Baryonic Decays of Charmonium at BESIII

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(On the behalf of BESIII collaboration)

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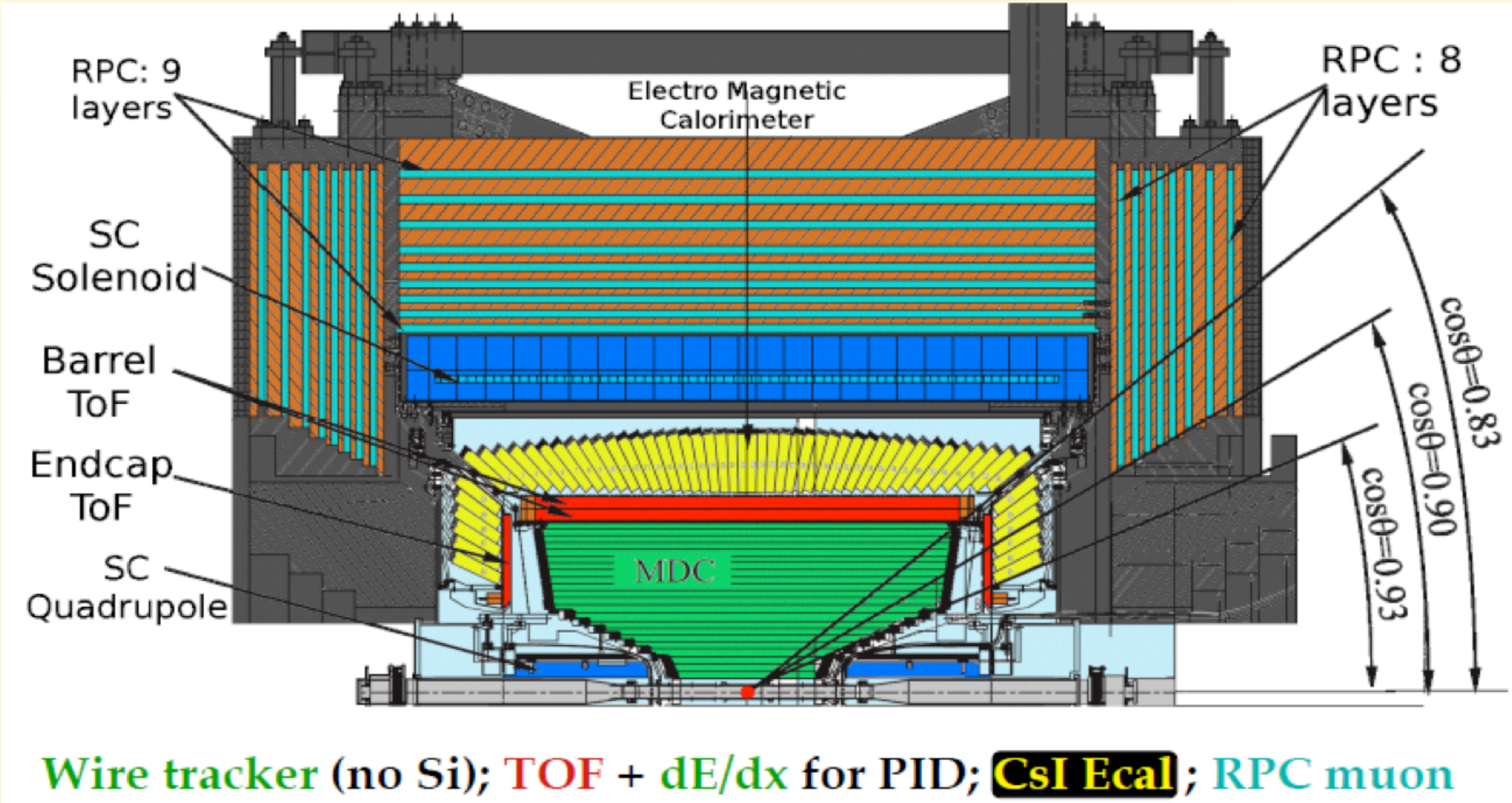
Motivation

- A measurement of $\psi(3686) \to p\bar{p}/n\bar{n}$ allows testing of symmetries, such as flavor-SU(3).[1]
- Relative phase angle between the strong and electromagnetic interactions could be studied via this kind of two-body decays.[2–9]
- The distribution $dN/d\cos\theta \propto 1 + \alpha\cos^2\theta$ of neutral vector resonance decay into a particle-antiparticle pair needs more check.[10–18] And more precise measurement of $\psi(3686) \to p\bar{p}$ is neccessary.

