Belle和Belle II上$\Lambda_c^+ \to \Xi^0 K^+$的不对称参数的测量

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第五届粒子物理天问论坛

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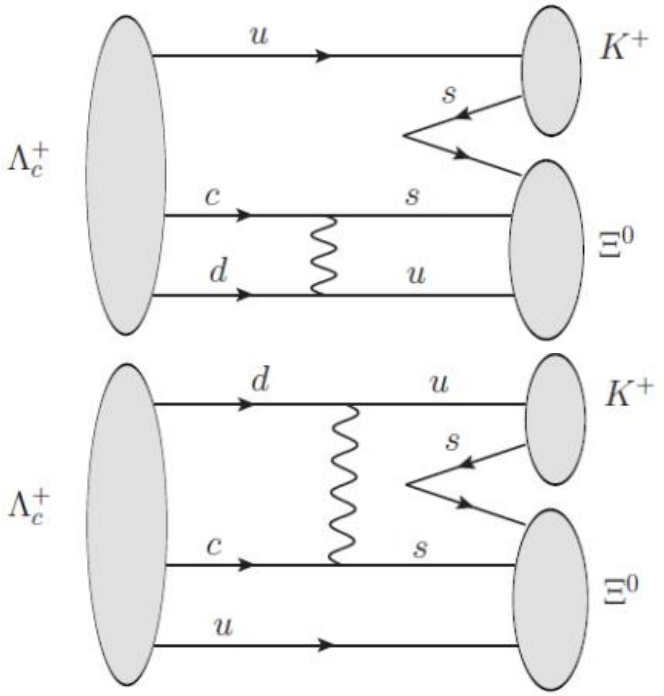
一.研究目的

- $\Lambda_c^+ \to \Xi^0 K^+ \to (\Lambda^0 \pi^0) K^+ \to (p\pi^-)\pi^0 K^+$
- $\frac{1}{2}^+ \to \frac{1}{2}^+ + 0^-$ $\qquad \alpha = \frac{2Re(s*p)}{|s|^2+|p|^2}$
- 理论现状

理论计算	$\alpha_{\Lambda_c^+}$	参考文献
Körner(1992), CCQM	0	Phys. C55, 659 (1992)
Xu(1992), Pole	0	Phys. Rev. D 46, 270 (1992)
Zencaykowski(1994), Pole	0	Phys. Rev. D 50, 5787 (1994)
Ivanov(1998), CCQM	0	Phys. Rev. D 57, 5632 (1998)
Sharma(1999), CA	0	Eur. Phys. J. C 7, 217-224 (1999)
Geng(2019), SU(3)	$0.94^{+0.06}_{-0.11}$	Phys. Lett. B 794, 19-28 (2019)
Zou(2020), CA	0.90	Phys. Rev. D 101, no.1, 014011 (2020)
Zhong (2023), SU(3)	0.99 ± 0.01	J. High Energ. Phys. 2023, 235 (2023)



- 实验现状

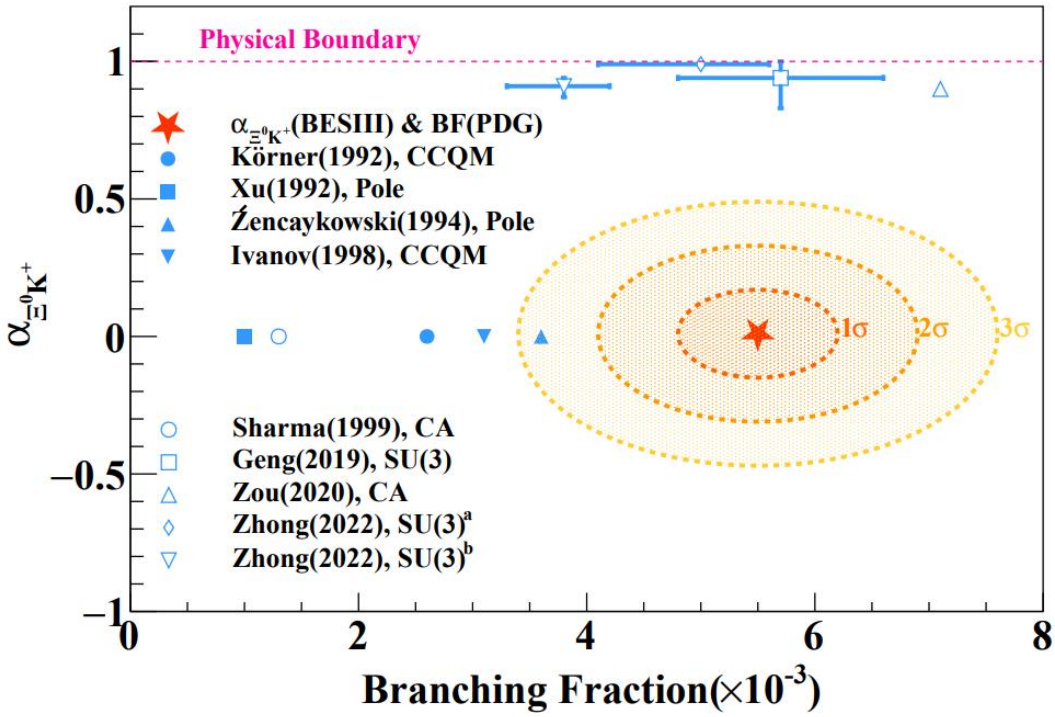
目前 BESIII 实验组基于4.4 /fb在对$\Lambda_c^+ \to \Xi^0 K^+$过程的衰变不对称参数进行测量 arXiv:2309.02774 [hep-ex]

$0.01 \pm 0.16(stat.) \pm 0.03(syst.)$

Belle+Belle II 上，基于980+424 /fb

预计统计量比BESIII实验测量结果提高一个量级

预计统计误差小一个量级



arXiv:2309.02774 [hep-ex]

二.主要内容—实验装置

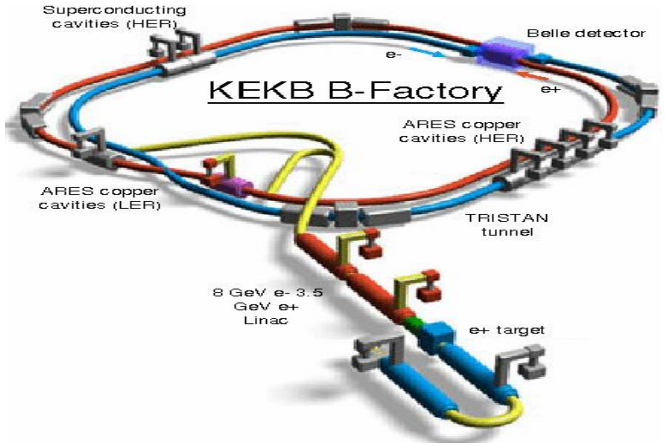
- 基于KEKB上的 Belle 探测器和Super KEKB上的 Belle II 探测器采集到的980 /fb、424 /fb数据样本研究

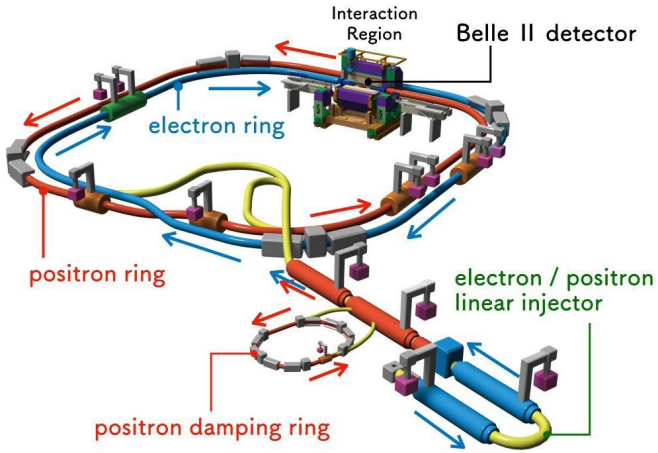
  $e^+e^- \to c\bar{c} \to \Lambda_c^+ X + c.c.$　　$\Lambda_c^+ \to \Xi^0 K^+ \to (\Lambda^0 \pi^0) K^+ \to (p\pi^-)(\gamma\gamma) K^+$

