Low-x Meeting 2016

Gyongyos (Hungary), June 6^{th}-11^{th} 2016

$\Psi(2S)/J/\psi$ ratio at HERA

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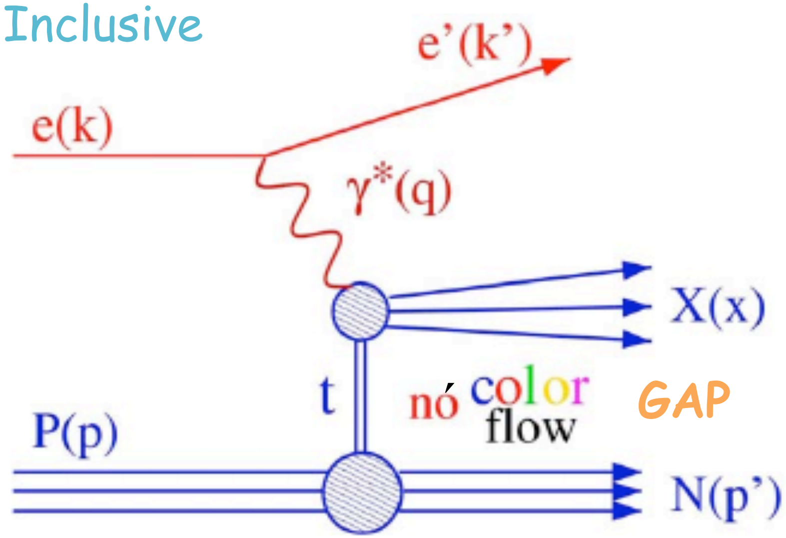
Univ. Piemonte Orientale & INFN-Torino, Italy

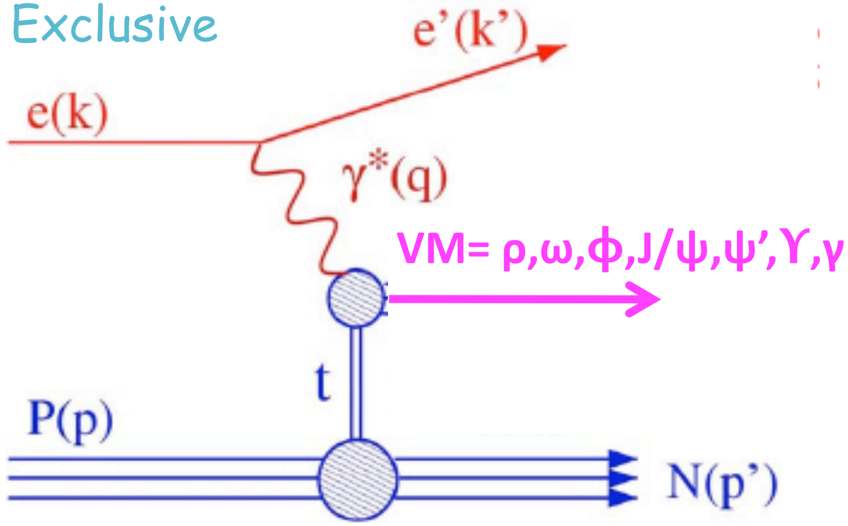
ZEUS

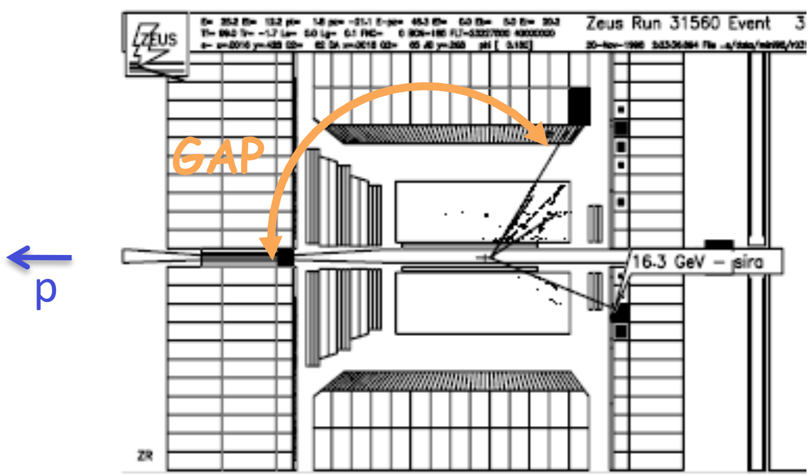
Inclusive and exclusive diffraction

Inclusive

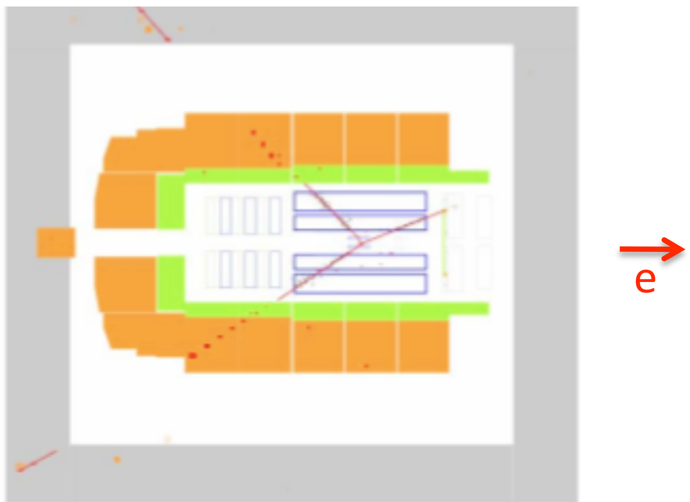


Exclusive





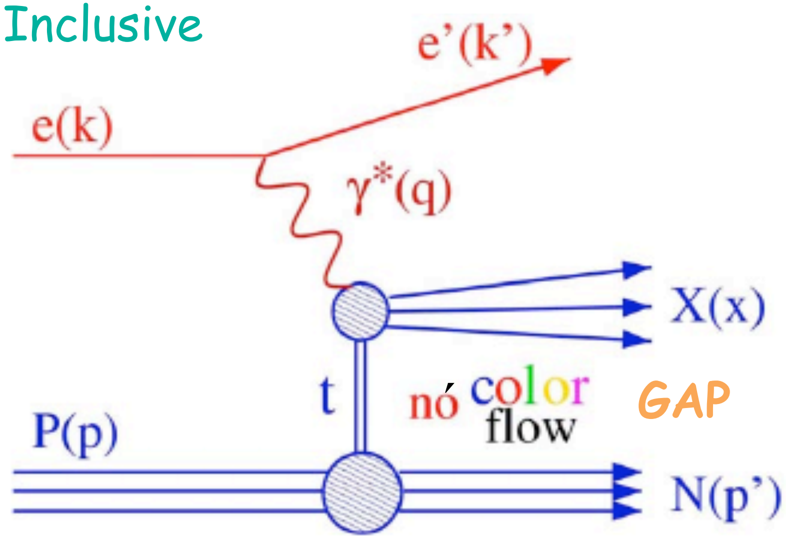
$e\ p \rightarrow e'\ X\ p$



$e\ p \rightarrow e'\ J/\psi\ p \quad J/\psi \rightarrow \mu^+\mu^-$

Inclusive and exclusive diffraction

Inclusive



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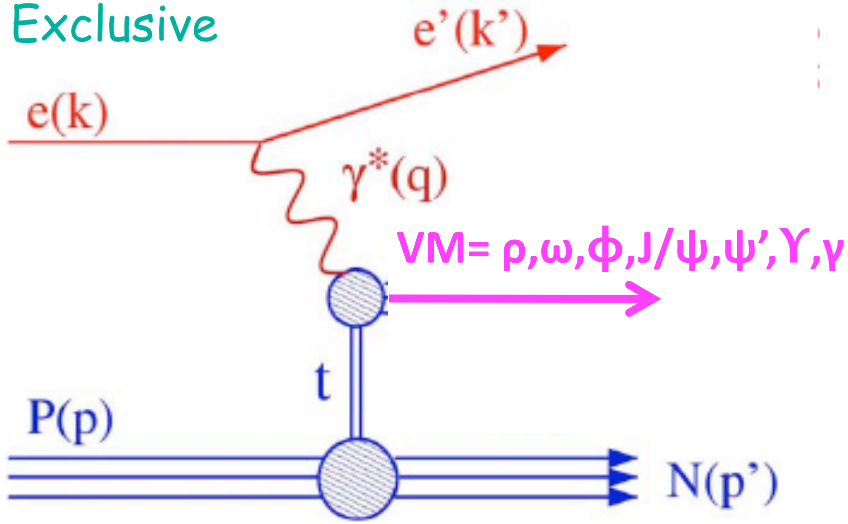


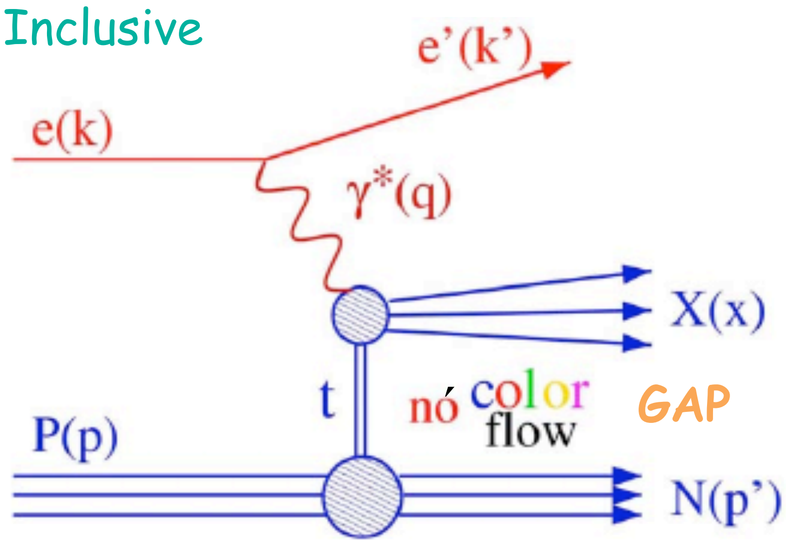
Alternatively:

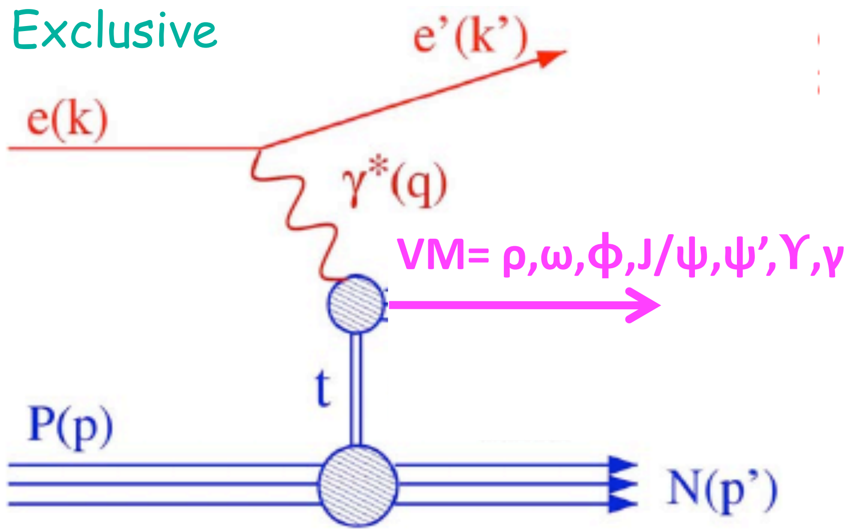
- require the large rapidity gap (LRG)
- tag the proton with spectrometers

VM decay products and nothing else in the central detector

Proton undetected

Inclusive and exclusive diffraction





Q^2 = virtuality of photon =
= (4-momentum exchanged at e vertex)^2

W = invariant mass of γ^*-p system

t = (4-momentum exchanged at p vertex)^2
typically: $|t|<1$ GeV^2

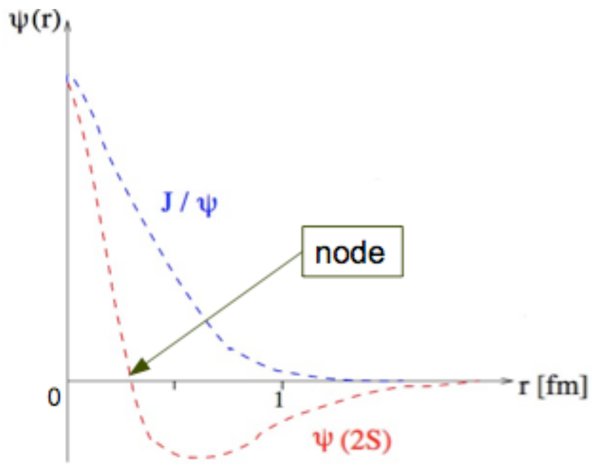
M_X = invariant mass of γ^* -IP system

x_{IP} = fraction of proton's momentum carried by IP

β = Bjorken's variable for the IP
= fraction of IP momentum carried by struck quark
= x/x_{IP}

- Single diffraction/elastic: N=proton
- Double diffraction: proton-dissociative

Motivation



- Ψ(2S) wave function different from J/ψ wave function
- Ratio $R = \frac{\sigma_{\gamma p \to \psi(2S)p}}{\sigma_{\gamma p \to J/\psi p}}$ sensitive to radial wave function of charmonium

pQCD models predict R ≈ 0.17 (photoproduction) and rise of R with Q^2

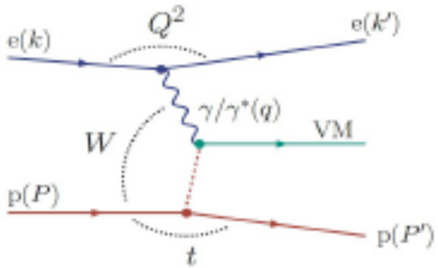
Samples

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

- Data sample: all ZEUS data (1996-2007)
  integrated luminosity 468 pb^{-1}

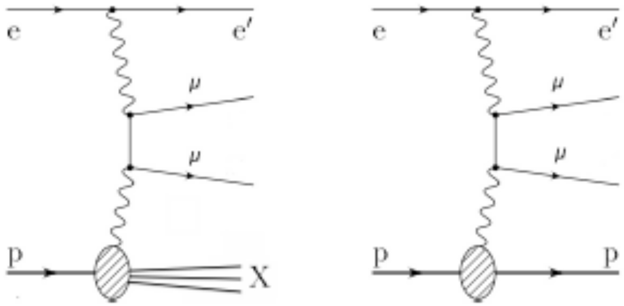
- Monte Carlo samples:
  - **signal**

    DIFFVM exclusive VM production



  - **background**

    GRAPE Bethe-Heitler elastic and proton dissociative dimuon production



Event selection

$30 \leq W \leq 210$ GeV
$2 \leq Q^2 \leq 80$ GeV^2
$|t| \leq 1$ GeV^2

- Scattered electron detected
- Scattered proton undetected
- Two reconstructed tracks identified as muons and nothing else in the detector above noise level

