

Towards precision determination of uPDFs

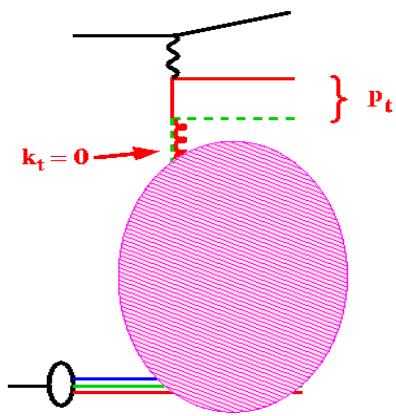
M. Hansson (Lund), H. Jung (DESY)

- Why unintegrated parton density functions (uPDFs) ?
- The parameters of the uPDFs
- State of the art:
 - uPDFs from inclusive measurements
 - **the problem**
 - uPDFs from hadronic final state measurements
- Conclusion

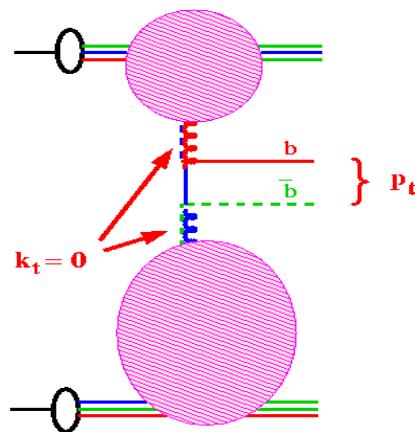
Need for uPDFs: transverse momenta

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

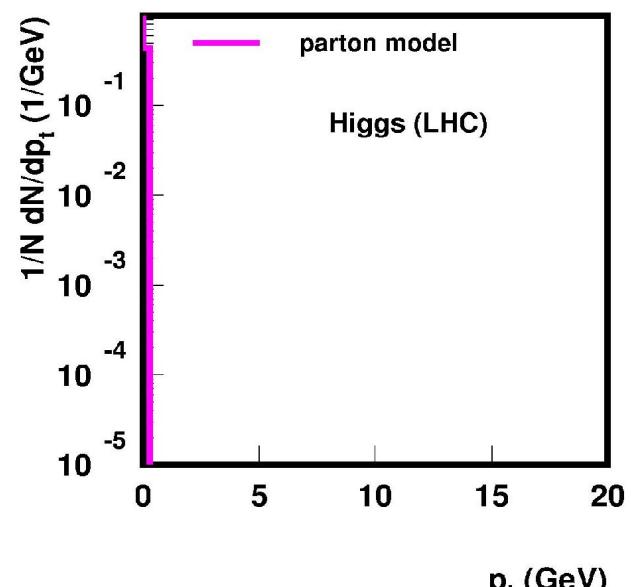
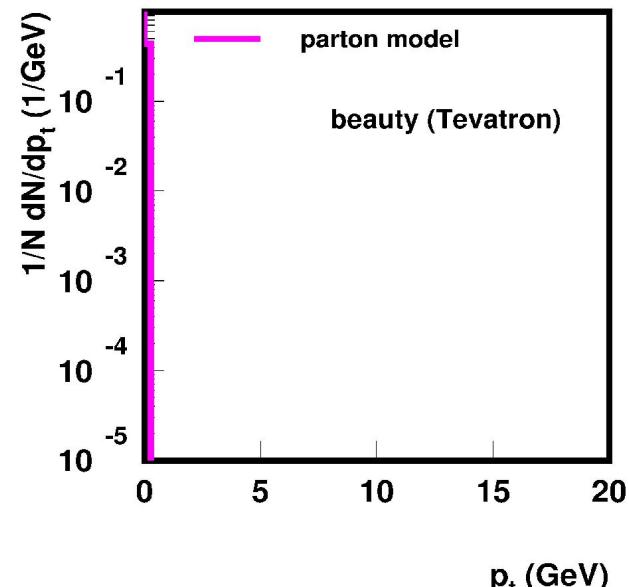
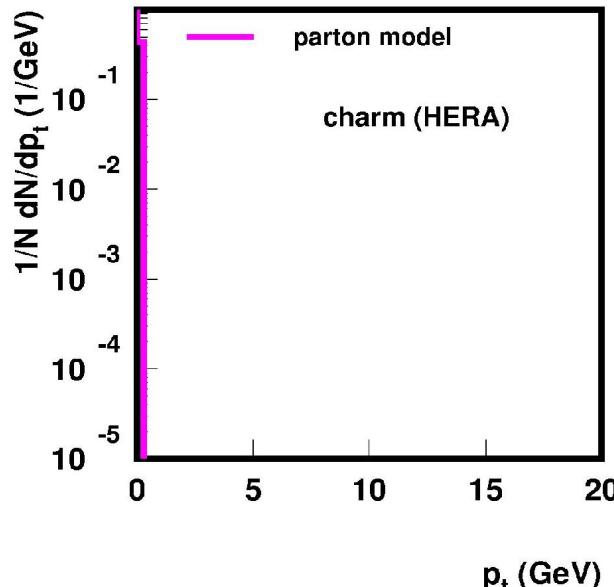
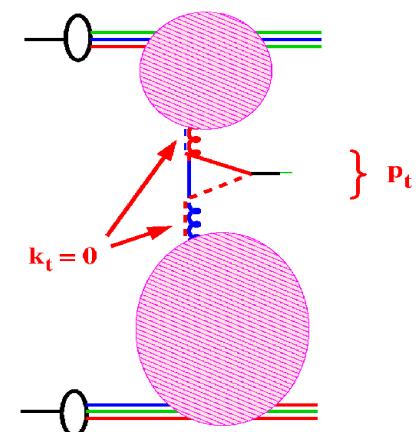
heavy quarks at HERA



heavy quarks at pp



Higgs at pp

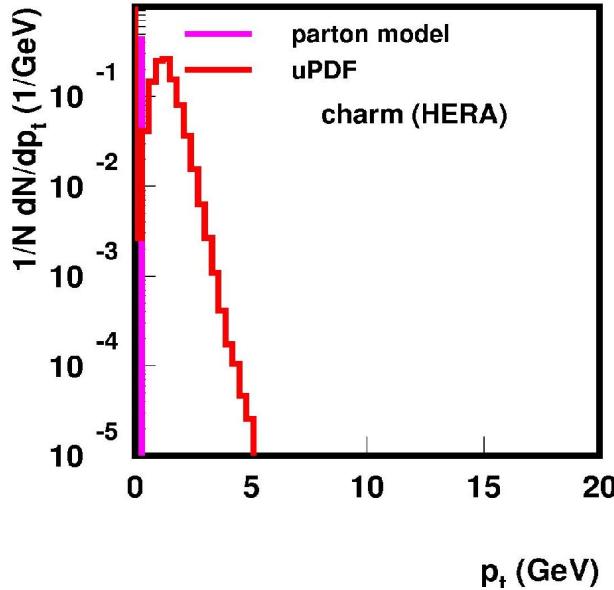
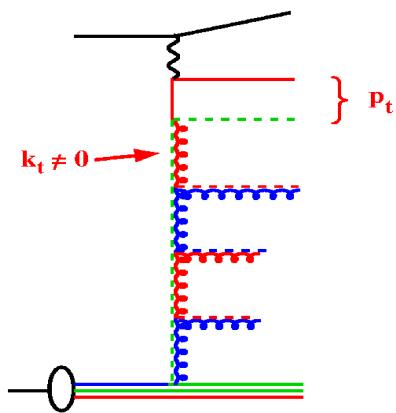


→ NLO corrections will be very large for these LO processes

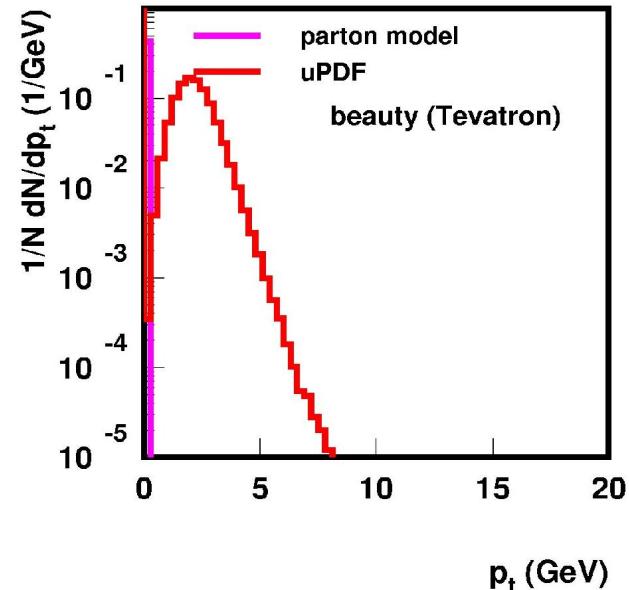
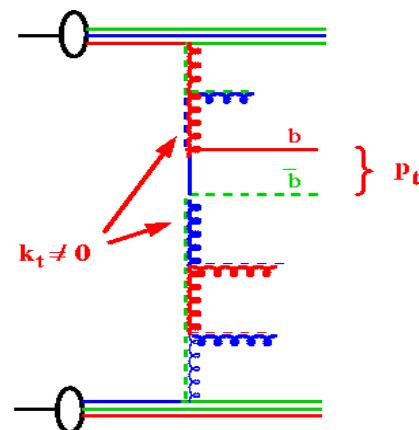
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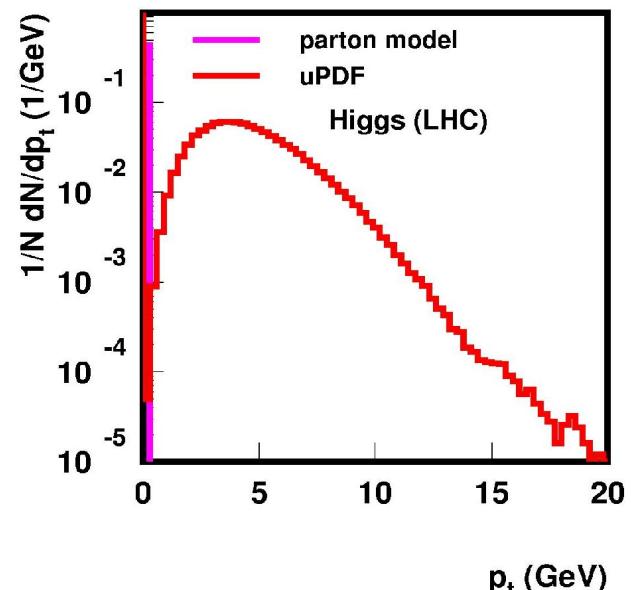
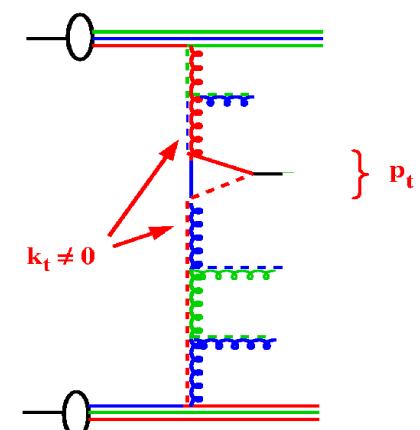
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→ doing kinematics correct at LO, reduces NLO corrections ... NEED uPDFs !

