Multiplicity distributions for jet parton showers in the medium

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in collaboration with

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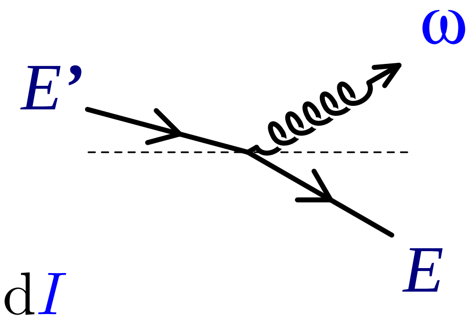
Jet parton showers in the medium



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

$\Rightarrow$ 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 NEW

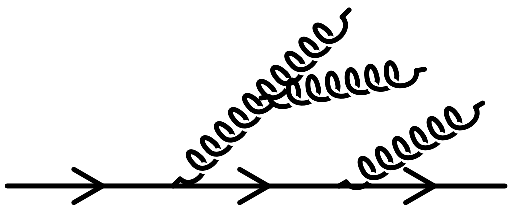
Modified **L**eading **L**ogarithmic **A**pproximation

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



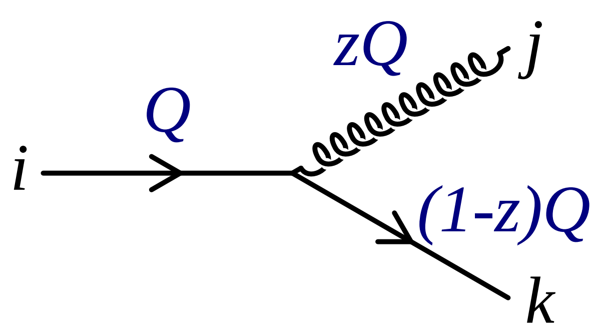
- Includes in a systematic way next-to-leading-order corrections $\mathcal{O}(\sqrt{\alpha_s(\tau)})$!
- Hadronization through "Local Parton-Hadron Duality" (LPHD)

MLLA:
generating functional

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

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

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



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

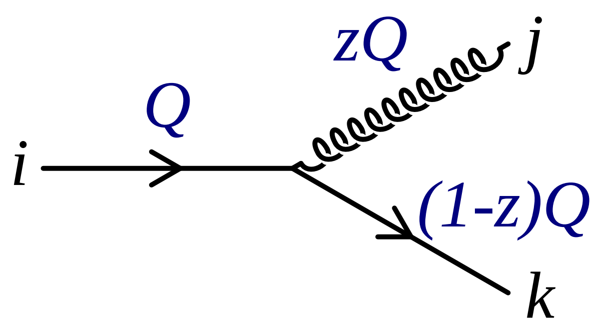
probability to have no branching with angle $< \Theta$

between Θ and Θ'

