Multiplicity distributions for jet parton showers in the medium

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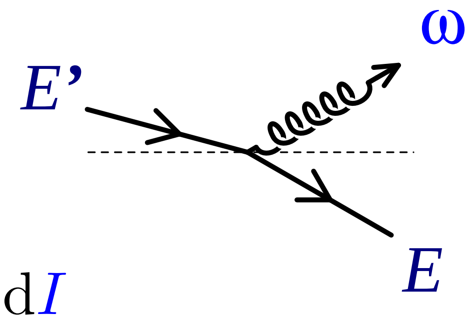
Jet parton showers in the medium



Jet quenching modelled by medium-induced successive emission of independent soft gluons by a fast parton

⇒ spectrum of radiated energy per unit length: $\dfrac{\omega\, \mathrm{d}I}{\mathrm{d}\omega\, \mathrm{d}\ell}$

Novel features of the approach presented here:

- Primary and secondary parton splittings treated equally
- Energy-momentum conserved at each splitting

☞ we implement this as a medium-induced modification of

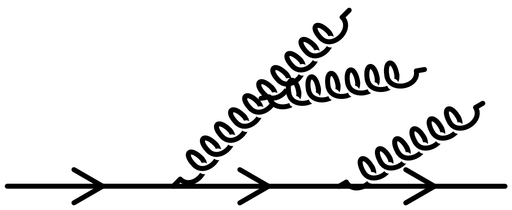
Modified **L**eading **L**ogarithmic **A**pproximation

N.B. & U.A. Wiedemann, hep-ph/0506218

MLLA: main ingredients

- Resummation of double- and single-logarithms in $\ln \frac{1}{x}$ and $\ln \frac{E_{\rm jet}}{\Lambda_{\rm eff}}$
- Intra-jet colour coherence:
  - *independent* successive branchings $g \to gg$, $g \to q\bar{q}$, $q \to qg$
  - with angular ordering of the sequential parton decays:

    at each step in the evolution, the angle between father and offspring partons decreases



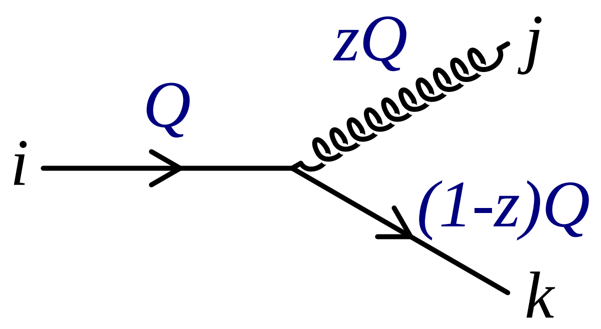
- Includes in a systematic way next-to-leading-order corrections $\mathcal{O}(\sqrt{\alpha_s(\tau)})$!
- Hadronization through "Local Parton-Hadron Duality" (LPHD)

MLLA:
generating functional

Central object : generating functional $Z_i[Q, \Theta; u(k)]$

☞ generates the various cross sections ($\to ggg, \to ggq\bar{q}\dots$) for a jet coming from a parton i ($= g, q, \bar{q}$) with energy Q in a cone of angle Θ

$$Z_i[Q, \Theta; u(k)] = \mathrm{e}^{-w_i(Q,\Theta)}\, u(Q) + \sum_j \int^{\Theta} \frac{\mathrm{d}\Theta'}{\Theta'} \int_0^1 \mathrm{d}z\, \mathrm{e}^{w_i(Q,\Theta') - w_i(Q,\Theta)} \frac{\alpha_s(k_\perp)}{2\pi} \times P_{ji}(z)\, Z_j[zQ, \Theta'; u]\, Z_k[(1-z)Q, \Theta'; u]$$



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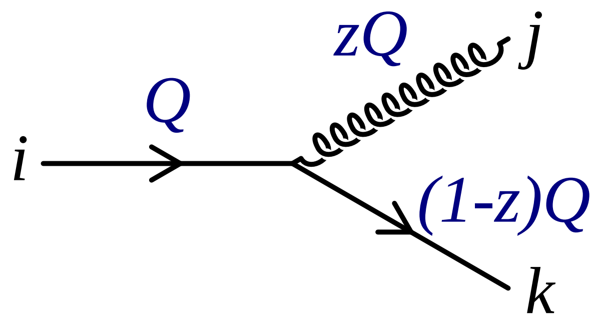
probability to have no branching with angle $< \Theta$ between Θ and Θ'

angular ordering

$k_\perp \approx z(1-z)Q$

splitting function $i \to jk$

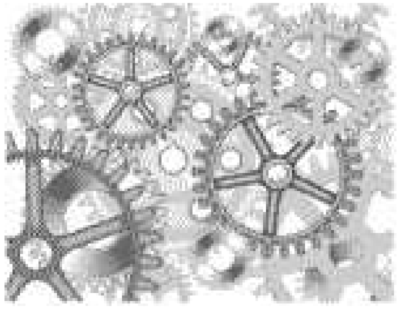


MLLA: limiting spectrum

The parton distribution in a jet with "energy" $\tau \equiv \ln \frac{Q}{\Lambda_{\text{eff}}}$ is given by

