Anomalous charged charmonium-like states observed in process $e^+e^- \to \pi^+\pi^-\psi(3686)$

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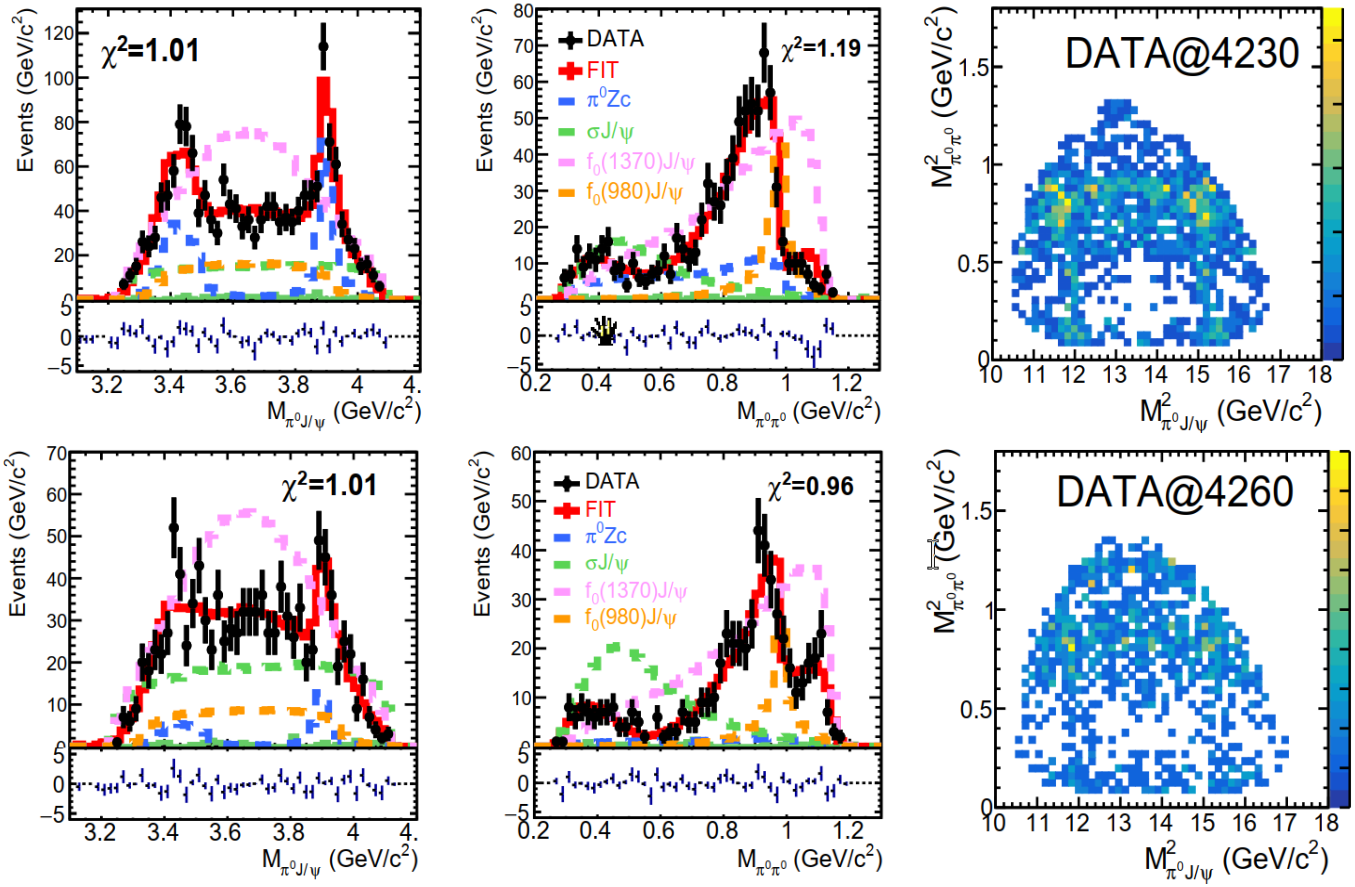
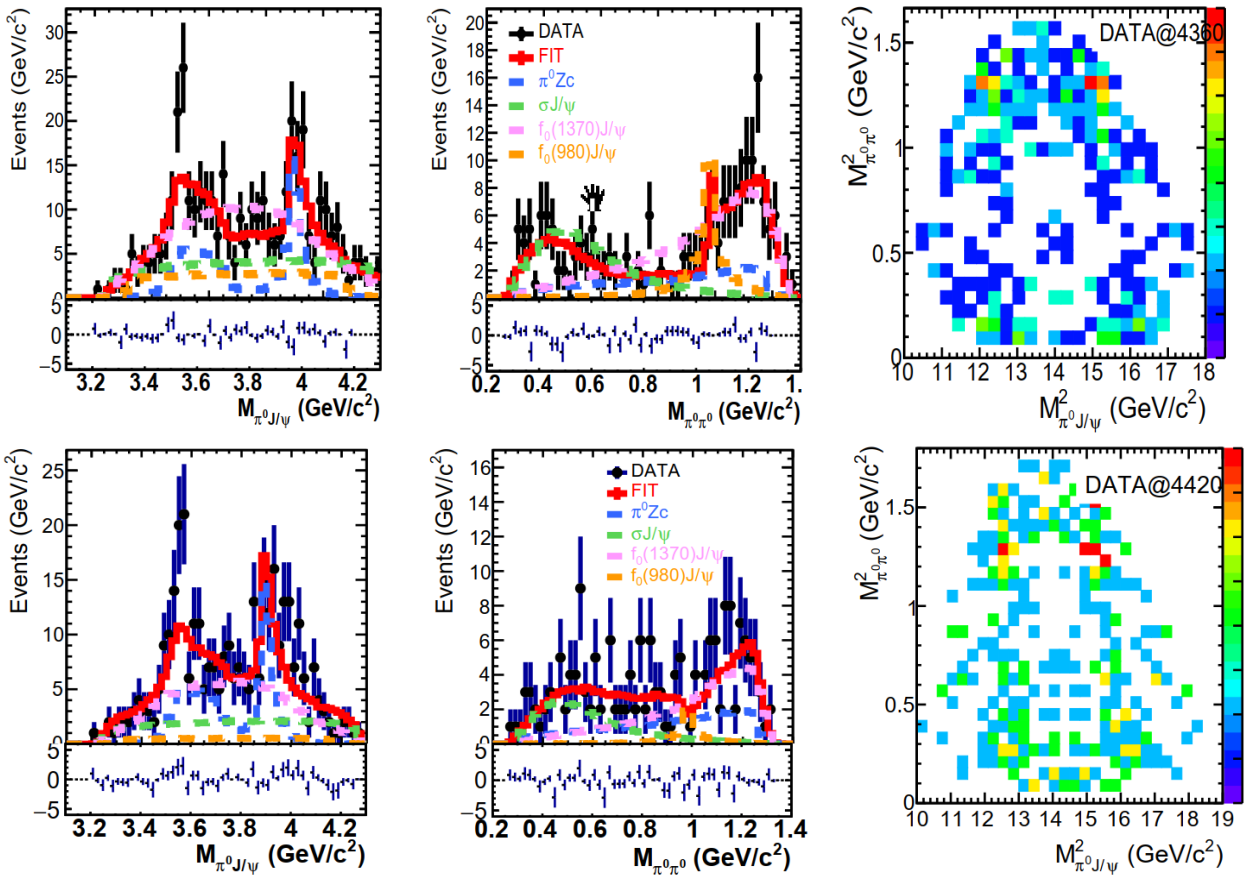
Motivation



https://docbes3.ihep.ac.cn/DocDB/0007/000722/004/Pi0Pi0Jpsi_memo_v1.6.pdf

- For process $e^+e^- \to \pi^0\pi^0 J/\psi (or\ \pi^+\pi^- J/\psi)$, clear Zc(3900) state can be observed in $M(\pi J/\psi)$ spectra
- The reflection of Zc(3900) can be seperated easily
- For different energy points under Y(4220) state, $M(\pi J/\psi)$ distributions are similar

