The difference of reconstruction efficiency of photons and charged tracks between data and MC for $J/\psi \to \phi\eta$ study

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Introduction

Motivation

This is part of the systematic uncertainties estimations in measuring of the branching fraction of $J/\psi \to \phi\eta$ in the decay chain:

$$\psi(3686) \to \pi^+\pi^- J/\psi, \quad J/\psi \to \phi\eta, \quad \phi \to K^+K^-, \quad \eta \to \gamma\gamma$$

Essential parts of main analysis:

- We select events with two opposite charged soft pions with recoil mass of $M^{rec}_{\pi^+\pi^-} \in [3.092, 3.102]$ GeV/c^2
- We require two opposite charged kaons
- We require at least two photons
- We perform 5C kinematic constraints and choose two photons with minimal χ^2_{5C}
- We select η for the invariant mass $M^{inv}_{\gamma\gamma}$
- We select ϕ for the invariant mass $M^{inv}_{K^+K^-}$

The most important components of systematic uncertainties

- Photon reconstruction efficiency
- Track reconstruction efficiency

- the resulting combined statistical error is 2.6%
- the value $2 \times 1\%$ as the estimation of systematic uncertainty for each of these efficiencies looks too big for this analysis
- we performed additional study to estimate difference in reconstruction efficiencies of eta and kaons between data and MC

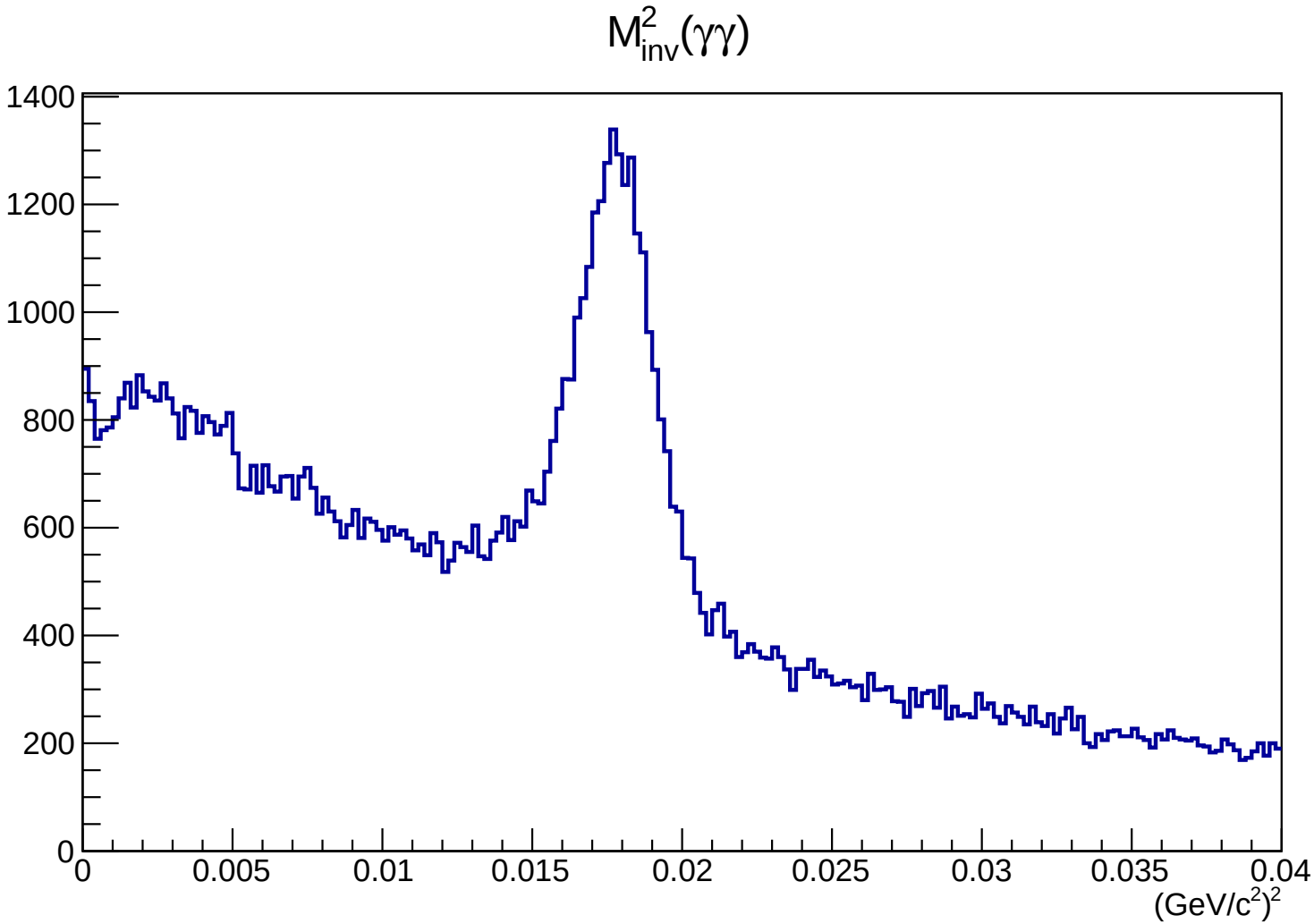
Data & Monte-Carlo samples

- We used DST for $\psi(3686)$ 2009 and 2012
- We used $\psi(3686)$ inclusive Monte Carlo simulated data for 2009 and 2012 (official samples)
- We used two versions of the BOSS software
  - **6.6.4p1** for 2009: data and MC
  - **6.6.4p3** for 2012: data and MC

Study of η reconstruction efficiency

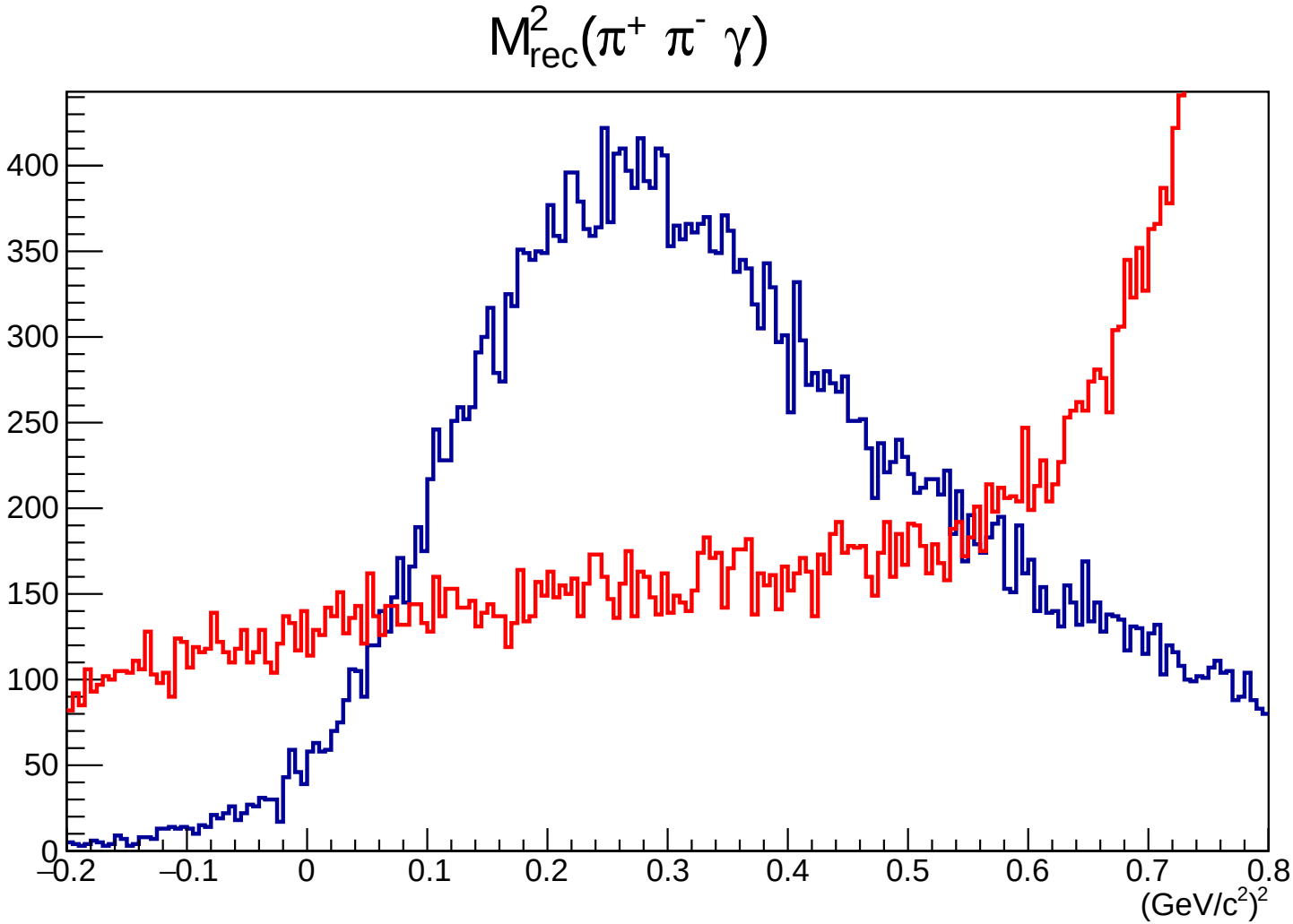
We used process: $\psi' \to \pi^+\pi^- J/\psi, \quad J/\psi \to \gamma\eta, \quad \eta \to \gamma\gamma$

