HEP 2013, The 2013 European Physical Society Conference on High Energy Physics

Stockolm , July 18th-24th 2013

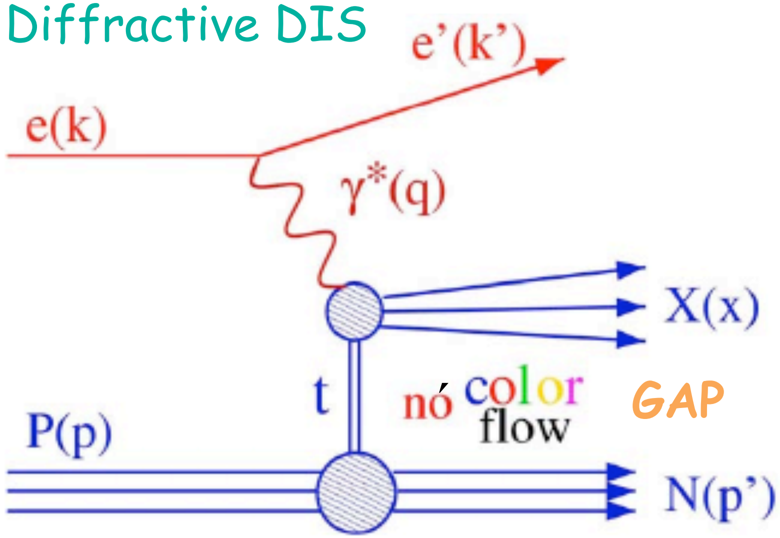
INCLUSIVE DIFFRACTION and VECTOR MESON PRODUCTION at HERA

Marta Ruspa

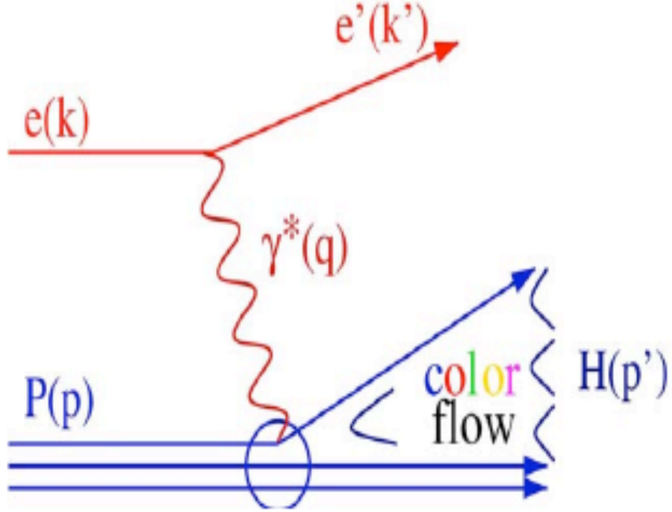
Univ. Piemonte Orientale & INFN-Torino, Italy

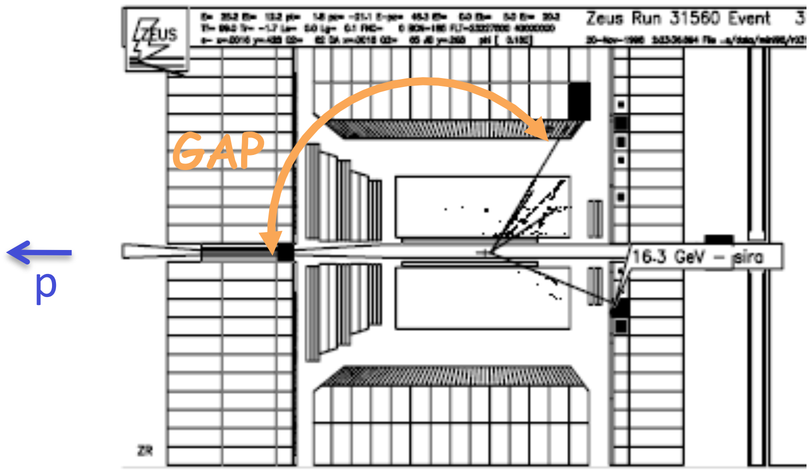
Diffractive dissociation of the (virtual) photon at HERA

