A study of J/ψ decay using the BES-II detector

(J/$\psi \to \Lambda \bar{\Lambda}$ 過程の研究)

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Motivation

- **To measure Branching fraction:**

  $Br(J/\psi \to \Lambda \bar{\Lambda})$

  ※This measurement supersedes the current world average!

- **To observe direct CP violation:**

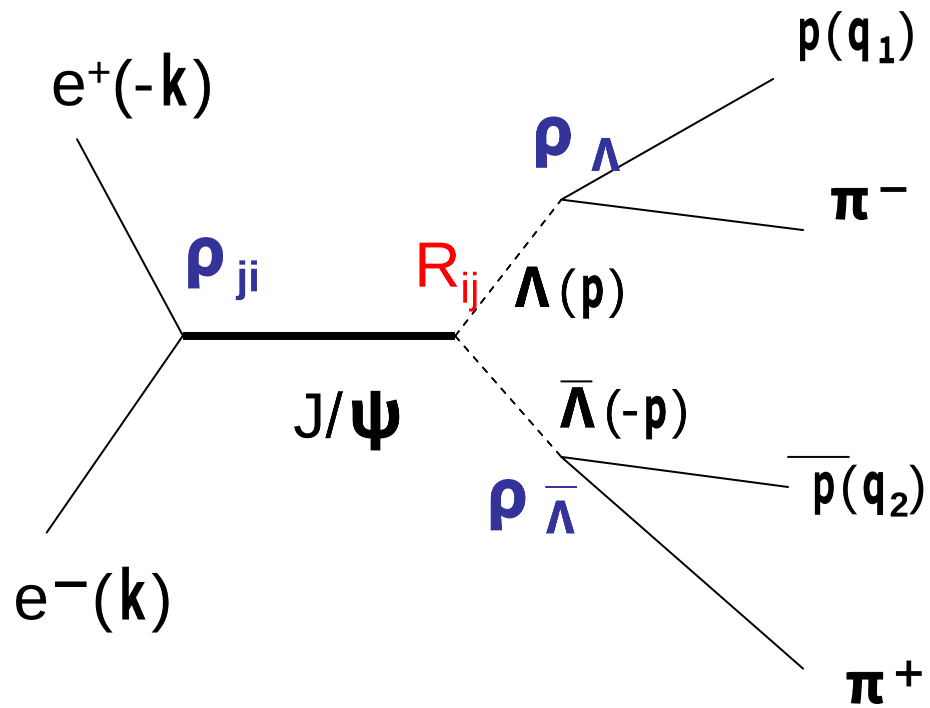
  →comes from CP violating part of the decay amplitude

Phenomenology

※Measuring CP violation in 2 body decay

decay mode：

$e^+e^- \to J/\psi \to \Lambda(s_1)\bar{\Lambda}(s_2)$ s1,s2: spin vector



To measure CP violation
→the information of spin polarization is important!!

※CP-odd observables are used by analyzing secondary decay:

$\Lambda \to p\pi^-$ (Br＝63.9%)

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

Method of calculating CP-odd observable

Decay mode:

$$J/\psi \rightarrow \Lambda\,\bar{\Lambda}$$

The decay amplitude M:

$$\mathcal{M}(J/\psi \rightarrow \Lambda\overline{\Lambda}) = \epsilon^{\mu}\overline{u}_{\Lambda}(p_1)[\gamma_{\mu}(a+b\gamma_5)+(p_{1i}-p_{2i})(c+id\gamma_5)]v_{\overline{\Lambda}}(p_2), \tag{1}$$

a,b,c,d : complex parameter

$\epsilon^{\mu}=(0,\vec{\epsilon})$: a polarization vector of J/ψ

The decay matrix R_{ij}:

$$\begin{aligned} R_{ij} = {} & \overline{u}_{\Lambda}(p_1,s_1)[\gamma_{\mu}(a+b\gamma_5)+(p_{1i}-p_{2i})(c+id\gamma_5)]v_{\overline{\Lambda}}(p_2,s_2) \\ & \times\overline{v}_{\overline{\Lambda}}(p_2,s_2)[\gamma_{\mu}(a^{*}+b^{*}\gamma_5)+(p_{1j}-p_{2j})(c^{*}+id^{*}\gamma_5)]u_{\Lambda}(p_1,s_1), \end{aligned} \tag{2}$$

$i, j = x, y, z$

The spin density matrices

- Λ decay:

$\Lambda \to p \pi^-$ (Br=63.9%)

- e^+e^-annihilation

$e^+e^- \to J/\psi$

Spin density matrices:

$\rho_\Lambda = 1 + \alpha_- s_1 \cdot q_1$

$\rho_{\bar{\Lambda}} = 1 - \alpha_+ s_2 \cdot q_2$

$\alpha_-(\sim \alpha_+) = 0.642$

Spin density matrix:

$$\rho_{ij} = \frac{1}{3}\delta_{ij} + \frac{1}{2i}\epsilon_{ijk}\hat{k}_k C - (\hat{k}_i\hat{k}_j - \frac{1}{3}\delta_{ij})D.$$

- Expectation value of a general experimental observable *O*:

$$< O >= \frac{1}{N}\frac{\beta}{8\pi}\frac{1}{(4\pi)^3}\int d\Omega_p d\Omega_{q1} d\Omega_{q2} O Tr[R_{ij}\rho_{ji}\rho_{\Lambda}\rho_{\overline{\Lambda}}]$$

Trace is done to average about unobserved spins.

- CP-odd observable:

$$\overline{\Lambda}(p) \rightarrow \bar{p}(q_1) + \pi^-$$
$$\Lambda(-p) \rightarrow p(q_2) + \pi^+$$

$$A = \theta(p\cdot(q_1 \times q_2)) - \theta(-p\cdot(q_1 \times q_2))$$
$$B = \theta(p\cdot(q_1 \times q_2))$$

- The expectation values of *A* and *B:*

$$< A >= -\frac{\alpha^2\beta^2}{48N} M^2 (2mRe(da^*) + (M^2 - 4m^2)Re(dc^*))$$
$$< B >= -\frac{48}{27\pi} < A >$$

- The averaged observable A is equal to

$$<\mathbf{A}> = \frac{\mathbf{N^+ - N^-}}{\mathbf{N^+ + N^-}}$$

where

N^+, N^-: **the number of events which have $\mathrm{sgn}(p \cdot (q_1 \times q_2)) = +$ and $-$**

The d-parameter

- The origin of CP-violating d-term
  - ✓electric dipole moment of **Λ**, d_{Λ}
  - ✓CP violating coupling between Z and **Λ**
  - ✓etc.

  →※only d_{Λ} is considered

- d parameter is described as

$$\mathbf{d} = -\frac{2}{3}\frac{g_V}{M^2} e d_{\Lambda}$$

Expectation value of *A*

- The observable A has the terms Re(da*) and Re(dc*). Since the relative contributions of these two terms cannot be determined. Therefore two cases must be considered.

- The upper limit of *A*:

$$|<A>| = \begin{cases} 5.6\times10^{-3} d_\Lambda/(10^{-16} e\mathrm{cm}), & (a\text{-term dominant}) \\ 1.25\times10^{-2} d_\Lambda/(10^{-16} e\mathrm{cm}), & (c\text{-term dominant}). \end{cases}$$

- The present value (PDG)

$$|d_\Lambda| < 1.5\times10^{-16}\ (e\mathrm{cm})$$

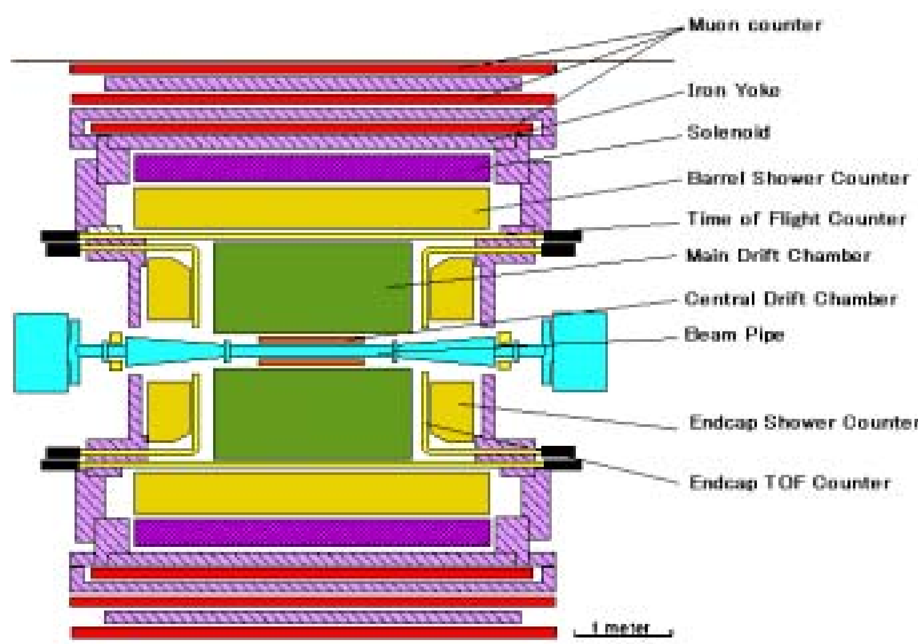
It is expected that interesting result is acquired if one has 10^7 J/ψ events!!

