From LHeC to LHC and back:

the issue of forward jets

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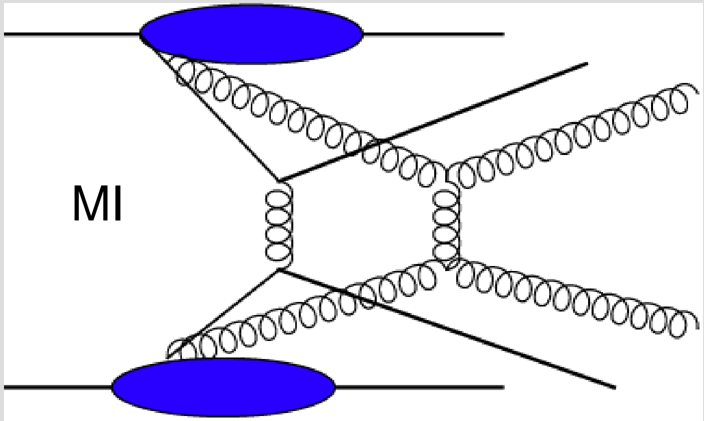
MOTIVATIONS

- Multiple Interactions usually studied in context of hadron – hadron collision
- One can study this issues also using DIS
- Unique possibility to investigate the amount of MI dependence on Q at very low x
- One could more clearly disantangle:

  multiple interactions,
  rescatterings
  effects of kt shower

Problem of MI in p-p

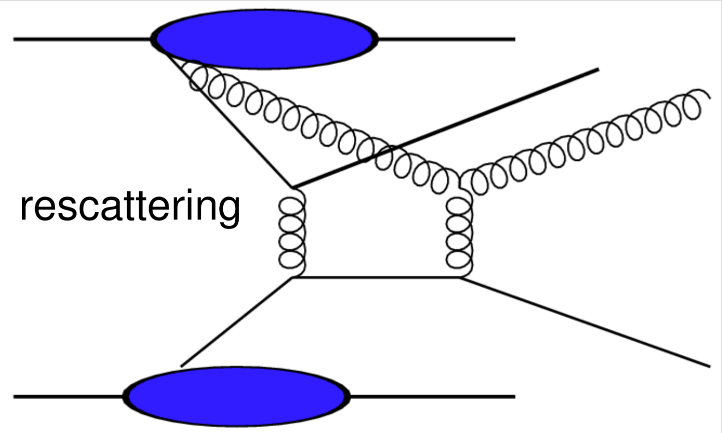
$$\frac{d\sigma}{dp_\perp^2} = \sum_{i,j} \int dx_1 \int dx_2\, f_i(x_1, Q^2)\, f_j(x_2, Q^2)\, \frac{d\hat{\sigma}}{dp_\perp^2}$$



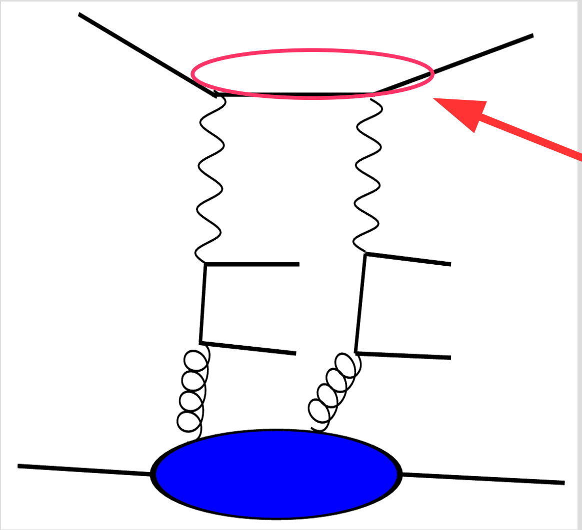
Cross -section diverges

Color screening

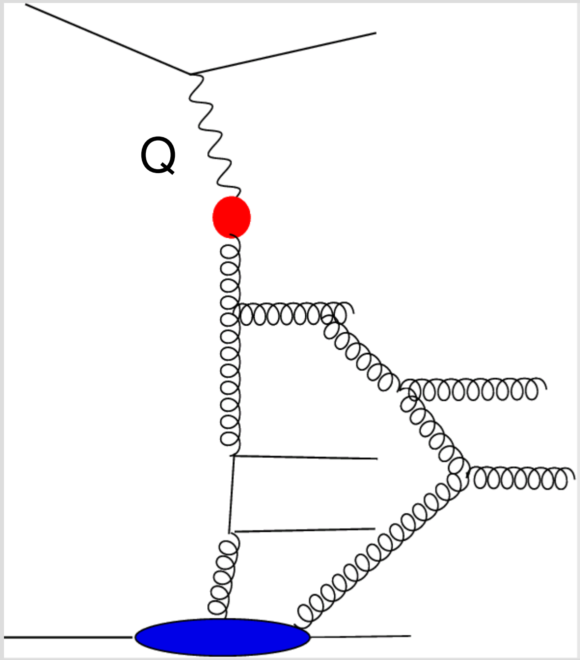
$$\frac{d\hat{\sigma}}{dp_\perp^2} \propto \frac{\alpha_S^2(p_\perp^2)}{p_\perp^4} \to \frac{\alpha_S^2(p_{\perp 0}^2 + p_\perp^2)}{(p_{\perp 0}^2 + p_\perp^2)^2}$$



