Recent results on Charmonium production at HERA

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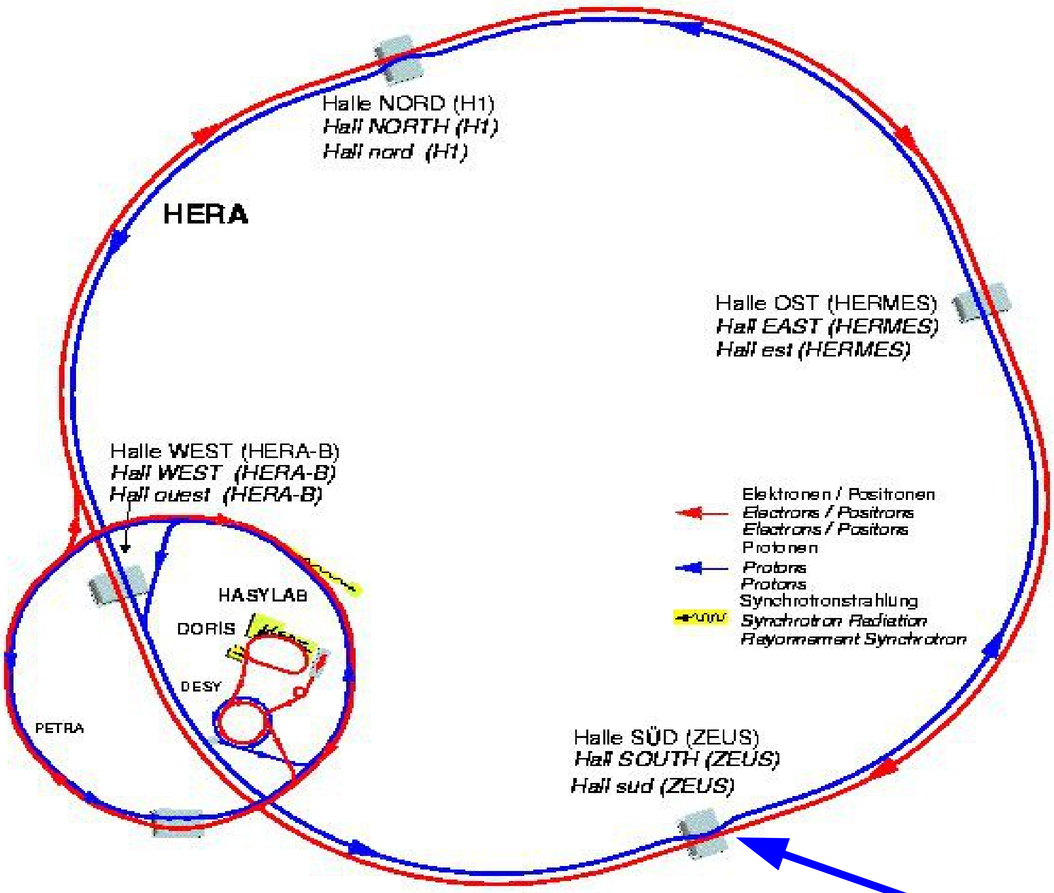
Outline

- HERA and ZEUS
- Diffractive vector meson production at HERA
- Data selection and signal extraction
- Results

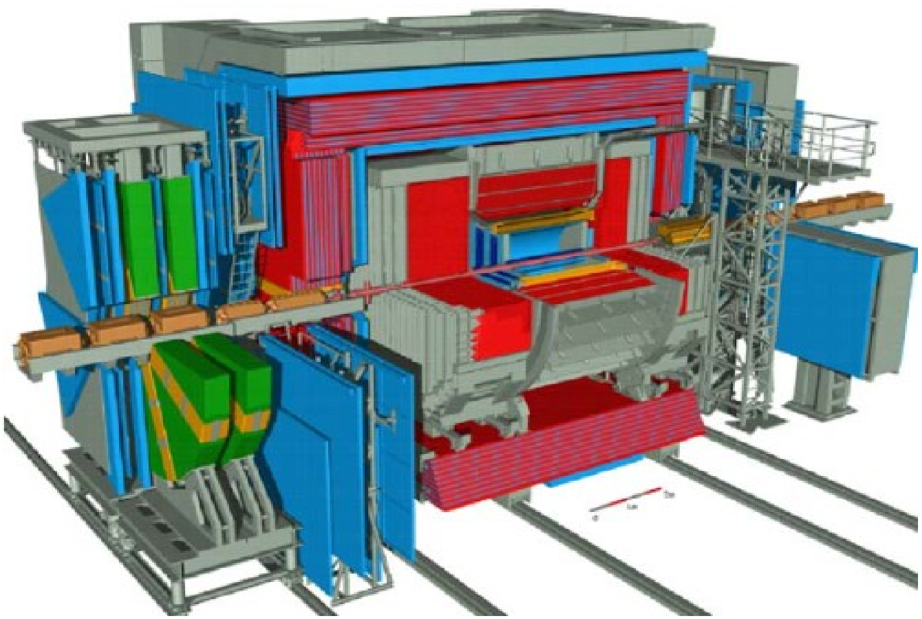
HERA and ZEUS

HERA: ep collider



- Colliding beams:

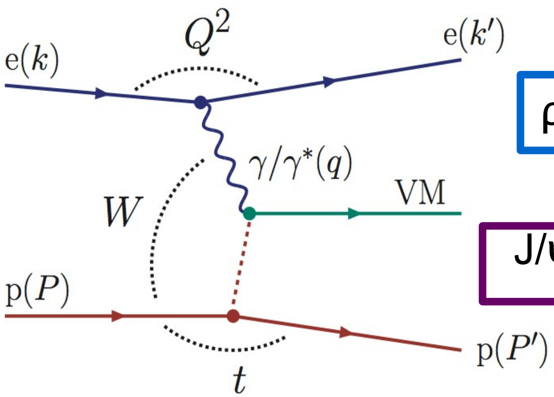
  920 GeV **p** and 27.5 GeV **$e^{\pm}$**
- $\sqrt{s} = 318\,GeV$
- Data taking: 1992 - 2007



- **ZEUS** – hermetic multipurpose detector
- Total collected luminosity: ~0.5 fb^{-1}

Diffractive vector meson (VM) production at HERA

elastic (exclusive)



