Gosta in Hamburg

- Gosta Gustafson was/is guest professor at Hamburg university
  - lecture series on

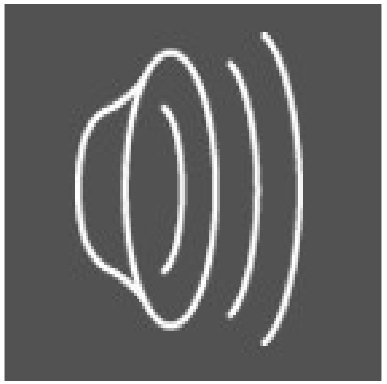
    Color Dipoles
    - available as webcast and mp4

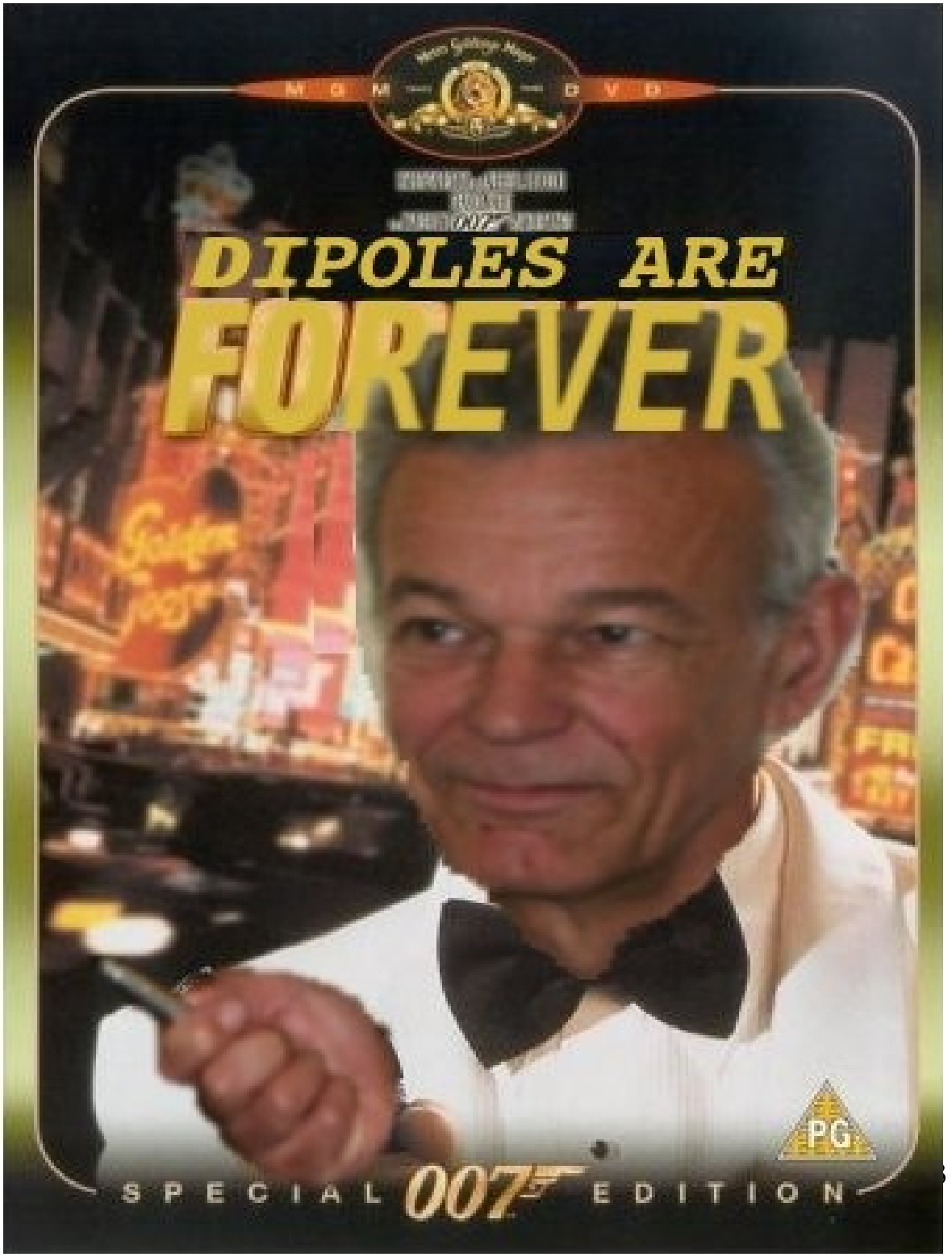
      http://webcast.desy.de/webcast_archiv.htm.de

      http://www.terascale.de/research_topics/rt1_physics_analysis/lectures/
  - many discussion sessions and mini workshops on saturation and multiparton interactions, also with Al Mueller et al
  - paper and contributions to discussion week on Dipole Shower with Pino Marchesini
  - common project of DAAD and STINT for exchange between DESY and Lund
  - many new things we learned, both on experimental and theoretical issues...

Thanks very much Gosta for being here

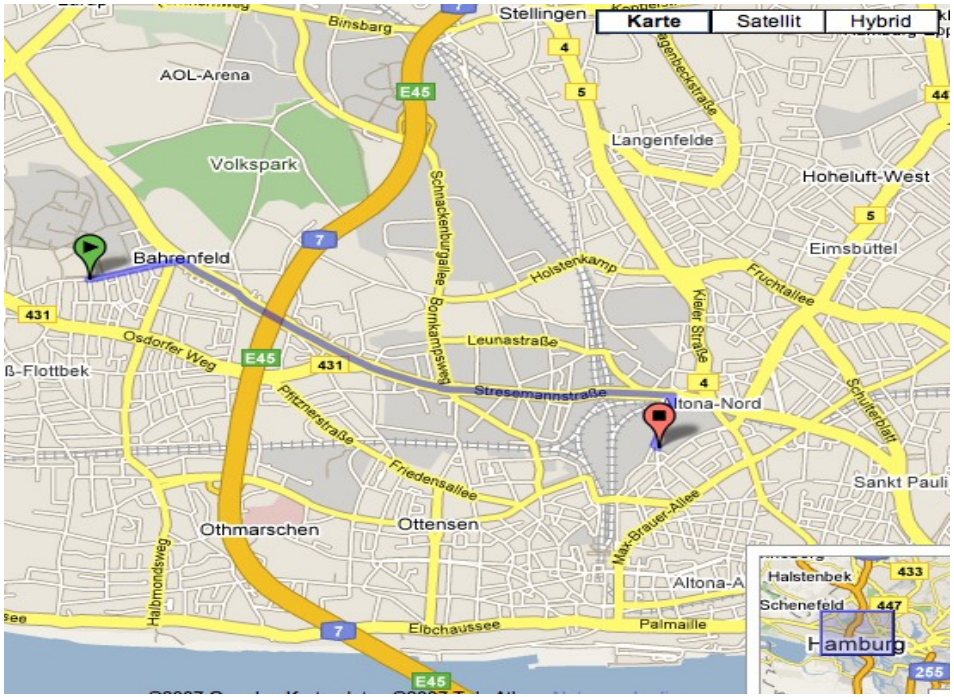
Dipoles are forever,
They are all I need to please me,
They can stimulate and tease me, ...





Plan for tonight

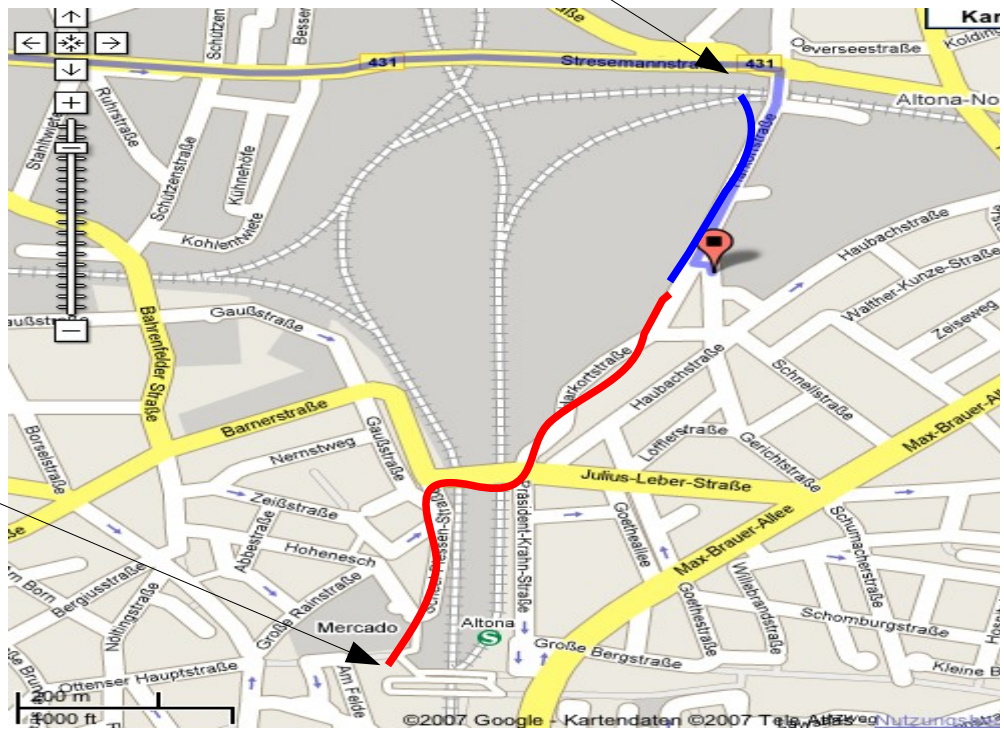
- Going out together to Blaue Blume .....



Blaue Blume
Gerichtstr. 49, 22765
Hamburg
040/385869

Bus Nr 3: Kaltenkircher Platz

Bus Nr 1: Altona



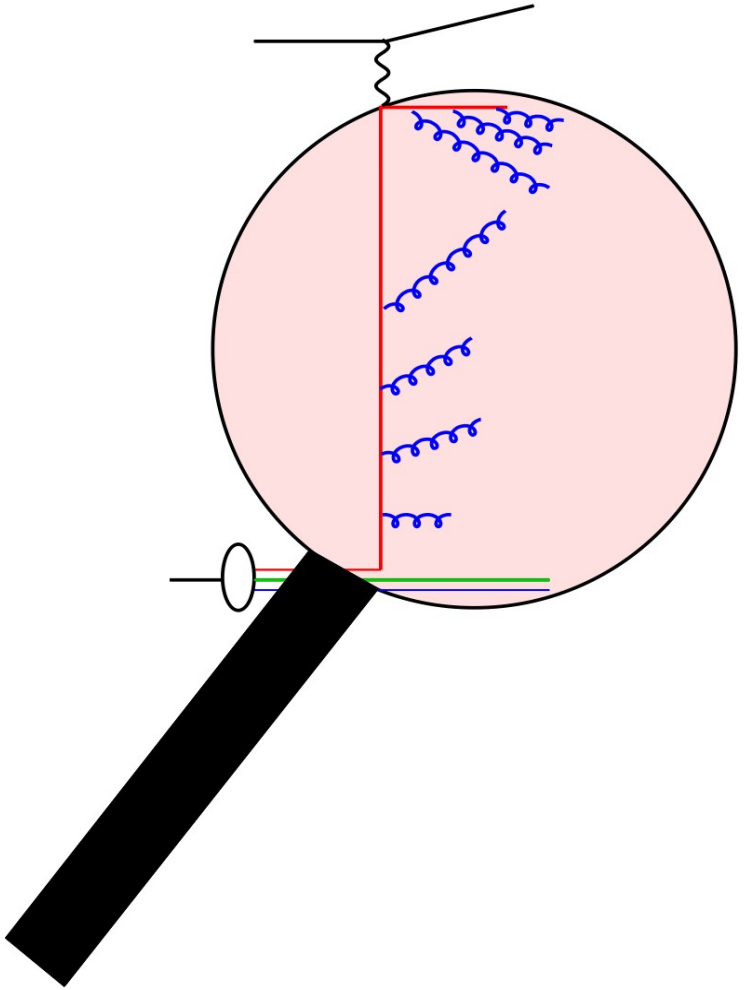
Please sign, if you want to join

Small x processes at HERA

H. Jung (DESY, University Antwerp)

- Measurements we have
- do we really understand small x
- what next ?

