MESON 2006

9th International Workshop on Meson Production, Properties and Interaction
KRAKÓW, POLAND
9 - 13 June 2006

Charmonium Production at HERA

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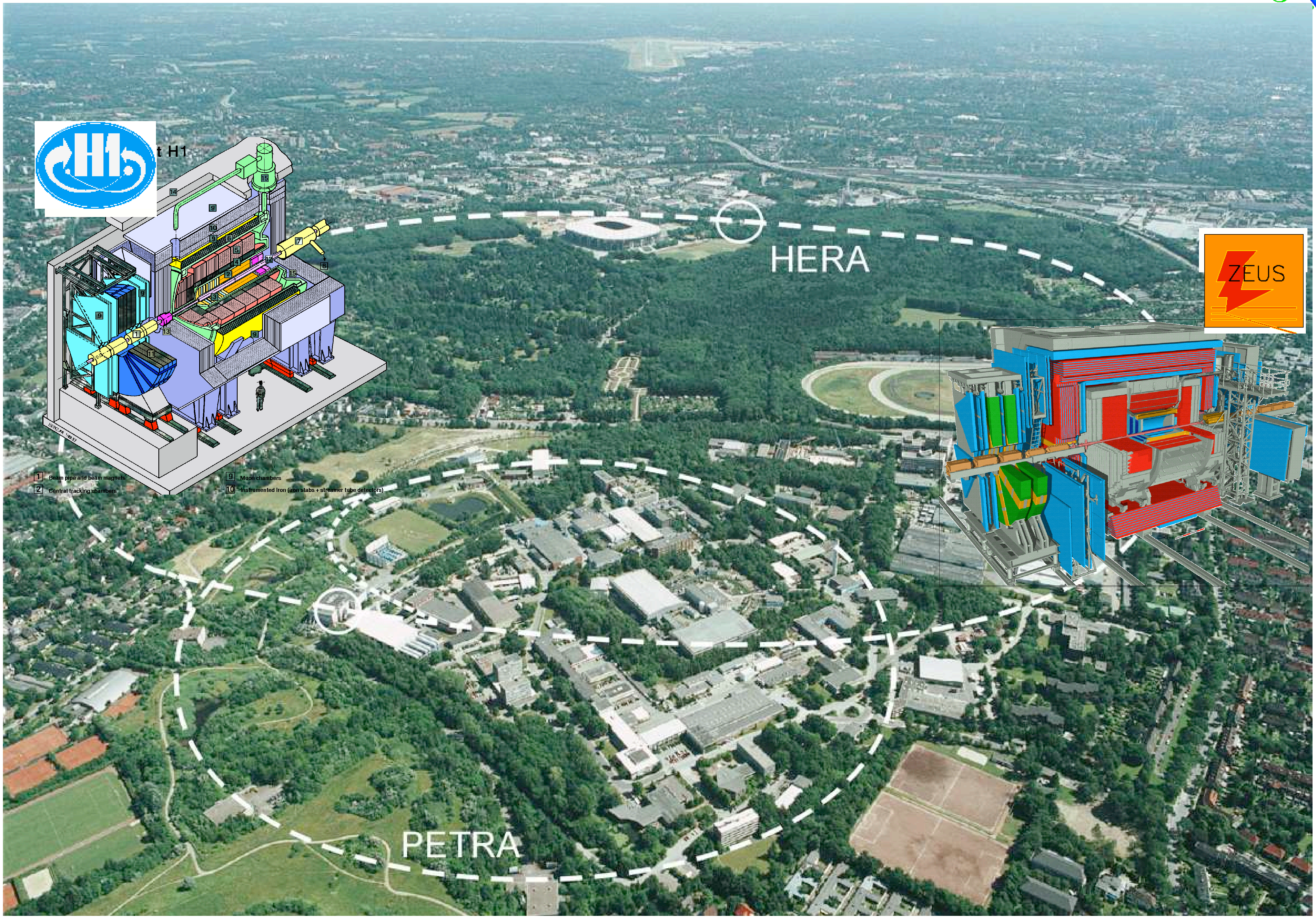
DESY

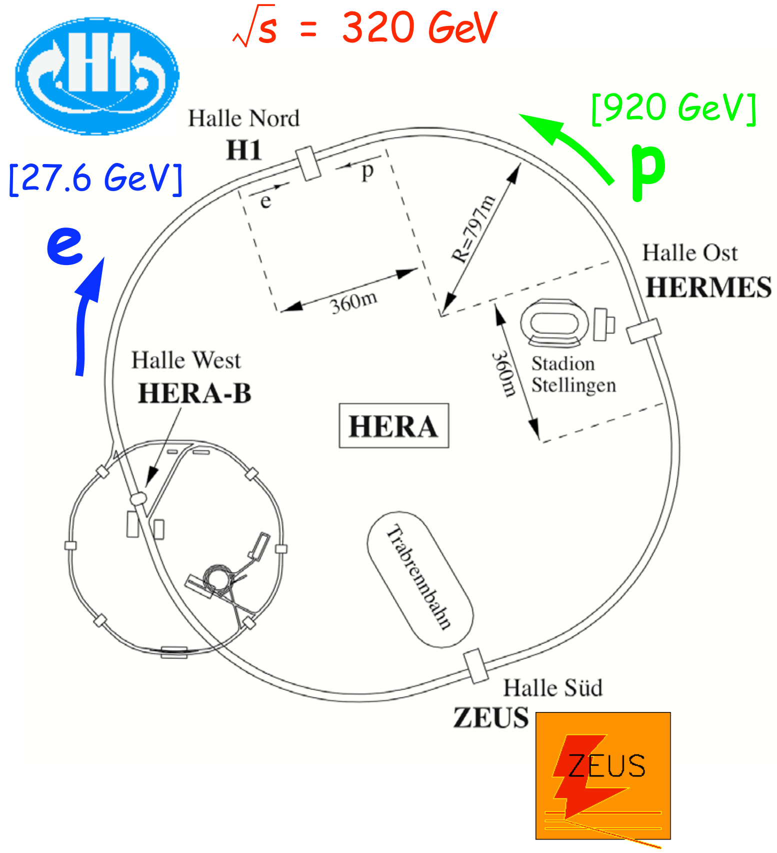
ZEUS

H1

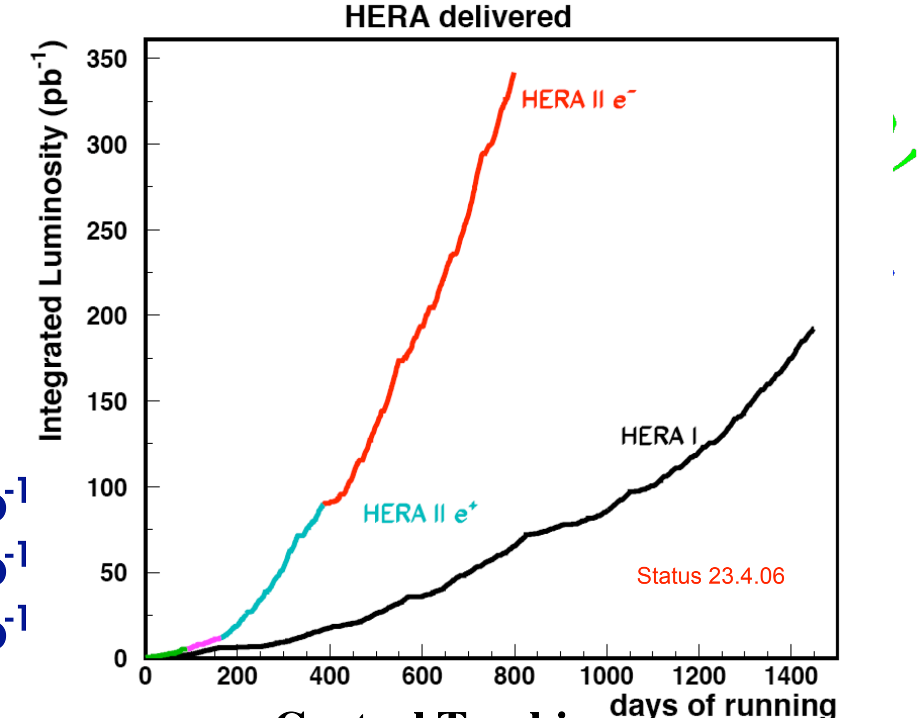
Electron-Proton Collider HERA

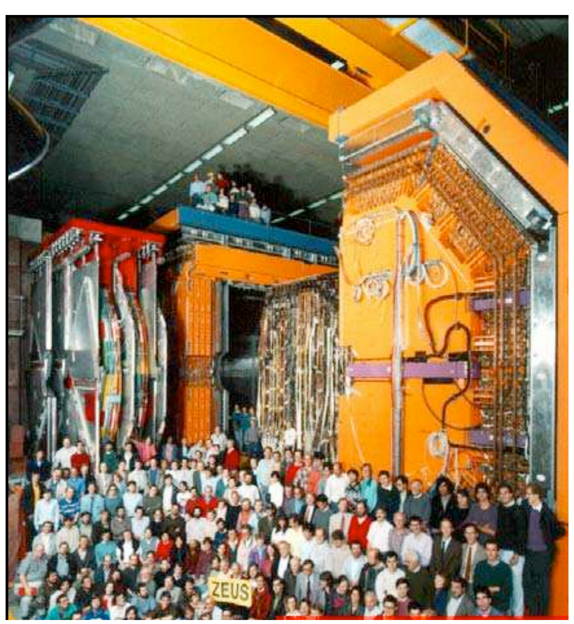


Experiments H1 and ZEUS

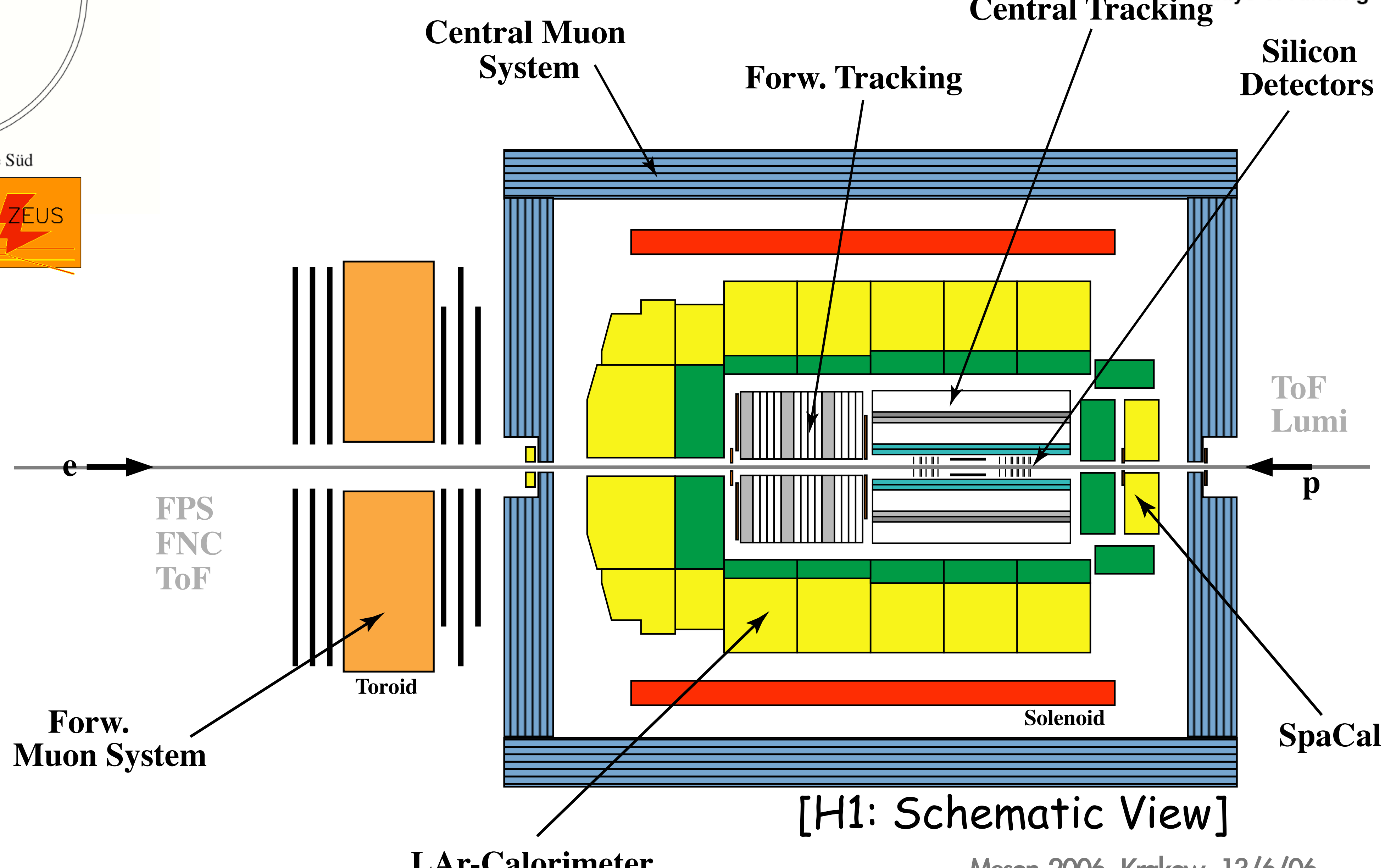


Integrated Luminosity:
HERA-I: 92-00: recorded 120pb^{-1}
HERA-II: 03-05: recorded 180pb^{-1}
expected total by mid 2007: ~650pb^{-1}





[ZEUS Collaboration]

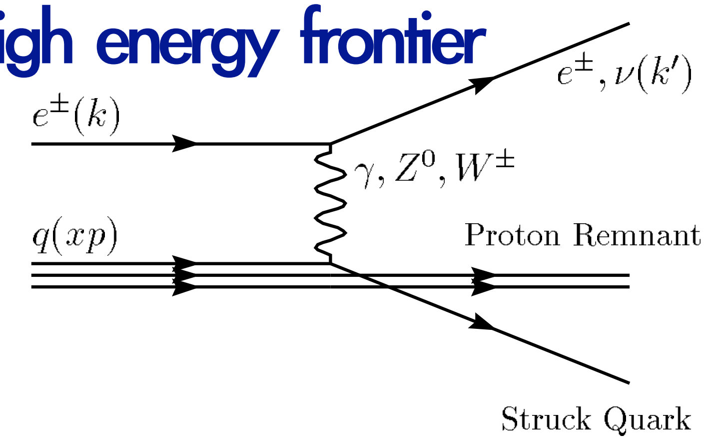


[H1: Schematic View]

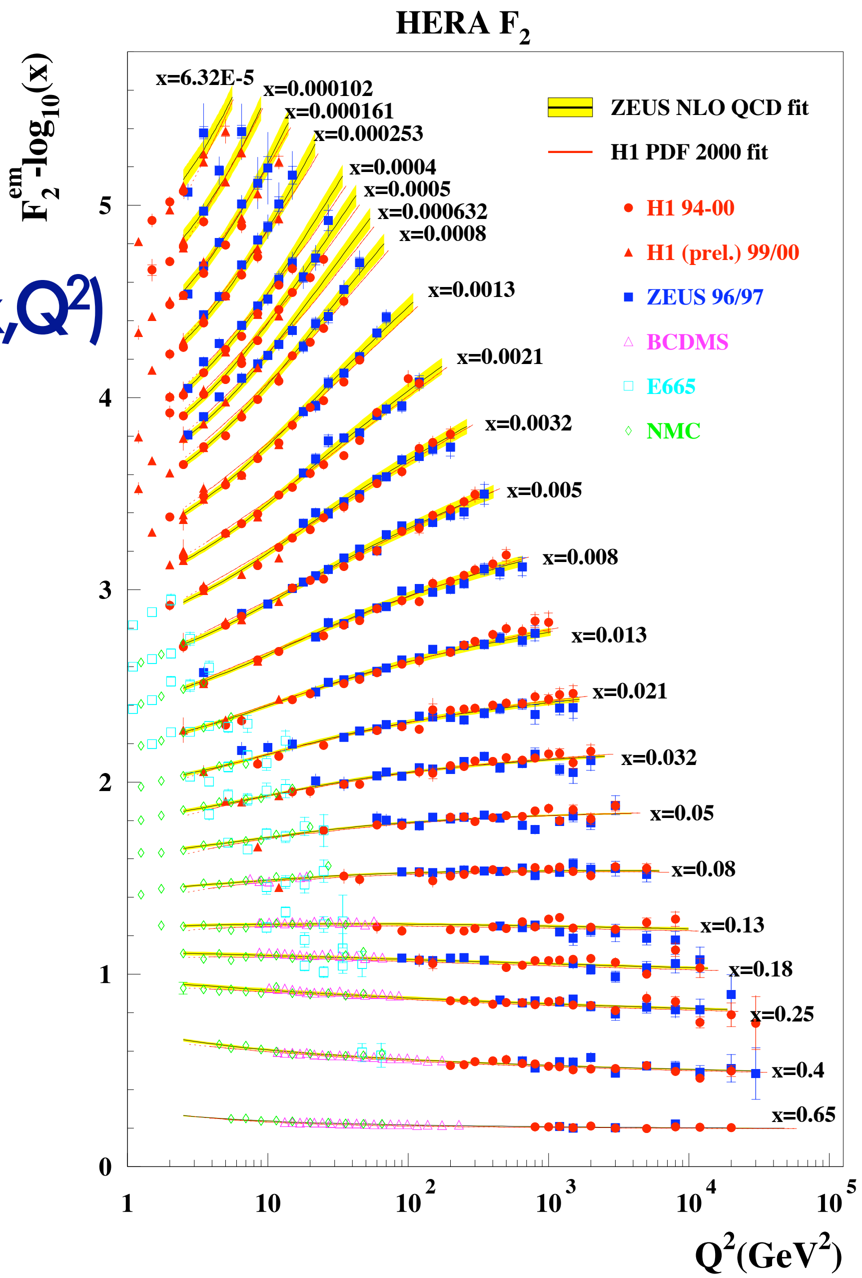
HERA Physics

$$\sqrt{s_{ep}} \sim 320 \text{ GeV}$$

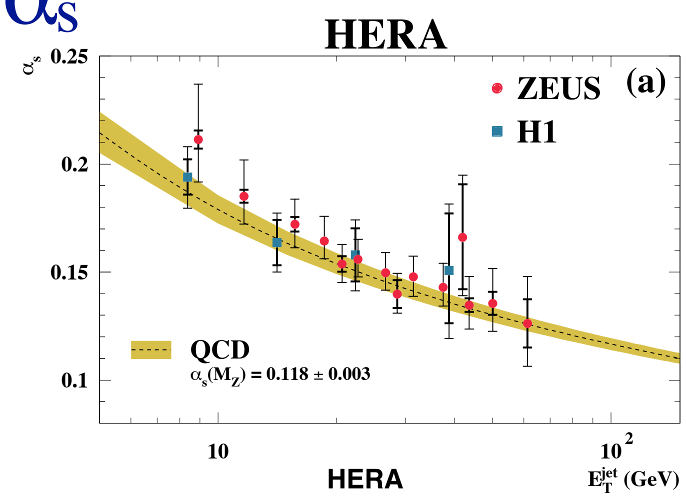
- Multipurpose experiments at the high energy frontier
  - QCD measurements
  - Electroweak physics
  - Searches for new physics

