Biased showers

a framework to compare high P_T observables

Thorsten Renk

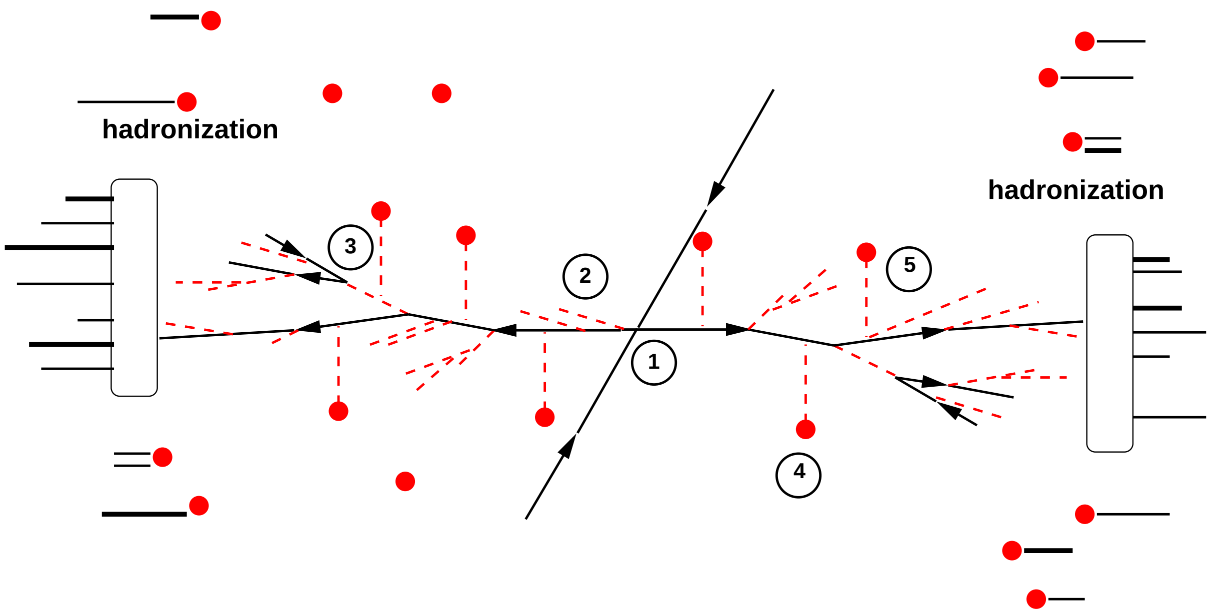
UNIVERSITY OF JYVÄSKYLÄ

Suomen Akatemia

HELSINKI INSTITUTE OF PHYSICS

Based on T. Renk, 1212.0646 [hep-ph].

MEDIUM-MODIFIED JETS IN THE EYE OF A THEORIST



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

- series of splittings $a \rightarrow bc$ with decreasing t

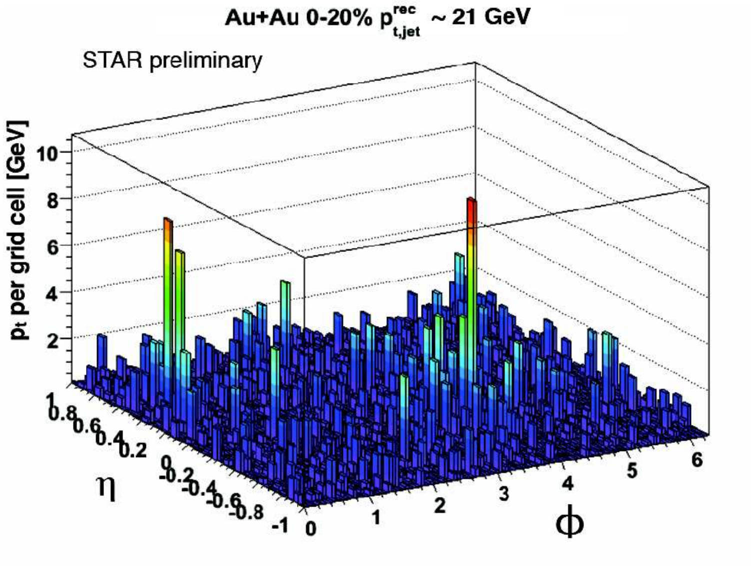
$$dP_a = \sum_{b,c} \frac{\alpha_s(t)}{2\pi} P_{a\rightarrow bc}(z) dt dz \quad \text{with} \quad t = \ln Q^2/\Lambda_{QCD} \quad \text{and} \quad z = E_d/E_p$$

$$P_{q\rightarrow qg}(z) = \frac{4}{3}\frac{1+z^2}{1-z} \quad P_{g\rightarrow gg}(z) = 3\frac{(1-z(1-z))^2}{z(1-z)} \quad P_{g\rightarrow q\overline{q}}(z) = \frac{N_F}{2}(z^2 + (1-z)^2)$$

- add medium perturbations, terminate at a soft virtuality scale t_0 or Q_0 and hadronize

$\Rightarrow$ compute the fate of the hard parton *forward* in time to get the final hadron shower

Medium-modified jets in the eye of an experimentalist



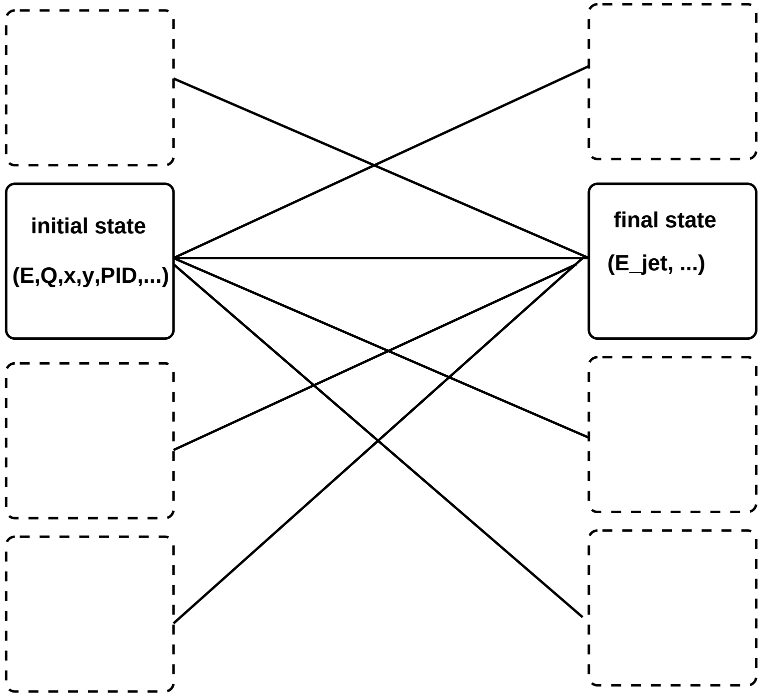
- 'Where is my jet, what belongs to it and what doesn't?'

→ triggered observables and background subtraction techniques

→ form 'modified over unmodified' ratios

⇒ conclude from the observed jet *backward* in time what the hard process and the modification might have been

Does this matter?



