CHARGED HADRON R_{AA}

as a function of p_T at the LHC

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INTRODUCTION

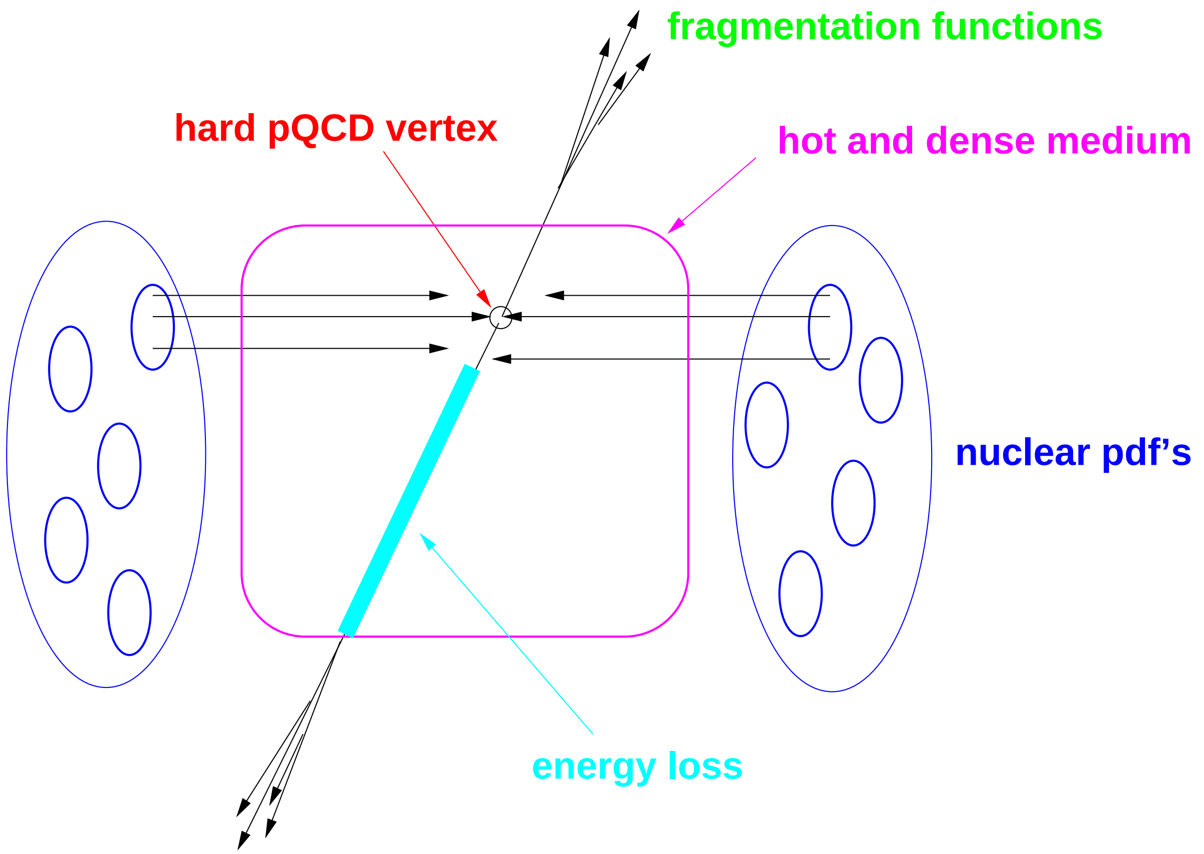
Basic ingredients for R_{AA}

THE MODEL

- soft medium
- hard parton energy loss probability density

RESULTS

Basic Ingredients



$$d\sigma_{med}^{AA\to\pi+X} = \sum_f d\sigma_{vac}^{AA\to f+X} \otimes \langle P_f(\Delta E, E)\rangle_{T_{AA}} \otimes D_{f\to\pi}^{vac}(z,\mu_F^2)$$

$$d\sigma_{vac}^{AA\to f+X} = \sum_{ijk} f_{i/A}(x_1,Q^2) \otimes f_{j/A}(x_2,Q^2) \otimes \hat{\sigma}_{ij\to f+k}$$

Basic Ingredients

New ingredients beyond pQCD from p-p to A-A collisions:

- $f_{i/N}(x_1, Q^2) \to f_{i/A}(x_1, Q^2)$ (can be studied in p-A collisions)
- vertex-averaged energy loss probability $\langle P_f(\Delta E, E)\rangle_{T_{AA}}$

$\Rightarrow$ medium-modified hard processes $\Leftrightarrow$ access to averages of energy-loss probabilities

