Reconstructed jets vs. correlations

— why clustering may not lead to the desired effect

Thorsten Renk

UNIVERSITY OF JYVÄSKYLÄ

Suomen Akatemia

HELSINKI INSTITUTE OF PHYSICS

Introduction

Sensitivity

- what is measured by jet reconstruction?

Complexity

- what makes a meaninful comparison with experiment?

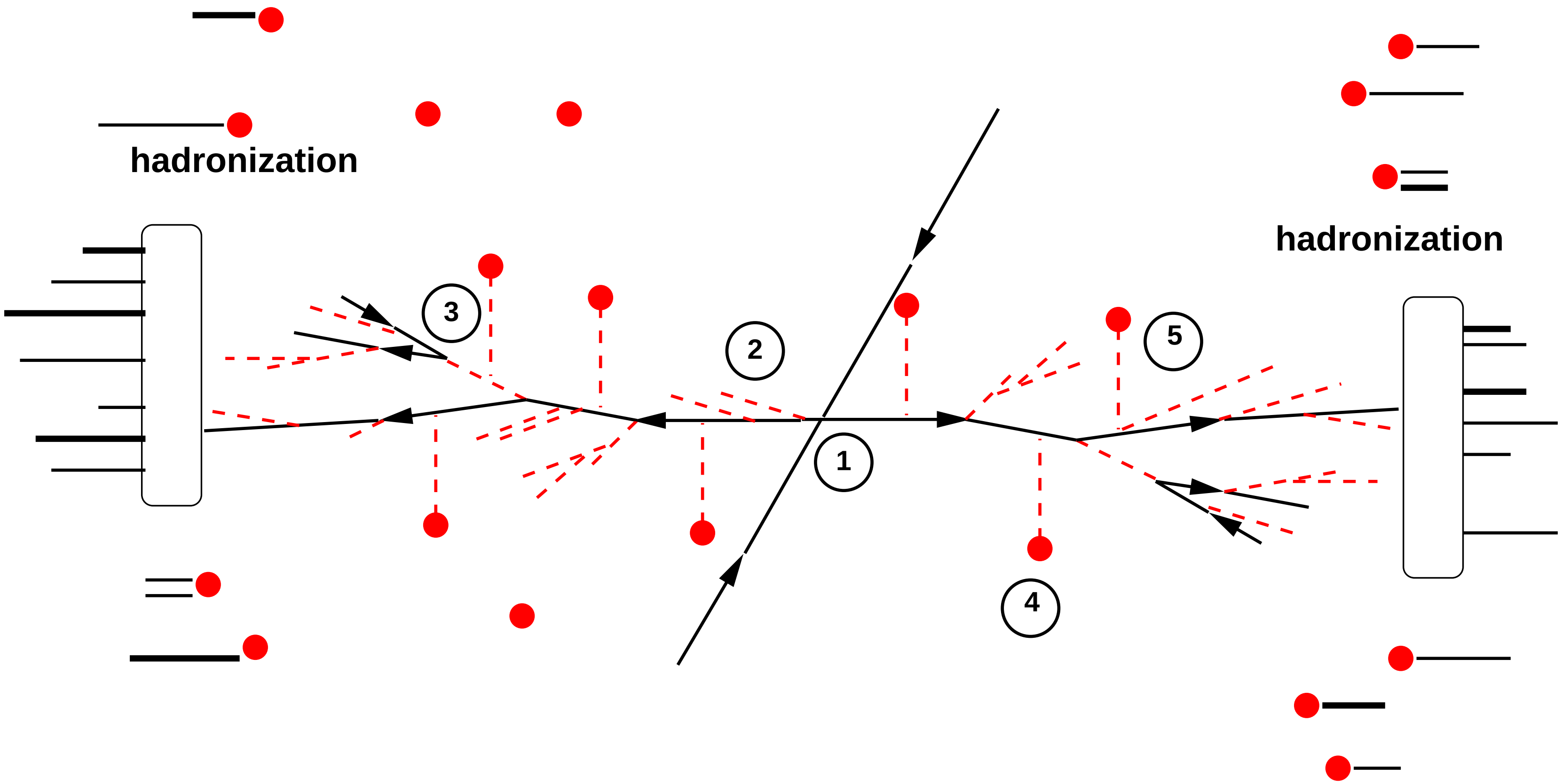
Universality

- what is the fate of soft gluons in a medium?

Case study: Dihadrons vs. Dijets

THE 'STANDARD' JET QUENCHING PICTURE

pQCD radiative energy loss for hard partons interacting with the medium



1) hard process 2) vacuum shower 3) medium-induced radiation 4) medium evolution
5) medium correlated with jet by interaction

Access via a) single hadrons b) triggered correlations c) reconstructed jets

Physics questions

- What is the physics of parton-medium interaction, what are the medium dof?
  - transport coefficients $\hat{q}, \hat{e}$,...
- What can we deduce about the medium geometry?
  - initial profile, fluctuations, freeze-out conditions, scales . . .
- How does the medium react to a perturbation?
  - energy redistribution, shockwaves, speed of sound. . .

This talk:

What is the best way to address these — triggered correlations or reconstructed jets?