• initial state assumed by the theorist can lead to final states which are not triggered (and remain unobserved)

• experimental final state can come from initial states theory did not consider (background fluctuations, 'fake jets',. . .)

⇒ a correct comparison requires to compute for *all* initial states, taking the *biases* by the experimental observation into account

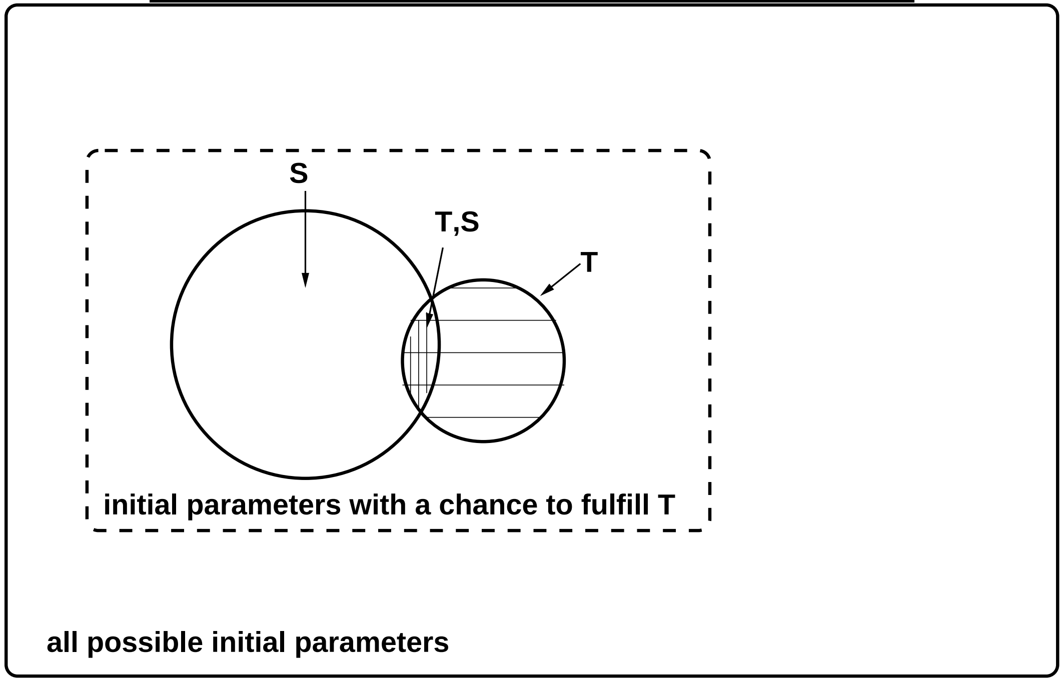
It has mattered!

• predictions before experiments are done (and no experimental procedure is known):
∗ compute FF for quark jets with fixed E for constant path through medium
$\longrightarrow$ see significant medium modification
∗ measure FF for jets with fixed E_{jet} range averaged over all medium paths
$\longrightarrow$ see no significant medium modification over large kinematic range
$\Rightarrow$ claim death of radiative energy loss paradigm at QM Annecy

• toy model based interpretations of experimental findings
∗ I_{AA} in h-h correlations $\approx R_{AA}$ at RHIC
$\longrightarrow$ popular explanation: tangential emission, same path on near and away side
∗ I_{AA} at LHC $> R_{AA}$
$\longrightarrow$ so triggered dihadrons originate preferably from close to away side??
$\Rightarrow$ puzzling. . .

• in both cases, **biases** are essential to understand the findings

Biases in a nutshell

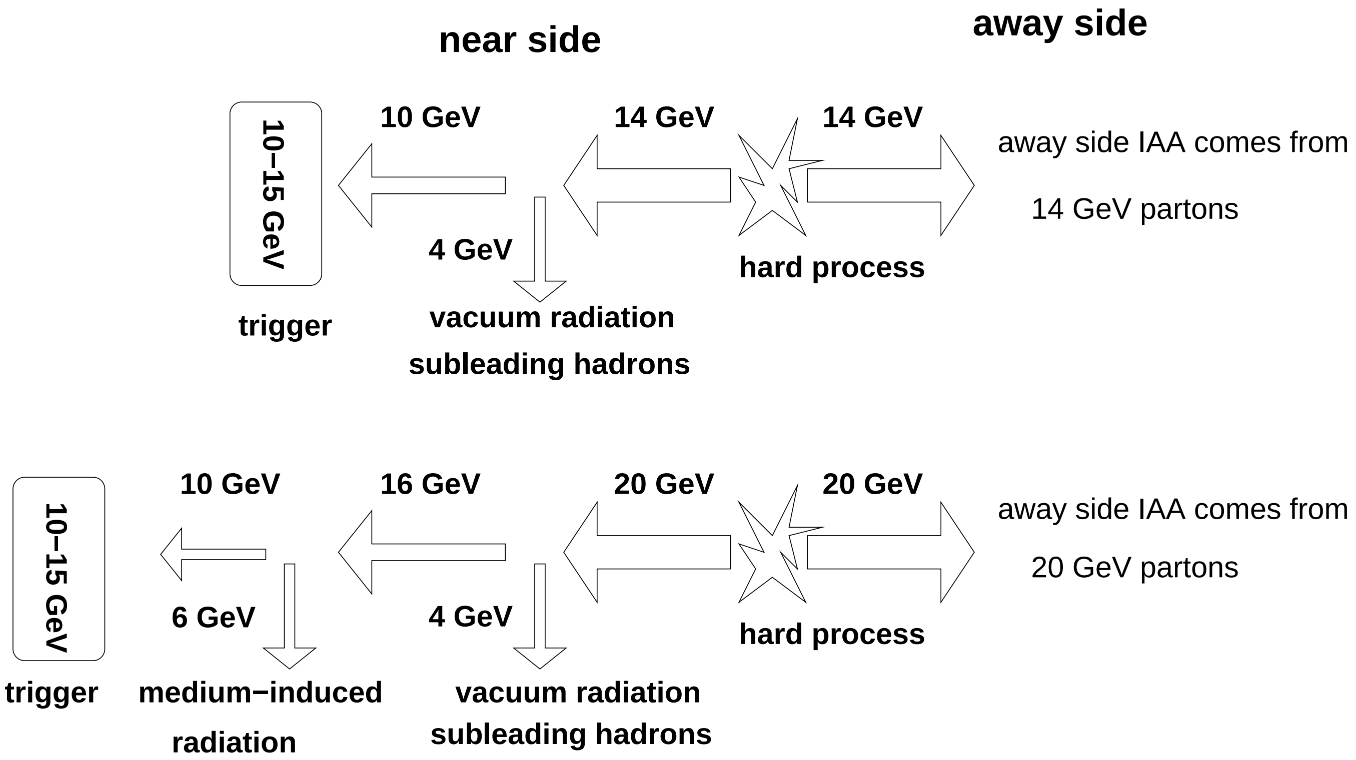


- triggered observation of observable $S \leftrightarrow$ subset of all initial states A evolved which $\rightarrow$ have property S and fulfill trigger T (conditional probability)
- if T is a small subset of all possible events, this subset is usually not typical $\rightarrow$ thus $T \cap S$ is different from S, it is *biased* (unless T and S are correlated)
- size(T)/size(A) is the normalized rate at which triggered events occur $\rightarrow$ related to *disappearance observables* such as $R_{AA} =$ size(T)$_{med}$/size(T)$_{vac}$

