Study of $\eta' \to \pi^+\pi^-\pi^+\pi^-$ and $\eta' \to \pi^+\pi^-\pi^0\pi^0$ via $J/\psi \to \gamma\eta'$

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Outline

- Motivation
- Data Sample and MC Simulation
- Analysis of $\eta' \to \pi^+\pi^-\pi^+\pi^-$
- Analysis of $\eta' \to \pi^+\pi^-\pi^0\pi^0$
- Summary
- Backup

Motivation

- The decays of the η/η' meson are of interest as probes of some aspects of the strong interaction , and also as sources of information on physics beyond the standard model.
- Many theorists have proposed many models to explain the decay mechanism of $\eta' \to 4\pi$ when η' was discovered. Within the framework of the quark model ,the decay rate of $\eta' \to 4\pi$ (including $\eta' \to \pi^+\pi^-\pi^+\pi^-$ and $\eta' \to \pi^+\pi^-\pi^0\pi^0$)was predicted to be $\Gamma(\eta' \to 4\pi)=2.4 \times 10^{-4}$MeV [1]. Experimentally CLEO Collaboration reported the branching fraction upper limits are presented to be $\mathcal{B}(\eta' \to \pi^+\pi^-\pi^+\pi^-) < 2.4 \times 10^{-4}$ and $\mathcal{B}(\eta' \to \pi^+\pi^-\pi^0\pi^0) < 2.6 \times 10^{-3}$,which contradicts the prediction of the quark model.
- A sample of 10047.9×10^6 J/ψ events was collected with the BESIII detector since 2017,which allows us to search for $\eta' \to 4\pi$ with a higher sensitivity. We can compare that with previous measurements, The correctness of chiral perturbation theory and vector meson model to describe decay properties of $\eta' \to \pi^+\pi^-\pi^+\pi^-$ and $\eta' \to \pi^+\pi^-\pi^0\pi^0$ is further verified.

[1] D.Parashar.$\eta' \to 4\pi$ DECAY IN A BROKEN SU(6) X O(3)QUARK MODEL.Phys.Rev.,D19:268-270,1979.

Data Samples and MC Simulation

- BOSS version: 7.0.8
- Data sample: 1312M J/ψ taken in 2009 and 2012
- Inclusive MC: 1225M J/ψ Inclusive MC in 2009 and 2012
- Signal MC:

2009 : 2012=1 : 5 total 300k for $J/\psi \to \gamma\eta'$,$\eta' \to \pi^+\pi^-\pi^+\pi^-$ and $J/\psi \to \gamma\eta'$, $\eta' \to \pi^+\pi^-\pi^0\pi^0$ respectively.

