# MC modeling of diffraction at HERA - LHC

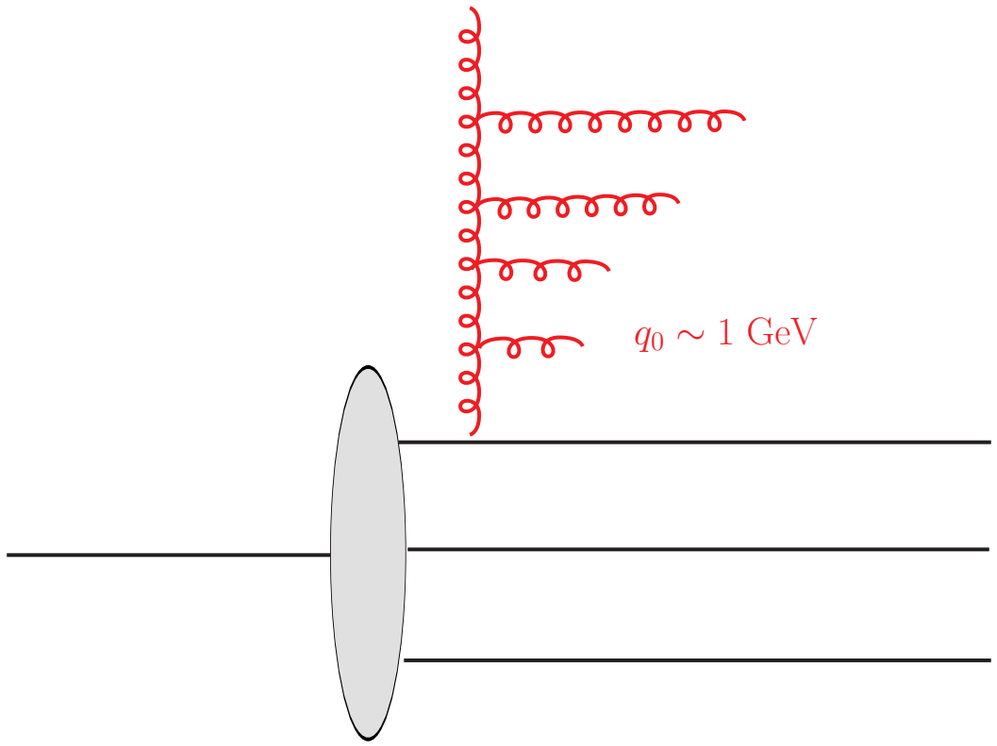
- how diffraction is modelled at HERA
- what has that to do with LHC
- how to relate diffraction at HERA with LHC
  - gap survival and multiple interaction
- importance to non diffractive processes

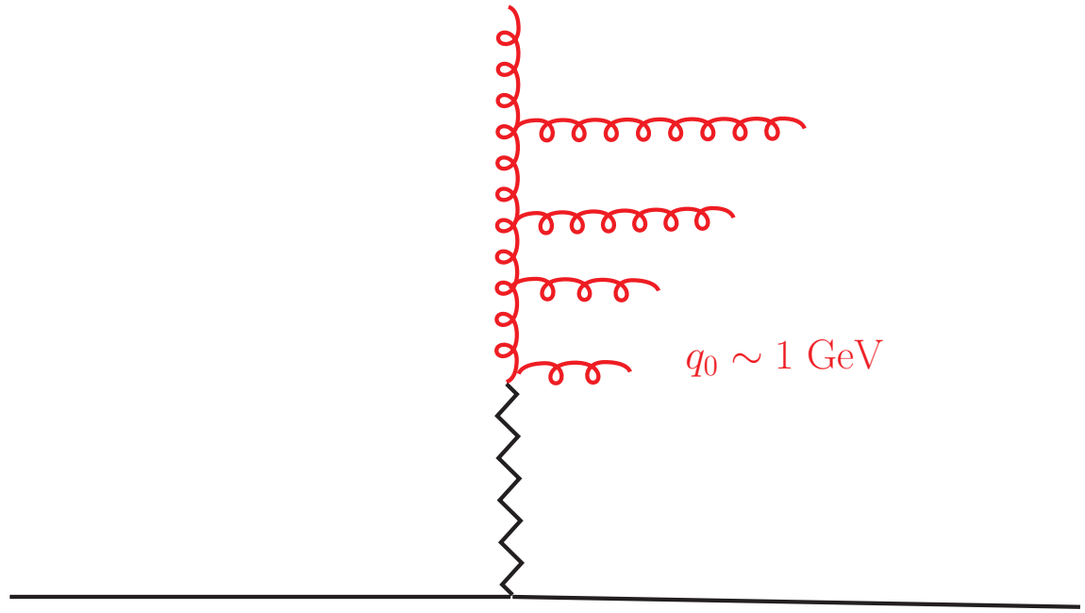
# diffractive PDFs

- factorisation theorem of Collins et al (J. Collins Phys.Rev.D57:3051-3056,1998, Erratum-ibid.D61:019902,2000)

$$d\sigma = \sum_i \int d\xi f_i^{(D)}(\xi, x_{pom}, t; \mu) d\hat{\sigma}_i + \text{non} - \text{leading power of } Q$$

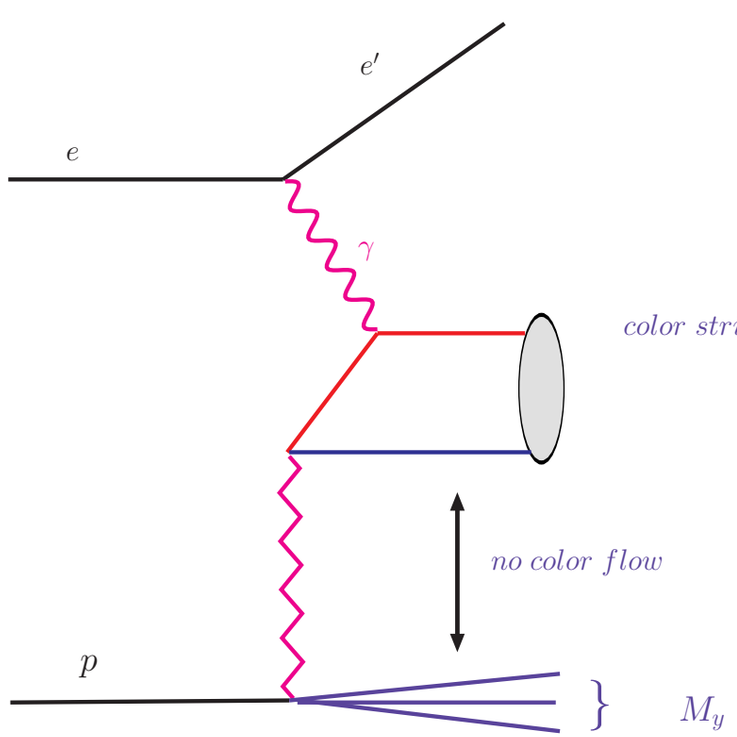
- dPDFs obey same Q2 evolution as usual PDFs
- diffraction is included in the initial condition of the PDF

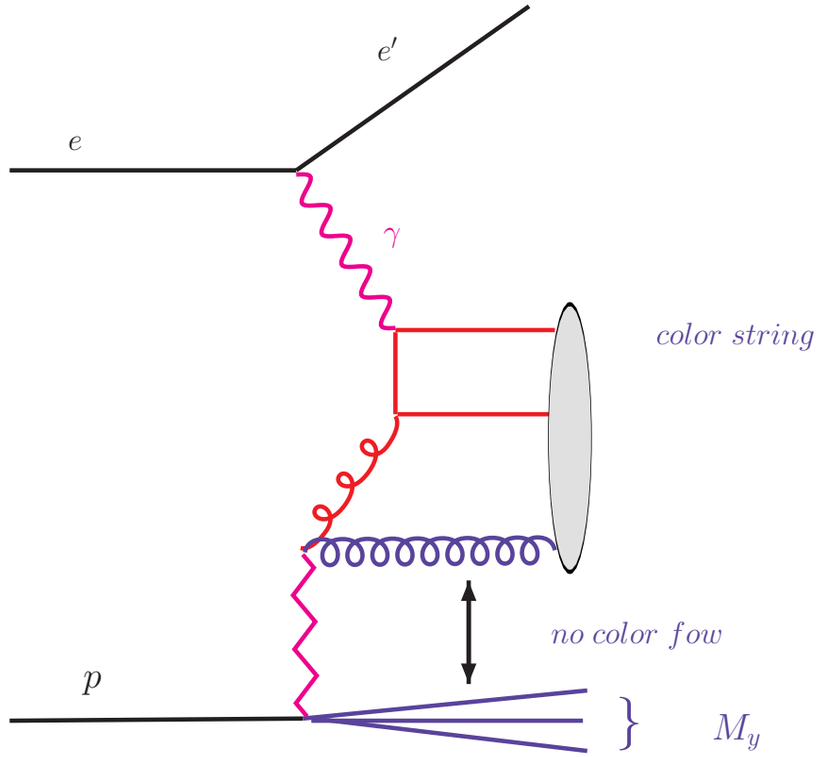


# Diffraction at HERA in DIS

- Simulation of hard scattering:




- hard scattering consists of: with a hard scale set by $Q^2, p_t^2, etc$

$$\gamma^* q \rightarrow q$$
$$\gamma^* q \rightarrow qg$$
$$\gamma^* g \rightarrow q\bar{q}$$

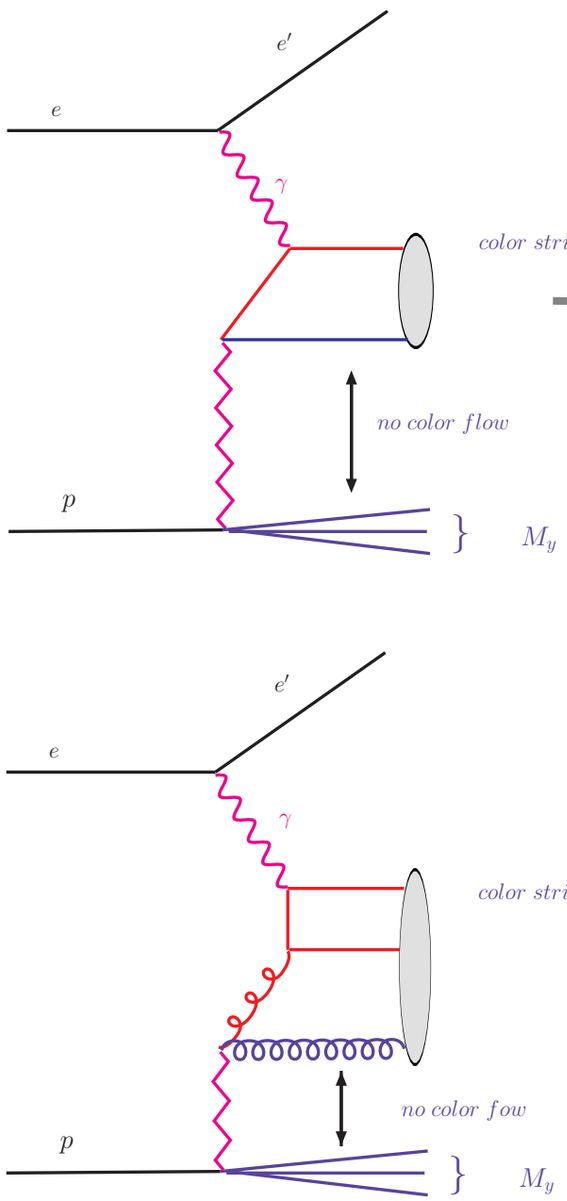
- parton densities: diffractive pdfs: $xq(x, \xi, \mu^2)$
- initial and final state parton shower ala DGLAP: PYTHIA like virtuality ordered
- dissociation of low mass diffractive system including all resonances

