Preliminary analysis for the decay of $\psi(2S)\rightarrow\gamma\eta_c(2S)\rightarrow\gamma\pi^+\pi^-\eta(\gamma\gamma)$

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Outline

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Motivation

- Measurements about $\eta_c(2S)$ decay are scarce.
- Maybe there is certain relationship between hadronic decays of $\eta_c(2S)$ and η_c , like J/ψ and $\psi(2S)$.

$\eta_c(2S)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	hadrons	not seen	
Γ_2	$K\overline{K}\pi$	(1.9±1.2) %	
Γ_3	$K\overline{K}\eta$	(5 ±4) $\times 10^{-3}$	
Γ_4	$2\pi^+2\pi^-$	not seen	
Γ_5	$\rho^0\rho^0$	not seen	
Γ_6	$3\pi^+3\pi^-$	not seen	
Γ_7	$K^+K^-\pi^+\pi^-$	not seen	
Γ_8	$K^{*0}\overline{K}^{*0}$	not seen	
Γ_9	$K^+K^-\pi^+\pi^-\pi^0$	(1.4±1.0) %	
Γ_{10}	$K^+K^-2\pi^+2\pi^-$	not seen	
Γ_{11}	$K^0_S K^-2\pi^+\pi^-$ + c.c.	seen	
Γ_{12}	$2K^+2K^-$	not seen	
Γ_{13}	$\phi\phi$	not seen	
Γ_{14}	$p\overline{p}$	seen	
Γ_{15}	$\gamma\gamma$	(1.9±1.3) $\times 10^{-4}$	
Γ_{16}	$\gamma J/\psi(1S)$	< 1.4 %	90%
Γ_{17}	$\pi^+\pi^-\eta$	not seen	
Γ_{18}	$\pi^+\pi^-\eta'$	not seen	
Γ_{19}	$\pi^+\pi^-\eta_c(1S)$	< 25 %	90%

PDG 2019

- Search for potential structure with the channel, $\eta_c(2S) \rightarrow \pi^+\pi^-\eta$.

BOSS version and Data set

- BOSS version: 7.0.4
- Data samples:

  ✓09 ψ(2S) data (161.63 pb^{-1})
  ✓12 ψ(2S) data (506.92 pb^{-1})
  ✓off-resonance data at 3.65 GeV (43.88 pb^{-1})

- Official inclusive MC samples for 09/12 ψ(2S) data are used.
- Exclusive MC

  ✓ $\psi(2S) \longrightarrow \gamma\eta_c(2S)$, $\eta_c(2S) \longrightarrow \pi^+\pi^-\eta$
  ✓ $\psi(2S) \longrightarrow \gamma\chi_{cJ}$, $\chi_{cJ} \longrightarrow \pi+\pi-\pi^0/\eta$
  ✓ $\psi(2S) \longrightarrow \gamma\pi^+\pi^-\eta$
  ✓ $\psi(2S) \longrightarrow \pi^+\pi^-\eta\gamma_{FSR}$

Selection

- Charged tracks

  ✓ $|\cos\theta|<0.93$, $R_z < 10.0$ cm, $R_{xy} < 1.0$ cm

  Exactly 2 good charged tracks with 0 net charge.

- PID

  ✓ Prob(π) > Prob(K)

  ✓ Prob(π) > 0.001

- Photons

  ✓ E > 25 MeV(Barrel), E > 50 MeV (Endcap)

  ✓ Dang > 20^o

  ✓ TDC $\in$ [0,14] (in the unit of 50 ns).

  At least 3 good photons.

Selection

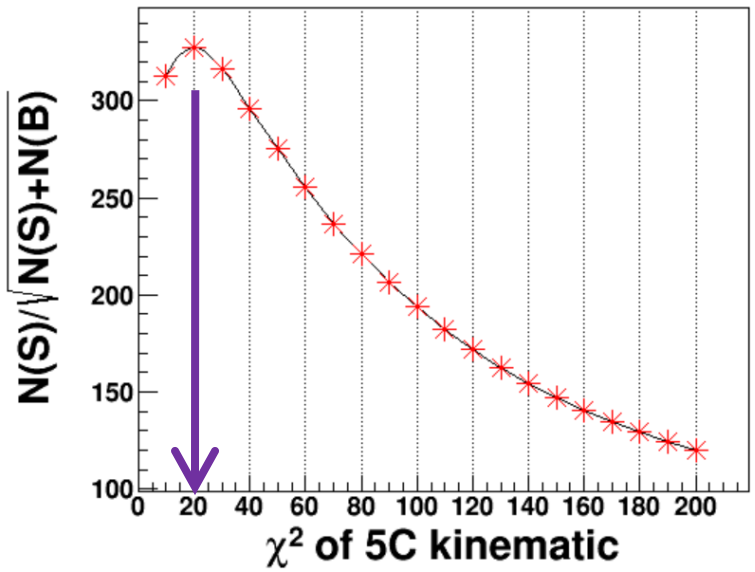
- 5C kinematic fit ($\psi(2S)\longrightarrow\gamma\pi^+\pi^-\eta(\gamma\gamma)$)
  - ✓ Four momentum and η mass
  - ✓ Iterate the fit over all combination of η candidates and the radiative photon
  - ✓ The combination with the least $\chi^2(5C)$ will be taken as the best one

