Parton showers with medium-modified splitting functions

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(a non expert on heavy ions!)

1. **Introduction**
2. **Angular-ordered parton showers (HERWIG)**
3. **Medium-modified Altarelli–Parisi splitting functions**
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6. **Conclusions**

N. Armesto, G. C., L. Cunqueiro and C.A. Salgado, JHEP 1109 (2009) 122;
G. C., Q-HERWIG release, in progress.

RHIC observations: jet quenching (suppression of high-p_T particles with respect to pp collisions); disappeareance or distortion of particle spectra

Typical explanation: higher energy loss in a dense medium

Analytical calculations are suitable to describe inclusive quantities, but not to yield exclusive final states

Monte Carlo generators are integral part of any experimental analysis: hard-scattering processes, parton showers, hadronization and underlying event

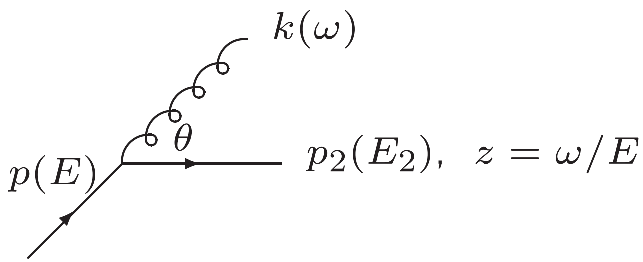
Great interest in having Monte Carlo generators for heavy-ion collisions capable of describing jet quenching

A simple prescription: medium-modified Altarelli–Parisi splitting functions (BDMPS approximation) to enhance branching probability and radiative loss in a medium

Implementation of modified splitting functions in Q-PYTHIA (ordering in virtuality and string hadronization) giving results in qualitative agreement with RHIC measurements

Recent work towards Q-HERWIG: modified angular-ordered showers with cluster hadronization

Monte Carlo event generators: multiple radiation soft or collinear approximation



$$d\mathcal{P} = \frac{\alpha_S}{2\pi}\ P(z)dz\ \frac{dQ^2}{Q^2}\ \Delta_S(Q^2_{\rm max}, Q^2)$$

Q^2: **ordering variable**

$\Delta_S(Q^2_{\rm max}, Q^2)$ **Sudakov form factor: no radiation in** $[Q^2, Q^2_{\rm max}]$

$$\Delta_S(Q^2_{\rm max}, Q^2) = \exp\left[-\frac{\alpha_S}{2\pi}\int_{Q^2}^{Q^2_{\rm max}} \frac{dQ'^2}{Q'^2}\int_{z_{\rm min}}^{z_{\rm max}} dz P(z)\right]$$

HERWIG : $Q^2 = E^2(1-\cos\theta) \simeq E^2\theta^2/2$ **Soft approximation: angular ordering**

