Measurement of the cross-section ratio $\sigma_{\psi(2S)}/\sigma_{J/\psi}$ in deep inelastic exclusive *ep* scattering at HERA

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(University of Hamburg)
on behalf of the **ZEUS Collaboration**

Outline:

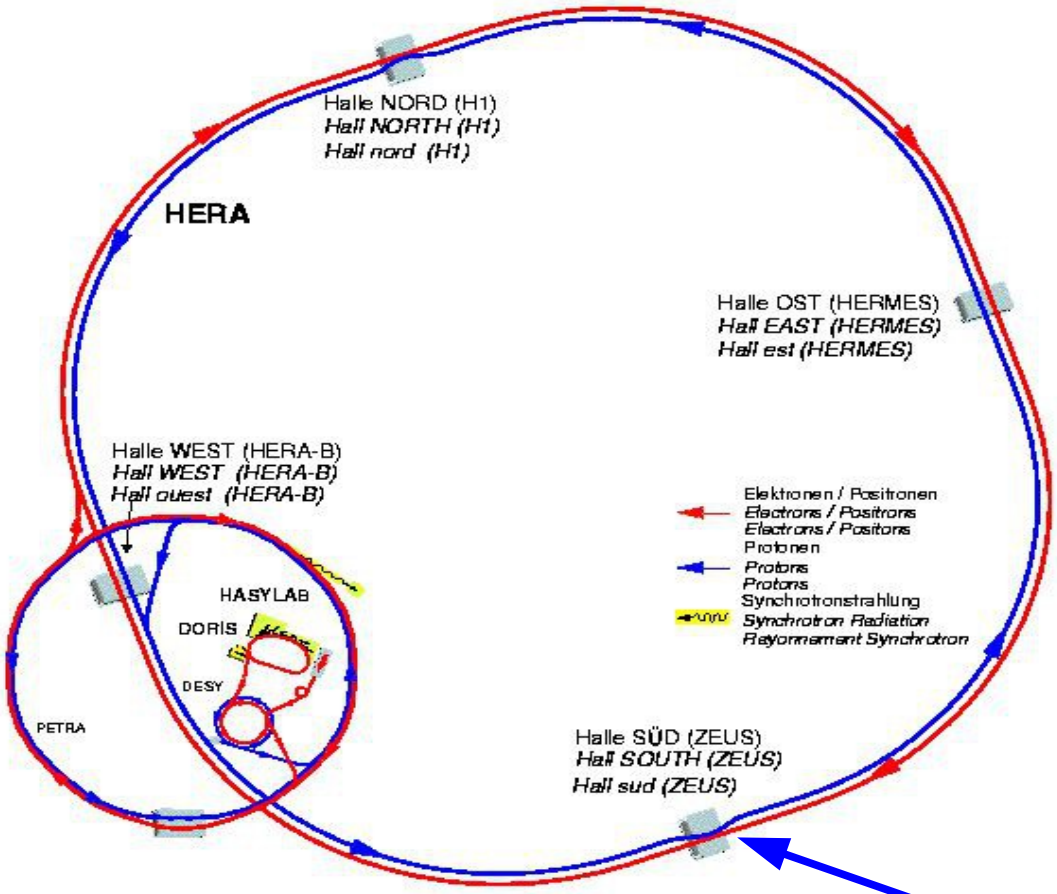
- HERA and ZEUS
- Diffractive vector meson production at HERA
- Data selection and signal extraction
- Results

DIS 2015
XXIII International Workshop on Deep-Inelastic Scattering and Related Subjects

Dallas, Texas
April 27 – May 1, 2015

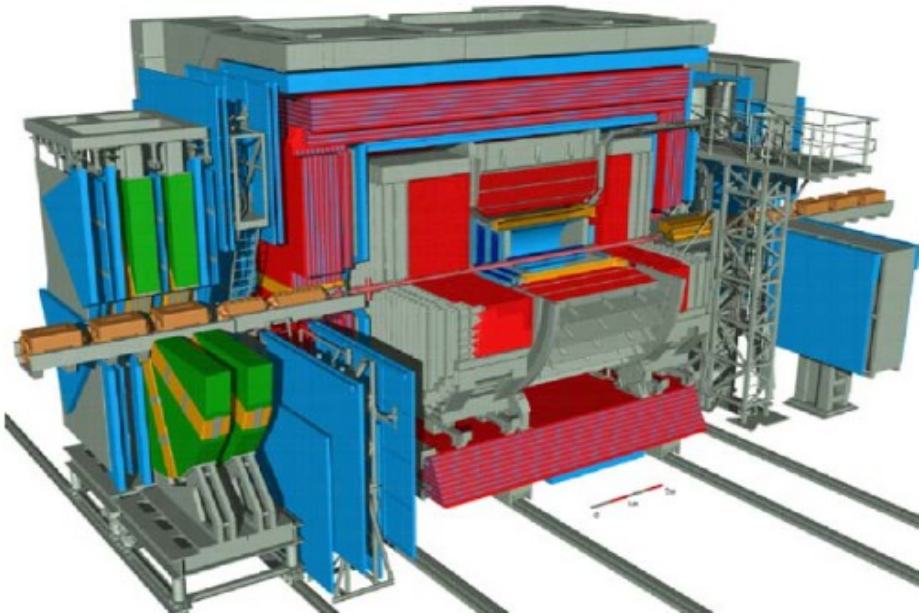
HERA and ZEUS

HERA: *ep* collider



- Colliding beams:

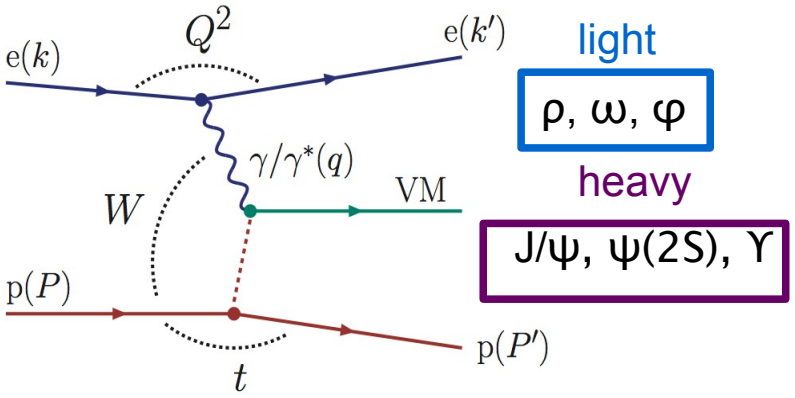
  920 GeV **p** and 27.5 GeV **e**$^{\pm}$
- $\sqrt{s} = 318\,GeV$
- Data taking: 1992 - 2007



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

Diffractive vector meson (VM) production at HERA

elastic (exclusive)