DIS: the probe for high energy PDFs



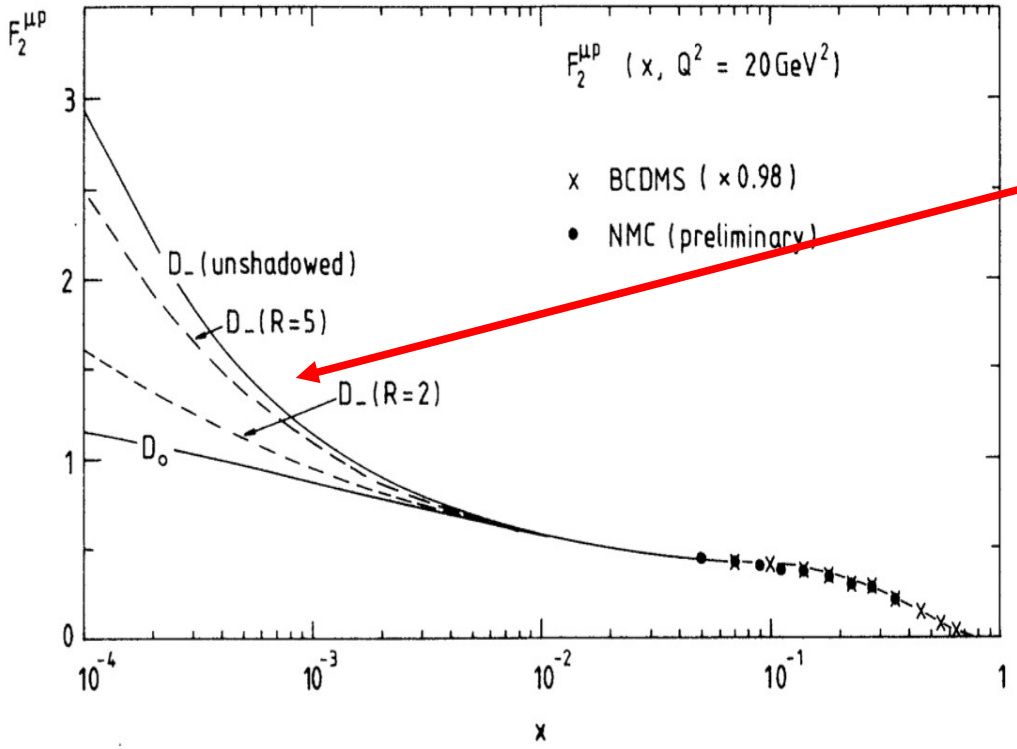
- Deep Inelastic Scattering is a incoherent sum of $e^+q \to e+q$
- only 50 % of p momentum carried by quarks
- need a large gluon component
- partonic part convoluted with parton density function $f_i(x)$
- BUT we know, PDF depends on resolution scale Q^2

$$\sigma(e^+p \to e^+X) = \sum_i f_i(x,Q^2)\sigma(e^+q_i \to e^+q_i)$$

Remember the pre-HERA times

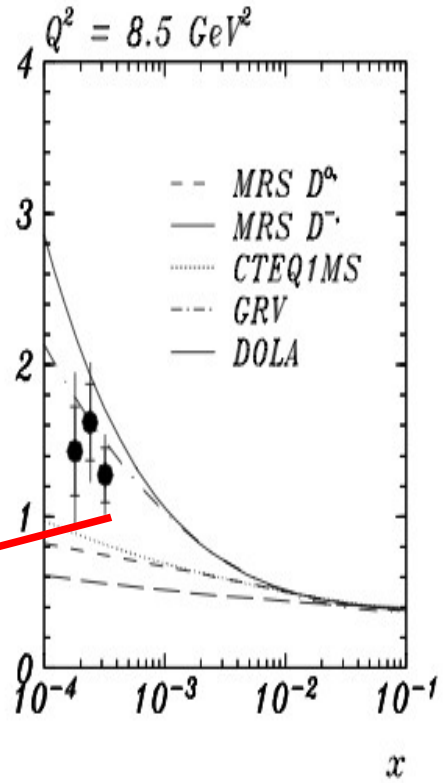
- Just before HERA started in 1992, new PDF fits (NLO DGLAP) were released, using all existing high precision data

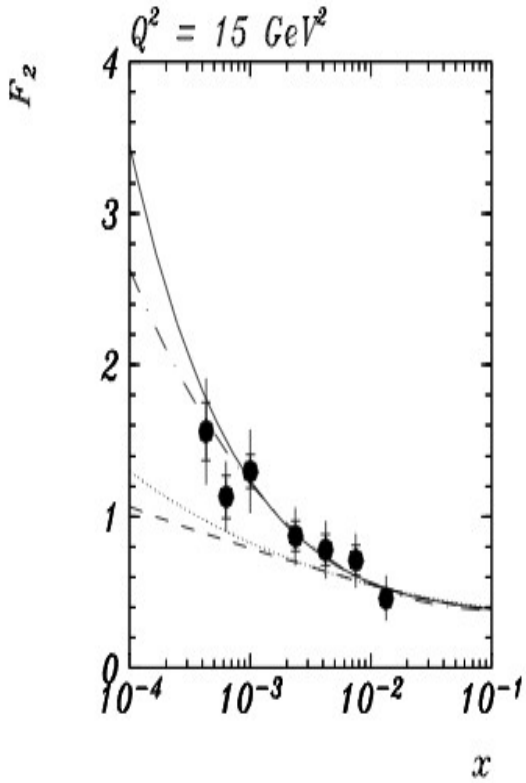
Martin, Stirling, Roberts Apr 1992.
Phys.Rev.D47:867-882,1993.



