High-p_T suppression and surface effects in nucleus-nucleus collisions (within the Parton Quenching Model)

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based on work in collaboration with:
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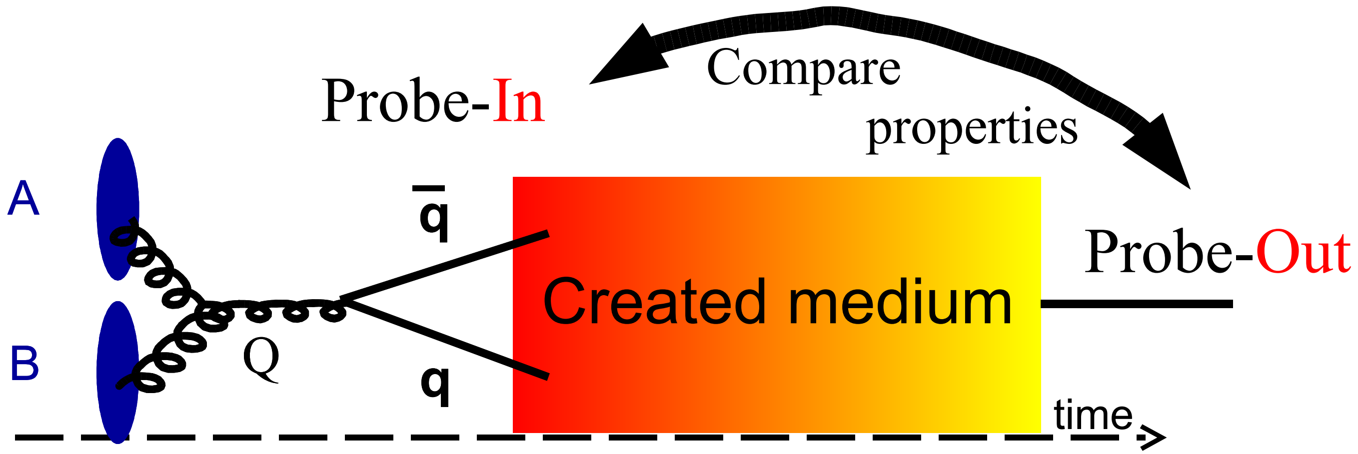
Outline

- High-pt suppression at RHIC
- Phenomenology of Parton Energy Loss
- Details of the Parton Quenching Model
  - BDMPS-Z-SW quenching weights
  - Glauber geometry
  - Parton-by-parton approach
- Confrontation with RHIC data
  - Analysis of trigger biases
- Opacity problem

Hard probes in nucleus-nucleus collisions



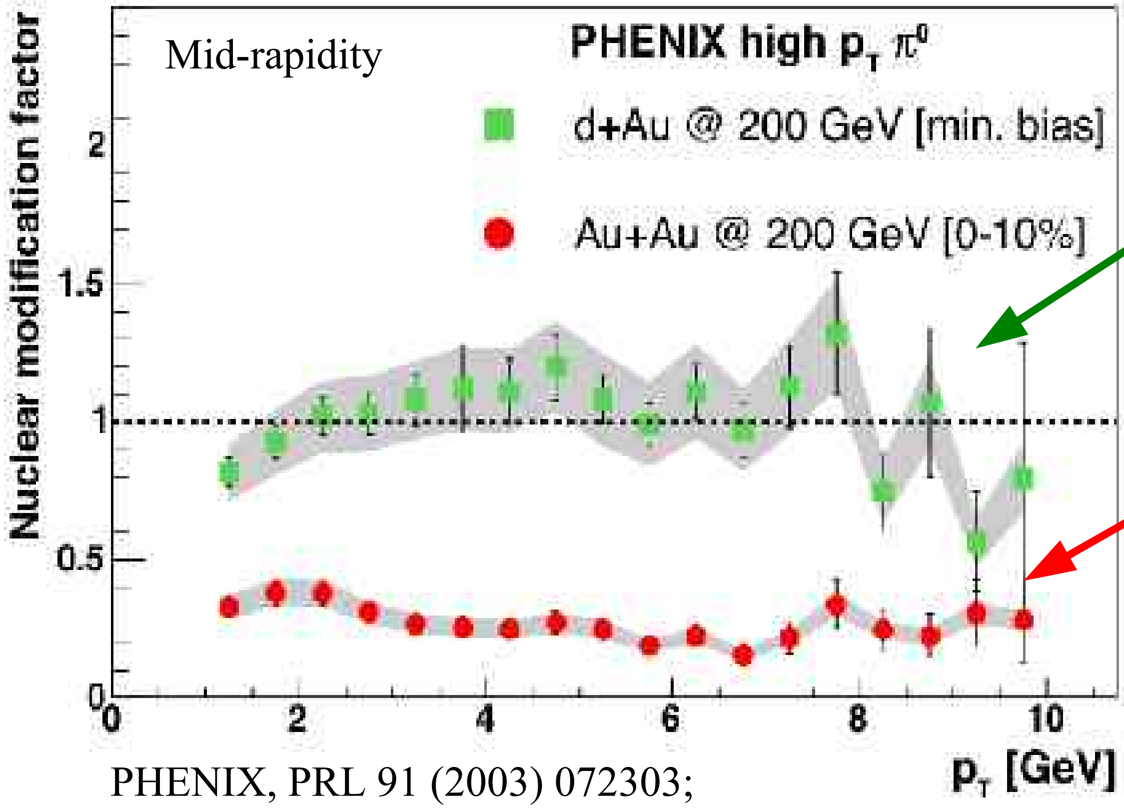
- Large virtuality Q leads to
  small "formation time" Δ t ~ 1/Q and small α_s
- Initial yields and p_T distributions in A+B are predicted by
  pp measurements + pQCD + collision geometry (Glauber)
  + additional "known" nuclear (initial state) effects (e.g. nPDFs)
- Observed deviations are attributed to the medium

Leading-particle suppression at RHIC

Comparison of p_T distributions at high p_T measured in pp, dAu and AA (for different centralities)

Quantification via the Nuclear Modification Factor

$$R_{AB}(,p_T,\eta)=\frac{1}{N_{coll}}\times\frac{dN_{AB}/dp_T}{dN_{pp}/dp_T}(p_T,\eta)$$



PHENIX, PRL 91 (2003) 072303;
STAR, PRL 91 (2003) 072304;
many more (see eg. RHIC white papers).

Control measurement in d+Au no suppression ($R_{dA}\approx 1$)

Central Au+Au collision up to factor 5 suppressed ($R_{AuAu} = 0.2$)

→ **Final-state effect**

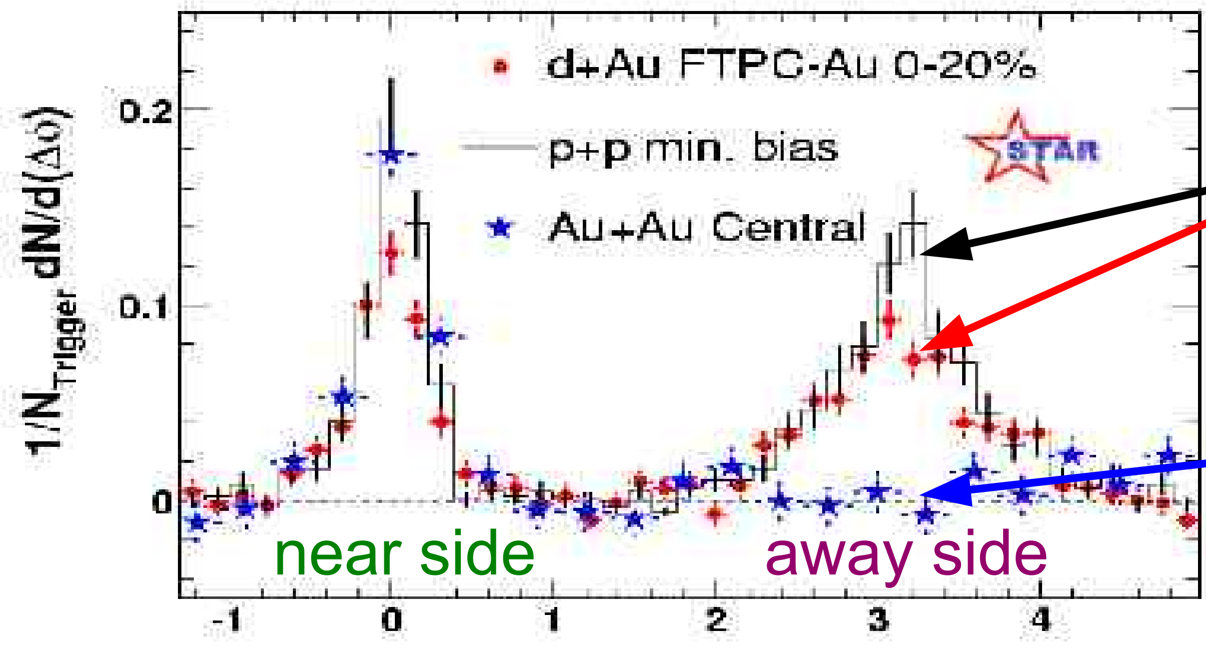
Suppression of away-side correlations at RHIC

Comparison of azimuthal distributions rel. to high p_T trigger particle measured in pp, dAu and AA (for different centralities)

- Trigger: highest p_T track with p_T>4 GeV
- Associated particles: 2 GeV < p_T < $p_T^{trigger}$

Away-side suppression quantified via

$$I_{AB}^{away} = \int_{away} dN_{AB} / \int_{away} dN_{pp}$$



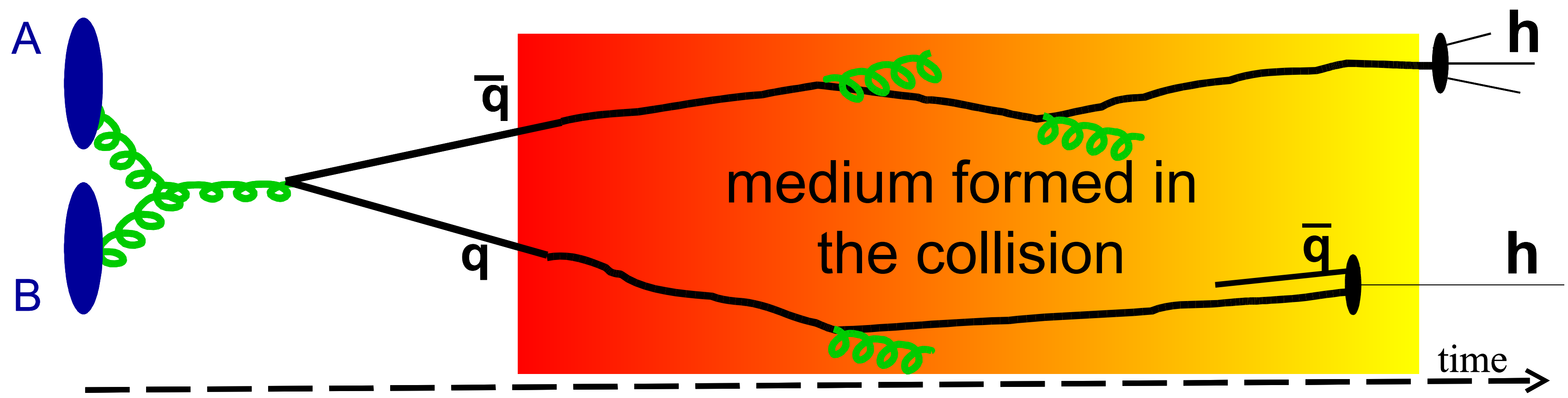
STAR, PRL 93 (2004) 252301.

Measurement in pp and d+Au not suppressed ($I_{AA} \approx 1$)

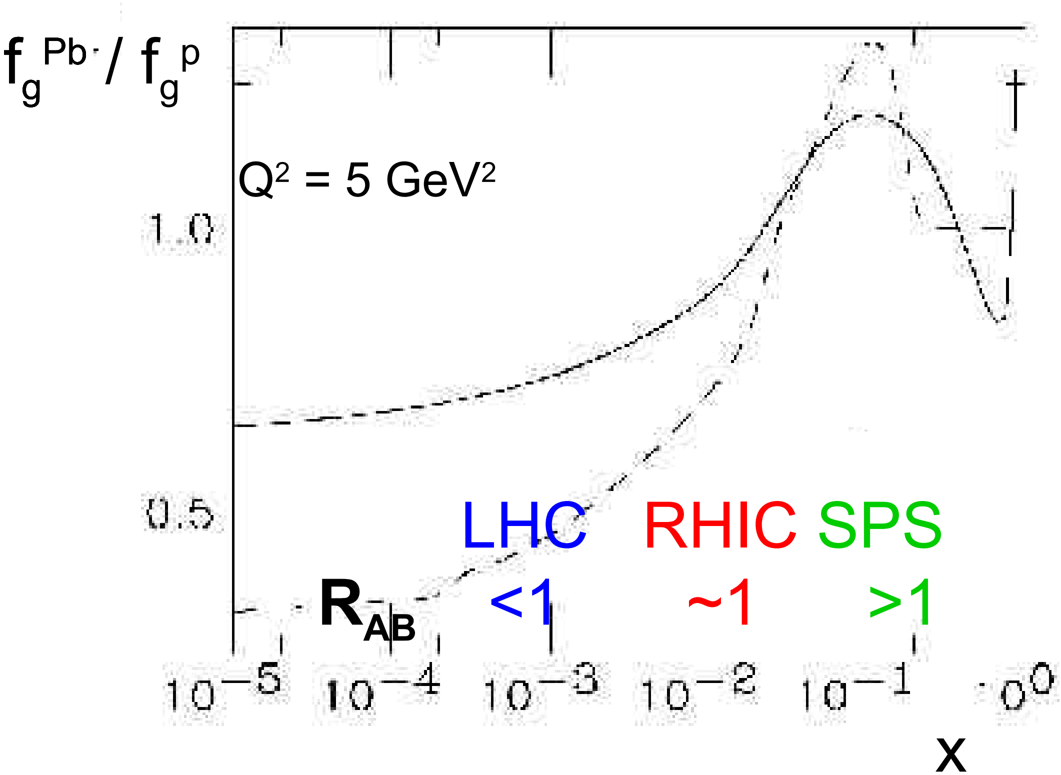
Central Au+Au collision strongly suppressed ($I_{AA} \approx 0.1$)

Final-state effect

High-p_T particle production in A+B collisions



- Proton-Proton baseline (pQCD)
- Initial-state effects
  - Nuclear PDF (anti-/shadowing)
  - K_T broadening (Cronin)
- Final-state effects
  - Energy loss
  - In-medium hadronization (coalescence)



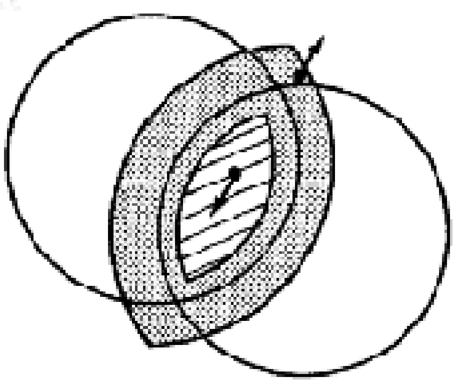
Parton energy loss

- Partons travel a few (~4) fm in the high color-density medium
- Bjorken (`82): energy loss due to elastic (collisional) scattering

High energy quarks and gluons propagating through quark-gluon plasma suffer differential energy loss via elastic scattering from quanta in the plasma.

...

An interesting signature may be events in which the hard collision occurs near the edge of the overlap region, with one jet escaping without absorption and the other fully absorbed.



Bjorken, FERMILAB-Pub-82/59-THY (1982).

Parton energy loss inspired by pQCD

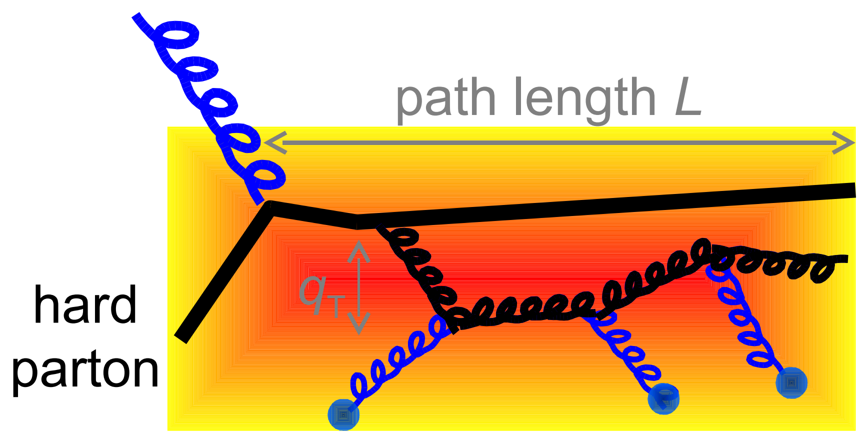
- Successive calculations (`92++) revealed that medium-induced gluon radiation (QCD bremsstrahlung) dominates:

$$\omega \frac{dI}{d\omega dk} = \alpha_S C_R / \omega^2 \, F\left(\eta(\xi)\sigma(r)\right)$$

$$\rightarrow \frac{1}{2}\hat{q}(\xi) r \quad \text{(multiple soft)}$$

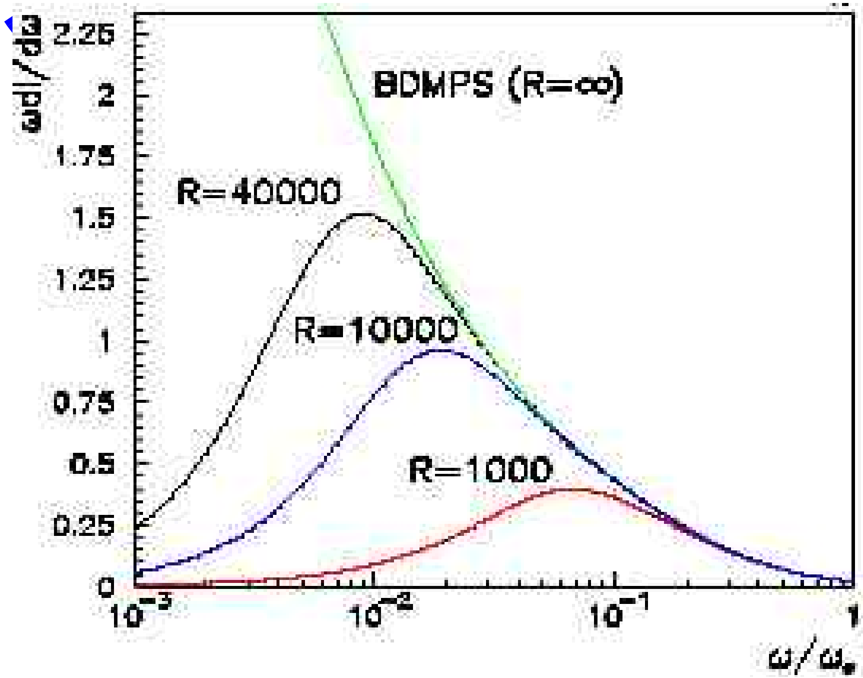
$$\rightarrow \left(n(\xi)\sigma(r \quad \text{(single hard)}$$

Coherent wave-function gluon acummulates k_T due to multiple inelastic scatterings in the medium until decoheres and is radiated off the original hard parton



Bjorken, Gyulassy, Plümer, Thoma, Wang, Wang, Baier, Dokshitzer, Müller, Peigne', Schiff, Levai, Vitev, Zhakarov, Salgado, Wiedemann, ...

Parton energy loss in pQCD (BDMPS-Z)



BDMPS-Z formalism

STATIC MEDIUM

$$\hat{q} = \frac{\langle q_T^2 \rangle}{\lambda}$$ transport coefficient

Radiated-gluon energy distrib.:

$$\omega \frac{dI}{d\omega} \propto \alpha_S C_R \begin{cases} \sqrt{\omega_c / \omega} & \text{for } \omega < \omega_c \\ (\omega_c / \omega)^2 & \text{for } \omega \geqslant \omega_c \end{cases}$$

C_R	Casimir coupling factor: 4/3 for q, 3 for g
$\omega_c = \hat{q} L^2 / 2$	determines the scale of the radiated energy
$R = \omega_c L$	related to constraint $k_T < \omega$ and controls shape at $\omega << \omega_c$

Baier, Dokshitzer, Müller, Peigne‘, Schiff, NPB 483 (1997) 291.
Zakharov, JTEPL 63 (1996) 952.
Salgado, Wiedemann, PRD 68(2003) 014008.

Calculating the energy loss

$$\langle \Delta E \rangle \approx \int_0^{\omega_c} d\omega\, \omega \frac{dI}{d\omega} \propto \alpha_S\, C_R\, \omega_C \propto \alpha_S\, C_R\, \hat{q}\, L^2$$

$$\langle \Delta E \rangle \propto \hat{q} \propto \rho \int dq_T^2\, q_T^2\, d\sigma / dq_T^2$$

(gluons volume-density and interaction cross section)

Probe the medium

Finite parton energy (qualitatively)

- If E< ω_c (e.g. small p_T with traversing large L) :

$$\langle \Delta E \rangle \approx \int_0^{E} d\omega\, \omega \frac{dI}{d\omega} \propto \alpha_S\, C_R\, \sqrt{E\,\omega} \propto \alpha_S\, C_R\, \sqrt{E}\, \sqrt{\hat{q}}\, L$$

  - Introduces dependence on parton energy
  - Reduces sensitivity to density
  - Leads to linear dependence on path length

Expanding medium

- Time-dep. density of scattering centers

$$\hat{q}(\tau) = \hat{q}_0 \times \left(\frac{\tau_0}{\ldots}\right)^{\alpha}$$

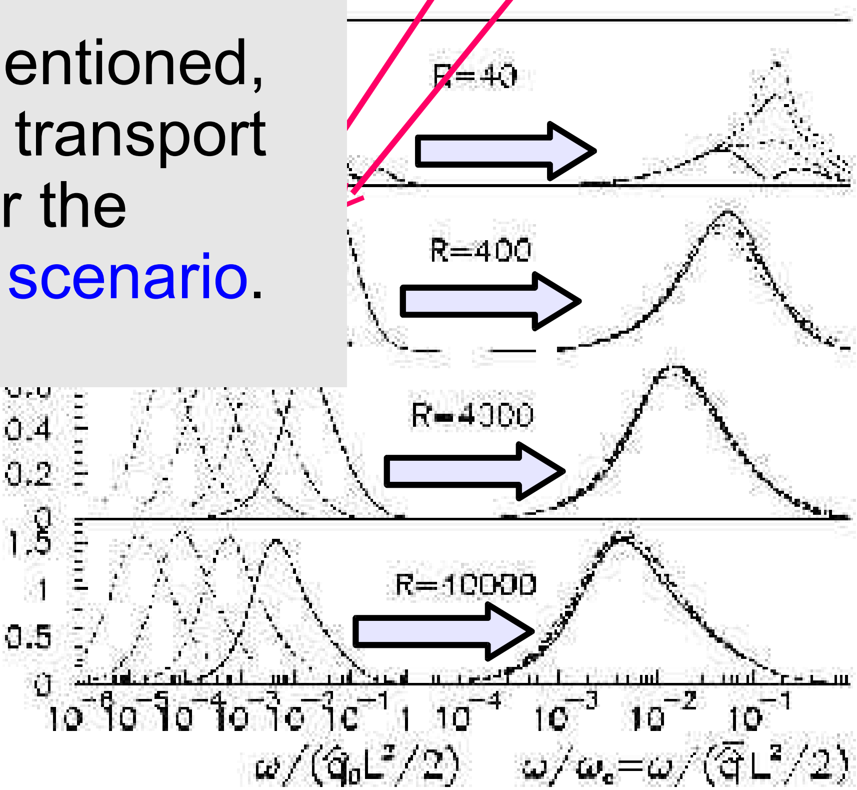
- Dynamical sc
  same spectru
  for an equiva
  transport coe

$$\bar{\hat{q}} = \frac{2}{L^2} \int_{\tau_0}^{L+\tau_0} d\tau \left(\tau - \tau_0\right) \hat{q}(\tau)$$

If not explicitly mentioned, all values for the transport coefficient are for the equivalent static scenario.

EQUIVALENT STATIC SCENARIO

α = 1.5, 1.0, 0.5, 0



Calculations for a static scenario apply for also for expanding systems

Salgado, Wiedemann, PRL 89 (2002) 092303.