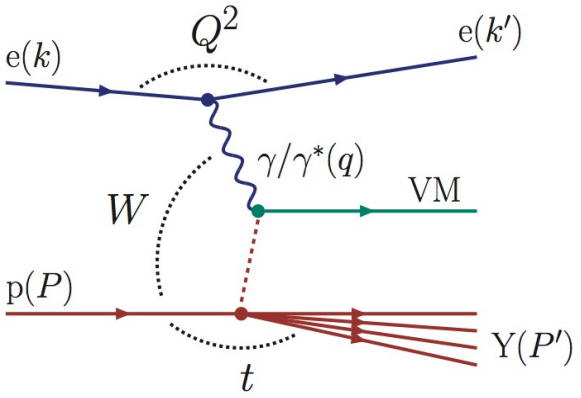
light

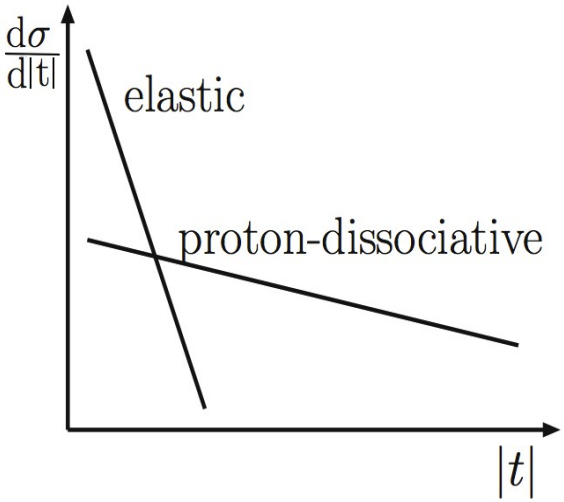
ρ, ω, φ

heavy

J/ψ, ψ(2S), ϒ

proton-dissociative





Q^2 — photon virtuality

$Q^2 < 1$ GeV^2 — γp

$Q^2 \gtrsim 1$ GeV^2 — DIS

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

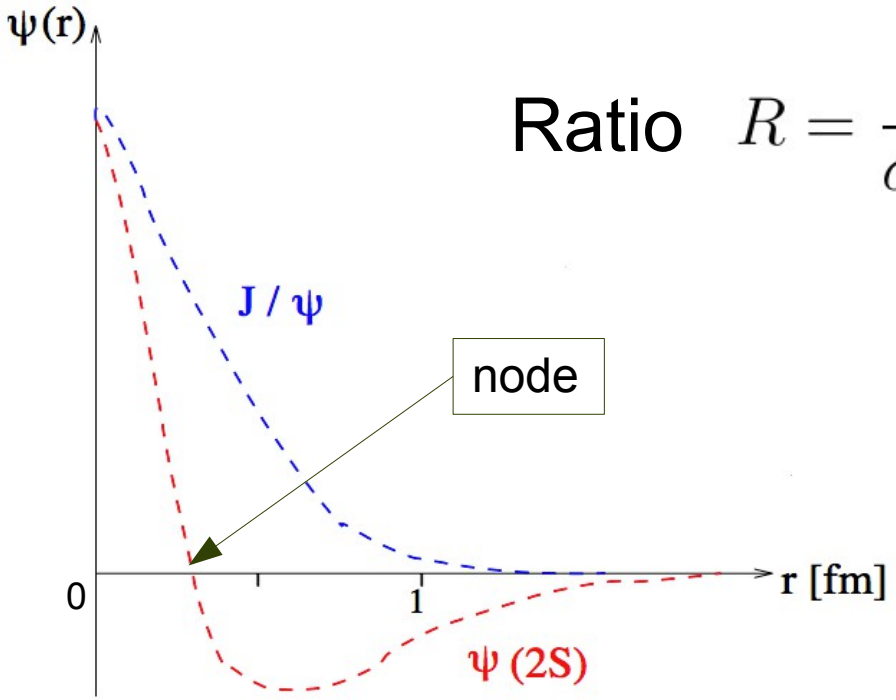
W — photon-proton CMS energy

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

t — 4-mom. transfer squared at proton vertex

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

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



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

sensitive to radial wave function of charmonium

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

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

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

Investigated channels and samples

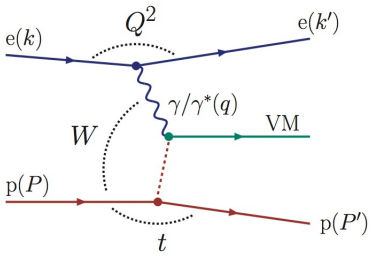
$\psi(2S) \rightarrow J/\psi\, \pi^+ \pi^-;\ J/\psi \rightarrow \mu^+ \mu^-$
$\psi(2S) \rightarrow \mu^+ \mu^-$
$J/\psi \rightarrow \mu^+ \mu^-$

Data samples

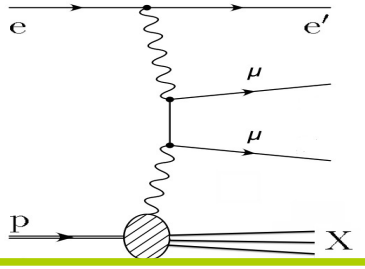
HERA I + HERA II data (1996 — 2007)
Integrated luminosity: 468 pb^{-1}

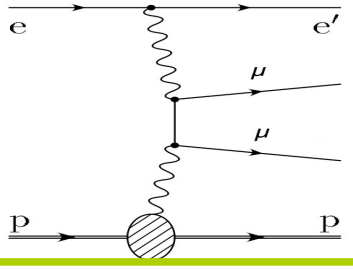
MC-data samples

Signal MC: DIFFVM for exclusive VM production



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





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

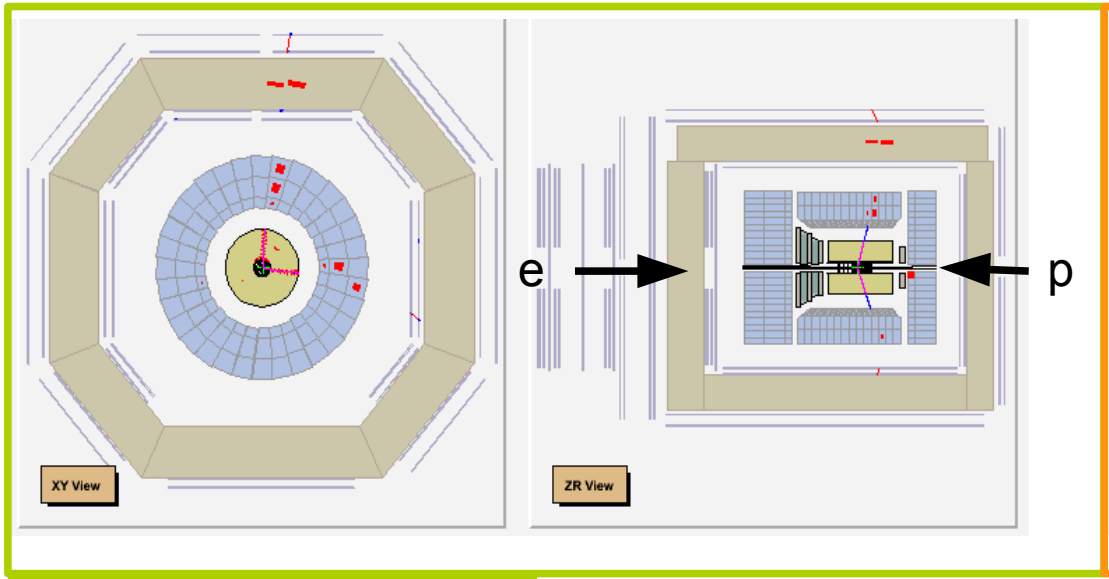
- Scattered *e* with E > 10 GeV reconstructed in CAL
- Scattered *p* undetected
- Two reconstructed tracks identified as muons

