Studying heavy-ion collisions exploiting high-pt particles at STAR

The 6th International Workshop of high-pt particles

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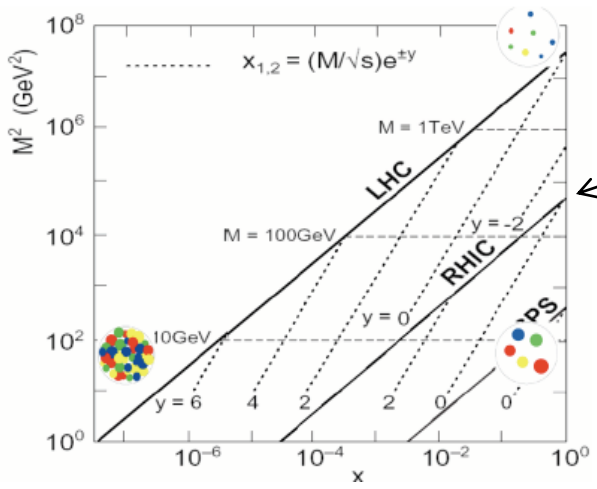
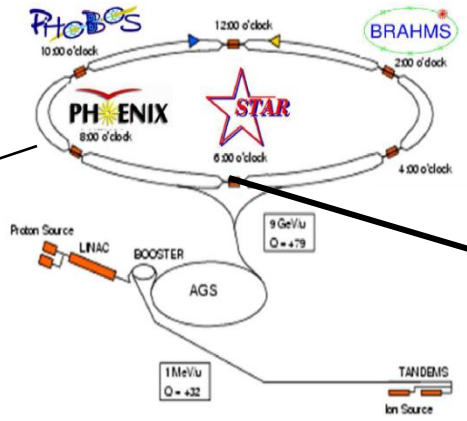
for the STAR Collaboration

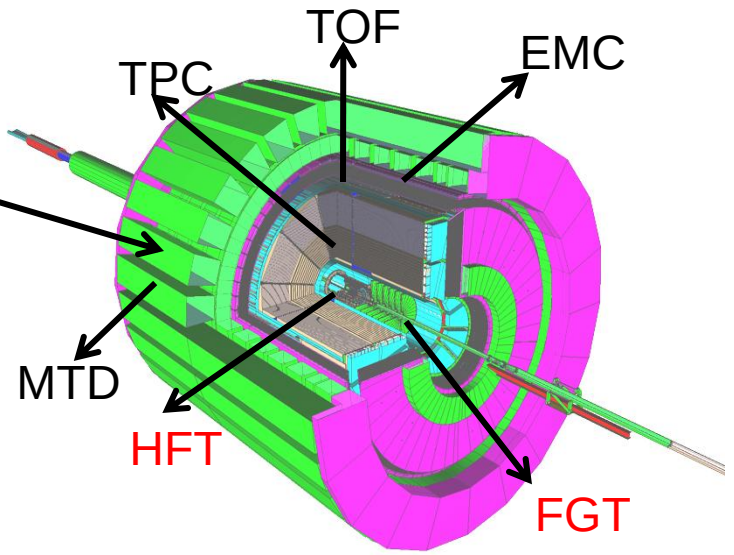
(Texas A&M University)