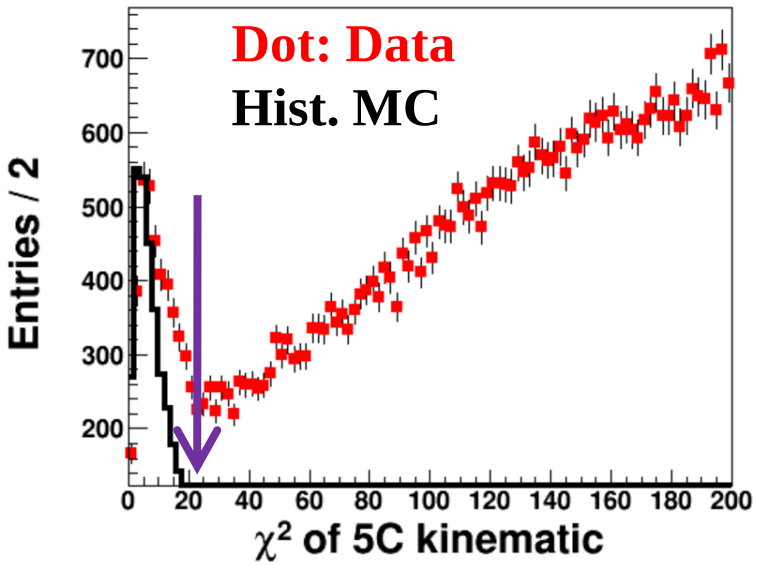
- In order to suppress the background from $\psi(2S)\longrightarrow\gamma\gamma\eta(\gamma\gamma)\pi^+\pi^-$, and $\psi(2S)\longrightarrow\eta(\gamma\gamma)\pi^+\pi^-\gamma_{FSR}$, the requirement below is applied to the sample:

$$\chi^2(5C) < \chi^2_{2\gamma}(5C),\ \ \chi^2(5C) < \chi^2_{4\gamma}(5C)$$

Selection

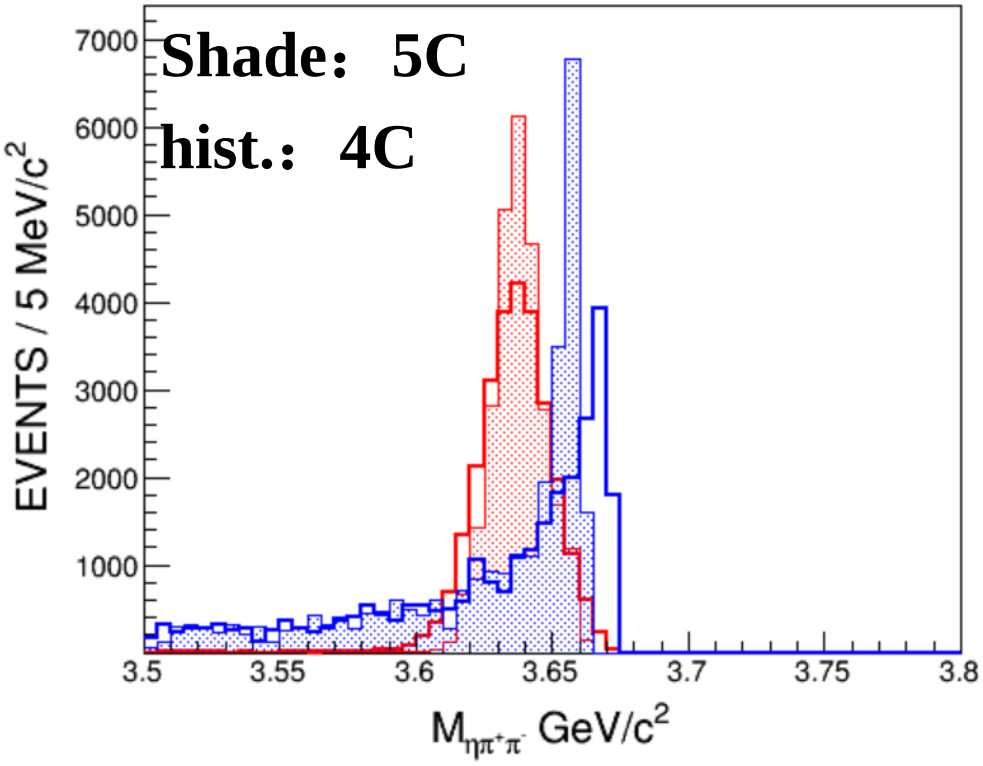
- 5C kinematic fit ($\psi(2S) \longrightarrow \gamma\pi^+\pi^-\eta(\gamma\gamma)$)