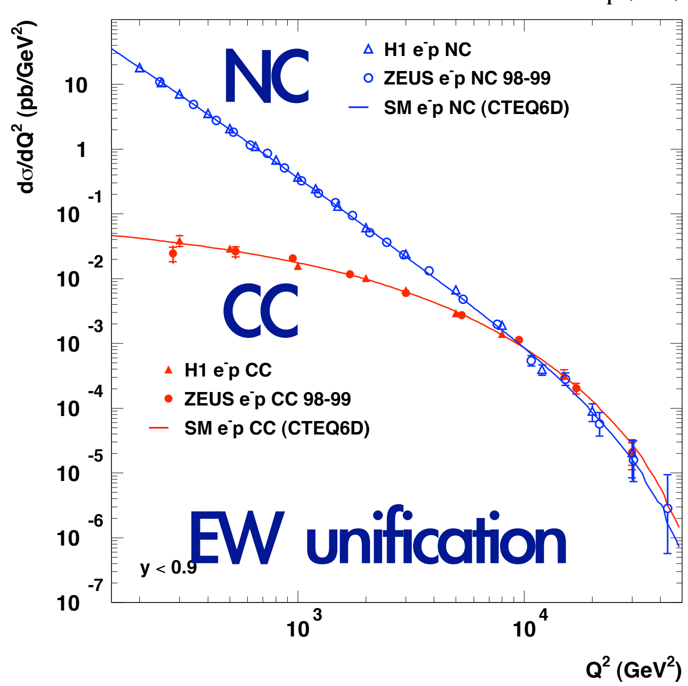


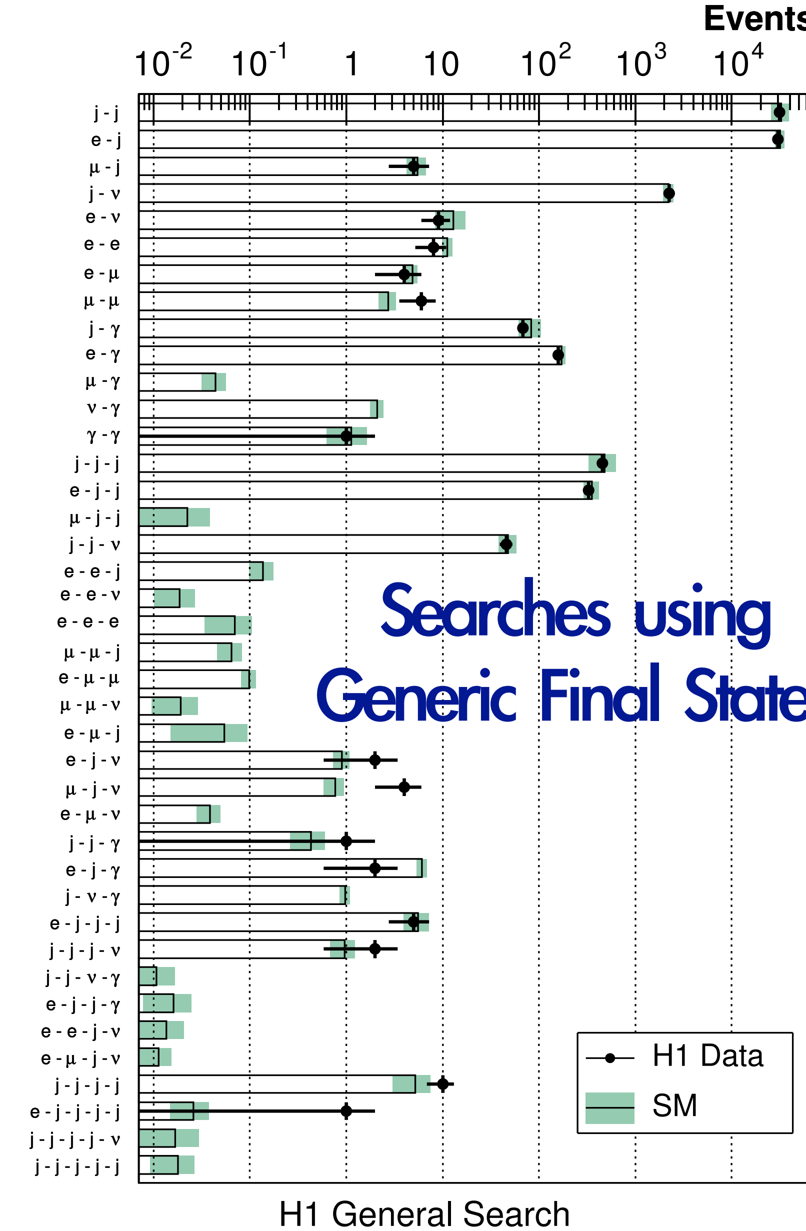
F2(x,Q²)

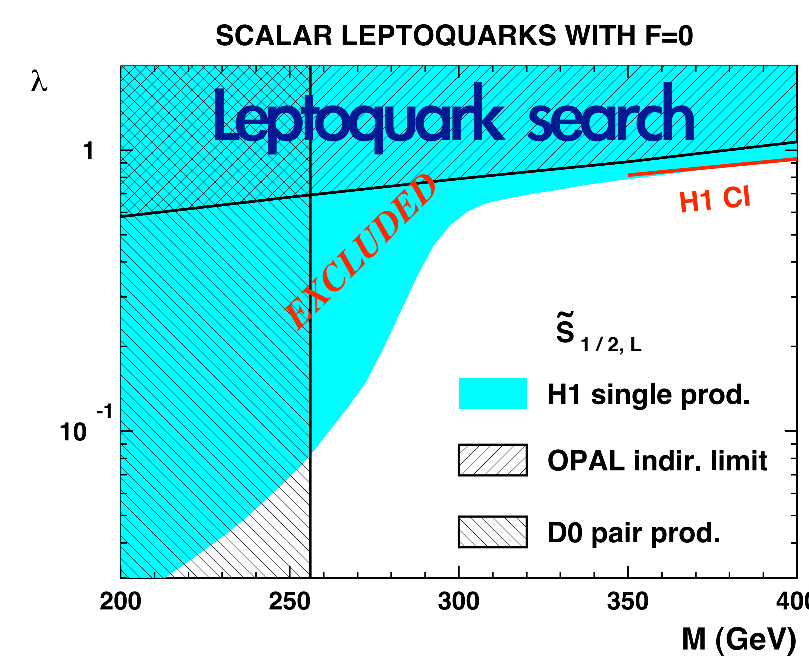


α_s

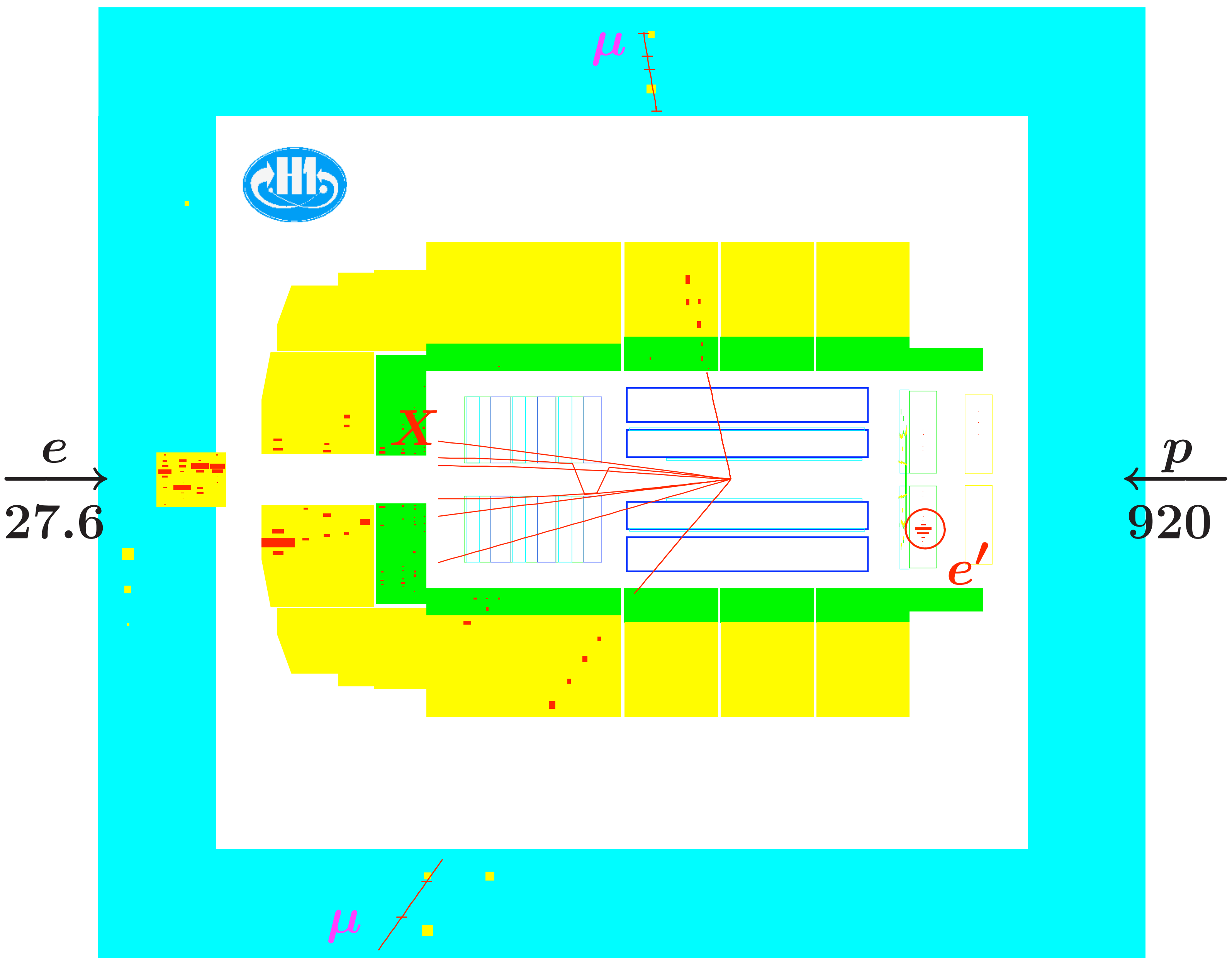




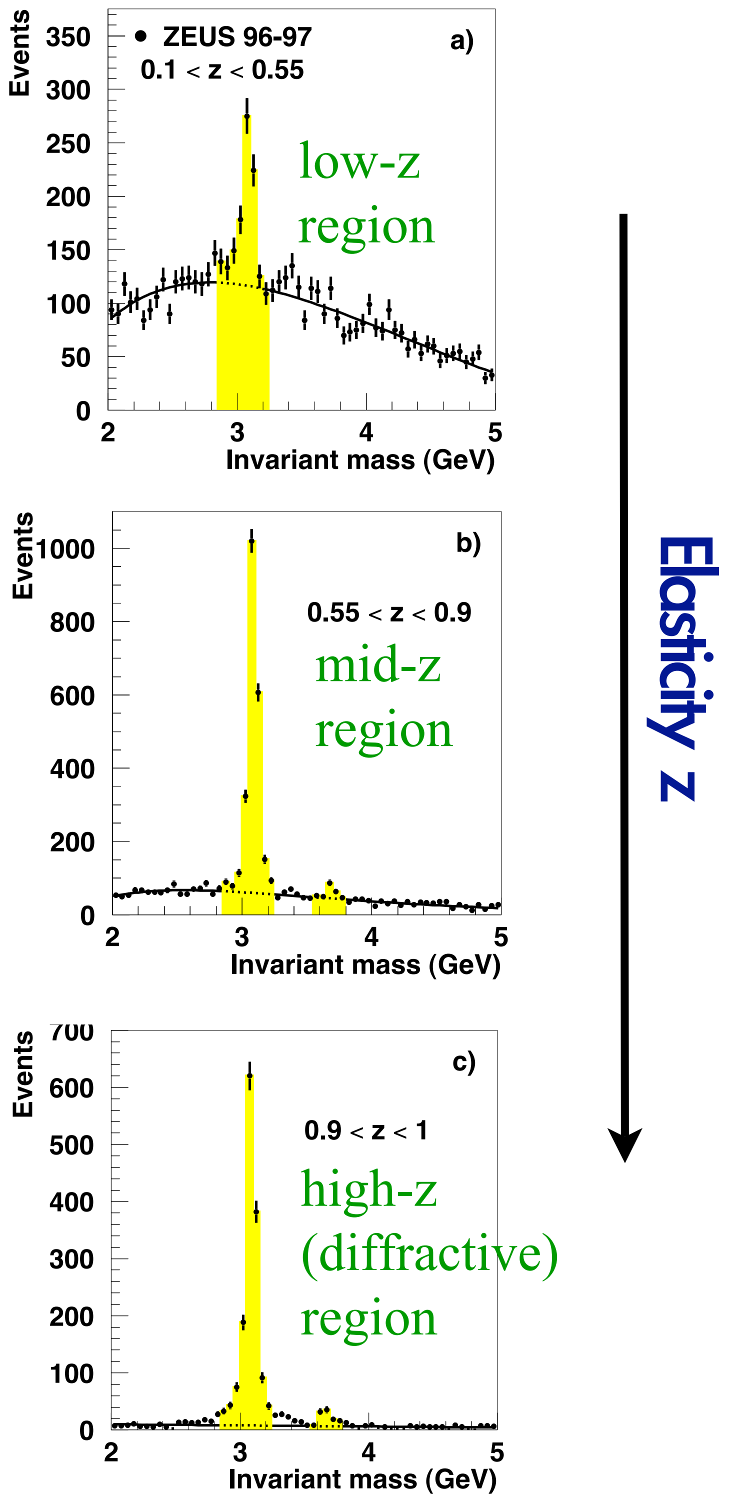




Charmonium at HERA

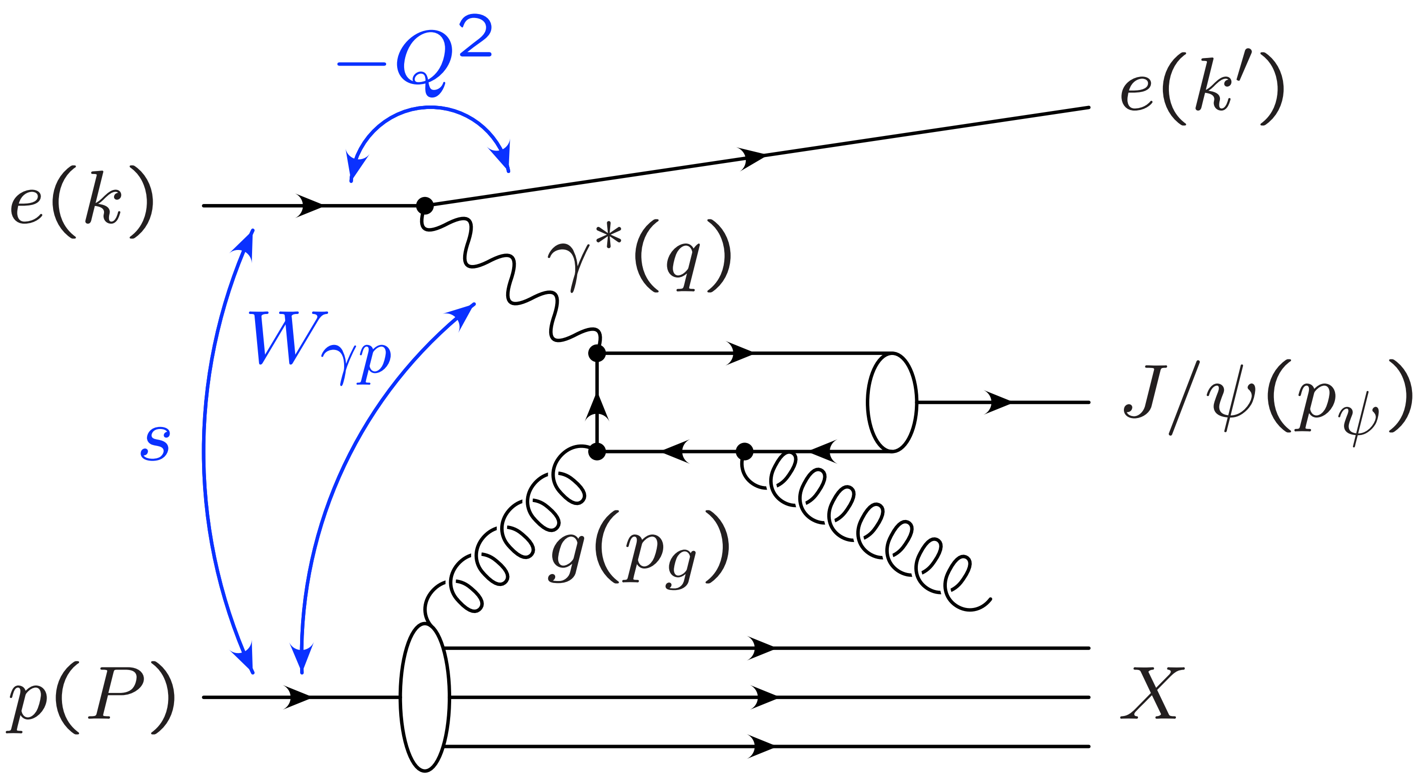


38 pb^{-1}



Have measured J/ψ and ψ(2S) in decays into e^+e^- and $\mu^+\mu^-$

Event Kinematics



- Photoproduction (γp): $Q^2 \sim 0$
  beam electron scattered under low angles,
  (not detected in main detector)

- Electroproduction (DIS): $Q^2 > 2\ \mathrm{GeV}$

kinematic variables

$$Q^2 = -q^2$$

$$s = (P+k)^2$$

$$W_{\gamma p} = \sqrt{(P+q)^2}$$

$$z = \frac{p_\psi \cdot P}{q \cdot P}$$

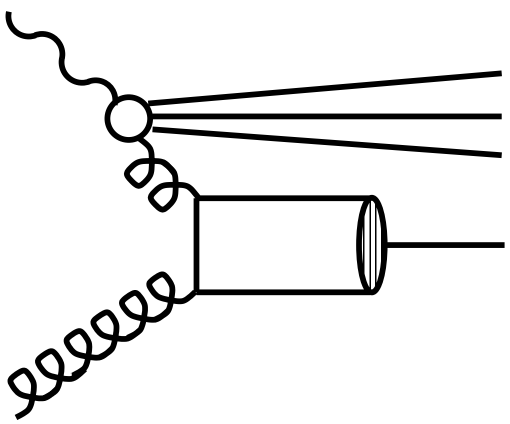
$$= \frac{E^*_\psi}{E^*_\gamma} \text{ in } p \text{ rest frame}$$

Production Mechanisms

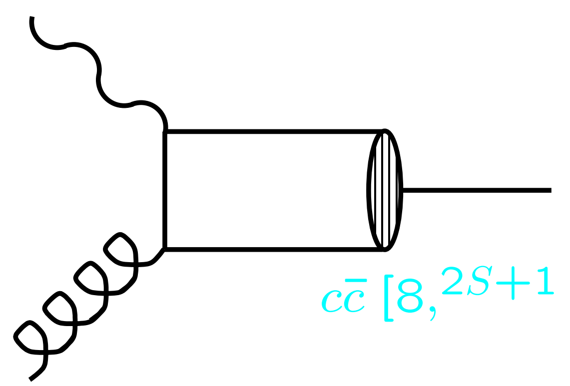
inelastic
boson-gluon fusion

diffractive
exchange of colourless state

resolved (hadron-like)