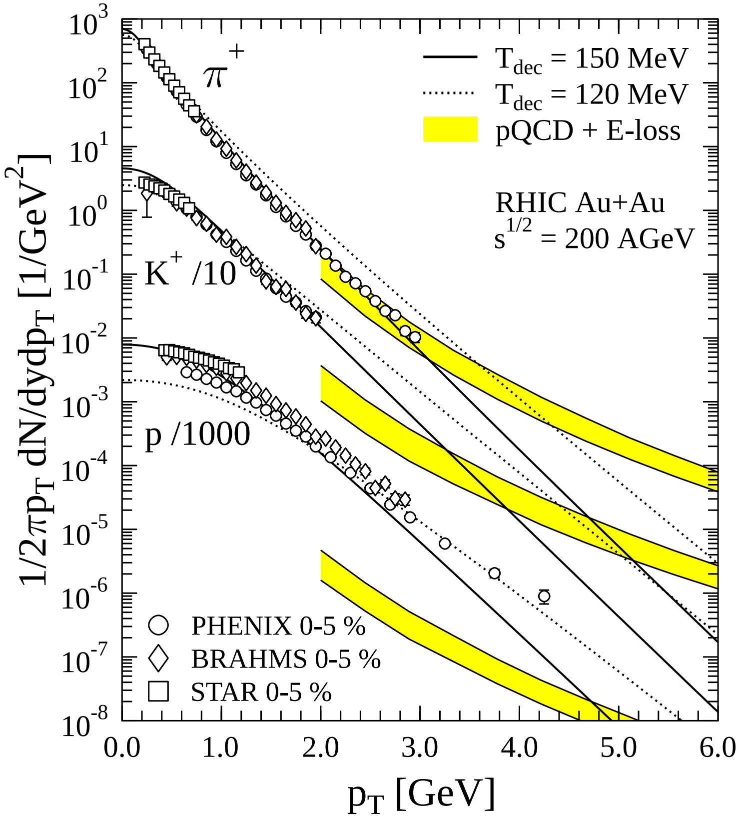
$\langle P(\Delta E, E)\rangle$ depends on:
(1) interaction of medium and hard parton
(2) spacetime distribution of medium density relative to hard vertices

Thus, we need:

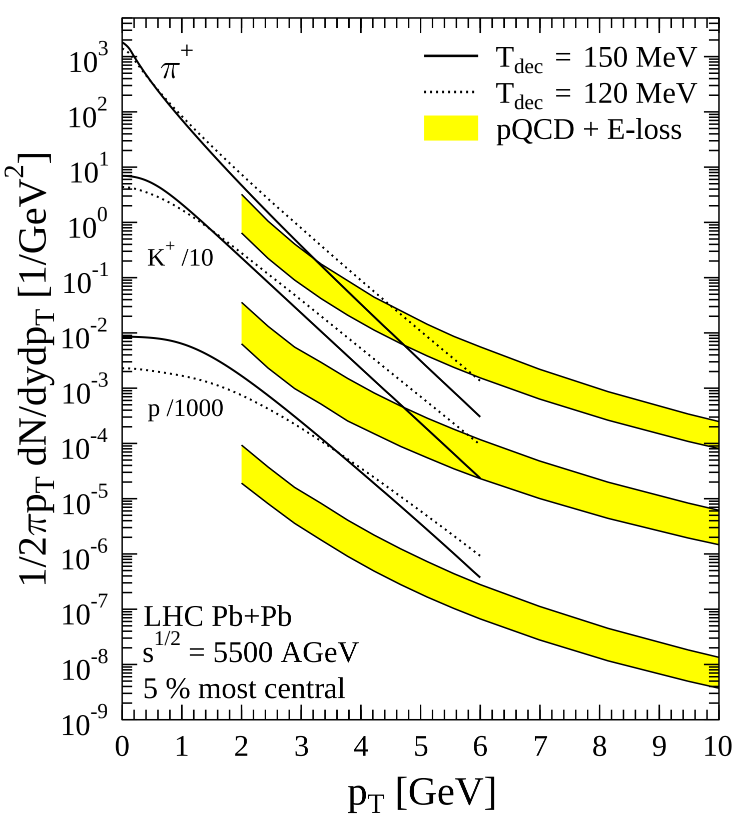
- medium model with predictive power
- energy loss model calibrated on RHIC data
- pQCD calculation of hard parton production at LHC

The medium model

RHIC



LHC



EKRT initial state saturation + 2+1D hydrodynamics, tested at RHIC

$\longrightarrow$ talks by K. Eskola and H. Niemi

DEFINING $\langle P(\Delta E, E)\rangle_{T_{AA}}$

Hard vertices for impact parameter **b** have a probability distribution given by

$$P(x_0, y_0) = \frac{T_A(\mathbf{r_0} + \mathbf{b/2})T_A(\mathbf{r_0} - \mathbf{b/2})}{T_{AA}(\mathbf{b})},$$

where $T_A(\mathbf{r}) = \int dz \rho_A(\mathbf{r}, z)$.

If the probability of energy loss along a given path (determined by medium, vertex $\mathbf{r_0} = (x_0, y_0)$, rapidity y and transverse angle ϕ is $P(\Delta E, E)_{path}$ we can define:

$$\langle P(\Delta E, E)\rangle_{T_{AA}} = \frac{1}{2\pi}\int_0^{2\pi} d\phi \int_{-\infty}^{\infty} dx_0 \int_{-\infty}^{\infty} dy_0 P(x_0, y_0) P(\Delta E, E)_{path}.$$

The medium information is now in details of $P(\Delta E, E)_{path}$. For R_{AA}, this is averaged over the overlap geometry.

DEFINING $\langle P(\Delta E, E)\rangle_{path}$

Transport coefficient $\hat{q} = K \cdot 2 \cdot \epsilon^{3/4}(\cosh\rho - \sinh\rho\cos\alpha)$

K is, for given assumptions about the medium, adjusted to R_{AA} in central Au-Au collisions at RHIC

$$\omega_c(\mathbf{r_0}, \phi) = \int_0^\infty d\xi \xi \hat{q}(\xi) \quad \text{and} \quad \langle \hat{q} L\rangle(\mathbf{r_0}, \phi) = \int_0^\infty d\xi \hat{q}(\xi)$$

as input for 'quenching weights' $P(\Delta E, E)_{path}$.

