Diffractive Phenomena at HERA

Paul Newman

University of Birmingham

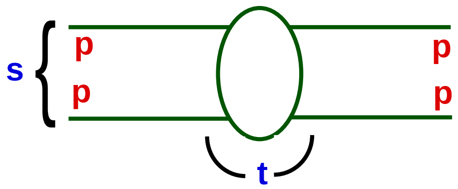
Representing the H1 and ZEUS Collaborations.

Selected topics in . . .

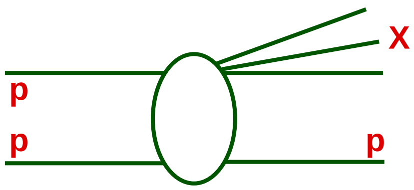
- Diffractive Vector Meson Photoproduction and Electroproduction.
- The Diffractive Dissociation Cross Section in DIS.
- The Hadronic Final State in DIS Diffractive Dissociation.
- Leading Baryons and Other Colour Singlet Exchanges.

Diffractive Processes and the Pomeron

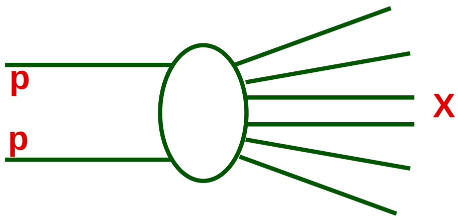
Soft diffraction: elastic, total and dissociation cross sections.



$\sigma^{\rm el}(pp \to pp)$



$\sigma^{\rm diss}(pp \to pX)$



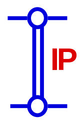
$\sigma^{\rm tot}(pp \to X)$

(via the optical theorem)

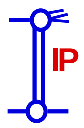
It is useful to think in terms of the exchange of an object with net vacuum quantum numbers - the "pomeron" ($\mathbb{P}$).

- $\alpha_{\mathbb{P}}(t) \simeq 1.081 + 0.26t$ [$\mathbb{P}$ 'trajectory'].
- 'FACTORISES!' Describes the energy dependence of all such hadron-hadron cross sections where $s \gg t$.
- BUT The partonic structure of the interaction is unspecified! ...This structure can be investigated at HERA.

Regge Predictions

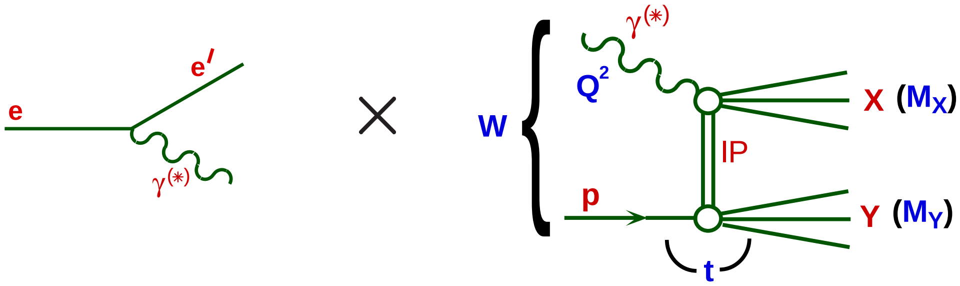


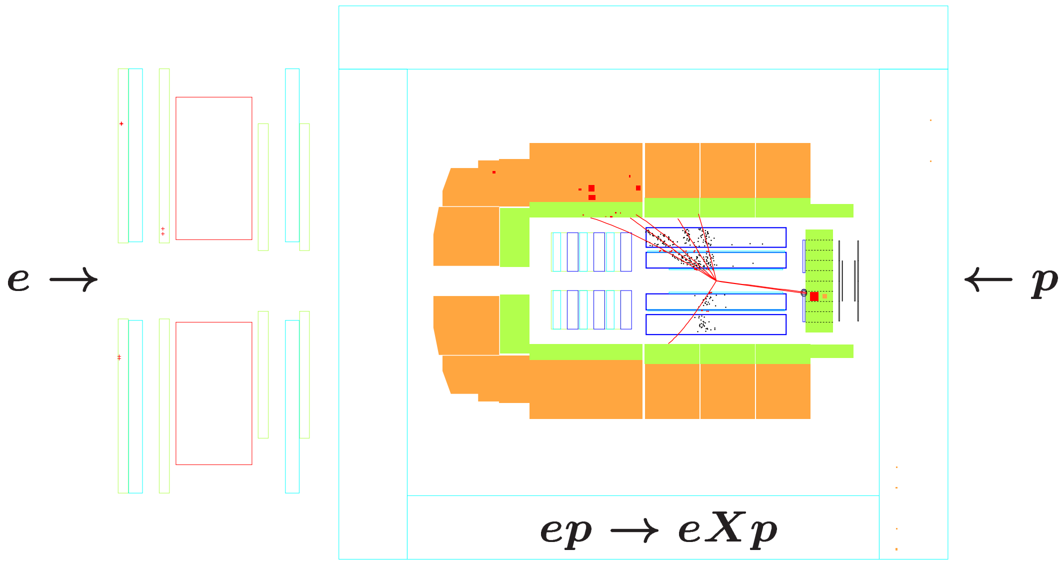
$$\mathrm{d}\sigma^{\mathrm{el}}/\mathrm{d}t \propto s^{2\alpha_{\mathbb{P}}(t)-2}$$



Diffraction at HERA

At the HERA ep collider, diffractive $\gamma^{(\star)}p$ interactions can be studied.



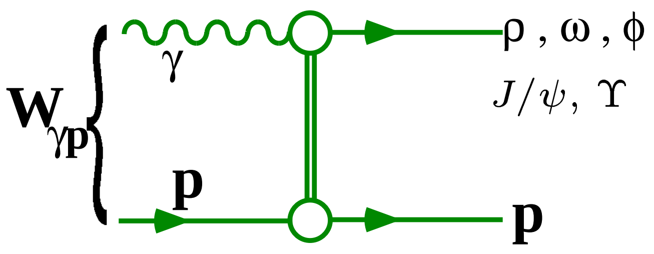


All five kinematic variables can be measured:

- $Q^2 \sim 0$, $|t| \sim 0$. → similar to soft h-h diffraction.
- Large Q^2. → γ^* probes IP structure.
- Large $|t|$. → search for perturbative (BFKL?) IP.

. . . the non-perturbative ↔ perturbative transition.

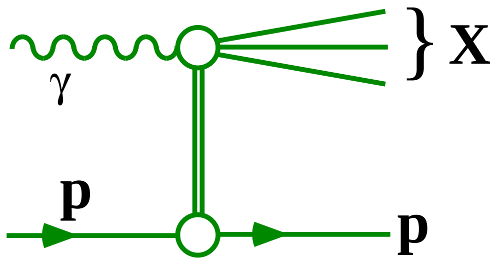
COLOUR SINGLET EXCHANGE PROCESSES IN γ^*-p INTERACTIONS



QUASI ELASTIC VECTOR MESON PRODUCTION

(EL)

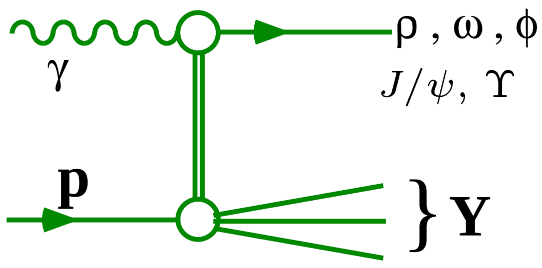
$\gamma p \longrightarrow Vp$



SINGLE PHOTON DISSOCIATION

(GD)

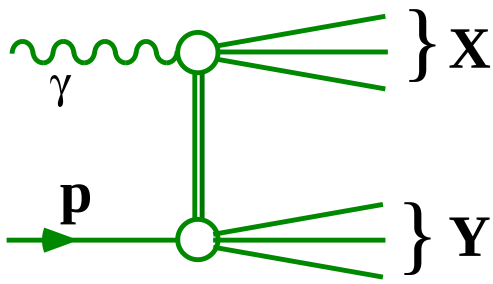
$\gamma p \longrightarrow Xp$



SINGLE PROTON DISSOCIATION

(PD)

$\gamma p \longrightarrow VY$



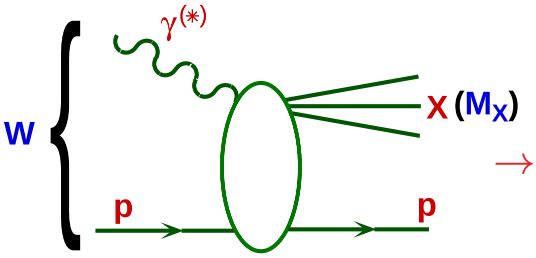
DOUBLE DISSOCIATION

(DD)

$\gamma p \longrightarrow XY$

Experimental Techniques

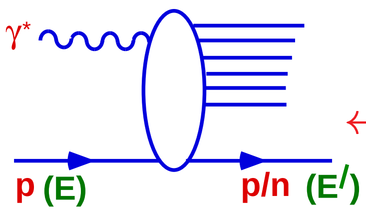
1. Rapidity Gap Selections (H1, ZEUS).



$\rightarrow$ Largest rapidity gap among final state hadrons.

$\Delta\eta$ large when $M_X \ll W$

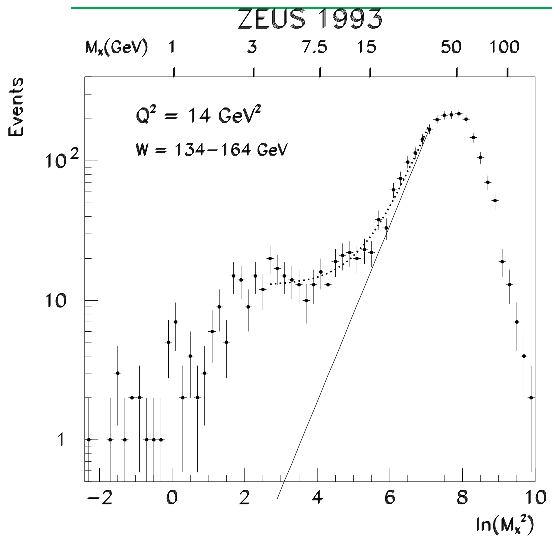
2. Direct Tagging of Leading Baryons (H1, ZEUS).



$\leftarrow$ May or may not be a large rapidity gap.

$x_{I\!P} = E'/E$ if exclusive p / n at proton vertex.

3. Decompose Visible M_X Distribution (ZEUS).



Exponential suppression in M_X distribution for "standard" DIS.

Diffractive contribution identified as excess at small M_X above fit to $Ae^{b \ln M_X}$

‘Elastic’ Vector Meson Production

$Q^2 = -q^2$
$W^2 = (q+p)^2$
$t = (p-p')^2$

Phenomenological parameterisation in Regge theory:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} \propto \left(\frac{W^2}{W_0^2}\right)^{2\alpha_{I\!P}(t)-2} e^{b_0 t} \quad ; \quad b_0 \sim R_p^2 + R^2_{\gamma^{(*)}\to V}$$

For soft processes, expect $\alpha_{I\!P}(t) \sim 1.08 + 0.25t$.

Signatures of hard processes:

- Increase in effective $\alpha_{I\!P}(0)$.
- Decrease in $\alpha'_{I\!P}$.
- $R^2_{\gamma^{(*)}\to V} \to 0 \quad ; \quad b_0 \to R_p^2$

Possible quantitative QCD description where hard scales availiable:

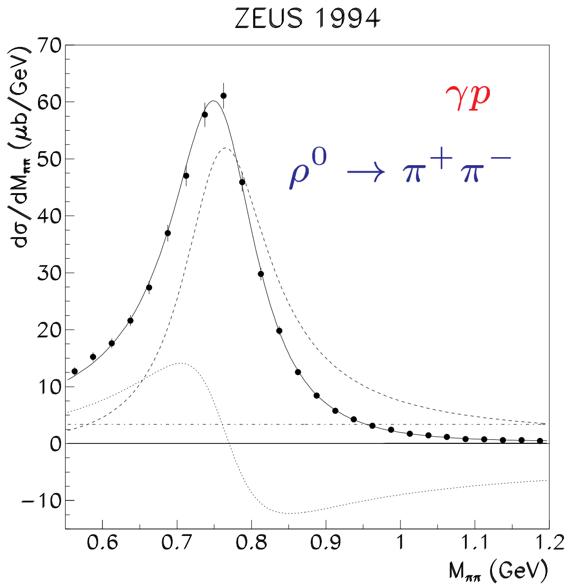
Simple exchange of 2 gluons
at lowest order.

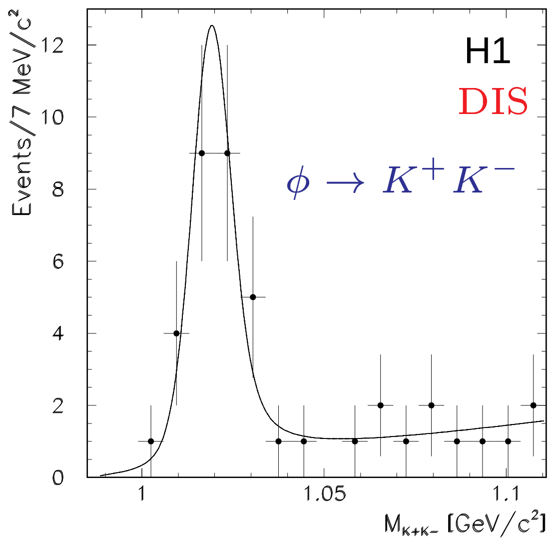
$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}t}\right|_{t=0} \sim |xg(x)|^2$

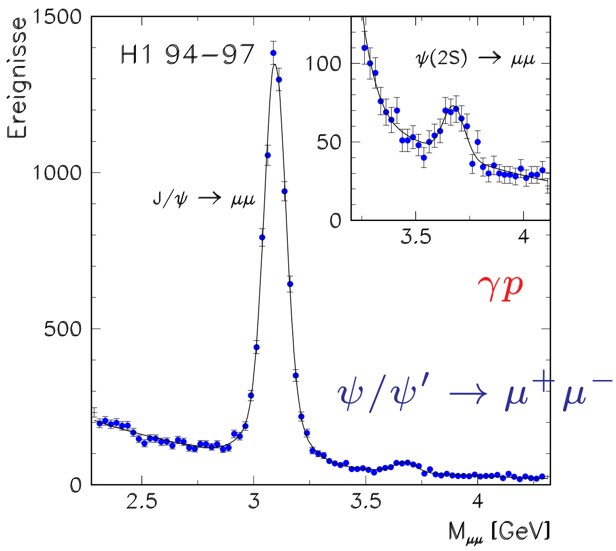
Vector Meson Signals

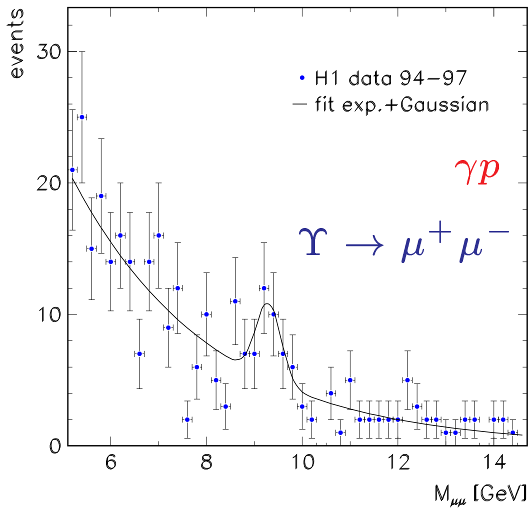
Vector Meson Production Studied over a wide range in kinematic variables Q^2, t, W, m_V.

Results on ρ, ω, ϕ, J/ψ, Υ, ρ', ψ'.