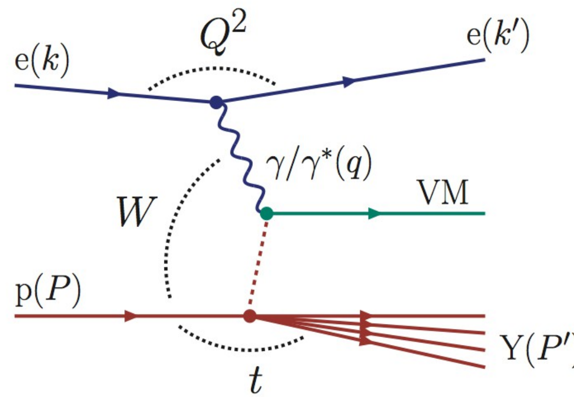
light

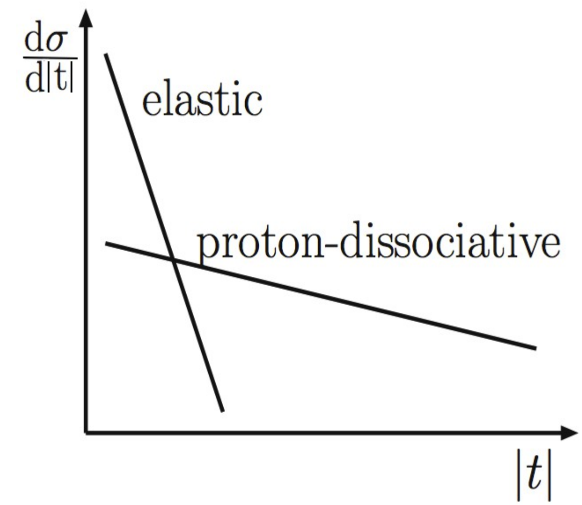
$\boxed{\rho,\ \omega,\ \varphi}$

heavy

$\boxed{J/\psi,\ \psi(2S),\ \Upsilon}$

proton-dissociative





Q^2 — photon virtuality

$Q^2 < 1\ \mathrm{GeV}^2$ — γp
$Q^2 \gtrsim 1\ \mathrm{GeV}^2$ — DIS

$Q^2 = -q^2 = -(k - k')^2$

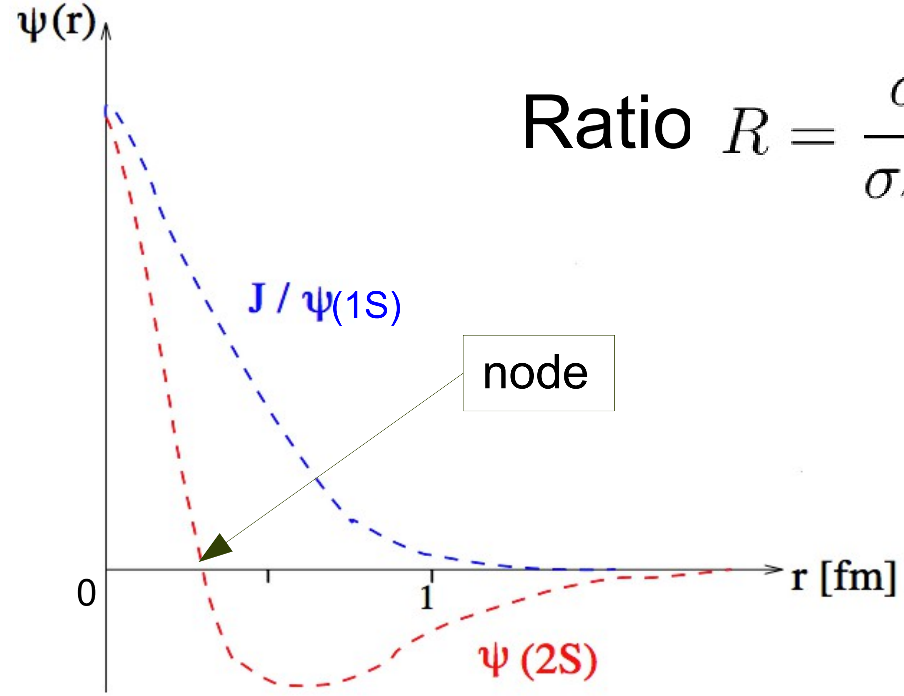
W — photon-proton CMS energy

$W^2 = (q + P)^2$

t — 4-mom. transfer squared at proton vertex

$t = (P - P')^2$

Measurement of the cross-section ratio $\sigma_{\psi(2S)}/\sigma_{J/\psi(1S)}$ in DIS



Ratio $R = \dfrac{\sigma_{\gamma p \to \psi(2S) p}}{\sigma_{\gamma p \to J/\psi(1S) p}}$ gives information about the dynamics of hard process

sensitive to radial wave function of charmonium

ψ(2S) wave function different from J/ψ(1S) wave function:

- Has a node at ≈ 0.35 fm
- $\langle r^2_{\psi(2S)} \rangle \approx 2 \langle r^2_{J/\psi(1S)} \rangle$

pQCD model calculations predicts R ~ 0.17 (PhP) and rise of R with Q^2 (DIS)

Investigated channels and samples

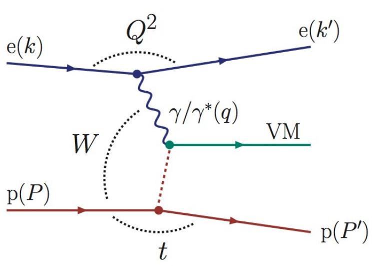
$\psi(2S) \rightarrow J/\psi\, \pi^+ \pi^-;\ J/\psi \rightarrow \mu^+ \mu^-$
$\psi(2S) \rightarrow \mu^+ \mu^-$
$J/\psi(1S) \rightarrow \mu^+ \mu^-$

Data samples

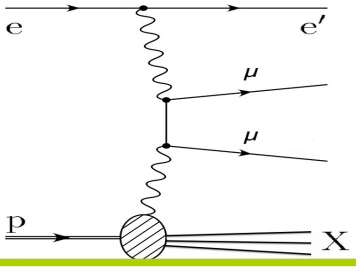
HERA II data (2003 — 2007)
Integrated luminosity: 354 pb^{-1}