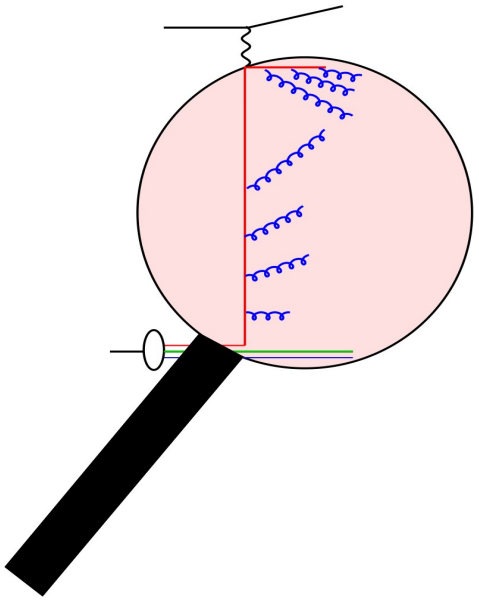
- 1st HERA data 1992

H1 Nucl. Phys. B407 (1993) 515

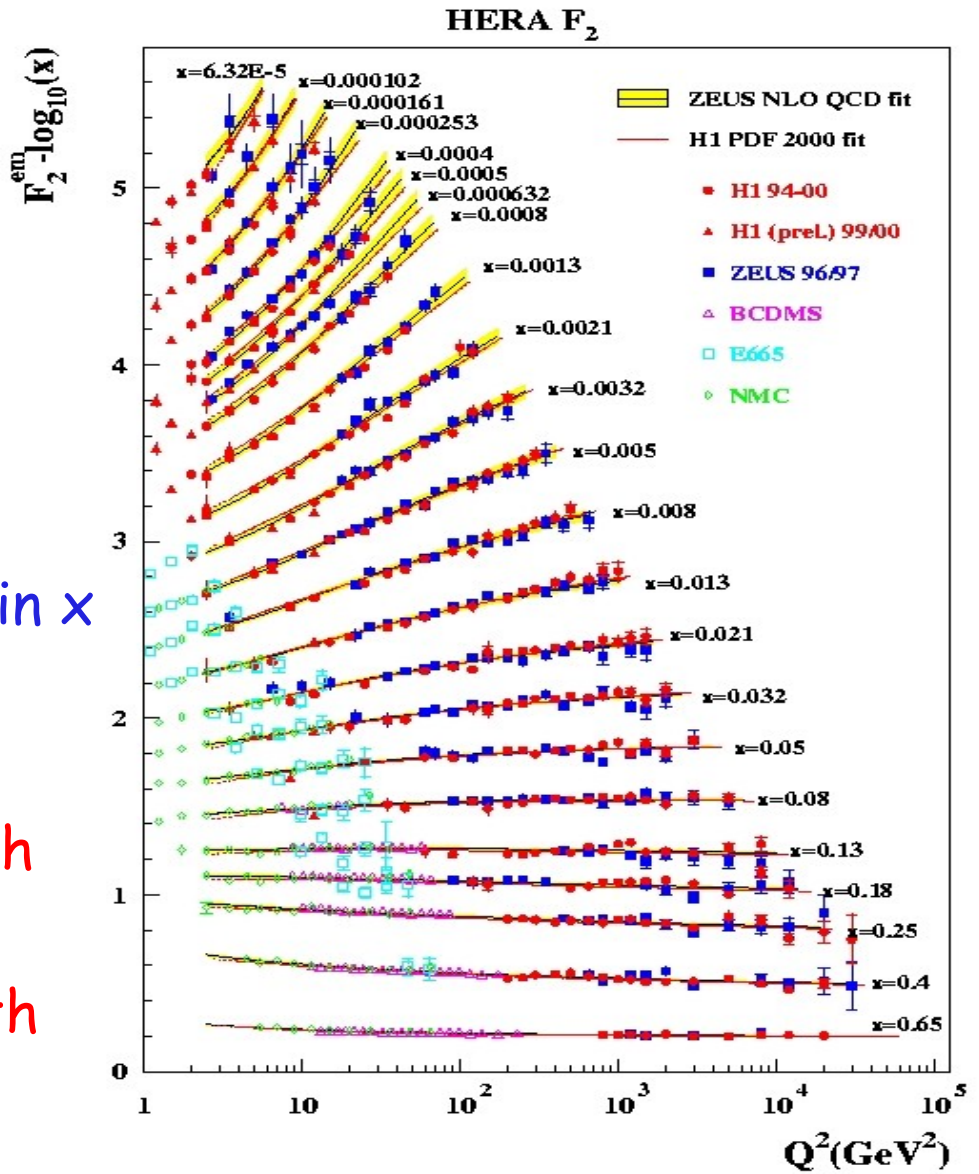




DIS: obtain precise PDFs



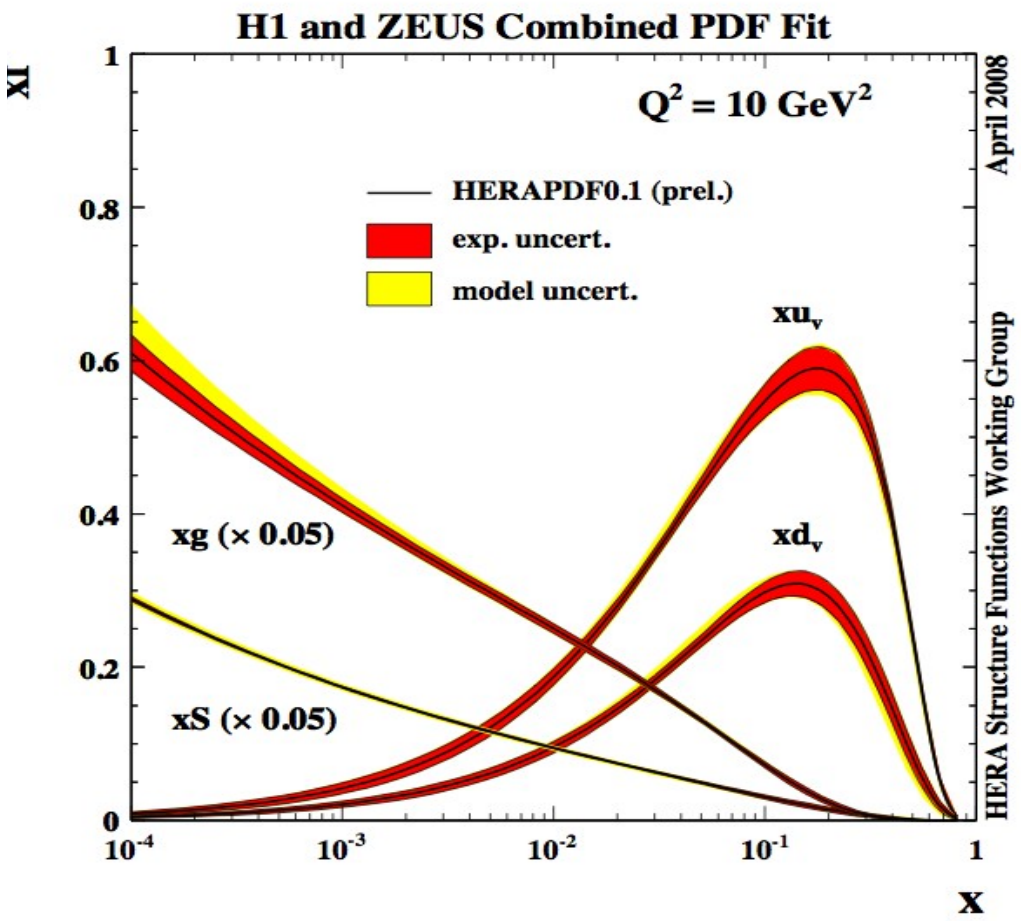
$$\sigma(e^+p \to e^+X) = \sum f_i(x,Q^2)\sigma(e^+q_i \to e^+q_i)$$

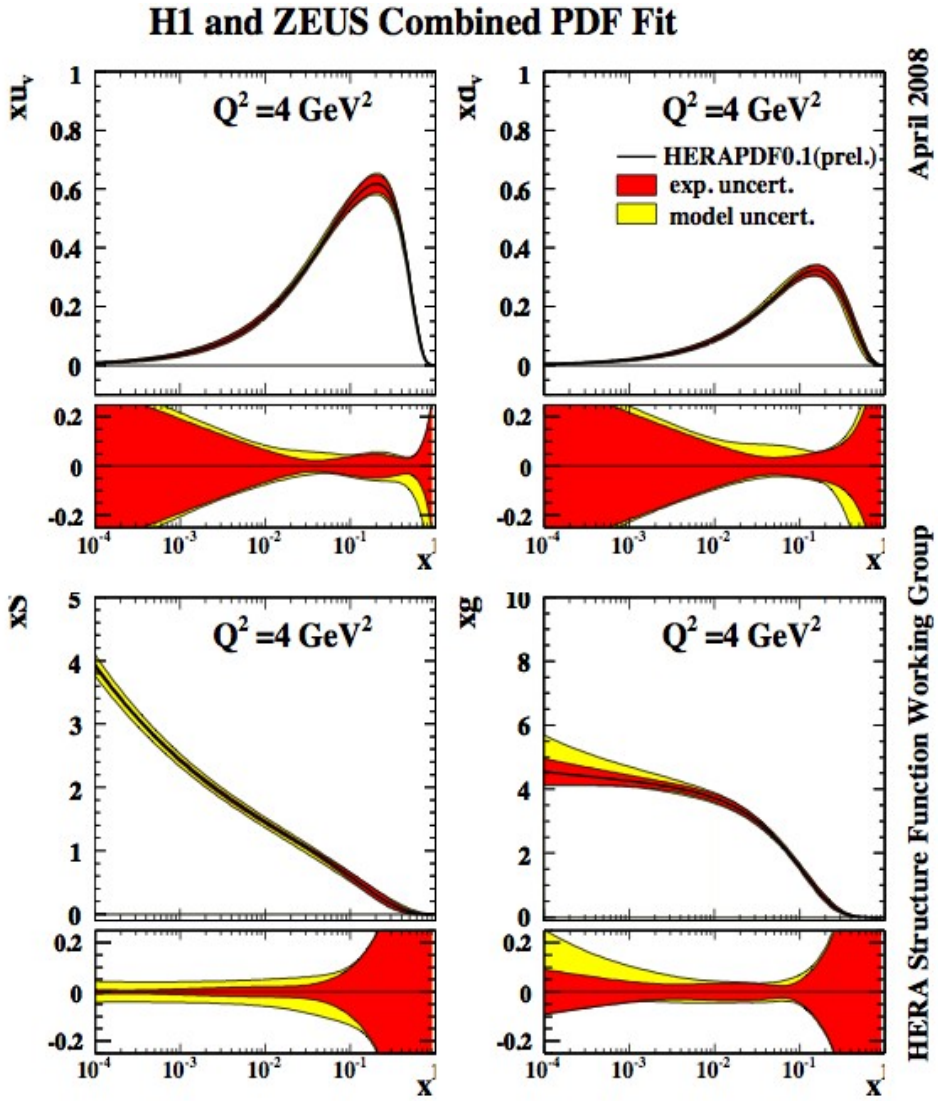


- perfect description of precise measurements of HUGE range in x and Q^2
- Theory works well.....
  - ➔ extract parton densities, which are universal ....
  - ➔ to be used for any process with protons in initial state

PDFs ... (combined H1 & ZEUS)

- quark and gluon PDFs





➔ very precise measurment of integrated pdfs ...

What happens at small x ?