The BES-II Detector

✓A multi-purpose detector operated at the BEPC(Beijing Electron-Positron collider), IHEP, Beijing, China.

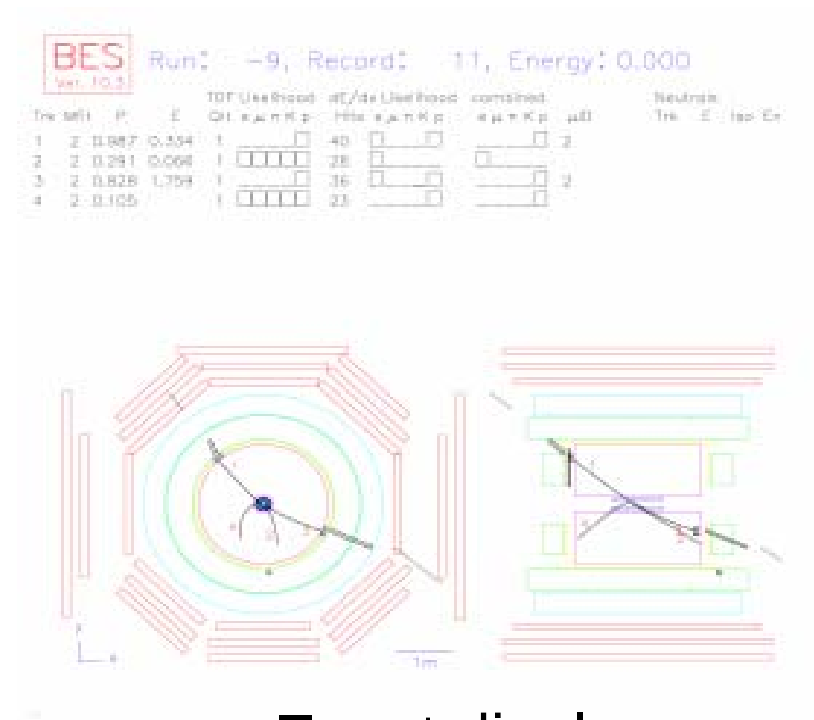
✓The beam energy range of BEPC is from 1.5GeV to 2.8GeV.

✓This detector is designed for charm and τ physics.



Detector	Major parameter	BESI	BESII
VC	$\sigma_{xy}(\mu m)$	200	100
	$\epsilon_{trk}(\%)$	no	97
MDC	$\epsilon_{wire}(\%)$	96	96
	$\sigma_{xy}(\mu m)$	200-250	190-220
	$\Delta p/p$ (%)	$1.76\sqrt{1+p^2}$	$1.78\sqrt{1+p^2}$
	$\sigma_{dE/dx}$ (%)	7.9	8.4
BTOF	σ_T (ps)	375	180
	L_{atten} (m)	1.0 - 1.2	3.5 - 5.5
ETOF	σ_T (ps)		720
BSC	$\Delta E/\sqrt{E}$ (%)	24	21
	σ_z(cm)	4.5	2.3
ESC	$\Delta E/\sqrt{E}$ (%)	24.4	22.1
μ counter	$\epsilon_{trk}(\%)$	95	95
	σ_z(cm)	5.5	5.5
DAQ	dead time (ms)	20	8

BES-II parameter



Event display

- 2.86×10^7(hadronic events): collected from 1999 to 2000.
- Reconstructed tool: DRUNK
- Monte Carlo event generator: GENSIM
  - ✓GEANT3 based
  - ✓100000 $J/\psi \rightarrow \Lambda\bar{\Lambda}$ was generated.

Event selection

1. Nch=4: with good charged track fitting.

   |cos θ|<0.8: for all charged track.

2. Combination cut

   ※due to decay kinematics, momenta of p and p are larger than those of momentum π^+ and π^-.