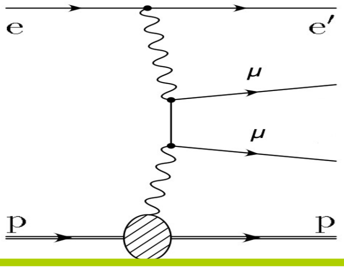
MC-data samples

Signal MC: DIFFVM for exclusive VM production



Background MC: GRAPE
for Bethe-Heitler
mu-pair production



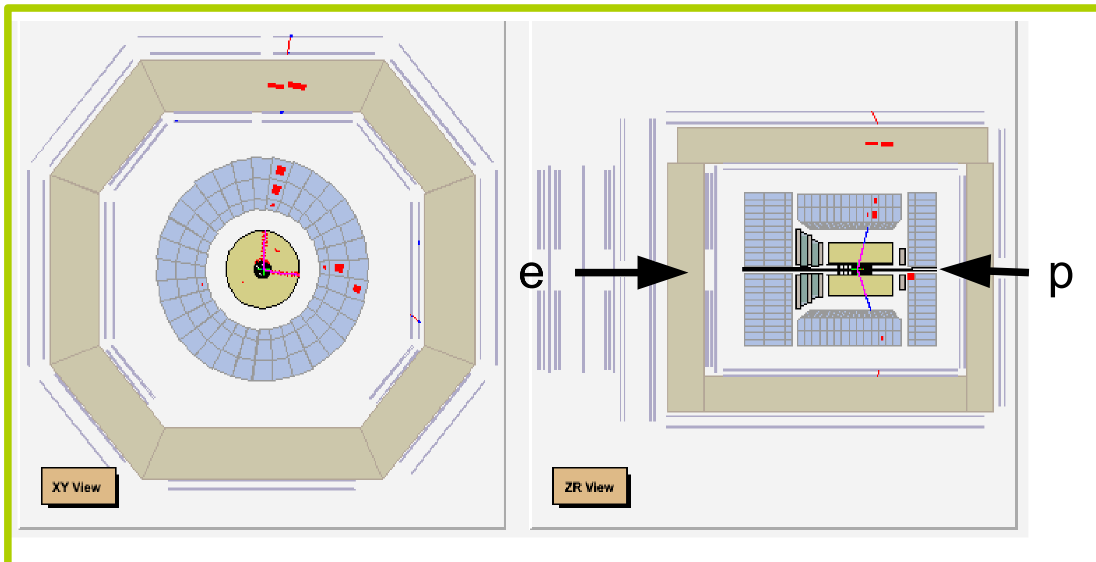


$\psi(2S) \to \mu^+\mu^-$ and $J/\psi(1S) \to \mu^+\mu^-$

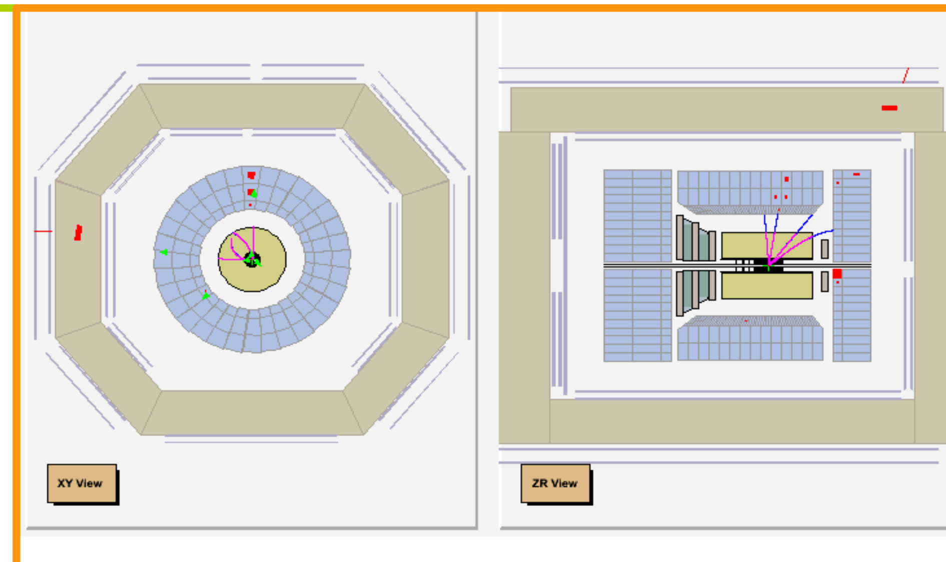
$30 \leq W \leq 210$ GeV
$5 \leq Q^2 \leq 70$ GeV^2
$|t| \leq 1$ GeV^2

- Scattered *e* with E > 10 GeV reconstructed in CAL
- Scattered *p* undetected
- Two reconstructed tracks identified as muons

  and for $\psi(2S) \to J/\psi\, \pi^+\pi^-$ additionally two pion tracks from $\mu\mu$ vertex
- Nothing else in detector (above noise)