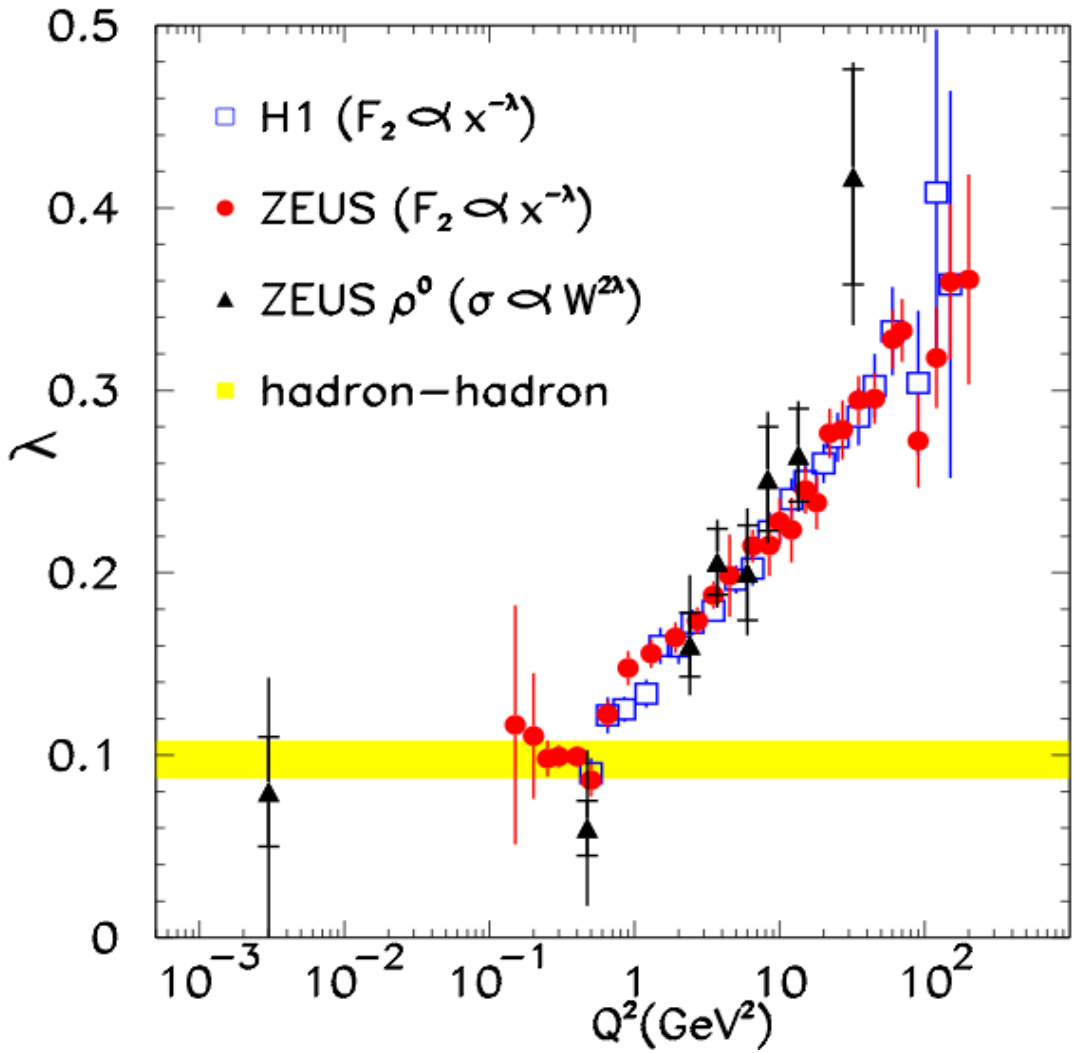
- slope

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

- flattens at

  $Q^2 \sim 0.5 GeV^2$

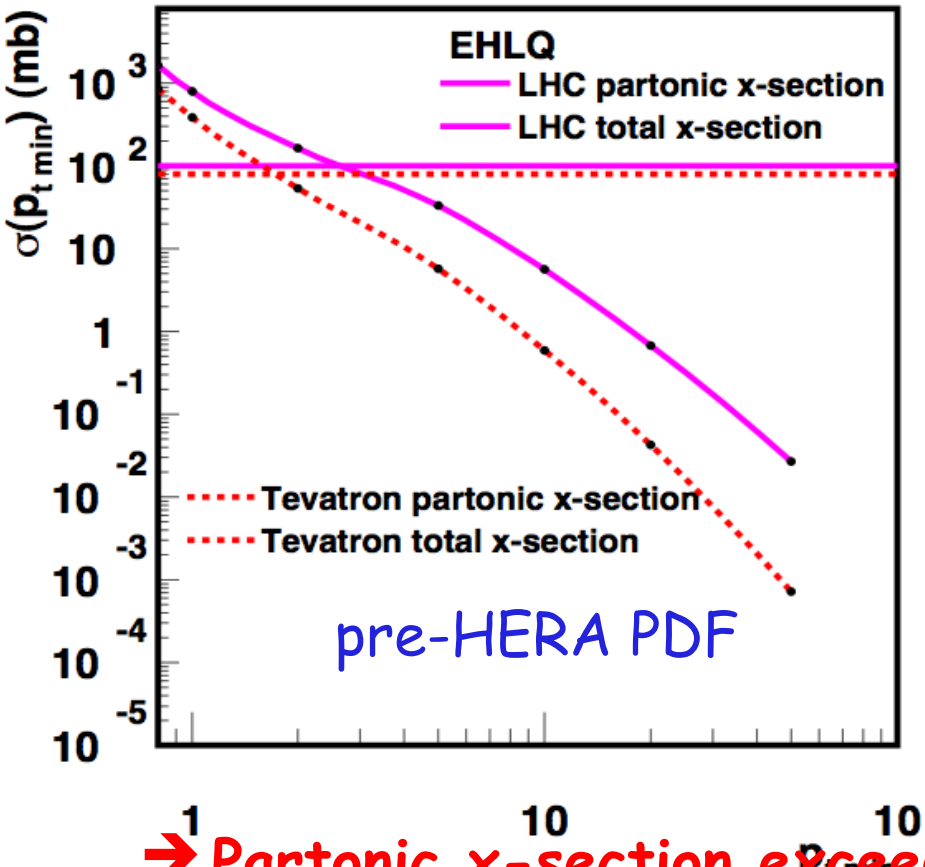
- suggestive for saturation and transition to non-perturbative region
- dipole models can parameterise this !!!
- how to deal with this in partonic picture ?

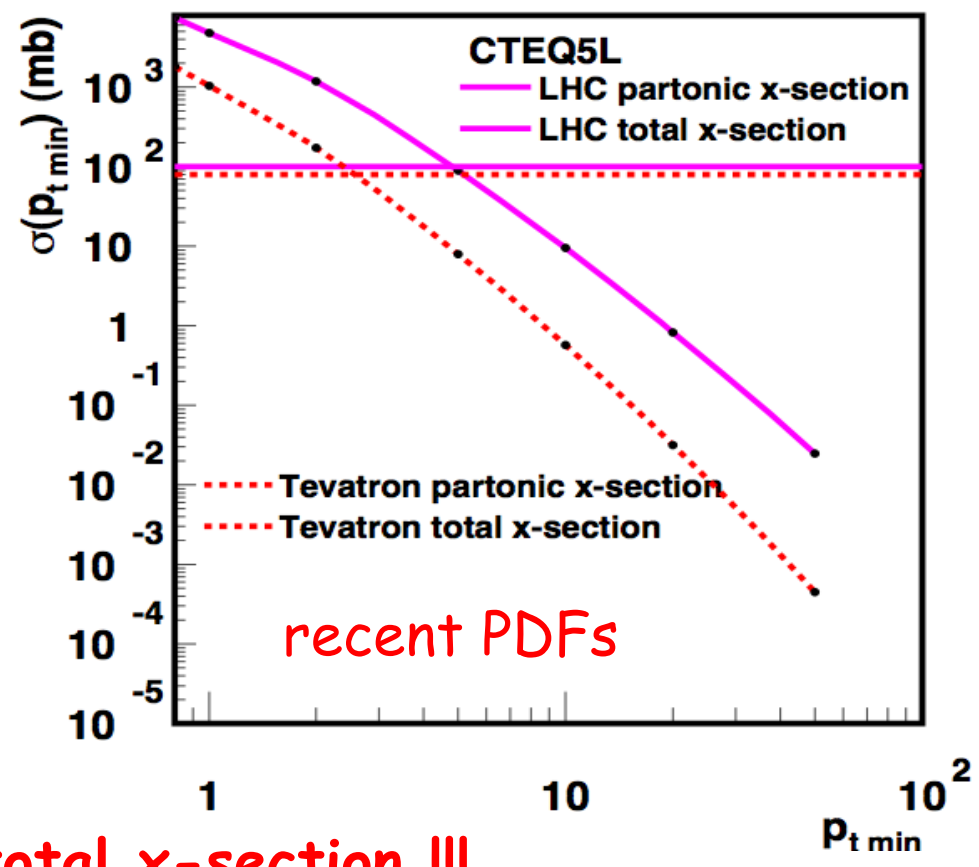


Consequences: cross sections

$$\sigma_{\rm hard}(p^2_{\perp\rm min}) = \int_{p^2_{\perp\rm min}} \frac{d\sigma_{\rm hard}(p^2_\perp)}{dp^2_\perp} dp^2_\perp$$

- Cross section at Tevatron/LHC





➔ Partonic x-section exceeds total x-section !!!

➔ with HERA PDFs .... at larger values of p_{tmin} !!!!!

Consequences: cross sections

$$\sigma_{\rm hard}(p^2_{\perp\rm min}) = \int_{p^2_{\perp\rm min}} \frac{d\sigma_{\rm hard}(p^2_\perp)}{dp^2_\perp} dp^2_\perp$$

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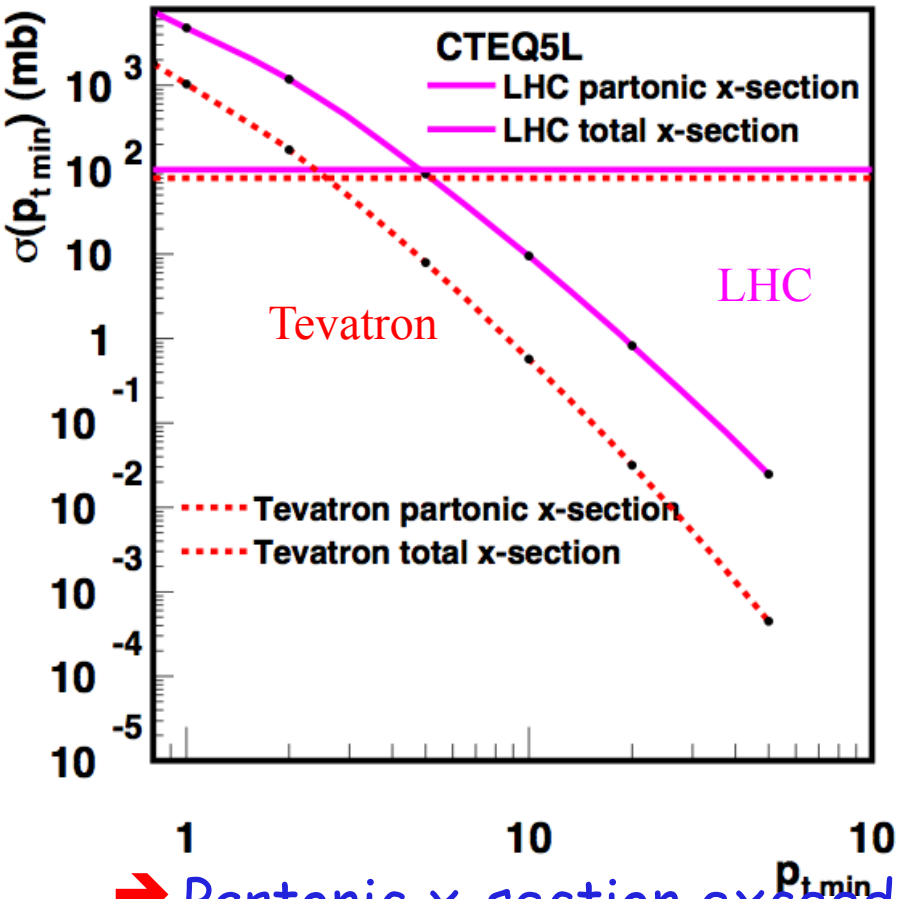
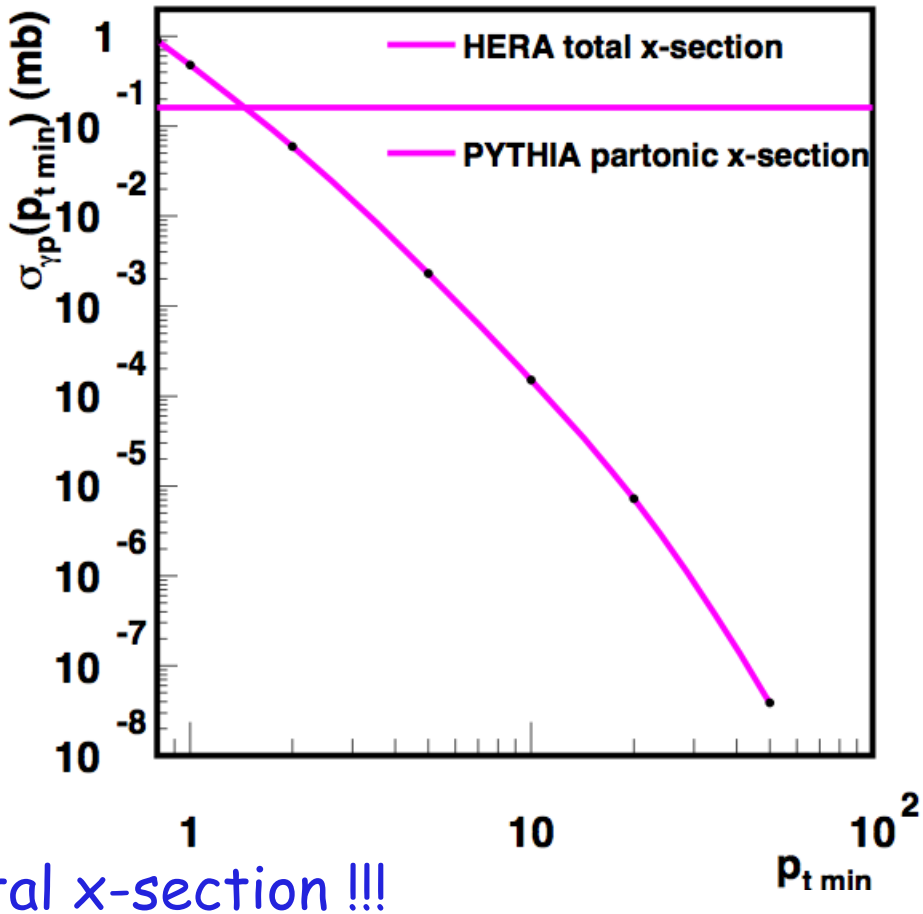