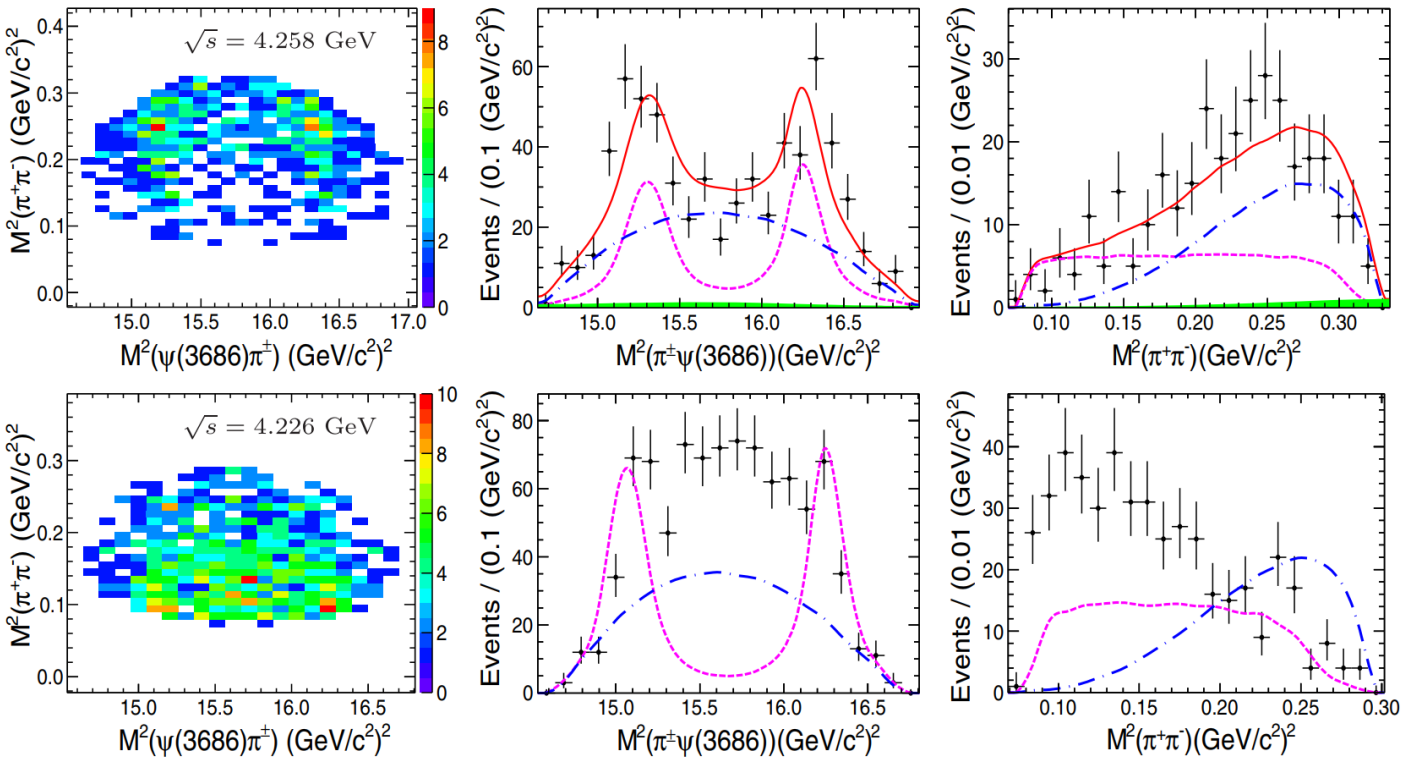
Motivation



https://docbes3.ihep.ac.cn/DocDB/0007/000722/004/Pi0Pi0Jpsi_memo_v1.6.pdf

- For high energy points, $M(\pi^0 J/\psi)$ spectra are hard to understand
- The "reflection" is too narrow to undrstand
- It's hard to distinguish signal from the reflection (Zc(3900) or Zc(4020)?)

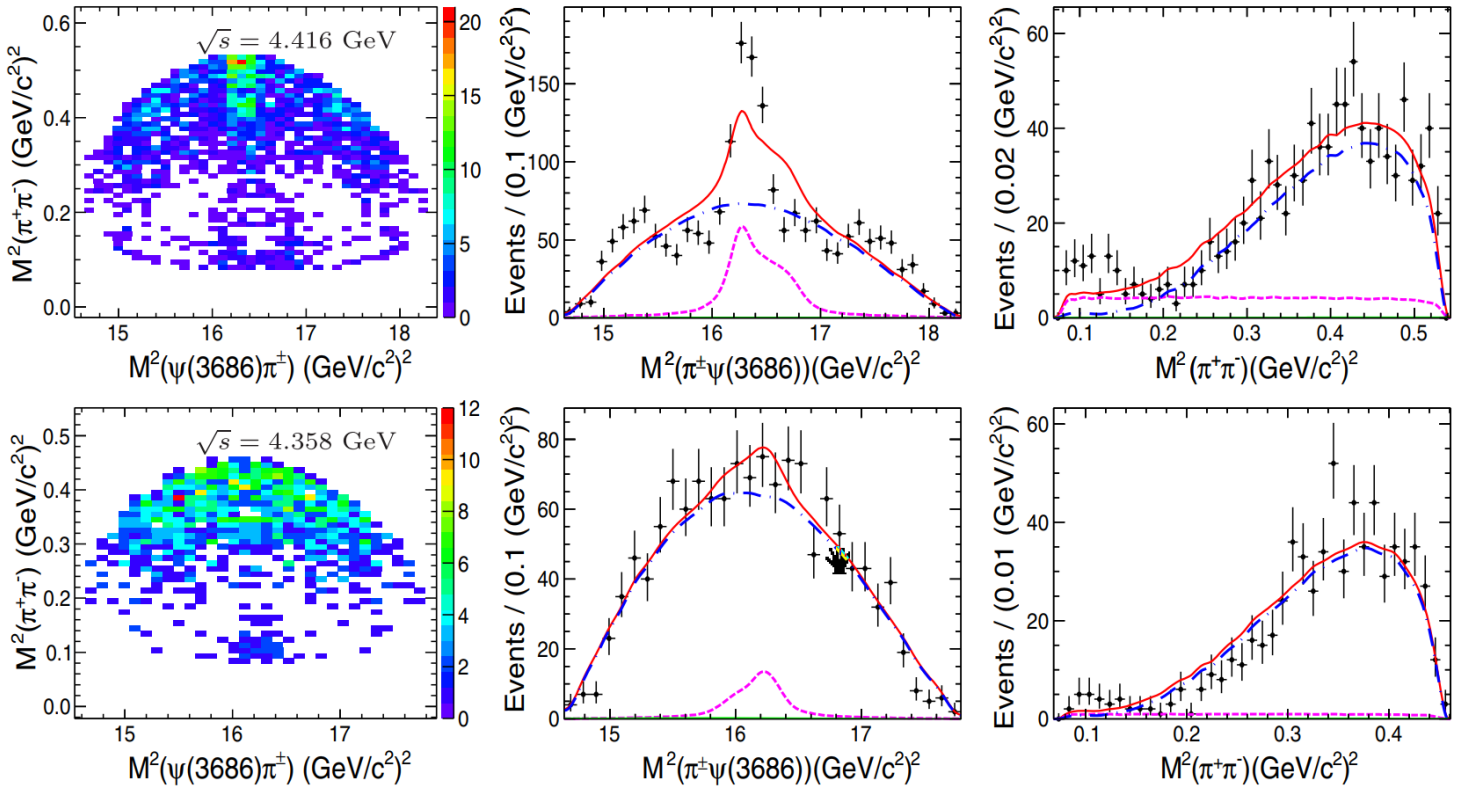
Motivation



PHYSICAL REVIEW D 96, 032004 (2017)

- BESIII also observed charged charmonium-like structures in $M(\pi^{\pm}\psi(3686))$ spectra through process $e^+e^- \to \pi^+\pi^-\psi(3686)$
- Two peaks are observed but hard to distinguish the signal from its reflection (Zc(3900) or Zc(4020)?)