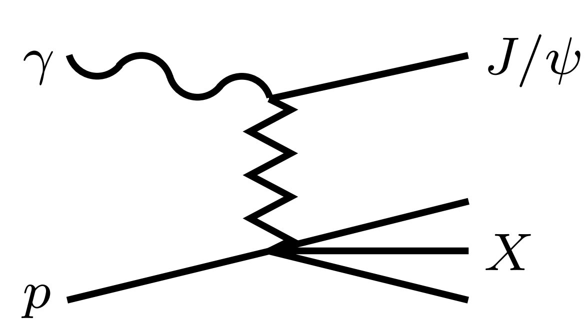


direct



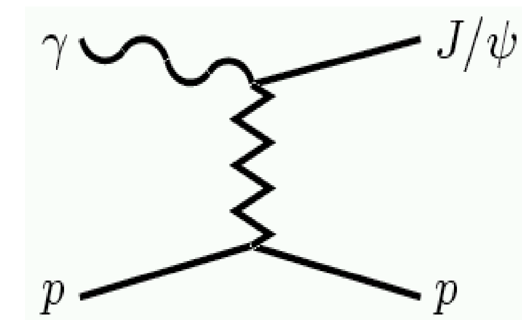
$M_X \gg m_p$

p-dissociation



$M_X \sim m_p$

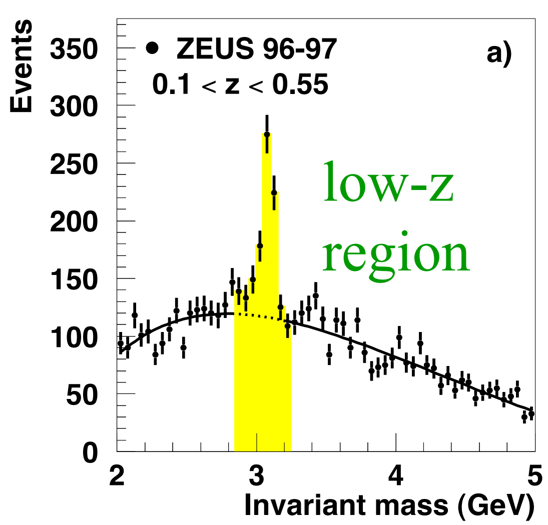
elastic

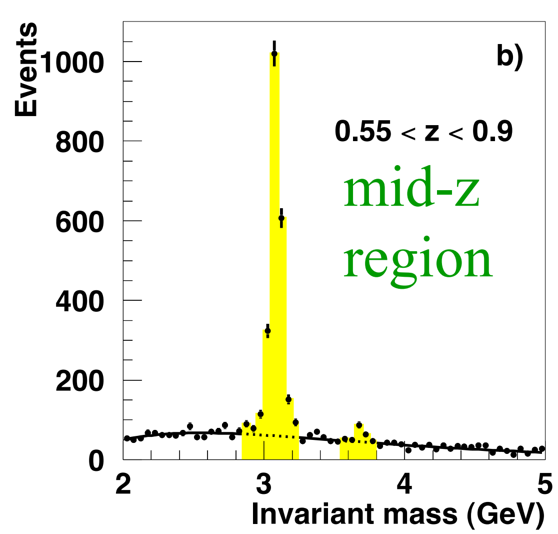


$M_X = m_p$

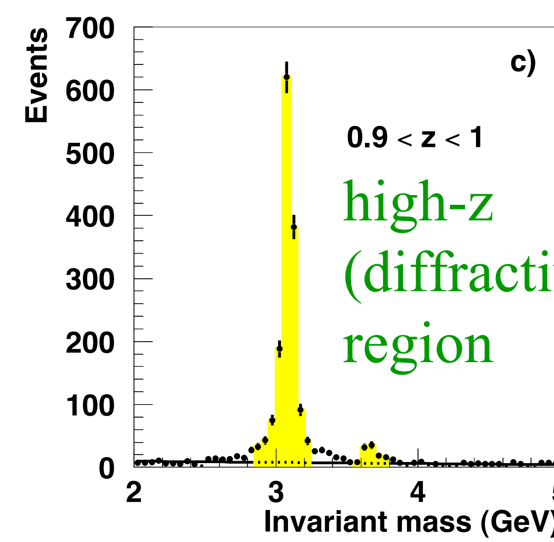
z>0.05 z~0.9 z~1

Elasticity





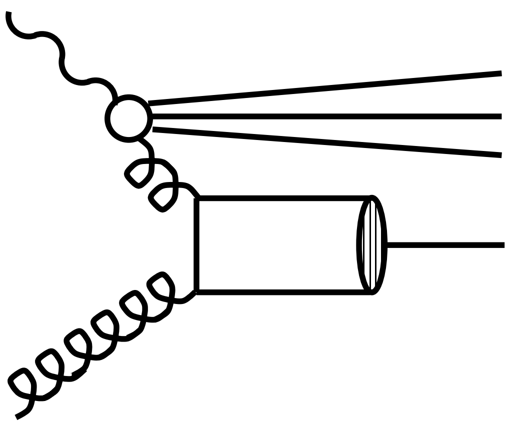
38 pb^{-1}



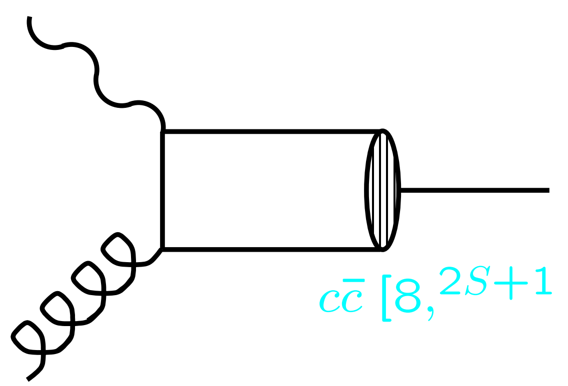
Production Mechanisms

inelastic
boson-gluon fusion

resolved (hadron-like)



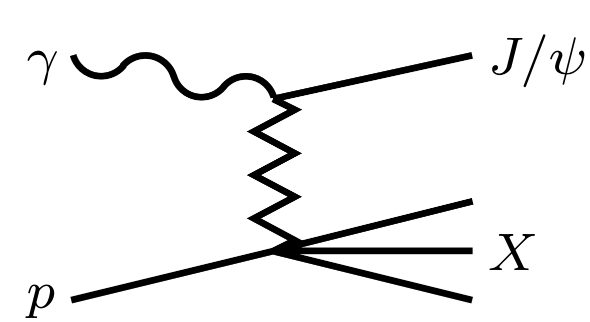
direct



$M_X \gg m_p$

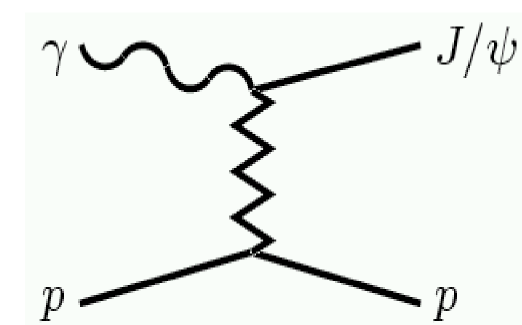
diffractive
exchange of colourless state

p-dissociation



$M_X \sim m_p$

elastic



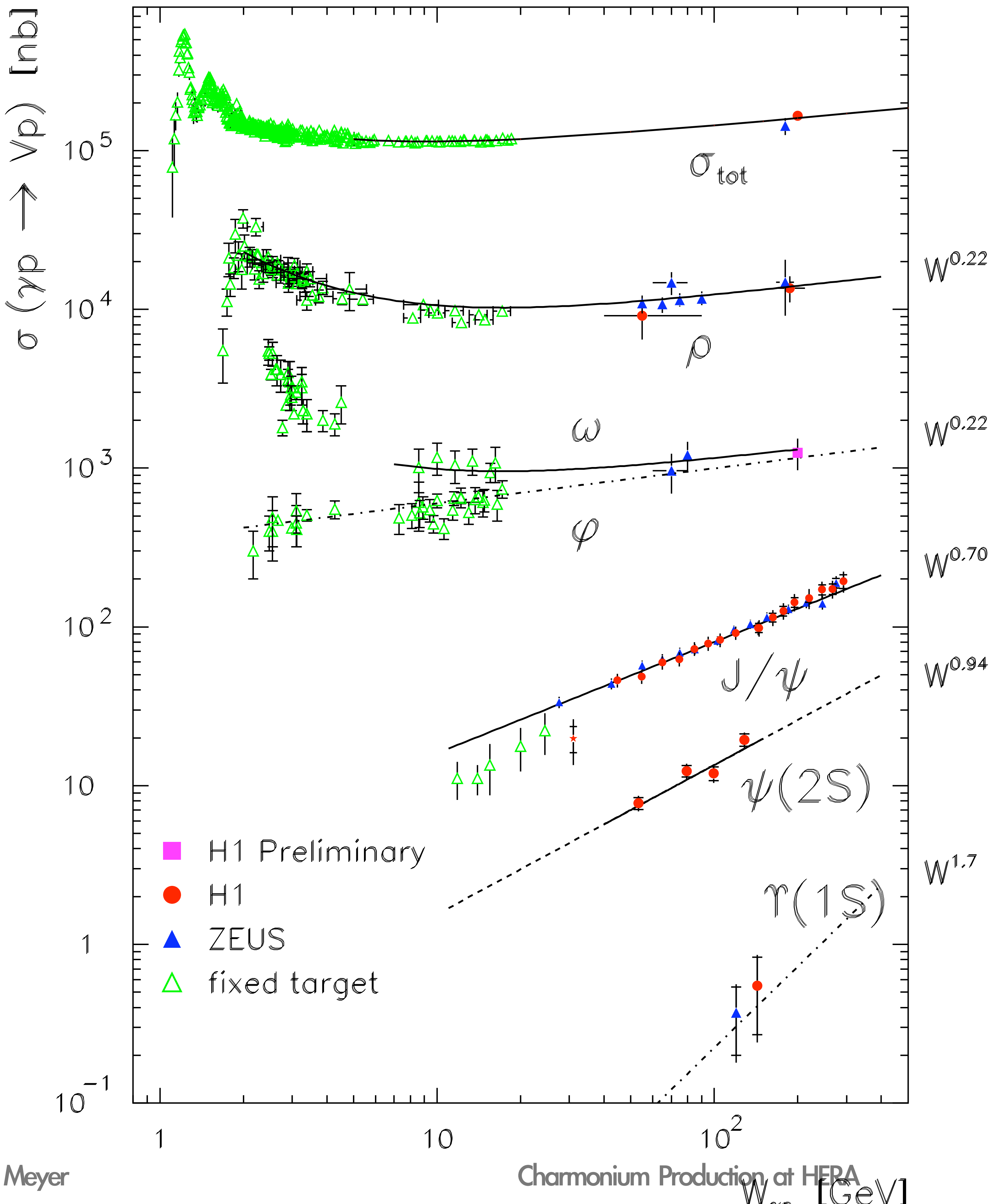
$M_X = m_p$

z>0.05 z~0.9 z~1

Elasticity

- Backgrounds to inelastic sample (not subtracted):
  - J/ψ from B decays (5% of inelastic, up to 25% at lowest z, resolved)
  - J/ψ from χ_c decays (1% of inelastic, up to 7% at lowest z, resolved)
  - J/ψ from $\psi(2S)$ decays (~15%, see later)

Elastic VM Production at HERA



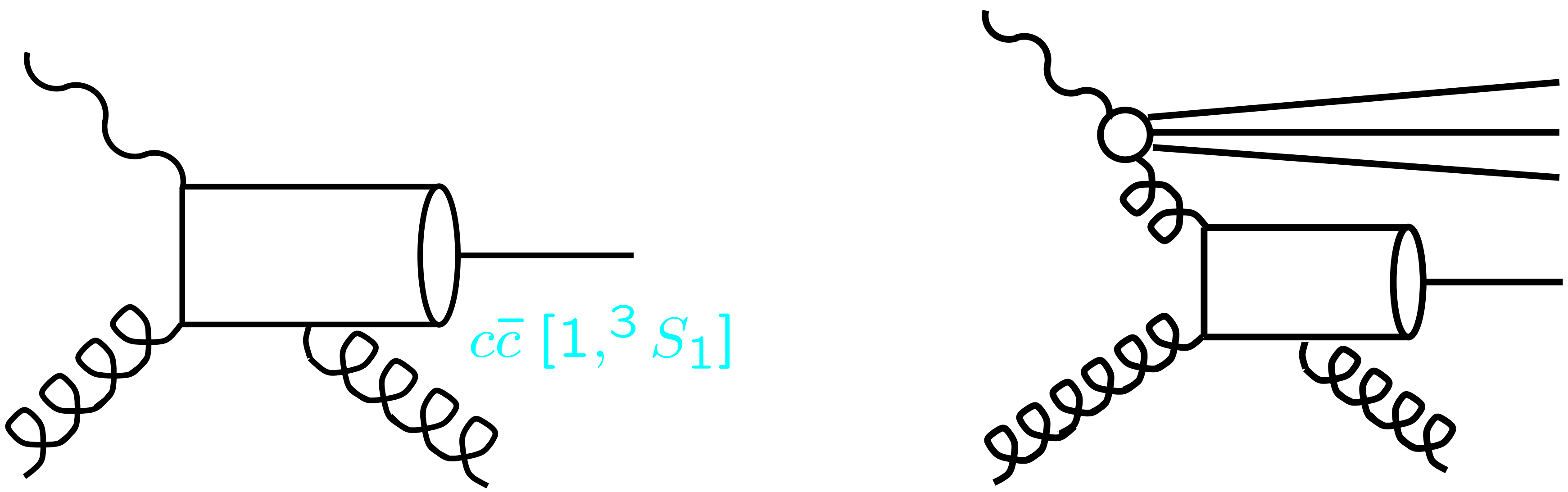
Wealth of Measurements of elastic VM Production from HERA

Not covered in this talk

Inelastic J/ψ Production

- Colour Singlet Model

direct: $\gamma g \to c\bar{c}$ resolved: $gg \to c\bar{c}$



CS: one parameter
fixed from $\Gamma(J/\psi \to \ell^+\ell^-)$

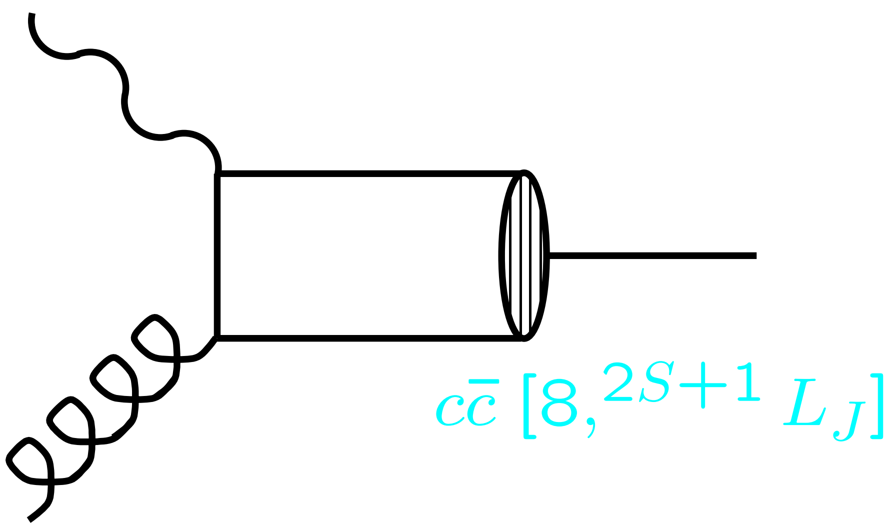
LO: Berger et al, Baier et al, 1981
NLO (direct): Kraemer et al, 1995

χ_c states are suppressed in (direct) ep and γp

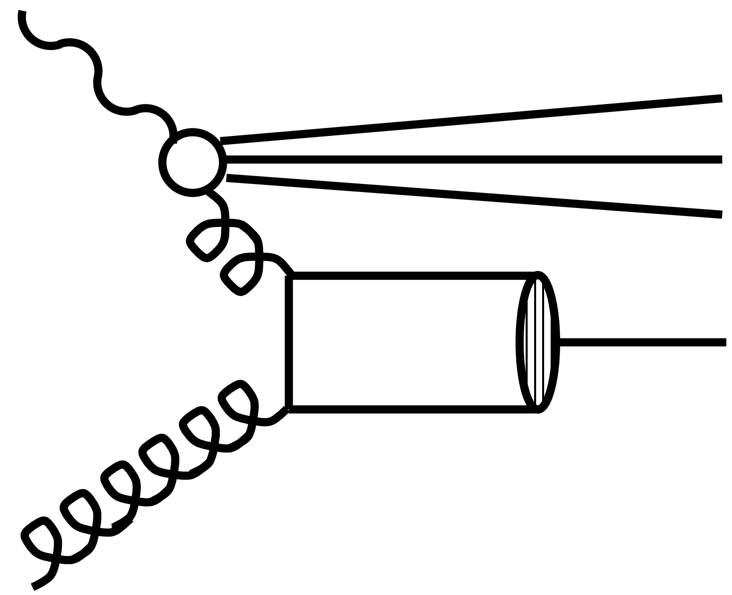
Inelastic J/ψ Production

- Colour Octet Contributions (soft gluon radiation)

direct: $\gamma g \rightarrow c\bar{c}$



resolved: $gg \rightarrow c\bar{c}$



NRQCD-factorization:

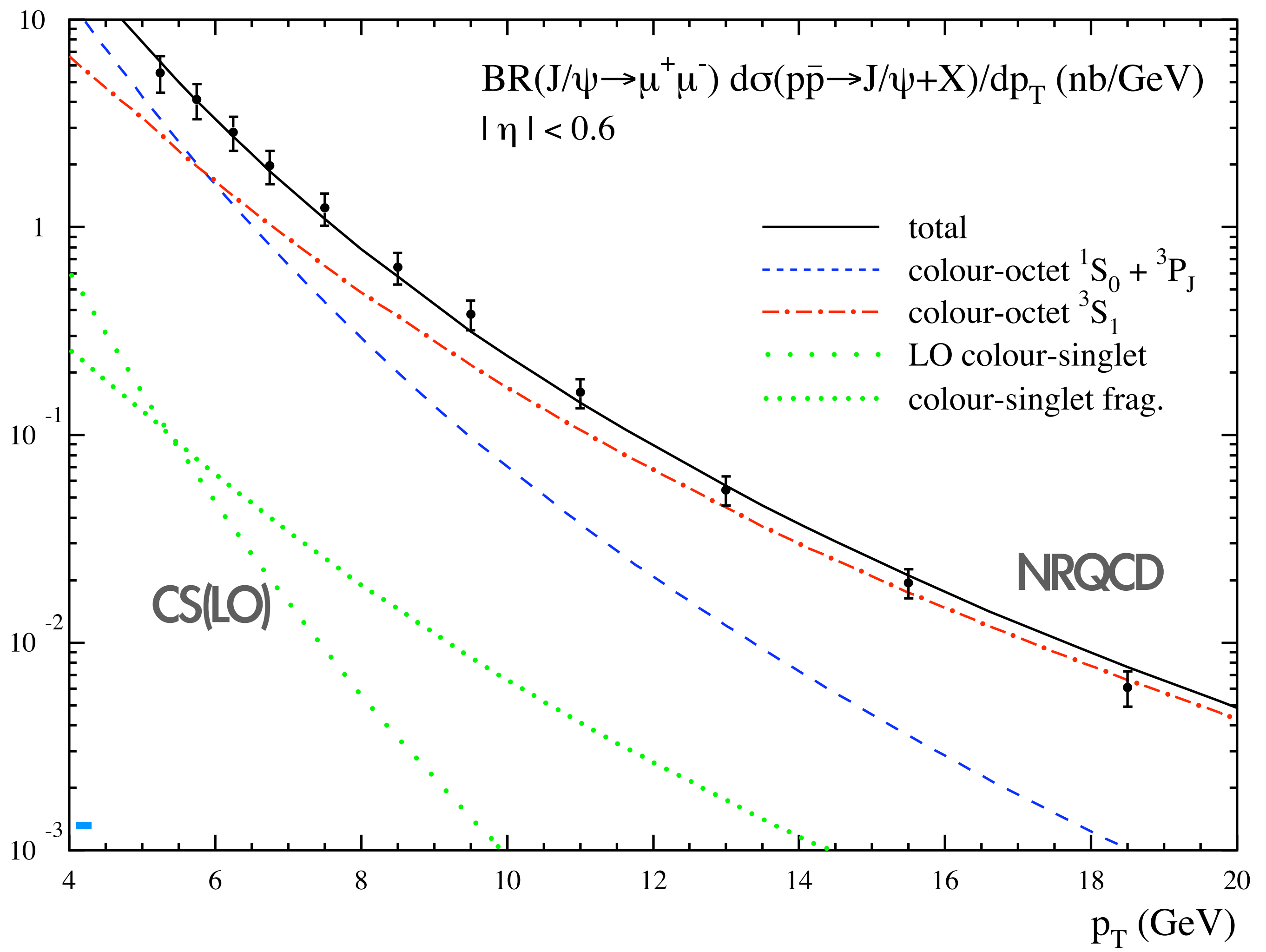
$$\sigma_{J/\psi X} = \sum \hat{\sigma}(p\bar{p} \rightarrow c\bar{c}[n]X) \times \mathrm{LDME}[n]$$

