Jet Quenching

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Jet Quenching via Jet Collimation

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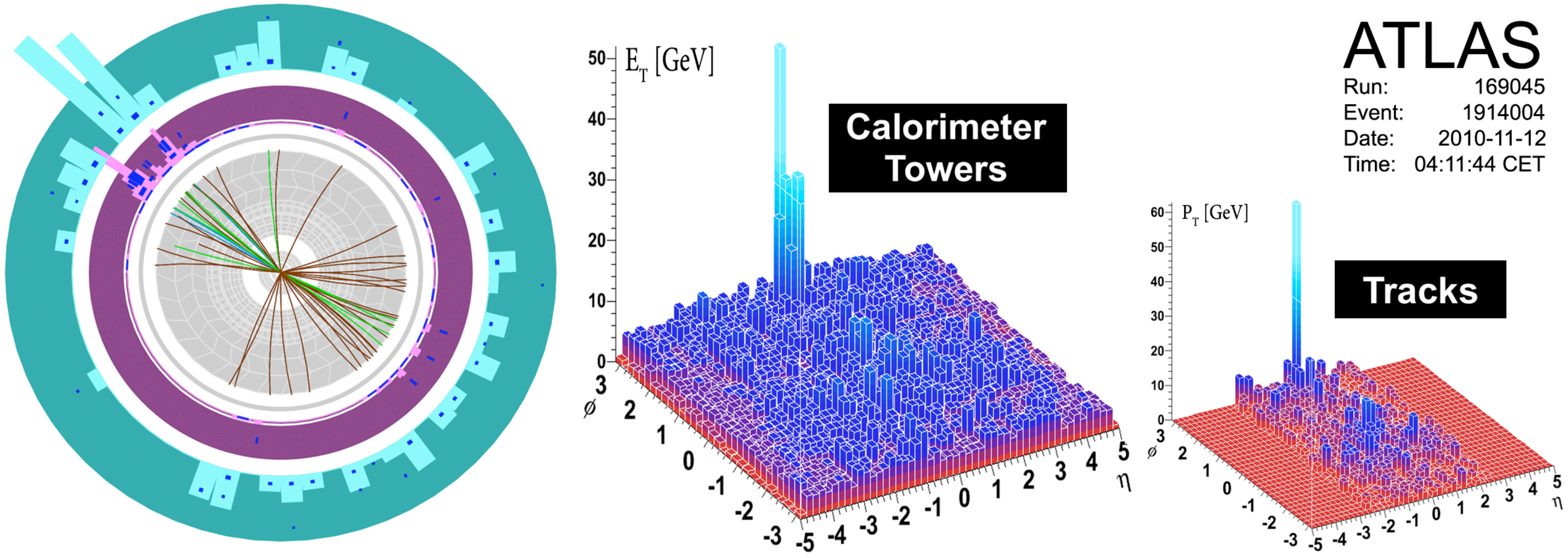
Quenched Jets

(on the event display)

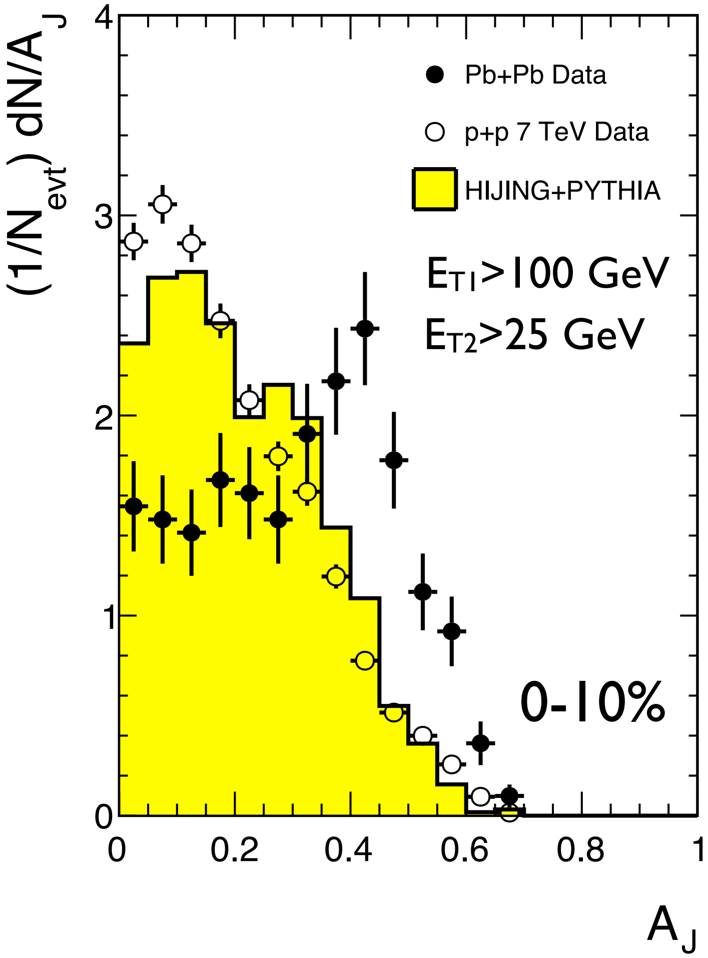


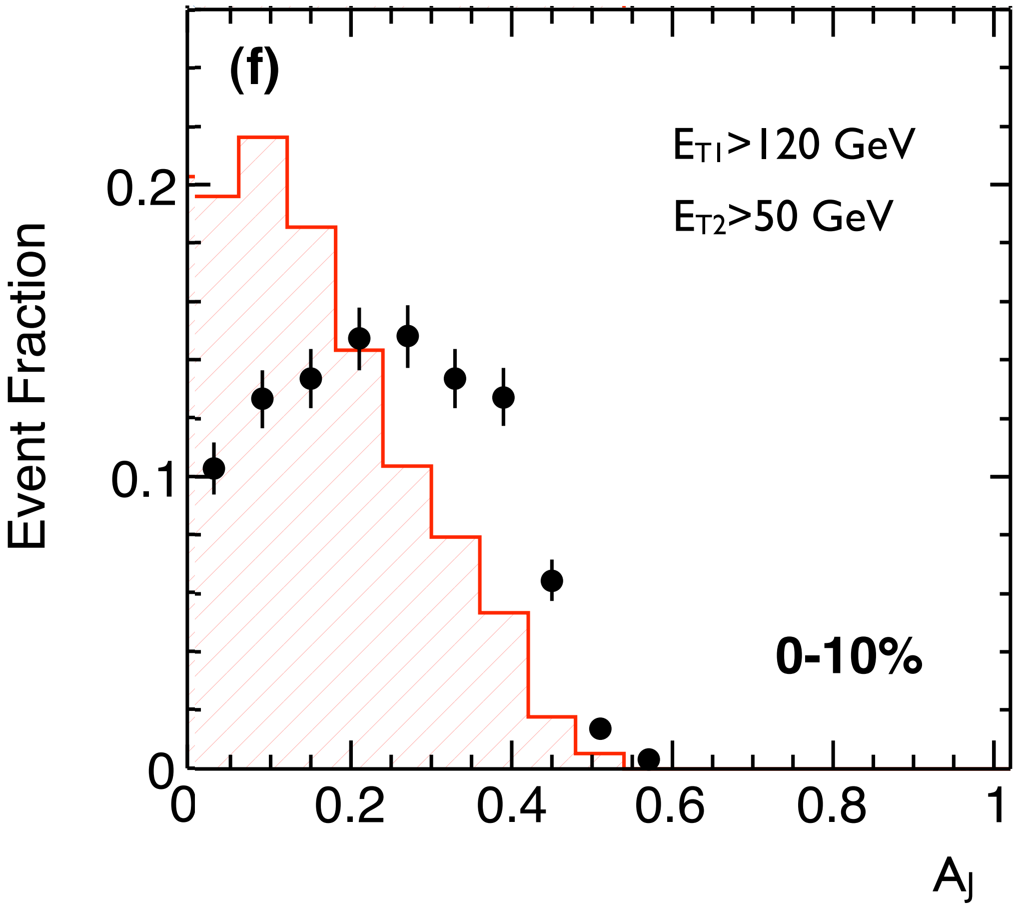
(not the typical event but not infrequent)

Plan for the talk:

- Quick discussion of the di-jet asymmetry data.
- Simple kinematical arguments ⇒ Jet frequency Collimation
- Early estimate on medium parameters.