- $\pi^+\pi^-$ pair was selected with the same criteria as in main analysis
- no other charged tracks
- at least two photons with standard quality criteria
- there is no pair of photons from the π^0 decay
- the photon from J/ψ decay must be such that the recoil mass $M^{rec}_{\pi^+\pi^-\gamma} = \sqrt{(P_{ecm} - P_{\pi^+} - P_{\pi^-} - P_\gamma)^2}$ is about M_η
- we tag event as $J/\psi \to \gamma\eta$ decay if missing mass of $\pi^+\pi^-\gamma\gamma$ is close to 0 and the invariant mass of «missing photon» and the second photon is about M_η
- if the number of photons is more than two, we select two with a minimum missing mass
- we checked whether γ was reconstructed or not

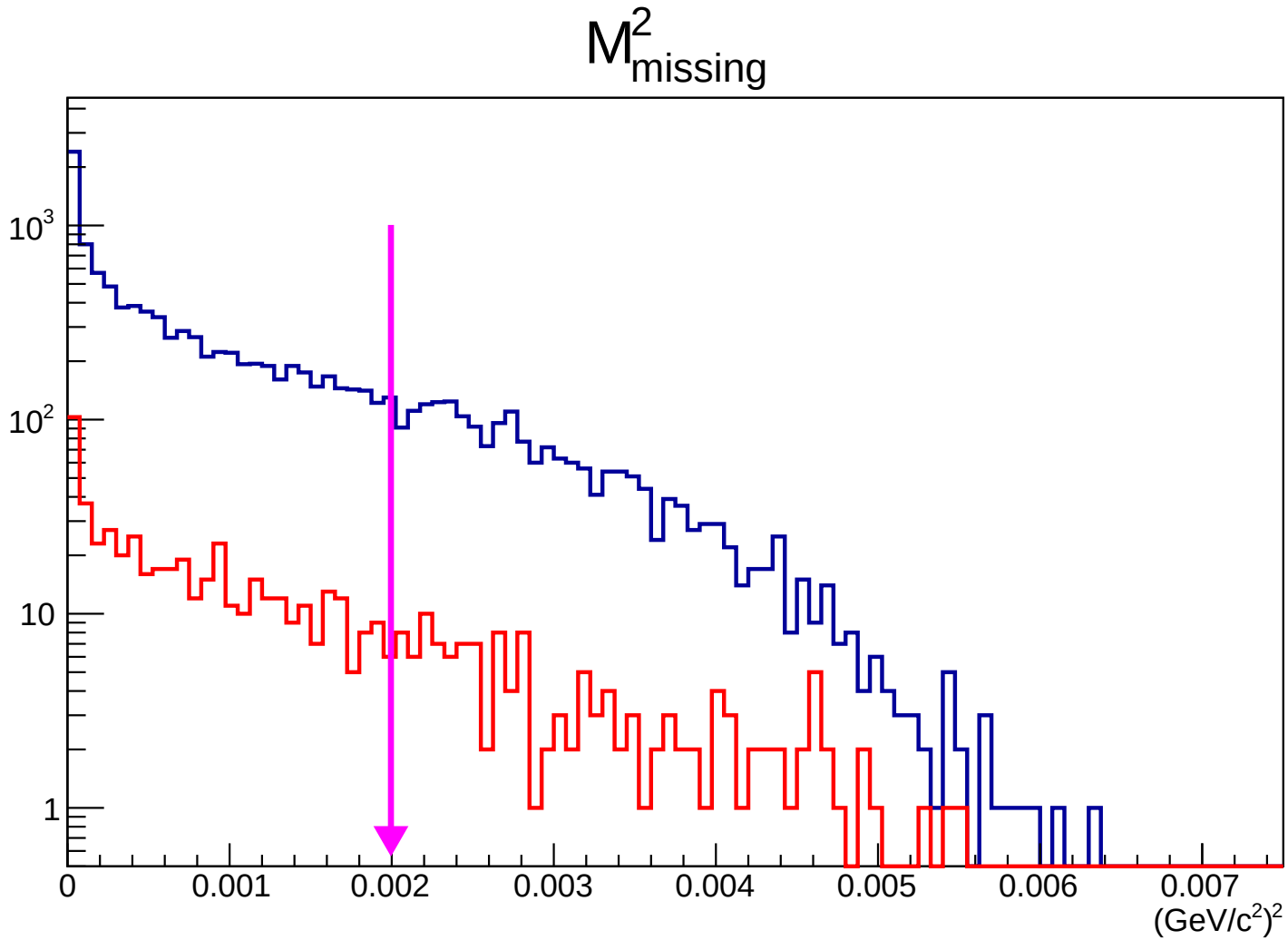


- π^0 suppression: we reject event if

$$0.013 < M^2_{inv}(\gamma\gamma) < 0.022 \ (\mathrm{GeV}/c^2)^2$$