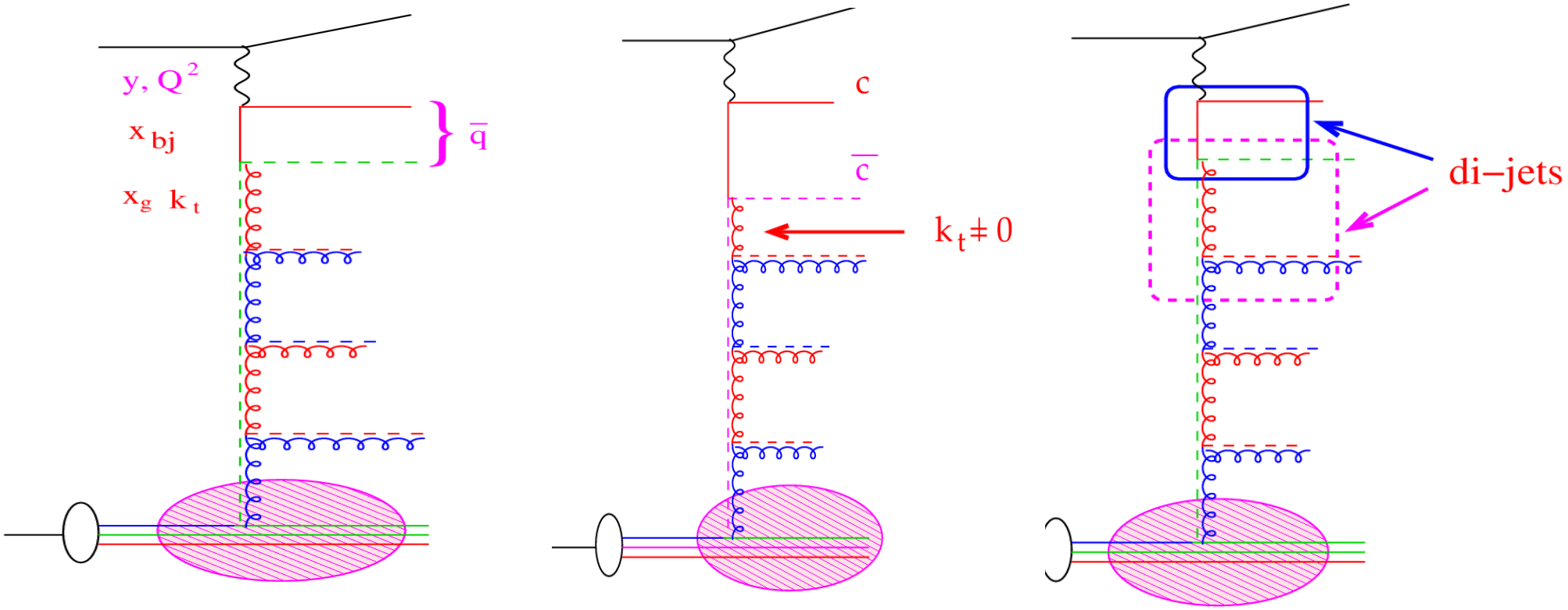
- Cross section at HERA



➔ Partonic x-section exceeds total x-section !!!

➔ at HERA at small values of p_{tmin} !!!

Better use uPDFs with BFKL/CCFM

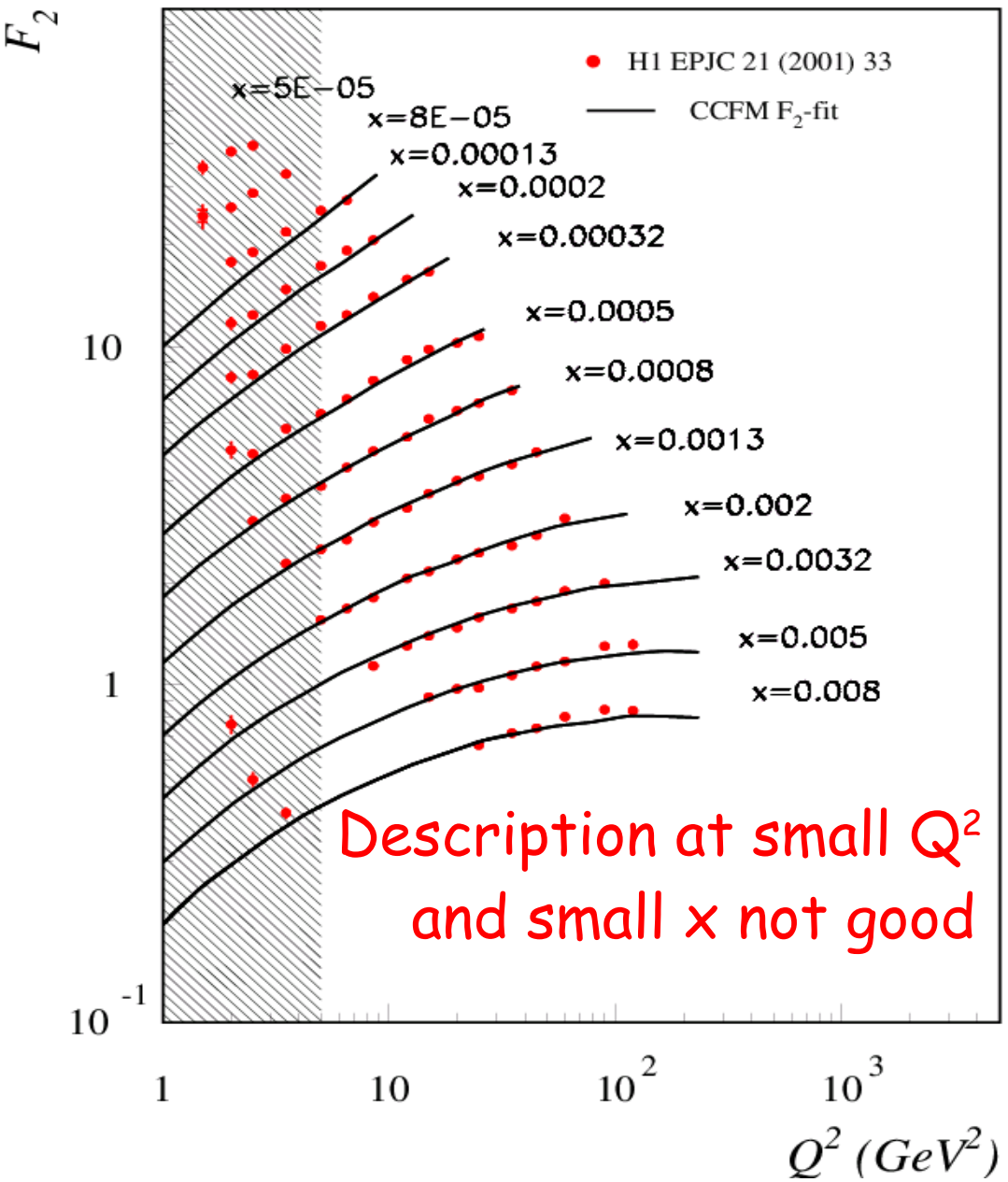


- small x phenomena cannot be described with DGLAP
- need to go beyond: BFKL/CCFM

- Does is really work better ?

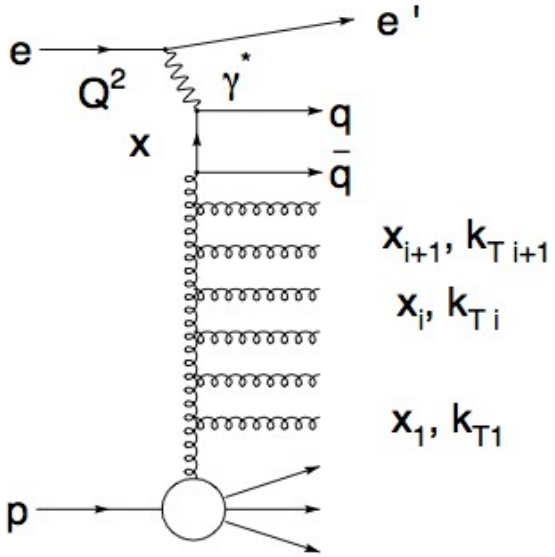
uPDF fit to F_2: x-dependence

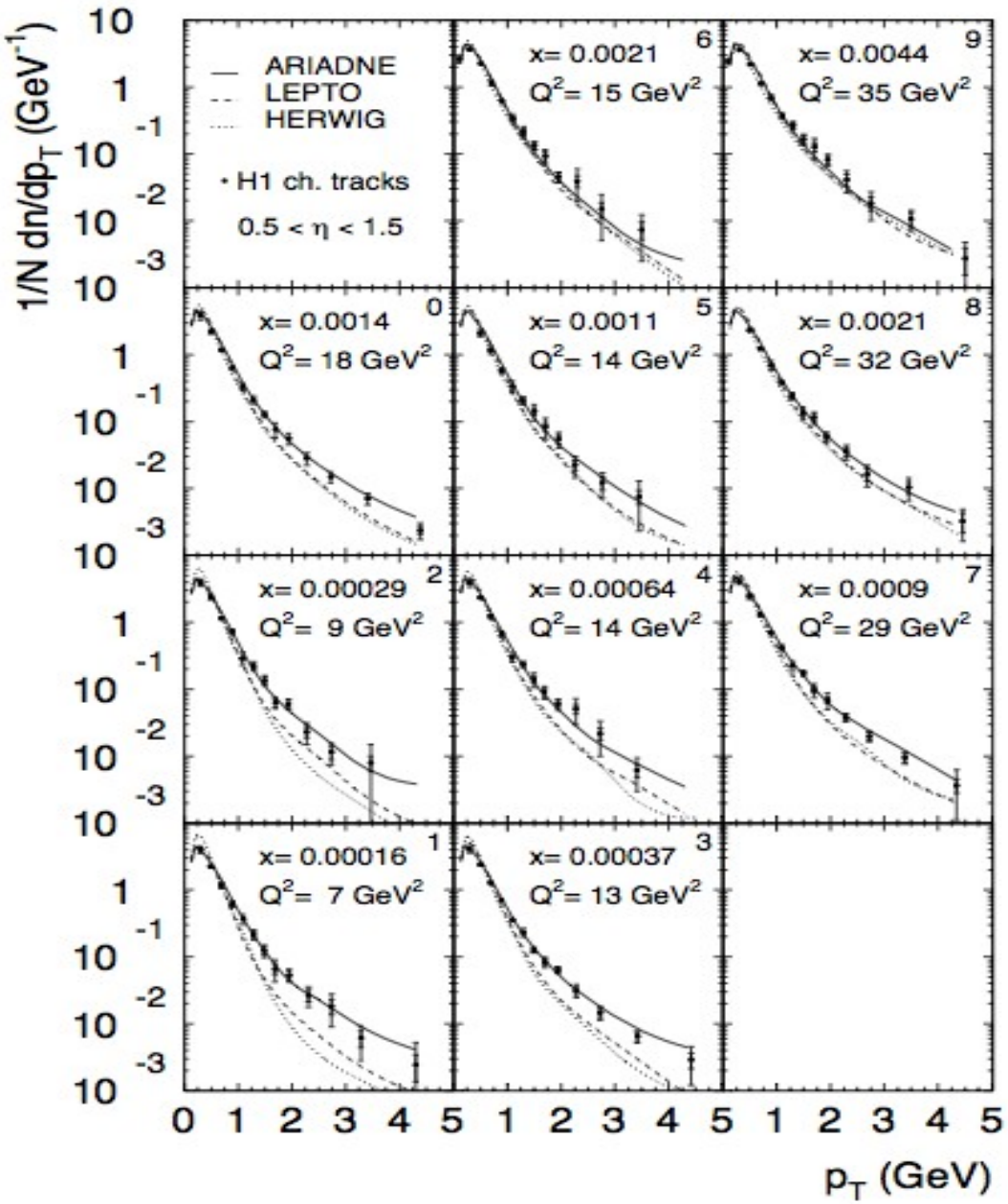
- $$\chi^2 = \sum_i \left(\frac{(T-D)^2}{\sigma_i^{2\ stat} + \sigma_i^{2\ uncor}} \right)$$
- fit parameters of starting distribution
  $$x\mathcal{A}_0(x,\mu_0) = Nx^{-B_g} \cdot (1-x)^4$$
- using F_2 data H1
  (H1 Eur. Phys. J. C21 (2001) 33-61, DESY 00-181)
  $$x < 0.05 \quad Q^2 > 5\ \mathrm{GeV}^2$$
- parameters: $\mu_r^2 = p_t^2 + m_{q,Q}^2$
  $$m_q = 250\ \mathrm{MeV}, m_c = 1.5\ \mathrm{GeV}$$
- Fit (only stat+uncorr):
  $$\frac{\chi^2}{\mathrm{ndf}} = \frac{111.8}{61} = 1.83$$
  $$B_g = 0.028 \pm 0.003$$
  ➔ similar to DGLAP fits (~1.5)