Analysis of $\eta' \to \pi^+\pi^-\pi^+\pi^-$

Initial Event selection

Good charged tracks

- $|V_r| < 1.0cm, |V_z| < 10.0cm, |\cos\theta| < 0.93$
- $N=4$, $N_p = N_m = 2$

PID for pion

- $Prob(\pi) > Prob(K)$ and $Prob(\pi) > Prob(P)$

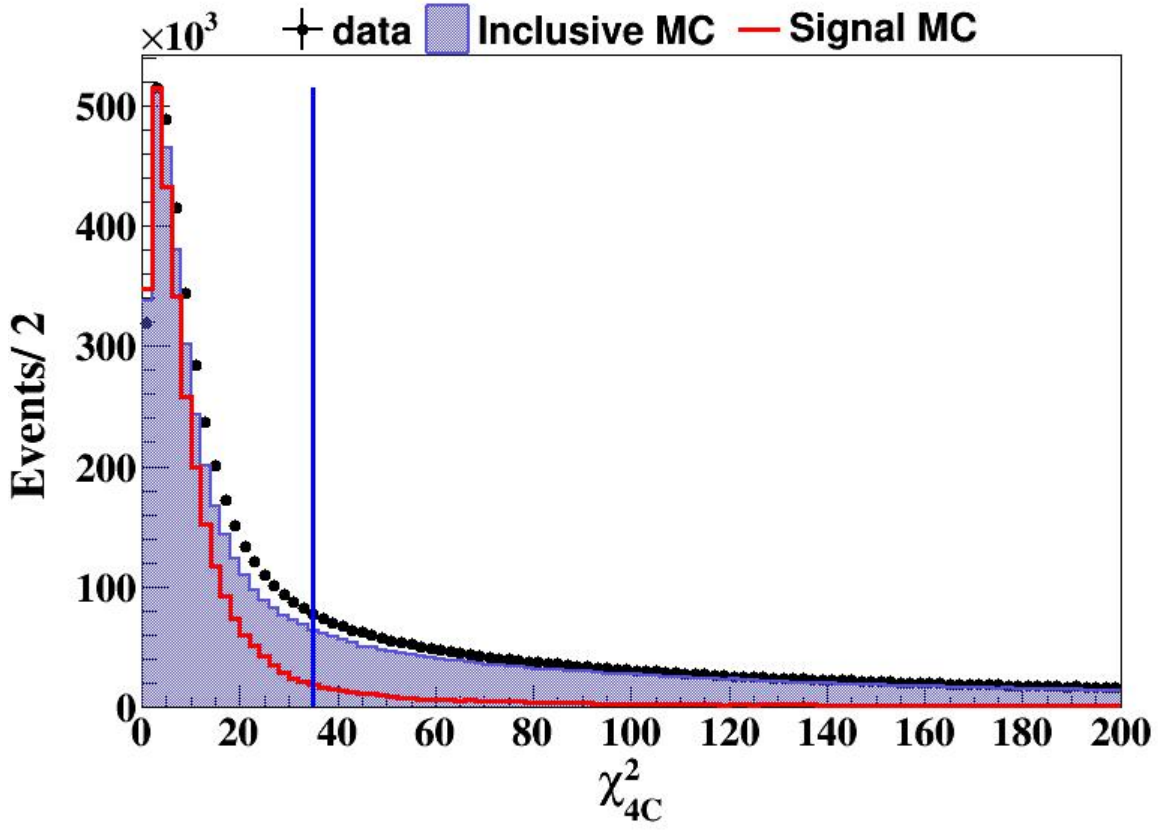
Good Photons

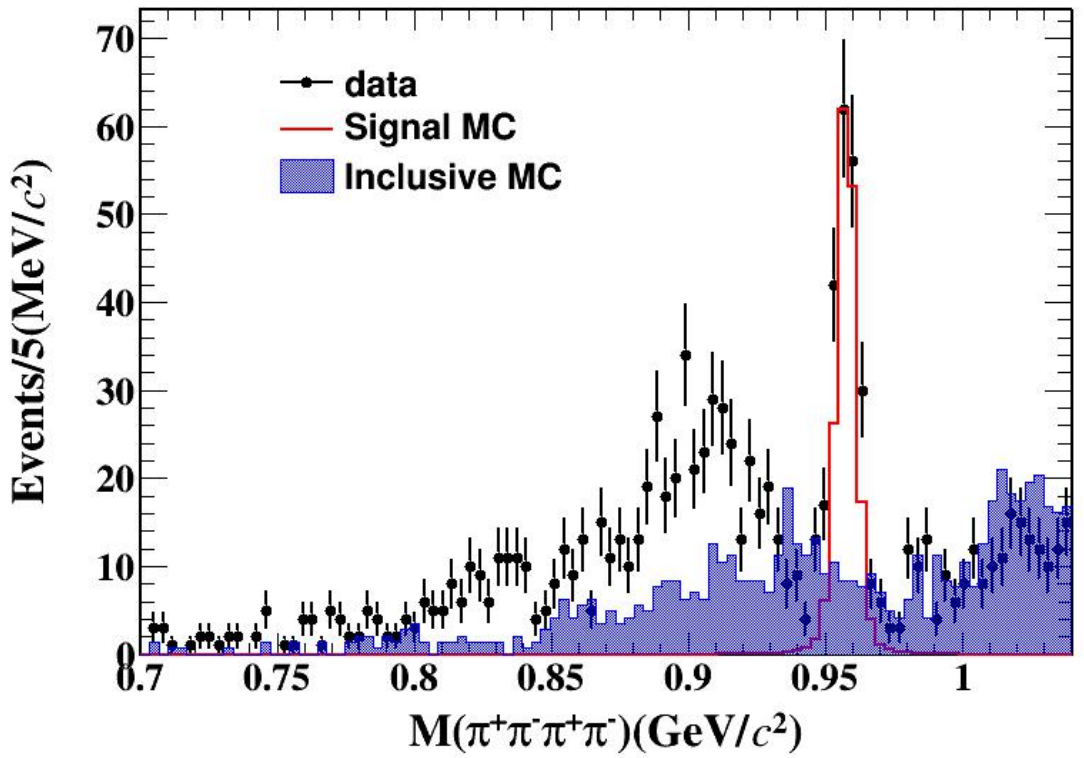
- $E_{barrel} > 25MeV$, $|\cos\theta| < 0.8$
- $E_{endcap} > 50MeV$, $|\cos\theta| \in (0.86, 0.92)$
- The Timing information from EMC: $0 \le t \le 14$
- $N_\gamma \geq 1$

4C kinematic with $J/\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$

- Additional 4C Kinematic fit for $\gamma\gamma\pi^+\pi^-\pi^+\pi^-$ final states.

