

Measurement of $\Psi(2S) \rightarrow \Omega^+ \Omega^-$

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Outline

- Introduction
- Data sets MC samples
- Event selection
- Study the angular distributions in single tag and double tag analysis
- Use new generator to measure the cross section of $e^+e^- \rightarrow \Omega^+\Omega^-$ at the center energy in 3.773GeV and 4.18GeV
- Summary and next to do

Introduction

Motivation : several other experiments have searched for higher-order multipole amplitudes, in this decay model, $\Psi(2S)$ can't decay in phase space, but there is no provision in theory, so we will :

- Study the angular distribution of $\Omega^+\Omega^-$ in $\Psi(2S) \rightarrow \Omega^+\Omega^-$ decay,
- Measure the branching ratio of $\Psi(2S) \rightarrow \Omega^+\Omega^-$ with a better precision
- Use new generator to measure the cross section of $e^+e^- \rightarrow \Omega^+\Omega^-$

Introduction

Decay chains : $\psi(2S) \rightarrow \Omega^- \bar{\Omega}^+$

$$\Omega^- \rightarrow K^- \Lambda \quad \bar{\Omega}^+ \rightarrow K^+ \bar{\Lambda}$$

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

Analysis method:

- ◆ **Inclusive analysis**: reconstruct only one Ω via $\Omega \rightarrow K\Lambda$, and the number of signal events is obtained by fitting the invariant mass of $K\Lambda$ requiring the recoiling mass of $K\Lambda$ to be in the Ω signal region
- ◆ **Exclusive analysis**: reconstruct both Ω^- and $\bar{\Omega}^+$ via $\Omega \rightarrow K\Lambda$, and the number of signal events is obtained by fitting the invariant mass of $K^-\Lambda$ requiring the invariant mass of $K^+\bar{\Lambda}$ to be in the Ω signal region

MC and Data sample

Data sets:

Experimental data: **341.1M(2012)** $\psi(2S)$ data

MC Signal: **0.2M(2012)** generated with KKMC and all the samples are generated in PHSP

Boss version: **6.6.4.p03**

Event selection

- The polar angle of each charged track is required to satisfy $|\cos\theta| < 0.93$;

Charged particles are identified with **only dE/dx information**

- Proton and anti-proton: $\text{Prob}(p) > \text{Prob}(\pi) \ \&\& \ \text{Prob}(p) > \text{Prob}(K)$,
- Kaons: $\text{Prob}(K) > \text{Prob}(\pi) \ \&\& \ \text{Prob}(K) > \text{Prob}(p)$,
- The left particles are assumed to be pions

- **Λ Reconstruction via $\Lambda \rightarrow p\pi$:** loop over the $p\pi$ combination to reconstruct Λ , the $p\pi$ pair should pass the first vertex fit ,and keep the one with $p\pi$ invariant mass closest to Λ mass,
- **Ω Reconstruction via $\Omega \rightarrow K\Lambda$:** loop over the $K\Lambda$ combination to reconstruct Ω , the $K\Lambda$ pair should pass the first and secondary vertex fit , and keep the one with least secondary vertex fit chi square.

Requirements of single tag analysis

signal tag analysis: reconstruct only one Ω via $\Omega \rightarrow K\Lambda$, and the number of signal events is obtained by fitting the invariant mass of $K\Lambda$ requiring the recoiling mass of $K\Lambda$ to be in the Ω signal region

Requirements:

- At least three good charged tracks are identified as $K^- p(\pi^-)$ or $K^+ \bar{p}(\pi^+)$, and the number of good charged tracks are less than eight
- The Transverse momentum of $K^- p \pi^-$ or $K^+ \bar{p} \pi^+$ is required larger than 0.1GeV
- One Λ (or Λ_{bar}) candidate is found, and the invariant mass of $p\pi$ is required to be in the mass window: **(1.110, 1.122)GeV**
- The invariant mass of $K^+ \bar{\Lambda}$ is required to be in the mass window : **(1.663, 1.681) GeV**
- One Ω^- (or $\bar{\Omega}^+$) candidate is reconstructed after the Λ mass window cut and the recoiling mass of $K\Lambda$ is required to be in the Ω mass window: **(1.640, 1.692) GeV**

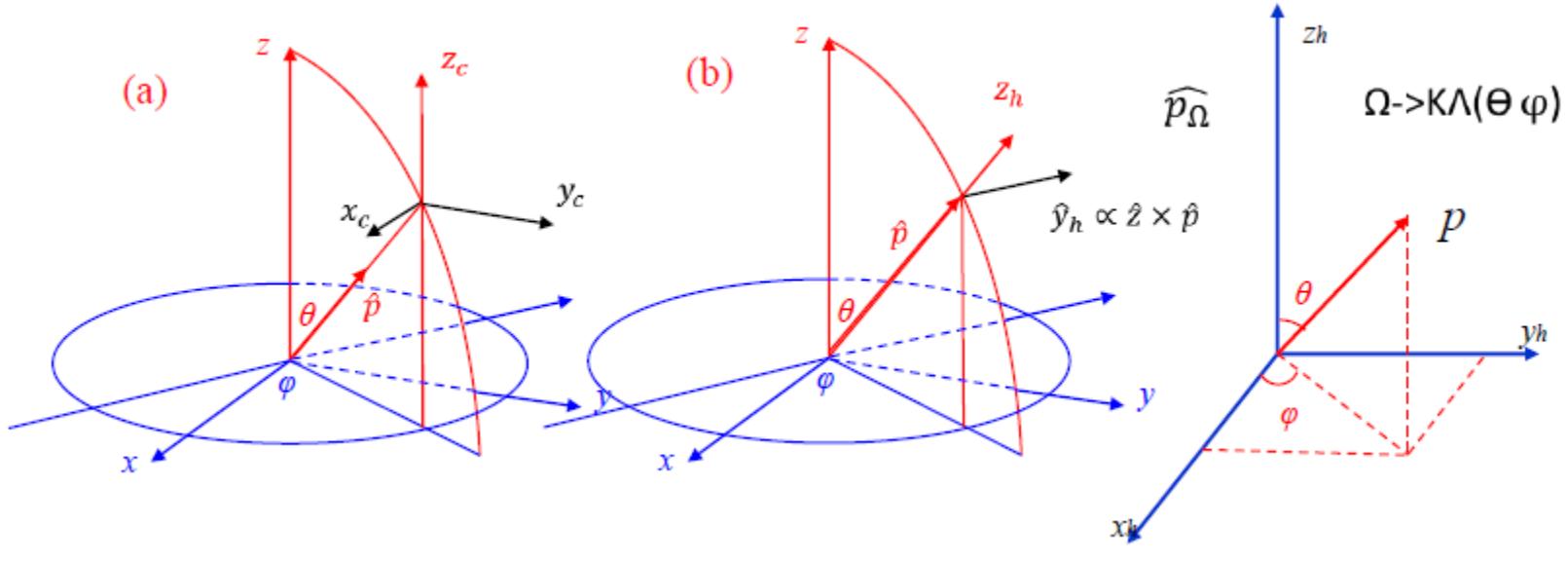
Requirements of double tag analysis

double analysis : reconstruct both Ω^- and $\bar{\Omega}^+$ via $\Omega \rightarrow K\Lambda$, and the number of signal events is obtained by fitting the invariant mass of $K^-\Lambda$ requiring the invariant mass of $K^+\bar{\Lambda}$ bar to be in the Ω signal region

Requirements:

- At least six good charged tracks are identified as $K^- p(\pi^-)$ and $K^+ \bar{p}(\pi^+)$ and the number of good charged tracks are smaller than eight
- The Transverse momentum of $K^- p \pi^-$ and $K^+ \bar{p} \pi^+$ is required larger than 0.1GeV
- One Λ and one $\bar{\Lambda}$ candidates are found, and the invariant mass of $p\pi$ is required to be in the mass window: **(1.110, 1.122)GeV**
- One Ω^- and one $\bar{\Omega}^+$ candidates are reconstruct after Λ mass window
- The invariant mass of $K^+\bar{\Lambda}$ is required to be in the mass window : **(1.663, 1.681) GeV**
- The invariant mass of $\bar{\Omega}^+\Omega^-$ is required to be in the mass window : **(3.65, 3.75) GeV**