Motivation



PHYSICAL REVIEW D 96, 032004 (2017)

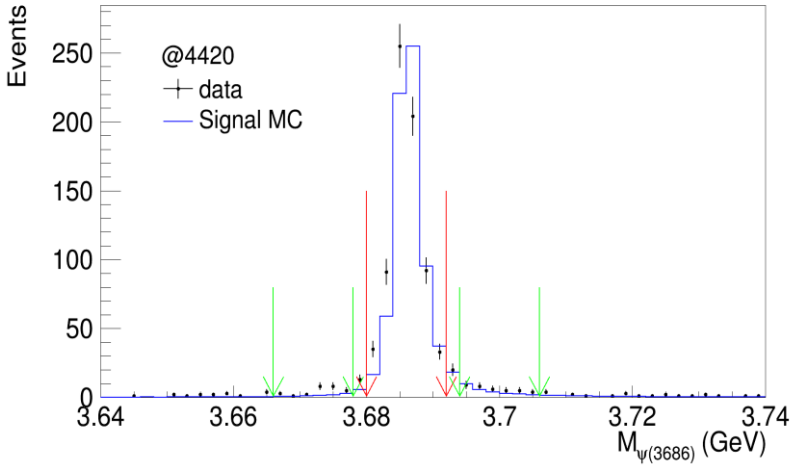
- The structures observed are different for low energy points and high energy points
- There are still unresolved discrepancies between the simple BW fit model and data
- Further analysis is necessary to study the intermediate structures

Data Set and Event Selection

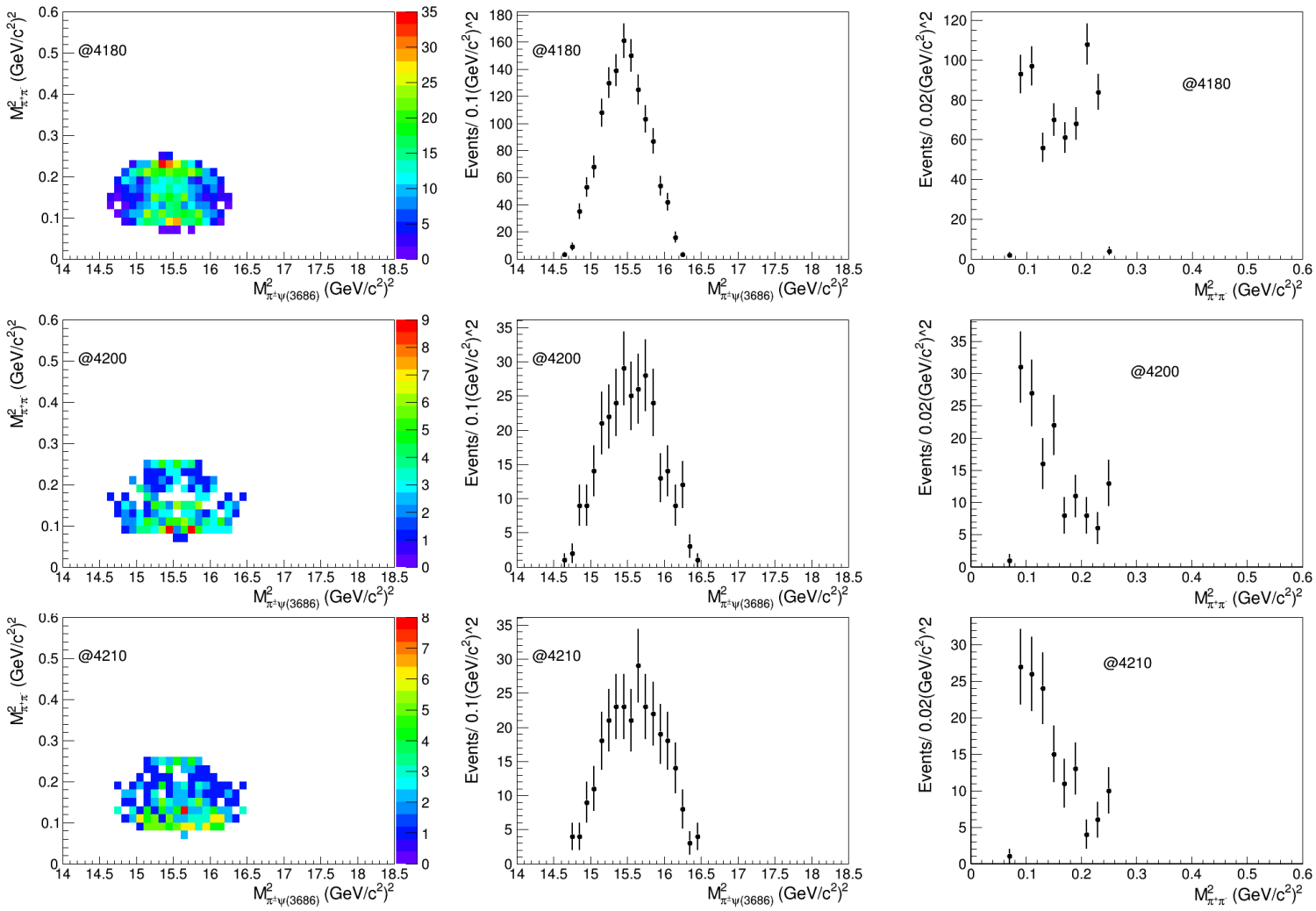
- Data Set:
  - **Signal channel:** $e^+e^- \to \pi^+\pi^-\psi(3686)$
  - **Boss version:** 703 + 704
  - **Data:** old XYZ data + new XYZ data
- Event Selection:
  - Charged channel: $\psi(3686) \to \pi^+\pi^- J/\psi$
  - Neutral channel: $\psi(3686) \to neutrals + J/\psi$

  (Details can be found in my collaboration meeting report)
  https://indico.ihep.ac.cn/event/8797/session/18/contribution/72/material/slides/0.pdf

- Signal:
  $M(\psi(3686)) \in [3.68,3.692]$ GeV
- Side band:
  $M(\psi(3686)) \in [3.666,3.678]$&& $[3.694,3.706]$ GeV