ω_c sets the scale of energy loss. In constant medium: L^2 pathlength dependence.

In general

$$\langle P(\Delta E)\rangle = T\delta(\Delta E) + S \cdot P(\Delta E) + A \cdot \delta(\Delta E - E)$$

- T: 'transmission', no energy loss
- S: 'shift', parton emerges after finite energy loss, 'sideward shift' of spectrum
- A: 'absorption', parton thermalizes, 'downward shift' of spectrum

C. A. Salgado and U. A. Wiedemann, Phys. Rev. D **68** (2003) 014008.

Hydrodynamics vs. Black Core

Two scenarios:

• hydrodynamics: quenching in both hadronic and partonic phase, $K = 4.2$, $\hat{q}$ at 1 fm/c in medium center 11.7 GeV^2/fm

$\longrightarrow$ even distribution, weak surface bias

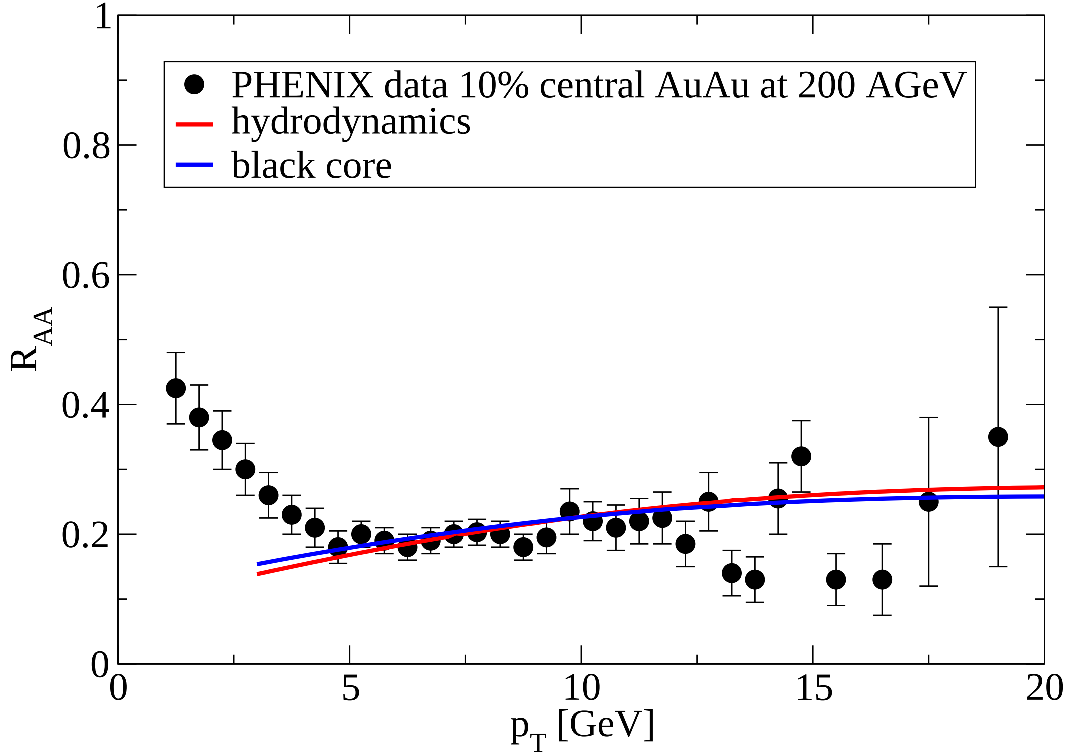
• hydrodynamics — black core: quenching only in partonic phase, $K = 17.3$, $\hat{q}$ at 1 fm/s in medium center 48.7 GeV^2/fm