Multiple Interactions in DIS



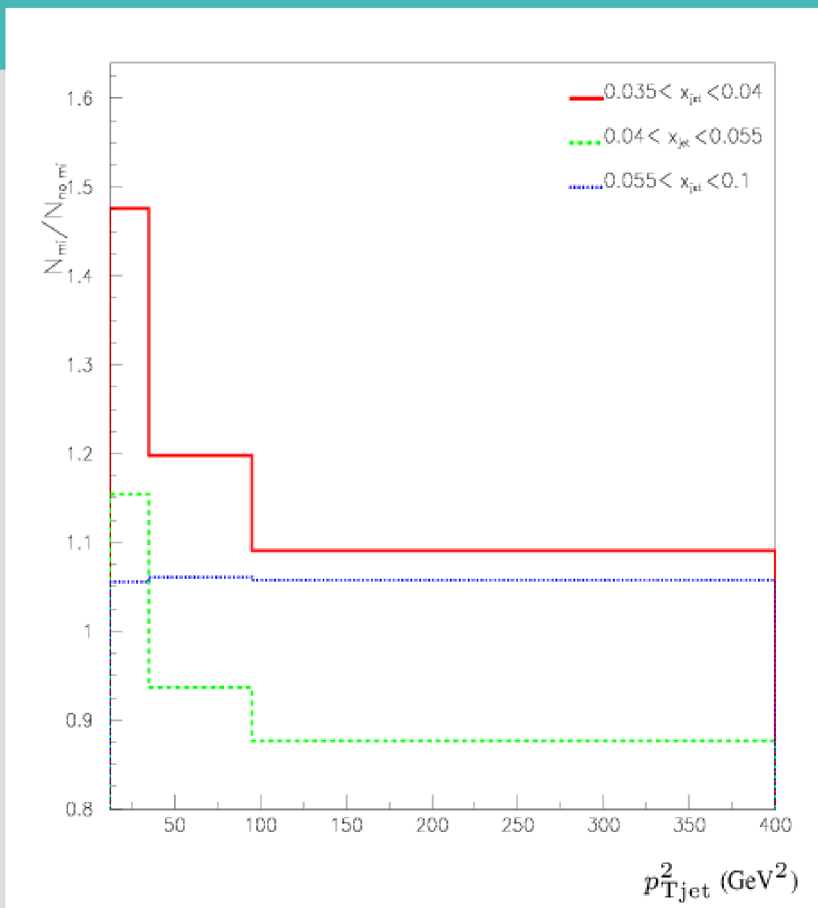
Small coupling suppressed



"Resolved photon"

- DGLAP approach but strict ordering broken, pt of jet > Q

Multiple Interactions in DIS-forward jets



Problems with description using standard DGLAP

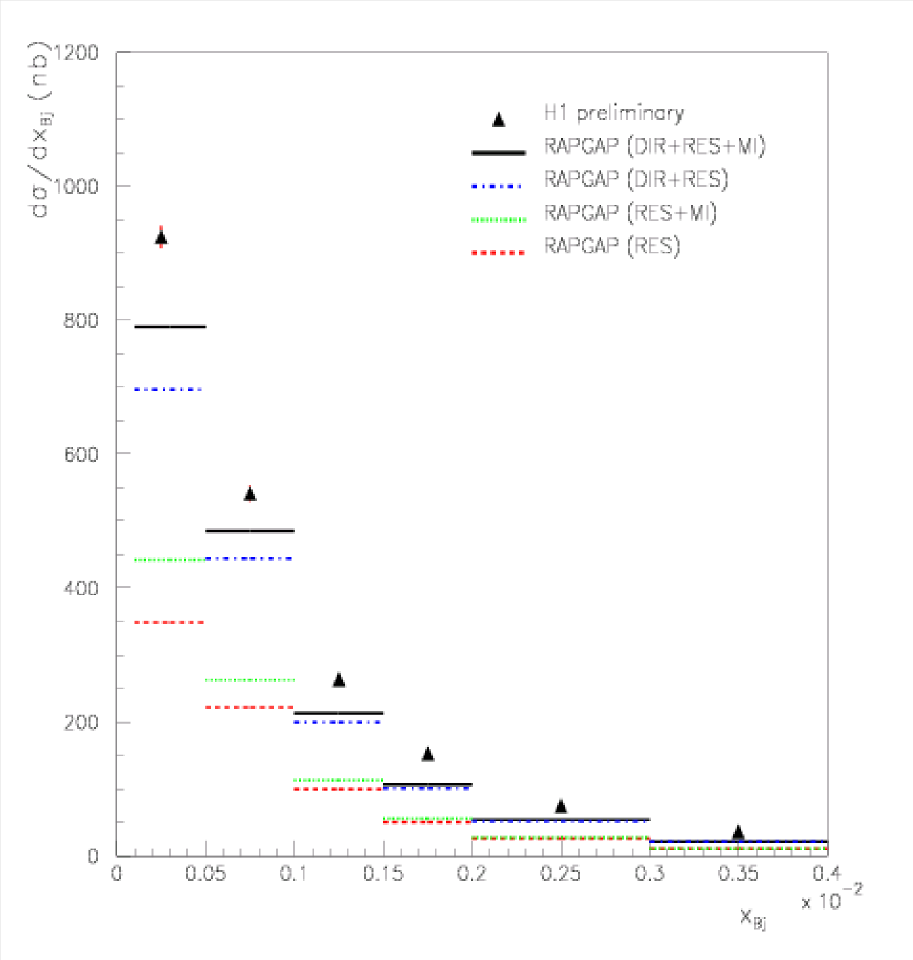
What is the impact of MI on forward jets cross section?