- 实验装置

  KEKB：第一代B介子工厂

  - 周长3公里，地下11米
  - 能量不对称的正负电子对撞机
  - 产生10.58 GeV质心系能量（$B\overline{B}$阈值上）

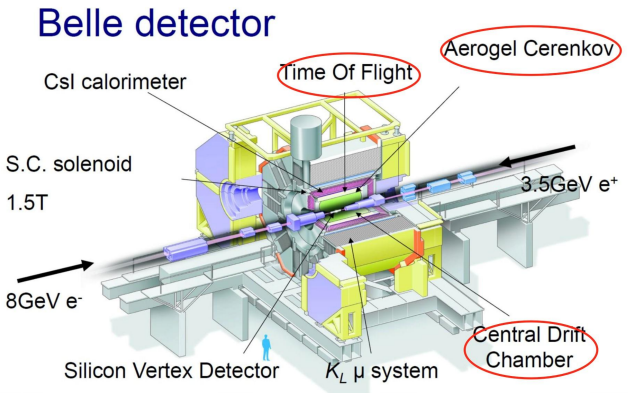


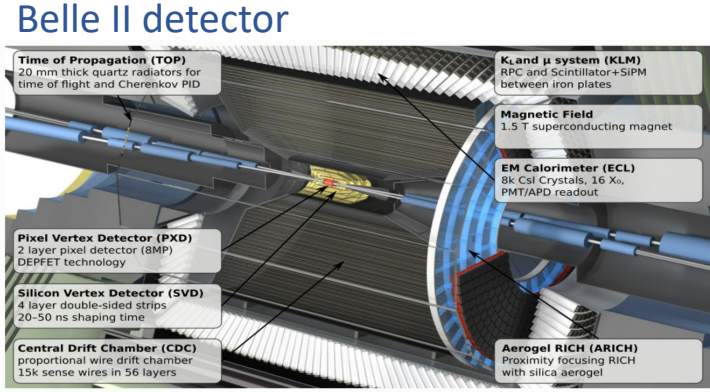


运行时间：1999年-2010年，累计采集~1 ab^{-1}

Belle 探测器：位于束流管的对撞区域

KEKB → SuperKEKB　　Belle → Belle II

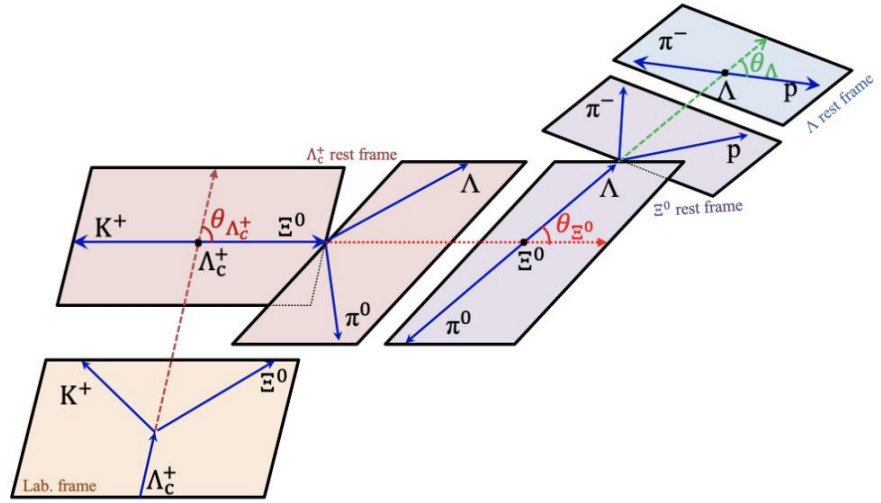




二.主要内容—研究方法

- 进行候选事例的选择
- 拟合微分衰变率公式得到$\alpha_{\Lambda_c^+}$

$$\frac{\mathrm{dN}}{\mathrm{d}\cos\theta_{\Xi^0}\,\mathrm{d}\cos\theta_{\Lambda}} \propto 1+\alpha_{\Lambda_c^+}\alpha_{\Xi^0}\cos\theta_{\Xi^0}+\alpha_{\Lambda}\alpha_{\Xi^0}\cos\theta_{\Lambda}+\alpha_{\Lambda}\alpha_{\Lambda_c^+}\cos\theta_{\Xi^0}\cos\theta_{\Lambda}$$



$\alpha_{\Xi^0} = -0.375 \pm 0.0034 \pm 0.0016$ [arXiv:2305.09218]

$\alpha_{\Lambda} = 0.7519 \pm 0.0036 \pm 0.0019$ [PRL 129 13, 131801(2022)]

  - 将$[\cos\theta_{\Xi^0}, \cos\theta_{\Lambda}]$分成5×5个bins，分别拟合M($\Xi^0K^+$)
  - 进行效率修正

三.分析样本

Signal MC 样本： Signal MC 样本由EvtGen产生。$e^+e^- \to c\bar{c}$使用PYCONT模型模拟，$\Lambda_c^+ \to \Xi^0 K^+$，$\Xi^0 \to \Lambda^0 \pi^0$，$\Lambda^0 \to p\pi^-$，$\pi^0 \to \gamma\gamma$衰变由PHSP产生，产生100万样本。

目的：计算探测器的探测效率$\varepsilon_{\Xi^0 K^+}$

Generic MC 样本：

Belle: $\Upsilon(4S) \to B^+B^-/B^0\overline{B}^0$、$e^+e^- \to q\bar{q}(q = u, d, s, c)(\sqrt{S} = 10.52、10.58、10.867\ GeV)$

Belle II: MC15_rd generic MC

目的：分析真实 data 样本中的本底成分

Data 样本： Belle data$(980\ fb^{-1})$ + Belle II data$(424\ fb^{-1})$

四.事例筛选条件

Belle

K^+: R(K|p)>0.6 R(K|π)>0.6

Λ^0(mdst): $|dM_{\Lambda^0}| < 3.5\ MeV/c^2$, $\cos(\alpha^{\Lambda^0}_{xyz})>0$,
dr>0.35 cm, KFit, R(p|π)>0.2 , R(p|K)>0.2

π^0(mdst): $E_\gamma > 50$ MeV(Endcaps), $E_\gamma >$ 30 MeV(Barrel),
$|dM_{\pi^0}| < 17.4\ MeV/c^2$, p>0.15 GeV/c

Ξ^0using goodXi0(loose): $1.290\ GeV/c^2 < M_{\Xi^0} < 1.339\ GeV/c^2$, $\cos(\alpha^{\Xi^0}_{xyz}) > 0$ $\cos(\alpha^{\Lambda^0}_{xy}) < \cos(\alpha^{\Xi^0}_{xy})$, $\sqrt{dr^2 + dz^2}$>0.5 cm,
$\sqrt{dx^2_{\Xi^0} + dy^2_{\Xi^0} + dy^2_{\Xi^0}} > 0$, $\sqrt{dx^2_{\Xi^0} + dy^2_{\Xi^0} + dy^2_{\Xi^0}} < \sqrt{dx^2_{\Lambda^0} + dy^2_{\Lambda^0} + dy^2_{\Lambda^0}}$

Λ_c^+: $2.2\ GeV/c^2 < M_{\Lambda_c^+} < 2.38\ GeV/c^2$,
x_p>0.5(optimized), treeFit