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

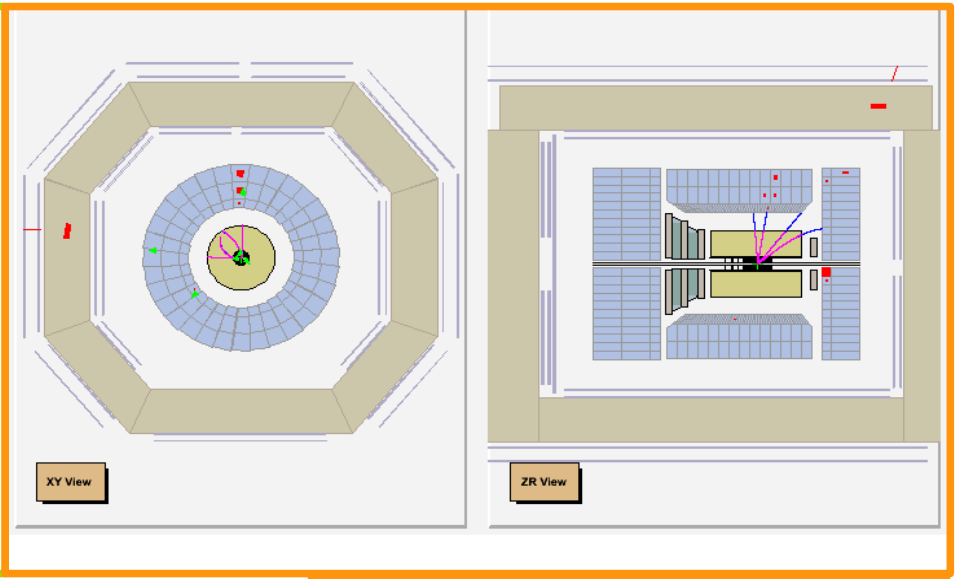
$30 \leq W \leq 210$ GeV

$2 \leq Q^2 \leq 80$ GeV^2

$|t| \leq 1$ GeV^2

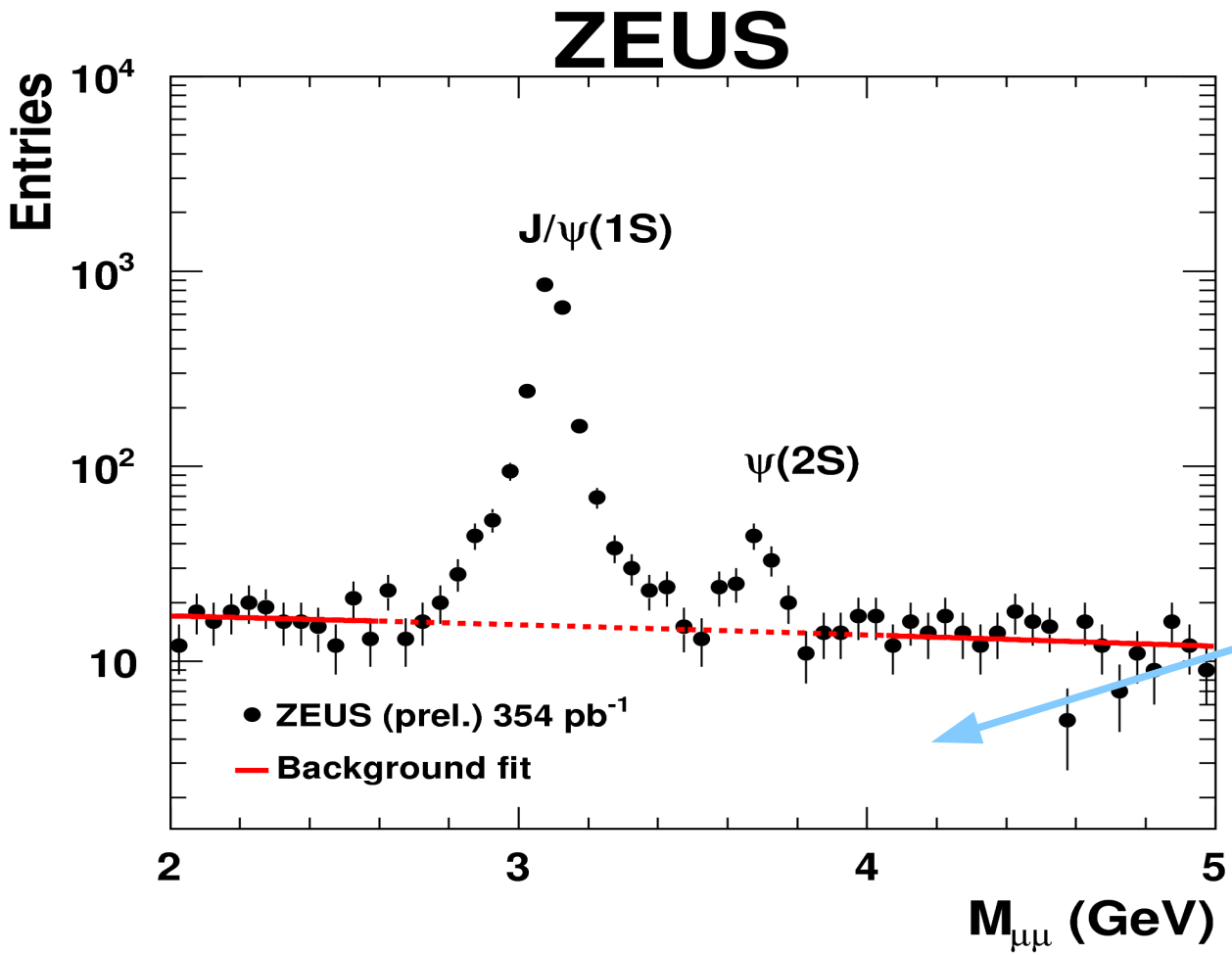


$J/\psi \rightarrow \mu^+\mu^-$



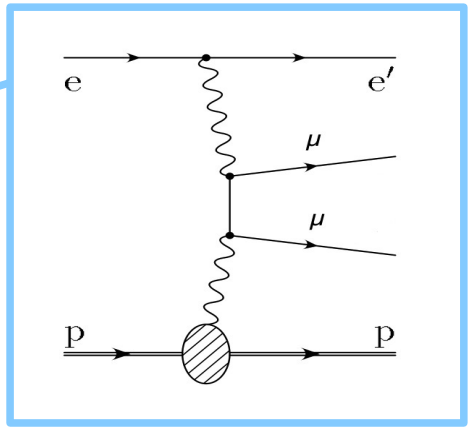
$\psi(2S) \rightarrow J/\psi\ \pi^+\pi^-$

Background subtraction



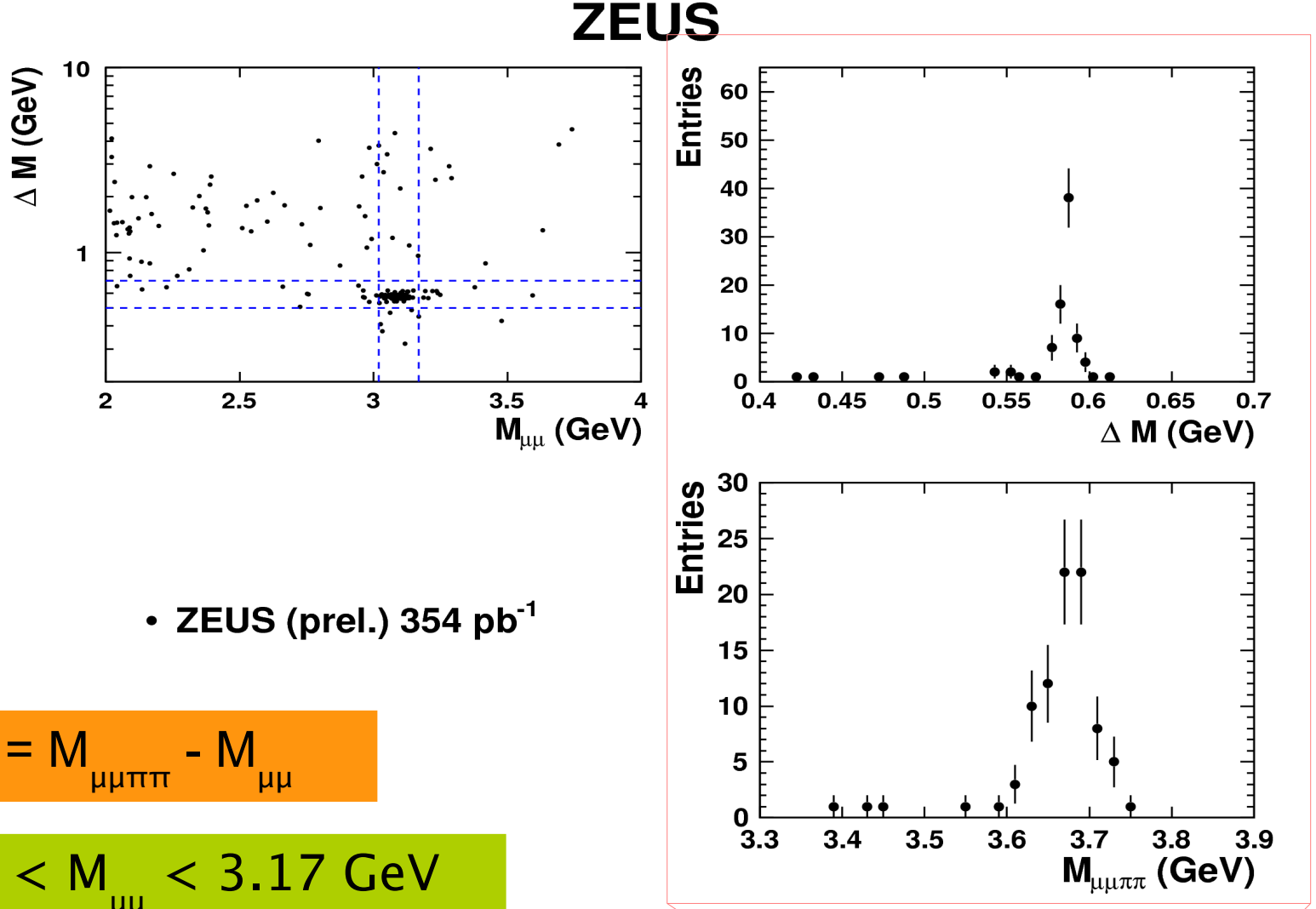
$J/\psi \rightarrow \mu^+\mu^-$

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



Sideband of the signal: $2.00 < M_{\mu\mu} < 2.62$ GeV and $4.05 < M_{\mu\mu} < 5.00$ GeV fitted by straight line

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



- **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 $M_{\mu\mu}$

≤ 3 events background

σ(ψ(2S))/σ(J/ψ) 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	$0.28 \pm 0.03^{+0.02}_{-0.01}$

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

Both ratio measurements agree

Method

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

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

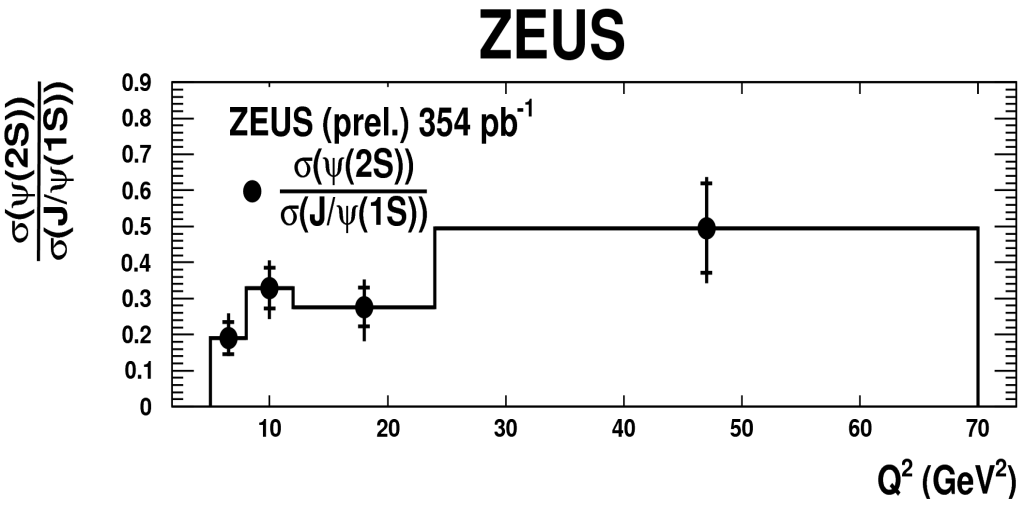
BR(ψ(2S)→J/ψπ$^+$π$^-$) = (33.6 ± 0.4) %

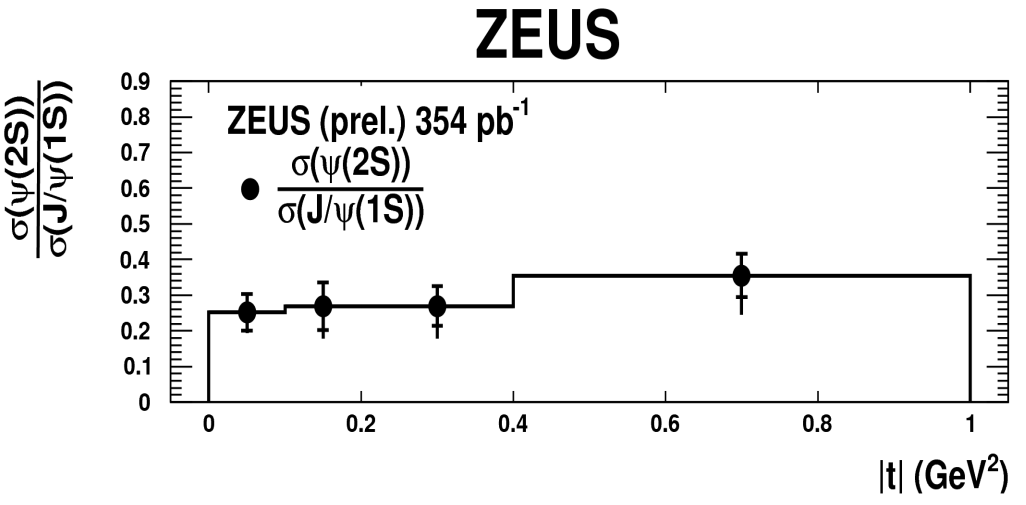
BR(ψ(2S)→μ$^+$μ$^-$) = (7.7 ± 0.8)x10^{-3}

