Study of forward jet production in kt-factorisation in Cascade Monte Carlo generator

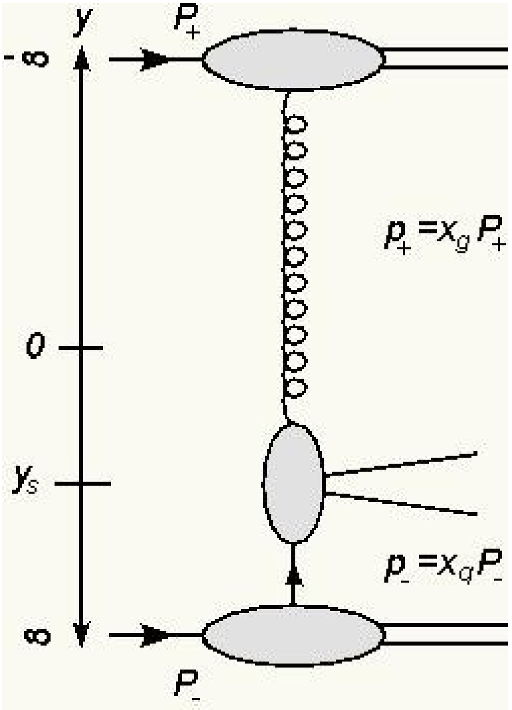
Michal Deák, Krzysztof Kutak,
Hannes Jung
DESY, Hamburg

Motivation

- particles with large rapidities when $p_+ << p_-$ $\rightarrow$ $y = \frac{1}{2} \ln \frac{p_+}{p_-}$

- momentum fractions of partons exchanged are disbalanced

- sensitivity to small-x dynamics expected



Motivation

- **a good probe for such a kinematical situation turns out to be hard sub-process *qg* □ *qg* – gluons dominated by small-x, quarks with larger-x**

$$\left.\begin{array}{l} x_g \approx 10^{-5} \\ x_q \approx 10^{-1} \end{array}\right\} \Rightarrow y_s \approx 5$$

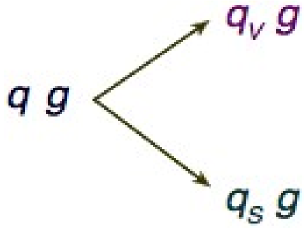
- **failure of DGLAP evolution expected at very small-x**
- **in Monte Carlo generator <u>Cascade</u> CCFM evolution for gluons**
- **CCFM – angular ordering for coherence**

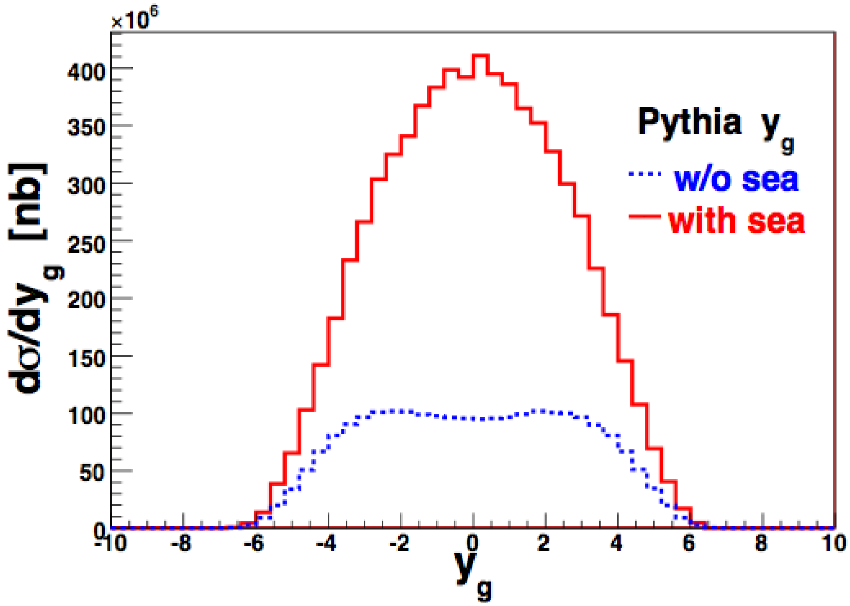
$$q_{i\perp} > \frac{z_{i+1} q_{i+1\perp}}{1 - z_{i+1}} \xrightarrow{z_{i+1} \to 0} q_{i\perp} > z_{i+1} q_{i+1\perp}$$