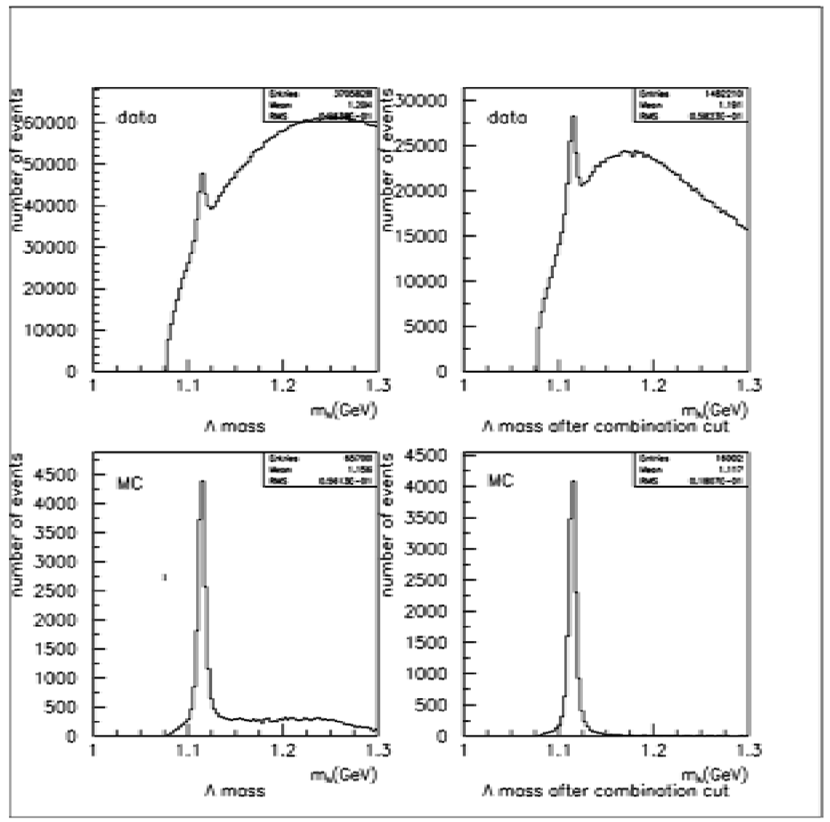
   P_{pmin}=0.767 GeV

   $P_{\pi max}$=0.309 GeV

   4 particles are unambiguously identified!

   →Combining a charge and momentum comfigurations.

Combination cut



Comparison of the m_Λ peak before and after combinational cut

✓Effectively reduces combinational background!

3. $2.95\ \text{GeV} \leqq E_{sum} \leqq 3.20\ \text{GeV}$

lower energy cut must be treated carefully!

→other dibaryon decay modes :

$J/\psi \to \Sigma^0 \Sigma^0$	$(Br = 1.27 \times 10^{-3})$
$\Sigma^0 \to \Lambda \gamma$	$(Br = 100\%)$
$J/\psi \to \Xi^0 \Xi^0$	$(Br = 1.80 \times 10^{-3})$
$\Xi^0 \to \Lambda \gamma$	$(Br = 99.51\%)$
$\to \Lambda \pi^0$	$(Br = 0.118\%)$

※these are $\Lambda\bar{\Lambda}$ events associated with photons!

4. $1.49\ \text{GeV} \leqq E_{\Lambda}, E_{\bar{\Lambda}} \leqq 1.60\ \text{GeV}$

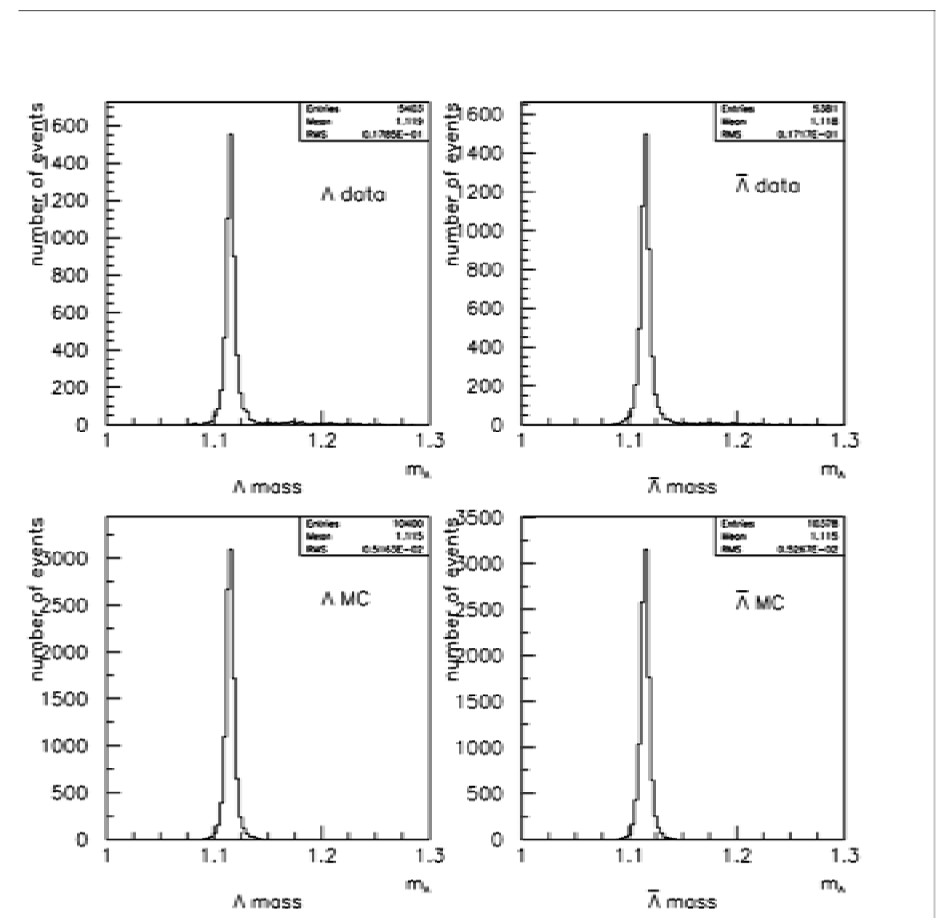
→E_{Λ} and E_{Λ} are one half of the J/ψ mass in the J/ψ rest frame.

