Diffractive Phenomena at HERA

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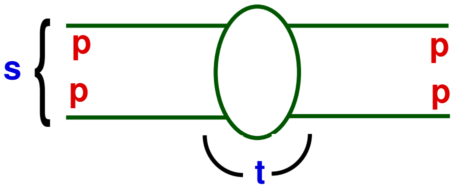
Representing the H1 and ZEUS Collaborations.

Selected topics in . . .

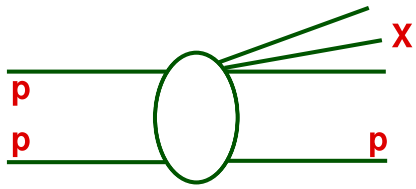
- Diffractive Vector Meson Photoproduction and Electroproduction.
- The Diffractive Dissociation Cross Section in DIS.
- The Hadronic Final State in DIS Diffractive Dissociation.
- Leading Baryons and Other Colour Singlet Exchanges.

Diffractive Processes and the Pomeron

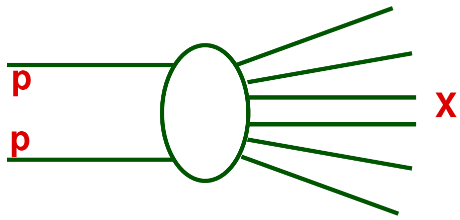
Soft diffraction: elastic, total and dissociation cross sections.



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



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



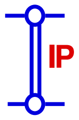
$\sigma^{\mathrm{tot}}(pp \to X)$

(via the optical theorem)

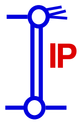
It is useful to think in terms of the exchange of an object with net vacuum quantum numbers - the "pomeron" ($\mathbb{P}$).

- $\alpha_{\mathbb{P}}(t) \simeq 1.081 + 0.26t$ [$\mathbb{P}$ '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

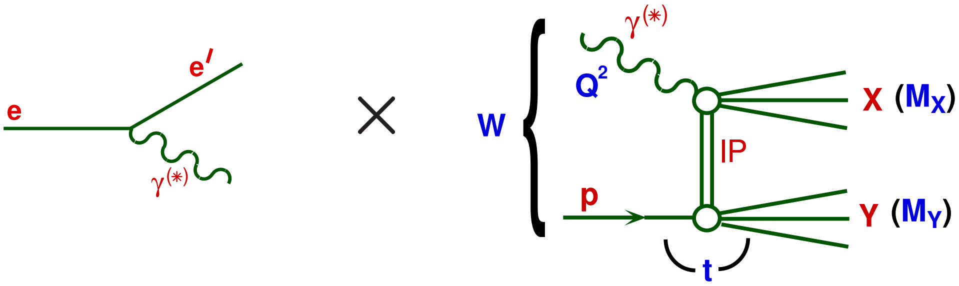


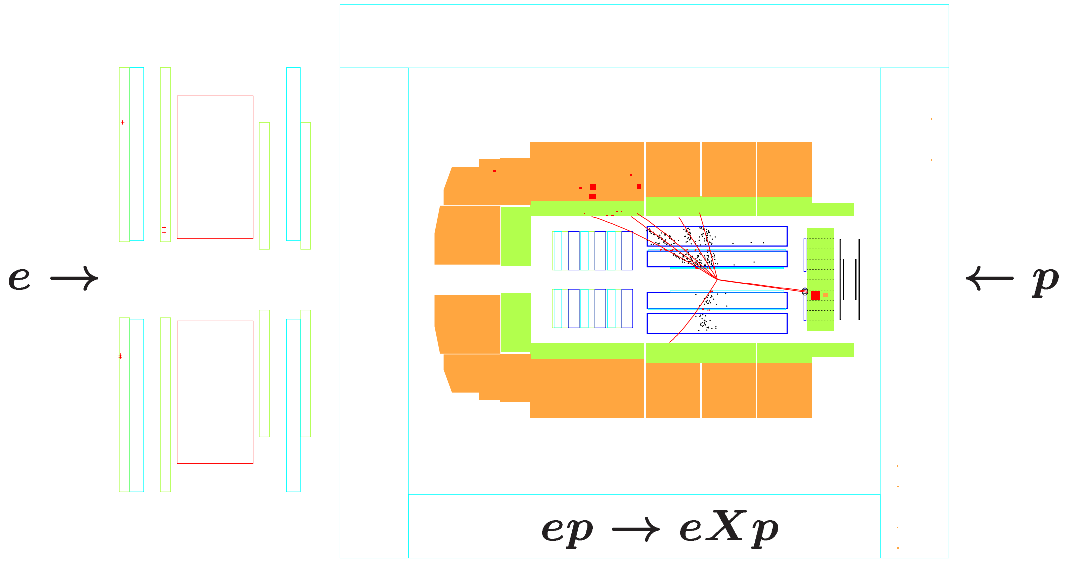
$$\mathrm{d}\sigma^{\mathrm{el}}/\mathrm{d}t \propto s^{2\alpha_{\mathbb{P}}(t)-2}$$



Diffraction at HERA

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



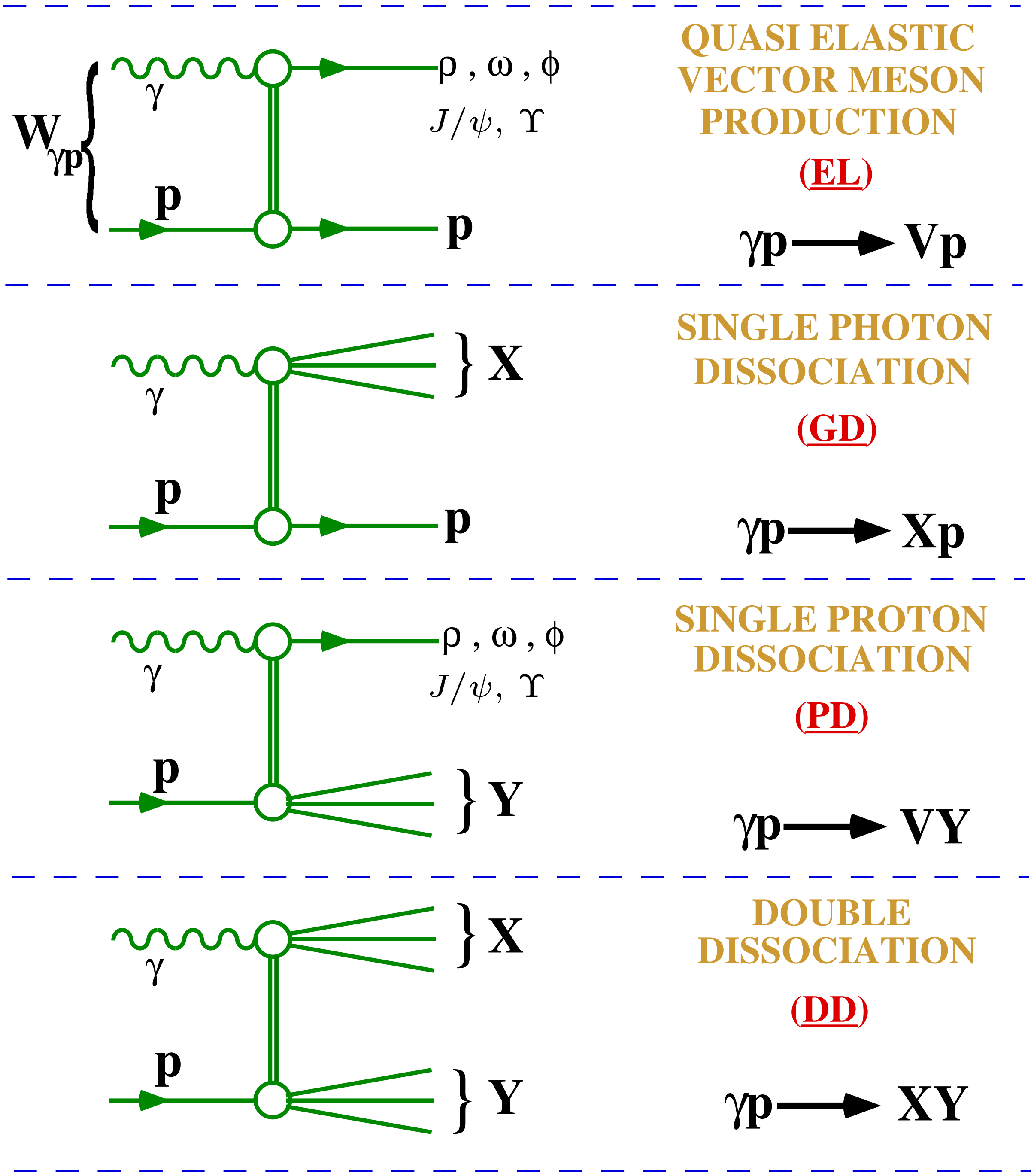


All five kinematic variables can be measured:

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

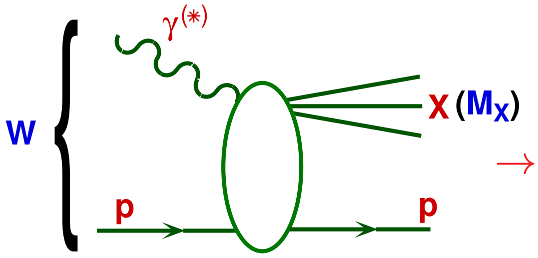
...the non-perturbative $\leftrightarrow$ perturbative transition.

COLOUR SINGLET EXCHANGE PROCESSES IN γ^*-p INTERACTIONS



Experimental Techniques

1. Rapidity Gap Selections (H1, ZEUS).

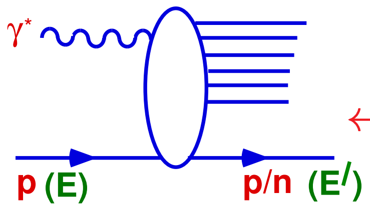


$\rightarrow$ Largest rapidity gap among final state hadrons.

$\Delta\eta$ large when

$M_X \ll W$

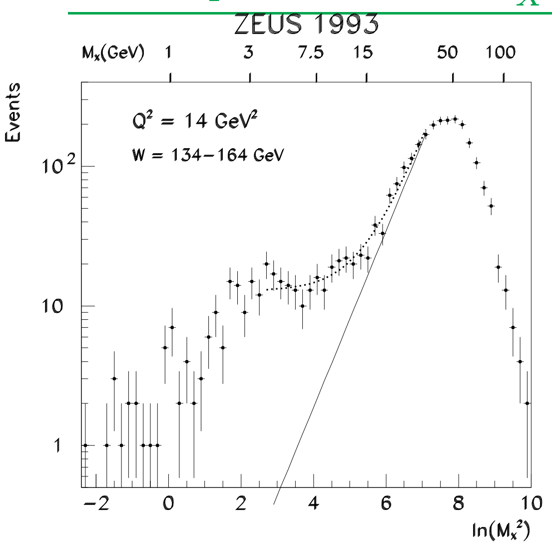
2. Direct Tagging of Leading Baryons (H1, ZEUS).



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

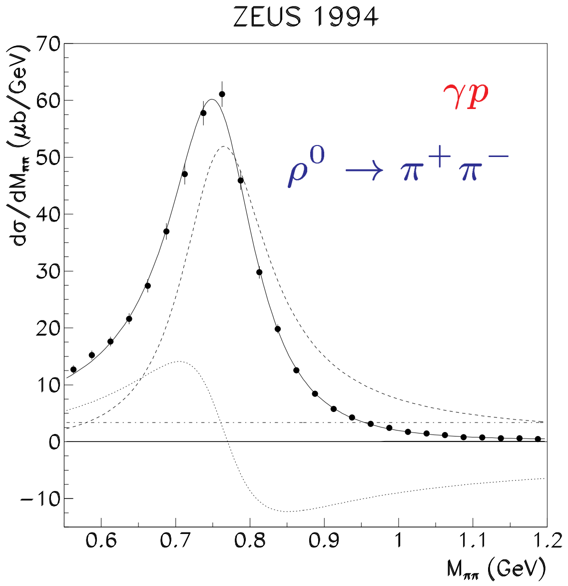
Possible quantitative QCD description where hard scales availiable:

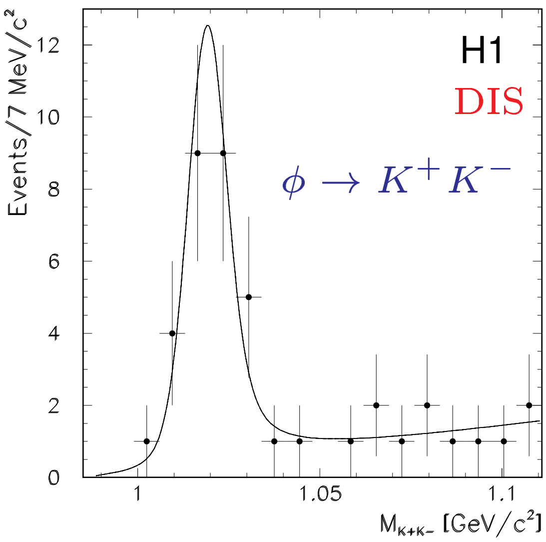
Simple exchange of 2 gluons at lowest order.

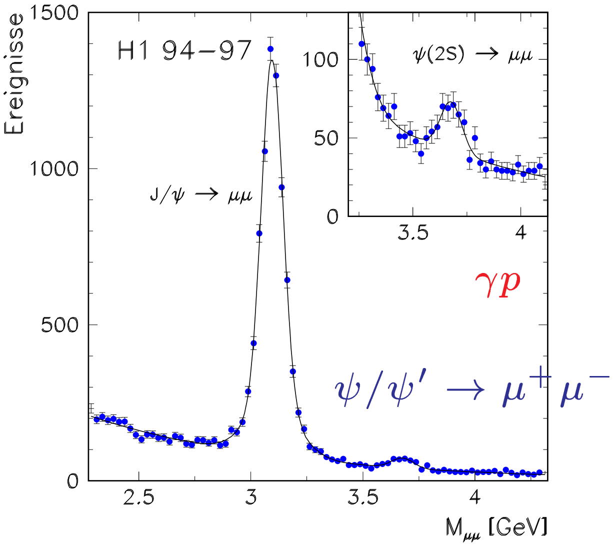
$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}t}\right|_{t=0} \sim |xg(x)|^2$$

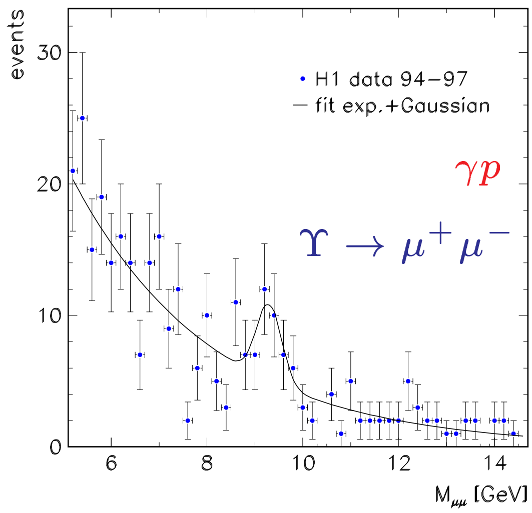
Vector Meson Signals

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'.

