Introduction to Diffraction and low-x Dynamics

Diffraction at HERA

- total cross section

- vector mesons

- test of Regge Factorization

virtual photons ($0 < Q^2 < 1$ Gev^2)

- expectations

- approach to photoproduction limit, Regge interpretation

Deeply virtual photons, pQCD

- structure functions

- x-dependence

- the rise of F_2

Hard Diffraction

- factorization, $F_2^{D(3)}$

- partonic description

- $F_2^{D(3)}/F_2$

- dipole / resolved Pomeron description

- jets

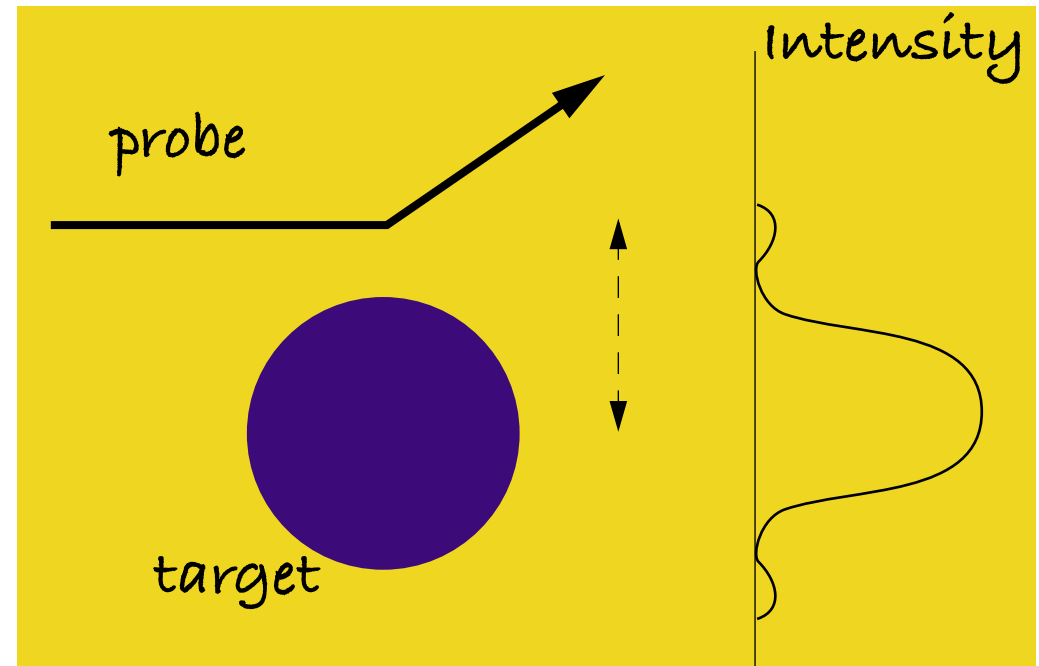- diffractive charm

- Tevatron

Outlook

Conclusion

Some Characteristics of Diffraction

Optical analogy

- target participates as a whole

- $d\sigma/dt \sim e^{bt}$

- t-distribution is an indicator of size

- effective size:
  $r^2_{eff} = r^2_{probe} + r^2_{target}$

- soft energy dependence:
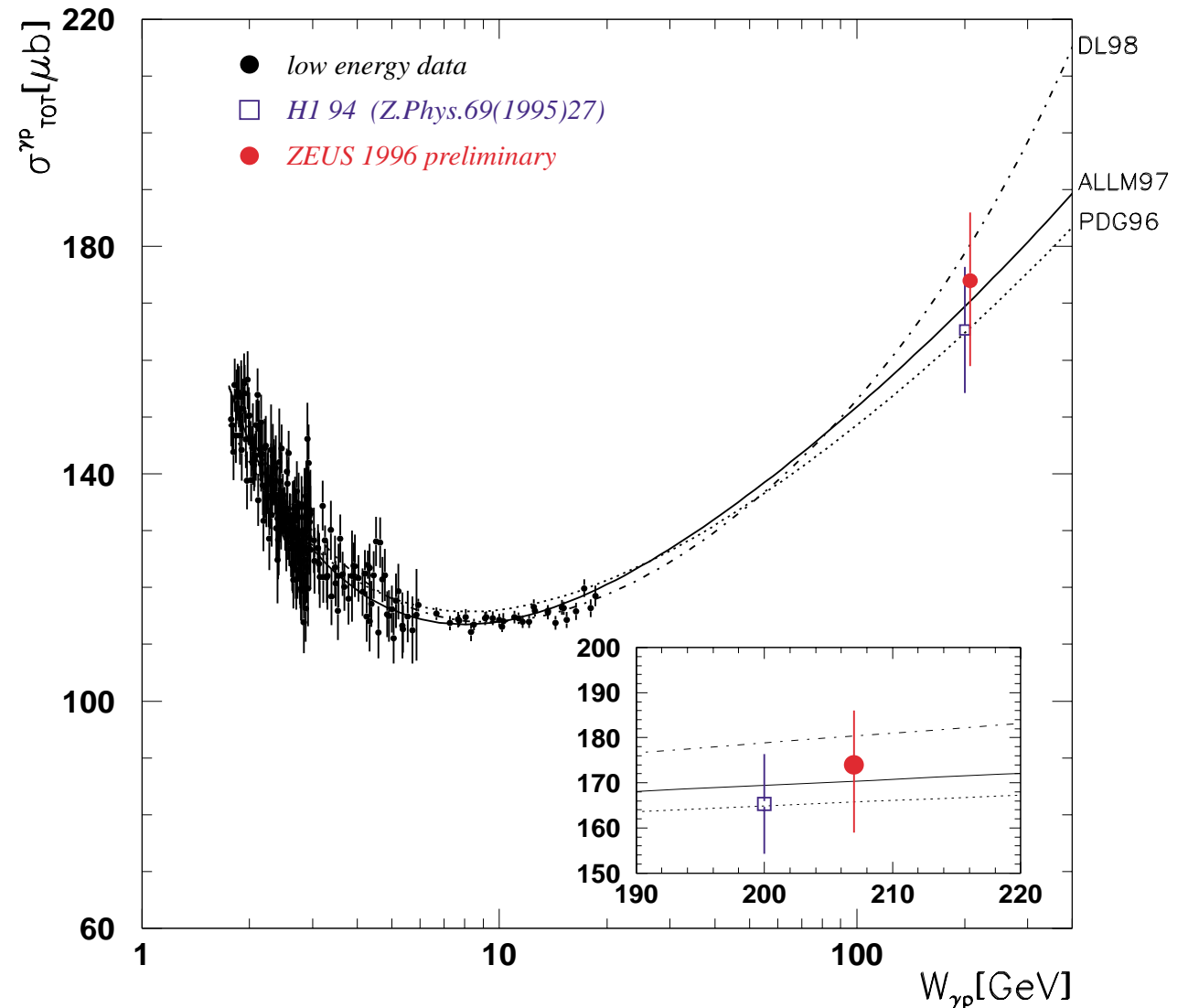 W-dependence arises when exciting higher angular momentum states; e.g.

  $d\sigma/dt \sim ((W/W_0)^2)^{2(\alpha-1)} e^{bt}$ and (optical theorem)

  $\sigma \sim (W^2)^{\alpha-1}$

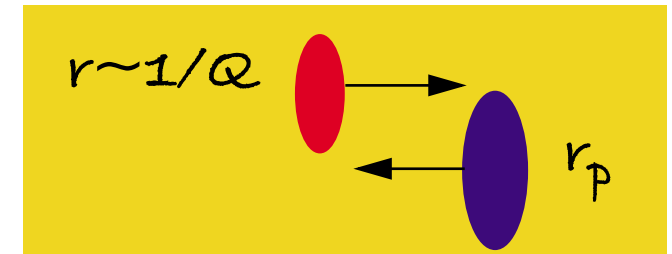# Total Cross Section

Total cross section

- initial Fall off with W (Reggeon exchange)

- gentle rise with W for large W

$$\sigma \sim (W^2)^{0.08}$$

- at HERA

$$W^2 \sim Q^2 (1/x - 1)$$
(trivial relation diffraction-low x)

Soft Diffraction at HERA

Some more considerations on size at HERA:

- lab system
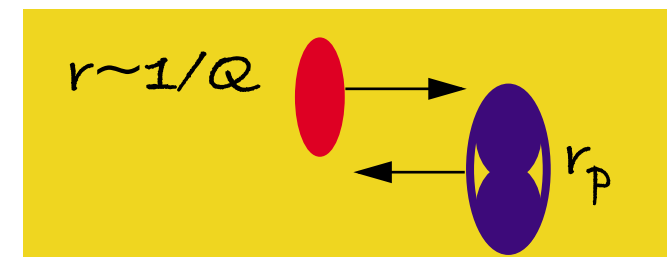 a disc (lorentz contracted) is hit by a probe

Size of probe:

- $r \gg r_p$ in photoproduction ($Q^2 = 0$)

- $r \sim 1/1000 \; r_p$ (at the largest values of Q^2)

Size of target:

- elastic processes: size of proton
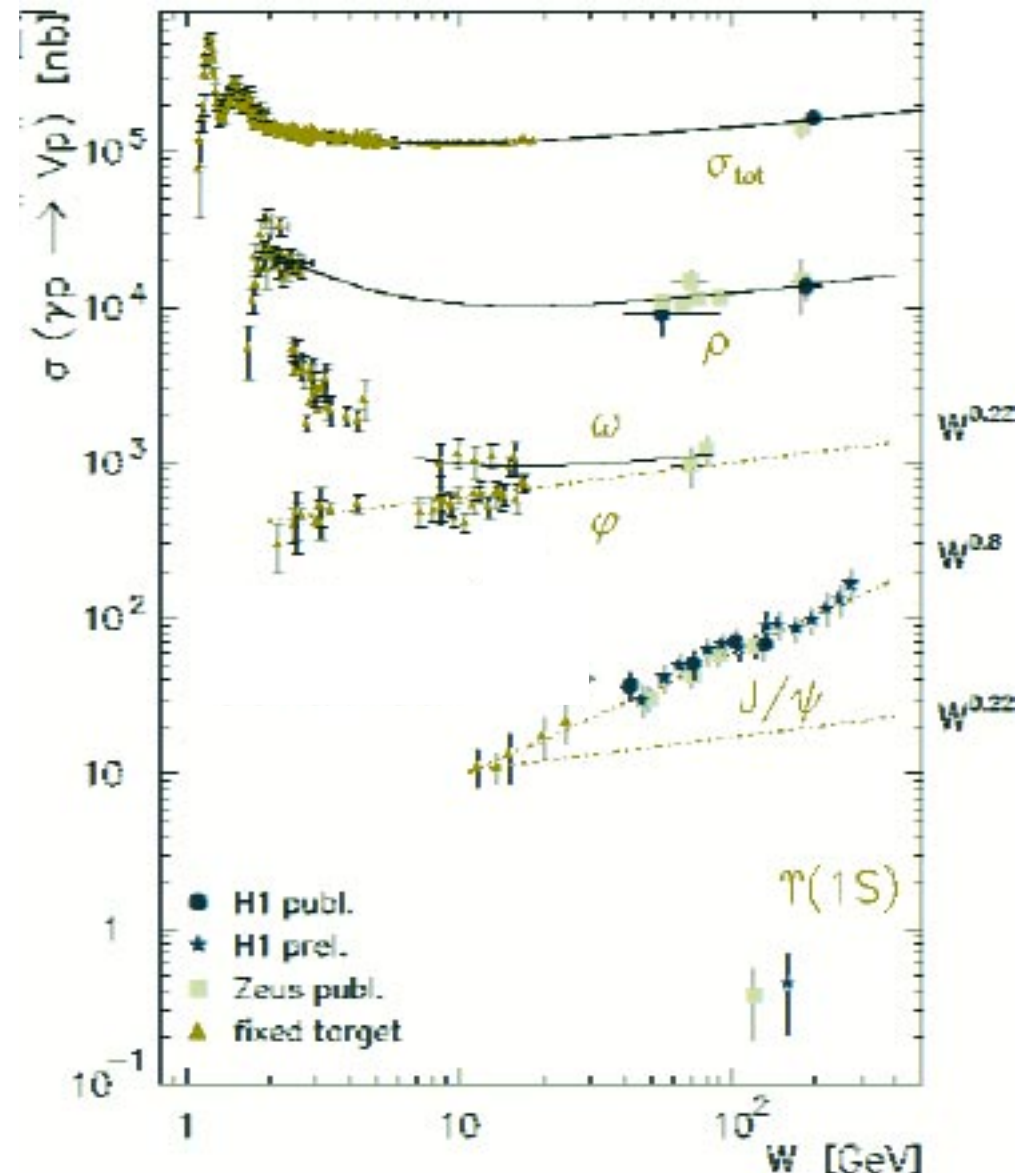- inelastic processes; proton break-up; fraction of the size of a proton

Elastic Vector Meson Production

Photon turns into Vector Meson

- t-dependence reveals size of object

- W-dependence shows devia-tions from soft picture

Once a "hard" scale, such as m^2, is requested the soft energy dependence is lost.

