QCD interpretation of diffraction in *ep* collisions

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On behalf of the H1 and ZEUS collaborations

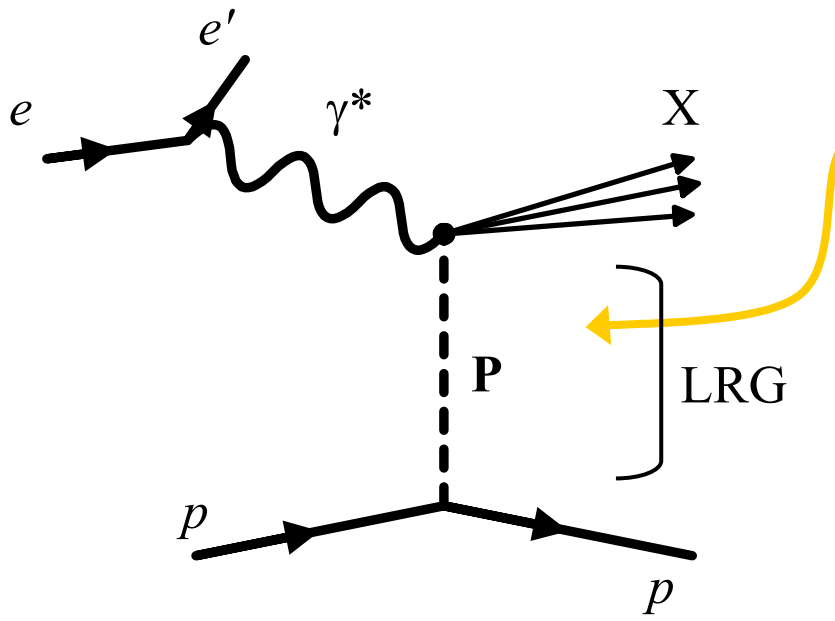
- pQCD approach to diffraction
  - Comparison with pQCD-based models
  - Analysis of diffractive pdfs

… are confronted with HERA data

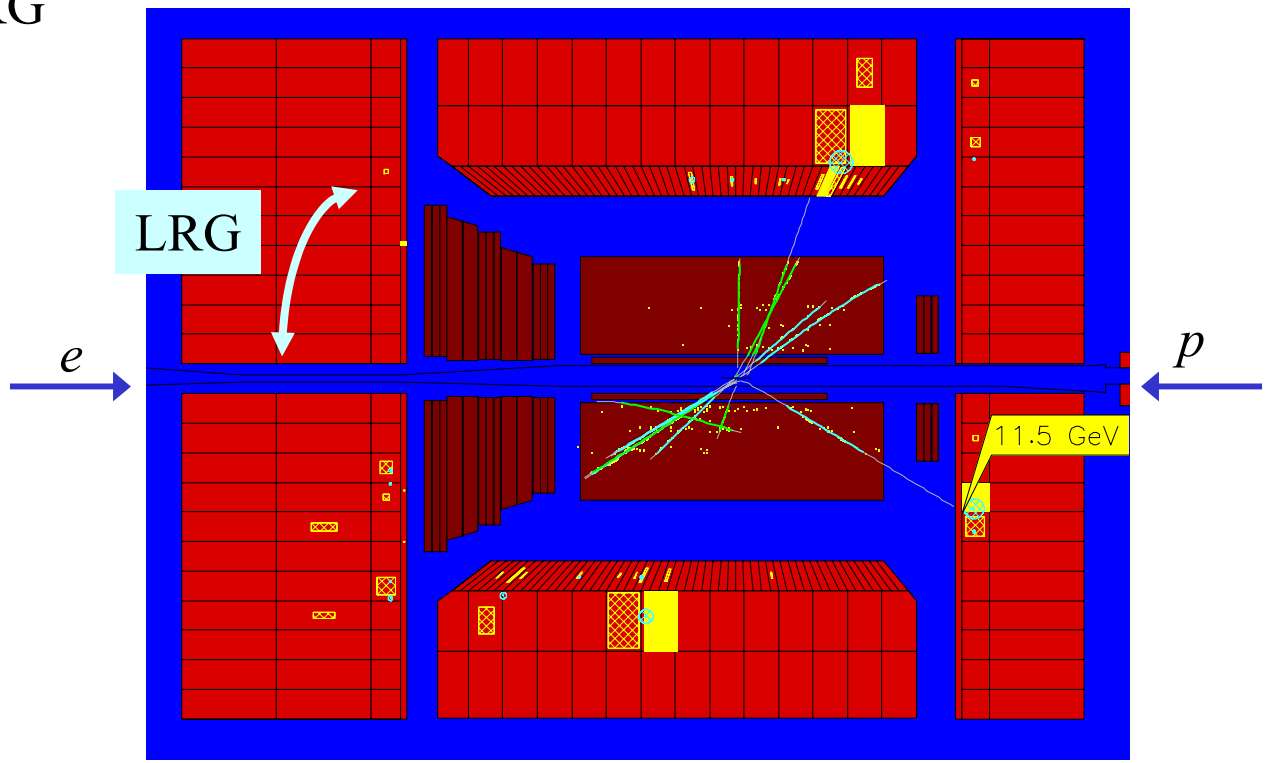
The symbol of the city of Osaka is taken from a beacon for waterways.

Osaka is a sister city of Hamburg, where DESY and the *ep*-collider HERA are located.