Belle II

K^+: R(K|p)>0.6 R(K|π)>0.6

Λ^0(mdst): $|dM_{\Lambda^0}| < 3.5\ MeV/c^2$, $\cos(\alpha^{\Lambda^0}_{xyz})>0$,
dr>0.35 cm, protonID>0.01

stdPhotons(loose): $E_\gamma > 50$ MeV(Endcaps), $E_\gamma >$ 30 MeV(Barrel)
π^0: $|dM_{\pi^0}| < 17.4\ MeV/c^2$, p>0.15 GeV/c

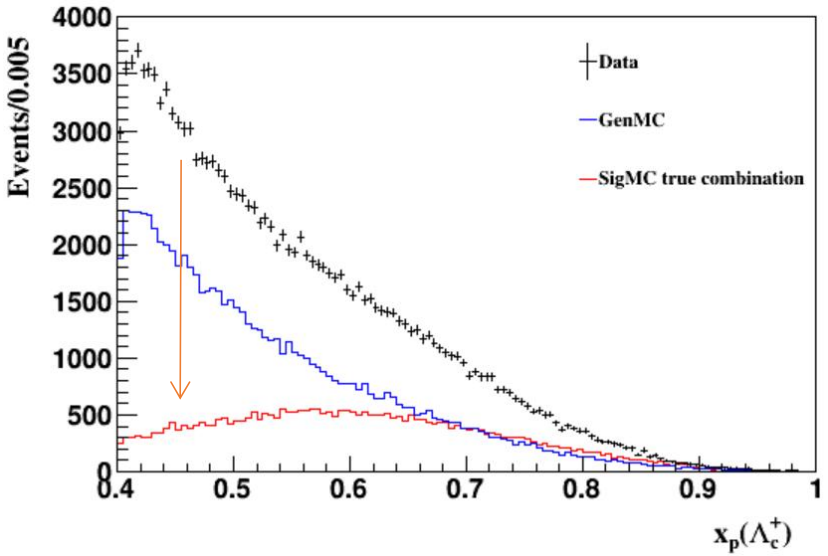
Ξ^0using goodXi0(loose): $1.290\ GeV/c^2 < M_{\Xi^0} < 1.339\ GeV/c^2$, $\cos(\alpha^{\Xi^0}_{xyz}) > 0$, $\cos(\alpha^{\Lambda^0}_{xy})<\cos(\alpha^{\Xi^0}_{xy})$, $\sqrt{dr^2 + dz^2}$>0.5 cm,
$\sqrt{dx^2_{\Xi^0} + dy^2_{\Xi^0} + dy^2_{\Xi^0}} > 0$, $\sqrt{dx^2_{\Xi^0} + dy^2_{\Xi^0} + dy^2_{\Xi^0}} < \sqrt{dx^2_{\Lambda^0} + dy^2_{\Lambda^0} + dy^2_{\Lambda^0}}$

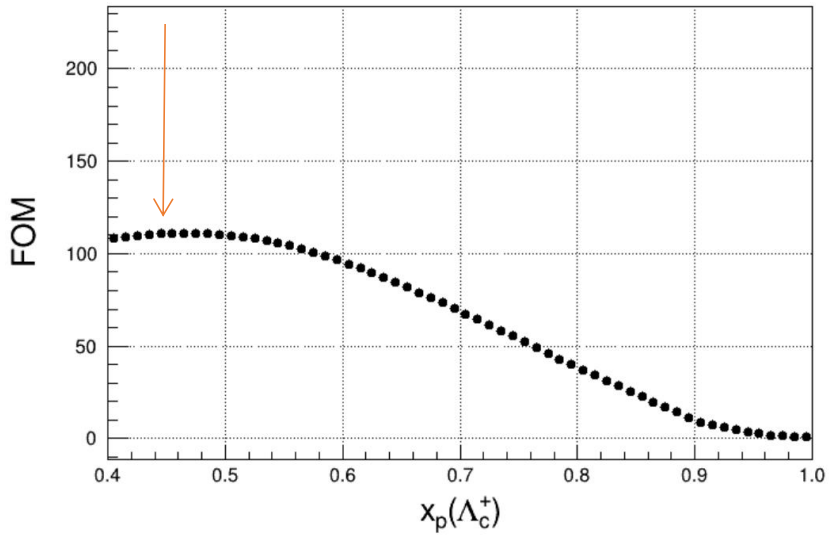
Λ_c^+: $2.2\ GeV/c^2 < M_{\Lambda_c^+} < 2.38\ GeV/c^2$,
x_p>0.5(optimized), treeFit

归一化的动量x_p分布及优化

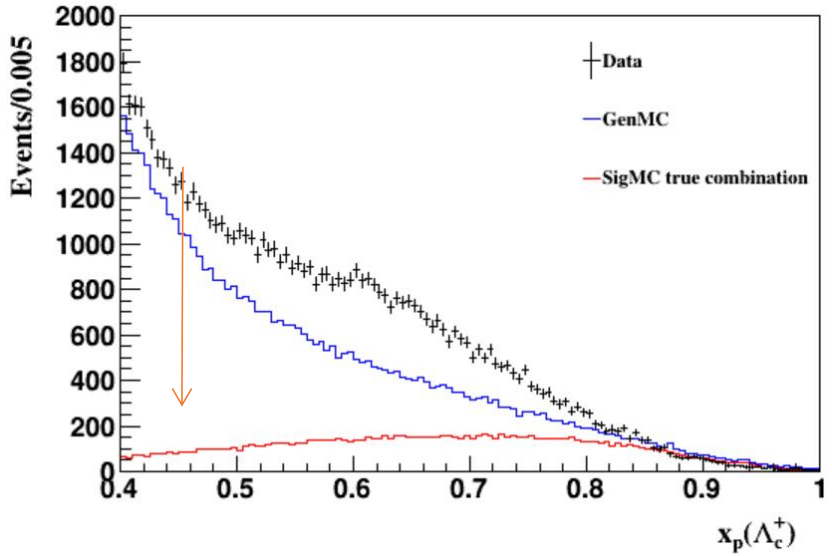
$$x_p = p^* / \sqrt{E_{beam}{}^2 - M^2}$$

