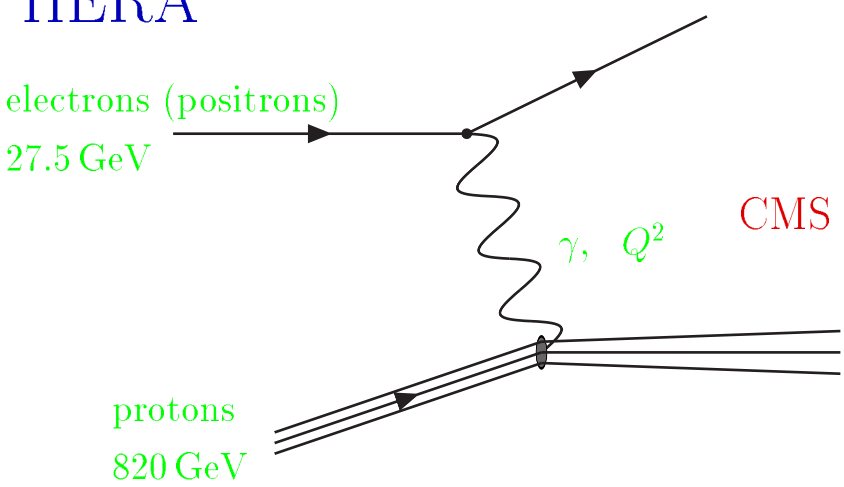
The Structure of the Pomeron

OUTLINE

- Introduction: deep inelastic scattering at HERA
- Diffraction, rapidity gaps and pomeron exchange
- Pomeron structure
- Large rapidity gaps
- Another contribution
- Comparison with experiment
- Summary

INTRODUCTION

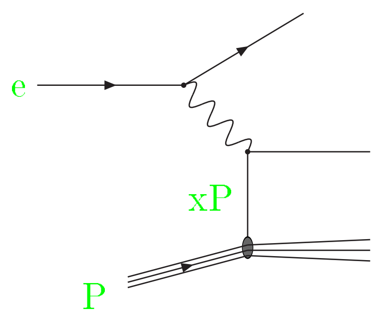
HERA



CMS energy: $\sqrt{s} \approx 300\,\text{GeV}$

- high Q^2 photons $\rightarrow$ probe structure of proton
- small x $\rightarrow$ gluonic structure of proton

Parton model and QCD



- Structure function

$$F_2(x) = x \sum_i e_i^2 f_i(x)$$

quarks parton density function

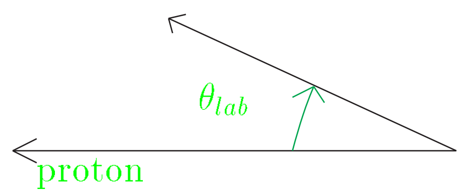
- QCD

$$F_2 \longrightarrow F_2(x, Q^2)$$

DIFFRACTION

- proton emerges intact, large rapidity gap observed

$$\eta = -\ln \tan\left(\frac{\theta_{lab}}{2}\right) \qquad \text{(HERA lab frame)}$$



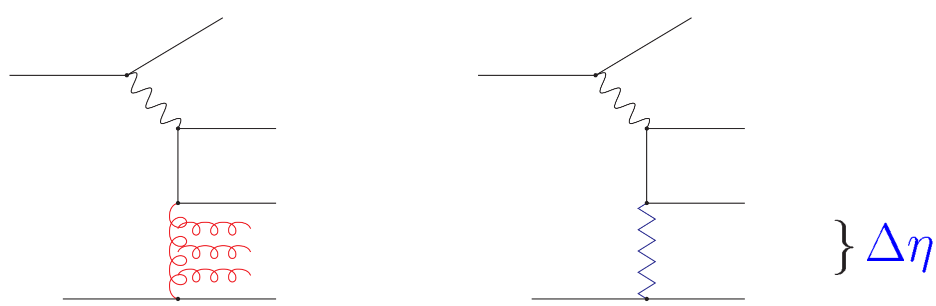
$\longrightarrow$ H1 rapgap event

- more LRG events seen than expected from QCD

$\longrightarrow$ H1 plot

- rapidity gap indicates colourless exchange

$\longrightarrow$ pomeron, $I\!\!P$



Pomeron

- Regge theory
- describes proton-(anti)proton elastic scattering $\longrightarrow$ D&L figure
- vacuum quantum numbers
- strongly interacting

$\longrightarrow$ quark and gluon structure?