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

- Two reconctructed tracks identified as muons, two pion tracks and nothing else in the detector above noise level

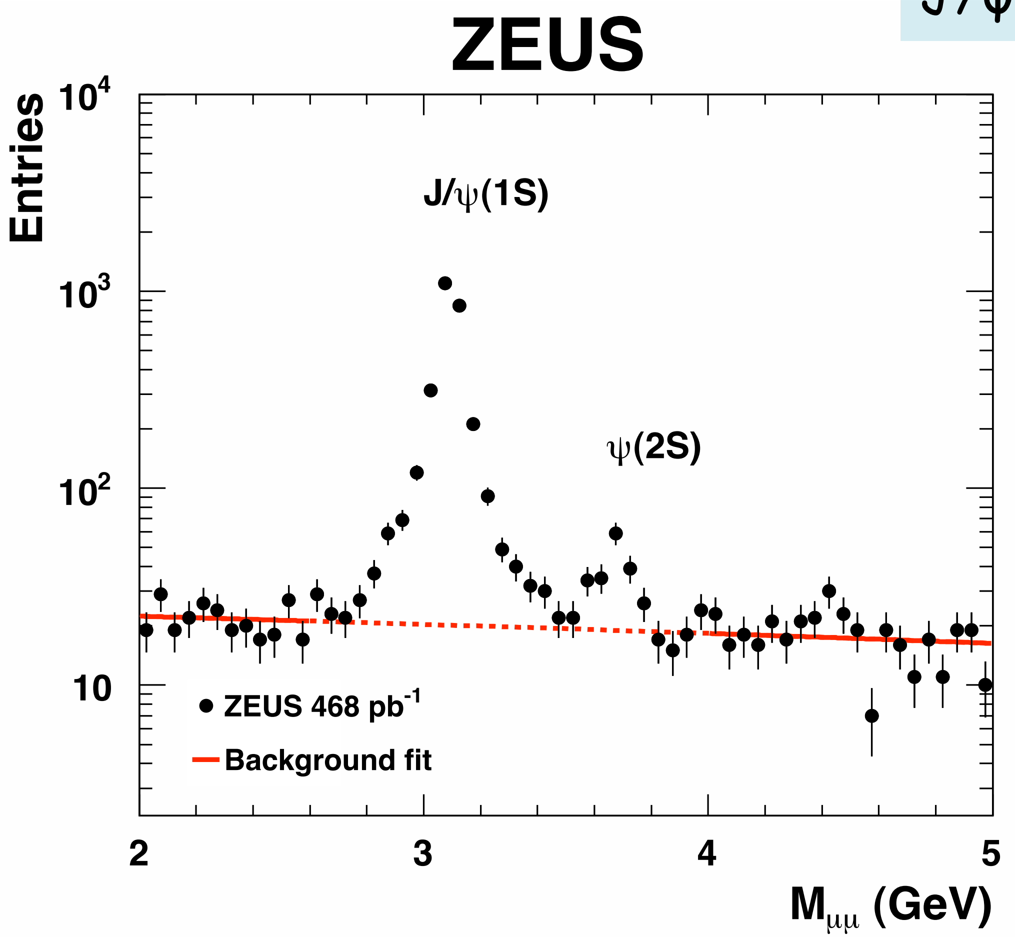
$\Psi(2S) \rightarrow J/\psi\ \pi^+ \pi^{--}$ $J/\psi \rightarrow \mu^+ \mu^-$

→ Proton dissociative events removed above masses ~ M_N 4 GeV
Assuming cross section ratio does not vary with M_N , results not affected by proton dissociation background

Background subtraction

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

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



Number of events above background in the ranges

$3.59 < M_{\mu+\ \mu-} < 3.79$ GeV $\rightarrow N_{\psi(2S)}$

$3.02 < M_{\mu+\ \mu-} < 3.17$ GeV $\rightarrow N_{J/\psi}$

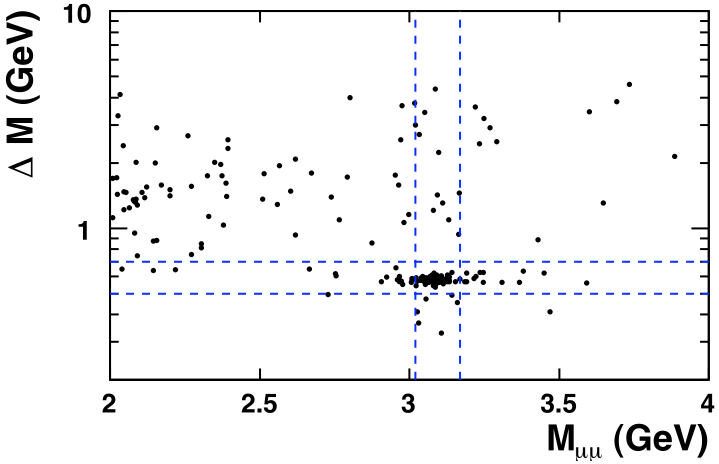
Dimuon background fit to straight line for

$2 < M_{\mu+\ \mu-} < 2.62$ GeV and $4.05 < M_{\mu+\ \mu-} < 5$ GeV

Quadratic function used for the fit and $M_{\mu+\ \mu-}$ varied as systematic checks

Background subtraction

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

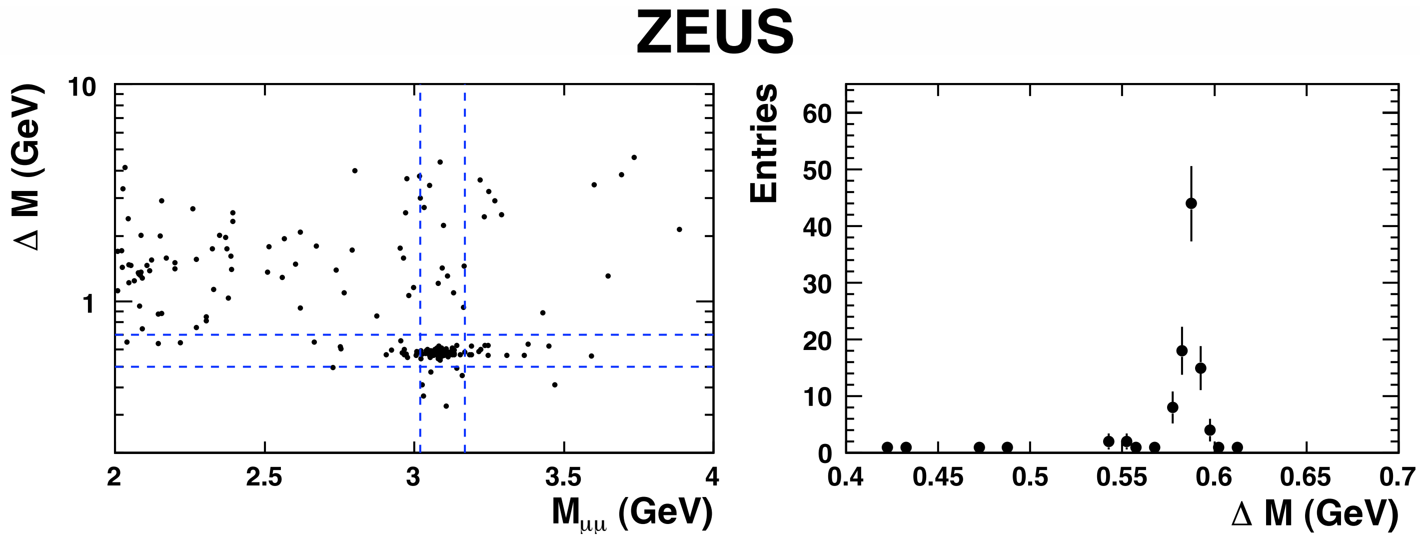


- ZEUS 468 pb^{-1}

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

Background subtraction

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



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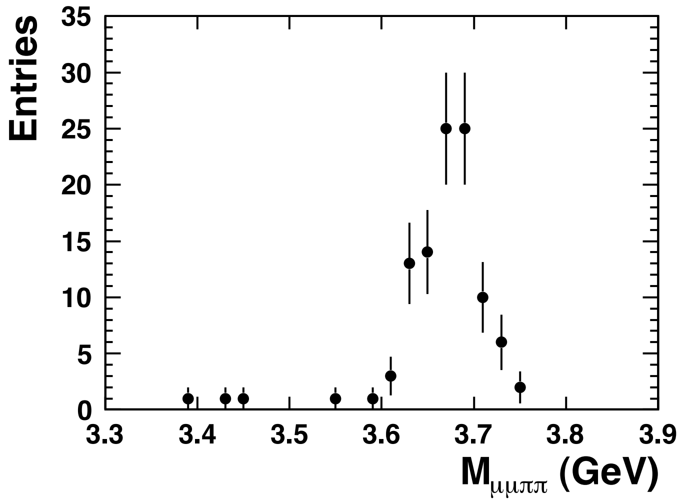


No background (upper limit of 3 events at 90% C.L. estimated)

$0.5 < \Delta M < 0.7$ GeV $\rightarrow N_{\psi(2S)}$

Cut applied above:
$3.02 < M_{\mu\mu} < 3.17$ GeV

Measured ratios

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

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

R_{comb} = combination of $R_{J/\psi\pi\pi}$ and $R_{\mu\mu}$

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

BR[ψ(2S) → J/ψ ππ] = (33.6±0.4)%

BR[ψ(2S) → μμ] = (7.7±0.8)x10^{-3}%

BR[J/ψ → μμ] = (5.93±0.06)%

Measured ratios

$R_{J/\psi\pi\pi}$	$0.26 \pm 0.03^{+0.01}_{-0.01}$
$R_{\mu\mu}$	$0.24 \pm 0.05^{+0.02}_{-0.03}$
R_{comb}	$0.26 \pm 0.02^{+0.01}_{-0.01}$
$R_{\psi(2S)}$	$1.1 \pm 0.2^{+0.2}_{-0.1}$

$$R_{\psi(2S)} = R_{J/\psi\,\pi\pi}/R_{\mu\mu}$$

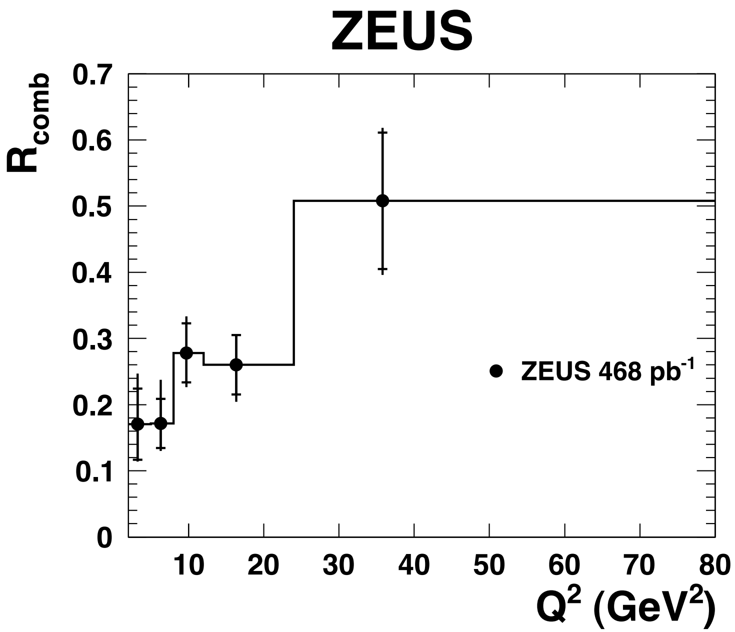
30 ≤ W ≤ 210 GeV
2 ≤ Q^2 ≤ 80 GeV^2
|t| ≤ 1 GeV^2

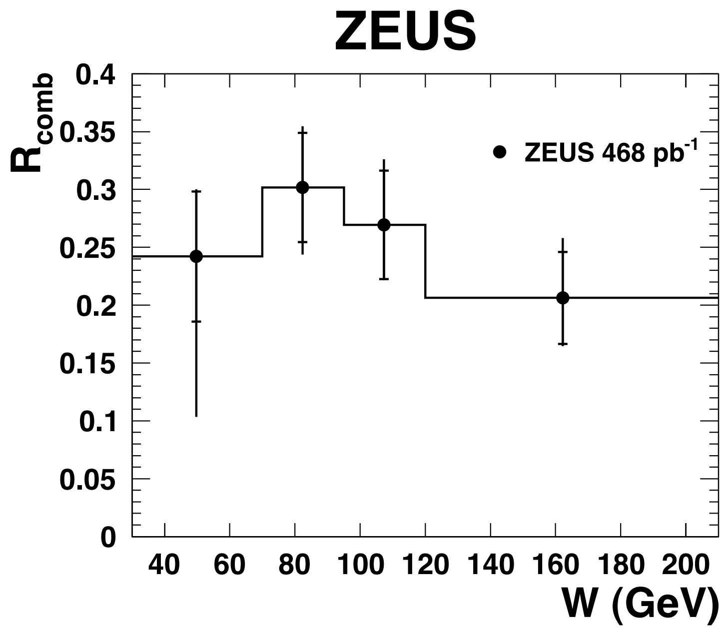
Q^2 (GeV^2)	$R_{J/\psi\pi\pi}$	$R_{\mu\mu}$	R_{comb}	$R_{\psi(2S)}$
2 – 5	$0.21 \pm 0.07^{+0.04}_{-0.03}$	$0.10 \pm 0.09^{+0.09}_{-0.09}$	$0.17 \pm 0.05^{+0.05}_{-0.02}$	–
5 – 8	$0.19 \pm 0.05^{+0.02}_{-0.02}$	$0.13 \pm 0.06^{+0.12}_{-0.03}$	$0.17 \pm 0.04^{+0.05}_{-0.02}$	$1.5 \pm 0.8^{+0.4}_{-0.7}$
8 – 12	$0.27 \pm 0.05^{+0.06}_{-0.01}$	$0.29 \pm 0.08^{+0.03}_{-0.08}$	$0.28 \pm 0.05^{+0.03}_{-0.03}$	$0.9 \pm 0.3^{+0.4}_{-0.1}$
12 – 24	$0.27 \pm 0.05^{+0.04}_{-0.03}$	$0.24 \pm 0.08^{+0.01}_{-0.08}$	$0.26 \pm 0.05^{+0.01}_{-0.03}$	$1.1 \pm 0.4^{+0.6}_{-0.1}$
24 – 80	$0.56 \pm 0.13^{+0.04}_{-0.09}$	$0.42 \pm 0.17^{+0.12}_{-0.04}$	$0.51 \pm 0.10^{+0.04}_{-0.04}$	$1.3 \pm 0.6^{+0.3}_{-0.6}$