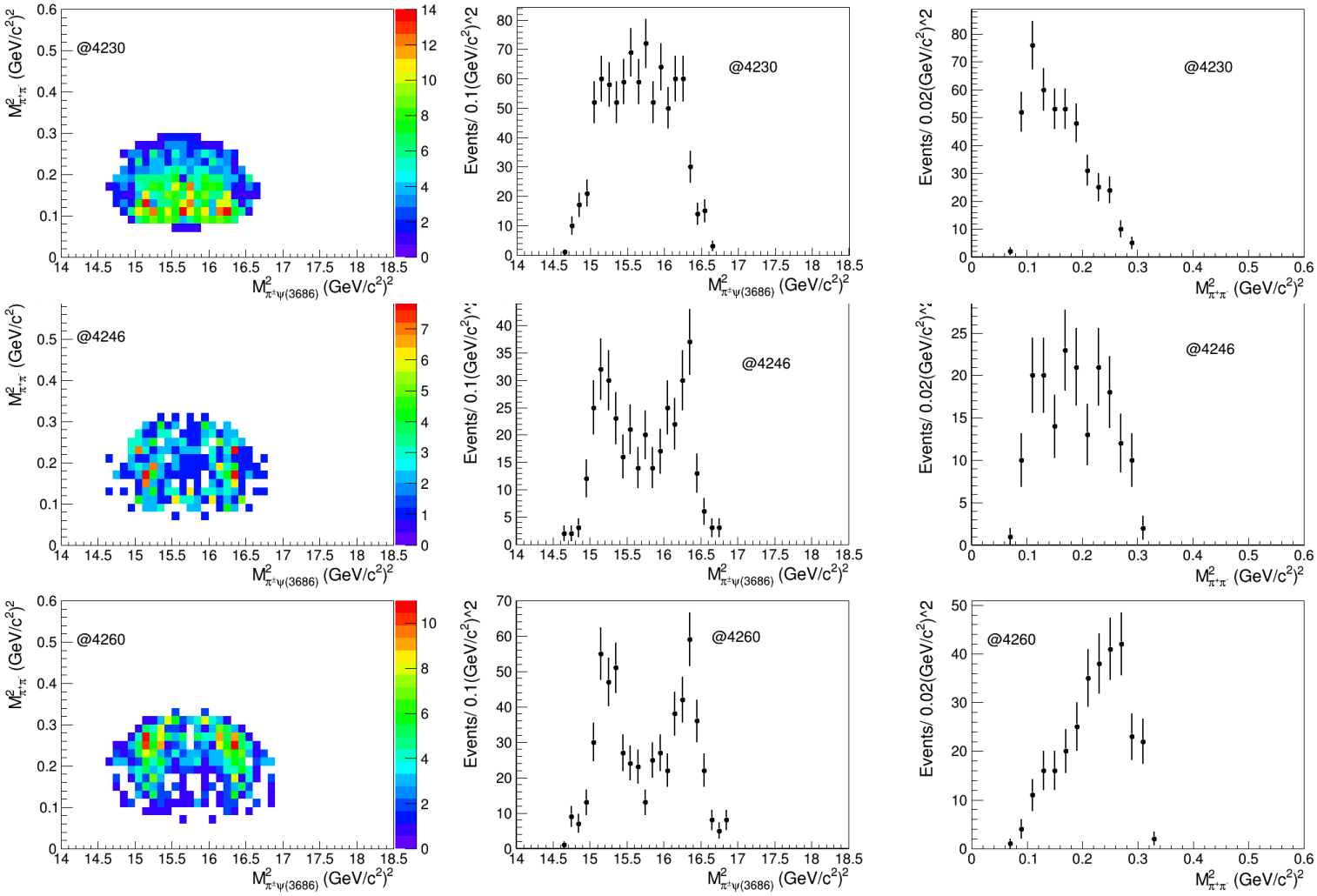


Mass Distributions



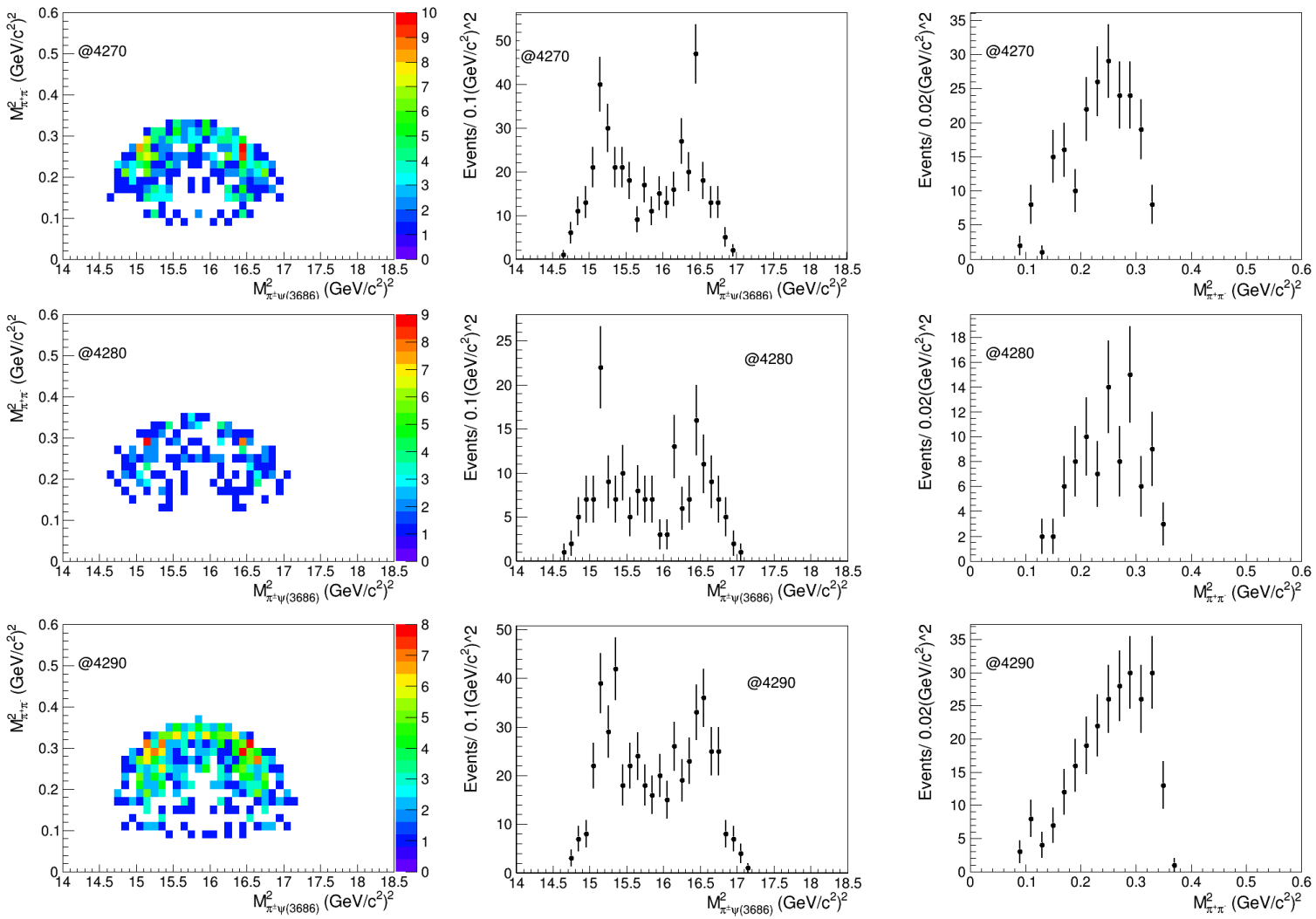
- Small phase space may limit the production of possible charged charmonium-like states