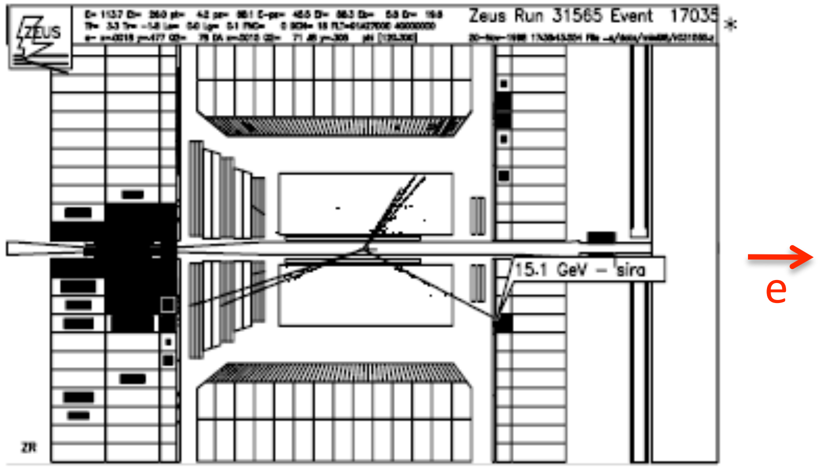
Diffractive DIS



Standard DIS

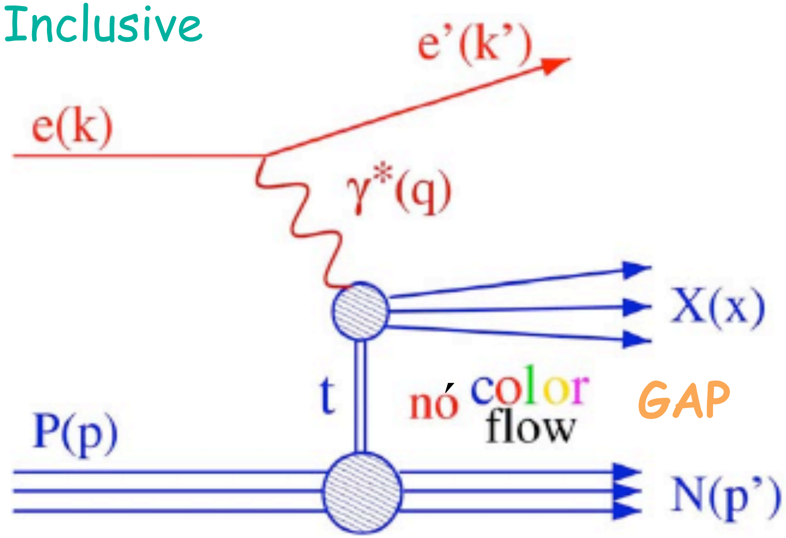




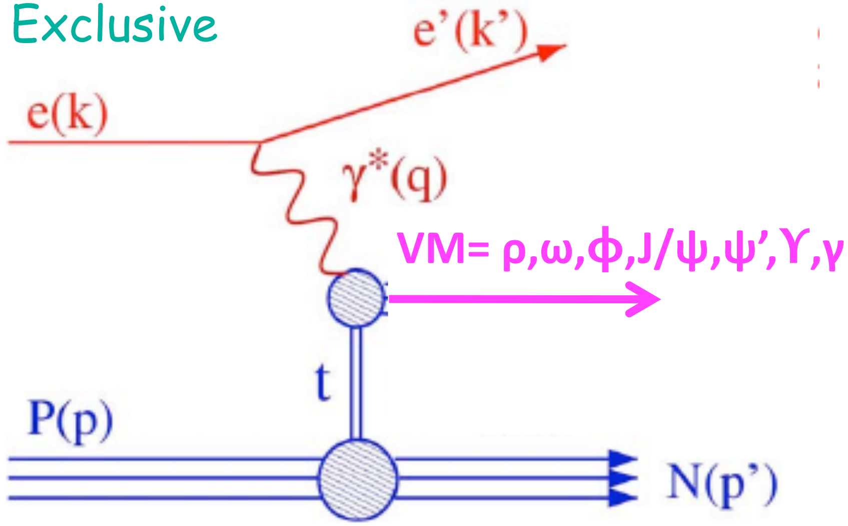


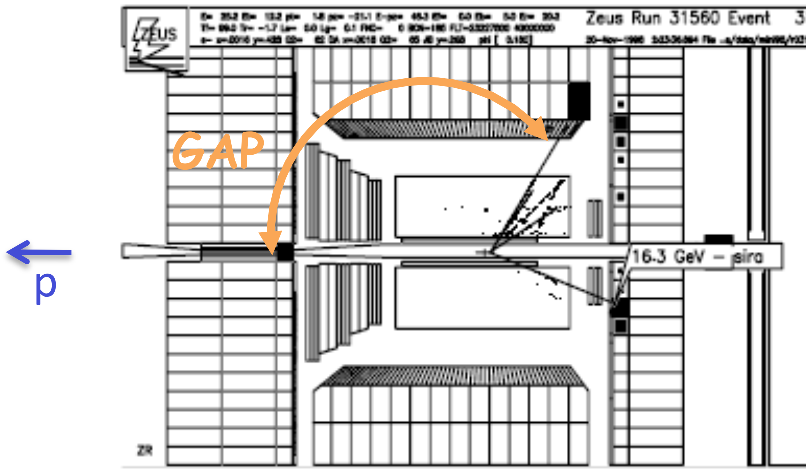
Inclusive and exclusive diffraction

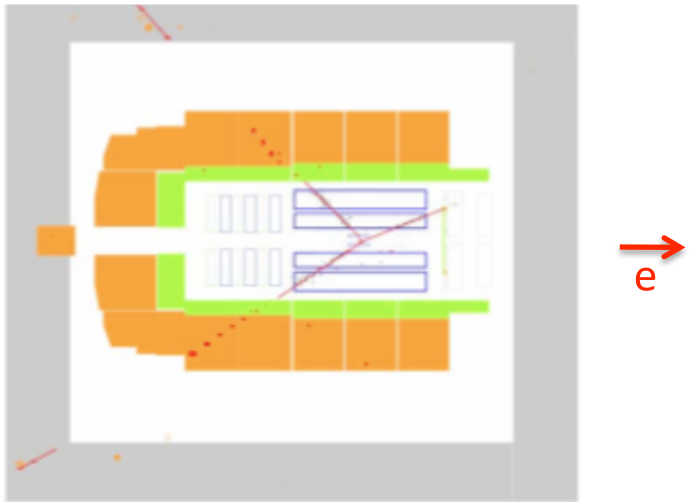
Inclusive



Exclusive





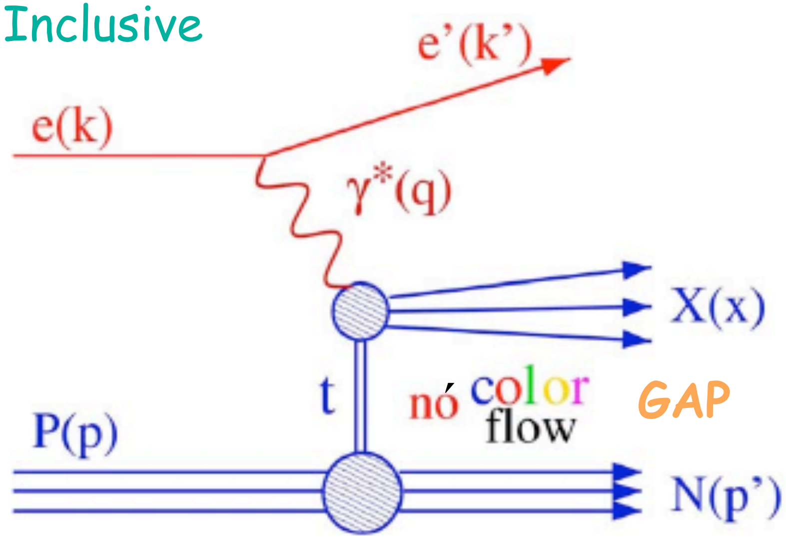


e p → e' X p

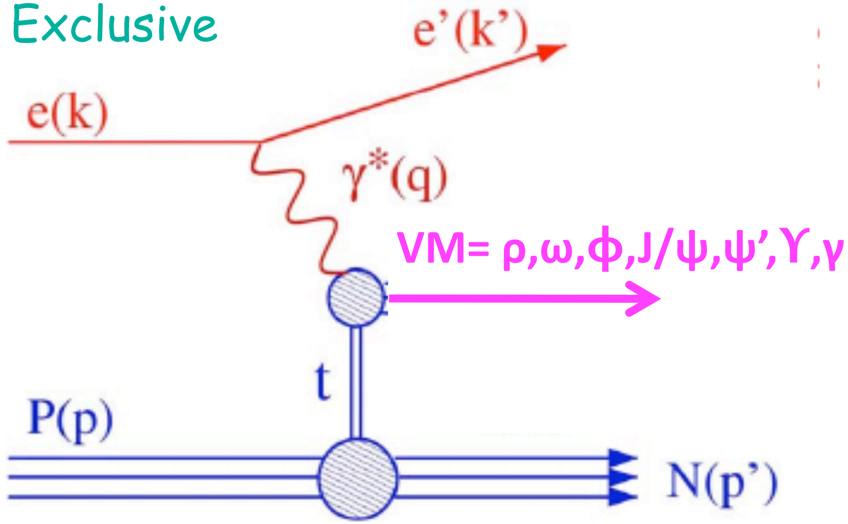
e p → e' J/ψ p J/ψ → $\mu^+\mu^-$

Inclusive and exclusive diffraction

Inclusive



Exclusive



Alternatively:

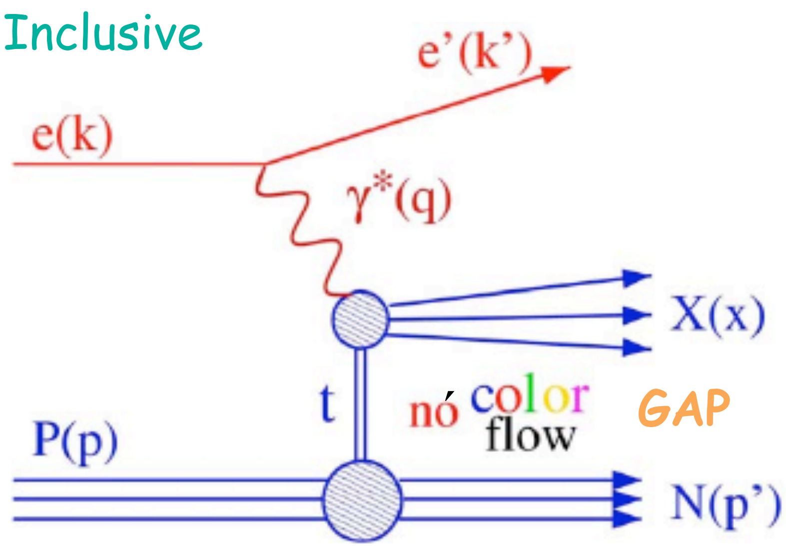
- require the large rapidity gap (LRG)
- tag the proton with spectrometers

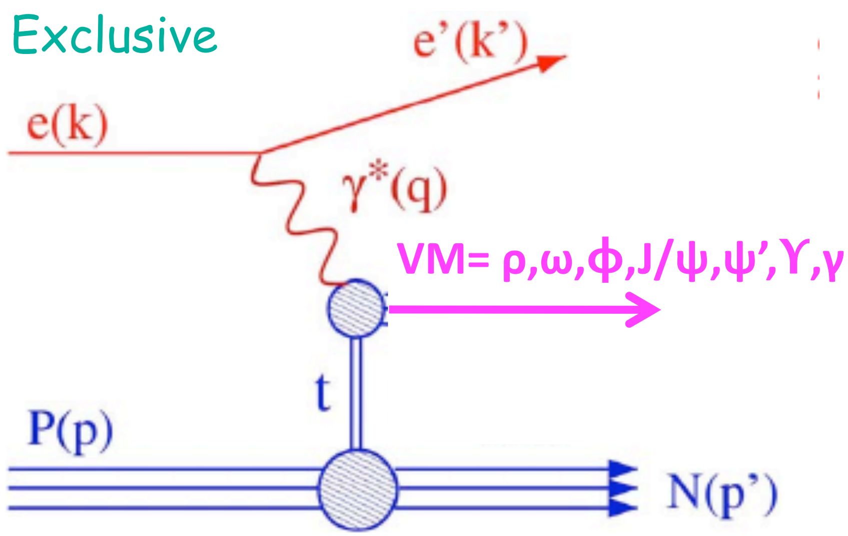
→ ZEUS Leading Proton Spectrometer (LPS)
→ H1 Forward Proton Spectrometer (FPS)
→ H1 Very Forward Proton Spectrometer (VFPS)

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

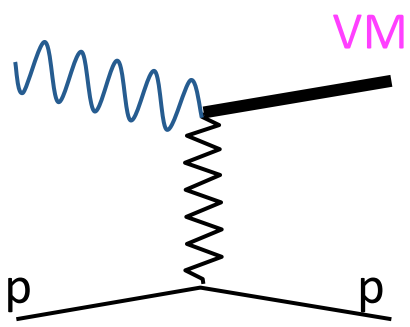
M_X = invariant mass of γ^* -IP system

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

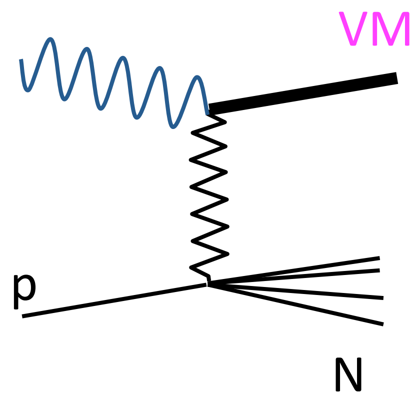
β = Bjorken's variable for the IP
= fraction of IP momentum carried by struck quark
= x/x_{IP}

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

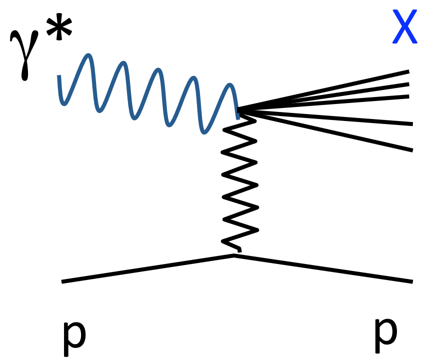
Photon and proton dissociation processes



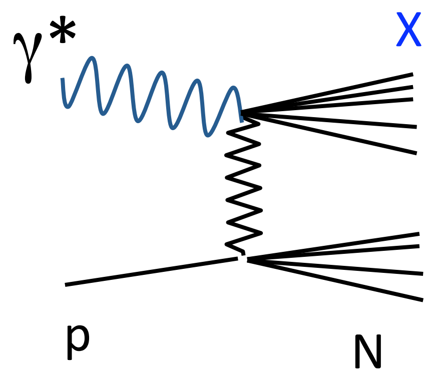
Elastic
vector meson production



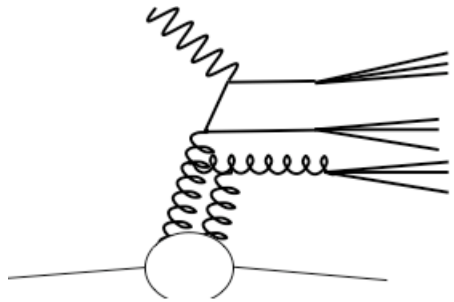
Proton dissociative
vector meson production



Single diffraction



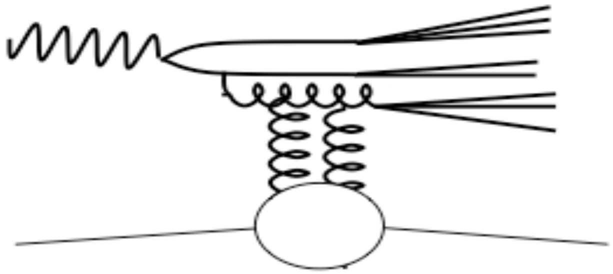
Double diffraction



Breit frame (proton very fast)

γ^* probes partonic content of the diffractive exchange

→Collinear factorization
Diffractive PDFs
Generalized PDFs



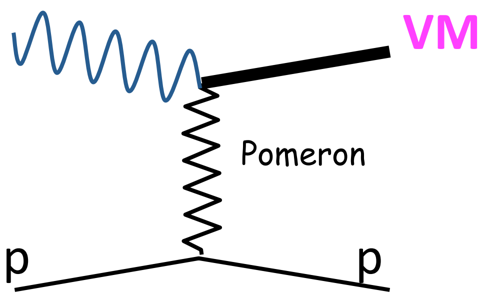
Proton rest frame

γ^* fluctuates into qqbar,qqbarg states (color dipoles) of transverse size proportional to $1/\sqrt{(Q^2+M_{qq}{}^2)}$

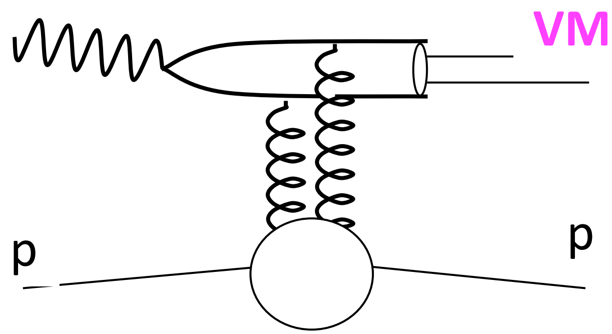
→ Dipole models
$\sigma \propto [xg(x,Q^2)]^2$