$\Rightarrow$ impenetrable core, pronounced halo, strong surface bias

Test both at LHC with these values of K

FROM CROSSECTION TO NUCLEAR SUPPRESSION

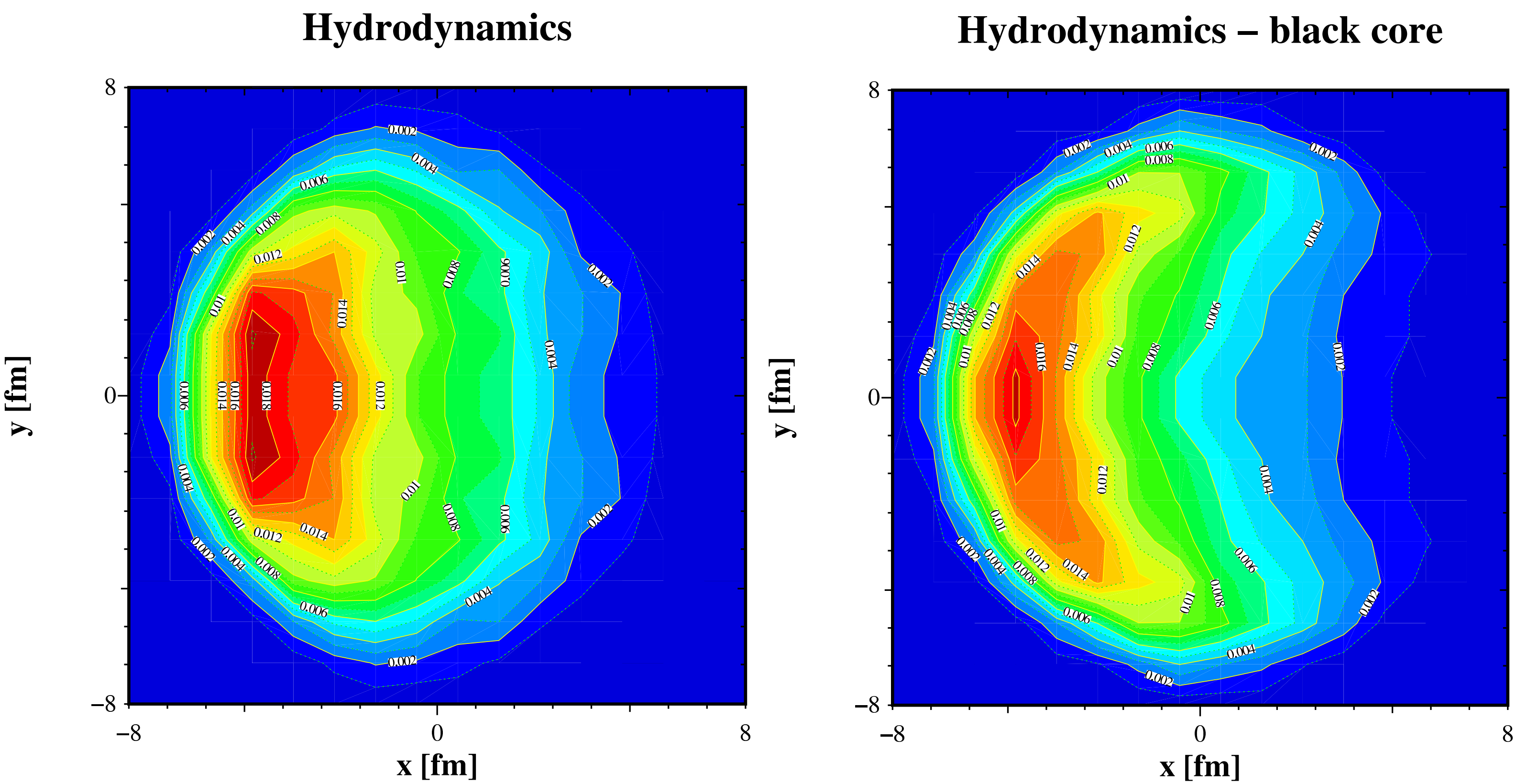
$$R_{AA}(p_T, y) = \frac{d^2N^{AA}/dp_T dy}{T_{AA}(0) d^2\sigma^{NN}/dp_T dy}$$



AT RHIC: Both scenarios cannot be distinguished using R_{AA}, hydrodynamics exhibits a little more rise with p_T

Hydrodynamics vs. Black Core

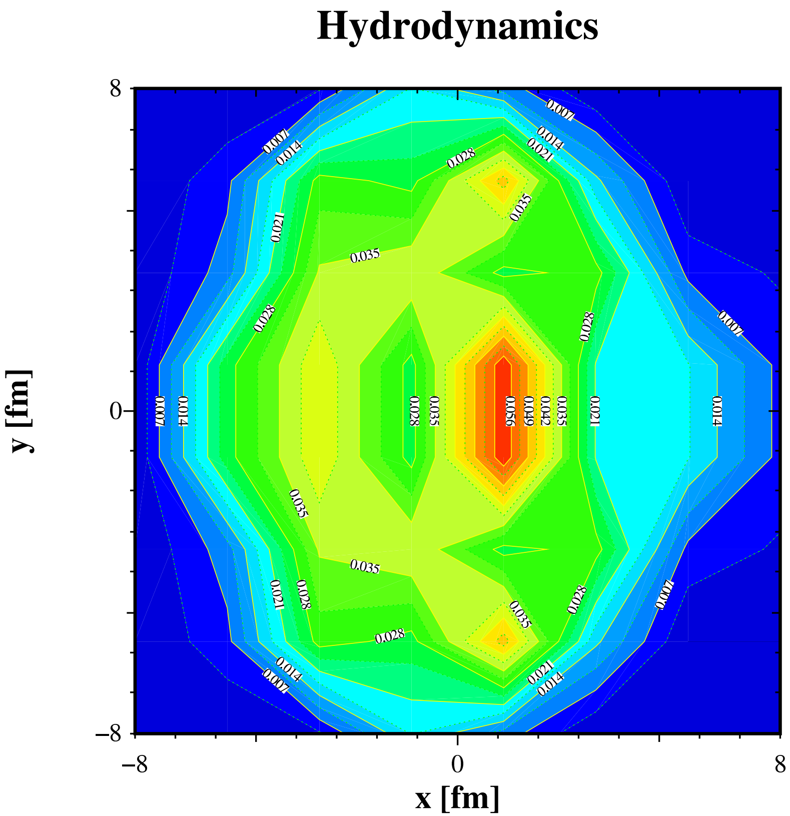
Spatial distribution of hard vertices contributing to 8 GeV hadrons

