# Determination of the number of Ψ(3686) events at BESIII

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# Motivation

- BESIII experiment has accumulated the world's largest $\Psi(3686)$ data sample in electron-positron collisions, which provides an excellent place to precisely study the transition of $\Psi(3686)$ and the subsequent charmonium state
- to search for rare decays for physics beyond the standard model
- precision of $\Psi(3686)$ will directly affect the accuracy of these measurements

# Method

- with inclusive Ψ(3686) hadronic decays, whose branching ratio is known rather precisely (97.85±0.13)%, in the PDG
- QED background yield under the Ψ(3686) peak is evaluated by analyzing the two sets of off-resonance data samples(i.e. $\sqrt{s}$=3.65GeV collected in 2009 with an integrated luminosity of about 44$pb^{-1}$) and 4 energy points(ranging from 3.542 to 3.600GeV collected in 2012)

# Event selection

- data at the Ψ(3686) peak:
  - $\boxed{\text{Ψ(3686) decays to hadrons}}$ or lepton pairs(e+e-, mu+mu-, tao+tao-)
  - radiative return to J/Ψ, and J/Ψ decay
  - non-resonant(QED) processes, namely continuum background
    - e+e- -> gam* ->hadrons, lepton pairs
    - e+e- -> e+e- + hadroms, lepton pairs
  - non-collision events
    - cosmic rays
    - beam-associated backgrounds
    - electronic noises

# Event selection

- commen selection for BESIII
  - charged tracks within 1cm of beam line in the plane perpendicular to the beam
  - charged tracks within 10cm from the Interaction Point in beam direction
  - for $|\cos\theta| < 0.80$, energy > 25MeV
  - for $0.86 < |\cos\theta| < 0.92$, energy > 50MeV
  - EMC cluster timing [0, 700]ns
- number of charged tracks
  - type-I: $N_{good} = 1$, a nuetral hadron $\pi^0$ candidate is required
  - type-II: $N_{good} = 2$, momentum of each track < 1.7 GeV/c, angle < 176°
  - type-III: $N_{good} > 2$

# Event selection

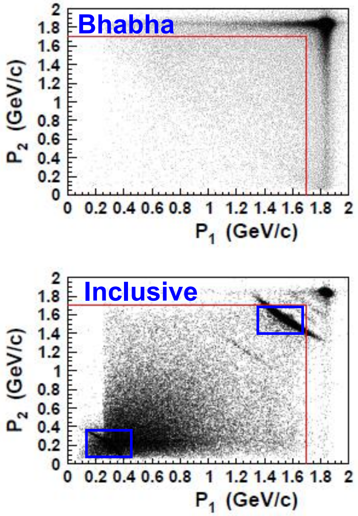


Fig. 1. Scatter plots of the momenta of the first charged tracks versus that of second charged tracks of type-II candidates for Bhabha (top) and inclusive $\psi(3686)$ (bottom) MC events. In the bottom plot, the event accumulation in the top-right corner comes from $\psi(3686) \rightarrow e^+e^-, \mu^+\mu^-$, while the different event bands nearby come from $\psi(3686) \rightarrow neutral + J/\psi, J/\psi \rightarrow e^+e^-, \mu^+\mu^-$ *etc*. The event band in the bottom-left comes from $\psi(3686) \rightarrow \pi^0\pi^0 J/\psi, J/\psi \rightarrow e^+e^-, \mu^+\mu^-$ with lepton pairs missing. The horizontal and vertical lines show the selection requirements to suppress Bhabha and dimuon events.

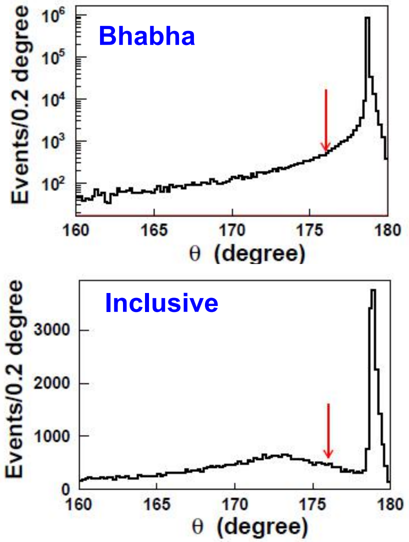


Fig. 2. Distributions of the opening angle between the two charged tracks for the type-II candidates from Bhabha (top) and inclusive $\psi(3686)$ (bottom) MC events. The arrow shows the angle requirement used to suppress Bhabha and dimuon events.

