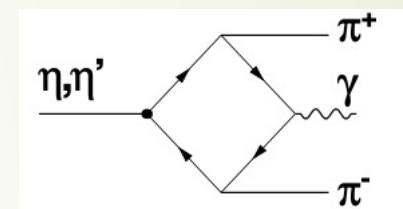# Updated Study of η' → $\gamma\pi^+\pi^-$ Decay Dynamic

Liqing Qin

06/02, 2022

Selection criteria for J/ψ → γη', η'→ γπ⁺π⁻

$E_\gamma^{CMS} = 1.4$ GeV

- Common ones for the **good charged tracks** and **good photons** candidates:
  - N_ch =2, net_ch= 0
  - Nγ ≥ 2, where the deposited energy is larger than 40 MeV for barrel rather than 25 MeV.
- PID: without any PID
- **Vertex Fit**
- **4C Kinematic Fit**
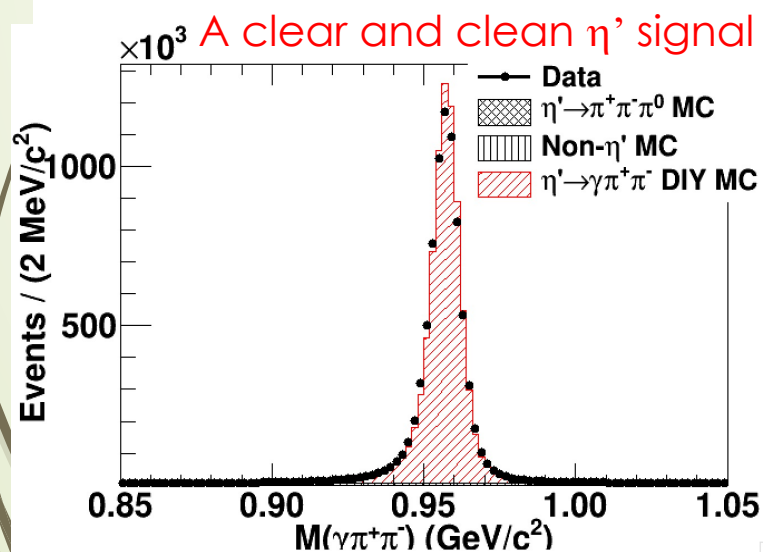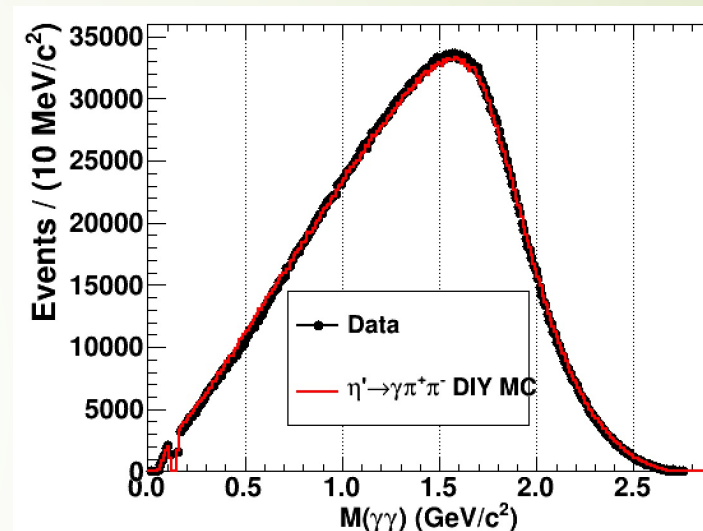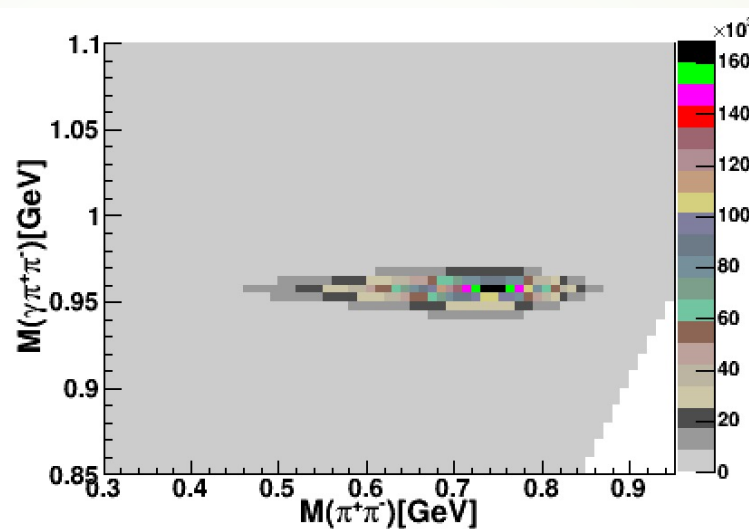 - $\chi^2(\pi^+\pi^-\gamma\gamma) < 100$
  - Photon with maximum energy is taken as the radiative one from J/ψ.
  - $\chi^2(\pi^+\pi^-\gamma\gamma) < \chi^2(\pi^+\pi^-\gamma\gamma\gamma)$

- **Veto background events with π⁰ in the final state:** J/ψ→π⁺π⁻π⁰, γπ⁺π⁻π⁰, ...
  - | M(γγ) - m_{π0} | > 20 MeV
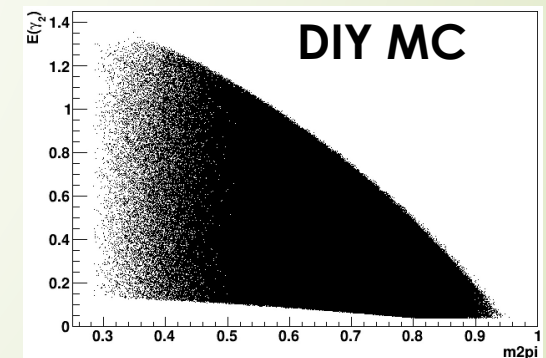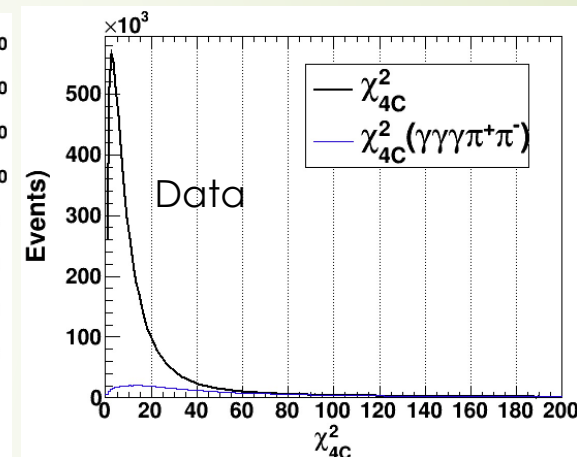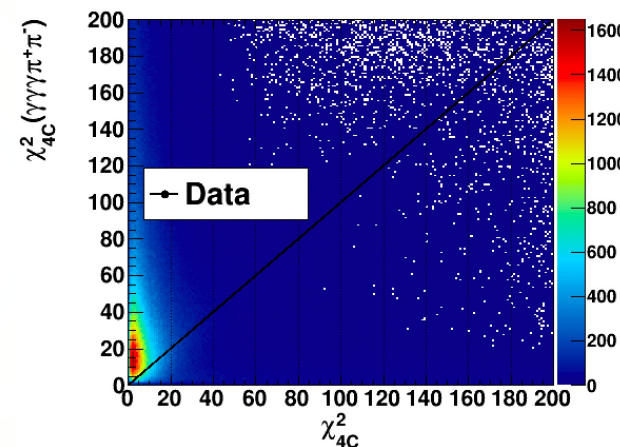
Selection criteria

Data vs DIY MC of η' → γπ⁺π⁻

A clear and clean η' signal
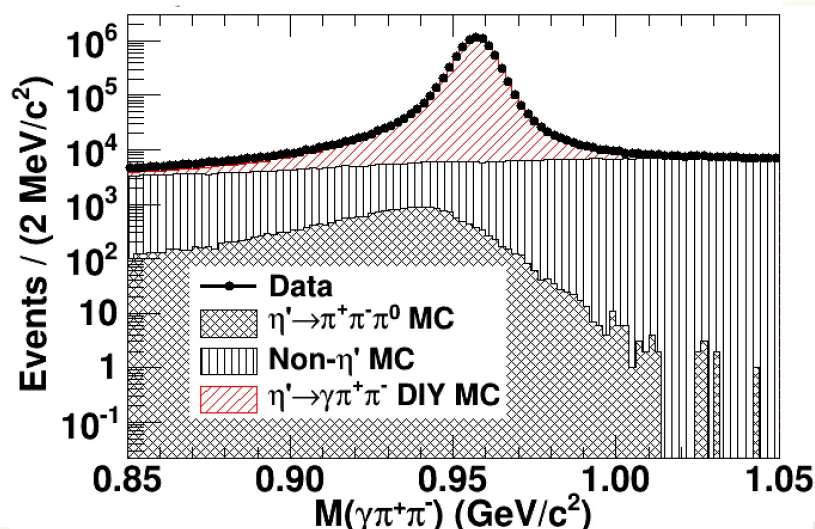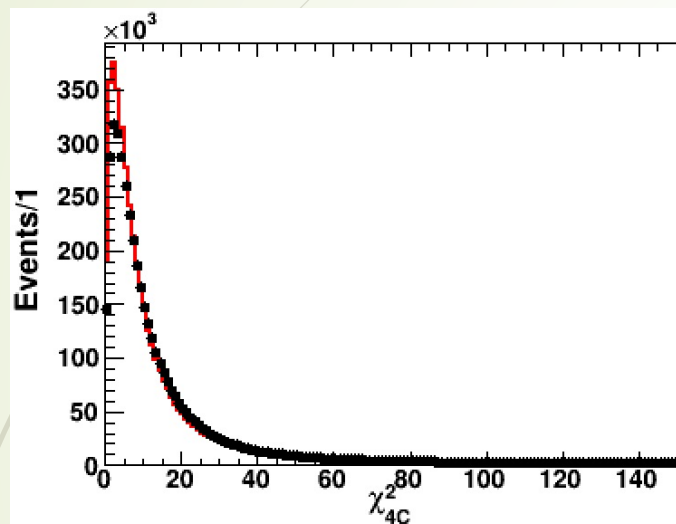
➤ **η' candidates:**

