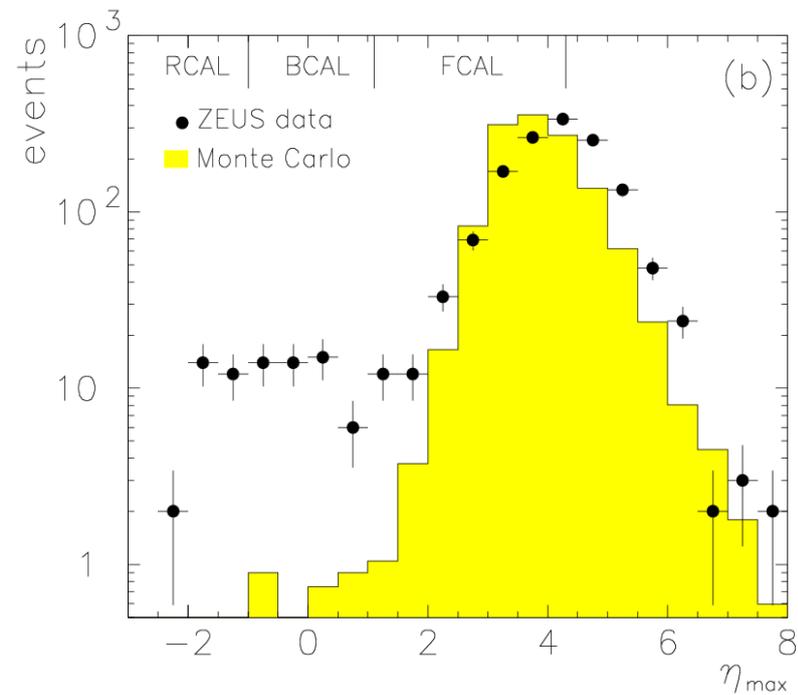# Diffraction @ HERA

K. Wichmann
on behalf of the H1 and ZEUS Collaborations

- **Something old** (mature measurements)
  - Inclusive diffractive cross sections

- **Something new** (never done before)
  - Diffractive data combination

- **Something out of the blue** (a puzzle)
  - Diffractive factorization

- **Horn of plenty**
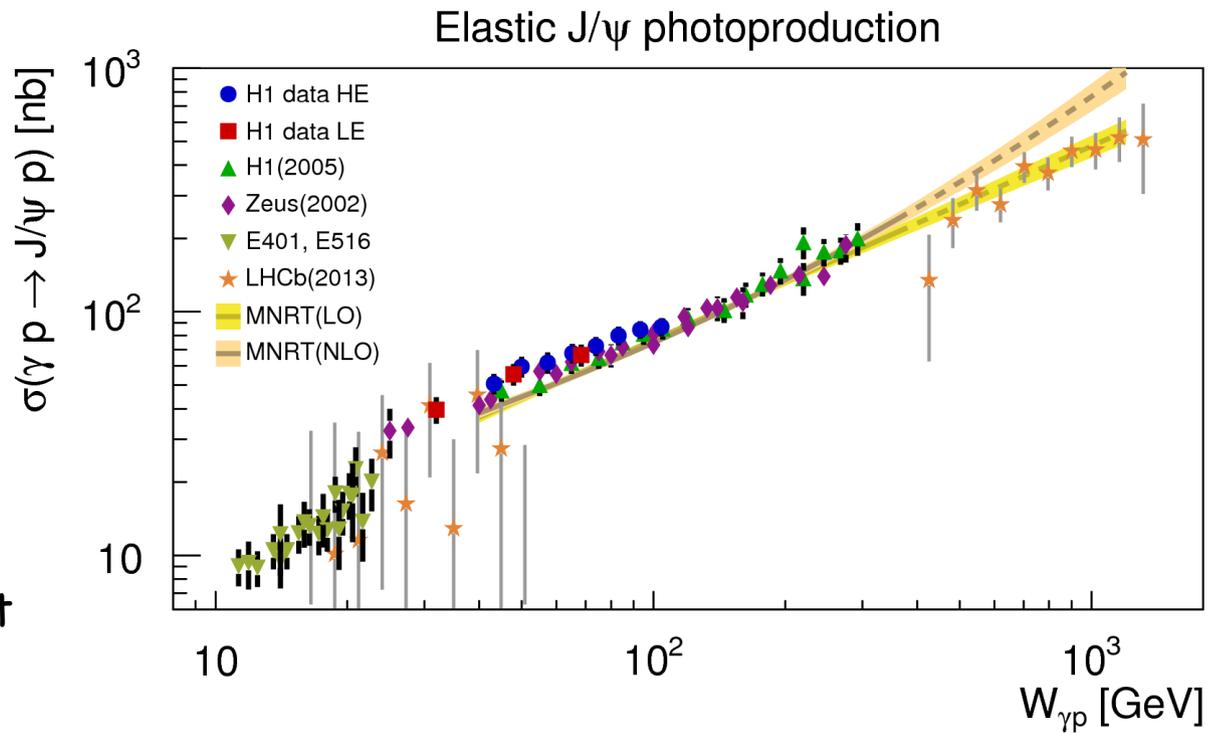 - Vector meson production

20 years of diffraction @ HERA

First:

ZEUS Collab., Phys. Lett. B 315 (1993) 481-493

Observation of Events with a Large Rapidity Gap in Deep Inelastic Scattering at HERA
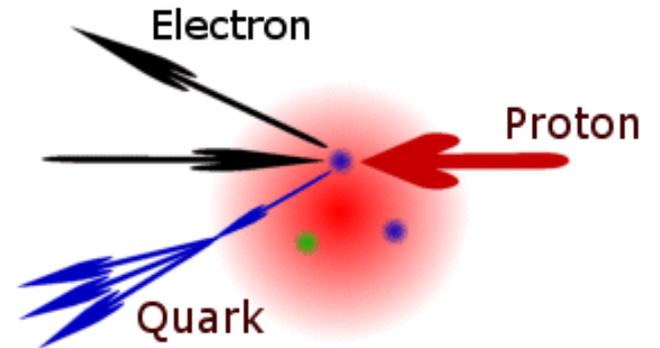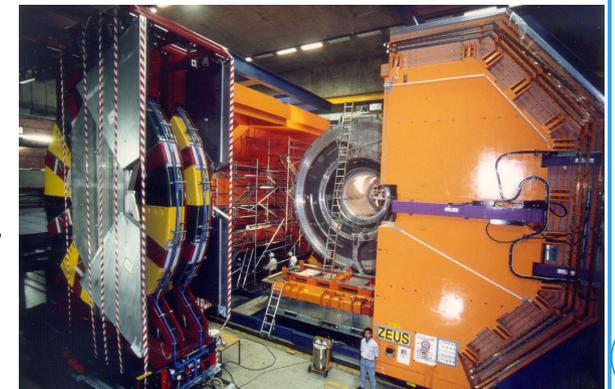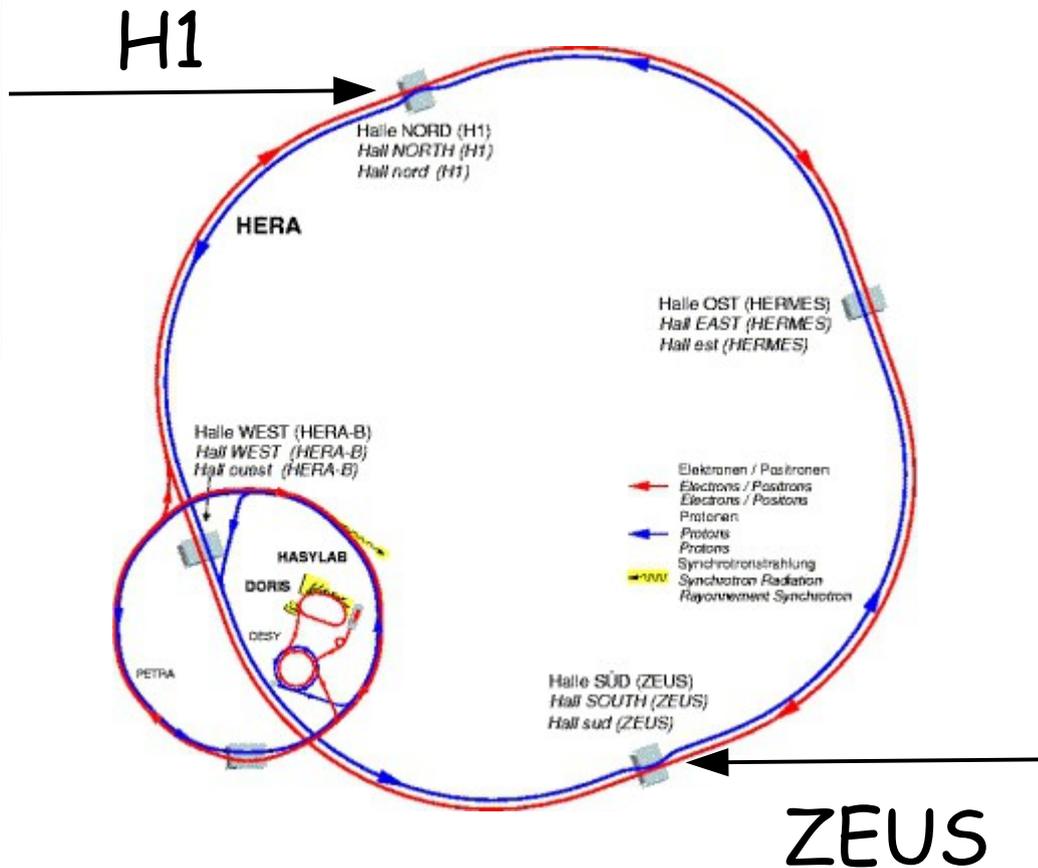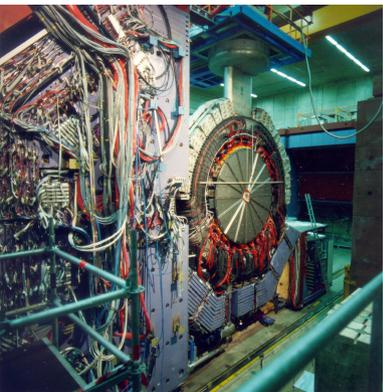
Latest (not last!):

H1 Collab., Eur. Phys. J. C73 (2013) 2466

Elastic and Proton-Dissociative Photoproduction of J/psi Mesons at HERA

Elastic J/ψ photoproduction

HERA Accelerator

Electron
Proton
Quark

- HERA: ep collider, $\sqrt{s}$ = 320 GeV
- 2 colliding-beam experiments: H1 & ZEUS
- collected 0.5 fb^{-1}/exp of luminosity in 1992-2007

H1

Halle NORD (H1)
Hall NORTH (H1)
Hall nord (H1)

HERA

Halle OST (HERMES)
Hall EAST (HERMES)
Hall est (HERMES)

Halle WEST (HERA-B)
Hall WEST (HERA-B)
Hall ouest (HERA-B)

HASYLAB

DORIS

DESY

PETRA

Elektronen / Positronen
Electrons / Positrons
Electrons / Positons
Protonen
Protons
Protons
Synchrotronstrahlung
Synchrotron Radiation
Rayonnement Synchrotron

Halle SÜD (ZEUS)
Hall SOUTH (ZEUS)
Hall sud (ZEUS)