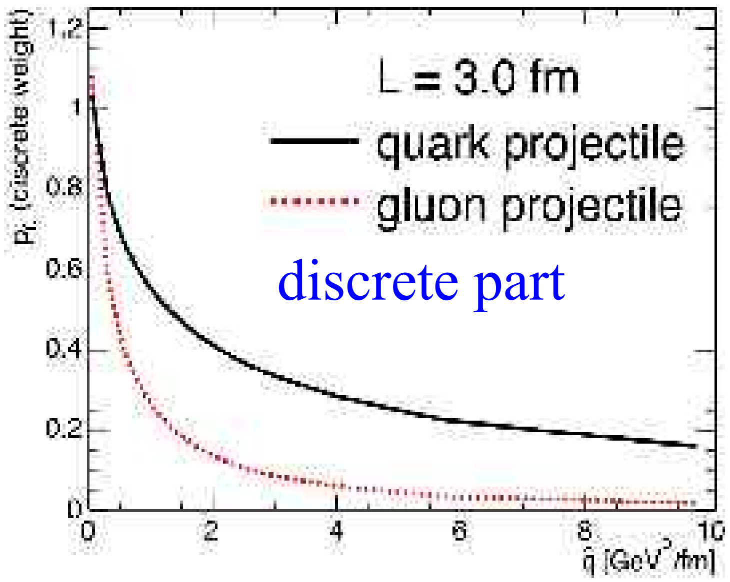
Quenching weights

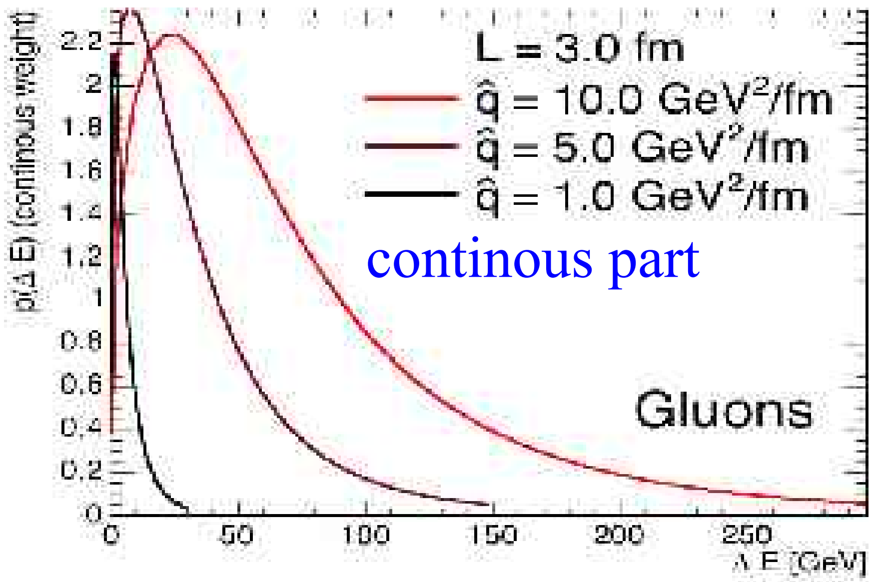
- Compute energy loss probability distributions

$$P(\Delta E) = \sum_{n=0}^{\infty} \left[\prod_{i=1}^{n} \int d\omega_i \frac{dI(\omega_i)}{d\omega} \right] \delta\left(\Delta E - \sum_{i=0}^{n} \omega_i \right) \exp\left[-\int d\omega \frac{dI}{d\omega} \right]$$

- Calculated from $\omega \; dI/d\omega$ in the $E \to \infty$ approximation (no E dep.)

$$P(\Delta E; C_R, \hat{q}, L) = p_0(C_R, \hat{q}, L) + p(\Delta E; C_R, \hat{q}, L) \qquad \left[\alpha_S = 1/3\right]$$





BDMS, JHEP 0109 (2001) 033
Salgado, Wiedemann, PRD 68 (2003) 014008

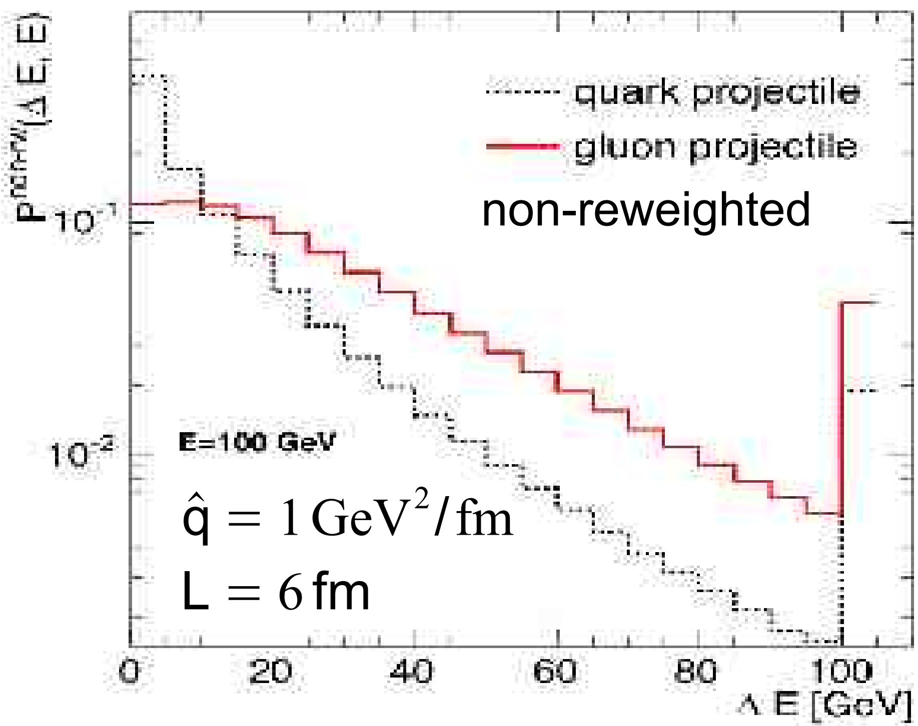
→ **Constrained weights**

Constrained quenching weights

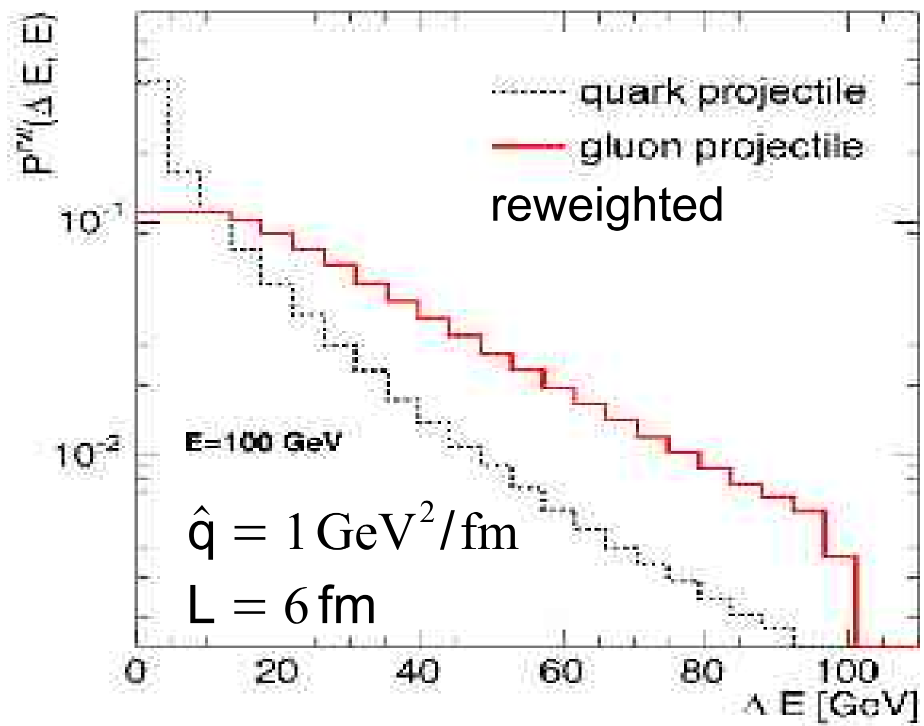
Construct constrained weights from quenching weights

$$P(\Delta E; C_R, \hat{q}, L, E) \text{ with } \Delta E \leq E$$

a) non-reweighted weight
(thermalize for $\Delta E > E$)



b) reweighted weight
(truncate + renormalize at $\Delta E = E$)



Calculating unquenched particle spectra

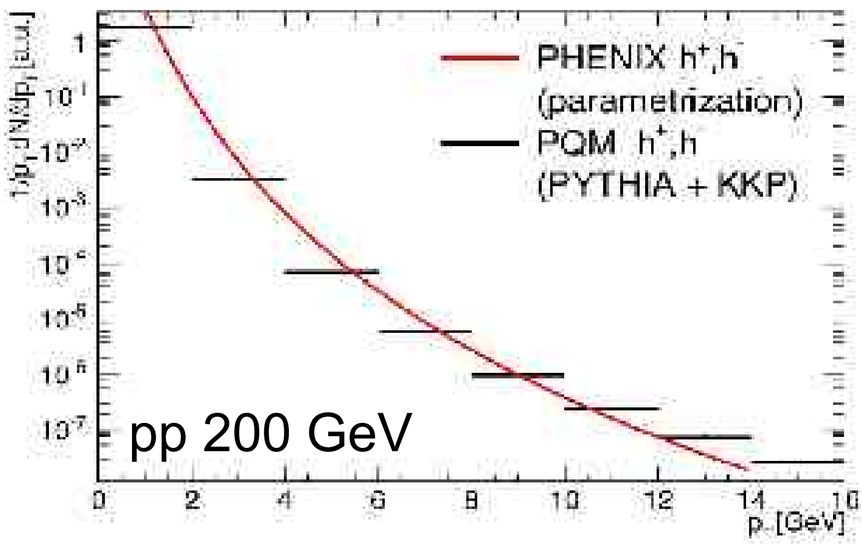
Standard pQCD + collinear factorization + vacuum fragmentation

$$\left.\frac{d^2\sigma^h}{dp_T\,dy}\right|_{y\approx 0} = \sum_{a,b,j} \int dF_{ab} \; dz_j \left.\frac{d^2\sigma^{ab\to jX}}{dp_{T,j}\,dy}\right|_{y\approx 0} \times \frac{D_{h/j}(z_j)}{z_j^2}$$

Monte Carlo approach:

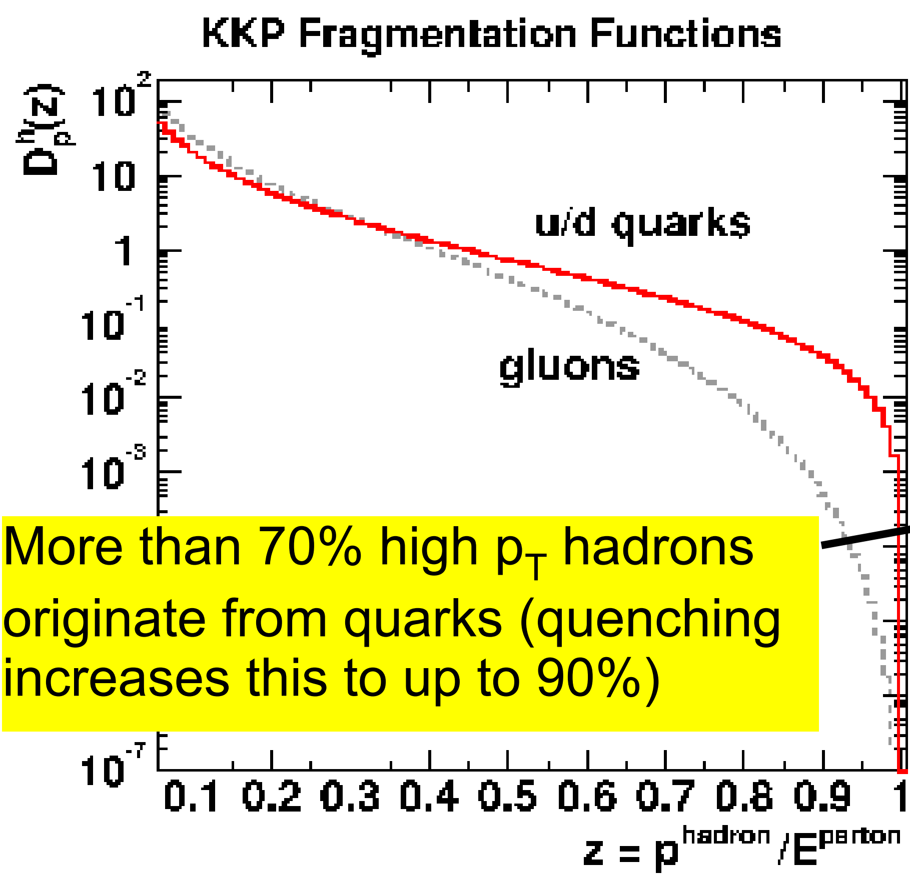
Verify shape with PHENIX parametrization for pp

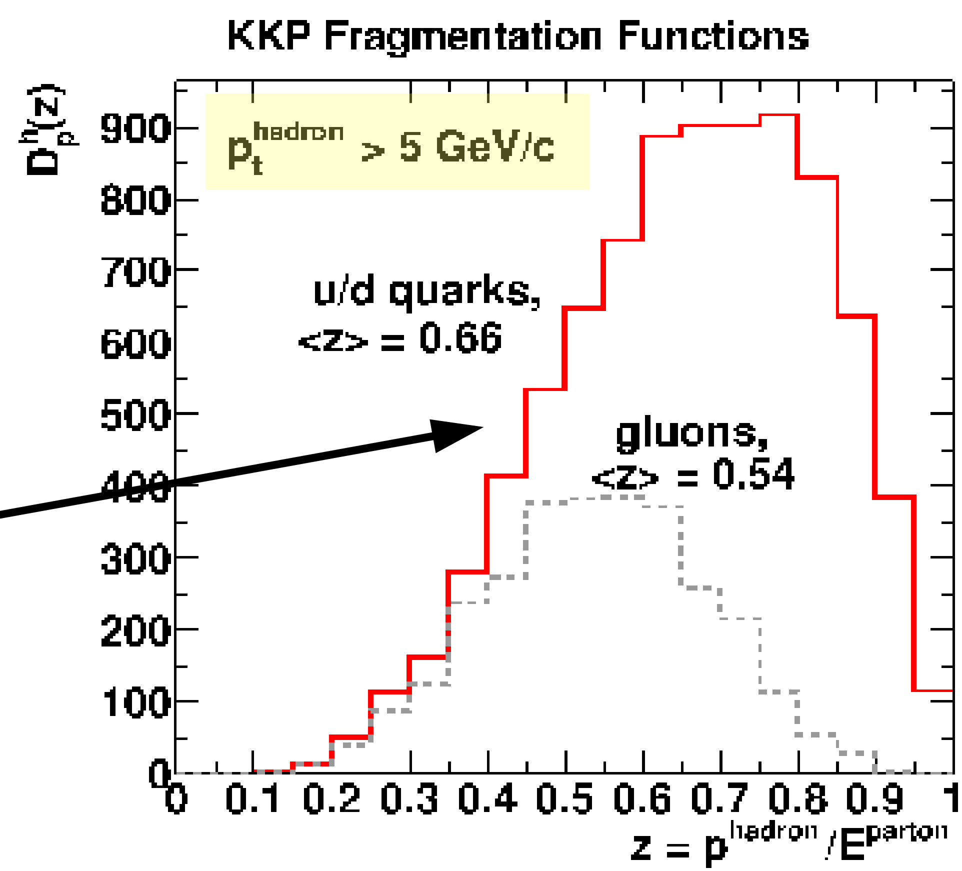
$$\frac{1}{p_T}\frac{d^2N}{dp_T} = C\left(1+\frac{p_0}{p_T}\right)^n + r(p_T)$$



PYTHIA + KKP fragmentation

PYTHIA p_T parton distributions + relative ratio of quarks-to-gluons at 200 GeV cms energy using CTEQ 4L + KKP at LO





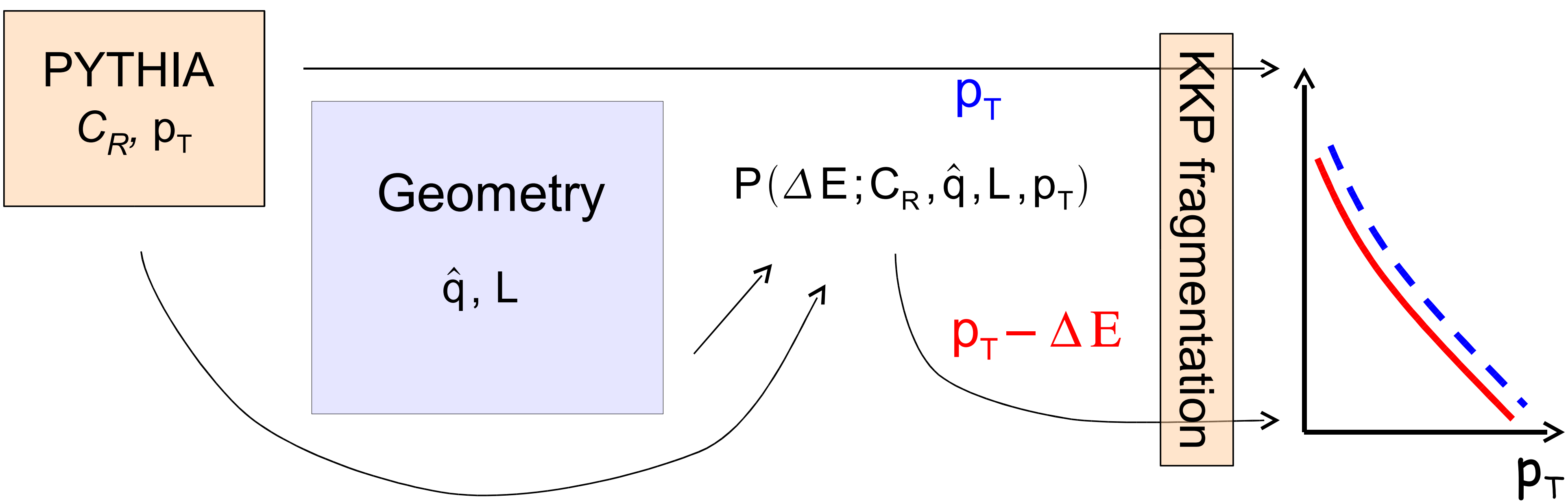
More than 70% high p_T hadrons originate from quarks (quenching increases this to up to 90%)

Calculating quenched particle spectra

Factorized pQCD + final state quenching + vacuum fragmentation

$$\left.\frac{d^2\sigma^{h}_{quenched}}{dp_T\,dy}\right|_{y\approx 0} = \sum_{a,b,j}\int dF_{ab}\,d\Delta E_j\,dz_j \left.\frac{d^2\sigma^{ab\to jX}}{dp^{init}_{T,j}\,dy}\right|_{y\approx 0} \times$$
$$\delta(p^{init}_{T,j}-p_{T,j}-\Delta E_j)\,P(\Delta E_j;C_j,\hat{q}_j,L_j,p_{T,j})\,\frac{D_{h/j}(z_j)}{z_j^2}$$

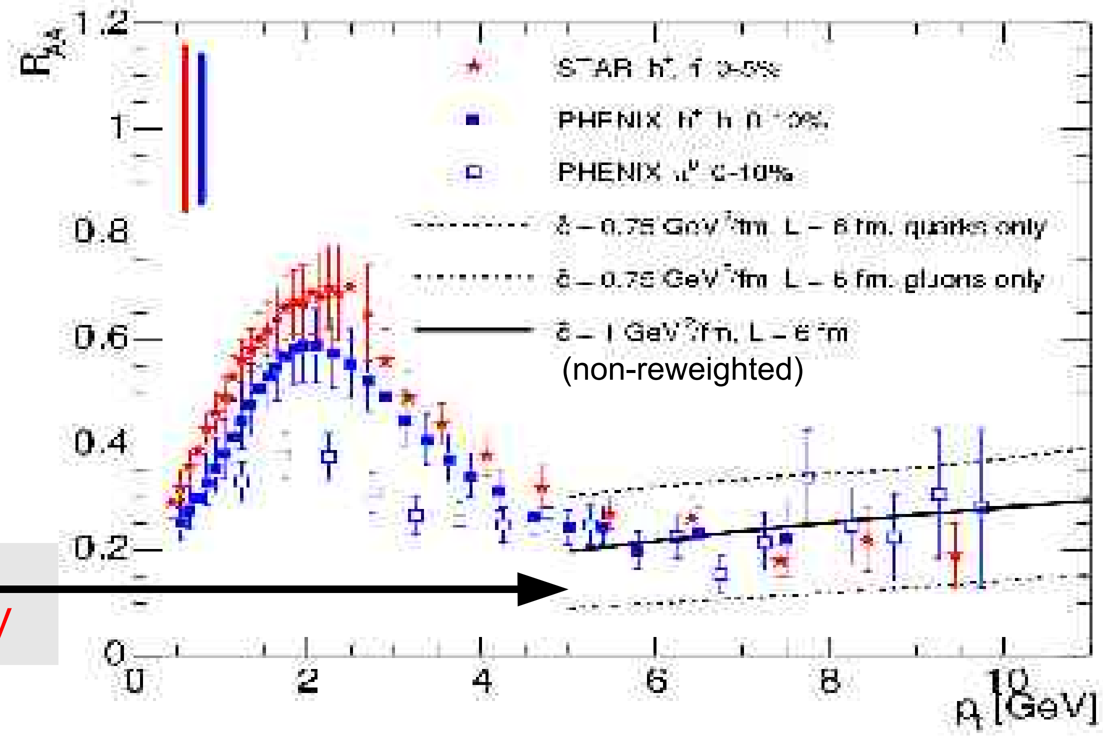
Monte Carlo approach:



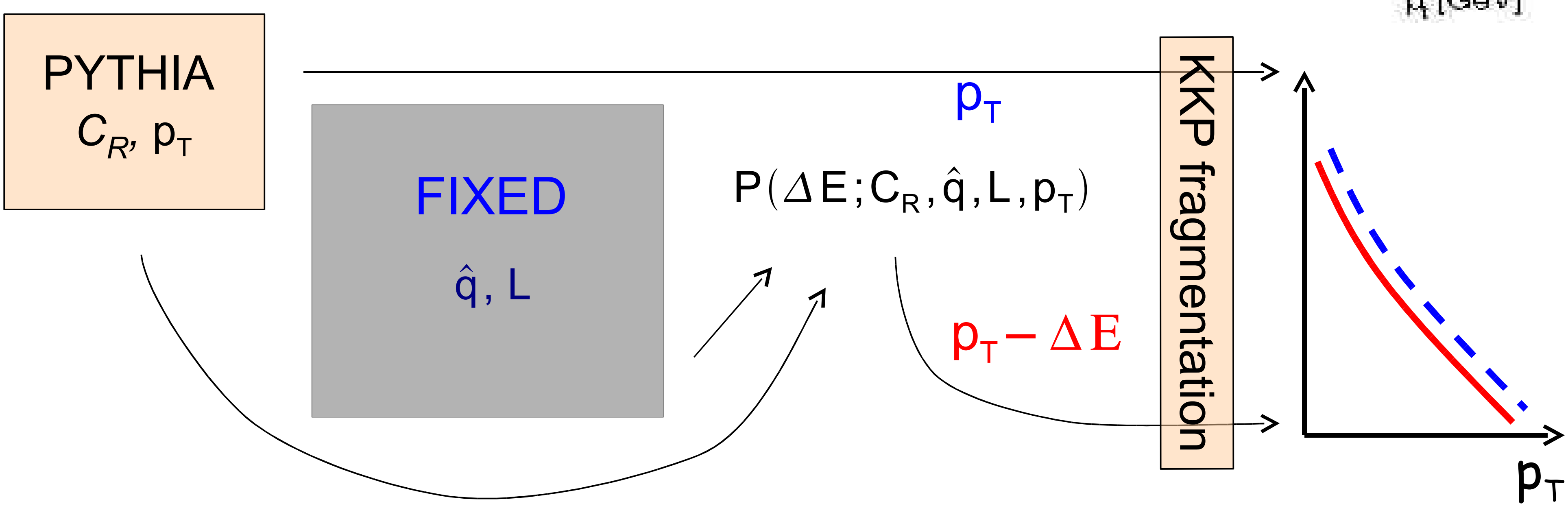
Need

$$\hat{q} = 1\,\mathrm{GeV}^2/\mathrm{fm}$$

to describe the measured suppression in 0-10% Au+Au for fixed length of 6 fm



No initial-state effects and in-medium hadronization: p_T > 5 GeV

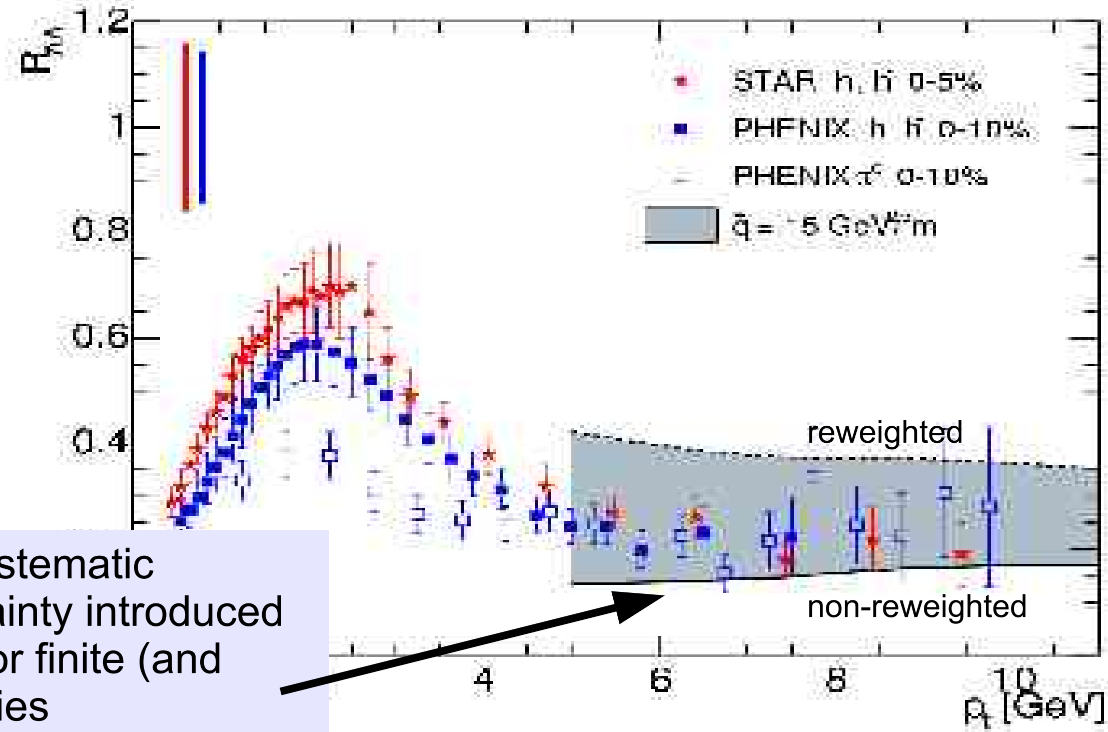


R_{AA} in central Au+Au at 200 GeV (2)