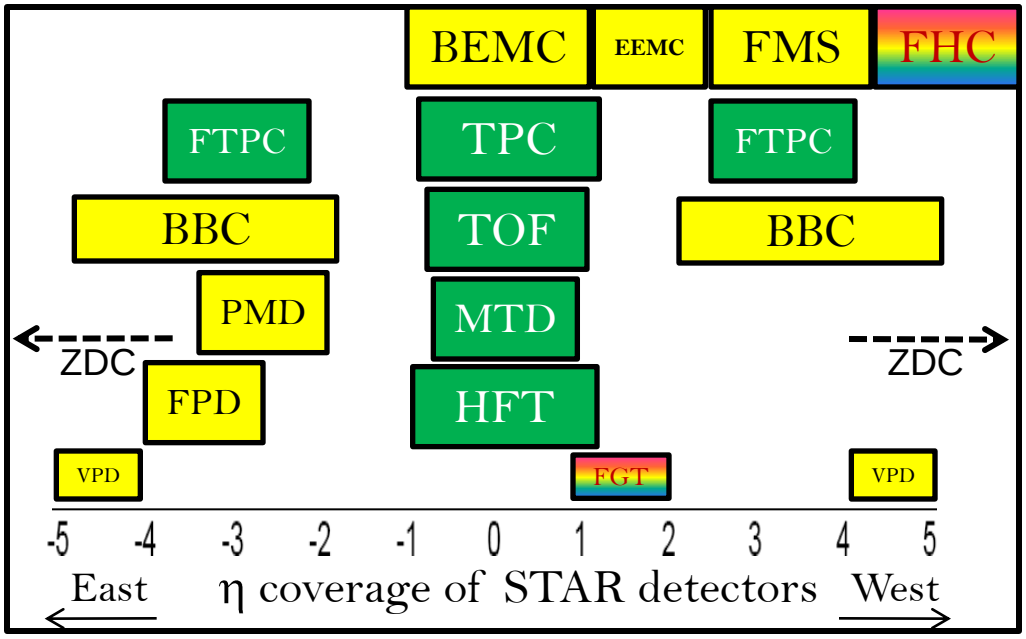
STAR experiment

STAR 2011









Correlation machine:

- In full Φ
- At mid and forward η
- At low and high p_T
- Considerable capabilities for particle identifications
- Reasonable efficiency for particle reconstructions

➢ STAR probes $0.001 < x < 0.2$ in PDF at $\sqrt{s} = 200$ GeV

Contents

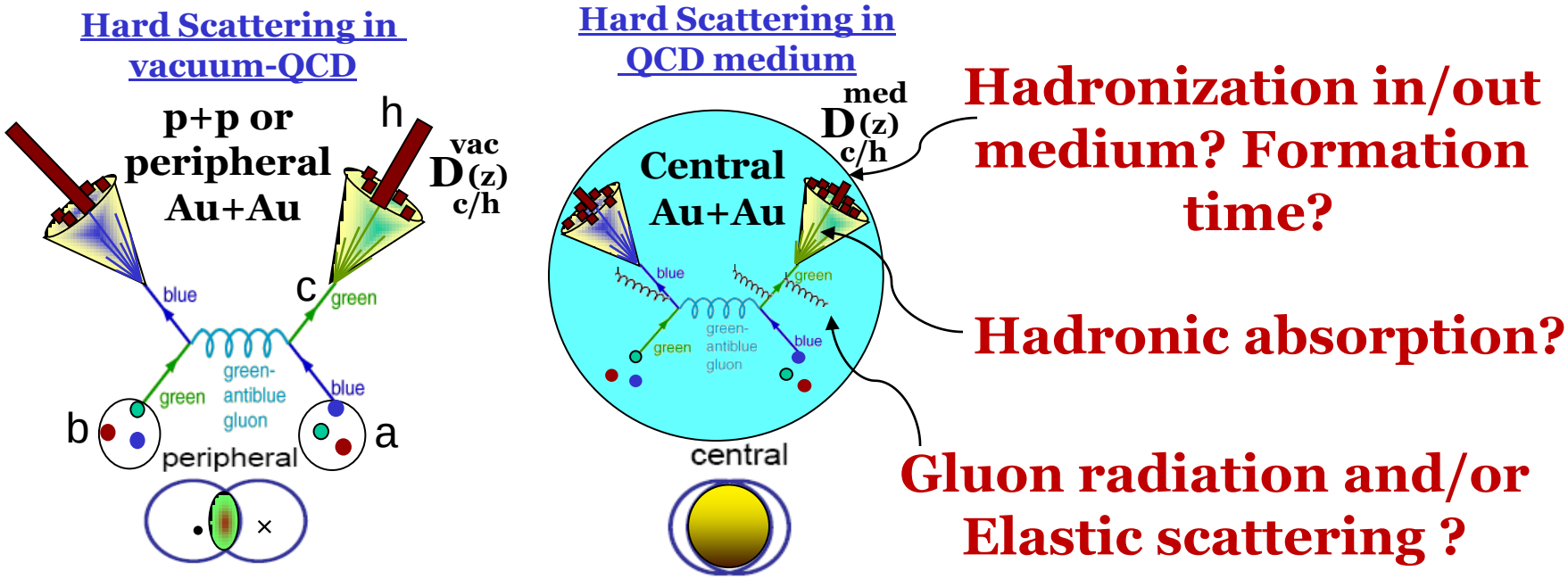
- Lessons from high-p_T era before RHIC
- Methods of exploiting high-pt particles and STAR capabilities
- Answered and unanswered questions from STAR high-p_T measurements

A particular focus of this talk is to discuss to what extent the high-p_T particles produced (STAR) can be taken as evidence for the RHIC paradigm of jet quenching "Parton traverses QDC medium (partonic matter) and loses energy".