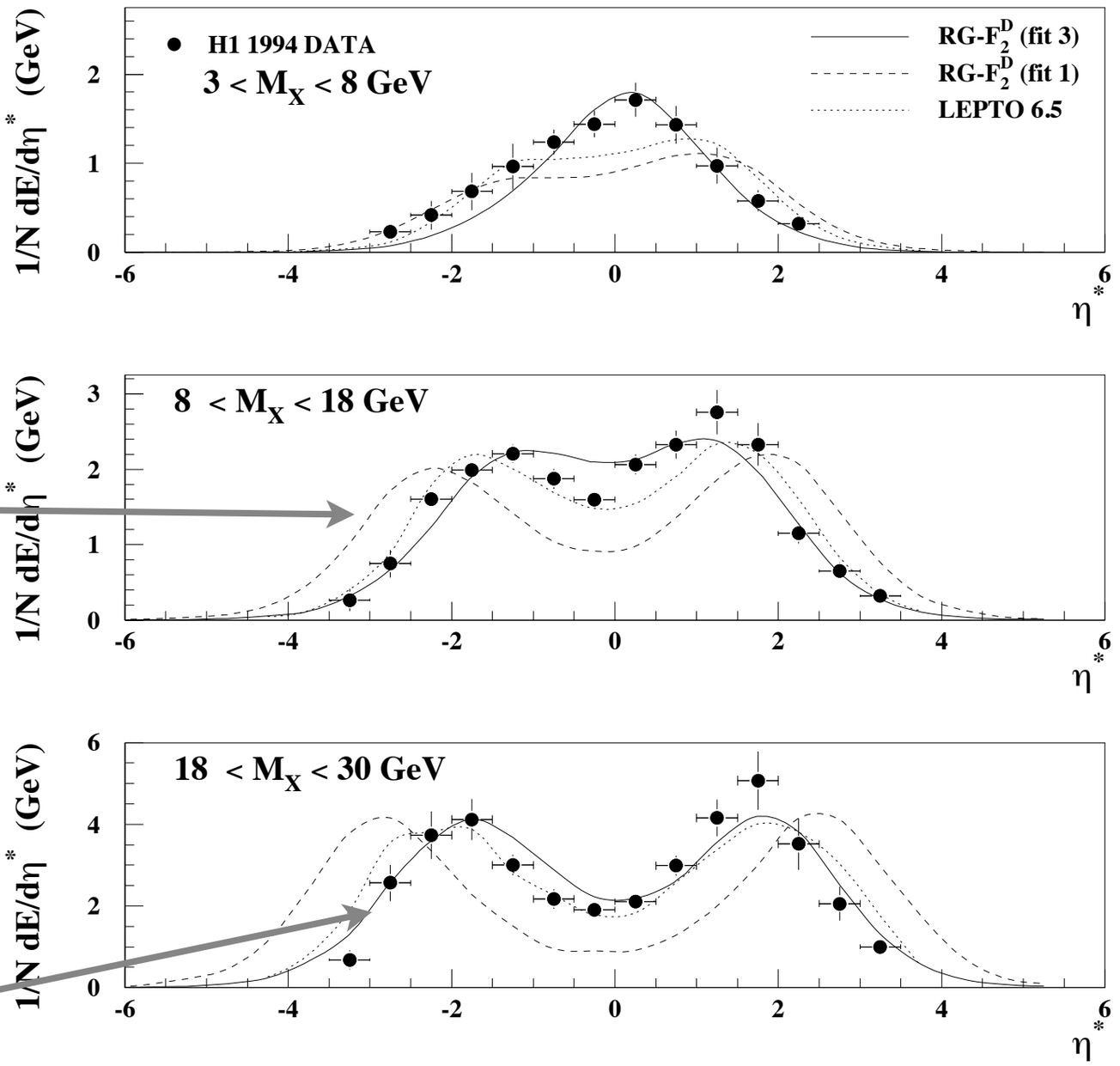
# Applications at HERA

- Main programs used at HERA:
  - DIS: RAPGAP
  - photoproduction: RAPGAP & POMPYT
- special programs:
  - RIDI (2-gluon exchange), SATRAP (dipole model)
- diffractive PDFs:
  - obtained from NLO DGLAP fits to $F_2^D(x, \beta, Q^2)$
    - parametrisation from H1 & ZEUS & ACTW
- inclusion of secondary trajectories (in H1 dPDF)
- pion exchange (charged and neutral)
  - RAPGAP & POMPYT
- dissociation of low mass proton system
  - RAPGAP using detailed features of low mass diffraction including the resonance region

# Examples: energy flow in diffraction

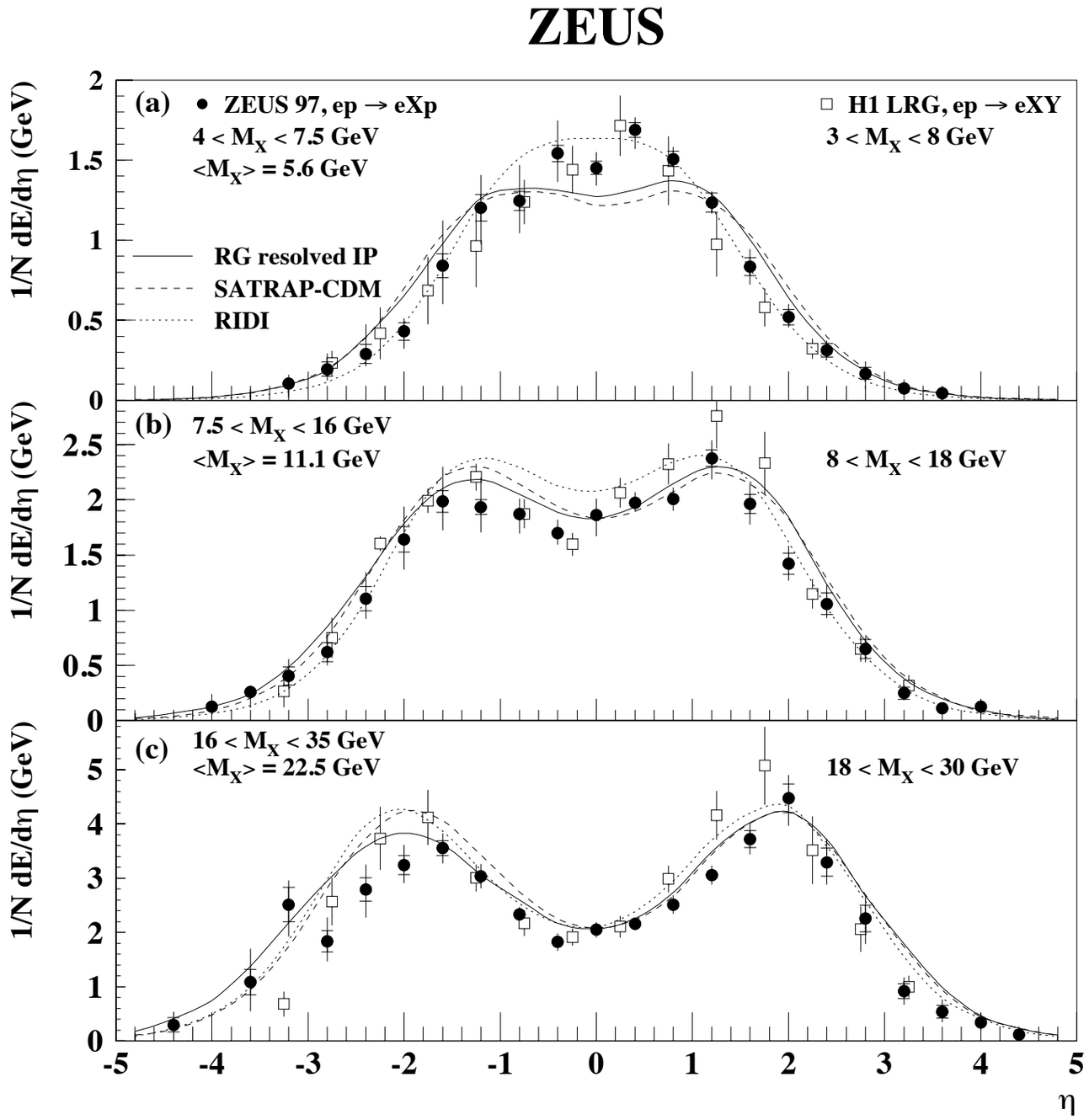
- energy flow in diffraction depends whether it is a $q\bar{q}$ or a $q\bar{q}g$ state



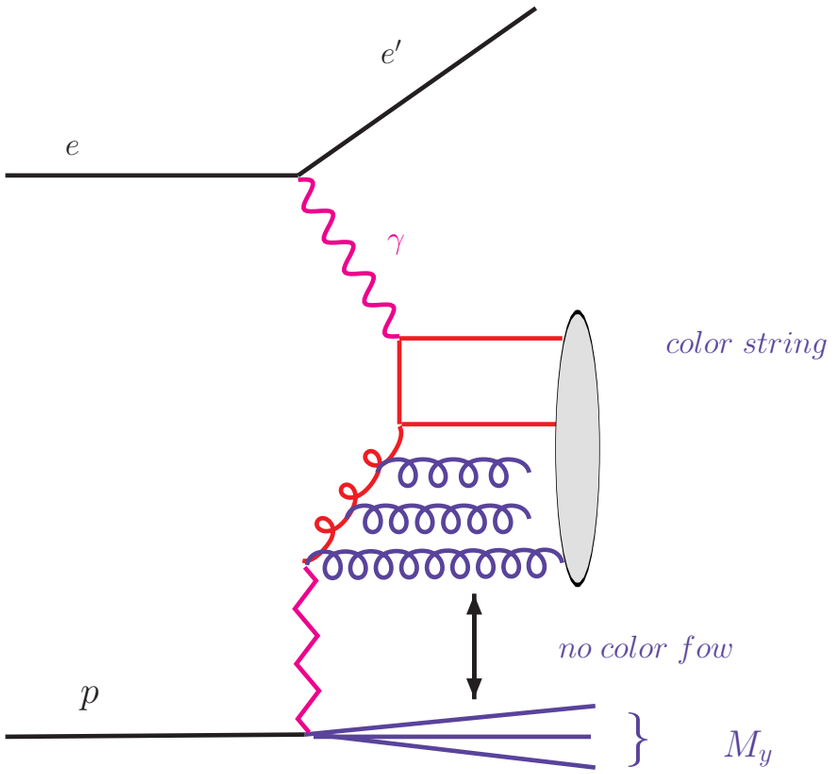
# Examples: energy flow in diffraction

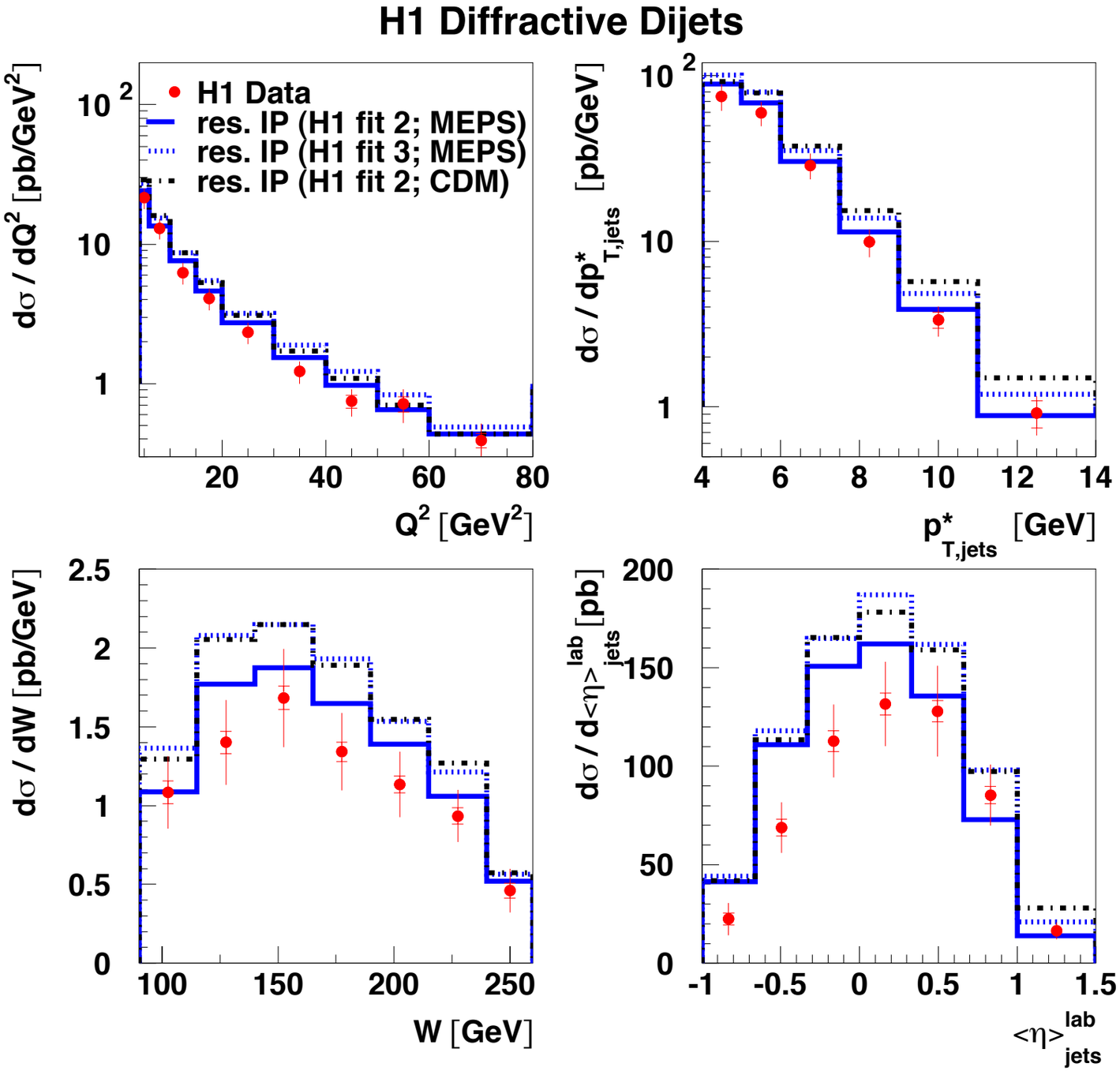
- energy flow in diffraction is reasonably well described with model of diffractive PDFs and pQCD hard scattering.
- details depend on the parametrisation of the dPDFs and the quark-gluon mix !



