LHC JET PHYSICS

in the context of RHIC data

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INTRODUCTION
RHIC CONSTRAINTS FOR ENERGY LOSS
RHIC ERA EXPECTATIONS
- longitudinal momentum distribution of jets
- transverse momentum distribution of jets
LHC JET OBSERVABLES
CONCLUSIONS

PROPERTIES OF ENERGY LOSS

I. What did we know about energy loss?

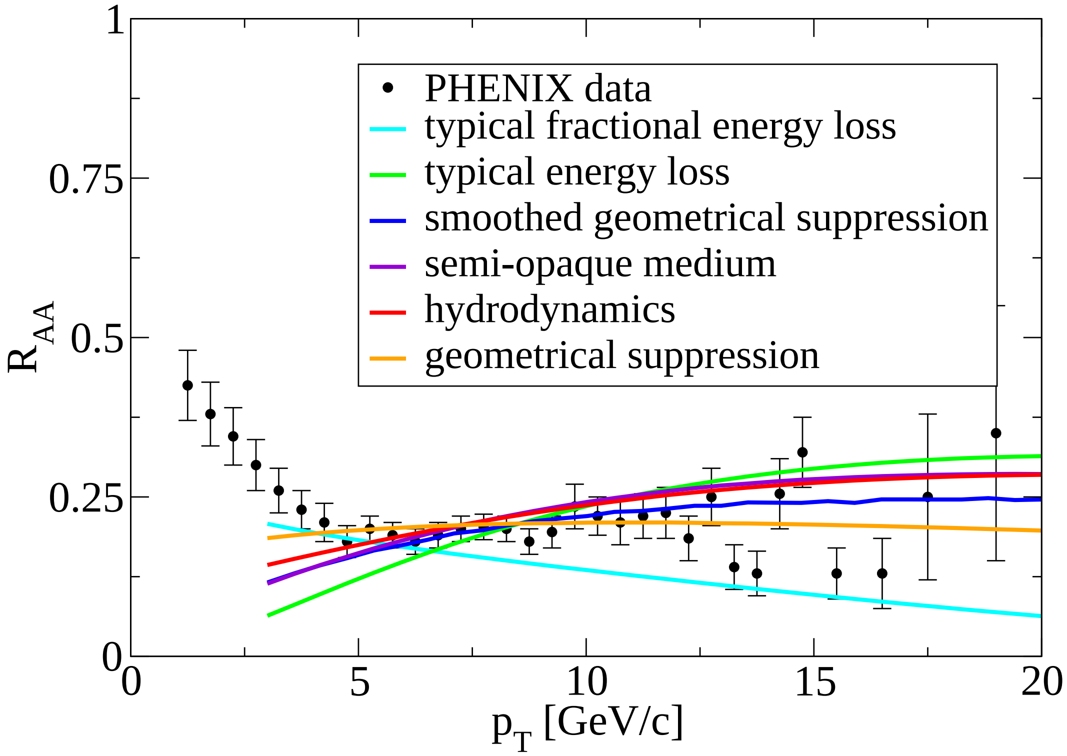
RHIC results

ENERGY LOSS IS NOT FRACTIONAL

- 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

T. R., Phys. Rev. C **74** (2006) 034906



- 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

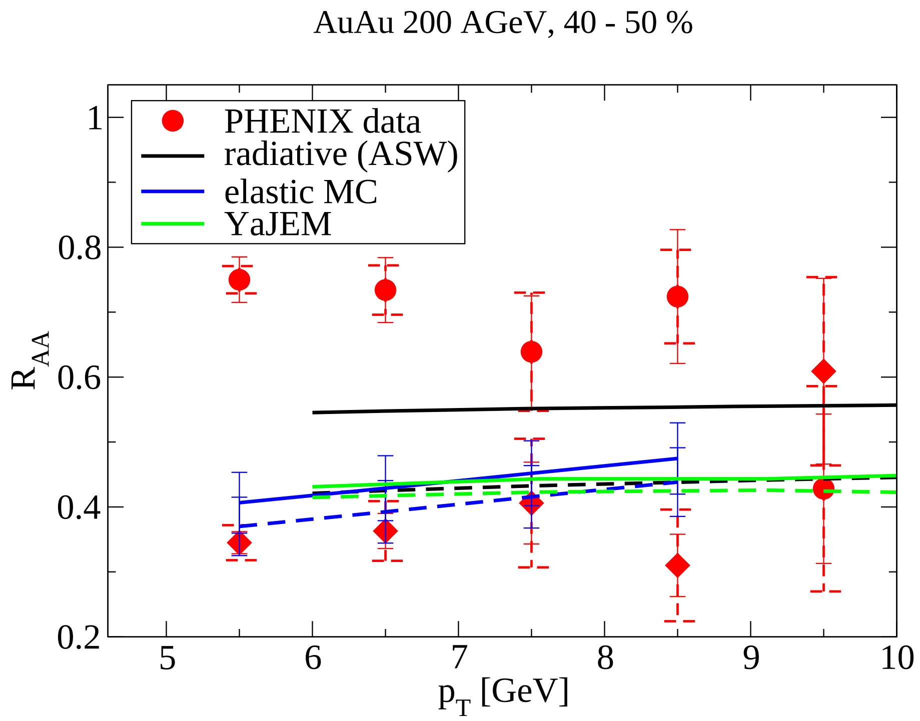
→ power law is a very bad approximation

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

T. R., Phys. Rev. C **76** (2007) 064905; J. Auvinen, K. J. Eskola, H. Holopainen and T. R., Phys. Rev. C **82** (2010) 051901



