Cross section Ratio $\psi(2S)/J/\psi$ in PHP (request for preliminary)

G. Grzelak, J. Ciborowski

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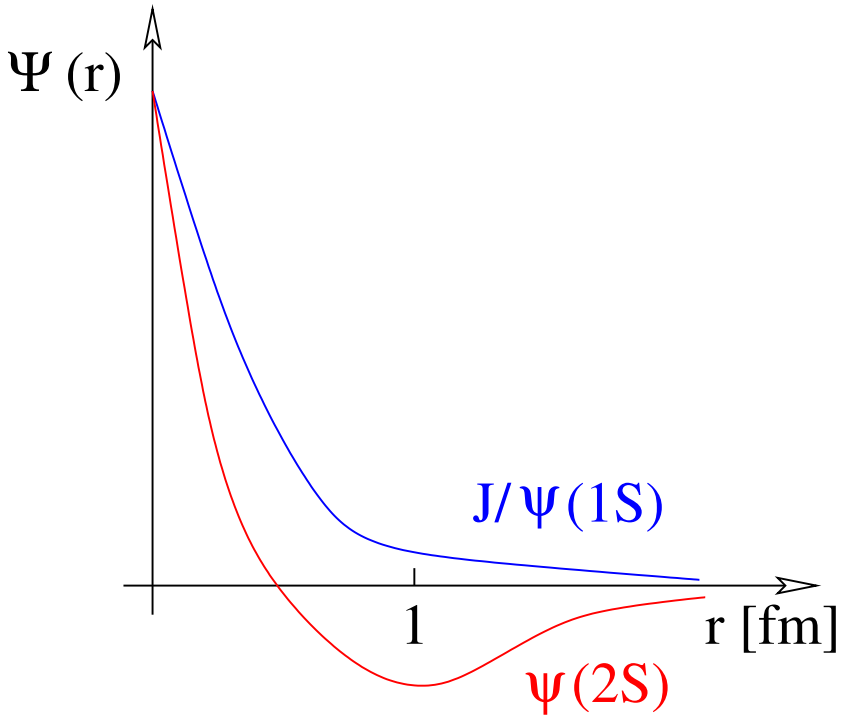
Outlook

- motivation
- selection cuts
- draft with abstract, selections cuts and plots
  $\rightarrow$ circulated
- control plots (incl. acceptances, number of events, ratio)
- plots for preliminary marked with
  ZEUS Preliminary, L $=$ 333 pb^{-1}
  (to be presented on ICHEP18 poster session)

Motivation

- physics of excited states of heavy quarkonia (charmonium) $\rightarrow$ (next page)
- photoproduction channel (PHP) – complementary analysis to already published by ZEUS $\psi(2S)/J/\psi$ ratio in DIS
- very clean exclusive final state ...
- ... but very challenging from the experimental point of view – requires very good understanding of detector efficiency for muons incl. all 3 trigger levels (never before fully studied for HERA-II)
- this is first ZEUS measurement on exclusive $\psi(2S)$ production in PHP
- much higher statistic of J/ψ events comparing to ZEUS HERA-I paper

Cross section ratio $\psi(2S)/J/\psi(1S)$ in PHP



Ratio $R = \dfrac{\sigma_{\gamma p \to \psi(2S) p}}{\sigma_{\gamma p \to J/\psi(1S) p}}$

- sensitive to radial wave function of charmonium
- provides insight into the dynamics of the hard process

- $J/\psi(1S)$ and $\psi(2S)$ have distinctive wave functions
- $\psi(2S)$ has a node at ≈ 0.4 fm
- $\langle r^2_{\psi(2S)} \rangle \approx 2 \langle r^2_{J/\psi(1S)} \rangle$
- pQCD predict $R \sim 0.17$ in PHP and moderate rise of R with Q^2 in DIS
- ψ' cross section is expected to be suppressed w.r.t. the J/ψ production

2PR: Selection cuts

- trigger chains:
  $(BRMUO : FLT\ and\ SLT\ and\ TLT)\ or$
  $(FMUO : FLT\ and\ SLT\ and\ TLT)\ or\ \ (BAC : FLT\ and\ SLT\ and\ TLT)$
- $N_{trk} = 2$, both tracks from primary vertex, opposite charge
- vertex cuts: $|Z_{VTX}| < 30$ cm and $\rho_{VTX} < 0.5$ cm (w.r.t. beam-spot)
- COSMIC rejection: $cos(\vec{p^+}, \vec{p^-}) > -0.9$
- DIS rejection: no Sinistra cand. with $prob > 0.9$ and $E_e > 5$ GeV
- elasticity cut on ZUFOS:
  no zufo unmatched to track with $E^{CAL}_{ZUFO} > 0.5$ GeV
- anti-p.diss cut: $E_{FCALin1^{st}IR} < 1.0$ GeV

2PR: Selection cuts (cont.)

- track length: for muon tracks $N_{SL} >= 3$
  $\rightarrow$ limits η range to approx. $(-2, 2)$
- muon tracks $p_T^{\mu} > 1.0$ GeV
- (muon tracks $p^{\mu} > 1.0$ GeV) consistency with MV finder
- muon identification using GMUON:
  Quality > 0, ZTT track match
  both muons identified by CAL MV finder
  (enhanced by Prob. cut $p_{MV} > 0.7$ and isolation cuts)
  and at least one muon found in MUON chambers
  (BRMUO or FMUON) or in BAC
- W cut: $30 < W < 180$ GeV
- $|t| < 5$ GeV

Offline muon identification algorithms from GMUON

- FMUON: MAMMA or MPMATCH
  (with GMUON Quality > 0 and ZTT track match)
- B/RMUON: GLOMU or BREMAT
  (with GMUON Quality > 0 and ZTT track match)
- BAC: MUBAC or BACMAT
  (with GMUON Quality > 0 and ZTT track match)
- CAL: MV NN finder $\rightarrow$ CAL MIP Islands