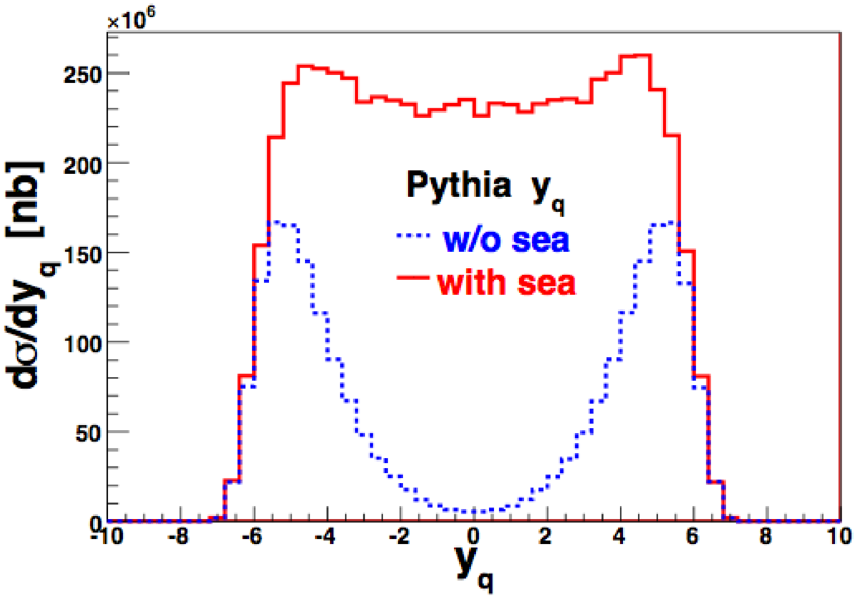
- **interpolation between DGLAP and BFKL**
- **only gluons and valence quarks**

Motivation

- **Forward partons in *qg* → *qg* in Pythia**
- **Initial state can be split into two contributions**