I. Sensitivity

jets are less sensitive to medium modifications than leading hadrons

Purpose of clustering in vacuum

Underlying (idealized) concept:

• a jet represents a virtual hard parton and its subsequent evolution
→ do high Q^2 pQCD without worrying about low Q^2 non-perturbative aspects

Experimental reality (a bit catchy):

• 'a contract between experimentalist and theorist'

What this means is:

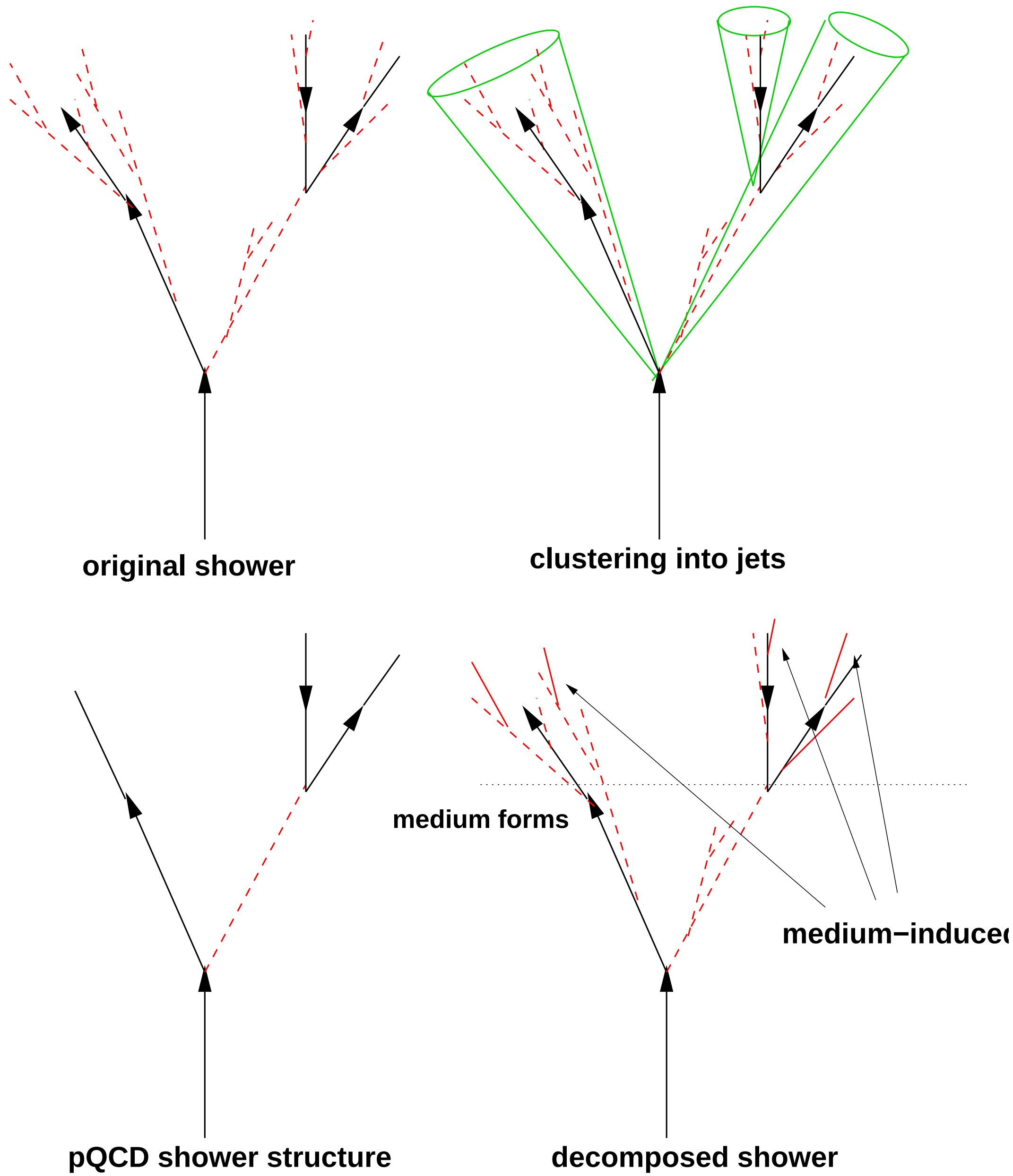
• hadrons are combined into jets by jet definitions/algorithms (SiSCone, anti-k_T,. . .)
→ but jet definitions are chosen cleverly based on pQCD arguments

Thus, for *measured* jets:

• jet finding algorithm needs to be quoted
• a bias for hard events to fit the particular definition exists
→ measured jets never capture 'all' of the parton evolution

But: parton level (pQCD) ≈ hadron level (particles hitting detector) ≈ detector level (calorimeter towers)