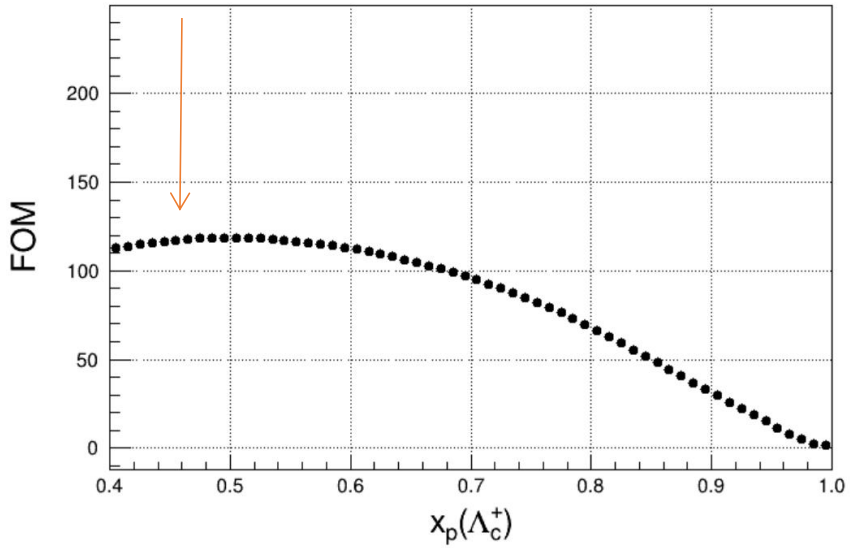
Belle





Belle II



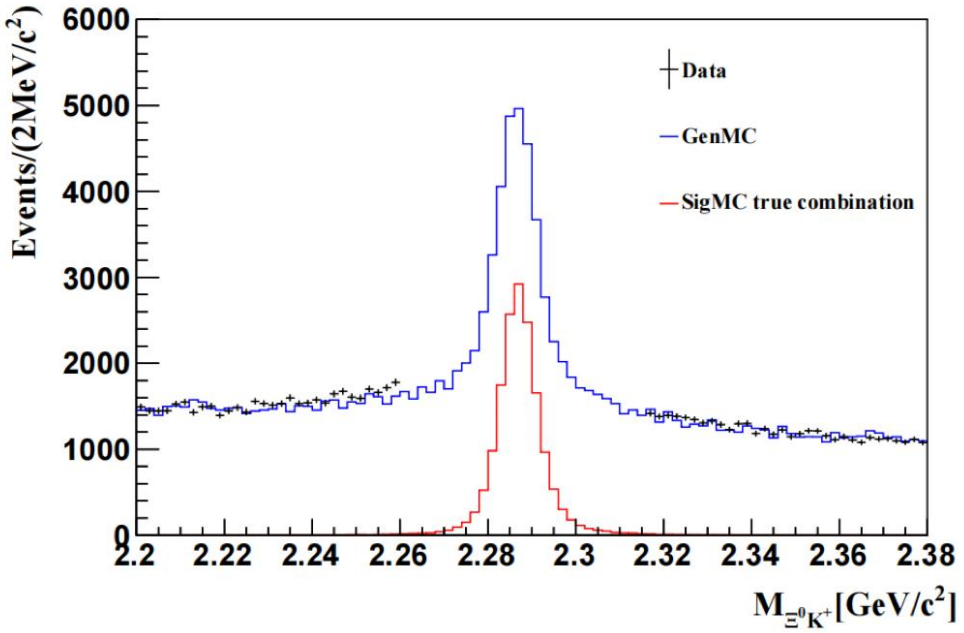


$$FOM = \frac{S}{\sqrt{S+B}}$$

S：预估的信号MC的产额
B：Generic MC中的本底数

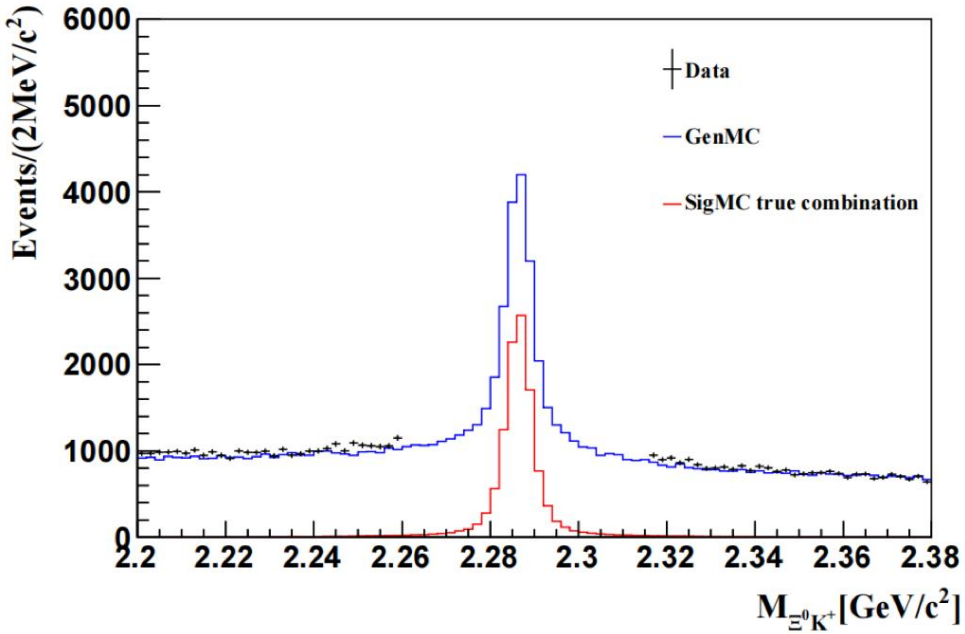
$\Lambda_c^+(\to \Xi^0 K^+)$的重建和探测效率 ε

Belle



$\varepsilon = 4.2\%$

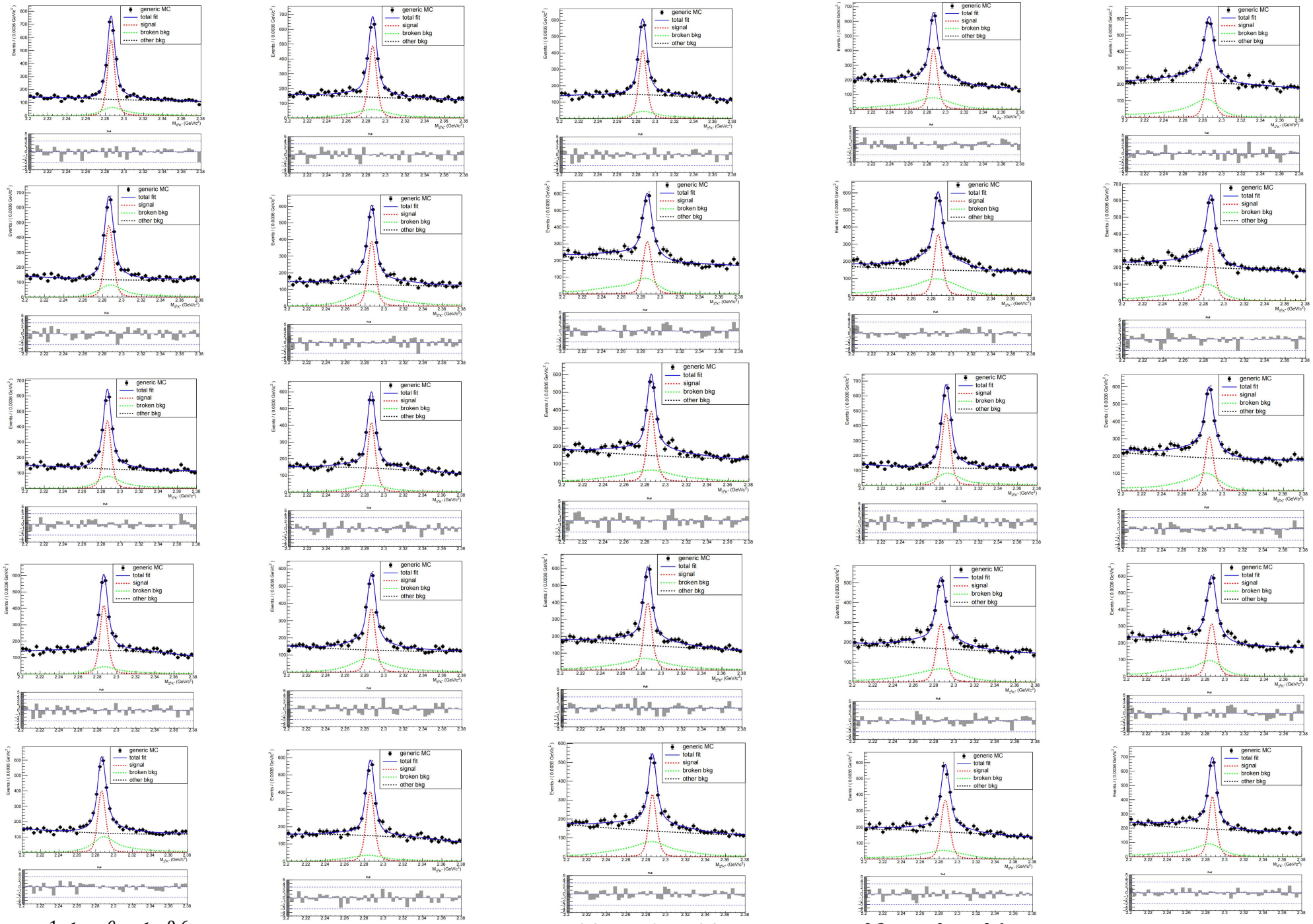
Belle II



$\varepsilon = 7.1\%$

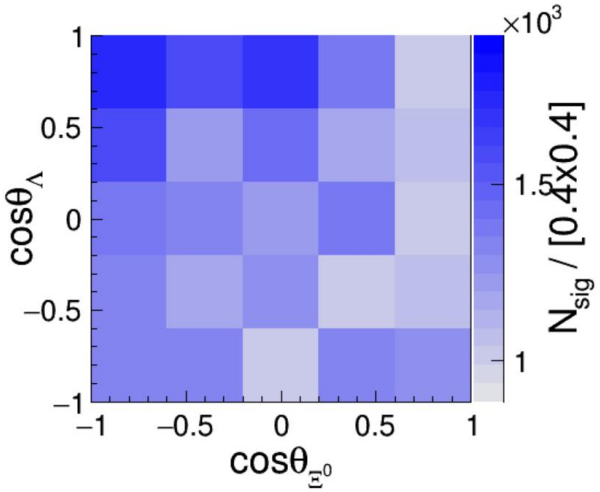
Blind Analysis(盲分析方法)