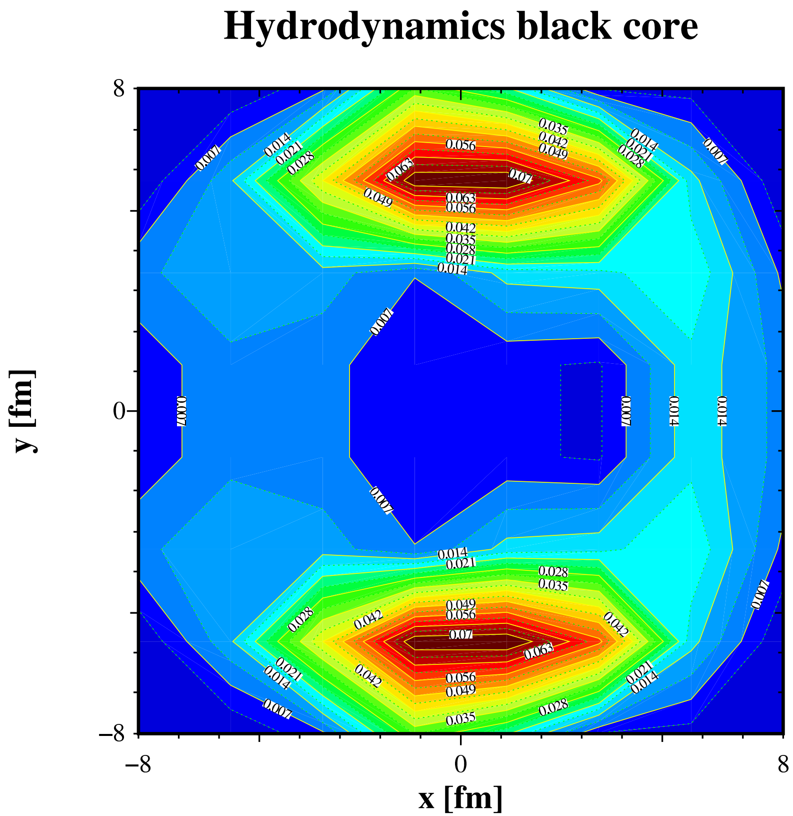


For single hadron distributions, the black core scenario shows strong surface bias

Hydrodynamics vs. Black Core

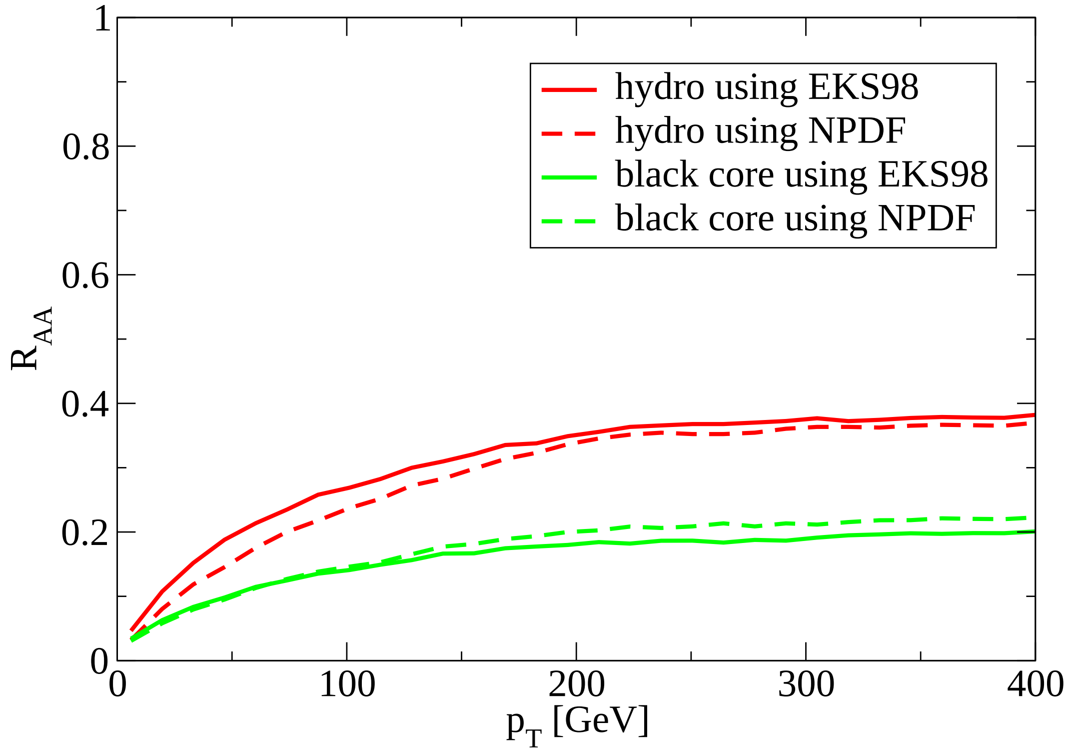
Spatial distribution of hard vertices contributing to 8 GeV hadrons back-to-back with 4 GeV hadrons





For dihadron distributions, the black core scenario shows tangential emission

Results for LHC



- rise of R_{AA} with p_T
- weak dependence on the use of a particular set of nuclear PDF
- clean separation between black core and hydrodynamics

Is there a simple way to understand this?