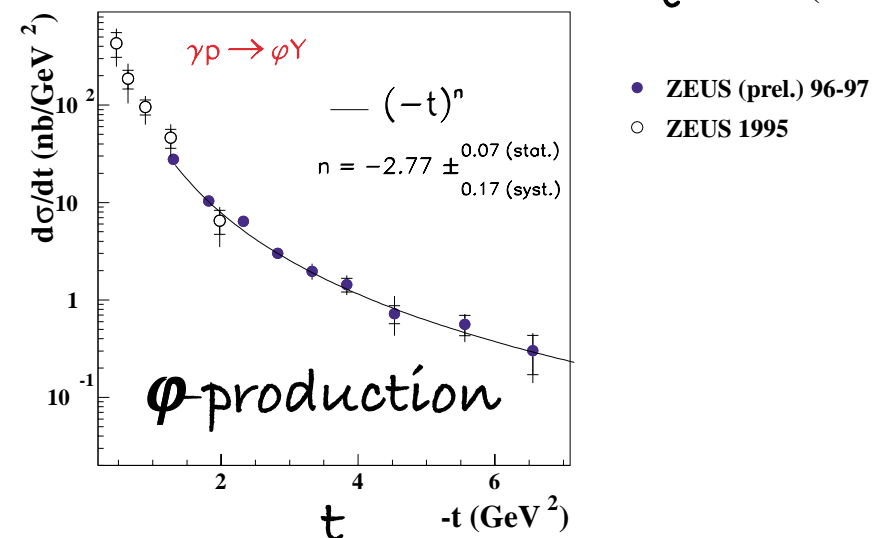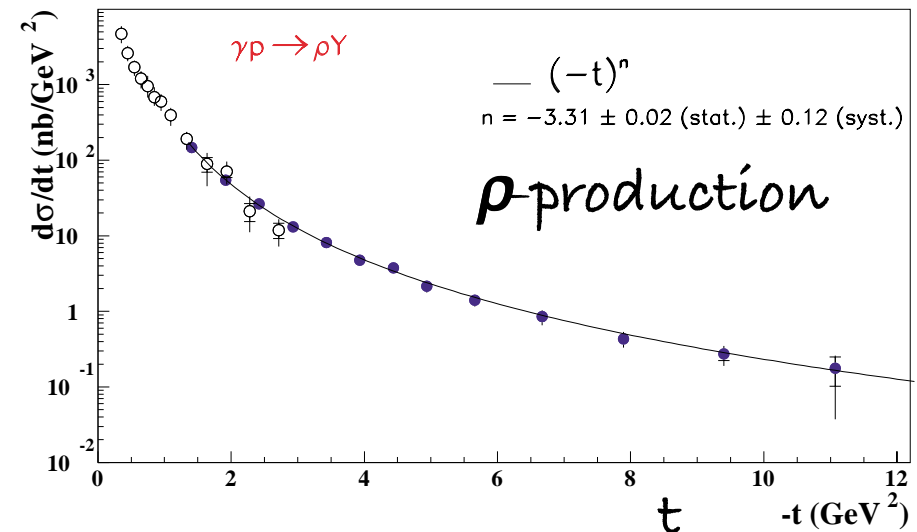# Dissociative Diffractive Scattering

Proton break-up

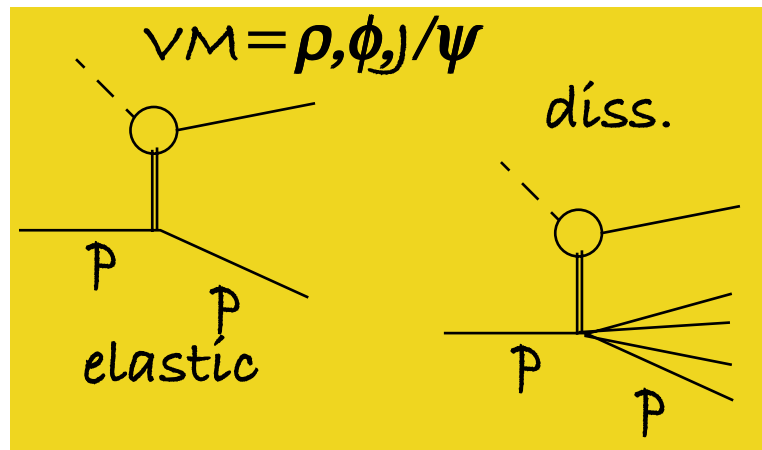- probe interacts with a part of the proton – a different size object

t-dependence

- at small t exponential fall-off $\sim e^{bt}$ with $b\sim3$

- at large t power law behaviour $(-t)^{n}$ with $n\sim3$

ZEUS

$\gamma p \rightarrow \rho Y$

— $(-t)^{n}$

$n = -3.31 \pm 0.02$ (stat.) ± 0.12 (syst.)

ρ-production

$\gamma p \rightarrow \varphi Y$

— $(-t)^{n}$

$n = -2.77 \pm \genfrac{}{}{0pt}{}{0.07 \text{ (stat.)}}{0.17 \text{ (syst.)}}$

φ-production

● ZEUS (prel.) 96-97
○ ZEUS 1995

Test of Regge Factorization

$VM = \rho, \phi, J/\psi$
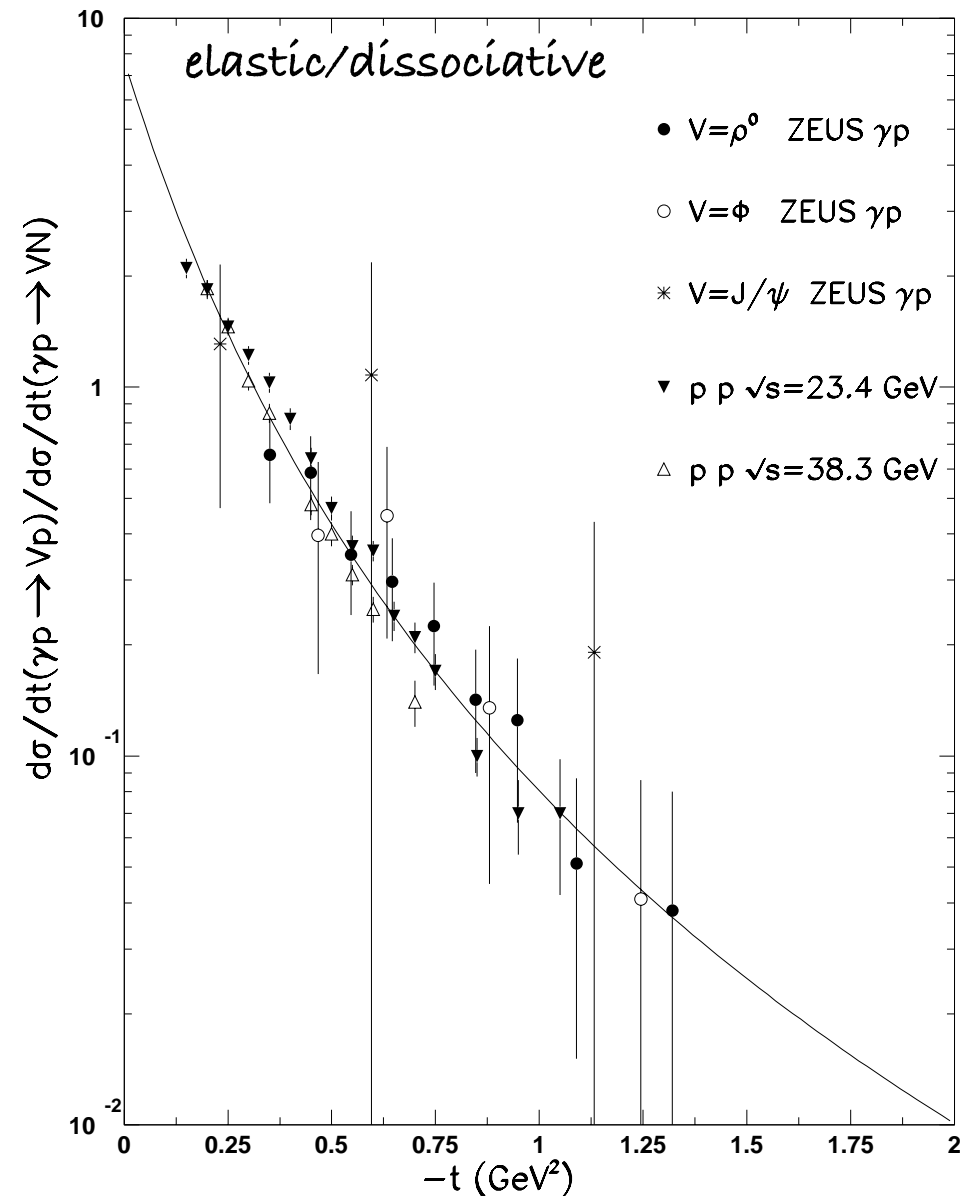
diss.

P

P

elastic

P

P

P

Ratio elastic/dissociative

- elastic
  $$d\sigma/dt \sim F_V^{2*} F_p^{2*} |A|^2$$

- dissociative
  $$d\sigma/dt \sim F_V^{2*} |A|^2$$

- universal t-dependence for all VM

elastic/dissociative

- $V=\rho^0$ ZEUS γp
- $V=\phi$ ZEUS γp
- $V=J/\psi$ ZEUS γp
- $p\,p$ $\sqrt{s}=23.4$ GeV
- $p\,p$ $\sqrt{s}=38.3$ GeV

$d\sigma/dt(\gamma p \rightarrow Vp)/d\sigma/dt(\gamma p \rightarrow VN)$

$-t$ (GeV^2)

DIS - Virtual Photons

Structure functions $F_2(x, Q^2)$ and $F_L(x, Q^2)$

- $d^2\sigma / dx\, dQ^2 \sim 1/xQ^{4} *$
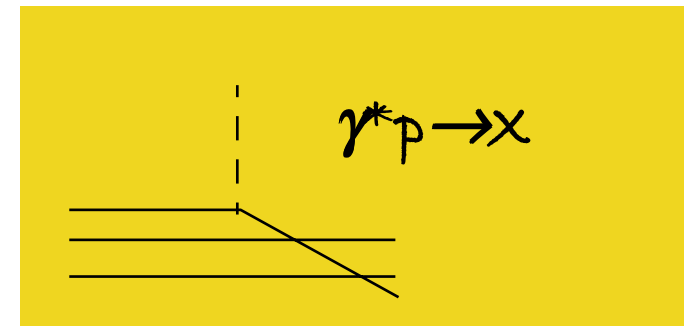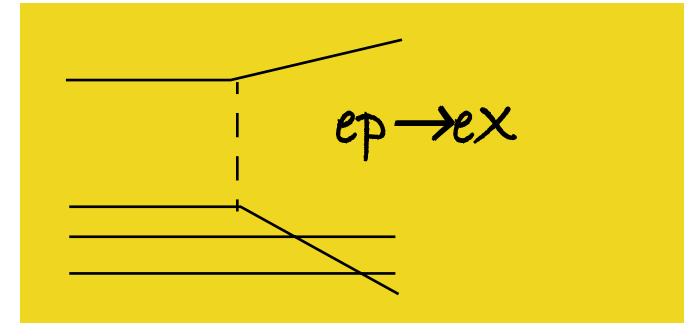 $(\,(1 + (1-y)^2) * F_2(x, Q^2) - y^2 * F_L(x, Q^2)\,)$

  DIS region
  partonic description

Total $\gamma^* p$ cross section

- $\sigma \sim 4\pi a^2 / Q^2 * F_2$

For small Q^2

- since $\sigma \sim$ const.
  for $Q^2 \to 0$, $F_2 \sim Q^2$
  conservation of electromagnetic current