ZEUS

Diffractive kinematics

$$Q^2 = -q^2 = -\left(k - k'\right)^2$$

Deep Inelastic Scattering (DIS) variables

$$\left\{ \quad x = \frac{Q^2}{2p \cdot q} \qquad y = \frac{p \cdot q}{p \cdot k} \right.$$

$$s = \left(p + k\right)^2 \qquad Q^2 = x \cdot y \cdot s$$
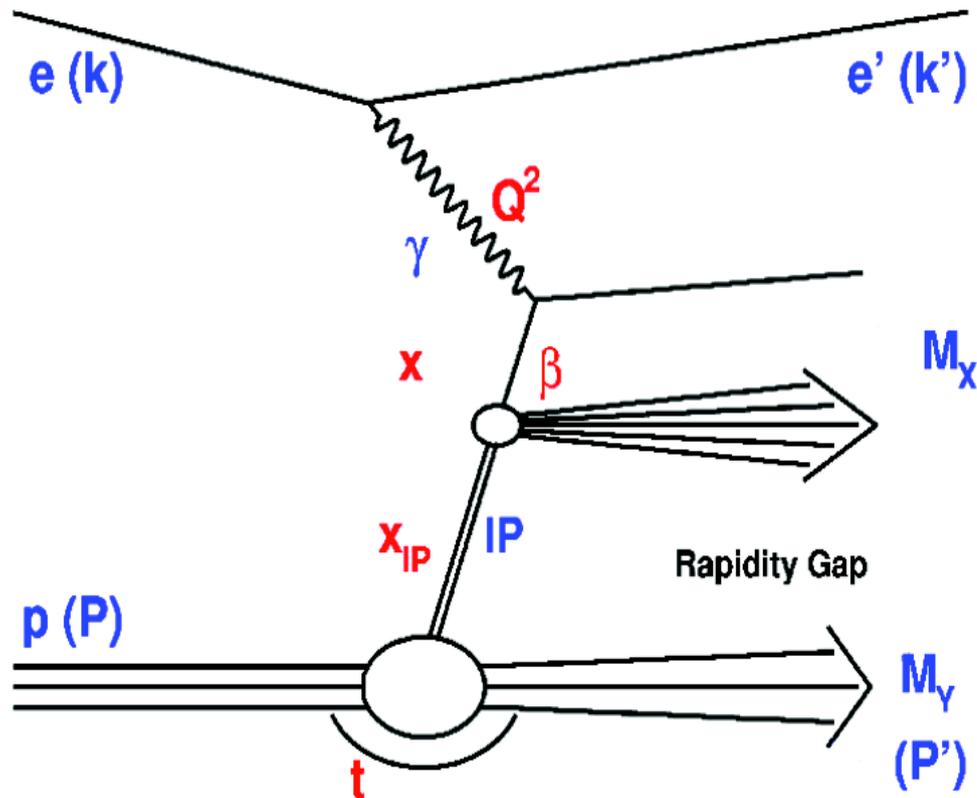
Diffractive variables

$$x_{IP} = q(P' - P)/qP = 1 - E'_p/E_p$$
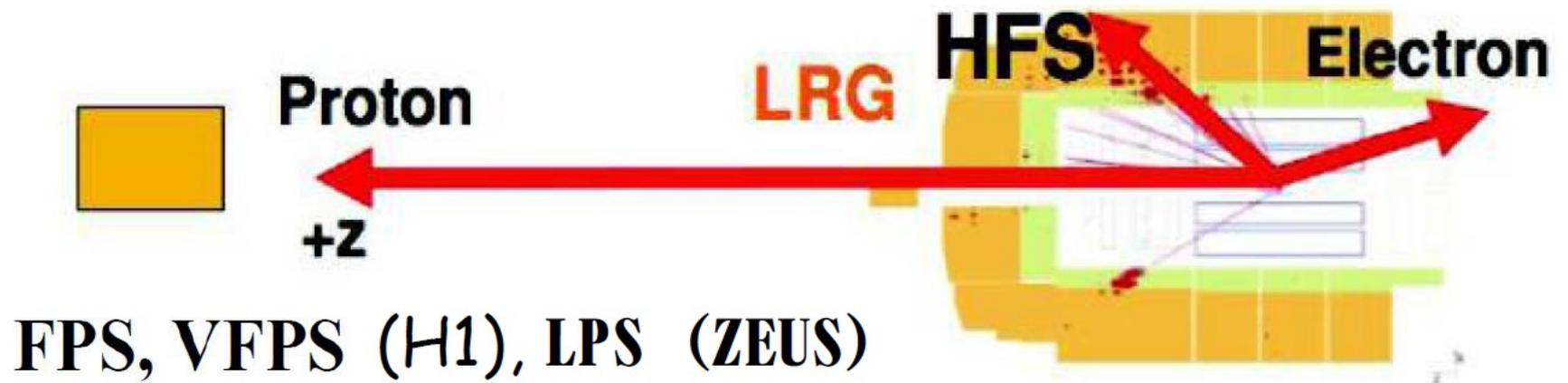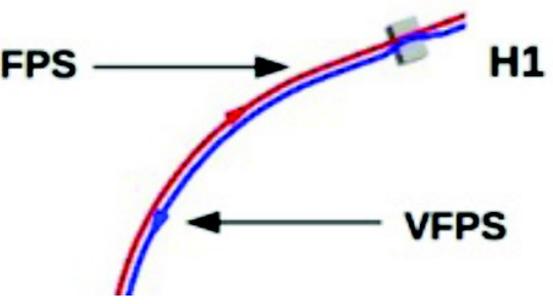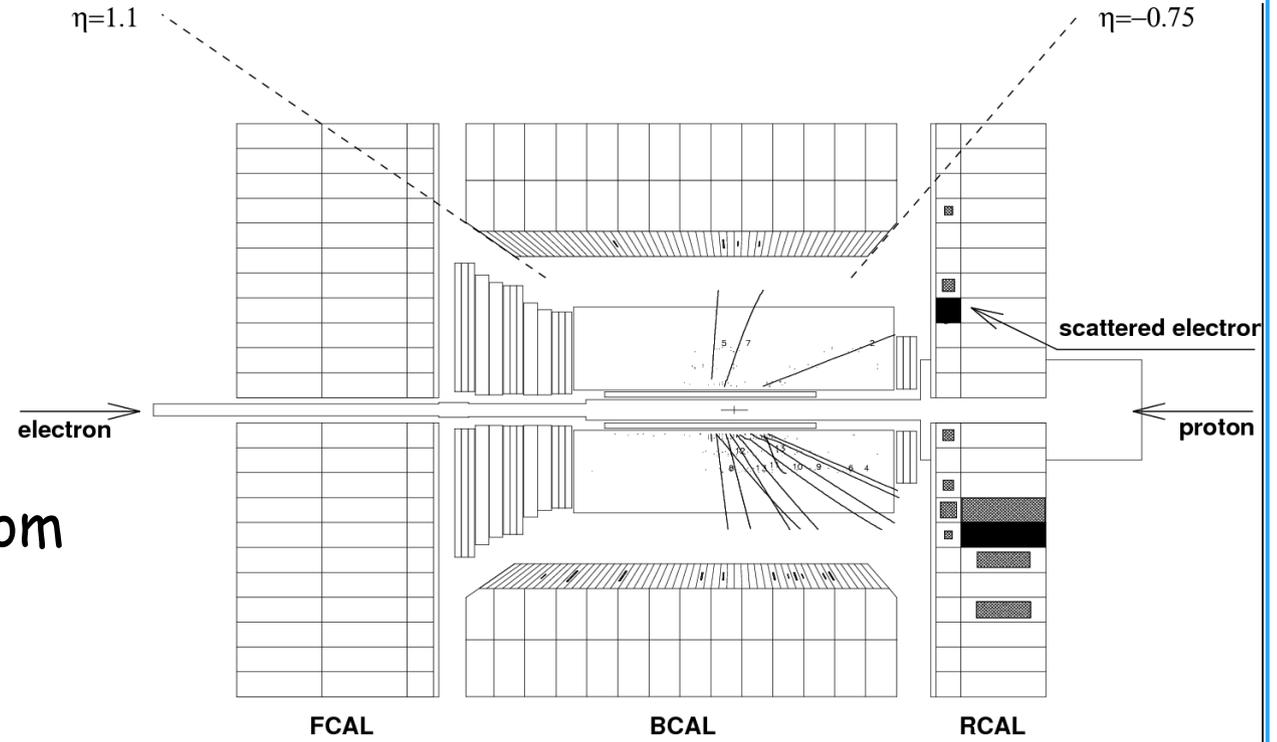
$$\beta = x/x_{IP}$$
$$z_{IP} = (Q^2 + M_{jj}^2)/x_{IP}ys$$

$M_Y = m_p$ .... intact proton
$m_p \leq M_Y \leq 1.6$ GeV .... intact proton or proton dissociation

Experimental Methods

- Selecting Large Rapidity Gap (LRG) events

  - For example with η_{max}

- Proton measured with Roman pots 60-220 m from interaction point

Scope of Diffraction @ HERA

- Amazing amount of precise measurement based on various experimental techniques and compared to various theory predictions

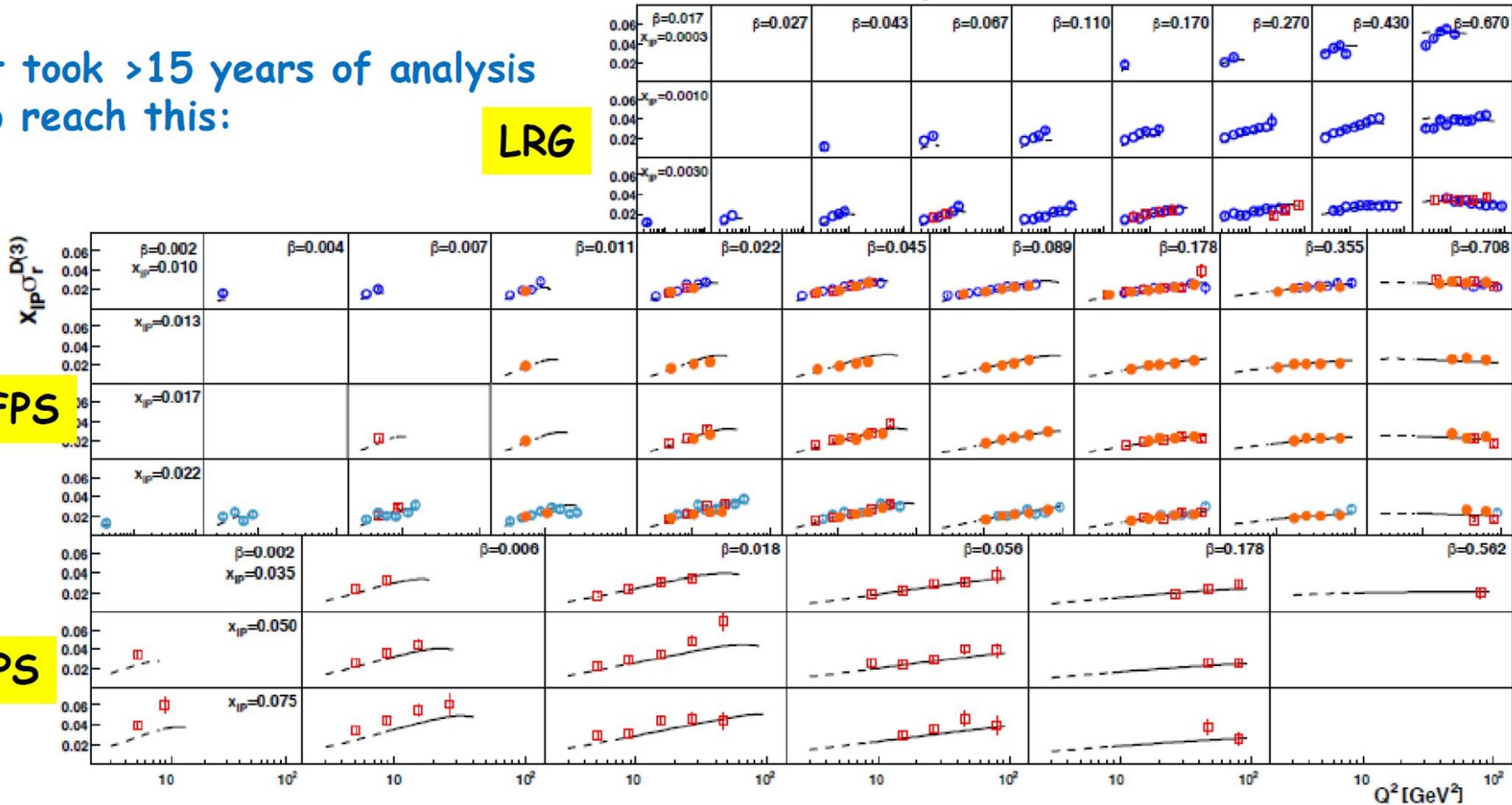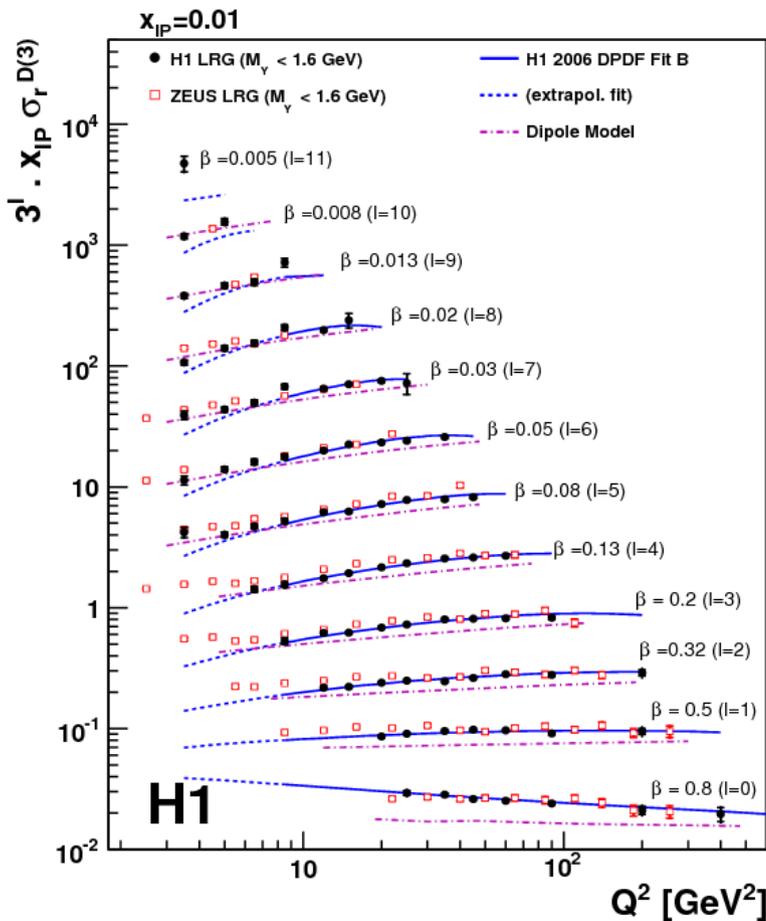# Inclusive Diffractive DIS