Substantial effect in the lowest pt bin

Ratio of forward jets with and without MI

Setup Q = 3 GeV, x=0.0001

Multiple Interactions in DIS-forward jets

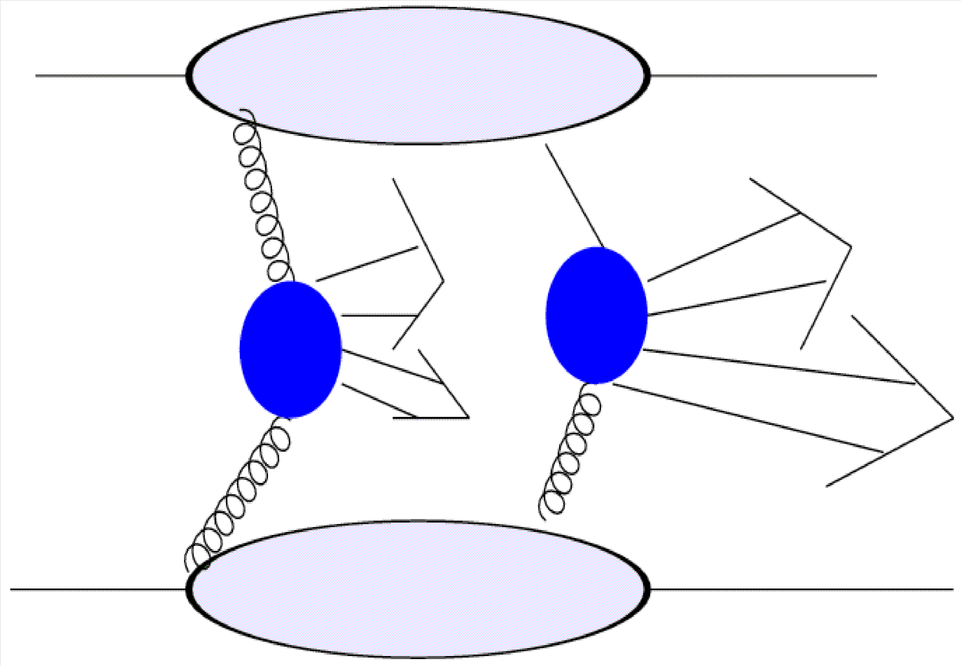


Problems with description using standard DGLAP

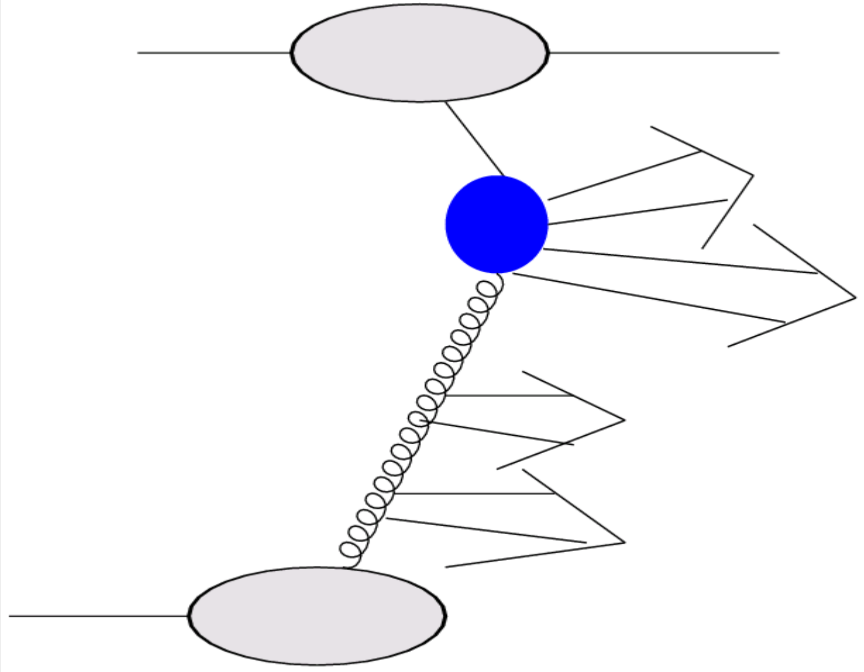
What is the impact of MI on forward jets cross section?

Enhancement in the lowest x bin

Forward jets at LHC
MI vs high energy factorisation

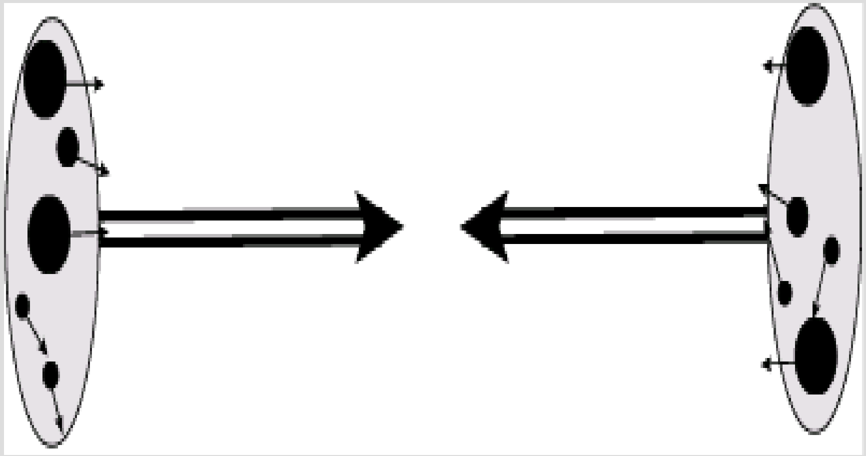


possible configuration for multijet activity in collinear approach



possible configuration for multijet activity in high energy factorisation approach