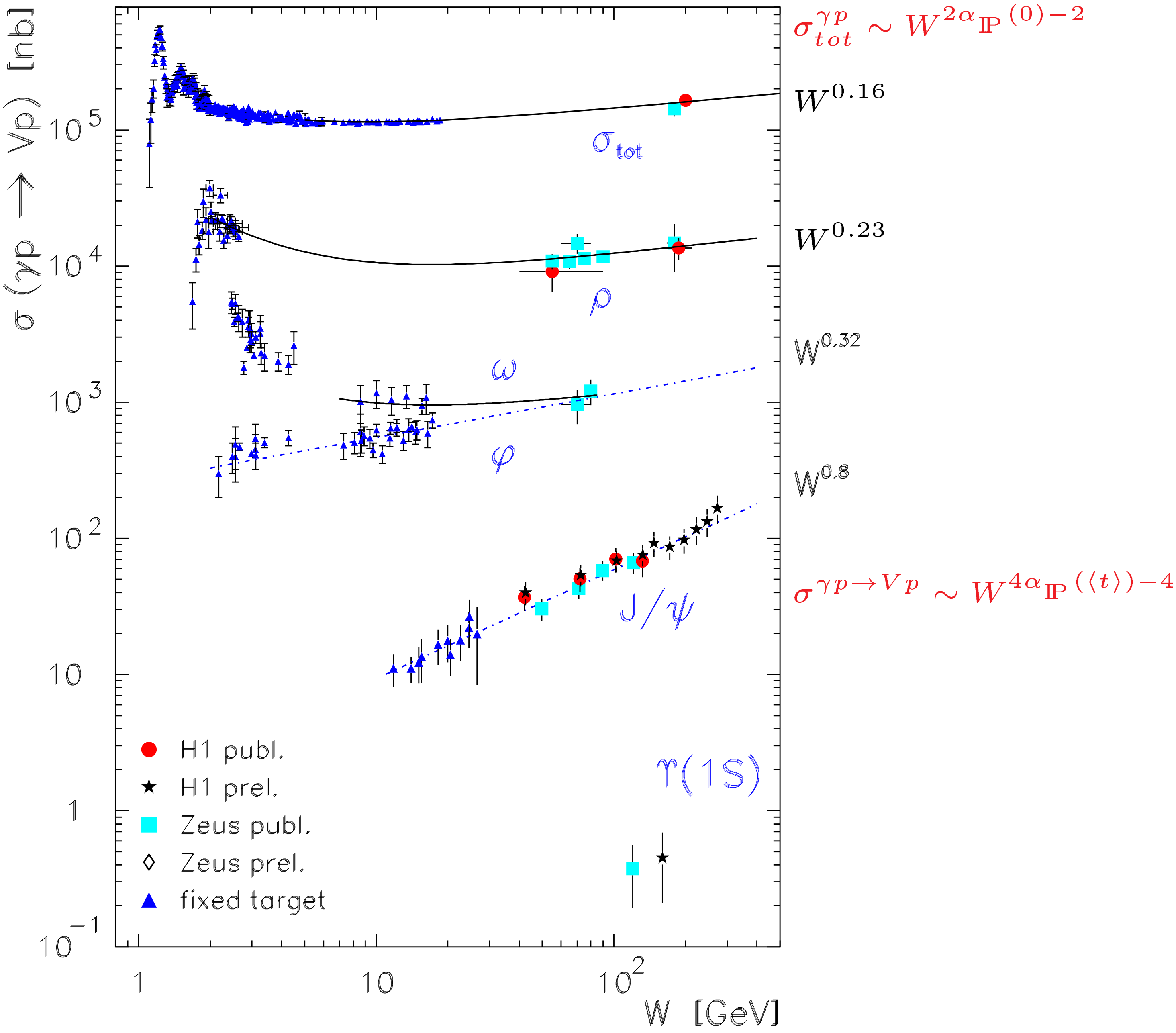






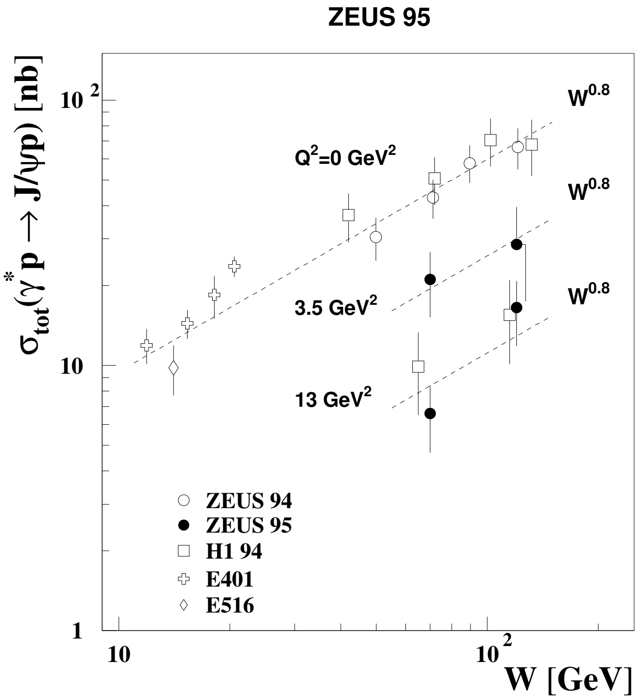


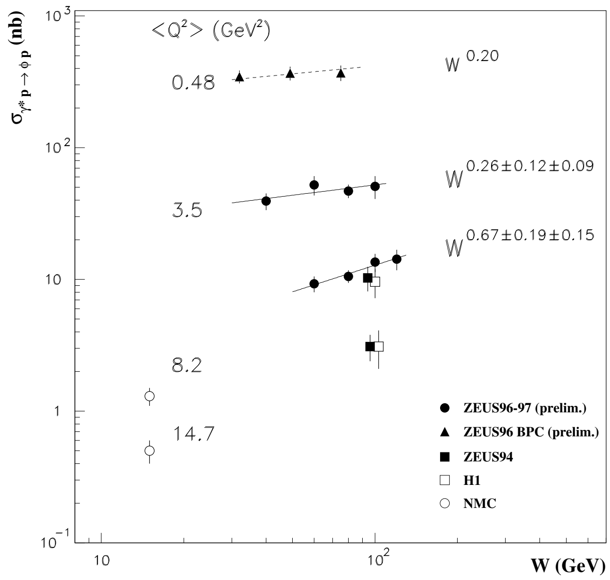
Energy Dependence of Vector Meson Photoproduction

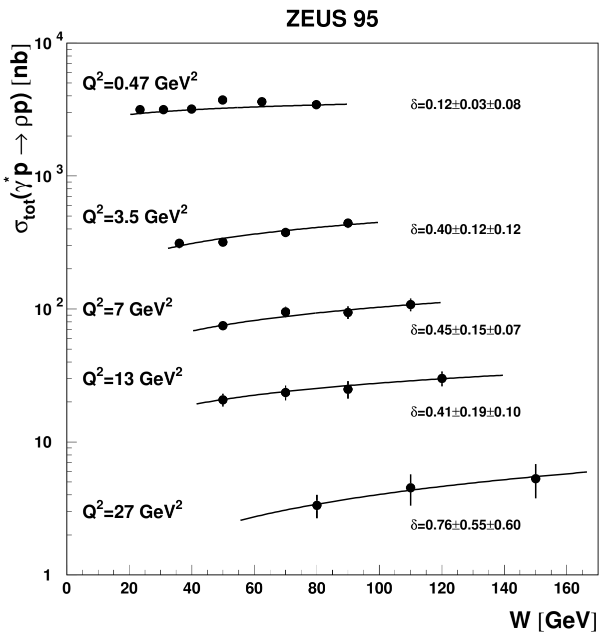


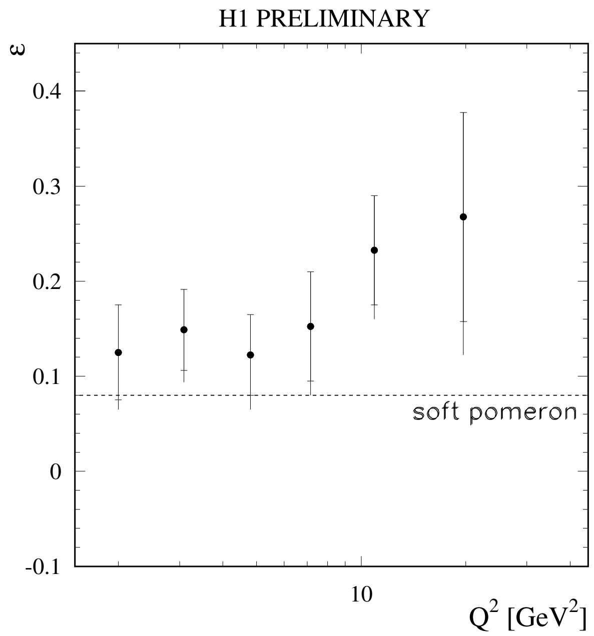
Effective $\alpha_{IP}(0)$ depends on vector meson mass at $Q^2 = 0$.

Energy Dependence of Vector Meson Electroproduction









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

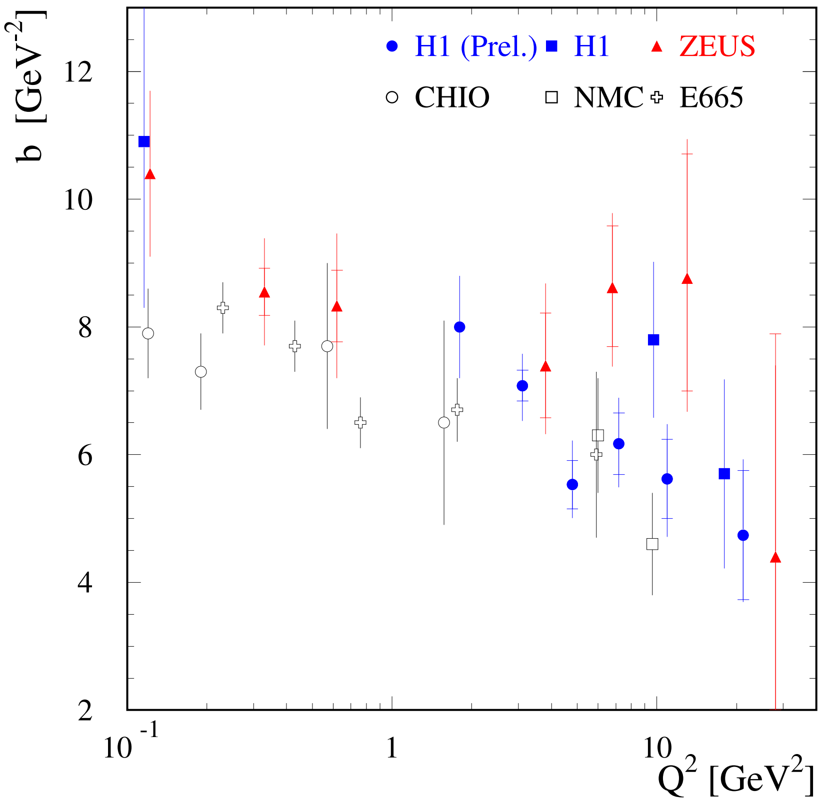
J/ψ has strong W dependence at $Q^2 = 0$

ρ, ϕ dependence on W steepens with Q^2

ϕ steepens faster than ρ?

t Dependence of Vector Meson Production

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

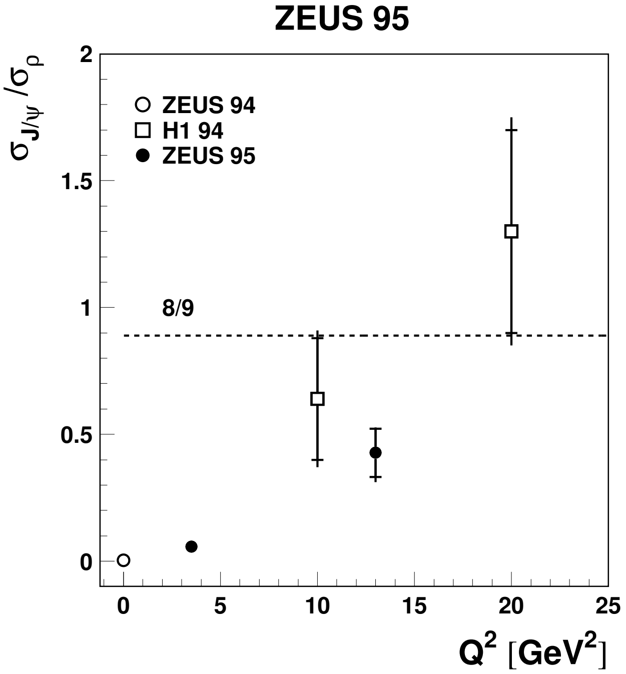


For J/ψ, $b \sim 4 - 5$ at $Q^2 = 0$.

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.