Helicity Coordinate System



The orientation of the coordinate systems associated with a particle at rest in the (a) canonical ($\hat{x}_c \hat{y}_c \hat{z}_c$), and (b) helicity description ($\hat{x}_h = \hat{y}_h \times \hat{z}_h$, $\hat{y}_h = \hat{z} \times \hat{p}$, $\hat{z}_h = \hat{p}$)

The joint amplitude of single tag analysis

$$|M|^2 = \sum_{\substack{\omega_1, \omega_2, \\ \bar{\omega}_1, \bar{\omega}_2, \\ \lambda_1, \lambda_2, \lambda_p}} \rho^{(\omega_1 - \bar{\omega}_1, \omega_2 - \bar{\omega}_2)} (\Theta \varphi) A_{\omega_1 \bar{\omega}_1} A_{\omega_2 \bar{\omega}_2}^* B_{\lambda_1} B_{\lambda_2}^* C_{\lambda_p} C_{\lambda_p}^*$$
$$D_{\omega_1 \lambda_1}^{\frac{3}{2}*} (\Theta_1 \varphi_1) D_{\omega_2 \lambda_2}^{\frac{3}{2}} (\Theta_1 \varphi_1) D_{\lambda_1 \lambda_p}^{\frac{1}{2}*} (\Theta_2 \varphi_2) D_{\lambda_2 \lambda_p}^{\frac{1}{2}} (\Theta_2 \varphi_2)$$

$$\rho^{(i,j)}(\Theta, \varphi) = \sum_{K=\pm 1} D_{i,k}^1(\Theta \varphi) D_{i,k}^{1*}(\Theta \varphi)$$

Integral φ get the ρ

$$\begin{bmatrix} \pi(1 + \cos(\Theta))^2 & 0 & 0 \\ 0 & 2\pi \sin(\Theta)^2 & 0 \\ 0 & 0 & \pi(1 + \cos(\Theta))^2 \end{bmatrix}$$

The particles J^P

$$\Omega^- : \frac{3}{2}+ \quad \Lambda : \frac{1}{2}+ \quad K^- : 0- \quad p : \frac{1}{2}+ \quad \pi^- : 0-$$

$$\Omega^+ : \frac{3}{2}- \quad \bar{\Lambda} : \frac{1}{2}- \quad K^+ : 0- \quad \bar{p} : \frac{1}{2}- \quad \pi^+ : 0$$

Helicity amplitudes

$$\psi(2S) \rightarrow \Omega - \bar{\Omega}^+ \quad A_{\lambda v} = \begin{bmatrix} A_{\frac{3}{2}, \frac{3}{2}} & A_{\frac{3}{2}, \frac{1}{2}} & \cancel{A_{-\frac{3}{2}, \frac{1}{2}}} & \cancel{A_{\frac{3}{2}, -\frac{3}{2}}} \\ \cancel{A_{\frac{1}{2}, \frac{3}{2}}} & A_{\frac{1}{2}, \frac{1}{2}} & A_{\frac{1}{2}, -\frac{1}{2}} & \cancel{A_{-\frac{1}{2}, \frac{3}{2}}} \\ \cancel{A_{\frac{1}{2}, -\frac{3}{2}}} & A_{\frac{1}{2}, -\frac{1}{2}} & A_{\frac{1}{2}, \frac{1}{2}} & A_{\frac{1}{2}, \frac{3}{2}} \\ \cancel{A_{-\frac{3}{2}, \frac{3}{2}}} & \cancel{A_{-\frac{3}{2}, \frac{1}{2}}} & A_{\frac{3}{2}, \frac{1}{2}} & A_{\frac{3}{2}, -\frac{3}{2}} \end{bmatrix}$$

Angular momentum conservation:
 $\lambda - v \leq 1$
P parity conservation:
 $A_{\lambda v} = A_{-\lambda - v}$
so there are five parameters

$$|A_{\frac{1}{2}, -\frac{1}{2}}|^2 + |A_{\frac{1}{2}, \frac{3}{2}}|^2 + |A_{\frac{3}{2}, \frac{1}{2}}|^2 + 2(|A_{\frac{1}{2}, \frac{1}{2}}|^2 + |A_{\frac{3}{2}, -\frac{3}{2}}|^2) = 1 \text{ so:}$$

$$|A_{\frac{3}{2}, -\frac{3}{2}}|^2 = 0.5 \times (1 - (|A_{\frac{1}{2}, -\frac{1}{2}}|^2 + |A_{\frac{1}{2}, \frac{3}{2}}|^2 + |A_{\frac{3}{2}, \frac{1}{2}}|^2 + 2|A_{\frac{1}{2}, \frac{1}{2}}|^2))$$

$$\Omega \rightarrow K\Lambda \quad B_{\lambda v} = \begin{bmatrix} B_{-\frac{1}{2}, 0} \\ B_{\frac{1}{2}, 0} \end{bmatrix} \bar{B}_{\lambda v} = \begin{bmatrix} \bar{B}_{-\frac{1}{2}, 0} \\ \bar{B}_{\frac{1}{2}, 0} \end{bmatrix} \quad \alpha_{\Omega^-} = \frac{B_{\frac{1}{2}, 0}^2 - B_{-\frac{1}{2}, 0}^2}{B_{\frac{1}{2}, 0}^2 + B_{-\frac{1}{2}, 0}^2} B_{\frac{1}{2}, 0}^2 + B_{-\frac{1}{2}, 0}^2 = 1 \quad \alpha_{\Omega^+} \text{ is similarly}$$

$$\alpha_{\Omega^-} = 0.0180 \quad \alpha_{\Omega^+} = -0.0180$$

$$\Lambda \rightarrow p\pi \quad C_{\lambda v} = \begin{bmatrix} C_{-\frac{1}{2}, 0} \\ C_{\frac{1}{2}, 0} \end{bmatrix} \bar{B}_{\lambda v} = \begin{bmatrix} \bar{C}_{-\frac{1}{2}, 0} \\ \bar{C}_{\frac{1}{2}, 0} \end{bmatrix} \quad \alpha_{\Lambda} = \frac{C_{\frac{1}{2}, 0}^2 - C_{-\frac{1}{2}, 0}^2}{C_{\frac{1}{2}, 0}^2 + C_{-\frac{1}{2}, 0}^2} C_{\frac{1}{2}, 0}^2 + C_{-\frac{1}{2}, 0}^2 = 1 \quad \alpha_{\Lambda bar} \text{ is similarly}$$

$$\alpha_{\Lambda} = 0.642 \quad \alpha_{\Lambda bar} = -0.71$$

The joint amplitude of double analysis

$$|M|^2 = \sum_{\substack{\omega_1, \omega_2, \\ \bar{\omega}_1, \bar{\omega}_2, \\ \lambda_1, \lambda_2, \lambda b_1, \lambda b_2, \lambda p b}} \rho^{(\omega_1 - \bar{\omega}_1, \omega_2 - \bar{\omega}_2)} (\Theta \varphi) A_{\omega_1 \bar{\omega}_1} A_{\omega_2 \bar{\omega}_2}^* B_{\lambda_1} B_{\lambda_2}^* \bar{B}_{\lambda b_1} \bar{B}_{\lambda b_2}^* C_{\lambda p} C_{\lambda p}^* \bar{C}_{\lambda p b} \bar{C}_{\lambda p b}^*$$

$$\rho^{(i,j)}(\Theta, \varphi) = \sum_{K=\pm 1} D_{i,k}^1(\Theta \varphi) D_{i,k}^{1*}(\Theta \varphi)$$

$$D_{\omega_1 \lambda_1}^{\frac{3}{2}*}(\Theta_1 \varphi_1) \quad D_{\omega_2 \lambda_2}^{\frac{3}{2}}(\Theta_1 \varphi_1) \quad D_{\omega b_1 \lambda b_1}^{\frac{3}{2}*}(\overline{\Theta_1} \overline{\varphi_1}) \quad D_{\omega b_2 \lambda b_2}^{\frac{3}{2}}(\overline{\Theta_1} \overline{\varphi_1})$$

$$D_{\lambda_1 \lambda p}^{\frac{1}{2}*}(\Theta_2 \varphi_2) \quad D_{\lambda_2 \lambda p}^{\frac{1}{2}}(\Theta_2 \varphi_2) \quad D_{\lambda b_1 \lambda p b}^{\frac{1}{2}*}(\overline{\Theta_2} \overline{\varphi_2}) \quad D_{\lambda b_2 \lambda p b}^{\frac{1}{2}}(\overline{\Theta_2} \overline{\varphi_2})$$

