[very brief] Comments on Jet Quenching

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:: evidence for longitudinal softening of leading parton ::

:: very sketchy theory primer





—o medium characterized by BDMPS transport coefficient

$$\hat{q} \simeq \frac{\mu^2}{\lambda}$$

—o how much energy is lost ?

:: very sketchy theory primer



:: very sketchy theory primer







what does LHC data teach us so far? [calorimetric jets + reconstruction algorithms] constrained dynamics?

:: di-jet asymmetry

- jet energy within a cone R=0.4 [ATLAS] (R=0.5 [CMS]) with

 \hookrightarrow E_{T1} > 100 GeV (120 GeV) [leading jet]

E_{T1} > E_{T2} > 25 GeV (50 GeV) [recoiling jet] with azimuthal
 separation Δφ > π/2 (2/3 π)

- energy asymmetry

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

jet finding in high multiplicity environment is challenging
 (c.f. Gavin's talk)



:: di-jet asymmetry



← very mild dependence for azimuthal distribution [also unchanged from pp]



:: most central events



- clear suppression of more symmetric events [0 < A_J < 0.2]

- o enhancement of events with $A_J \approx 0.5$
- very mild modification of the azimuthal angle distribution

:: few observations [pp]

- o pp jets are asymmetric



E_{T1} good approximation to E_{tot} [data sample biased to leading jets with 'little' energy loss] (0.1)

x= E_{T2}/E_{T1} (0,2) [fractional energy in associated jet]

(0.3)

(0.4)

→ significant out of cone radiation [average fractional in associated jet]

$$\langle x \rangle_{pp} \leq \frac{\langle E_{T2} \rangle_{pp}}{N_{evt}} \approx \frac{1}{N_{evt}} \int dx x \frac{dN}{dx} = 0.67$$

$$\frac{\langle E_{T2} \rangle_{PbPb}}{N_{evt}} \leq \frac{1}{N_{evt}} \int dx x \frac{dx}{dx} = 0.67$$

$$\frac{\langle E_{T2} \rangle_{PbPb}}{E_{Total}} < \frac{1}{N_{evt}} \int dx x \frac{dN}{dx} = 0.54$$

$$(0.6)$$

wide energy distribution

$$\frac{\Delta E}{E_{Total}} = \frac{\langle E_{T2} \rangle_{pp} - \langle E_{T2} \rangle_{PbPb}}{E_{Total}} > 0.1 \tag{0.8}$$

:: out-of-cone radiation in PbPb



← estimate energy loss

• [underestimate] all jets interact equally

$$\frac{\langle E \rangle}{E_T} > 0.1$$

$\alpha < 0.5$

• [overestimate] only fraction (1- α) interact [corona effect] $\frac{\langle E \rangle}{E_{T}} < 0.2$

:: requires medium induced transverse broadening ::

:: out-of-cone emission

—o large angle medium induced hardish radiation ?



deflects recoiling jet → sizeable modification of azimuthal distribution

:: out-of-cone emission

—o transport of radiated gluons



the medium acts as a frequency collimator efficiently trimming away the soft components of the jet

:: (in .vs. out) of cone radiation

--- no missing transverse momentum [CMS] :: who is where?

- —o given A_J achieved in PbPb by outof-cone radiation of extra soft modes
 - ←→ medium strongly enhances outof-cone soft radiation
- mild softening of in-cone radiation pattern





a simple underlying dynamical mechanism ? [beyond and before any specific formal implementation]

:: enhanced asymmetry
:: unchanged azimuthal distribution
:: small in-cone effect
:: increase of out-of-cone soft radiation

:: jet collimation

[with Jorge Casalderrey-Solana and Urs Wiedemann]

arXiv:1012.0745 [hep-ph], J Phys G (2011)



