Soft sector: promises, promises...

- $\varepsilon \sim 10$ GeV/fm^3 >> ε_C (Bjorken / hydro)
- Early thermalization (v2 / hydro)

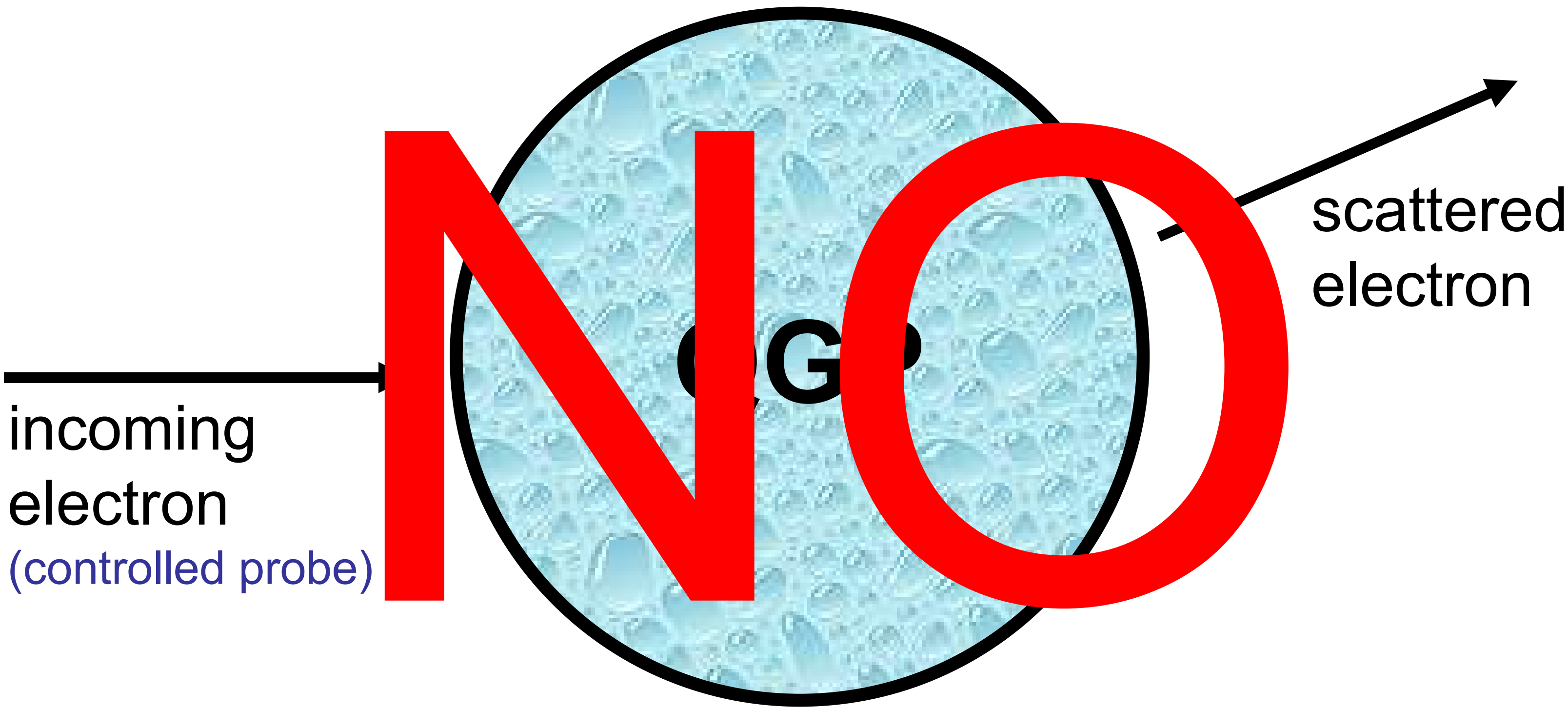
- $T_{chem} \sim T_H \sim T_c \sim 170$ MeV
- $\mu_b \sim 30$-40 MeV -- near baryon free $\rightarrow$ connection to lattice?

- further evolution (P·dV work?) & expansion leading to...
- cooling and bulk collective motion (pT spectra, v2, HBT, K-π)

Can we use an external probe to explore further?

Discovery and Properties: The Ideal Experiment

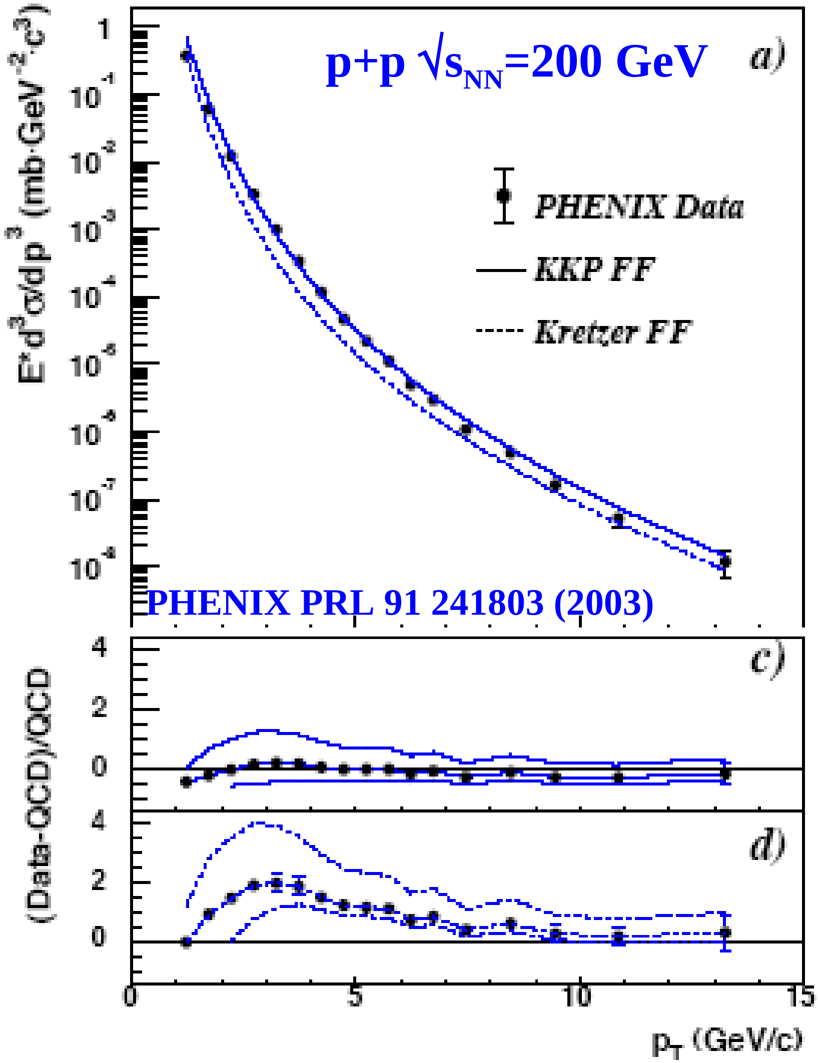
Can we do the same at RHIC?



But we can get close ………

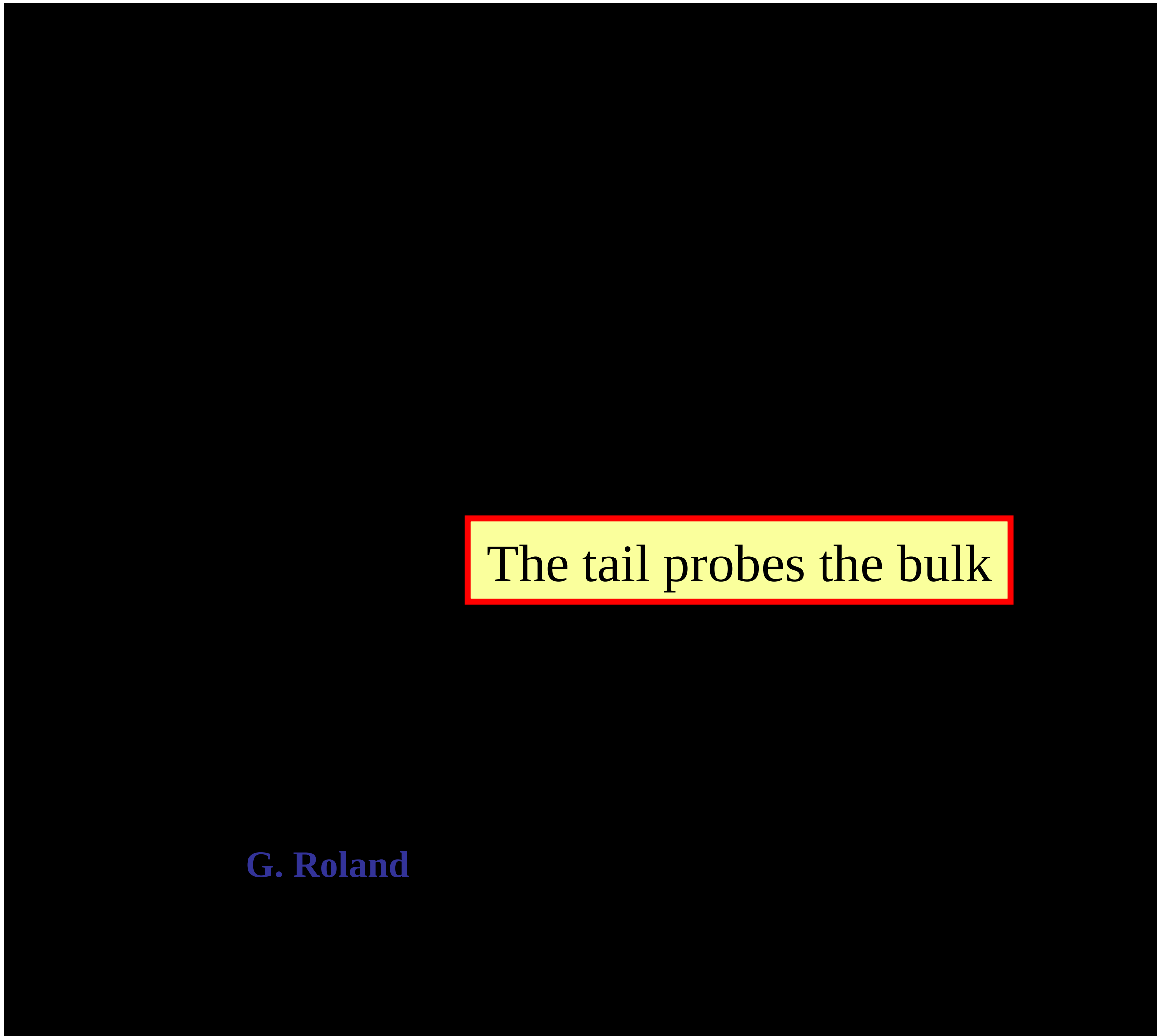
Fast Partons (Quarks & Gluons) Traversing Matter