4 types of biases in the following

The kinematic bias

- same trigger condition in vacuum and medium $\neq$ same initial kinematics



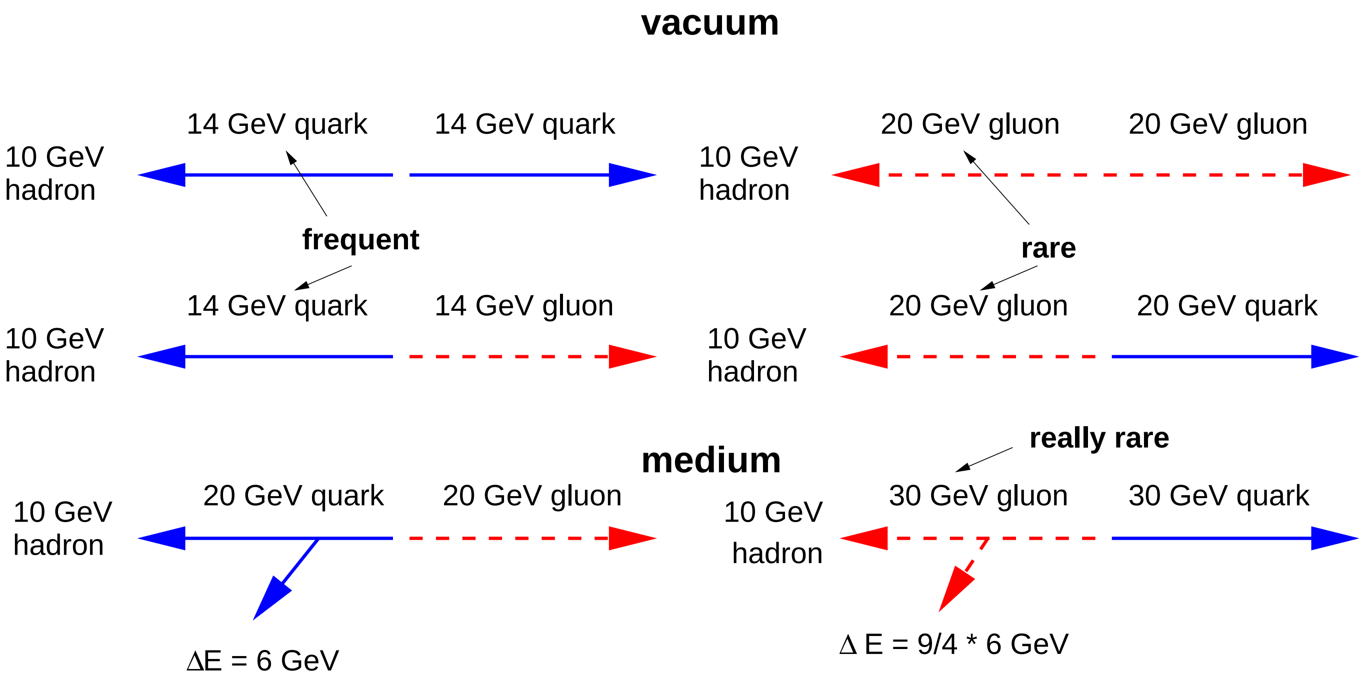
$\rightarrow$ counter-intuitively tends to *increase* I_{AA} in medium, naive argument misses this

- also other complications, intrinsic k_T points on average in trigger direction,. . .

The energy of a trigger object $\neq$ parton energy. This relation changes in a medium.

The parton type bias

- same trigger condition in vacuum and medium $\neq$ same parton types



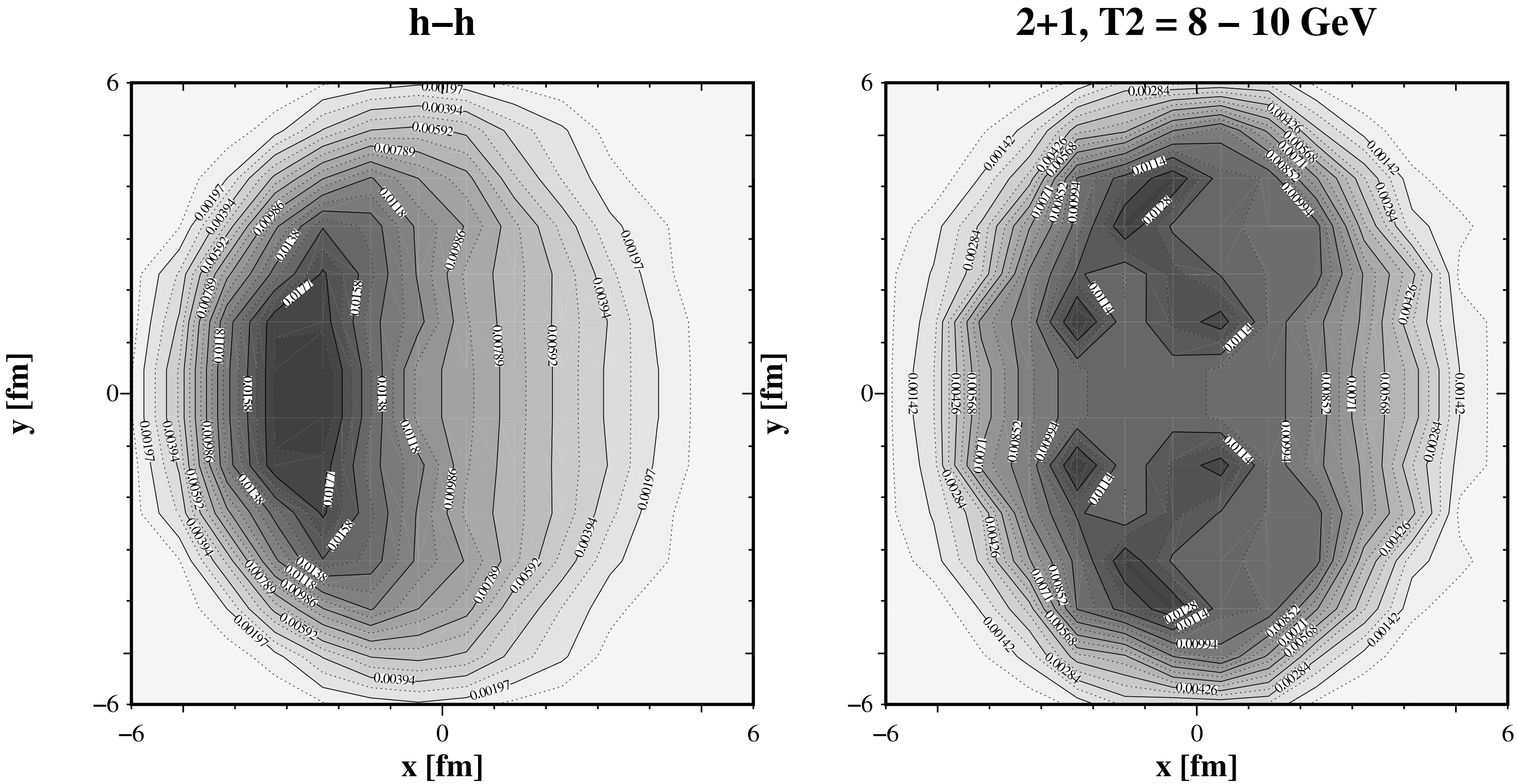
- most trigger conditions enhance the fraction of quark jets on the trigger side
$\rightarrow$ if $qg \rightarrow qg$ is important, this may enhance away side gluon fraction