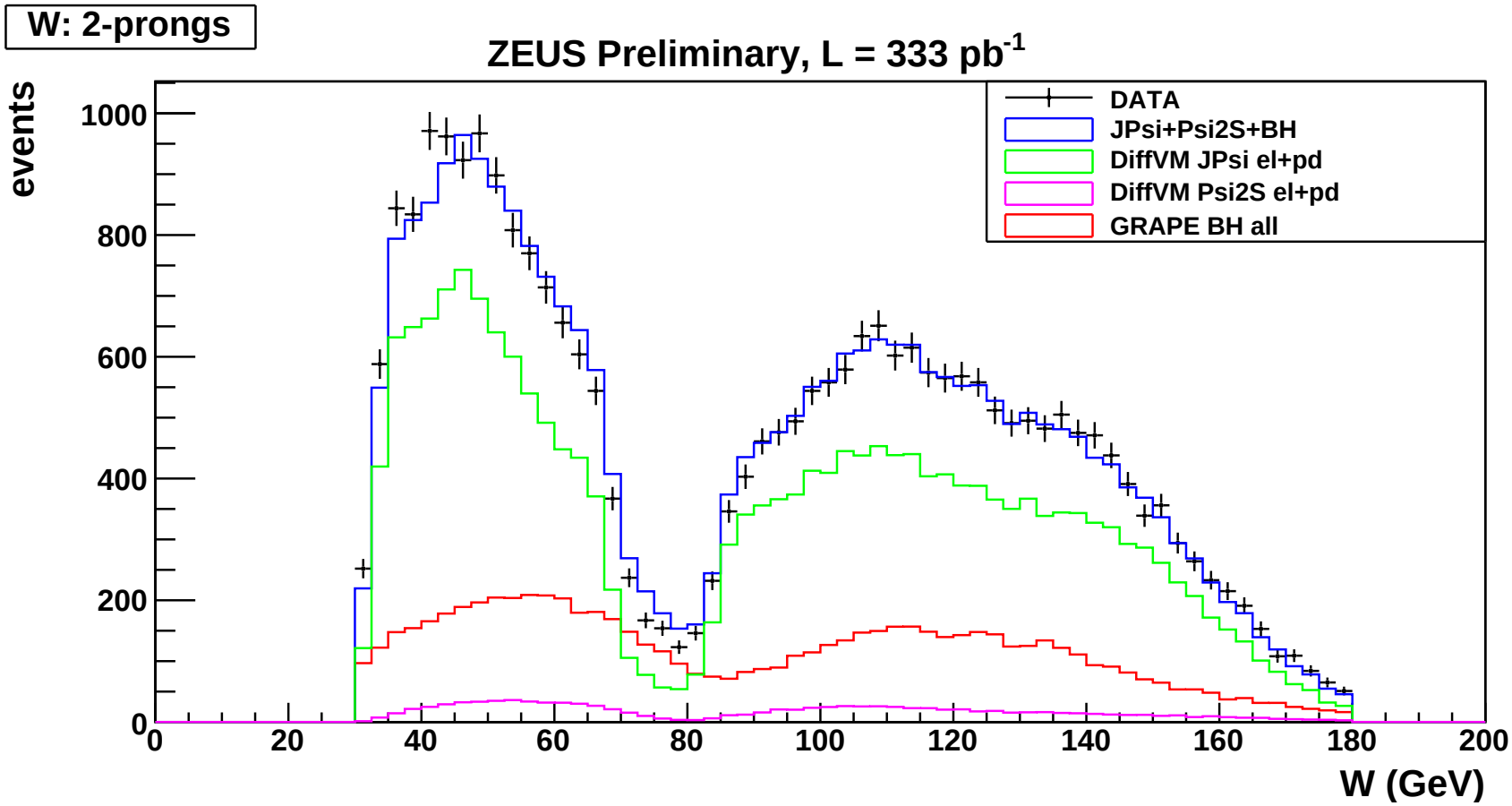
4-prongs: differences w.r.t. the 2-prongs channel

- (4-prongs: $\psi(2S) \to \mu^+\mu^-\pi^+\pi^-$)
- $N_{trk} = 4$, all tracks from primary vertex
- two highest momentum tracks are muon candidates (the pions are SLOW)
- opposite charge of muon and pion candidates
- no anit-cosmic cut
- both pion tracks: $p_T^\pi > 0.12$ GeV
- $M(\mu^+, \mu^-)$ in J/ψ window (2.8 – 3.4) GeV
- $M(\mu^+, \mu^-, \pi^+, \pi^-) - M(\mu^+, \mu^-)$ in window (0.5 – 0.7) GeV

Corrections applied on MC level

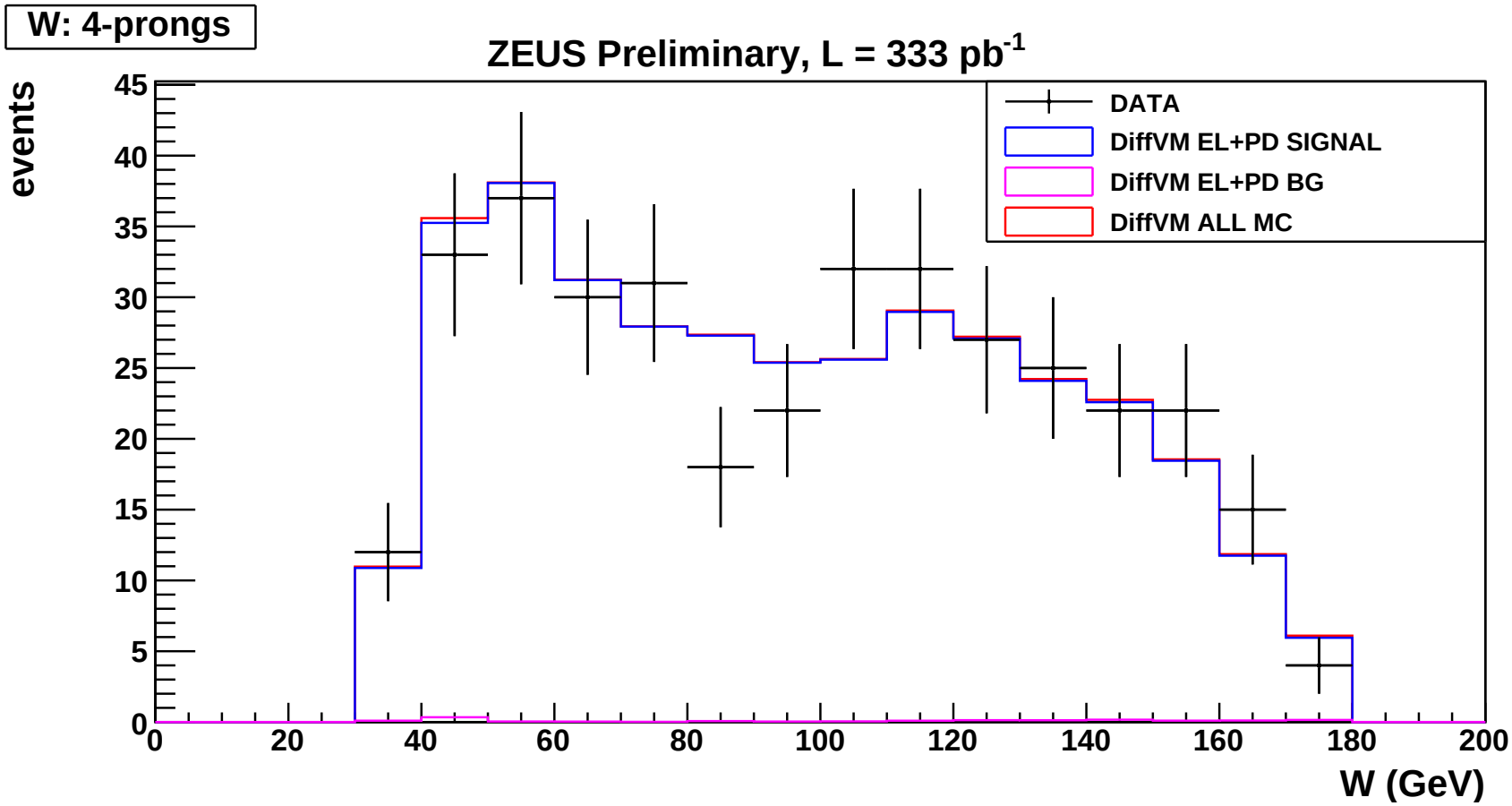
- muon (in)efficiency/acceptance corrections for F/B/RMUON and BAC (trigger and off-line) and CAL (off-line only)
- slow pions corrections for 4PR channel
- phase space correction for 4PR channel (DIFFVM)
- fake $\chi_{c0,1,2}$ decays removed from DIFFVM (4PR only)
  $\mu^+\mu^-\pi^0\pi^0$ rescaled accordingly to account for the MC event loss (negligible effect on 4PR BG)

