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:

  $(448.1 \pm 2.9) \times 10^6$ ψ' events taken at $\sqrt{s} = 3.686$ GeV in 2009 ($(107.0 \pm 0.8) \times 10^6$) and 2012 ($(161.63 \pm 0.13)\mathrm{pb}^{-1}$), $(506.92 \pm 0.23)\mathrm{pb}^{-1}$).

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

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

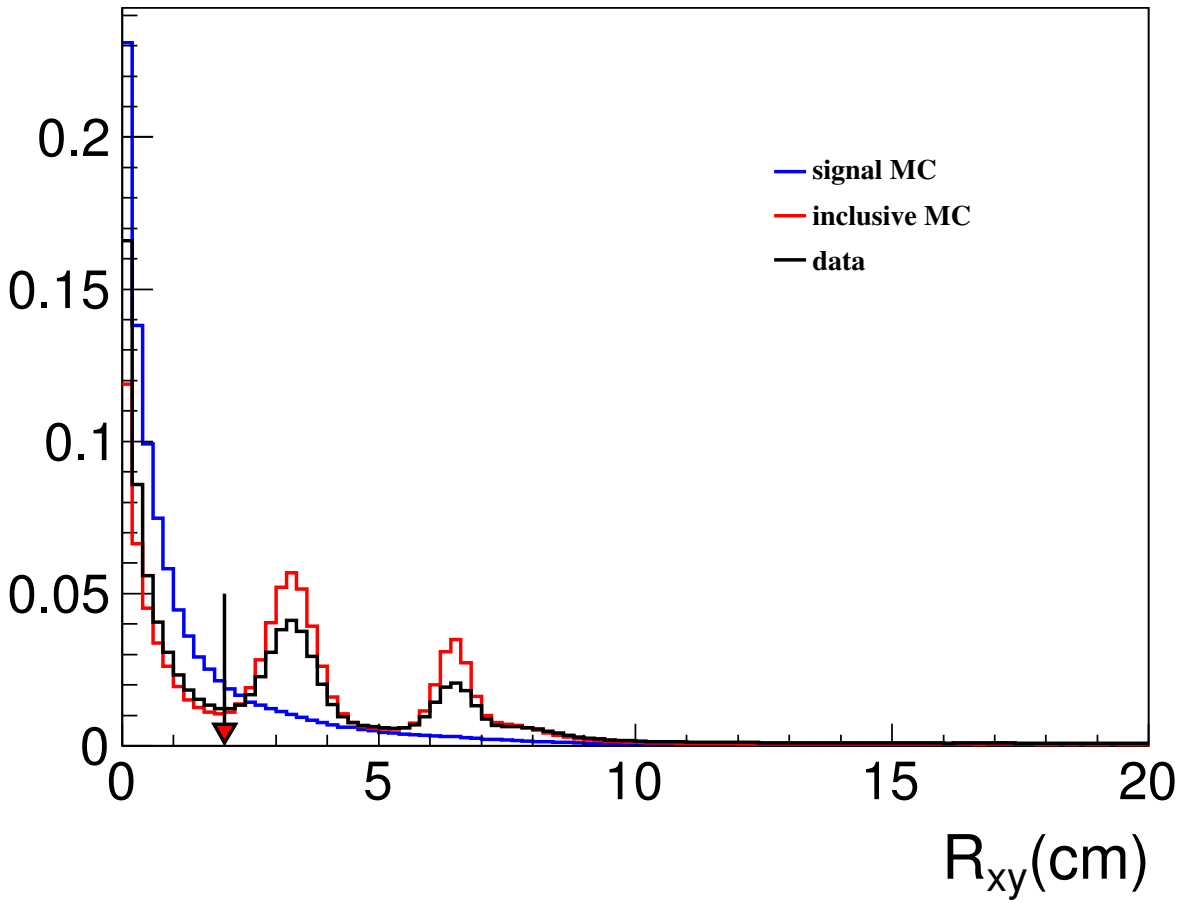
Event Selection

- 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

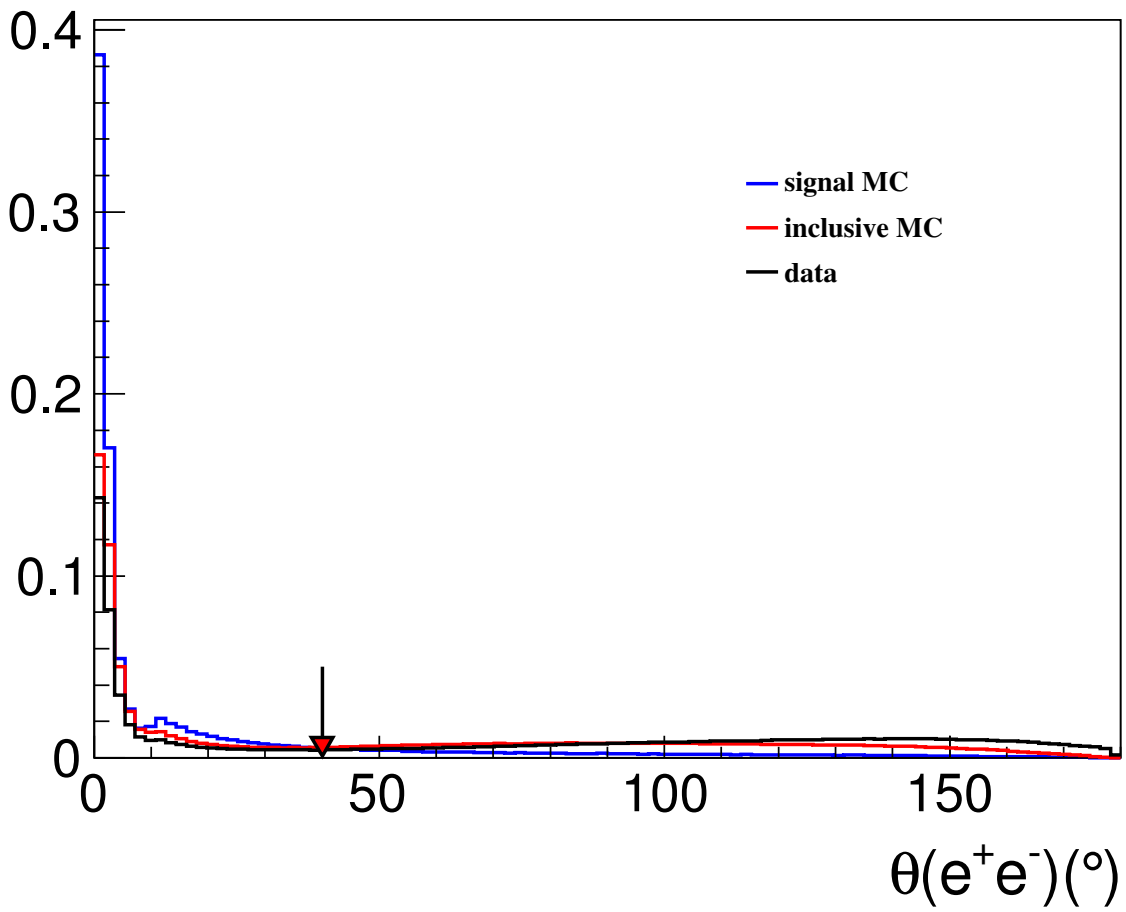
$R_{xy} < 2$ cm.