5. $1.10\ \text{GeV} \leqq m_{\Lambda}, m_{\bar{\Lambda}} \leqq 1.13\ \text{GeV}$

→$p\pi^{-}(p\pi^{+})$ invariant mass correspond to $\Lambda(\bar{\Lambda})$ mass.

peak: 1.1152 GeV (data)

1.1150 GeV(MC)



6. The events with photons must be eliminated.

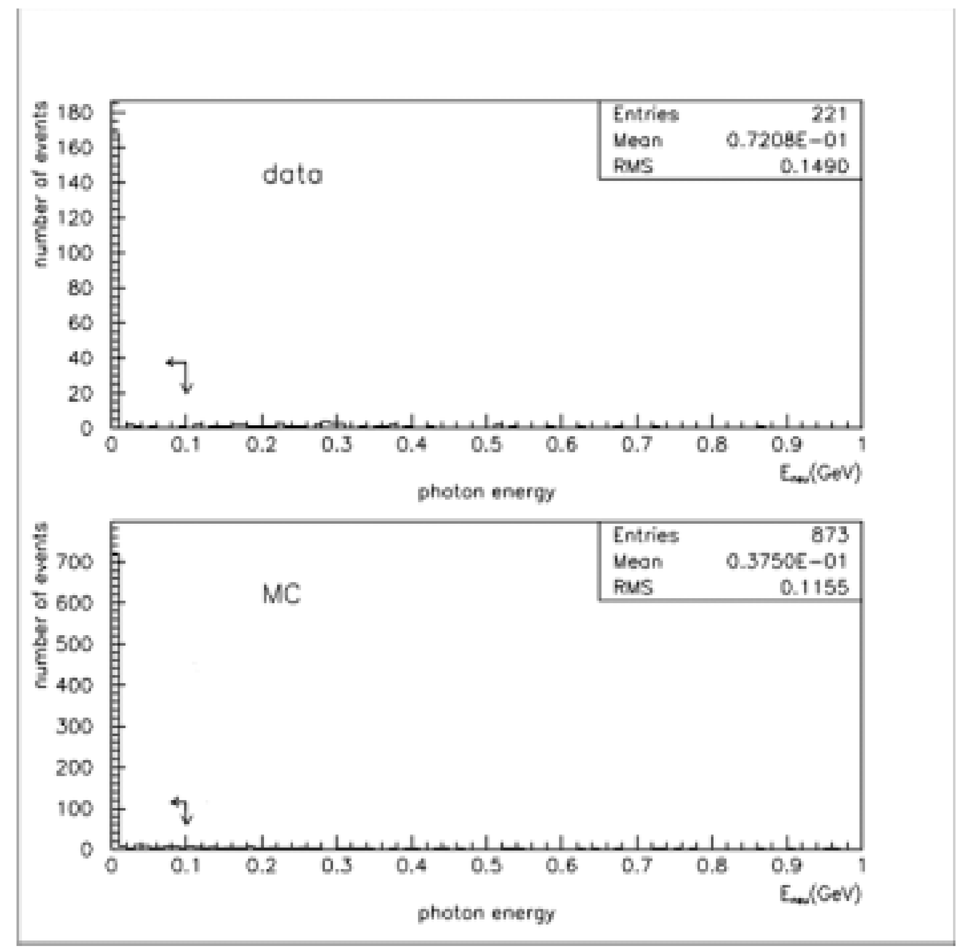
→The charged hadrons create energy clusters with larger size due to the nuclear interactions.

Analysis(Bhabha events):

※0.2m at the inner surface of the shower counter.

→More than 0.4m far from any charged tracks.

