Challenges of HERA

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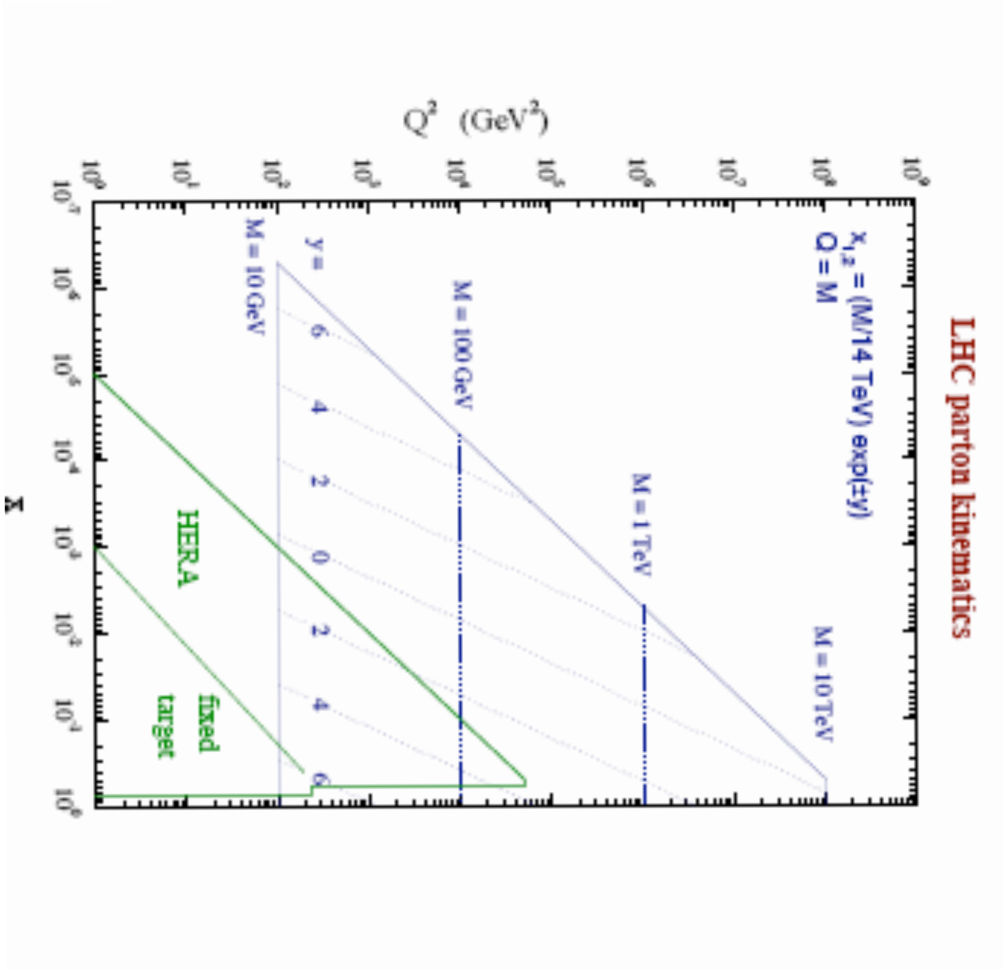
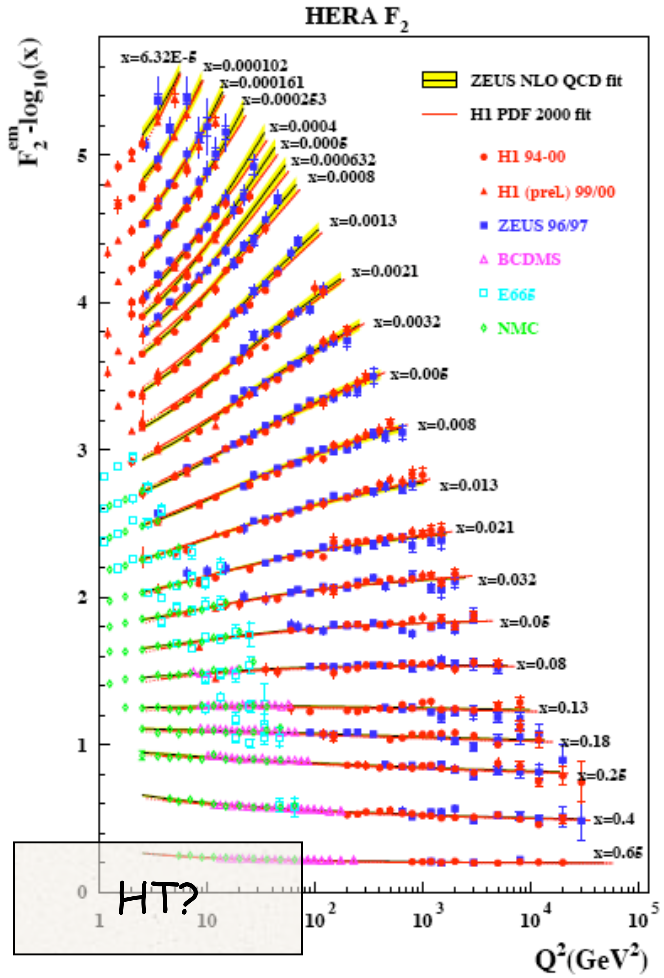
- Global fits of PDFs
- Diffraction
- Jets

PDFs from global fits to F_2





Weakness of global DGLAP fits at low x

- At low x, short lever arm in Q^2
- Constraints to low x from high x only at high Q^2
- Backward evolution uses unmeasured region of low x
- At large x, HT effects at most parametrised!

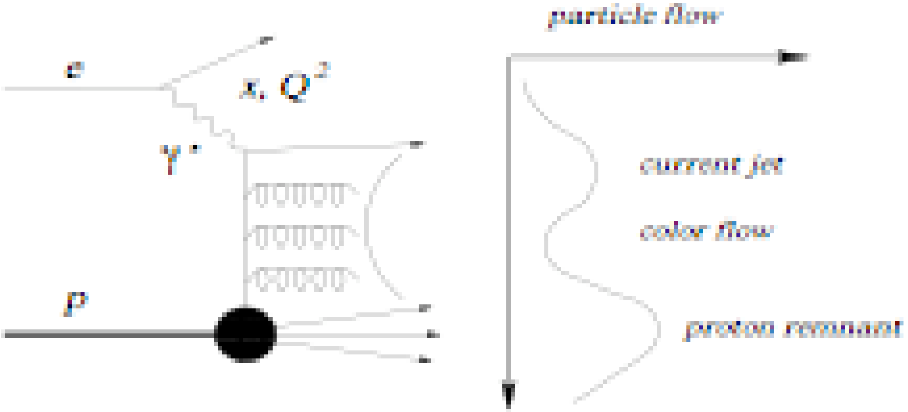
- No rigorous proof that solution is unique
- Theoretically large ($\alpha_S \ln 1/x$) terms expected (BFKL)
- Good χ^2 may not be the ultimate proof

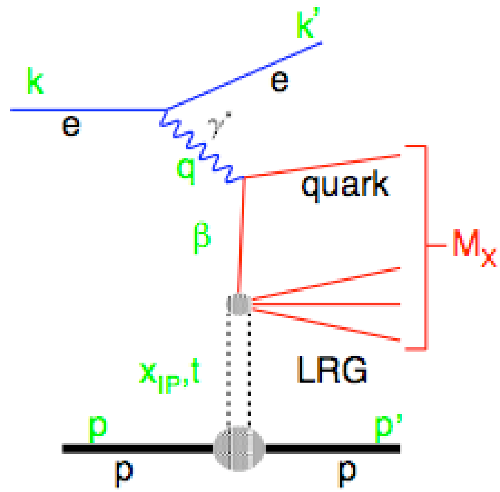
- Measurements of F_L - independent test of gluons in the same region of x and Q^2 - may turn out to be essential

Signs of problems: Diffraction

- Large fraction of DIS events have LRG (visible 10%)

DGLAP





$$Q^2 = -q^2 = -(k-k')^2$$
$$x = \frac{Q^2}{2P\cdot q}$$
$$y = \frac{q\cdot P}{k\cdot P}$$
$$W^2 = (q+P)^2$$

$$t = (p-p')^2$$
$$x_{I\!P} = \frac{q\cdot(p-p')}{q\cdot p} \simeq \frac{Q^2+M_X^2}{Q^2+W^2}$$
$$\beta = \frac{Q^2}{2q\cdot(p-p')} \simeq \frac{Q^2}{Q^2+M_X^2}$$

