Production of Hyperon Resonances in $\Lambda_c^+ \to pK_S\pi^0$ decays in the Belle experiment

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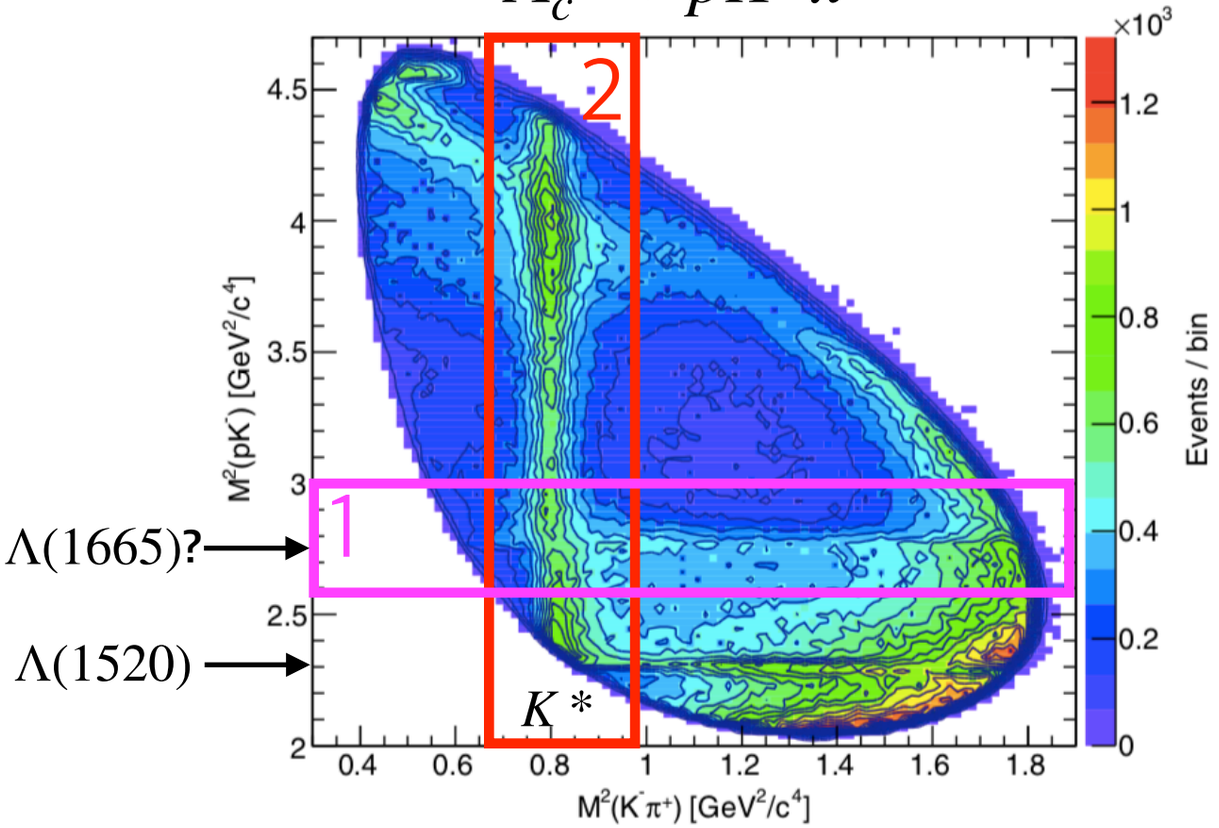
Hadron & Nuclear Physics Lab

Physics Analysis Motivation

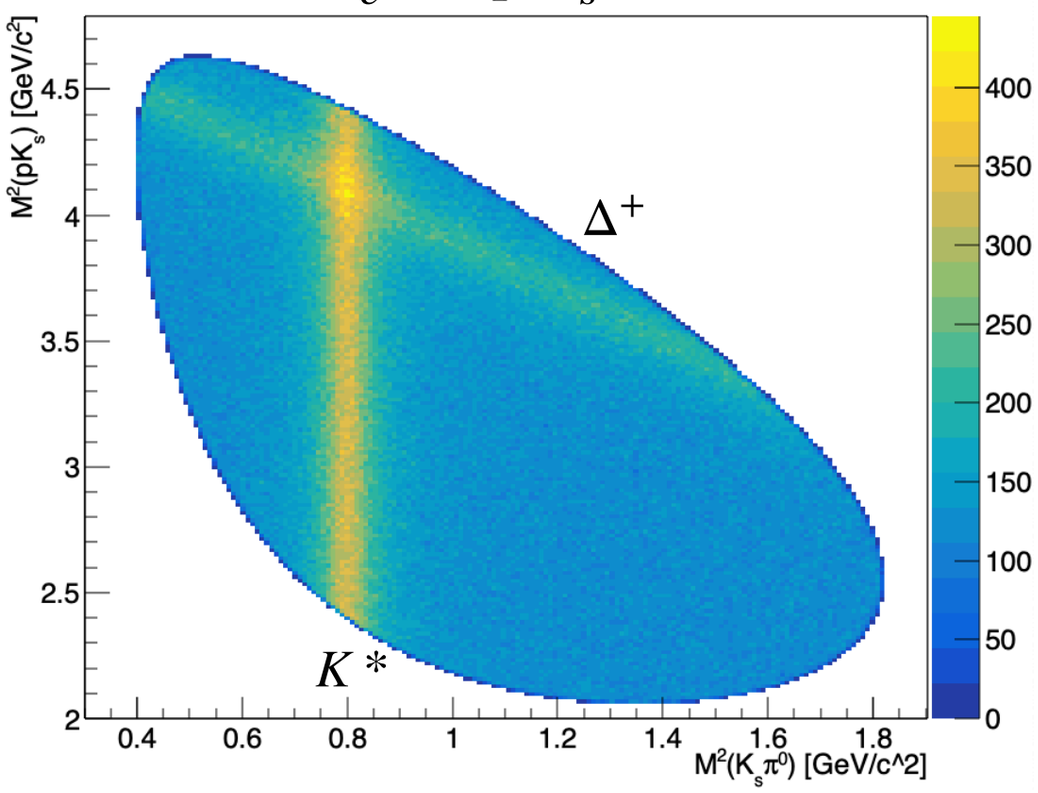
1. **Reconfirmation of the $\Lambda(1665)$ peak in $\Lambda_c^+ \to pK_s^0\pi^0$**
2. **Interference effect between Λ^*/Σ^* and K* channels**
3. Updates on BR($\Lambda_c^+ \to pK_s^0\pi^0$) with resonances

$\Lambda_c^+ \to pK^-\pi^+$



PRL **117**, 011801 (S.B. Yang)

$\Lambda_c^+ \to pK_s^0\pi^0$



Belle Generic MC

Physics Analysis Motivation

1. Reconfirmation of the $\Lambda(1665)$ peak in $\Lambda_c^+ \to pK_s^0\pi^0$
2. Interference effect between Λ^*/Σ^* and K* channels
3. **Updates on BR($\Lambda_c^+ \to pK_s^0\pi^0$) with resonances**

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
	Hadronic modes with a *p* or *n*: $S = -1$ final states			
Γ_1	pK_S^0		(1.58± 0.08) %	S=1.1
Γ_2	$pK^-\pi^+$		(6.23± 0.33) %	S=1.4
Γ_3	$p\overline{K}^*(892)^0$	[a]	(1.94± 0.27) %	
Γ_4	$\Delta(1232)^{++}K^-$		(1.07± 0.25) %	
Γ_5	$\Lambda(1520)\pi^+$	[a]	(2.2 ± 0.5) %	
Γ_6	$pK^-\pi^+$ nonresonant		(3.4 ± 0.4) %	
Γ_7	$pK_S^0\pi^0$		(1.96± 0.13) %	S=1.1
Γ_8	$nK_S^0\pi^+$		(1.82± 0.25) %	
Γ_9	$p\overline{K}^0\eta$		(1.6 ± 0.4) %	
Γ_{10}	$pK_S^0\pi^+\pi^-$		(1.59± 0.12) %	S=1.2
Γ_{11}	$pK^-\pi^+\pi^0$		(4.42± 0.31) %	S=1.5
Γ_{12}	$pK^*(892)^-\pi^+$	[a]	(1.4 ± 0.5) %	
Γ_{13}	$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(4.5 ± 0.8) %	
Γ_{14}	$\Delta(1232)\overline{K}^*(892)$		seen	
Γ_{15}	$pK^-2\pi^+\pi^-$		(1.4 ± 0.9) $\times 10^{-3}$	
Γ_{16}	$pK^-\pi^+2\pi^0$		(10 ± 5) $\times 10^{-3}$	
Γ_{17}	$pK^-\pi^+3\pi^0$			

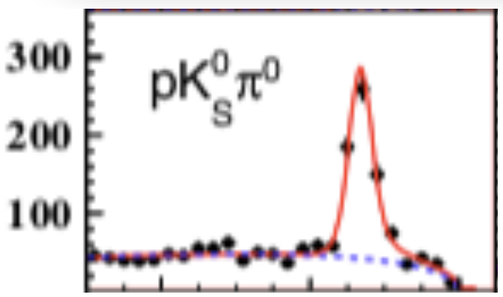
$\Gamma(pK_S^0\pi^0)/\Gamma_{\text{total}}$ **Γ_7/Γ**

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
1.96±0.13 OUR FIT Error includes scale factor of 1.1.					
1.87±0.13±0.05	558	ABLIKIM	16	BES3	$e^+e^- \to \Lambda_c\overline{\Lambda}_c$, 4.599 GeV

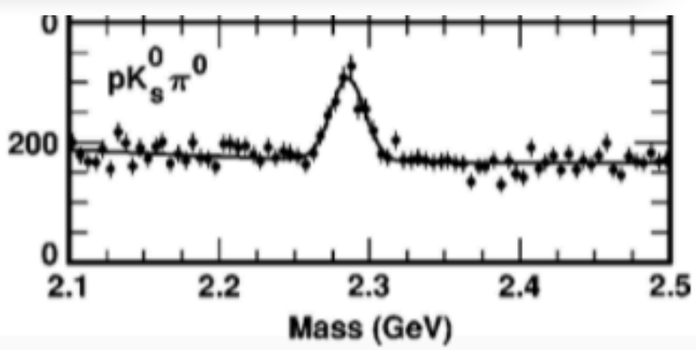
$\Gamma(pK_S^0\pi^0)/\Gamma(pK^-\pi^+)$ **Γ_7/Γ_2**

Measurements given as a $\overline{K}^0$ ratio have been divided by 2 to convert to a K_S^0 ratio.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.314±0.018 OUR FIT					
0.33 ±0.03 ±0.04	774	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$



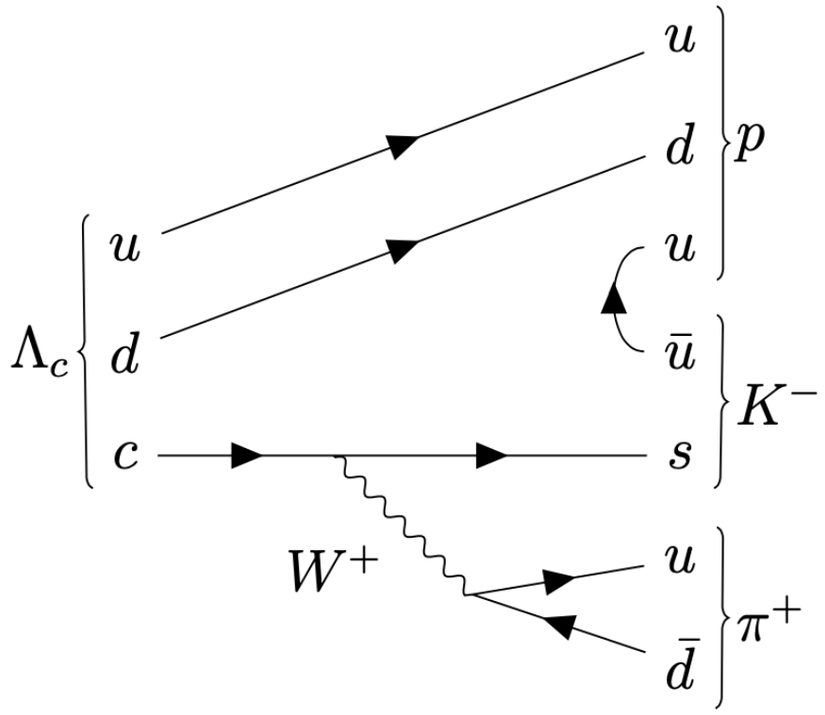
PRL **116**, 052001
M. Ablikim *et al.* (BESIII Collaboration)