POMERON STRUCTURE

- diffractive DIS $\equiv$ photon probing structure of $I\!P$
- Ingelman & Schlein (1985):

pomeron $\sim$ *hadronic* particle

Pomeron in parton model:

- $I\!P$ couples to on shell partons: $k^2 \lesssim 1\,\mathrm{GeV}^2$

Diffractive structure function

$$\frac{\mathrm{d}^3\sigma_{diff}}{\mathrm{d}\beta\,\mathrm{d}Q^2\,dx_{I\!P}} = \frac{2\pi\alpha^2}{\beta Q^4}(1+(1-y)^2)F_2^{D(3)}(\beta, Q^2, x_{I\!P})$$

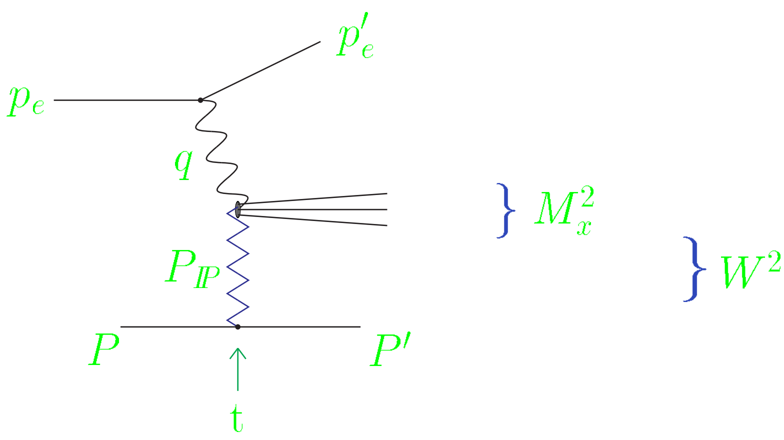
Pomeron exchange $\longrightarrow$ $F_2^{D(3)}$ factorizes:

$$F_2^{D(3)}(\beta, Q^2, x_{I\!P}) = f^{I\!P}(x_{I\!P})\,F_2^{I\!P}(\beta, Q^2)$$

Pomeron structure function

KINEMATICS

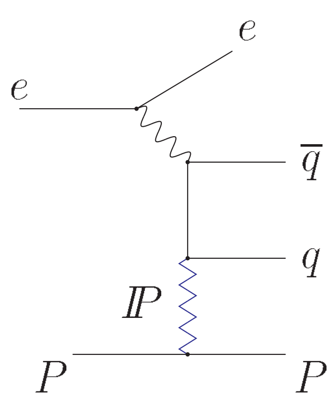
$$e + P \rightarrow e + P + X$$



$$Q^2 = -q^2 \quad \text{photon virtuality}$$

$$x = \frac{Q^2}{2P \cdot q} \quad \text{Bjorken variable} \qquad y = \frac{Q^2}{x\, s}$$

Leading order diffractive event: $\gamma \longrightarrow q\bar{q}$



$\Rightarrow$ jet

$\Rightarrow$ jet

"dijet event"

$$x_{I\!P} = \frac{P_{I\!P} \cdot q}{P \cdot q} \approx \frac{Q^2 + M_x^2}{Q^2 + W^2} \quad \text{fraction of proton momentum in } I\!P$$

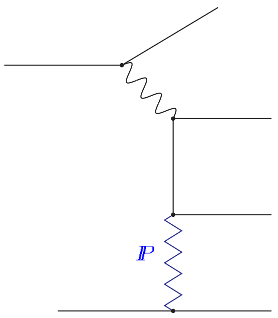
$$t = (P - P')^2 \quad \text{momentum transfer at } P - I\!P \text{ vertex}$$

$$\beta \approx \frac{Q^2}{Q^2 + M_x^2} \quad \text{fraction of } I\!P \text{ momentum in struck quark}$$

$$x = \beta x_{I\!P}$$

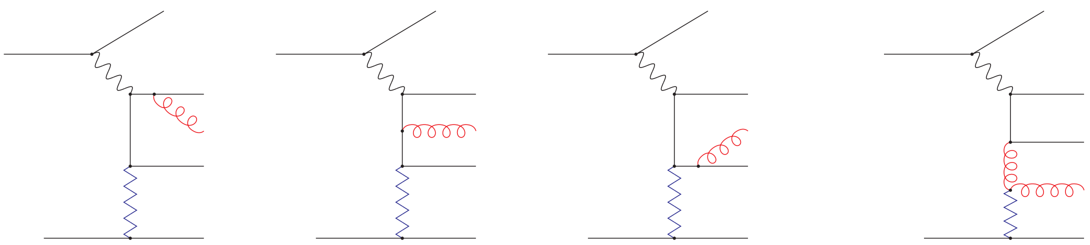
H1 ANALYSIS OF DIFFRACTION

Leading contribution:



$\longrightarrow$ quark structure

Higher order (in α_s):



