Dijet invariant mass with ALICE

Oskari Saarimäki

University of Jyväskylä
& Helsinki Institute of Physics

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Credits

- I have been supported by many people, some of them listed here:
- PhD supervisors:
  - DongJo Kim
  - Sami Räsänen
- Colleagues:
  - Beomkyu Kim
  - Tomas Snellman

A hard probe

- Energy loss of a high energy parton in a medium depends in some way on transport coefficient $\hat{q}$ and path lenghth L.
    - Exactly what kind of dependences?

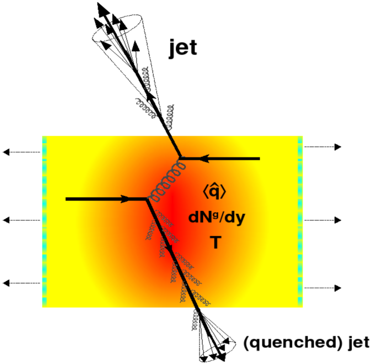

Figure: Partons losing energy while propagating the QGP medium[1]

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[1] Image source: David d'Enterria (MIT, LNS), Nucl.Phys. A827 (2009) 356C-364C, DOI: 10.1016/j.nuclphysa.2009.05.078

A hard probe

Dijets

Dijet invariant mass can be written quite simply

$$\begin{aligned} M_{\mathrm{jj}}^2 &= (p_1 + p_2)^2 \\ &= m_1^2 + m_2^2 + 2\left(m_{\mathrm{T},1} m_{\mathrm{T},2} \cosh(\Delta y) - p_{\mathrm{T},1} p_{\mathrm{T},2} \cos(\Delta\phi)\right) \\ &\approx 2 p_{\mathrm{T},1} p_{\mathrm{T},2} \left(\cosh(\Delta\eta) - \cos(\Delta\phi)\right) \\ &\overset{\substack{\text{ideal} \\ \text{back-2-back}}}{\longrightarrow} 4 p_{\mathrm{T}}^2, \end{aligned}$$

where 1 and 2 represent the two jets forming the dijet, and $\Delta x = x_1 - x_2$.

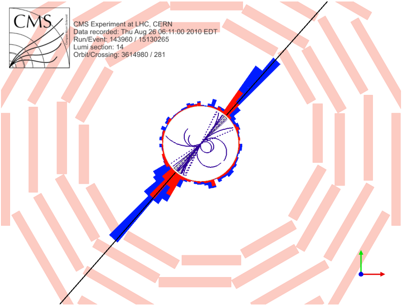


Figure: Two jets seen in CMS proton–proton collision.

Probe

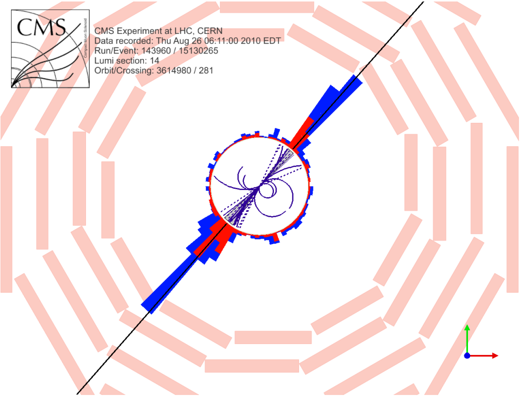


Figure: A dijet in CMS proton–proton collision. Dijet is clearly symmetric.

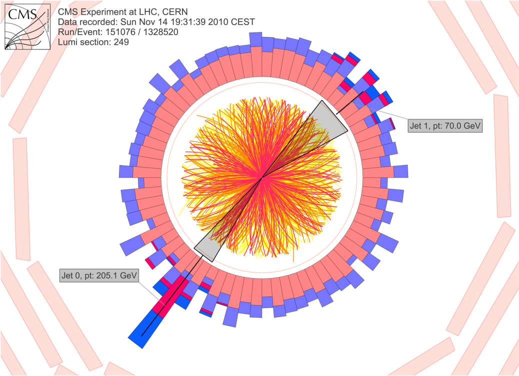
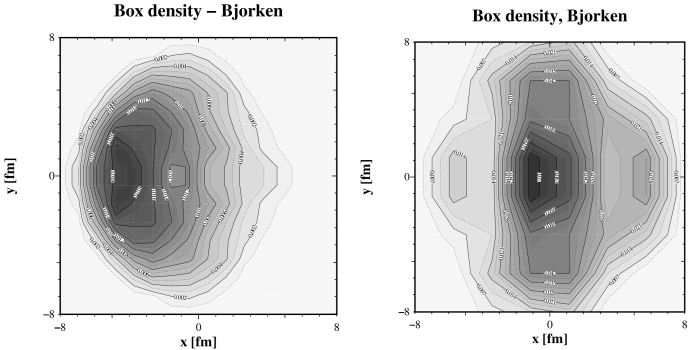


Figure: A dijet in CMS lead–lead collision. Dijet has large asymmetry, leading jet transverse momentum is 200 GeV and subleading 70 GeV.