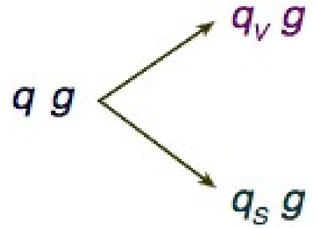


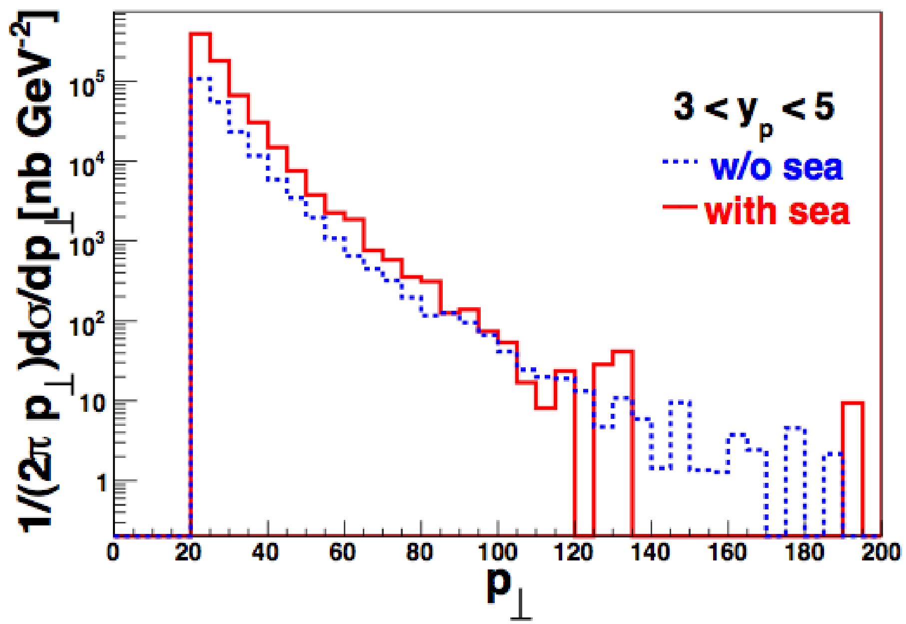


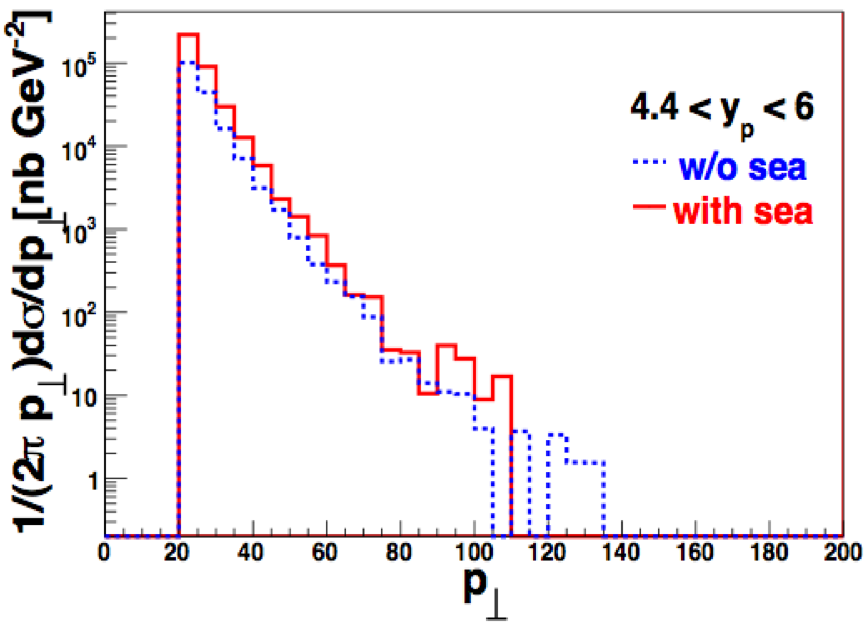
- **sea quarks contribute considerably to the cross section in the central rapidity region**

Motivation

- **Forward partons in *qg* → *qg* in Pythia**
- **Initial state can be split into two contributions**

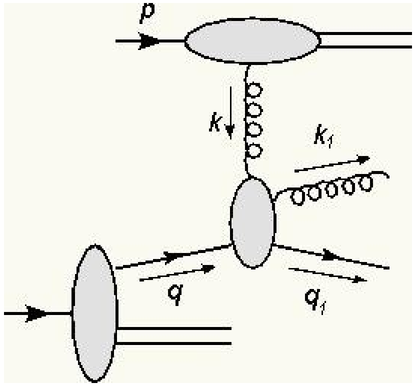






- **sea quarks contribute less in forward region**

Matrix element

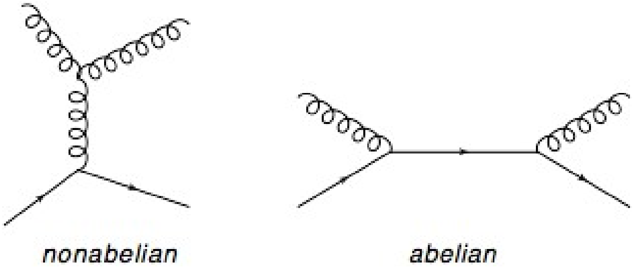


- we take initial state gluon off-shell – transversal momentum of gluon not neglected
- calculation in axial gauge with polarisation sum of the gluon:

$$\frac{k_\perp^\mu k_\perp^\nu}{|k_\perp|^2}$$

- the calculation is more involving because of additional degree of freedom of gluon