五.对衰变不对称参数$\alpha_{\Lambda_c^+}$的研究

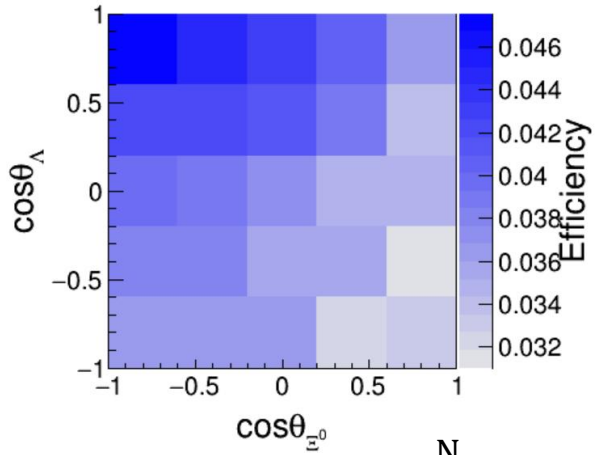

0.6 < cosθ_Λ0 < 1
0.2 < cosθ_Λ0 < 0.6
−0.2 < cosθ_Λ0 < −0.2
−0.6 < cosθ_Λ0 < −0.2
−1 < cosθ_Λ0 < −0.6
generic MC
total fit
signal
broken bkg
other bkg
−1 < cosθ_Ξ0 < −0.6
−0.6 < cosθ_Ξ0 < −0.2
−0.2 < cosθ_Ξ0 < 0.2
0.2 < cosθ_Ξ0 < 0.6
0.6 < cosθ_Ξ0 < 1

Belle

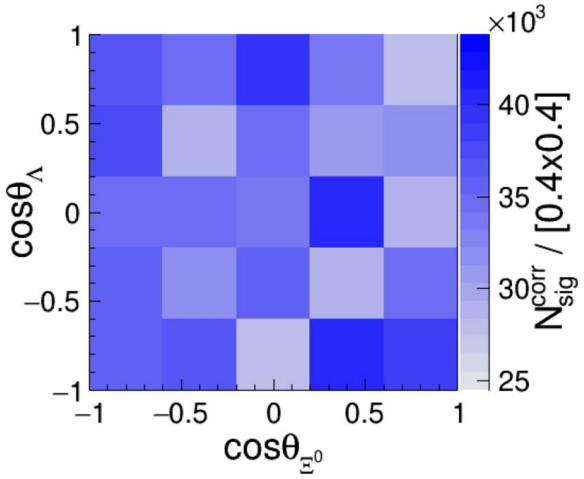
1.在Belle上对generic MC的$\alpha_{\Lambda_c^+}$ 的测量



