Forward jet production at the LHC

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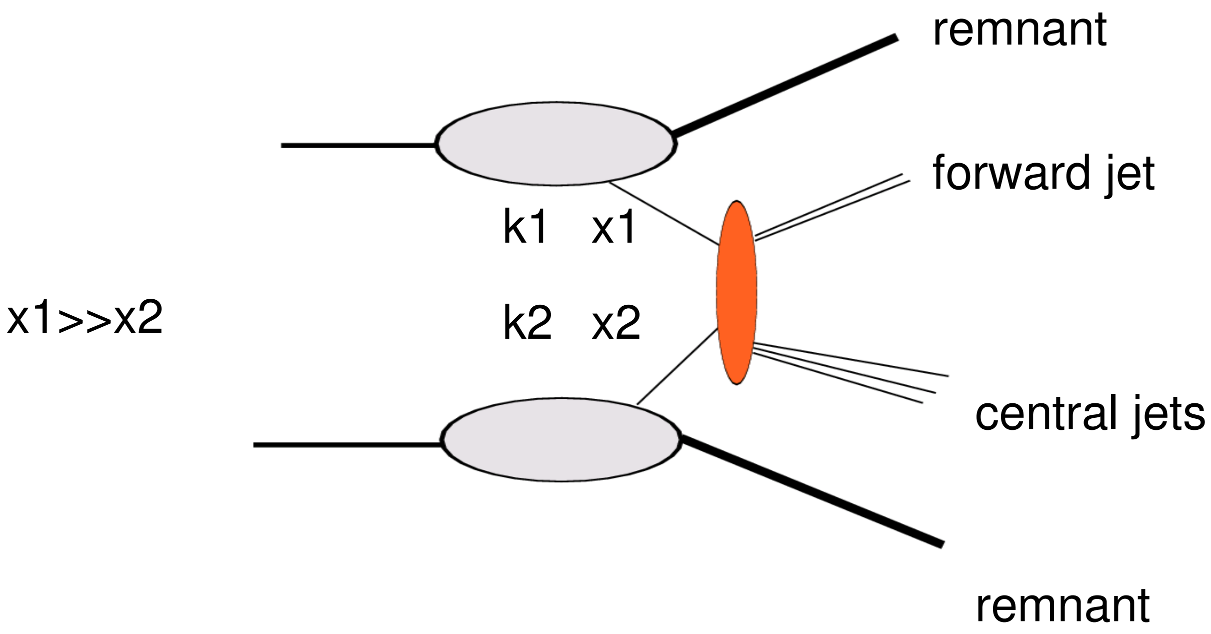
Large part based on based on:
JHEP09(2009)121, M. Deak, H. Jung, F. Hautmann, K. Kutak

MOTIVATIONS

Mueller,Tang,Webber, Royon,
Marquet, Peschanski,...

Jet production at the LHC



- gg -> qq
- gg -> gg
- qg -> qg

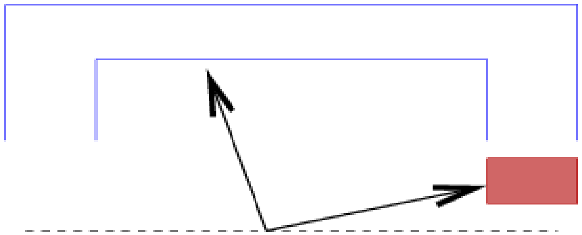
- Phase space opening for large energies
  - Unique coverage of large rapidities

Physcis of hard processes with multiple hard scales

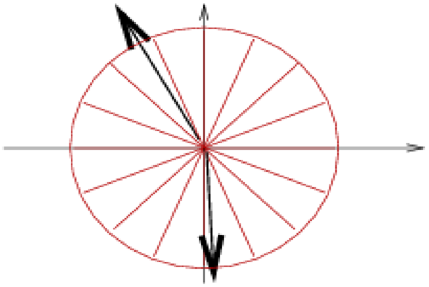
And highly sensitive to parton dynamics at x -> 0 and x -> 1

MEASUREMENT

- Polar angles small but far enough from beam axis
  - Measure azimuthal plane correlations



central + forward detectors



azimuthal plane

CMS Coll, CERN-LHCC-2006-001; CMS PAS FWD-08-001 (2008);

CMS Coll., TOTEM Coll, CERN-LHCC-2066-039/G -124 (2006)

CMS Coll, CERN-LHCC-2006-001; CMS PAS FWD-08-001 (2008);

M. Grothe, arXiv:0901.0998; D. d'Enterria, arXiv:0806.0883;

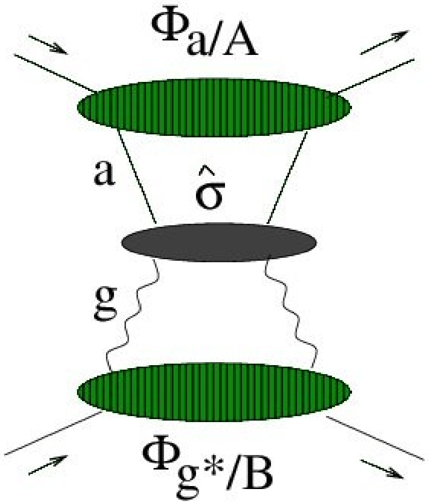
X. Aslanoglou et al., CERN-CMS-NOTE-2008-022 (2008)

H. Jung et al., HERA-LHC Proc. arXiv:0903.3861;

HIGH ENERGY AT FIXED TRANSVERSE MOMENTUM – FORWARD JETS AT LHC

$$\frac{d\sigma}{dQ_T^2 d\varphi} = \sum_a \int \phi_{a/A} \otimes \frac{d\widehat{\sigma}}{dQ_T^2 d\varphi} \otimes \phi_{g^*/B}$$