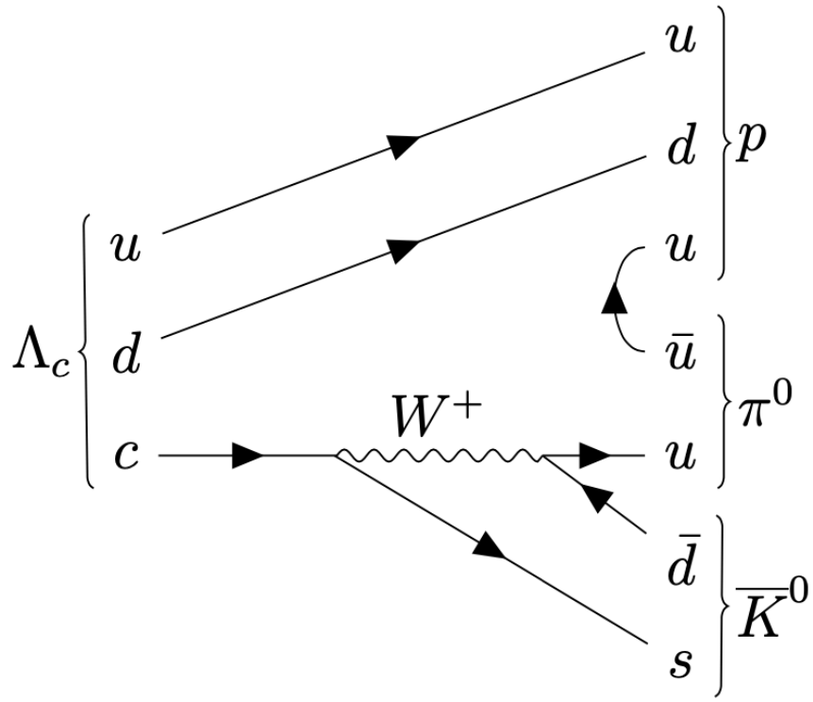


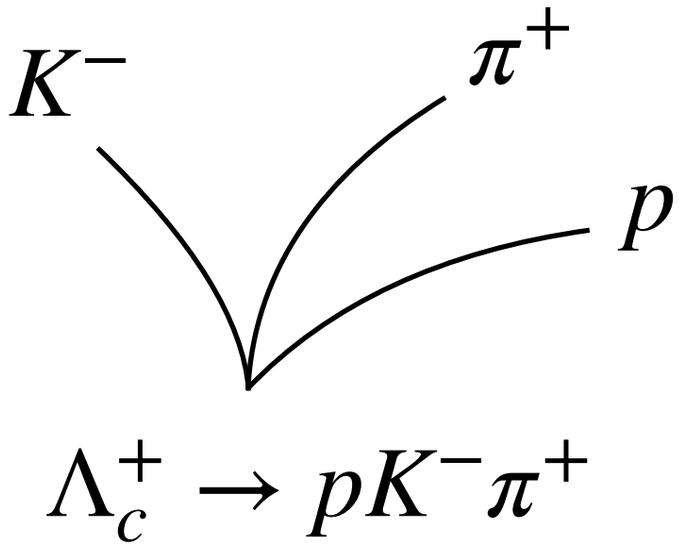
PRD **57**, 4467
M. S. Alam *et al.* (CLEO Collaboration)

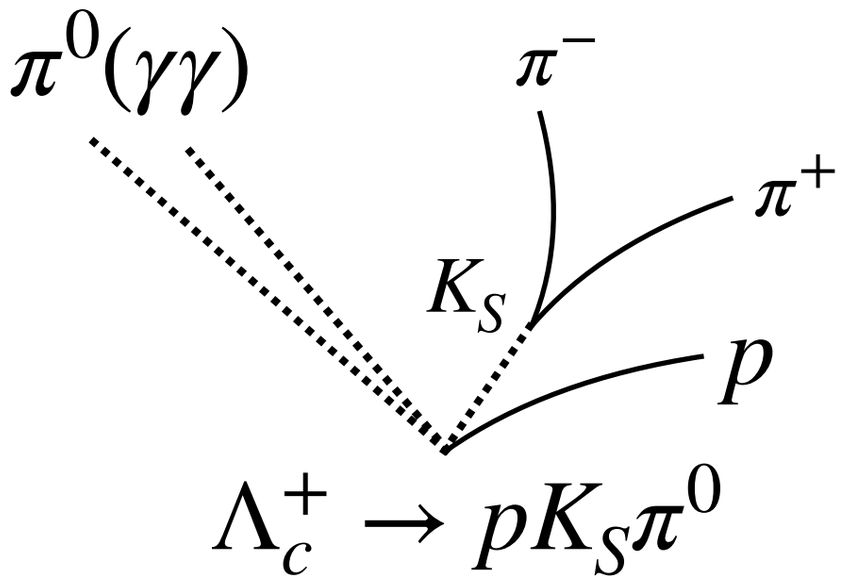
- ~100 times more statistics is expected.
- Measurement of BR of resonance states.

Λ_c^+ Reconstruction



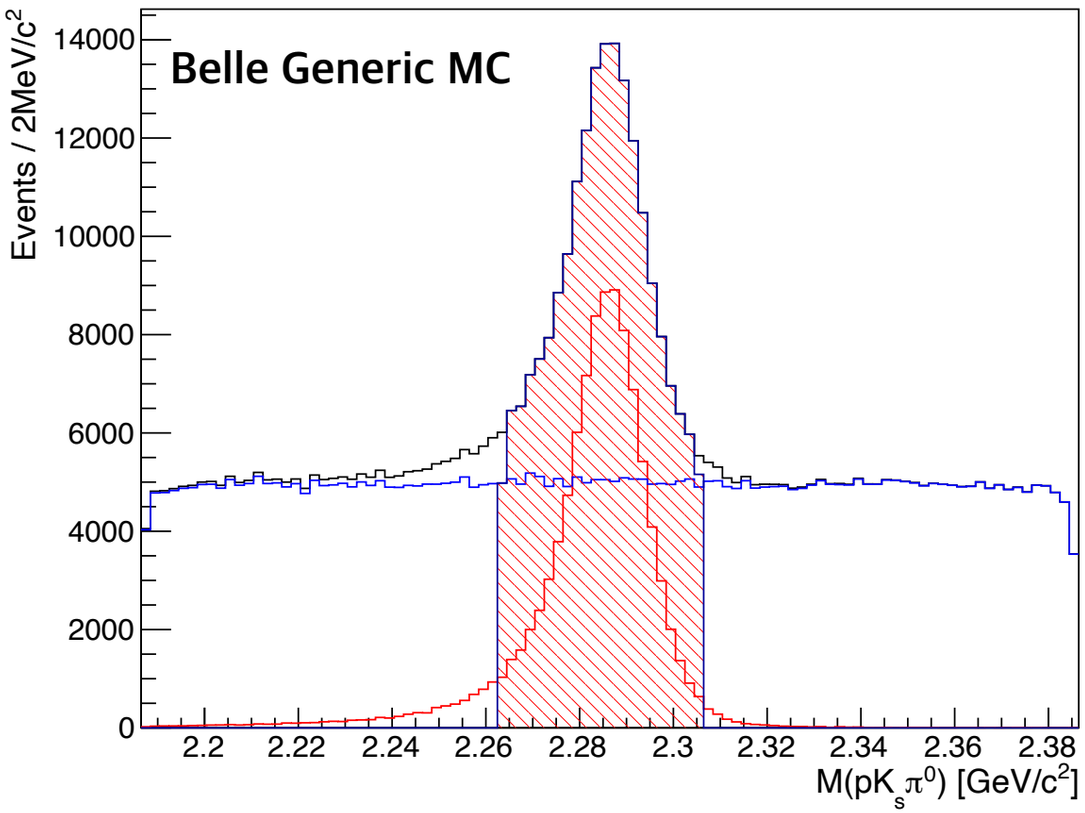






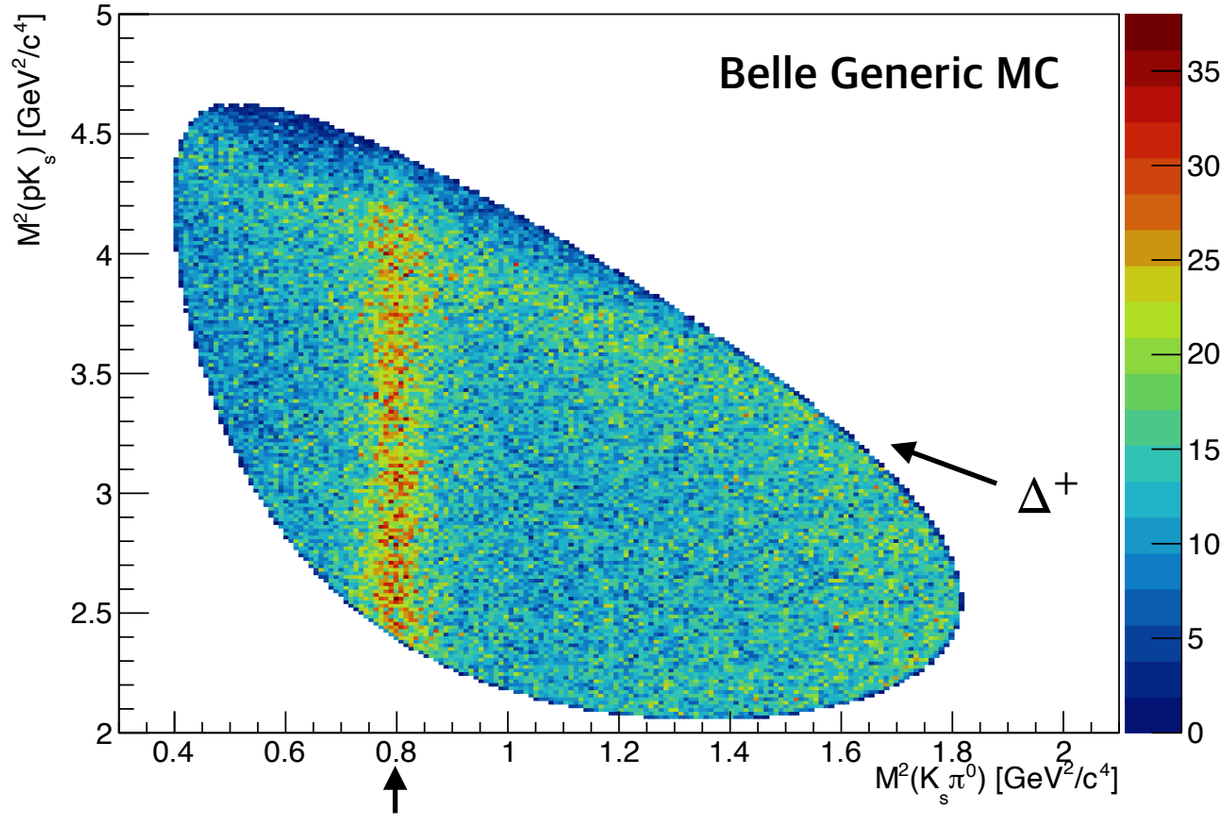
$pK_s^0\pi^0$ Invariant mass / Dalitz plot

Invariant Mass



signal region (2.263, 2.306)

