Saturation effects in final states due to CCFM with absorptive boundary

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Acknowledgement to: E. Avsar, G. Gustafson, A. Mueller, E. Iancu for discussions

Motivation

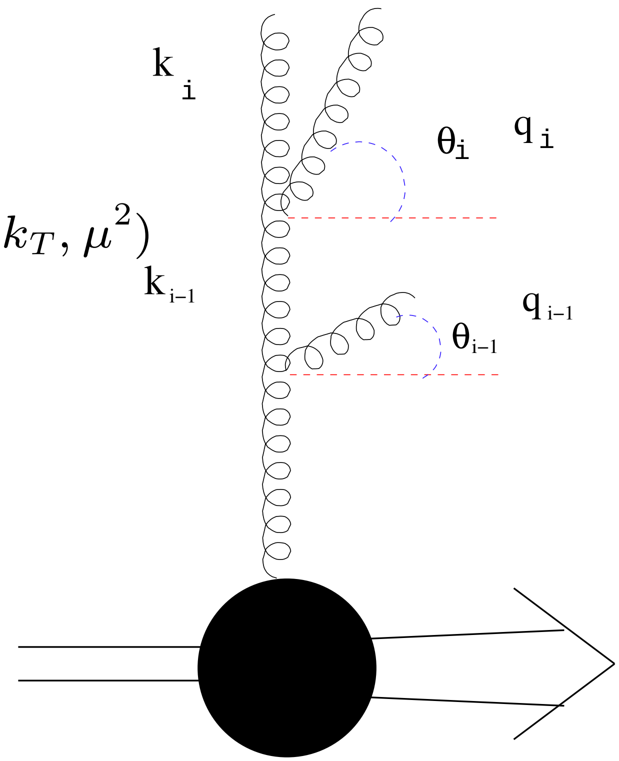
- HERA $\longrightarrow$ hints that at small fraction of proton momentum $x \sim 10^{-4}$ and low virtuality of the parton $\longrightarrow$ new kind of dynamics: BFKL growth? saturation?
- However, at HERA we cannot clearly see it. In the future we will probe gluon density at smaller proton momentum fraction.
- We know that NLO corrections to BFKL and for DGLAP are large.
- Important $\longrightarrow$ use BFKL + DGLAP $\longrightarrow$ one is source of subleading corrections for the other. Compact way $\longrightarrow$ CCFM.
- Be prepared for description of dense partonic system $\longrightarrow$ possible saturation effects
- In k_T factorisation approach one can address problems of saturation.
- Monte Carlo approach allows us to study exclusive processes.
- CASCADE is MC in k_T factorisation approach where saturation -high density physics can be addressed

CCFM evolution equation

Strong ordering in angle of emitted gluons: $\theta_i \gg \theta_{i-1}$

Integral equation:

$$xA(x, k_T, \mu^2) = xA_0(x, k_T, \mu^2) + K \otimes xA(x, k_T, \mu^2)$$



k_T transverse momentum of the most upper gluon μ, factorization scale, $xA_0(x, k_T, \mu^2) \leftarrow$ to be determined by fit.

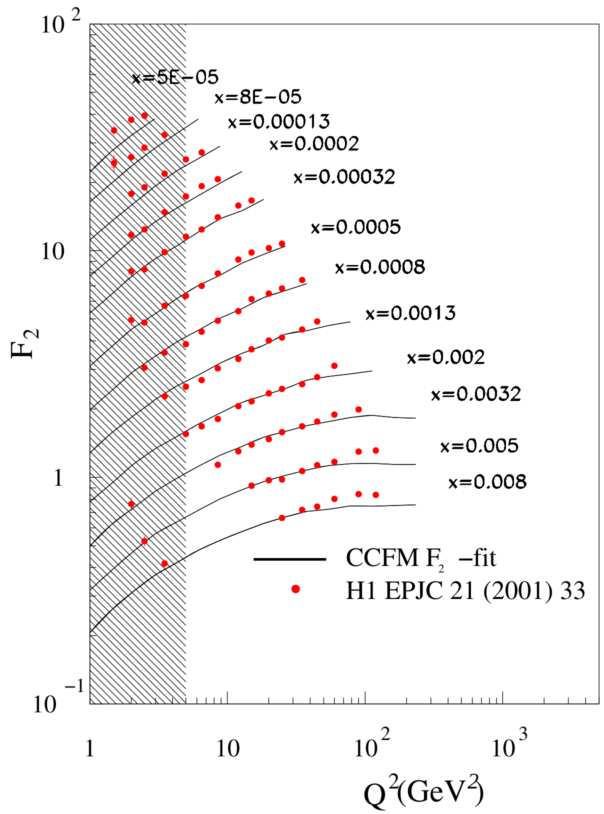
Contains $1/z$ and $1/(1-z)$ singularities $\longrightarrow$ BFKL, DGLAP