Transition soft-hard

Soft - Regge



Hard - QCD



With increasing scale (Q^2, M_{VM}, t)

$$\sigma(W) \propto W^{\delta}$$

- Expect δ to increase from soft (~0.2, 'soft Pomeron' value) to hard (~0.8, reflecting large gluon density at low x)

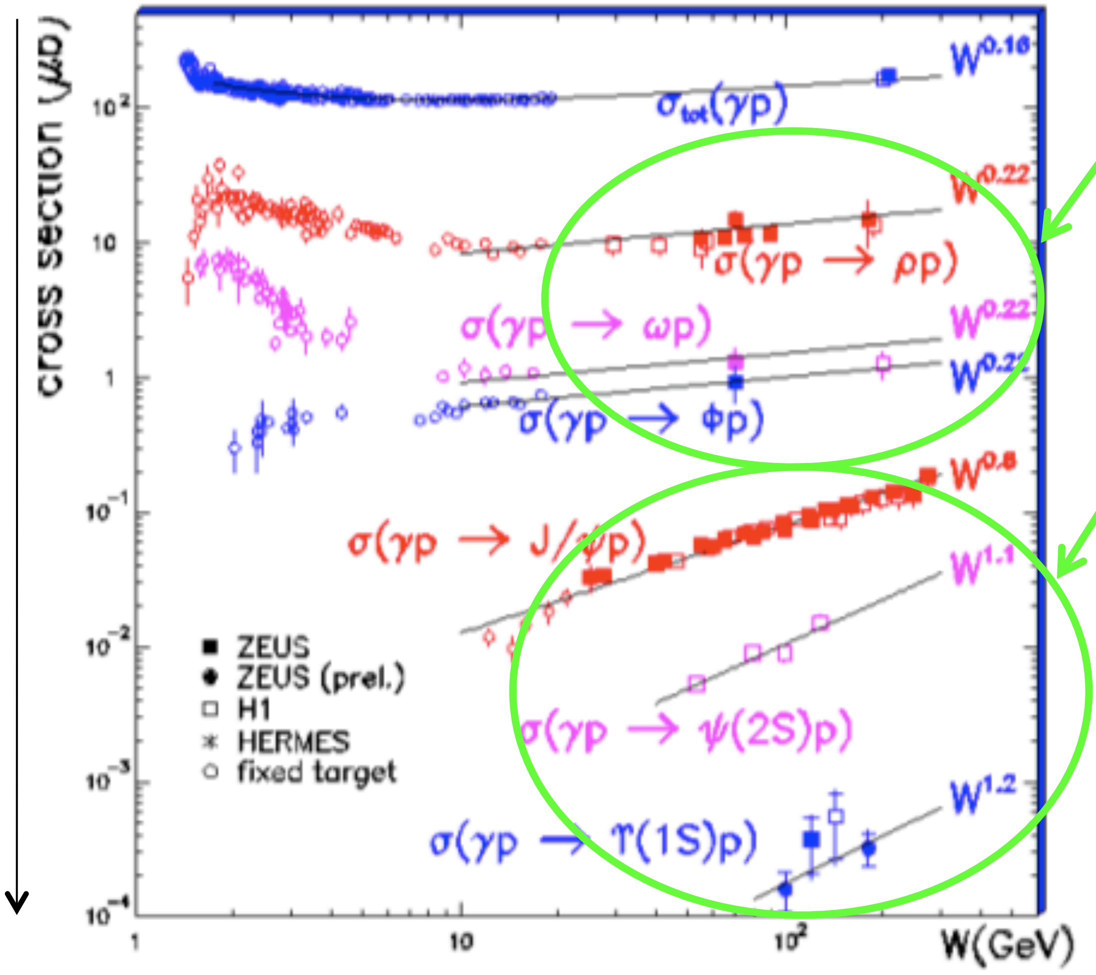
$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

- Expect b to decrease from soft (~10 GeV^{-2}) to hard (~4-5 GeV^{-2})

Transition soft-hard, energy dependence

Photoproduction, $Q^2 = 0$

M_{VM}



~1/√x

small M_{VM} (~ 1 GeV^2): transverse size of dipole ~ size of proton

large M_{VM}: small dipole size

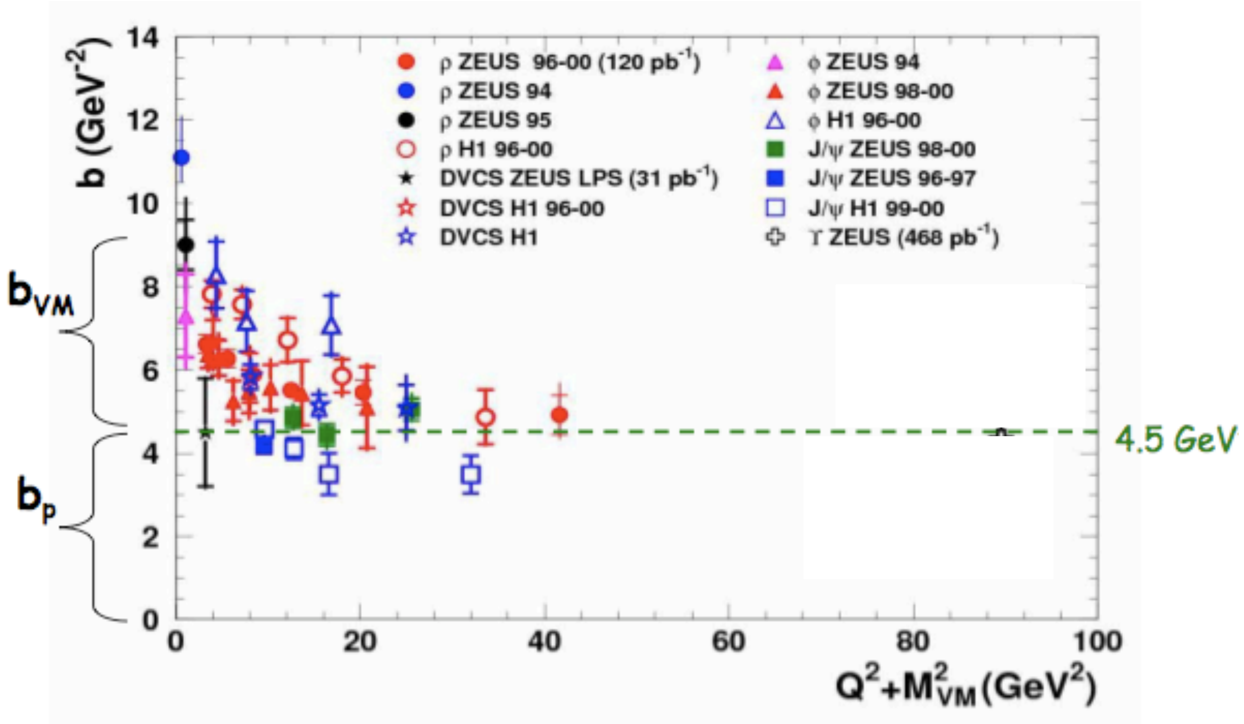
→cross section much smaller

→dipole resolves partons in the proton

VM data can help determine gluon density!

Here scale is M_{VM} – same observed when varying Q^2 for a given VM

Transition soft-hard,t-slope dependence



$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

As in optical diffraction, size of diffractive cone related to size of interacting objects

$b \sim b_{VM} + b_p$

VM production at HERA, what's up

Rich harvest documented by tens of publications
Large W interval, wide range of several scales (Q^2, t, M_{VM})

Presently H1 and ZEUS are finalizing analyses of post-upgrade data

- key measurements repeated with full statistics

- runs at reduced center of mass energy originally devoted to F_L extraction allow studies with different kinematics

- low cross section processes benefit from higher lumi

NEW: Elastic and proton dissociative J/ψ photoproduction, [arXiv:1304.5162]

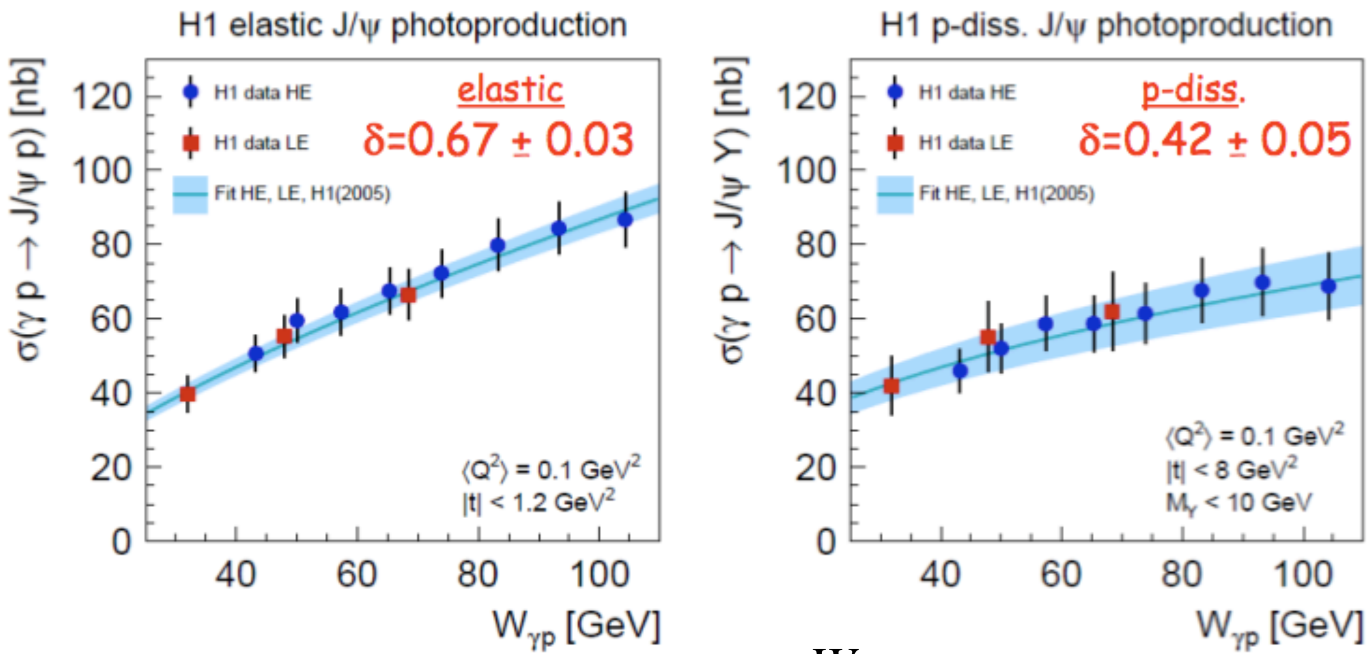
NEW: t-slope extraction in Υ photoproduction [Phys. Lett. B 708 (2012) 14]

Elastic and p-diss J/ψ photoproduction

ENERGY DEPENDENCE

Cross sections for elastic and p-diss processes measured simultaneously

Two energy ranges: HE ($\sqrt{s}$ = 318 GeV) and LE ($\sqrt{s}$ = 225 GeV)
LE data allow extension to lower $W_{\gamma p}$