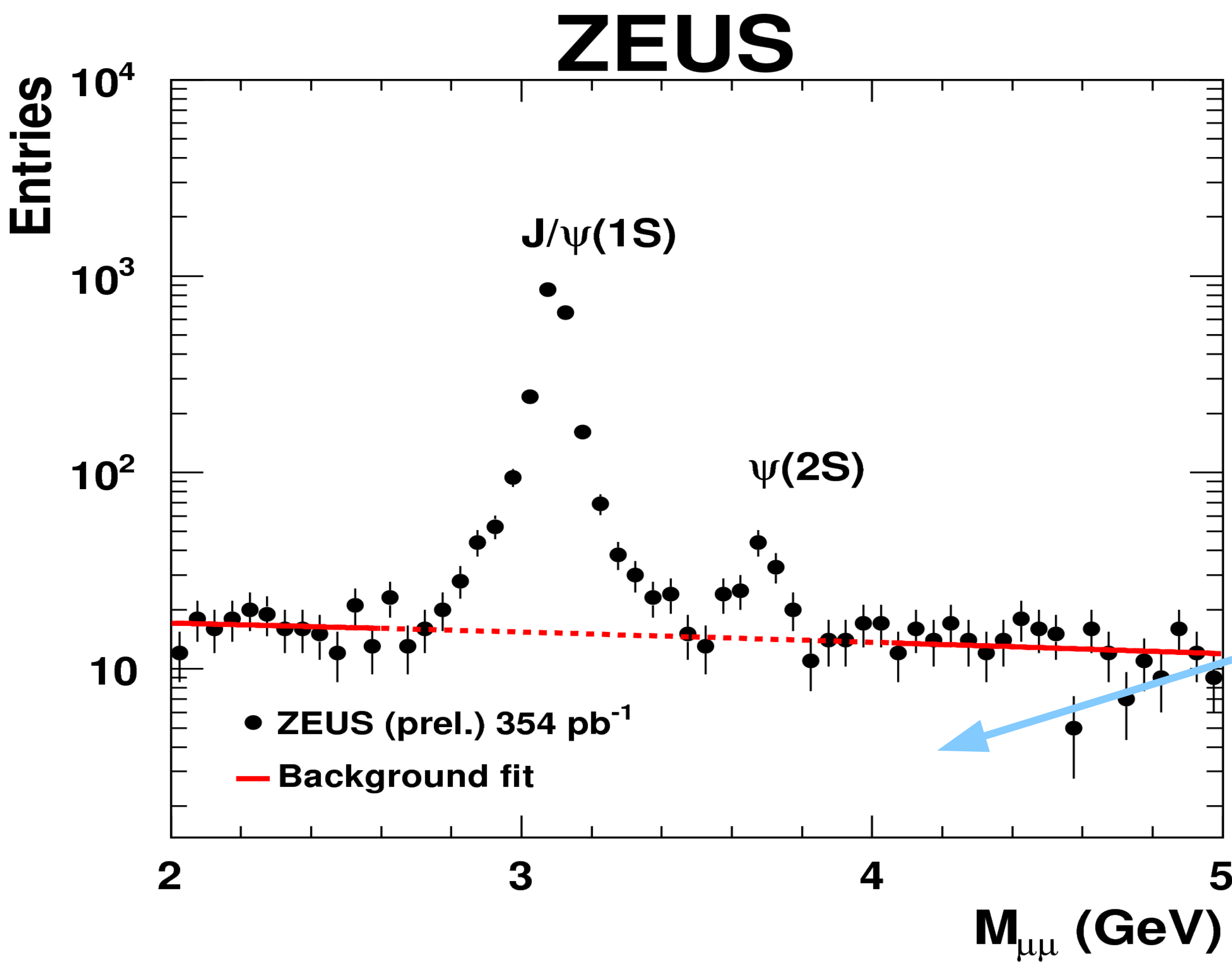


$J/\psi(1S) \to \mu^+\mu^-$



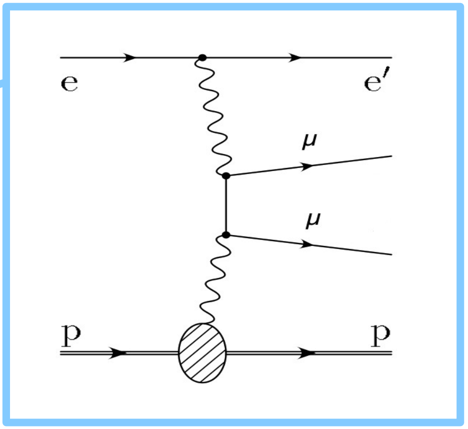
$\psi(2S) \to J/\psi\, \pi^+\pi^-$

Background subtraction



$J/\psi(1S) \to \mu^+\mu^-$

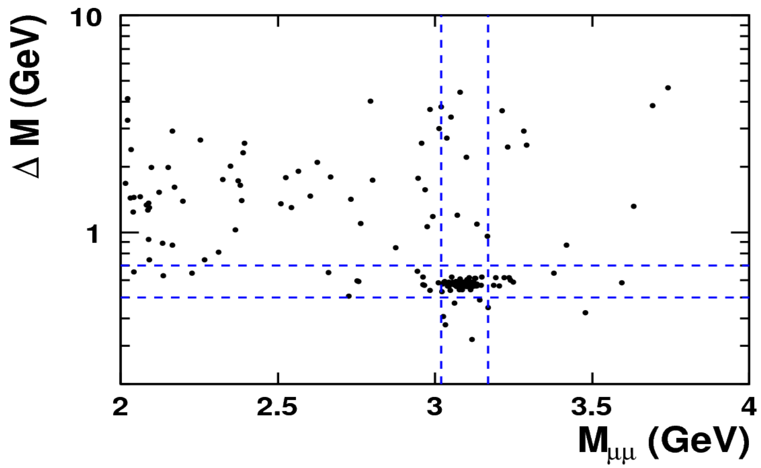
$\psi(2S) \to \mu^+\mu^-$

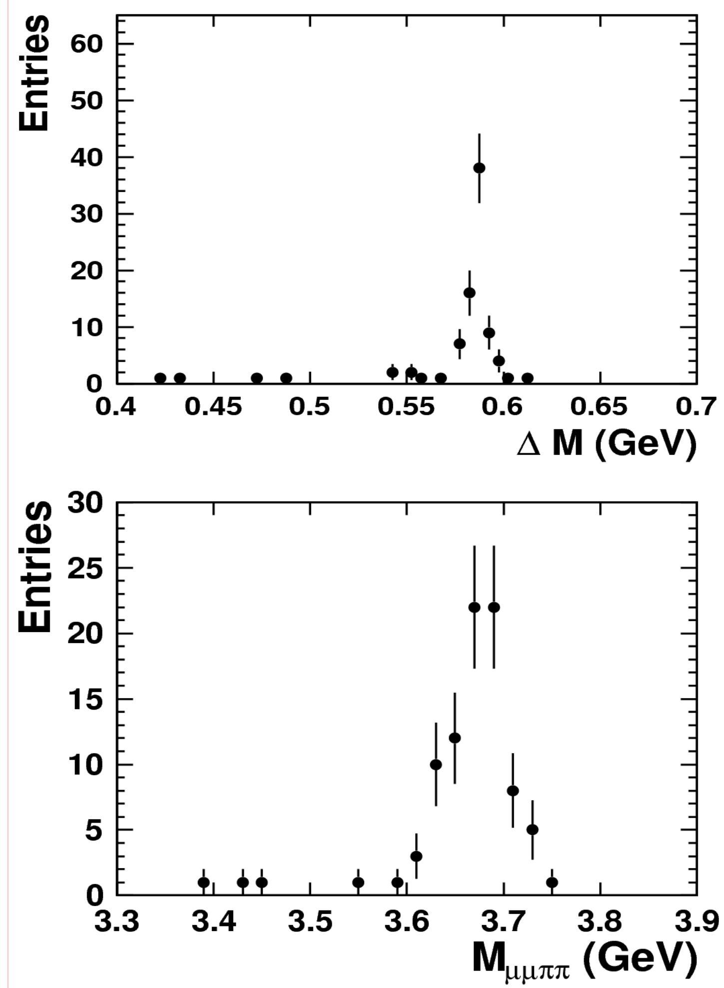


Sideband of the signal: $2 < M_{\mu\mu} < 2.62$ GeV and $4.05 < M_{\mu\mu} < 5$ GeV fitted by straight line