Jet surface bias

- Jets have a surface bias.
- Dijet vertices may lie deeper in the medium.
  - Also generally longer in-medium path length.
    - → May get better grasp at L



[1] Probability density of finding a hard scattering vertex at (x,y). Leading parton travels to $-x$ direction.
Left: Leading hadron **$8 < p_T < 15$ GeV**
Right: Leading hadron **$8 < p_T < 15$ GeV** AND away-side hadron **$4 < p_T < 6$ GeV**

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[1] Image source: Eskola and Renk, Phys.Rev. C75 (2007) 054910, arXiv:hep-ph/0610059

Some past dijet studies

- ATLAS experiment dijet energy asymmetry measurement [1]. The asymmetry is defined as

$$A_J = \frac{E_{\mathrm{T},1} - E_{\mathrm{T},2}}{E_{\mathrm{T},1} + E_{\mathrm{T},2}}$$

- ATLAS[1] kinematical cuts: $E_1 > 100$ GeV and $E_2 > 25$ GeV.
- CMS[2] also has a similar measurement with kinematical cuts: $p_{\mathrm{T},1} > 130$ GeV and $p_{\mathrm{T},2} > 30$ GeV.
  - → At the moment ALICE studies dijets with $p_{\mathrm{T},1}, p_{\mathrm{T},2} > 20$ GeV.
    - Lower dijet mass reach

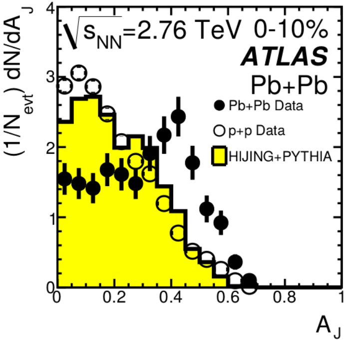

Figure: ATLAS experiment dijet energy asymmetry measurement. [1]

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[1] Source: ATLAS, Phys.Rev.Lett. 105 (2010) 252303, DOI: 10.1103/PhysRevLett.105.252303

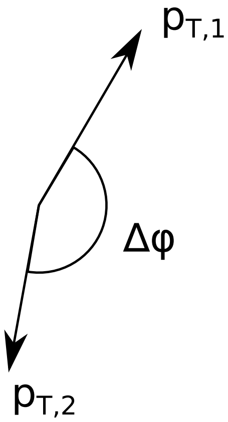
[2] Source: CMS,Phys. Lett. B712 (2012) 176, DOI: 10.1016/j.physletb.2012.04.058

Analysis plan

- ALICE dijet invariant mass measurements: pp, p–Pb and Pb–Pb.
- The final goal: Dijet mass in Pb–Pb in centrality bins vs. proton–proton results.
  - → Essentially a dijet invariant mass R_{AA}.
- Goal at the moment: p–Pb and pp results with a comparison.
  - → A dijet invariant mass R_{pA}.

Jet and dijet definitions

- Jets are clustered using the anti-k_{T} algorithm, with $R = 0.4$.
- Dijets will be formed from leading and back-to-back subleading jets.
- Dijets are required to have $p_{\mathrm{T},1}, p_{\mathrm{T},2} > 20$ GeV.
    - Acoplanarity: $|\Delta\phi - \pi| < \frac{\pi}{2}$



Four-momentum background subtraction[1]

Background subtraction is essential in p–Pb and Pb–Pb. It is done with k_{T} reconstructed jets.

$$p_{\mathrm{T,jet}} = \sum_{i \in \mathrm{jet}} p_{\mathrm{T},i}, \qquad m_{\mathrm{jet}} = \sum_{i \in \mathrm{jet}} \left(\sqrt{p_{\mathrm{T},i}^2 + m_i^2} - p_{\mathrm{T},i} \right),$$

where i runs over all the particles in that specific k_{T} reconstructed jet. Densities can be calculated from

$$\rho = \operatorname*{median}_{\mathrm{jets}} \left\{ \frac{p_{\mathrm{T,jet}}}{A_{\mathrm{jet}}} \right\} \qquad \rho_m = \operatorname*{median}_{\mathrm{jets}} \left\{ \frac{m_{\mathrm{jet}}}{A_{\mathrm{jet}}} \right\},$$

where A_{jet} is the jet area in ϕ–η plane, calculated using ghost particles in fastjet. In my analysis two of the most energetic jets are left out of this density estimation.