Di-Jet Asymmetry



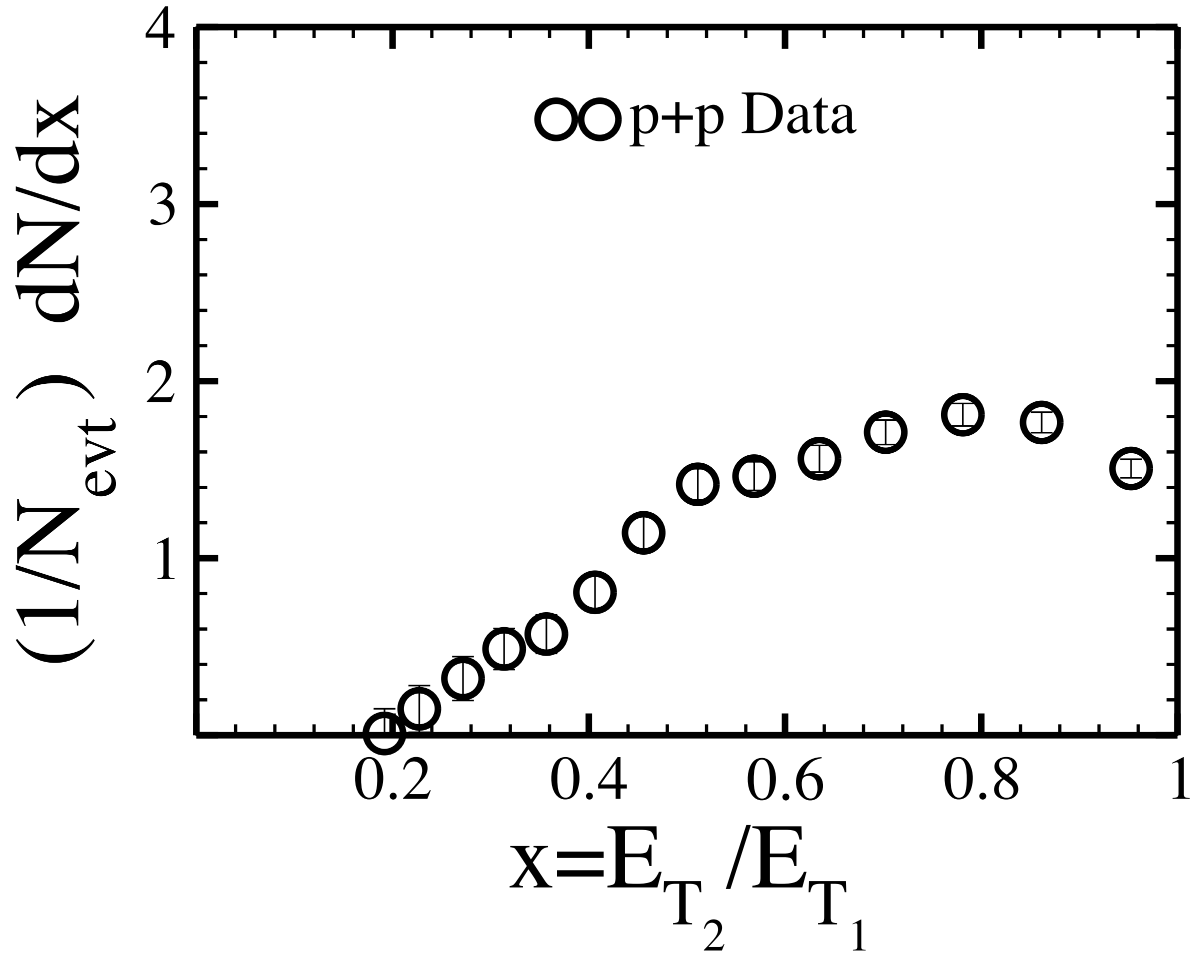


- Jet energy within a cone $E_{T1} > E_{T2}$.
- Energy asymmetry between leading and associated jet

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

- The jet asymmetry grows with centrality.
- Many caveats on the measurement such as background fluctutions (Cacciari, Salam, Soyez 11). But not so many for the CMS cuts

p-p events are Asymmetric!



- The steeply falling spectrum ⇒ E_{T1} good proxy for E_{Total}

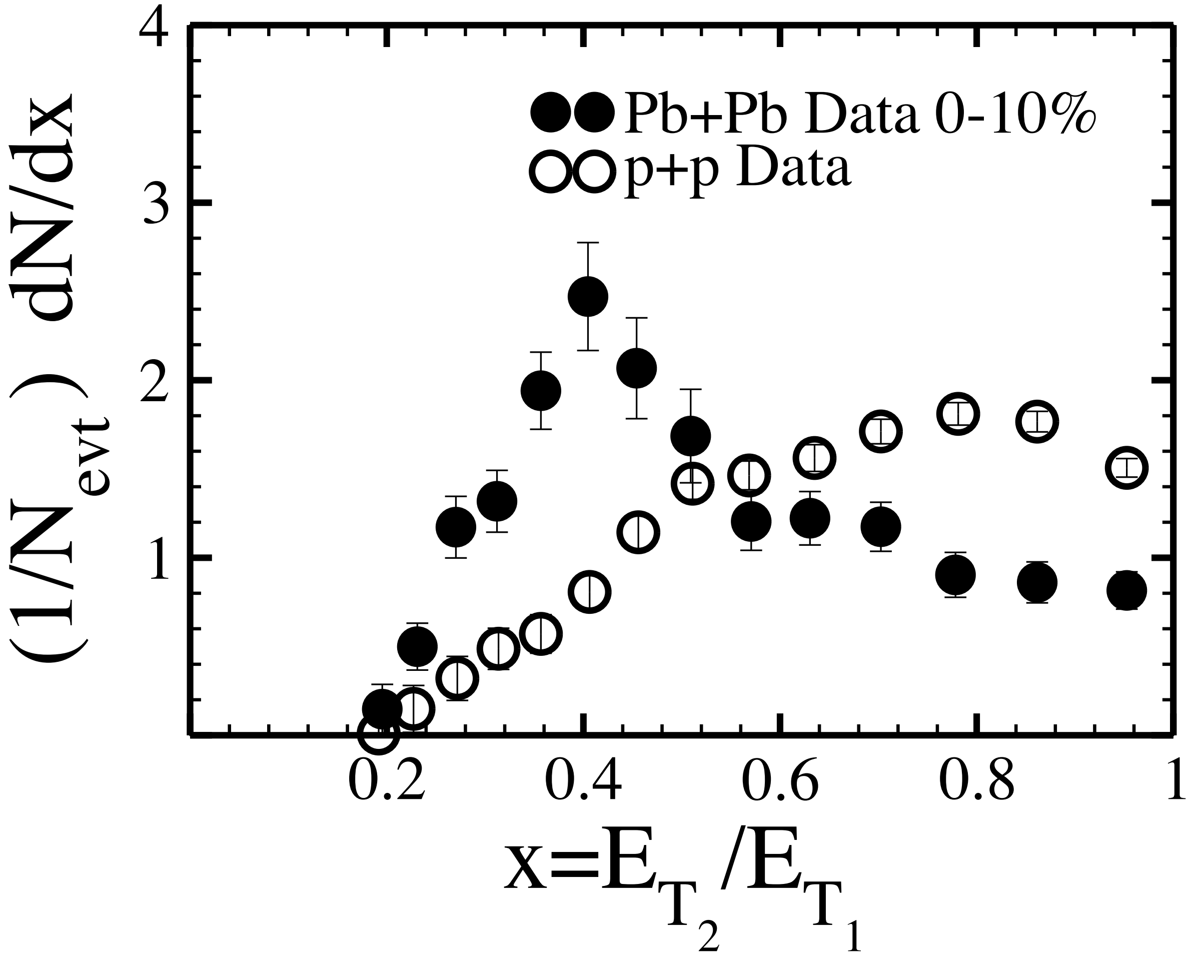
  $x=E_{T2}/E_{T1}$ ≈ fractional energy in the assoc. cone