Need

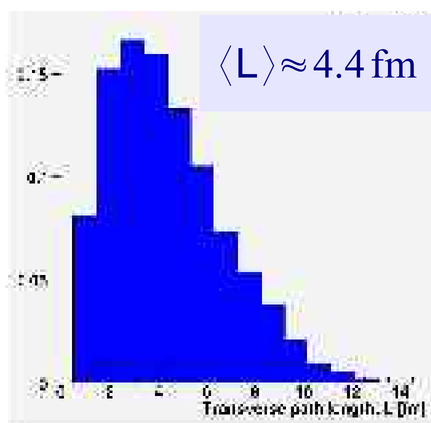
$$\hat{q} = 15\,\mathrm{GeV}^2/\mathrm{fm}$$

to describe the measured suppression in 0-10% Au+Au for <u>Glauber-based length distribution</u>



Band represents systematic (theoretical) uncertainty introduced by the constraints for finite (and small) parton energies

PYTHIA
C_R, p_T



and FIXED $\hat{q}$

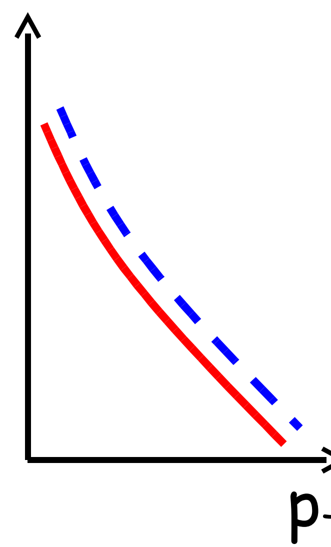
$$L = \frac{\int dl\, l\, \rho(x_0+l, y_0+l; b)}{\int dl\, \rho(x_0+l, y_0+l; b)}$$

$$P(\Delta E; C_R, \hat{q}, L, p_T)$$

p_T

$p_T - \Delta E$

KKP fragmentation



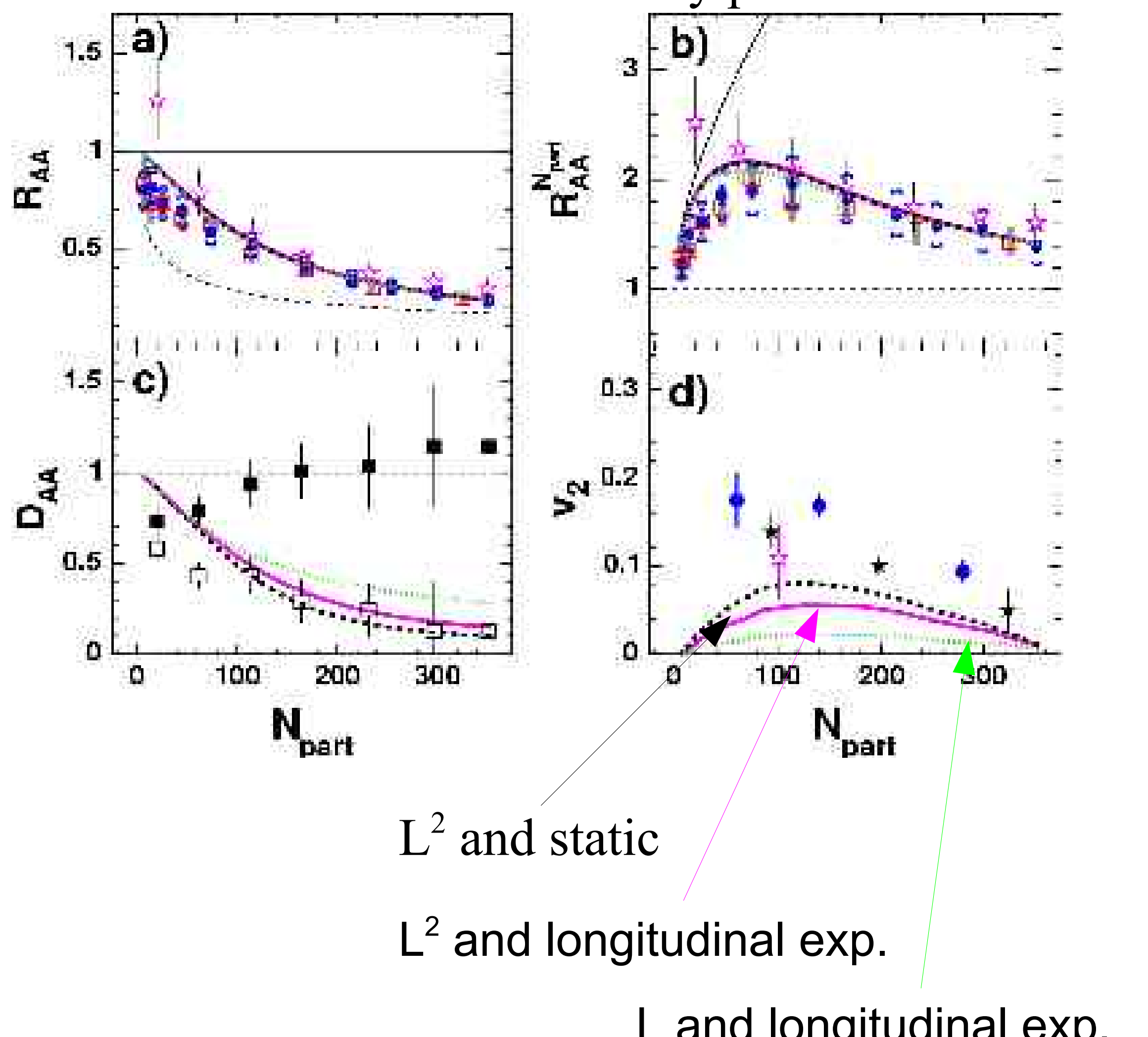
Role of collision geometry

- Parton production according to $\rho_{\text{coll}}(x, y; b)$
- Parton absorption according:

  $f = \exp(-k\, l)\;;\; l \propto \int f(l)\, \rho(l)\, dl$

  independent on p_T
  where l is line-integral over density-profile for different expansion scenarios
- Results relatively independent on detailed modelling of matter (not shown) and absorption patterns

Wood-Saxon density profile



➡ **Opaque medium: geometry dominates**

Drees, Feng, Jia, PRC 71 (2005) 034909.

PQM parton-by-parton approach

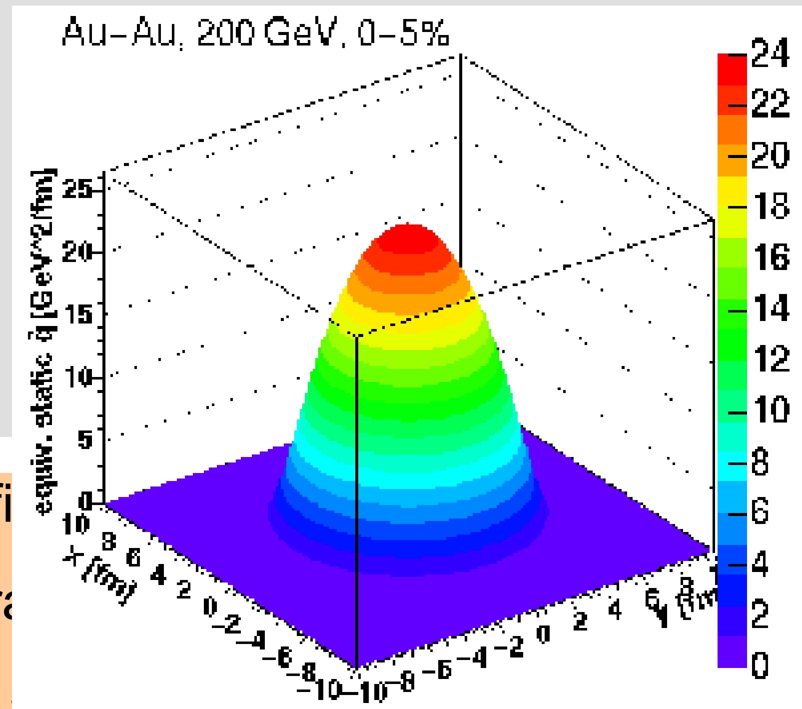
- Define “local” transport coefficient

$$\hat{q}\left(\xi;x_{0,}y_{0,}\phi_0;b\right)=k\times T_A T_B\left(x_0+\xi\cos\phi_{0,}y_0+\xi\sin\phi_0;b\right)$$

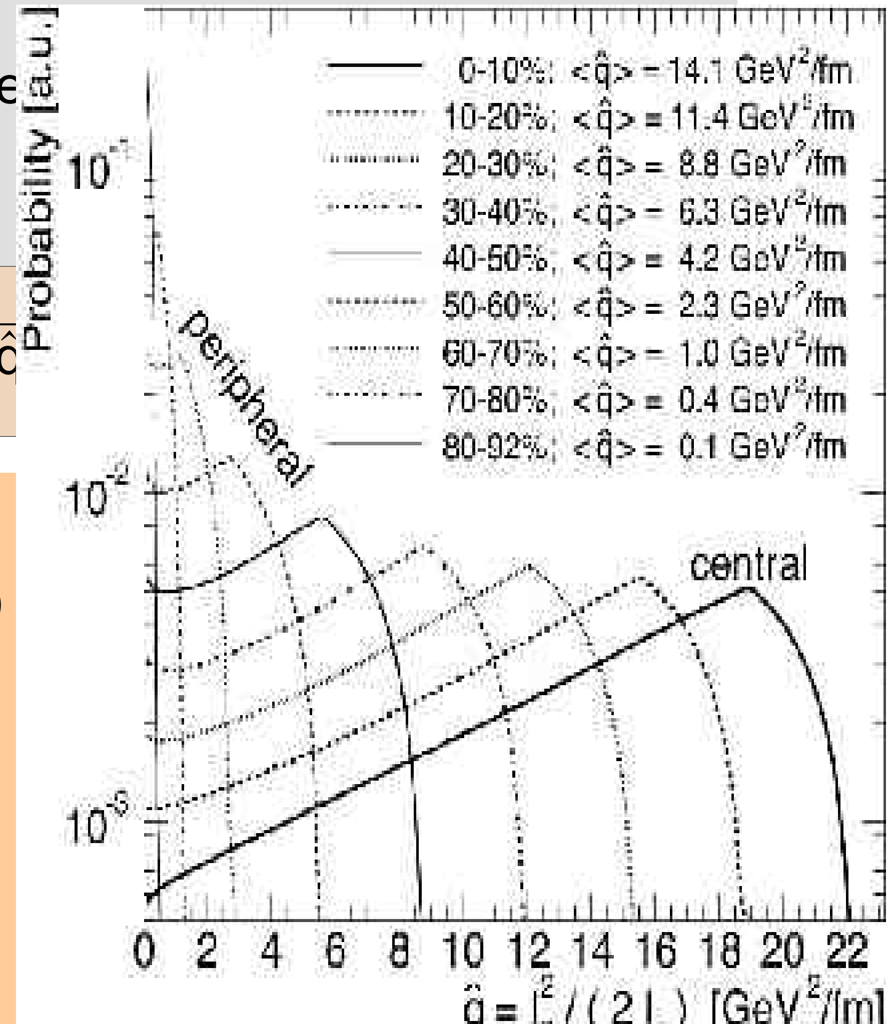
(note

ts

nt $\hat{q}$



- Defi
- Para nce)
  –
  - Implicitly depends on systems and energy (see later)
  - Use Glauber to scale to other centralities
  - Report $\langle\hat{q}\rangle\propto k$ for a given centrality range



Dainese, Loizides, Paic, EPJC (2005) 461.

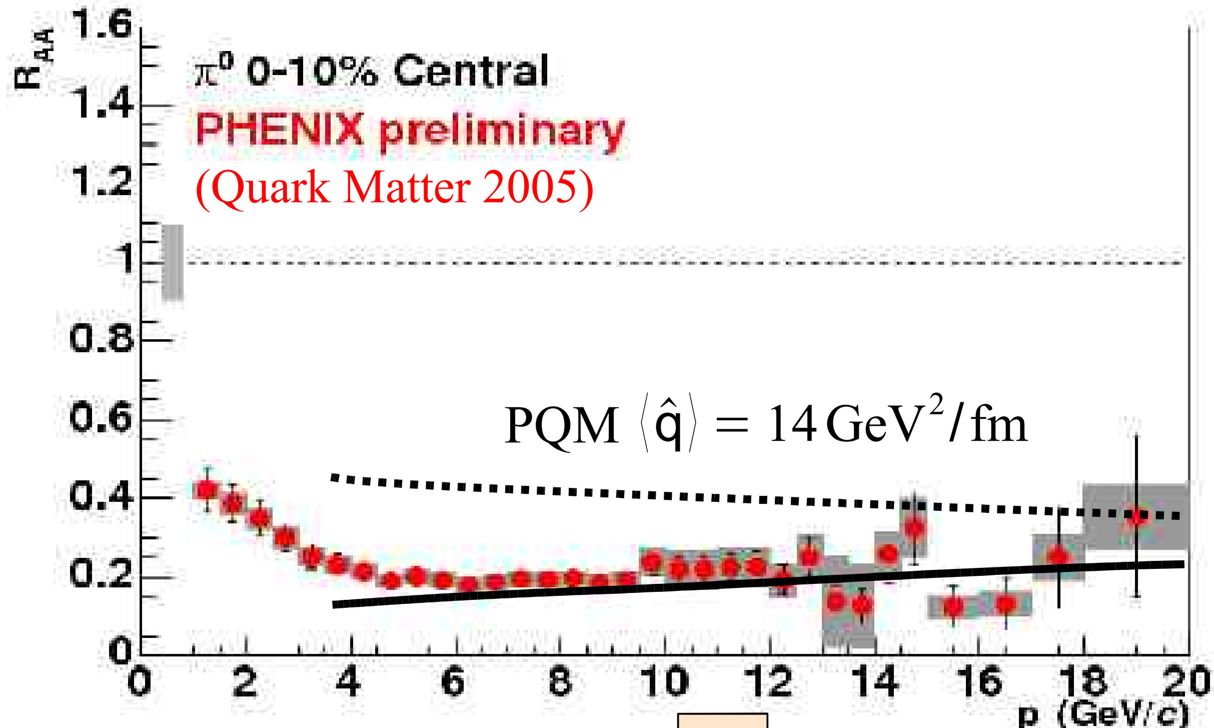
R_{AA} in central Au+Au at 200 GeV (3)

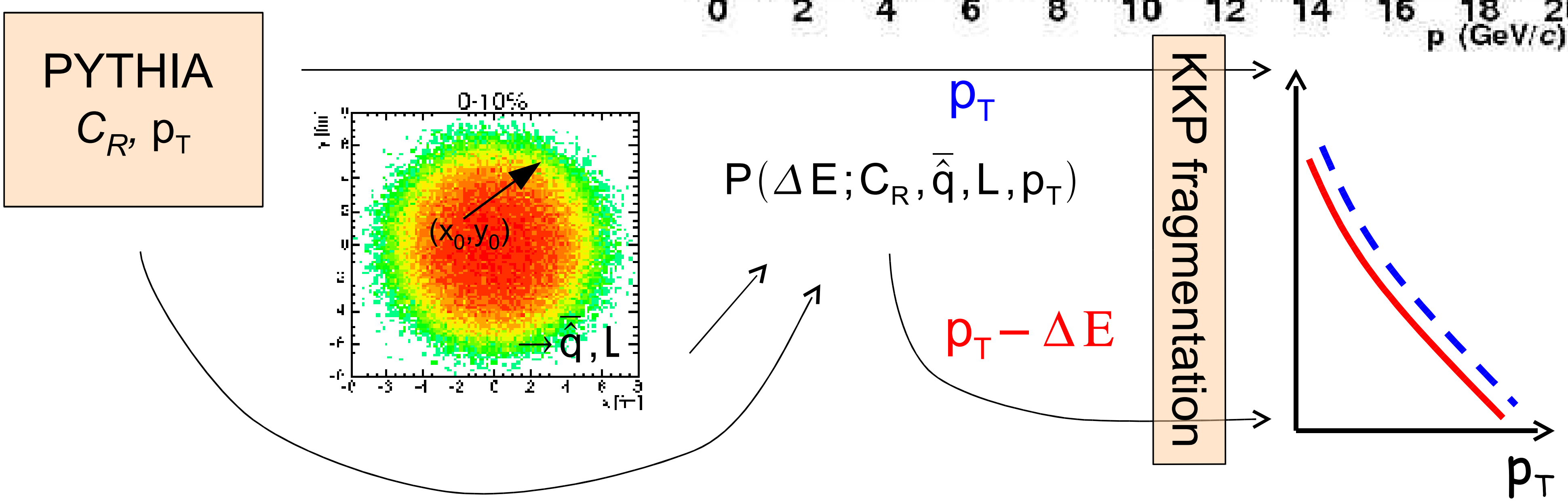
Find

$$\langle \hat{q} \rangle = 14\,\mathrm{GeV}^2/\mathrm{fm}$$

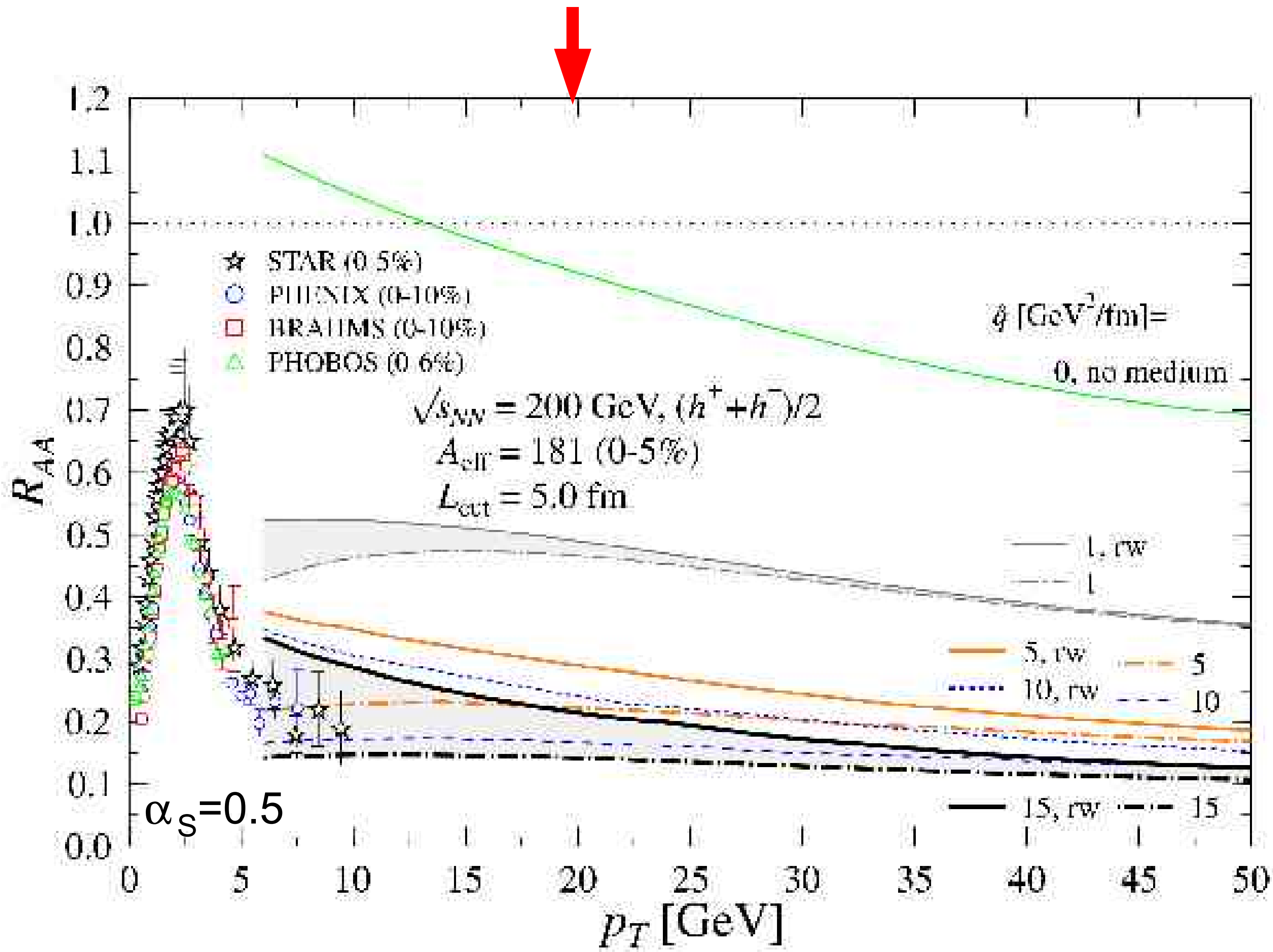
to describe the measured suppression in 0-10% Au+Au for <u>the parton-by-parton approach</u>

Dainese, Loizides, Paic, EPJC (2005) 461.