Mass Distributions



- Clear structures can be observed

Mass Distributions



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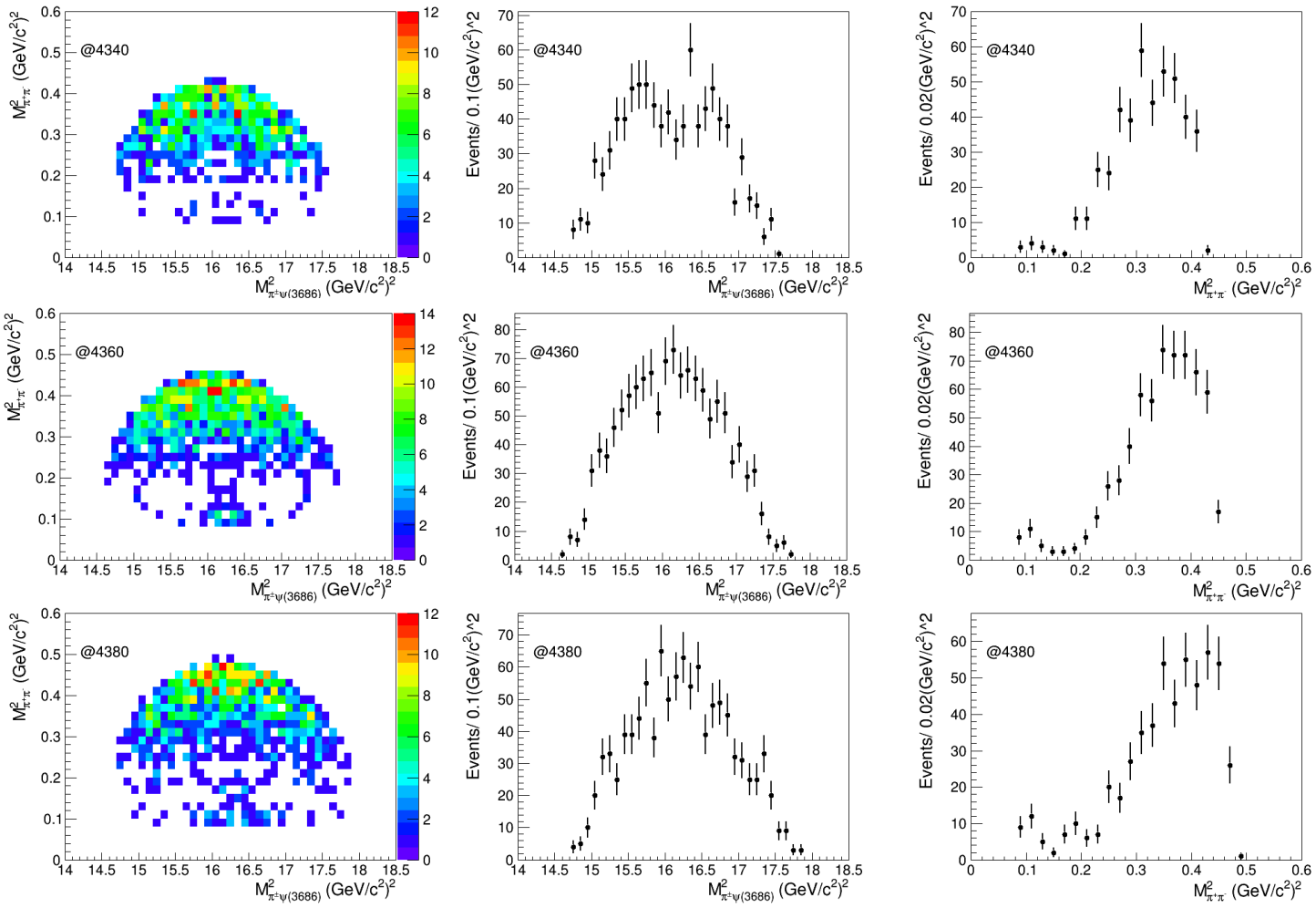
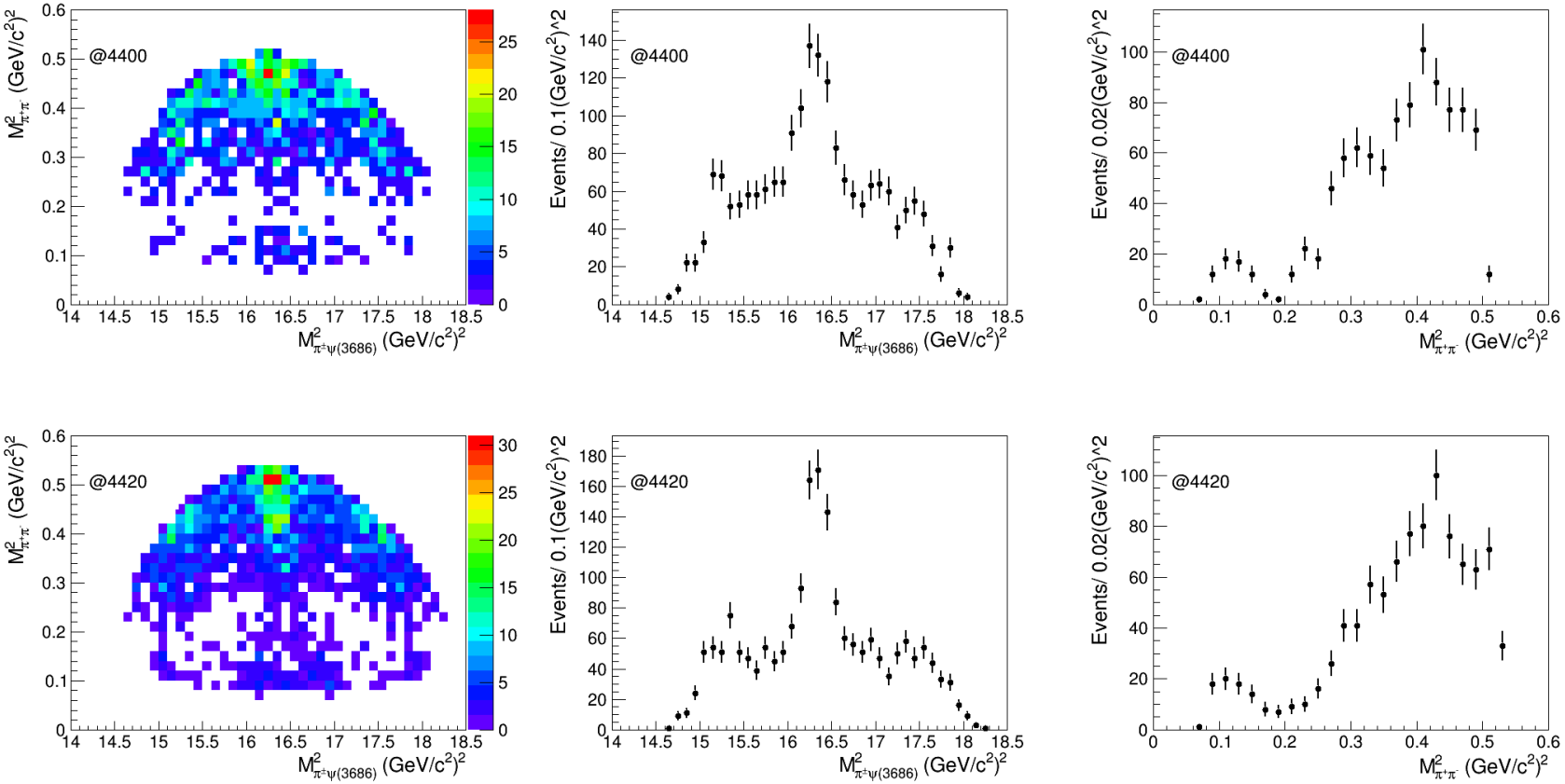
Mass Distributions