Integral φ get the ρ

$$\begin{bmatrix} \pi(1 + \cos(\Theta))^2 & 0 & 0 \\ 0 & 2\pi \sin(\Theta)^2 & 0 \\ 0 & 0 & \pi(1 + \cos(\Theta))^2 \end{bmatrix}$$

Fitting in the same method
but no background

The particles J^P

$$\Omega^- : \frac{3}{2}+ \quad \Lambda : \frac{1}{2}+ \quad K^- : 0- \quad p : \frac{1}{2}+ \quad \pi^- : 0-$$

$$\Omega^+ : \frac{3}{2}- \quad \bar{\Lambda} : \frac{1}{2}- \quad K^+ : 0- \quad \bar{p} : \frac{1}{2}- \quad \pi^+ : 0$$

Fitting methods

- The joint angular distribution of the decay sequence can be written as $w(\theta, \theta_1, \phi_1, \theta_2, \phi_2, A_{1212}, A_{1232}, A_{3212}, A_{12m12})$
- to determine the four parameters, we perform maximum likelihood method to fit the angular distributions.
- $\bar{w}(A) = \sum_{j=1}^N \frac{w(\theta_{(j)}, \theta_1(j), \phi_1(j), \theta_2(j), \phi_2(j), A)}{N}$, $\bar{w}(A)$ is determined by using phase space distributed MC sample , and N is the number of selected events ,so the normalized probability-density function (pdf) becomes:

$$f(\theta, \theta_1, \phi_1, \theta_2, \phi_2, A) = \frac{w(\theta_{(j)}, \theta_1(j), \phi_1(j), \theta_2(j), \phi_2(j), A)}{\bar{w}(A)}$$

- The logarithm of the likelihood is $\ln L_s = \ln L - \ln L_b$, $L = \prod_{i=1}^{N_t} f(\theta(i), \theta_1(i), \phi_1(i), \theta_2(i), \phi_2(i), A)$, N_t is the total number enevts , $L_b = \prod_{j=1}^{N_b} f(\theta(j), \theta_1(j), \phi_1(j), \theta_2(j), \phi_2(j), A)$, N_b is the number of background events. By minimizing $-\ln L_s$, the optimal four A will be obtained.

fitting results(normalized condition)

	Likelihood	A3212	A1232	A1212	A12m12
Omega+	-29.19 -29.38	0.91+/-0.022 -0.059+/-0.042	-0.026+/0.042 0.041+/-0.048	-0.063+/-0.076 -0.118+/-0.050	-0.048+/-0.040 0.90+/-0.021
		-0.91 0.059	0.026 -0.041	-0.063 -0.118	0.048 -0.90
Omega-	-39.72 -41.95	-0.12+/-0.05 0.20+/-0.060	0.89+/-0.02 0.028+/-0.045	0.013+/-0.08 -0.26+/-0.052	0.089+/-0.042 0.81+/-0.033
		-0.12 -0.20	0.89 -0.028	0.013 -0.26	0.089 -0.81
OmegaOmega	-2.75	-0.28+/-0.22	-0.33+/-0.20	0.24+/-0.16	0.67+/-0.15
		0.28	0.33	0.24	-0.67

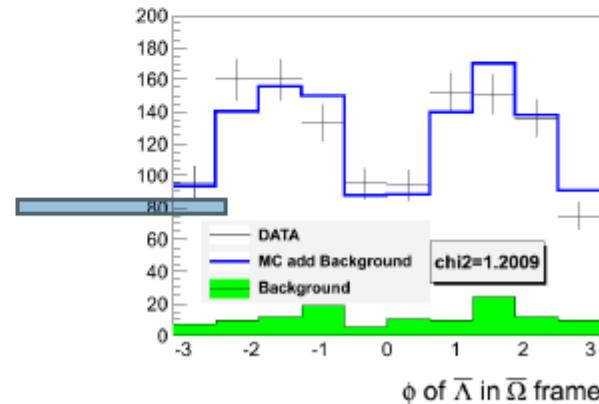
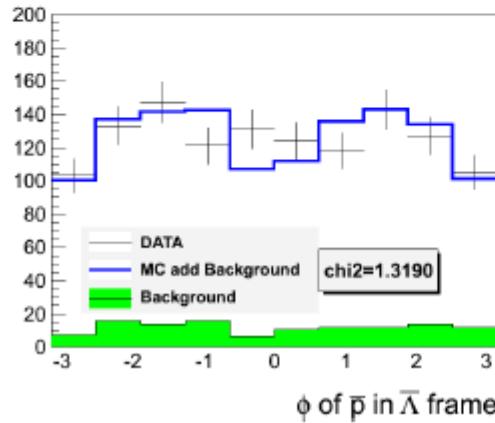
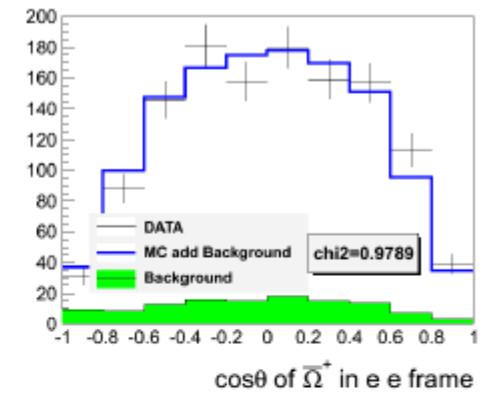
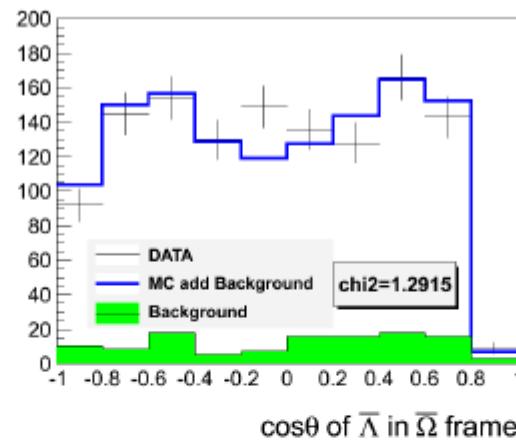
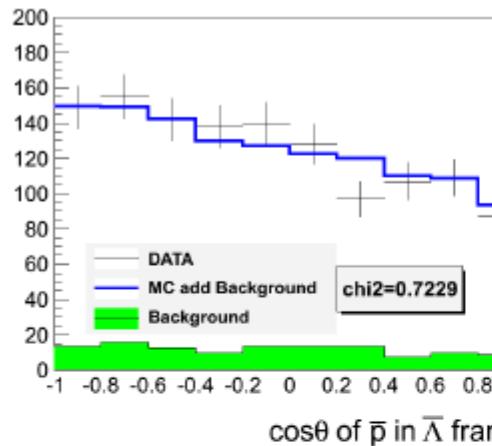
A3212(Ω^+)=A1232(Ω^-), A1232(Ω^+)=A1232(Ω^-), A1212(Ω^+)=A1212(Ω^-), A12m12(Ω^+)=A12m12(Ω^-)