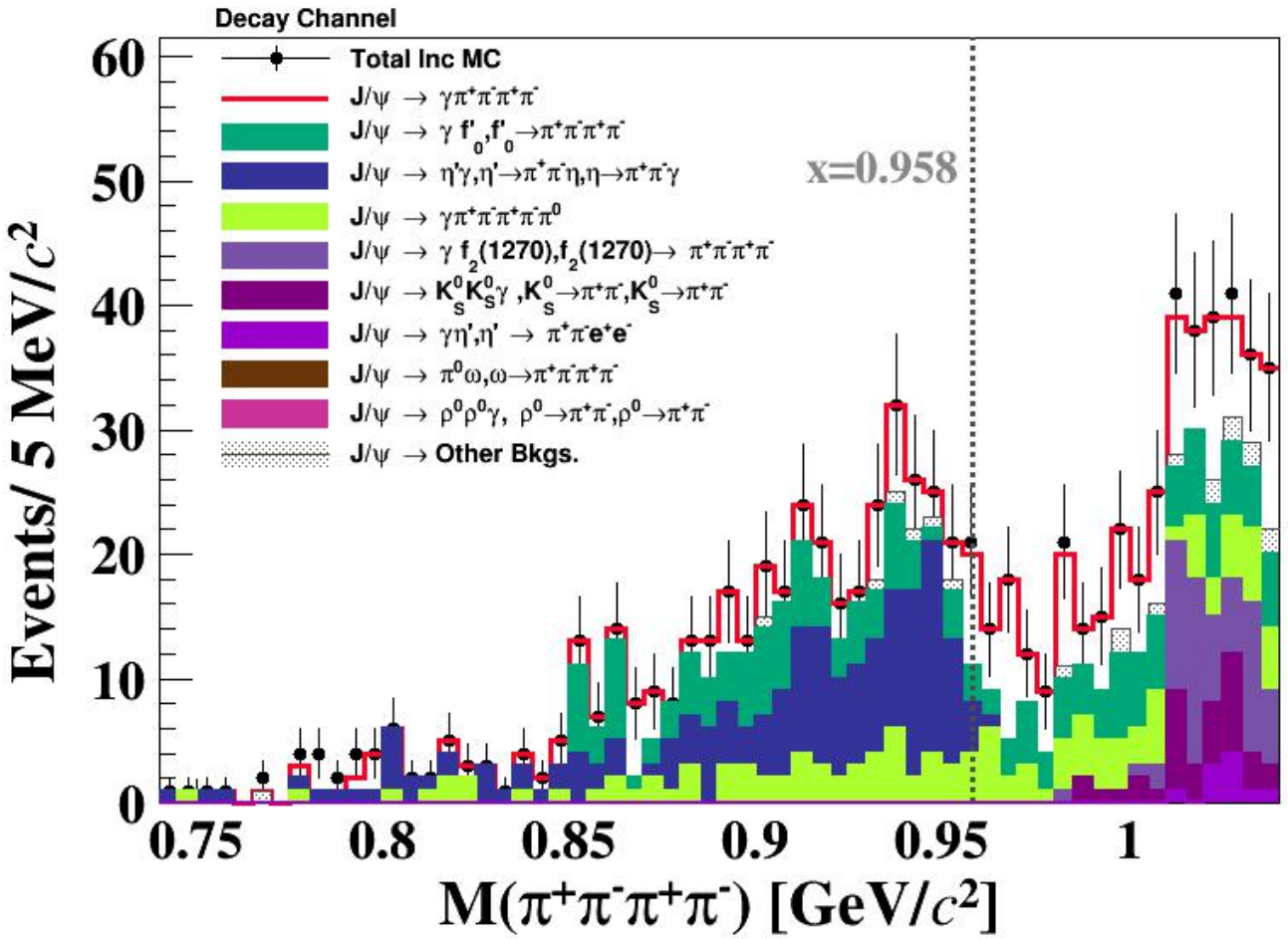
Event selection

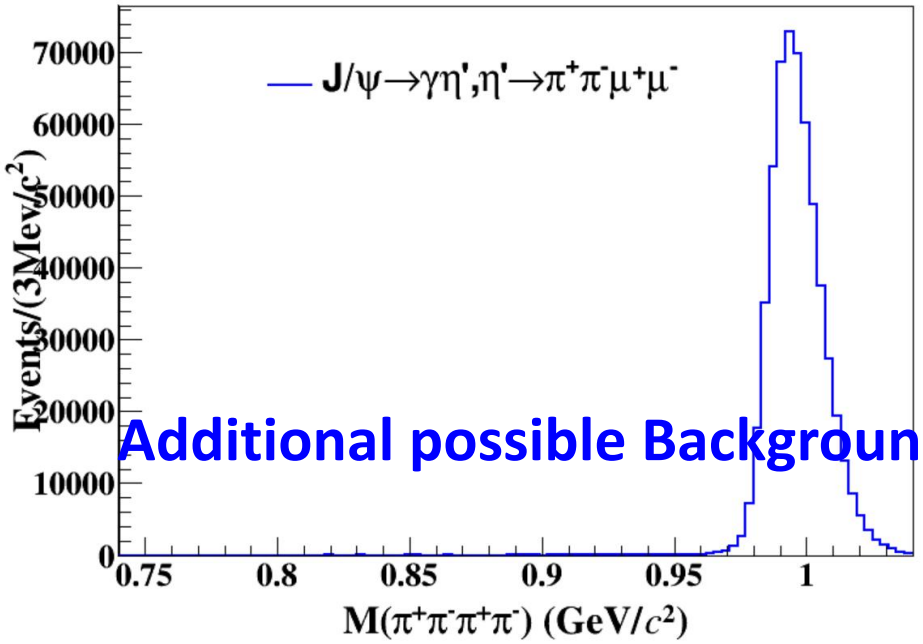




- $\chi^2_{4C} < 35$
- $\chi^2_{4C}(\gamma\pi^+\pi^-\pi^+\pi^-) < \chi^2_{4C}(\gamma\gamma\pi^+\pi^-\pi^+\pi^-)$

Background Study



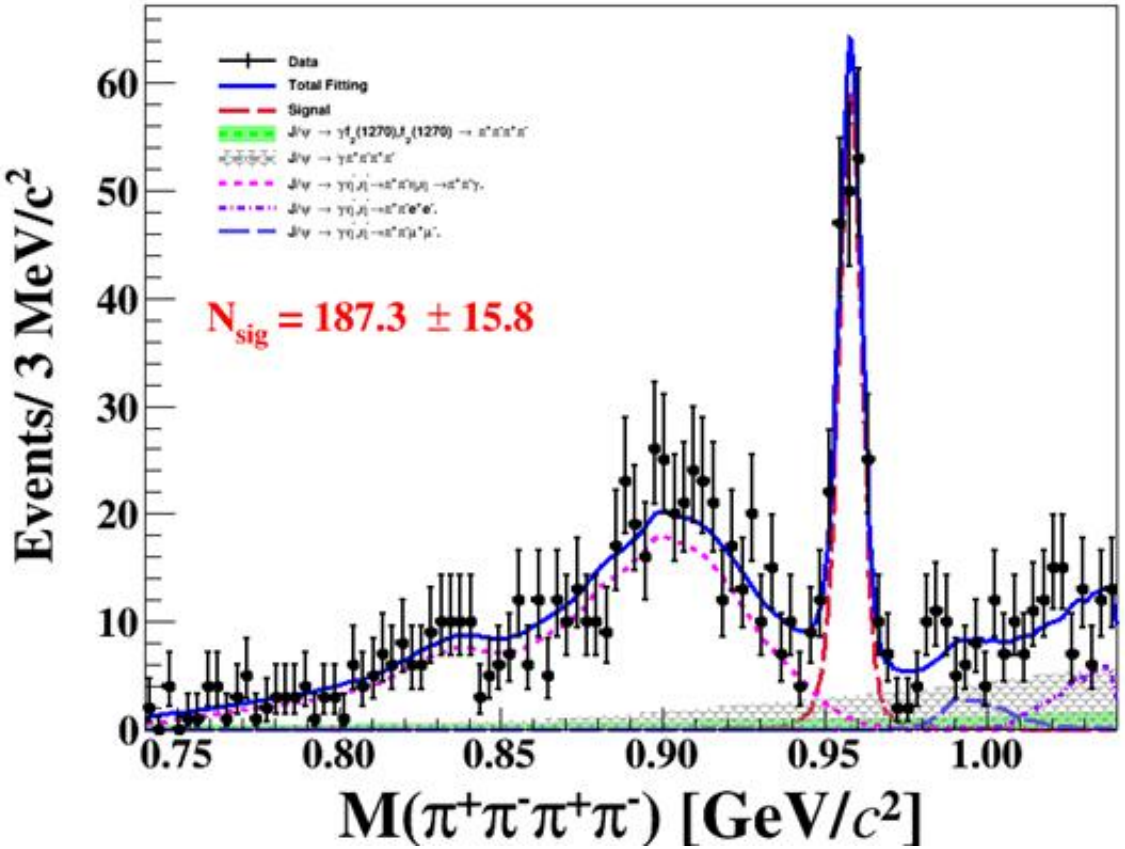


Additional possible Background*

*Proposed by Baician Ke

Fitting result of $M(\pi^+\pi^-\pi^+\pi^-)$

Significance: 20.2σ



- Signal: PDF shape
- Background :

  PDF shape of peak background($J/\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$),

  PDF shape of peak background($J/\psi \to \gamma\eta', \eta' \to \pi^+\pi^-\eta, \eta \to \pi^+\pi^-\gamma$),

  PDF shape of peak background($J/\psi \to \gamma\eta'$, $\eta' \to \pi^+\pi^-e^+e^-$),

  PDF shape of peak background($J/\psi \to \gamma\eta'$, $\eta' \to \pi^+\pi^-\mu^+\mu^-$)

  fixed BW convolution Gaussian function of $f_2(1270)$.

