Jets vs. hadrons

— status now and future potential

Thorsten Renk

UNIVERSITY OF JYVÄSKYLÄ

Suomen Akatemia

HELSINKI INSTITUTE OF PHYSICS

Why jets in e^+e^- and p-p?
Why jets in medium?
A case study
Next generation jet observables?
Discussion

Jets in e^+e^- and p-p

Problem: pQCD theory knows partons, experiment sees collimated sprays of hadrons
(or just calorimeter energy deposition)
$\longrightarrow$ observables are cross sections for hadron production

To solve this, either
• supplement theory with non-perturbative ingredients (FFs, Lund model,. . .)
$\longrightarrow$ not rigorously controlled, significant systematic errors

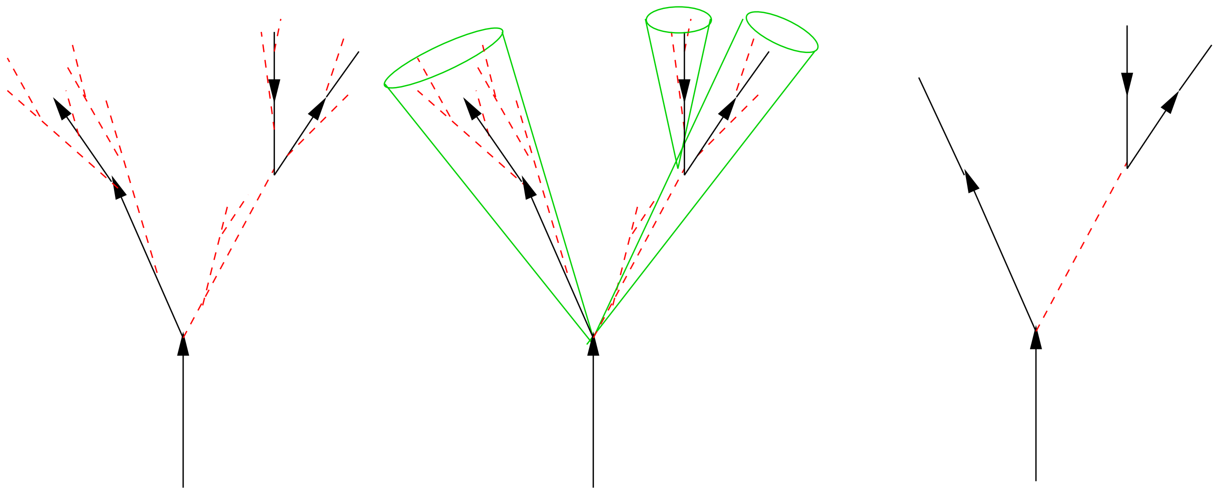
or
• define an experimental quantity which resembles a parton
$\longrightarrow$ take care to keep calculable, IR and collinear safety are **theory** requirements!

$\Rightarrow$ Jet definitions

Jets are 'a contract between theory and experiment', made to define something that can be observed by experiment, is not plagued by systematic uncertainty in theory and as directly as possible resembles the relevant physics of pQCD — a **jet** is designed to be **a proxy for a parton**.

JETS IN e^+e^- AND P-P

The role of clustering: systematically reduce observables to the hard pQCD structure



• keeps interesting hard physics, designed to suppress physics at Λ_{QCD}
$\longrightarrow$ subjets allow to systematically access hard parton branchings

• relevant theory can be compared with data even on analytical level
$\longrightarrow$ clustering removes need to resum soft and collinear gluon emissions

• experimentally fairly easy, just need energy deposition in calo towers
$\longrightarrow$ no need to PID or track, no need to distinguish particles inside a tower, . . .

Jets in A-A

Problem: observing interactions between medium (fluid) and partons (pQCD)
→ observables are ratios and conditional probabilities

Scale separation: hard scale p_T O(20-1000) GeV, soft scale T O(0.1 - 0.5) GeV
→ the medium **can not** affect the hard process of hard splittings

(There are hundreds of papers on medium-induced soft gluon emission, but I'm not aware of a single one that claims the medium can affect hard splittings.)

• medium affects low Q^2 partonic evolution when scales become similar, $Q^2 \sim \Delta Q^2$
→ interesting physics is at semi-hard scales between T and few $T \sim$ few GeV

• at scale T, DOFs change as soft gluons are indistinguishable from medium
→ rather than partons, fluid elements carry energy and momentum

• substantial (correlated and uncorrelated) background due to underlying event
→ conceptual definition of what is part of the hard process becomes blurry

Jets in A-A

The role of clustering for medium modifications of hard processes:

• ~~keeps interesting physics~~, designed to suppress physics at $\Lambda_{QCD} \sim T$
→ systematically suppresses the region where the medium modifications sit

• ~~relevant theory can be compared with data even on analytical level~~
→ Lisbon Jet Workshop 2014: Theory = MC, analytical calculations are irrelevant

I don't shy away from MC, but theory $\neq$ MC, MC is just a tool to solve a particular type of numerical integral. There's no virtue as such in event generators, what matters is how to dig out the interesting physics, and here non-MC techniques are often superior.

• ~~experimentally fairly easy, just need energy deposition in calo towers~~
→ background subtraction, unfolding of fluctuations, track requirements . . .