High-pt particles: era before RHIC

Produced from jet fragmentation of partons scattered with large Q^2

Rates: framework of pQCD in terms of the asymptotically free pointlike parton



- **DIS off nuclei and Drell-Yan process on nuclear target**: nPDF is **universal** and **factorization** holds up to NLO.
- **What about the FFs (Fragment distributions in jet energy)? in NN collisions and in AA collisions?**

Methods of exploiting high-pt

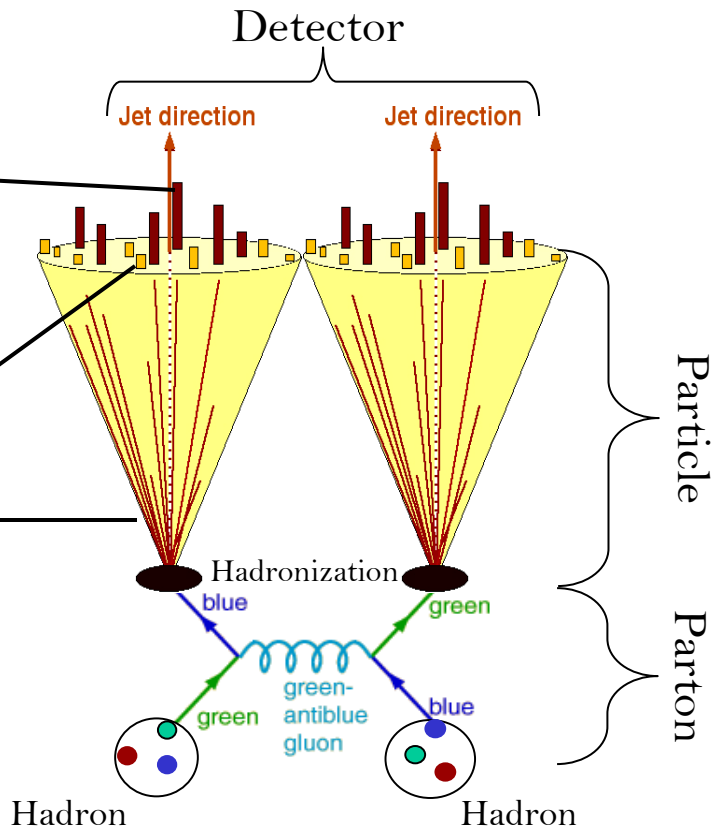
Particle level:

- Leading particle (spectra and R_{AA})

$$R_{AB} = \frac{dN^h_{AB}}{< N_{coll} >_f \, dN^h_{NN}}$$

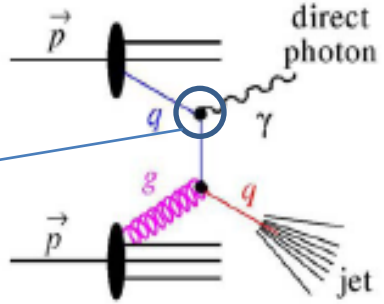
- Fragment distributions in leading particle momentum (near and away-sides) and I_{AA}

$$D = (1/N_{trig}) dN/d(\Delta\phi) \qquad I_{AA} = \frac{D_{AA}}{D_{NN}}$$



Parton level:

- Jet reconstructions
- Direct γ



fragmentation free measurements

STAR capabilities at high-pt

Particle level:

➢ Spectra

Different particles : different coupling to the medium and different τ_{form}

(γ, $\pi^{\pm}$, π^{0}, K, ρ, η, ω, Φ, p, pbar, Λ, Ξ …, J/ψ, Y,..,$W^{\pm}$)

➢ Correlations

1. Two particle correlations in Φ, and η
   - At mid η
   - At forward η
2. Multi particle correlations in Φ,η
3. Correlation w.r.t reaction plane

Parton level:

➢ Spectra and correlations for direct γ and jets

Spectra and Correlations

- At $\sqrt{s_{NN}}$ = 7.7 GeV – 500 GeV
- Baseline: pp and pQCD comparison,
- Control experiment: dAu for CNM

Answered and unanswered questions - STAR

STAR:124 papers of which 48 papers in high-pt for inclusive and different particles at different energy and collision systems.