	$\mathcal{B}$ (in 10^{-4})	α
World average [26]	2.88 ± 0.10	
World average (fit) [26]	3.00 ± 0.13	
E835 [27]		$0.67 \pm 0.15 \pm 0.04$
BESII [28]	$3.36 \pm 0.09 \pm 0.25$	$0.85 \pm 0.24 \pm 0.04$
CLEO [50]	$2.87 \pm 0.12 \pm 0.15$	
BaBar [51]	$3.14 \pm 0.28 \pm 0.18$	
CLEOc data [52]	$3.08 \pm 0.05 \pm 0.18$	

- Due to the Okubo-Zweig-Iizuka (OZI) mechanism, the decays of J/ψ and $\psi(3686)$ to hadrons are mediated via three gluons or a single photon at the leading order. Perturbative QCD predicts the "12% rule".[20–22]
- With the large $\psi(3686)$ sample, we are able to measure $\psi(3686) \to n\bar{n}$ for the first time.

BESIII Detector



- A CsI(Tl) electromagnetic calorimeter (EMC) measures photon energies with a resolution of 2.5% (5%) at 1 GeV in the barrel (end-caps).

Data sample

- 1.07×10^8 events data sample collected at $\psi(3686)$ peak
- 44pb^{-1} continuum data sample, taken at 3.65GeV
- 106M inclusive MC
- 1M signal MC is generated with an angular distribution of $1 + \alpha\cos^2\theta$ for $\psi(3686) \to p\bar{p}/n\bar{n}$, using the α values obtained from this analysis.

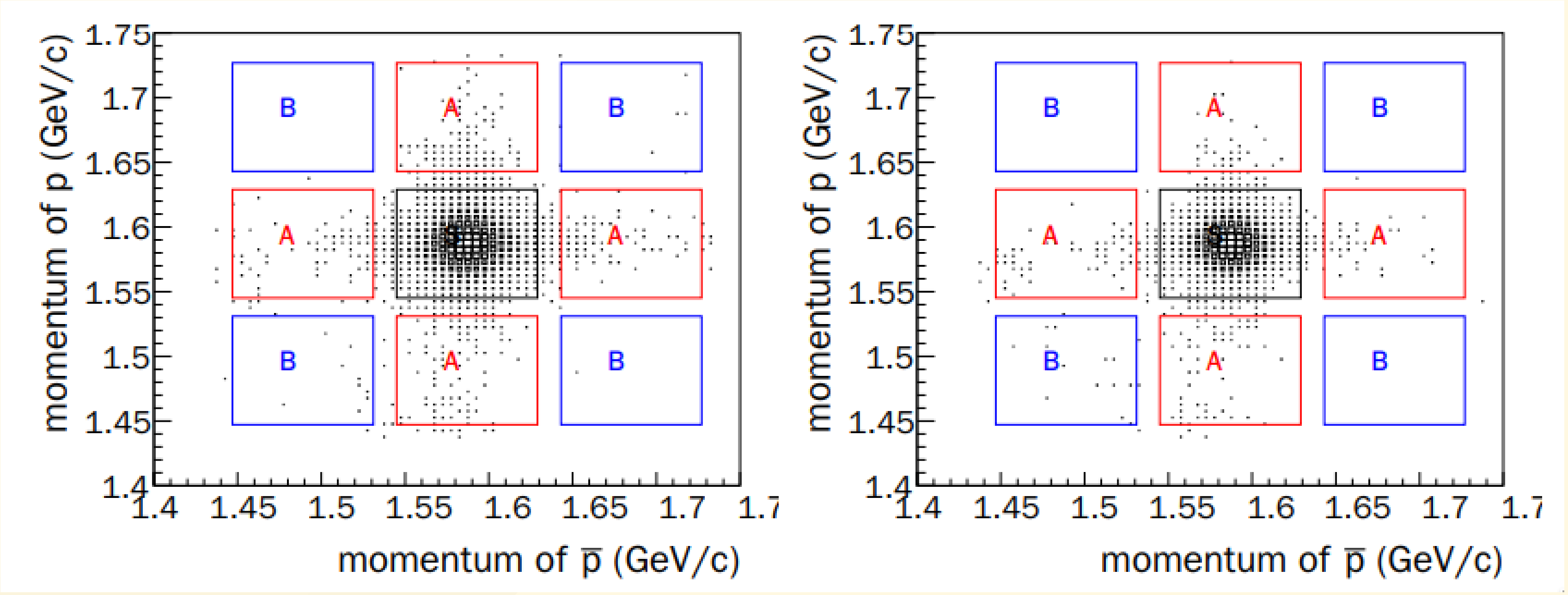
Measurement of $\psi(3686) \to p\bar{p}$

Event selection for $\psi(3686) \to p\bar{p}$

- $|V_r| < 1.0\mathrm{cm}$ and $|V_z| < 10.0\mathrm{cm}$, here V_r and V_z are the closest approach distances from the interaction point to the reconstructed track projected in a plane transverse to or along the beam direction respectively.
- Two charged track candidates with net charge zero are required.
- The momentum of each track is required to satisfy $1.546 < p < 1.628\mathrm{GeV/c}$ in the C.M. system.
- The polar angle $\cos(\theta) < 0.8$.
- PID is done with the infromation from the barrel TOF, likelihoods $\mathcal{L}_i$ for different particle hypotheses.
- Open angle of these two tracks $\theta_{open} > 3.1$ rad is required.