- There is significant out of cone radiation in p-p

$$\frac{\langle E_{T2}\rangle_{pp}}{E_{T1}} \approx \frac{1}{N_{evt}} \int dx x \frac{dN}{dx} = 0.67$$

- The distribution of vacuum energy is quite wide.
- How large is the PbPb effect?

E-loss Estimates



- "Moderate" additional out of cone E-loss in PbPb.

$$\frac{\langle E_{T2}\rangle_{PbPb}}{E_{T1}} < \frac{1}{N_{evt}}\int dx x\frac{dN}{dx} = 0.54$$

- Estimate 1: all jets interact equally (underestimate).

Jet shape based
E$_{T1}$~0.8 E$_{Total}$

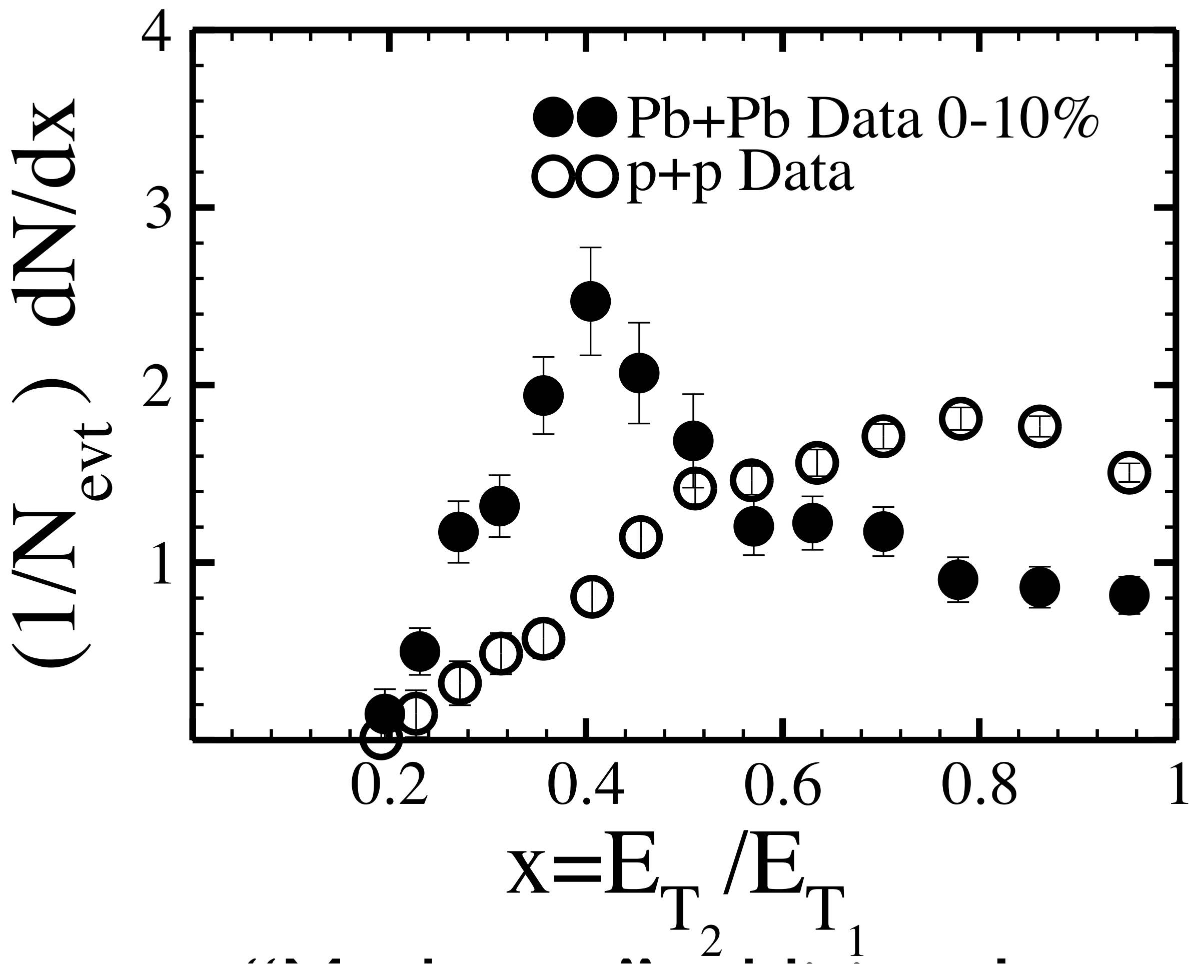
$$\frac{\Delta E}{E_{Total}} \approx 0.8\frac{\langle E_{T2}\rangle_{pp} - \langle E_{T2}\rangle_{PbPb}}{E_{T1}} > 0.1$$