Bodwin, Braaten, Lepage 1995

Long distance matrix elements (LDME) - from NRQCD fits to Tevatron data

Tevatron

J/ψ Production at CDF (Run-I)



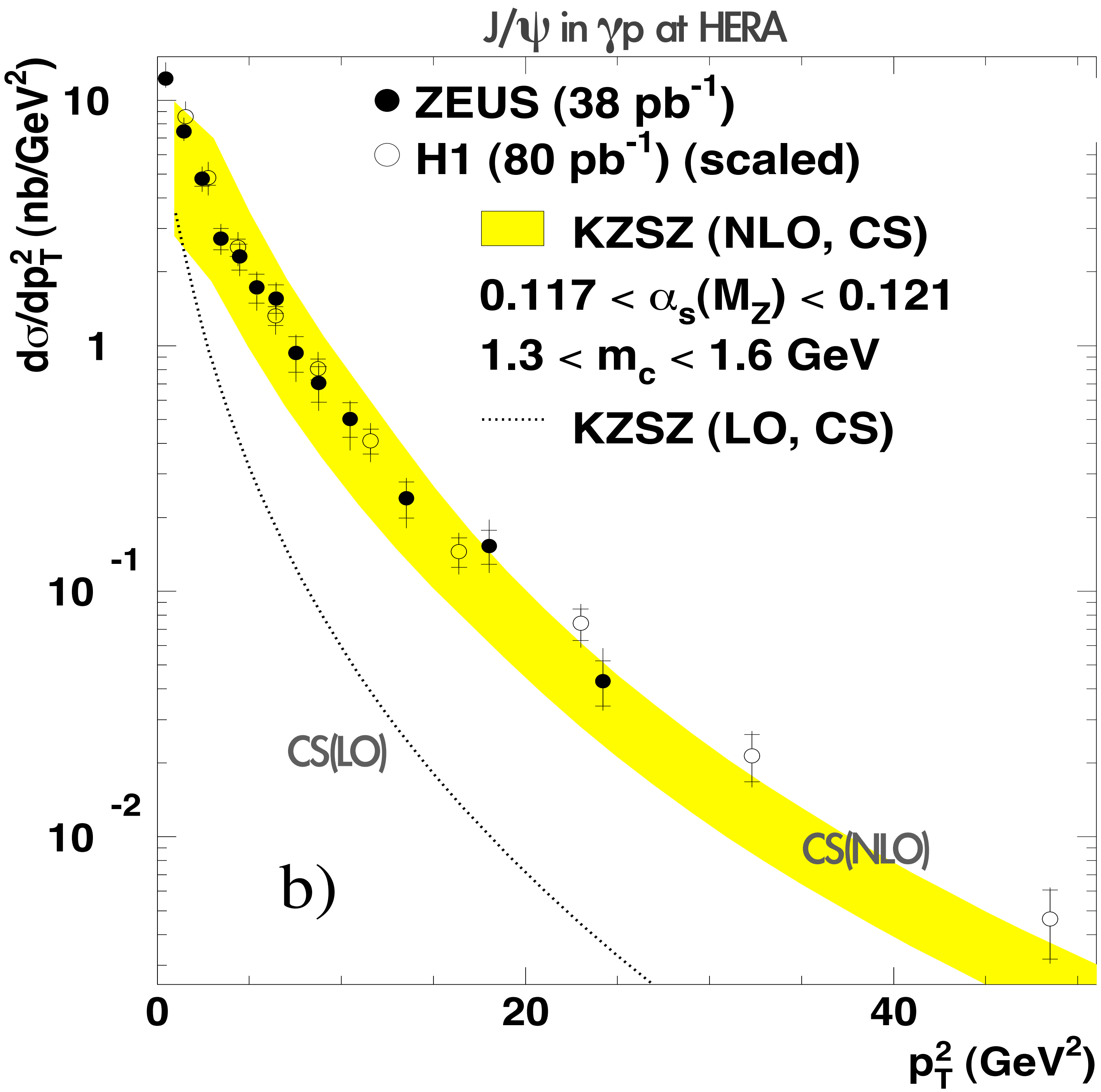
NRQCD calculations:
LO only
NLO still underway

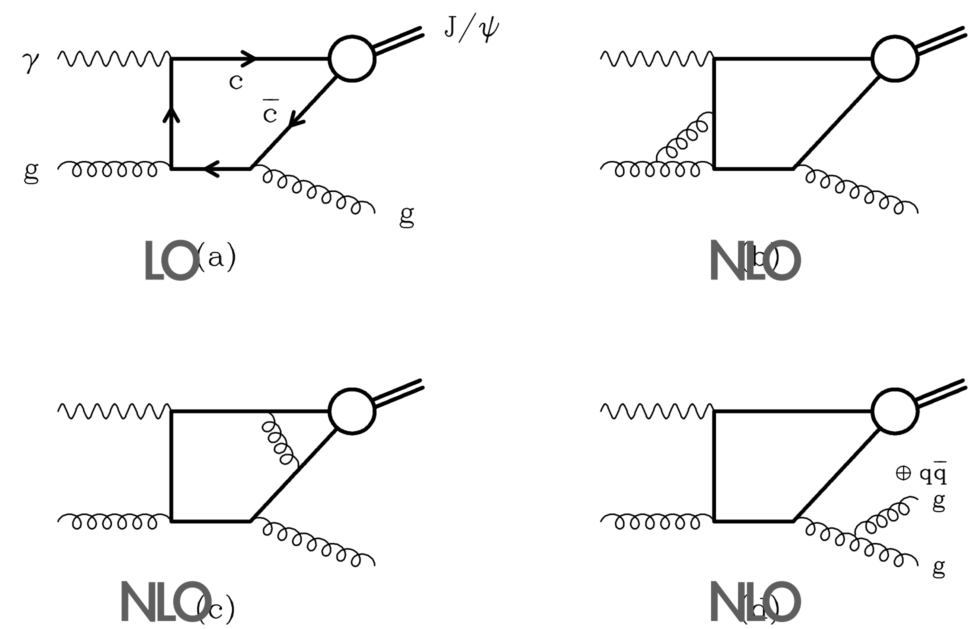
NRQCD-factorization:

$$\sigma_{J/\psi X} = \sum \hat{\sigma}(p\bar{p} \to c\bar{c}[n]X) \times \mathrm{LDME}[n]$$

Test universality of LDME at other experiments (e.g. HERA, LEP, b-facts.)

J/ψ Photoproduction at HERA



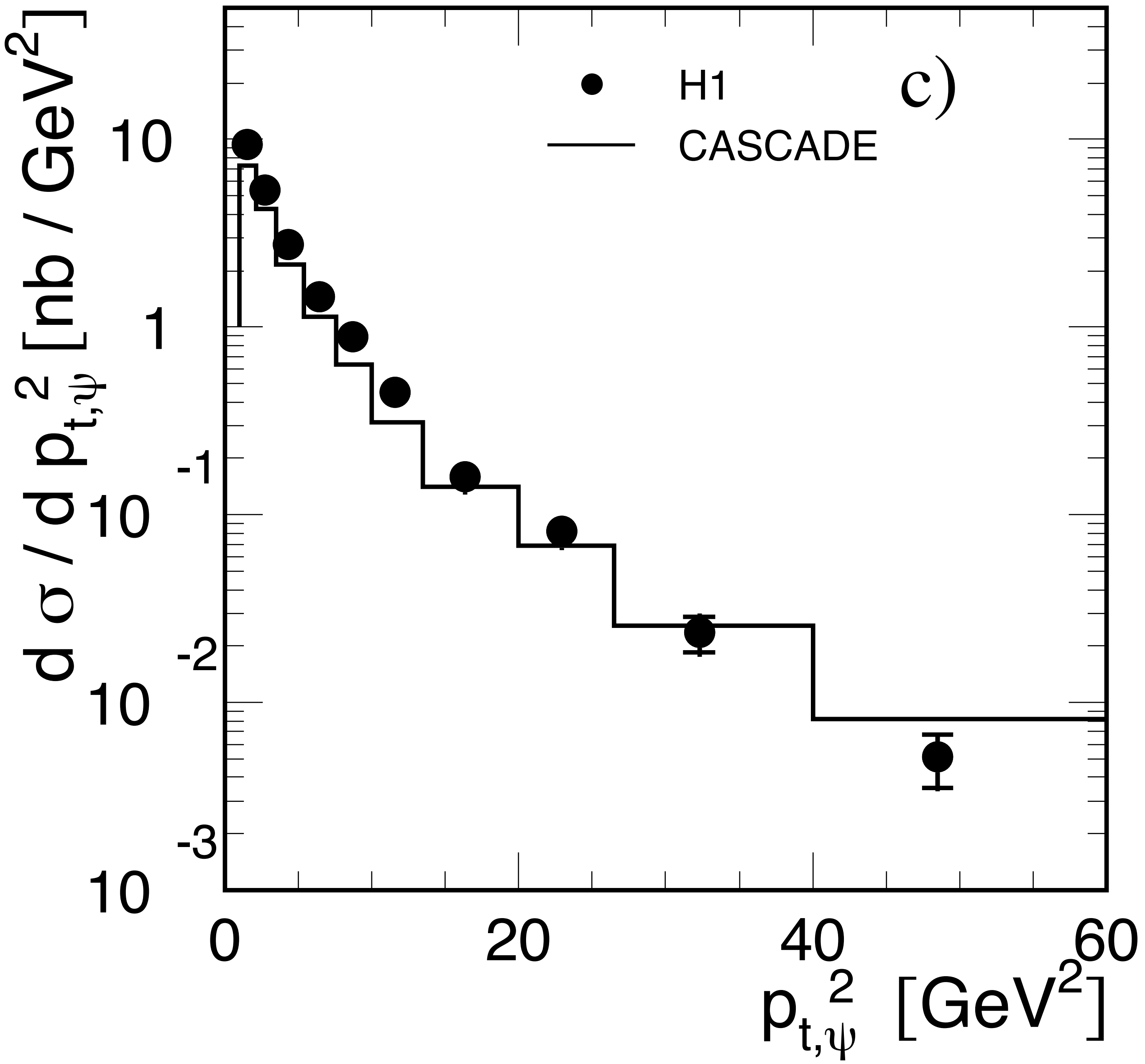


Color singlet model:
NLO calculation is available for γp

NLO (direct): Kraemer et al, 1995

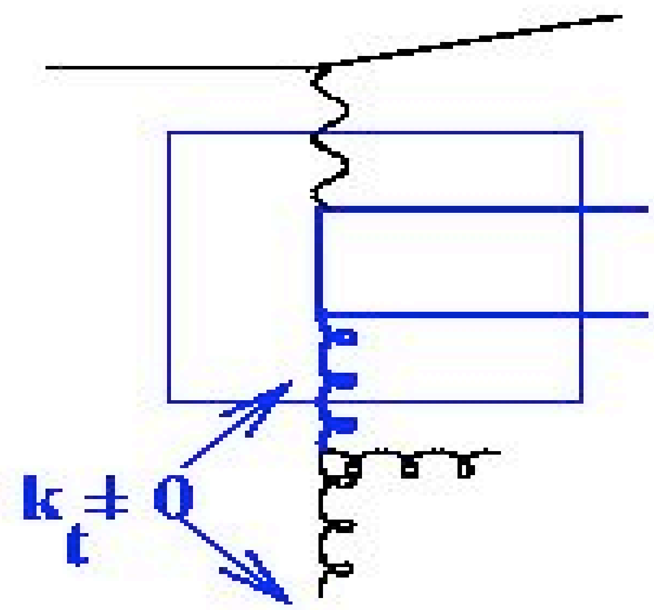
CS (LO) too steep, too low (like in $p\bar{p}$)
CS (NLO) alone describes data