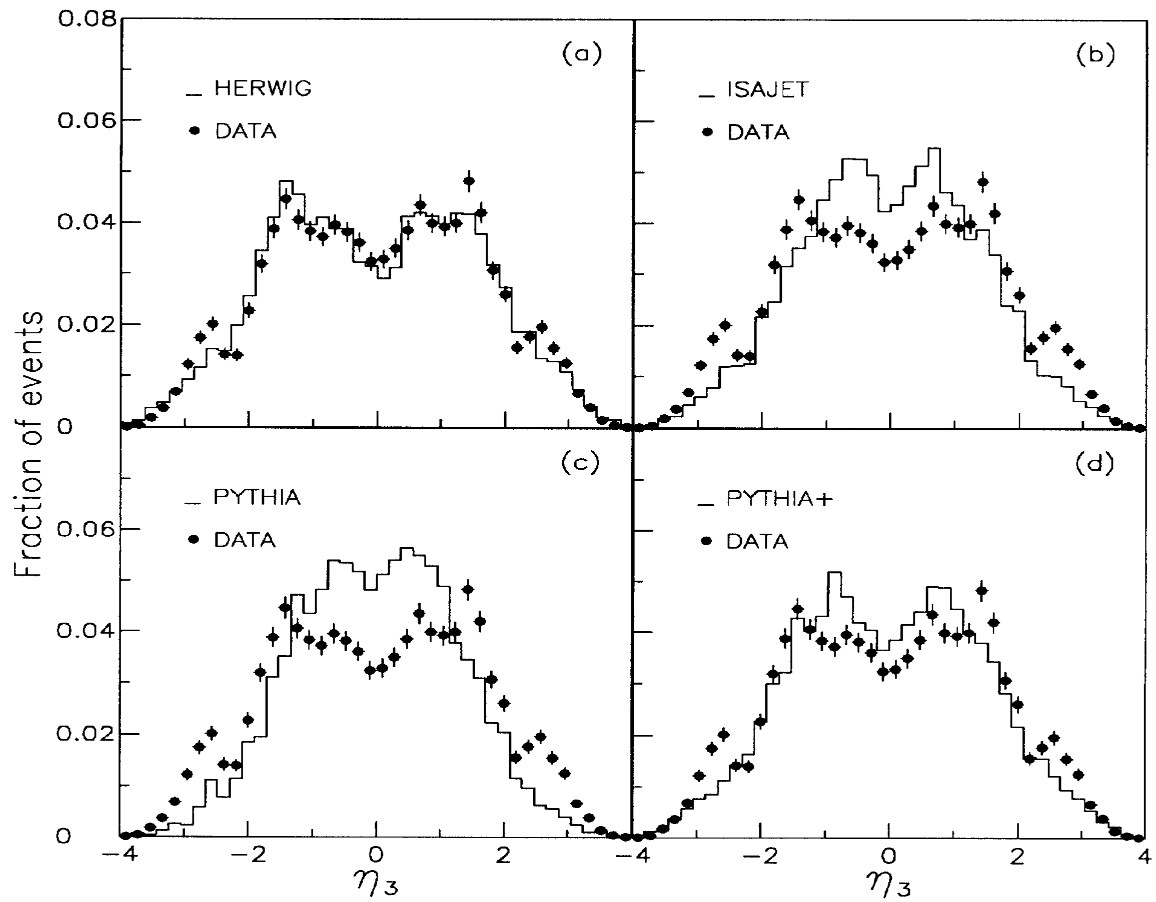
PYTHIA: virtuality evolution $p^2 \simeq 2z(1-z)Q^2$

It includes angular ordering by an additional veto

PYTHIA 6.3: transverse-momentum ordering $k_T^2 \simeq 2z^2(1-z)^2Q^2$

Hard and large-angle radiation: matrix-element corrections

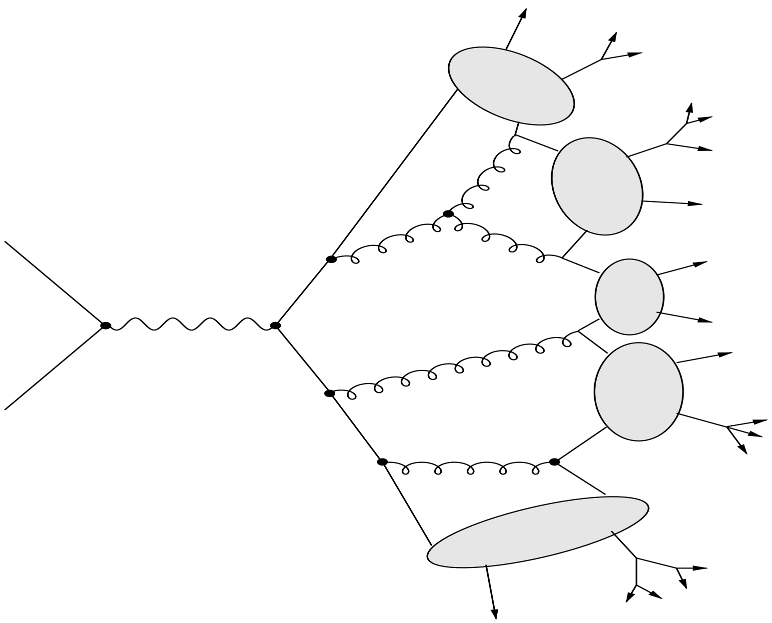
Evolution variable relevant on observables sensitive to colour coherence (CDF)



0.08
0.06
0.04
0.02
0
Fraction of events
(a)
HERWIG
DATA
(b)
ISAJET
DATA
(c)
PYTHIA
DATA
(d)
PYTHIA+
DATA
−4
−2
0
2
4
η_3

Figure 10:

Hadronization models



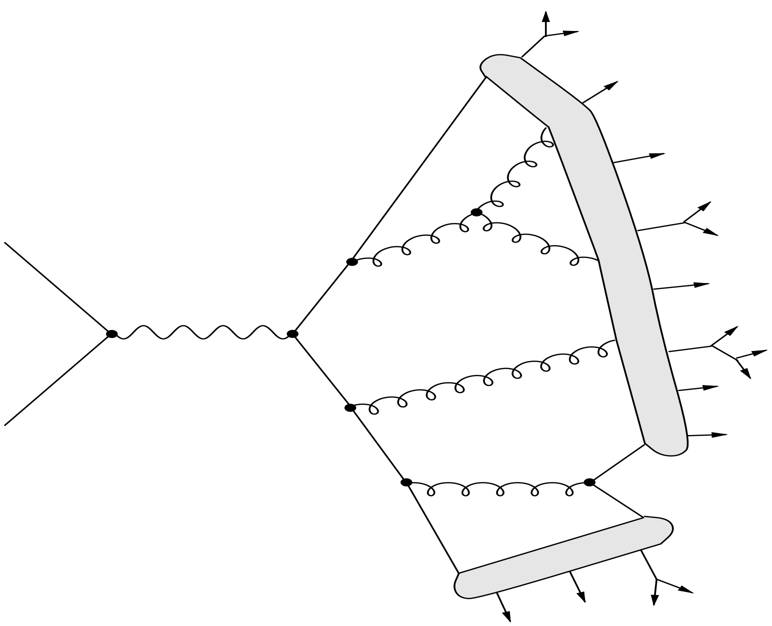
Cluster model (HERWIG)

Perturbative evolution ends at $Q^2 = Q_0^2$

Angular ordering $\Rightarrow$ colour preconfinement

Forced gluon splitting $(g \to q\bar{q})$

Colour-singlet clusters decay into the observed hadrons



String model (PYTHIA)

q and $\bar{q}$ move in opposite direction

The colour field collapses into a string, with uniform energy density

$q\bar{q}$ pairs are produced

The string breaks into the observed hadrons

Figures from R.K. Ellis, W.J. Stirling and B.R. Webber, QCD and Collider Physics

Medium-modified splitting functions: $P(z) \to P(z) + \Delta P(z, p^2, \hat{q}, L)$

$\hat{q} = \langle k_T^2 \rangle / \lambda$: **transport coefficient;** L: **medium length;** p^2: **virtuality**

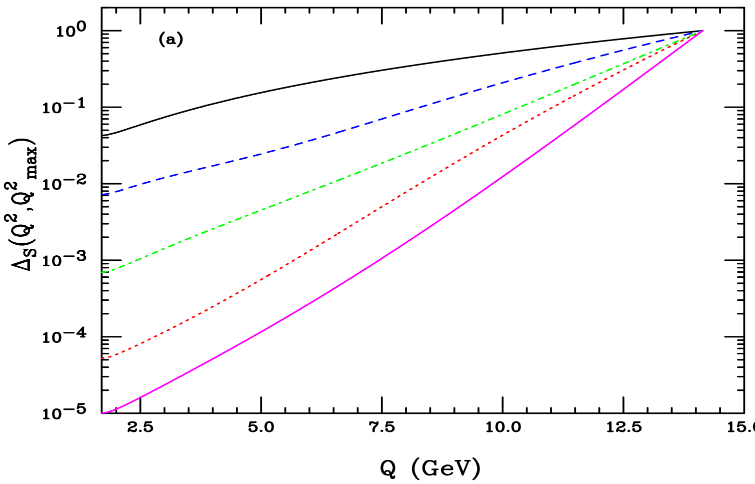
ΔP **from BDMPS i.e. collinear multiple radiation off static scattering centres with a screening potential:** $V(x) = \frac{e}{4\pi} \frac{\exp(-\mu|\vec{x}-\vec{x}_i|)}{|\vec{x}-\vec{x}_i|}$

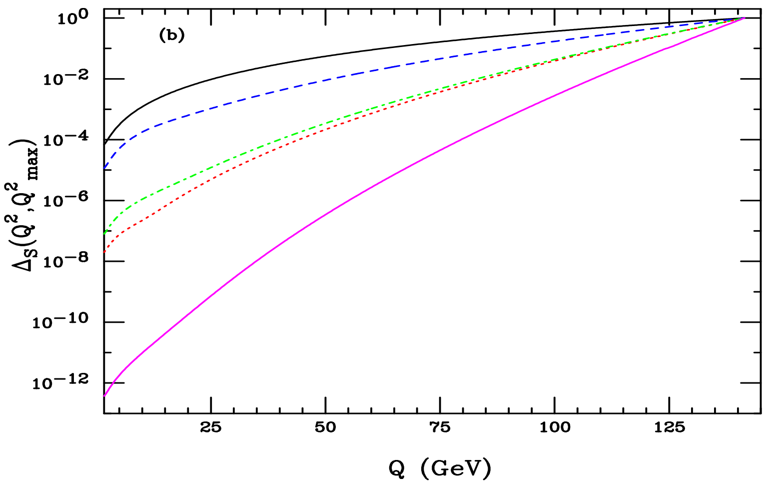
$$\frac{d^2 I}{dz dp_T^2} = \frac{\alpha_S}{2\pi} \frac{P(z)}{p_T^2} + \frac{d^2 I_{\rm med}}{dz dp_T^2} \Longrightarrow \Delta P(z, p^2, \hat{q}, L) = \frac{2\pi p_T^2}{\alpha_S} \frac{d^2 I_{\rm med}}{dp_T^2 dz}$$

