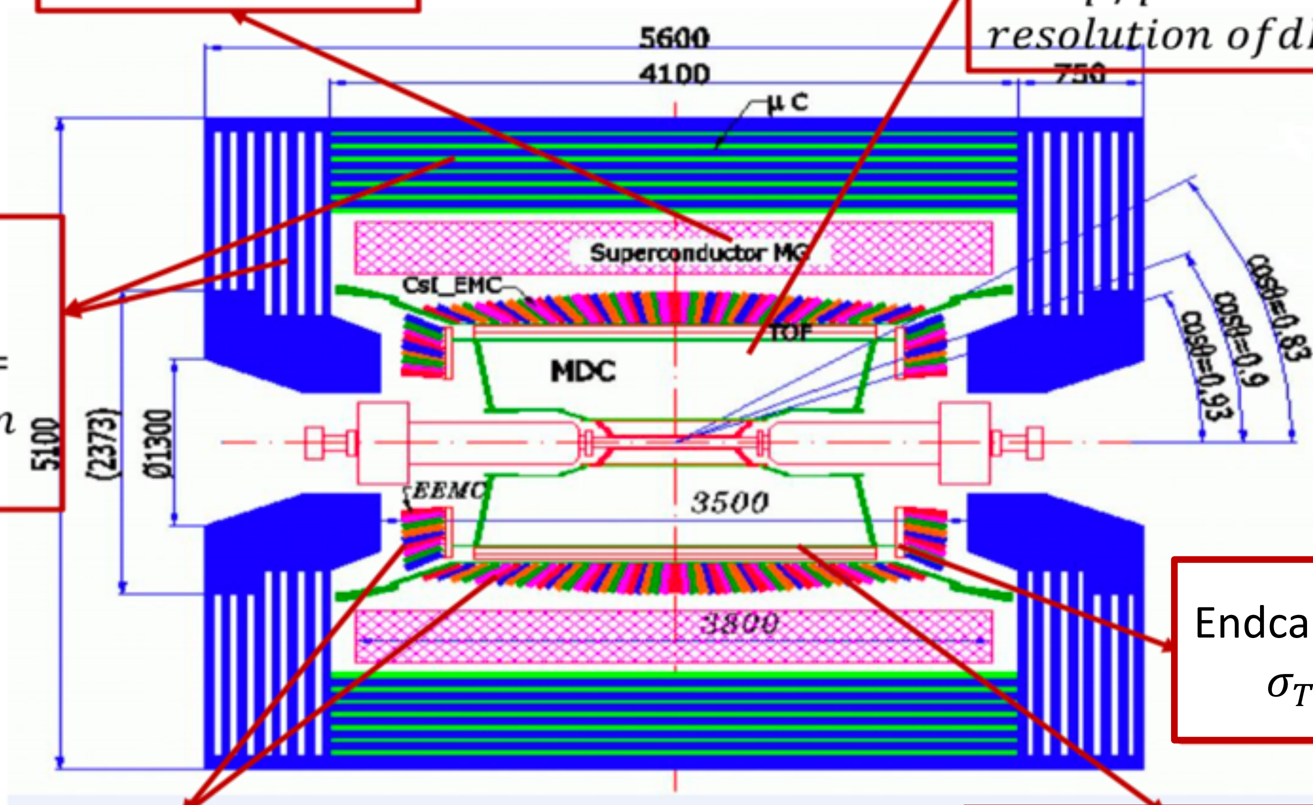


01 Introduction: BESIII Detector

MDC: $\sigma_{r\phi} = 115\mu m$
$\Delta p/p = 0.47\%@1GeV$
$resolution\ of dE/dx\ = 5.2\%$

SC Magnet: 1T

Barrel and endcap Muon counter: $\sigma_{r\phi} =$ $14mm{\sim}15mm$
$\sigma_z{\sim}17mm$



Endcap TOF: MRPC
$\sigma_T = 70\ ps$

Barrel and endcap EMCAL
$\Delta E/E = 2.5\%\ @1GeV\ , \sigma = 6\ mm/\sqrt{E}$

Barrel TOF: Scintillator
$\sigma_T = 80\ ps$

- General purpose detector at BEPCII, $E_{cm} \approx$ 2-4.6 GeV, $L_{peak} \approx 10^{33}/cm^2/s$
- Versatile researches in τ-charm physics

