Vector Mesons and Deeply Virtual Compton Scattering at HERA

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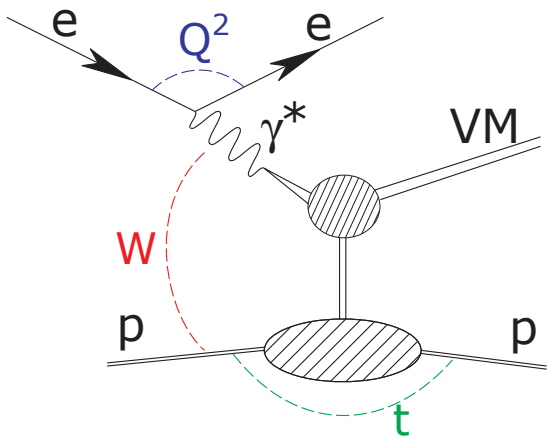
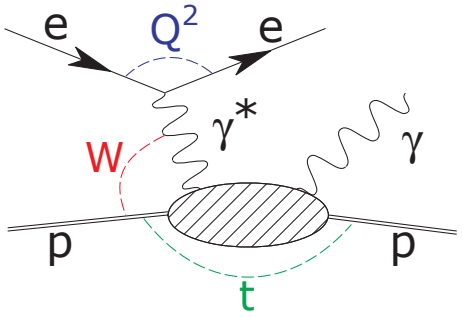
6th Small x and Diffraction Workshop

ETH Institute for Particle Physics

Overview



- Results on vector meson production:
  - Trajectory measurements
  - Comparisons to pQCD models
- Results on Deeply Virtual Compton Scattering
- Conclusion and outlook



Diffractive Vector Meson Production

"Soft" processes well described by Regge Theory (Soft Pomeron)

vs.

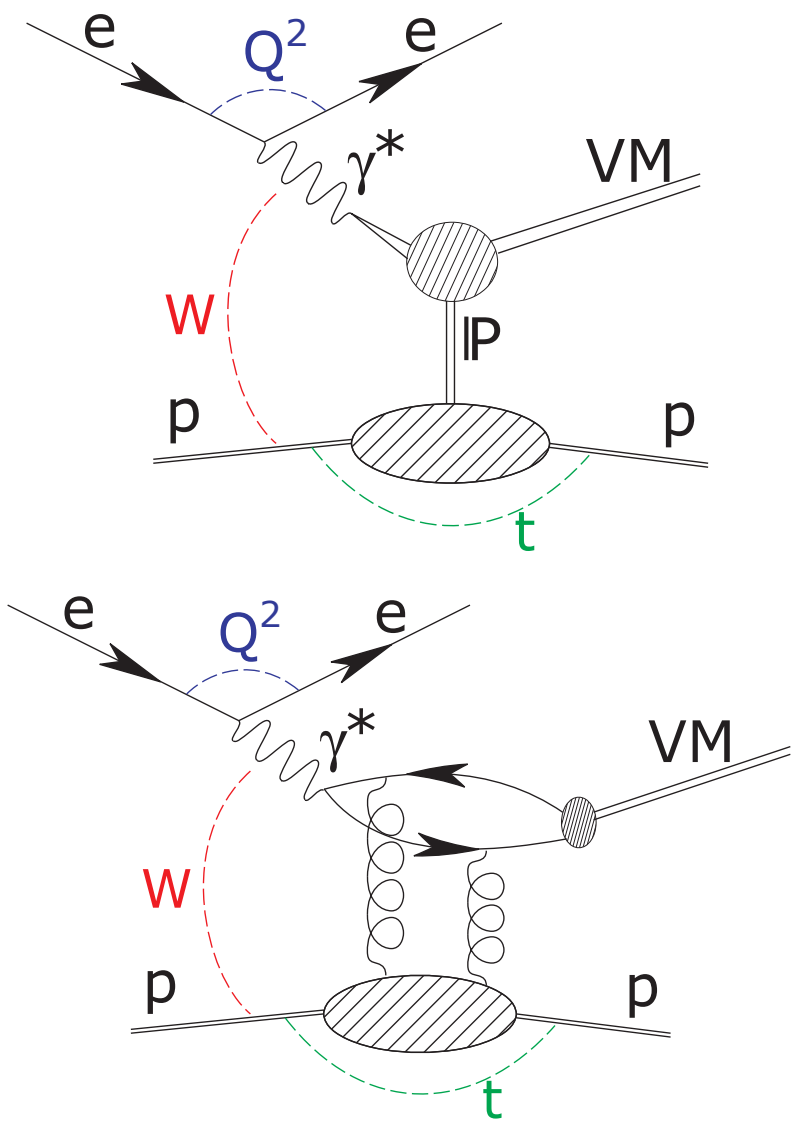
"Hard" processes calculable in pQCD

Hard scale can be set by:

- Q^2 (electroproduction)
- VM mass (J/ψ, Υ)
- t

Soft: Pomeron trajectory

Hard: Gluon densities, evolution equations, s-channel helicity non-conservation



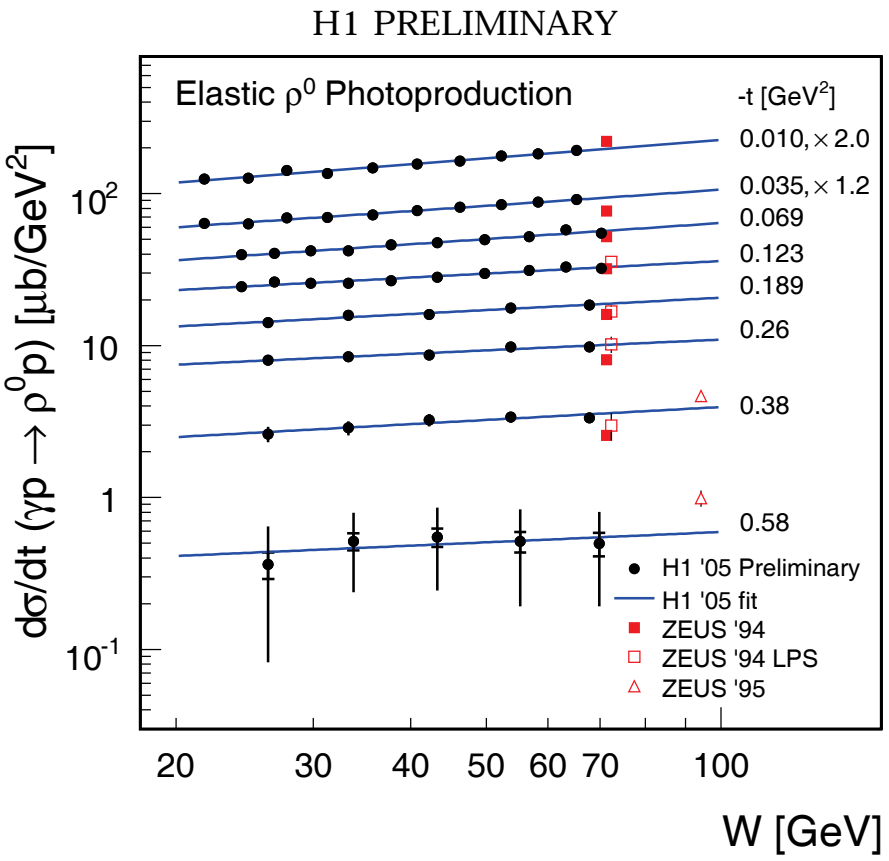
ρ - extracting the pomeron trajectory

- ZEUS: measure at large *W*, in bins of *t*, combine with OMEGA data at low *W*
- Fit $\sigma \propto W^{4(\alpha(t)-1)}$ in each *t* bin
- Large lever arm, but large uncertainty due to relative normalisation

ZEUS: Eur.Phys.J. C 14 (2000) 213

- H1: Determine trajectory from a single experiment
- Smaller lever arm but NO relative normalistaion uncertainty

H1 Preliminary 06-011 (DIS 2006)



ρ - pomeron trajectory

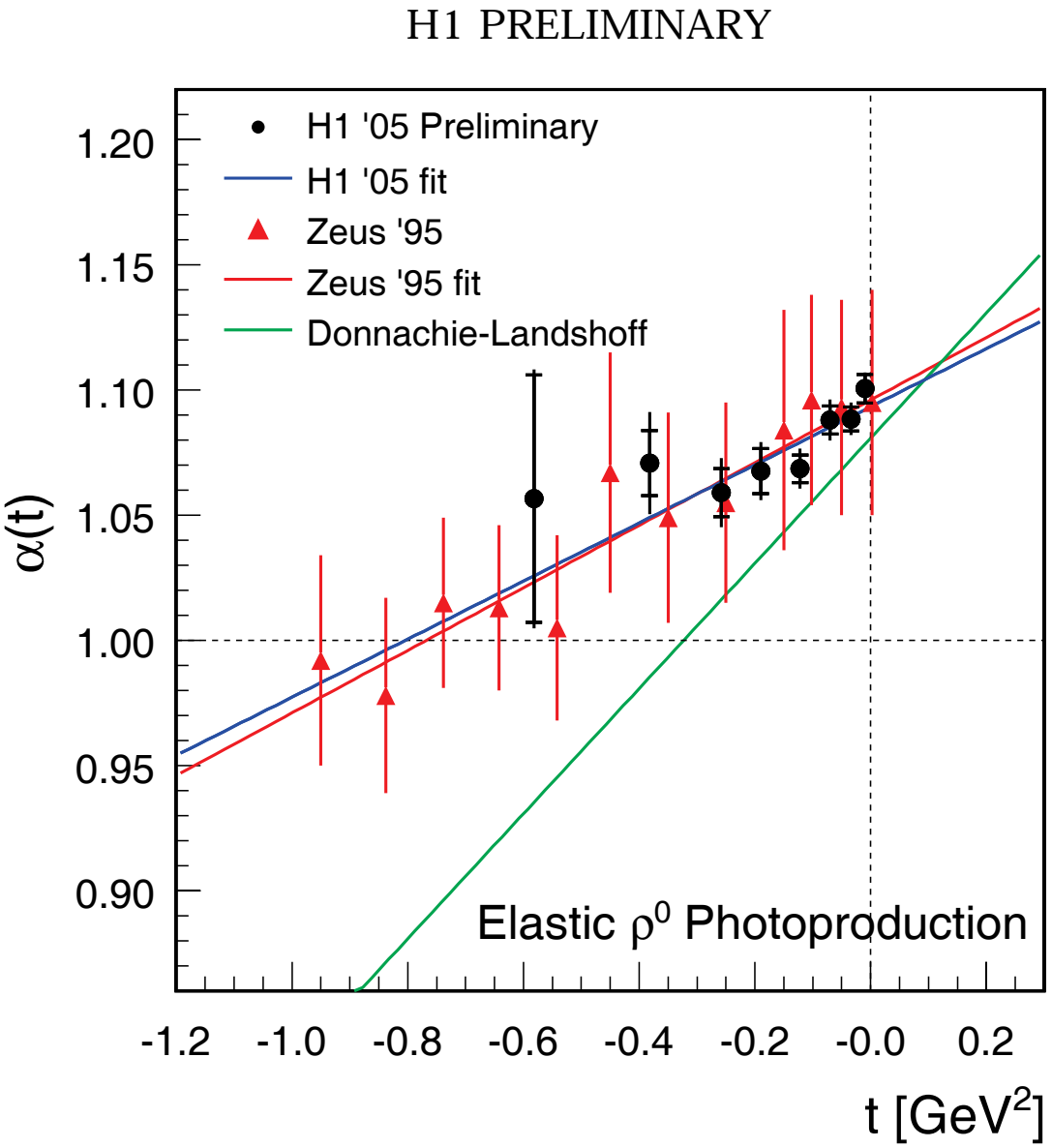
- ZEUS result:

$\alpha_P(0) = 1.096 \pm 0.021$
$\alpha'_P = 0.125 \pm 0.038\ \text{GeV}^{-2}$

- H1 preliminary result:

$\alpha_P(0) = 1.093 \pm 0.003^{+0.008}_{-0.007}$
$\alpha'_P = 0.116 \pm 0.027^{+0.036}_{-0.046}\ \text{GeV}^{-2}$