Effective length to account for parton formation length: $L = L_0 - 2zE/k_T^2$

$E = 10$, 100 **GeV;** $\hat{q} = 1$, 10 **GeV^2/fm;** $L_0 = 2$, 5 **fm;** $\hat{q}L_0 = 2$, 5, 20, 50 **GeV^2**

Gluon Sudakov form factors: $E = 10$ **GeV (a) and** 100 **GeV (b)**



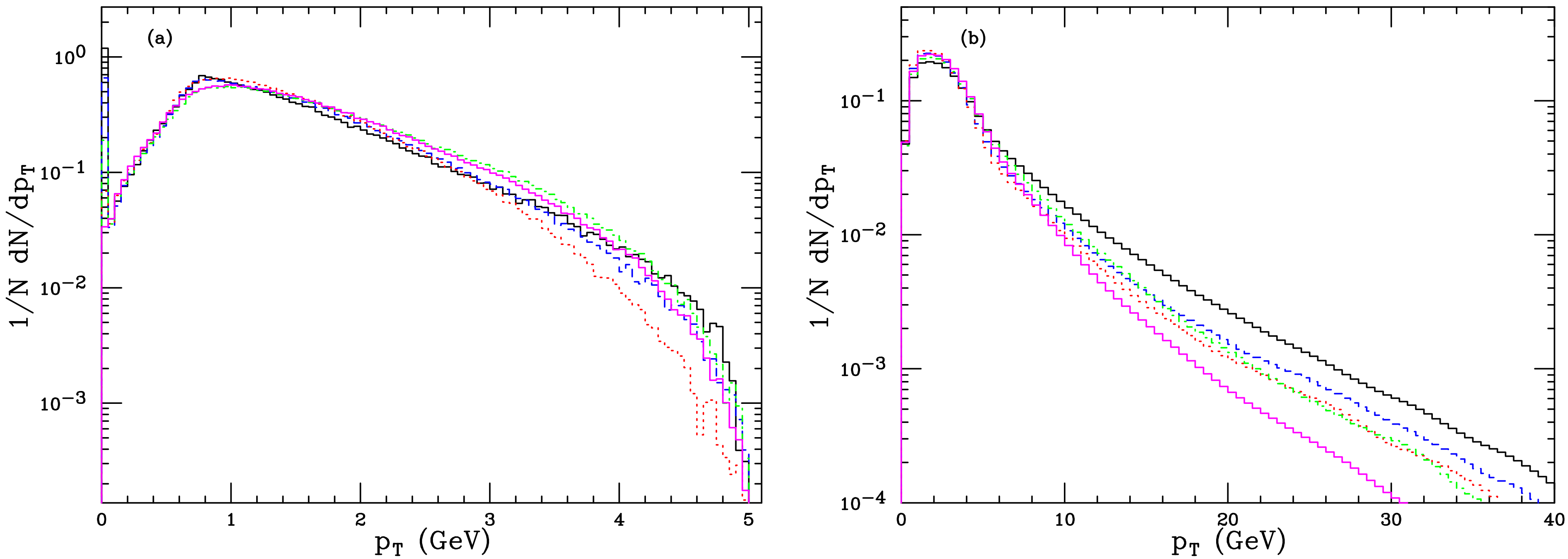


Solid: vacuum; **Dashes:** $\hat{q}L_0 = 2$ **GeV^2**; **Dots:** $\hat{q}L_0 = 5$ **GeV^2**; **Dot-dashes:** $\hat{q}L_0 = 20$ **GeV^2** **Solid:** $\hat{q}L_0 = 50$ **GeV^2**

Showers initiated by gluons of 10 and 100 GeV - average parton multiplicities:

E	$\hat{q}L_0 = 0$	$\hat{q}L_0 = 2$ GeV^2	$\hat{q}L_0 = 5$ GeV^2	$\hat{q}L_0 = 20$ GeV^2	$\hat{q}L_0 = 50$ GeV^2
10 GeV	2.56	3.05	4.14	3.60	4.56
100 GeV	6.95	7.41	8.79	8.93	11.70