01 Introduction: BESIII Collaboration

Fuente: https://www.cia.gov/library/publications/cia-maps-publications
Adaptación por: Colomet

Europe (16)

Germany(6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster

Italy(3): Ferrara University, INFN, University of Turin,

Netherlands(1): KVI/University of Groningen

Russia(2): Budker Institute of Nuclear Physics, Dubna JINR

Sweden(1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK(2): University of Manchester, University of Oxford

USA(5)

Carnegie Mellon University
Indiana University
University of Hawaii
University of Minnesota
University of Rochester

Mongolia(1)

Institute of Physics and Technology

Korea(1)

Seoul National University

Japan(1)

Tokyo University

Thailand(1)

Suranaree University of Technology

Pakistan(3)

COMSATS Institute of Information Technology
University of the Punjab,
University of Lahore

India(1)

Indian Institute of Technology madras

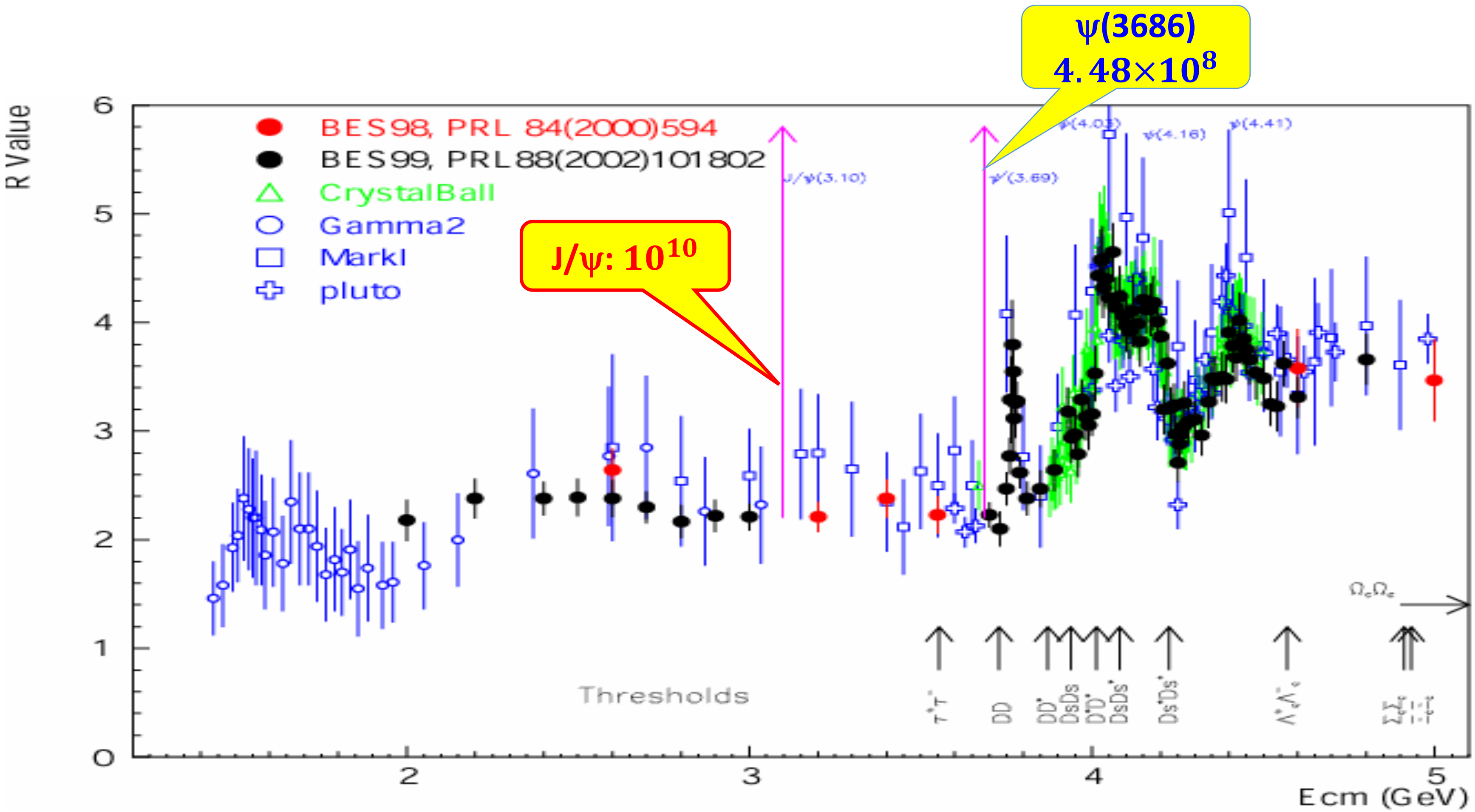
China (47)