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

Ciafaloni **C**atani **F**iorani **M**archesini evolution equations

→ **CCFM** treats explicitly real gluon emissions

→ according to color coherence ... angular ordering

→ angular ordering includes **DGLAP** and **BFKL** as limits...

- k_t dependence in PDFs: from collinear to k_t factorization

- cross section (in k_t factorization) :

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

→ can be reduced to the collinear limit:

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

The parameters of uPDFs

- only gluons densities are considered here !!!

$$x\mathcal{A}(x, k_\perp, \bar{q}) = \int dx_0 \mathcal{A}_0(x_0, \mu_0) \cdot \frac{x}{x_0} \tilde{\mathcal{A}}\left(\frac{x}{x_0}, k_\perp, \bar{q}\right)$$

$$x\mathcal{A}_0(x, \mu_0) = Nx^{-B_g} \cdot (1-x)^4 \cdot \exp(-(k_{t0} - \mu)^2/\sigma^2)$$

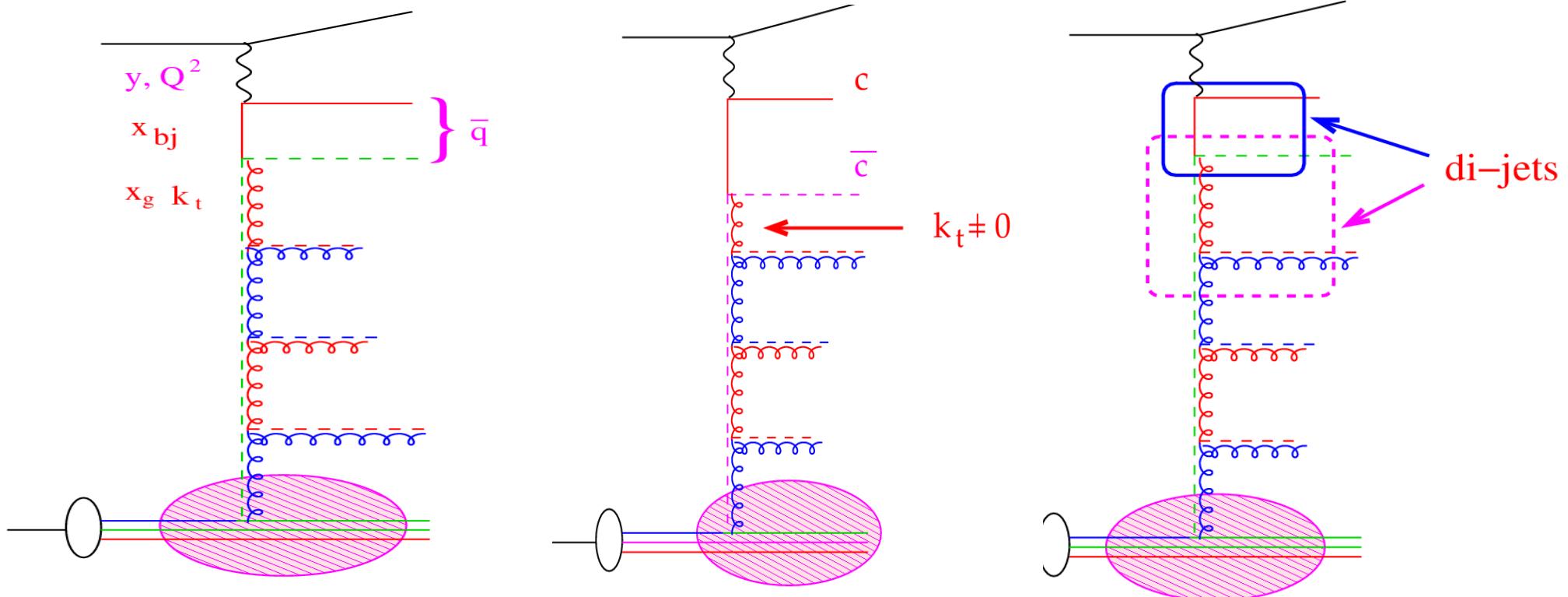
- initial distribution: $\mathcal{A}_0(x_0)$

- starting scale for evolution: here $\mu_0 = 1.2$ GeV
- x -dependence: parameters determined here
- intrinsic k_t -dependence: parameters determined here

- evolution equation: here CCFM is used

- splitting function: full splitting function including non-sing terms
- α_s parameters: here $\alpha_s(M_Z) = 0.118$
- renormalization scale: here $p_t^2 + 4m^2$
- factorization scale: here $Q_t^2 + s$

The strategy



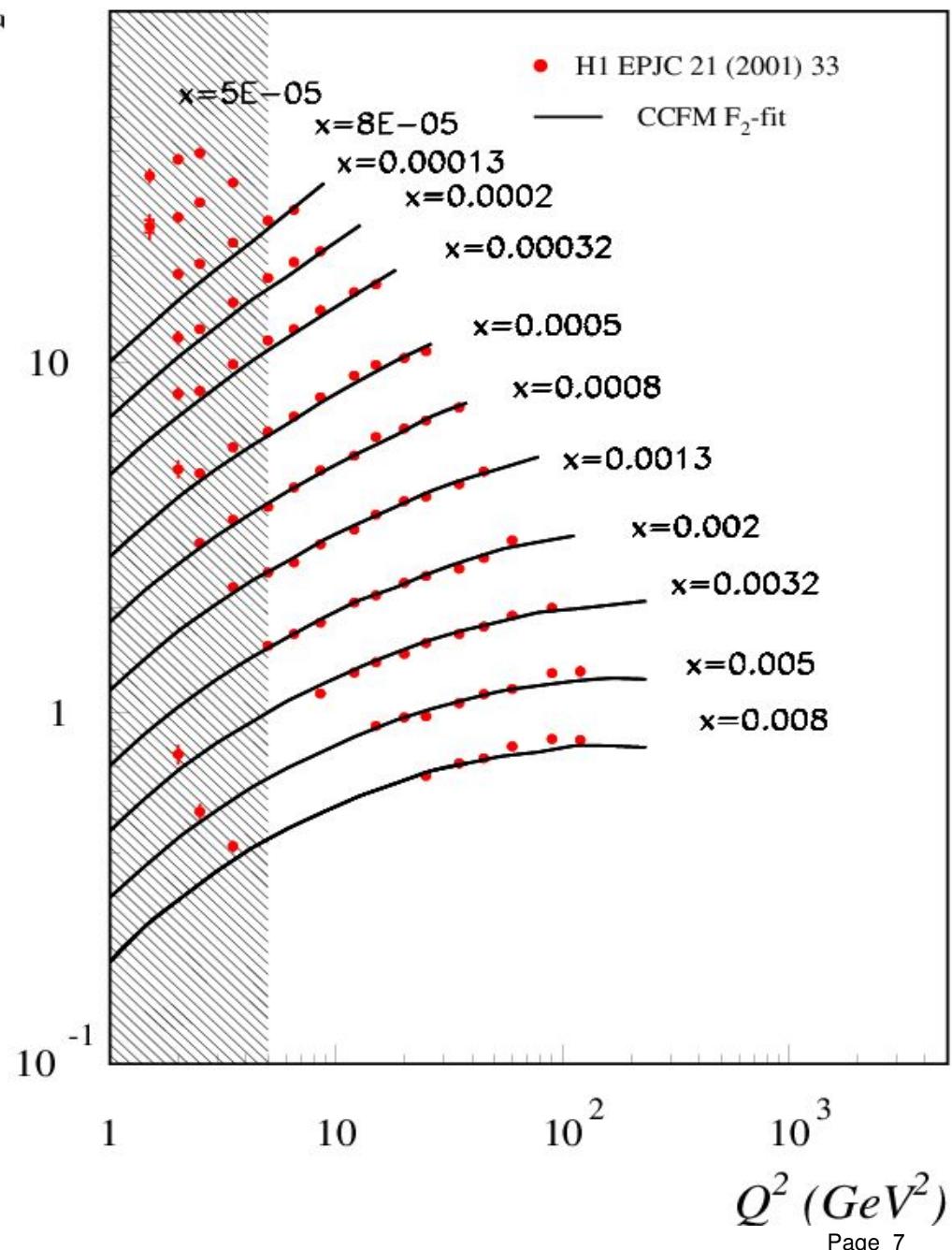
- inclusive: F_2
- x-section, normalization,
- x dependence, small
- average k_t
- fits performed

- semi-incl.: F_2^c, F_2^b
- x-dependence,
- larger average k_t
- fits performed.
- difference to $F_{2..}$