Consistent resumation both logs of rapidity and logs of hard scale



Deak, Jung, Hautmann & K JHEP(2009) 121

◇ ϕ_a near-collinear, large-x; ϕ_{g^*} $k_\perp$-dependent, small-x
◇ $\widehat{\sigma}$ off-shell continuation of hard-scattering matrix elements

HIGH ENERGY AT FIXED TRANSVERSE MOMENTUM – FORWARD JETS AT LHC

$\phi_{g^*/B}$ - sum up terms - $$\sum_n \sum_m \alpha_s^m ln^n (s/\mu)$$

Lipatov ,Fadin, Kuraev "77
Ciafaloni '89, Catani, Fiorani, Marchesini,

$\phi_{a/A}$ - sum up terms - $$\sum_n \sum_m \alpha_s^m \ln^n (p_T/\Lambda_{QCD})$$

DGLAP

$\hat{\sigma}$ - takes into account logs of hard scale and of energy

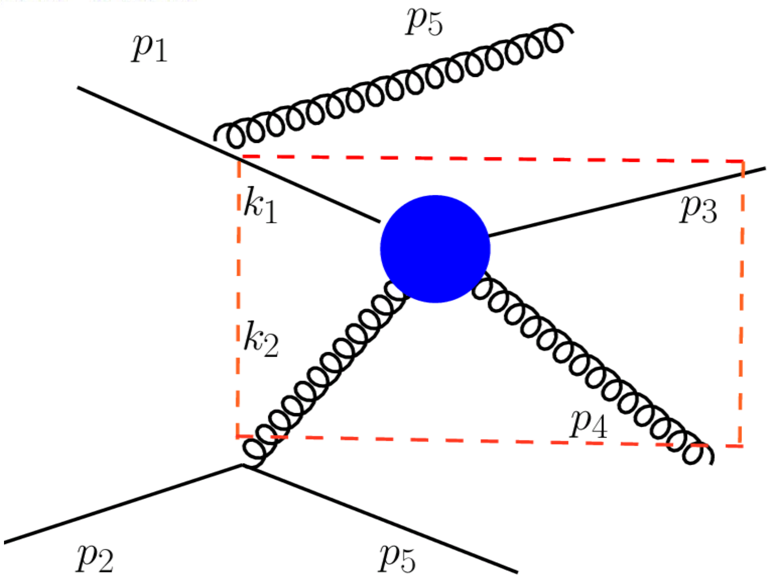
HARD SCATTERING CROSS SECTIONS qg -> qg

- Matrix elements for fully exclusive events with forward jets
- Both quark and gluon channels found to be important for realistic phenomenology

$$\mathcal{M}_{qg\to qg} = g^4\left(\frac{k_1\,k_2}{k_1\,p_2}\right)^2\left[\frac{(N_c^2-1)}{(4N_c^2)}\,\frac{(k_1\,p_2)^2+(p_2\,p_3)^2}{(k_1\,p_4)\,(p_3\,p_4)}+\frac{C_1C_A}{(2C_F)}\,\frac{(k_1\,p_2)^2+(p_2\,p_3)^2}{(k_1\,p_4)\,(p_3\,p_4)}\times\right.$$

$$\left.\left(\frac{(p_3\,p_4)\,(k_1\,p_2)}{(k_1\,p_3)\,(p_2\,p_4)}+\frac{(k_1\,p_4)\,(p_2\,p_3)}{(k_1\,p_3)\,(p_2\,p_4)}-1\right)\right]$$

- in collinear limit reduce to standard matrix elements.

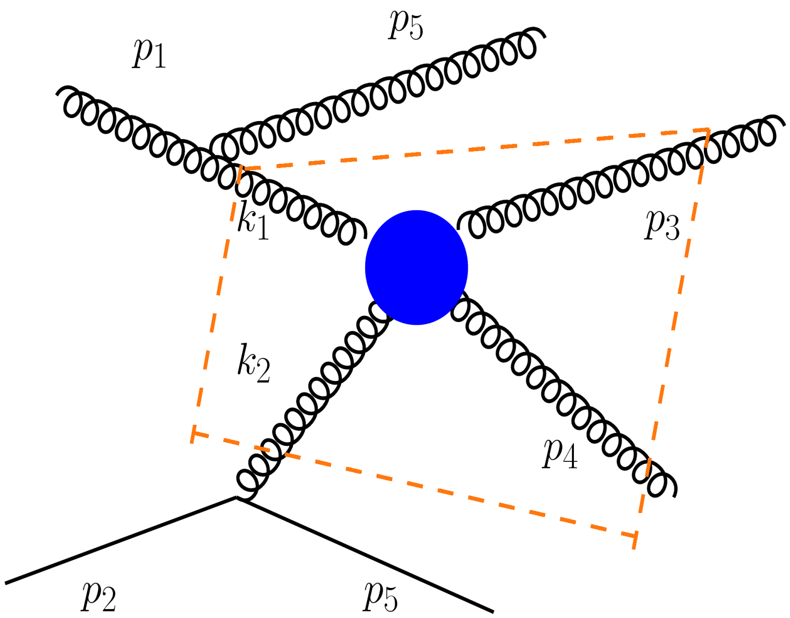


HARD SCATTERING CROSS SECTIONS gg-> gg

- Matrix elements for fully exclusive events with forward jets
- Both quark and gluon channels found to be important for realistic phenomenology

$$\mathcal{M}_{gg\to gg} = \frac{g^4 N_c^2}{(N_c^2-1)} \left(\frac{k_1\, k_2}{k_1\, p_2}\right)^2 \frac{(p_3\, p_4)(k_1\, p_2)+(k_1\, p_4)(p_2\, p_3)+(p_2\, p_4)(k_1\, p_3)}{(p_2\, p_4)(k_1\, p_4)(p_3\, p_4)(k_1\, p_2)(p_2\, p_3)(k_1\, p_3)} \times$$