Diffraction at HERA

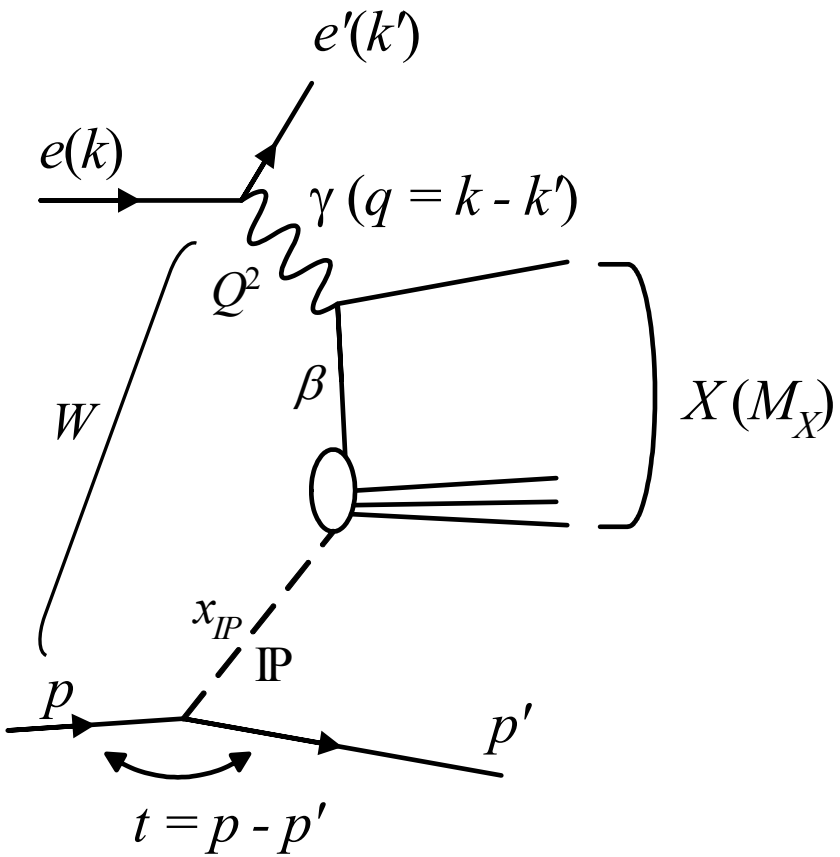


Historically explained by a hypothetical particle "**P**omeron" exchanged between hadrons
(Regge theory)
How can we understand this by pQCD ?



- About 10 % of DIS showing Large Rapidity Gap (LRG) via colourless exchange
  Photon dissociates into hadrons

Diffractive DIS and kinematical variables



W : cms energy of γp
M_X : mass of
the photon-dissociated system

- Studying the partonic structure of the diffractive exchange through the virtual photon
  - hard scale given by Q^2
- Photon vertex variables
  - Q^2 : photon virtuality
  - $\beta = Q^2 / (Q^2 + M_X^2)$: x_{Bj} for "Pomeron" longitudinal momentum fraction of the parton in the exchange
- Proton vertex variables:
  - t : transverse kick of the proton
  - $x_{\boldsymbol{P}} = (Q^2 + M_X^2) / (Q^2 + W^2)$: longitudinal momentum fraction carried by the exchange to the proton

pQCD approach (1): partonic exchange

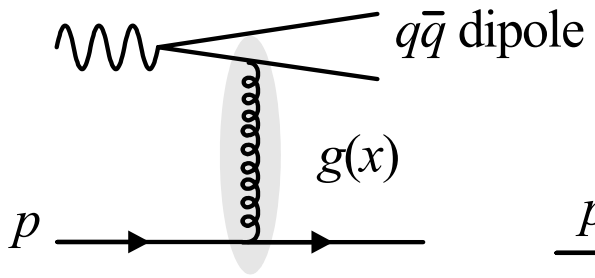
- Exchanging partons
  (short distance !)
  between proton and qq dipole
- Inelastic at low-x: 1-gluon
- Colourless: 2-gluons
- Basic idea:
  - a photon $\rightarrow$ qq dipole
  - 2-gluons: by proton pdf $g(x)$

$$\sigma \propto |\, g(x)\,|^2$$

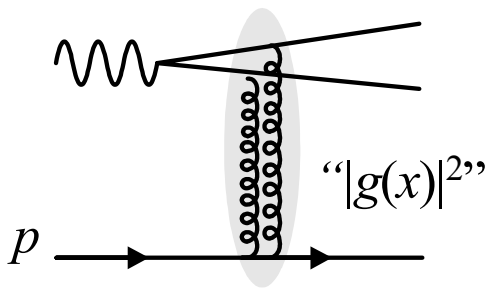
- Take a look on pure qq state:
  VM production $\rightarrow$