- abelian and non-abelian part

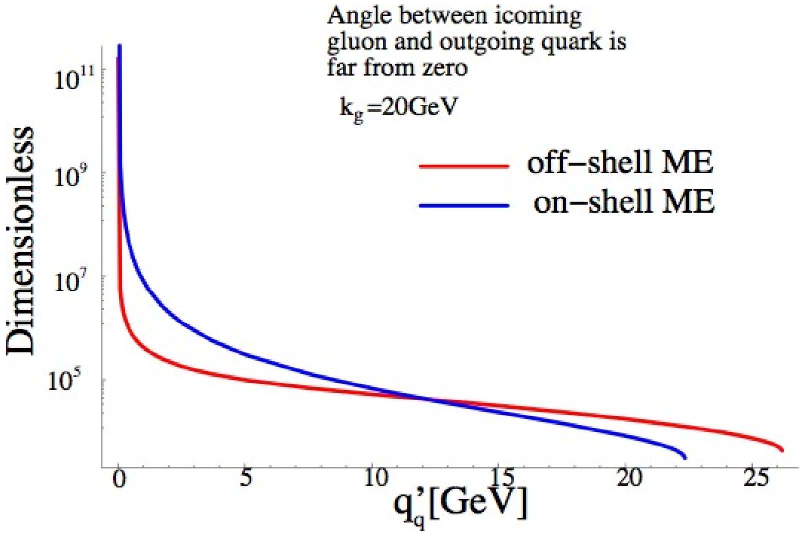


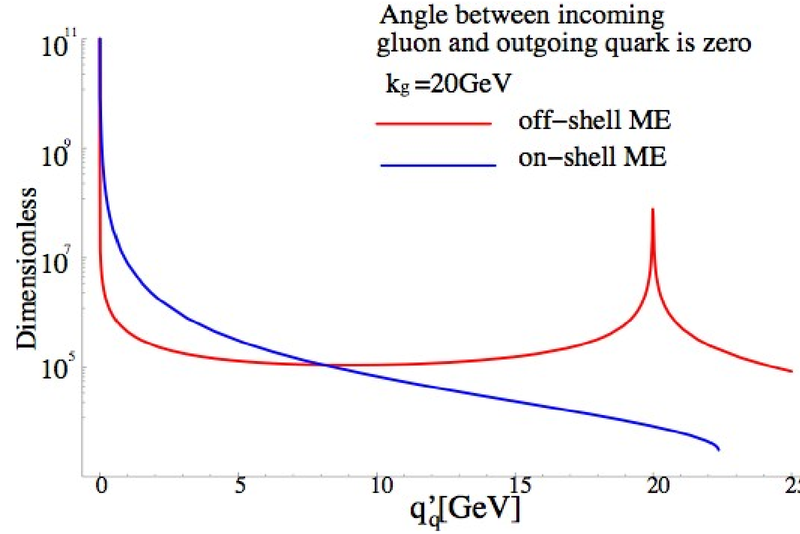
$$|M_{ab}|^2 = \frac{C_A C_F^2}{N_C(N_C^2-1)}\left(\frac{k.q}{p.q}\right)^2 \frac{(p.q)^2+(p.q_1)^2}{k_1.q\, k_1.q_1}$$

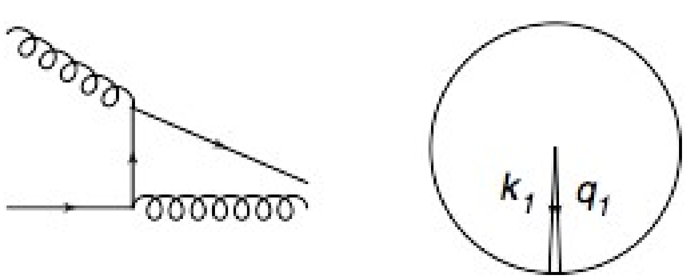
$$|M_{nab}|^2 = \frac{C_A^2 C_F}{2N_C(N_C^2-1)}\left(\frac{k.q}{p.q}\right)^2 \frac{(p.q)^2+(p.q_1)^2}{k_1.q\, k_1.q_1}\left(-\frac{2k_1.q_1\, p.q}{\hat{t}\, k_1.p}-\frac{2k_1.q\, p.q_1}{\hat{t}\, k_1.p}-1\right)$$