$$\left[(p_2\, p_4)^4+(k_1\, p_2)^4+(p_2\, p_3)^4\right]$$

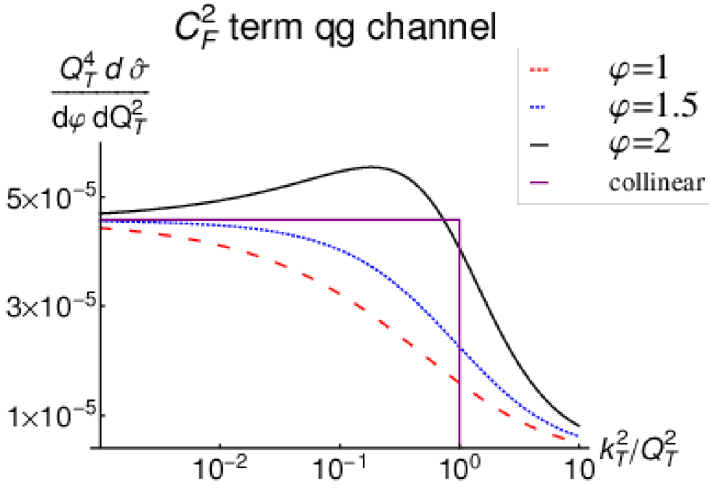


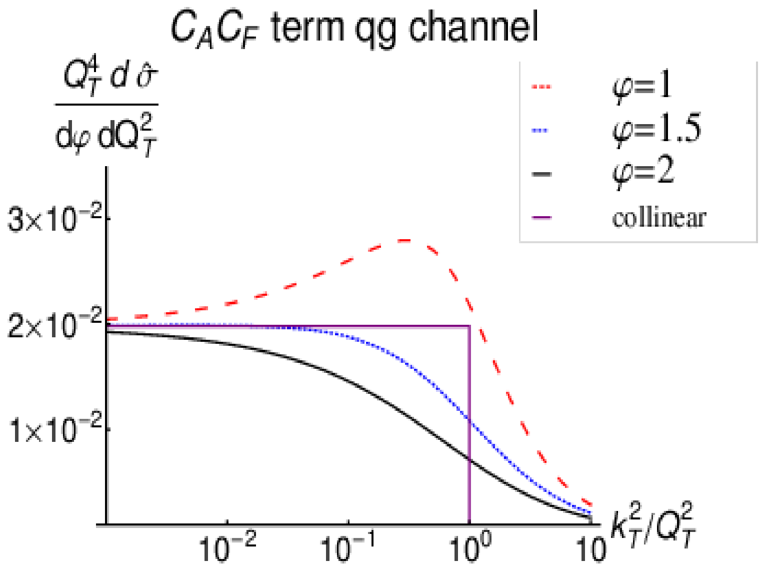
- in collinear limit reduces to standard matrix element.

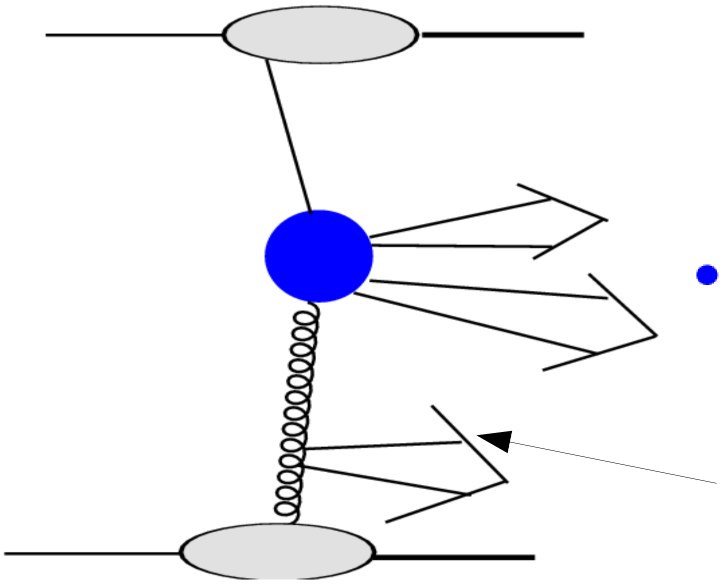
BEHAVIOR AT LARGE kt qg CHANNEL

k_T = transversal momentum of incoming gluon = transverse momentum carried away by extra jets

$k_T/Q_T \rightarrow 0$ leading order process


C_F^2 term qg channel


$C_A C_F$ term qg channel



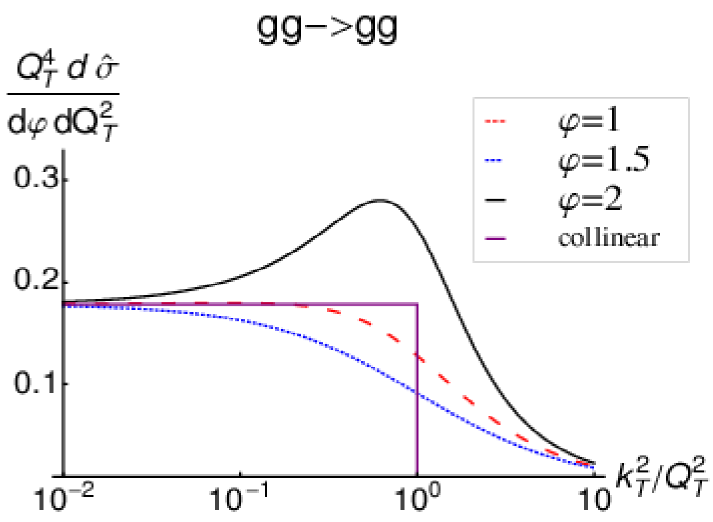
- dynamical cut-off at $k_T \sim Q_T$ set by coherence effects
  - ▷ non-negligible terms from finite k_T tail