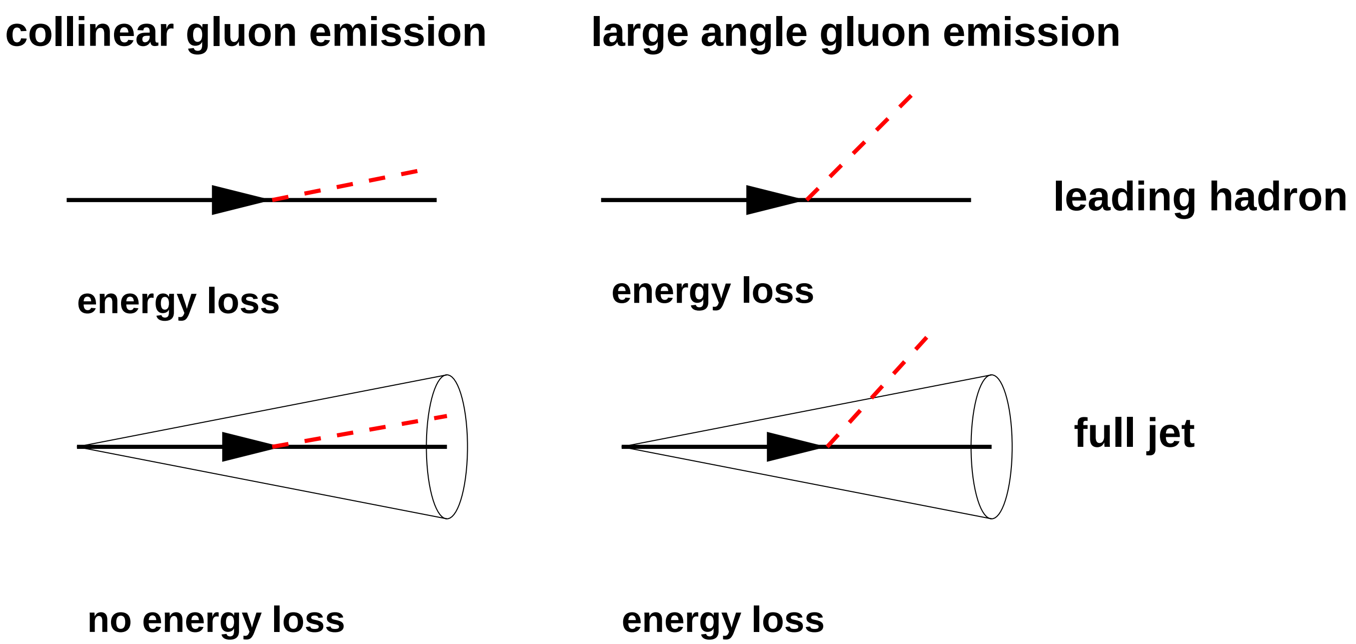
Properties of clustering



- clustering designed to focus on high Q^2 hard perturbative physics
$\rightarrow$ typical hard scale for LHC jets: $Q^2 = 900$ GeV^2
- typical medium-induced virtuality scale $\hat{q}L$ (depends on whom you ask)
$\rightarrow \Delta Q^2 = 2 - 20\text{GeV}^2$
- $\Delta Q^2 \ll Q^2$
$\rightarrow$ clustering suppresses medium effect by design
- formation time $\tau \sim E/Q^2$
$\rightarrow \tau \ll \tau_0$
$\rightarrow$ jet structure is determined before medium is formed and color decoherence can be an issue

Properties if clustering

- jet energy loss requires transport of energy out of the jet definition



- jets are more robust against medium modification than single hadrons

→ jets are *less sensitive* to medium modifications

II. Complexity

calculating medium modified jets is more complicated than calculating leading hadrons

Medium modified jets

What is a medium-modified jet?

- theorist's first answer: the output of my jet quenching MC
- experimentalist's first answer: the output of jet finding, run on my event

Absolutely not the same thing!

⇒ for low P_T hadrons in a jet, we cannot pretend that $\tau \sim E_h/m_h^2$ is large
→ ill-defined in-medium hadronization, breakdown of theory

⇒ jet reconstruction works different if a background is present

M. Cacciari, J. Rojo, G. P. Salam, G. Soyez, Eur. Phys. J. **C71** (2011) 1539

⇒ uncorrelated fluctuations in jet area have strong influence

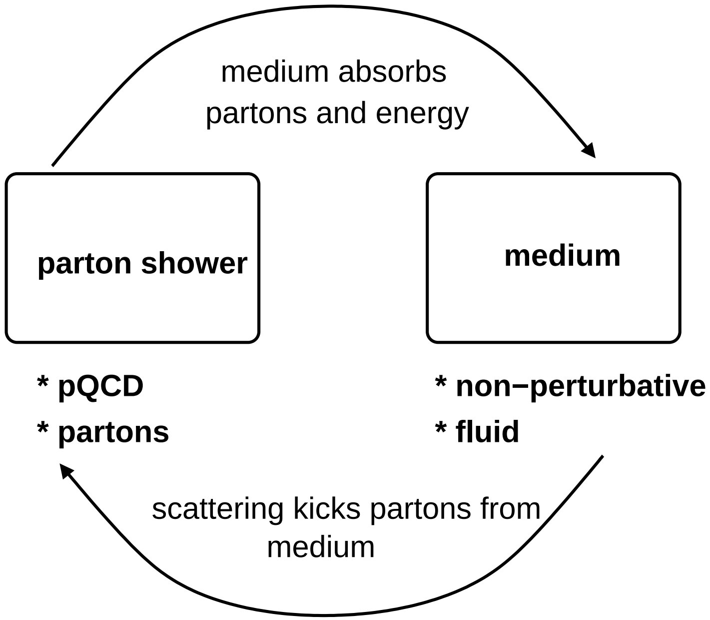
M. Cacciari, G. P. Salam and G. Soyez, Eur. Phys. J. C **71** (2011) 1692