$\chi^2(5C)<20$

Selection

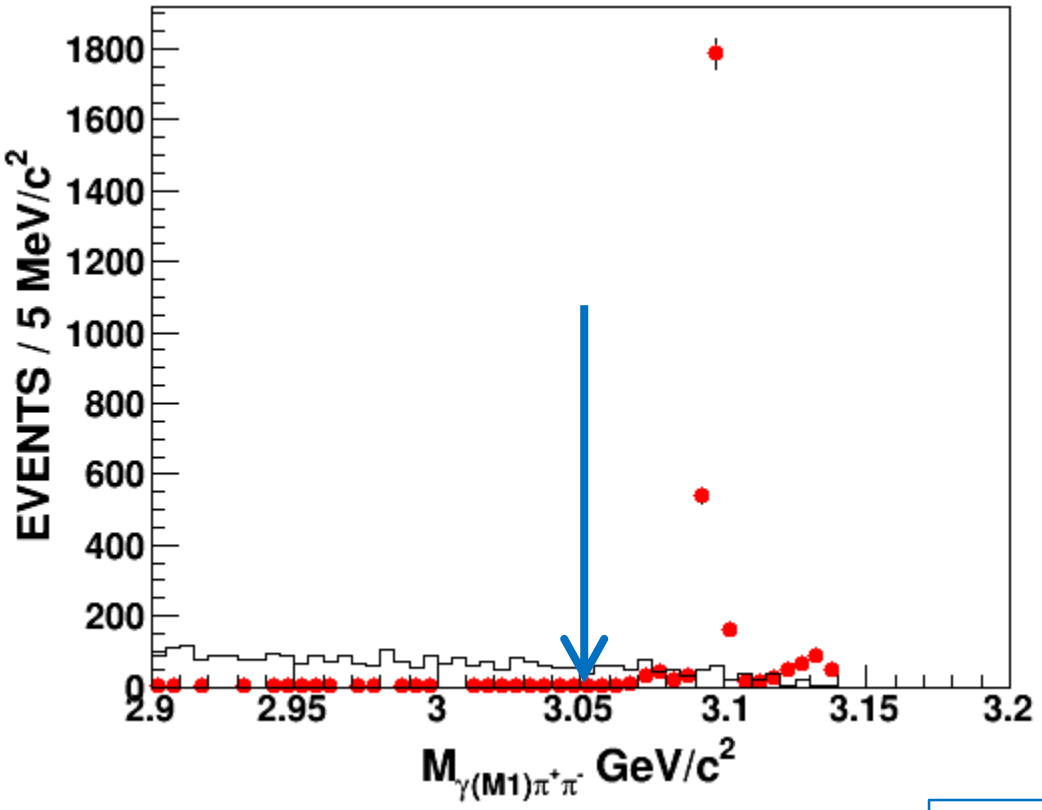


4C： the constraints for mass of η and four momentum are retained, but the mass of radiative photon is floated.