$$\bar{D}_i(x,\tau) \equiv Q \frac{\delta}{\delta u(xQ)} Z_i[\tau; u(k)]\Big|_{u\equiv 1}$$

infrared cutoff



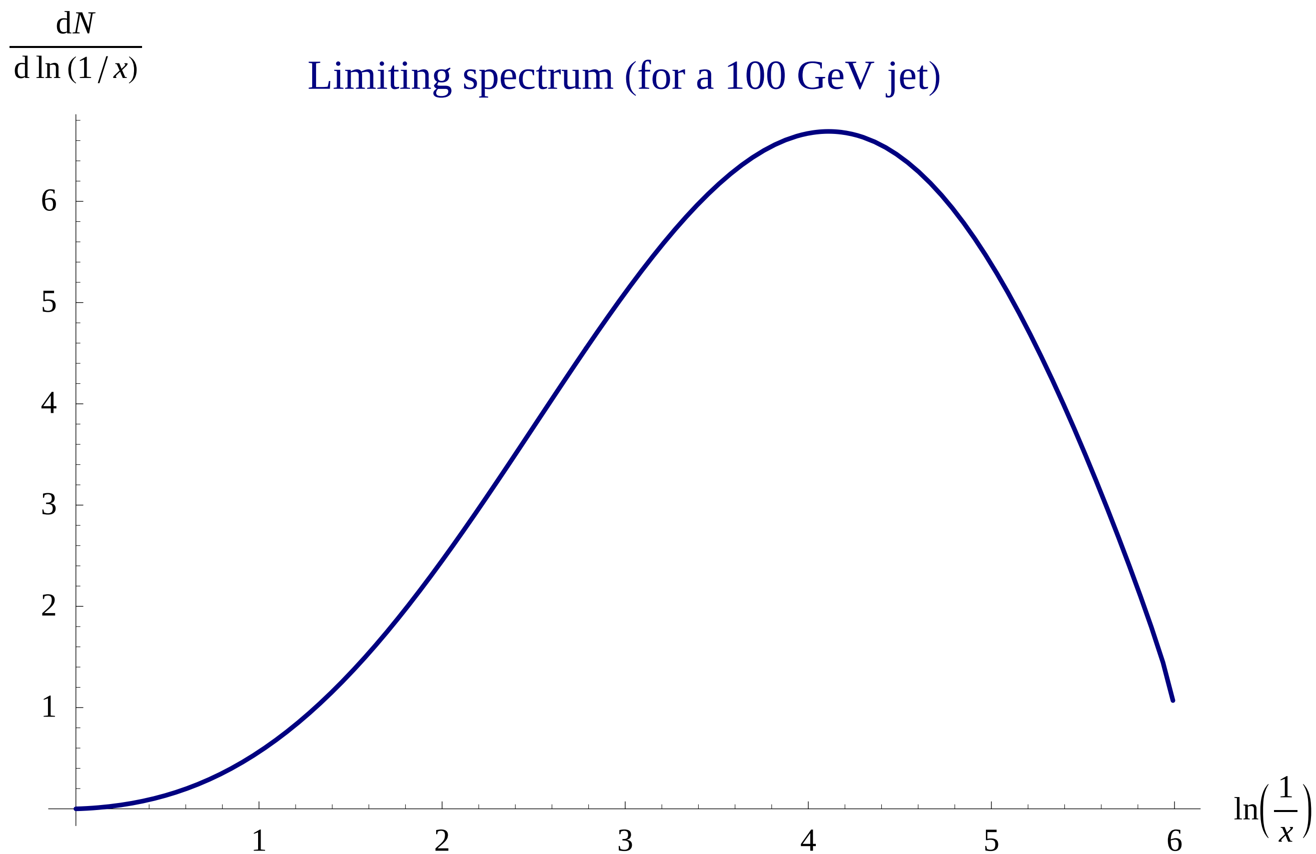
"Limiting spectrum":

$$\bar{D}^{\text{lim}}(x,\tau,\Lambda_{\text{eff}}) = \frac{4N_c\tau}{bB(B+1)} \int_{\epsilon-\mathrm{i}\infty}^{\epsilon+\mathrm{i}\infty} \frac{\mathrm{d}\nu}{2\pi\mathrm{i}}\, x^{-\nu}\, \Phi(-A+B+1, B+2; -\nu\tau)$$

with

$$A \equiv \frac{4N_c}{b\nu}, \qquad B \equiv \frac{a}{b}, \qquad a \equiv \frac{11}{3}N_c + \frac{2N_f}{3N_c^2}, \qquad b \equiv \frac{11}{3}N_c - \frac{2}{3}N_f$$

