Measurement of branching fractions of $\psi' \to e^+e^-\eta_c$

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Outline

Motivation I

- $\psi' \to \gamma\eta_c$ is a "hindered" M1 transition which can help us understand the spin interactions between charmonia. [a]
- $\psi' \to e^+e^-\eta_c$ is an electromagnetic (EM) Dalitz decay in which the virtual photon is internally converted into a lepton pair. From this decay, we could probe the interactions between ψ' and the photon. [b,c]
- From the e^+e^- invariant mass distribution, we can get the q^2 dependent transition form factor (TFF) $F(q^2)(q^2 = m^2_{e^+e^-})$. The TFF would be helpful for further theoretical development.

[a] T.Barnes, S.Godfrey and E.S.Swanson, Phys.Rev.D72,054026(2005)

[b] L.G.Landsberg, Phys.Rept.128,301(1985)

[c] J.Fu, H.B.Li, X.Qin and M.Z.Yang, Mod.Phys.Lett.A27,125022(2012)

Motivation II

- Such EM Dalitz decays of light-quark mesons have been widely studied both in theory and experiment. [d].
- In 2012, Ref [c] firstly studied the EM Dalitz decays of charmonium state J/ψ. In the following years, BESIII have studied several EM Dalitz decays of charmonia states. [d]
- In Ref [c], they did not consider the polarization of J/ψ. Considering the polarization of J/ψ and ψ' at BESIII, Xinxin in our group modified the formula of the amplitude in Ref [c] and wrote the generator which is called "DalitzJPLL".
- This analysis is the first time to measurement $B(\psi' \to e^+e^-\eta_c)$.

[c] J.Fu, H.B.Li, X.Qin and M.Z.Yang, Mod.Phys.Lett.A27,125022(2012)

[d] C.Patrignani $et\ al.$ [Partical Data Group], Chin.Phys.C40,100001(2016)

Data Sample

- Data:

  4.481×10^8 ψ' events taken at $\sqrt{s} = 3.686$ GeV in 2009 (1.070×10^8) and 2012 (3.411×10^8).

- Monte Carlo:

  Inclusive Monte Carlo Sample: official 506 Million inclusive Monte Carlo sample

  Signal Monte Carlo Sample:

Decay chain	Generated
$\psi' \to e^+e^-\eta_c,\ \eta_c \to X$	1×10^7

  $\psi' \to e^+e^-\eta_c$ is generated by using the "DalitzJPLL" generator.

- BOSS version : 6.6.4.p03

Analysis Method

- Firstly, we only reconstruct the electron pair to obtain the $B(\psi' \to e^+e^-\eta_c)$.
- Secondly, we fully reconstruct $e^+e^-\eta_c$ with multi η_c decay modes to determine the $B(\psi' \to e^+e^-\eta_c)$.

$$\psi' \to e^+e^-\eta_c,\ \eta_c \to X$$

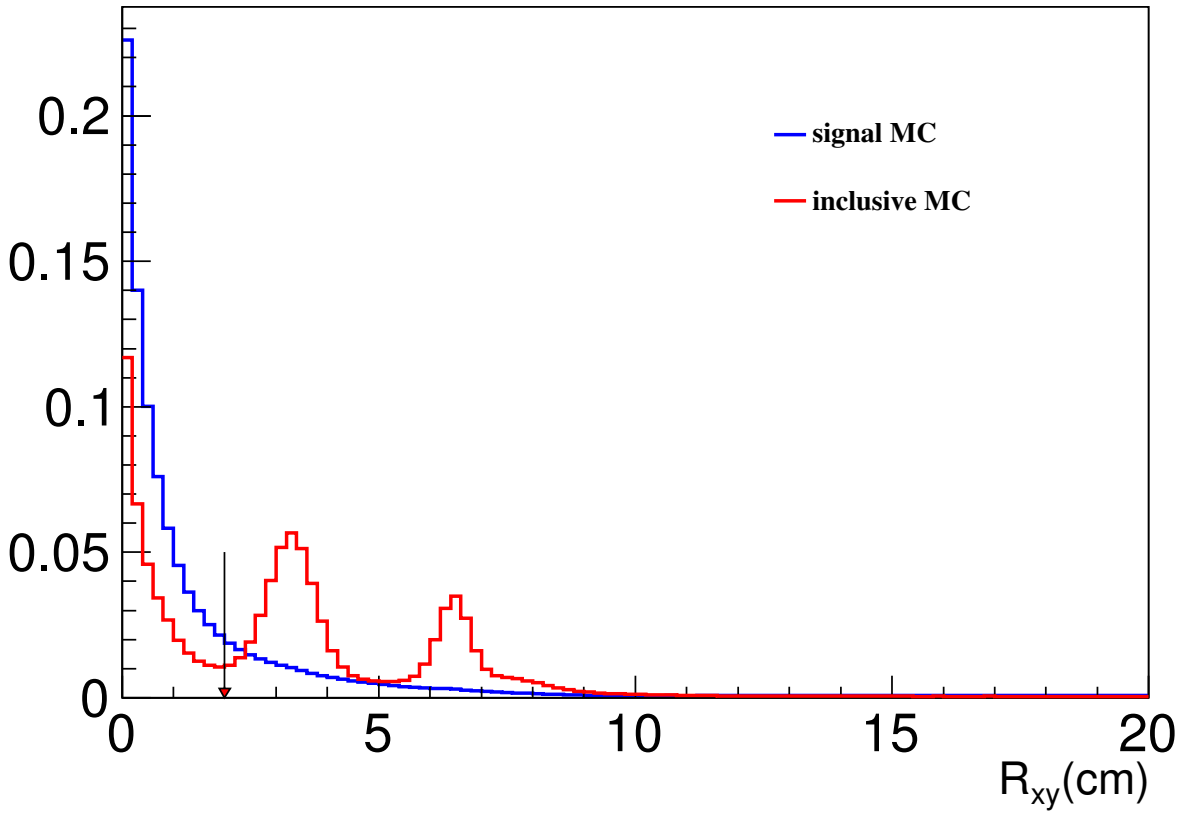
Event Selection

- Good Charged Tracks Selection
  - distance of the track from interaction position on x-y plane: $|R_{xy}| < 1$ cm
  - distance of the track from interaction position in z direction: $|R_z| < 10$ cm
  - the polar angle of the track: $|\cos\theta| < 0.93$
- Electron PID
  - dE/dx + TOF + EMC
  - $\mathrm{prob(e)} > 0$
  - $\mathrm{prob(e)} > \mathrm{prob}(\pi)$
  - $\mathrm{prob(e)} > \mathrm{prob(K)}$
  - $\frac{\mathrm{prob(e)}}{\mathrm{prob(e)}+\mathrm{prob}(\pi)+\mathrm{prob(K)}} > 0.8$
- Good Neutral Tracks Selection
  - minimum energy for barrel showers ($|\cos\theta| < 0.8$) : $E_{\mathrm{min}} > 25$ MeV.
  - minimum energy for endcap showers ($0.86 < |\cos\theta| < 0.92$) : $E_{\mathrm{min}} > 50$ MeV.
  - showers in other $|\cos\theta|$ regions are not detected.
  - EMC time requirements : $T \in [0, 14]$ ($\times 50$ns)