Red :$\psi(2S)\rightarrow\gamma\eta_c(2S)\rightarrow\gamma\pi^+\pi^-\eta(\gamma\gamma)$

Blue :$\psi(2S)\rightarrow\pi^+\pi^-\eta(\gamma\gamma)$

Selection

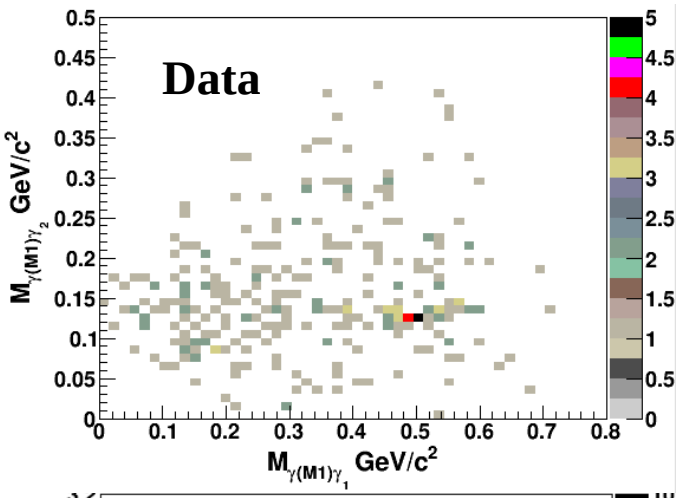


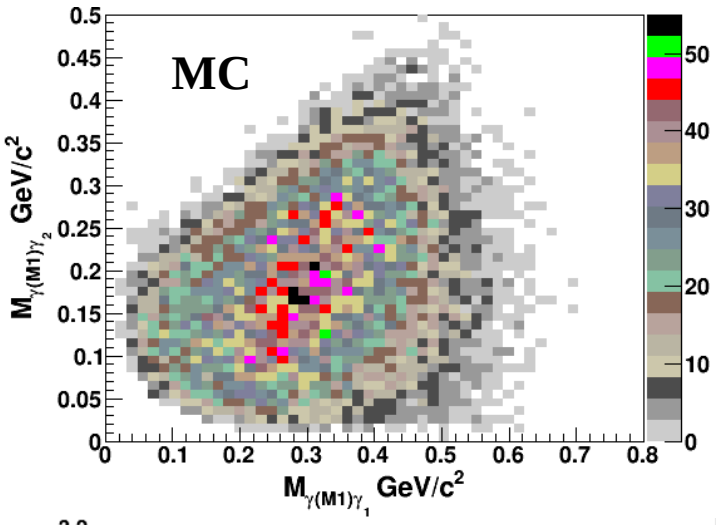
$M_{\gamma(M1)\,\pi^+\pi^-} < 3.05\ \mathrm{GeV}/c^2$

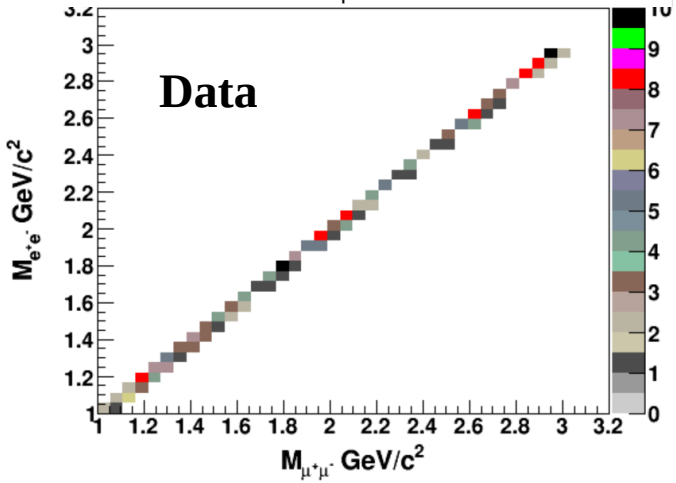
Veto backgrounds associated with J/ψ

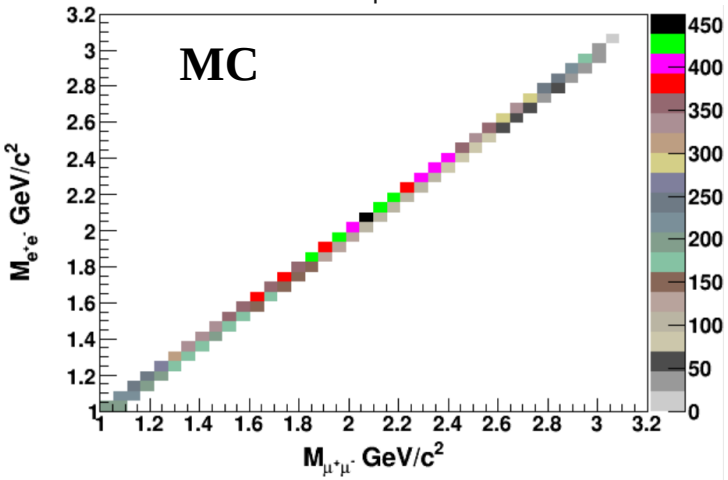
Final efficiency: ε=19.8%

Selection









There are no obvious π^0 and J/ψ signals in the invariant mass of $\gamma(M1)\gamma_{1/2}$ and $\mu^+\mu^-/e^+e^-$

