Measurements of Decay Parameter α_0 and $\bar{\alpha}_0$ by $J/\psi \to \Lambda \bar{\Lambda}$ at BESIII

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Outline

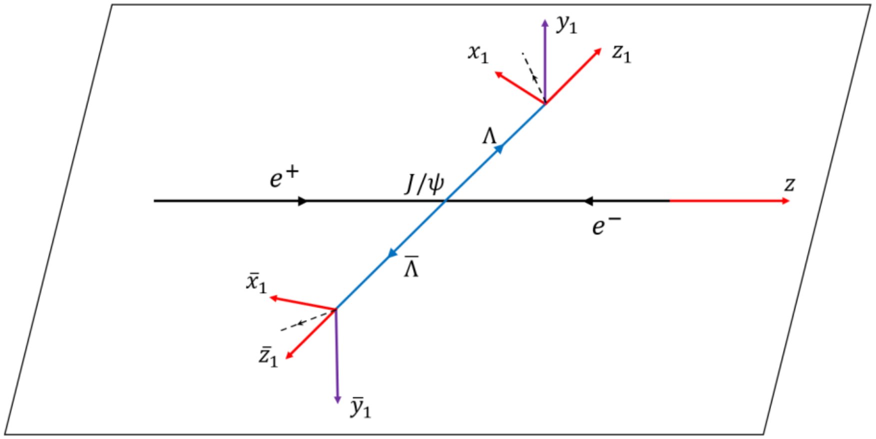
- **Brief Introduciton**
- **Event Selection of** $J/\psi \to \Lambda(\to n\pi^0)\bar{\Lambda}(\to \bar{p}\pi^+)$
- **Event Selection of** $J/\psi \to \Lambda(\to p\pi^-)\bar{\Lambda}(\to \bar{n}\pi^0)$
- **Input Output Check**
- **Discussion**

My Work Introducion

- α_0 **determine by** $J/\psi \to \Lambda(\to n\pi^0)\bar{\Lambda}(\to \bar{p}\pi^0)$
- $\bar{\alpha}_0$ **determine by** $J/\psi \to \bar{\Lambda}(\to \bar{n}\pi^0)\Lambda(\to p\pi^-)$

$$\mathcal{W}(\xi) = \mathcal{F}_0(\xi) + \alpha\mathcal{F}_5(\xi) + \alpha_1\alpha_2(\mathcal{F}_1(\xi) + \sqrt{1-\alpha^2}\cos(\Delta\Phi)\mathcal{F}_2(\xi) - \alpha\mathcal{F}_6(\xi)) + \sqrt{1-\alpha^2}\sin(\Delta\Phi)(-\alpha_1\mathcal{F}_3 + \alpha_2\mathcal{F}_4)$$

$$\begin{aligned}
\mathcal{F}_0 &= 1,\\
\mathcal{F}_1 &= \sin^2\theta\sin\theta_1\sin\theta_2\cos\phi_1\cos\phi_2 - \cos^2\theta\cos\theta_1\cos\theta_2,\\
\mathcal{F}_2 &= \sin\theta\cos\theta(\sin\theta_1\cos\theta_2\cos\phi_1 - \cos\theta_1\sin\theta_2\cos\phi_2),\\
\mathcal{F}_3 &= \sin\theta\cos\theta\sin\theta_1\sin\phi_1,\\
\mathcal{F}_4 &= \sin\theta\cos\theta\sin\theta_2\sin\phi_2,\\
\mathcal{F}_5 &= \cos^2\theta,\\
\mathcal{F}_6 &= \cos\theta_1\cos\theta_2 - \sin^2\theta\sin\theta_1\sin\theta_2\sin\phi_1\sin\phi_2
\end{aligned}$$



MC Sample Sets for IO Check

- **BOSS Version: 7.0.8**
- **MC Samples:**
  - **mDIY MC:**
    - $J/\psi \to \Lambda(\to n\pi^0)\bar{\Lambda}(\to \bar{p}\pi^0)$ **50samples (each sample = data)**
    - $J/\psi \to \bar{\Lambda}(\to \bar{n}\pi^0)\Lambda(\to p\pi^-)$ **50samples (each sample = data)**

    4250w events
  - **mDIY Truth: (for independent MC integration check)**
    - $J/\psi \to \Lambda(\to n\pi^0)\bar{\Lambda}(\to \bar{p}\pi^0)$ **50samples (each sample = x10 data)**

Parameters	$\alpha_{J/\psi}$	$\Delta\Phi$	α_-	α_+	α_0	$\bar{\alpha}_0$
Value	0.4747	0.7521	0.7519	-0.7559	0.74	-0.692

Initial Event Selection of $\Lambda(\to n\pi^0)\bar{\Lambda}(\to \bar{p}\pi^+)$

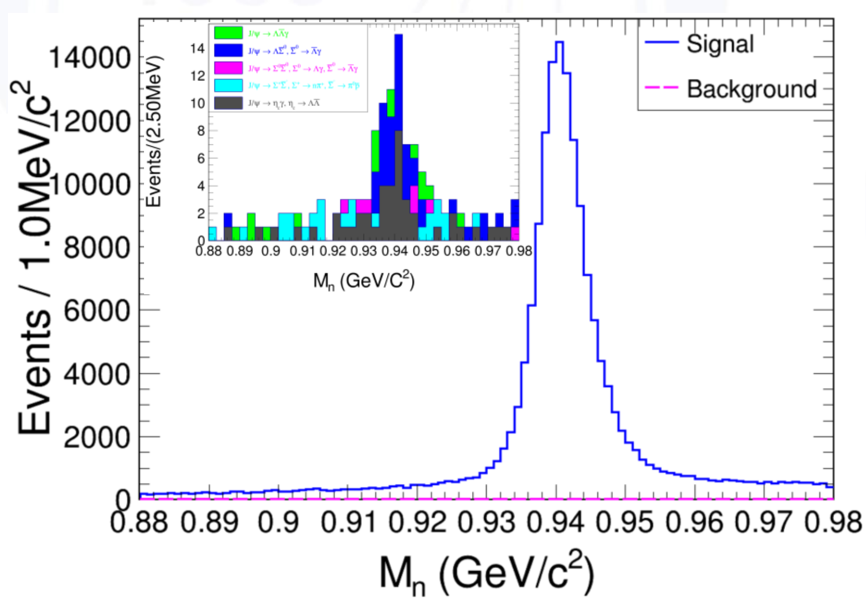
- **Charged Tracks**
  - $V_r \leq 10cm, \quad |V_z| \leq 30cm$
  - $|cos\theta| < 0.93$
- **PID (Use dedx+TOF)**
  - **Proton:** $p > 0.5$ **GeV/c && PID:**
    Prob(p) > Prob(K/π)
  - **Pion:** $p < 0.5$ **GeV/c && PID:**
    Prob(π) > Prob(K/p)
  - **nProton $\geq$ 1; nPion $\geq$ 1**
- **$\bar{\Lambda}$ Reconstruction**
  - **Primary and Secondary vertex fit**
  - **Choose $\bar{p}\,\pi^+$ with least χ^2_{Sec}**
  - $L/\sigma_L \ > 2.0$
  - $\chi^2_{sec} < 15$
  - $|M_{\bar{p}\pi^+} - 1.1157| < 0.008\ (GeV/c^2)$
  - $M^{recoil}_{\bar{p}\pi^+} < 1.15\ GeV/c^2$
- **Shower Selection**
  - $|cos\theta| \leq 0.8\,,\ E > 25MeV$
  - $0.86 \leq \ |cos\theta| \leq 0.92\,, E > 50MeV$
  - $0 \leq TDC \leq 14$
  - **Nshower** ≥ 2
  - $Ang_{shower,ChgTrk} \geq 10°$ **(for $\bar{p} \geq 20°$)**
- **Kinematic fit**
  - **Loop all γ pairs, do π^0 1C and kinematic fit on hypothesis $\bar{\Lambda}n\gamma\gamma$**
  - $75 < M_{\gamma\gamma} < 175$ **(MeV/c^2)**
  - **$\bar{\Lambda}$ is from secondary vertex fit**
  - **Neutron is treated as a missing particle**
  - **Constrain $M_{n\pi^0} = M^{PDG}_{\Lambda}$**
  - $\chi^2_{kmfit} + \chi^2_{\pi^0\ 1C} < 70$

Potential Background

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to \pi^0 n, \bar{\Lambda} \to \pi^+ \bar{p}$	$\pi^0\pi^+ n\bar{p}$	0	187192	187192
2	$J/\psi \to \Lambda\bar{\Lambda}\gamma, \Lambda \to \pi^0 n, \bar{\Lambda} \to \pi^+ \bar{p}$	$\pi^0\pi^+ n\bar{p}\gamma$	2	106	187298
3	$J/\psi \to \Lambda\bar{\Sigma}^0, \Lambda \to \pi^0 n, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \bar{\Lambda} \to \pi^+ \bar{p}$	$\pi^0\pi^+ n\bar{p}\gamma$	11	106	187404
4	$J/\psi \to \Sigma^0\bar{\Sigma}^0, \Sigma^0 \to \Lambda\gamma, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \Lambda \to \pi^0 n, \bar{\Lambda} \to \pi^+ \bar{p}$	$\pi^0\pi^+ n\bar{p}\gamma\gamma$	6	58	187462
5	$J/\psi \to \Sigma^+\bar{\Sigma}^-, \Sigma^+ \to \pi^+ n, \bar{\Sigma}^- \to \pi^0 \bar{p}$	$\pi^0\pi^+ n\bar{p}$	7	50	187512
6	$J/\psi \to \eta_c\gamma, \eta_c \to \Lambda\bar{\Lambda}, \Lambda \to \pi^0 n, \bar{\Lambda} \to \pi^+ \bar{p}$	$\pi^0\pi^+ n\bar{p}\gamma$	8	48	187560
7	$J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to \pi^0 n, \bar{\Lambda} \to \pi^+ \bar{p}\gamma^f$	$\pi^0\pi^+ n\bar{p}\gamma^f$	15	43	187603
8	$J/\psi \to \pi^0\pi^+ K^0_S K^-, K^0_S \to \pi^+\pi^-$	$\pi^0\pi^+\pi^+\pi^- K^-$	1	27	187630
9	$J/\psi \to \pi^+\Delta^0\bar{p}, \Delta^0 \to \pi^0 n$	$\pi^0\pi^+ n\bar{p}$	9	25	187655
10	$J/\psi \to \Delta^0\bar{\Delta}^0, \Delta^0 \to \pi^0 n, \bar{\Delta}^0 \to \pi^+ \bar{p}$	$\pi^0\pi^+ n\bar{p}$	5	19	187674
11	$J/\psi \to \bar{\Lambda}\Sigma^0, \bar{\Lambda} \to \pi^+ \bar{p}, \Sigma^0 \to \Lambda\gamma, \Lambda \to \pi^0 n$	$\pi^0\pi^+ n\bar{p}\gamma$	17	19	187693
12	$J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to \pi^0 n, \bar{\Lambda} \to \pi^+ \bar{p}\gamma^F$	$\pi^0\pi^+ n\bar{p}\gamma^F$	25	19	187712
13	$J/\psi \to \pi^0\pi^+ n\bar{p}$	$\pi^0\pi^+ n\bar{p}$	32	18	187730