Suppess γ Conversion Background

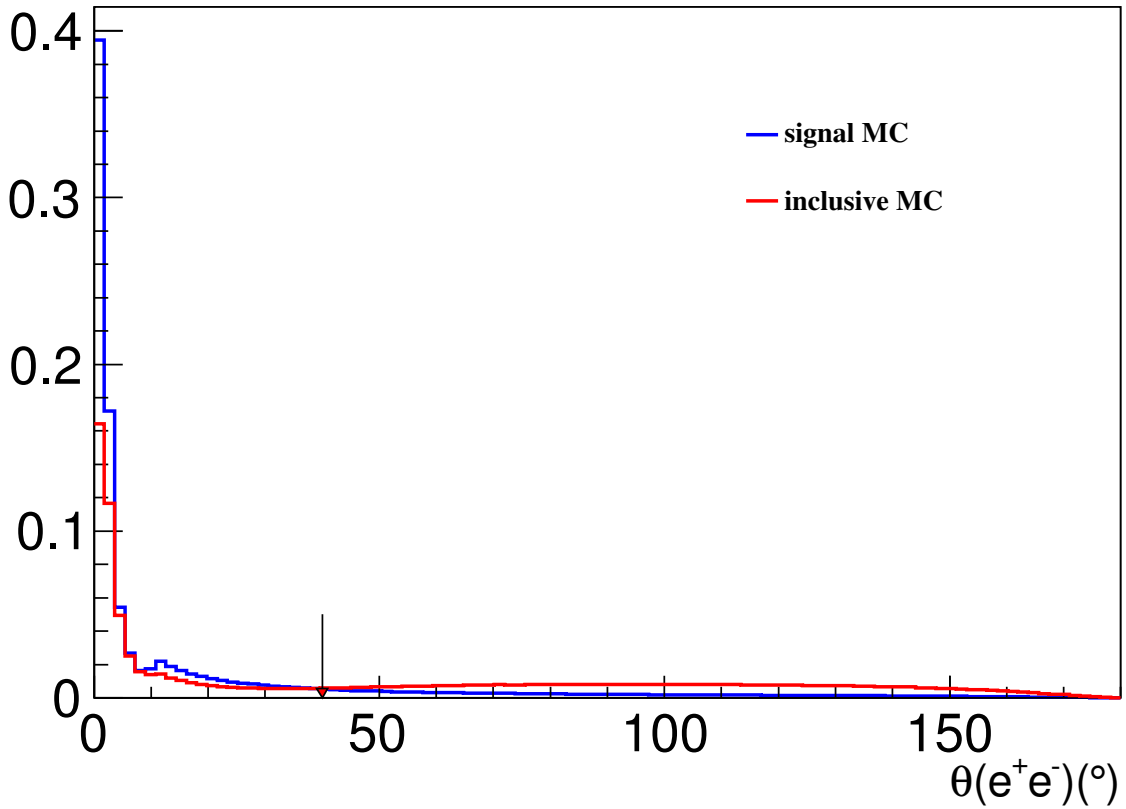
$R_{xy} < 2$ cm.

R_{xy} is defined as the distance between the reconstructed electron pair vertex and interaction position on x-y plane.



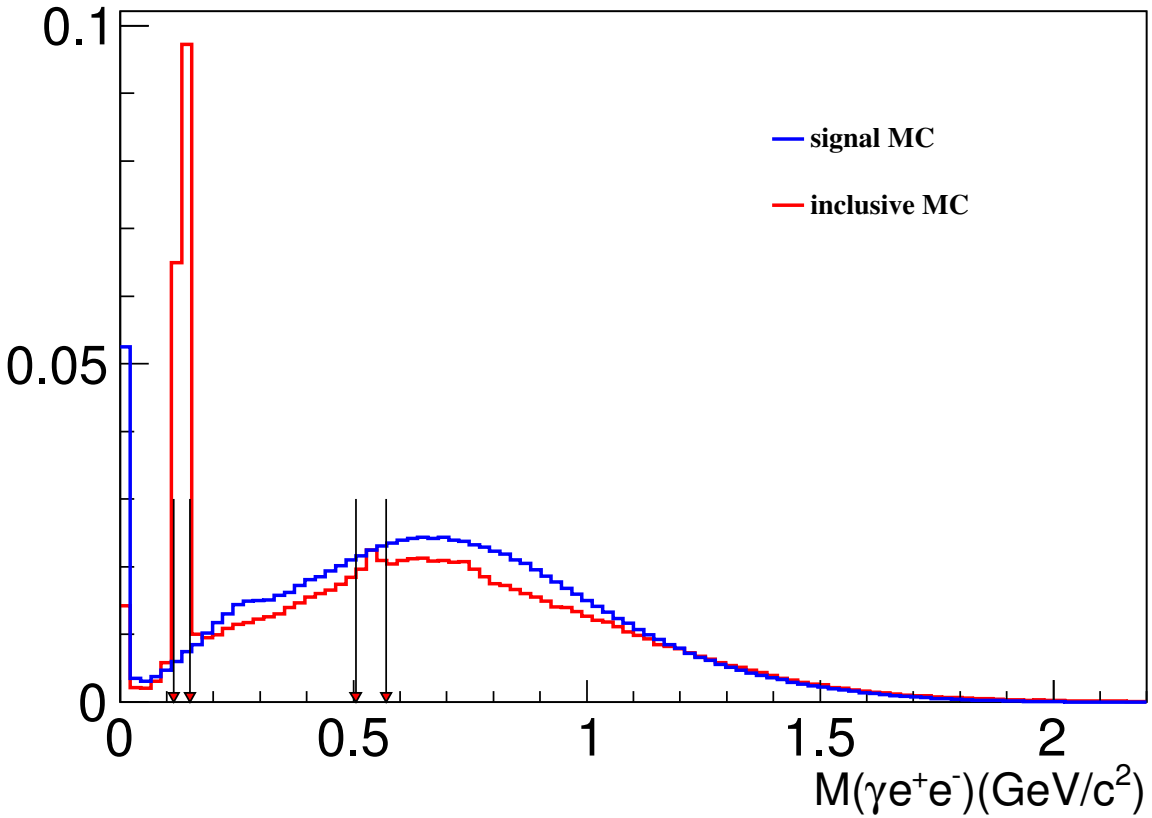
Requirement on $\theta(e^+e^-)$

$\theta(e^+e^-) < 40^\circ$



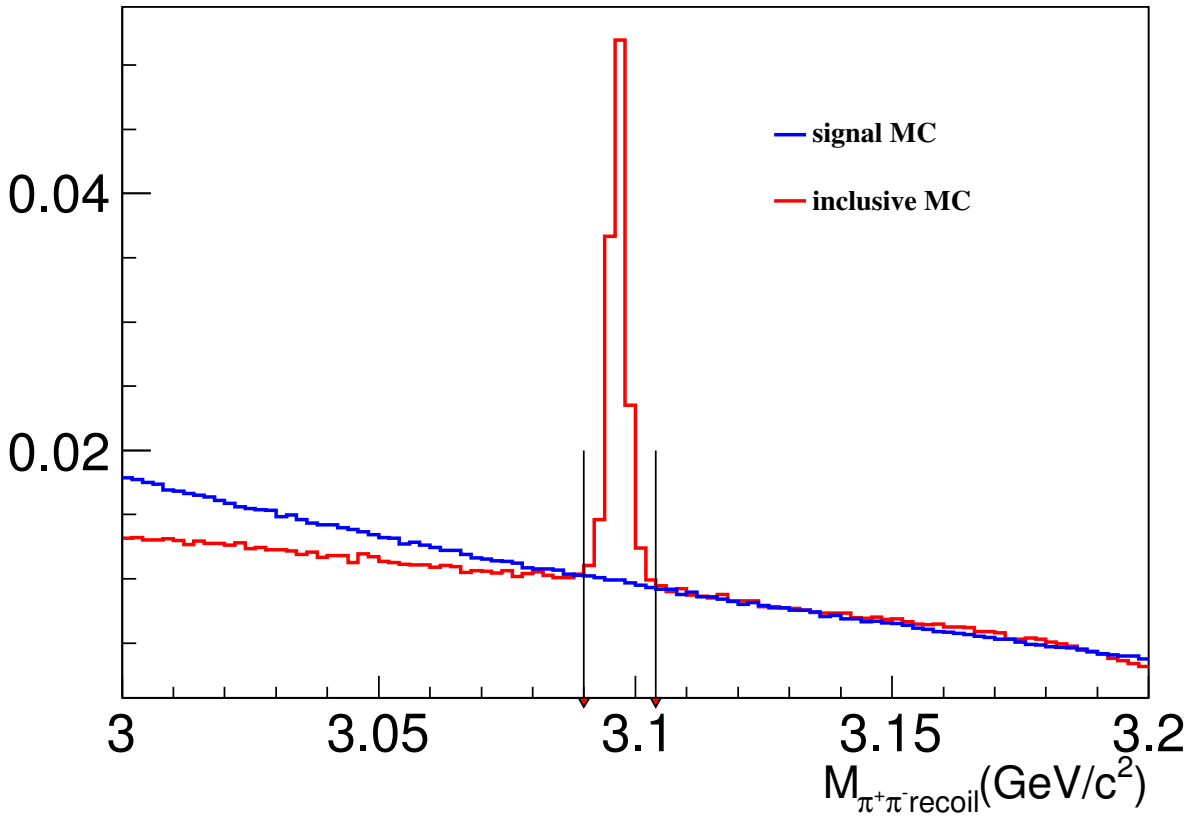
Veto $\pi^0/\eta \to \gamma e^+e^-$ Events