Beijing Institute of Petro-chemical Technology, Beihang University, China Center of Advanced Science and Technology, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Huazhong Normal University, Huangshan College, Hunan University, Hunan Normal University, Institute of High Energy Physics, Institute of Modern Physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu Normal University, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiao Tong University, Soochow University, South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, Zhejiang University, Zhengzhou University

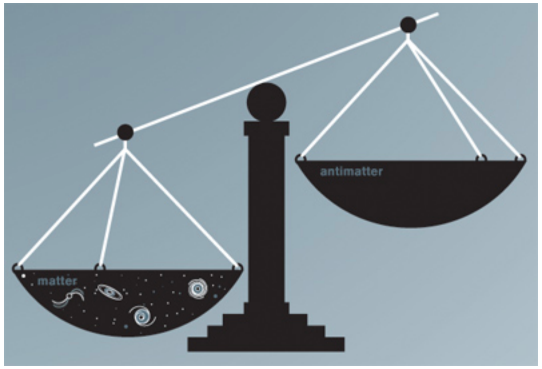
BESIII: ~500 members
76 institutes
15 countries.

01 Introduction: Data Samples

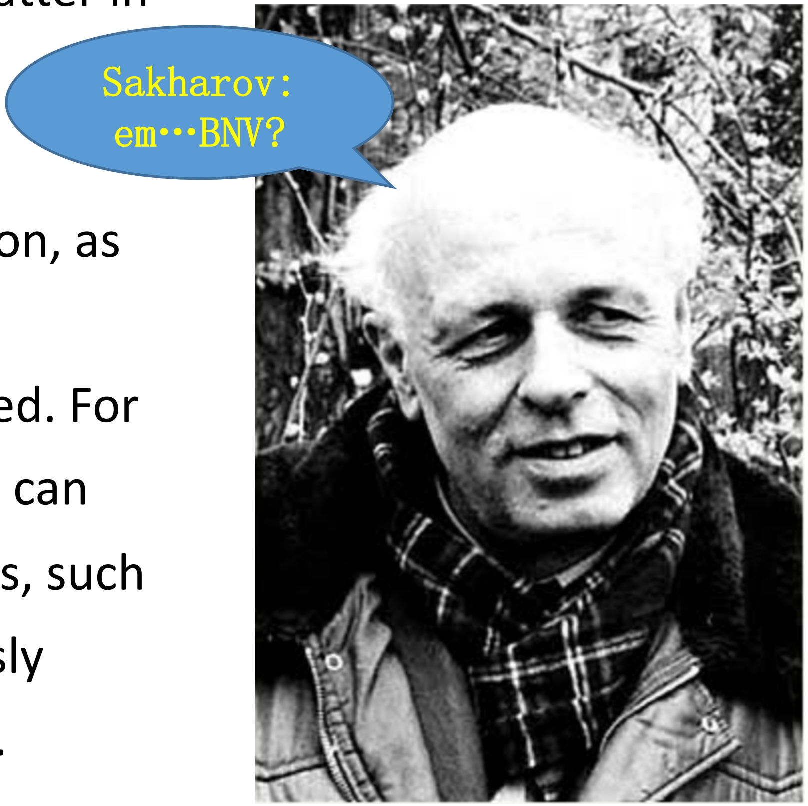
World largest charmonium data sets directly produced from e^+e^- collision on J/ψ and ψ(3686) resonance, large data sets taken at center-of-mass energies 3.773 , 4.008, 4.18 ….. GeV



02 Search for $J/\psi \to \Lambda_c^+ e^-$: Why BNV?



- Asymmetry of matter and anti-matter: big problem in the universe evolution.
- C and CP violation: precisely tested by theory and experiments in decades, however not enough to address the asymmetry of matter and anti-matter in the universe.
- BNV: even a small amount would have major consequences on the universe and its evolution, as many theories have suggested.
- Many theoretical models where BNV is allowed. For example, in the Grand Unified Theory, proton can decay into several modes through leptoquarks, such as $p \to e^+\pi^0$. Such mechanism simultaneously breaks BN and LN while conserving $\Delta(B-L)$.