α value and error

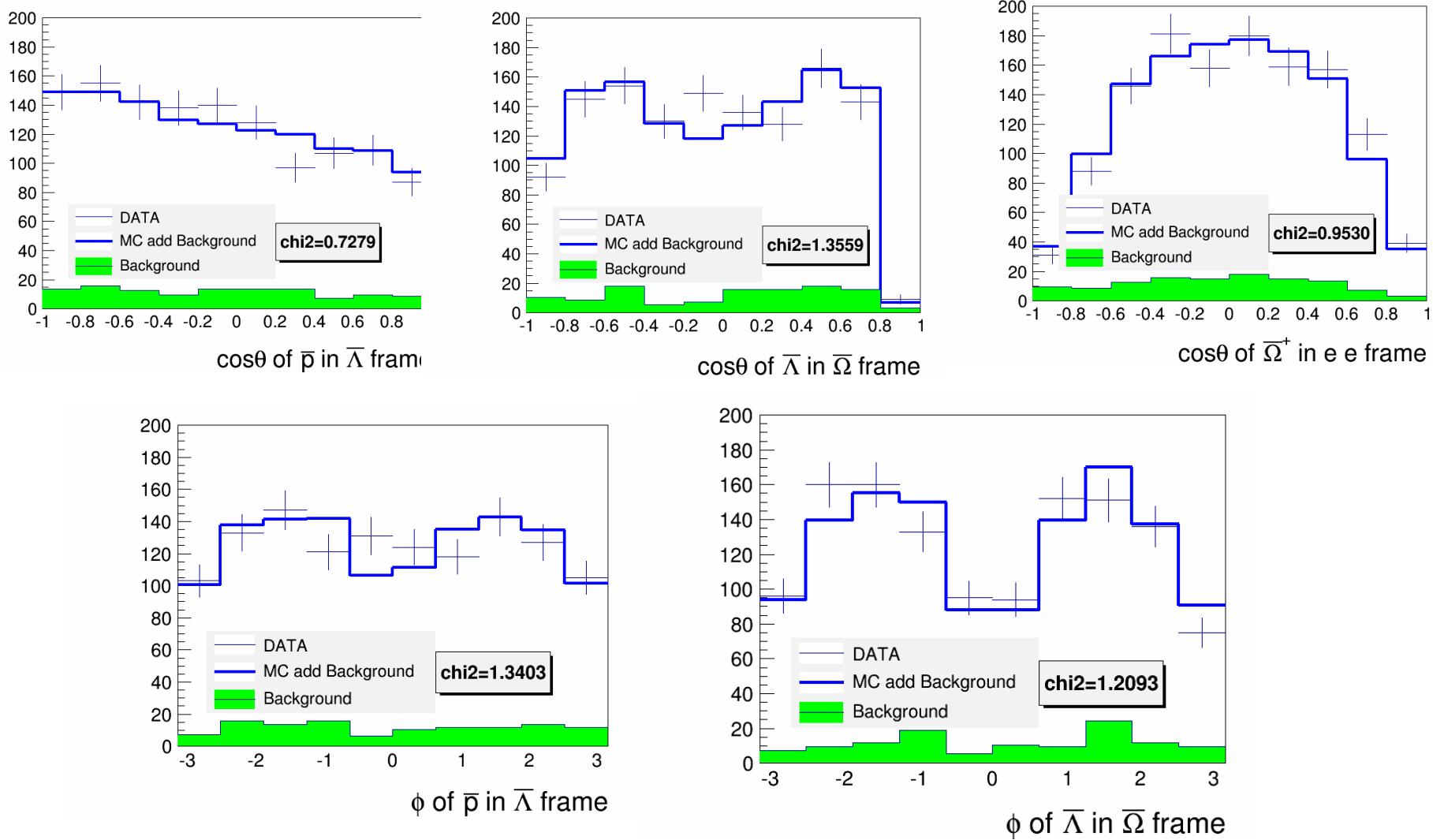
$$\alpha = \frac{|A_{1/2,-1/2}|^2 + |A_{1/2,3/2}|^2 + |A_{3/2,1/2}|^2 - 2(|A_{1/2,1/2}|^2 + |A_{3/2,3/2}|^2)}{|A_{1/2,-1/2}|^2 + |A_{1/2,3/2}|^2 + |A_{3/2,1/2}|^2 + 2(|A_{1/2,1/2}|^2 + |A_{3/2,3/2}|^2)}.$$

	α value	Error
$\Omega+$	0.66	0.08
	0.63	0.08
Ω^-	0.62	0.08
	0.39	0.09
$\Omega+\Omega^-$	0.27	0.32

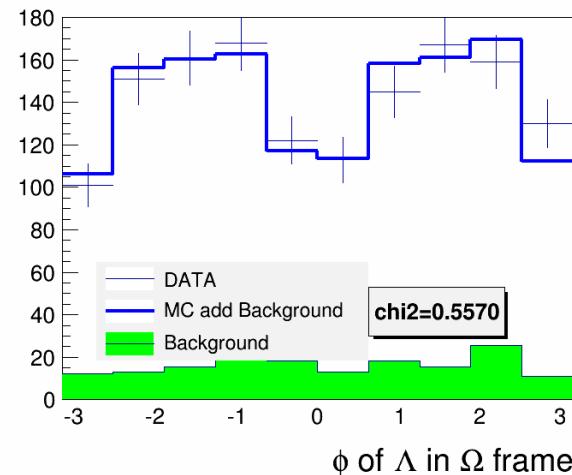
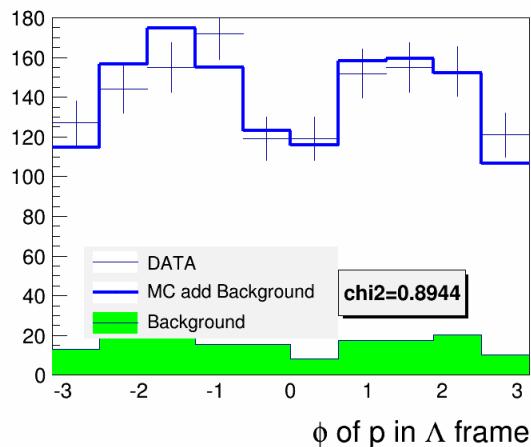
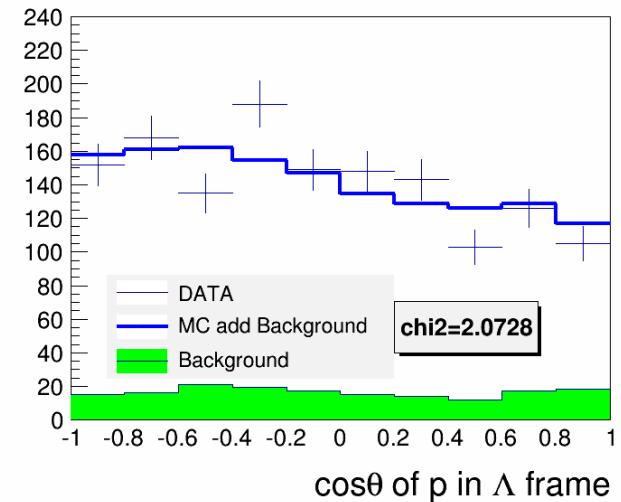
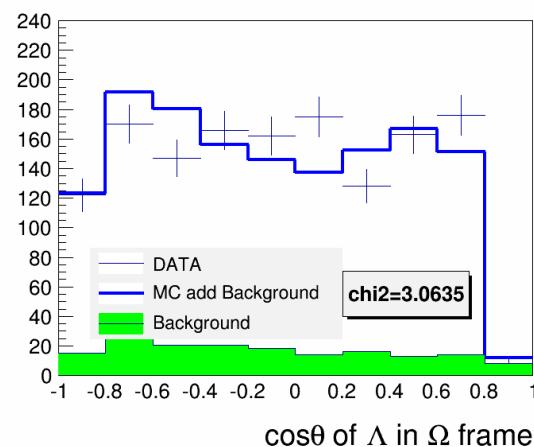
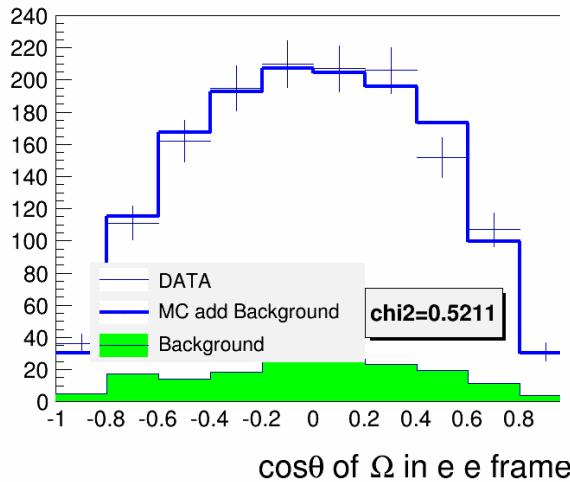
The first fitting result of Ω^+