- systematic uncertainty on S^{in}_{out} due to choice of hydro: factor two (!)

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

- side note: $R_{AA}(\phi)$ works fine as long as transverse hydro expansion is neglected

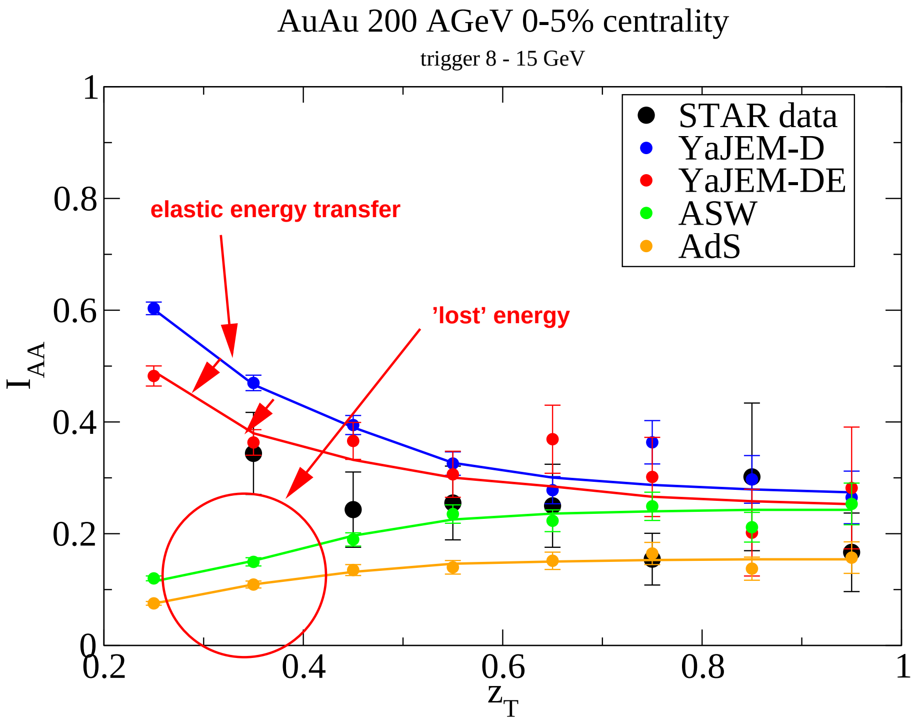
$\rightarrow$ Bjorken cylinder is a very bad approximation

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

T. R. and K. J. Eskola, Phys. Rev. C **84** (2011) 054913, T. R., Phys. Rev. C **84** (2011) 067902



- medium-induced radiation is experimentally observed

→ constrains elastic contribution from below to $\sim 10\%$

CONSTRAINTS SUMMARY

- summary analysis (T. R., Phys. Rev. C **85** (2012) 044903)

→ 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!