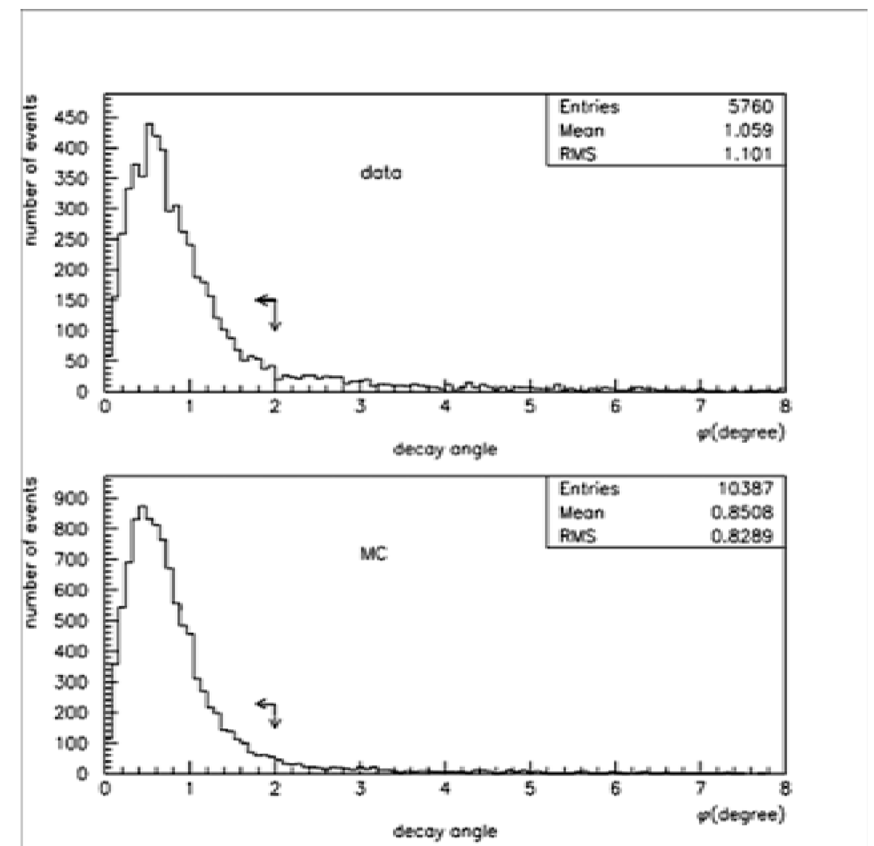
$E_{photon} \leqq 0.1$ GeV



7. $\phi \leqq 2.0°$, where ϕ is a decay angle between Λ and $\bar{\Lambda}$.

→ Λ and $\bar{\Lambda}$ are decay back-to-back.

※The initial radiation makes an angle fall out from 180°!