Final states: particle spectra

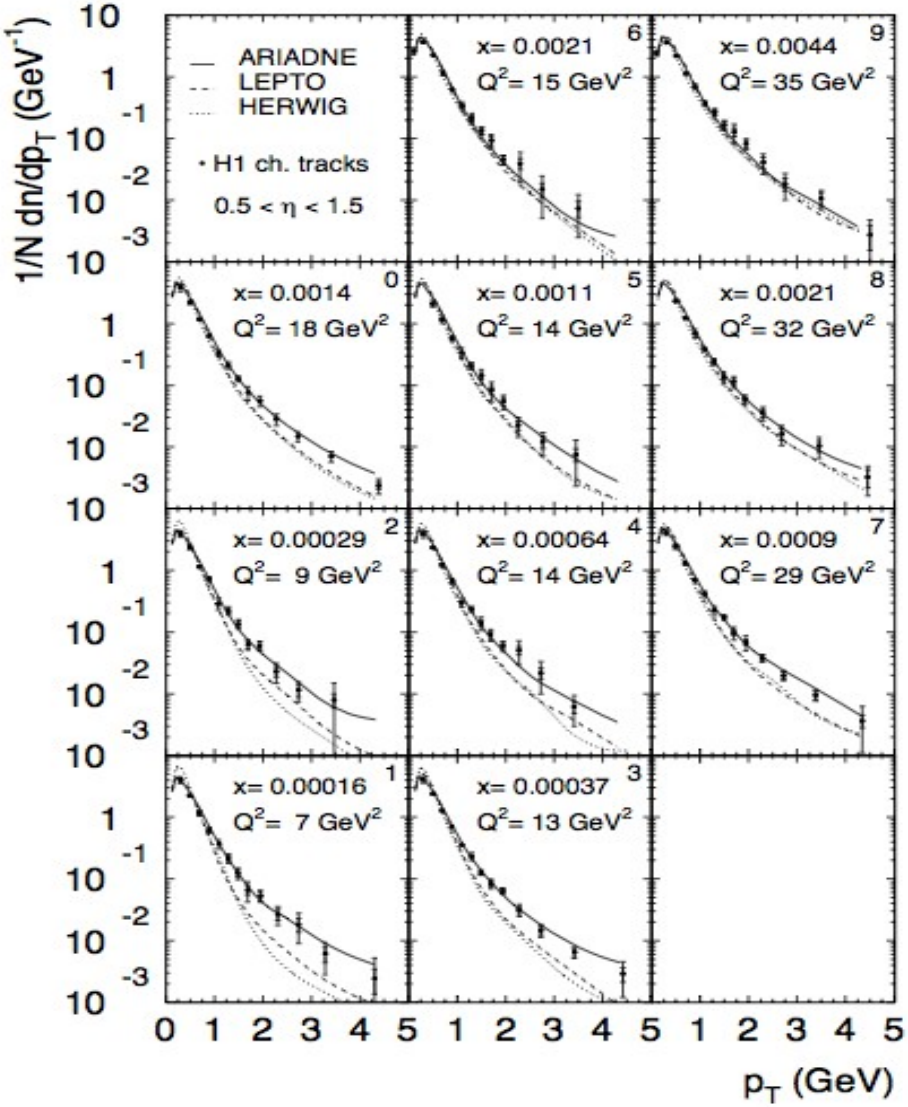
- Charged particle spectra

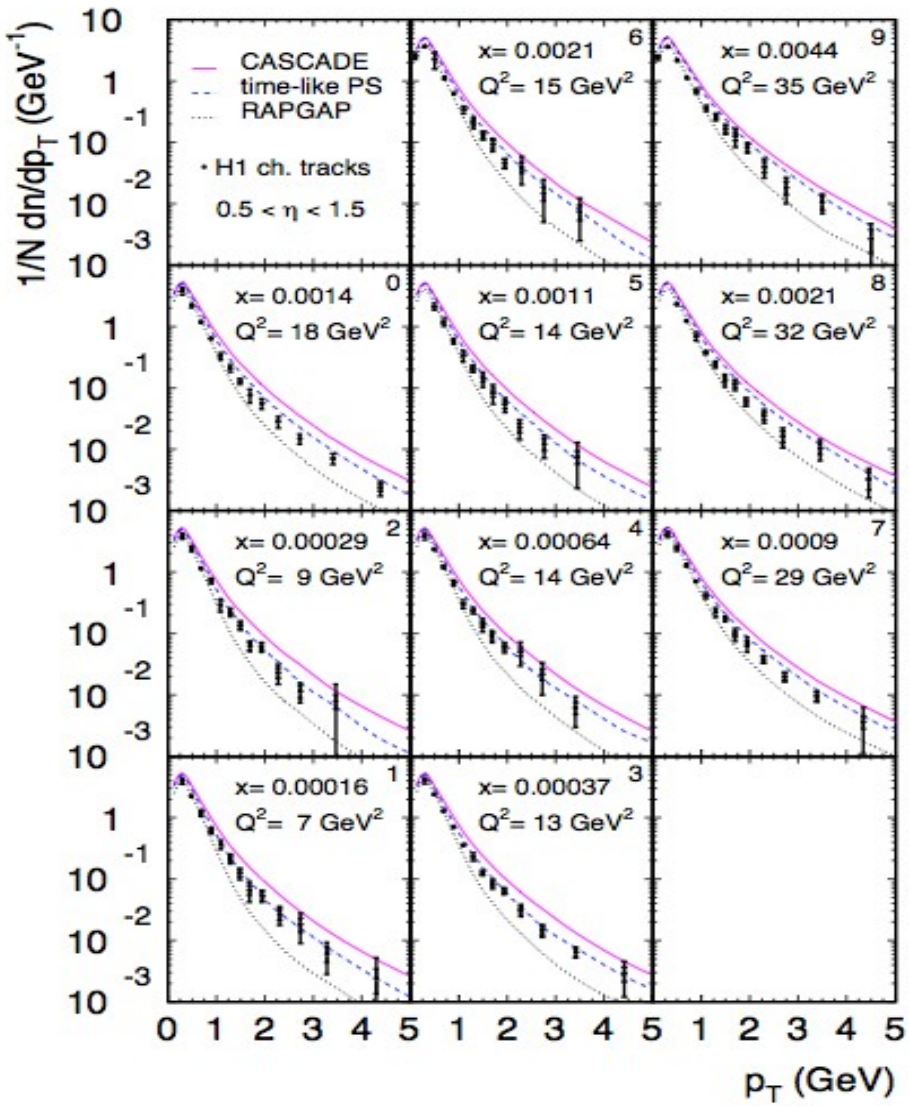




Final states: particle spectra

- Charged particle spectra

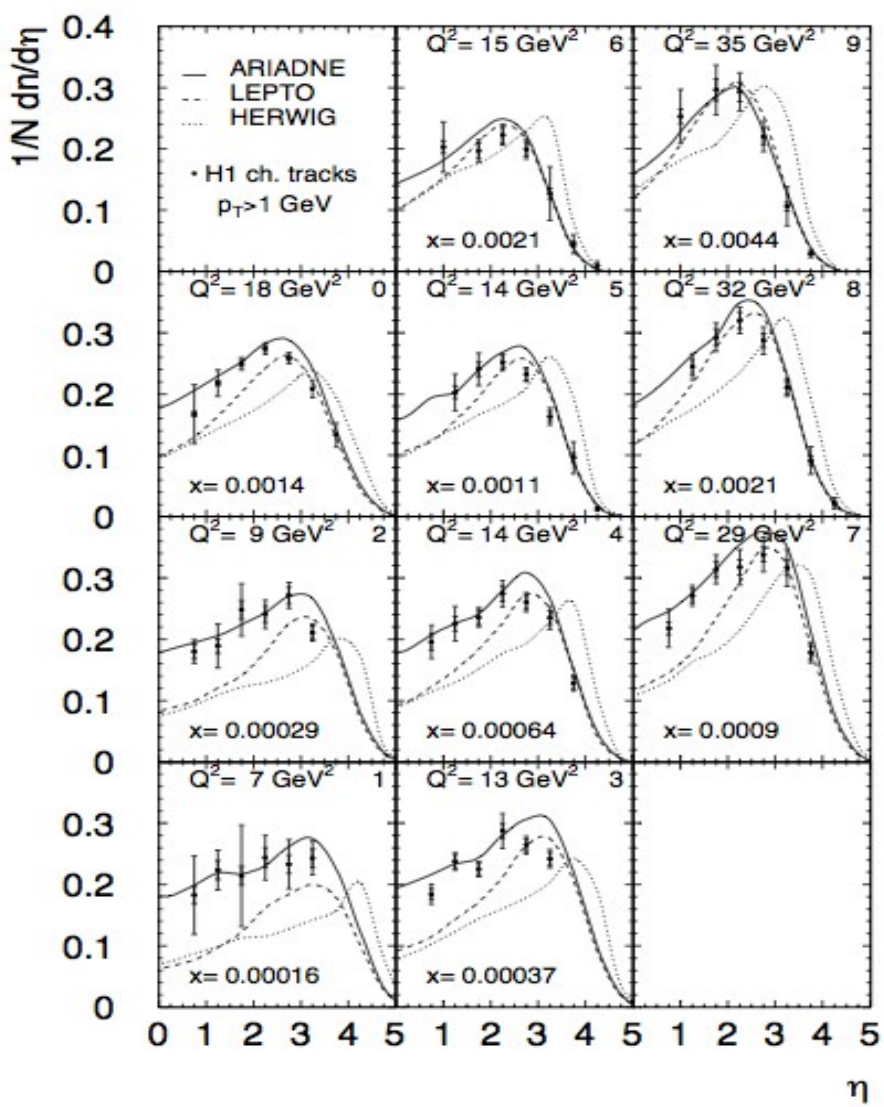


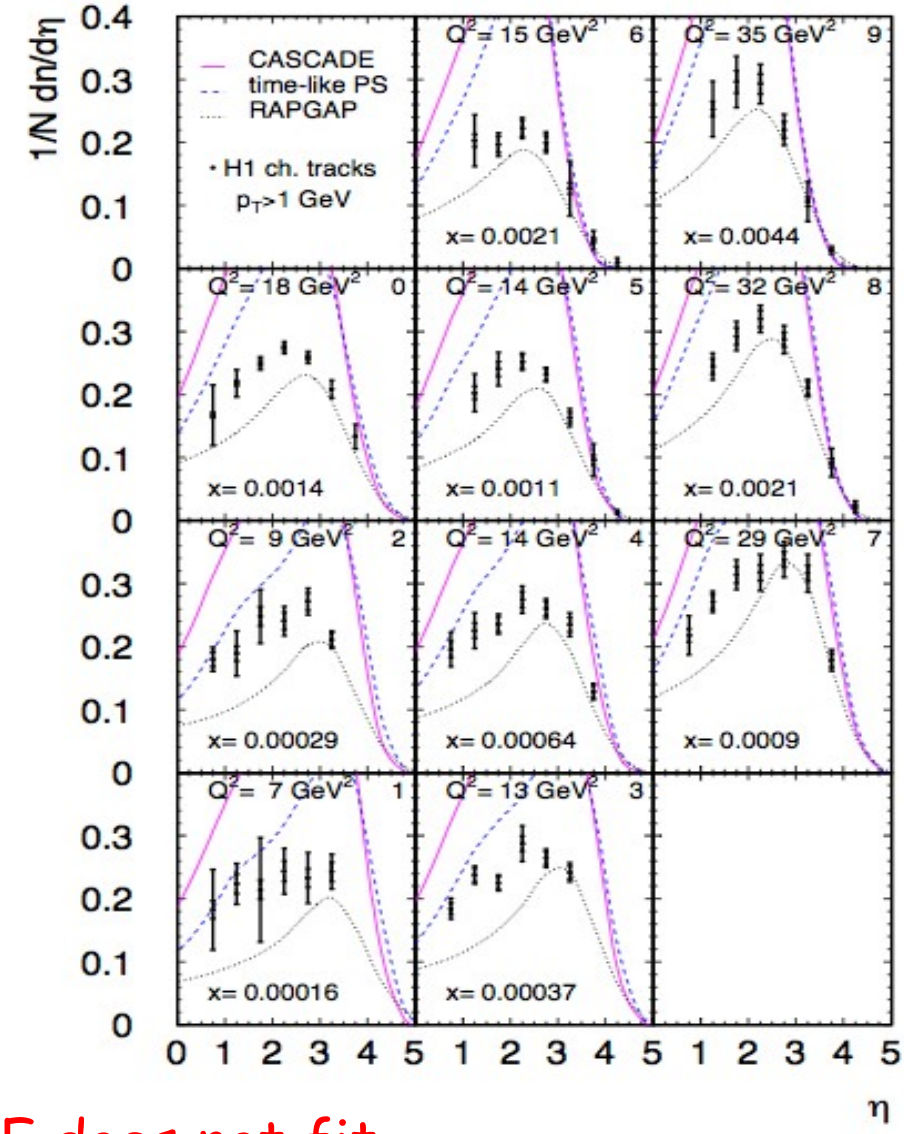


➔ CASCADE with uPDF is better than DGLAP

Final states: particle spectra

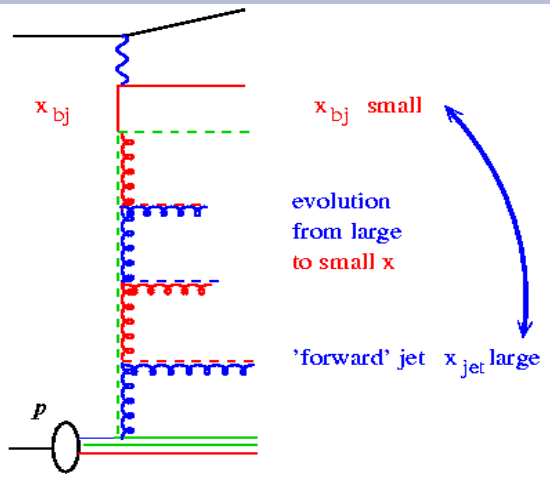