02 Search for $J/\psi \to \Lambda_c^+ e^-$: Why Collider Experiment?

- Searches for physics beyond the SM with collider experiments are complementary to searches with specifically designed precision detection experiments.
- For example, dark sector searching at collider experiments VS dedicated direct detection experiments; Majorana neutrinos searching at flavor factory and high energy frontier VS the neutrino-less double beta decay experiments.
- The two independent ways of searching for new physics are fruitfully supporting each other.

02 Search for $J/\psi \to \Lambda_c^+ e^-$: Current Status

BNV @ baryons: many!
BNV @ quarkonium: none!

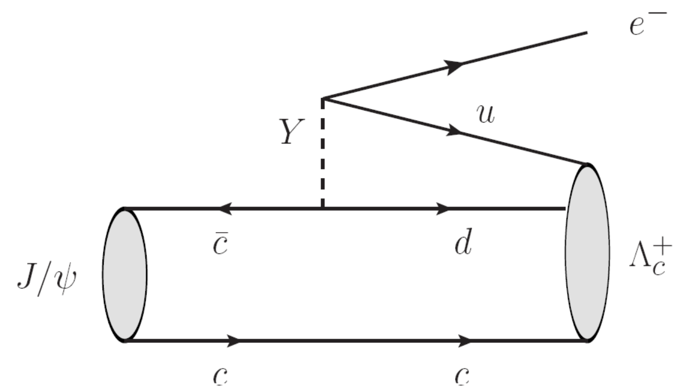
Decay Mode	$B_{90\%}$ $(\times 10^{-8})$	Experiment	Year
$D^0 \to pe^-$	1000	CLEO-c [PRD79, 097101]	2009
$D^0 \to \bar{p}e^+$	1100		
$B^0 \to \Lambda_c^+ \mu^- (e^-)$	180 (520)	BABAR [PRD83, 091101(R)]	2011
$B^- \to \Lambda \mu^- (e^-)$	6.2 (8.1)		
$B^- \to \bar{\Lambda} \mu^- (e^-)$	6.1 (3.2)		
$\Lambda \to K^+ e^- (\mu^-)$	200 (300)	CLAS [PRD92, 072002]	2015
$\Lambda \to K^- e^+ (\mu^+)$	200 (300)		
$\Lambda \to \pi^+ e^- (\mu^-)$	60 (60)		
$\Lambda \to \pi^- e^+ (\mu^+)$	40 (60)		
$\Lambda \to \bar{p}\pi^+$	90		
$\Lambda \to K_S^0 \nu$	2000		
$D^+ \to \Lambda(\Sigma^0) e^+$	110 (170)	BESIII [PRD101, 031102(R)] (refer to Bo Zheng's Talk: [id=68] Radiative and Rare Charm Decays at BESIII)	2020
$D^+ \to \bar{\Lambda}(\bar{\Sigma}^0) e^+$	65 (130)		