Implementation of CCFM in Monte Carlo $\longrightarrow$ CASCADE (H.Jung)

F_2 from CCFM

$$F_2(x, Q^2) = \Phi(k_T^2) \otimes xA(x, k_T^2, Q^2)$$

- Good description
- However, at lower x...



Possible new effects

- CCFM is a linear $A(x, k_T, \mu^2) \sim x^\beta$
- Unitarity requirements $\rightarrow$ $A(x, k_T, \mu^2)$ "less steep growth" e. g. $log(x)$$\rightarrow$ saturation

Saturation sort of recombination of partons

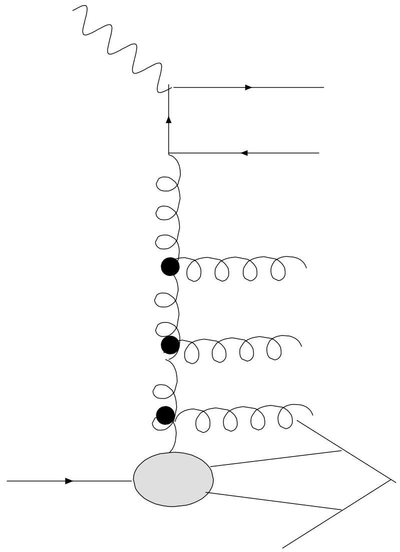
$\downarrow$

introduces part of unitarity corrections

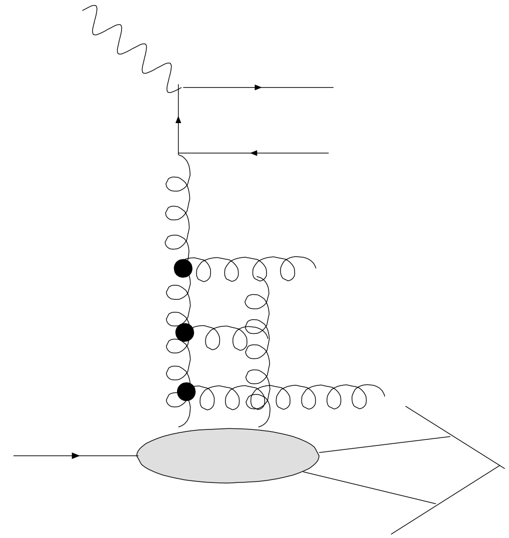
$\downarrow$

modeled by nonlinear evolution equations (Balitsky-Kovchegov, JIMWLK)

Saturation, Feynman diagrams and evolution equation



Leads to linear evolution equation
BFKL, CCFM



Leads to nonlinear evolution equations
BK, GLR,..