angular ordering

splitting function $i \to jk$

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

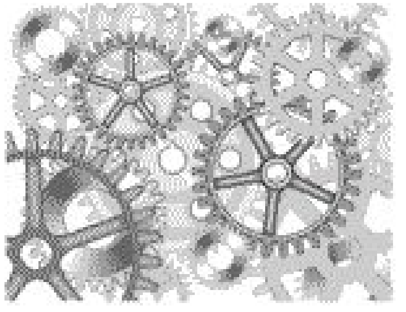


MLLA: limiting spectrum

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

infrared cutoff

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



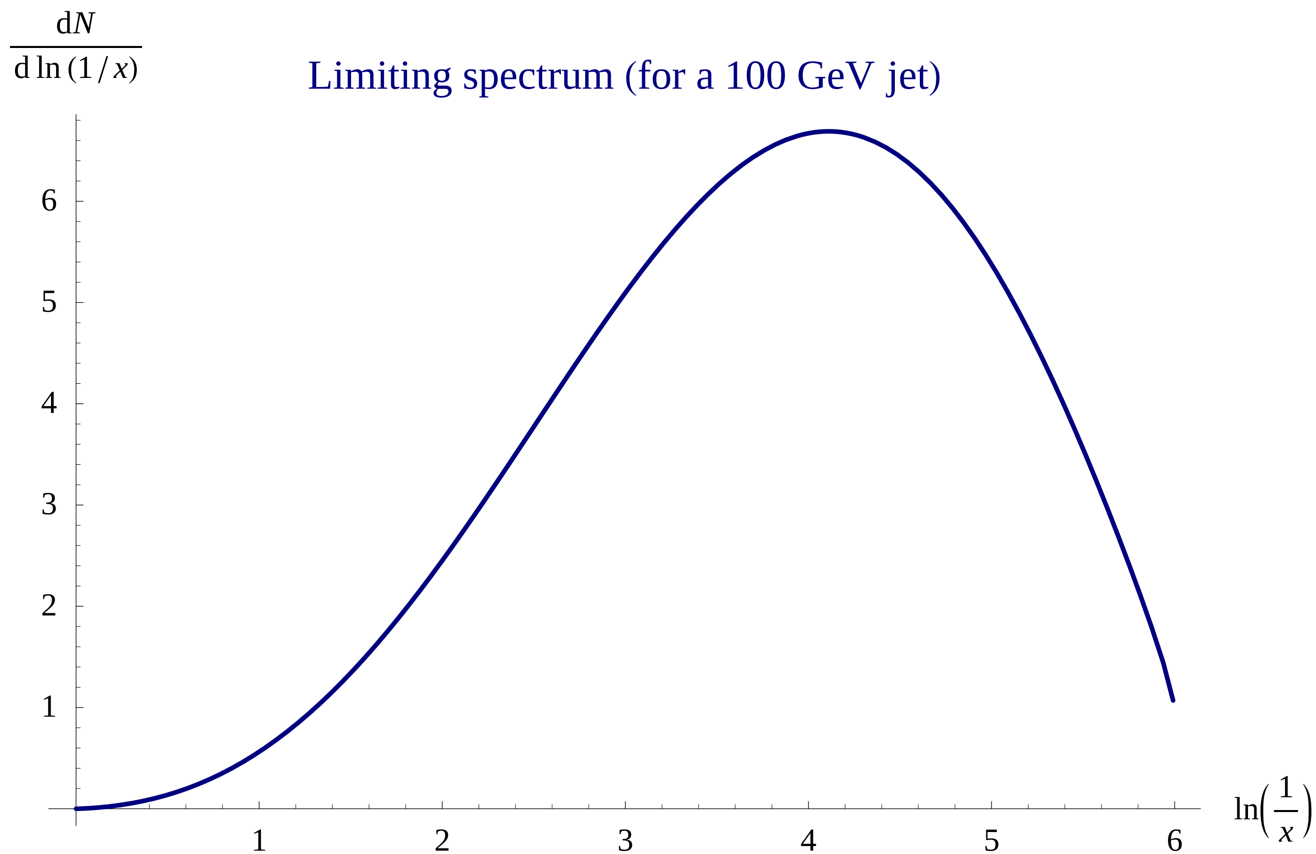
"Limiting spectrum":