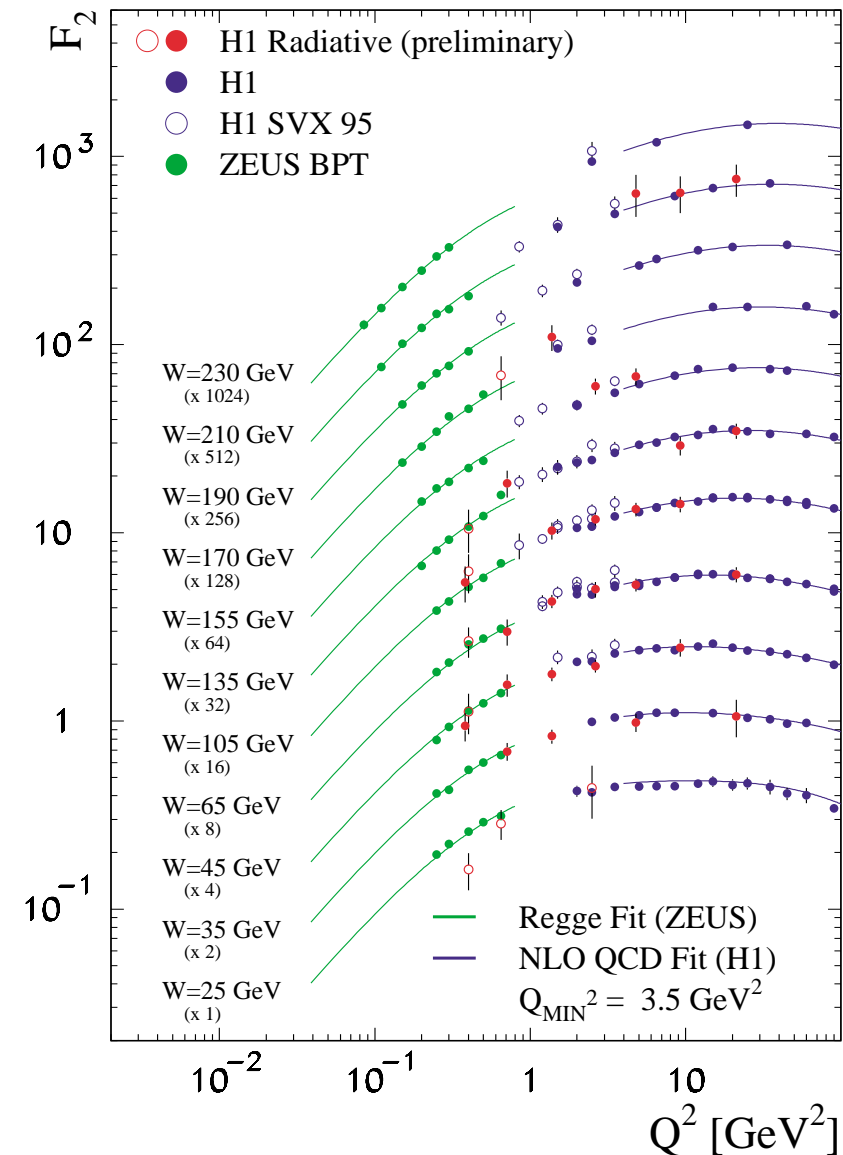

$ep \to eX$

$\gamma^* p \to X$

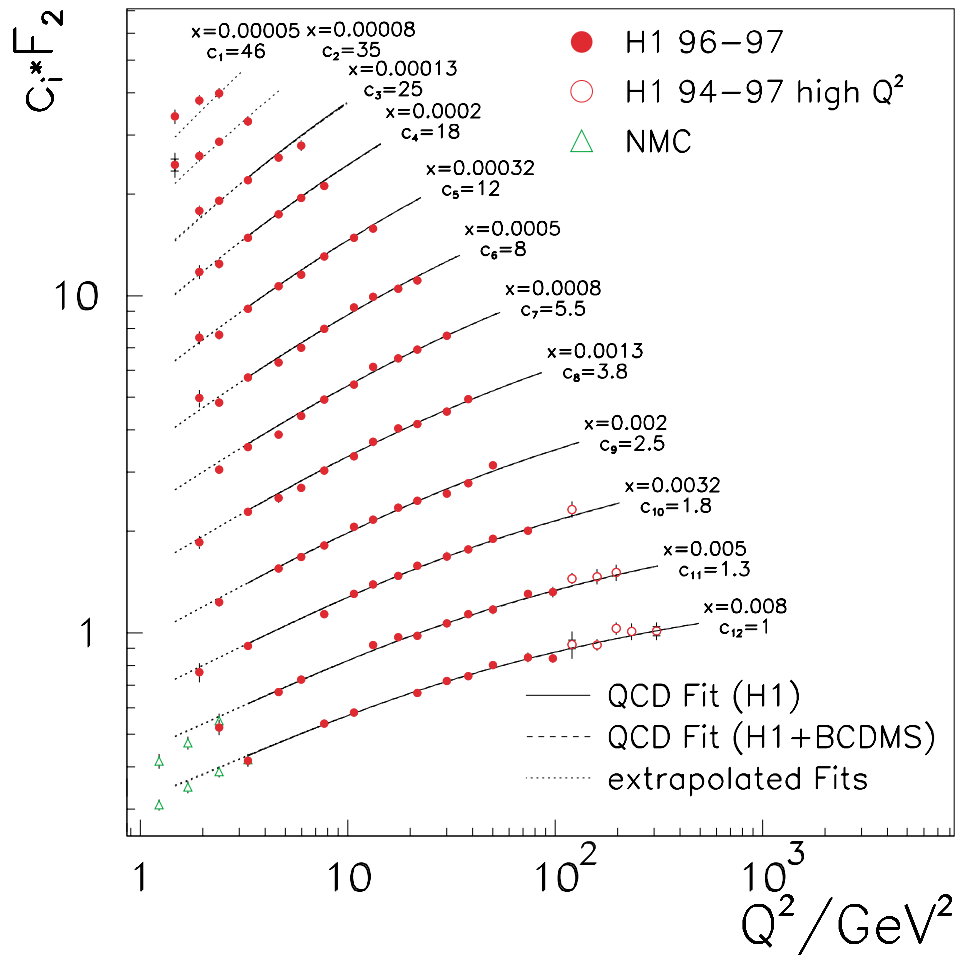# F_2 in the low Q^2 region

Approach to Photoproduction Limit

- explored for $Q^2 \sim 0.1$ GeV^2

- data well compatible with the expected vanishing behaviour of F_2

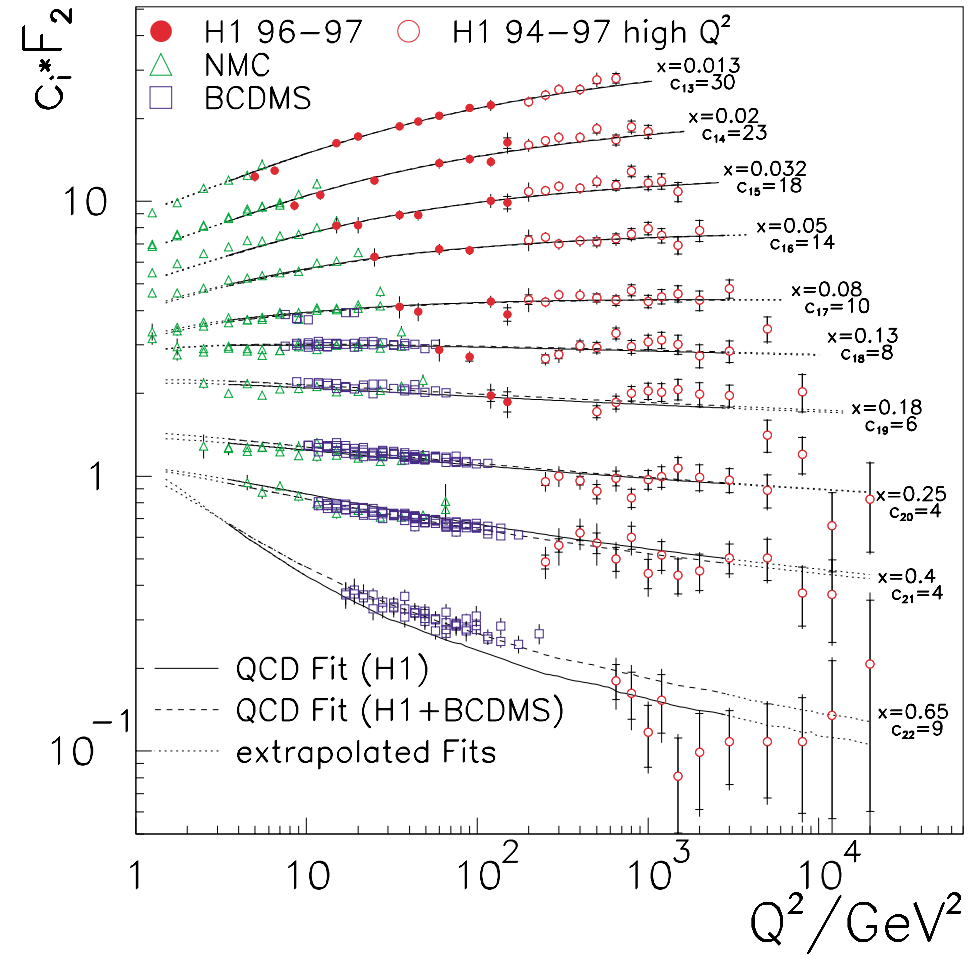- smooth approach to the photopro-duction limit

Regge inspired fits at low Q^2

- GVDM model $\alpha_{\mathbb{P}}(0) \sim 1.12$

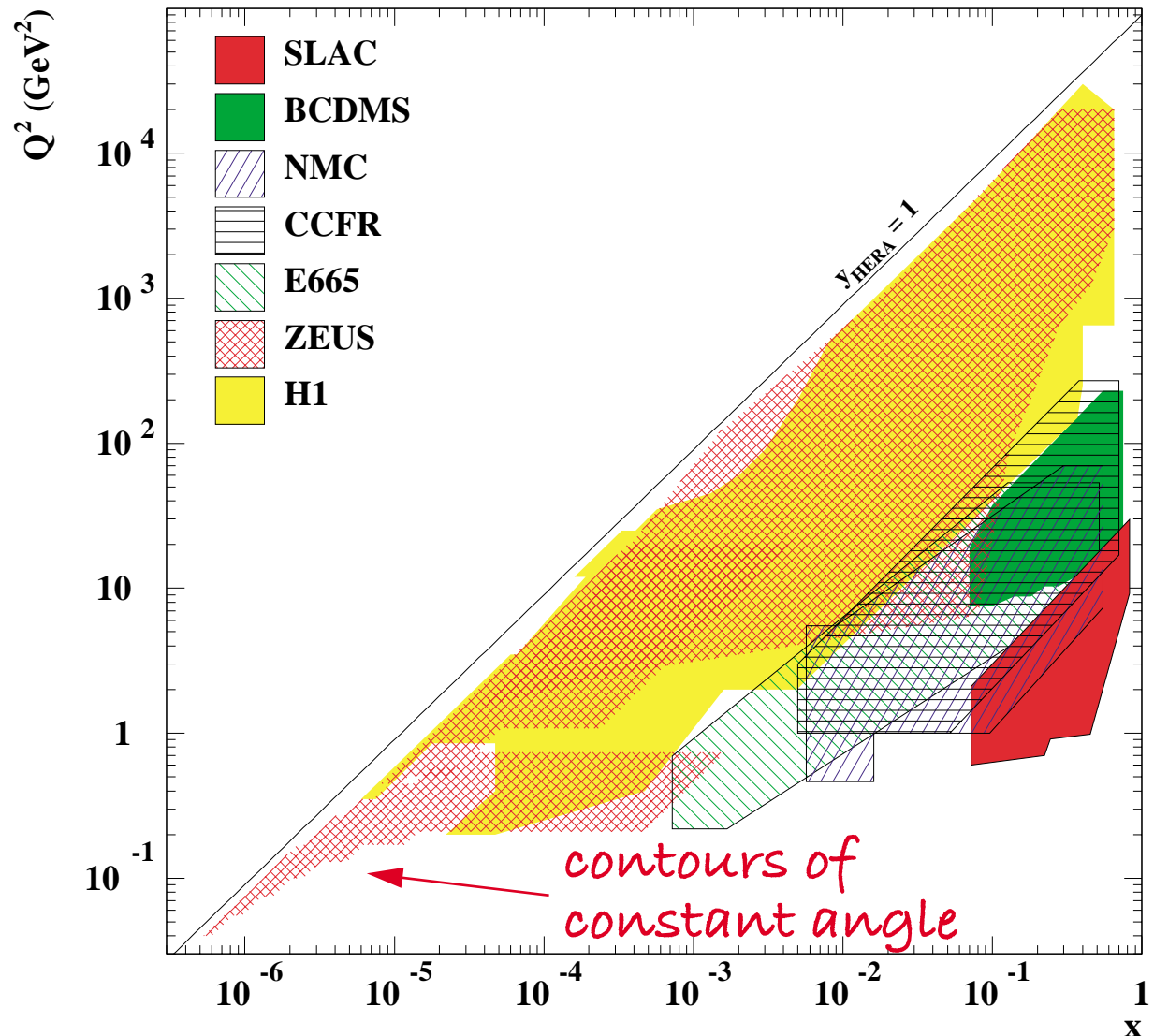# F_2 for large Q^2

F_2 scaling violations:

F_2 function of x and Q^2

Experimental x-Q^2 Correlation

Kinematic reach at small x

- $Q^2 = xys$ is largely restricted by acceptance limitations, i.e beam pipe
- experimental effort to measure at largest x for given Q^2
- ZEUS and H1 have built specific detectors

contours of constant angle

pQCD Expectations

Qualitative Picture

- pQCD valid for $Q^2 > 1$ GeV^2, since implicitly x is large: Scaling Violation

- at very small x expect to enter the high density region where the scaling behaviour will change due to massive gluon self interaction

- Hence interest is in

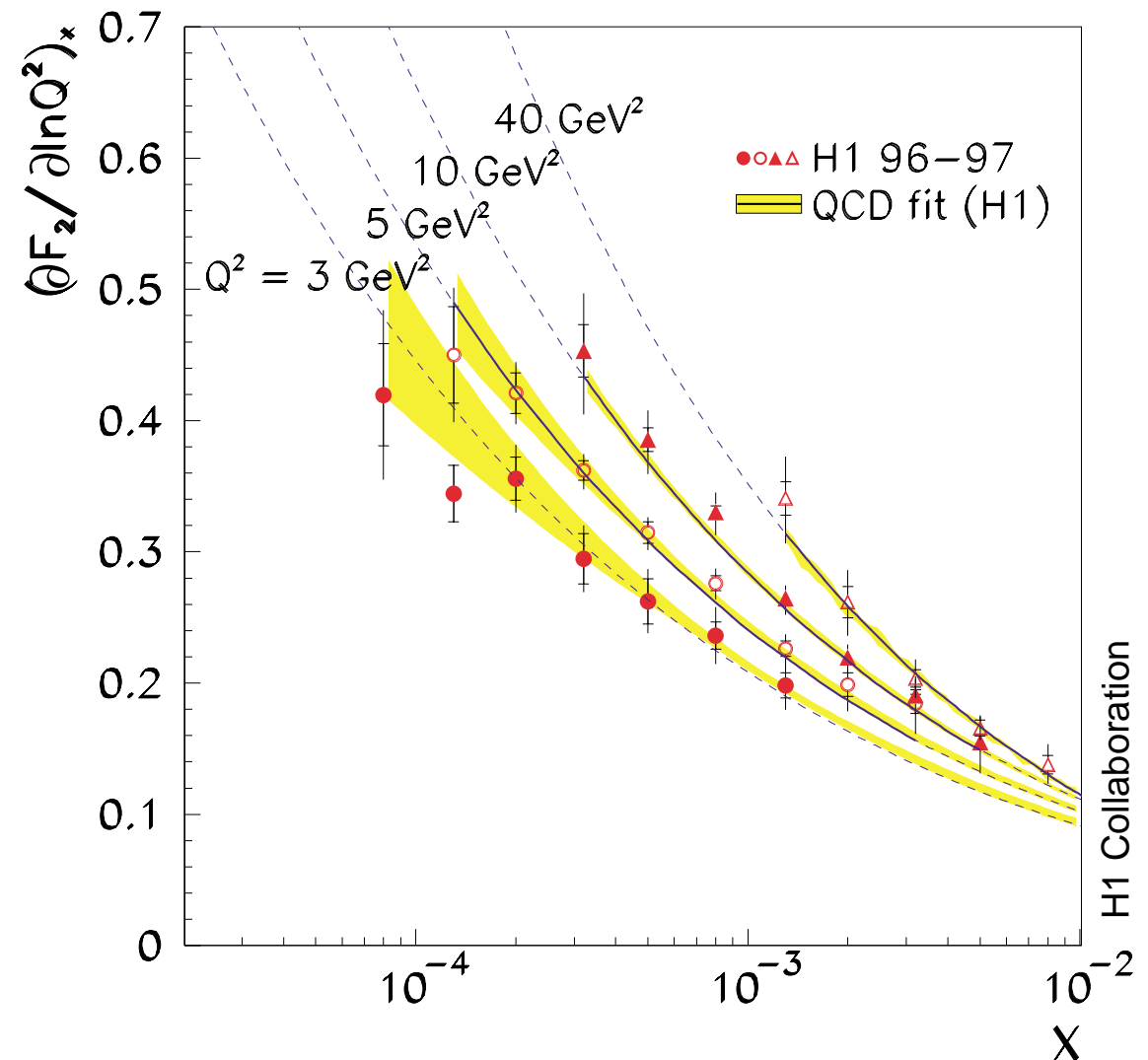 $d\ln F_2/d\ln x$ at fixed Q^2, i.e. constant resolution
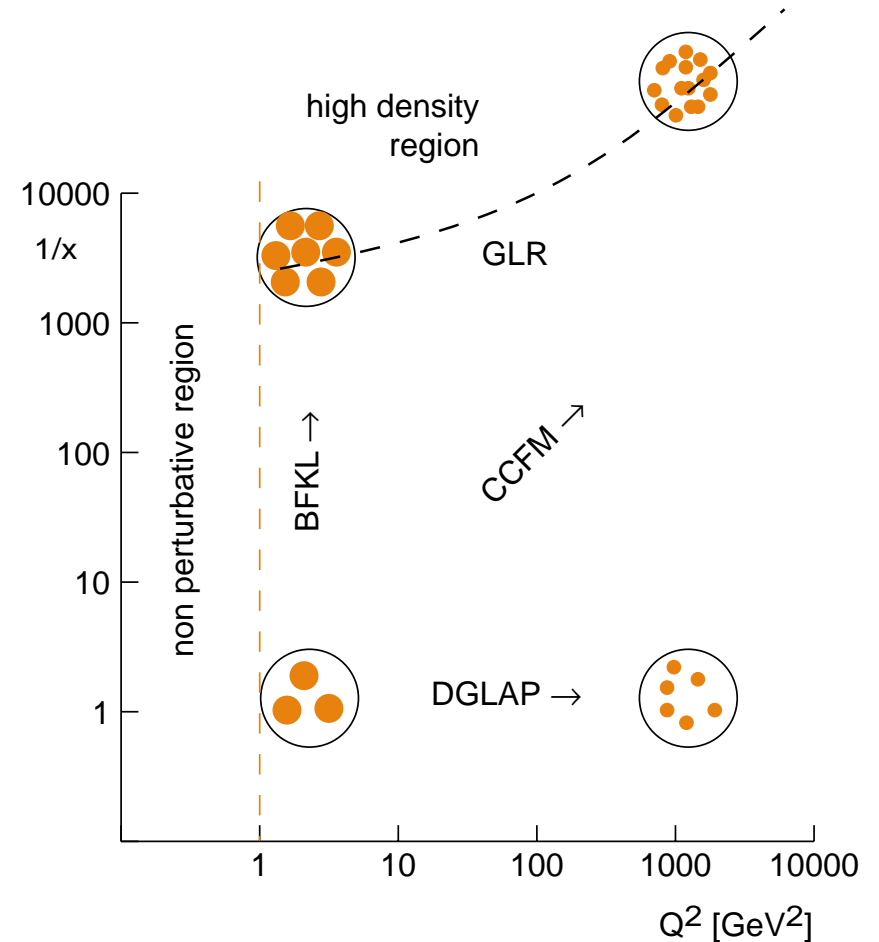
Are the contours as suggested?