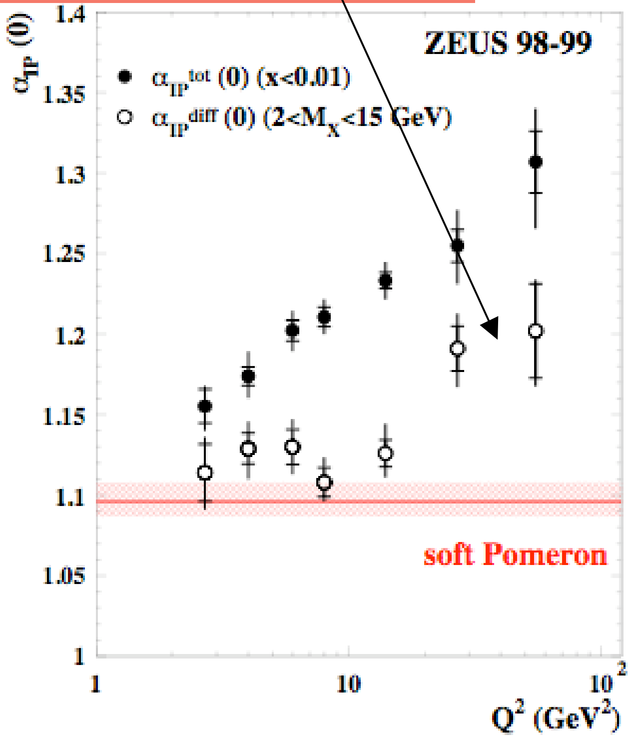
LRG cannot be generated by DGLAP.
Maybe it is there in the initial condition?

Diffraction soft/hard?

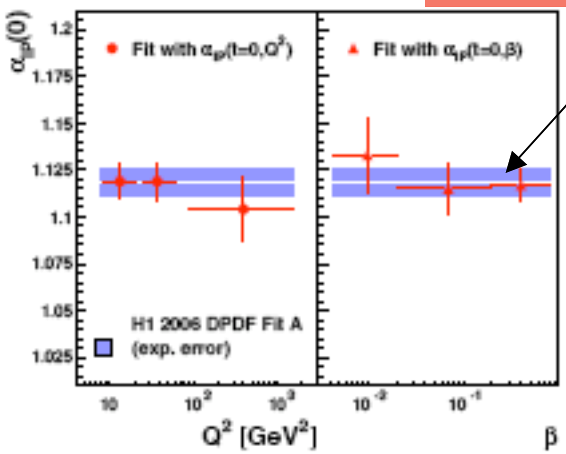
- Extraction of α_{IP} from DIS diffraction

$$\sigma_{tot} \propto s^{\alpha_{IP}(0)-1}$$

Incompatible with LRG in initial condition



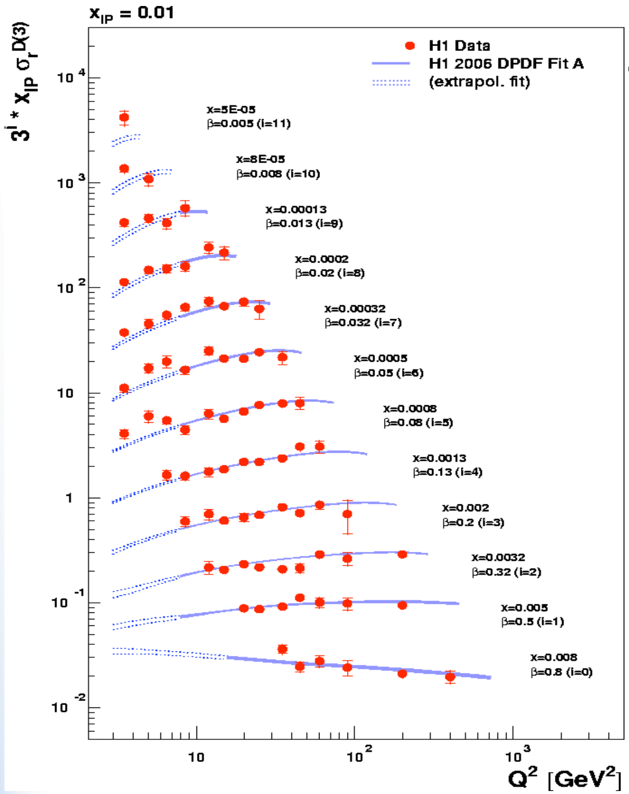
Compatible with LRG in initial condition

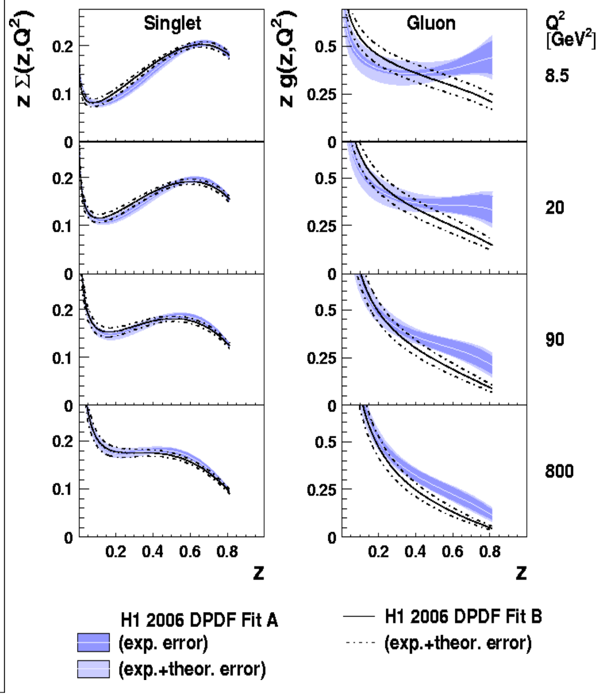


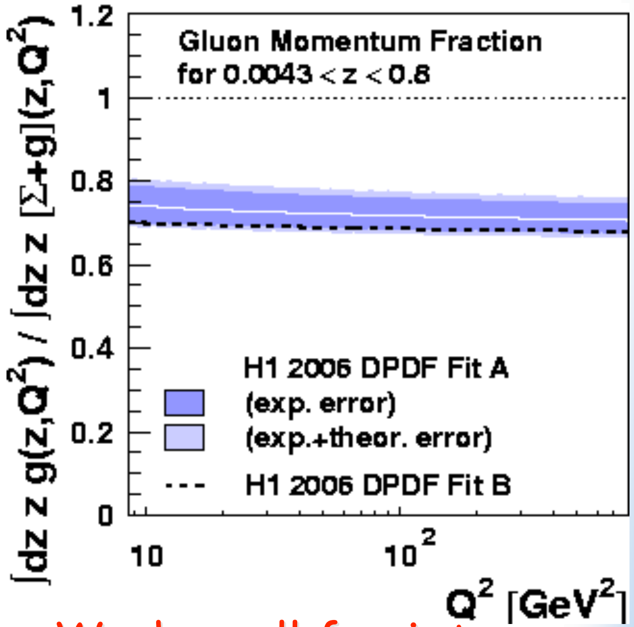
Indication that α_{IP} in DIS harder than in hadron-hadron

QCD factorisation for diffraction in DIS?

• QCD factorisation holds for diffractive PDF = that fraction of proton PDF that lead to LRG events