EPJ C72 (2012) 2074

- H1 diffractive measurements combined to one LRG cross sections set
- Increase in statistics 3-33 times
- Large reduction of uncertainties

- Comparison with H1 2006 DPDF FitB and dipole model
  - Low Q^2: better description by dipole model
  - High Q^2: better description by H1 2006 DPDF FitB

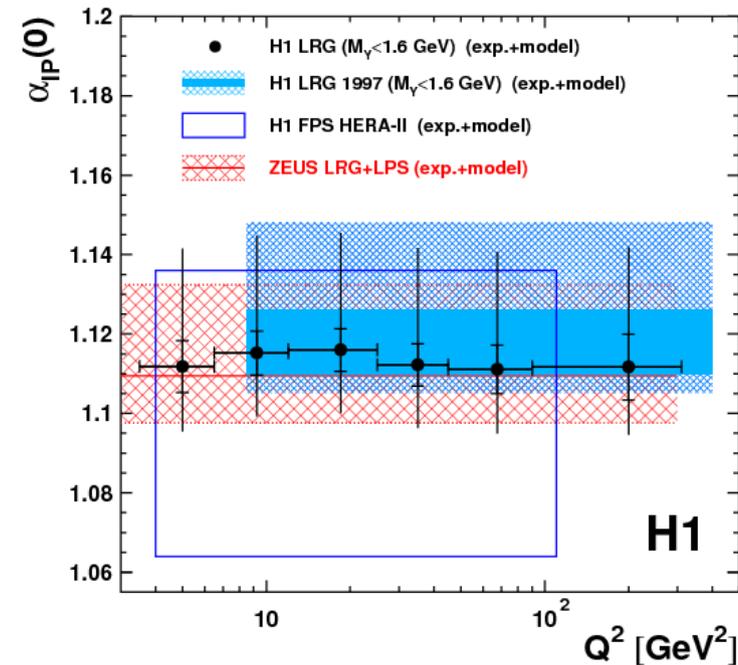High precision HERA data available for comparison with various models
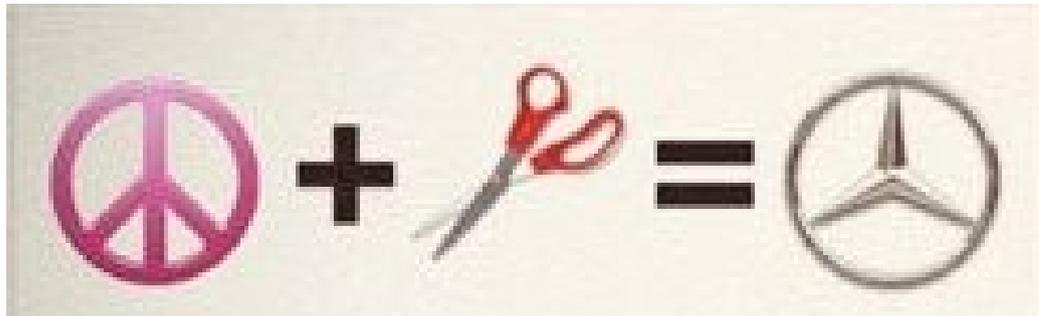
Pomeron Trajectory

- Pomeron trajectory measured

$$\alpha_{IP}(0) = 1.113 \pm 0.002 \, (exp) \, ^{+0.029}_{-0.015} \, (mod)$$

- No Q^2 dependence

- Agreement with previous measurements

- $\alpha_{IP}(0)$ consistent with "soft" pomeron

Supports proton vertex factorization hypothesis

Combination
of H1 and ZEUS Results

Combined inclusive diffractive cross sections measured with forward proton spectrometers in deep inelastic ep scattering at HERA

EPJ C72 (2012) 2175

- First combined inclusive diffractive cross sections
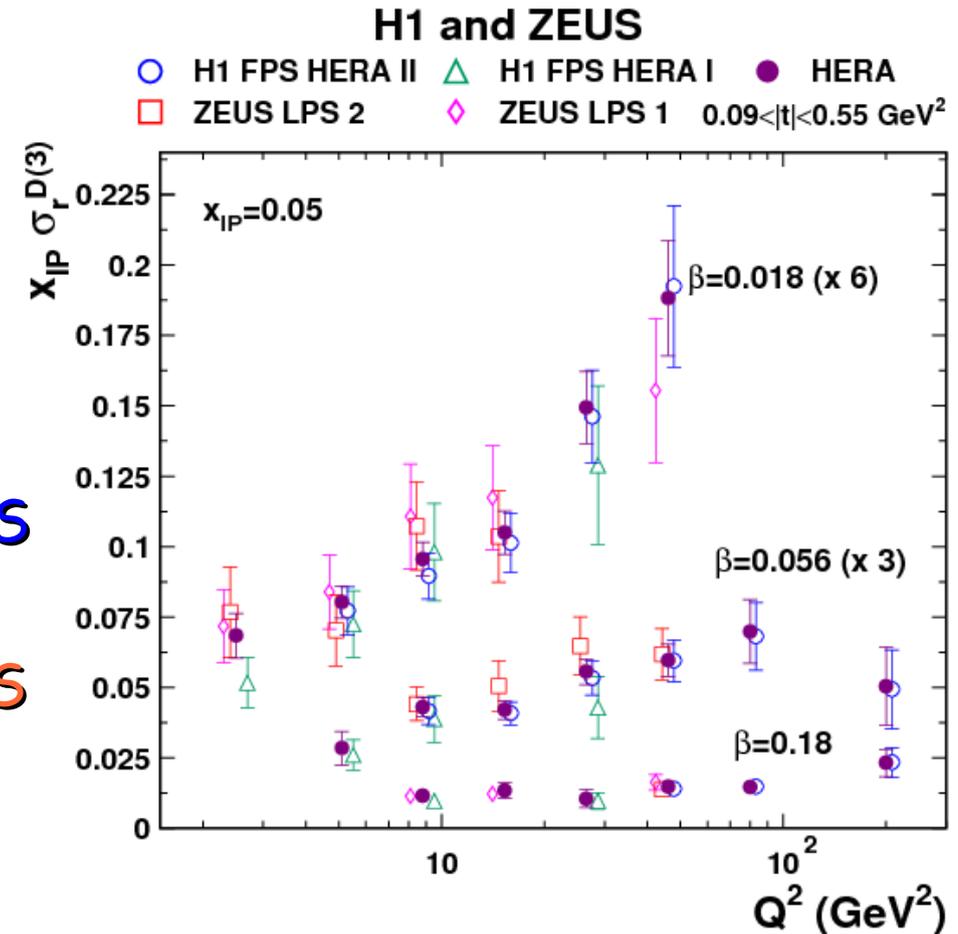
- Measurements using forward proton spectrometers
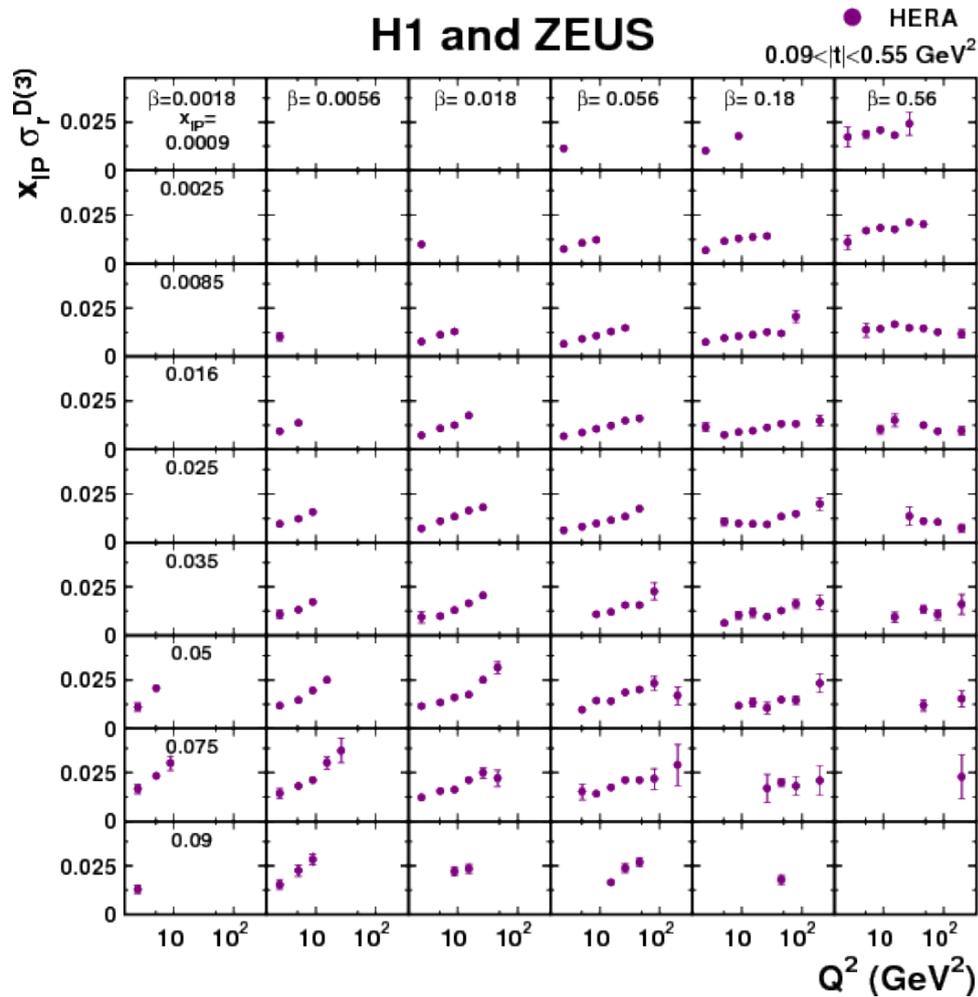
  - *EPJ C71 (2011) 1578*
  - *EPJ C48 (2006) 749*
  - *Nucl. Phys B816 (2009) 1*
  - *EPJ C38 (2004) 43*