- Triple pomeron vertex (Bartels, Wüsthoff) $\longrightarrow$ nonlinearity
- On solid grounds for nuclei, model for nucleon
- Leads to slower rate of growth of gluon density

Nonlinear equation for k_t factorisable gluon density

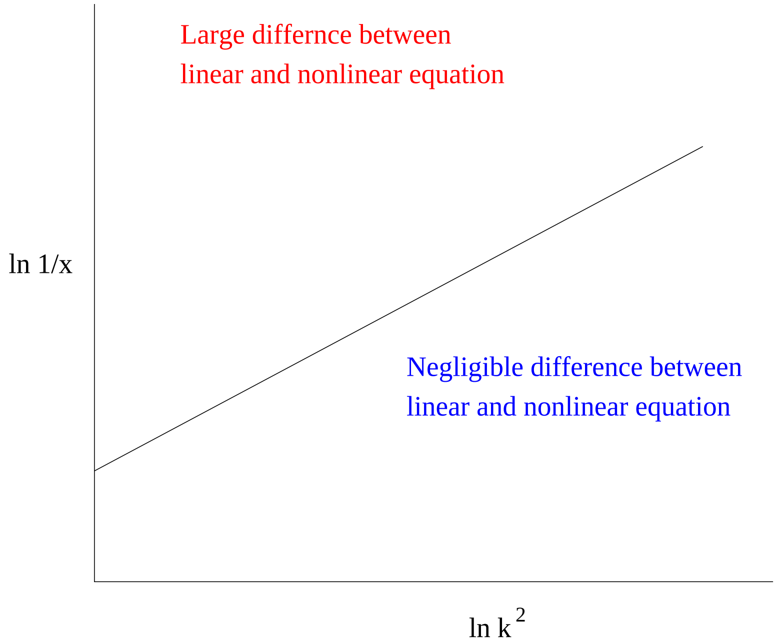
This slide is dedicated to the memory of Jan Kwieciński

The fan diagram equation reads (Bartels, Kutak):

$$\frac{\partial f(x,\mathbf{k}^2)}{\partial \ln 1/x} = K_{BFKL} \otimes f(x,k^2) - \frac{\alpha_s^2}{R^2} \left\{ \mathbf{k}^2 \left(\int_{\mathbf{k}^2}^{\infty} \frac{d\mathbf{l}^2}{\mathbf{l}^4} f(x,\mathbf{l}^2) \right)^2 + f(x,\mathbf{k}^2) \int_{\mathbf{k}^2}^{\infty} \frac{d\mathbf{l}^2}{\mathbf{l}^4} \ln\left(\frac{\mathbf{l}^2}{\mathbf{k}^2}\right) f(x,\mathbf{l}^2) \right\}$$

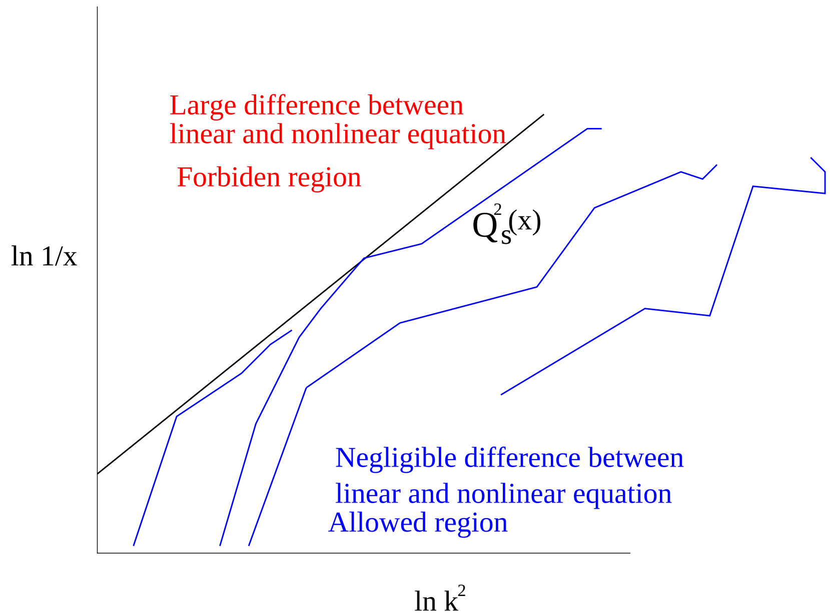
- related to BK equation in coordinate space via Fourier transform (Kwieciński, Martin, Kimber and Bartels, Lipatov, Vacca)
- in this form easy to implement kinematical constraint in linear (Golec-Birnat, Martin, Kwiecinski, Motyka, Staśto) and nonlinear term (Kutak)
- nonlinear term gets main contribution from the anticollinear region, in collinear limit the nonlinearity vanishes. Prevents diffusion to small momenta $\longrightarrow$ solves difussion problems of BFKL.
- nonlinearity introduces ordering in k_T^2, chain becomes ordered at low x in $\ln 1/x$ and k_T^2, saturation scale emerges...