Dipole picture

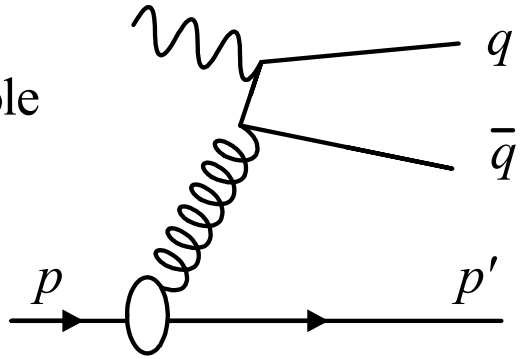
Inclusive

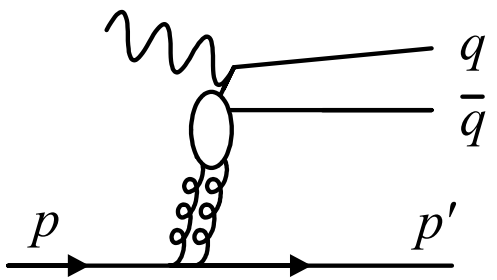


qq

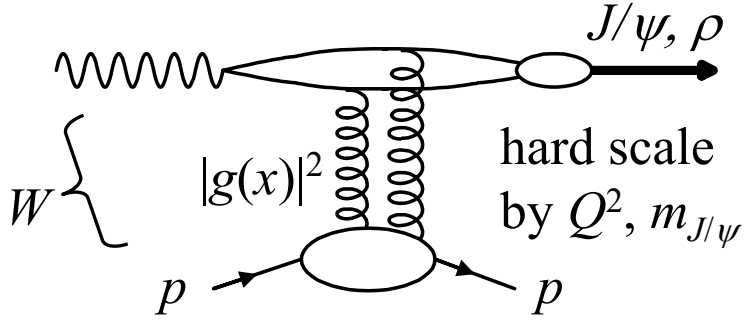


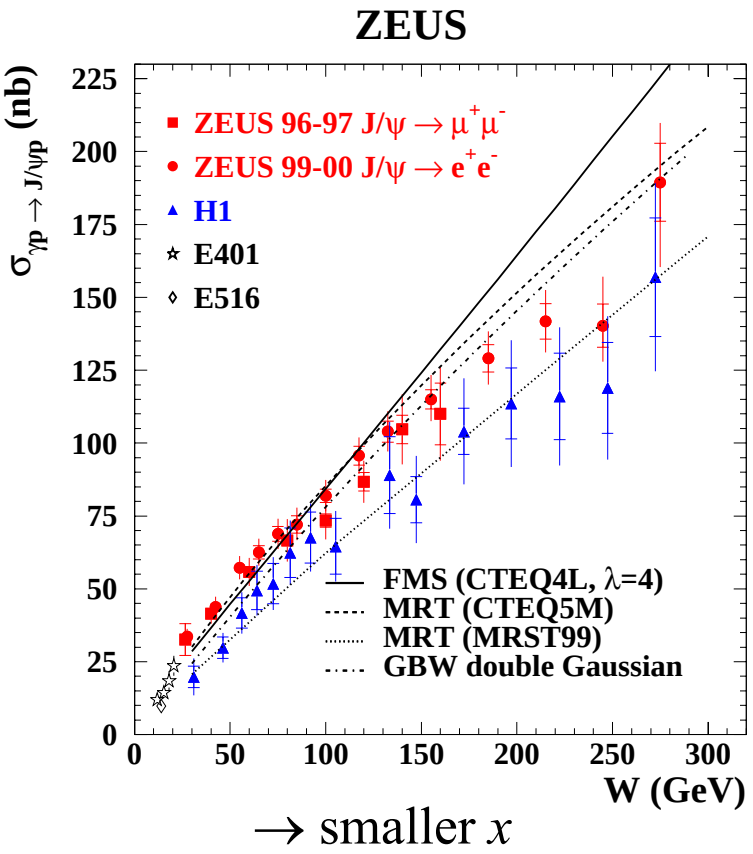
Normal picture for DIS



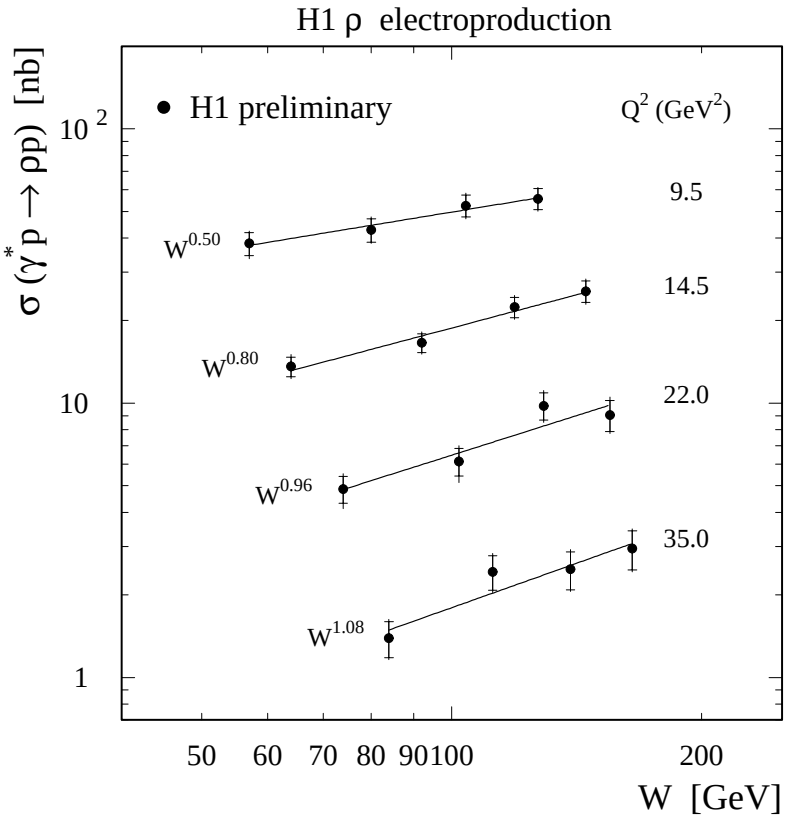


Exclusive vector meson production



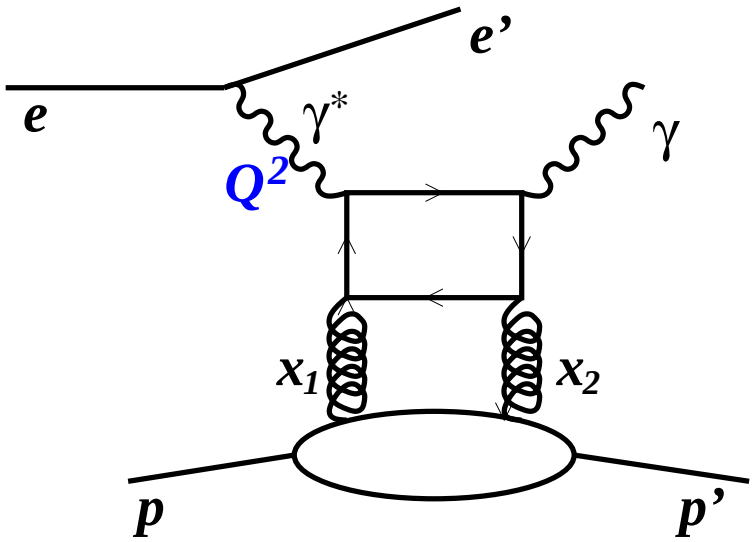


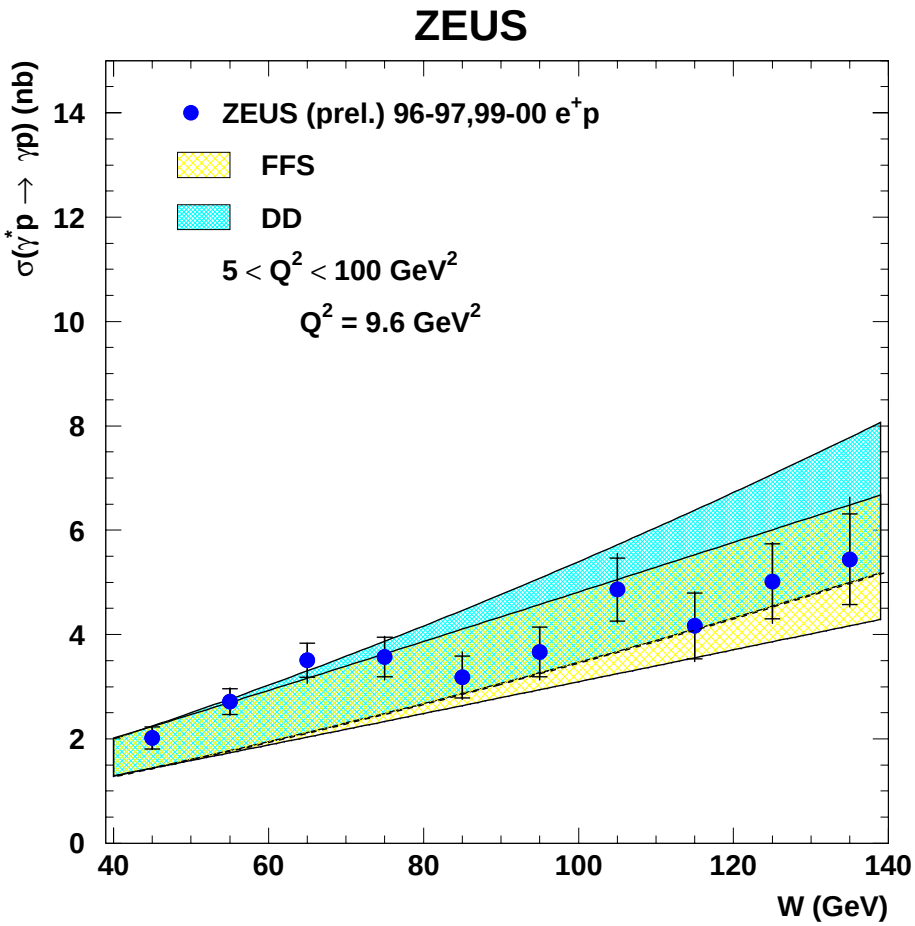
→ smaller x



- Steep rise in W: reflection of $g(x)$ increase towards low-x ($W \sim 1/x$)
- Steep rise also at high-Q^2 where a hard scale is available