$M(\gamma e^+e^-) < 0.115$ GeV/c^2 or 0.150 GeV/c^2 $< \mathrm{M}(\gamma \mathrm{e}^+\mathrm{e}^-) < 0.505$ GeV/c^2 or $M(\gamma e^+e^-) > 0.570$ GeV/c^2



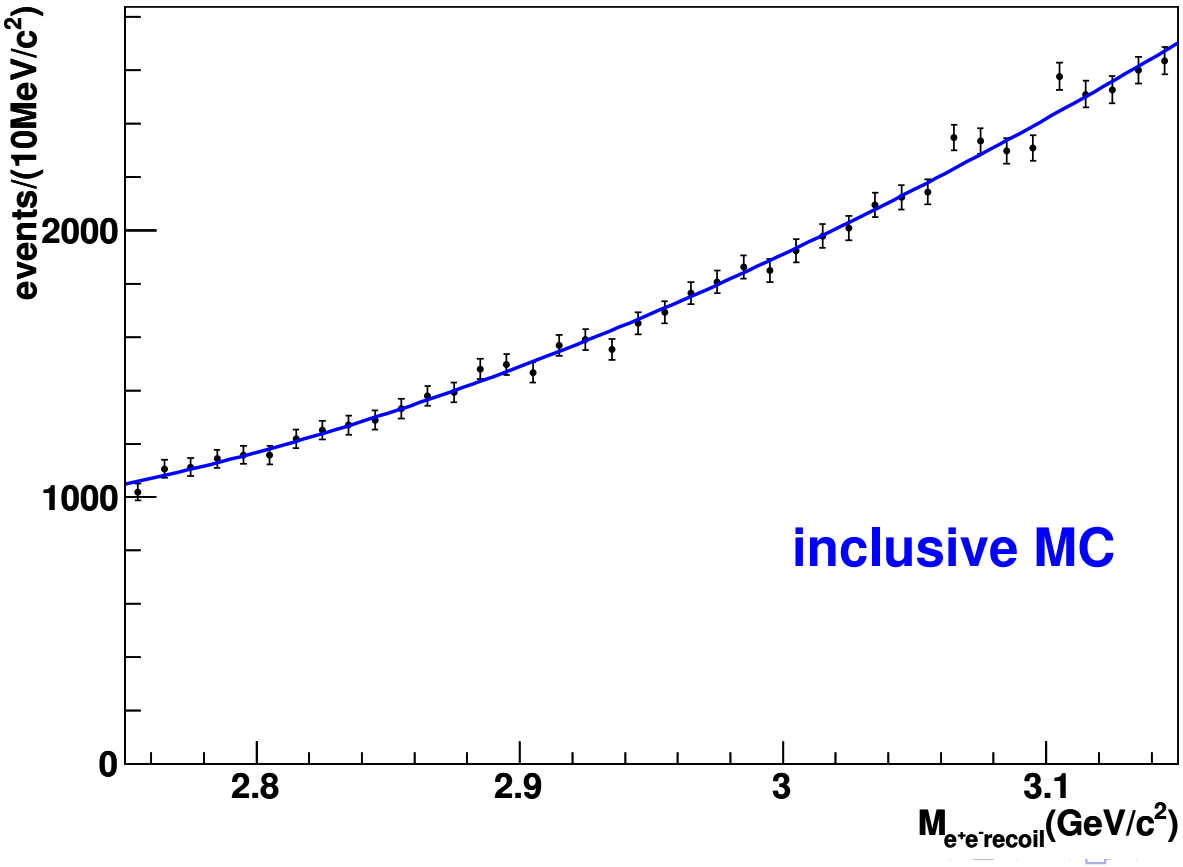
Veto $\psi' \to \pi^+\pi^- J/\psi$ Events

$M_{\pi+\pi-\text{recoil}} < 3.090\ \text{GeV/c}^2$ or $M_{\pi+\pi-\text{recoil}} > 3.104\ \text{GeV/c}^2$



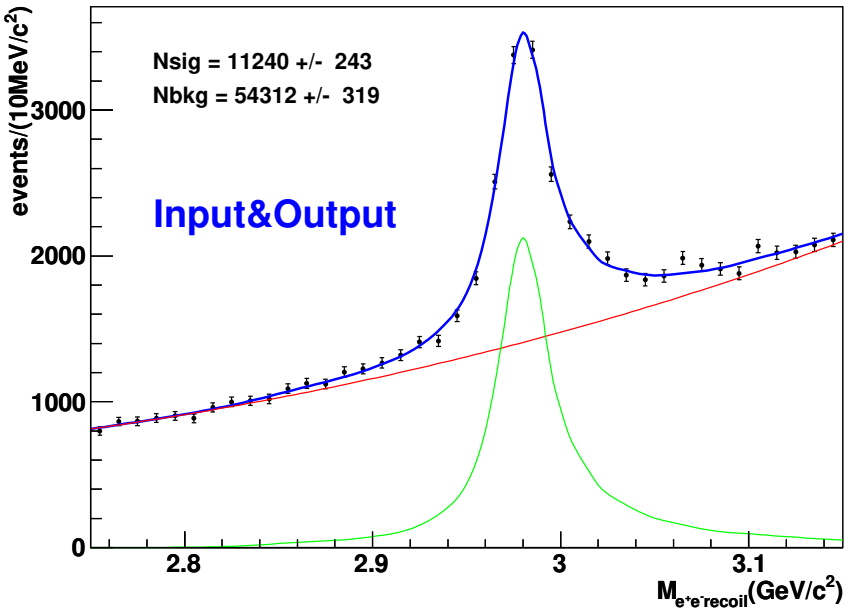
$M_{e+e^-\text{recoil}}$ Distribution

Finally, we use $M_{e+e^-\text{recoil}}$ to obtain the signal yields.
From the $M_{e+e^-\text{recoil}}$ distribution of inclusive Monte Carlo, we could find that there is no peaking background and the background could be described well by third order Chebyshev polynomial.