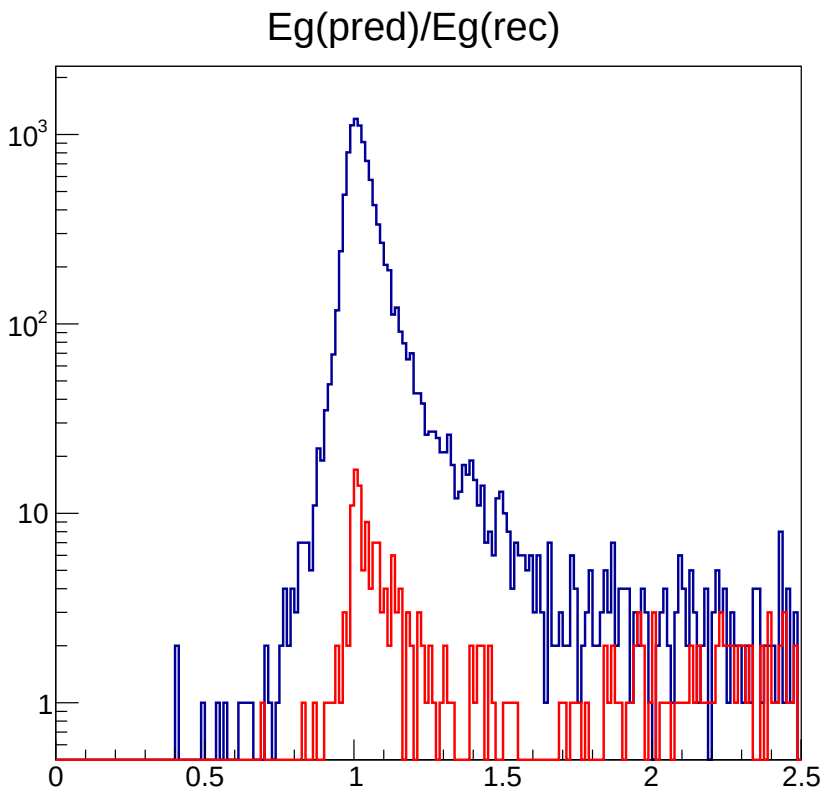


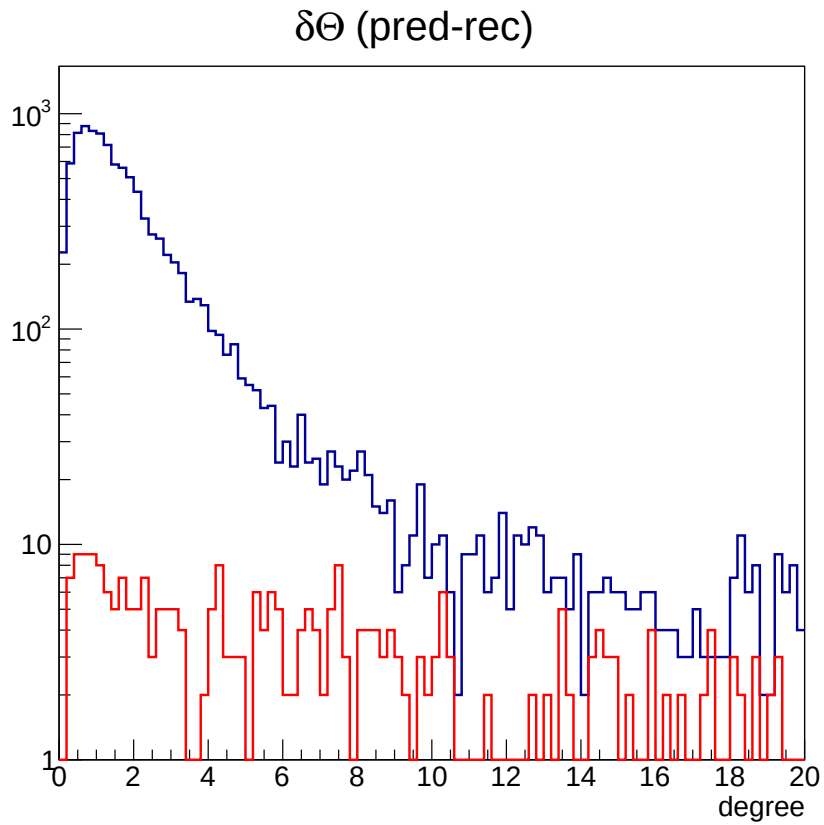
- selection of a photon from the decay J/ψ by recoil mass:
$$(M^{rec}_{\pi^+\pi^-\gamma})^2 = (P_{ecm} - P_{\pi^+} - P_{\pi^-} - P_\gamma)^2$$
- blue line – signal; red line – background
- we select event if $0.1 < (M^{rec}_{\pi^+\pi^-\gamma})^2 < 0.5\ (\mathrm{GeV}/c^2)^2$



- missing mass of $\pi^+\pi^-\gamma\gamma$
- blue line – signal; red line – background
- we select event if $M^2_{missing} < 0.002\ (\mathrm{GeV}/c^2)^2$

Search for reconstructed photon



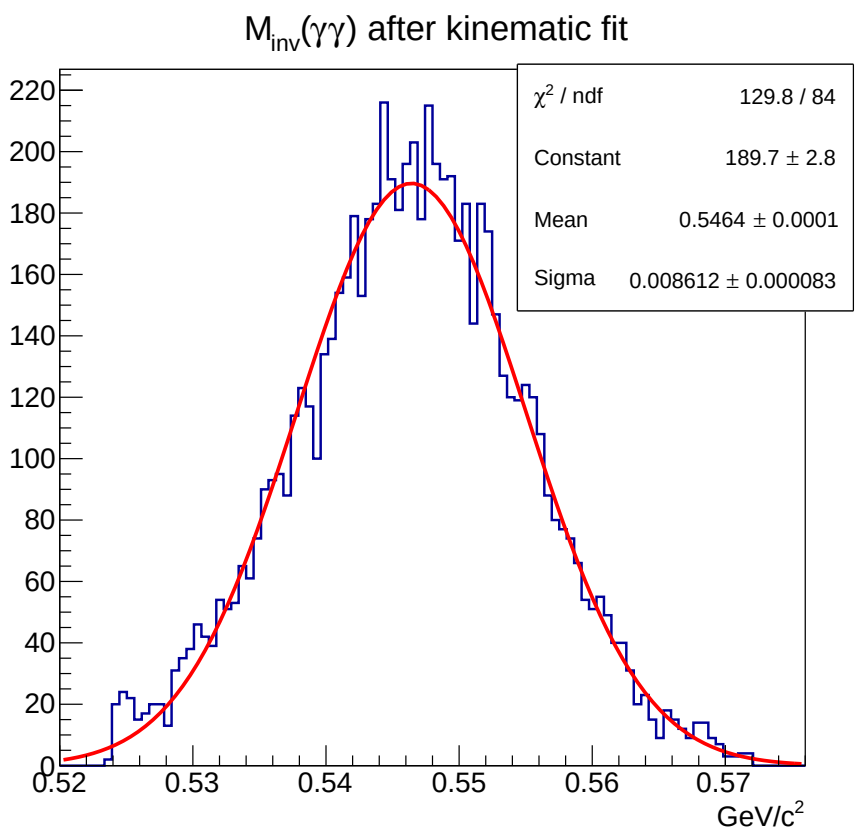


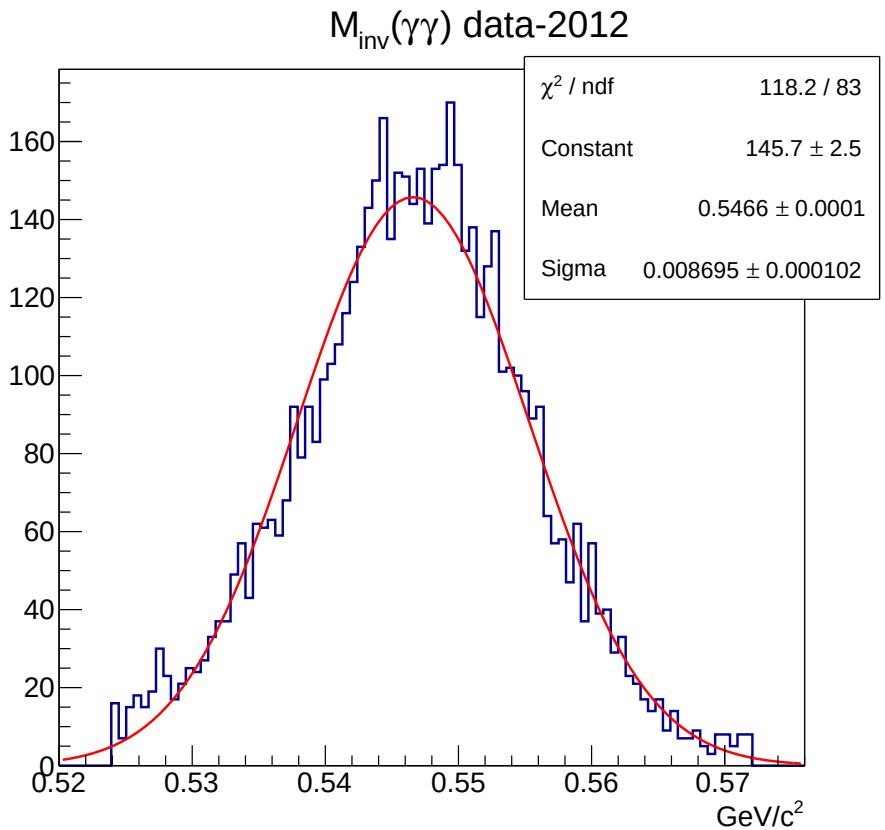
- blue line – signal; red line – background
- photon is found if $0.4 < \frac{E_\gamma(pred)}{E_\gamma(rec)} < 1.8$ and $\delta\Theta(pred - rec) < 10^\circ$