	$R_{AA}^{RHIC}(\phi)$	$R_{AA}^{LHC}(P_T)$	I_{AA}^{RHIC}	I_{AA}^{LHC}	A_J^{LHC}	$A_J^{LHC}(E)$
elastic	**fails!**	?	**fails!**	?	?	?
ASW	works	?	marginal	?	N/A	N/A
AdS	works	?	marginal	?	N/A	N/A
YaJEM	fails	?	fails	?	?	?
YaJEM-D	works	?	marginal	?	?	?
YaJEM-DE	works	?	works	?	?	?

II. What did we expect to see at LHC?

pre- and some postdictions

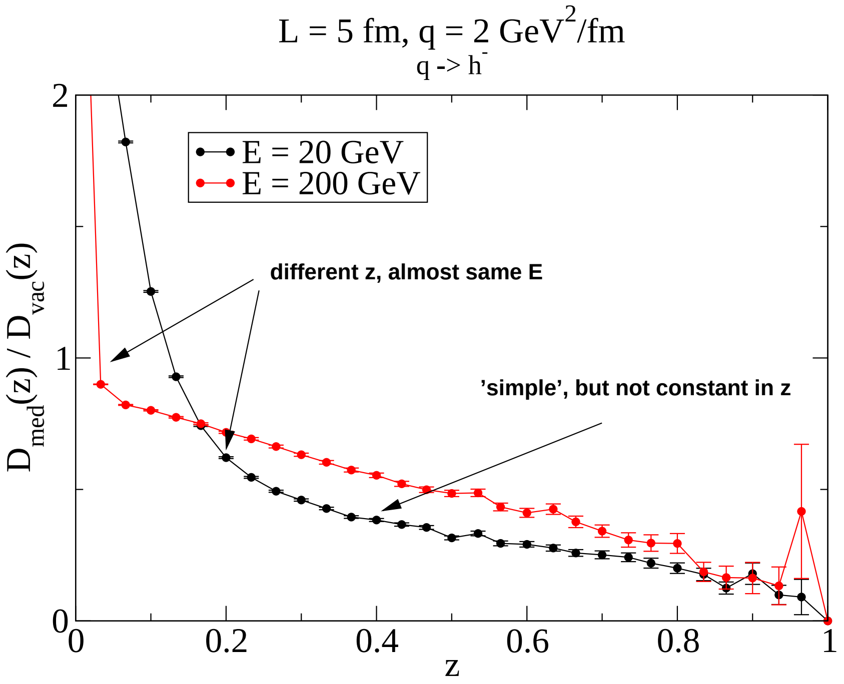
LONGITUDINAL SHOWER STRUCTURE

- in vacuum shower

→ splitting kernels $P_{i\to jk}(z)$ with $z = E_{daughter}/E_{parent}$ are **scale-invariant**
→ fragmentation functions $D(z)$ are self-similar, do not strongly depend on energy
→ logarithmic corrections due to the running of α_s

- if $\Delta E \sim E$, then this could be cast into $P'_{i\to jk}(z)$ and would yield $D'(z)$ as MMFF

→ we know that is not true
→ instead, the MMFF is changed at a fixed energy ∼ few T, not at any fixed z