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



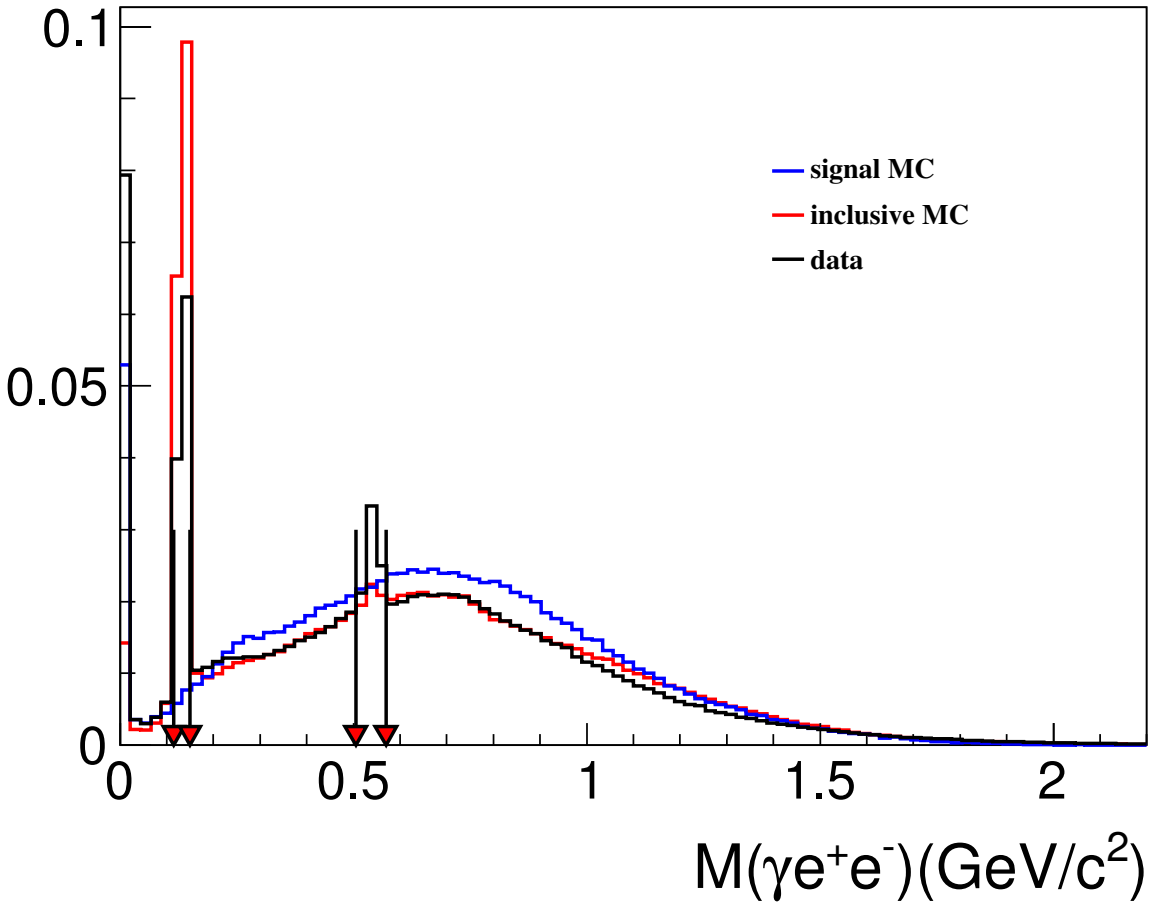
Requirement on $\theta(e^+e^-)$