Main background

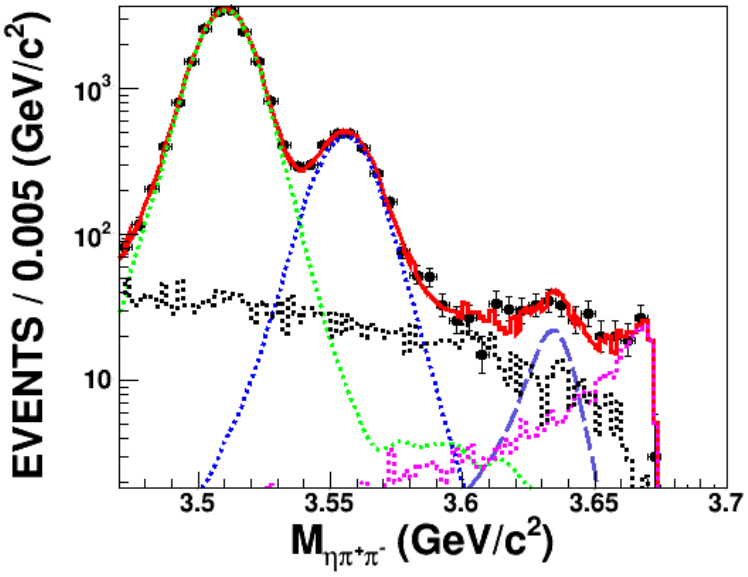
- According to the study with inclusive MC, the main backgrounds are :

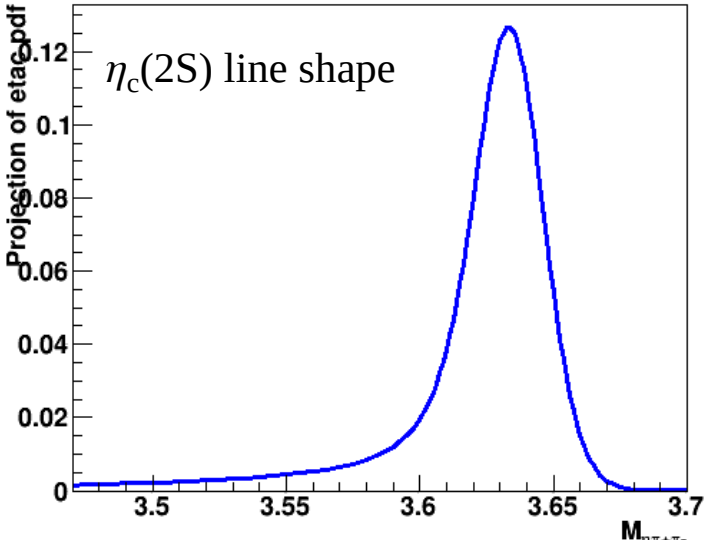
  - ✓ $\psi(2S) \longrightarrow \gamma\chi_{c1/2}$, $\chi_{c1/2} \longrightarrow \pi^+\pi^-\pi^0/\eta$
  - ✓ $\psi(2S) \longrightarrow \gamma\, \pi^0\, (\eta)\pi^+\pi^-$ (including resonances, ω, ρ^0,…)
  - ✓ $\psi(2S) \longrightarrow \pi^+\pi^-\eta(\gamma_{FSR})$

Fit of Mass spectrum

- Signal line shape: $\left(E_\gamma^3 \cdot BW(m) \cdot DMP(E_\gamma)\right) \otimes$ Gaussian
  - ✓ m : *invariant mass of* $\pi^+\pi^-\eta$
  - ✓ $E_\gamma : \dfrac{m_{\psi(2S)}^2 - m^2}{2m_{\psi(2S)}}$
  - ✓ $BW(m)$: *Breit – Wigner function*
  - ✓ $DMP(E_\gamma) : \dfrac{E_0^2}{E_\gamma E_0 + (E_\gamma - E_0)^2}$ $\left(E_0 = \dfrac{m_{\psi(2S)}^2 - m_{\eta_c(2S)}^2}{2m_{\psi(2S)}} \right)$ (V.V. Anashin *et al.*, arXiv:1012.1694 [hep-ex])
- Other components
  - ✓ $\psi(2S) \longrightarrow \gamma\chi_{c1/2}$, $\chi_{c1/2} \longrightarrow \pi^+\pi^-\eta$: MC⊗Gaussian
  - ✓ $\psi(2S) \longrightarrow \gamma\eta\pi^+\pi^-$: MC shape
  - ✓ $\psi(2S) \longrightarrow \pi^+\pi^-\eta(\gamma_{FSR})$: MC shape