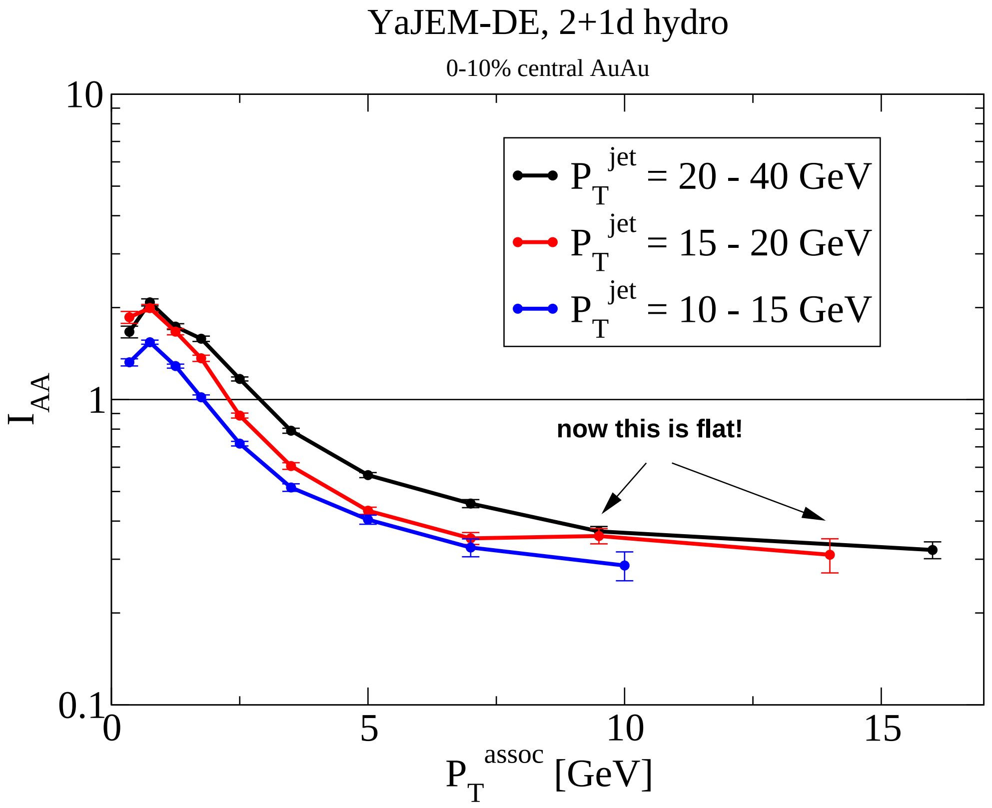


T. R.,Phys. Rev. C **81** (2010) 014906

LONGITUDINAL SHOWER STRUCTURE

- a real experiment has trigger bias (jet finding bias)

→ for instance jet-h correlations by STAR



- 'unmodified', rate suppressed 'FF' above 2-3 GeV, modifications below

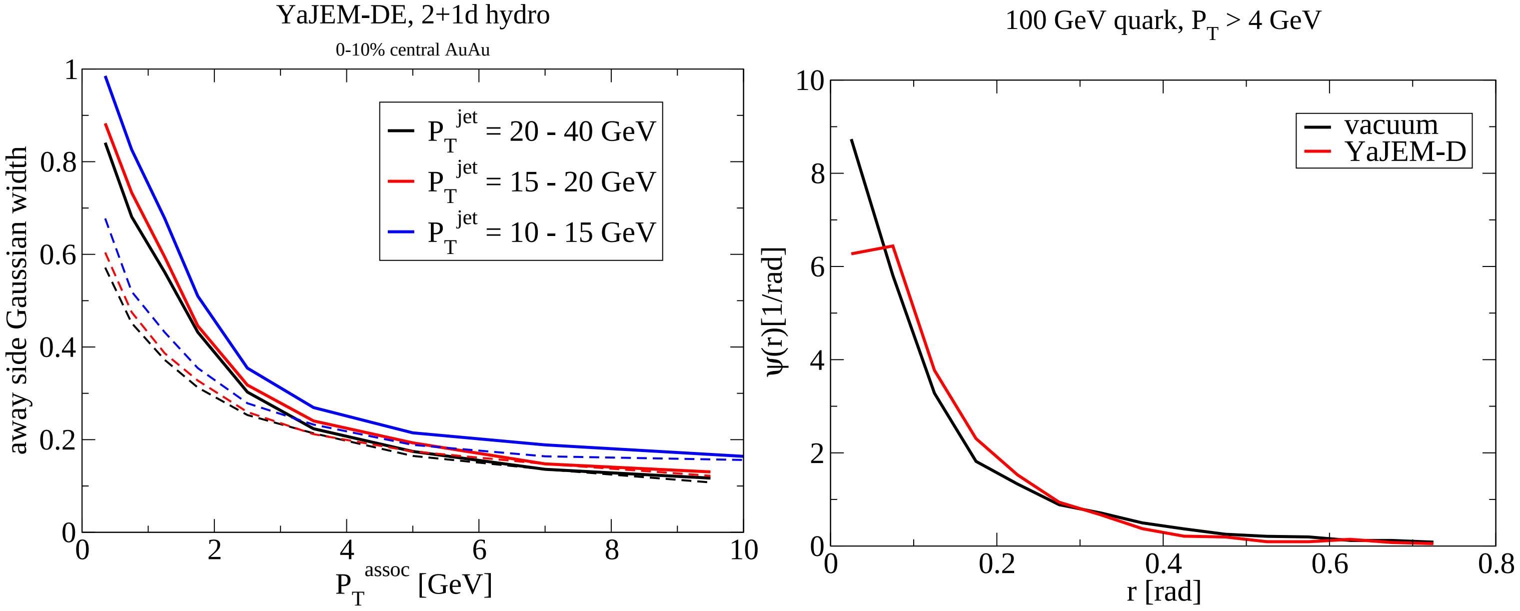
→ jets become different at the thermal scale