True elastic: Deeply virtual Compton scattering





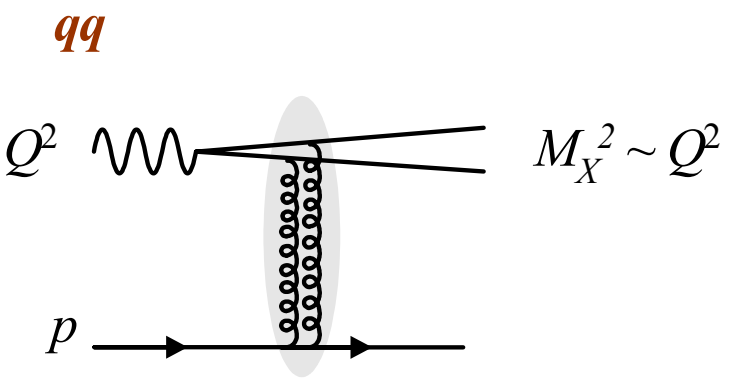
- Photon wave function known: ideal probe for testing pQCD
- Access to generalised parton density $(x_1 \neq x_2)$

VM production: well described by pQCD if a hard scale is available

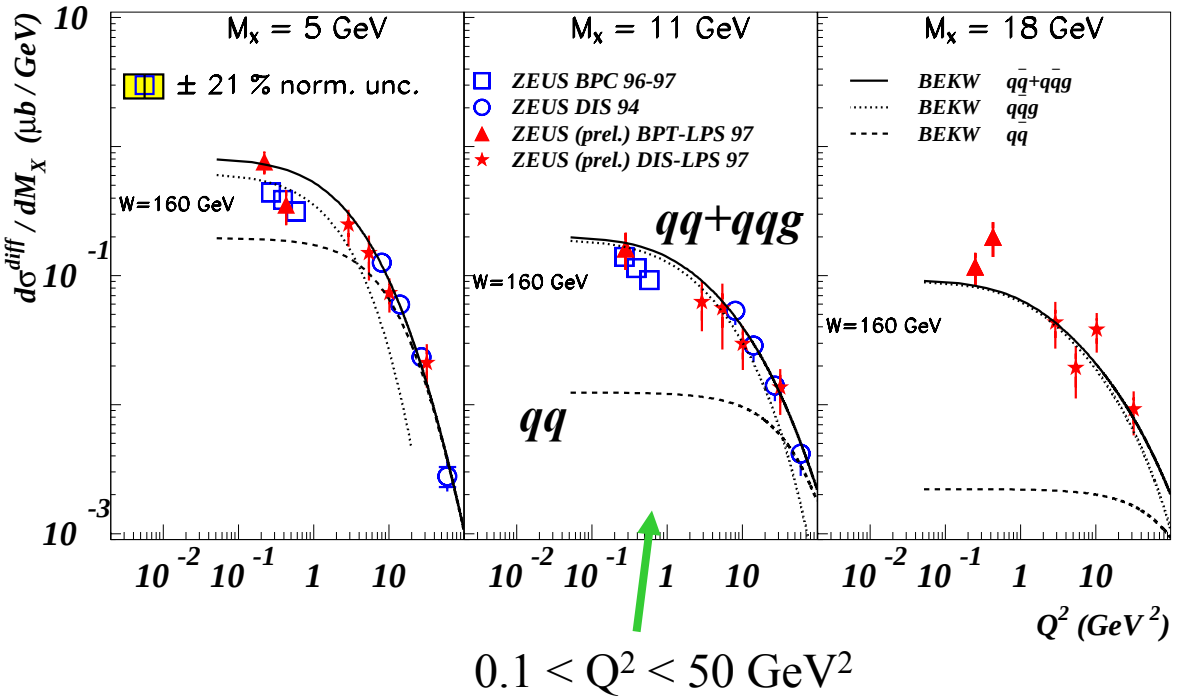
- Similar feature as VM production: steep W dependence

Inclusive reaction: confronting with pQCD models

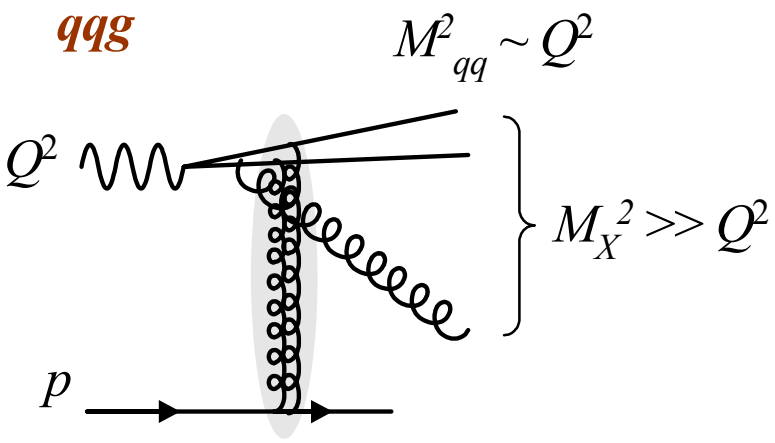
- Pure 2-gluon exchange is dominant for $Q^2 \sim M_X^2$
- For $Q^2 << M_X^2$, only part of the 2-gluon system interacts with the virtual photon



