The HERA challenges for LHC

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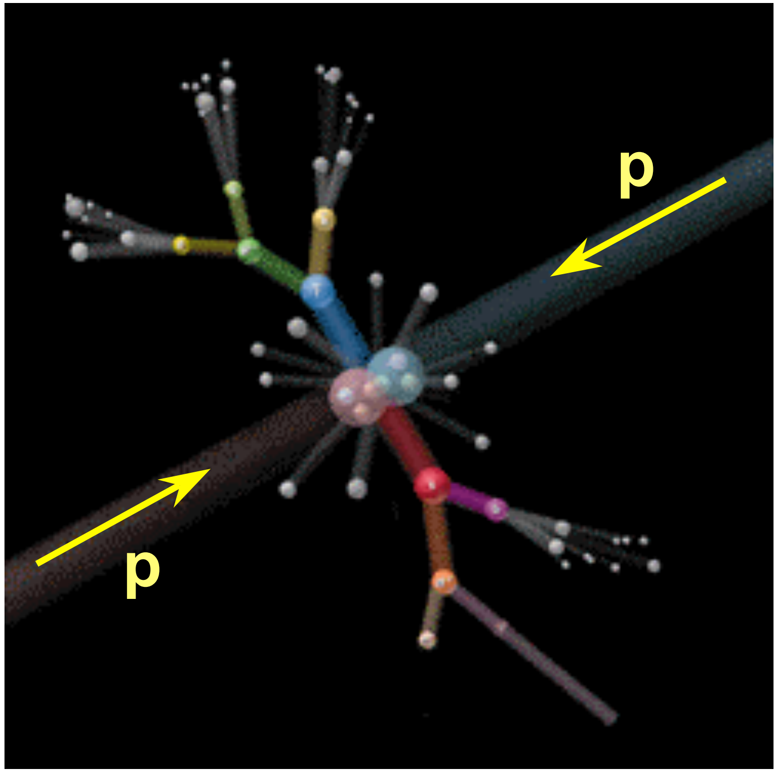
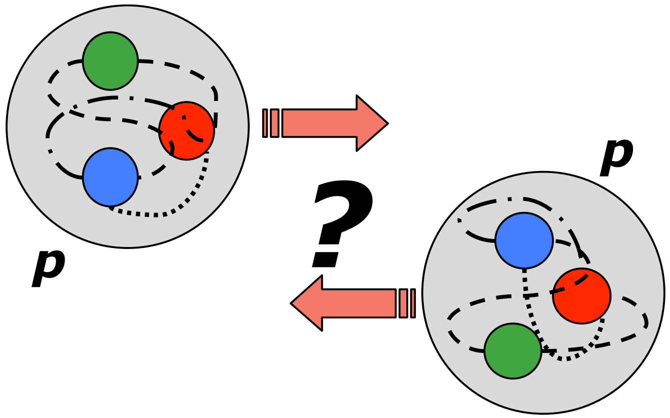
- Comments on PDFs
- Diffraction
- Jets

Hard pp interactions at LHC



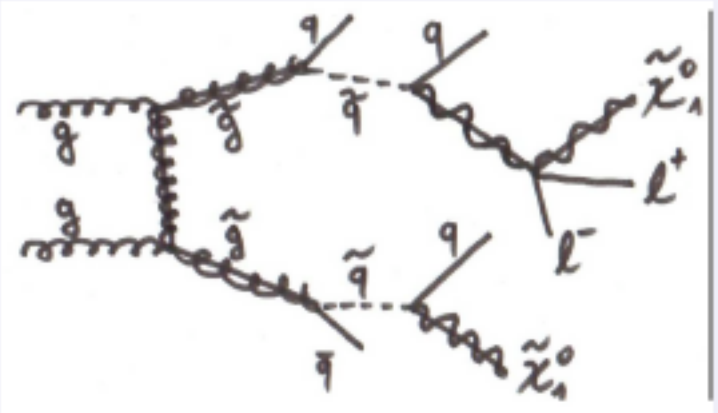


$$d\sigma_{pp} = \sum_{ab} \int_{x_1} \int_{x_2} dx_1 dx_2 f_p(x_1, \mu^2) f_p(x_2, \mu^2) d\hat{\sigma}_{ab}(x_1, x_2, \mu^2)$$

Example of worries at LHC

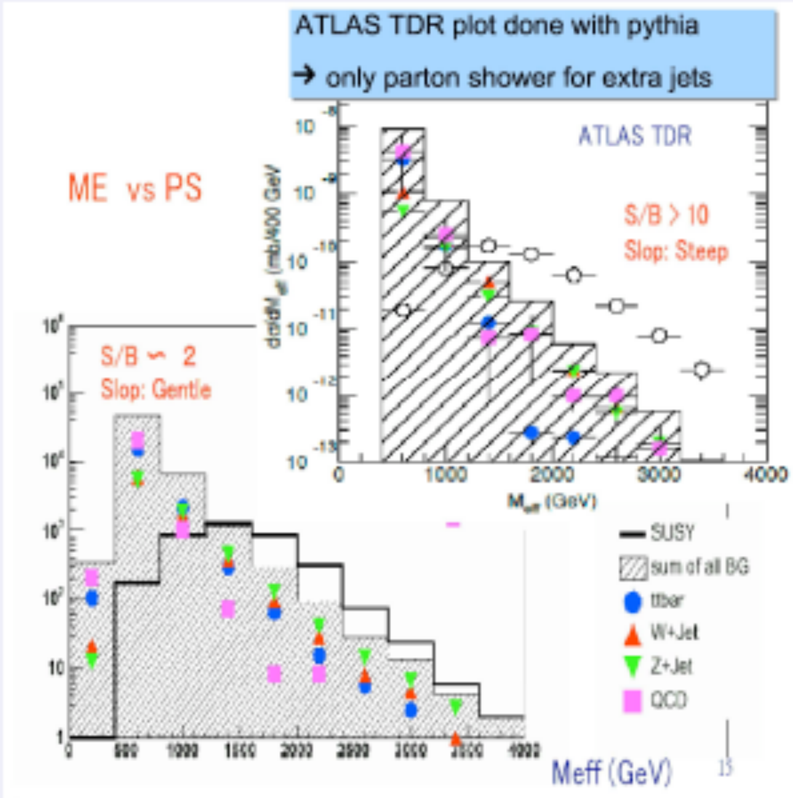
From the talk by F. Krauss at DIS06, co-author of Sherpa

SUSY searches

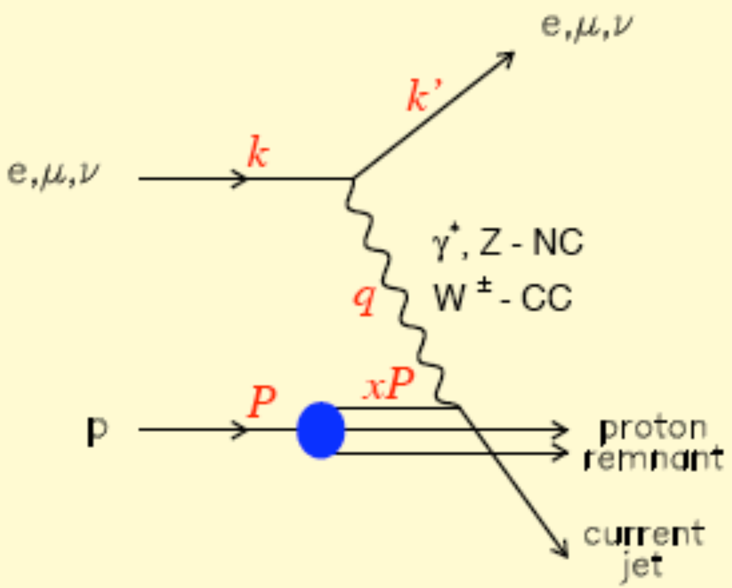


- Large σ_{prod}
- Many hard jets.
- $M_{\text{eff}} = \sum p_\perp^{\text{hard}}$.

Quick Discovery?



Deep inelastic scattering - kinematics



- Q^2 - virtuality of exchanged boson

$$Q^2 = -q^2 = -(k - k')^2$$

- s - lp centre of mass energy

$$s = (k + P)^2$$

- W - hadronic centre of mass energy

$$W^2 = (q + p)^2$$

- x - Bjorken variable

$$x = \frac{Q^2}{2P \cdot q} = \frac{Q^2}{Q^2 + W^2}$$

- y - inelasticity

$$y = \frac{P \cdot q}{P \cdot k}$$

Global fits of parton distributions

- Postulate x dependence of all partons at some Q_0^2
- Solve DGLAP evolution equations for these initial conditions (NLO, NNLO, …)
- Calculate appropriate physical quantities which have been measured (F_2, jets, heavy flavors, ….)
- Compare data and expectations
- Iterate till good agreement is achieved