- Charged particle spectra



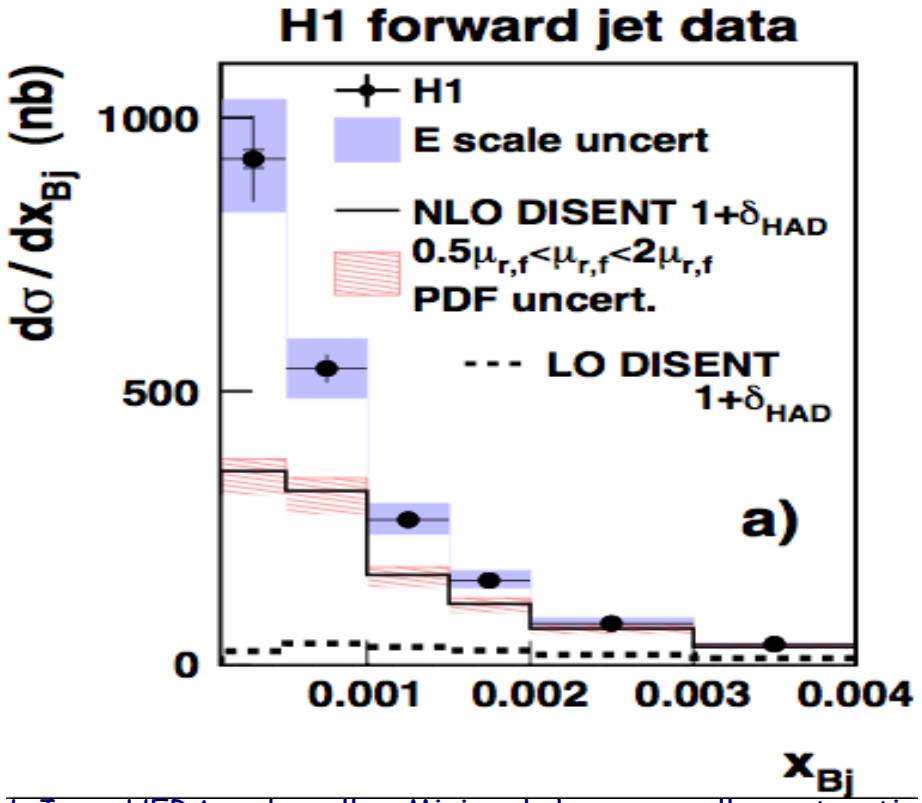


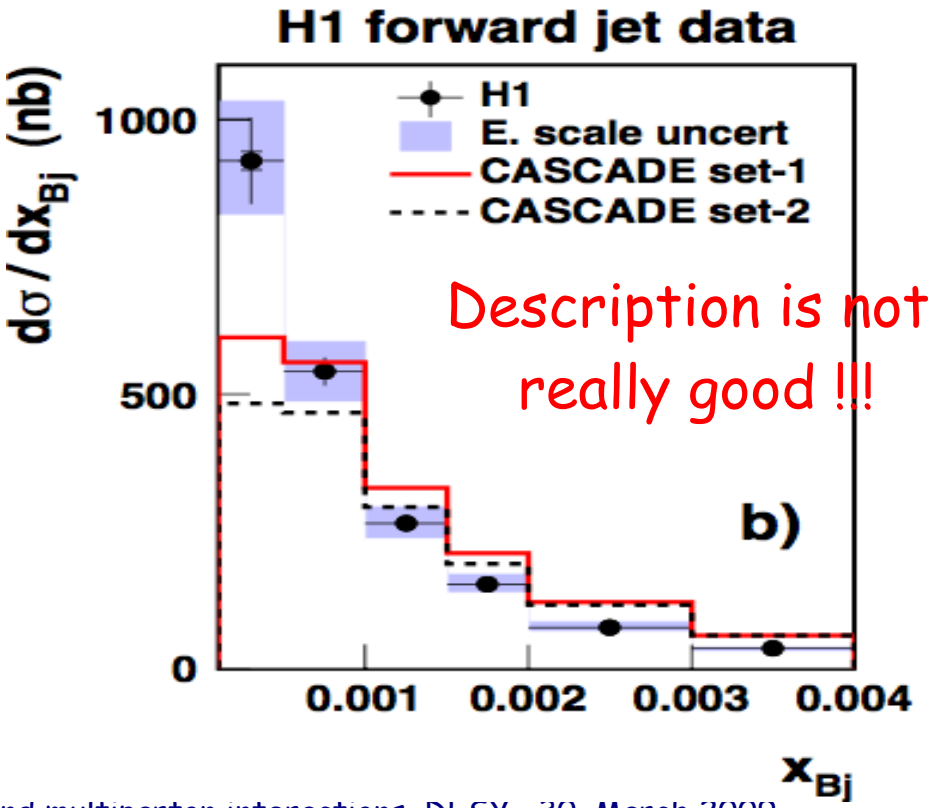
➔ CASCADE with uPDF does not fit ...

Forward jets

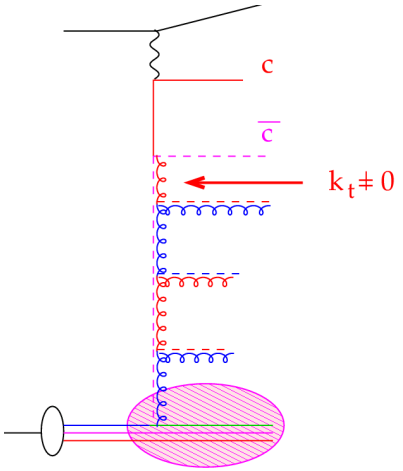


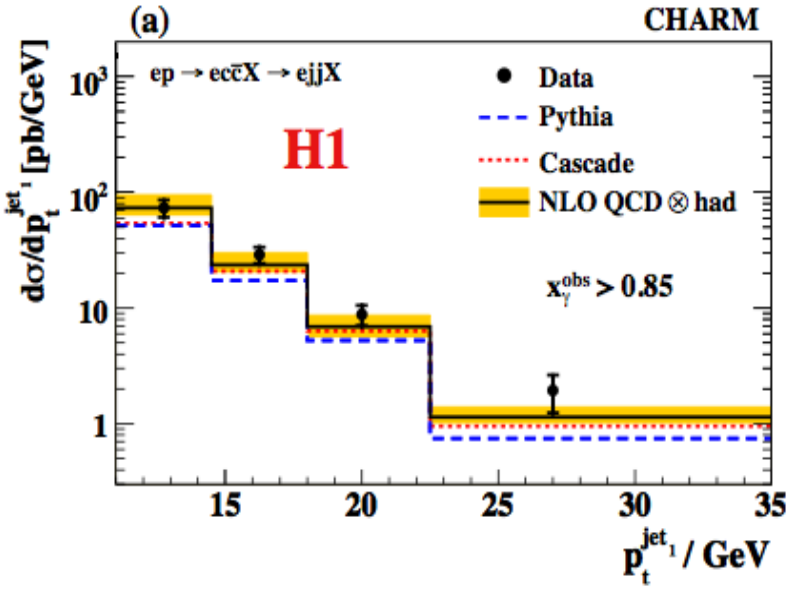
- DIS and forward jet:
  - $1.7 < \eta_{jet} < 2.8$
  - $x_{jet} > 0.035$
  - $0.5 < \frac{p_{t\,jet}^2}{Q^2} < 5$
  - $\sigma(\text{fwd jet})/\sigma(\text{DIS}) \sim 1\%$