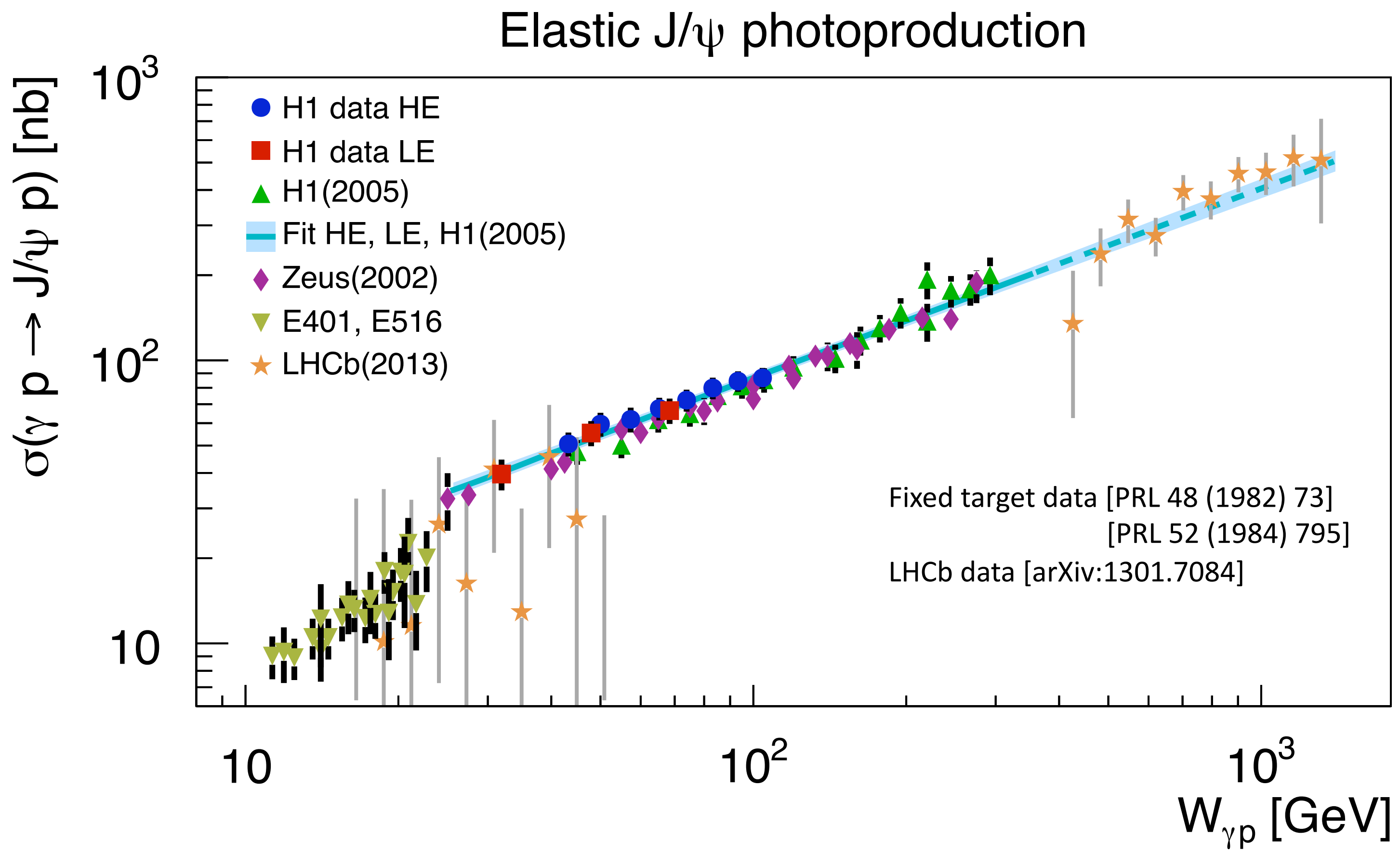
Simultaneous fit to the form $\sigma = N(\frac{W_{\gamma p}}{W_0})^{\delta}$

$x\, g(x,\mu^2) = N\, x^{-\lambda}$
$\delta_{el} \approx 4\, \lambda_{J/\psi}$
[PLB 662 (2008) 252]

$\lambda_{J/\psi}$ agrees remarkably with λ_{incl}

Elastic and p-diss J/ψ photoproduction

ENERGY DEPENDENCE

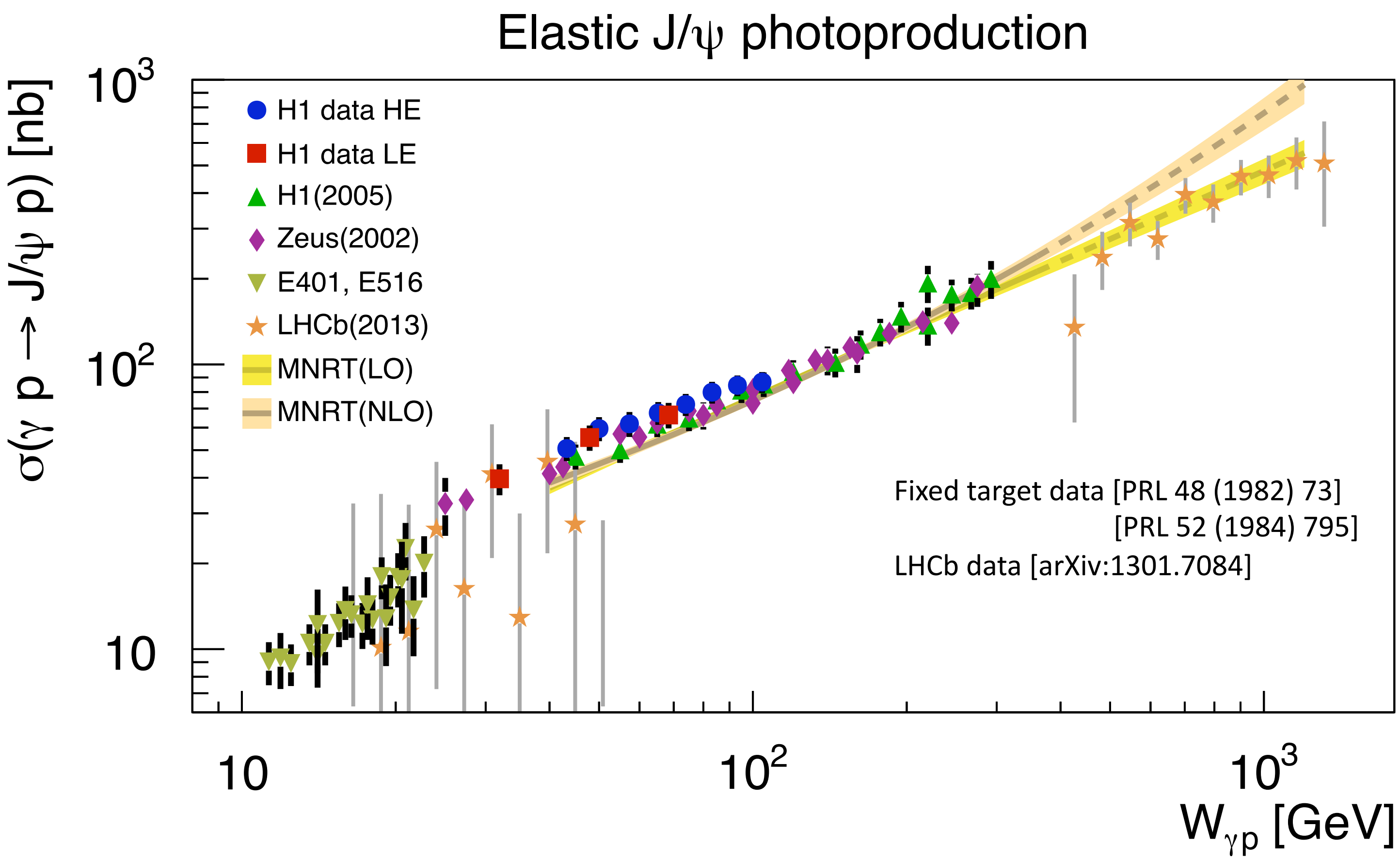


New LE measurements fill the region between fixed target and previous HERA data

Fixed target data: steeper slope, lower normalisation (?)

Fit to H1 data extrapolated to higher $W_{\gamma p}$ describes LHCb data

Elastic and p-diss J/ψ photoproduction
ENERGY DEPENDENCE



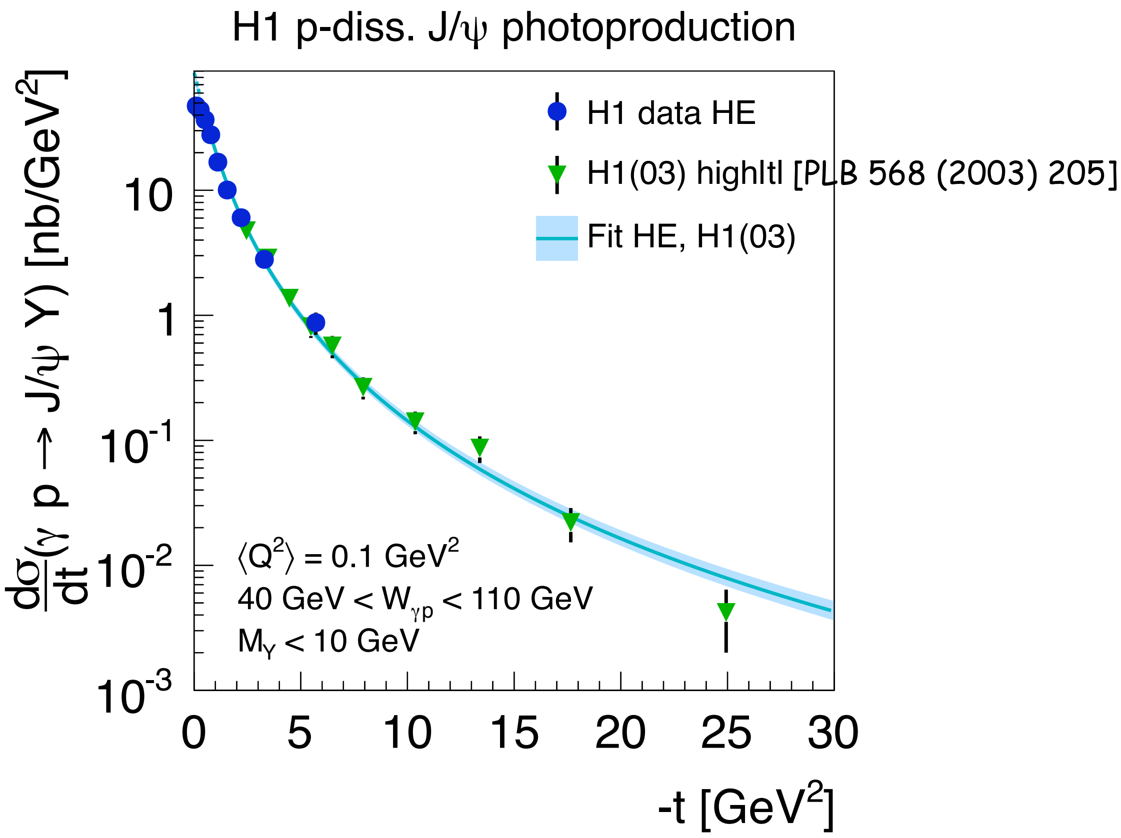
LO and NLO fits to previous J/ψ measurements at HERA [PLB 662 (2008) 252]