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

with

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

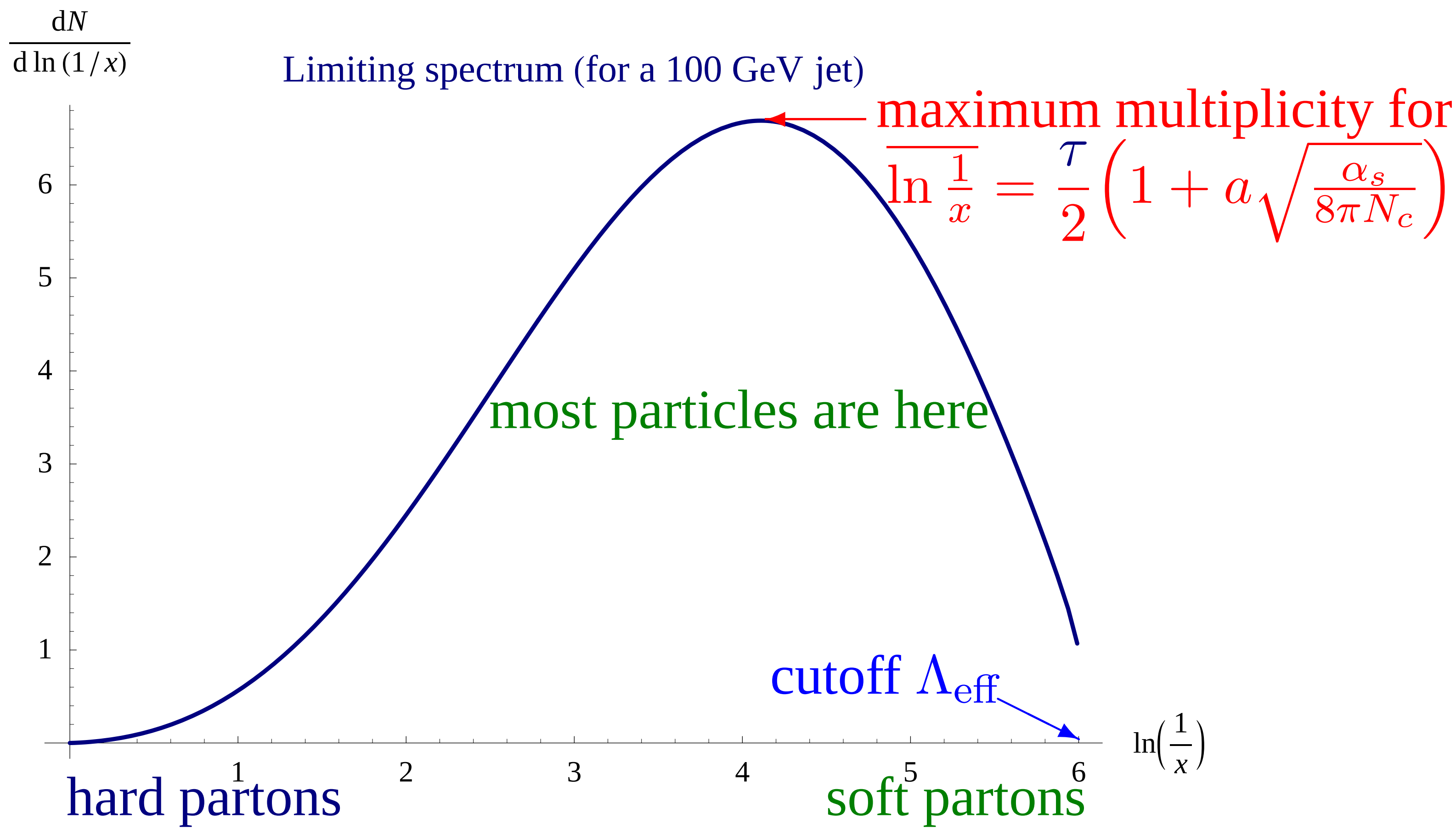
MLLA: limiting spectrum



☞ "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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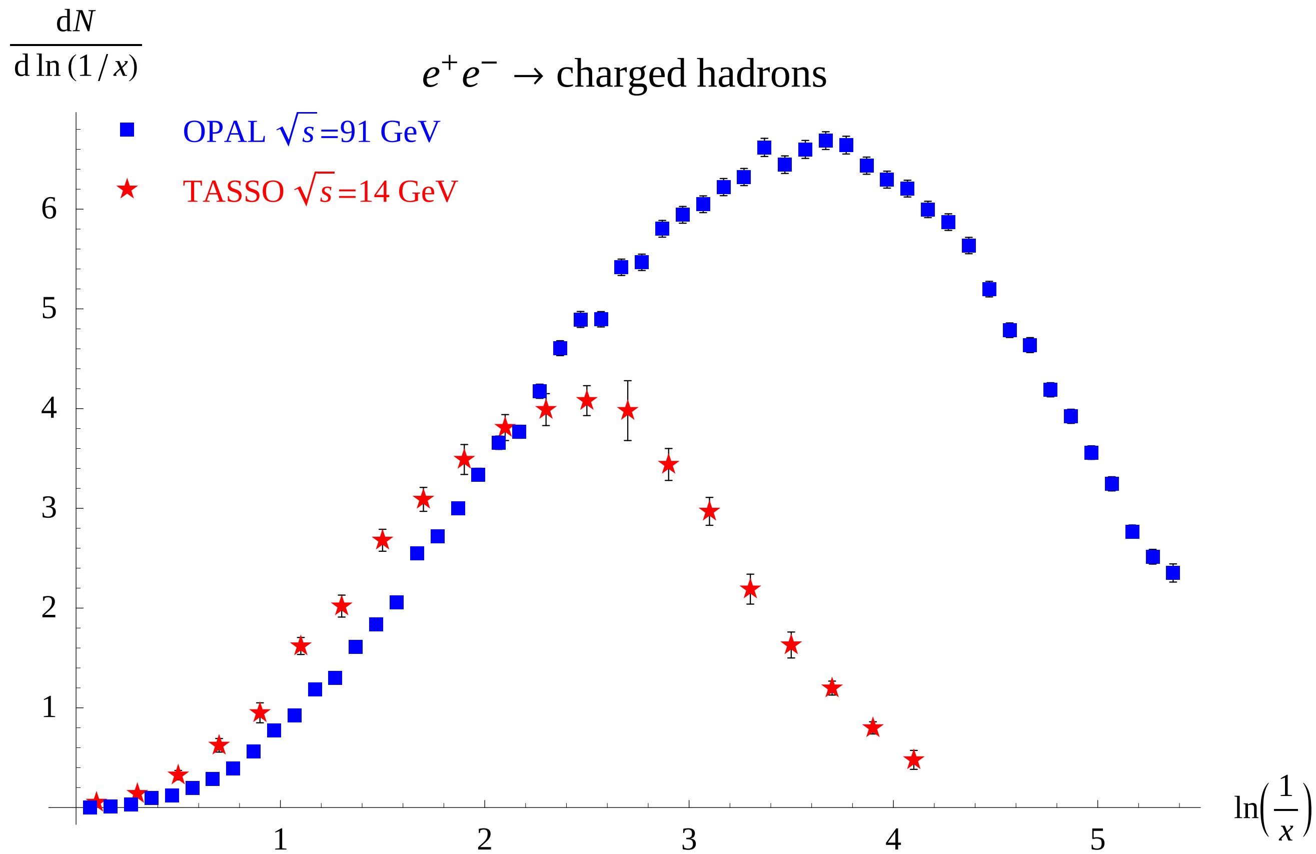
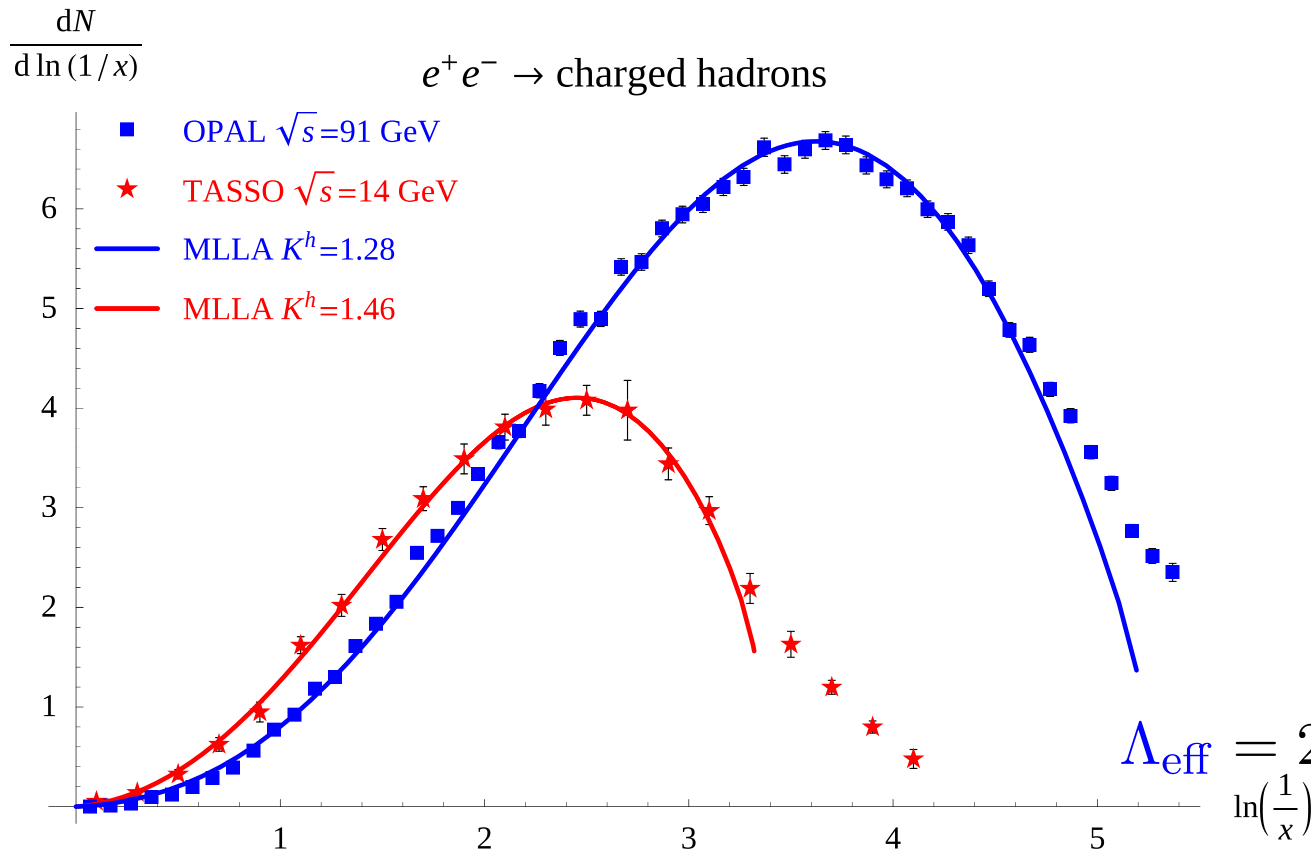
MLLA vs. e^+e^- data