$M_X^2 \sim 100$ GeV^2

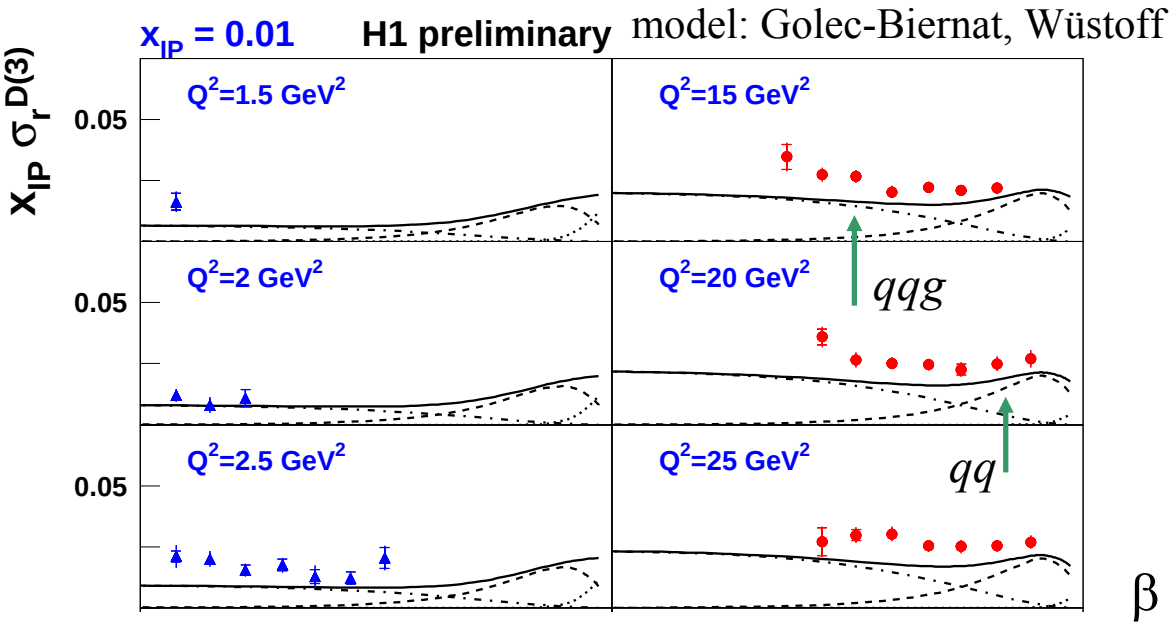


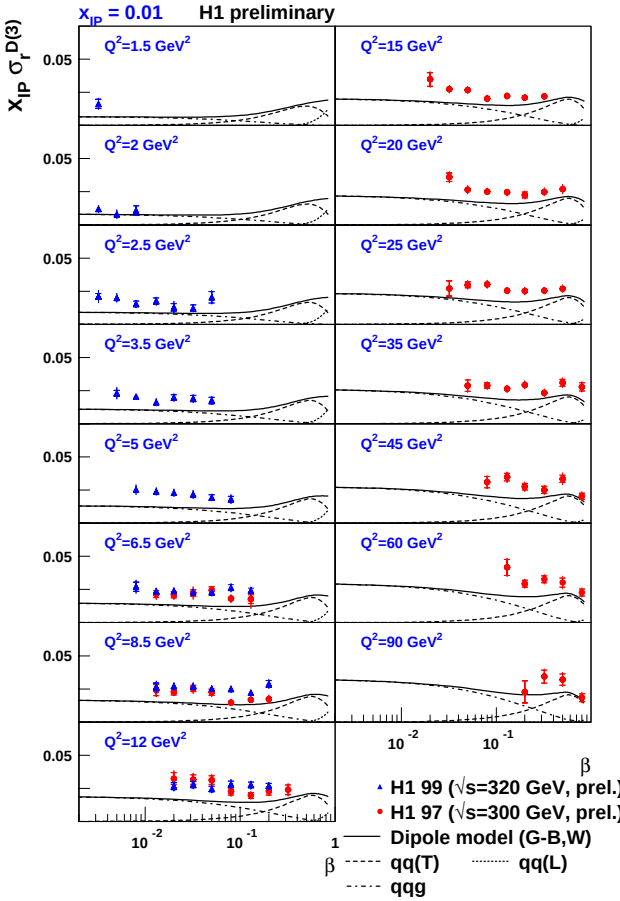
$0.1 < Q^2 < 50$ GeV^2



Need *qqg* component

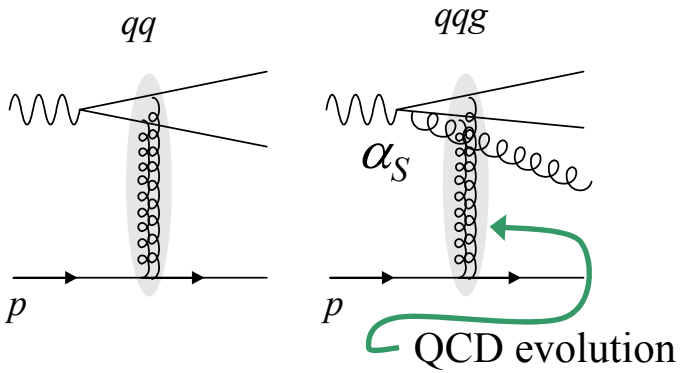
Incl. diffraction with pQCD model





- qq component is well described (cf. vector meson)
- qqg component
  - Low Q^2: underestimation ($O(\alpha_S)$ diagram)
  - Low x : Q^2 evolution needs working out

pQCD good but not perfect → trying pragmatic approach

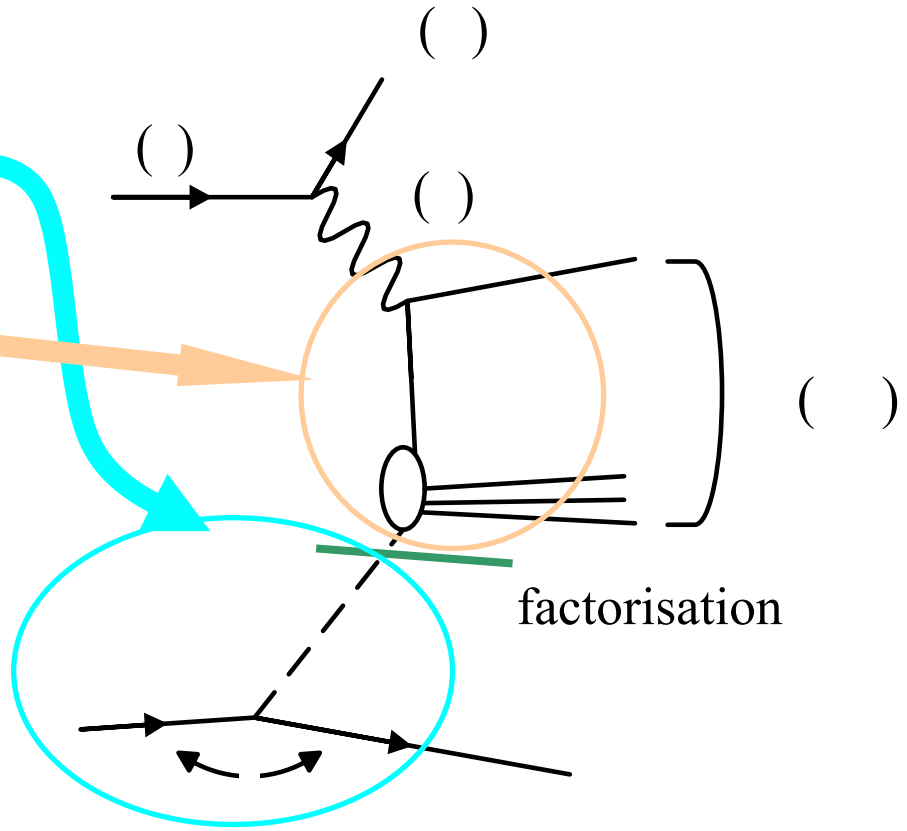


pQCD approach (2): Regge-factorisation and diffractive parton densities

- Diffractive cross sections are factorised into:
  - non-perturbative colourless exchange: the "Pomeron flux" $f_{P/p}(x_P, t)$ and
  - "Pomeron"-virtual photon: point-like interaction $F_2^P(\beta, Q^2)$