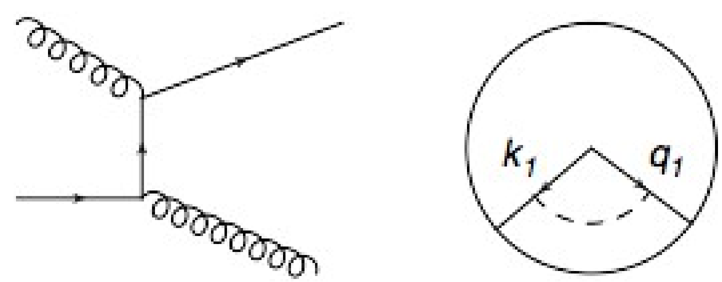
Matrix element

- **Singularity structure**



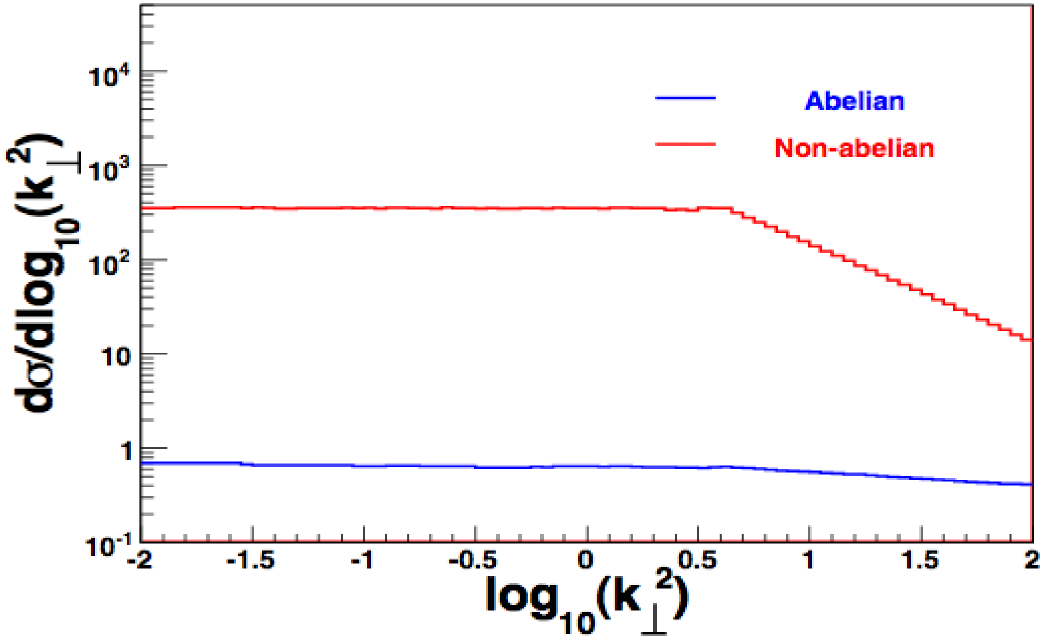






Matrix element

- **abelian and non-abelian part as functions of k_T**
- **Fixed momentum fractions x_1, x_2 and proton-proton collision energy. Integrated over the final state with p_t > 1 GeV**
- **Starts to fall at $\sim 4(p_t)^2$**



- **abelian part negligible**

Matrix element and cross section

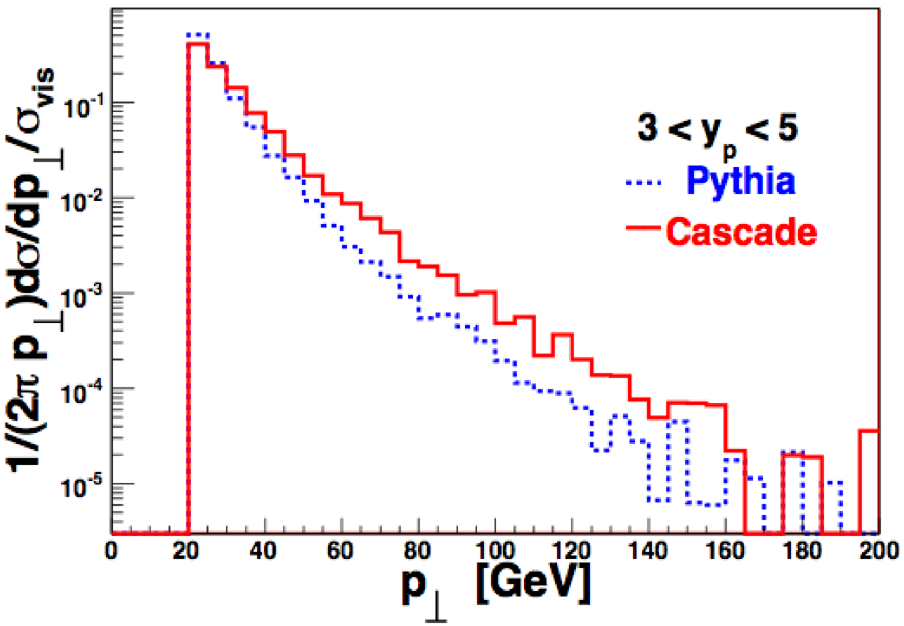
- **more exact kinematics**
- **final state parton transversal momenta not balanced**
- **additional cuts compared to collinear calculation**
- **singular when final state particle collinear with initial state quark**
- **simple solution: cuts on transversal momenta in laboratory frame of final state particles**
- ***unintegrated parton density function* - uPDF**
- **the cross section**