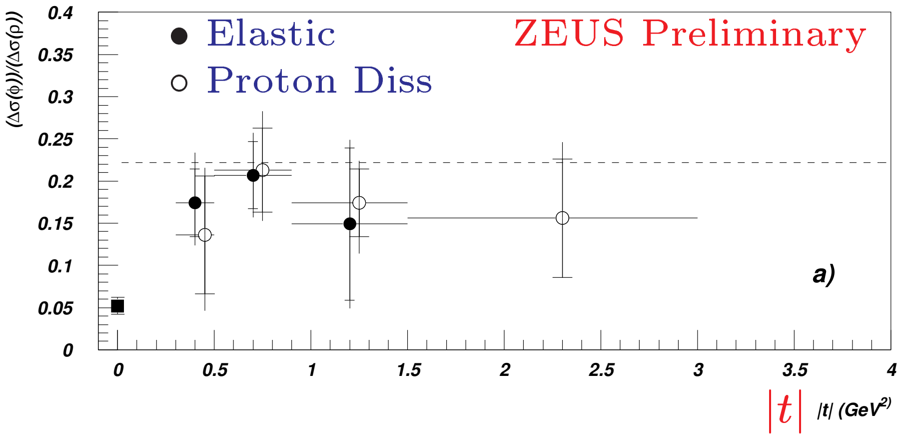
Ratios of Vector Meson Cross Sections



$\frac{8}{9}$

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

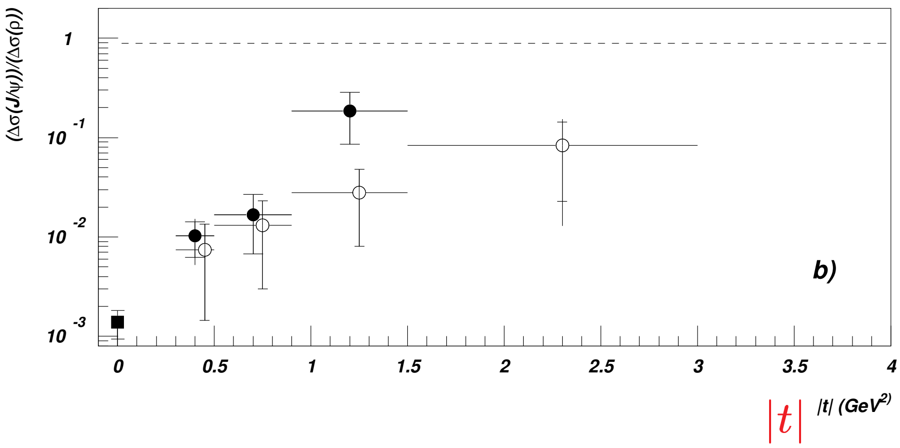
$\frac{\sigma(\phi)}{\sigma(\rho)}$



$\frac{2}{9}$

$|t|$

$\frac{\sigma(J/\psi)}{\sigma(\rho)}$

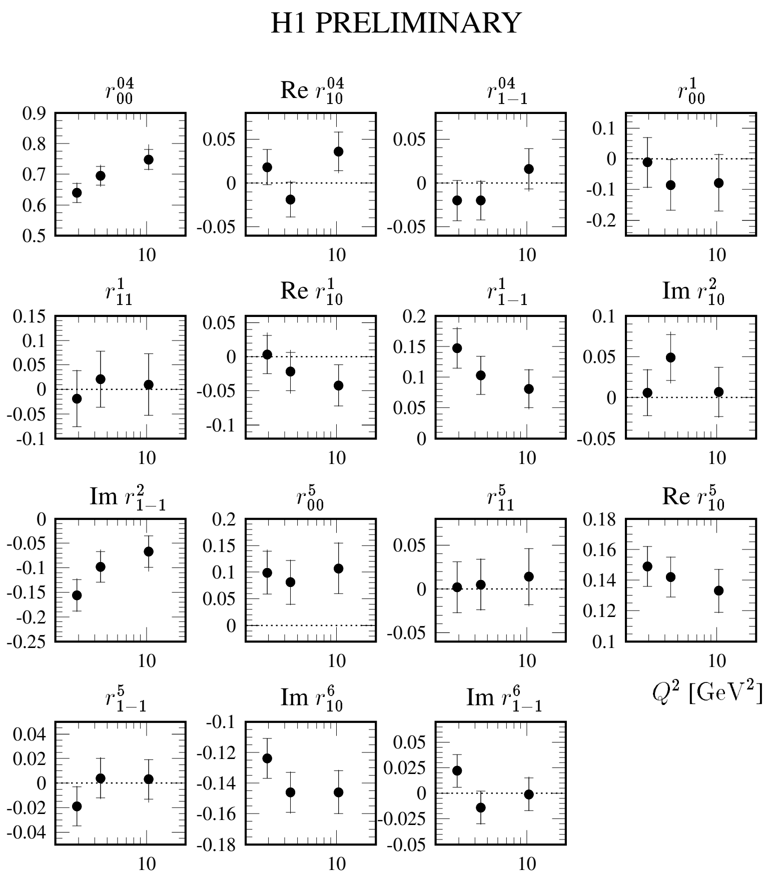


$\frac{8}{9}$

$|t|$

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 $\gamma^* \to$ transverse ρ

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

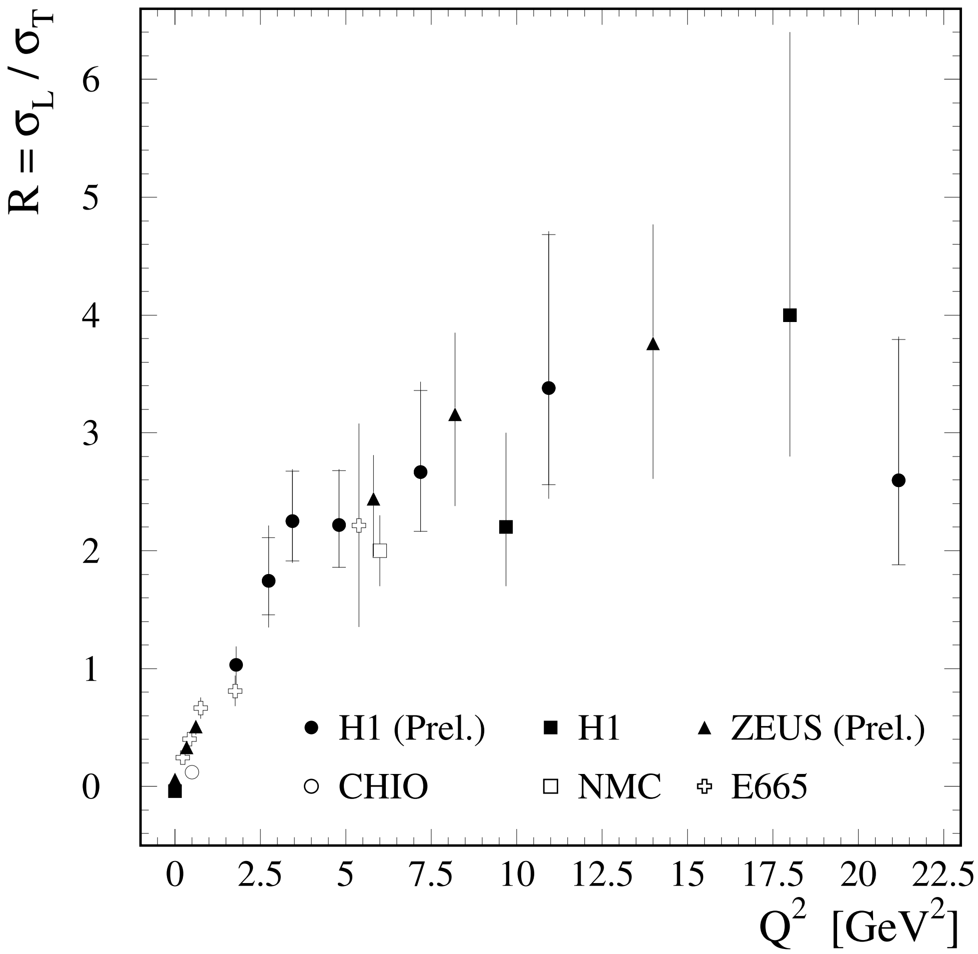
Also observed by ZEUS in ρ and ϕ electroproduction

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:

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

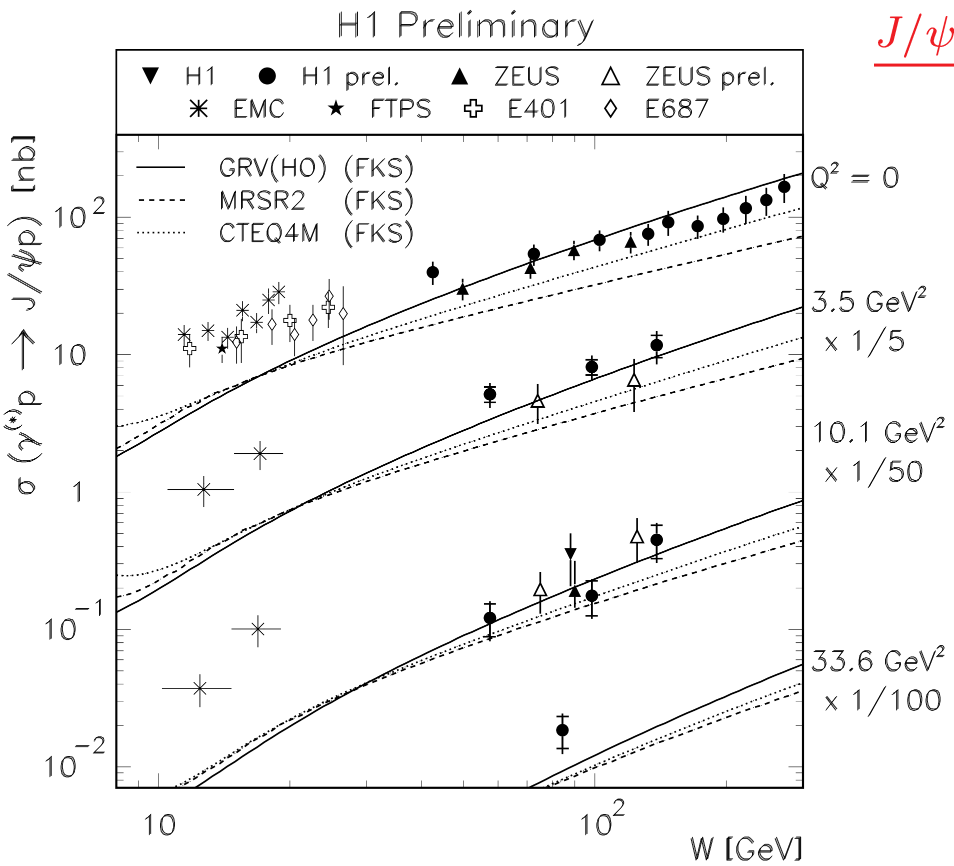


Longitudinal γ^* cross section dominant at large Q^2.

Example pQCD Model of VM Production

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

J/ψ, $(\sigma_L + \sigma_T)$



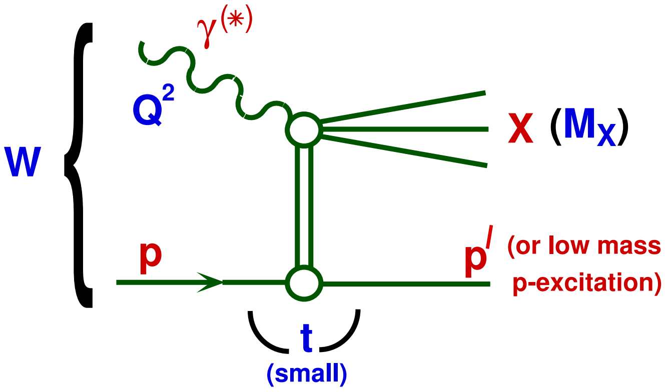
Compared to model of Frankfurt et al.,

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

and different gluon distributions.

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

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



- $Q^2 = -q^2$ (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:

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

$\rightarrow$ 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:

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

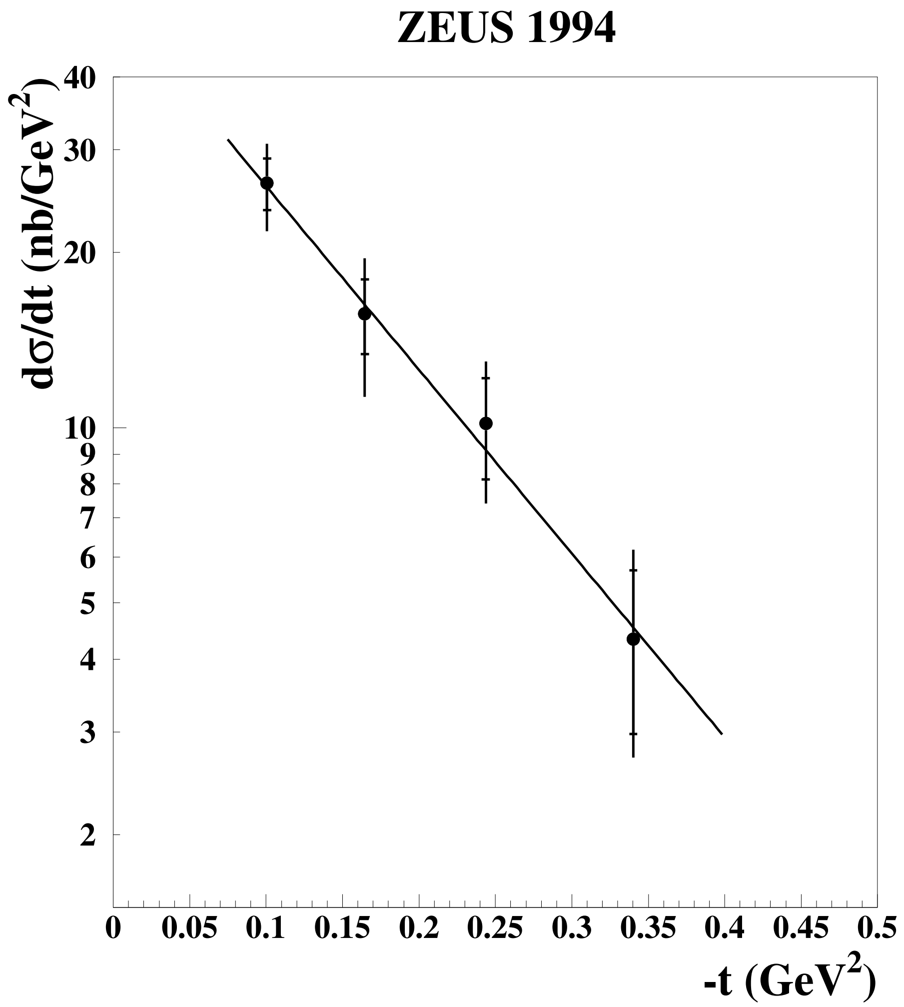
$\rightarrow$ Frac. of $\mathrm{I\!P}$ momentum carried by quark coupling to $\gamma^\star$.

($x_{\mathrm{Bj}} = \beta \cdot x_{I\!P}$)

Measurement of the t Dependence

$5 < Q^2 < 20\ \mathrm{GeV}^2 \qquad 0.015 < \beta < 0.5$

$x_{I\!P} < 0.03$



From Direct Proton tagging

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

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

$\rightarrow$ Highly peripheral scattering.