- final states
- x-dependence,
- differential in k_t
- NEW ... presented here

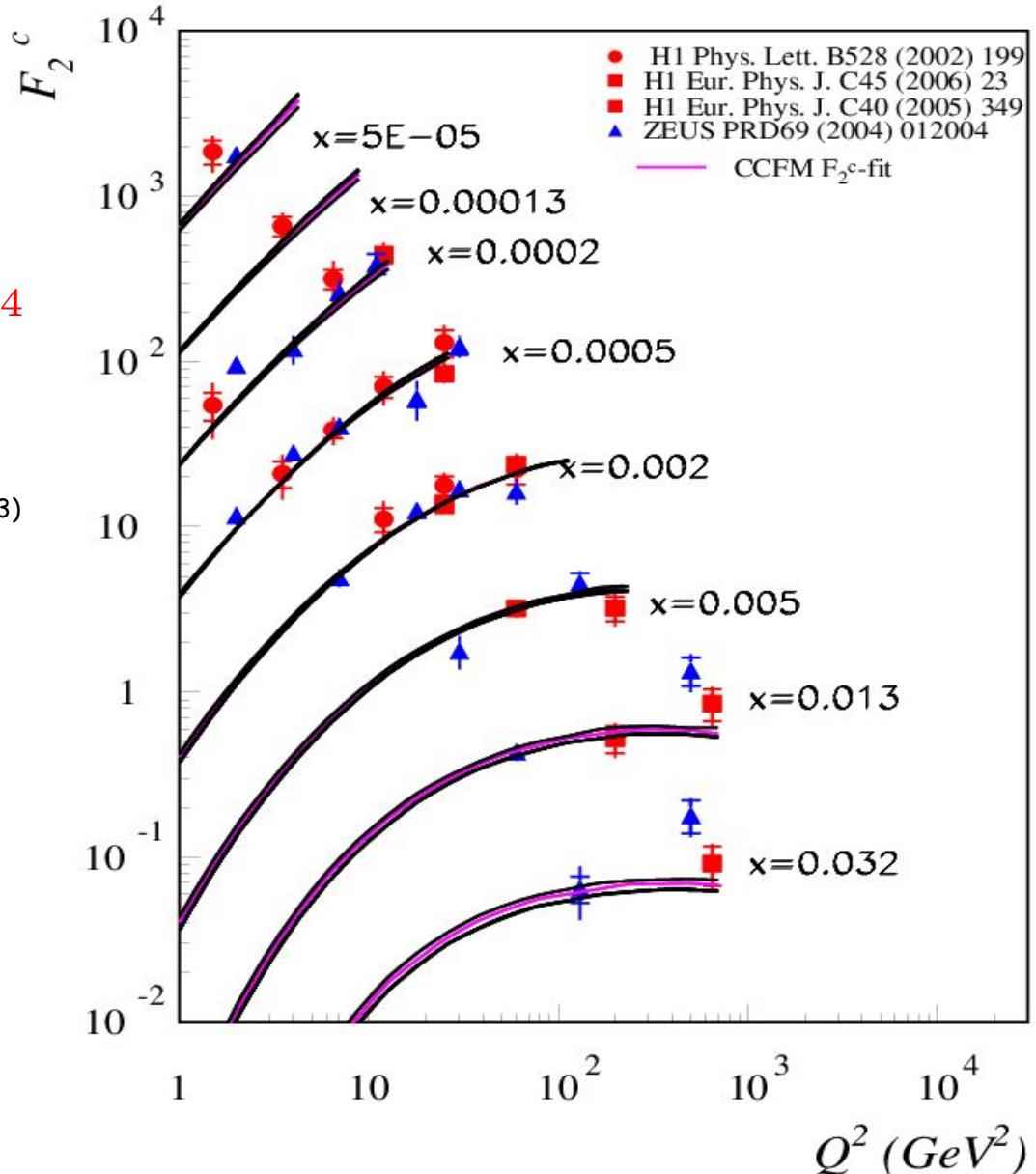
uPDF fit to F_2 : x -dependence

- $\chi^2 = \sum_i \left(\frac{(T - D)^2}{\sigma_i^2 \text{stat} + \sigma_i^2 \text{uncor}} \right)$
- 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)
 $x < 0.05 \quad Q^2 > 5 \text{ GeV}^2$
- parameters: $\mu_r^2 = p_t^2 + m_{q,Q}^2$
- $m_q = 250 \text{ MeV}, m_c = 1.5 \text{ GeV}$
- Fit (only stat+uncorr):
 $\frac{\chi^2}{\text{ndf}} = \frac{111.8}{61} = 1.83$
 $B_g = 0.028 \pm 0.003$
→ similar to DGLAP fits (~ 1.5)



uPDF fit to F_2^c : x -dependence

- $\chi^2 = \sum_i \left(\frac{(T - D)^2}{\sigma_i^2 \text{stat} + \sigma_i^2 \text{syst}} \right)$
- fit parameters of starting distribution
 $x\mathcal{A}_0(x, \mu_0) = Nx^{-B_g} \cdot (1-x)^4$
- using F_2^c data H1
(H1 PLB528 (2002) 199, EPJC 40 (2005) 349 ,EPJC45 (2006) 23)
 $Q^2 > 1 \text{ GeV}^2$
- fit result: $\frac{\chi^2}{\text{ndf}} = \frac{18.8}{20} = 0.94$
with $B_g = 0.286 \pm 0.002$
→ higher than for F_2 !?!?!



uPDF fit to F_2^c : x -dependence

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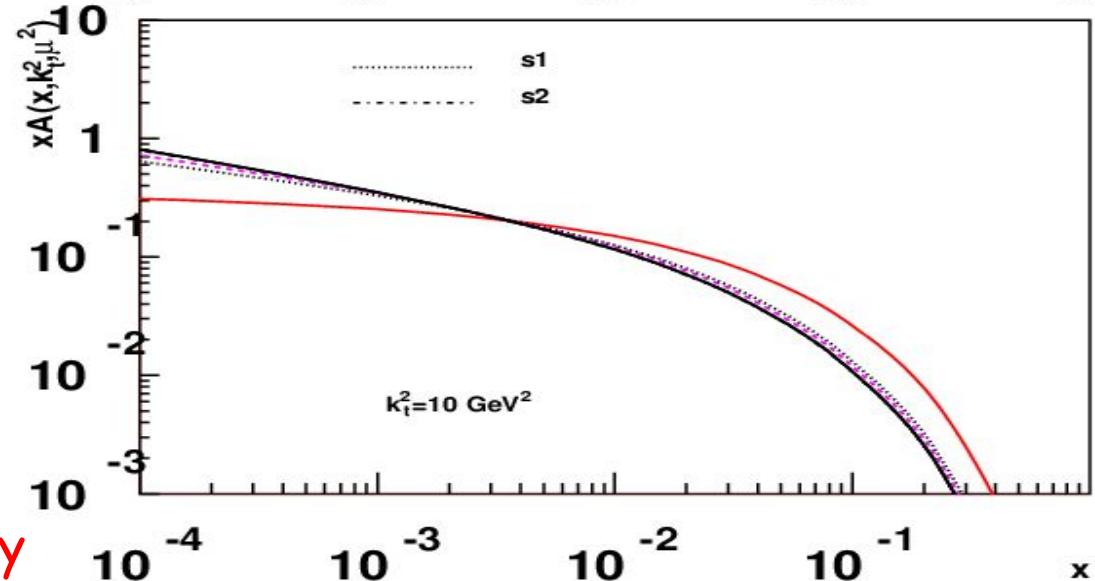
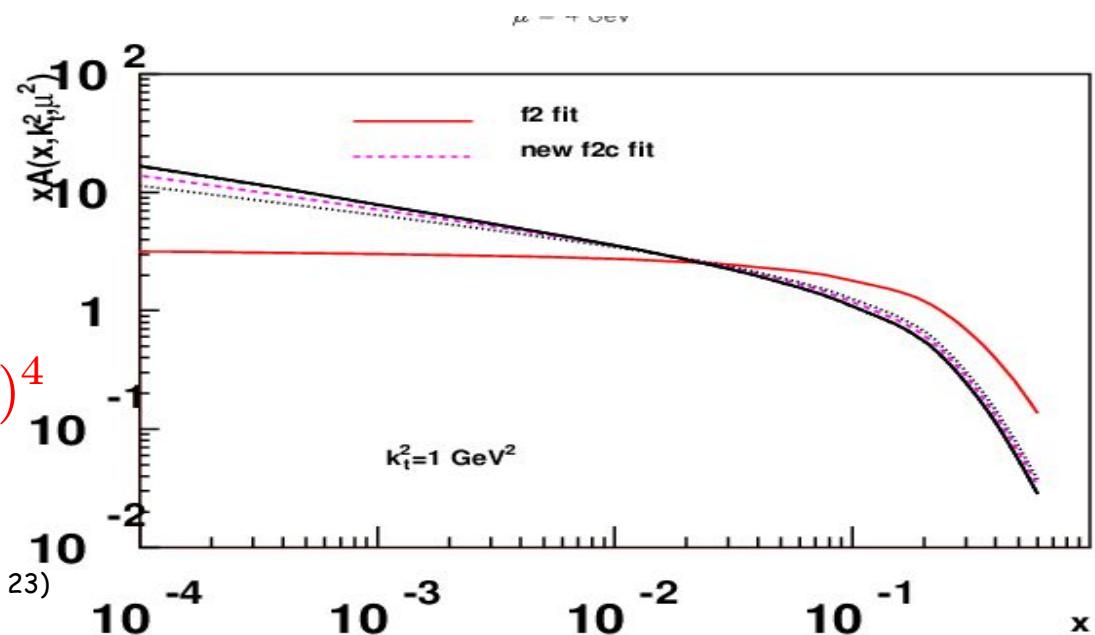
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- higher than for F_2 !? !? !?
- significant change of uPDF
- not covered by uncertainty obtained from exp uncertainties

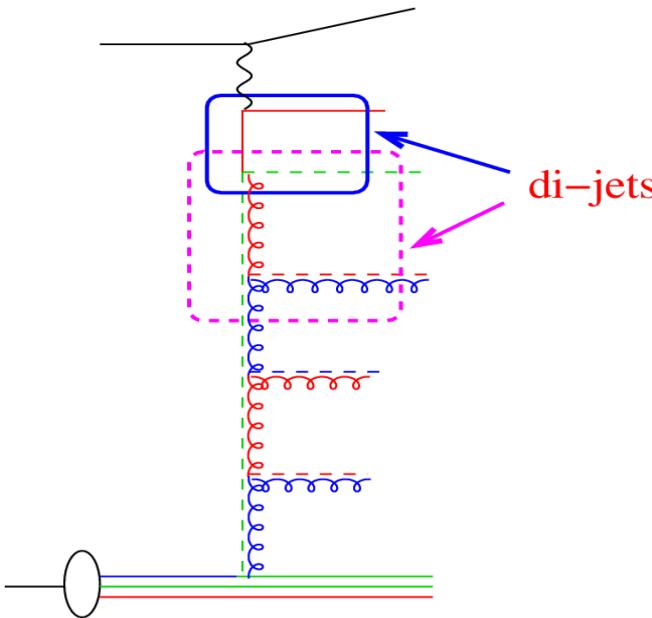


How to resolve discrepancy ?

check with other measurements:

→ DIS di-jet cross sections

uPDFs from di-jets: x -dependence



- Using H1 jet measurements

(H1 EPJC 33 (2004) 477)

$$5 < Q^2 < 100 \text{ GeV}^2$$

$$-1 < \eta < 2.5$$

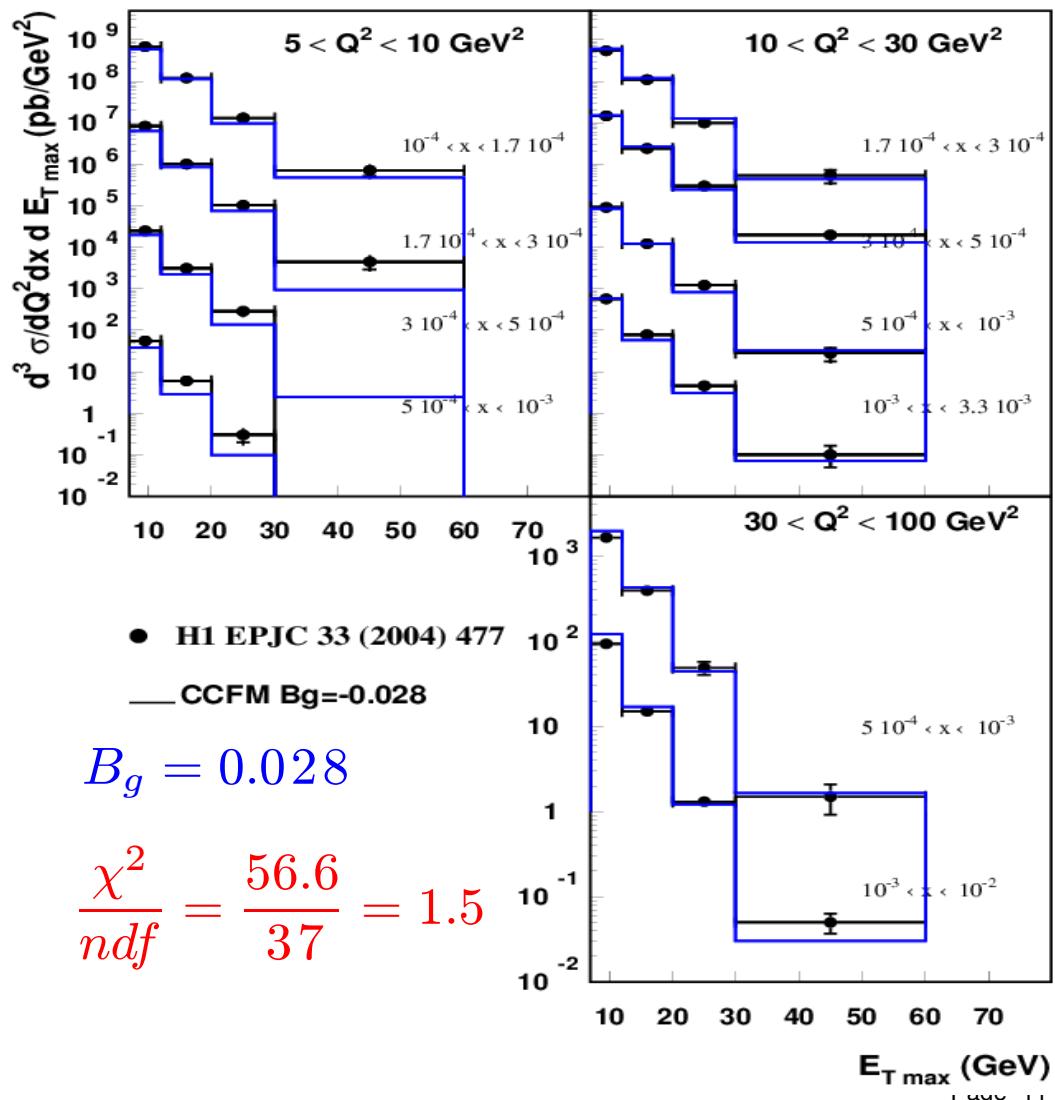
$$E_T > 5 \text{ GeV}$$

- investigate x - and k_t - dependence of starting dist.

- x dependence with

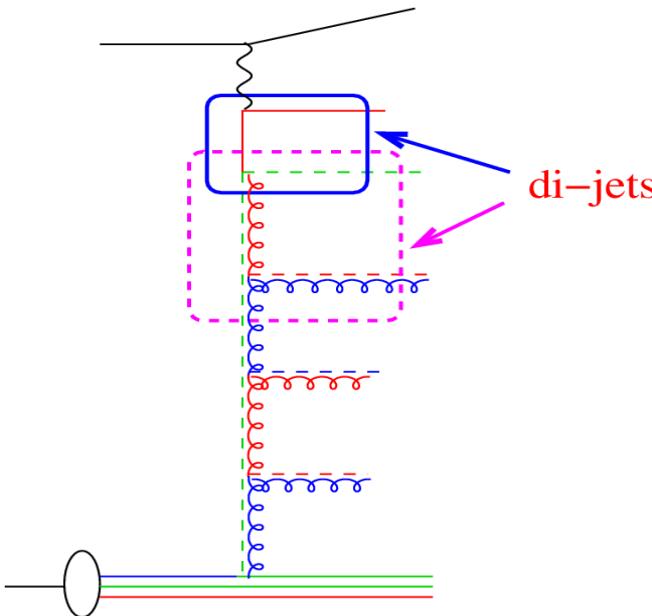
$$\frac{d^3 \sigma}{dE_T^{max} dx dQ^2}$$

$$x \mathcal{A}_0(x, \mu_0) = N x^{-B_g} \cdot (1 - x)^4$$



$$\frac{\chi^2}{ndf} = \frac{56.6}{37} = 1.5$$

uPDFs from di-jets: x -dependence



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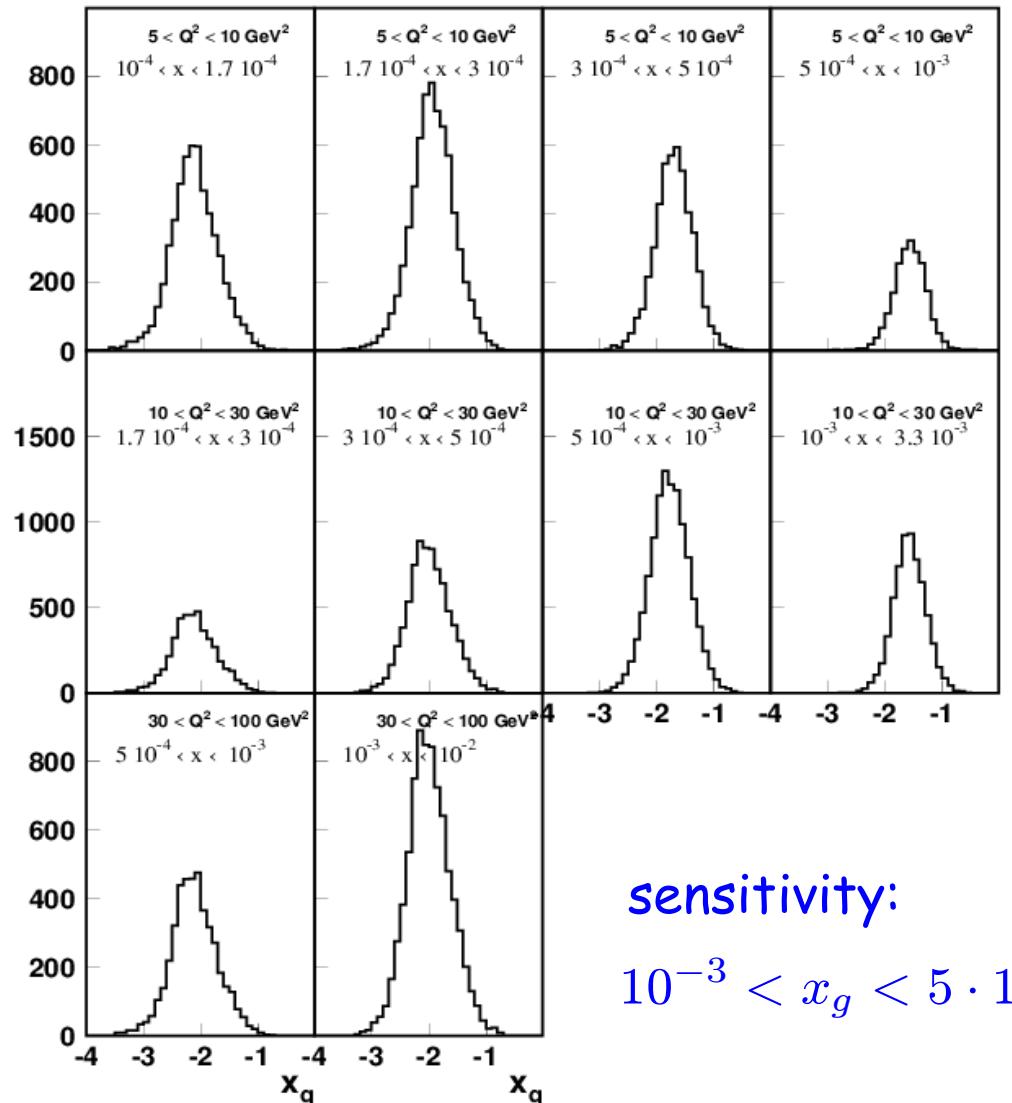
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x_g distribution for E_T cross sections