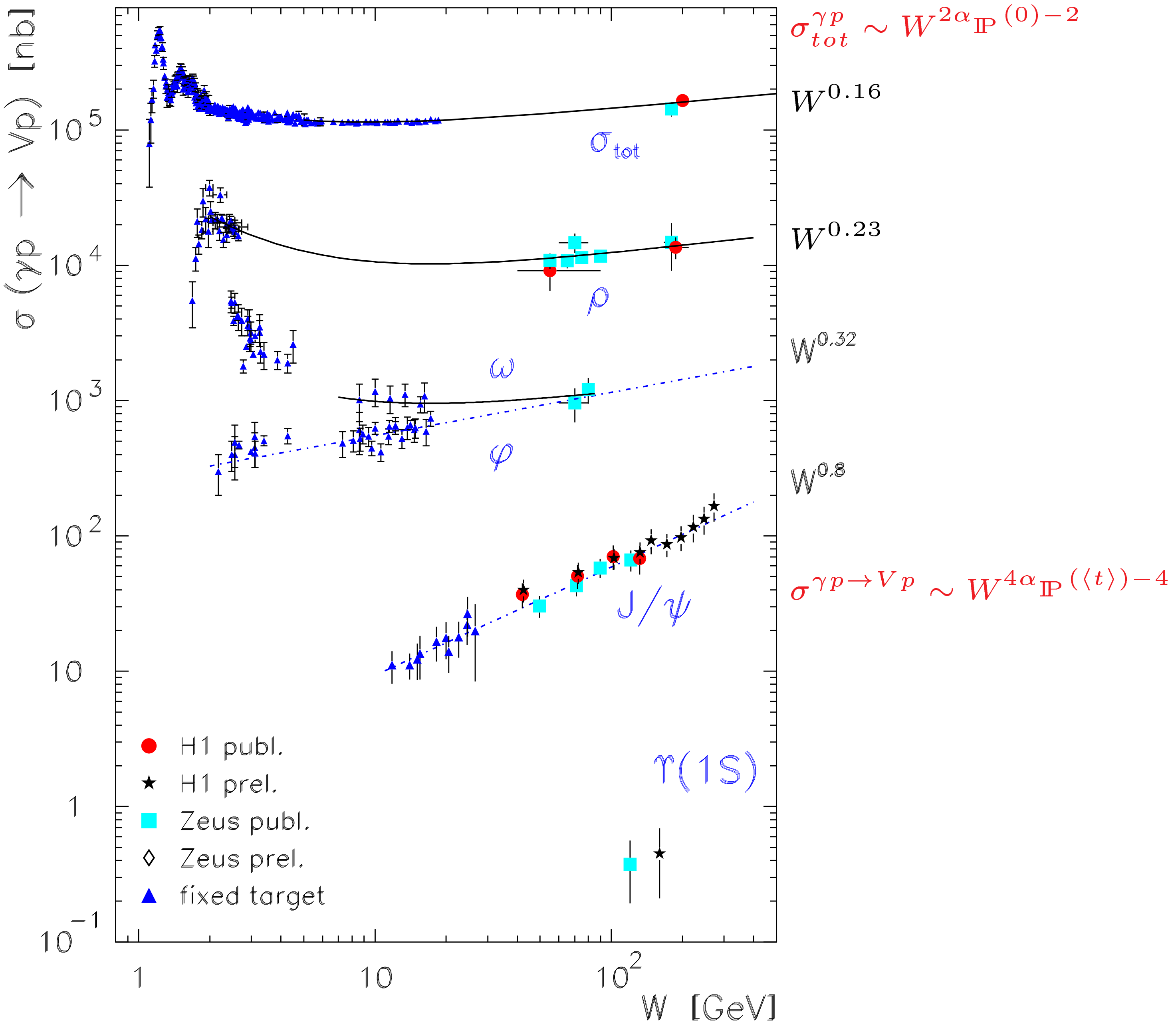






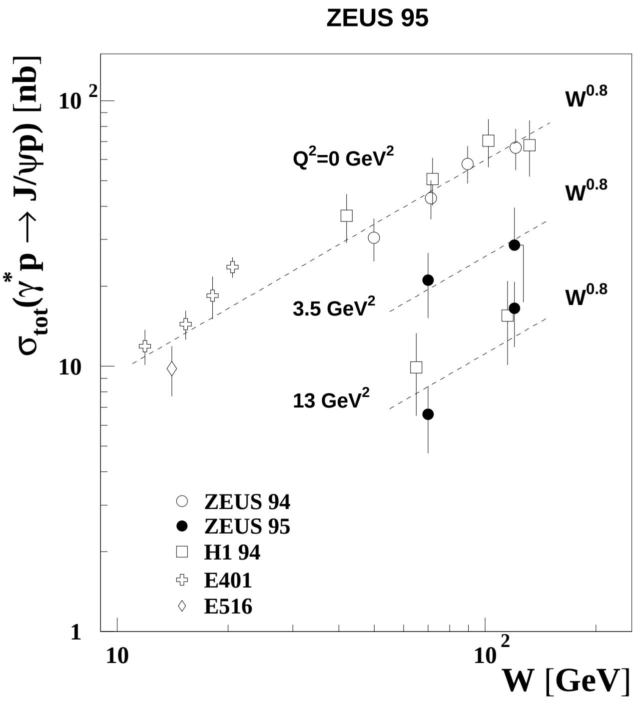


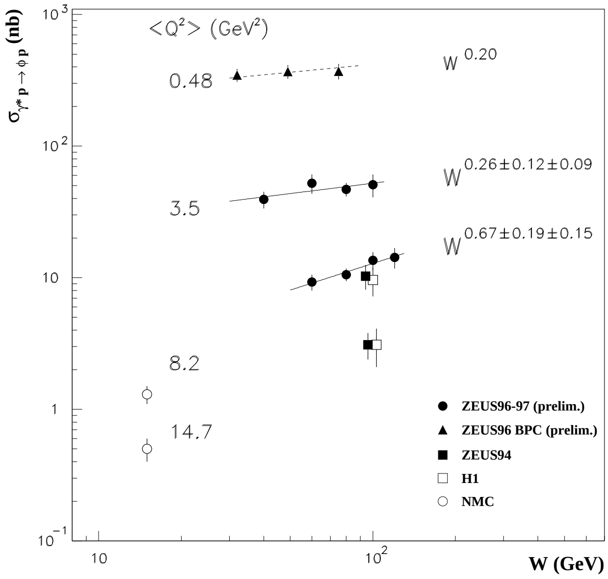
Energy Dependence of Vector Meson Photoproduction

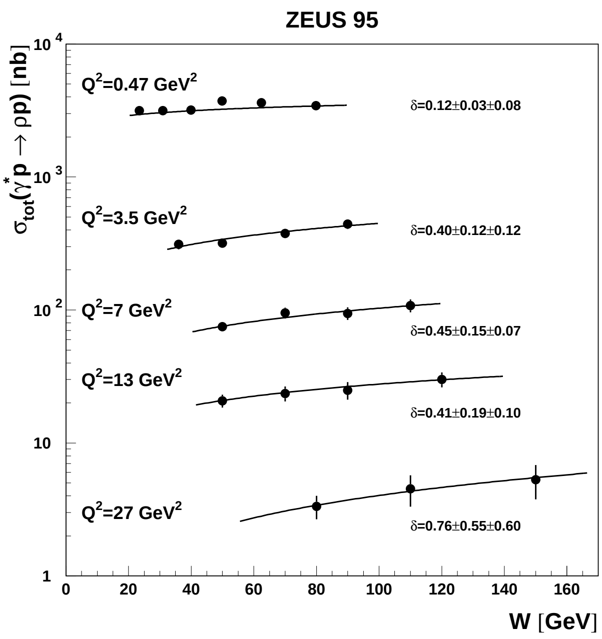


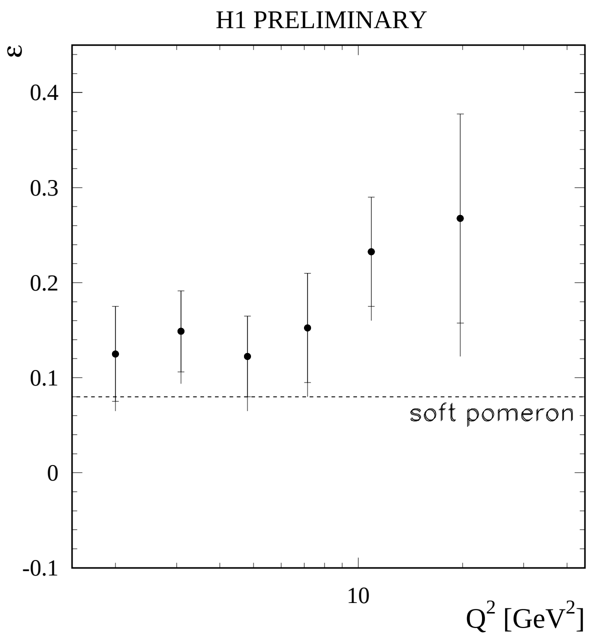
Effective $\alpha_{\mathbb{P}}(0)$ depends on vector meson mass at $Q^2 = 0$.

Energy Dependence of Vector Meson Electroproduction









Effective $\alpha_{\mathbb{P}}(0)$ depends on Q^2 and vector meson mass.

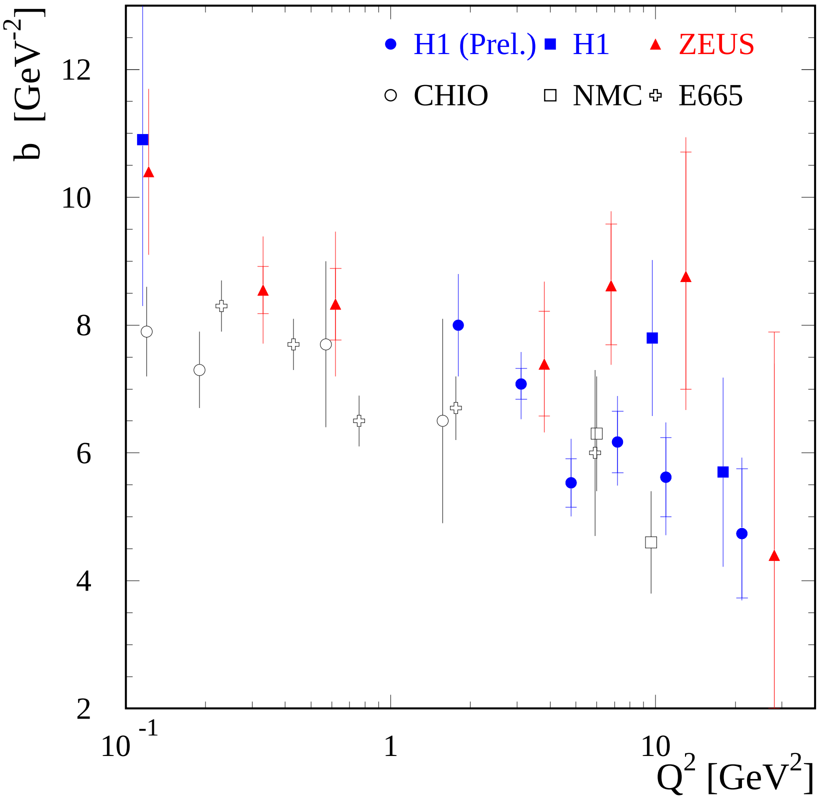
J/ψ has strong W dependence at $Q^2 = 0$

ρ, ϕ dependence on W steepens with Q^2

ϕ steepens faster than ρ?

t Dependence of Vector Meson Production

Fits to $\mathrm{d}\sigma/\mathrm{d}t \propto e^{bt}$

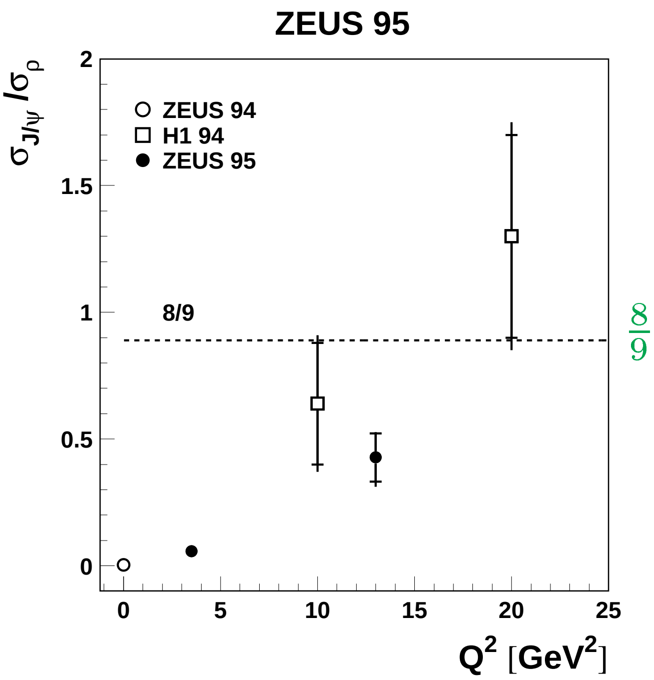


For J/ψ, $b \sim 4-5$ at $Q^2 = 0$.

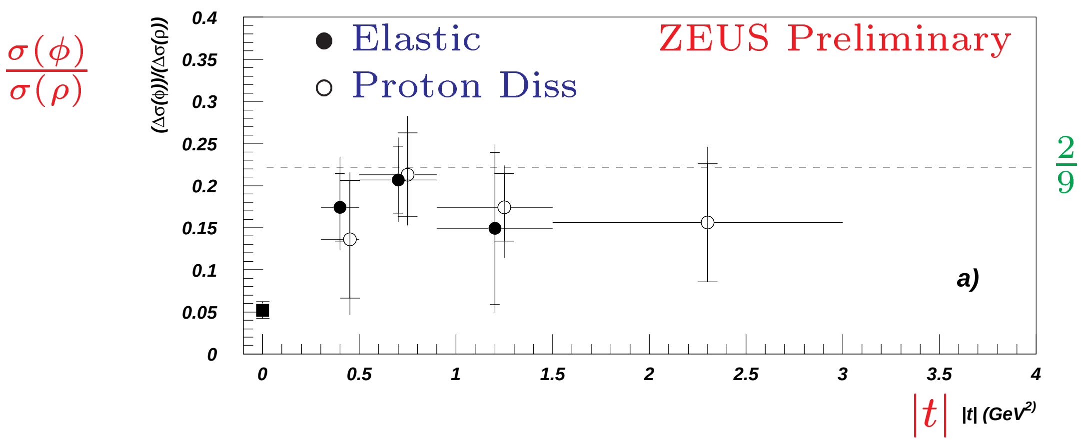
Slope parameter decreases as Q^2 or the vector meson mass increases.

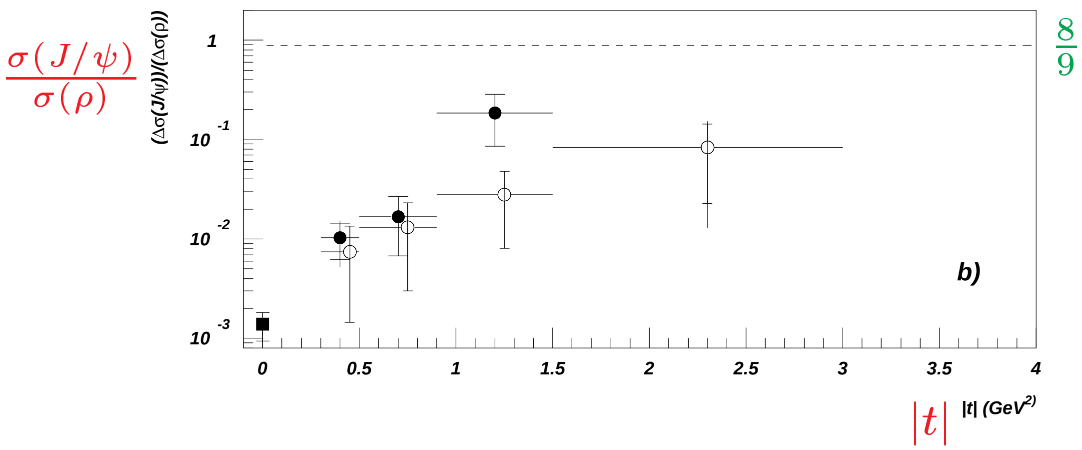
If $b \to R_p^2$ as scales increase and increasingly small sized $q\bar{q}$ configurations are active, $R_p^2 \sim 4\ \mathrm{GeV}^{-2}$; $R_p \sim 0.4$ fm.