2PR: *W* distribution



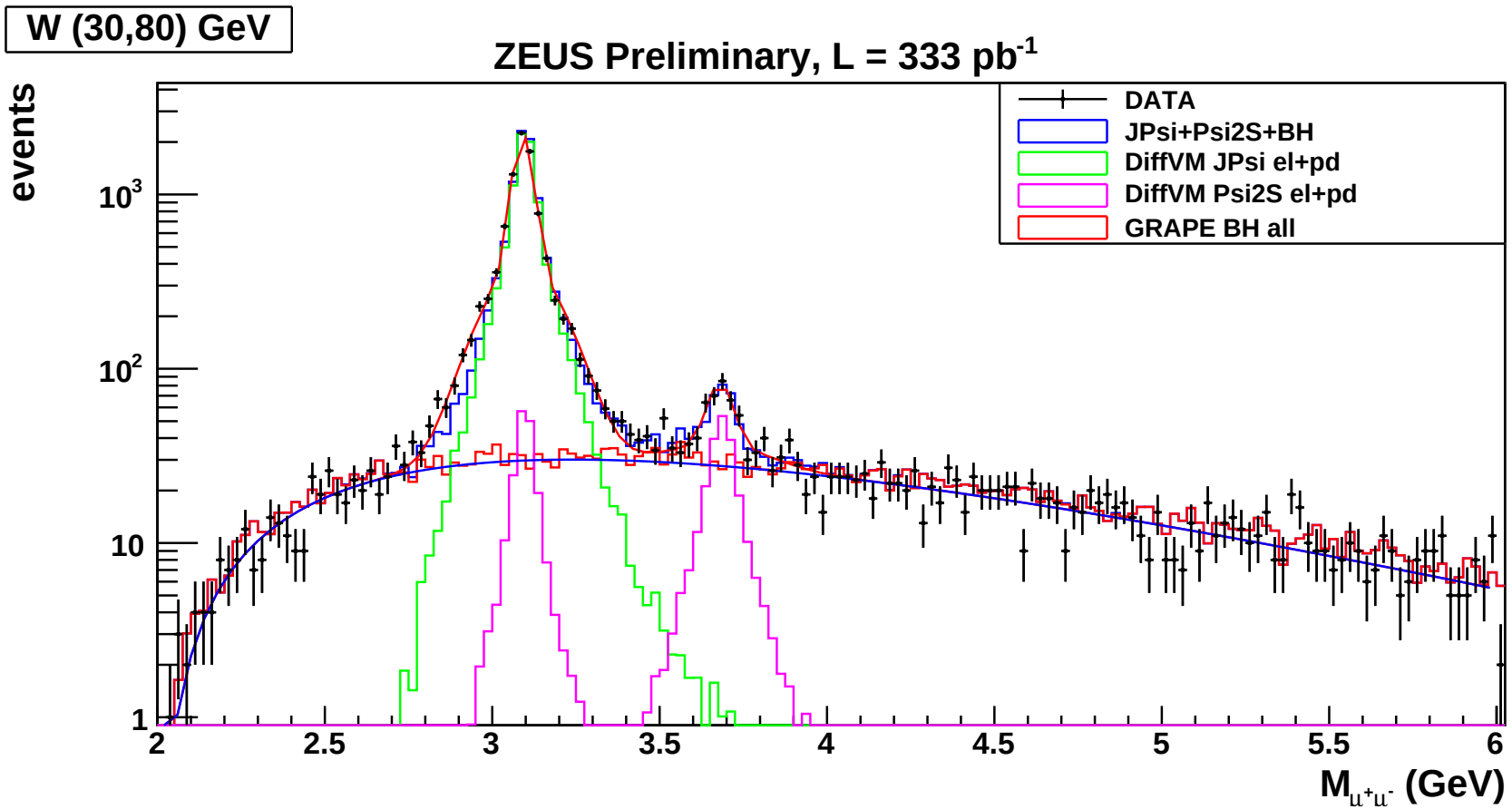
- *W* in 2-prongs channel

4PR: *W* distribution



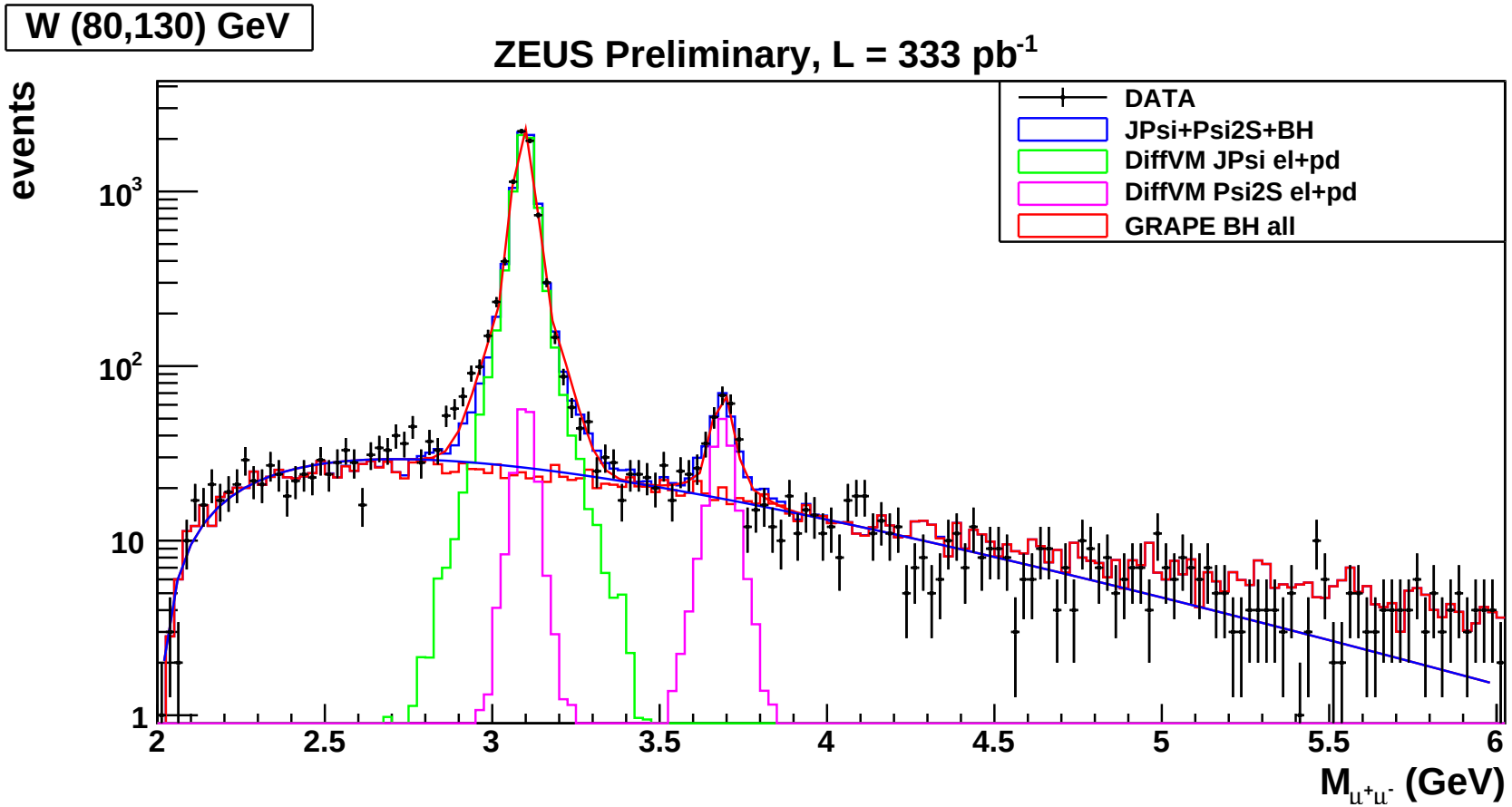
- *W* in 4-prongs channel

2PR: di-muon M in W1 bin



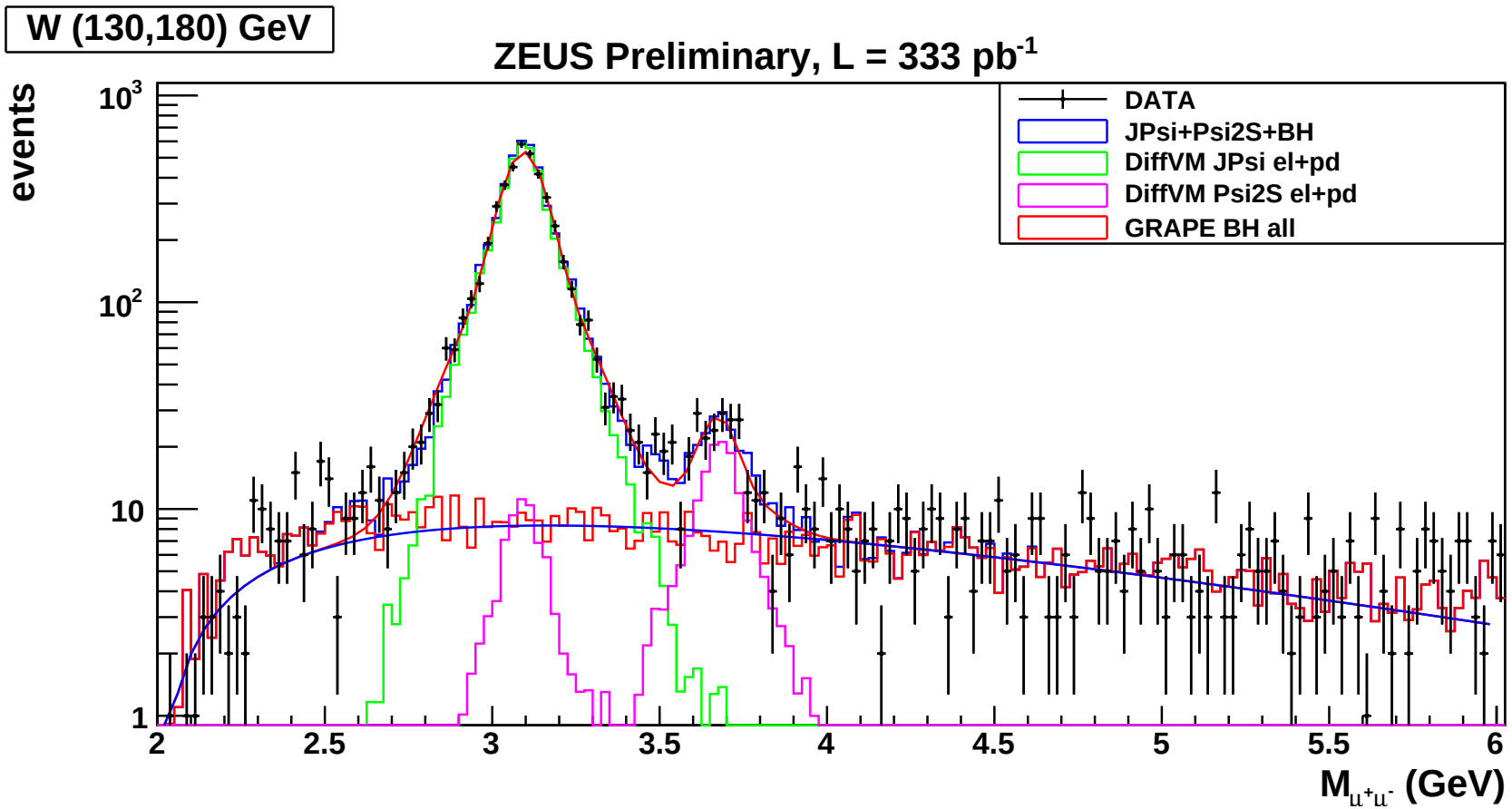
- W (30-80) GeV
- MC: DIFFVM (J/ψ and $\psi(2S)$ el + pd) and GRAPE (Bethe-Heitler BG)