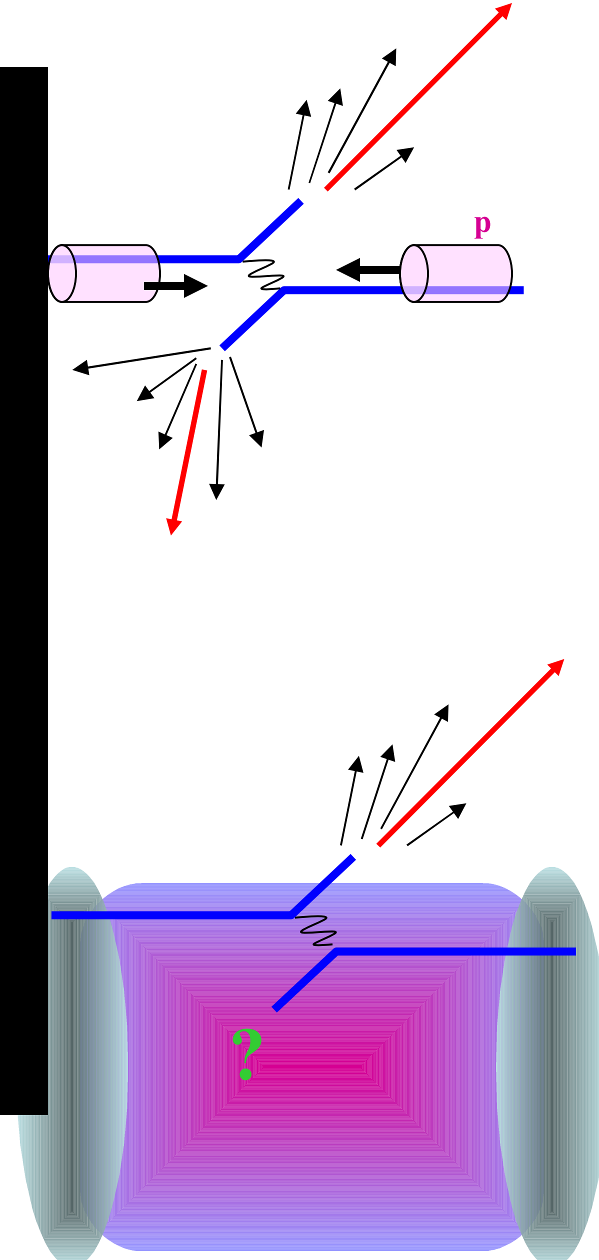
- Jets:
  - high-p_T parton produced in a hard (high-Q) scatt process
  - Calculable in QCD (at high-p_T)
  - partons fragment into many correlated white had
    - emitted in a cone
  - created **early** in the collision



leading particle
(highest-p particle)

Fate of jets in heavy ion collisions?





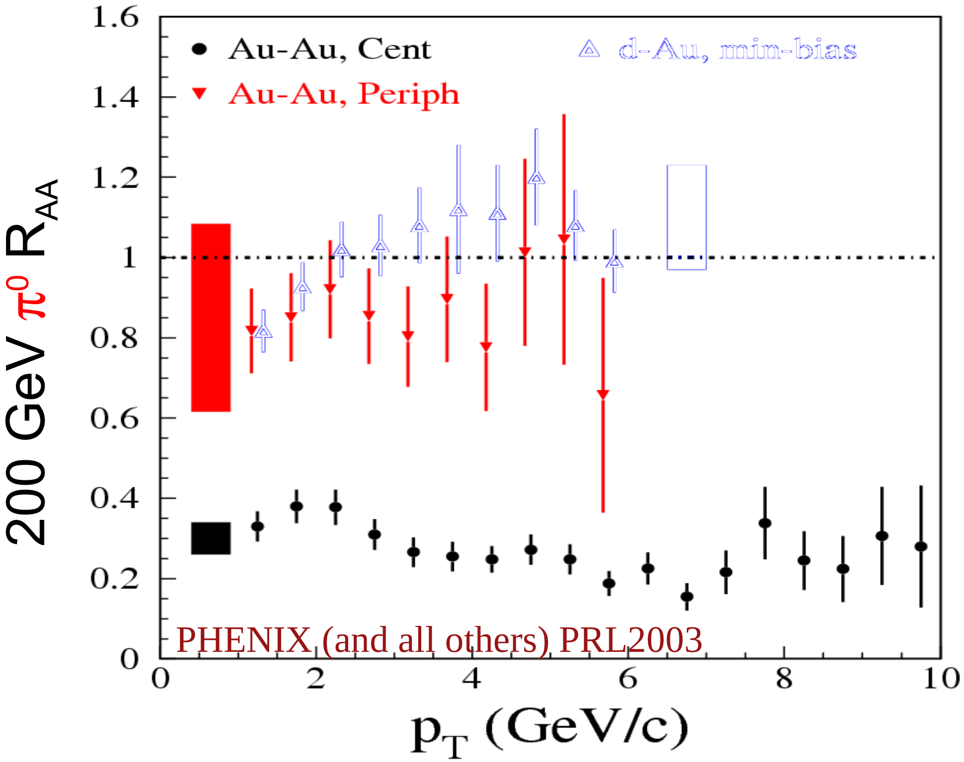
Au+Au

The Ubiquitous R_{AA}…

5x fewer high p_T particles than "expected" in AuAu

Required checks:

- saturation (initial-state) effect?



Nuclear overlap model to calculate # incoherent NN collisions (no shadowing etc)

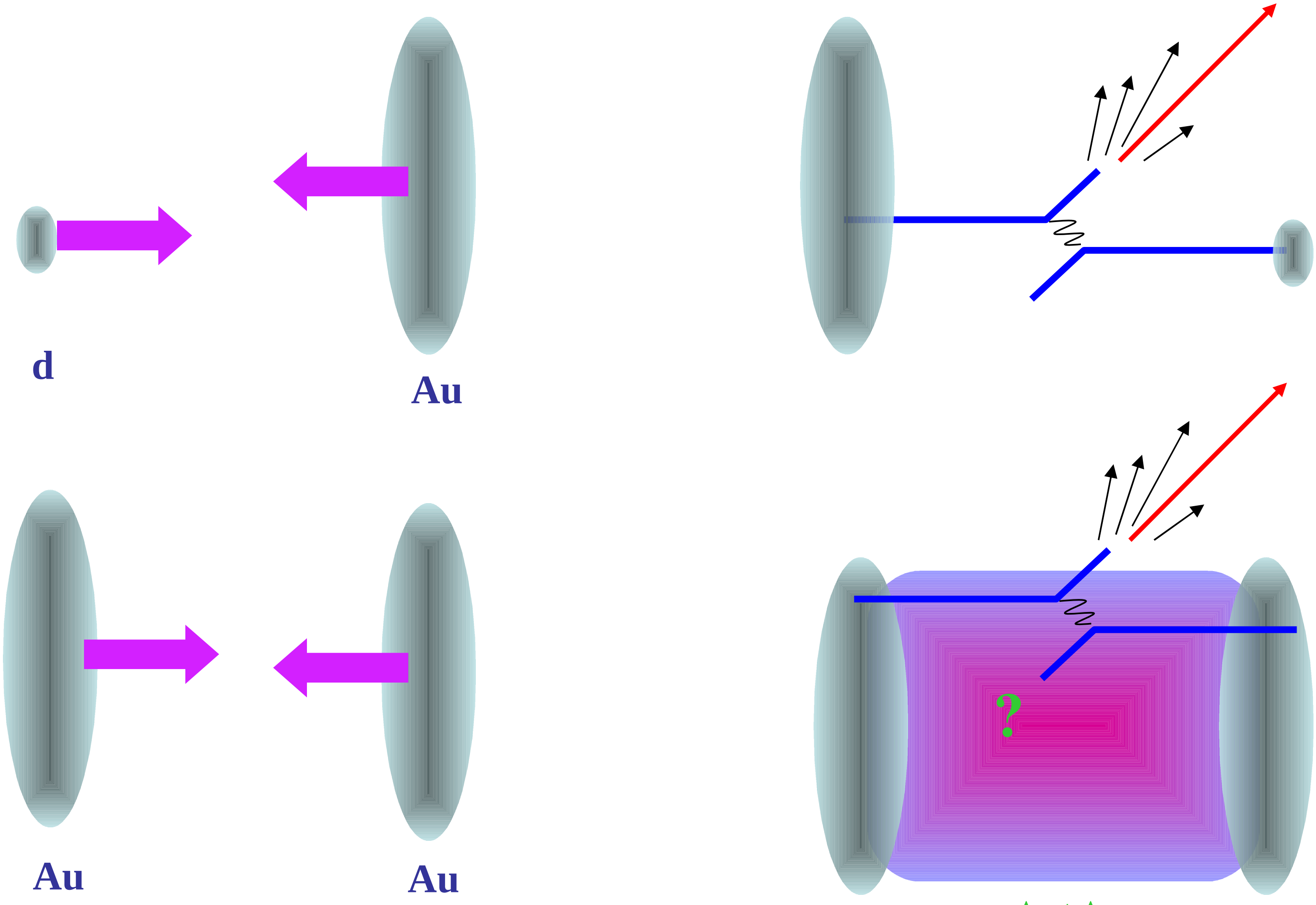
$$\langle T_{AB}\rangle_f = \frac{\int_f T_{AB}(b)\, d^2b}{\int_f \left(1 - e^{-\sigma_{NN} T_{AB}(b)}\right) d^2b} = \frac{\langle N_{coll}\rangle_f}{\sigma_{NN}}$$

R_{AA} = (# seen in nuclear collision) / (# expected)

$$R_{AB} = \frac{dN^P_{AB}}{\langle T_{AB}\rangle_f \times d\sigma^P_{NN}} = \frac{dN^P_{AB}}{\langle N_{coll}\rangle_f \times dN^P_{NN}}$$