02 Search for $J/\psi \to \Lambda_c^+ e^-$: Result

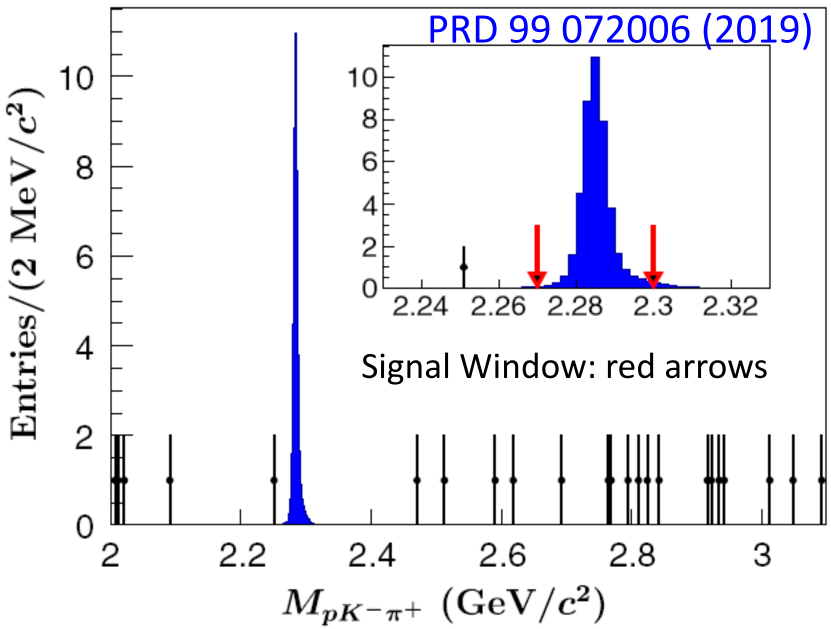
- 1.3 billion J/ψ
- First search of $J/\psi \to \Lambda_c^+ e^-$
- Check $M_{pK\pi}$ distribution, no signal events in the signal region
- Total systematic uncertainty (~7%)
- Upper limits on BF (90% CL)

  $B(J/\psi \to \Lambda_c^+ e^-) < 6.9\times10^{-8}$

- The first BNV searching in charmonium decay

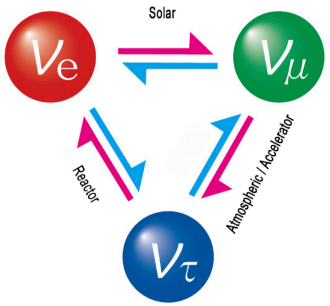


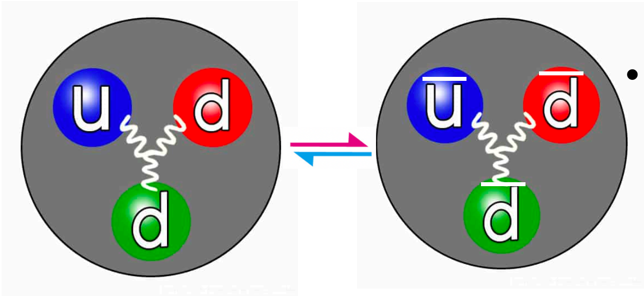
Data: dot with error bar
MC: blue filled histogram (normalized arbitrarily)



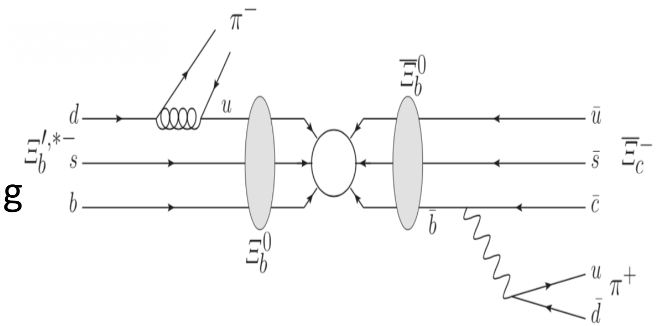
03 Search for $\Lambda - \bar{\Lambda}$ Oscillation

- The discoveries of neutrino oscillations have made $N - \bar{N}$ oscillation to be quite plausible theoretically[PRL96, 061801(2006)], if small neutrino masses are to be understood as a consequence of the seesaw mechanism, which indicates the existence of $\Delta(B-L) = 2$ interactions.

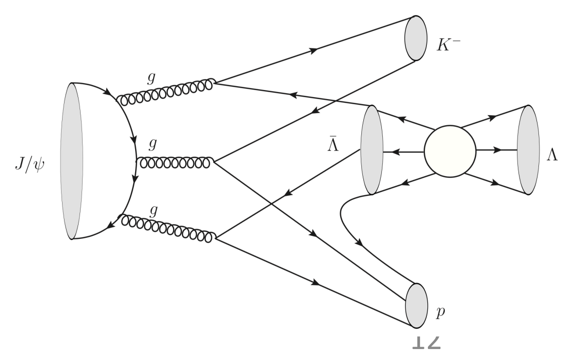




- Since 1980[PRL44,1316], there have been many experiments searching for BNV through $n - \bar{n}$ oscillation[PDG2019] with upper limit results, while few results from other baryons.