- double-Gaussian+BG fit to resonant peaks (used for signal extraction)

2PR: di-muon *M* in W2 bin



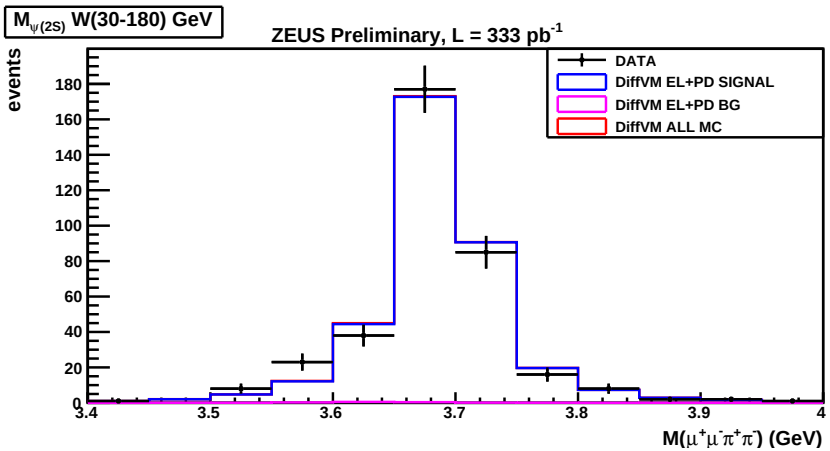
- *W* (80-130) GeV
- MC: DIFFVM (J/ψ and $\psi(2S)$ el + pd) and GRAPE (Bethe-Heitler BG)
- double-Gaussian+BG fit to resonant peaks (used for signal extraction)

