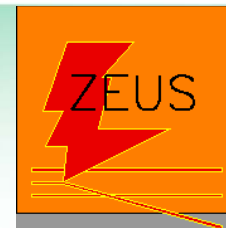# Results on Diffraction using Proton Spectrometers at HERA

Low-x Meeting: Paphos, Cyprus, June 27 - 30, 2012

M.Kapishin, JINR

on behalf of the H1 and ZEUS Collaborations

- Diffraction at HERA: LRG and leading proton methods

- Combination of H1 and ZEUS leading proton data

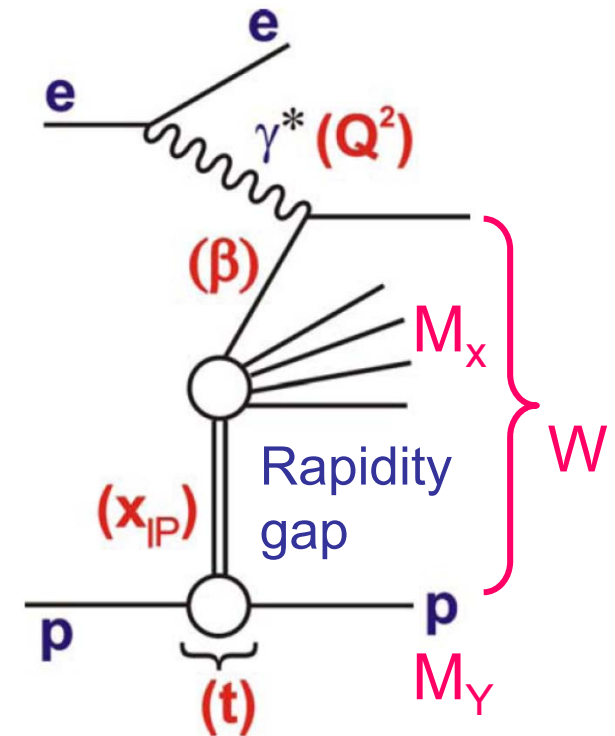- Dijet production in DIS with leading proton

Diffractive DIS at HERA

$$\frac{d^4\sigma}{d\beta\,dQ^2\,dx_{IP}\,dt} = \frac{4\pi\alpha^2}{\beta Q^4}\left(1 - y + \frac{y^2}{2}\right)\sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t)$$

Momentum fraction of color singlet carried by struck quark

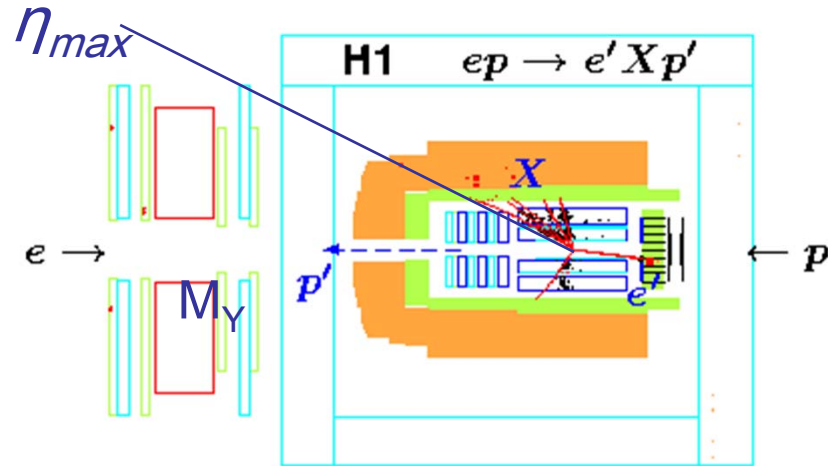$$\beta = \frac{x}{x_{IP}} \approx \frac{Q^2}{Q^2 + M_X^2}$$

Momentum fraction of proton carried by color singlet exchange

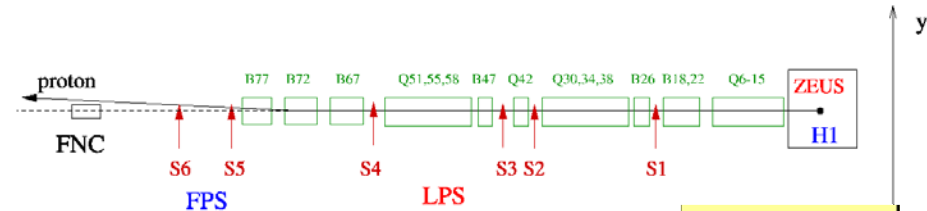$$x_{IP} = \frac{q\cdot(p - p')}{q\cdot p} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

Squared 4-momentum transfer

Selection of diffraction at HERA

Large rapidity gap (LRG) between leading proton p and X

η_{max}

M_Y

H1 $ep \rightarrow e'Xp'$

X

$e \rightarrow$

p'

$\leftarrow p$

e

- high statistics, data integrated over $|t| < 1\,\text{GeV}^2$
- p-dissociation contribution
- limited by systematic uncertainties related to missing proton
- ➔ LRG and FPS methods have different systematic uncertainties

Proton Spectrometers (PS)

proton

FNC

B77 B72 B67   Q51,55,58 B47 Q42 Q30,34,38 B26 B18,22 Q6-15   ZEUS

H1

S6 S5   S4   S3 S2   S1

FPS   LPS

$$x_{IP} = 1 - \frac{E'_p}{E_p}$$
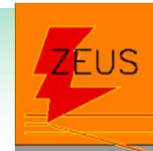
H1 FPS + ZEUS LPS 60-90m
+ H1 VFPS 220m

- free of p-dissociation background
- x_{IP} and t-measurements
- access to high x_{IP} range (IP+IR)
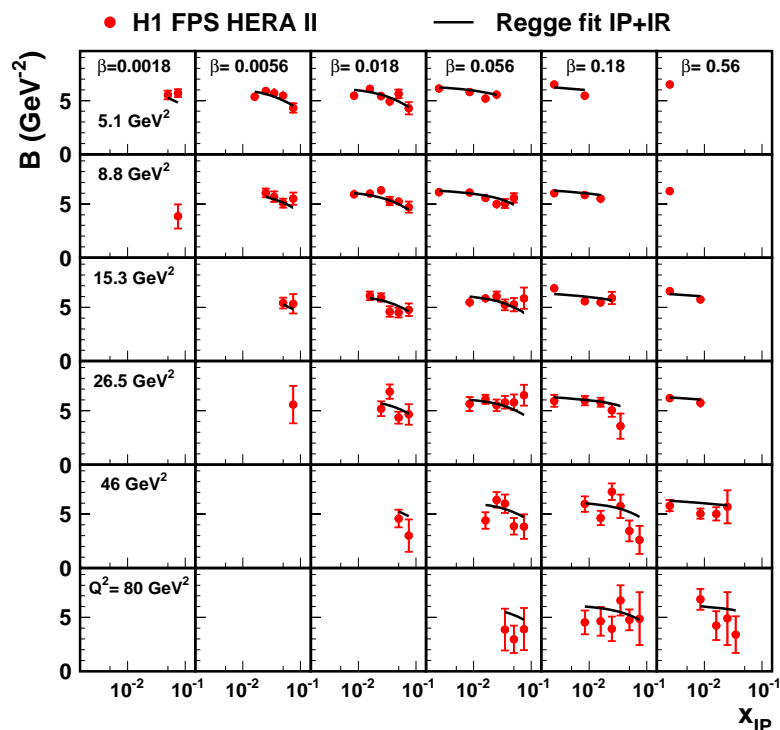- low geometrical acceptance

HERA-2:

- ➢ H1 FPS detector upgrade
- ➔ 20 times higher statistics than collected at HERA-1
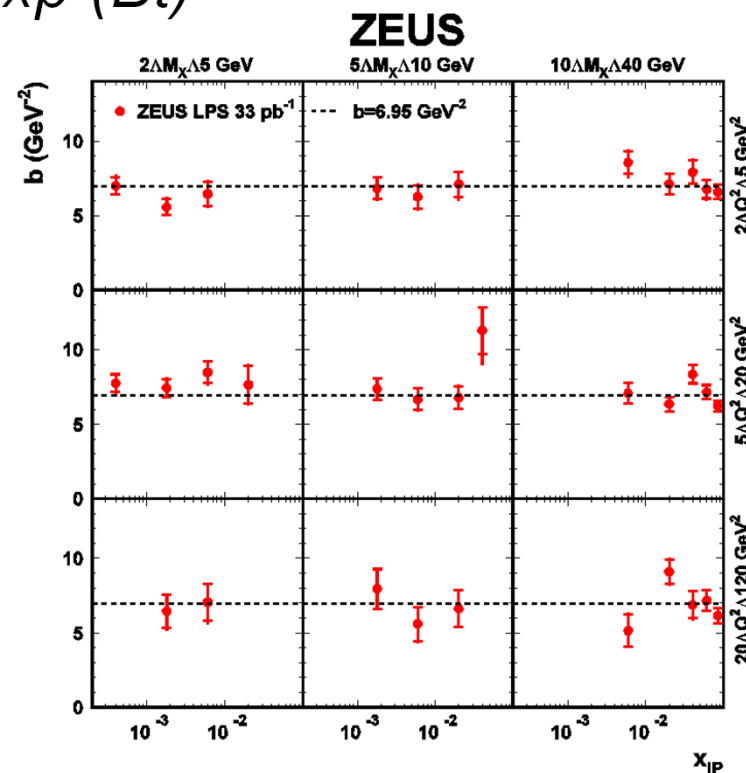- ➢ H1 VFPS has high acceptance

t-slope as a function of Q^2, β, M_X, x_{IP}

$$d\sigma/dt \sim exp(Bt)$$

H1 FPS: IR contribution at large x_{IP}

ZEUS LPS: no strong effect from IR contribution

H1 and ZEUS: t-slope does not change with β, M_x or Q^2 at fixed x_{IP}
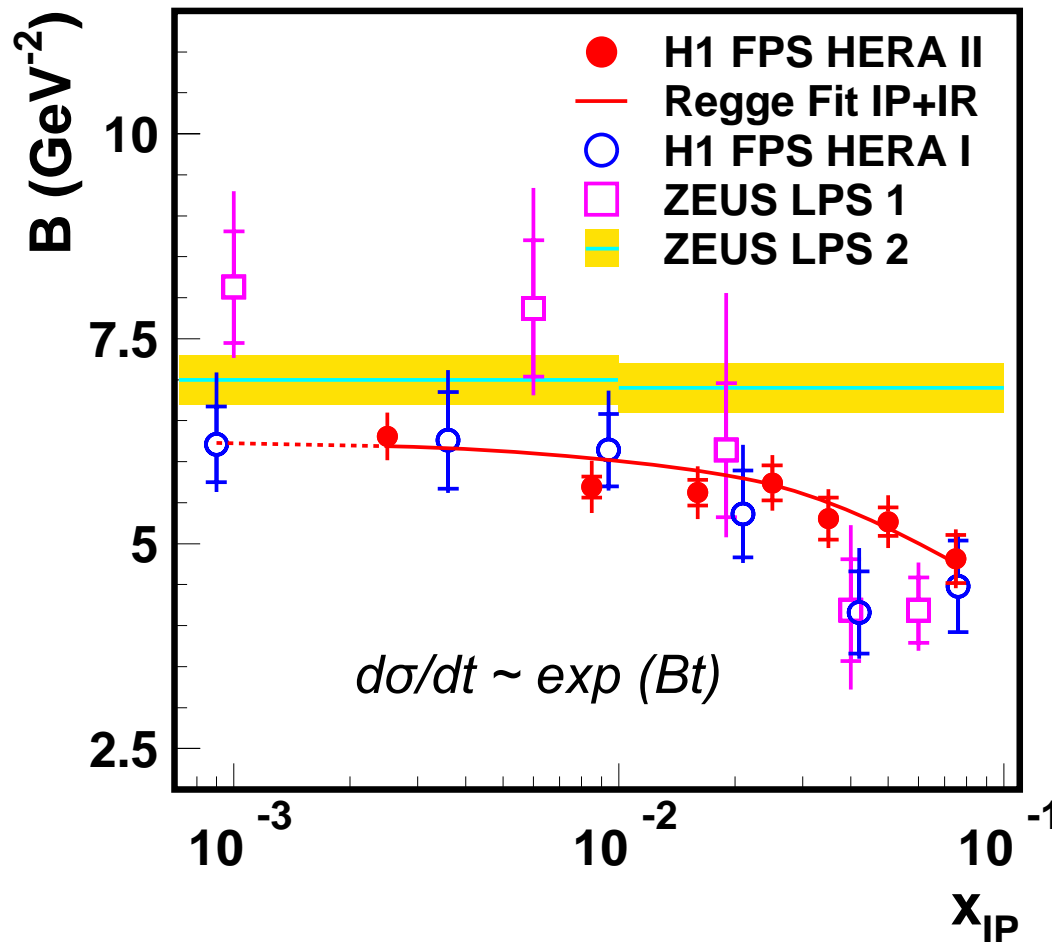➔ data consistent with proton vertex factorisation

t-slope as a function of x_{IP}

H1 Regge fit result:
$$B(x_{IP}) = f_{IP}(x_{IP}) \cdot B_{IP}(x_{IP}) + f_{IR}(x_{IP}) \cdot B_{IR}(x_{IP})$$


Legend:
- ● **H1 FPS HERA II**
- — **Regge Fit IP+IR**
- ○ **H1 FPS HERA I**
- □ **ZEUS LPS 1**
- ▬ **ZEUS LPS 2**

$d\sigma/dt \sim \exp(Bt)$

B (GeV^{-2}), x_{IP}

- x_{IP}-dependence of t-slope, data averaged over Q^2 and β

➔ H1 FPS HERA-1 and HERA-2 data are consistent, B~5-6 GeV^{-2}

➔ IR contribution at high x_{IP}

➔ ZEUS LPS2 measures higher t-slope: B ~ 7 GeV^{-2}

➔ are H1 / ZEUS uncertainties underestimated ?

➔ combine H1 and ZEUS proton spectrometer cross sections in visible t-range: $0.09 < |t| < 0.55$ GeV^2

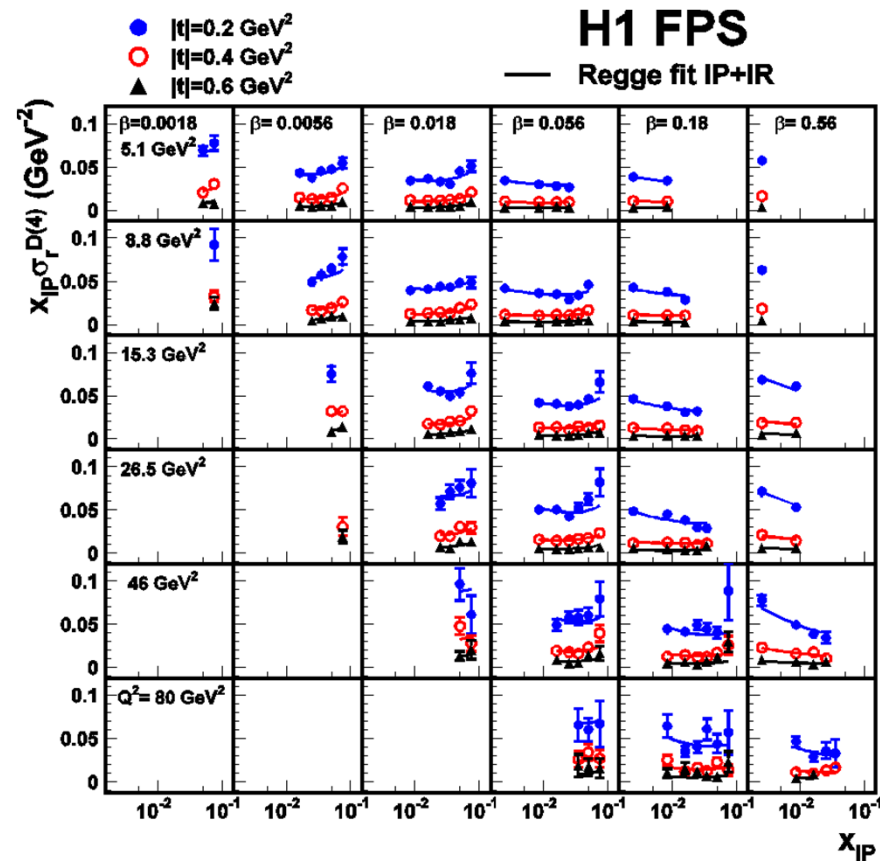M.Kapishin   Diffraction using Proton Spectrometers at HERA   5