# Example: diffractive dijet production

- Diffractive dijet production at large $Q^2$ are reasonably well described using MC with parton shower and diffractive PDFs



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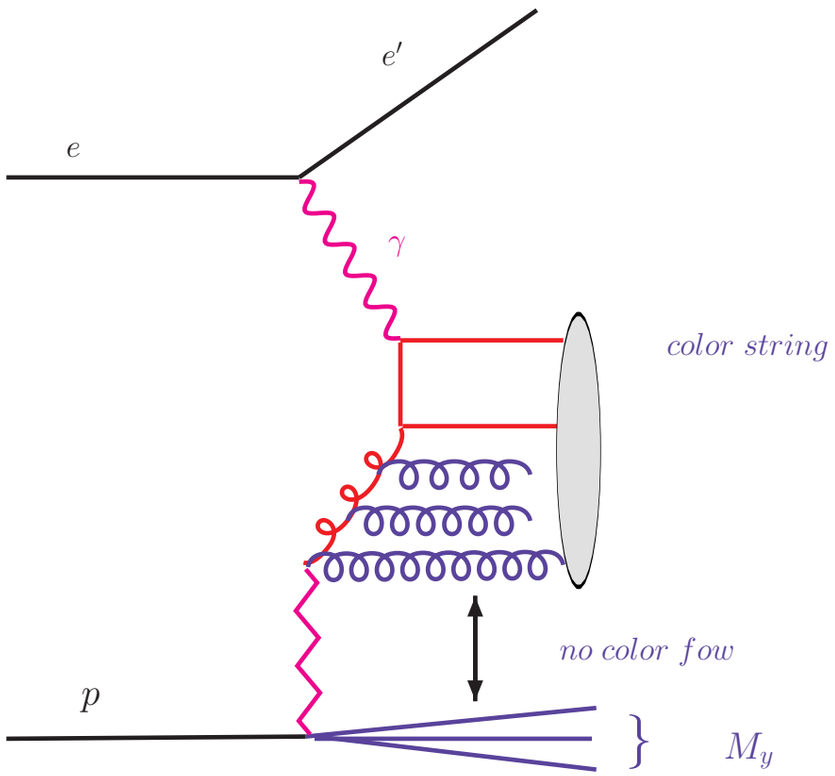
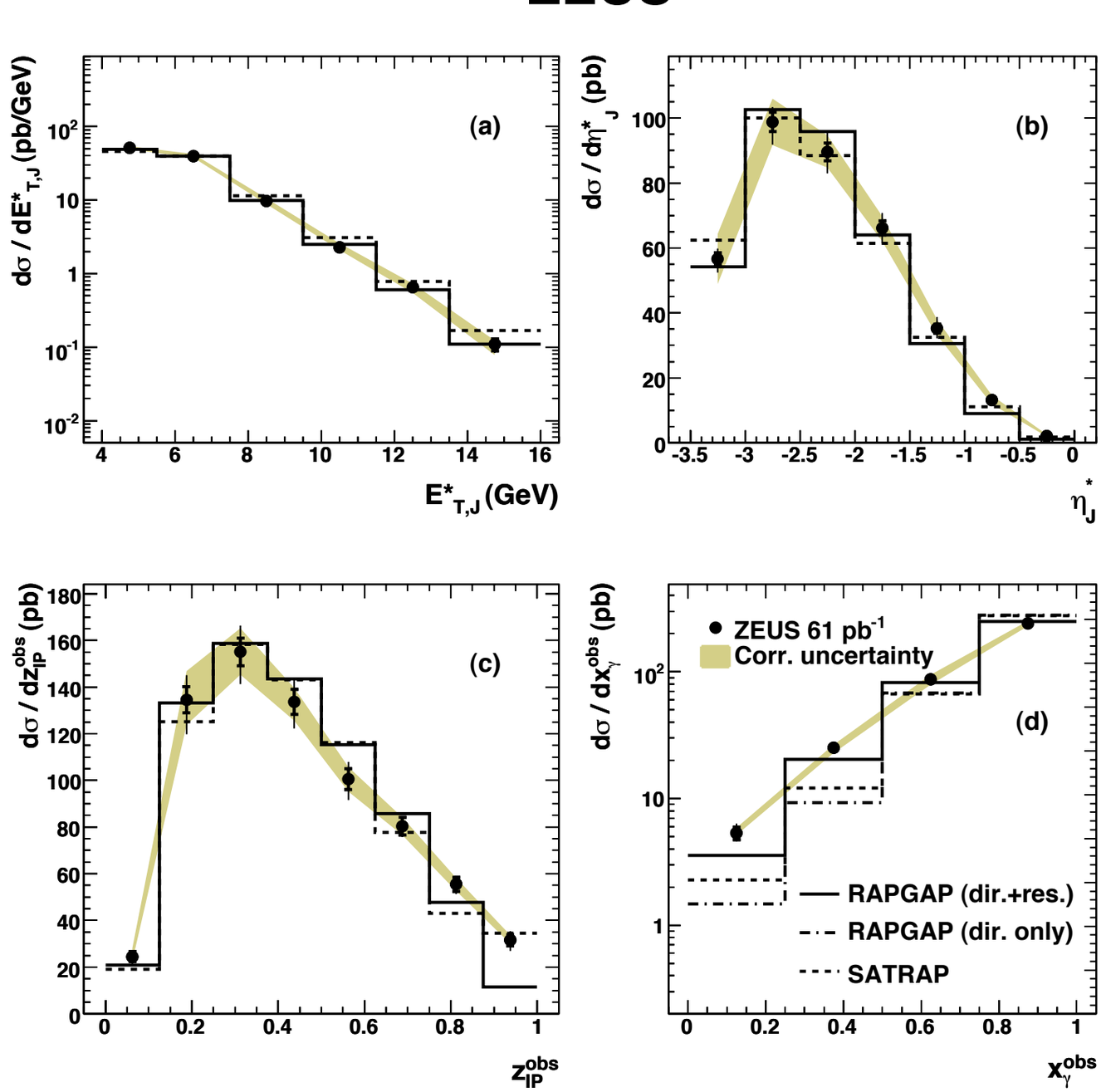
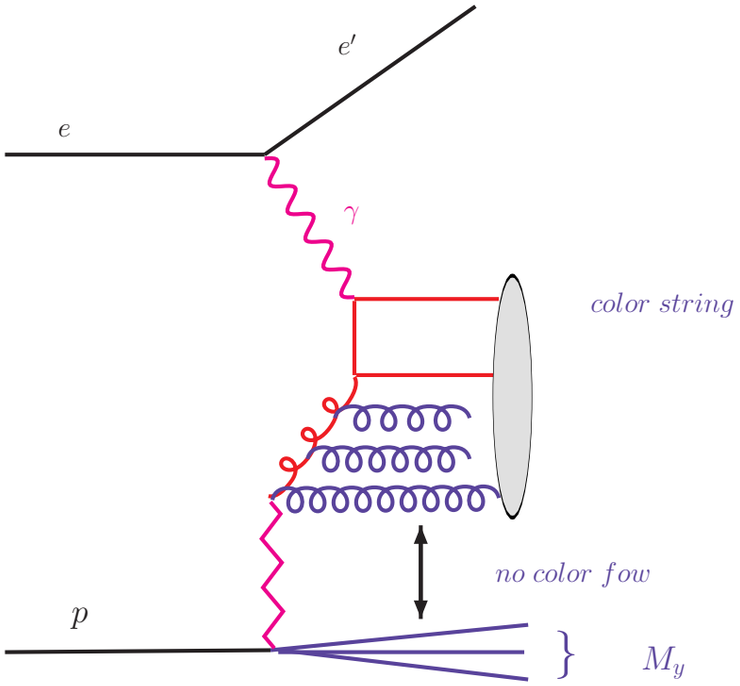
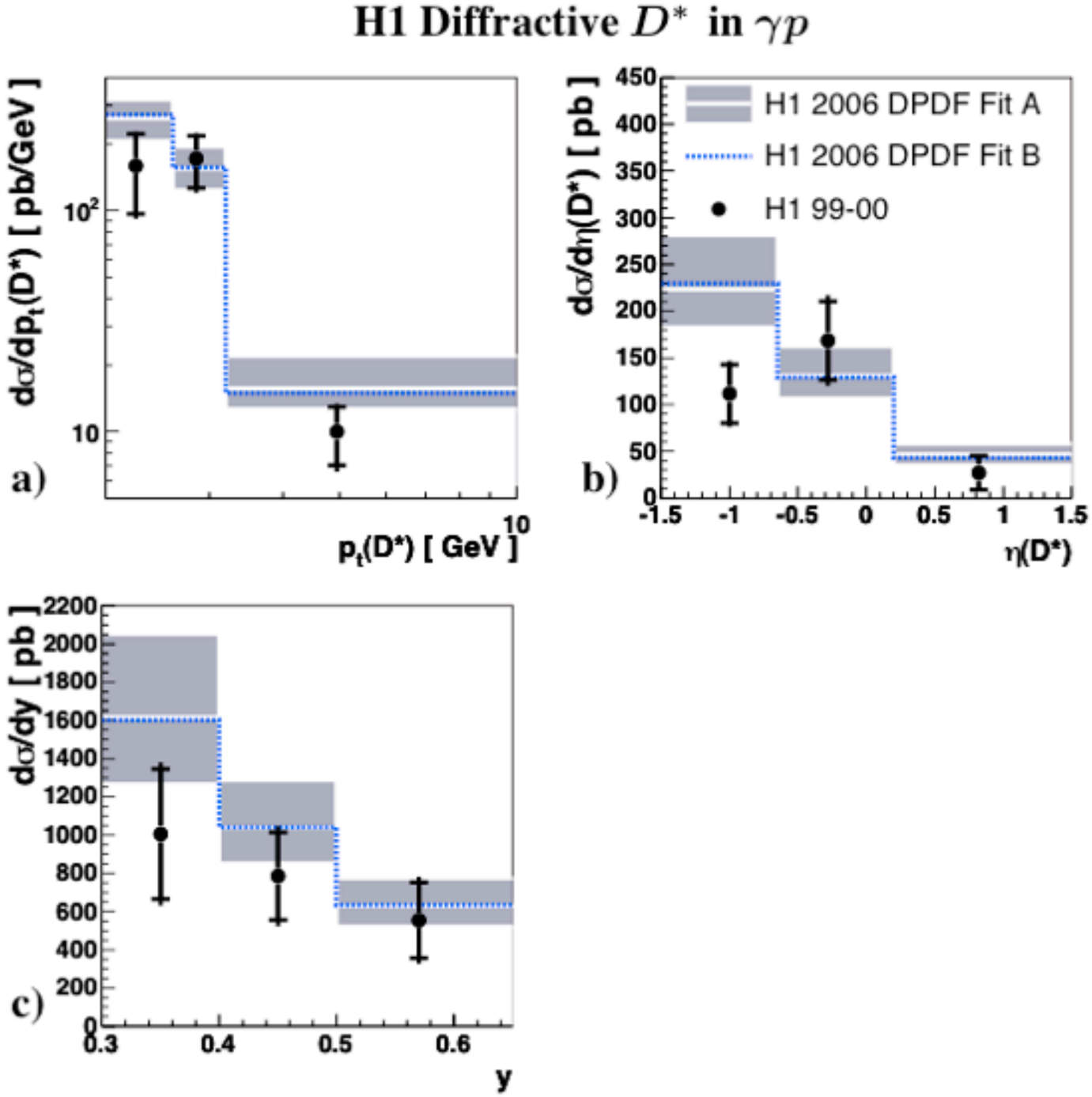


# Diffractive charm production

- Diffractive charm production also reasonably well described with dPDFs and hard scattering processes in LO and NLO.