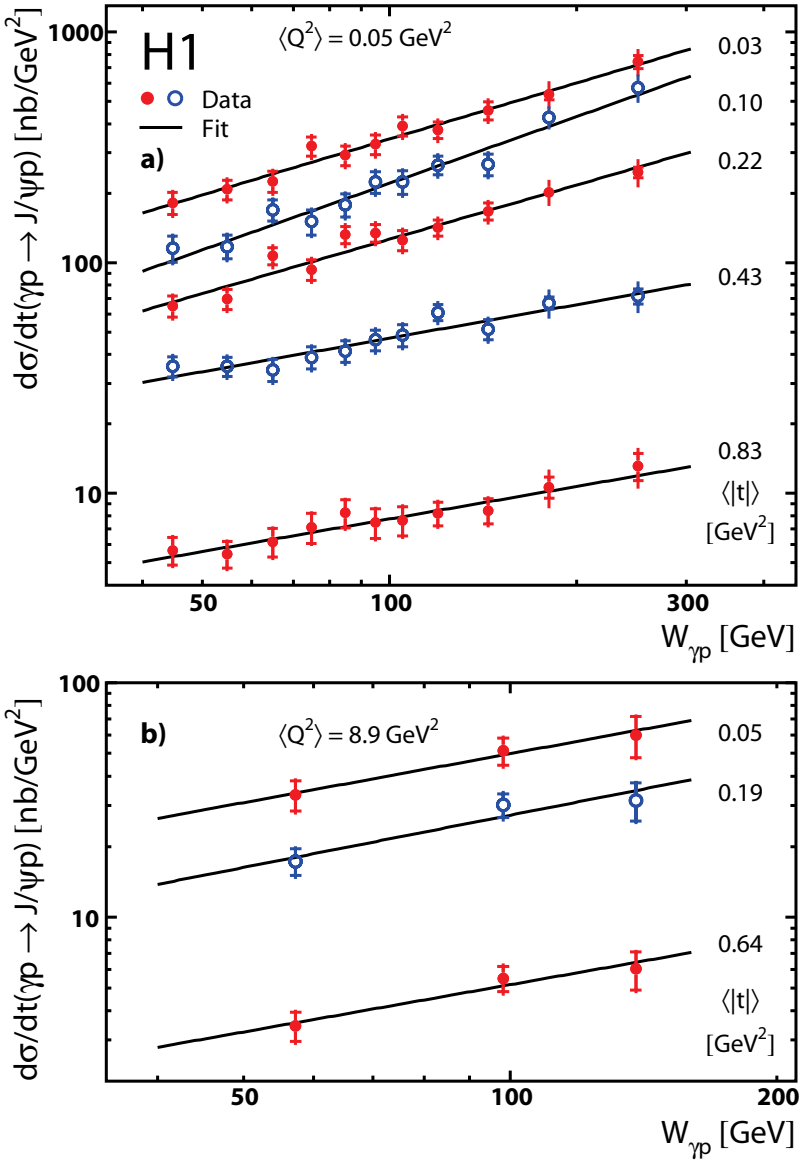
- Results compatible, half the Donnachie-Landshoff shrinkage



J/ψ - extracting the pomeron trajectory

- Determine dependence of cross section on W in bins of t
- Fit $\sigma \propto W^{4(\alpha(t)-1)}$ in each t bin
- Photo- and electroproduction

H1: Eur.Phys.J. C46 (2006) 585
ZEUS: Nucl. Phys. B 695 (2004) 3 (DIS)
Eur.Phys.J. C 24 (2002) 345 (γp)



J/ψ - pomeron trajectory

- Alternatively: do a 2-D fit
- J/ψ harder than predicted by soft pomeron (γp):

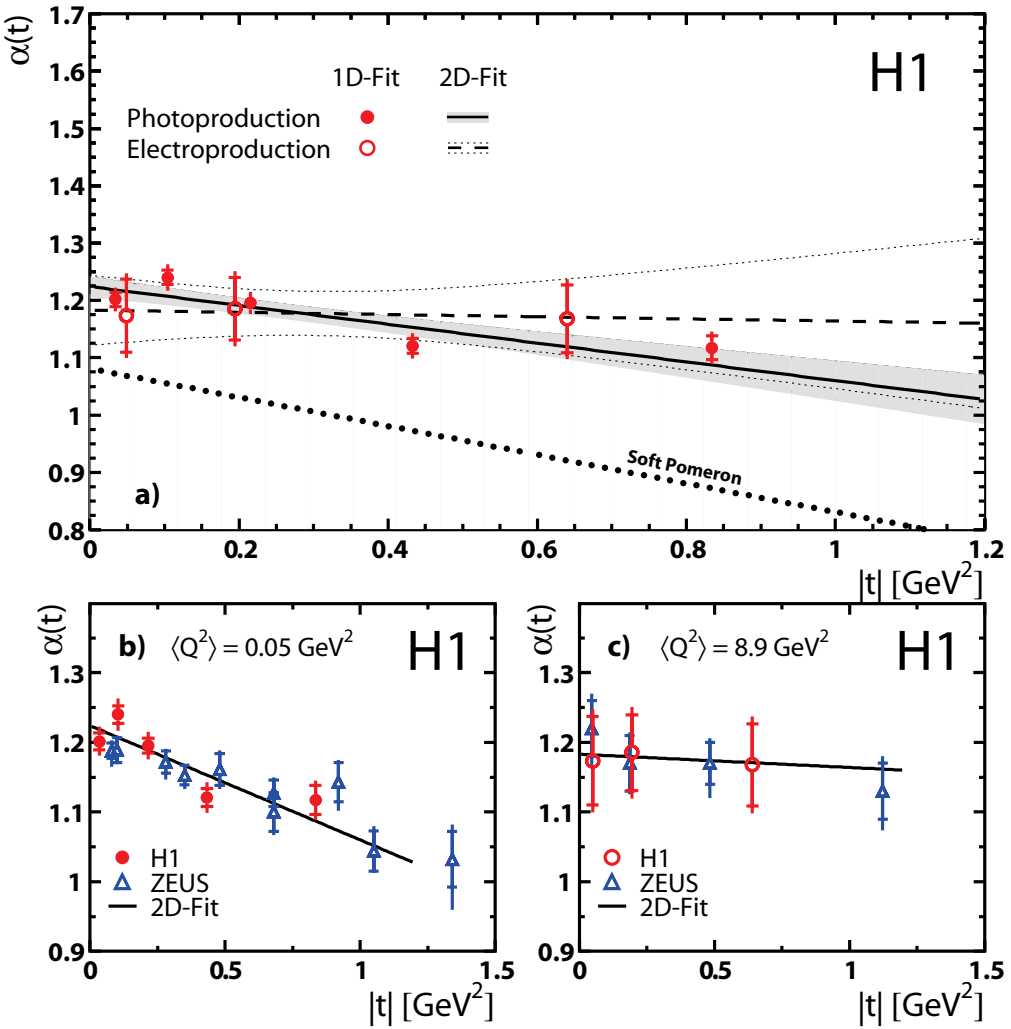
$\alpha_P(0) = 1.224 \pm 0.010 \pm 0.012$

$\alpha'_P = 0.164 \pm 0.028 \pm 0.030\,\mathrm{GeV}^{-2}$

- Significant *t* dependence in photoproduction:
  4σ evidence for shrinkage, but also 2σ below soft pomeron
- Electroproduction: compatible with no shrinkage

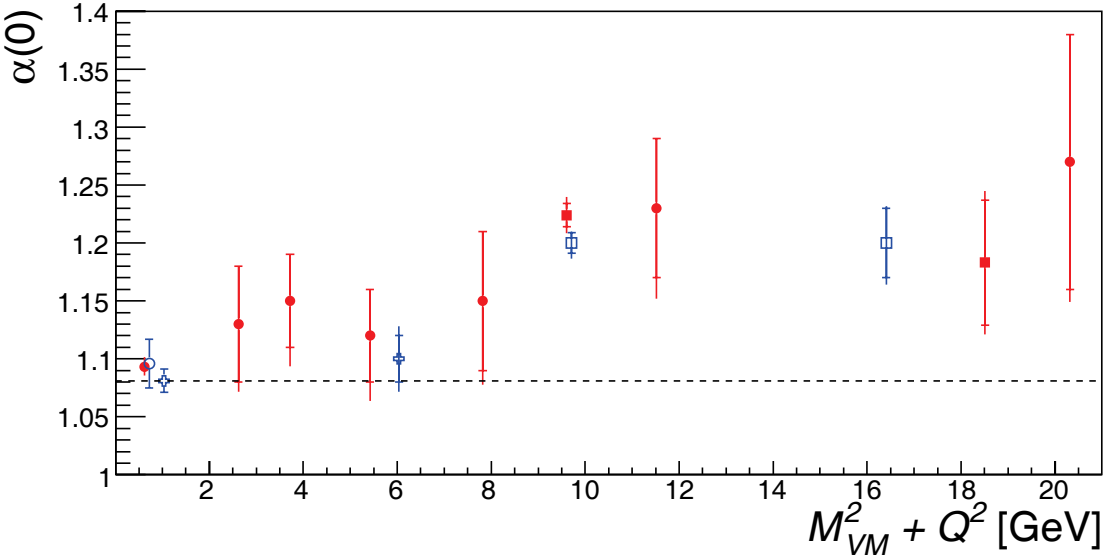
$\alpha_P(0) = 1.183 \pm 0.054 \pm 0.030$

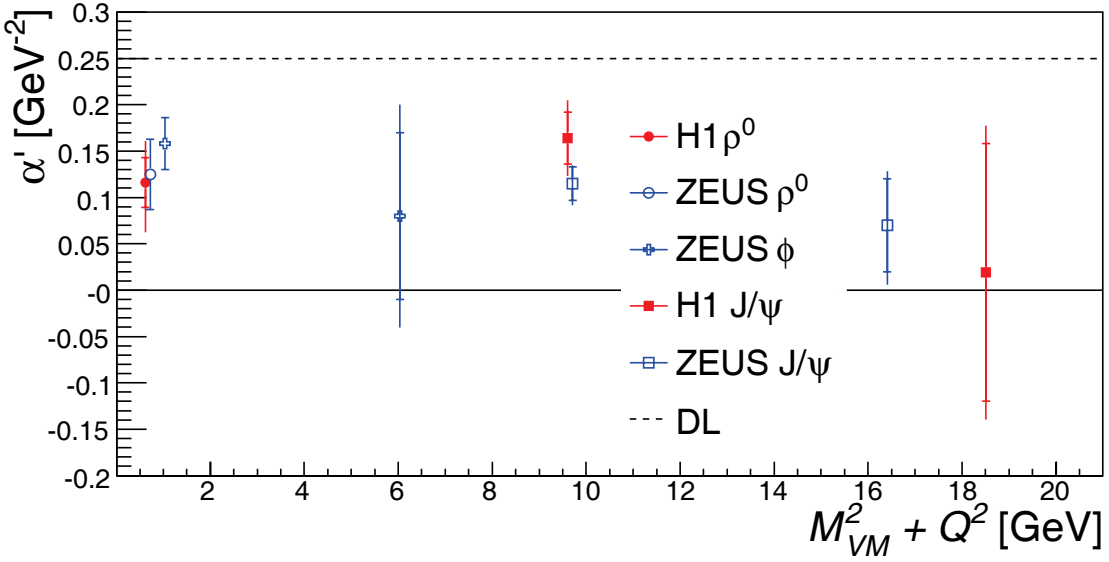
$\alpha'_P = 0.019 \pm 0.139 \pm 0.076\,\mathrm{GeV}^{-2}$



Summary of trajectory measurements

- Intercept rises with scale
- Slope more difficult to measure
- Data consistent with being flat at ~0.13 GeV^{-2}
- Data inconsistent with Donnachie-Landshoff slope of 0.25 GeV^{-2}