Dalitz plot



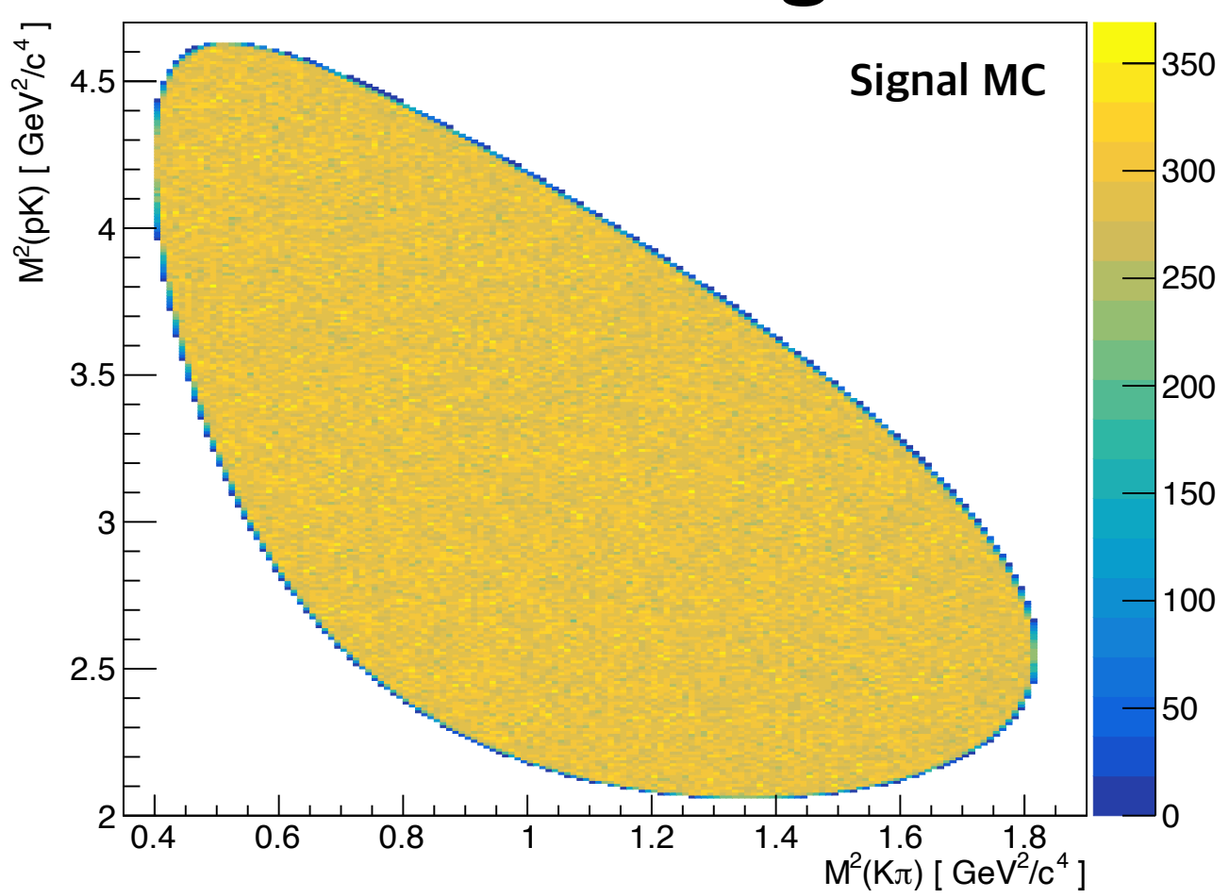
Detection Efficiency

64M signal MC

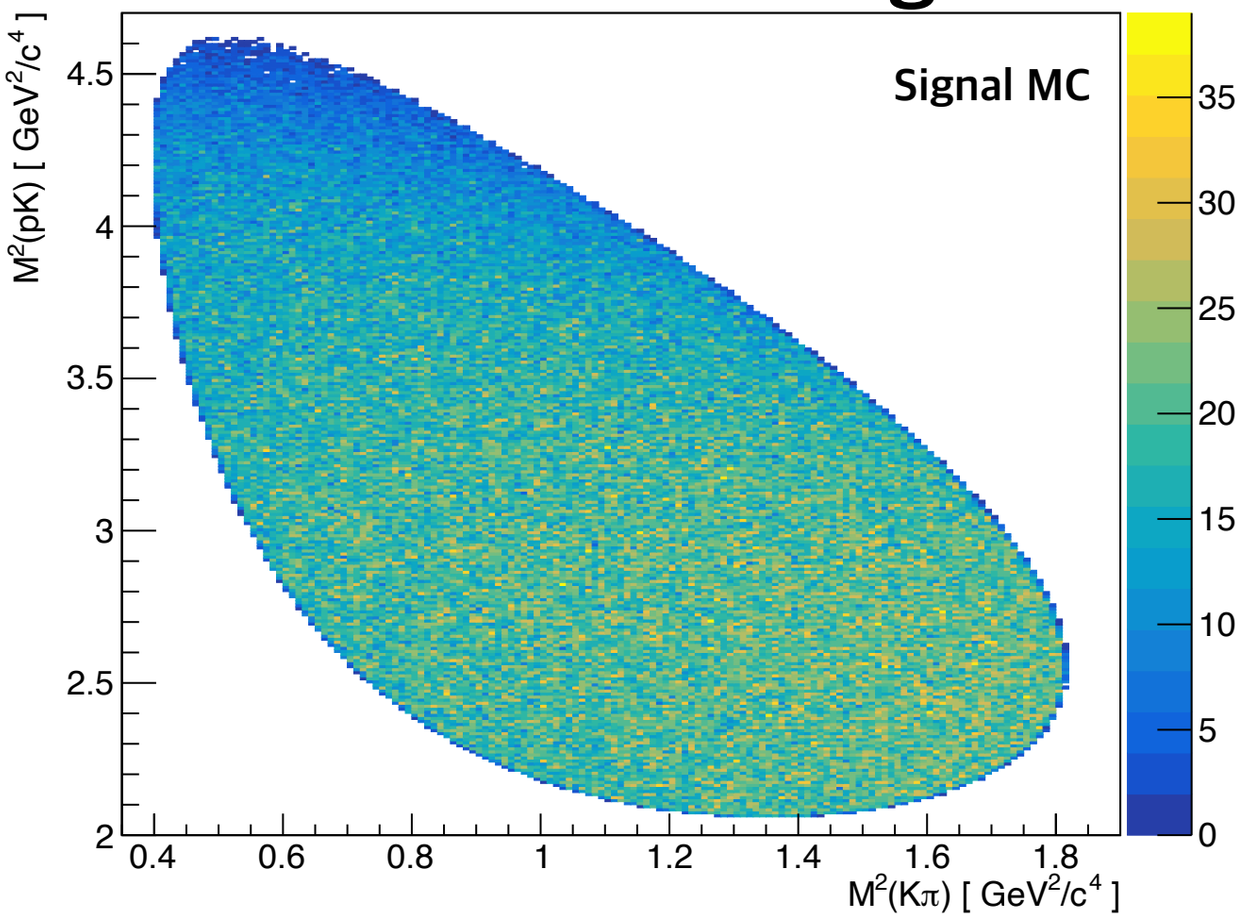
Non-resonant decay

$$\Lambda_c^+ \to pK_S\pi^0$$
$$\pi^0 \to \gamma\gamma$$
$$K_S \to \pi^+\pi^-$$

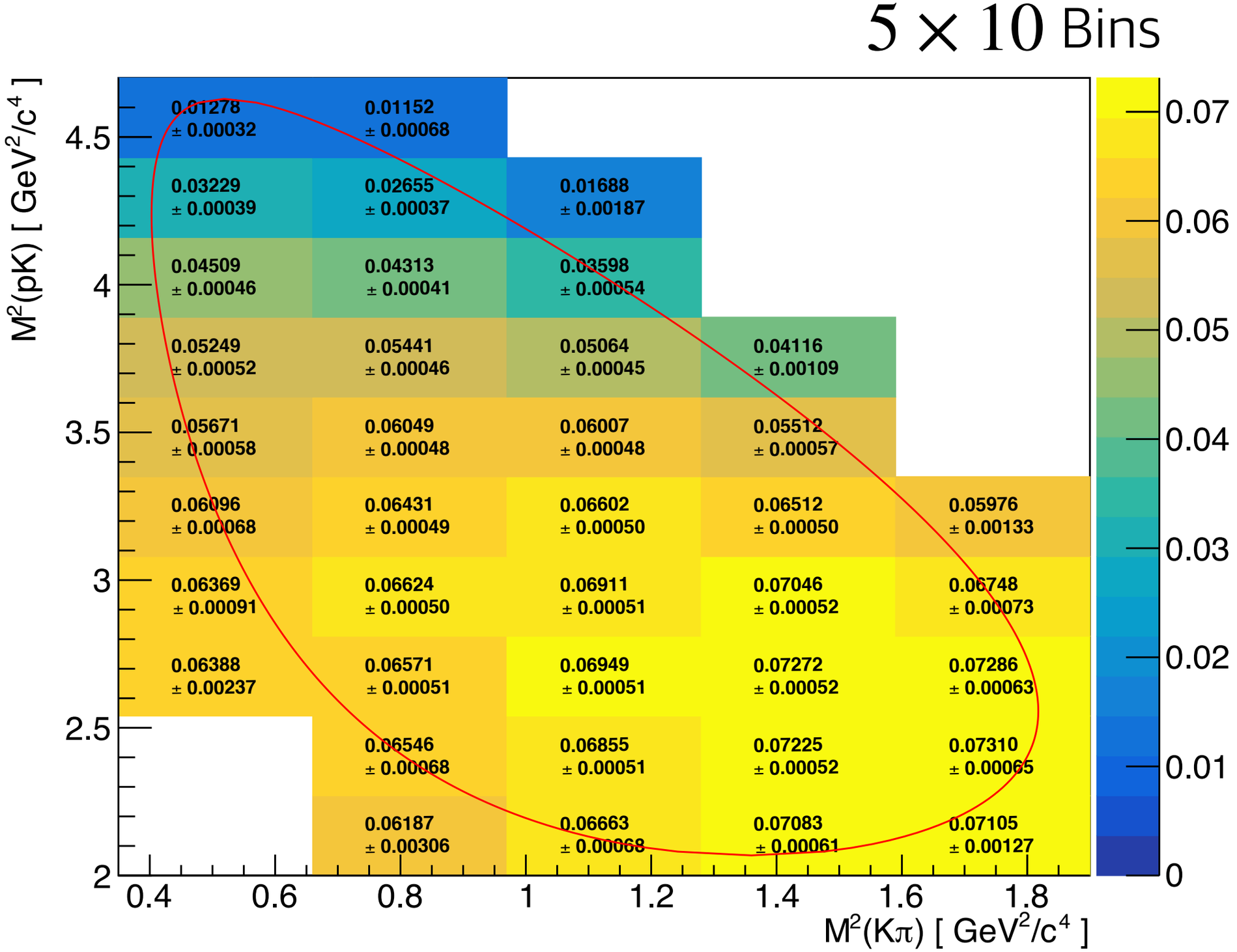
Generated Signals



Reconstructed Signals

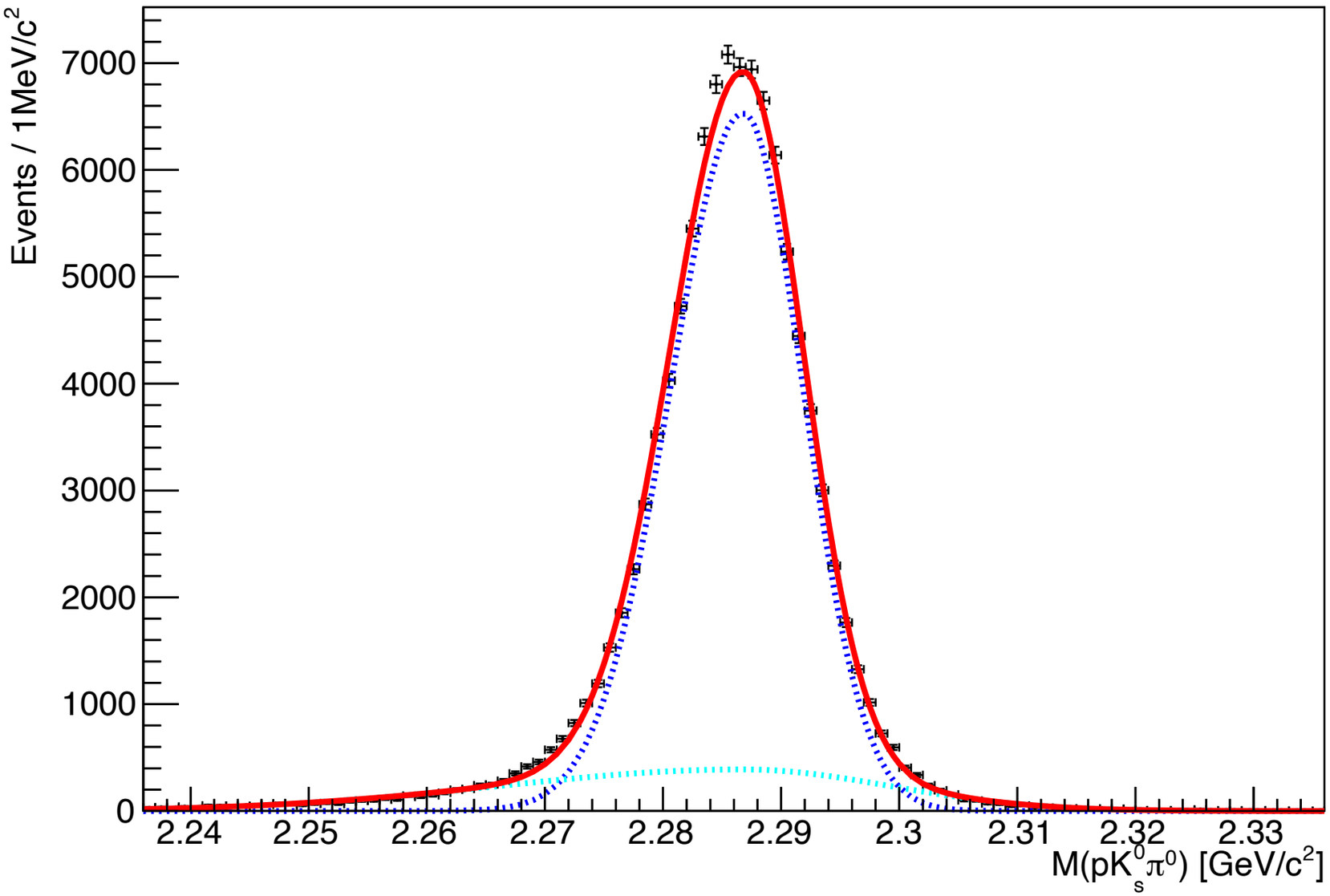


Detection Efficiency



Signal PDF

64M signal MC data sample

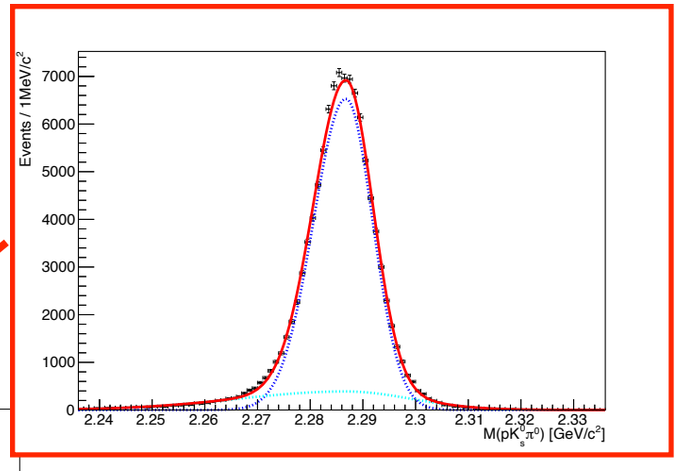


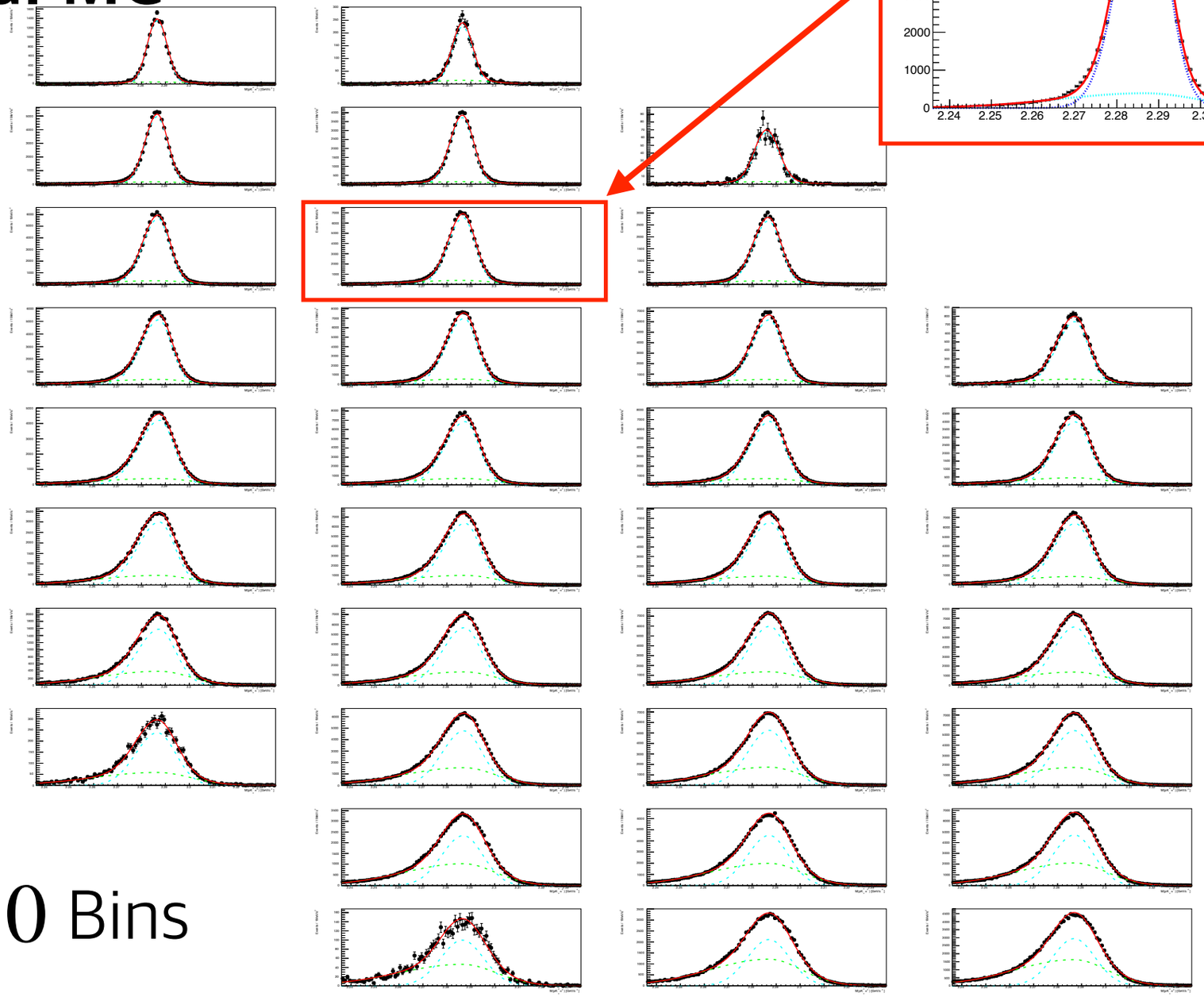
- Signal PDF : Two **A**symmetric **G**aussians :

$$h_1 \times AG(m, \sigma_{L1}, \sigma_{R1}) + h_2 \times AG(m, \sigma_{L2}, \sigma_{R2})$$