Search for Deviations
of the pQCD Behaviour of $F_2(x, Q^2)$

Probing the Q^2 dependence
of $F_2(x, Q^2)$

- in the kinematic region
  of pQCD the rising behav-
  iour of F_2 is unchanged
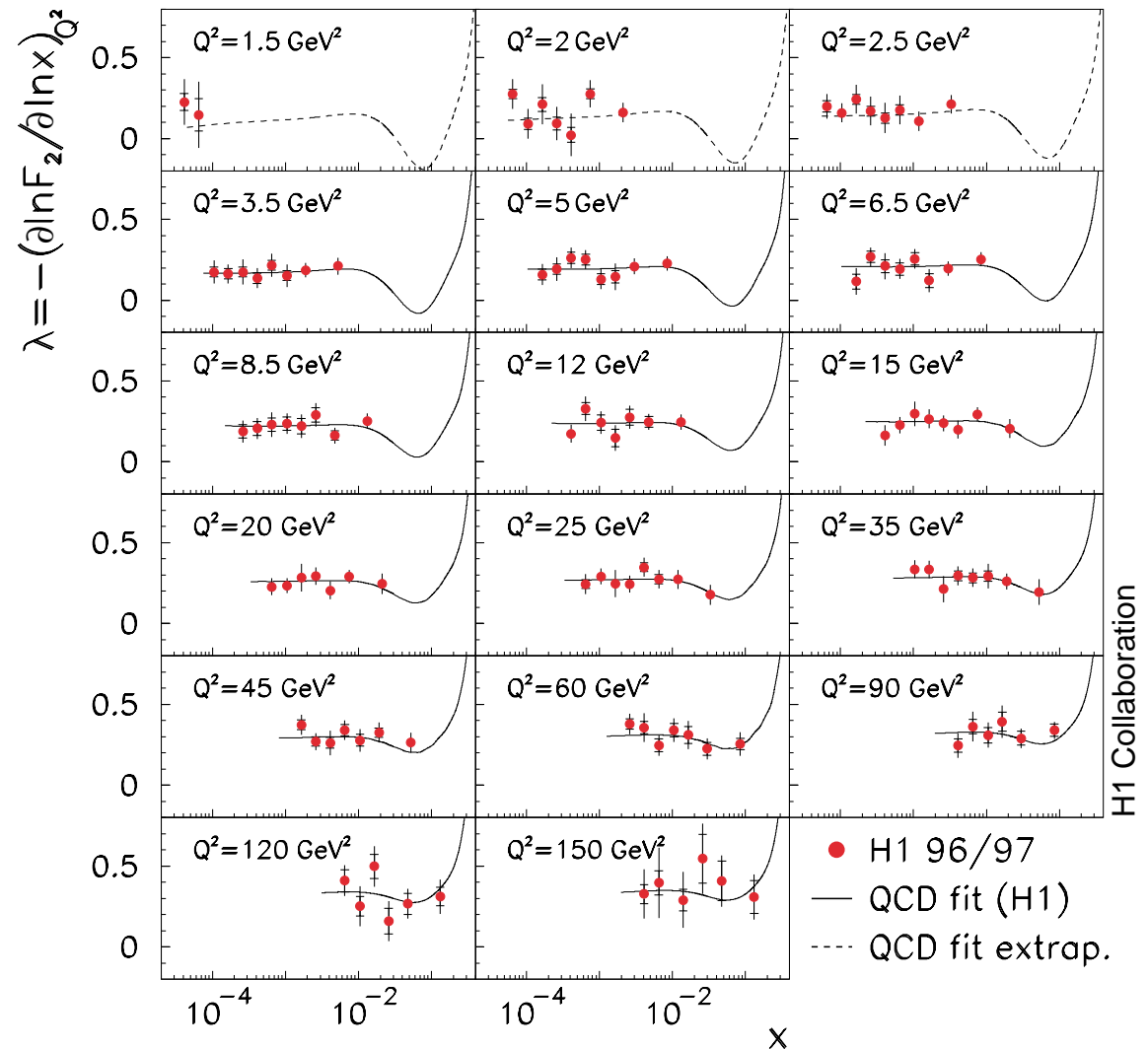
- the rise of F_2 becomes
  shallower when $Q^2 \to 0$.

Search for Deviations cont'd…

Probing the x dependence of
$F_2(x,Q^2)$

$\lambda = -d\ln F_2/d\ln x$

- for x<0.01 λ is compatible with being independent of x!

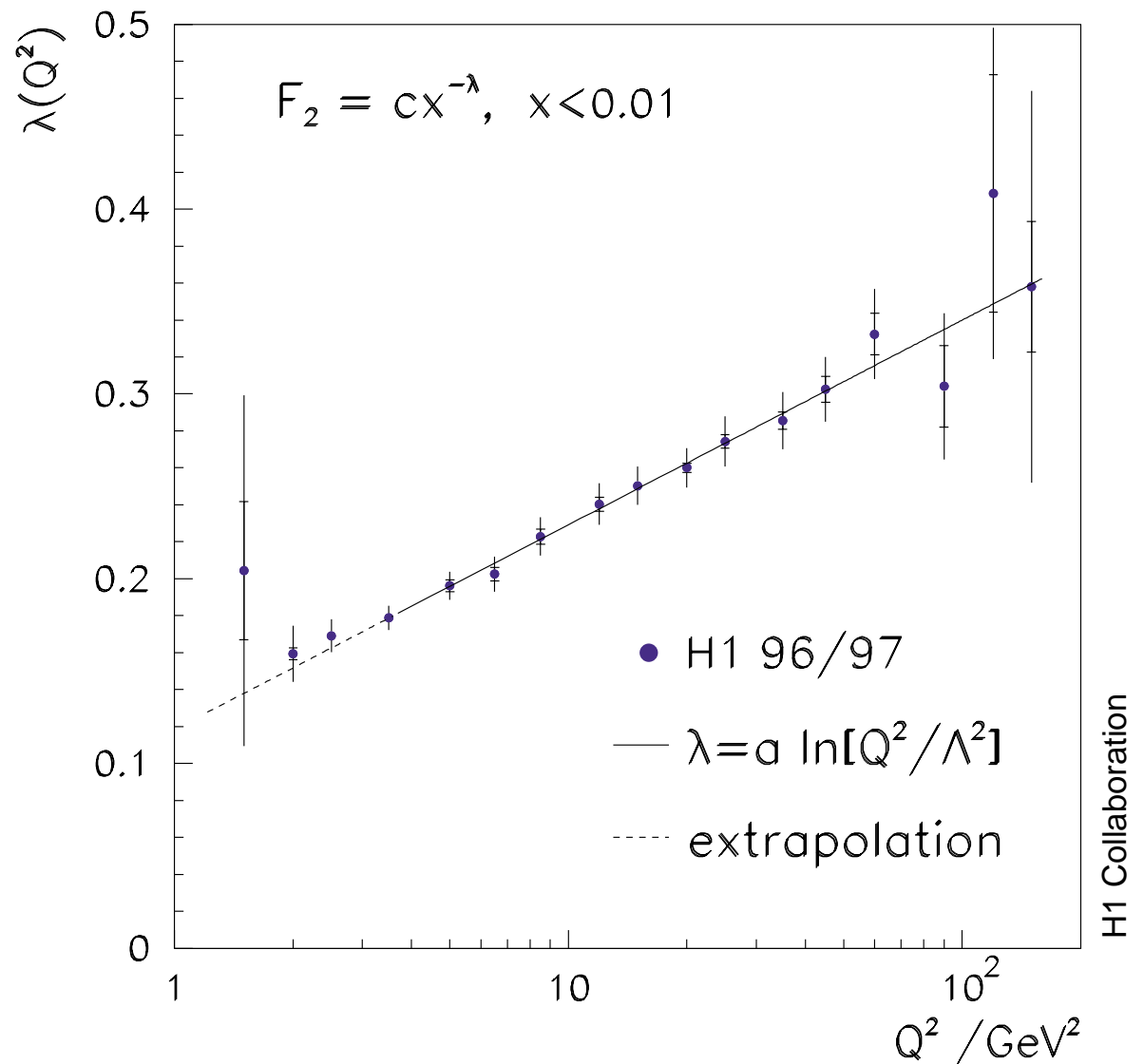Hence the onset of modifications of the rising behaviour occurs only at smaller x

The Q^2 Dependence of the Rise

$F_2(x, Q^2) \sim x^{-\lambda}$

- λ is independent of x
- $\lambda = \lambda(Q^2)$

λ rises linearly with Q^2

surprisingly simple
behaviour of the sea,
driven by the gluon

$F_2 = c x^{-\lambda}, \quad x < 0.01$

● H1 96/97

—— $\lambda = a \ln[Q^2/\Lambda^2]$

---- extrapolation

H1 Collaboration

$\lambda(Q^2)$

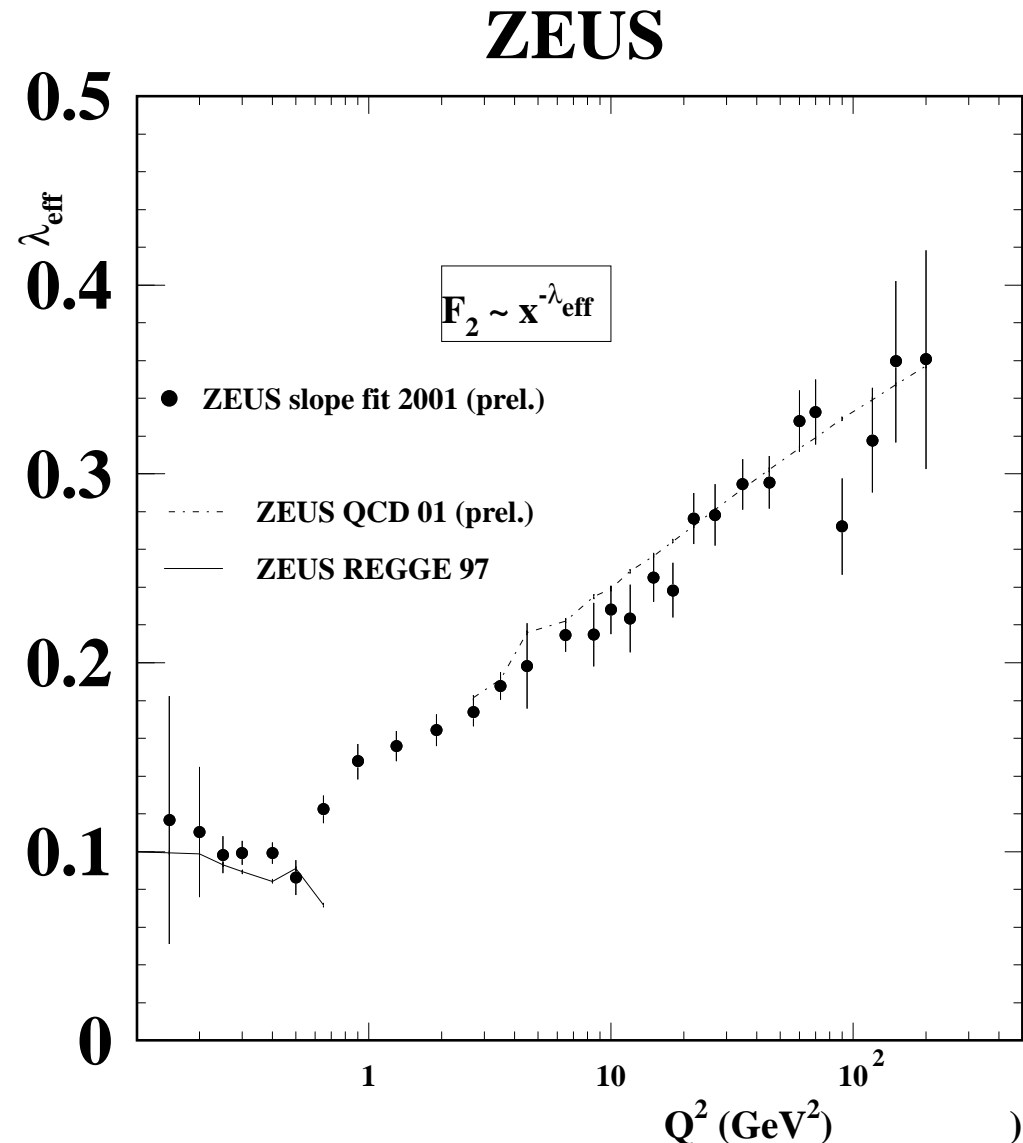Q^2 / GeV^2

Transition Region

$Q^2 < 1$ GeV^2

- BPC/BPT provided access to data below 1 GeV^2

Observations

- clear change of slopes at $Q^2 \sim 1$ GeV^2

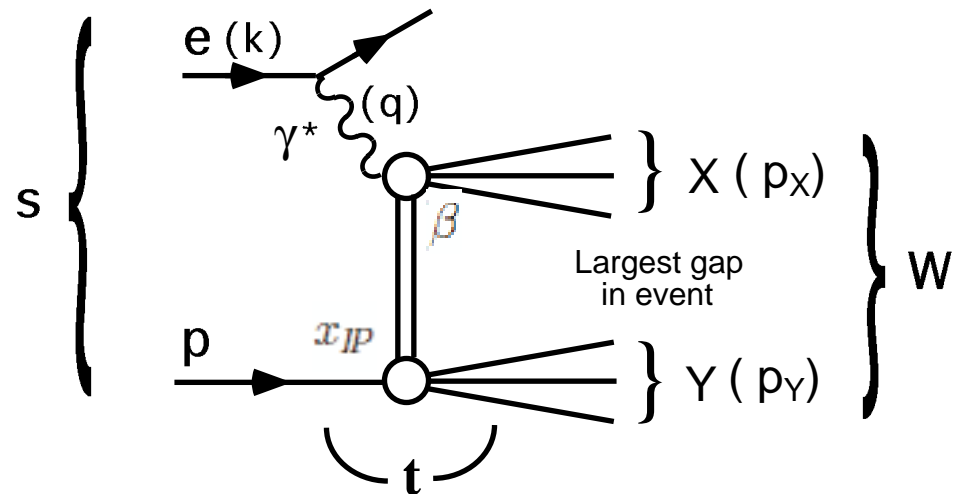- at small Q^2 λ is constant in agreement with the expectation for the total cross section