- gluon jets in medium get additional penalty due to $9/4$ higher interaction strength
$\rightarrow$ in-medium away side may be much more gluon-populated than naively expected

Quark showers are more likely to trigger. The probability is changed by the medium.

The geometry bias

• if medium modification on average increases with medium length and density
→same trigger condition in vacuum and medium ≠ same geometry probed

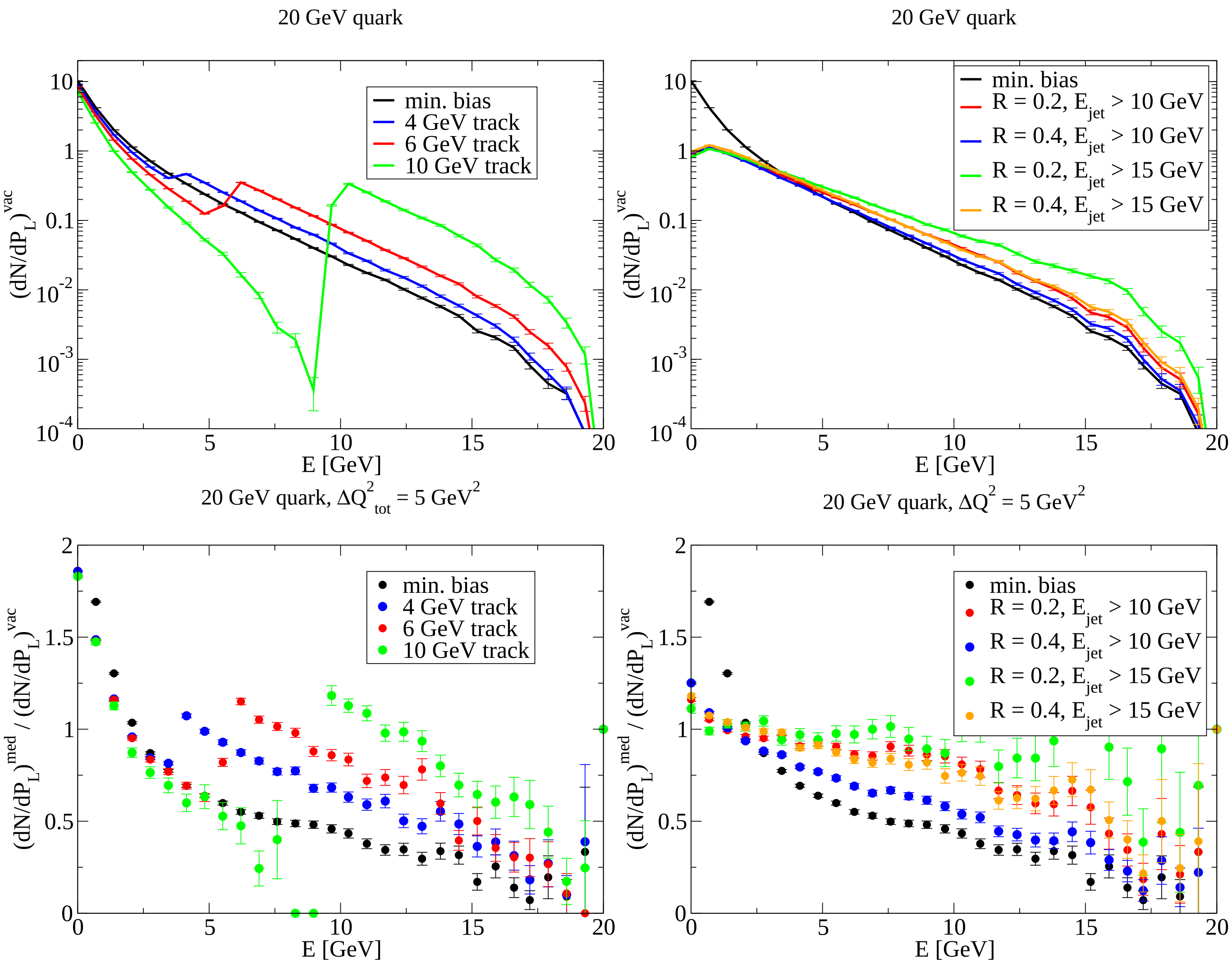


• partons with short in-medium paths have higher chance of fulfilling trigger condition
→ vertex distribution of triggered events is biased in a characteristic way

Triggered objects in medium do not represent typical geometry.

The shower bias

- a trigger condition biases the shower in which the trigger is created



- suppresses medium-modifications — highly modified showers don't trigger

$\longrightarrow$ explains CMS 'mystery' of unmodified fragmentation function

Disclaimer

The following studies

• do not involve fit of any free parameter to data, or explore hydro systematics
$\longrightarrow$ should be seen as qualitative illustrations of effects

• are done using my MC code YaJEM-DE
$\longrightarrow$ but are not model-specific, qualitatively the same happens in any model in which

- in-medium jets in general soften
- in-medium jets in general broaden
- gluon jets are on average softer and broader than quark jets
- medium modifications grow with density and pathlength

• do not involve anything really novel
$\longrightarrow$ but connect dots between known effects systematically

A comparison of I_{AA}

Case study I: compare away side I_{AA} for different trigger objects

- the away side has no shower bias, because trigger is not from away side shower

- γ-h, h-h, jet-h (anti-k_T with $R = 0.4$, $P_T > 2$ GeV, STAR PID cuts), i(deal)jet-h (anti-k_T $R = 0.4$)