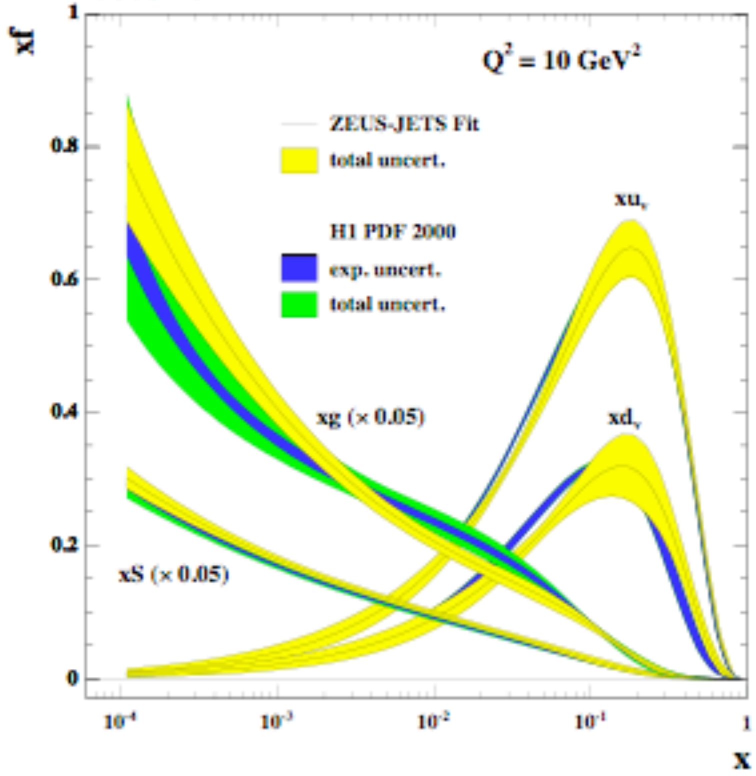
↓

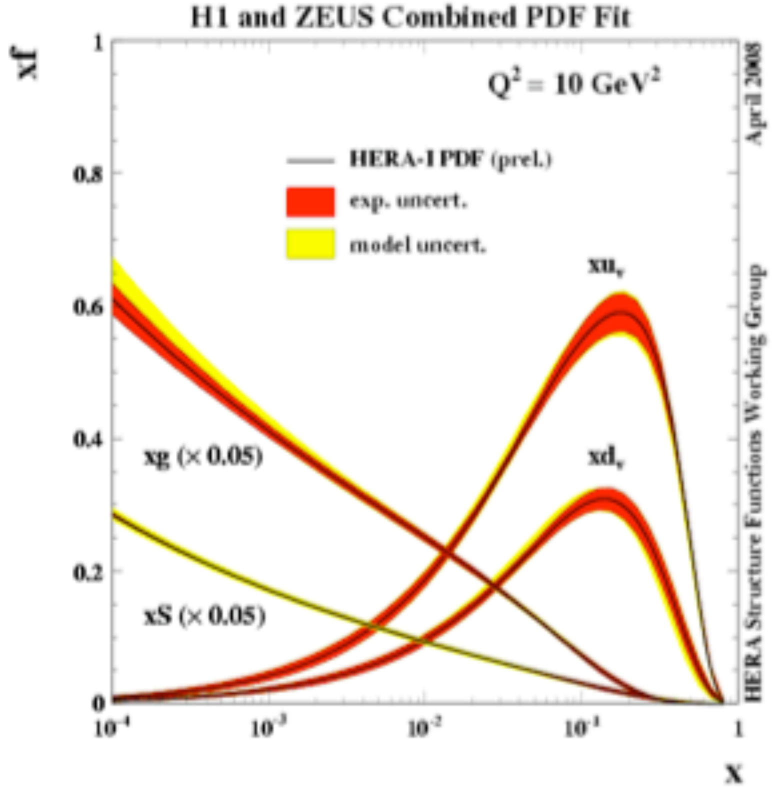
PDFs

Global fits

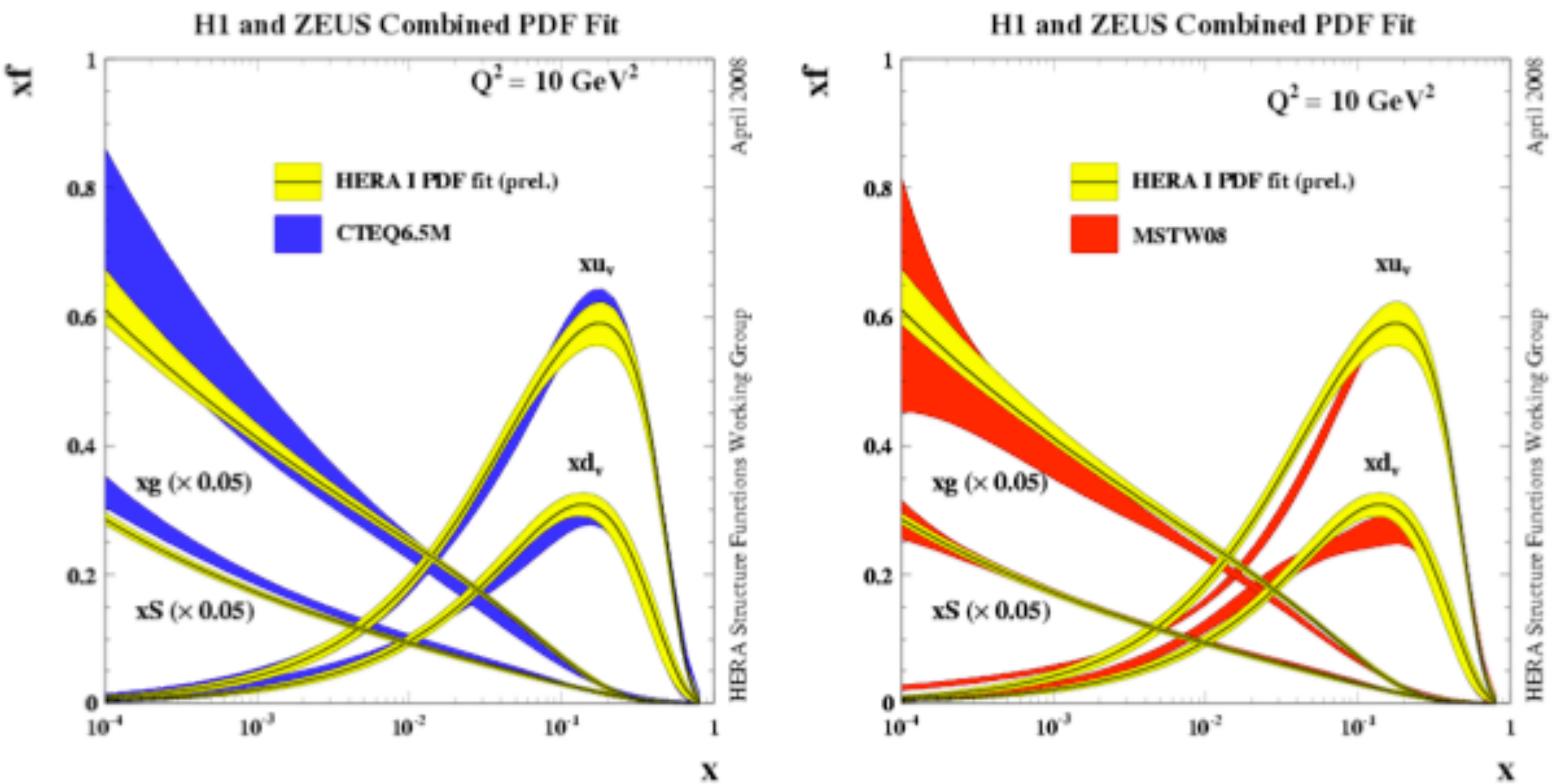
Example of PDFs

Note in published PDFs H1 has alphas variation included in model error, ZEUS does not.