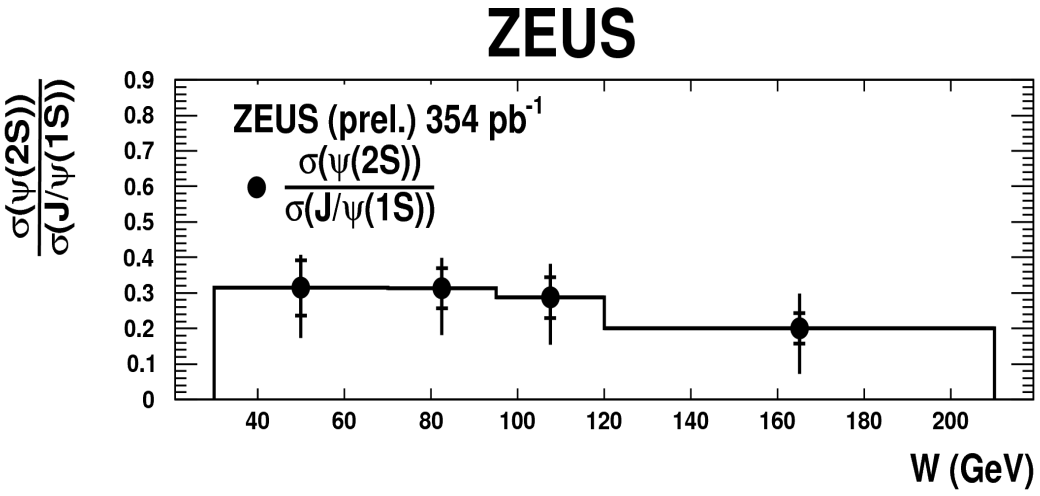
BR(J/ψ→μ$^+$μ$^-$) = (5.93 ± 0.06)%

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

$\sigma(\psi(2S))/\sigma(J/\psi)$ vs Q^2, W and $|t|$



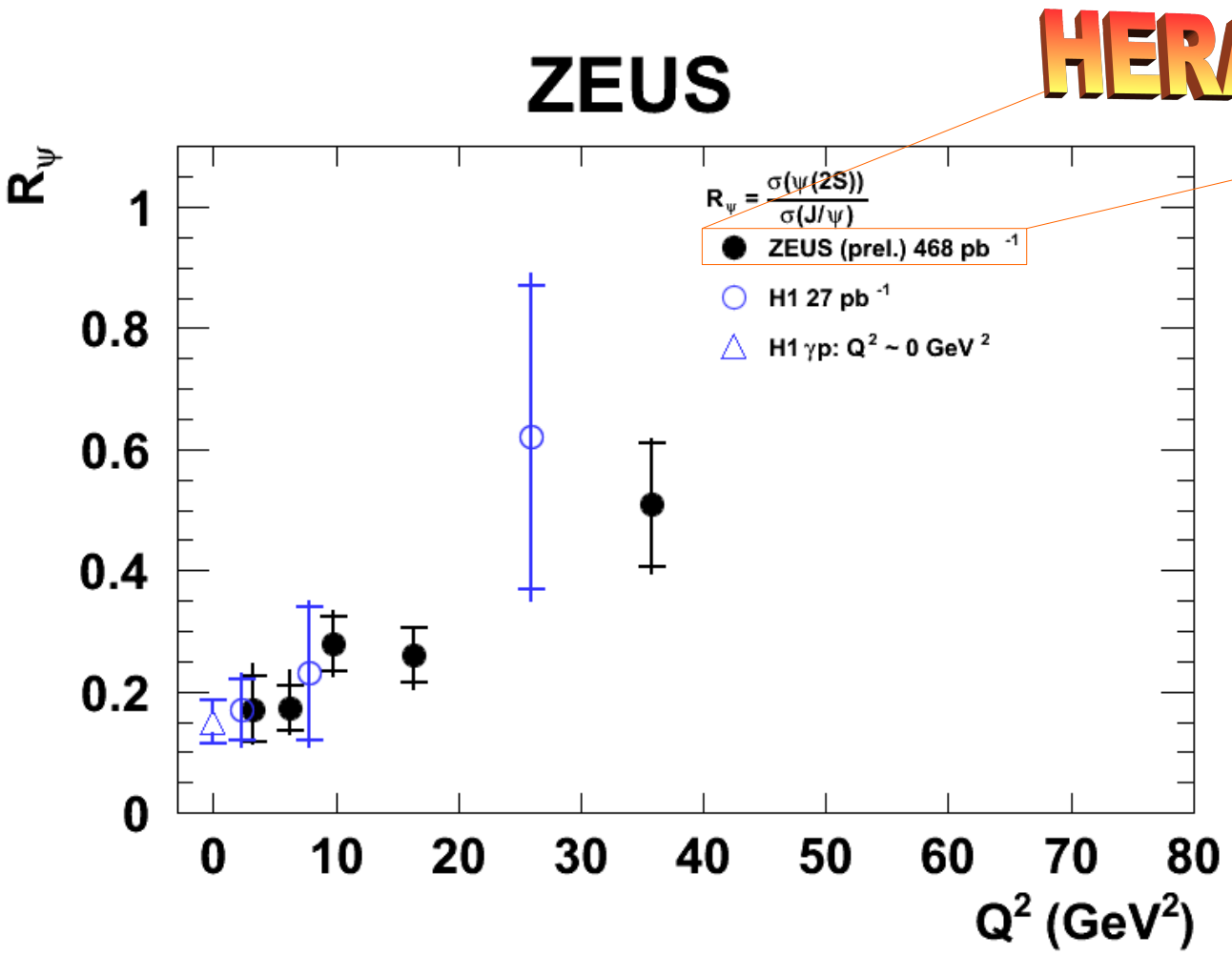




$\sigma(\psi(2S))/\sigma(J/\psi)$

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

ZEUS — H1 comparison



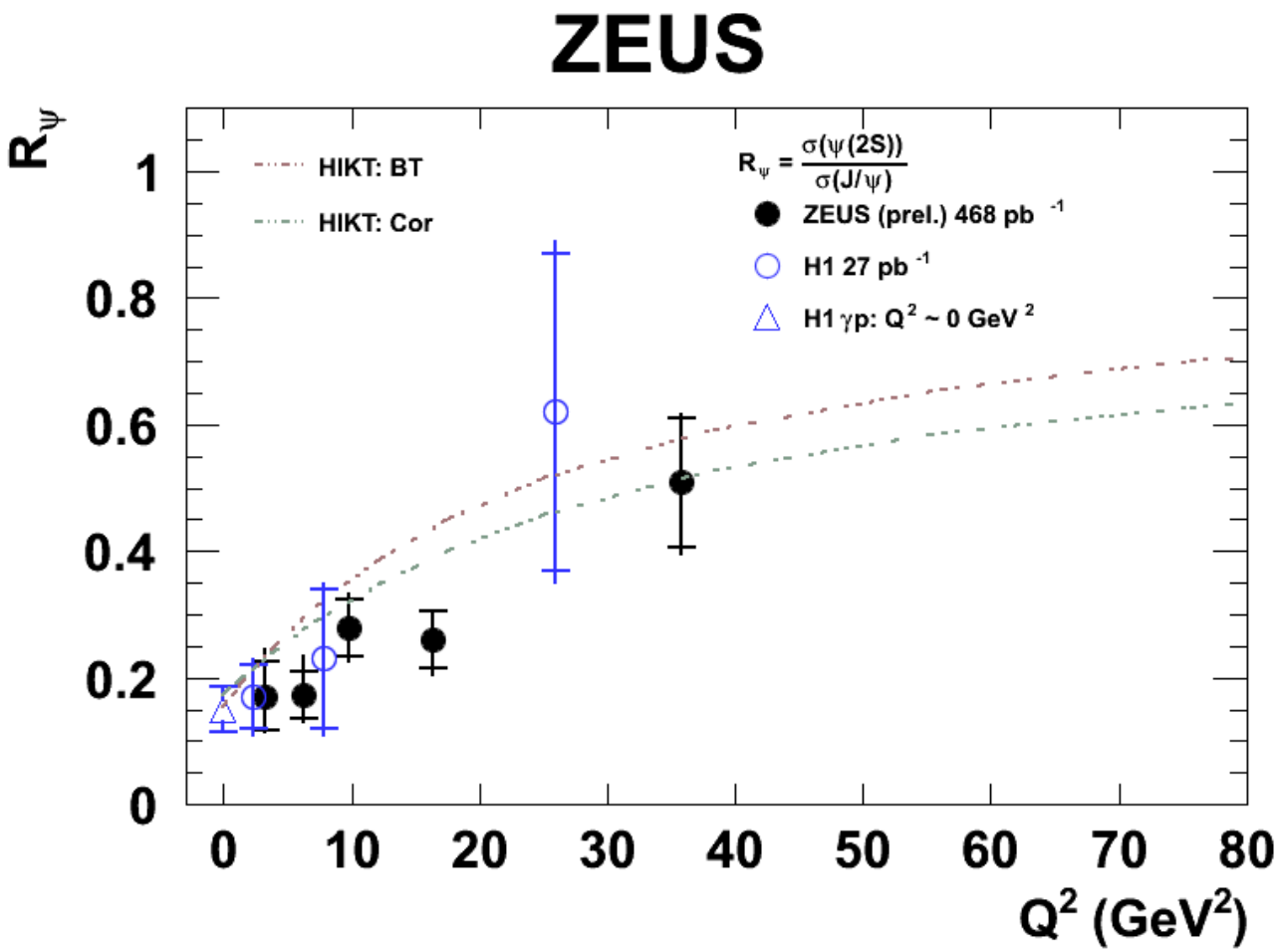
H1 collaboration:

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

Results agree - $\sigma(\psi(2S))/\sigma(J/\psi)$ increases with Q^2

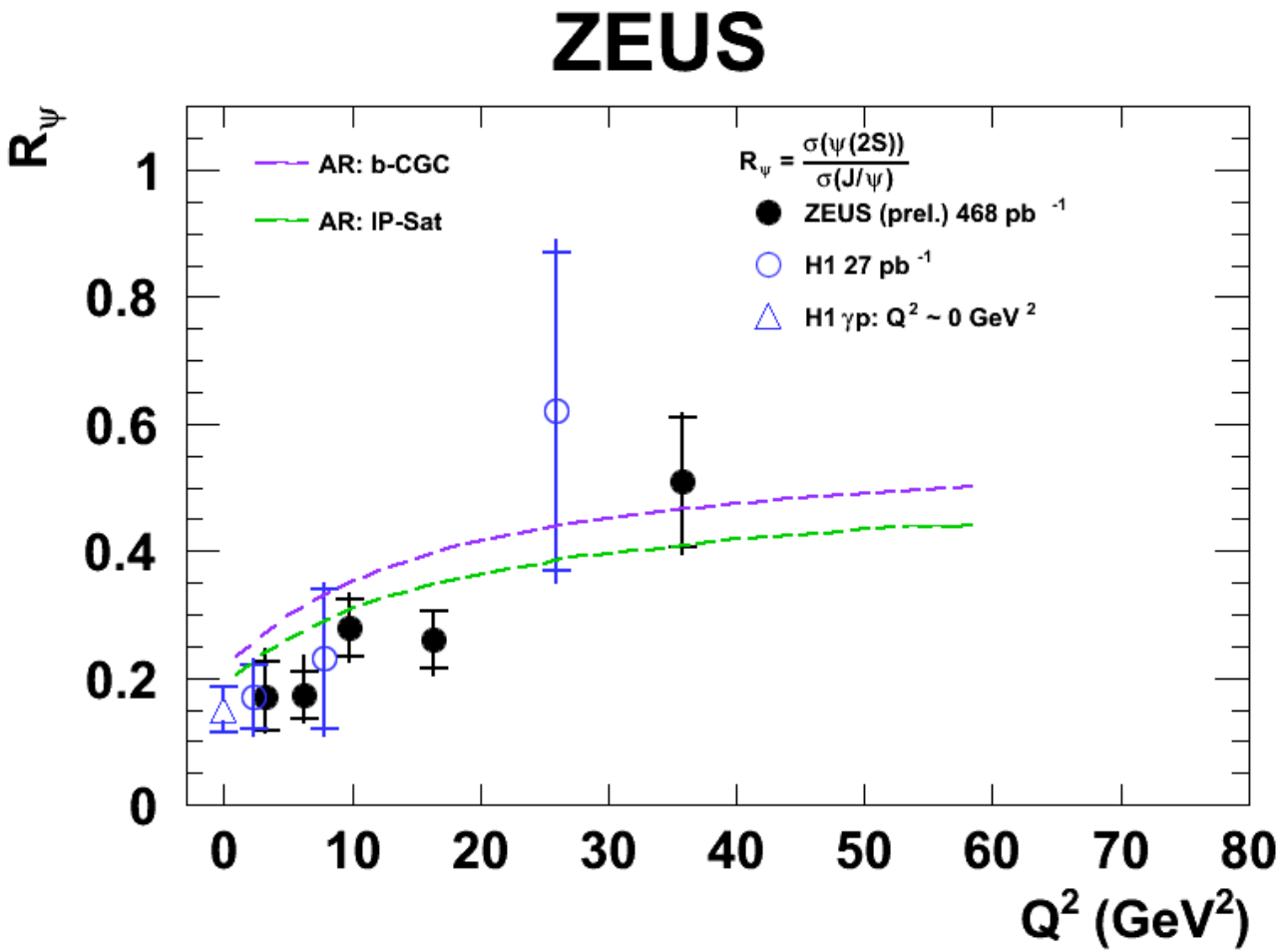
Significantly improved accuracy thanks to increased integrated luminosity

Model predictions



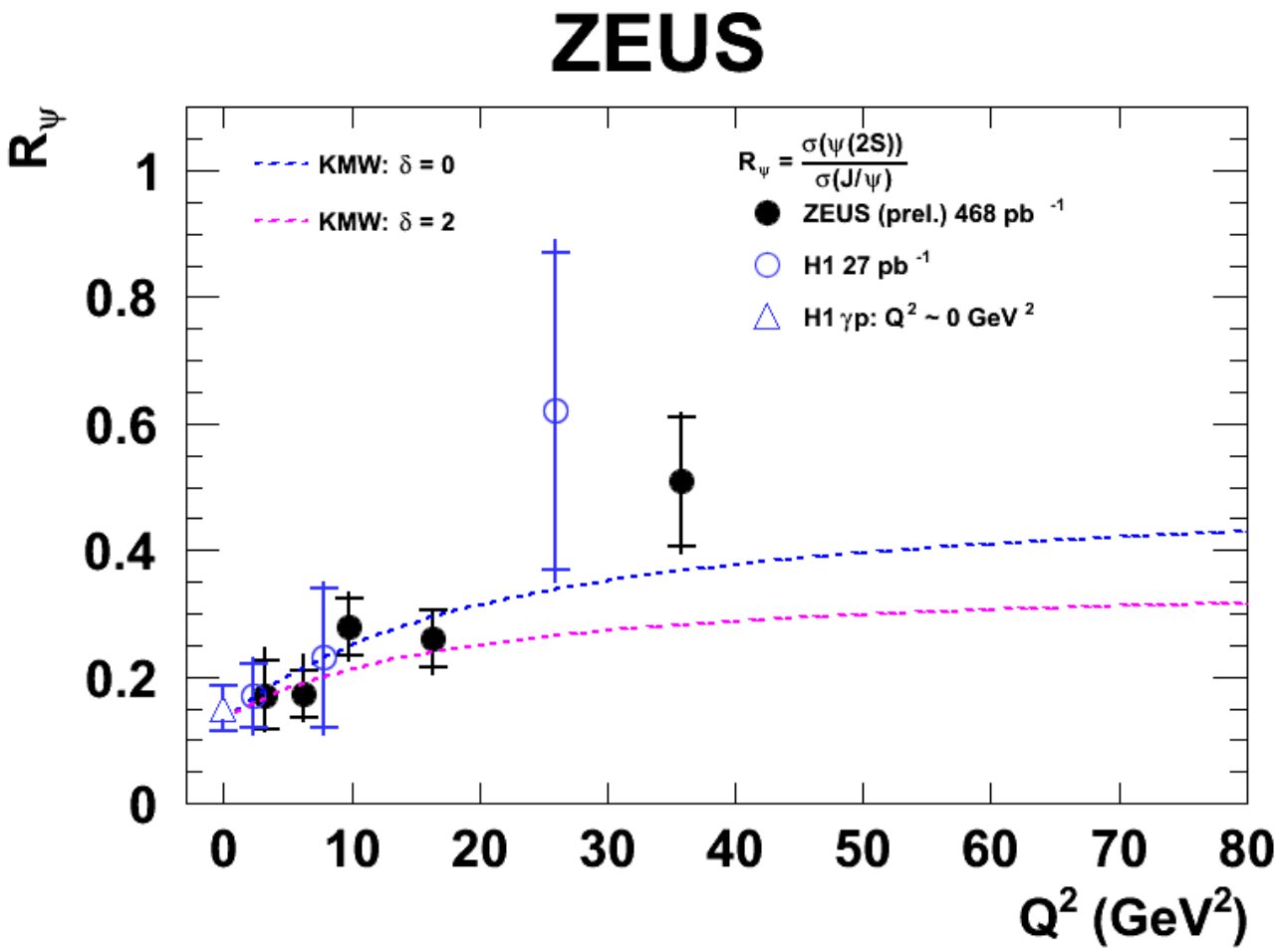
HIKT — from Hufner et al.,
use the dipole model to predict VM production, the dipole–proton interaction cross section is constrained by inclusive DIS data from HERA