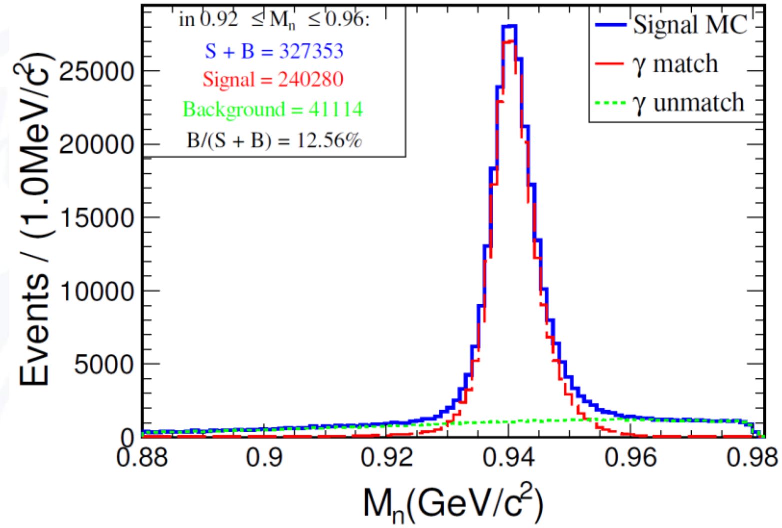
- **After cut, the BKG is 0.40%**

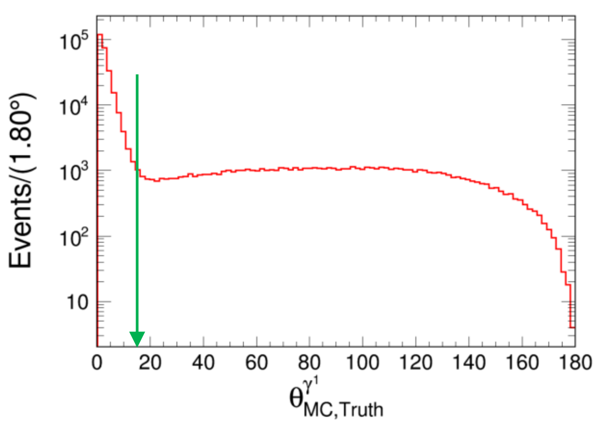
Selection Criteria	Absolute Efficiency (%)	Relative Efficiency (%)
Good Charged Tracks and PID	66.74	–
Vertex Fit	65.22	97.73
Good Shower Selection	57.68	88.45
Kinematic Fit	48.39	83.89
$\chi^2_{sec} < 15$ and $L/\sigma_L > 2.0$	42.88	88.61
$\chi^2_{corr} < 70$	35.17	82.01
$\lvert M_{\bar{p}\pi^+} - M_{\bar{\Lambda}} \rvert < 8 MeV/c^2$	33.19	94.37
$M^{recoil}_{\bar{p}\pi^+} < 1.15 GeV/c^2$	32.92	99.19

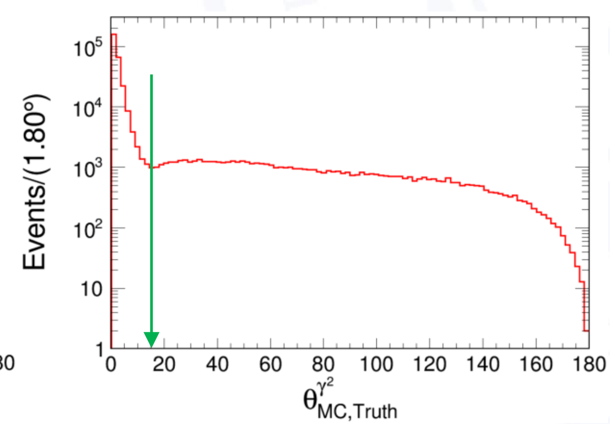


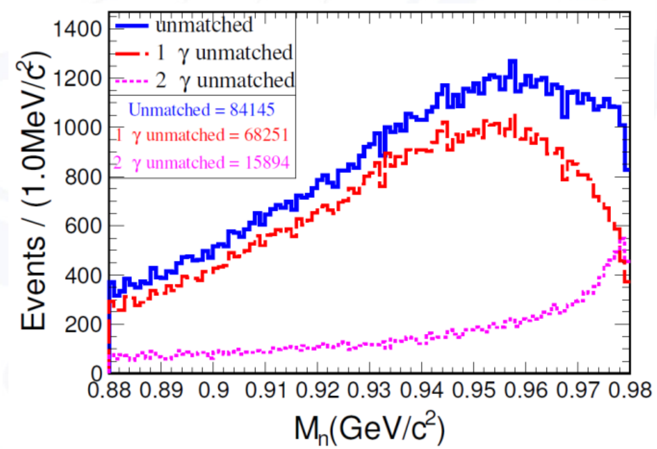
Self-Background

- We used $15°$ as the matched angle
  - ✓ $\theta_{\gamma1}$: Match angle between reconstructed low photon and truth.
  - ✓ $\theta_{\gamma2}$: Match angle between reconstructed high photon and truth.
- γ unmatched is 12.56% in fit range.