- $\mathcal{B}(\eta' \to \pi^+\pi^-\pi^+\pi^-) = \frac{N_{sig}}{N_{J/\psi} \cdot B(J/\psi \to \gamma\eta') \cdot \varepsilon}$

Mode	N_{sig}	ε(%)	$\mathcal{B}(\times 10^{-5})$
$\eta' \to \pi^+\pi^-\pi^+\pi^-$	187.3±15.8	33.29	8.35±0.70($stat$)

Analysis of $\eta' \to \pi^+\pi^-\pi^0\pi^0$

Initial Event selection

Good charged tracks

- $|V_r| < 1.0cm, |V_z| < 10.0cm, |\cos\theta| < 0.93$
- $N=2, N_p = N_m = 1$

PID for pion

- $Prob(\pi) > Prob(K)$ and $Prob(\pi) > Prob(P)$

Good Photons

- $E_{barrel} > 25MeV, |\cos\theta| < 0.8$
- $E_{endcap} > 50MeV, |\cos\theta| \in (0.86, 0.92)$
- The Timing information from EMC: $0 \le t \le 14$
- $\boldsymbol{N_\gamma \geq 5}$

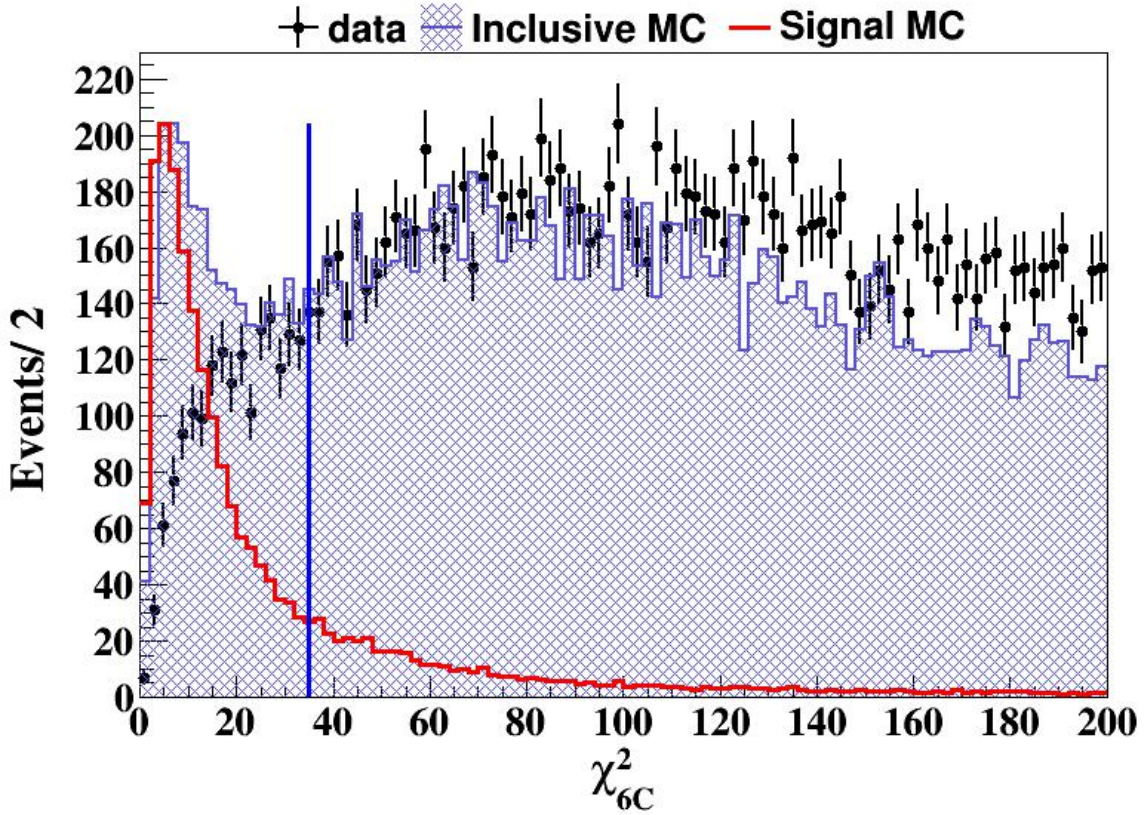
1C kinematic for π^0

A kinematic fit is performed on the selected photon pairs by constraining their invariant mass to the π^0 mass.

6C kinematic with $J/\psi \to \pi^+\pi^-\gamma\gamma\gamma\gamma$.

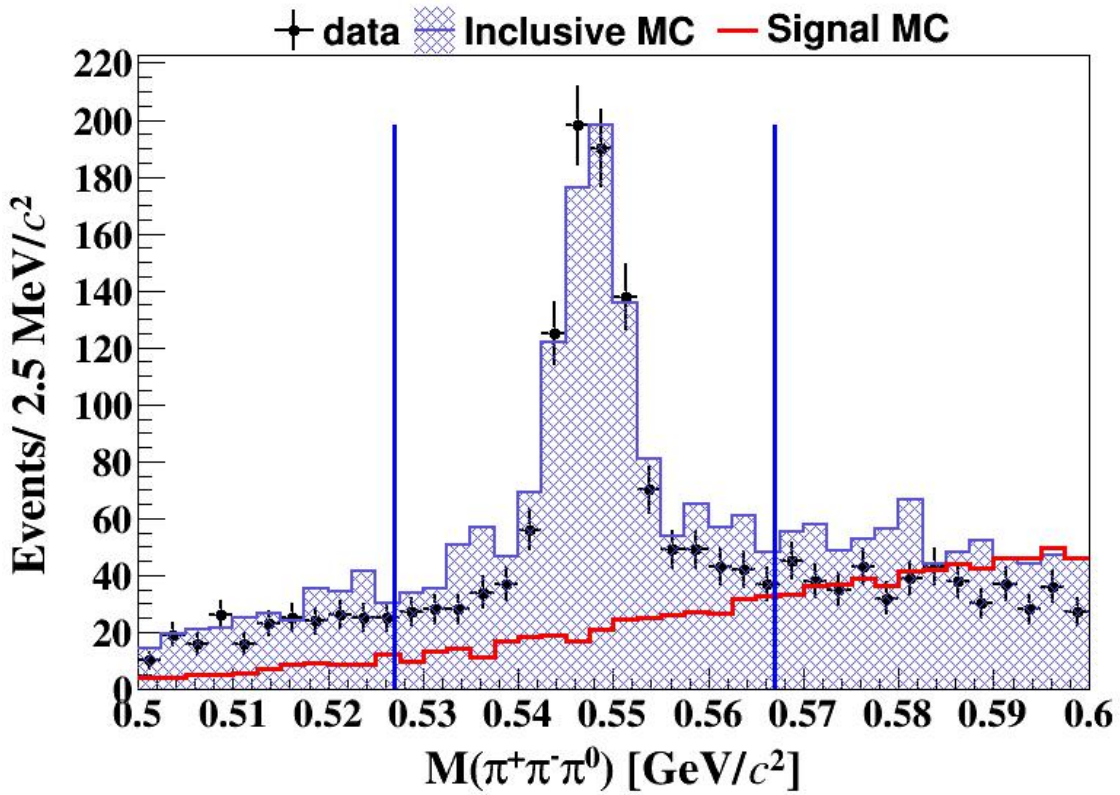
- Additional 6C Kinematic fit for $\gamma\pi^+\pi^-\pi^0\pi^0$ and $\gamma\gamma\pi^+\pi^-\pi^0\pi^0$ final states.