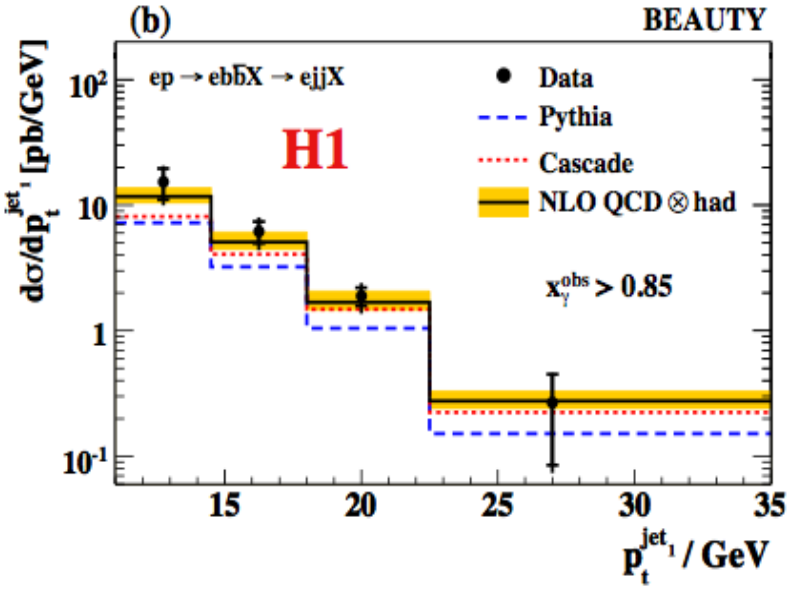


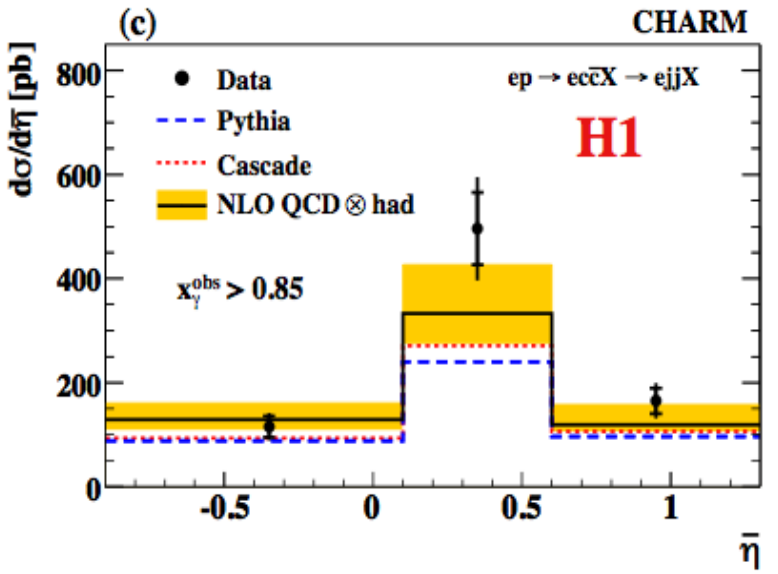


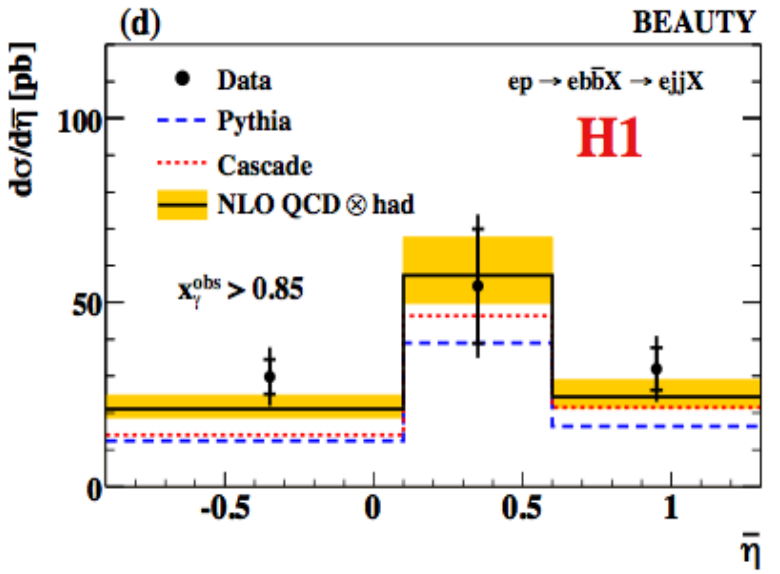
Heavy Flavours





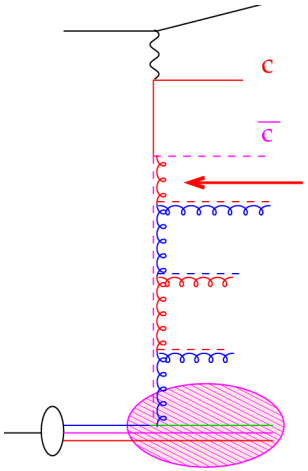


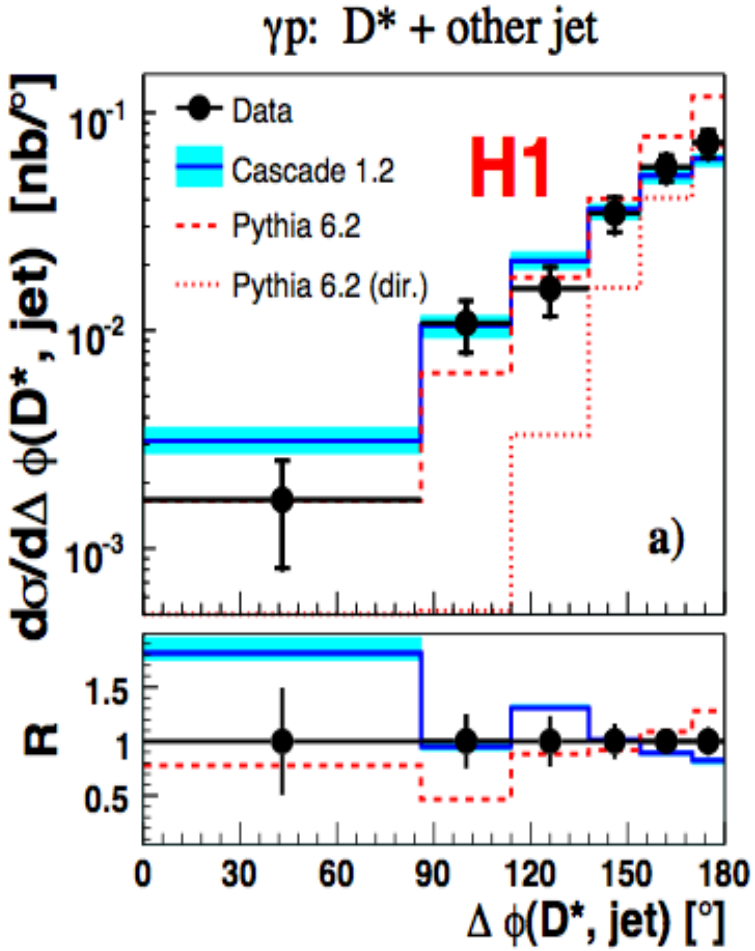


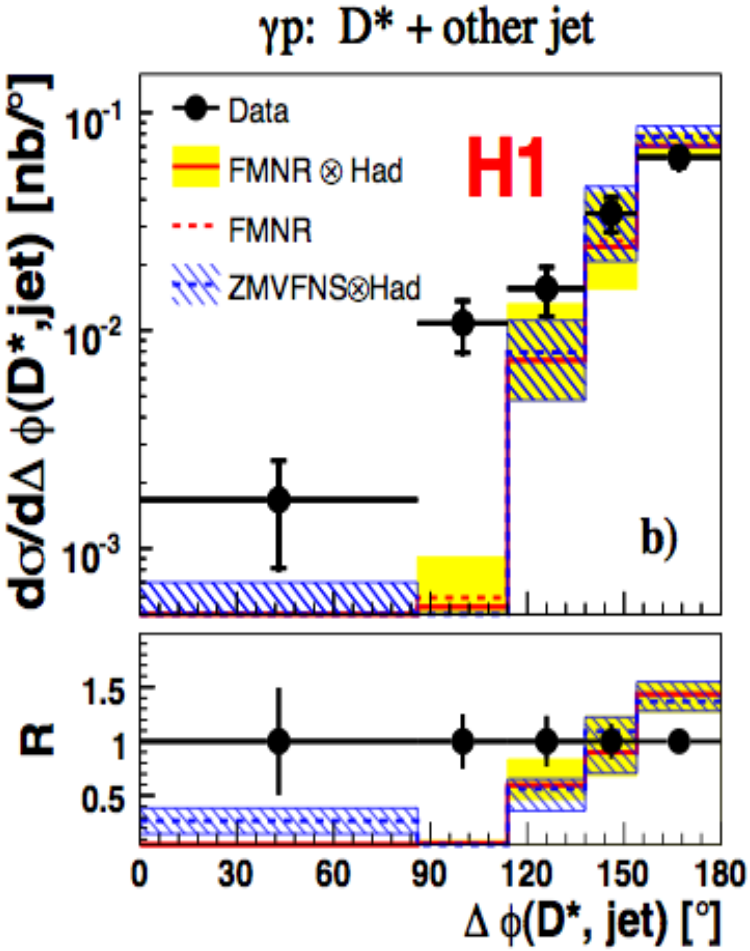


➔ heavy flavor jets are w descibed

Heavy flavors



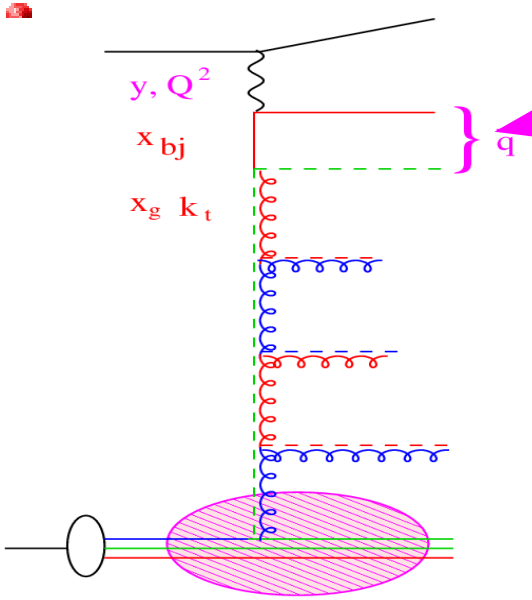




- D* + jet x-sections are also well descibed

Do we really understand small x ?

- need to go beyond DGLAP and standard parton showers
  - kt-factorization approach with uPDFs from HERA works fine for
  - ➔ observables coming from quark box
  - ➔ and clearly gluon initiated processes
  - problems occur for inclusive processes, where also quark uPDFs could play a role
  - ➔ charged particle spectra in DIS
  - ➔ forward jets, forward pions etc



quark box well described

parton radiation details need improvements, including uPDF for quarks etc...

Next steps ?

- Continue for detailed and precise uPDF fits for gluons
- Develop formalism for uPDF for quarks
  - include quarks in evolution
  - include quarks in parton showering
- ...
- .....
- .....
- Develop formalism for multiple interactions... or can we live with soft underlying events idea again ?

Conclusions

- At small x DGLAP cannot be the appropriate description
- BFKL/CCFM are much better suited

BUT:

- ➔ uPDFs need to be better understood and determined
- ➔ details of parton radiation (kinematics etc) matter
- ➔ study and validate CCFM parton evolution against others

- Experimental issues:
  - already many important measurements available, which MUST be used for validation of parton radiation at small x
  - differential particle, mini-jet spectra and energy flow measurements are extremely important
  - multi jet x-sections help to understand parton radiation

It is still a challenge to describe small x, saturation, multiparton interaction, diffraction and high density QCD