Search for reconstructed η

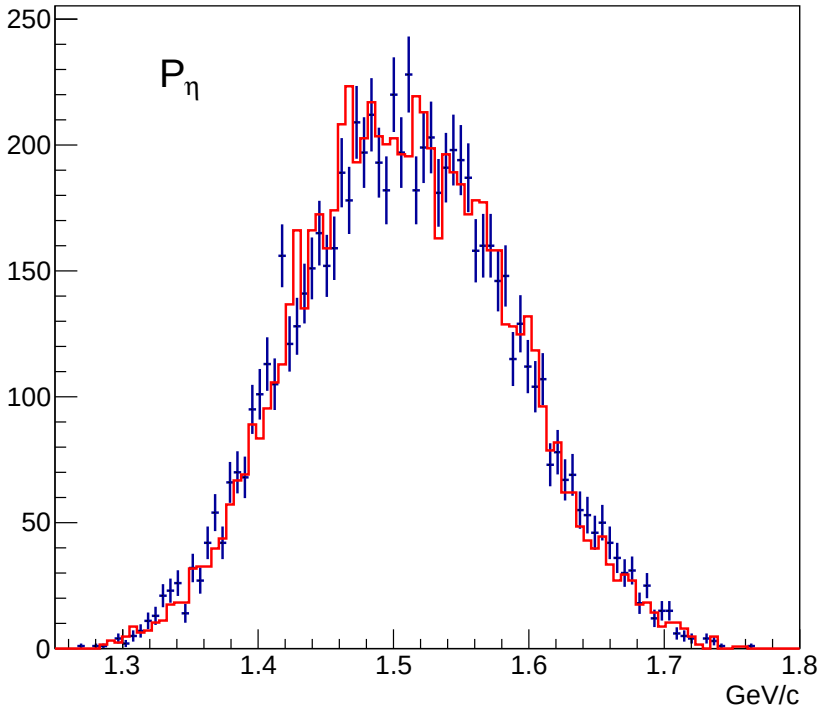
after we find two photons, we require exactly the same conditions for η reconstruction as in the main analysis:

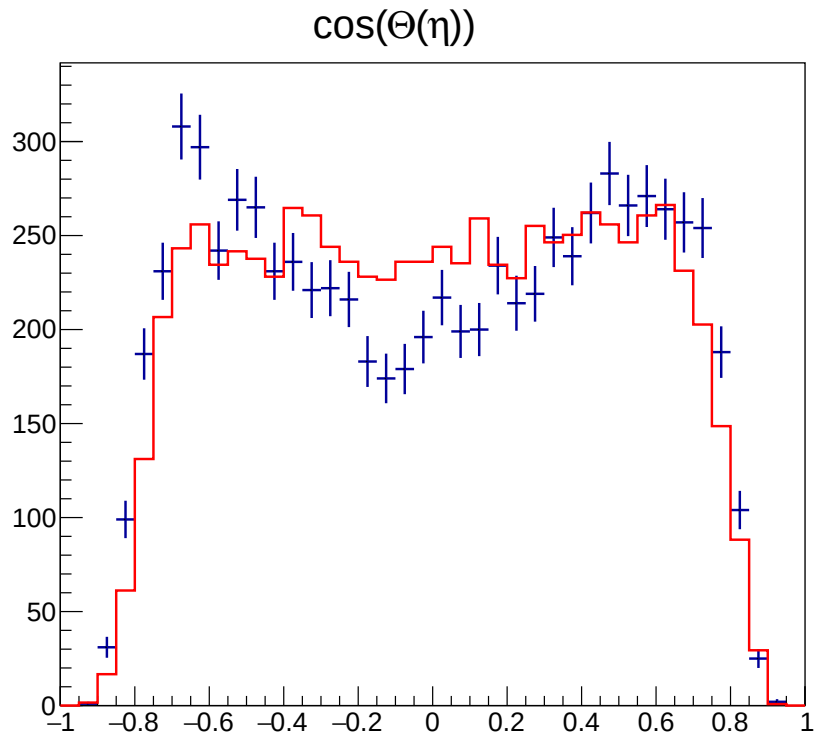
- we do 4C kinematic fit
- η is reconstructed if the invariant mass $|M_{\gamma\gamma}^{inv} - M_{\eta}| < 0.024$ GeV$/c^2$