$|M(\gamma\pi^+\pi^-) - m_{\eta'}| < 20$ MeV

➤ Non- η':

40 MeV $< |M(\gamma\pi^+\pi^-) - m_{\eta'}| < 60$ MeV
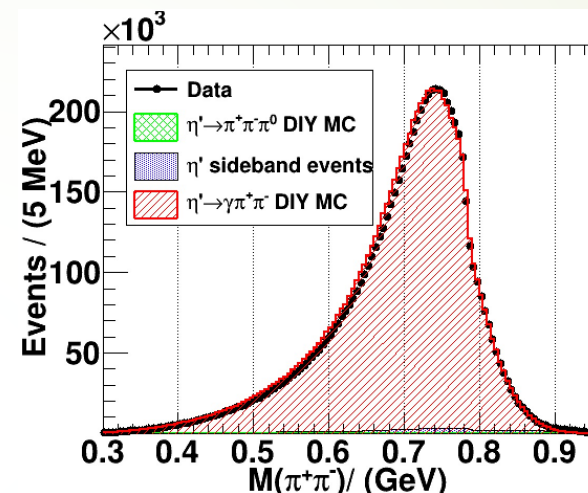
Selection criteria

- Peaking bkg: $\eta' \to \pi^+\pi^-\pi^0$

$\eta' \to \pi^+\pi^-\pi^0$	Cases	N_gen	N_ survived	ε (%)	N_normalized
09+12 DIY mc	signal region	6,200,000	274,014	4.42	1061
	sideband region		109,901	1.77	426
18+19 DIY mc	signal region	40,000,000	1,688,220	4.22	6777
	sideband region		685,091	1.71	2750
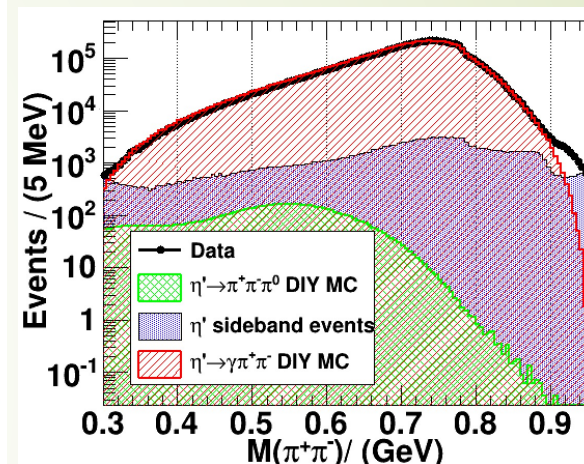
M($\pi^+\pi^-$):   non$-\eta'$ decays from inc. mc
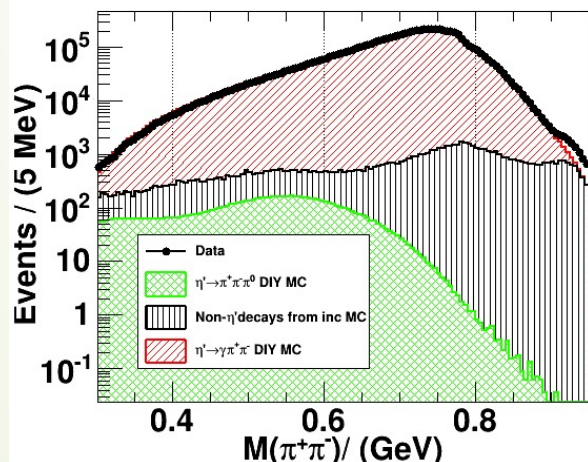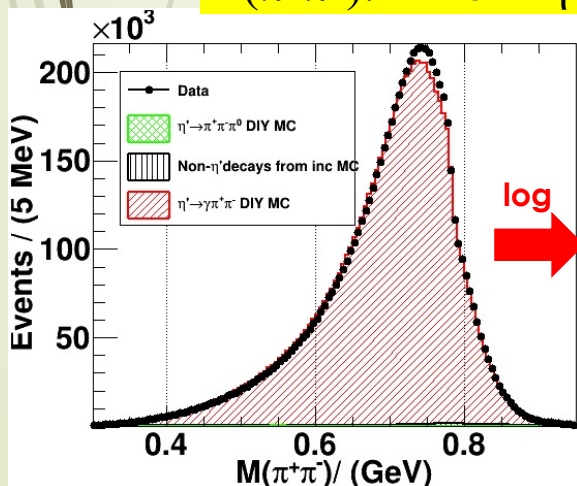
M($\pi^+\pi^-$): non$-\eta'$ decays from η'-sideband
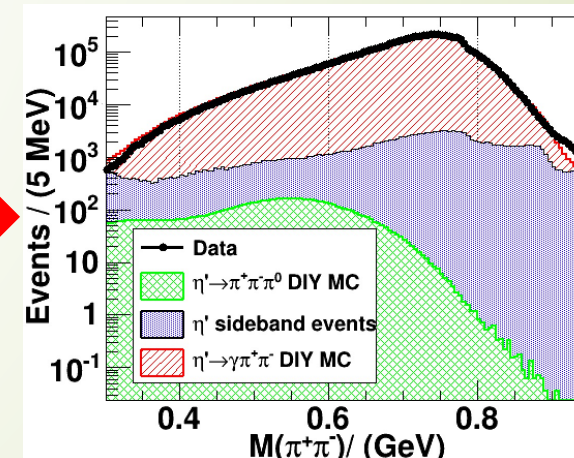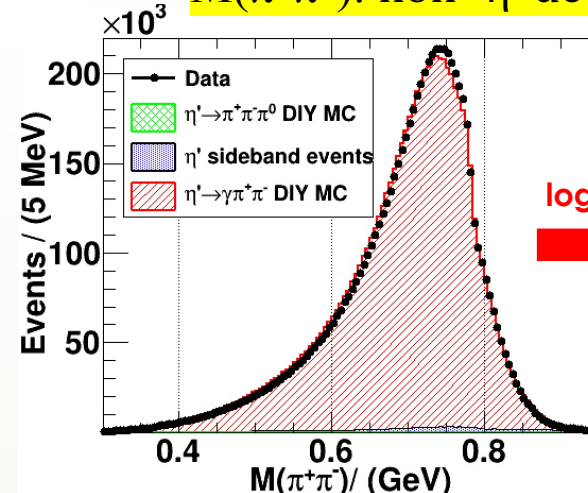
Background study with inclusive MC

Without cut: $\chi^2(\pi^+\pi^-\gamma\gamma) < \chi^2(\pi^+\pi^-\gamma\gamma\gamma)$

Table 1: Event trees and their respective initial-final states.

index	event tree (event initial-final states)	iEvtTr	iEvtIFSts	nEvts	nCmltEvts
1	$e^+e^- \to J/\psi, J/\psi \to \eta'\gamma, \eta' \to \pi^+\pi^-\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma)$	0	0	7777179	7777179
2	$e^+e^- \to J/\psi, J/\psi \to \eta'\gamma, \eta' \to \pi^+\pi^-\gamma\gamma_{FSR}$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma_{FSR})$	3	2	117891	7895070
3	$e^+e^- \to J/\psi, J/\psi \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma)$	1	0	25019	7920089
4	$e^+e^- \to J/\psi, J/\psi \to \pi^0 h_1(1170), h_1(1170) \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma\gamma)$	7	1	13696	7933785
5	$e^+e^- \to J/\psi, J/\psi \to \pi^0 h_1(1170), h_1(1170) \to \pi^-\rho^+, \rho^+ \to \pi^0\pi^+$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma\gamma)$	2	1	11085	7944870
6	$e^+e^- \to J/\psi, J/\psi \to \pi^0 h_1(1170), h_1(1170) \to \pi^+\rho^-, \rho^- \to \pi^0\pi^-$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma\gamma)$	5	1	11027	7955897
7	$e^+e^- \to J/\psi, J/\psi \to \eta'\gamma, \eta' \to \pi^0\pi^+\pi^-$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma)$	4	3	8415	7964312
8	$e^+e^- \to J/\psi, J/\psi \to \rho^0\eta, \rho^0 \to \pi^+\pi^-, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma)$	12	0	5408	7969720
9	$e^+e^- \to J/\psi, J/\psi \to e^+e^-\gamma_{FSR}\gamma_{FSR}$ $(e^+e^- \to e^+e^-\gamma_{FSR}\gamma_{FSR})$	16	7	4594	7974314
10	$e^+e^- \to J/\psi, J/\psi \to e^+e^-\gamma_{FSR}$ $(e^+e^- \to e^+e^-\gamma_{FSR})$	25	11	4185	7978499
11	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\omega, \omega \to \pi^0\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma)$	15	3	3388	7981887
12	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\eta\gamma, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma)$	9	3	2725	7984612
13	$e^+e^- \to J/\psi, J/\psi \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-\gamma_{FSR}$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma_{FSR})$	17	2	2475	7987087
14	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma)$	18	0	2454	7989541
15	$e^+e^- \to J/\psi, J/\psi \to \eta_c\gamma, \eta_c \to \pi^0\pi^+\pi^-$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma)$	34	3	2093	7991634
16	$e^+e^- \to J/\psi, J/\psi \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma)$	23	3	1629	7993263
17	$e^+e^- \to J/\psi, J/\psi \to e^+e^-$ $(e^+e^- \to e^+e^-)$	13	5	1243	7994506