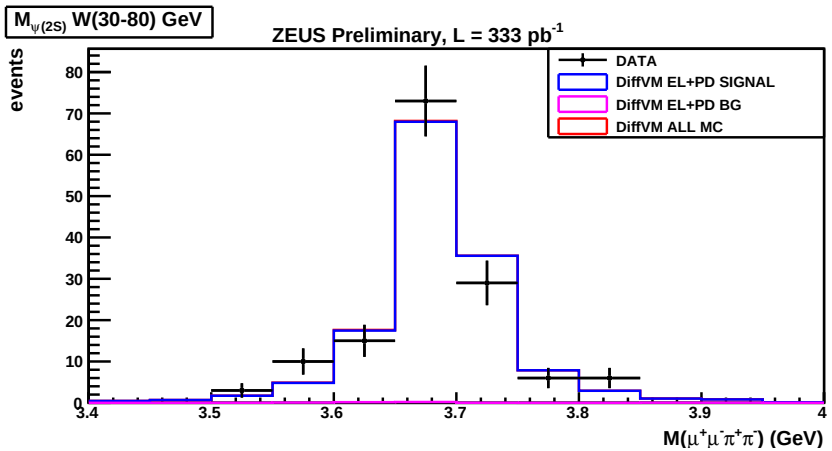
2PR: di-muon *M* in W3 bin

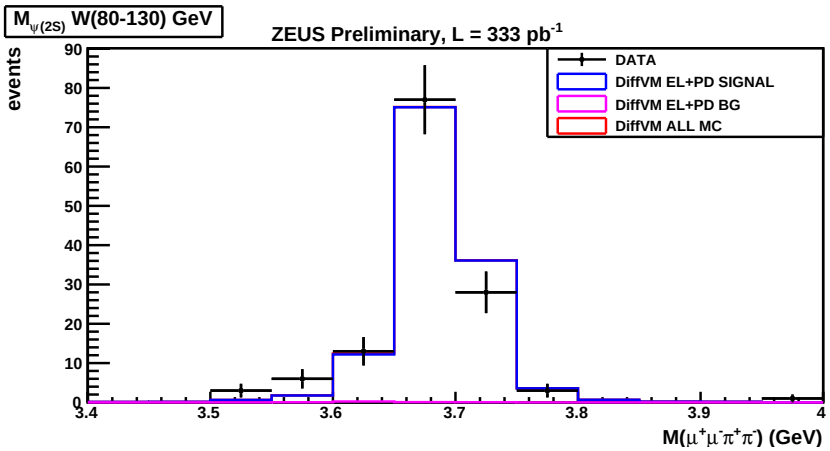


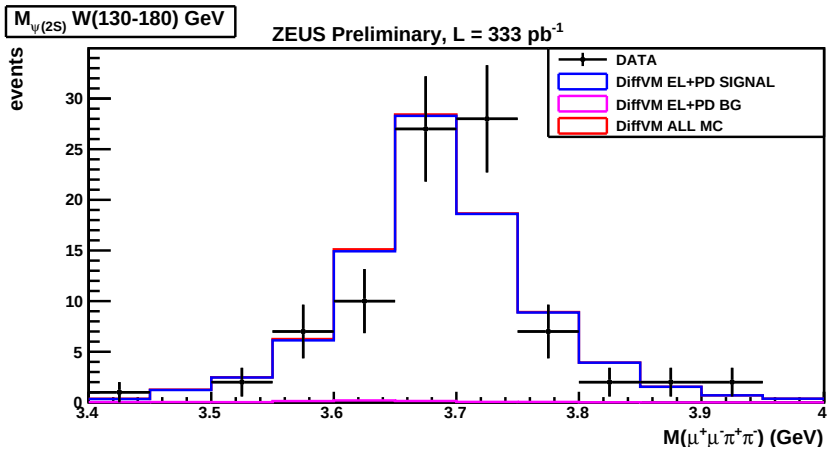
- *W* (130-180) GeV
- MC: DIFFVM (J/ψ and $\psi(2S)$ el + pd) and GRAPE (Bethe-Heitler BG)
- double-Gaussian+BG fit to resonant peaks (used for signal extraction)

4PR: $M(\mu^+, \mu^-, \pi^+, \pi^-)$



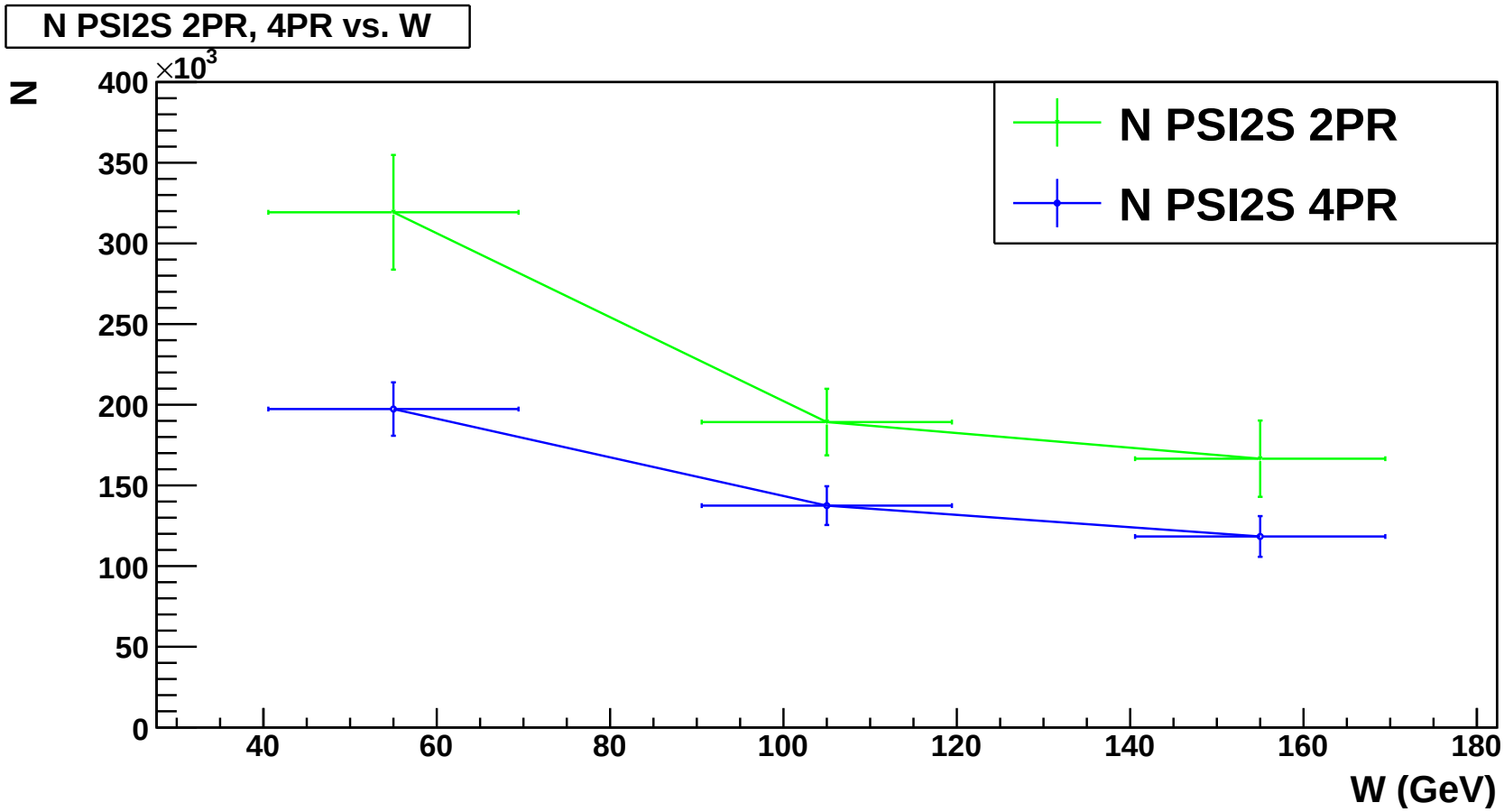






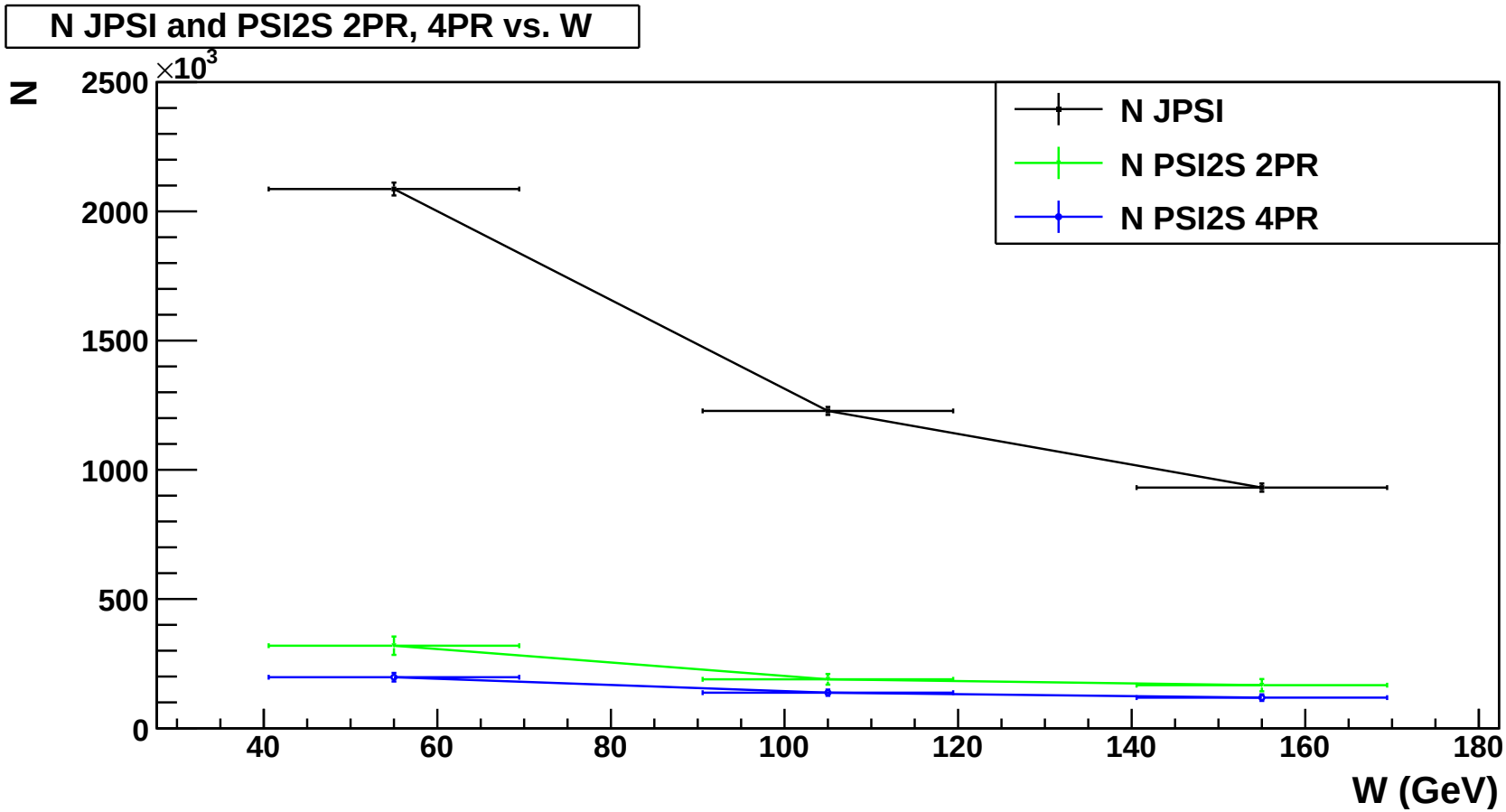
- W : ALL and W1,W2,W3 bins
- MC: DIFFVM (4PR $\psi(2S)$ el + pd for signal and BG)