Charged hadron R_{AA} at LHC was essentially a 'day one' measurement. Jet R_{AA} didn't follow for a long time. Hard charged hadrons seem to be much easier experimentally.

• ~~creates unique absence of systematic uncertainties due to FF~~
→ in ratios and conditional probabilities, the FF dependence largely cancels

A toolkit for terascale physics isn't necessarily as suitable for jet quenching.

A study in constraints

Idea: Assess the constraints of jet vs. hadron high P_T observables.

Start with three different scenarios, of which we know two to be **grossly incorrect**
$\Rightarrow$ start to constrain with **jet** observables, see at which point we find out

- **YaJEM-DE**

$\rightarrow$ constrained by available RHIC and LHC data
$\rightarrow$ pathlength dependence driven by $Q_0 \sim \sqrt{E/L}$, 10% elastic energy loss
$\rightarrow$ broadens showers, breaks self-silimarity at fixed P_T

- **YaJEM-E**

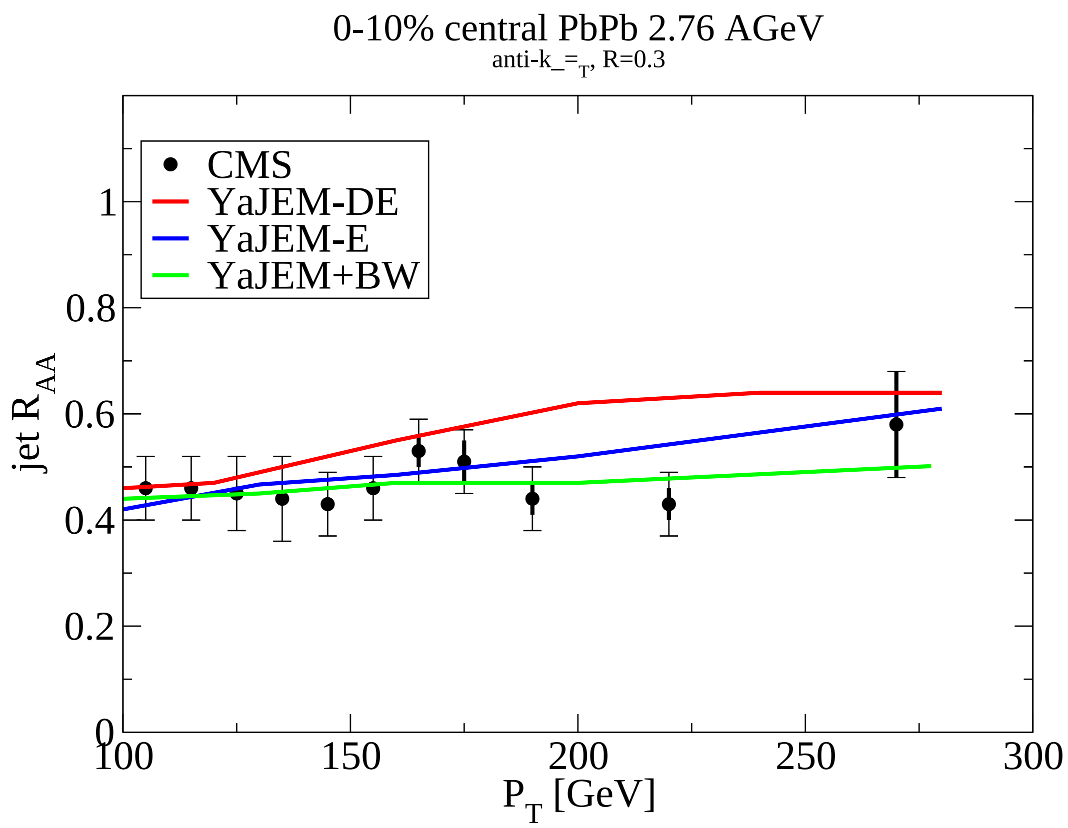
$\rightarrow$ incoherent, 100% elastic energy transfer into the medium as drag force
$\rightarrow$ **collimates** showers, breaks self-similarity at fixed P_T

- **YaJEM+BW**

$\rightarrow$ utilizes the Borghini-Wiedemann prescription to enhance low z gluon production
$\rightarrow$ pathlength dependence implemented as incoherent
$\rightarrow$ broadens showers, **preserves** self-similarity