Ratios of Vector Meson Cross Sections



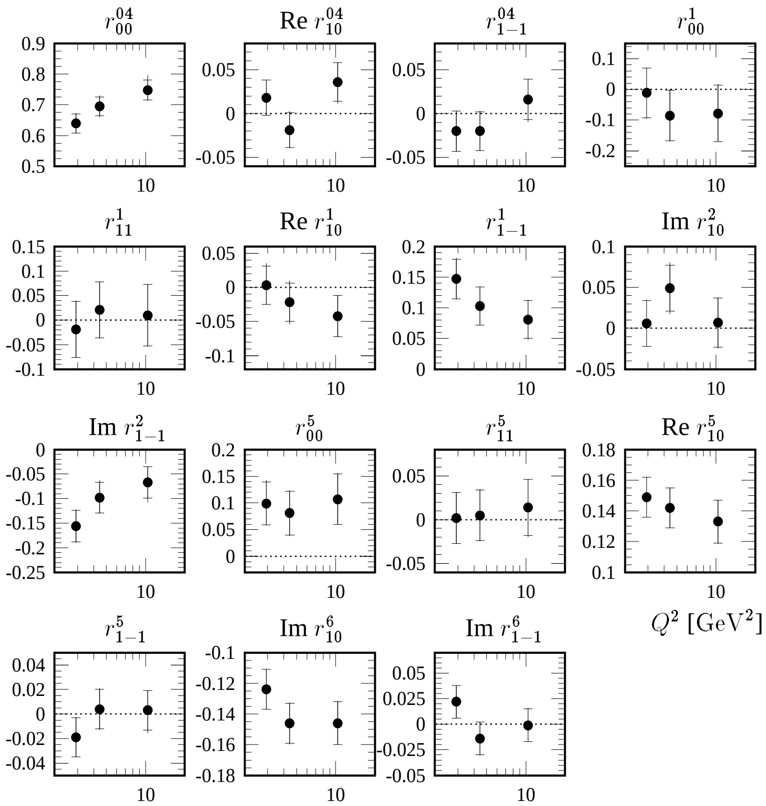
Ratios $J/\psi/\rho$, ϕ/ρ tend towards naive SU(4) predictions for flavour independent production mechanism as scales Q^2, $|t|$ increase.





ρ^0 Helicity Analysis

Spin density-matrix elements for $\gamma^* \to \rho^0$ extracted from angular distributions (θ^*, ϕ^* of $\rho \to \pi^+\pi^-$, and Φ between lepton scattering and ρ production planes).



- - - - s-channel helicity conservation & natural parity exchange.

$r^5_{00} \neq 0$, indicating a significant probability for longitudinal γ^* $\to$ transverse ρ

Ratio Helicity Flip Component / Non Flip $= 8 \pm 3$ %.

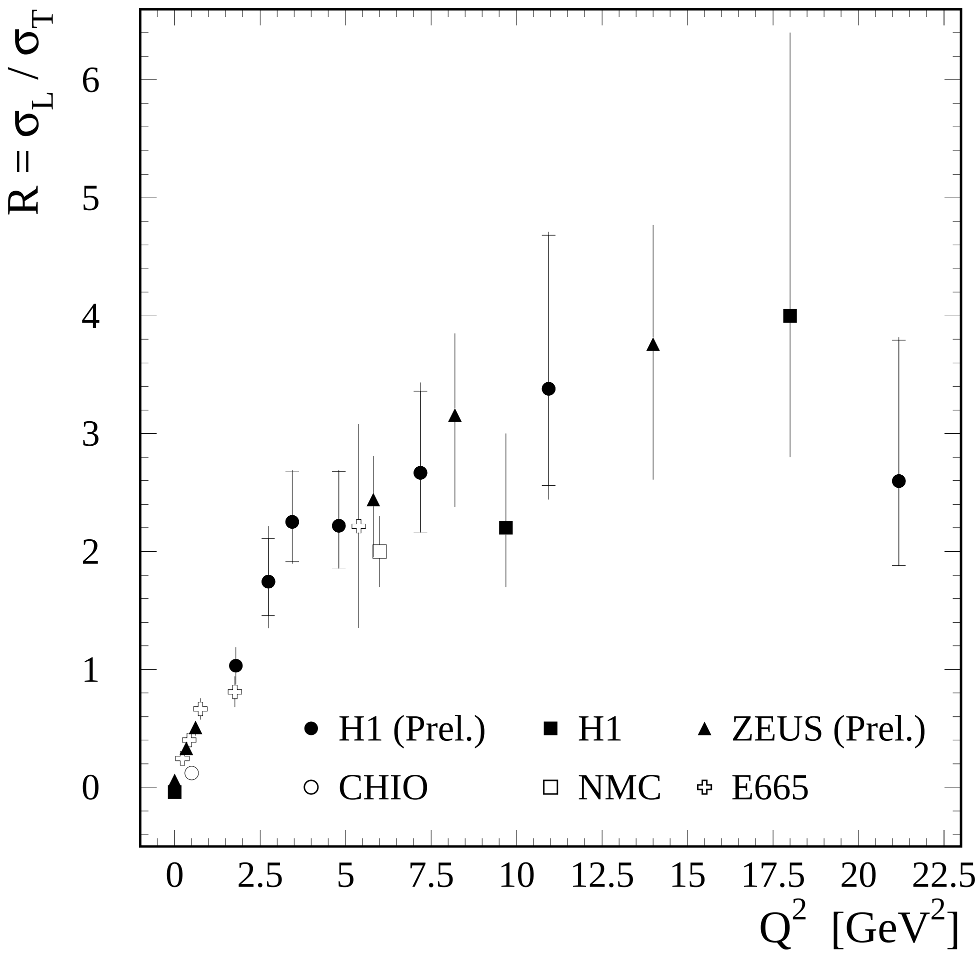
Also observed by ZEUS in ρ and ϕ electroproduction

The helicity-flip component is predicted in a model of vector-meson electroproduction based on the exchange of two gluons from the proton (Ivanov & Kirshner).

Ratio of Longitudinal to Transverse Photon Cross Sections

Under *approximation* of s-channel helicity conservation:

$$R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon}\,\frac{r^{00}_{04}}{1 - r^{00}_{04}} \qquad \text{with} \quad \epsilon = \frac{\Gamma_L}{\Gamma_T} = \frac{2(1-y)}{1+(1-y)^2}$$

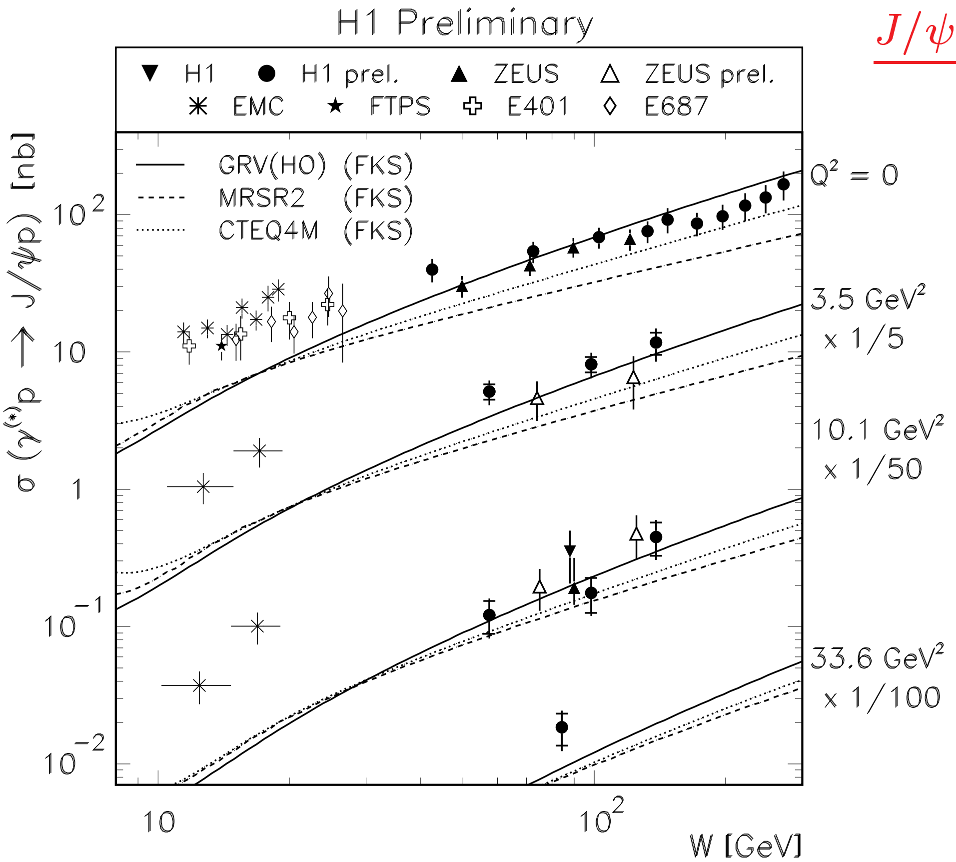


Longitudinal γ^* cross section dominant at large Q^2.

Example pQCD Model of VM Production

Indicators of 'hard' pomeron effects and dominance of σ_L encourage a perturbative QCD approach . . . .

J/ψ, $(\sigma_L + \sigma_T)$



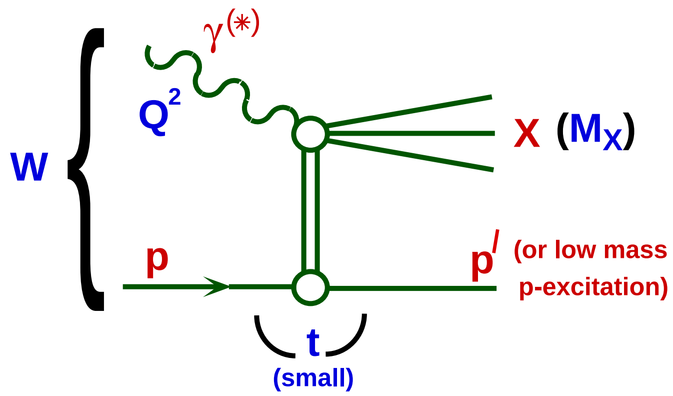
Compared to model of Frankfurt et al.,

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}t}\right|_{t=0} \sim \left|xg(x,\mu^2)\right|^2 \quad \text{with} \quad \mu^2 = (Q^2 + m_\psi^2)/4$$

and different gluon distributions.

Similar approaches have been applied to ρ at high Q^2.
. . . Distinguish between gluon distributions / pQCD models?

Inclusive Diffractive DIS, $\gamma^\star p \to Xp$



- $Q^2 = -q^2$ (Photon virtuality)
- $W^2 = (q+p)^2$ ($\gamma^\star p$ centre of mass energy)
- $t = (p-p')^2$ (4-momentum transfer squared)
- $M_X^2 = X^2$ (Invariant mass of X)

Long distance physics at p - vertex:

$$x_{I\!P} = \frac{q.(p-p')}{q.p} \simeq \frac{Q^2+M_X^2}{Q^2+W^2} = x_{\mathrm{I\!P}/\mathrm{p}}$$

$\to$ Fraction of p momentum transferred to $\mathrm{I\!P}$.
($\mathrm{I\!P}$ exchange dominates at low $x_{I\!P}$)

Short distance physics at $\gamma^\star$ - vertex:

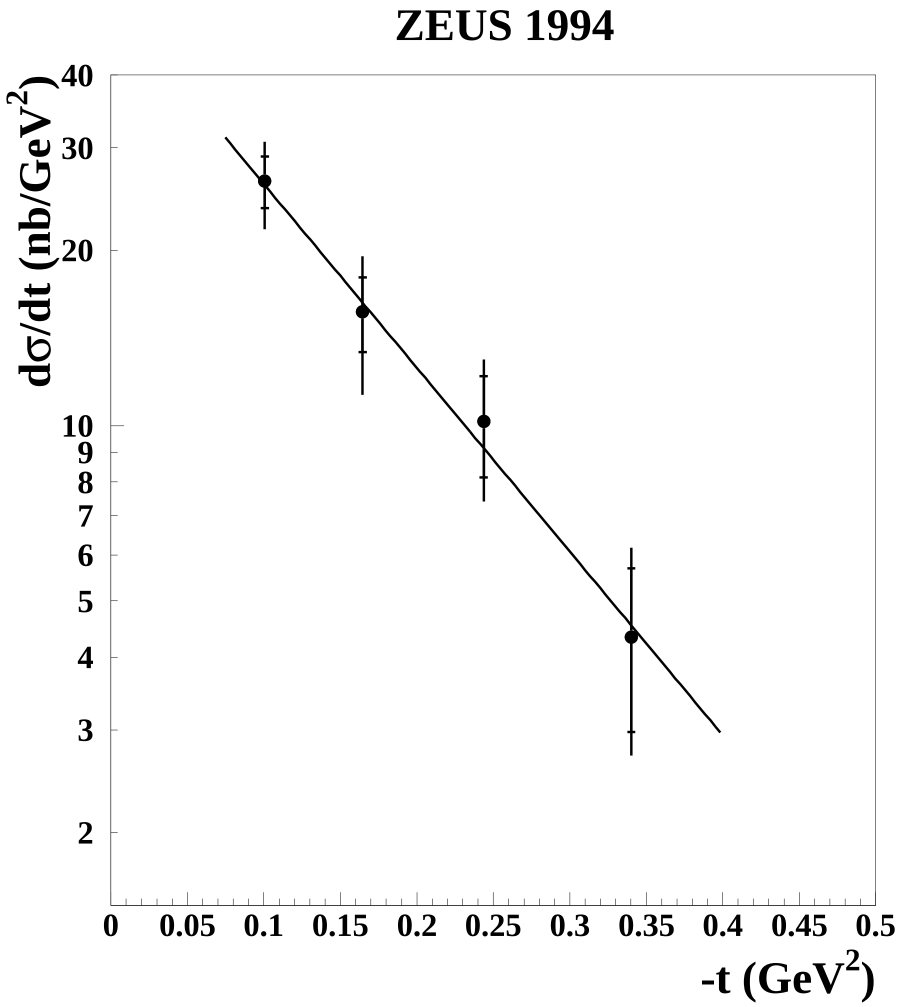
$$\beta = \frac{Q^2}{q.(p-p')} \simeq \frac{Q^2}{Q^2+M_X^2} = x_{q/\mathrm{I\!P}}$$

$\to$ Frac. of $\mathrm{I\!P}$ momentum carried by quark coupling to $\gamma^\star$.
($x_{\mathrm{Bj}} = \beta \cdot x_{I\!P}$)

Measurement of the t Dependence

$5 < Q^2 < 20$ GeV^2 $\quad 0.015 < \beta < 0.5$

$x_{I\!P} < 0.03$



From Direct Proton tagging

Fit to $\frac{d\sigma}{dt} \propto e^{bt}$

$b = 7.2 \ \pm 1.1(\text{stat.}) \ ^{+0.7}_{-0.9}(\text{syst.}) \ \text{GeV}^{-2}$

$\rightarrow$ Highly peripheral scattering.

$\rightarrow$ Slope parameter b is consistent with that expected from soft hadron-hadron diffraction.

The "Diffractive" Structure Function $F_2^{D(3)}$

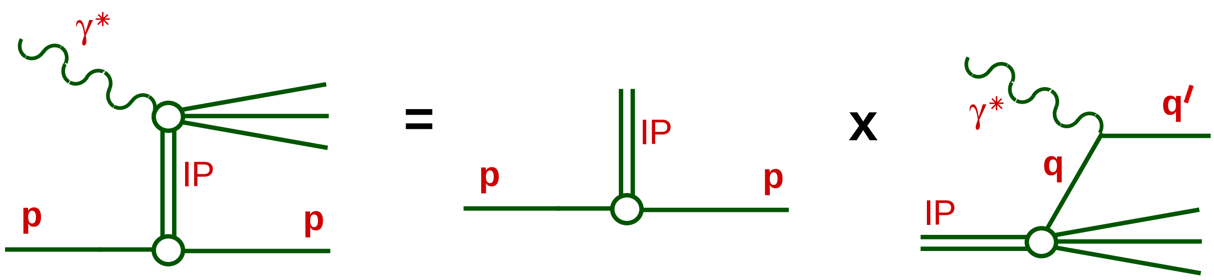
In rapidity gap based analyses, t is not measured.