2PR, 4PR: Number of events



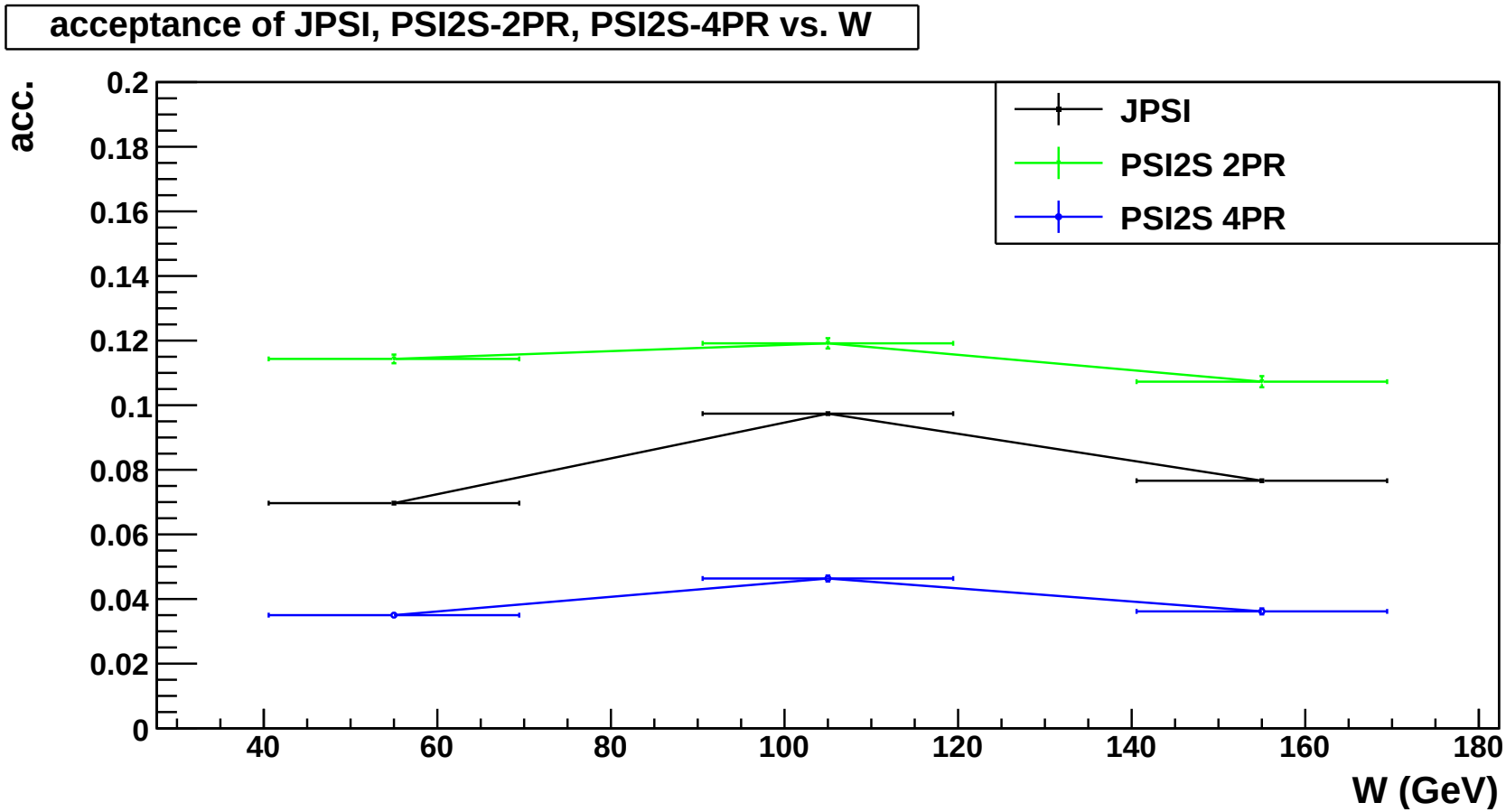
- Number of $\psi(2S)$ events from 2PR and 4PR corrected for acceptance and BR
- ("acceptance" means here "acceptance*efficiency")

2PR, 4PR: Number of events incl. J/ψ



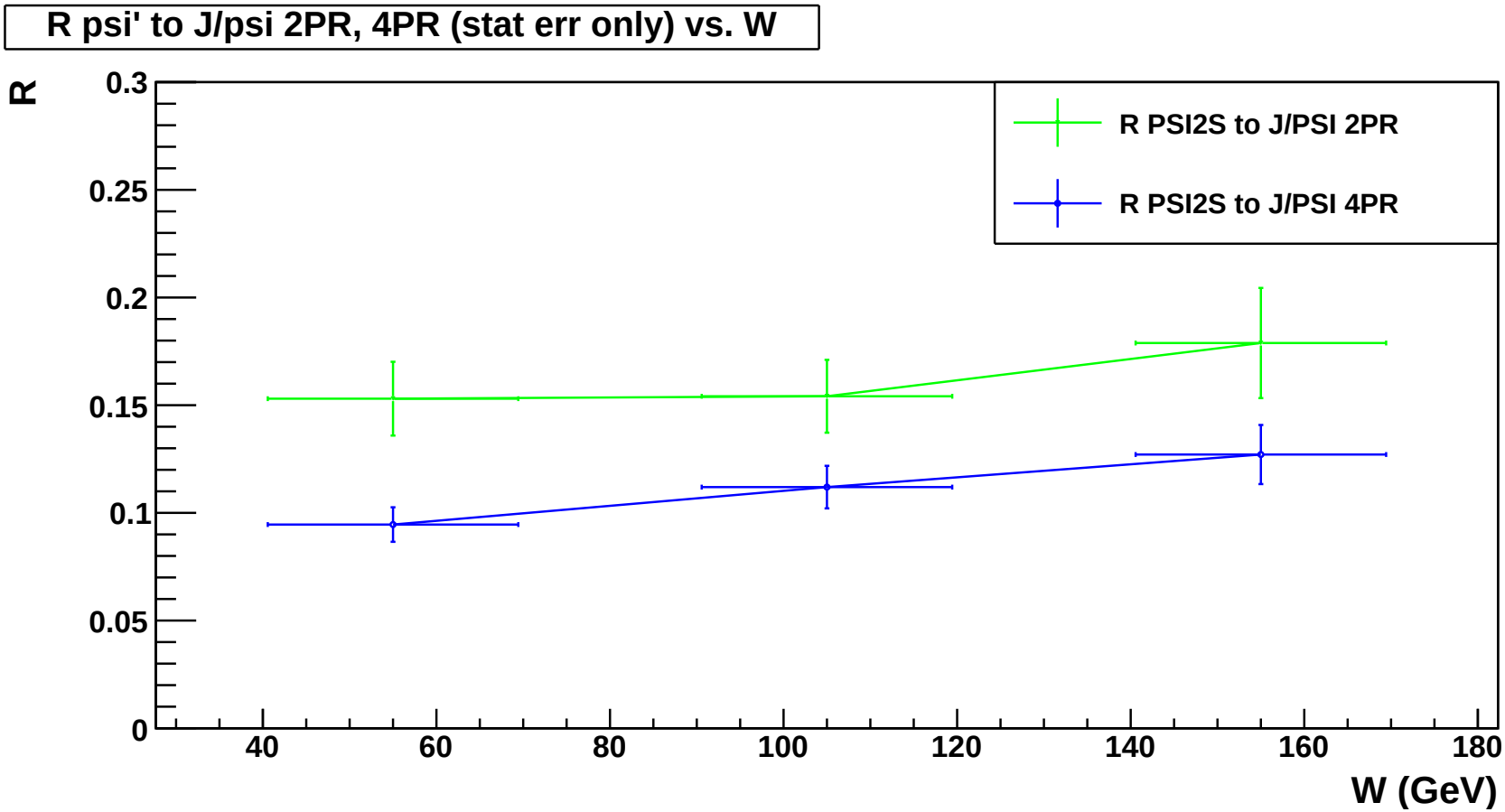
- Number of $\psi(2S)$ events from 2PR and 4PR and J/ψ events corrected for acceptance and BR