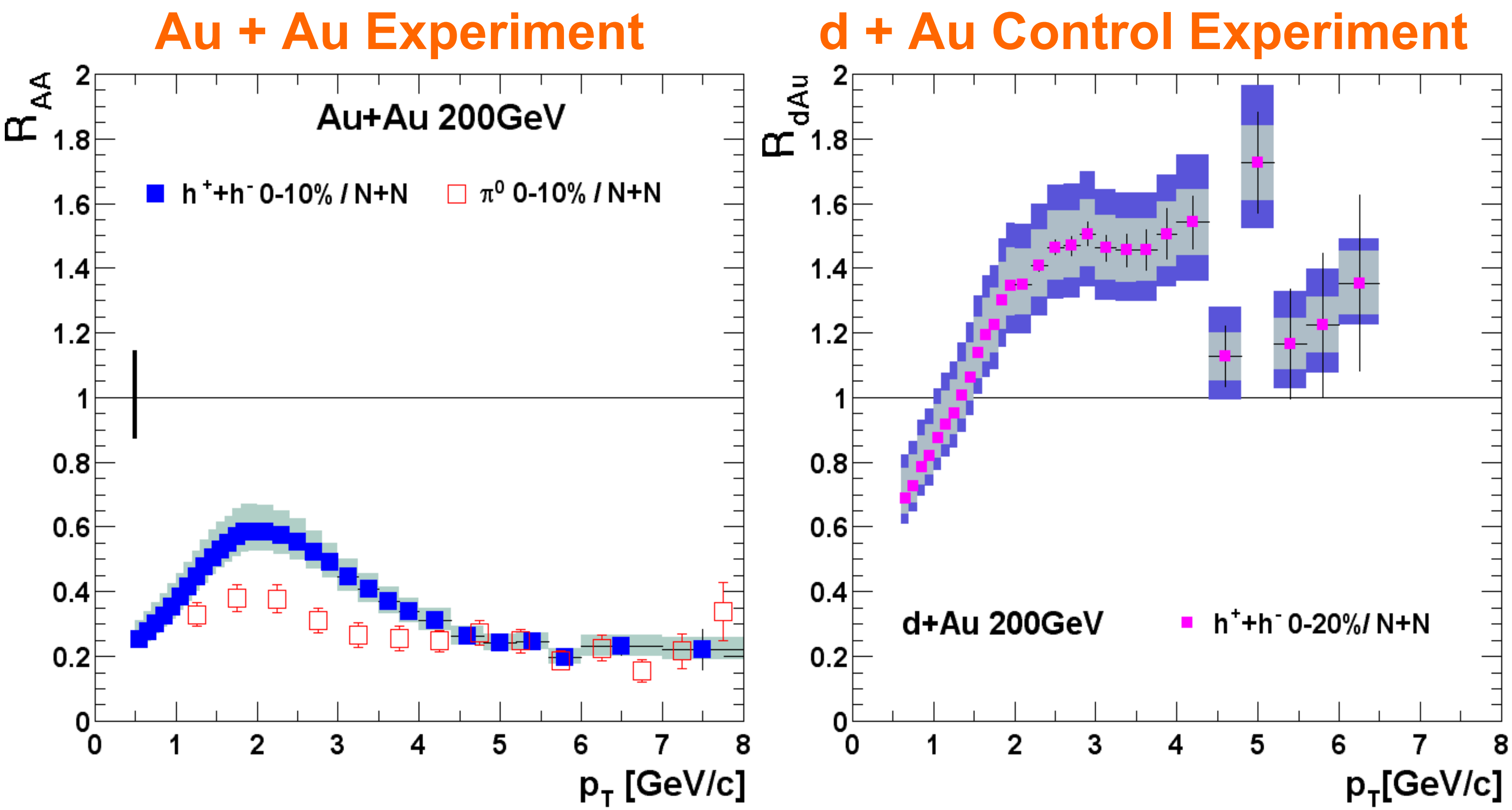
(PHENIX notation: *f*=centrality cut)

The control experiment: d+Au, 2003



Centrality Dependence

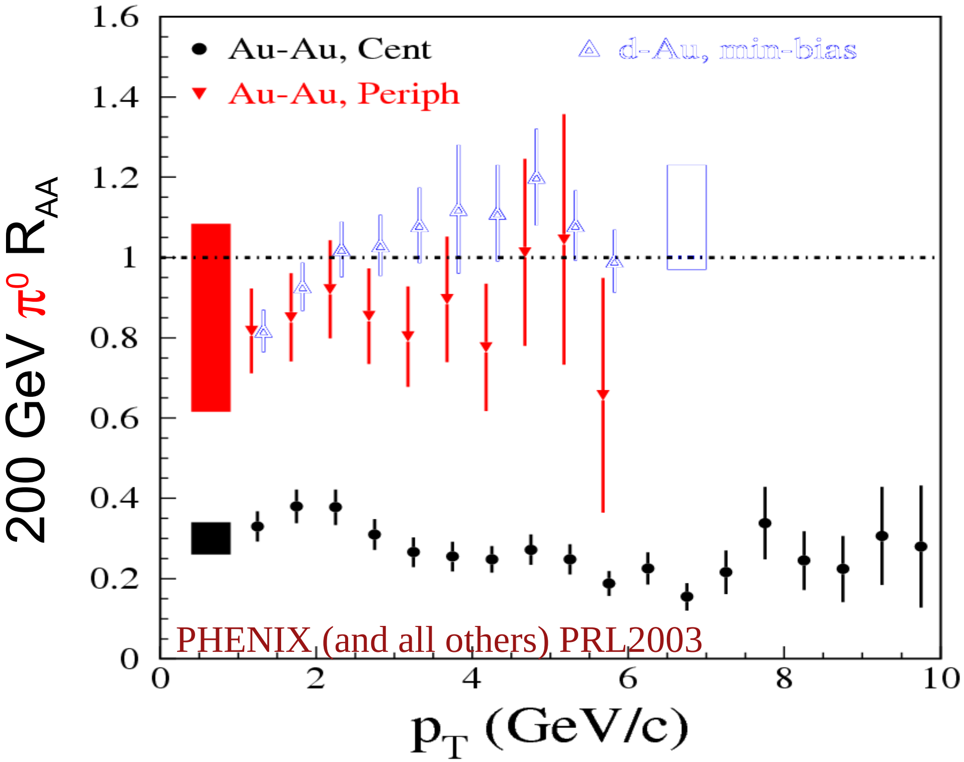
PHENIX '03



- Dramatically different and opposite centrality evolution of Au+Au experiment from d+Au control.
- Jet Suppression is clearly a final state effect.

The Ubiquitous R_{AA}…

5x fewer high p_T particles than "expected" in AuAu



Required checks:

- saturation (initial-state) effect?
  - d-Au null result
- hard scattering rates understood?
  - measure "robust" hard processes

Nuclear overlap model to calculate # incoherent NN collisions (no shadowing etc)

$$\langle T_{AB} \rangle_f = \frac{\int_f T_{AB}(b)\, d^2b}{\int_f (1 - e^{-\sigma_{NN} T_{AB}(b)})\, d^2b} = \frac{\langle N_{coll} \rangle_f}{\sigma_{NN}}$$

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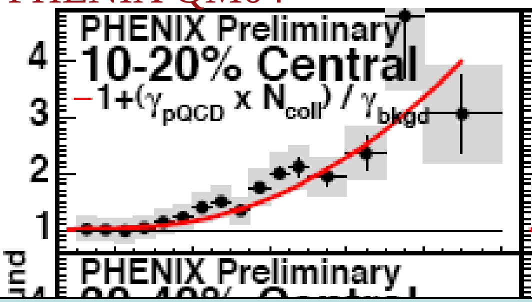
(PHENIX notation: f=centrality cut)

Hard non-mesonic ("direct") photons & non-photonic ("charming") electrons

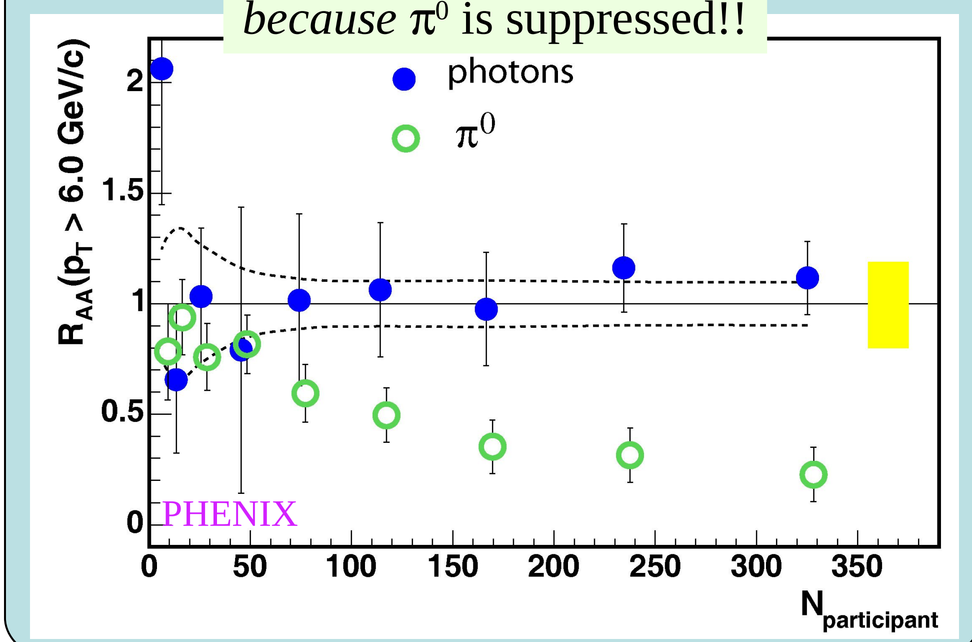
PHENIX QM04

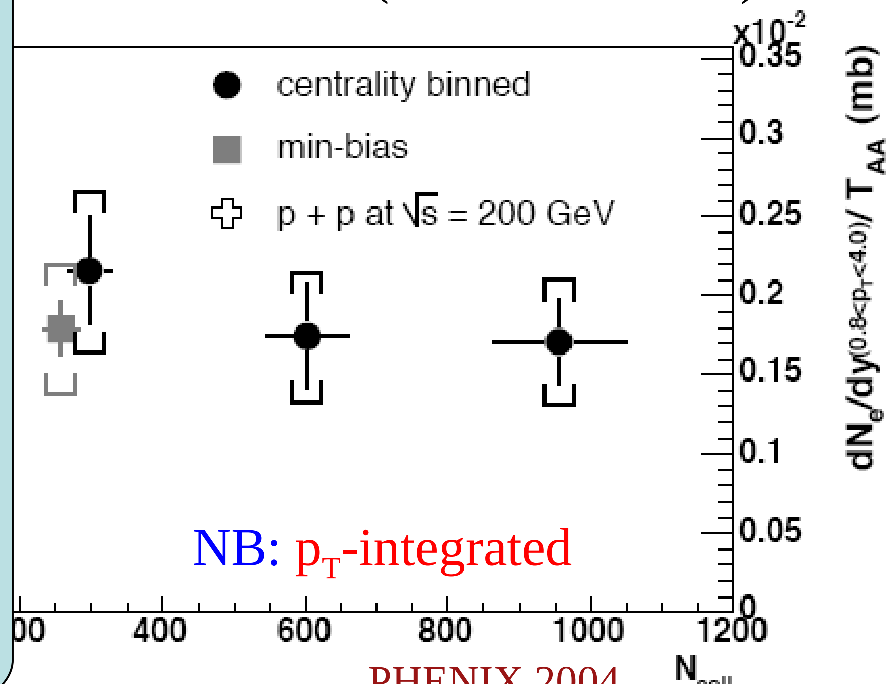


- Created in earliest, hardest parton scatterings & conserved thereafter
- binary scaling √
  - (probably some Cronin inside errors)

- probe-once-created *and* creation itself **in** are "calibrated" (better than d-Au)

Direct photons visible *because* π^0 is suppressed!!





