INTRODUCTION
RHIC CONSTRAINTS FOR ENERGY LOSS
RHIC ERA EXPECTATIONS
- longitudinal momentum distribution of jets
- transverse momentum distribution of jets
LHC JET OBSERVABLES
CONCLUSIONS
I. What did we know about energy loss?

RHIC results
• a form $\Delta E \sim zE$ is not supported by the data
→ study of $R_{AA}$ for different assumed functional forms for energy loss probability


• leads to decreasing $R_{AA}$ for higher $P_T$ — not seen at either RHIC or LHC
• side note: $\Delta E \sim zE$ works fine with power law parton spectrum instead of pQCD
→ power law is a very bad approximation
Energy loss is not incoherent

- A form $\Delta E \sim L$ is not supported by the data

  $\rightarrow$ studies of $R_{AA}(\phi)$ embedding elastic or parametric models in hydrodynamics


- PHENIX data radiative (ASW)
- elastic MC YaJEM

- $R_{AA}$ works fine as long as transverse hydro expansion is neglected

  $\rightarrow$ Bjorken cylinder is a very bad approximation

- Systematic uncertainty on $S_{out}^{in}$ due to choice of hydro: factor two (!)

  $\rightarrow$ $\Delta E \sim L$ fails by factor 6, elastic component of $\Delta E < 10\%$
Energy largely remains perturbative

- substantial energy dissipation into non-perturbative dof is *not* supported by data → studies of away side $I_{AA}$ using energy loss and shower modelling


- medium-induced radiation is experimentally observed → constrains elastic contribution from below to $\sim 10\%$
Constraints Summary

  → look at the full systematics of energy loss models and hydrodynamics

• assuming the best choice of hydro model for each parton-medium interaction model:
  (all models tuned to describe $R_{AA}$ in central 200 AGeV AuAu collisions)

• 'RHIC constraints matrix'
  → has a hydrodynamical modelling dimension which is projected out here!

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<tr>
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<th>$R_{AA}^{RHIC}(\phi)$</th>
<th>$R_{AA}^{LHC}(P_T)$</th>
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II. What did we expect to see at LHC?

pre- and some postdictions
• in vacuum shower
→ splitting kernels $P_{i \rightarrow jk}(z)$ with $z = \frac{E_{\text{daughter}}}{E_{\text{parent}}}$ are scale-invariant
→ fragmentation functions $D(z)$ are self-similar, do not strongly depend on energy
→ logarithmic corrections due to the running of $\alpha_s$

• if $\Delta E \sim E$, then this could be cast into $P'_{i \rightarrow jk}(z)$ and would yield $D'(z)$ as MMFF
→ we know that is not true
→ instead, the MMFF is changed at a fixed energy $\sim$ few $T$, not at any fixed $z$

$E = 20 \text{ GeV}$
$E = 200 \text{ GeV}$

$D_{\text{med}}(z)/D_{\text{vac}}(z)$

• a real experiment has trigger bias (jet finding bias)
→ for instance jet-h correlations by STAR

YaJEM-DE, 2+1d hydro
0-10% central AuAu

- 'unmodified', rate suppressed 'FF' above 2-3 GeV, modifications below
→ jets become different at the thermal scale

How does that work for transverse structure?
• Gaussian width of recoil peak in STAR jet-h correlations → significant deviations from vacuum below 2-3 GeV

• this implies almost unchanged jet shapes above 4 GeV → note that the Gaussian width is a very sensitive observable!

→ medium alters hard parton kinematics slightly
→ medium-induced soft gluon emission
→ medium alters soft gluon kinematics a lot, soft gluon thermalizes

• energy flow to large angles $R \gg 0.6$, hydro degrees of freedom relevant
→ not picked up by jet finders, mechanism of jet suppression

• probes medium physics, not jet physics
→ largely independent of specific shower-medium interaction assumptions

• not an issue for gluons with $p_T \sim \text{few } T$
→ more difficult to change their kinematics

→ not novel, observed already in 2009, requires explicit kinematics in models

***Universal*** mechanism: gluons with $p_T \sim T$ are effectively out of cone
III. Does this work for jet observables?

comparison with LHC jet data
• dijet imbalance ratio as function of $E_{jet}$ as measured by CMS (YaJEM-DE: RHIC constrained scenario, YaJEM-E: only elastic energy loss)

⇒ yes, this works just fine over the whole energy range

• probes medium-induced widening vs. kinematical collimation, gluon vs. quark jets

→ not as constraining as Gaussian width in jet-h correlations
LHC JETS

- reproduces weak dependence of $A_J$ on $R$ as observed by ATLAS

2.76 ATeV PbPb, 0-5% centrality

- also matches with ATLAS $R_{CP}^{jets} \approx 0.5$ in the 120+ momentum region
- has 'unmodified' fragmentation pattern above $\sim 3$ GeV
- more comparison underway
• assuming the best choice of hydro model for each parton-medium interaction model: (all models tuned to describe $R_{AA}$ in central 200 AGeV AuAu collisions)

• 'LHC constraints matrix'

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• so far, novel LHC constraints come from $R_{AA}$ rather than jet measurements
Conclusions

- Single hadrons, h-h, γ-h and jet-h correlations are powerful tools for jet physics → at least as powerful as reconstructed jets (but computationally cheaper)

- LHC jet physics re-discovers properties of showers described in different words → take a good look at STAR jet-h correlations — differential picture of the shower

- Jet quenching is 'radiative energy loss ++'
  → a small, ∼ 10% component of direct energy dissipation into the medium
  → there is no sign of AdS-like behaviour so far

- Detailed modelling and systematics matters!
  → with power law spectra and Bjorken cylinders, we would have missed all this

Time to shift from 'new ideas' to systematic, quantitative multi-observable modelling!
**Open Questions**

- How does energy flow into the medium?
  → can we measure the hadrochemistry of correlations in the 2-3 GeV region?
  → does energy dissipated into the medium flow, i.e. do we see harmonics?

- What happens with heavy quarks?
  → do they become 'light' at $P_T \gg M_q$?
  → how does the secondary hadron spectrum in a quenched $c$-quark jet look like?

- Why is it so hard to get $v_2$ at high $P_T$ right?
  → can we measure RP dependence of other observables?
  → can we try to fit hydro modelling to this constraint?

- Do jets 'image' early time granularity?
  → can we measure jet vs. the $\epsilon_3$ event plane?