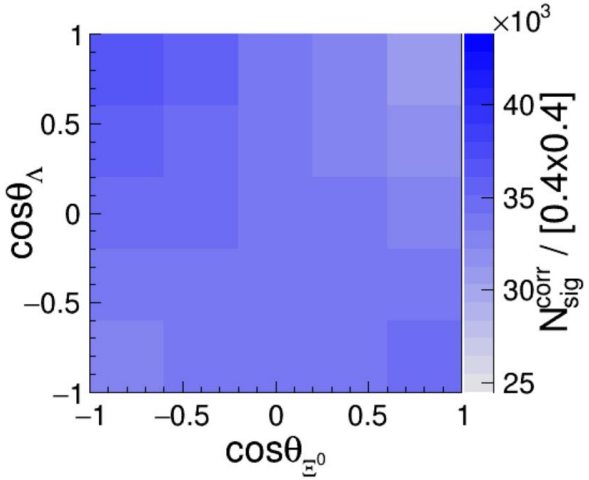
5×5 bins中$M_{\Lambda_c^+}$的拟合结果



效率平面 $\varepsilon = \frac{N_{rec}}{N_{gen}}$



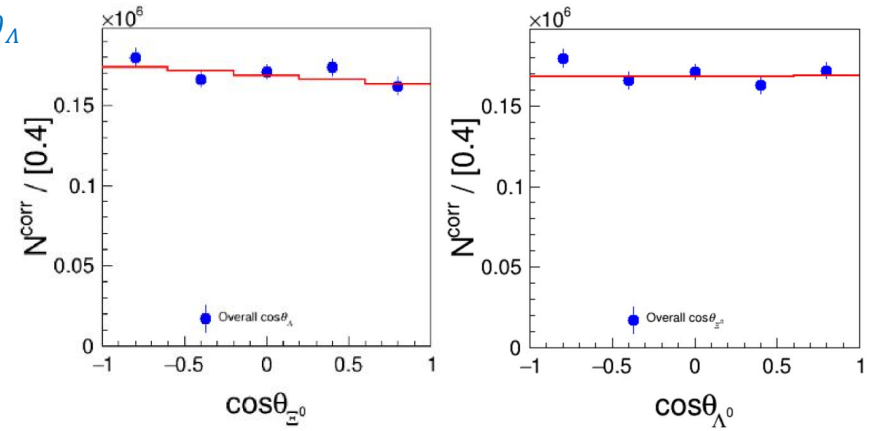
对拟合结果进行效率修正



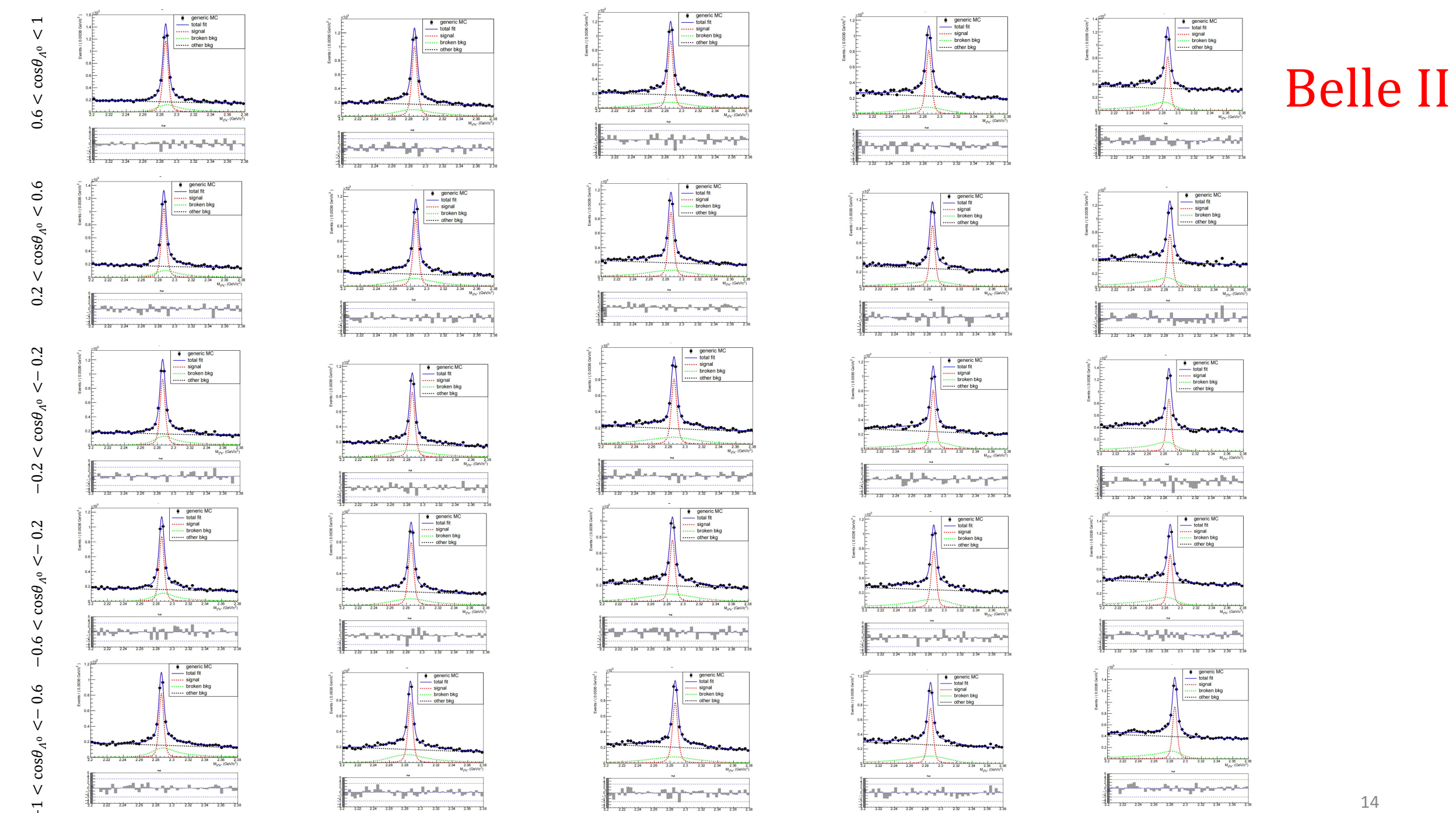
用二维函数拟合

$$\frac{dN}{d\cos\theta_{\Xi^0}\, d\cos\theta_{\Lambda}} \propto 1 + \alpha_{\Lambda_c^+}\alpha_{\Xi^0}\cos\theta_{\Xi^0} + \alpha_{\Lambda}\alpha_{\Xi^0}\cos\theta_{\Lambda} + \alpha_{\Lambda}\alpha_{\Lambda_c^+}\cos\theta_{\Xi^0}\cos\theta_{\Lambda}$$

$$\alpha_{\Lambda_c^+}\alpha_{\Xi^0} = -0.03929 \pm 0.02560$$
$$\alpha_{\Lambda}\alpha_{\Xi^0} = 0.00256 \pm 0.02399$$
$$\alpha_{\Lambda}\alpha_{\Lambda_c^+} = -0.08973 \pm 0.04746$$



向$\cos\theta_{\Xi^0}$，$\cos\theta_{\Lambda}$ 方向投影


0.6 < cosθ_Λ0 < 1
0.2 < cosθ_Λ0 < 0.6
−0.2 < cosθ_Λ0 < −0.2
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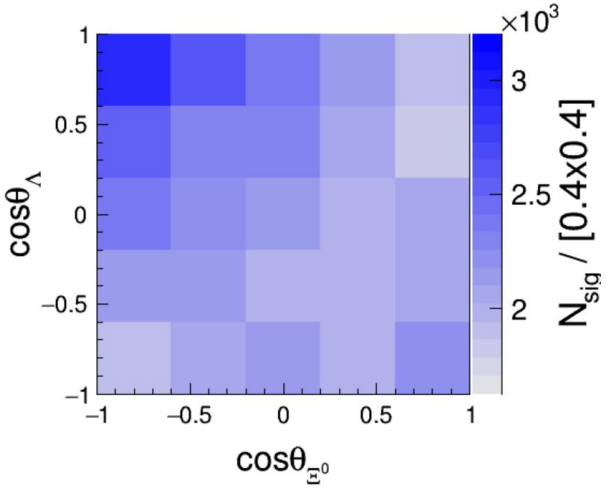
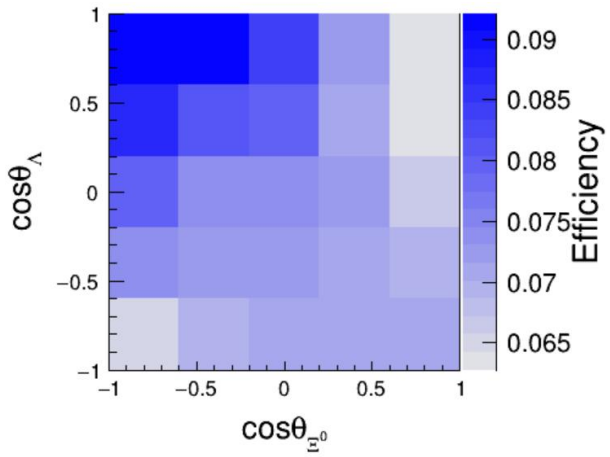
−1 < cosθ_Λ0 < −0.6
generic MC
total fit
signal
broken bkg
other bkg
−1 < cosθ_Ξ0 < −0.6
−0.6 < cosθ_Ξ0 < −0.2
−0.2 < cosθ_Ξ0 < 0.2
0.2 < cosθ_Ξ0 < 0.6
0.6 < cosθ_Ξ0 < 1

Belle II

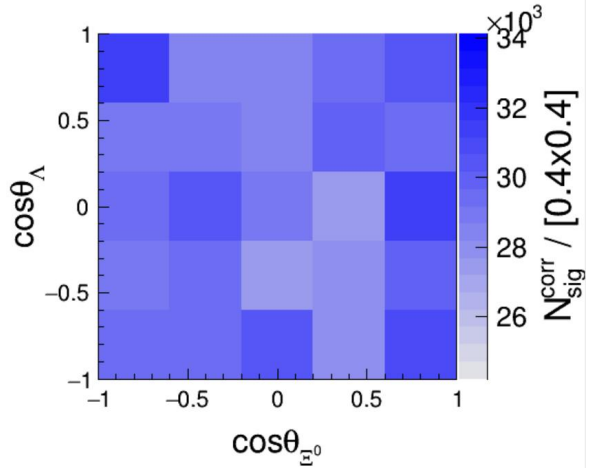
2.在Belle II上对generic MC的$\alpha_{\Lambda_c^+}$ 的测量