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



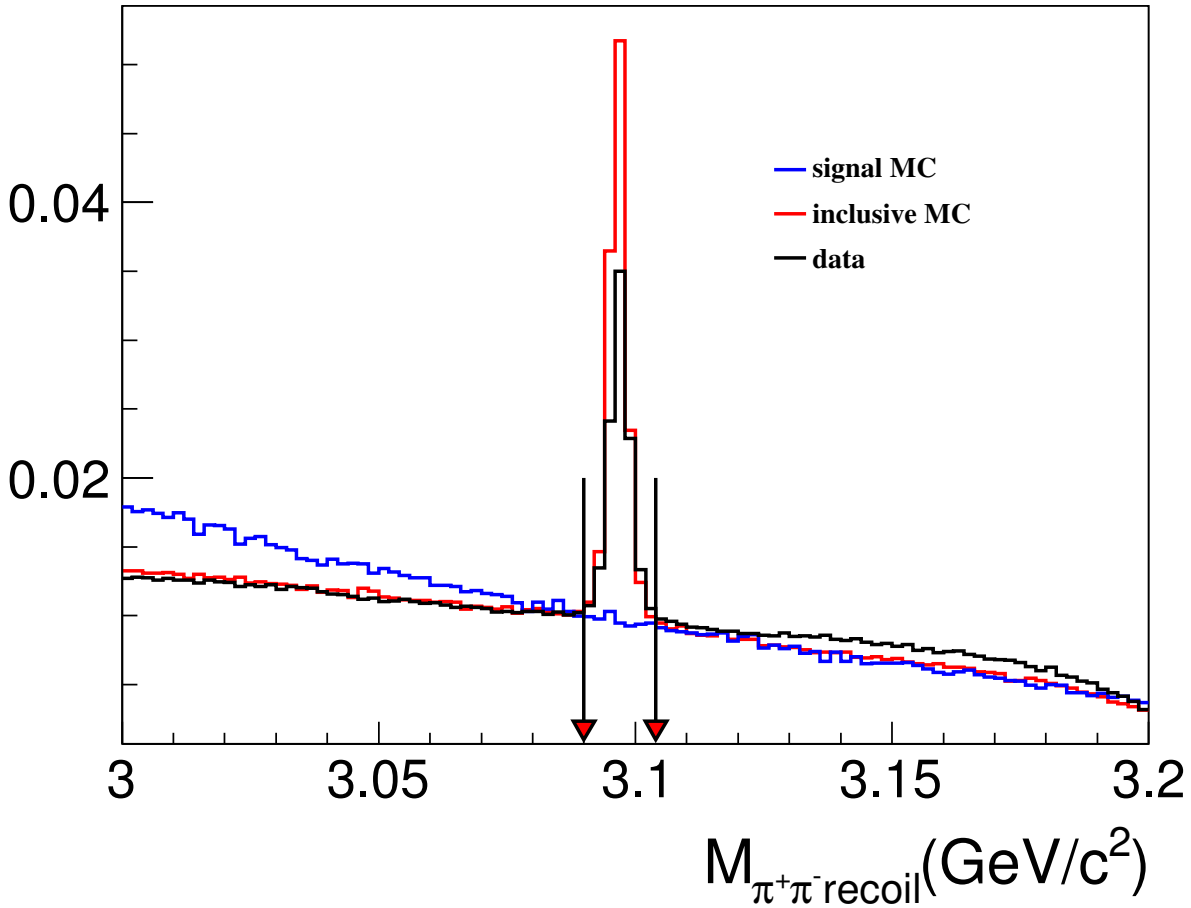
Veto $\pi^0/\eta \to \gamma e^+e^-$ Events