Note

with $F_2 \sim x^{-\lambda}$,
$\sigma \sim (W^2)^\lambda$, at fixed Q^2

ZEUS

$F_2 \sim x^{-\lambda_{\text{eff}}}$

- ZEUS slope fit 2001 (prel.)

-·-·- ZEUS QCD 01 (prel.)

——— ZEUS REGGE 97

Diffraction in DIS

Additional variable Q^2

- Observation of events with a large rapidity gap, seemingly independent of Q^2

- absence of colour flow

Interpretation Resolved Pomeron
(à la Ingelman & Schlein)

- partonic description of the colourless exchange in terms of pdf f_i^D:

$$f_i^D(x, Q^2, x_\mathbb{P}, t) = f_{\mathbb{P}/P}(x_\mathbb{P}, t) * f_i^\mathbb{P}(\beta = x/x_\mathbb{P}, Q^2)$$

Regge Analysis of $F_2^{D(3)}$

Decompose into

- Pomeron (Reggeon)

$$F_2^D(x_{\mathbb{P}}, \beta, Q^2) = f_{\mathbb{P}}(x_{\mathbb{P}}) A_{\mathbb{P}}(\beta, Q^2) +$$
$$f_{\mathbb{R}}(x_{\mathbb{P}}) B_{\mathbb{R}}(\beta, Q^2)$$

with $f_{\{\mathbb{P},\mathbb{R}\}}(x_{\mathbb{P}})$ from integration of energy dependence using
$$\alpha_{\{\mathbb{P},\mathbb{R}\}}(t) = \alpha_{\{\mathbb{P},\mathbb{R}\}}(o) + \alpha_{\{\mathbb{P},\mathbb{R}\}}' \, t$$
and DGLAP term for pdf which results in

$$\alpha_{\mathbb{P}}(o) = 1.173 \pm +0.018 \,(\text{stat.}) \pm$$
$$0.017 \,(\text{syst.}) +$$
$$0.063_{\,-0.035} \,(\text{model})$$

- cf. soft exchange:
$$\alpha_{\mathbb{P}}(o) = 1.08$$
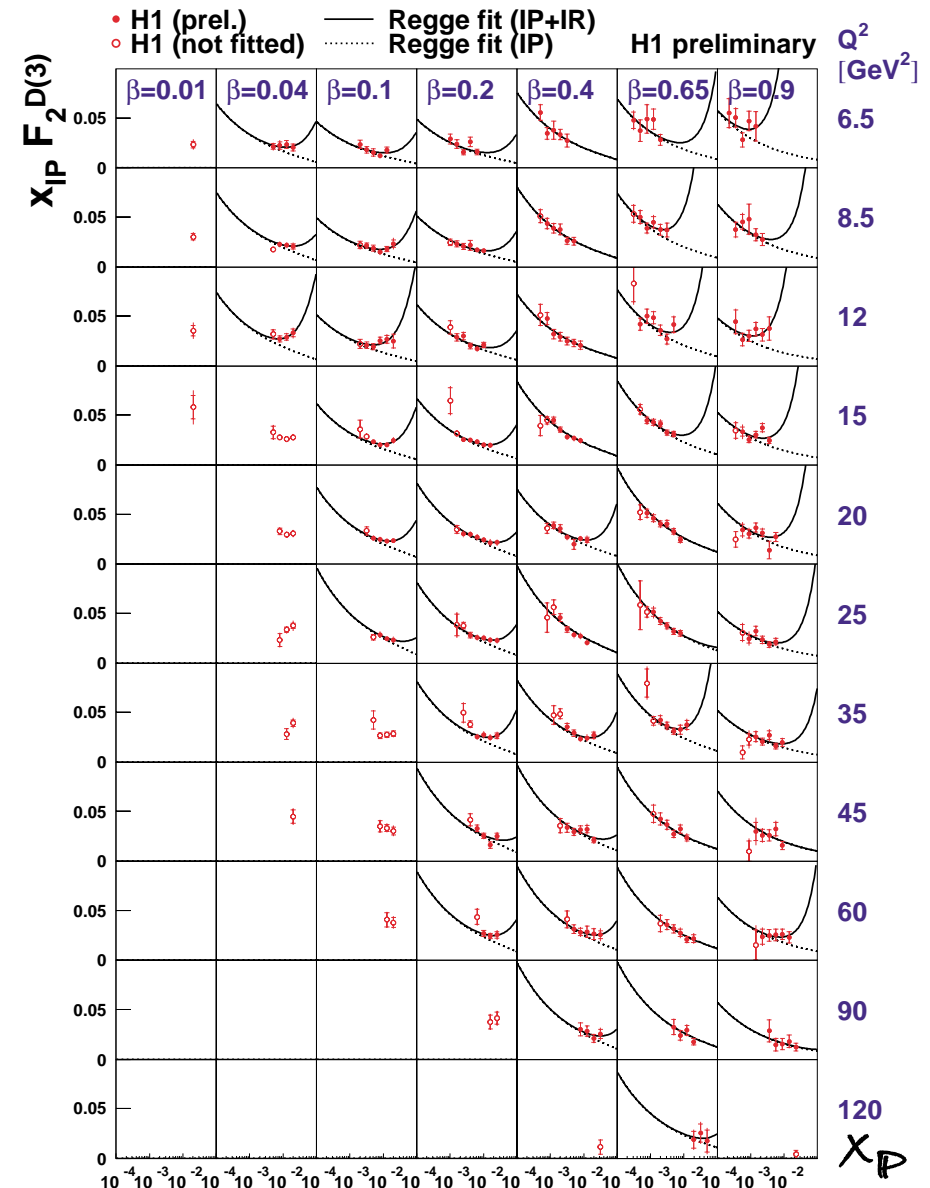
Comparison Inclusive and Incl. Diffractive

From Fits

- diffractive intercepts in broad agreement with those from the inclusive analysis

- diffractive slopes tend to be smaller than inclusive

Effective $\alpha_{IP}(0)$

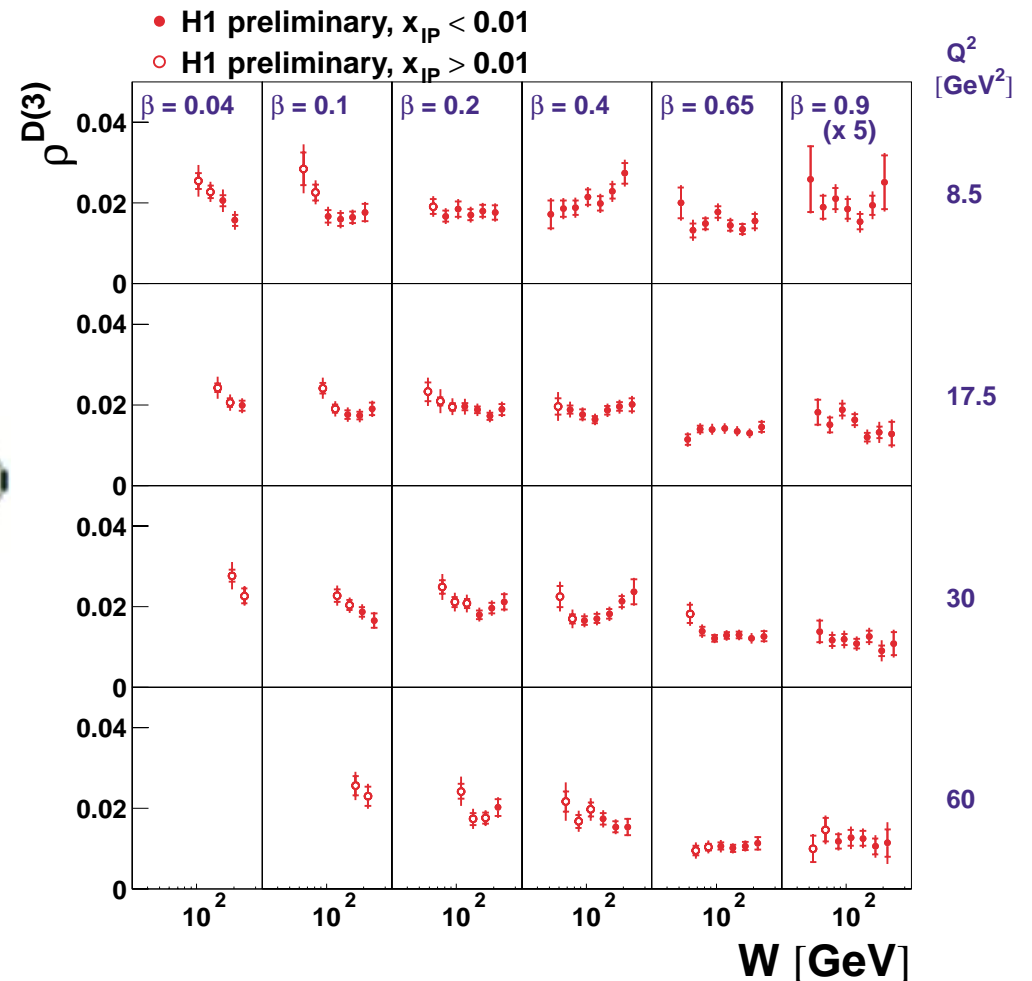**Inclusive**
- ■ H1 F_2 96-97

Diffractive
- ▲ H1 $F_2^{D(3)}$ 94
- ● H1 $F_2^{D(3)}$ 97 (prel.)

soft IP

$\alpha_{IP}(0)$

Q^2 [GeV^2]
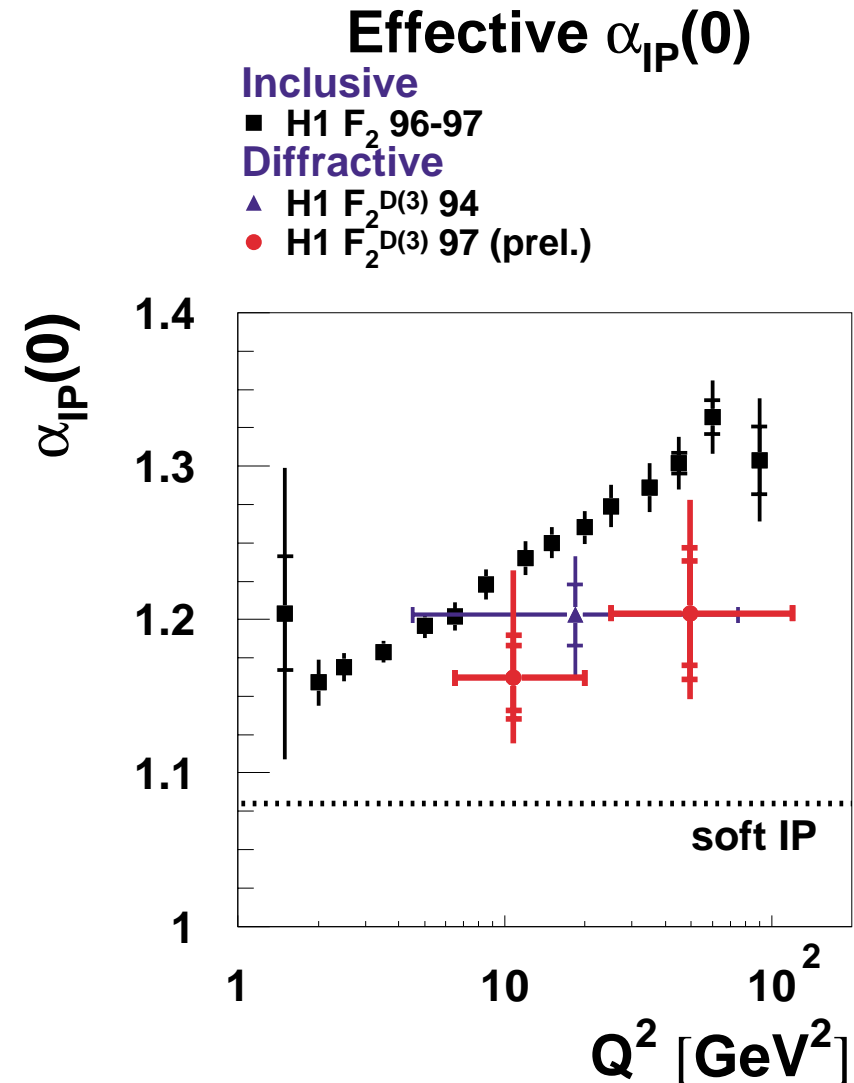
Energy Dependence of Diffractive / Total

The ratio $F_2^{D(3)}/F_2$

$$\bar{\rho}^{D(3)}(\beta, Q^2, x) = \frac{M_x^2 \, x}{Q^2} \cdot \frac{F_2^{D(3)}(\beta, Q^2, x_{I\!P})}{F_2(x, Q^2)}$$

after t-integration,

$$\bar{\rho}^{D(3)} = M_x^2 \frac{d\sigma(\gamma^* p \to XY)}{dM_x^2} \Big/ \sigma(\gamma^* p \to X)$$

- ratio seen to be largely independent of β, W and Q^2, except at low W and large β

- trend to decrease with Q^2, leading twist?!