- 2007, K.-B. Luk pointed out that $\Lambda - \bar{\Lambda}$ oscillation may also exist.
- 2010, X.-W. Kang and H.-B. Li[PRD81,051901] give a prospect of searching for $\Lambda - \bar{\Lambda}$ oscillation at the BESIII experiment.
- 2017, the LHCb experiment presented a constraint on $\Xi_b^0 - \bar{\Xi}_b^0$ oscillation.
- The theoretical advantage for using $\Lambda - \bar{\Lambda}$ is it has a second generation quark, which can give further information compared with the result of proton decay which only have the first generation quark.
- A six-fermion operator, which could arise in models with leptoquarks or R-parity violating supersymmetric extensions of the SM, could allow BNV while being consistent with the experimental limit on the proton lifetime[PLB721, 82(2013)].



03 Search for $\Lambda - \bar{\Lambda}$ Oscillation

- Starting with a beam of free $\bar{\Lambda}$, the probability of generating a Λ after time *t* can be described by

$$\mathcal{P}(\Lambda, t) = \sin^2(\delta \mathrm{m}_{\Lambda\bar{\Lambda}} \cdot \mathrm{t})$$

where $\delta m_{\Lambda\bar{\Lambda}}$ is the oscillation parameter and *t* is the decay time.

- Since there is no vertex detector at the BESIII, we can only measure the time integrated result

$$\mathcal{P}(\Lambda) = \frac{\int_0^\infty \sin^2(\delta \mathrm{m}_{\Lambda\bar{\Lambda}} \cdot \mathrm{t}) \cdot \mathrm{e}^{-\mathrm{t}/\tau_\Lambda} \cdot \mathrm{dt}}{\int_0^\infty e^{-t/\tau_\Lambda} \cdot dt}$$

where $P(\Lambda)$ is the time integrated oscillation rate of $\bar{\Lambda} \to \Lambda$, $\tau_\Lambda = (2.632 \pm 0.020)\times 10^{-10}$ (s) is the life time of Λ baryon.

- Therefore, the oscillation parameter can be deduced as

$$(\delta m_{\Lambda\bar{\Lambda}})^2 = \frac{\mathcal{P}(\Lambda)}{2 \cdot (\tau_\Lambda/\hbar)^2}$$

03 Search for $\Lambda - \bar{\Lambda}$ Oscillation

- Oscillation event (charge conjugation implied)

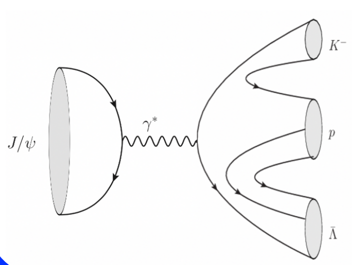
$$J/\psi \to pK^-\bar{\Lambda} \xrightarrow{oscillating} pK^-\Lambda$$

- Time integrated oscillation rate

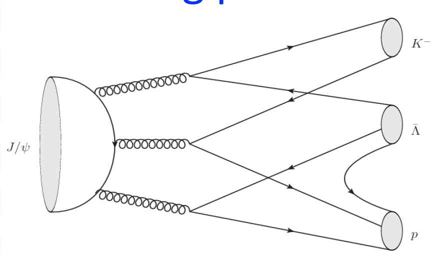
$$\mathcal{P}(\Lambda) = \frac{\mathcal{B}(J/\psi \to pK^-\Lambda \to pK^-p\pi^-)}{\mathcal{B}(J/\psi \to pK^-\bar{\Lambda} \to pK^-\bar{p}\pi^+)} = \frac{N_{\mathrm{WS}}^{obs}/\epsilon_{\mathrm{WS}}}{N_{\mathrm{RS}}^{obs}/\epsilon_{\mathrm{RS}}}$$

- Most of the systematic uncertainties cancelled.