Further Event selection(I)

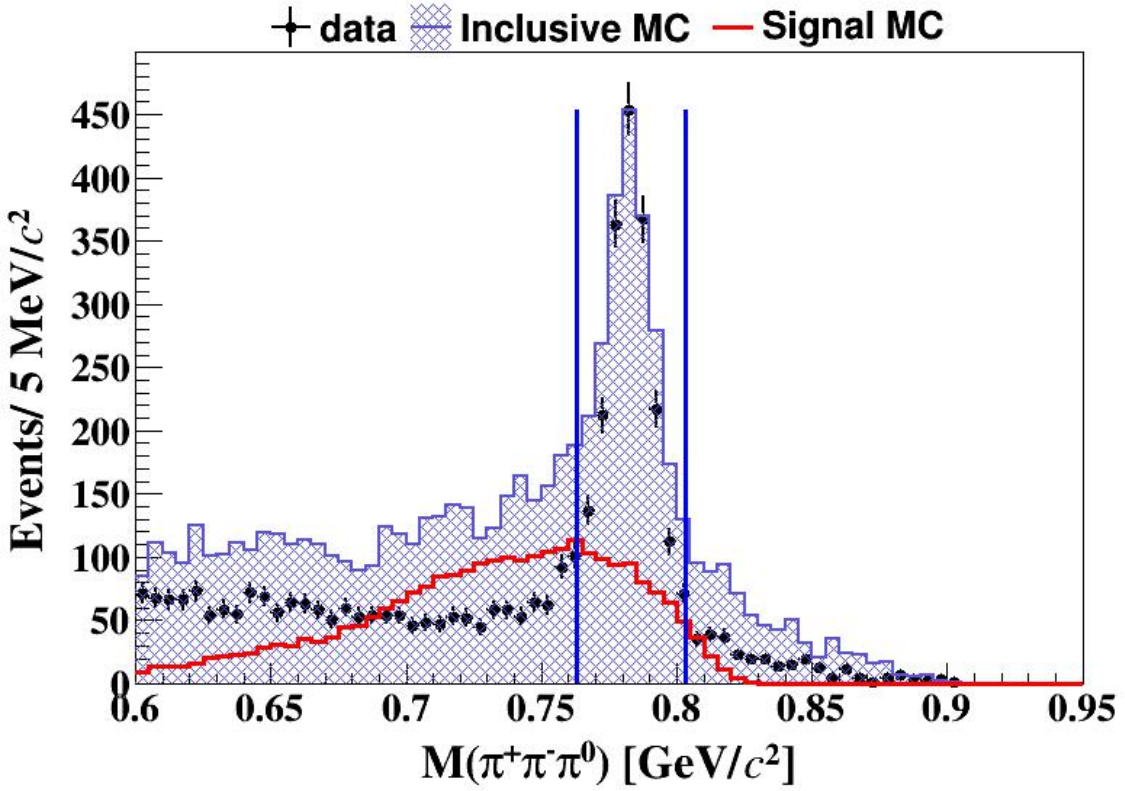


- $\chi^2_{6C} < 35$
- $\chi^2_{6C}(\gamma\pi^+\pi^-\pi^0\pi^0) < \chi^2_{6C}(\gamma\gamma\pi^+\pi^-\pi^0\pi^0)$

Further Event selection(II) Veto on $\eta/\omega \rightarrow \pi^+\pi^-\pi^0$



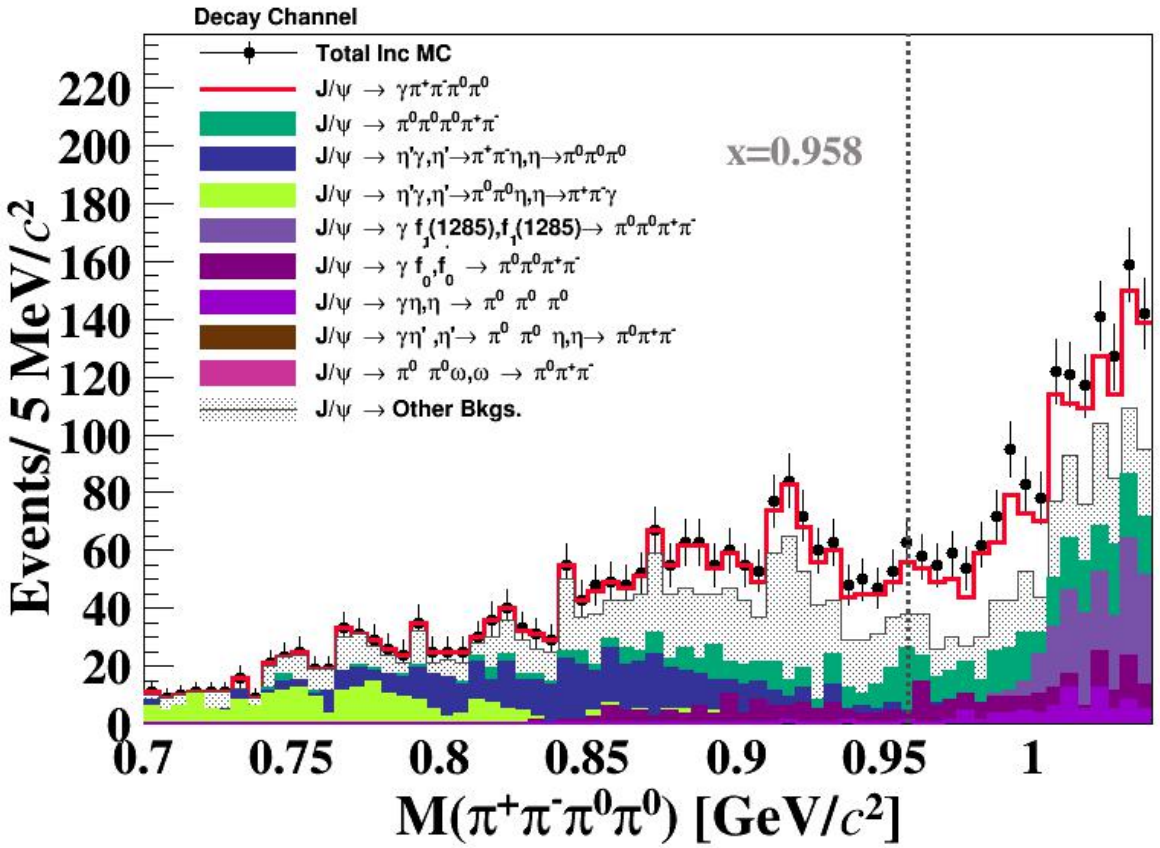
- $|M(\pi^+\pi^-\pi^0) - m_\eta| > 0.02 Gev/c^2$