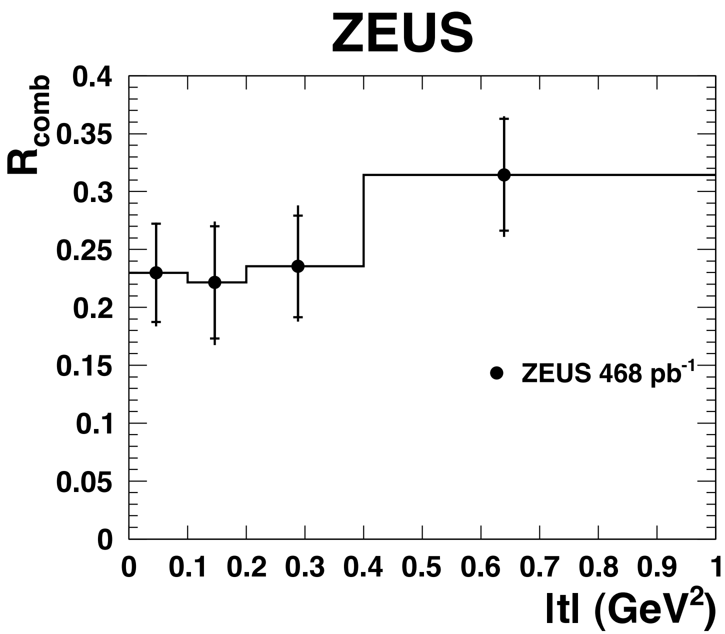
W (GeV)	$R_{J/\psi\pi\pi}$	$R_{\mu\mu}$	R_{comb}	$R_{\psi(2S)}$
30 – 70	$0.24 \pm 0.07^{+0.01}_{-0.13}$	$0.24 \pm 0.10^{+0.03}_{-0.14}$	$0.24 \pm 0.06^{+0.01}_{-0.13}$	$1.0 \pm 0.5^{+0.5}_{-0.2}$
70 – 95	$0.30 \pm 0.06^{+0.01}_{-0.04}$	$0.31 \pm 0.09^{+0.09}_{-0.03}$	$0.30 \pm 0.05^{+0.02}_{-0.03}$	$1.0 \pm 0.3^{+0.1}_{-0.2}$
95 – 120	$0.28 \pm 0.06^{+0.05}_{-0.01}$	$0.24 \pm 0.08^{+0.04}_{-0.05}$	$0.27 \pm 0.05^{+0.03}_{-0.01}$	$1.2 \pm 0.5^{+0.5}_{-0.2}$
120 – 210	$0.22 \pm 0.05^{+0.07}_{-0.01}$	$0.17 \pm 0.07^{+0.02}_{-0.05}$	$0.21 \pm 0.04^{+0.03}_{-0.01}$	$1.3 \pm 0.6^{+0.7}_{-0.2}$

$\|t\|$ (GeV^2)	$R_{J/\psi\pi\pi}$	$R_{\mu\mu}$	R_{comb}	$R_{\psi(2S)}$
0 – 0.1	$0.23 \pm 0.05^{+0.02}_{-0.02}$	$0.23 \pm 0.09^{+0.04}_{-0.05}$	$0.23 \pm 0.04^{+0.01}_{-0.02}$	$1.0 \pm 0.4^{+0.3}_{-0.2}$
0.1 – 0.2	$0.22 \pm 0.06^{+0.02}_{-0.03}$	$0.23 \pm 0.09^{+0.02}_{-0.06}$	$0.22 \pm 0.05^{+0.02}_{-0.02}$	$0.9 \pm 0.4^{+0.5}_{-0.2}$
0.2 – 0.4	$0.27 \pm 0.06^{+0.06}_{-0.01}$	$0.18 \pm 0.07^{+0.05}_{-0.06}$	$0.24 \pm 0.04^{+0.03}_{-0.02}$	$1.5 \pm 0.6^{+0.5}_{-0.2}$
0.4 – 1	$0.32 \pm 0.06^{+0.05}_{-0.03}$	$0.30 \pm 0.08^{+0.02}_{-0.05}$	$0.32 \pm 0.05^{+0.01}_{-0.02}$	$1.1 \pm 0.3^{+0.3}_{-0.1}$

Ratios vs Q^2, W and t



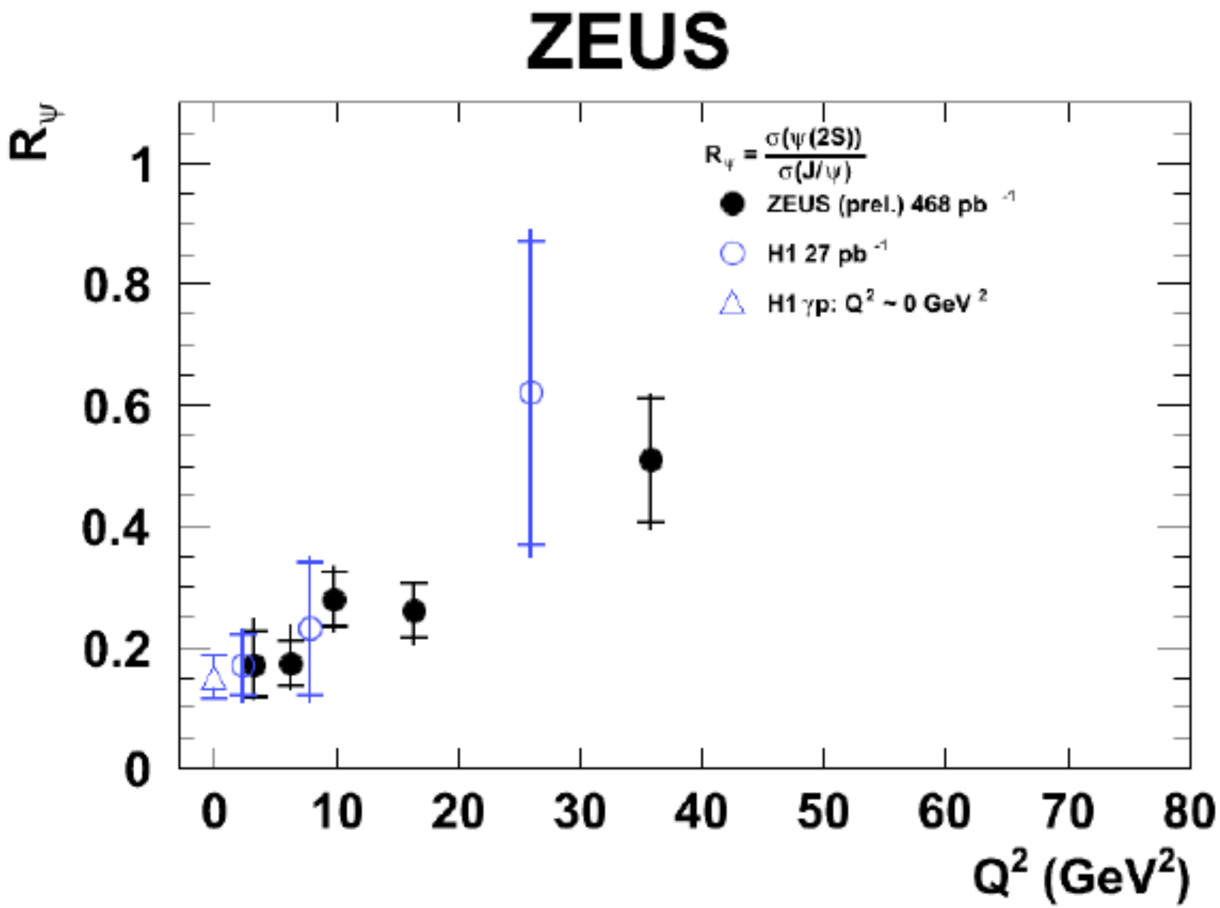




→ Increasing with Q^2

→ Independent of W and t

Comparison with H1 earlier measurement

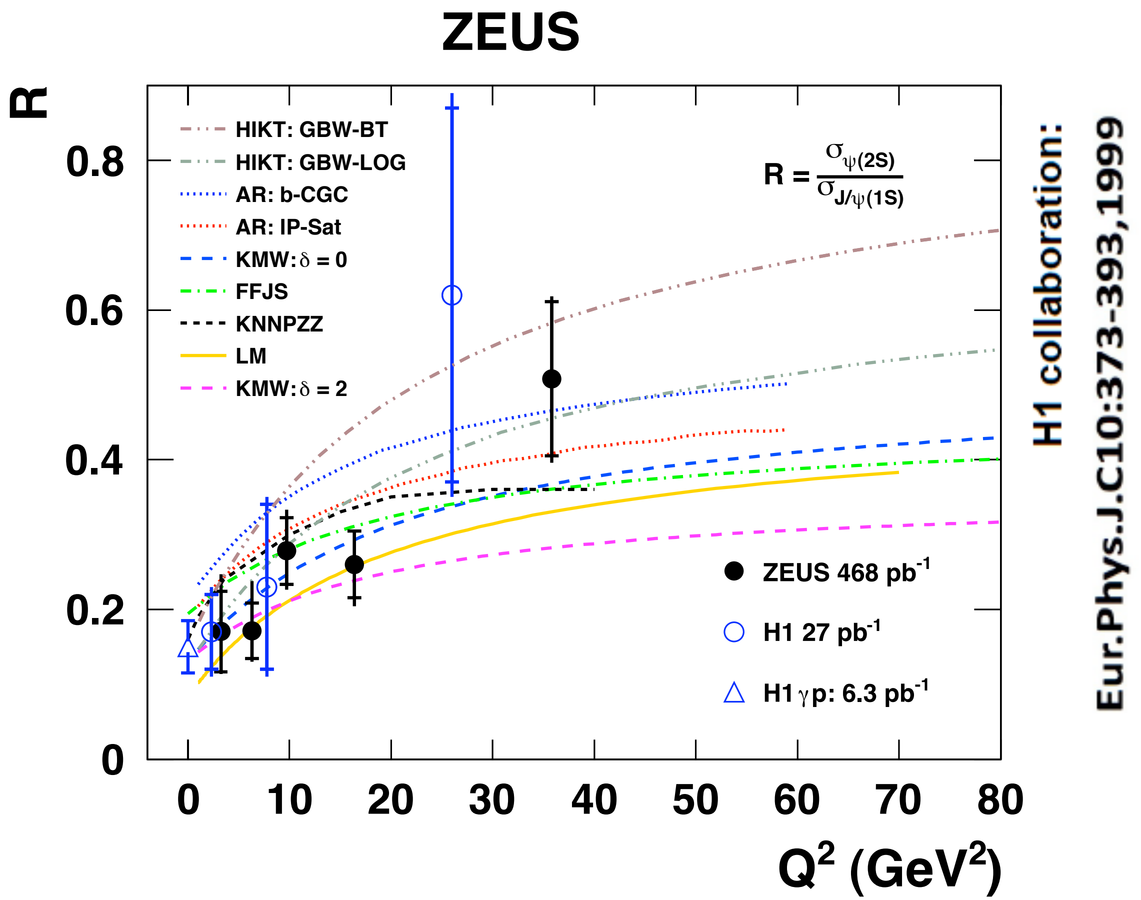


H1 collaboration:

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

→ Much larger luminosity in ZEUS measurement (HERA I + HERA II)

Comparison with models and with H1



HIKT, Hüfner et al.: dipole model, dipole-proton constrained by inclusive DIS data
AR, Armesto and Rezaeian: impact parameter dependent CGC and IP-Sat model
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HIKT calculation

[J. Hüfner et al., Phys. Rev. D 62, 094022 (2000)]

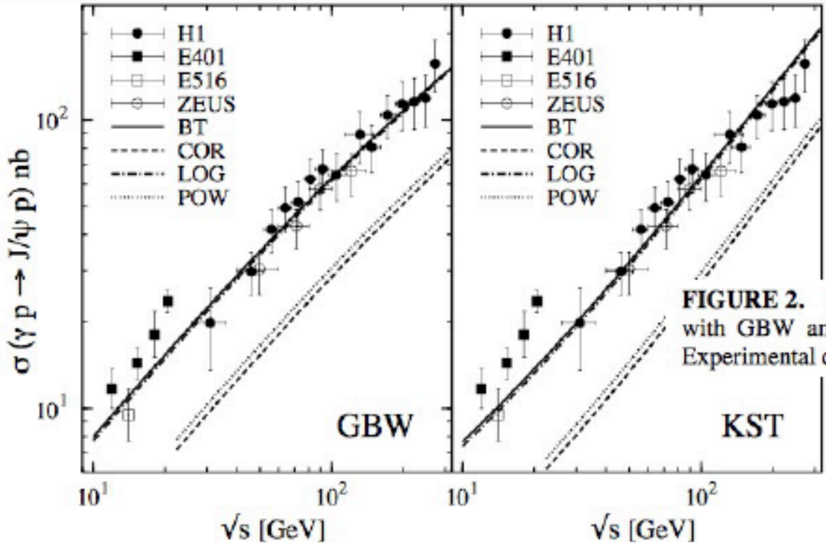
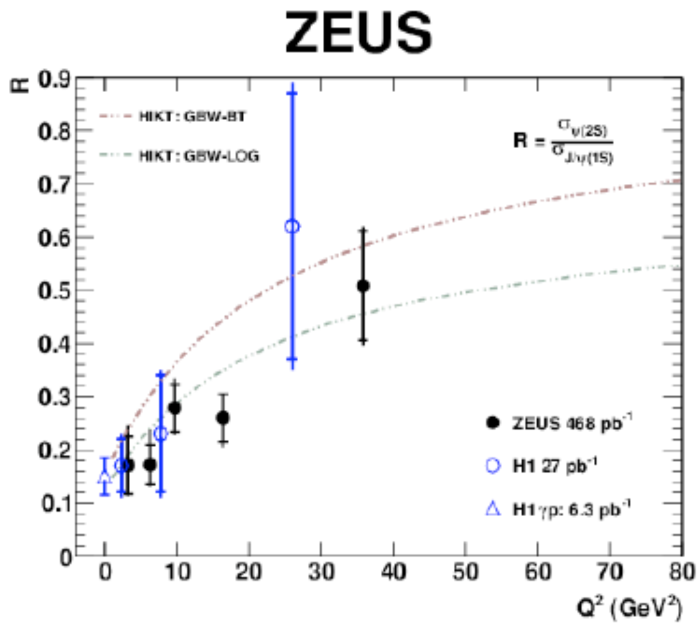


FIGURE 2. Integrated cross section for elastic photoproduction with real photons ($Q^2 = 0$) calculate with GBW and KST dipole cross sections and for four potentials to generate J/ψ wave function Experimental data points from the H1 [20], E401 [21], E516 [22] and ZEUS [23] experiments.