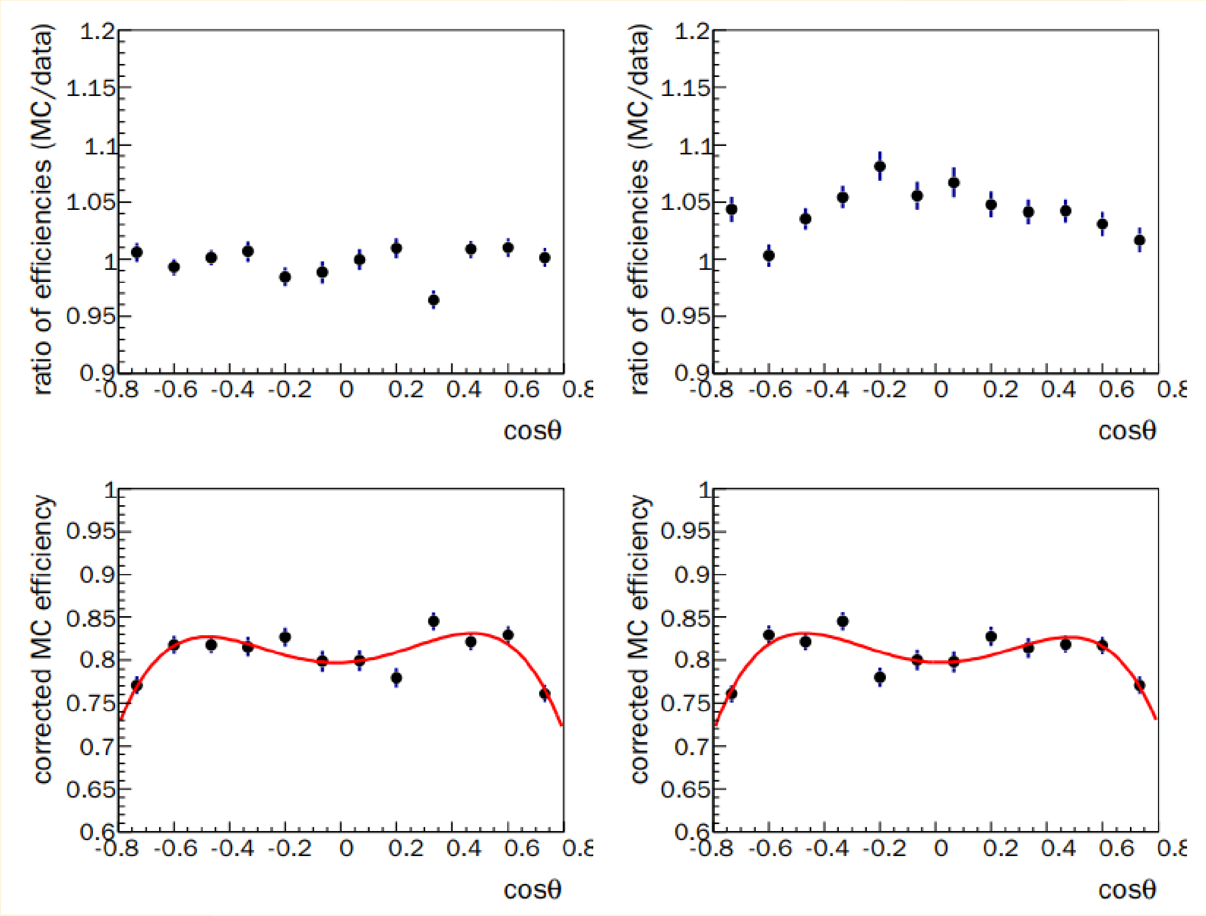
Background estimation

- The dominant background is from the initial state or final state radiation events of $\psi(3686) \to p\bar{p}$.