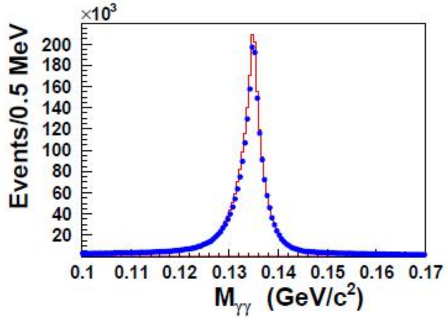


Fig. 4. Distribution of $M_{\gamma\gamma}$ in the $\pi^0$ mass re gion for the type-I events.

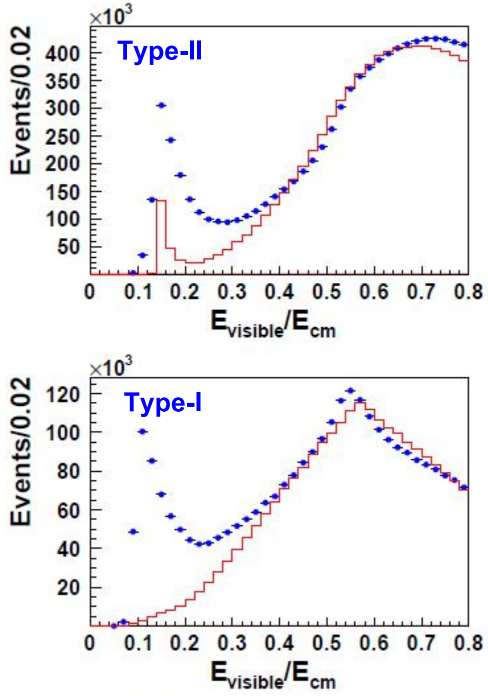


Fig. 3. Distribution of $E_{\mathrm{visible}}/E_{\mathrm{cm}}$ for the type-II (top) and type-I (bottom) events. The MC distributions are scaled arbitrarily to data with the same entries at $E_{\mathrm{visible}}/E_{\mathrm{cm}} = 0.4$.

# Event selection

To discriminate the non-collision background from the collision events, a variable, the average vertex in Z direction is defined:

$$\bar{V}_Z = \frac{\sum_{i=1}^{N_{\text{good}}} V_Z^i}{N_{\text{good}}}$$

where $V^i_Z$ is the (signed) distance along the beam direction between the point of closest approach of ith track and the IP.

$$N^{\text{obs}} = N_{\text{signal}} - N_{\text{sideband}}$$

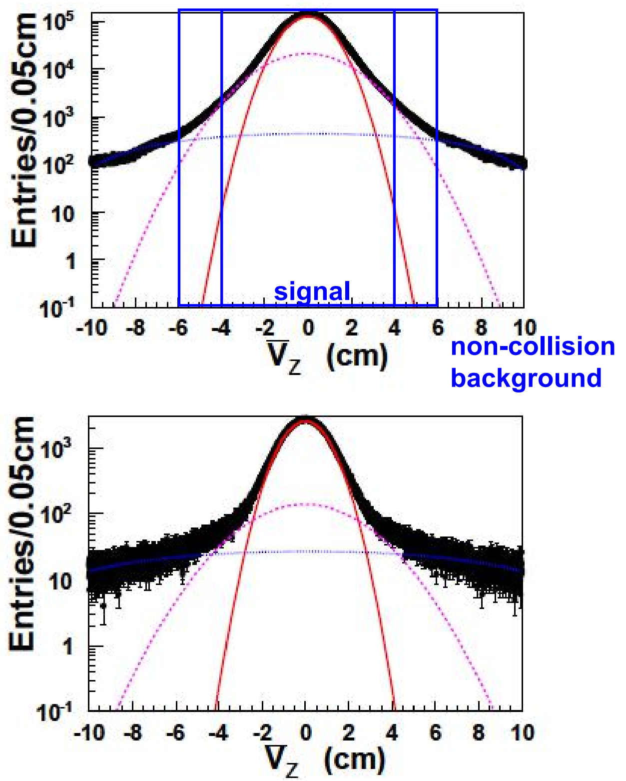


Fig. 5. Fits to the $\bar{V}_Z$ distributions of the accepted hadronic events in the $\psi(3686)$ (top) and off-resonance (bottom) data. The solid (red) and dashed (pink) curves show the double Gaussian line shapes for the signal and the dotted (blue) lines show the polynomial function for the non-collision events.