How does that work for transverse structure?

TRANSVERSE SHOWER 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!

T. R., Phys. Rev. **C80** (2009) 044904.

PHYSICS PICTURE

$\longrightarrow$ medium alters hard parton kinematics slightly
$\longrightarrow$ medium-induced soft gluon emission
$\longrightarrow$ medium alters soft gluon kinematics a lot, soft gluon thermalizes

- energy flow to large angles $R \gg 0.6$, hydro degrees of freedom relevant

$\longrightarrow$ not picked up by jet finders, mechanism of jet suppression

- 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' J. Casalderrey-Solana *et al.*, J. Phys. G G **38** (2011) 035006

$\longrightarrow$ not novel, observed already in 2009, requires explicit kinematics in models

T. R., Phys. Rev. C **80** (2009) 044904.

Universal mechanism: gluons with $p_T \sim T$ are effectively out of cone

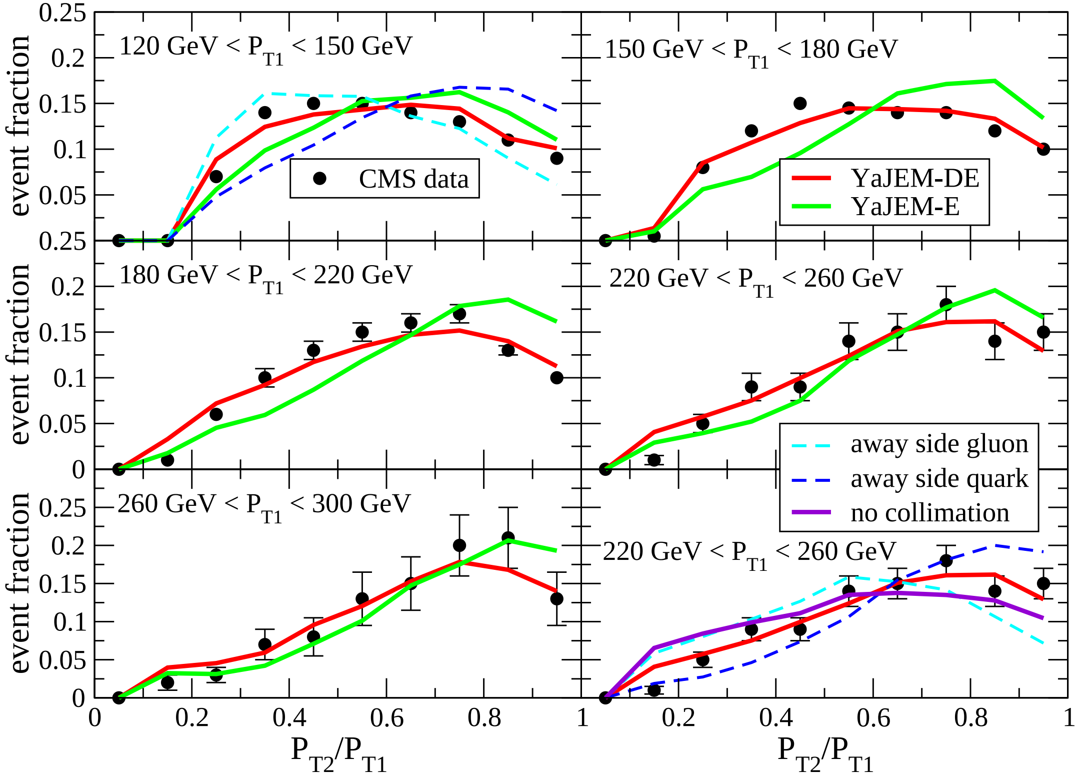
III. Does this work for jet observables?