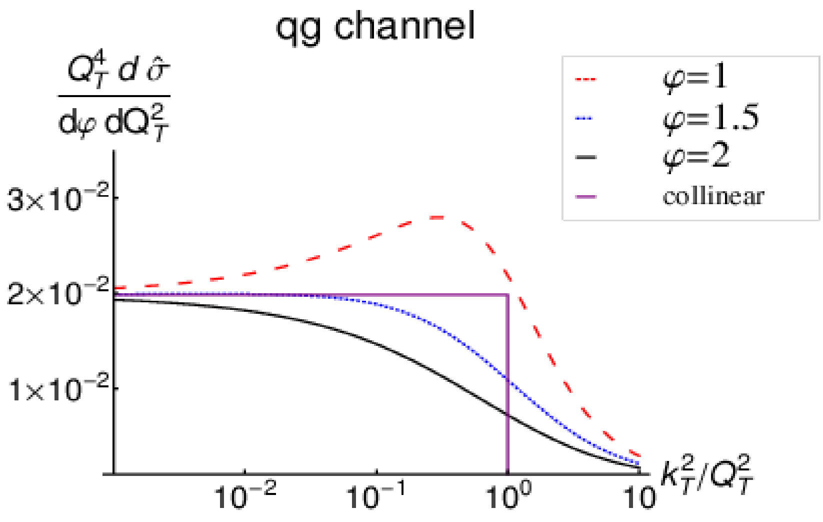
Such hard emission is not possible at LO DGAP parton shower. High energy approach allows for it

BEHAVIOR AT LARGE kt gg vs. qg

k_T = transversal momentum of incoming gluon = transverse momentum carried away by extra jets

$k_T/Q_T \to 0$ leading order process



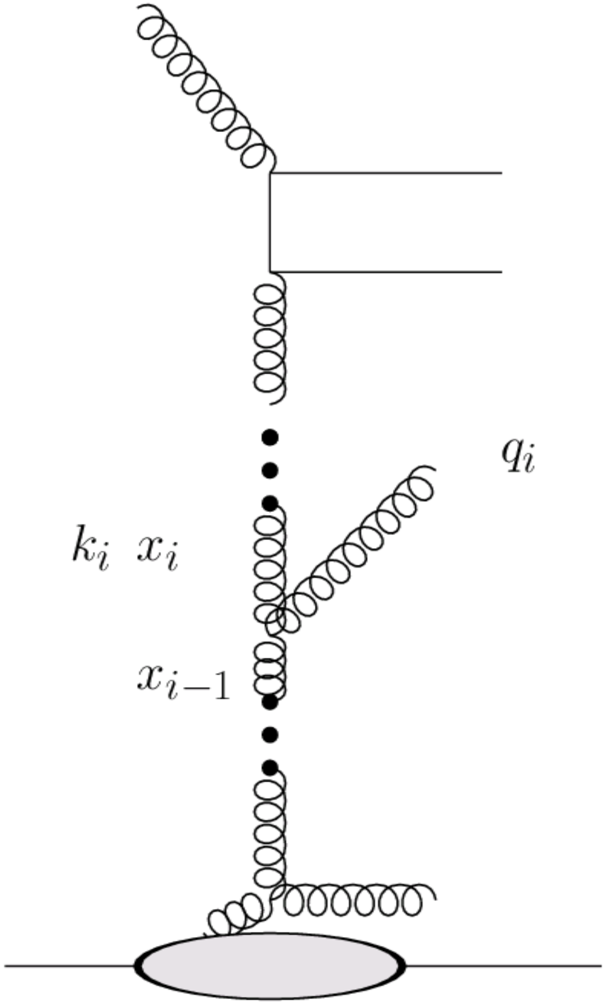


[Deák, Hautmann, Jung, & K JHEP09(2009)121]

- gluon dominates on matrix element level

PARTON DENSITY FROM CCFM

Equation based on strong ordering in angle and coherence effects at high energies. Interpolates between DGLAP and BFKL .



$$p = \frac{q}{1-z} \qquad z = \frac{x_i}{x_{i-1}} \qquad \overline{p} = \frac{\overline{q}}{1-z}$$

Implemented in CASCADE Monte Carlo (H. Jung)

$$\xi = \frac{z_i p_i^2}{x_i^2 E}$$

Sudakov form factor. No branching.

$$\mathcal{A}(x,k,\overline{p}) = \overline{\alpha}_s \int_x^1 dz \int \frac{d^2p}{\pi p^2} \theta(\overline{p} - zp) \Delta_s(\overline{p}, zp)$$

$$\times \left(\frac{\Delta_{ns}(k,z,p)}{z} + \frac{1}{1-z} \right) \mathcal{A}\left(\frac{x}{z}, |k + (1-z)p, p| \right)$$

Non-Sudakov form factor. Regularizes 1/z singularity

PHENOMENOLOGY

- We can calculate the convolution formula for the cross section using a Monte Carlo generator and study jet observables
- Look for small-x dynamics effects at forward calorimeter

We can study two jet correlations:

-one jet in the central rapidity region $-2 < |y| < 2$ $p_t > 10\mathrm{GeV}$

-the other in the forward rapidity region $3 < |y| < 5$ $p_t > 10\mathrm{GeV}$

TOWARD JET OBSERVABLES

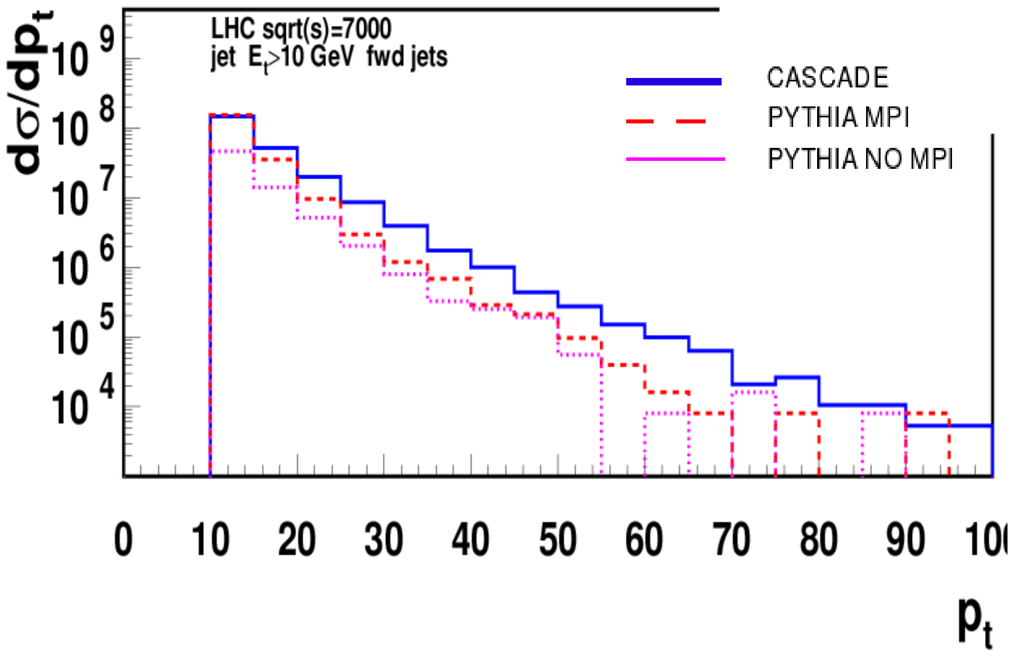
- CASCADE

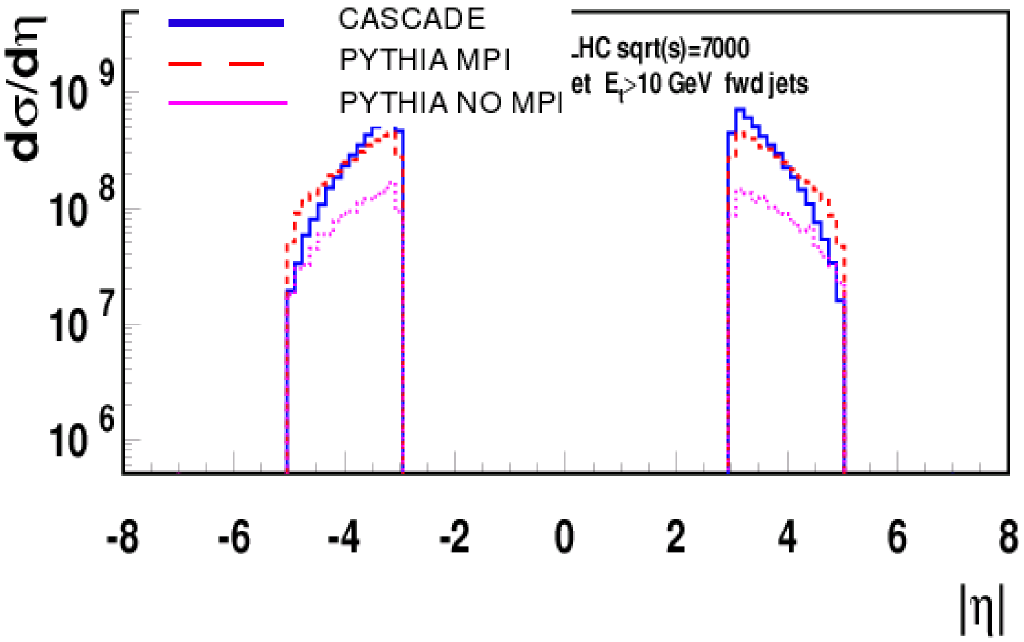
- unintegrated gluon density from CCFM (can be run in DGLAP mode too)
- unintegrated valence quark density from integrated CTEQ, CCFM-like evolution
-no sea quarks

- PYTHIA

-integrated pdfs CTEQ
-sea quarks included but small contribution
-run both in multiple and no multiple interactions mode