$\psi(2S) \rightarrow J/\psi(1S)\ \pi^+ \pi^-$

ZEUS





• **ZEUS (prel.) 354 pb^{-1}**

$\Delta M = M_{\mu\mu\pi\pi} - M_{\mu\mu}$

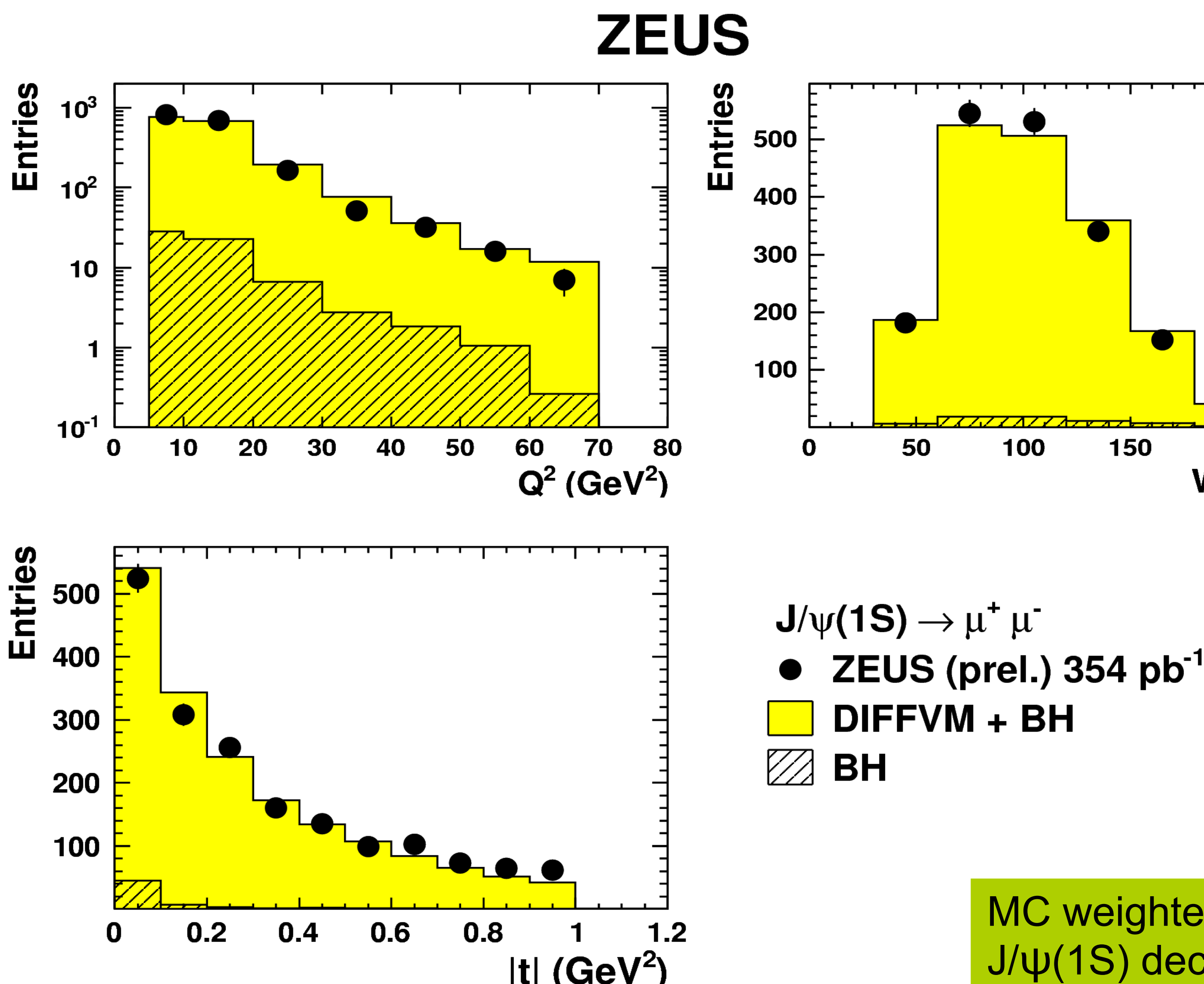
$3.02 < M_{\mu\mu} < 3.17$ GeV

$0.5 < \Delta M < 0.7$ GeV

After cut on $M_{\mu\mu}$

$\leq$ 3 events background

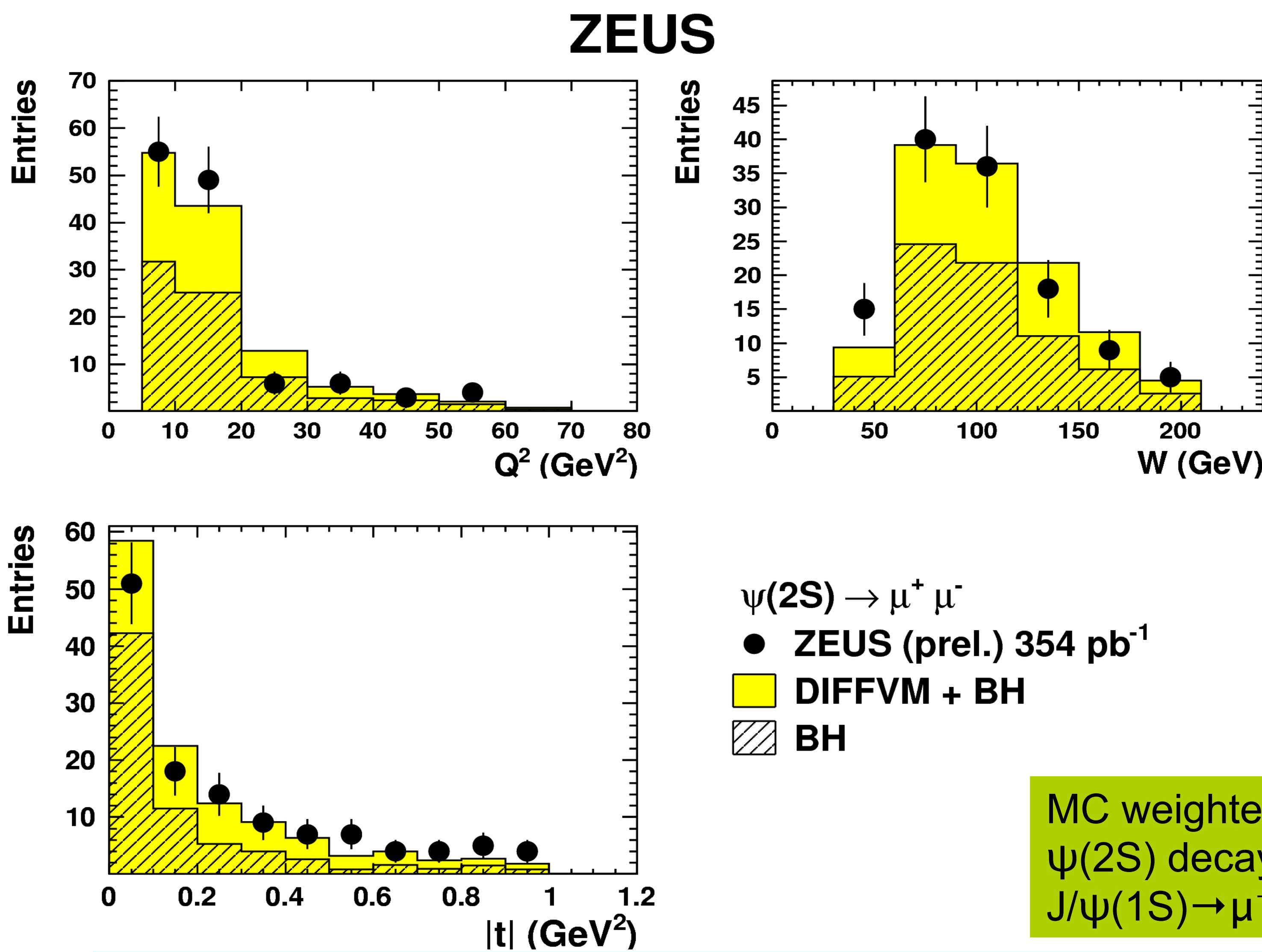
