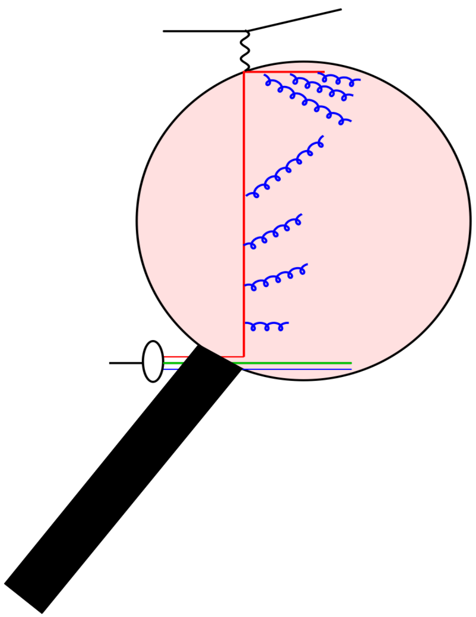
Small x parton dynamics

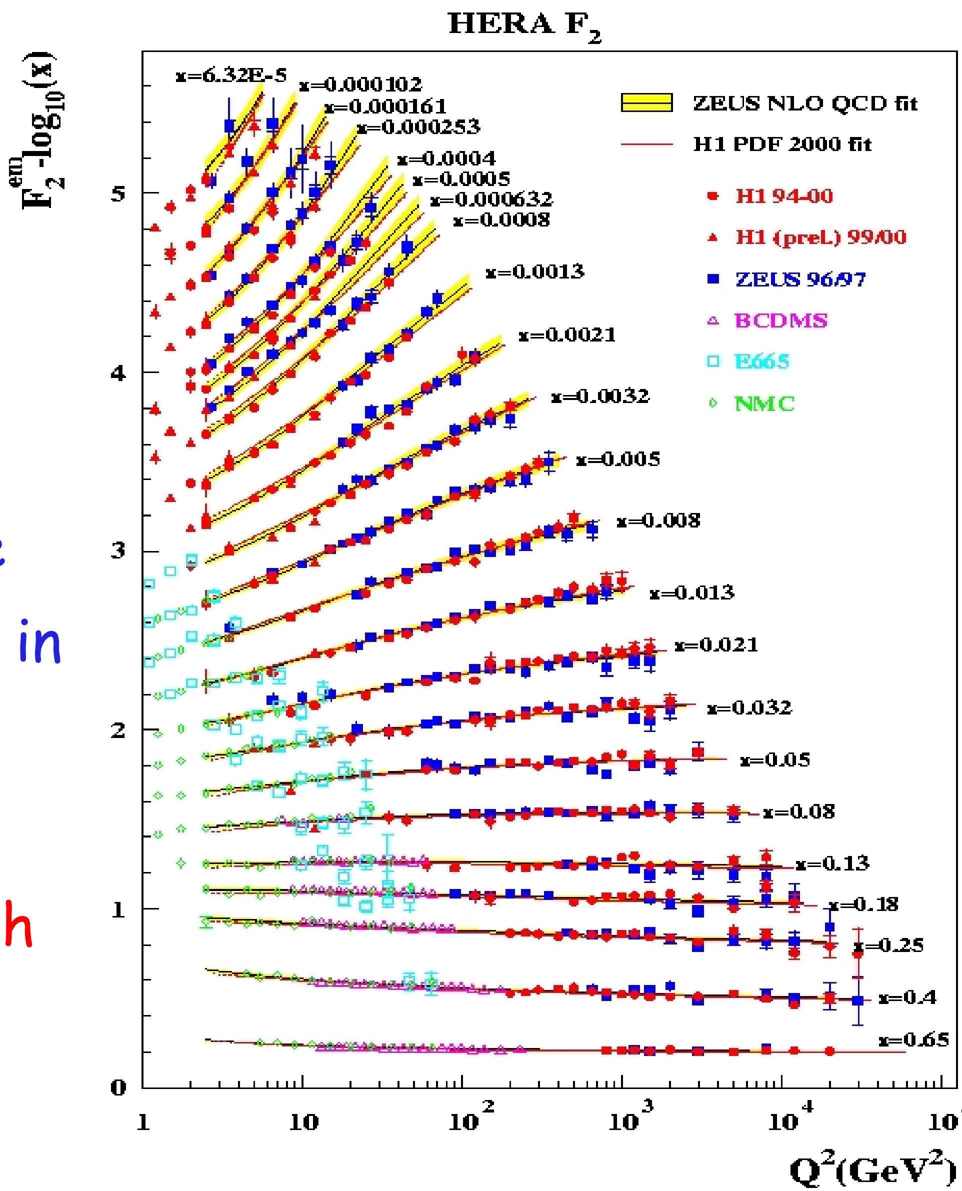
H. Jung (DESY)

- What did we learn from HERA ?
- What is still open ?
- Where LHeC could contribute ?

The fun with ep scattering



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



- perfect description of precise measurements of HUGE range in x and Q^2
- Theory works well.....

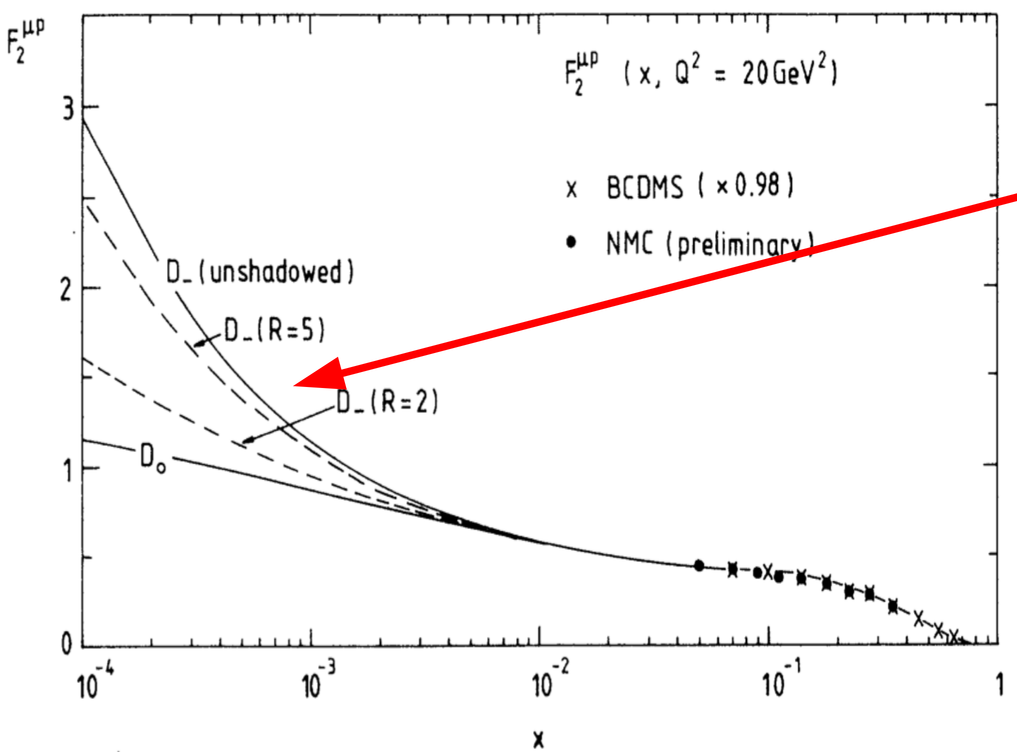
➔ extract parton densities, which are universal

➔ to be used at LHC.....

Remember the pre-HERA times

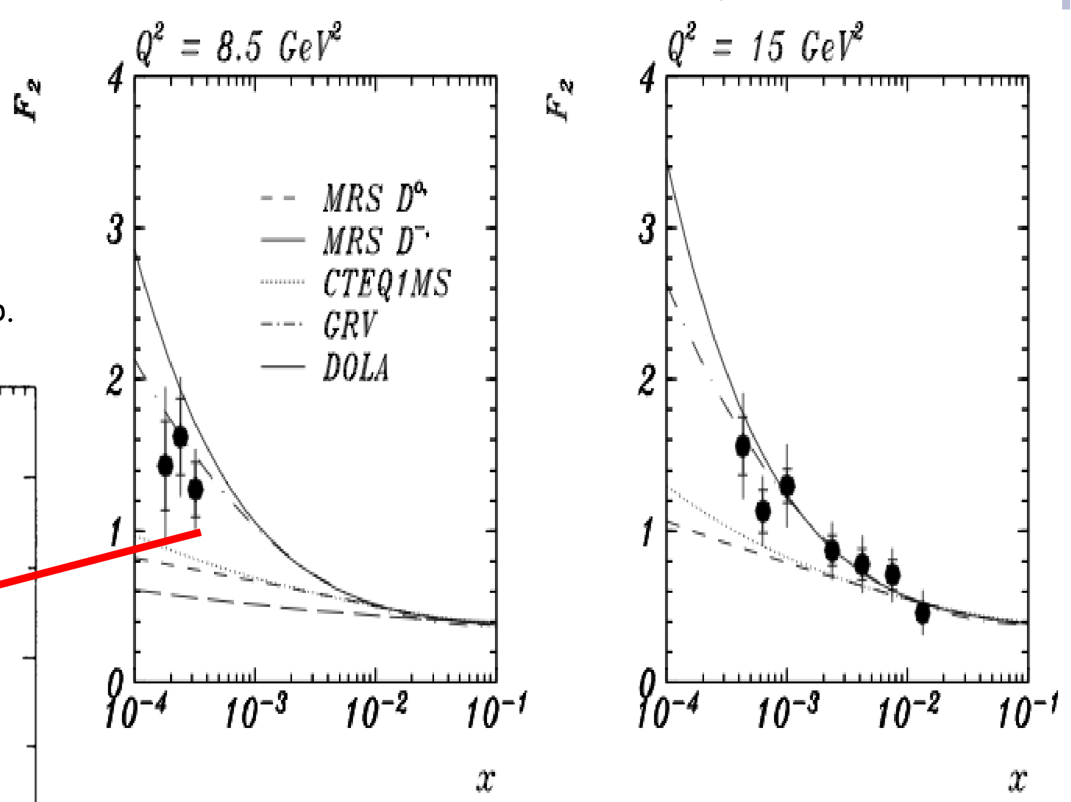
- Just before HERA started in 1992, new PDF fits (NLO DGLAP) were released, using all existing high precision data

Martin, Stirling, Roberts Apr 1992. 49pp.
Phys.Rev.D47:867-882,1993.



- 1st HERA data 1992

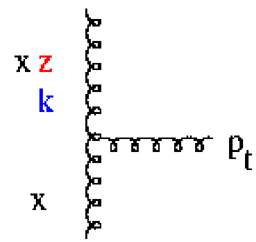
H1 Nucl. Phys. B407 (1993) 515

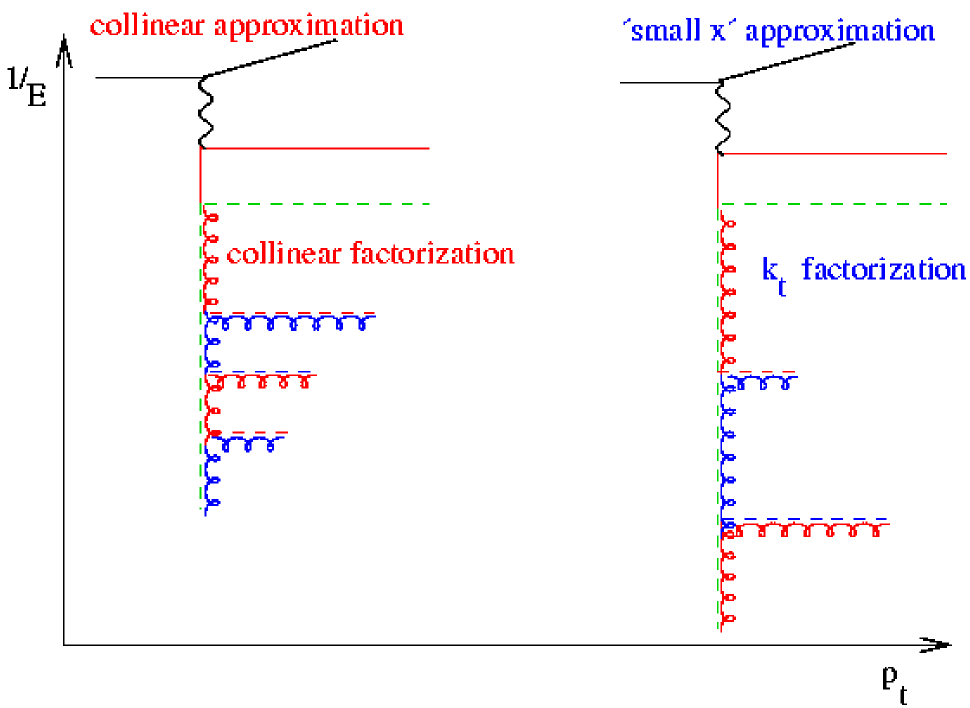


Theory recap: what are we doing ?

gluon bremsstrahlung

$$\sim \frac{1}{k^2}\left(\frac{1}{z} + \cdots\right)$$





Dokshitzer **G**ribov **L**ipatov **A**ltarelli **P**arisi

- collinear singularities factorized in pdf
- evolution in $Q^2 \sim k^2$, or k_t^2 or ?
- $$\sigma = \sigma_0 \int \frac{dz}{z} C^a\left(\frac{x}{z}\right) f_a(z, Q^2)$$

Balitski **F**adin **K**uraev **L**ipatov

- k_t dependent pdf → unintegrated pdf
- evolution in x
- $$\sigma = \int \frac{dz}{z} d^2k_t \hat{\sigma}\left(\frac{x}{z}, k_t\right) \mathcal{F}(z, k_t)$$

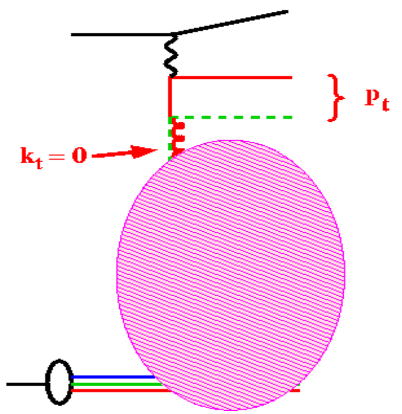
Questions from this ...

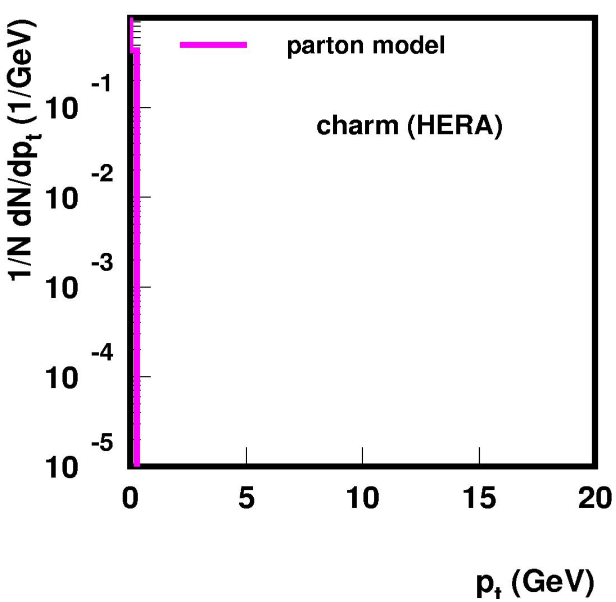
- Strong rise of structure function at small x:
  - ➔ where is it coming from ?
    - ➔ typical BFKL behavior ?
    - ➔ or
    - ➔ steep starting distribution at which scale ?
    - ➔ or
    - ➔ generated dynamically from a small scale (GRV ansatz) ?
- if high parton density at small x, do we also observe saturation and parton recombination
- How is initial state parton cascade generated ?

Problems in Collinear Approximation

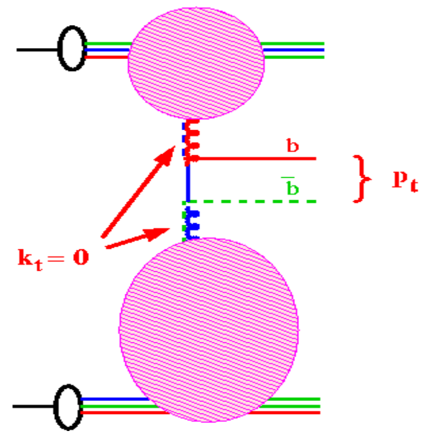
J. Collins, H. Jung hep-ph/0508280

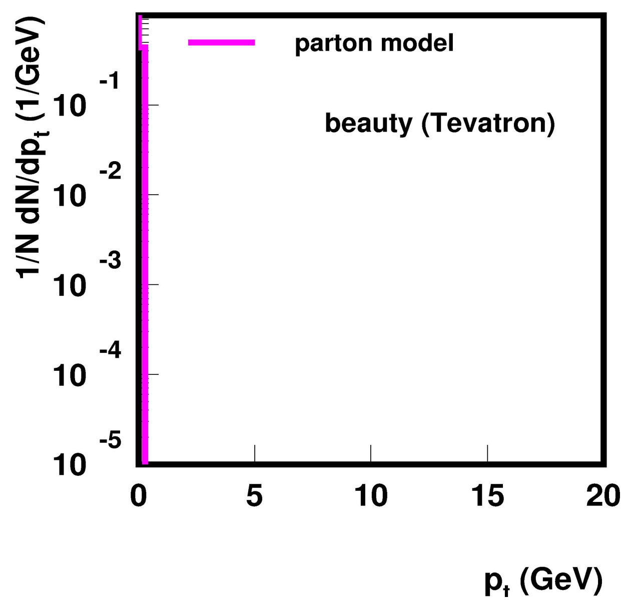
heavy quarks at HERA



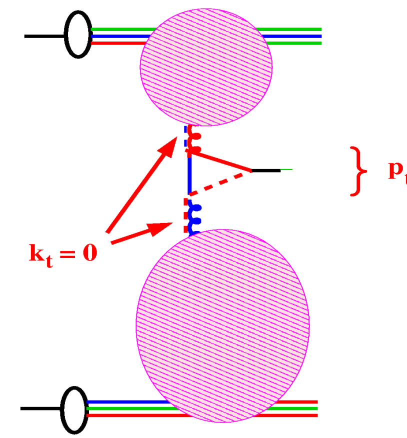


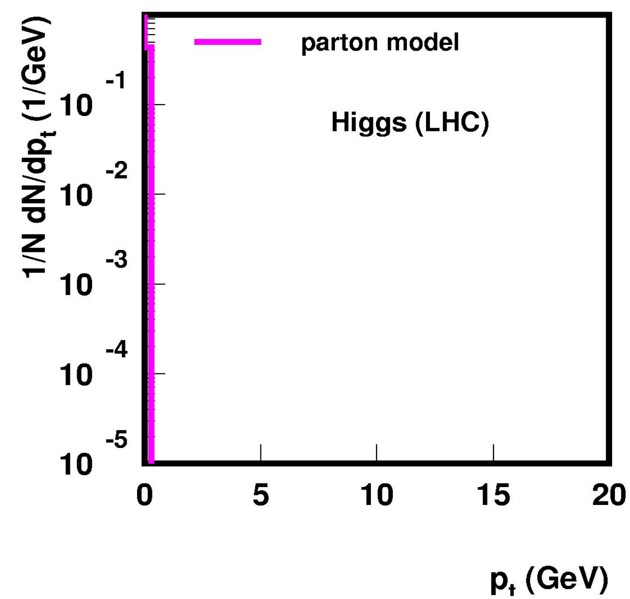
heavy quarks in





Higgs in pp



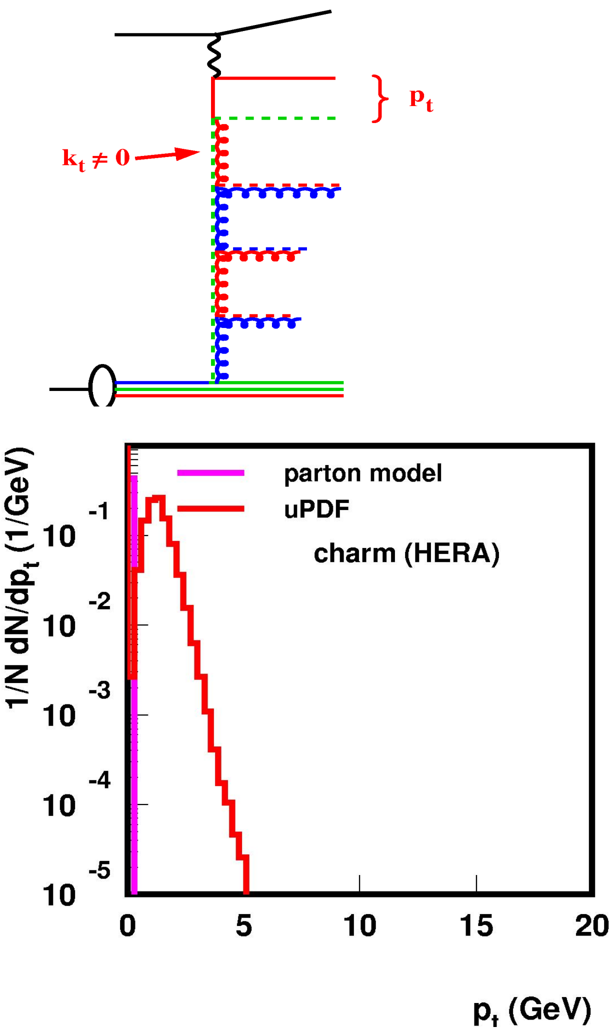


➔ NLO corrections will be very large for these LO processes .....