Signal PDF

signal MC



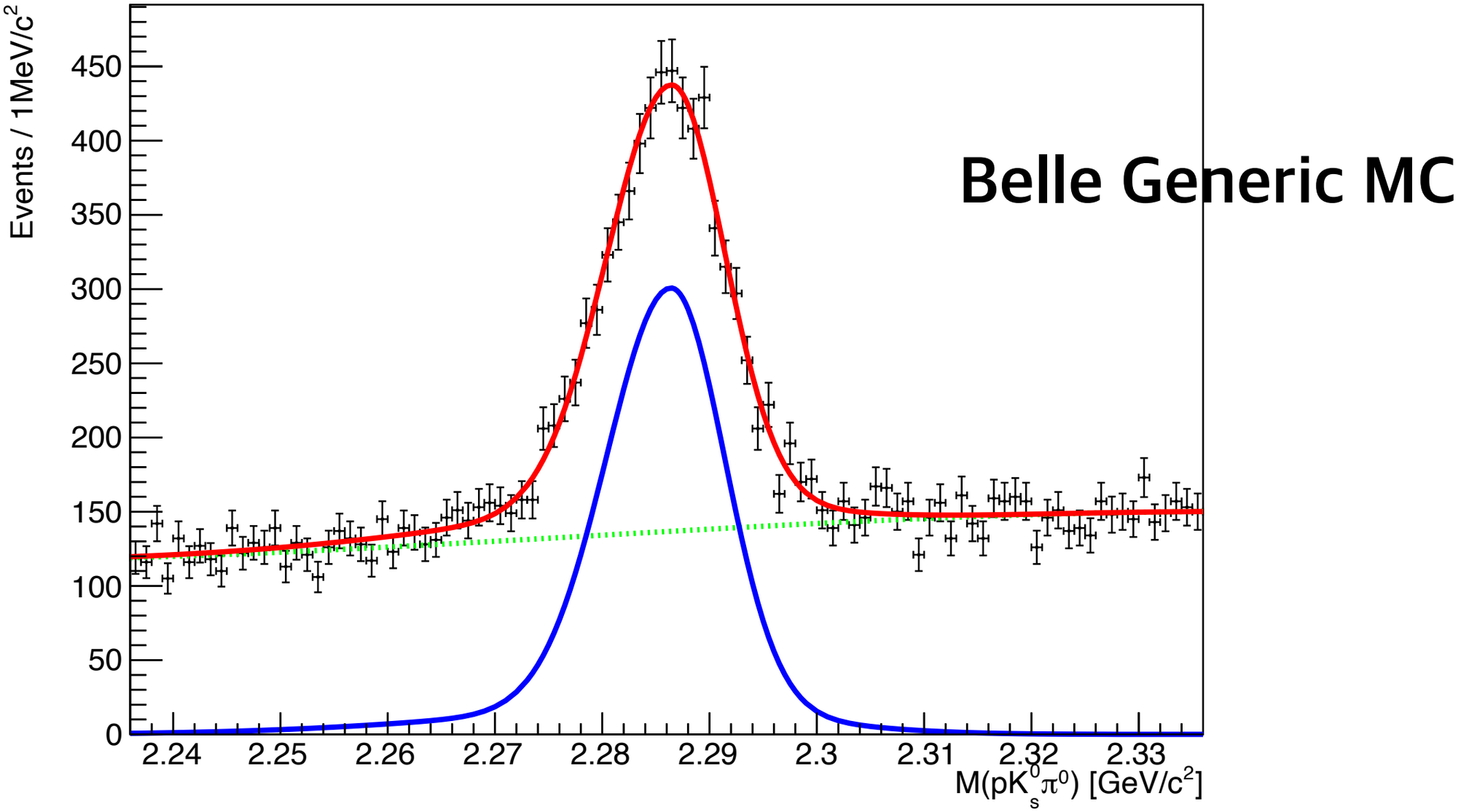


5×10 Bins

- Signal PDF : Two asymmetric Gaussians
- $h_1 \times AG(m, \sigma_{L1}, \sigma_{R1}) + h_2 \times AG(m, \sigma_{L2}, \sigma_{R2})$

h_1/h_2, σ_{R1}/σ_{L1}, σ_{R2}/σ_{L1}, σ_{L2}/σ_{L1}
→ Fixed for each Dalitz bin

Signal Yield Extraction



- Signal PDF : Two **A**symmetric **G**aussians :

$$h_1 \times AG(m, \sigma_{L1}, \sigma_{R1}) + h_2 \times AG(m, \sigma_{L2}, \sigma_{R2})$$

- Background PDF : 3rd order Chebyshev

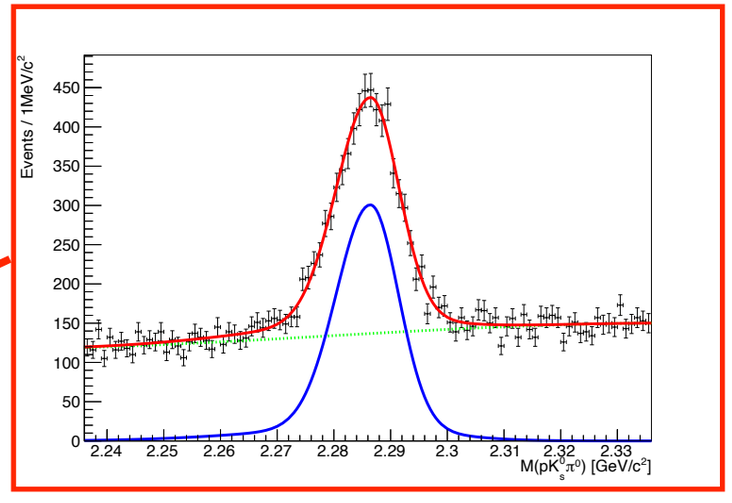
$h_1/h_2,\ \sigma_{R1}/\sigma_{L1},\ \sigma_{R2}/\sigma_{L1},\ \sigma_{L2}/\sigma_{L1} \rightarrow$ Fixed