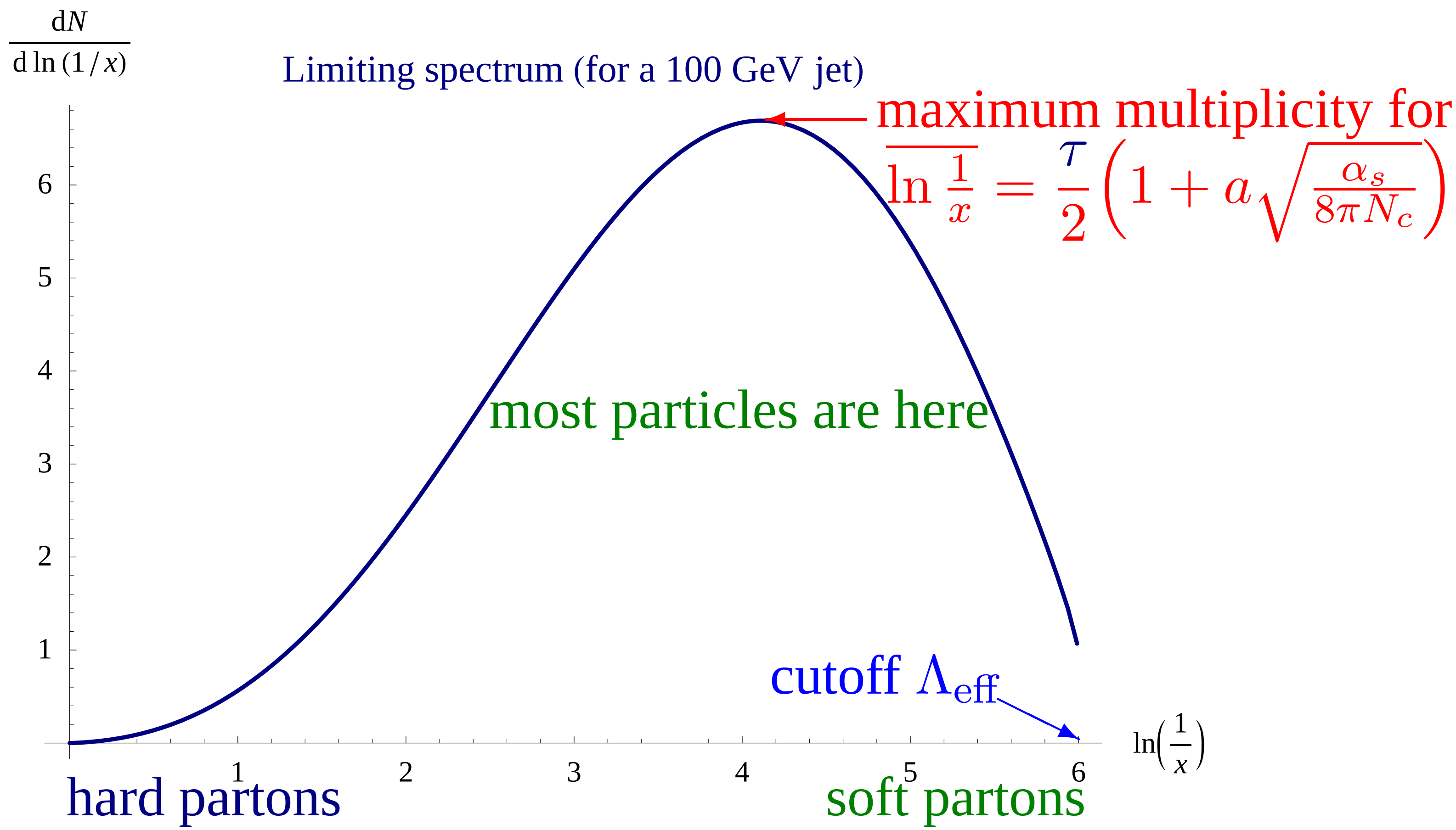
MLLA: limiting spectrum



☞ "Hump-backed plateau"

Note: hump dominated by the singular parts $(\frac{1}{z}, \frac{1}{1-z})$ of the $P_{ji}(z)$