  FPS

  LPS

- H1 and ZEUS employed different experimental techniques
  - reduced uncertainties in combination

Combined Diffractive Measurements

- Wide kinematic range and improved precision

  - Q^2:   2.5 – 200 GeV^2

  - β: 0.0018 - 0.816

  - x_{IP}:   0/00035 - 0.09
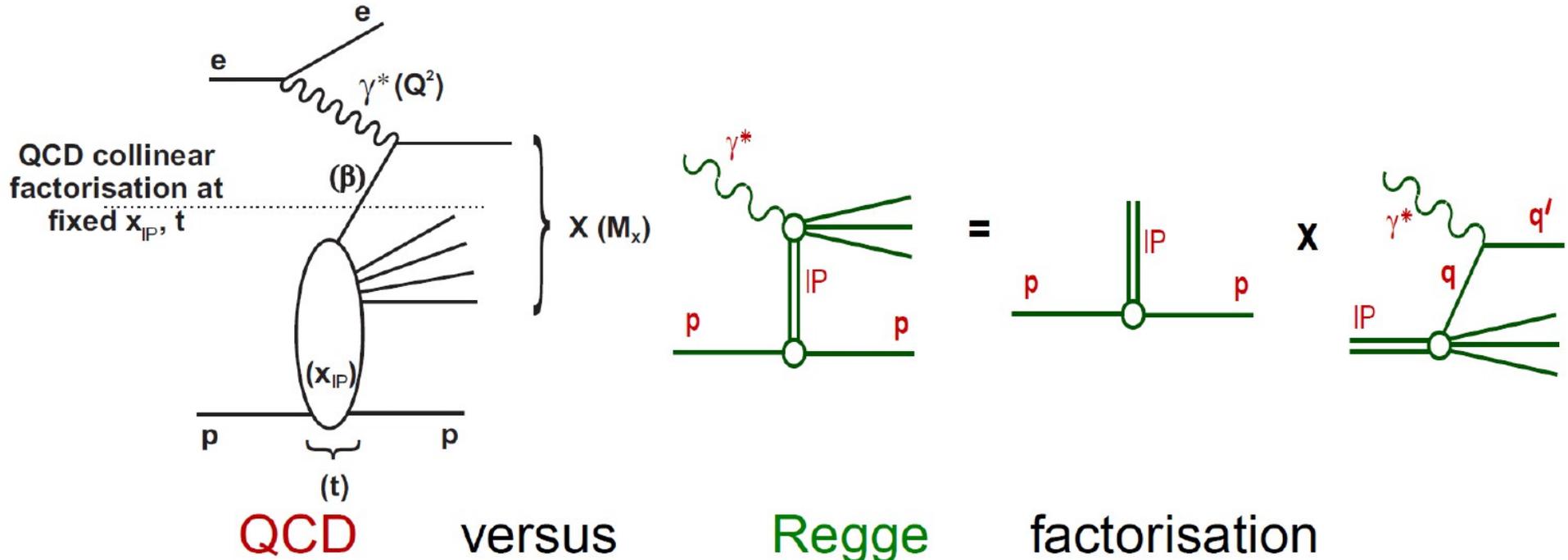
  - $|t|$:   0.9 - 0.55

- Diffractive DIS allows to probe the parton content in the colorless nucleon

Important input to diffractive PDFs

Diffractive factorization puzzle

Factorization in diffraction

QCD   versus   Regge   factorisation

Collins factorisation, proven:

$$d\sigma^{ep\rightarrow eXp}(\beta,Q^2,x_{IP},t)=\sum_i f_i^D(\beta,Q^2,x_{IP},t)\cdot d\sigma^{ei}(\beta,Q^2)$$

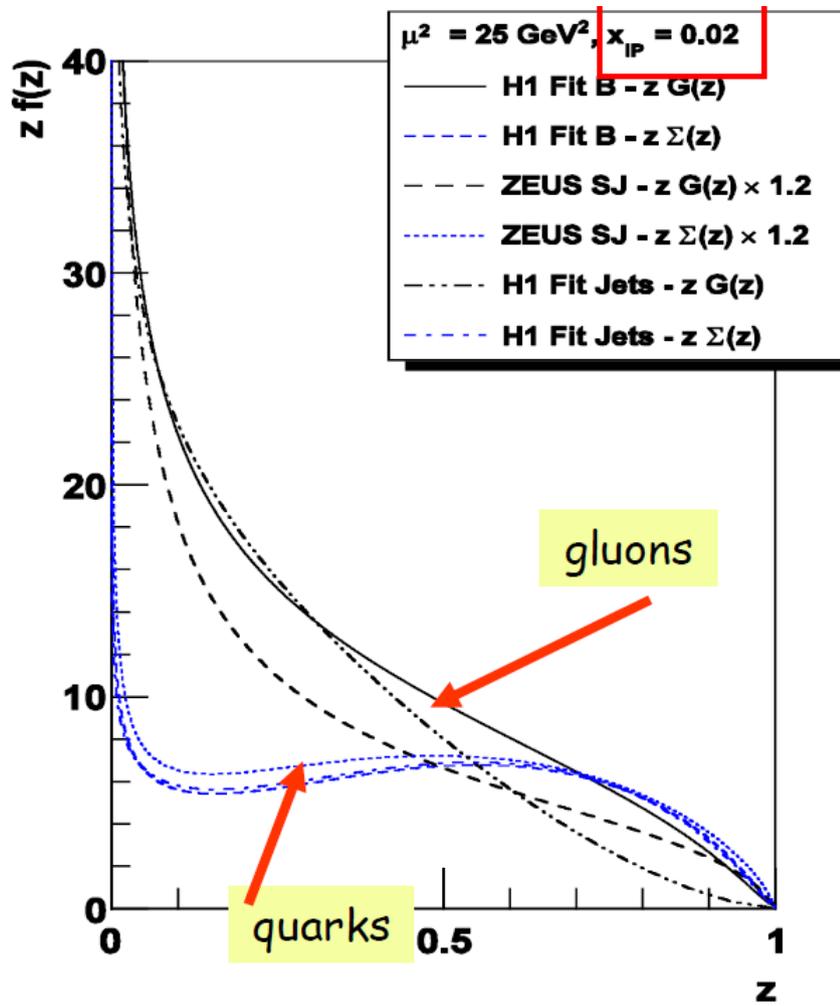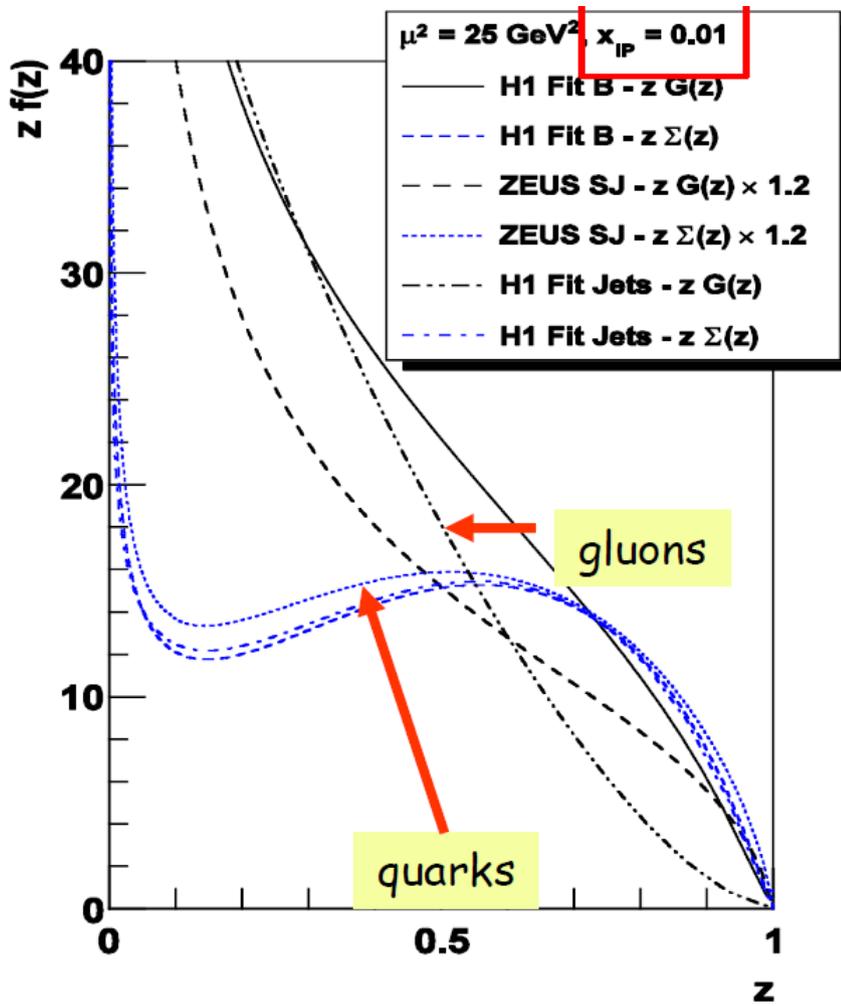**Proton Vertex Factorisation**, consistent with data: still being tested

$$f_i^D(\beta,Q^2,x_{IP},t)=f_{IP/p}(x_{IP},t)\cdot f_i(\beta,Q^2)$$

PDF from inclusive diffraction -> predict cross sections for exclusive diffraction
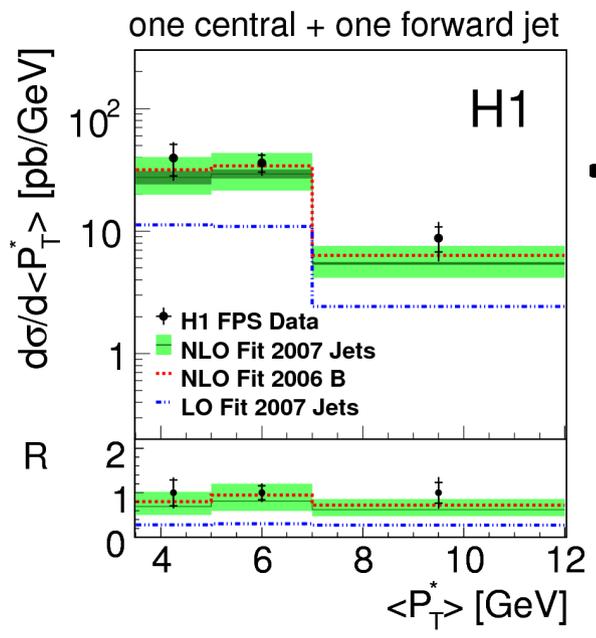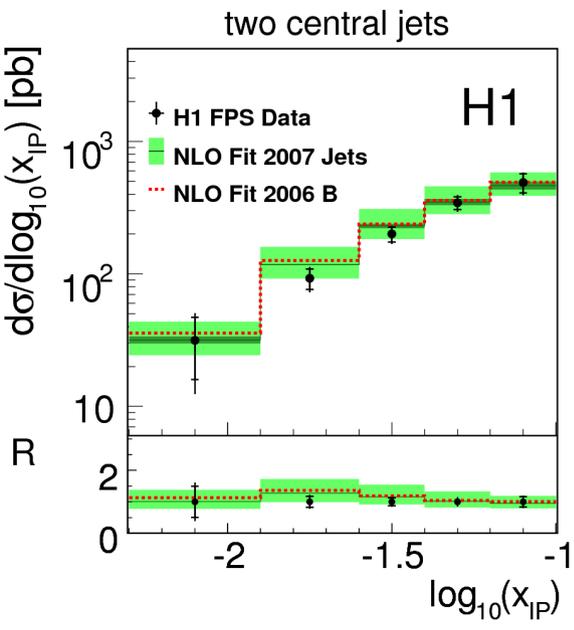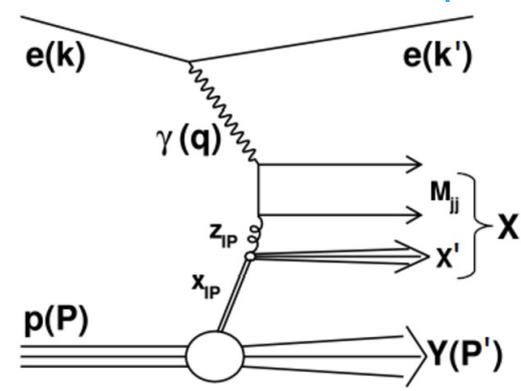
Diffractive PDFs in DIS