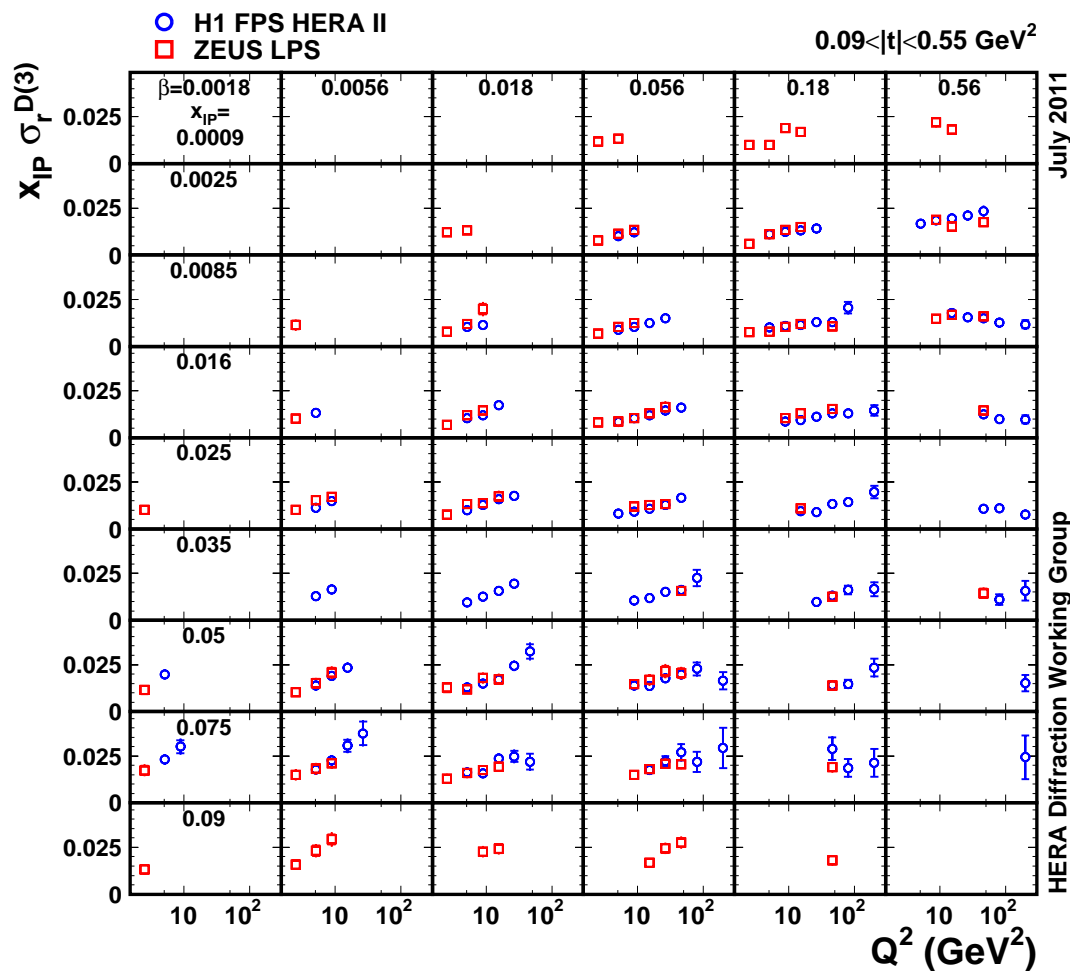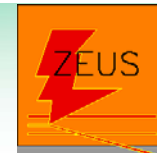## Proton spectrometer data
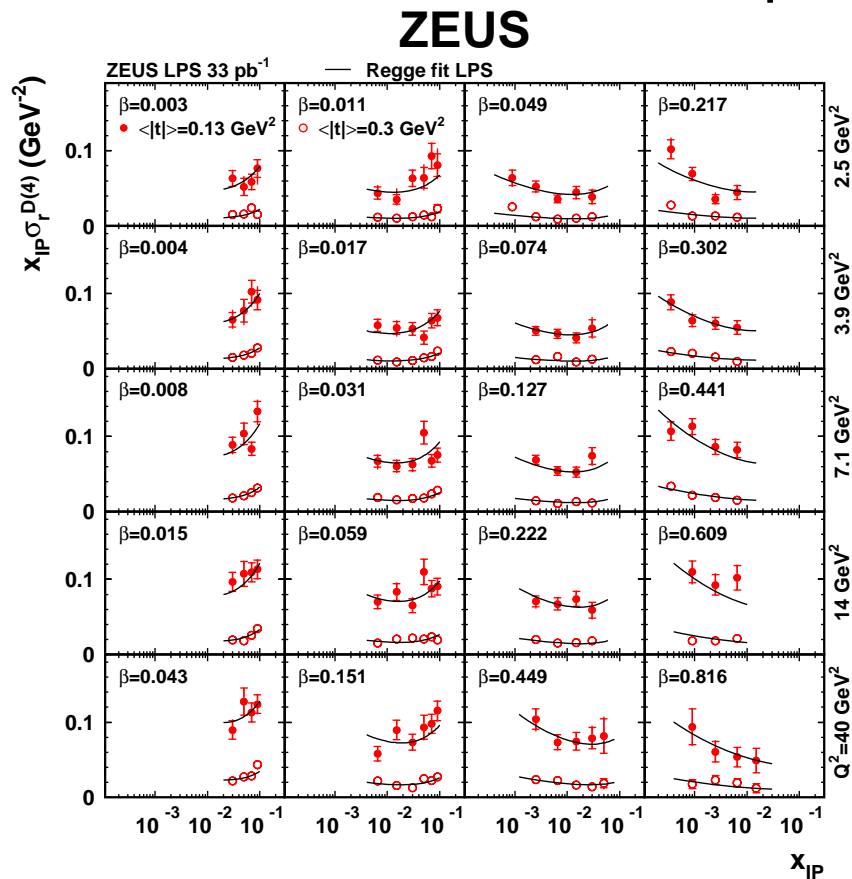
ZEUS

H1 FPS

[Nucl.Phys. B816 (2009) 1]

ZEUS LPS HERA-I, 33pb⁻¹

[Eur.Phys.J. C71 (20011) 1578]

H1 FPS HERA-II, 157 pb⁻¹

$\sigma_r^{D(3)}$: H1 FPS vs ZEUS LPS

Proton Spectrometer data in $0.09<|t|<0.55\,\text{GeV}^2$

Q^2-dependence in (β, x_{IP}) bins

• H1 FPS norm. uncertainty 4.8%, ZEUS LPS norm. uncertainty 7%

H1 / ZEUS: = 0.91 +/- 0.01(stat.) +/- 0.03(syst.) +/- 0.08(norm.)

→ Reasonable agreement of H1 FPS HERA-2 and ZEUS LPS data in shape & normalisation

→ Combine H1 and ZEUS cross sections to extend phase space and reduce uncertainties