MLLA: limiting spectrum



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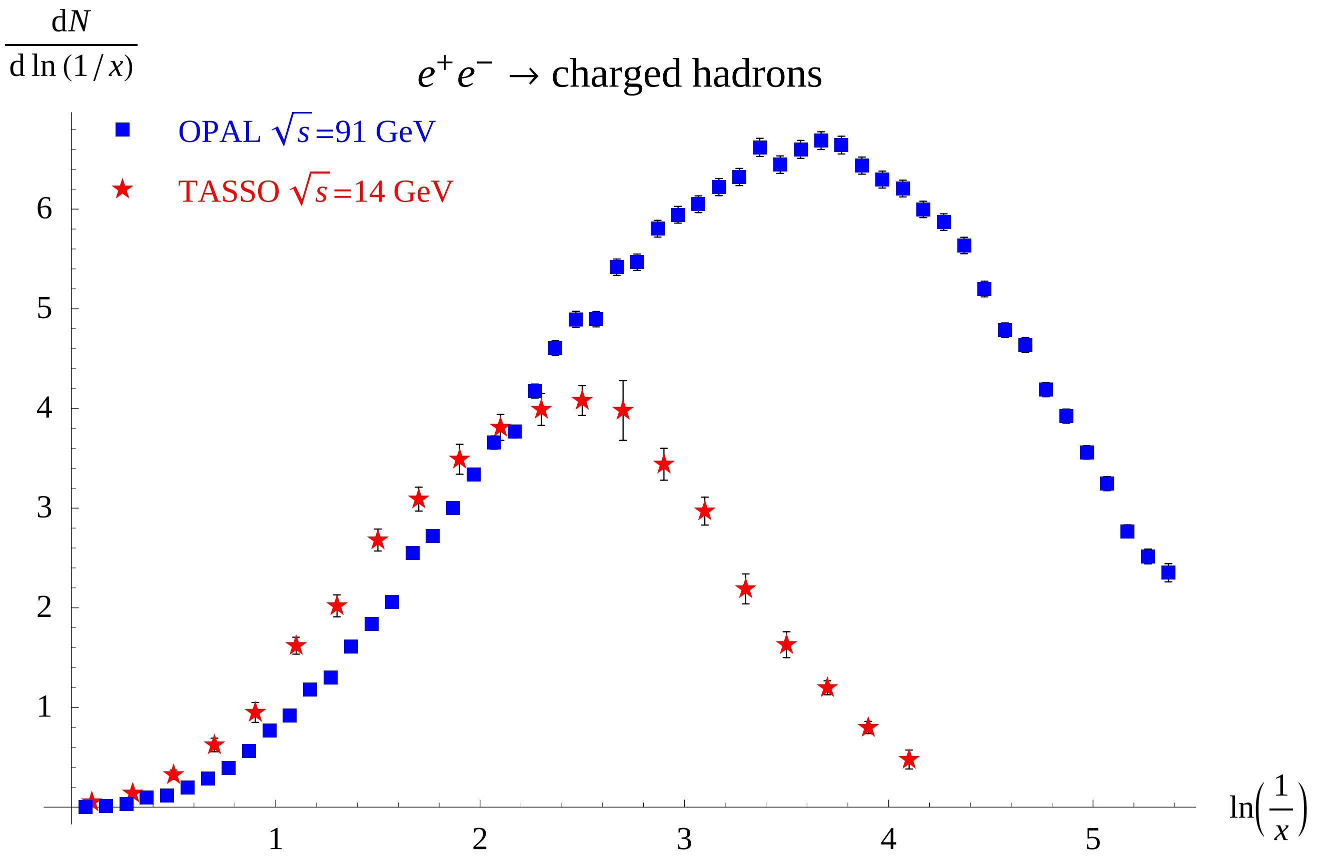
MLLA vs. e^+e^- data



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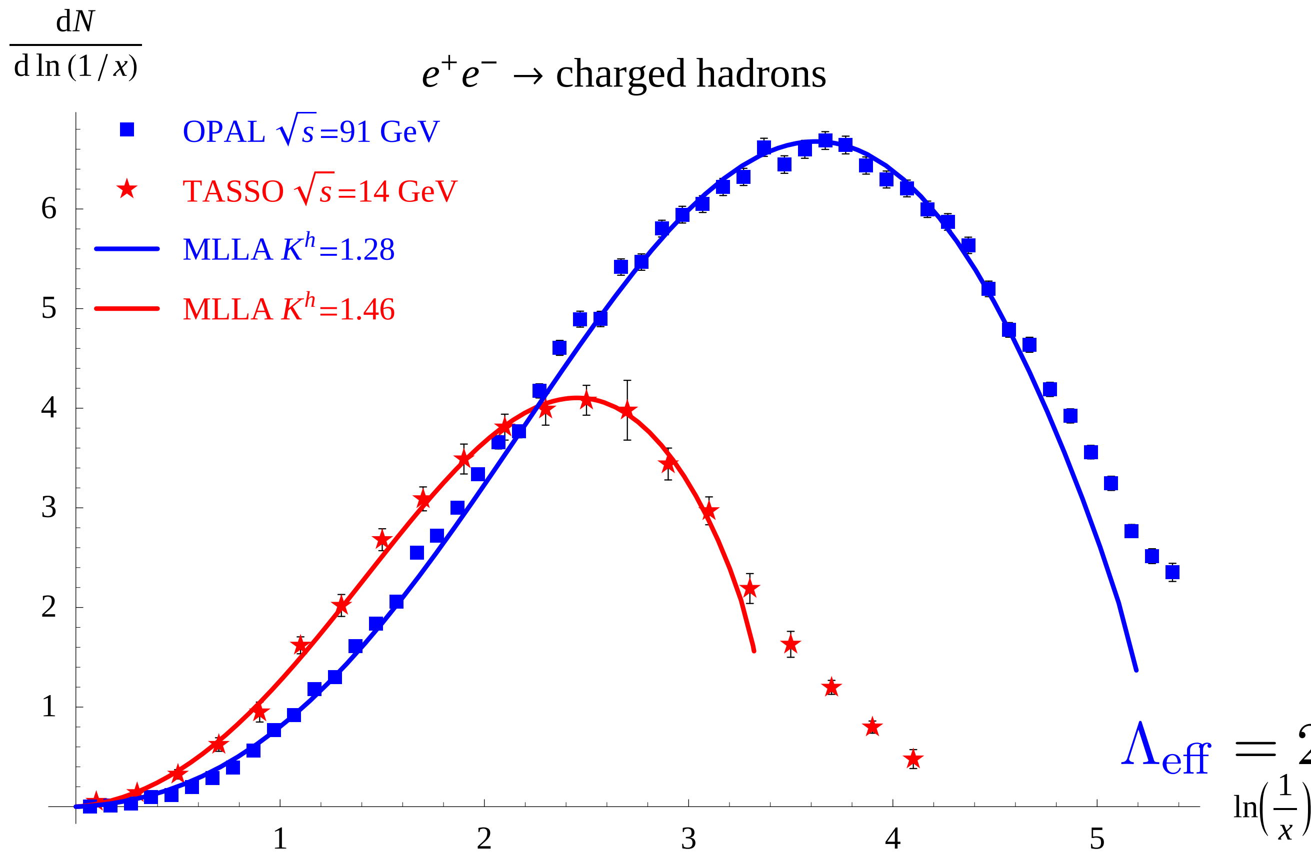