J/ψ Photoproduction at HERA



CS model using kt-factorization (CASCADE) also describes shape of data

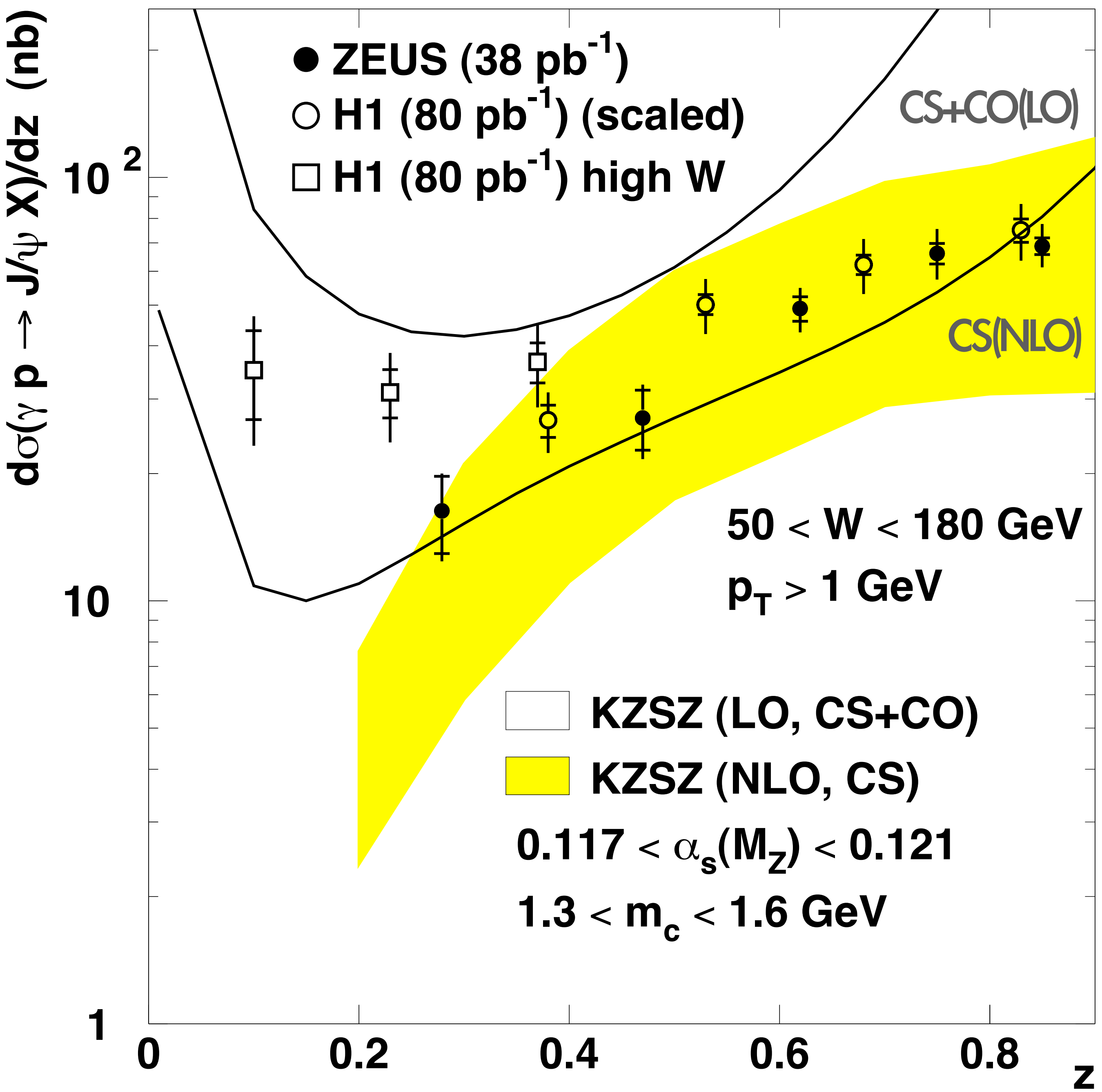
H.Jung, 2001

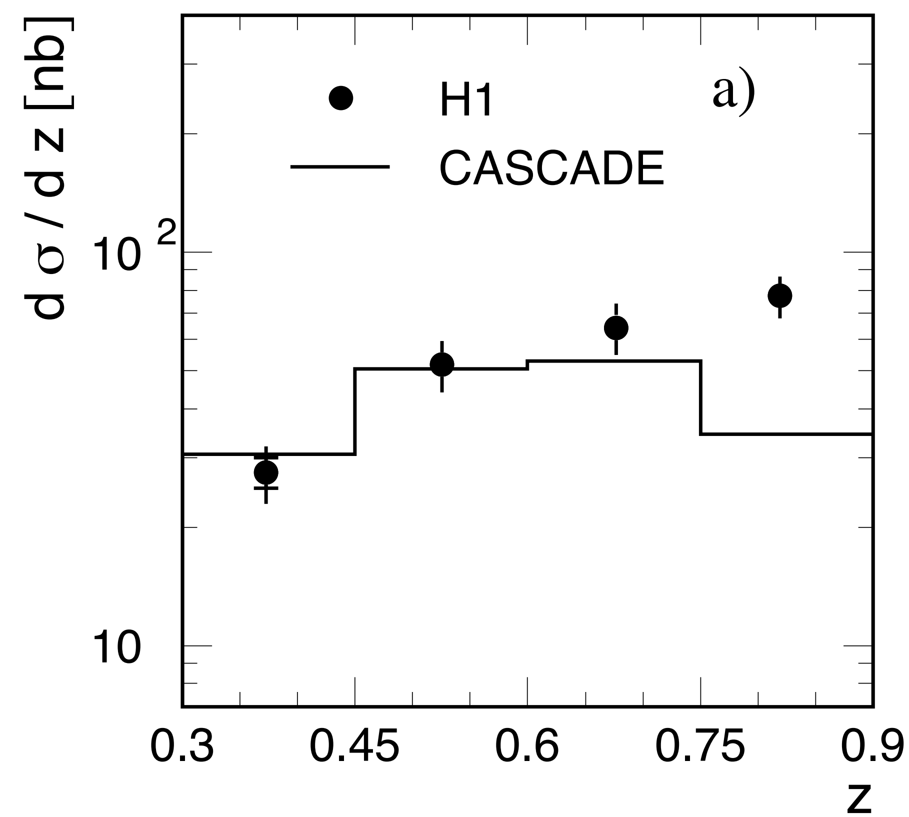


CCFM evolution of unint. gluon density contains part of NLO corrections

M.Ciafaloni et al, 1988

J/ψ Photoproduction at HERA



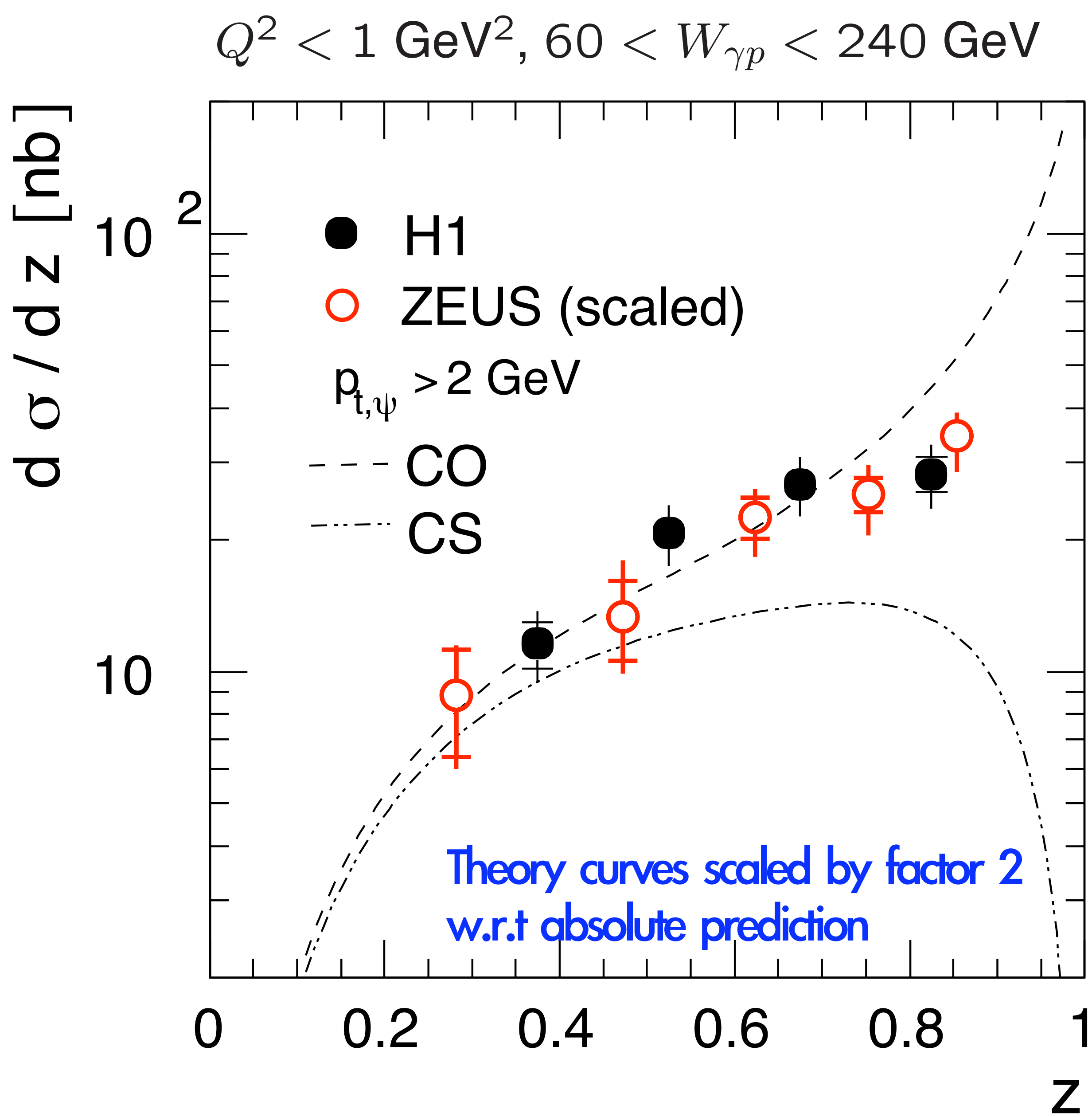


CASCADE: too low at large z

$$z = \frac{E_\psi}{E_\gamma}$$ in p rest frame

CS (NLO): z distribution reasonably well described
CS+CO (LO): also ok

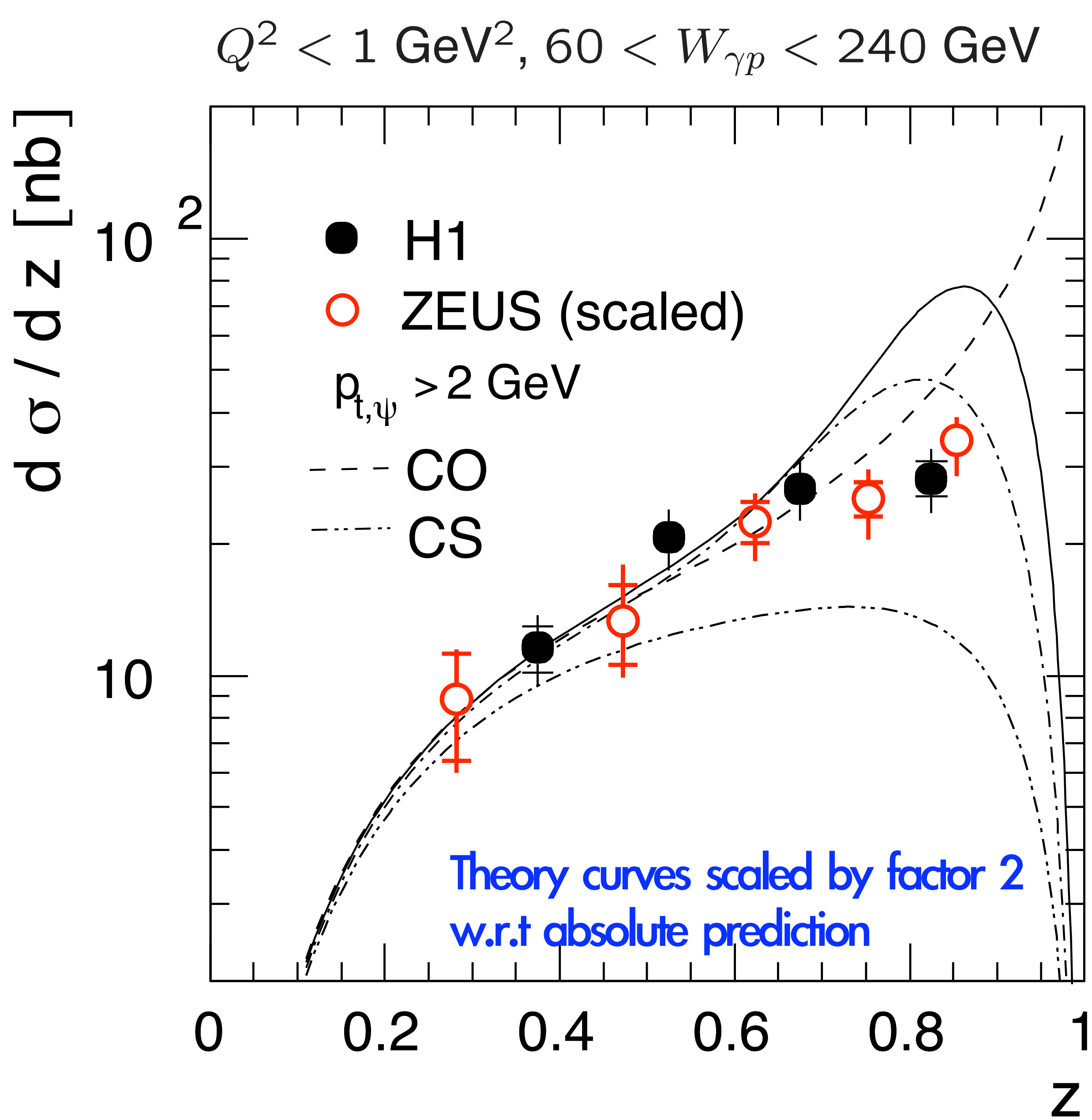
z-Distribution



LO Color-Octet Contribution
→no hard gluon
→rises to large z

Color Singlet contribution:
→hard gluon
→falling off at large z

z-Distribution



LO Color-Octet Contribution
→no hard gluon
→rises to large z

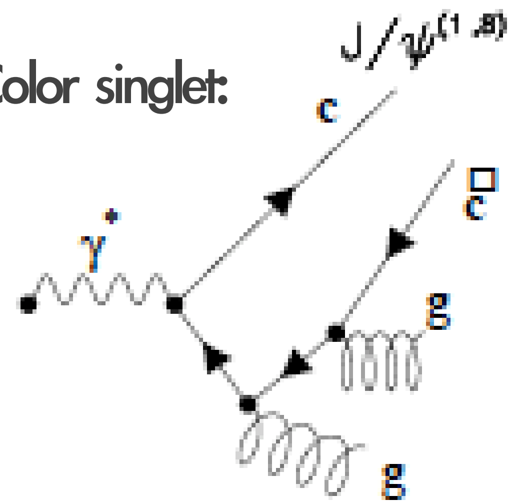
Color Singlet contribution:
→hard gluon
→falling off at large z

soft Color Octet gluons resummed:
→reasonable description of shape

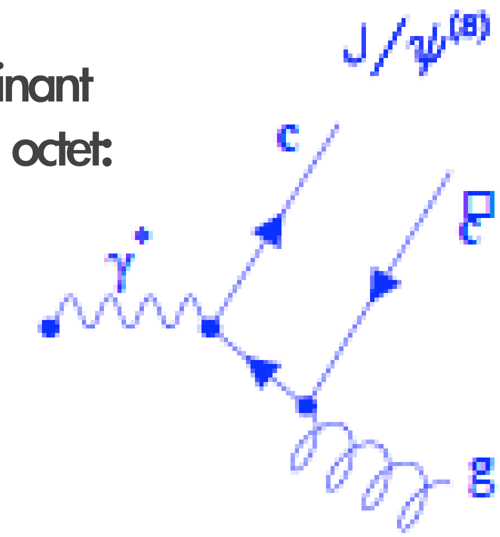
M.Beneke, G.A. Schuler, S.Wolf

Compare with J/ψ at b-factories

Color singlet:



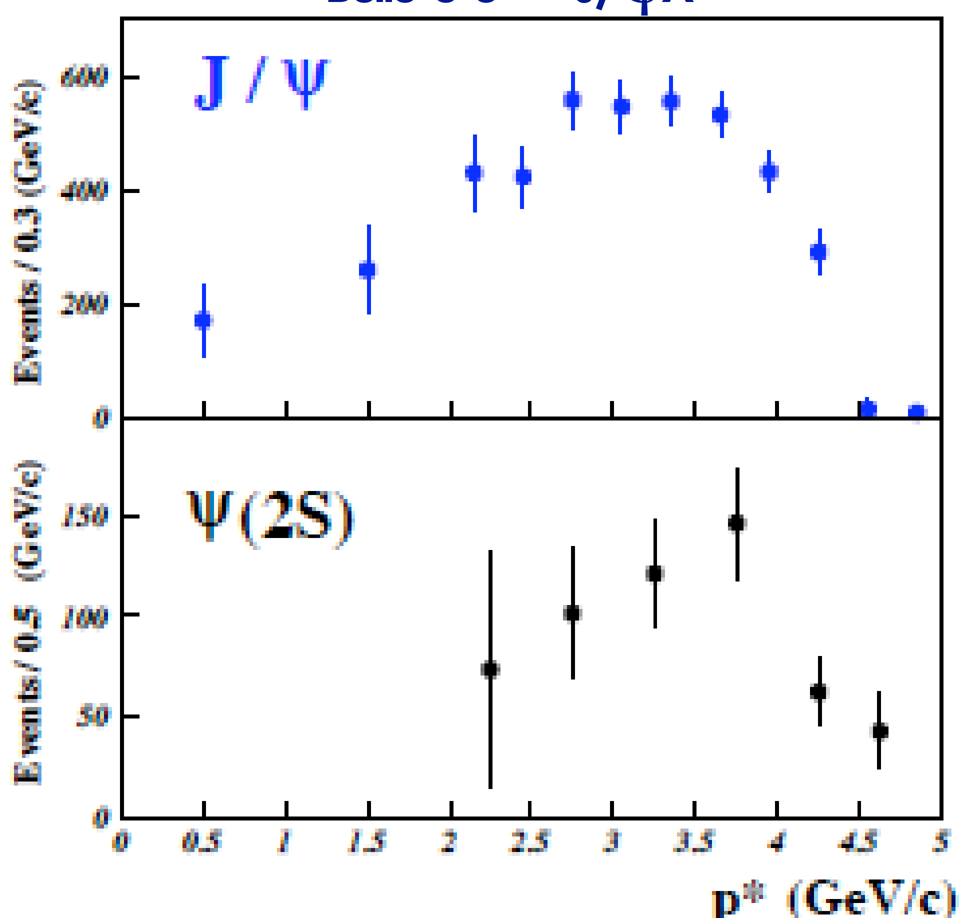
Dominant color octet:



singularity at large z,
(as for NRQCD at HERA)

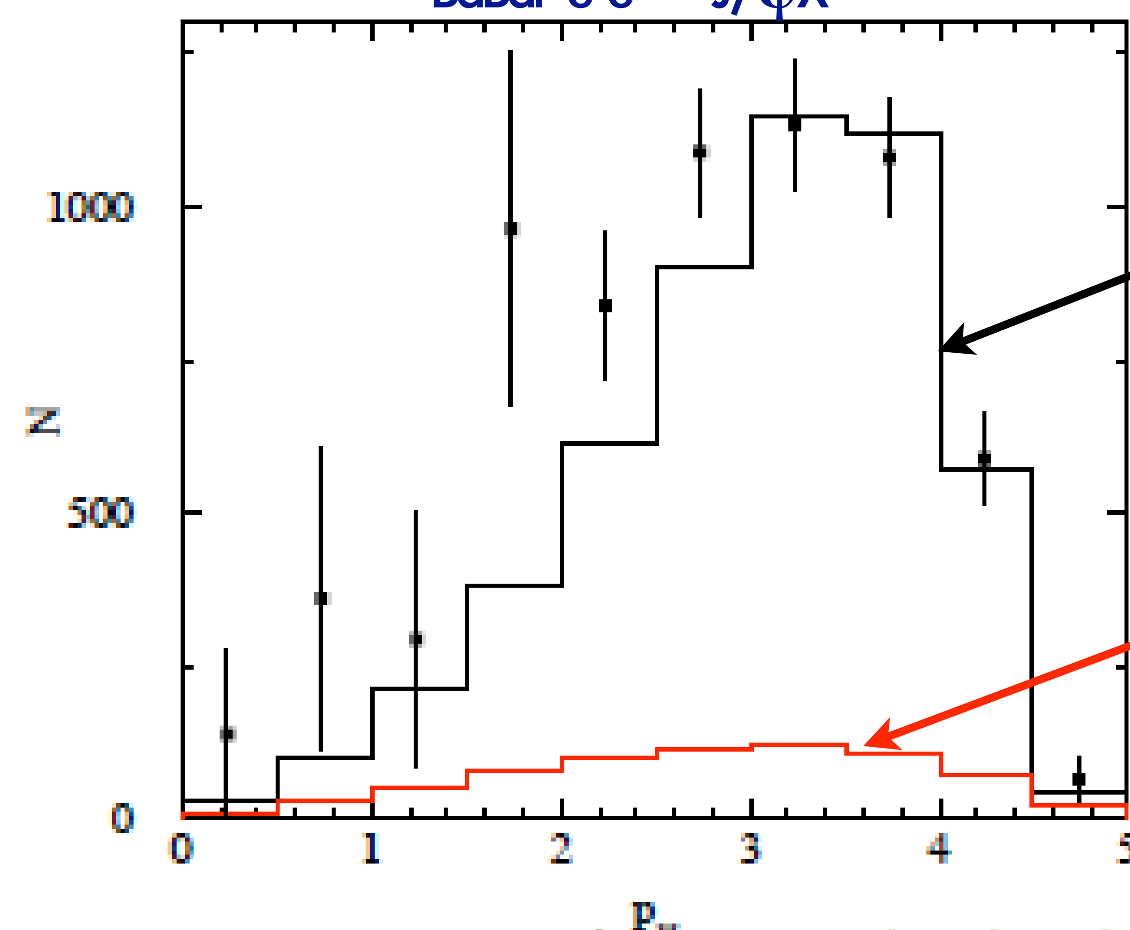
gluon resummation to
describe data at endpoint

Belle $e^+e^- \to J/\psi X$



data falling towards p* endpoint

BaBar $e^+e^- \to J/\psi X$

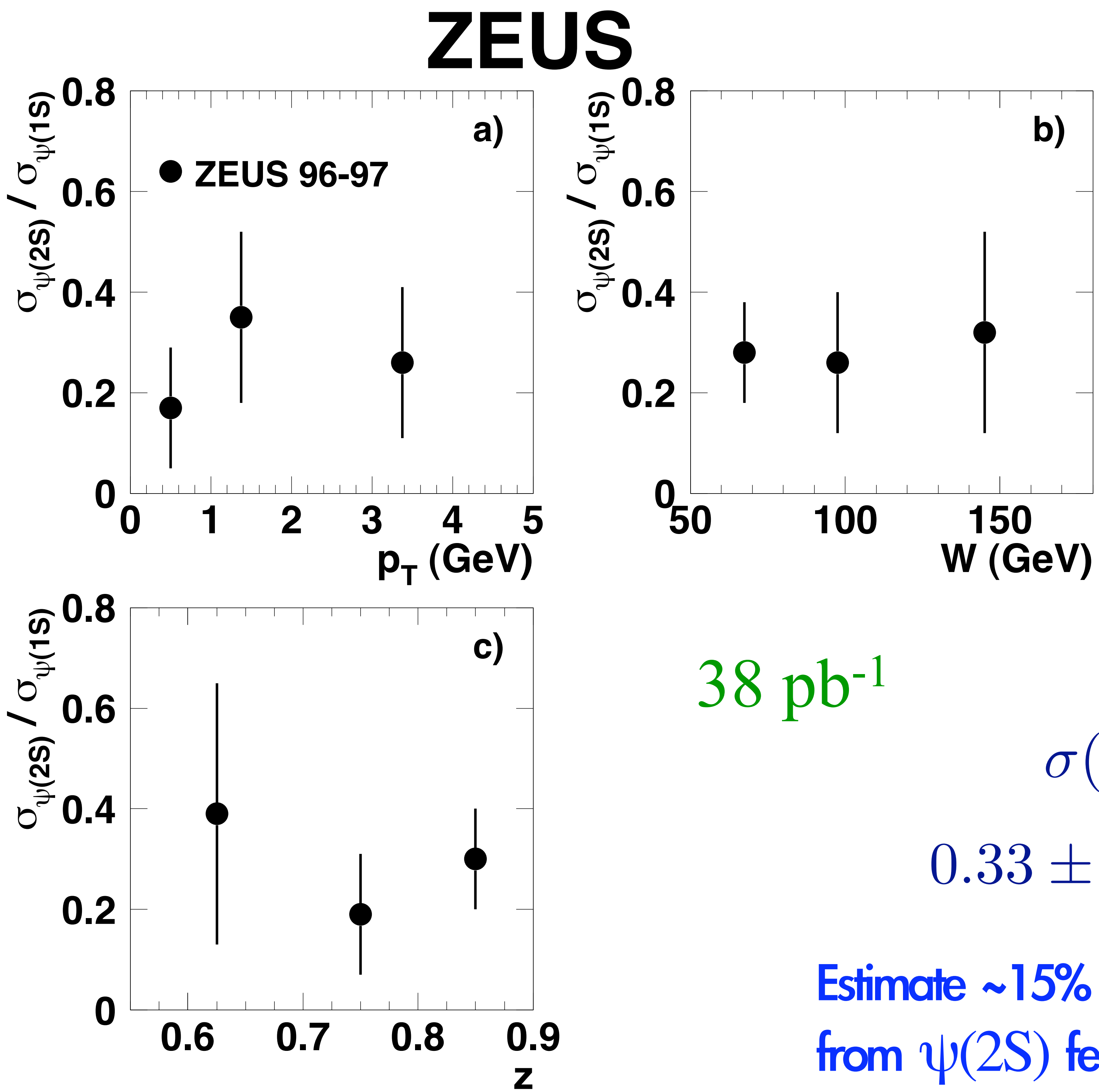


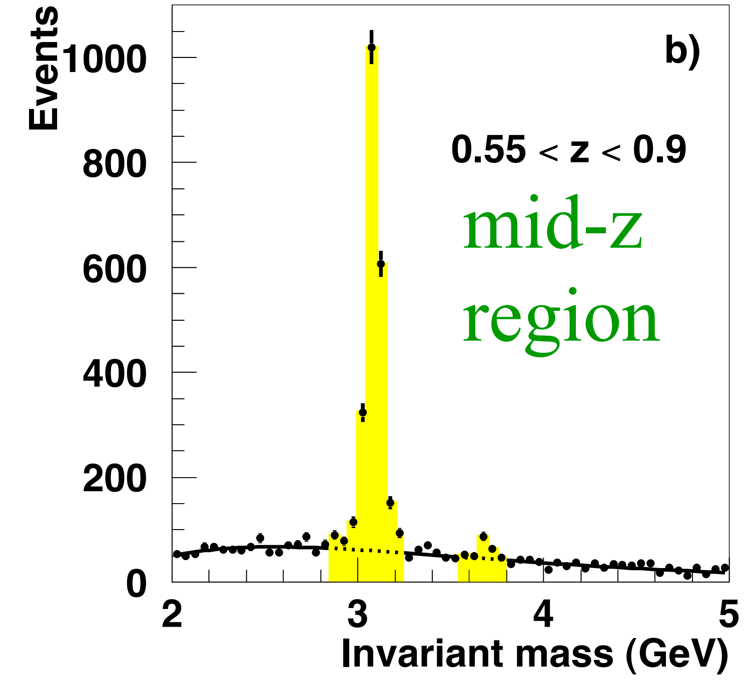
resummed NRQCD
(normalised to data,
absolute normalization
too low)