Model predictions



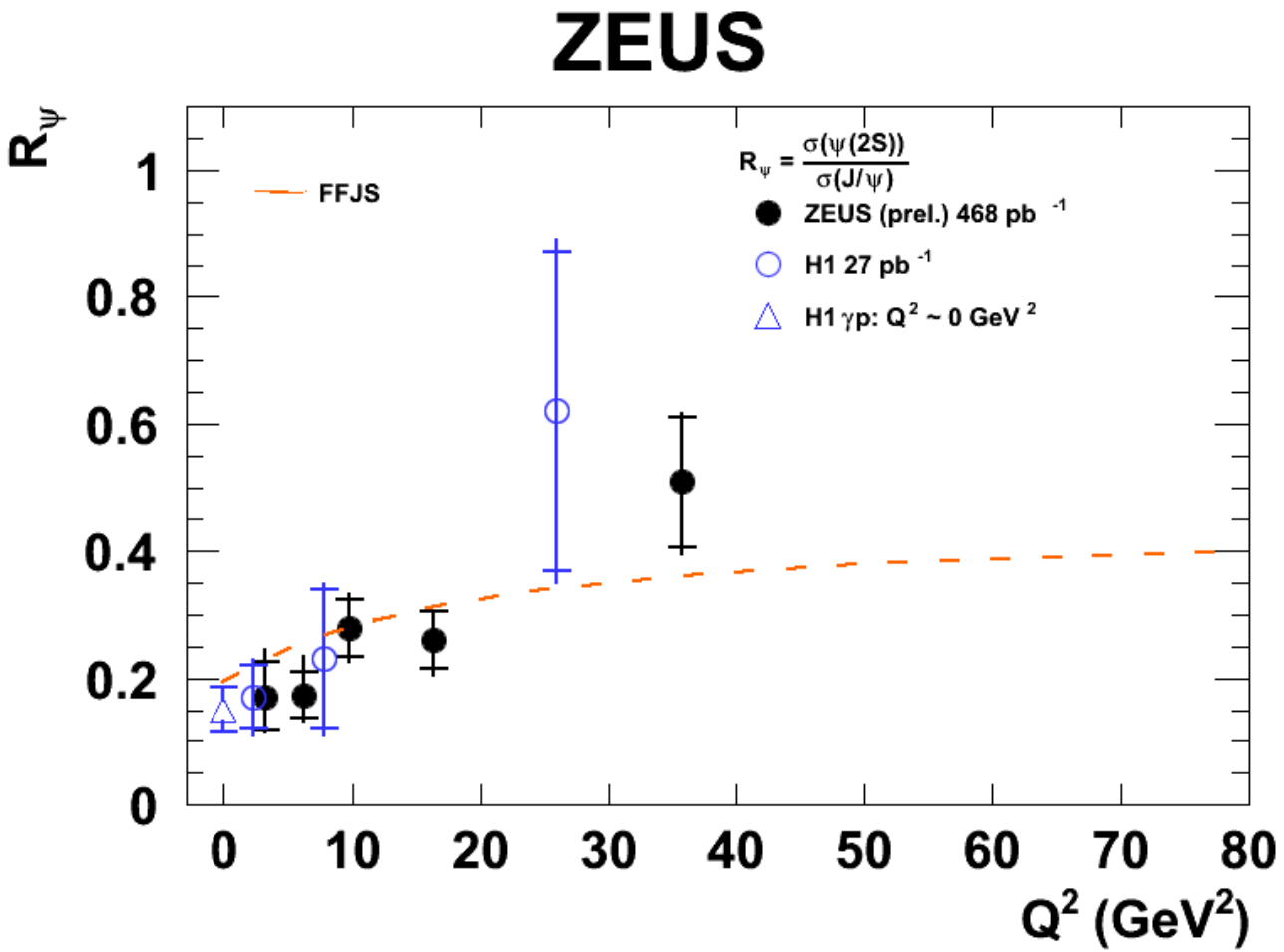
AR — from Armesto and Rezaeian,
two predictions are considered: results from the Impact-Parameter dependent Color Glass Condensate (b-CGC) and the Saturation (IP-Sat) dipole models

Model predictions



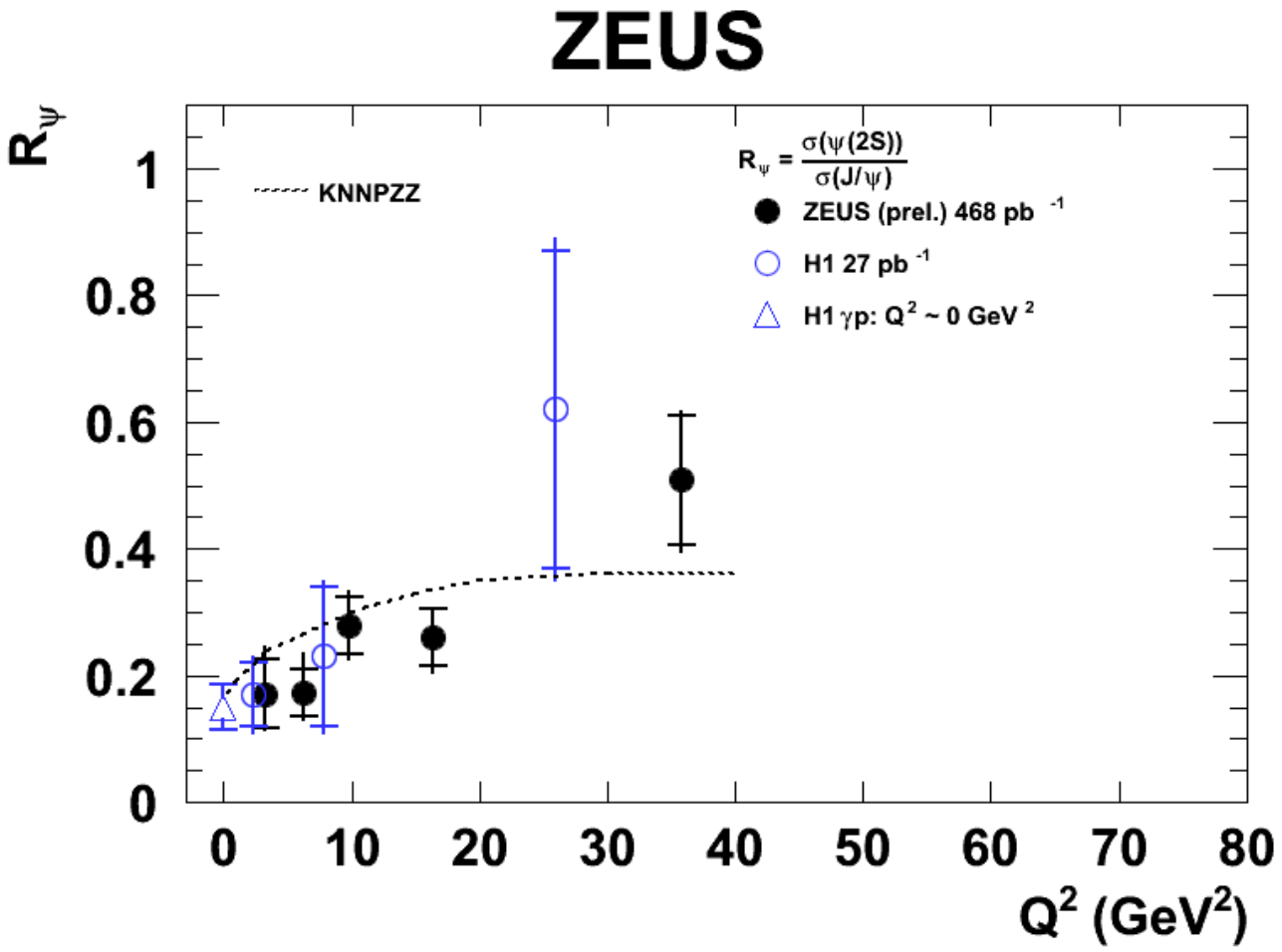
KMW — from Kowalski, Motyka, Watt,
based on the QCD description and an assumption of universality of the quarkonia production mechanism