NB: p_T-integrated

PHENIX 2004

The Ubiquitous R_{AA}…

5x fewer high p_T particles than "expected" in AuAu

Required checks:

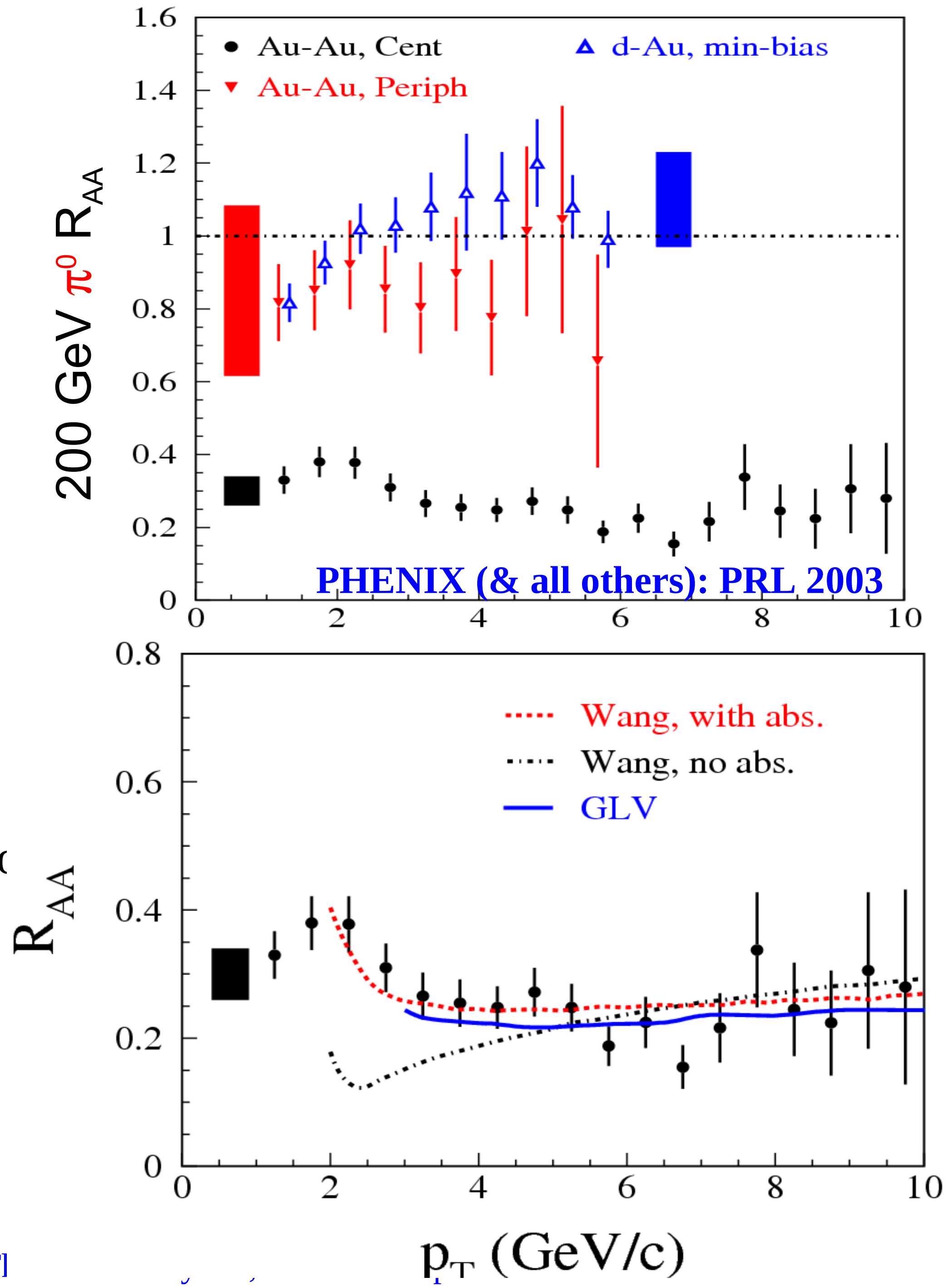
- saturation (initial-state) effect?
  - d-Au null result
- hard scattering rates understood?
  - measure "robust" hard processes
  - charm / direct γ follow N_{binary}

Accepted view

- final state effect is partonic energy lo
  in **color-charge-dense**
  (not necc. deconfined) medium

$\forall\ \varepsilon$ = 15 GeV/fm³ @ τ = 0.2 fm

- ~ consistent w/ ε_{BJ} and hydro…



The Ubiquitous R_{AA}…

5x fewer high p_T particles than "expected" in AuAu

Required checks:

- saturation (initial-state) effect?
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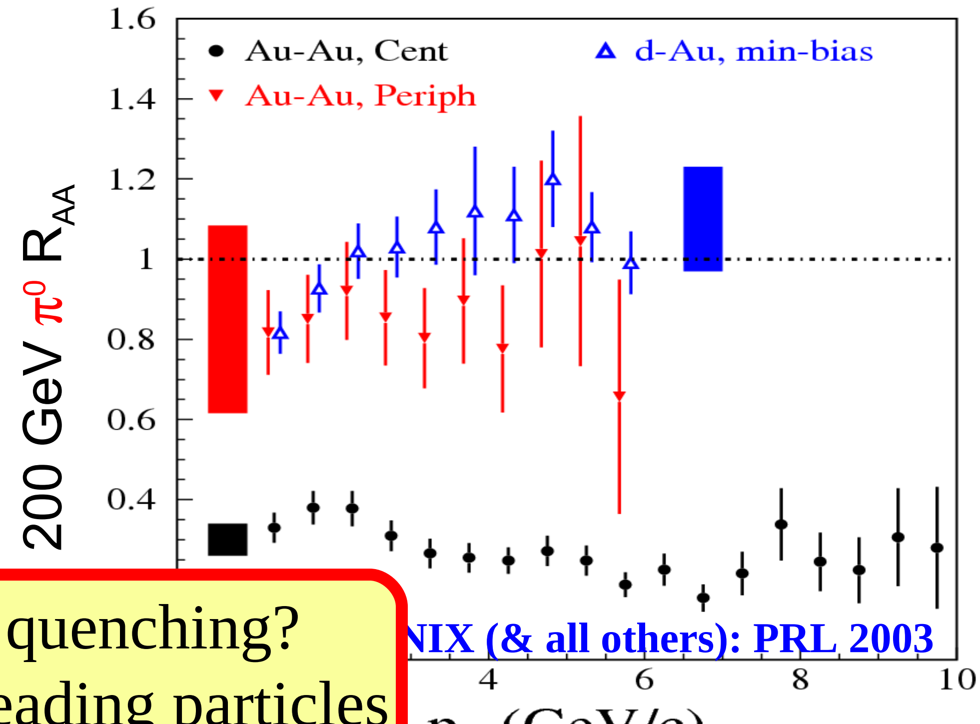
- hard scattering rates understood?
  - measure "robust"
  - charm / direct γ fo



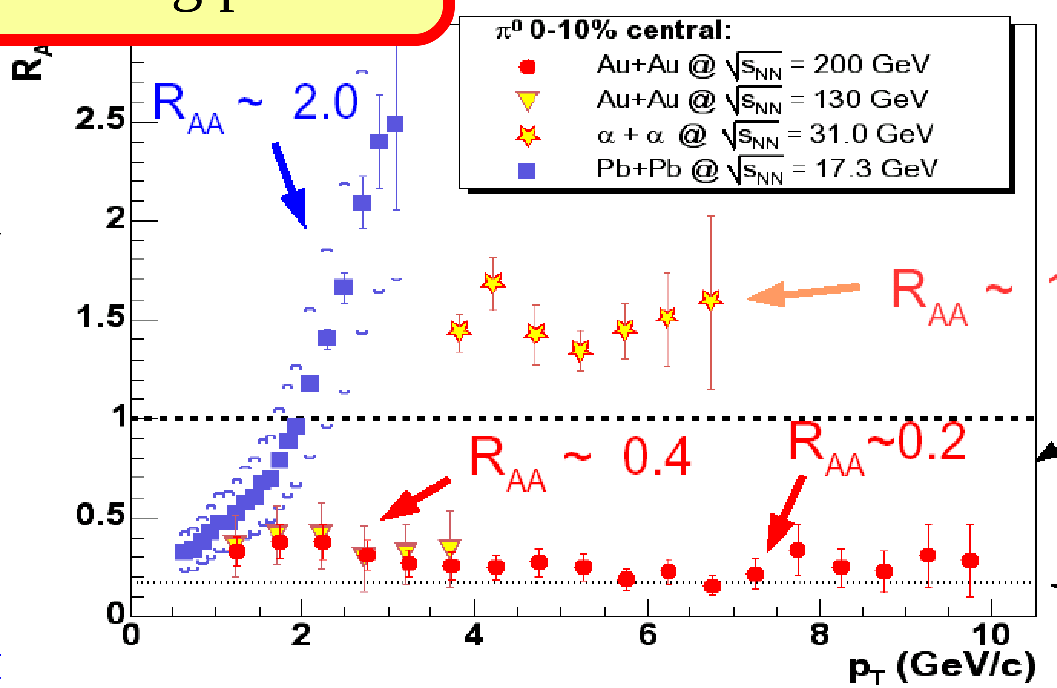
is it "jet" quenching?
Go beyond leading particles

Accepted view

- final state effect is partonic energy l in **color-charge-dense** (not necc. deconfined) medium