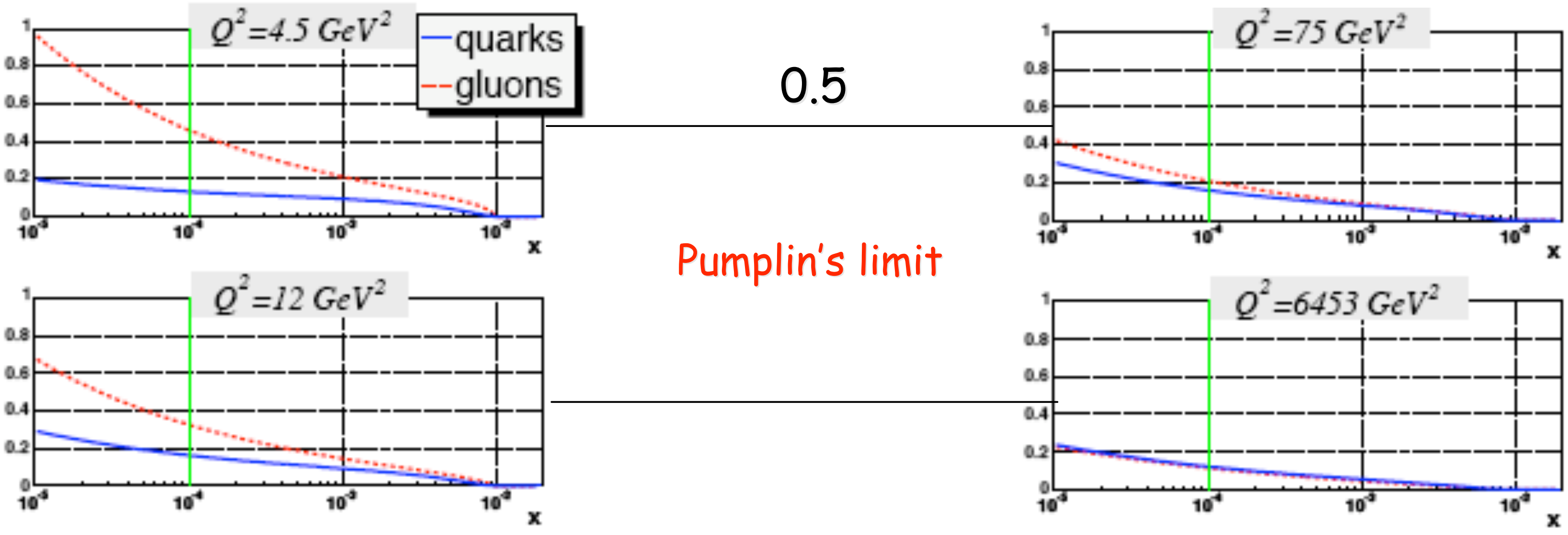
Works well for jets and heavy flavor

Diffraction as sign of screening?

Diffraction as elastic
$\gamma^* p \rightarrow \gamma^* p$

$$P_g^D(x,Q^2) = \frac{\int_{x/0.01}^1 d\beta \, \frac{1}{\beta} f_{\mathbb{P}/P}(\frac{x}{\beta}) \, g^{\mathbb{P}}(\beta,Q^2)}{g^P(x,Q^2)},$$

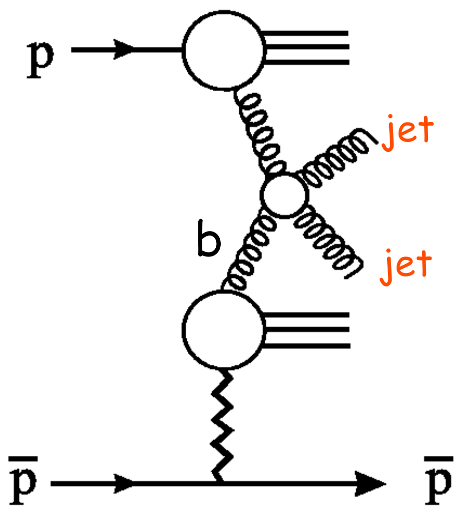
$$P_q^D(x,Q^2) = \frac{\sum_i \int_{x/0.01}^1 d\beta \, \frac{1}{\beta} f_{\mathbb{P}/P}(\frac{x}{\beta}) \, q_i^{\mathbb{P}}(\beta,Q^2)}{\sum_i q_i^P(x,Q^2)},$$

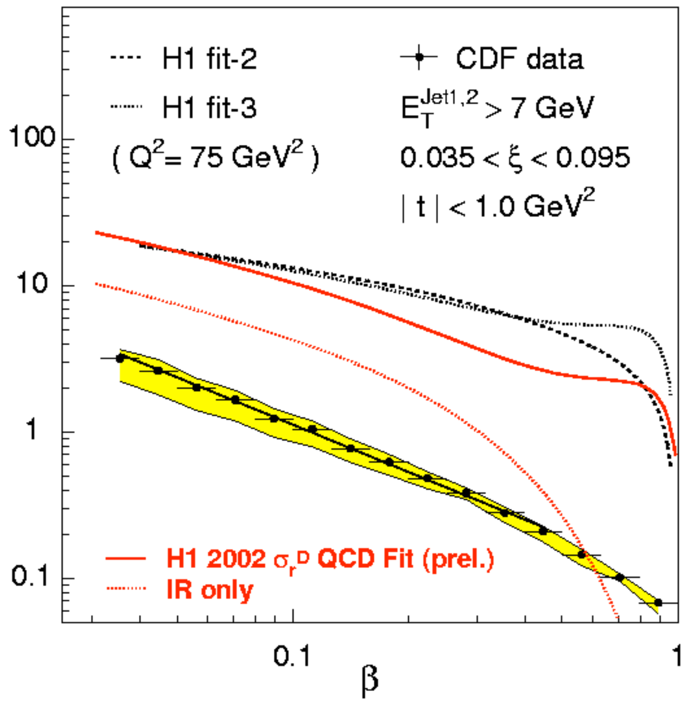


Sign of black body limit???

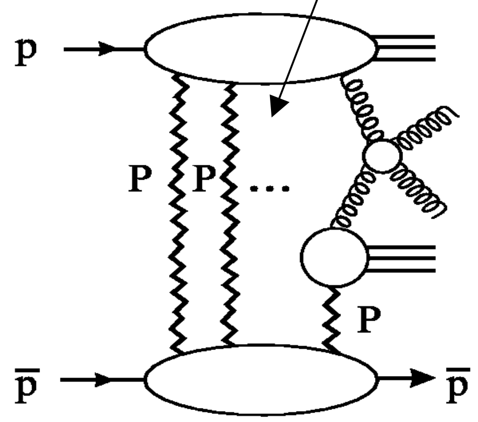
What about QCD factorization?

- Diffractive PDF's expected to be non-universal (J. Collins)!