Transverse momentum distributions:

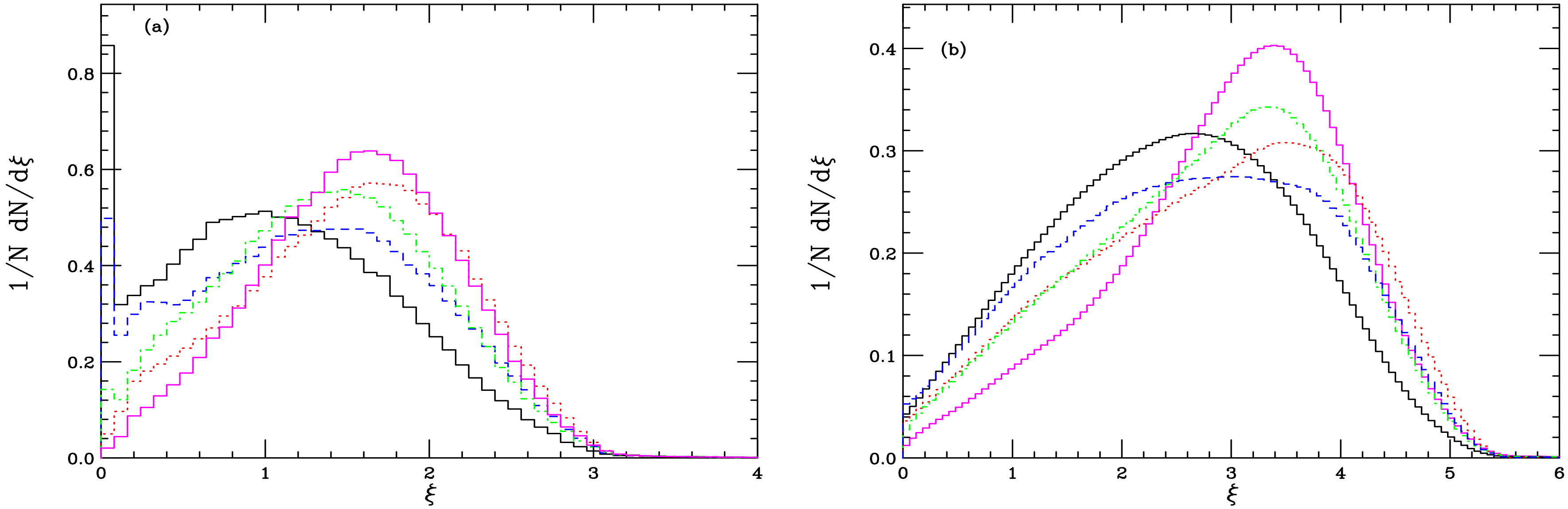


(a): $E = 10$ **GeV; (b):** $E = 100$ **GeV**

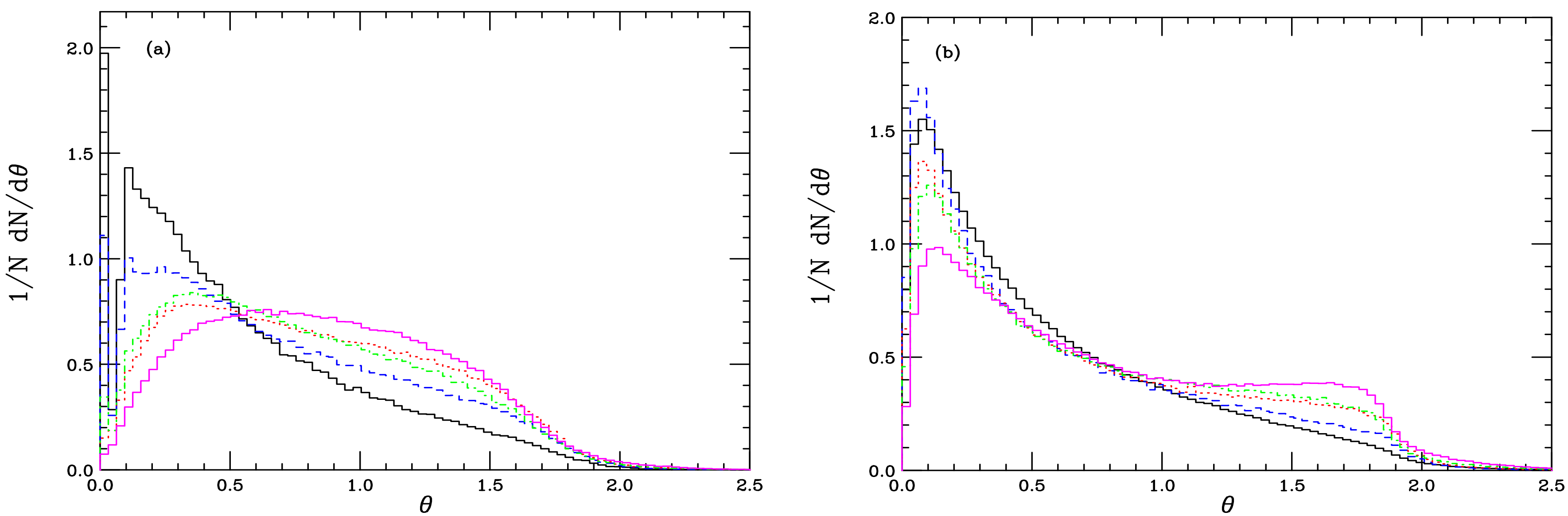
Solid: vacuum; **Dashes:** $\hat{q}L_0 = 2$ **GeV**^{2}; **Dots:** $\hat{q}L_0 = 5$ **GeV**^{2}; **Dot-dashes:** $\hat{q}L_0 = 20$ **GeV**^{2} **Solid:** $\hat{q}L_0 = 50$ **GeV**^{2}