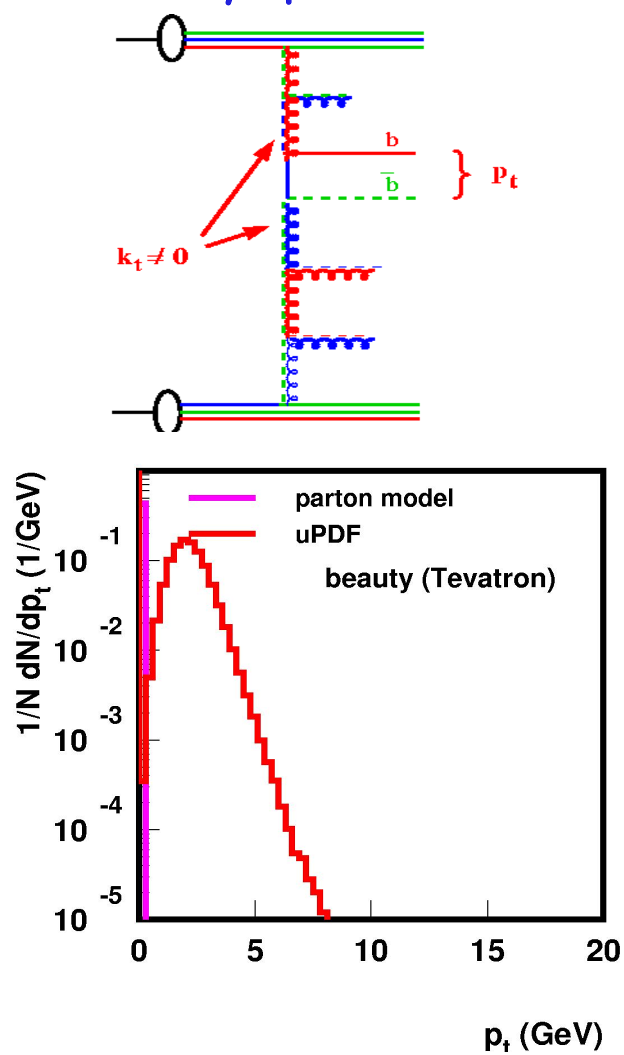
Doing much better with uPDFs ...

J. Collins, H. Jung hep-ph/0508280

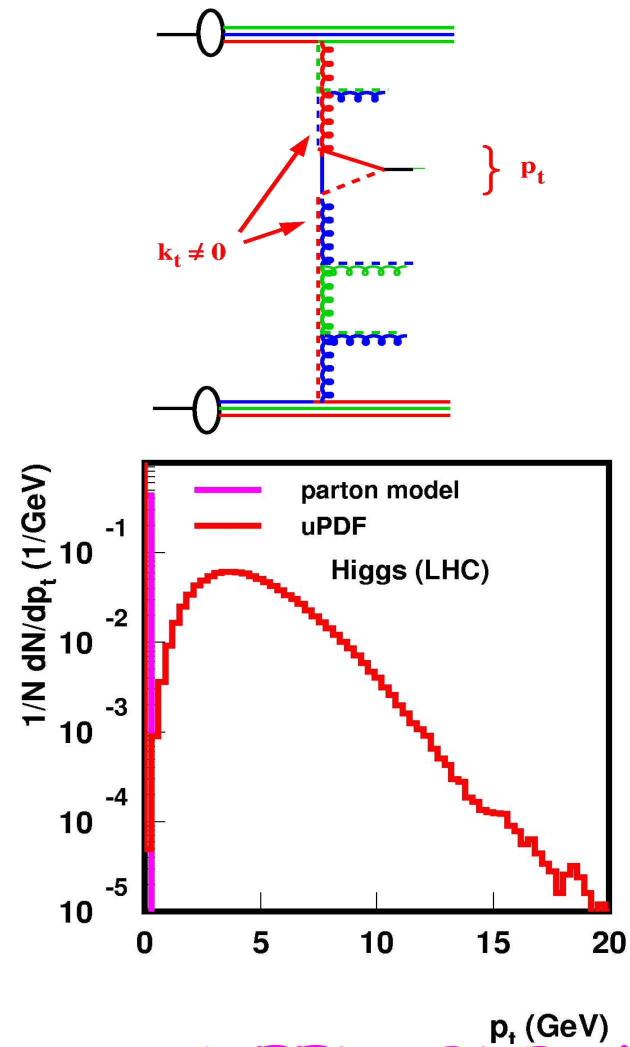
heavy quarks at HERA



heavy quarks in

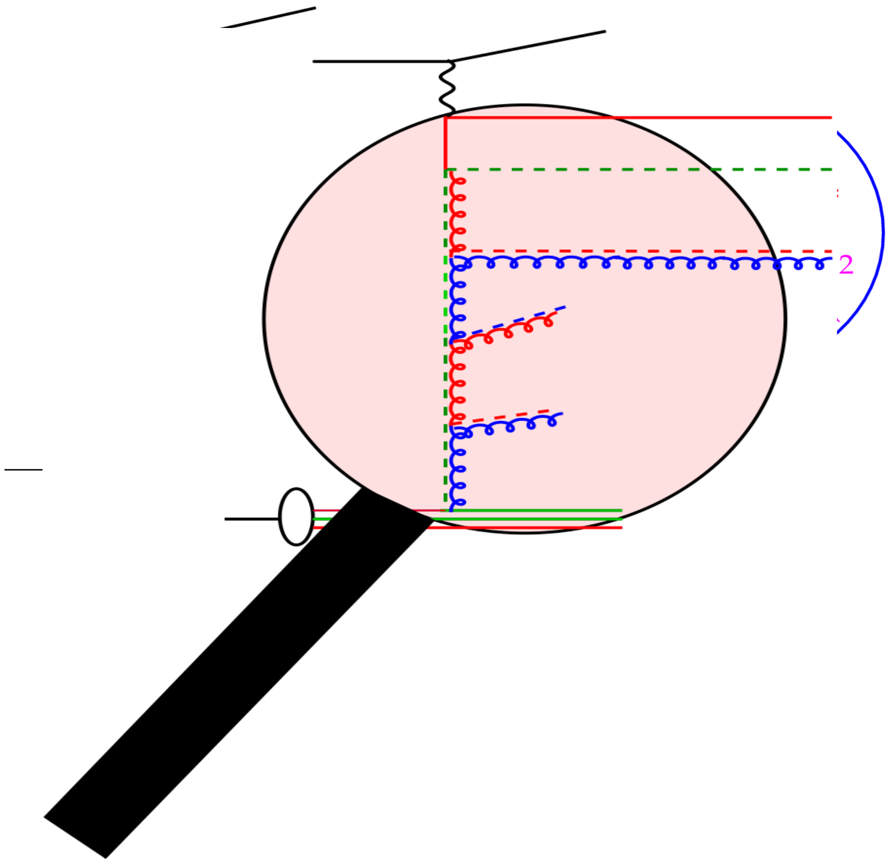


Higgs in pp



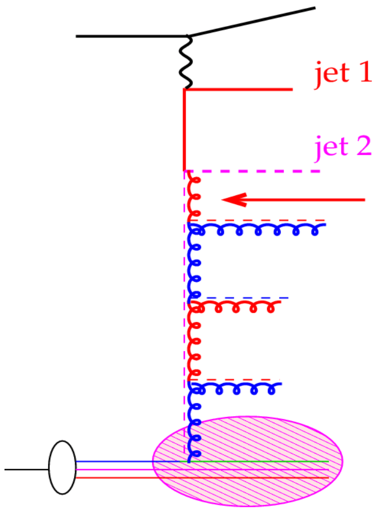
➔ doing kinematics correct at LO, reduces NLO corrs,.... NEED uPDFs !!!!

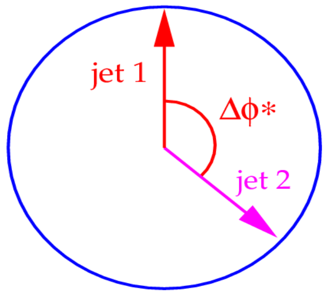
Walking down the ladder ...



- H1 prel data $5 < Q^2 < 100\ \text{GeV}^2$
  $-1 < \eta < 2.5$
  $E_T > 5\ \text{GeV}$

Walking down the ladder ...





- H1 prel data $5 < Q^2 < 100$ GeV^2
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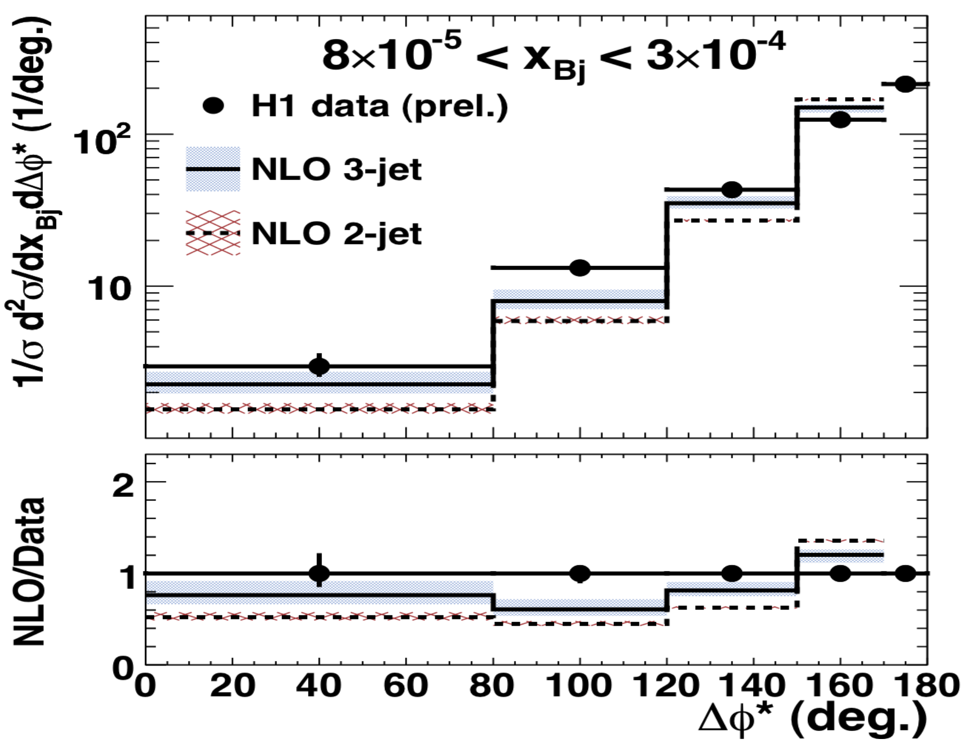
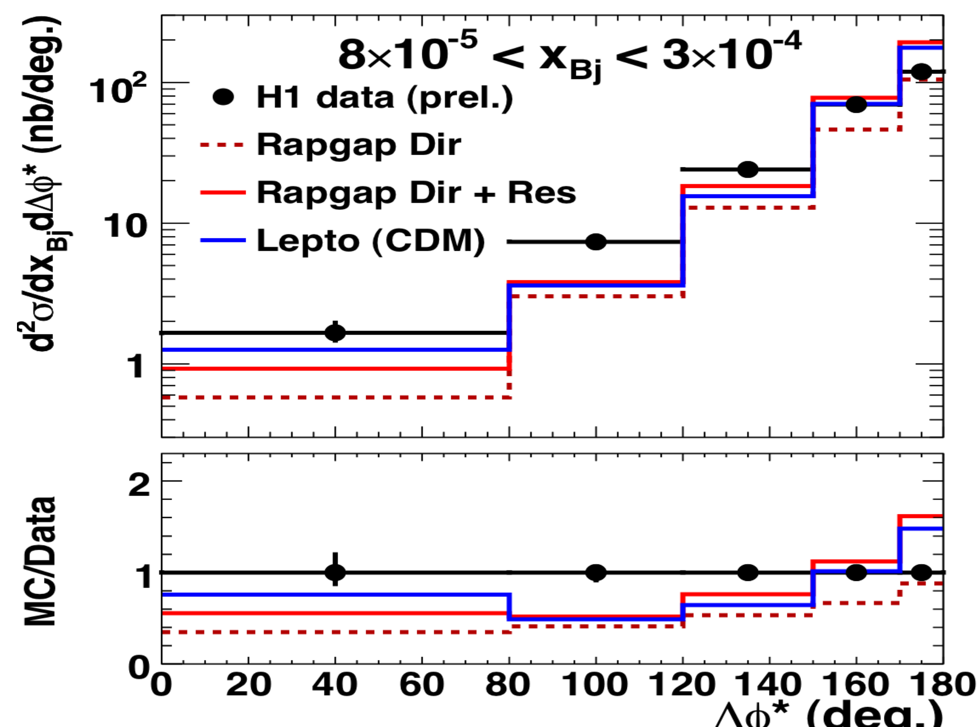
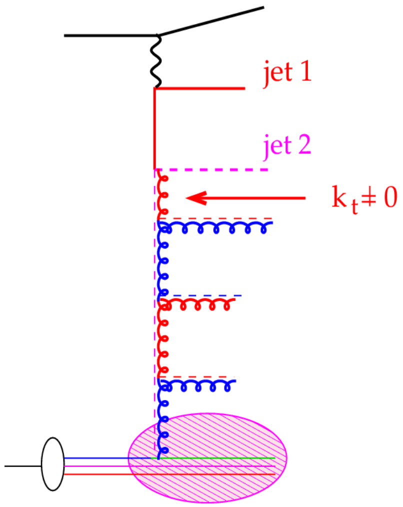
➔ None of the calculations can describe measurements !!!

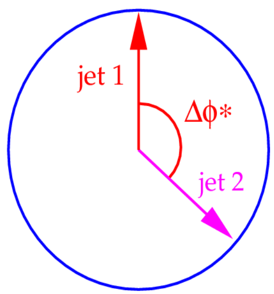


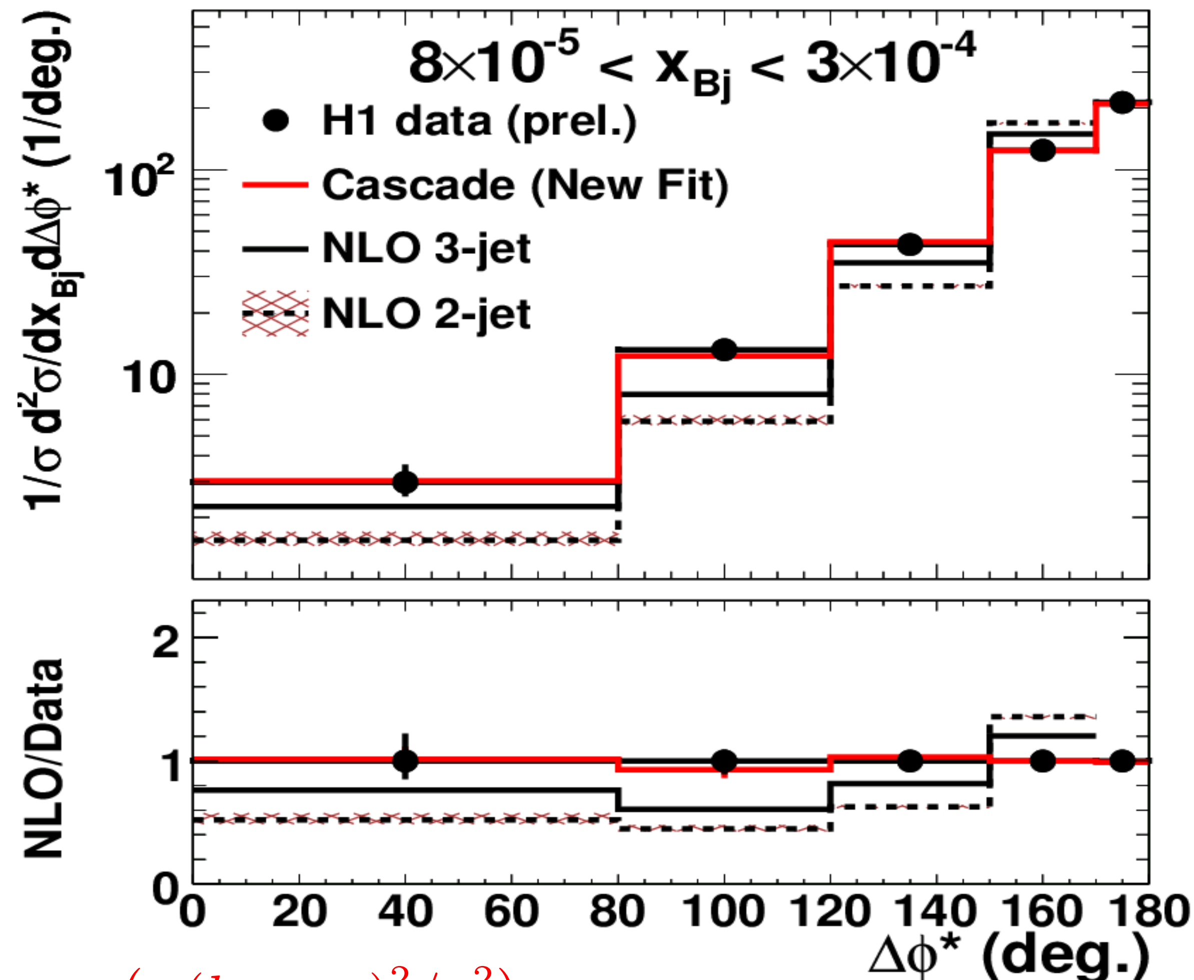


uPDFs from di-jets: k_t-dependence

Hansson, Jung arXiv:0707.4276







- H1 prel data

  $$5 < Q^2 < 100 \text{ GeV}^2$$
  $$-1 < \eta < 2.5$$
  $$E_T > 5 \text{ GeV}$$

- determine small k_t region with

$$x\mathcal{A}(x,\mu_0^2) = N x^{-B_g} \cdot (1-x)^4 \cdot \exp\left(-(k_{t0}-\mu)^2/\sigma^2\right)$$

- large k_t from evolution

➔ perfect description of shape and rate

uPDFs from di-jets: intrinsic k_t

$$xA(x, k_\perp, \bar{q}) = \int dx_0 A_0(x_0, \mu_0) \times \frac{x}{x_0} \tilde{A}\left(\frac{x}{x_0}, k_\perp, \bar{q}\right)$$

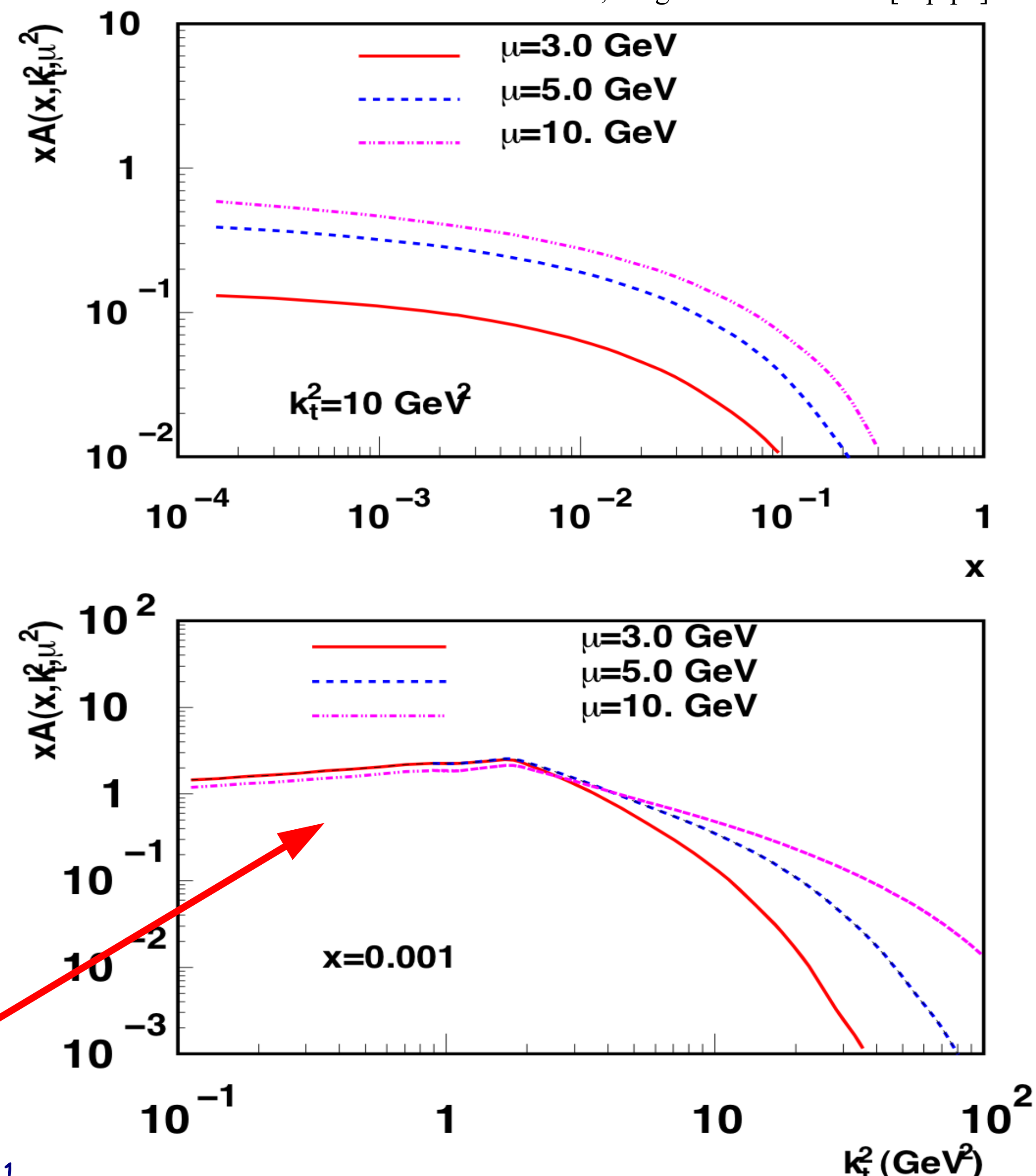
- different intrinsic k_t-distributions only accessible in uPDFs
- sensitive to the mix of small and large k_t