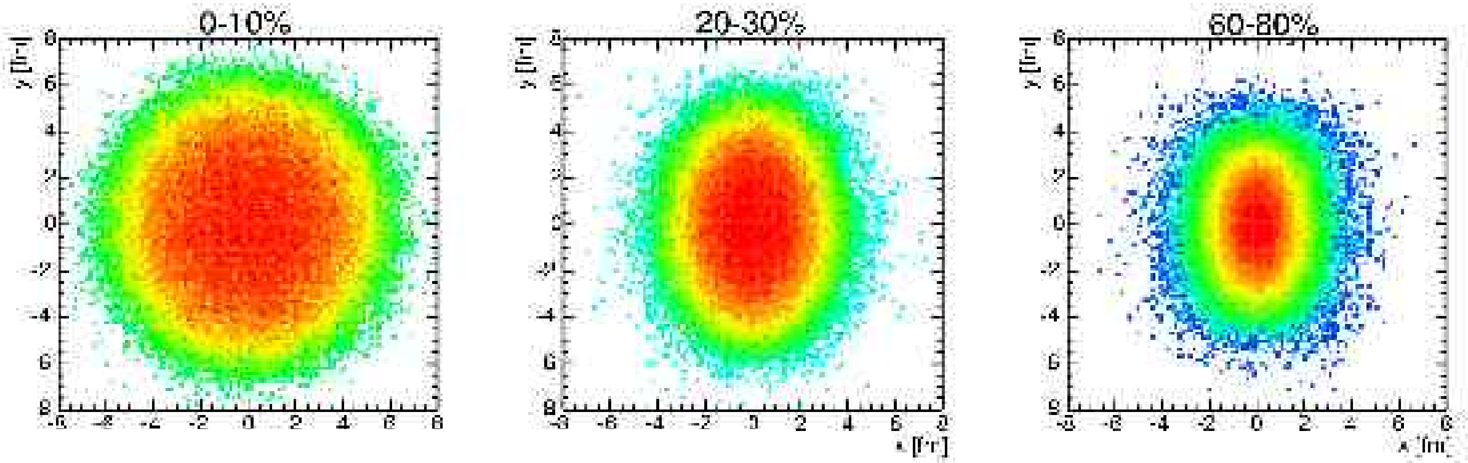


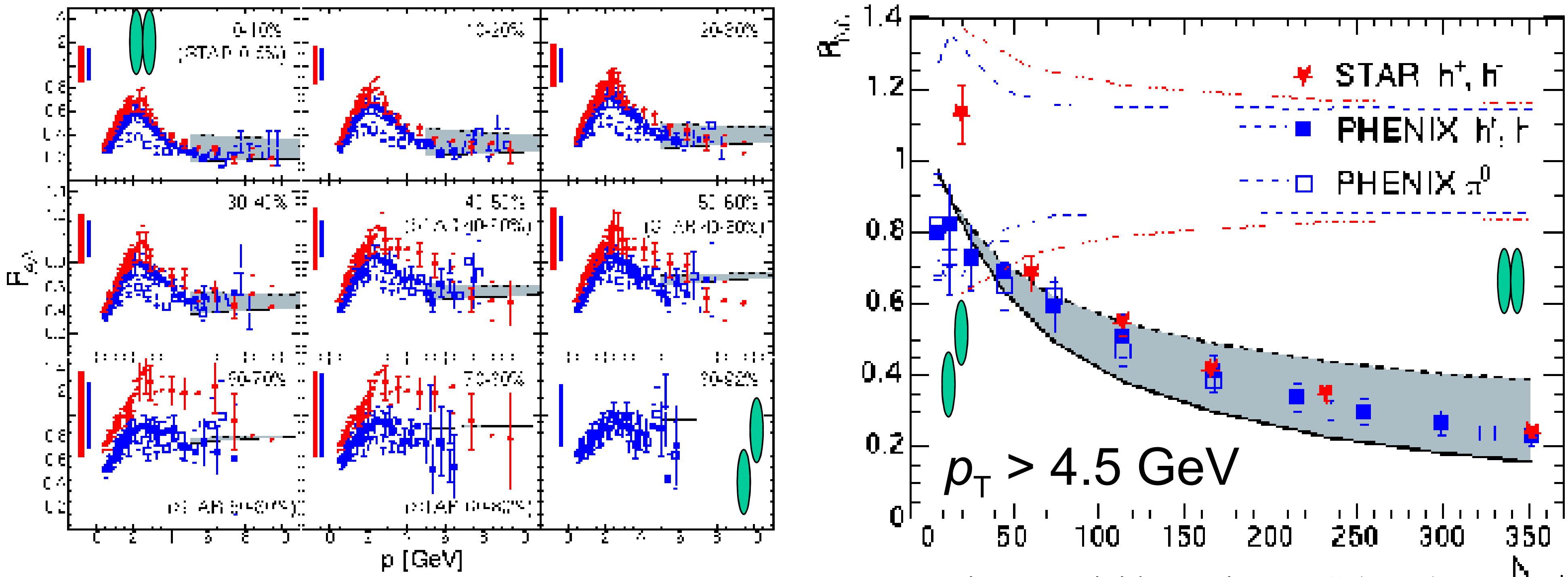
R_{AA} in central Au+Au at 200 GeV (4)



Eskola, Honkanen, Salgado, Wiedemann, NPA 747 (2005) 511.

Glauber: $\hat{q}(b) = k^{AuAu,\,200\,GeV} \times T_A T_B(b)$

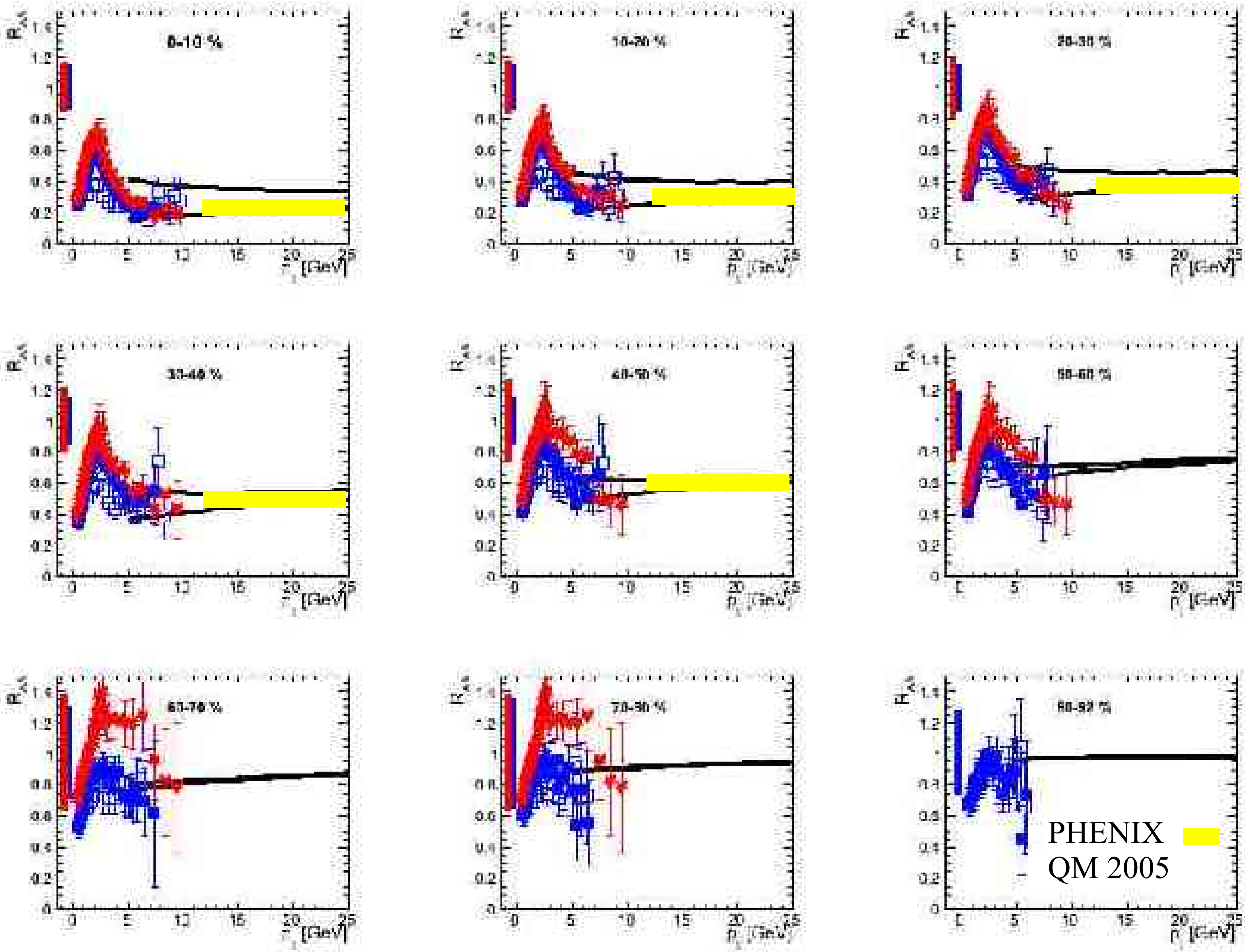




Dainese, Loizides, Paic, EPJC (2005) 461.

Centrality dep. of R_{AA} for Au+Au at 200 GeV (2)

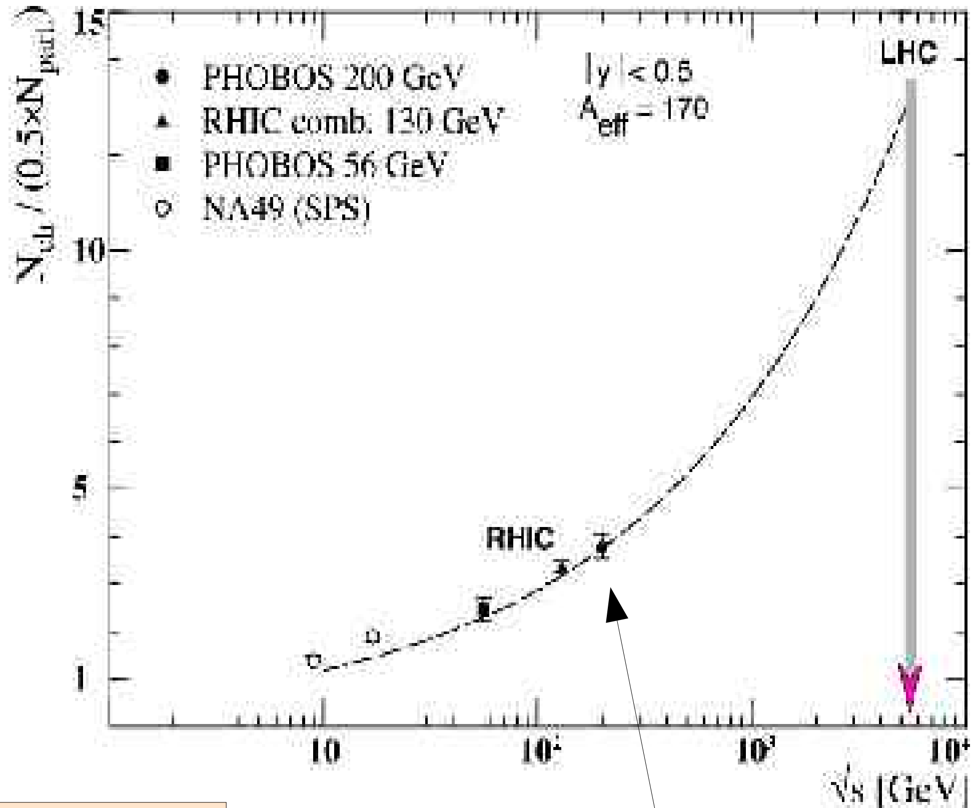
New π^0 R_{AA} data for 200 GeV Au Au from PHENIX



Extrapolation to other systems

The transport coefficient is proportional to the gluon density, which according to the saturation model (EKRT) scales with

$$\langle \hat{q} \rangle \propto n^{\text{gluons}} \propto A^{0.383} \sqrt{s_{NN}}^{0.574}$$



Using the extracted value at Au+Au 200 GeV gives (for 0-10% collisions)

$$\langle \hat{q} \rangle = \left(A/197\right)^{0.383} \left(\sqrt{s_{NN}}/200\right)^{0.574} \times 14 \left[\text{GeV}^2/\text{fm}\right]$$

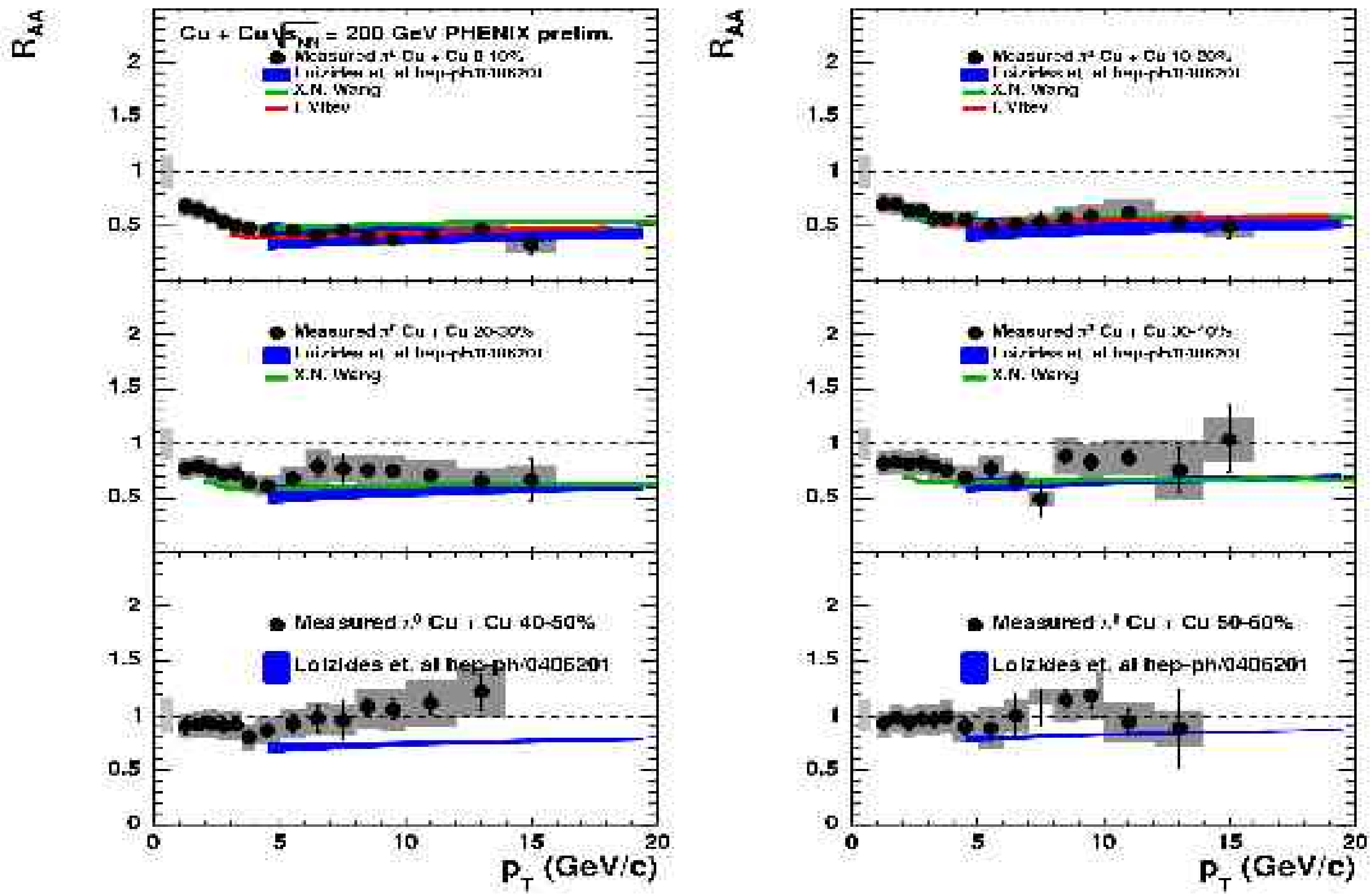
CuCu/AuAu≈1,
PHOBOS, nucl-ex/0510042

Scale with 0.5 for 62.4 GeV Au+Au;
with 0.63 for 200 GeV Cu+Cu
(Factor 7 for 5.5 TeV Pb+Pb)

Eskola, Kajantie, Ruuskanen, Tuominen, NPB 570 (2000) 379.

Extrapolation to other systems (2)

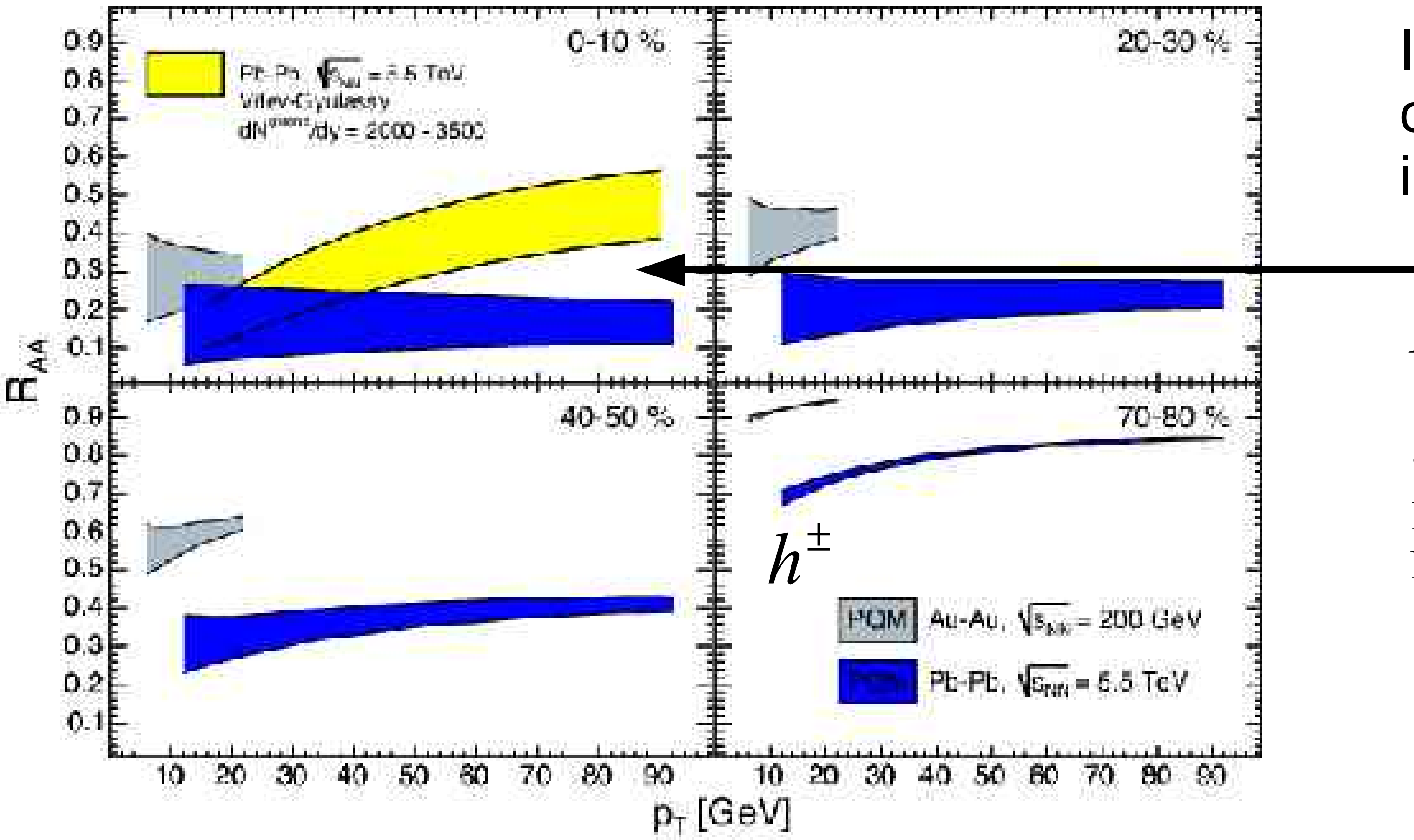
$$\langle \hat{q}^{200,\mathrm{CuCu}} \rangle = 9\,\mathrm{GeV}^2/\mathrm{fm}$$



➡ **species/energy extrapolation works reasonably well**

R_{AA} prediction for LHC

$\langle \hat{q}^{5500,\mathrm{PbPb}} \rangle \approx 25 - 100\,\mathrm{GeV}^2/\mathrm{fm}$



Interesting(?) difference in predictions.

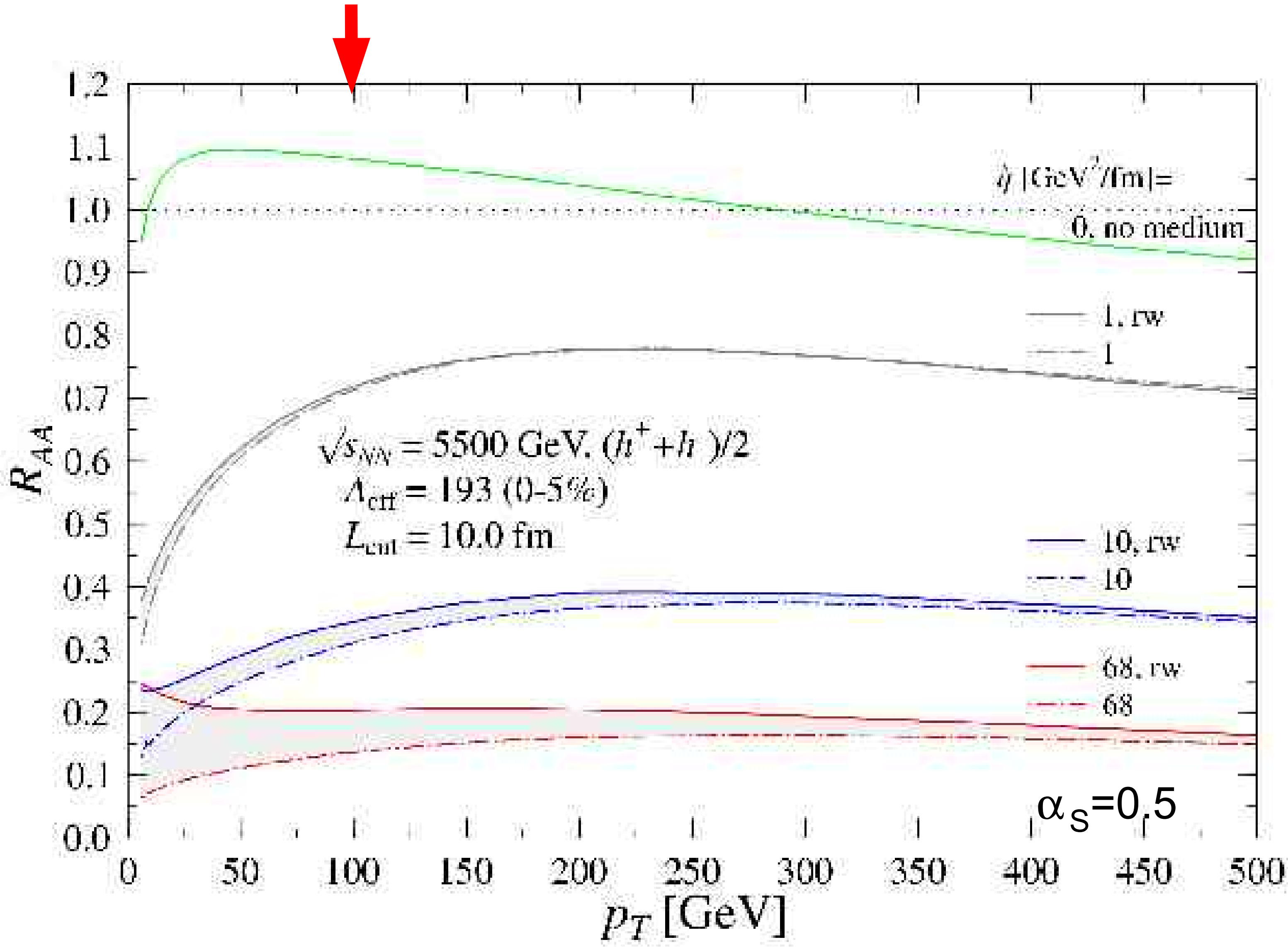
$$R_{AA}^{5.5\ \mathrm{TeV}} \approx \frac{R_{AA}^{200\ \mathrm{GeV}}}{2}$$

Similar results:
Eskola et.al.
NPA 747 (2005) 511.

PQM predics also for large p_T a rather p_T-independent R_{AA} (for central collisions)

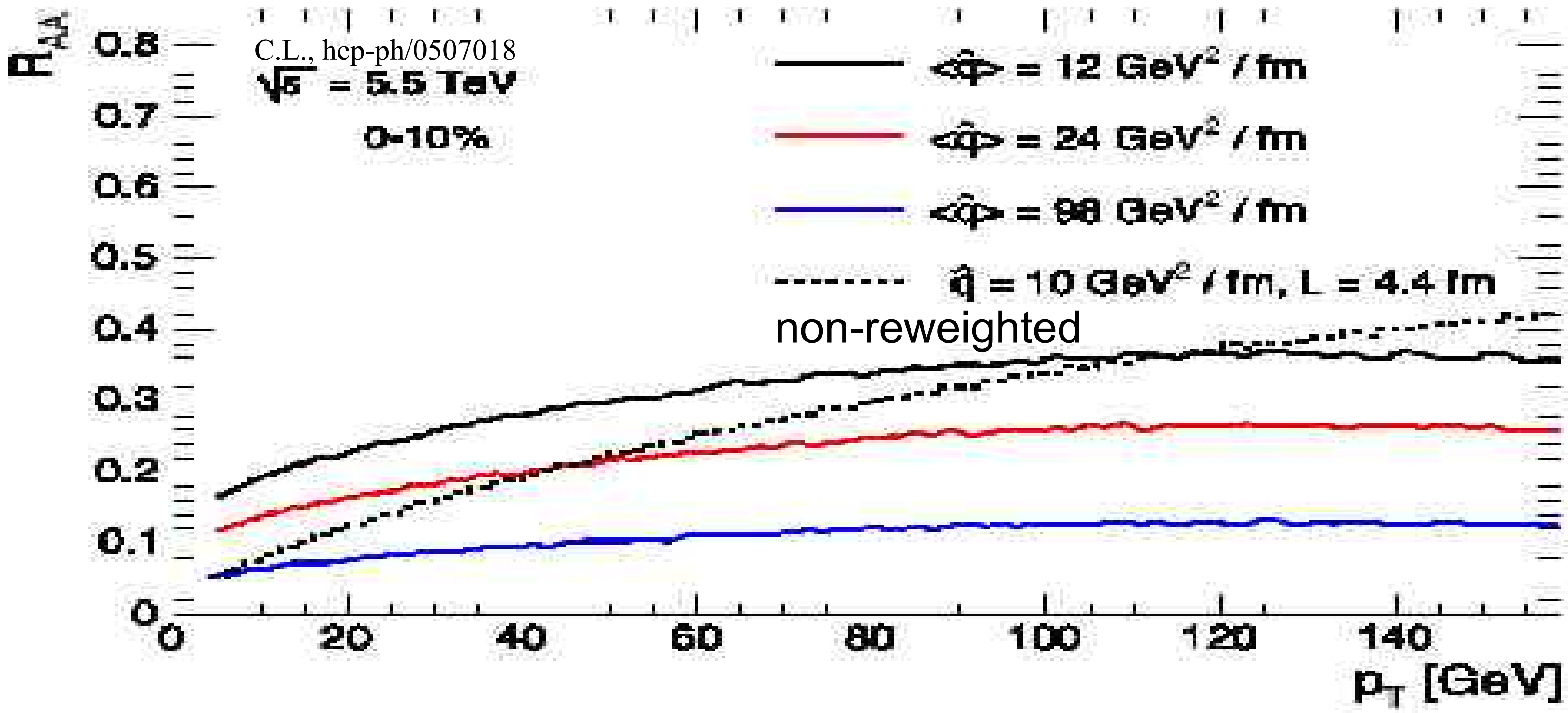
Vitev and Gyulassy, PRL 89 (2002) 252301.
Dainese, Loizides, Paic, EPJC38 (2005), 461.