SETUP

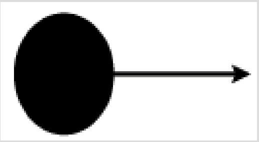


On-shell

Large longitudinal momentum

fraction x1p1

No kt

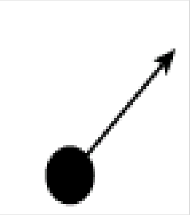


Off-shell

Low longitudinal momentum

fraction x2 p2

kt

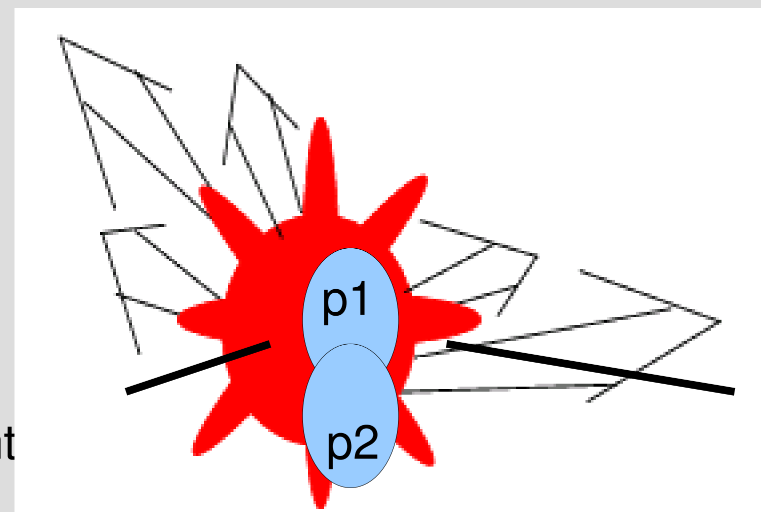


Forward jets at LHC

Jet production at the LHC

central jets

x1 >> x2



remnant

forward
jet

remnant

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

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

Phase space opening for large energies

Unique coverage of large rapidities

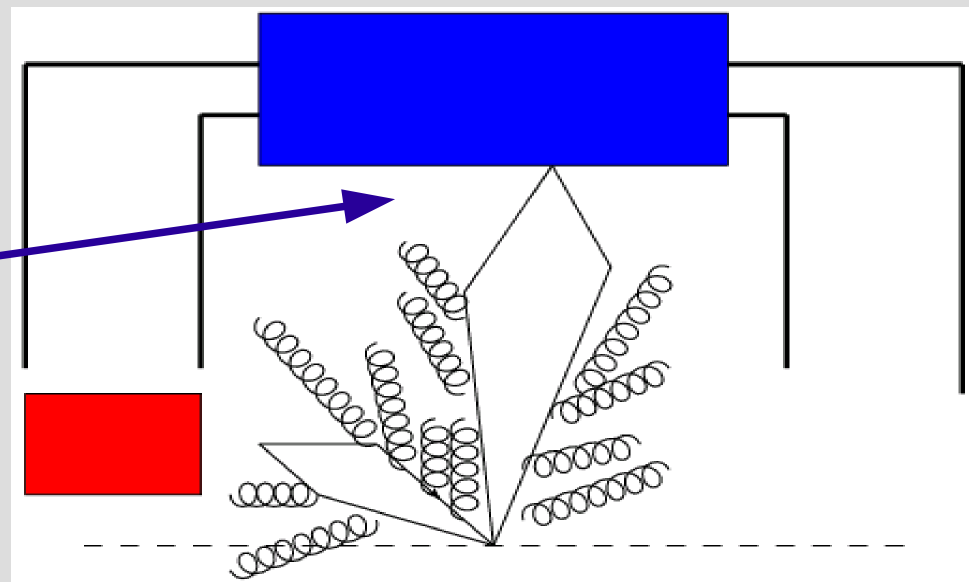
Physcis of hard processes with multiple hard scales

And highly sensitive to parton dynamics at x2 -> 0 and x1 ->1

MEASUREMENT

Polar angles small but far enough from beam axis

Measure: energy flow, spectra of jets



central detector

forward detector

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);

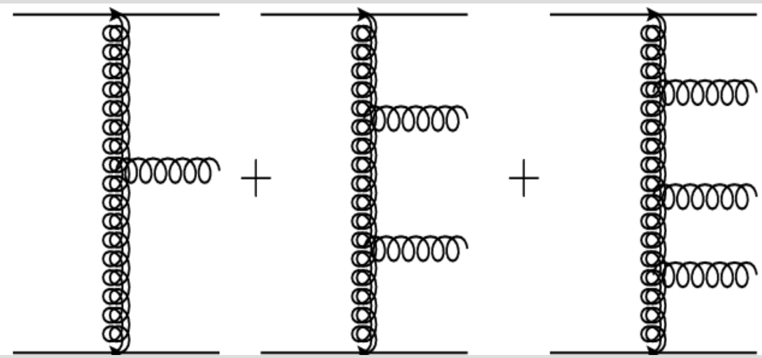
M. Grothe, arXiv:0901.0998; D. d'Enterria, arXiv:0806.0883;

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

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

HIGH ENERGY LIMIT QCD

f(x,k) - sum up diagrams -



$$+ \ldots = \Sigma_n^{\infty} \ln^n s/s_0$$

s-square of total energy

Y~ln1/x ~total energy

$$\partial_Y f(Y,k^2) = K_{BFKL} \otimes f(Y,k^2)$$

Lipatov ,Fadin, Kuraev "77

Ciafaloni '89, Catani, Fiorani, Marchesini,

possible nonlinear extensions to account for dense partonic systems

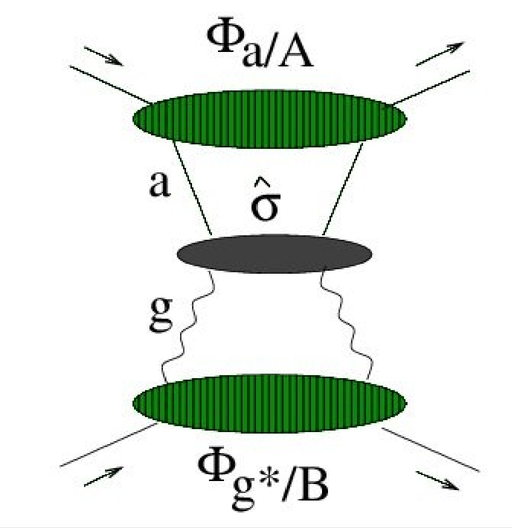
$\hat{\sigma}$ - takes into account logs of hard scale and of energy