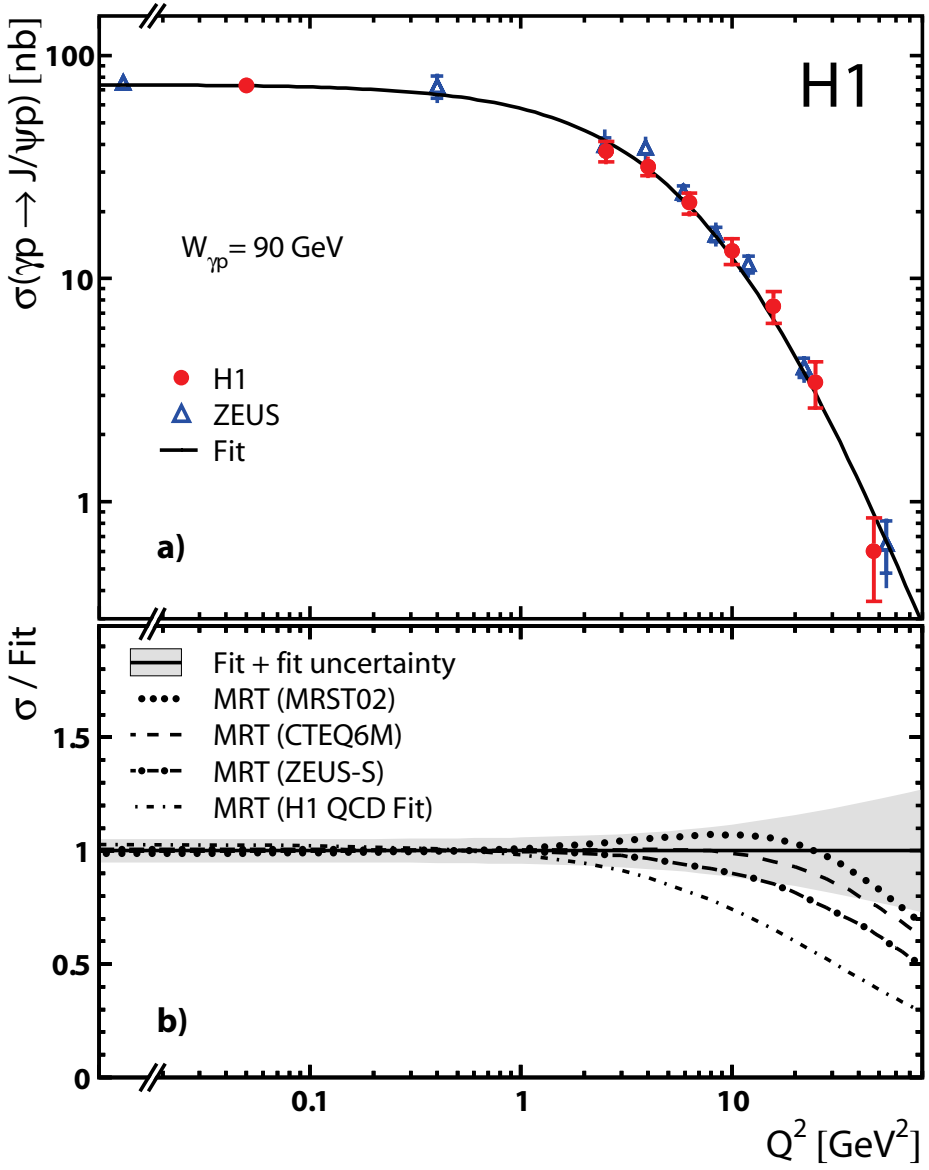
J/ψ - testing gluon densities?

- High J/ψ mass provides a hard scale - calculable in QCD
- Measure cross section as a function of Q^2, W, compare to models
- Phenomenological fit $(Q^2+M^2)^{-n}$

Martin, Ryskin and Teubner: pQCD model based on k_T factorisation and a parton-hadron duality ansatz

(Phys.Rev.D 62 (2000) 014022)

- Prediction normalised to data - shape comparison can constrain gluon density



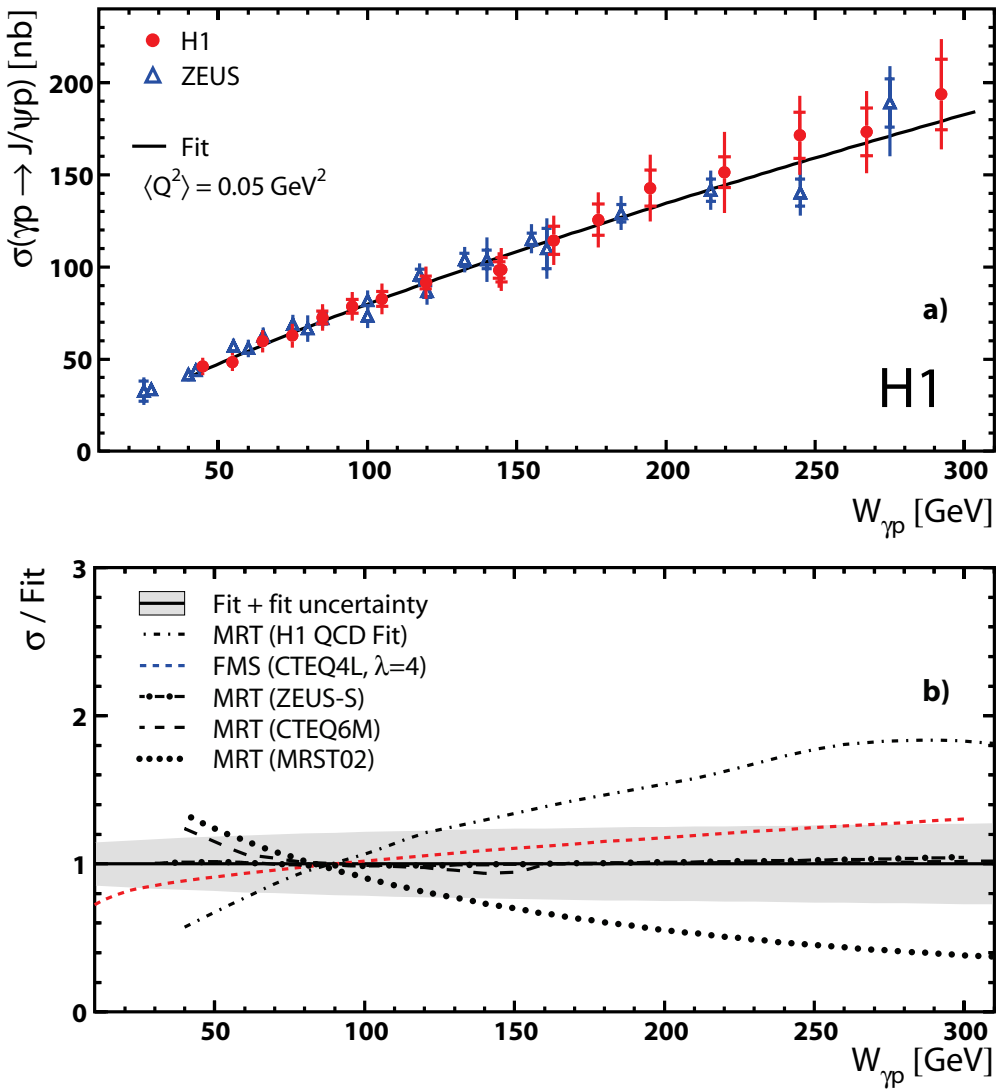
J/ψ - testing gluon densities!

- Even more prominent in *W* dependence
- Normalise predictions at *W* = 90 GeV, compare shapes
- Access to gluon densities in regions poorly constrained by inclusive DIS data (very low *x*)
- Uncertainties on Gluon distributions not taken ito account

Theoretical alternative: Dipole model by Frankfurt, McDermott and Strikman (FMS)
(JHEP 0103 (2001) 045)

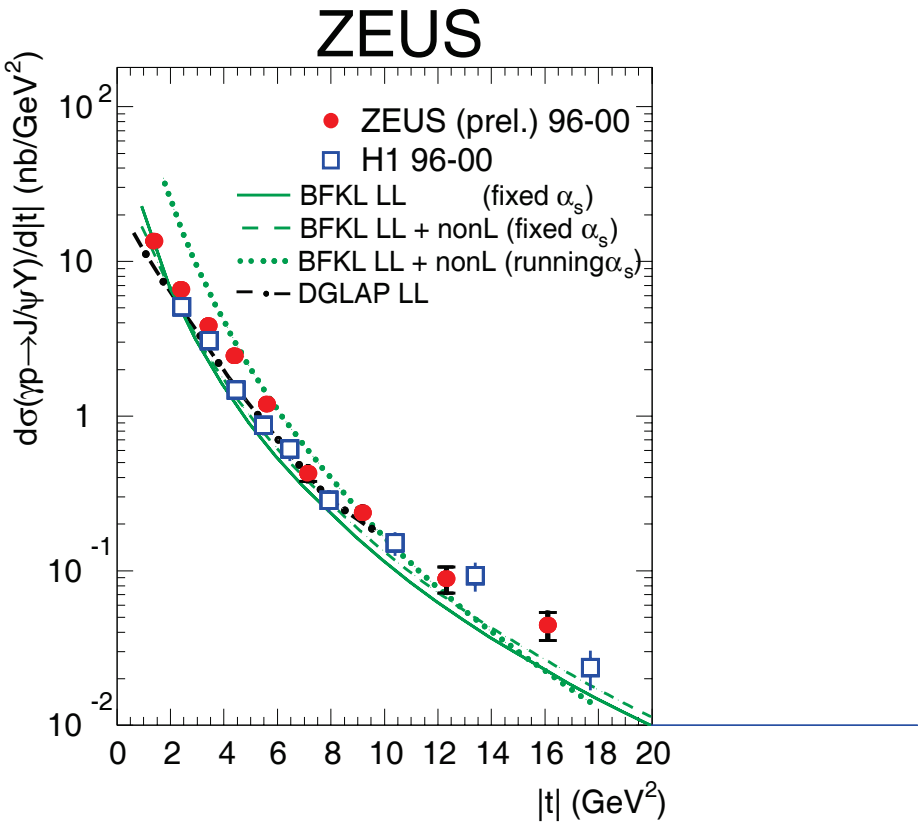
H1: Eur.Phys.J. C46 (2006) 585

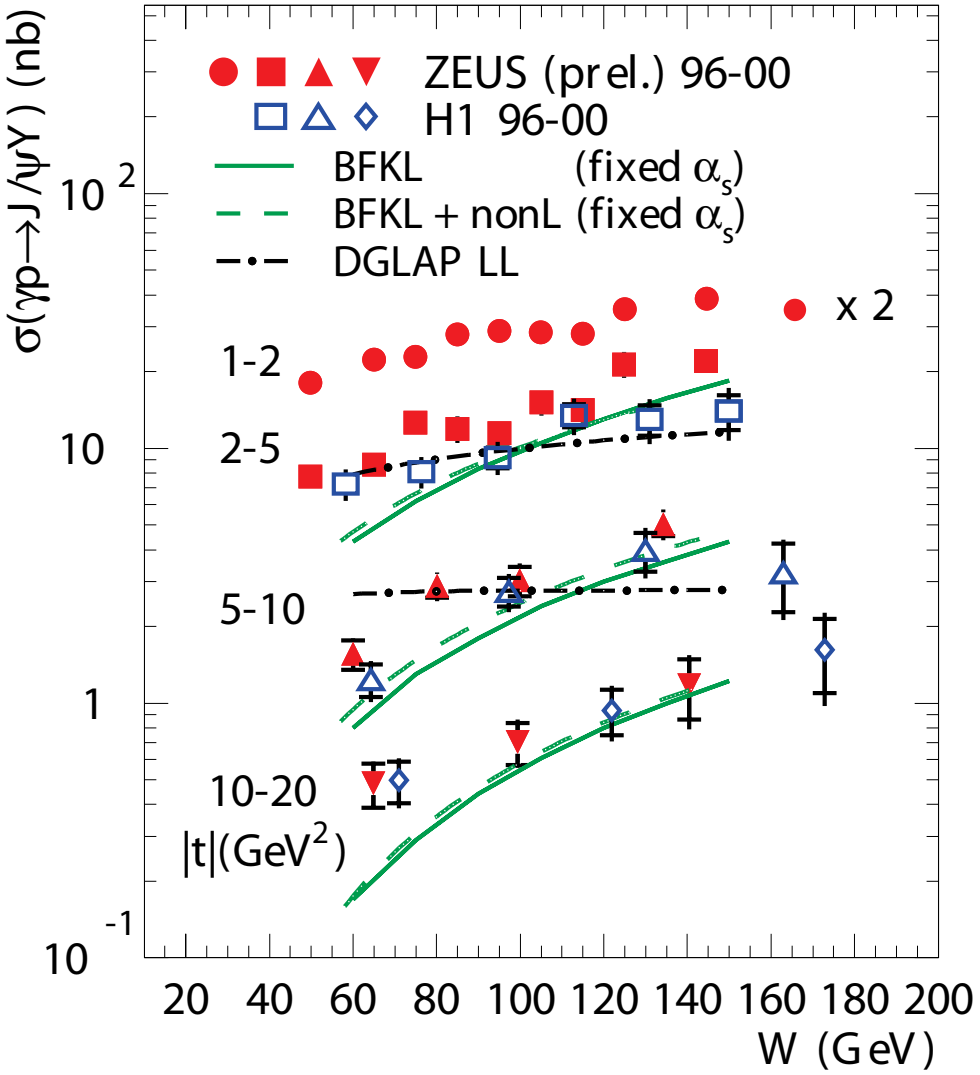
ZEUS: Nucl. Phys. B 695 (2004) 3 (DIS)
Eur.Phys.J. C 24 (2002) 345 (γp)