R_{AA} prediction for LHC (2)



Eskola, Honkanen, Salgado, Wiedemann, NPA 747 (2005) 511.

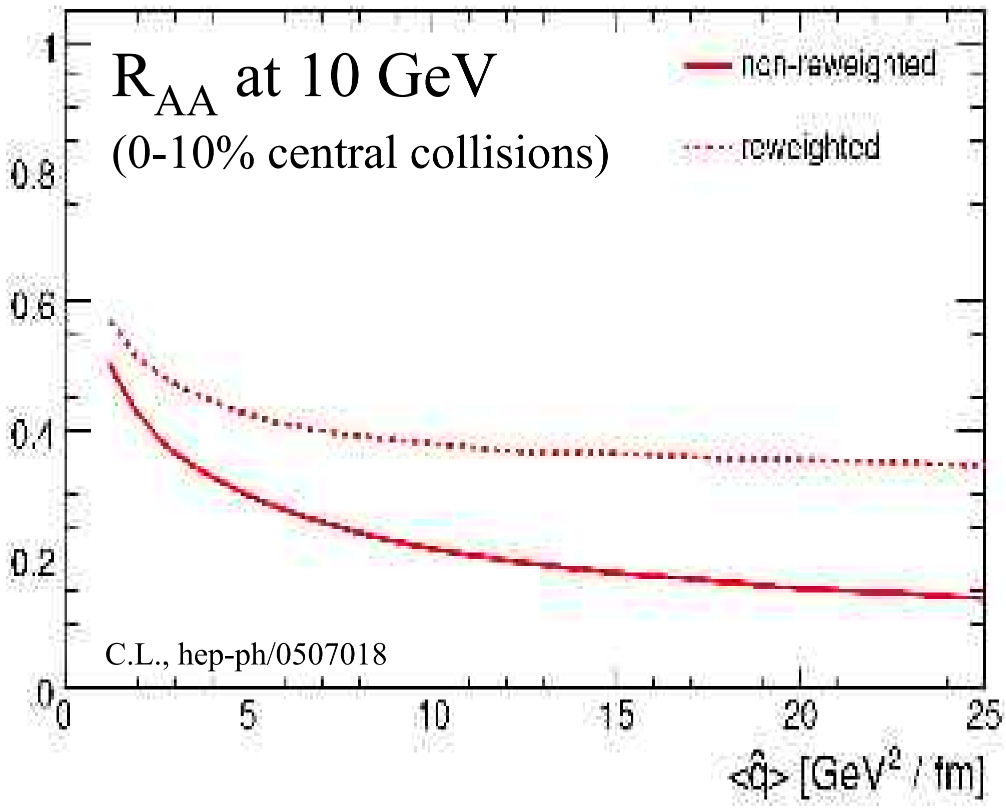
Why is R_{AA} flat?



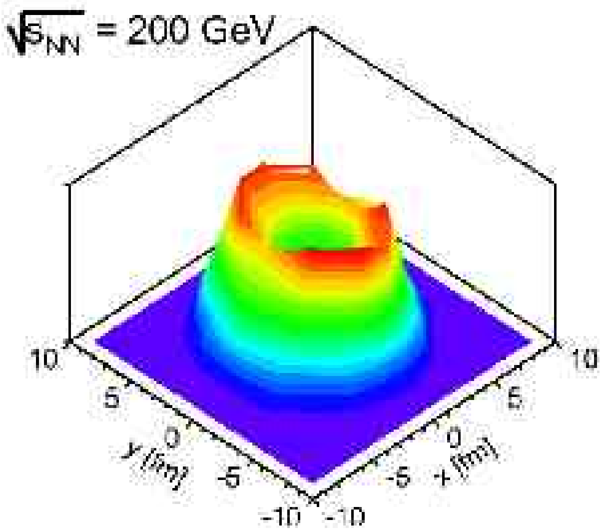
- The larger the parton energy the longer the possible explorable path length
  - For very large medium density R_{AA} flattens because all partons pay about the same prize for traversing the medium ($\Delta E/E \sim E^{\alpha}$, α >0.5)
  - Check: For fixed geometry R_{AA} rises as expected

Dainese, Loizides, Paic, EPJC38 (2005), 461.

Limited medium-sensitivity of R_{AA}



"Leading-particle probes are fragile!"

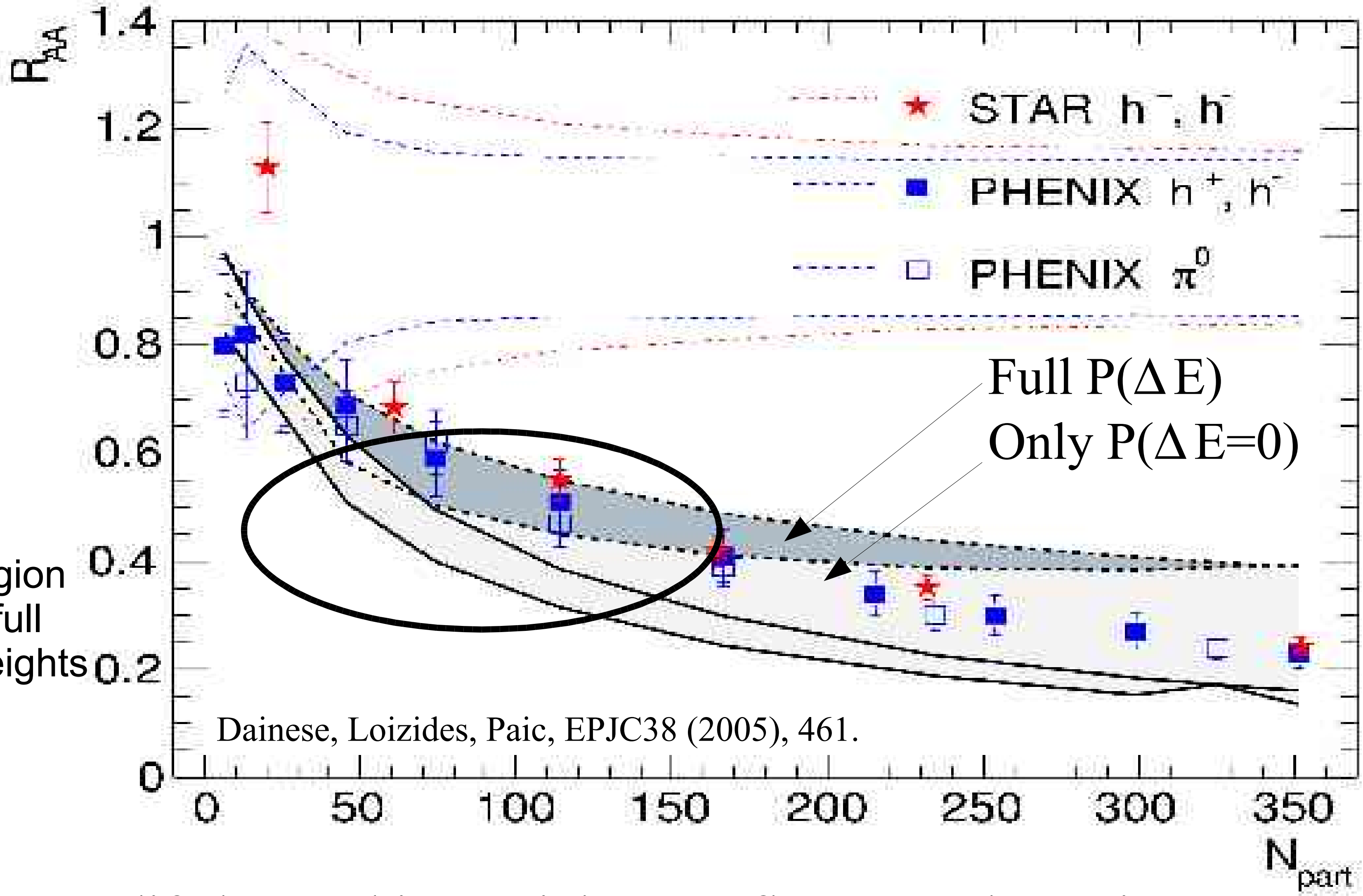


- Strong suppression requires very large densities
- Opaque medium leeds to surface emission
- R_{AA} determined by geometry rather than by density

→ **Study peripheral collisions or/and more differential observables**

Müller, PRC67 (2003) 061901.
Escola, Honkanen, Salgado, Wiedemann, NPA747 (2005) 511.

Construct extreme case of absorption

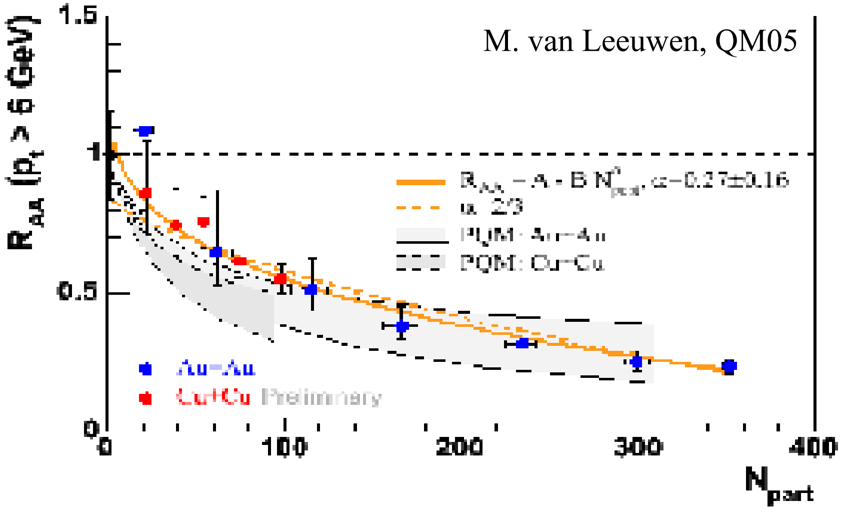


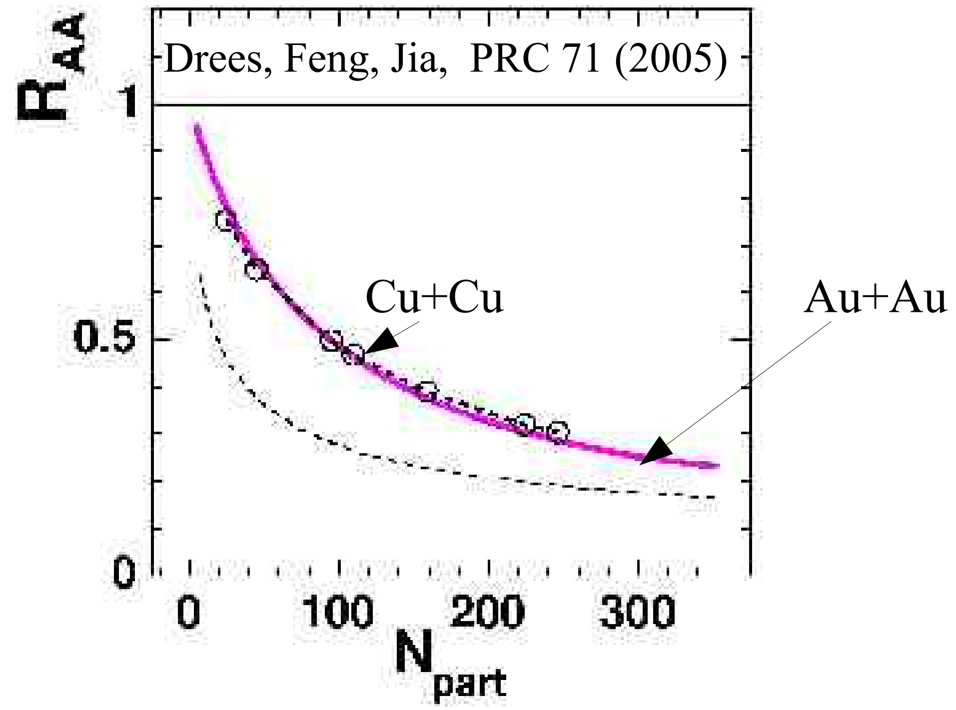
Interesting region which needs full quenching weights

Construct modifed quenching weights to reflect pure absorption:

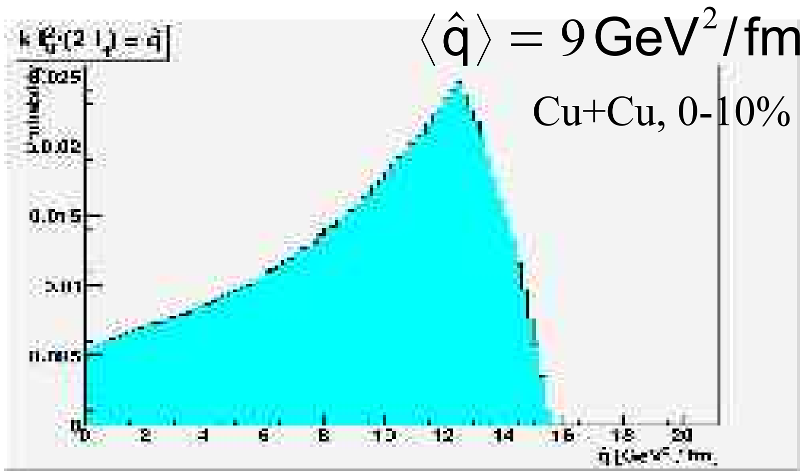
$$P^{mod}(\Delta E, E; H) \approx P(\Delta E=0, E; H)\, \delta(\Delta E) + (1 - P_0(\Delta E=0, E; H))\, \delta(E - \Delta E)$$

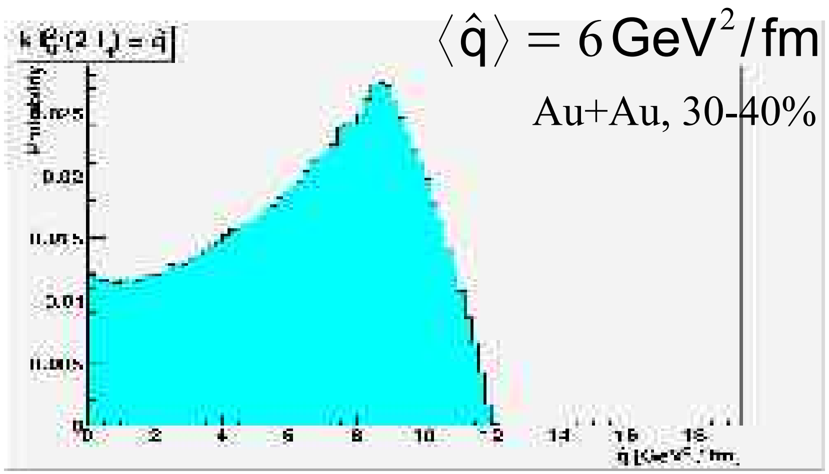
Simple(r) models are quite successful





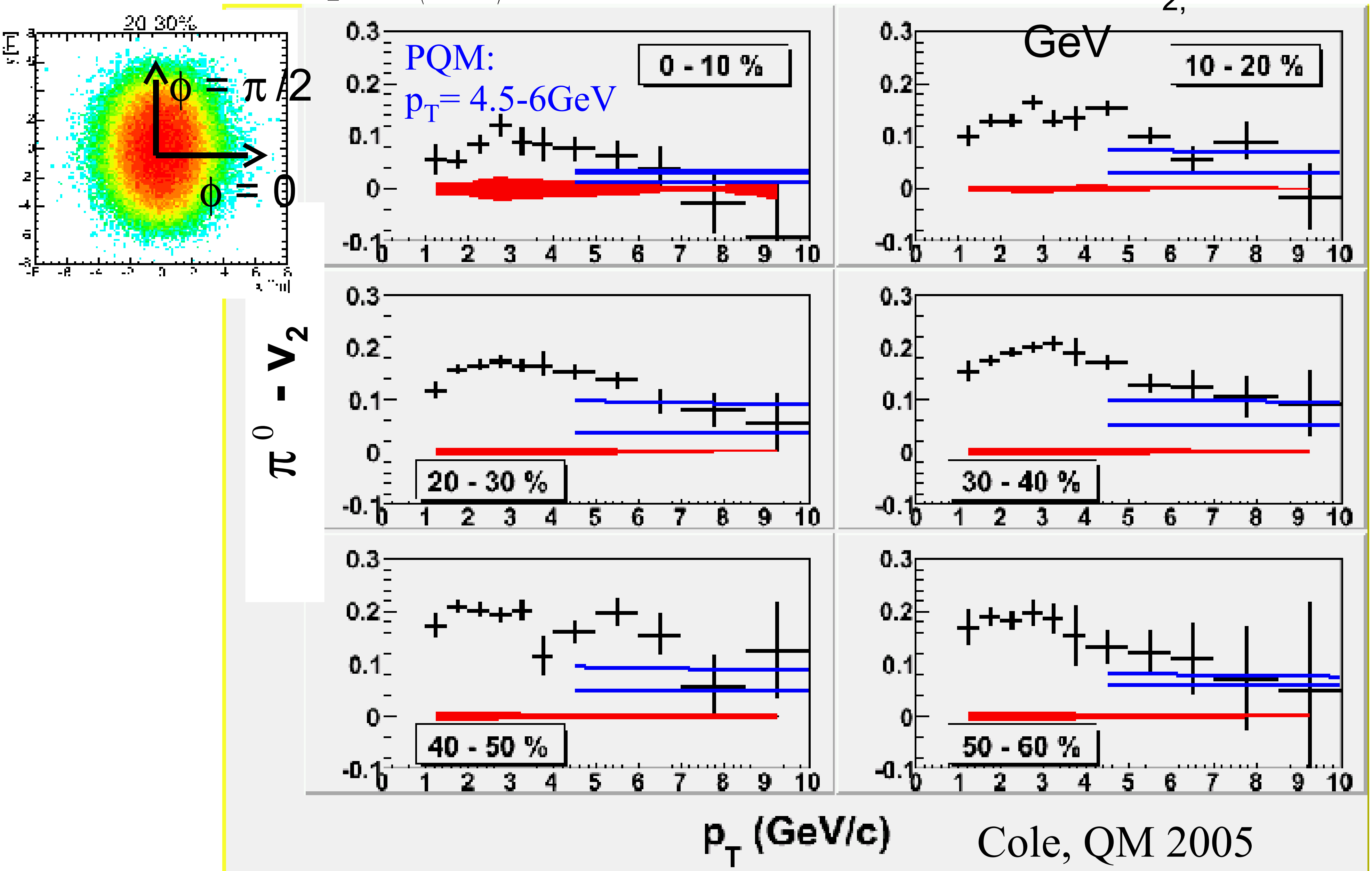
Need to refine our scaling with EKRT?





$dN/d\phi \propto 1 + 2 v_2 \cos(2\phi)$

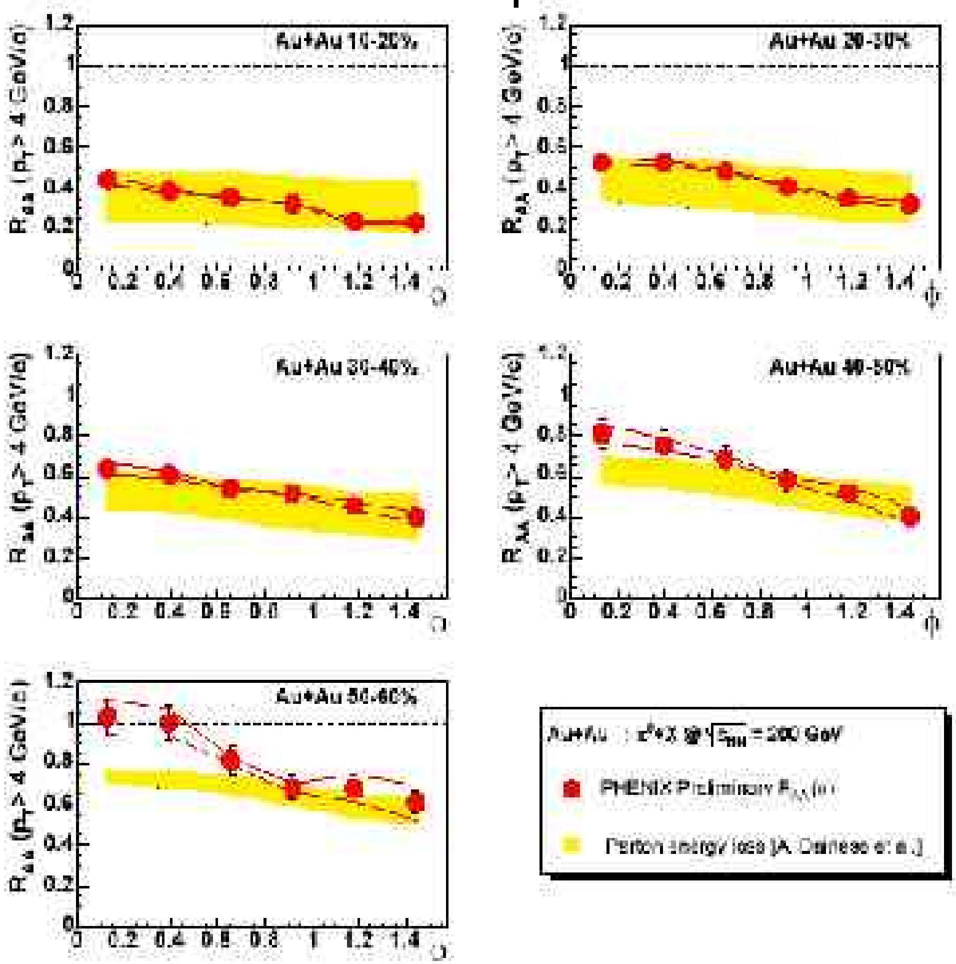
$\pi^0 - v_2$, 200 GeV



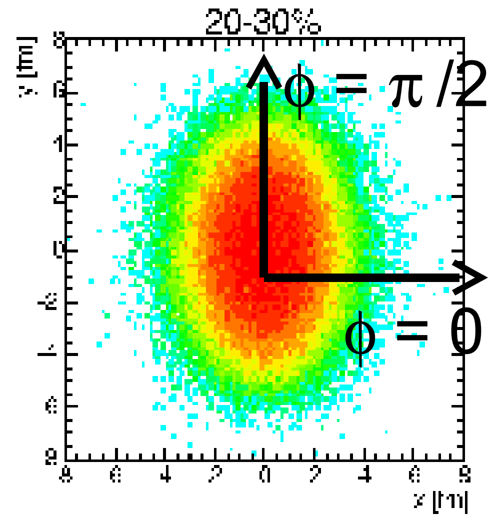
Cole, QM 2005

→ Further handle on *L*-dependence*

PHENIX π^0 prel. vs PQM



D. d'Enterria (nucl-ex/0504001)



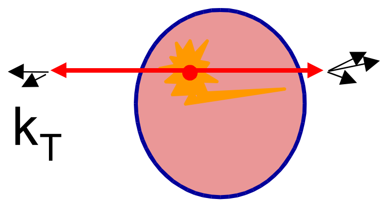
Data show stronger ϕ dep. than PQM model

Note: model is not $\Delta E \propto L^2$, rather $\Delta E \propto L$

* ***Beware:*** effect of collective flow on R_{AA} vs ϕ !?!