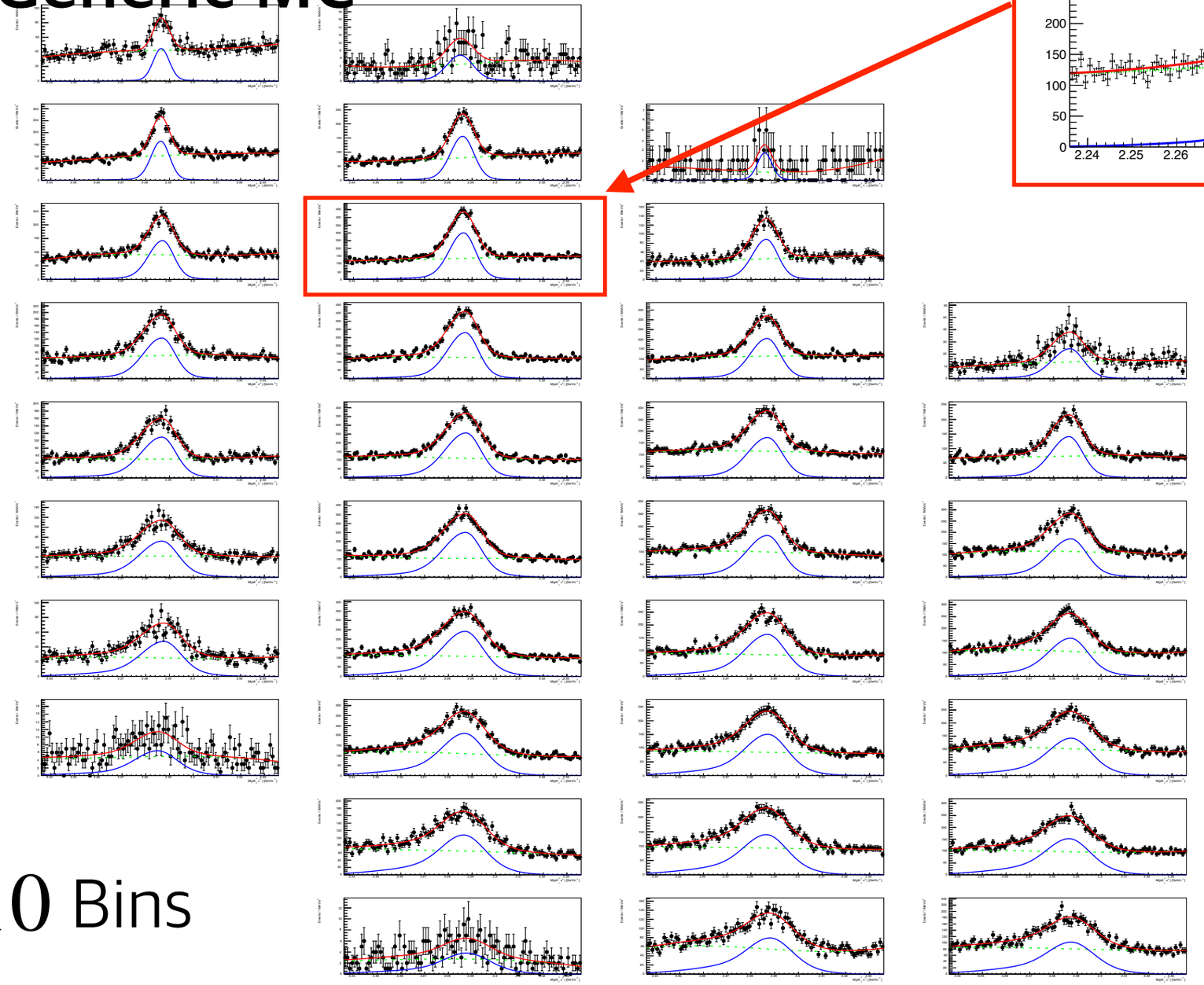
$h_1,\ \sigma_{L1},\ m$ + Chebyshev pars

$\rightarrow$ Free parameters

Signal Yield Extraction

Belle Generic MC





5×10 Bins

- Signal PDF : Two **A**symmetric **G**aussians :

$$h_1 \times AG(m, \sigma_{L1}, \sigma_{R1}) + h_2 \times AG(m, \sigma_{L2}, \sigma_{R2})$$

- Background PDF : 3rd order Chebyshev

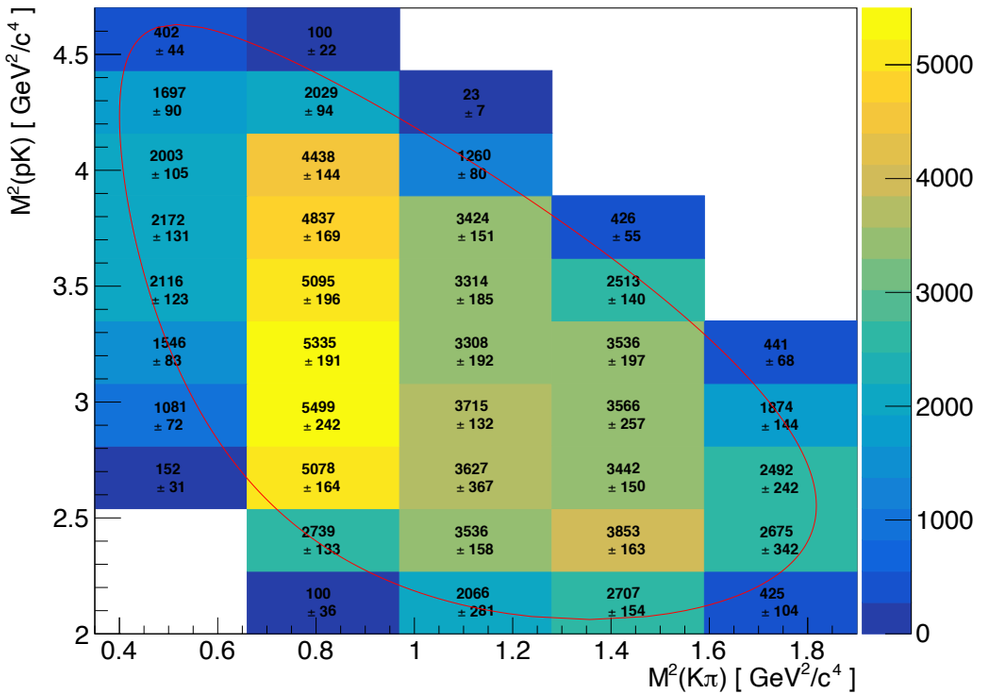
$h_1/h_2,\ \sigma_{R1}/\sigma_{L1},\ \sigma_{R2}/\sigma_{L1},\ \sigma_{L2}/\sigma_{L1} \rightarrow$ Fixed