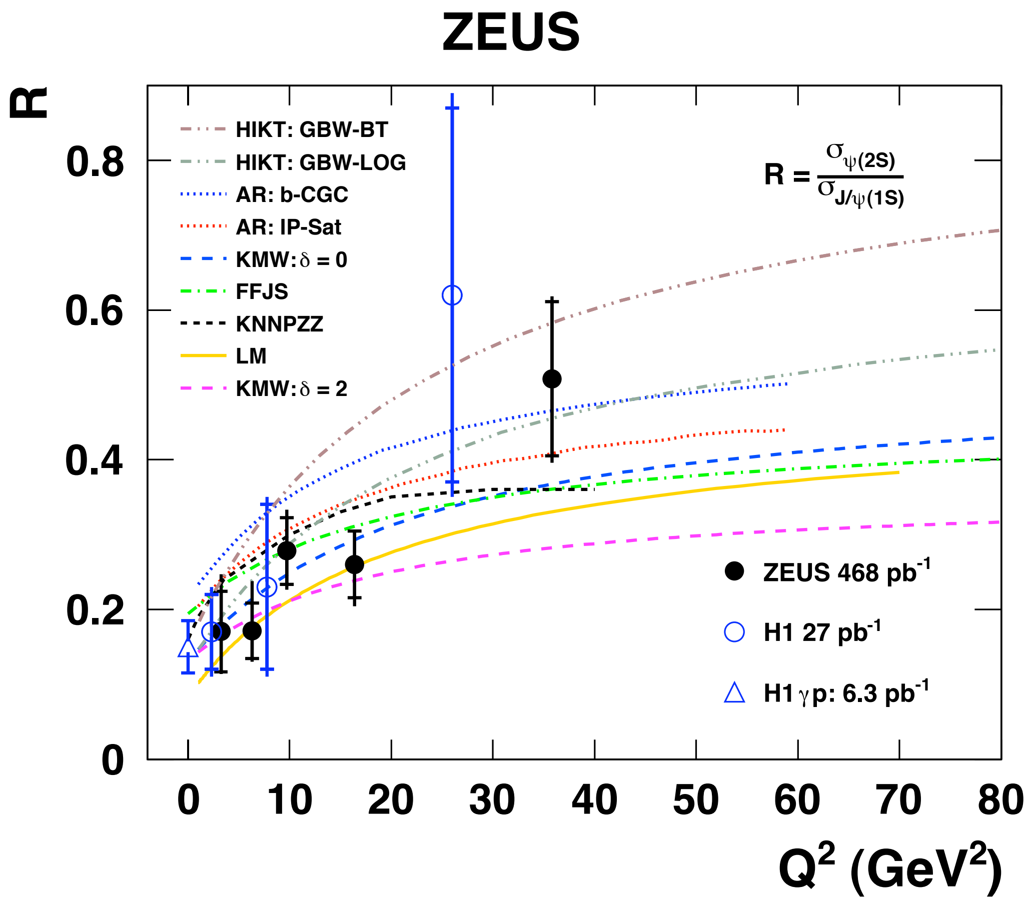


- Two parameterization of the dipole cross section (GBW and KST)

- Four phenomenological potentials of the wave functions:
  - BT, LOG with $m_c \approx 1.5$ GeV
  - COR and POW with $m_c \approx 1.8$ GeV

→ BT predictions larger than the data

Comparison with models and with H1



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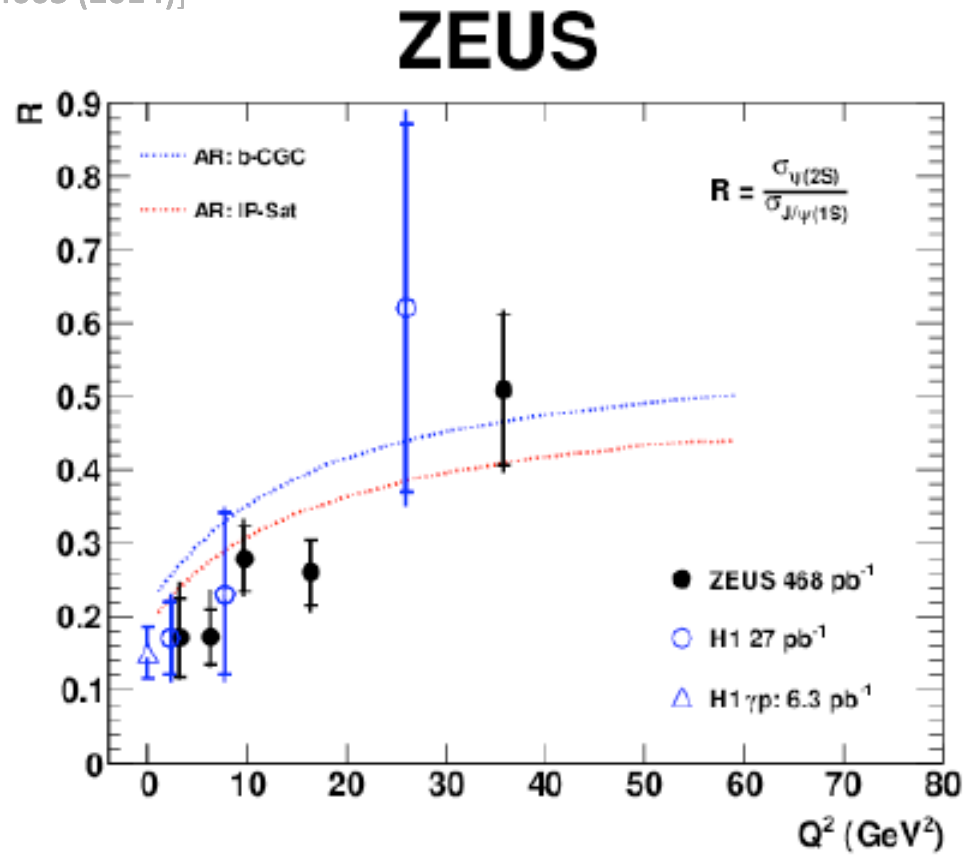
AR calculation

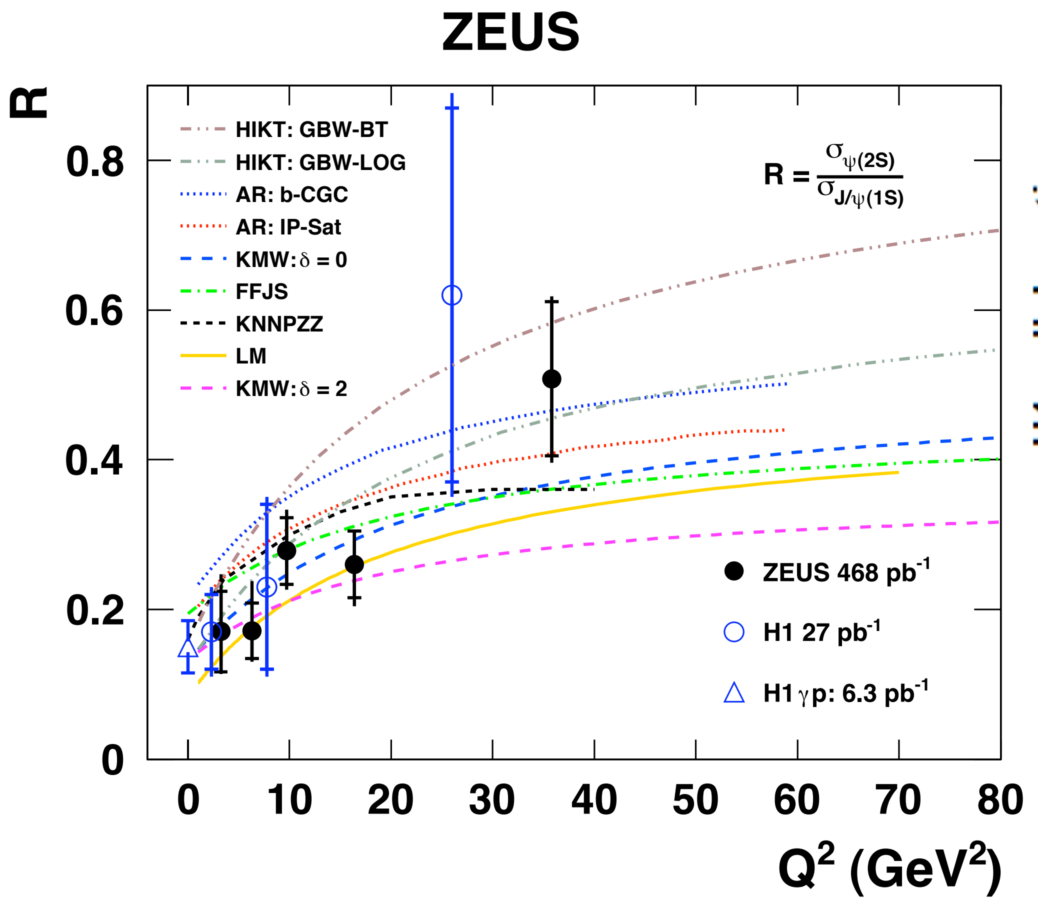
[N. Armesto and A. H. Reazeian, Phys. Rev. D 90, 054003 (2014)]



- Impact-parameter-dependent Color Glass Condensate model (b-CGC) or Saturation model (IP-Sat)

→IP-Sat prediction about 30% lower and gives a better description of the data

Comparison with models and with H1



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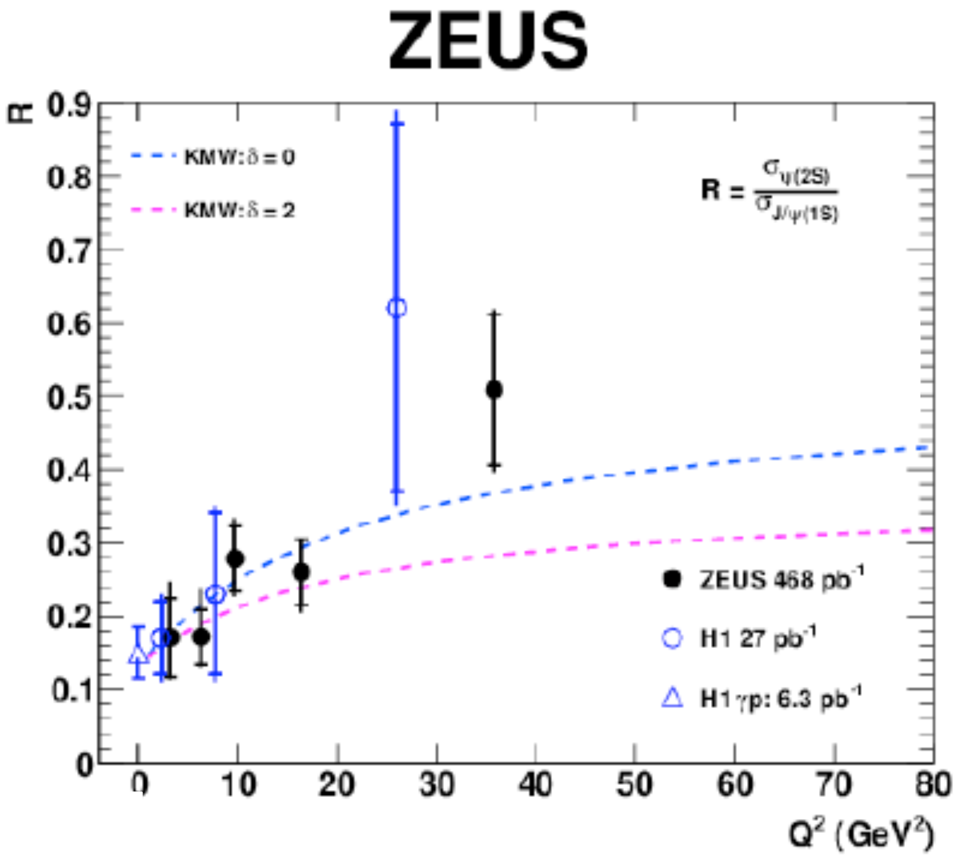
KMW calculation

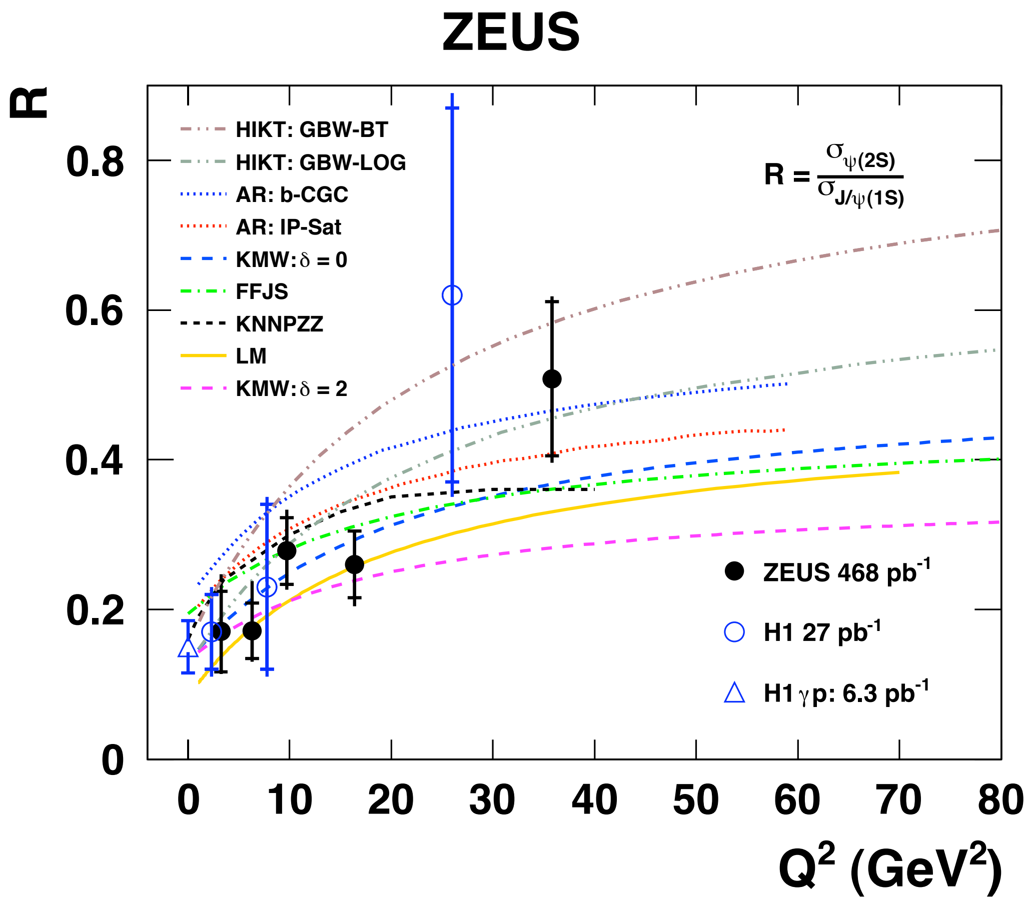
[H. Kowalski et al., Phys. Rev. D 74, 074016 (2006)]



- Assumes universality of production of vector quarkonia states. Parameter δ depends on the choice of the charmonium wave function