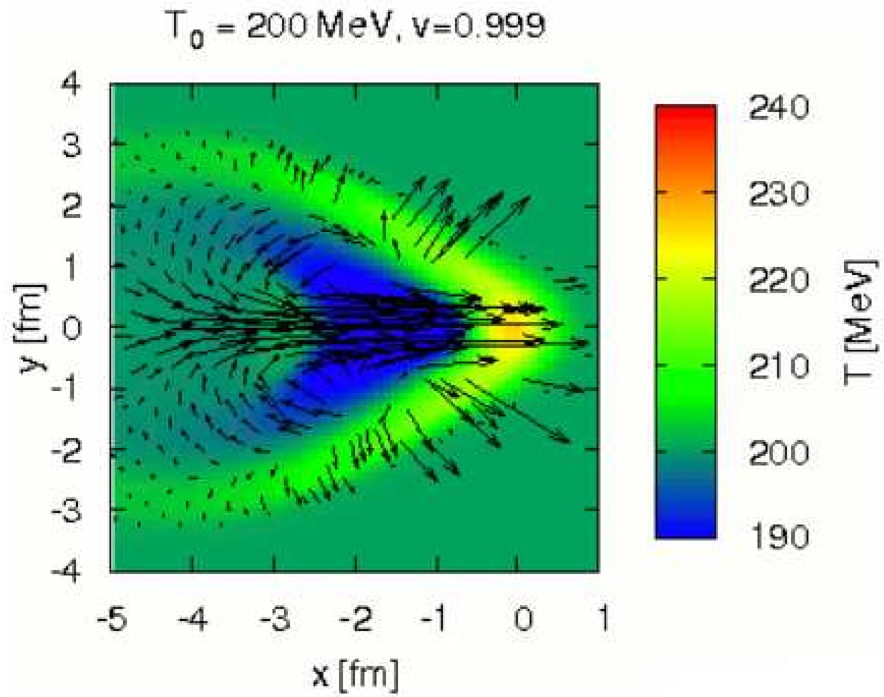
⇒ what about *correlated* background fluctuations?

Experimental in-medium jets are **not** purely perturbative objects!

Medium modified jets

- momentum in perturbative and non-perturbative modes – parton $\neq$ detector level





- What is the in-medium jet?
  - the perturbative part of the shower ($E_{jet} < E_{parton}$)?
  - everything causally correlated with the shower initiator ($E_{jet} > E_{parton}$)?
  - the flow of original 4-momentum ($E_{jet} = E_{parton}$)?

$\rightarrow$ jet finding algorithms look for the perturbative core

$\rightarrow$ also picks up non-perturbative physics in jet area

Medium modified jets

Sources of correlated medium fluctuations:

• jets emerge from binary N-N collision points
$\longrightarrow$ the same collision points determine the location of fluid hotspots
$\Rightarrow$ jets are likely to emerge from fluctuation hotspot regions

T. Renk, H. Holopainen, J. Auvinen and K. J. Eskola, 1105.2647 [hep-ph].

• triggers usually tend to look for unmodified objects
$\longrightarrow$ bias for partons to go perpendicular to surface (shortest path out)
$\longrightarrow$ any radial flow-driven effect also goes $\perp$ surface (pressure gradient)
$\Rightarrow$ accidential correlation

• medium reaction to jet energy loss
$\Rightarrow$ dependent on jet finding details, may be seen as background or not

• I have no idea how large these effects are in practice, but:

No reason to expect all fluctuations to be uncorrelated!

Medium modified jets

- proper computation of medium-modified jets comparable with experiment requires:

$\longrightarrow$ consistent initial state for jet and EbyE fluctuating hydro
$\longrightarrow$ co-evolution of jet and medium, back-reaction of medium to energy deposition
$\longrightarrow$ mapping of hadronic final state to detector response
$\longrightarrow$ clustering using the experimental procedure

- no calculation has demonstrated the full chain so far

$\longrightarrow$ although MUSIC + MARTINI is rather far

- breakdown of theory problems remain!

- experimental unfolding works only if fluctuations are uncorrelated!

Meaningful comparison between experiment and theory is complicated!

$\Rightarrow$ these problems largely do not exist when looking at high P_T hadron correlations

III. Universality

soft gluons in the medium don't carry information

(they thermalize)

Universality

- place a gluon with $p_T \sim T$ into the thermalized medium, what will happen?

$\longrightarrow$ it will not be distinct from the medium, i.e. it will become thermal

$\Rightarrow$ energy and momentum of soft medium-induced gluons will be widely distributed

- this is *not* seen in some theoretical approximations

$\longrightarrow$ if radiated gluons are eikonal

$\longrightarrow$ if medium only affects splitting probabilities, not kinematics

$\longrightarrow$ if pQCD soft gluons are distinct by definition

$\Rightarrow$ this is a problem of theory approximations, not different physics

- this is seen generically

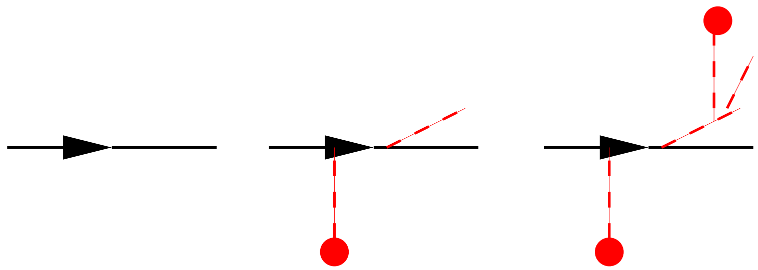
$\longrightarrow$ when soft gluons explicitly scatter with pQCD cross sections