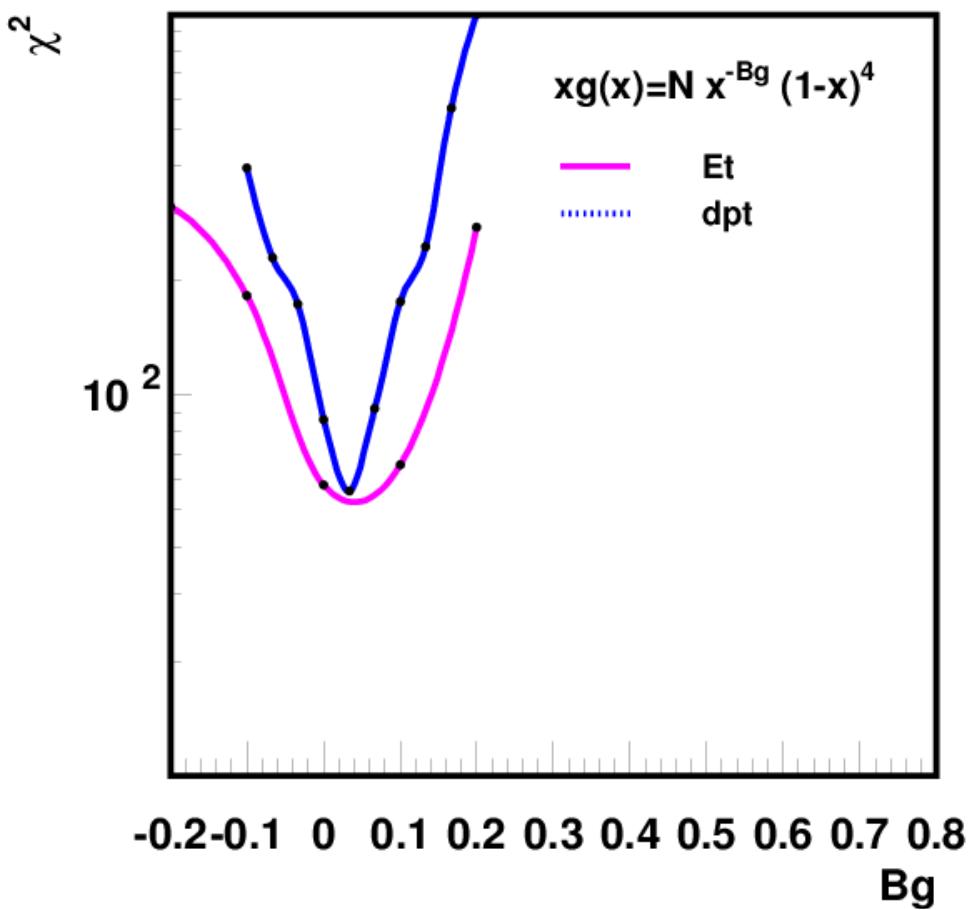
sensitivity:

$$10^{-3} < x_g < 5 \cdot 10^{-1}$$

uPDFs from di-jets: x -dependence

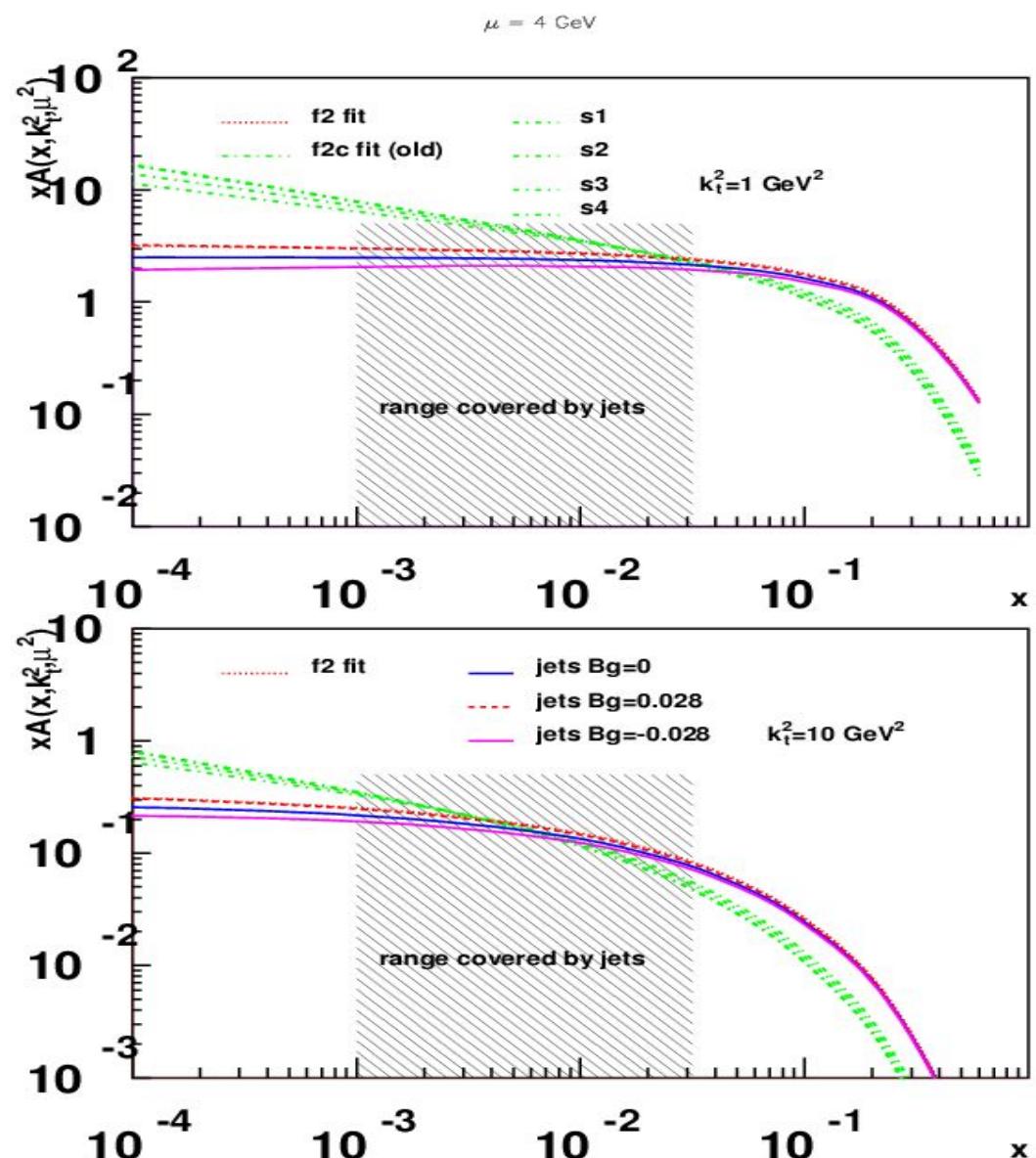
- Determination of B_g :

$$x\mathcal{A}_0(x, \mu_0) = N x^{-B_g} \cdot (1-x)^4$$



→ very similar to F_2 gluon!
→ even in normalization!!!

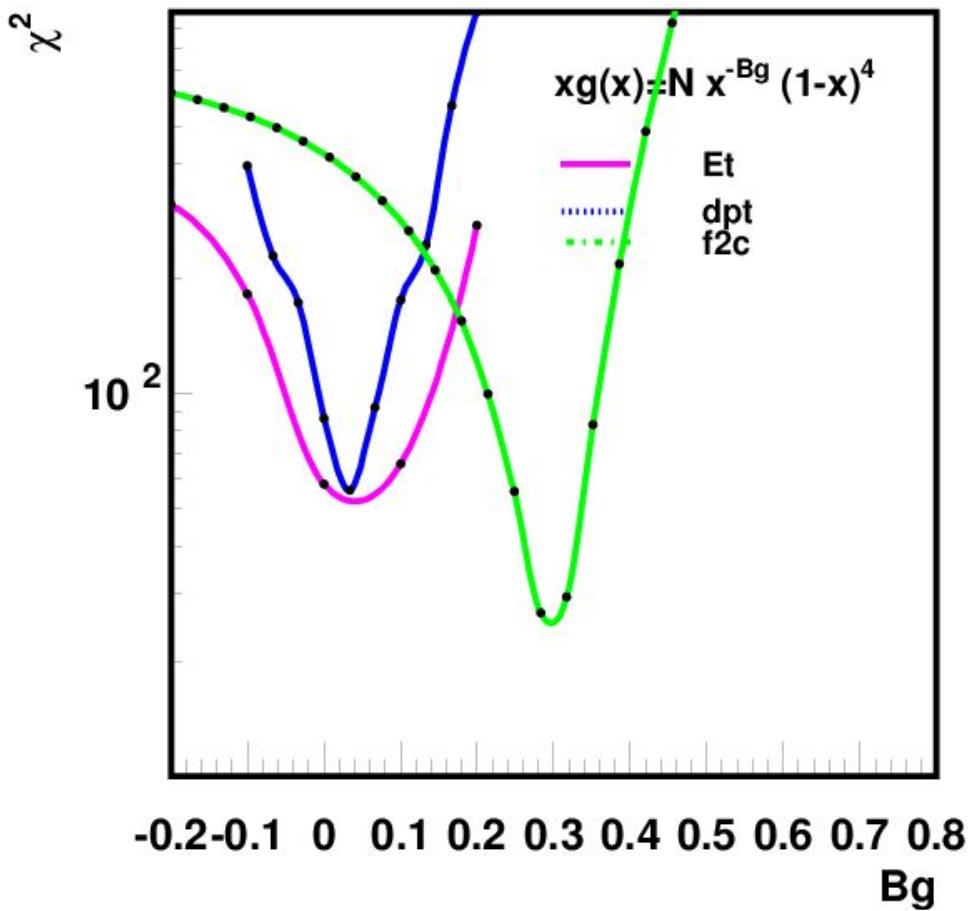
- resulting gluon distribution:



uPDFs from di-jets: x -dependence

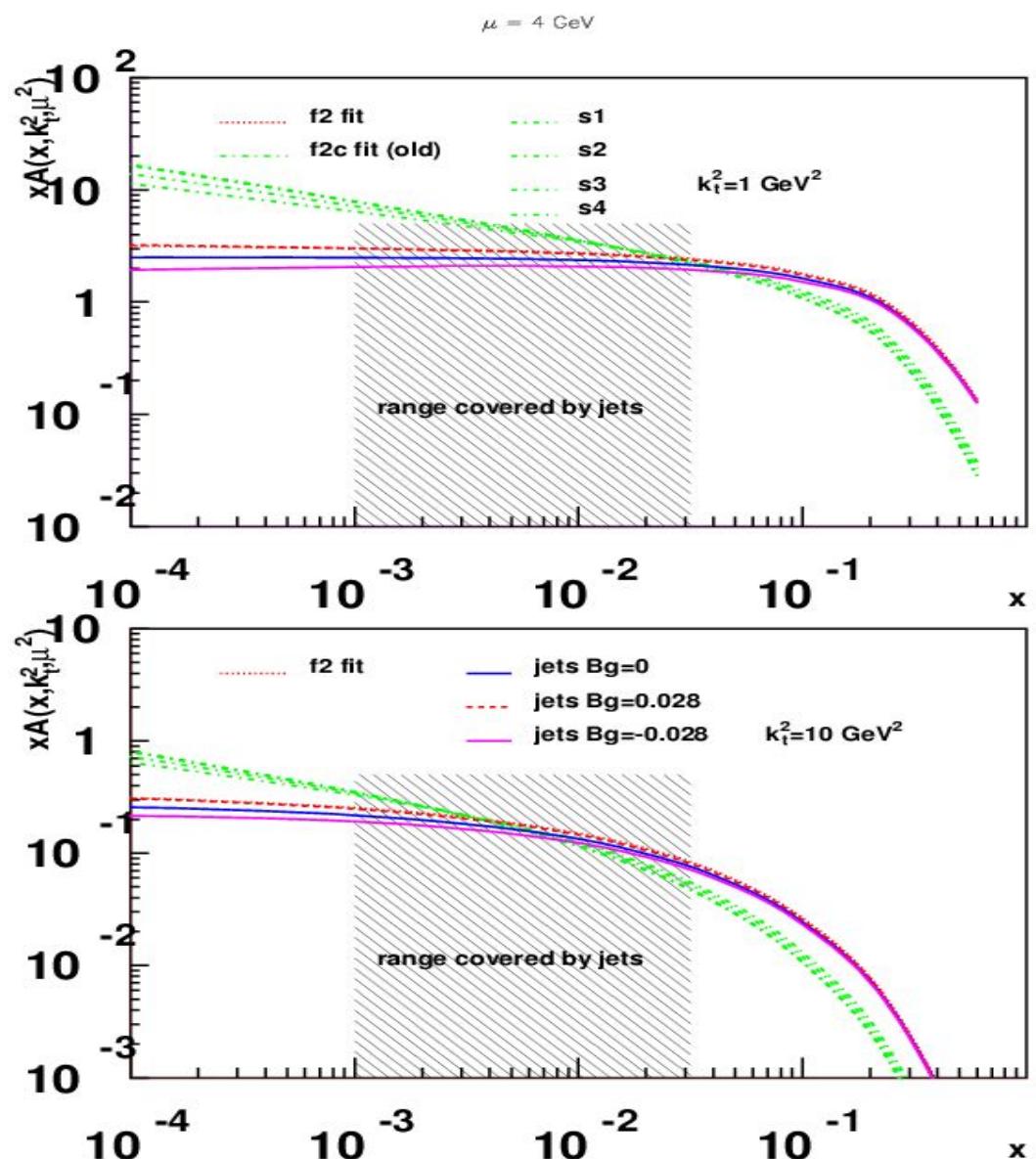
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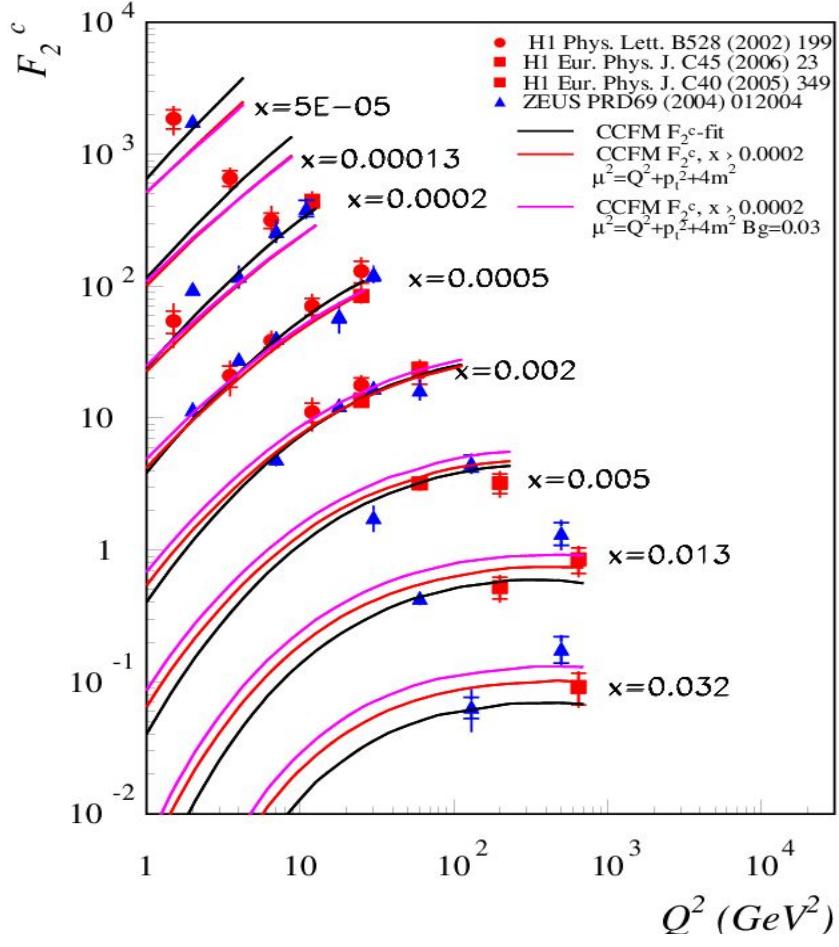


How to resolve discrepancy with F_2^c ?

- check other measurements:
 - F_2^b, F_L (see talk by N.Zotov in SF)
 - F_2^b clearly prefers F_2 solution:
 - using F_2 fit: $\frac{\chi^2}{ndf} = \frac{7.4}{8} = 0.92$
 - using F_2^c fit: $\frac{\chi^2}{ndf} = \frac{16.7}{8} = 2.1$
- hadronic final states:
 - DIS di-jet cross sections
 - also prefer a F_2 like gluon !!!!
 - investigate F_2^c again
 - rise of gluons comes from lowest x points

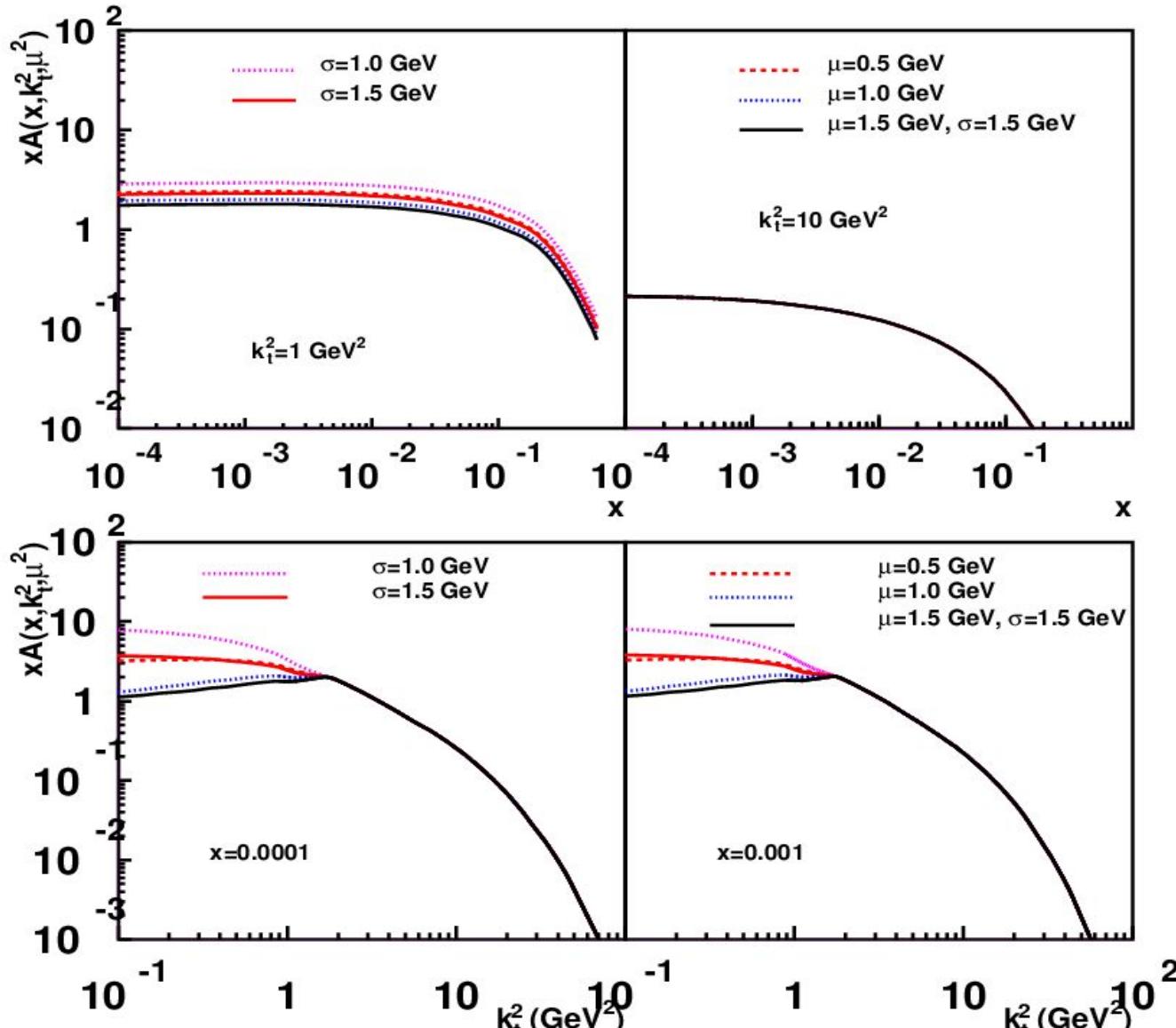
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- hadronic final states:
 - DIS di-jet cross sections
 - also prefer a F_2 like gluon !!!!
 - investigate F_2^c again
 - rise of gluons comes from lowest x points
- restrict fit to $x > 0.0002$ gives for $x\mathcal{A}_0(x, \mu_0) = Nx^{-B_g} \cdot (1-x)^4$
 - $B_g = 0.15$ and $\chi^2/ndf = 0.8$
 - even $B_g = 0.028$ gives $\chi^2/ndf = 1.1$