- Obtained from inclusive, dijet and D^* measurements
  - H1 fit B, H1 fit Jets, ZEUS SJ

  - Difference mainly in gluons

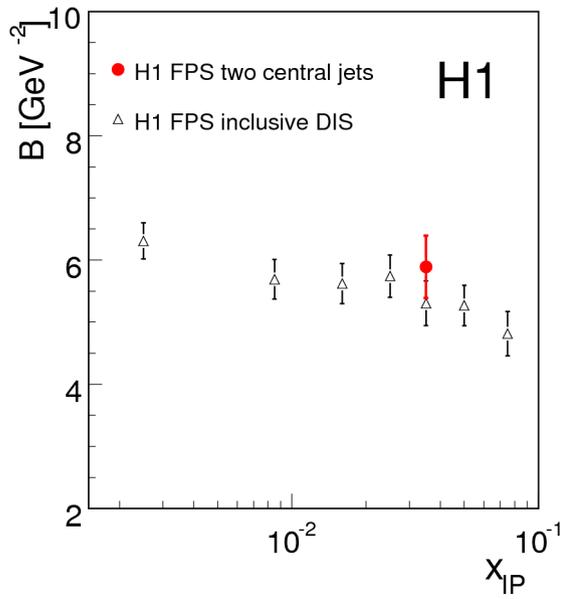K. Wichmann, ISMD2013, Diffraction @ HERA

Diffractive dijets in DIS

EPJ C72 (2012) 1970

- Data well described by QCD predictions with inclusive DPDFs
  - 2 central dijets
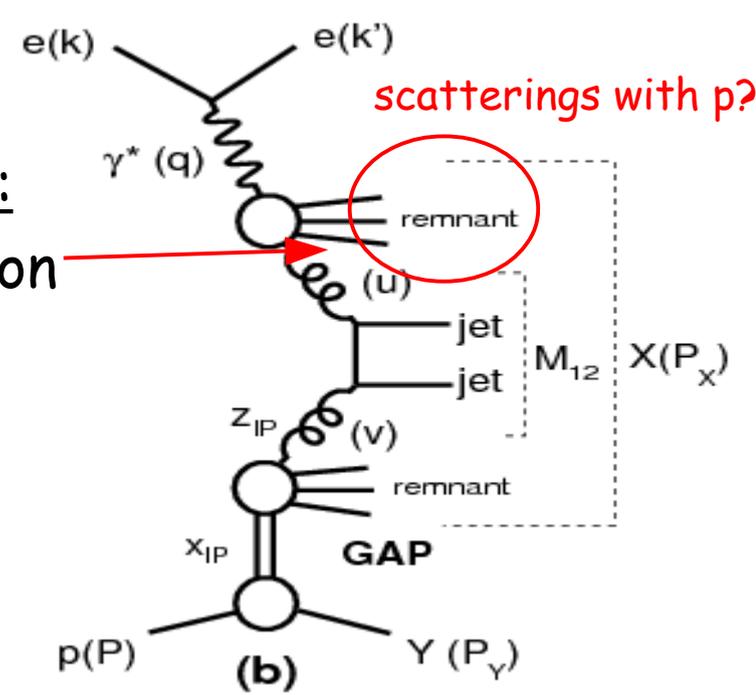 - 1 central + 1 forward jet

Supports universality of DPDFs

t-slope consistent with measurement in inclusive DDIS with leading proton

confirms validity of proton vertex factorisation for dijet production in diffractive DIS
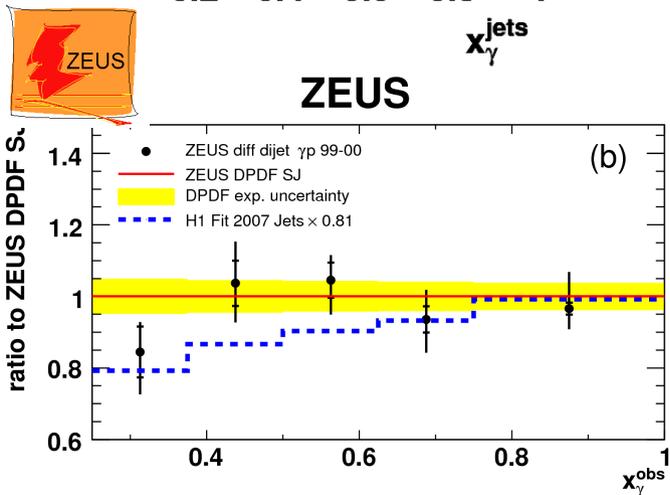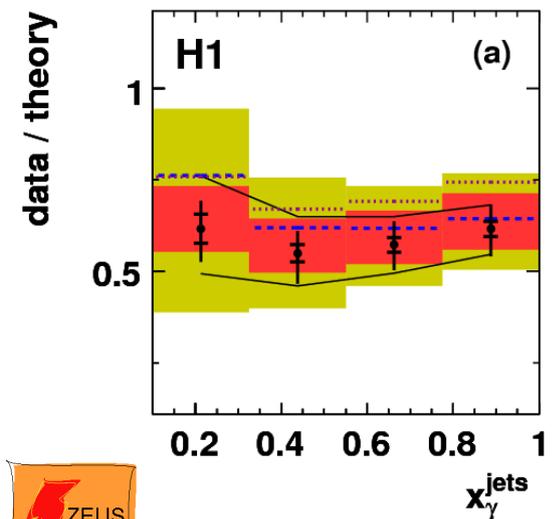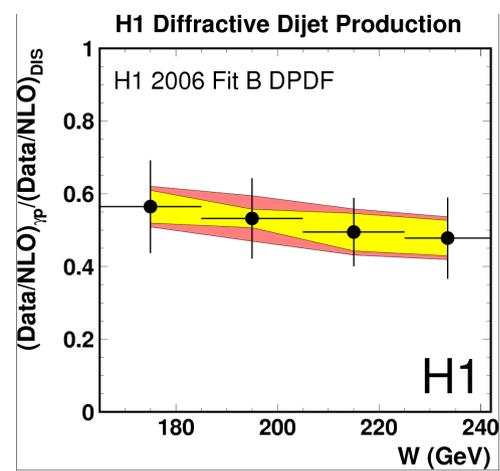
Diffractive dijets in PhP

H1 Diffractive Dijet Production

H1 2006 Fit B DPDF

$(Data/NLO)_{\gamma p}/(Data/NLO)_{DIS}$

W (GeV)

H1

- **Resolved photoproduction:** theory predicts suppression

- Previous measurements
- EPJ C51 (2007) 549
  - Suppression 0.5 ± 0.1

- EPJ C68 (2010) 381
  - Suppression 0.58 ± 0.21

- Nucl. Phys. B381 (2010)
  - NO suppression

data / theory

H1 (a)

x_{γ}^{jets}

ZEUS

- ZEUS diff dijet γp 99-00
- ZEUS DPDF SJ
- DPDF exp. uncertainty
- H1 Fit 2007 Jets $\times$ 0.81

ratio to ZEUS DPDF S.

(b)

x_{γ}^{obs}

- Different phase space
- ZEUS larger $E_T - E_T$ dependence?
- tagged/untagged PhP

New H1 measurement

- H1 measured dijets in photoproduction with VFPS
- Measured cross sections lower then NLO prediction

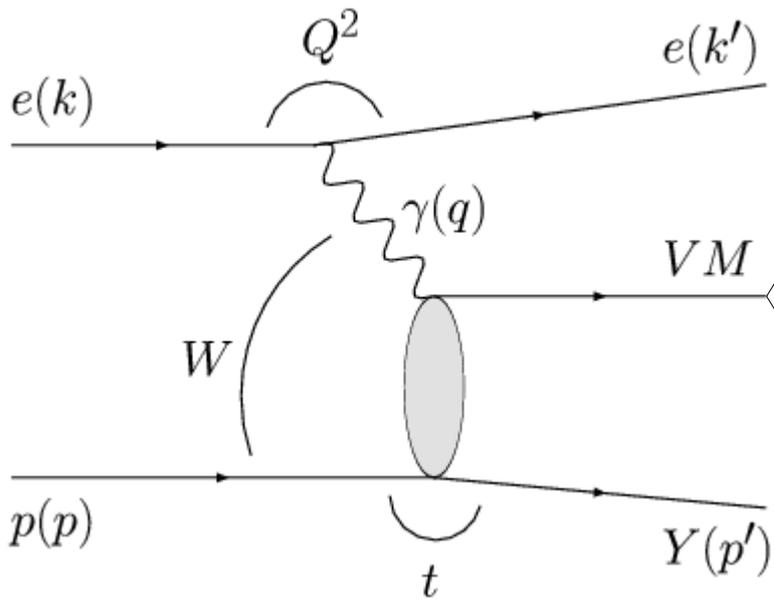$$\sigma_{DATA}/\sigma_{NLO} = \boxed{0.67} \pm 0.04\,(\text{stat.}) \pm 0.09\,(\text{syst.}) \pm 0.20\,(\text{scale}) \pm 0.14\,(\text{DPDF})$$
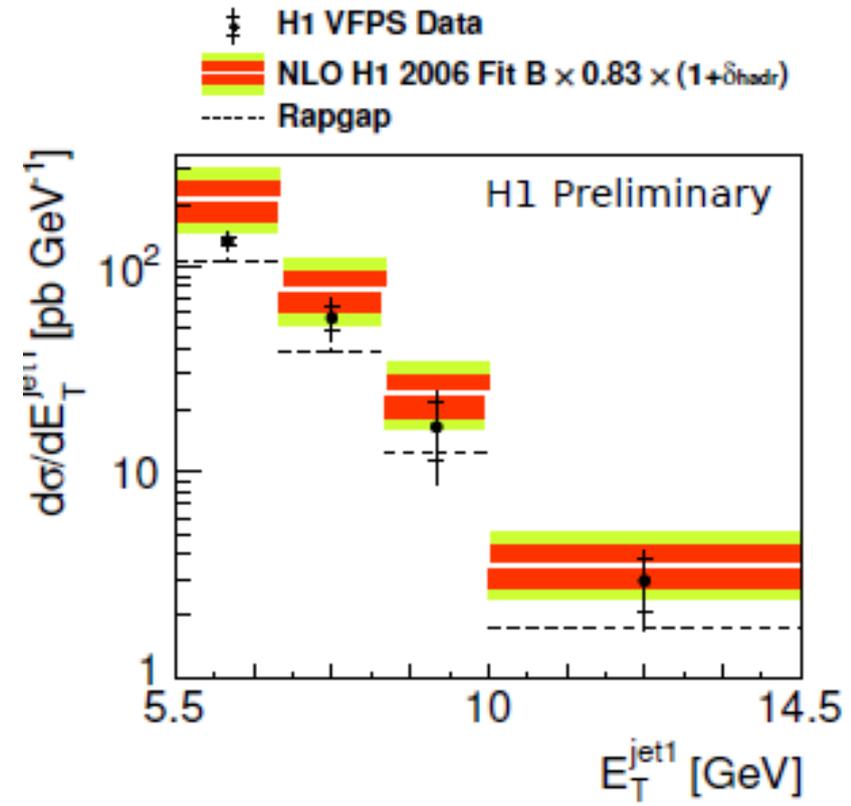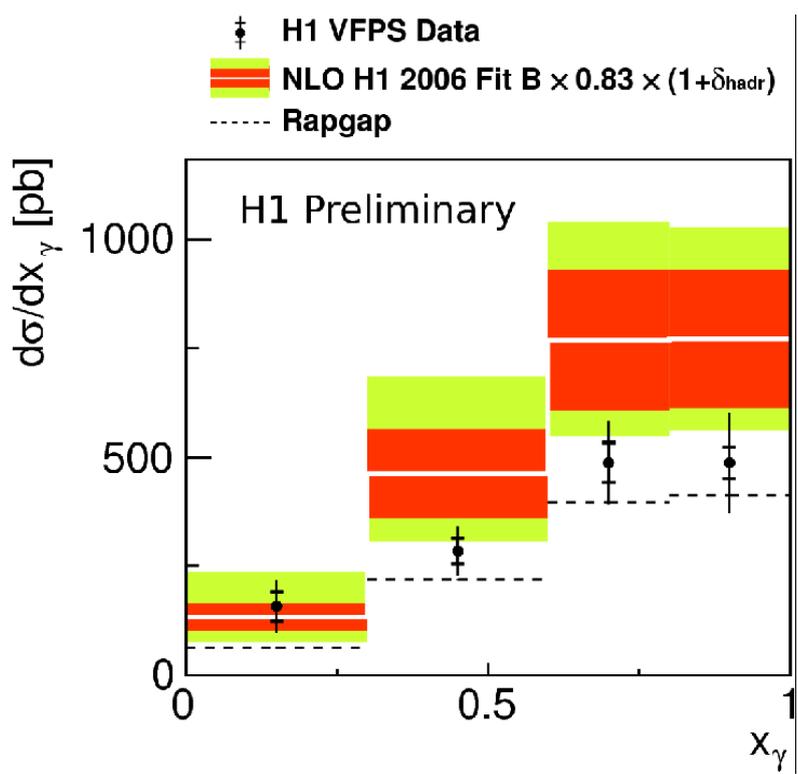
Even with new H1 measurement "suppression puzzle" remains