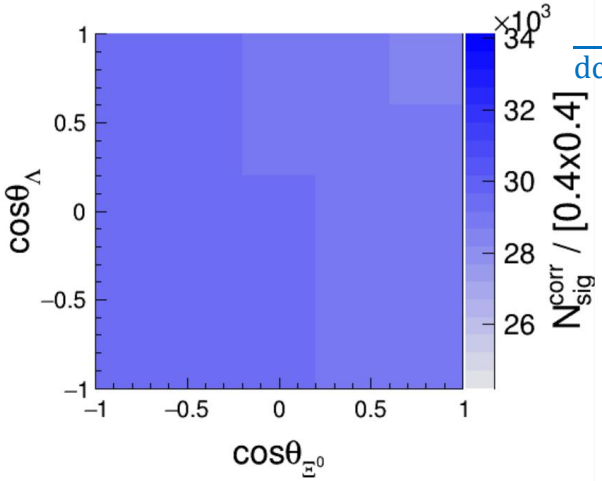
5×5 bins中$M_{\Lambda_c^+}$的拟合结果



效率平面 $\varepsilon = \frac{N_{rec}}{N_{gen}}$



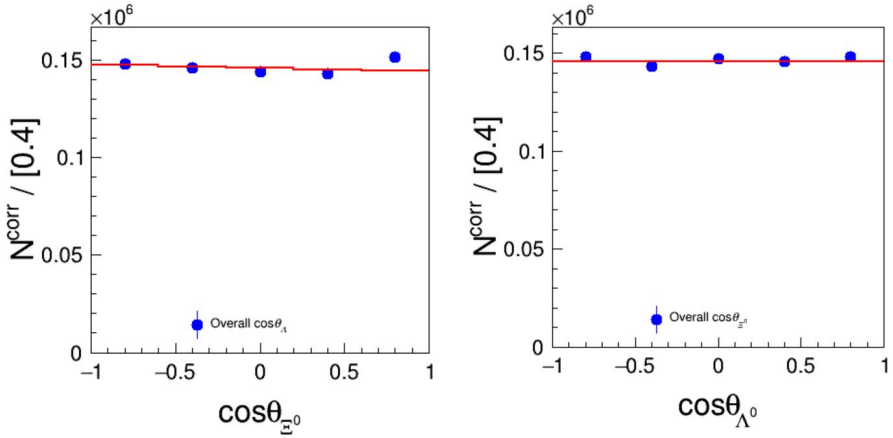
对拟合结果进行效率修正



用二维函数拟合

$$\frac{dN}{d\cos\theta_{\Xi^0}\, d\cos\theta_{\Lambda}} \propto 1 + \alpha_{\Lambda_c^+}\alpha_{\Xi^0}\cos\theta_{\Xi^0} + \alpha_{\Lambda}\alpha_{\Xi^0}\cos\theta_{\Lambda} + \alpha_{\Lambda}\alpha_{\Lambda_c^+}\cos\theta_{\Xi^0}\cos\theta_{\Lambda}$$

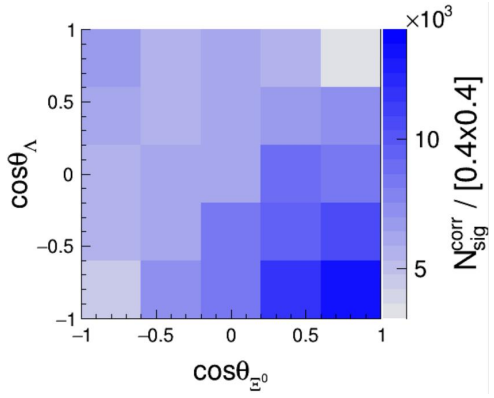
$$\alpha_{\Lambda_c^+}\alpha_{\Xi^0} = -0.0127 \pm 0.0119$$
$$\alpha_{\Lambda}\alpha_{\Xi^0} = -0.0013 \pm 0.0123$$
$$\alpha_{\Lambda}\alpha_{\Lambda_c^+} = -0.0099 \pm 0.0201$$



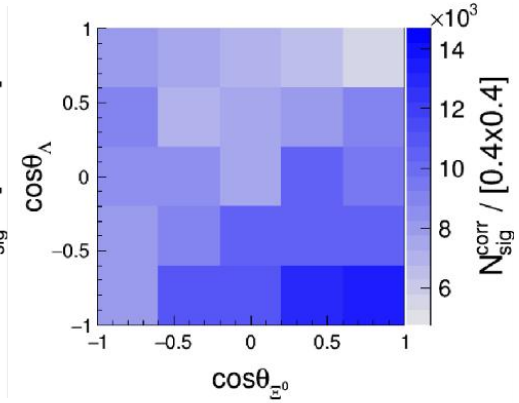
向$\cos\theta_{\Xi^0}$，$\cos\theta_{\Lambda}$ 方向投影