Away-side suppression within PQM

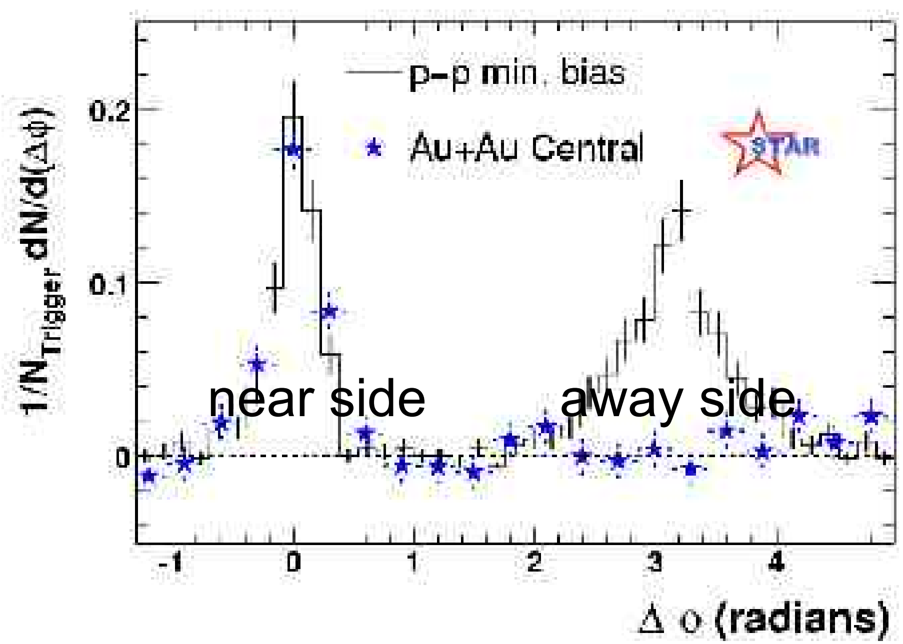
Back-to-back partons in PQM: no k_T

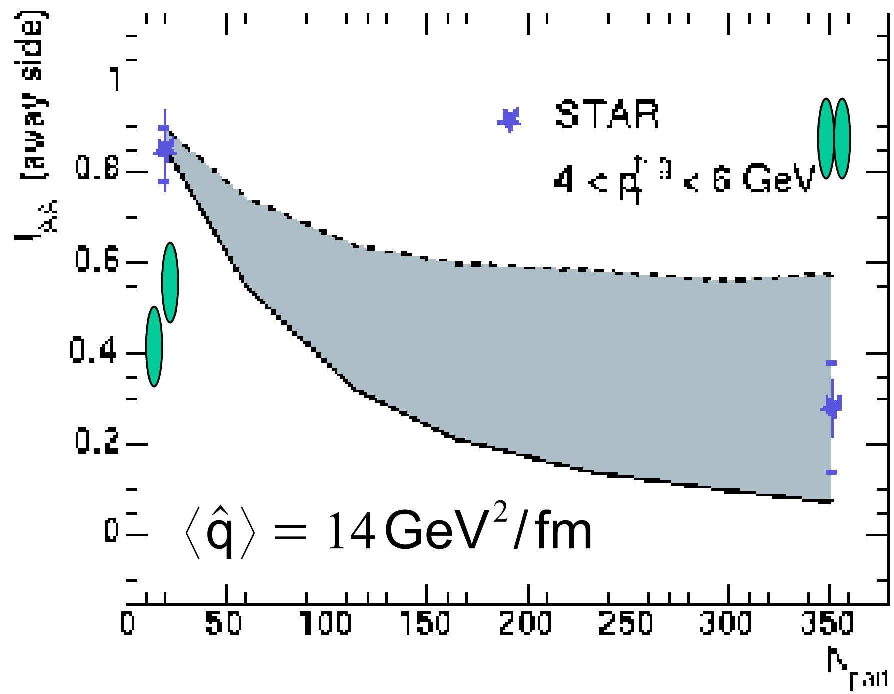


$$I_{AB}^{away} = \int_{away} dN_{AB} / \int_{away} dN_{pp}$$

Trigger $4 < p_T^{trigger} < 6$ GeV

$\Delta\phi$ distribution: 2 GeV $< p_T < p_T^{trigger}$





STAR Coll., PRL 90 (2003) 082302

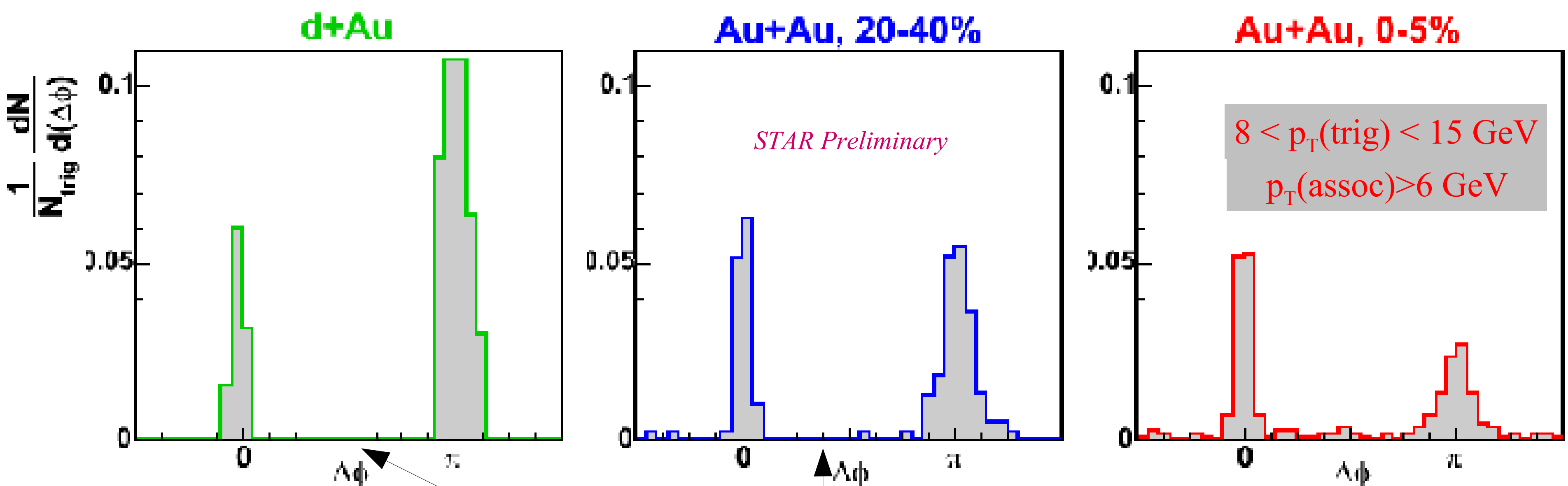
STAR Coll., nucl-ex/0501016

Dainese, Loizides, Paic, EPJC38 (2005), 461.

Emergence of true di-jets in AuAu

Au+Au Run4 allows jet-like two-particle correlations with much higher statistics

QM 2005, Dan Magestro

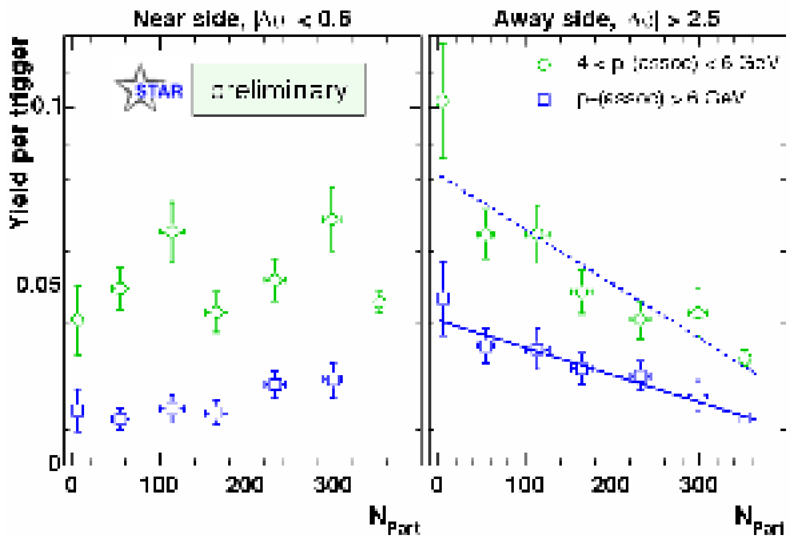


No background substraction!!!

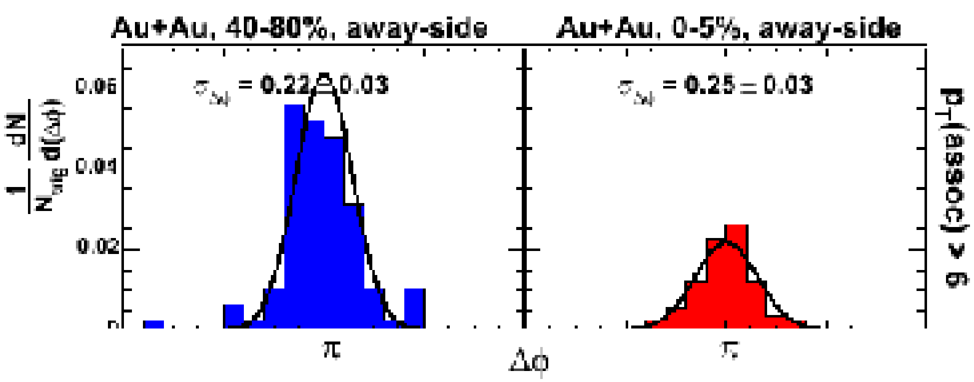
For the first time clear jet-like peaks seen on near + away-side in central Au+Au collisions

Combined di-jets observations

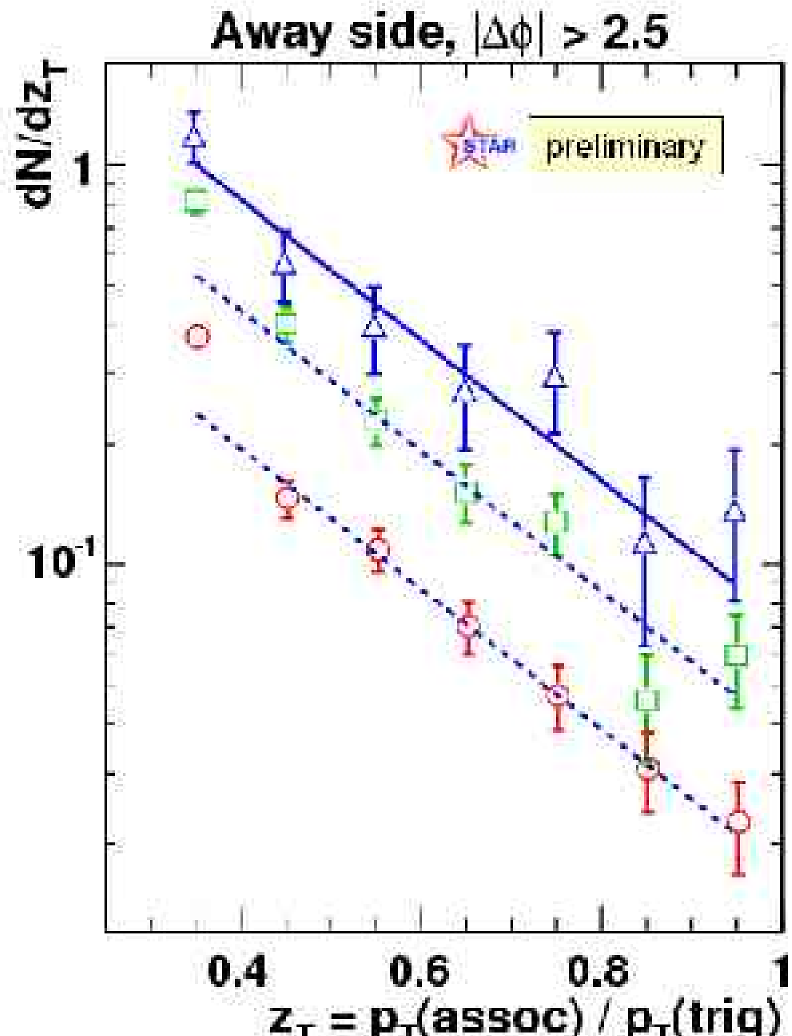
Dijets more suppressed from d+Au to central collisions



Away-side widths similar for central, noncentral



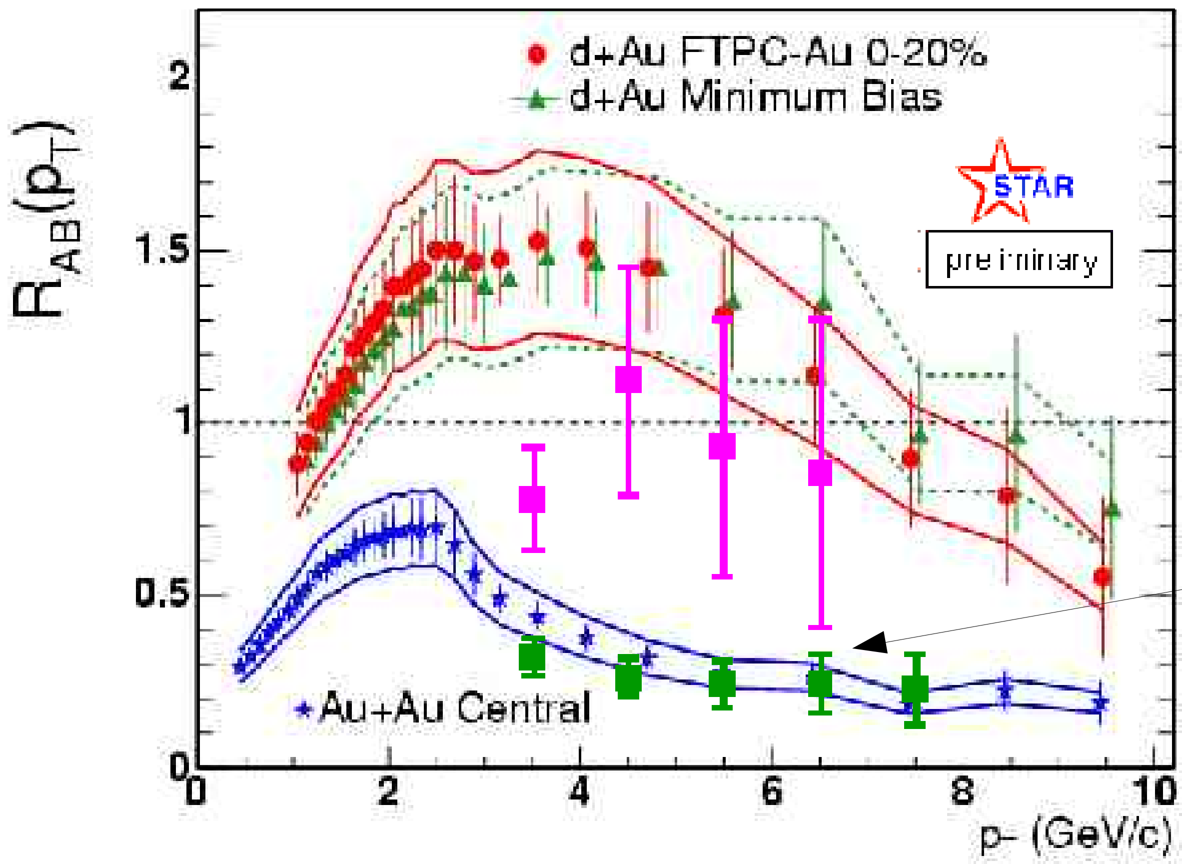
Away-side fragmentation pattern unchanged



QM 2005, courtesy Dan Magestro

Dijet associated yields (I_{AA})

STAR, Phys. Rev. Lett. 91 (2003) 072304



QM 2005, Dan Magestro

8 < p_T(trig) < 15 GeV/c

= Near-side I_{AA}

= Away-side I_{AA}

I_{AA}=0.2-0.3

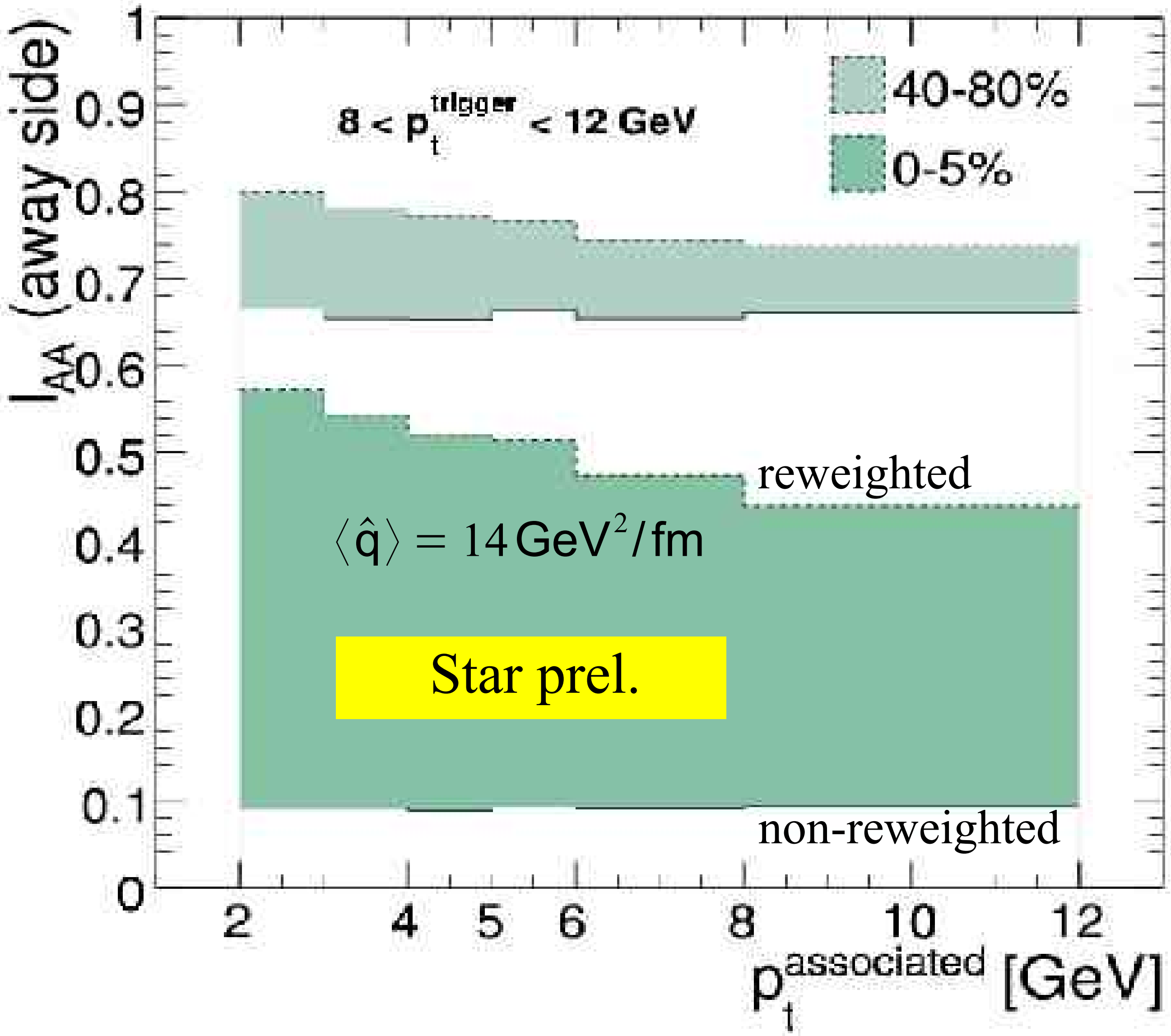
I_{AA} = Yield(0-5% Au+Au) / Yield(d+Au)

- Near-side yields consistent with unity
- Away-side associated yields similar to R_{AA} values

PQM prediction before QM 2005

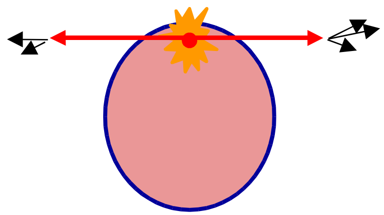
Density ($\hat{q}$) still "tuned" to match R_{AA} in central Au+Au at 200 GeV

$$I_{AB}^{away} = \int_{away} dN_{AB} / \int_{away} dN_{pp}$$



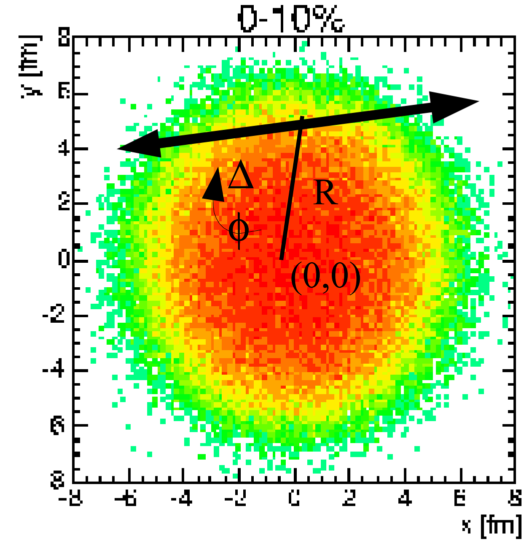
Reweighted approach leads to large systematic error (see next slide)

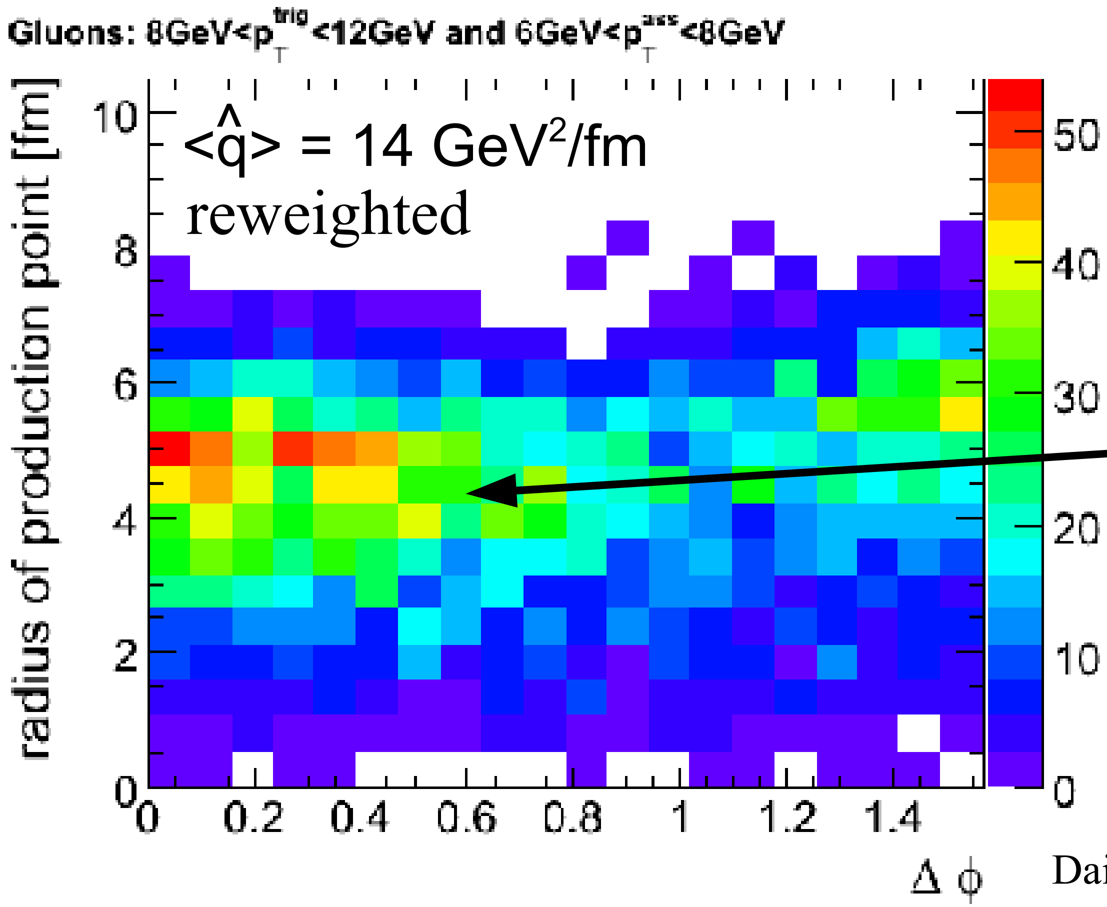
PQM: Tangential di-jet emission?



transverse plane

What is the phase space of parton pairs which yield hadrons that contribute to the away-side I_{AA}?





Unphysical "second channel" introduced by reweighting!!!