Data-MC comparison for J/ψ(1S)



MC weighted in Q^2, |t| and J/ψ(1S) decay angles to match the data

Good description of the data by the weighted Monte Carlo

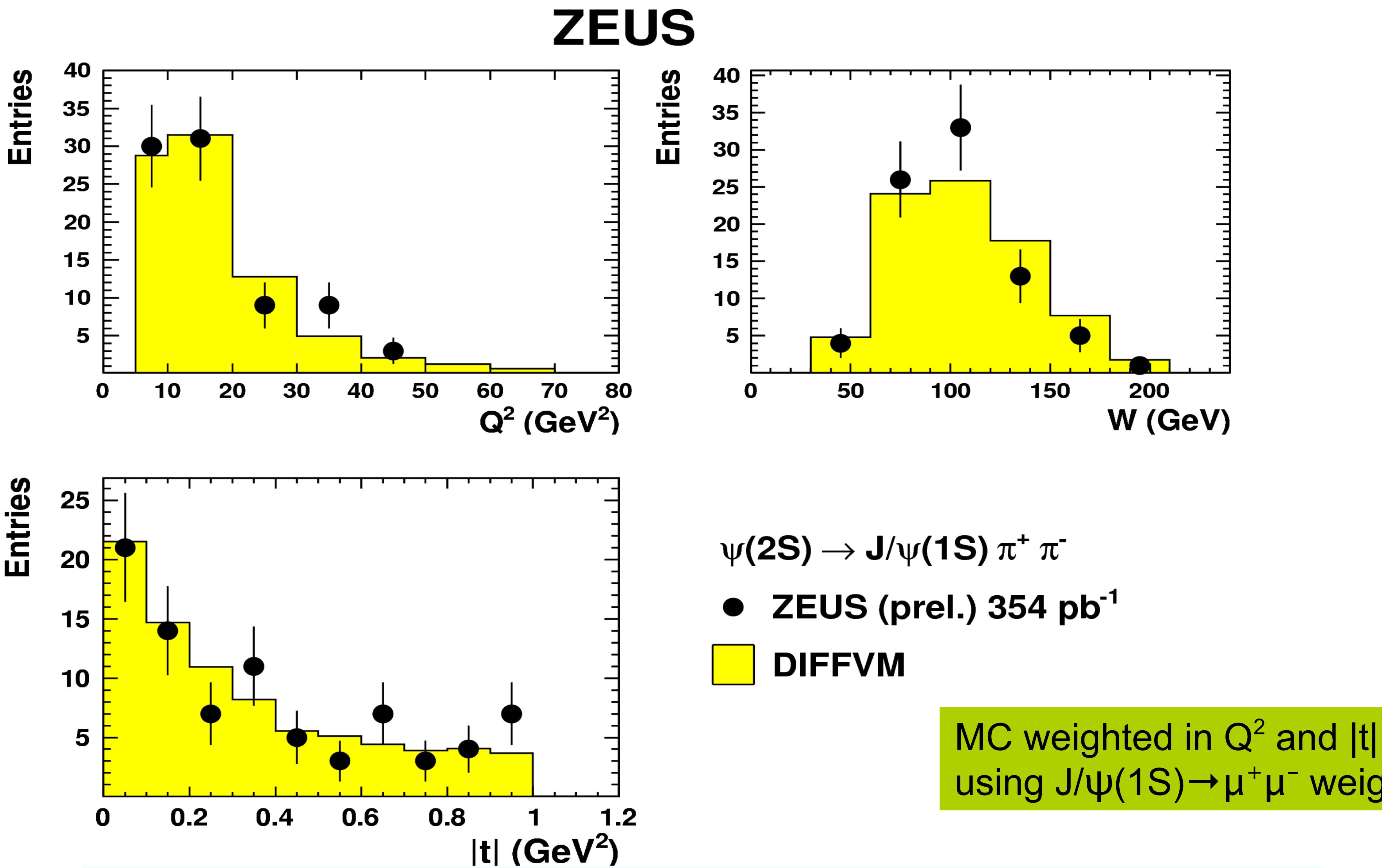
Data-MC comparison for $\psi(2S) \to \mu^+\mu^-$



MC weighted in Q^2, $|t|$ and $\psi(2S)$ decay angles using $J/\psi(1S) \to \mu^+\mu^-$ weights