CSM (absolute
normalization)

S.Fleming, A.K.Leibovich and T.Mehen 2003

ψ(2S) Contribution





38 pb^{-1}

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

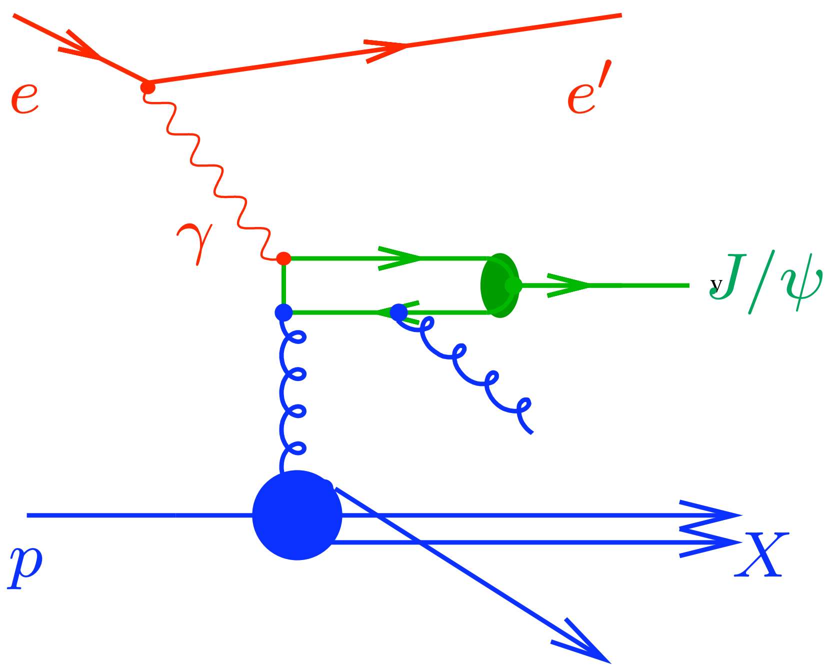
$$0.33 \pm 0.1(stat.)^{+0.01}_{-0.02}(syst.)$$

Estimate ~15% of measured J/ψ to come from ψ(2S) feed down (corrected in predictions)

Elastic Vector Meson Production

Inelastic

Boson Gluon Fusion



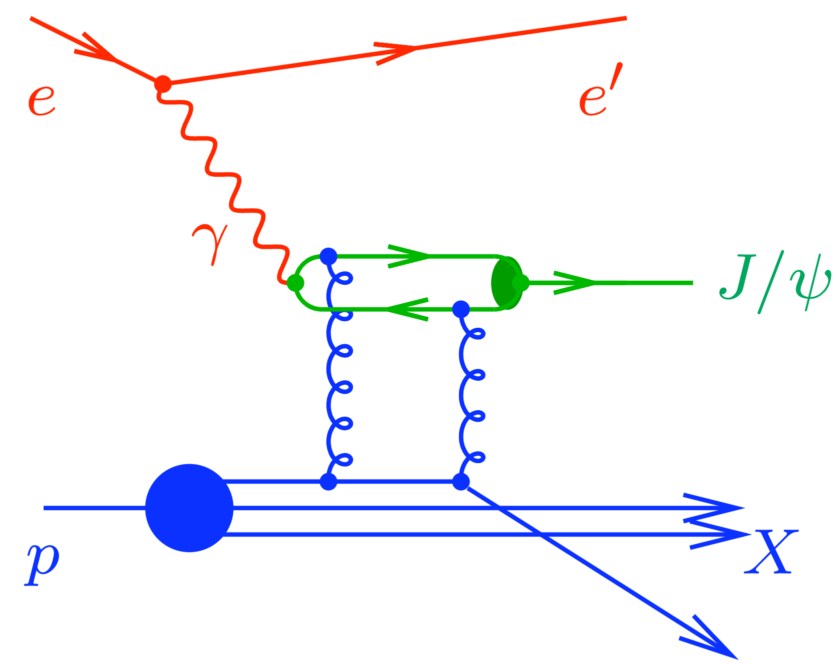
$\sum \hat{\sigma}(\gamma p \to c\bar{c}[n]X) \times \mathrm{LDME}[n])$

$\sigma \propto |xg(x)|$ **moderate rise with $W_{\gamma p}$**

$d\sigma/dp_{t,\psi}^2 \propto (p_{t,\psi}^2 + M_\psi^2)^{-4\ldots5}$

Diffractive

Colourless exchange: 2 gluons (LO)



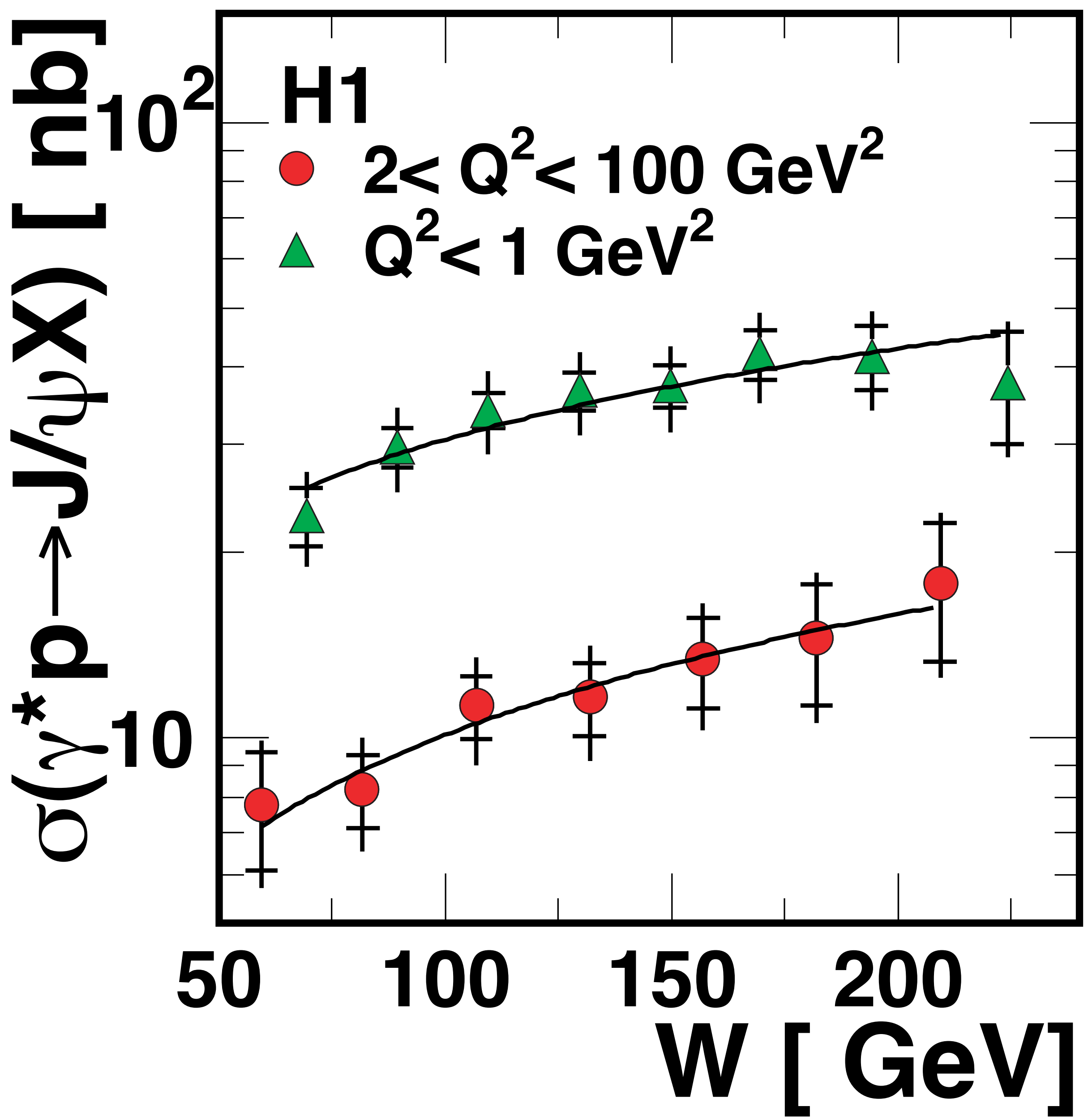
$\Psi(\gamma \to c\bar{c}) \otimes \sigma_{dipole}^2 \otimes \Phi(J/\psi)$

$\sigma \propto |xg(x)|^2$ **fast rise with $W_{\gamma p}$**

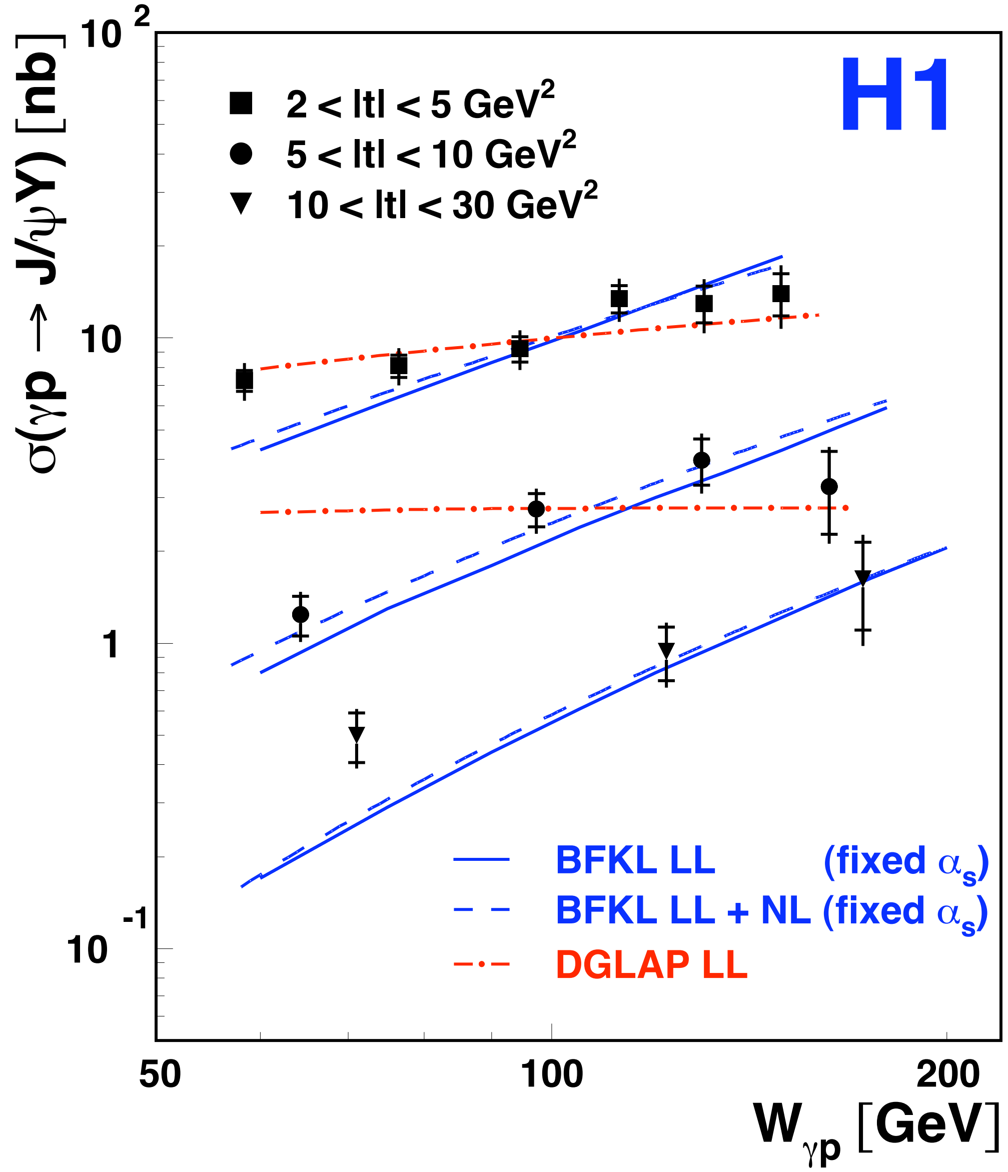
$d\sigma/dt \propto -t^{-3}$

Energy-Dependence

0.3<z<0.9



z>0.95, |t|>2 GeV²



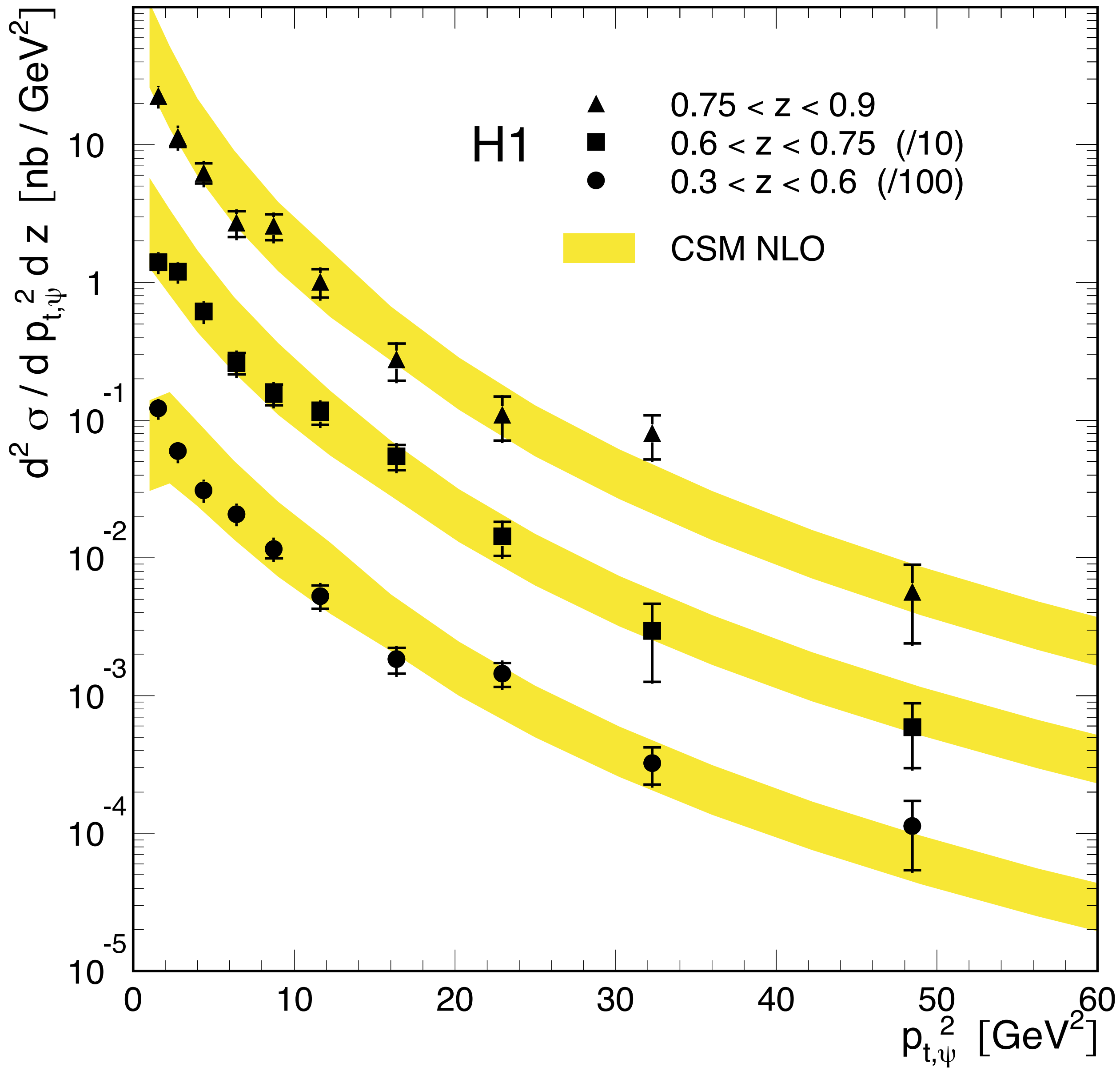
Fit W^{δ}: $\delta \sim 0.49 \pm 0.16$

$\delta \sim 0.77 \pm 0.14 \pm 0.10$ (lowest t-bin)