MLLA vs. e^+e^- data



$\Lambda_{\rm eff} = 253$ 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 $P_{ji}(z)$…

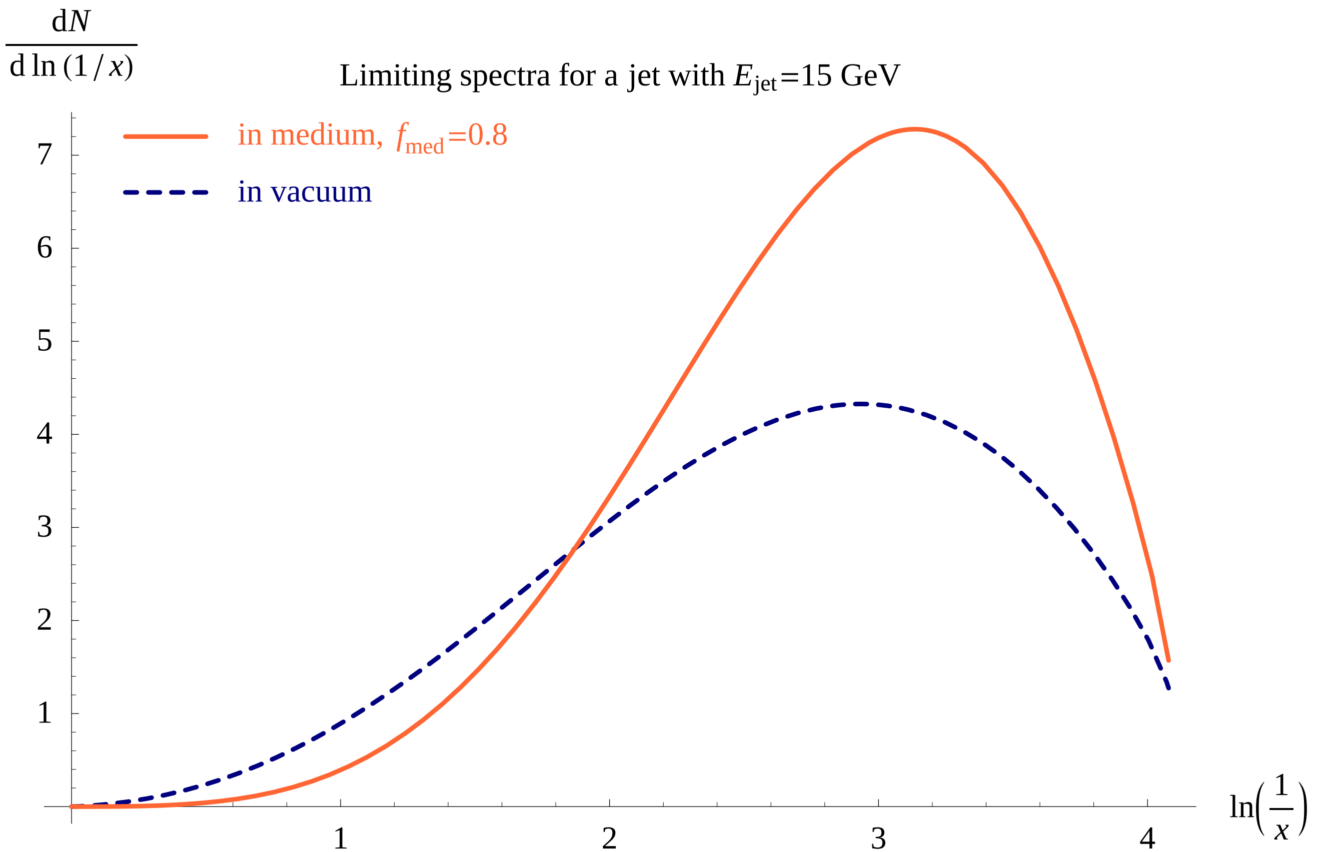
(see e.g. Guo & Wang, PRL **85** (2000) 3591)