Appearance of the shift term

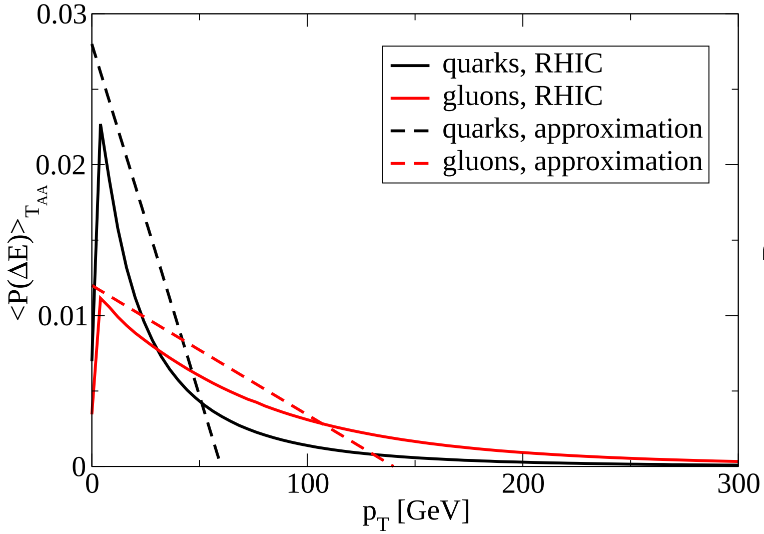
Simple model:

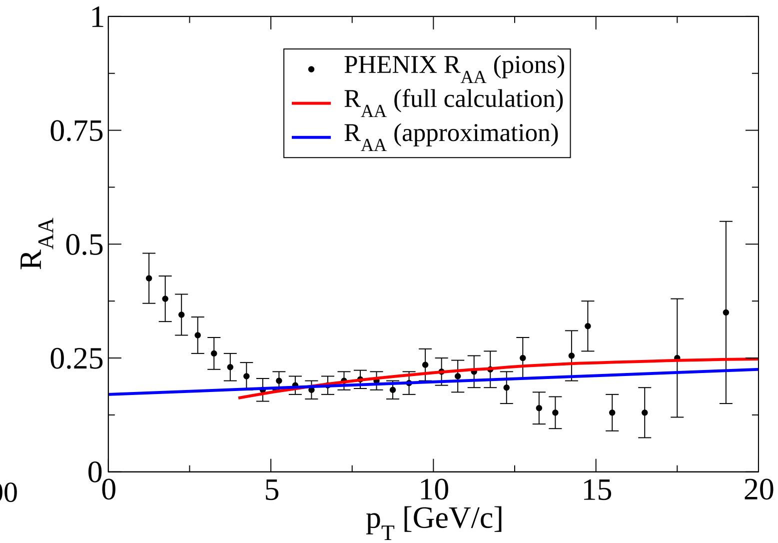
- assume a power-law spectrum $\sim 1/p_T^n$ ($n \approx 7, 8$ at RHIC and 4 at LHC)
- for massless partons, energy loss ΔE changes the spectrum to $1/(p_T + \Delta E)^n$, thus

$$R_{AA} \approx \int d\Delta E \langle P(\Delta E)\rangle_{T_{AA}} 1/(1 + \frac{\Delta E}{p_T})^n$$

- approximate expressions for shift term $P(\Delta E)$

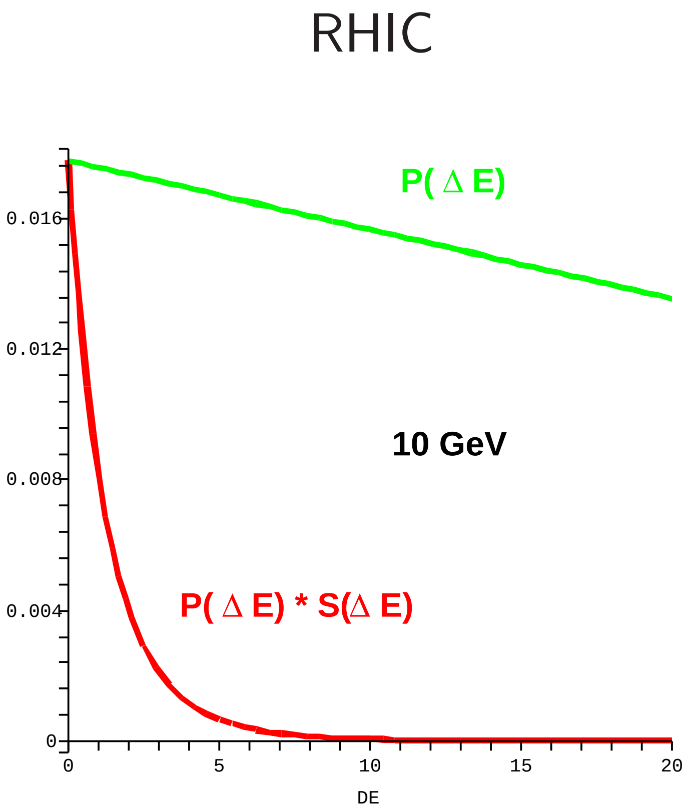
$\Rightarrow$ decent description of R_{AA}