$\longrightarrow$ when soft gluons are subject to $\hat{q}, \hat{e}$ changing kinematics

$\Rightarrow$ implementation details do not matter, for $p_T \sim T$ angular decorrelation occurs

Universality

• chain of events:
$\longrightarrow$ medium alters hard parton kinematics slightly
$\longrightarrow$ medium-induced soft gluon emission
$\longrightarrow$ medium alters soft gluon kinematics a lot



Once a gluon has $p_T \sim T$, it is effectively out of cone

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

• probes medium physics, not jet physics
$\longrightarrow$ largely **independent** of specific shower-medium interaction assumptions

• not an issue for gluons with $p_T \sim$ few T
$\longrightarrow$ more difficult to change their kinematics

• now denoted 'frequency collimation'
$\longrightarrow$ not novel, observed already in 2009 T. R., Phys. Rev. C **80** (2009) 044904.

IV. Case study — dihadrons vs. dijets

dijets do not carry much dof or tomographic information

Case study

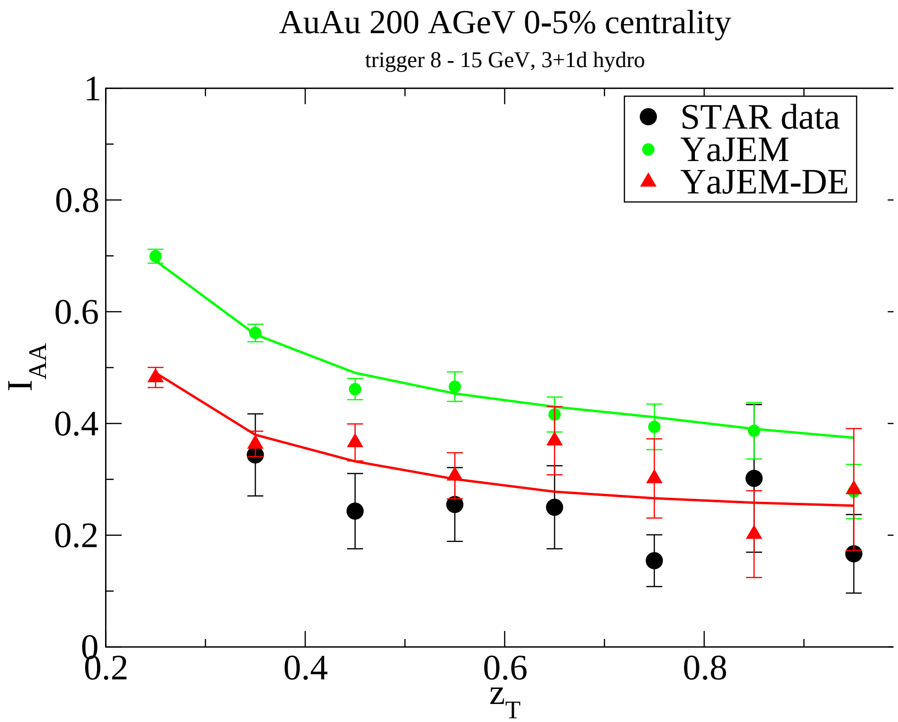
• three scenarios for shower-medium interaction:
→ best fit to RHIC and LHC R_{AA} and I_{AA} — YaJEM-DE
(dominant radiative, 10% elastic, L-dependent minimum in-medium shower scale)
→ 100% elastic energy loss — YaJEM-E
(linear L dependence, collimates jet shapes)
→ dominant radiative, 10% elastic — YaJEM
(linear L dependence)

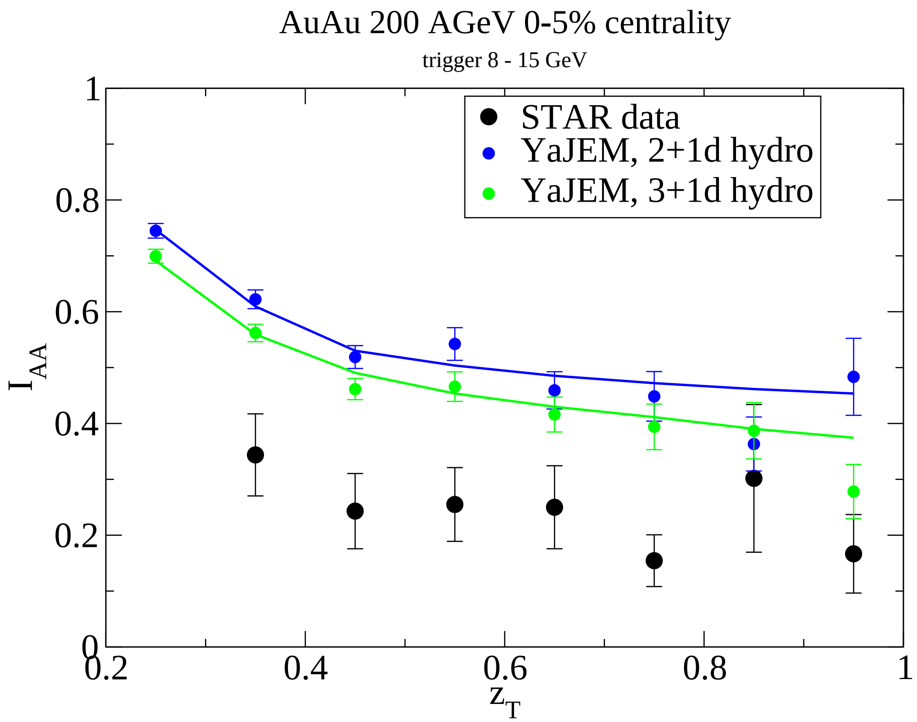
• three hydrodynamical codes (2+1d RHIC, 3+1d RHIC, 2+1d LHC)