… 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:

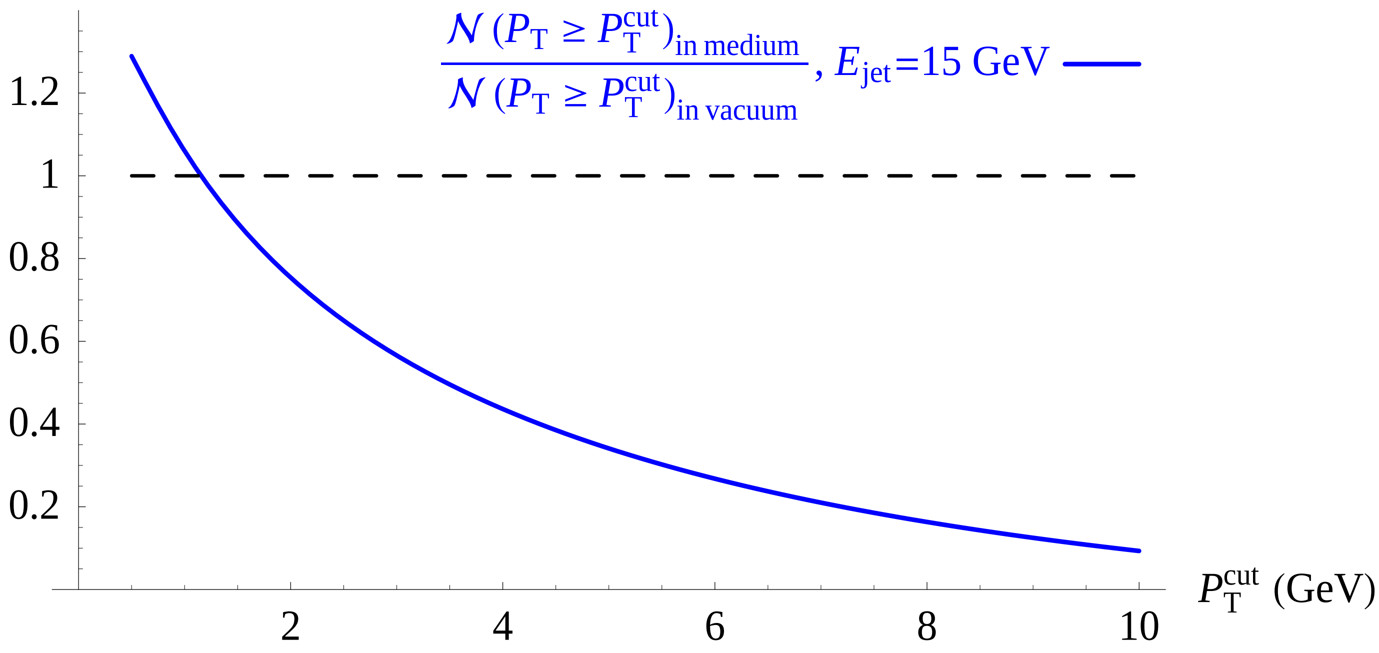
$$\mathcal{N}(P_T \geq P_T^{\rm cut})_{\rm medium}$$