Fit of Mass spectrum





η_c(2S) line shape

Red curve: total fit

Blue dashdoted: η_c(2S)

Green dash and Blue dash: χ_{c1} and χ_{c2}

Purple dash: $\psi(2S) \longrightarrow \pi^+\pi^-\eta(\gamma_{FSR})$ (FSR)

Black dash : $\psi(2S) \longrightarrow \gamma\eta\pi^+\pi^-$ (PHSP)

Fitting result

η_c(2S) : 105 ±21 (5.83σ)

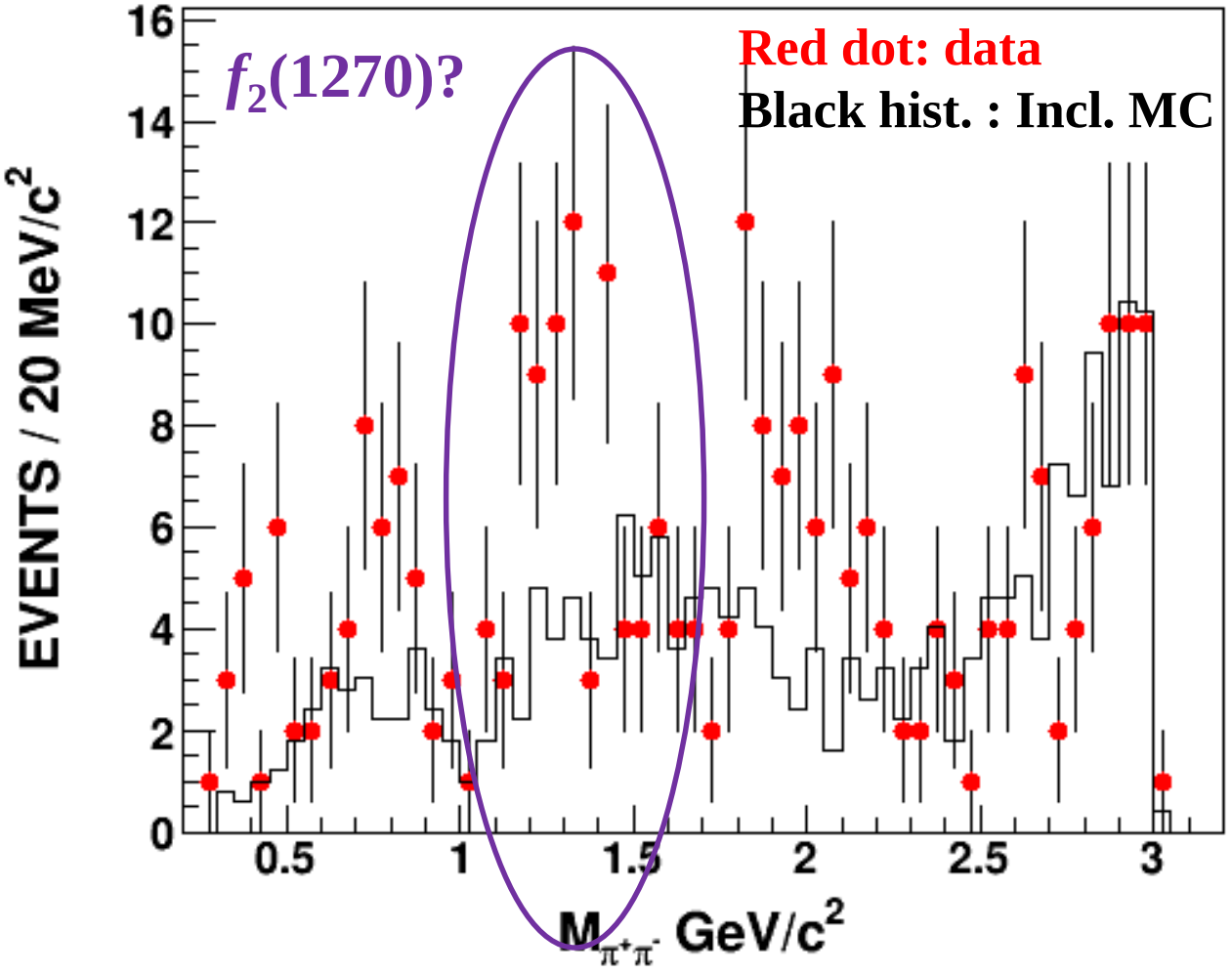
χ_{c1}:17554 ±145

χ_{c2}:2563 ±63

FSR:161 ±23

PHSP:900 ±98

Invariant mass spectrum of $\pi^+\pi^-$ within $\eta_c(2S)$ mass region (3.60--3.65)



Summary

- Using $\psi(2S)$ data sample collected at BESIII, the channel, $\eta_c(2S) \longrightarrow \pi^+\pi^-\eta$, has been observed for the first time with 5.83σ
- The branching fraction of $\eta_c(2S) \longrightarrow \pi^+\pi^-\eta$ is determined to be:

$$Br = \frac{N_{signal}}{N_{\psi(2S)} \cdot \varepsilon \cdot Br_1 \cdot Br_2} = (4.29 \pm 0.86) \times 10^{-3}$$