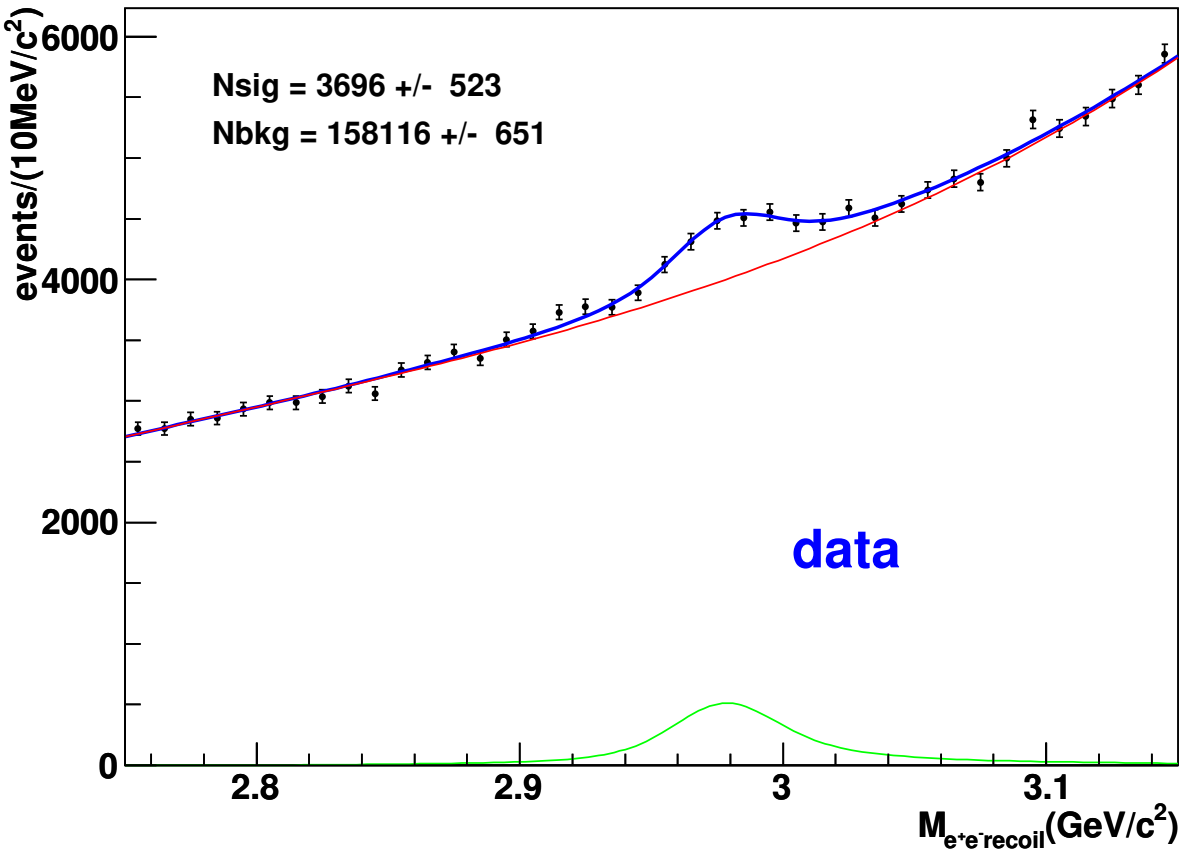
Input and Output Check

- Input : $B(\psi' \to e^+e^-\eta_c) = 1.50 \times 10^{-4}$
  0.06M signal Monte Carlo + 400M official inclusive Monte Carlo.
- Output : $B(\psi' \to e^+e^-\eta_c) = (1.51 \pm 0.03) \times 10^{-4}$.
- IO result keeps consistent within statistical uncertainty.



$B(\psi' \to e^+e^-\eta_c)$

The statistical significance of this channel is more than 9.8 σ. With the efficiency $\epsilon = 18.61\%$, we obtain $B(\psi' \to e^+e^-\eta_c) = (4.43 \pm 0.63) \times 10^{-5}$.



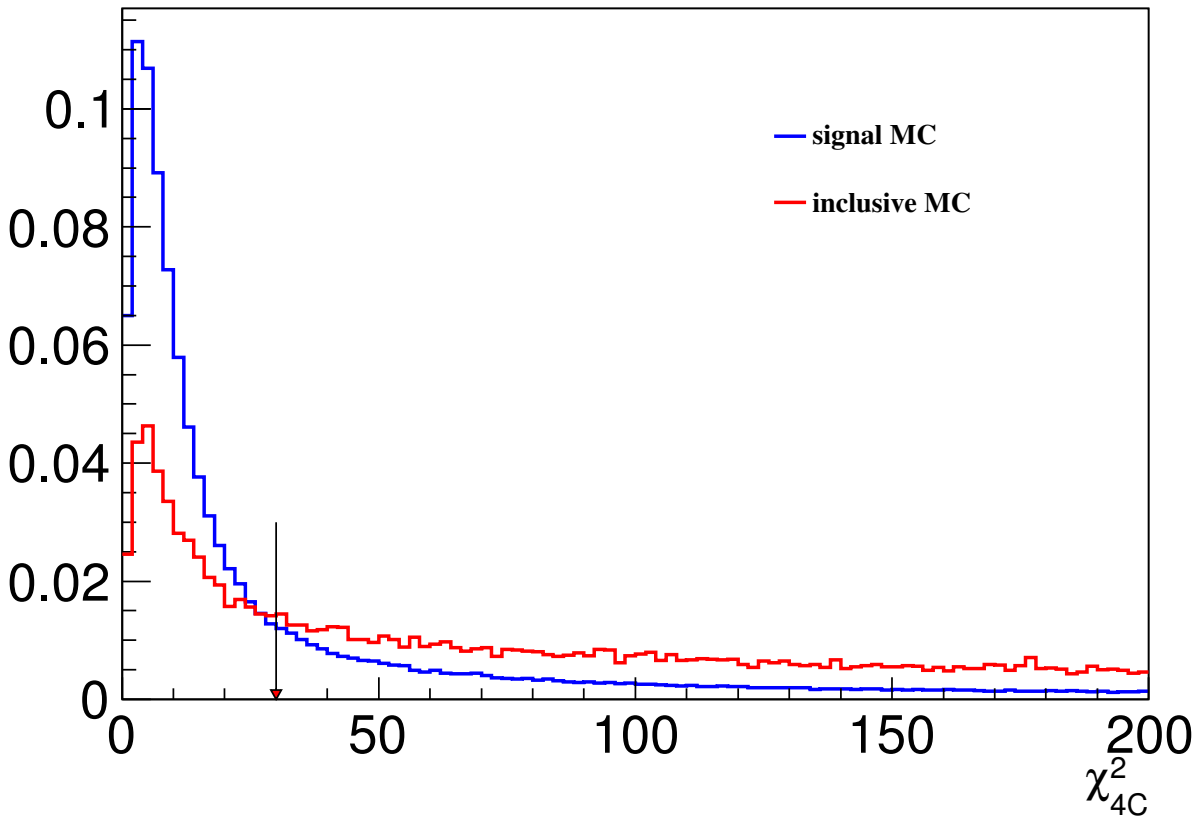
$$\psi' \to e^+e^-\eta_c,\ \eta_c \to \text{muli mode}$$

Event Selection

- Reconstruct η_c with multi tag modes
  - EtactoKsKPi = mode 601
  - EtactoKKPi0 = mode 602
  - EtactoEtaPiPi = mode 603
  - EtactoEtaPiPiPiPi = mode 604
  - EtactoKKPiPiPi0 = mode 605
  - EtactoKsKPiPiPi = mode 606
  - EtactoPiPiPi0Pi0 = mode 607
  - EtactoPiPiPiPiPi0Pi0 = mode 608
  - EtactoPiPiPiPiPiPi = mode 609
- Electron PID
  - dE/dx + TOF + EMC
  - $\mathrm{prob(e)} > 0$
  - $\mathrm{prob(e)} > \mathrm{prob}(\pi)$
  - $\mathrm{prob(e)} > \mathrm{prob(K)}$
  - $\frac{\mathrm{prob(e)}}{\mathrm{prob(e)}+\mathrm{prob}(\pi)+\mathrm{prob(K)}} > 0.8$
- Perform 4C Fit