J/ψ at high *t*

- ZEUS higher and steeper than H1
- BFKL better than DGLAP





ZEUS: Preliminary, Lepton-Photon 2005 (291)
H1: Phys.Lett. B 568 (2003), 205

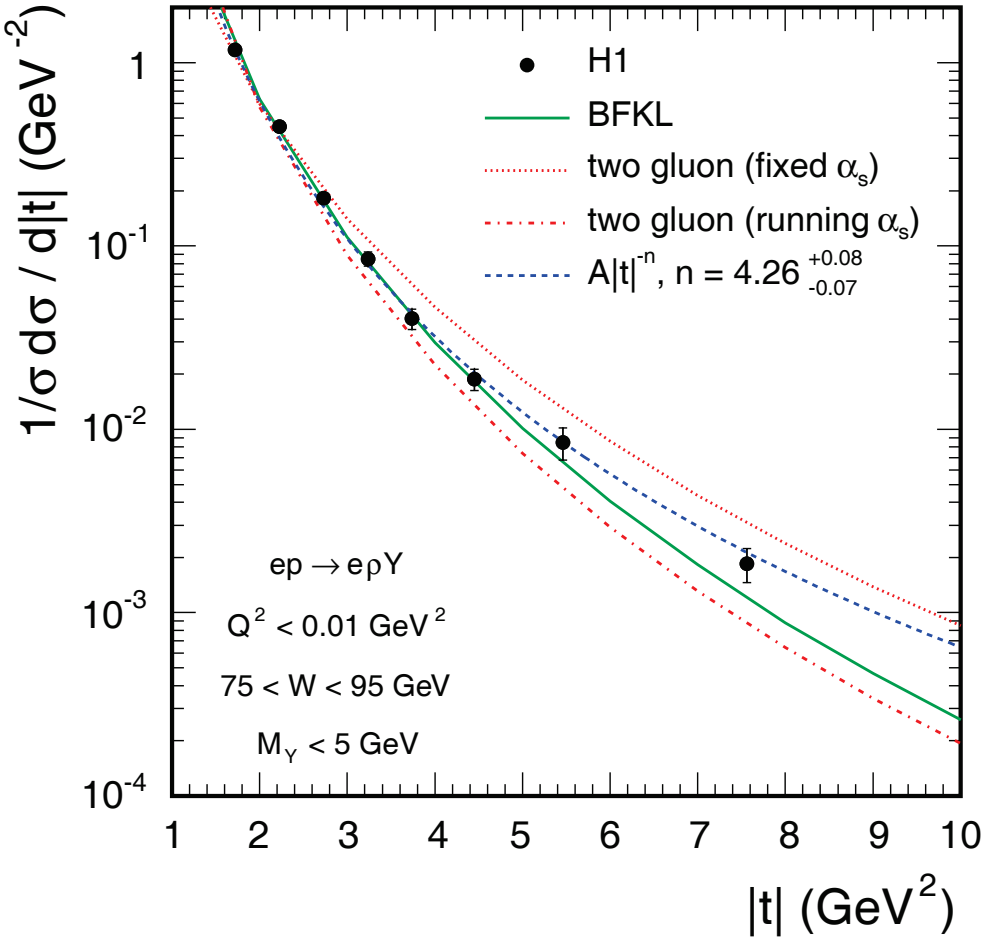
High t ρ^0 in photoproduction

$Q^2 < 0.01$ GeV^2
$75 < W < 95$ GeV
$1.5 < |t| < 20$ GeV^2
$M_Y < 5$ GeV

$\frac{d\sigma}{dt} \propto |t|^{-n}$ fits data well

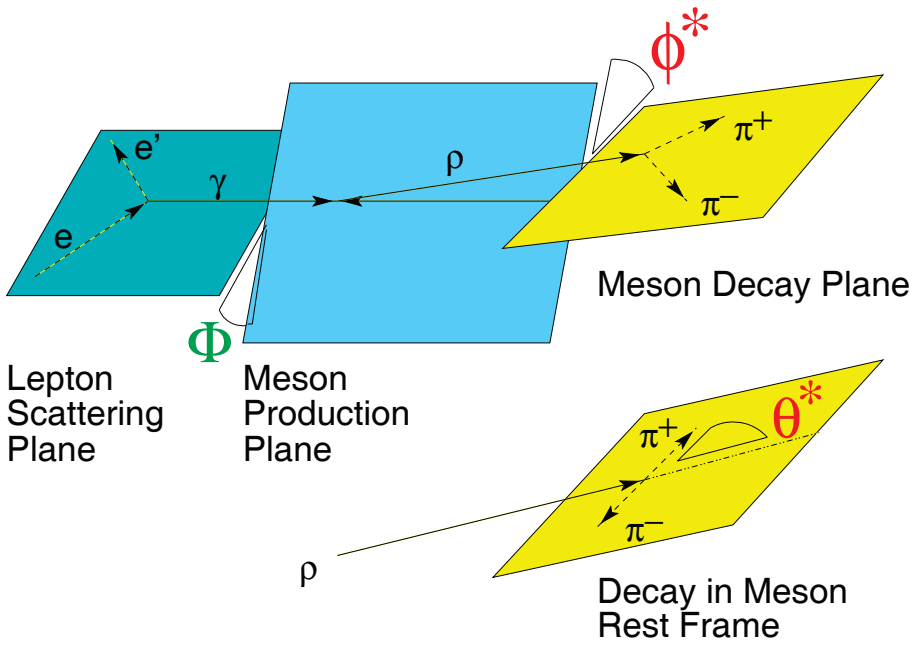
$n = 4.26 \pm 0.06\ ^{+\ 0.06}_{-\ 0.04}$

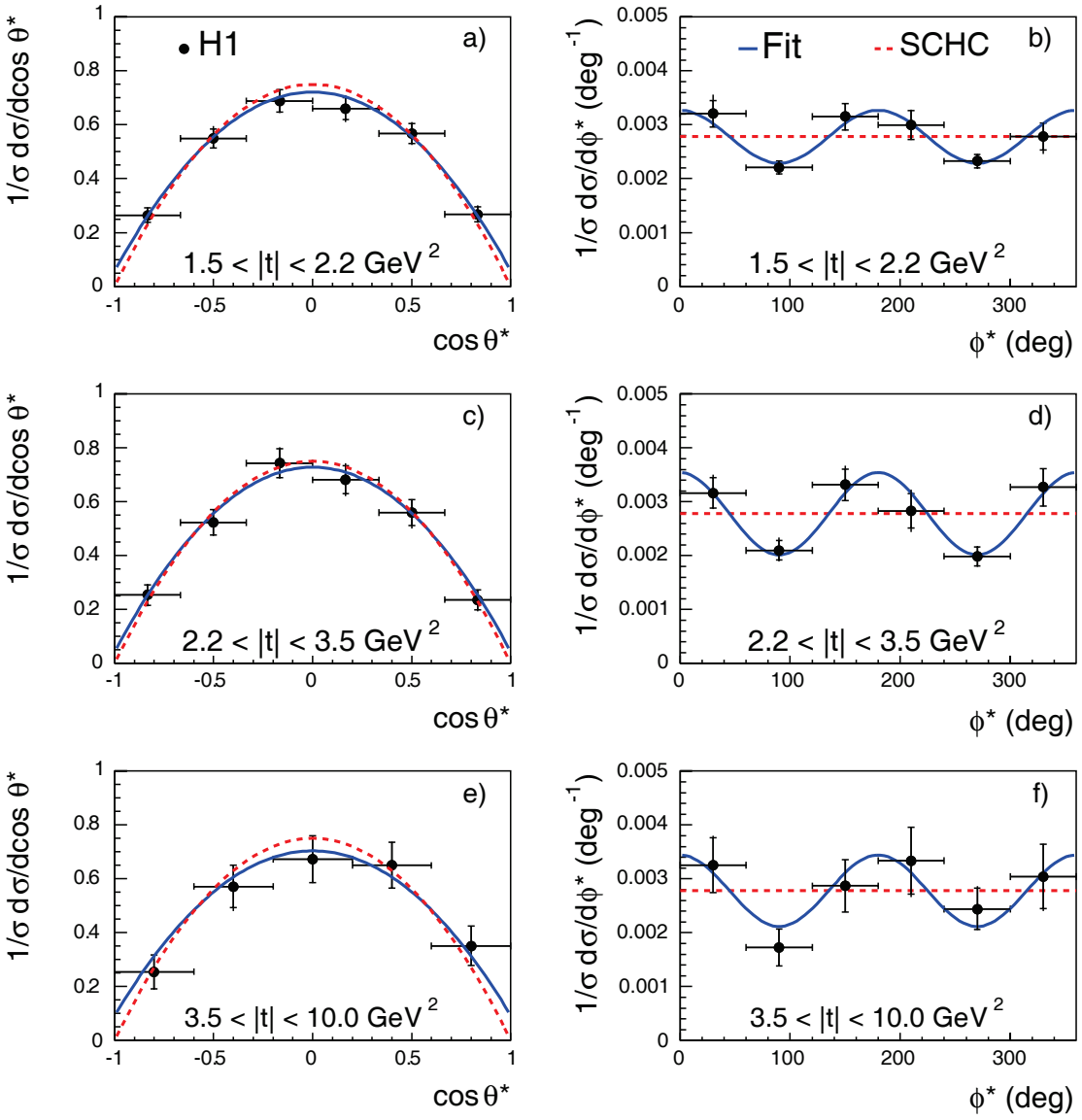
- Two gluon models don't describe data
- BFKL model gives reasonable description
  (G.G. Poludnikowski et al., JHEP 312 (2003) 002)



H1 Collab., A. Aktas et al.
Phys. Lett. B 638 (2006) 422

High t ρ^0: Angular distributions





Look for s-channel helicity NON-conservation (departure from Vector Dominance)