Calculated by taking appropriate polarisation sum for incoming off-shell gluon

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

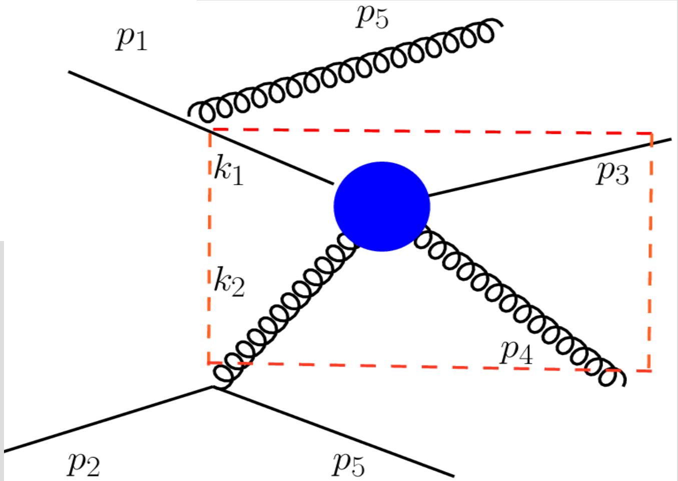
◊ $\widehat{\sigma}$ off-shell continuation of hard-scattering matrix elements

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

$$\mathcal{M}_{qg\to qg} = g^4 \left(\frac{k_1\,k_2}{k_1\,p_2}\right)^2 \left[\frac{(N_c^2-1)}{(4N_c^2)}\frac{(k_1\,p_2)^2+(p_2\,p_3)^2}{(k_1\,p_4)\,(p_3\,p_4)} + \frac{C_1 C_A}{(2C_F)}\frac{(k_1\,p_2)^2+(p_2\,p_3)^2}{(k_1\,p_4)\,(p_3\,p_4)}\times \right.$$
$$\left.\left(\frac{(p_3\,p_4)\,(k_1\,p_2)}{(k_1\,p_3)\,(p_2\,p_4)} + \frac{(k_1\,p_4)\,(p_2\,p_3)}{(k_1\,p_3)\,(p_2\,p_4)} - 1\right)\right]$$

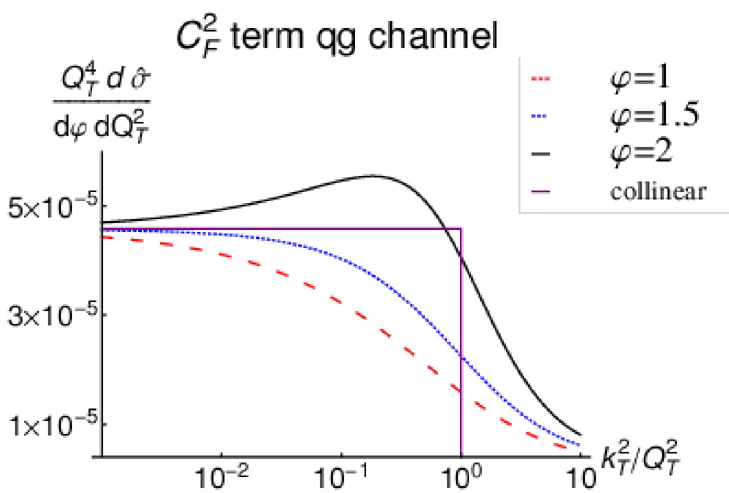


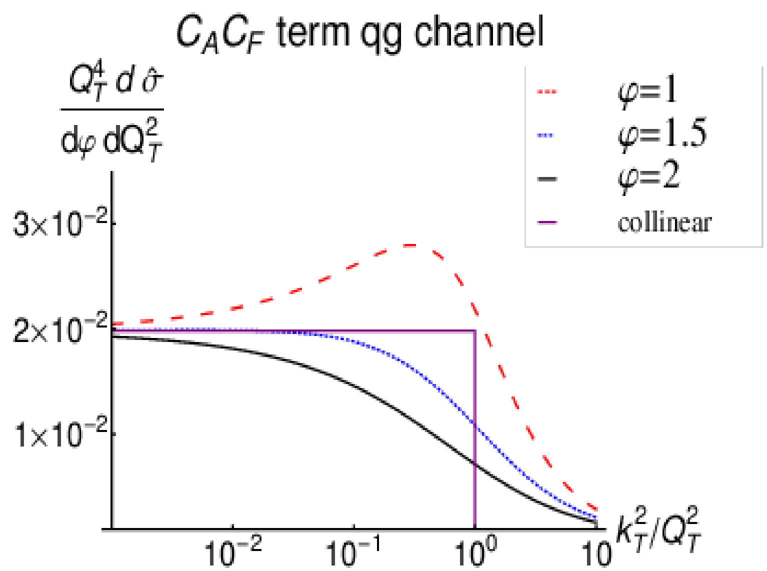
- in collinear limit reduce to standard matrix elements
  - gauge invariant with respect to incoming gluon

BEHAVIOR AT LARGE kt qg CHANNEL

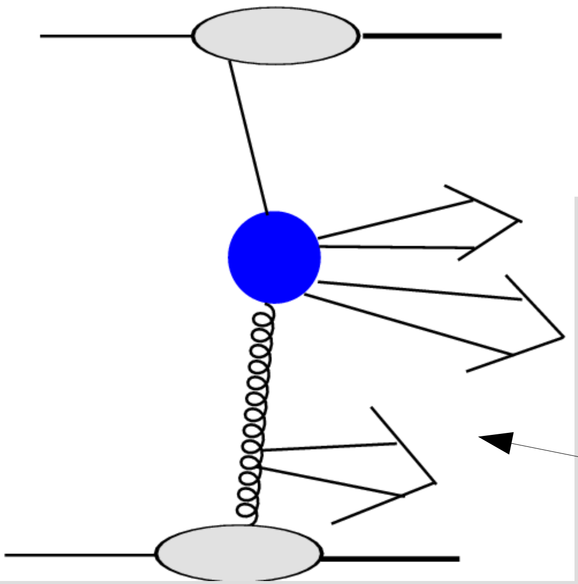
k_T = transversal momentum of incoming gluon = transverse momentum carried away by extra jets