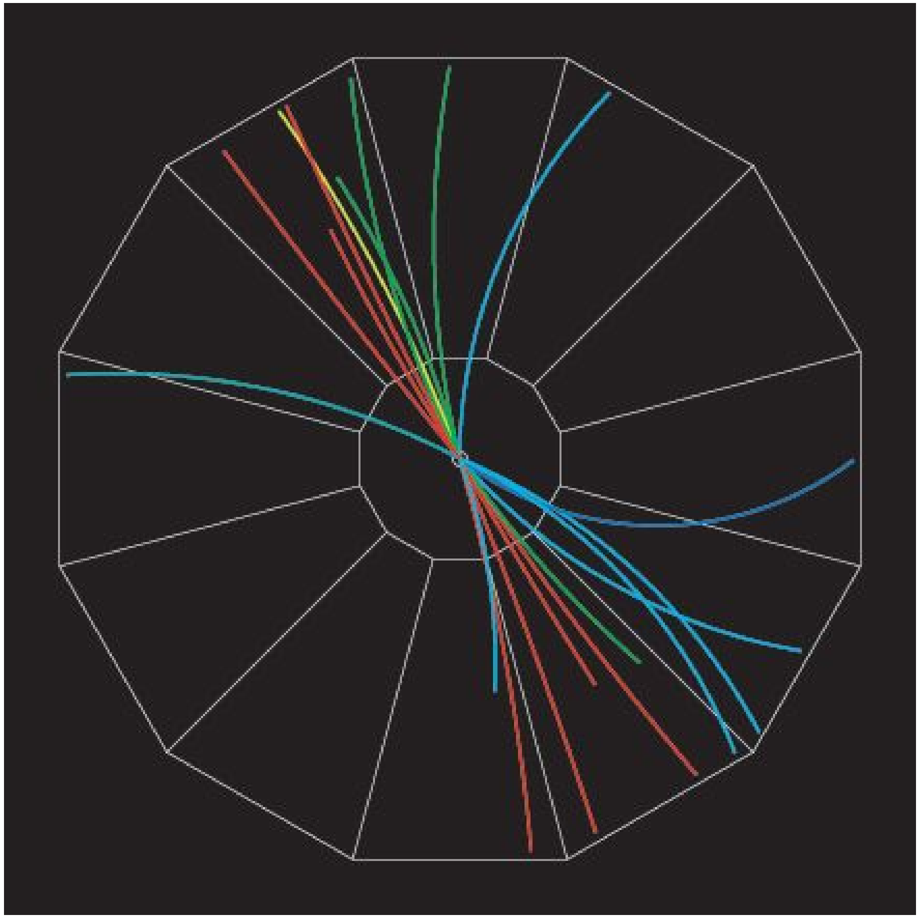
∀ ε = 15 GeV/fm³ @ τ = 0.2 fm

- ~ consistent w/ ε_{BJ} and hydro…

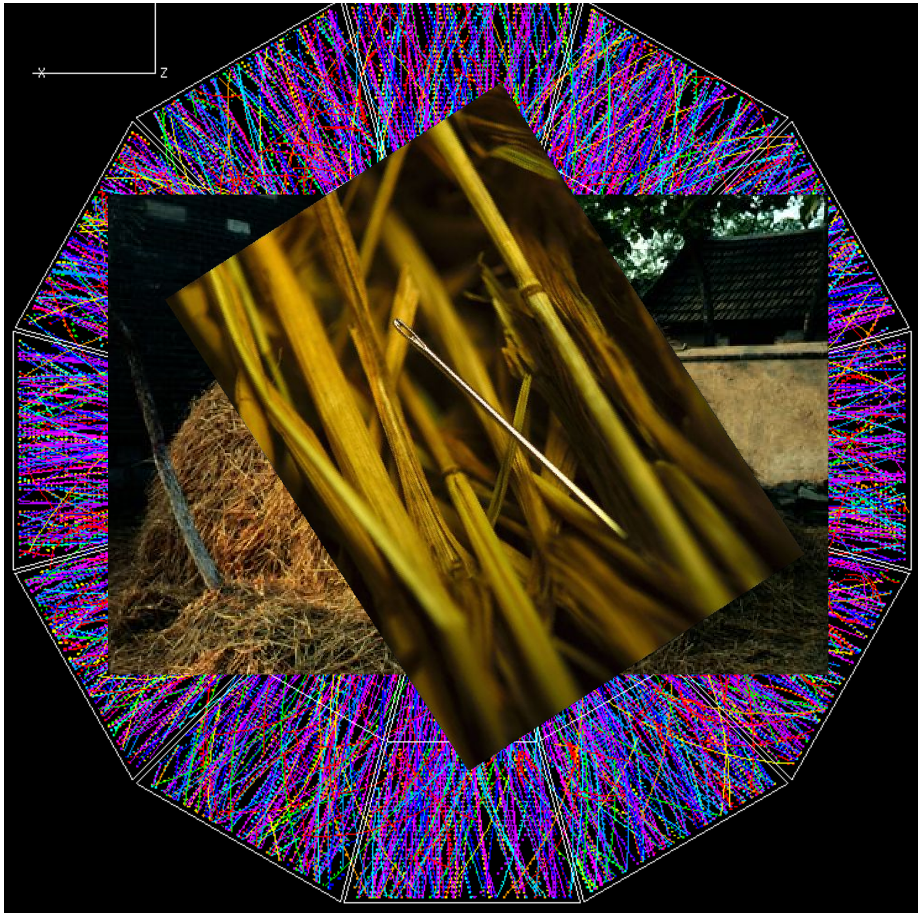


Beyond leading particles

STAR p+p event



STAR Au+Au event

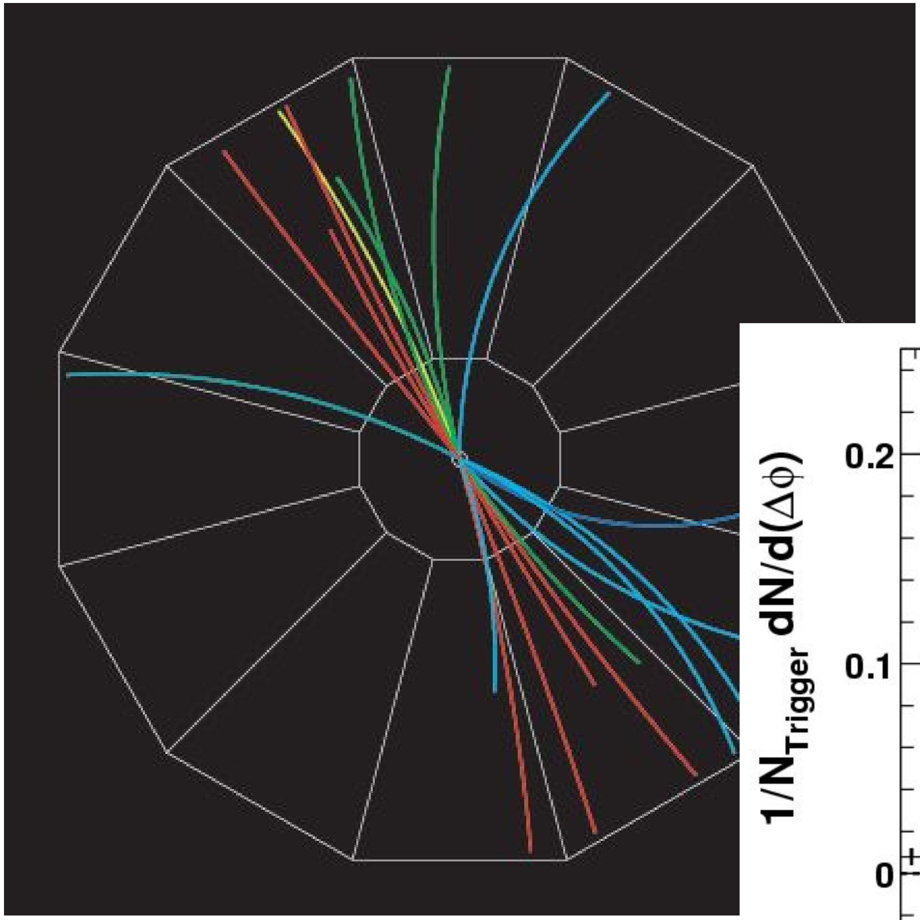


find this…

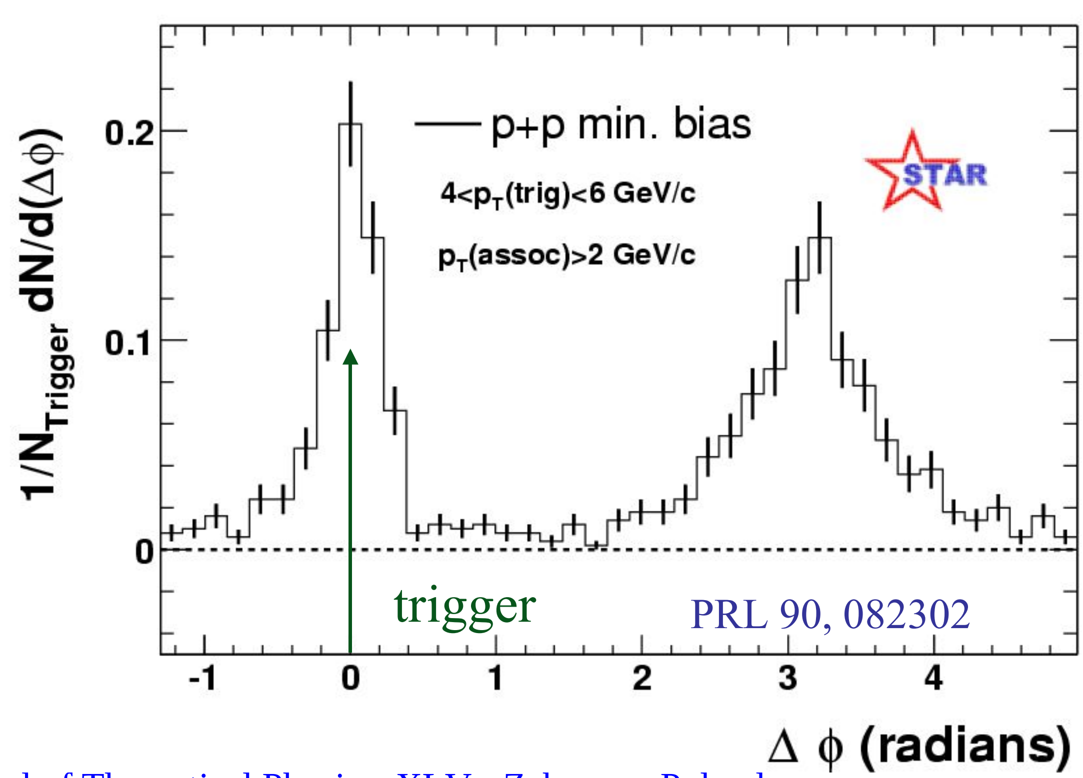
…in this

Jets via azimuthal correlations

STAR p+p event

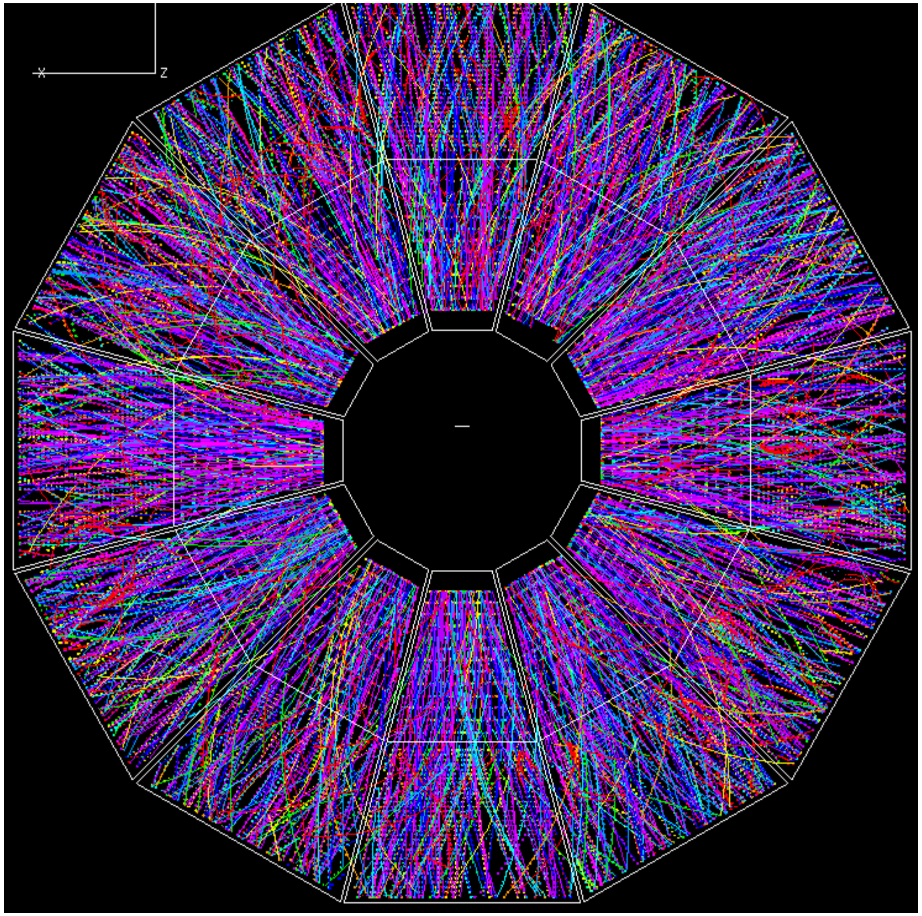


- trigger: highest p_T track, p_T>4 GeV/c
- $\Delta\phi$ distribution for $2<p_T<p_T^{trigger}$
- normalize to number of triggers