Photoproduction: e escapes through beampipe; only ϕ^* and θ^* accessible

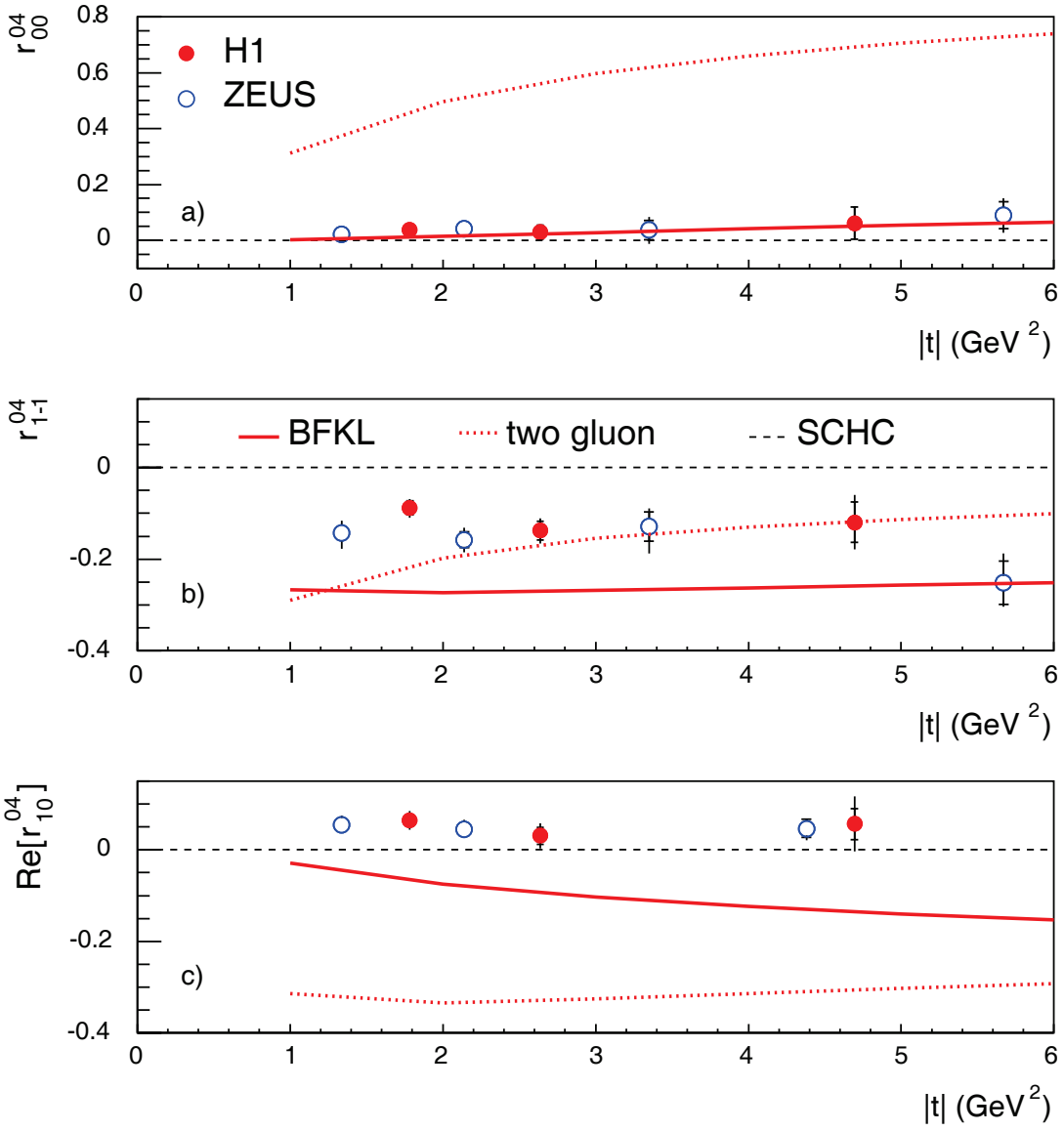
High t ρ^0: SCH-Non-Conservation

Matrix elements 0 for SCHC
Compare to 2-gluon and BFKL models

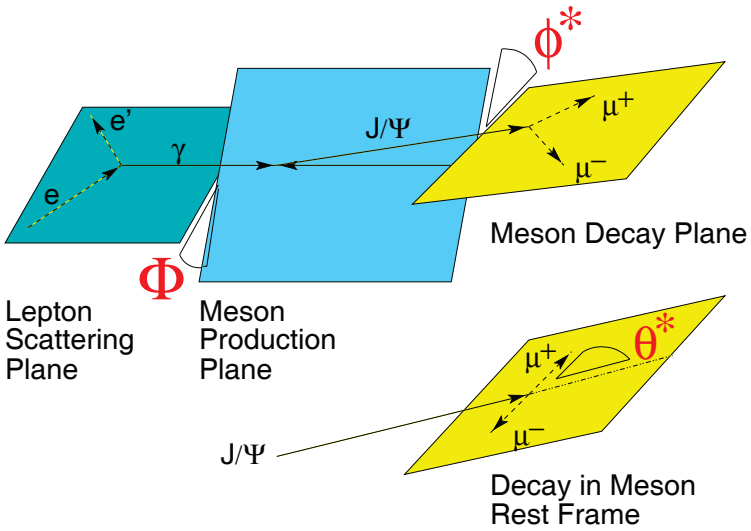
r_{00}^{04} in accordance with SCHC

r_{1-1}^{04} and Re[r_{10}^{04}] violate SCHC

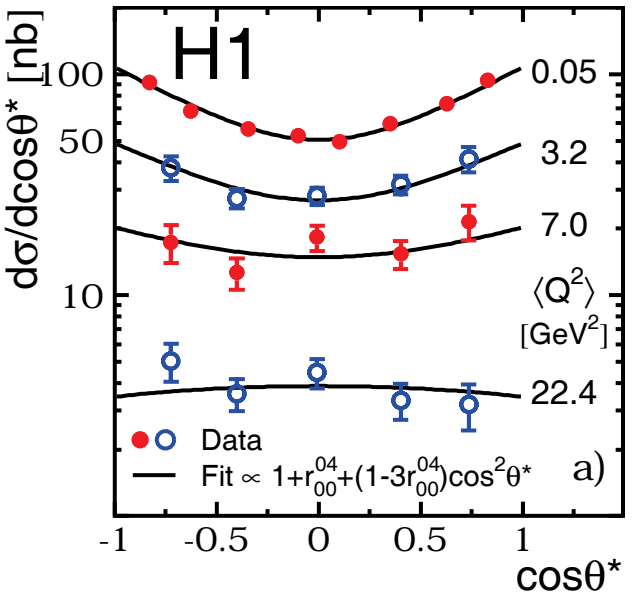
- Two gluon model fails
- BFKL based model describes r_{00}^{04}, has difficulties with r_{1-1}^{04} and fails for Re[r_{10}^{04}]

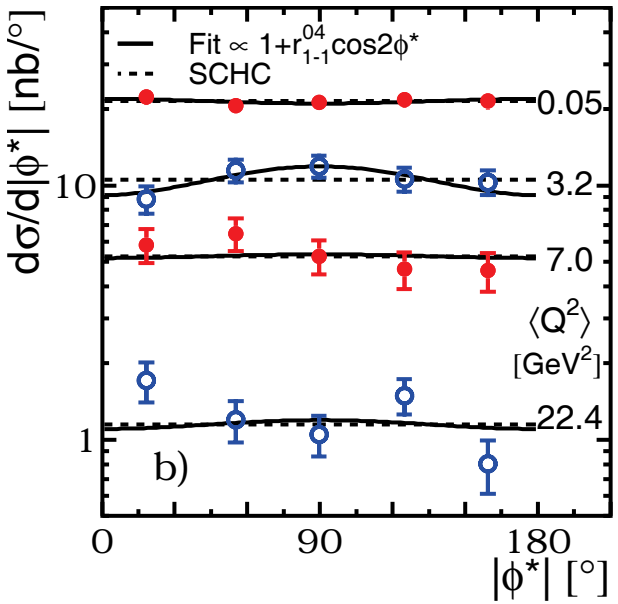


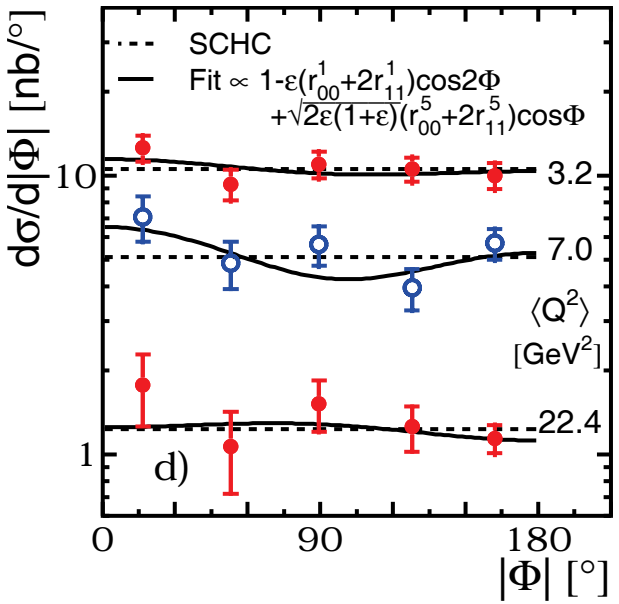
J/ψ - Helicity Analysis



- All three angles accessible in electroproduction
- Use also proton dissociative events to increase statistics