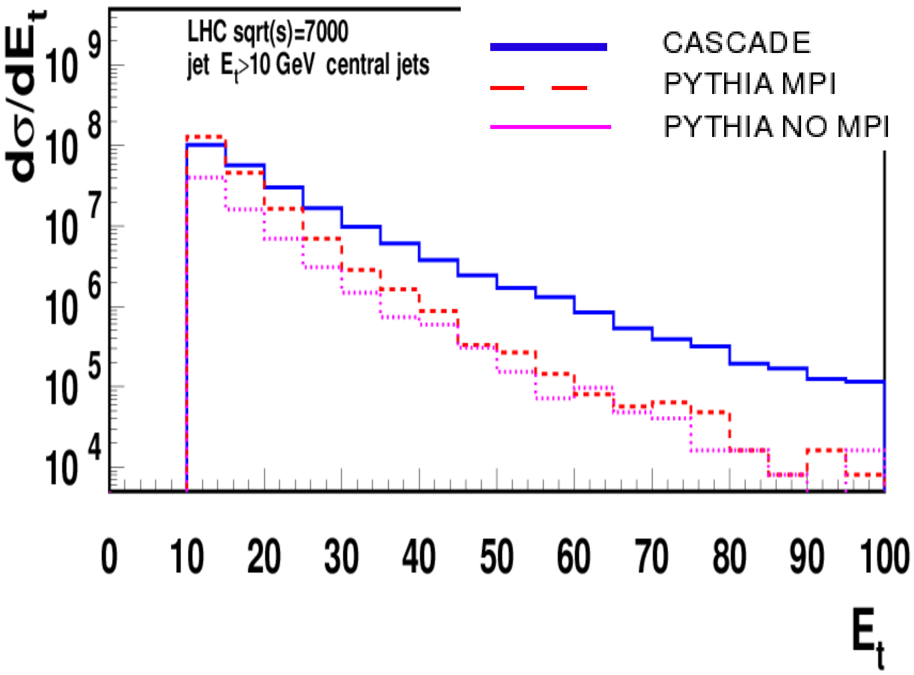
SPECTRA OF PRODUCED FORWARD JET

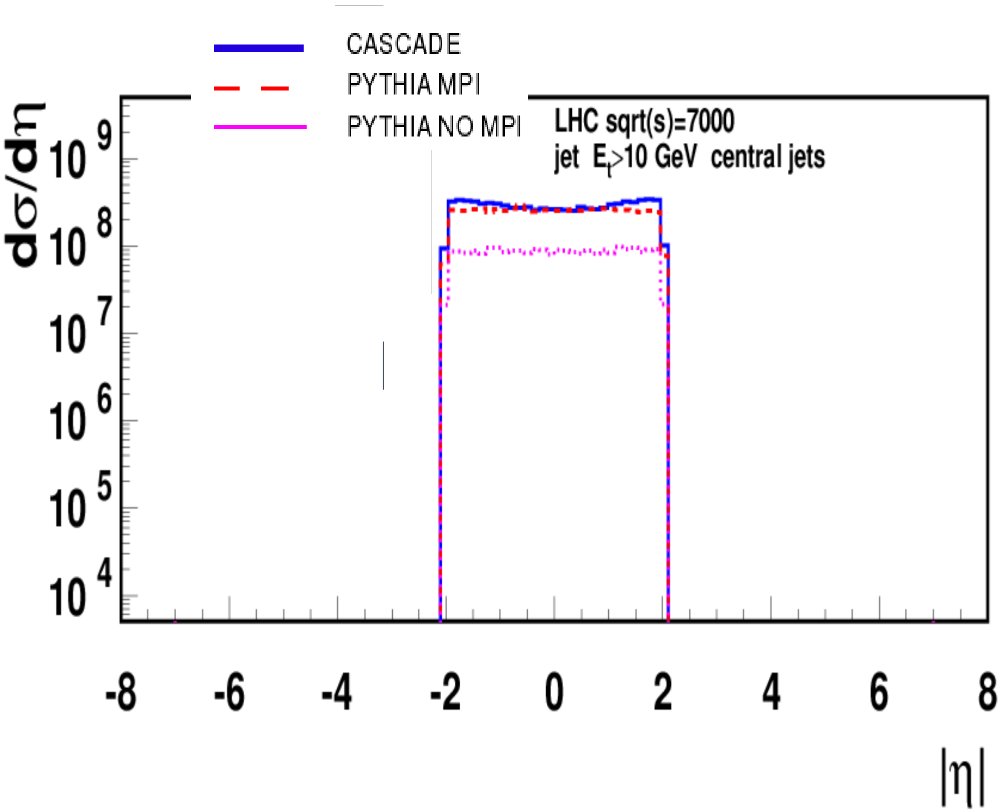




- kt of incoming gluon and coherence allows for harder spectrum
- CASCADE uses CFFM like parton showers which are not ordered in kt
- Multiple interactions and collinear shower clearly different from high
- energy factorization
- At central pseudo-rapidities the high energy factorization tends to agree with MPI approach