uPDFs from di-jets: intrinsic k_t

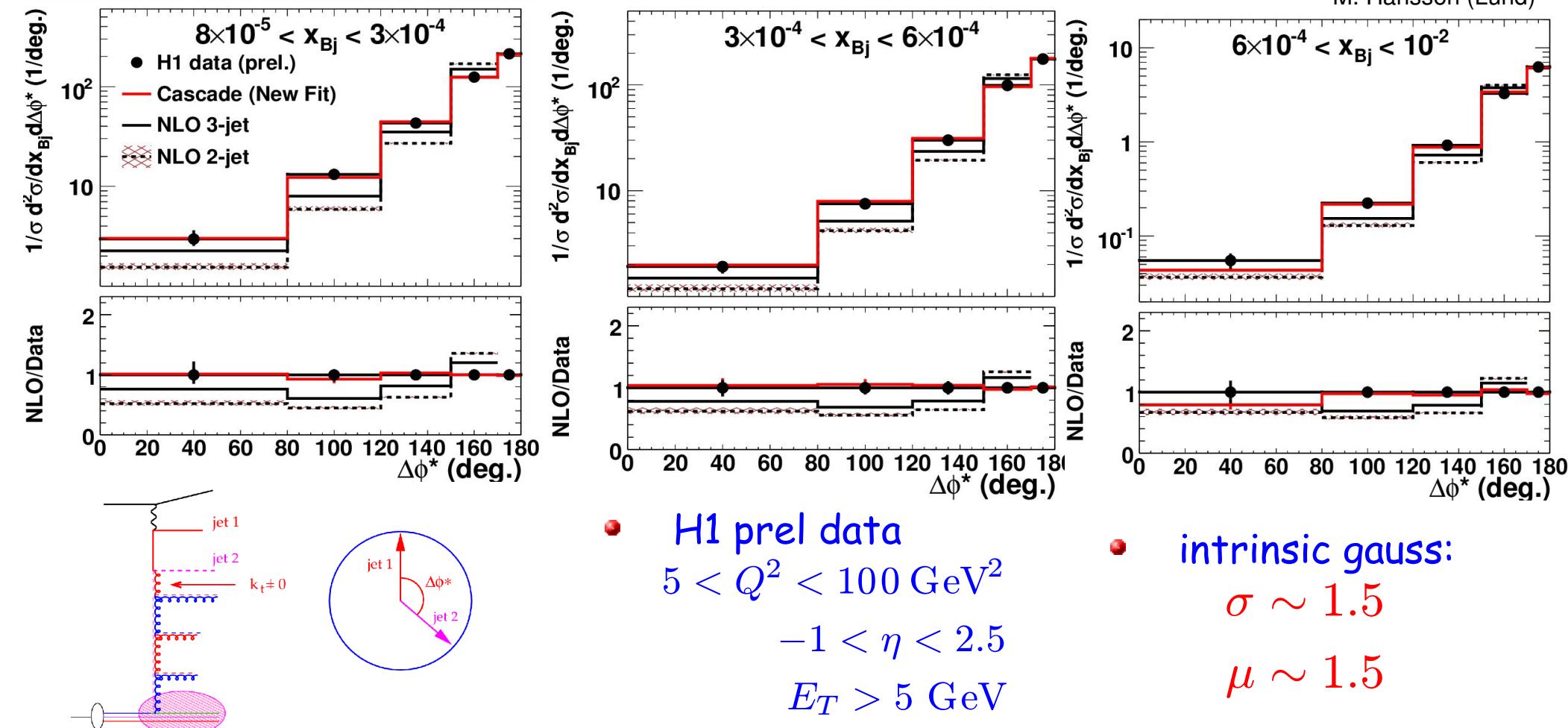
$$x\mathcal{A}(x, \mu_0^2) = Nx^{-B_g} \cdot (1-x)^4 \cdot \exp(-(k_{t0} - \mu)^2/\sigma^2)$$



- different intrinsic k_t -distributions only accessible in uPDFs
- sensitive to the mix of small and large k_t
 - small k_t determines total x -section
 - large k_t influences perturbative tails ...

uPDFs from di-jets: k_+ -dependence

- k_+ dependence with $\frac{1}{\sigma} \frac{d^2\sigma}{d\Delta\phi^* dx}$, with $x\mathcal{A}(x, \mu_0^2) = Nx^{-B_g} \cdot (1-x)^4 \cdot \exp(-(k_{t0} - \mu)^2/\sigma^2)$



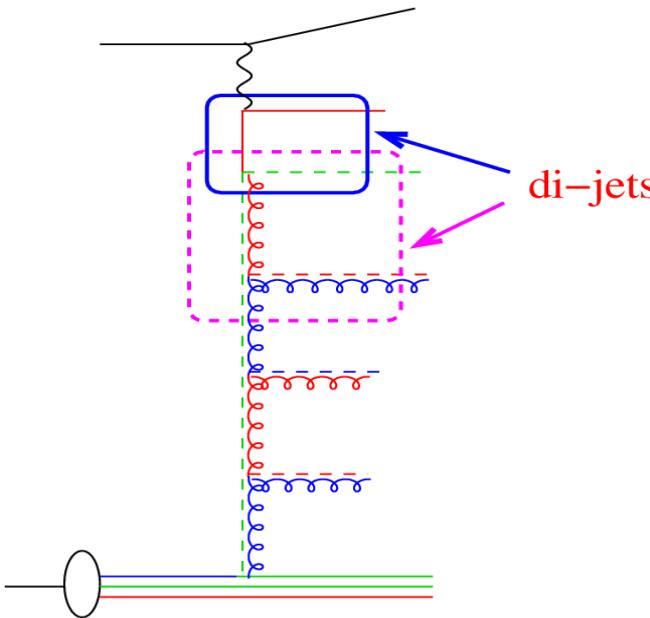
- 1st direct determination of intrinsic k_+ distribution
- consistent with gauss... but other distributions not excluded

Conclusion

- Full treatment of kinematics in calculations is necessary - NEED uPDFs
 - NLO corrections are MUCH smaller than
 - uPDFs are needed for precision calculations at LHC: ... see heavy quarks, Higgs etc ...
 - Determination of free parameters of uPDFs:
 - x - dependence:
 - from F_2, F_2^c and jets is consistent with a flat gluon distribution
 - except smallest x points in F_2^c
 - k_t - dependence:
 - consistent with a gauss with mean ~ 1.5 and width of ~ 1.5 GeV
 - 1st direct and independent determination of intrinsic k_t distribution
 - Towards precision fits:
 - combination of F_2 and jets, uncertainties ... to come ...
- **uPDFs become fascinating with many applications !!!!!!!**

Backup slides

uPDFs from di-jets: x -dependence



- Using H1 jet measurements

(H1 EPJC 33 (2004) 477)

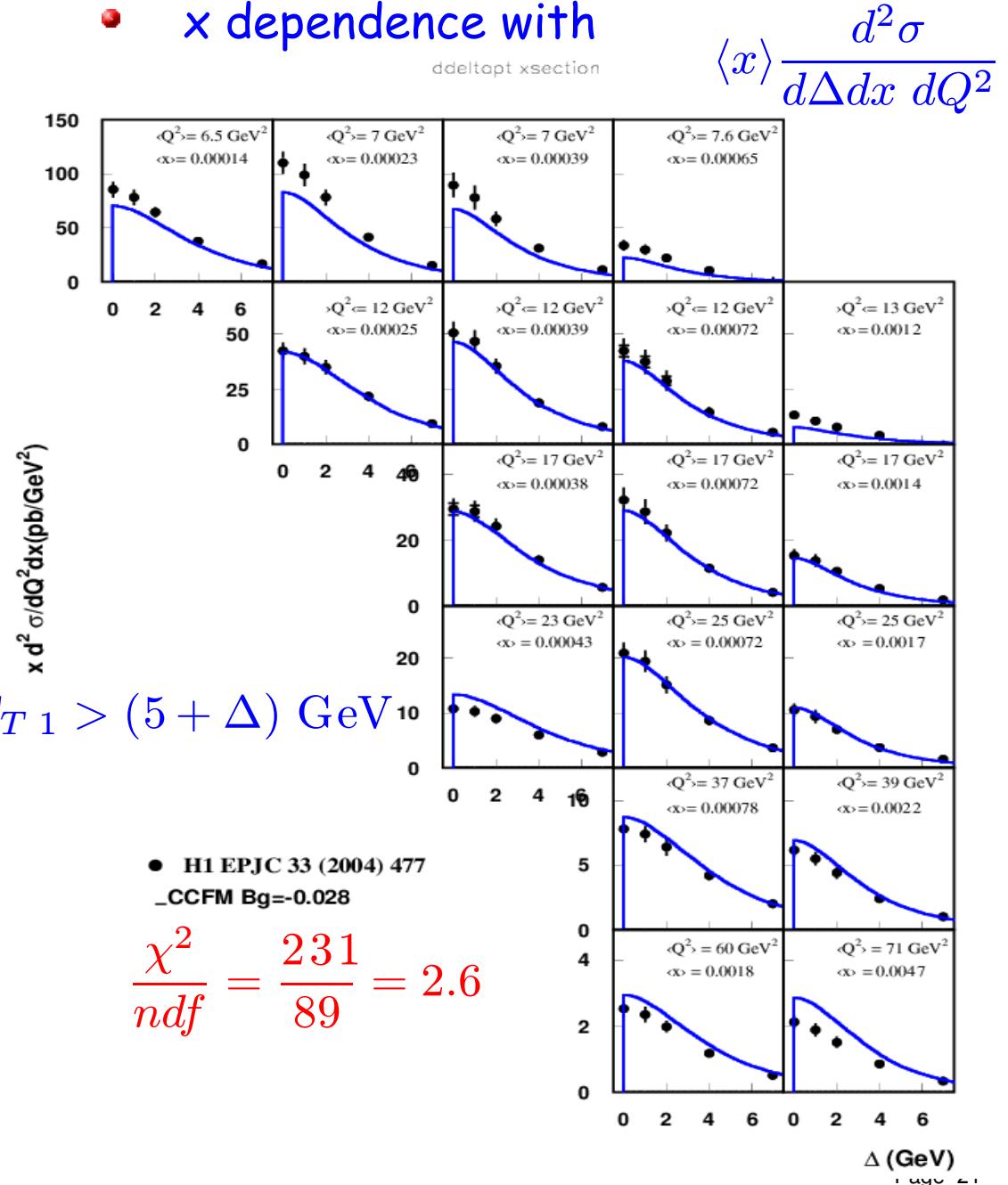
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$$-1 < \eta < 2.5$$

$$E_T > 5 \text{ GeV}$$

- investigate x - and k_t - dependence of starting dist.