H1 prel-11-111, ZEUS prel-11-011
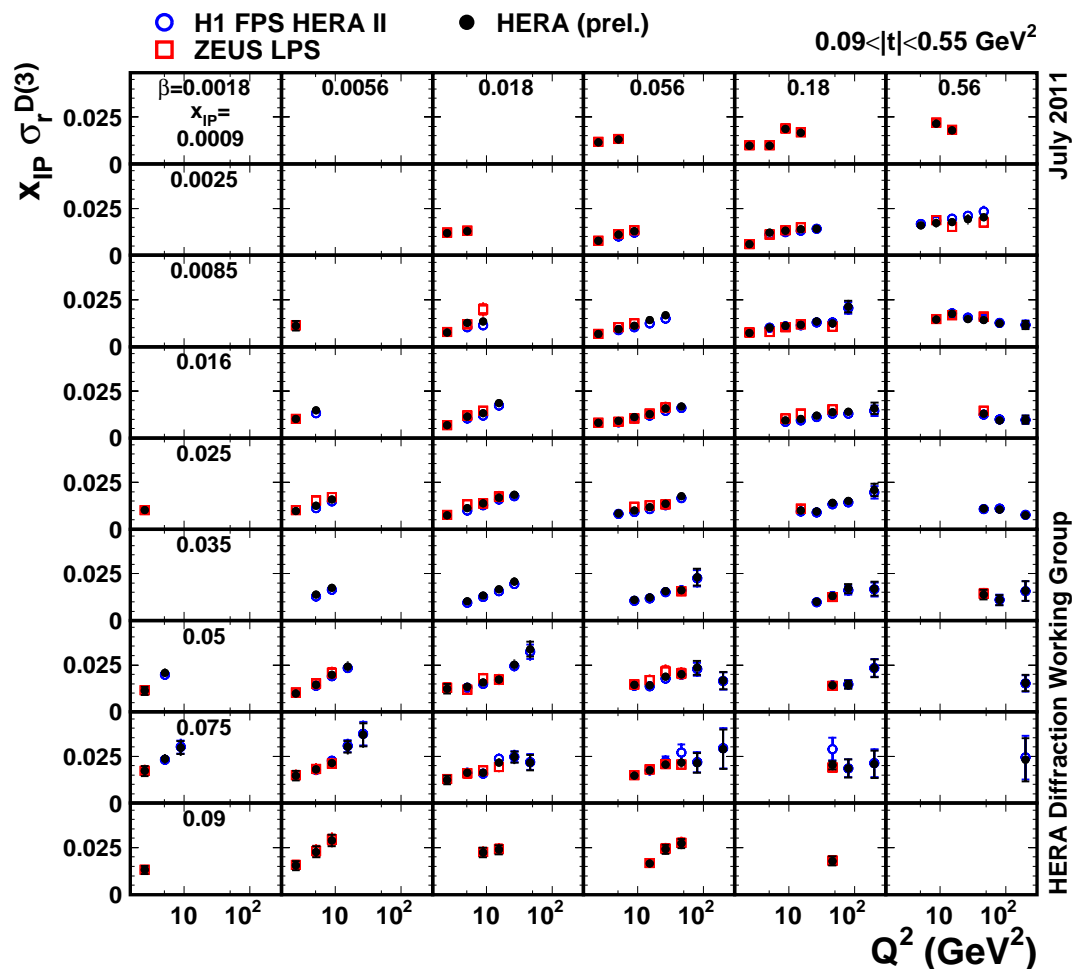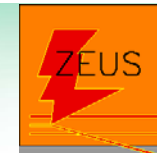
Combination method

Combination is based on χ^2 minimisation method used for HERA inclusive cross section combination: [A. Glazov, AIP Conf. Proc. 792 (2005) 237]

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

• $\boldsymbol{m}$ and $\boldsymbol{b}$ are fitted data and systematic shifts at data point i for sys source j

• $\boldsymbol{\mu}$ and γ are measured data and correlated errors at data point i for sys source j

• δ_{stat} and δ_{uncor} are stat error and uncorrelated systematic at data point i

→ Prior to combination, swim ZEUS data to H1 (Q^2,β,x_{IP}) grid using ZEUS DPDF SJ [NP B831 (2010) 1]

→ Additional procedural uncertainties: ZEUS→H1 data swimming factors(~1%), multiplicative vs additive errors (~1.4%), correlation between H1 and ZEUS error sources, treatment of some correlated errors as uncorrelated (~1%)

$\sigma_r^{D(3)}$: H1 FPS vs ZEUS LPS

First combination of H1 and ZEUS diffractive data from proton spectrometers

➔ Combination method uses iterative χ^2 minimisation and include full error correlations

$\chi^2/\text{ndf} = 52/58$

➔ A model independent tool to study data consistency and to reduce systematic uncertainties
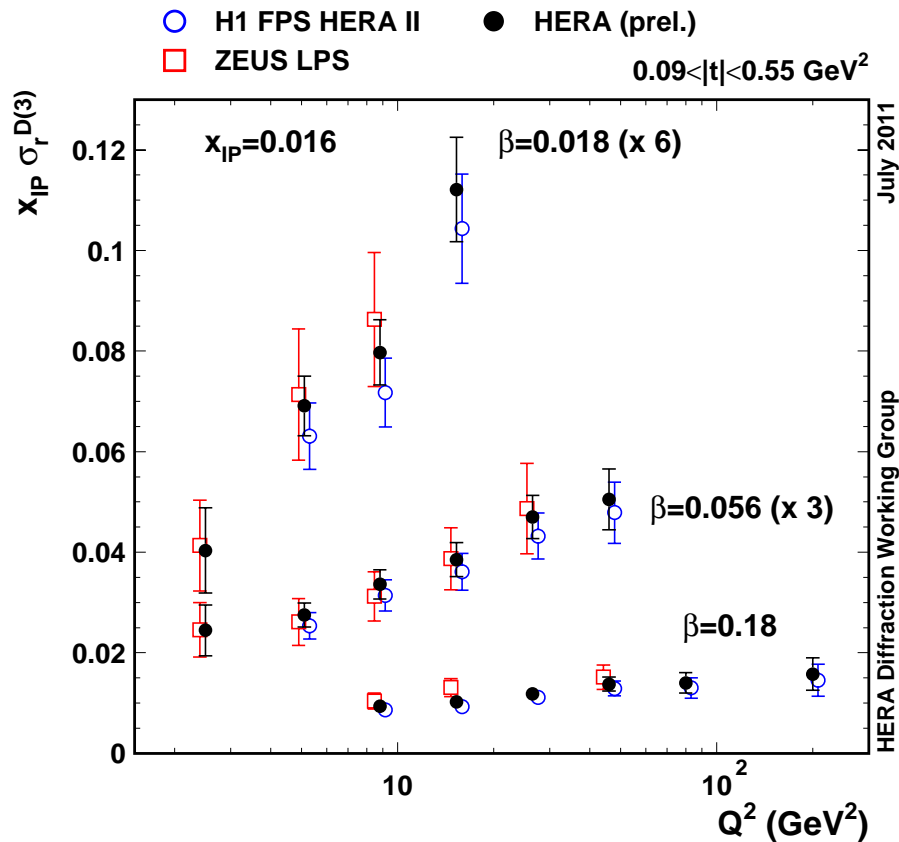
[A. Glazov, AIP Conf. Proc. 792 (2005) 237]

H1 prel-11-111, ZEUS prel-11-011

$\sigma_r^{D(3)}$: H1 FPS vs ZEUS LPS

- A detailed look to the combined data

○ H1 FPS HERA II   ● HERA (prel.)
□ ZEUS LPS
0.09<|t|<0.55 GeV^2

$x_{IP}\sigma_r^{D(3)}$

x_{IP}=0.016   β=0.018 (x 6)

β=0.056 (x 3)

β=0.18

July 2011

HERA Diffraction Working Group

Q^2 (GeV^2)

H1 prel-11-111, ZEUS prel-11-011

Combination of H1 and ZEUS diffractive data from proton spectrometers

➔ Consistency between data sets

➔ Two experiments calibrate each other resulting in reduction of systematic uncertainties

➔ combined data have ~25% smaller experimental uncertainties with respect to H1 data

➔ Total uncertainty in most precise points ~6%

➔ Normalisation uncertainty ~4%
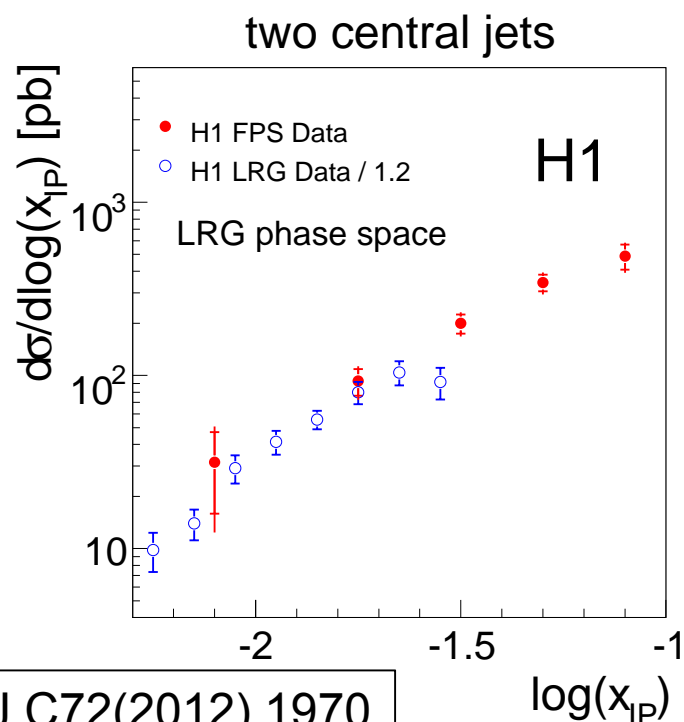
Dijets in DIS with leading proton