$h_1,\ \sigma_{L1},\ m$ + Chebyshev pars

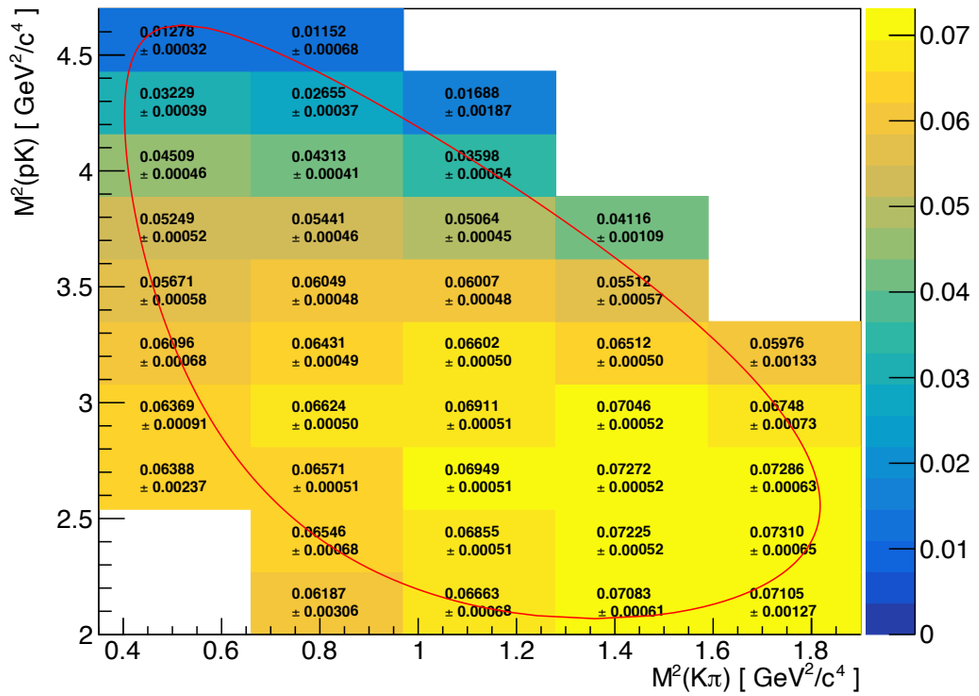
$\rightarrow$ Free parameters

Efficiency Correction

Signal Yield



Reconstruction Efficiency

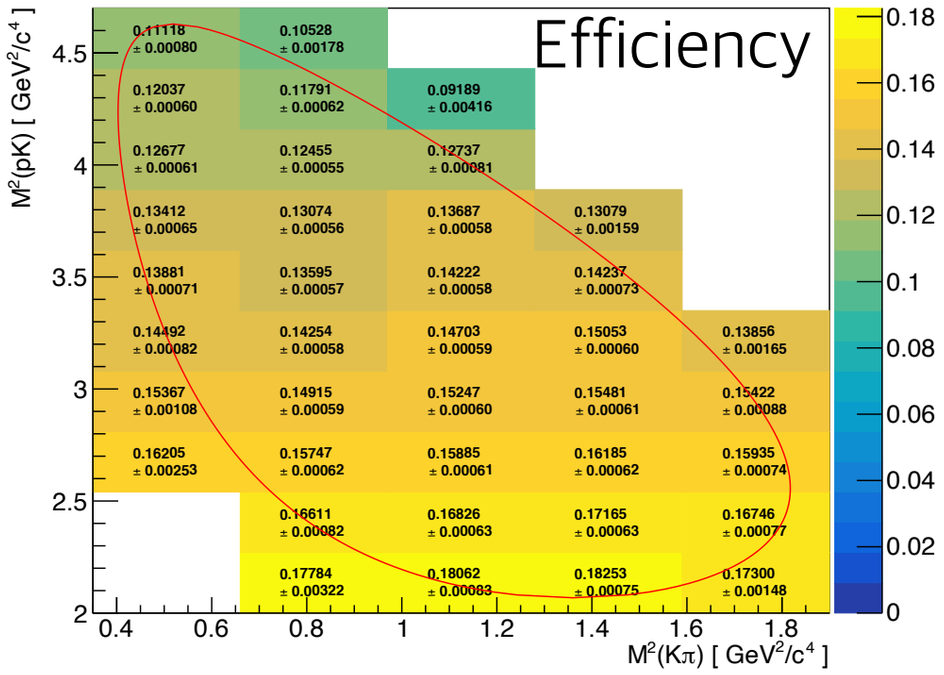


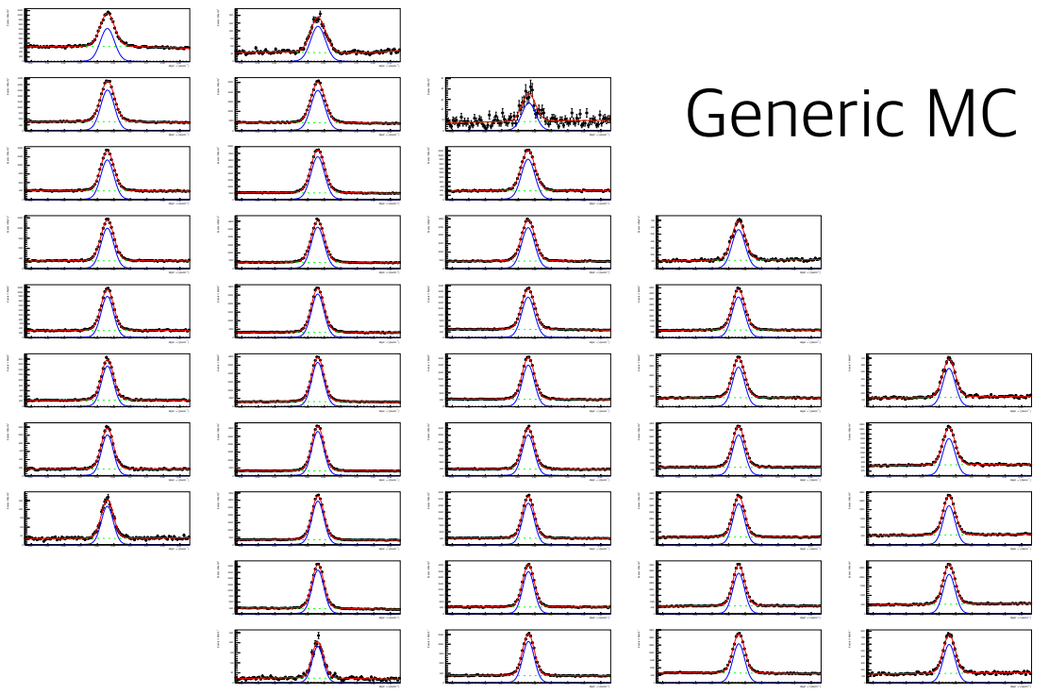
Efficiency corrected yield

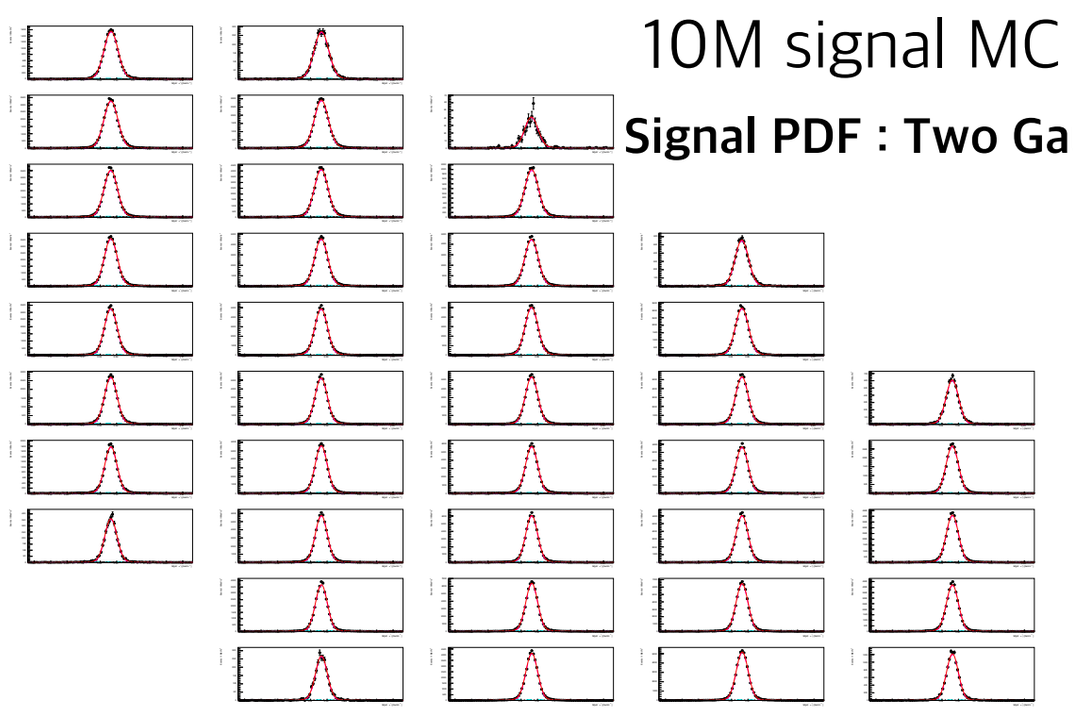
$$N = \sum_i \frac{N_i}{\epsilon_i}$$

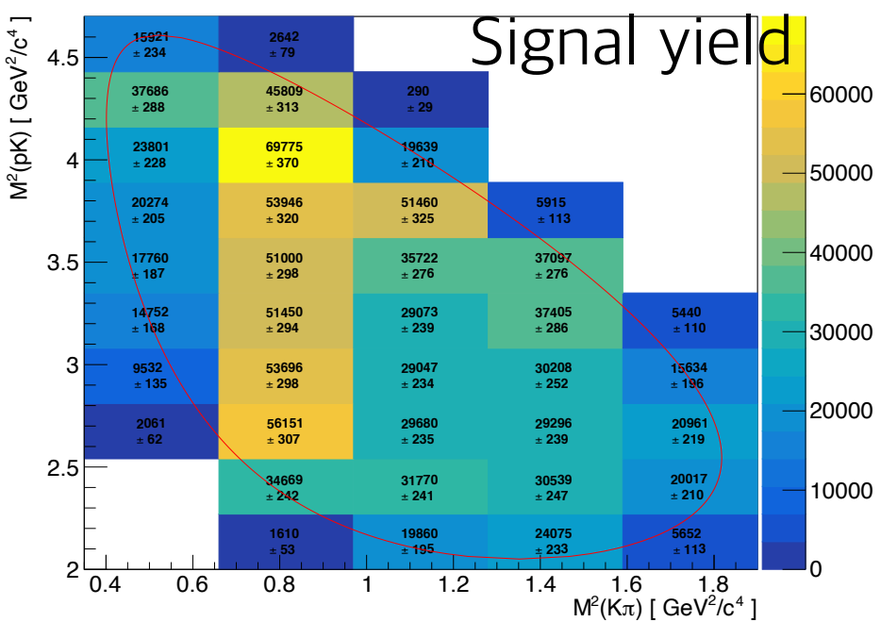
Generated signal events (Generic MC)	Efficiency corrected yield
1713618	1709117 ± 17369

$\Lambda_c^+ \to pK^-\pi^+$

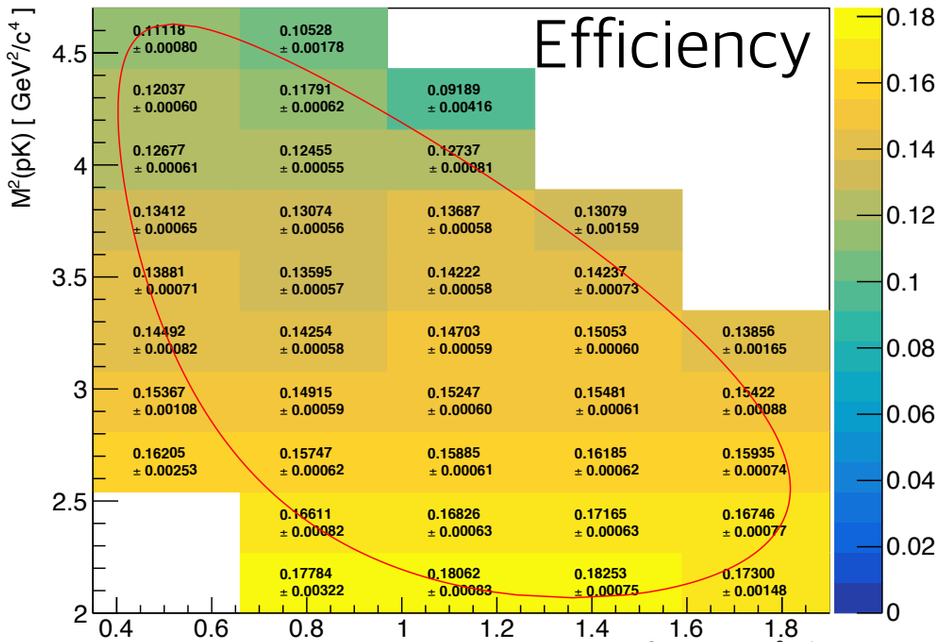


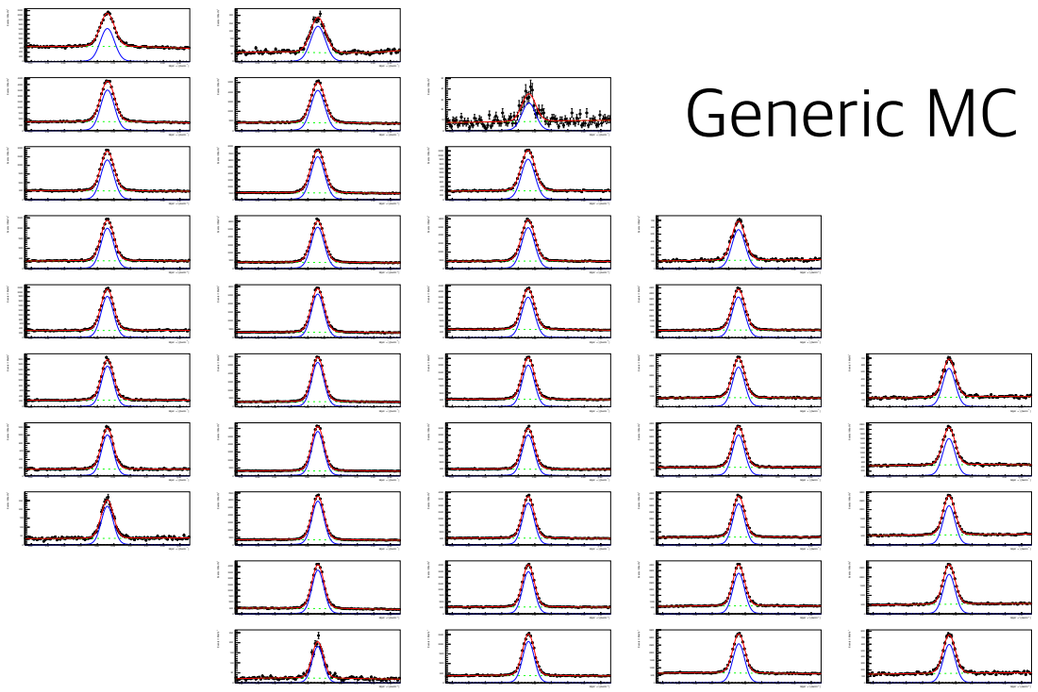


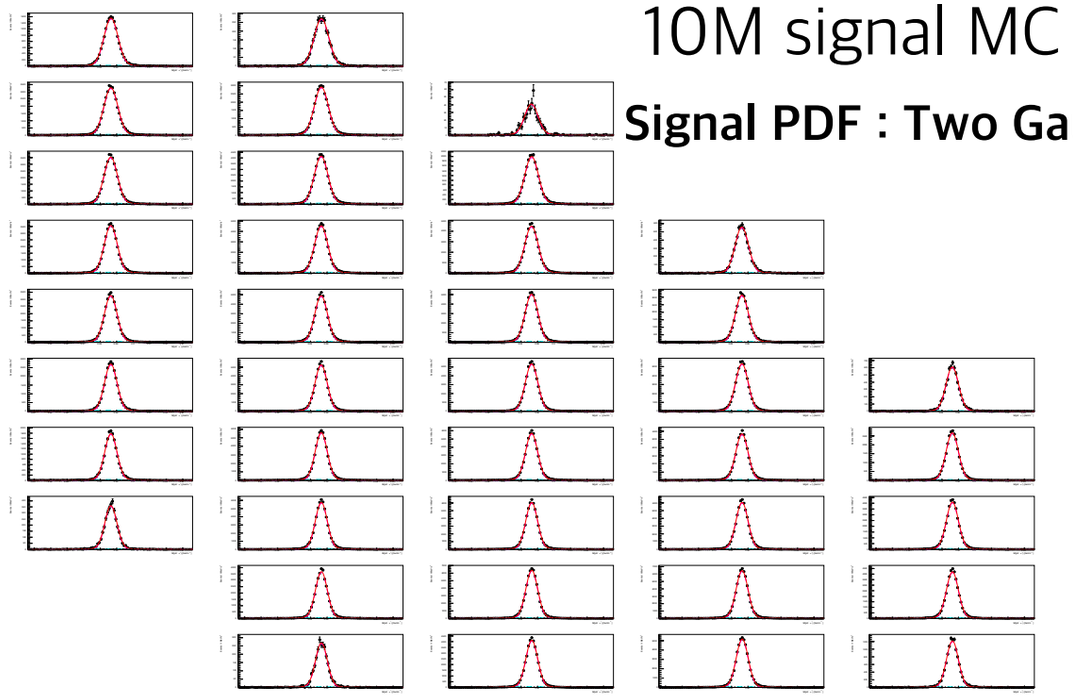


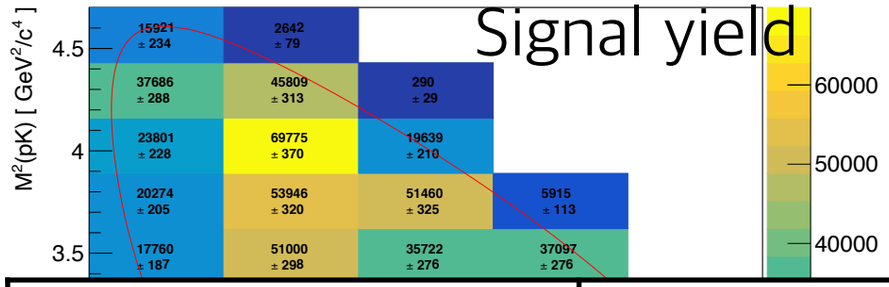


$\Lambda_c^+ \to pK^-\pi^+$









Generated signal events (Generic MC)	Efficiency corrected yield
7499353	7479512 ± 12211

Branching Ratio ($K_S \to \pi^+\pi^-$, $\pi^0 \to \gamma\gamma$)

$K_S \to \pi^+\pi^-$ (68.61%) $\pi^0 \to \gamma\gamma$ (98.799%)

	Generated signal events (Generic MC)	Efficiency corrected yield
$\Lambda_c^+ \to pK_S\pi^0$	1713618	1709117 ± 17369
$\Lambda_c^+ \to pK^-\pi^+$	7499353	7479512 ± 12211

	Event counting	Efficiency corrected yield	Difference
$\frac{\Gamma(\Lambda_c^+ \to pK_S\pi^0)}{\Gamma(\Lambda_c^+ \to pK^-\pi^+)}$	22.8502% (33.71%)	22.8506 ± 0.2352%	$4.37 \times 10^{-4} \pm 1.03\%$

Summary

- We performed MC study of $\Lambda_c^+ \to pK_S\pi^0$ channel.
  - Selection criteria optimization
  - Reconstruction efficiency
  - Validation of the branching ratio measurement
    - very small bias, 1% statistical uncertainty