$M(\gamma e^+e^-) < 0.115$ 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



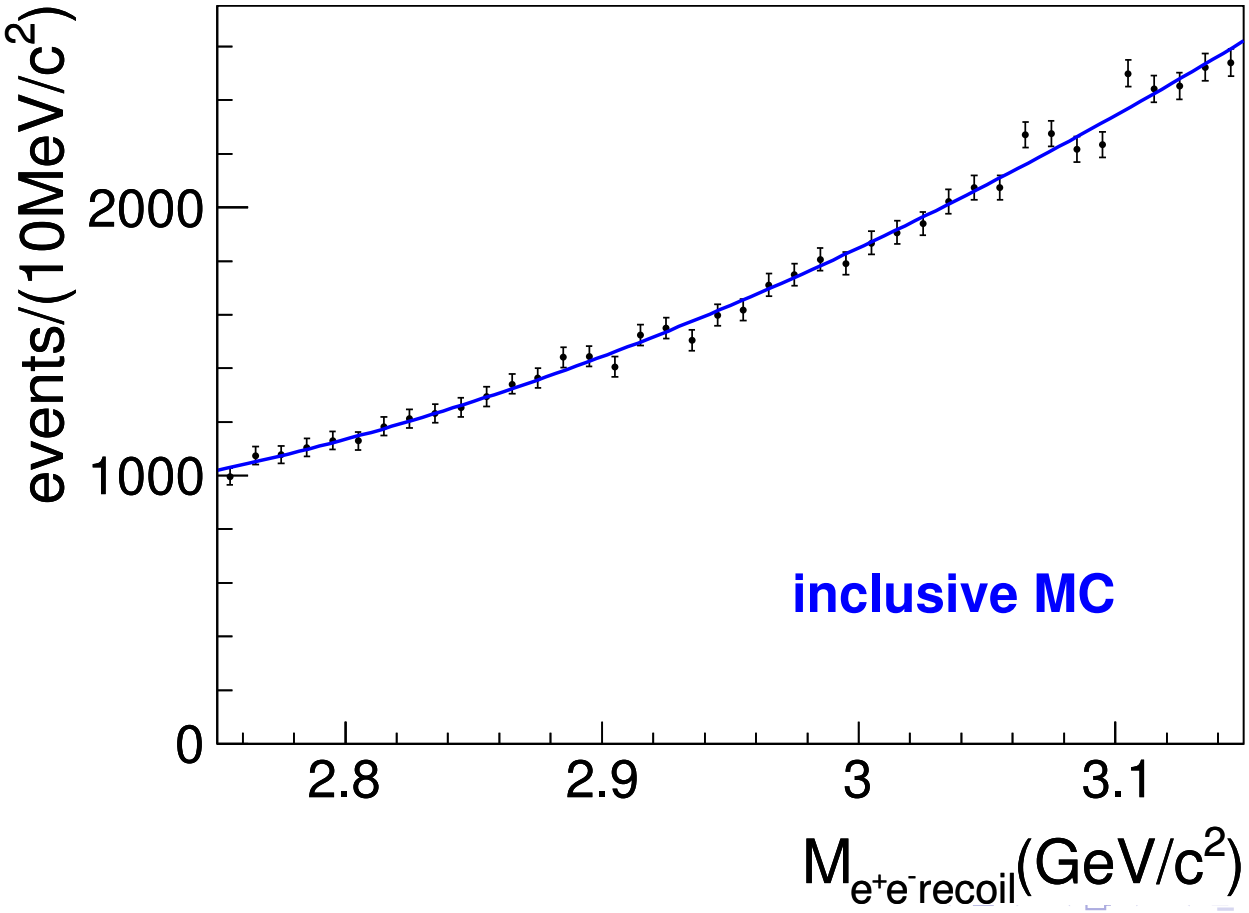
Veto $\psi' \to \pi^+\pi^- J/\psi$ Events

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



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



The Line Shape of η_c

- The q^2-dependent differential width of $\psi' \to Pl^+l^-$ is[c]

$$\begin{aligned}\frac{d\Gamma(\psi' \to Pl^+l^-)}{dq^2} =& \frac{1}{3}\frac{\alpha^2}{24\pi m_{\psi'}^3}\frac{|f_{\psi' P}(q^2)|^2}{q^2}(1-\frac{4m_l^2}{q^2})^{\frac{1}{2}}(1+\frac{2m_l^2}{q^2}) \\ & \times[(m_{\psi'}^2 - m_P^2 + q^2)^2 - 4m_{\psi'}^2 q^2]^{\frac{3}{2}}\end{aligned} \tag{1}$$

- For the corresponding radiative decay of $\psi' \to P\gamma$, the decay width is[c]

$$\Gamma(\psi' \to P\gamma) = \frac{1}{3}\frac{\alpha(m_{\psi'}^2 - m_P^2)^3}{8m_{\psi'}^3}|f_{\psi' P}(0)|^2 \tag{2}$$