Fits extrapolated to higher $W_{\gamma p}$

LO fit describes LHCb data

Elastic and p-diss J/ψ photoproduction

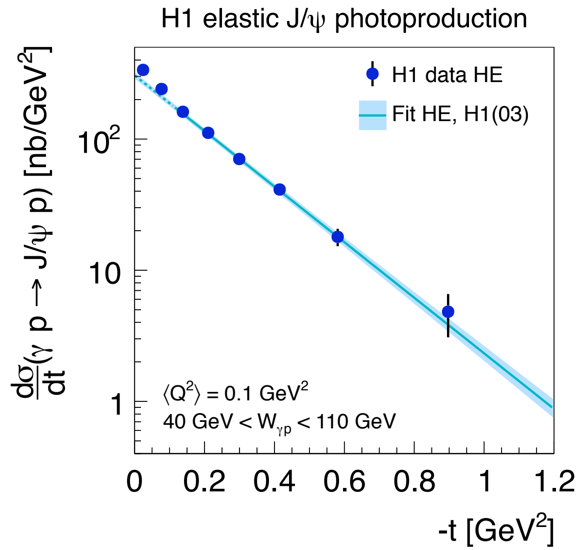
t-slope DEPENDENCE

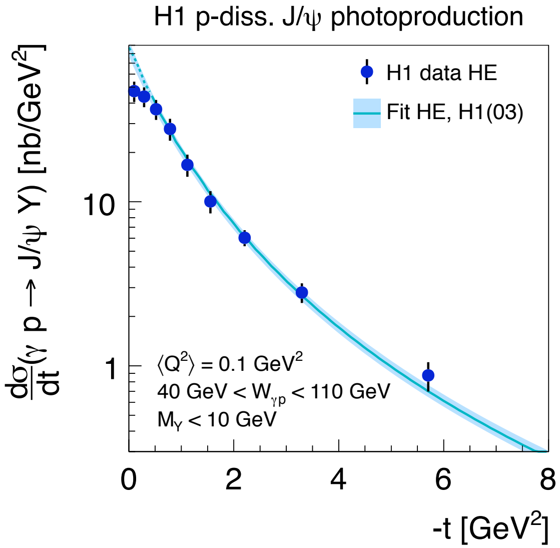


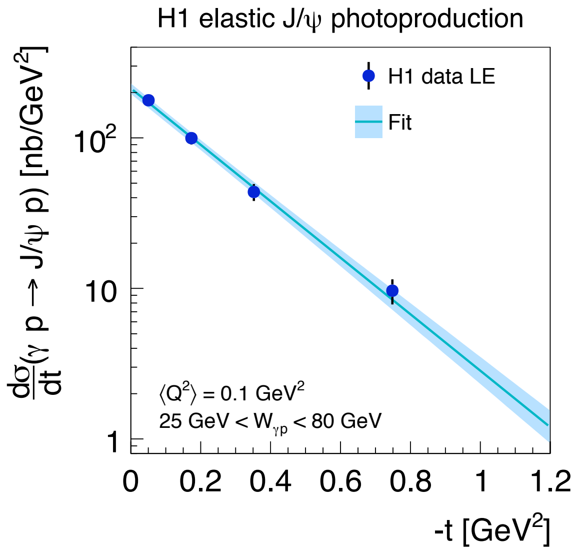
The new data extend the reach to small values of $|t|$

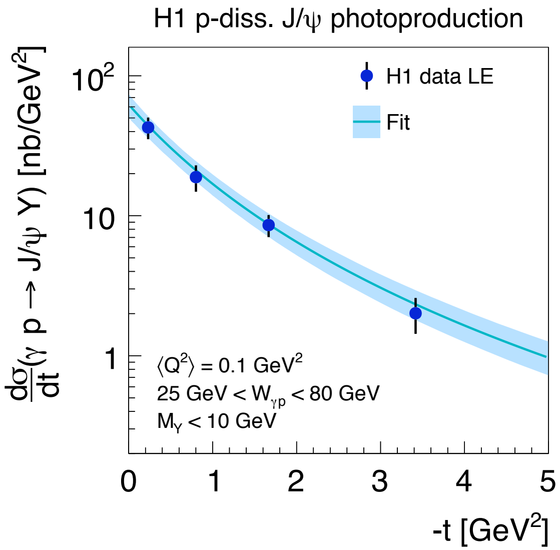
Elastic and p-diss J/ψ photoproduction

t-slope DEPENDENCE









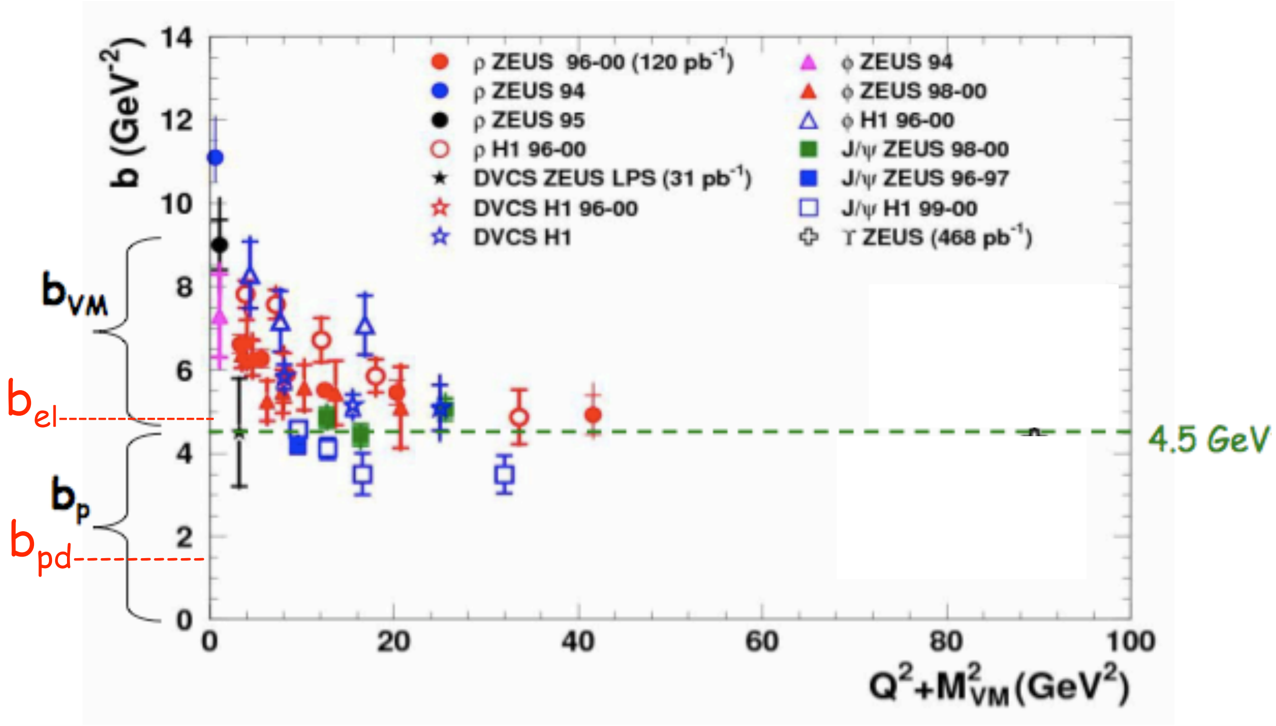
Simultaneous* fit to the forms

- $\frac{d\sigma_{el}}{dt} = N_{el} e^{-b_{el}|t|}$ elastic
- $\frac{d\sigma}{dt} = (N_{pd}(1 + \frac{b_{pd}}{n})|t|)^{-n}$ p-diss

*Fit includes old data H1(03) [PLB 568 (2003) 205]

→ b_{el} = 4.88 ± 0.15 GeV^{-2}(HE)
b_{pd} = 1.79 ± 0.12 GeV^{-2}(HE)
b_{el} = 4.3 ± 0.2 GeV^{-2} (LE)
b_{pd} = 1.6 ± 0.2 GeV^{-2} (LE)

Transition soft-hard,t-slope dependence



$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

As in optical diffraction, size of diffractive cone related to size of interacting objects