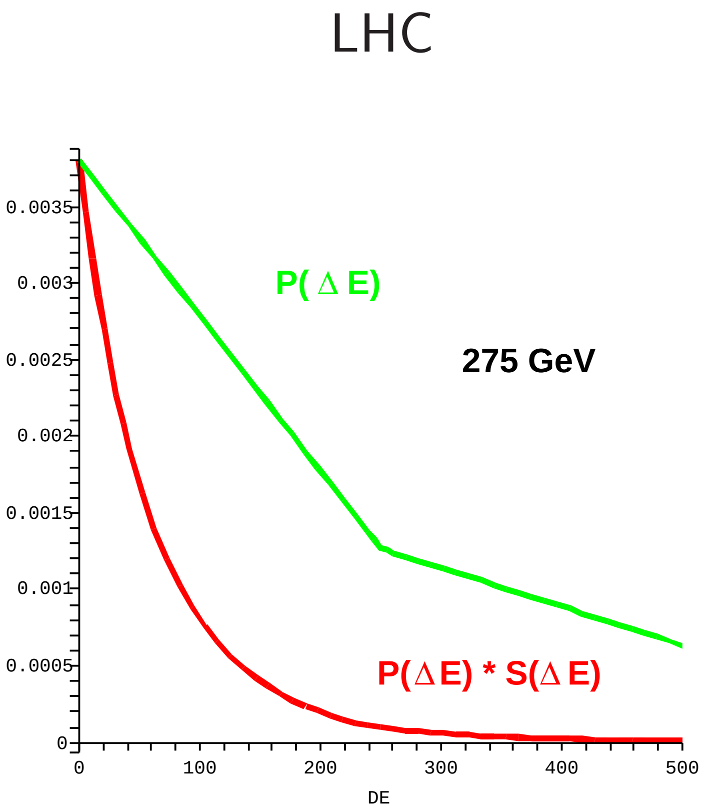




APPEARANCE OF THE SHIFT TERM

- suppression by $\Delta E \Leftrightarrow$ penalty factor $S(\Delta E) = 1/(1+\frac{\Delta E}{p_T})^n$
- at a scale p_T, we observe $\langle P(\Delta E)\rangle_{T_{AA}}$ through this filter





This is added to the transmission term — with higher p_T, more of the shift is 'seen'
$\Rightarrow$ fundamental reason for rise of R_{AA}

What can LHC do?

When going to higher energies

- the medium density grows like $\sim \log(\sqrt{s})$ (PHOBOS) or $\sim \sqrt{(s)}^{0.574}$ (EKRT)
- the kinematically accessible region grows like $\sim \sqrt{s}/2$

$\Rightarrow$ the kinematical window will always win out

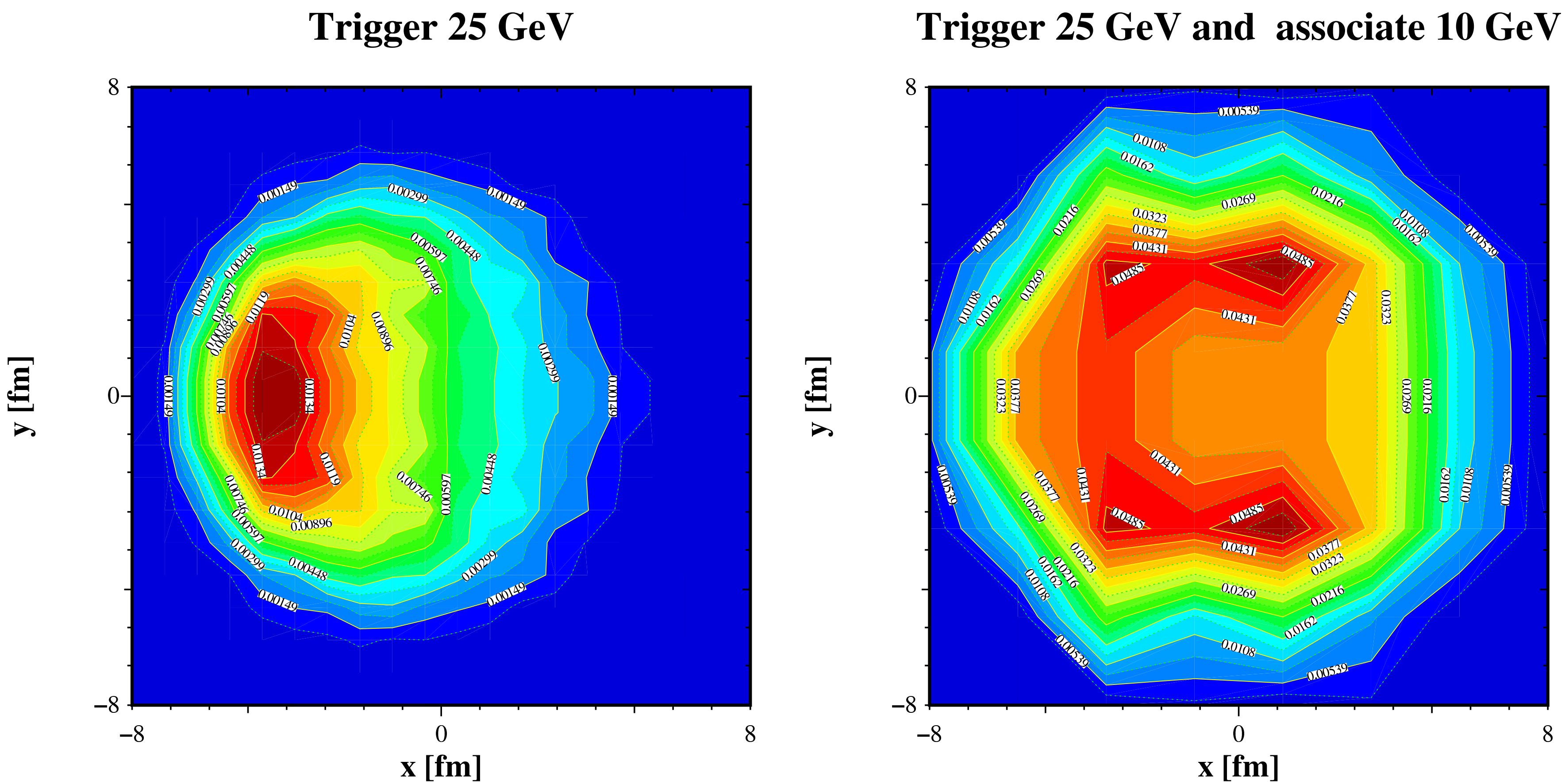
$\Rightarrow$ quite generic expectation for a rise of R_{AA} in the p_T range of LHC