Semi-inclusive cross section measurements are presented as a 'diffractive' structure function $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$, defined as

$$\frac{d\sigma^{ep\to eXY}}{d\beta\ dQ^2\ dx_{I\!P}} = \frac{4\pi\alpha^2}{\beta Q^4}\ (1 - y + \frac{y^2}{2})\ F_2^{D(3)}(\beta, Q^2, x_{I\!P})$$

In the H1 case, $|t| < 1\ \mathrm{GeV}^2$ and $M_Y < 1.6$ GeV.

If the $p I\!P p$ vertex factorises (as expected from hadron-hadron physics) then ...



$$F_2^{D(3)}(\beta, Q^2, x_{I\!P}) \quad \propto \quad f_{I\!P/p}(x_{I\!P}) \quad \times \quad F_2^{I\!P}(\beta, Q^2)$$

...such that $x_{I\!P}$ dependence is universal at all β and Q^2.

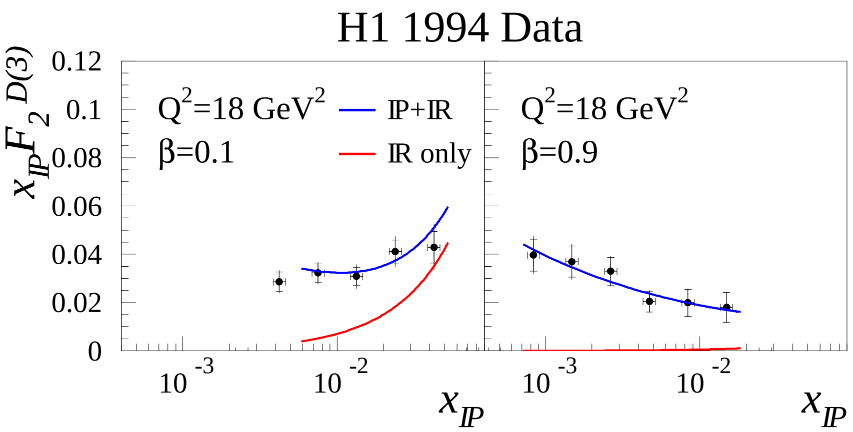
The $x_{I\!P}$ Dependence of $F_2^{D(3)}$

Regge theory gives us a means of parameterising the long distance physics at the proton vertex:

$$f_{I\!P/p}(x_{I\!P}) = \int_{-1\,\mathrm{GeV}^2}^{t_{min}(x_{I\!P})} \left(\frac{1}{x_{I\!P}}\right)^{2\alpha_{I\!P}(t)-1} e^{B_{I\!P}t}\,\mathrm{d}t$$

with $\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P}\,t$.

$x_{I\!P}$ dependence is found to vary with β ...



$$\frac{\chi^2}{\text{n.d.f.}} = \frac{258}{168}\ (I\!P\ \text{only})$$

$$\frac{\chi^2}{\text{n.d.f.}} = \frac{121}{121}\ (I\!P + I\!R)$$

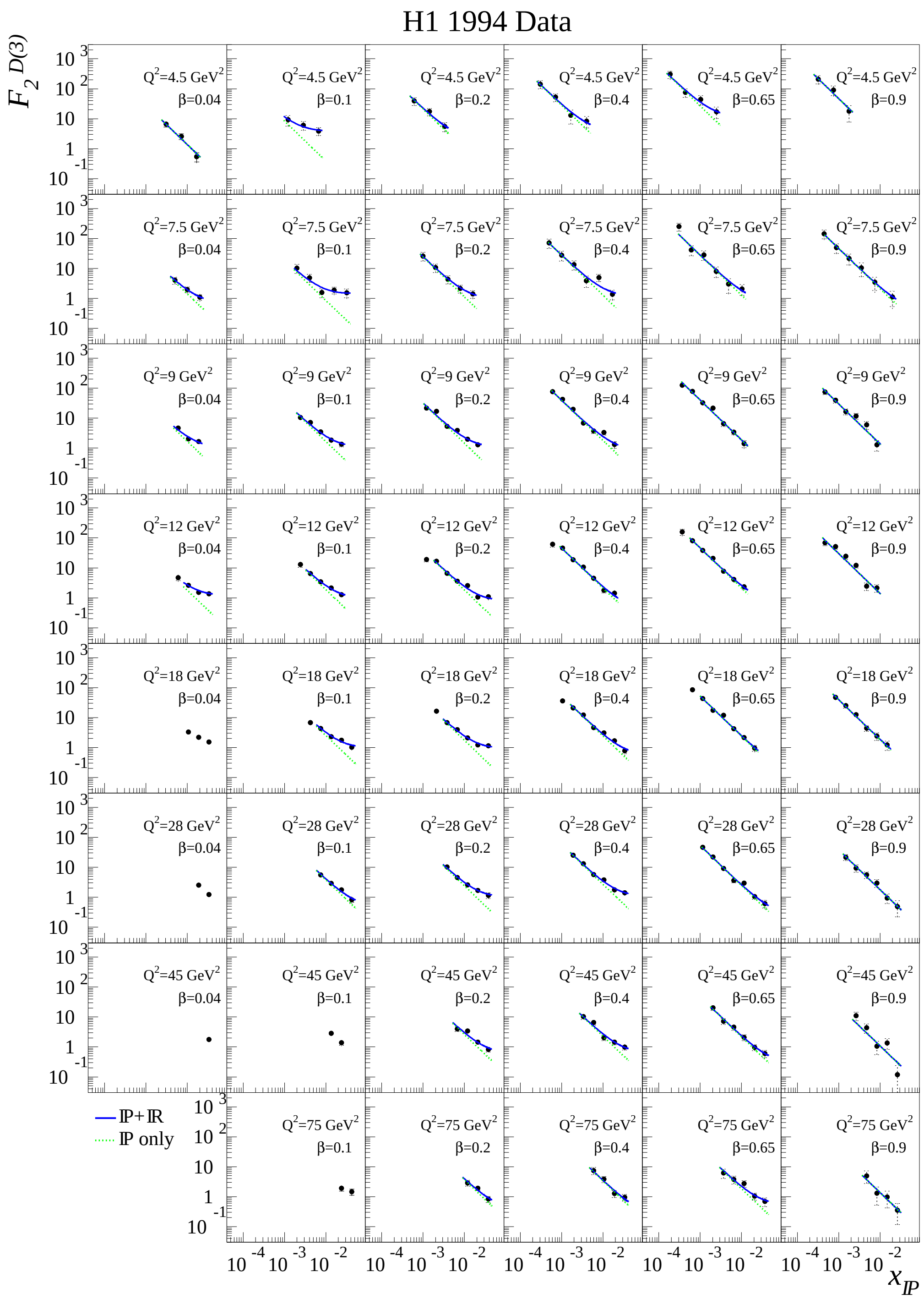
...in a Regge model, the measured data require a minimum of two exchanges:

Good fits obtained throughout kinematic range using:

$$F_2^{D(3)} = f_{I\!P/p}(x_{I\!P})\,F_2^{I\!P}(\beta,Q^2) + f_{I\!R/p}(x_{I\!P})\,F_2^{I\!R}(\beta,Q^2)$$

$\alpha_{I\!P}(0)$, $\alpha_{I\!R}(0)$, $F_2^{I\!P}(\beta,Q^2)$, $F_2^{I\!R}(\beta,Q^2)$ free fit parameters.

$F_2^{D(3)}$ with Phenomenological Regge Fit.



Characteristic diffractive dependence on energy.

$\sim 1/x_{I\!P}$

Deviations from simple Regge model at large $x_{I\!P}$, small β.

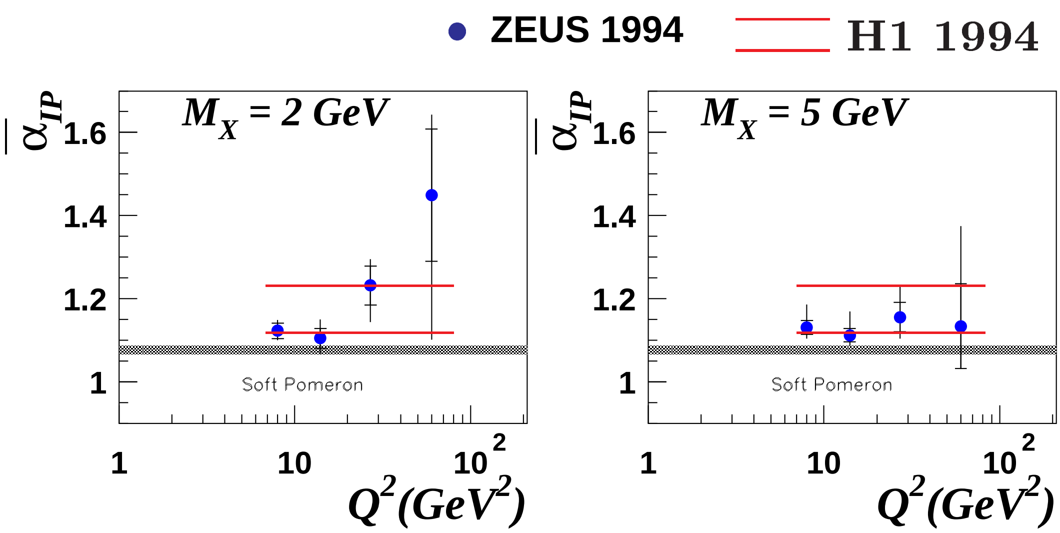
The pomeron intercept and Q^2

From H1 Phenomenological fits:

$\alpha_{I\!P}(0) = 1.203 \pm 0.020 \text{ (stat.)} \pm 0.013 \text{ (syst.)} {}^{+0.030}_{-0.035} \text{(model)}$

Larger than in soft hadron-hadron physics ($\alpha_{I\!P}(0) \sim 1.1$).
Similar to exclusive J/ψ production.

Comparison of H1 and ZEUS results:



...No significant variation with Q^2 within measured kinematic range to present precision.

Intercept of the sub-leading exchange in the H1 fits:

$\alpha_{I\!R}(0) = 0.50 \pm 0.11 \text{ (stat.)} \pm 0.11 \text{ (syst.)} {}^{+0.09}_{-0.10} \text{(model)}$

Consistent with f, ω, ρ or a exchange.

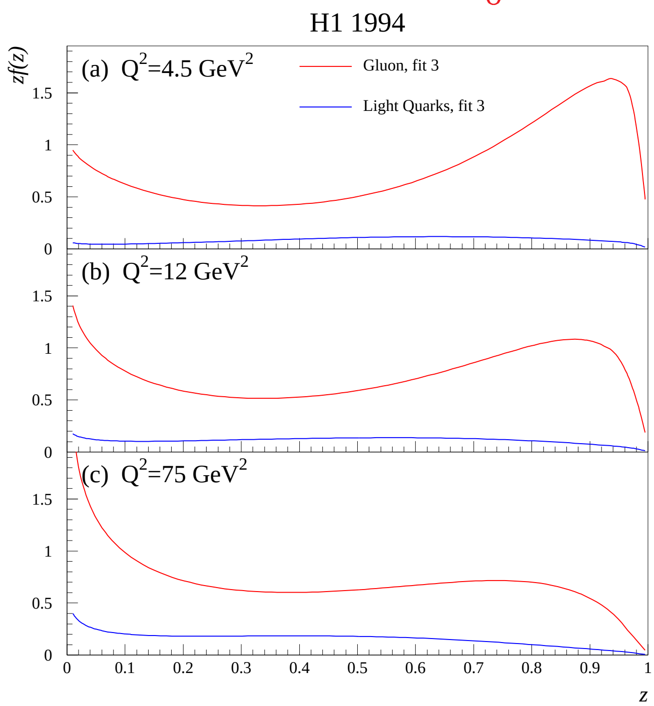
DGLAP Fits to $F_2^{D(3)}(x_{I\!P}, \beta, Q^2)$

Can we think of the pomeron as a partonic object with single partons entering the hard interaction?

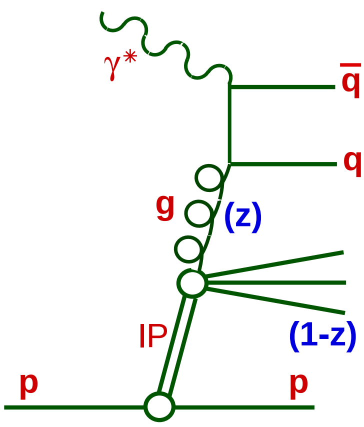
…Investigate the deep-inelastic structure of the exchange.

Extend the Regge fits to $x_{I\!P}$ dependence with a QCD motivated model of the β/Q^2 dependence.

- Paramterise $I\!P$ q_s and g distributions with Chebychev polynomials at starting scale $Q_0^2 = 3$ GeV^2.
- Assume a π structure function for $I\!R$.
- Evolve to $Q^2 > Q_0^2$ using NLO DGLAP equations.



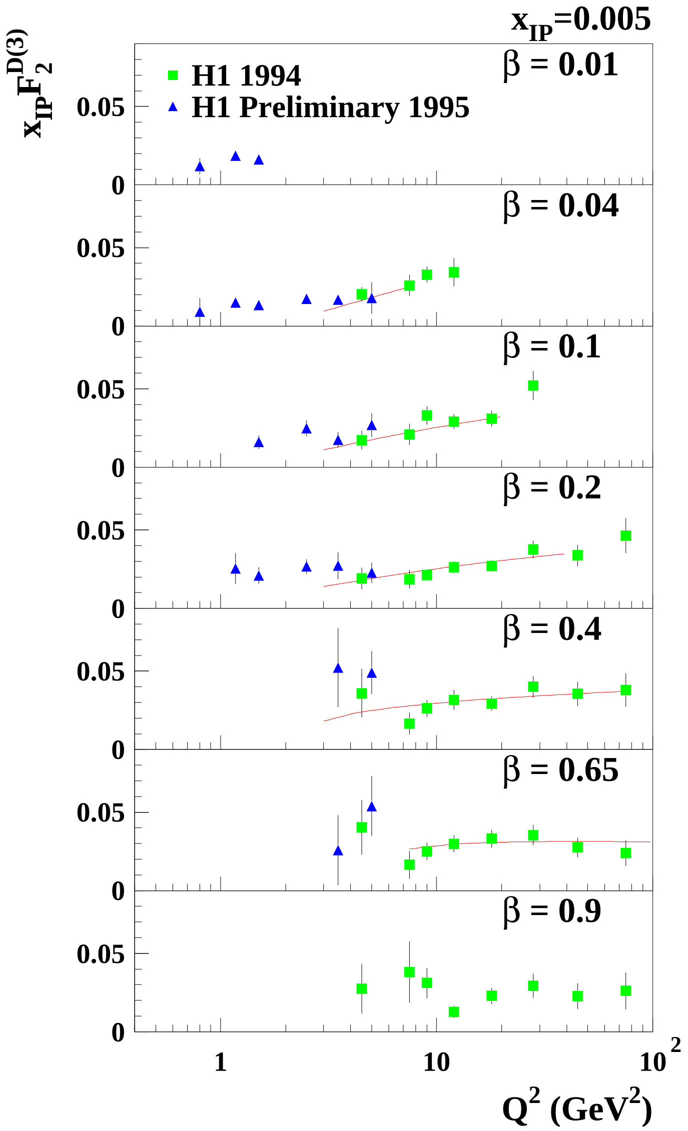
Acceptable fits only when $I\!P$ is dominated by "hard" gluons.