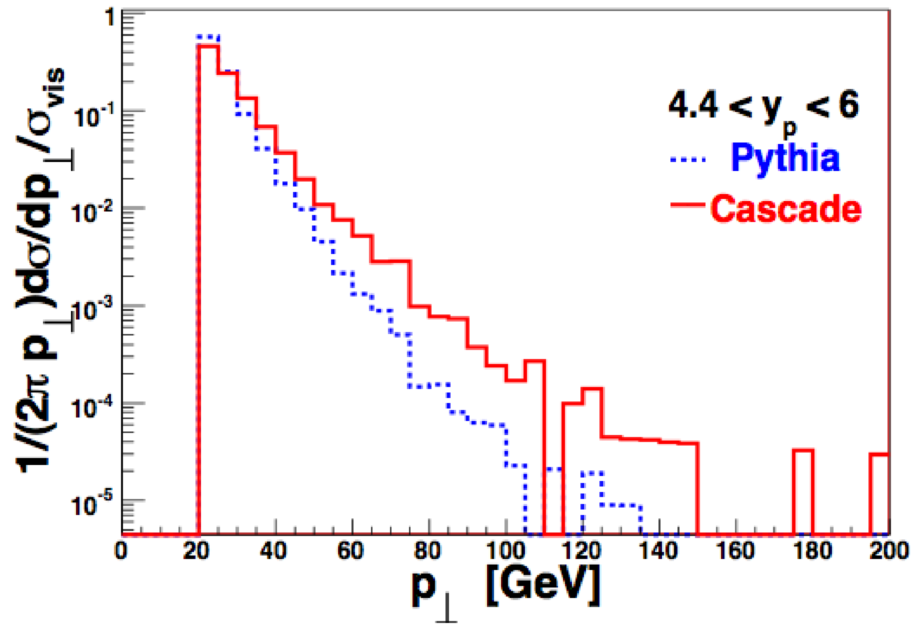
$$\sigma \sim \hat{\sigma}\left(x_1, x_2, k_{1\perp}\right) \otimes \mathcal{G}\left(x_1, k_{1\perp}, \mu^2\right) \mathcal{Q}\left(x_2, \mu^2\right)$$

- **valence quarks CTEQ6L; evolved by CCFM - transverse momentum neglected in the matrix element, not in kinematics.**

Comparison with Pythia

- **Jet Nr. 1:** ***$-2 < y < 2$,*** ***$p_T > 20$ GeV***
- **Jet Nr. 2:** ***$3 < y < 5$* and $4 < y < 6.6$,** ***$p_T > 20$ GeV***
- **Shape comparison**