• require that all model combinations give the same trigger rate
→ thus they have the same (hadron/jet) R_{AA} at the trigger energy

• compute correlation observables I_{AA}, A_J
→ does that tag model differences?

DIHADRONS





- strong sensitivity to L-dependence of models

$\longrightarrow$ linear dependence of YaJEM (and YaJEM-E) ruled out

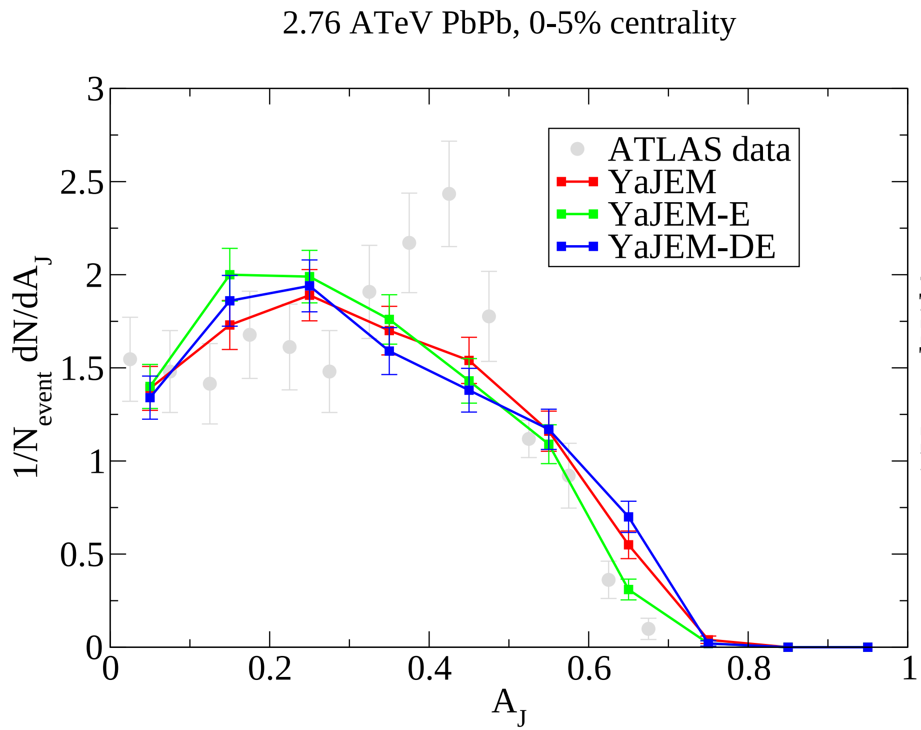
- somewhat weaker, but statistically significant sensitivity to hydro geometry

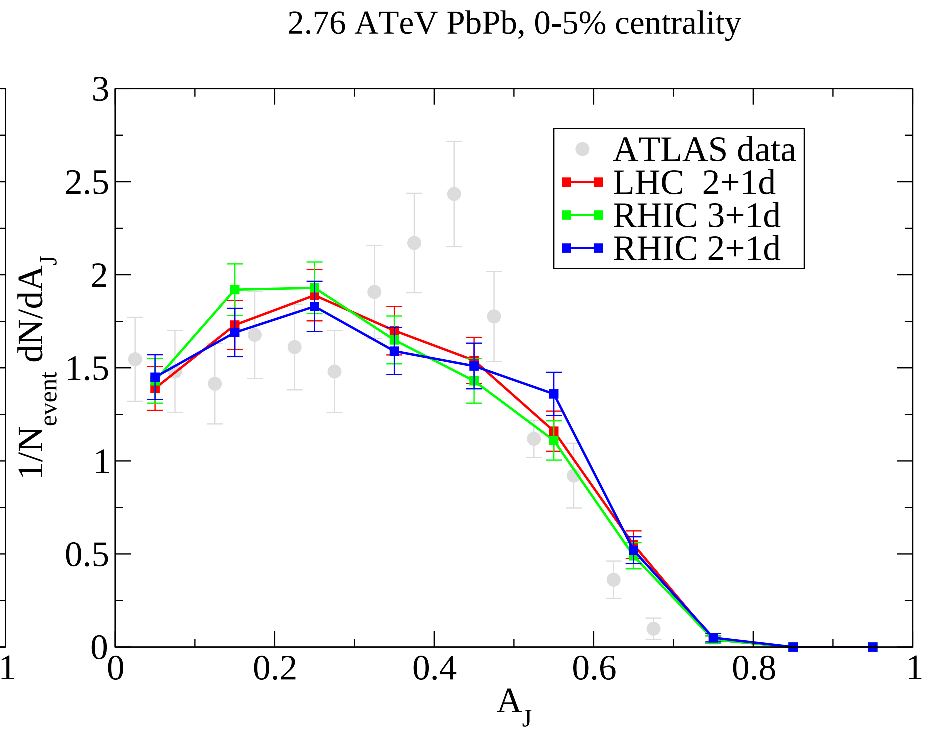
$\longrightarrow$ (more pronounced for stronger L dependence, not shown)