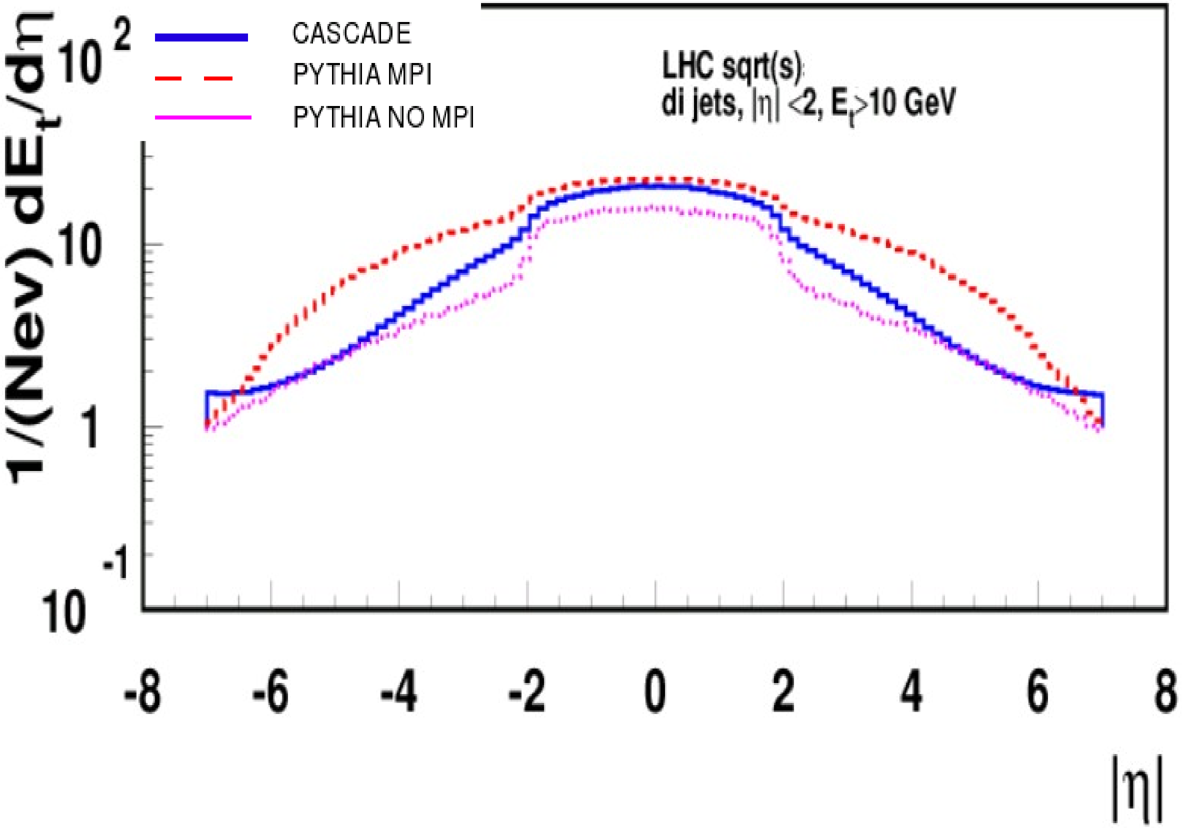
SPECTRA OF PRODUCED CENTRAL JET





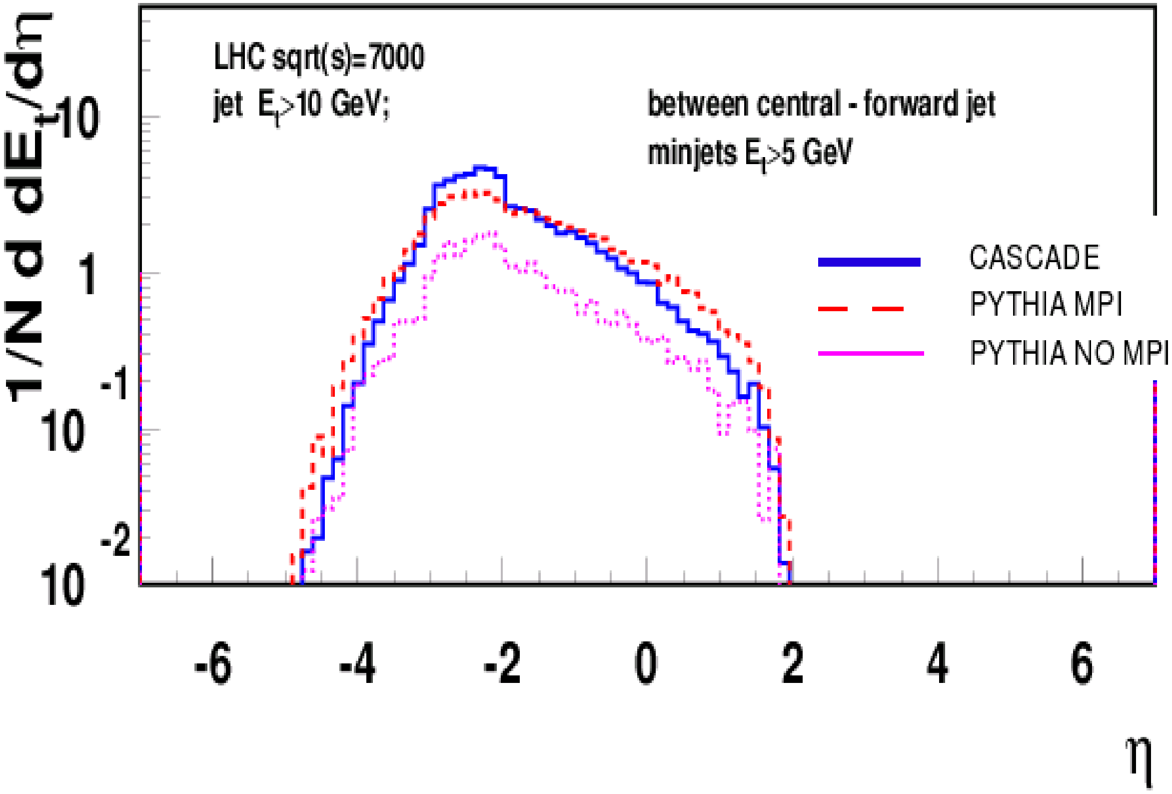
- kt of incoming gluons and coherence allows for harder spectrum
- CASCADE uses CCFM like parton showers which are not ordered in kt
- Multiple interactions model in some regions mimics high energy factorization

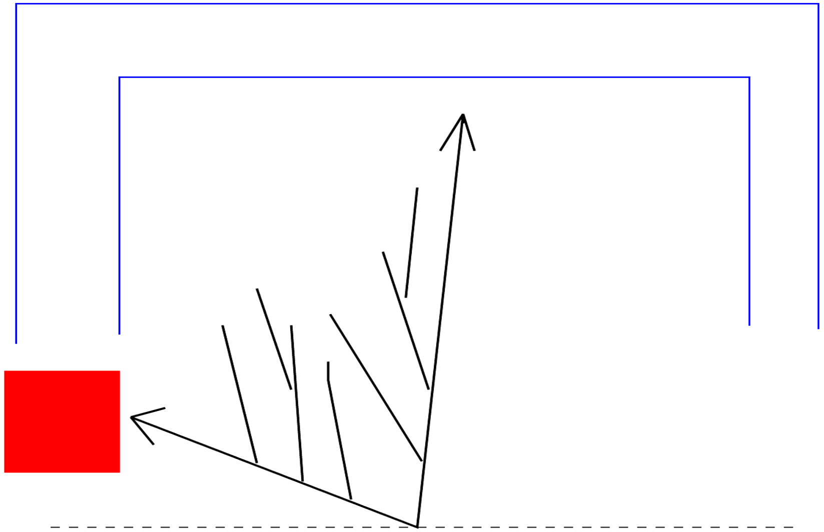
ENERGY FLOW – ONE OF THE FIRST MEASUREMENTS IN FORWARD GROUP AT LHC



- GLOBAL OBSERVABLE , SIMPLEST TO MEASURE
  - IN CENTRAREGION CASCADE AND MPI PYTHIA SIMILAR
    - LARGER ENERGY PREDICTED BY MPI PYTHIA IN THE FORWARD