# Hard diffraction and non-diffraction in ep

- Diffractive contribution is already implicitly included in parton densities.
- Inclusive di-jets include already diffractive di-jets
- How is it done in MC
  - in DIS we know how to do it (we have factorisation theorem for hard diffraction in DIS)
  - calculate diffractive x-section

$$F_2(x,Q^2)^{non\ diff} = F_2(x,Q^2) - \int d\beta F_2^D(x_{pom},\beta,Q^2)\delta(x_{pom}\beta - x)$$

- calculate inclusive x-section
  - decide whether to generate diffractive or non-diffractive process
  - generate all lowest order and order alphas processes
  - perform parton shower and remnant fragmentation

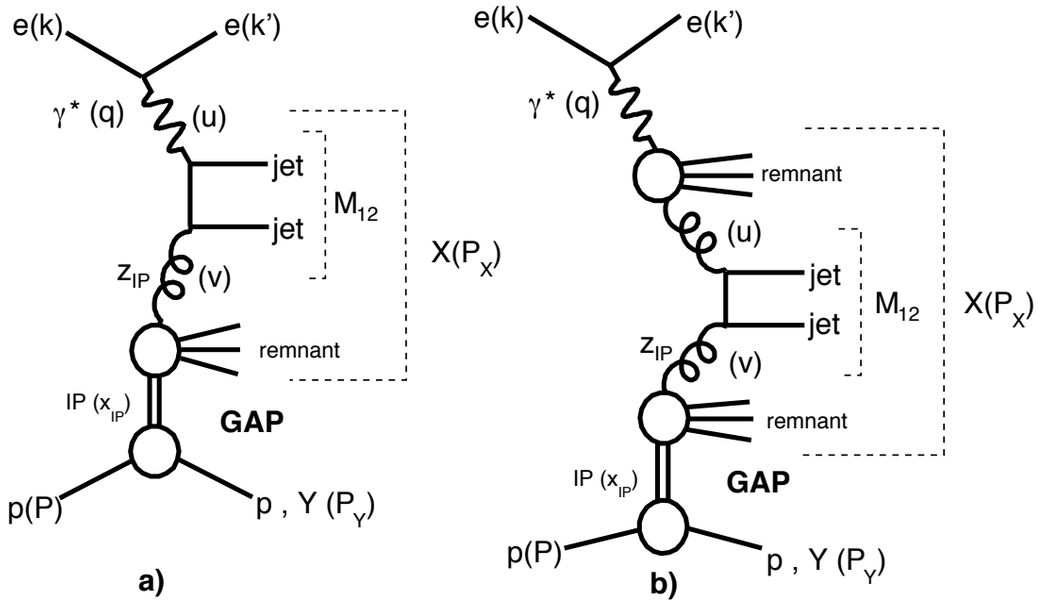
☑ no double counting

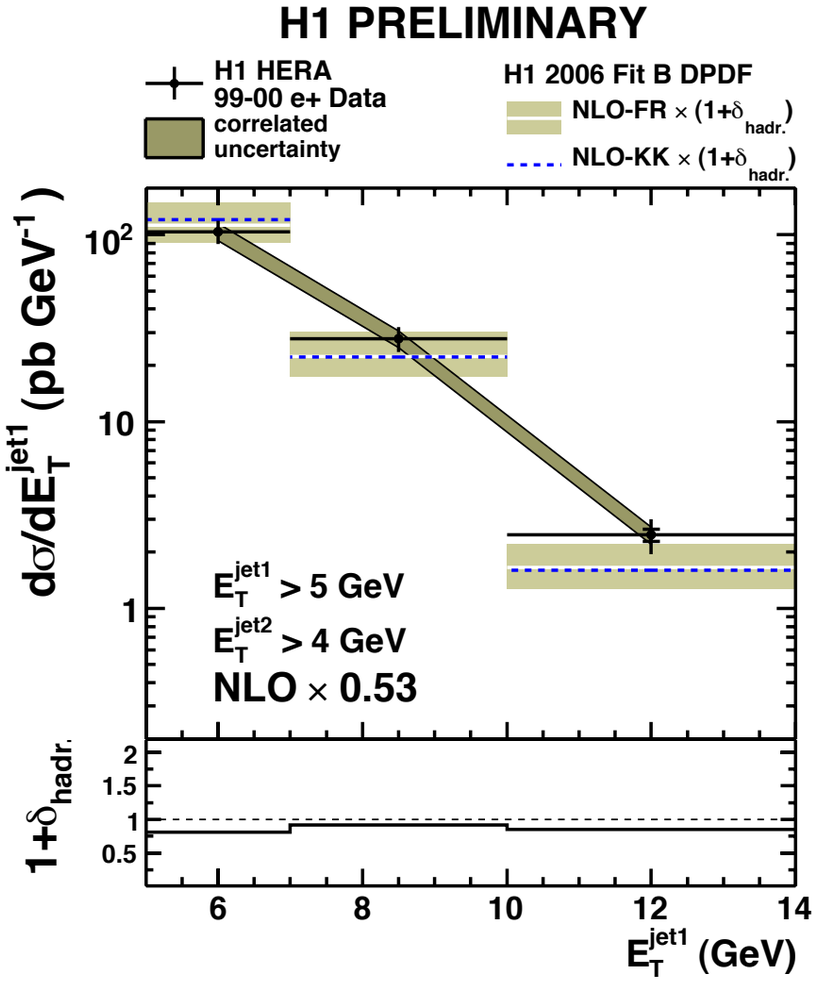
☑ correct mix of diffractive and non-diffractive events are obtained

☑ correct according to factorisation theorem

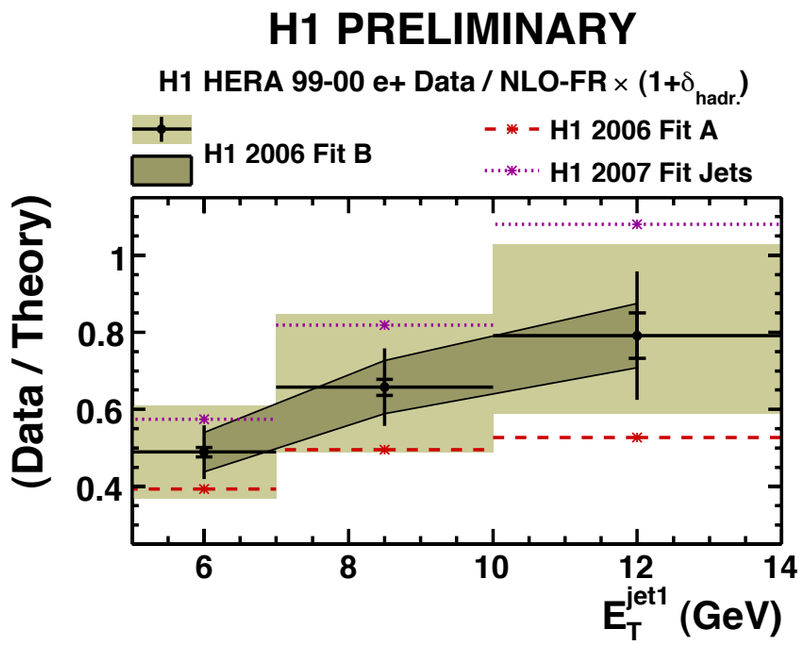
# From DIS to pp

- photon has a hadronic component
- bridge form DIS to pp




- observe factorisation breaking with NLO
- beware: there is an issue on NLO calc and the prediction of LO+PS MCs...
  - LO+PS MCs (RAPGAP) does describe both DIS and photoprod.
- there could be issues on initial and final state parton showering....

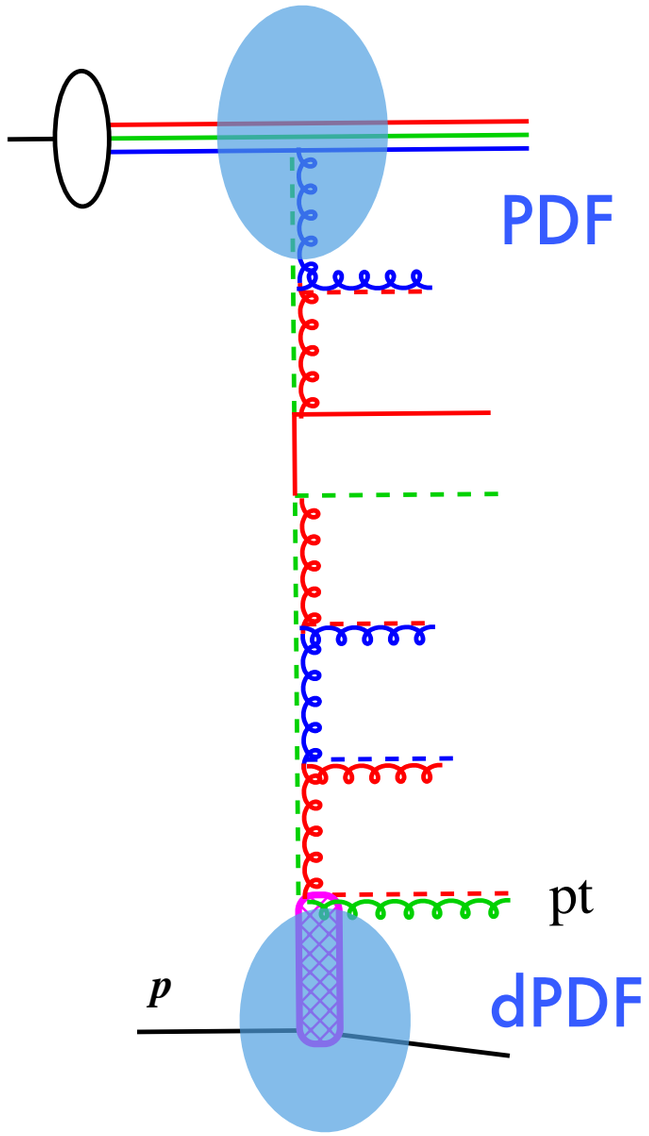


# Diffraction in pp

- Assume same dPDFs as in DIS
- convolute with standard hard processes

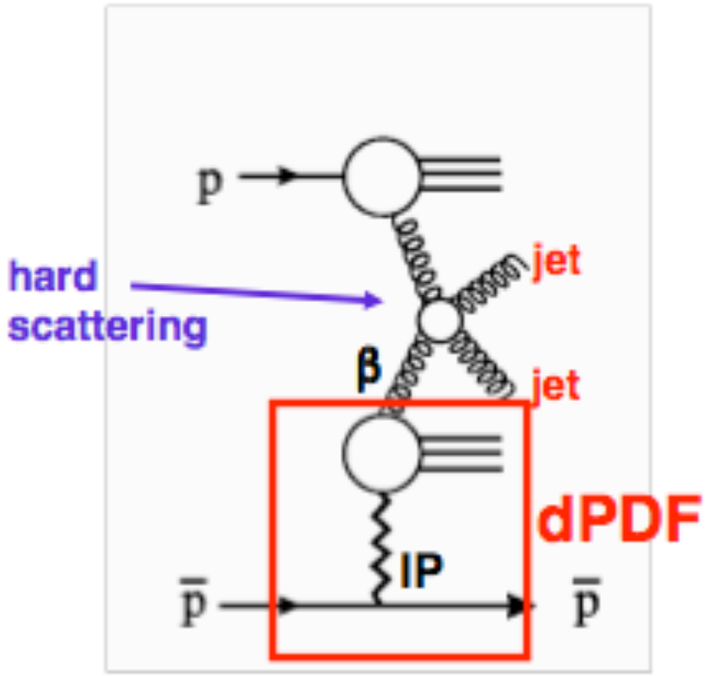
- Issues on hard diffraction in ep and pp
  - how well do we understand the diffractive remnant ?
    - details of remnant determine the rapidity gap
    - details of remnant determine colour flow
    - what is the pt of the remnant ?
      - non-pert. or hard ?