$\Lambda_{\rm eff} = 253$ MeV

$$\bar{D}^h(x,\tau,\Lambda_{\rm eff}) = K^h \bar{D}^{\rm lim}(x,\tau,\Lambda_{\rm eff})$$

Good description in both RHIC and LHC regimes!

Influence of the medium: a possibility

- The hump of the limiting spectrum is mostly due to the singular parts of the splitting functions
- In medium, the emission of soft gluons by a fast parton increases

☞ One can model medium-induced effects by modifying the parton splitting functions $P_{ji}(z)$…

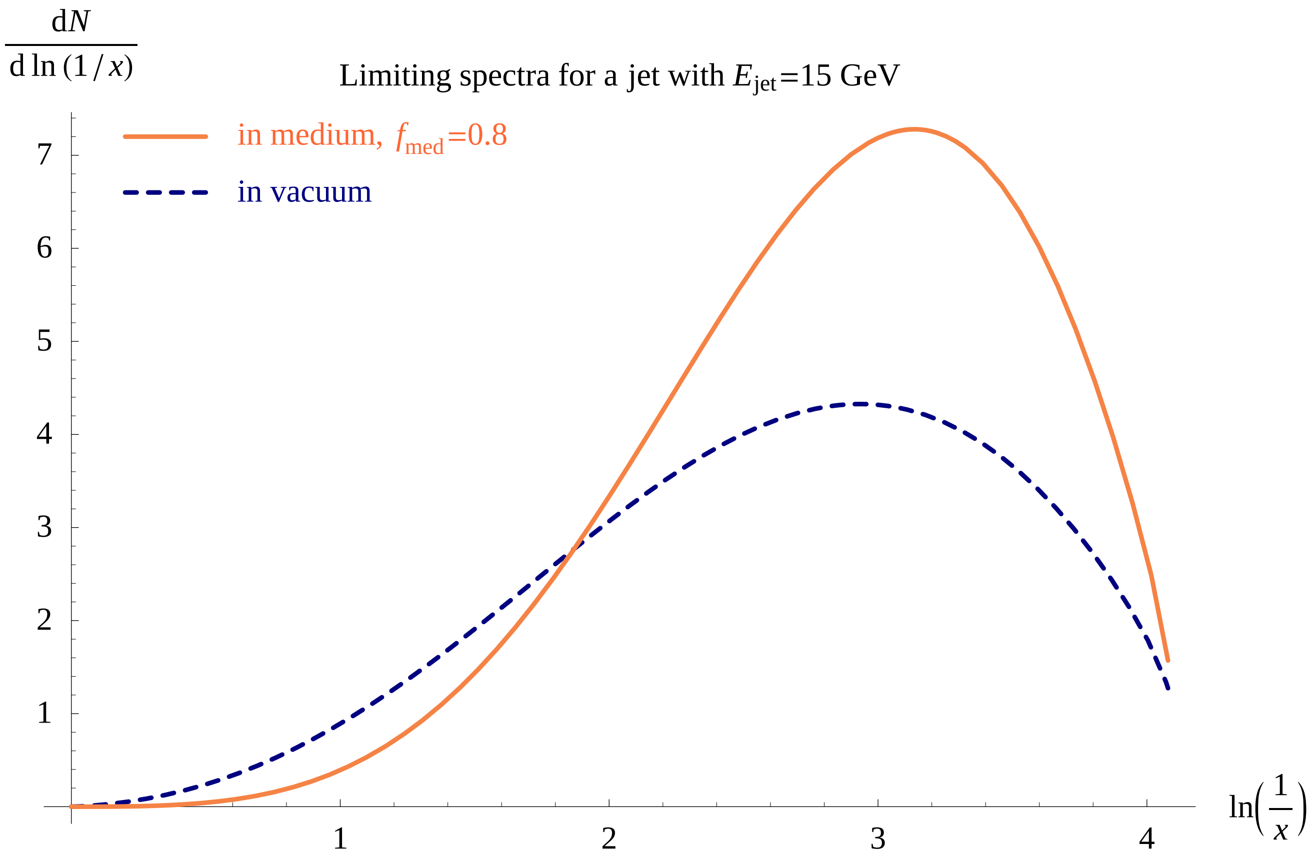
(see e.g. Guo & Wang, PRL **85** (2000) 3591)

… and especially their singular parts:

$$P_{qq}(z) = \frac{4}{3}\left[\frac{2(1+f_{\rm med})}{(1-z)_+} - (1+z)\right]$$

$f_{\rm med} > 0 \Rightarrow$ Bremsstrahlung increases

Influence of the medium on the parton spectrum



$f_{\rm med}$ fixed to reproduce R_{AA} ☞ redistribution of radiated partons:

high p_T (large x) $\longrightarrow$ low p_T (small x)