Background level: 1.51%

where the ratio of peaking bkg η' → $\pi^+\pi^-\pi^0$: ~0.1% (7.0%)

Background study with inclusive MC

With cut: $\chi^2(\pi^+\pi^- \gamma\gamma) < \chi^2(\pi^+\pi^- \gamma\gamma\gamma)$

| index	event tree (event initial-final states)	iEvtTr	iEvtIFSts	nEvts	nCmltEvts
1	$e^+e^- \to J/\psi, J/\psi \to \eta'\gamma, \eta' \to \pi^+\pi^-\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma)$	0	0	7604955	7604955
2	$e^+e^- \to J/\psi, J/\psi \to \eta'\gamma, \eta' \to \pi^+\pi^-\gamma\gamma_{FSR}$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma_{FSR})$	4	3	91480	7696435
3	$e^+e^- \to J/\psi, J/\psi \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma)$	1	0	23565	7720000
4	$e^+e^- \to J/\psi, J/\psi \to \rho^0\eta, \rho^0 \to \pi^+\pi^-, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma)$	8	0	5338	7725338
5	$e^+e^- \to J/\psi, J/\psi \to e^+e^-\gamma_{FSR}\gamma_{FSR}$ $(e^+e^- \to e^+e^-\gamma_{FSR}\gamma_{FSR})$	10	5	4403	7729741
6	$e^+e^- \to J/\psi, J/\psi \to e^+e^-\gamma_{FSR}$ $(e^+e^- \to e^+e^-\gamma_{FSR})$	16	7	4118	7733859
7	$e^+e^- \to J/\psi, J/\psi \to \eta'\gamma, \eta' \to \pi^0\pi^+\pi^-$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma)$	2	1	3460	7737319
8	$e^+e^- \to J/\psi, J/\psi \to \pi^0 h_1(1170), h_1(1170) \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma\gamma)$	5	2	2980	7740299
9	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma)$	11	0	2422	7742721
10	$e^+e^- \to J/\psi, J/\psi \to \pi^0 h_1(1170), h_1(1170) \to \pi^+\rho^-, \rho^- \to \pi^0\pi^-$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma\gamma)$	3	2	2187	7744908
11	$e^+e^- \to J/\psi, J/\psi \to \pi^0 h_1(1170), h_1(1170) \to \pi^-\rho^+, \rho^+ \to \pi^0\pi^+$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma\gamma)$	19	2	2091	7746999
12	$e^+e^- \to J/\psi, J/\psi \to e^+e^-$ $(e^+e^- \to e^+e^-)$	9	4	1224	7748223
13	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\omega, \omega \to \pi^0\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma)$	24	1	1046	7749269
14	$e^+e^- \to J/\psi, J/\psi \to \pi^+\pi^-\eta\gamma, \eta \to \gamma\gamma$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma)$	7	1	997	7750266
15	$e^+e^- \to J/\psi, J/\psi \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-\gamma_{FSR}$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma\gamma_{FSR})$	14	3	958	7751224
16	$e^+e^- \to J/\psi, J/\psi \to \eta\omega, \eta \to \gamma\gamma, \omega \to \pi^+\pi^-$ $(e^+e^- \to \pi^+\pi^-\gamma\gamma)$	13	0	855	7752079
17	$e^+e^- \to J/\psi, J/\psi \to \eta'\gamma, \eta' \to \mu^+\mu^-\gamma$ $(e^+e^- \to \mu^+\mu^-\gamma\gamma)$	32	12	807	7752886

Background level: 0.87%

where the ratio of peaking bkg $\eta' \to \pi^+\pi^-\pi^0$: ~0.045% (5.1%)

Efficiency loss: ~ 2.65%
Veto background: ~44.2%

Corrections for the dipion mass spectrum

- M($\pi^+\pi^-$)–dependent **detection efficiency**, **mass resolution**, and the **mass shift**
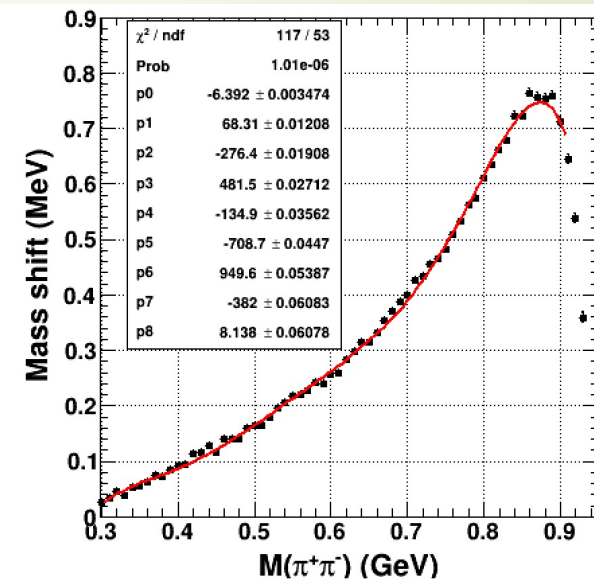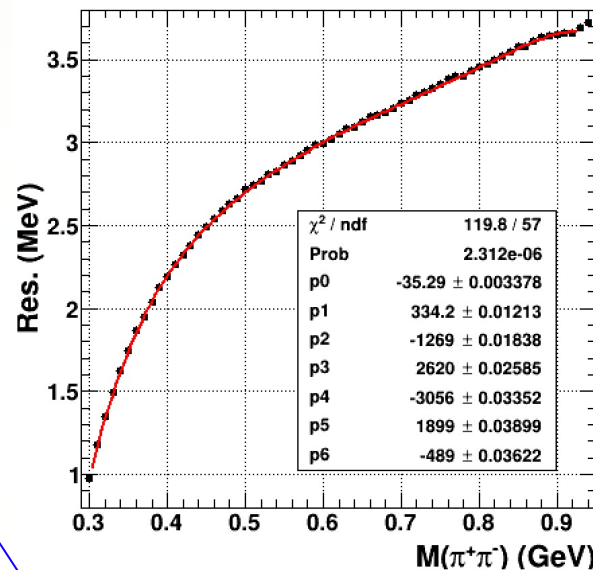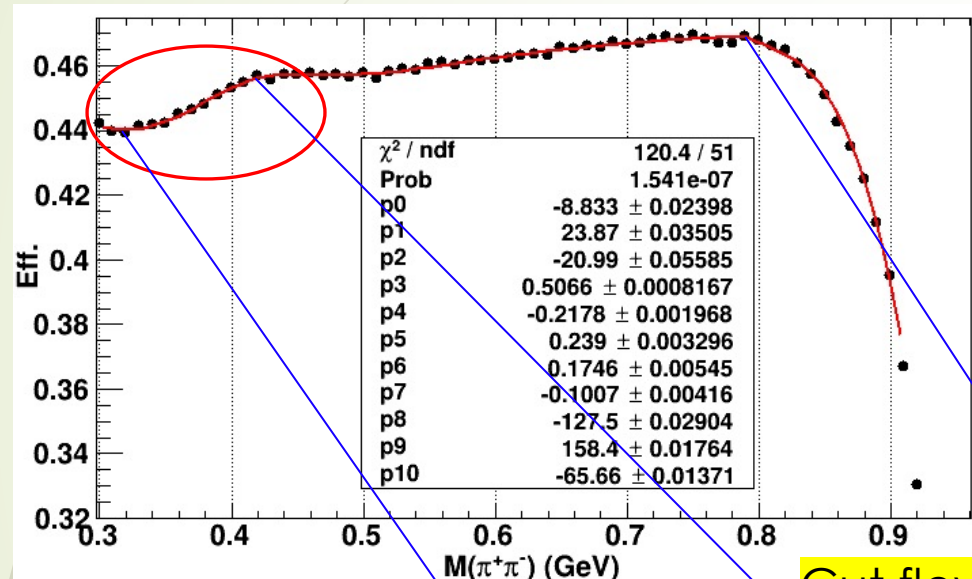