Dainese, Loizides, Paic, nucl-ex/0511045

R_{AA} for non-reweighted band

Constrained quenching weights fulfill:

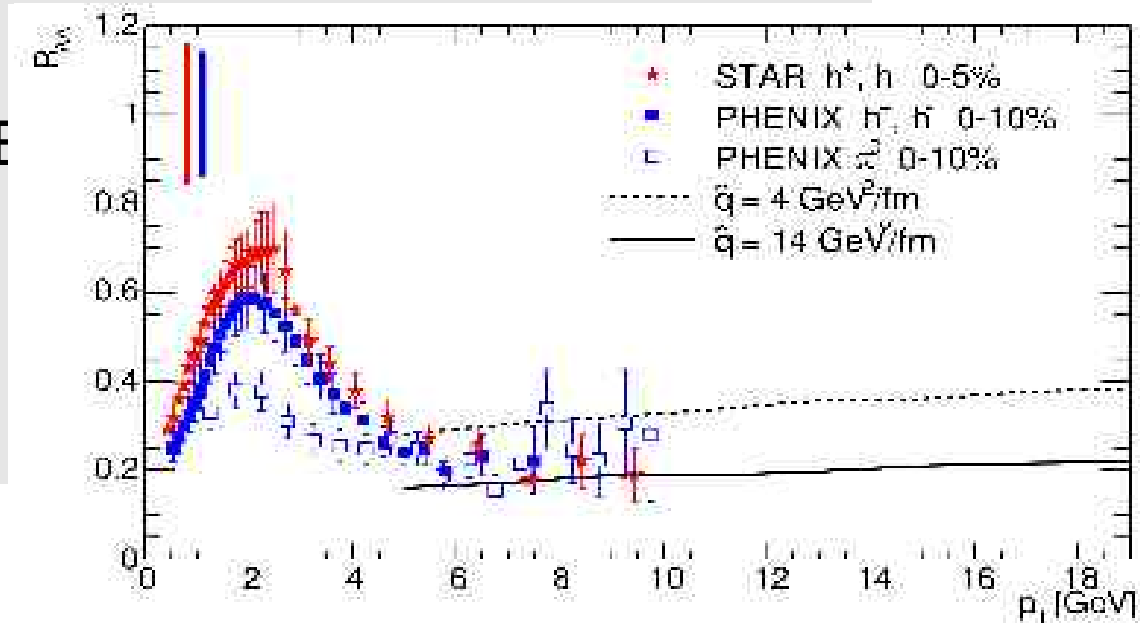
$$\lim_{E\to\infty} P^{rw}(\Delta E, E) = \lim_{E\to\infty} P^{nrw}(\Delta E, E) = P(\Delta E)$$

For dense medium:

$$\lim_{L \text{ or } \hat{q}\to\infty} P^{nrw}(\Delta E = 0, E$$

However,

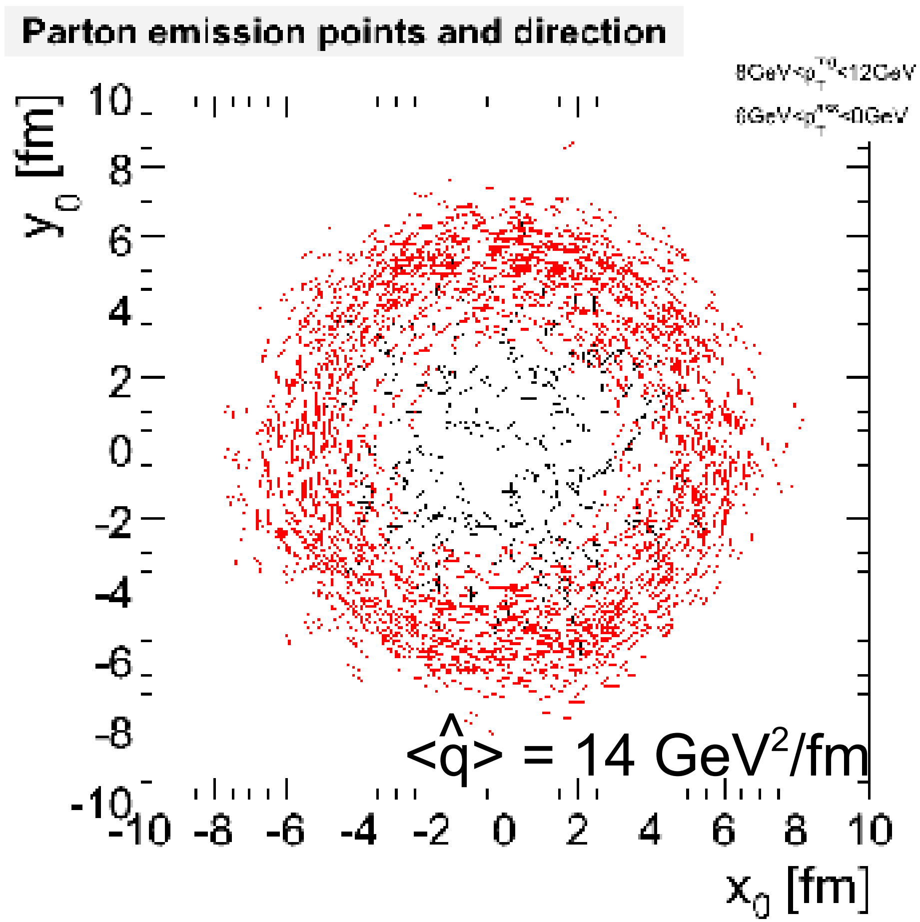
$$\lim_{L \text{ or } \hat{q}\to\infty} P^{rw}(\Delta E, E) >$$

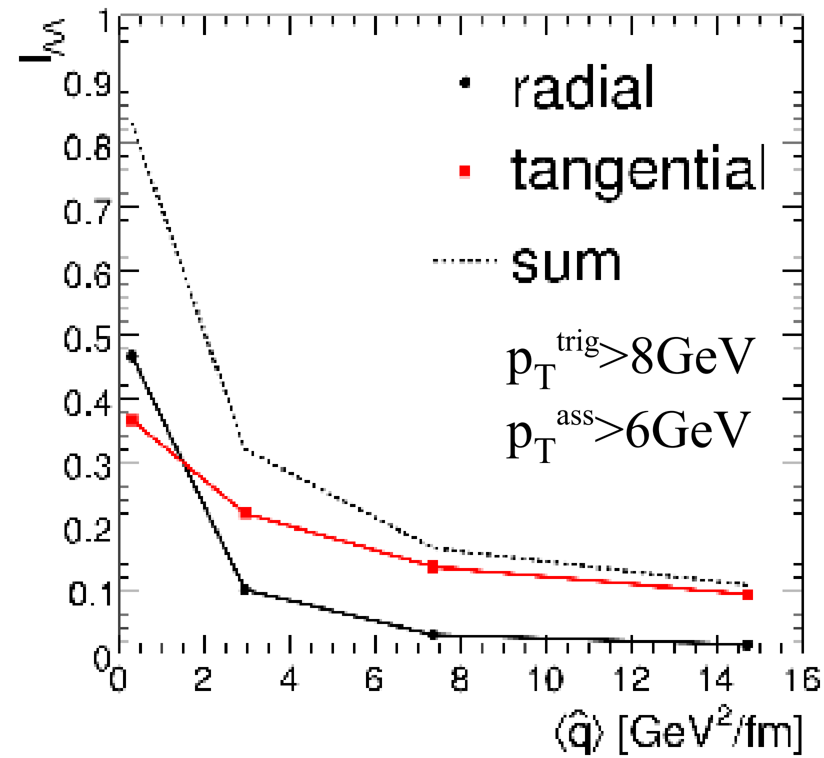


Use non-reweighted only

$$\langle \hat{q} \rangle = 4 - 14\, \text{GeV}^2/\text{fm}$$

PQM: Tangential di-jet emission?





Radial (black): one jet crosses inner core of R=2.5 fm

Tangential (red) lines: none of the jets crosses inner core

➡ **Large medium density biases dijets towards edges of surface ("tangential emission")**

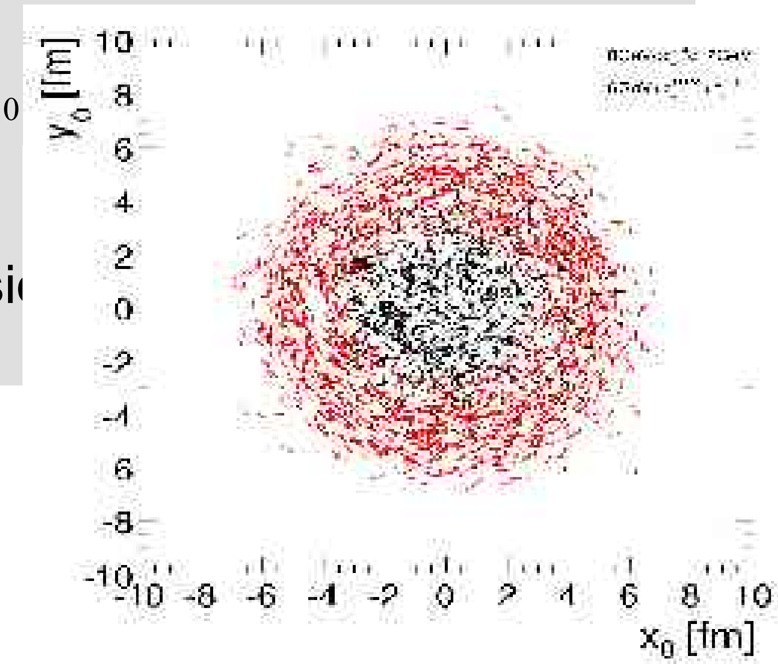
Müller, PRC67 (2003) 061901.
Dainese, Loizides, Paic, QM 2005 Poster.

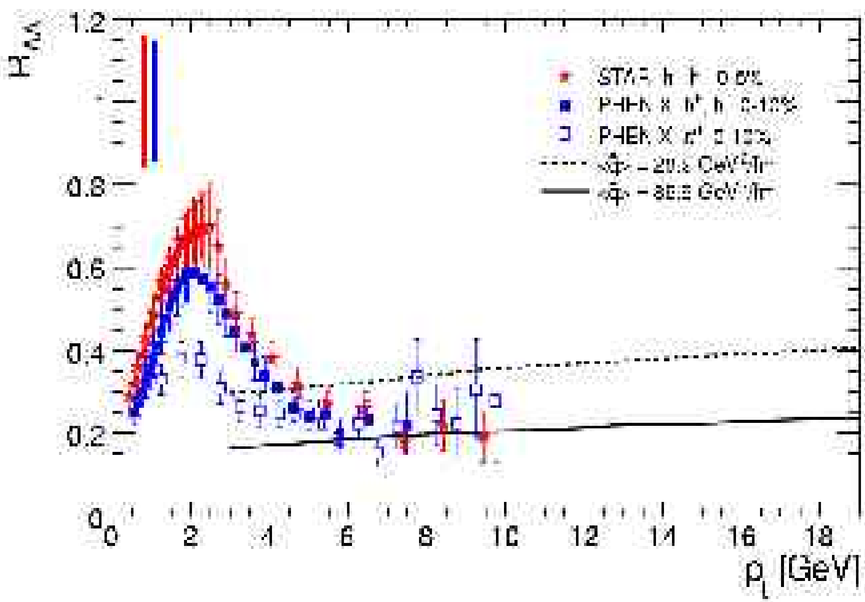
Static scenario vs. Bjorken expansion

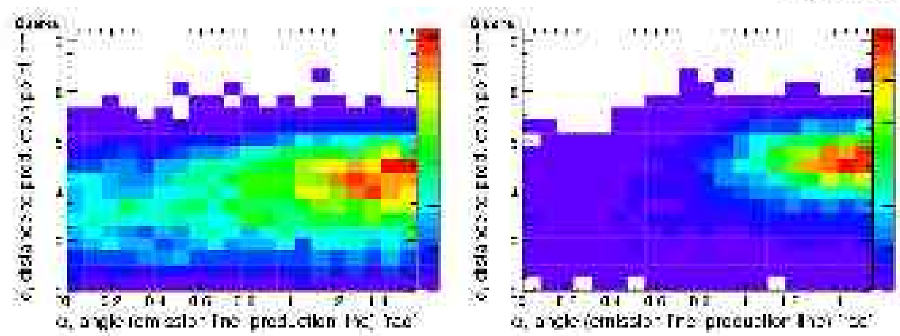
- Define time-dependent "local" transport coefficient

$$\hat{q}(\xi; x_{0,} y_{0,} \phi_0; b) = \left(\frac{\tau_0}{\tau_0 + \xi}\right)^{\alpha} \times k \times T_A T_B(x_0$$

- So far, α =1 in one-dim Bjorken expansi





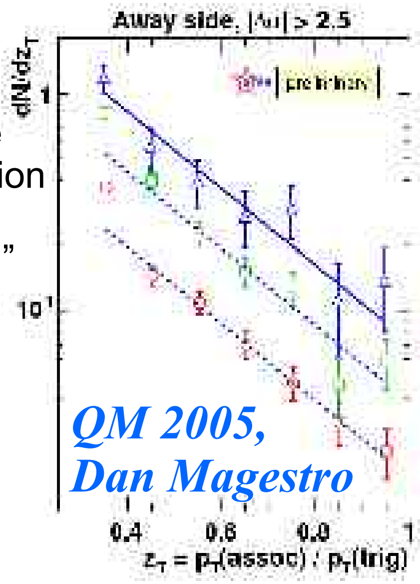


No qualitative change

Static scenario vs. Bjorken expansion

	Static	1-dim Bjorken a =1
Medium	7 GeV^2/fm	58 GeV^2/fm
R_{AA} (10GeV)	0.25	0.25
IAA (highest cuts)	0.13	0.16
dE/dx (all partons)	2 GeV/fm	4-5 GeV/fm
dE/dx (all survivors)	200-300 MeV/fm	200-300 MeV/fm
dE/dx (away jet)	20 MeV/fm	40 MeV/fm

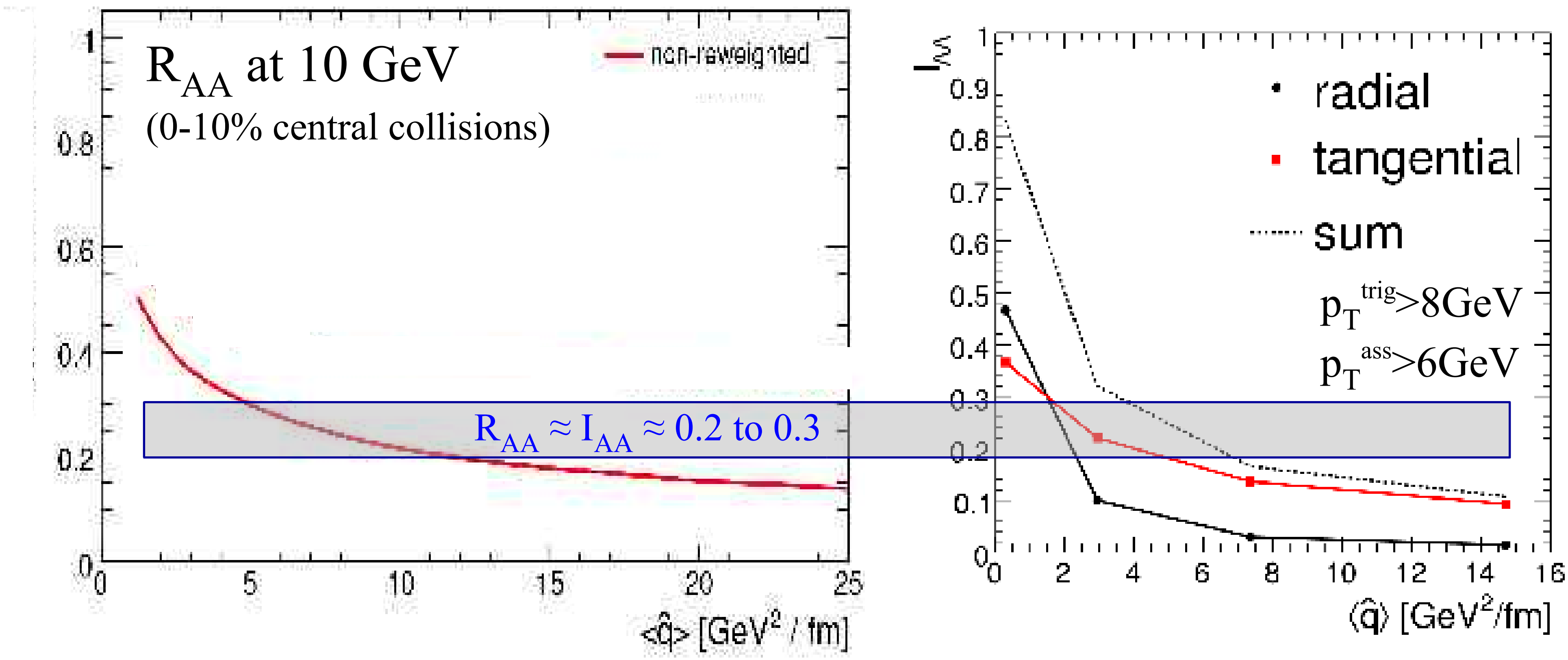
"Away-side fragmentation pattern unchanged"



Due to the trigger bias, the energy loss the surving partons suffered is of the order of cold nuclear matter. Dijets essentially emerge in vacuum.

Dainese, Loizides, Paic, nucl-ex/0511045

PQM: Putting pieces together

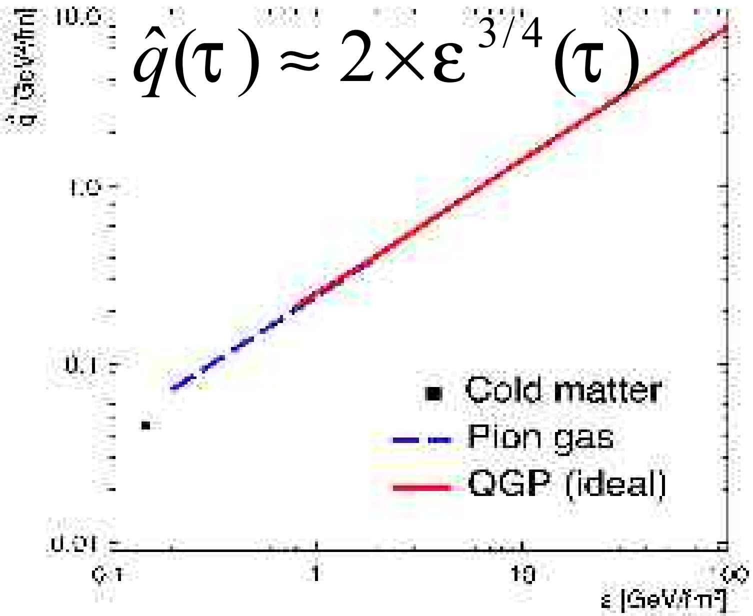


Consistently R_{AA} and I_{AA}

$$\langle \hat{q} \rangle = 4 - 8\,\mathrm{GeV}^2/\mathrm{fm}$$

The opacity problem

- To what extent do we probe the medium?
  And to what extent do we control the probe?
- Need to relate extracted $\hat{q}$ to energy density ε
- QCD estimate for ideal QGP: $c^{pQCD} = 2$



- Estimate $c = \dfrac{q(\tau_0)}{\epsilon(\tau_0)^{4/3}}$
- using $\hat{q}(\tau) = \hat{q}_0 \times \left(\dfrac{\tau_0}{\tau}\right)^{\alpha}$

  and $\bar{\hat{q}} = \dfrac{2}{L^2} \int_{\tau_0}^{L+\tau_0} d\tau (\tau - \tau_0)\, \hat{q}(\tau)$
- For $\epsilon(\tau_0) \leq 100\,\mathrm{GeV/fm^3}$

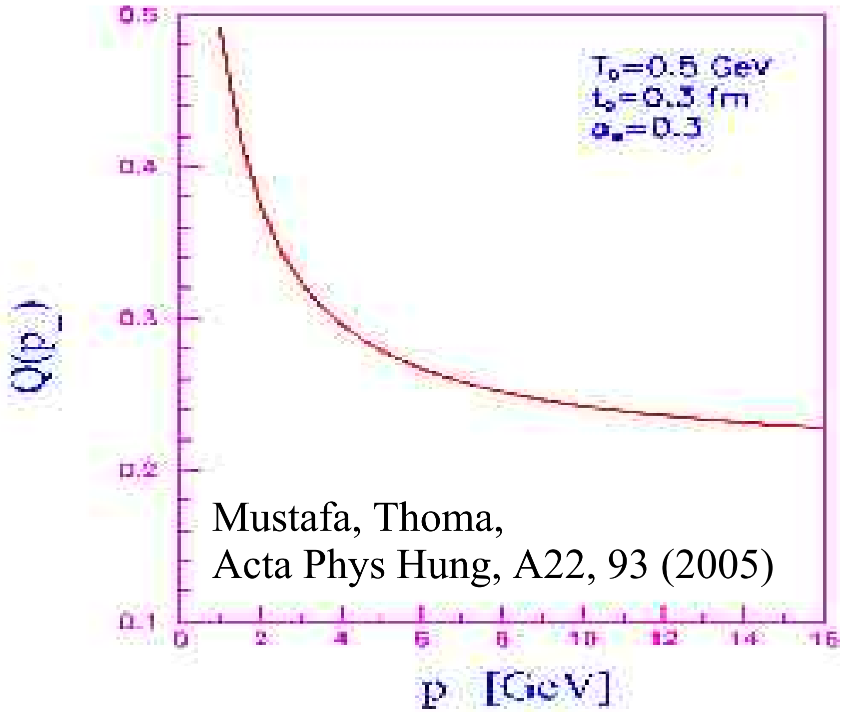
  and $0.75 < \alpha < 1$

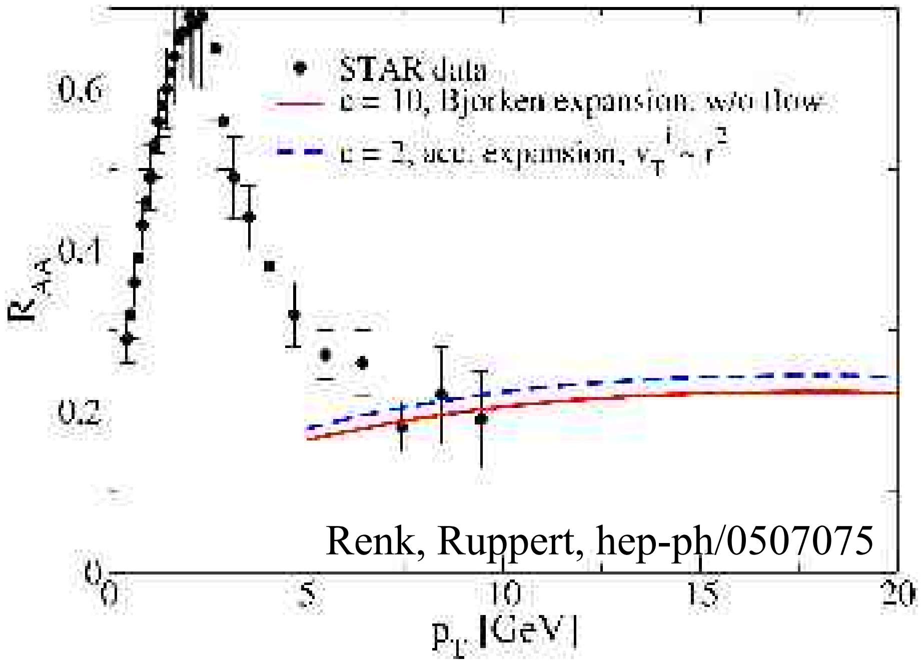
$\Rightarrow$ $c = 8 \ldots 20$

The interaction of the hard parton with the medium is much stronger than (perturbatively) expected

R.Baier, Nucl. Phys. A715 (2003) 209
Escola, Honkanen, Salgado, Wiedemann, NPA747 (2005) 511.

The opacity problem (2)





- Collisional energy
  - Boltzmann Transport
  - Bjorken Expansion
- Cylinder geometry used
  - Realistic geometry ?