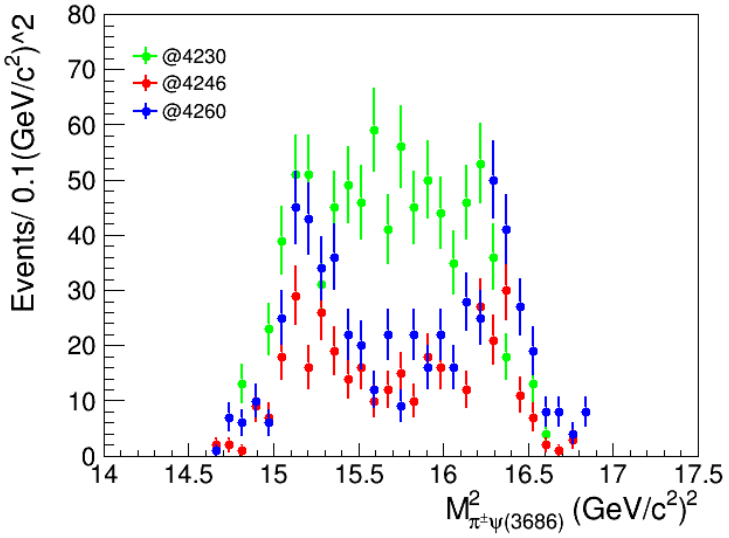
- $M(\pi^{\pm}\psi(3686))$ spectrum at 4380 is similar to distribution at 4360

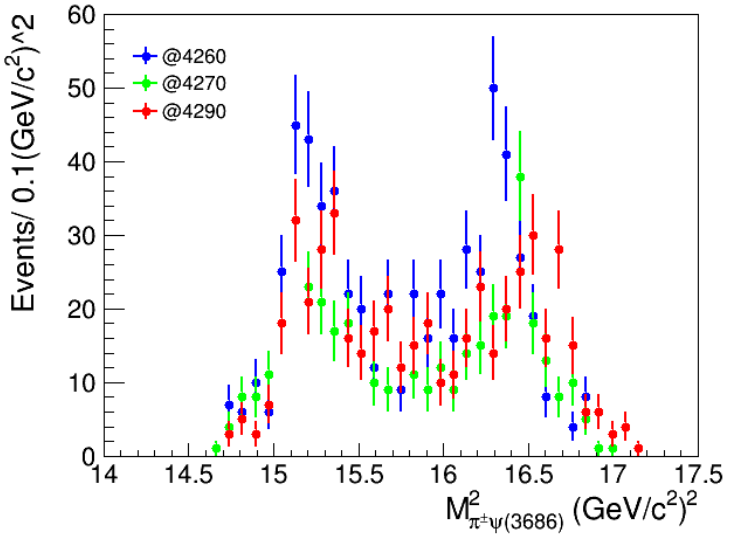
Mass Distributions



- 4290,4340,4380,4400 are from preliminarily reconstructed data sets
- $M(\pi^{\pm}\psi(3686))$ spectrum at 4400 is similar to distribution at 4420

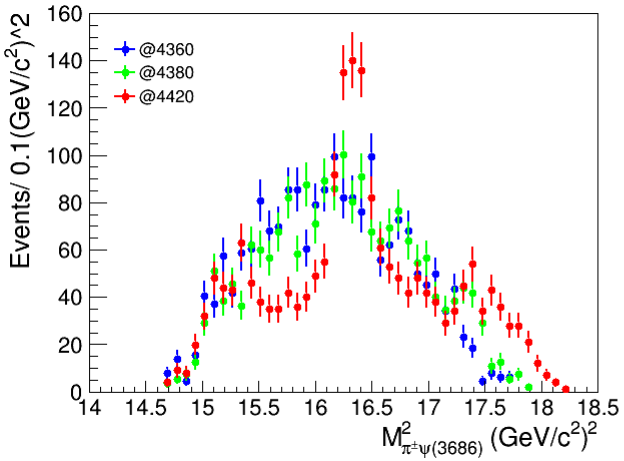
Mass Distribution

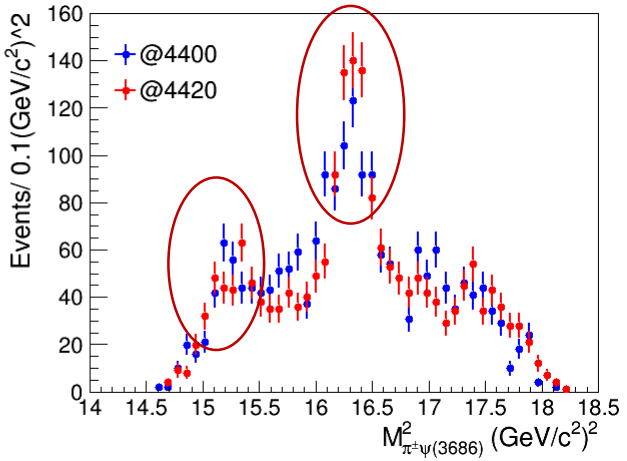




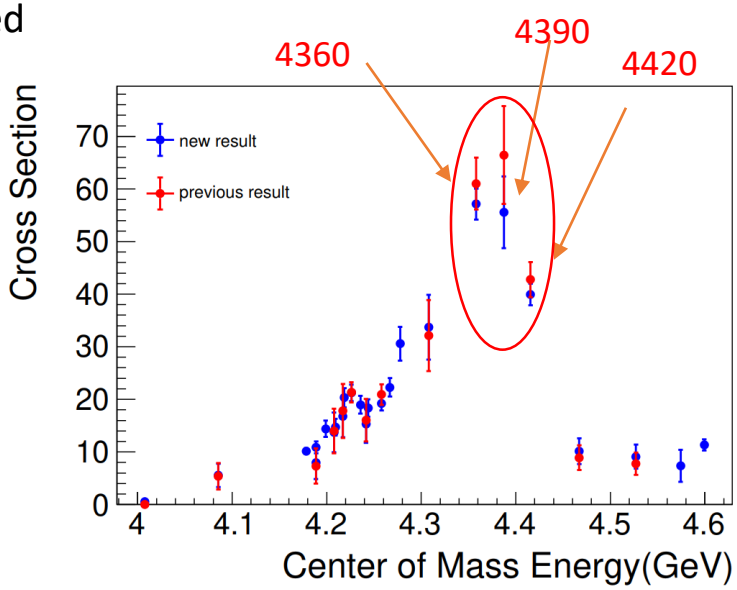
- Two clear peaks are observed for energy points 4230~4290
- The first peak is stable at ~3.9 GeV in $M(\pi^{\pm}\psi(3686))$ spectra
- The second peak varies with different energy, looks like a reflection
- This charged charmonium-like state is Zc(3900) decaying from Y(4220) instead of Zc(4020)