➔ small kt determines total x-section

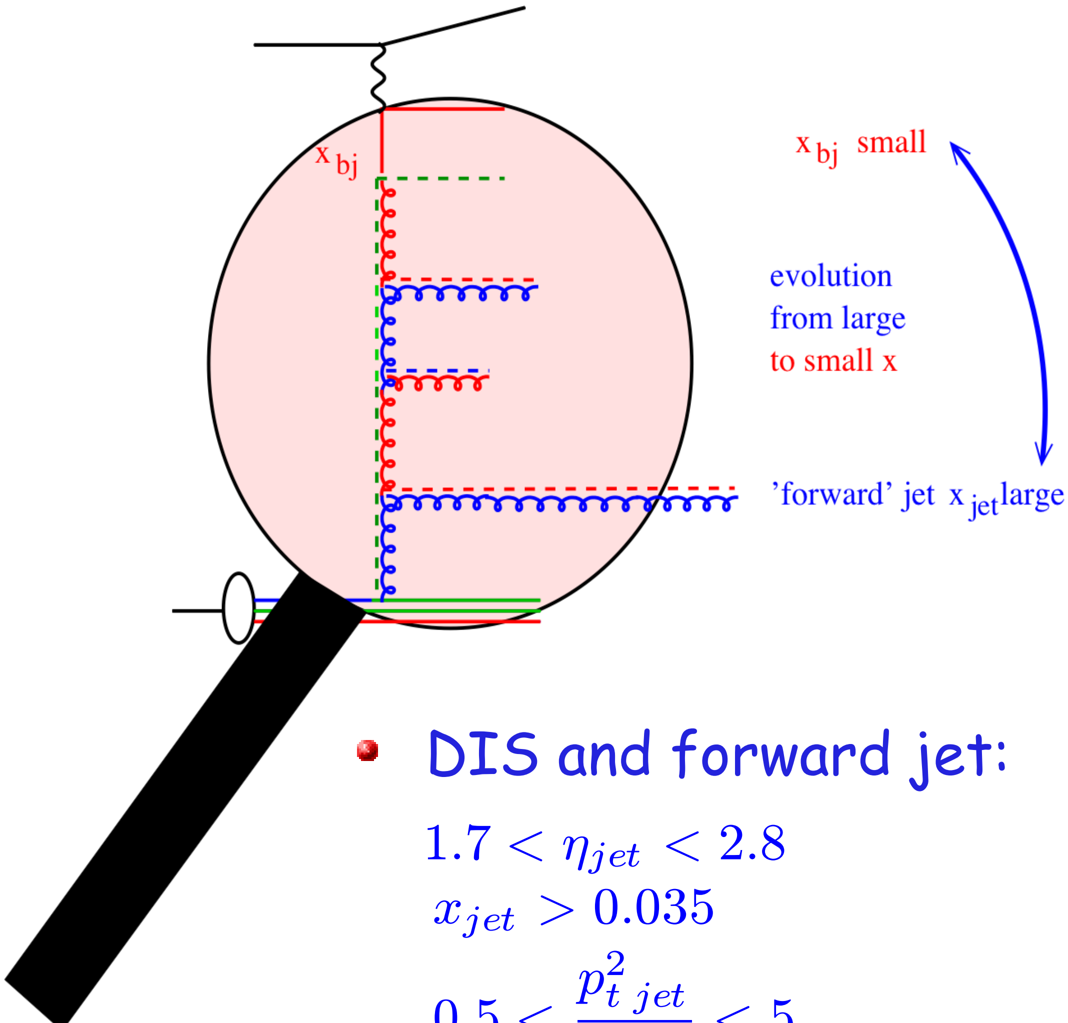
➔ large kt influences perturbative tails ...

BUT .....

Hautmann, Jung arXiv:0712.0568 [hep-ph]



Looking forward ...



- DIS and forward jet:

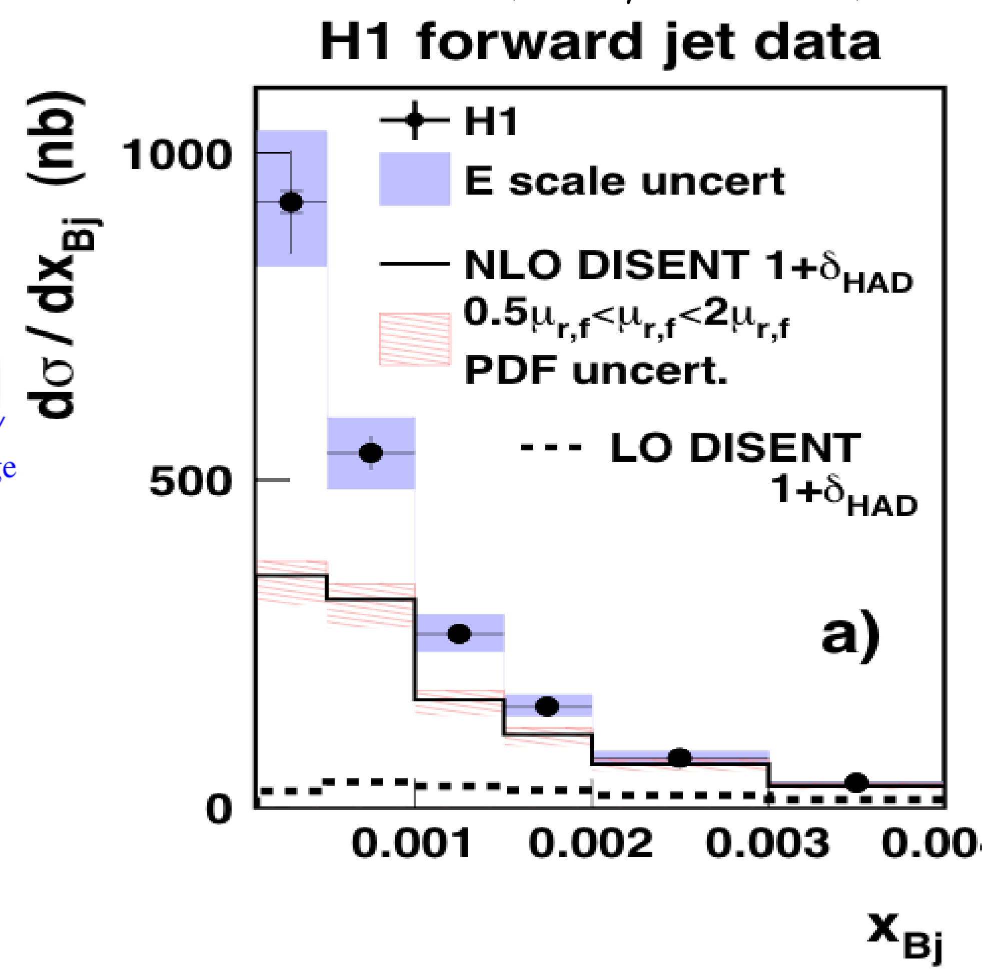
$$1.7 < \eta_{jet} < 2.8$$

$$x_{jet} > 0.035$$

$$0.5 < \frac{p_{t\ jet}^2}{Q^2} < 5$$

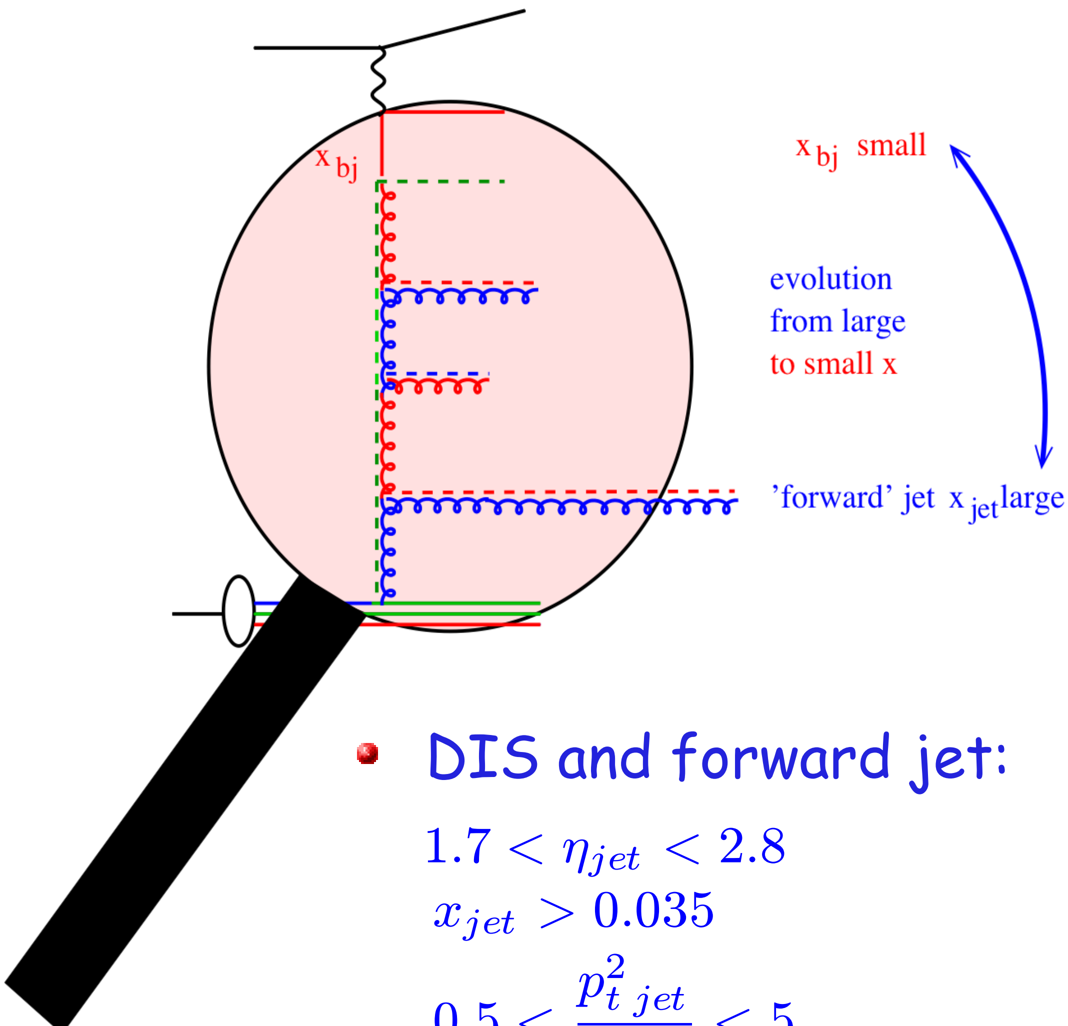
$$\sigma(\mathrm{fwd\ jet})/\sigma(\mathrm{DIS}) \sim 1\%$$

H1, Eur.Phys.J.C46:27-42,2006.



➔ NLO calcároooooo low !!!

Looking forward ...



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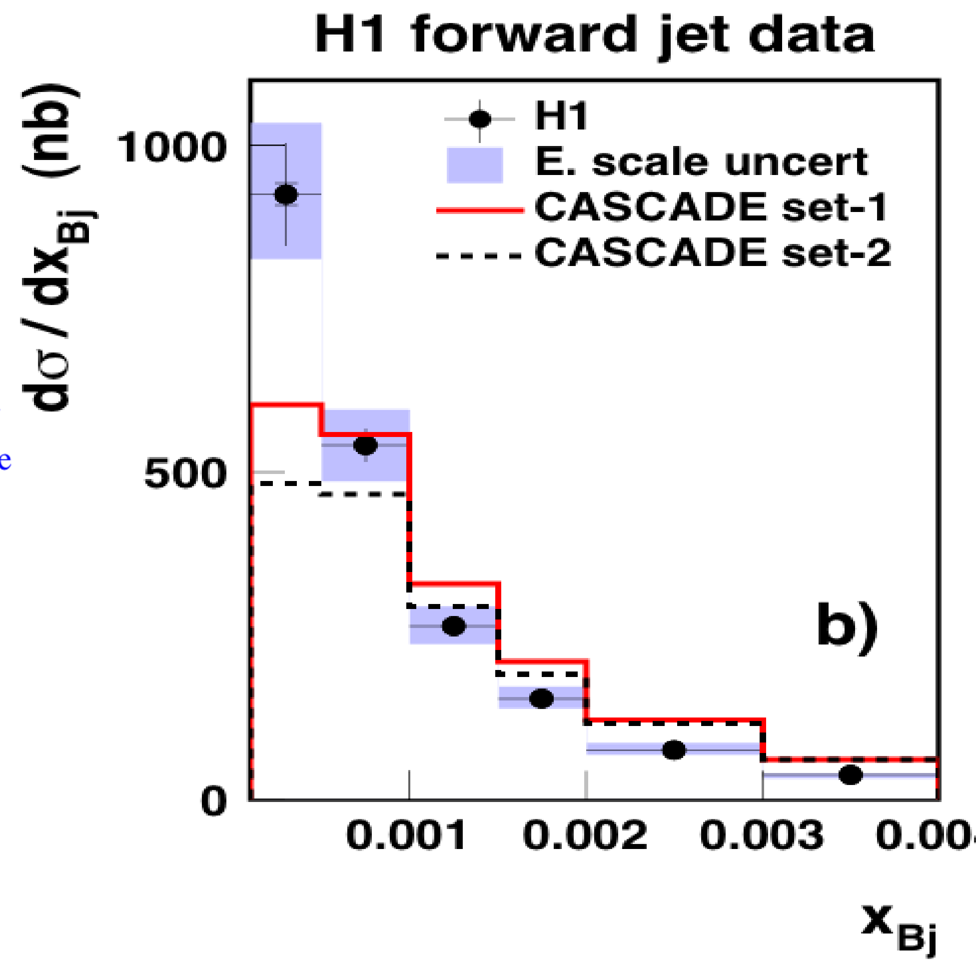
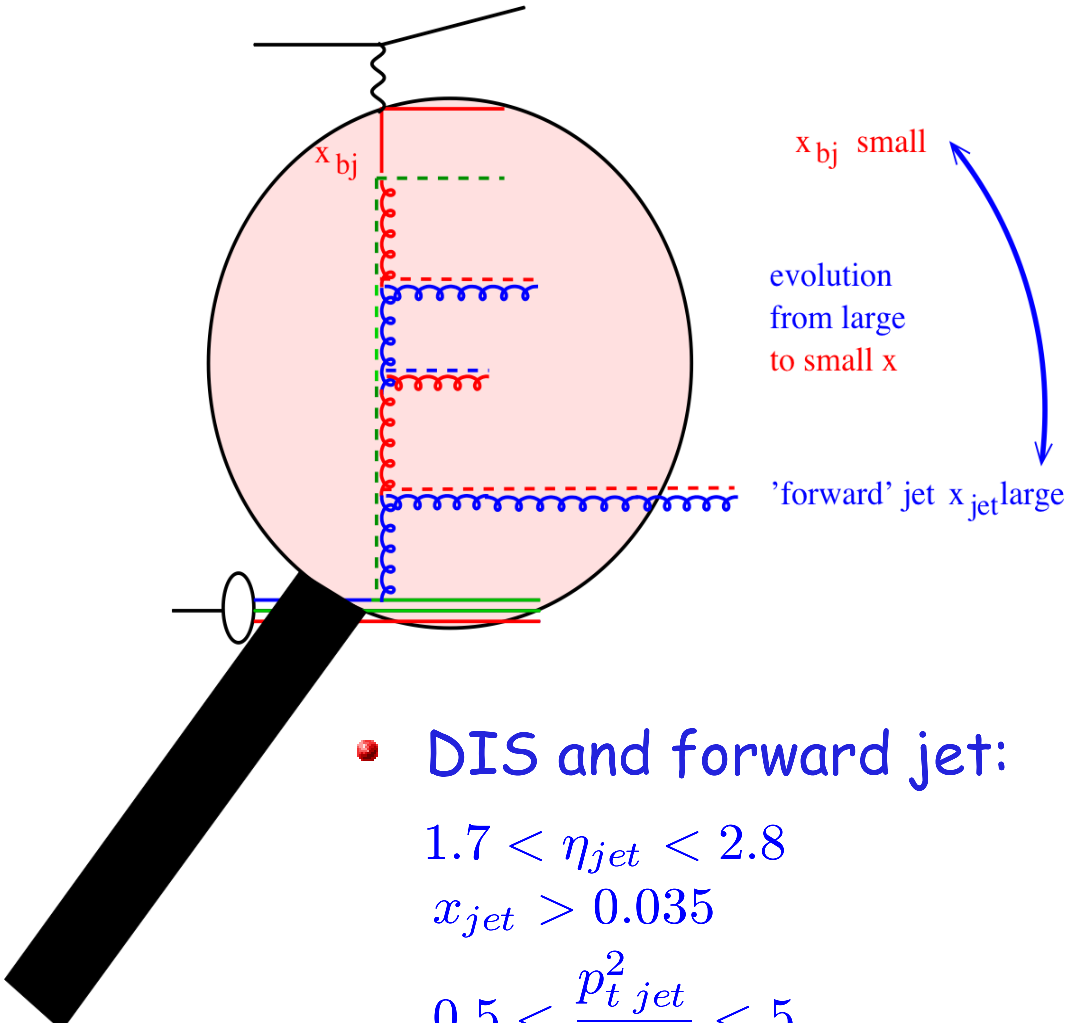


➔ Hmmmmm,
not really very good !!!!!

Looking forward ...



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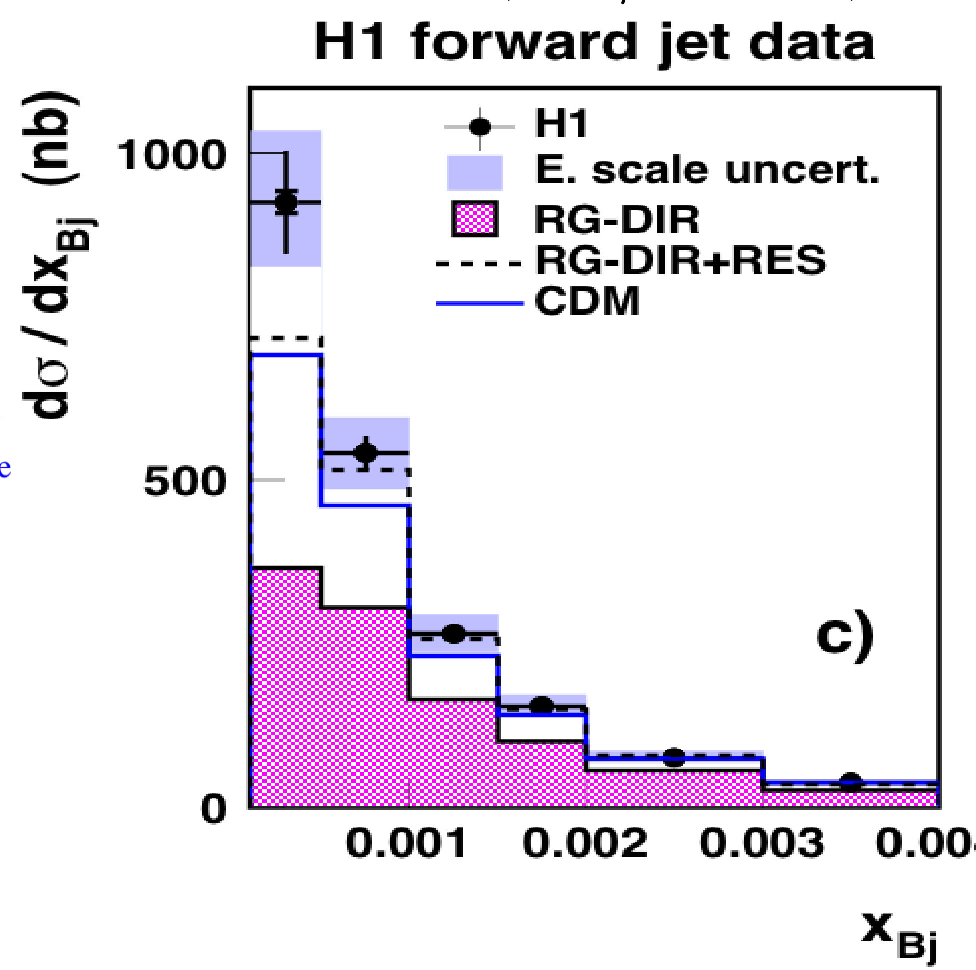

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➔ CDM (ARIADNE) pretty good ....

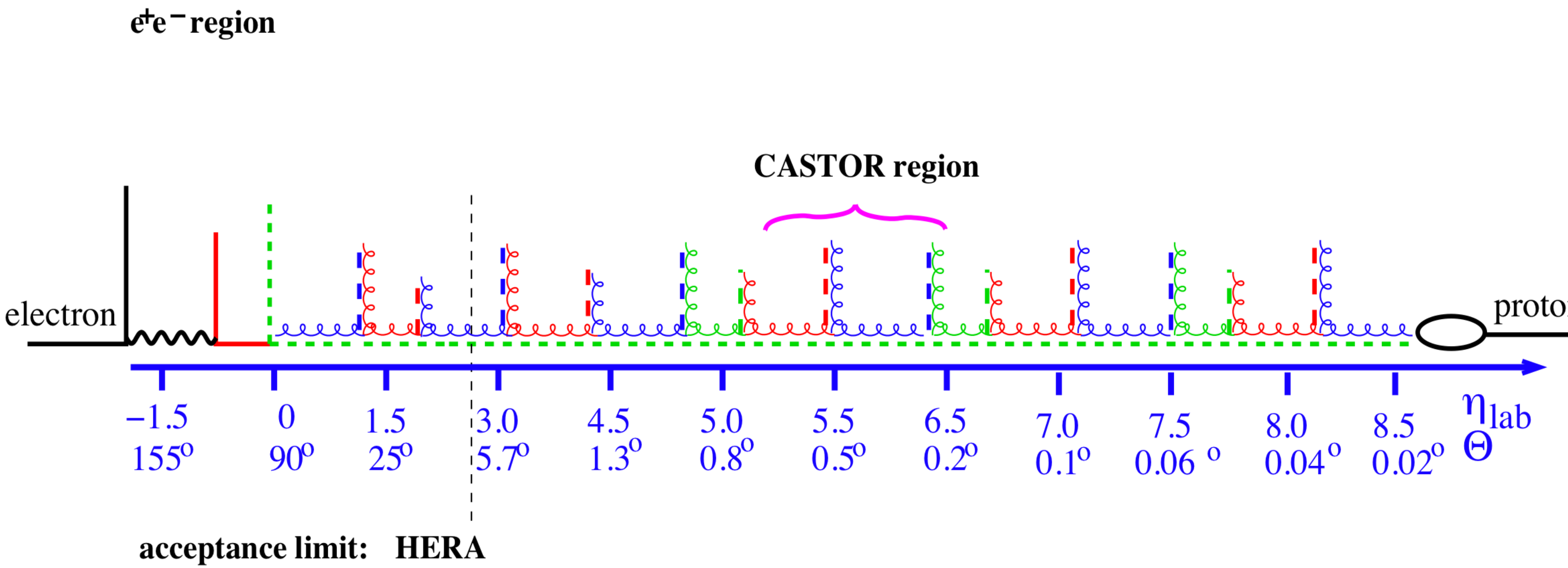
what did we learn ...