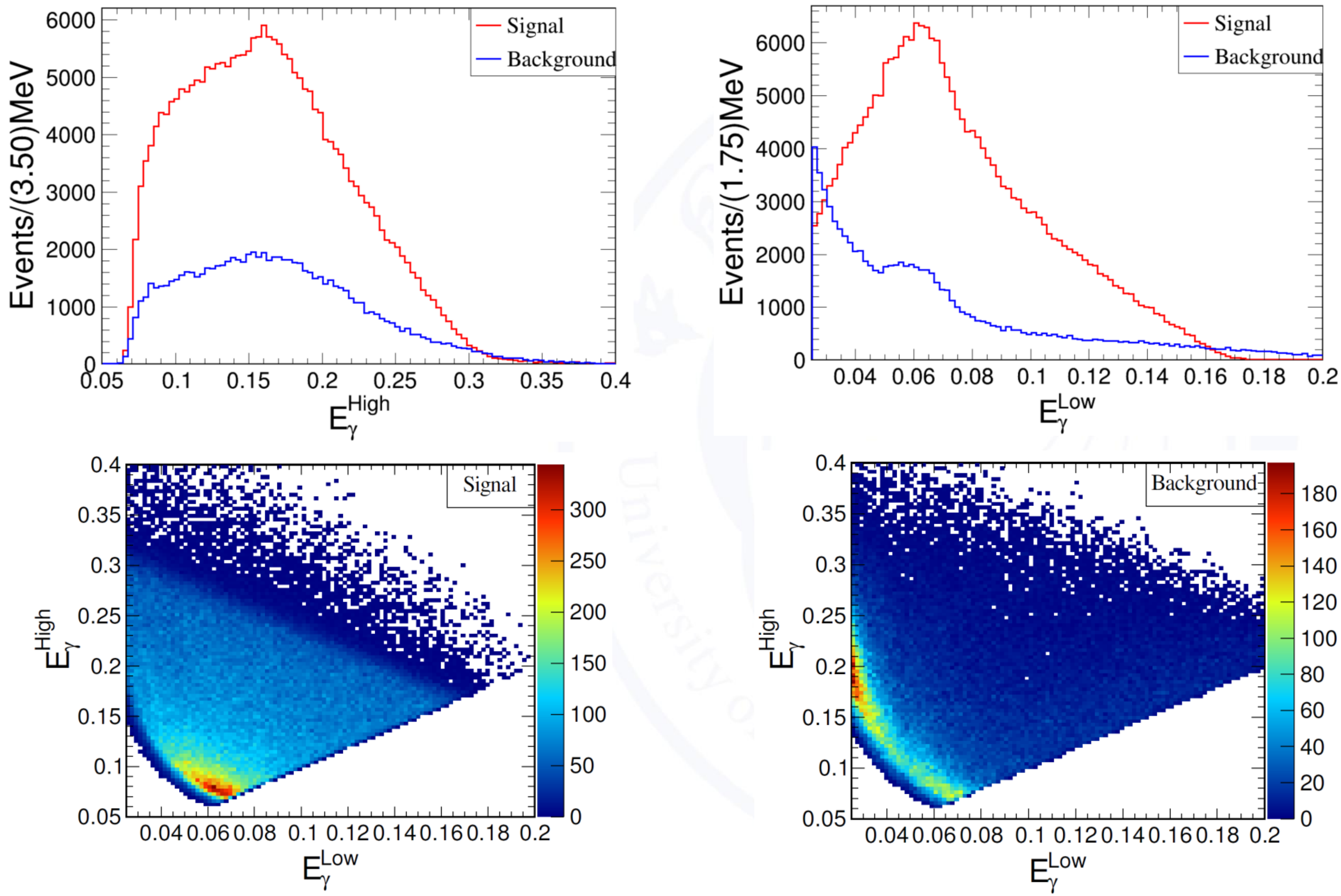








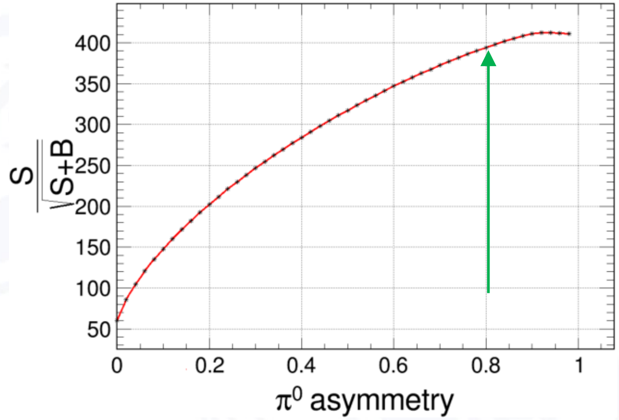
γ Energy Distribution

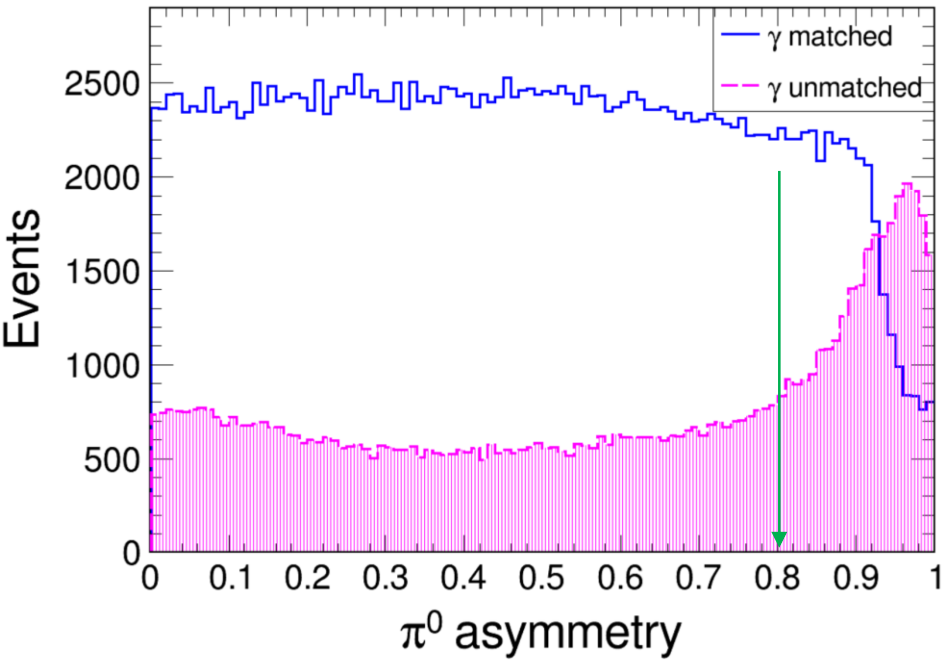


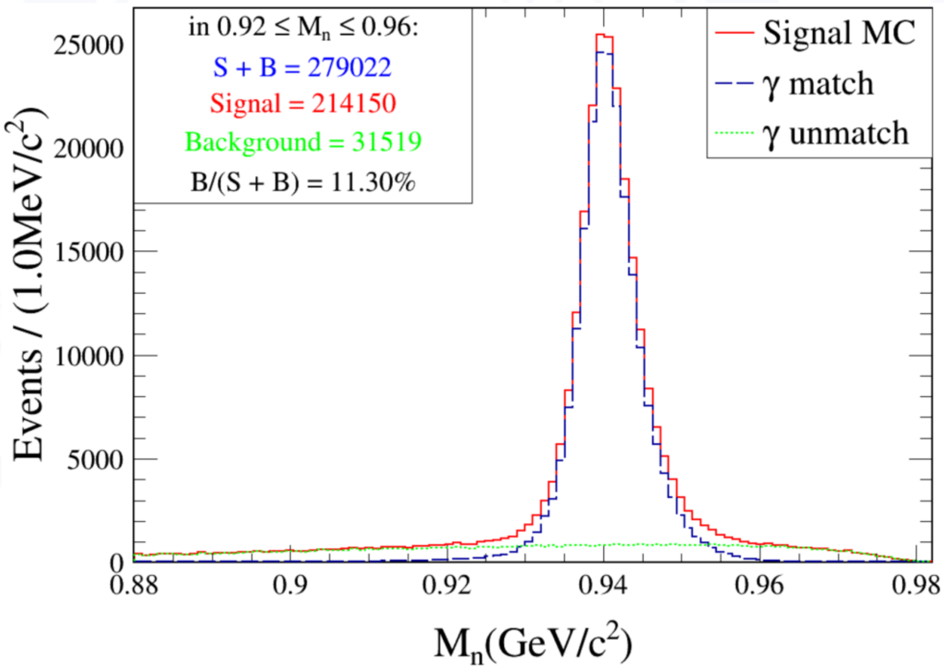
π^0 Asymmetry Cut

- $\pi^0\ asym < 0.8$ **排除(大光子+小噪声光子)组合**
- **After cut, the BKG is 11.3% in fit range**
- **π^0 asymmetry is defined as**

$$\pi^0\ asym = \frac{|E_{\gamma 1} - E_{\gamma 2}|}{p_{\pi^0}}$$

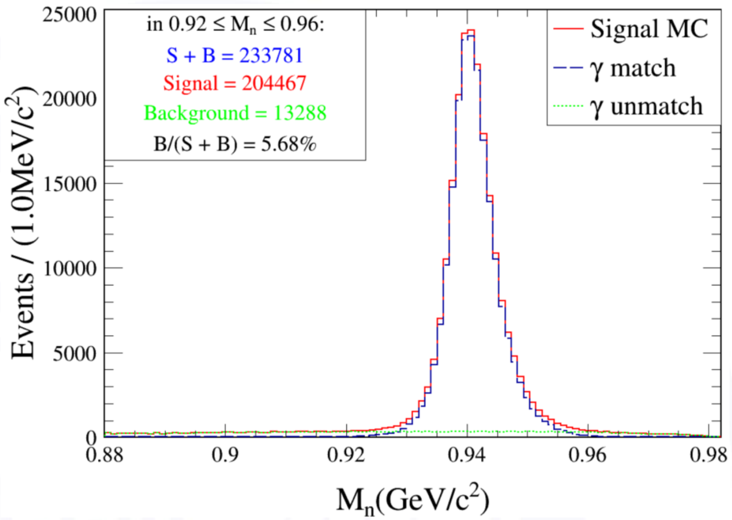


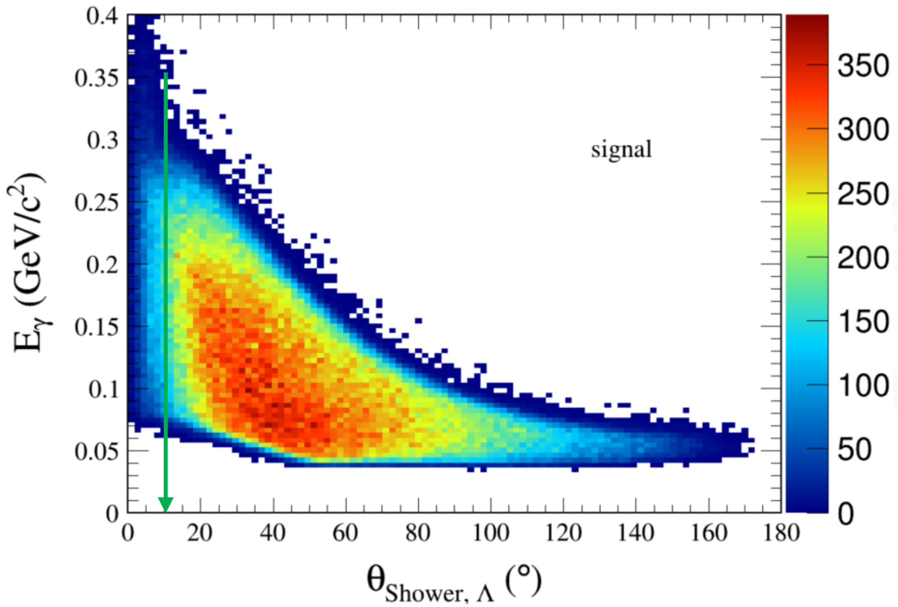


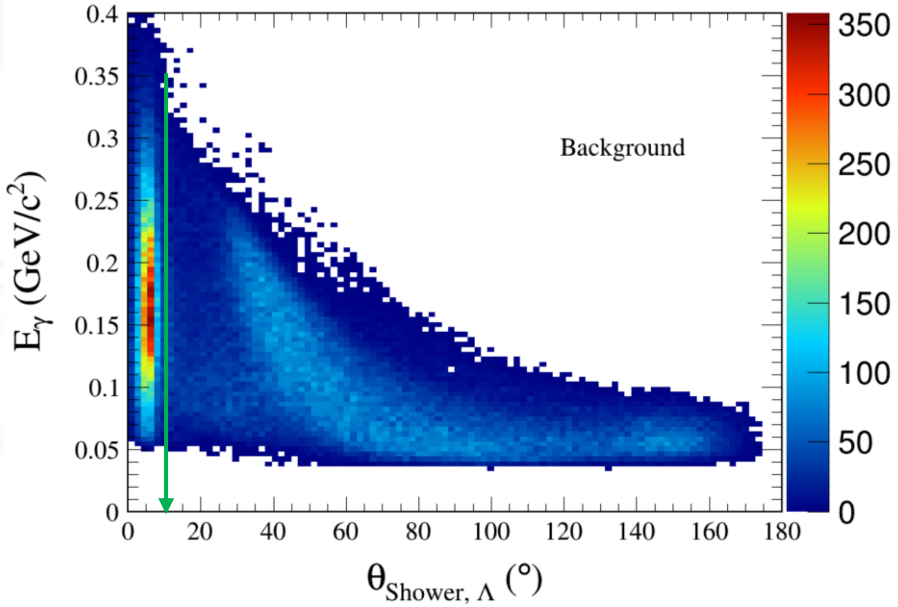


Neutron in EMC → Photon

- **Neutron might leave a shower in EMC. This shower might be mistakenly chosen as a γ.**
- **Neutron will inherit most of Λ's momentum so that $\theta_{n,\Lambda}$ should be every small.**
- $\theta_{Shower,\Lambda} > 10°$, **the BKG goes to 5.68%**