Saturation and linear evolution equation



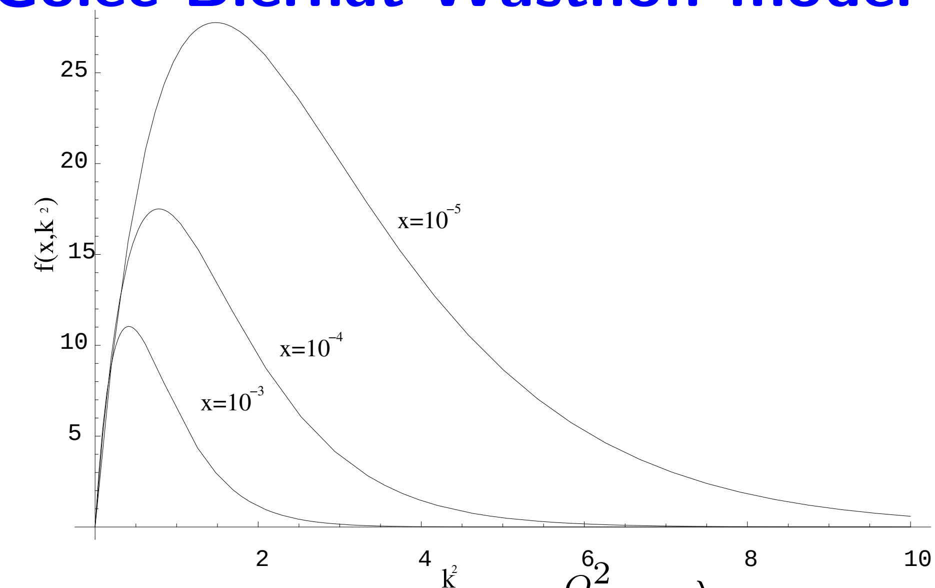
- plane is divided into two regions

Saturation and nonlinear evolution equation



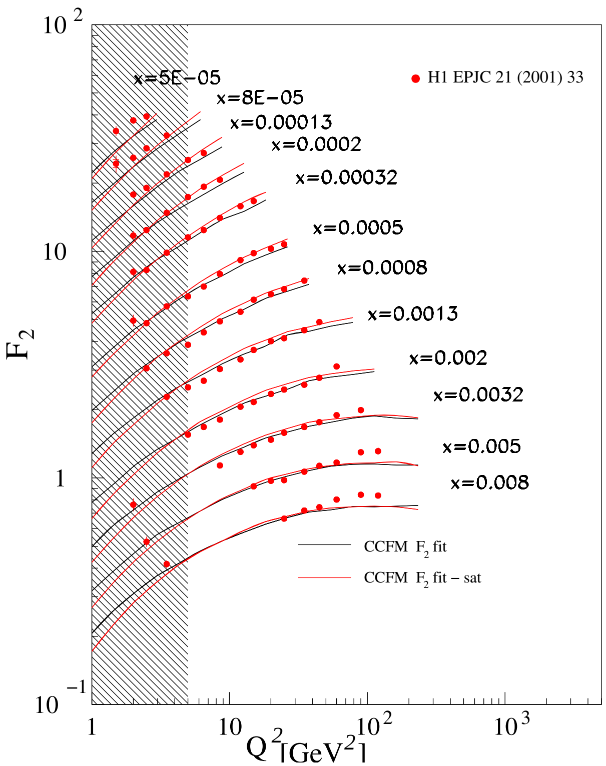
- One can require the amplitude coming from linear evolution equation (BFKL, CCFM) for some combination of gluon momentum and rapidity to be constant and close to unity $\longrightarrow$ this defines saturation line in "linear approach" (Mueller, Trintafyllopoulos).
- Monte Carlo $\longrightarrow$ it means that events that end up in saturated region are rejected