EM process



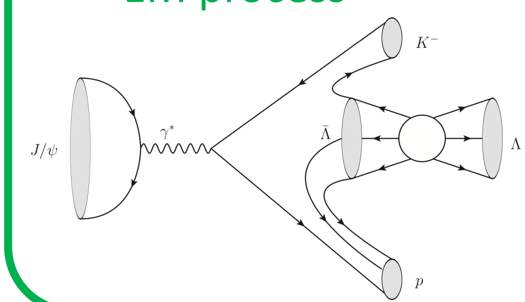
Strong process



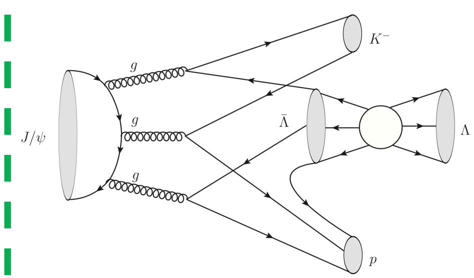
Right Sign Channel (Opposite Charge)

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

EM process



Strong process



Wrong Sign Channel (Same Charge)

$J/\psi \to pK^-\Lambda \to pK^-(p\pi^-)$

03 Search for $\Lambda - \bar{\Lambda}$ Oscillation

- Result based on 1.3 billion J/ψ events
- $J/\psi \to pK^-\bar{\Lambda} \xrightarrow{oscillate} pK^-\Lambda$
- Almost background free.
- Upper limit based on TROLKE (90% CL)

$$P(\Lambda) = \frac{\mathrm{B}(J/\psi \to pK^-\Lambda)}{\mathrm{B}(J/\psi \to pK^-\bar{\Lambda})} < 4.4\times10^{-6}$$

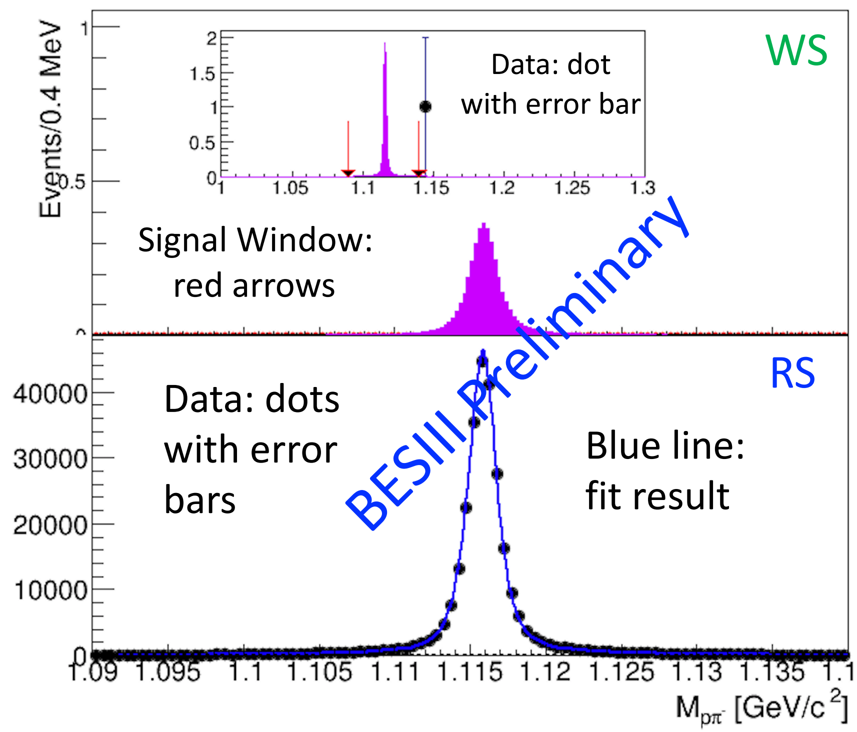
BESIII Preliminary

- Oscillation parameter (90% CL)

$$\delta m_{\Lambda\bar{\Lambda}} < 3.8\times10^{-15}\ \text{MeV}$$

BESIII Preliminary

WS
MC: pink filled histogram (normalized arbitrarily)



RS
Signal shape: simulated MC shape ⊗ a Gaussian function.
Background shape: inclusive MC sample after excluding RS events.

04 Summary

- With the world largest e^+e^- annihilation J/ψ data including more than 1.3 billion J/ψ events, the BESIII collaboration presented the first constraints on $J/\psi \to \Lambda_c^+ e^-$ and $\Lambda - \bar{\Lambda}$ oscillation.
- Better results for more decay channels based on 10 billion J/ψ events are coming soon.
- New data taking plan and more charmonium data sets at other CM energy have been approved! Better/more constraints on BNV/LNV processes can be expected.

南開大學
Nankai University


Děkujeme!
谢谢！
THANKS