A STUDY IN CONSTRAINTS

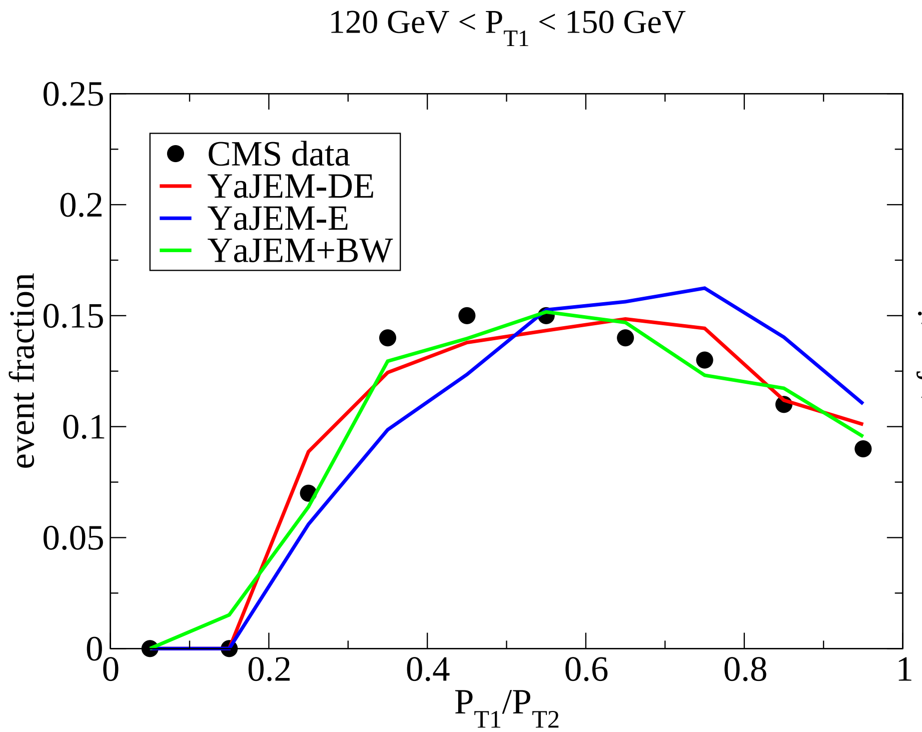
Jet disappearance:

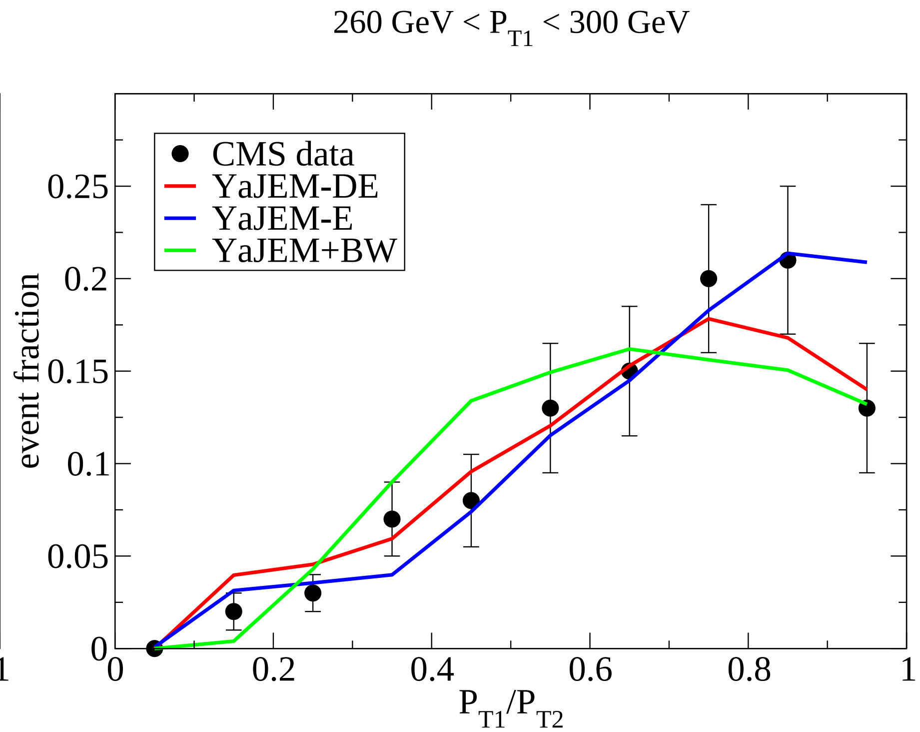


• decent description of jet R_{AA} P_T dependence (YaJEM-DE does actually worst)
$\rightarrow$ no sensitivity to pathlength dependence, broadening, self-similarity. . .

A study in constraints

Jet-jet correlations:





- tension for both YaJEM-E and YaJEM+BW if full P_T dependence is used

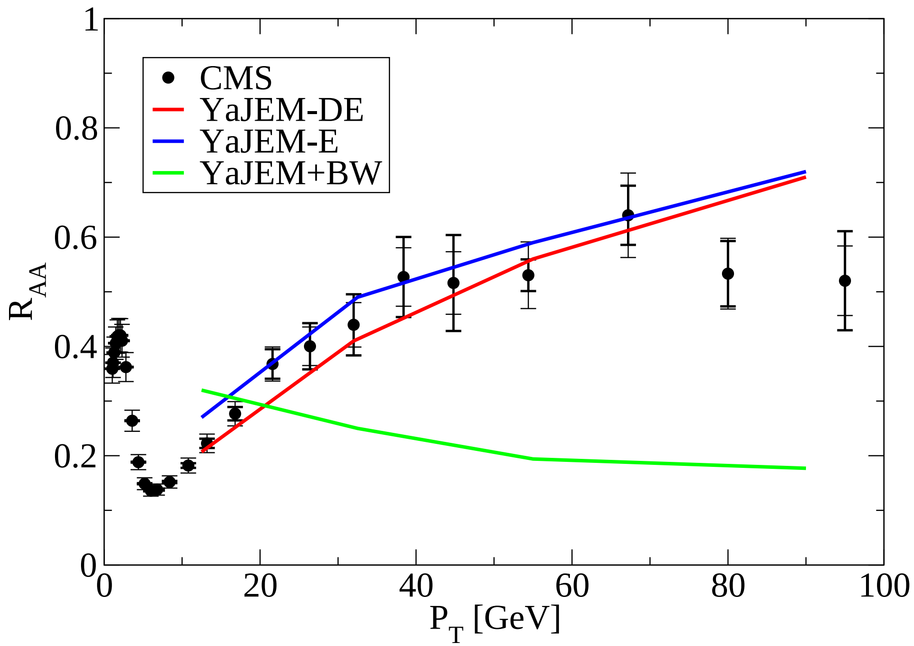
$\longrightarrow$ see self-similarity of YaJEM+BW as unchanged shape