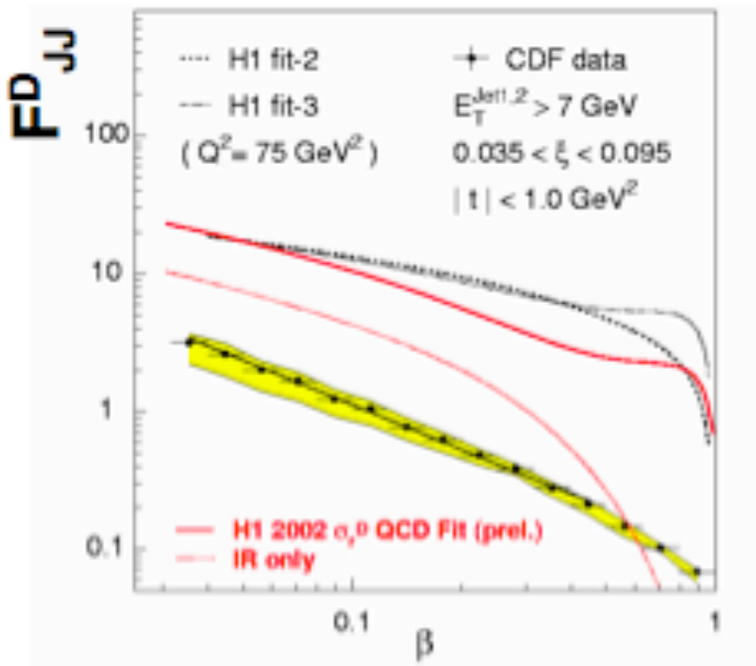
  - how well do we understand the parton shower ?



# Diffraction in pp

- Proper mixing of hard diffraction and non - diffraction is also needed in pp
  - BUT … we have factorisation breaking in pp



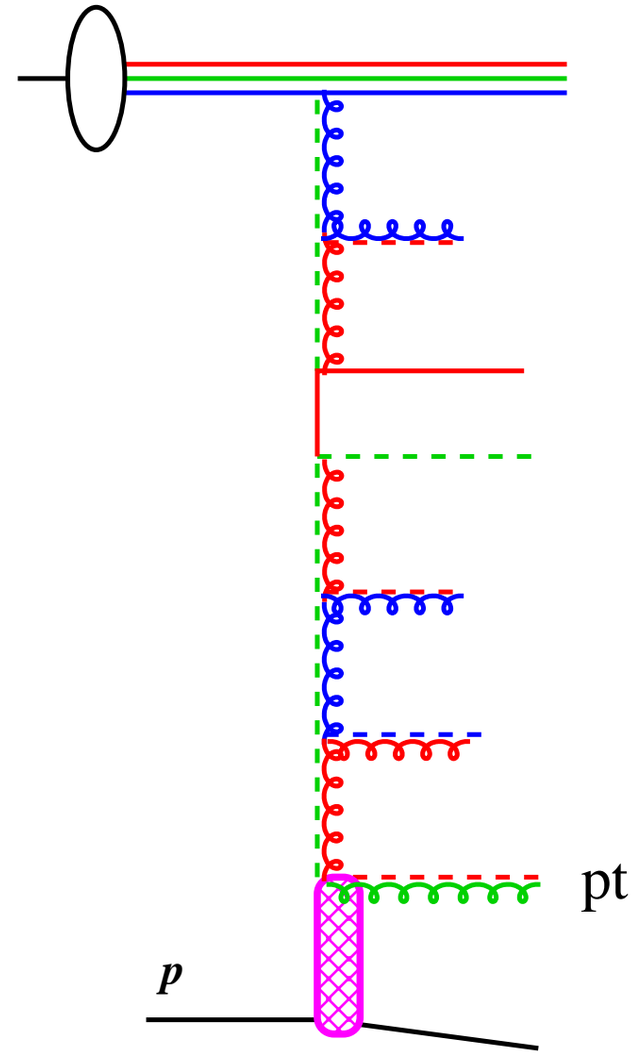




**Normalisation discrepancy (x10)**
**(lots more evidence available !)**

- How can we properly generate diffraction and non-diffraction without double counting and violation of factorisation ansatz ?

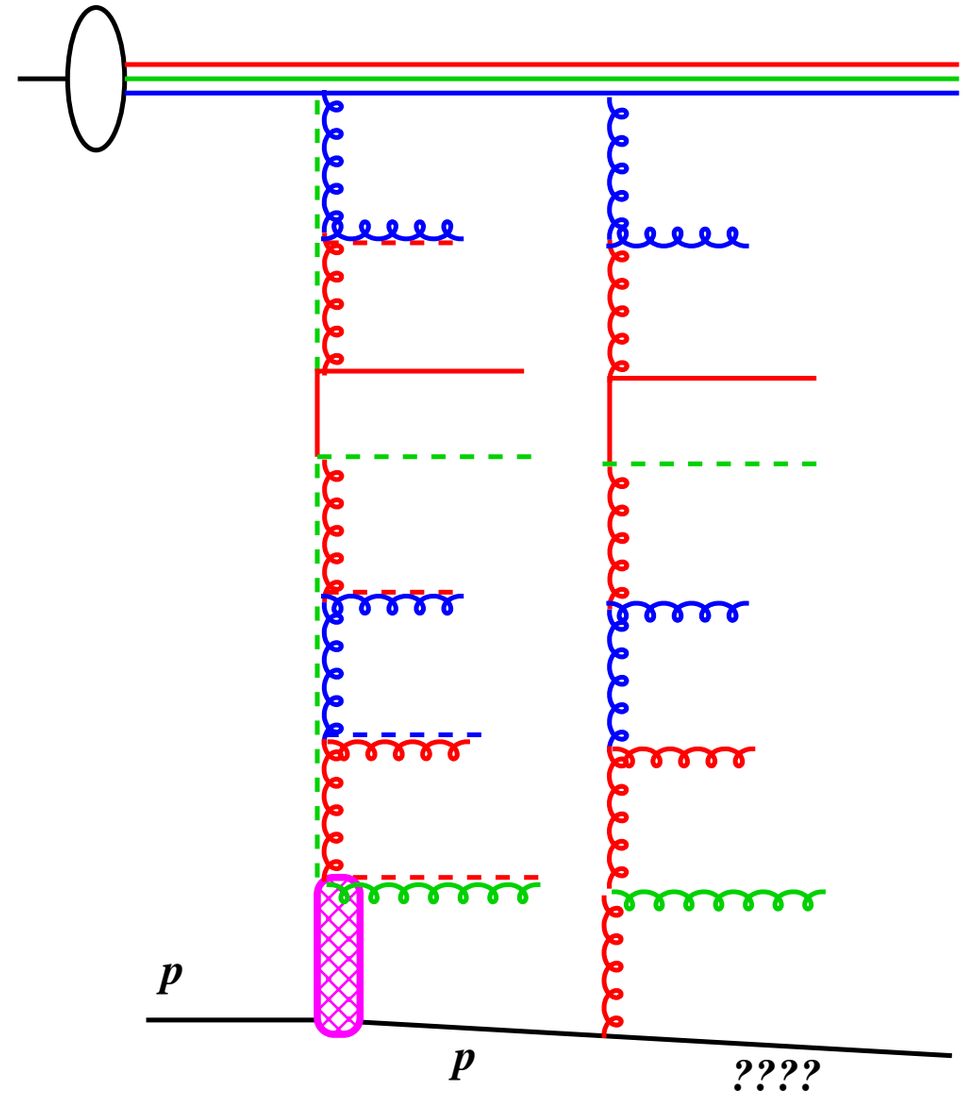
# Multiparton interaction and diffraction

- Assume factorisation for every single chain
- use dPDF and inclusive PDFs on same footing



# Multiparton interaction and diffraction

- Assume factorisation for every single chain
- use dPDF and inclusive PDFs on same footing
- Multiparton interaction including diffractive processes
- Where is rescattering happening ?
  - multi-parton scattering between remnant and leading proton
    - can be simulated, since secondary scattering happens on a proton ...
    - does it depend on the order of the scatterings:
      - 1st diffraction,
      - 2nd non-diffraction ?
- HOWEVER: this is not implemented it any Monte Carlo for multiparton interaction



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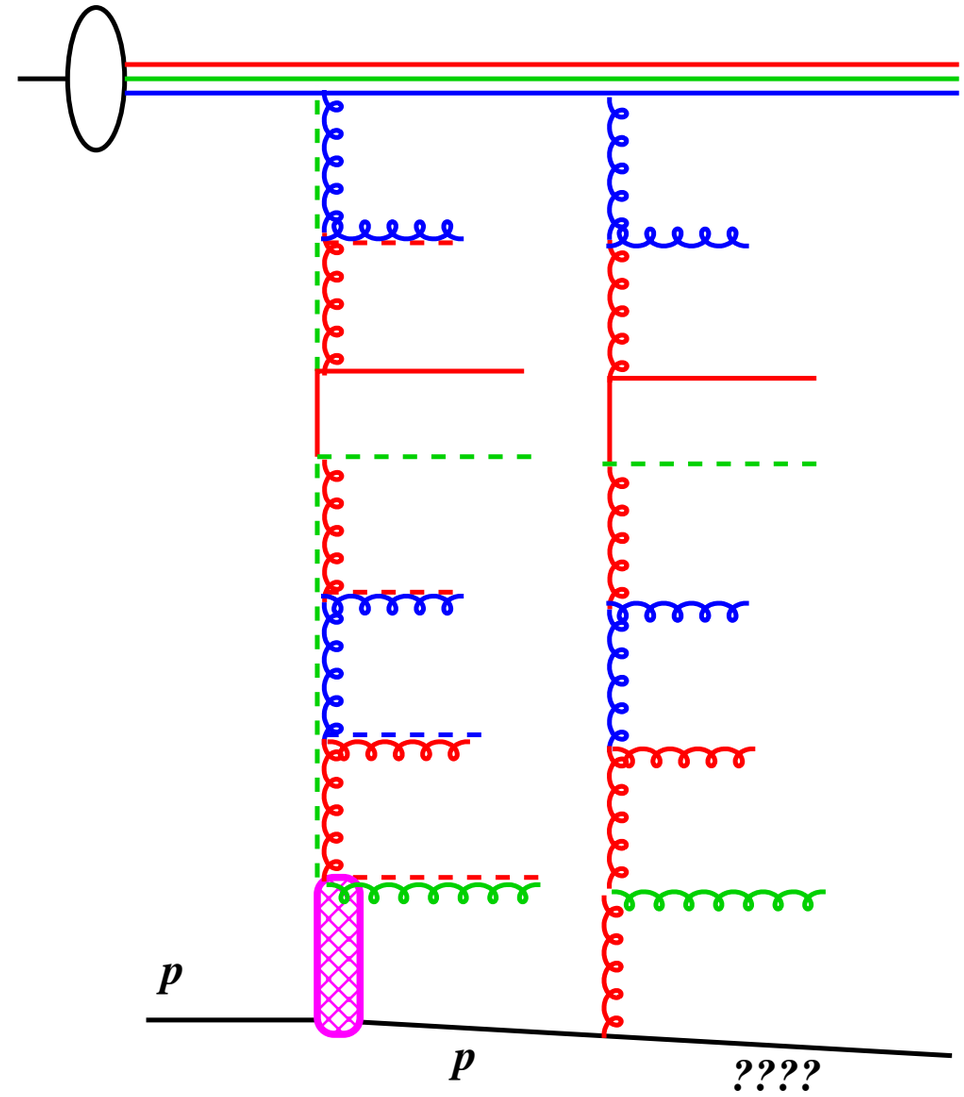