- trigger momentum range 12-15 GeV

- study away side charged hadron I_{AA}

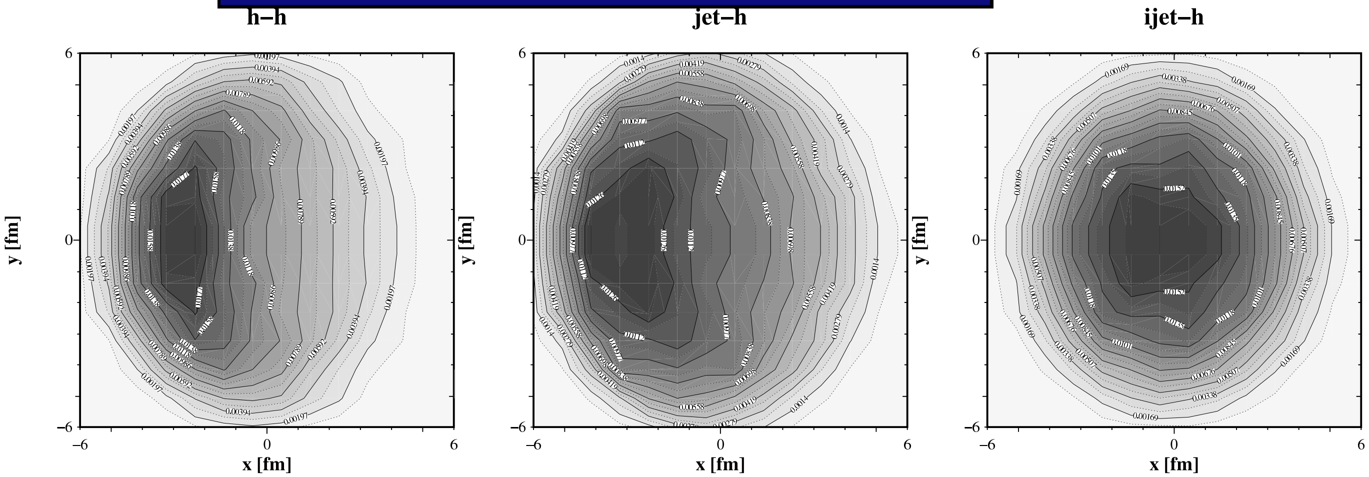
- RHIC kinematics (steeply falling parton spectra, energetic partons strongly penalized)

- LHC kinematics (energetic partons accessible)

- *not* quantitative predictions, no attempt made to adjust model to data

A COMPARISON OF I_{AA}

RHIC:

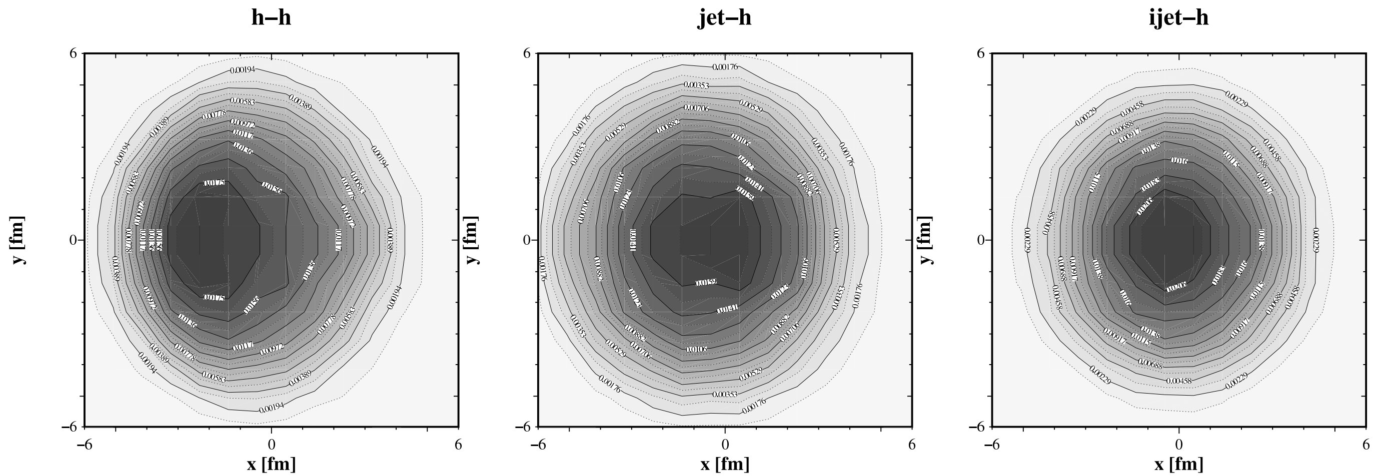


- completely different surface bias

$\rightarrow$ unbiased for γ-h, nearly unbiased for ijet-h, highly biased for h-h

$\rightarrow$ note that bias depends on jet definition!

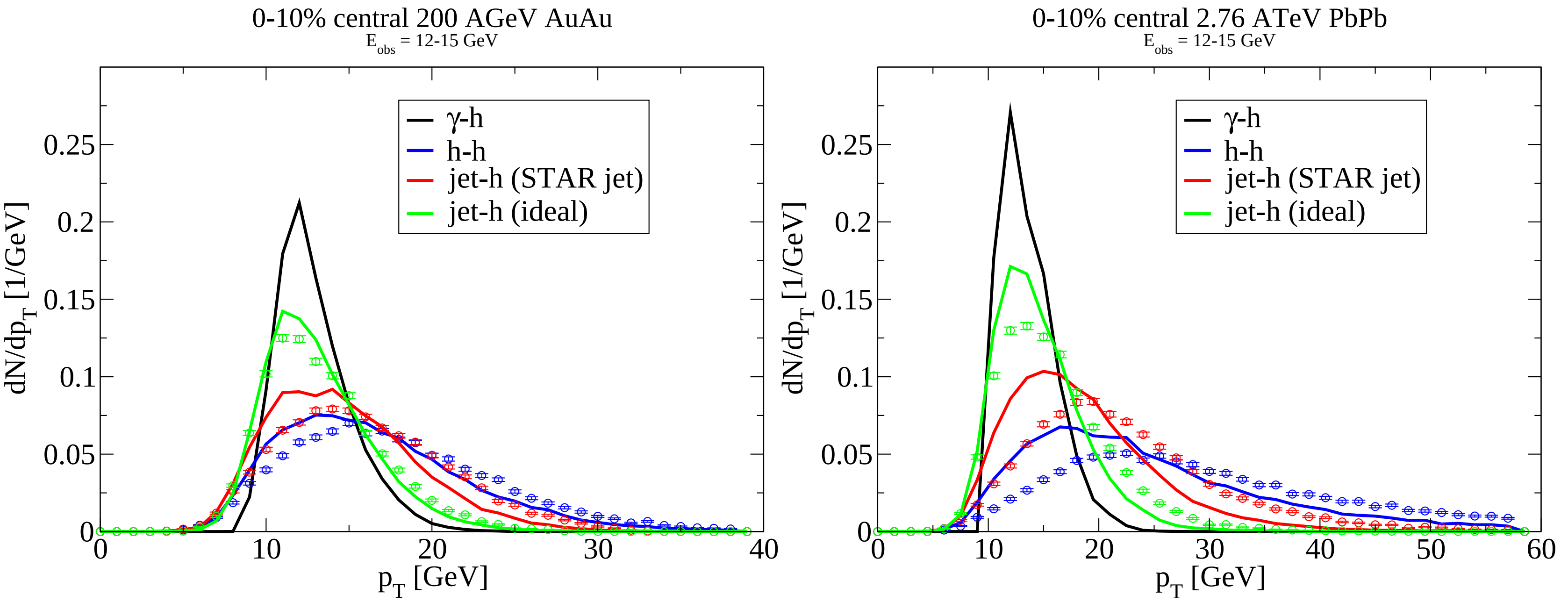
LHC:



- harder spectrum unbiases geometry

A comparison of I_{AA}

- distribution of away side parton p_T ($\approx$ scale of back-to-back event)



- different trigger objects imply rather different kinematics for same trigger P_T
- also different response to medium

$\rightarrow$ misleading to compare I_{AA} for same trigger kinematics

$\rightarrow$ only for same parton type and kinematics a comparison becomes useful

A comparison of I_{AA}

RHIC

trigger	f^{vac}_{glue} near	f^{vac}_{glue} away	f^{med}_{glue} near	f^{med}_{glue} away
γ-h	N/A	0.03	N/A	0.03
h-h	0.04	0.69	0.04	0.69
jet-h	0.12	0.68	0.08	0.69
ijet-h	0.44	0.55	0.33	0.61

LHC

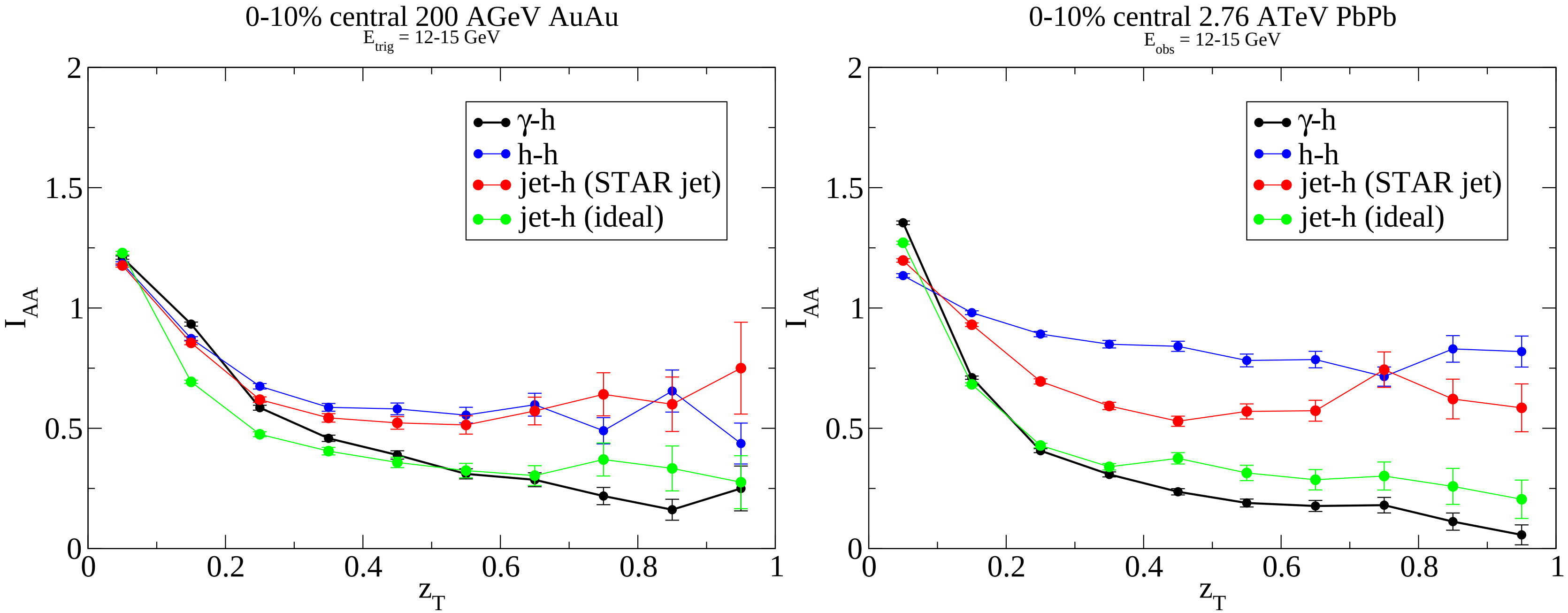
trigger	f^{vac}_{glue} near	f^{vac}_{glue} away	f^{med}_{glue} near	f^{med}_{glue} away
γ-h	N/A	0.04	N/A	0.04
h-h	0.33	0.79	0.32	0.78
jet-h	0.47	0.79	0.38	0.80
ijet-h	0.77	0.78	0.69	0.78

- moderately different parton type distribution, especially on near side

$\longrightarrow$ γ-h is really quite different in having quarks on the away side

$\longrightarrow$ also needs to be considered before comparison

A comparison of I_{AA}



• at RHIC, results fairly similar — mere coincidence, completely different physics!

• at LHC, better separation, kinematic bias is seen to be very important
$\longrightarrow$ pushed I_{AA} strongly up for h-h

• if one can resist simplistic interpretation, there is lots of variation in

- geometry
- parton type
- kinematics

that is probed here

An observation

By changing e.g. the jet definition for the trigger, one can vary

- geometry probed in the reaction
- kinematics accessed
- involed pQCD subchannel and parton type

One can move the trigger momentum such that mean kinematics is the same
$\Rightarrow$ get to selectively vary geometry and parton type

The main kinematic and parton type bias structure is given by vacuum QCD
$\Rightarrow$ this doesn't even have a large model dependence

> If I were an experimentalist, I would use biases to my advantage to design measurements to specifically scan through geometry or parton type variations. This looks terribly useful to me, much more useful than measurements with a small bias, because they never probe specific situations.

(But I'm a theorist of course. . .)

Long. momentum distribution of jet particles

Case study II: the longitudinal distribution of hadrons in a 100-110 GeV range (this is what CMS refers to as 'fragmentation function')

- not real FF because in FF $z = E_{had}/E_{part}$ whereas here $z = E_{had}/E_{jet}$ with $E_{jet} < E_{part}$