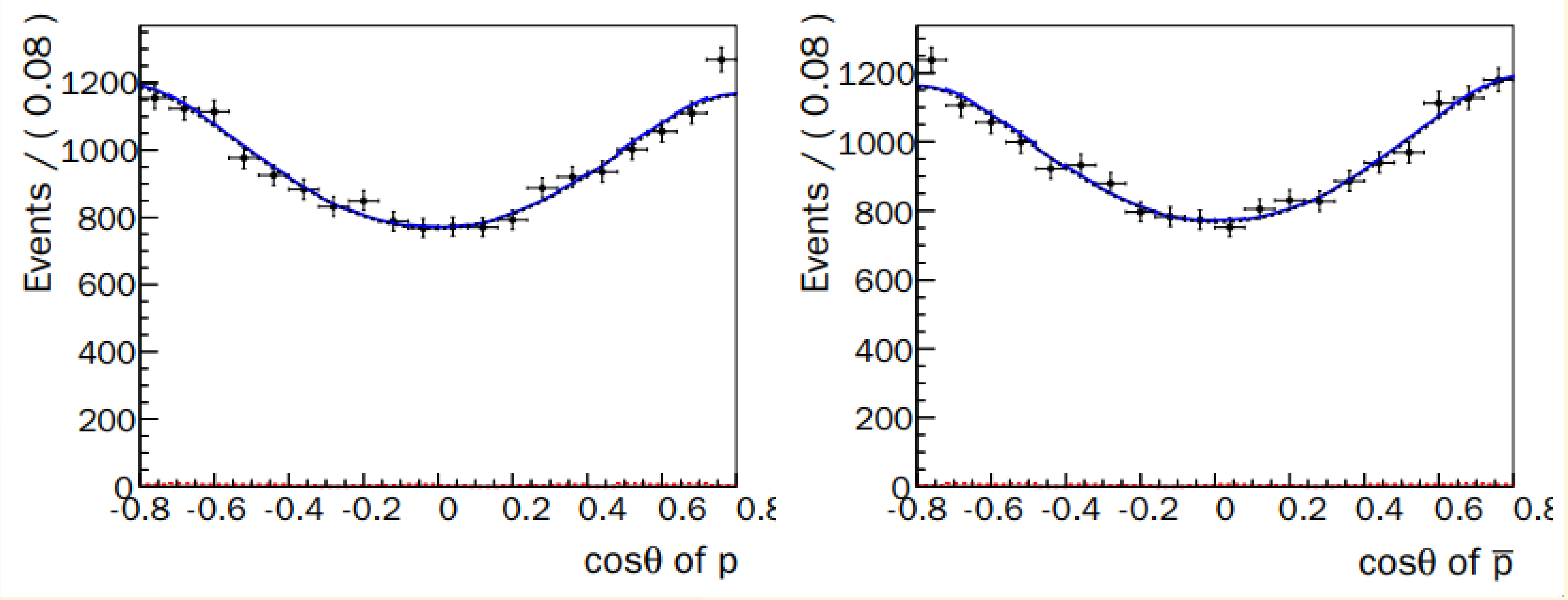
Scatter plots of momenta of proton versus anti-proton. The left plot is data, and the right one is for inclusive MC.

Polar angle dependent efficiency correction



(Top row) Ratios of efficiencies of MC simulation over data, and (Bottom row) the corrected MC efficiency to select the signal events $\psi(3686) \to p\bar{p}$. The left plots are for the proton, and the right ones for the anti-proton.

Branching fraction and angular distribution



- $\mathcal{B}(\psi(3686) \to p\bar{p}) = (3.05 \pm 0.02) \times 10^{-4}$ with the corrected efficiency of $\epsilon = 58.1\%$
- $\alpha = 1.03 \pm 0.06$

Systematic uncertainties

- Different descriptions of the corrected efficiency result the maximum changes of the branching fraction and α value, 3.3% and 2.1%, respectively. From input/output checks, the average relative differences between measured and true values are 1.1% for the branching fraction and 2.0% for α.

	Br (in %)	α (in %)
Resolution	0.5	-
Background	0.1	-
Tracking and PID	3.3	2.3
Method	1.1	2.0
Binning	-	1.0
Physics Model	1.8	-
Trigger	-	-
Number of $\psi(3686)$	0.7	-
Total	4.0	3.2

- $\mathcal{B}(\psi(3686) \to p\bar{p}) = (3.05 \pm 0.02 \pm 0.12) \times 10^{-4}$
- $\alpha = 1.03 \pm 0.06 \pm 0.03$

Measurement of $\psi(3686) \to n\bar{n}$

Event selection of $\psi(3686) \to n\bar{n}$

- Good cluster
  - $E > 25\mathrm{MeV}$ for the barrel EMC ($|\cos\theta| < 0.8$)
  - $E > 50\mathrm{MeV}$ for the endcap EMC ($0.86 < |\cos\theta| < 0.92$)
- Event level
  - No charged track at all
  - **1st shower**: the most energetic cluster in EMC (n or $\bar{n}$ candidates)
  - **1st group**: all clusters within 0.9 rad cone around **1st shower**. Its direction is defined as the energy-weighted average of the directions of all clusters within this group; its energy, hits and moments are defined as the sum of relevant variables of all clusters within this group.
  - **2nd shower**: the most energetic shower except what in **1st group** (n or $\bar{n}$ candidates)
  - **2nd group**: all clusters within 0.9 rad cone around **2nd shower**
  - **remained showers**: showers not fall in the two shower groups.
  - Require $|\cos\theta| < 0.8$ for both shower groups.