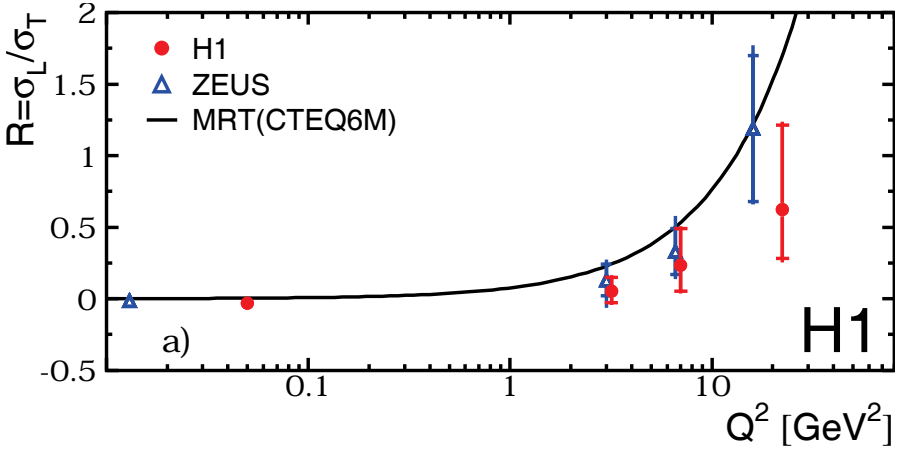


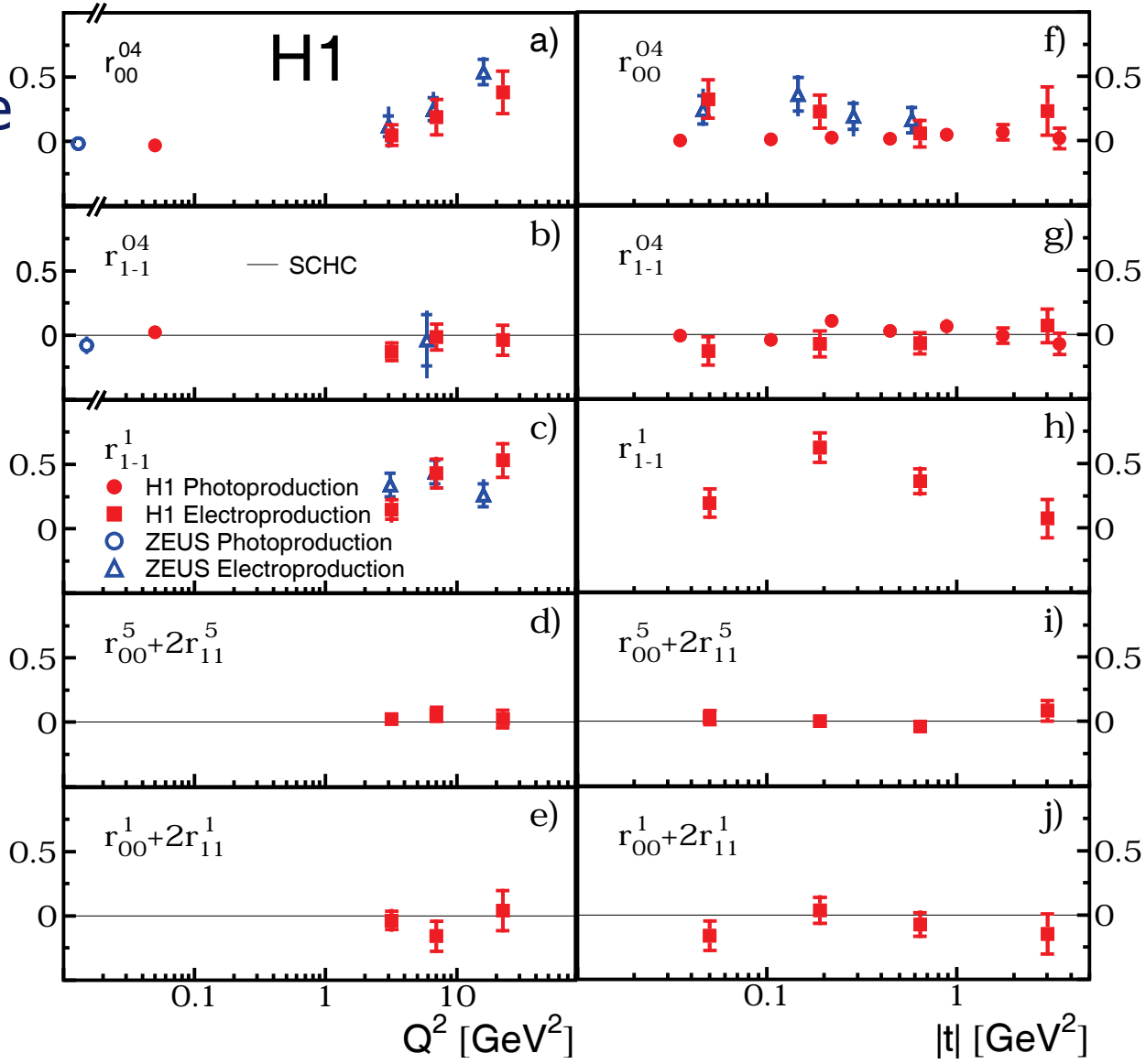
J/ψ - Helicity Analysis

The 5 measured spin-density matrix elements are in agreement with SCHC
For SCHC, the ratio

$$R = \frac{\sigma^L}{\sigma^T}$$

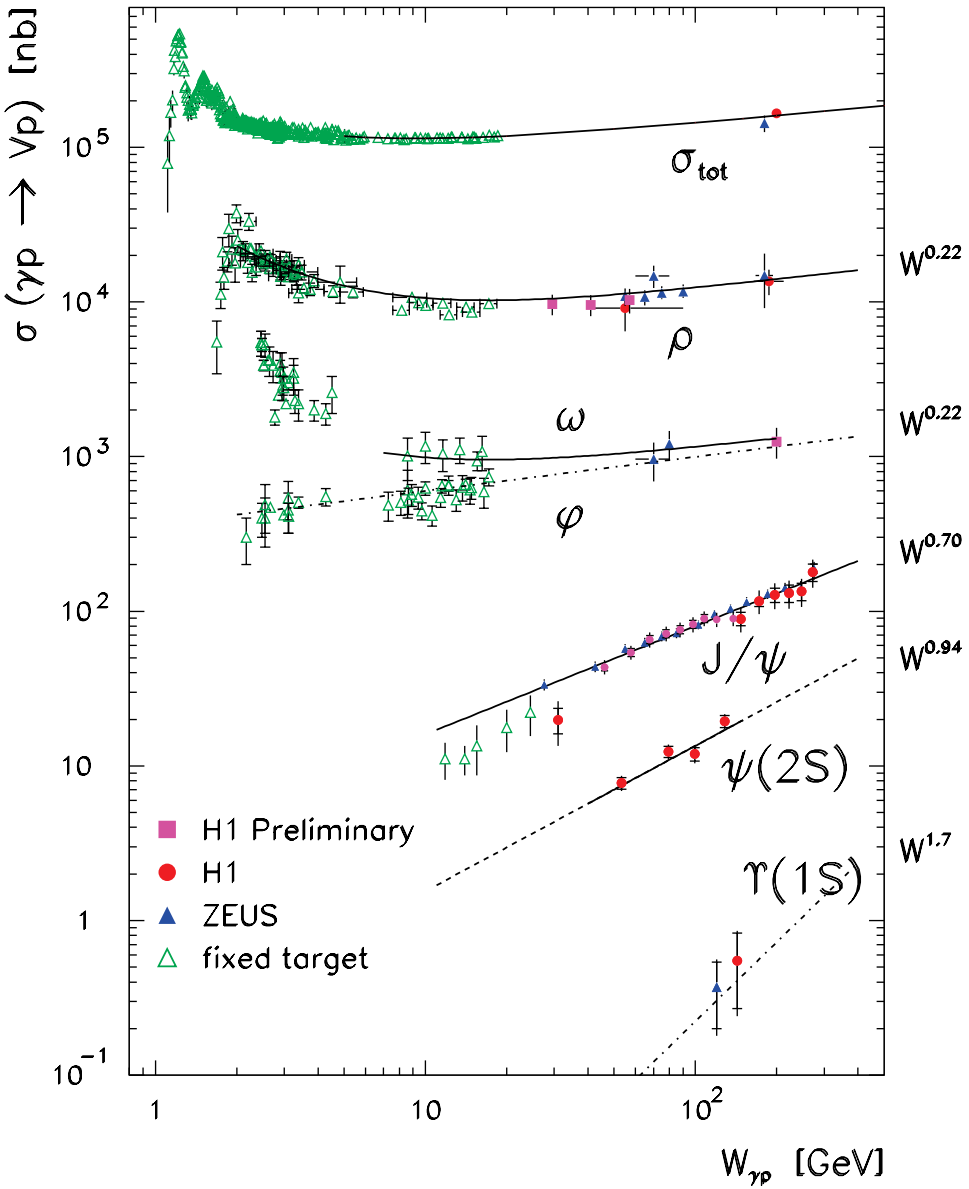
can be determined from r^{04}_{00}





Vector Mesons: Summary

- Intercepts increase with scale - slopes universal?
- J/ψ production calculable in pQCD, sensitive to gluon densities and evolution
- SCHC violated for high $|t|$ ρ^0, no evidence for violation in J/ψ production



Deeply Virtual Compton Scattering

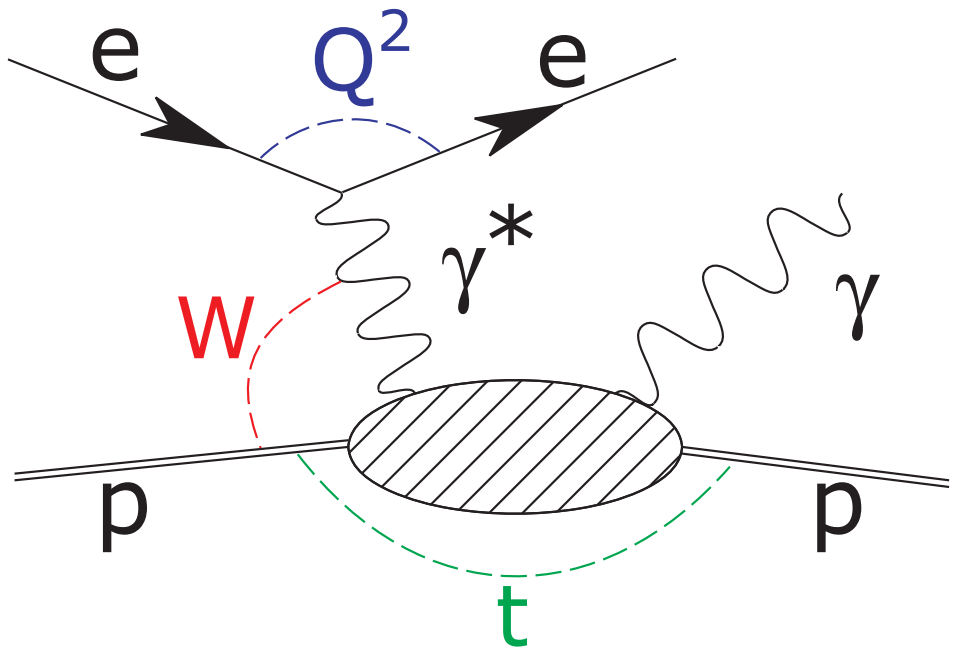
Scattering of a virtual photon off the proton producing a real photon:

$$e + p \rightarrow e + \gamma + p$$

In principle very clean channel:

- Factorisation theorem: First diffractive process fully calculable in QCD
- No uncertainty due to VM wave-function
- Clean final state

H1: Eur.Phys.J. C 44 (2005) 1 (HERA I)
Preliminary ICHEP 2006 (HERA II)
ZEUS: Phys.Lett. B 573 (2003) 46

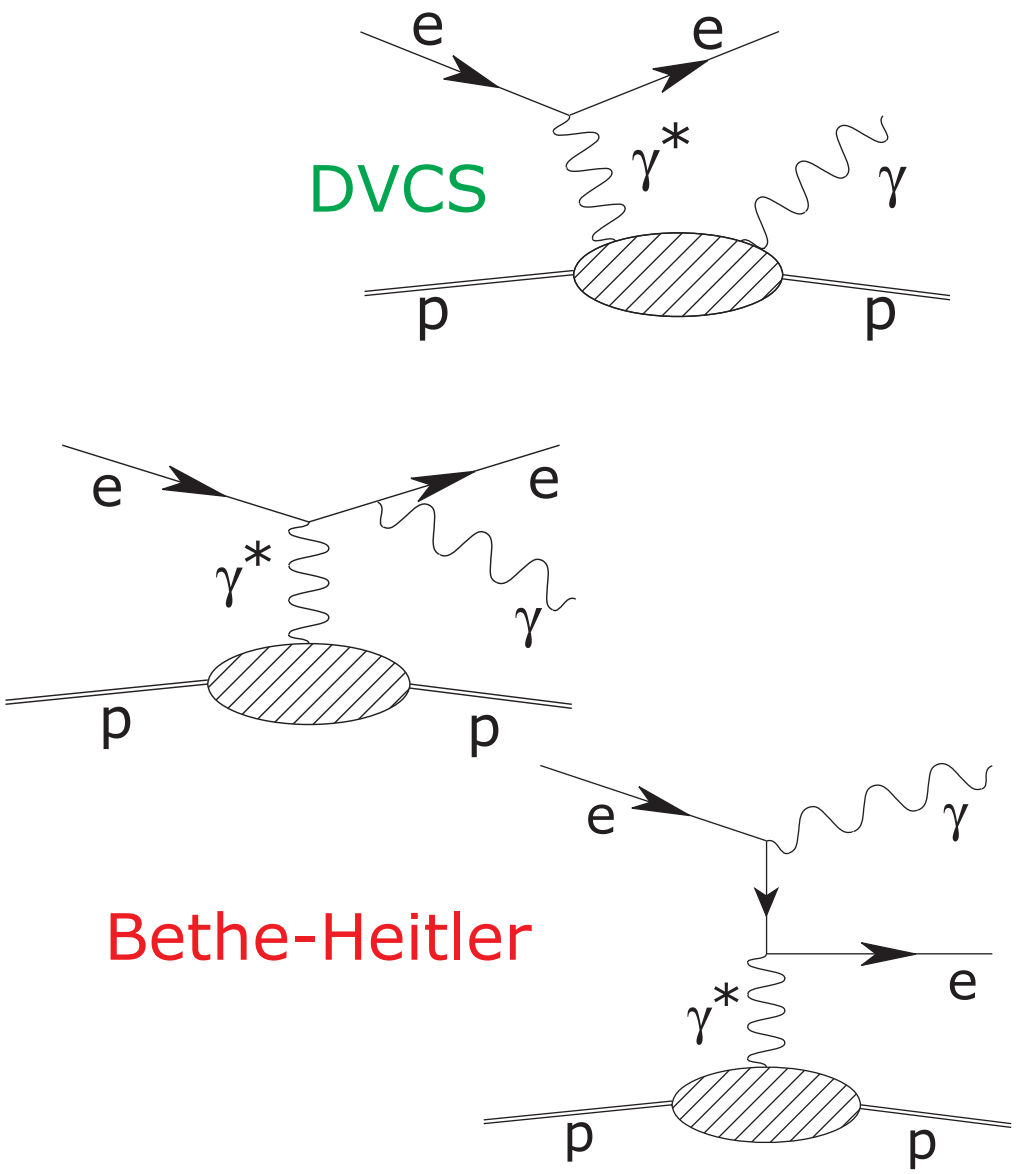


NLO leading twist calculation by A. Freund and M. McDermott Eur. Phys. J. C23 (2002) 651
Factorisation Theorem:
Collins & Freund Phys.Rev.D 59 (1999) 074009
Ji & Osborne Phys.Rev. D 58 (1998) 094018