K. Wichmann, ISMD2013, Diffraction @ HERA

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Horn of plenty

Diffractive Vector Meson Production

Proton stays intact or dissociates

H1 $J/\psi \to \mu^+\mu^-$ photoproduction

ZEUS

- ZEUS 96/07 (468 pb^{-1})
- BH $\gamma\gamma \to \mu^+\mu^-$
- Υ(1S,2S,3S) $\to \mu^+\mu^-$
- BH + Υ(1S,2S,3S)

Υ

H1 $J/\psi \to e^+e^-$ photoproduction
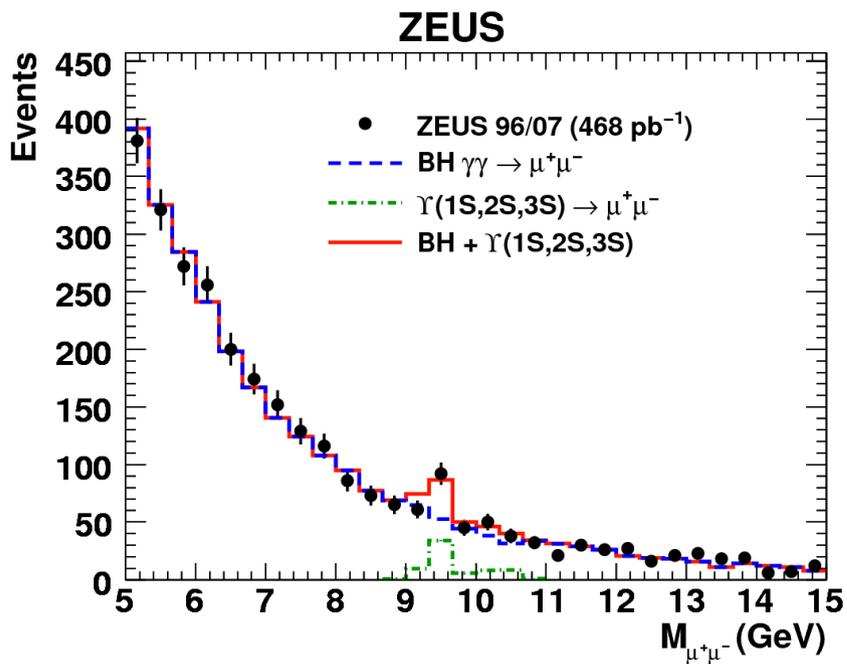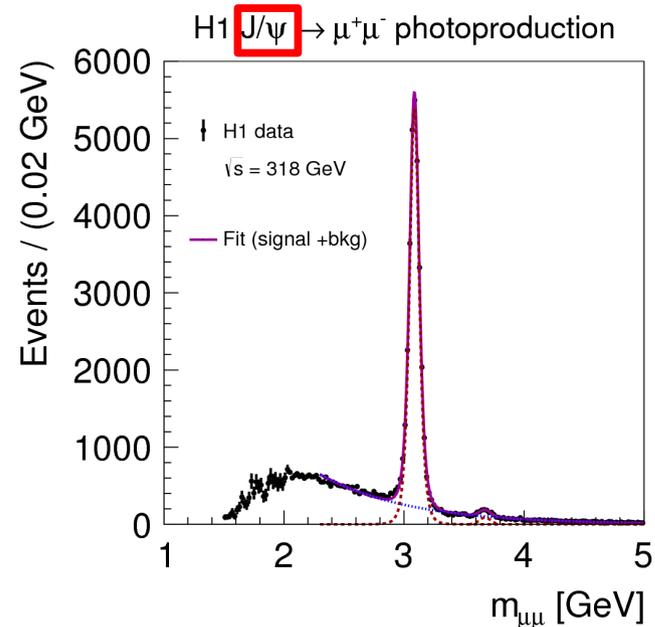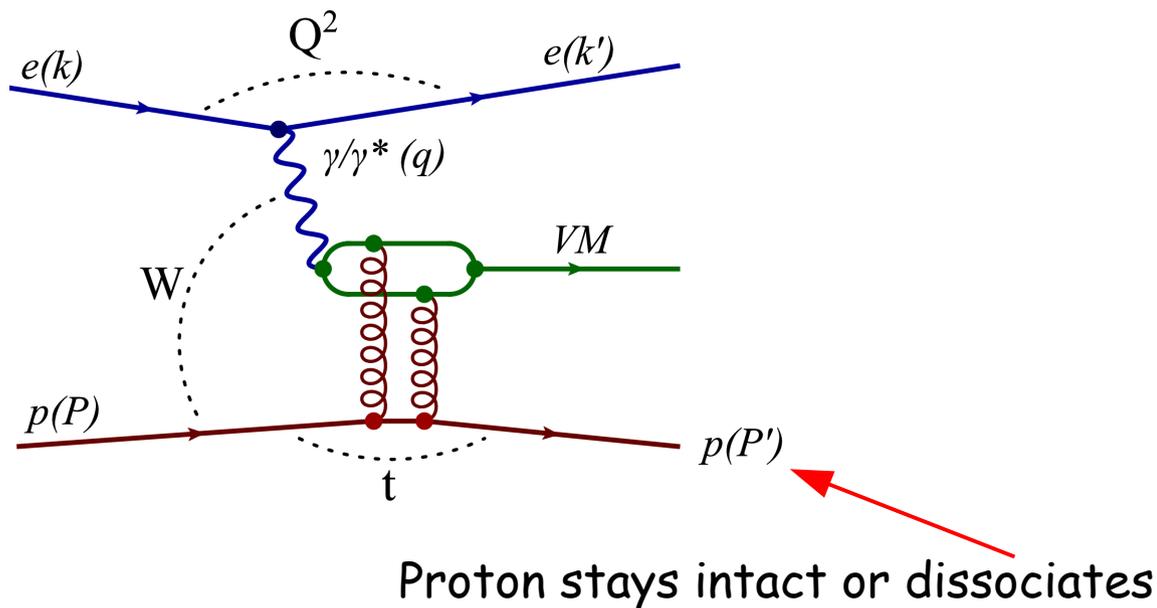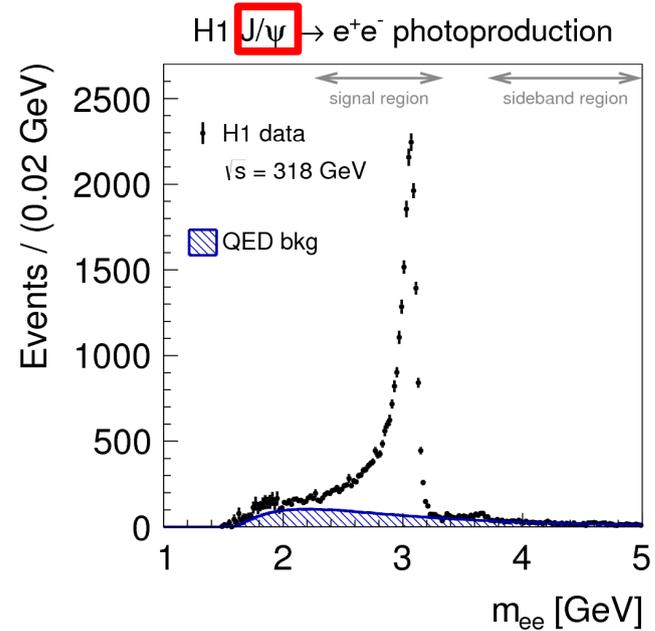
ϒ(1s) Production