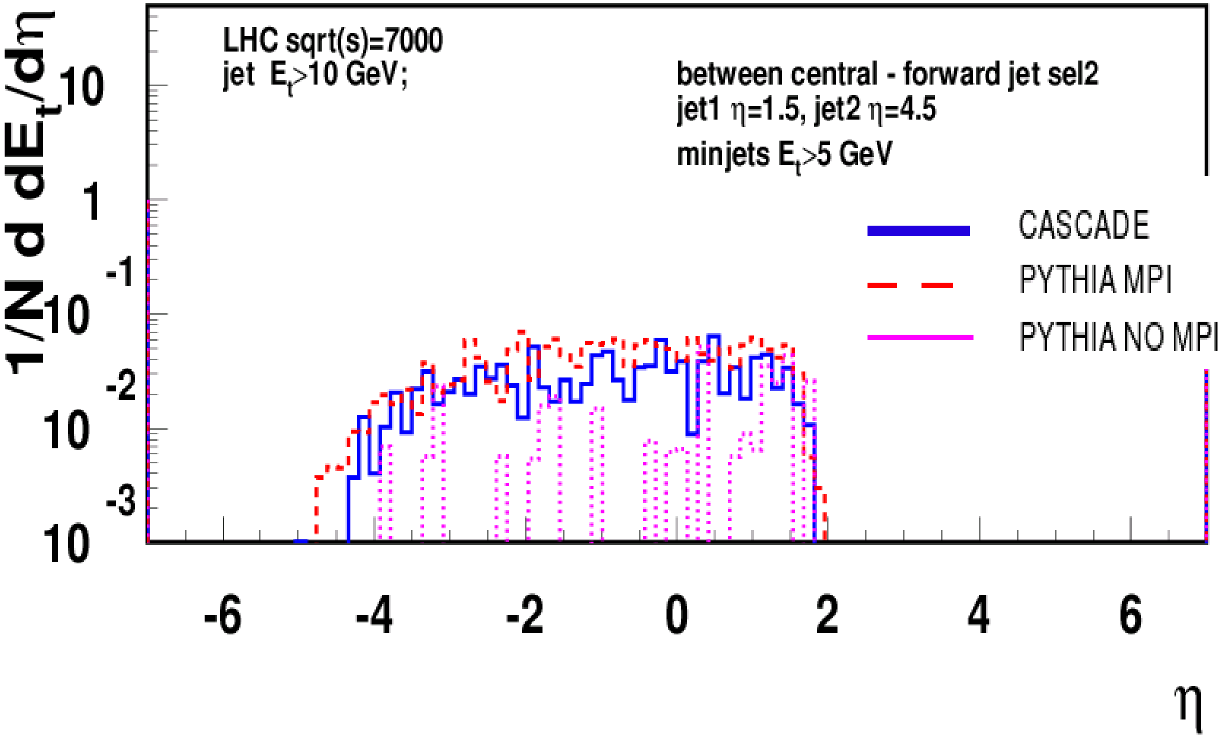
TRANSVERSE ENERGY FLOW

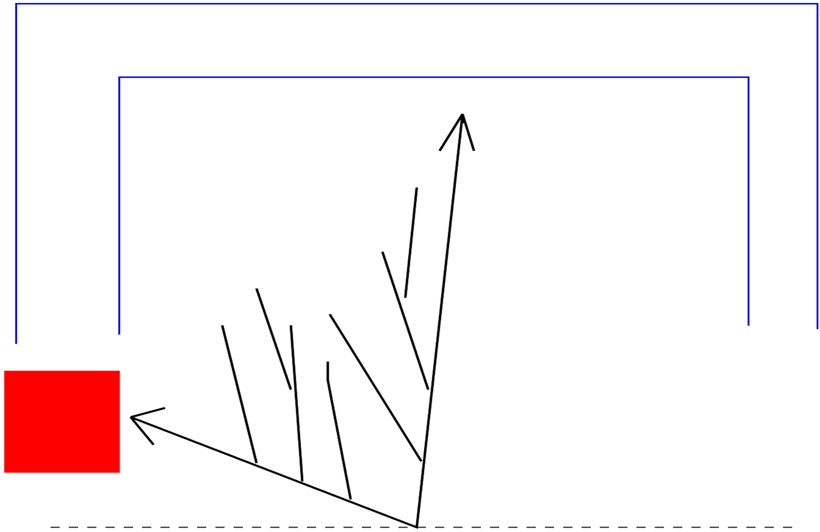




- Larger energy flow in central region predicted by CASCADE and MPI-PYTHIA

TRANSVERSE ENERGY FLOW-MINIJETS





- Much lower rates at which minijets are emitted in collinear approach
  - Multiple interactions model mimics CCFM shower

Conclusions

- LHC opens phase space for large center-of -mass energies and for presence of multiscales
- This brings perturbative corrections which are summed up by high energy factorization
- We developed an approach which from first principles allows for studies of forward jet phenomena at LHC
- Considered by us observables allow for discrimination between different approaches