- Transverse flow
- Local transport coefficient

$$\langle \hat{q} \rangle = c\ \epsilon^{3/4} \left(T^{n_T} T^{n-T} \right)$$

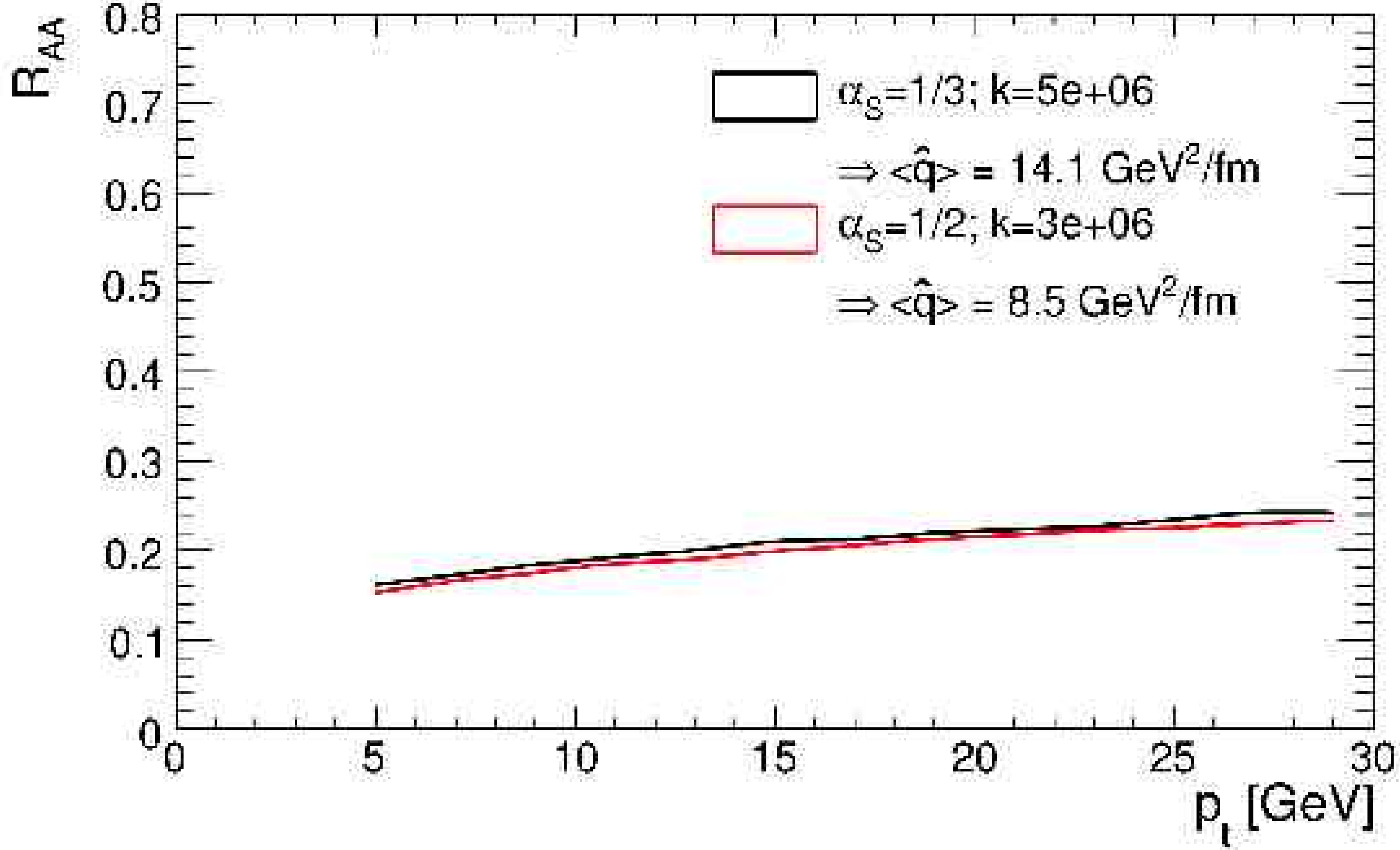
- Fireball model for expansion (transverse and longitudinal)

Summary

- Parton Quenching Model
  - BDMPS framework with Glauber geometry
  - Simple model with one single parameter
  - Quite consistently describes most high-p_T RHIC data
  - Reveals trigger biases in R_{AA} and I_{AA}
    - Dijets emerge in vacuum; its fragmentation properties are unaltered.
- Recent data shown at QM 2005 constrains
  - Light probes $\langle \hat{q} \rangle = 4 - 8\,\mathrm{GeV}^2/\mathrm{fm}$
  - Heavy probes $\langle \hat{q} \rangle = 4 - 14\,\mathrm{GeV}^2/\mathrm{fm}$ (see Armesto et.al, hep-ph/0511257)
- Opacity problem:
  - Need to include collisional energy loss?
  - Need to include transverse flow?
  - Need to include hadronic rescattering?

Backup Slides

Change to larger α_S

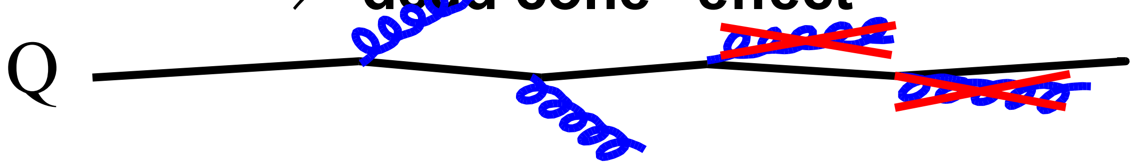


Lower E loss for heavy quarks ?

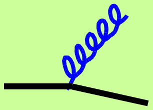
Courtesy by A.Dainese

- In vacuum, gluon radiation suppressed at $\theta < m_Q/E_Q$

→ **"dead cone" effect**



Gluonsstrahlung probability

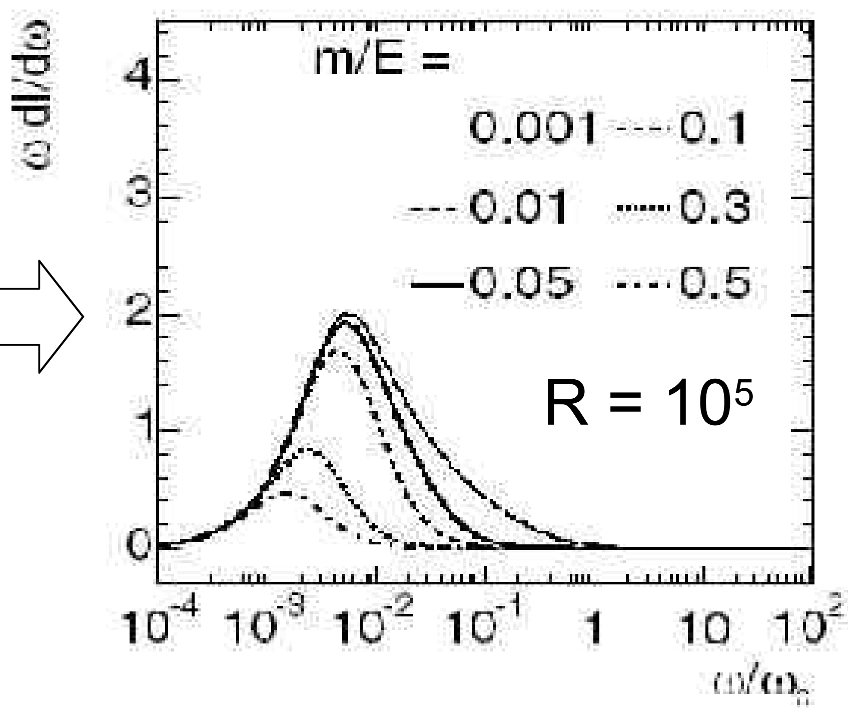


$$\propto \frac{1}{[\theta^2 + (m_Q/E_Q)^2]^2}$$

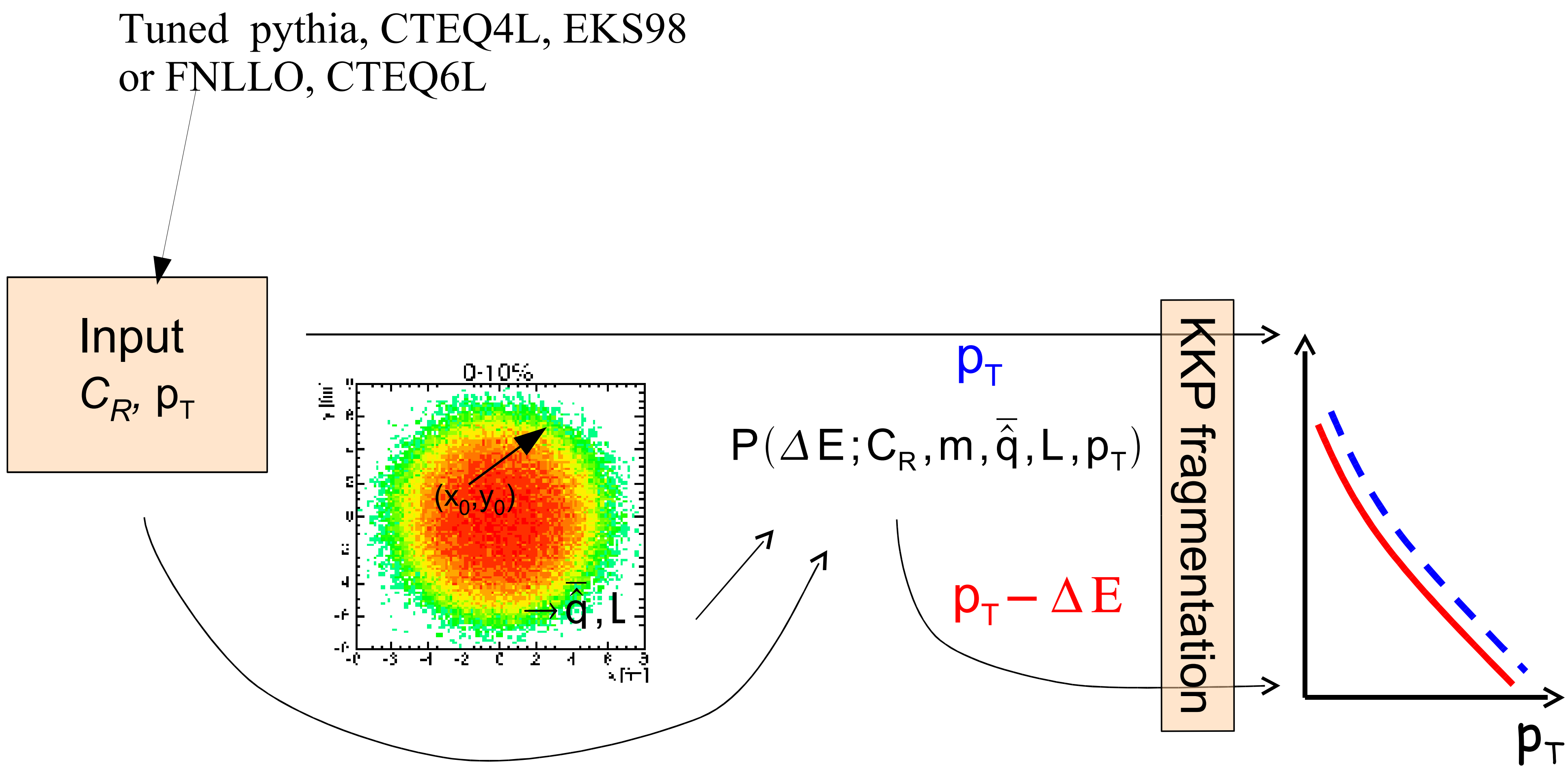
- *Dead cone implies lower energy loss* (Dokshitzer-Kharzeev, 2001):
  - energy distribution $\omega\ dI/d\omega$ of radiated gluons suppressed by angle-dependent factor
  - suppress high-ω tail

Detailed massive calculation confirms this qualitative feature

(Armesto, Salgado, Wiedemann, PRD 69 (2004) 114003)



Dokshitzer, Khoze, Troyan, JPG 17 (1991) 1602.
Dokshitzer and Kharzeev, PLB 519 (2001) 199.

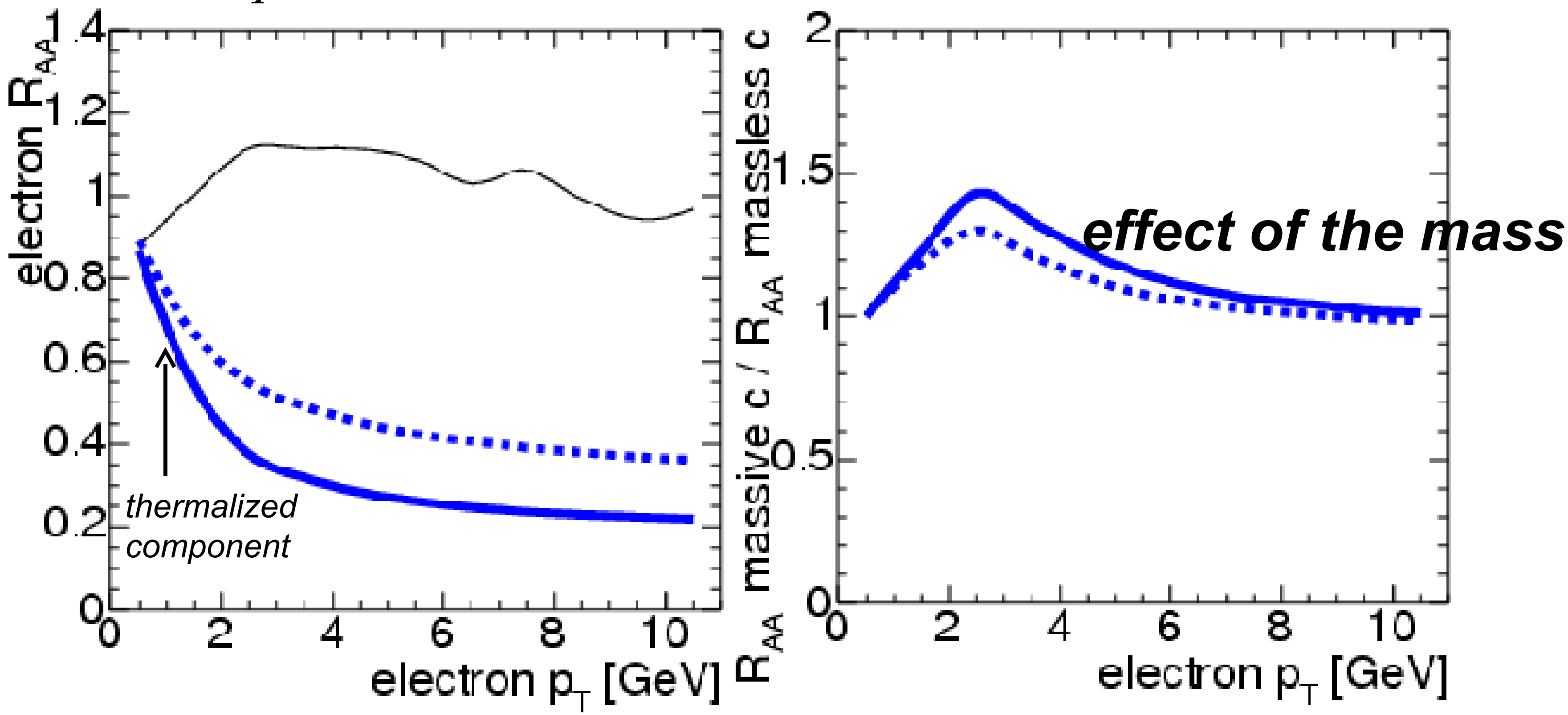


Tuned pythia, CTEQ4L, EKS98
or FNLLO, CTEQ6L
Input
C_R, p_T
0-10%
(x_0,y_0)
$\to \bar{\hat{q}}, L$
$P(\Delta E; C_R, m, \bar{\hat{q}}, L, p_T)$
p_T
$p_T - \Delta E$
KKP fragmentation
p_T

Charm R_{AA} at RHIC

Courtesy by A.Dainese

$\hat{q} = 4 \div 14\ \mathrm{GeV}^2/\mathrm{fm}$ (extracted from light-hadron data)



Small effect of mass for charm (~50% for D, ~30% for e) at low p_T [large uncertainties!]

Basically no effect in "safe" p_T-region

Armesto, Dainese, Salgado, Wiedemann, PRD 71 (2005) 054027.

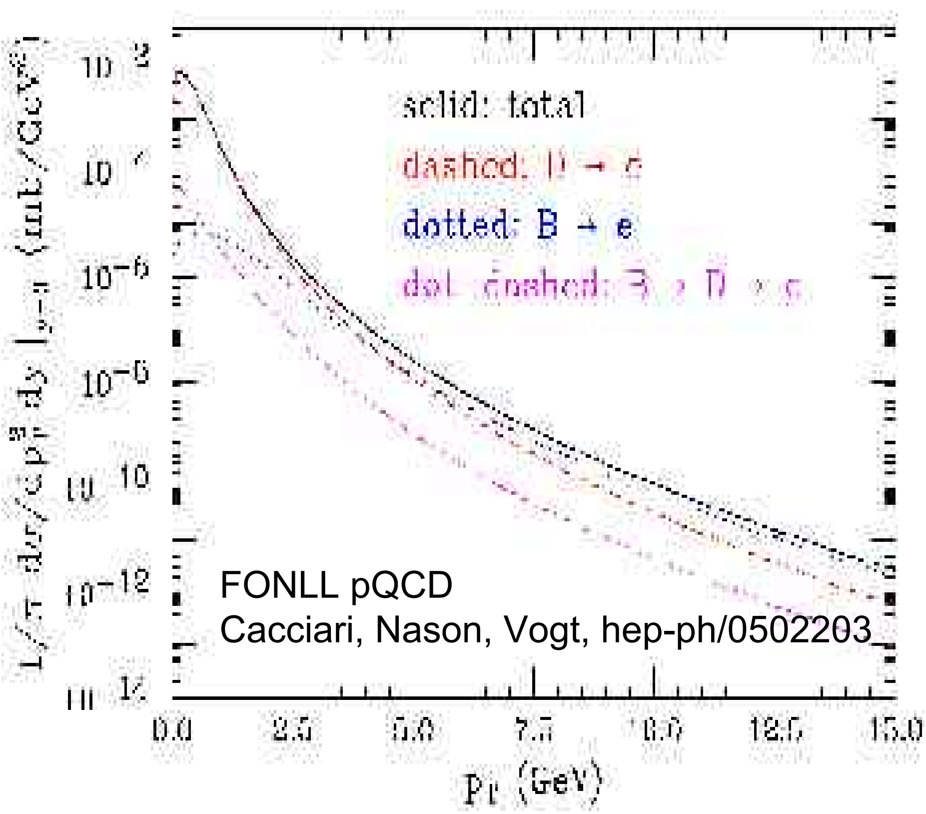
Role of beauty at RHIC?

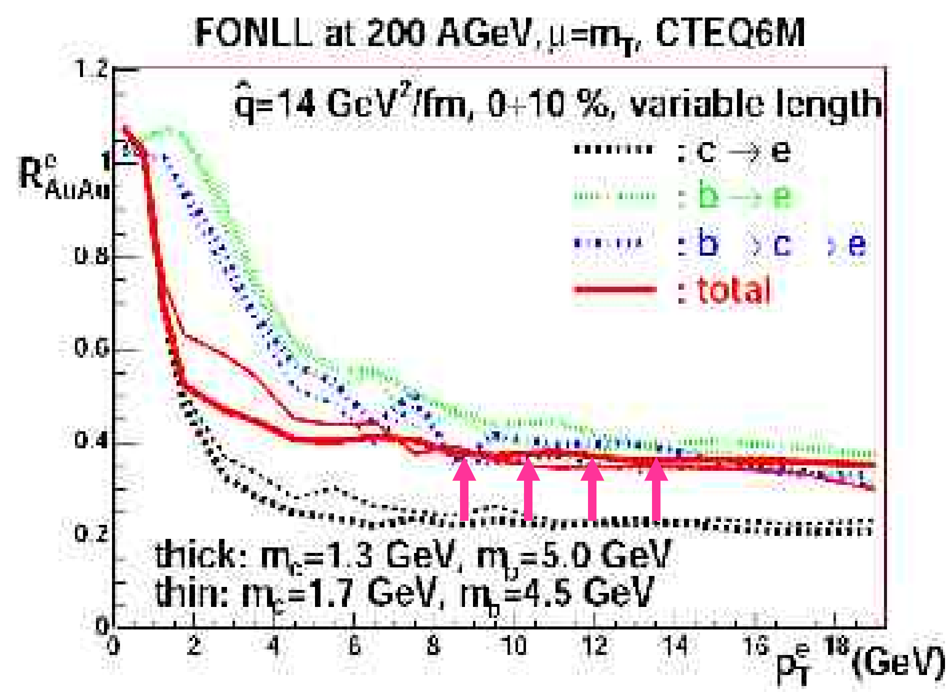
c + b (?) decay $e^{\pm}$ R_{AA} at RHIC

Courtesy by A.Dainese

FONLL:
Electron spectrum may be
~50% charm + ~50% beauty
for 3 < p_T < 8 GeV

Due to larger mass of b quark electron R_{AA} incresed by ×2
(mass uncertainty also studied)

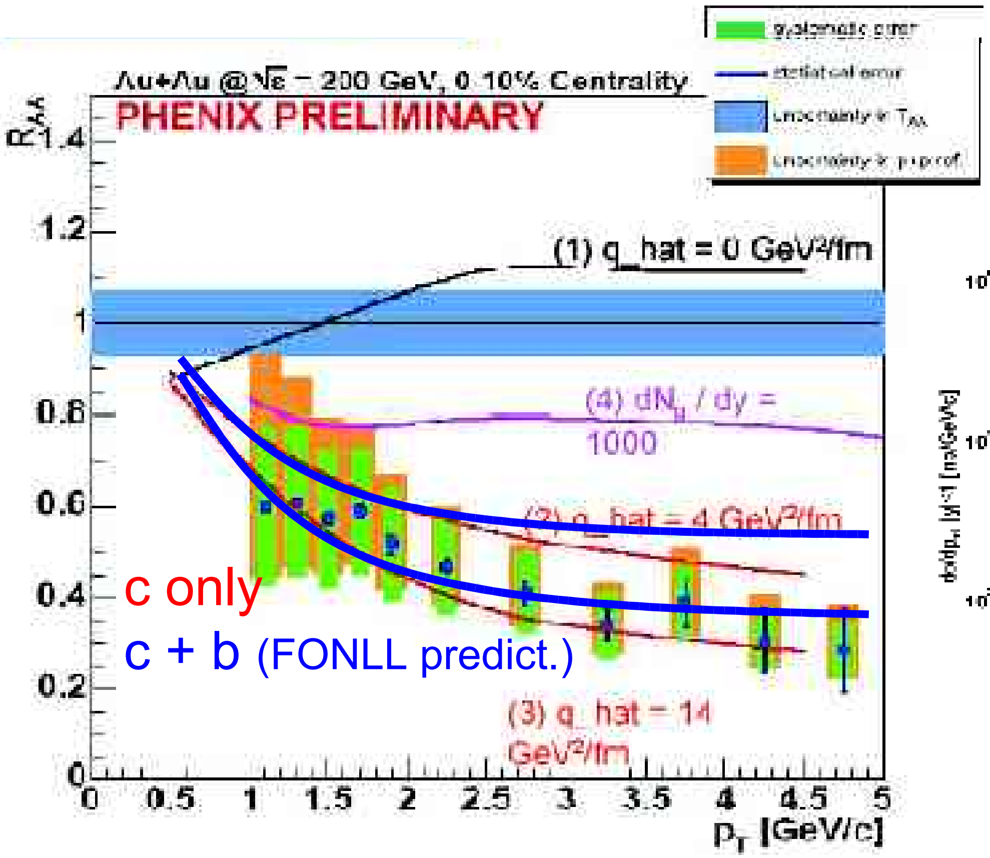




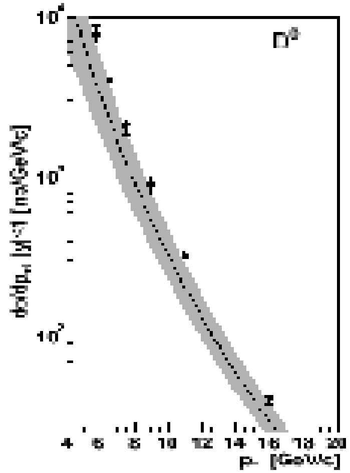
Armesto, Cacciari, Dainese, Salgado, Wiedemann, in preparation,
Armesto @ Quark Matter 05

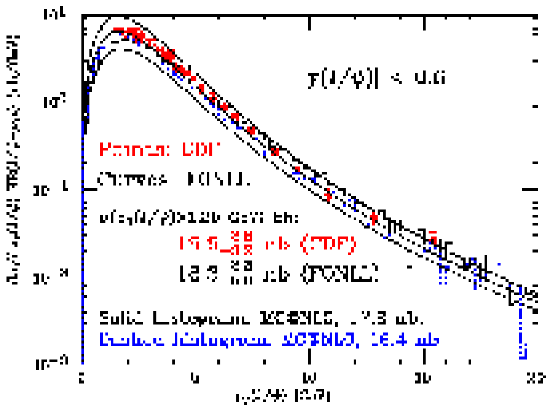
Heavy-flavour data in Au-Au 200 GeV

Courtesy by A.Dainese



Reminder: FONLL@Tevatron:
D production underpredicted
B, instead, is OK





R_{AA} down to 0.3 for p_T > 4 GeV/c! Heavy-quark quenching.

Similar to that of light! Small room for mass effect …

Comparison to predictions: compatible, provided the charm fraction is higher than predicted by FONLL

Armesto, Dainese, Salgado, Wiedemann, PRD 71 (2005) 054027 + w/Cacciari, in preparation