Group I

- Is AA collision an incoherent superposition of NN/NA collisions?
- Does NA collisions resemble NN collisions?
- What is the role of the precursor state, the proposed CGC, if it exists?

Inclusive particles are sufficient to address these questions

Group II

- Hadron suppression: Hadronic absorption and/or partonic energy loss?
- What is the mechanism of energy loss (radiative/elastic)?
- What is the functional form of energy loss (E,L,C_R,f) ?

Identified particles and access to parton level are needed to address these questions

The basic question

➢ Whether AA creates a medium long-lived and extend over sizable volume and reached the thermodynamics limit to have particular thermodynamic and transport properties.?!

Group I

- Is AA collision an incoherent superposition of NN/NA collisions?

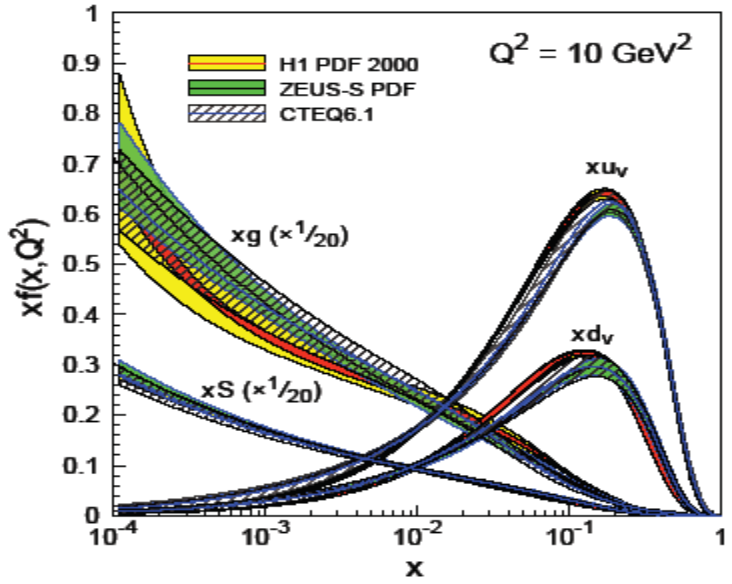
$$E\frac{d^3\sigma}{dp^3}(p_T, A) = E\frac{d^3\sigma}{dp^3}(p_T, 1)A^{\alpha(p_T)}$$

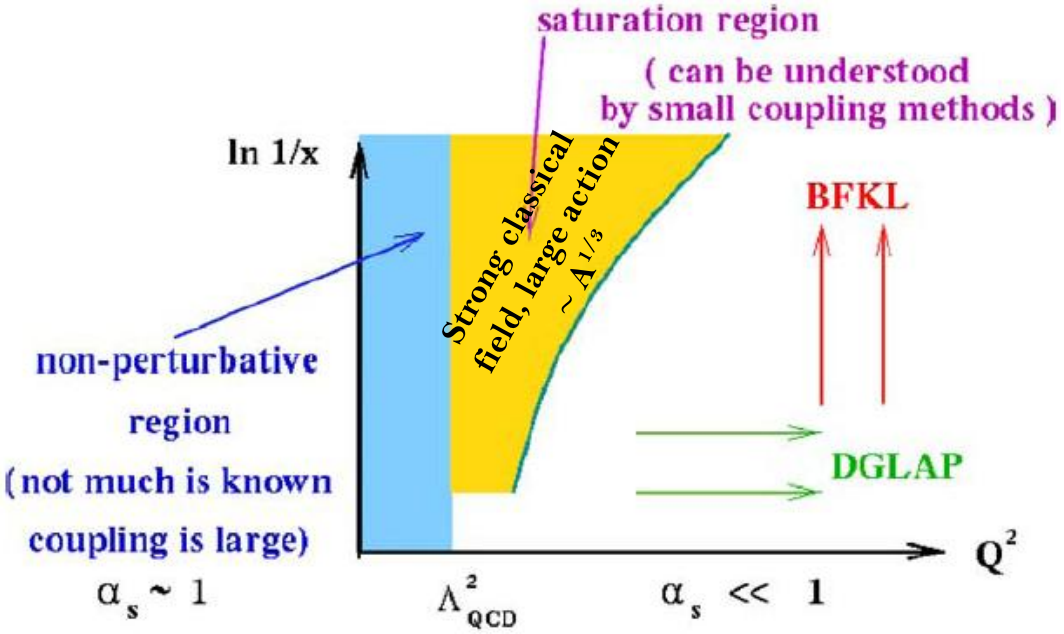
- Does NA collisions resemble NN collisions?