Good description of the data by the weighted Monte Carlo

Data-MC comparison for $\psi(2S) \to J/\psi\, \pi^+\pi^-$



MC weighted in Q^2 and $|t|$ using $J/\psi(1S) \to \mu^+\mu^-$ weights

Good description of the data by the weighted Monte Carlo

σ(ψ(2S))/σ(J/ψ(1S)) in full kinematic range

$\psi(2S)$ decay mode	$\sigma(\psi(2S))/\sigma(J/\psi(1S))$
$\to J/\psi(\to \mu^+\mu^-)\pi^+\pi^-$	$0.29 \pm 0.04^{+0.02}_{-0.01}$
$\to \mu^+\mu^-$	$0.25 \pm 0.05^{+0.04}_{-0.02}$
combined	$0.28 \pm 0.03^{+0.02}_{-0.01}$

Both ratio measurements agree

$30 \leq W \leq 210$ GeV
$5 \leq Q^2 \leq 70$ GeV^2
$|t| \leq 1$ GeV^2

Method

$$R_{\psi(2S)\to J/\psi\pi^+\pi^-} = \frac{\sigma_{\psi(2S)}}{\sigma_{J/\psi(1S)}} = \frac{N_{\psi(2S)}}{N_{J/\psi(1S)}} \cdot \frac{Acc_{J/\psi(1S)\to\mu^+\mu^-}}{Acc_{\psi(2S)\to J/\psi\pi^+\pi^-}} \cdot \frac{1}{BR_{\psi(2S)\to J/\psi\pi^+\pi^-}}$$

$$R_{\psi(2S)\to\mu^+\mu^-} = \frac{\sigma_{\psi(2S)}}{\sigma_{J/\psi(1S)}} = \frac{N_{\psi(2S)}}{N_{J/\psi(1S)}} \cdot \frac{Acc_{J/\psi(1S)\to\mu^+\mu^-}}{Acc_{\psi(2S)\to\mu^+\mu^-}} \cdot \frac{BR_{J/\psi(1S)\to\mu^+\mu^-}}{BR_{\psi(2S)\to\mu^+\mu^-}}$$

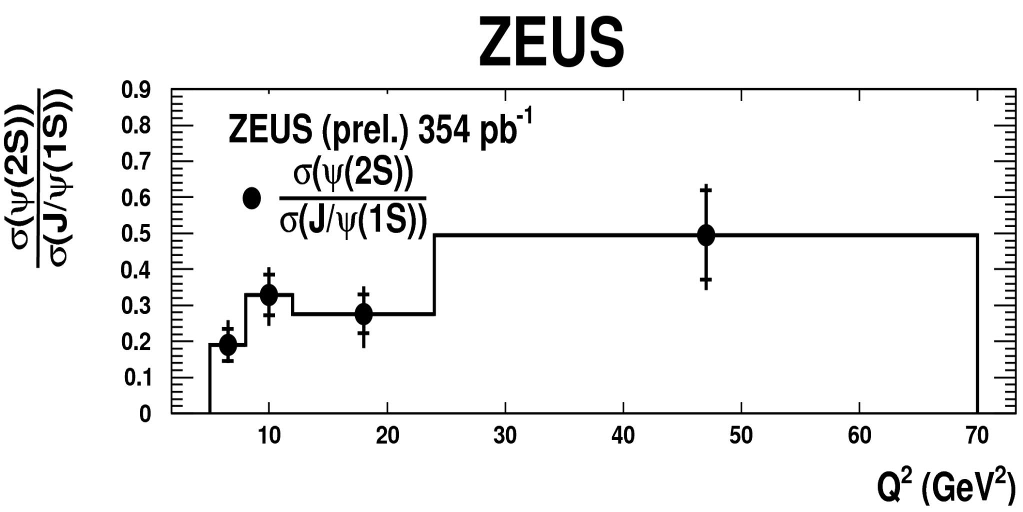
BR($\psi(2S)\to J/\psi\pi^+\pi^-$) = (33.6 ± 0.4) %

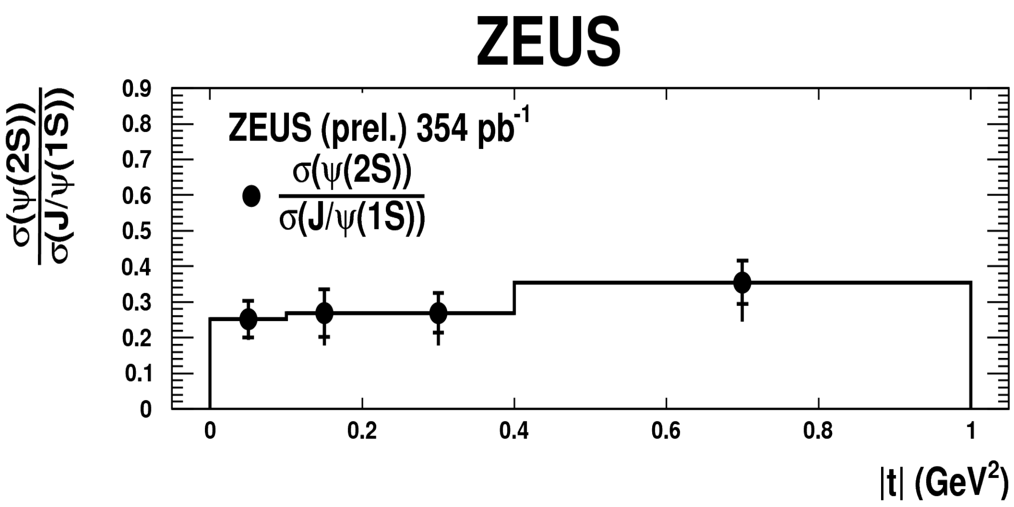
BR($\psi(2S)\to\mu^+\mu^-$) = (7.7 ± 0.8)x10^{-3}