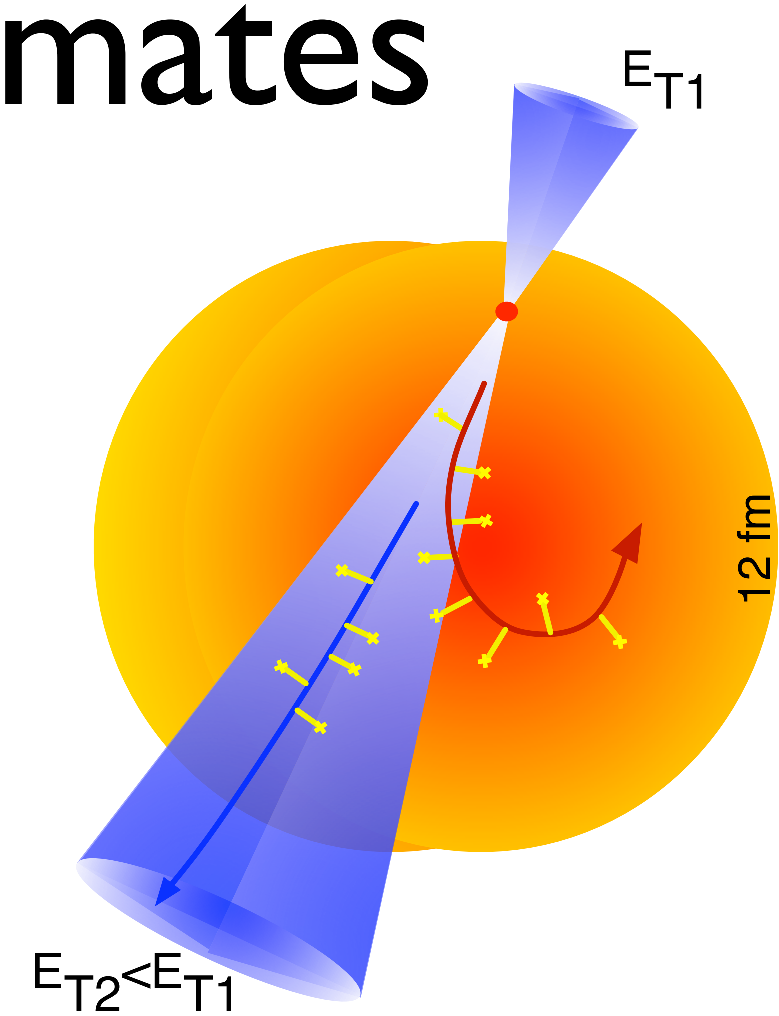
- Estimate 2: only a fraction (1-α) of jets interact (overestimate).

$$\frac{\Delta E}{E_{Total}} < \frac{1}{1-\alpha}\frac{\langle E_{T2}\rangle_{pp} - \langle E_{T2}\rangle_{PbPb}}{E_{Total}} < 0.2$$

(α<0.5)

E-loss Estimates





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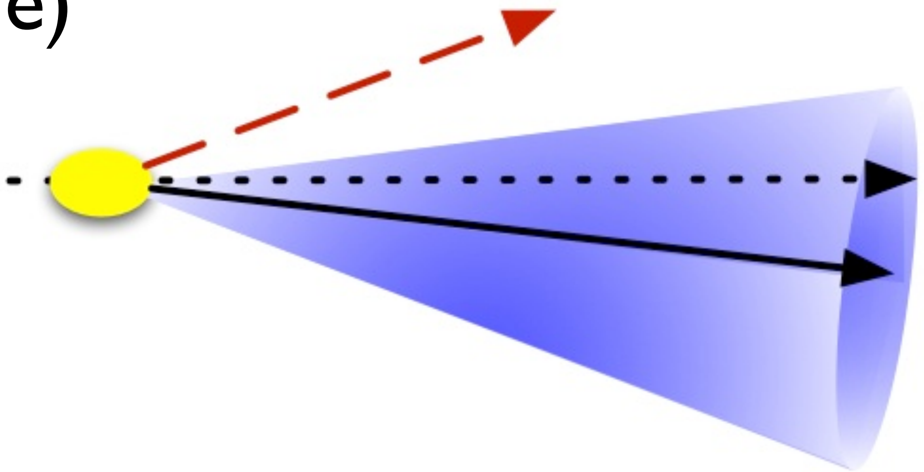
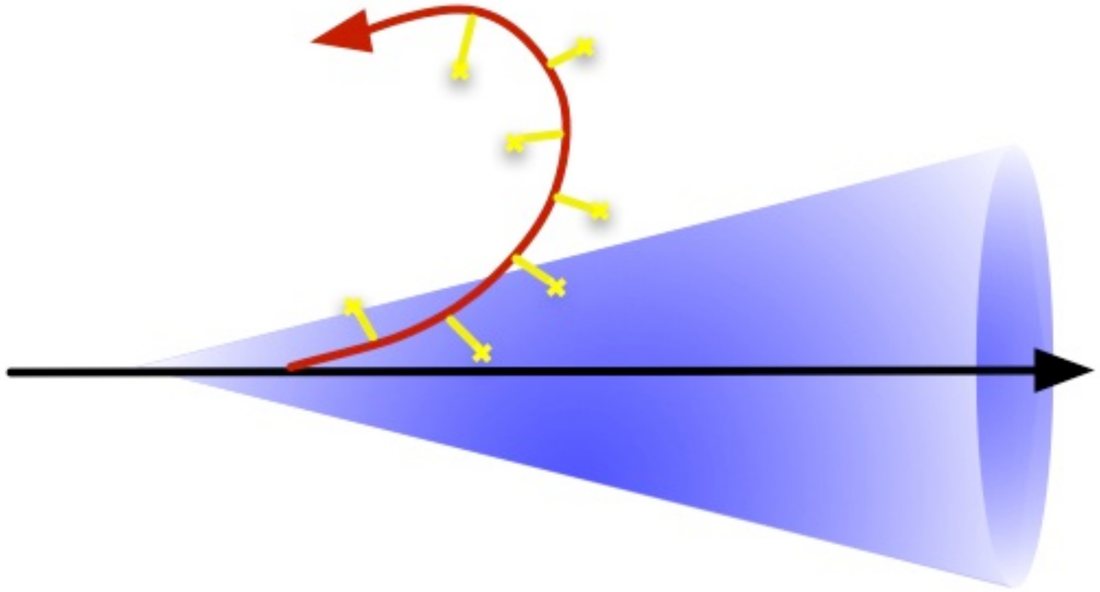
Possible Mechanisms

- Large angle medium-induced (hard) radiation (formed outside of the cone)



Leads to recoil of the hard jet

- Transport of radiated gluons out of cone after formation

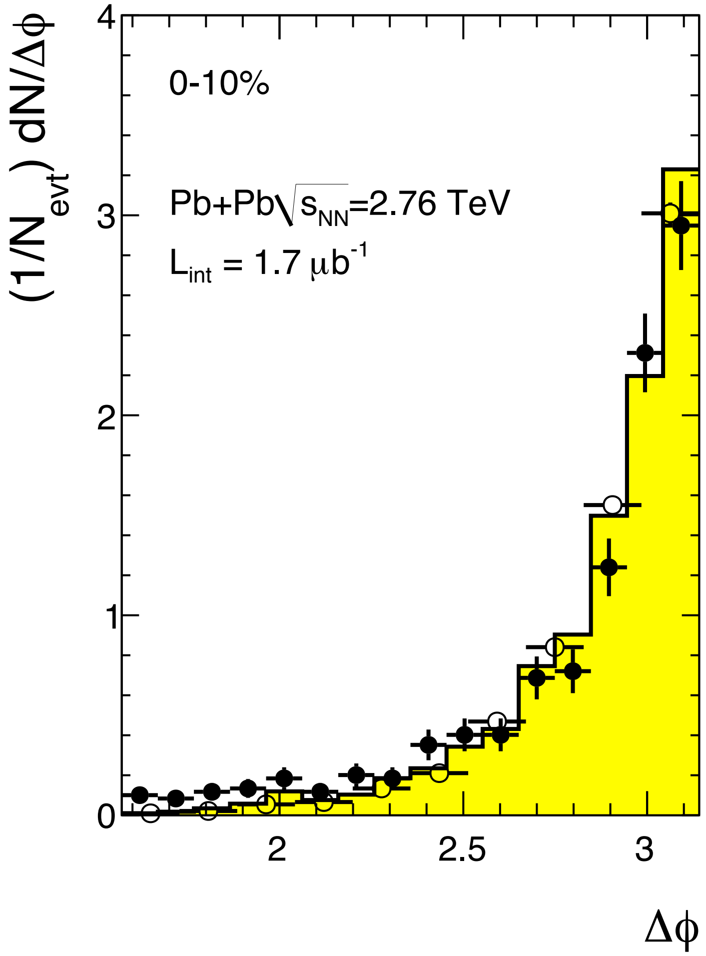


More effective for softer components

The medium effectively trims away soft jet components.