Initial Event Selection of $\Lambda(\to p\pi^-)\bar{\Lambda}(\to \bar{n}\pi^0)$

Charged Tracks

- $V_r \leq 10cm, \ |V_z| \leq 30cm$
- $|cos\theta| < 0.93$

PID (Use dedx+TOF)

- **Proton:** $p > 0.5$ **GeV/c && PID:**
  Prob(p) > Prob(K/π)
- **Pion:** $p < 0.5$ **GeV/c && PID:**
  Prob(π) > Prob(K/p)
- **nProton $\geq$ 1; nPion $\geq$ 1**

Λ Reconstruction

- **Primary and Secondary vertex fit**
- **Choose $p\pi^-$ with least χ^2_{Sec}**
- $L/\sigma_L > 2.0$
- $\chi^2_{sec} < 15$
- $|M_{p\pi^-} - 1.1157| < 8$ **MeV/c^2**

Shower Selection

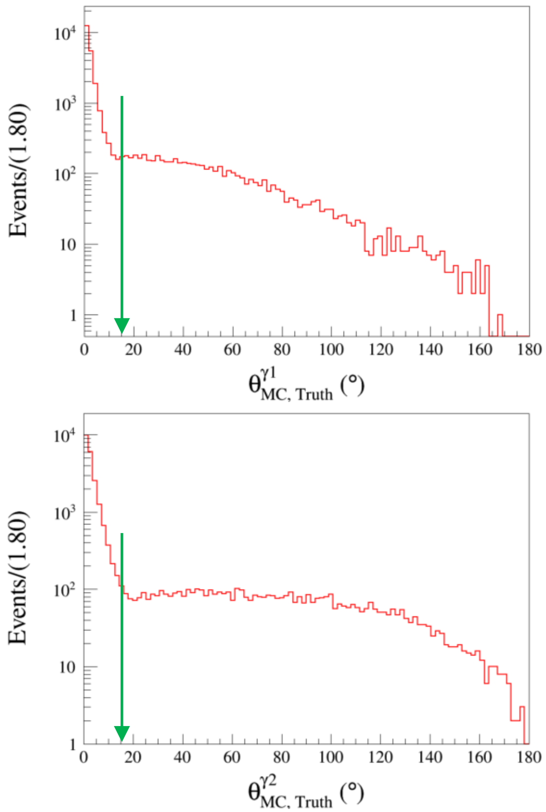
- $|cos\theta| \leq 0.8\,,\ E > 25MeV$
- $0.86 \leq\ |cos\theta| \leq 0.92\,, E > 50MeV$
- $0 \leq TDC \leq 14$
- **Nshower** ≥ 2
- $\theta_{Trk,\gamma} \geq 10°$