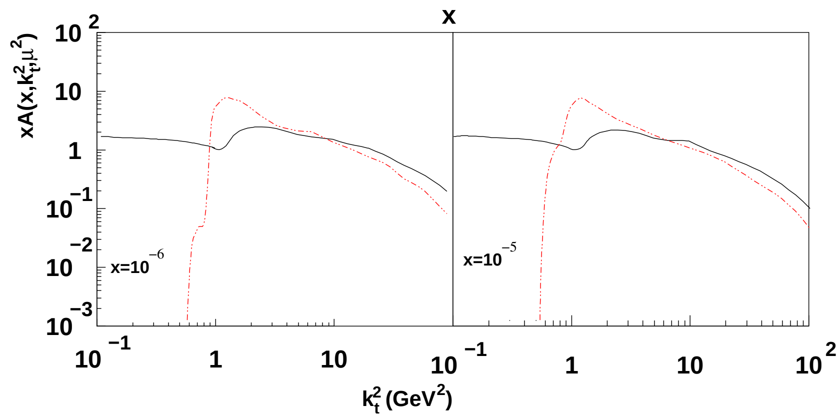
Simple model with inbuild saturation effects: Golec-Biernat Wüsthoff model



- Given by formula $\longrightarrow f(x,k^2) = N\frac{\mathbf{k}^2}{Q_O^2}(\frac{x}{x_O})^\lambda e^{-\frac{Q_O^2}{\mathbf{k}^2}(\frac{x}{x_O})^\lambda}$
- Saturation scale emerges $\longrightarrow$ $\mathbf{k}_{sat} = \frac{1}{Q_O}(\frac{x}{x_O})^{\lambda/2}$
- Universality$\longrightarrow$ similar spectrum emerges when one is using BK equation (nonlinear extaension of BFKL). Formula for saturation scale can be used as energy dependent cut-off in MC simulations

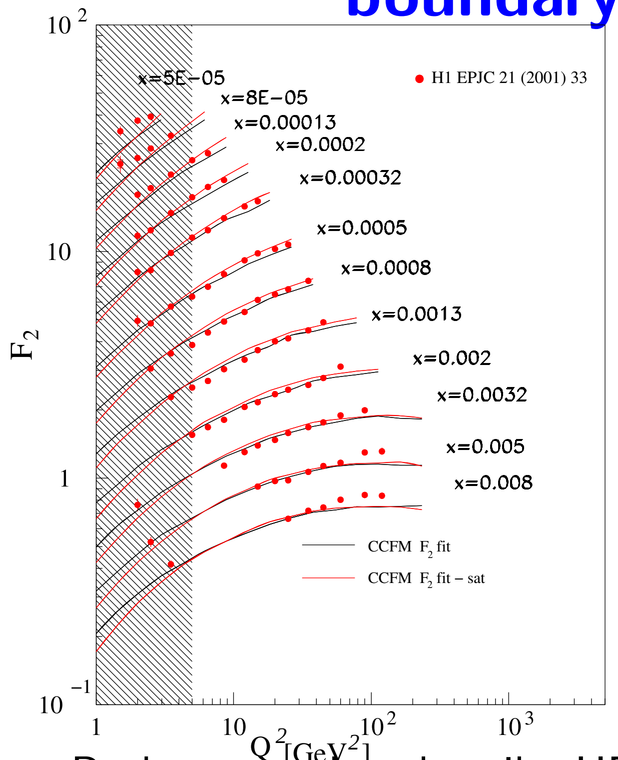
F_2 and gluon density from CCFM with absorptive boundary - very preliminary results