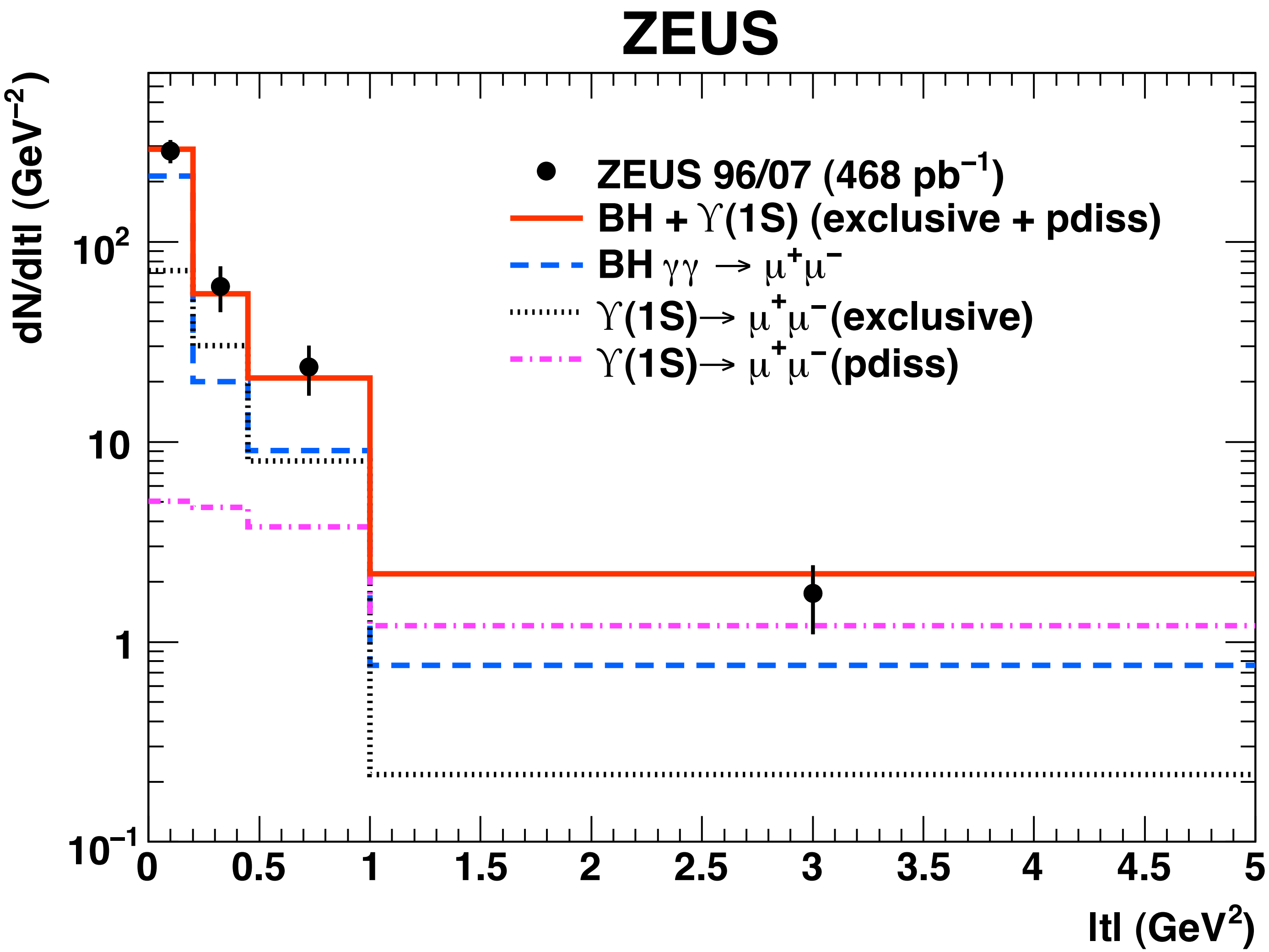
$b \sim b_{VM} + b_p$

J/ψ has small size compared to proton

For p-diss proton breaks → b_{pd} is smaller than b_{el}

Elastic Υ(1S) photoproduction

t-slope DEPENDENCE



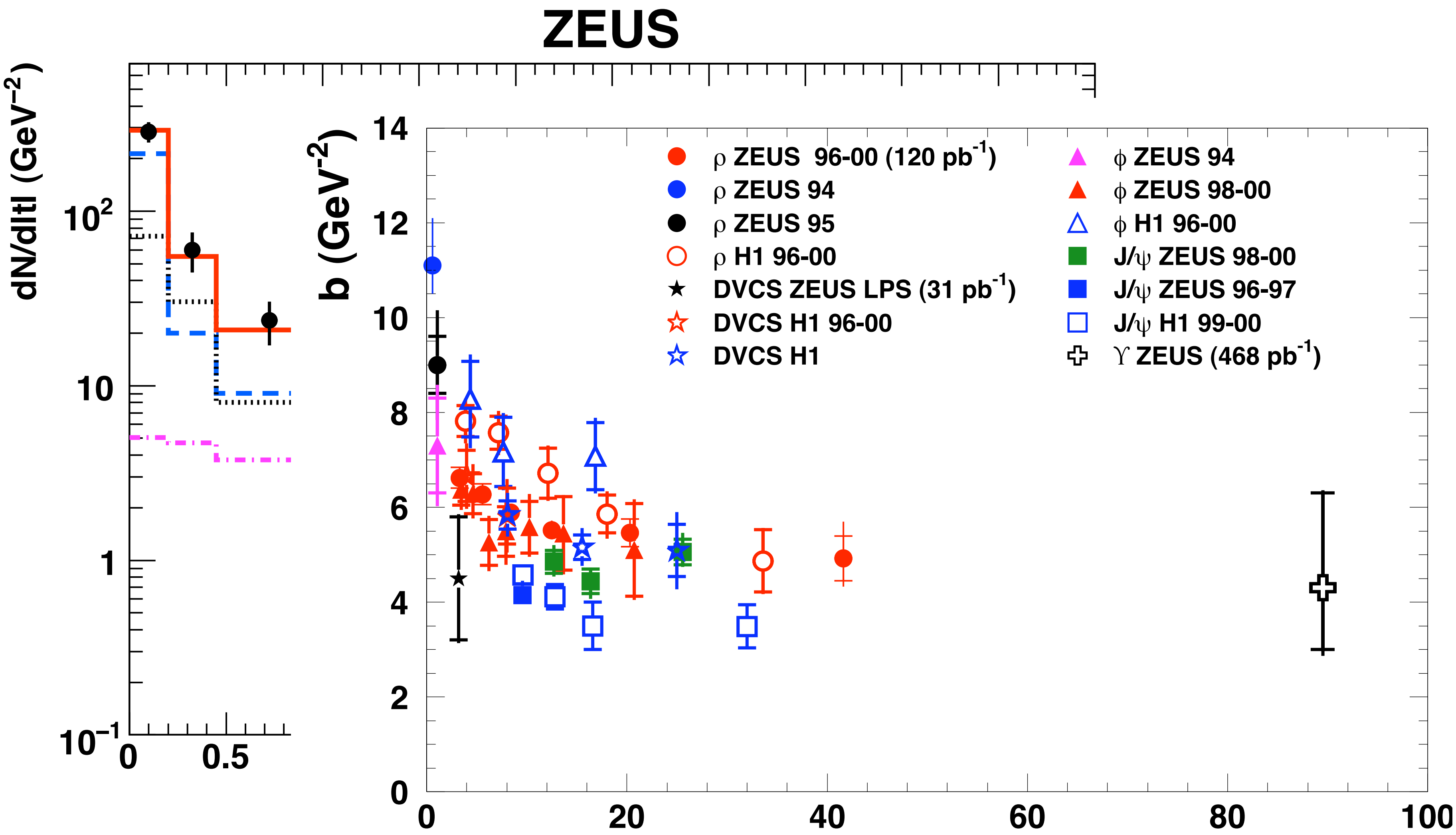
Fit to the form

$$\frac{d\sigma}{dt} = e^{-b|t|}$$

$$b = 4.3^{+2.0}_{-1.3}(stat.)^{+0.5}_{-0.6}(syst.)GeV^{-2}$$

Elastic Υ(1S) photoproduction

t-slope DEPENDENCE



$$b = 4.3^{+2.0}_{-1.3}(stat.)^{+0.5}_{-0.6}(syst.)GeV^{-2}$$

Inclusive diffraction at HERA, what's up

Several publication based on the proton spectrometer method (LPS, FPS) and on the large rapidity gap (LRG) method

H1 LRG	H1 Collab., Eur. Phys. J. C48 (2006) 715 H1 Collab., Eur. Phys. J. C72 (2012) 2074	NEW! See next talk
ZEUS LRG	ZEUS Collab., Nucl. Phys. B816 (2009) 1	Consistent results from the two methods
H1 FPS	H1 Collab., Eur. Phys. J. C71 (2011) 1578 H1 Collab., Eur. Phys. J. C48 (2006) 749	Comparison H1-ZEUS
ZEUS LPS	ZEUS Collab., Nucl. Phys. B816 (2009) 1 ZEUS Collab., Eur. Phys. J. C38 (2004) 43	QCD analysis and PDFs extraction

Combining the measurements can provide more precise and kinematically extended data than the individual sets

Proton spectrometer results now combined
(first combination in diffraction at HERA!)

Data sets for combination

- H1 FPS HERA II
  [Eur.Phys.J. C71 (2011) 1578]
  Luminosity = 156.6 pb^{-1}
  Visible range |t| = 0.1 - 0.7 GeV^2
  Norm unc ~ ± 6%

- H1 FPS HERA I
  [Eur.Phys.J. C48 (2006) 749]
  Luminosity = 28.4 pb^{-1}
  Visible range |t| = 0.08 - 0.5 GeV^2
  Norm unc ~ ± 10%

- ZEUS LPS 2
  [Nucl.Phys. B816 (2009) 1]
  Luminosity = 32.6 pb^{-1}
  Visible range |t| = 0.09 - 0.55 GeV^2
  Norm unc ~ +11 -7%

- ZEUS LPS 1
  [Eur.Phys.J. C38 (2004) 43]
  Luminosity = 3.6 pb^{-1}
  Visible range |t| = 0.075 - 0.35 GeV^2
  Norm unc ~ +12% - 10%

Diffractive reduced cross sections $\sigma_r^{D(3)}$

$$\frac{d^2\sigma^{ep\to e'Xp'}}{d\beta dQ^2 dx_{IP} dt} = \frac{4\pi\alpha^2}{\beta Q^4}\left[1 - y + \frac{y^2}{2(1+R^D)}\right]\cdot F_2^{D(4)}(\beta, Q^2, x_{IP}, t)$$
$$= \frac{4\pi\alpha^2}{\beta Q^4}\left[1 - y + \frac{y^2}{2}\right]\cdot \sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t)$$

$$\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) = \int \sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t)\,dt$$

Combination performed in the ZEUS visible t range |t| = 0.09 - 0.55 GeV^2

Prior to combining, ZEUS cross section points swam to H1 (Q^2, β, x_{IP}) grid

Combination method

- χ^2 minimization which includes full error correlations
[A. Glazov, AIP Conf. Proc. 792 (2005) 237]

- Used for previous combined HERA results [JHEP 1001 (2010) 109]

- Key assumption is that H1 and ZEUS are measuring the same cross sections at the same kinematic points

→ Model independent check of the data consistency and reduction of the systematic uncertainty

Combination method

- χ^2 minimization which includes full error correlations
[A. Glazov, AIP Conf. Proc. 792 (2005) 237]

- Used for previous combined HERA results [JHEP 1001 (2010) 109]

- Key assumption is that H1 and ZEUS are measuring the same cross sections at the same kinematic points

→ Model independent check of the data consistency and reduction of the systematic uncertainty

For a single data set:

$$\chi^2_{\exp}(\vec{m},\vec{b}) = \sum_i \frac{[m^i - \sum_j \gamma^i_j m^i b_j - \mu^i]^2}{\delta^2_{i,stat}\mu^i (m^i - \sum_j \gamma^i_j m^i b_j) + (\delta_{i,uncor} m^i)^2} + \sum_j b_j^2$$

μ^i measured cross section values

m^i combined cross section values

b_j shifts of correlated systematic uncertainty sources in σ units

γ^i_j relative correlated systematic unc.

δ^i_{stat} relative statistical unc.

δ^i_{uncor} relative uncorrelated systematic unc.