- x dependence with $\frac{d^2\sigma}{d\Delta dx dQ^2}$



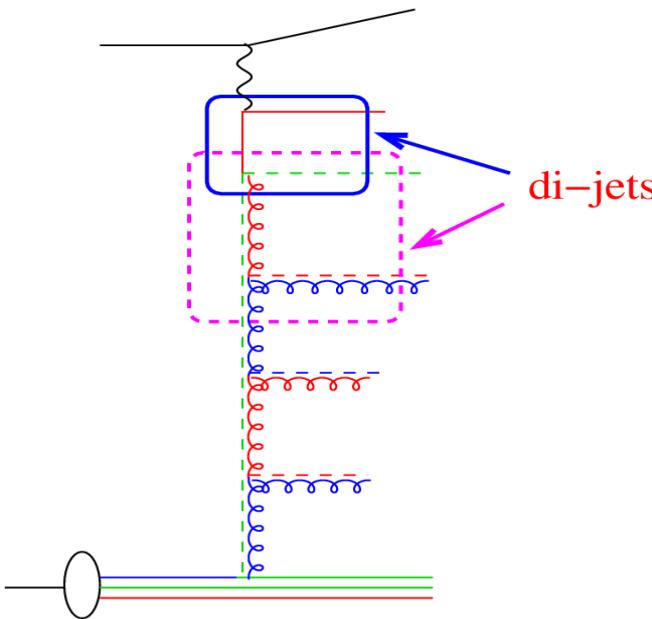
$$E_T > (5 + \Delta) \text{ GeV}$$

• H1 EPJC 33 (2004) 477
-CCFM Bg=-0.028

$$\frac{\chi^2}{ndf} = \frac{231}{89} = 2.6$$

$$\langle x \rangle \frac{d^2\sigma}{d\Delta dx dQ^2}$$

uPDFs from di-jets: x -dependence



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(H1 EPJC 33 (2004) 477)

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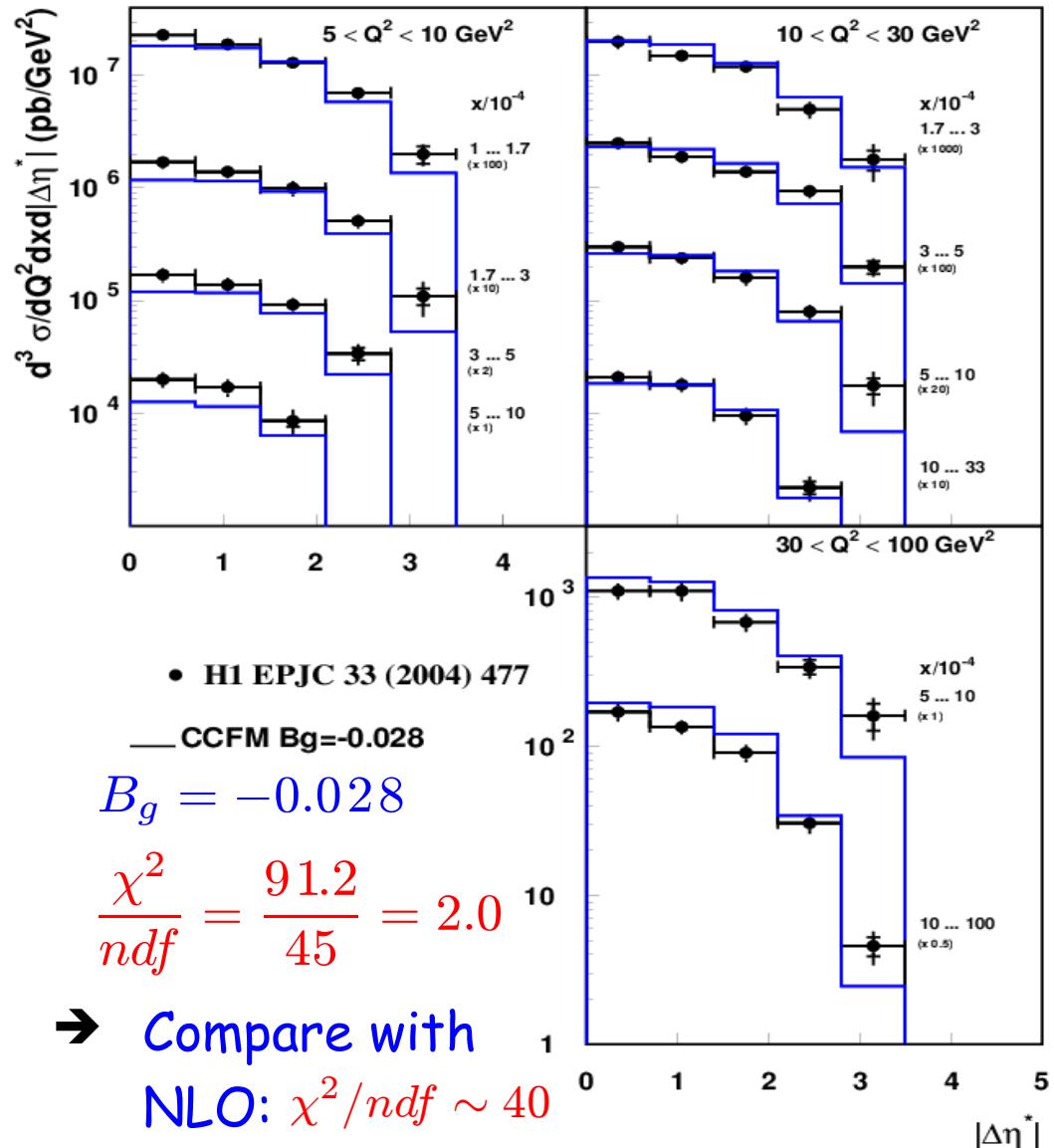
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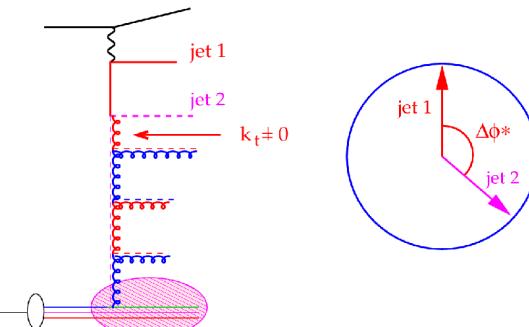
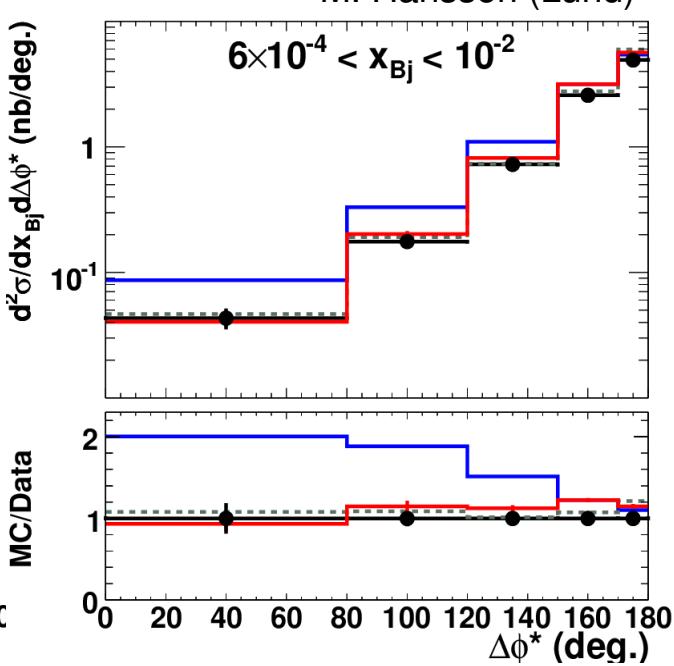
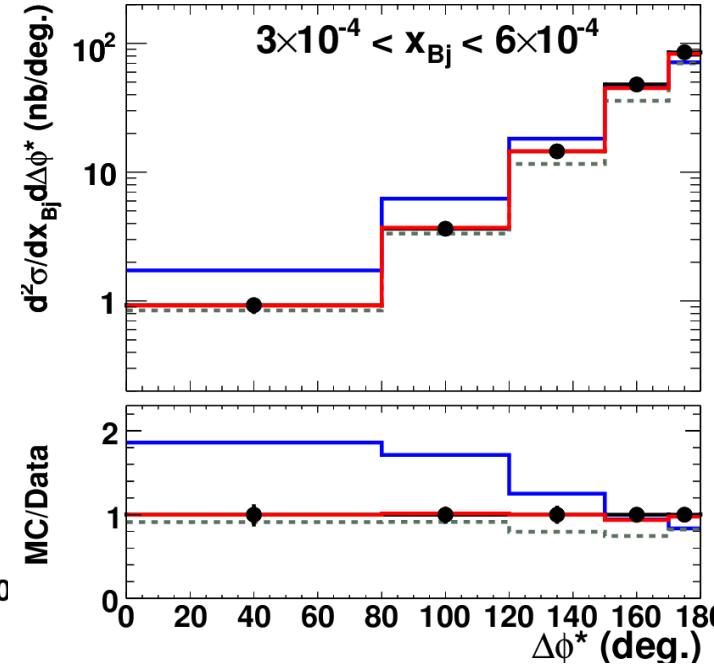
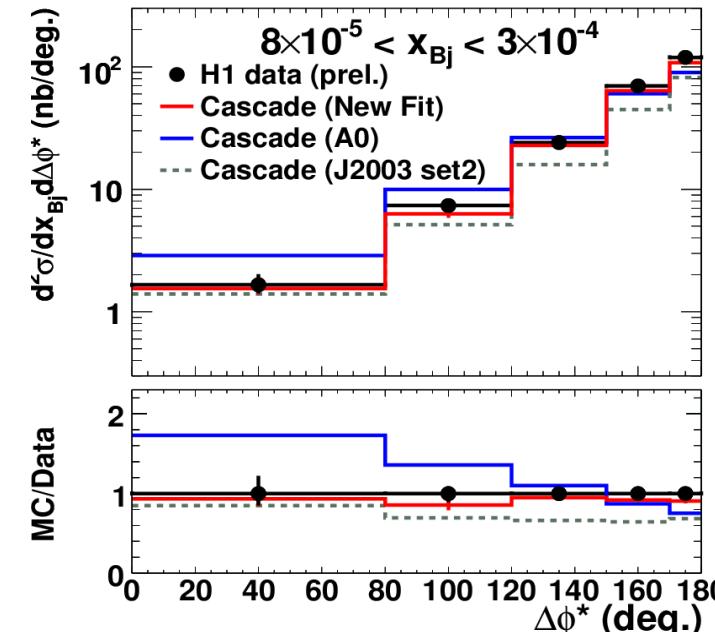
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- k_+ dependence with $\frac{d^2\sigma}{d\Delta\phi^* dx}$, with $x\mathcal{A}(x, \mu_0^2) = Nx^{-B_g} \cdot (1-x)^4 \cdot \exp(-(k_{t0} - \mu)^2/\sigma^2)$



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

- intrinsic gauss:
 $\sigma \sim 1.5$
 $\mu \sim 1.5$

- 1st direct determination of intrinsic k_+ distribution
- consistent with gauss... but other distributions not excluded