Peak at $p_T = 0$**: events with no branchings, depending on** $\Delta_S(Q_0^2, Q_{\max}^2)$

Logarithmic energy fraction $\xi = \ln(E_g/|p|)$

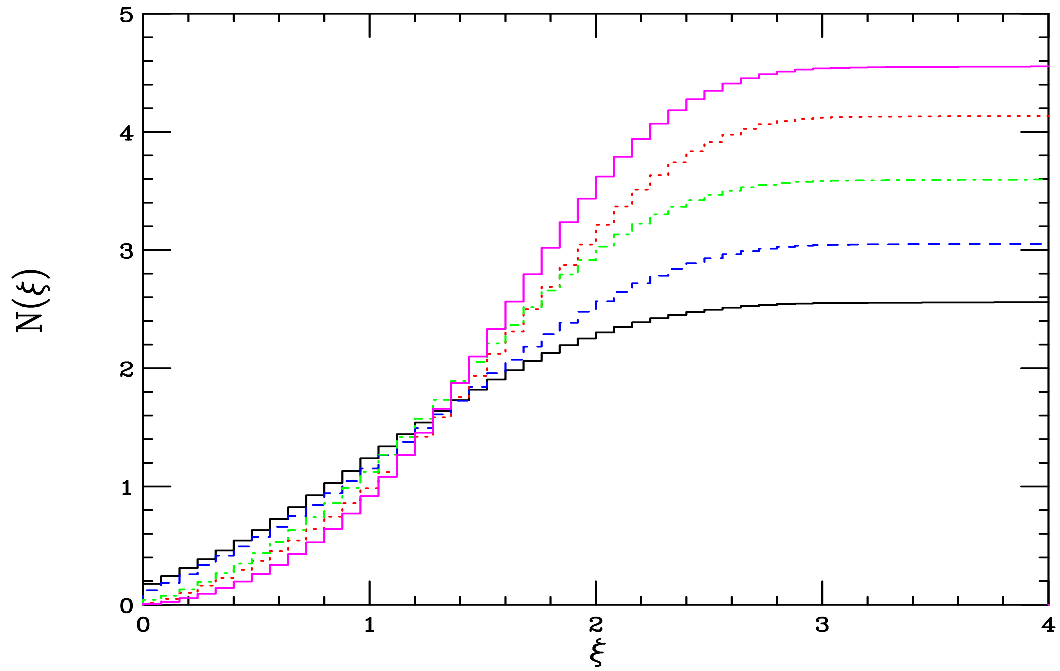


Emission angle θ (dead zone for $\theta > \pi/2$)