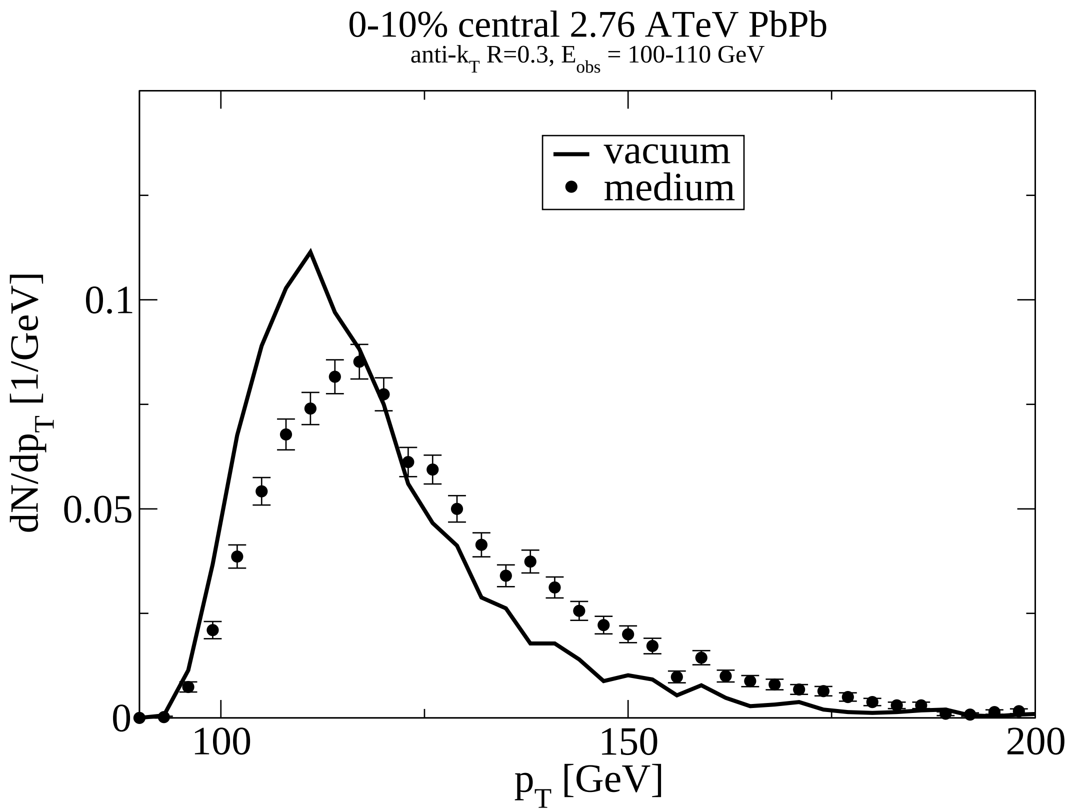
- 'trigger' analysis by finding $E_{jet} = 100 - 110$ GeV clustered with ant-k_T $R = 0.3$, $P_T > 1$ Ge, no PID cut
  (the requirement that you found a jet is equivalent to a trigger condition)

→ trigger is from the same shower which is later analyzed — **shower bias!**

- LHC kinematics - 2.76 ATeV 0-10% central PbPb collisions or p-p collisions

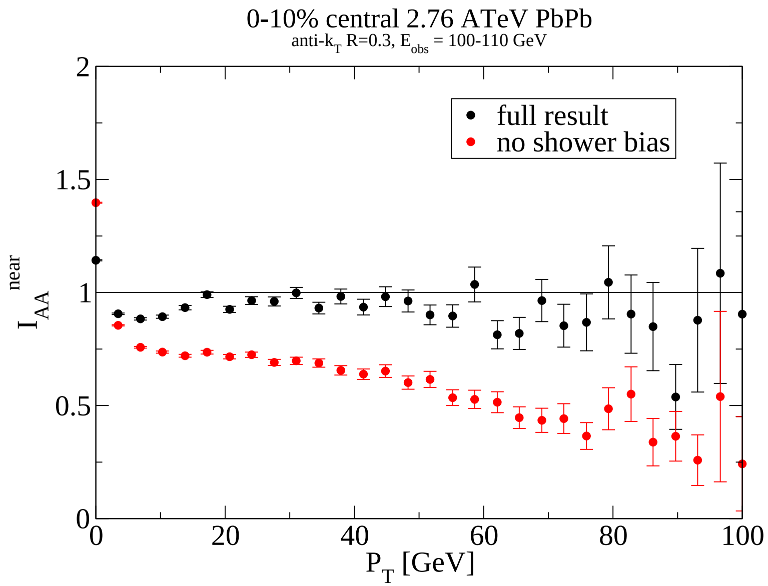
- not significantly geometry-biased

Long. momentum distribution of jet particles



- probes wide range of parton energies despite narrow trigger energy range
- significant number of showers carry 2/3 of energy inside $R = 0.3$
$\longrightarrow$ shower bias important
- $f^{vac}_{glue} = 0.44$, $f^{med}_{glue} = 0.36$ — moderate gluon filtering

Long. momentum distribution of jet particles



- without shower bias: strong depletion at high z, enhancement below 3 GeV (taking real kinematics, geometry and parton type bias into account)

- with shower bias, completely different picture:
  - enhancement below 3 GeV
  - depletion between 3 and 20 GeV
  - compatible with unmodified above 20 GeV

- shower bias reduced depletion, f_{glue}^{med} at high z dies out, I_{AA} grows

$\longrightarrow$ essentially compensates depletion due to medium modification

$\Rightarrow$ the 'mystery' has an easy solution

Dihadron triggered correlations

Case study III: away side I_{AA} in dihadron triggered correlations

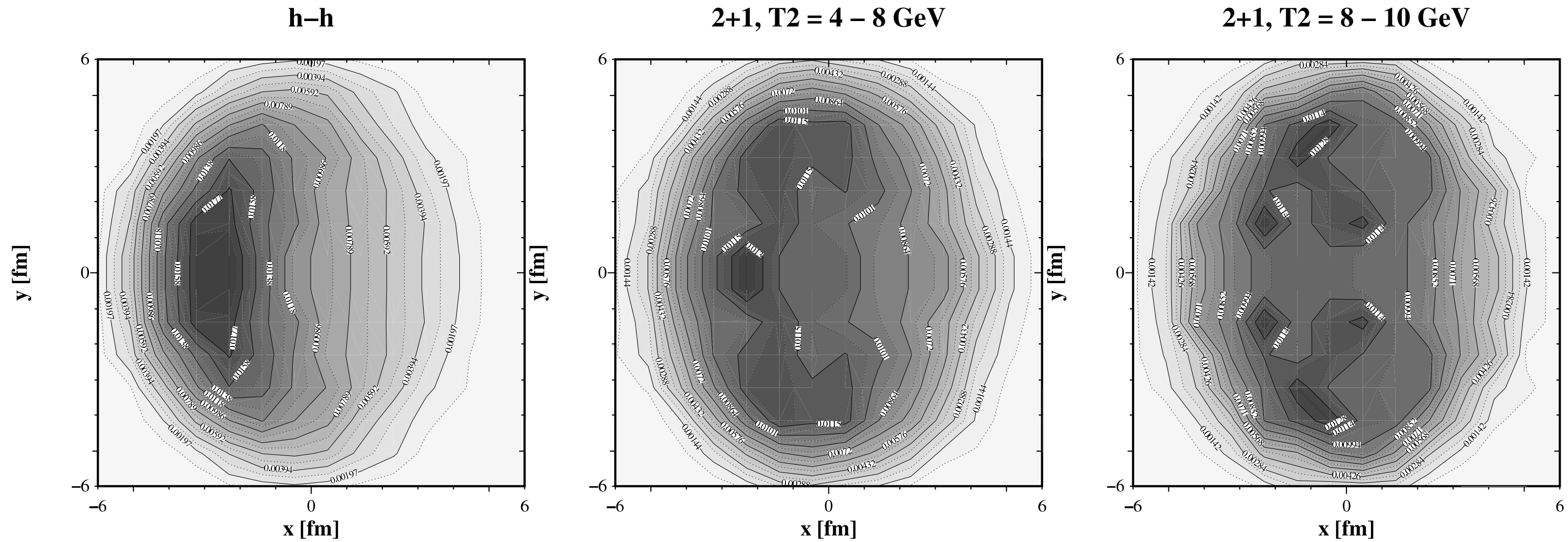
- coincidence of 12 GeV $<$ T1 $<$ 15 GeV on the near side and T2 on the away side
$\rightarrow$ shower bias!