# Background subtraction

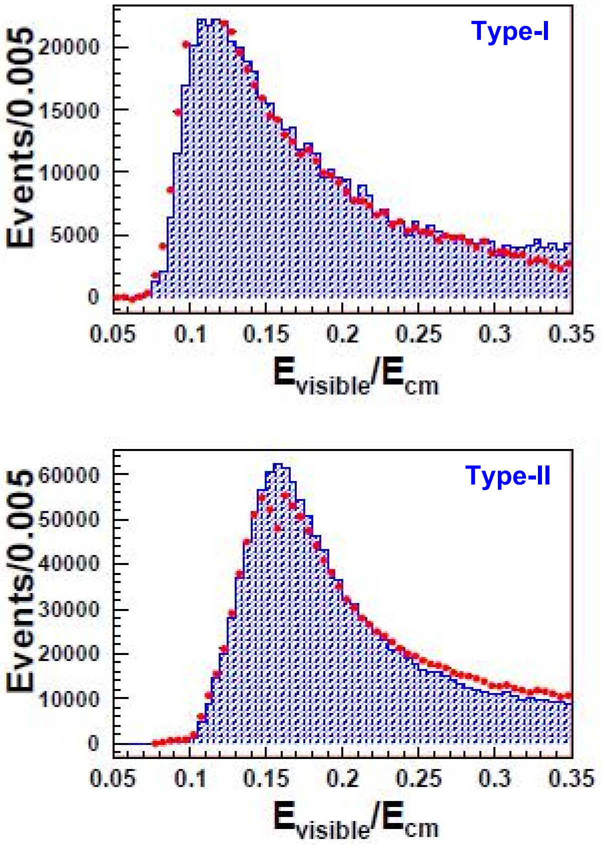


Fig. 6. Comparison of the $E_{\mathrm{visible}}/E_{\mathrm{cm}}$ distributions for the type-I (top) and type-II (bottom) LEB events between the $\psi(3686)$ and scaled off-resonance data. The dots with error bars denote the former, and the shade histogram denotes the latter.