- inclusive DIS xsection well described by NLO DGLAP
  - xsection rises strongly for small x
  - large gluon/sea quark densities
  - ➔ is linear evolution enough ?
  - ➔ saturation effects ?
- understanding parton evolution at high energies still challenging:
  - hdronic final state not really understood
  - kt distribution, delta phi
  - forward jet production

➔ best description still by CDM (ARIADNE) although effects from extended dipoles...

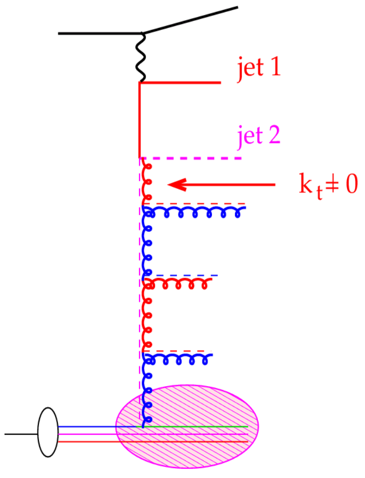
➔ best theory .. (CCFM) still lacking good description.....!!!!

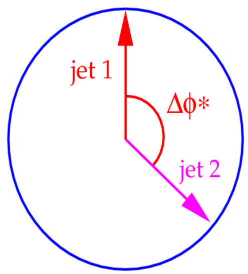
How to make progress ?



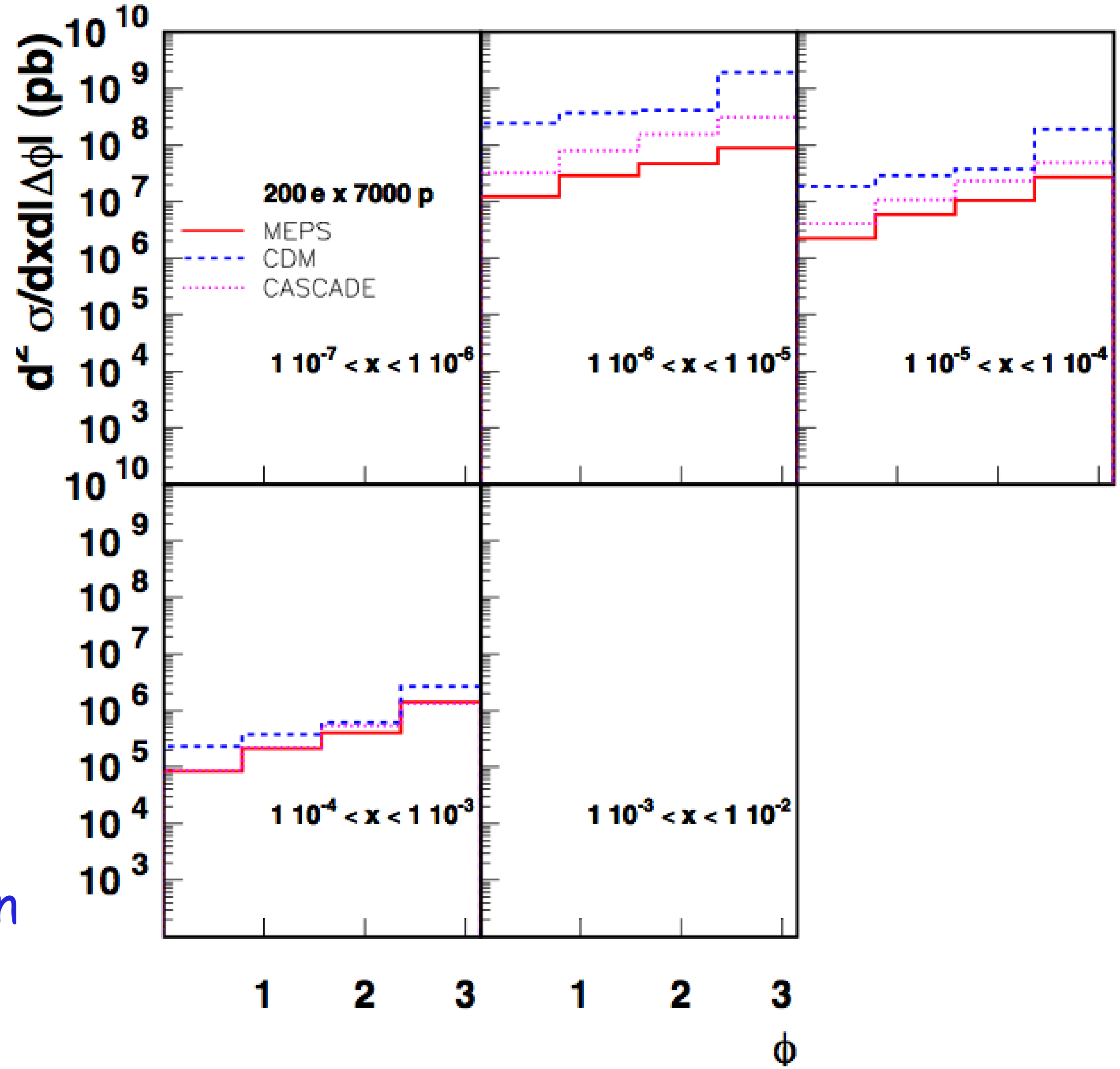
- measure jets in central region
- measure jets in forward region ($\eta > 3$).... extend HERA
- measure jets in very forward region ($\eta > 5$)
  - cover at least same range as CMS... (CASTOR)
  - go even more forward to proton fragmentation region

di-jets: at large energies

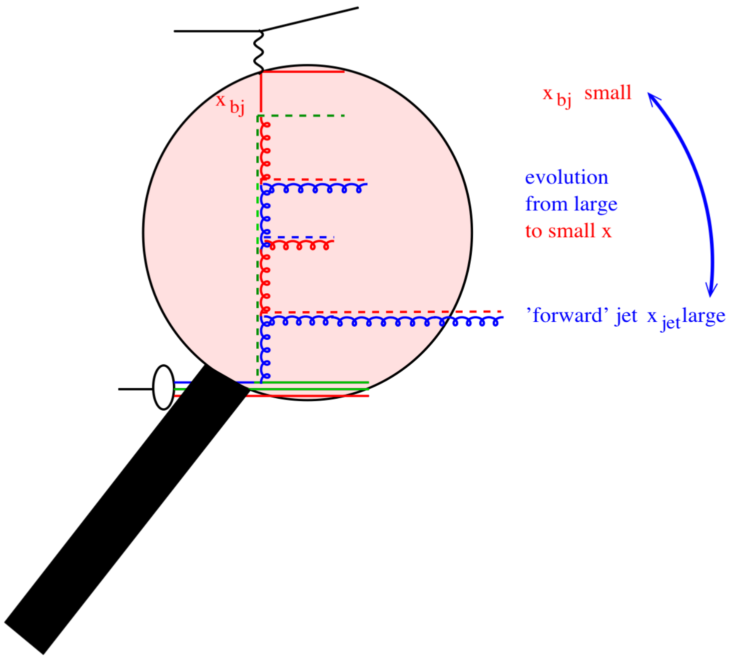




- $$5 < Q^2 < 100 \text{ GeV}^2$$
  $$-1 < \eta < 2.5$$
  $$E_T > 5 \text{ GeV}$$
- small $k_t \rightarrow \Delta\phi \sim 180$
- large k_t from evolution



Forward jets at LHeC



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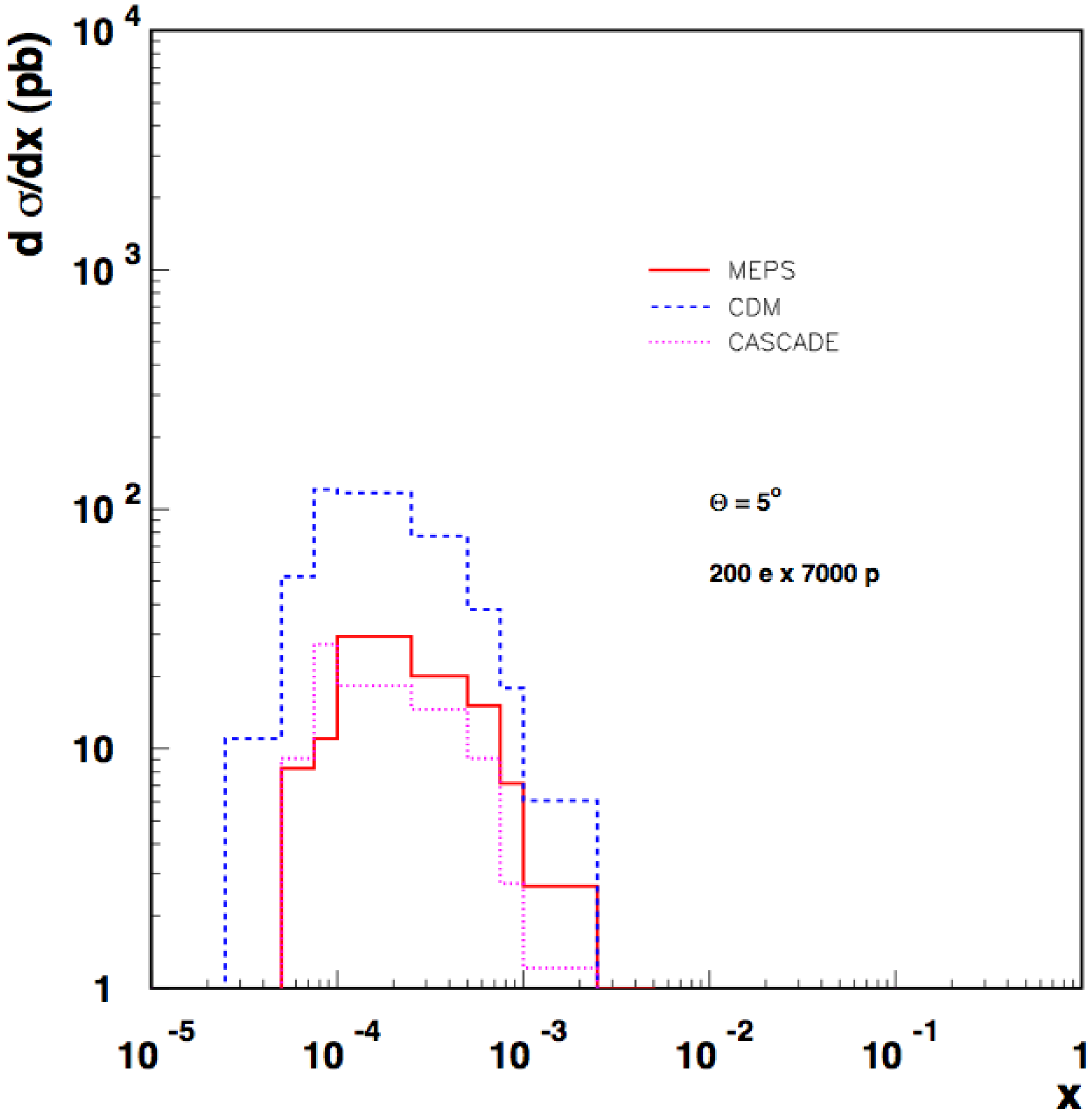
$x_{jet} > 0.03$

$0.5 < \frac{p_{t\ jet}^2}{Q^2} < 2$



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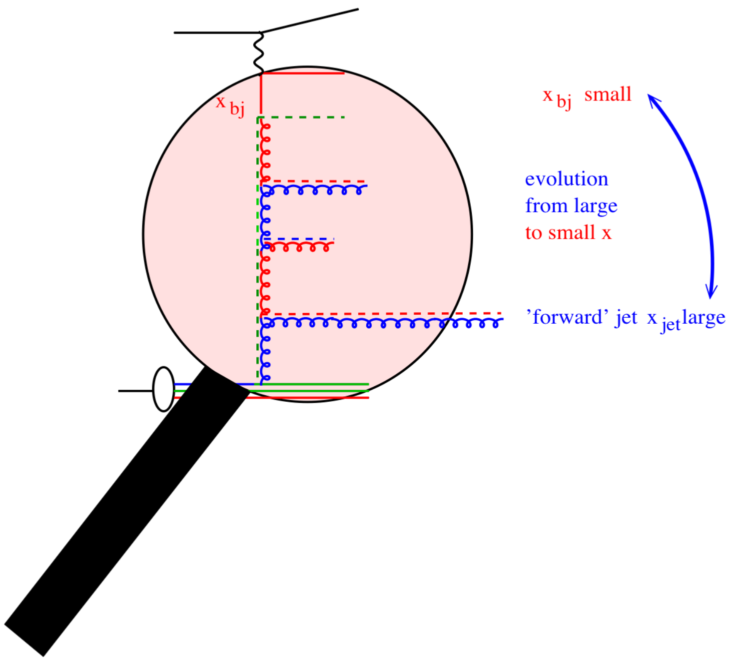

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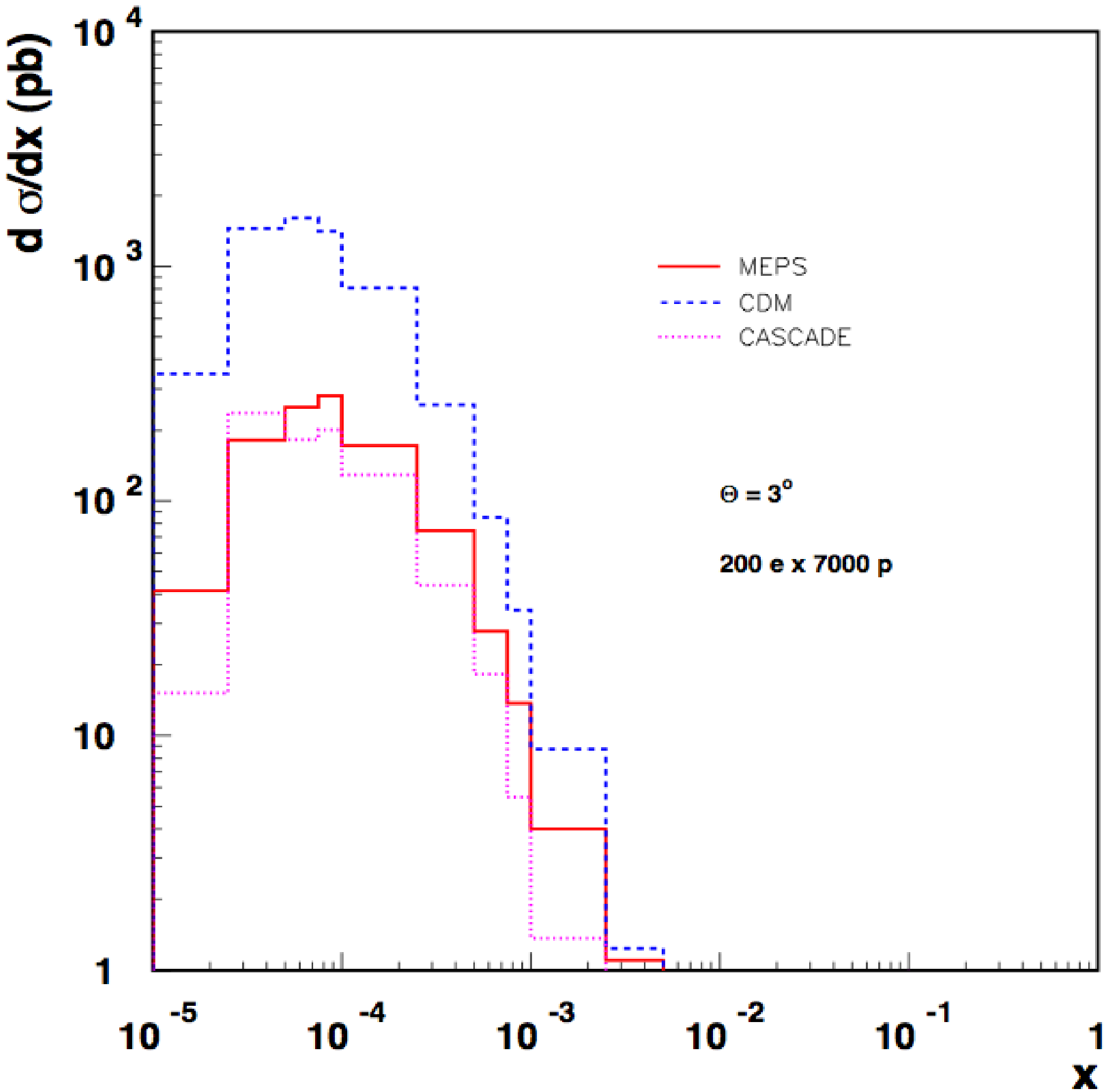

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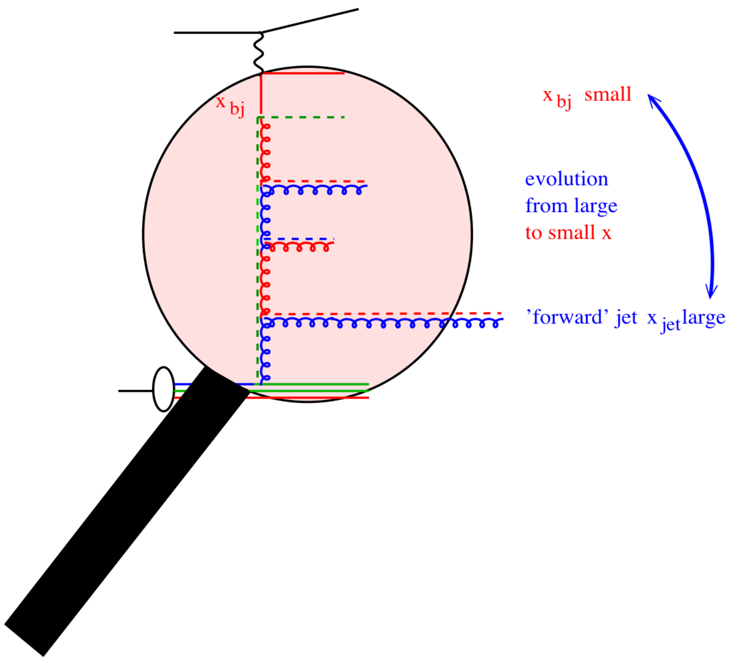

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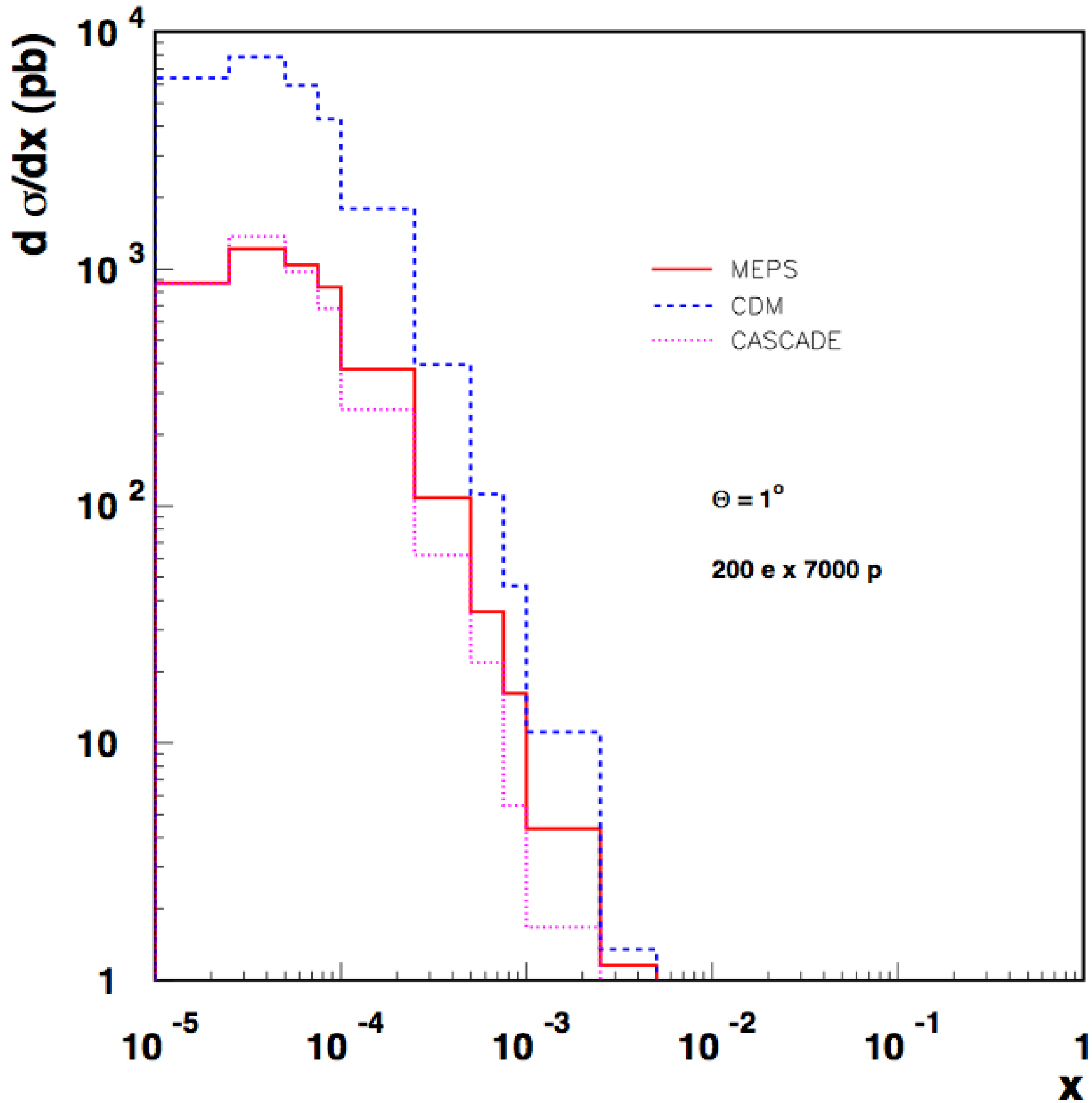