- analysis on hadrons after triggers have been removed

- RHIC kinematics — strong geometry bias expected

- hard coincidences are rare events, statistics is pretty lousy, events are highly biased

Dihadron triggered correlations



- as the range of T2 increases, tangential bias develops

$\longrightarrow$ partons from the medium center are disfavoured

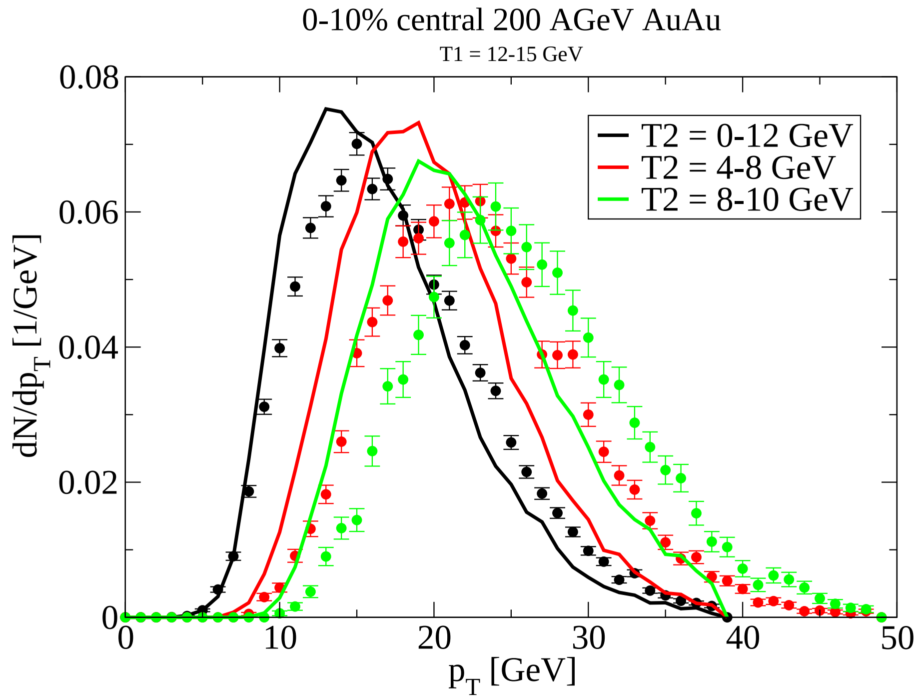
- using variations of jet definitions, almost any region can be selectively probed

$\longrightarrow$ design measurement to be sensitive to certain regions

- this gets blurred for harder parton spectrum

$\longrightarrow$ a genuine strength of RHIC measurements

Dihadron triggered correlations

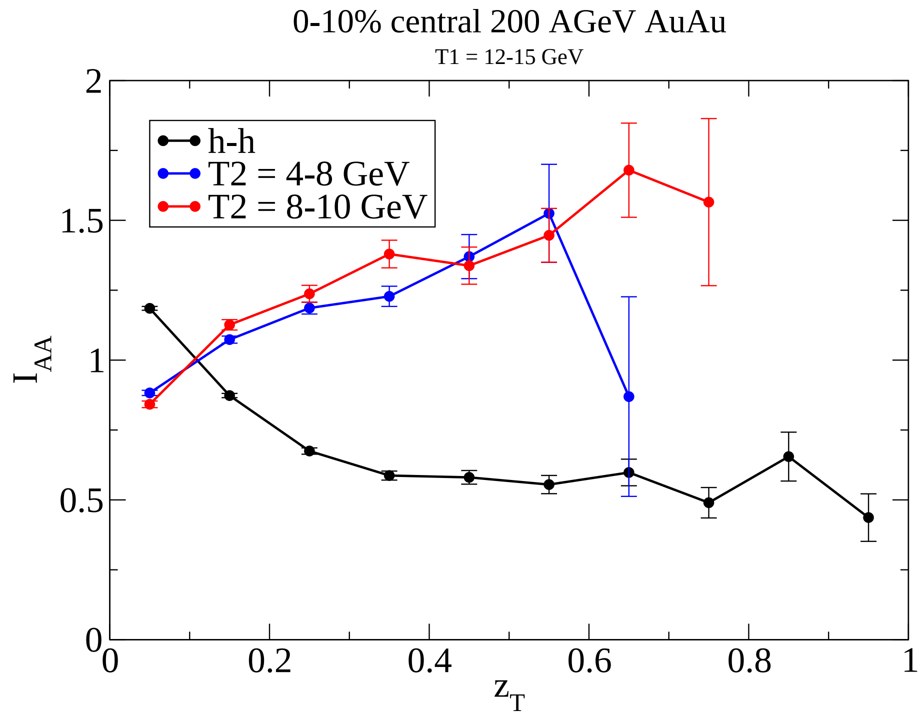


- increasing T2 corresponds to a significant shift in parton kinematics

trigger	f_{glue}^{vac} near	f_{glue}^{vac} away	f_{glue}^{med} near	f_{glue}^{med} away
h-h	0.04	0.69	0.04	0.69
T2 $=$ 4-8 GeV	0.071	0.49	0.07	0.38
T2 $=$ 8-10 GeV	0.10	0.29	0.05	0.20

- increasing T2 kills away side gluon jet contribution

Dihadron triggered correlations



- I_{AA} looks completely unfamiliar and shows now enhancement
$\longrightarrow$ highly unusual events, completely different kinematics and parton types
- also shower bias is active (but smoothed over)

Summary

Biases are

- very generic
  - whenever model broadens and softens in-medium showers
  - whenever quark and gluon interactions strength is different
  - whenever modifiaction increases with medium length and density
- almost everywhere — any triggered measurement is biased
- correlated with R_{AA} — the smaller R_{AA}, the stronger medium-induced biases
  - R_{AA}: measure of size of observed ('triggered') event class med/vac
  - bias $\sim$ size of all events over triggered event class
- extremely useful
  - think designing a measurements to specifically vary just one parameter

Summary

Sun Tzu says:

> *”It is said that if you know your enemies and know yourself, you will not be imperiled in a hundred battles; if you do not know your enemies but do know yourself, you will win one and lose one; if you do not know your enemies nor yourself, you will be imperiled in every single battle.”*

I say:

> *”If you understand parton medium interaction and the involved biases, everything will become clear. If you understand parton-medium interaction but not the biases, some observables will make sense, others will appear as puzzles; but if you have neither an understanding of biases nor a good model of parton-medium interaction, you can not know the implication of any hard probe.”*