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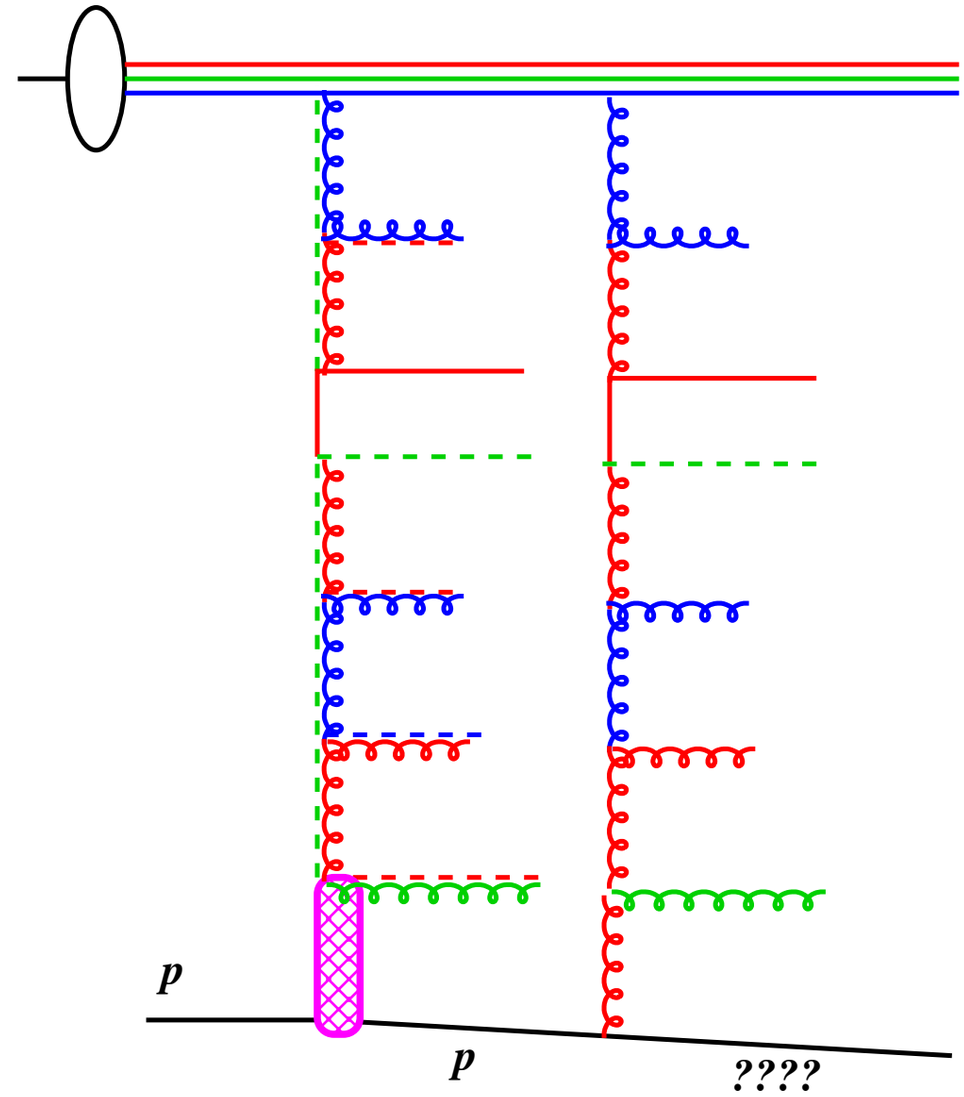
  - *particle multiplicity vrs average pt (in UE studies)*

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- Assume factorisation for every single chain
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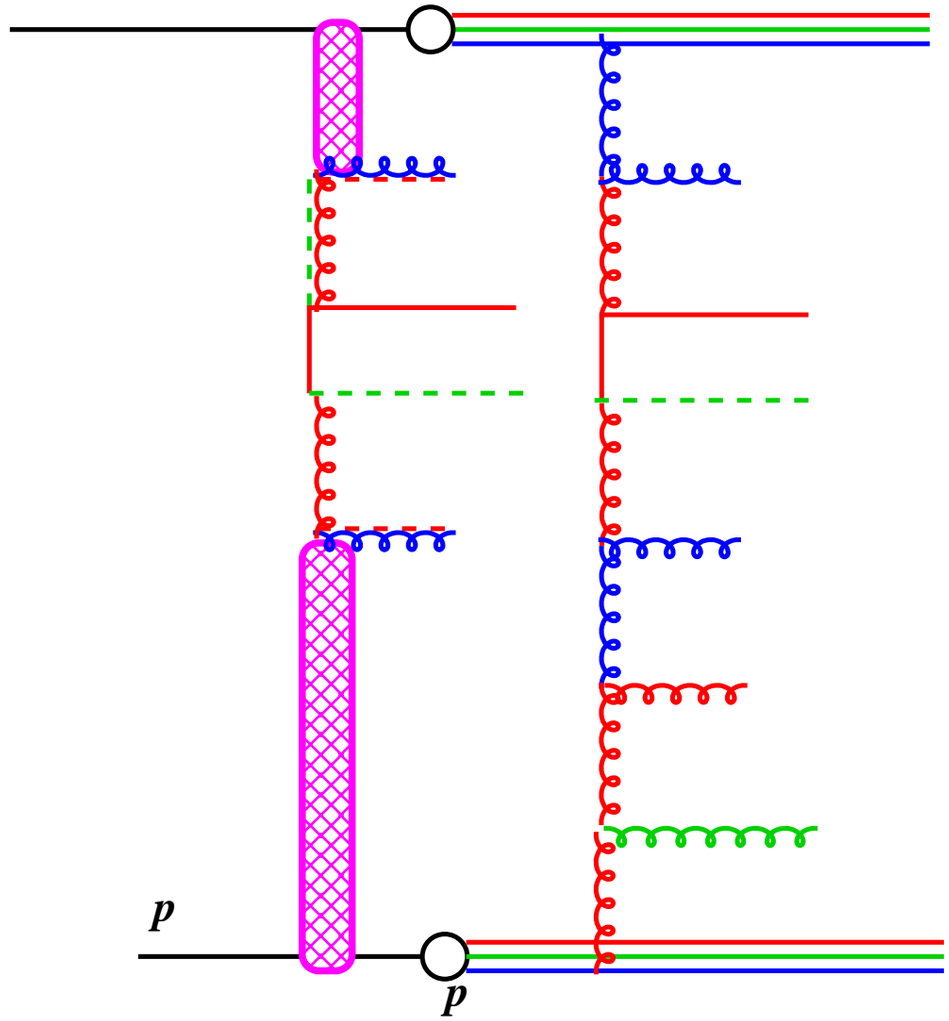
- Multiparton interaction including diffractive processes
- **examples:**
  - *energy flow in forward region*
    - *gap survival probability will change*
    - *transverse energy flow will change*
  - *particle multiplicity vrs average pt (in UE studies)*
    - *multiplicity in central region will change*

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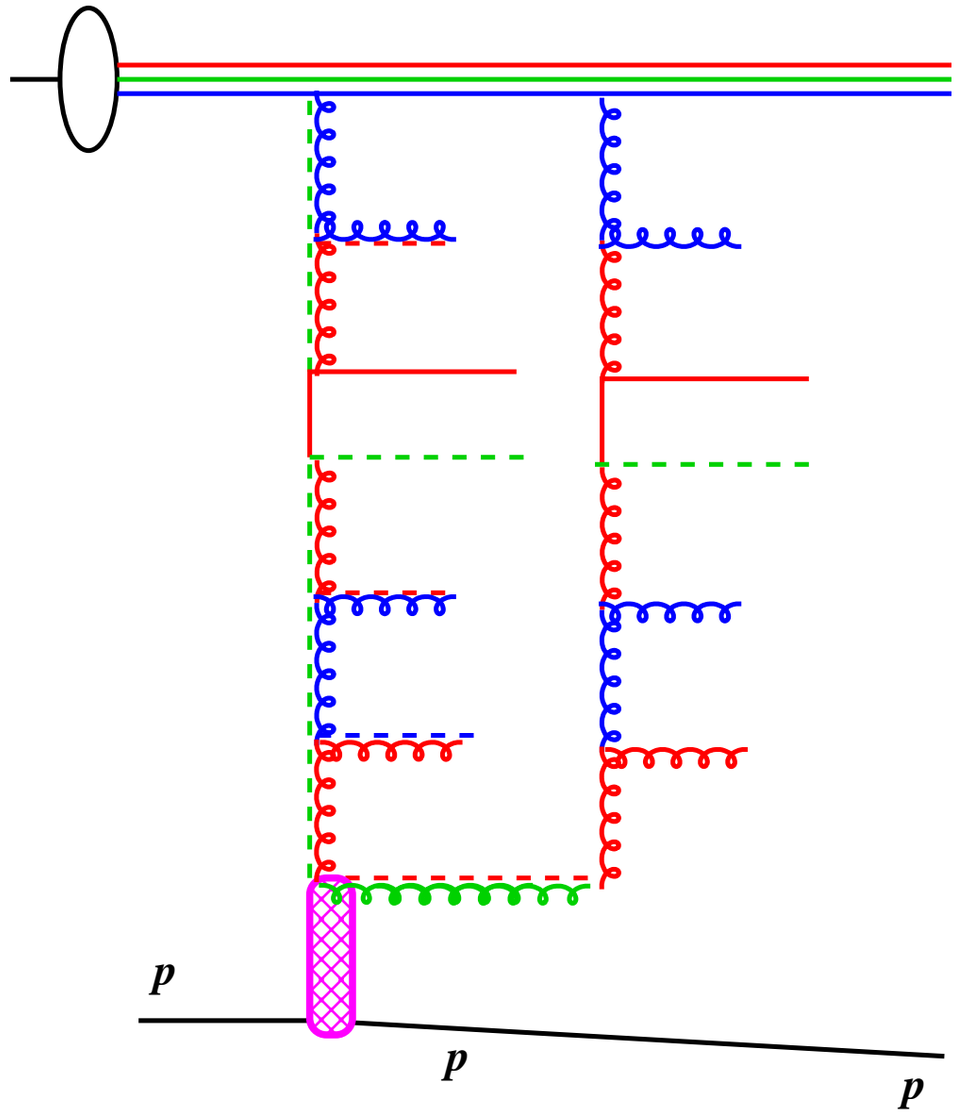
# Origin of rescattering

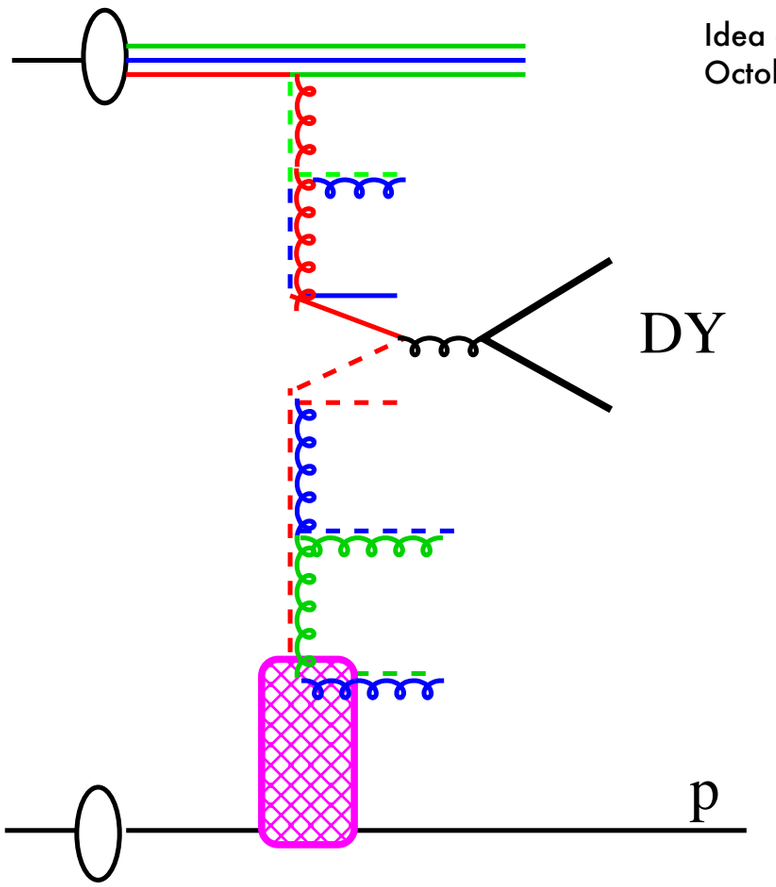
- Where is rescattering happening ?
  - multi-parton scattering between remnant and leading proton
    - changing leading baryon nature
  - multiparton scattering between remnants (of proton and pomeron) ?