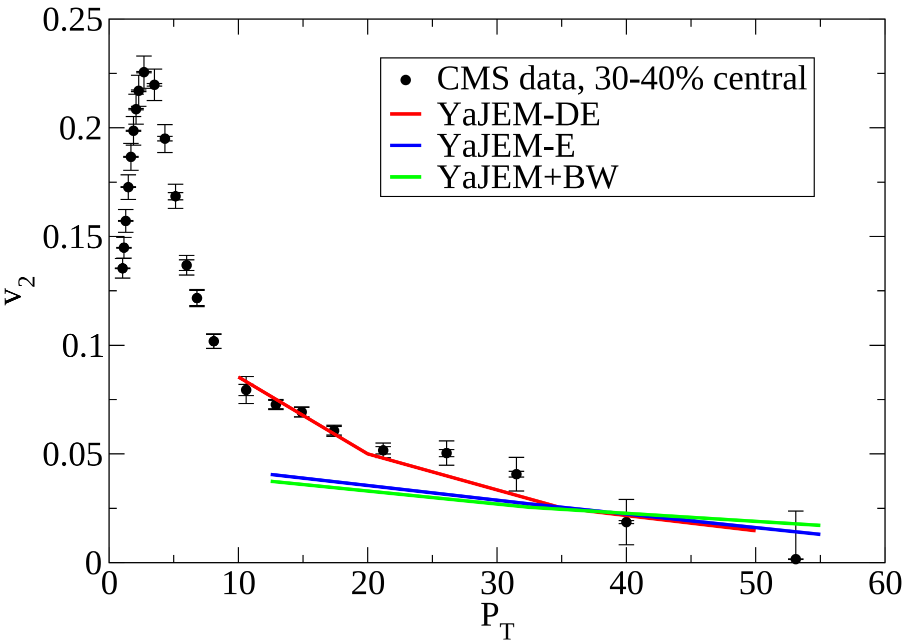
- perhaps one might rule out YaJEM-E based on this

$\longrightarrow$ however, we usually ask for something more substantial to rule things out

A study in constraints

Hadron disappearance:





- in the hadronic sector, YaJEM+BW is completely off

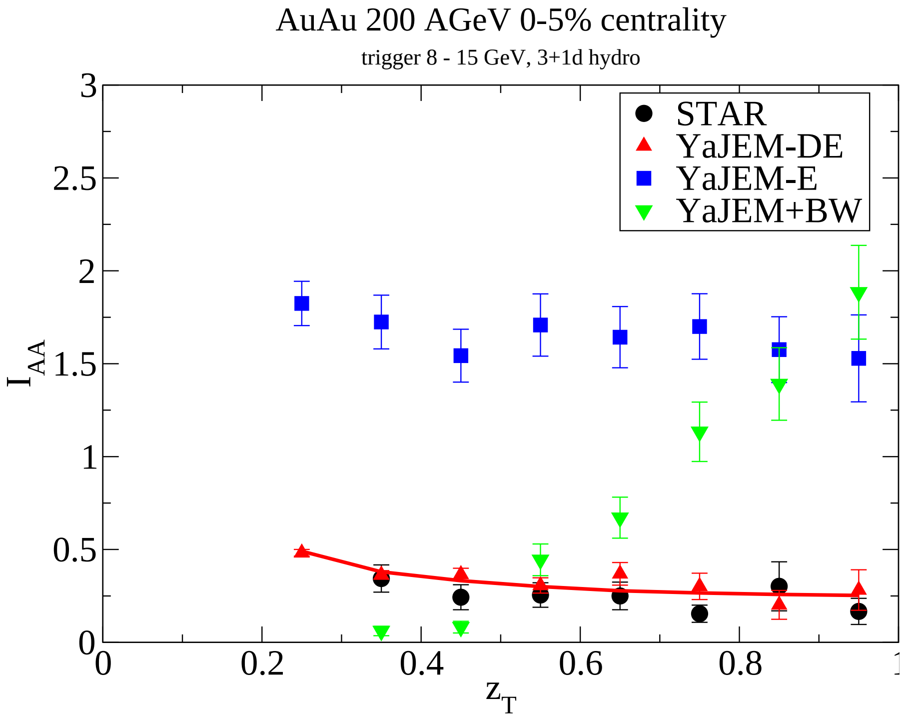
$\longrightarrow$ leading hadron R_{AA} clearly is not fractional energy loss