 $\langle k_{\perp} \rangle \sim \sqrt{\hat{q}L}$

- soft modes are formed early



—o sufficiently soft modes are decorrelated from the jet direction

$$\omega \le \sqrt{\hat{q}L}$$

$$\mathbf{F}_{\text{T2}} < \mathbf{F}_{\text{T1}}$$

(the medium filters out soft components of the jet 'wave-function']

> the mechanism does not require further splitting [but it is further enhanced by it]

:: energy fraction in soft components



(7)

$$\frac{E(z)}{E_T} = \int_{\log 1/z}^{\infty} d\xi$$

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 $E_T \in G_l$ 3: Dashed e_{lp} lusive parton distribution in a jet of energy $E_{\Gamma} = 100$ GeV obtained by MLLA evolution from an : an estimate it a factor (R), (R = 0.4) up to a final partonic scale $Q_f = 1$ GeV. Solid: same distribution obtained by a small z. medium modified MLLA kernel [15]. Note that due to kine- ΔE matical constraints, there are proposed with $z < E_T \sin \theta/Q$. > 0.1use estimates for out-of-cone energy loss E_{Total} to a final scale Q_f is shown in Fig. 3 (dashed line). Con-0.5 sistent with the praxis in Monte Carlo event generator we choose $Q_f = 1$ GeV as the lowest scale for partonic eveloperation of the scale fore 0.4 tion. At this scale, one sees that high energy jets contain E(z)/ET ΔE 0.3 already many soft pappons. From the share inclusive distribution, the average quergy fraction of the jet carried $^{2}Total$ partons with energy fraction smaller than z is given 0.1 $\frac{E(z)}{0.15} q = \int_{0,20}^{\infty} d\xi \ e^{-\xi} \frac{dD}{d\xi} ,$ 0.10 0.05FIG. 4: Fraction of the total jet energy, E_T , carried by paron distribution in a jet of enwhich is shownless Fign & (dathed blained EAge Pig. as the by MLLA evolution from an Free Tationainvolverashed) soft both in medium (solid) (Tha = 0.4) up to a final partonic provides a good approximation of $E_z \to E_T$ only valid at e distribution obtained by a medium modification, we can estimate $\hat{q} L$ by determin-[15]. Note that due to kinegluons with $2 < E_{\rm III} \sin \theta / Q_{\rm c}$ ing formaining in Apthenvaluesz for the induction for the indication of the sector of onjeg fragineider wit but he ibos fts . OA merzyn bos of Eqch (3) Fig. 3 (dashed line). Conand then the Sicener partonic with oughly consistent with a final factors in the second distribution] te Carlo event generator we est scale for partonic evoluin Fig. 3 and Fig. 4 (solid lines). Since there is a larger hat high energy jets contain fraction of the oraciet energy stored in soft components, om the single inclusive disa collimation up to the same frequency $\sqrt{\hat{q}L}$ leads to a fraction of the jet carried larger energy loss. In this case, we obtain (8)

ion smaller than z is given

with E_T the jet energy given in units of $E_0 = 100$ GeV.

FIG. 4: Fraction of the to tons of energies less than ω Eq. (7) in vacuum (dashed) plot does not extend to z

can obtain simple model of jet fragmentation funct medium-enhancement wh factor 5 suppression of le in Fig. 3 and Fig. 4 (soli a fraction of the total jet er a collimati<mark>e</mark>n up to the larger energy loss. In this

 $30 \left(\frac{E_T}{E_0}\right)^2 \le \hat{q}L \le 60$

These estimates are su Amongst the model-intrin of the final resolution sc pact on the distributions lines). Moreover, there a of order $\mathcal{O}\left(\sqrt{\hat{q}L}/R\right)$ the side the jet cone. Includ will require a discussion o estimates at face value, an mation about the distribution To arrive at first referen fm $(L \sim 10 \text{ fm})$ yields 5 $6 \text{ GeV}^2/\text{fm}$). It is clear, not replace detailed mode

both the suppressio_ <u>19</u>



jet frequency collimation is a natural mechanism to explain existing data