Phys. Lett. B 708 (2012) 14

- U(1s) photoproduction
- First measure of U(1s) b-slope

- 60 < W < 220 GeV
- $Q^2 < 1$ GeV^2
- **0.5 fb^{-1} of data used**

b = 4.3 $^{+2.0}_{-1.2}$ (stat) $^{+0.5}_{-0.6}$ (syst) GeV^{-2}
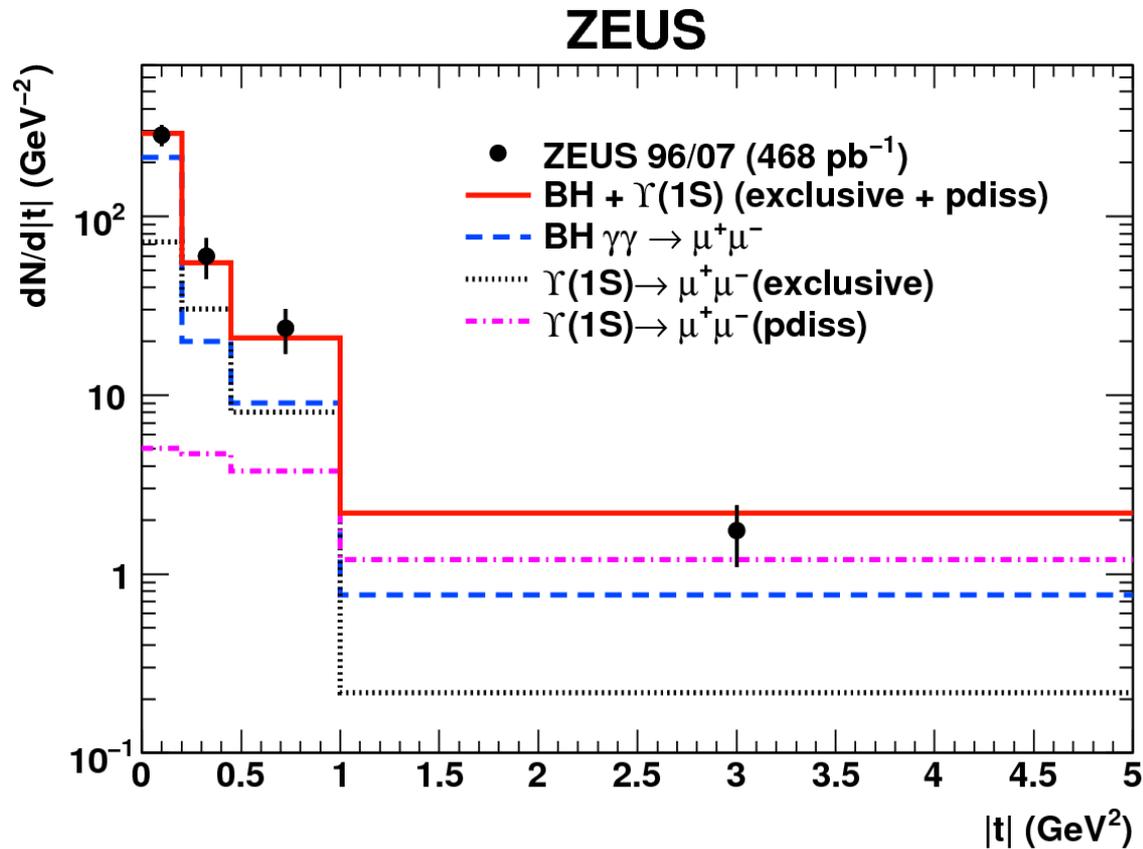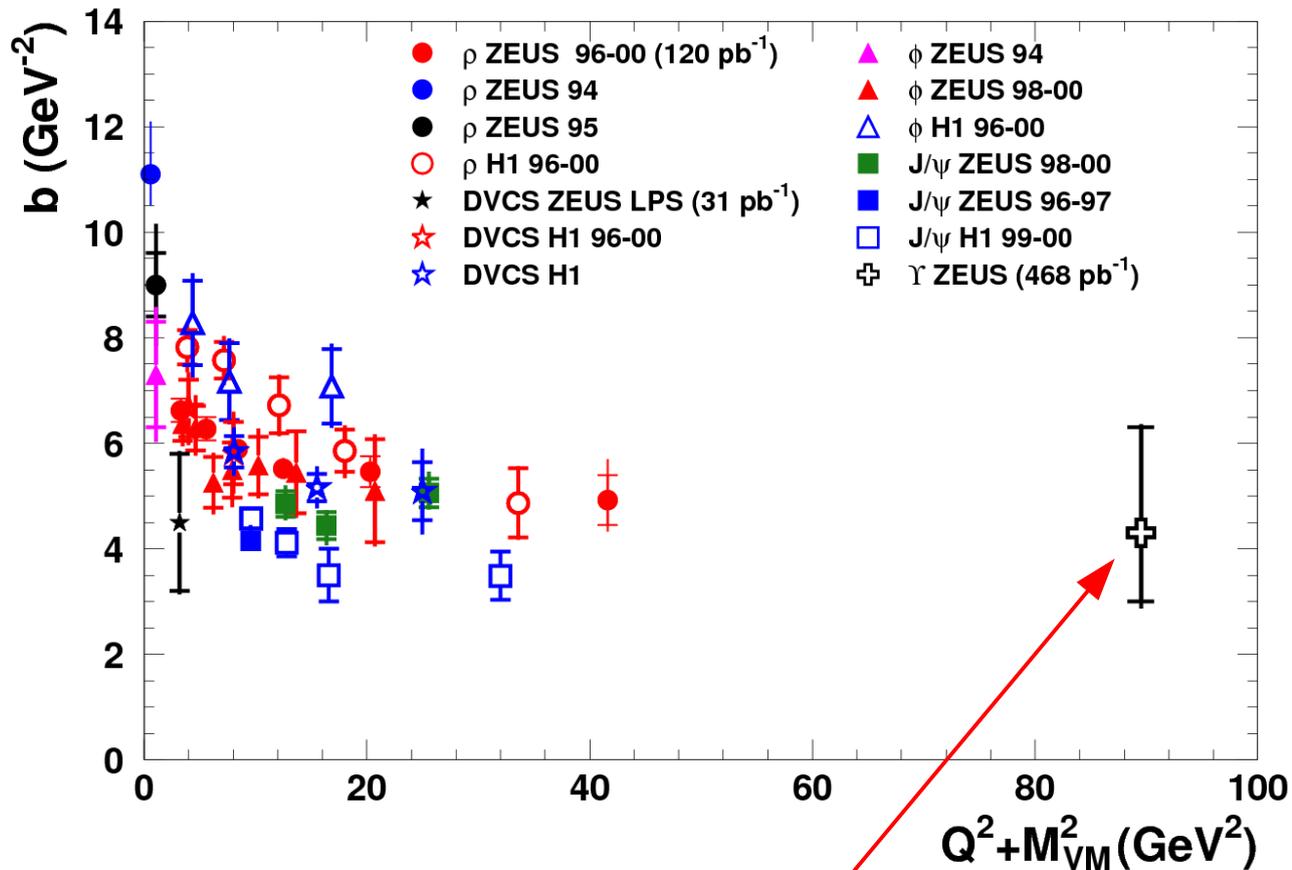
Υ(1S) Production

- Highest so far value of $Q^2+M_{vm}^2$ of ~90 GeV^2

- In agreement with asymptotic behavior of b-slope in terms of $Q^2+M_{vm}^2$
  - Reflects proton radius

- Consistent with pQCD models predictions of b = 3.68 GeV^{-2} (JHEP 0906 (2009) 034)

Elastic J/ψ Photoproduction

EPJ C73 (2013) 2466
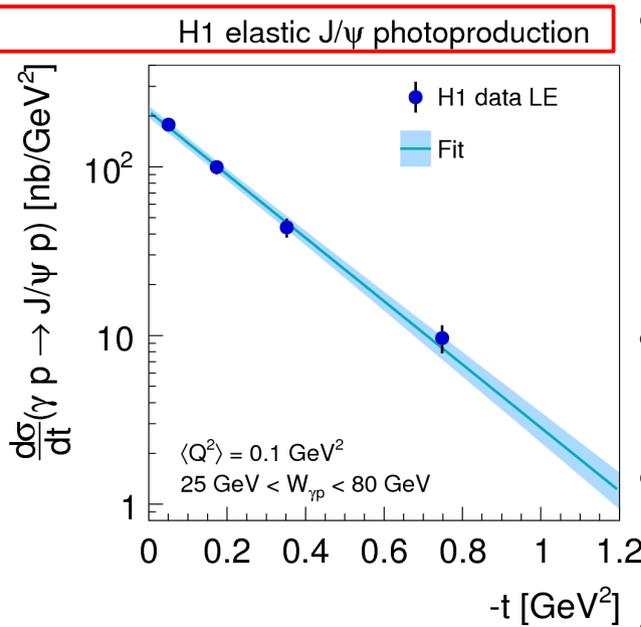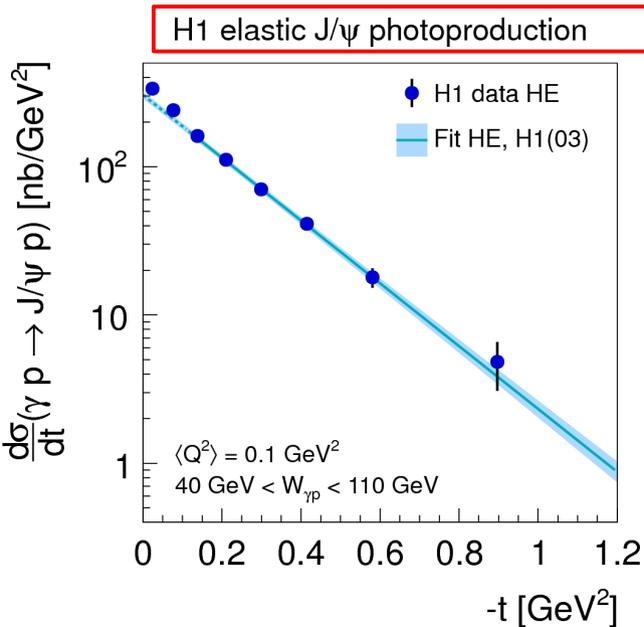
- Elastic and proton-dissociative cross sections as a function of |t|
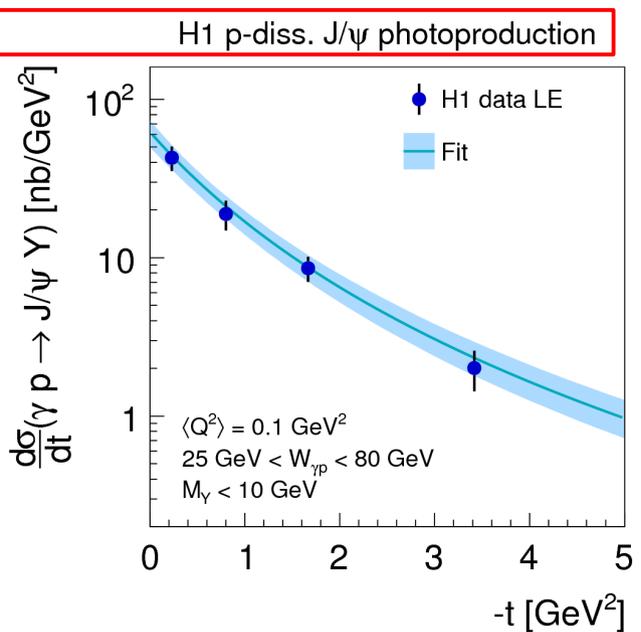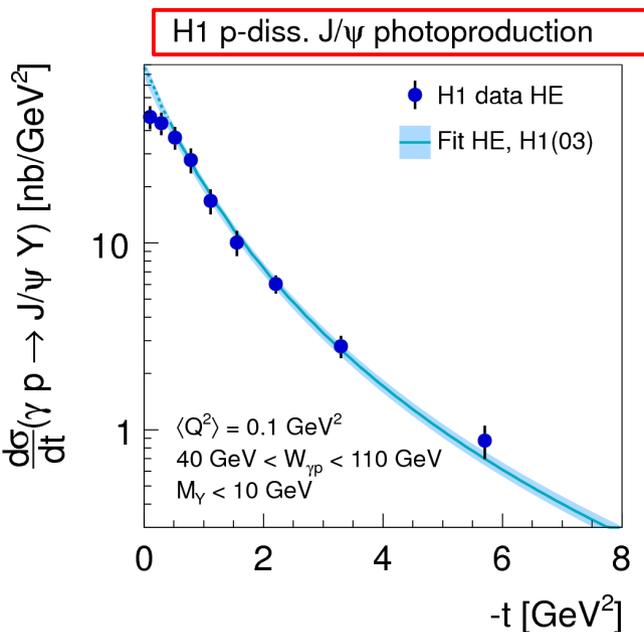 - difference in shape

- High energy (HE) and low energy (LE) data

- includes previous H1 high t-data (hep-ex/0306013)