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

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

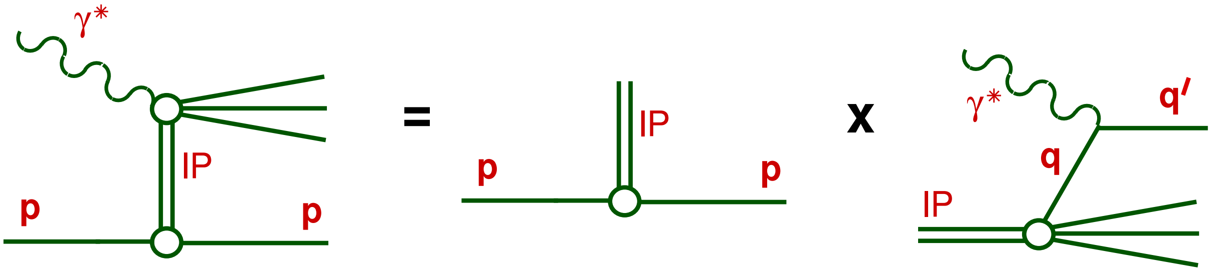
In rapidity gap based analyses, t is not measured.

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

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

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

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



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

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

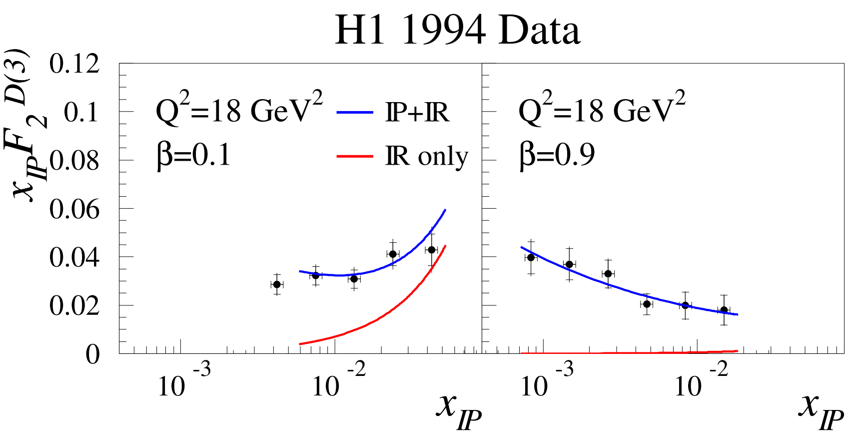
The $x_{I\!P}$ Dependence of $F_2^{D(3)}$

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

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

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

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



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

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

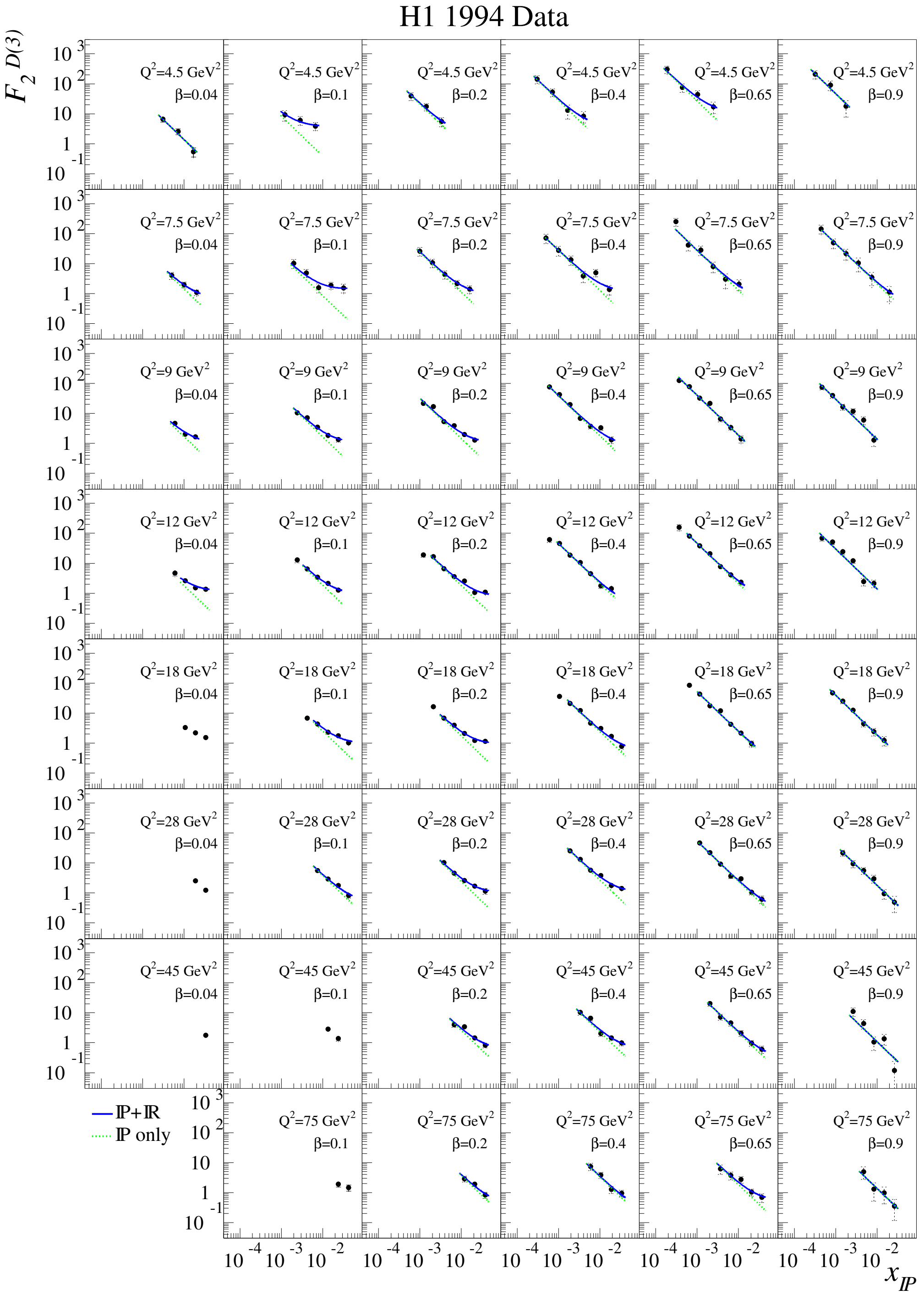
...in a Regge model, the measured data require a minimum of two exchanges:

Good fits obtained throughout kinematic range using:

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

$\alpha_{\mathrm{I\!P}}(0)$, $\alpha_{\mathrm{I\!R}}(0)$, $F_2^{\mathrm{I\!P}}(\beta, Q^2)$, $F_2^{\mathrm{I\!R}}(\beta, Q^2)$ 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

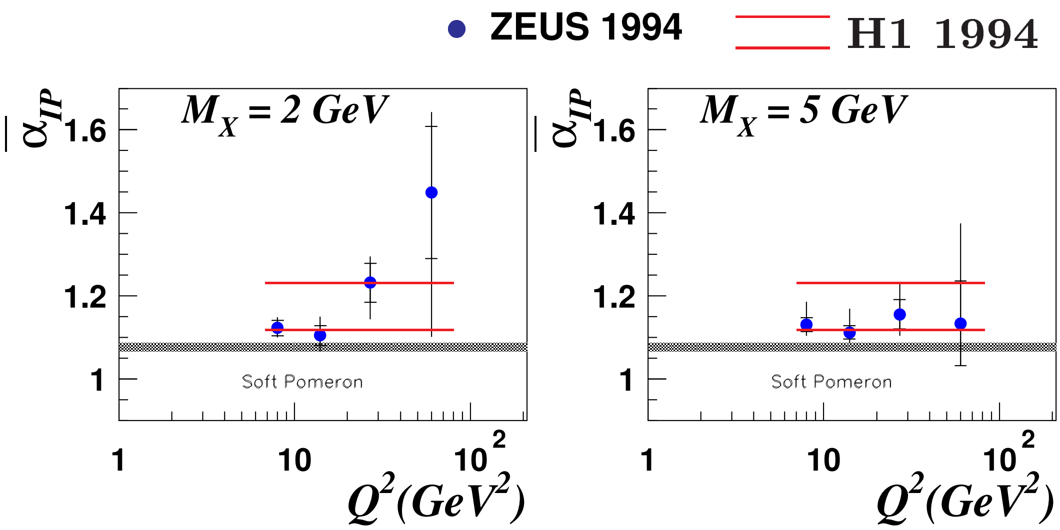
From H1 Phenomenological fits:

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

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.

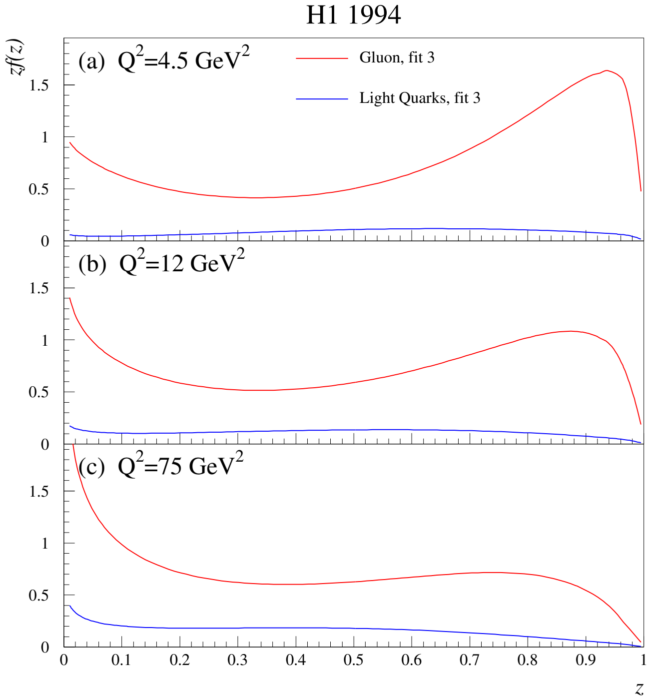
DGLAP Fits to $F_2^{D(3)}(x_{I\!P}, \beta, Q^2)$

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

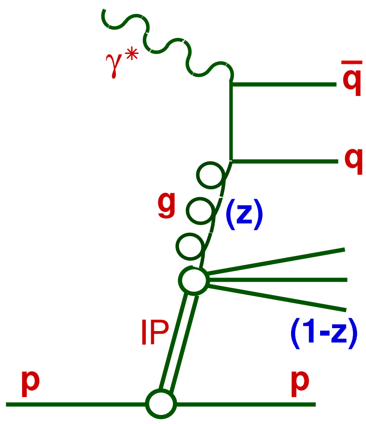
…Investigate the deep-inelastic structure of the exchange.

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.



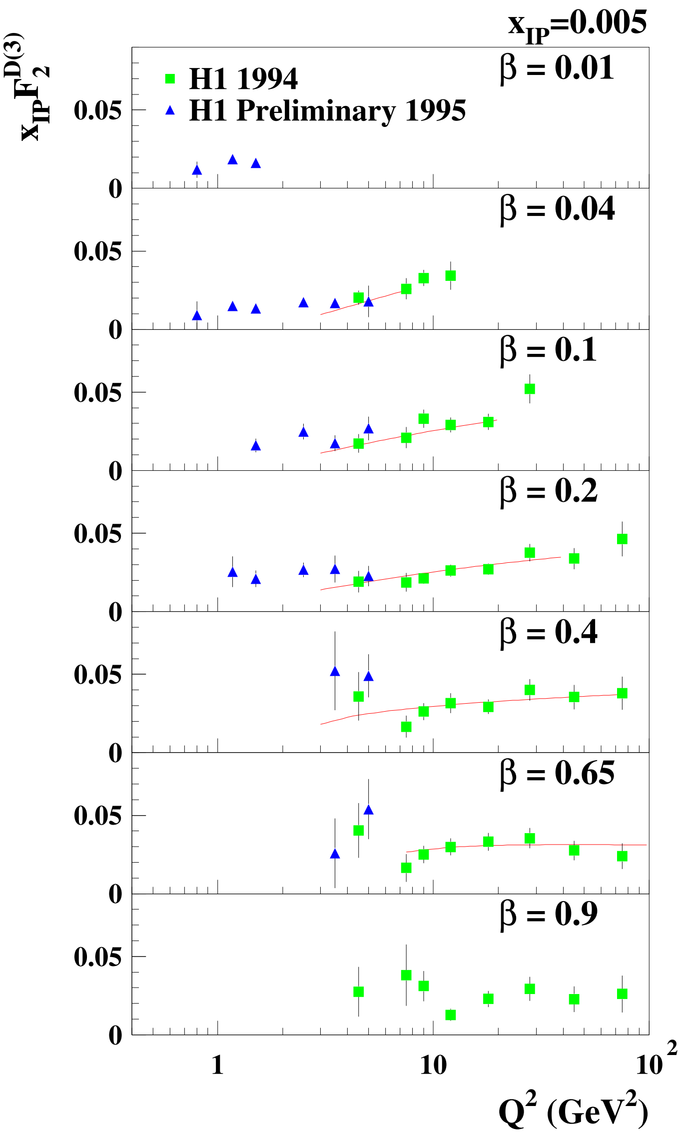
Acceptable fits only when $I\!P$ is dominated by "hard" gluons.

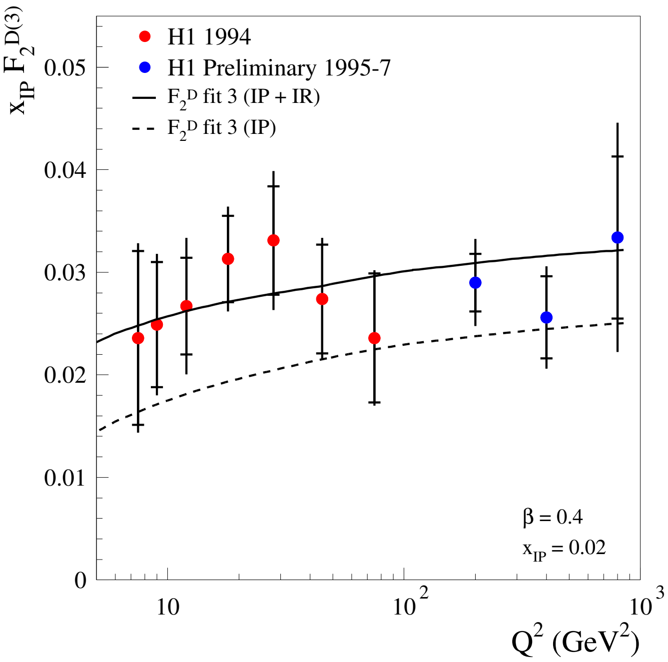


$\sim 90\%$ gluon at $Q^2 = 4.5$ GeV^2, $\sim 80\%$ at $Q^2 = 75$ GeV^2.