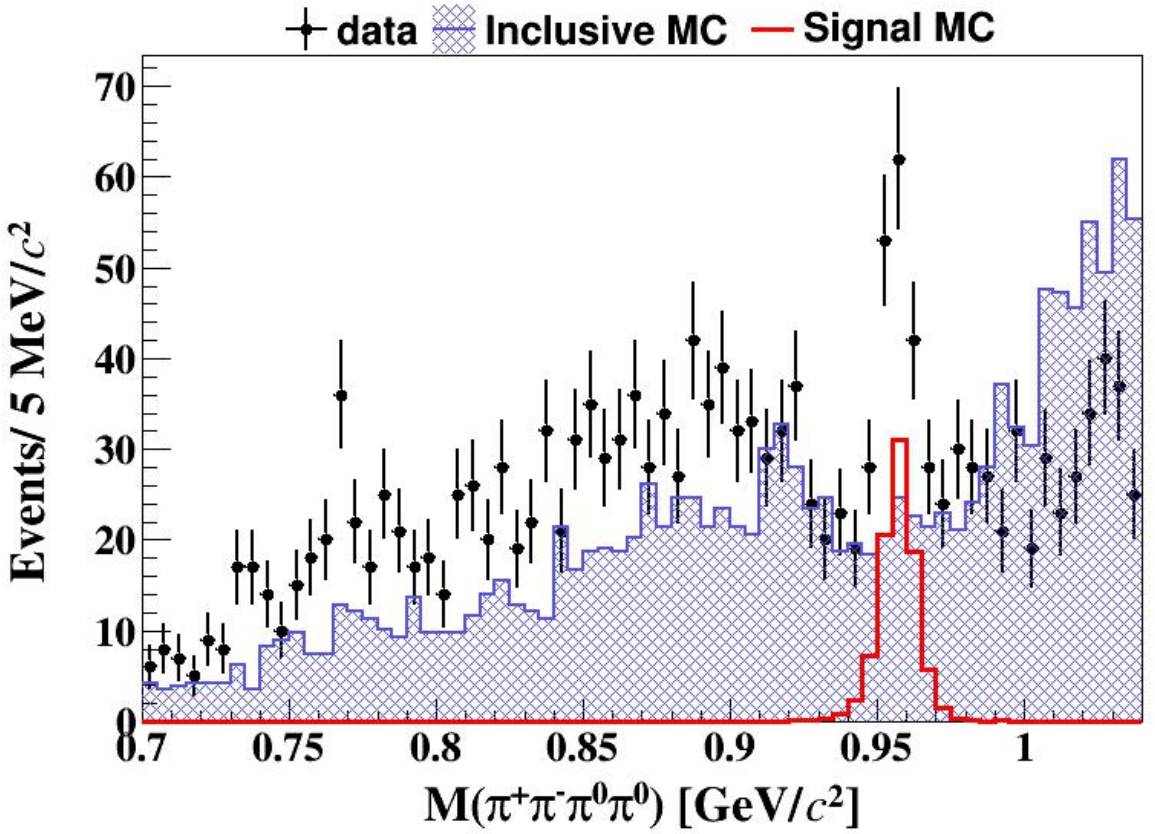


- $|M(\pi^+\pi^-\pi^0) - m_\omega| > 0.02 Gev/c^2$

Background Study

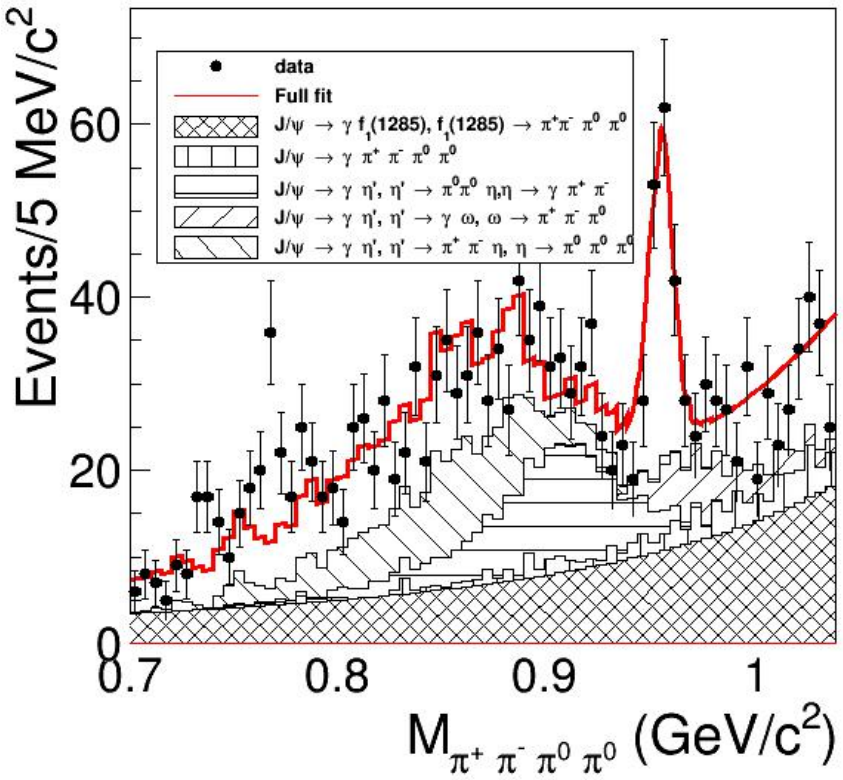
- After all the selections, the rest of inclusive MC sample is listed:





Fitting result of $M(\pi^+\pi^-\pi^0\pi^0)$

☐ **Significance: 8σ**



■ Background :

PDF shape of peak background($J/\psi \to \gamma\pi^+\pi^-\pi^0\pi^0$), ($J/\psi \to \gamma\eta', \eta' \to \pi^+\pi^-\eta, \eta \to \pi^0\pi^0\pi^0$), ($J/\psi \to \gamma\eta', \eta' \to \pi^0\pi^0\eta, \eta \to \pi^+\pi^-\gamma$) and($J/\psi \to \gamma\eta', \eta' \to \gamma\omega, \omega \to \pi^+\pi^-\pi^0$) ,fixed BW convolution Gaussian function of $f_1(1285)$.