Integrated ξ spectrum with $E = 10$ GeV to remove the spike:

$$N(\xi) = \int_0^{\xi} d\xi' \frac{dN}{d\xi'}$$

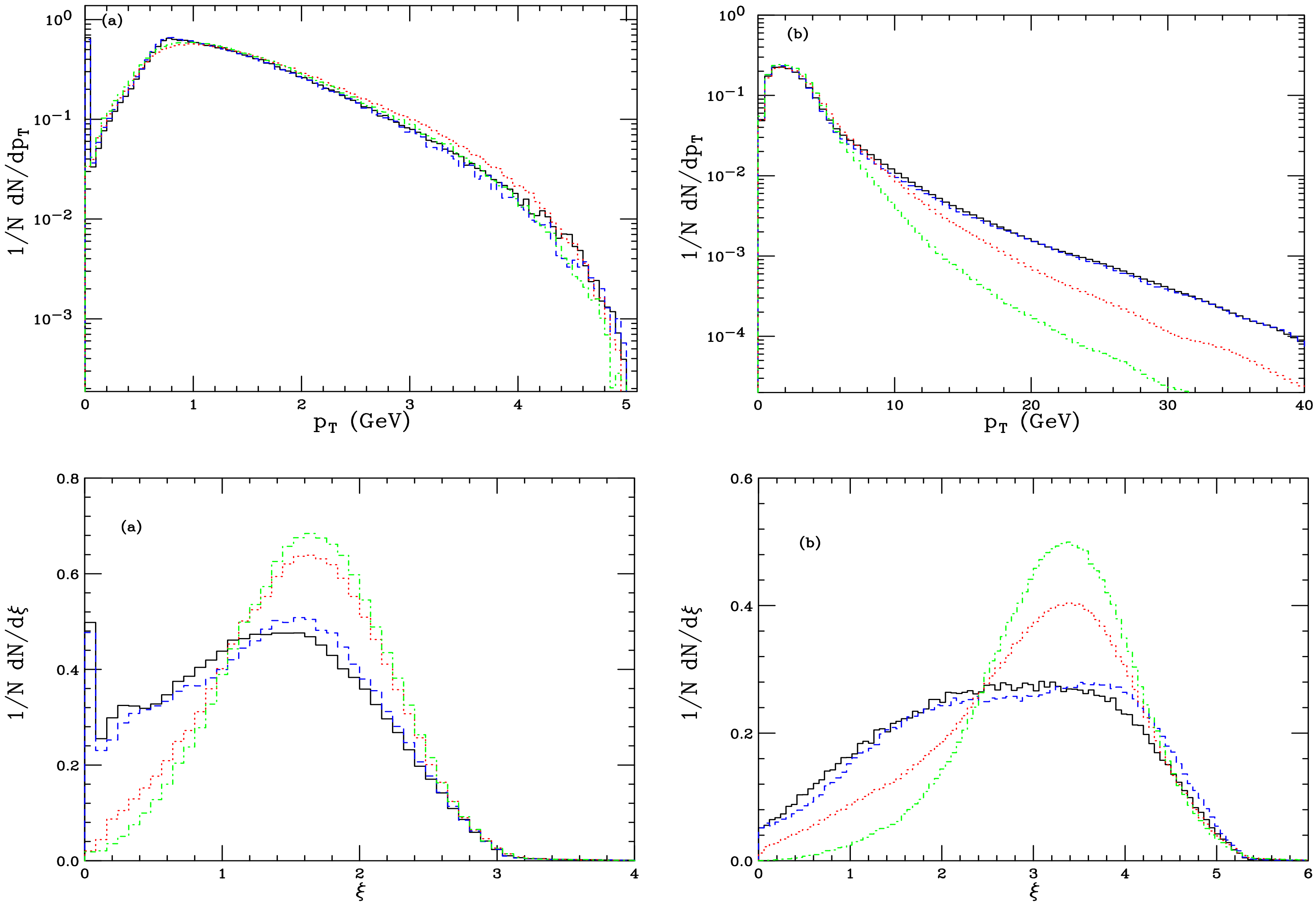


Solid: vacuum; **Dashes:** $\hat{q}L_0 = 2$ **GeV^2**; **Dots:** $\hat{q}L_0 = 5$ **GeV^2**;

Dot-dashes: $\hat{q}L_0 = 20$ **GeV^2**; **Solid:** $\hat{q}L_0 = 50$ **GeV^2**

$\xi = 0.5$: **suppression from** 10% ($\hat{q}L_0 = 2$ GeV^2) **to** 60% ($\hat{q}L_0 = 50$ GeV^2)