→ δ = 0 provides a better description of the data

Comparison with models and with H1



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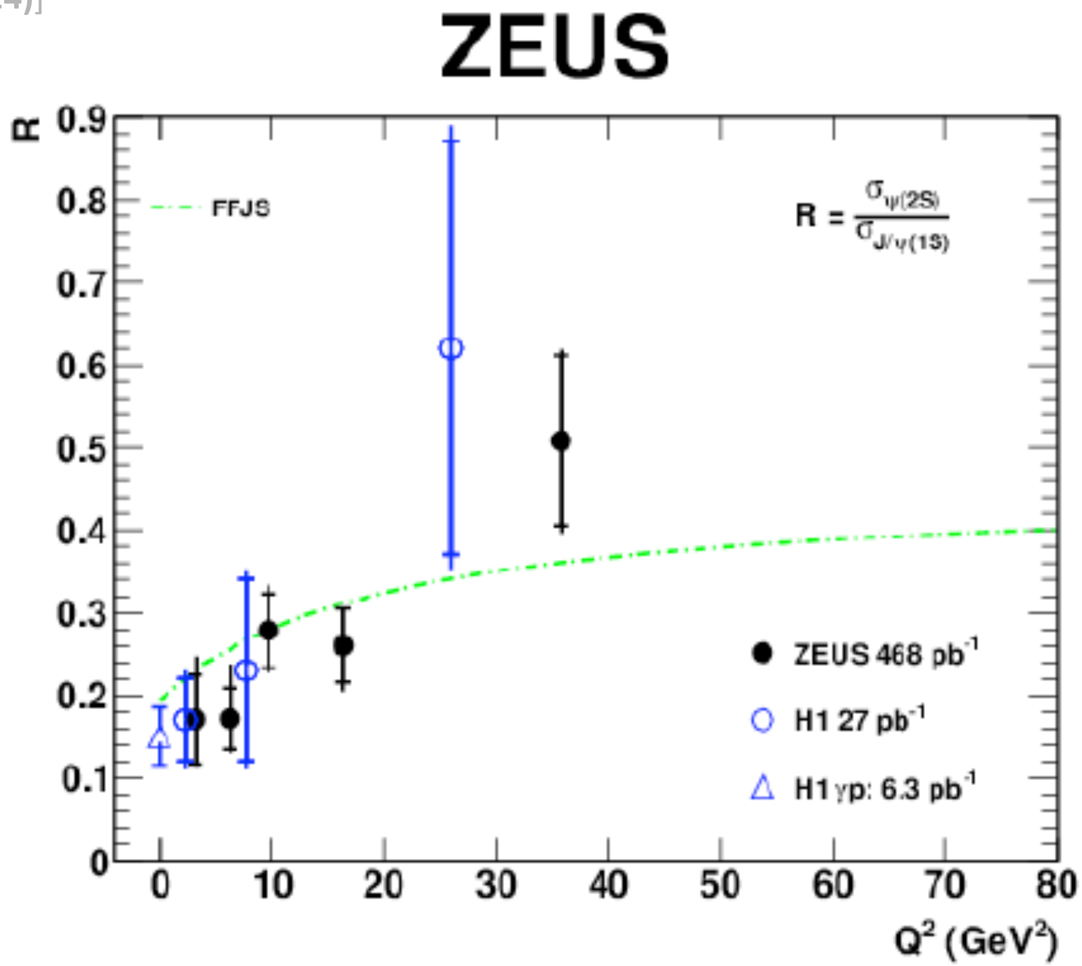
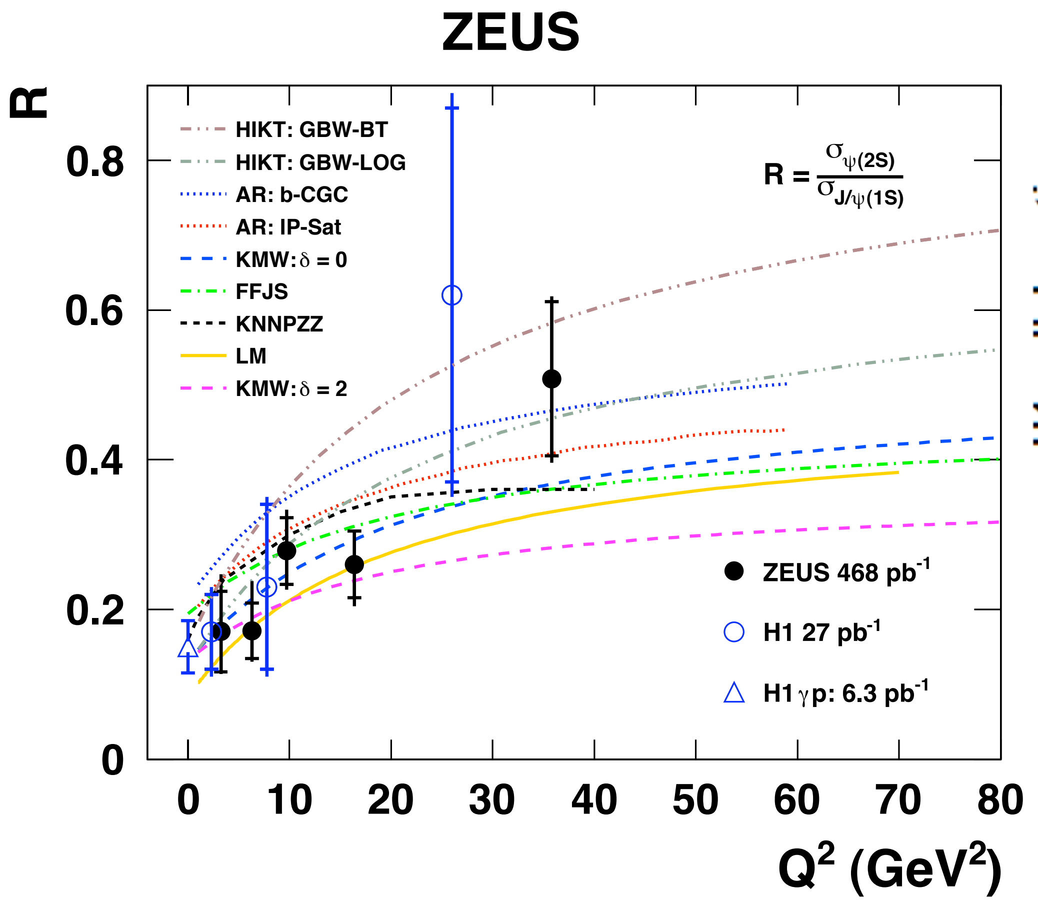
FFJS calculation

[S. Fazio et al., Phys. Rev. D 90, 016007 (2014)]

- Two-component Pomeron model



Comparison with models and with H1



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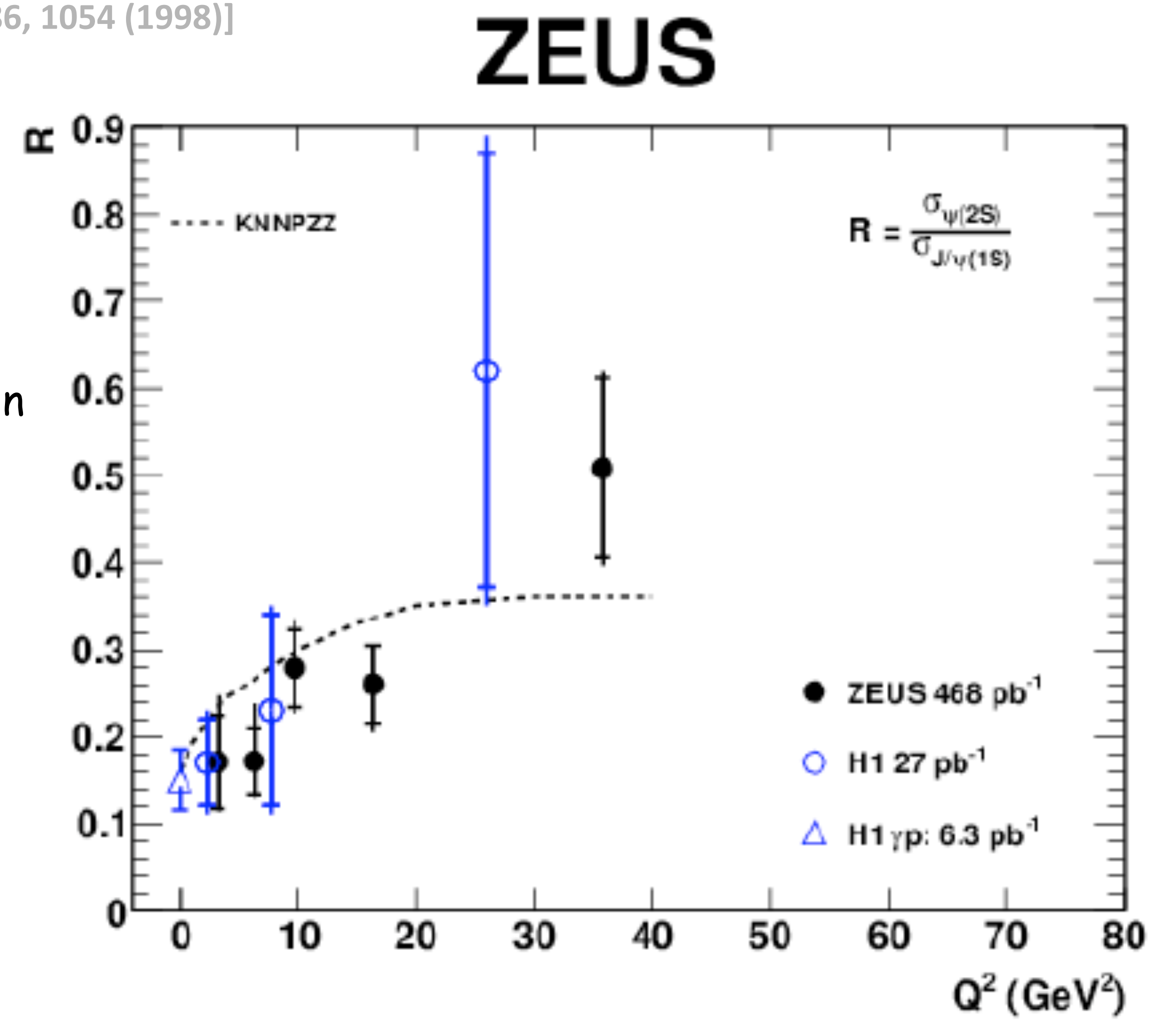
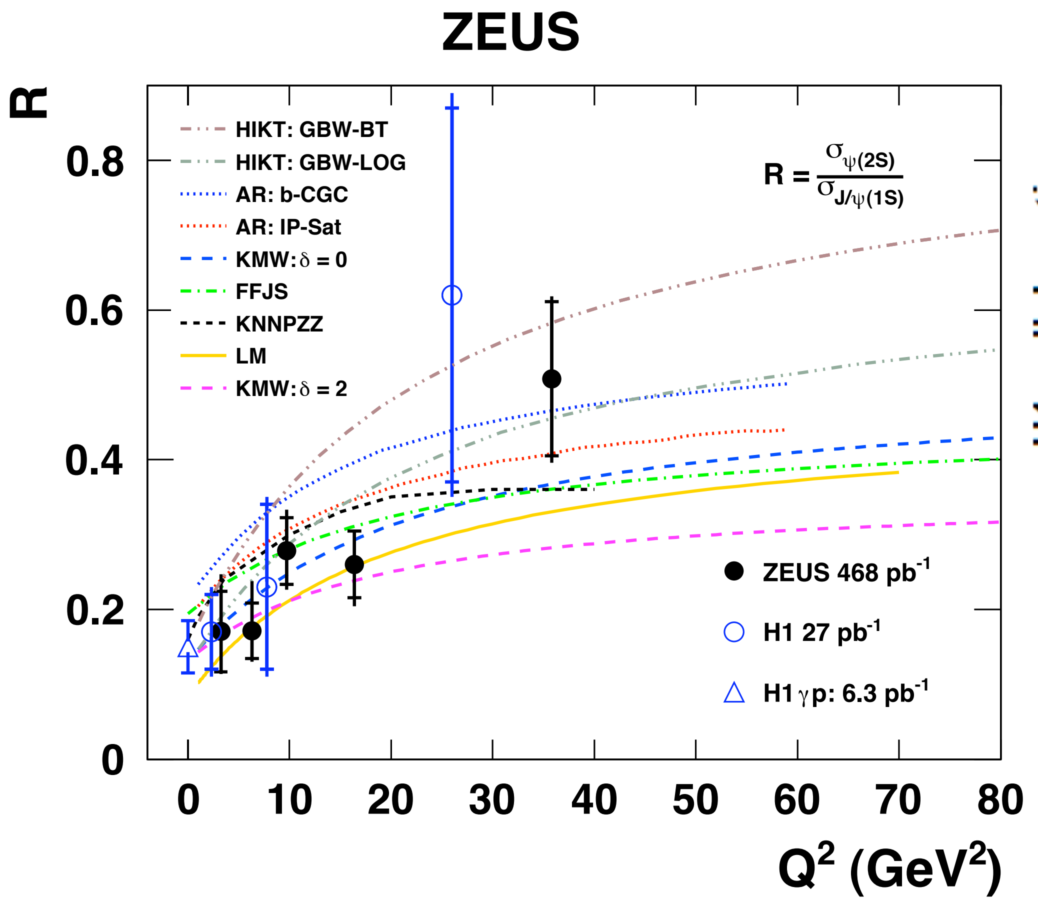
KNNPZZ calculation

[B. Kopeliovich et al., Phys. Rev D 44, 3466 (1991),
B. Kopeliovich et Al., Phys. Lett. B 324, 469 (1994)
J. Nemchik et al., Phys. Lett. B 341, 228 (1994)
J. Nemchik et al., J. Exp. Theor. Phys. 86, 1054 (1998)]