comparison with LHC jet data

LHC JETS

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

0-20% 2.76 ATeV PbPb

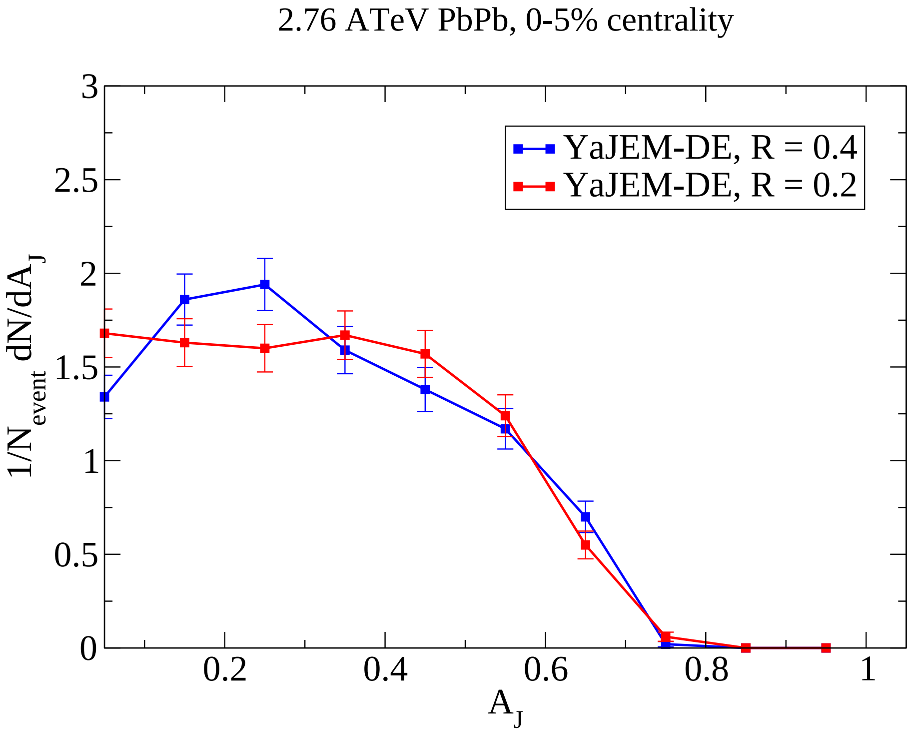


⇒ yes, this works just fine over the whole energy range

- 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



- also matches with ATLAS $R_{CP}^{jets} \approx 0.5$ in the 120+ momentum region
- has 'unmodified' fragmentation pattern above ~ 3 GeV
- more comparison underway

CONSTRAINTS SUMMARY

- 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'

	$R_{AA}^{RHIC}(\phi)$	$R_{AA}^{LHC}(P_T)$	I_{AA}^{RHIC}	I_{AA}^{LHC}	A_J^{LHC}	$A_J^{LHC}(E)$
elastic	**fails!**	works	**fails!**	fails	works	fails
ASW	works	fails	marginal	works	N/A	N/A
AdS	works	**fails!**	marginal	works	N/A	N/A
YaJEM	fails	fails	fails	fails	works	works
YaJEM-D	works	works	marginal	marginal	works	works
YaJEM-DE	works	works	works	works	works	works

- 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, $\sim 10\%$ 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 ϵ_3 event plane?