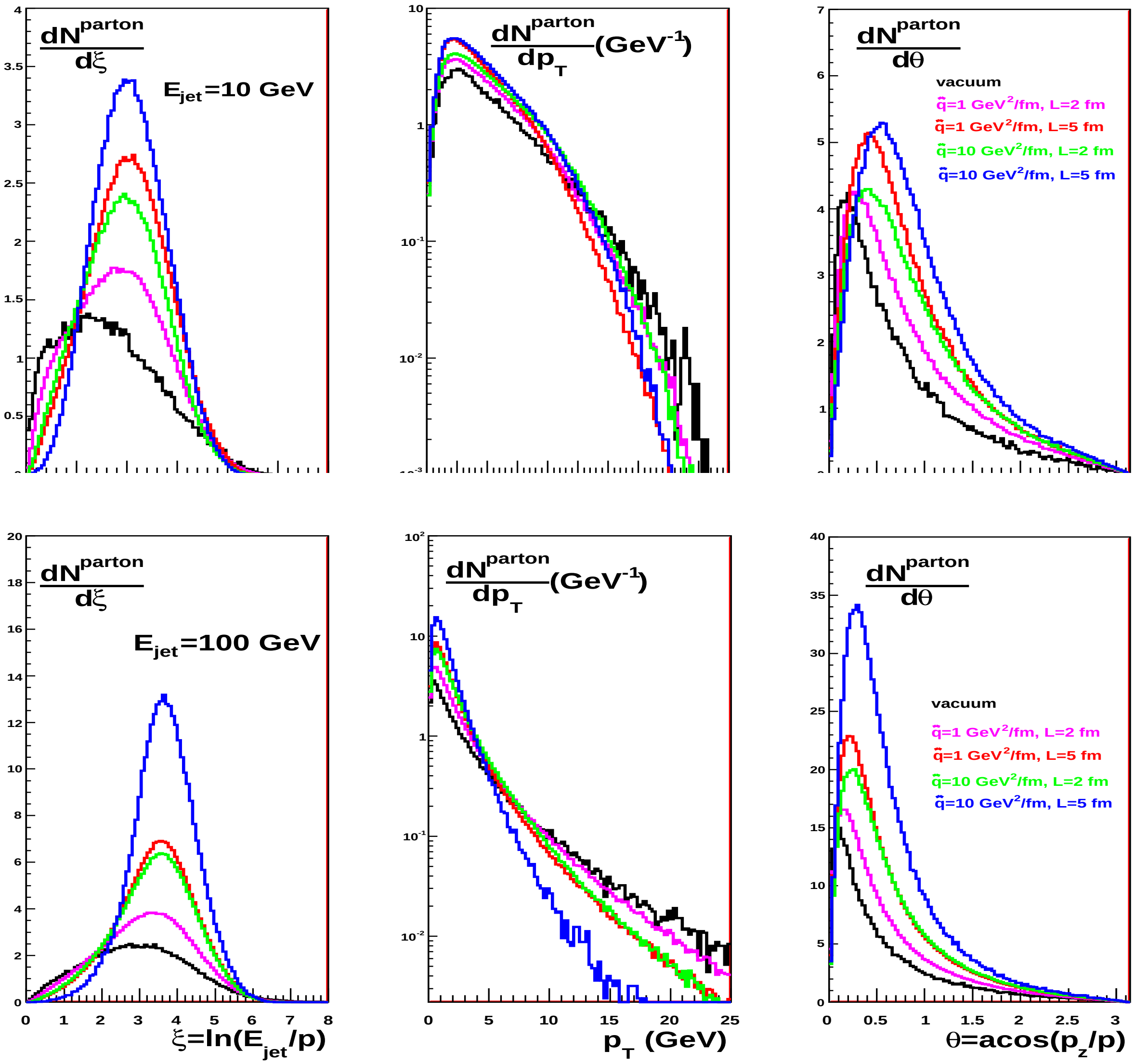
Spectra for fixed $L = L_0$: larger medium-induced effects



Solid: $\hat{q}L_0 = 2$ **GeV^2, variable** L; **Dashes:** $\hat{q}L_0 = 2$ **GeV^2, fixed** L;
Dots: $\hat{q}L_0 = 50$ **GeV^2, variable** L; **Dot-dashes:** $\hat{q}L_0 = 50$ **GeV^2, fixed** L

Results using Q-PYTHIA (comparison in progress)

N. Armesto, L. Cunqueiro, C.A. Salgado, Eur.Phys.J.C63 (2009) 679



Larger medium effects in Q-PYTHIA – no peak at $p_T = \theta = 0$

Conclusions and outlook

Medium-modified splitting functions in the HERWIG angular-ordered parton shower algorithm

Larger energy loss (suppression in the Sudakov form factor)

Results on transverse-momentum, energy-fraction and angular distributions

Remarkable impact of medium effects

Higher parton multiplicity, suppression at large transverse momentum, wider angular distributions, small-ξ suppression

In progress:

Analysis at hadron level and comparison with Q-PYTHIA: role played by ordering variables and hadronization models

Comparison with RHIC data and predictions for LHC

Release of Q-HERWIG event generator

HERWIG++ for jet quenching?