- Sub-branching ratio analysis for resonances is ongoing

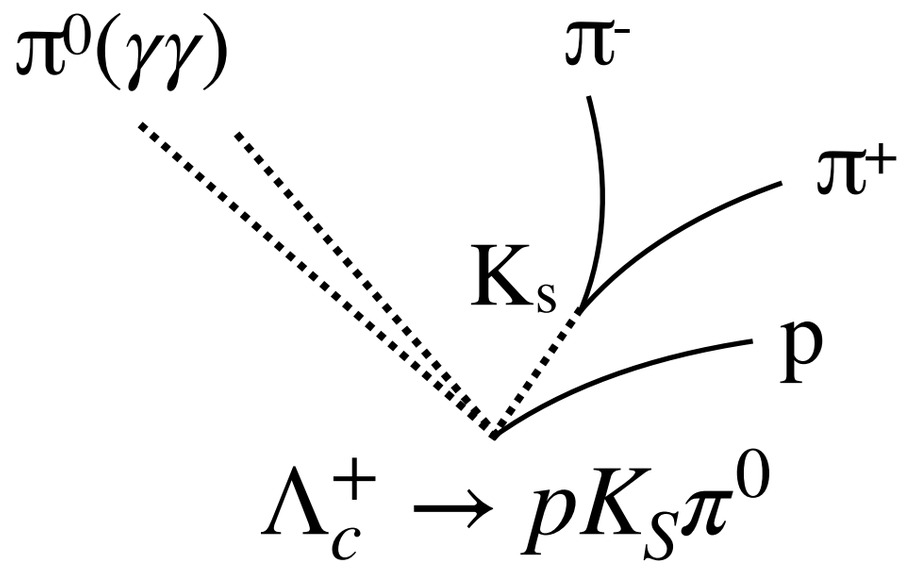
back up

Λ_c Reconstruction & Preselection

- Λ_c
  - 2.18646 < mass < 2.38646 GeV/c^2
  - x_p > 0.5
- proton
  - R(p | π) > 0.8
  - R(p | K) > 0.8
  - eid < 0.9

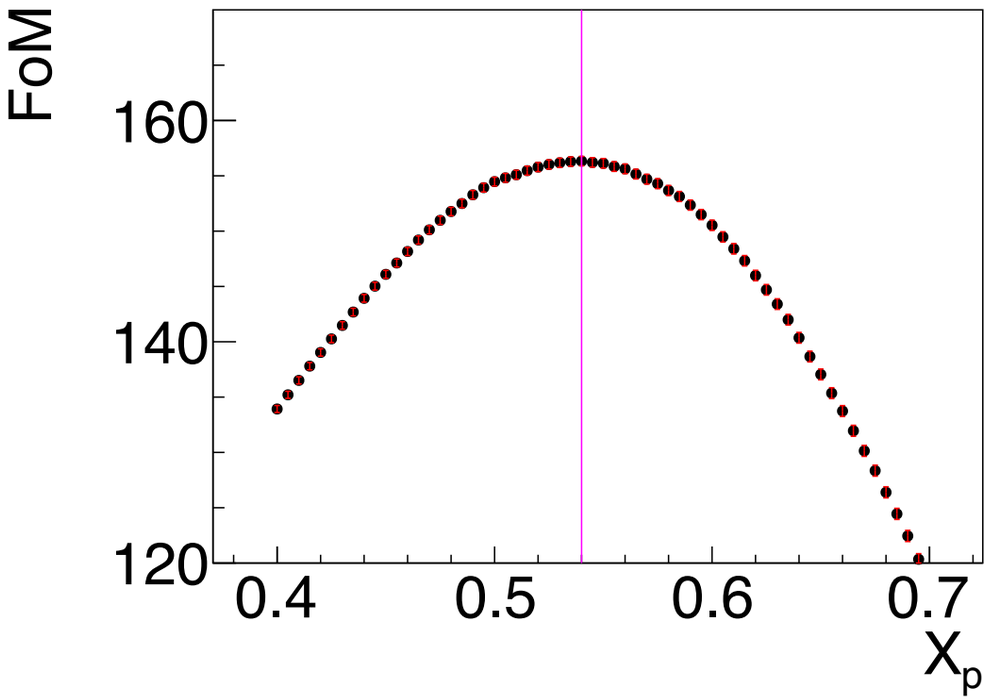
  ] PID
  - dr < 0.3 cm
  - dz < 3.0 cm
  - Number of SVD hits
    - rφ-layer > 0
    - z-layer > 0

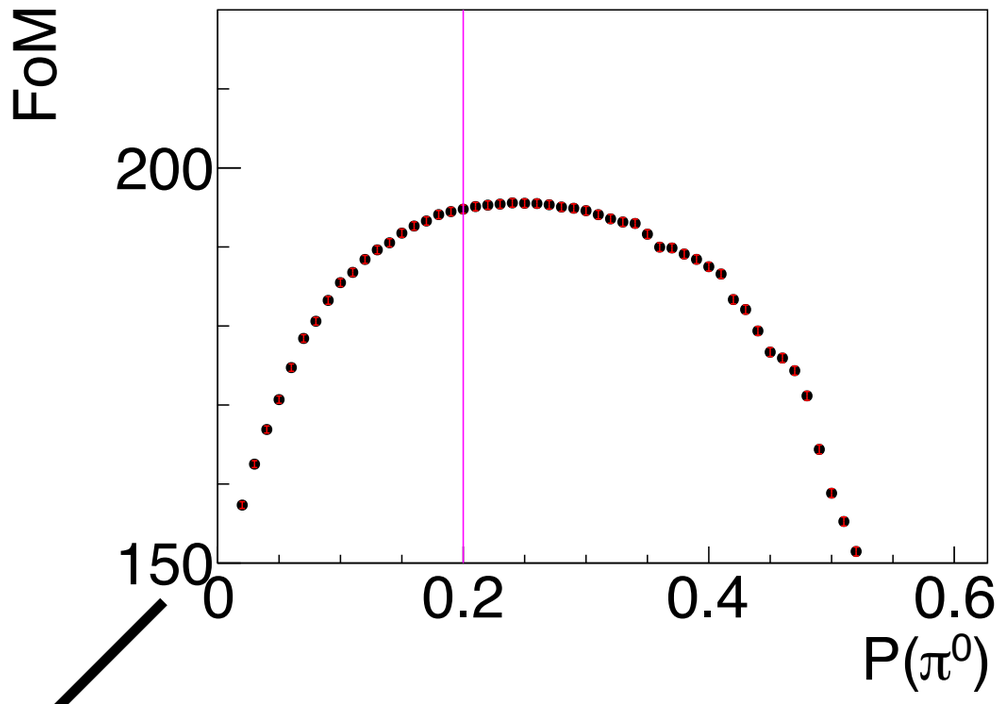
  ] Impact parameter
- π^0
  - 0.12 < mass < 0.15 GeV/c^2
  - E_γ > 50, 100MeV (Barrel, Endcap)
- K_s
  - 0.487611 < mass < 0.507611 GeV/c^2
  - R(p | π) < 0.4
  - R(K | π) < 0.4
- For Λ_c, π^0, K_s
  - kvertex fit χ2 < 40

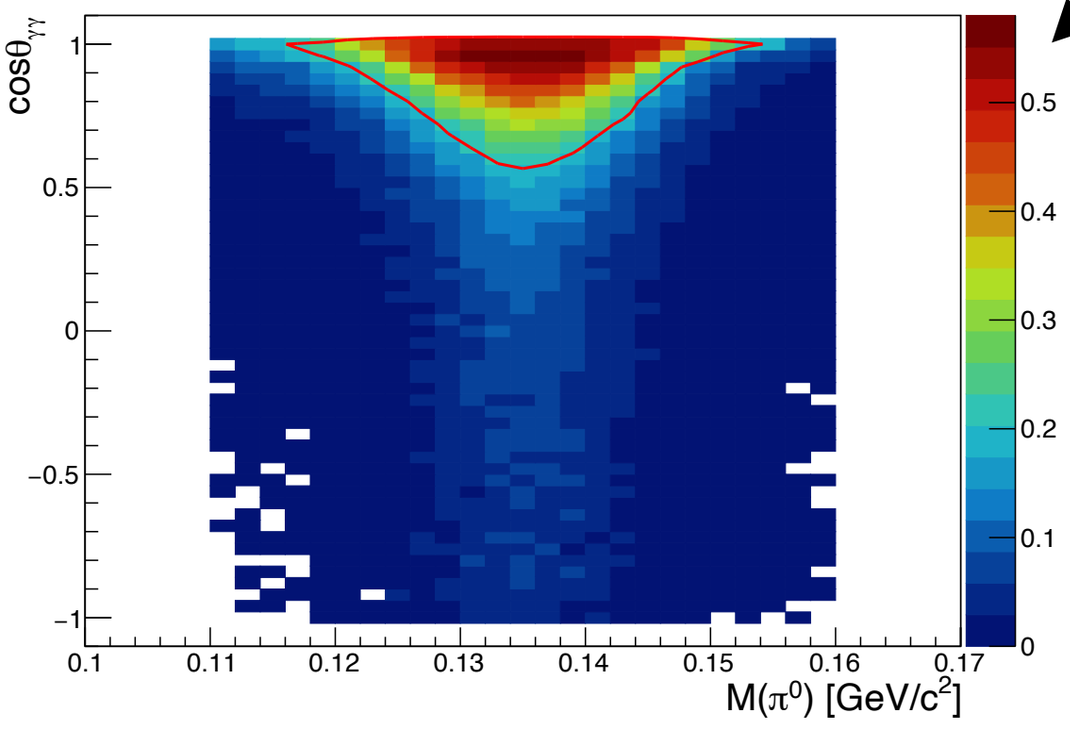


Selection Criteria Optimization

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



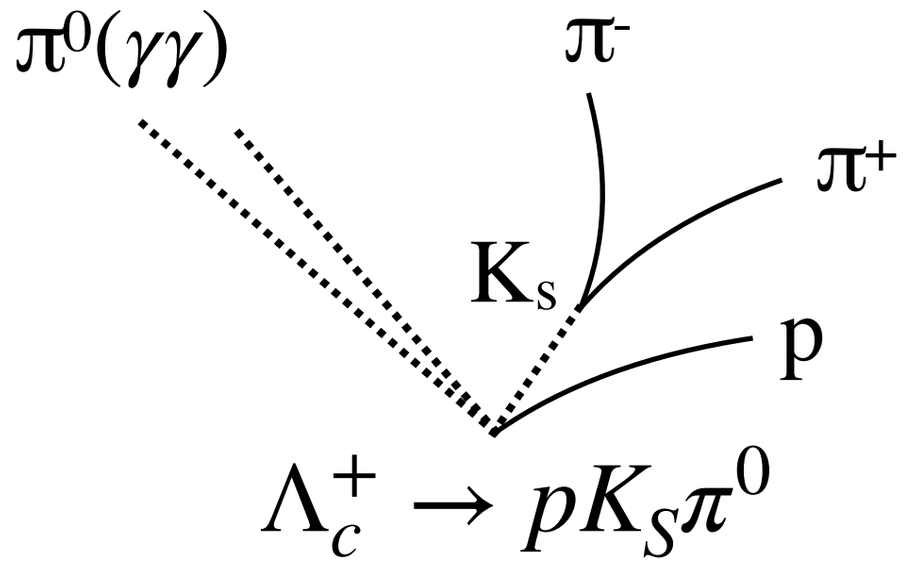




- Two dimensional cut for π^0 selection
- π^0 Probability $P(\pi^0) = \frac{S}{B}$

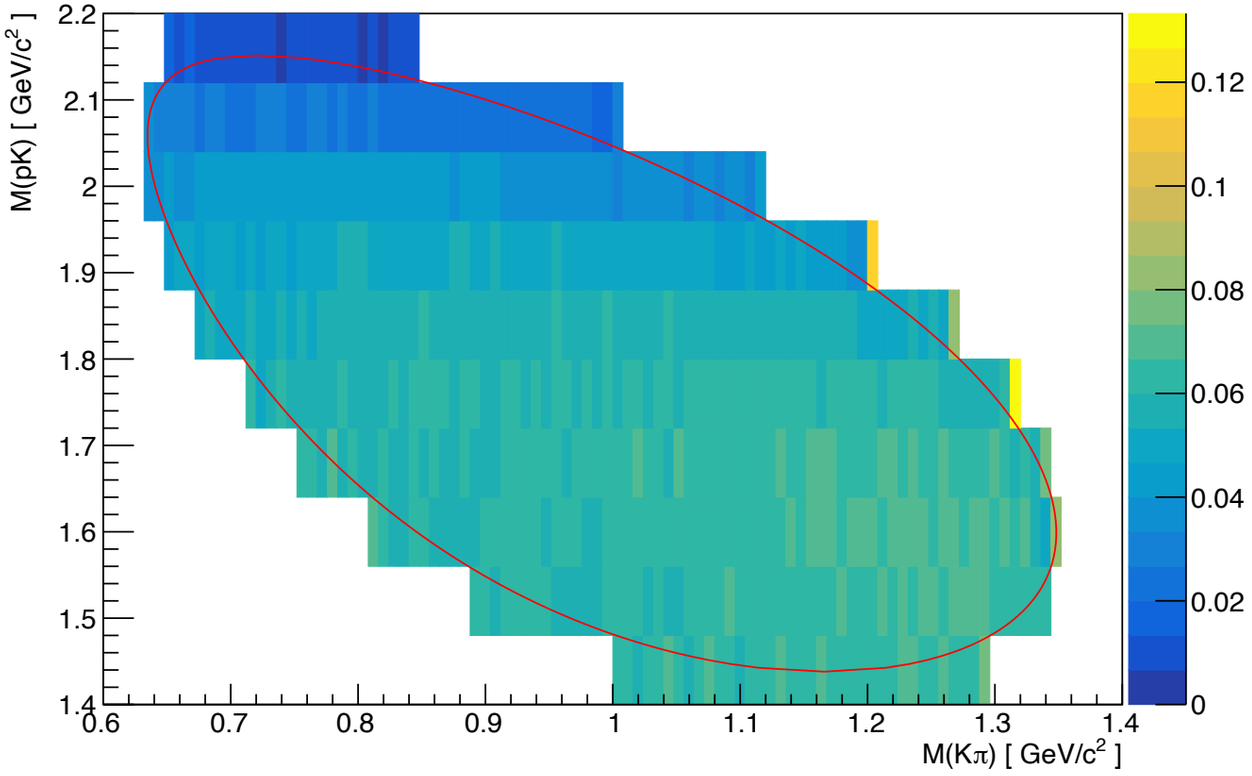
Selection Criteria Optimization

- Λ_c
  - 2.18646 < mass < 2.38646 GeV/c^2
  - x_p > 0.54
- proton
  - R(p | π) > 0.9
  - R(p | K) > 0.9
  - eid < 0.9
  - dr < 0.1 cm
  - dz < 2.0 cm
  - Number of SVD hits
    - rφ-layer > 0
    - z-layer > 0
- π^0
  - Probability > 0.2
  - E_γ > 50, 100MeV (Barrel, Endcap)
- K_s
  - nisKsFinder nb_standard = 1
- For Λ_c, K_s
  - kvertex fit χ2 < 40