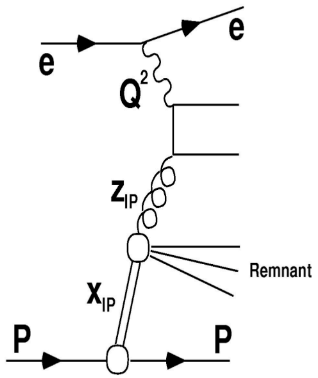


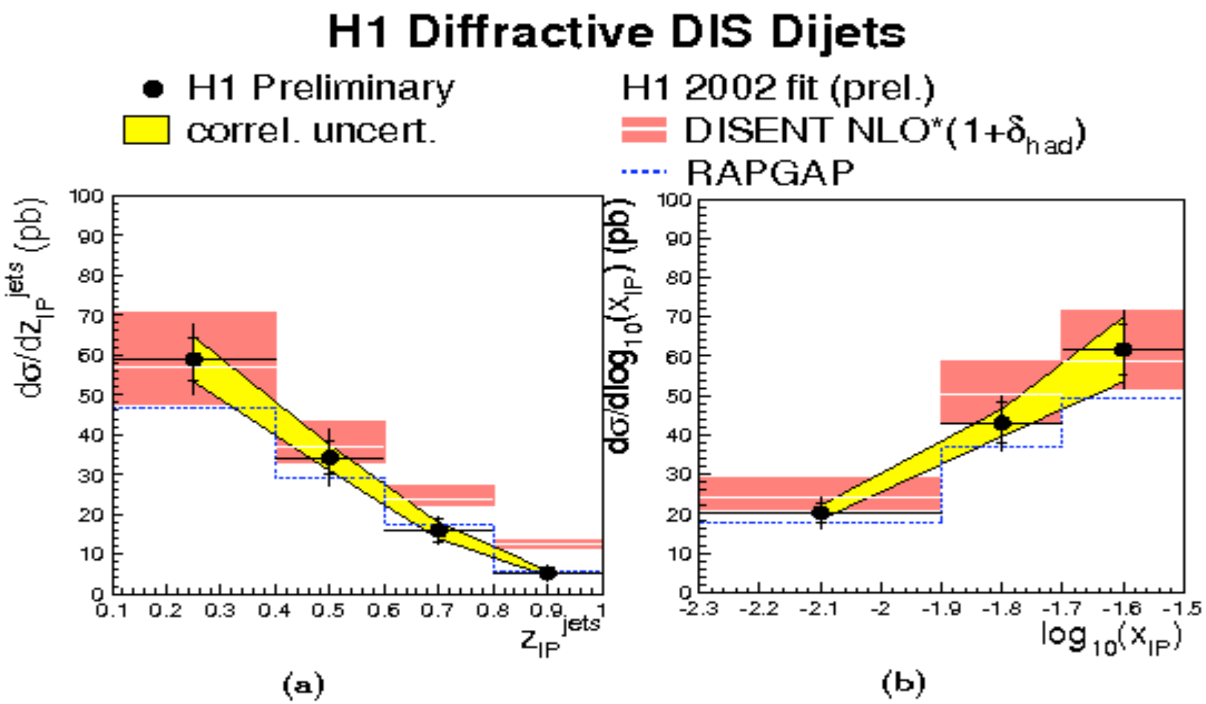


Possible explanation
- rescattering



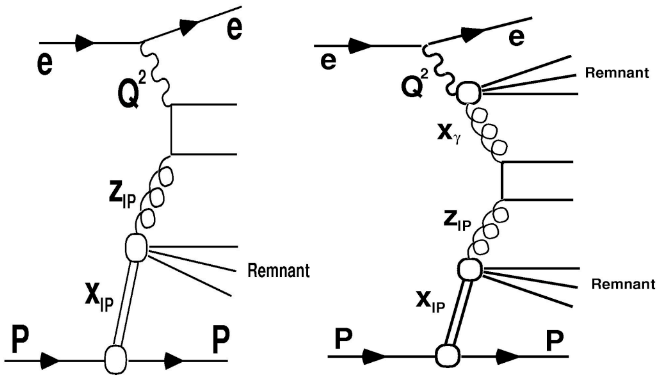
Diffractive dijet production in DIS



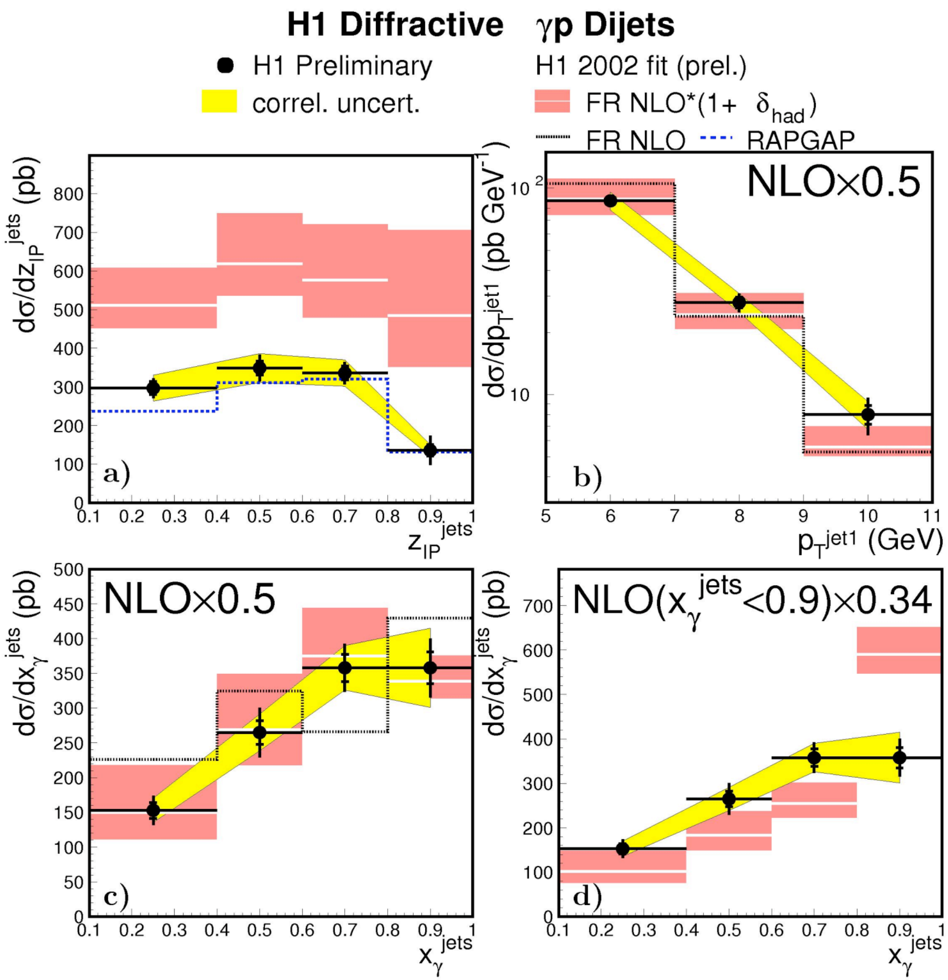


- use diffractive pdfs, obtained from F2D
- predict cross section in diffractive DIS
- x section is described

Diffractive factorization in γp



- use diffractive pdfs also for photo production dijets
- predicted cross section ~ factor 2 too large
- similar effect seen in proton-proton collisions
- factorization is broken



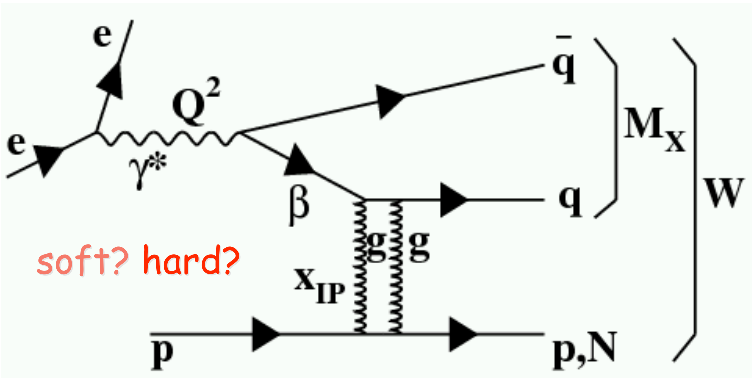
QCD factorization !!!

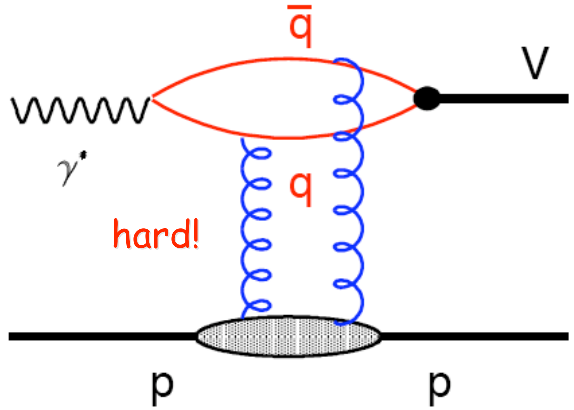
- Of the order of 10% of DIS (LRG) cross section cannot be accounted for in pp, nor in γp
- Inclusive factorization seems to be preserved by rescattering !!!

o Possible implications for MPI…

Diffraction has a hard component

- Exclusive Vector Meson production





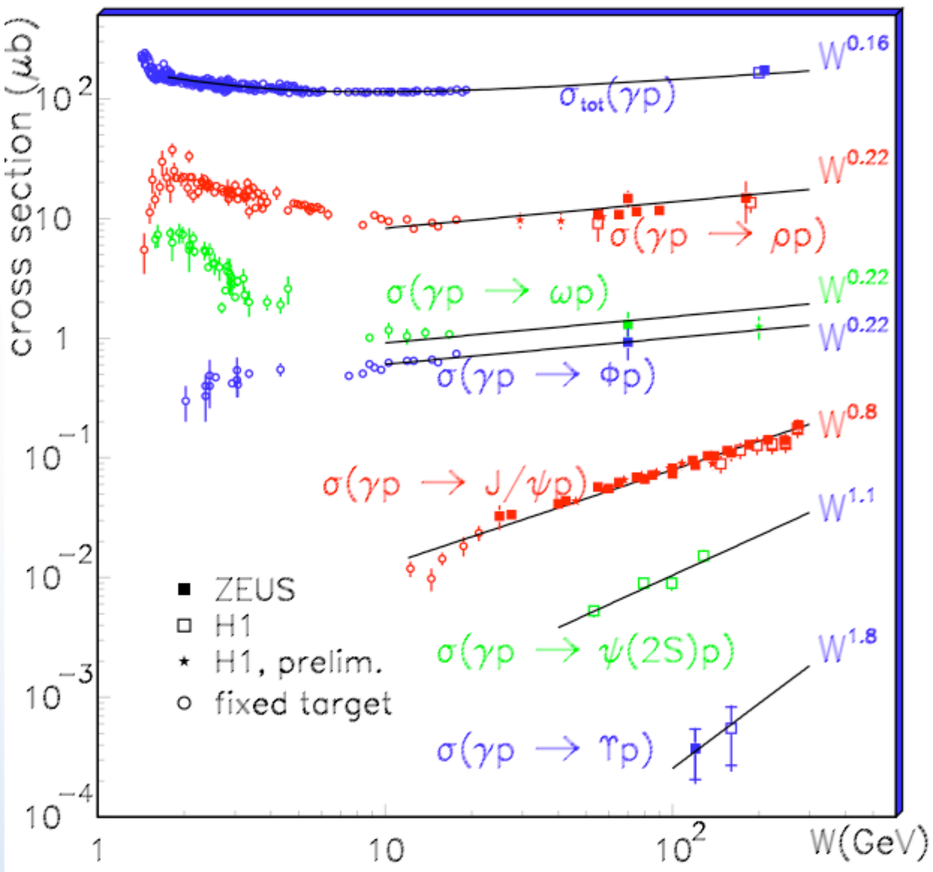
$$\sigma(W) \Rightarrow \delta \quad (\propto W^{\delta})$$