Model predictions



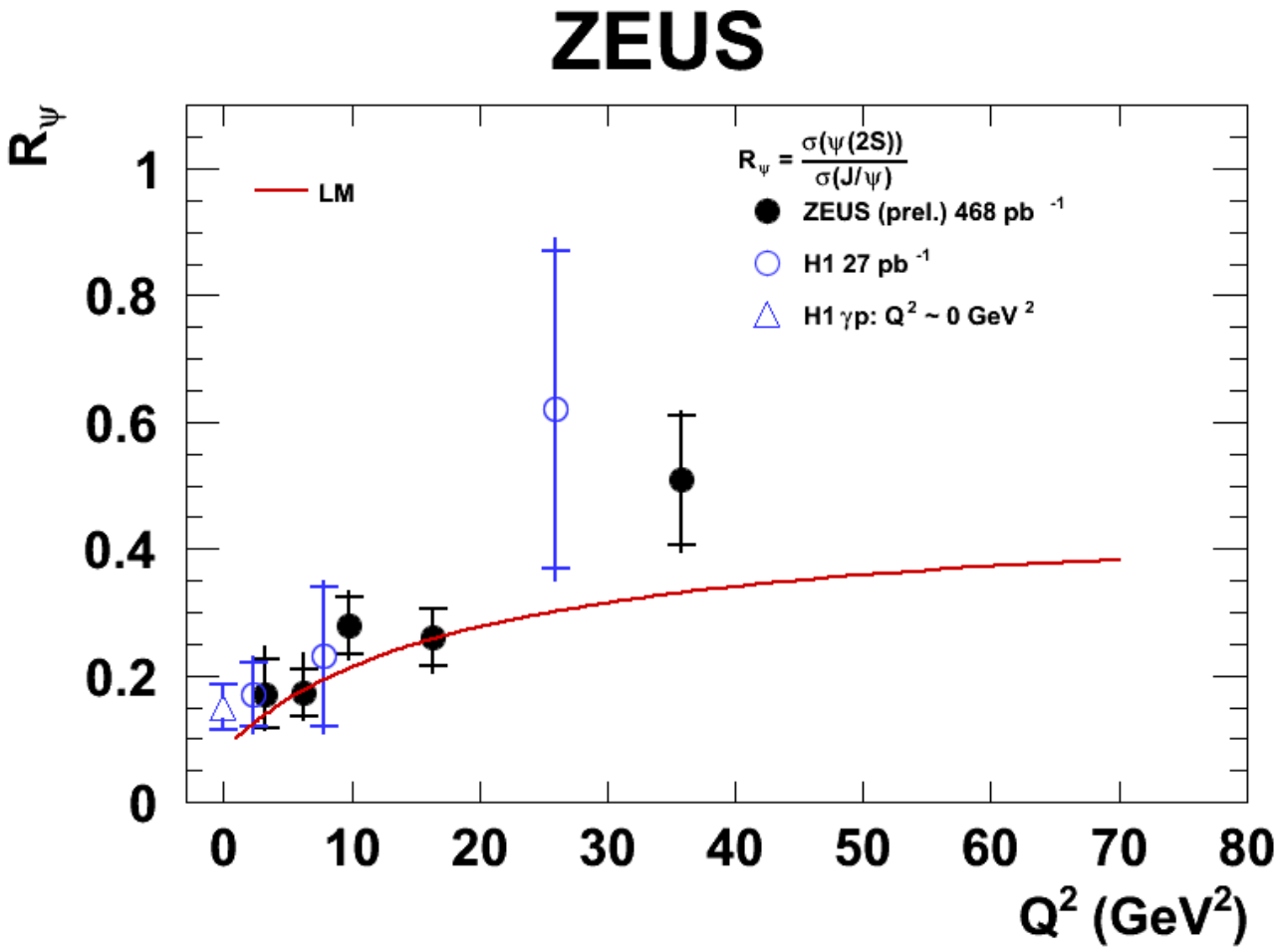
FFJS — from Fazio et al.,
use a two component Pomeron model to predict the cross sections for VM production

Model predictions



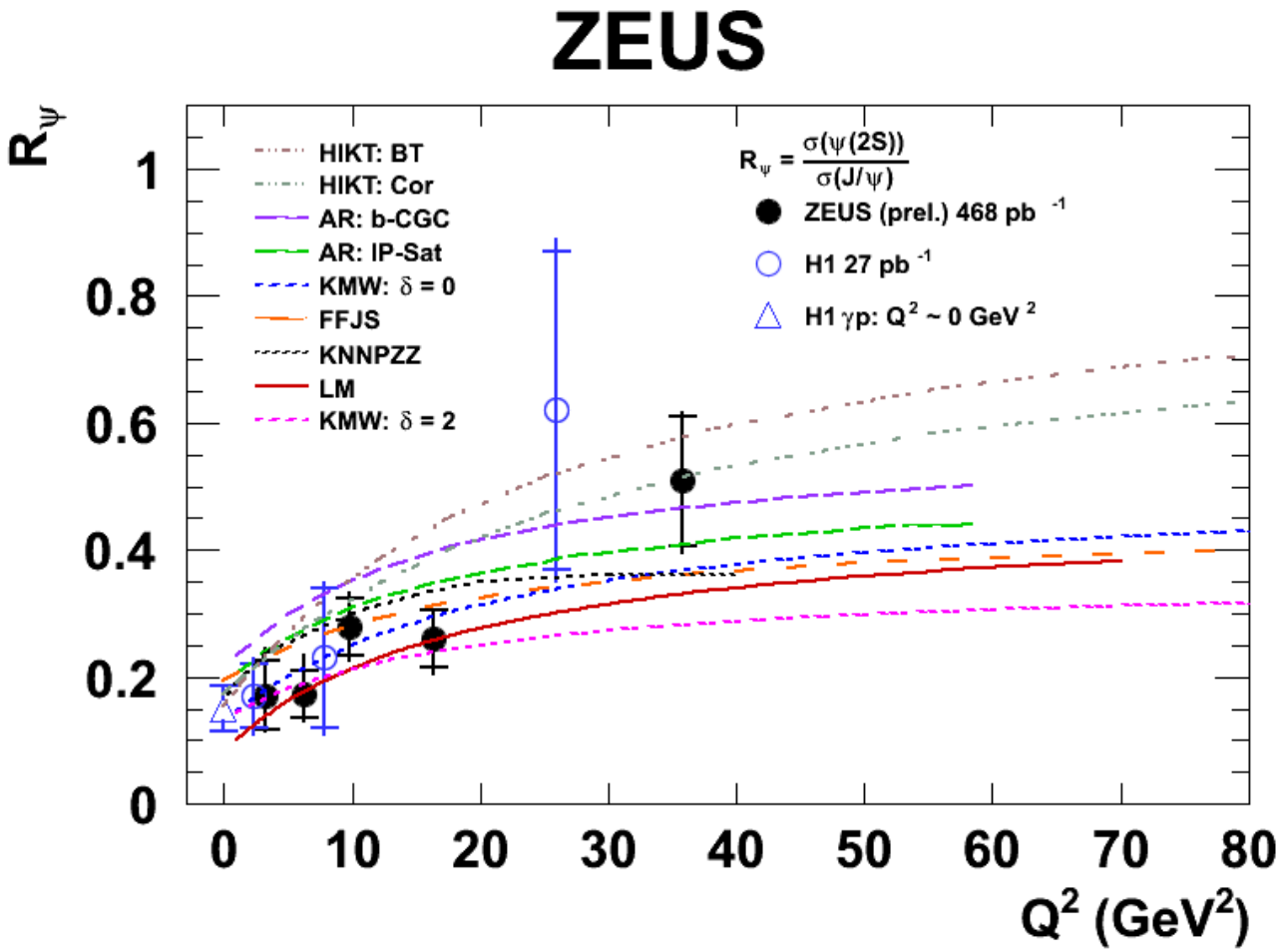
KNNPZZ — from Nemchik et al.,
describe the BFKL pomeron in terms of the colour-dipole cross section which is a solution of the generalised BFKL equations

Model predictions



LM — from Lappi and Mäntysaari,
use dipole picture in the IP-Sat model to predict VM production

Model predictions



All models exhibit an increase of $\sigma(\psi(2S))/\sigma(J/\psi)$ with increasing Q^2
Theoretical predictions are consistent with the data

Summary and outlook

- Using HERA I+II data $\sigma(\psi(2S))/\sigma(J/\psi)$ in exclusive DIS has been measured for the first time by ZEUS in the kinematic range:
$30 \leq W \leq 210$ GeV, $2 \leq Q^2 \leq 80$ GeV^2, $|t| \leq 1$ GeV^2

- The accuracy has been improved compared to the H1 HERA I results

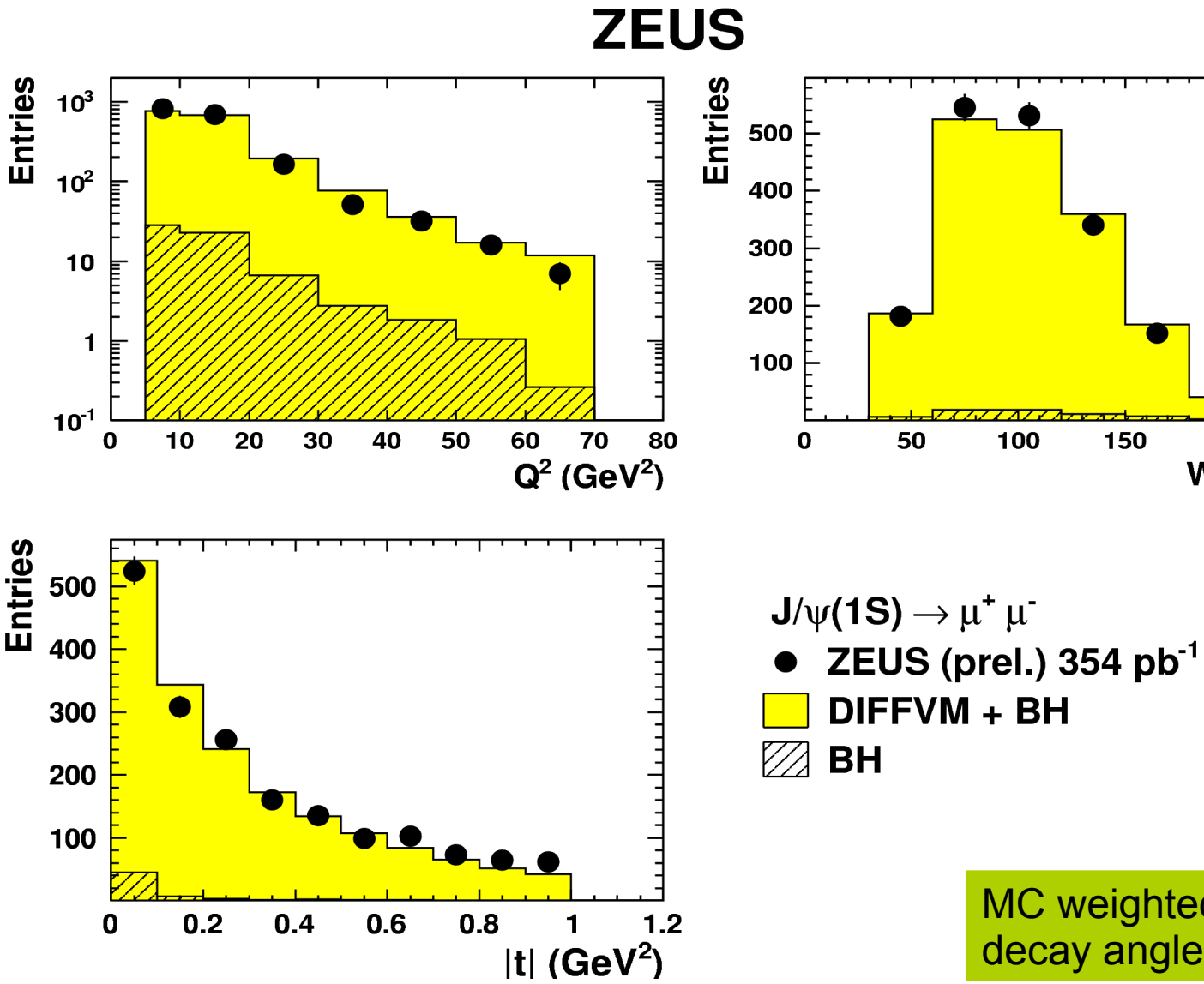
- $\sigma(\psi(2S))/\sigma(J/\psi)$ ratio is compared with models of vector-meson production, all predictions are consistent with the data

- $\sigma(\psi(2S))/\sigma(J/\psi(1S))$:
increases with Q^2 and independent of W and $|t|$

Thank you very much for your attention!