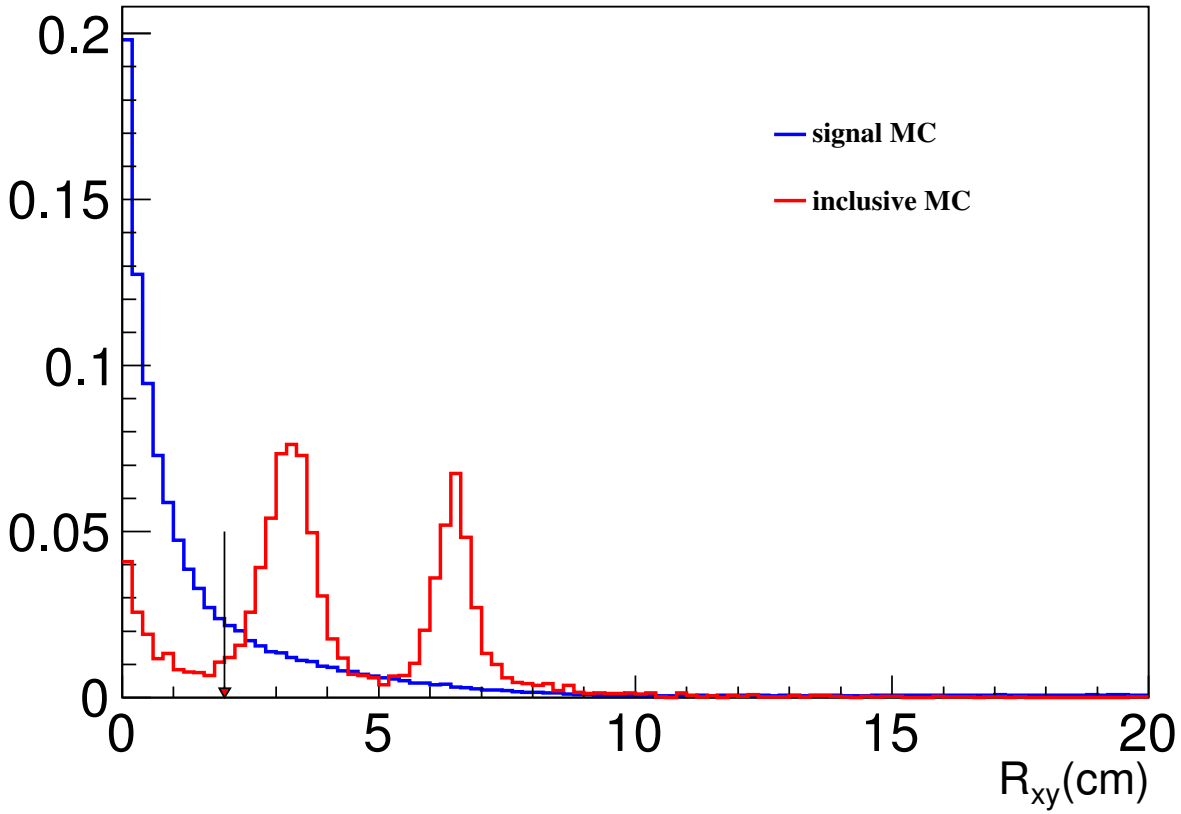
Requirement on χ^2_{4C}

$\chi^2_{4C} < 30$



Suppess γ Conversion Background

$R_{xy} < 2$ cm.



Requirement on $\theta(e^+e^-)$

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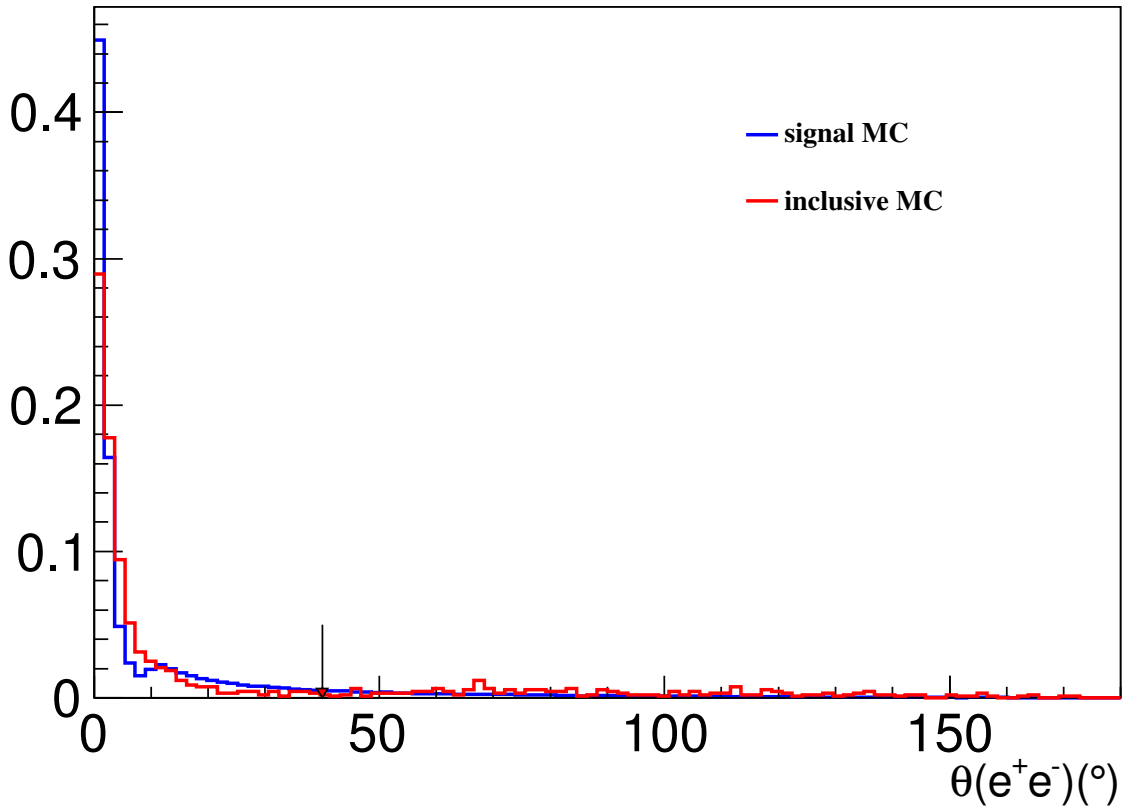
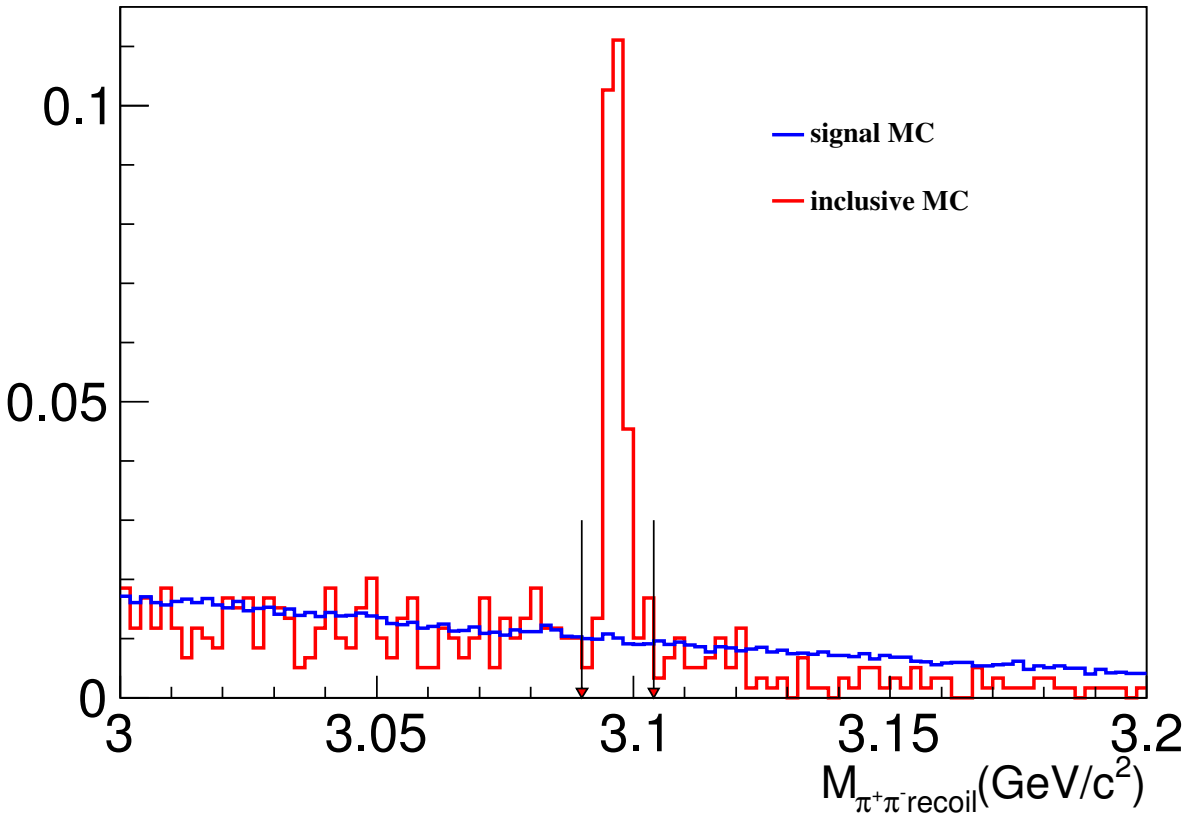