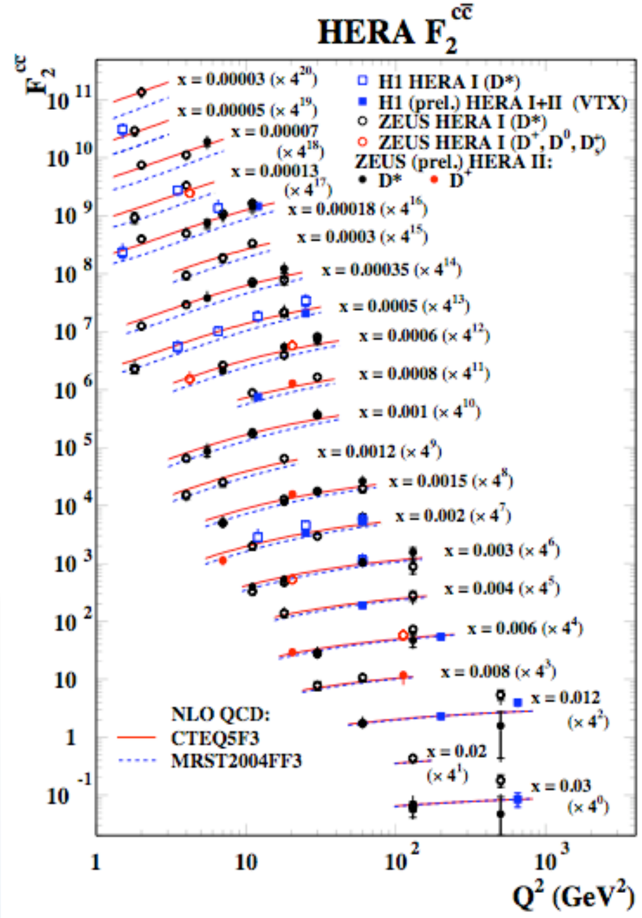
Global fits

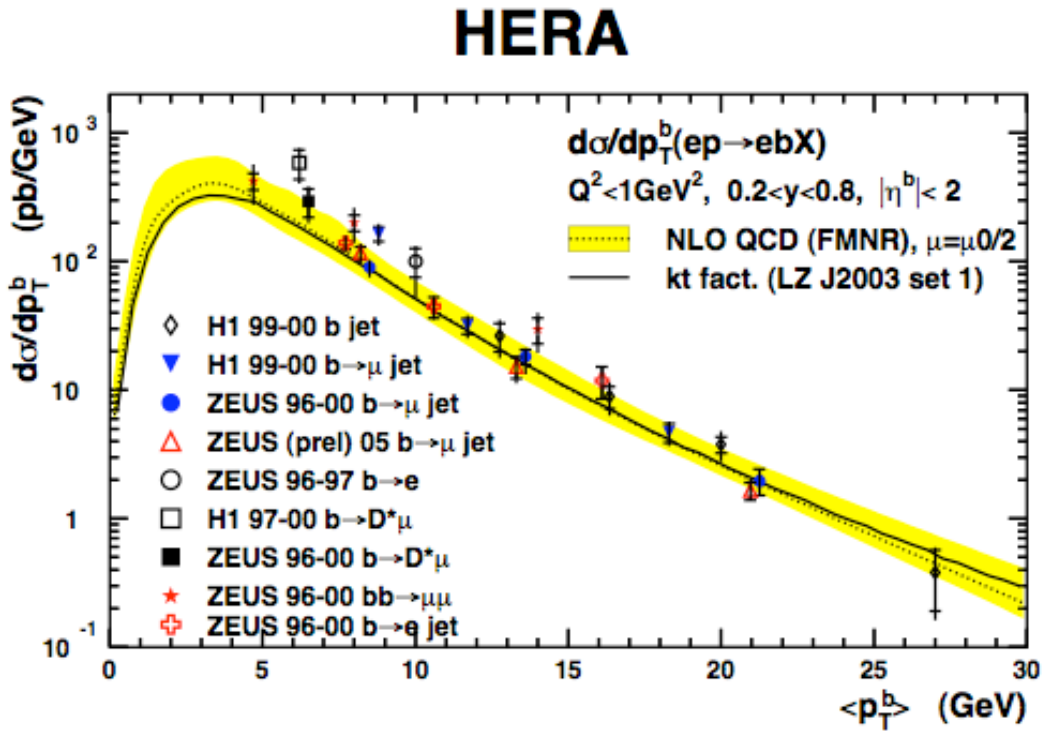


Preleased version of MSTW08

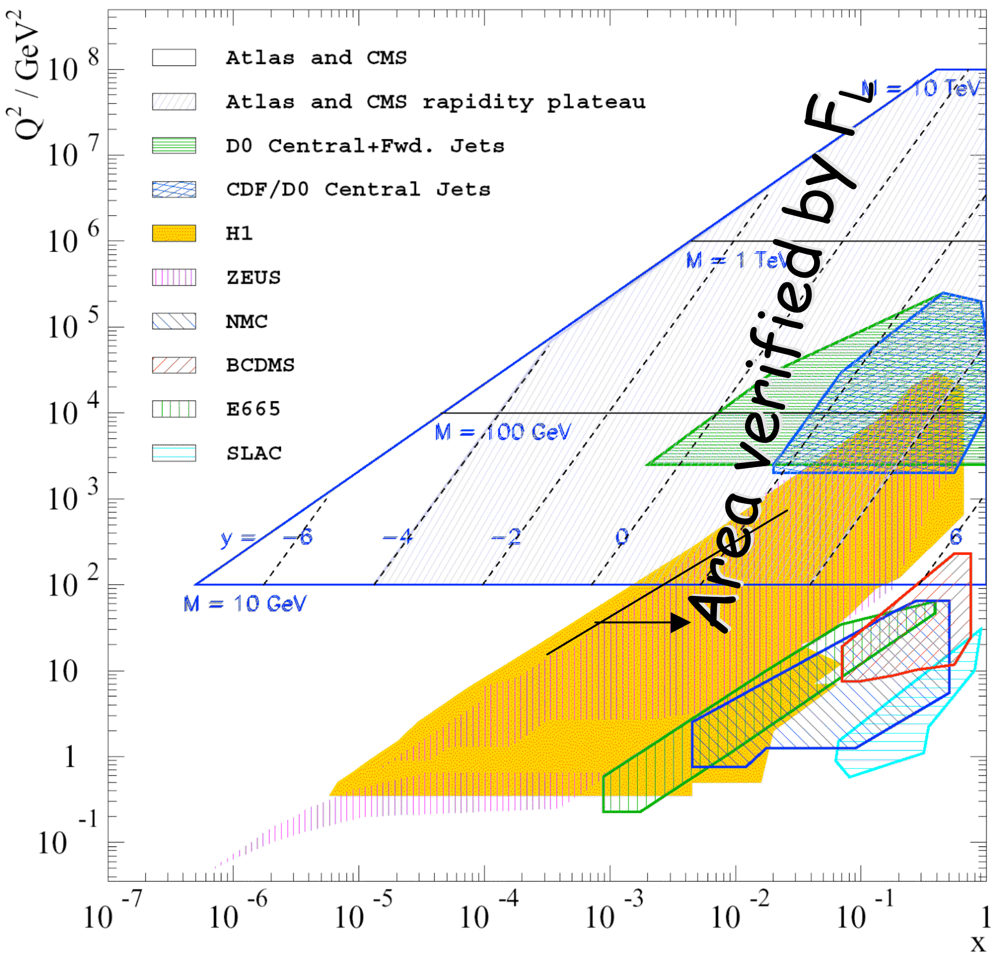
Heavy flavors c,b

Dynamically generated from gluons - schemes under discussion





Extrapolation in x,Q^2 for LHC



Large gluon density???

Gribov, Levin, Ryskin (1983)

- Number of gluons per unit area:

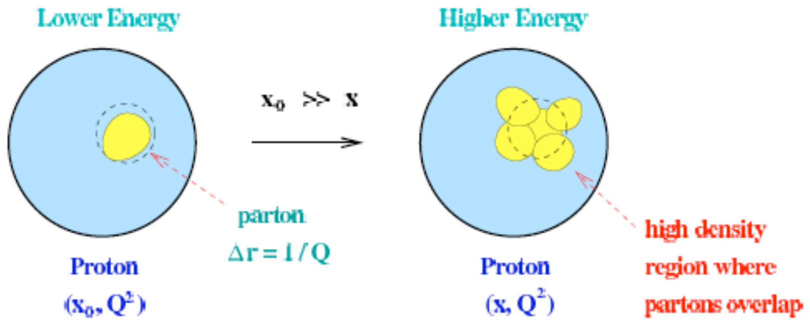
$$\rho \sim \frac{xG_A(x,Q^2)}{\pi R_A^2}$$

- Recombination cross-section:

$$\sigma_{gg\to g} \sim \frac{\alpha_s}{Q^2}$$

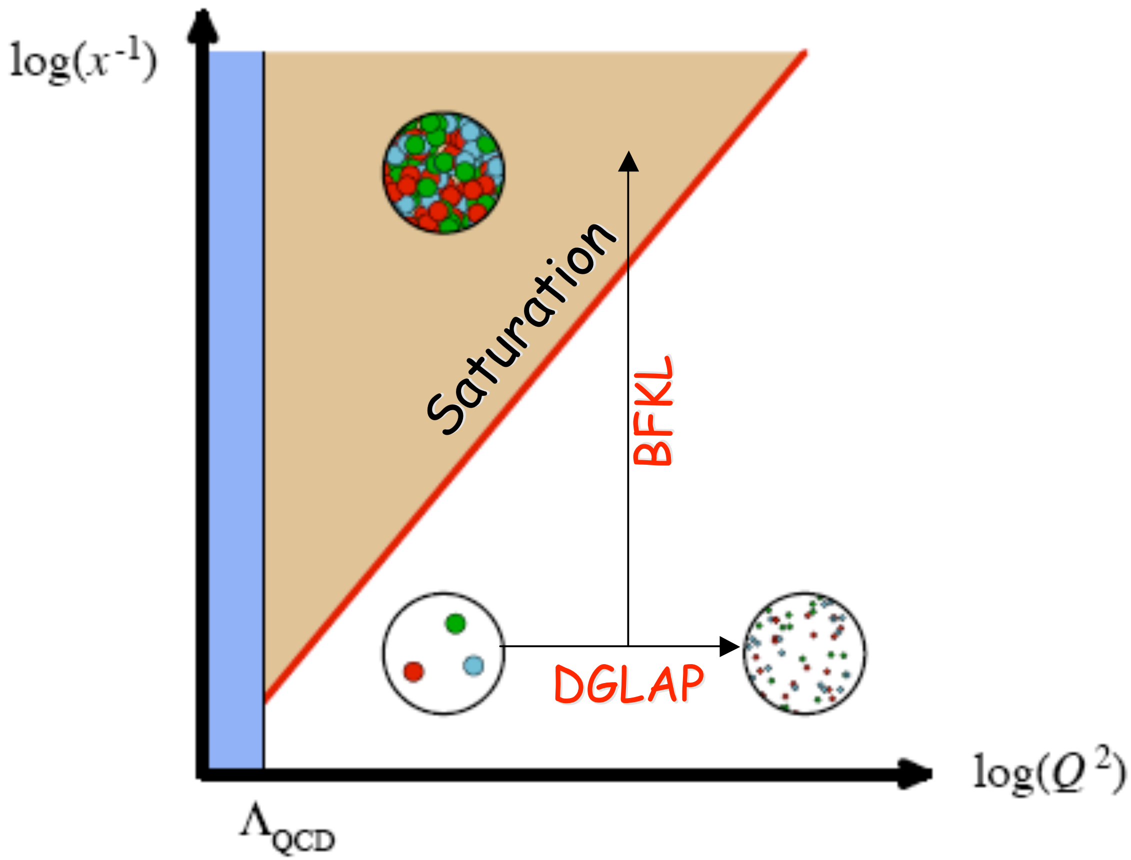
- Recombination happens if $\rho\sigma_{gg\to g} \gtrsim 1$, i.e. $Q^2 \lesssim Q_s^2$, with:

$$Q_s^2 = \frac{\alpha_s x G_A(x,Q_s^2)}{\pi R_A^2}$$



Large gluon density???

DGLAP evolution will not hold and coherent effects may show up



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!

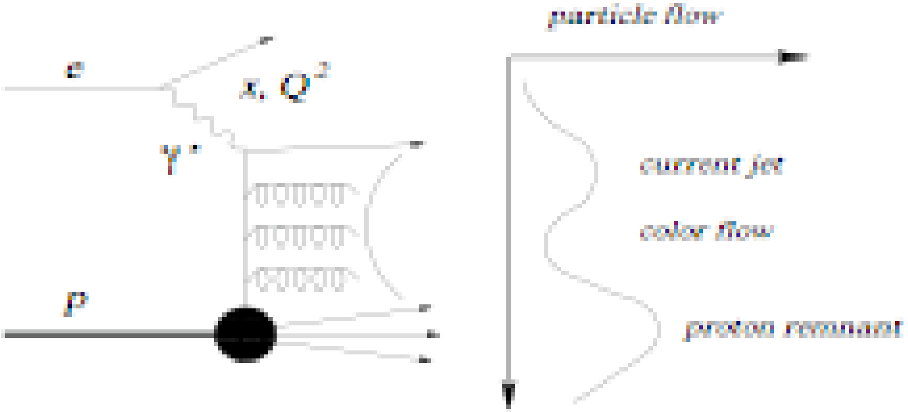
- No rigorous proof that solution is unique
- Theoretically large ($\alpha_S \ln 1/x$) terms expected (BFKL)
- Good χ^2 may not be the ultimate proof

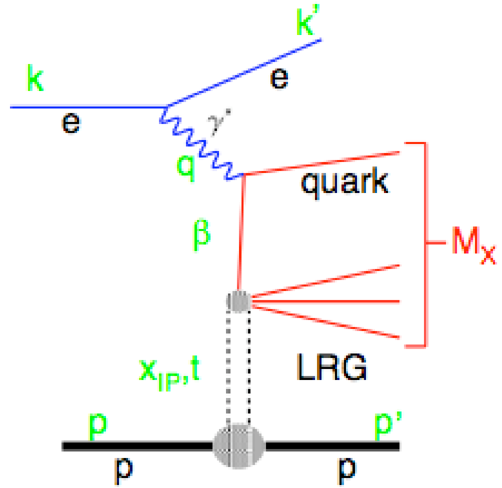
- Measurements of F_L - independent test of gluons in the same region of x and Q^2 - probes a small region