2PR, 4PR: acceptances



- acceptances for $\psi(2S)$ for 2PR and 4PR channels for and J/ψ events
- acceptances calculated w.r.t. the PHP phase space $Q^2_{gen} < 1$ GeV

R: stat only errors

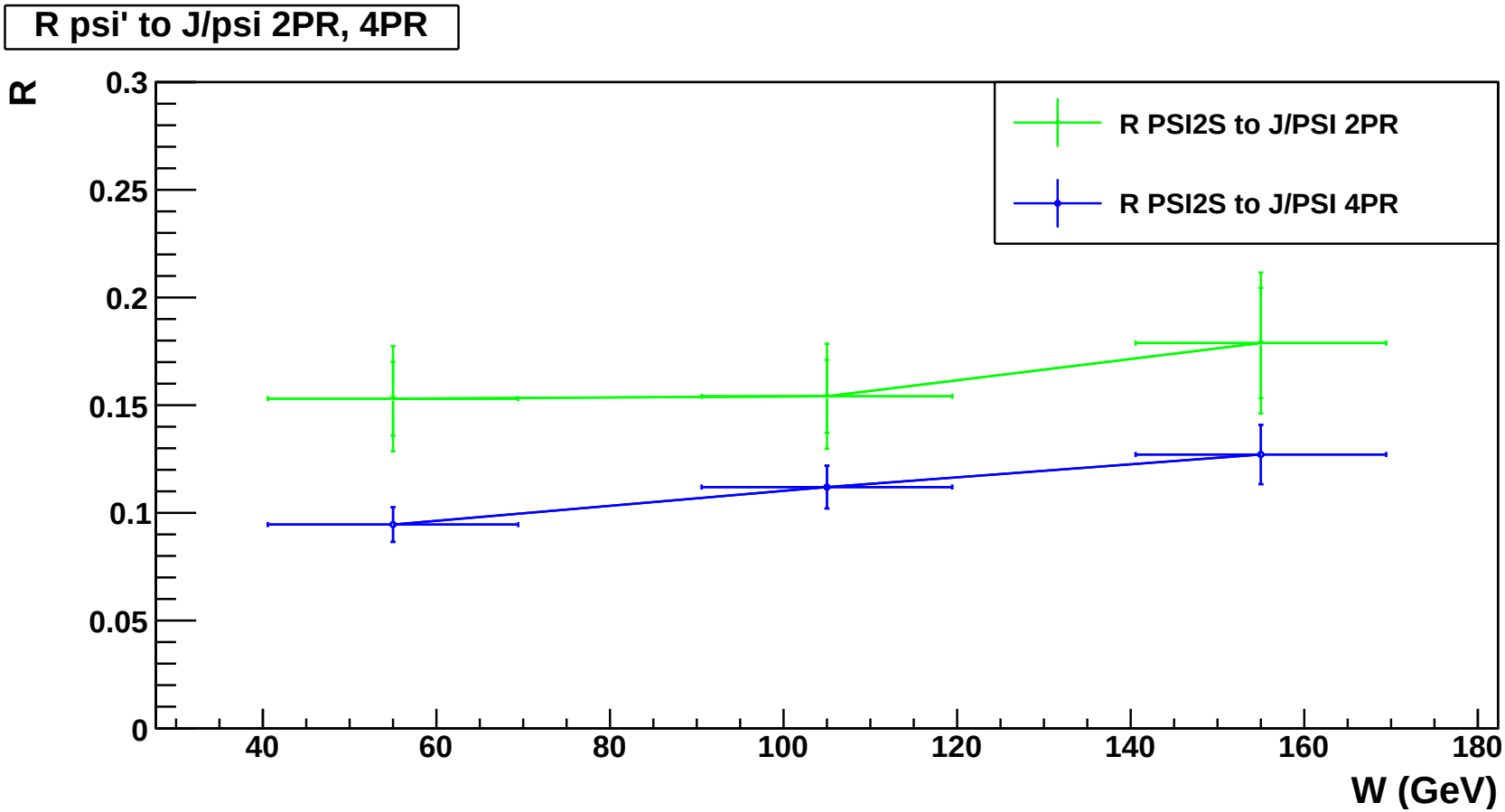


- cross section ratio R of $\psi(2S)$ to J/ψ from 2PR and 4PR
- stat only errors

Branching ratios and its uncertainties

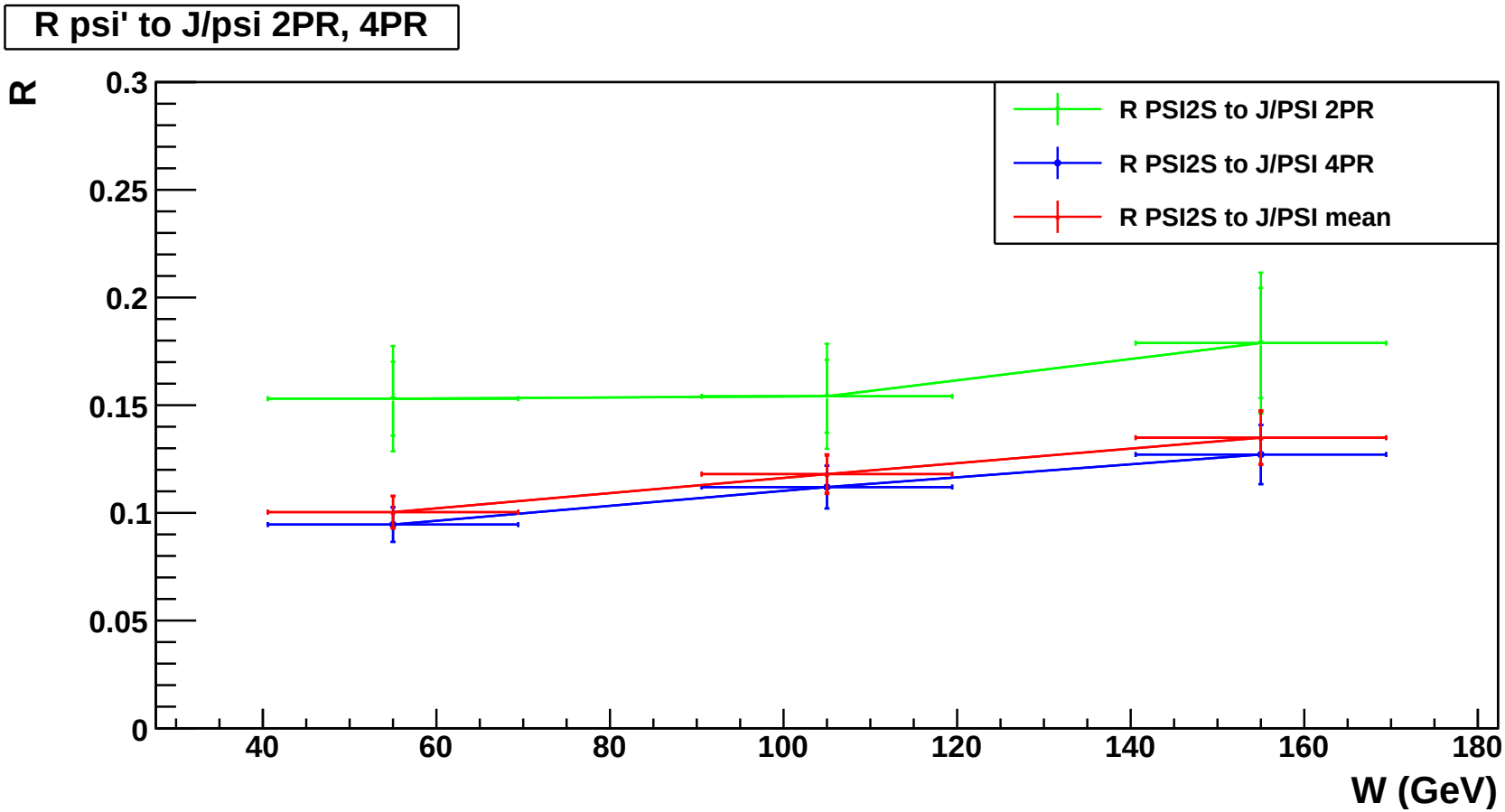
- $BR(J/\psi \to \mu + \mu^-) = 0.05961 \pm 0.00033$
- $BR(\psi(2S) \to \mu + \mu^-) = 0.0079 \pm 0.0009$
- $BR(\psi(2S) \to J/\psi\pi + \pi^-) = 0.3449 \pm 0.0030$
- $BR(\psi(2S) \to \mu + \mu^-\pi + \pi^-) = 0.02056 \pm 0.00021$

R: stat errors plus BR errors



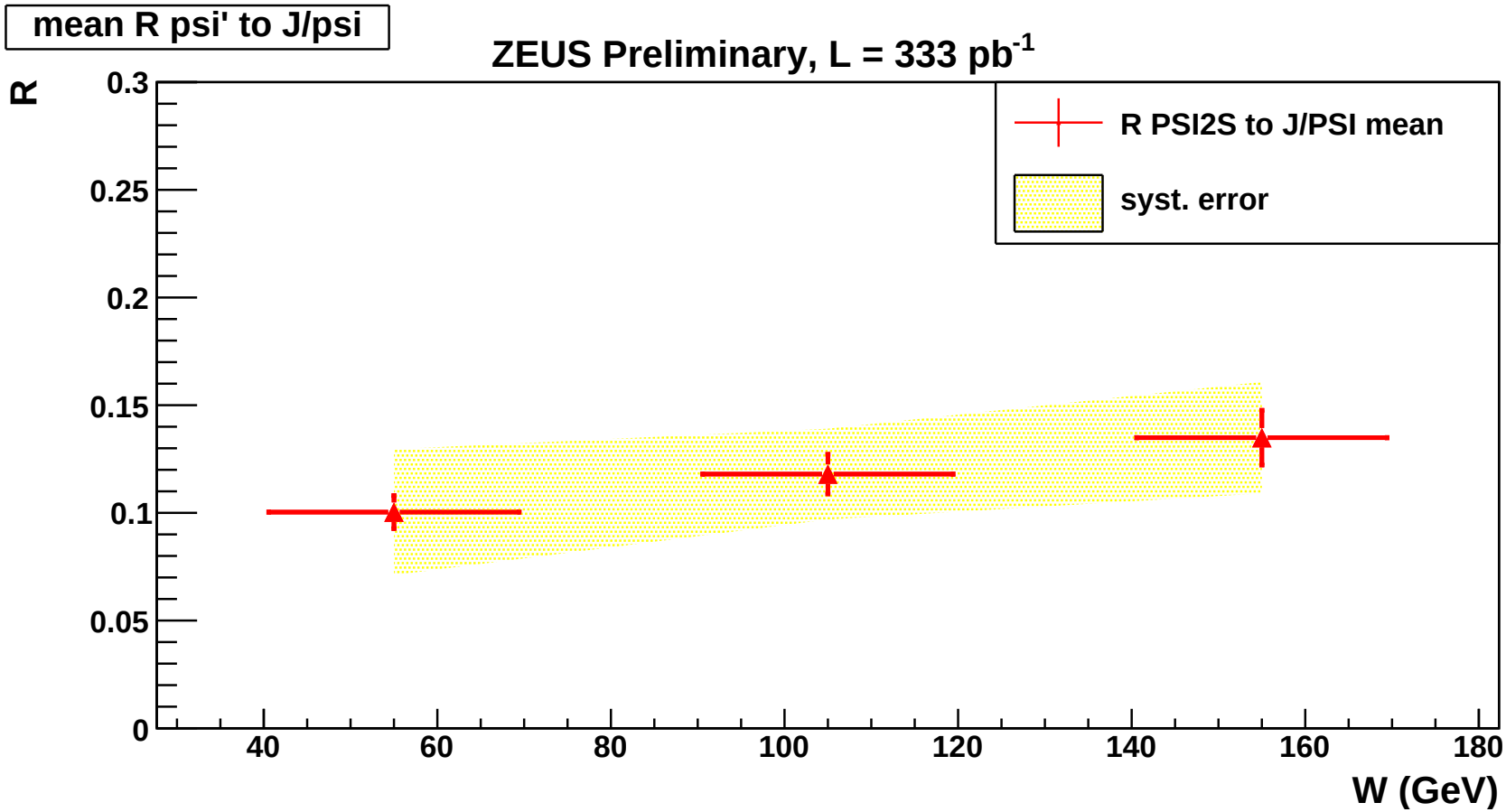
- cross section ratio R of $\psi(2S)$ to J/ψ from 2PR and 4PR
- stat errors combined with the syst due to the BR uncertainty

R: mean value



- cross section ratio R of $\psi(2S)$ to J/ψ from 2PR and 4PR
- weighted mean value

R: mean value with syst error band



- cross section ratio R of $\psi(2S)$ and J/ψ from 2PR and 4PR
- weighted mean value with syst error band due to slow pions inefficiency (does not cancel in ratio)

Summary/Conclusions

- moderate rise of cross section ratio $R = \psi(2S)/J/\psi$ as a function of W visible in both decay channels...
- ... but within errors also consistent with a flat W dependence
- some discrepancy between 2-prong and 4-prong channels
- 2-prong: bigger stat. errors (due to large background) and bigger systematics due to the $BR(\psi(2S) \to \mu + \mu^-)$
- 2-prongs: corrections due to the CTD FLT inefficiency are expected to cancel
- 4-prong: very clean channel, smaller stat. errors, smaller BR uncertainties but new source of systematics due to the slow pions
- 4-prongs: corrections due to the muon inefficiency (trigger and offline) are expected to cancel
- 4-prongs: corrections due to the CTD FLT inefficiency cancel only partially
- for the preliminary the observed difference between 2- and 4-prong channels used to estimate the systematics errors (required further investigation)