■ $$\mathcal{B}(\eta' \to \pi^+\pi^-\pi^0\pi^0) = \frac{N_{sig}}{N_{J/\psi}\cdot\mathcal{B}(J/\psi\to\gamma\eta')\cdot\varepsilon\cdot\mathcal{B}(\pi^0\to\gamma\gamma)\mathcal{B}(\pi^0\to\gamma\gamma)}$$

$$= \frac{103.9}{13.1254\times10^8\times0.075\times5.16\times10^{-3}\times0.98^2}$$

Mode	N_{sig}	ε(%)	$\mathcal{B}(\times10^{-4})$
$\eta' \to \pi^+\pi^-\pi^0\pi^0$	103.9**±15.6**	7.5	**2.12±0.31**$(stat)$

Summary & Next to do

Using 1312M J/ψ data sample collected at BESIII in 2009 and 2012

✓ The branching fraction of $\eta' \to \pi^+\pi^-\pi^+\pi^-$ and $\eta' \to \pi^+\pi^-\pi^0\pi^0$ is performed a measurement.

Mode	N_{sig}	$\varepsilon(\%)$	$Br(\eta' \to X)$(this work)	Significance(σ)	$Br(\eta' \to X)$[1](pre.result)
$\eta' \to \pi^+\pi^-\pi^+\pi^-$	187.3±15.8	33.29	$(8.35\pm0.70(stat))\times 10^{-5}$	20.2	$(8.41\pm0.68(stat))\times 10^{-5}$
$\eta' \to \pi^+\pi^-\pi^0\pi^0$	103.9±15.6	7.5	$(2.12\pm0.31(stat))\times 10^{-4}$	8	$(1.90\pm0.36(stat))\times 10^{-4}$

✓ The result is consistent with PDG value.

Next to do

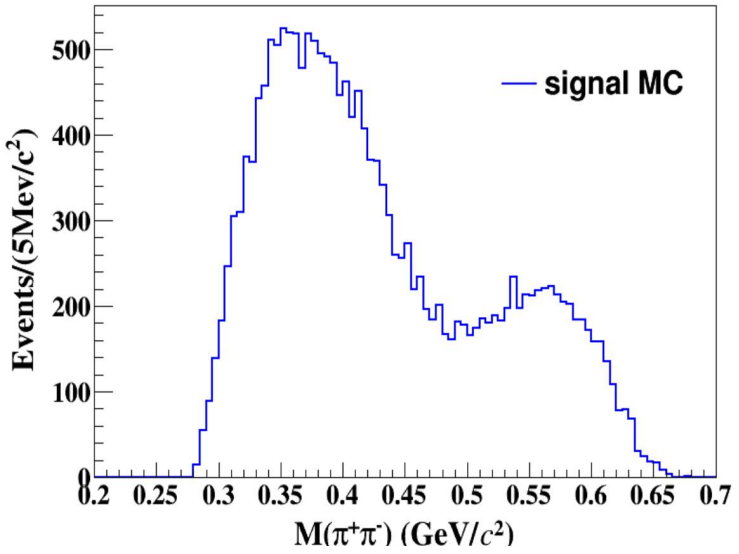
- Add 2018 and 2019 J/ψ data samples
- Finish systematic uncertainty

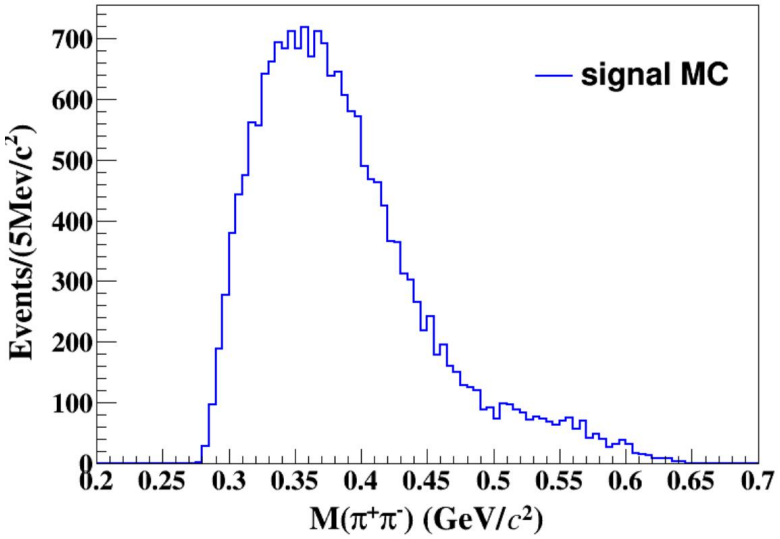
THANKS!☺

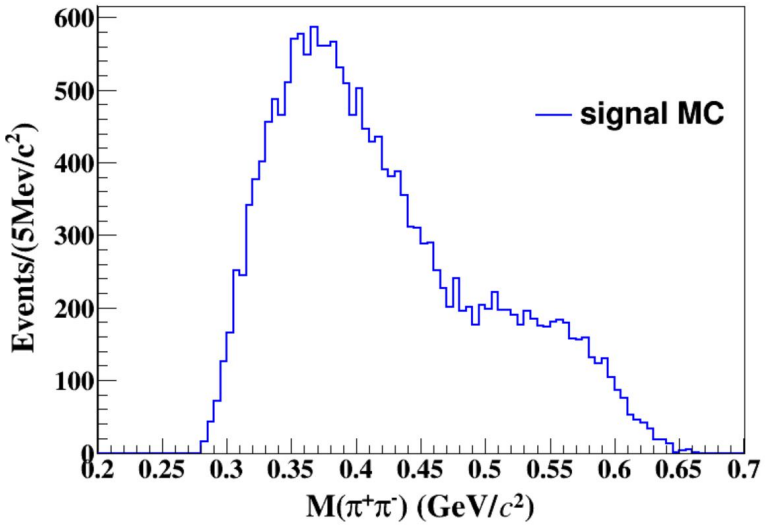
[1]BAM-00101,Observation of etap --> pi+pi-pi+pi- by Huijuan LI et al.