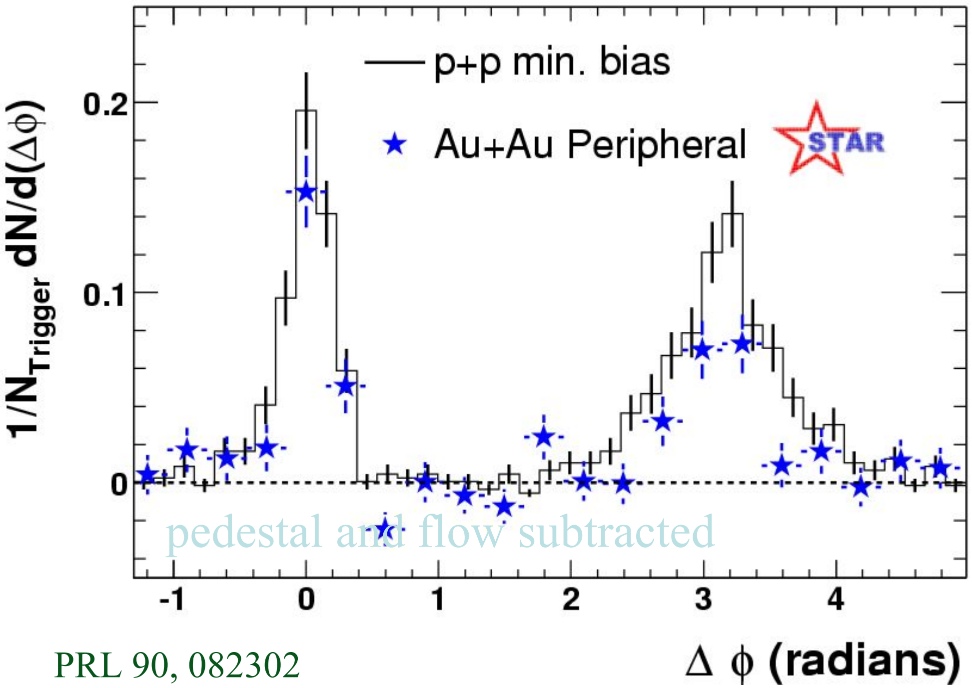
Jets via azimuthal correlations

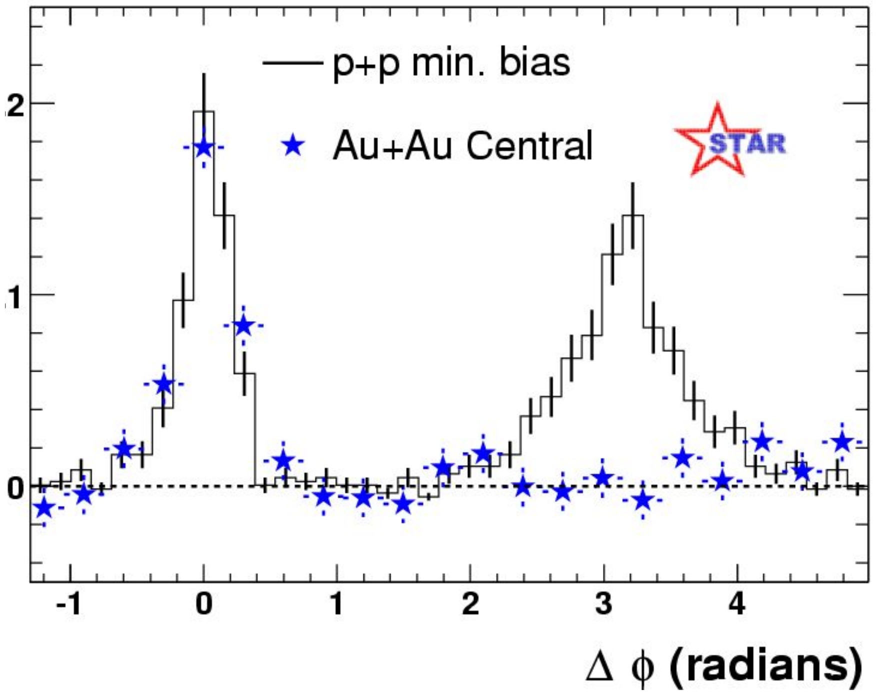
STAR Au+Au event



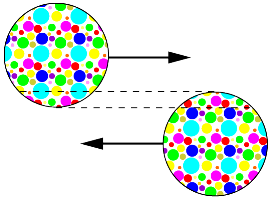
Try the same in Au-Au (large combinatorics)…

Azimuthal distributions in Au+Au

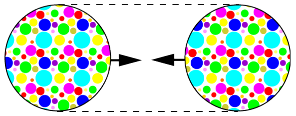




PRL 90, 082302

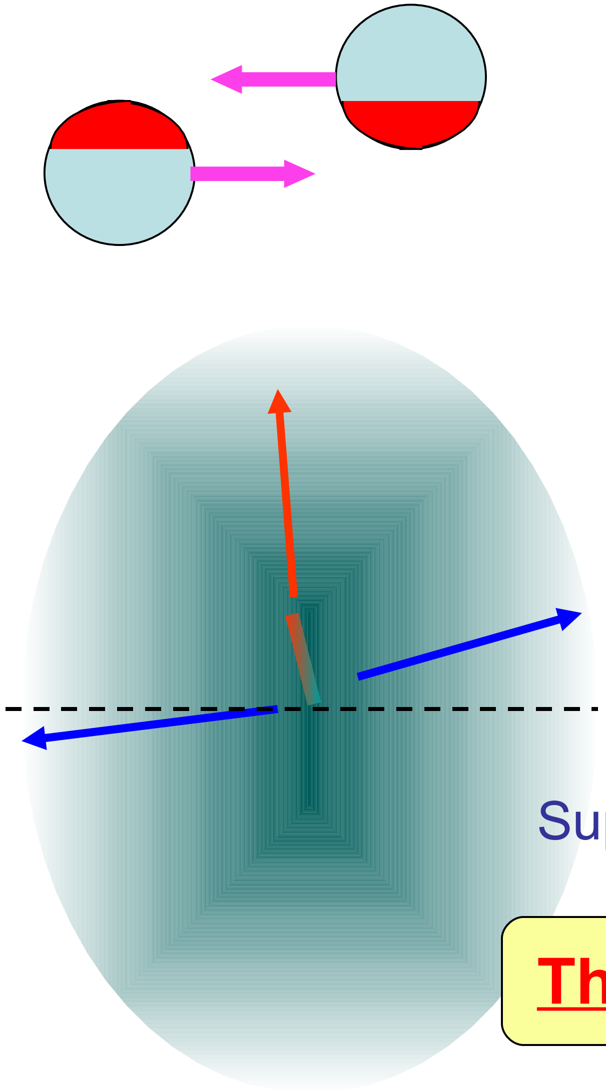


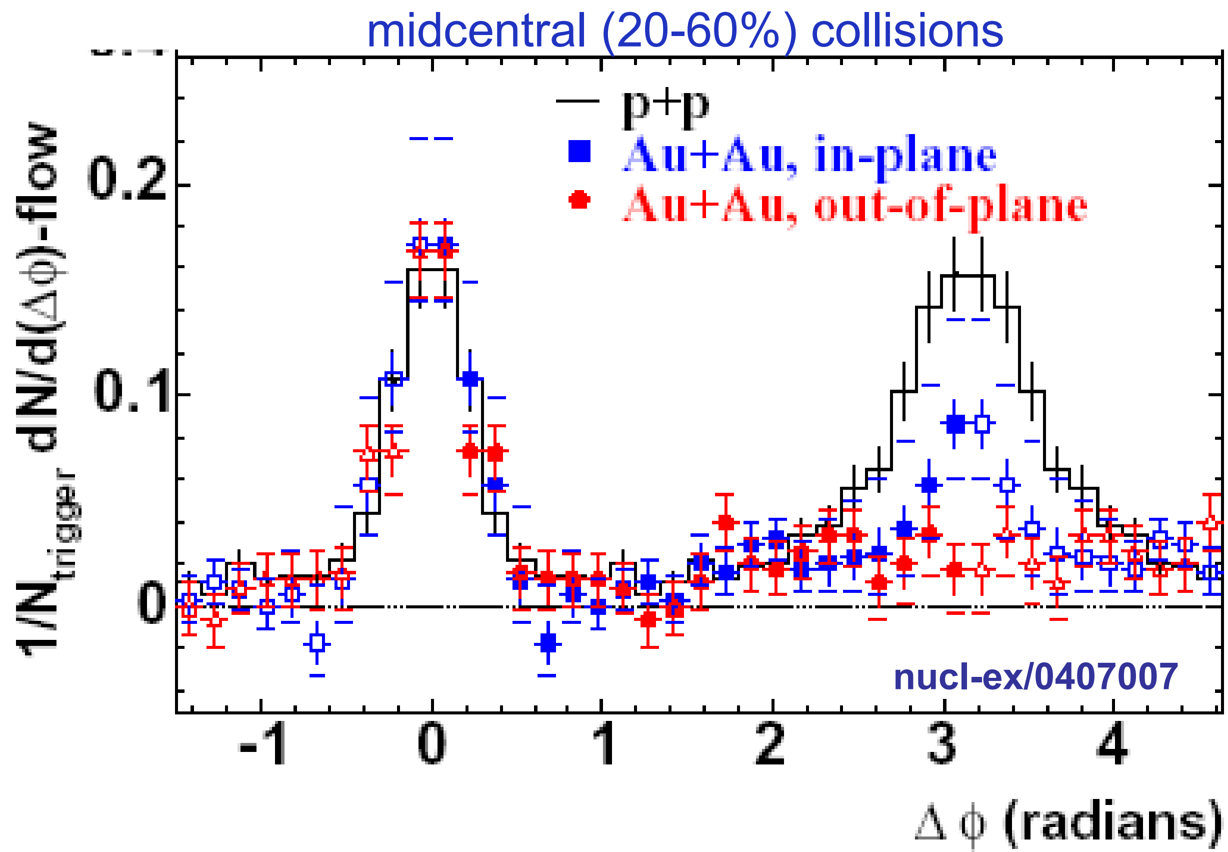
Peripheral collisions:
- very similar to p+p