Cut flow

cuts	ε of M($\pi^+\pi^-$) bin at 0.32 GeV	ε of M($\pi^+\pi^-$) bin at 0.42 GeV	ε of M($\pi^+\pi^-$) bin at 0.79 GeV	ε of M($\pi^+\pi^-$) bin at 0.90 GeV
after pre-sel.	47.53%	49.50%	50.97%	47.93%
|M($\gamma\gamma$) - m$_{\pi0}$| > 20 MeV	99.57%	99.66%	99.45%	99.64%
E$_{\gamma2}$ > 40 MeV	99.97%	99.97%	99.64%	89.77%
$\chi^2(\pi^+\pi^-\gamma\gamma)$ < 100	97.89%	97.71%	96.93%	95.64%
|M($\gamma\pi^+\pi^-$) − m$_{\eta'}$| < 20 MeV	94.90%	94.86%	95.83%	96.35%
$\chi^2(\pi^+\pi^-\gamma\gamma)$ < $\chi^2(\pi^+\pi^-\gamma\gamma\gamma)$	97.69%	97.59%	97.66%	98.00%

M($\pi^+\pi^-$) bin at 0.90 GeV
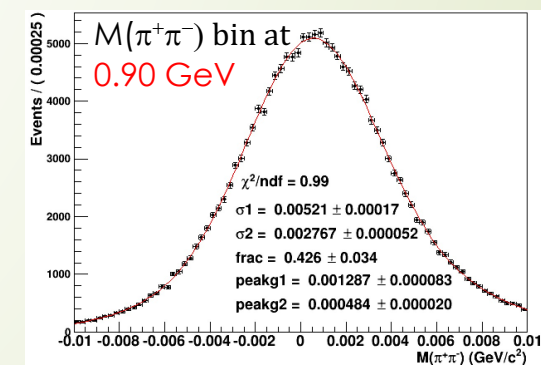
A Further Check on The Corrections

➡ M($\pi^+\pi^-$)–dependent **mass resolution**, and the **mass shift,** where the M($\pi^+\pi^-$) is reconstructed with info. before 4C-kinematic fit.
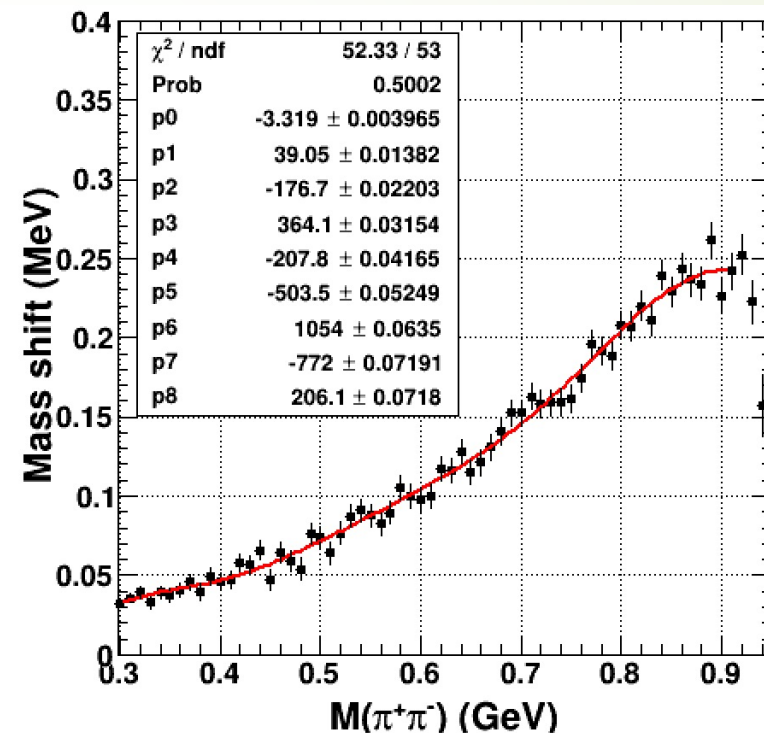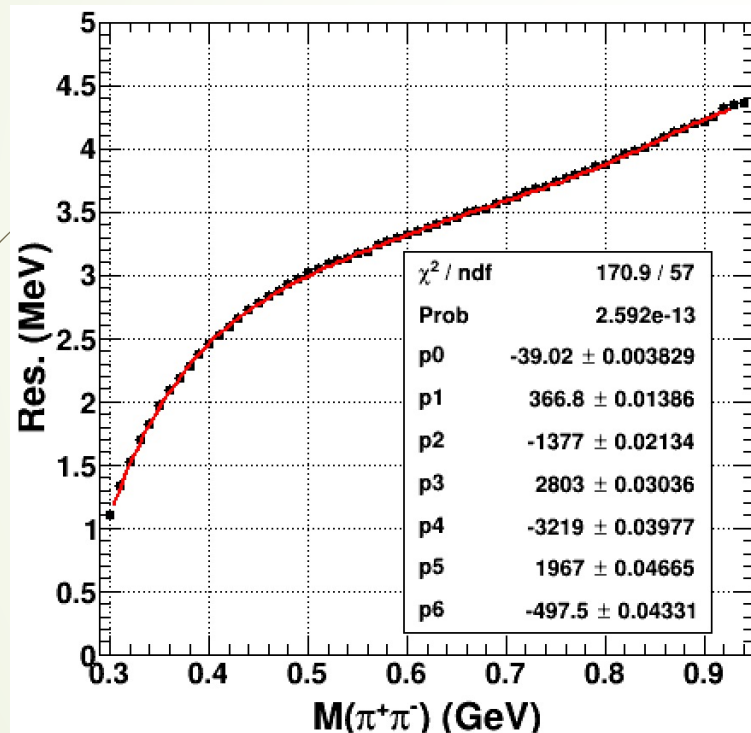
==Similar line-shape as those obtained after 4C-kinematic fit==

➡ with 4c-fit: Res. is improved, while the mass shift is getting larger.