DVCS and Bethe-Heitler

DVCS has the same final state as the Bethe-Heitler process:

- Interference gives access to amplitudes via asymmetries (angles, beam charge)
- DVCS cross section via sub-traction of B-H (calculable in QED) - Interference cancels in integration over angles



DVCS: Data selection

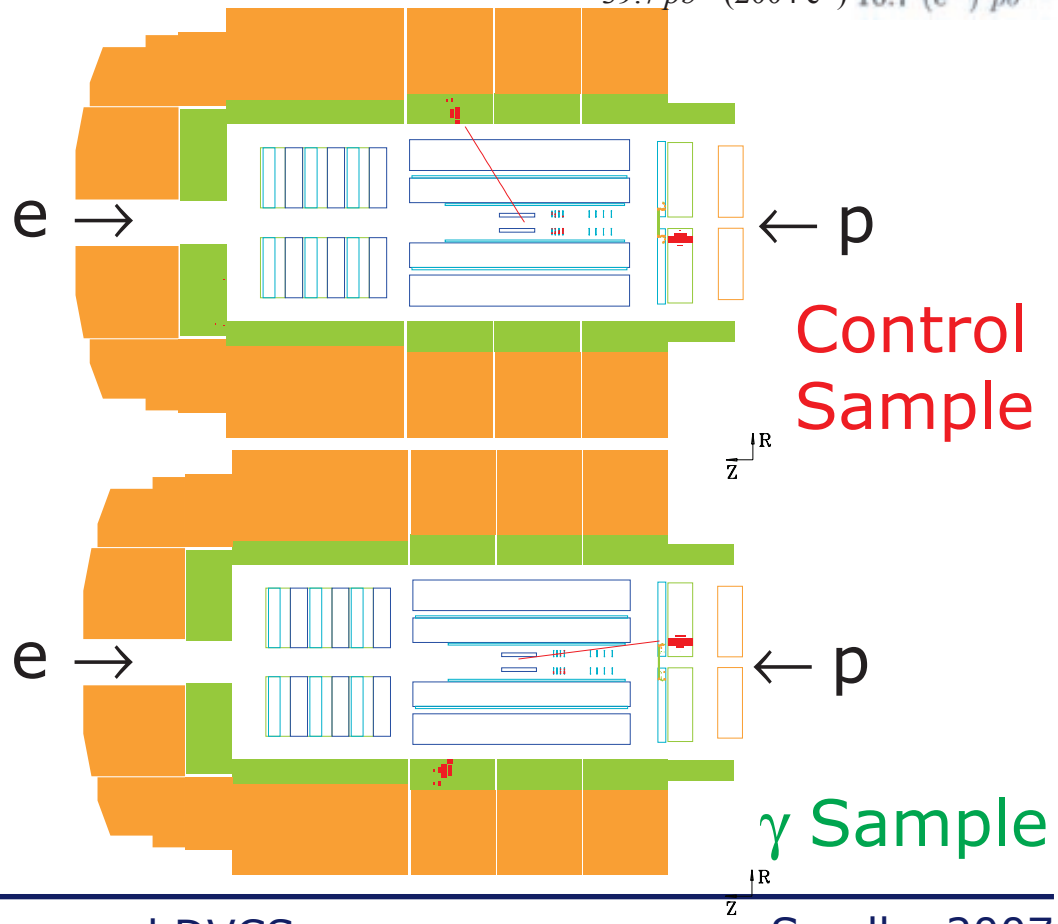
Expect one photon, one electron and nothing else in detector

	H1	ZEUS
$E_1 >$	15 GeV	10 GeV
$p_{T_2} >$	1 GeV	
$E_2 >$		3 GeV
$E_3 <$	0.5 GeV	0.2 GeV
elast.	no track, Fwd	no track
Lumi	46.5 pb^{-1} (e^+)	95 (e^+) pb^{-1}
	39.7 pb^{-1} (2004 e^+)	16.7 (e^-) pb^{-1}

Two samples:

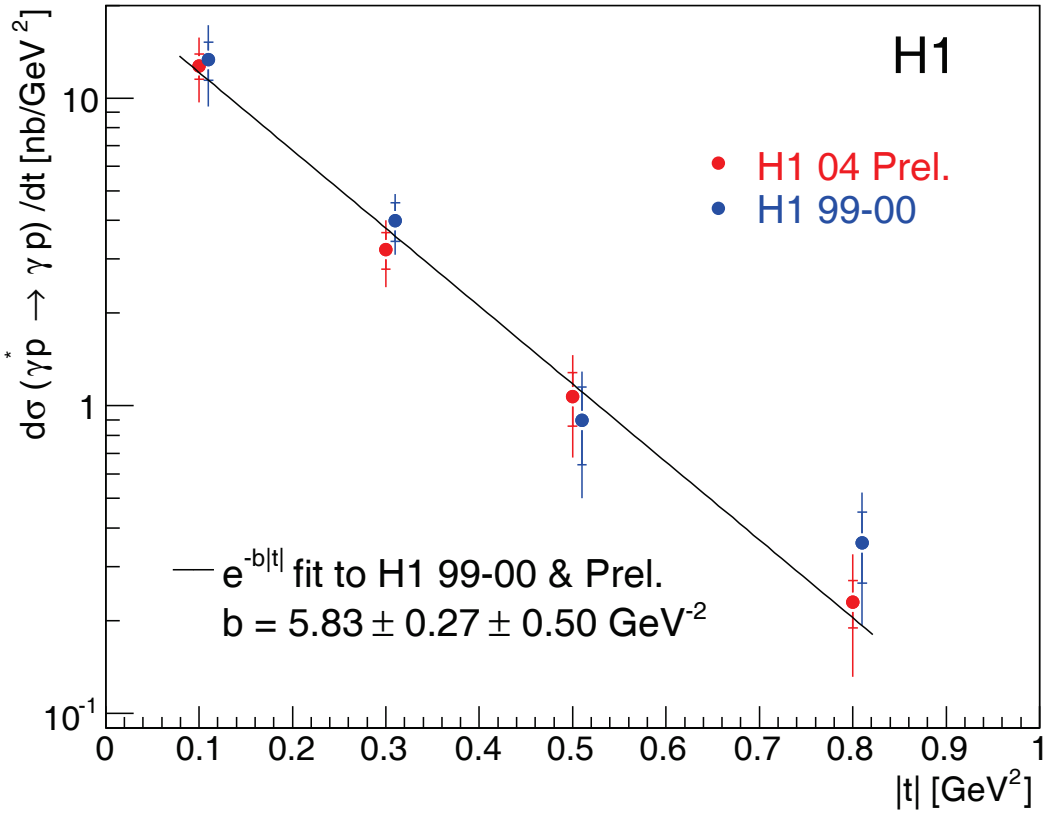
- Electron in barrel, photon in backward direction (Mainly Bethe-Heitler)
- Photon in barrel, electron in backward direction (DVCS and Bethe-Heitler)

Use first sample to understand detector response

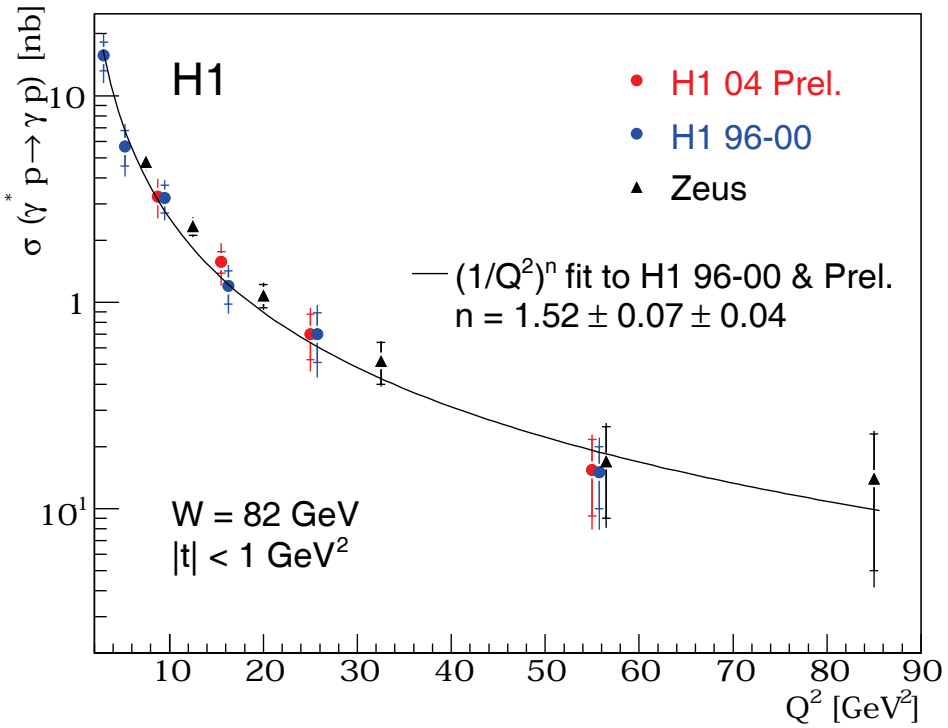


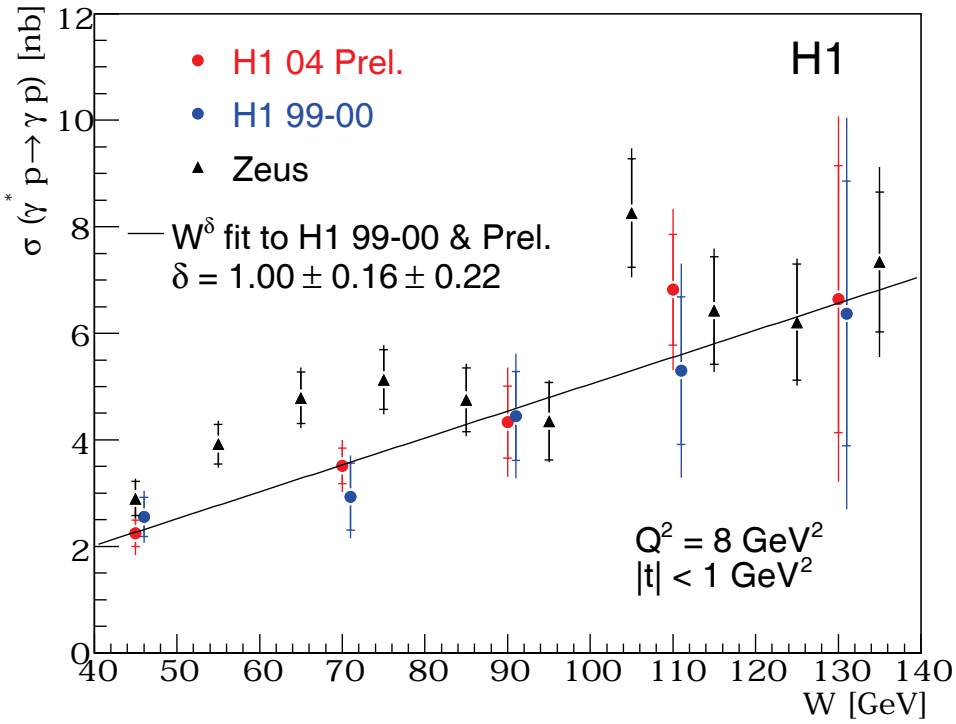
DVCS: t dependence

- H1 has first result with HERA-II data, more to come
- Exponential fit in t:
  $d\sigma/dt \propto e^{-bt}$
  $b = 5.83 \pm 0.27 \pm 0.50$ GeV^{-2}
  at $Q^2 = 8$ GeV, $W = 82$ GeV
- Compatible with old measurement
- Constrains theory normalisation