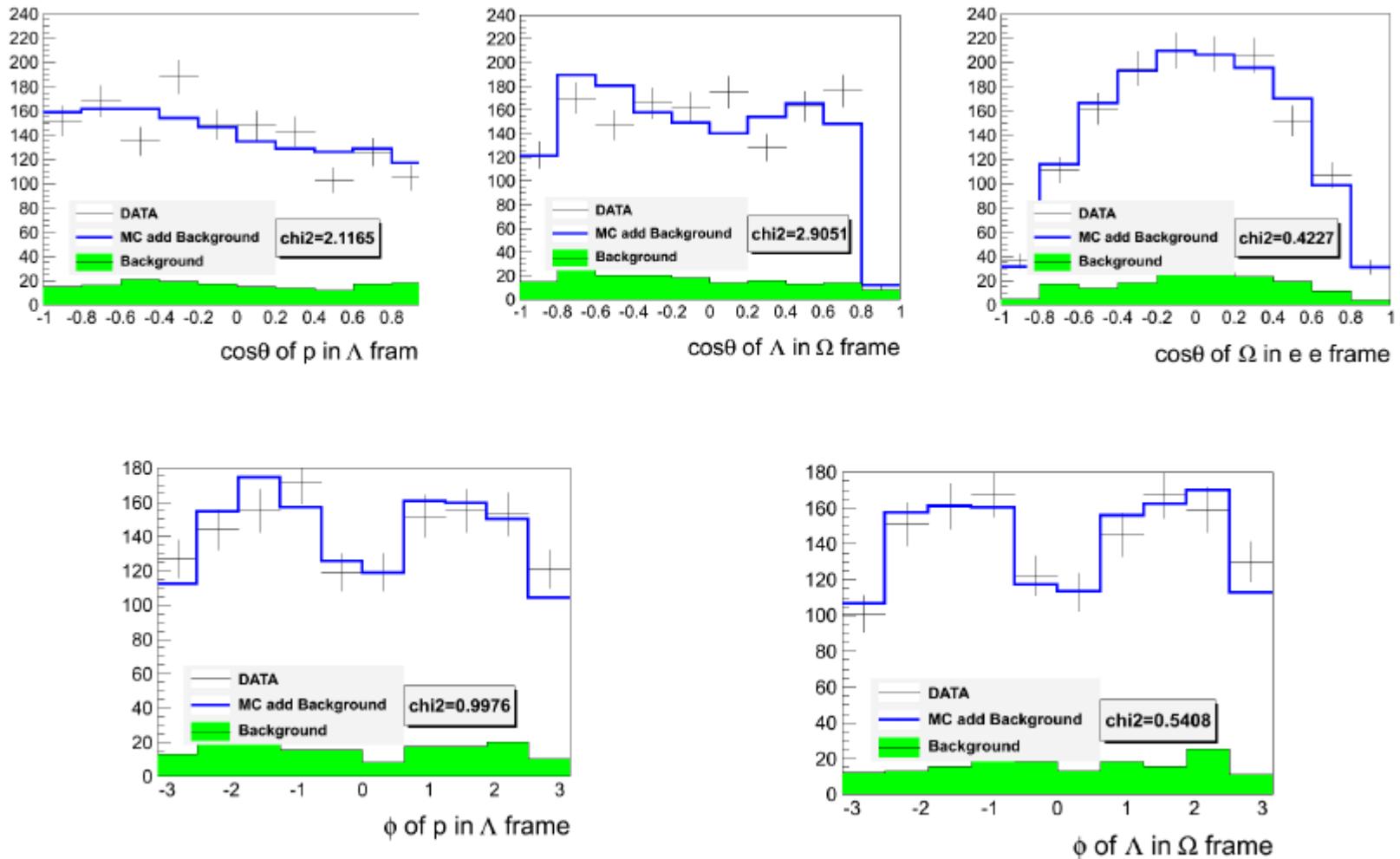
The second fitting result of Ω^+



The first fitting result of Ω^-



The second fitting result of Ω^-



Simultaneous fitting $\Omega^+ \Omega^-$

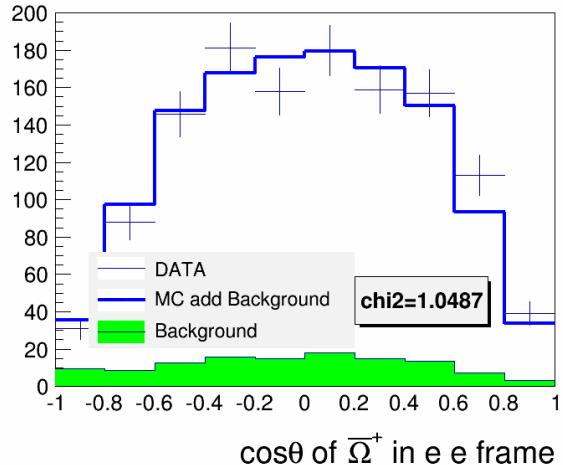
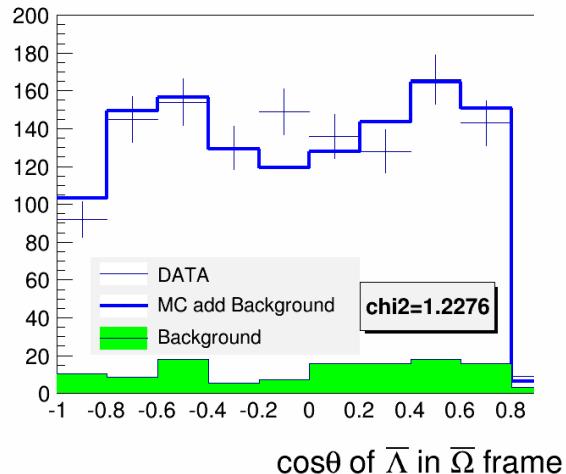
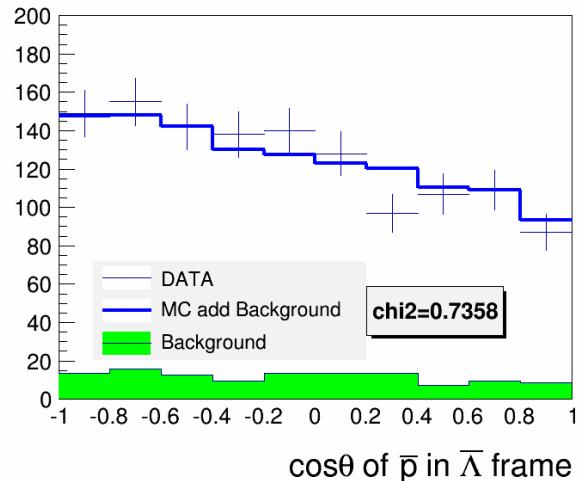
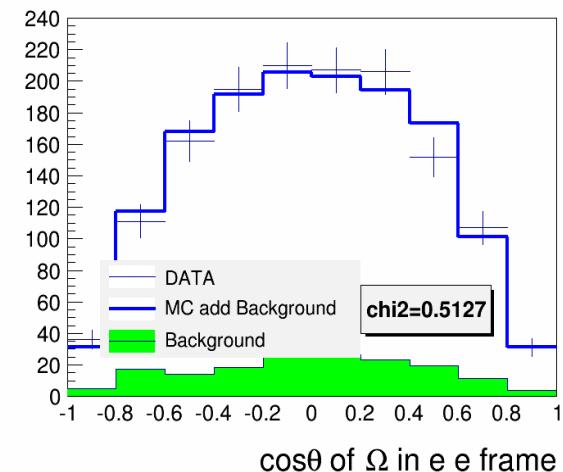
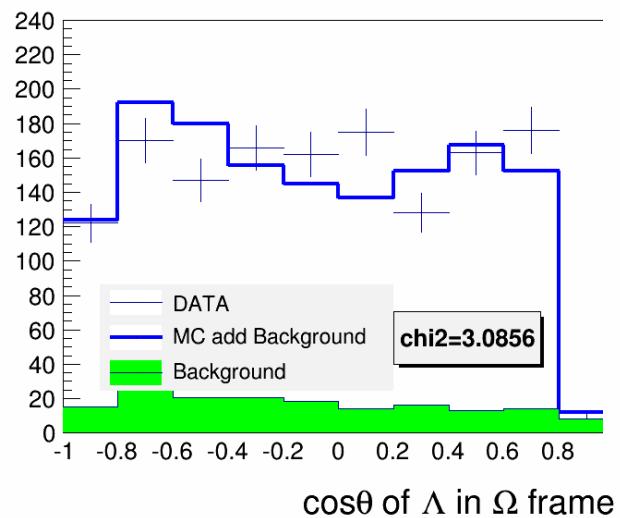
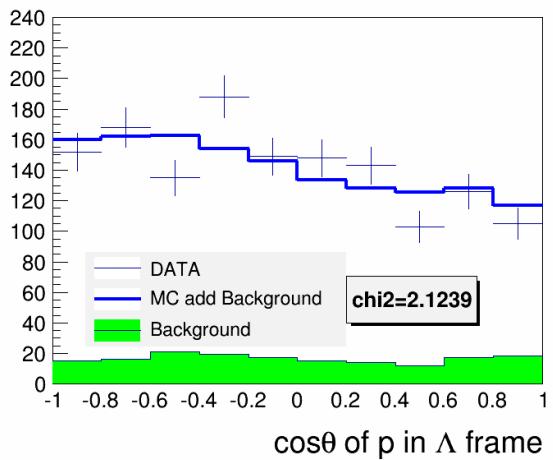
Likelihood	A3212(Ω^+) A1232(Ω^-)	A1232(Ω^+) A3212(Ω^-)	A1212(Ω^+) A1212(Ω^-)	A12m12(Ω^+) A12m12(Ω^-)
-63.95	0.901+/-0.014 -0.901+/-0.014	-0.071+/-0.031 0.071+/-0.031	-0.033+/-0.055 -0.033+/-0.055	0.018+/-0.029 -0.018+/-0.029
-65.56	-0.0147+/-0.030 0.0147+/-0.030	0.107+/-0.037 -0.107+/-0.037	-0.182+/-0.034 -0.182+/-0.034	0.867+/-0.017 -0.867+/-0.017