Then background is subtracted with

$$p^{\mu}_{\mathrm{corr}} = p^{\mu} - \left[(\rho + \rho_m)\, A^{E}_{\mathrm{jet}},\ \rho A^{x}_{\mathrm{jet}},\ \rho A^{y}_{\mathrm{jet}},\ (\rho + \rho_m)\, A^{z}_{\mathrm{jet}} \right].$$

When using p_{T} scheme the ρ_m will be zero.

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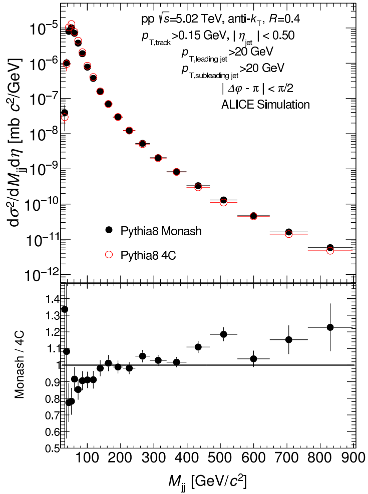
[1] Source: Gregory Soyez et al. Phys.Rev.Lett. 110 (2013) no.16, 162001 DOI: 10.1103/PhysRevLett.110.162001

Analysis status

- Pythia tune comparison between Monash and 4C tunes.
- In near future: need MC generators with jet quenching.
  - → JETSCAPE framework, JEWEL, etc.
- pp and p–Pb ALICE data has been unfolded, at the moment I am working with systematic uncertainties.



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Summary

- I introduced dijet invariant mass as a possible probe for QGP.
- ALICE aims also for lower invariant masses.
- Current goal:
  - pp and p–Pb dijet invariant mass results.
  - Comparison: dijet invariant mass R_{pA}
- Future goal:
  - Centrality binned Pb–Pb results.
  - Comparison to pp: dijet invariant mass R_{AA}
- This measurement will benefit from comparisons to MC generators with jet quenching implemented.

The end

Thank you for listening

Questions?

Area four-vector

$$\begin{aligned} p^{\mu} &= (E, p_x, p_y, p_z) \\ &= (m_{\mathrm{T}} \cosh y, p_{\mathrm{T}} \cos\phi, p_{\mathrm{T}} \sin\phi, m_{\mathrm{T}} \sinh y) \\ &= p_{\mathrm{T}} \left(\sqrt{1 + \left({}^{m}\!/\!{}_{p_{\mathrm{T}}}\right)^2} \cosh y, \cos\phi, \sin\phi, \sqrt{1 + \left({}^{m}\!/\!{}_{p_{\mathrm{T}}}\right)^2} \sinh y \right), \end{aligned}$$

and for massless particles (like FastJet ghost particles) this simpilfies to

$$\begin{aligned} p^{\mu} &= p_{\mathrm{T}} (\cosh\eta, \cos\phi, \sin\phi, \sinh\eta) \\ &\equiv p_{\mathrm{T}} \; n^{\mu}(\phi, \eta) \, . \end{aligned}$$

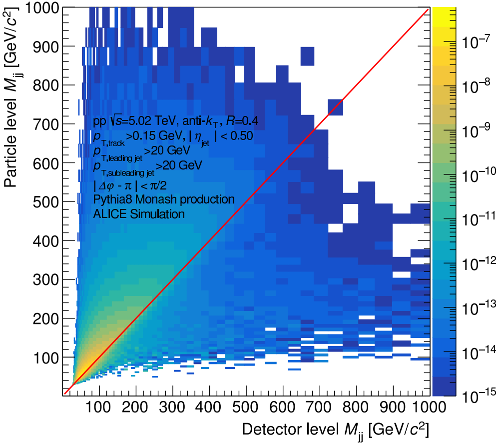
With the help of n^{μ} the area four-vector has been defined in FastJet as

$$A^{\mu} = \iint\limits_{A_{\mathrm{jet}}} \mathrm{d}\phi \mathrm{d}\eta \; n^{\mu}(\phi, \eta) \, ,$$

where the integral is over the area of the jet at hand in the ϕ–η plane.

pp MC simulation

- For unfolding, the leading and subleading jets are matched between true MC and detector simulated MC.
- If matched, compare dijet masses in unfolding matrix.
- In figure:
    - Particle level = true MC dijets
    - Detector level = detector effects simulated MC dijets



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