$\longrightarrow$ H1 analysis

- $x_{I\!P}$ dependence factorizes for wide range of parameters
- cross section not sensitive to pseudo-rapidity cuts
- 80-90 % of $I\!P$ momentum carried by gluons
- at low Q^2 ($\sim$ 5 GeV^2) almost all $I\!P$ momentum in exchanged gluon

$\longrightarrow$ unusual distribution for hadronic particle

LARGE RAPIDITY GAPS

Early H1 and ZEUS analyses selected LRG events

Consequence: "leading" diagrams don't contribute

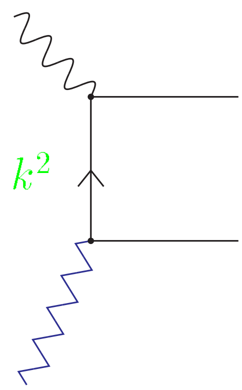
Ellis, Ross

Proof:

Large rapidity gap cuts: $\eta_{max} \Longrightarrow \theta_{lab}^{min}$

Boost to $\gamma^* - I\!\!P$ CMS: $\theta_{lab}^{min} \Longrightarrow \theta_{cms}^{min} \Longrightarrow k_{min}^2$

Quark virtuality (dijet production):



$$-k^2 = \frac{Q^2}{2\beta}(1 - \cos\theta_{cms})$$

$$\Rightarrow -k_{min}^2 = \frac{Q^2}{2\beta} \frac{(1+\beta_1)(1-\beta_2^2)}{1 - \beta_1 \cos\theta_{lab}^{min} - \sqrt{1-\beta_1^2}\beta_2 \sin\theta_{lab}^{min}} (1 - \cos\theta_{lab}^{min})$$

β_1, β_2, boost parameters (functions of Q^2, β and $x_{I\!\!P}$)

$\longrightarrow$ quark virtuality

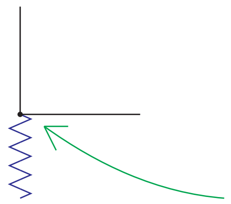
Virtuality constraint on events with 3 or more jets:

$$-k^2 > -\frac{1}{2}k_{min}^2$$

EXPLANATION OF LRG EVENTS

1. Direct coupling – "form factor" approach

- Donnachie-Landshoff



$\beta_0 \gamma^\mu f(k^2)$

- approximate point-like coupling
- $f(k^2)$ preserves scaling of $F_2^{D(3)}$

form factor:

$$f(k^2) = \frac{\Lambda^2}{\Lambda^2 - k^2} \qquad \Lambda \sim 200\,\text{MeV}$$

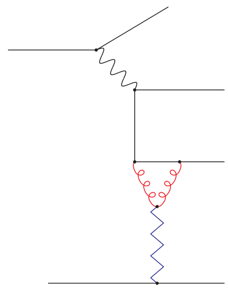
- very sensitive to virtuality, k^2

- Ellis-Ross

$$f(k^2) = \sqrt{\frac{\Lambda^2}{\Lambda^2 - k^2}}$$

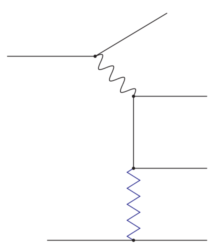
- softer k^2 dependence
- logarithmic scaling violations

2. Another Resolved Contribution



- gluons on shell, exchanged quark not constrained
- insensitive to pseudo-rapidity cuts
- consistent with previous proton-proton analyses
- consistent with QCD

Compare with



$\longrightarrow$ extra $1/k^2$ in cross section
$\longrightarrow$ identify with form factor $f^2(k^2)$

$\Longrightarrow$ approximate by ER form factor model

BONUS?

- extra Q^2 scaling violation might provide more natural explanation of H1 result

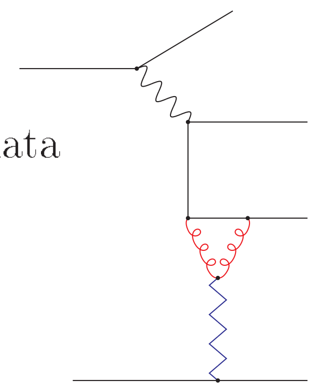
$\longrightarrow$ comparison with data

SUMMARY AND CONCLUSIONS

Where are we now?

- LRG diffractive deep inelastic scattering
- diffractive DIS $\rightarrow$ probing pomeron structure
- "leading" contribution excluded by experimental cuts

$\Rightarrow$ need a new contribution



- good fit to existing data
- insensitive to LRG cuts
- proton-proton explanation ok
- consistent with QCD
- more natural H1 fit?

Where to now?

- better calculation of 2-gluon contribution
- look at transverse momentum distributions of jets as further test
- we need better LRG data!!