- Fitted simultaneously using phenomenological models:
  - elastic

$$\mathrm{d}\sigma/\mathrm{d}t = N_{el}\, e^{-b_{el}|t|}$$

b = (4.88 ± 0.15) GeV⁻²

  - P-diss

$$\mathrm{d}\sigma/\mathrm{d}t = N_{pd}\,(1 + (b_{pd}/n)|t|)^{-n}$$

b = (1.79 ± 0.12) GeV⁻²

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t-dependence of J/ψ photoproduction

- HE proton-diss data extend to low values of |t|
- Good agreement in overlap region
- High-t data included in fits

H1 p-diss. J/ψ photoproduction

$\langle Q^2 \rangle = 0.1 \text{ GeV}^2$
$40 \text{ GeV} < W_{\gamma p} < 110 \text{ GeV}$
$M_Y < 10 \text{ GeV}$

- H1 data HE
- H1(03) high|t|
- Fit HE, H1(03)

$\frac{d\sigma}{dt}(\gamma p \rightarrow J/\psi\ Y)$ [nb/GeV^2]

-t [GeV^2]

H1 p-diss. J/ψ photoproduction

- H1 data HE
- H1 data LE
- Fit HE, LE, H1(2005)

$\langle Q^2 \rangle = 0.1 \text{ GeV}^2$
$|t| < 8 \text{ GeV}^2$
$M_Y < 10 \text{ GeV}$

$\sigma(\gamma p \rightarrow J/\psi\ Y)$ [nb]

$W_{\gamma p}$ [GeV]
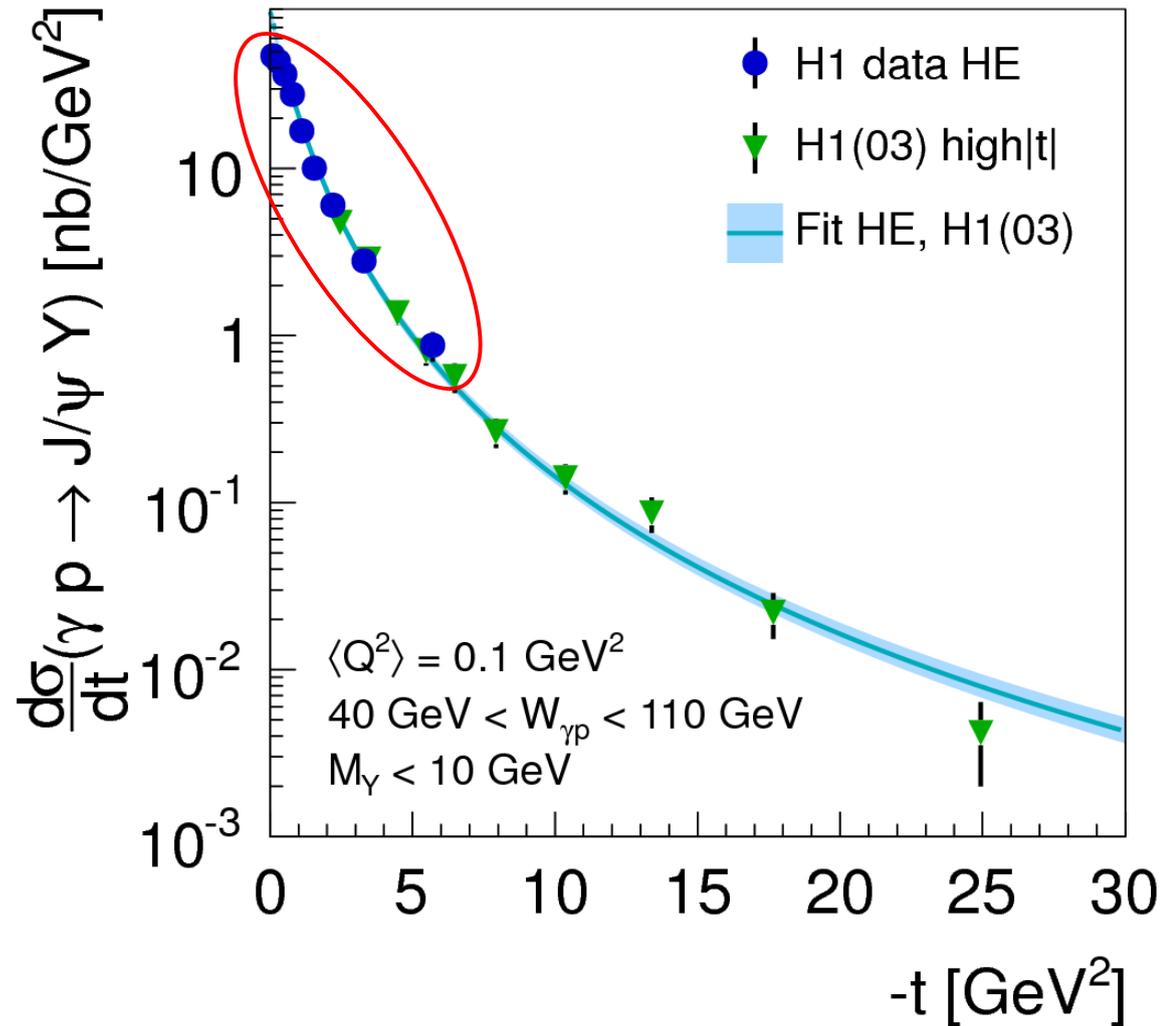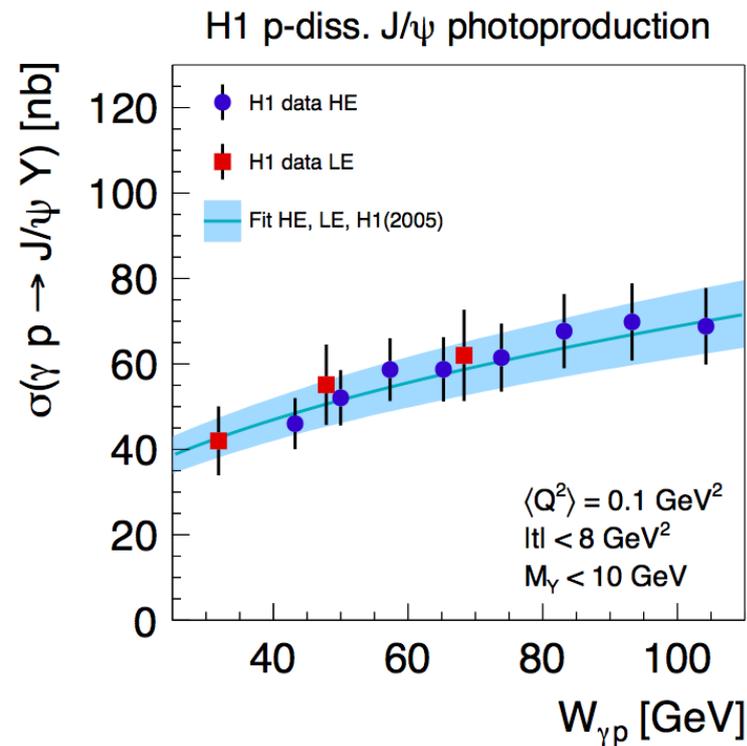
- Good seperation of p-dissoc from elastic down to lowest |t|

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W-dependence of elastic J/ψ photoproduction

- H1 measurement cover region between fix target and LHCb results
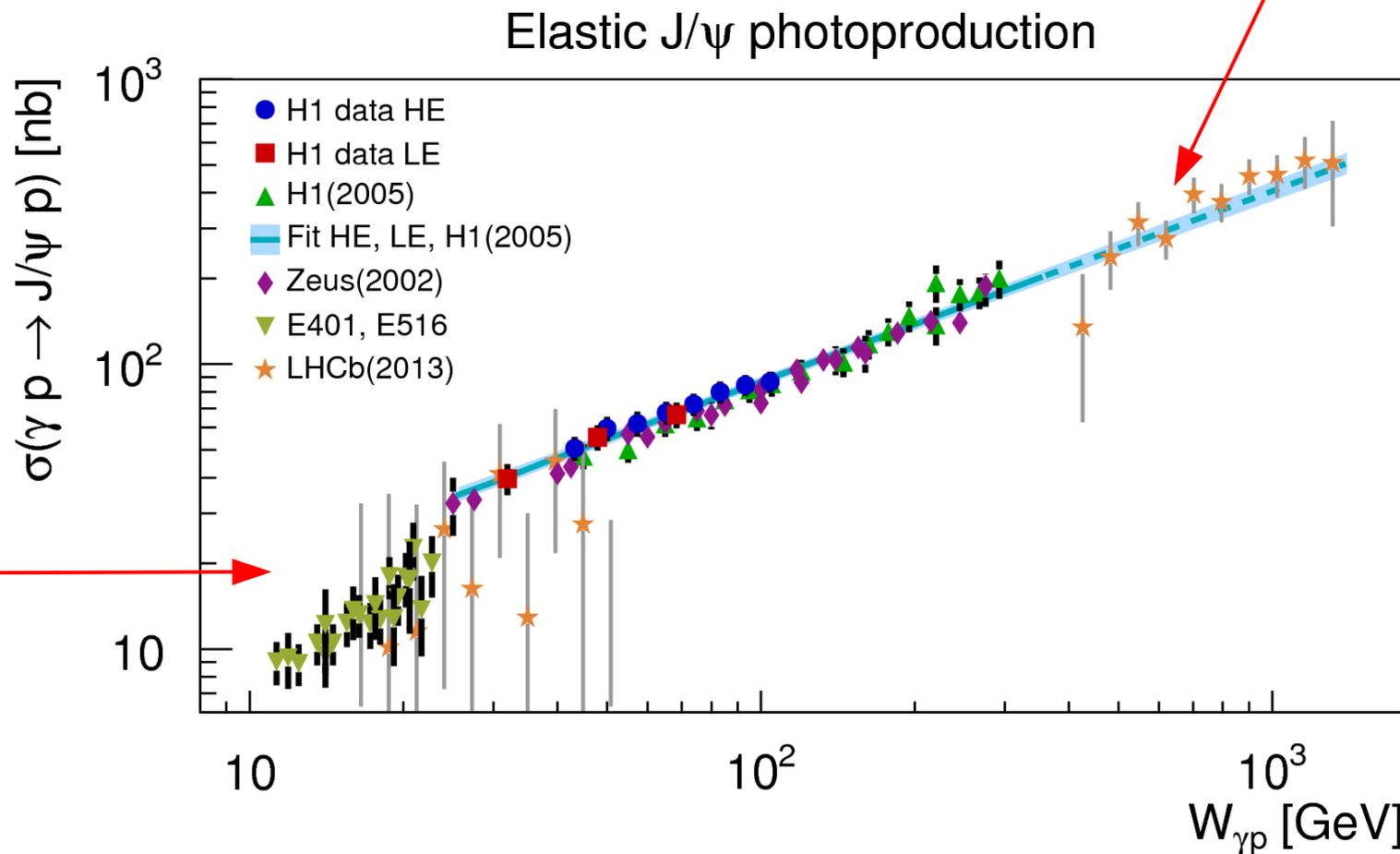- Compatible with previous HERA measurements
- Fixed target: lower normalization, steeper slope
- Fit to H1 data extrapolated to higher W in agreement with LHCb

Elastic J/ψ photoproduction

Legend:
- H1 data HE
- H1 data LE
- H1(2005)
- Fit HE, LE, H1(2005)
- Zeus(2002)
- E401, E516
- LHCb(2013)

$\sigma(\gamma p \rightarrow J/\psi\, p)$ [nb]

$W_{\gamma p}$ [GeV]

Summary

- HERA delivers diffractive results since 20 years

  - Still more to come!

- Many beautiful inclusive diffractive measurements implementing various experimental techniques

- First diffractive combination done

- Diffractive factorization confirmed by dijet measurements in DIS

- data to study diffractive PDFs in PhP available, but no results so far

- Vector mesons measured with high precision

  - Extended range of diffractive variables

  - HERA precise measurements fill phase-space between fixed target experiments and LHCb