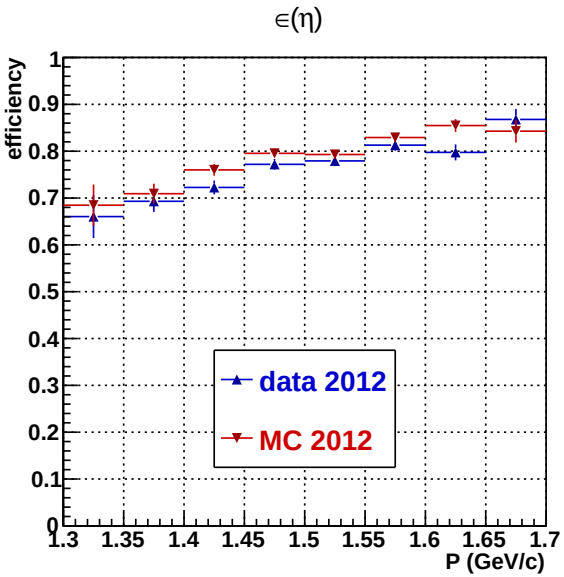
Data vs Monte Carlo

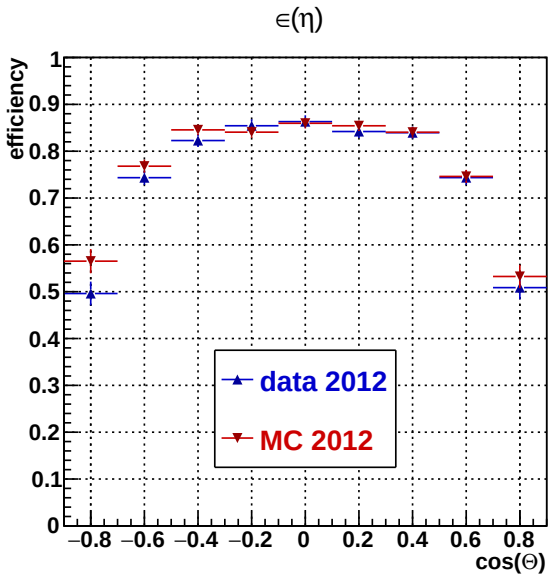


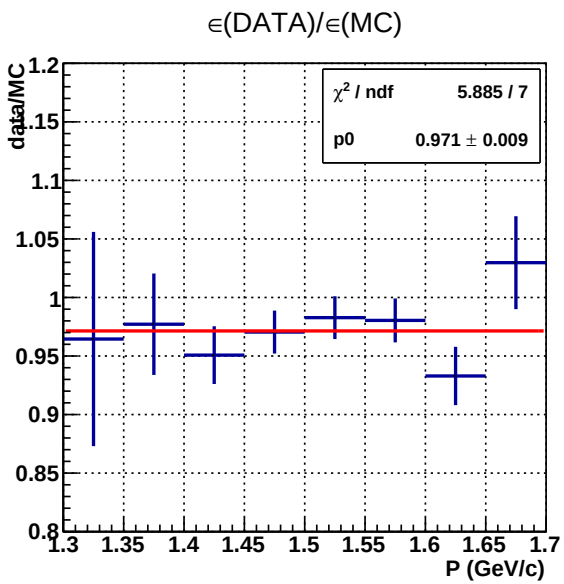


- blue – data 2012 red line – inclusive MC 2012 normalized on data
- Momentum and *cos*(Θ) distributions for fully and partially reconstructed η
- Purity for fully reconstructed is $> 99\%$ for partially rec.: $\sim 90\%$

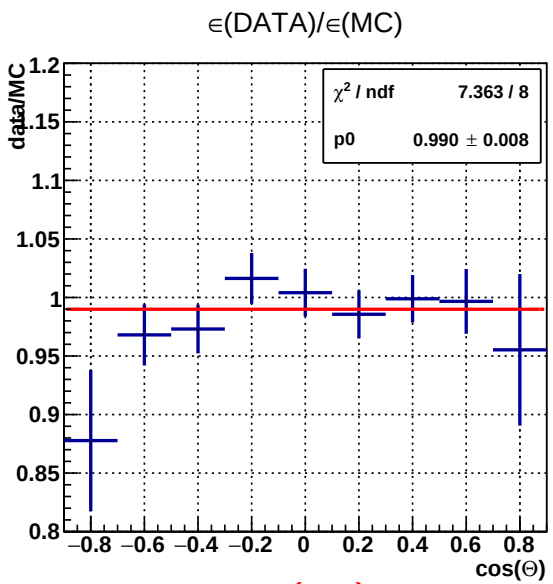
Reconstruction efficiency: Data vs MC 2012







Momentum



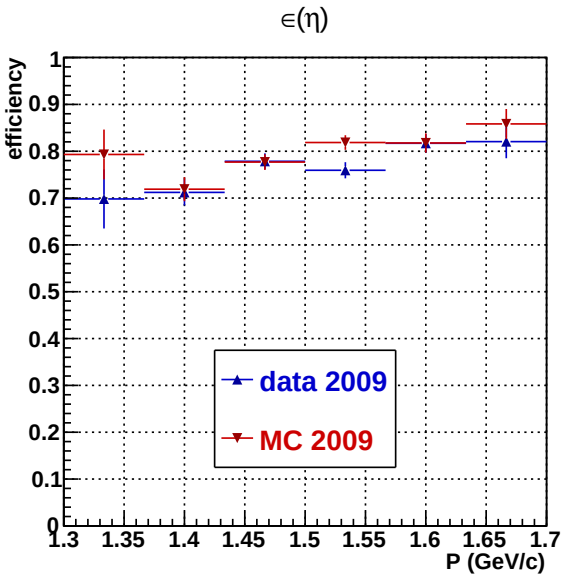
cos(Θ)

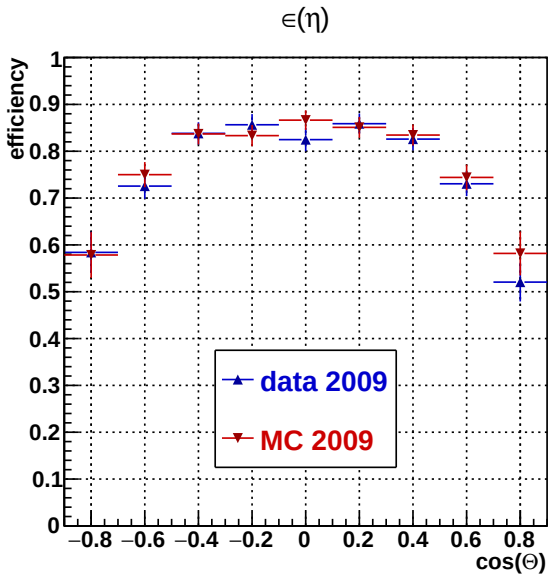
$$\epsilon = \frac{N_f}{N_f + N_p}$$

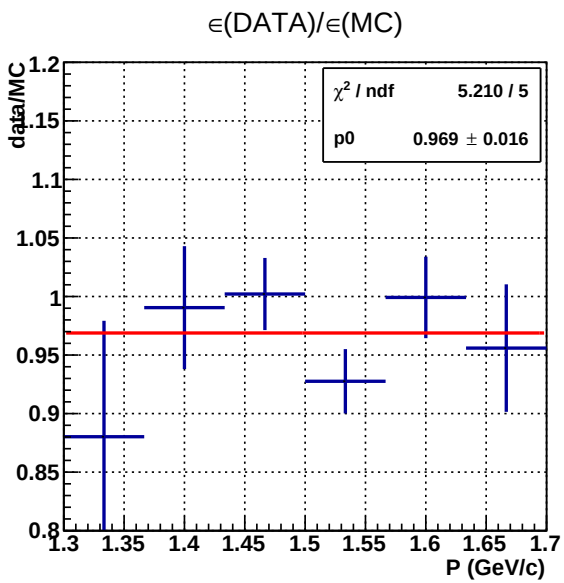
N_f — all photons (tracks) reconstructed