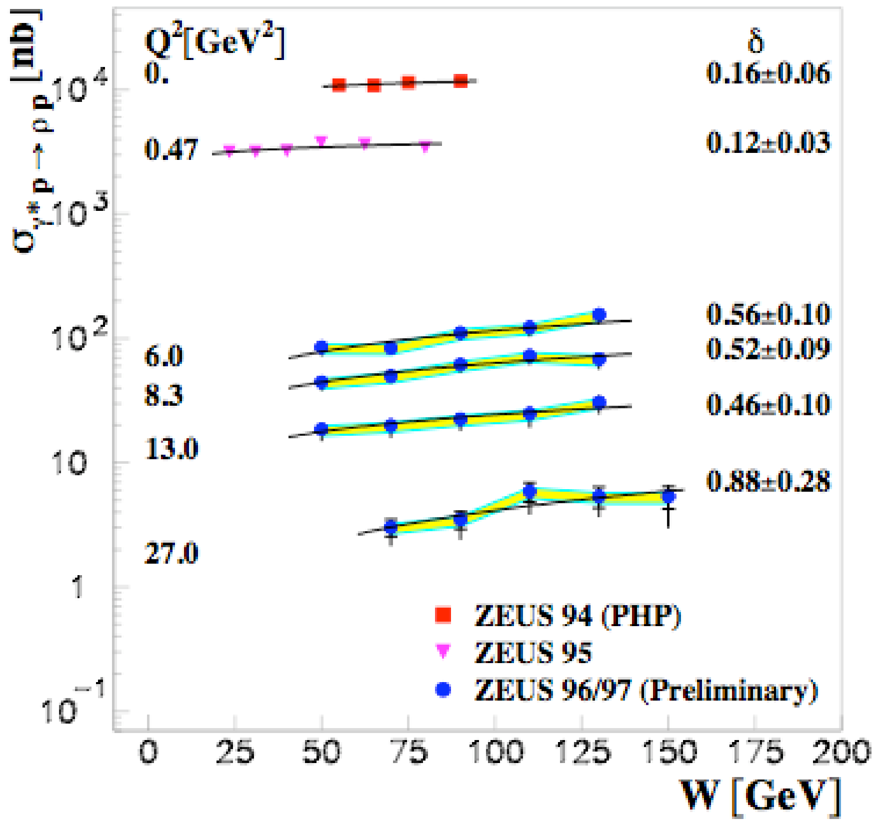
$$\sigma(Q^2) \Rightarrow n \quad (\propto (Q^2 + M^2)^{-n})$$

$$\frac{d\sigma}{dt} \Rightarrow b(Q^2) \ (\propto e^{-b|t|}) \ , \ \alpha_{IP}(t) \ (\propto W^{4(\alpha_{IP}-1)}) \ , \ n \ (\propto |t|^{-n} \text{ at large} |t|)$$