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

Fit indicates
80-90% of the
momentum
made up by
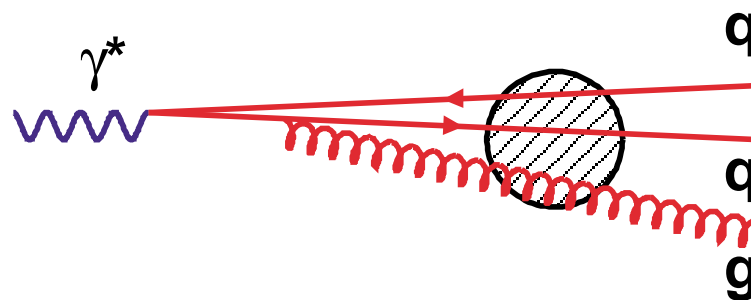gluons rather
independently
of Q^2

$\beta = 0.4$ H1 preliminary

$x_{IP}=0.001$, $x=0.0004$
$x_{IP}=0.003$, $x=0.0012$
$x_{IP}=0.01$, $x=0.004$
$x_{IP}=0.03$, $x=0.012$

$x_{IP} F_2^{D(3)}(x_{IP},\beta,Q^2)$ $F_2(x,Q^2)$

Q^2 [GeV^2]

● $F_2^{D(3)}(x_{IP},\beta,Q^2)$ H1 prel.
■ $F_2(x,Q^2)$ H1 96-97

$\beta = 0.9$ H1 preliminary

$x_{IP}=0.001$, $x=0.0009$
$x_{IP}=0.003$, $x=0.0027$
$x_{IP}=0.01$, $x=0.009$
$x_{IP}=0.03$, $x=0.027$

$x_{IP} F_2^{D(3)}(x_{IP},\beta,Q^2)$ $F_2(x,Q^2)$

Q^2 [GeV^2]

● $F_2^{D(3)}(x_{IP},\beta,Q^2)$ H1 prel.
■ $F_2(x,Q^2)$ H1 96-97
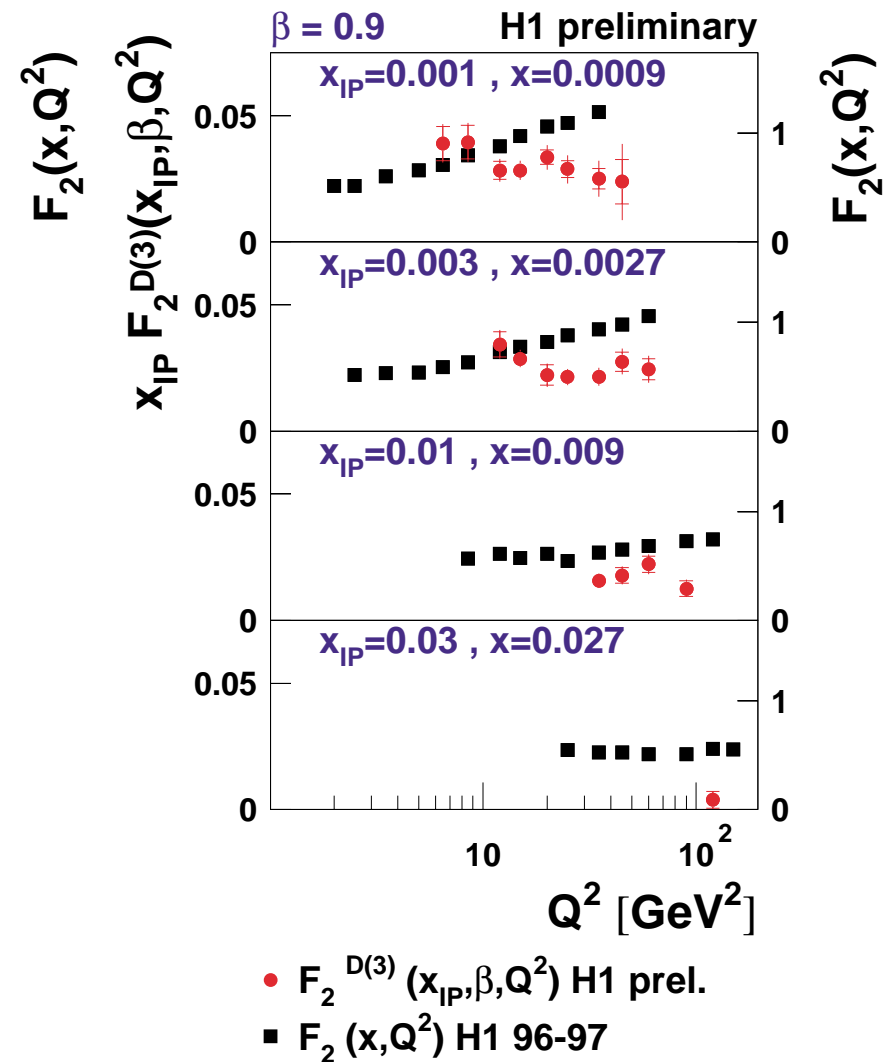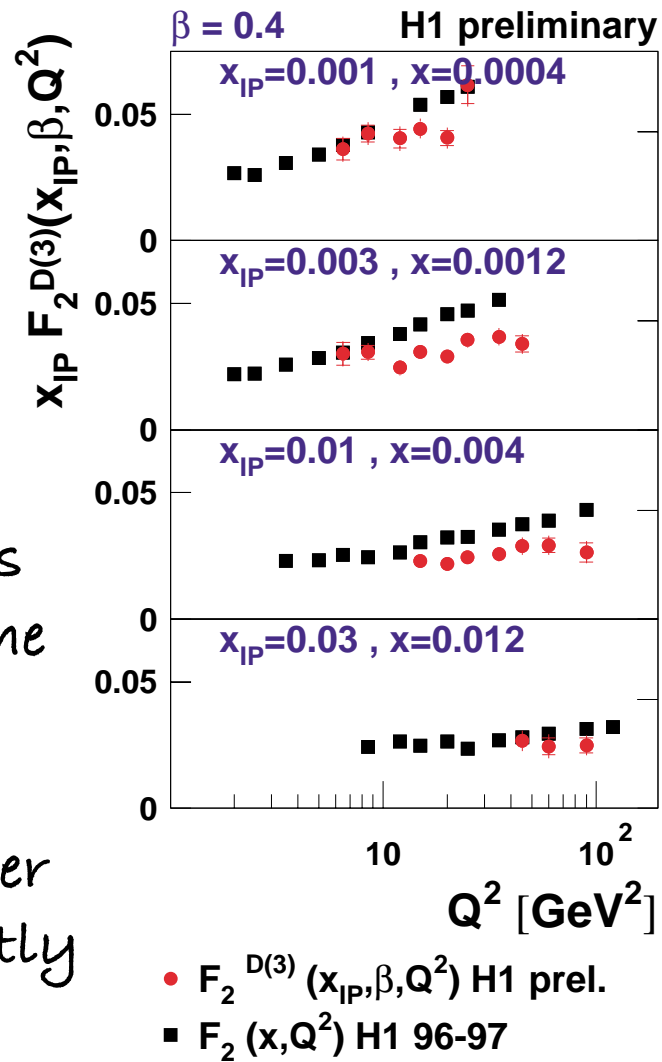
Modelling the Interaction
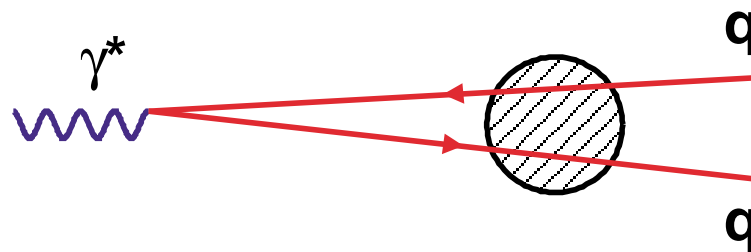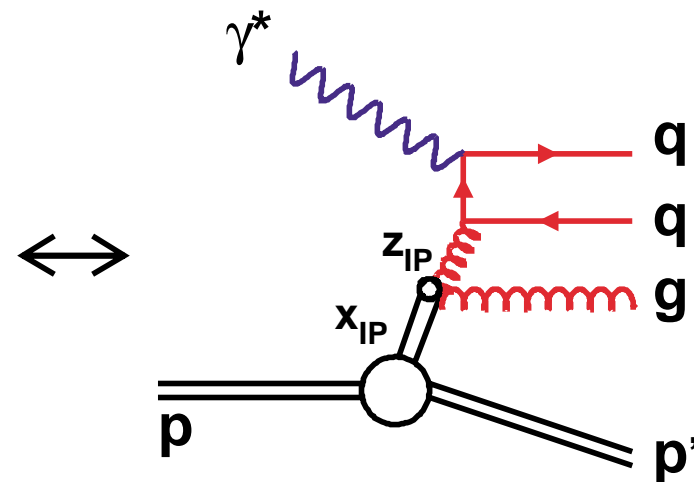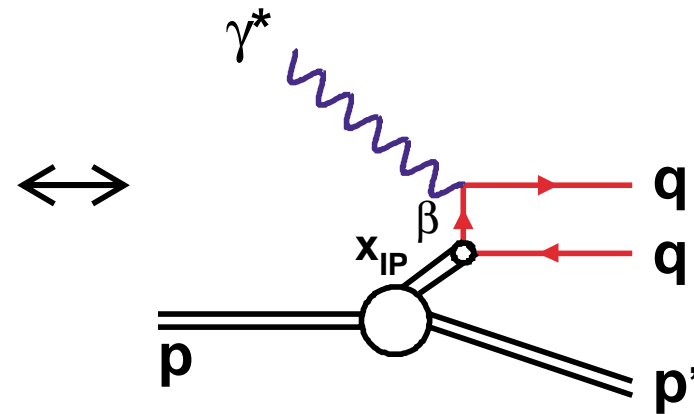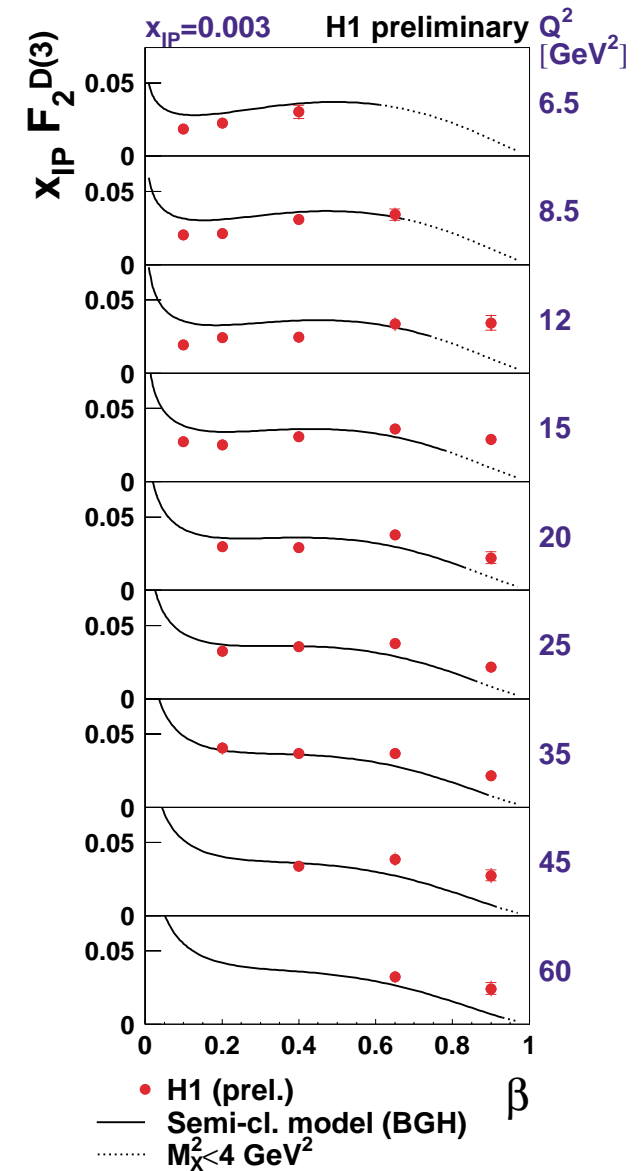
Comparison of Models
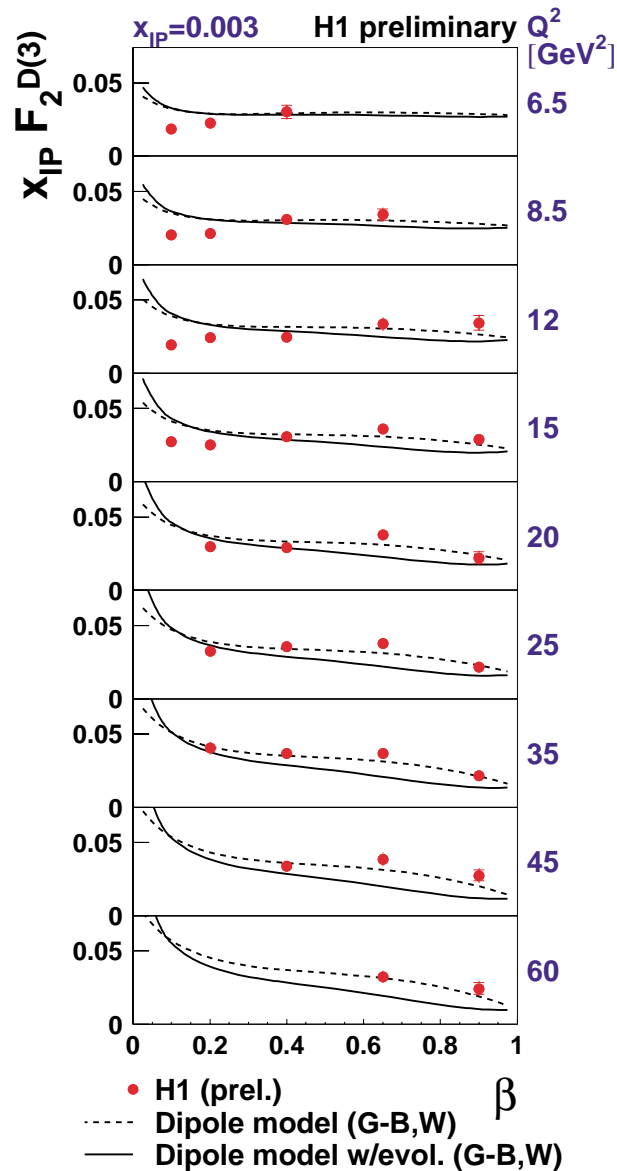
Both picture lead to fair description of the data