Signs of problems: Diffraction

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

DGLAP





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

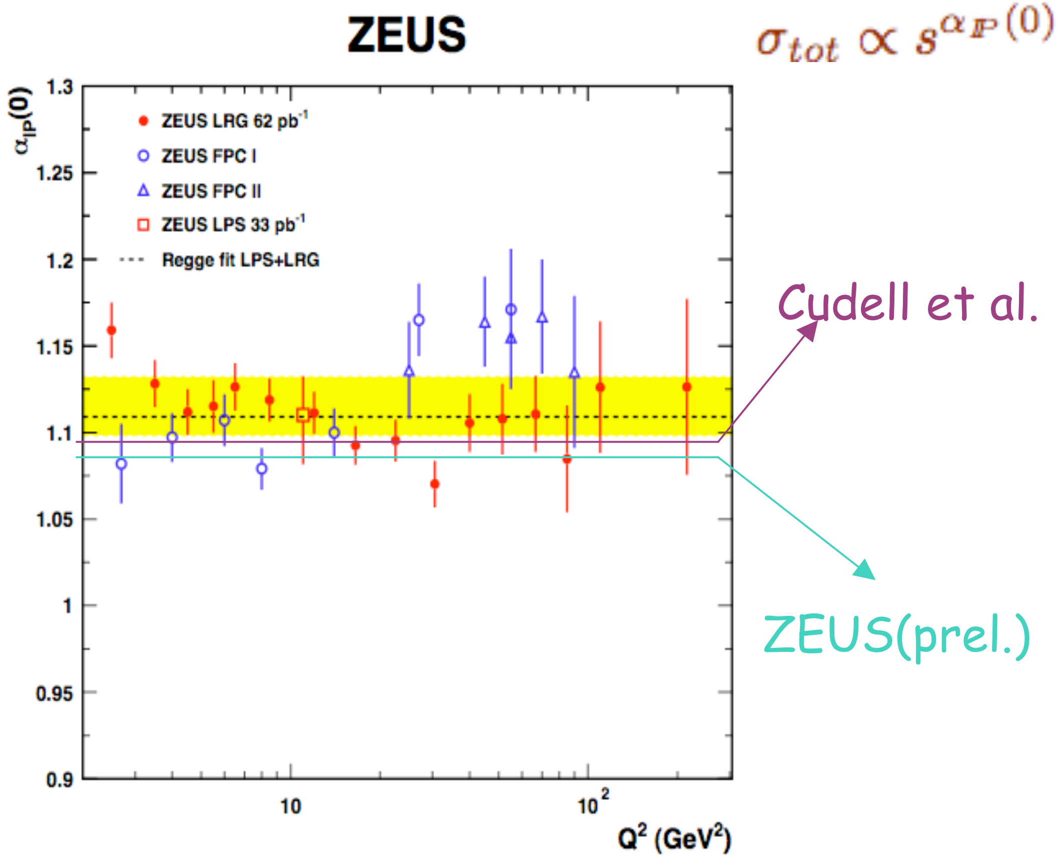
$$t = (p-p')^2$$
$$x_{\mathbb{P}} = \frac{q\cdot(p-p')}{q\cdot p} \simeq \frac{Q^2+M_X^2}{Q^2+W^2}$$
$$\beta = \frac{Q^2}{2q\cdot(p-p')} \simeq \frac{Q^2}{Q^2+M_X^2}$$

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

Diffraction soft/hard?

- Extraction of α_{IP} from DIS diffraction

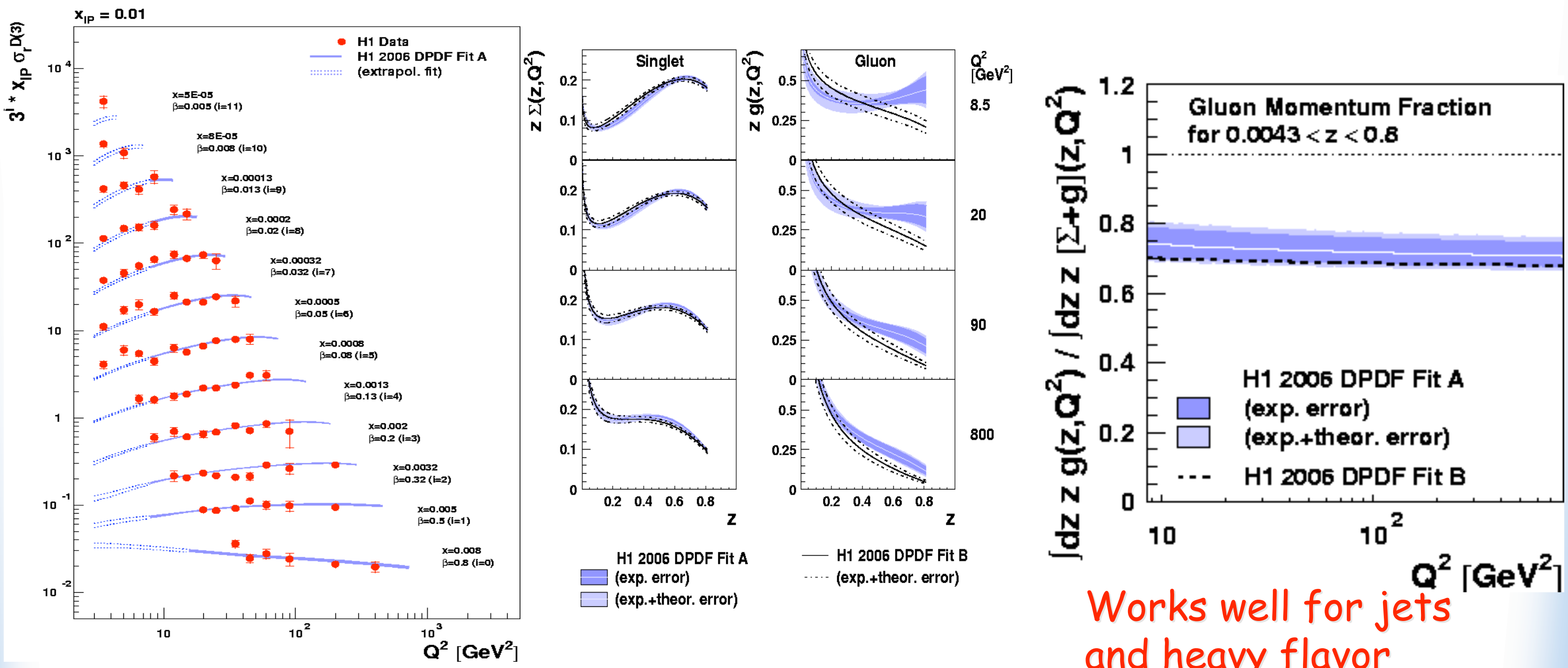
$$\sigma_{tot} \propto s^{\alpha_{I\!P}(0)-1}$$



However, indication that α_{IP} in DIS harder than in hadron-hadron

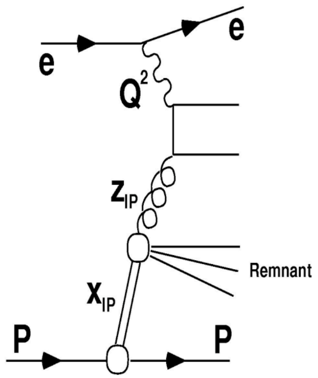
QCD factorisation for diffraction in DIS?

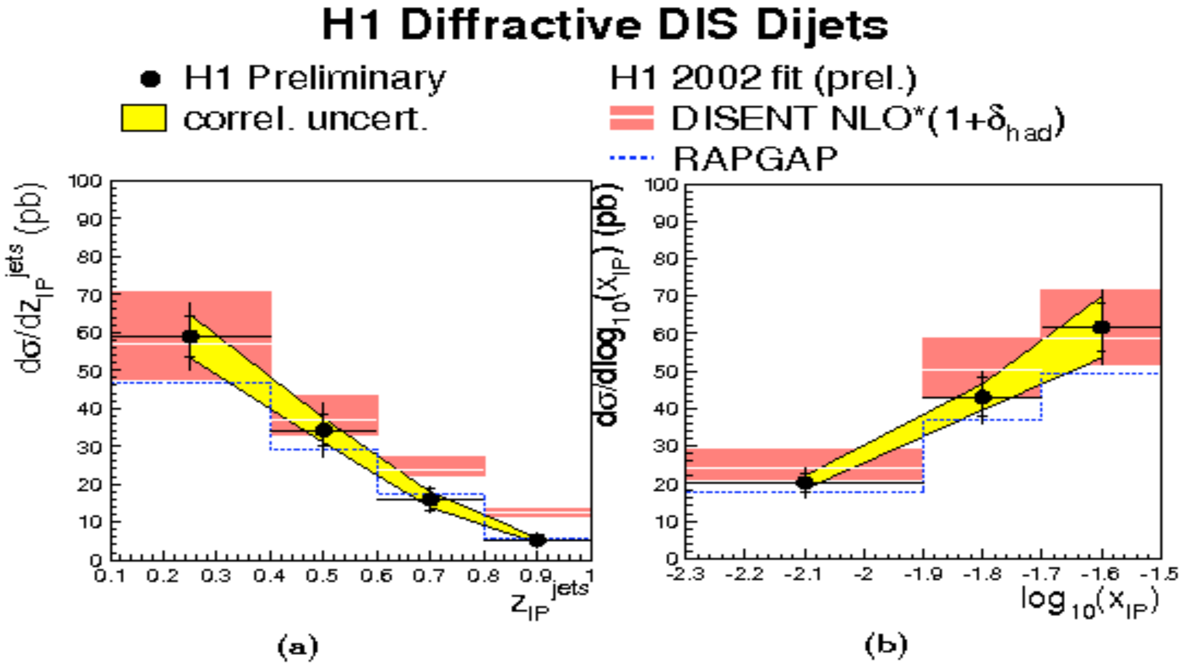
• QCD factorisation holds for diffractive PDF = that fraction of proton PDF that lead to LRG events



Works well for jets and heavy flavor

Diffractive dijet production in DIS



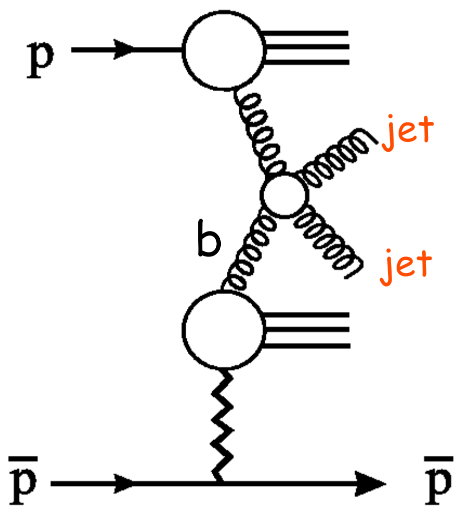


- use diffractive pdfs, obtained from F2D
- predict cross section in diffractive DIS
- x section is well described

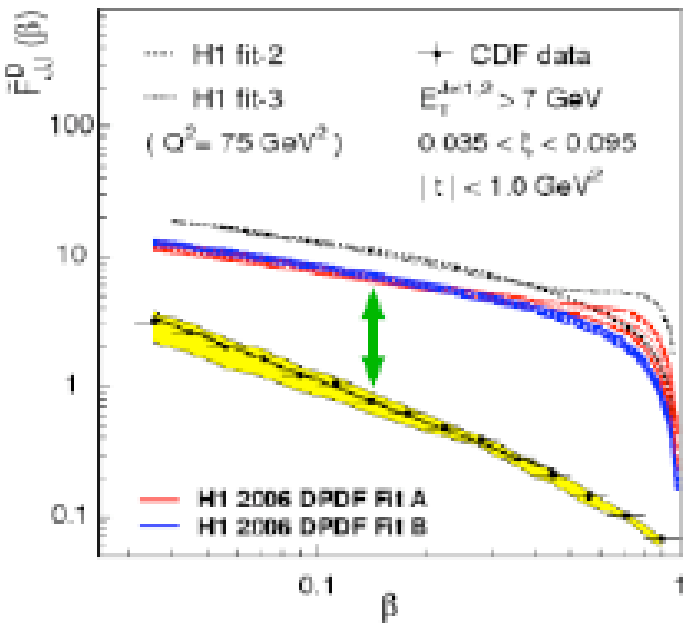
What about QCD factorization?