Full χ^2_{tot} built from the sum of the χ^2_{exp} of each data set, assuming the individual data sets to be statistically uncorrelated

X^2_{tot} minimized wrt m^i and b_j

Uncertainties

- Input cross sections published with their statistical and systematic uncertainties; the latter classified into point-to-point uncorrelated and correlated
- Global normalisations included in the fit
- H1 and ZEUS systematic uncertainties treated as independent
- A few procedural uncertainties considered:
  - i. additive vs multiplicative nature of the error sources
  - ii. correlated systematic error sources ZEUS-H1
  - iii. swimming factors applied to ZEUS points
  - iv treatment of the uncertainty on the H1 hadronic energy scale (in the nominal average taken as correlated separately for $x_{IP} < 0.012$ and $x_{IP} > 0.012$)

Results

352 data points combined to 191 cross section measurements

Good consistency: χ^2/n_{dof} = 133/161

Source	Shift (σ units)	Reduction factor %
FPS HERA II hadronic energy scale $x_{I\!P} < 0.012$	−1.61	56.9
FPS HERA II hadronic energy scale $x_{I\!P} > 0.012$	0.13	99.8
FPS HERA II electromagnetic energy scale	0.49	85.9
FPS HERA II electron angle	0.67	66.6
FPS HERA II β reweighting	0.15	90.4
FPS HERA II $x_{I\!P}$ reweighting	0.05	98.3
FPS HERA II t reweighting	0.70	79.8
FPS HERA II Q^2 reweighting	0.09	97.6
FPS HERA II proton energy	0.05	45.6
FPS HERA II proton p_x	0.62	74.5
FPS HERA II proton p_y	0.27	86.5
FPS HERA II vertex reconstruction	0.07	97.0
FPS HERA II background subtraction	0.84	89.9
FPS HERA II bin centre corrections	−1.05	87.3
FPS HERA II global normalisation	−0.39	84.4
FPS HERA I global normalisation	0.81	48.9
LPS 2 hadronic energy scale	−0.02	55.0
LPS 2 electromagnetic energy scale	−0.14	62.4
LPS 2 $x_{I\!P}$ reweighting	−0.32	98.2
LPS 2 t reweighting	−0.26	86.4
LPS 2 background subtraction	0.40	94.9
LPS 2 global normalisation	−0.53	67.7
LPS 1 global normalisation	0.86	44.1

Table 3: Sources of point-to-point correlated systematic uncertainties considered in the combination. For each source the shifts resulting from the combination in units of the original uncertainty and the values of the final uncertainties as percentages of the original are given.

Influence of several correlated systematic uncertainties reduced significantly for the combined result

Cross calibration brings average improvement of experimental uncertainty of 27% wrt most precise single data set (FPS HERA II)

Correlated part of experimental uncertainty reduced from about 69% in FPS HERA II to 49%

Results

352 data points combined to 191 cross section measurements

Good consistency: χ^2/n_{dof} = 133/161

Statistical uncertainty: 11%

Statistical + correlated + uncorrelated: 13.8%

Procedural uncertainty: 2.9%

Total uncertainty on cross section 14.3% on average and 6% for most precise points

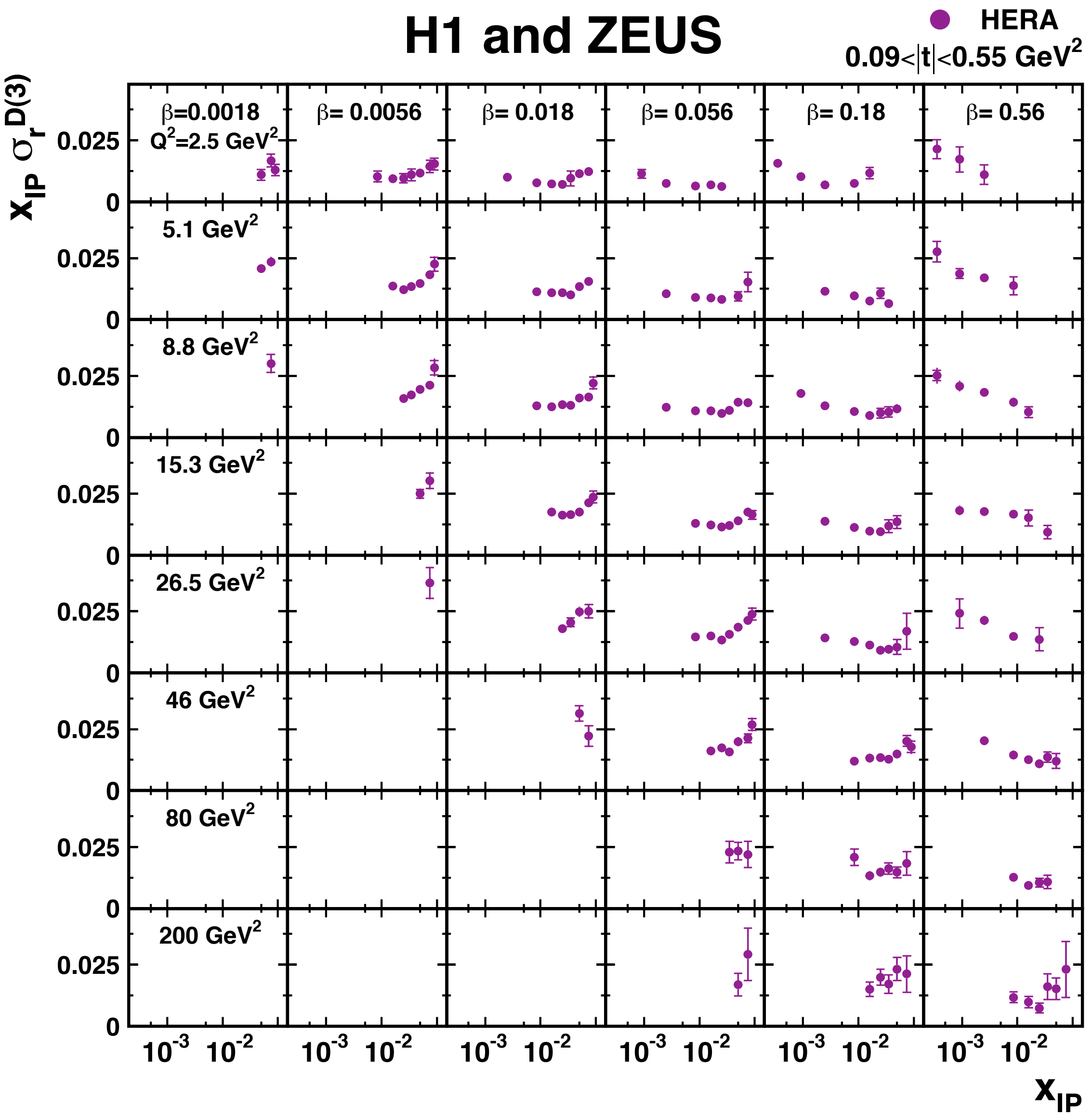
Normalization uncertainty: 4%

Kinematic coverage extended wrt single input measurements

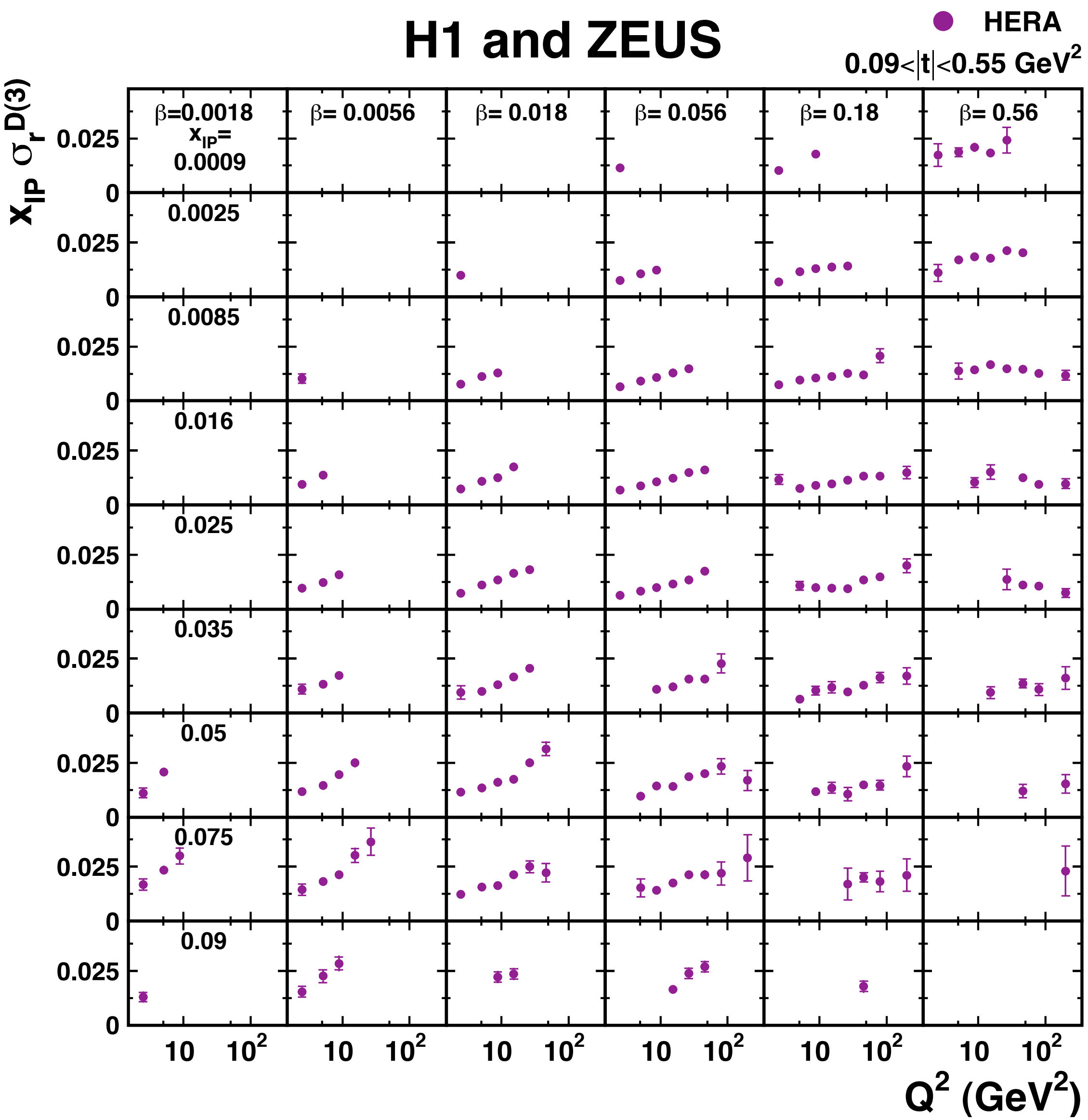
Q^2 = 2.5 - 200 GeV^2
β = 0.0018 - 0.816
x_{IP} = 0.00035 - 0.09
$|t|$ = 0.09 - 0.55

At low x_{IP}, where the proton spectrometer data are free from proton dissociation background, these combined data provide the most precise determination of the absolute normalisation of the diffractive cross section