Veto $\psi' \to \pi^+\pi^- J/\psi$ Events

$M_{\pi+\pi-\text{recoil}} < 3.090\ \text{GeV/c}^2$ or $M_{\pi+\pi-\text{recoil}} > 3.104\ \text{GeV/c}^2$



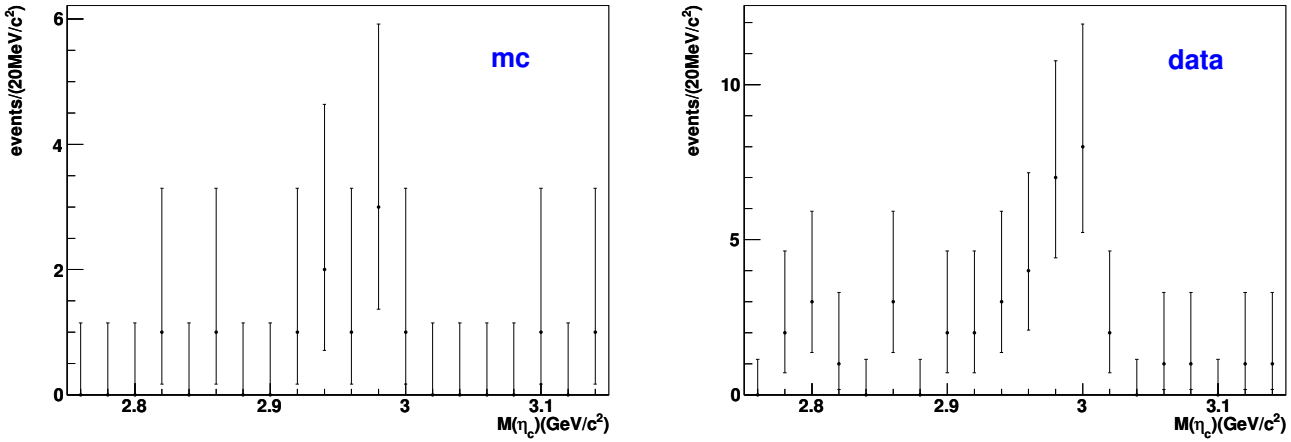


Figure: mode 601 : $K_s K^+ \pi^-$

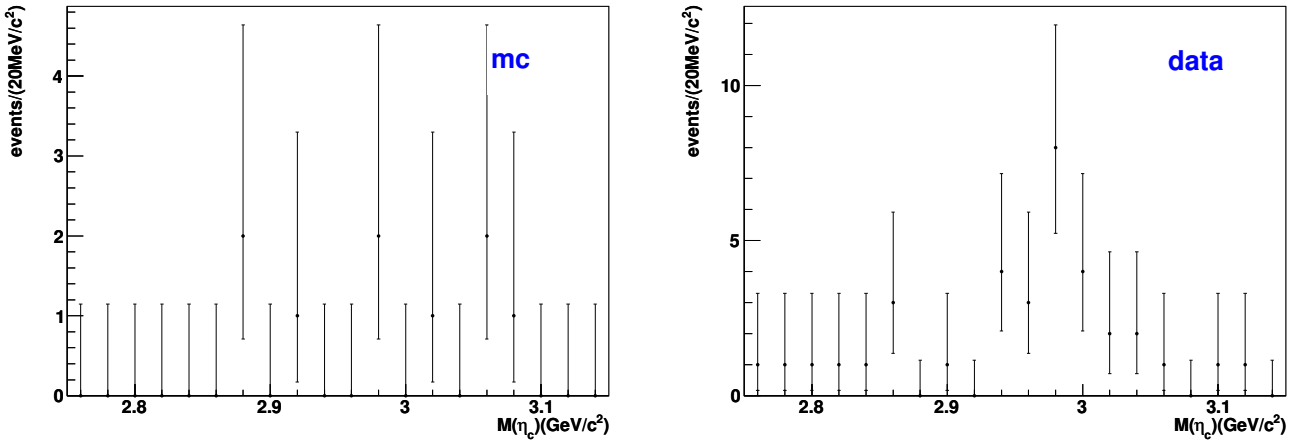


Figure: mode 602 : $K^+ K^- \pi^0$

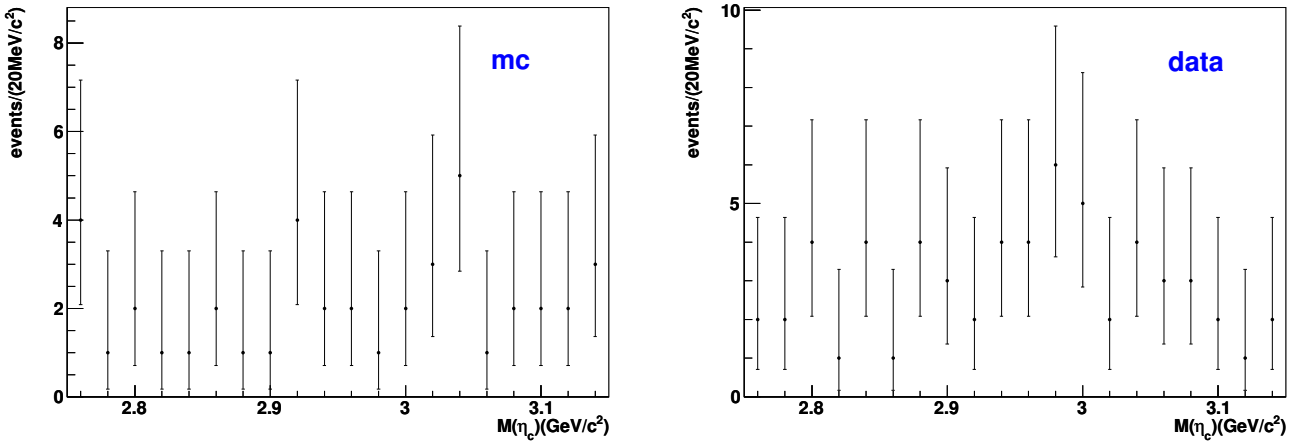


Figure: mode 603 : $\eta\pi^+\pi^-$

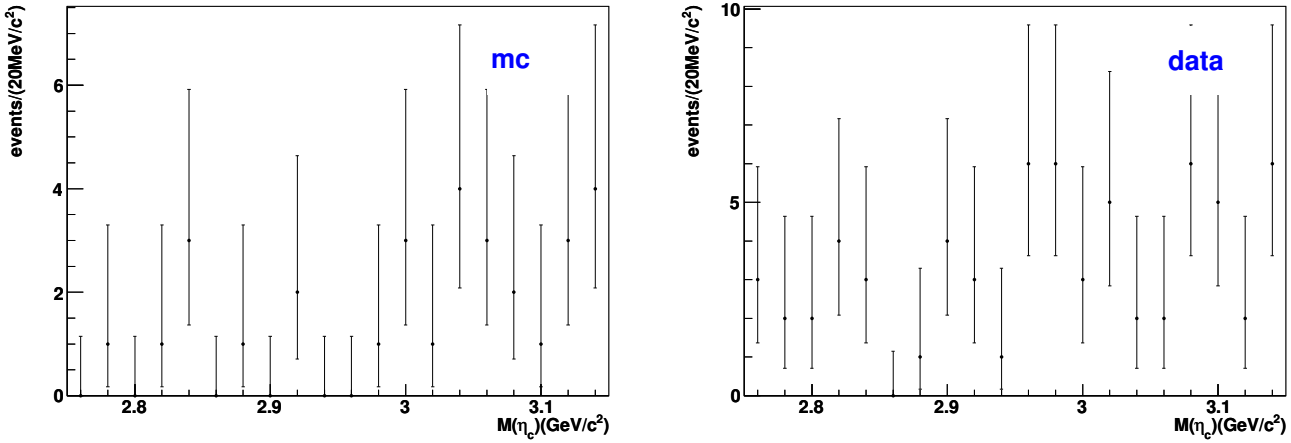