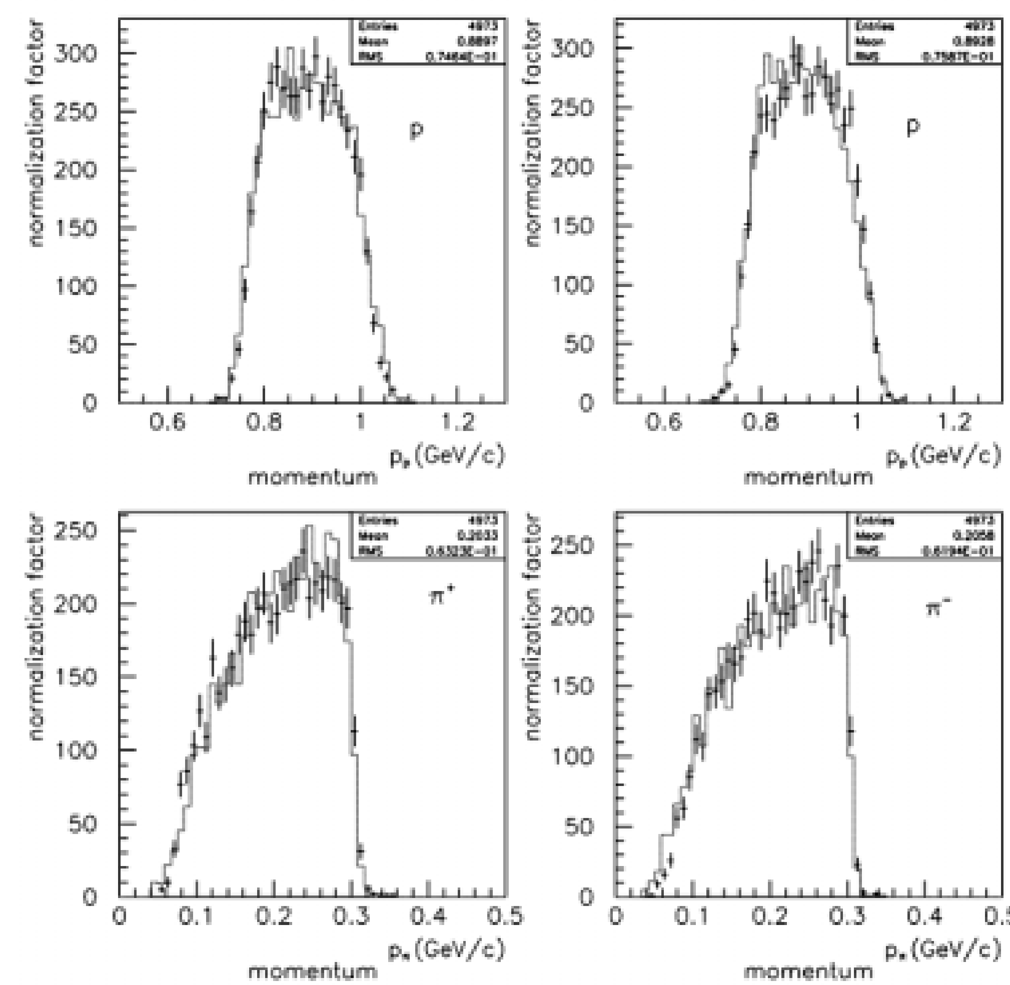
The obtained events

Monte Carlo：1.0×10^5

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

N_{MC}=9587

data：N=4973



Minimum momentum

Maximum momentum

→as expected by the kinematics!

The measurement of Br($J/\psi \to \Lambda\ \Lambda$)

- Br($J/\psi \to \Lambda \bar{\Lambda}$) is calculated to be

$$Br(J/\psi \to \Lambda \bar{\Lambda}) = \frac{N}{\varepsilon N_0 Br(\Lambda \to p\pi)^2}$$

N: The number of observed events.

ε : The efficiency of Monte Carlo simulation

N_0: total number of J/ψ events.

value	number
N	4973
N_0	3.39×10^7
ϵ	0.235
$Br(\Lambda\to p\pi)^2)$	0.639
$Br(J/\psi\to\Lambda\bar{\Lambda})$	1.34×10^{-3}

Table 1: The list of the values which are used for calculating branching fraction

- Branching fraction

$Br(J/\psi \to \Lambda \bar{\Lambda}) = 1.34 \pm 0.02 \times 10^{-3}$

PDG: $1.30 \pm 0.12 \times 10^{-3}$

Systematic errors

source	cyst. errors(%)
Monte Carlo statistics	1.0
background	0.53
E_Λ	0.28
m_Λ	0.63
φ	0.008
N_0	2.0
$Br(\Lambda \to p\pi)$	0.5
Total systematic error of $Br(J/\psi \to \Lambda\bar{\Lambda})$	2.5

Table 2: The list of the sources of the systematic error

- Total systematic error: 2.5%
- Result

$$Br(J/\psi \to \Lambda \bar{\Lambda}) = 1.34 \pm 0.02 \pm 0.03 \times 10^{-3}$$

Total number of J/ψ events

- Decay mode:

$$J/\psi \rightarrow \mu^- \mu^+$$

- Back grounds:

$$e^- e^+ \rightarrow \mu^- \mu^+$$
$$e^- e^+ \rightarrow e^- e^+$$
$$J/\psi \rightarrow e^- e^+$$

※50000 MC event samples are generated and are analized.

$$N_{J/\psi} = \frac{N - N_{B.G.}}{\varepsilon_{trg} \varepsilon_{\mu\mu} Br(J/\psi \rightarrow \mu\mu)}$$

- Cuts
  - ✓ $N_{ch}=2$
  - ✓ $|\cos\theta|<0.6$
  - ✓ 1.0 GeV≦p+, p-≦2.1 GeV
  - ✓ vertex:

    $|r_{+,-}|<0.015$

    $|z_{+,-}|<0.15$
  - ✓ tof:

    $|T_{+}-T_{-}|<1.0$ nsec

    $|T-T_{exp}|<0.7$ nsec

decay mode	obs. events
$J/\psi\to\mu\mu$	8.26×10^{5}
$e^{+}e^{-}\to\mu\mu$	5.84×10^{4}
$J/\psi\to\mu\mu$	1.38×10^{2}
Bhabha	50.8
$N_{J/\psi}$	3.39×10^{7}

Table 1: The list of the number of observed events.

Total number of J/ψ:

$$N_{J/\psi}=3.39\pm0.07\times10^{7}$$

error: 2.0%

The analysis of CP violation

- Asymmetry A

$$\langle \mathbf{A} \rangle = \frac{\mathbf{N^+ - N^-}}{\mathbf{N^+ + N^-}}$$

- Analysis

  N^+=2571,

  N^-=2402

→$\langle A \rangle = 3.40 \times 10^{-2}$

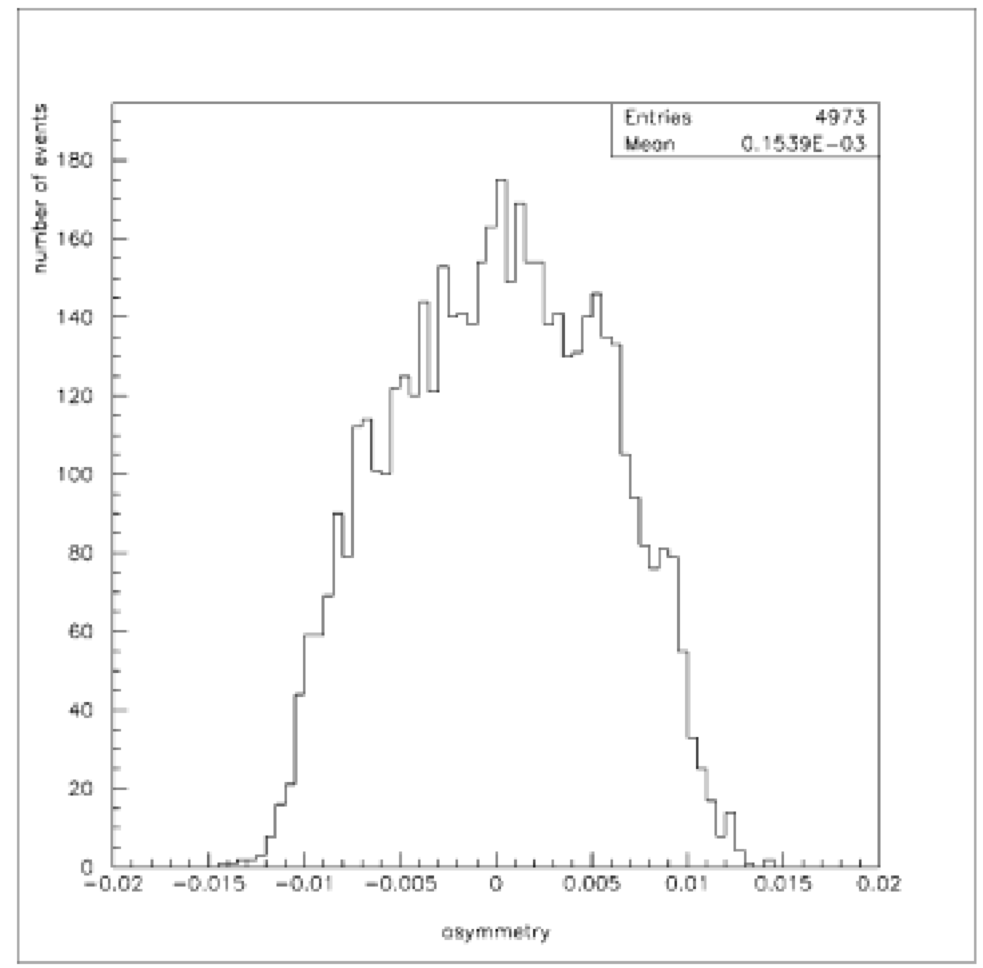


Figure 1: The distribution of asymmetry A.

Systematic errors

source	syst. errors(%)
background	0.53
E_Λ	0.28
m_Λ	0.63
φ	0.008
angular resolution	0.48
momentum resolution	0.56
Total systematic error of asymmetry	1.1

Table 3: The list of the sources of the systematic error

- Total systematic error: 1.1%
- Result

$<A>=3.40\pm1.43\pm0.3\times10^{-2}$

$|<A>|<5.78\times10^{-2}$ CL=90%

$$|d_\Lambda| < \begin{cases} 10.3\,(\times10^{-16}e\text{cm}), & \text{(a-term dominamt)} \\ 4.62\,(\times10^{-16}e\text{cm}), & \text{(c-term dominamt)} \end{cases}$$

Results

- Branching fraction

$Br(J/\psi \to \Lambda \bar{\Lambda}) = 1.34 \pm 0.02 \pm 0.03 \times 10^{-3}$

→This measurement supersedes current world average.

- Asymmetry

$|\langle A \rangle| < 5.78 \times 10^{-2}$

→It seems to have a sign of CP violation?

※this problem needs to analyze more precisely.

Discussion

- Asymmetry *A* is 2.5 σ above zero.

  $|d_\Lambda| < 1.5 \times 10^{-16}$ (ecm)

→This upper limit is restricted electric and colour dipole moment of strange quark?

(c.f. hep-ph/0010105(2000))

- Advanced analysis

  ① Using whole the BES J/ψ events.

  ※5.0×107 J/ψ events are already collected (from 1999 to 2002).

  →the upper limit of d_Λ will improve.

② Using other CP-odd observables.

→constructed from momenta k, p ,q_+ , q_-.

ex.) tensor observable

$$T_{ij} = (q_- - q_+)_i (\boldsymbol{q}_- \times \boldsymbol{q}_+)_j + (q_- - q_+)_j (\boldsymbol{q}_- \times \boldsymbol{q}_+)_i.$$

※But it is difficult to evaluate the consequence in this case.

This problem needs to analyze more precisely.