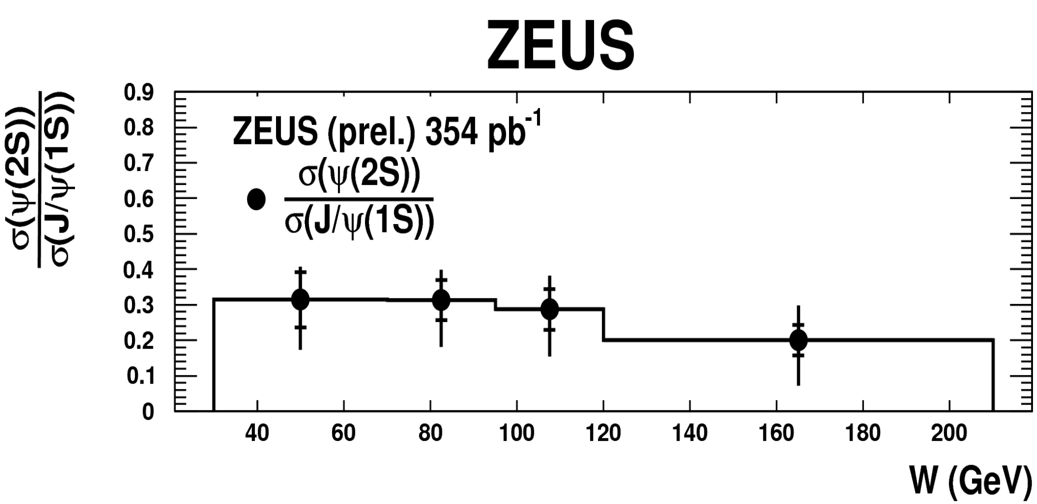
BR($J/\psi\to\mu^+\mu^-$) = (5.93 ± 0.06)%

$$Acc_i = \frac{N_i^{reco}}{N_i^{true}}$$

σ(ψ(2S))/σ(J/ψ(1S)) vs Q^2, W and |t|







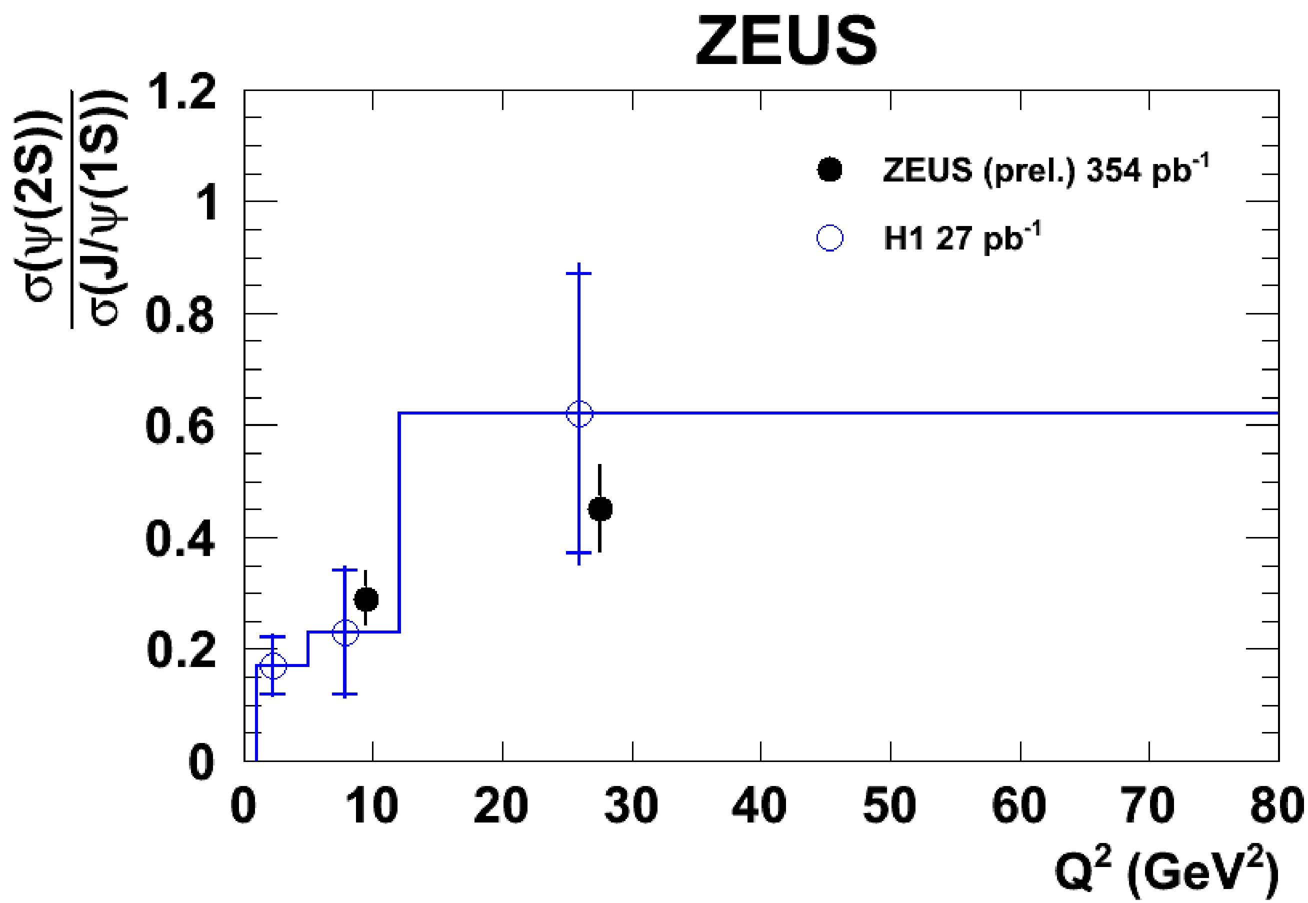
σ(ψ(2S))/σ(J/ψ(1S))

- Indication of an increase with Q^2
- Independent of W
- Independent of |t|

ZEUS - H1comparison

• ZEUS data analysed in Q^2 bins used by H1 (Q^2: 5 — 12 and 12 — 80 GeV^2)

40 < W < 180 GeV
1 < Q^2 < 80 GeV^2



H1 collaboration:
Eur.Phys.J.C10:373-393,1999

Results agree - $\sigma(\psi(2S))/\sigma(J/\psi(1S))$ increases with Q^2
Significantly improved accuracy thanks to increased integrated luminosity

Summary and outlook

- Using HERA II data $\sigma(\psi(2S))/\sigma(J/\psi(1S))$ in exclusive DIS has been measured for the first time by ZEUS in the kinematic range:
  $30 \leq W \leq 210$ GeV, $5 \leq Q^2 \leq 70$ GeV^2, $|t| \leq 1$ GeV^2
- The accuracy has been improved compared to the H1 HERA I results
- $\sigma(\psi(2S))/\sigma(J/\psi(1S))$:
  increases with Q^2 and independent of W and $|t|$

Theoretical calculations of $\sigma(\psi(2S))/\sigma(J/\psi(1S))$
in exclusive DIS are welcome

Thank you very much for your attention!