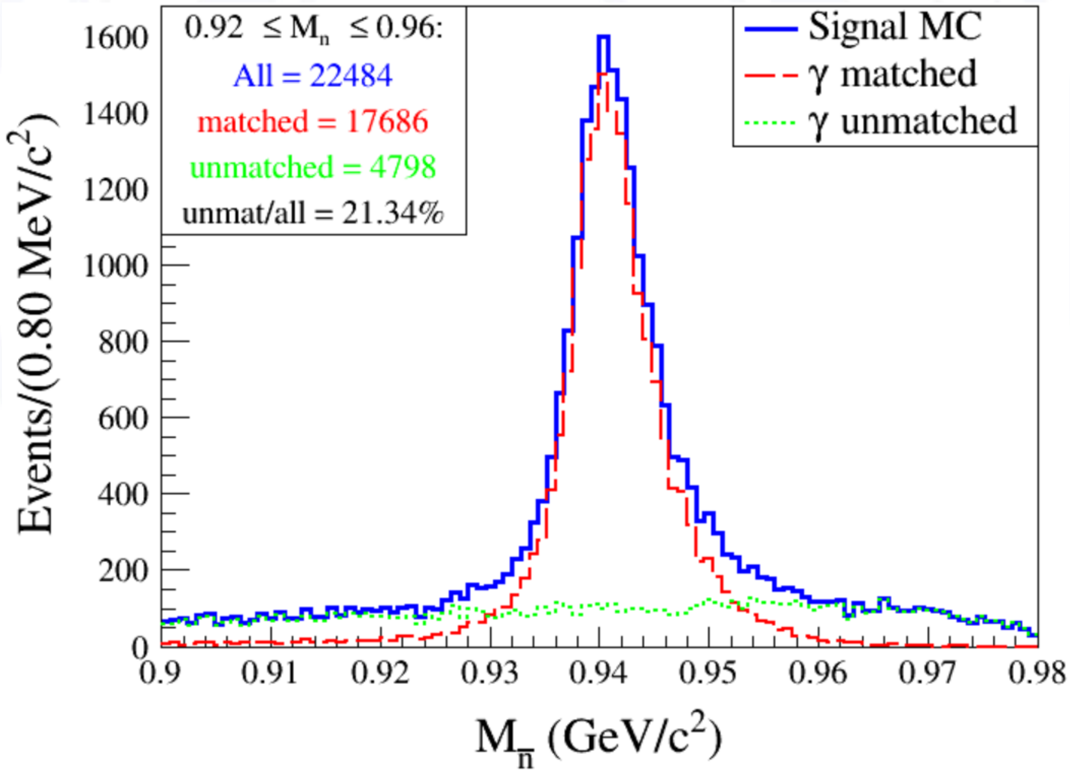
2C Kinematic fit

- **Loop all γ pairs, 2C kinematic fit is performed on the hypothesis of $\Lambda\bar{n}\gamma\gamma$**
- $75 < M_{\gamma\gamma} < 175$ **(MeV/c^2)**
- **Λ is from secondary vertex fit**
- **Anti-neutron is treated as a missing particle**
- **Constrain $M_{\bar{n}\pi^0} = M^{PDG}_{\bar{\Lambda}}$**
- **Constrain $M_{\gamma\gamma} = M^{PDG}_{\pi^0}$**
- $\chi^2_{kmfit} < 100$
- $M_{\bar{n}} \in [0.9, 0.98]\ GeV/c^2$

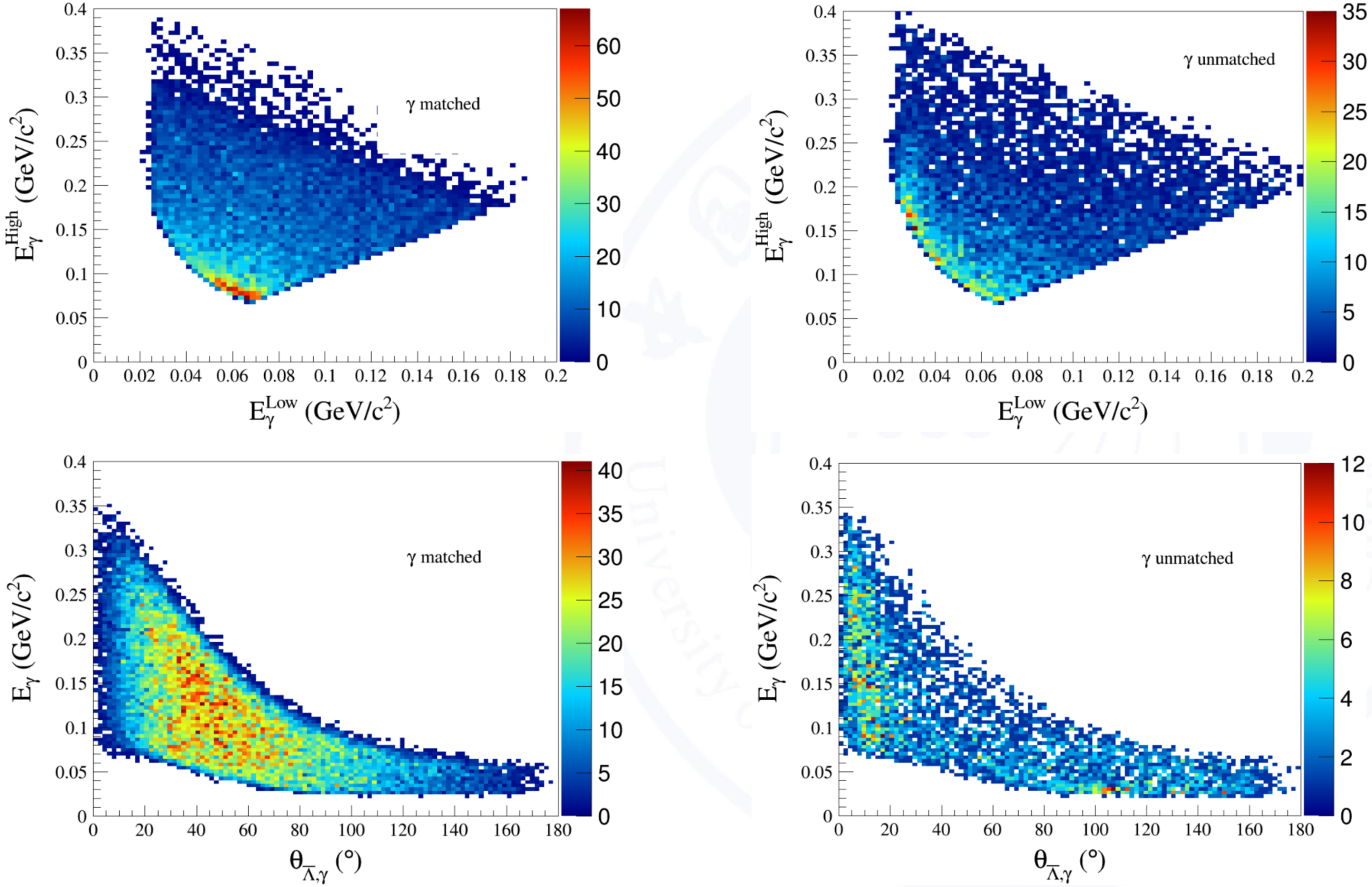
Self-Background

- **Same as npi0**
- γ **unmatched:** $\theta_{MC,Truth} > 15°$, gamma level
- π^0 **unmatched:** at least one gamma of π^0 is unmatched, event level



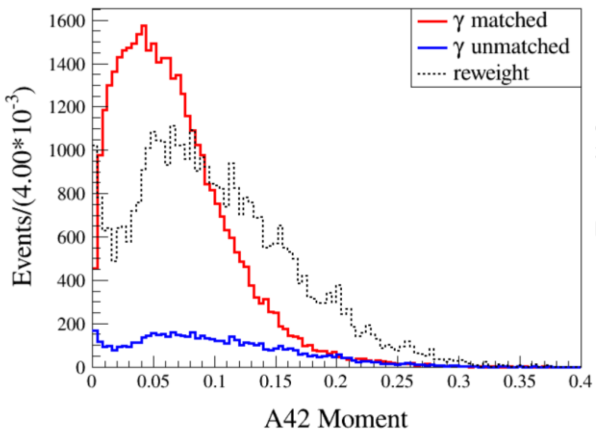


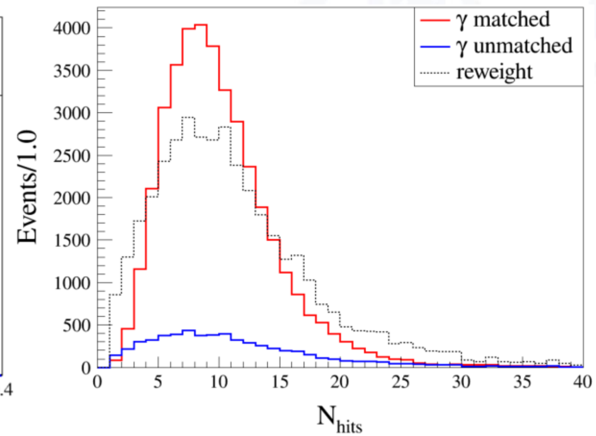
γ Distribution

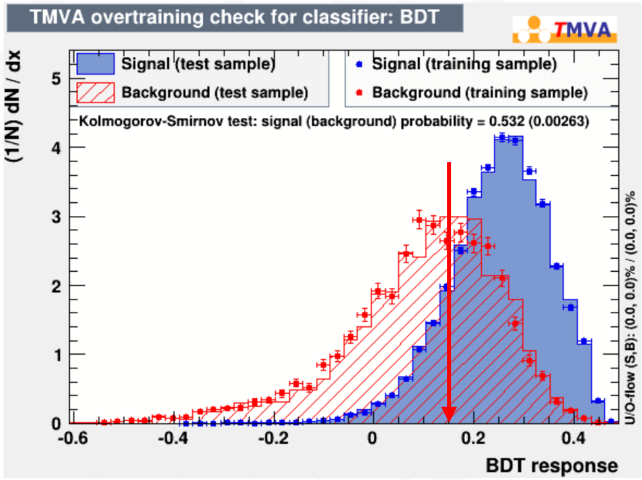


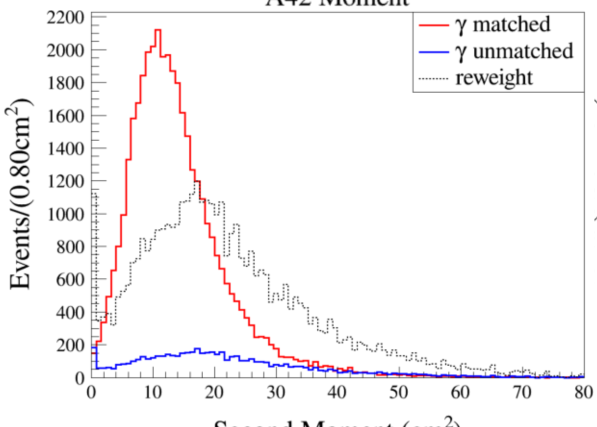
Shower Shape Comparison

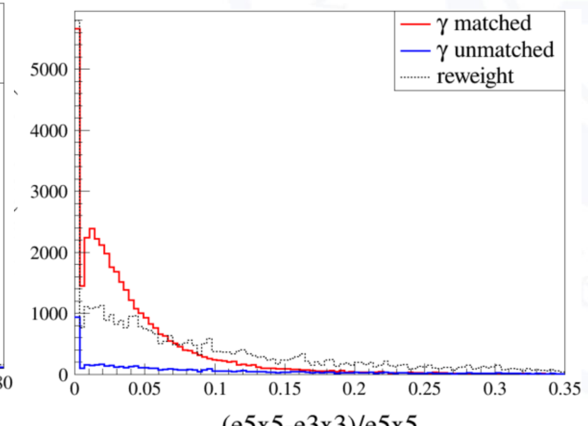
- **Secondary showers of antineutron are misidentified as good photons.**
- **TMVA Method to exclude unmatched gamma**
- **BDT > 0.15, BKG goes to 13.26%**