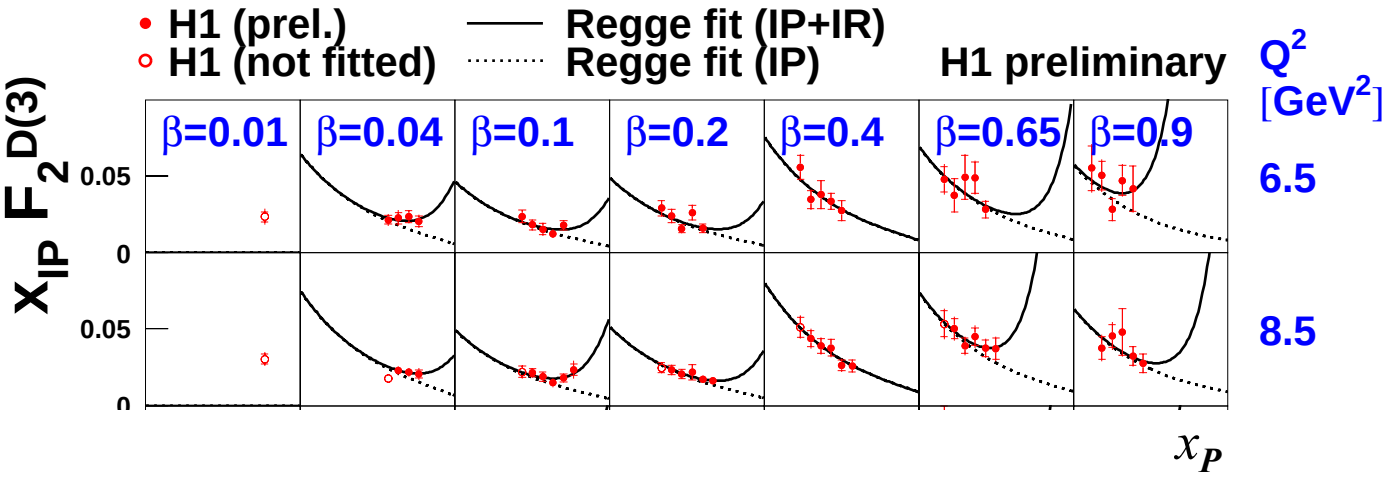
$$F_2^D \propto f_{\mathbf{P}/p}(x_{\mathbf{P}}, t) \cdot F_2^{\mathbf{P}}(\beta, Q^2)$$

- Parton dynamics of the exchange: investigated by extracting **diffractive pdfs** by a QCD fit



W : cms energy of γp
M_X : mass of the photon-dissociated system

Inclusive diffraction – Regge-factorisation

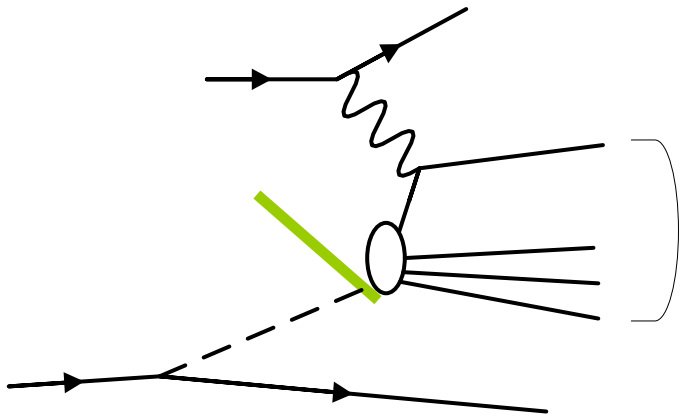


- Fit the cross section using factorisation assumption

$$F_2^D \propto \frac{f(t)}{x_{\mathbf{P}}^{2\alpha_{\mathbf{P}}(t)-1}} \cdot F_2^{\mathbf{P}}(\beta, Q^2) \Rightarrow \frac{1}{x_{\mathrm{P}}^{\mathrm{a}}} \cdot b(\beta, Q^2)$$