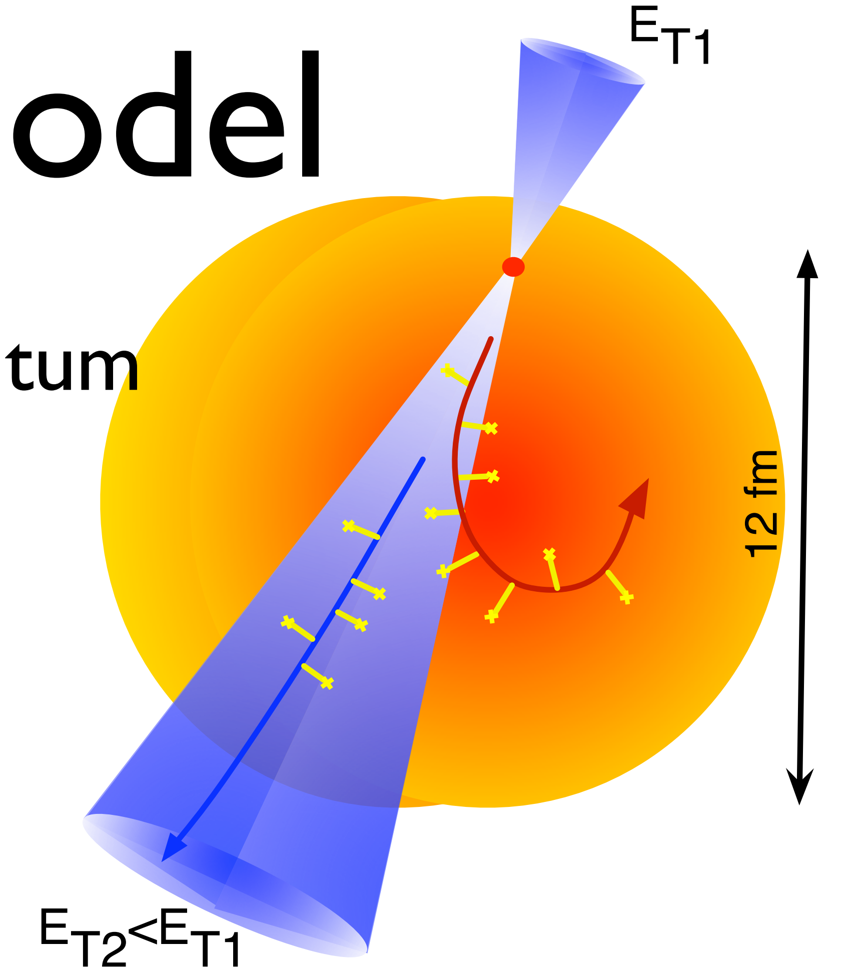
“ jet frequency collimator” or filter

Soft Emissions



- Angular distribution of the associated jet is largely unchanged. Differences occur at large angles, but those are a small fraction.
- These data support a model of soft emissions.
- Can “jet collimation” account for the observed asymmetry?

Jet Collimation Model



- The medium is characterized by a momentum broadening parameter $\hat{q}$

- Collinear modes are put on shell faster by interaction with the medium.

$$\langle \tau \rangle \sim \sqrt{\frac{\omega}{\hat{q}}}$$

soft modes are formed early!

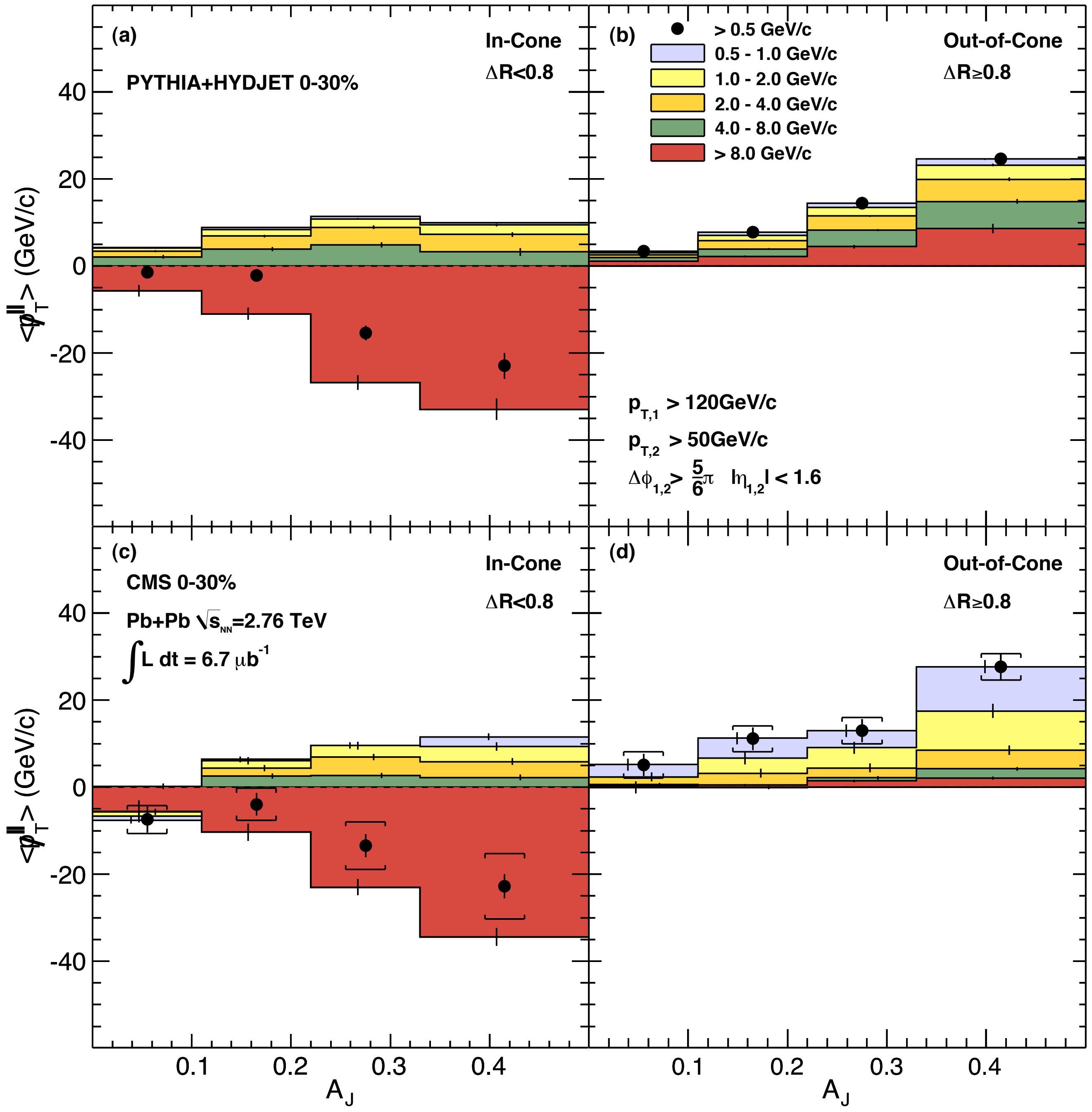
- After formation, all modes in the "jet wave function" suffer additional momentum broadening.