Dipole model:

- β dependence not fully reproduced
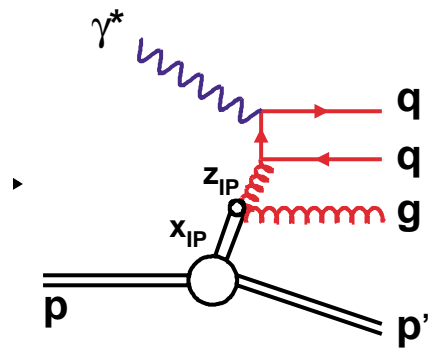- inclusion of evolution does not improve

Semi-Classical model:
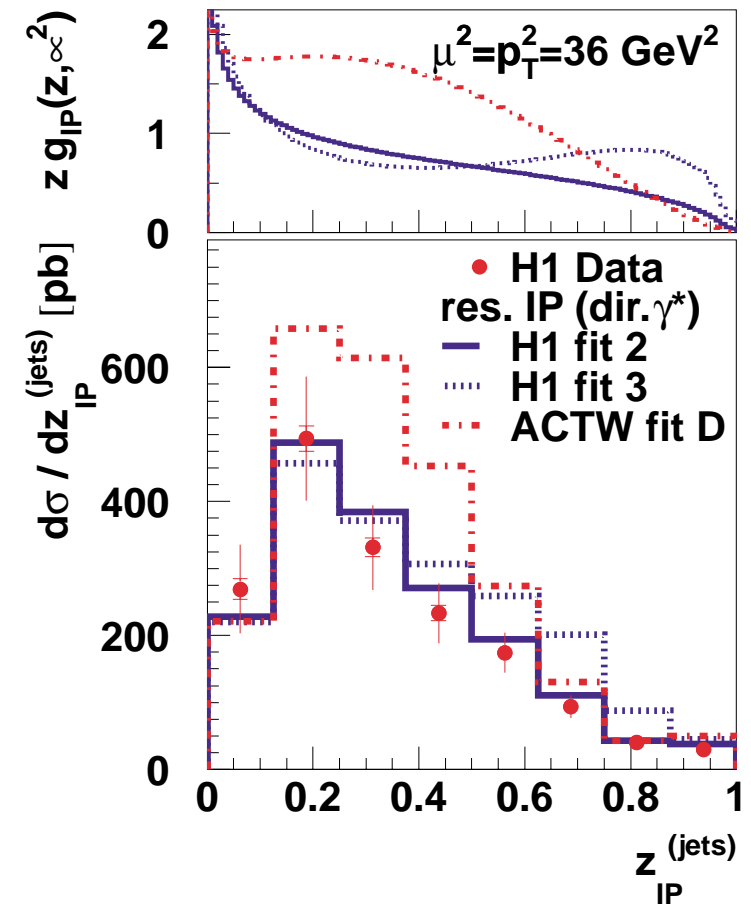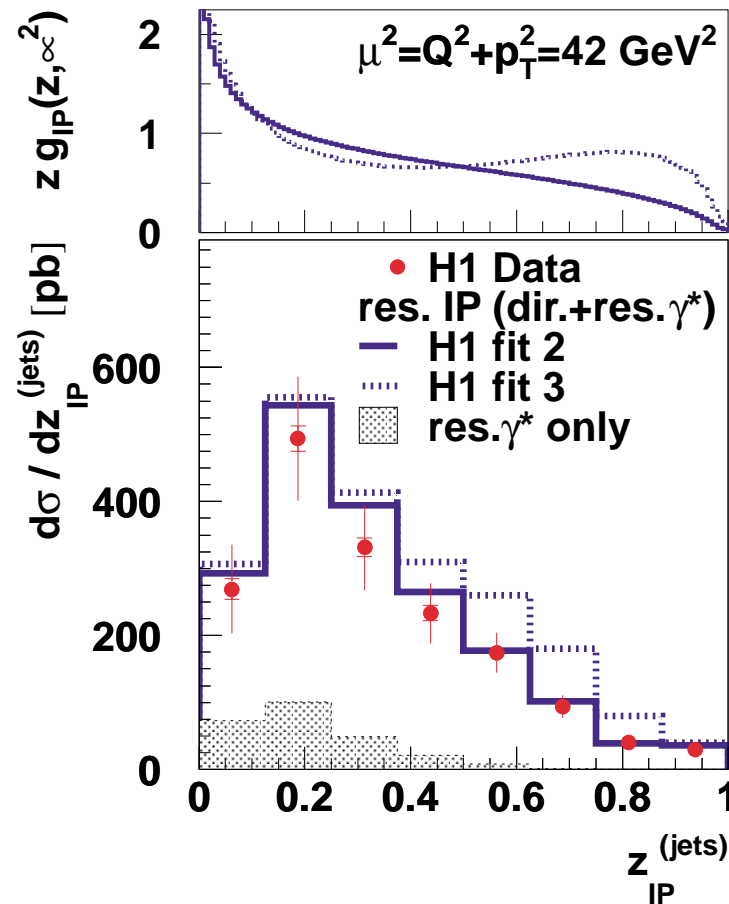
- low Q^2, low β

Diffractive Jets

Sensitivity to partonic content

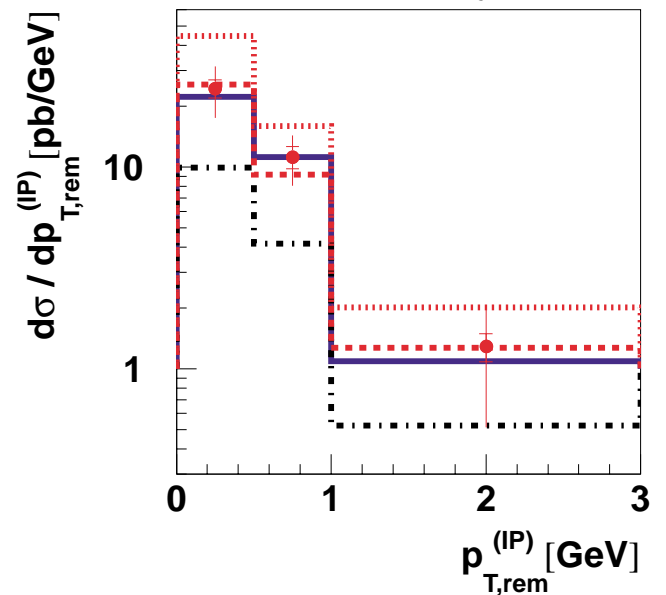- the colourless exchange is gluon domi- nated
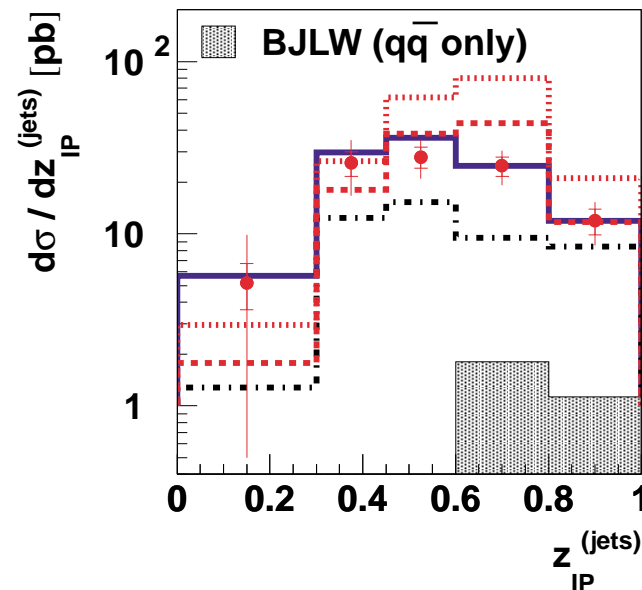
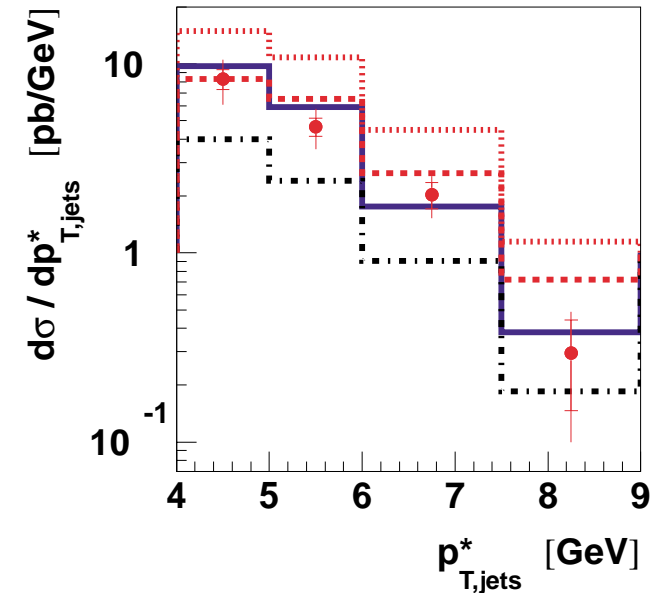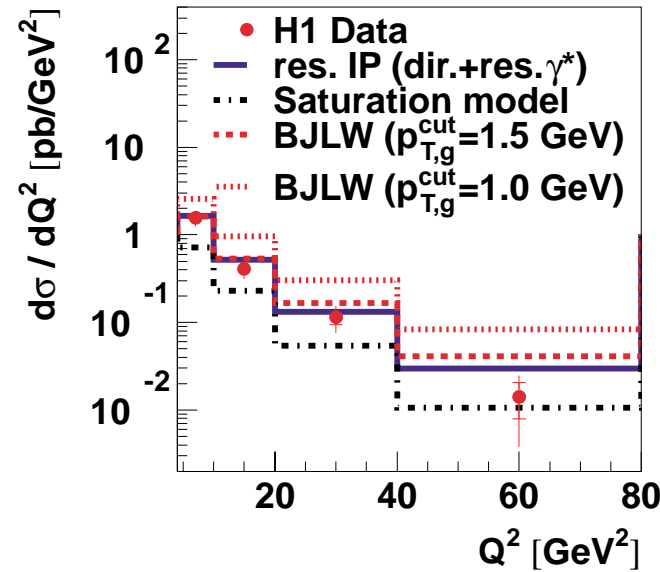$z_{I\!P}$ measured in final state

H1 Diffractive Dijets

Dipole Models and Dijet Data

for x_P < 0.01
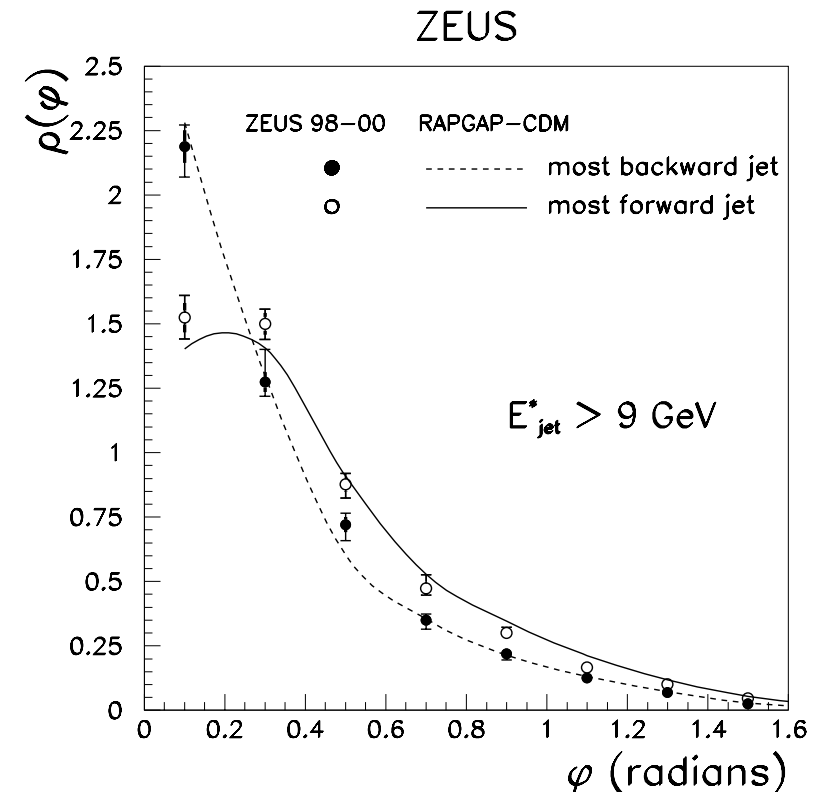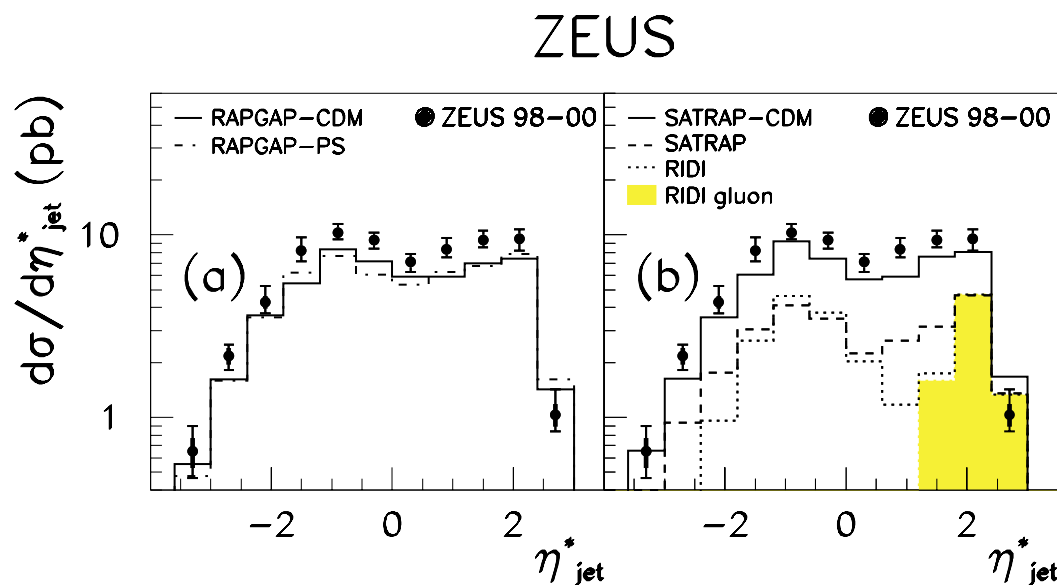
- Dipole model "with saturation" below data

- 2-gluon exchange model some arbitrariness in normalisation...