Dijets with leading proton vs LRG data
EPJ C72(2012) 1970   JHEP 0710:042

• Dijet LRG data corrected for p-diss

• Leading proton data extend x_{IP} range by a factor of 3

Dijets vs inclusive DIS with leading proton   EPJ C71(2011) 1578
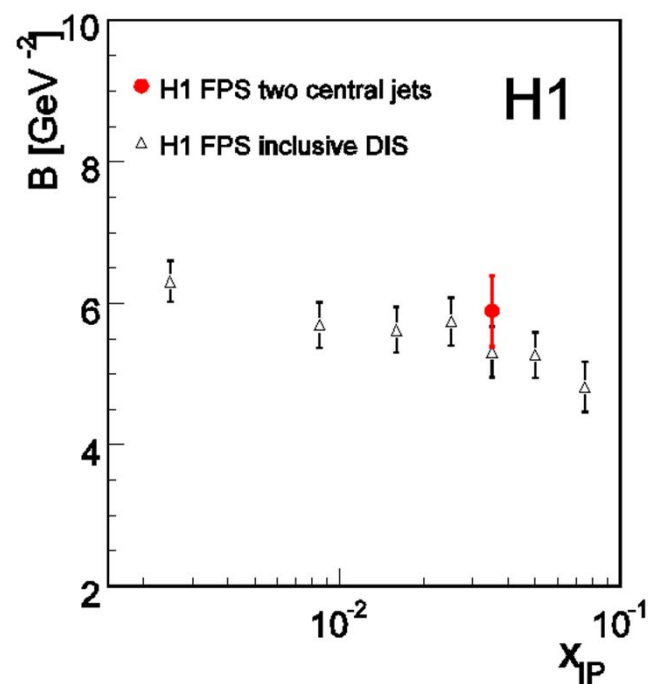
• t-dependence is consistent with inclusive diffractive DIS

$$d\sigma/dt \sim exp\ (Bt)$$

two central jets


EPJ C72(2012) 1970

LRG inclusive DIS + Dijets DIS ➔ DPDFs

- Parameterize quark singlet and gluon PDFs at starting scale Q_0 and evolve with Q^2 using NLO DGLAP

- Proton vertex factorisation assumption to fit data from different x_{IP} with complementary β, Q^2 coverage

z_{IP} is momentum fraction of IP carried by gluon

- Inclusive diffractive DIS cross sections constrain quark singlet and gluon (via scaling violations)

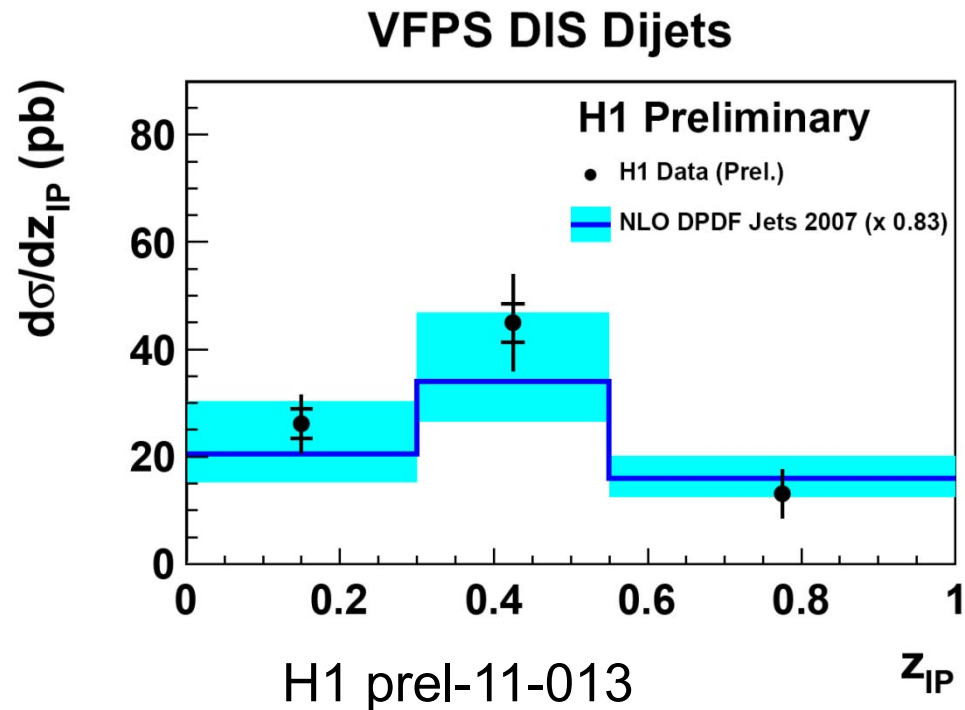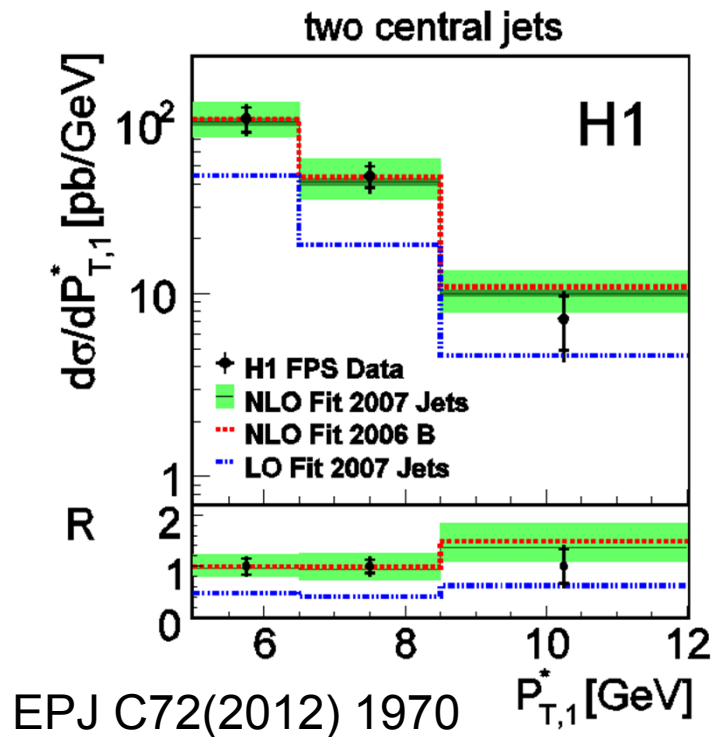- Dijet DIS cross sections constrain high z gluon, jet p_T provides an additional hard scale
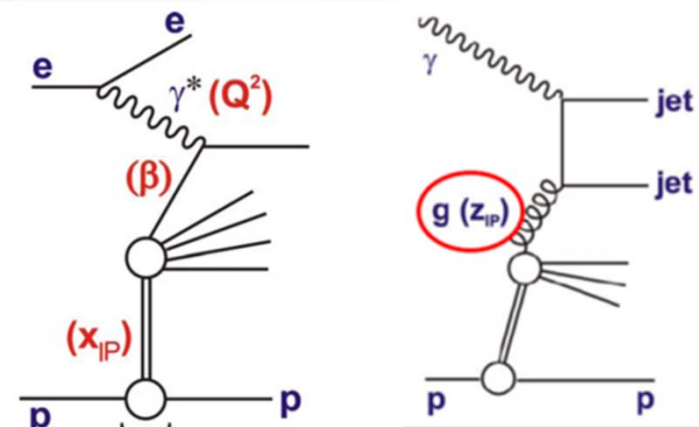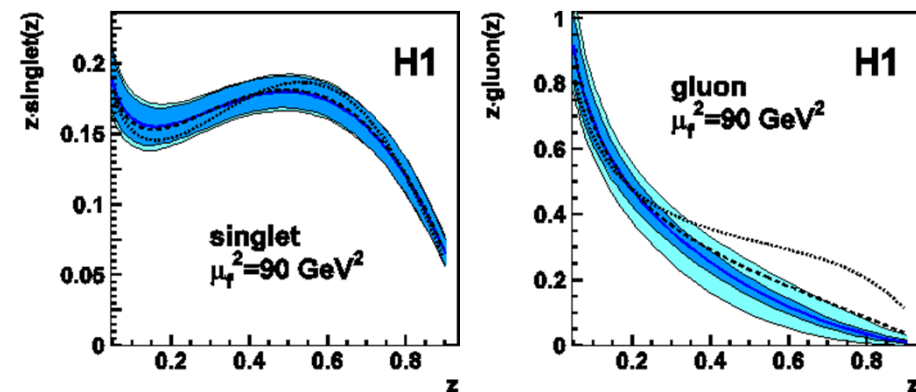
➔ Test diffractive PDFs in Dijet production in DIS with leading proton