Momentum of π^+ vs π^-

reconstructed after 4C fit

M($\pi^+\pi^-$) bin at 300MeV M($\pi^+\pi^-$) bin at 320MeV M($\pi^+\pi^-$) bin at 420MeV M($\pi^+\pi^-$) bin at 520MeV M($\pi^+\pi^-$) bin at 790MeV M($\pi^+\pi^-$) bin at 900MeV
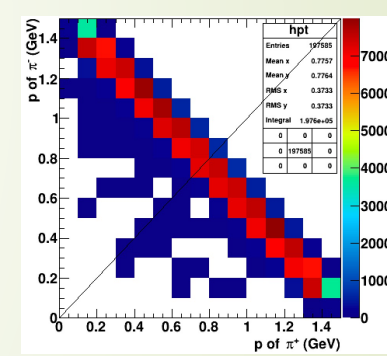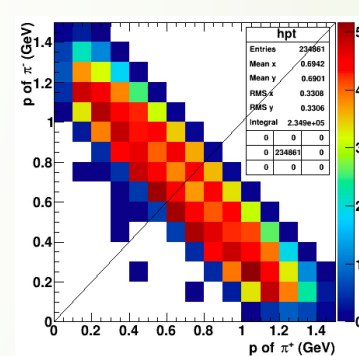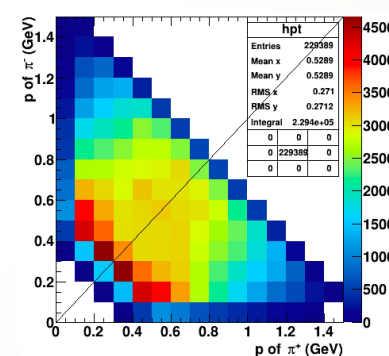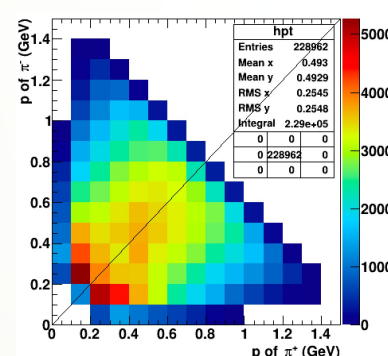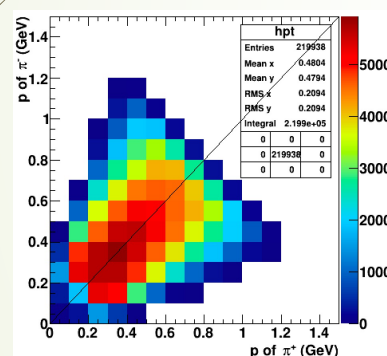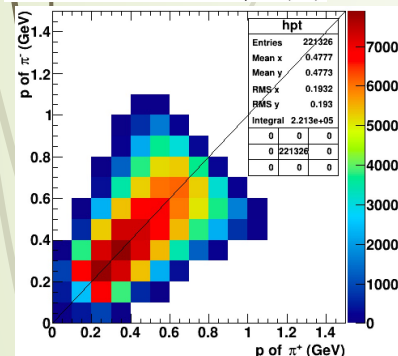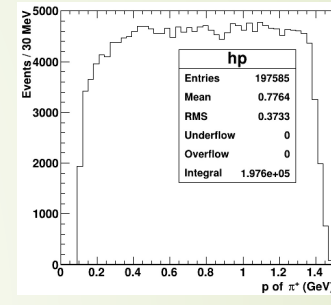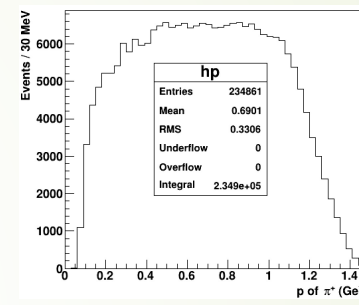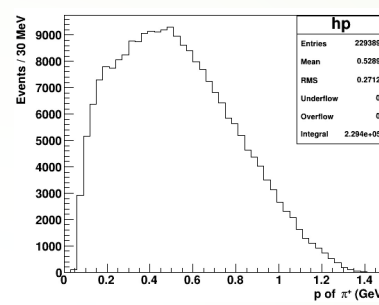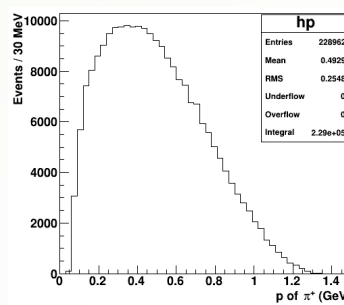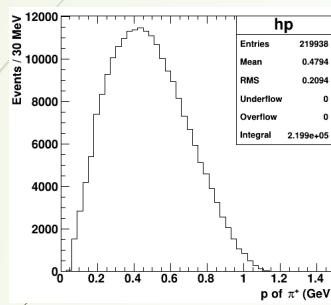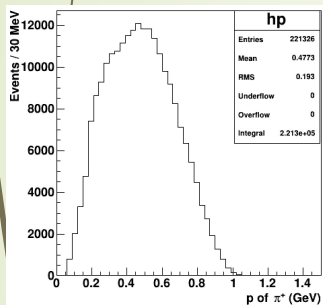
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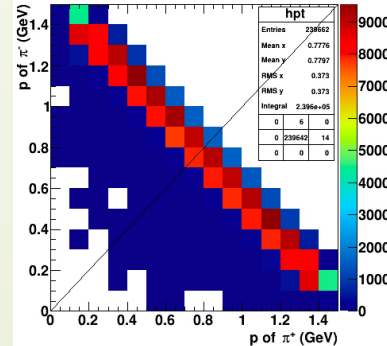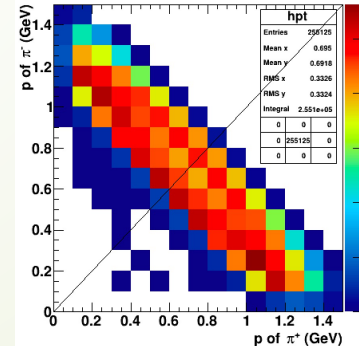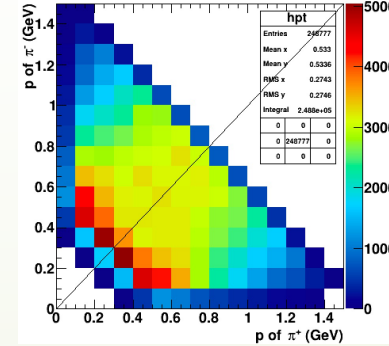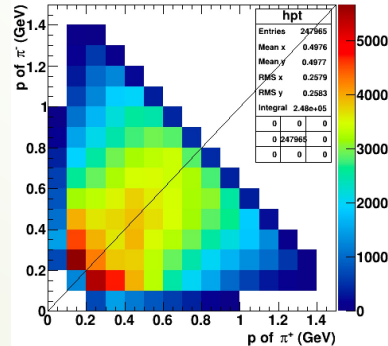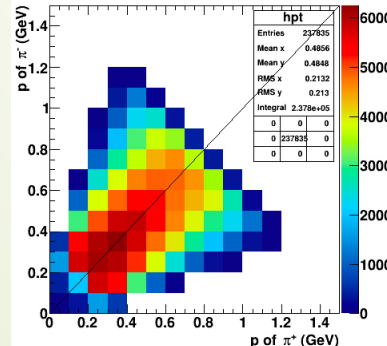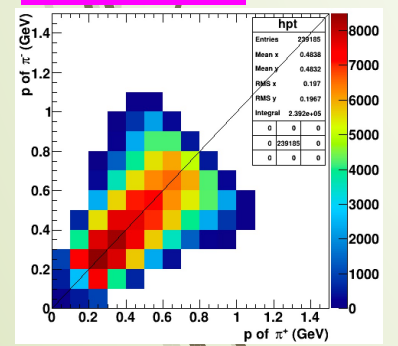
Model-dependent study

- Differential rate $[d\Gamma/dM(\pi^+\pi^-)] = [k_\gamma^3 q_\pi^3(s)/48\pi^3]|\mathcal{A}|^2,\;\; k_\gamma = (m_{\eta'}^2 - s)/(2m_{\eta'}),\; q_\pi(s) = \sqrt{s - 4m_\pi^2}/2$

- Decay amplitude:

$$\mathcal{A} = \frac{BW_\rho^{\mathrm{GS}}(s)\left(1 + \delta\frac{s}{M_\omega^2}BW_\omega(s)\right) + \beta BW_{\rho'}^{\mathrm{GS}}(s)}{1 + \beta}$$

$$\times 2\sqrt{48\pi M_\rho^{-4}} + \alpha,$$

δ, β are complex parameters.

α: a constant accounting for the box anomaly.

- The PDF is constructed to be: $PDF(m) = \sigma_{\mathrm{res}}(m) \otimes \left(\epsilon(m) \times \frac{d\Gamma}{dm}\right) + BKG(m)$

Model-dependent study

ρ⁰-ω-box anomaly

ρ⁰-ω-ρ(1450)

With cut: $\chi^2(\pi^+\pi^-\gamma\gamma) < \chi^2(\pi^+\pi^-\gamma\gamma\gamma)$

$\chi^2/ndf=9.8$

$\chi^2/ndf=5.2$

$\chi^2/ndf=18$

$\chi^2/ndf=10$

log

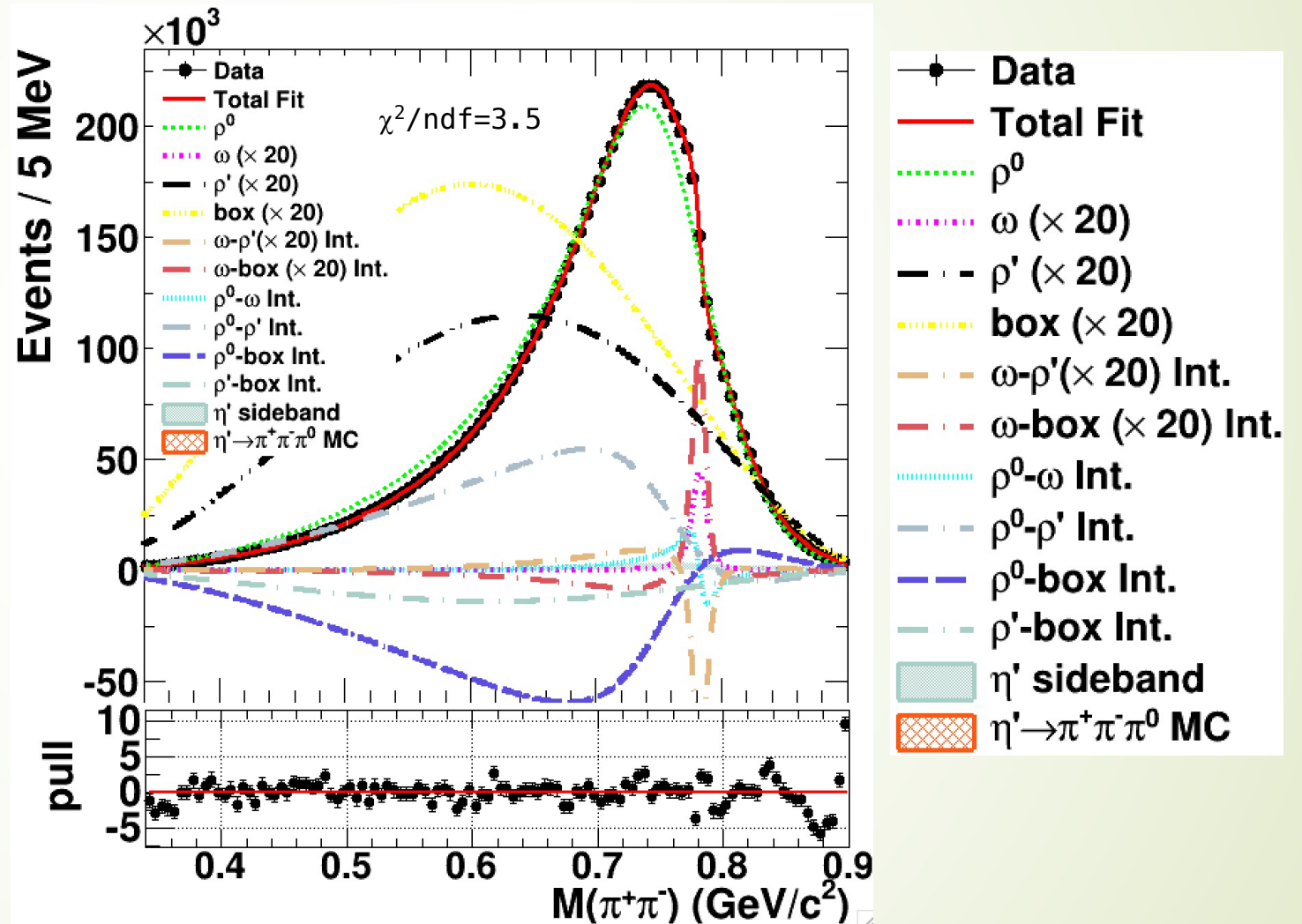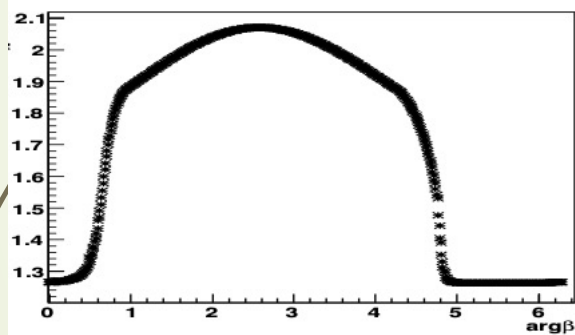PRL120, 242003