Backup

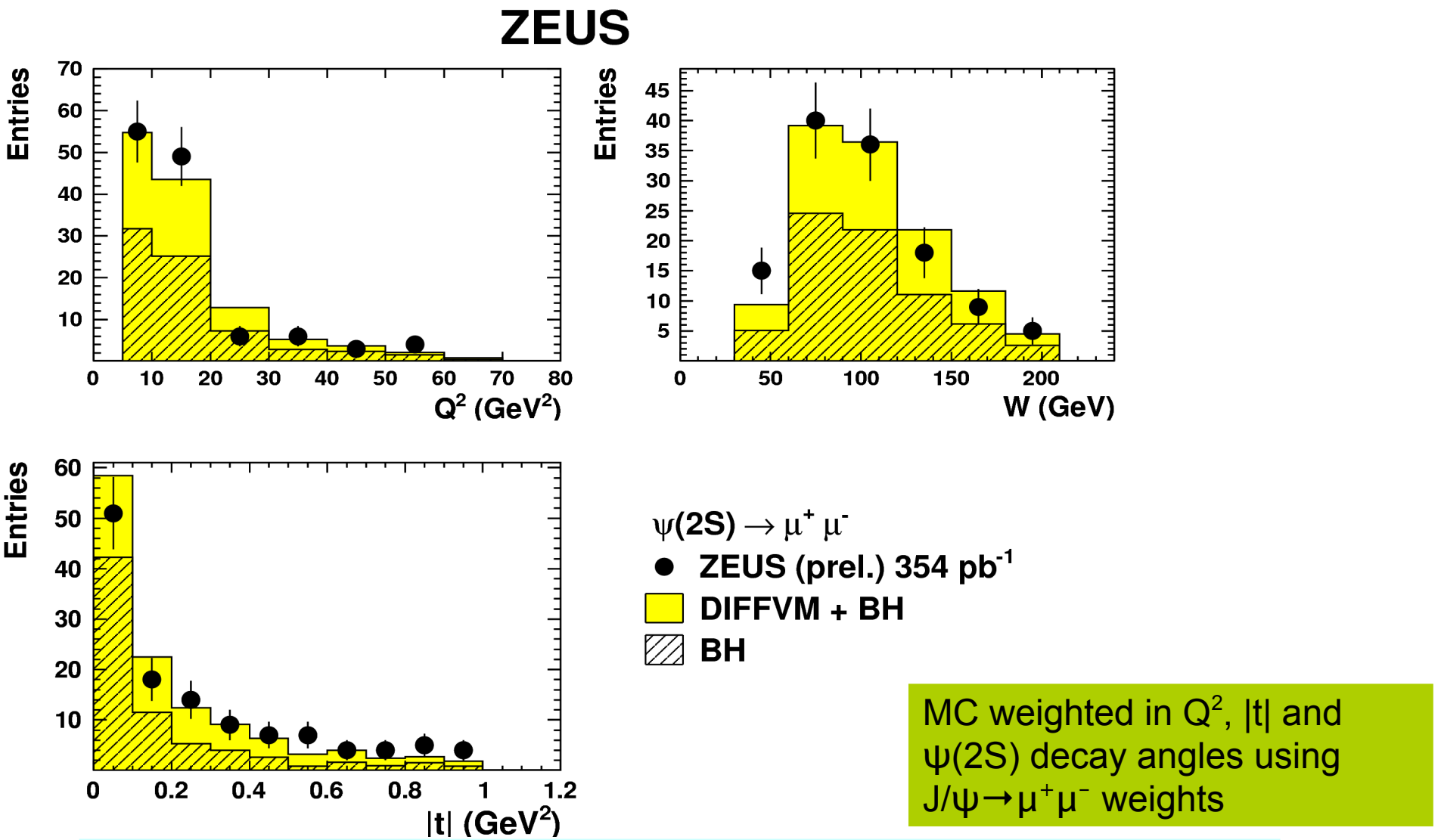
Data-MC comparison for J/ψ



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

Good description of the data by the weighted Monte Carlo

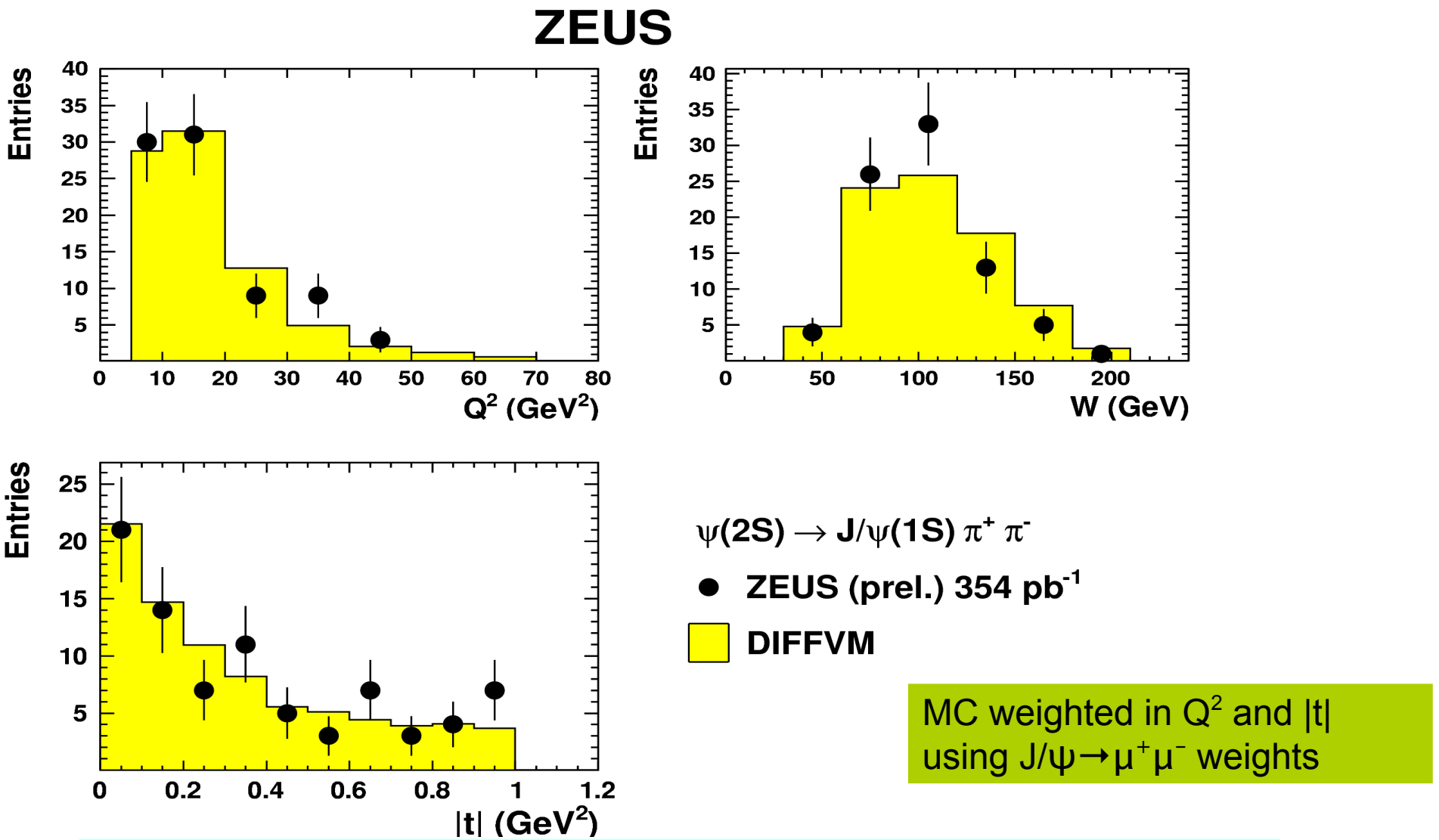
Data-MC comparison for $\psi(2S) \rightarrow \mu^+\mu^-$



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

Good description of the data by the weighted Monte Carlo

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



MC weighted in Q^2 and $|t|$ using $J/\psi \rightarrow \mu^+\mu^-$ weights

Good description of the data by the weighted Monte Carlo