Mass Distribution

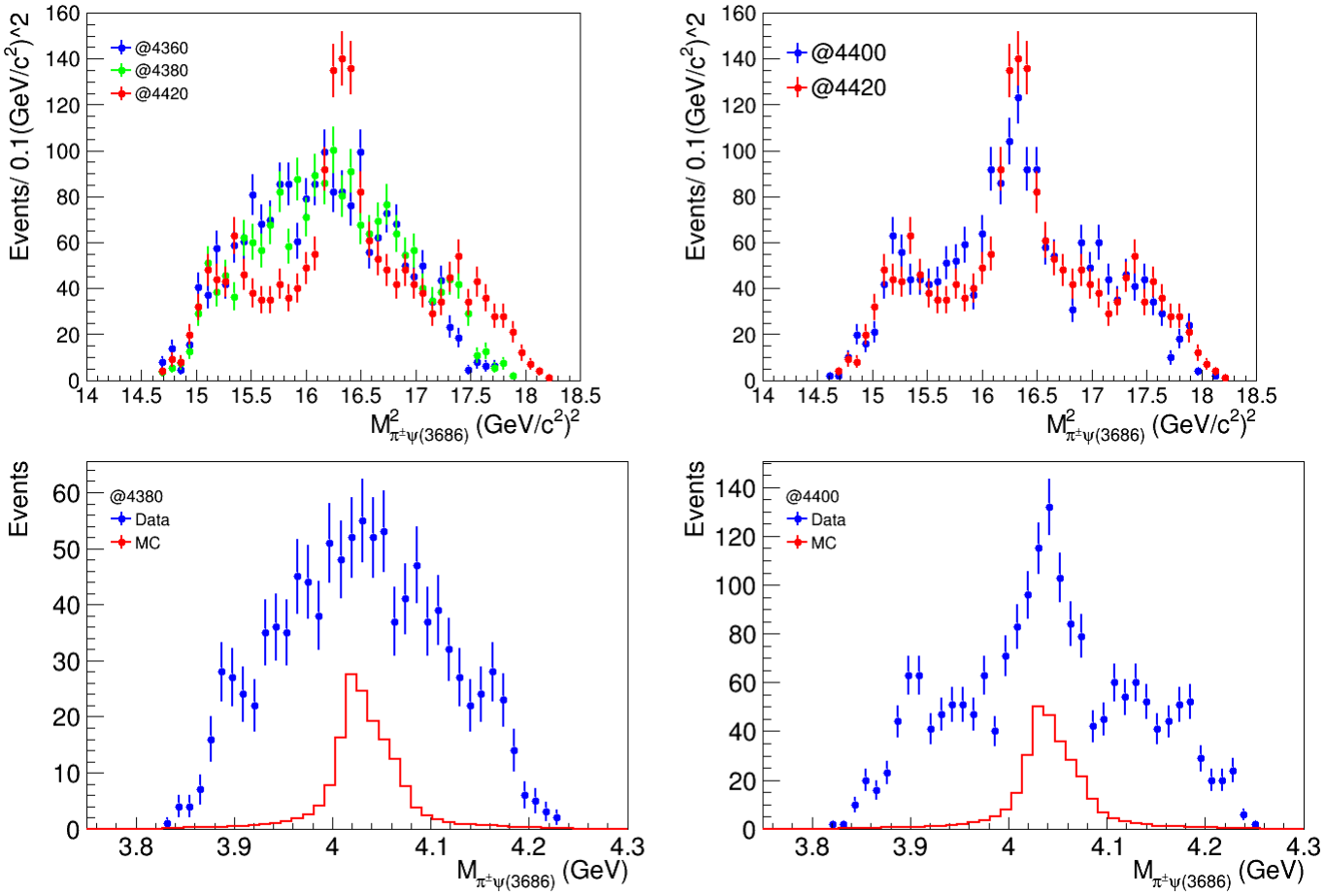




- Large difference in $M(\pi^{\pm}\psi(3686))$ spectra is observed for energy points under Y(4390) region
- Zc(3900) can be observed both in low and high energy region
- $\sqrt{s} \leq 4.38$ GeV, no obvious Zc(4020) is observed
- $\sqrt{s} \geq 4.40$ GeV, very clear Zc(4020) is observed
- **Assumption:**
  - Another very narrow states under 4.4~4.5 GeV region ? Say $e^+e^- \rightarrow ? \rightarrow \pi^{\pm}Z_c^{\mp}(4020)$ (waiting for data 4.44 GeV)



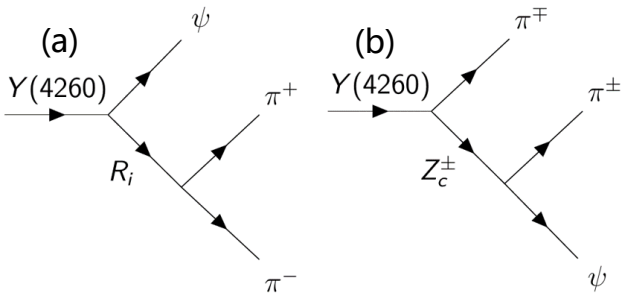
Mass Distribution



- MC with Zc(4020) is generated with mass of 4.025 GeV and width of 0.025 GeV, scaling with same ratio of 4420 point

Amplitude analysis

- To study the possible structures observed in process $e^+e^- \to \pi^+\pi^-\psi(3686)$, Partial Wave Analysis is necessary
- Amplitude construction：
  - **Method:** Helicity Method



(a) $$\mathcal{A}^{R}_{\lambda_Y\lambda_\psi} = F^{J_Y}_{\lambda_R,\lambda_\psi} D^{J_Y*}_{\lambda_Y,\lambda_R-\lambda_\psi}(\Omega_R) F^{J_R}_{0,0} D^{J_R*}_{\lambda_R,0}(\Omega_{\pi^+}) T_R$$

(b) $$\mathcal{A}^{Z_c}_{\lambda_Y\lambda_\psi} = \sum_{\lambda_{Z_c}} F^{J_Y}_{\lambda_{Z_c},0} D^{J_Y*}_{\lambda_Y,\lambda_{Z_c}}(\Omega_{Z_c}) F^{J_{Z_C}}_{\lambda_\psi,0} D^{J_{Z_c}*}_{\lambda_{Z_c},\lambda_\psi}(\Omega_\psi) T_{Z_c}$$

- Total invariant amplitude:

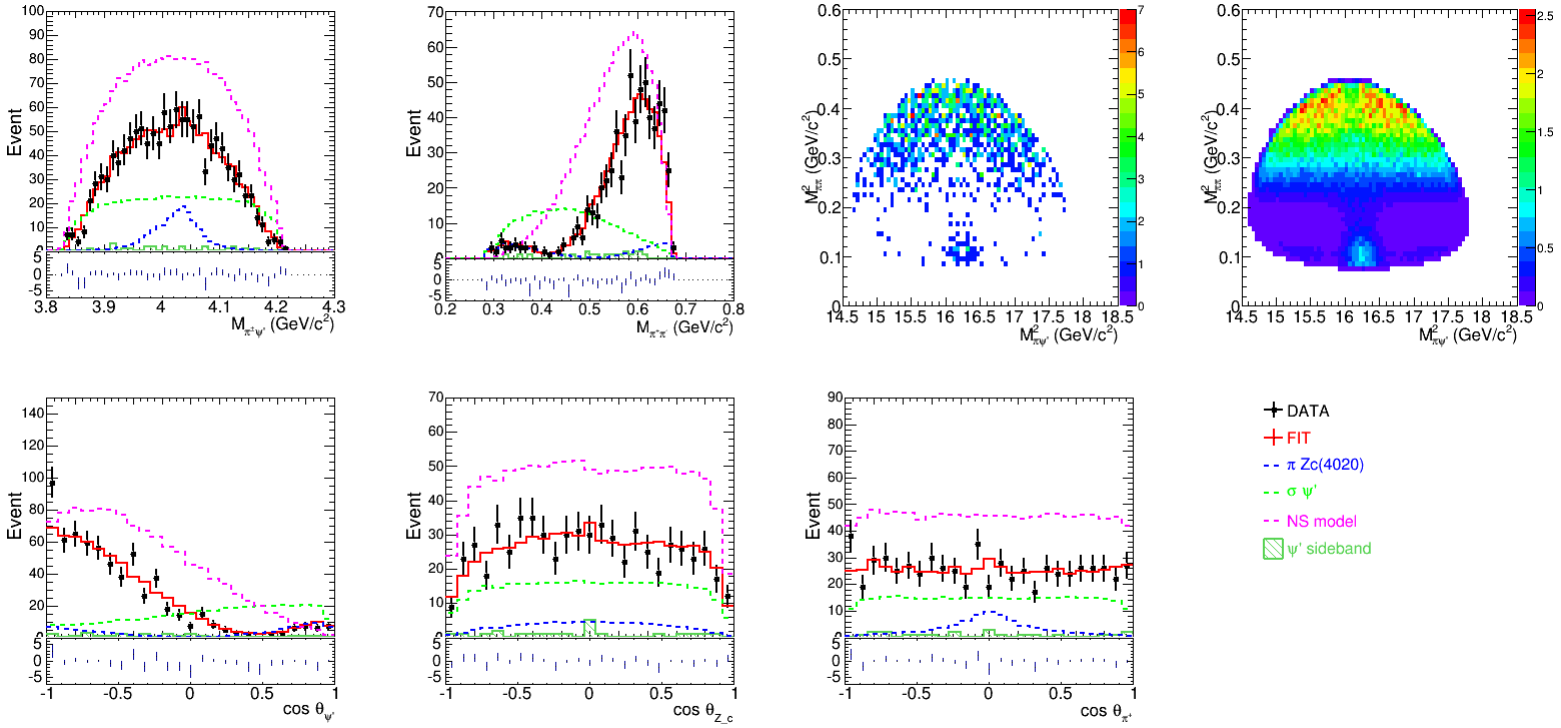
$$\sum_{\lambda_Y,\lambda_\psi} |\mathcal{M}_{\lambda_Y\lambda_\psi}|^2 = \sum_{\lambda_Y,\lambda_\psi} |\mathcal{A}^{R}_{\lambda_Y\lambda_\psi} + \sum_{\lambda'_\psi} d^{J_\psi}_{\lambda'_\psi,\lambda_\psi}(\theta_p) \mathcal{A}^{Z_c}_{\lambda_Y\lambda_\psi}|^2$$