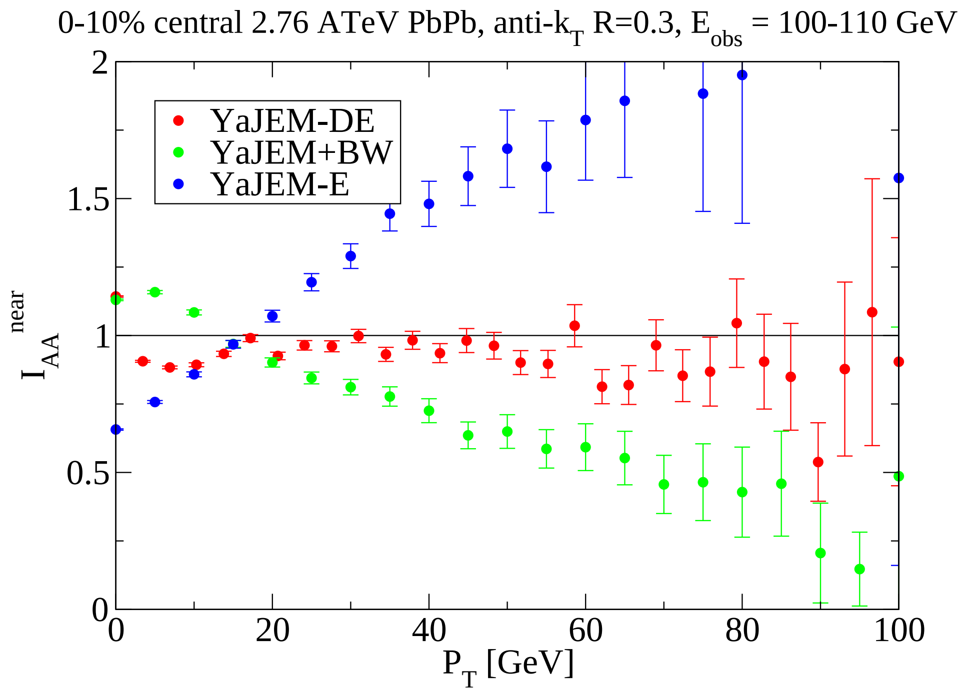
- even with normalization of v_2 open, an incoherent mechanism misses the v_2 shape

$\longrightarrow$ Q^2 evolution matters, and clustering obscures it

A study in constraints

Hadron-hadron back-to-back (RHIC) or jet-hadron near side (LHC):





- better constraints when **biases** align to magnify physics effects
- h-h: up to factor eight (!) difference to data

$\longrightarrow$ very sensitive to model differences

- intra-jet-h: still $> 50\%$ effects

$\longrightarrow$ jet-track correlations are progressively more constraining

A study in constraints

- clustered jet observables (R_{AA} or jet-jet) do not discriminate well
$\longrightarrow$ perhaps 10-20% effects

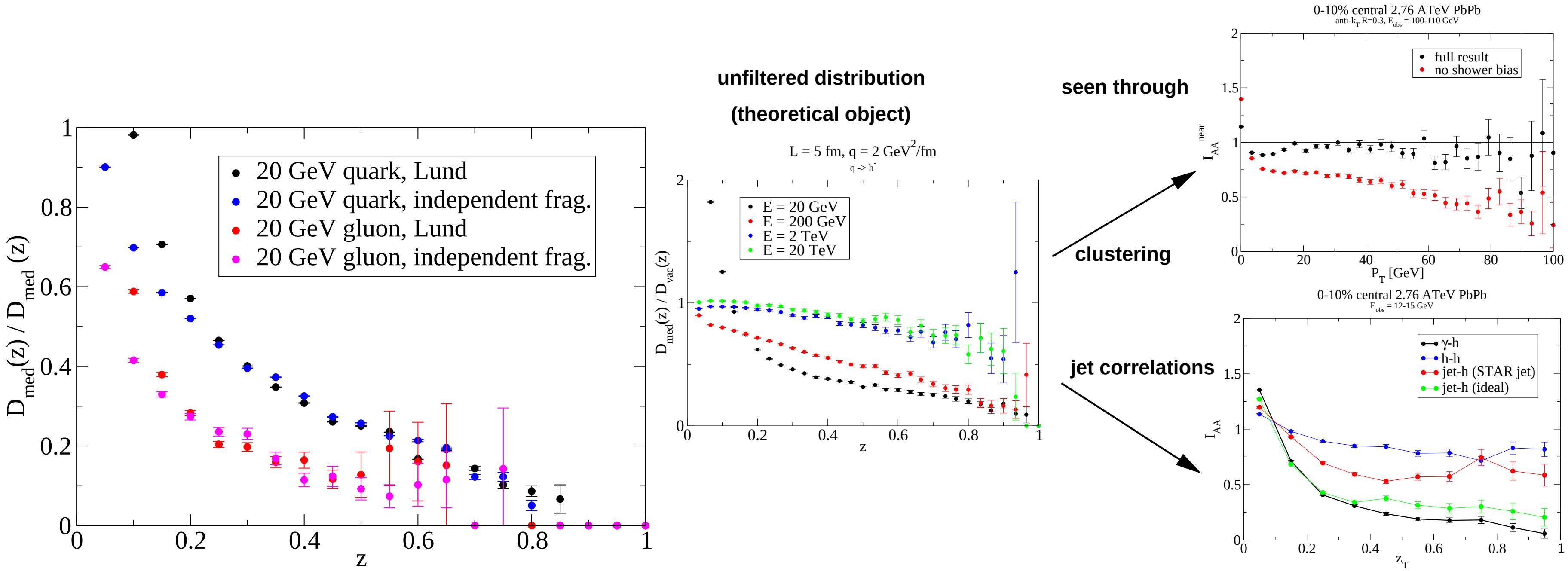
- intra-jet-track and hadron disappearance discriminate about equally well
$\longrightarrow$ about O(50)% effects