α value and error of simultaneous fitting

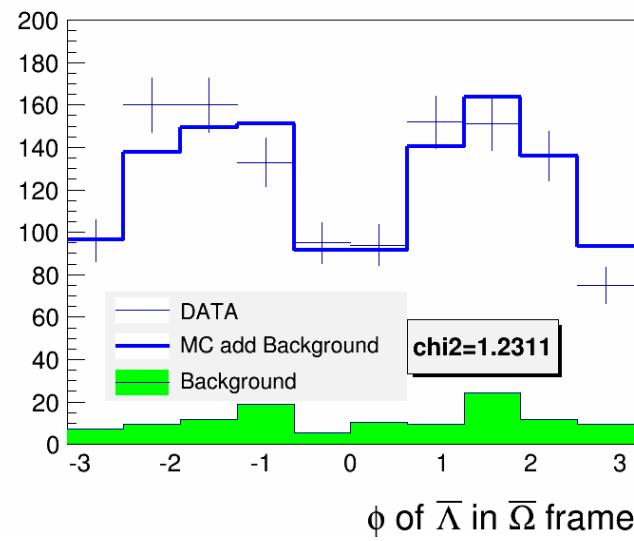
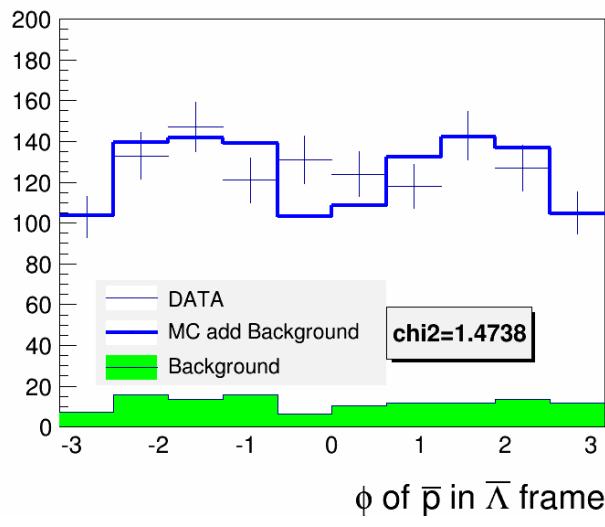
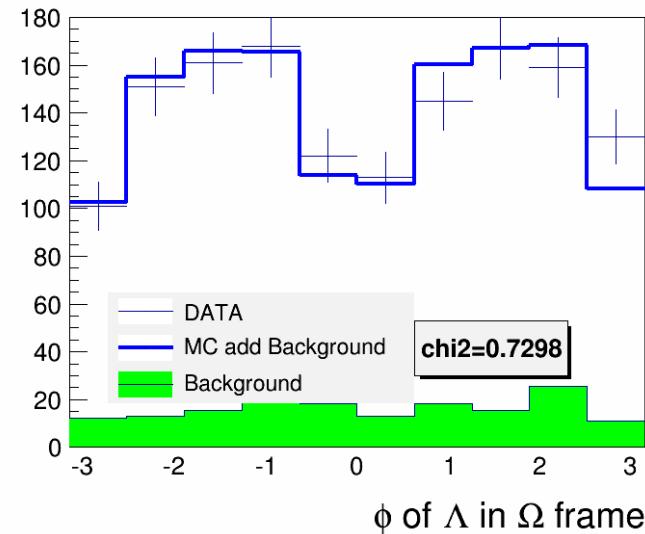
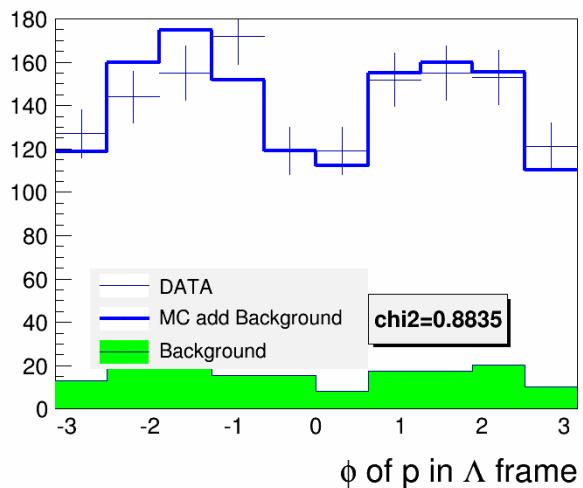
$$\alpha = \frac{|A_{1/2,-1/2}|^2 + |A_{1/2,3/2}|^2 + |A_{3/2,1/2}|^2 - 2(|A_{1/2,1/2}|^2 + |A_{3/2,3/2}|^2)}{|A_{1/2,-1/2}|^2 + |A_{1/2,3/2}|^2 + |A_{3/2,1/2}|^2 + 2(|A_{1/2,1/2}|^2 + |A_{3/2,3/2}|^2)}.$$