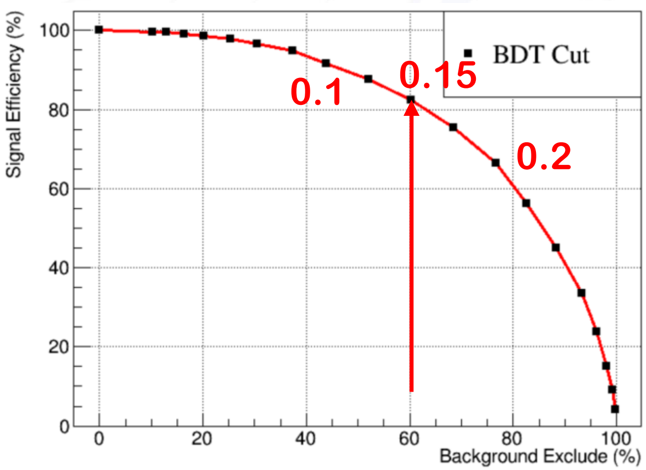




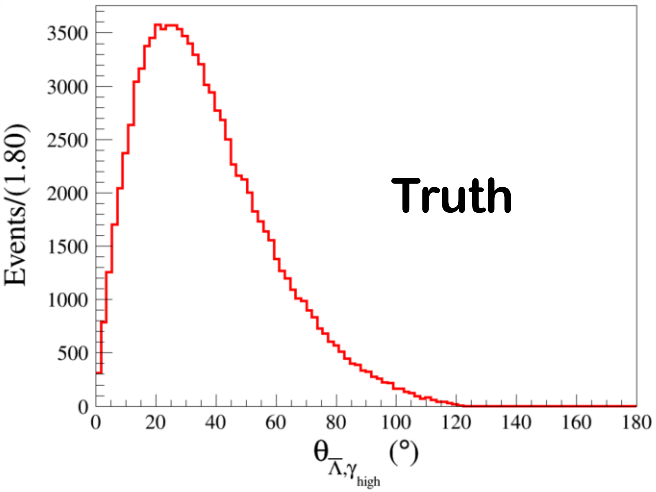


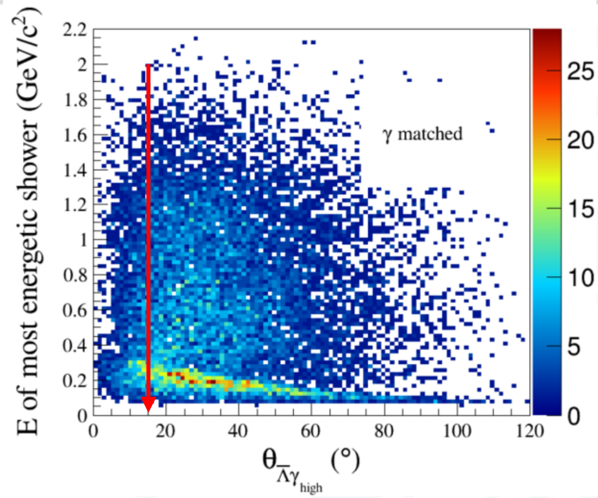


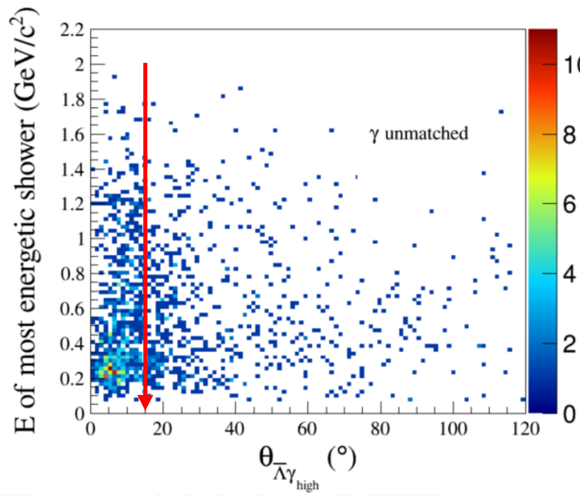


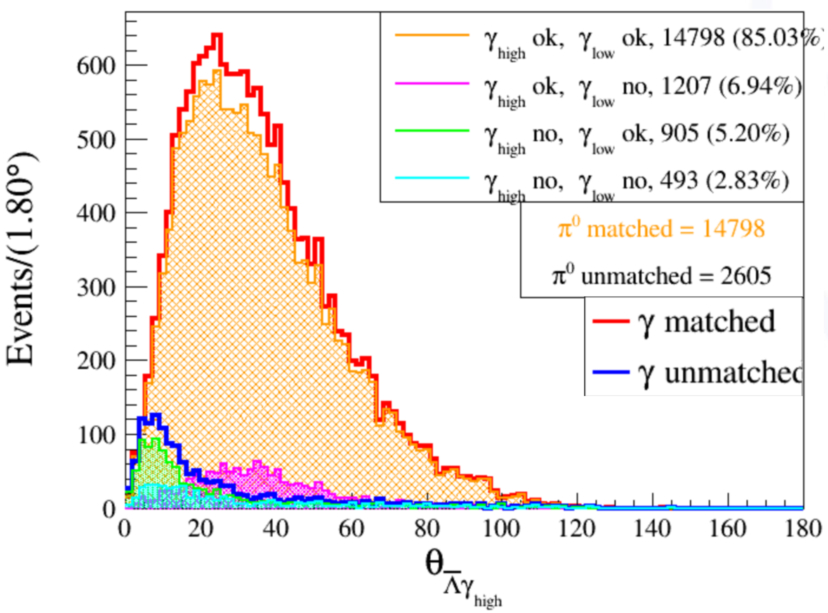


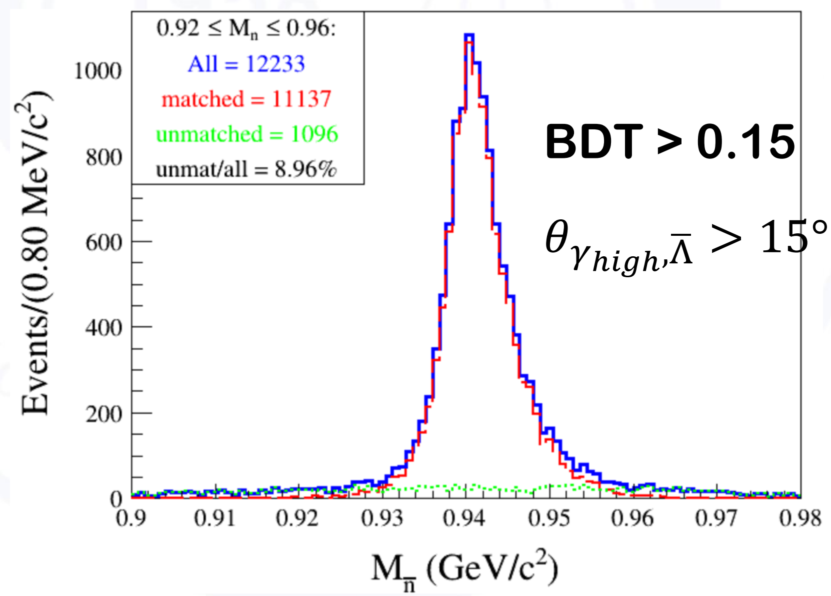
Anti-neutron in EMC → Photon



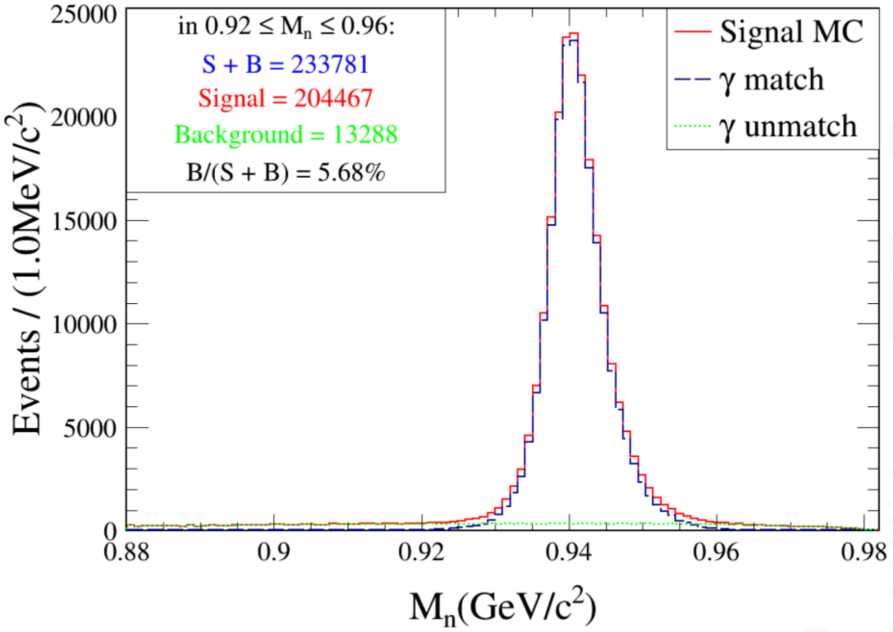


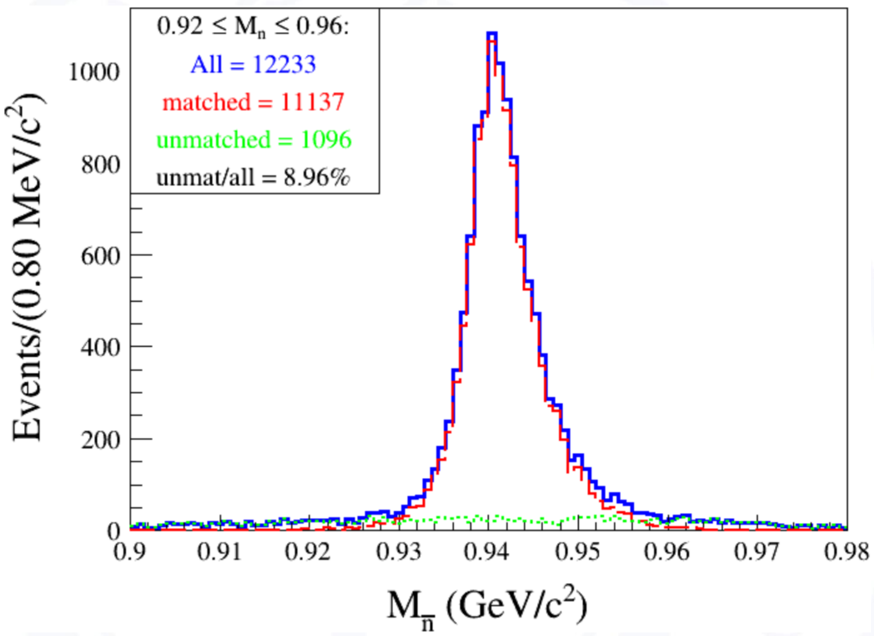






Analysis Summary





	$n\pi^0$	$\bar{n}\pi^0$
Signal Efficiency	21.09%	14.18%
BKG Exclude	5.68%	8.96%

IO Check

- Using **mDIY MC** to estimate normalization constant
- 1 sample = 1 data (Generate 425w events), 50 samples
- Toy MC 没有单独产生，从50个样本中抽样出10x data事例数, 50个样本共用MC积分

My pdf in likelihood fit:

$$\mathcal{P}(\xi_i;\alpha) = C\mathcal{W}(\xi_i;\alpha)\epsilon(\xi_i)$$

$$C^{-1} = \int d\xi \mathcal{W}(\xi;\alpha)\epsilon(\xi)$$

- 通常采用Mento Carlo方法估计MC积分
- 任意积分可表示为某个随机变量的数学期望
- 均匀分布对应PHSP MC

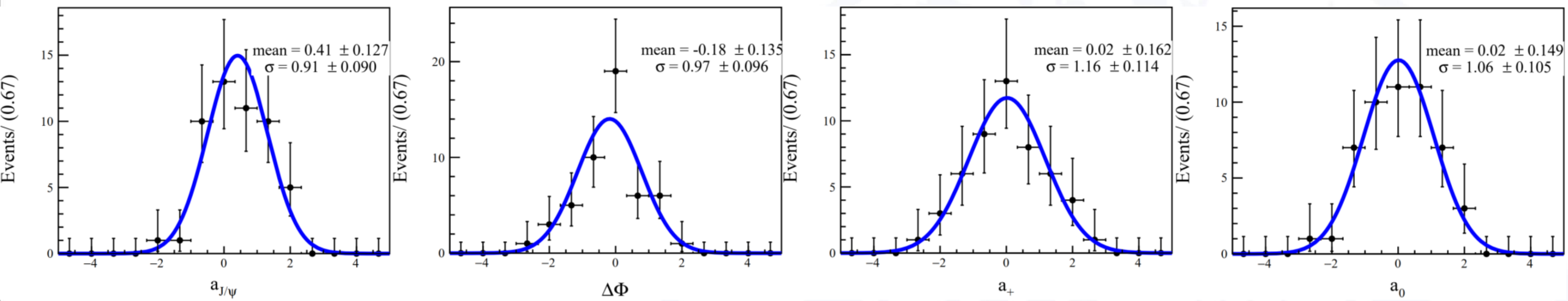
若选取与待积函数相近的随机分布，对积分的估计更准确：

$$C^{-1} = \int d\xi \frac{\mathcal{W}(\xi;\alpha)}{\mathcal{W}(\xi;\alpha')} \epsilon(\xi)\mathcal{W}(\xi;\alpha') = E\left[\frac{\mathcal{W}(\xi;\alpha)}{\mathcal{W}(\xi;\alpha')}\right] = \frac{1}{N_{ToyMC}} \sum_{i=1}^{N_{ToyMC}} \frac{\mathcal{W}(\xi_i;\alpha)}{\mathcal{W}(\xi_i;\alpha')}$$

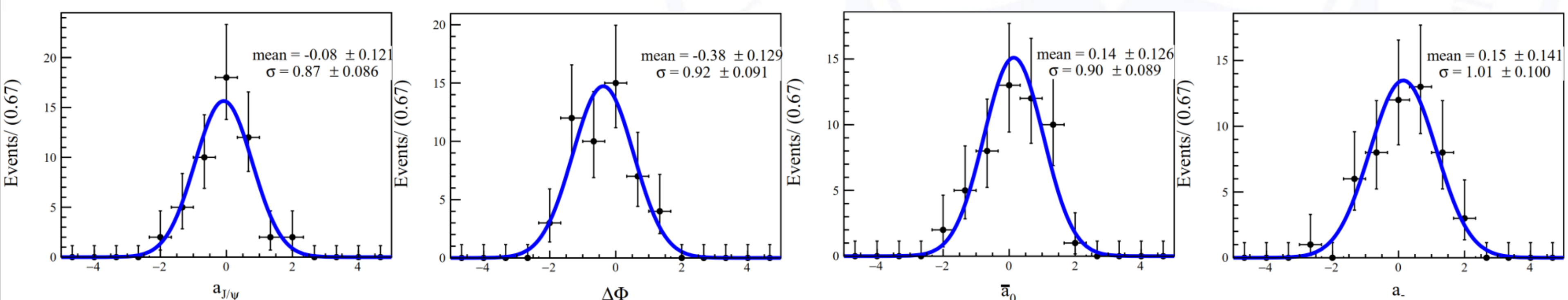
- N_{ToyMC}：已知参数的Toy MC经过事例筛选后的事例数
- $\mathcal{W}$：角分布振幅， ξ_i：运动学量， α'：Toy MC的已知角分布参数
- α：角分布振幅中的待测参数