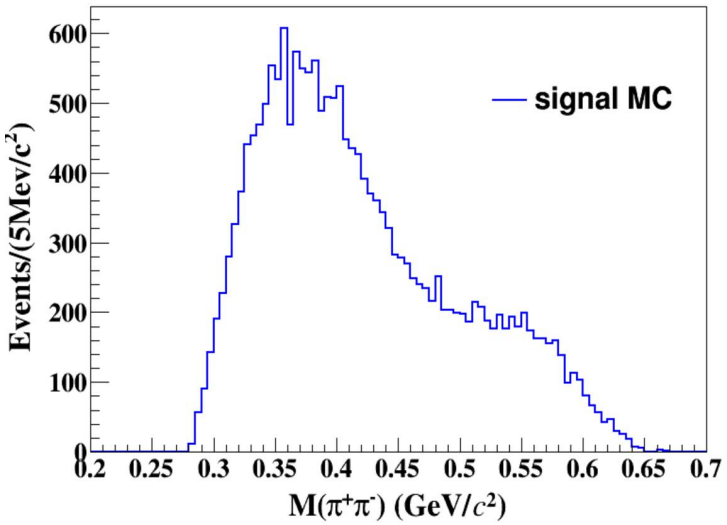
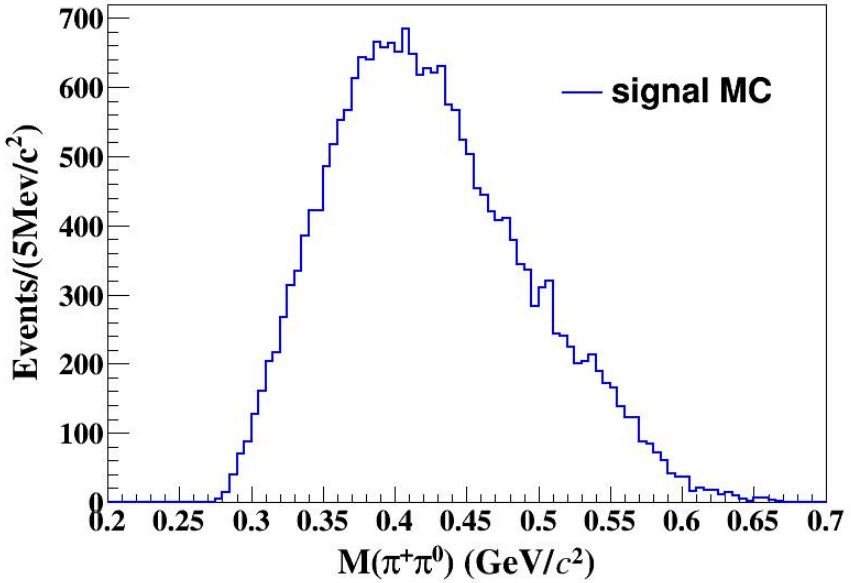
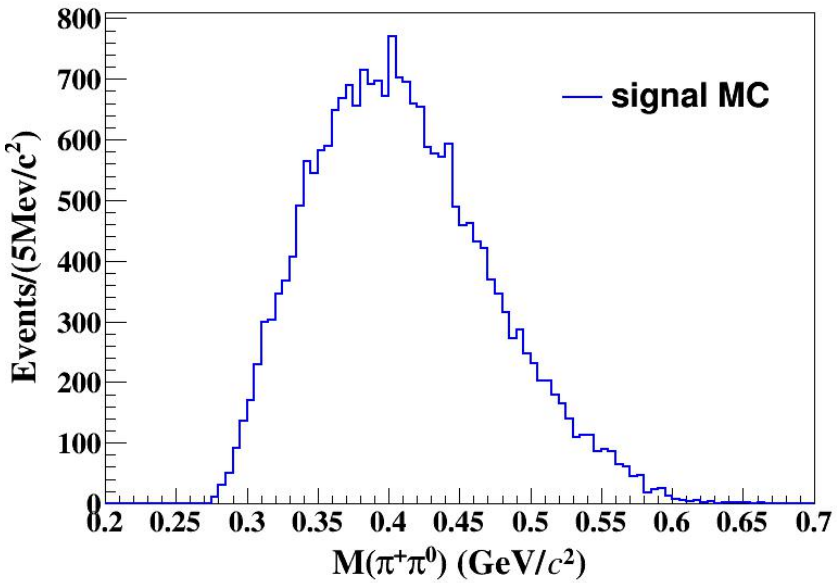
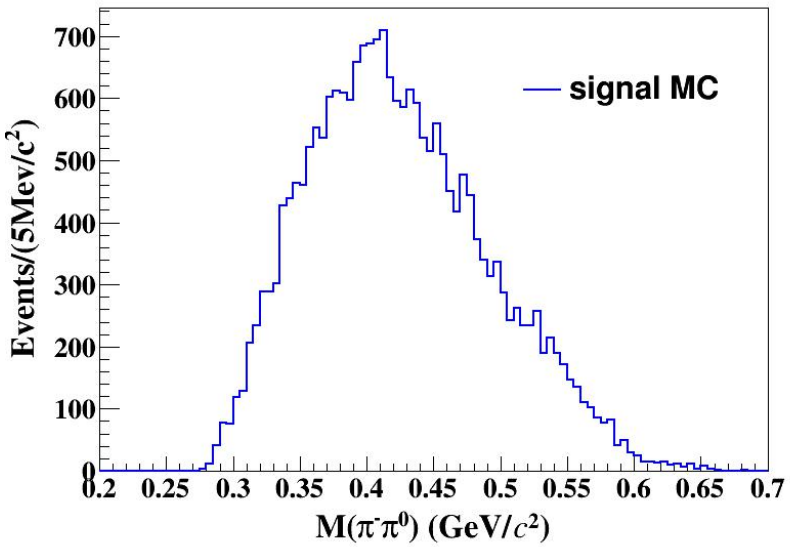
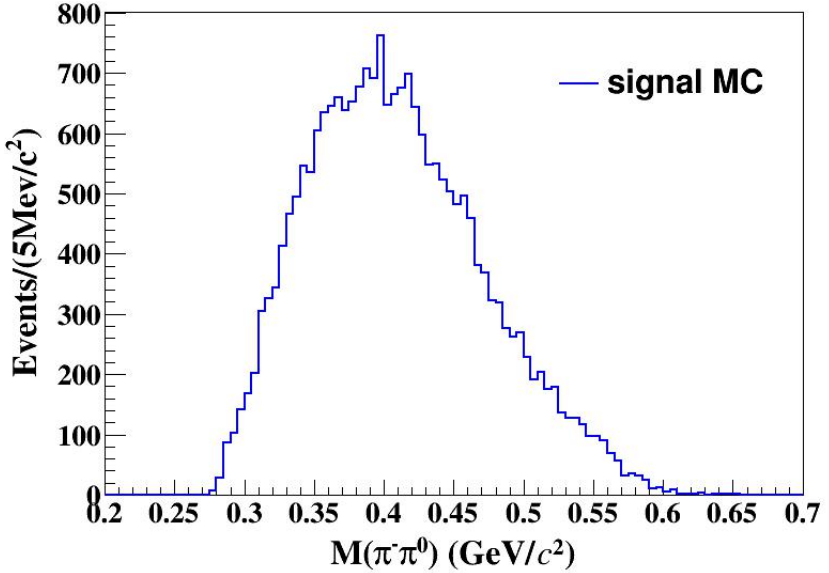
Backup

$M(\pi^+\pi^-)$ of $\eta' \to \pi^+\pi^-\pi^+\pi^-$









$M(\pi^+\pi^0)$ and $M(\pi^-\pi^0)$ of $\eta' \to \pi^+\pi^-\pi^0\pi^0$