α value	error
0.63	0.05
0.53	0.06

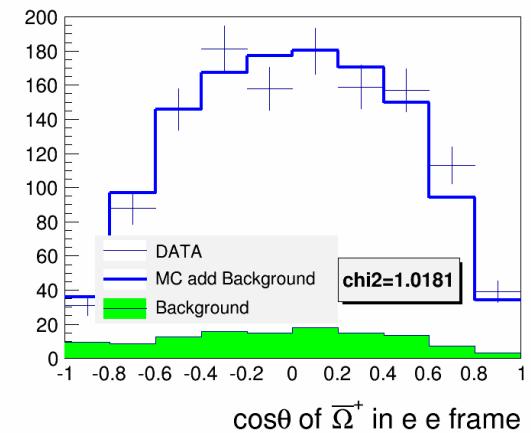
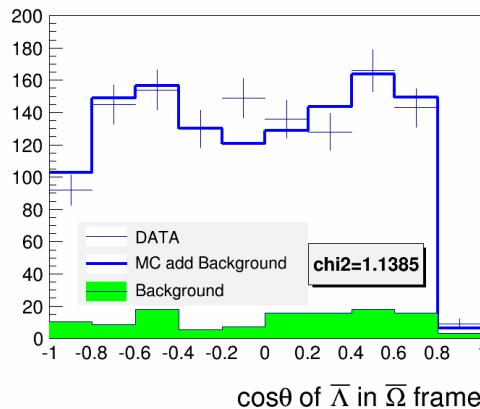
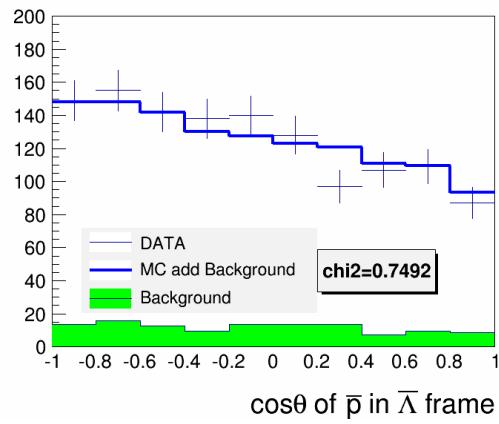
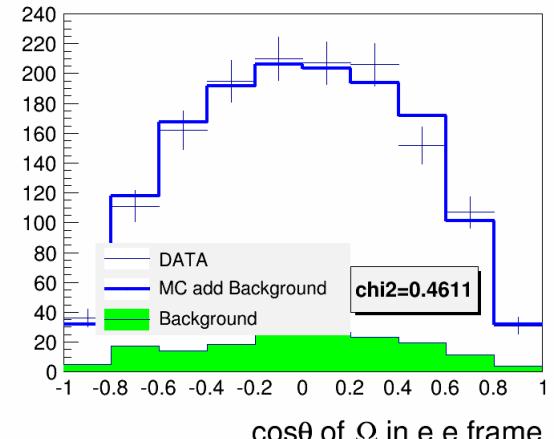
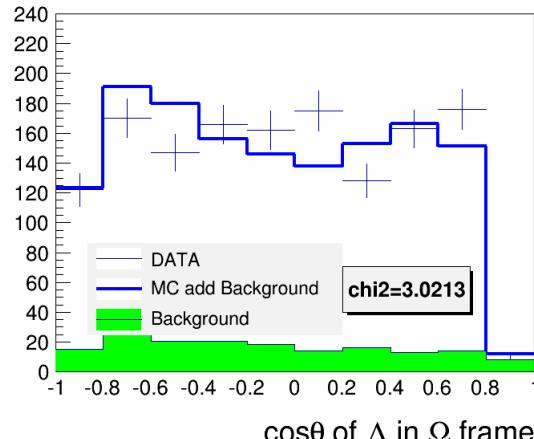
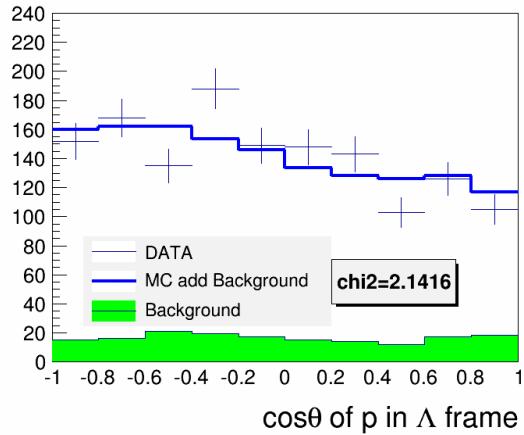
The first result of simultaneous fitting



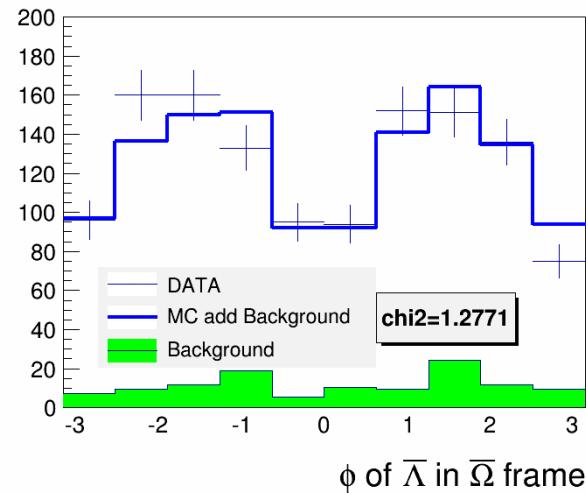
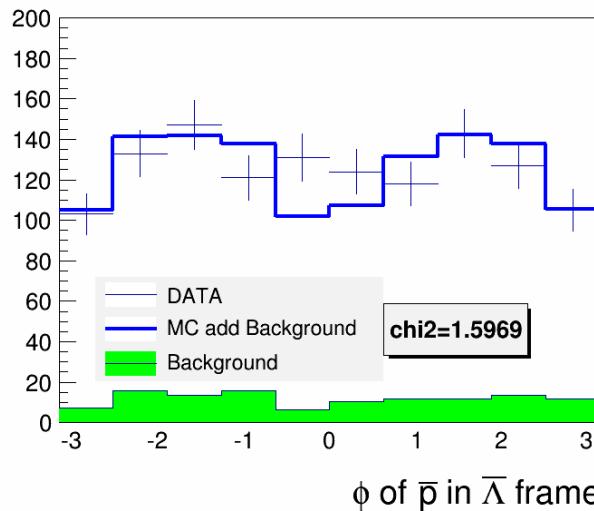
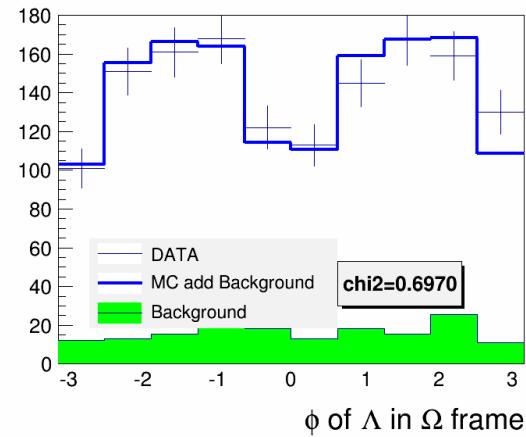
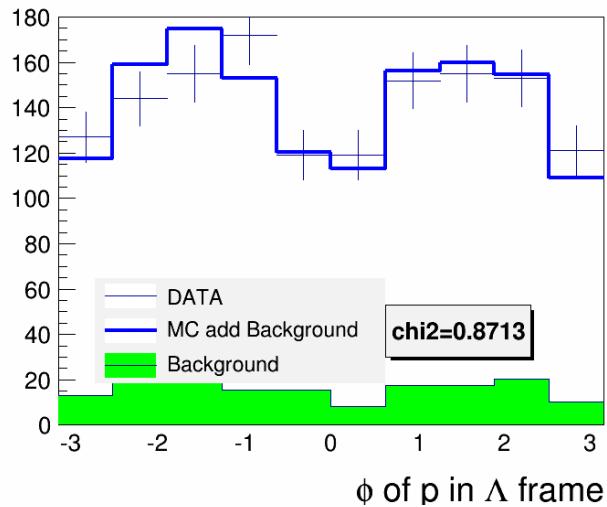
The first result of simultaneous fitting