$$r_{ij}^{k} \Rightarrow R(W) \ , \ R(Q^2)$$

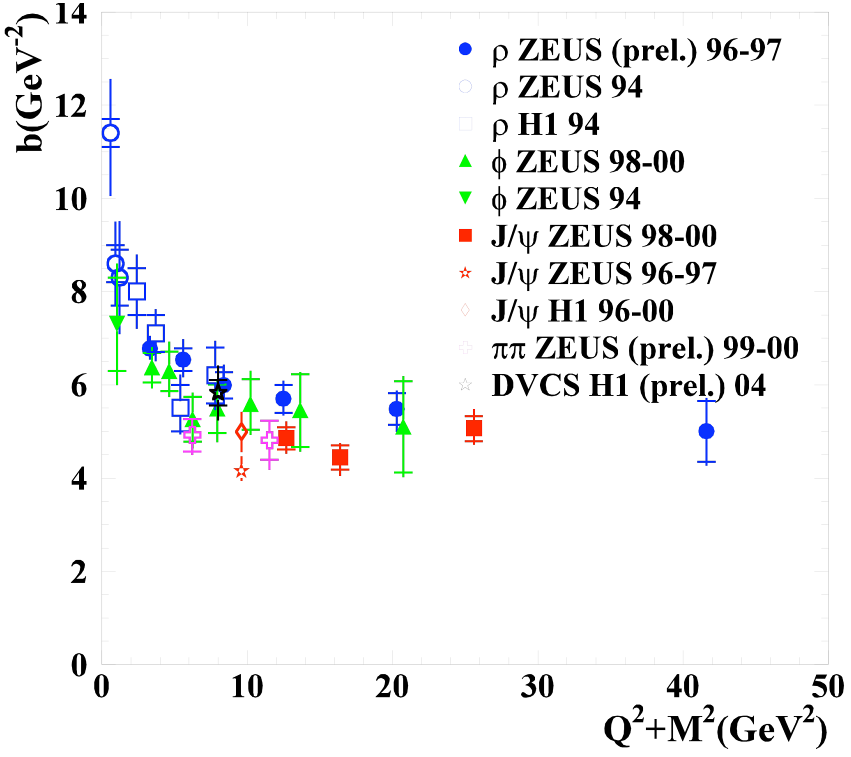
Exclusive processes

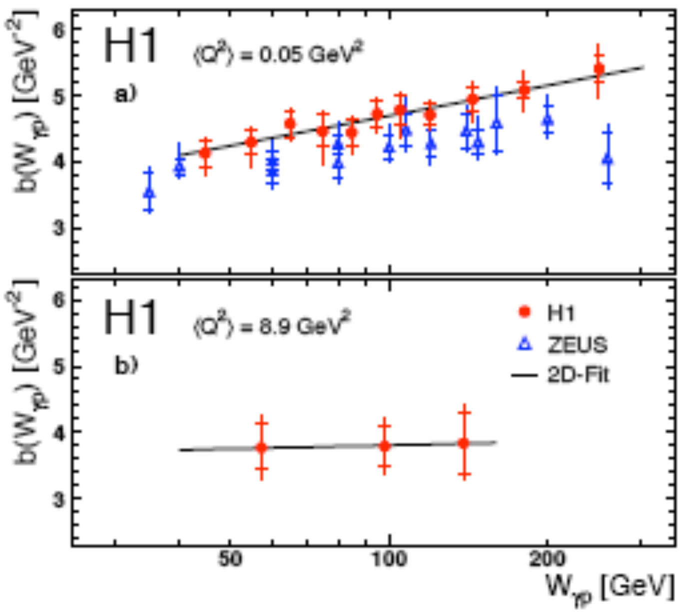




Exclusive VM production

Summary on b measurements



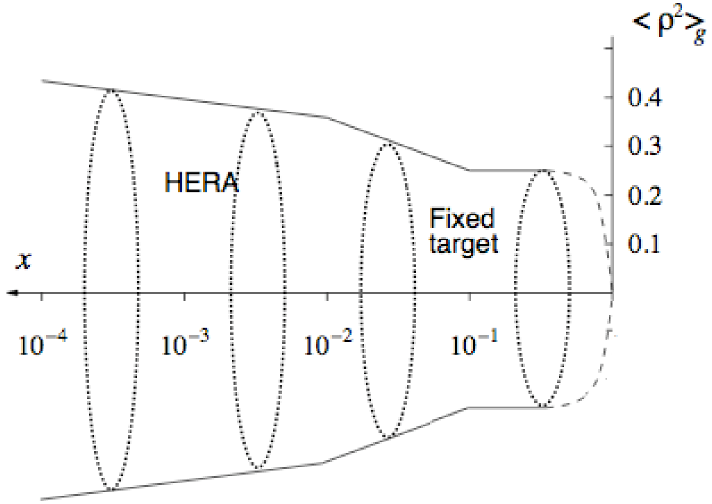


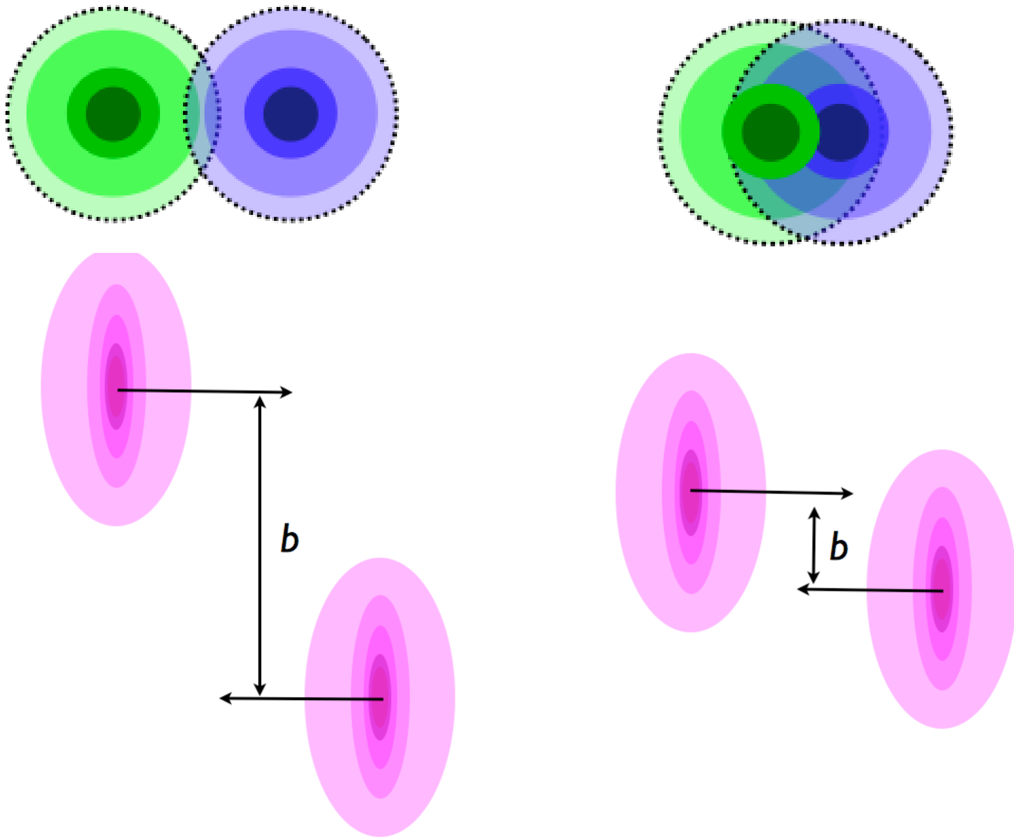
$$r_{glue} = 0.56 \text{ fm}$$
$$r_{proton} = 0.8 \text{ fm}$$

Magic formula $\Rightarrow < r^2 >= 2b \cdot (\hbar c)^2$

smaller x ⇒ larger r_{glue}

Implication for LHC



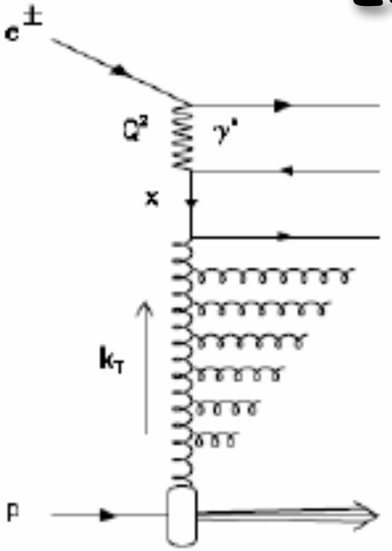


(a) Peripheral pp collision (b) Central pp collision

The harder the collision, the bigger the probability of another collision

Hadronic final states

Expectations based on parton radiation

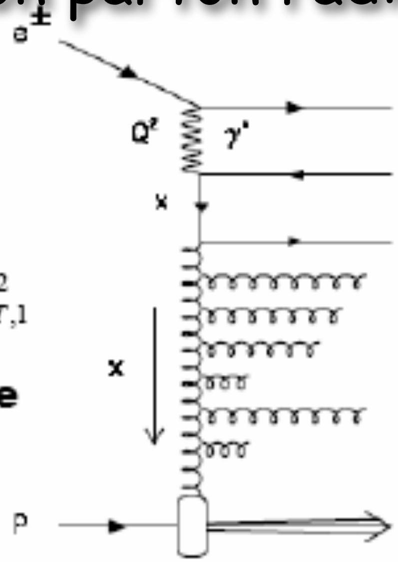


DGLAP

Evolution & resummation
in powers of *lnQ2*

$$Q^2 >> k_{T,n}^2 >> \ldots >> k_{T,2}^2 >> k_{T,1}^2$$

The DGLAP gluon cascade is strongly ordered in k_T and ordered in x



BFKL

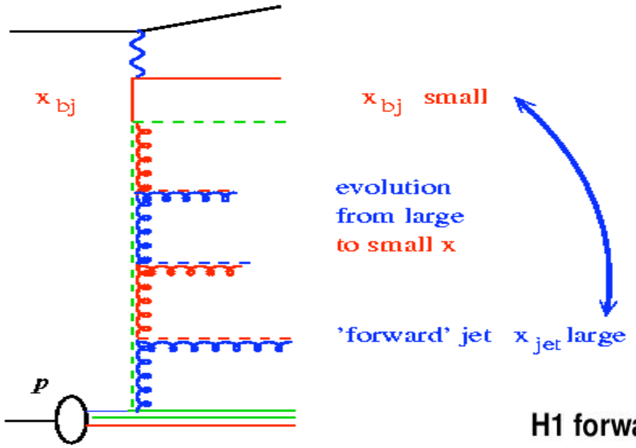
Evolution & resummation
in powers of *ln(1/x)*

$$x_1 >> x_2 >> \ldots >> x_n >> x$$

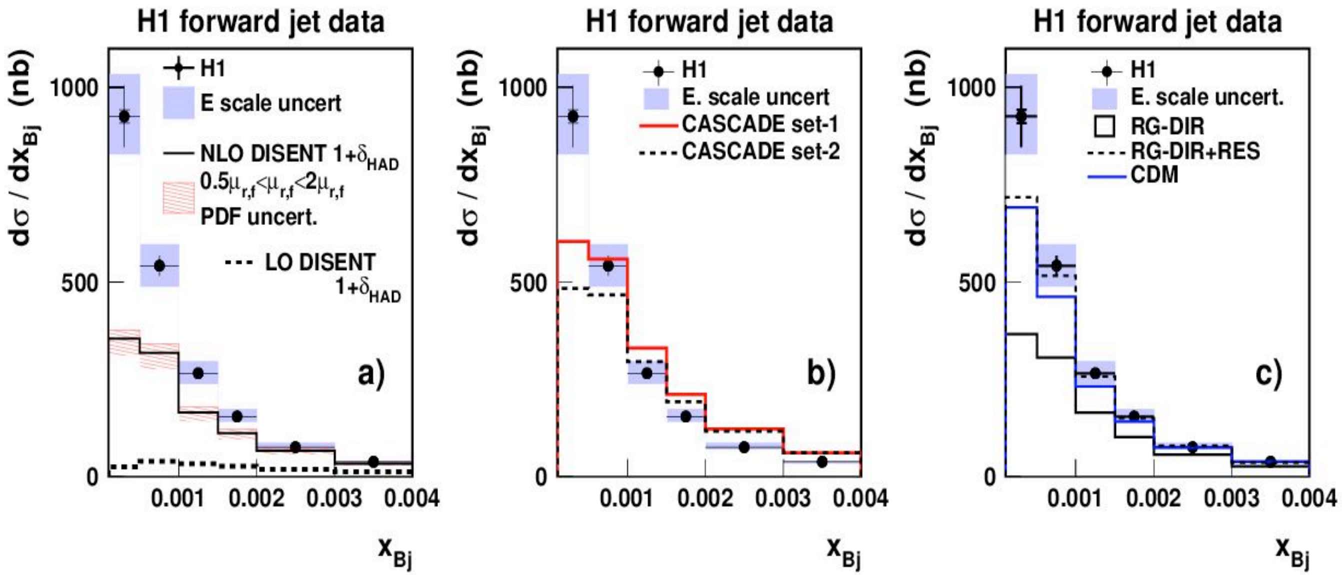
The BFKL is only strongly ordered in x

- High E_T forward jets
- Jets with $E_T > Q$ (resolved γ^*)
- Decorrelation in azimuthal angle