➢ At what rapidity? Mid or forward:

$$x_a = x_b \approx \frac{2p_T}{\sqrt{s}}$$

$$x_q \approx p_T/\sqrt{s}\,(e^{+\eta_1} + e^{+\eta_2})$$
$$x_g \approx p_T/\sqrt{s}\,(e^{-\eta_1} + e^{-\eta_2})$$



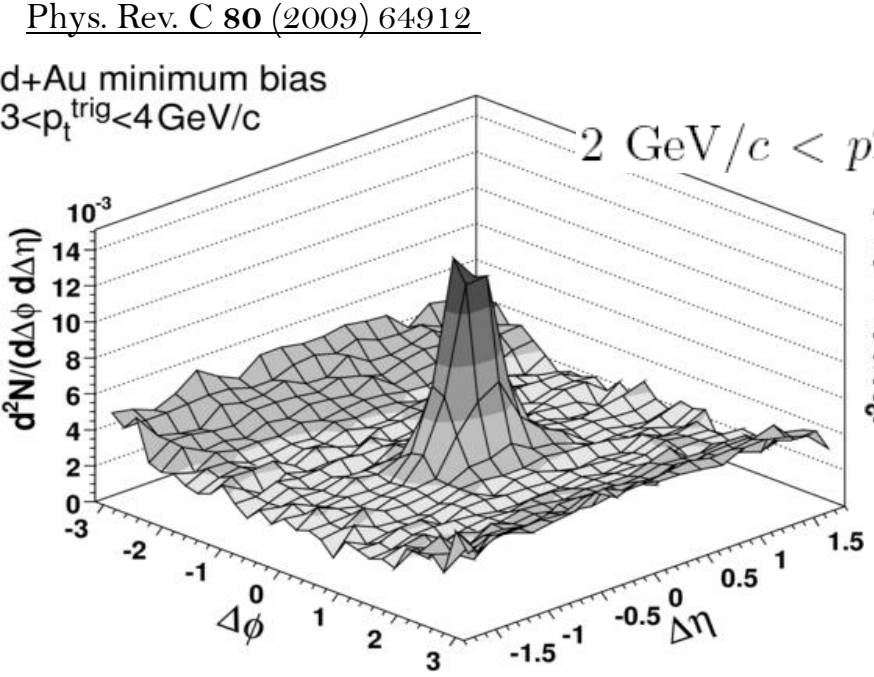


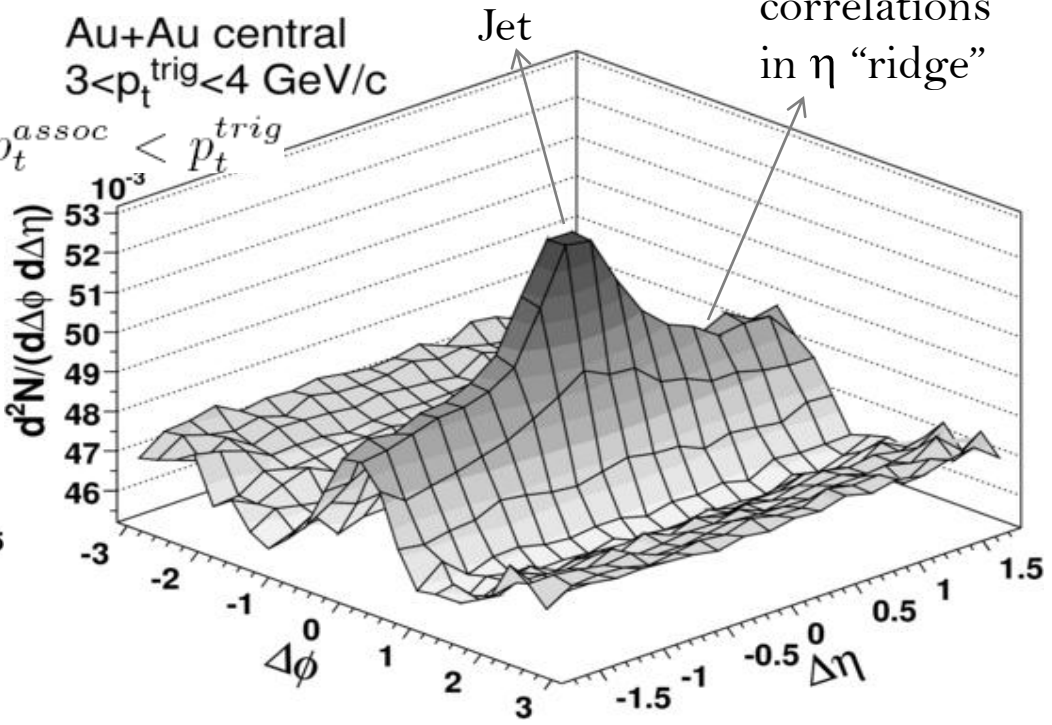
- What is the role of the precursor state, the proposed CGC, if it exists?