T. R. and K. J. Eskola, Phys. Rev. C **84** (2011) 054913

Dijets

- left: different models in LHC 2+1d hydro right: YaJEM for different hydros



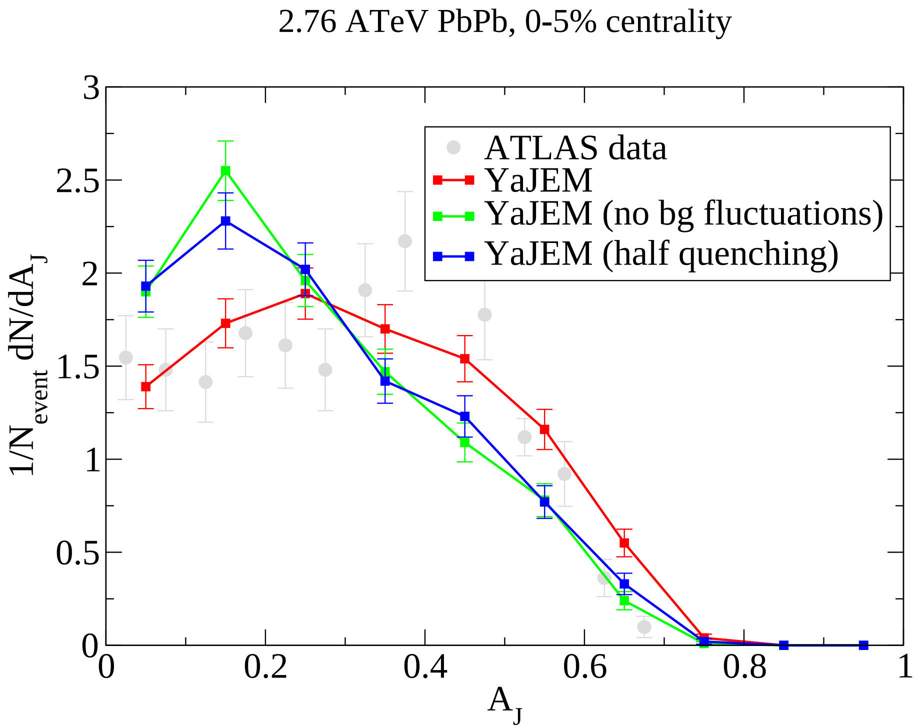


- no significant sensitivity to pathlength dependence of models
- no significant sensitivity to different jet shapes in YaJEM and YaJEM-E
- no significant sensitivity to hydro geometry
- basic agreement with the data (note jet definition is not identical)

T. R., arXiv:1202.4579 [hep-ph].

Dijets

- what do we see sensitivity to?



- overall strength of quenching

$\longrightarrow$ cheaper to obtain that from R_{AA}

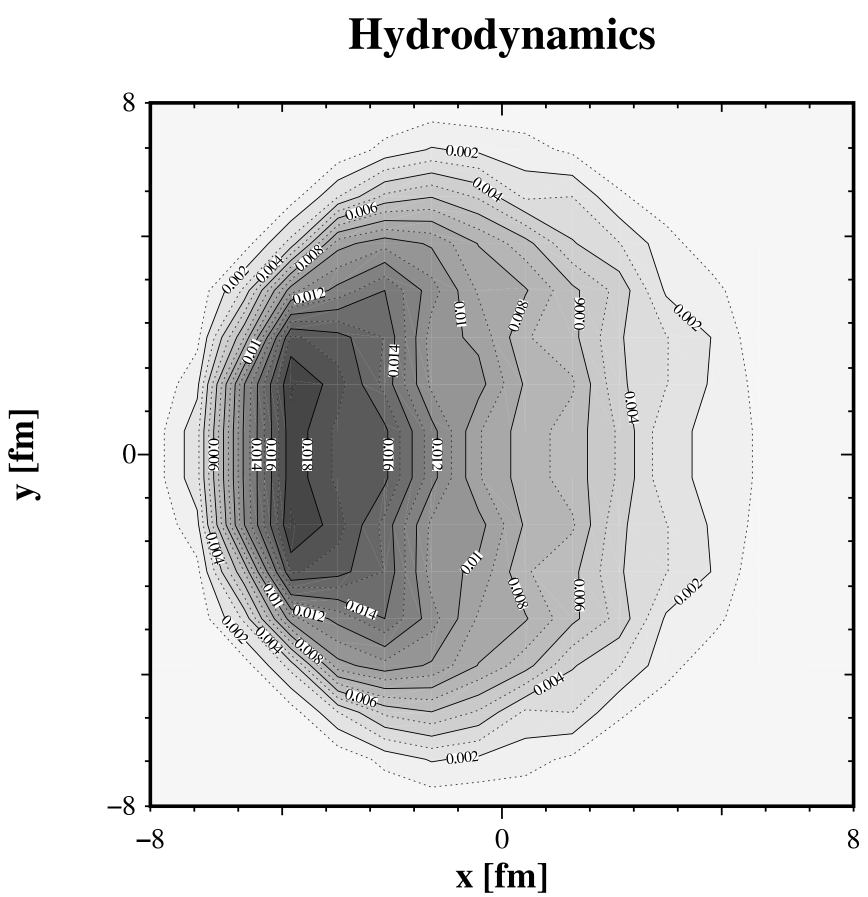
- modelling of background fluctuations and details of jet definition