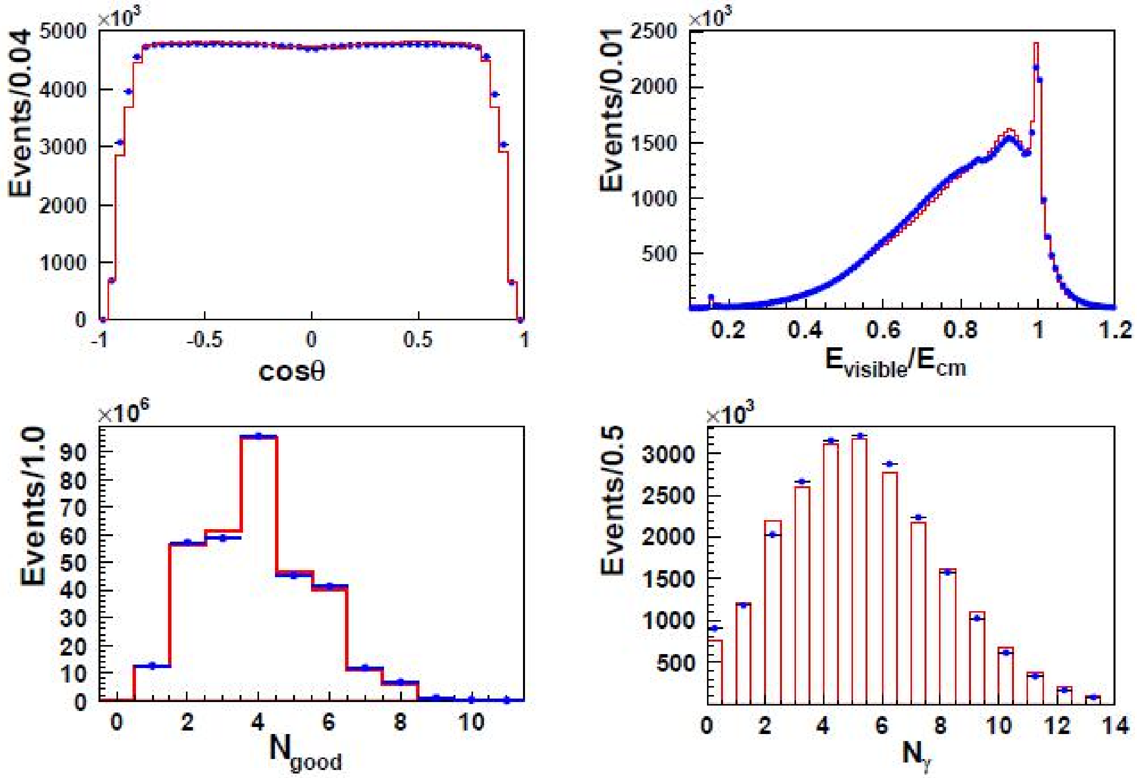


Fig. 7. The comparison of data/MC. (top-left) The $\cos\theta$ distribution. (top-right) The $E_{\mathrm{visible}}/E_{\mathrm{cm}}$ distribution. (bottom-left) The charged-track multiplicity distribution. (bottom-right) The photon multiplicity distribution.

# Numerical results

$$N_{\psi(3686)} = \frac{N_{\text{peak}}^{\text{obs}} - f \cdot N_{\text{off-resonance}}^{\text{obs}} - N_{\tau^+\tau^-}^{\text{uncanceled}}}{\epsilon}$$

Table 1. Numbers of the observed hadronic events and the total numbers of $\psi(3686)$ events ($\times 10^6$), the detection efficiencies of $\psi(3686) \to$ hadrons for different charged-track multiplicity requirements.

| Multiplicity | $N_{\text{good}} \geq 1$ | | $N_{\text{good}} \geq 2$ | | $N_{\text{good}} \geq 3$ | |
|---|---|---|---|---|---|---|
| Year | 2009 | 2012 | 2009 | 2012 | 2009 | 2012 |
| $N_{\psi(3686)}^{\text{obs}}$ | 107.72 | 343.51 | 103.72 | 329.04 | 82.28 | 259.98 |
| $N_{\text{off-resonance}}^{\text{obs}}$ | 2.23 | 1.325 | 2.01 | 1.245 | 0.74 | 0.400 |
| $N_{\tau^+\tau^-}^{\text{uncanceled}}$ | 0.036 | 0.57 | 0.034 | 0.54 | 0.013 | 0.21 |
| $\epsilon(\%)$ | 92.92 | 92.39 | 89.96 | 88.96 | 74.73 | 73.20 |
| $N_{\psi(3686)}$ | 107.2 | 341.7 | 107.2 | 340.5 | 106.6 | 343.6 |

# Systematic uncertainties

Table 2. Summary of systematic uncertainty (%).

| Source | 2009 | 2012 |
|---|---|---|
| Polar angle | 0.27 | 0.31 |
| Tracking | negligible | negligible |
| Charged-track multiplicity | 0.20 | 0.19 |
| Momentum and opening angle | negligible | 0.04 |
| LEB contamination | negligible | 0.09 |
| $N^{\mathrm{obs}}$ determination | 0.27 | 0.30 |
| Vertex limit | 0.32 | 0.21 |
| Scaling factor ($f$) | negligible | negligible |
| Choice of sideband region | 0.32 | 0.26 |
| $\pi^0$ mass requirement | 0.09 | 0.05 |
| 0-prong events | 0.25 | 0.18 |
| Trigger | negligible | negligible |
| MC modeling | negligible | negligible |
| $B(\psi(3686)\to \text{hadrons})$ | 0.13 | 0.13 |
| Total | 0.70 | 0.63 |

# Summary

- Number of $\Psi(3686)$ events taken by BESIII in 2012 is measured to be $(341.1\pm2.1)*10^6$ with the inclusive hadronic events, where the uncertainty is dominated by systematics, and the statistical uncertainty is negligible.
- Number of $\Psi(3686)$ events taken by in 2009 is also updated to be $(107.0\pm0.8)*10^6$.
- Adding them linearly yields the total number of $\Psi(3686)$ events for the two runs data taking to be $(448.1\pm2.9)*10^6$.

**Thanks!**