Variables used in MVA

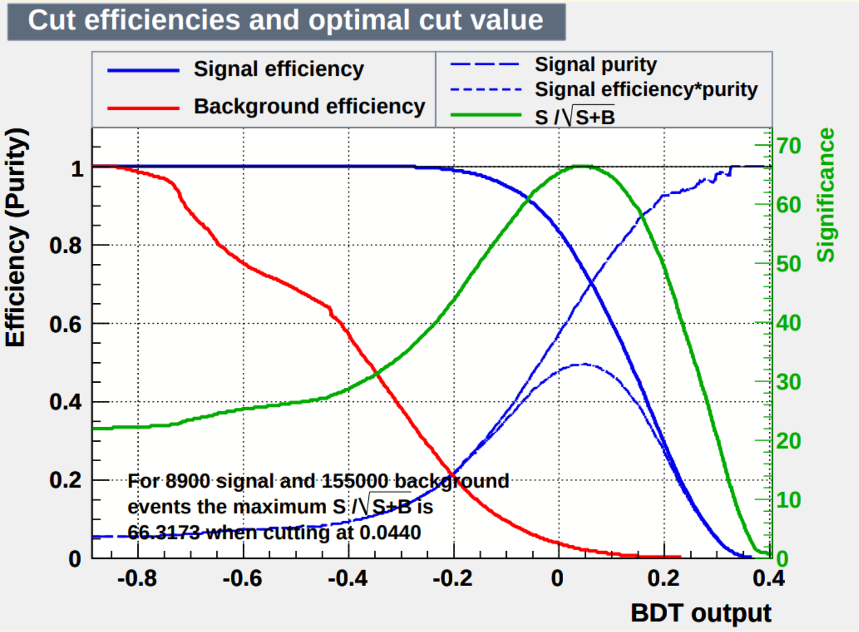
TABLE: The variables used in MVA and their definitions

Names	Definitions	Importance
numhit1	number of hits in the first SG	0.09
numhit2	number of hits in the second SG	0.06
ene1	energy of the first SG	0.10
ene2	energy of the second SG	0.21
secmom1	second moments of the first SG	0.06
secmom2	second moments of the second SG	0.06
latmom1	lateral moments of the first SG	0.09
latmom2	lateral moments of the second SG	0.05
bbang1	largest opening angle in the first SG	0.04
bbang2	largest opening angle in the second SG	0.05
numshow1	number of showers in the first SG	0.04
numshow2	number of showers in the second SG	0.04
numrem	number of remaining showers	0.06
enerem	energy of remaining showers	0.07

- The second moment is defined as $\sum_i E_i r_i^2 / \sum_i E_i$ and the lateral moment as $\sum_{i=3}^{n} E_i r_i^2 / (E_1 r_0^2 + E_2 r_0^2 + \sum_{i=3}^{n} E_i r_i^2)$. Here $r_0 = 5\text{cm}$ is the average distance between crystal centers in the EMC, r_i is the radial distance of crystal i from the cluster center, and E_i is the crystal energy in decreasing order.