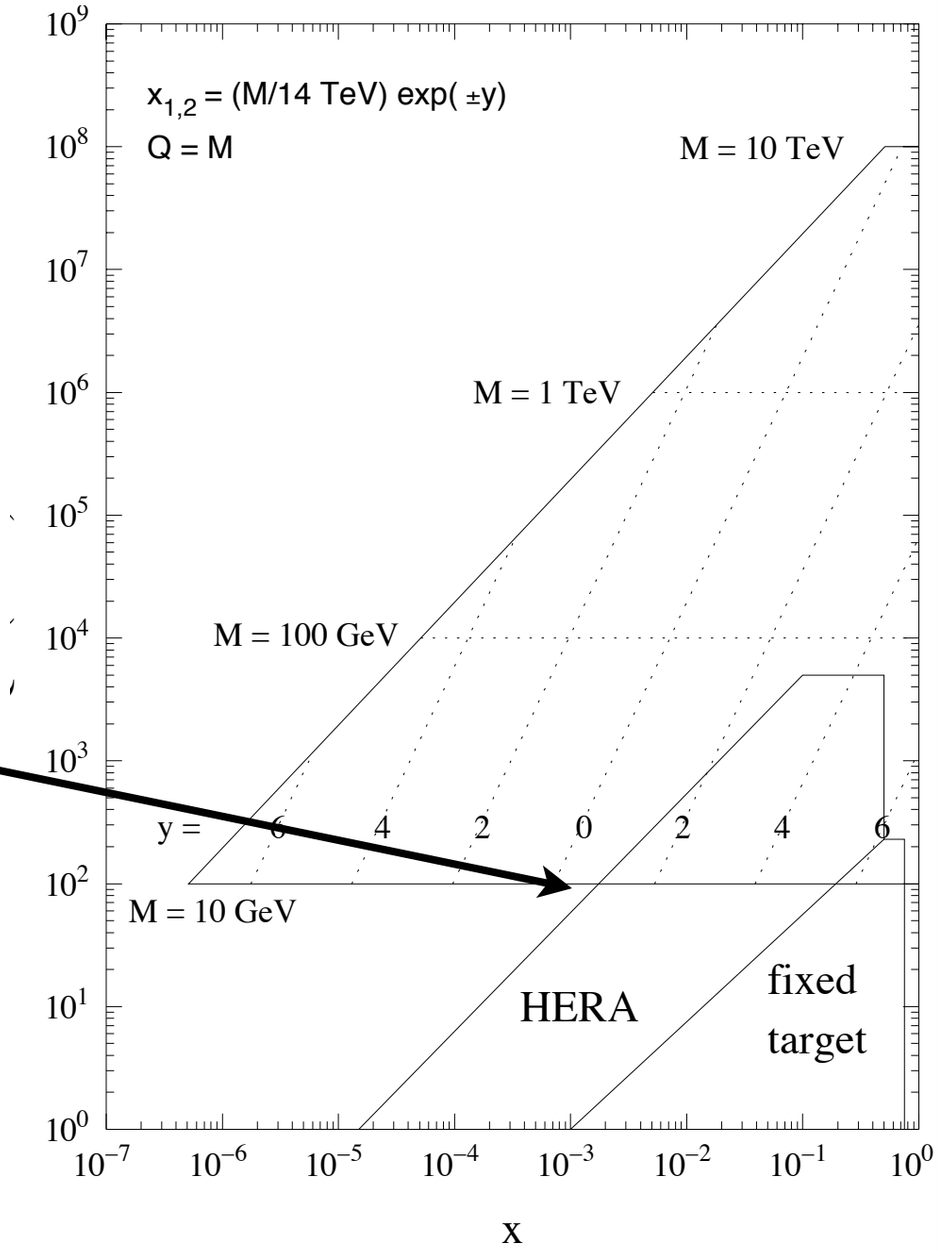

- ☑ how to separate scattering between diffractive remnant and proton from scattering between both protons ?
- ☑ is there any difference in showering from inclusive and diffractive scattering ?

# Low mass diffractive Drell Yan

- diffractive Drell Yan production
- Drell Yan in central region with mass similar to Q2 range of HERA




Idea at Lund - DESY meeting
October 2009, L. Lonnblad, G. Gustafson




- Diffractive DY xsection, comparable with HERA ?
- Diffractive DY + dijet, comparable with HERA ?

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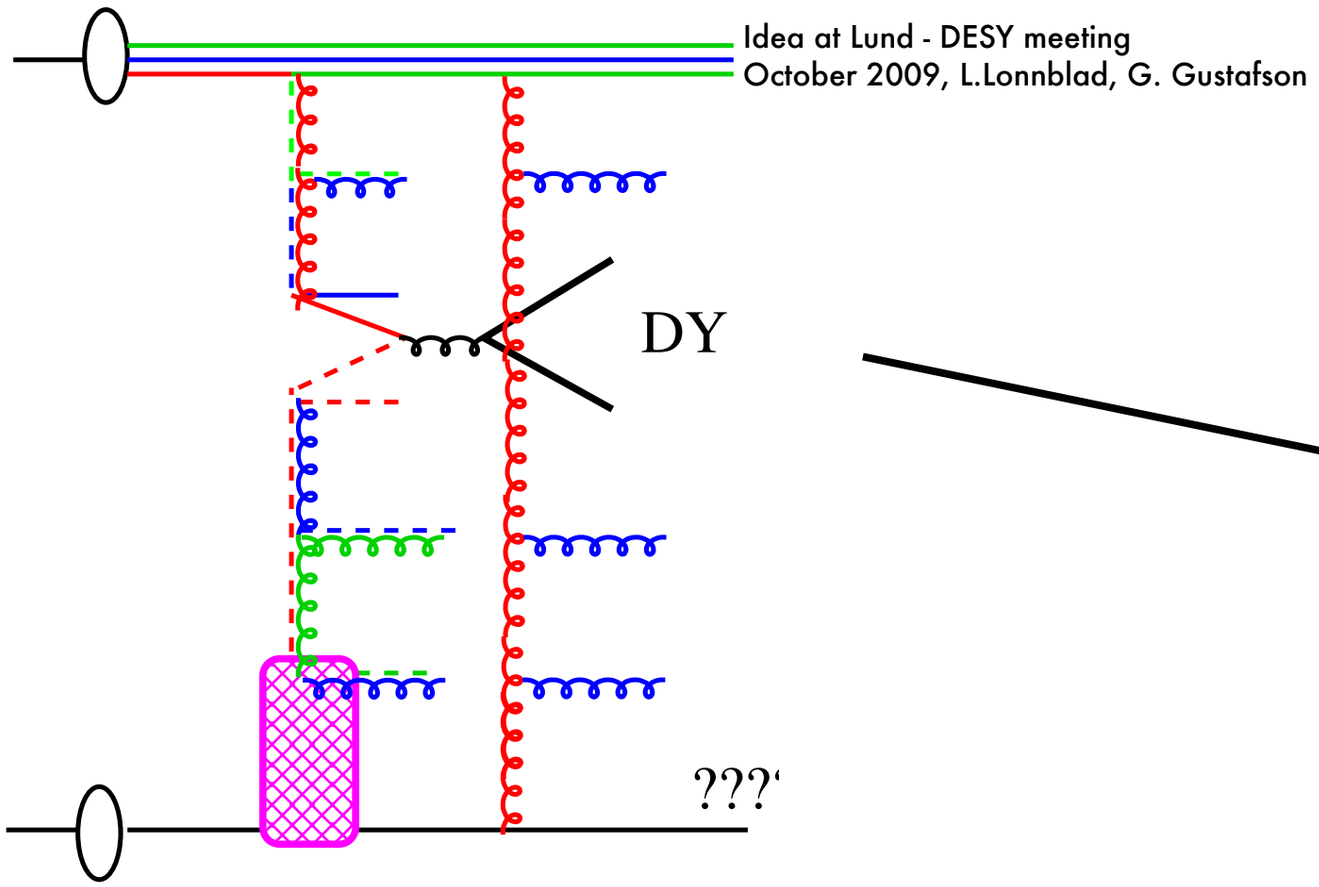
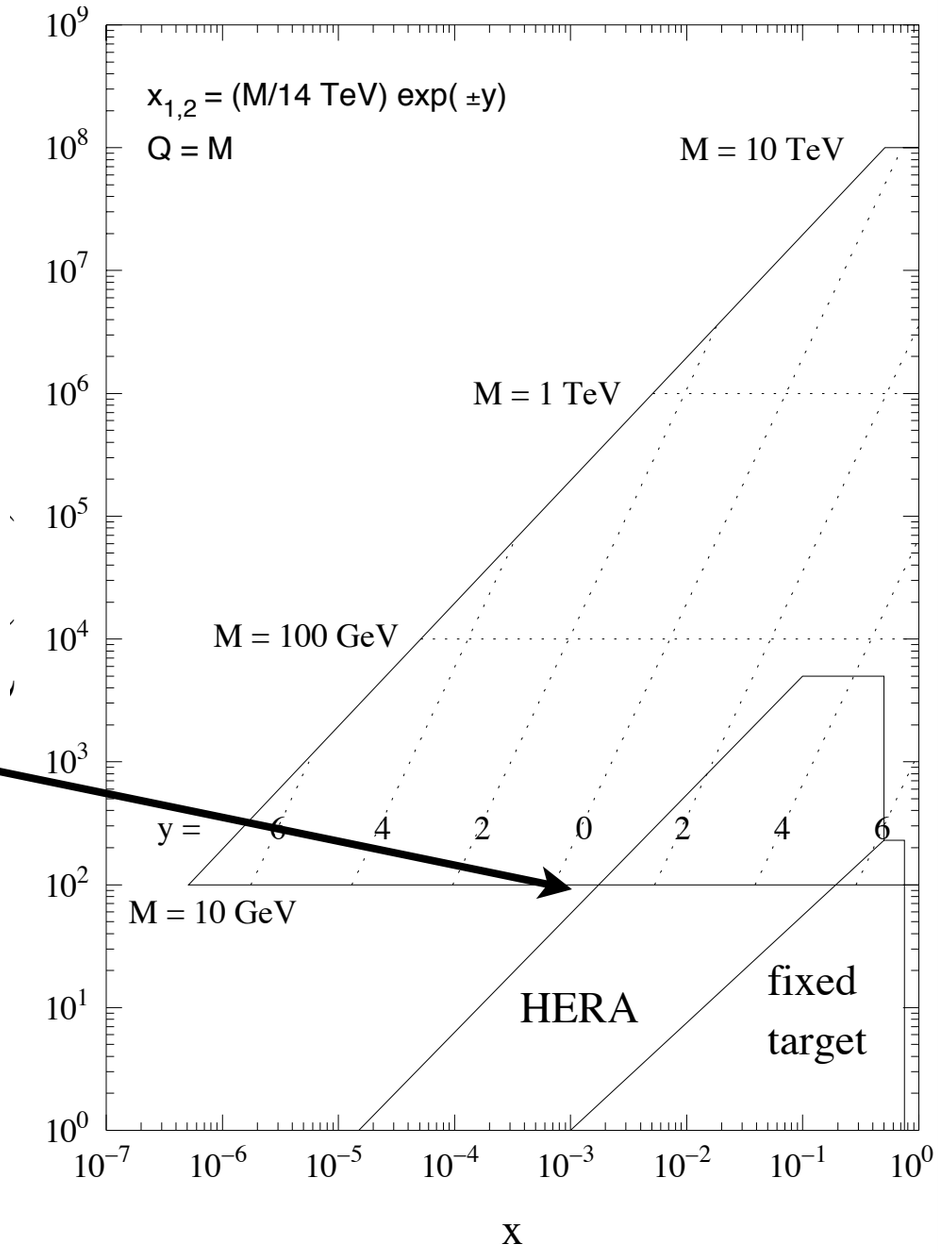
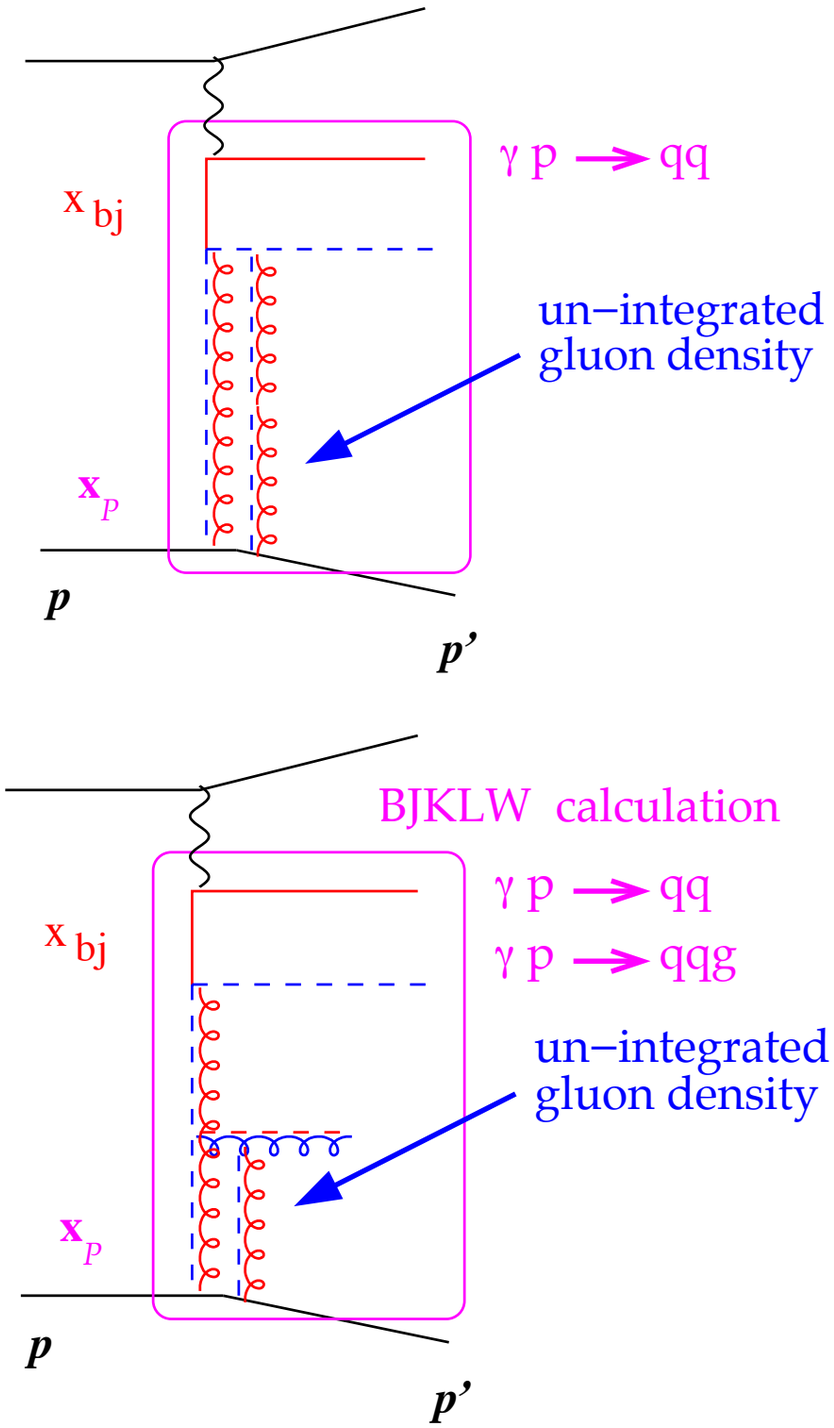