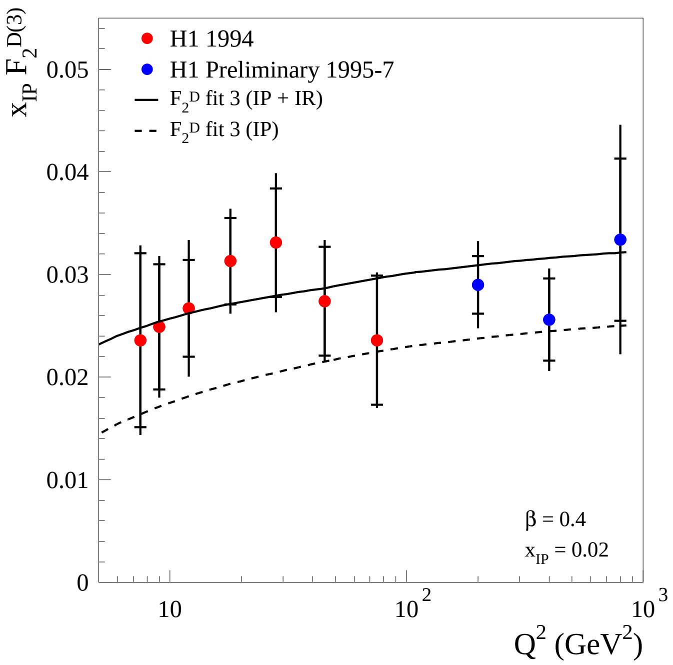


$\sim 90\%$ gluon at $Q^2 = 4.5$ GeV^2, $\sim 80\%$ at $Q^2 = 75$ GeV^2.

Uncertainties: applicability of DGLAP evolution / higher twist effects?

Scaling Violations of $F_2^{D(3)}$





Including data for

$0.8 < Q^2 < 800$ GeV^2

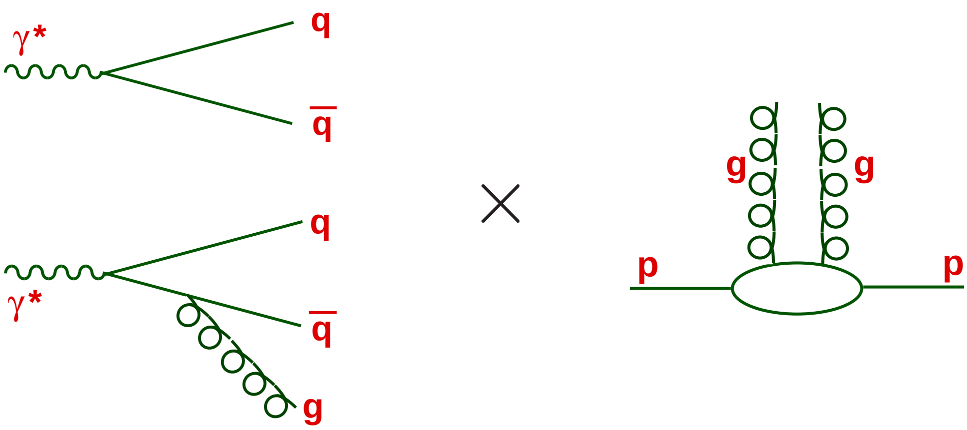
Rising scaling violations over large range of Q^2 up to large β [c.f. $F_2(x, Q^2)$].

Highly suggestive of a gluon dominated mechanism.

Two-gluon / BFKL Models of $F_2^{D(3)}$

Can F_2^D be viewed in terms of a 2-gluon exchange model?

$q\bar{q}$ / $q\bar{q}g$ production via the exchange of 2 gluons / BFKL ladder from the proton.



Investigate decomposition of data into leading / higher twist contributions, longitudinal / transverse photon interactions, $q\bar{q}$ / $q\bar{q}g$ final states.

e.g. Recent model (Bartels, Wüsthoff) with 3 significant contributions in convenient form to fit to F_2^D data.

$$F^{\mathrm{T}}_{q\bar{q}} \propto \left(\frac{x_0}{x_{I\!P}}\right)^{n2(Q^2)} \beta(1-\beta)$$

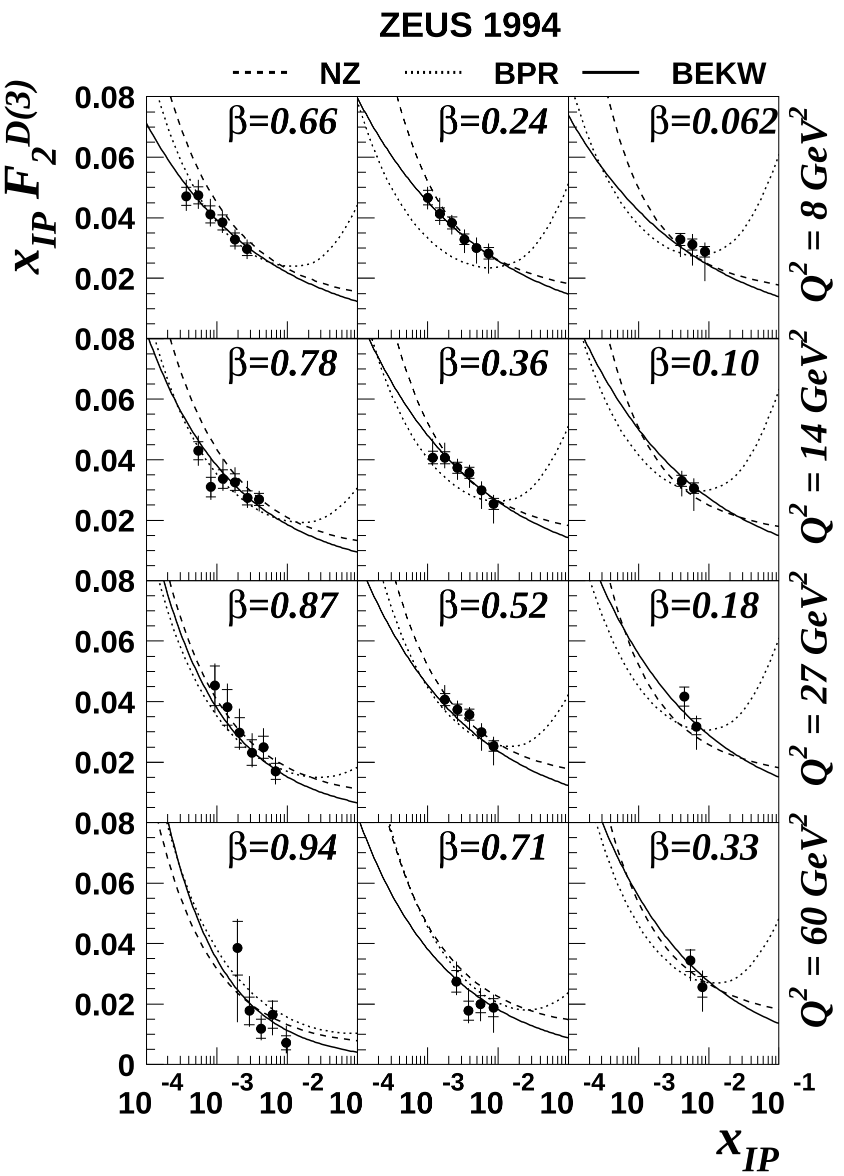
$$F^{\mathrm{T}}_{q\bar{q}g} \propto \left(\frac{x_0}{x_{I\!P}}\right)^{n2(Q^2)} \alpha_s \; \ln\left(\frac{Q^2}{Q_0^2}+1\right) \; (1-\beta)^{\gamma}$$

$$\Delta F^{\mathrm{L}}_{q\bar{q}} \propto \left(\frac{x_0}{x_{I\!P}}\right)^{n4(Q^2)} \frac{Q_0^2}{Q^2} \left[\ln\left(\frac{Q^2}{4Q_0^2\beta}+\frac{7}{4}\right)\right]^2 \beta^3(1-2\beta)^2$$

(HT)

2-gluon / BFKL Exchange Models

Nikolaev & Zakharov, Bialas & Peschanski and Bartels & Wüsthoff models:

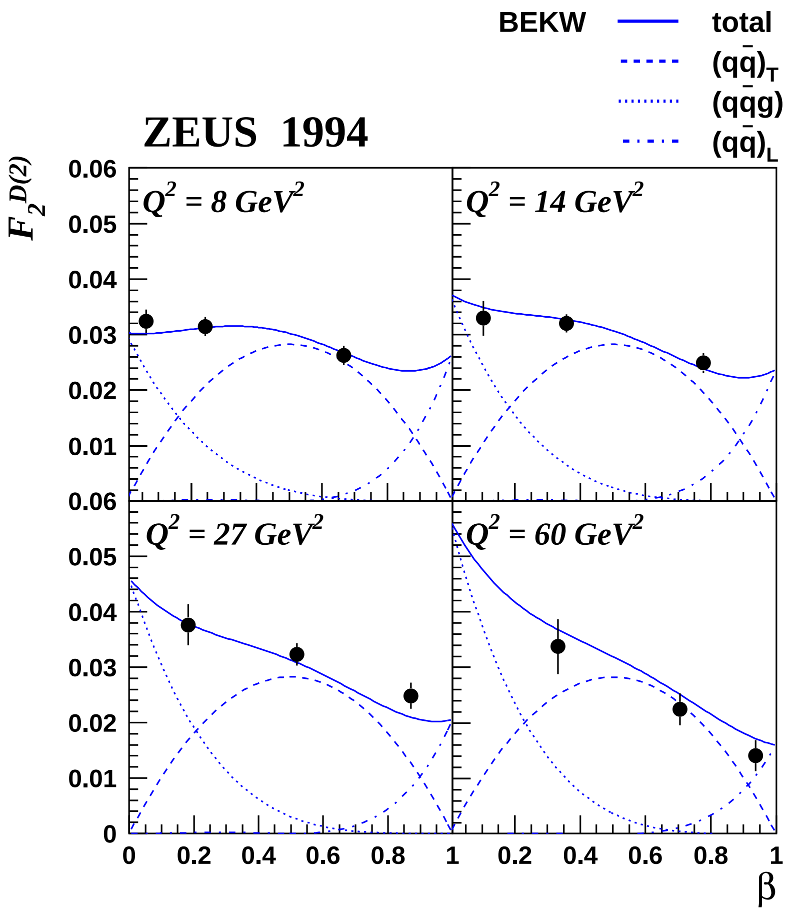


Photon fluctuation / 2-gluon exchange models can be made to fit $F_2^{D(3)}$, even at large β

BP contains extra $\mathbb{R}$ component (required by H1 data)

β dependence in the Bartels - Wüsthoff model.

Typical decomposition of the data in β and Q^2 in a two-gluon exchange model.

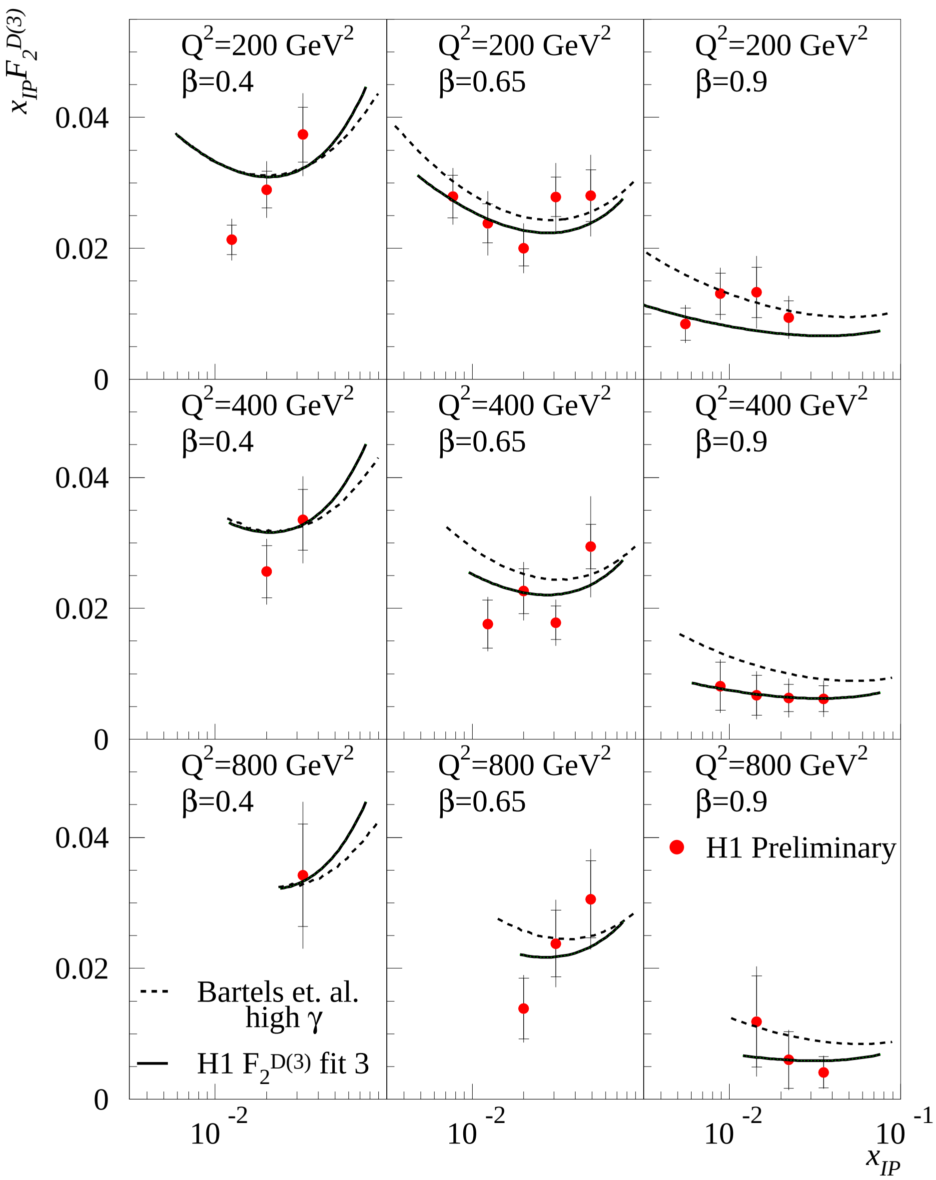


Mixture of $q\bar{q}$ and $q\bar{q}g$ final states.

Higher twist contribution important at large β.

These models make clear predictions for the partonic composition ($q\bar{q}$, $q\bar{q}g$) of the final state X

New $F_2^{D(3)}$ Data at large Q^2

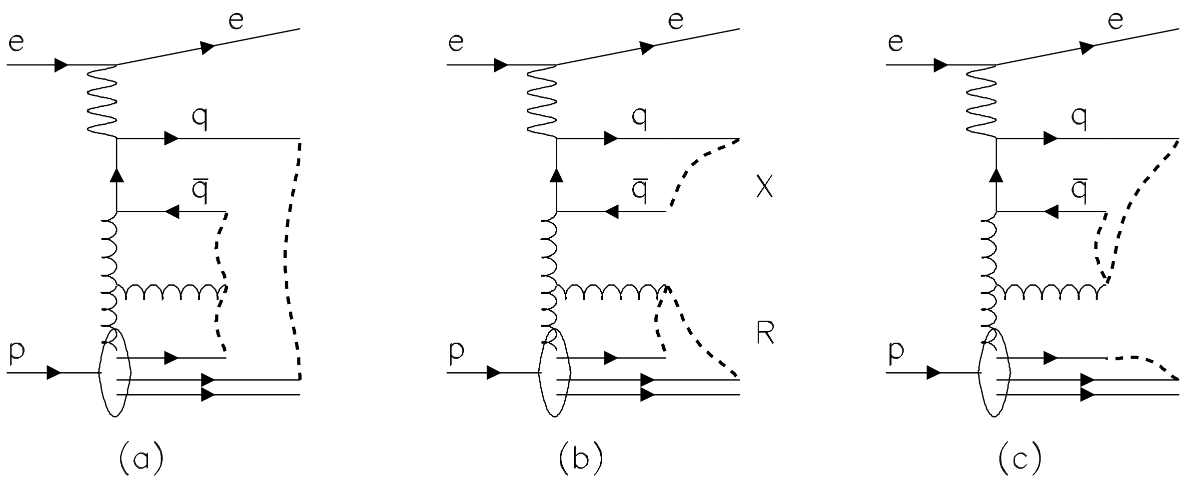


Extrapolations of both DGLAP and 2-gluon exchange models can describe the data up to $Q^2 = 800$ GeV^2.