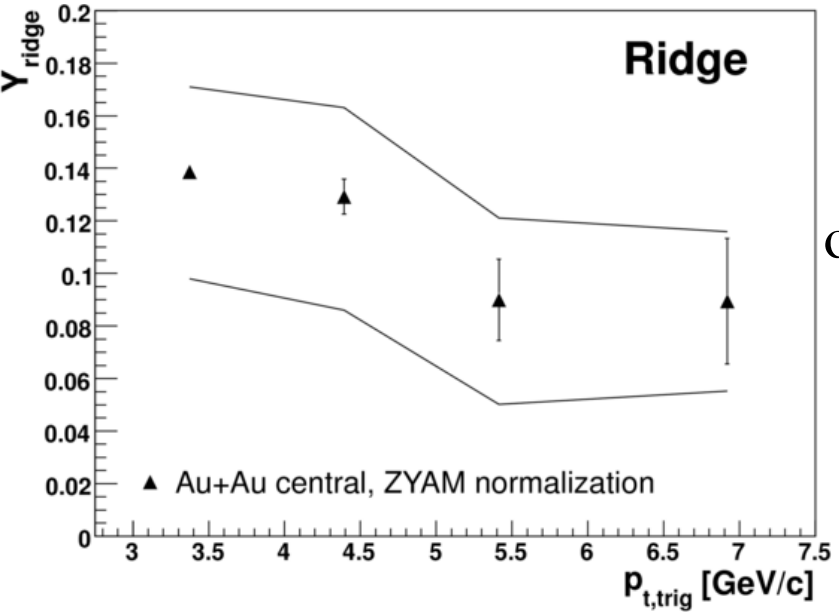
Correlations in pseudorapidity

Phys. Rev. C **80** (2009) 64912

Long range correlations in η "ridge"