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

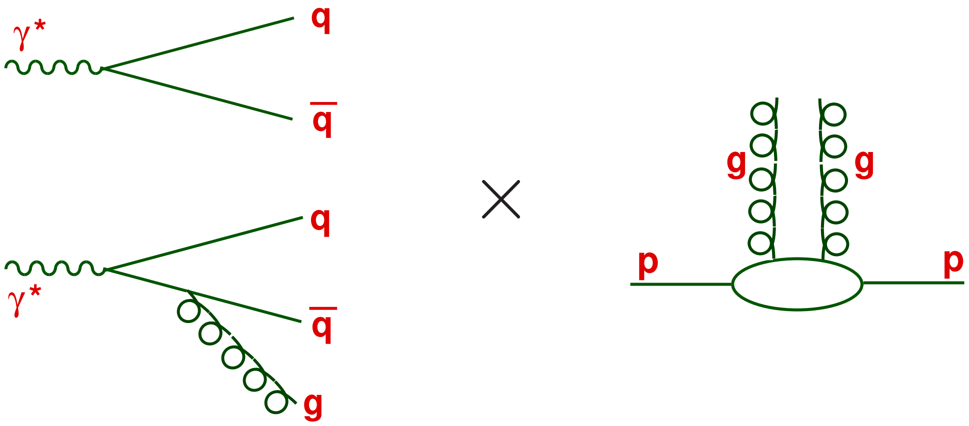
Rising scaling violations over large range of Q^2 up to large β [c.f. $F_2(x, Q^2)$].

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.

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

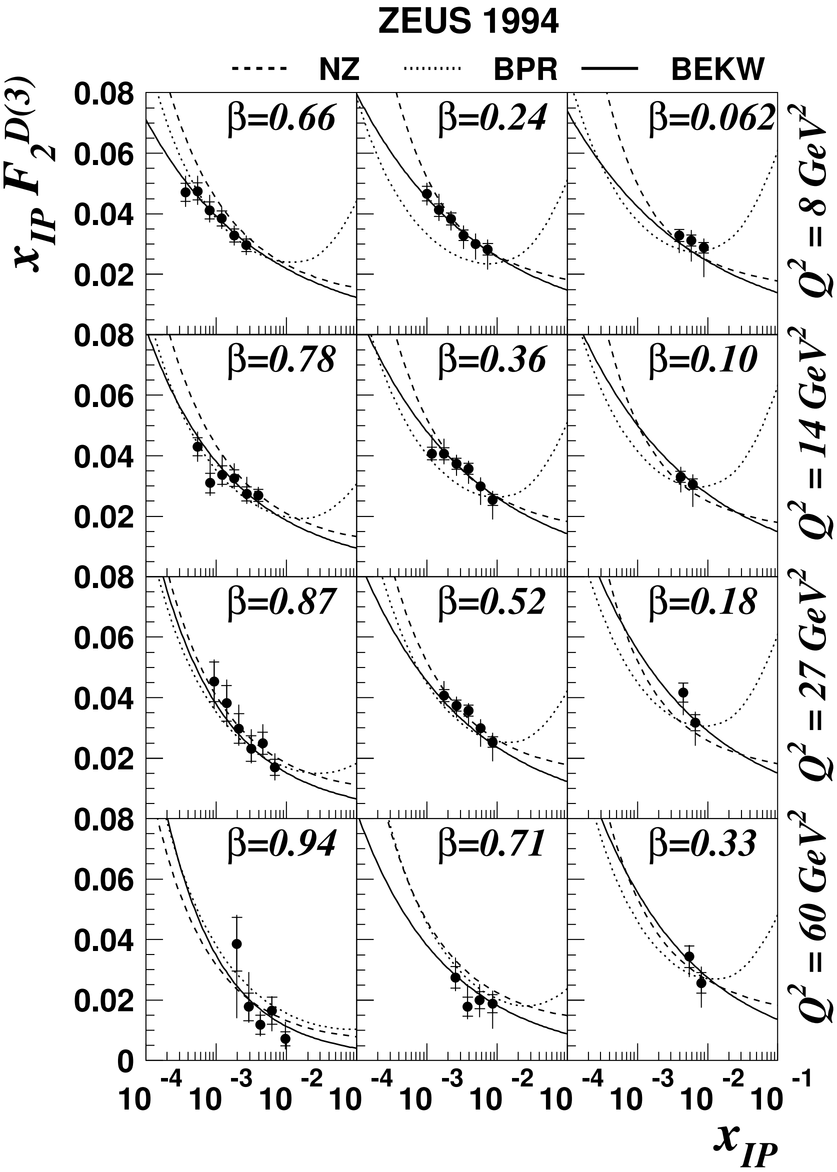
$$F_{q\bar{q}g}^{\mathrm{T}} \propto \left(\frac{x_0}{x_{I\!P}}\right)^{n2(Q^2)} \alpha_s \ \ln\left(\frac{Q^2}{Q_0^2}+1\right) \ (1-\beta)^{\gamma}$$

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

(HT)

2-gluon / BFKL Exchange Models

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

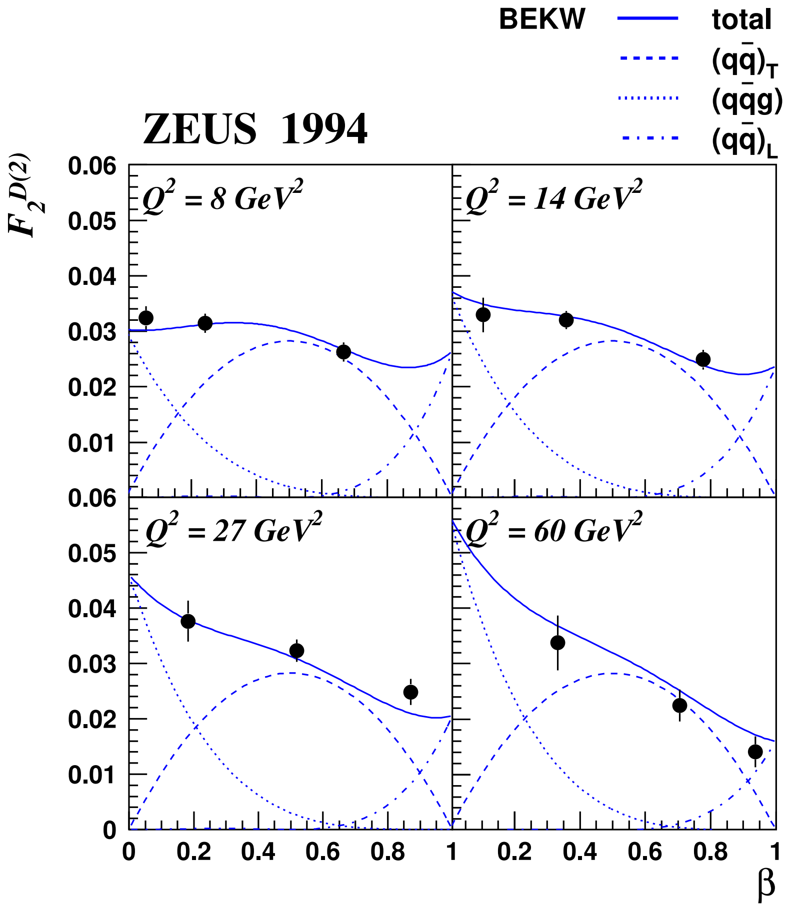


Photon fluctuation / 2-gluon exchange models can be made to fit $F_2^{D(3)}$, even at large β

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.

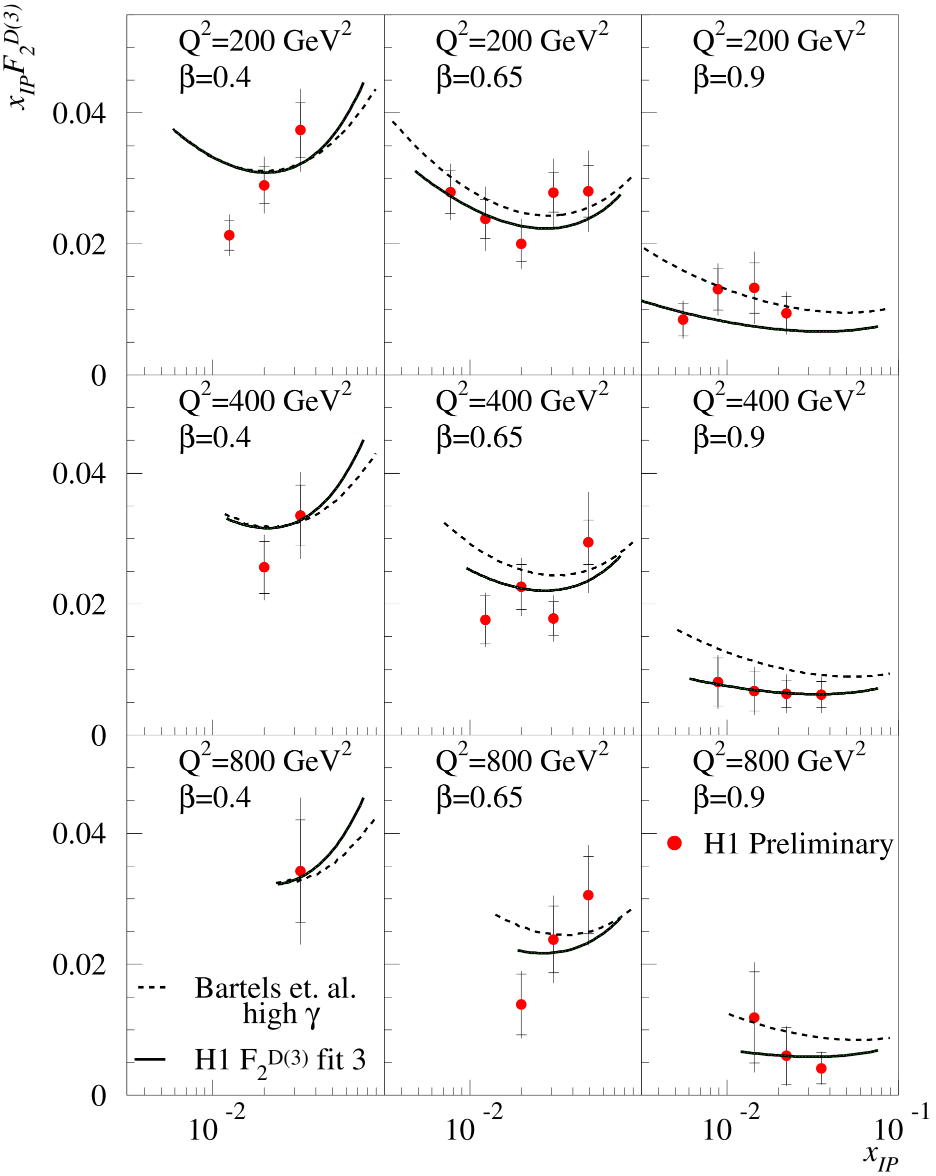


Mixture of $q\bar{q}$ and $q\bar{q}g$ final states.

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

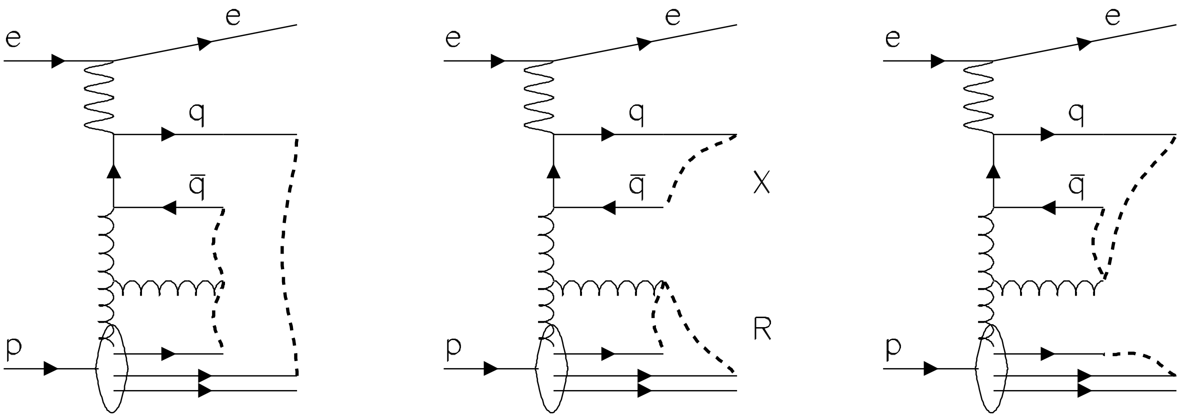


Extrapolations of both DGLAP and 2-gluon exchange models can describe the data up to $Q^2 = 800$ GeV^2.

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.