PRL120, 242003

$\chi^2/ndf=1.9$

$\chi^2/ndf=2.8$
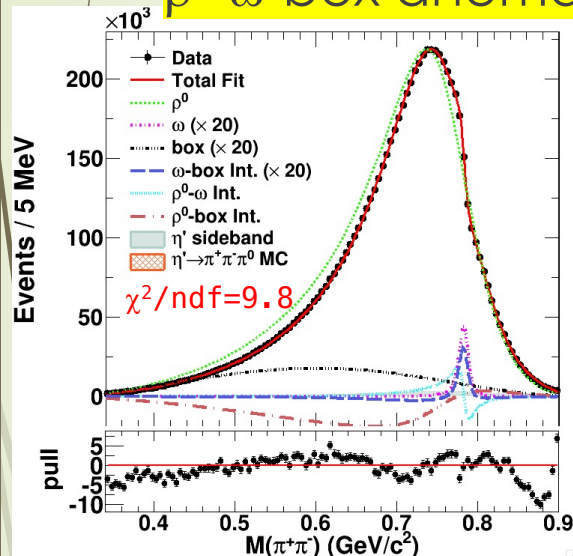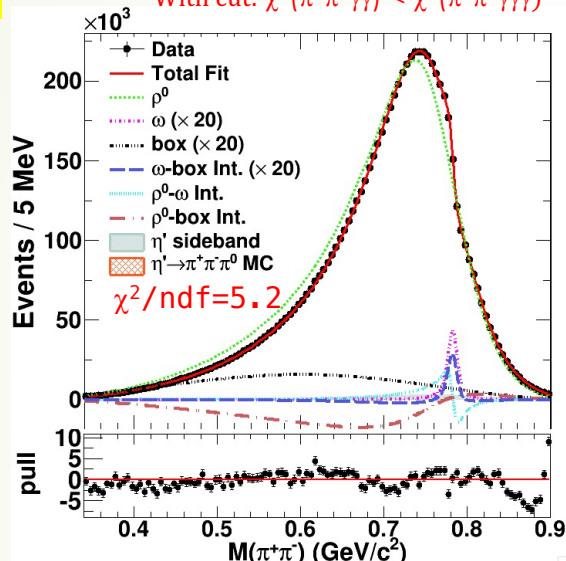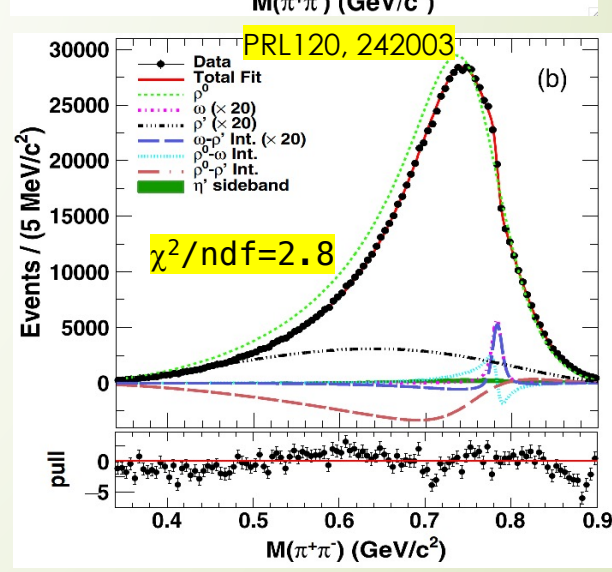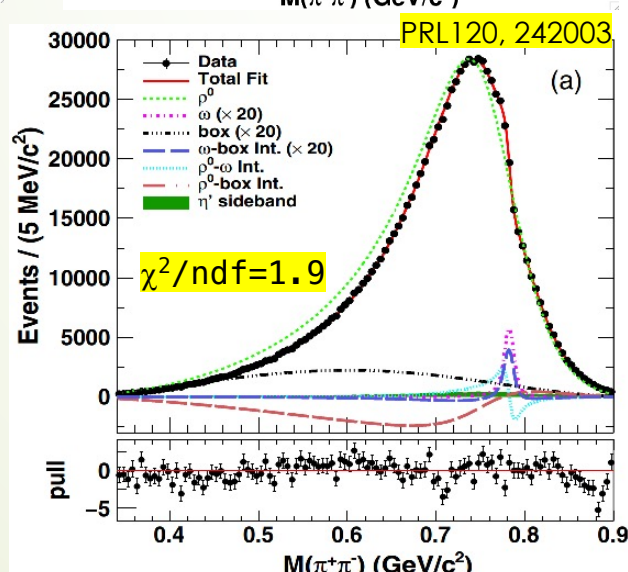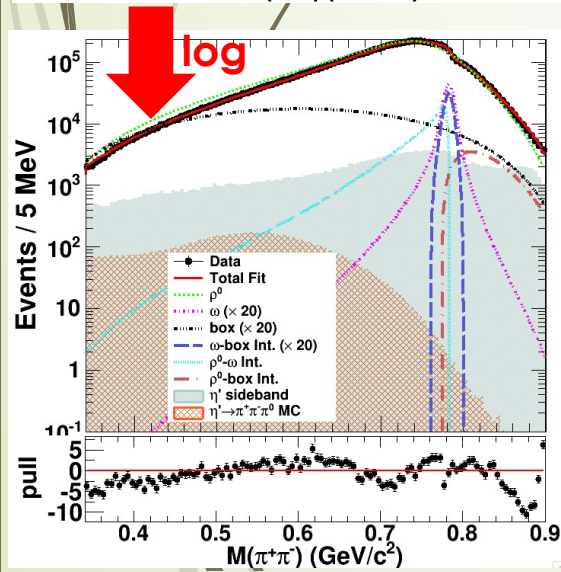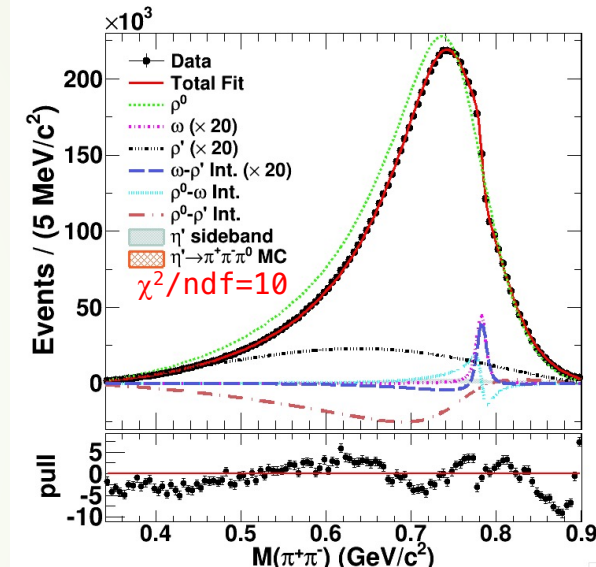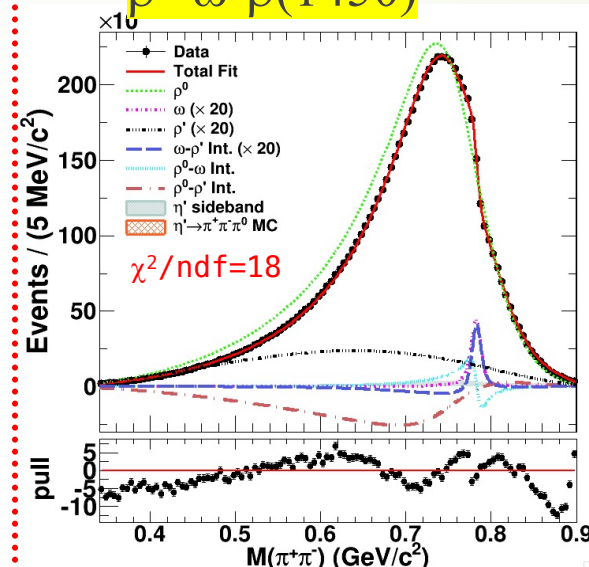
Model-dependent study

- ρ^0-ω-$\rho(1450)$-box anomaly

issues:

Correlation coefficient between α and $|\delta|$:
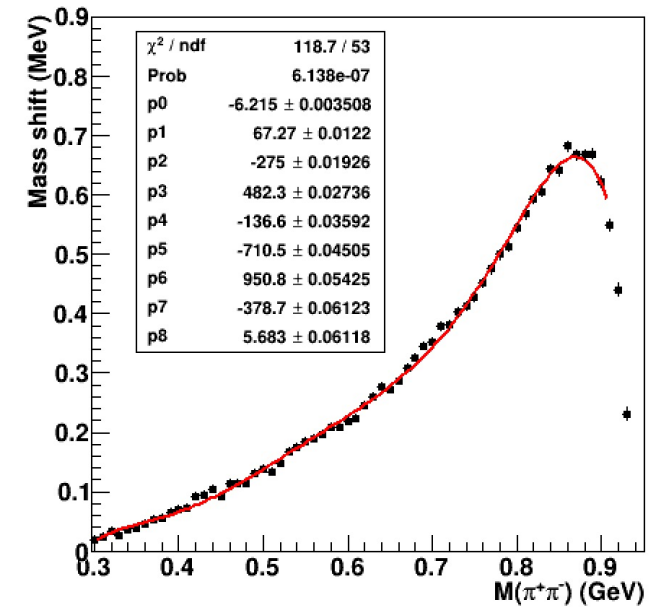-0.9887

multi-solution?
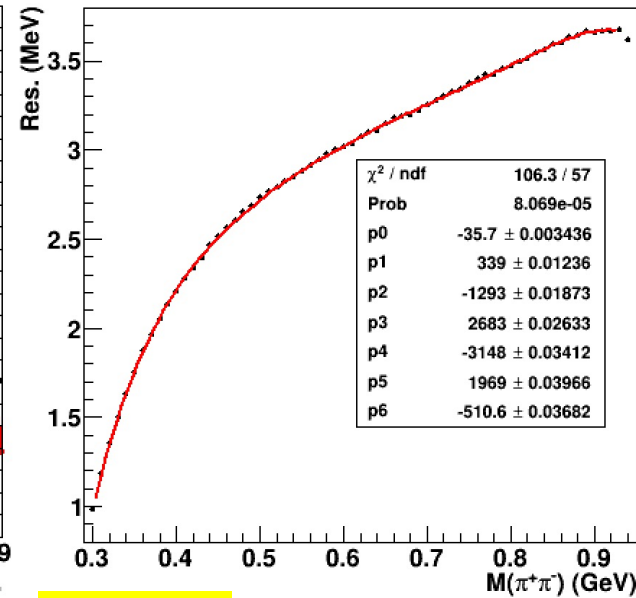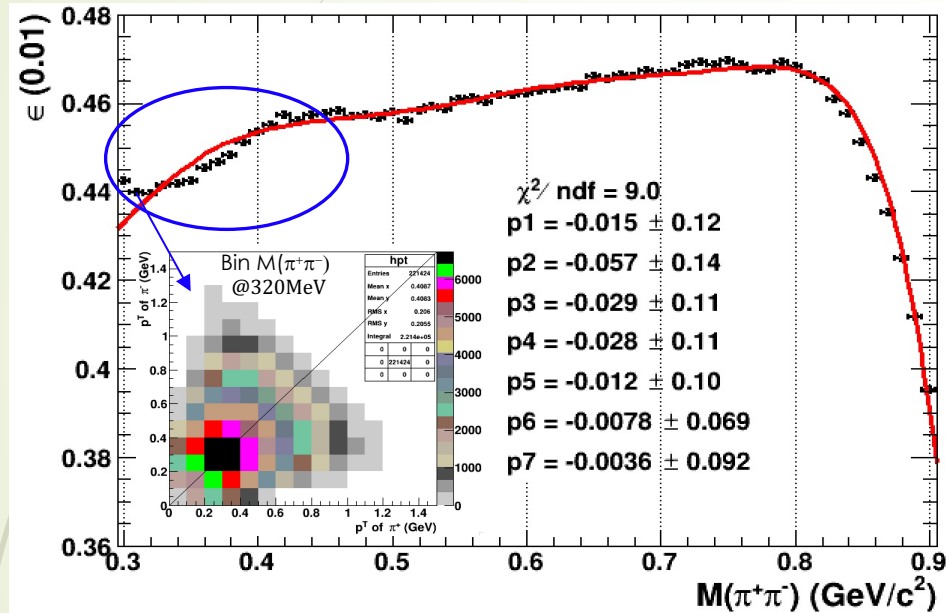
Model-independent study

- based on a combination of chiral perturbation theory (ChPT)-extended from SU(3) to U(3), and a dispersive analysis.

- Decay amplitude: $\mathcal{A} = N P(s) F_V(s)$

backup

Corrections for the dipion mass spectrum

- $M(\pi^+\pi^-)$–dependent **detection efficiency**, **mass resolution**, and the **mass shift**

Cut flow

cuts	ε of $M(\pi^+\pi^-)$ bin at 0.32 GeV	ε of $M(\pi^+\pi^-)$ bin at 0.42 GeV	ε of $M(\pi^+\pi^-)$ bin at 0.79 GeV	ε of $M(\pi^+\pi^-)$ bin at 0.90 GeV
$E_{\gamma 2} > 40$ MeV	47.40%	49.41%	50.69%	42.89%
$\chi^2(\pi^+\pi^-\gamma\gamma) < 100$	46.40%	48.28%	49.14%	41.01%
$\|M(\gamma\pi^+\pi^-) - m_{\eta'}\| < 20$ MeV	44.01%	45.77%	47.08%	39.51%
$\|M(\gamma\gamma) - m_{\pi 0}\| > 20$ MeV	43.95%	45.71%	46.91%	39.50%
Relative diff. of ε	7.12%	7.34%	7.46%	17.28%

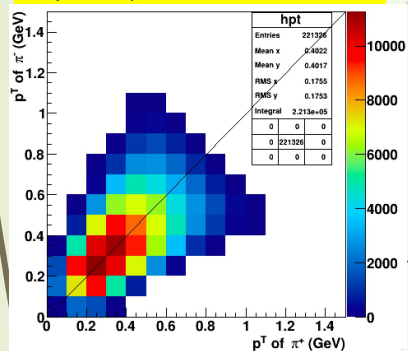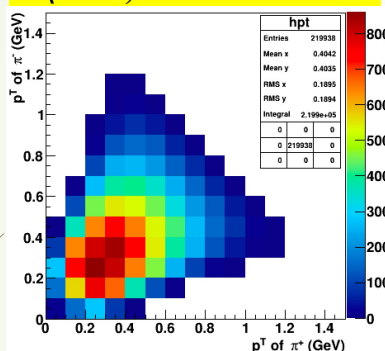# M($\pi^+\pi^-$)–dependent detection efficiency for 4 runs
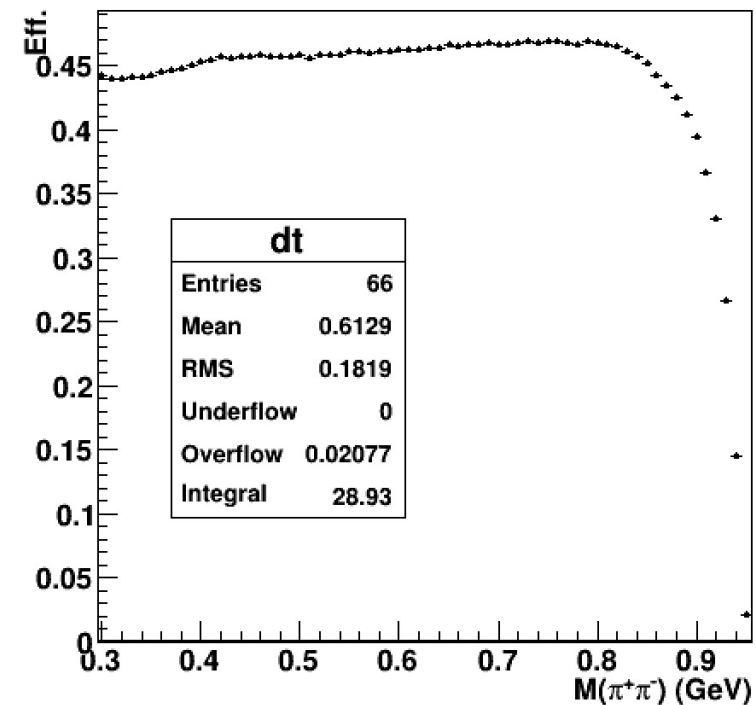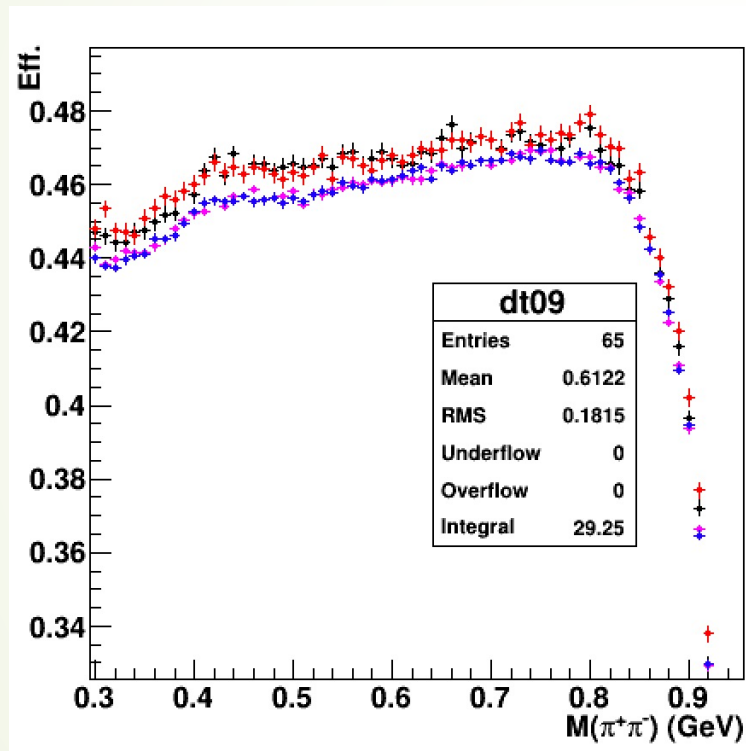
Transverse Momentum of π^+ vs π^-
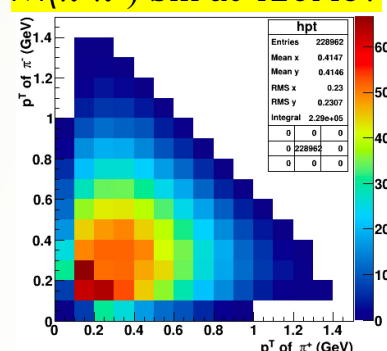
reconstructed after 4C fit: p^T