Medium-induced modification of the associated multiplicity

Ideal case: photon + jet

☞ photon gives jet energy E_T

- Count how many jet particles have a momentum larger than some given cut $P_T^{\rm cut}$ after propagating through the medium:

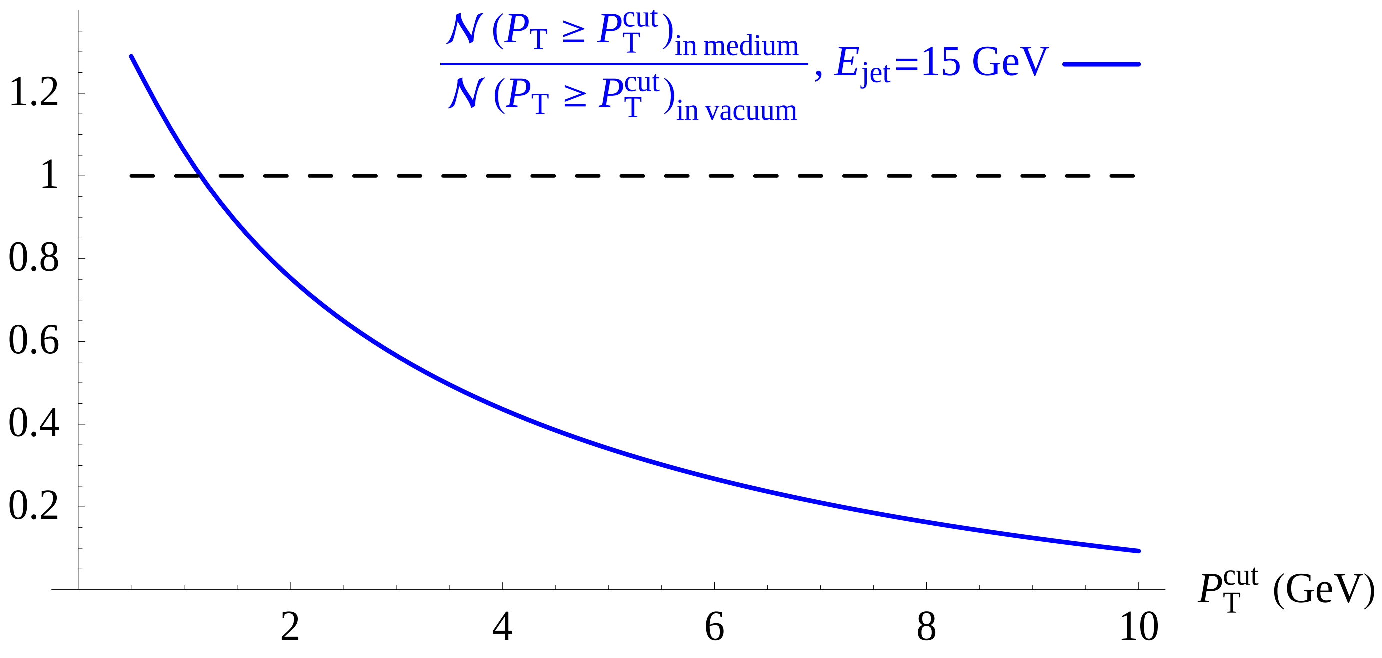
$$\mathcal{N}(P_T \geq P_T^{\rm cut})_{\rm medium}$$

- For a jet *in vacuum* with energy E_T, the spectrum is known $\Rightarrow$ one knows (measurement / *in vacuum* MLLA)

$$\mathcal{N}(P_T \geq P_T^{\rm cut})_{\rm vacuum}$$

- Compare $\mathcal{N}(P_T \geq P_T^{\rm cut})_{\rm medium}$ with $\mathcal{N}(P_T \geq P_T^{\rm cut})_{\rm vacuum}$

Medium-induced modification of the associated multiplicity



In the presence of a medium, less particles for $P_T \gtrsim 1.5$ GeV (particle excess for $P_T \lesssim 1.5$ GeV!)