- Generalized BFKL equation for ccbar dipole cross section



Comparison with models and with H1



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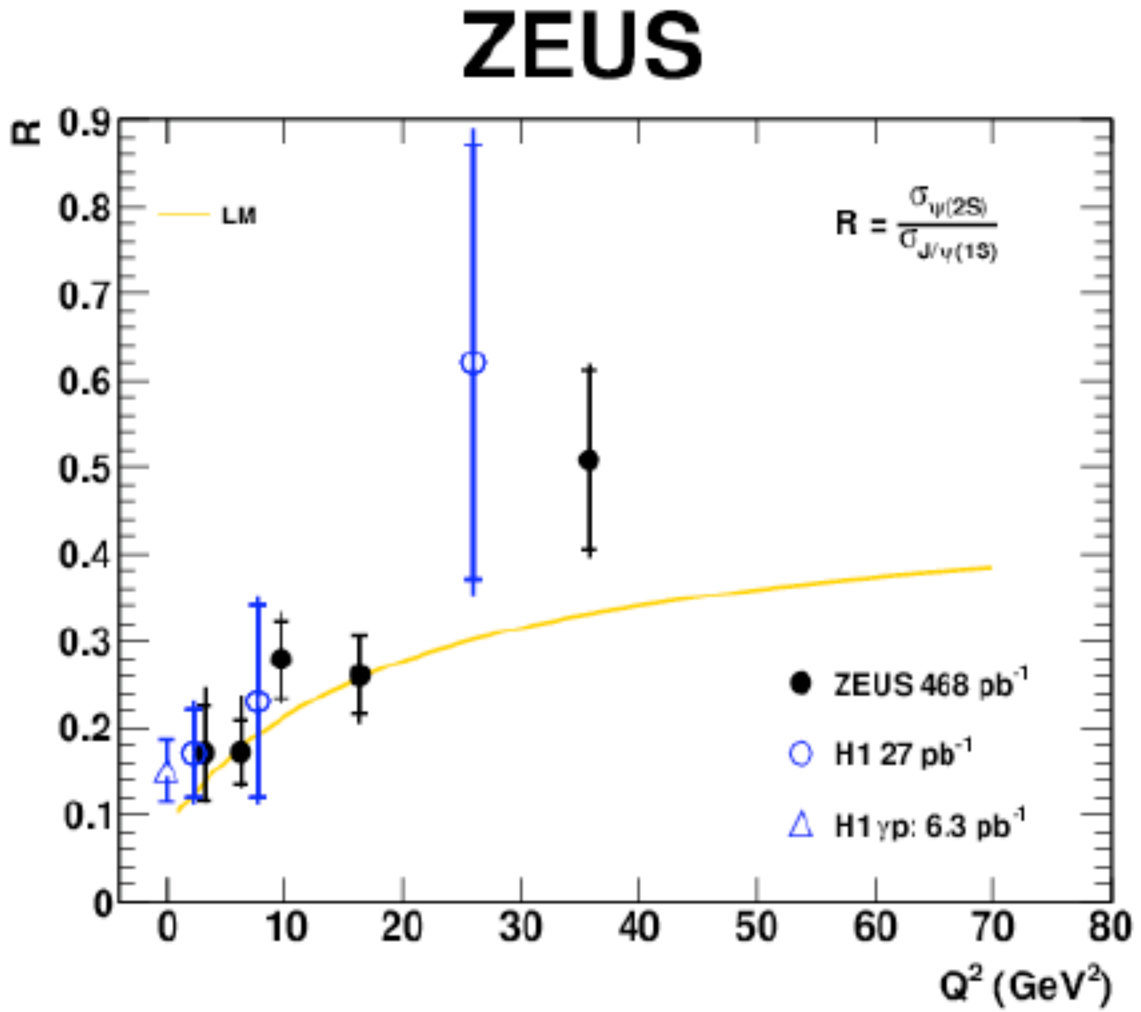
LM calculation

[T. Lappi and H. Mäntysaari, Phys. Rev. C 83, 065202 (2011),
T. Lappi and H. Mäntysaari, PoS (DIS2014), 069 (2014)]

- BFKL equation + IP-Sat



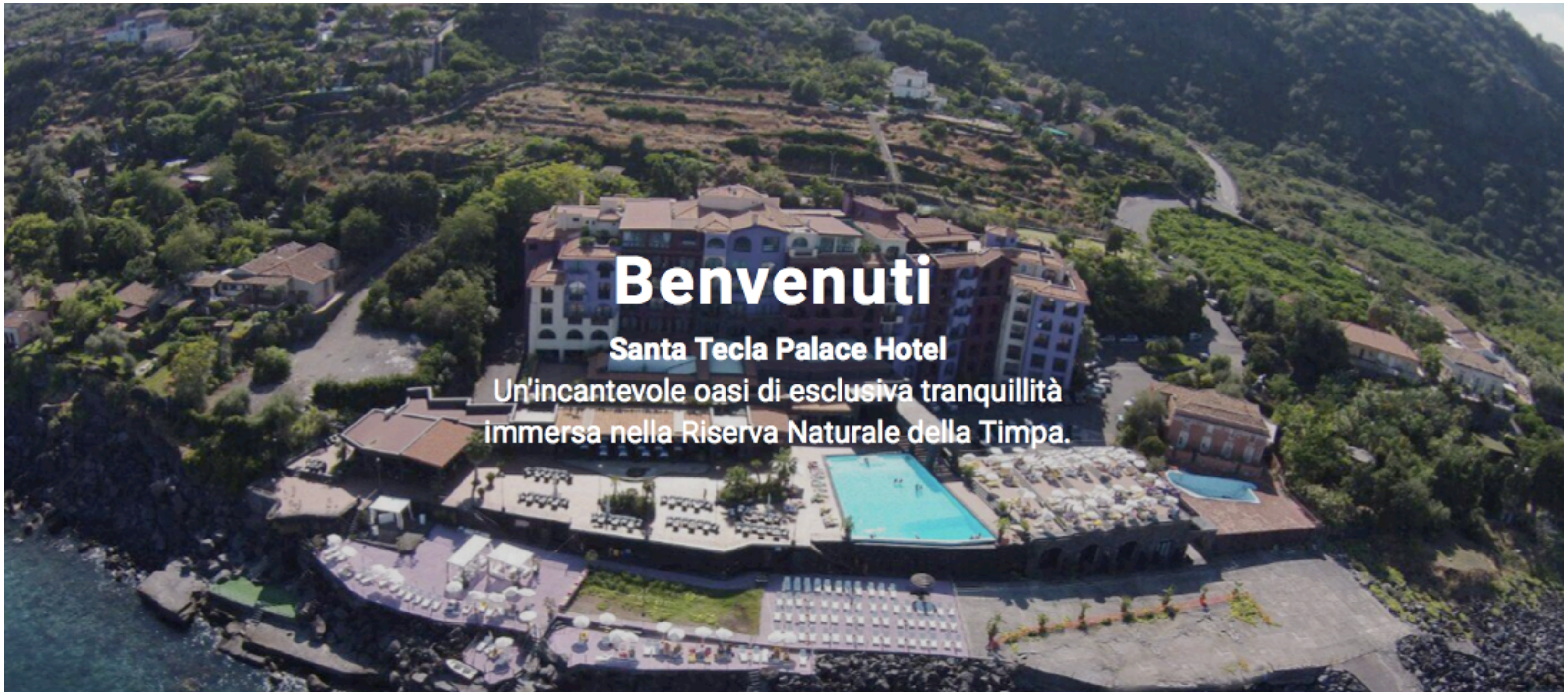
Summary

- $J/\psi(2S)/J/\psi$ measured by ZEUS with full HERA statistics
- $J/\psi(2S)/J/\psi$ rises with Q^2 and is constant in W and |t|
- Discrimination of different models possible

DESY 16-008, submitted to Nucl. Phys. B

Diffraction 2016 in Sicily (Sept 2-7)!

https://agenda.infn.it/conferenceDisplay.py?confId=1093



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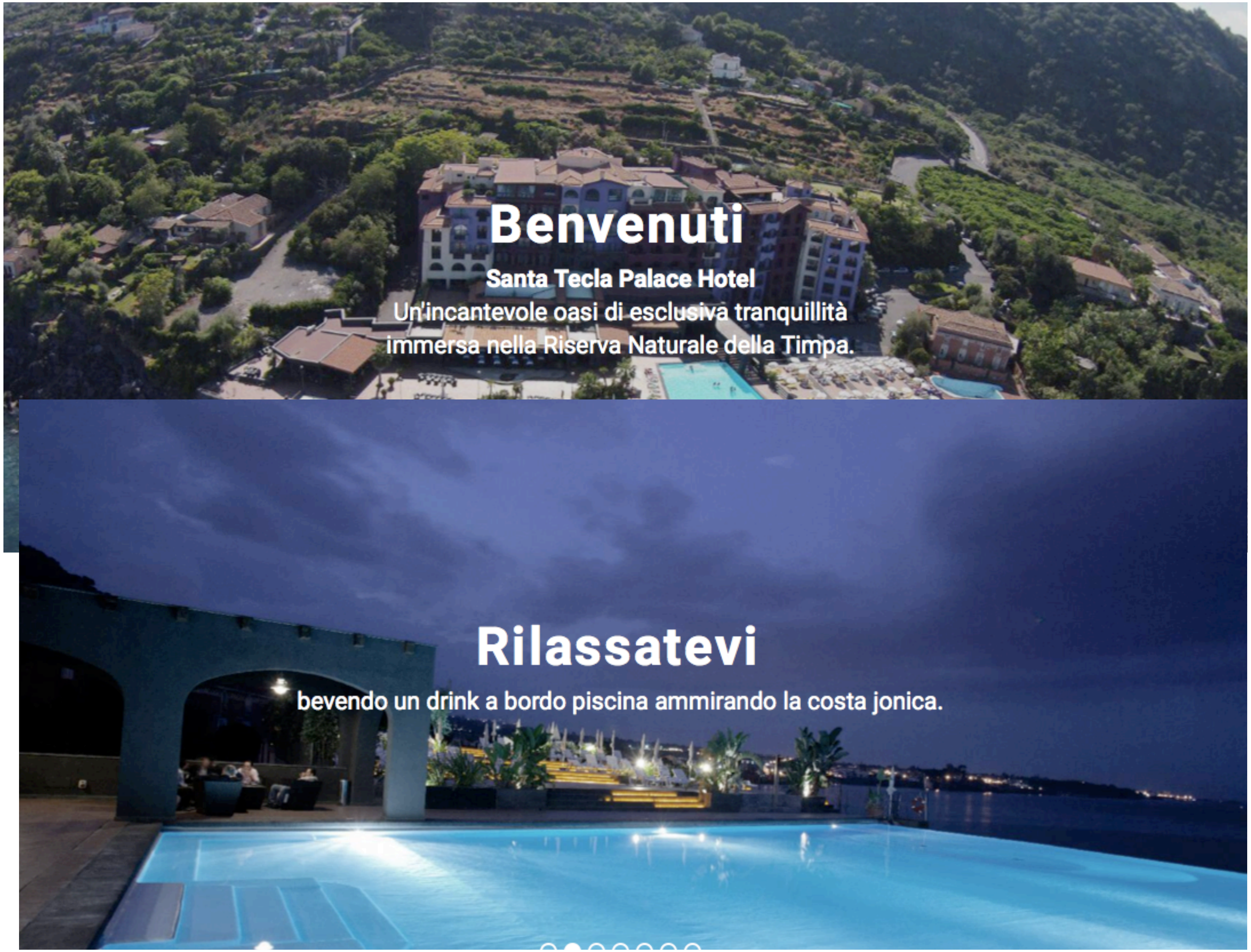
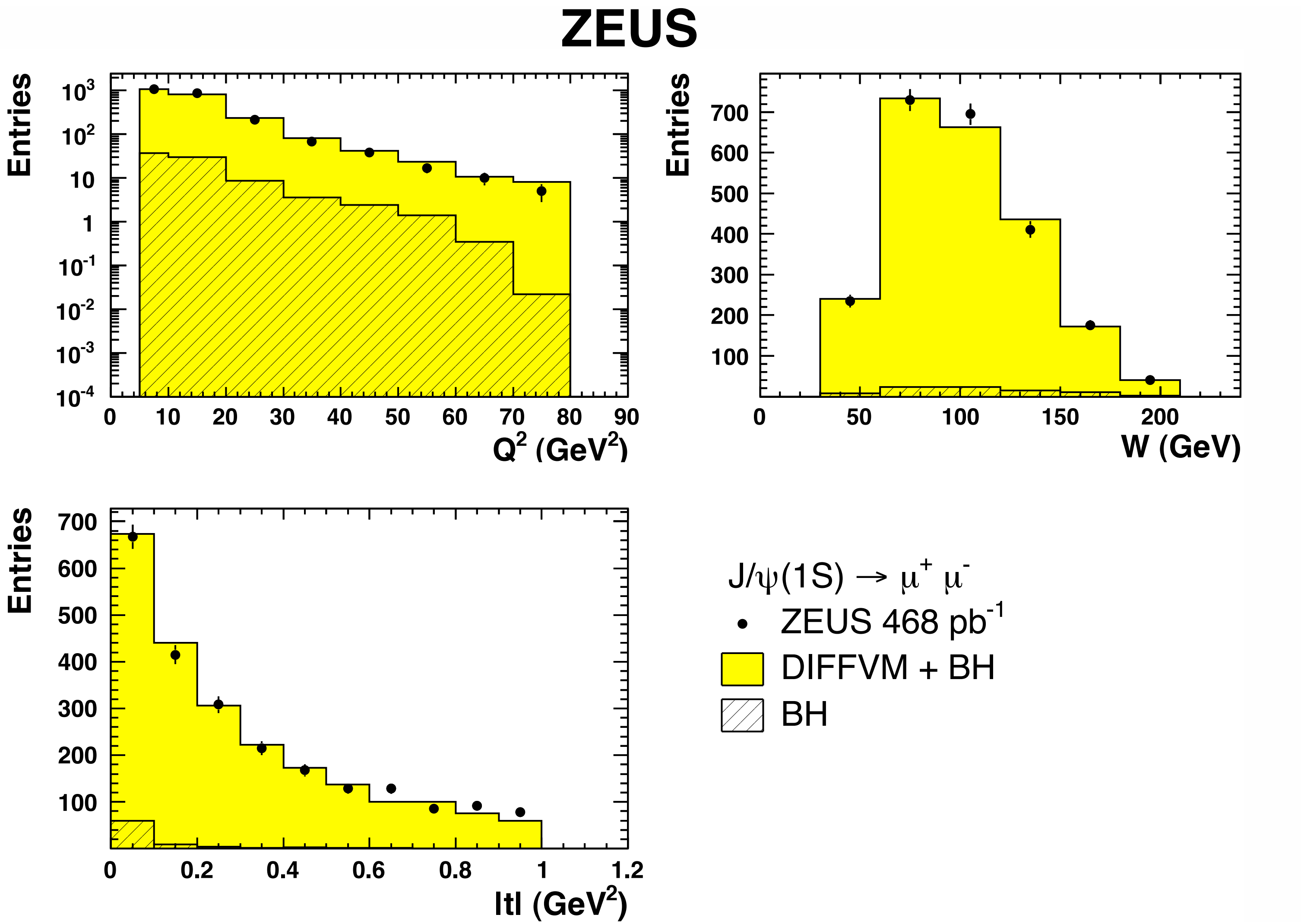