Central collisions:
- strong suppression of away-side jet

Further geometric detail





Suppression depends on pathlength thru medium

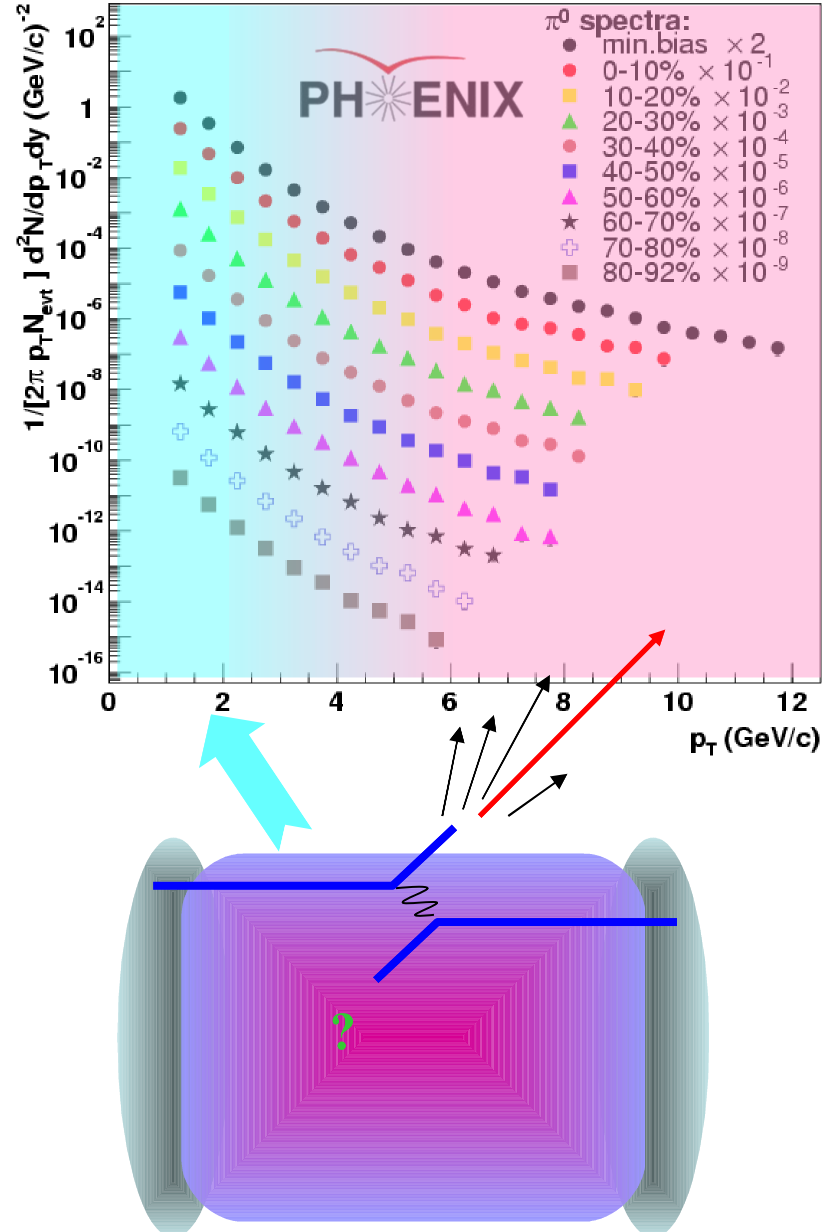
This analysis: cannot be initial state effect

anything new in-between?

Probes ***of*** the system (hard)
- interesting results
- important open questions

System ***itself*** (soft)
- interesting/important results
- important open questions

If we bridge the gap ("firm")?

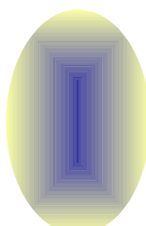


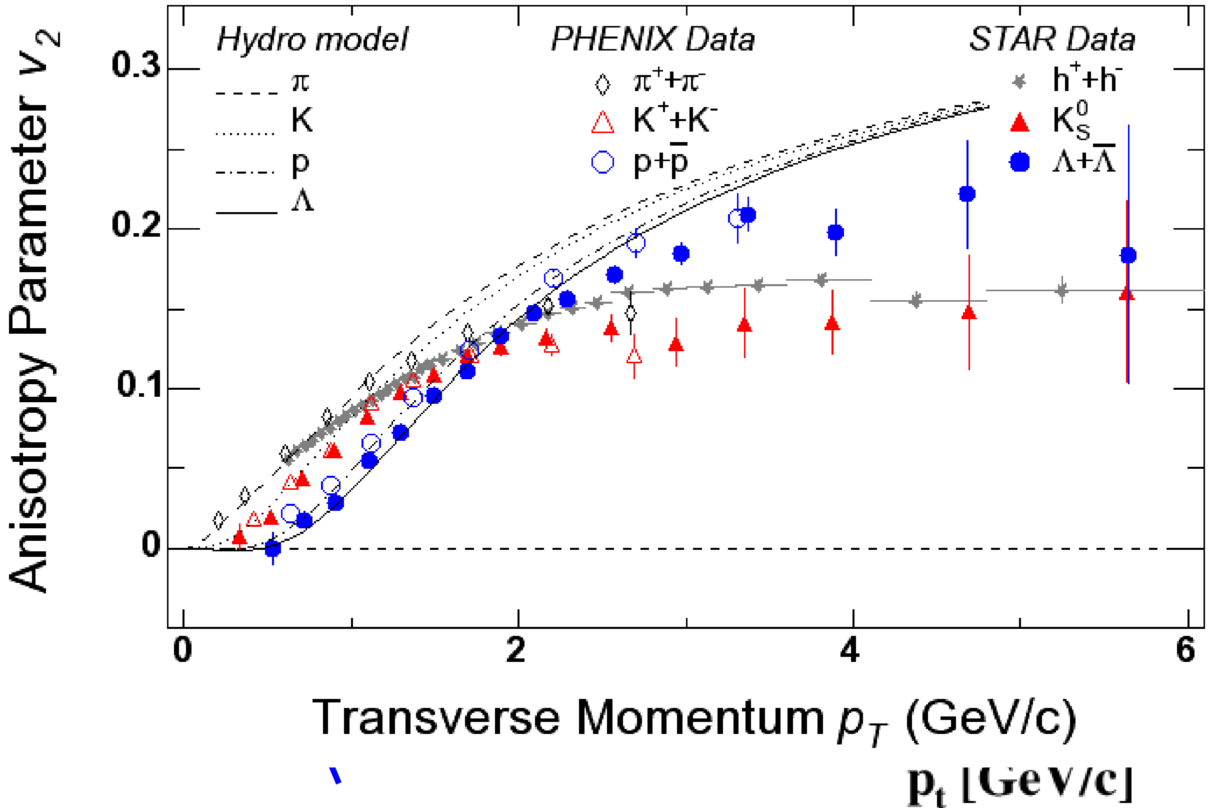
Connecting the sectors

soft-firm connection: v_2

- hydro breaks down above ~ 2 GeV/c (expected)
- mass systematic → meson/baryon systematic?
  - definitely not hydro!

v2 generated by anisotropic energy loss?





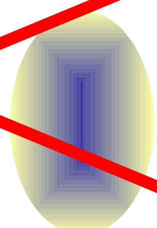
symmetry, thermal smearing

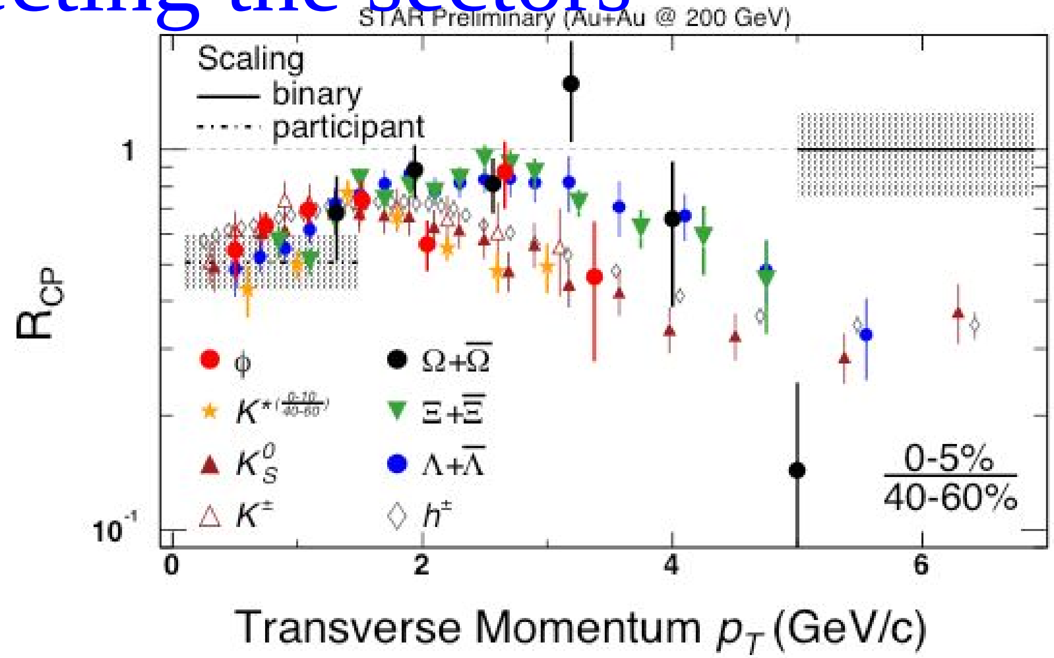
Connecting the sectors

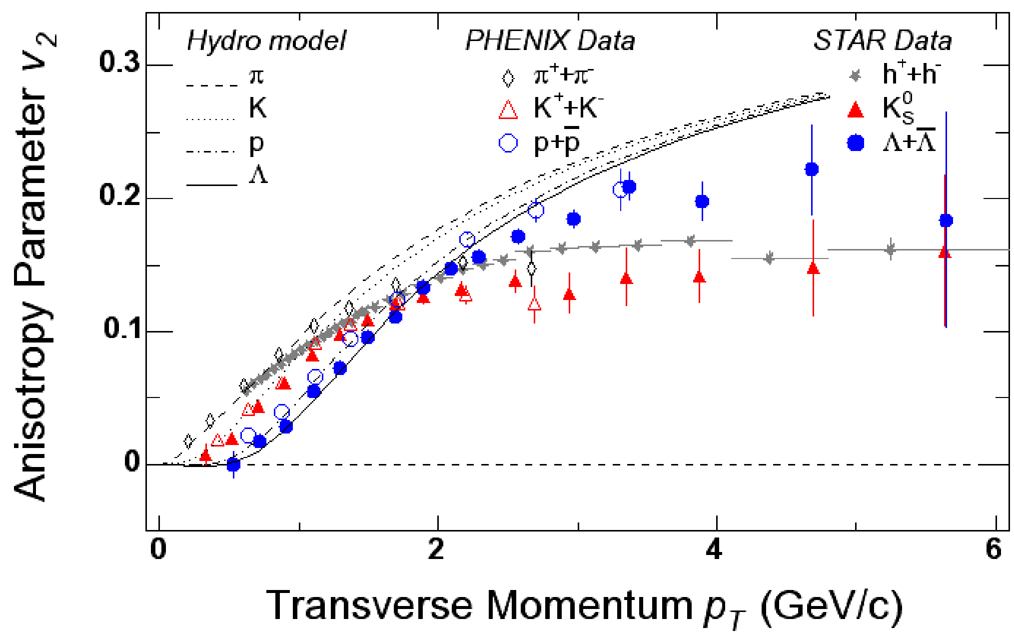
soft-firm connection: v_2

- hydro breaks down above ~ 2 GeV/c (expected)
- mass systematic → meson/baryon systematic?
  - definitely not hydro!

v2 generated by anisotropic energy loss?







hard-firm connection: R_{AA}

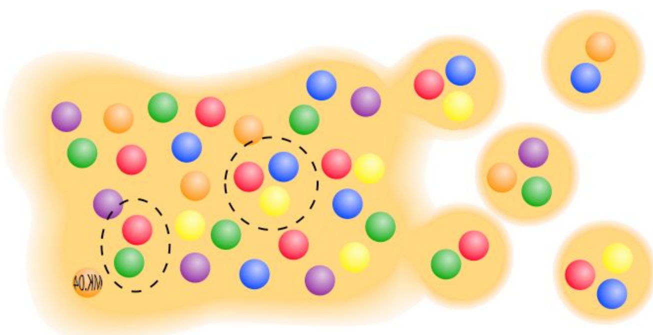
PID-differential
→meson/baryon systematic!