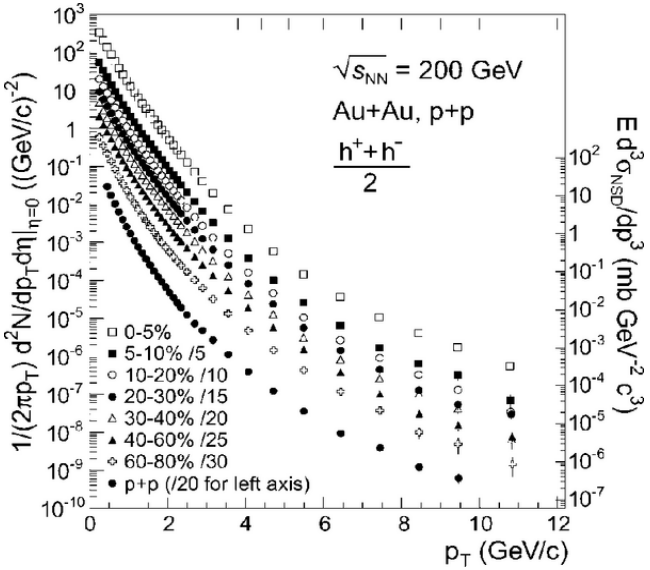


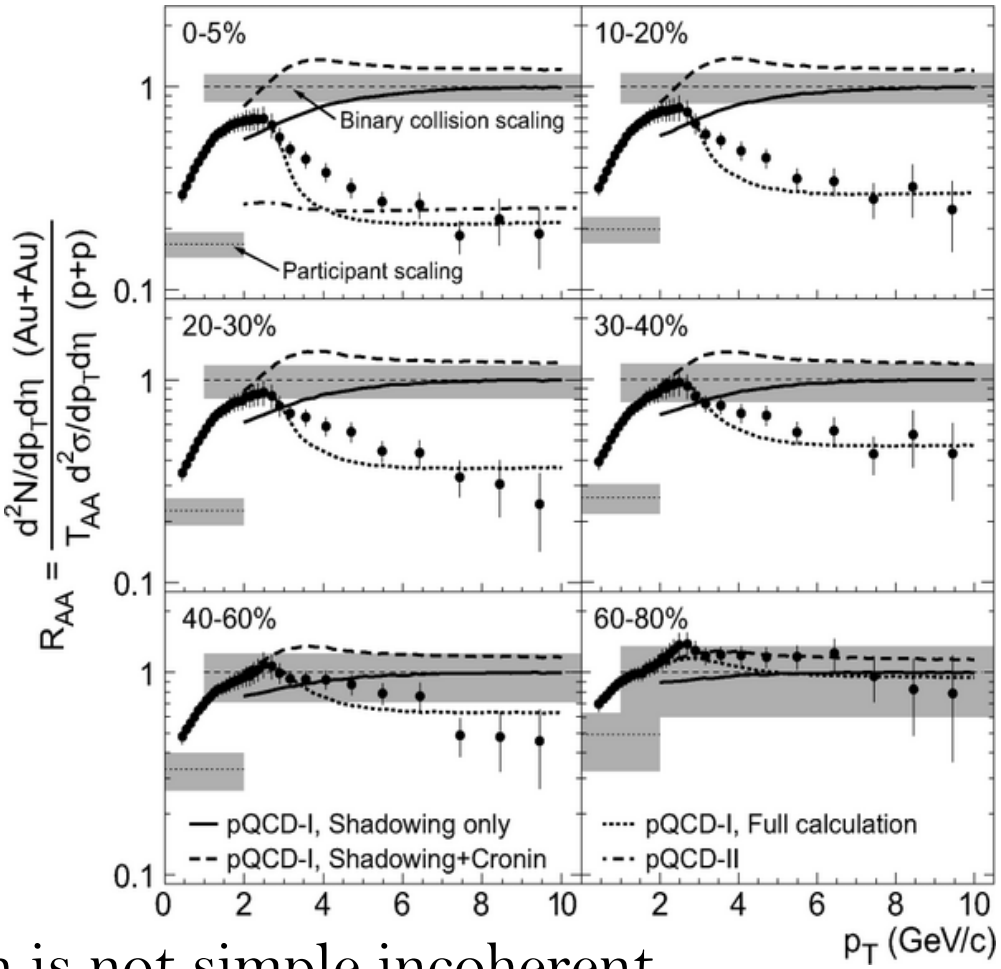


- Ridge correlated with jet direction and independent of trigger p_T and $\Delta\eta$ within current uncertainties. Ridge mechanisms?
- AA collision is not simple incoherent superposition of NA collisions from $\Delta\eta$ dimension