Truth

$\bar{p}\pi^{+}n\pi^{0}$

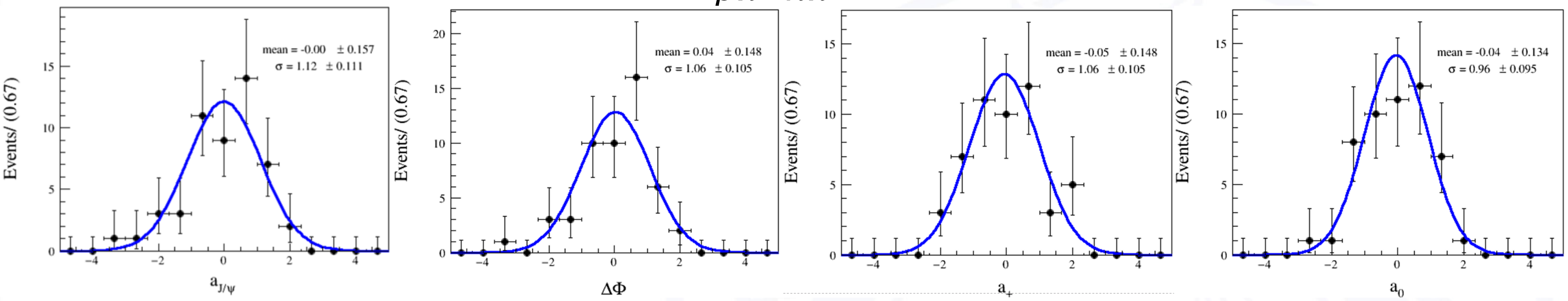


$p\pi^{-}\bar{n}\pi^{0}$

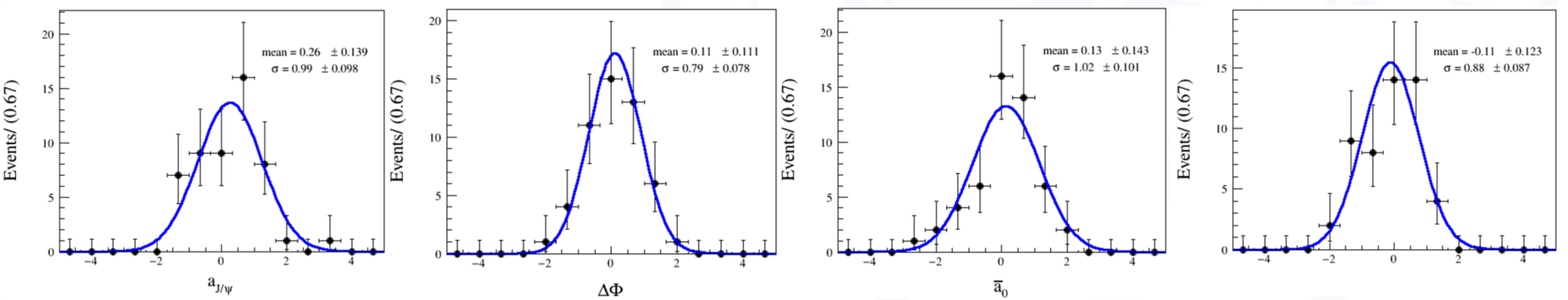


Reconstruction + γ Matched

$\bar{p}\pi^{+}n\pi^{0}$

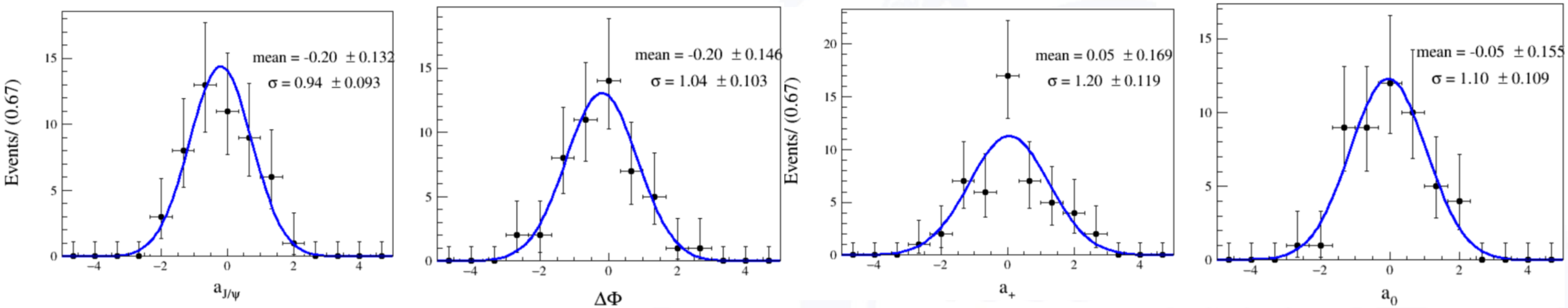


$p\pi^{-}\bar{n}\pi^{0}$

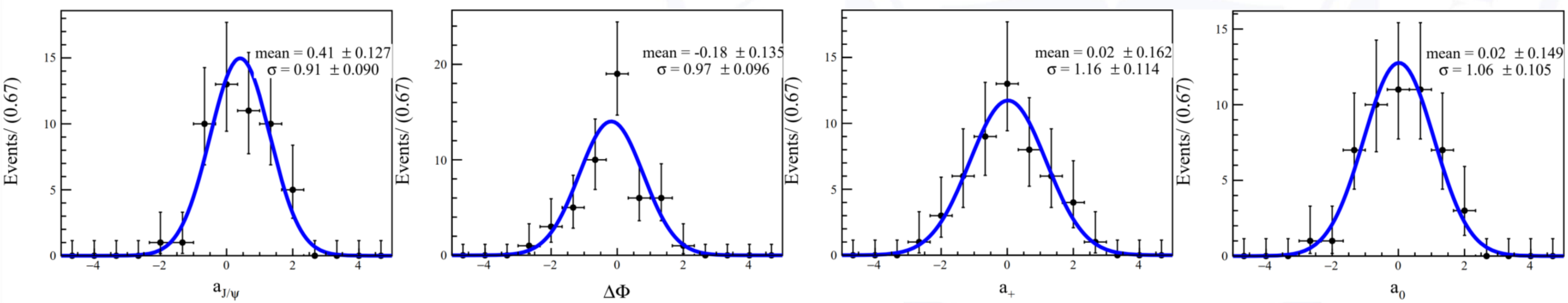


50 independent MC samples

独立的MC积分(x10)

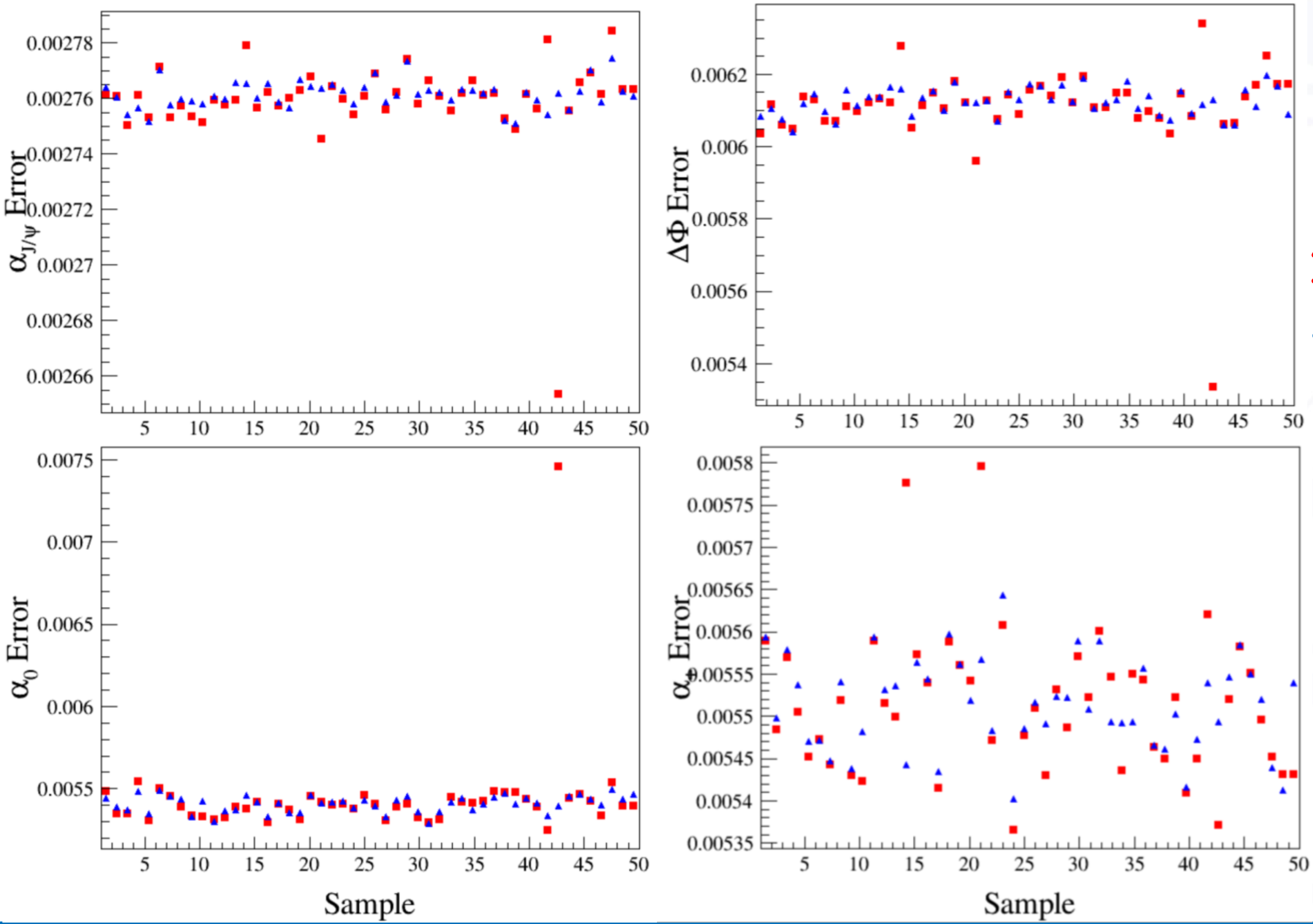


共用MC积分(x10)



An interesting mistake

- 提高MC积分的统计量可以让拟合的误差更稳定
- 需要进一步验证



红色：部分点统计量很小
蓝色：共用x50data

Discussion

- **共用MC积分 or 独立的MC积分?**
- **MC积分统计量应是数据的几倍?**

Discussion | Jianyu's IO Check

4.2 Input and Output Check

We perform the input/output check by using signal MC generated with the amplitude given by Eq. 1 to fit, and the free parameters $\alpha_{J/\psi}$, $\Delta\Phi$, α_-, α_+ of the amplitude is fixed. The yield of each set of signal MC is 68×10^6 which is about 7 times of data set. The results are shown in Table 3, in which the $\alpha_{avg} = (\alpha_+ - \alpha_-)/2$ is the average value of decay parameters.

Parameters	Input value	Output value	(output-input)/error
$\alpha_{J/\psi}$	0.4610	0.4602 ± 0.0008	1.0
$\Delta\Phi$	0.7400	0.7326 ± 0.0015	4.9
α_-	0.7540	0.7541 ± 0.0014	0.07
α_+	-0.7540	-0.7527 ± 0.0014	0.93
A_{CP}	0.0000	0.0010 ± 0.0018	
α_{avg}	0.7540	0.7534 ± 0.0004	

Table 3: Input/Output check results of signal MC. The mean value and the statistical uncertainty of output are the mean value and the root mean square of ten fit results respectively.

5.3 Fit Method

Toy MC are generated to estimate the uncertainty due to fit method. The difference between the input and output value is taken as the systematic uncertainty, which is shown in Table 3.

Discussion | Hongfei' IO Check

6.2 I/O check

After obtain the likelihood, We perform the input/output check by using 100 sets of DIY MC, in the fitting procedure we fix $\alpha_\Lambda(\bar{\alpha}_\Lambda)$ to 0.754(-0.754). The yield of each set of signal MC is 3.249×10^5 which is roughly same as data. The input/output values are shown in Table 5. The distributions of the fitting results are shown in Fig. 15 and Fig. 16. The output values are consistent with input.

Table 5: Input/Output check results of DIY MC.

	parameters	input	output	parameters	input	output
0.94	$\alpha_{J/\psi}$	0.5280	0.5331 ± 0.0054	A^{Ξ}_{CP}	0	0.00086 ± 0.0058
0.35	$\Delta\Phi$	1.190	1.184 ± 0.017	ϕ^{Ξ}_{CP}	0	0.0000 ± 0.0063
0.35	α_{Ξ^0}	-0.3795	-0.3784 ± 0.0031	$< \alpha_\Xi >$	-0.3795	-0.3782 ± 0.0022
0.48	$\bar{\alpha}_{\Xi^0}$	0.3795	0.3780 ± 0.0031	$< \phi_\Xi >$	0.0150	0.0192 ± 0.0074
	ϕ_{Ξ^0}	0.015	0.0193 ± 0.0108	Δ_w	0	0.001 ± 0.016
	$\bar{\phi}_{\Xi^0}$	-0.015	0.0191 ± 0.0084	Δ_s	-0.037	-0.051 ± 0.019

7.6 Fitting method

We fit the MC truth to estimate the uncertainty casued by fitting method. We use 273M PHSP MC events truth information and 10 sets of 2.73M DIY MC events truth information to perform the maximum likelihood fitting, the results are shown in Table 12. We take the difference of output mean value and input as the uncertainty.

(output-input)/error	parameters	input	output	parameters	input	output
0.5	$\alpha_{J/\psi}$	0.5280	0.5271 ± 0.0018	A_{CP}^{Ξ}	0	-0.0001 ± 0.0026
1/3	$\Delta\Phi$	1.190	1.188 ± 0.006	ϕ_{CP}^{Ξ}	0	-0.0007 ± 0.0020
0.5	α_{Ξ^0}	-0.3795	-0.3793 ± 0.0011	$< \alpha_{\Xi} >$	-0.3795	-0.3793 ± 0.0005
0.08	$\bar{\alpha}_{\Xi^0}$	0.3795	0.3794 ± 0.0012	$< \phi_{\Xi} >$	0.0150	0.0142 ± 0.0019
0.65	ϕ_{Ξ^0}	0.015	0.0135 ± 0.0023	Δ_w	0	0.002 ± 0.005
1/32	$\bar{\phi}_{\Xi^0}$	-0.015	-0.0149 ± 0.0032	Δ_s	-0.037	-0.037 ± 0.005

Table 12: Fit method uncertainty estimation. The mean value and the statistical uncertainty of output are the mean value and the root mean square of ten fit results respectively.