$k_T/Q_T \to 0$ leading order process





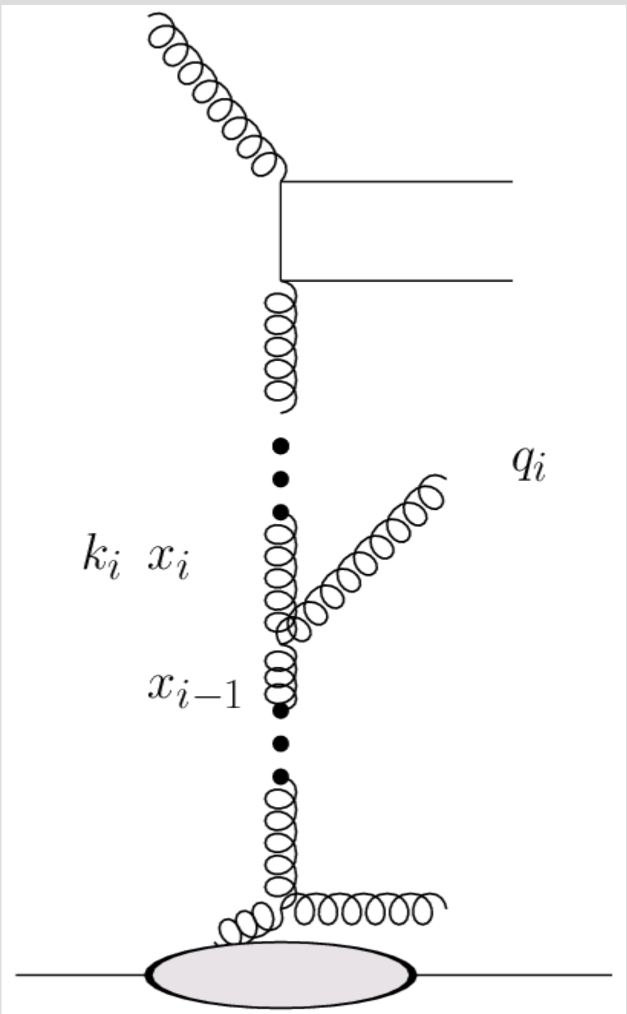
- dynamical cut-off at $k_T \sim Q_T$ set by coherence effects
  - ▷ non-negligible terms from finite k_T tail



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

GLUON DENSITYFROM 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

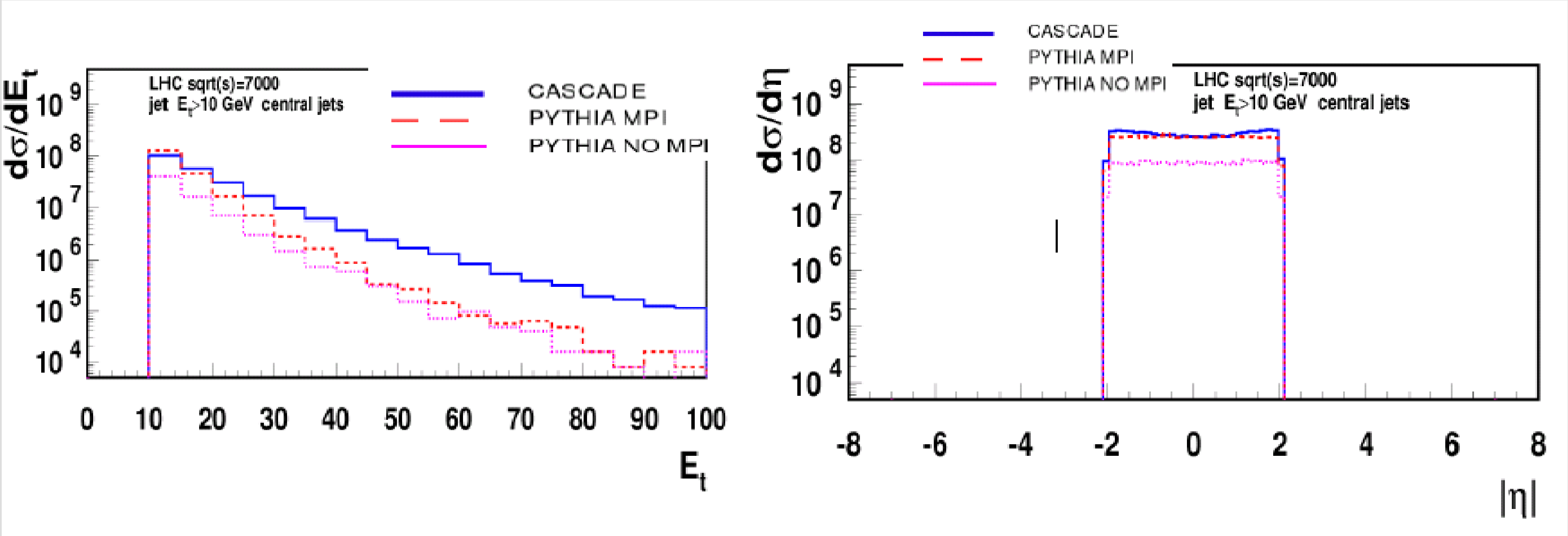
- We can calculate the convolution formula for the cross section using a Monte Carlo generator and study jet observables
- Look for small-x dynamics effects at forward calorimeter

We can study two jet correlations:

-one jet in the central rapidity region $-2 < |y| < 2$ pt > 10GeV

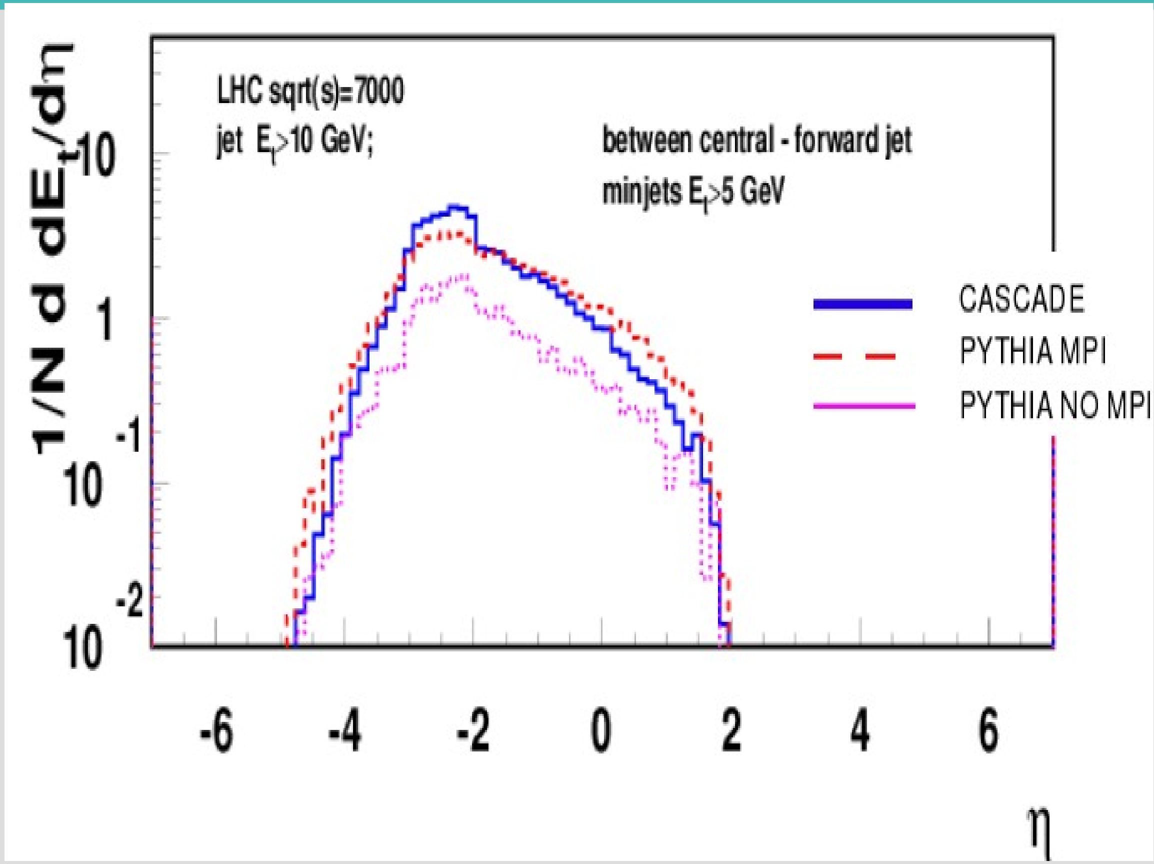
-the other in the forward rapidity region $3 < |y| < 5$ pt > 10GeV