- For each β and Q^2 bins,

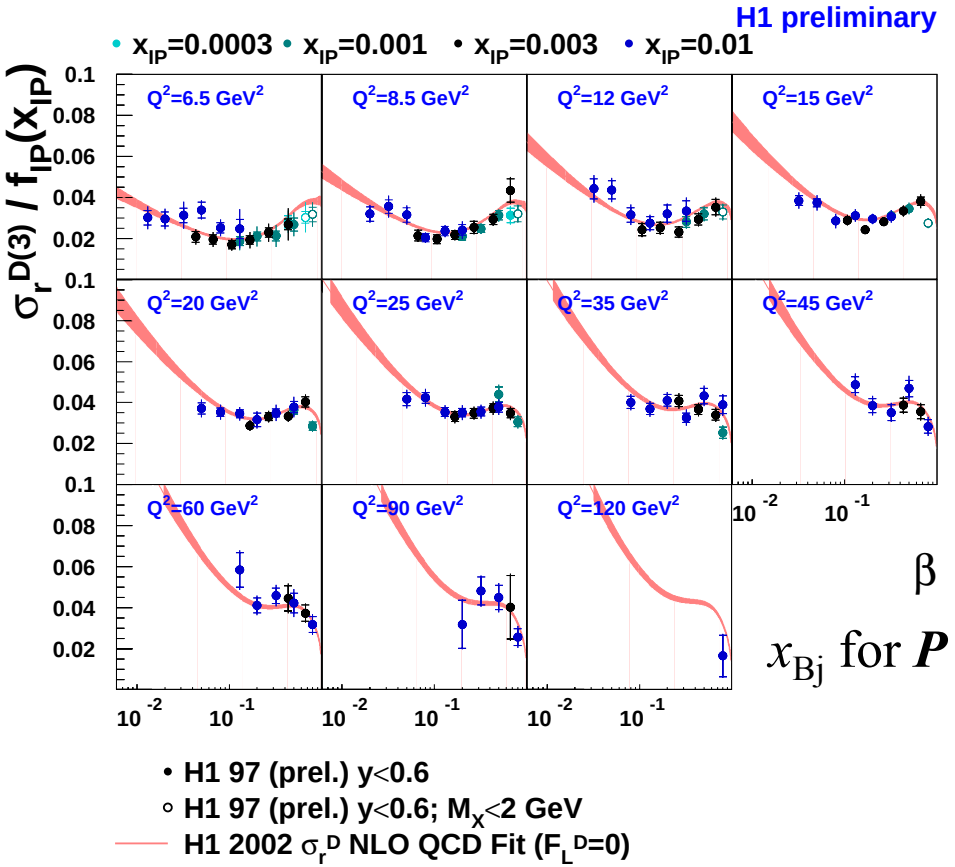
  the x_P dependence is about the same

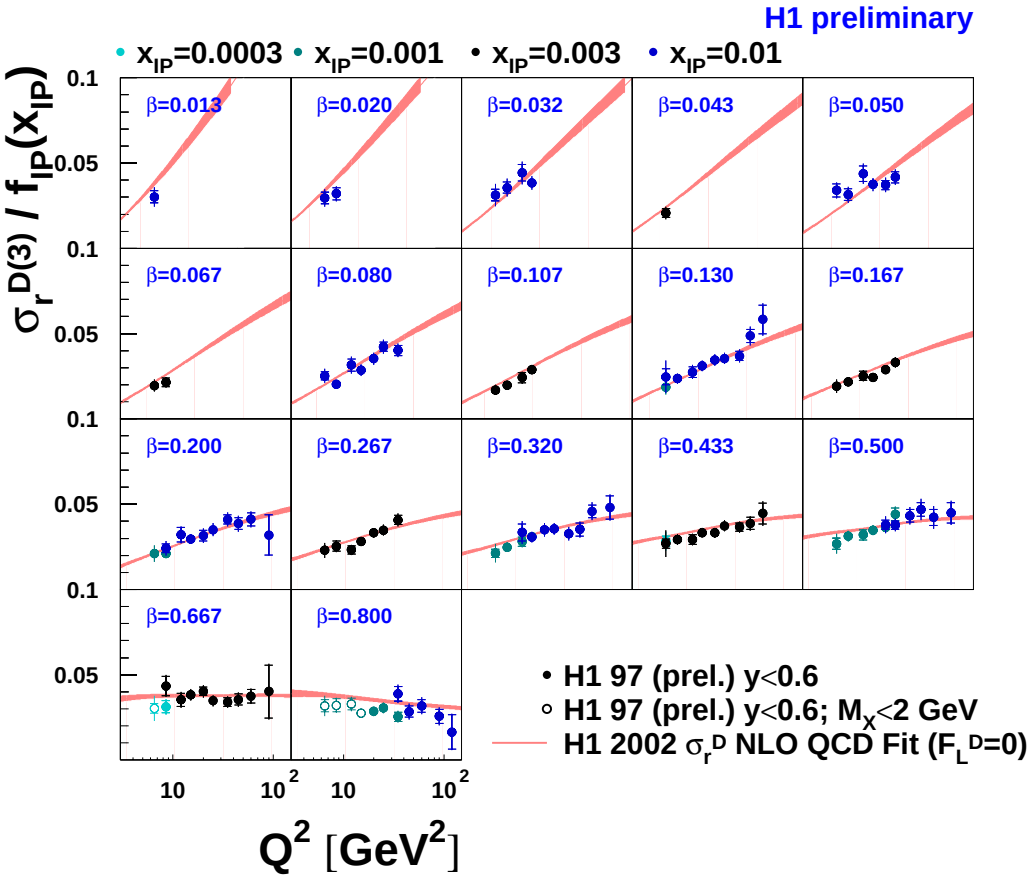


Cross section is factorised into
a long-life object and hard vertex

→ take a look on $F_2^{\mathbf{P}}(\beta, Q^2)$ …

NLO QCD fit – structure of the exchanged object

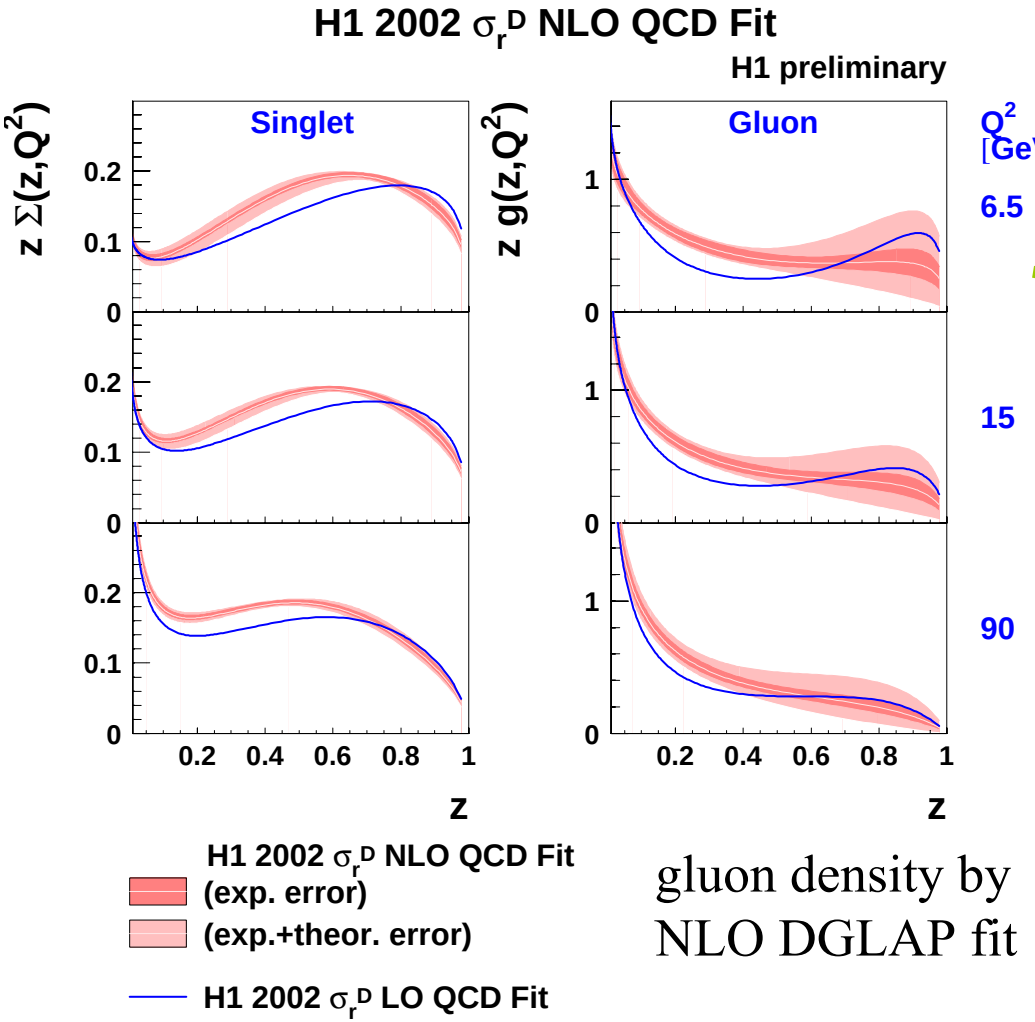




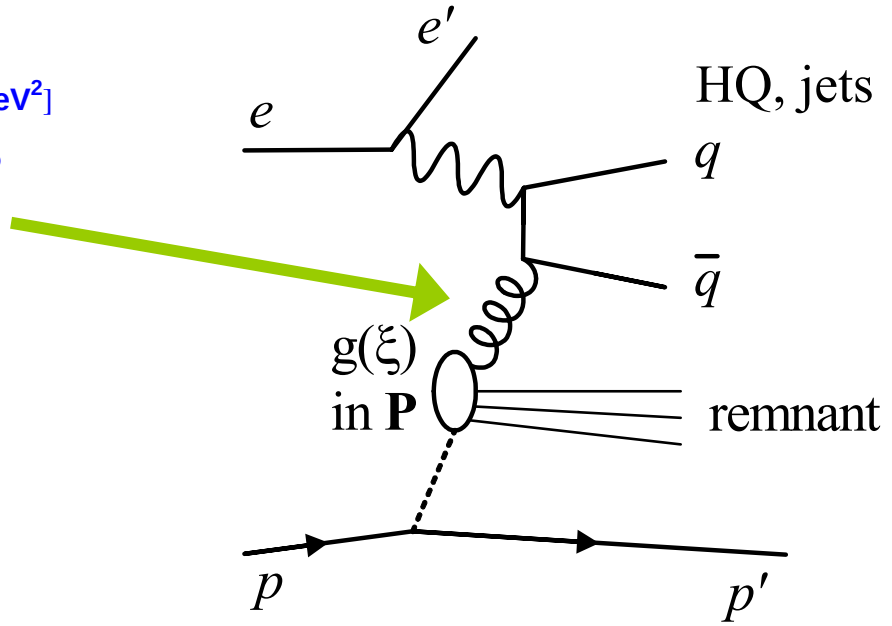
- Relatively flat in β
  – high momentum parton inside
  Unlike a proton, more like a photon

- Strong positive scaling violation in Q^2
  gauge boson inside (like γ pdf)
  <u>A gluon-rich object</u>

Result of the NLO QCD fit



gluon density by NLO DGLAP fit

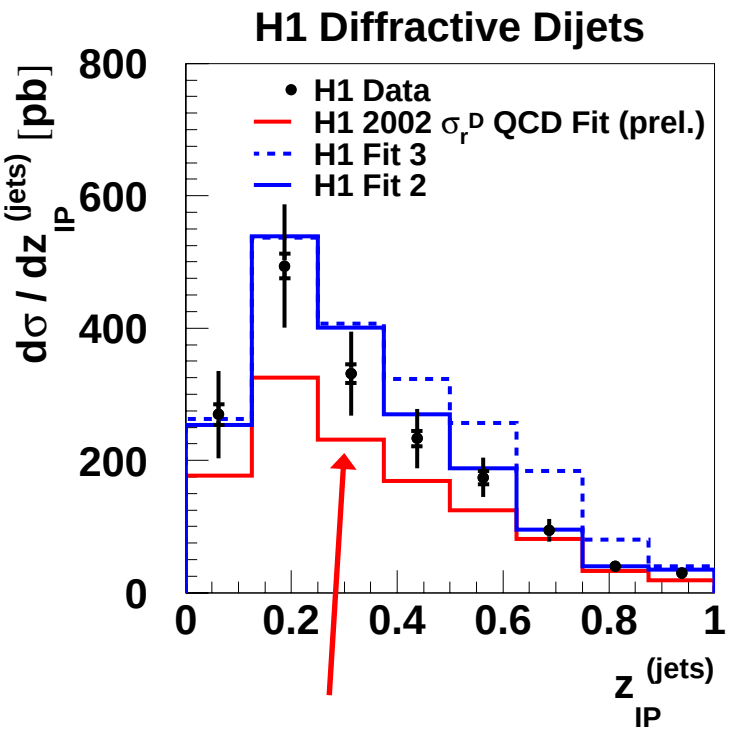


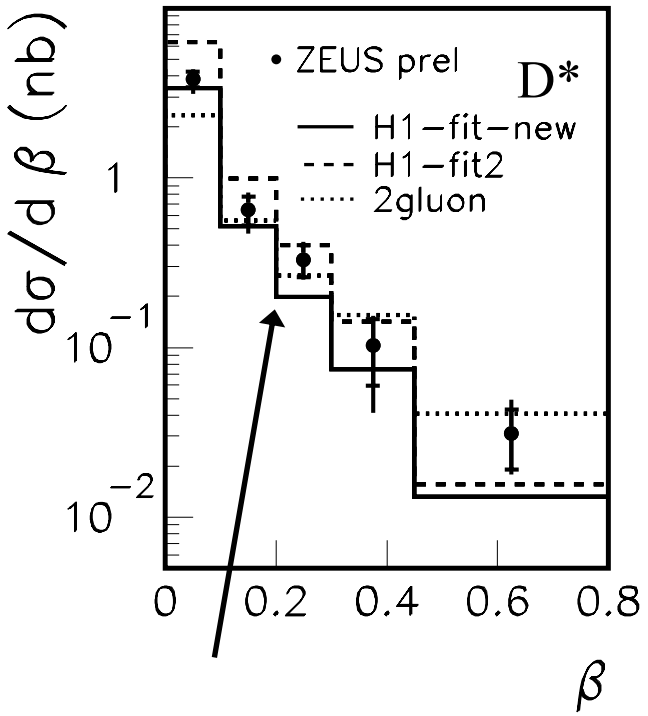
- Does the gluon density from scaling violation agree with the "direct" measurement from jets/charm ?

Gluon much more than quarks – consistent with 2-gluon + HO in pQCD approach

HFS (hadronic final state) in diffraction

by Hannes Jung





- Both H1 jets and ZEUS D* calculated by LO + H1 LO fit
- Prediction tend to be lower than the data: LO insufficient, NLO would explain it
- Uncertainty in pdf still large

Gluon density from DGLAP fit gives ~ right cross section for HFS, **NLO awaited**

Conclusion

- Two types of pQCD approaches are confronted to *ep* collision data
- Comparison with pQCD parton exchange model:
  - $q\bar{q}$ dipole works (short-distance)
  - higher order $q\bar{q}g$ component to be worked out (not only short distance)
- Regge-factorisation approximately OK: long-distance object
- Analysis of diffractive pdf:
  - gluon-dominated exchange
- Diffractive exchange : somewhere between

  long-distance and short-distance states

  Understanding using pQCD seems possible

  $\rightarrow$ insight to the **physics of confinement**