- h-h correlations, especially with RHIC spectral bias, discriminate best
$\longrightarrow$ factors of 5 and more

Clearly, doing jets to get better constraints for models is not the best motivation. Jet observables **are able to discriminate** models, but they are **more difficult to do experimentally**, **cannot be done semi-analytically** on the theory side and the **effect sizes are consistently smaller**, i.e. h-h correlations win in the cost-benefit analysis.

Some commonly argued points

• jets define observables independent of the fragmentation function
→ but ratio observables are generically independent of the FF choice
(unless for the low z hadron distribution)



• with jets, one can measure the FF and it medium modification
→ no, what one can measure is the momentum distribution inside a biased jet sample
→ what a theorist calls a FF is much better accessible in jet-h or γ-h

• clustering gives a jet axis, hadrons do not
→ true, but jet axis is hard physics and not interesting for parton-medium interaction

What jets do really well

- leading hadrons require high z fragmentation, which is not typical

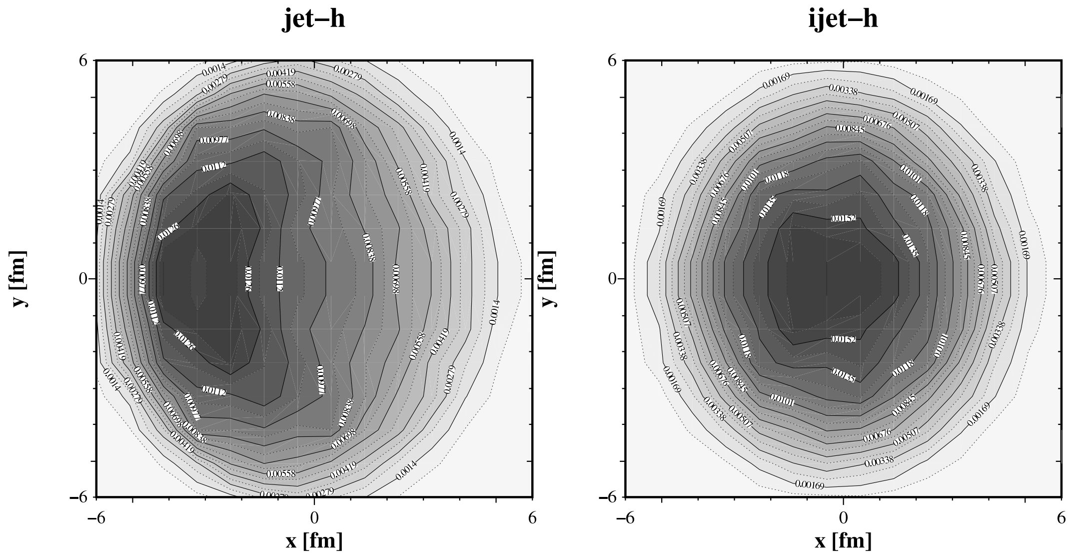
$\rightarrow$ jet triggers can give (much) higher statistics for same average parton p_T

- jet definition can be smoothly changed to create a more or less biased trigger object

$\rightarrow$ constituent P_T cuts are rather powerful (but needs MC because is manifestly not IRC safe)

$\Rightarrow$ **design** biases to magnify whatever it is you want to see

$\rightarrow$ for instance geometry:

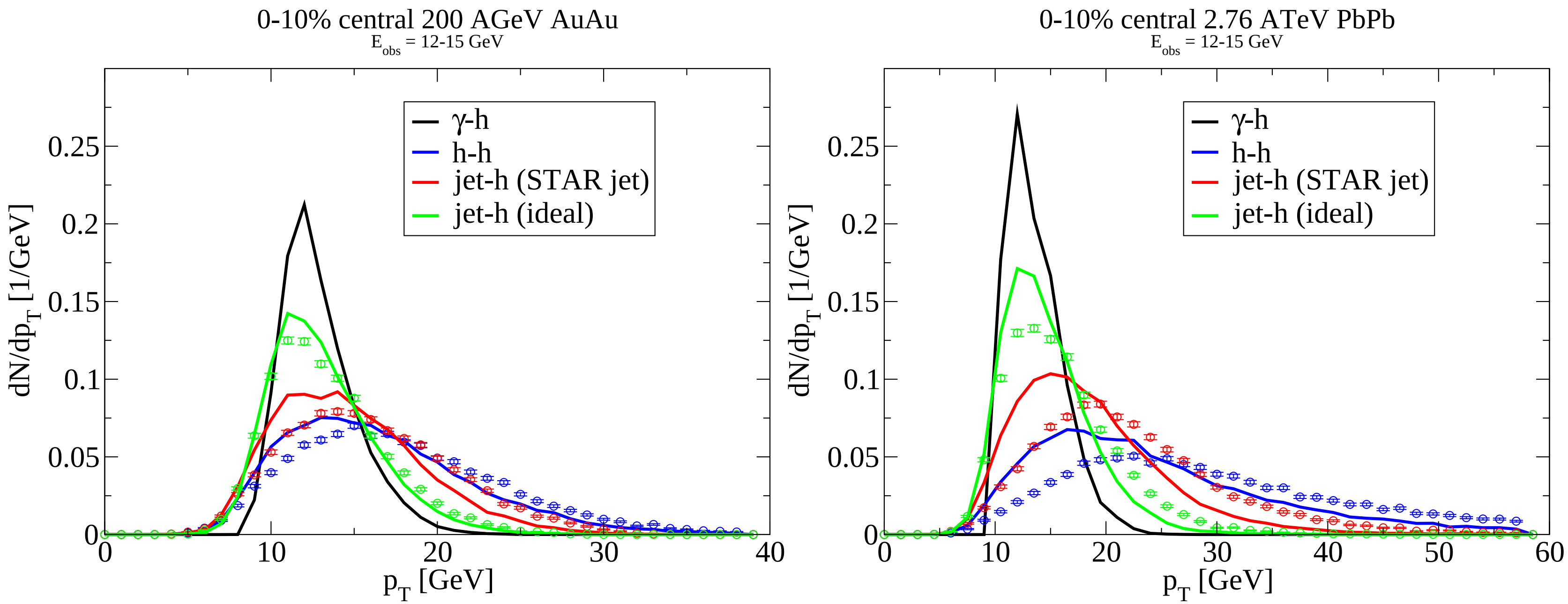


$\Rightarrow$ hadron or photon triggers do not allow this rich variety

Jets in medium excel as **triggers** rather than as **observables**!

RHIC vs. LHC

• relation between parton and trigger object kinematics

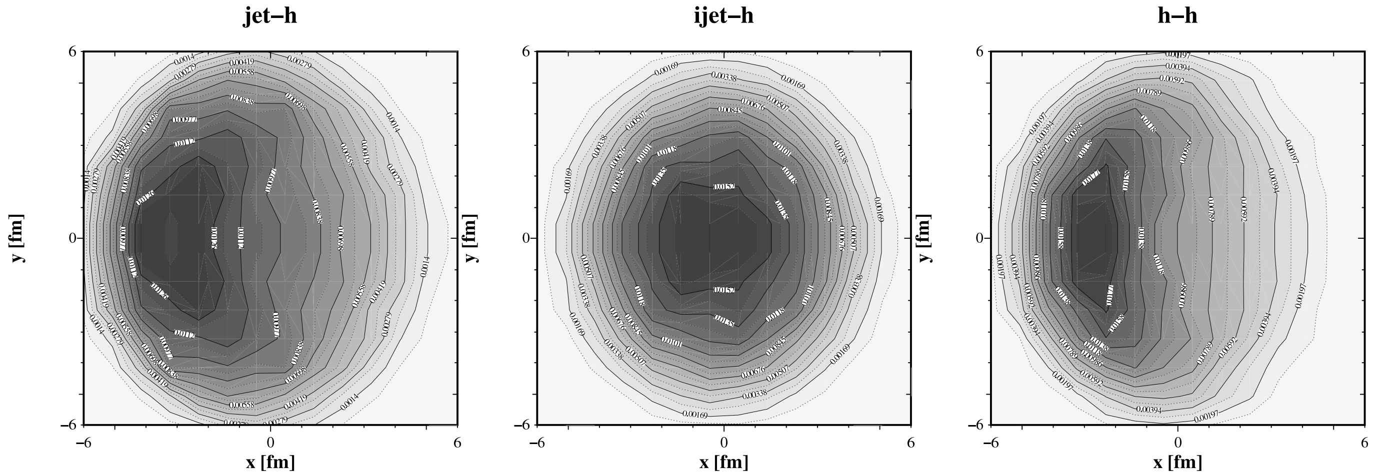


• hadron triggers at RHIC are almost as 'clean' as CMS flow-like jets at LHC
$\longrightarrow$ consequence of the steeply falling spectrum