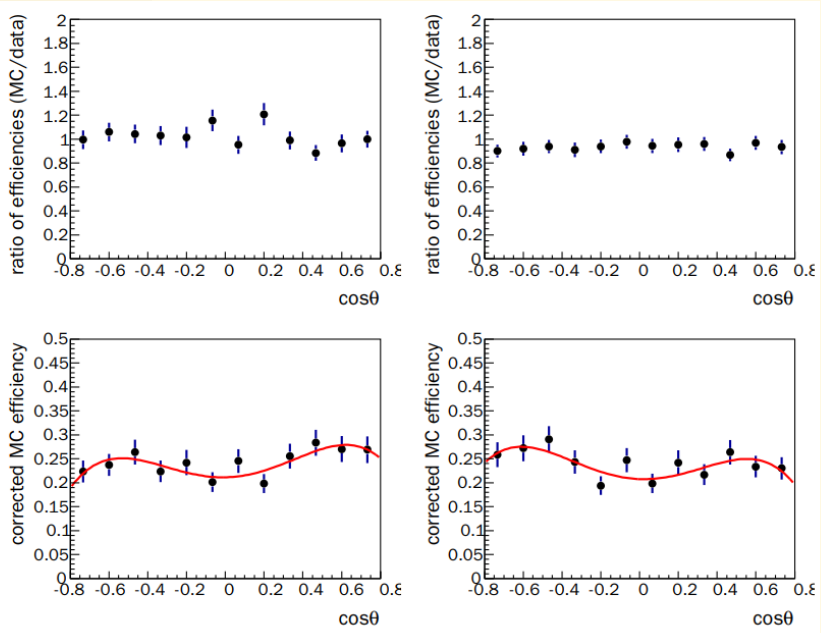
MVA analysis

- 50×10^3 signal and 100×10^3 background events are used as trainning samples
- The signal events are from signal MC simulation and the backgrounds are a weighted mix from continuum at 3.65 GeV, inclusive MC simulation and exclusive MC simulation of $\psi(3686) \to \gamma\chi_{c,J},\ \chi_{cJ} \to n\bar{n}(J=0,1,2)$.
- The optimized MVA selection criteria is determined within $\theta_{open} > 2.9$ region. θ_{open} is the openning angle between two shower groups in the e^+e^- C.M. system.
- Approximately 95% of the background is rejected while 76% of all signal events are retained.



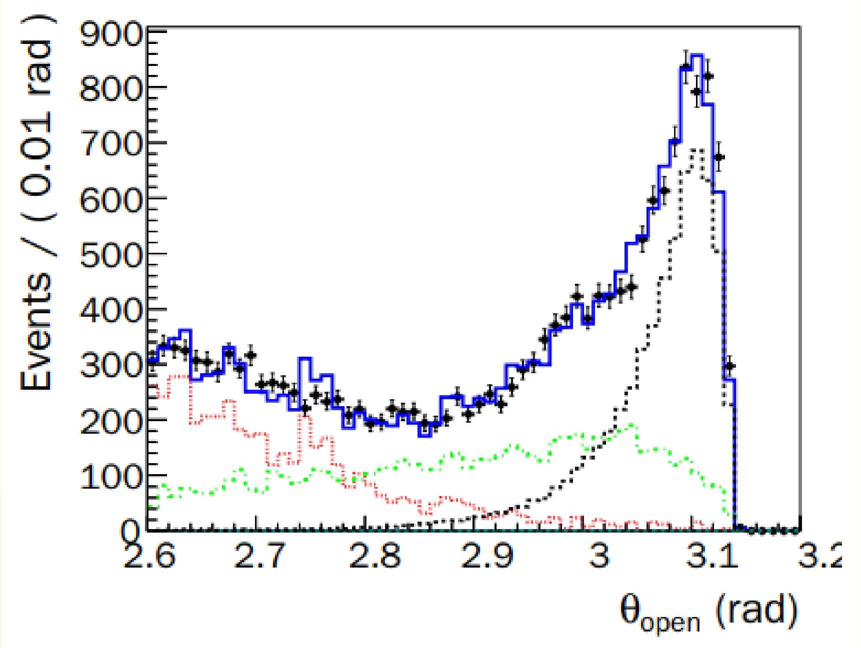
Polar angle dependent efficiency correction

- The neutron and anti-neutron efficiencies are corrected as a function of $\cos\theta$ in the e^+e^- C.M. system to account for the difference between data and MC simulation.
- Control samples of $\psi(3686) \to p\bar{n}\pi^- \ + \ c.c.$ are used to study the difference.
- The efficiencies of $\bar{n}$ or n have been defined as $\epsilon = N_{BDT}/N_{tot}$, where N_{tot} is the total number of anti-neutron events obtained by a fit to the $p\pi$ recoild mass distribution, and N_{BDT} is the number of anti-neutrons selected with the BDT method.