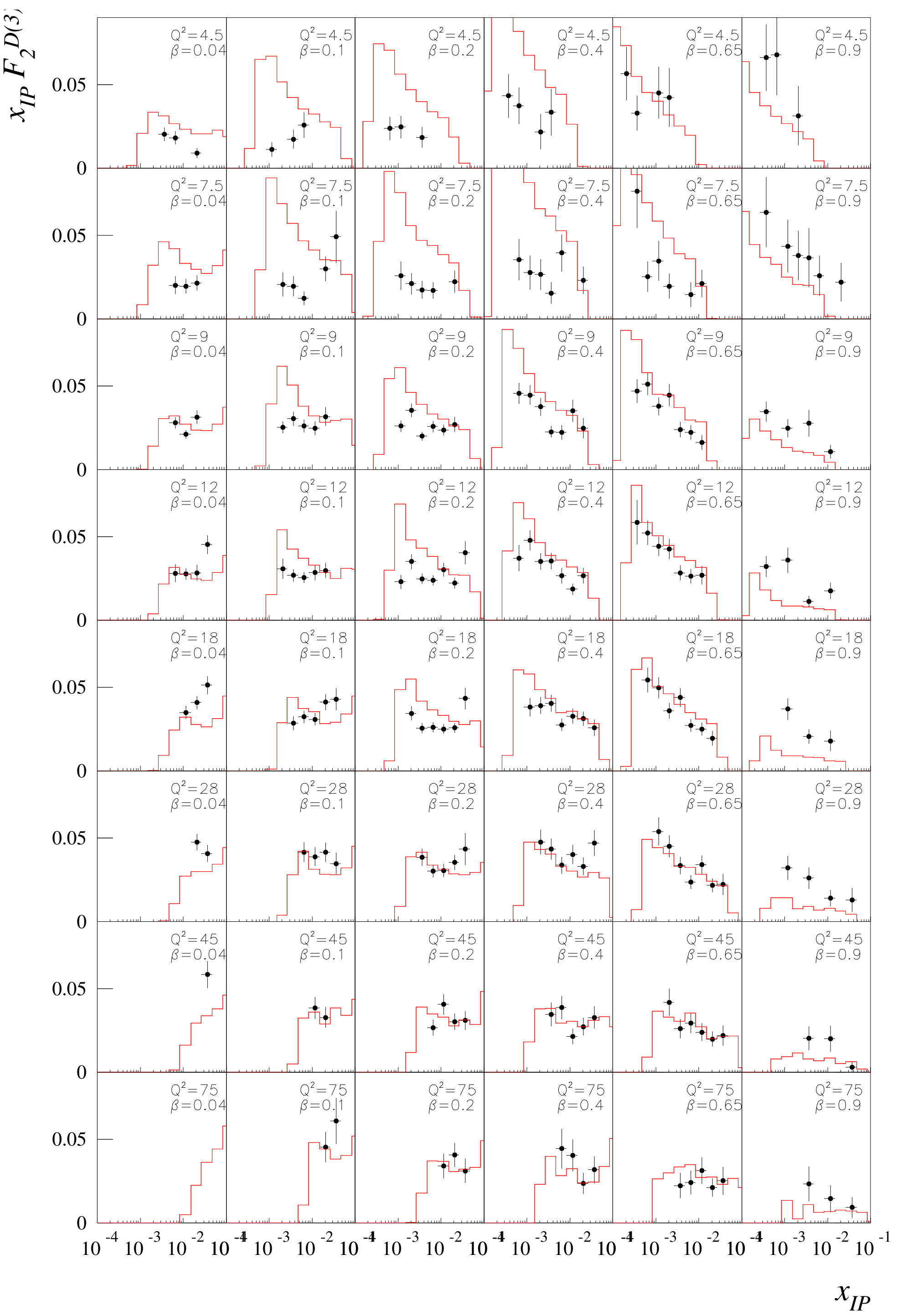


(a) (b) (c)

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]**

∼ reasonable shape in $x_{I\!P}$.

Does not describe Q^2 dependence.

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

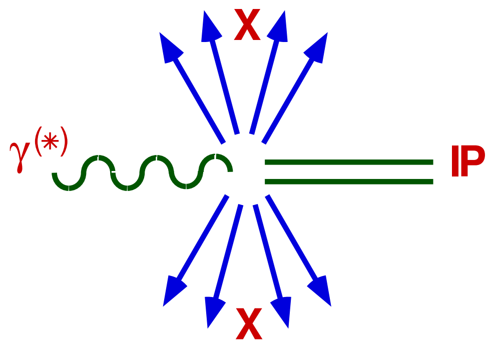
The final state X at low $x_{I\!P}$

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 ($\equiv \gamma^\star I\!P$ centre of mass).

p_T etc. measured relative to the photon (collision) axis in this frame.

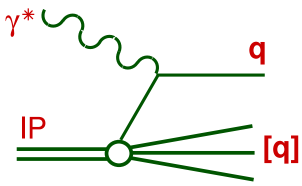


Predictions for the final state X

In terms of DGLAP evolving $I\!P$ model, distinguish between quark and gluon dominated pomeron.

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

QPM



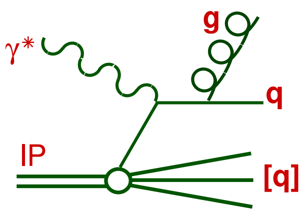
Hard processes

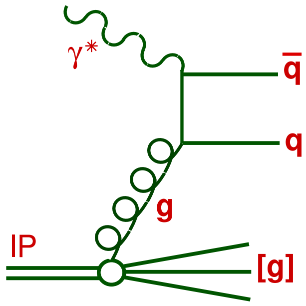
up to $\mathcal{O}(\alpha_s)$

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

QCD-C

BGF



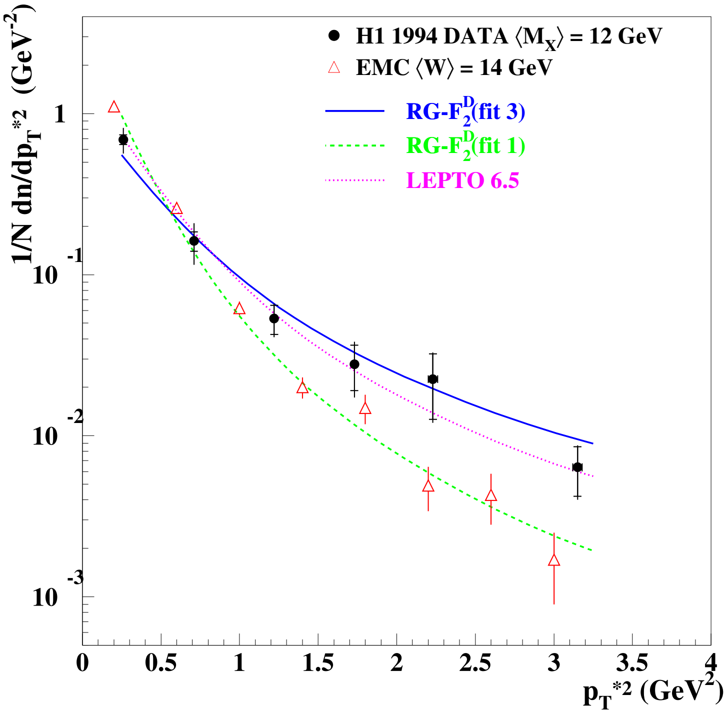


↑	↑
Quarkonic $I\!P$	Gluonic $I\!P$
Dominant $q\bar{q}$	Dominant $q\bar{q}g$
Low p_T / aligned	High p_T / non-aligned
Few jets	Many jets
$\sim 3_c\bar{3}_c$	$\sim 8_c8_c$

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

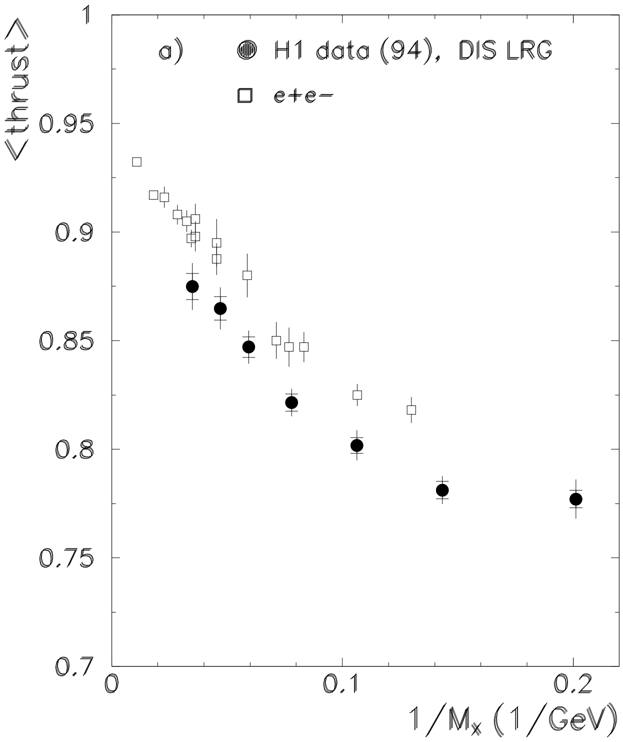
$p_T^\star$ measured relative to $\gamma^\star$ axis in rest frame of X



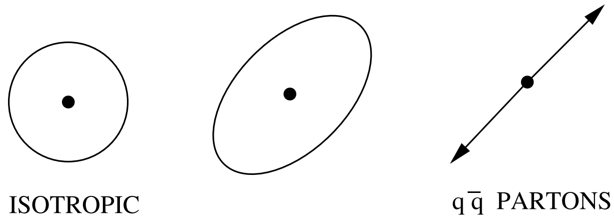
Gluons required to generate hard $p_T^\star$ distribution.

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

Thrust - measure of '2-jettiness'



1/2 < T < 1



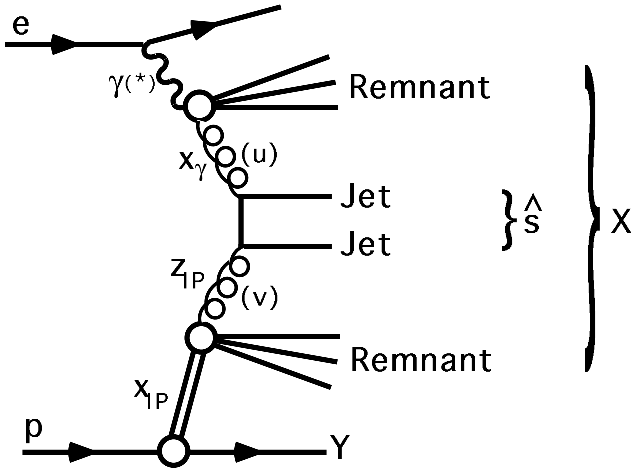
Gluons required to generate lower thrust than $q\bar{q}$.

Hadronisation effects decrease thrust at low M_X.

Diffractive Dijet Production

Search for dijet structures as components of the system X

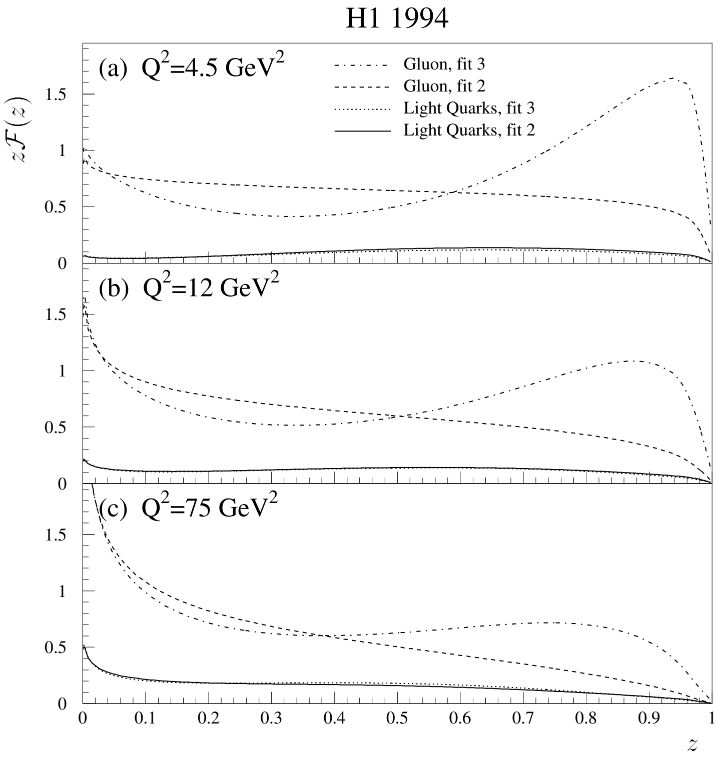
Cone algorithm requiring $p_T^{\text{jet}} > 5$ GeV relative to $\gamma^{(\star)}$ axis in rest frame of X.



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

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

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

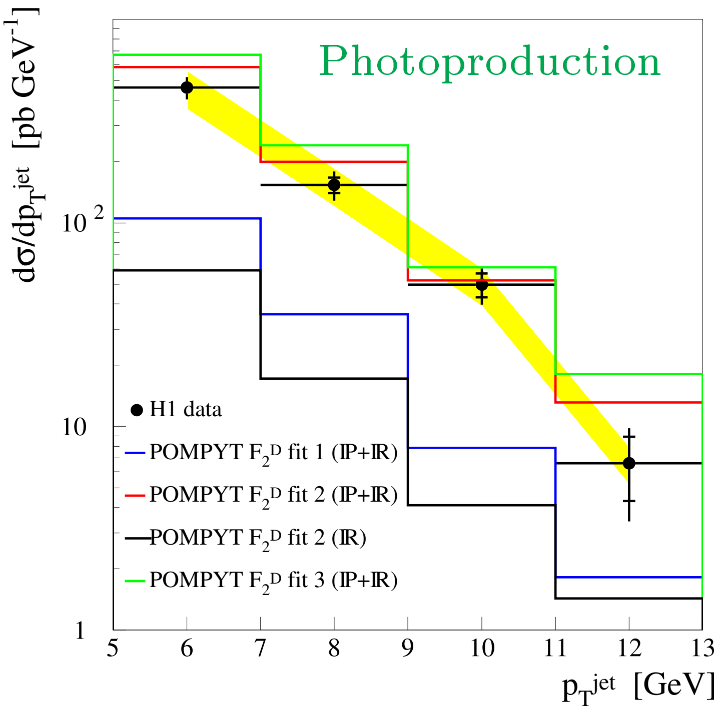


The results are compared with 3 sets of $\mathbb{P}$ and $\mathbb{R}$ parton distributions from DGLAP fits to F_2^D, evolving with $\hat{p_T}$ as a scale.

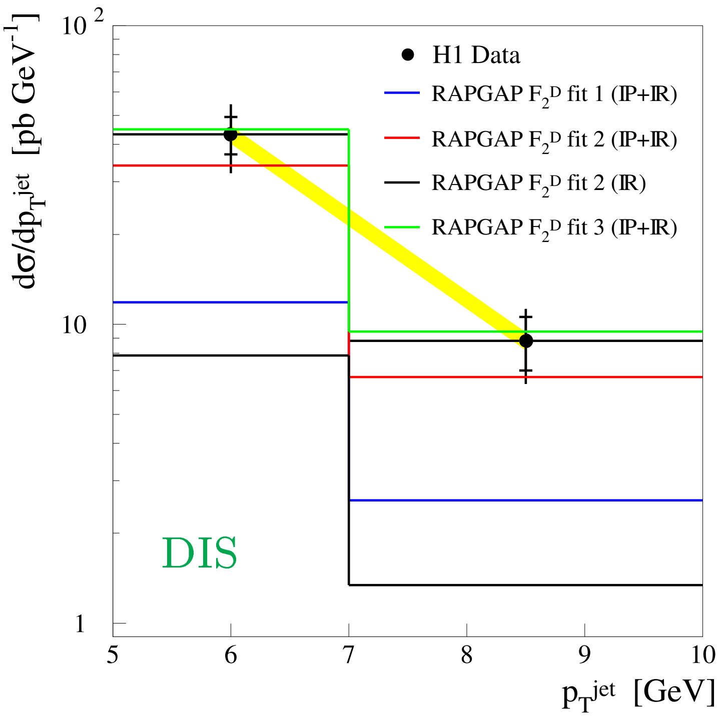
'Flat' and 'peaked' gluon dominated pomeron and quark dominated pomeron.