Figure: mode 604 : $\eta 2(\pi^+\pi^-)$

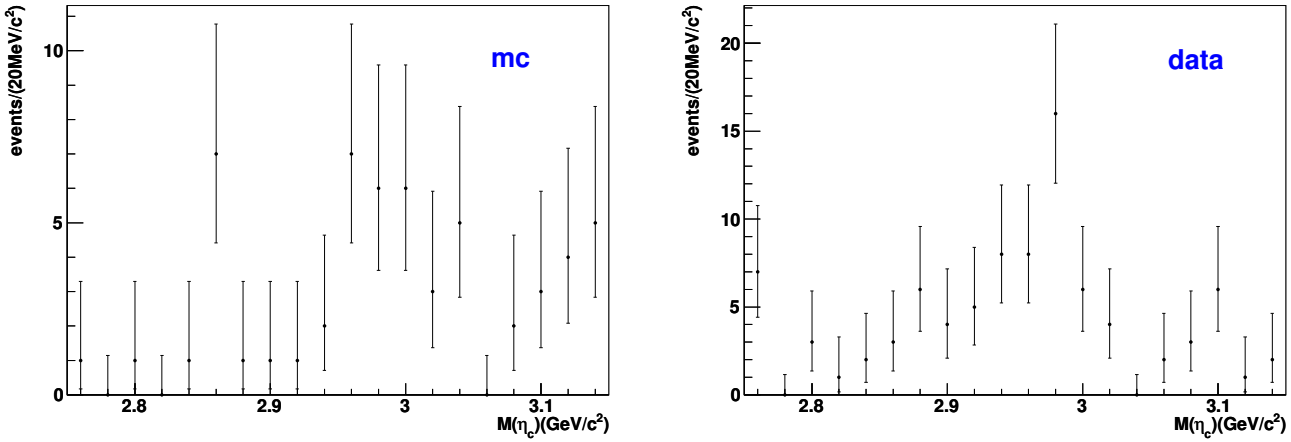


Figure: mode 605 : $K^+K^-\pi^+\pi^-\pi^0$

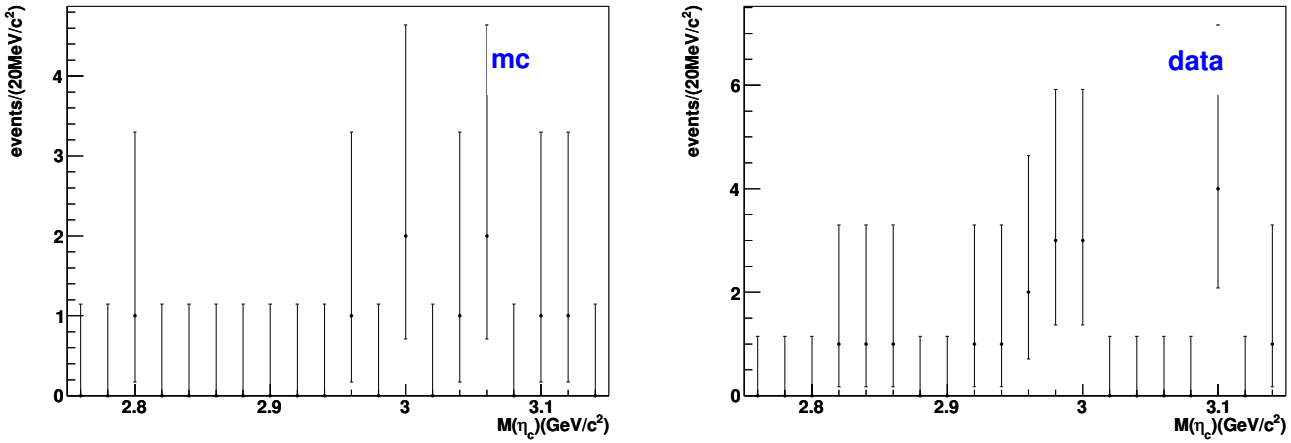
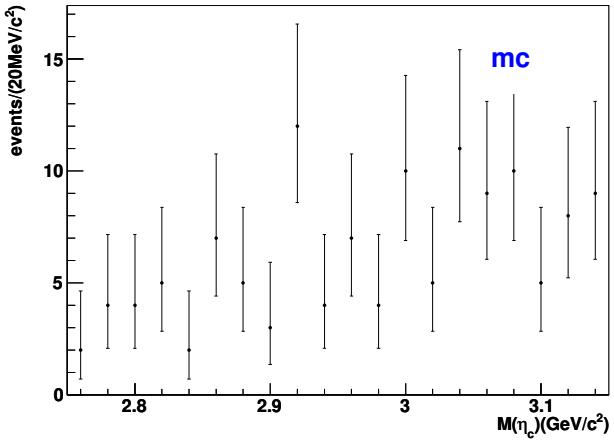


Figure: mode 606 : $K_sK^-\pi^+\pi^+\pi^-$



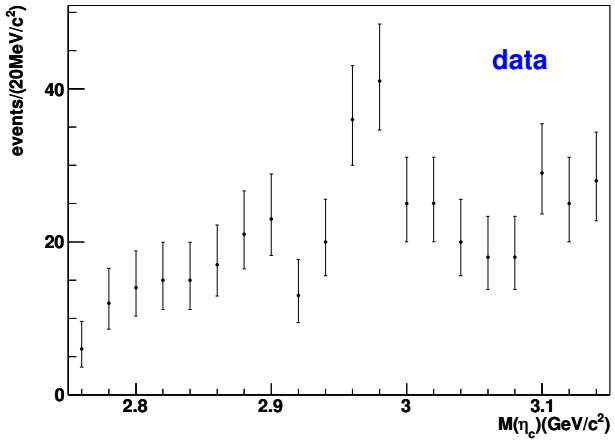
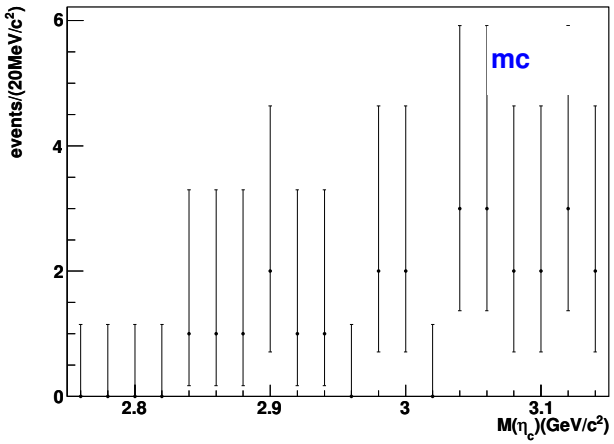


Figure: mode 608 : $2(\pi^+\pi^-\pi^0)$



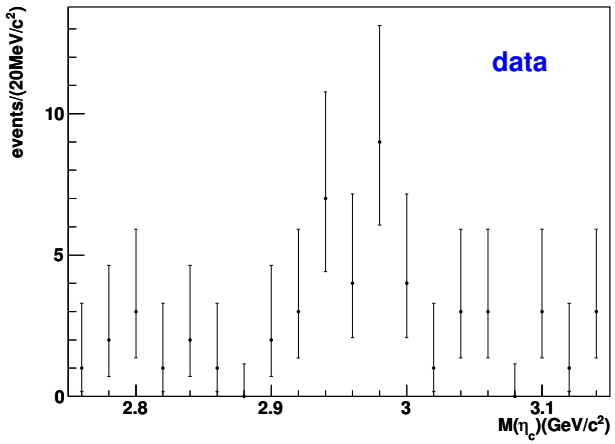
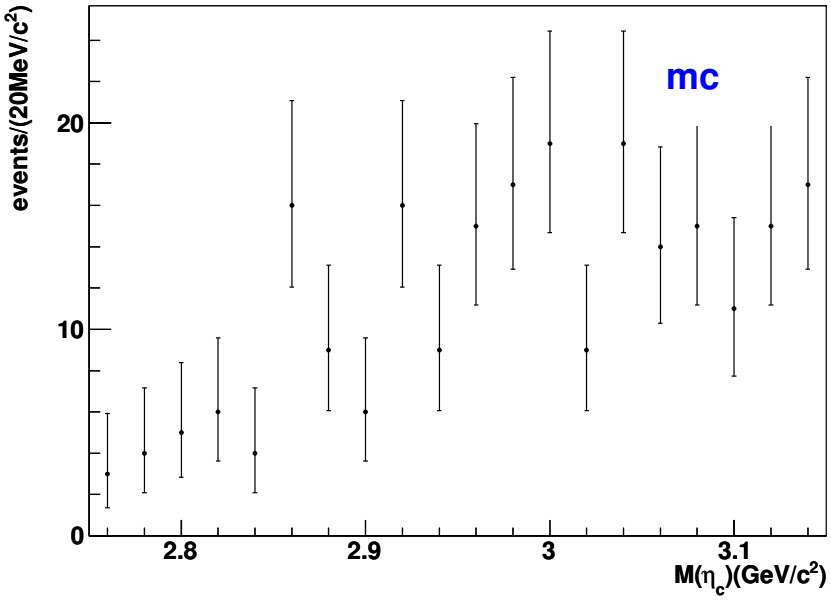