BUT!…

Non-hydro / non-ΔE origin of firm v_2?

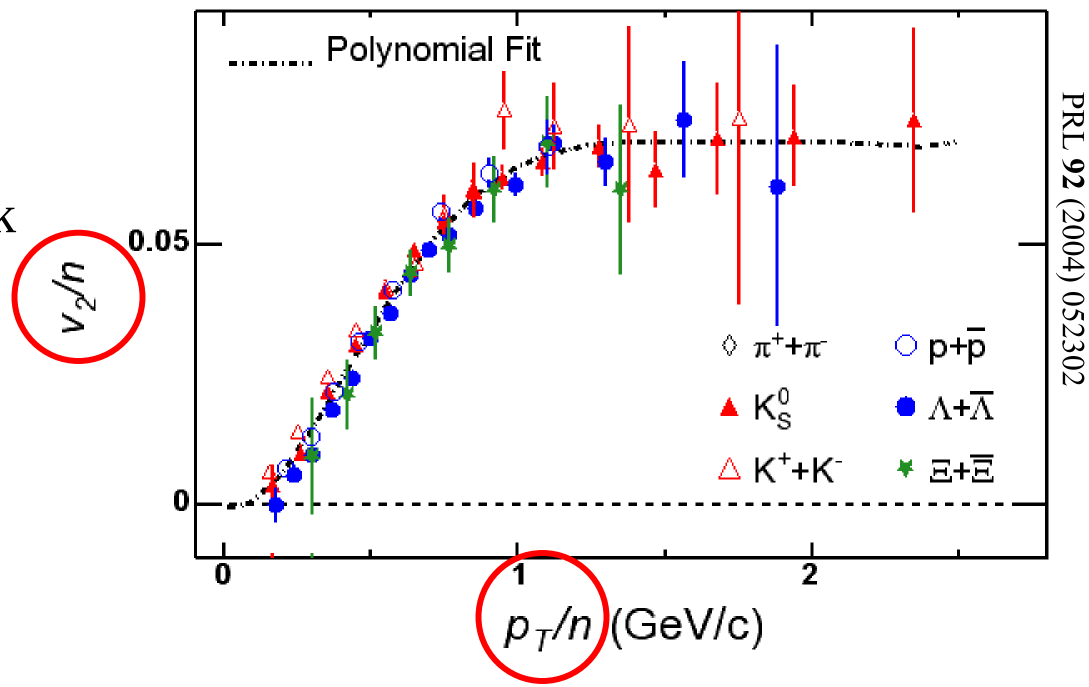
meson/baryon (i.e. constituent quark number) systematics suggest…

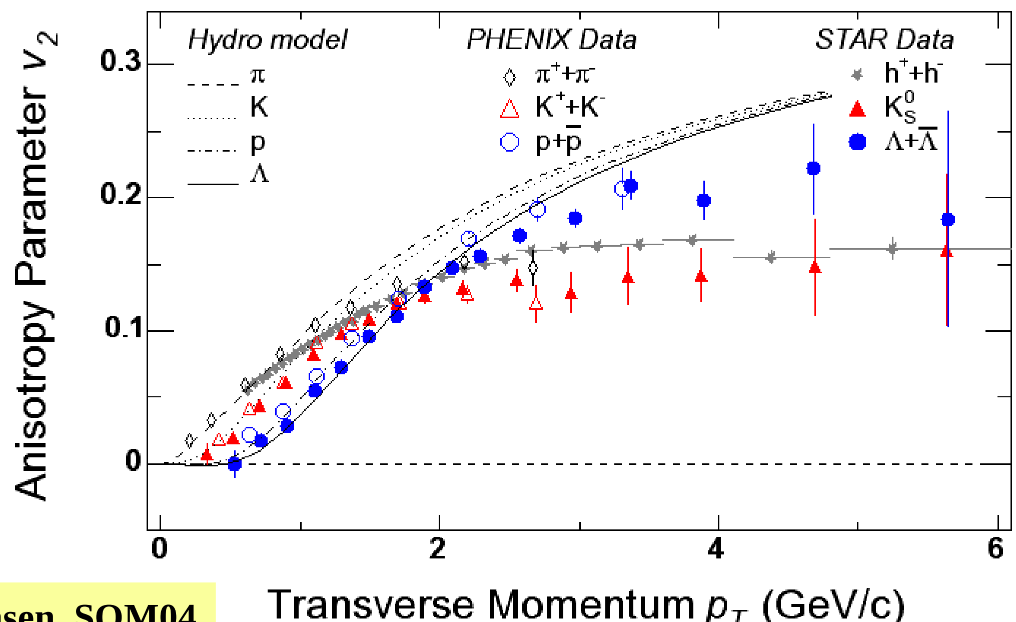
coalescence (“recombination”) of **already-flowing** (!!) partons (*)



$$v_2^{hadron}(p_T^{hadron}) \approx n v_2^{quark}(p_T^{quark})$$

$$p_T^{hadron} \approx n p_T^{quark}$$





* well, constituent quarks

A growth industry…

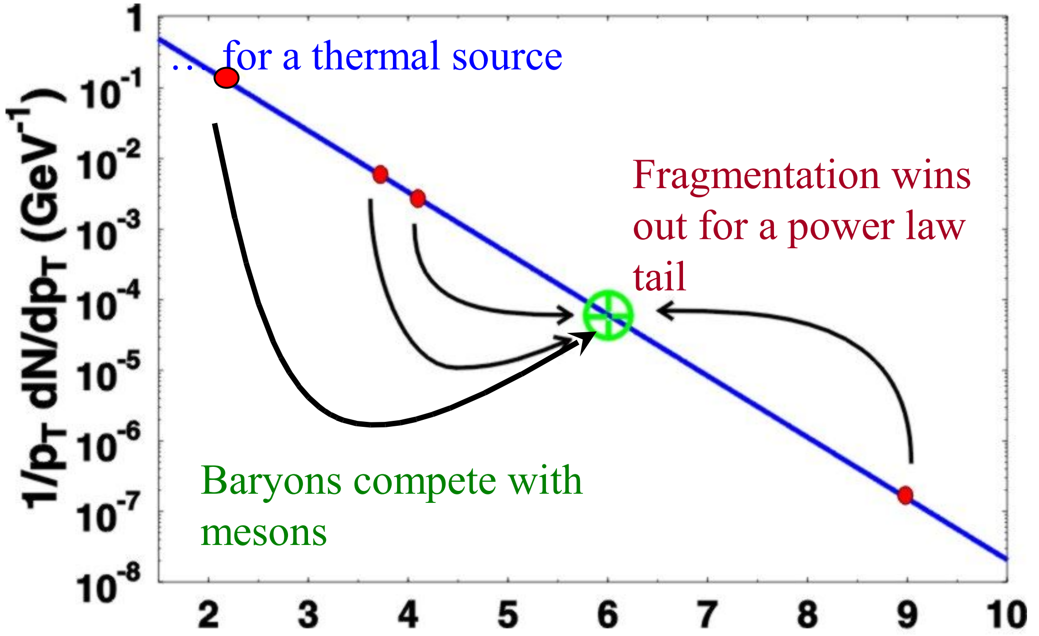
Many model variants

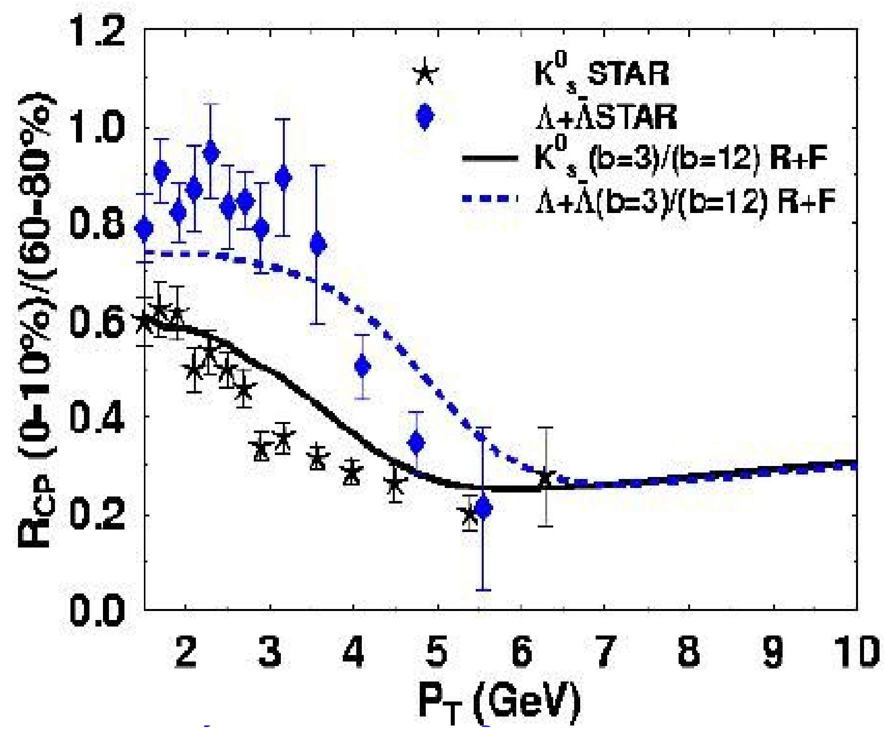
Lin, Molnar, Pratt,
Fries, Bass, Mueller,
Ko, Das, Levai, Hwa,
Greco, Voloshin, Nonaka…

Many schemes, all describe "anomalous" B/M, R_{AA}, v_2

But, data *themselves* (IMHO) clearly indicate exciting, collective partonic behaviour

Hope for a "hadronization testbed"?





“calibrated” probes:

final state effect

color-dense medium

new at RHIC (?)

sensible geometrical systematics

$\varepsilon \sim 10\ \varepsilon_0$

baryon / meson systematics

unexpected!

(constituent?) partonic collectivity?!

[possibility to test hadronization mechanisms?]

bulk, collective system

$\varepsilon \sim 10\ \varepsilon_0$

$T_{ch} \sim T_C \sim 170$ MeV; $\mu_b \sim 30$ MeV

$T_{kin} \sim 100$ MeV, $\beta_{flow} \sim 0.7c$

hydro works

early thermalization.

sensitivity to early-stage EoS