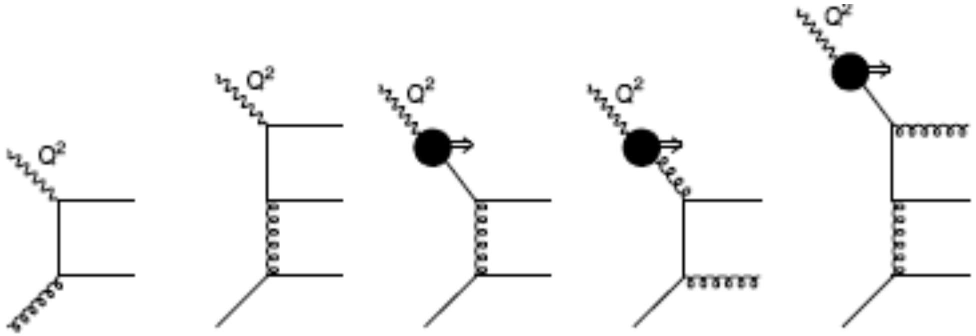
Hadronic final states - forward jets



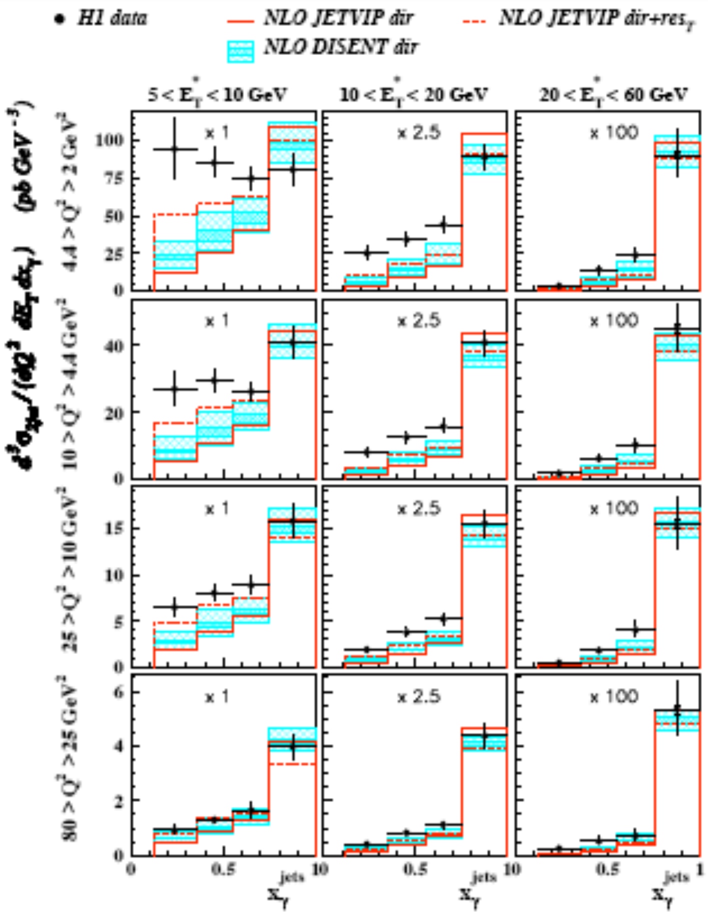
$$1.7 < \eta_{jet} < 2.8$$
$$x_{jet} > 0.035$$
$$0.5 < \frac{p_{t\ jet}^2}{Q^2} < 5$$



Resolved virtual photon



$$2 < Q^2 < 80 \text{ GeV}^2$$
$$0.1 < y < 0.85$$
$$E^*_{T1} > 7 \text{ GeV}, \ E^*_{T1} > 5 \text{ GeV}$$
$$x_\gamma^{\text{jets}} = \frac{\sum_{j=1,2}(E^\star_j - p^\star_{z,j})}{\sum_{\text{hadrons}}(E^\star - p^\star_z)}$$



Manifestation of even higher order corrections than NLO

Azimuthal correlations in di/tri-jets

H1 - dijets

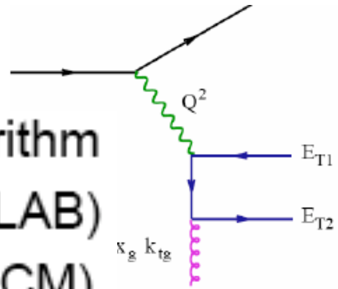
$5 < Q^2 < 100$ GeV^2

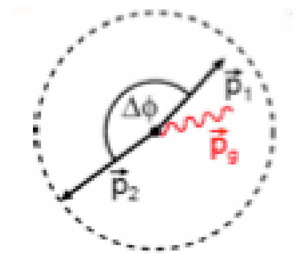
$0.1 < y < 0.7$

Inclusive k_T algorithm

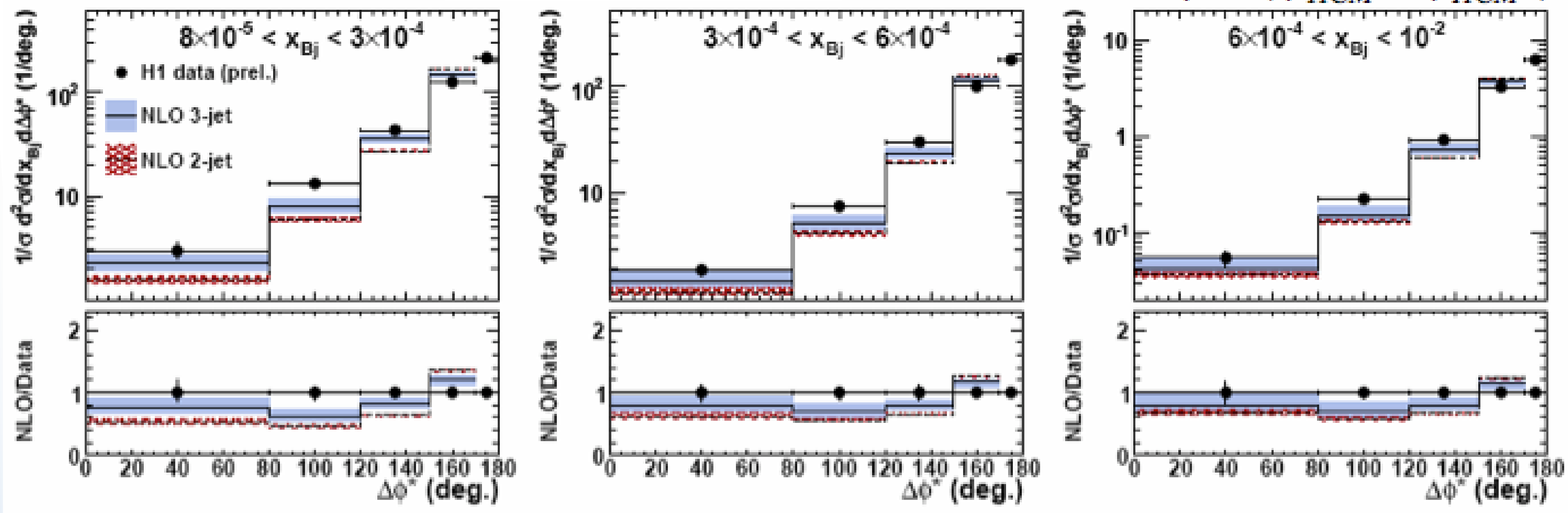
$-1 < \eta_{1,2} < 2.5$ (LAB)

$E^*_T > 5$ GeV (HCM)



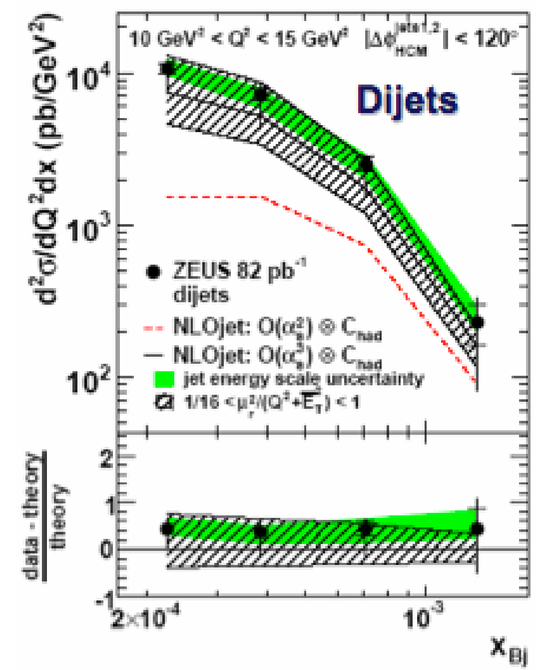


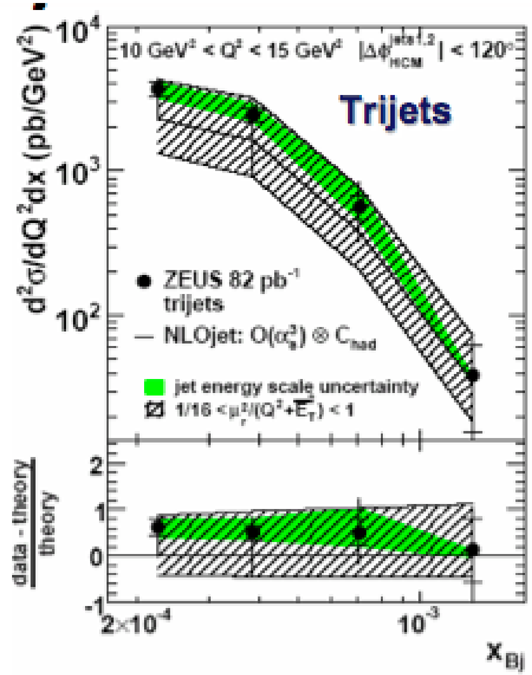
$$\Delta\phi^* = |\phi^{jet1}_{HCM} - \phi^{jet2}_{HCM}|$$