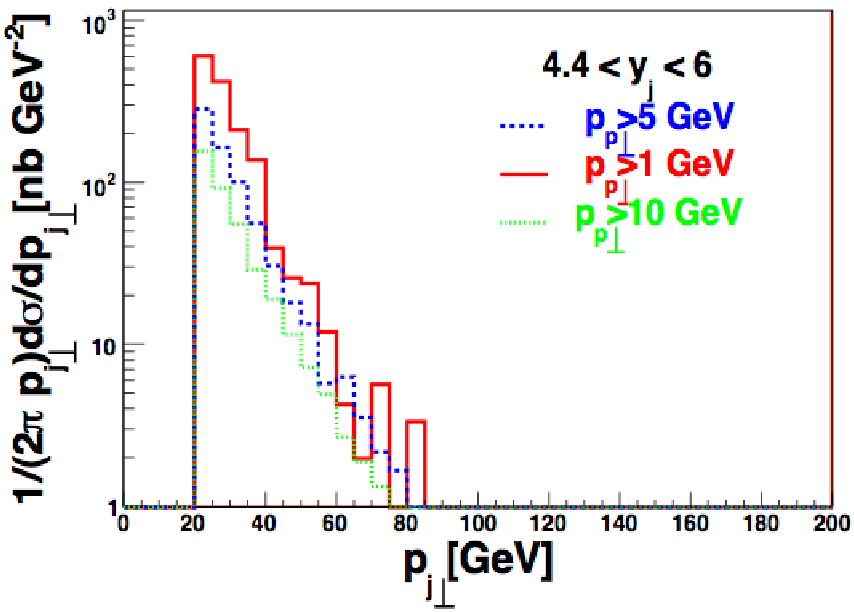


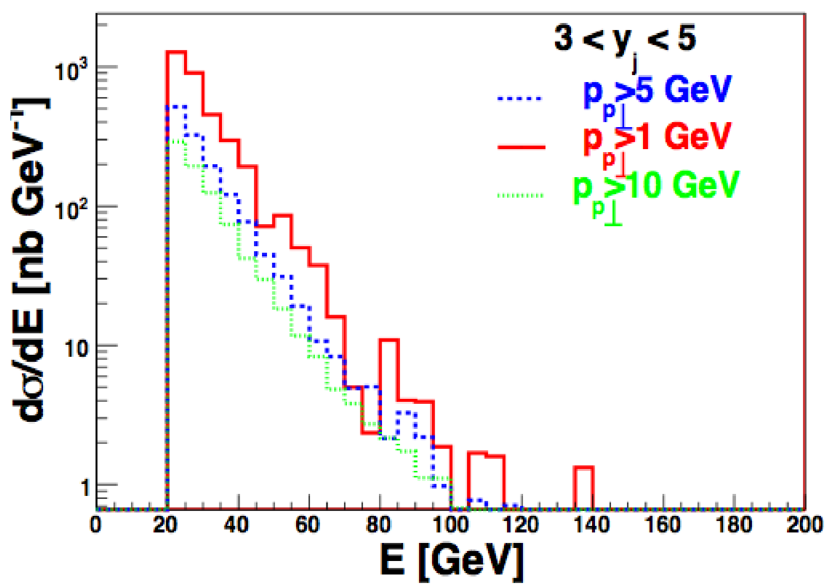
Summary

- **investigation of the small-x dynamics using forward jet production**
- **significant contribution coming from the subprocess $qg \to qg$**
- **study of the contribution of sea-quarks in forward rapidity region**
- **matrix element calculation with more correct kinematics; off-shell gluon**
- **study of the matrix element $qg^* \to qg$**
- **results for experimentally accessible region**
- **further studies still needed**
- **calculation will be included in the next CASCADE release**

Phenomenology

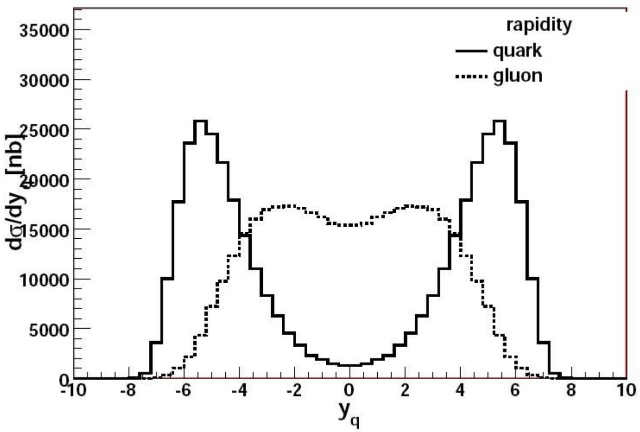
- CCFM showers are not necessarily ordered in transversal momentum
- partons from hard subprocess can combine with gluons from parton showers to form a jet
- by applying a cut on p_{jT} doesn't mean restriction for p_{pT}
- results in dependence of the visible jet cross section on the p_{pTmin} cut

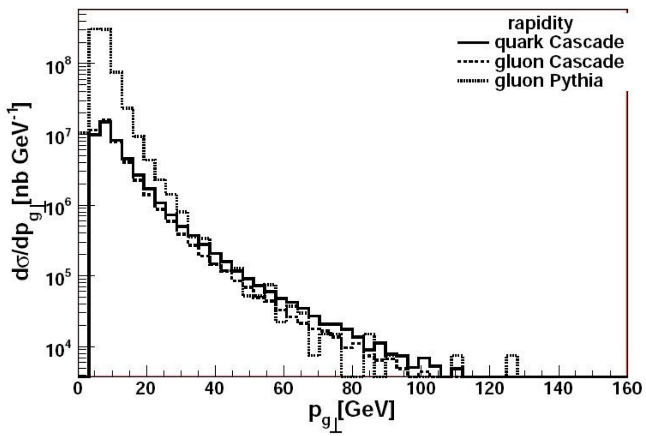




Parton-jet approximation

- **approximate jets by hard subprocess final state partons**
- **results:**
  - **rapidity distributions**
  - **p_t distributions**





- **distributions dominated by non-abelian part**
- **differences in normalization and shape**