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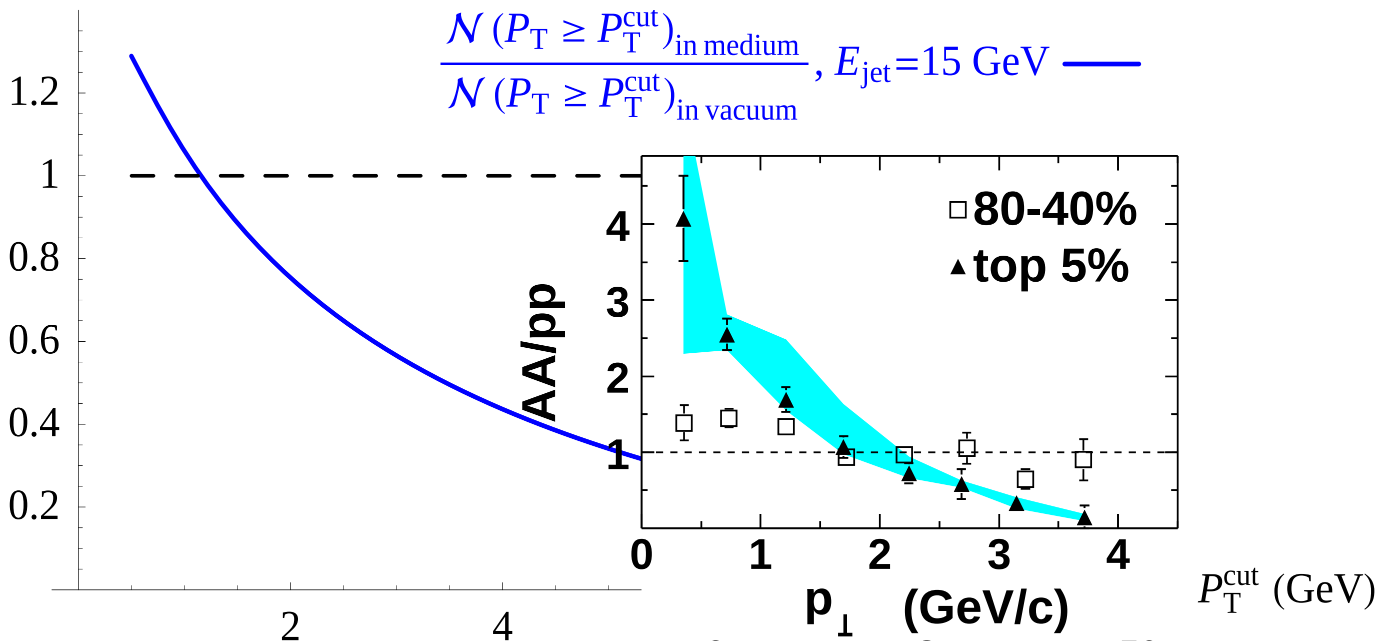

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cf. STAR PRL **95** (2005) 152301

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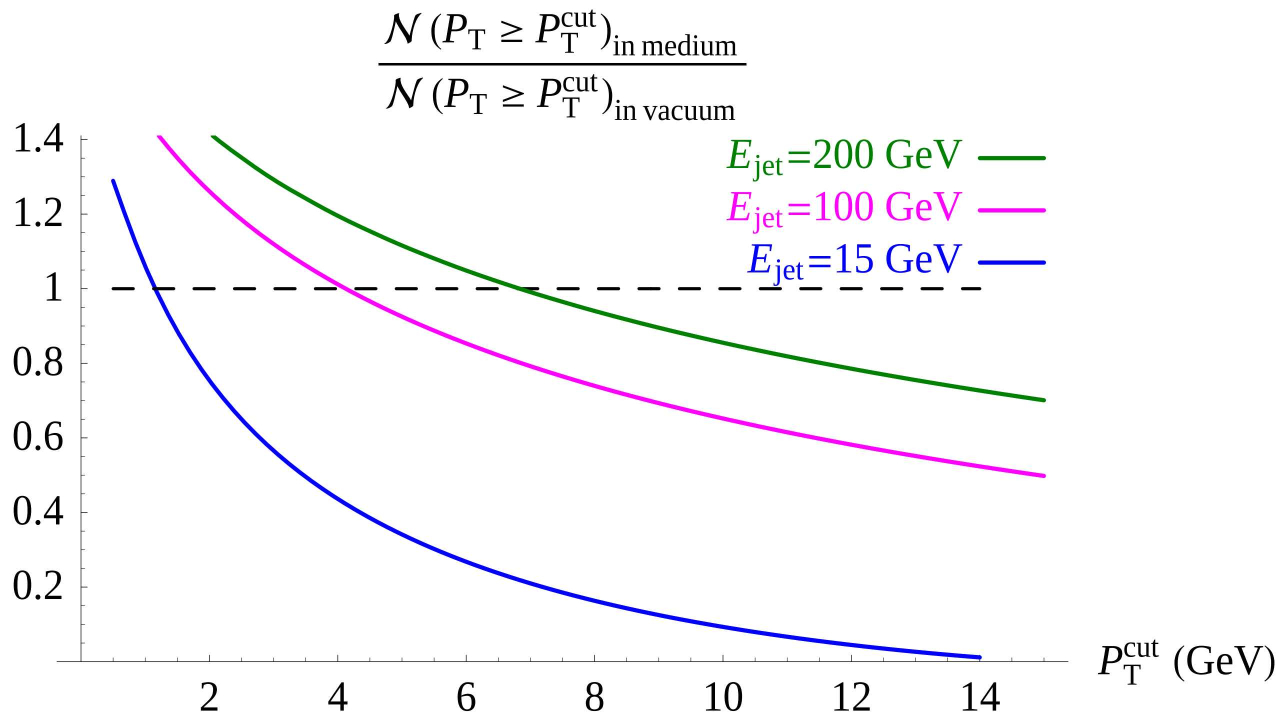


Measurement more promising at LHC:

the additional soft jet multiplicity can more easily be detected above the event background