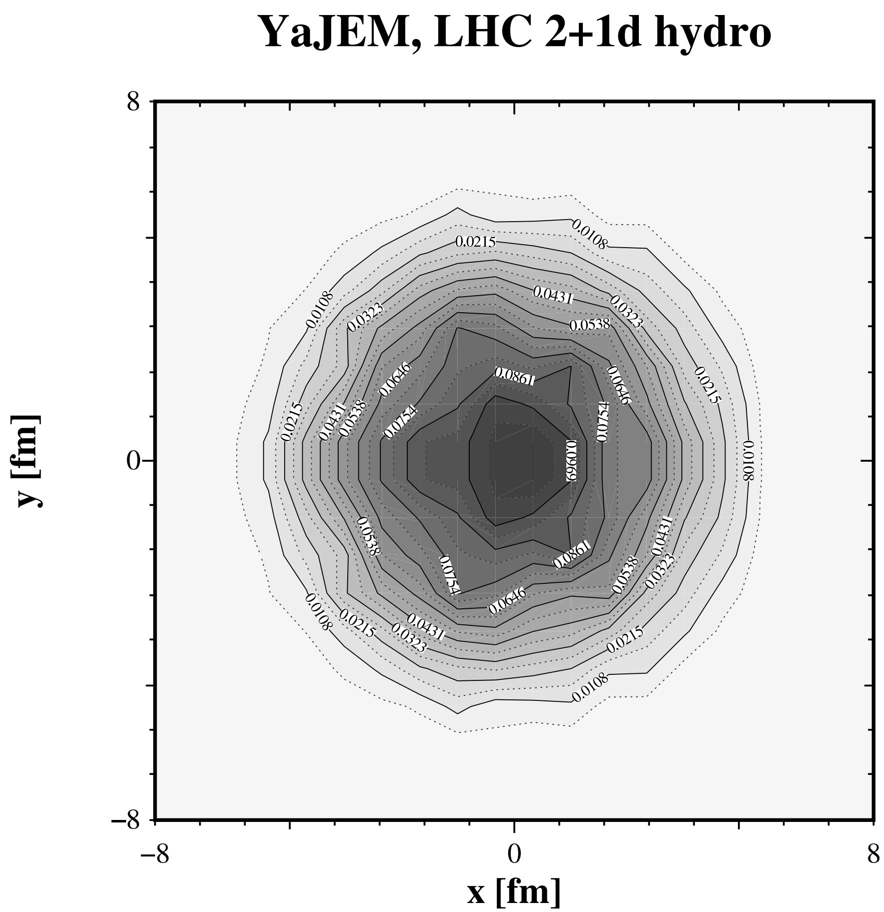
$\longrightarrow$ A_J is a sensitive probe for EbyE hydro

T. R., arXiv:1202.4579 [hep-ph].

Surface bias

- bias for the vertex position given a trigger (left: dihadrons, right: dijets)





⇒ dijets feel no strong geometry bias

T. R. and K. Eskola, Phys. Rev. C **75** (2007) 054910; T. R., arXiv:1202.4579 [hep-ph].

Explanation

• jets are quenched by soft gluons $p_T \sim T$ transferring momentum to large R
$\Rightarrow$ but this is not a model-specific mechanism

• gluon production at $p_T \sim$ few T is model-specific
$\longrightarrow$ but these gluons are largely clustered back into the jet
$\Rightarrow$ explains 'robustness', lack of surface bias
$\Rightarrow$ but implies no model-specific signal in the observable

• hard gluons $p_T \sim$ few GeV are almost exclusively produced in hard branchings
$\Rightarrow$ this is vacuum physics and doesn't probe the medium

Universality of soft gluon thermalization and suppression of low Q^2 physics by clustering explain the observed insensitivity of jet observables to medium physics

Implications

• Isn't this comparison unfair?
→ No, it isn't. Given R_{AA}, there is information in I_{AA} and this is probed here.

• Does this mean there is no information in jet observables?
→ The information (model differences) are much suppressed as compared to the dihadron case. Probably a factor 5-10 more accuracy in measurement and calculation would result in the ability to distinguish models using dijets.

• What if we look at jet longitudinal and transverse structure more differentially?
→ In principle this makes model differences more apparent, but in practice that still doesn't get you around the need to model things like the (un)-correlated background fluctuations very precisely before drawing *any* conclusions

• Is there a way around these problems?
→ hadron and γ-triggered multiparticle correlations as a function of the v_n plane angles should allow to dissect the hard part of the jet without running into non-perturbative problems early on and should allow to probe energy flow at large R

• Is there an advantage of reconstructing jets over hadron correlations?
→ From the theory side, none that I can see at this point. Maybe from the experimental side (?)