3.不同 $\alpha_{\Lambda_c^+}$ 值的输入输出检查

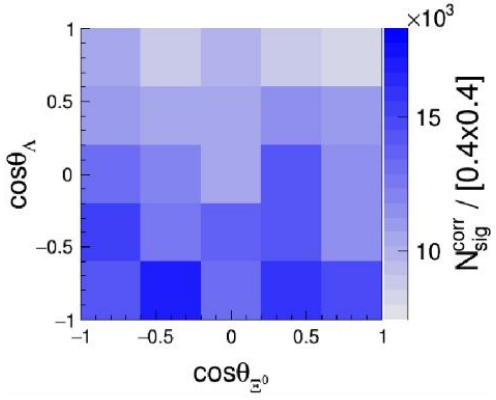
输入值：$\alpha_{\Lambda_c^+}$=-0.8



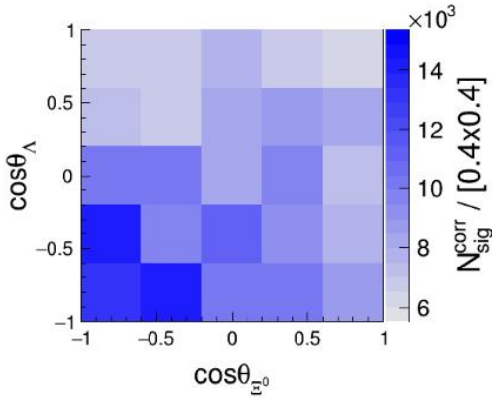
$\alpha_{\Lambda_c^+}$=-0.4



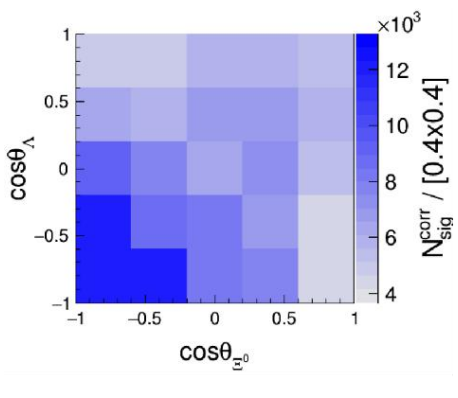
$\alpha_{\Lambda_c^+}$=0



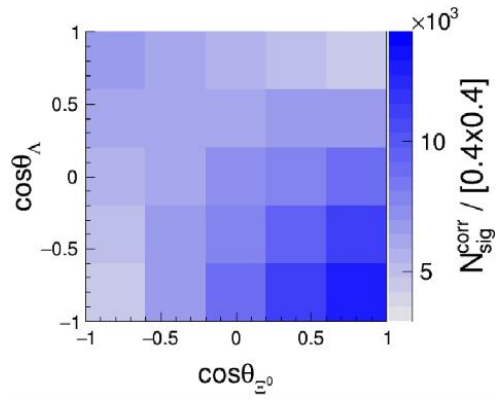
$\alpha_{\Lambda_c^+}$=0.4



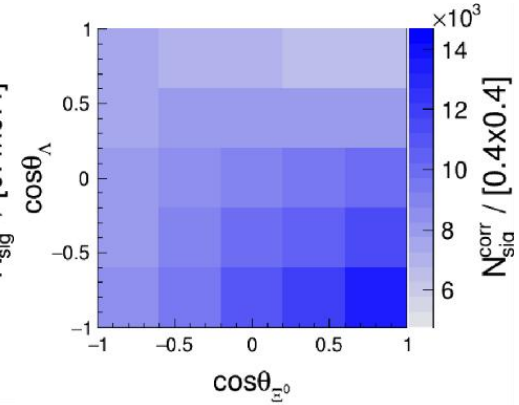
$\alpha_{\Lambda_c^+}$=0.8



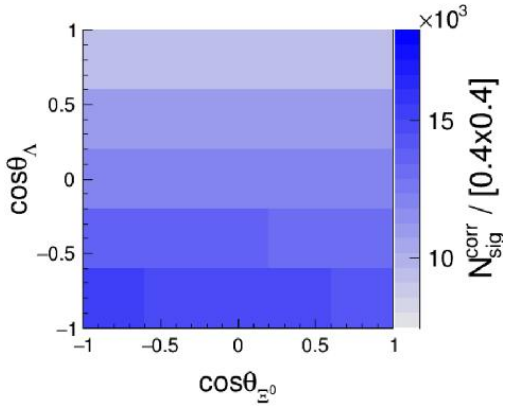
拟合值: -0.781 ± 0.052



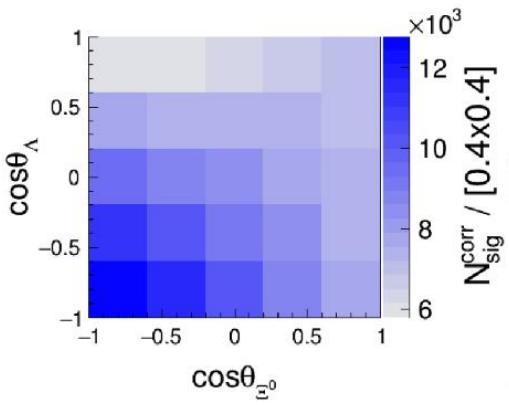
-0.362 ± 0.065



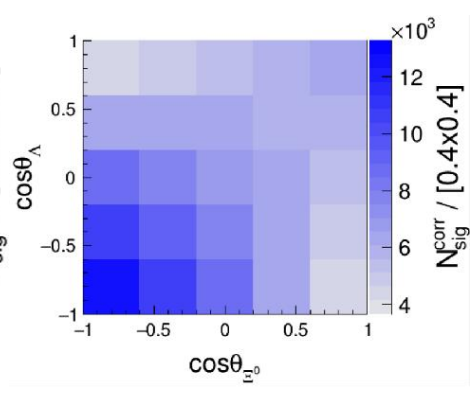
0.043 ± 0.061



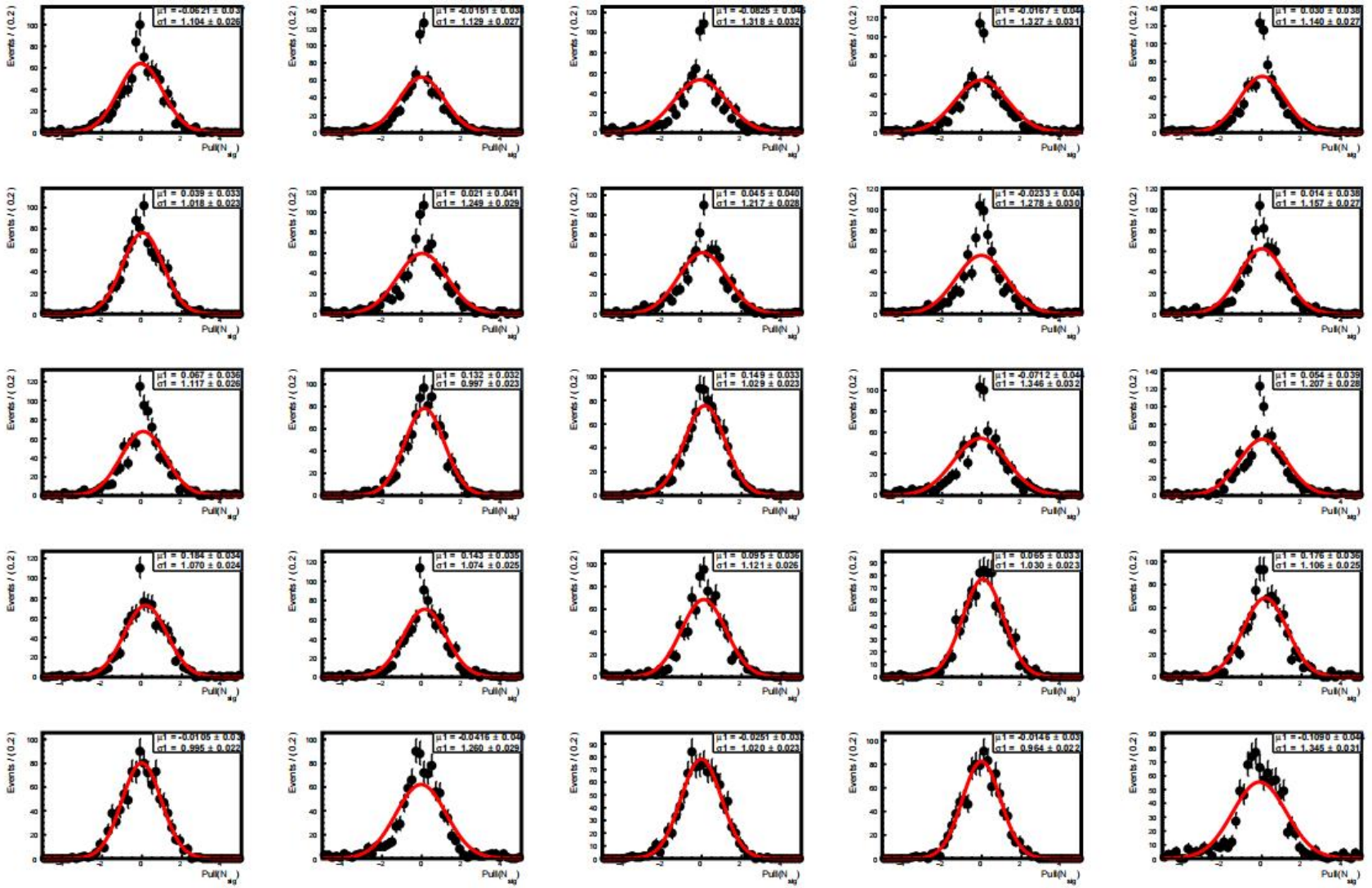
0.422 ± 0.067

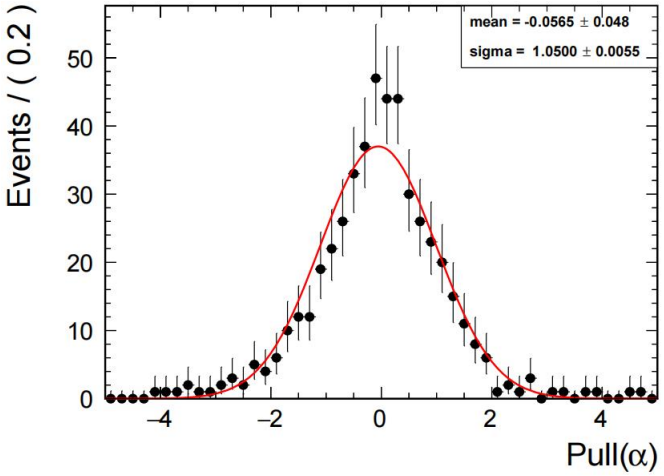


0.78 ± 0.052



4. 利用Toy MC进行无偏检验





5.系统误差分析(基于generic MC)

来源	$\alpha(\Lambda_c^+ \to \Xi^0 K^+)$
cosθ bins	0.034
效率平面的误差	0.012
拟合的偏移	0.022
总的系统误差	0.042
vs 统计误差	0.065

六.总结

已完成

- 事例筛选
- 对generic MC的$\alpha_{\Lambda_c^+}$ 的测量
- 不同 $\alpha_{\Lambda_c^+}$ 值的输入输出检查
- 无偏检验
- 系统误差

后续计划

- 提交Belle+Belle II note
- 完成对data样本的$\alpha_{\Lambda_c^+}$ 的测量

谢谢聆听!