- For a jet *in vacuum* with energy E_T, the spectrum is known ⇒ 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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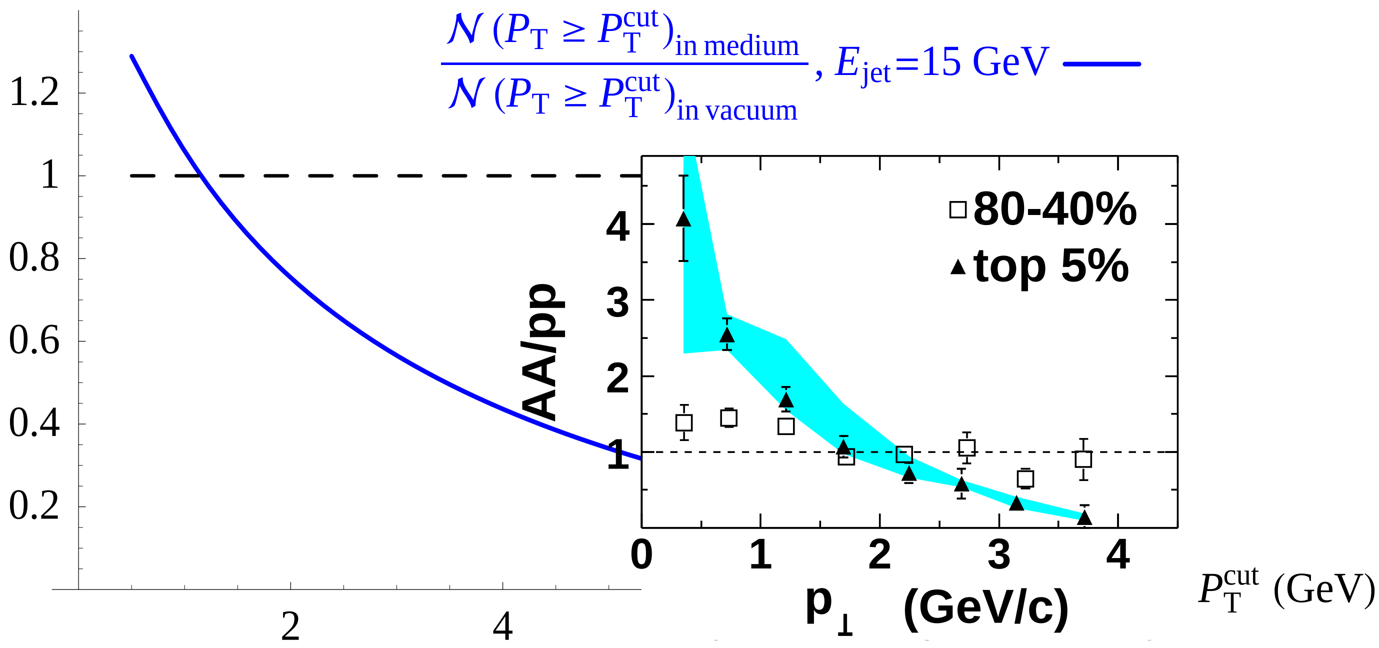

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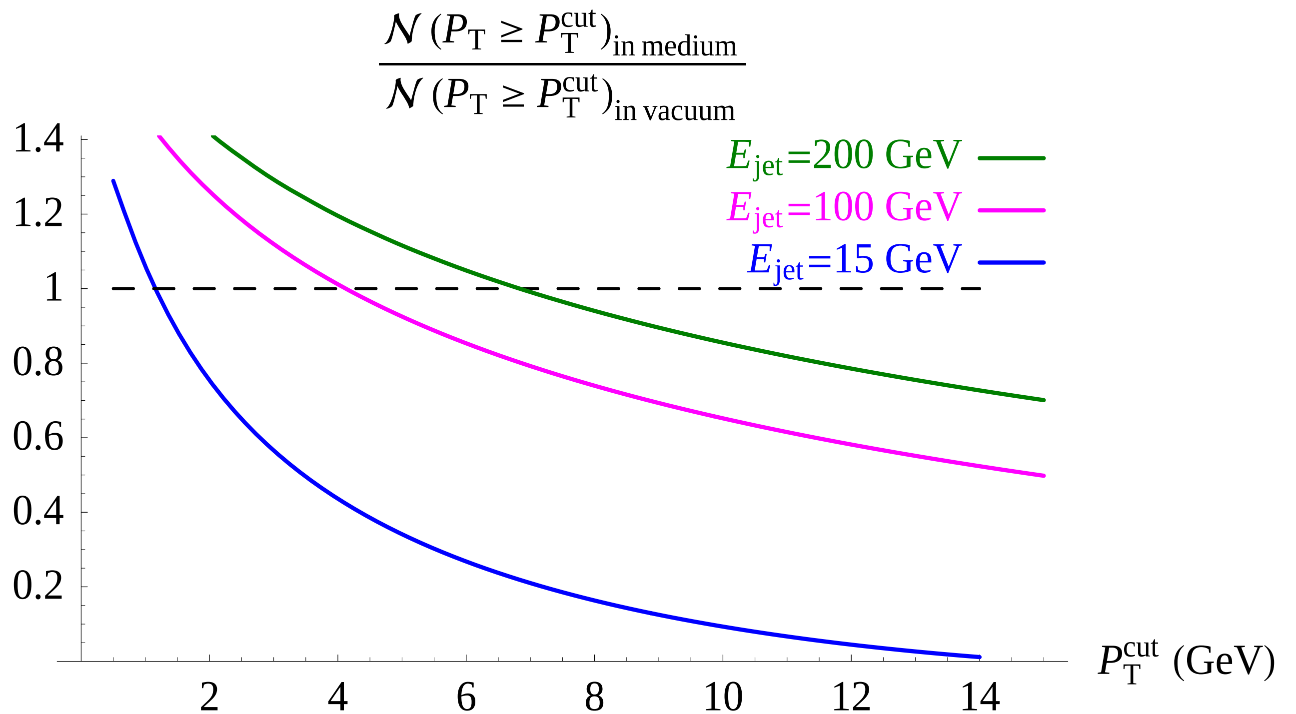
cf. STAR nucl-ex/0501016