Central Jets in DIS with leading proton

FPS: $x_{IP}<0.1$, $p^*_{T1}>5$GeV, $p^*_{T1}>4$GeV, $-1<\eta_{lab}<2.5$

VFPS: $0.009<x_{IP}<0.024$, $p^*_{T1}>5.5$GeV, $p^*_{T1}>4$GeV, $-3<\eta^*<0$

two central jets

H1

$d\sigma/dP^*_{T,1}$ [pb/GeV]

- + H1 FPS Data
- ▇ NLO Fit 2007 Jets
- ▪▪▪ NLO Fit 2006 B
- ▪▪▪ LO Fit 2007 Jets

R

$P^*_{T,1}$ [GeV]

EPJ C72(2012) 1970

VFPS DIS Dijets

H1 Preliminary

- • H1 Data (Prel.)
- ▇ NLO DPDF Jets 2007 (x 0.83)
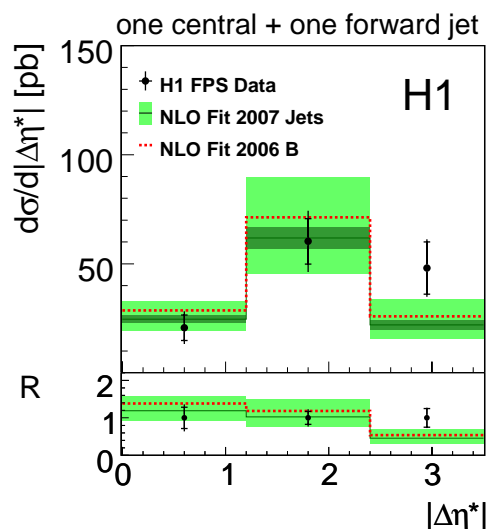
$d\sigma/dz_{IP}$ (pb)

z_{IP}

H1 prel-11-013

→ NLO predictions based on DPDFs H1 Jets an H1 Fit B describe central dijet production in DIS with tagged leading proton

→ LO DPDF predictions are factor ~2 below data
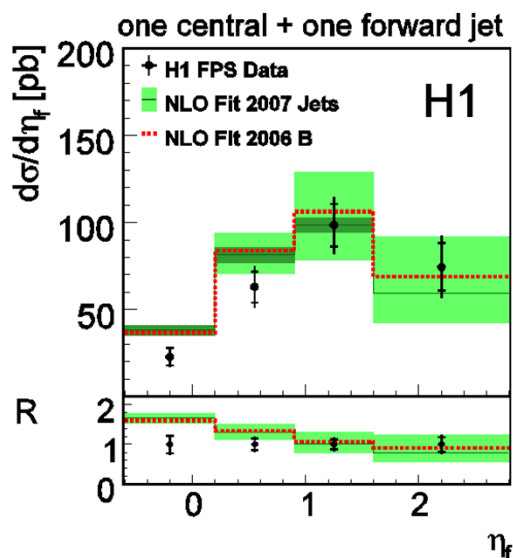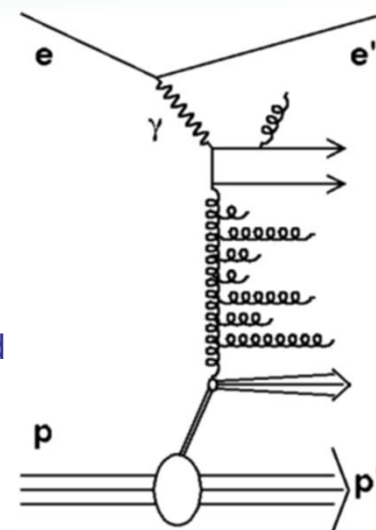
Forward Jets in DIS with leading proton

Dijet production in DIS with leading proton tagged in FPS:

Forward jet: $p^*_T > 4.5$ GeV, $1 < \eta_{fwd} < 2.8$
Central jet: : $p^*_T > 3.5$ GeV, $-1 < \eta_{cen} < \eta_{fwd}$

EPJ C72(2012) 1970

➔ extended η range compared to LRG dijet DIS data

➔ dijet selection with DGLAP p_t ordering broken

➔ no evidence for configurations beyond DGLAP & DPDF predictions

➔ some deviation of NLO DPDF from data for topology with 'forward' jet in central rapidity range

Dijet production in diffractive DIS
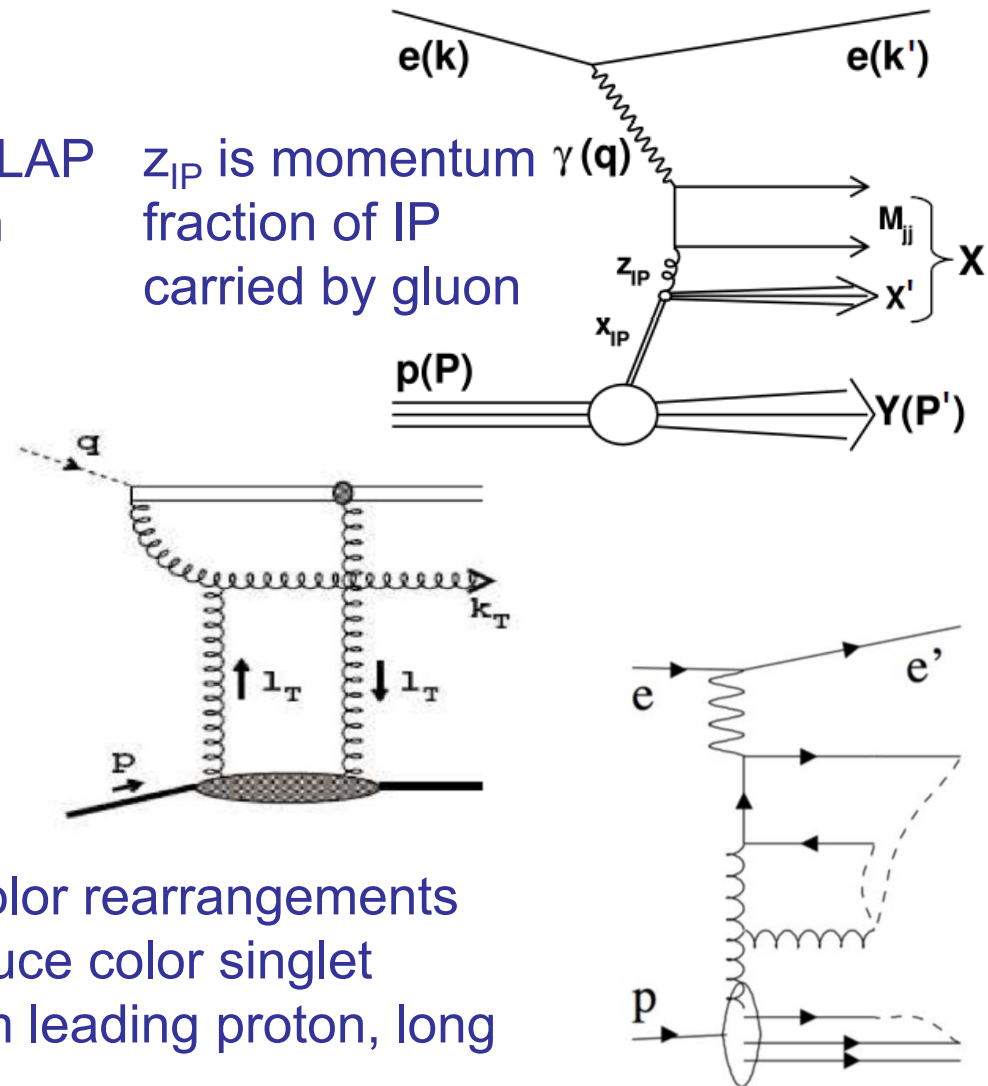
LO Monte Carlo models:

• Resolved Pomeron model: DGLAP evolution of IP DPDF and proton vertex factorisation

z_{IP} is momentum fraction of IP carried by gluon

• 2 Gluon Pomeron model: colorless pair of gluons (IP) couples to qq or qqg fluctuations of photon, valid at $x_{IP}<0.01$

• Soft Color Interaction model: color rearrangements between final state partons produce color singlet system separated in rapidity from leading proton, long strings are suppressed (GAL)
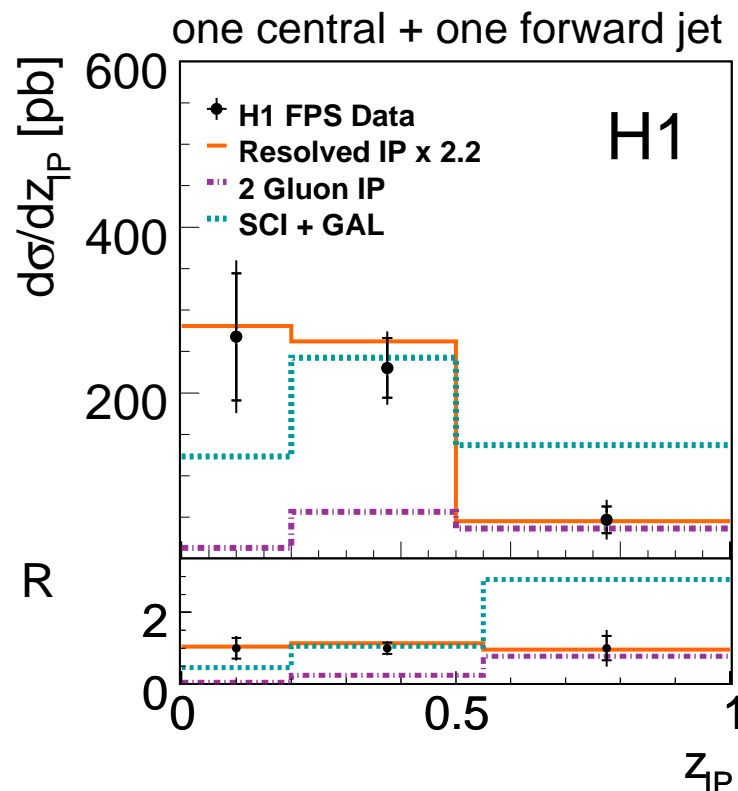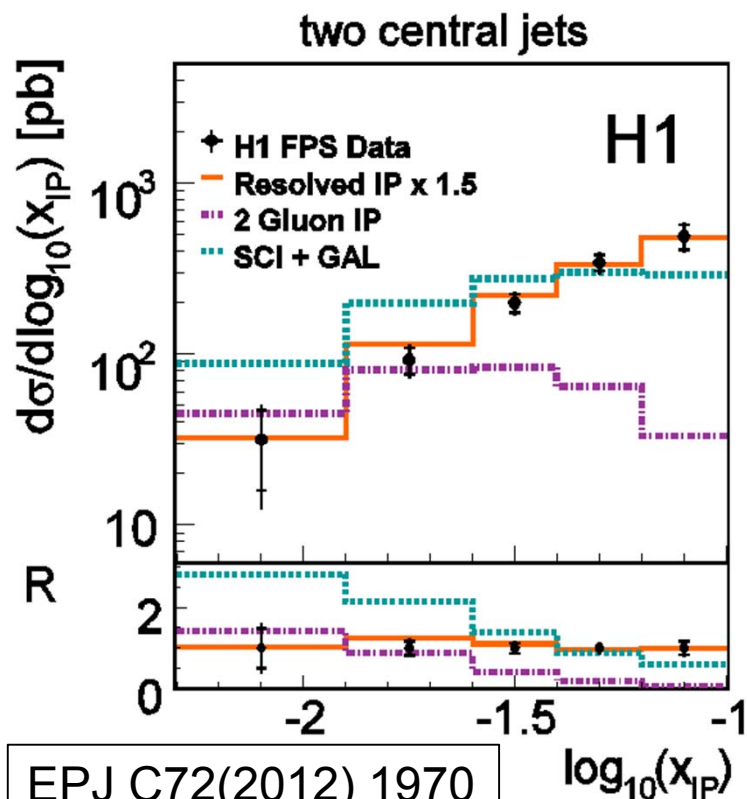
two central jets

one central + one forward jet

H1 FPS Data
Resolved IP x 1.5
2 Gluon IP
SCI + GAL

H1 FPS Data
Resolved IP x 2.2
2 Gluon IP
SCI + GAL

EPJ C72(2012) 1970

- Resolved IP describes shape but underestimates σ by 1.5 - 2.2

- Tuned SCI+GAL (P=0.3) does not describe shape of x_{IP}, z_{IP} distributions

- 2 Gluon IP is consistent with data only at low x_{IP}, high z_{IP}

Summary

- Recent results on diffractive DIS with leading proton in final state

➢ **First combination** of H1 and ZEUS diffractive data with leading proton give consistent results

➢ Systematic uncertainties of combined cross sections are reduced, kinematic range extended compared to separated data sets

➢ **Central and forward dijets** are measured in diffractive processes with leading proton

➢ NLO DGLAP predictions based on DPDFs describe central and forward dijet data within errors

➢ LO MC models do not describe shape & normalisation of dijet DIS data
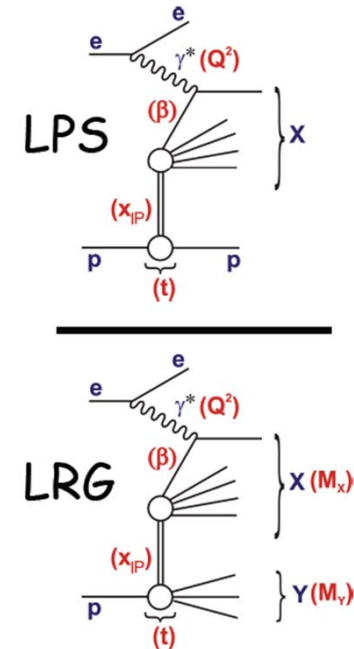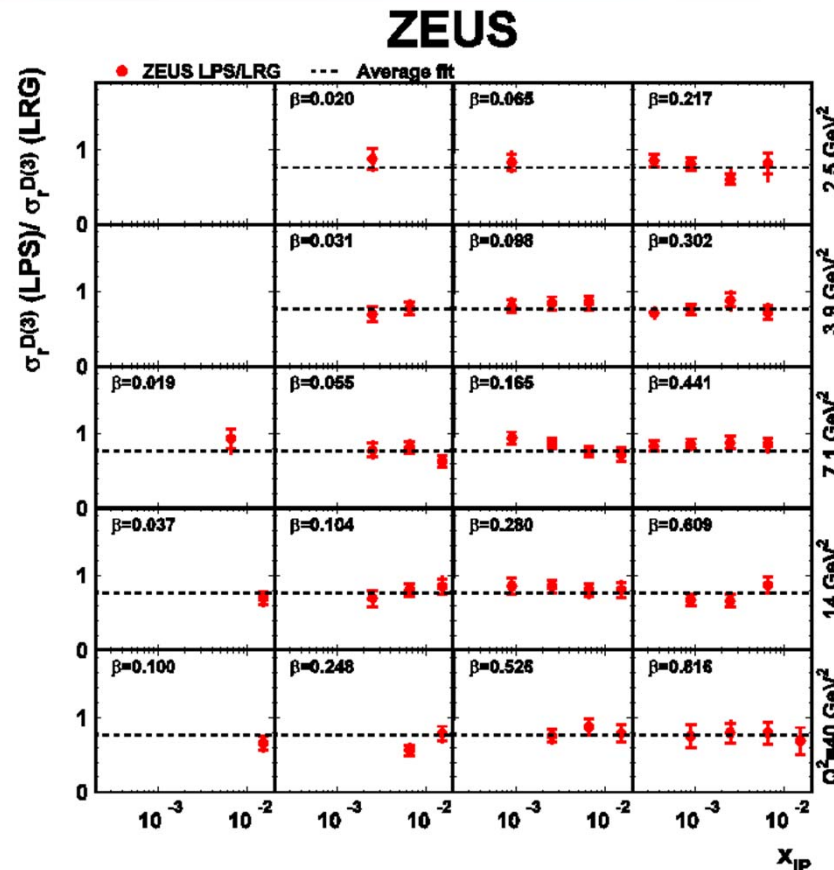
Backup slides