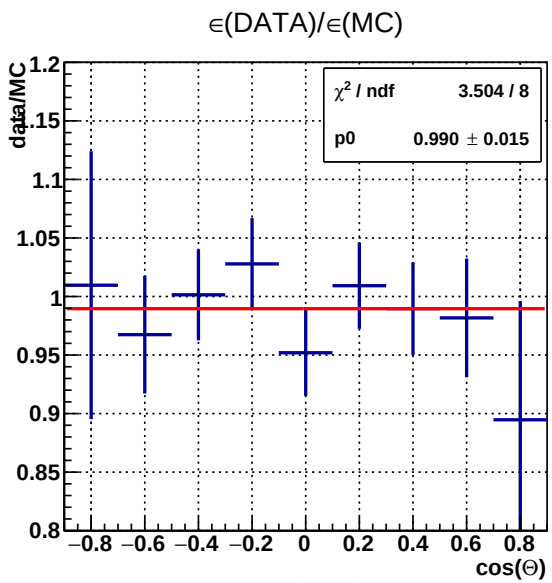
N_p — one photon (track) is missing

Reconstruction efficiency: Data vs MC 2009









Momentum *cos(Θ)*

Preliminary summary for η reconstruction efficiency

$\psi' \to \pi^+\pi^- J/\psi, \quad J/\psi \to \gamma\eta$

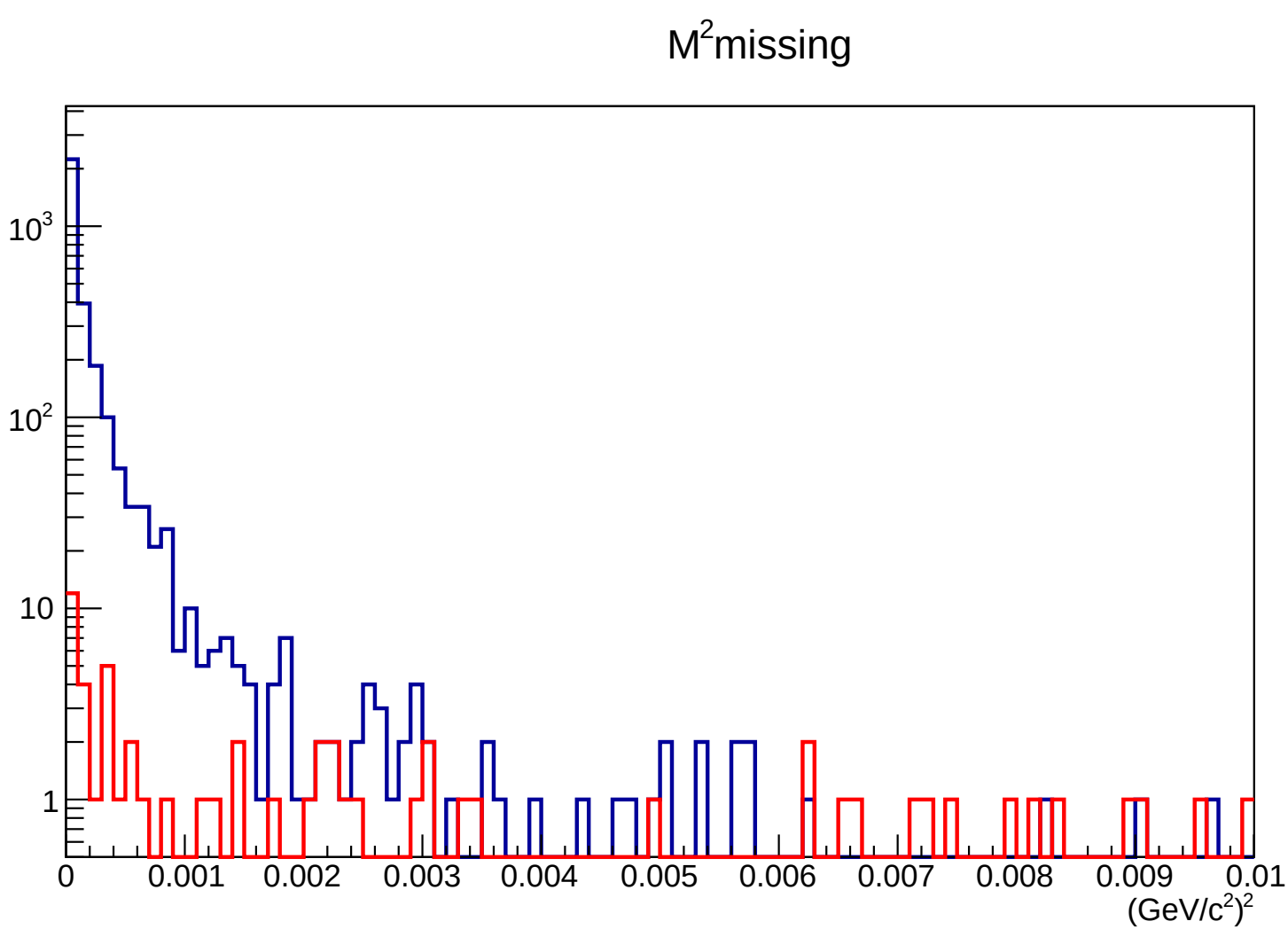
- We see a difference in the angular distribution of η between data and MC
- Noticeable background especially for events with a lost photon (10%)
- Momentum of η is slightly higher than in $J/\psi \to \phi\eta$ process
- Nevertheless, the ratio of efficiencies (data/MC) does not depend on the moment or on the angle of the η
- The ratio is 0.97 both in 2012 ($\pm$0.01) and 2009 ($\pm$0.016)

Verification is needed on another selection

Study of η reconstruction efficiency: $J/\psi \to \phi\eta$

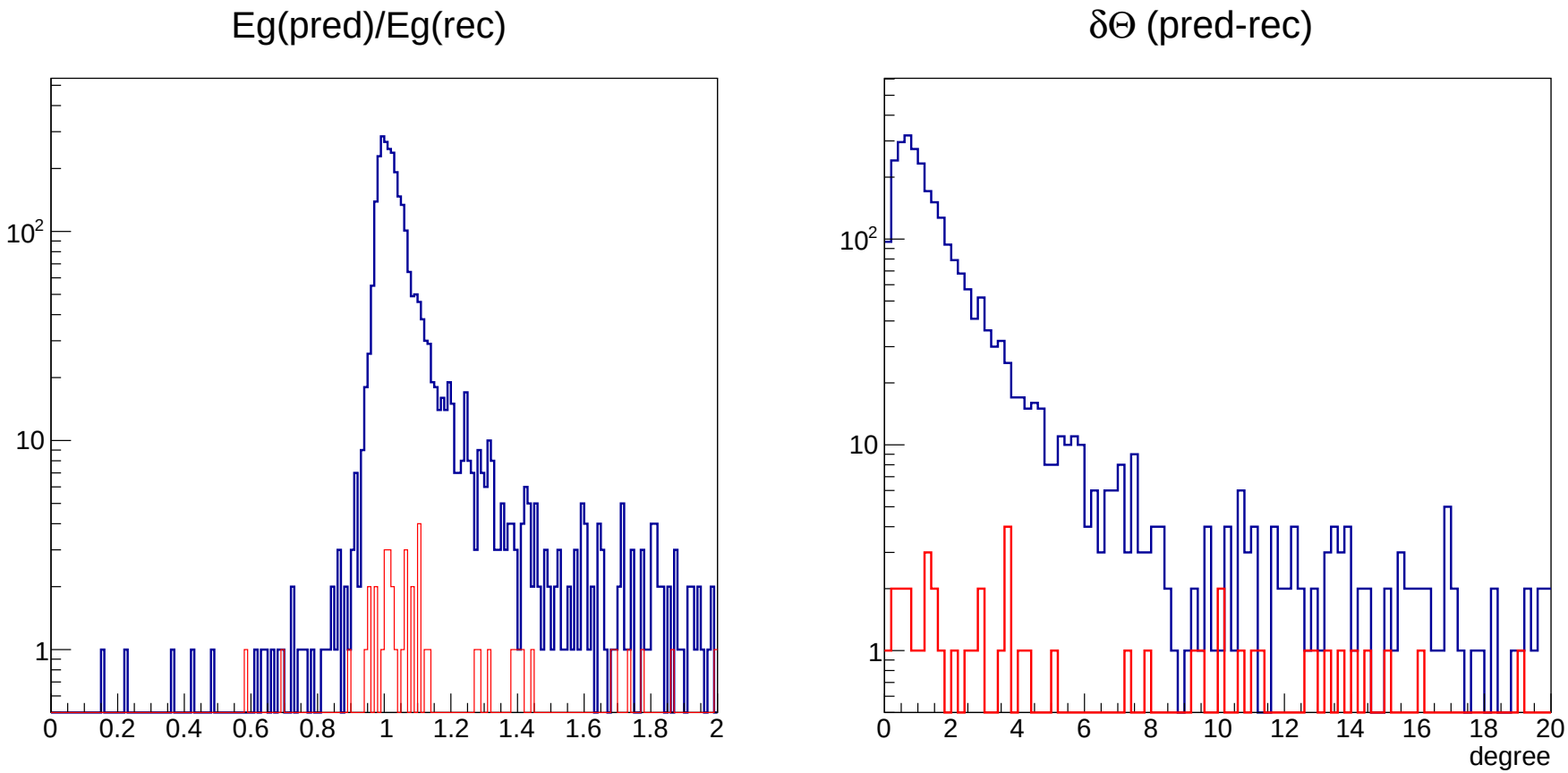
$\psi' \to \pi^+\pi^- J/\psi, \quad J/\psi \to \phi\eta, \quad \eta \to \gamma\gamma, \quad \phi \to K^+K^-$