Branching ratio

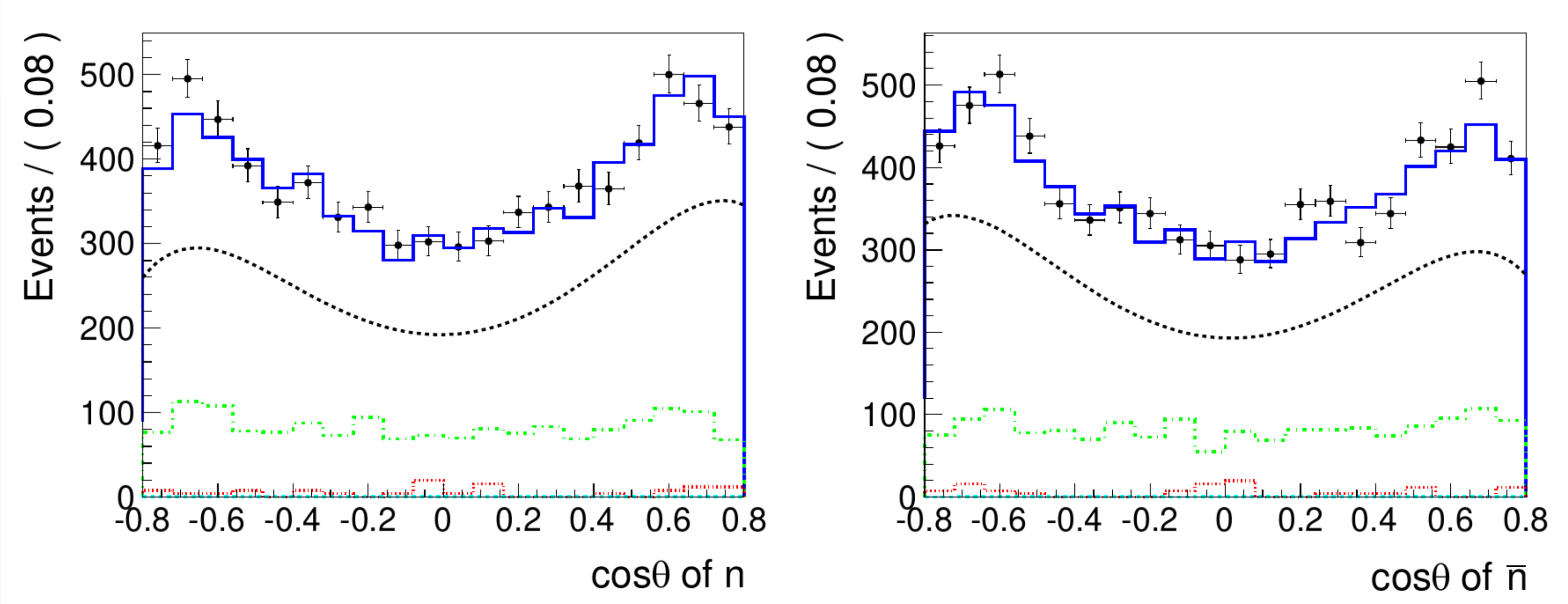
- The distribution of θ_{open} is fitted to yield the number of signal candidates and background events. The fit yields 6056 ± 117 $n\bar{n}$ events with $\chi^2/ndf = 3.24$.



The background is described by three components: continuum background in dotted red, inclusive MC sample in dash-dotted green, and the tiny contribution from $\psi(3686) \to \gamma\chi_{cJ},\ \chi_{cJ} \to n\bar{n}$ (not included in inclusive MC sample) in long-dashed cyan.

Angular distribution

- An additional selection criterion $\theta_{open} > 3.01$ is used to further suppress the continuum background.
- The signal PDF is constructed by the formula $(1 + \alpha\cos^2\theta)\epsilon(\theta)$, $\epsilon(\theta)$ is the polar angle dependent efficiency correction.