$$Br_1 : \psi(2S) \to \gamma\eta_c(2S)$$

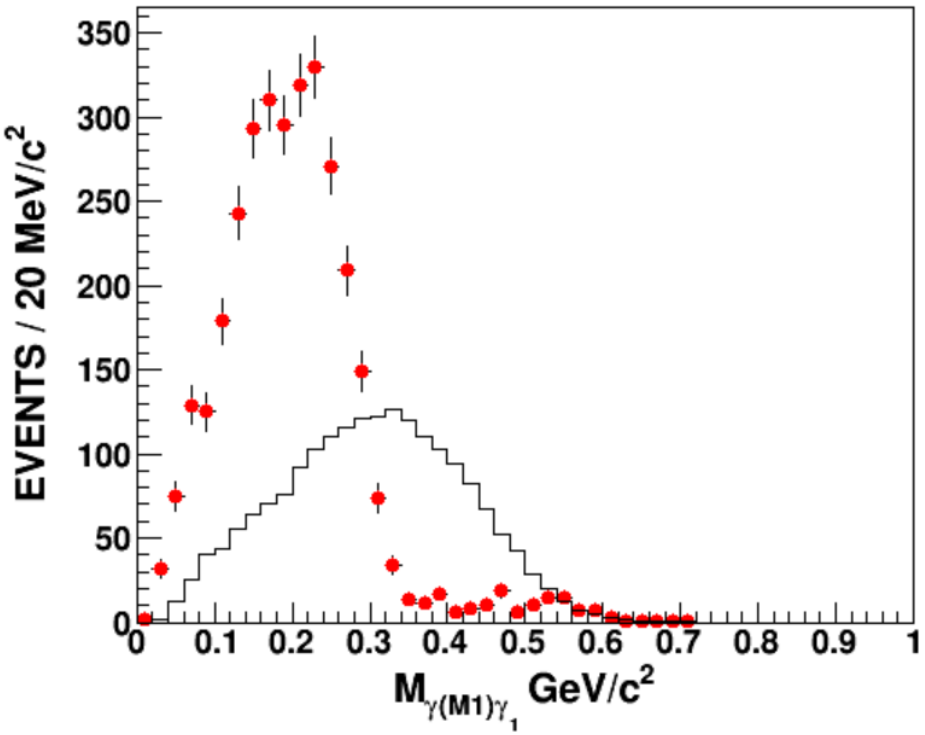
$$Br_2 : \eta \to \gamma\gamma$$

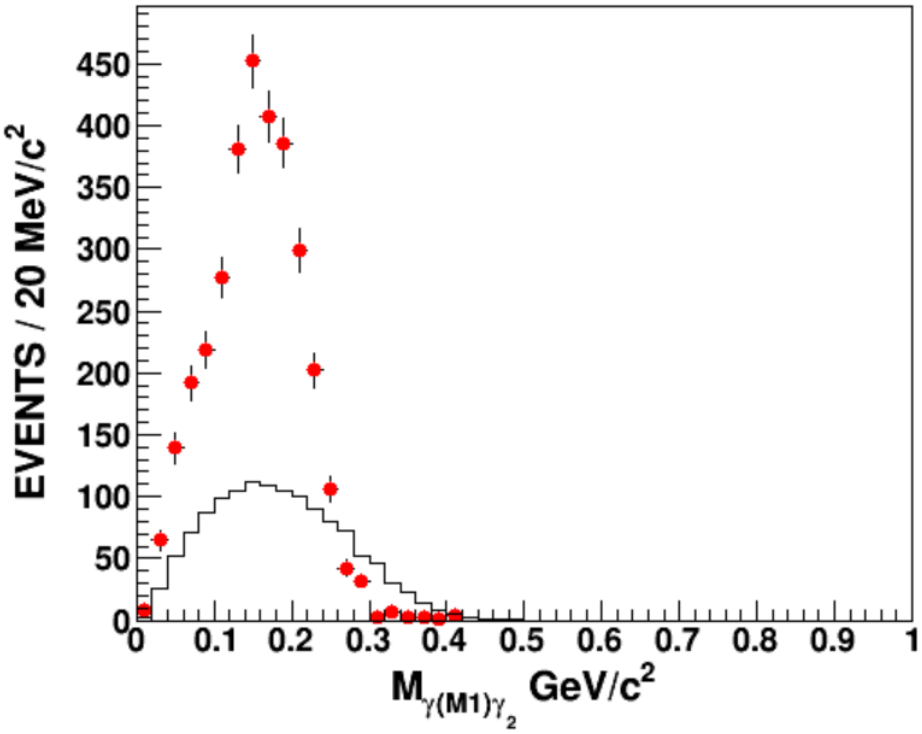
- There is an enhancement around $f_2(1270)$ in the mass spectrum of $\pi^+\pi^-$ within the mass region of $\eta_c(2S)$.

Thank you !

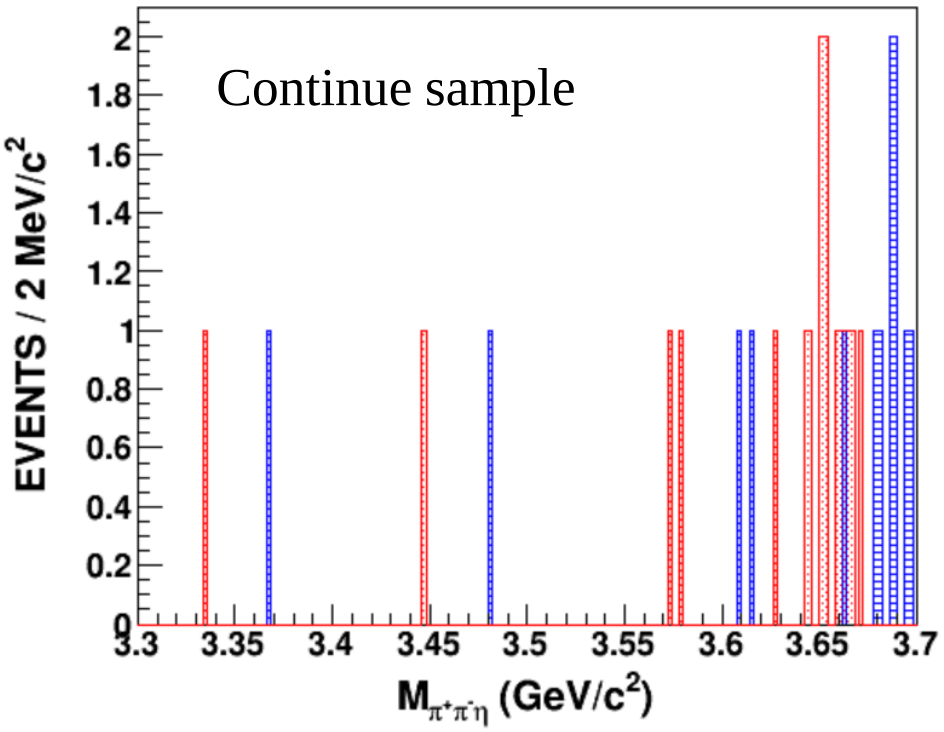
Back up

Data and MC





Back up



$$M \rightarrow a \times (M - M_0) + M_0$$

$$M_0 = 0.8271$$

$$a = 1.013$$

- 2 events after shifted within the range $M_{\pi+\pi-\eta} \in [3.60, 3.65]$ GeV/c^2.

- $$f = \frac{L_{\psi(2S)}}{L_{off-res}} \times \frac{E^2_{off-res}}{E^2_{\psi(2S)}} = 3.61 / 11.33 \ (2009 / 2012)$$