- Diffractive PDF's expected to be non-universal (J. Collins)!
- factor ~10 suppression relative to DIS, independently of final state (W, J/psi,….)

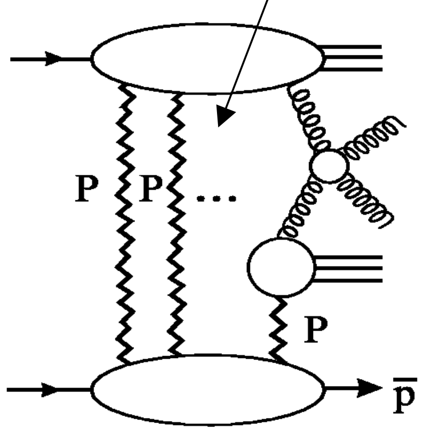
$F_{jj}^{diff}/F_{jj}^{incl}$



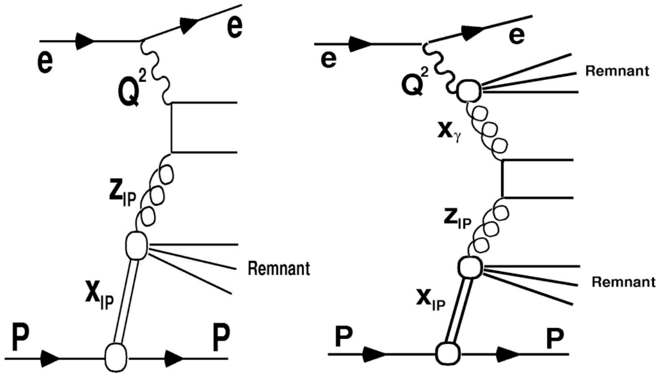
H1 fits vs. Tevatron



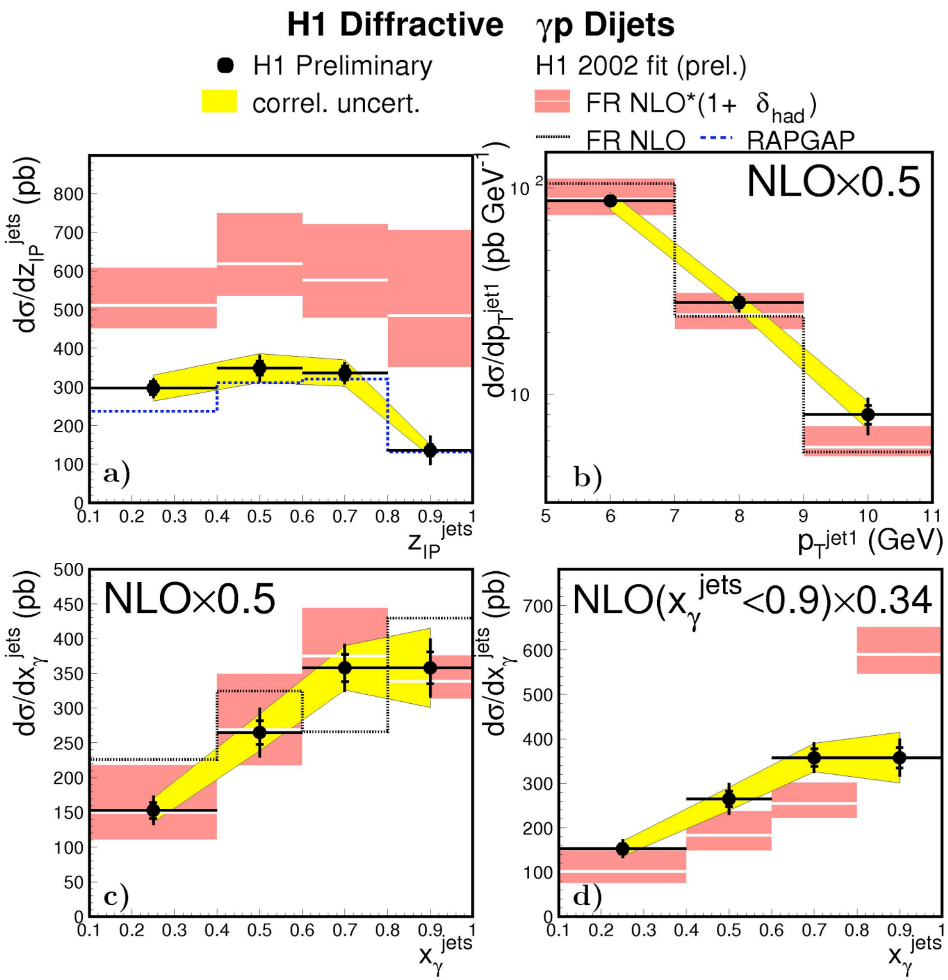
Possible explanation - rescattering



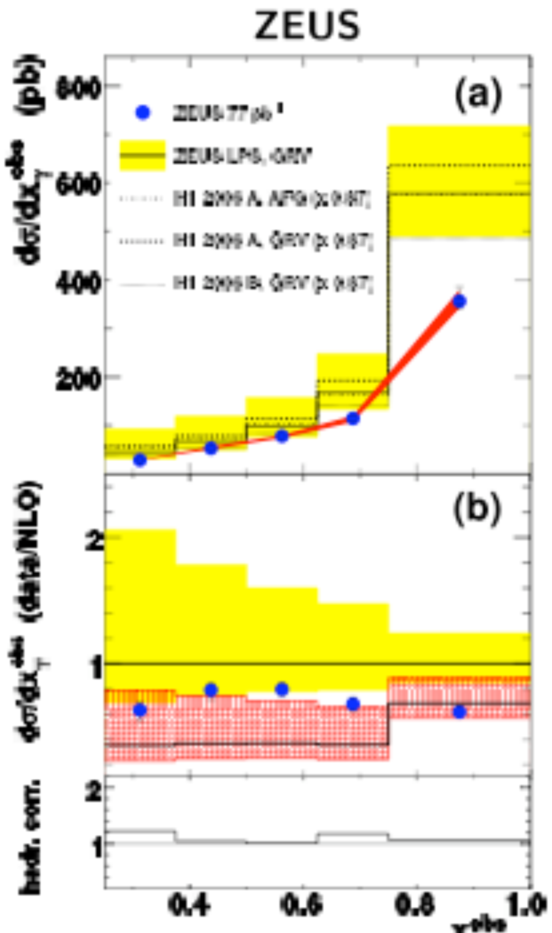
Diffractive factorization in γp

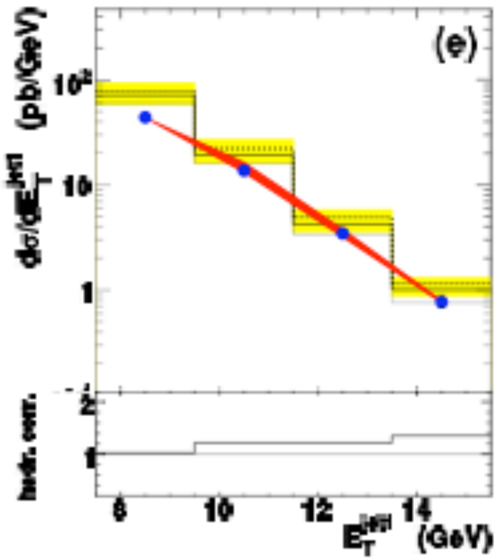


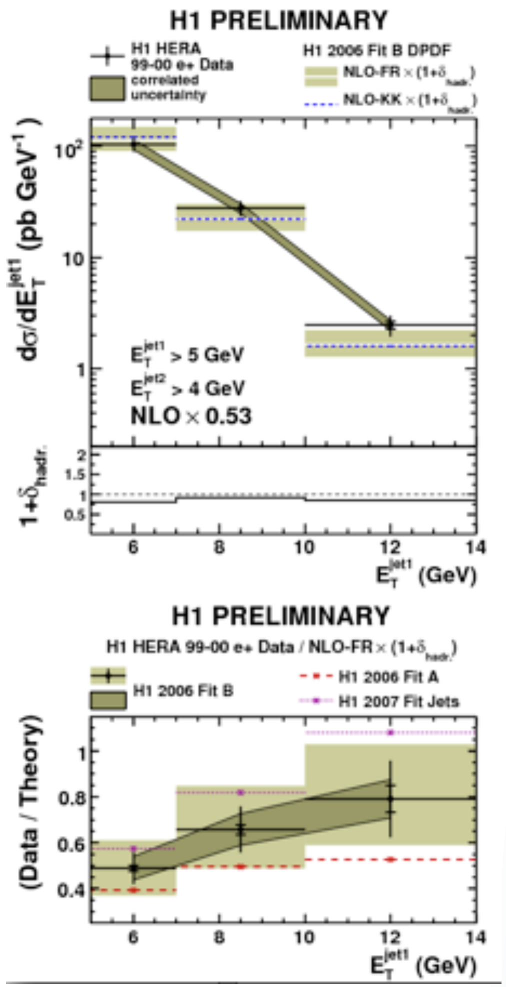
- use diffractive pdfs also for dijet photoproduction
- predicted cross section ~ factor 2 too large
- similar effect seen in proton-proton collisions
- factorization is broken



QCD factorization !!!