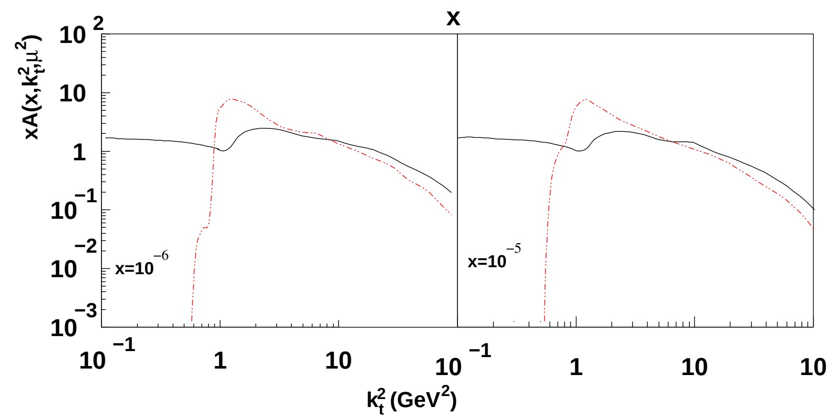




Parameters$\rightarrow xA_0(x,k^2) = Nx^{\alpha}(1-x)^4 e^{(k^2-k_0^2)/\mu}$, $Q_{sat} = Q_0(x_0/x)^{\lambda/2}$

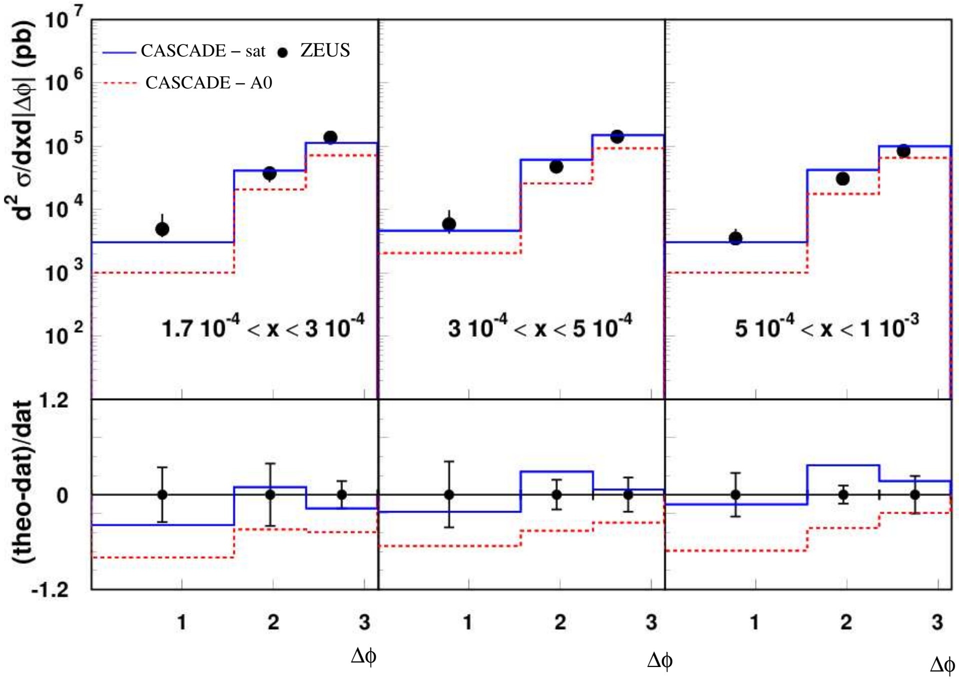
F_2 and gluon density from CCFM with absorptive boundary - very preliminary results