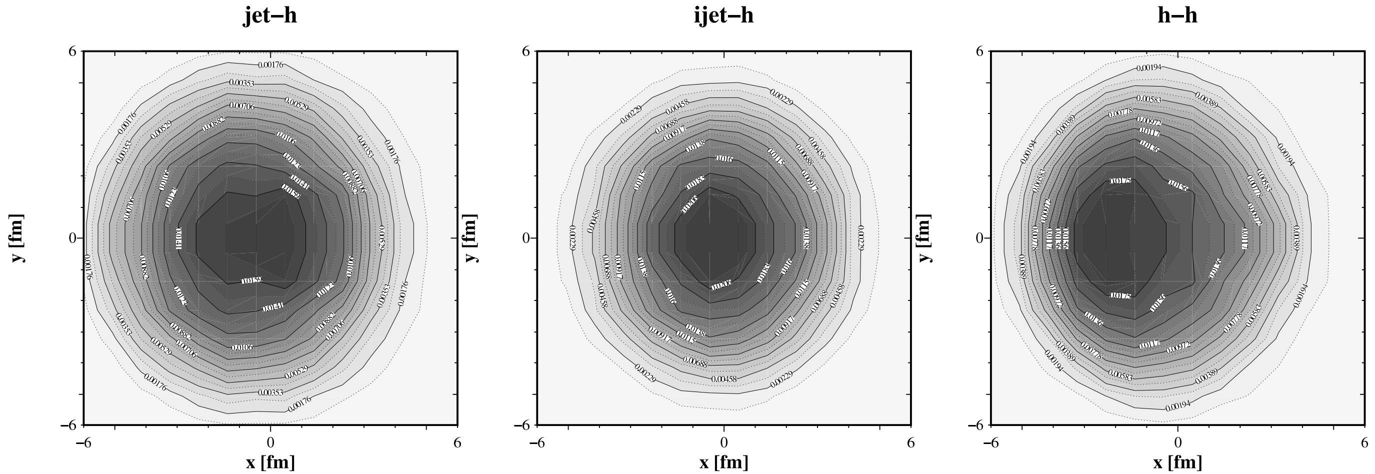
• such 'clean' kinematics makes connection to theory easier
$\longrightarrow$ **averaging is bad**

RHIC vs. LHC

- geometry bias design works much better at RHIC



- than at LHC



→ generically more difficult to align biases to magnify an effect with higher $\sqrt{s}$

Next generation jet observables?

$\Rightarrow$ the p-p like option?

Terascale physics $\neq$ thermal scale physics!

- interesting jet quenching physics signals sit at $\sim$ few T, not at hundreds of GeV
- jet tagging by prong topology and grooming (like used for top-jets)

$\rightarrow$ probes a completely different mass range without medium effect

- PU removal techniques like PUPPI, softkill, . . .

$\rightarrow$ will likely remove most of the medium modification signal

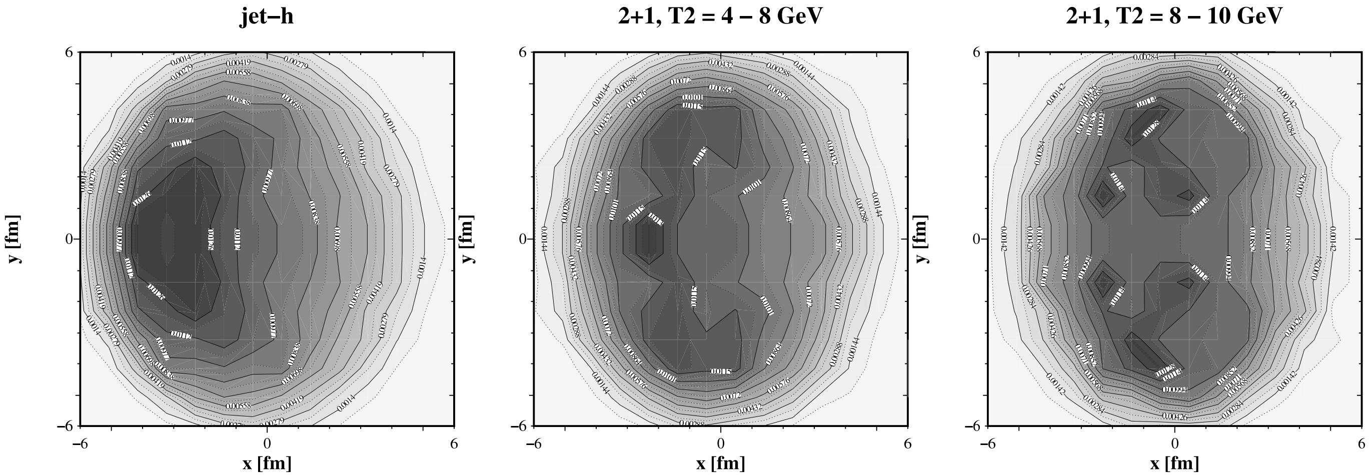
- quark/gluon discriminators like girth, . . . used for medium

$\rightarrow$ will sort medium-modified jets by shape, not quark from gluon modification

$\rightarrow$ that's the Texan sharpshooter problem

Next generation jet observables?

• tomography 2.0 — designed geometry biases probing reaction plane orientation
→ one can literally scan through selected regions of the medium



• possibility to define **key observables** with little sensitivity to medium specifics
→ validate model properties, constrain pathlength dependence, elastic channel,. . .

• possibility to define **tomographic observables** with maximal sensitivity
→ measure $\hat{q}$, near T_C enhancement, ϵ_n,. . .

Next generation jet observables?

$\Rightarrow$ the A-A option?

• distinction between **key observables** and **tomographic observables**
$\longrightarrow$ little vs. high sensitivity to the assumed geometry

• shift in the view of biases
$\longrightarrow$ the goal should not be to avoid them but to design them properly

• shift in view of jets
$\longrightarrow$ as observables, they are of modest use, as triggers they work perfectly

• shift in the view of the role of harder primary parton spectrum
$\longrightarrow$ often (statistics!) an advantage, sometimes (tomography) clearly not

If jets are a contract between theory and experiment, we don't need to take the p-p contract made for a completely different situation. We can re-negotiate it and make jets in A-A collision a bias-controlling tool to magnify the physics of jet quenching we actually want to see.