Backup

Data/MC

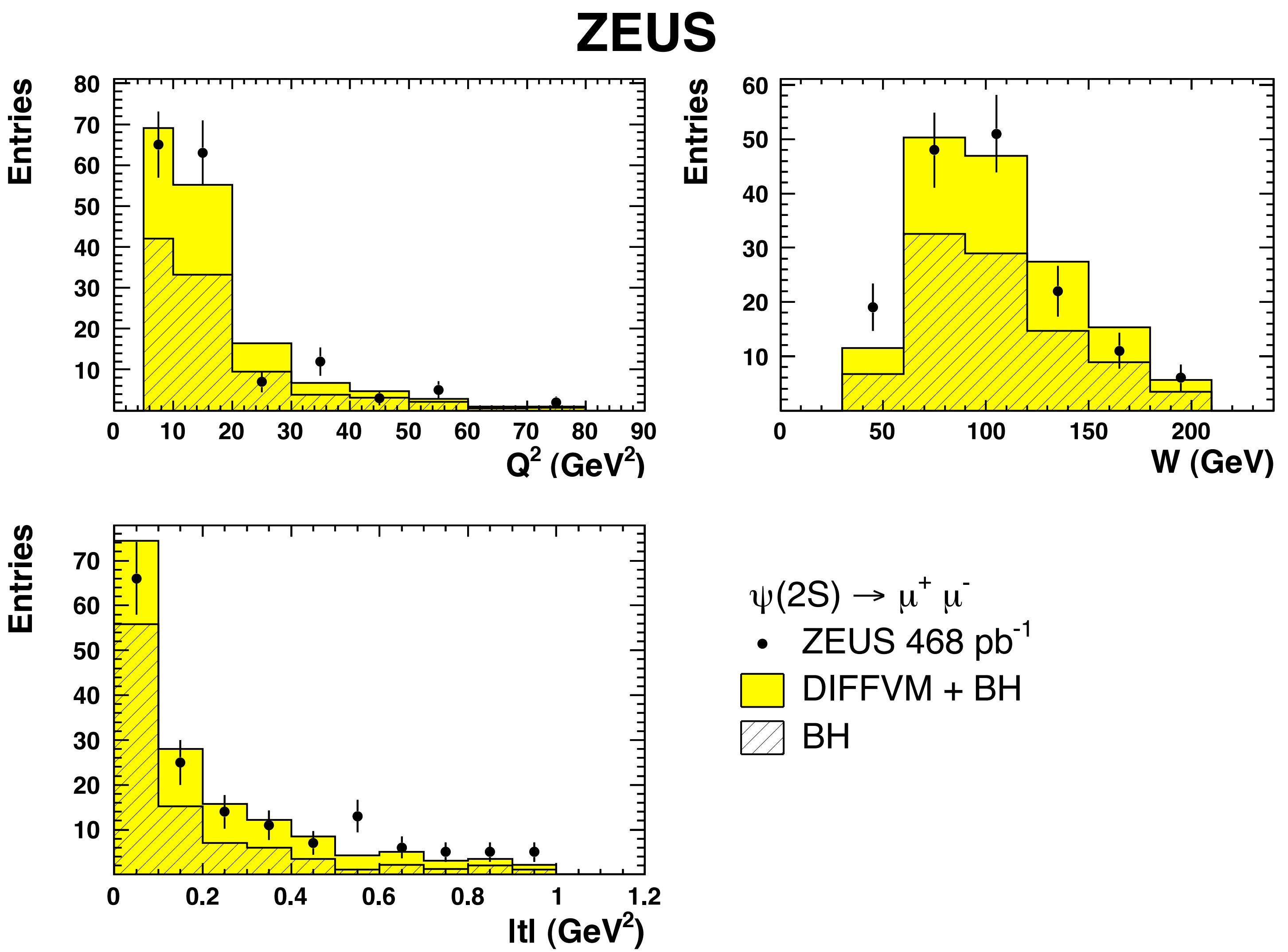
$J/\psi \rightarrow \mu^+ \mu^-$



Monte Carlo reweigthed in t, Q^2 and angular distributions

Data/MC

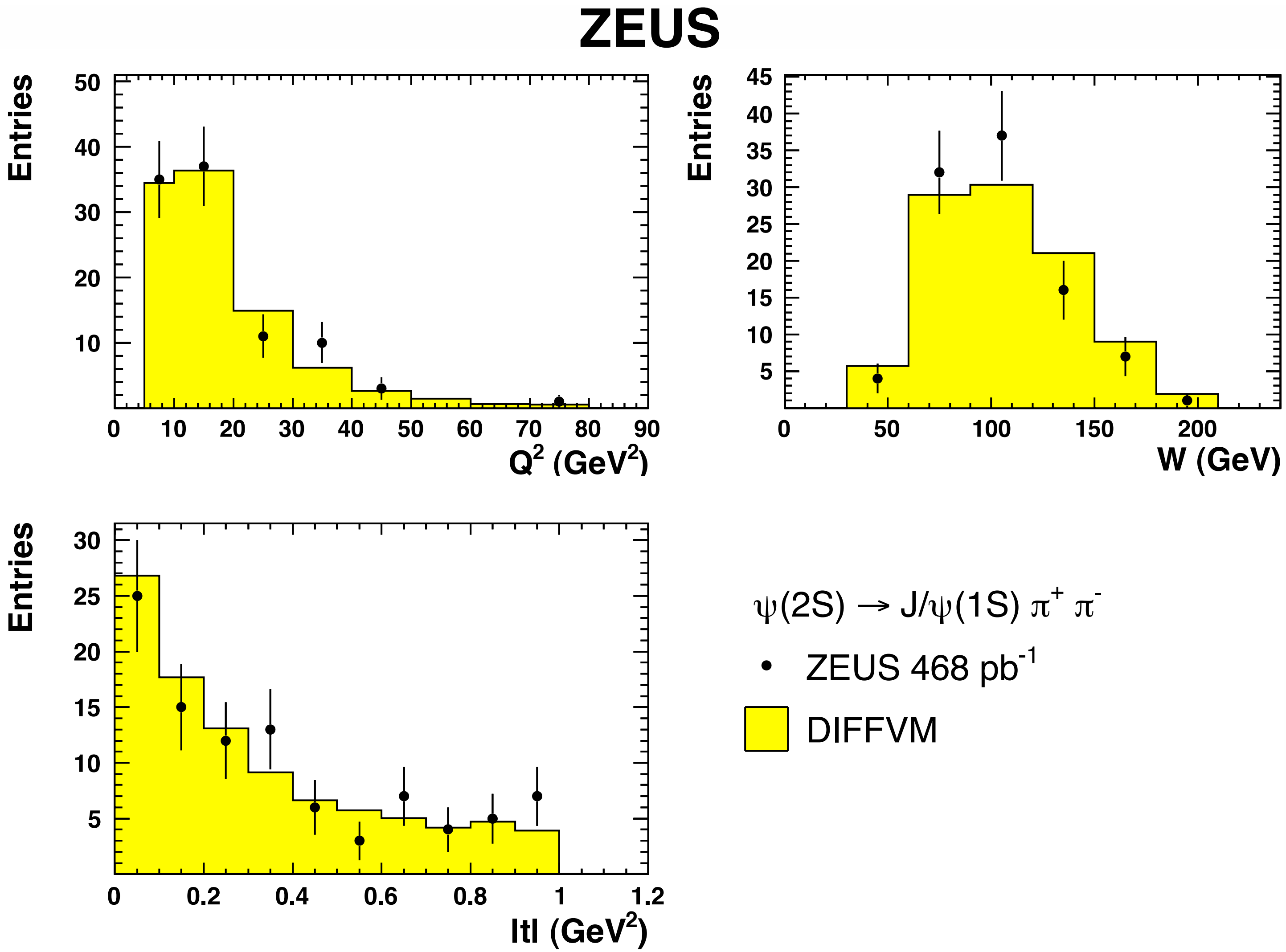
$\Psi(2S) \rightarrow \mu^+ \mu^-$



Monte Carlo reweigthed in t, Q^2 and angular distributions

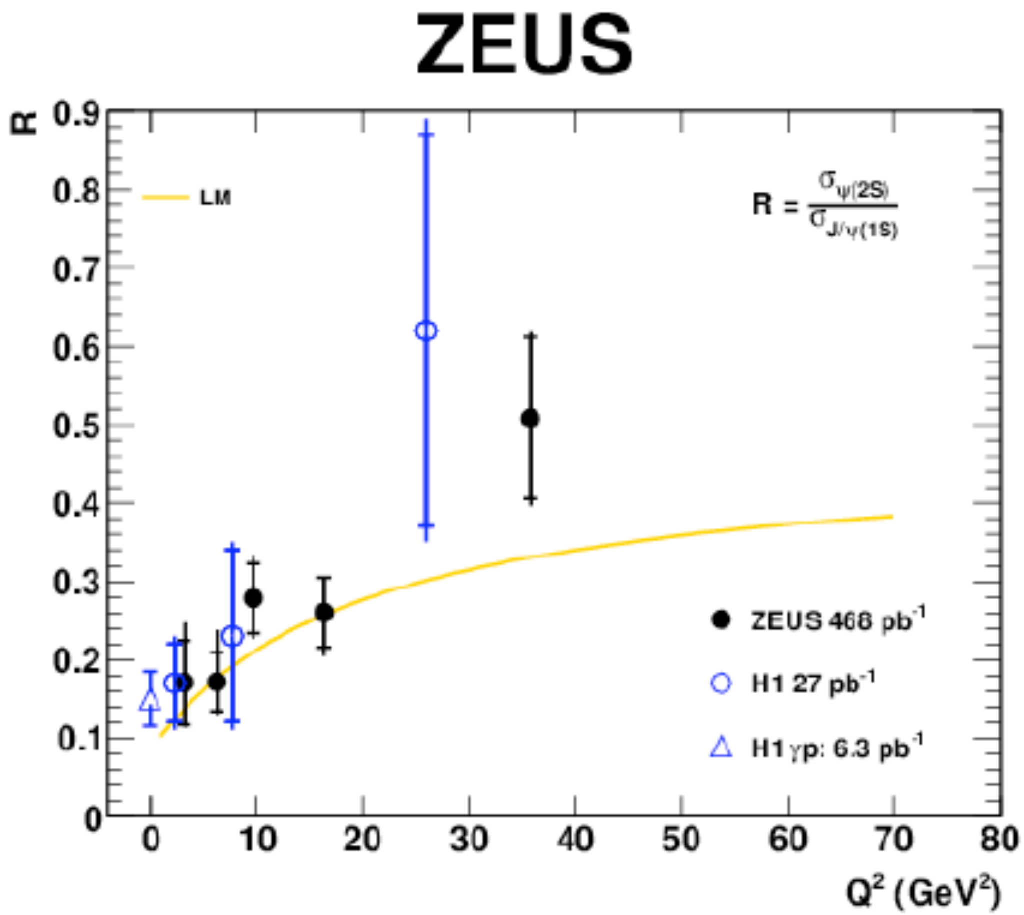
Data/MC

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

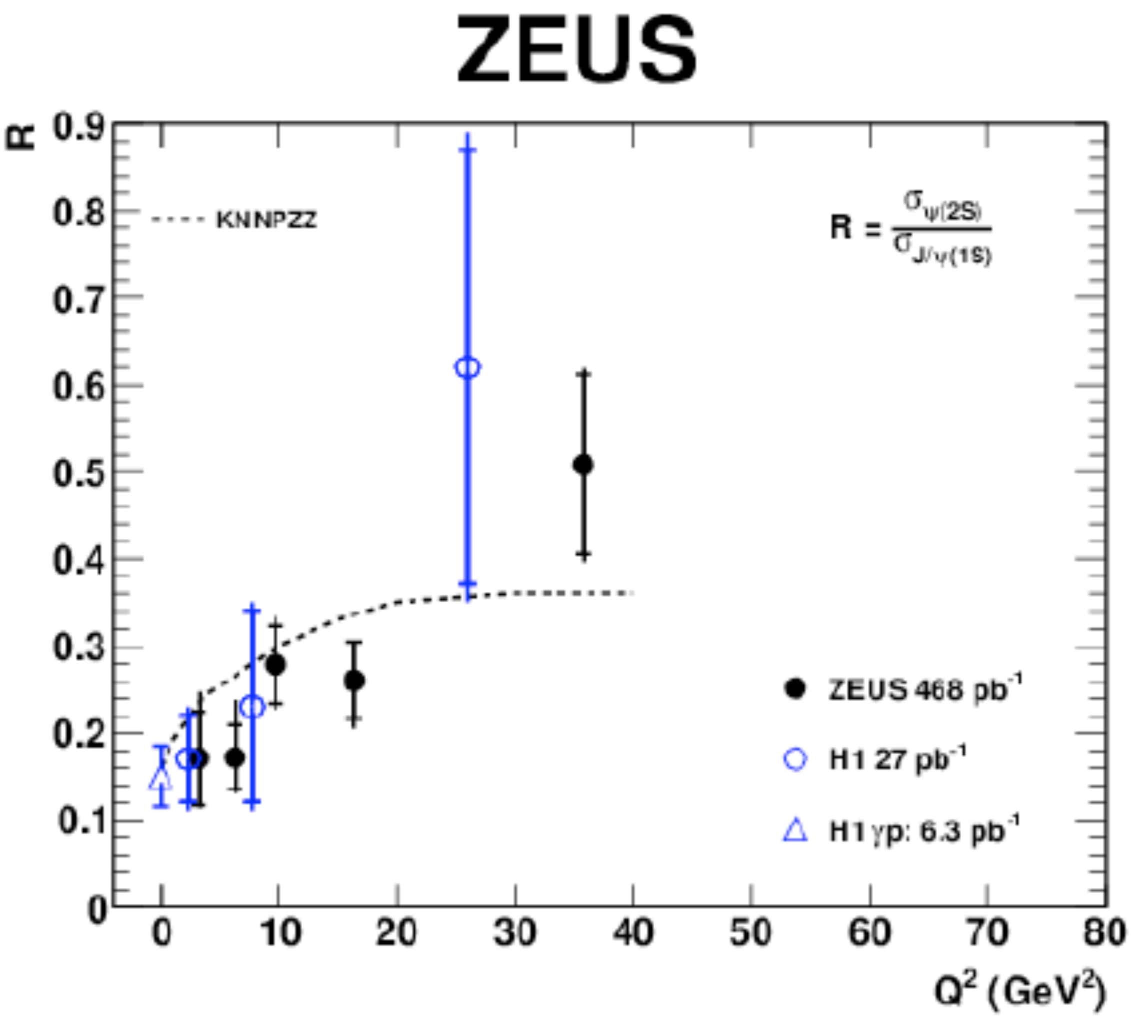


Monte Carlo reweigthed in t, Q^2 and angular distributions