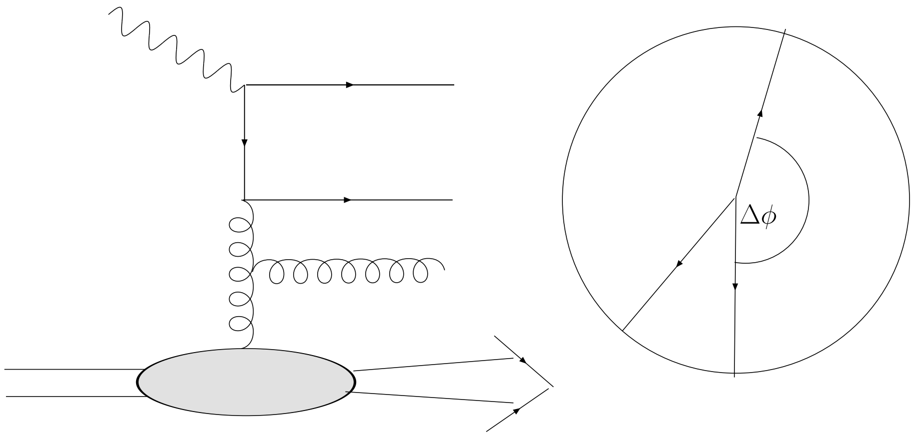




- Both approaches describe HERA data equally well. However, gluon densities are different...
- Possible implications for exclusive directly sensitive to k_T observables...

Angular distribution of 3-jets in DIS

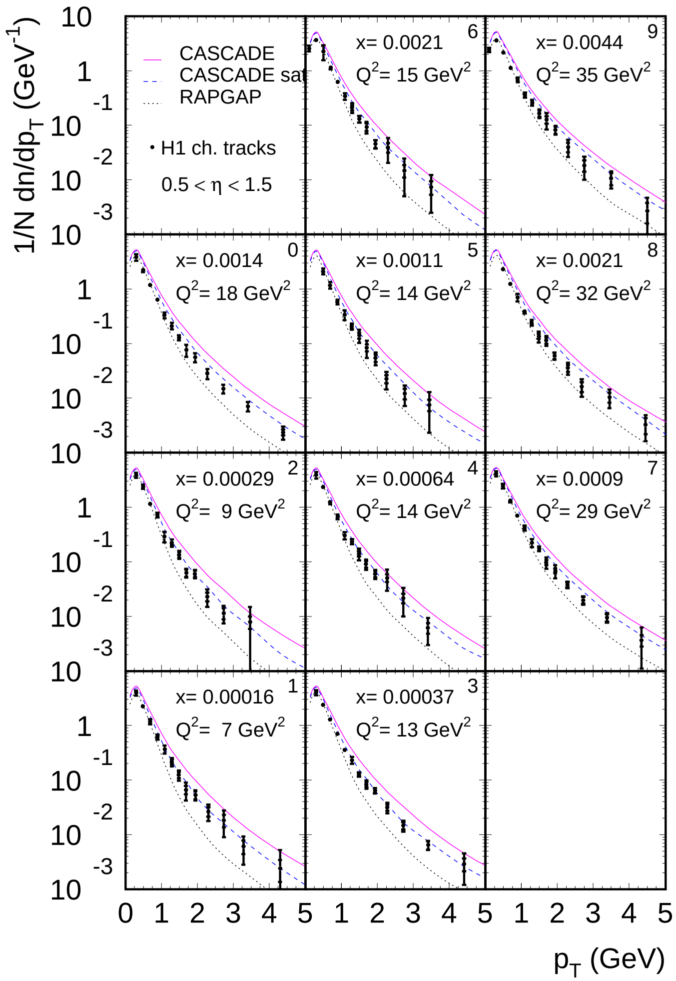




- $\Delta\phi$ $\longrightarrow$ angle beetwen two hardest jets
- Important region $\Delta\phi \simeq \pi$ $\longrightarrow$ sensitive to low k_T^2

Distribution of charged particles in DIS

Data → desy96-215-1



Conclusions and outlook

- We addressed saturation issues within CCFM Monte Carlo approach
- We obtained reasonable description of F_2 data
- We have description of exclusive observables with saturation
- We studied DIS but we can also adress hadron-hadron questions.

- Impact parameter issues
- Various scenarios for input distribution
- Still some other checks