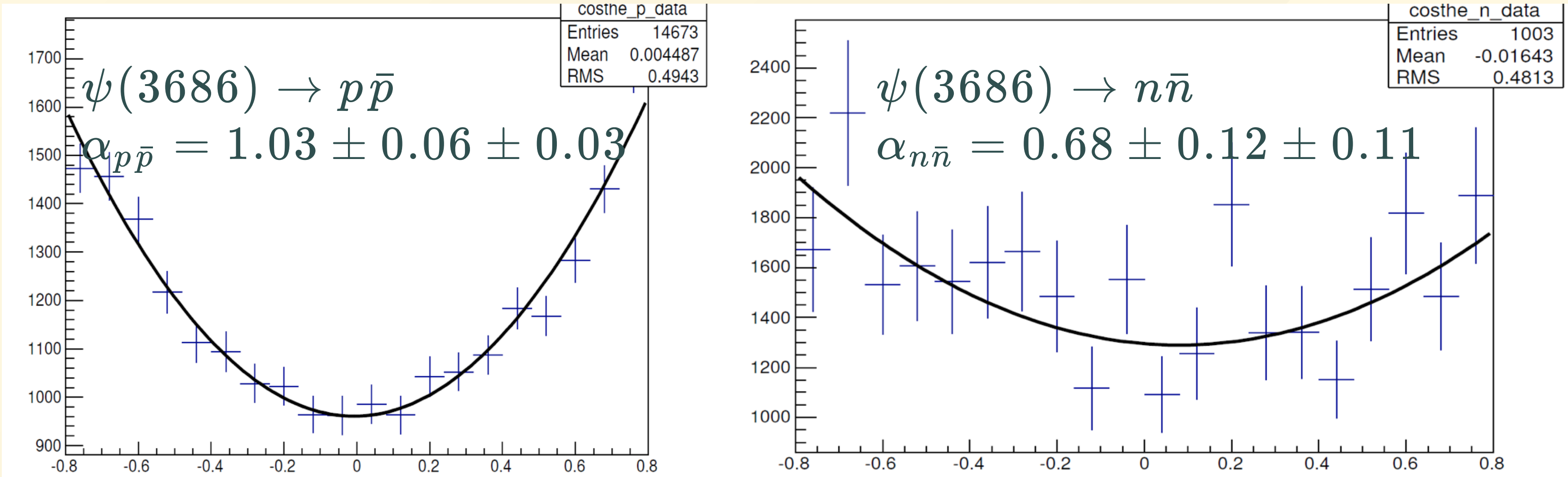
Systematic uncertainties

- The uncertainties associated with the background amplitudes are estimated by fitting the θ_{open} distribution with fixed contributions for the continuum and inclusive MC background. The reconstruction efficiency is corrected in bins of $\cos\theta$, and the uncertainty of the correction is taken to be the statistical uncertainty, which is about 2% per $\cos\theta$ bin.

Item	Br (in %)	α (in %)
Resolution	0.3	-
Background	0.8	9.2
Neutrals Eff.	2.2	12.8
Method	-	2.0
Binning	0.1	4.5
Physics Model	1.1	-
Trigger	3.4	-
Number of ψ'	0.7	-
Total	4.4	16.5

- $\mathcal{B}(\psi(3686) \to n\bar{n}) = (3.06 \pm 0.06 \pm 0.14) \times 10^{-4}$
- $\alpha_{n\bar{n}} = 0.68 \pm 0.12 \pm 0.11$

Polar angle distribution and branching ratio



- In $\psi(3686) \to p\bar{p}/n\bar{n}$, $\alpha_{p\bar{p}} \neq \alpha_{n\bar{n}}$ and $\mathcal{B}_{p\bar{p}} \approx \mathcal{B}_{n\bar{n}}$.
  - $\alpha_{p\bar{p}} = 1.03 \pm 0.06 \pm 0.03$, $\mathcal{B}_{p\bar{p}} = (3.06 \pm 0.02 \pm 0.13) \times 10^{-4}$
  - $\alpha_{n\bar{n}} = 0.68 \pm 0.12 \pm 0.11$, $\mathcal{B}_{n\bar{n}} = (3.09 \pm 0.06 \pm 0.14) \times 10^{-4}$
- In $J/\psi \to p\bar{p}/n\bar{n}$, $\alpha_{p\bar{p}} \approx \alpha_{n\bar{n}}$ and $\mathcal{B}_{p\bar{p}} \approx \mathcal{B}_{n\bar{n}}$.
  - $\alpha_{p\bar{p}} = 0.595 \pm 0.012 \pm 0.015$, $\mathcal{B}_{p\bar{p}} = (2.112 \pm 0.004 \pm 0.031) \times 10^{-3}$
  - $\alpha_{n\bar{n}} = 0.50 \pm 0.04 \pm 0.21$, $\mathcal{B}_{n\bar{n}} = (2.07 \pm 0.01 \pm 0.17) \times 10^{-3}$
- In other decay modes, such as $J/\psi \to \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}^0, \Xi^+\bar{\Xi}^-, \Sigma(1385)\bar{\Sigma}(1385), \Xi^0\bar{\Xi}^0$ and $\psi(3686) \to \Xi^+\bar{\Xi}^-, \Sigma(1385)\bar{\Sigma}(1385), \Xi^0\bar{\Xi}^0$, the measurements of polar angle have given different results [23–26], but there is no conclusive theoretical model for them.

Summary

- The process $\psi(3686) \to n\bar{n}$ is measured for the first time.
- The precision of the measurement of $\psi(3686) \to p\bar{p}$ is improved a lot compared to previous measurements.
- The "12% rule" is verified by these measurements

$$\frac{\mathcal{B}(\psi(3686) \to p\bar{p})}{\mathcal{B}(J/\psi \to p\bar{p})} = (14.4 \pm 0.6)\%, \ \frac{\mathcal{B}(\psi(3686) \to n\bar{n})}{\mathcal{B}(J/\psi \to n\bar{n})} = (14.8 \pm 1.2)\%$$

- In $\psi(3686)$ decays the branching fractions are quite close between the two decay modes $p\bar{p}$ and $n\bar{n}$, but the α values are not, which may imply a more complex mechanism in the decay of $\psi(3686) \to p\bar{p}/n\bar{n}$, in contrast to that of $J/\psi \to p\bar{p}/n\bar{n}$.

Thanks for your attention!

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