since the reason for the rise is the shift term becoming more and more visible

Magnitude and shape of the rise will reflect the shape of the underlying energy loss probability distribution - needs high statistics and large p_T range

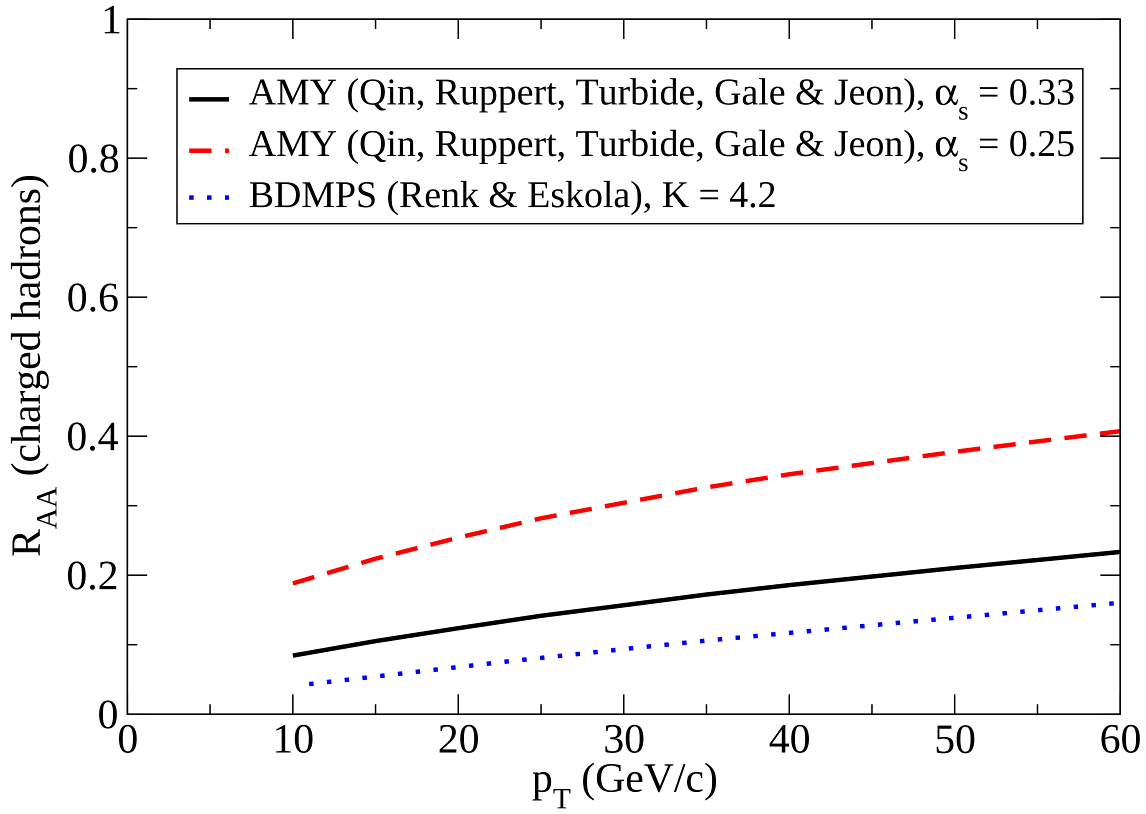
However: Only if energy loss is not strongly dependent on the initial parton energy!

Single hadron and dihadron suppression at LHC



Some degree of surface bias for lower p_T at LHC

IS THIS EXPECTATION UNIQUE?



Qualitatively similar expectation for rise from AMY formalism

...though differences in absolute numbers

Summary

Based on the RHIC experience:

- generic expectation of a rise of R_{AA} with p_T across a number of models
- weak uncertainty due to nPDF extrapolation
- strong dependence on assumptions about the medium

$\rightarrow$ good — finally R_{AA} can actually tell more about the medium!
$\rightarrow$ bad — no definite theory expectation

Disclaimer:

R_{AA} for reconstructed jets is different: In single hadron R_{AA} the momentum flow inside the shower is predominantly through one parton, i.e. it makes sense to calculate quenching for the leading parton. In an unbiased shower, this is not the case and momentum is shared across several partons — to know the energy loss of the leading parton is not enough to describe the situation adequately.