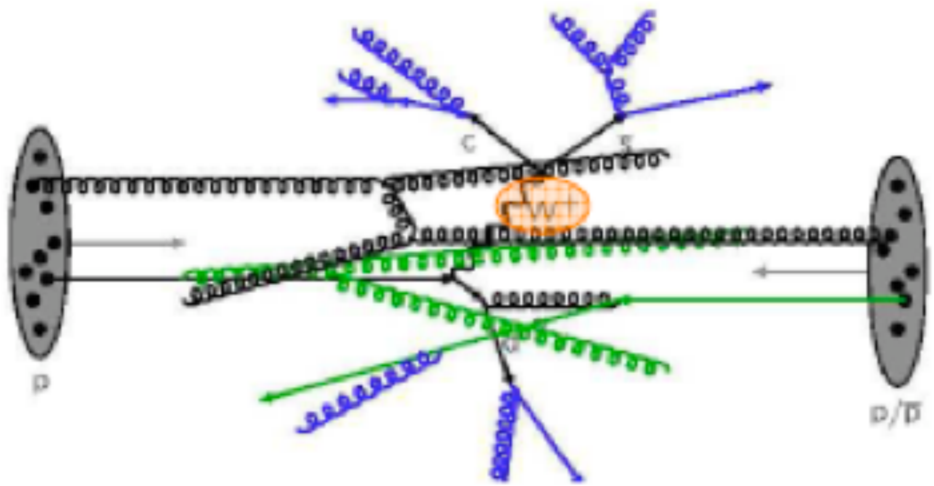




Suppression possibly dependent on the size of interacting object

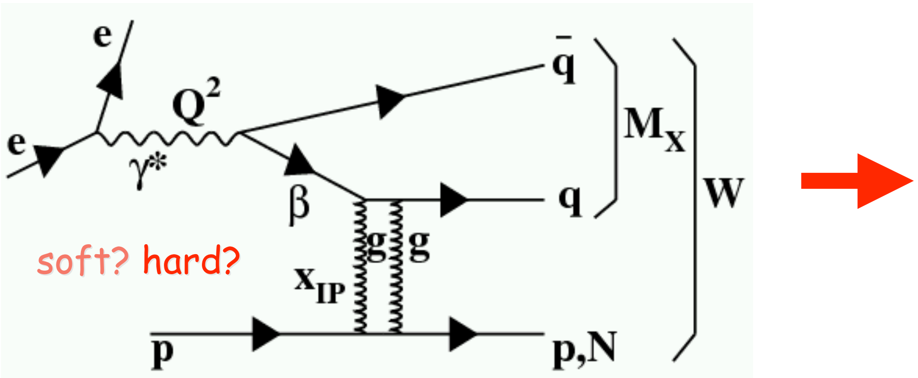
QCD factorization !!!

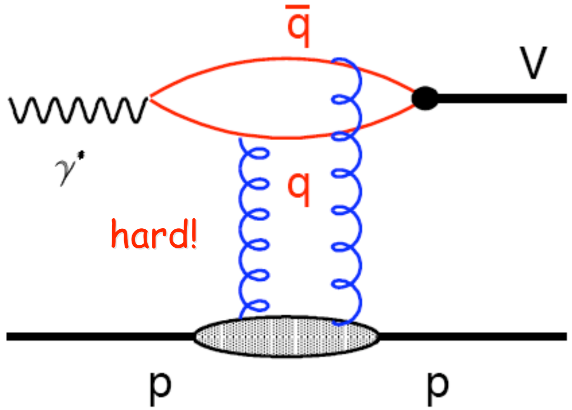
- Of the order of 10% of DIS (LRG) cross section cannot be accounted for in pp, nor in γp
- Inclusive factorization seems to be preserved (pp) by rescattering !!!
- Possible implications for MPI… (multiple-parton interactions)



Diffraction has a hard component

- Exclusive Vector Meson production





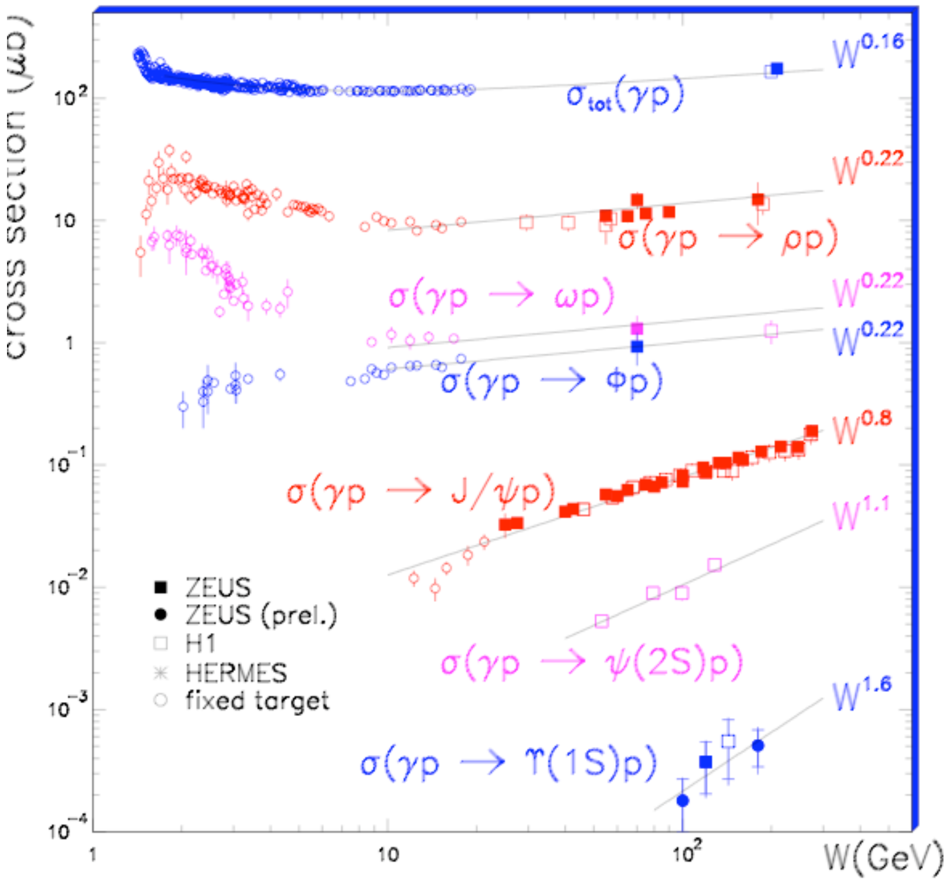
$$\sigma(W) \Rightarrow \delta \quad (\propto W^{\delta})$$

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

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

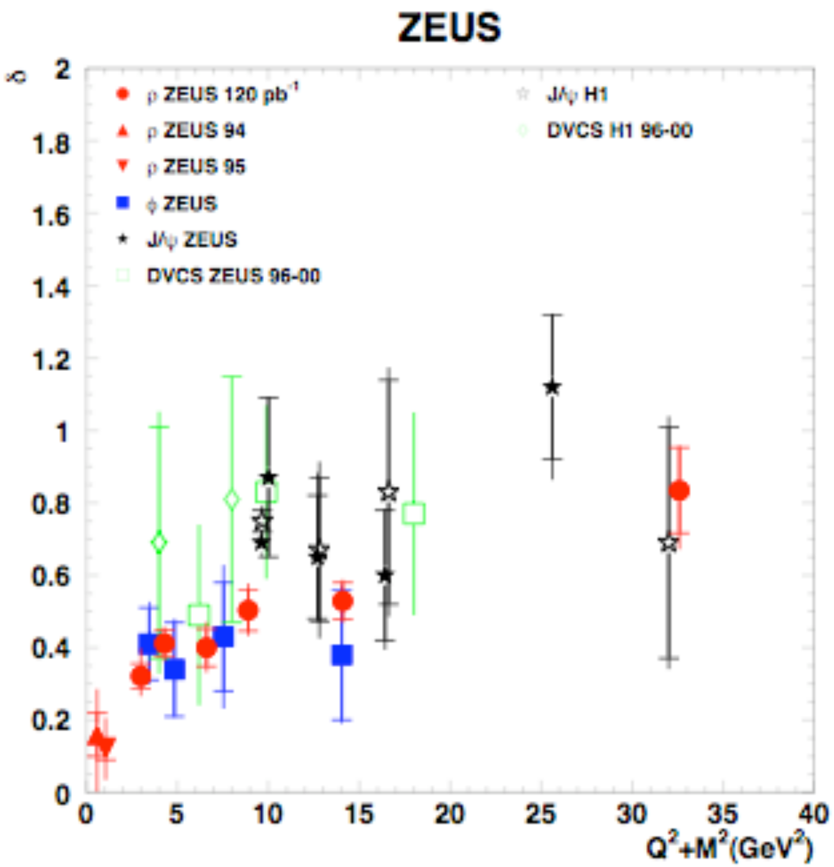
$$r_{ij}^{k} \Rightarrow R(W)\ ,\ R(Q^2)$$