- $\pi^+\pi^-$ pair was selected with the same criteria as in main analysis
- exactly two oppositely charged kaons and no other tracks
- at least one photon with standard quality criteria
- there is no pair of photons from the π^0 decay
- invariant mass of kaons is about M_ϕ
- we tag event as $J/\psi \to \phi\eta$ decay if missing mass of $\pi^+\pi^-K^+K^-\gamma$ is close to 0 and the invariant mass of «missing photon» and the reconstructed photon is about M_η
- if the number of photons is more than one, we select one with a minimum missing mass
- we checked whether γ was reconstructed or not



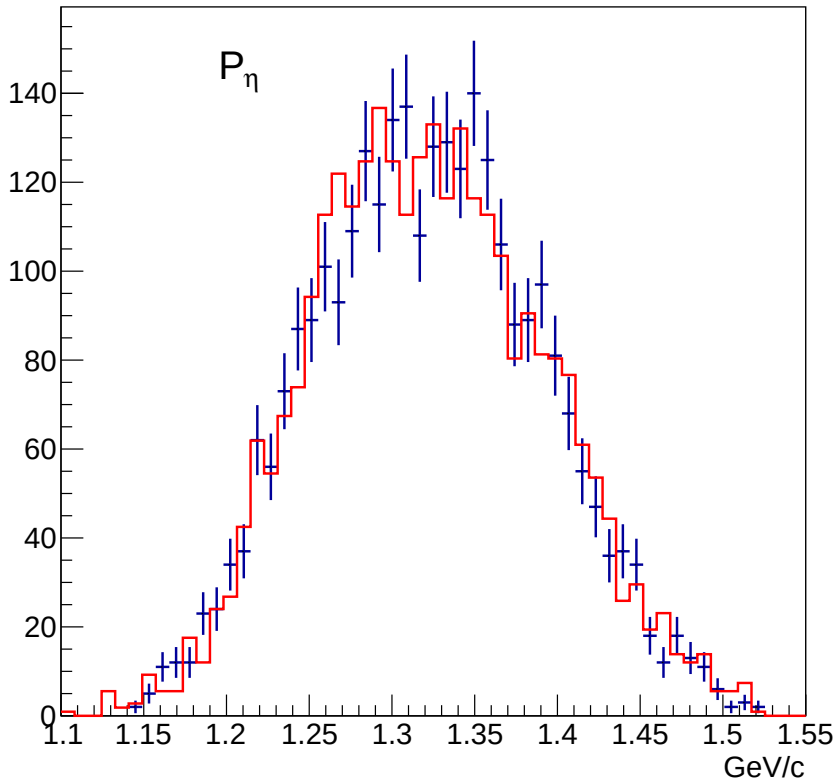
- missing mass of $\pi^+\pi^-K^+K^-\gamma$
- blue line – signal; red line – background
- we select event if $M^2_{missing} < 0.002\ (\mathrm{GeV}/c^2)^2$

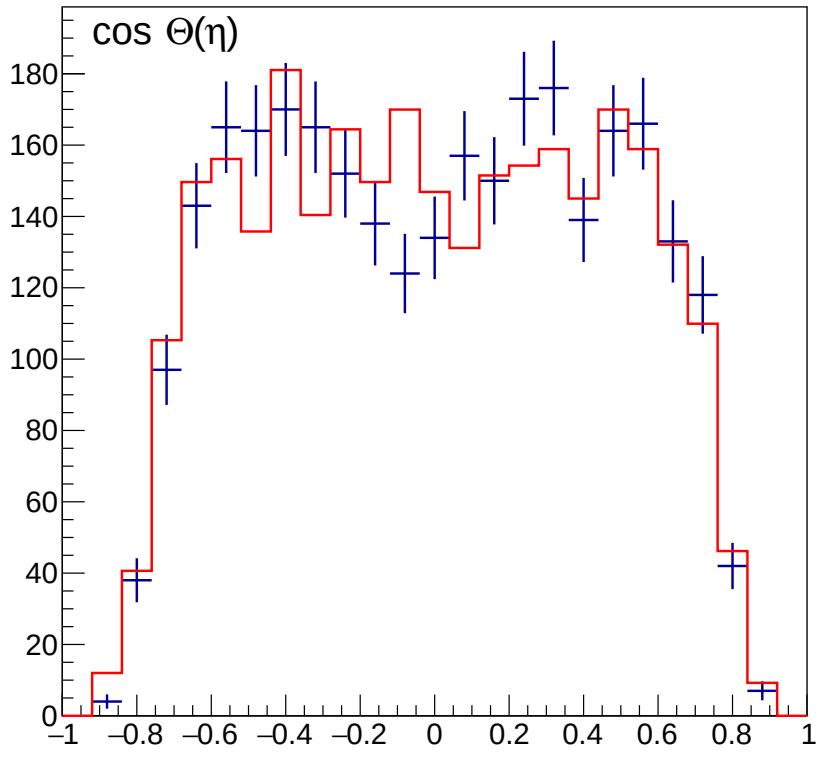
Search for reconstructed photon: $J/\psi \to \phi\eta$



- blue line – signal; red line – background
- photon is found if $0.4 < \frac{E_\gamma(pred)}{E_\gamma(rec)} < 1.8$ and $\delta\Theta(pred - rec) < 10^\circ$

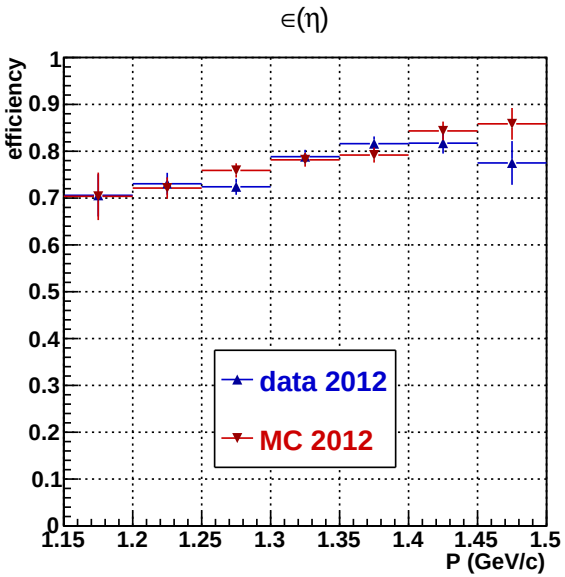
Data vs Monte Carlo: $J/\psi \to \phi\eta$