Discussion

Jianyu

Parameters	Input value	Output value	(output-input)/error
$\alpha_{J/\psi}$	0.4610	0.4602 ± 0.0008	1.0
$\Delta\Phi$	0.7400	0.7326 ± 0.0015	4.9
α_{-}	0.7540	0.7541 ± 0.0014	0.07
α_{+}	-0.7540	-0.7527 ± 0.0014	0.93

Xiongfei

Rec

(output-input)/error	parameters	input	output	parameters	input	output
0.5	$\alpha_{J/\psi}$	0.5280	0.5271 ± 0.0018	A_{CP}^{Ξ}	0	-0.0001 ± 0.0026
1/3	$\Delta\Phi$	1.190	1.188 ± 0.006	ϕ_{CP}^{Ξ}	0	-0.0007 ± 0.0020
0.5	α_{Ξ^0}	-0.3795	-0.3793 ± 0.0011	$< \alpha_{\Xi} >$	-0.3795	-0.3793 ± 0.0005
0.08	$\bar{\alpha}_{\Xi^0}$	0.3795	0.3794 ± 0.0012	$< \phi_{\Xi} >$	0.0150	0.0142 ± 0.0019
0.65	ϕ_{Ξ^0}	0.015	0.0135 ± 0.0023	Δ_w	0	0.002 ± 0.005
1/32	$\bar{\phi}_{\Xi^0}$	-0.015	-0.0149 ± 0.0032	Δ_s	-0.037	-0.037 ± 0.005

truth

(output-input)/error	parameters	input	output	parameters	input	output
0.5	$\alpha_{J/\psi}$	0.5280	0.5271 ± 0.0018	A_{CP}^{Ξ}	0	-0.0001 ± 0.0026
1/3	$\Delta\Phi$	1.190	1.188 ± 0.006	ϕ_{CP}^{Ξ}	0	-0.0007 ± 0.0020
0.5	α_{Ξ^0}	-0.3795	-0.3793 ± 0.0011	$< \alpha_{\Xi} >$	-0.3795	-0.3793 ± 0.0005
0.08	$\bar{\alpha}_{\Xi^0}$	0.3795	0.3794 ± 0.0012	$< \phi_{\Xi} >$	0.0150	0.0142 ± 0.0019
0.65	ϕ_{Ξ^0}	0.015	0.0135 ± 0.0023	Δ_w	0	0.002 ± 0.005
1/32	$\bar{\phi}_{\Xi^0}$	-0.015	-0.0149 ± 0.0032	Δ_s	-0.037	-0.037 ± 0.005

Summary and Next to do

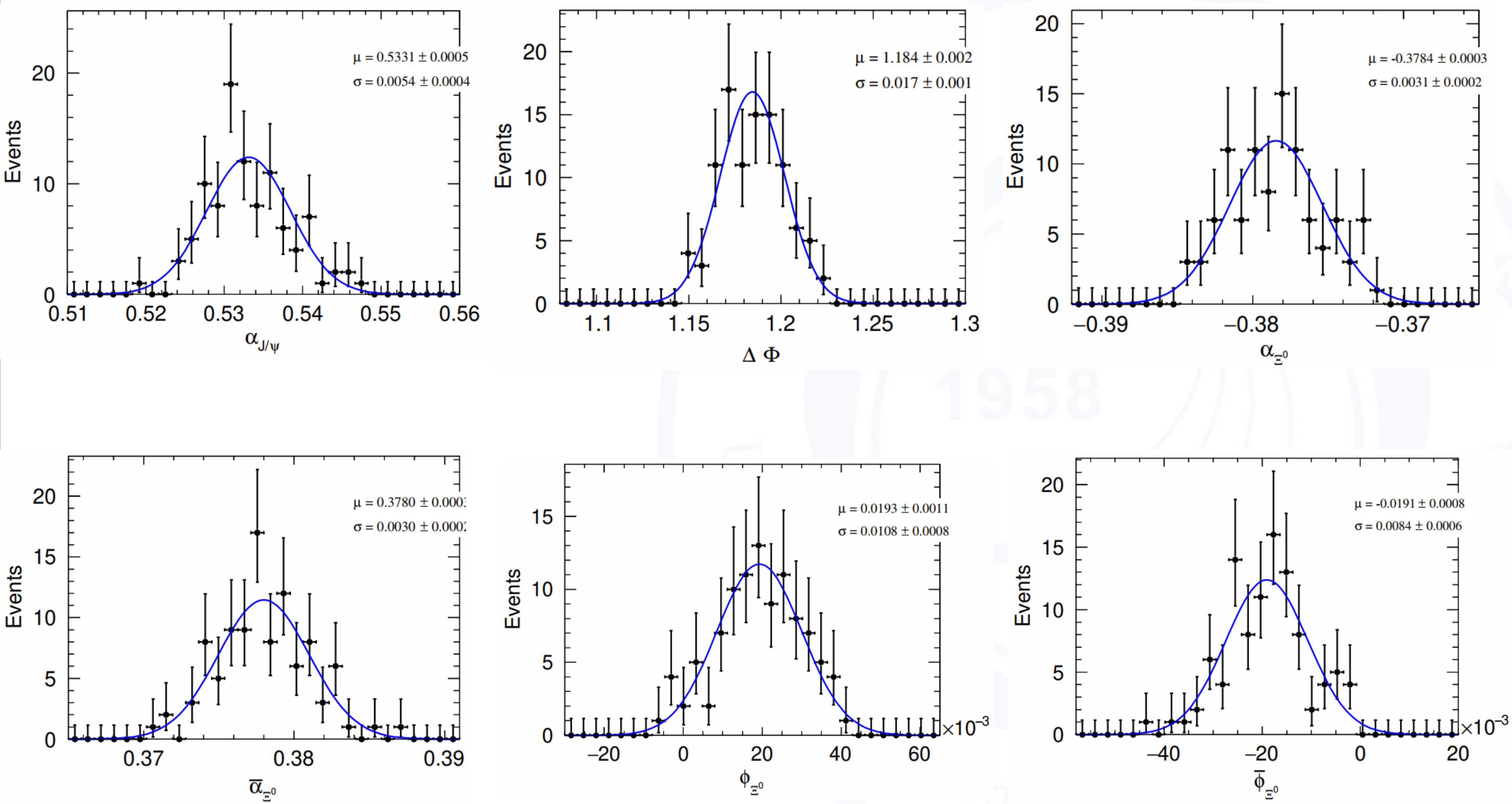
Summary

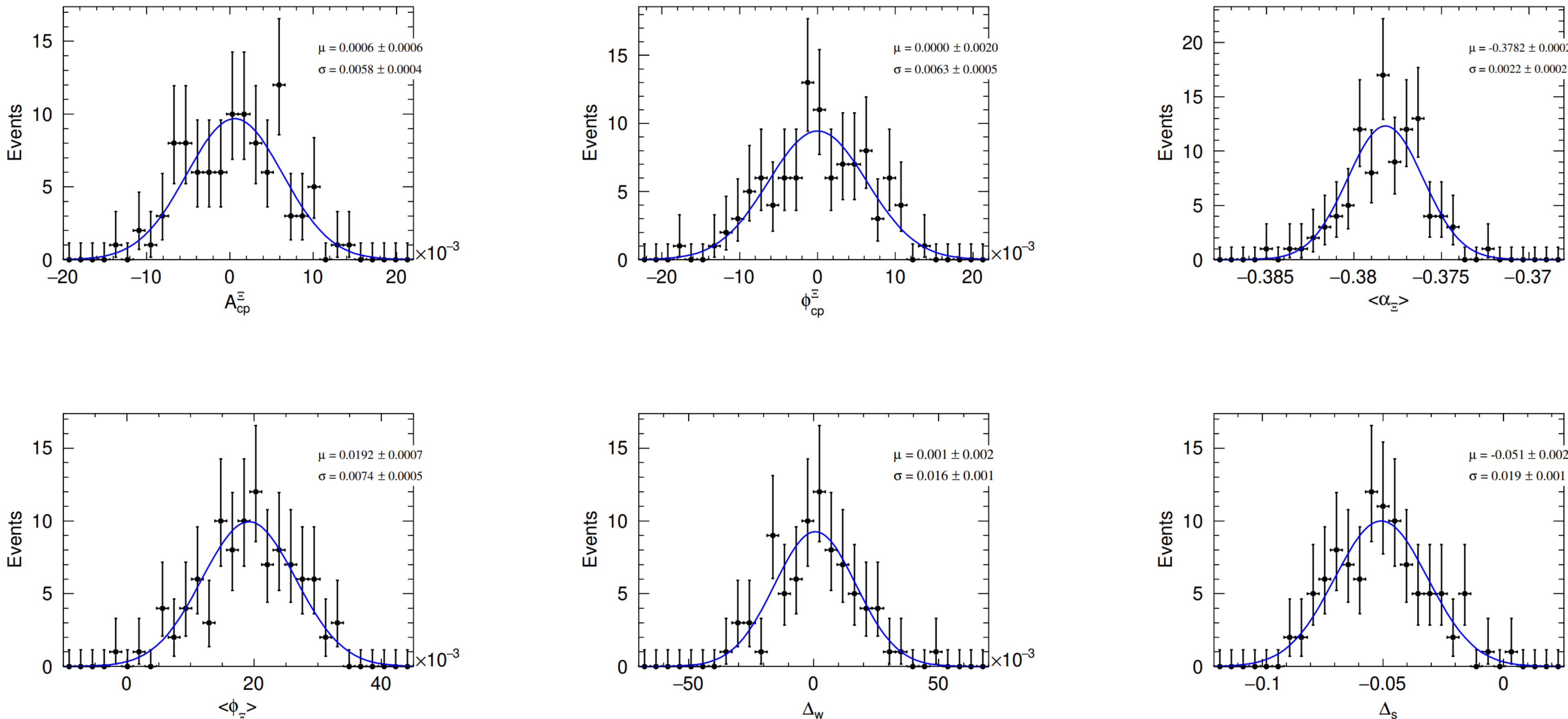
- Finished $n\pi^0$ and $\bar{n}\pi^0$ event selection
- Less than 10% background

Next to do

- Optimize cuts in $\bar{n}\pi^0$
- Perform IO Check under background

Back up


μ = 0.5331 ± 0.0005
σ = 0.0054 ± 0.0004
Events
α_J/ψ
μ = 1.184 ± 0.002
σ = 0.017 ± 0.001
Events
Δ Φ
μ = -0.3784 ± 0.0003
σ = 0.0031 ± 0.0002
Events
α_Ξ0
μ = 0.3780 ± 0.000
σ = 0.0030 ± 0.000
Events
ᾱ_Ξ0
μ = 0.0193 ± 0.0011
σ = 0.0108 ± 0.0008
Events
×10^-3
φ_Ξ0
μ = -0.0191 ± 0.0008
σ = 0.0084 ± 0.0006
Events
×10^-3
φ̄_Ξ0


μ = 0.0006 ± 0.0006
σ = 0.0058 ± 0.0004
Events
A_{cp}^{Ξ}
×10⁻³
μ = 0.0000 ± 0.0020
σ = 0.0063 ± 0.0005
Events
ϕ_{cp}^{Ξ}
×10⁻³
μ = -0.3782 ± 0.000
σ = 0.0022 ± 0.0002
Events
$\langle\alpha_{\Xi}\rangle$
μ = 0.0192 ± 0.0007
σ = 0.0074 ± 0.0005
Events
$\langle\phi_{\Xi}\rangle$
×10⁻³
μ = 0.001 ± 0.002
σ = 0.016 ± 0.001
Events
Δ_w
×10⁻³
μ = -0.051 ± 0.002
σ = 0.019 ± 0.001
Events
Δ_s