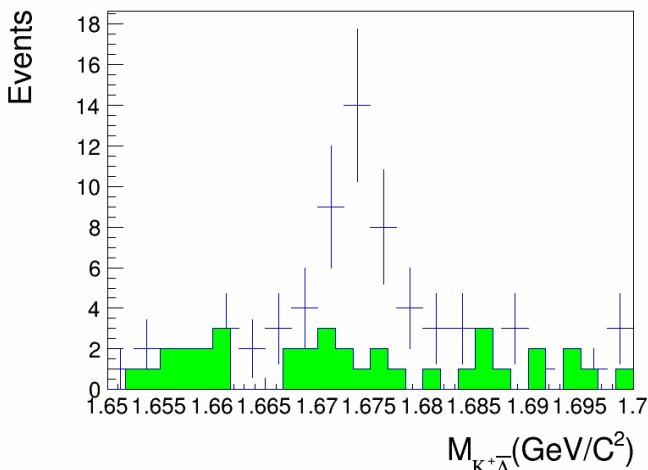
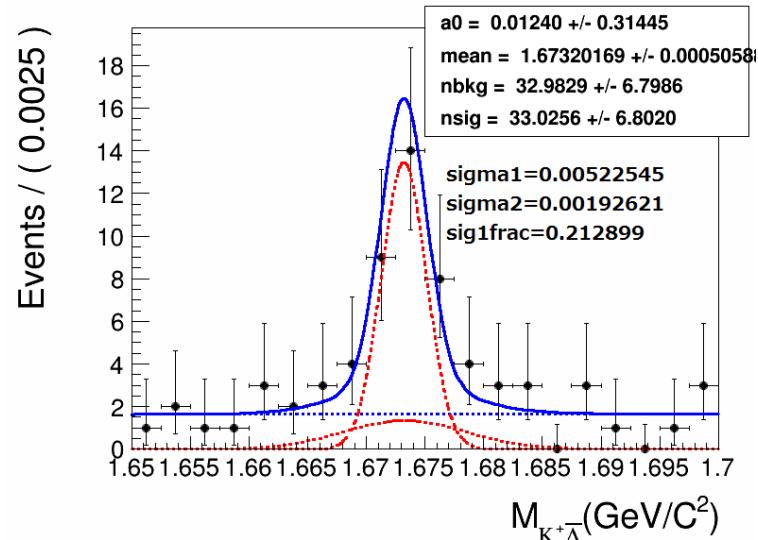
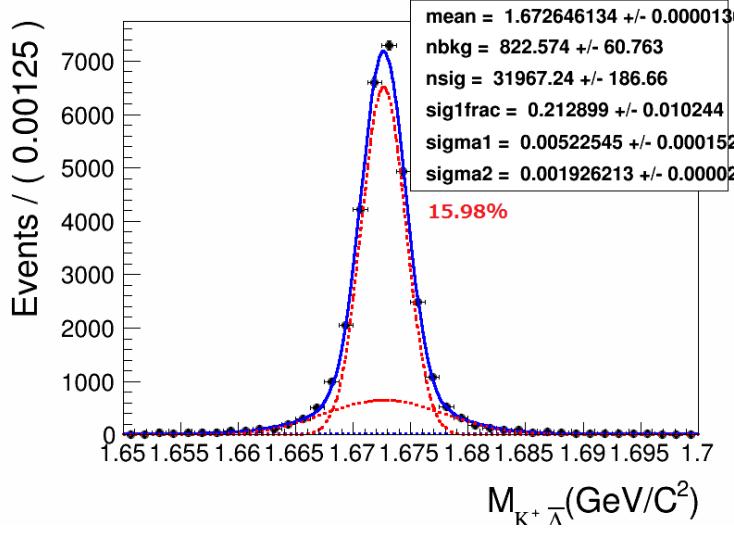
The second result of simultaneous fitting



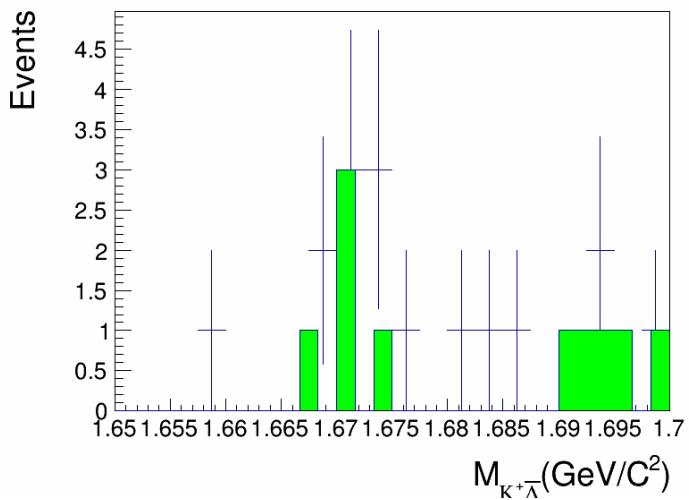
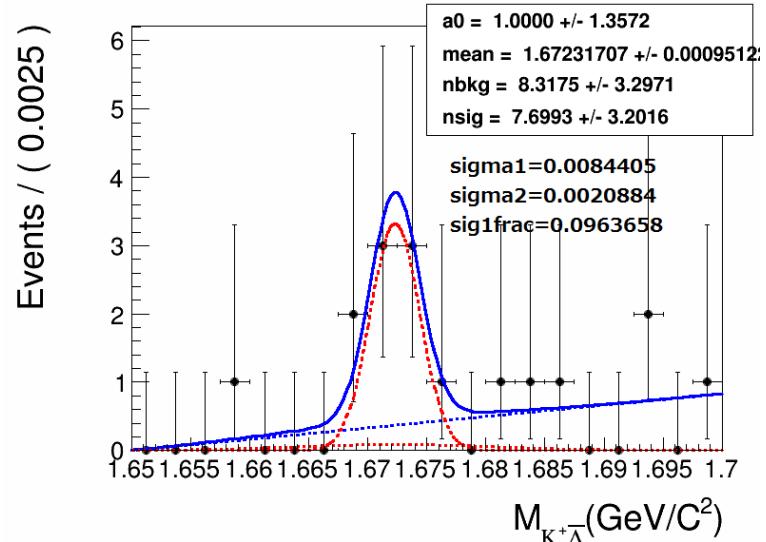
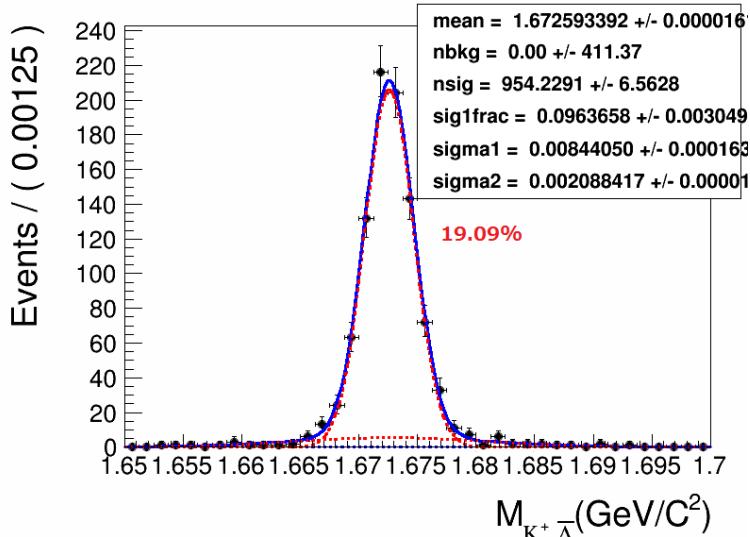
The second result of simultaneous fitting



New generator of Ω^+ at the energy in 3.773GeV



New generator of Ω^+ at the energy in 4.18GeV



Observation section measurement

$$\sigma^o = \frac{N^{obs}}{L \bullet \epsilon}$$

Energy(GeV)	Luminosity(pb ⁻¹)	Environment	σ^{obs} (10 ⁻²)
$\Psi(3770)$	2917	BOSS6.6.6.p03	7.08
4180	3160	BOSS7.0.2.p01	1.28

Summary and next to do

- Have got the preliminary fitting result and every analysis method has two results.
- Use the new generator to analyze the center energy at 3.773GeV and 4.18GeV.
- Will use the new generator to measure the branching ration of $\psi(2S) \rightarrow \Omega^+ + \Omega^-$ and the cross section of $e^+e^- \rightarrow \Omega^+ + \Omega^-$.

Thank you