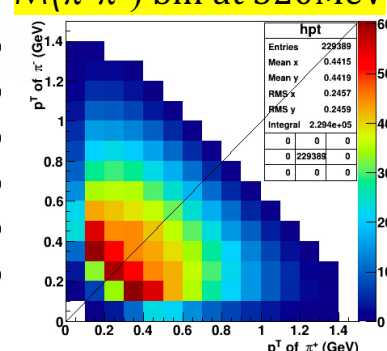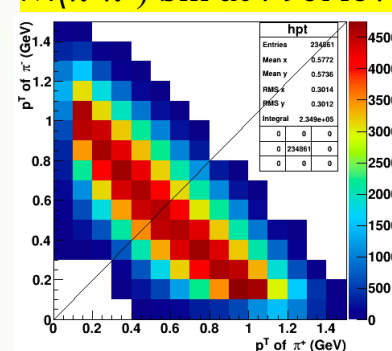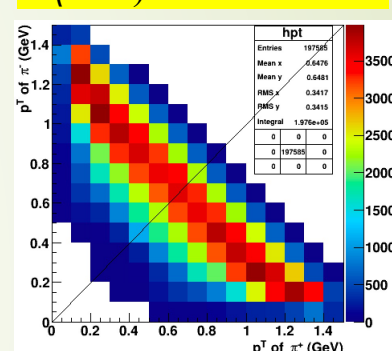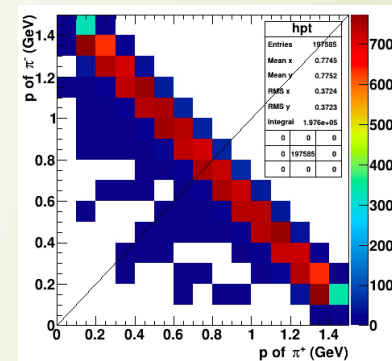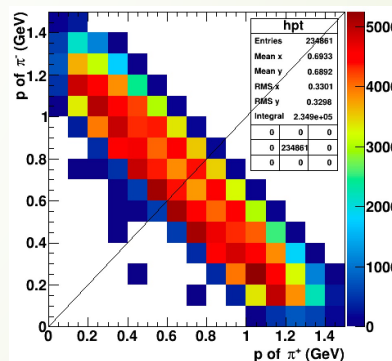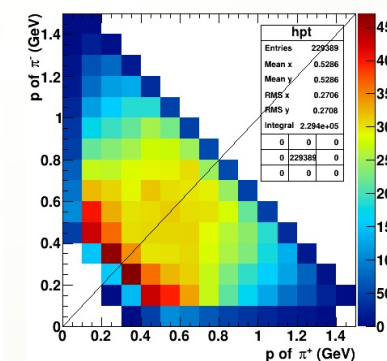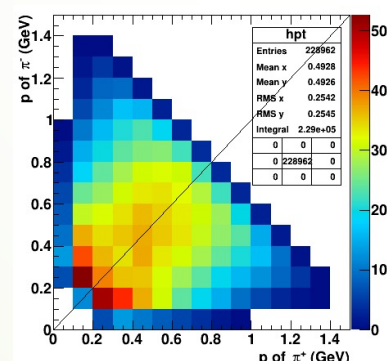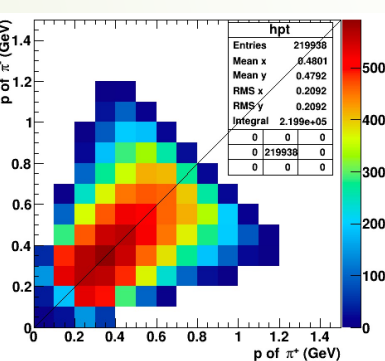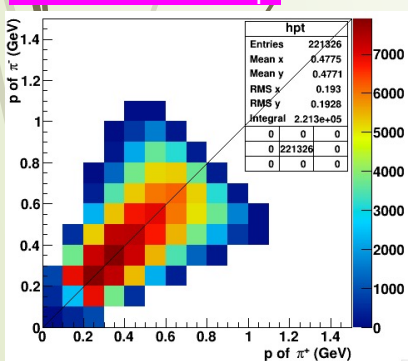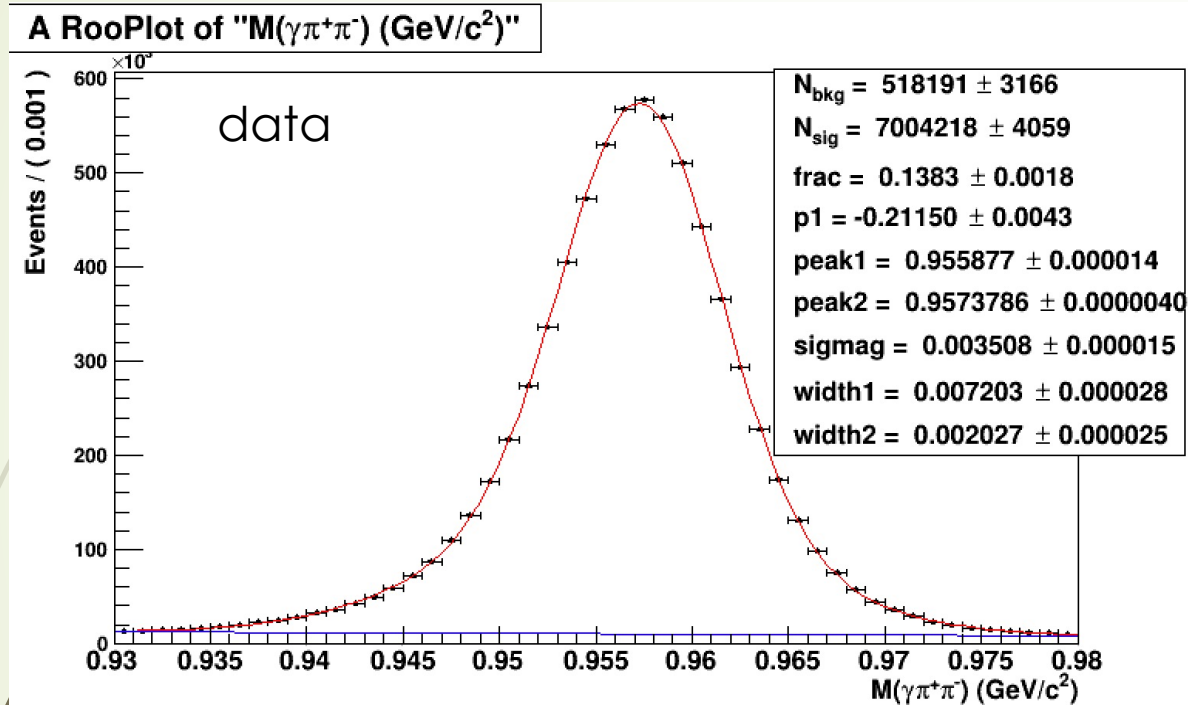M($\pi^+\pi^-$) bin at 300MeV   M($\pi^+\pi^-$) bin at 320MeV   M($\pi^+\pi^-$) bin at 420MeV   M($\pi^+\pi^-$) bin at 520MeV   M($\pi^+\pi^-$) bin at 790MeV   M($\pi^+\pi^-$) bin at 900MeV

at truth level: p

Check on the bkg level: a fit to $M(\gamma\gamma)$

A RooPlot of "$M(\gamma\pi^+\pi^-)$ (GeV/c^2)"

data

N_{bkg} = 518191 ± 3166

N_{sig} = 7004218 ± 4059

frac = 0.1383 ± 0.0018

p1 = -0.21150 ± 0.0043

peak1 = 0.955877 ± 0.000014

peak2 = 0.9573786 ± 0.0000040

sigmag = 0.003508 ± 0.000015

width1 = 0.007203 ± 0.000028

width2 = 0.002027 ± 0.000025

Background level: 6%