Dijet p_T^{jet} Distributions

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



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

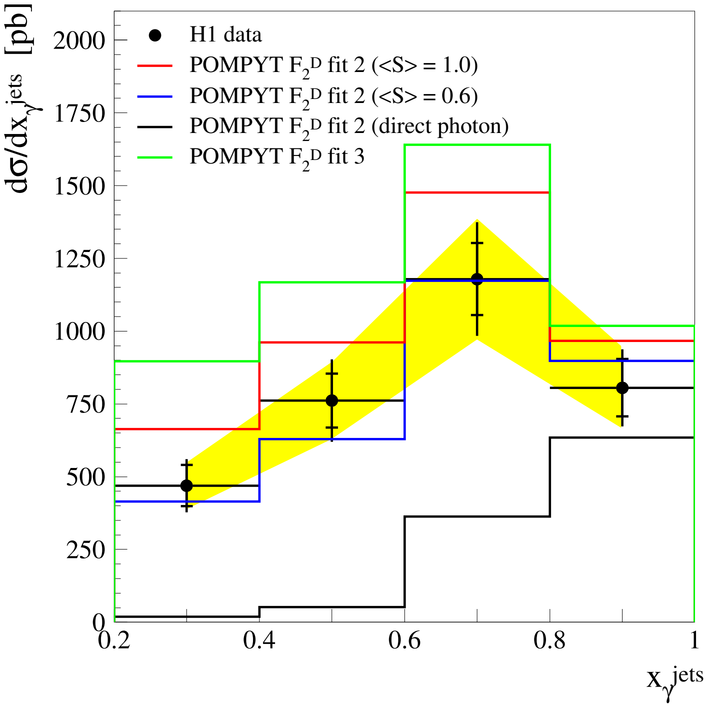


Data reasonably described by gluon dominated $\mathbb{P}$

Quark dominated $\mathbb{P}$ low by a factor ~ 5

x_γ^{jets} and $z_{I\!P}^{\text{jets}}$ Distributions

Fraction of γ momentum entering the hard scattering.



Photoproduction

Both direct $x_\gamma = 1$

and resolved $x_\gamma < 1$

contributions observed.

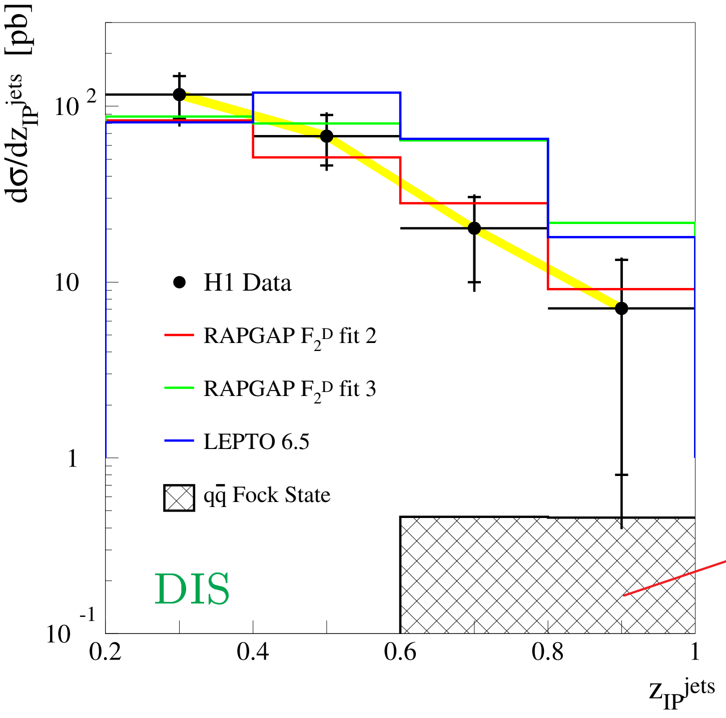
Possible rapidity gap

destruction effects

where there is a

photon remnant.

Fraction of $I\!P$ momentum entering the hard scattering.

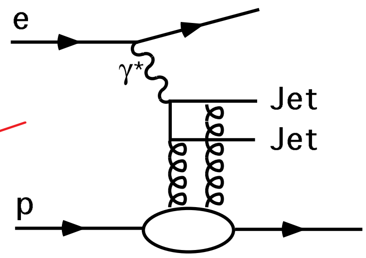


LEPTO - Pr(SCI) = 0.5

is close to DIS data.

$q\bar{q}$ final state alone

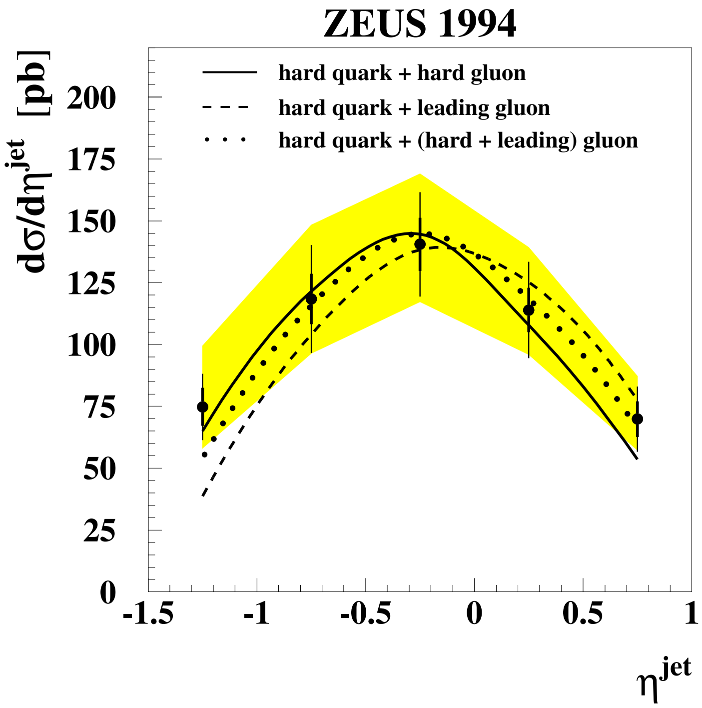
cannot describe data.



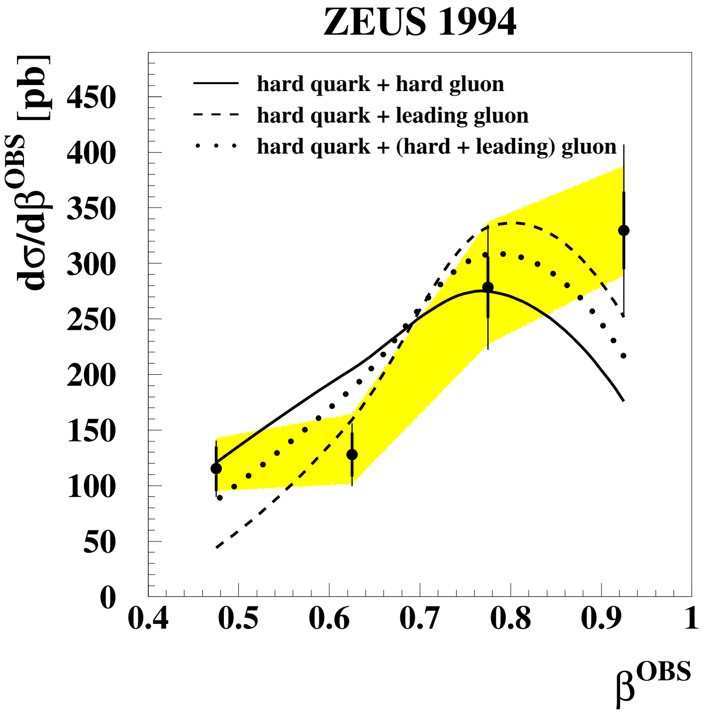
$q\bar{q}g$ states also required.

Combined DGLAP fit to F_2^D and photoproduction dijet rates

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



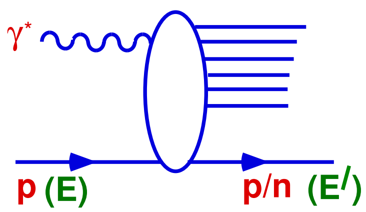
Acceptable fits only when pomeron is dominated by 'hard' gluons.



Resulting fraction of exchanged momentum carried by gluons is $\sim$ 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) $= x_{\mathrm{L}}$ (ZEUS) $= E'/E$

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

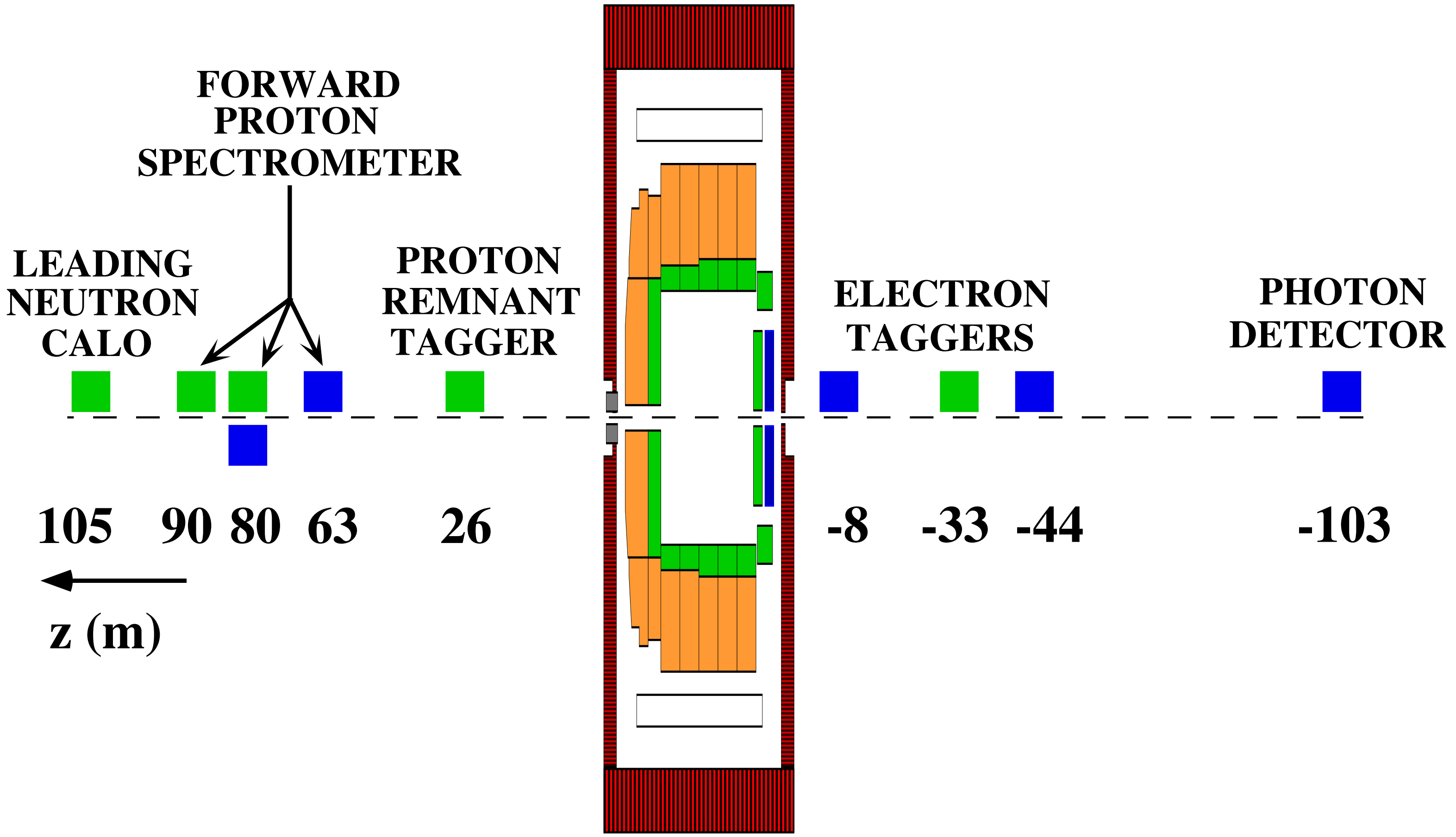
Leading protons: H1 ($p_T \lesssim 0.2$ GeV, $0.7 \lesssim x_{\mathrm{L}} \lesssim 0.9$)
ZEUS ($p_T \lesssim 0.85$, $0.6 \lesssim x_{\mathrm{L}} \lesssim 1$)

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

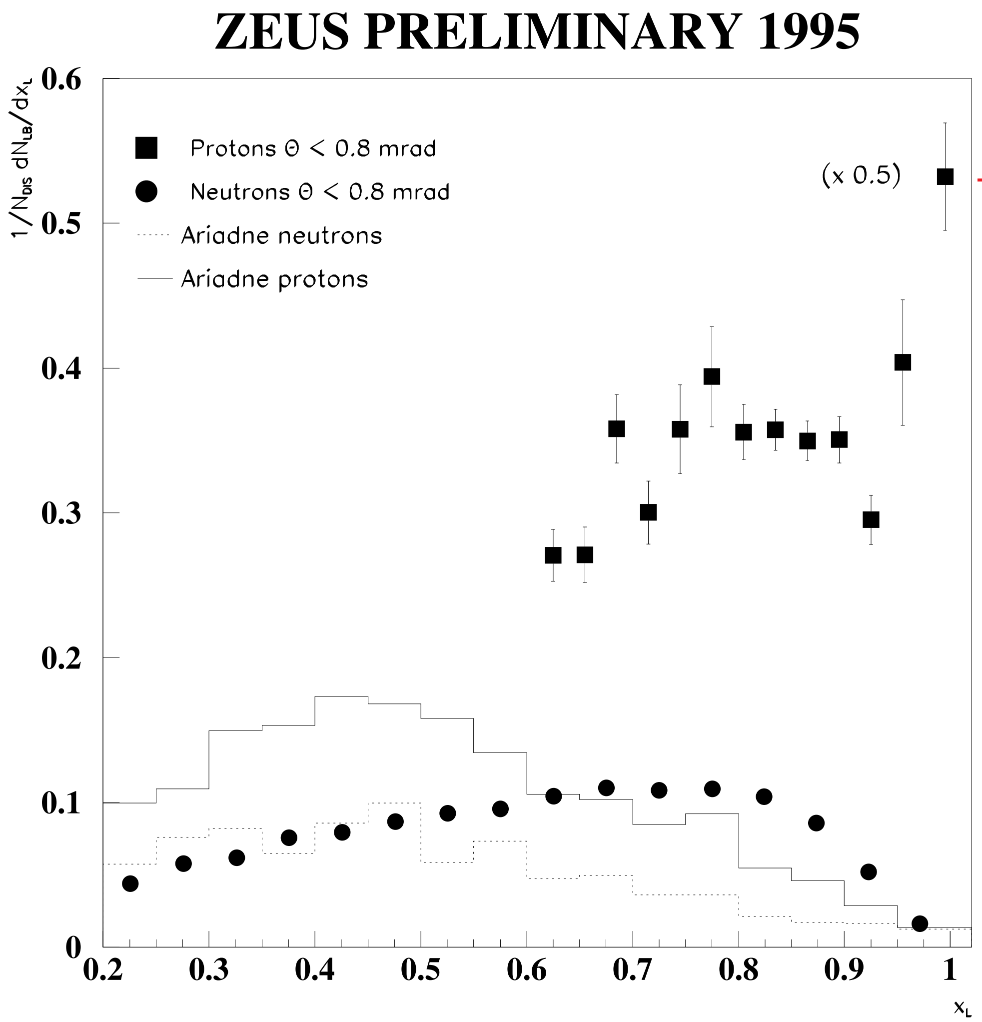
Several interesting issues ...