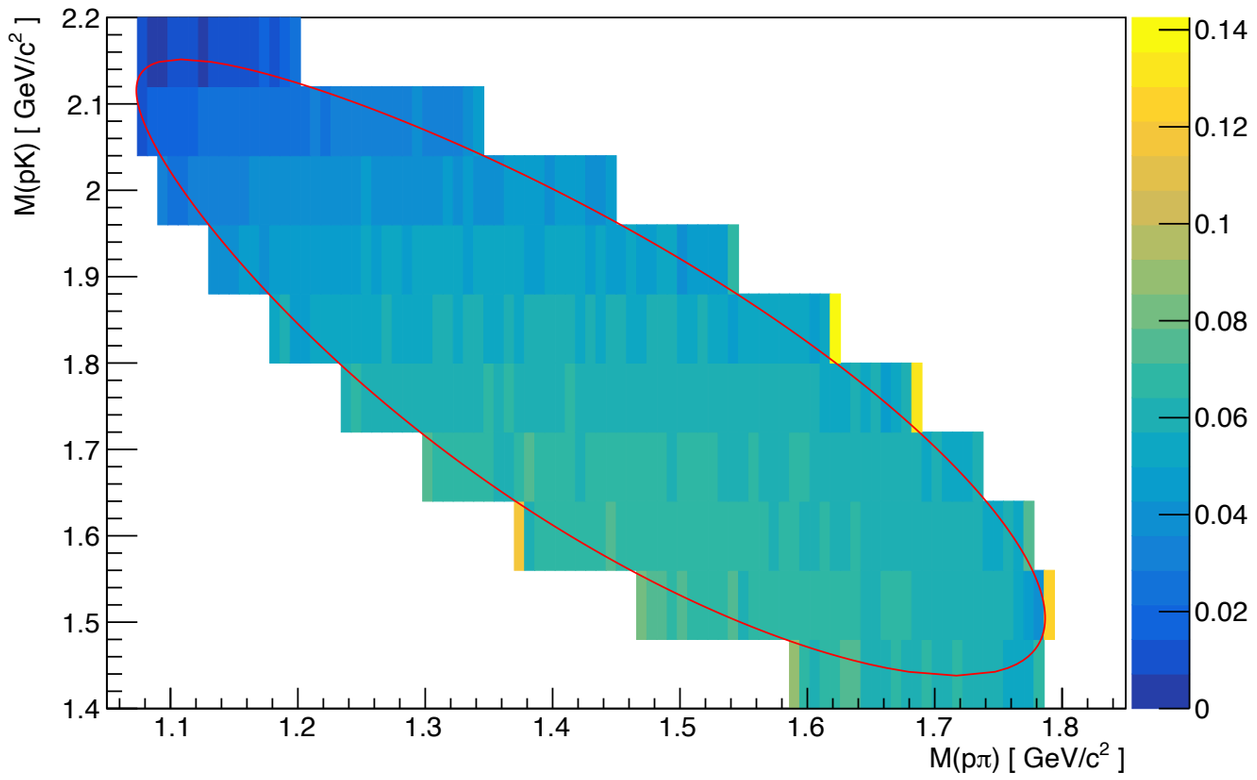


Sub-decay Channel Efficiency

Efficiency for $K_S\pi^0$ mass spectrum



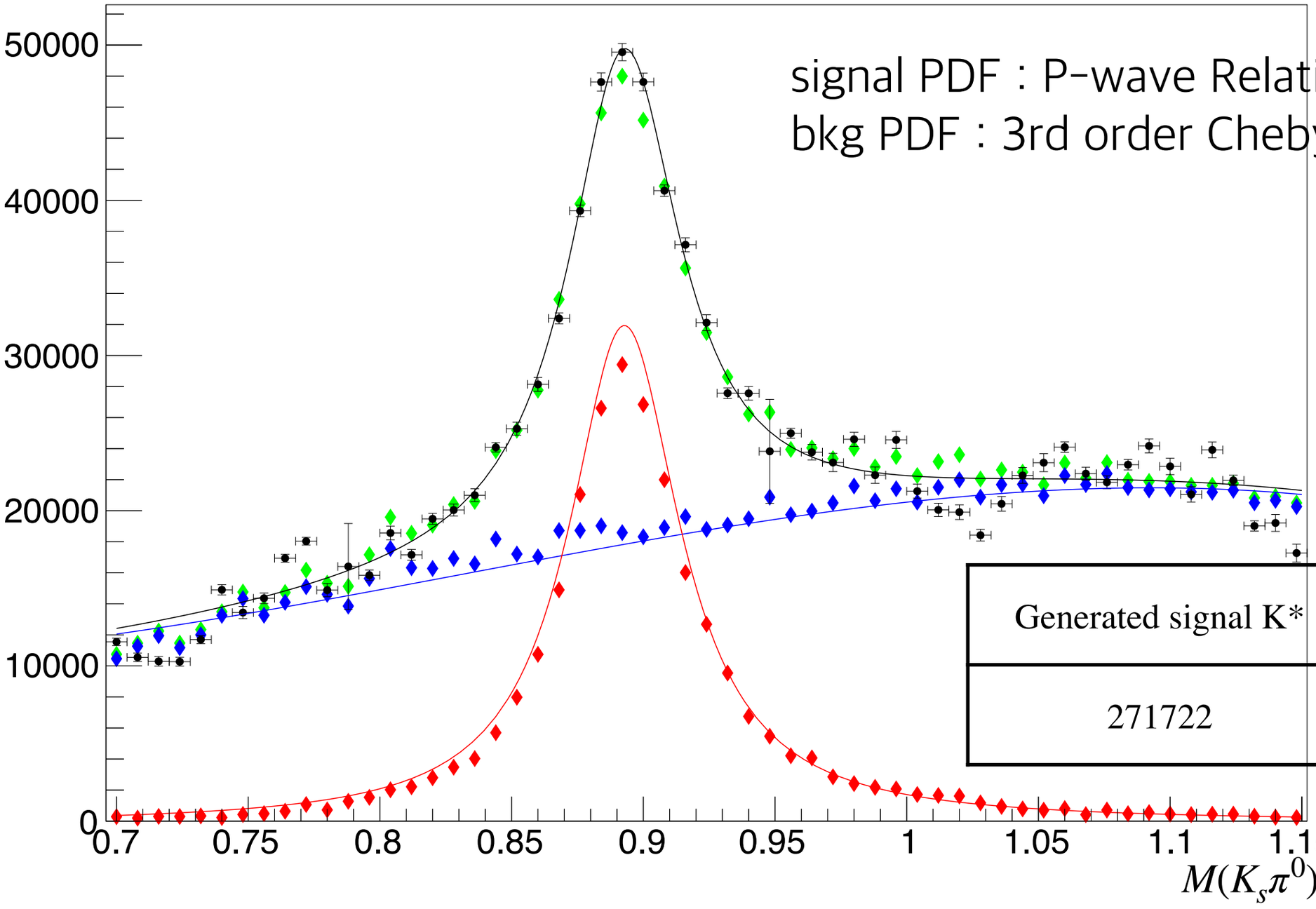
Efficiency for $p\pi^0$ mass spectrum



Efficiency correction → Λ_c yield extraction for each bin

→ Fit $M(p\pi)$ or $M(K\pi)$ with Relativistic BW + bkg PDF

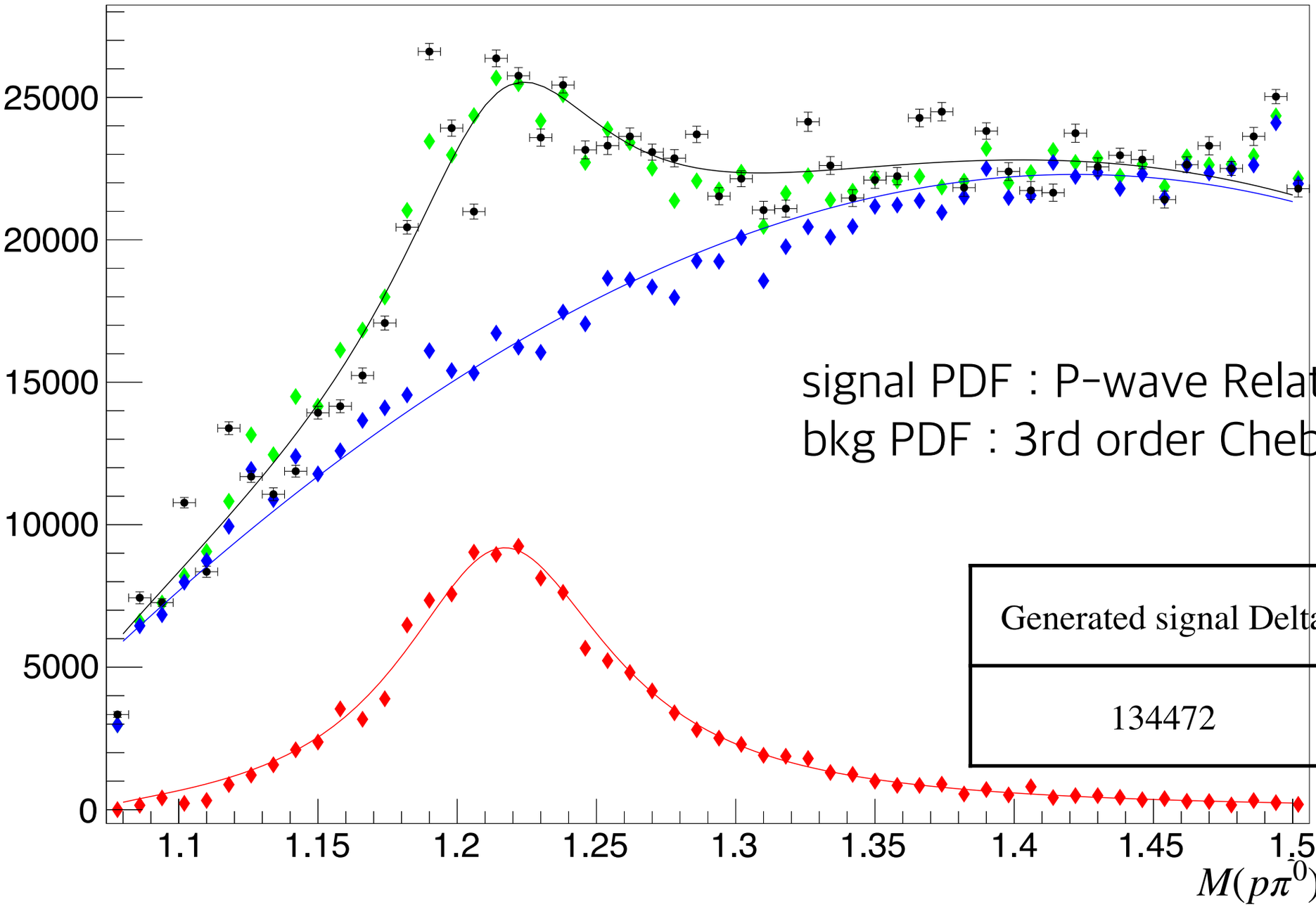
Sub-decay Channels K*



signal PDF : P-wave Relativistic Breit-Wigner
bkg PDF : 3rd order Chebyshev

Generated signal K*	Efficiency corrected yield
271722	292086 ± 1136

Sub-decay Channels Δ^+



signal PDF : P-wave Relativistic Breit-Wigner
bkg PDF : 3rd order Chebyshev

Generated signal Delta	Efficiency corrected yield
134472	137104 ± 2021