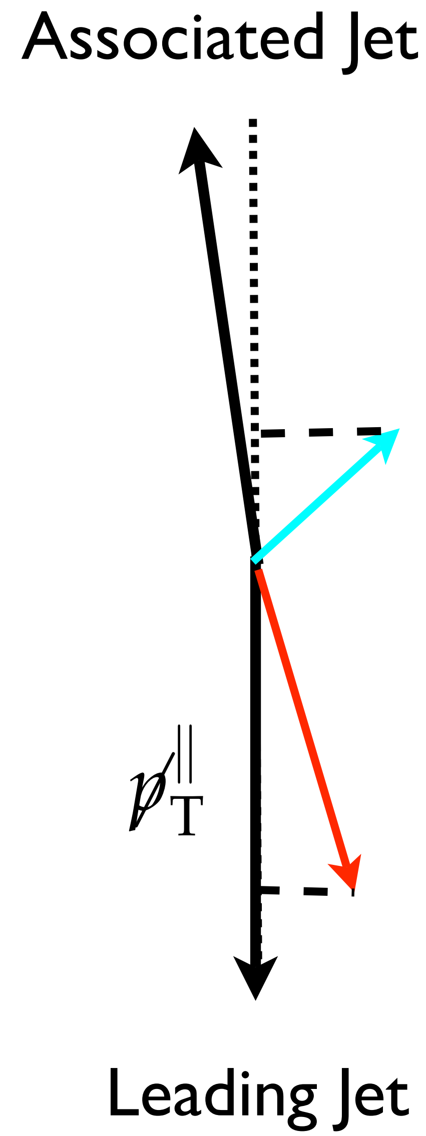
- Sufficiently soft modes are totally de-correlated with the jet direction.

$$\omega_d^2 \leq \hat{q}L \qquad \text{(non-eikonal motion)}$$

- The mechanism is at work even if there are no additional medium induced splittings.