Soft Colour Rearrangement Model of $F_2^{D(3)}$ ($\mathbb{P}$-free!)

Start from standard matrix elements / parton showers description of $F_2(x, Q^2)$ (dominantly BGF at low x).

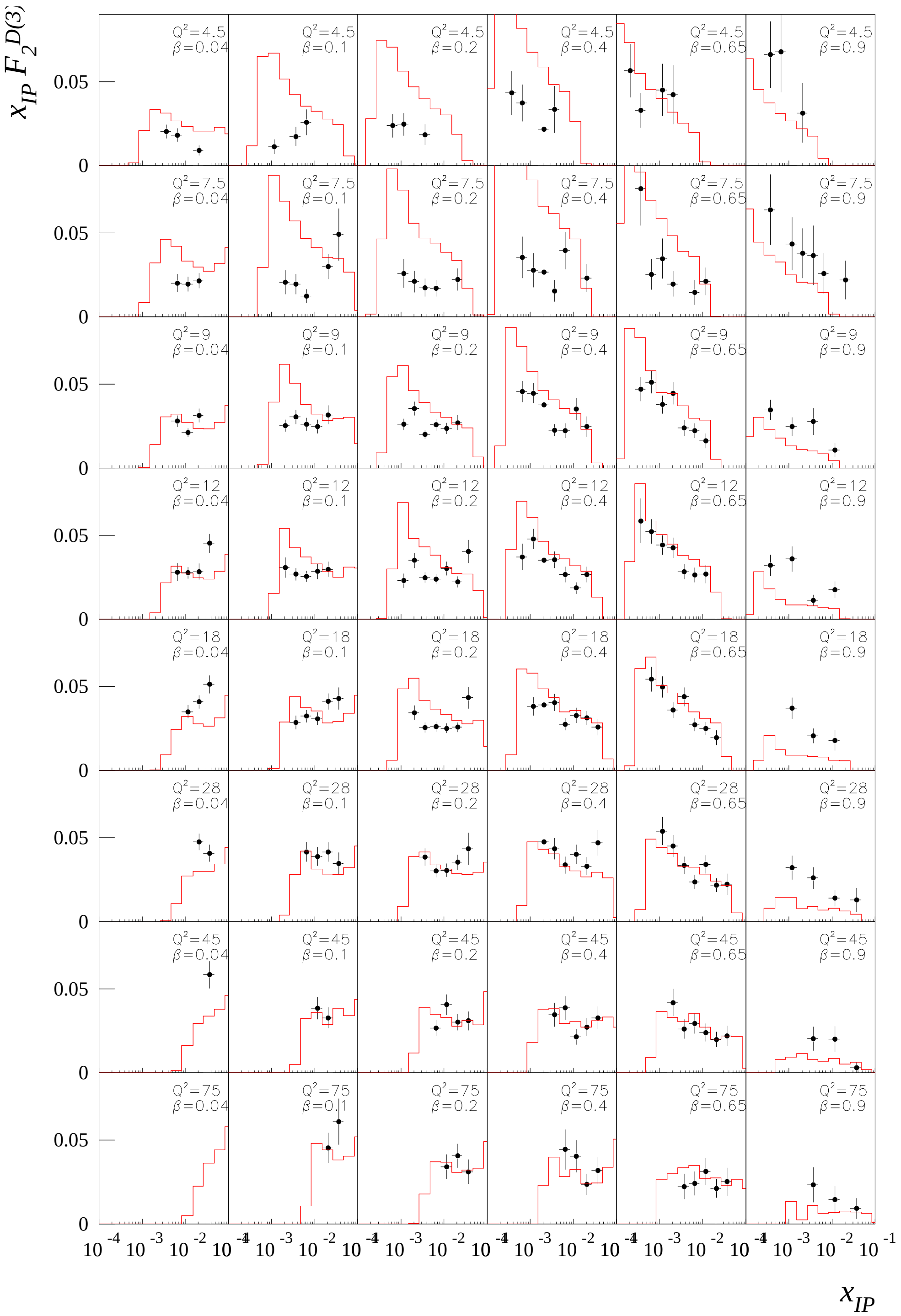
Additional non-perturbative interactions affect final state colour connections but not parton momenta.



Implemented in the Monte Carlo model LEPTO 6.5

Only one free parameter! - Probability of Soft Colour Interactions . . . to be fixed by data.

Comparison of $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ and LEPTO 6.5



• **H1 1994 Data**

— **LEPTO [Pr(SCI) = 0.5]**

$\sim$ reasonable shape in $x_{I\!P}$.

Does not describe Q^2 dependence.

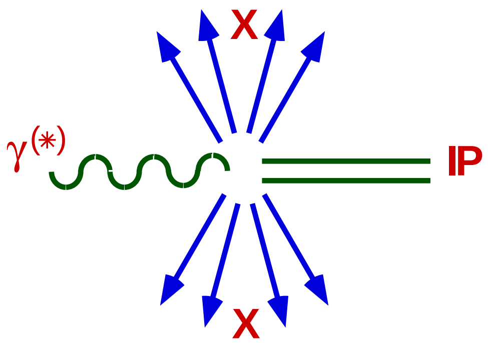
Fails at high β (= low M_X non-perturbative region).

The final state X at low $x_{\mathbb{P}}$

Many hadronic final state observables are sensitive to the QCD Structure of Diffraction

- Thrust, Sphericity
- Energy flow
- Particle spectra, multiplicities, correlations
- Open charm production
- Jet rates

Studies are made in the rest frame of X ($\equiv \gamma^{\star}\mathbb{P}$ centre of mass).
p_T etc. measured relative to the photon (collision) axis in this frame.

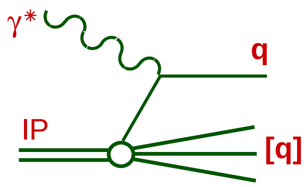


Predictions for the final state *X*

In terms of DGLAP evolving IP model, distinguish between quark and gluon dominated pomeron.

$\mathcal{O}(\alpha)$

QPM

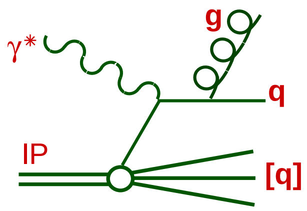


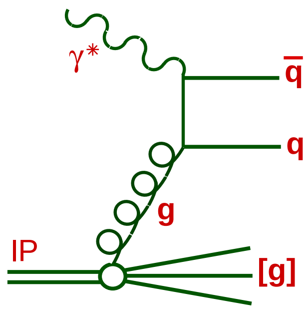
Hard processes up to $\mathcal{O}(\alpha_s)$

$\mathcal{O}(\alpha\ \alpha_s)$

QCD-C

BGF



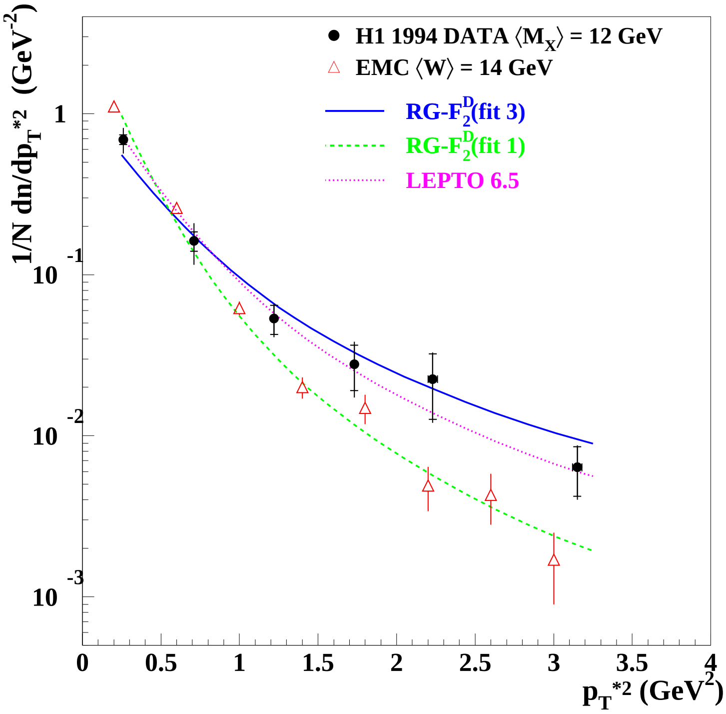


↑	↑
Quarkonic IP	Gluonic IP
Dominant $q\bar{q}$	Dominant $q\bar{q}g$
Low p_T / aligned	High p_T / non-aligned
Few jets	Many jets
$\sim 3_c\bar{3}_c$	$\sim 8_c 8_c$

In terms of 2-gluon exchange models, investigate the decomposition of the data into of $q\bar{q}$, $q\bar{q}g$ final states.

Charged Particle $p_T^\star$ Distribution

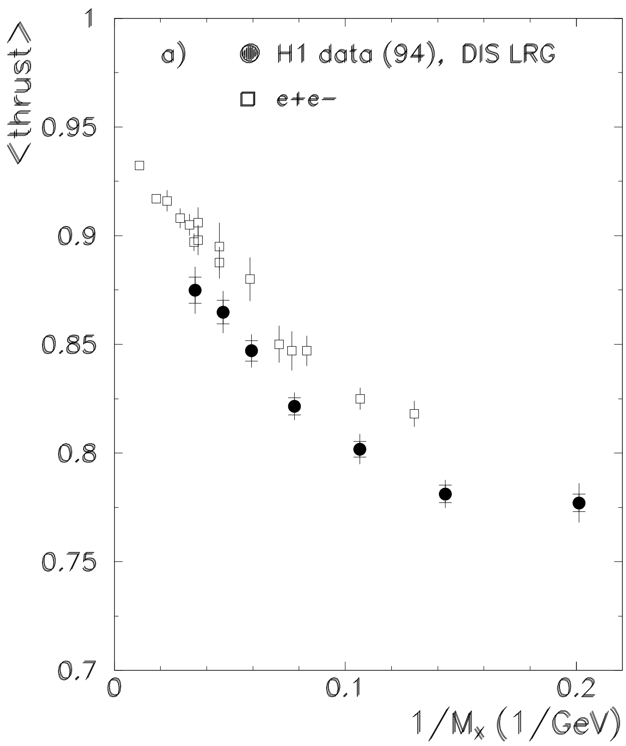
$p_T^\star$ measured relative to $\gamma^\star$ axis in rest frame of X



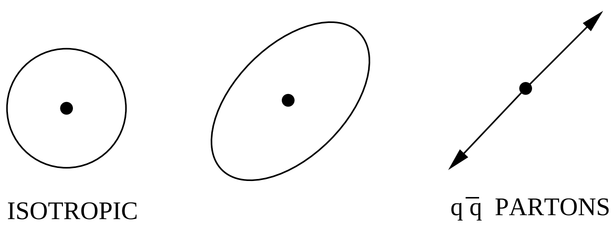
Gluons required to generate hard $p_T^\star$ distribution.

BGF / $q\bar{q}g$ contributions.

Thrust - measure of '2-jettiness'



$$1/2 < T < 1$$



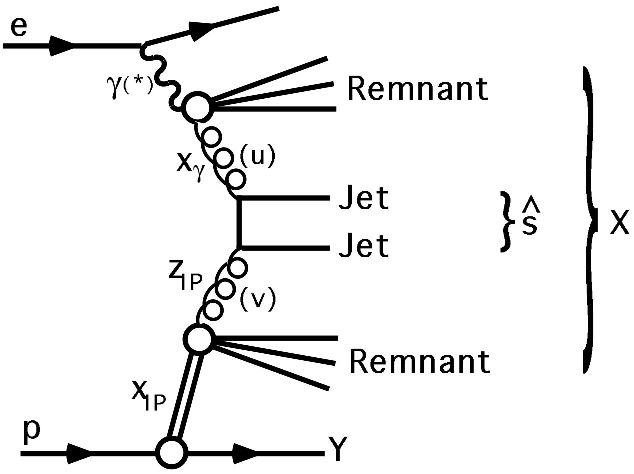
Gluons required to generate lower thrust than $q\bar{q}$.

Hadronisation effects decrease thrust at low M_X.

Diffractive Dijet Production

Search for dijet structures as components of the system X

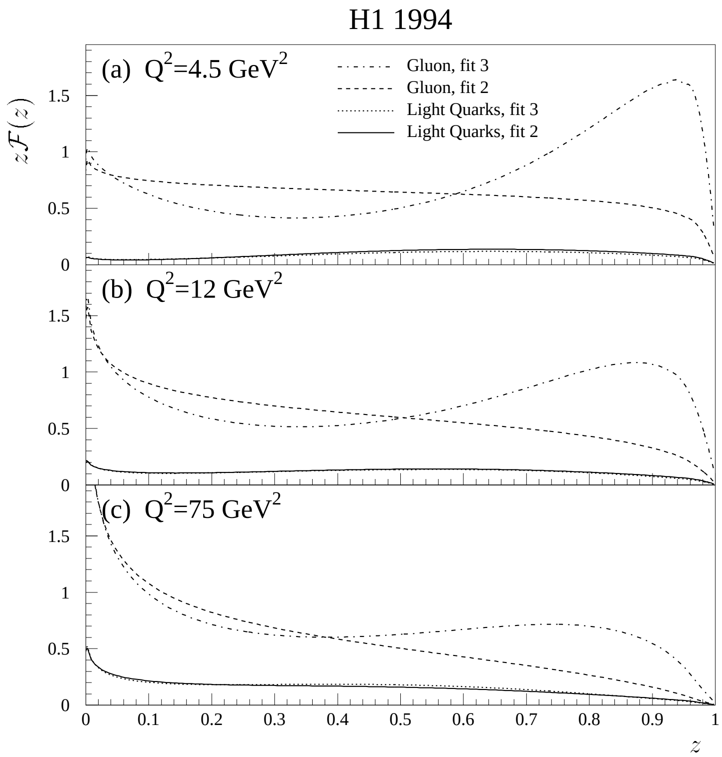
Cone algorithm requiring $p_T^{\mathrm{jet}} > 5$ GeV relative to $\gamma^{(\star)}$ axis in rest frame of X.



Can measure fractions of $\gamma^{(\star)}$ and $I\!P$ momentum transferred to the dijet system.

$$x_\gamma^{\mathrm{jets}} = (P.u) \,/\, (P.q)$$

$$z_{I\!P}^{\mathrm{jets}} = (q.v) \,/\, (q.[P-Y])$$

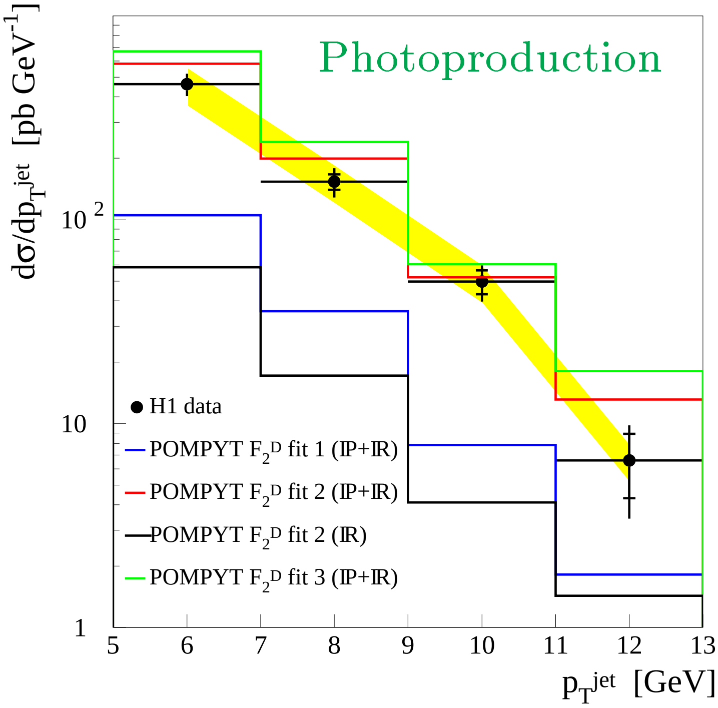


The results are compared with 3 sets of $I\!P$ and $I\!R$ parton distributions from DGLAP fits to F_2^D, evolving with $\hat{p_T}$ as a scale.