Figure: mode 609 : $3(\pi + \pi^-)$



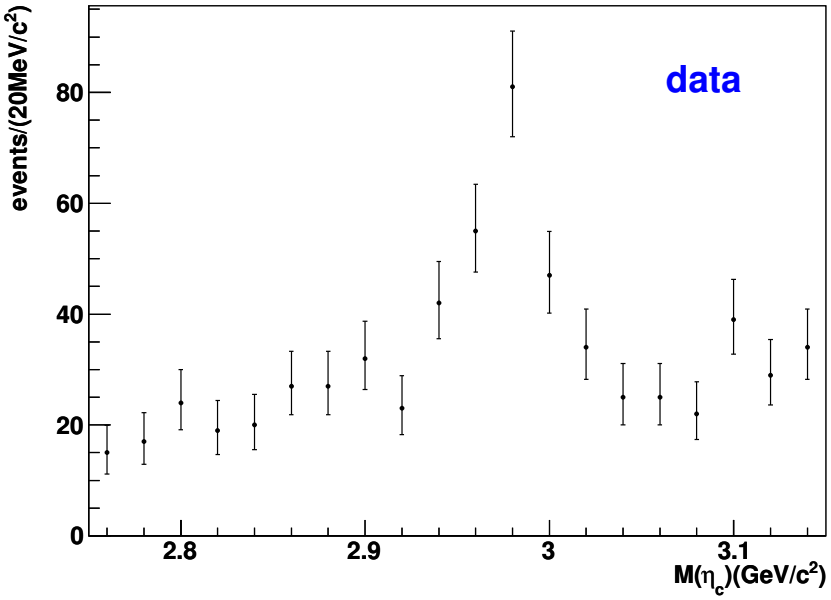
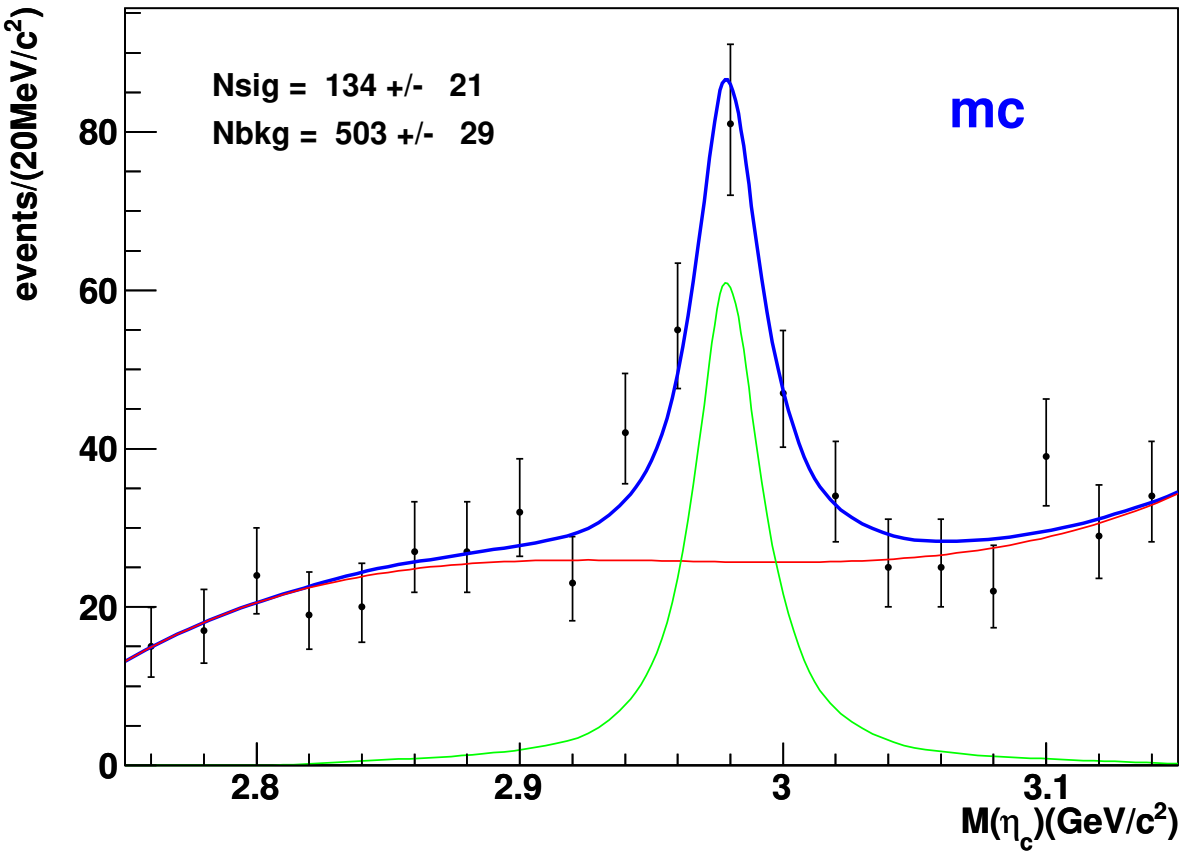


Figure: total modes

$B(\psi' \to e^+e^-\eta_c)$

The statistical significance of this channel is more than 7.2 σ. With the efficiency $\epsilon = 7.45\%$, we obtain $B(\psi' \to e^+e^-\eta_c) = (4.01 \pm 0.63) \times 10^{-5}$.



Summary

- Without reconstructing η_c, we obtain the branching fraction $B(\psi' \to e^+e^-\eta_c) = (4.43 \pm 0.63) \times 10^{-5}$.
- With fully reconstructing η_c by multi decay modes, we obtain the branching fraction $B(\psi' \to e^+e^-\eta_c) = (4.01 \pm 0.63) \times 10^{-5}$.
- The results from two methods are consistent with each other

Thank You!

BACK UP

Cited from Xinxin's report

After average over the polarizations of J/Ψ and sum over the spin of leptons. We can get

$$|T|^2 = \frac{32\pi^2\alpha^2 m_{J/\Psi}^2}{q^4}|f_{VP}(q^2)|^2 \cdot h \tag{16}$$

where

$$\begin{aligned} h = & k_1 \cdot k_2(q_x^2 + q_y^2 + 2q_z^2) \\ & + 2q_z^2(k_{1x}k_{2x} + k_{1y}k_{2y}) \\ & - 2q_z k_{2z}(k_{1x}q_x + k_{1y}q_y) \\ & - 2q_z k_{1z}(k_{2x}q_x + k_{2y}q_y) \\ & + 2k_{1z}k_{2z}(q_x^2 + q_y^2) \\ & + m_l^2(q_x^2 + q_y^2 + 2q_z^2) \end{aligned} \tag{17}$$

The experimenter can use the amplitude for MC simulation.

Cited from Xinxin's report

- ✓ θ is the angle between $\vec{q}$ and beam.
- ✓ θ also is the angle between the momentum of pseudoscalar and beam.
- ✓ The angle distribution is independent on the form factor.
- ✓ The figure shows such distribution, where $J/\Psi \to \eta e^+ e^-$
  - ✓ Form factor: $f_{VP}(q^2) = \frac{1}{1-q^2/m^2_{pole}}$
  - ✓ $m_{pole} = 3.686$ GeV