Exclusive processes

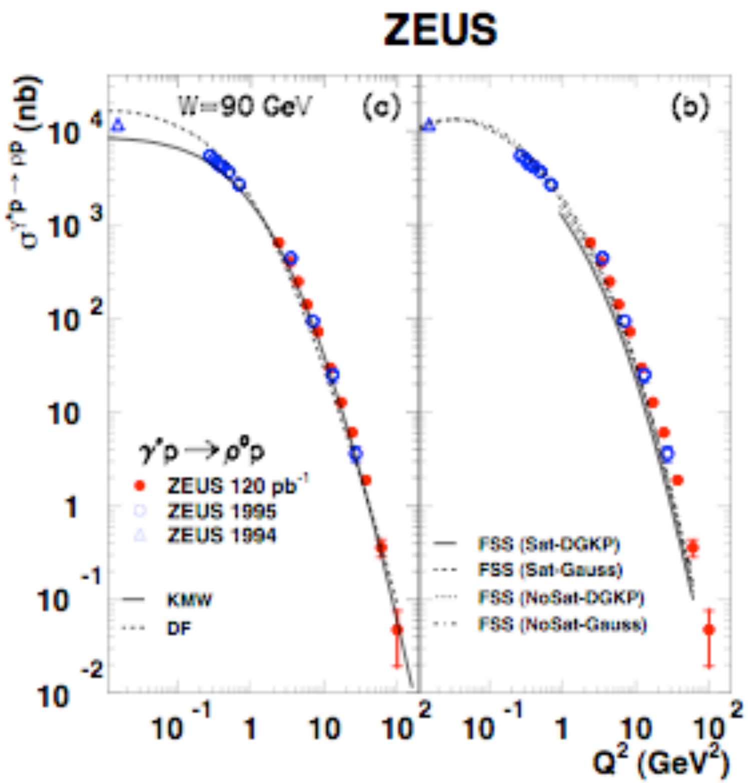


Exclusive processes

Compatible with 2g exchange

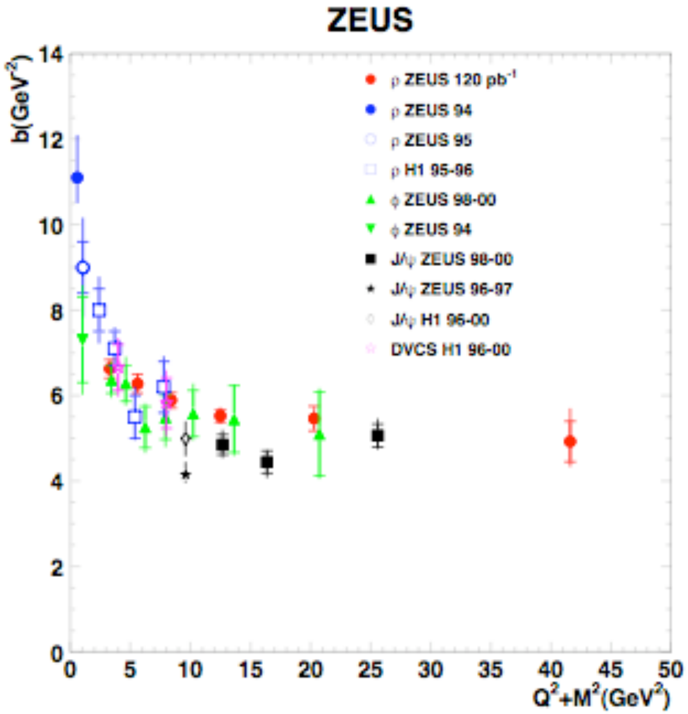


However it is HT effect



Exclusive VM production

dσ/dt - sensitive to transverse size



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

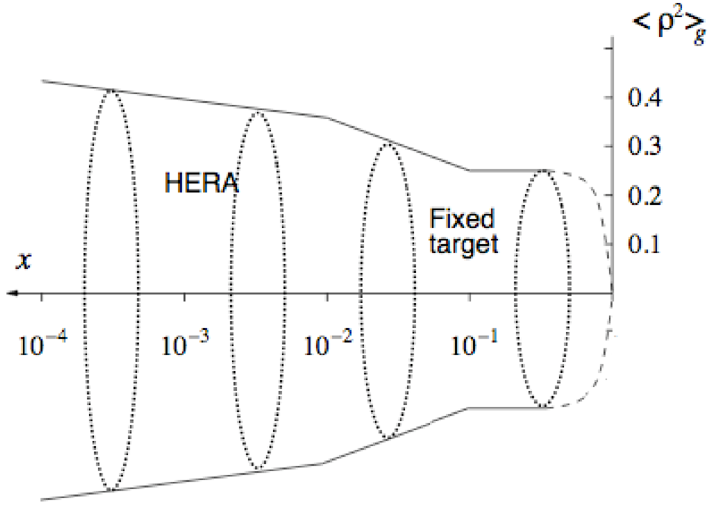
$r_{glue} = 0.56$ fm

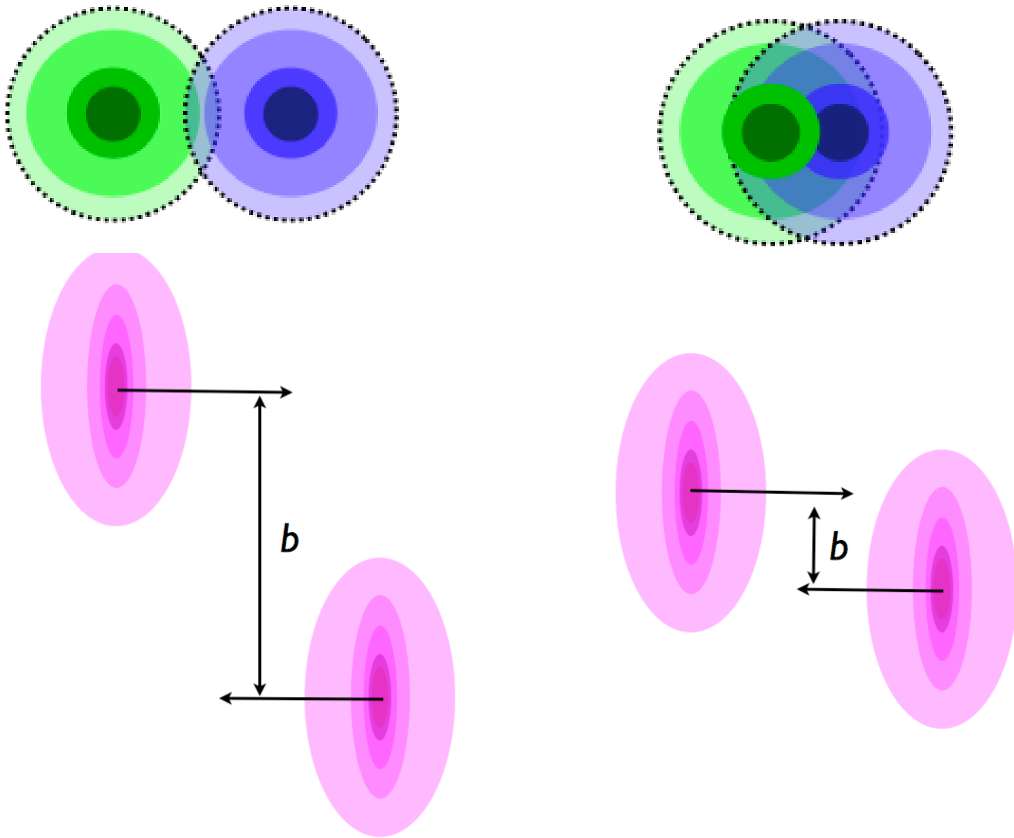
$r_{proton} = 0.8$ fm

smaller x ⇒ larger r_{glue}

This is just the beginning of learning about parton correlations in the proton (GPDs)

Implication for LHC





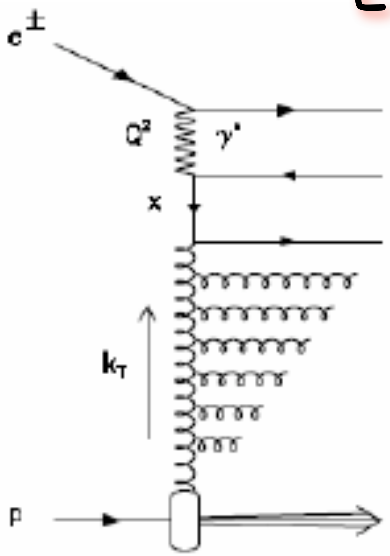
(a) Peripheral pp collision

(b) Central pp collision

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

Hadronic final states

Expectations based on parton radiation

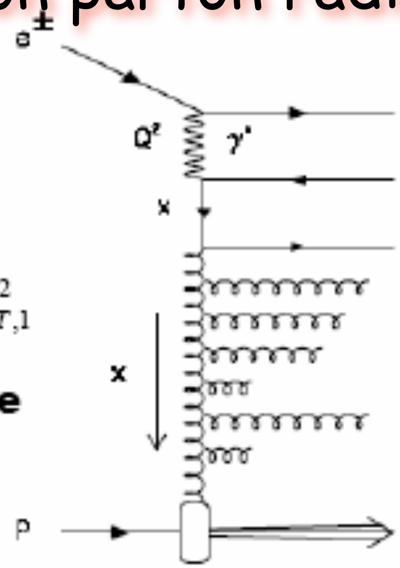


DGLAP

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

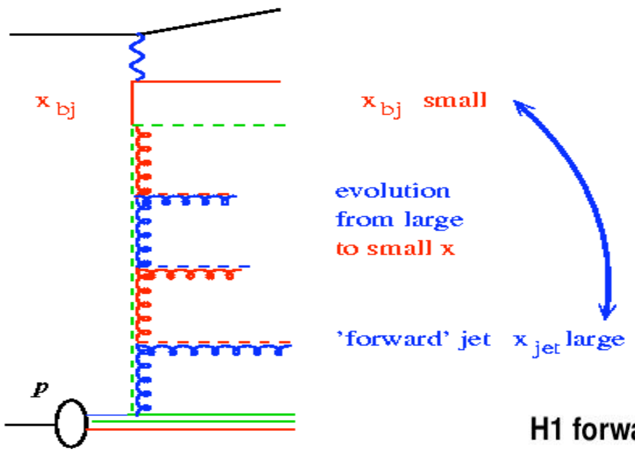
Evolution & resummation in powers of *ln(1/x)*