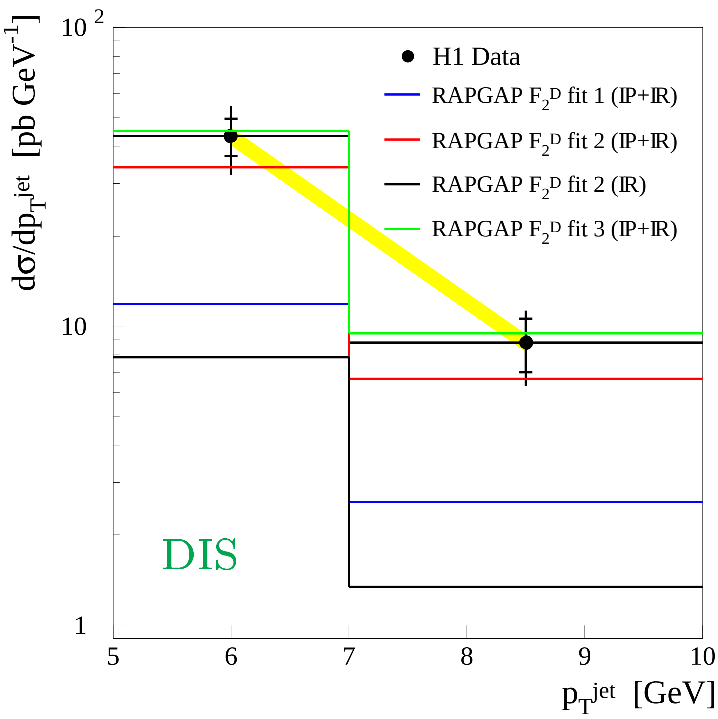
'Flat' and 'peaked' gluon dominated pomeron and quark dominated pomeron.

Dijet p_T^{jet} Distributions

p_T^{jet} relative to $\gamma^\star$ axis in rest frame of X



Sub-leading exchange contribution $\sim 15\%$

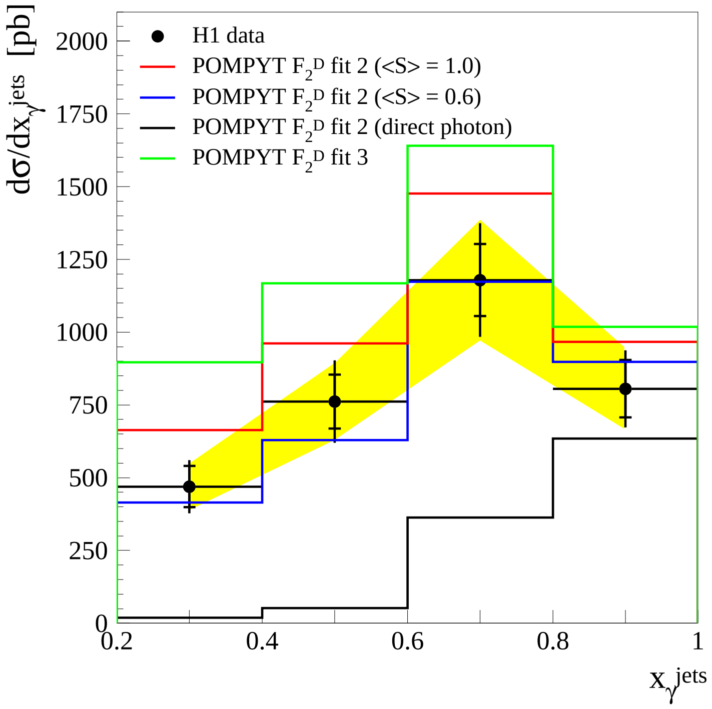


Data reasonably described by gluon dominated IP

Quark dominated IP low by a factor ~ 5

$x_\gamma^{\rm jets}$ and $z_{\rm I\!P}^{\rm jets}$ Distributions

Fraction of γ momentum entering the hard scattering.

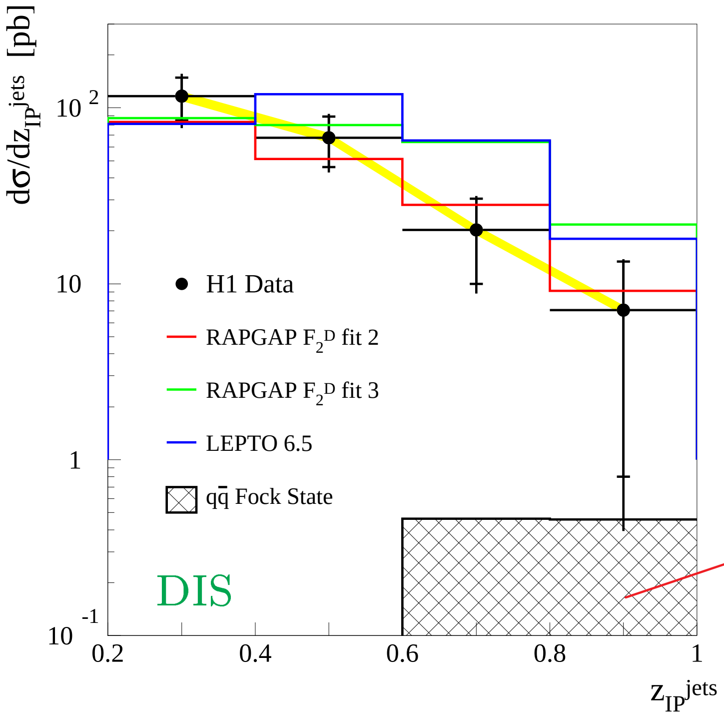


Photoproduction

Both direct $x_\gamma = 1$ and resolved $x_\gamma < 1$ contributions observed.

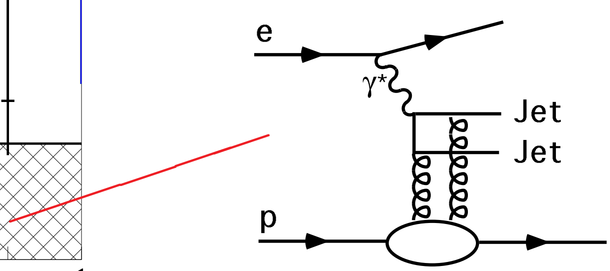
Possible rapidity gap destruction effects where there is a photon remnant.

Fraction of I P momentum entering the hard scattering.



LEPTO - Pr(SCI) $= 0.5$ is close to DIS data.

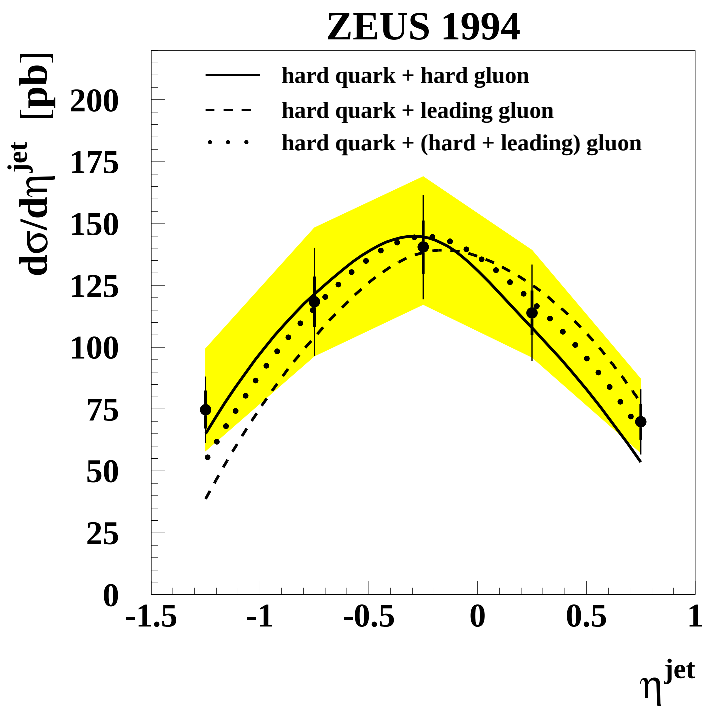
$q\bar{q}$ final state alone cannot describe data.



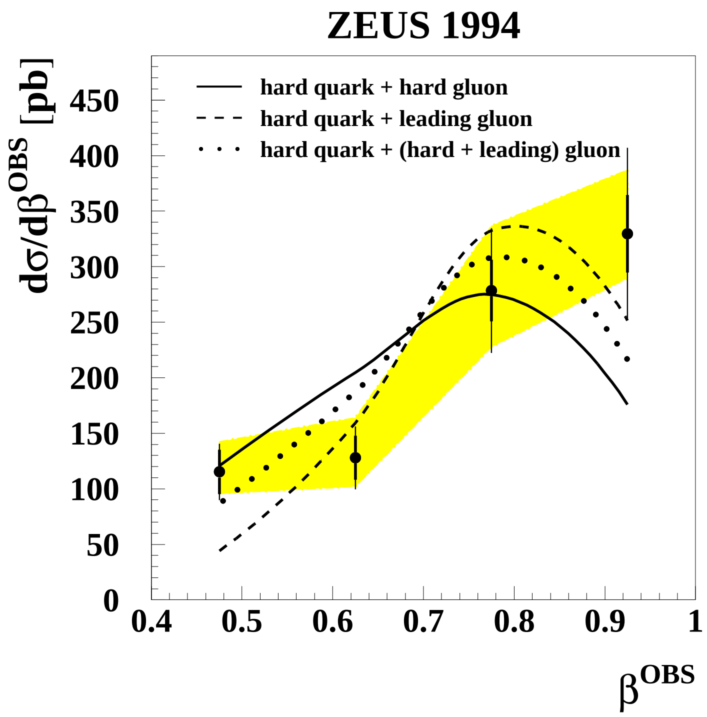
$q\bar{q}g$ states also required.

Combined DGLAP fit to F_2^D and photoproduction dijet rates

Taking various parameterisations for quark and gluon structure of the pomeron . . .



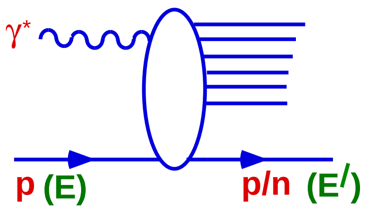
Acceptable fits only when pomeron is dominated by 'hard' gluons.



Resulting fraction of exchanged momentum carried by gluons is ∼ 70 - 90 % in region accessed.

Leading Baryon Production in DIS

ZEUS and H1 can detect and measure forward protons and neutrons with a wide range of energies.



z (H1) $= x_{\rm L}$ (ZEUS) $= E'/E$

($x_{\rm L} = 1 - x_{I\!P}$ if exclusive p / n at proton vertex.)

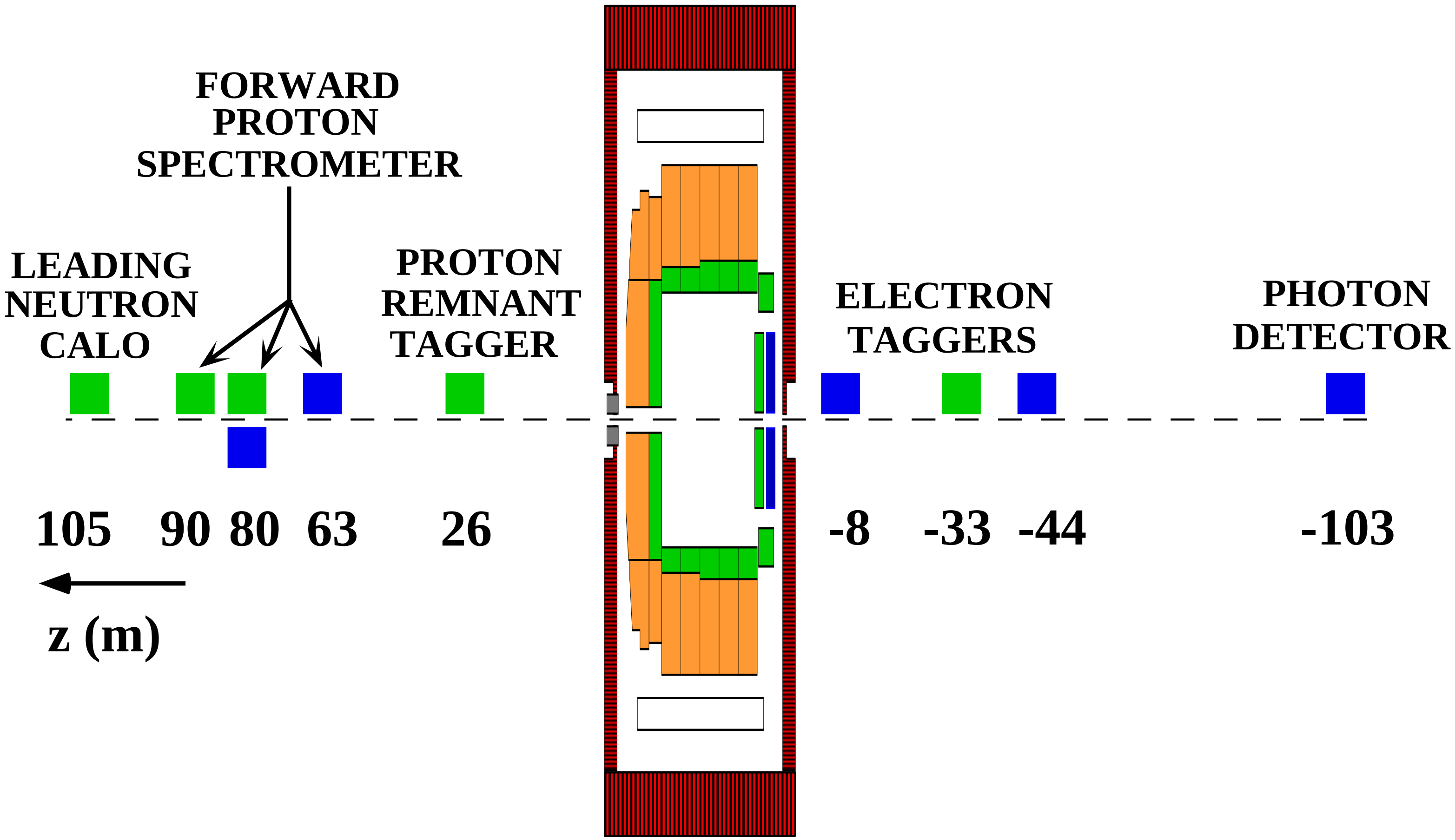
Leading protons: H1 ($p_T \lesssim 0.2$ GeV, $0.7 \lesssim x_{\rm L} \lesssim 0.9$)
ZEUS ($p_T \lesssim 0.85$, $0.6 \lesssim x_{\rm L} \lesssim 1$)

Leading neutrons: H1 ($p_T \lesssim 0.2$ GeV, $0.2 \lesssim x_{\rm L} \lesssim 1$)
ZEUS ($p_T \lesssim 0.85$, $0.2 \lesssim x_{\rm L} \lesssim 1$)

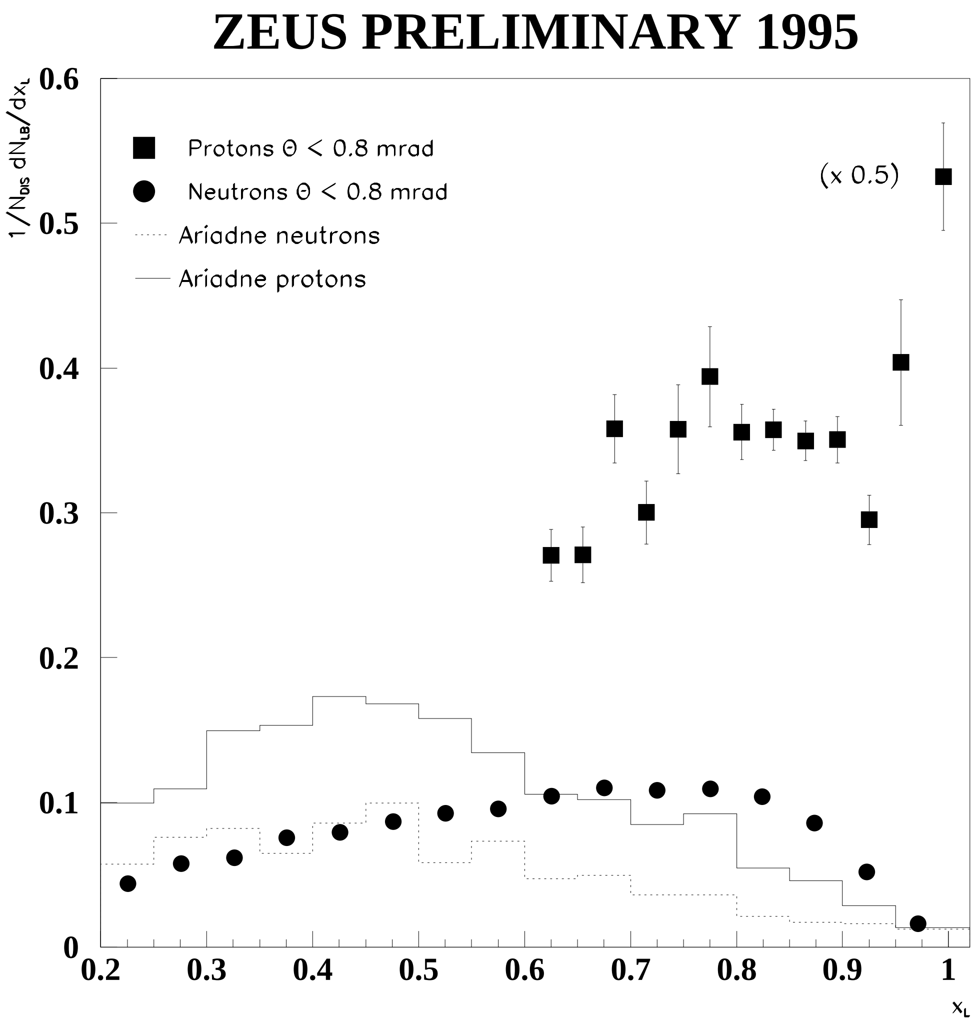
Several interesting issues . . .