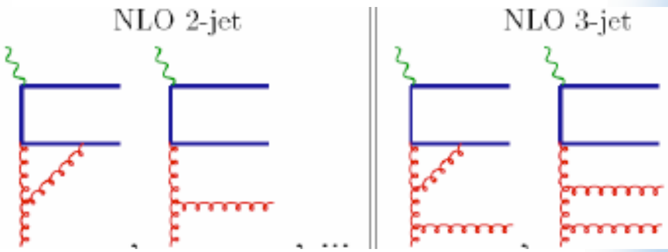
Azimuthal correlations in di/tri-jets

ZEUS: dijets and trijets $\Delta\phi^{j1,j2} < 120°$



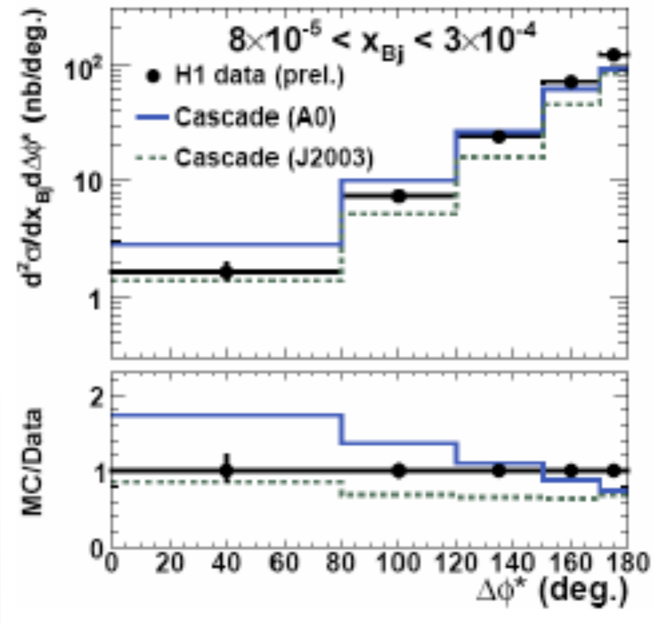


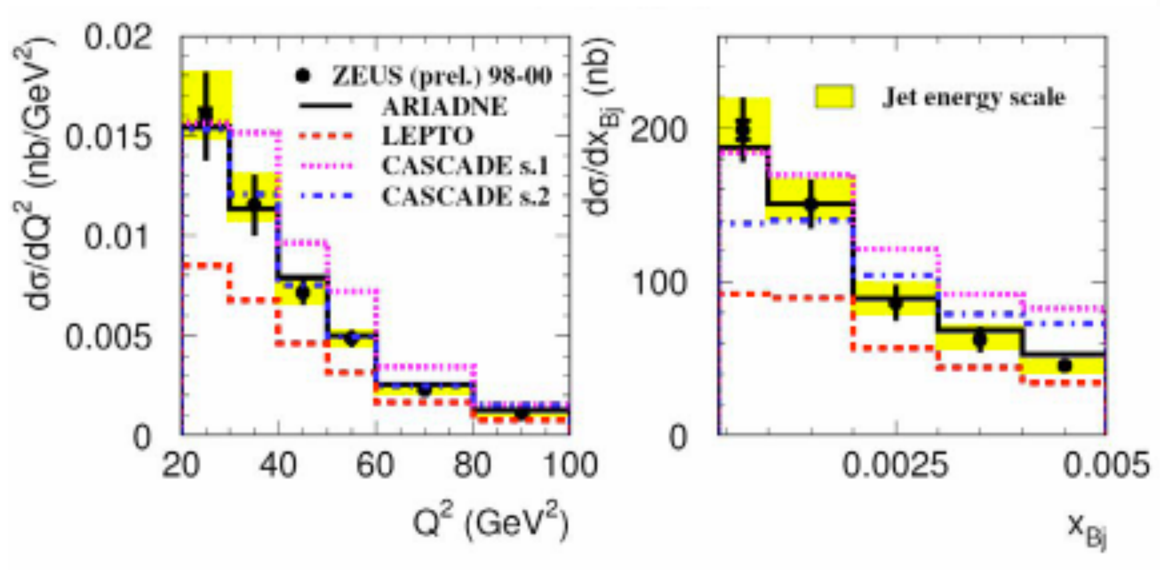
NLOjet calculations at $O(\alpha_s{}^3)$ describe dijet, trijet data



Hadronic final states - MC options

- LEPTO: LO ME+PS , (DGLAP)
- ARIADNE: LO, an implementation of Color Dipole Model (CDM)
- CASCADE: LO off mass shell ME + parton shower based on k_T factorized CCFM

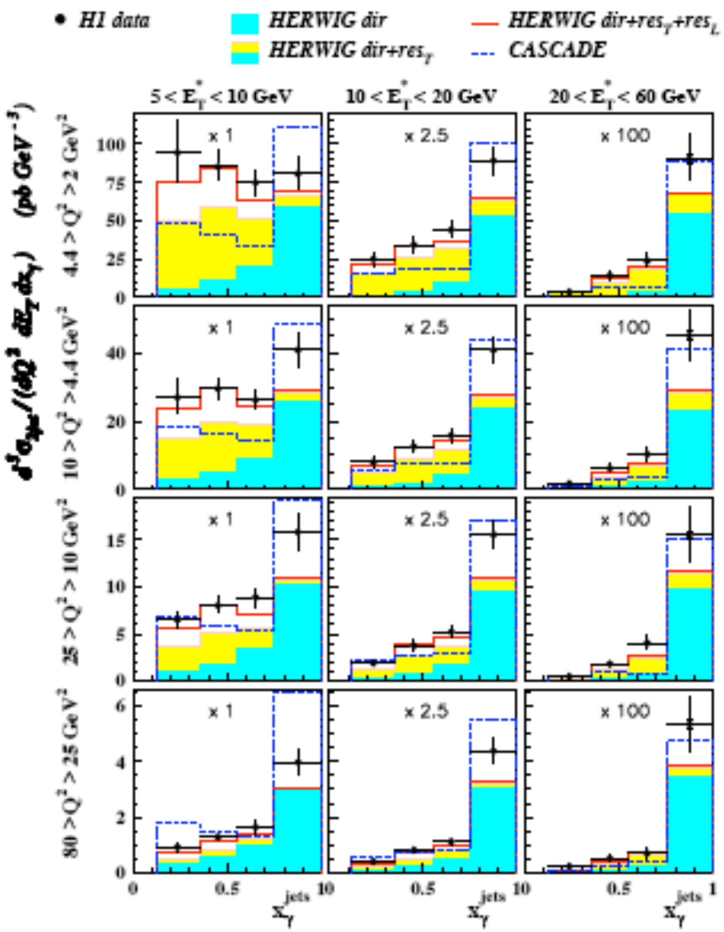




Hadronic final states - MC options

Resolved virtual "photon"

Fix the problem, by introducing a resolved component into the DIS MC



Summary

- There is a whole range of effects in low x ep, the physics of which is not well understood:
  - diffraction >10%
  - hard exclusive reactions ~1%
  - forward jets ~1%
  - resolved virtual γ^* ~10%
  - azimuthal correlations ~5%
- They are a manifestation of higher order effects and possibly more
- They have in common one thing - they all come from the high gluon density regime of HERA
- Judging from RIHC physics, their contribution to LHC physics may be substantial