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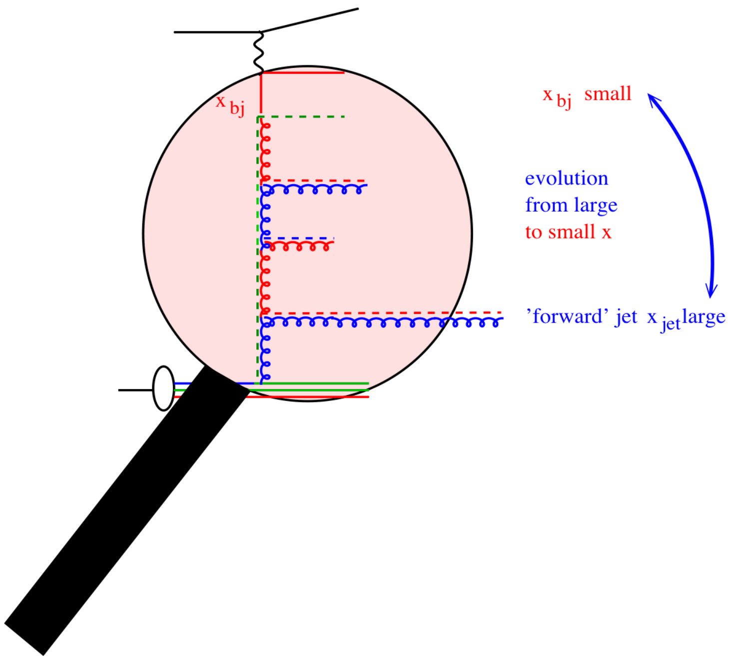

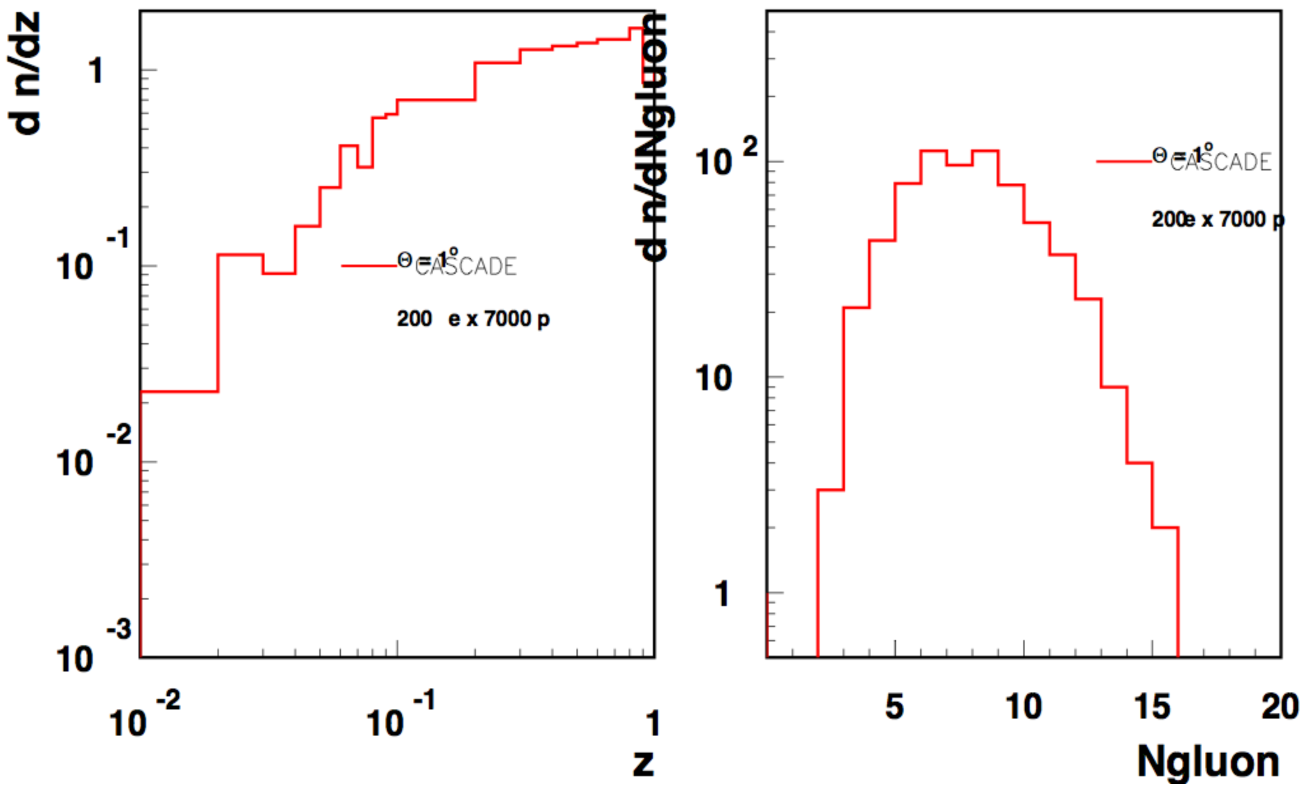

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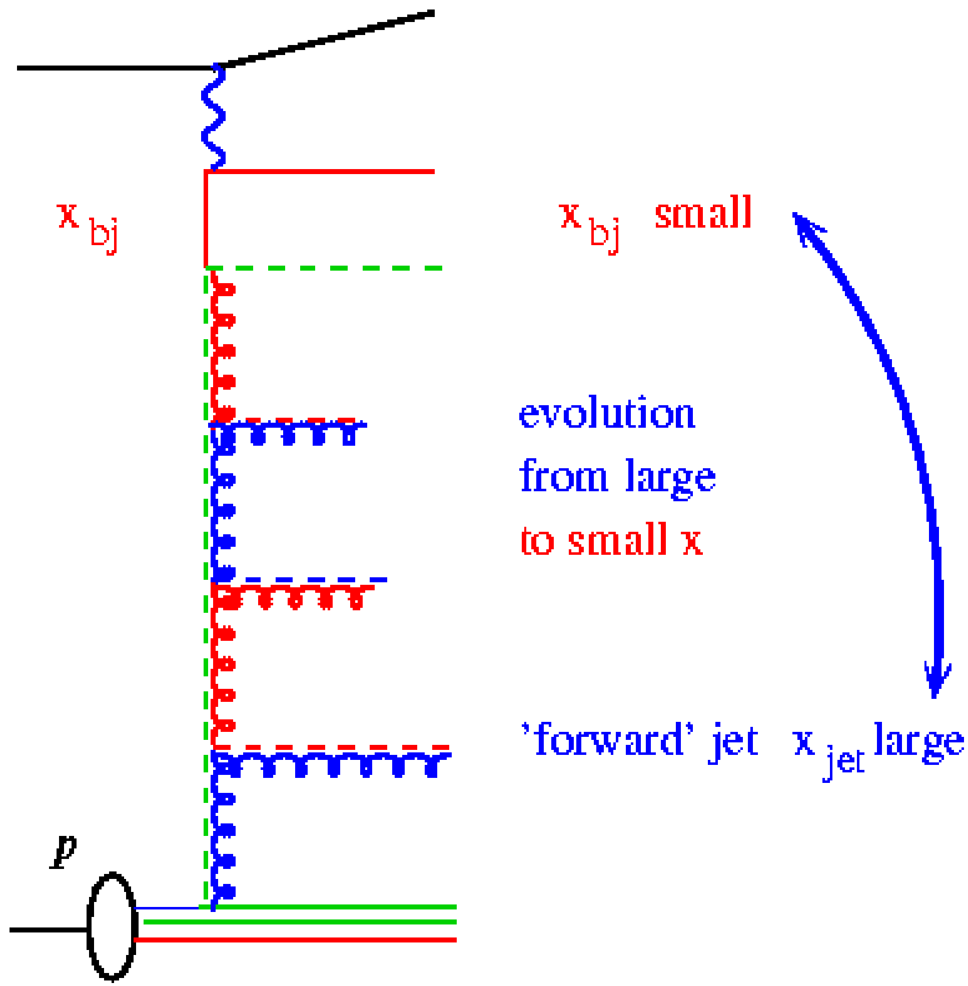
- consider all gluons in MCgenerator (pt > 1 GeV)

- z values in splitting fct are still far from asymptotic region
- large number of gluon radiation...

forward jet production and rap-gaps



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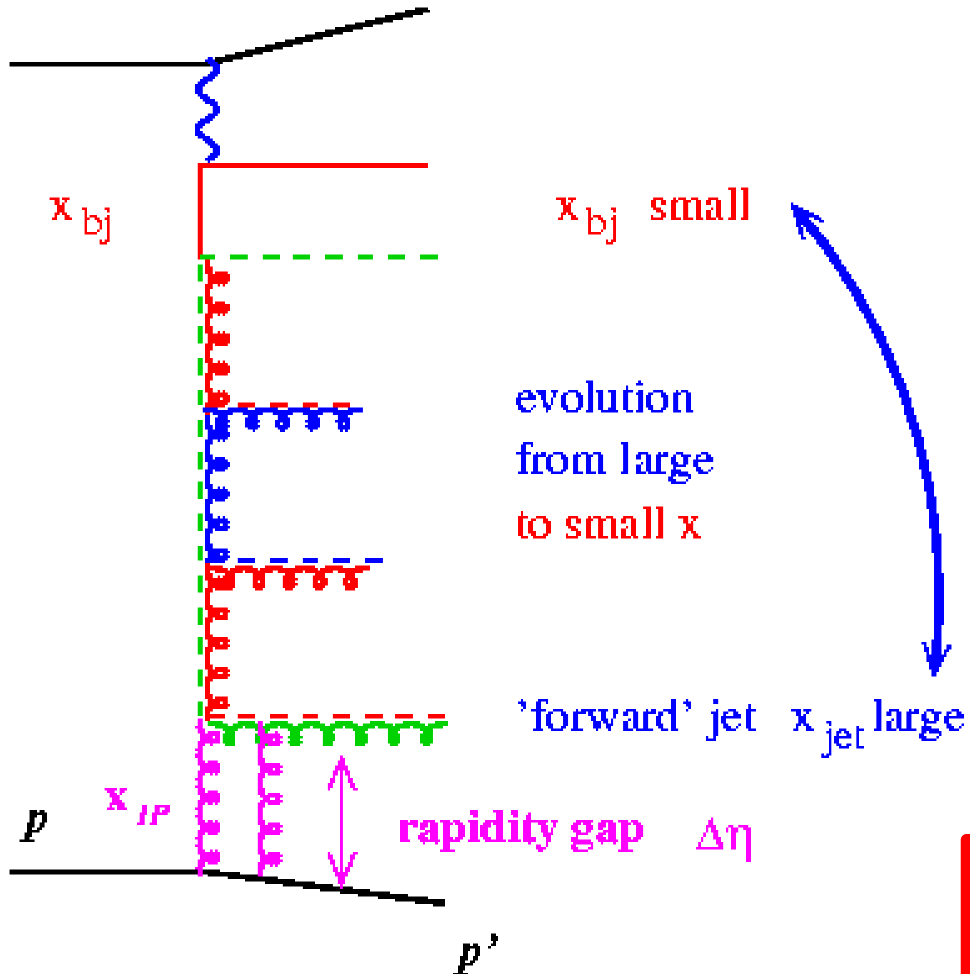

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$$0.5 < \frac{p^2_{t\ jet}}{Q^2} < 2$$

$$\sigma(\text{fwd jet})/\sigma(\text{DIS}) \sim 1\%$$

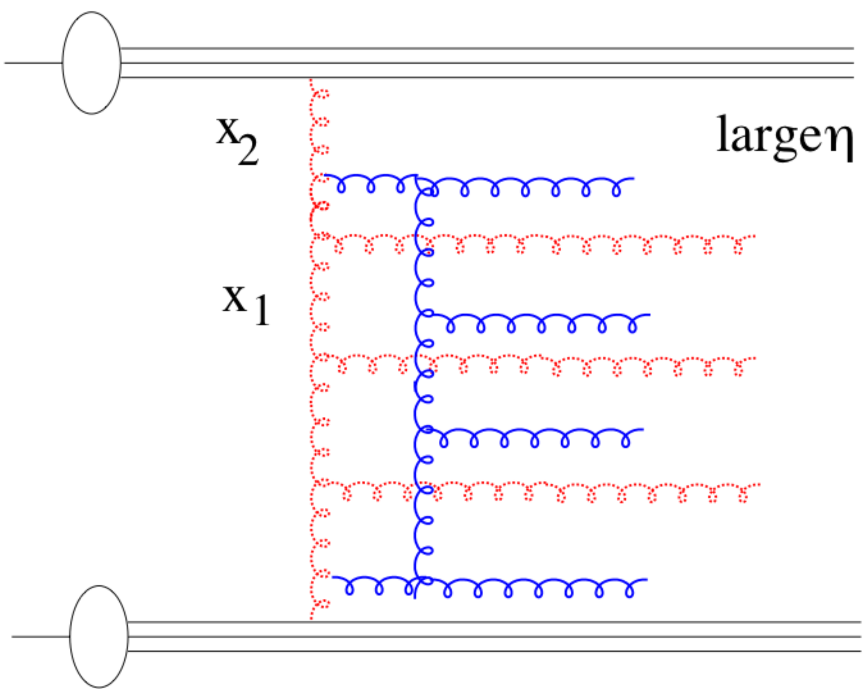
- in diffraction: forward jet close to rapidity gap

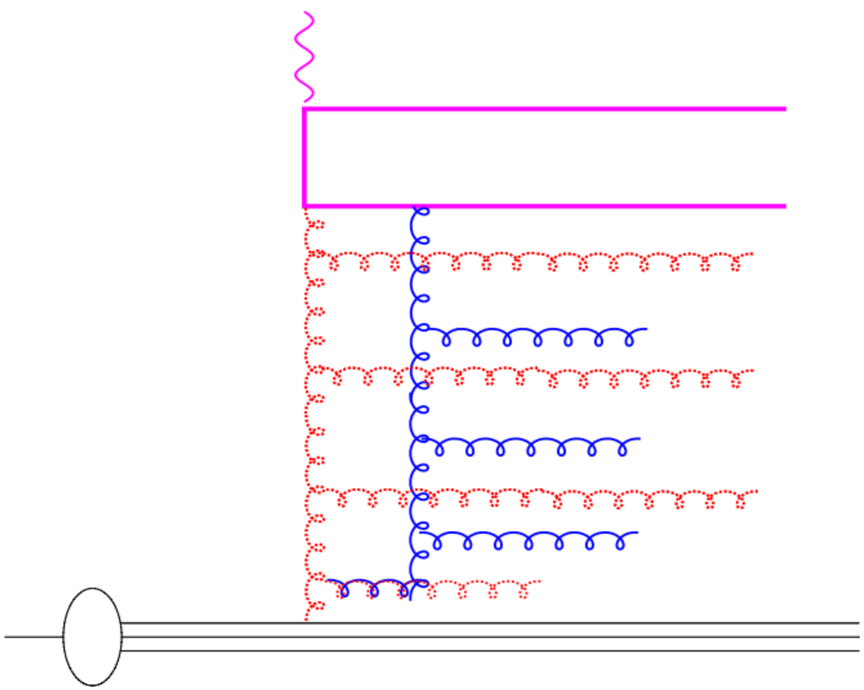
$$\sigma(\text{diff dijet})/\sigma(\text{DIS}) \sim 1\%$$

- understand radiation close to proton and radiation close to rapidity

LHC-pp and LHC-ep

- compare measurements with LHC - pp results
  - one proton side is identical
  - test factorisation and parton evolution
  - multi-parton interaction/saturation/diffraction





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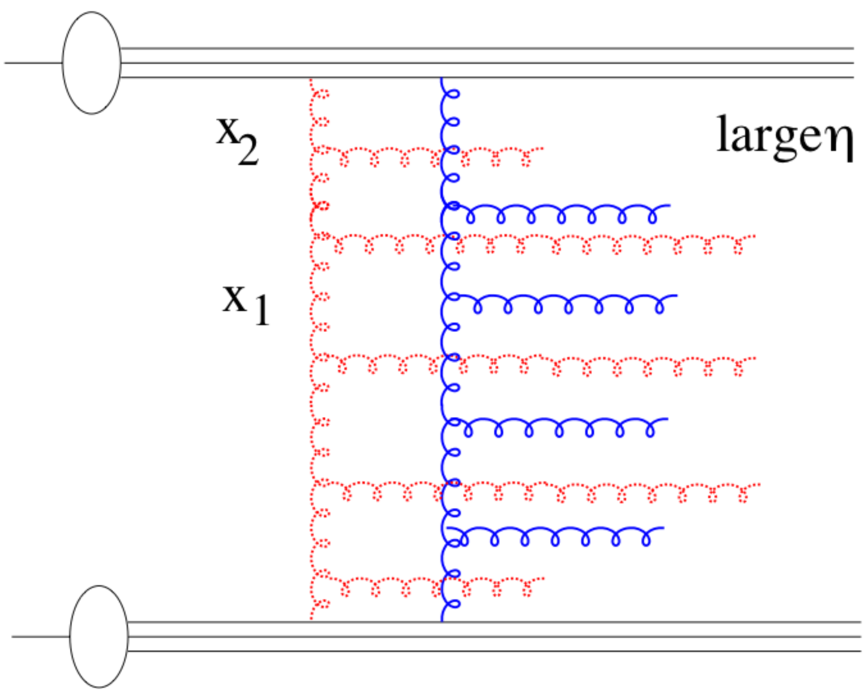
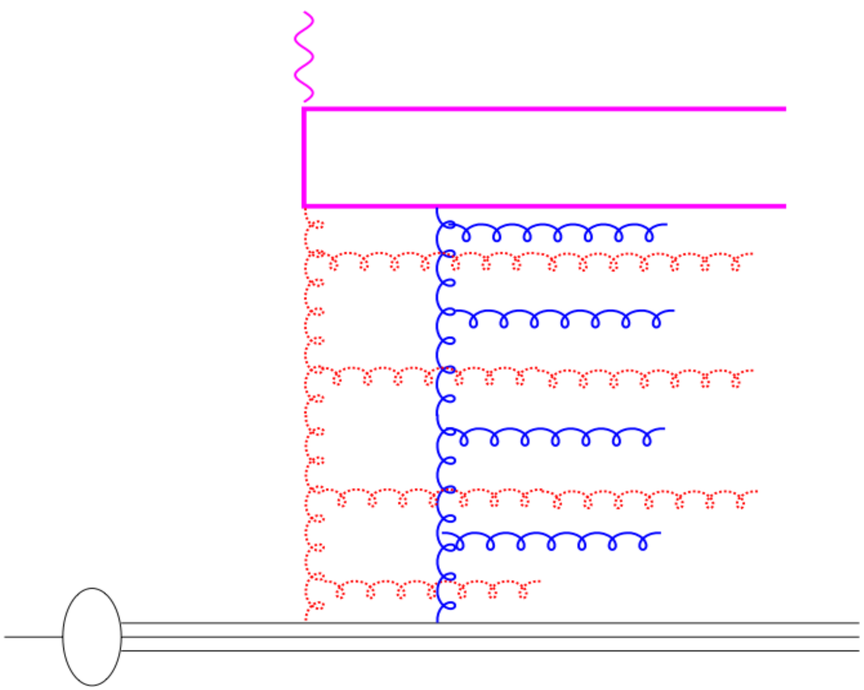
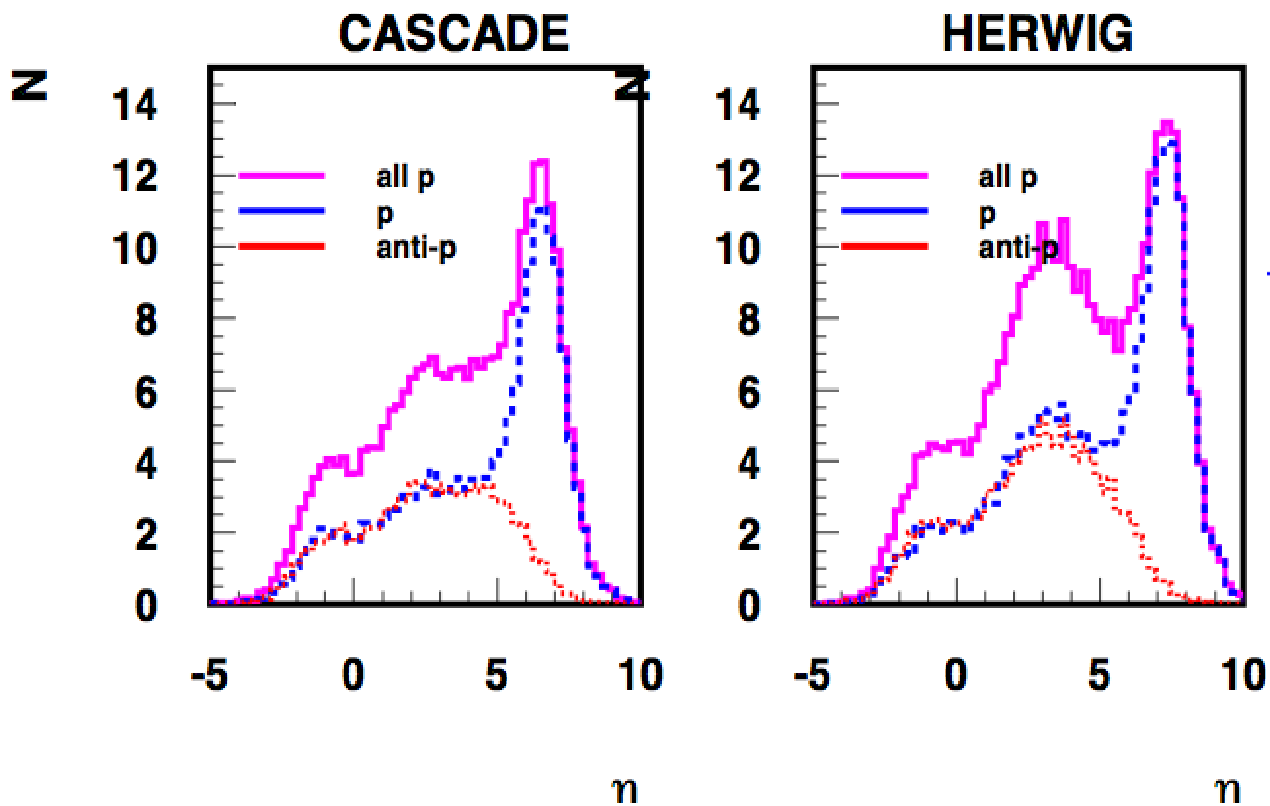
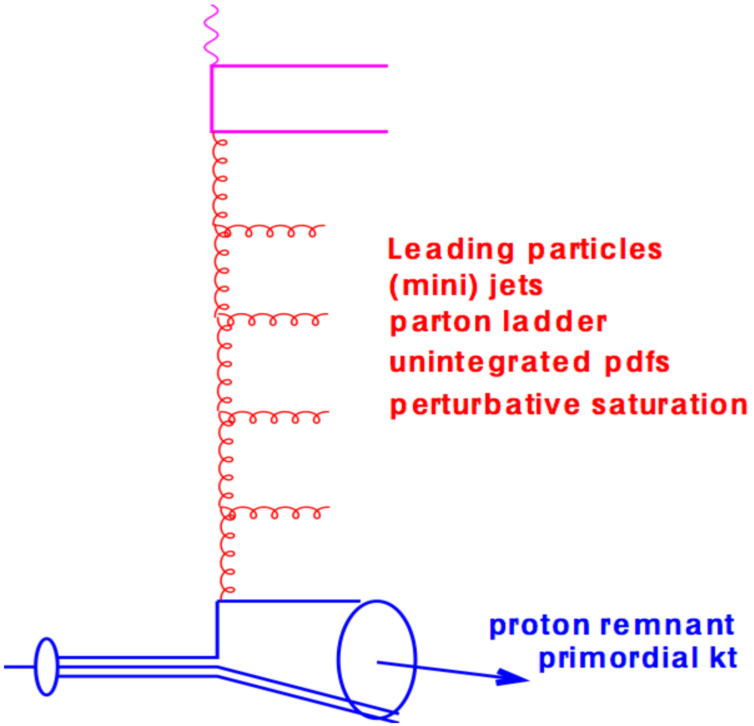