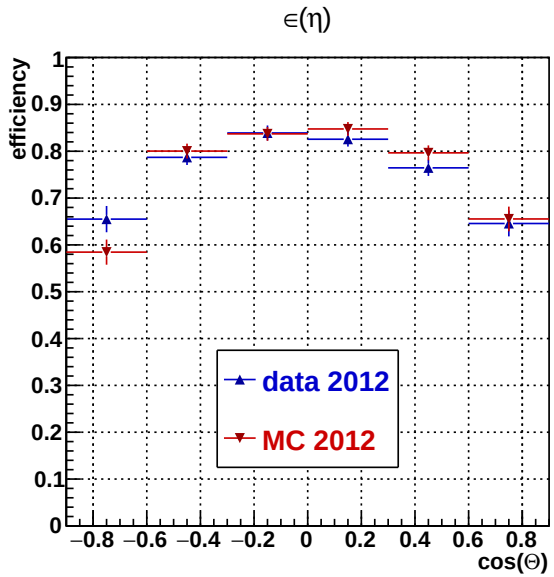


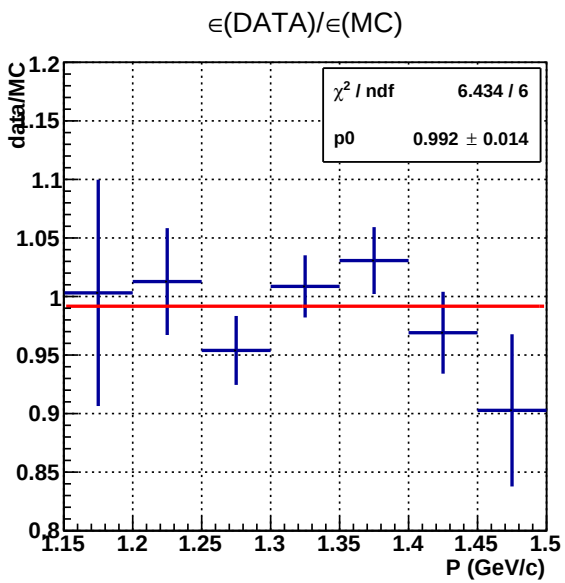


- blue – data 2012 red line – inclusive MC 2012 normalized on data
- Momentum and *cos*(Θ) distributions for fully and partially reconstructed η
- Purity for fully reconstructed is $> 99.5\%$ for partially rec.: $\sim 97\%$

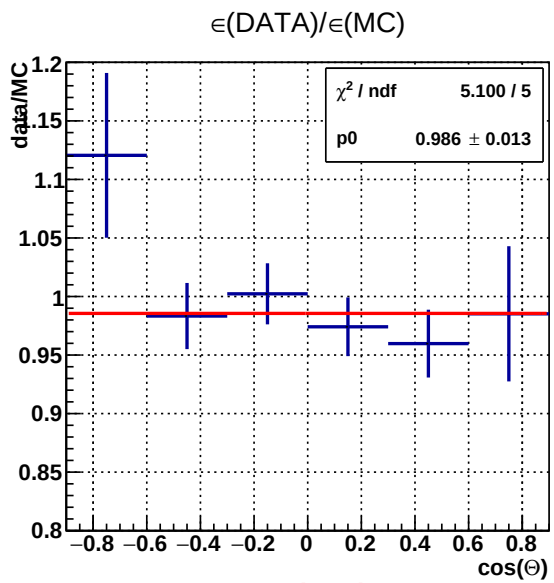
Rec. efficiency of η in $J/\psi \to \phi\eta$: Data vs MC 2012





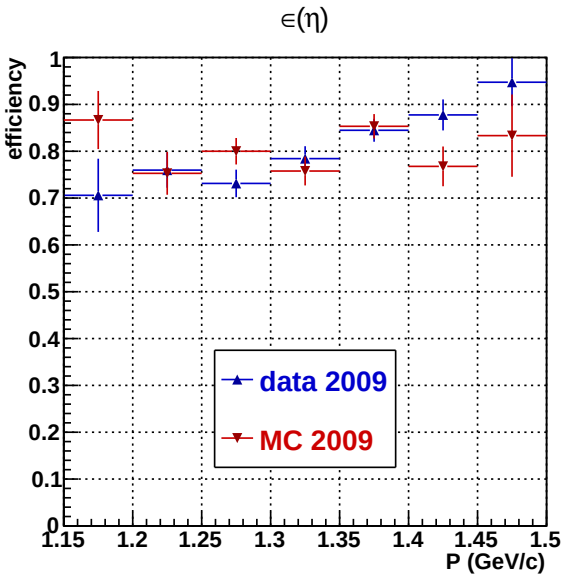


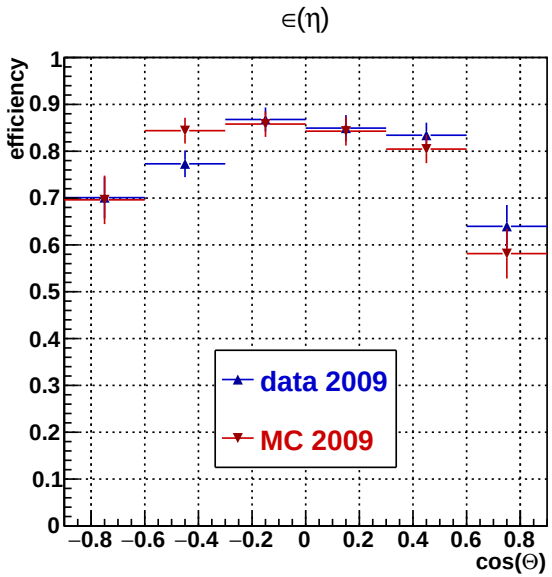
Momentum

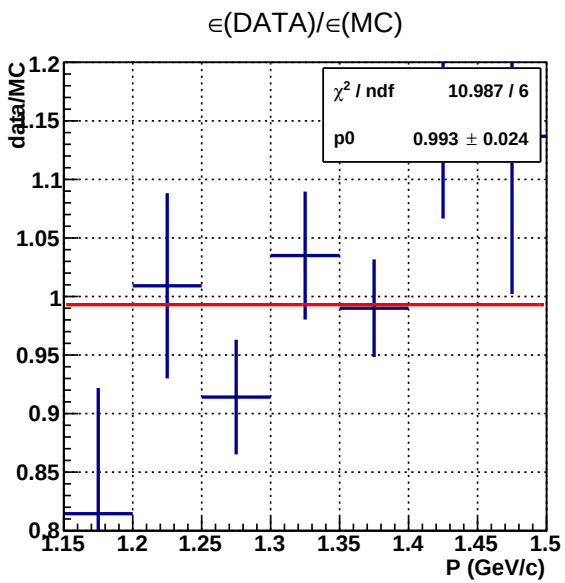


$cos(\Theta)$

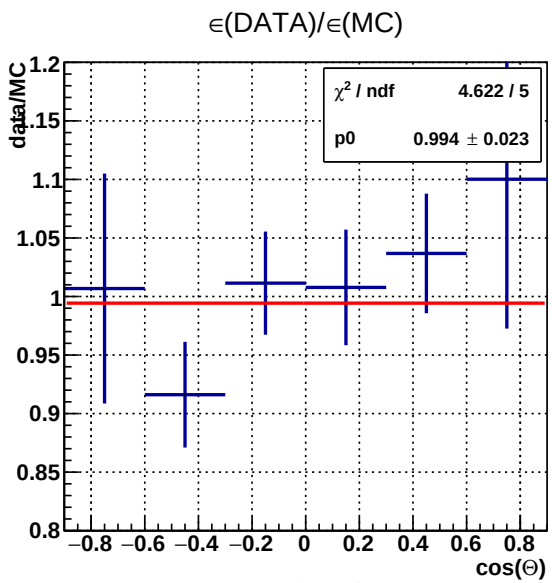
Rec. efficiency of η in $J/\psi \to \phi\eta$: Data vs MC 2009







Momentum



cos(Θ)

Conclusion

Summary for η reconstruction efficiency

- For 2012, corrections to η reconstruction efficiency estimated in two decay channels coincide within one sigma error:
  $J/\psi \to \gamma\eta$: 0.971 ± 0.009
  $J/\psi \to \phi\eta$: 0.992 ± 0.014
- We plan to combine the results of these channels
- For 2009, statistics, especially in the $J/\psi \to \phi\eta$, are too small
- Nevertheless, there is good agreement between 2012 and 2009, so we can use the result of 2012 with the corresponding error scaling

- ✓ We have all components to evaluate the total systematic uncertainty
- ✓ The result of the branching fraction for $J/\psi \to \phi\eta$ will be updated soon