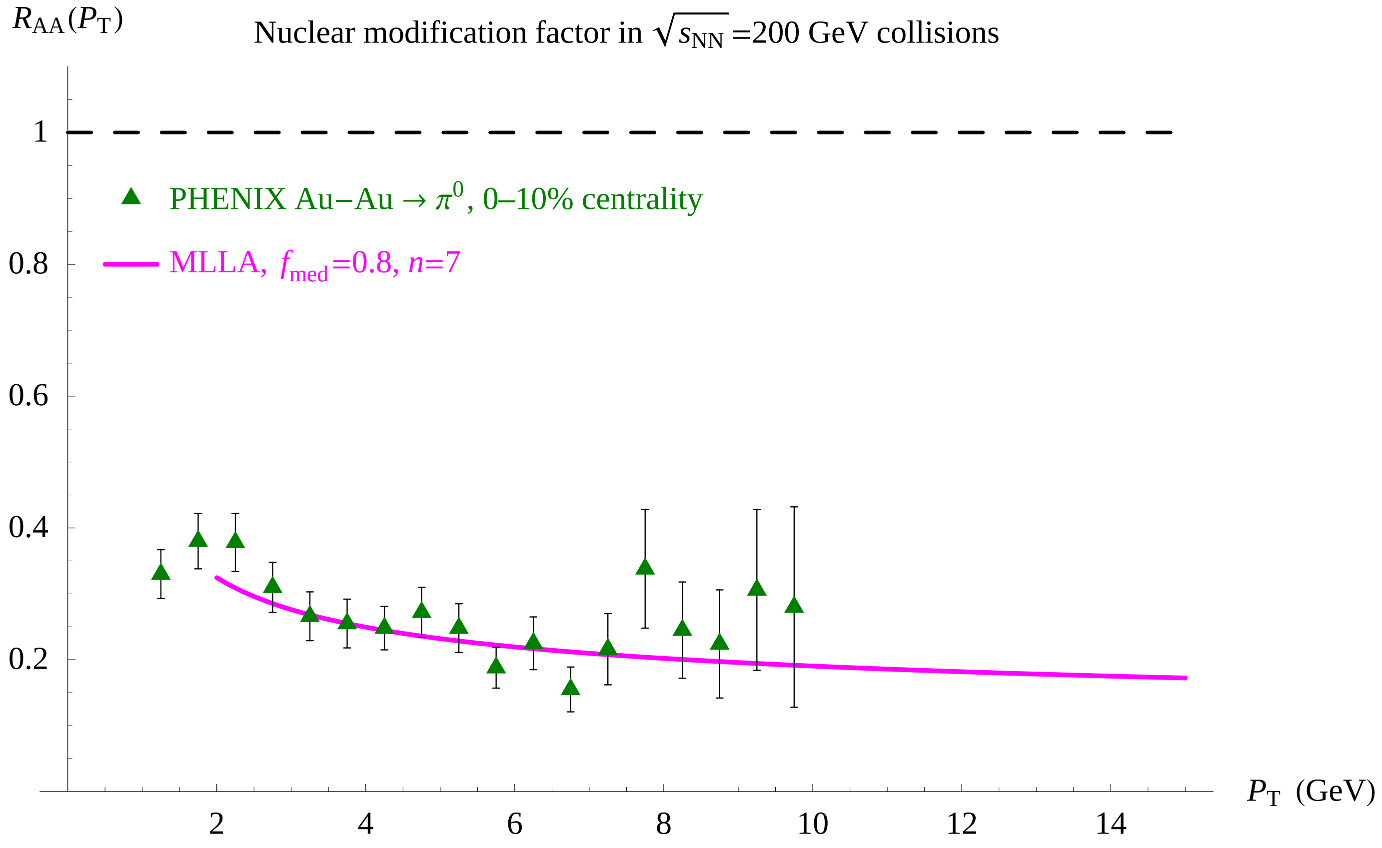
Medium-induced modification of the associated multiplicity