Universality of fragmentation: ep vrs pp

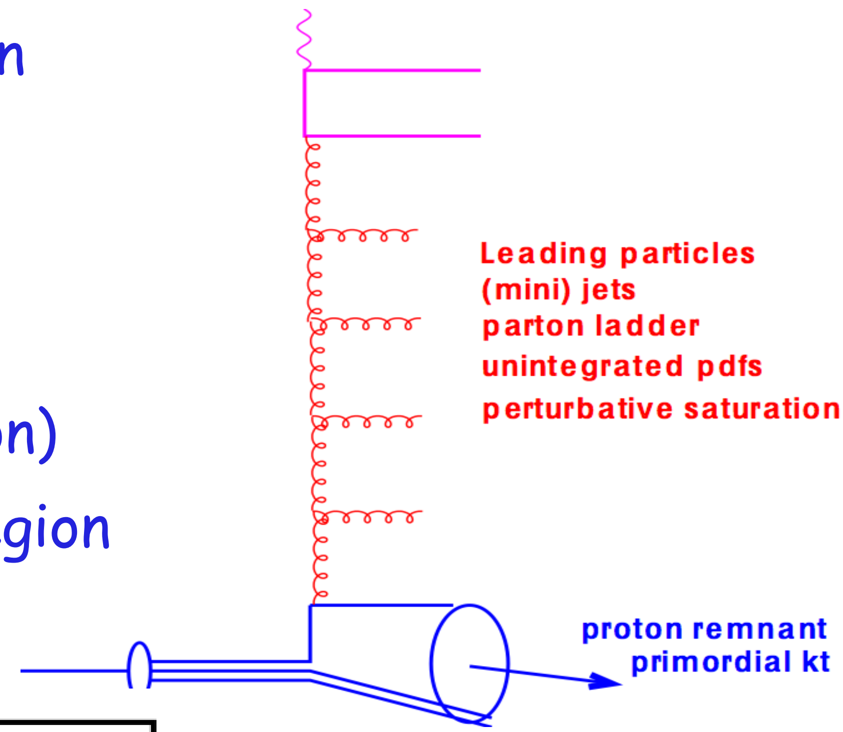
- leading particles in parton cascade ... universality of hadronization
-

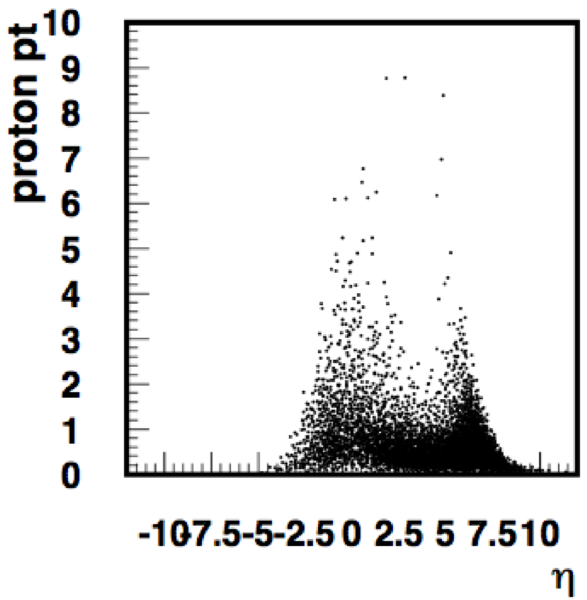


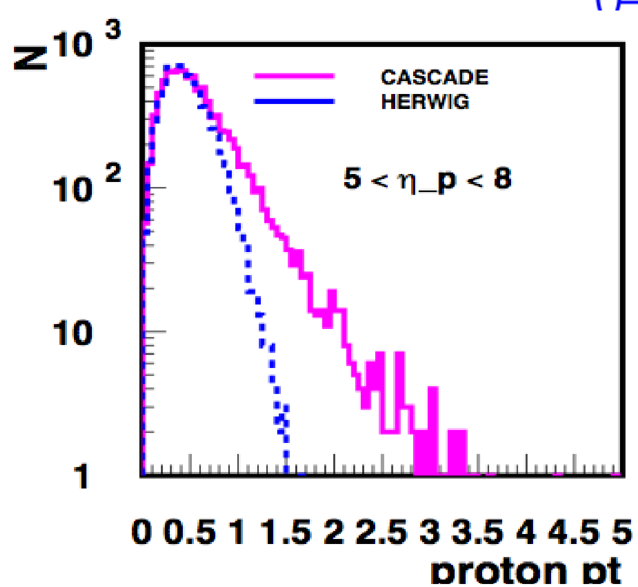


Universality of proton fragmentation region

- measuring toward proton fragmentation region
- investigate intrinsic kt – saturation effect ?
- measure leading baryon (proton/neutron) production close to p-fragmentation region



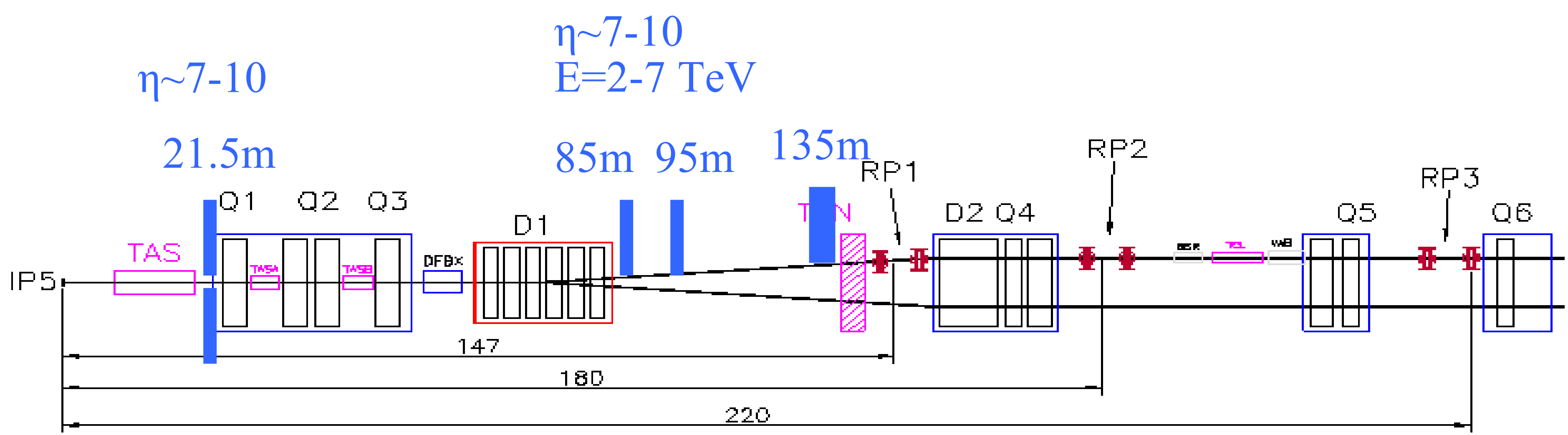




Going even more forward ...

- study on forward coverage for CMS done ...

  by V. Andreev. K. Borras, A. Bunyatian, H. Jung, M.Kapishin, L. Lytkine



- need improved studies.... with better performance and coverage
- will be one of the important issues....

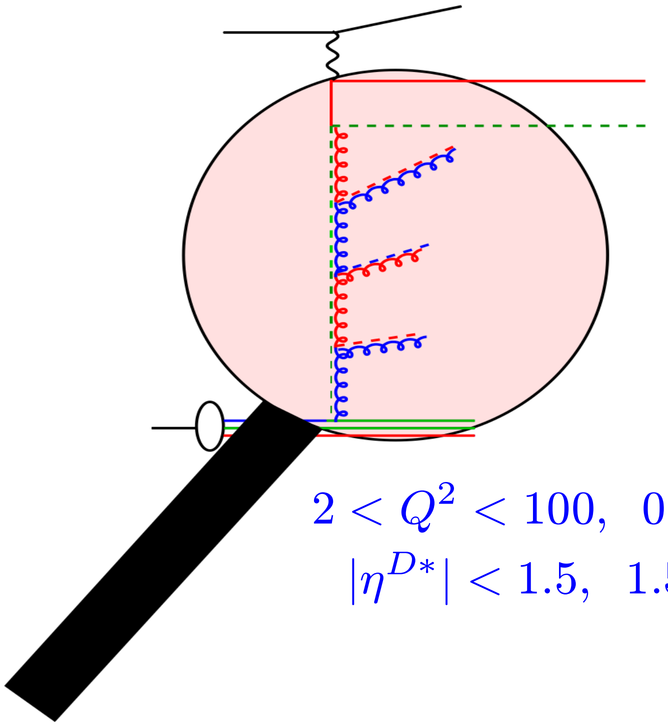
Conclusions

- HERA has left us with many questions in small x
  - small x evolution:
    - dijet production: correlations are tricky to describe
    - which approach can describe consistently fwd jets
    - fwd hadron production ?
    - rise of parton densities and saturation ?
- LHeC offers possibilty to investigate these effects
  - need good central detectors
  - need good forward coverage
  - small x effects are visible ...
  - need to be comparable to LHC-pp detectors for direct comparison
- Still..... LHeC might be not really in the asymptotic region.....

BACKUP SLIDES

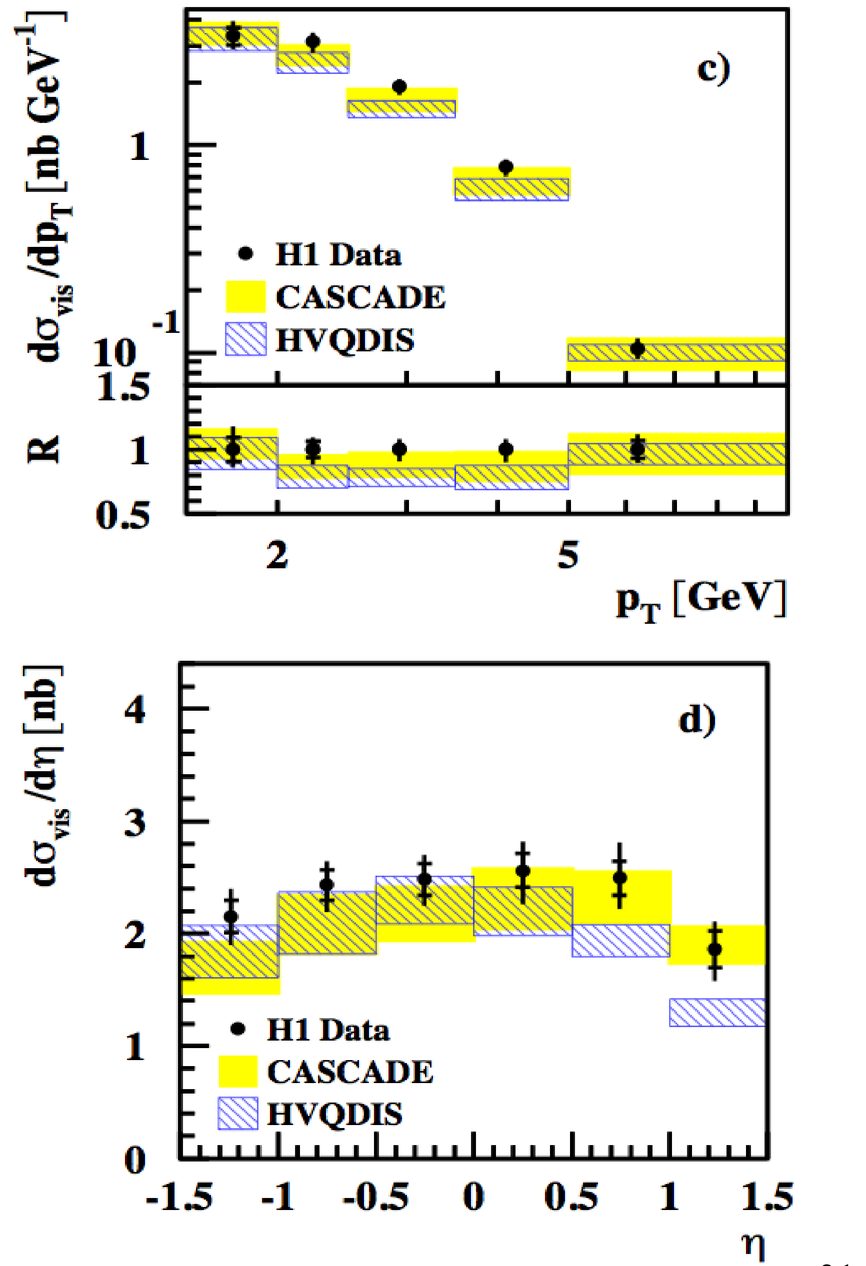
Walking down the ladder ...

- D* production in DIS

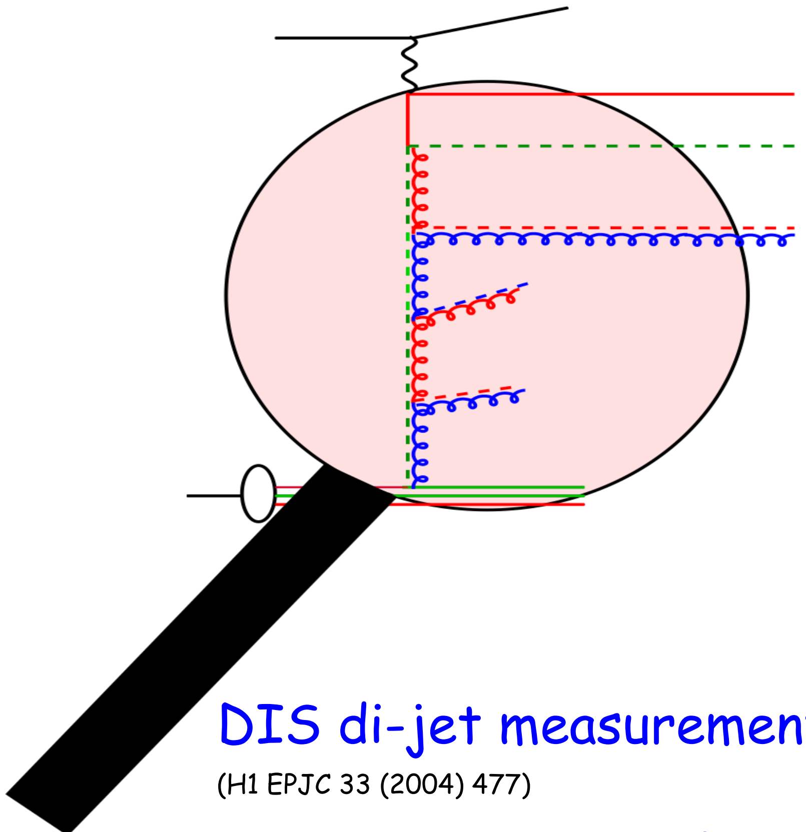


$$2 < Q^2 < 100, \;\; 0.05 < y < 0.7$$
$$|\eta^{D*}| < 1.5, \;\; 1.5 < p_T^{D*} < 15$$

- good description of inclusive D* production by NLO (HVQDIS) but also using kt-factorization and uPDFs (CASCADE) .....



Walking further down the ladder

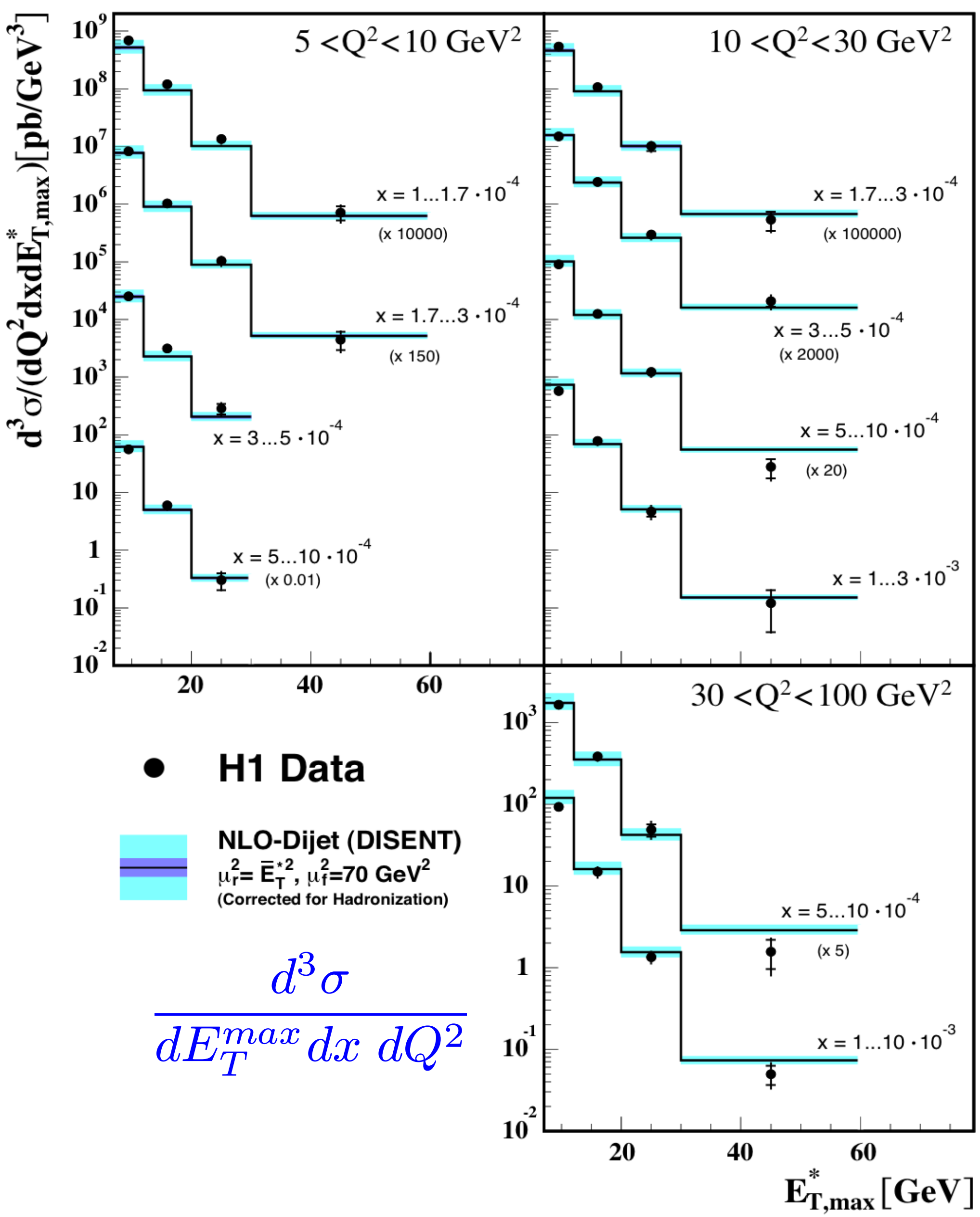


DIS di-jet measurements

(H1 EPJC 33 (2004) 477)

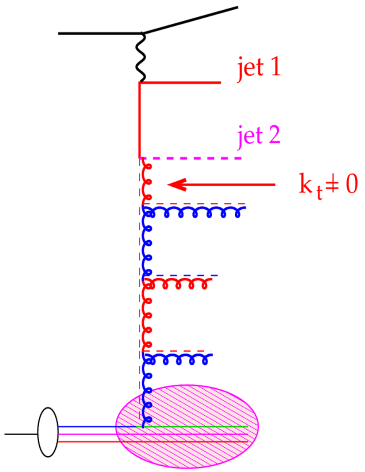
$$5 < Q^2 < 100 \text{ GeV}^2$$
$$-1 < \eta < 2.5$$
$$E_T > 5 \text{ GeV}$$

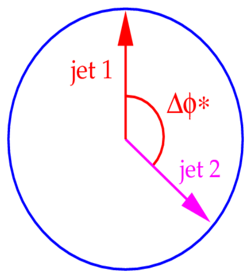
➔ calculation with at least 3 hard partons essential ...