Comparisons between Methods
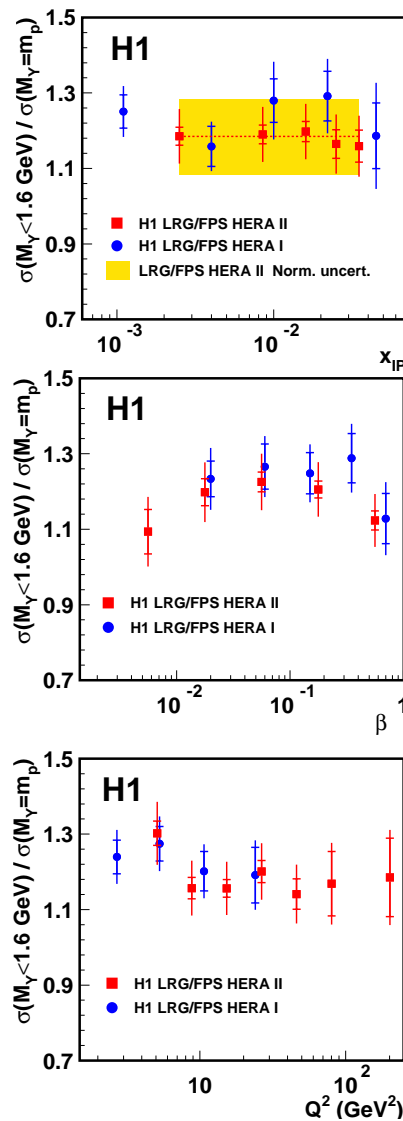
H1: $\sigma(M_Y<1.6\ \text{GeV}) / \sigma(M_Y=M_p)= 1.20 +/- 0.11(\text{exp.})$

➔ LRG data contain ~20% of p-diss contribution
➔ no significant dependence on Q^2, β, x_{IP}

M.Kapishin

Diffraction using Proton
Spectrometers at HERA

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Factorisation in Diffractive DIS

Assumption of proton vertex factorisation for leading *IP* and sub-leading *IR* exchanges ➜ hard scattering is independent of x_{IP} and t

$$F_2^{D(4)}(\beta, Q^2, x_{IP}, t) = f_{IP}(x_{IP}, t) \cdot F_2^{IP}(\beta, Q^2) + n_{IR} \cdot f_{IR}(x_{IP}, t) \cdot F_2^{IR}(\beta, Q^2)$$

- x_{IP} and t dependences are described by Regge motivated *IP* and *IR* fluxes:

$$f_{IP}(x_{IP}, t) = \frac{e^{B_{IP} t}}{x_{IP}^{2\alpha_{IP}(t)-1}}$$

$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha_{IP}' t$$

(β, Q²)

Proton vertex factorisation

(x_{IP}, t)   IP, IR

- Dominance of *IP* trajectory with $\alpha_{IP} > 1$ at $x_{IP} < 0.01$ and contribution of sub-leading *IR* trajectory with $\alpha_{IR} < 1$ at higher x_{IP}

- Shrinkage of exp t-slope with $\ln(1/x_{IP})$ ➜

$$\frac{d\sigma}{dt} \sim \exp B|t|$$

$$B = B_{IP} + 2\alpha'_{IP} \ln(1/x_{IP})$$

➜ Perform 'Regge' fits to diffractive data to extract parameters of *IP* flux
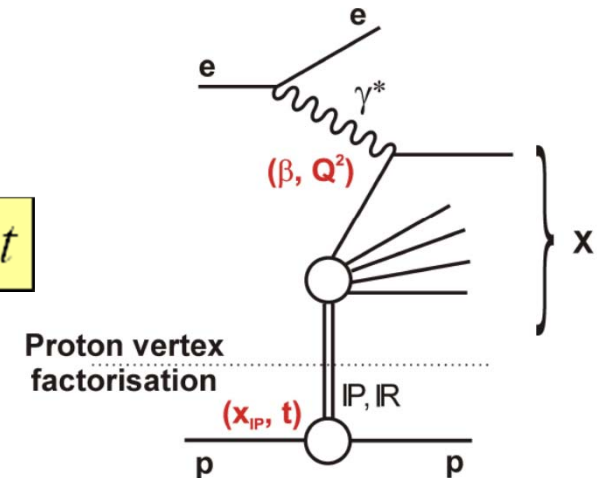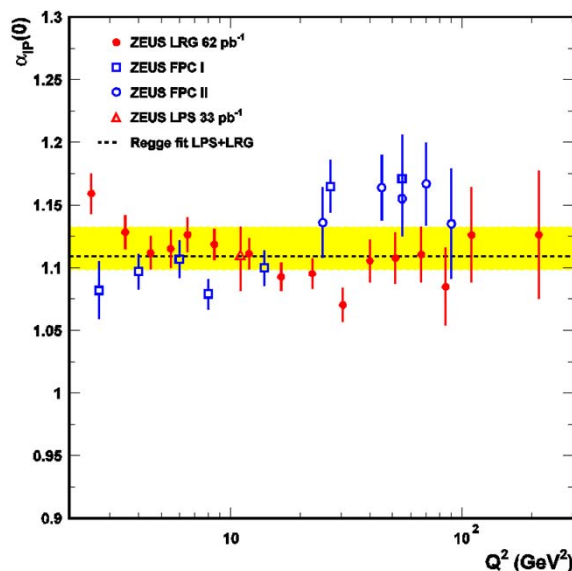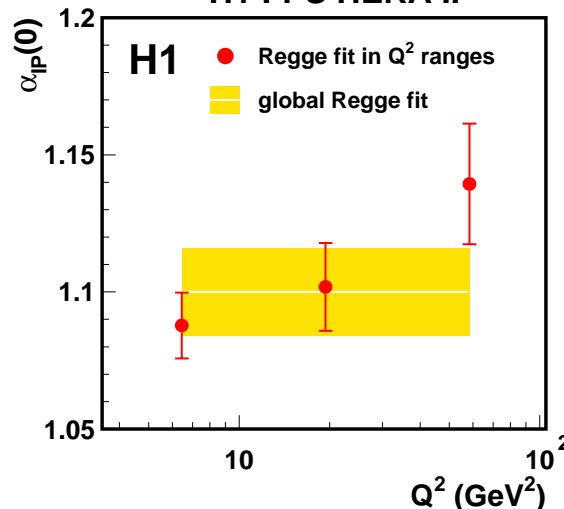
Proton Vertex Factorisation
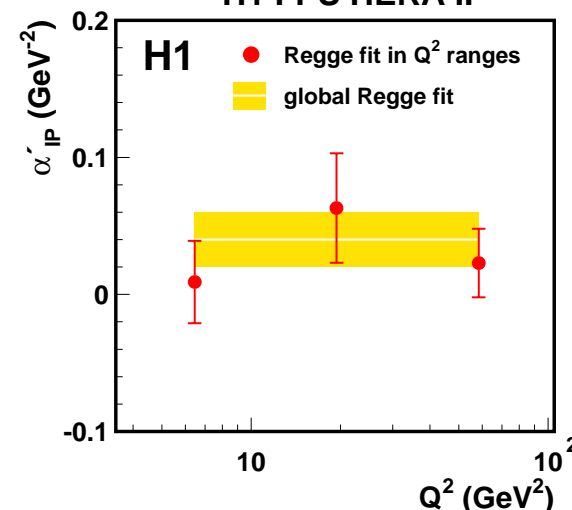
→ $\alpha_{IP}(0) \simeq 1.10$ in agreement with α_{IP} (soft)~1.08

→ $\alpha'_{IP} \simeq 0 \rightarrow$ no "shrinkage" < α'_{IP} (soft) ~0.25 GeV^{-2}

→ B_{IP} consistent with hard process

→ no strong dependence of $\alpha_{IP}(0)$, α'_{IP}, B_{IP} on Q^2

→ H1 and ZEUS results are consistent with proton vertex factorisation within uncertainties