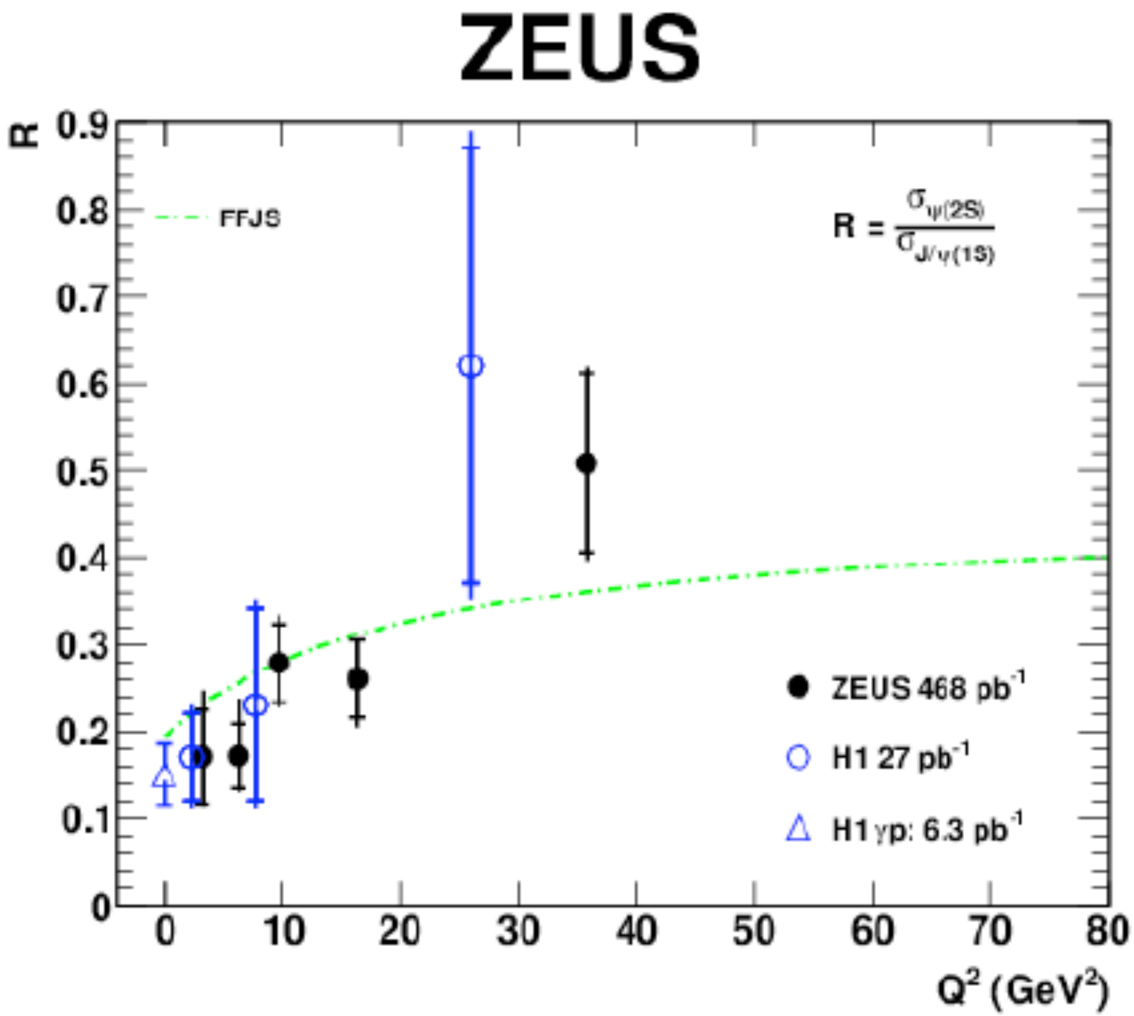
LM prediction



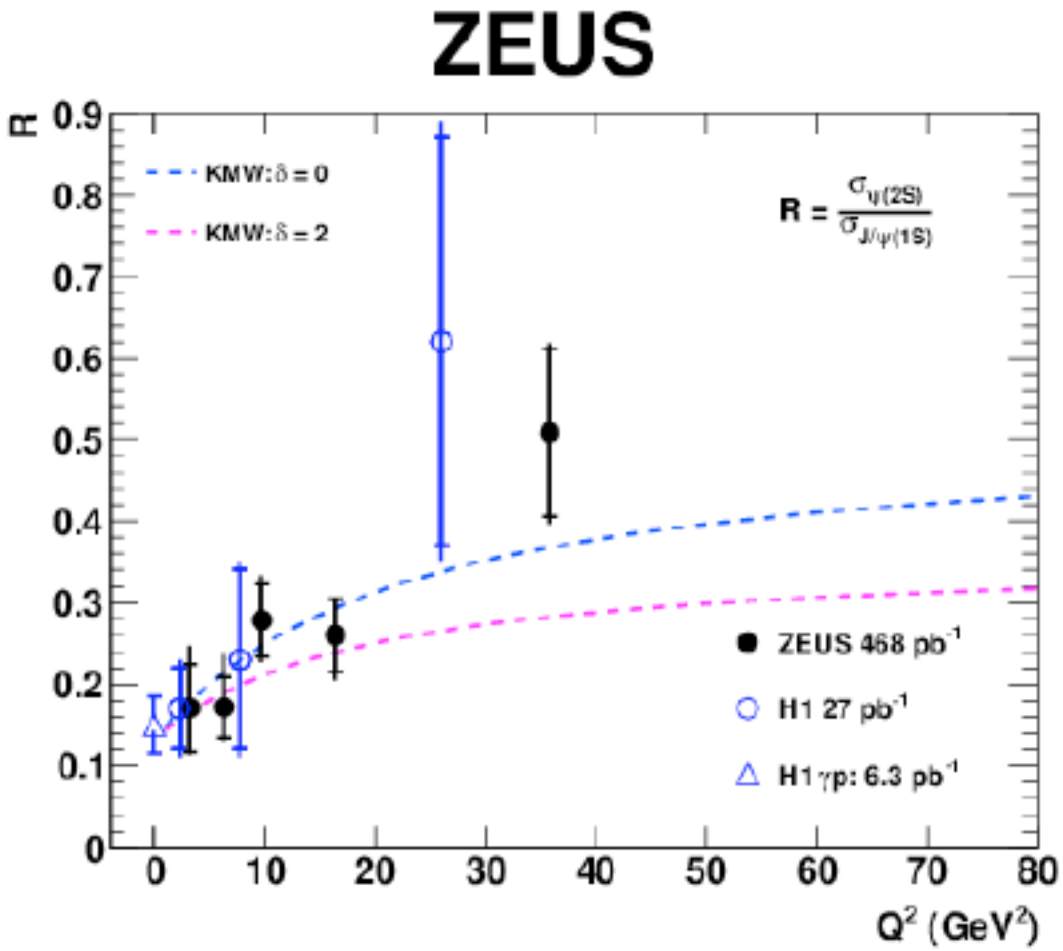
KNNPZZ prediction



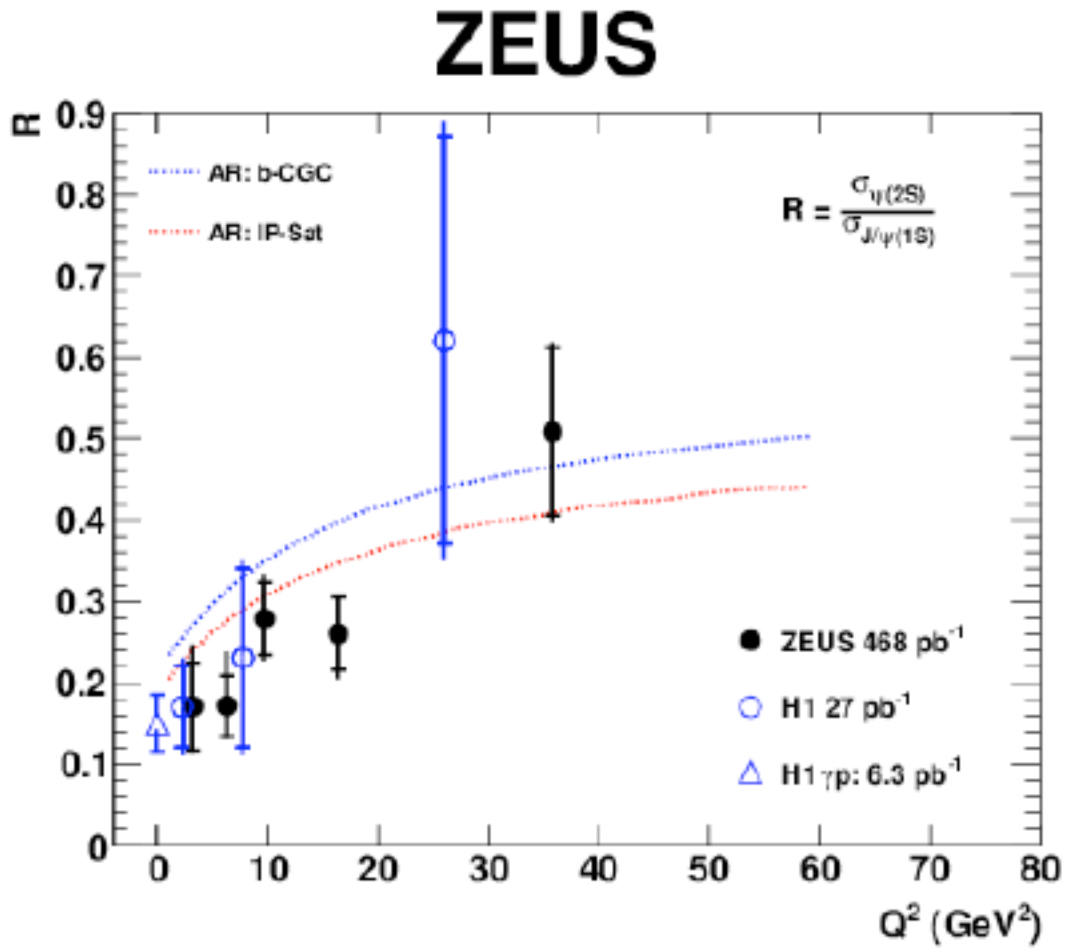
FFJS prediction



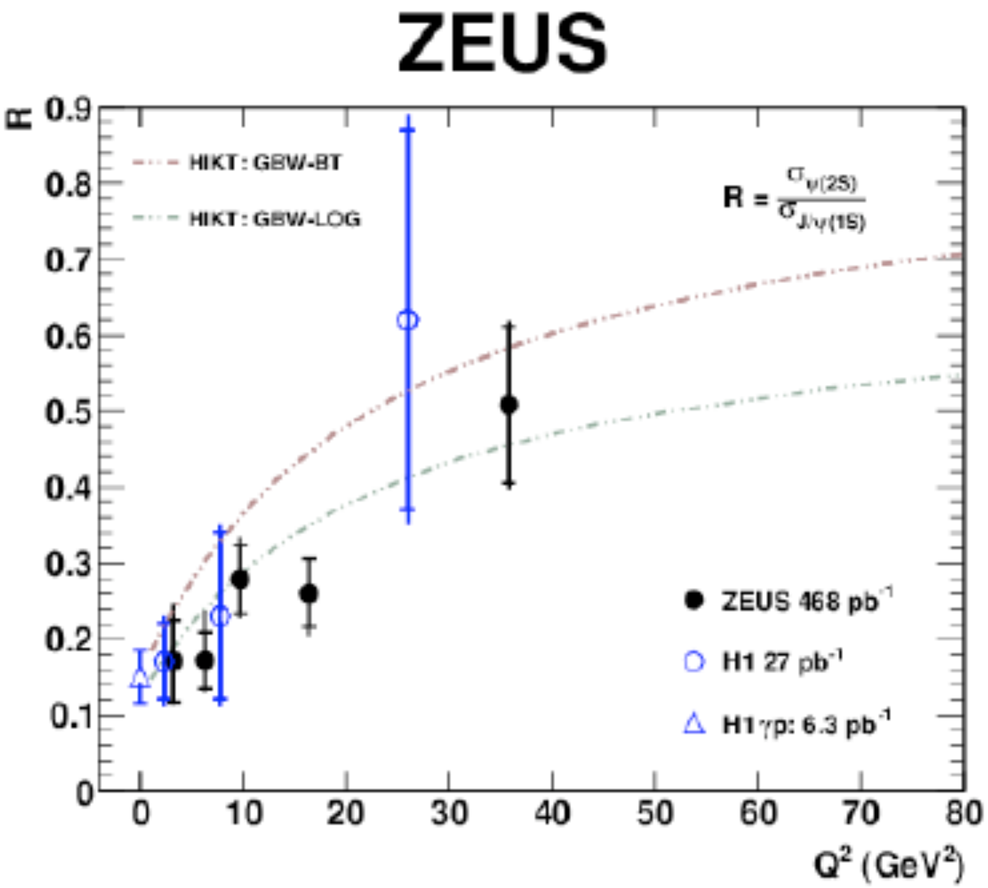
KMW prediction



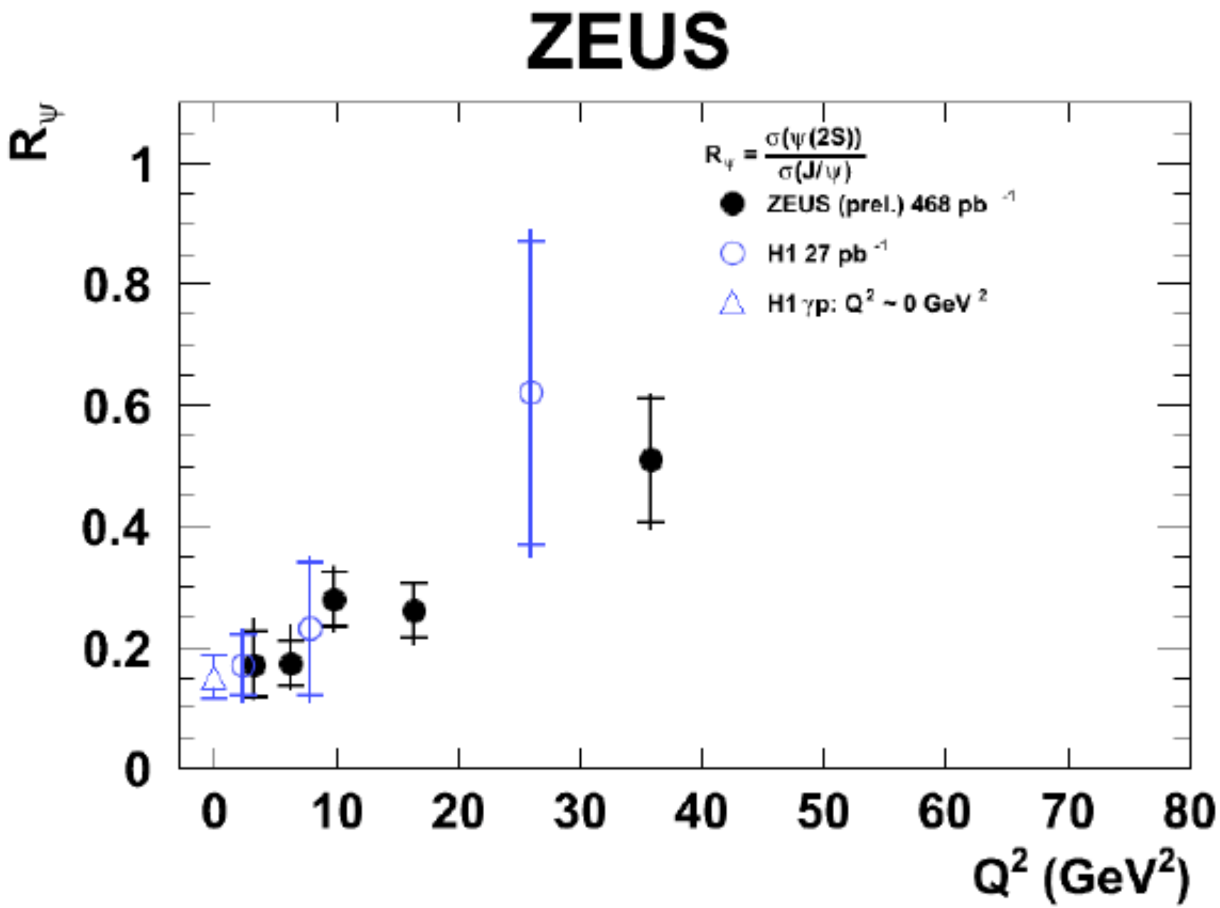
AR prediction



HIKT prediction



Comparison with H1 earlier measurement



H1 collaboration:

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

→ Much larger luminosity in ZEUS measurement (HERA I + HERA II)