Amplitude analysis

- Parameterization of intermediate states
  - $\pi Z_c(3900)$: : Flatte-like formula $BW(s) = \frac{1}{s - M^2_{Z_c^\pm} + i(g'_1\rho_{\pi J/\psi}(s) + g'_2\rho_{D^*\bar{D}}(s))}$ (fixed mass and g1, g2)
  - $\pi Z_c(4020)$: Breit-Wigner formula $BW(s) = \frac{1}{s - M_0^2 + i\sqrt{s}\Gamma}$ (float mass and width)
  - $\sigma(600)\psi(3686)$: $\Gamma(s) = \sqrt{1 - \frac{4m^2_{\pi^\pm}}{s}}\Gamma$ (fixed mass and width)
  - $f_2(1275)\psi(3686)$: $BW_R(s) = \frac{1}{s - M_R^2 + iM_R\Gamma_R}$ (fixed mass and width)
  - NS model: $\frac{d\sigma}{dm_{\pi\pi}} \propto |\vec{q}|\sqrt{q^2 - 4m_\pi^2} \times q^4$
  - Non-Resonance: $1 + ce^{i\phi}M^2_{\pi\pi}$ (float c and ϕ)

- Fit Method:
  - Fit tool: AmpTool package
  - Toy MC: UserDIY method with BesEvtGen

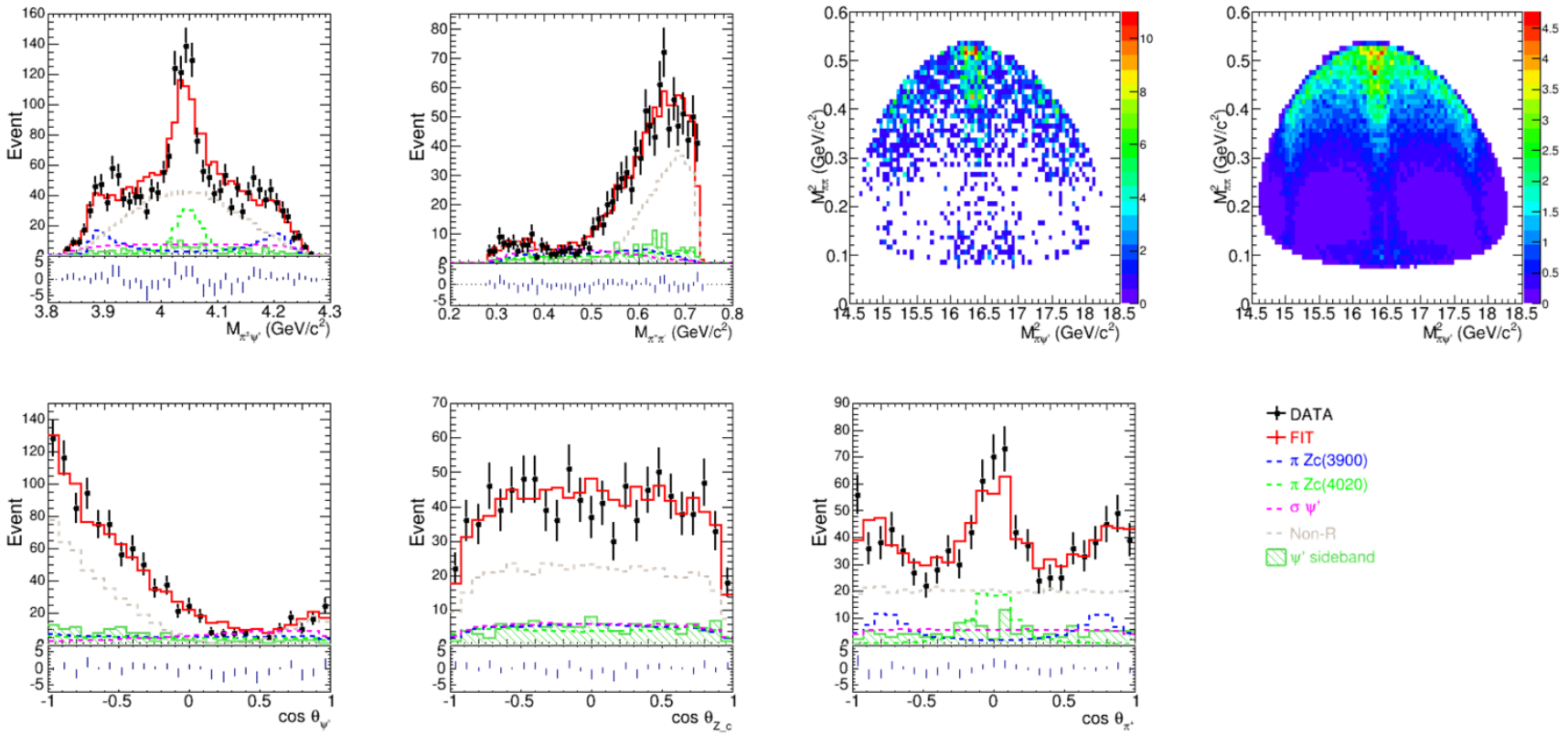
Preliminary results @ 4360



Zc(4020):

- Mass: $4015.5 \pm 14.1\ MeV/c^2$
- Width: $70.4 \pm 20.1\ MeV/c^2$

Preliminary results @4420



Zc(4020):

- Mass: $4050.0 \pm 2.4\ MeV/c^2$
- Width: $21.1 \pm 4.9\ MeV/c^2$

Summary

- Several behaviors of charged charmonium-like states in $M(\pi^{\pm}\psi(3686))$ spectra from process $e^+e^- \to \pi^+\pi^-\psi(3686)$
  - The signal in Y(4220) region is Zc(3900) state instead of Zc(4020) from the reflections of different energy points
  - Zc(3900) exists also at high energy region
  - Large differences in $M(\pi^{\pm}\psi(3686))$ spectra are observed under Y(4390) region, clear Zc(4020) is observed at $\sqrt{s} \geq 4.40$ GeV (existence of another narrow resonance in [4.4, 4.5] GeV?)

- Partial Wave Analysis is applied and preliminary results are given

- Next to do
  - Try more strategies to perform PWA
  - Resolution of PWA should be considered