DVCS: Q^2 and W dependencies





- Fit in Q^2: $(1/Q^2)^n$
  $n = 1.52 \pm 0.07 \pm 0.04$

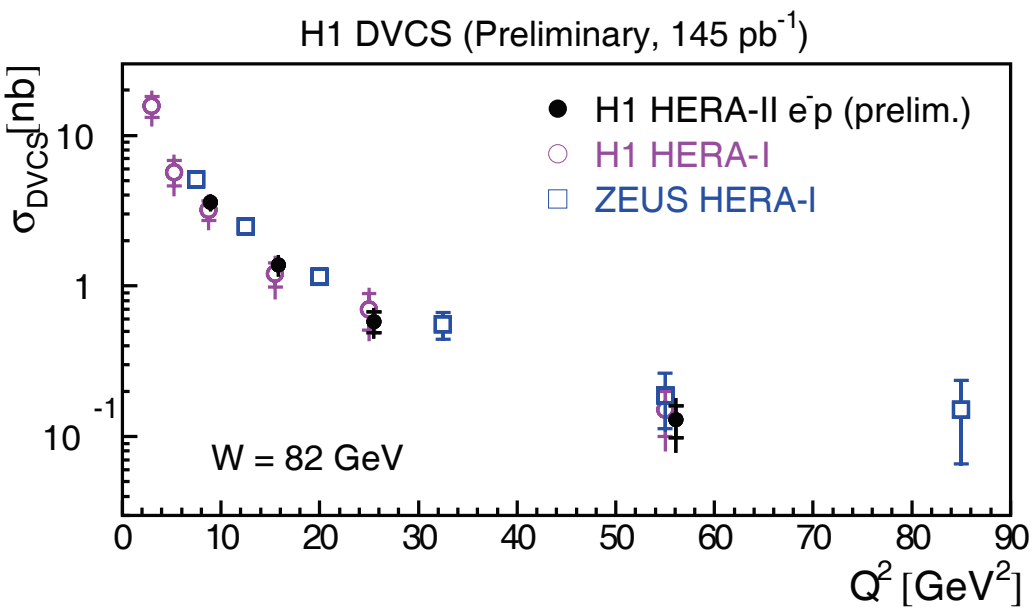
ZEUS: $n = 1.54 \pm 0.07 \pm 0.06$

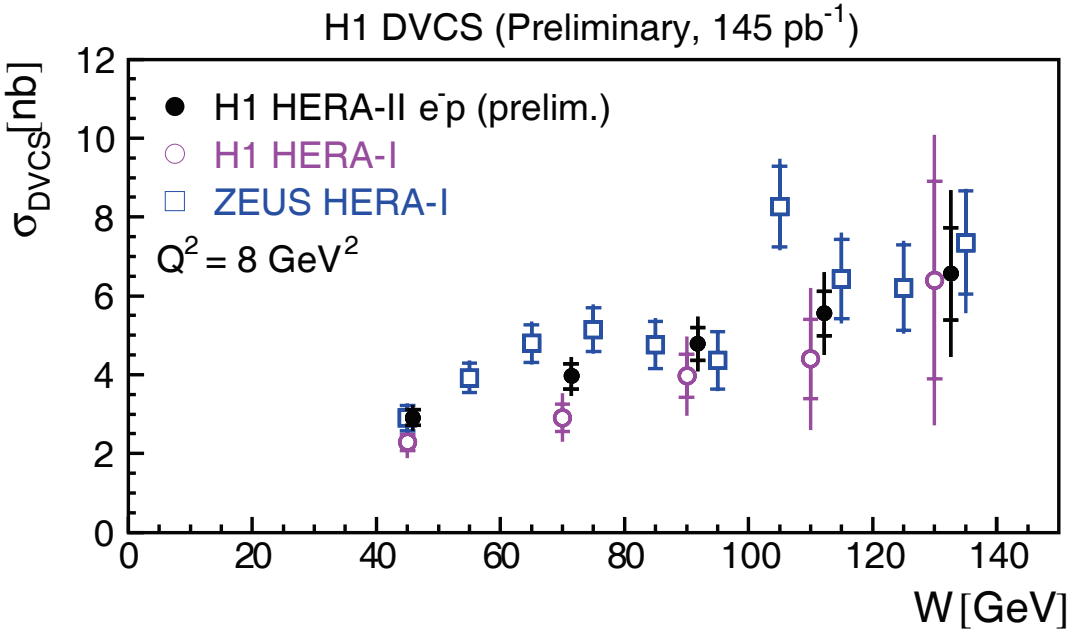
- W dependence Fit W^δ
  $\delta = 1.00 \pm 0.16 \pm 0.22$

ZEUS: $\delta = 0.75 \pm 0.15^{+0.08}_{-0.06}$

Indicates hard regime (cf. J/ψ Production)

DVCS: Q^2 and W dependencies

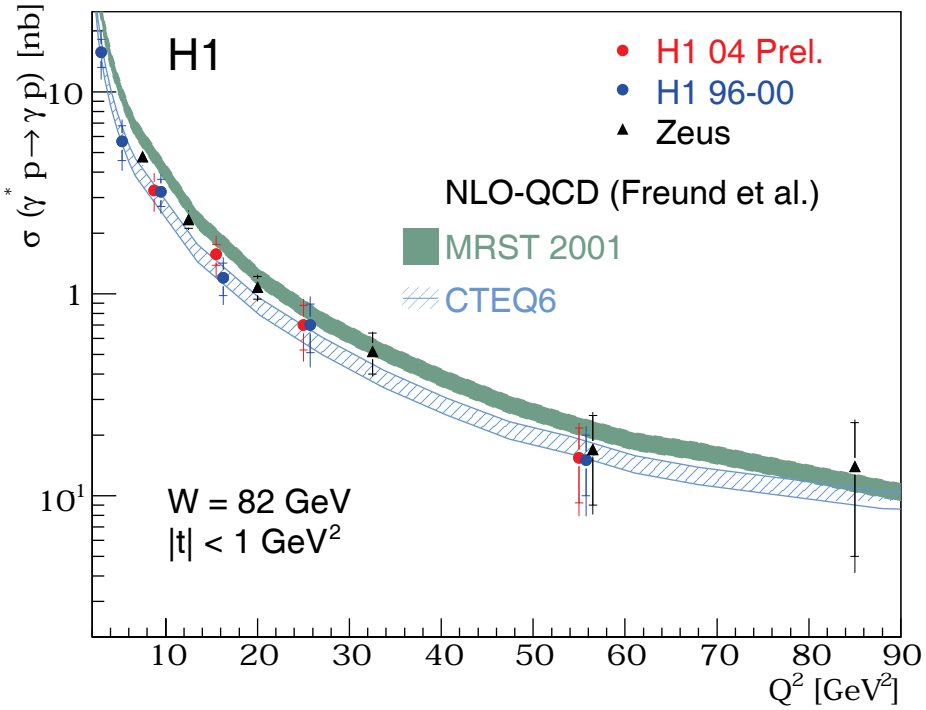


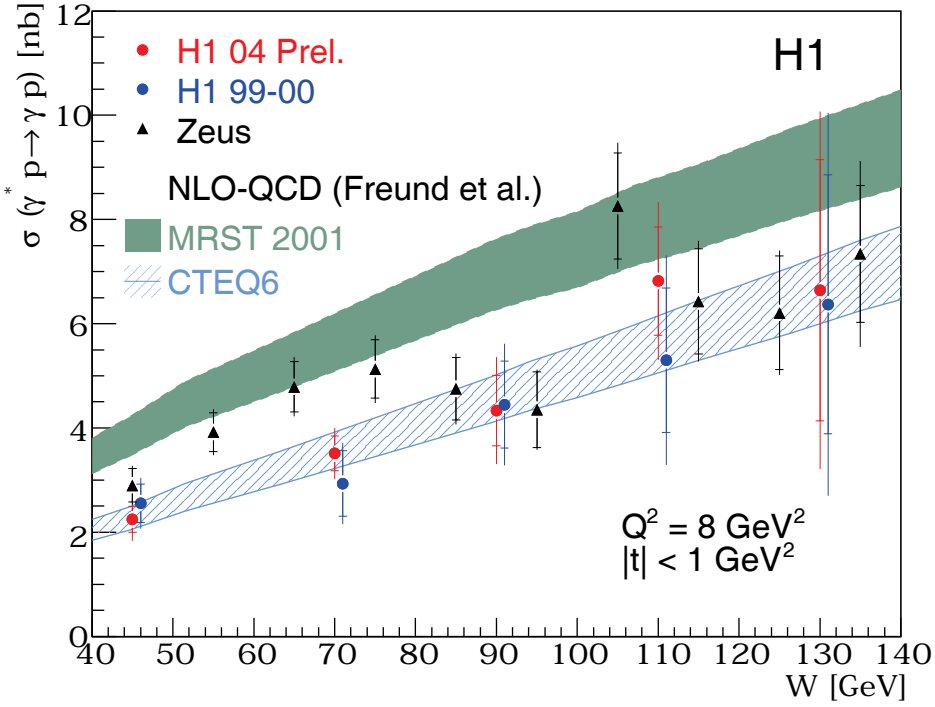


New: Complete HERA II e$^-$p data set analysed (145 pb^{-1})

Comparisons to models and more differential cross sections on the way

DVCS: Comparison with QCD Predictions



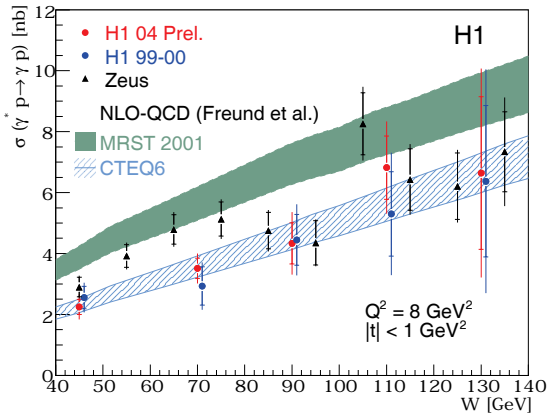


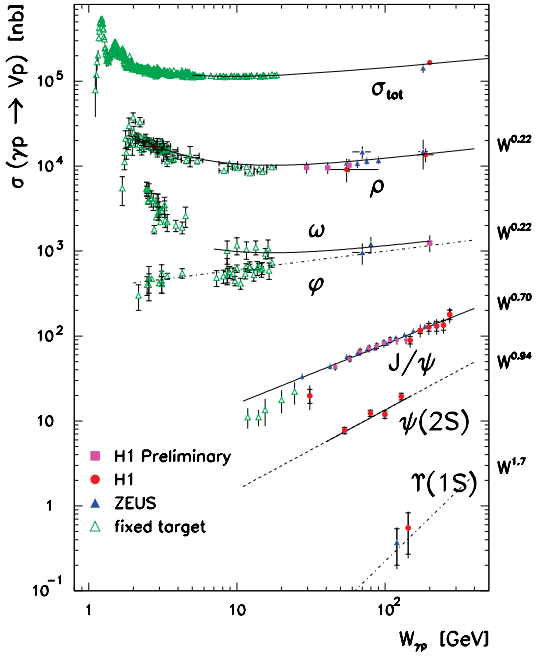
Comparison to NLO QCD:

- Band width reduced by *t* slope measurement
- Good description of the data (CTEQ6)
- Sensitive to PDF parametrisations?

Conclusion

- Trajectory intercepts rise with scale, slope universal?
- Experimental data from vector mesons and DVCS are beginning to constrain the proton structure
- Complimentary to inclusive analyses: Gluons at low x and transverse degrees of freedom become accessible
- There is still a lot to be measured and to be calculated





Outlook

- HERA II is coming to a close: ~ 400 pb^{-1} per experiment

- Running with half the proton energy until July (F_L, B. Loehr after lunch): Lower *W* becomes accesible

In the H1 pipeline:

- DVCS beam charge asymmetries
- Large ϕ meson photo-production sample