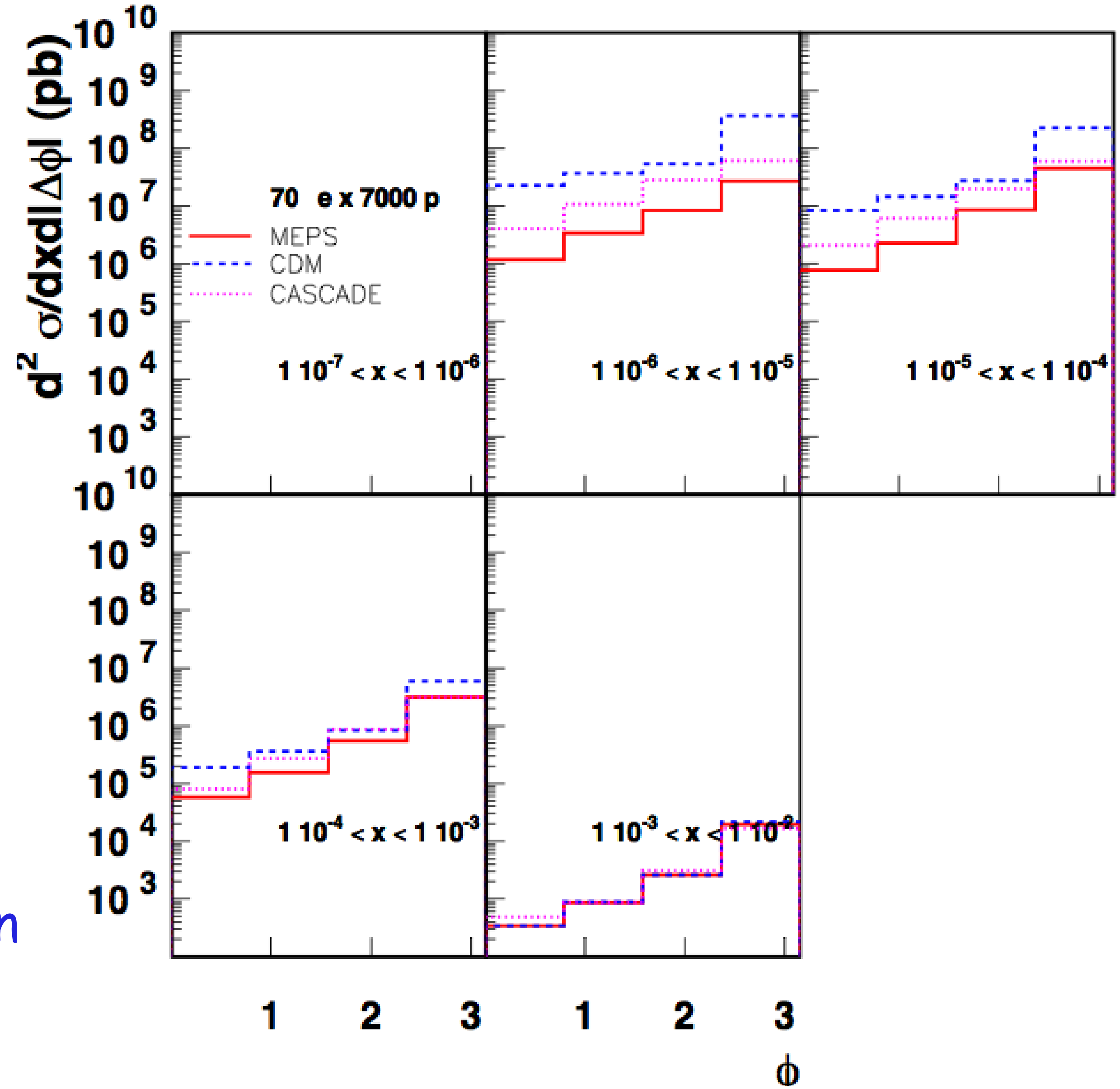
$$\frac{d^3\sigma}{dE_T^{max}\,dx\,dQ^2}$$

di-jets: at large energies





- $5 < Q^2 < 100 \text{ GeV}^2$
  $-1 < \eta < 2.5$
  $E_T > 5 \text{ GeV}$
- small k_t $\rightarrow \Delta\phi \sim 180$
- large k_t from evolution



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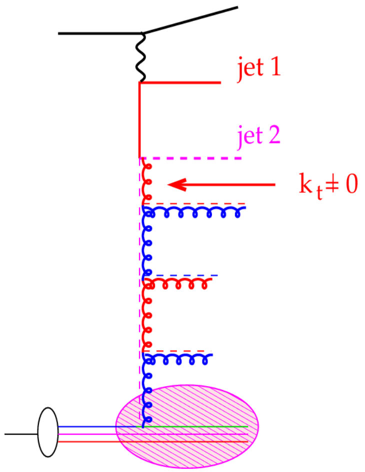

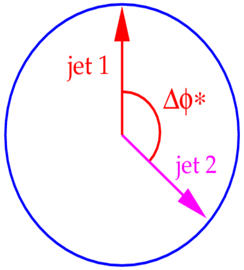

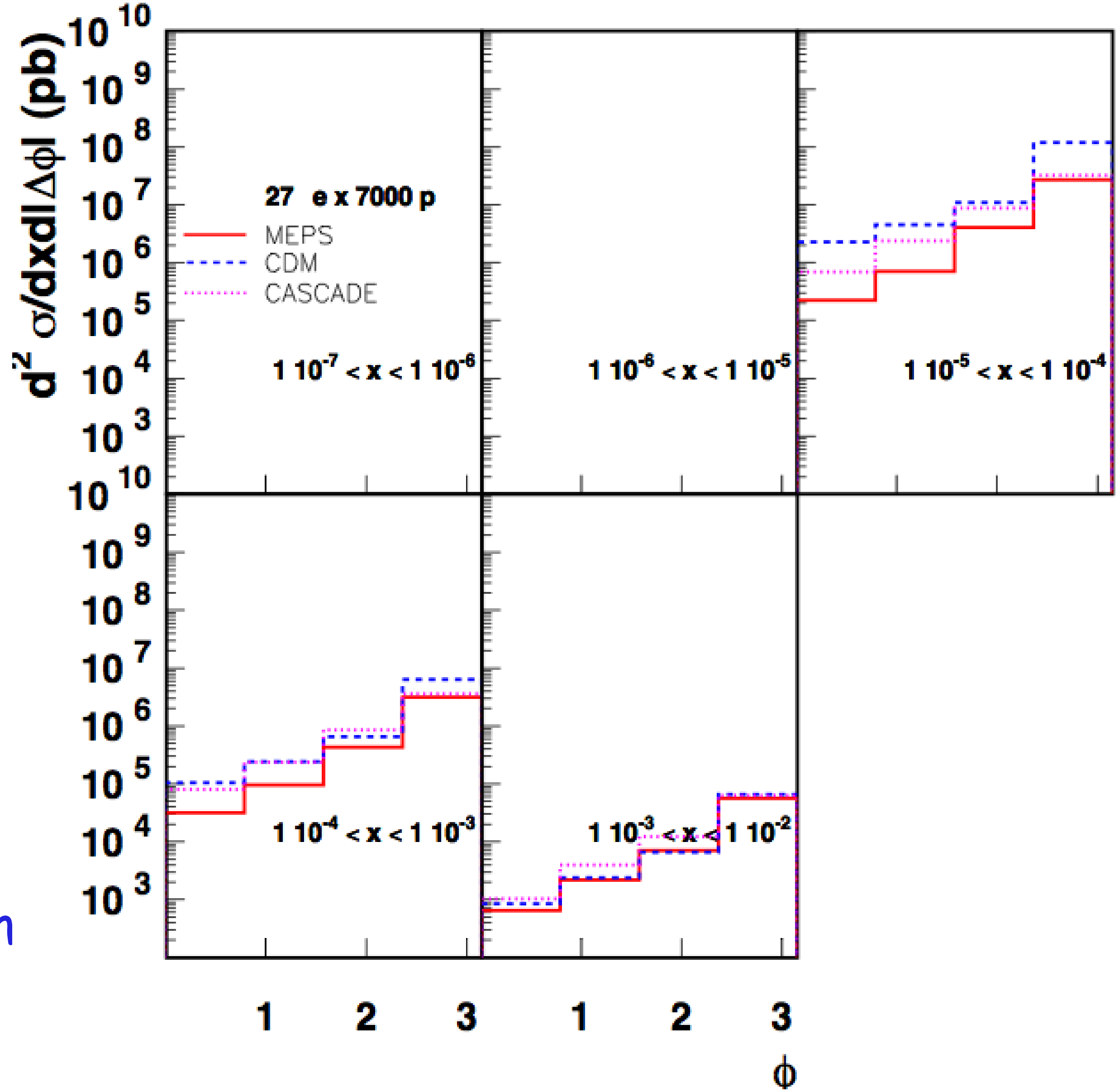

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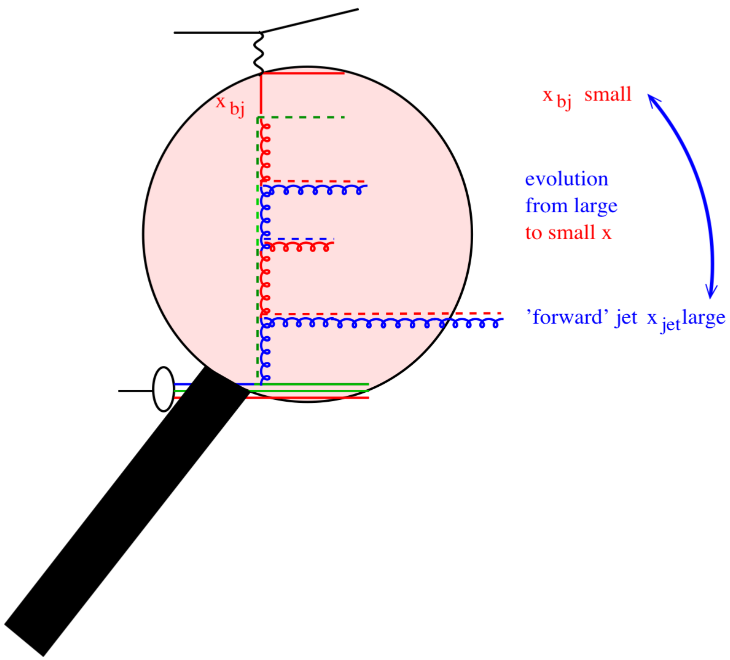
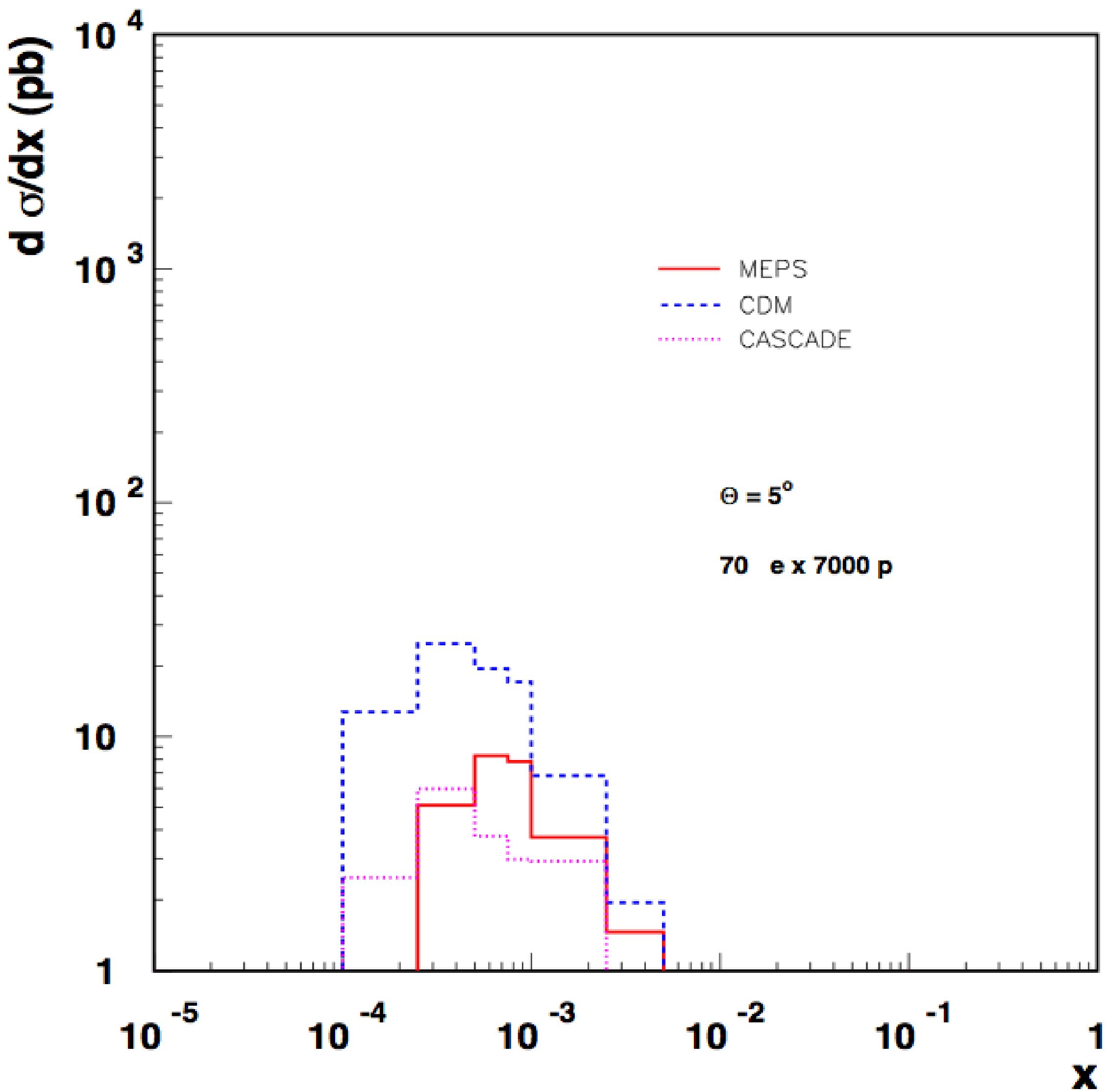
Forward jets at LHeC



- DIS and forward jet:

$$x_{jet} > 0.03$$

$$0.5 < \frac{p_{t\ jet}^2}{Q^2} < 2$$



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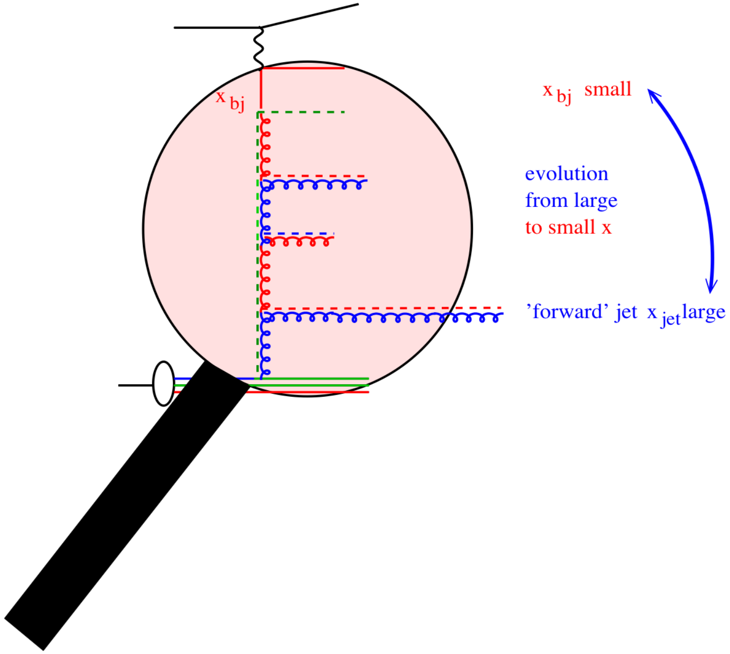

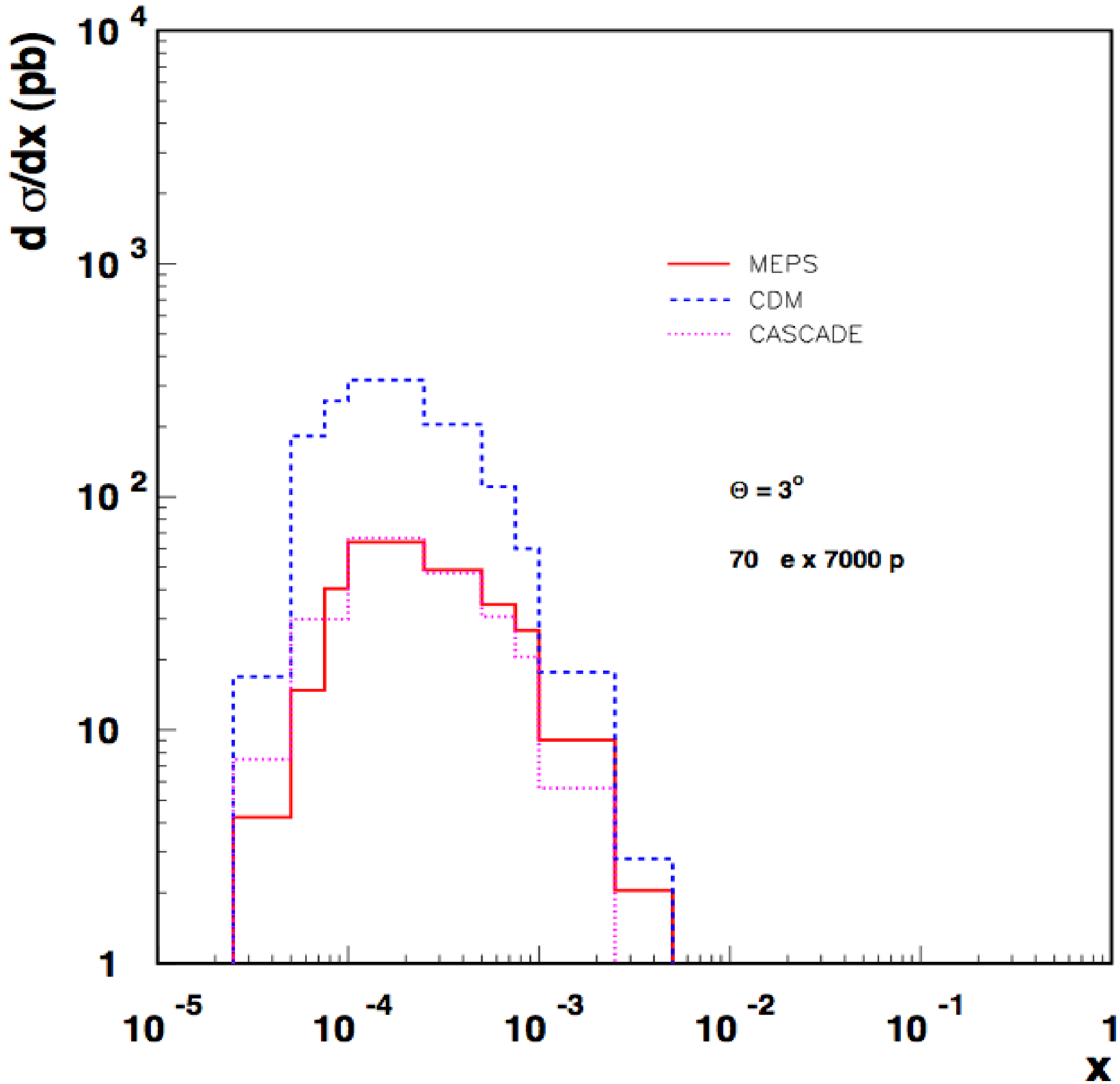

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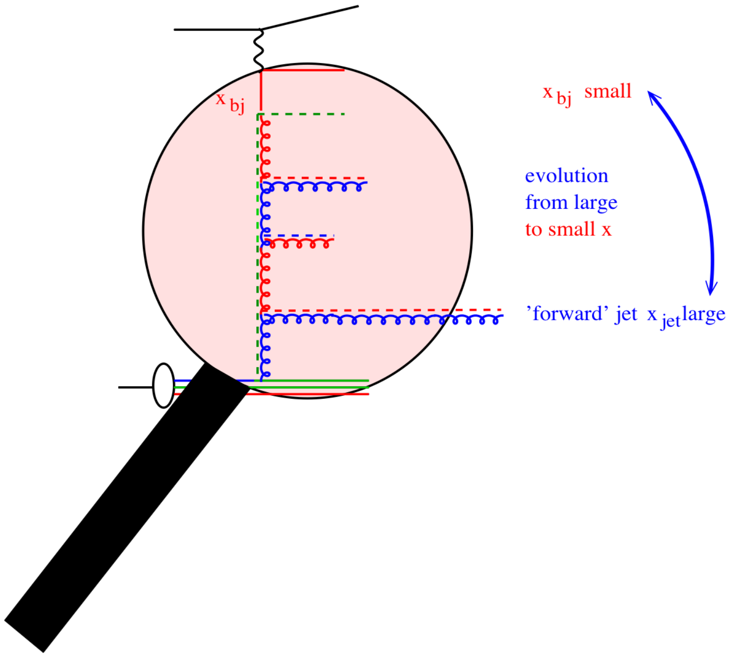