- Diffractive DY xsection, comparable with HERA ?
- Diffractive DY + dijet, comparable with HERA ?
- direct observation of rescattering/absorptive effects

# 2-gluon model for diffractive DIS

- Attempt to calculate hard diffraction from non-diffractive PDFs
  - use uPDFs $|x\mathcal{A}(x, k_t, \mu^2)|^2$
  - uPDFs of proton
- no additional assumptions are needed
- all partons are hard (perturbative)
  - "pomeron remnant" is hard
- implemented in RAPGAP
  - supplemented with final state PS and hadronization

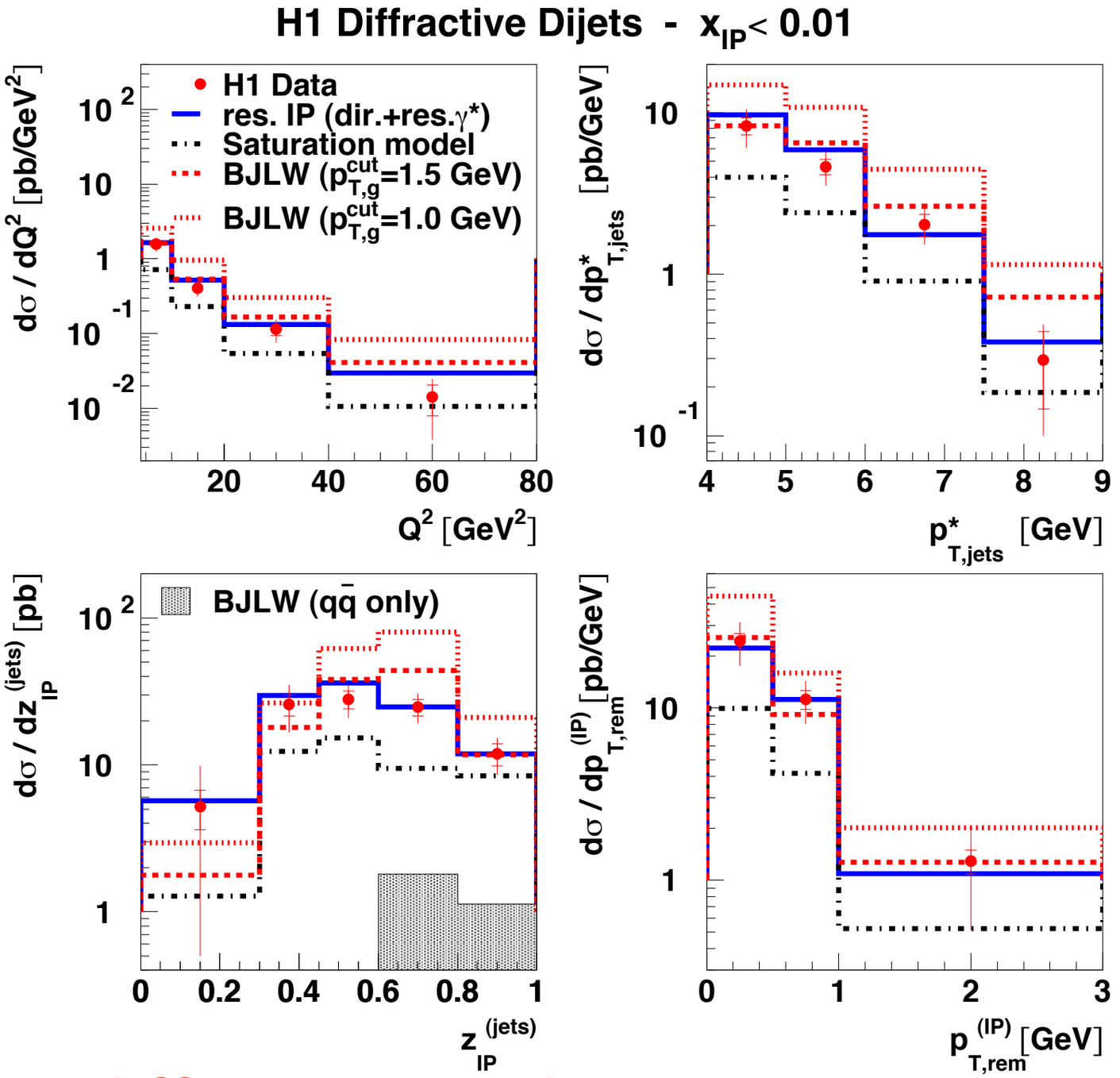


# Examples: dijets in DIS

- dijets in DIS
- also described with 2-gluon exchange mechanism
- but need:

$$p_t^{cut} > 1 \text{ GeV}$$

- require small xpom!
- perturbative calc works well, without any assumption on diffractive PDFs

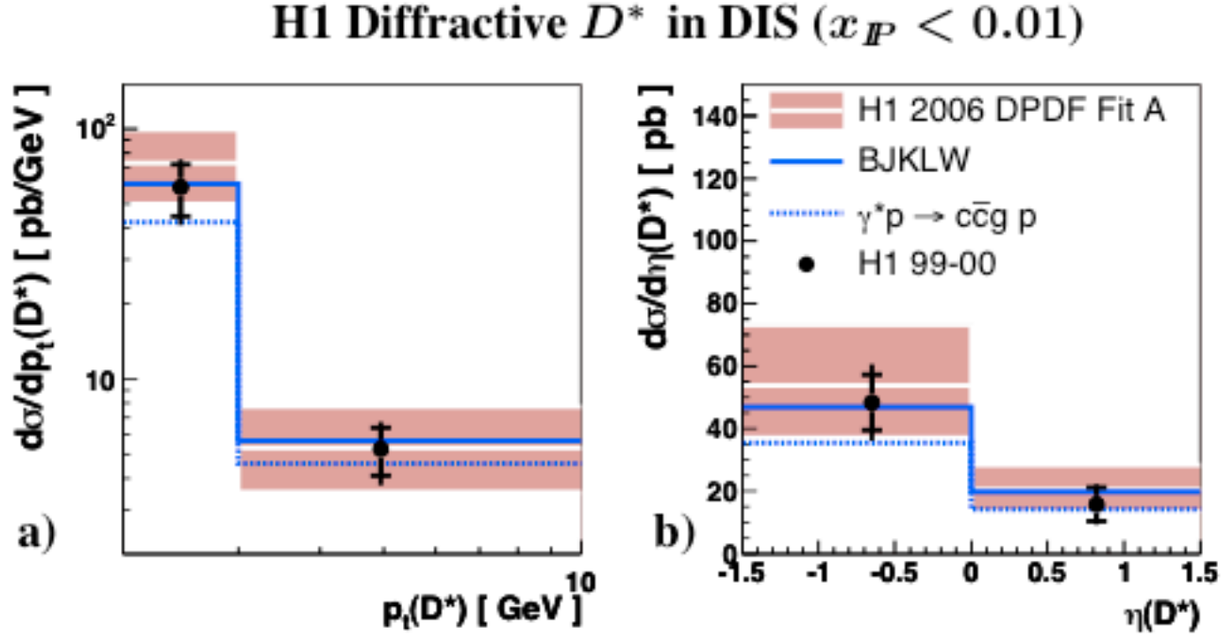



- perturbative model for diffractive exchange
- works reasonably well !

# Examples: charm

- diffractive charm in DIS
- 2-gluon exchange mechanism can describe measurement
- but need:

$p_t^{cut} > 2$ GeV

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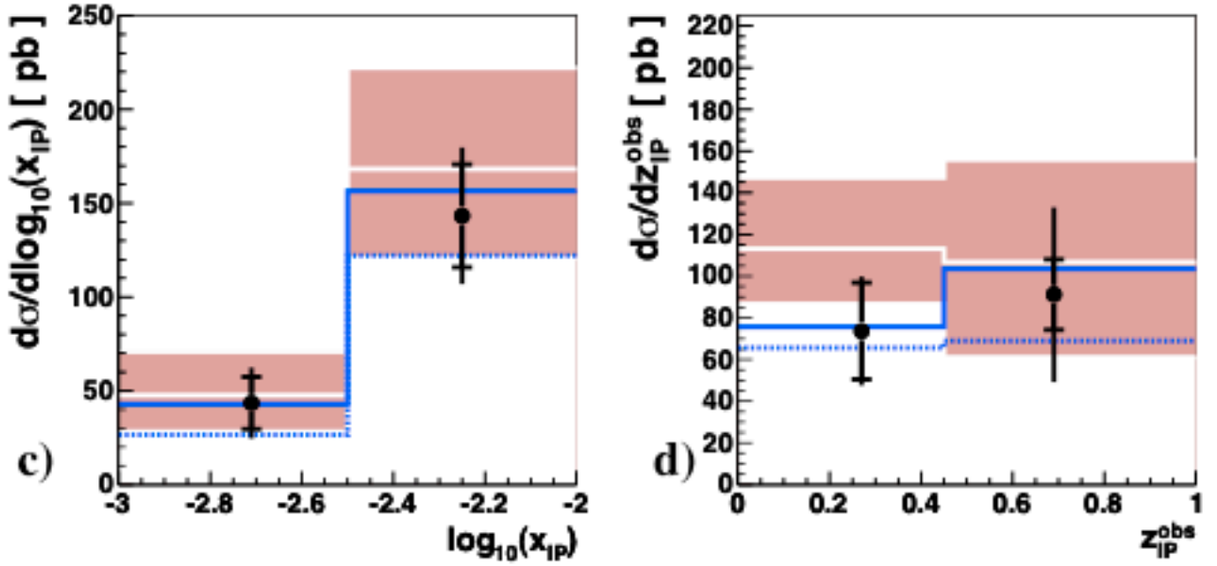


- perturbative model for diffractive exchange
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# Conclusions

- detailed studies of hadronic final states in diffraction available form HERA
  - this knowledge MUST go into MCs for pp
- treat diffraction (soft & hard) as part of the x-sections determined by PDFs
  - MUST be included in simulation of final state
- include hard diffraction into simulation of MB and inclusive processes
  - mixing of diffraction with non-diffraction
  - estimate of gap survival probability
  - obtain prediction for hadronic final state in  and central regions

Diffraction (hard) is very important for better understanding of MPI and UE and to understand color connection and reconnections