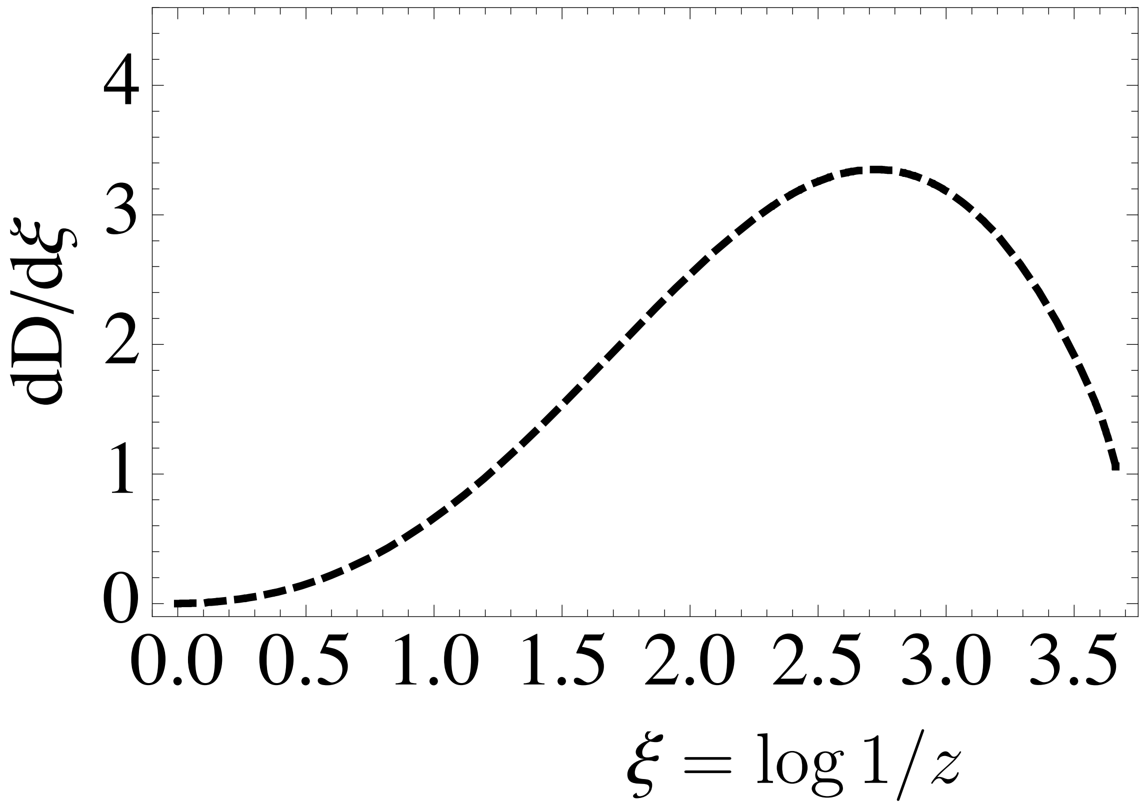
Momentum balance



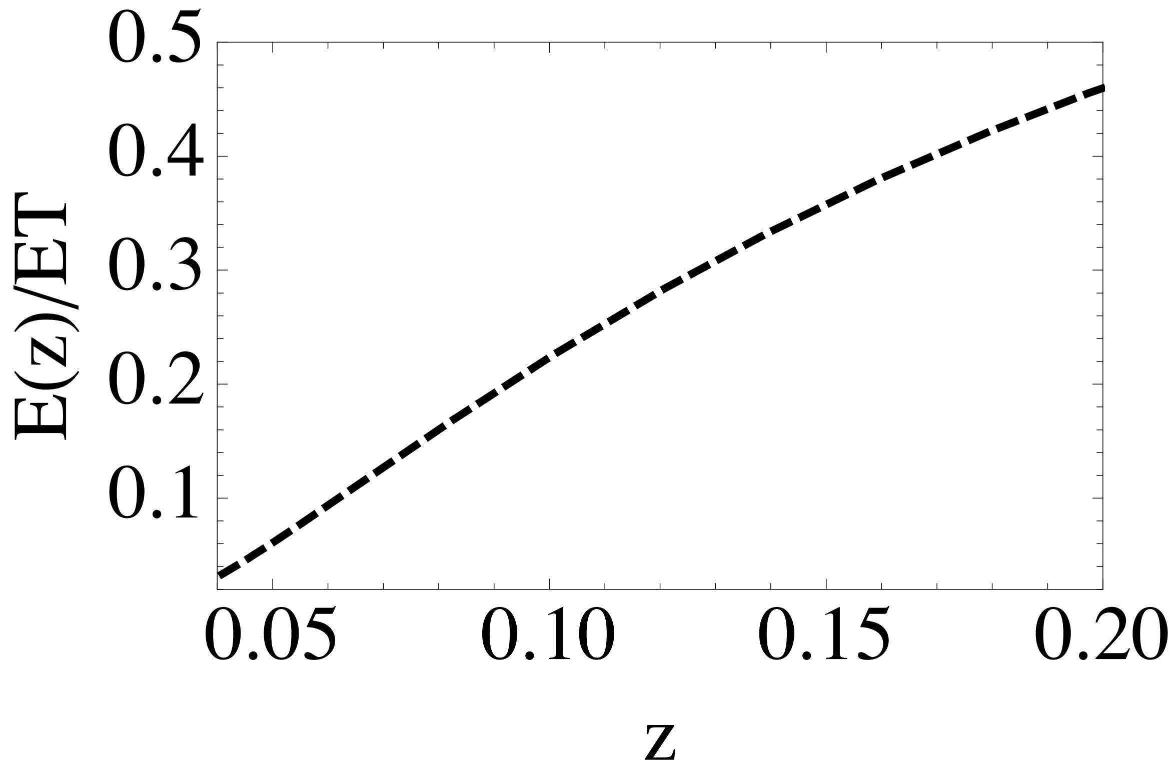


- Even for large cone radius, out of cone radiation is mostly soft
- The hard part of the near side seems mostly unchanged.

Vacuum Jets



$\Rightarrow$



- Vacuum jets have many soft parton with $z=E_{parton}/E_{Total}<<1$.

Parton distribution D within a jet determined with MLLA

(evolved to a partonic scale Q_0=1GeV)

- How much energy is carried by partons with $z_0<z$?

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

- A significant fraction of the jet energy is stored in relatively soft components.

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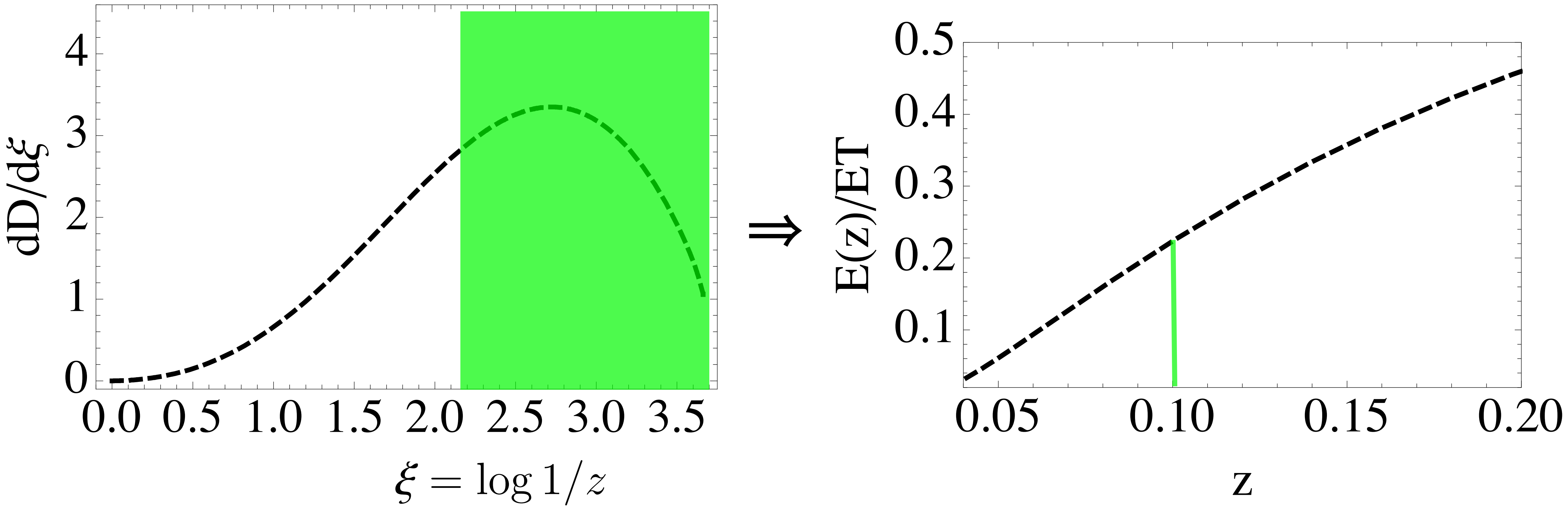

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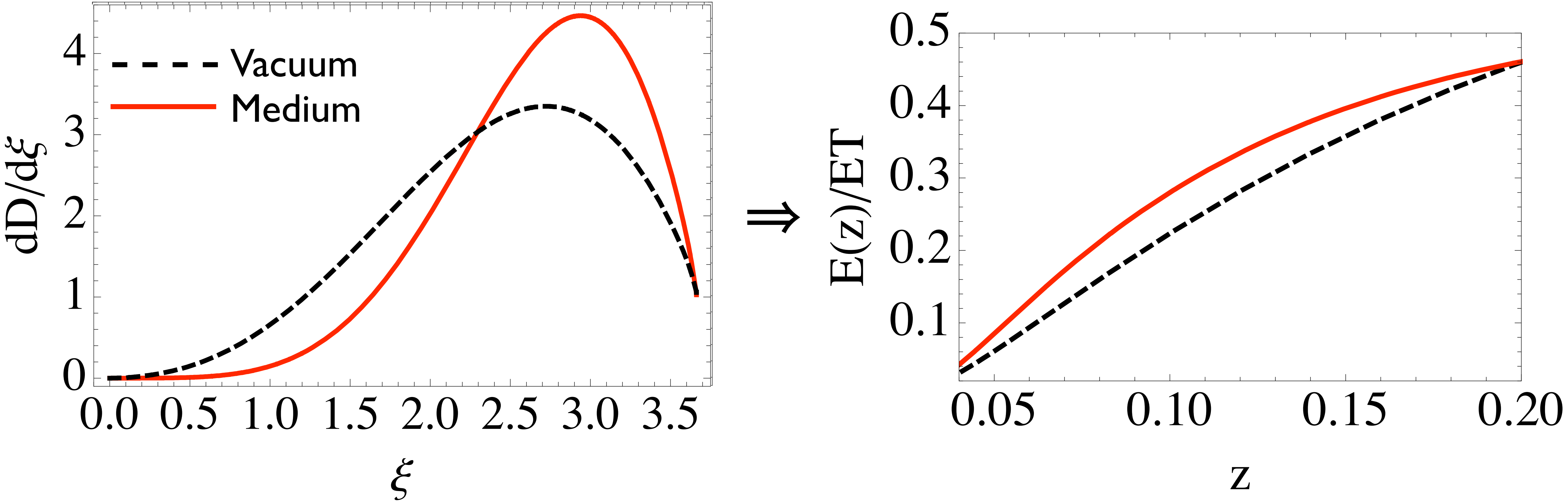
In-Medium Jets



- The medium softens the parton distribution via medium induced gluon radiation.
- The extra partons are emitted mostly collinearly.