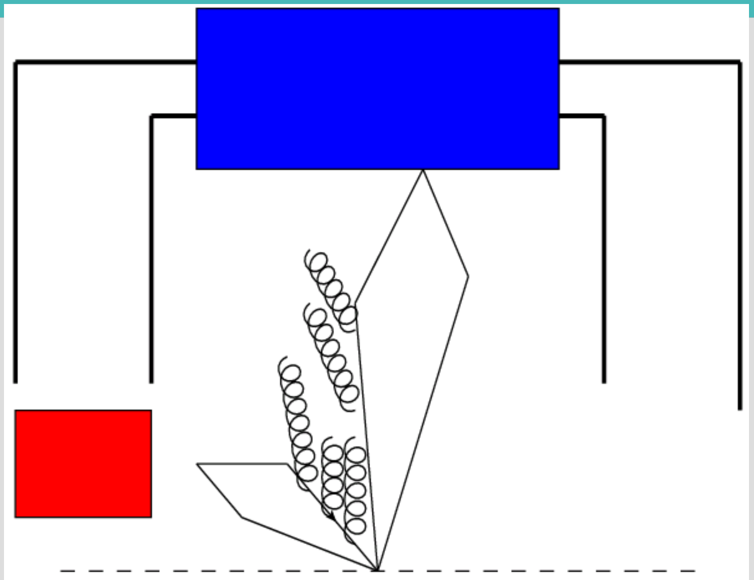
SPECTRA OF PRODUCED CENTRAL JET



- 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

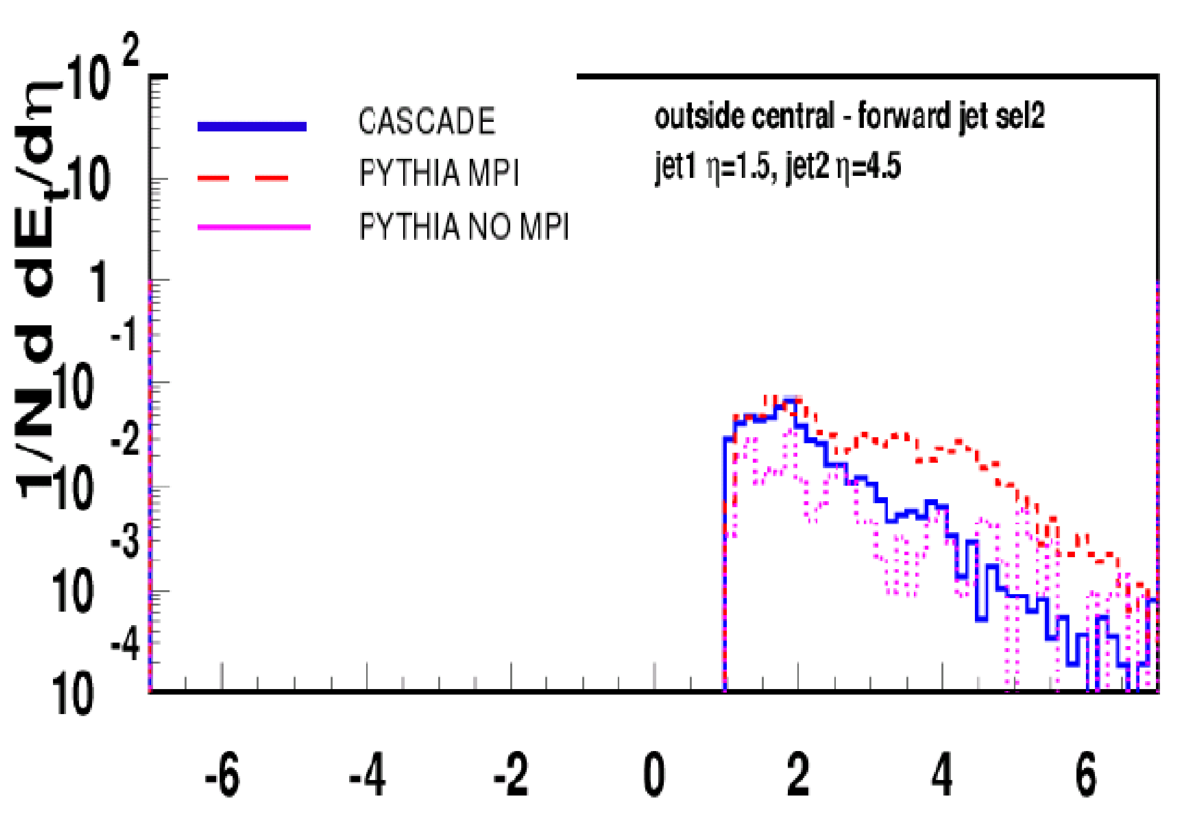
TRANSVERSE ENERGY FLOW - between

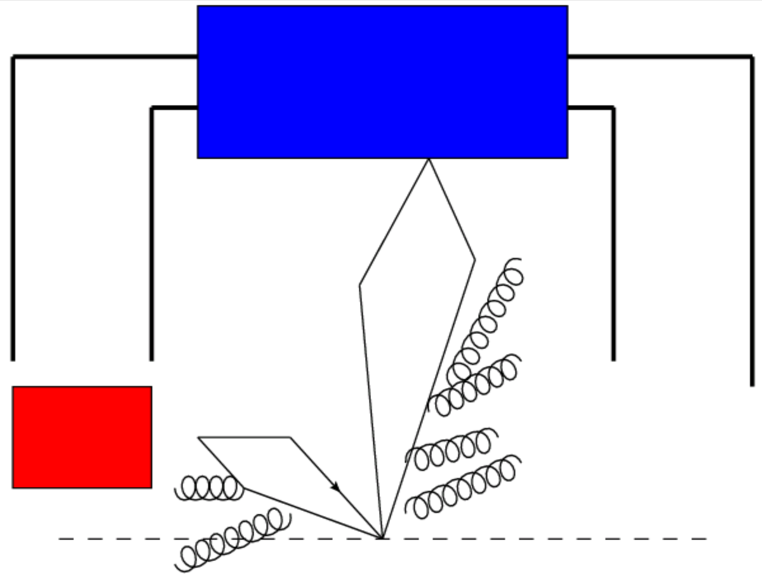




Larger energy flow in central region predicted by CASCADE and MPI-PYTHIA

TRANSVERSE ENERGYFLOW- outside

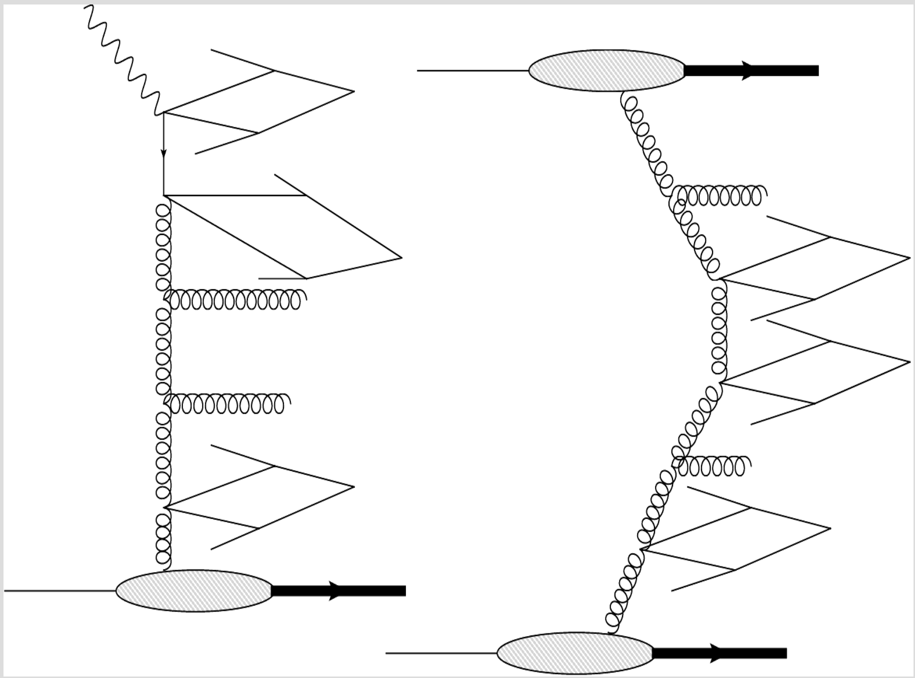




Larger energy flow in central region predicted by CASCADE and MPI-PYTHIA

Lower energy flow in more forward region

Conclusions



- LheC offers possibility to study physics
  of forward jets, MI at unique level
- We performed study of forward jets
  at LHC
- Interesting similarities and differences
  between high energy factorization
  and MI model
- Diagrams are different but kt dependent
  parton shower allows for hard jets
- More studies are to be done