3-Jet Analysis in Diffractive Events

Gluon jets known to be broader

- Analysis of 3-jet topologies in diffractive events

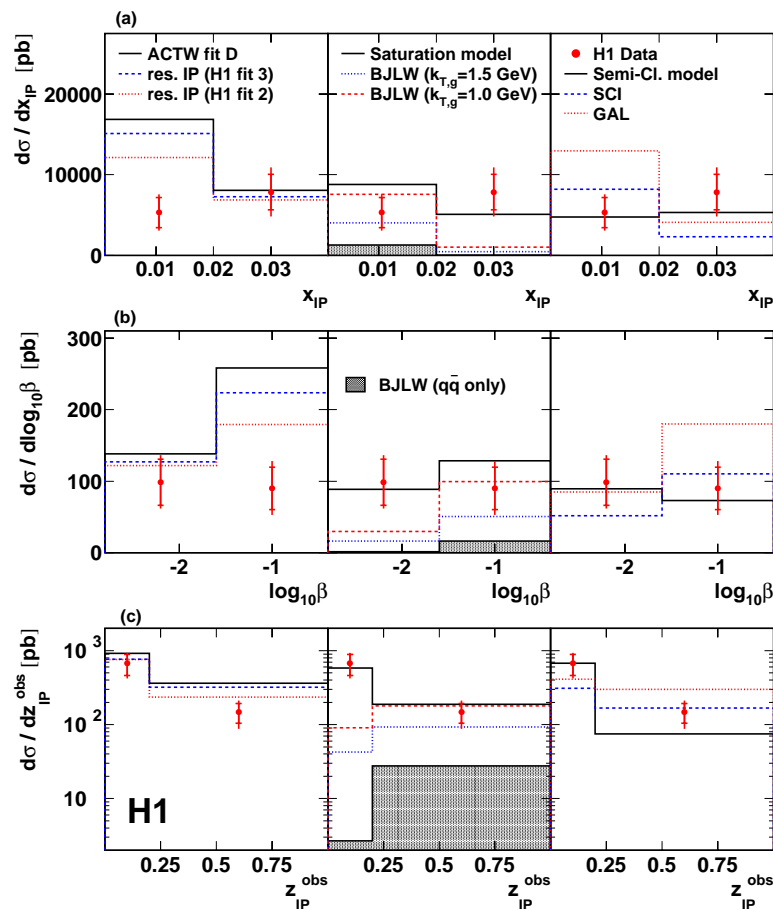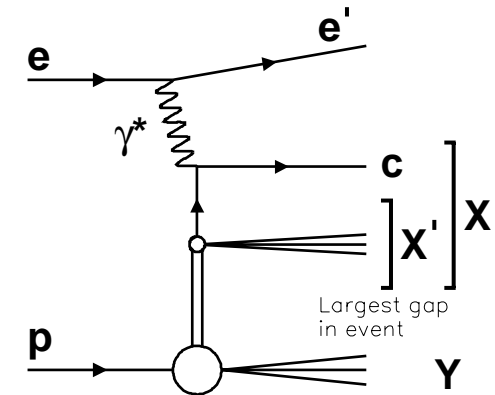- most forward/backward jets can be used to tag the colour singlet exchange

ZEUS

ZEUS

Forward jet seen to be broader
- smells like a gluon

Colour singlet exchange is gluon dominated

Diffractive Charm

Charm in final state

- production mechanism sensitive to quark content of the diffractive exchange.


Rates:

- smaller than expected

Model	cross section [pb]
resolved Pomeron	~400
SCI	203
GAL	328
H1 data	246±54±56

Diffractive Jets at the Tevatron

Comparison of the diffractive jets

- transfer the partonic description of the colourless exchange to Tevatron data.

- very large difference (significant despite the uncertainties at large β).

- recently: inclusion of Large Rapidity Gap (LRG) survival probability (Kaidalov et al.) yields agreement
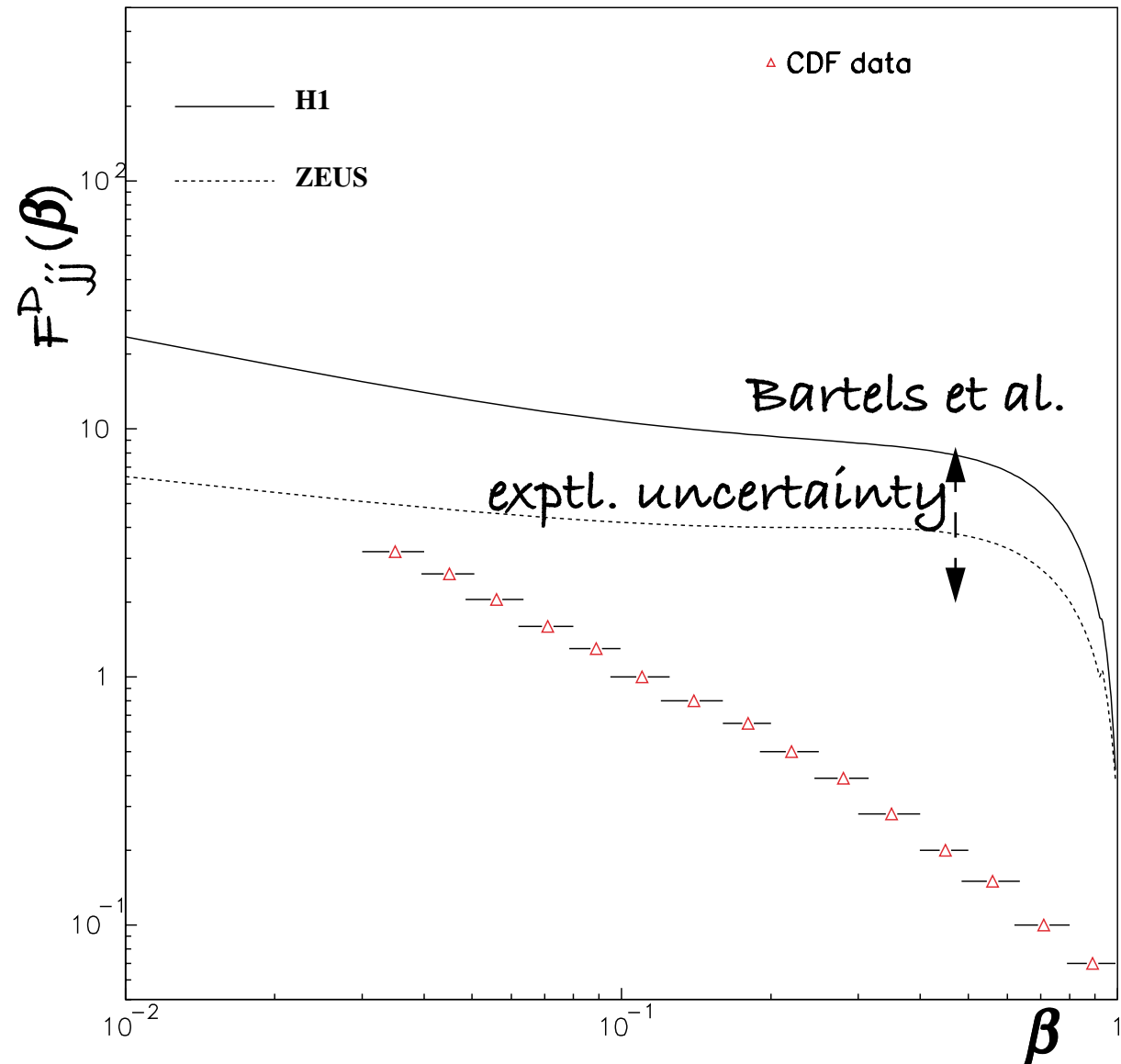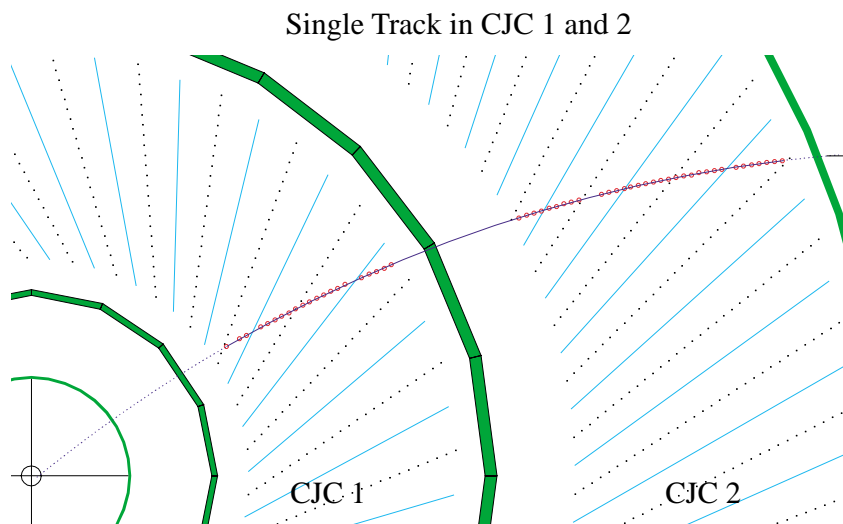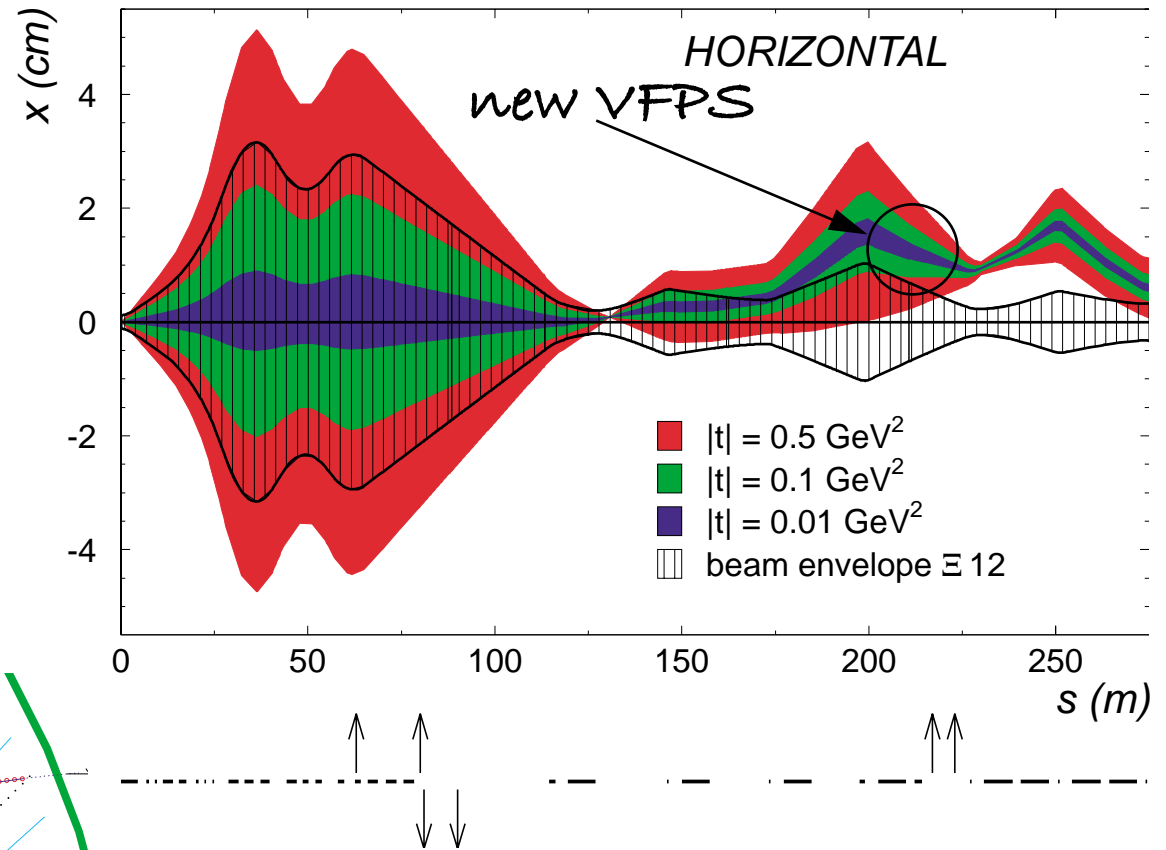
Outlook

After the Luminosity
upgrade of HERA

High acceptance forward
proton tagging

Improved track Triggering

Single Track in CJC 1 and 2

CJC 1   CJC 2

HORIZONTAL

new VFPS

🟥	$|t| = 0.5$ GeV^2
🟩	$|t| = 0.1$ GeV^2
🟪	$|t| = 0.01$ GeV^2
▦	beam envelope Ξ 12

x (cm)

s (m)

Benefits for

• incl. VM, D*, jets

• recognition of p-dissociative procs

Conclusion

Revival of Diffraction since HERA and Tevatron

- hard diffraction clearly established
- the colourless exchange persists at large virtualities
- transition soft – hard studied in several processes
- QCD interpretations are appealing; considerable progress; modelling is based on
  - dipole approach
  - partonic description
    not yet perfect
- low x

  - a powerful tool to study the energy dependence, $W^2 \sim Q^2/x$
  - available range not sufficient to study unitarity effects
- context with Tevatron not trivial;
  gap survival probabilities.