- For special situation $\psi' \to \eta_c\gamma$, the decay width is[d]

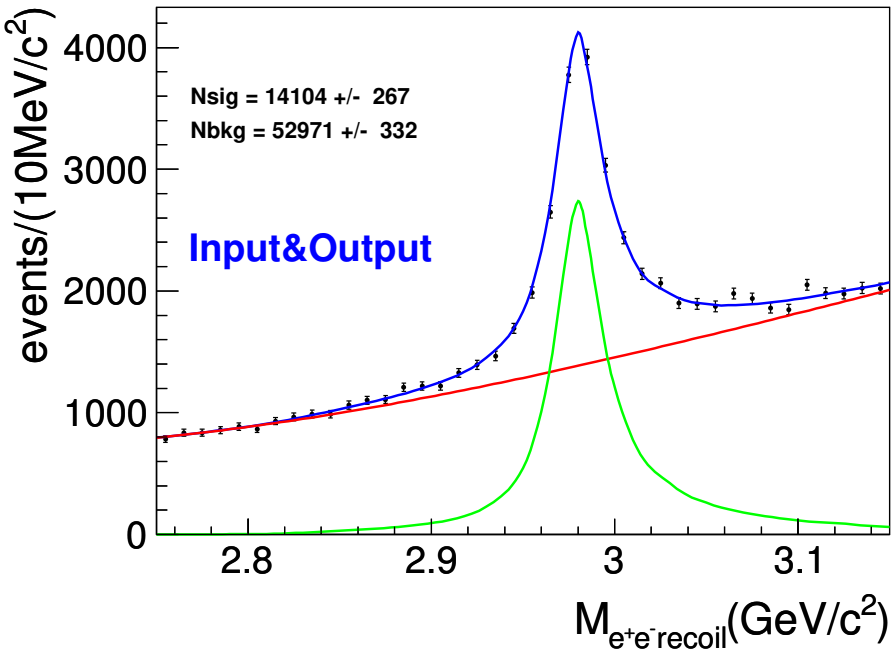
$$\begin{aligned}\Gamma(\psi' \to \eta_c\gamma) &= \frac{16}{3}\frac{4}{9}\frac{\alpha k_\gamma^3}{m_\psi^2}[1+ak_\gamma^2]^2, \quad k_\gamma = \frac{m_{\psi'}^2 - m_P^2 + q^2}{2m_{\psi'}} \\ &= \frac{1}{3}\frac{64}{9m_\psi^2}\frac{\alpha(m_{\psi'}^2 - m_P^2 + q^2)^3}{8m_{\psi'}^3}[1+a(\frac{m_{\psi'}^2 - m_P^2 + q^2}{2m_{\psi'}})^2]^2\end{aligned} \tag{3}$$

- So, we assume $f_{\psi' P}(q^2) = 1 + a(\frac{m_{\psi'}^2 - m_P^2 + q^2}{2m_{\psi'}})^2$

[c] J.Fu, H.B.Li, X.Qin and M.Z.Yang, Mod.Phys.Lett.A27,125022(2012)
[d] Nora Brambilla, Yu Jia, and Antonio Vairo Physical Review D 73, 054005 (2006)

Input and Output Check

- Input : $B(\psi' \to e^+e^-\eta_c) = 2.0 \times 10^{-4}$
  0.08M signal Monte Carlo + 400M official inclusive Monte Carlo.
- Efficiency $\epsilon = 17.84\%$
- Output : $B(\psi' \to e^+e^-\eta_c) = (1.98 \pm 0.04) \times 10^{-4}$.
- IO result keeps consistent within statistical uncertainty.



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

The Branching fraction is $B(\psi' \to e^+e^-\eta_c) = (4.72 \pm 0.63) \times 10^{-5}$. and the statistical significance of this channel is 10.2 σ.