- 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 - $I\!P$, $I\!R$, π exchange.
$I\!R$ is isoscalar (f, ω), $\rightarrow$ contributes to leading protons only.

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

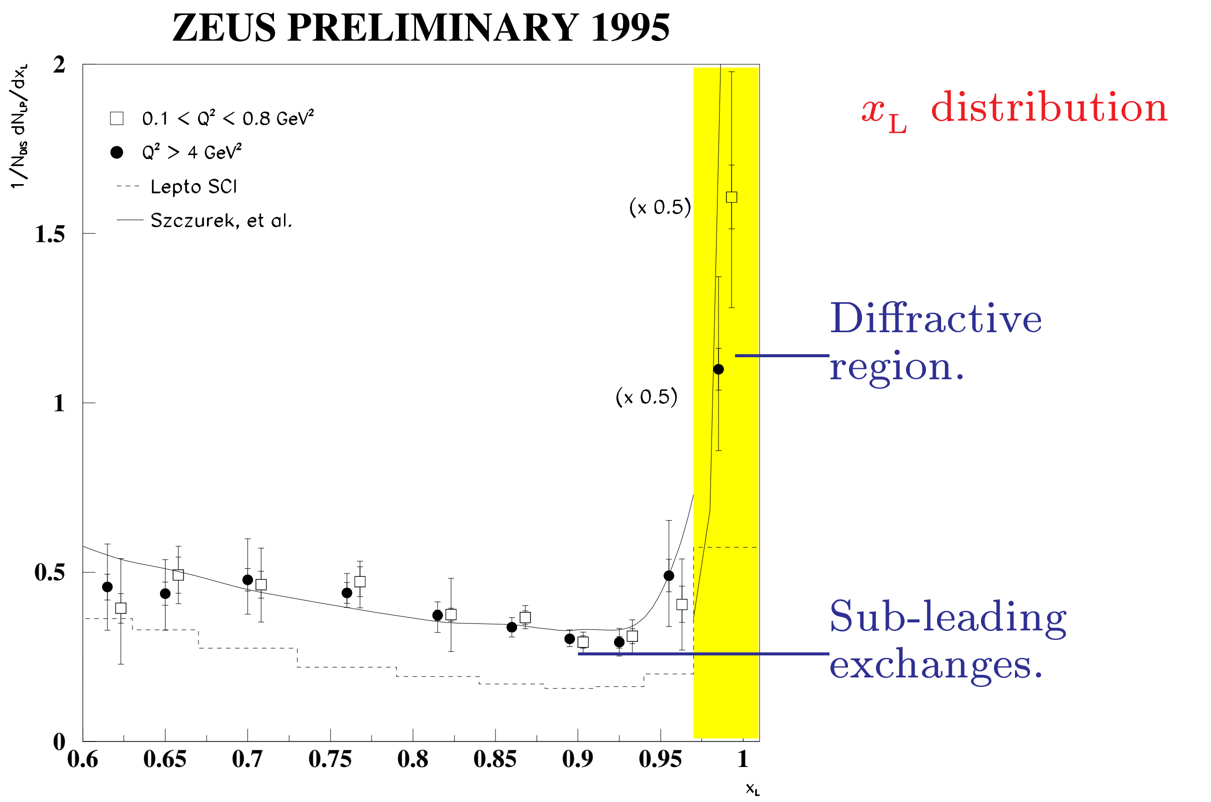
where $\beta = \frac{x}{1 - x_{\rm L}}$

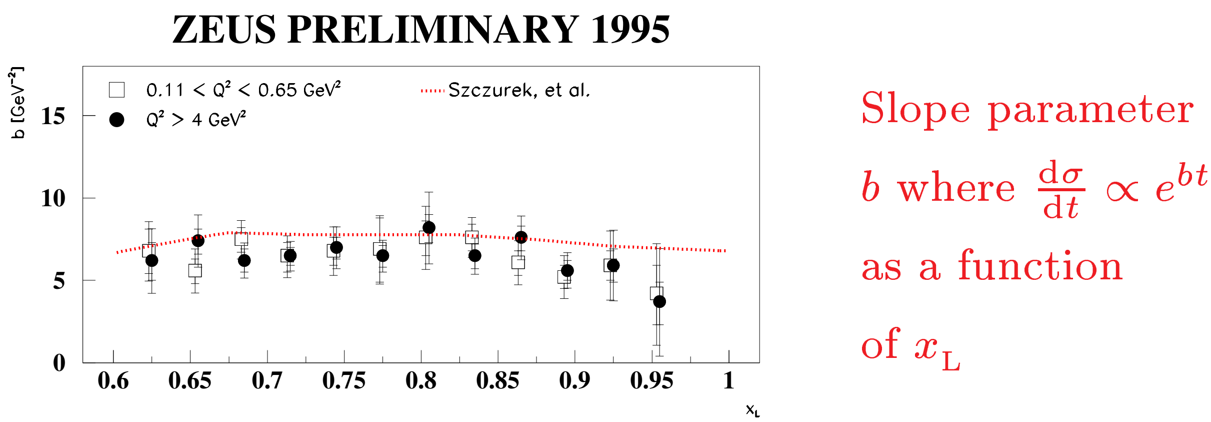
Assume: $I\!P$ $\alpha(0) \sim 1.2$, $I = 0$ - p
$I\!R$ (f, ω) $\alpha(0) \sim 0.5$, $I = 0$ - p
π $\alpha(0) \sim 0.0$, $I = 1$ - p, n

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



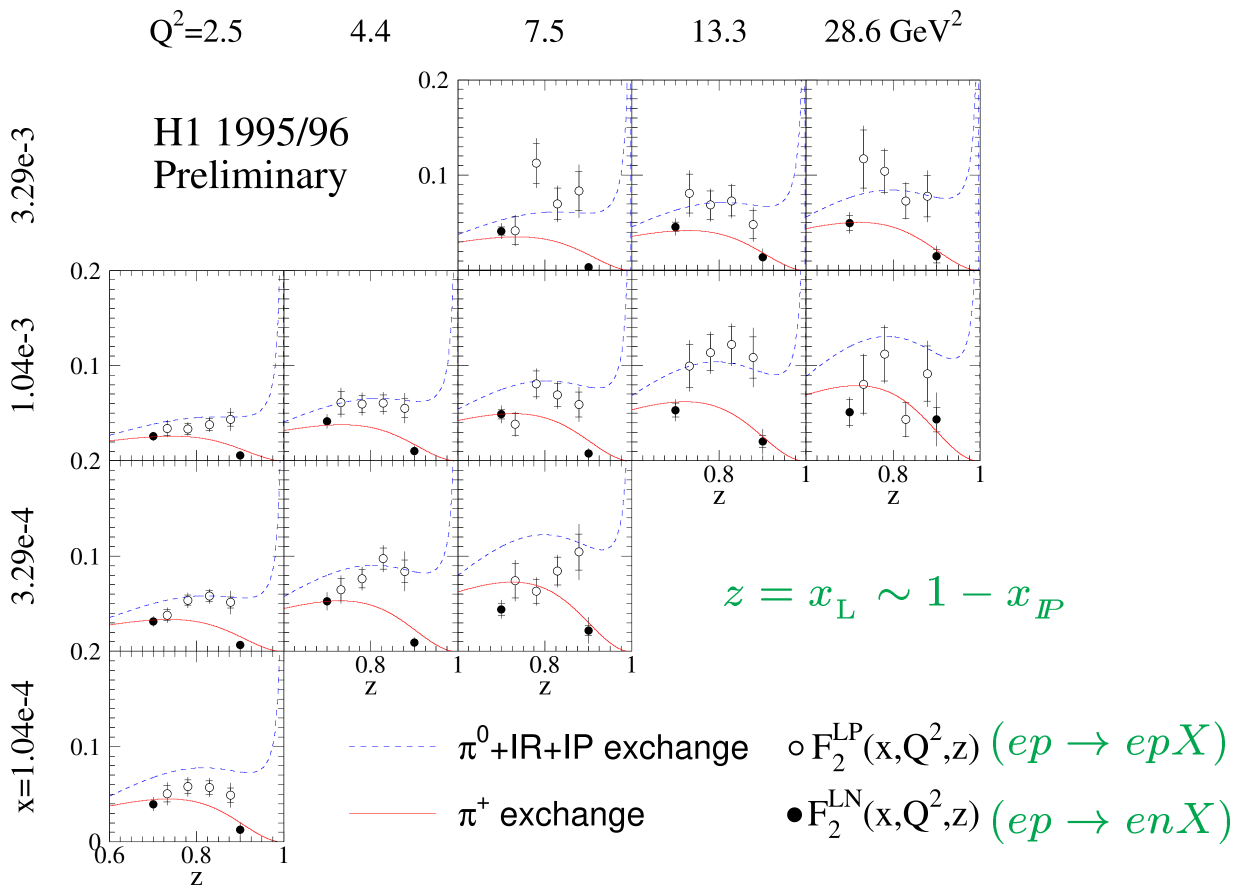


The Regge model describes the x_L and t deopendence of the proton data integrated over x and Q^2.

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.

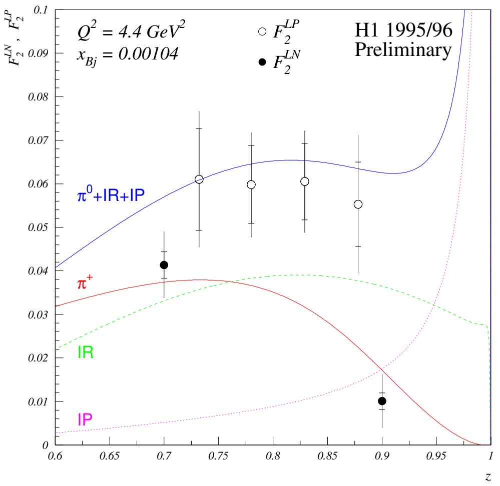
$$\frac{\mathrm{d}\sigma^{ep\to eNX}}{\mathrm{d}x\ \mathrm{d}Q^2\ \mathrm{d}x_{\mathrm{L}}} = \frac{4\pi\alpha^2}{xQ^4}\left(1-y+\frac{y^2}{2}\right)\ F_2^{LN(3)}(x,Q^2,x_{\mathrm{L}})$$



$z = x_{\mathrm{L}} \sim 1 - x_{I\!P}$

$(ep \to epX)$

$(ep \to enX)$



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.)

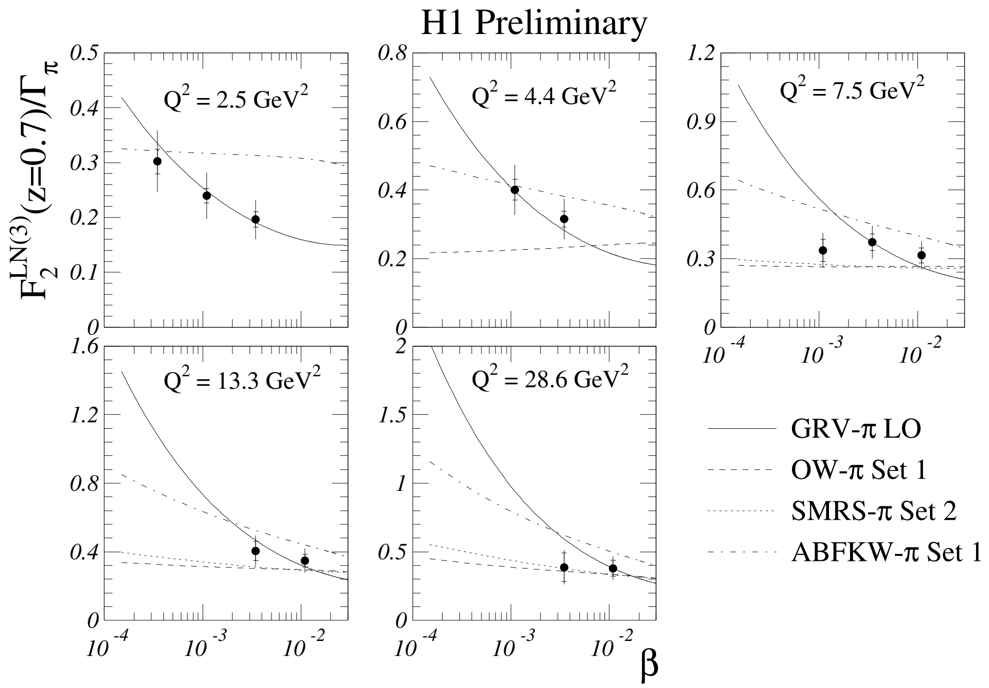
Investigation of the pion structure function

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

...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.