Data confirm expected trend

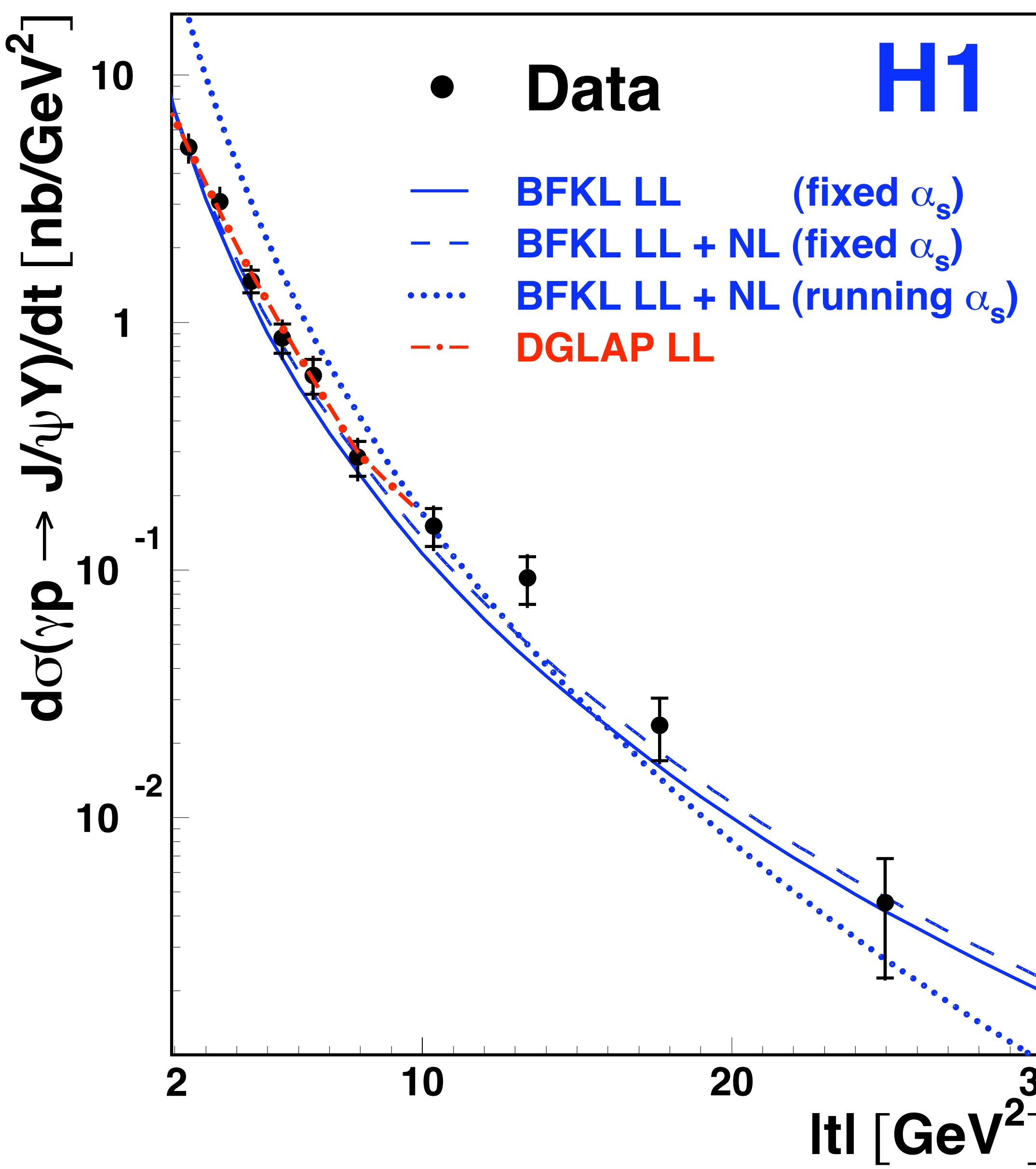
Transv. Momentum Distributions

0.3<z<0.9



$$(p_{t.\psi}^2 + M_\psi^2)^{-n}\text{: } n = 4.49 \pm 0.15$$

z>0.95, |t|>2 GeV^2



$$n = 6.63 \pm 0.13 \pm 0.08$$

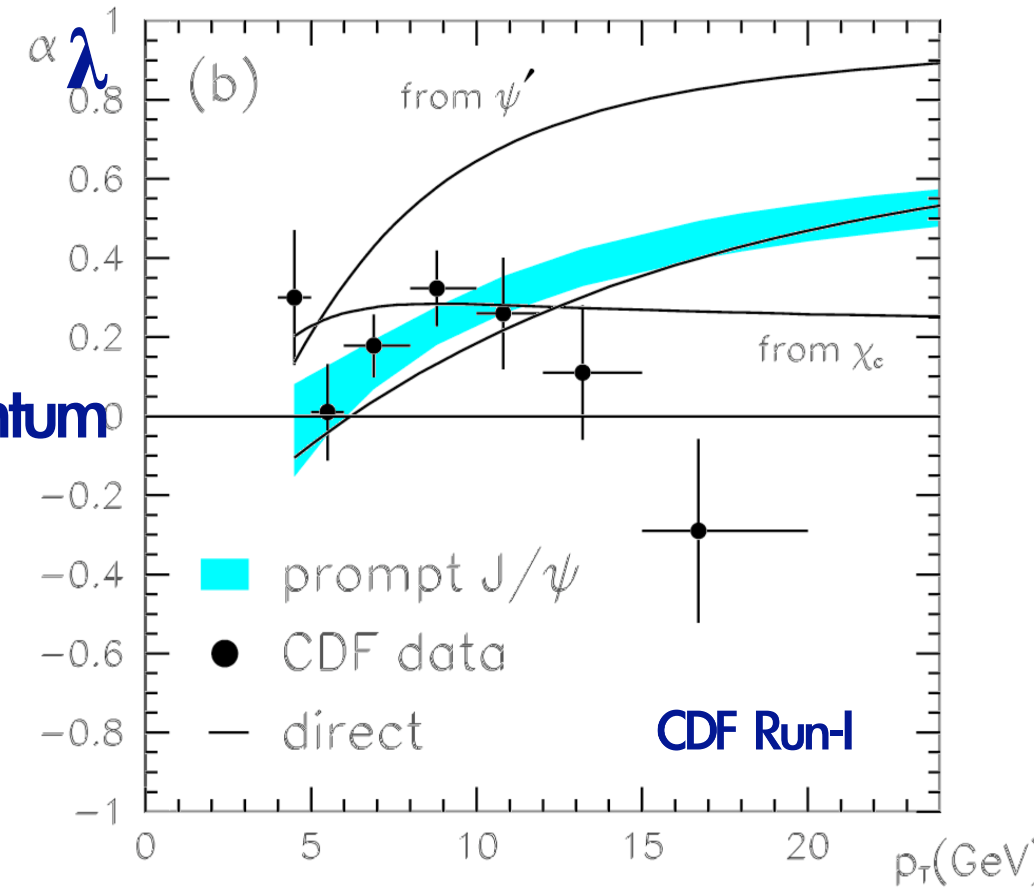
Data at large z somewhat steeper

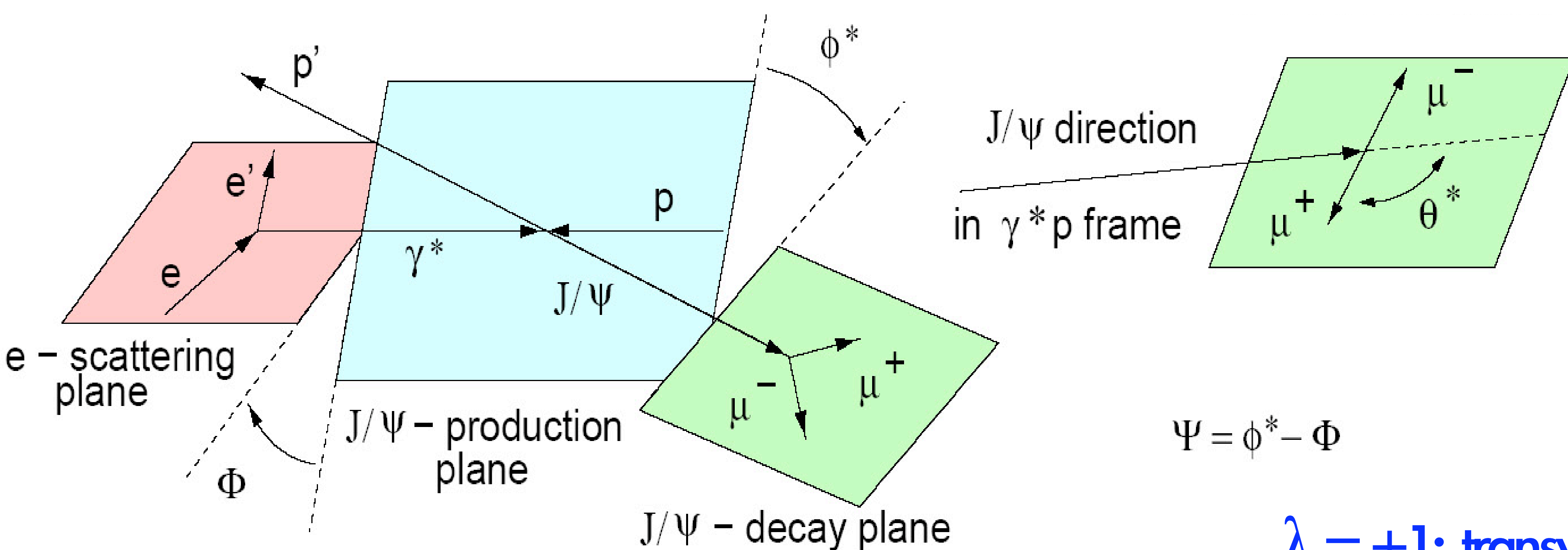
J/ψ Helicity Distributions

- **Firm NRQCD Prediction:**
  - Transverse polarization at high transverse momentum (from gluon splitting)

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} \propto 1 + \lambda\cos^2\theta^*$$

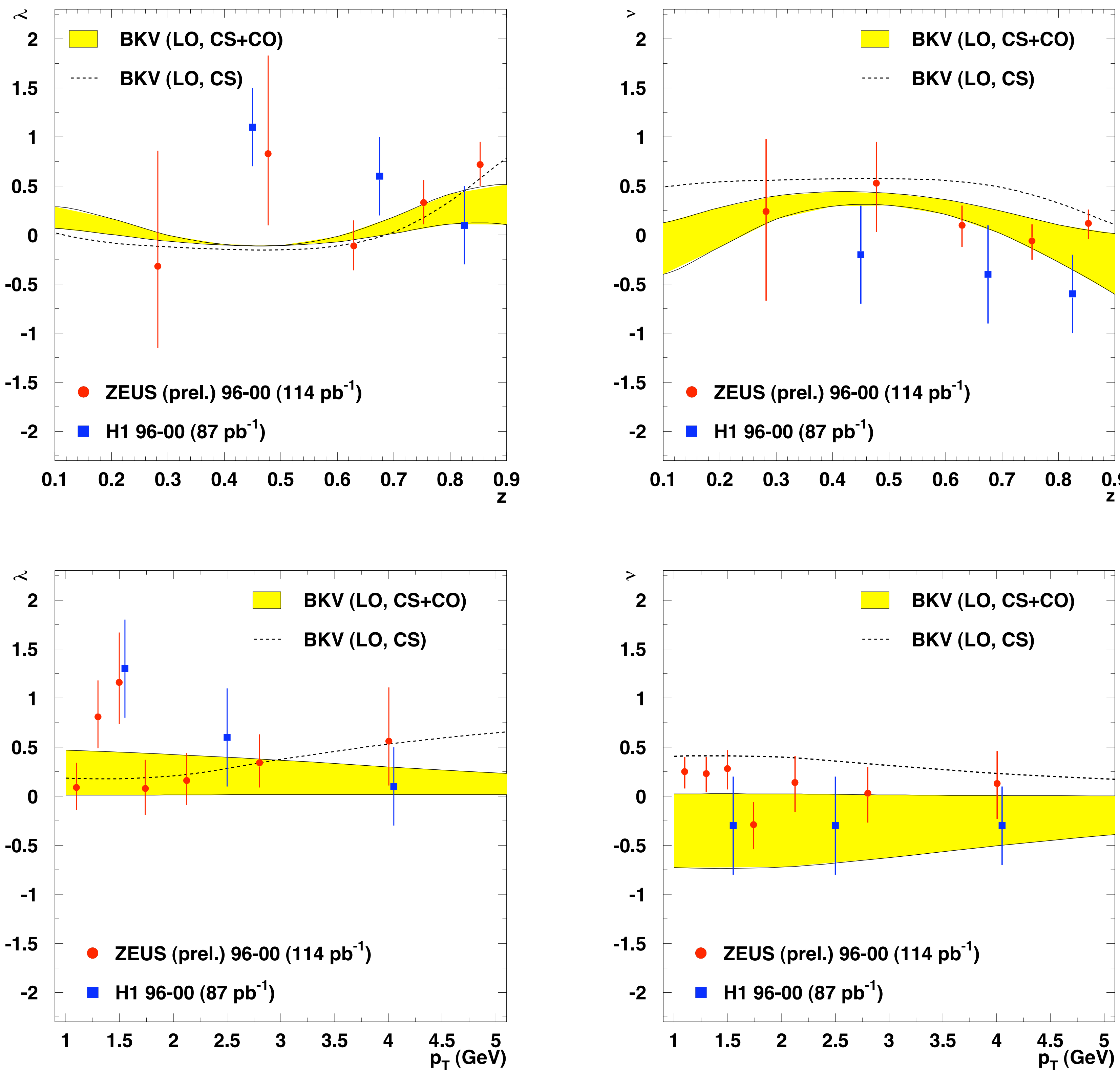
$$\frac{1}{\sigma}\frac{d\sigma}{d\Phi^*} \propto 1 + \frac{\lambda}{3} + \frac{\nu}{3}\cos 2\Phi^*$$





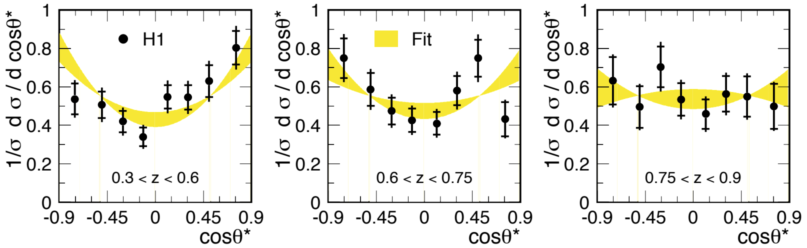
λ = +1: transverse polarisation

J/ψ Polarisation at HERA

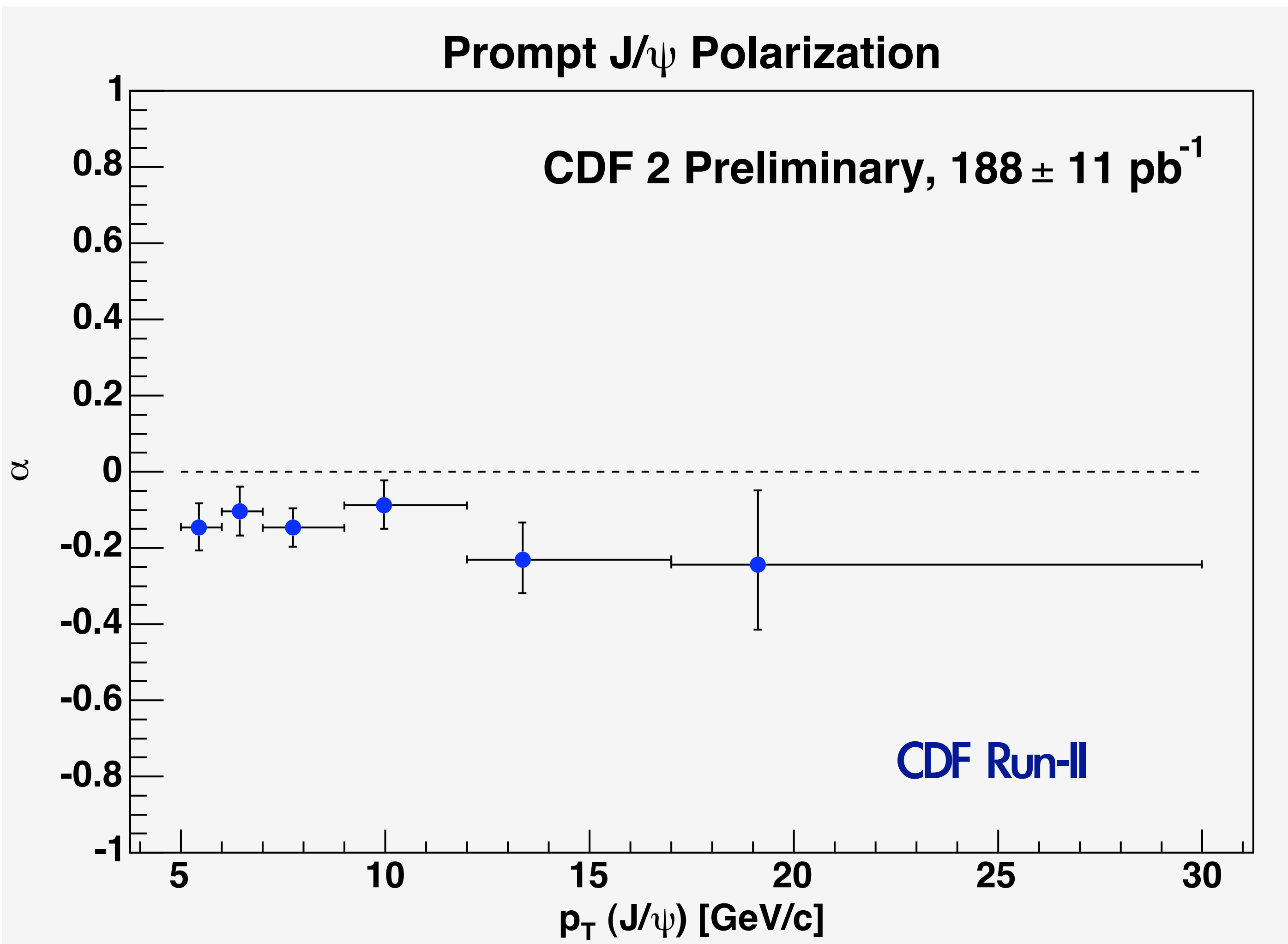


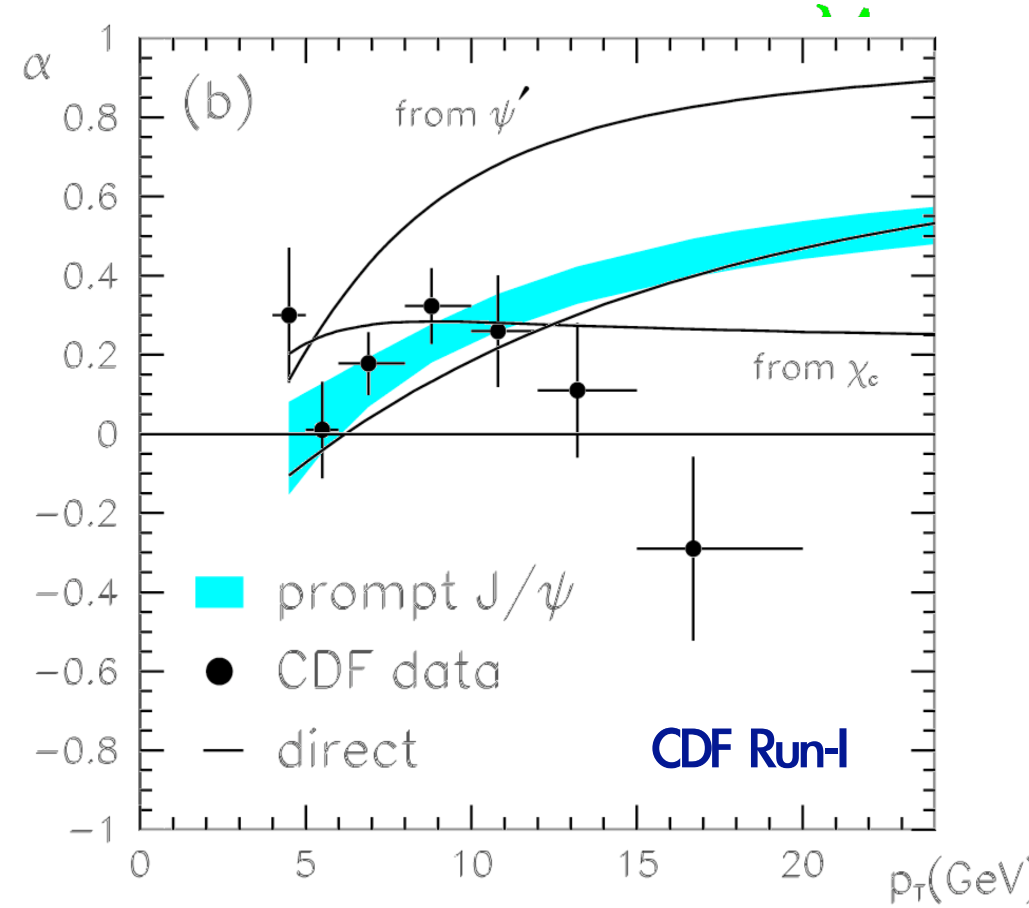
p_t -range at HERA:
too low for gluon splitting