Combined $\sigma_r^{D(3)}$

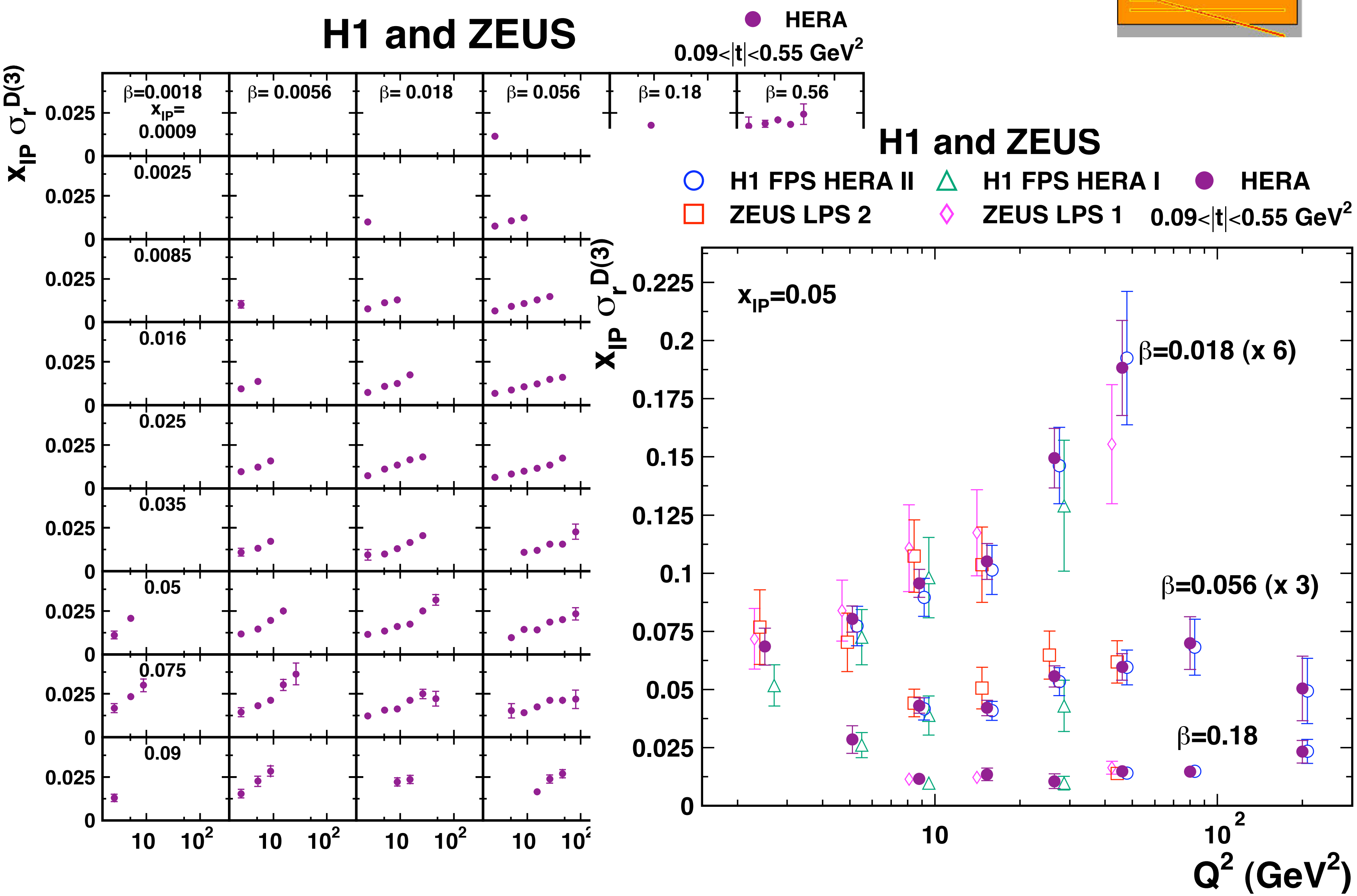


Combined $\sigma_r^{D(3)}$



Nice and precise measurement of the scaling violation in diffraction

Combined $\sigma_r^{D(3)}$



In a few words…

In 15 years of running HERA provided unique diffractive data

Presently H1 and ZEUS are

- finalizing analyses of post-upgrade data
  - key measurements repeated with full statistics
  (J/ψ production, inclusive diffraction)
  - low cross section processes benefit from higher lumi
  (ϒ production)

- combining their data (inclusive diffraction)

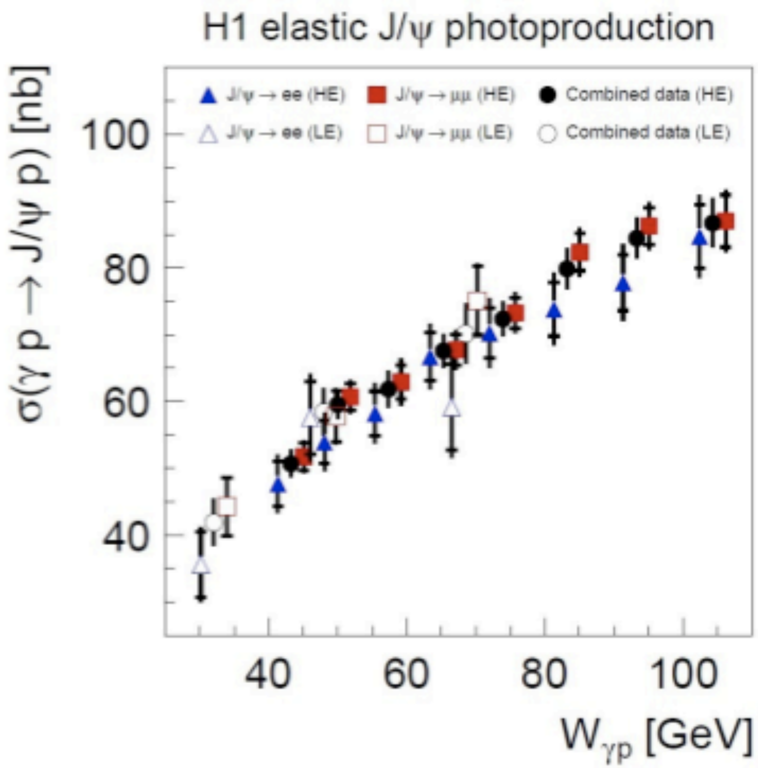
Backup

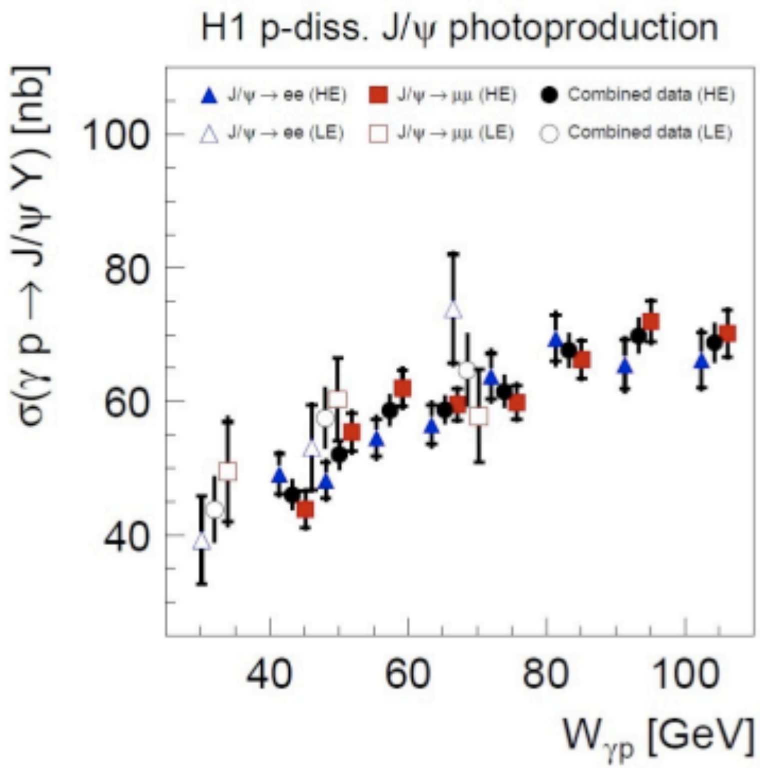
Elastic and p-diss J/ψ photoproduction

ENERGY DEPENDENCE

Cross sections for elastic and p-diss processes measured simultaneously

Two energy ranges: HE ($\sqrt{s}$ = 318 GeV) and LE ($\sqrt{s}$ = 225 GeV)
LE data allow extension to lower $W_{\gamma p}$

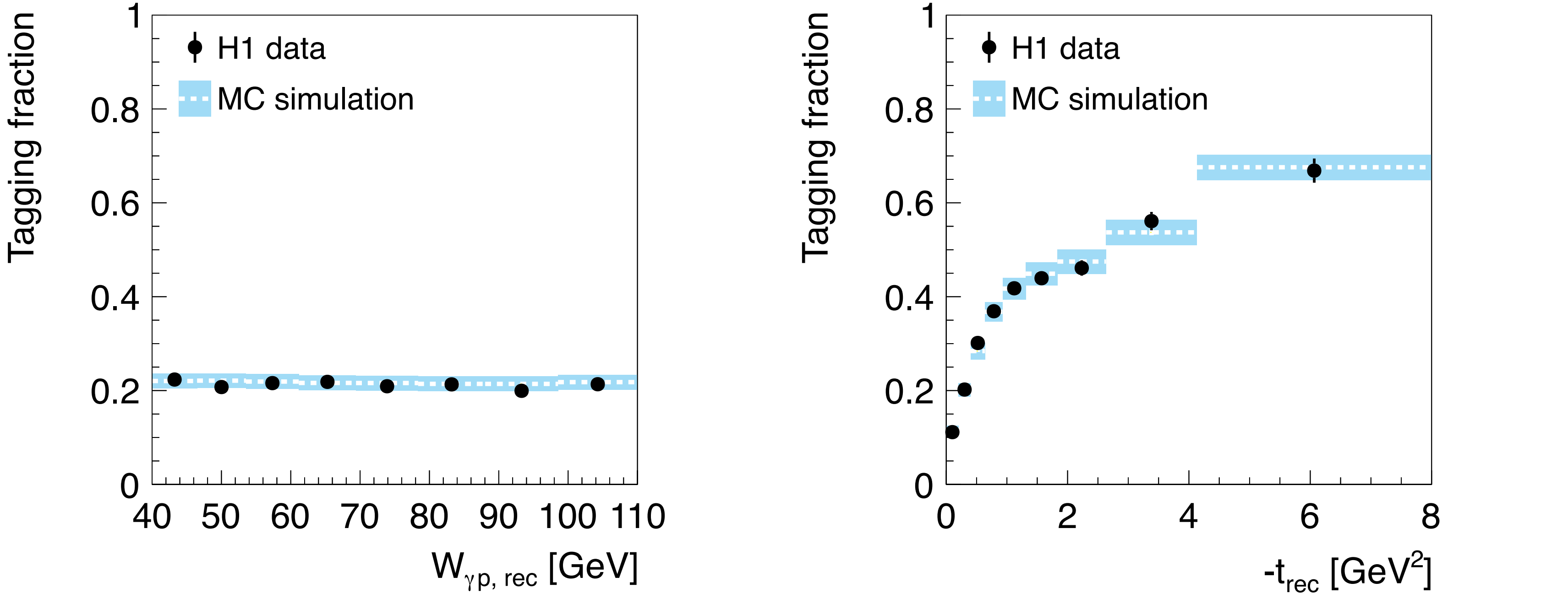




Combination of decay channels separately for elastic and p-diss processes
by X^2 minimisation with full error treatment

Elastic and p-diss J/ψ photoproduction

PROTON DISSOCIATION FRACTION



$\sigma_r^{D(3)}$ for combination