- Can standard fragmentation models describe the proton fragmentation region?
- Are Regge models applicable to the soft physics at the proton vertex in the large $x_{I\!P}$ region?
- In large $x_{I\!P}$ region, probe the sub-leading exchanges, especially $I = 1$ π-exchange.

BEAM-LINE INSTRUMENTATION



x_L Distributions of Protons and Neutrons



Diffractive region.

$\sim 12.5\%$ of DIS events have a leading p or n ($\theta < 0.8$ mrad, $0.6 < x_L < 0.9$).

Lots of leading baryons outside diffractive region.

Colour dipole (ARIADNE) and parton showers + SCI (LEPTO) fragmentation models fail to predict rates and shapes.

Leading proton rate > leading neutron rate. (expect $n = 2p$ if only $I = 1$ exchange (e.g. π).

Regge models of Leading Baryon Production

Try to simulataneously understand leading protons and neutrons in terms of combinations of exchanges.

Similar models employed by both collaborations - $\mathbb{P}$, $\mathbb{R}$, π exchange.

$\mathbb{R}$ is isoscalar (f, ω), $\rightarrow$ contributes to leading protons only.

$$\sigma^{\gamma^* p \rightarrow NX}(z, t, \beta, Q^2) \ \sim \sum_{i=\mathbb{P},\mathbb{R},\pi} f_{i/p}(z,t)\ F_2^i(\beta, Q^2)$$

$$\text{where } \beta = \frac{x}{1-x_{\mathrm{L}}}$$

Assume: $\mathbb{P}$ $\quad \alpha(0) \sim 1.2,\ I = 0$ - p

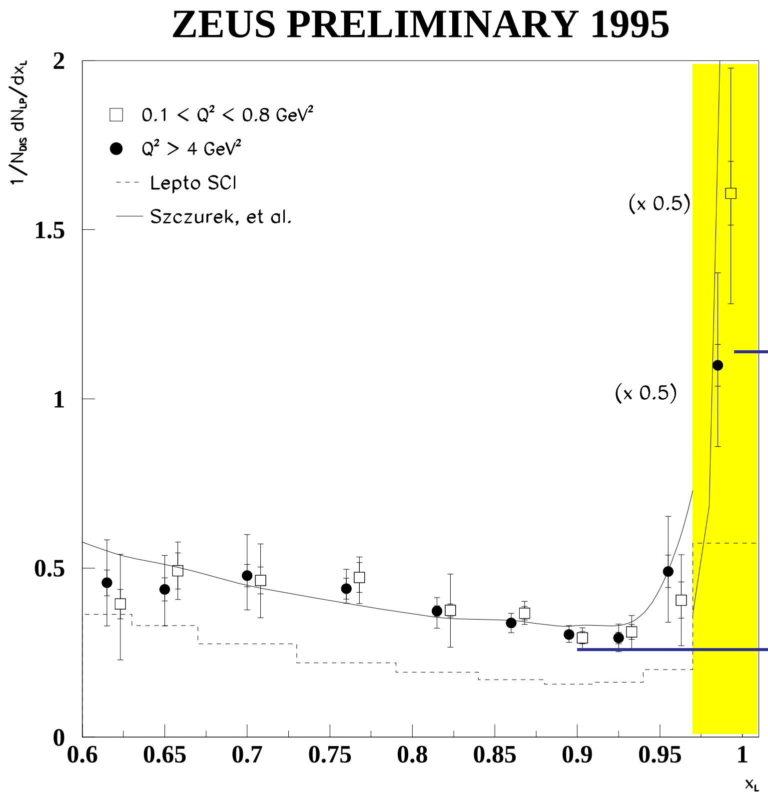
$\mathbb{R}$ $(f,\ \omega)$ $\alpha(0) \sim 0.5,\ I = 0$ - p

π $\quad \alpha(0) \sim 0.0,\ I = 1$ - p, n

Fluxes $f_{i/p}$ constrained by hadron-hadron data.

For F_2^i, assume low-x structure function universality (GRV-π for all contributions).

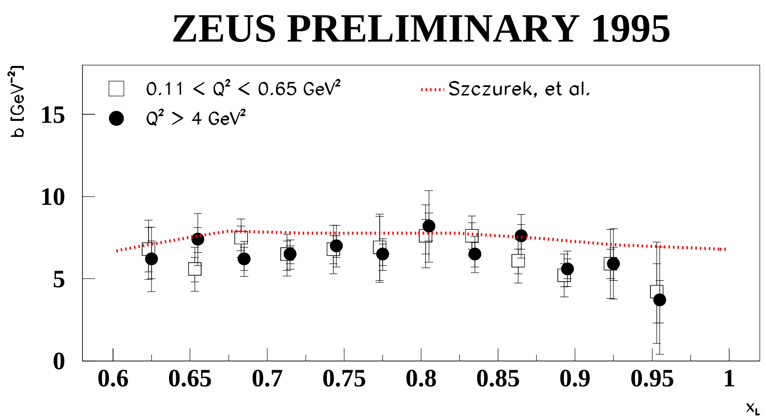
Leading Protons compared with Regge Model



x_{L} distribution

Diffractive region.

Sub-leading exchanges.



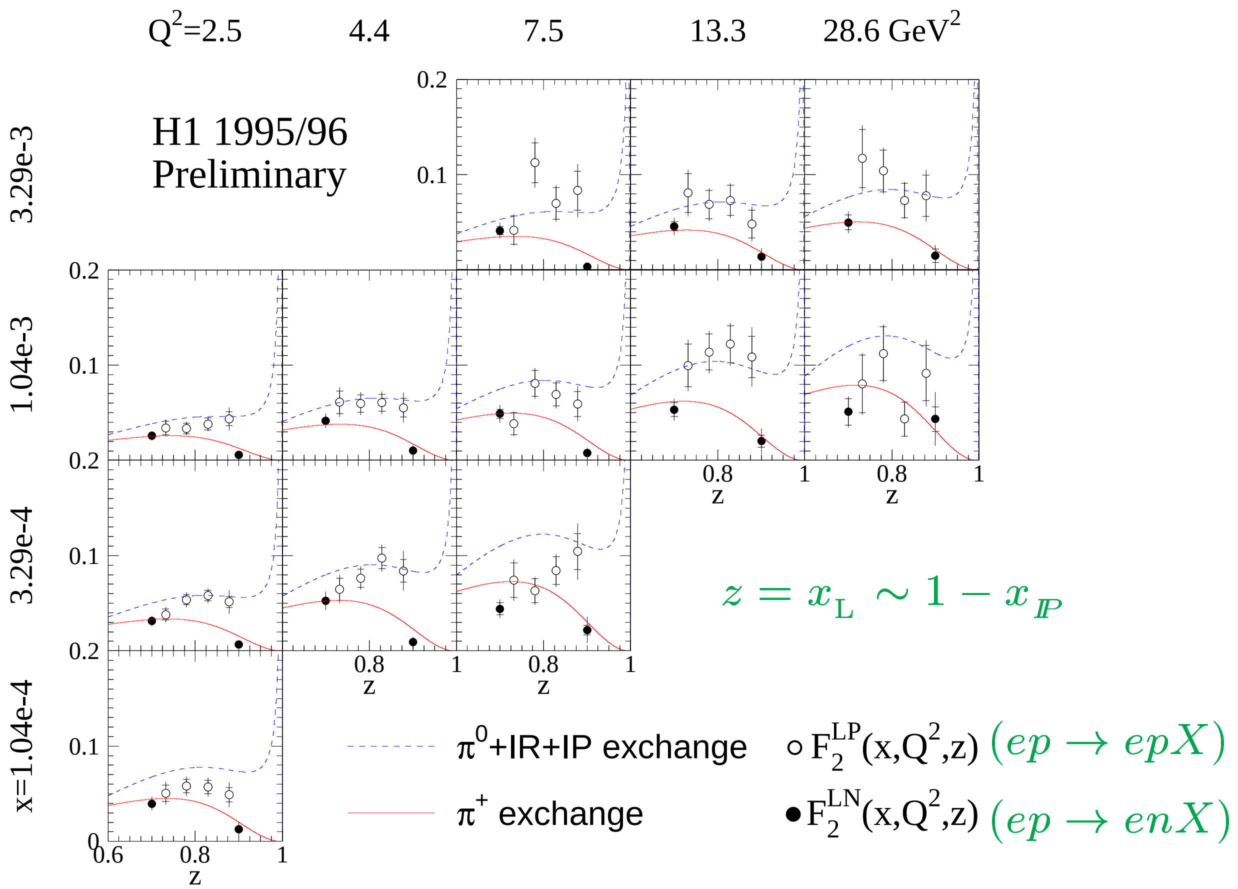
Slope parameter b where $\frac{\mathrm{d}\sigma}{\mathrm{d}t} \propto e^{bt}$ as a function of x_{L}

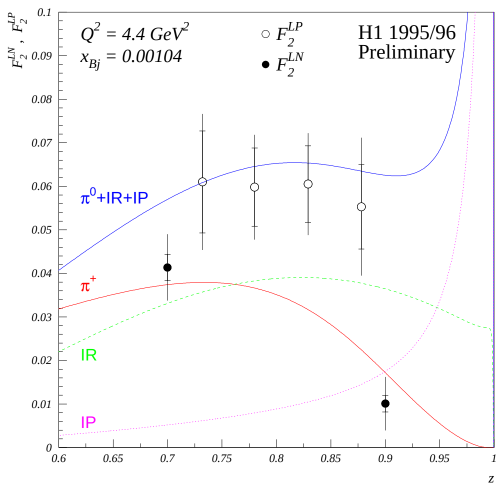
The Regge model describes the x_{L} and t deopendence of the proton data integrated over x and Q^2.

Leading Protons and Neutrons v. Regge model

H1 Define leading proton and neutron structure functions in the same way as $F_2^{D(3)}$, but for $p_T^p < 200$ MeV.

$$\frac{d\sigma^{ep\to eNX}}{dx\ dQ^2\ dx_L} = \frac{4\pi\alpha^2}{xQ^4}\left(1 - y + \frac{y^2}{2}\right)\ F_2^{LN(3)}(x, Q^2, x_L)$$





Proton and neutron x, Q^2

x_L dependences well described.

π exchange prediction saturates neutron cross section.

(Also true for $pp \to nX$ etc.)

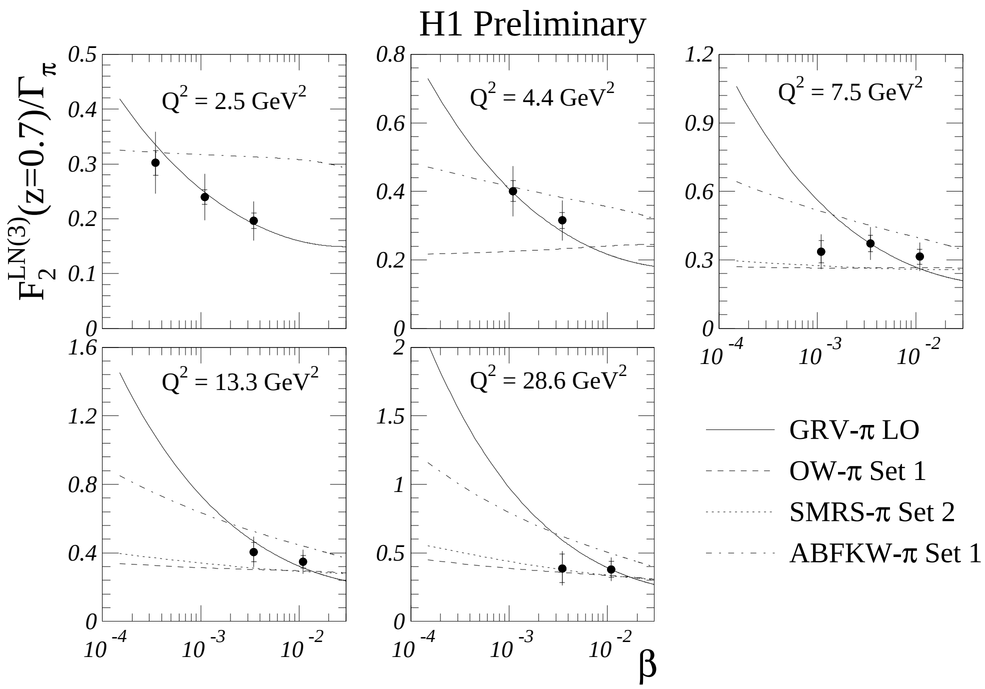
Investigation of the pion structure function

Since π exchange satureates the neutron production rate, within the Regge model the quantity ...

$$F_2^{\mathrm{LN}(3)}(\beta, Q^2, x_{\mathrm{L}} = 0.7) \ / \ \Gamma_\pi(x_{\mathrm{L}} = 0.7)$$

where $\Gamma_\pi = \int_{t_0}^{t_{\mathrm{min}}} f_{\pi/p}(z,t)\mathrm{d}t \sim 0.131$

...can be interpreted as a pion structure function.



Matches GRV parameterisation (based on high x Drell-Yan data) well.

A measurement of the pion structure function in a previously unexplored low x region?

Summary

- Colour-singlet exchange processes constitute a significant fraction of the DIS cross section.
- Data span the transition between 'soft' and 'hard' diffraction.
- Properties of the effective $\mathbb{P}$ describing vector meson production depend on Q^2, t, m_V.
- Where the pomeron is 'hard', 2-gluon exchange models of vector meson production are successful.
- $\mathbb{P}$ exchange also significant in DIS diffractive dissociation at low $x_{\mathbb{P}}$.
- $\alpha_{\mathbb{P}}(0)$ describing $F_2^{D(3)}$ larger than in soft hadronic interactions.
- $F_2^{D(3)}$ and final state studues indicate that the $\mathbb{P}$ is dominated by 'hard' gluons.
- Clear evidence for $q\bar{q}g$ as well as $q\bar{q}$ final states in DIS diffractive dissociation.
- Additional meson exchanges present at larger $x_{\mathbb{P}}$; π dominant in neutron channel, additional isosinglet $\mathbb{R}$ (f, ω) in proton channel.