Results not conclusive yet:
→ more stats. underway



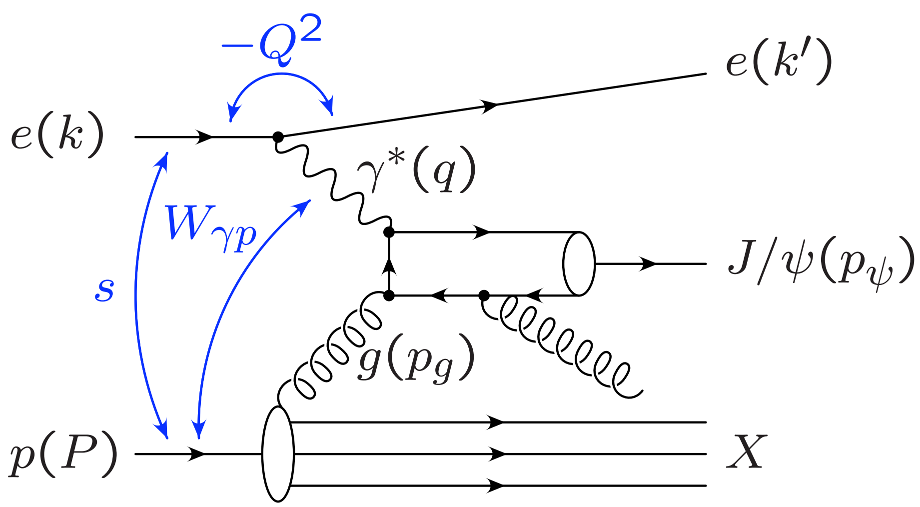
J/ψ Polarisation at the Tevatron

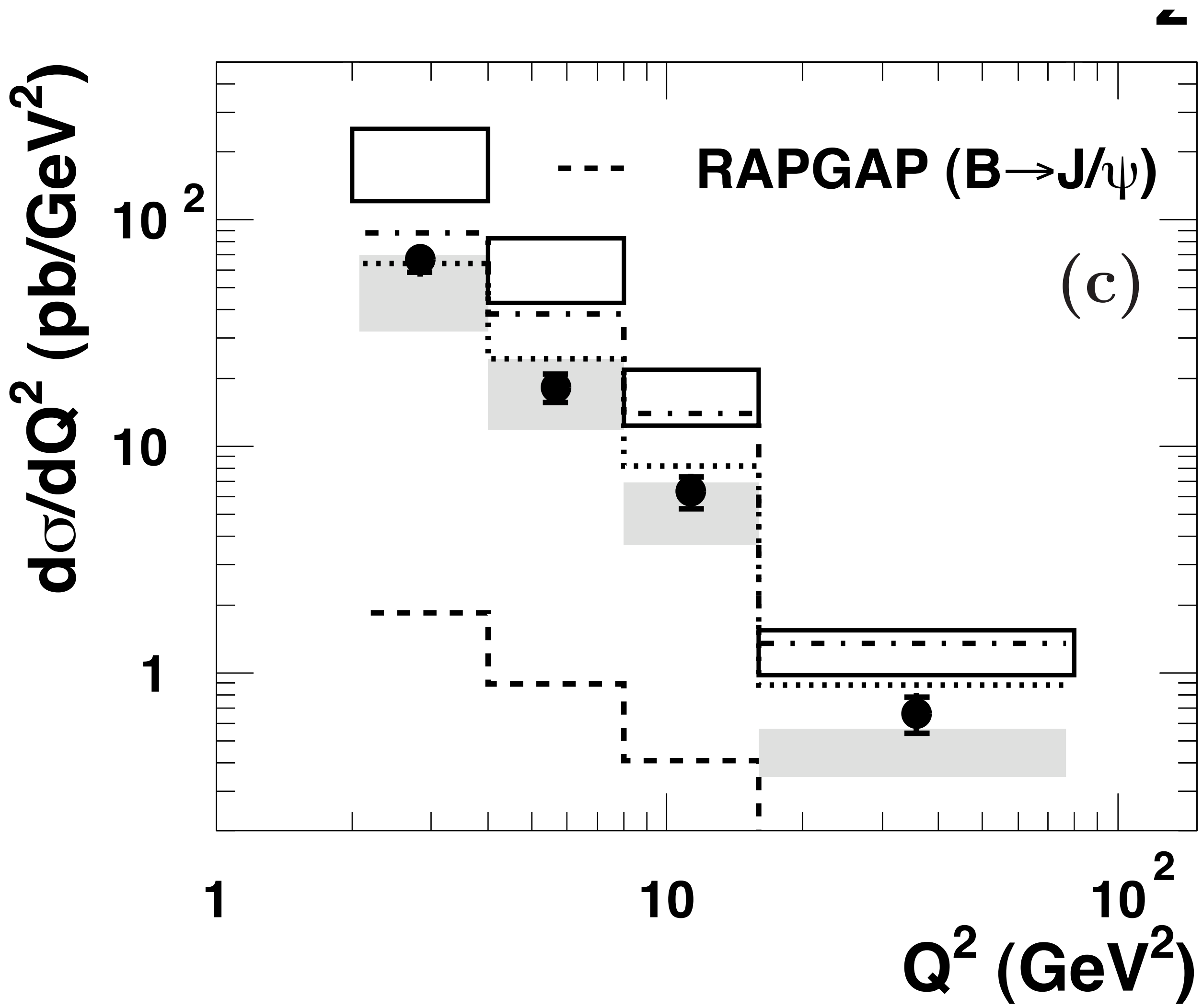




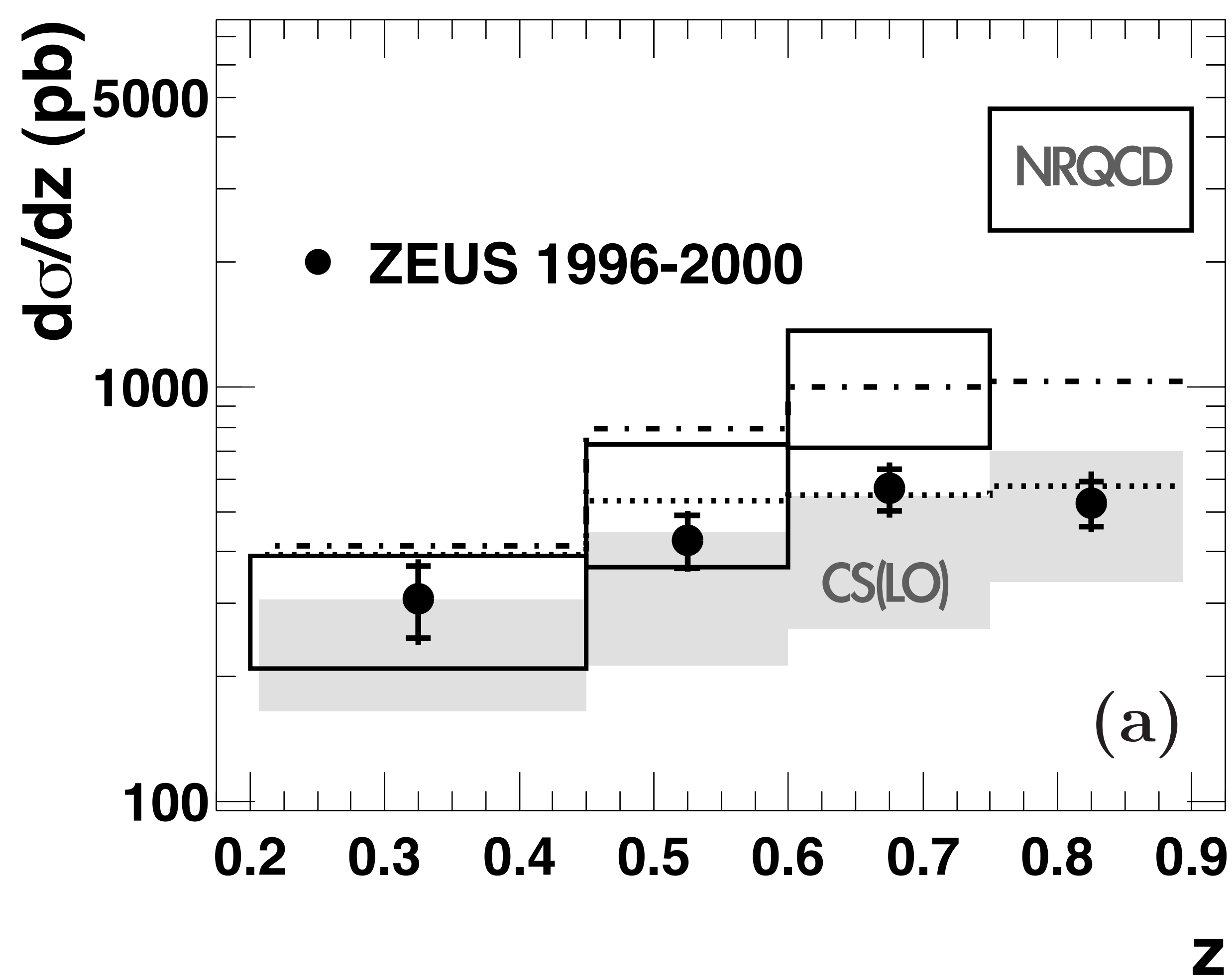
Both Run-I and Run-II data in contradiction to NRQCD expectation

J/ψ Electroproduction





$Q^2 > 2$ GeV^2

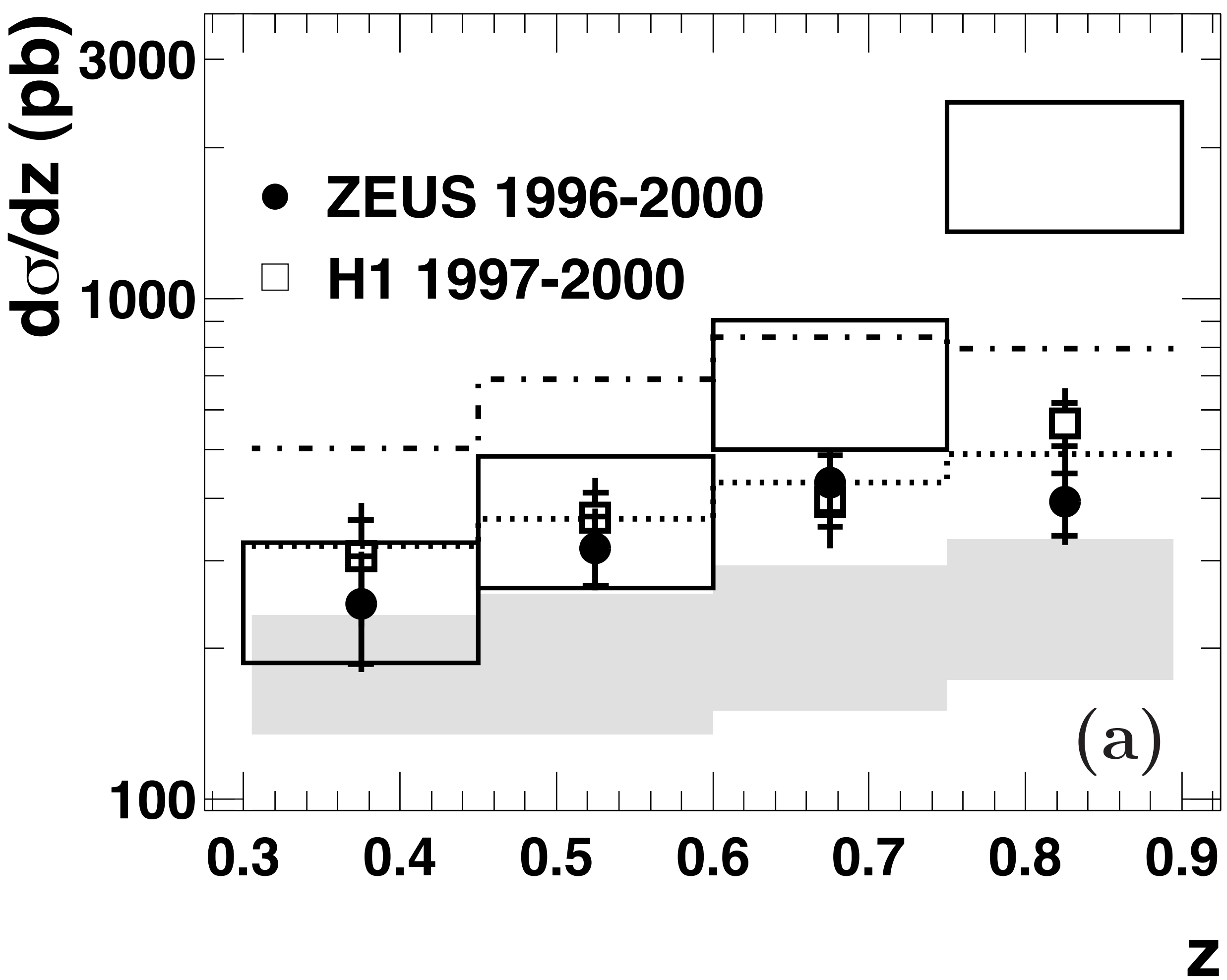


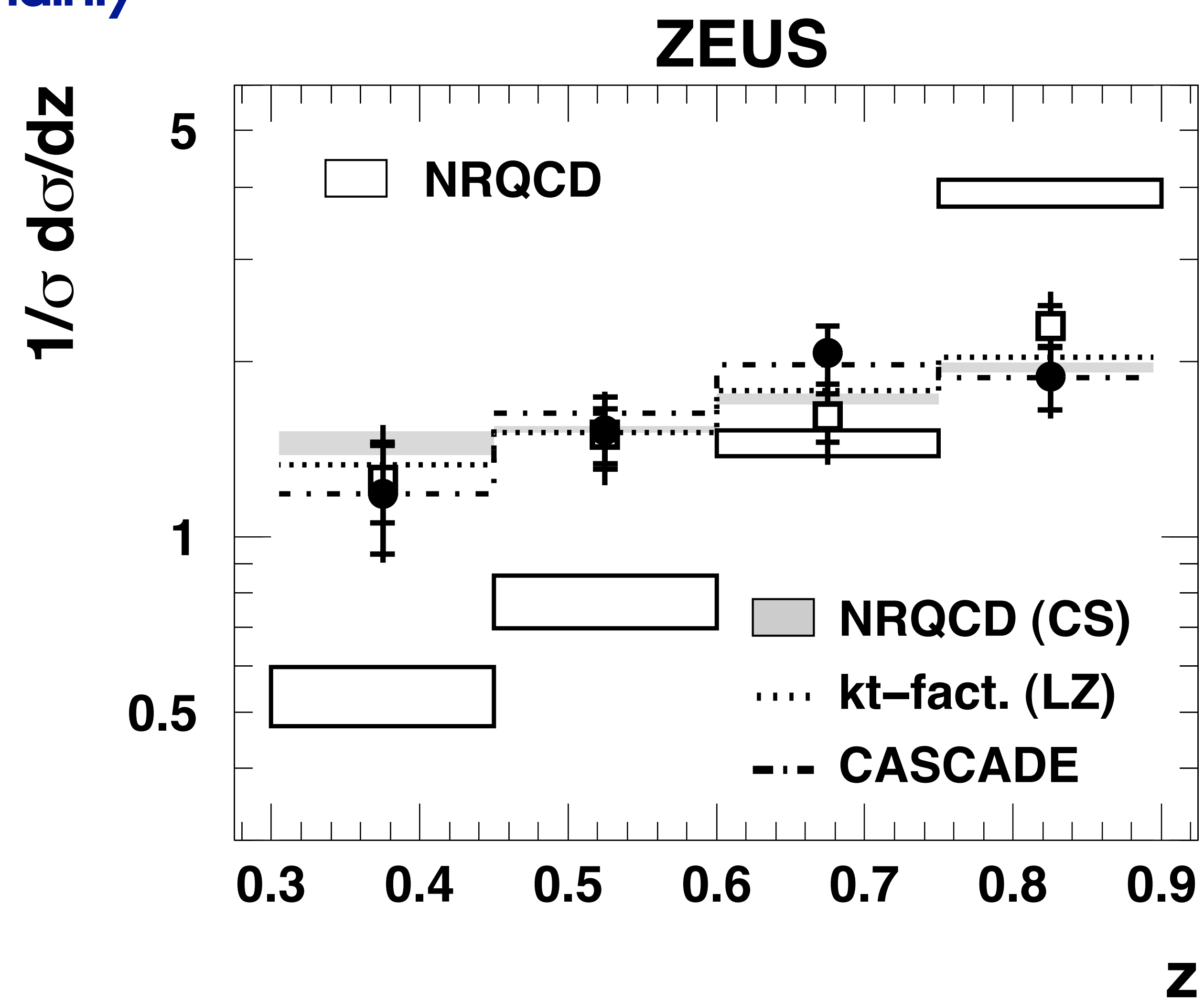
Kniehl, Zwirner 2001
Lipatov, Zotov 2002

CS (LO) alone agrees with data within errors
Full NRQCD (LO) too high

J/ψ Electroproduction

Additional cut on $p_t^* > 1$GeV:
remove regions of largest theor. uncertainty





- Agreement between ZEUS and H1 data
- CS underestimates normalization but describes shape
- CS+CO too high at high z
- CS with kt-factorization ok

Conclusions

- Published Measurements: HERA-I
  - ZEUS and H1 measurements of cross sections and helicity in agreement
  - Wealth of measurements of elastic vector meson production (not covered in this talk)

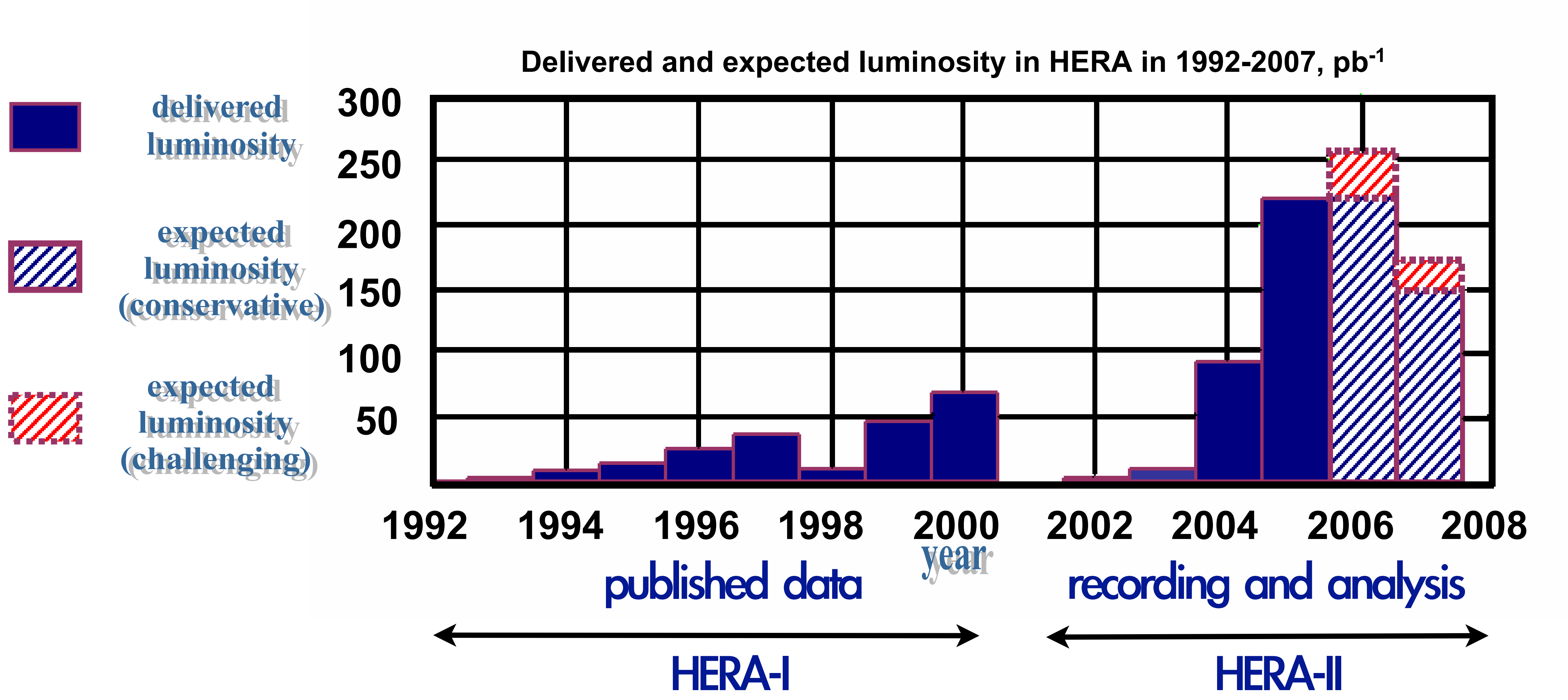
  - Color singlet model @ NLO or using kt-factorization describes γp data well
  - NRQCD (LO) predictions not satisfactory at HERA (or other experiments)

Description of Charmonium Production still causing trouble

Expect improved measurements and theory calculations

- Upcoming Measurements: HERA-II
  - Increased Luminosity, improved Statistics
    - Larger Q^2, p_t, Polarization
  - Measure contributions from B-decays
  - Look for CO contributions in X_c production at medium z, (where CS is suppressed)

Outlook



30-40% of Integrated Luminosity still ahead