Hadron spectra

What if the jet energy is unknown…

The measured hadron spectrum is the convolution of

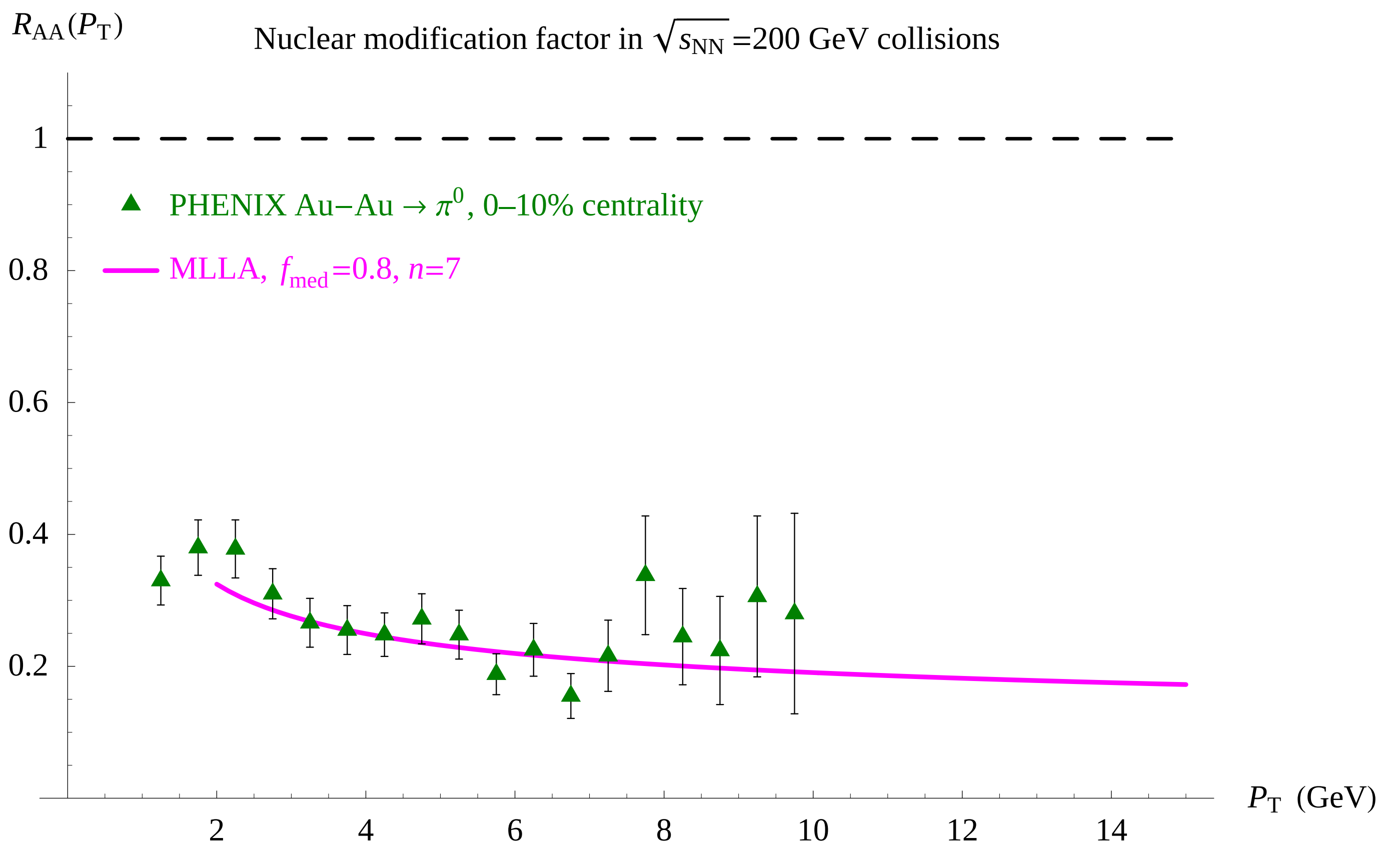
- a parton spectrum $\propto 1/(p_T)^n$ (with a p_T-dependent n to account for experimental biases)
- the "fragmentation function" $\bar{D}^h(x, \tau)$

$$\frac{\mathrm{d}N}{\mathrm{d}P_T} \propto \int \frac{\mathrm{d}x}{x^2} \frac{1}{{p_T}^n} \bar{D}^h(x, p_T) = \int \frac{\mathrm{d}x}{x^2} \frac{x^n}{{P_T}^n} \bar{D}^h\left(x, \frac{P_T}{x}\right)$$

which can be computed within MLLA for both a jet in vacuum and a jet propagating through a medium

$\Rightarrow$ gives the nuclear modification factor R_{AA}

Nuclear modification factor



MLLA parton shower in medium

MLLA analytical description of the particle distribution within a jet

Formalism generalized to the propagation in a medium

- Consistent treatment of parton branchings
  - energy-momentum conservation
  - all branchings treated on an equal footing
- Phenomenological consequences
  - distortion of the hump-backed plateau
  - large P_T range accessible at LHC will test Q^2-dependence of parton energy loss
  - multiplicity above a trigger cutoff
- First step towards further studies:
  - Intra-jet two-particle correlations
  - Monte-Carlo: geometry, $f_{\rm med}(Q^2)$...