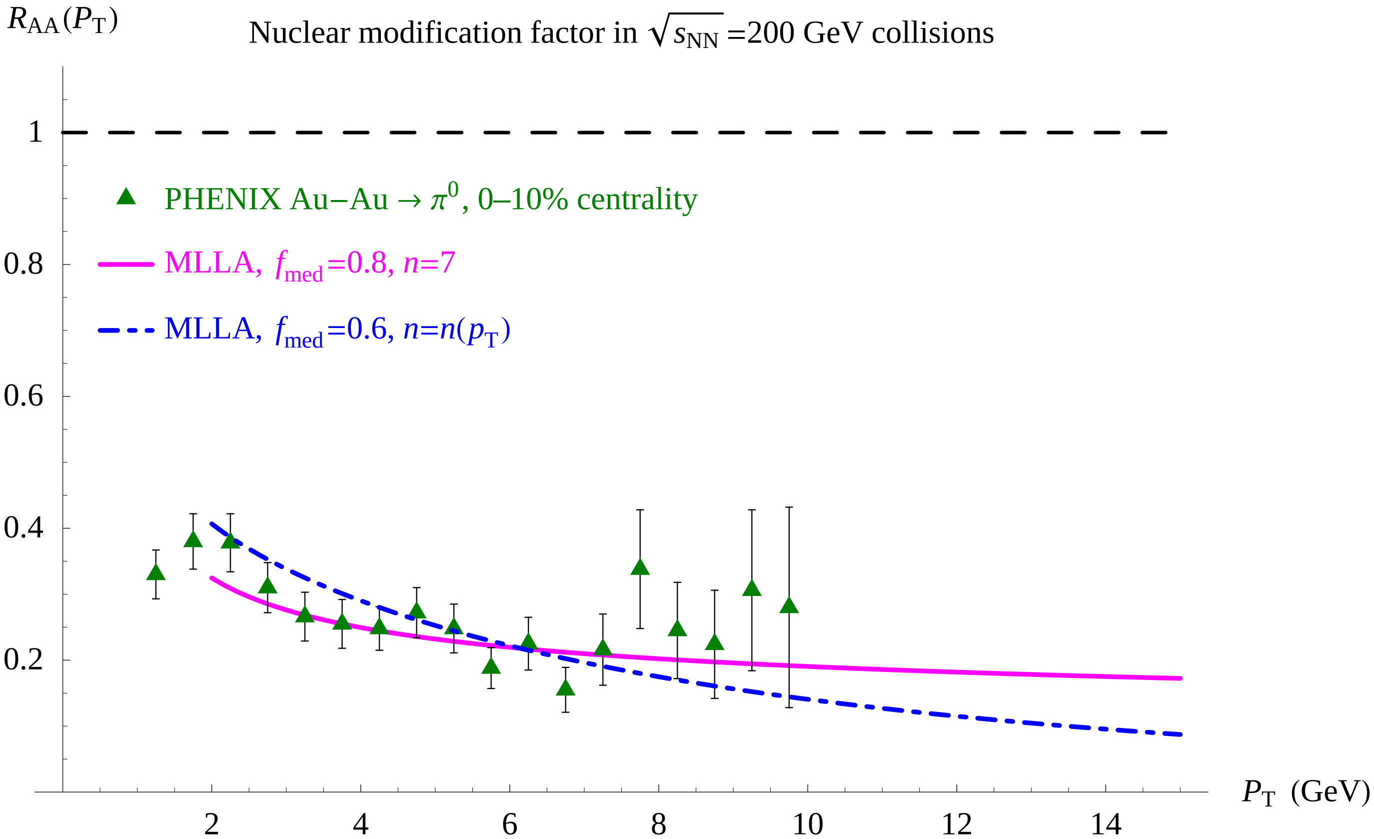
Measurement more promising at LHC:

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

Nuclear modification factor



Nuclear modification factor



$R_{AA}(P_T)$ decreases since higher P_T ⇒ higher Q ⇒ more splitting

☞ parton energy loss may depend on Q? e.g. $f_{med} \propto 1/Q^2$

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 (in progress)
  - multiplicity above a trigger cutoff
- First step towards further studies:
  - Intra-jet two-particle correlations 
  - Monte-Carlo: geometry, $f_{\text{med}}(Q^2)$...

MLLA parton shower in medium

Extra slides

Parton shower in medium

- Write the parton-distribution evolution equation with modified splitting functions

$$\vdots$$

$$\bar{D}^{\rm lim}(x,\tau) = \frac{4N_c\tau(1+f_{\rm med})}{b\hat{B}(\hat{B}+1)}\int_{\epsilon-{\rm i}\infty}^{\epsilon+{\rm i}\infty}\frac{{\rm d}\nu}{2\pi{\rm i}}\,x^{-\nu}\Phi(-\hat{A}+\hat{B}+1,\hat{B}+2;-\nu\tau)$$

$$\hat{A} \equiv \frac{4N_c(1+f_{\rm med})}{b\nu}, \qquad \hat{B} \equiv \frac{\hat{a}}{b}, \qquad \hat{a} \equiv \frac{11+12f_{\rm med}}{3}N_c + \frac{2N_f}{3N_c^2}$$

- Hadronization (LPHD) still takes place in vacuum: K^h unchanged

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}