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

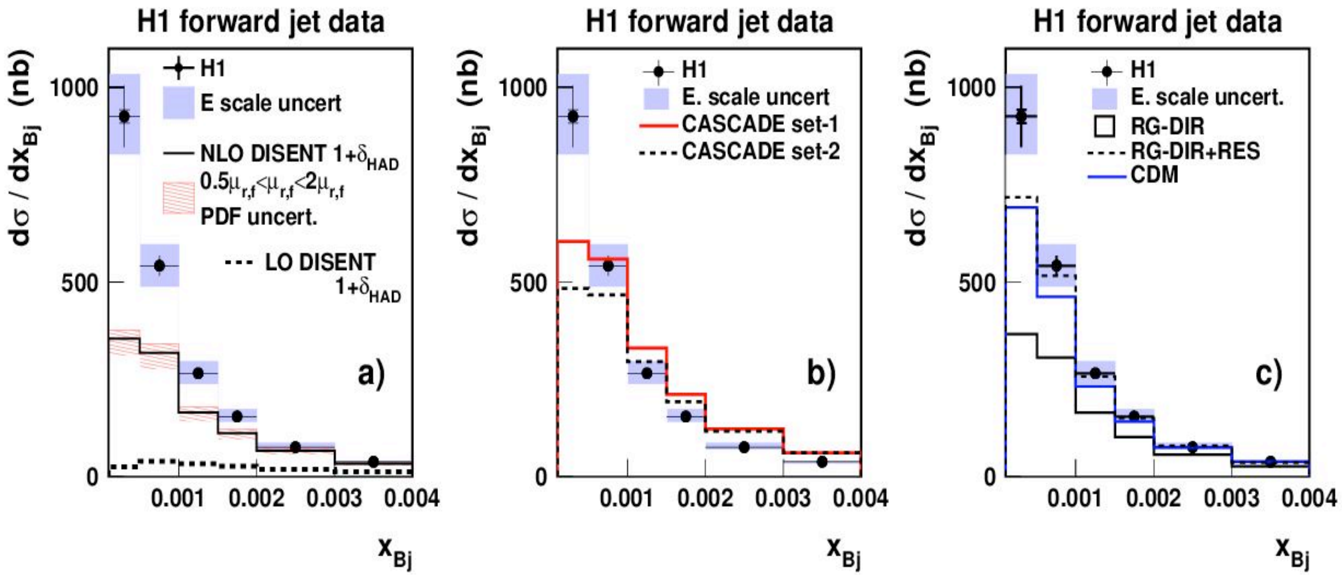
The BFKL is only strongly ordered in x

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

Hadronic final states - forward jets



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



Azimuthal correlations in di/tri-jets

H1 - dijets

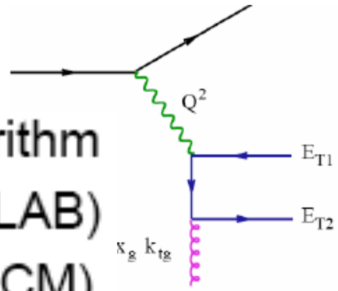
$5 < Q^2 < 100$ GeV^2

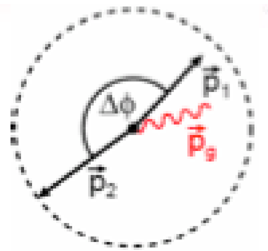
$0.1 < y < 0.7$

Inclusive k_T algorithm

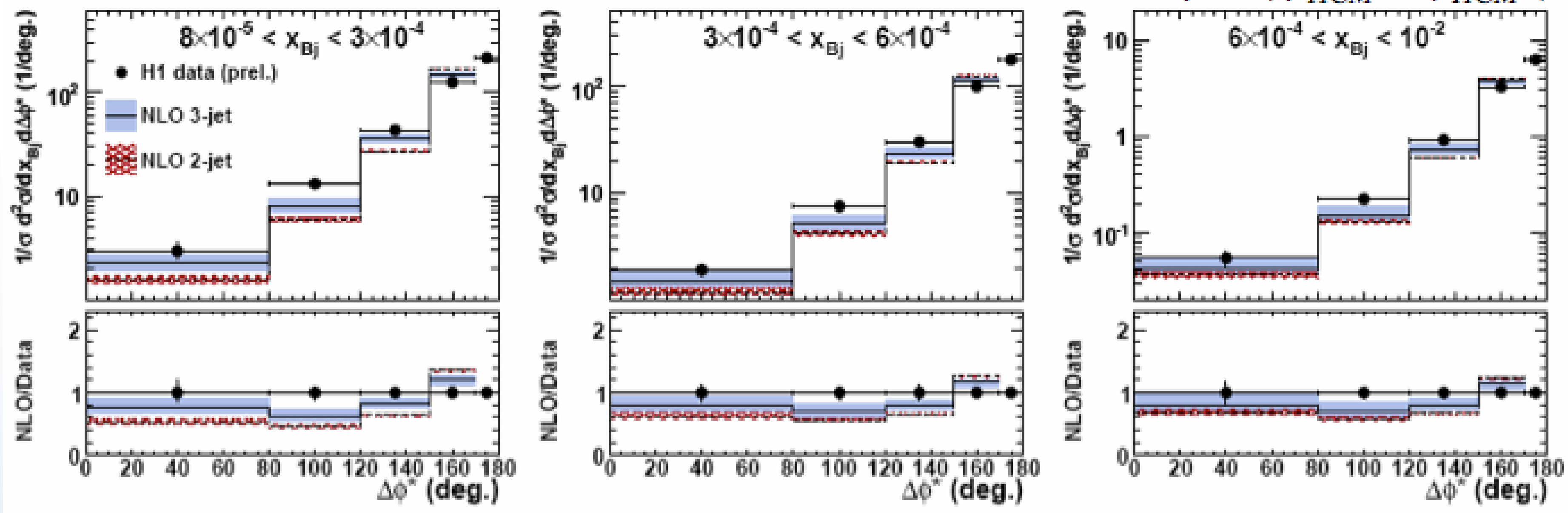
$-1 < \eta_{1,2} < 2.5$ (LAB)

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



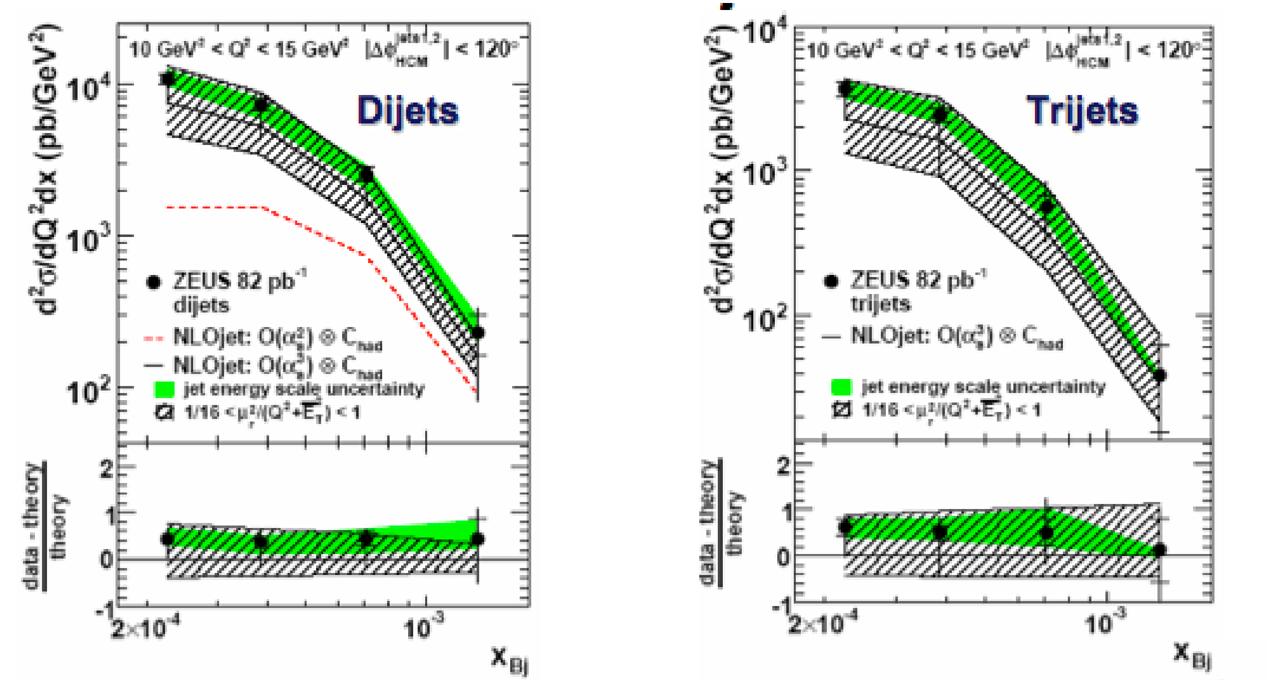


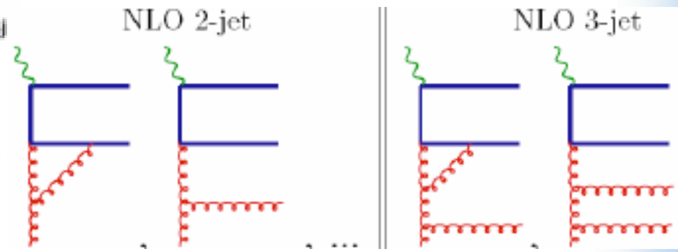
$$\Delta\phi^* = |\phi^{jet1}_{HCM} - \phi^{jet2}_{HCM}|$$



Azimuthal correlations in di/tri-jets

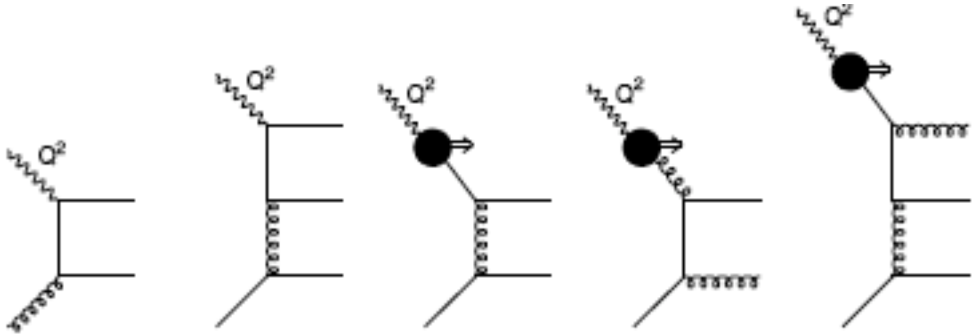
ZEUS: dijets and trijets $\Delta\phi^{j1,j2} < 120°$





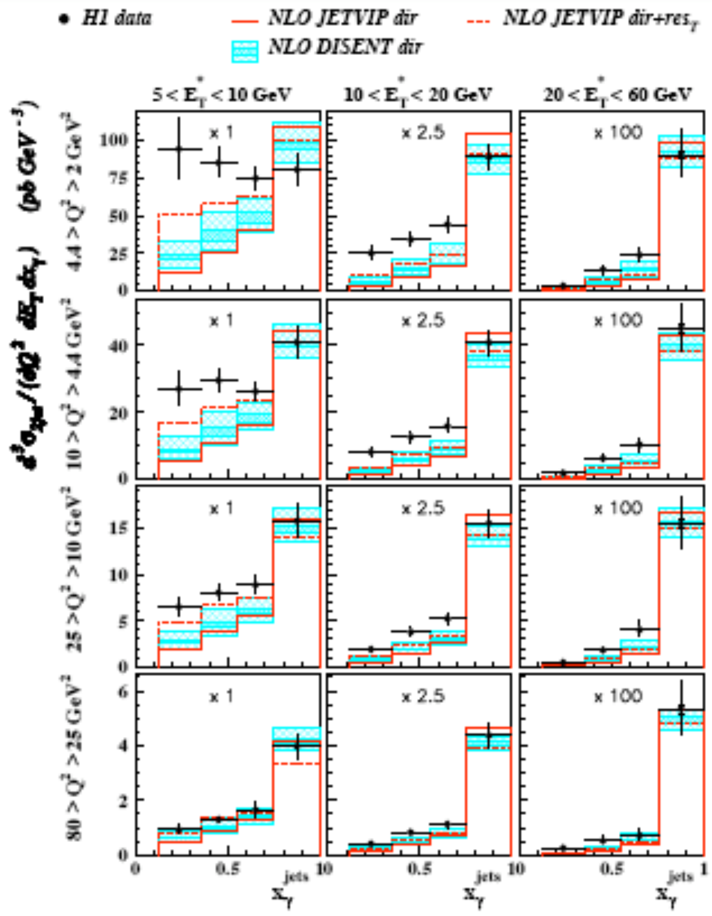
NLOjet calculations at $O(\alpha_s^3)$ describe dijet, trijet data

Dijets in DIS



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

Manifestation of even higher order corrections than NLO



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 RHIC physics, their contribution to LHC physics may be substantial