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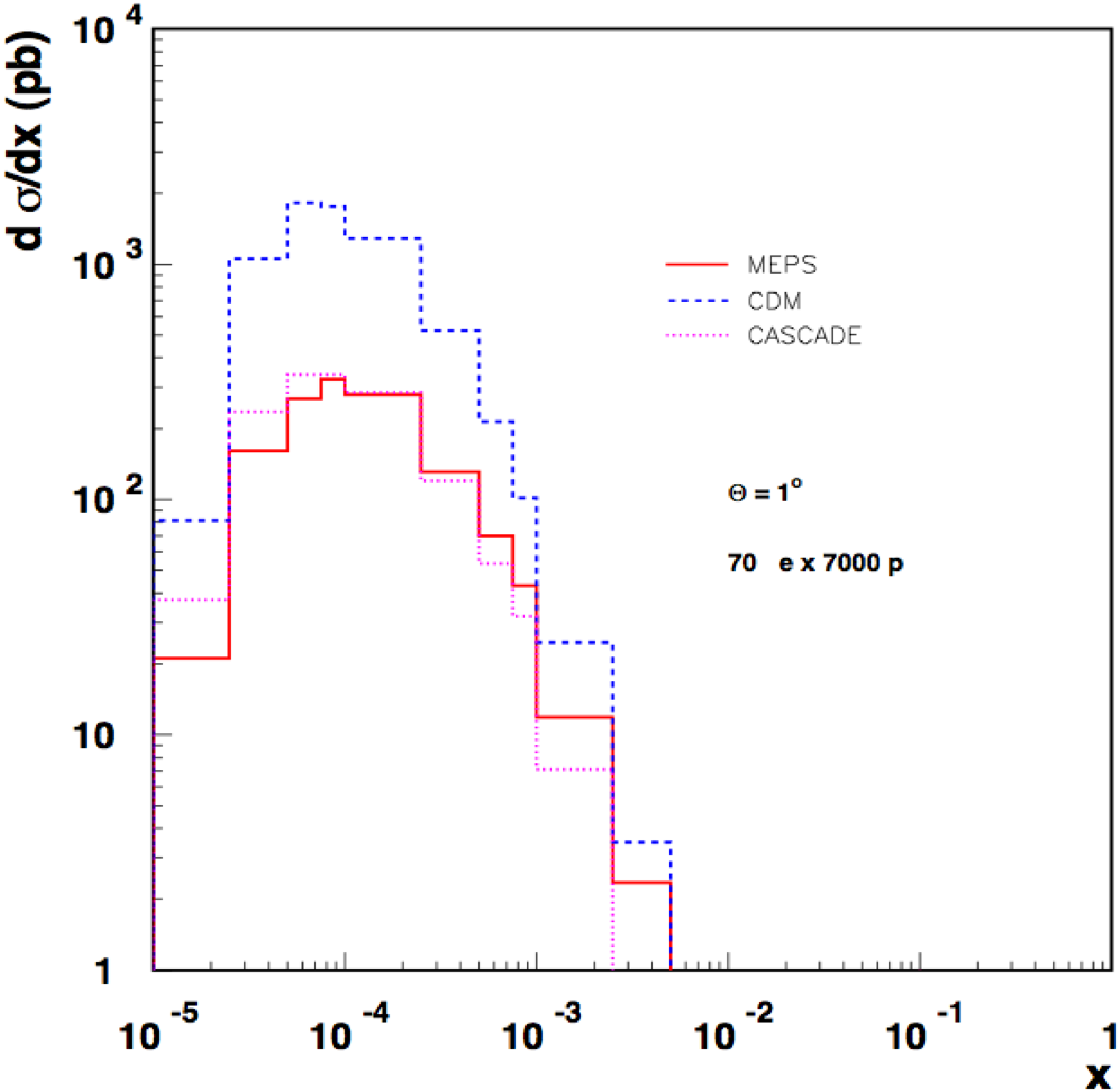

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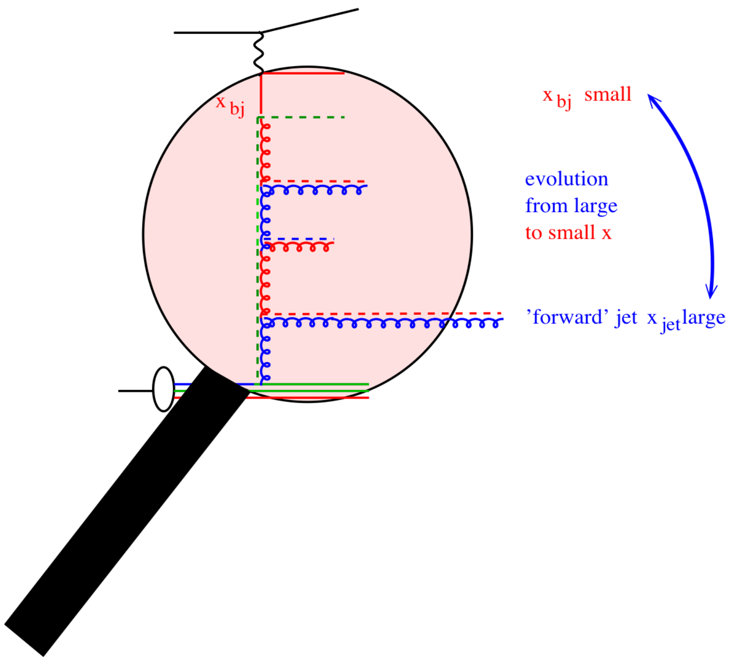

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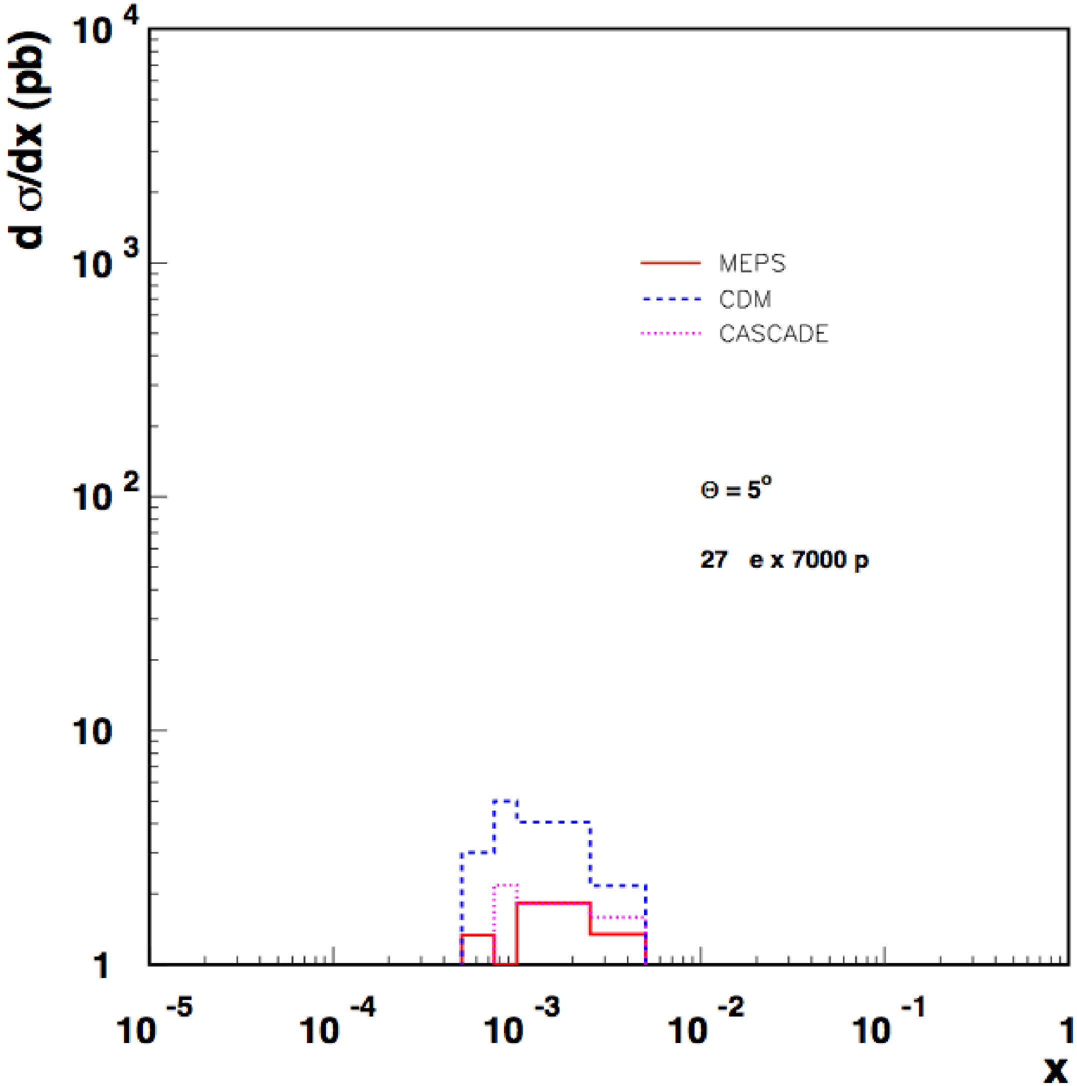

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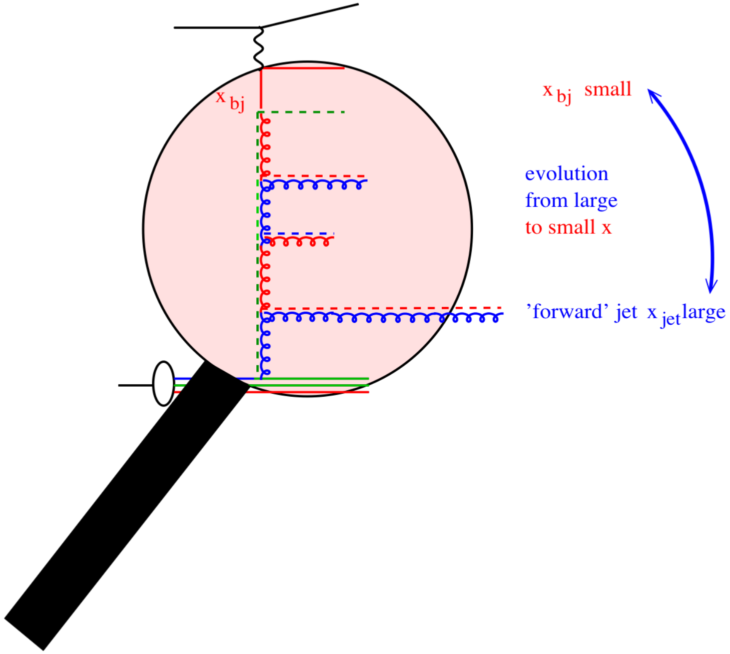

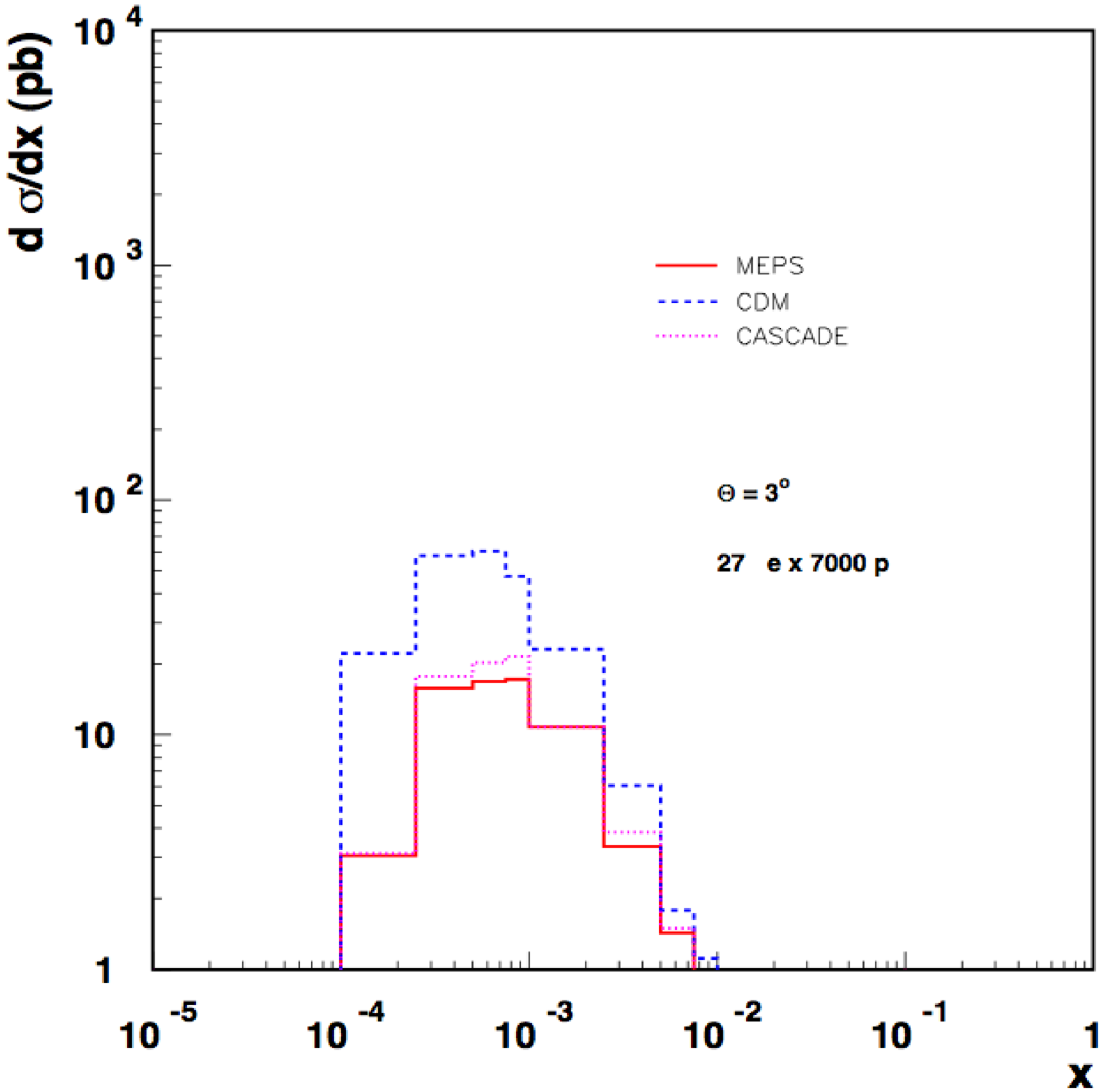

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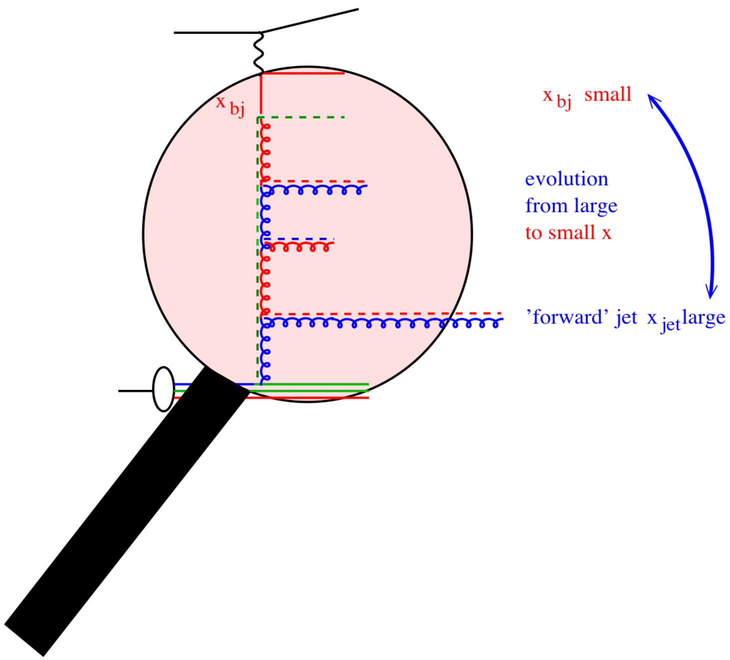

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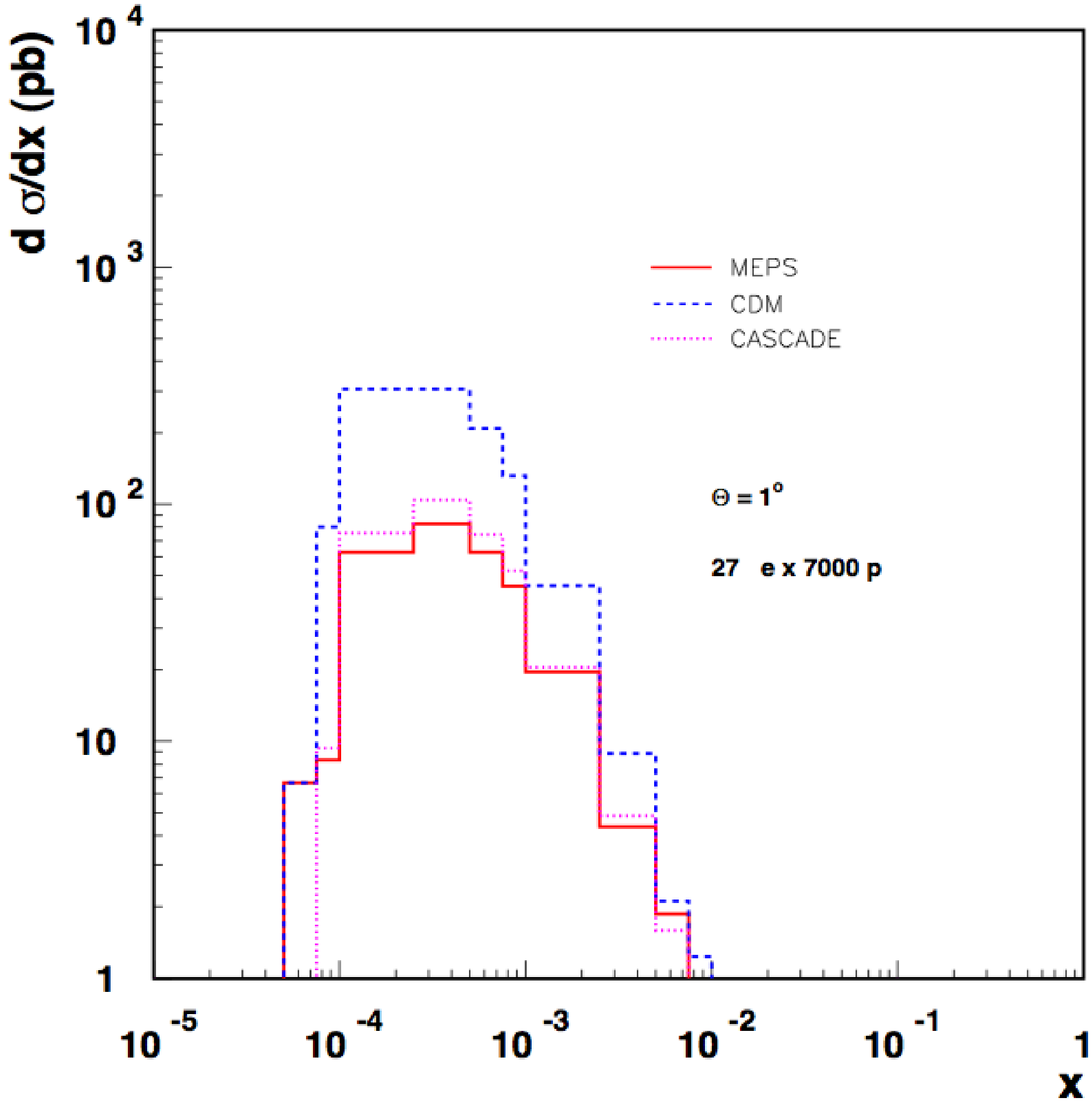

Evolution of uPDFs and x-section

- unintegrated PDFs (**uPDFs**): keep full k_t dependence during perturbative evolution
  - ➔ using **D**okshitzer**G**ribov**L**ipatov**A**ltarelli**P**arisi, **B**alitski**F**adin**K**uraev**L**ipatov or **C**iafaloni**C**atani**F**iorani**M**archesini /**L**iinked**D**ipole**C**hain evolution equations
  - ➔ **CCFM/LDC** treats explicitly real gluon emissions
    - ➔ according to color coherence ... angular ordering
    - ➔ angular ordering includes **DGLAP** and **BFKL** as limits...
- cross section (in k_t factorization) :

$$\frac{d\sigma^{jets}}{dE_T d\eta} = \sum \int \int \int dx_g \; dQ^2 d \ldots \left[dk_\perp^2 x_g \mathcal{A}_i(x_g, k_\perp^2, \bar{q})\right] \hat{\sigma}_i(x_g, k_\perp^2)$$

➔ can be reduced to the collinear limit:

$$\frac{d\sigma^{jets}}{dE_T d\eta} = \sum \int \int \int dx \; dQ^2 d \ldots x f_i(x, Q^2) \hat{\sigma}_i(x, Q^2, \ldots.)$$