At formation, the accumulated transverse momentum is

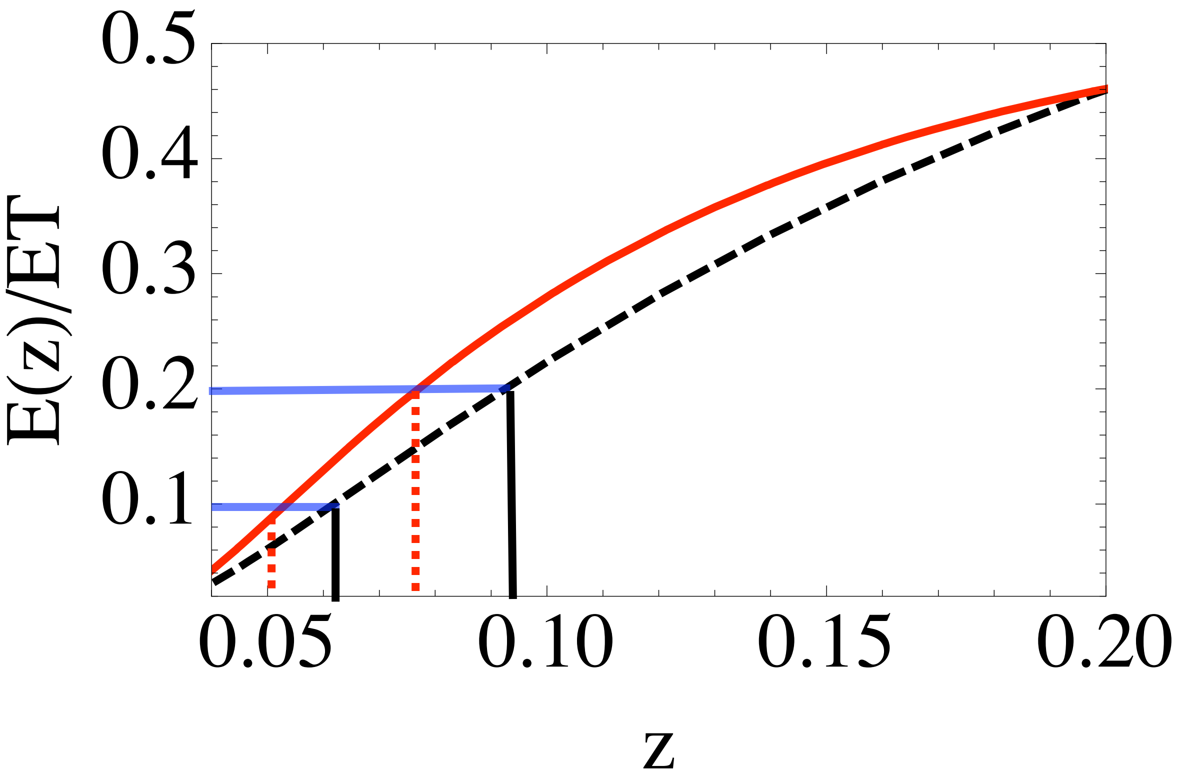
$$\hat{q}\tau \sim \sqrt{\hat{q}\omega} \ll \hat{q}L$$

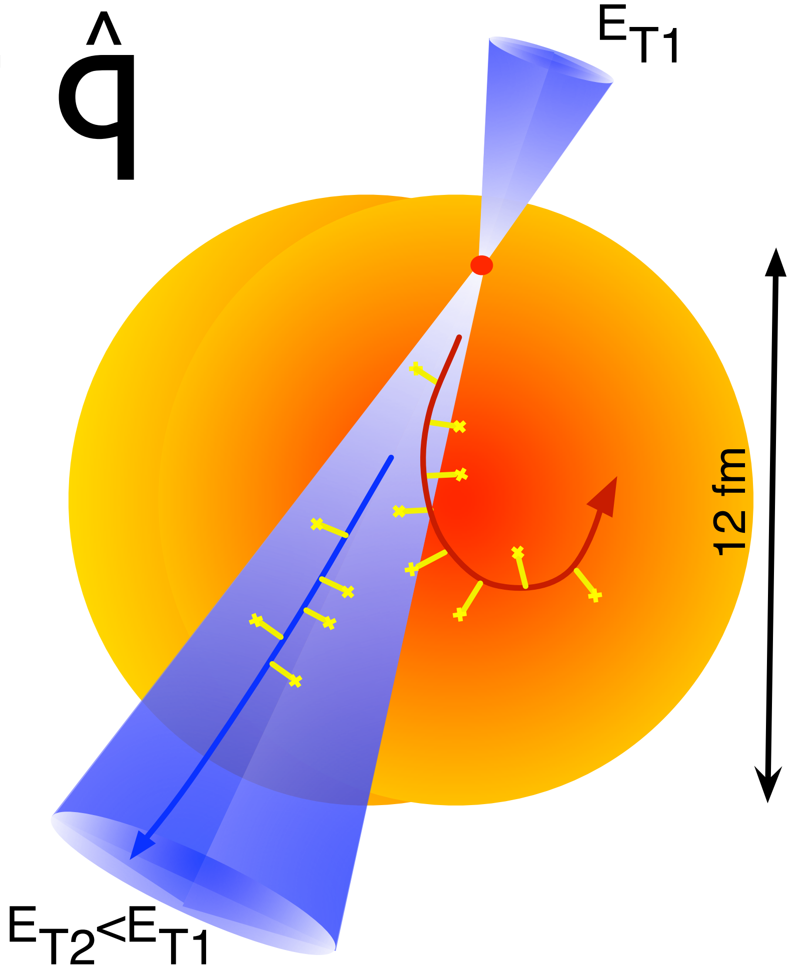
Soft modes accumulate a large momentum after formation

- Medium induced splitting increase the energy in soft modes. We estimate this enhancement with a medium-modified MLLA

(Borghini & Wiedemann 05)

Estimating $\hat{q}$





- The medium de-correlates all partons with

$$\omega_d^2 \leq \hat{q}L$$

- We use our estimates on energy-shift to estimate $\hat{q}$.

determining at which z the energy in soft components coincides with the estimated shift

$$35\left(\frac{E_T}{E_0}\right)^2 \leq \hat{q}L \leq 85\left(\frac{E_T}{E_0}\right)^2 \mathrm{GeV}^2$$ (vacuum distribution)

(E_0=100 GeV)

$$30\left(\frac{E_T}{E_0}\right)^2 \leq \hat{q}L \leq 60\left(\frac{E_T}{E_0}\right)^2 \mathrm{GeV}^2$$ (med. mod. distribution)

Towards Realistic Implementation

(steps to be done)

- Correct understanding of the time-structure of the parton shower and its modification by the medium

  are soft modes available at early time?

- Correct vacuum jet fragment distribution at the partonic level.

  MLLA is only an approximation valid at small z

- Improved medium induced gluon radiation treatment. (GLV, ASW, HT, AMY...)
- Non-eikonal treatment of broadening of soft modes.
- Exploring new mechanisms that lead to additional softening such as in-medium color decoherence (Mehtar-Tani, Salgado, Tywoniuk 10)

Conclusions

- Vacuum di-jets are very asymmetric
  Any explanation of in-medium asymmetry must take this into account.
- ATLAS and CMS data show increased di-jet asymmetries via soft emission.
- Simple kinematics ⇒ soft components are easily trimmed away from the jet

  Jet frequency Collimation
- Our simple estimate shows that this mechanism alone can account for the observed asymmetry yielding reasonable parameters
- Jet collimation is only a part of medium jet-modification.
  Longitudinal softening (additional splittings) must be also present.
- We hope that this simple idea will be implemented in future Monte Carlo effort.