Spectra at mid rapidity

Phys. Rev. Lett. **91** (2003) 172302



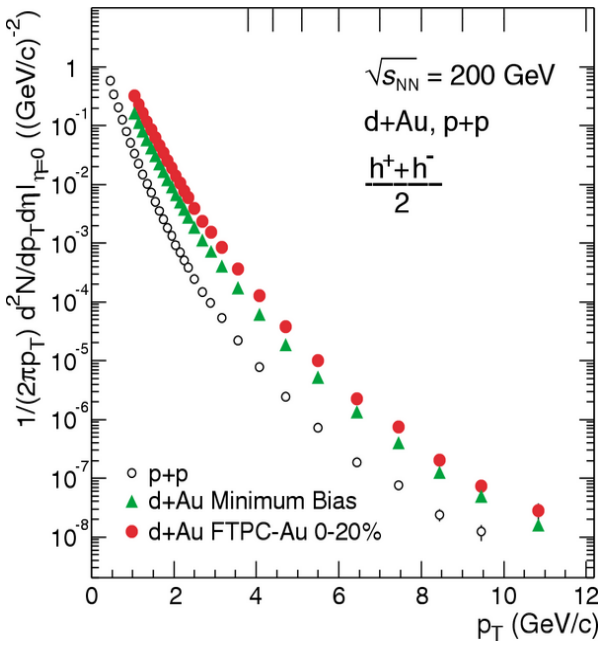


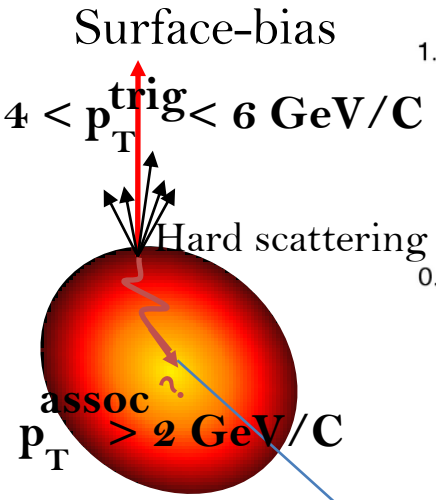
- AA collision is not simple incoherent superposition of NN collisions, assuming MC Glauber.
- Could it be initial state effect?

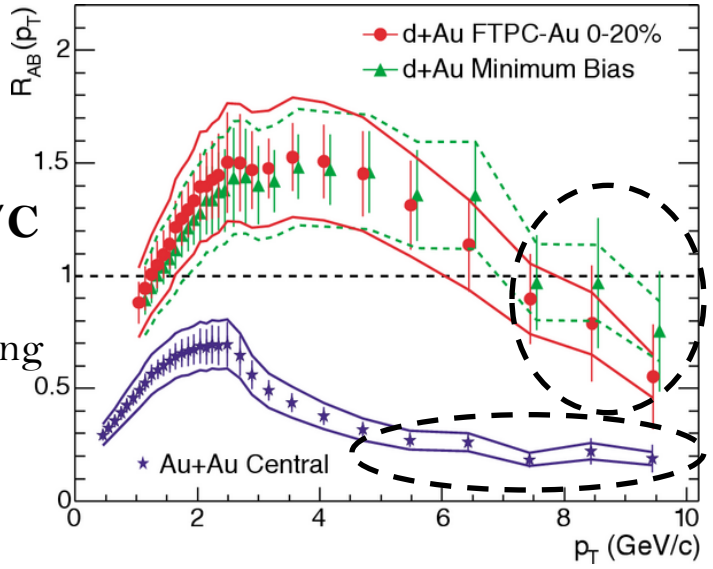
✓ But deviation from unity increases with multiplicity/centrality.

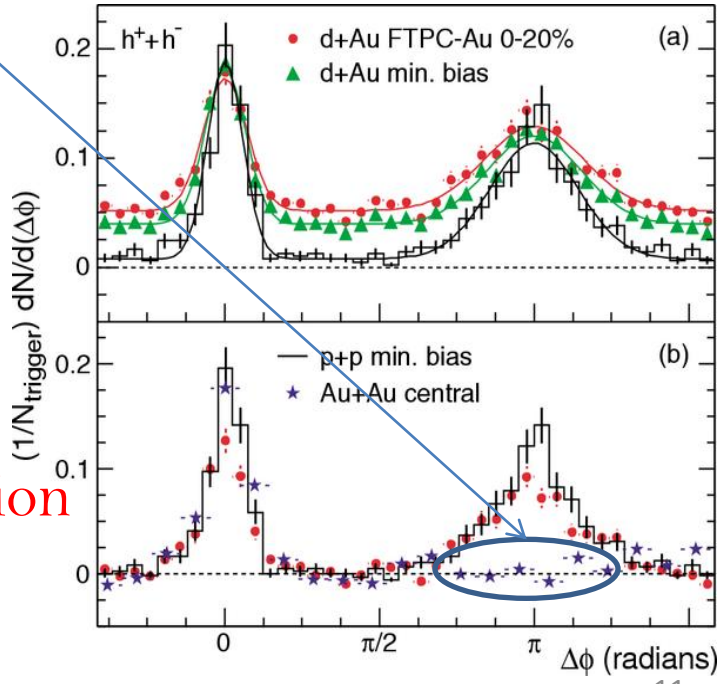
Spectra and correlations at mid rapidity

Phys. Rev. Lett. **91** (2003) 172304





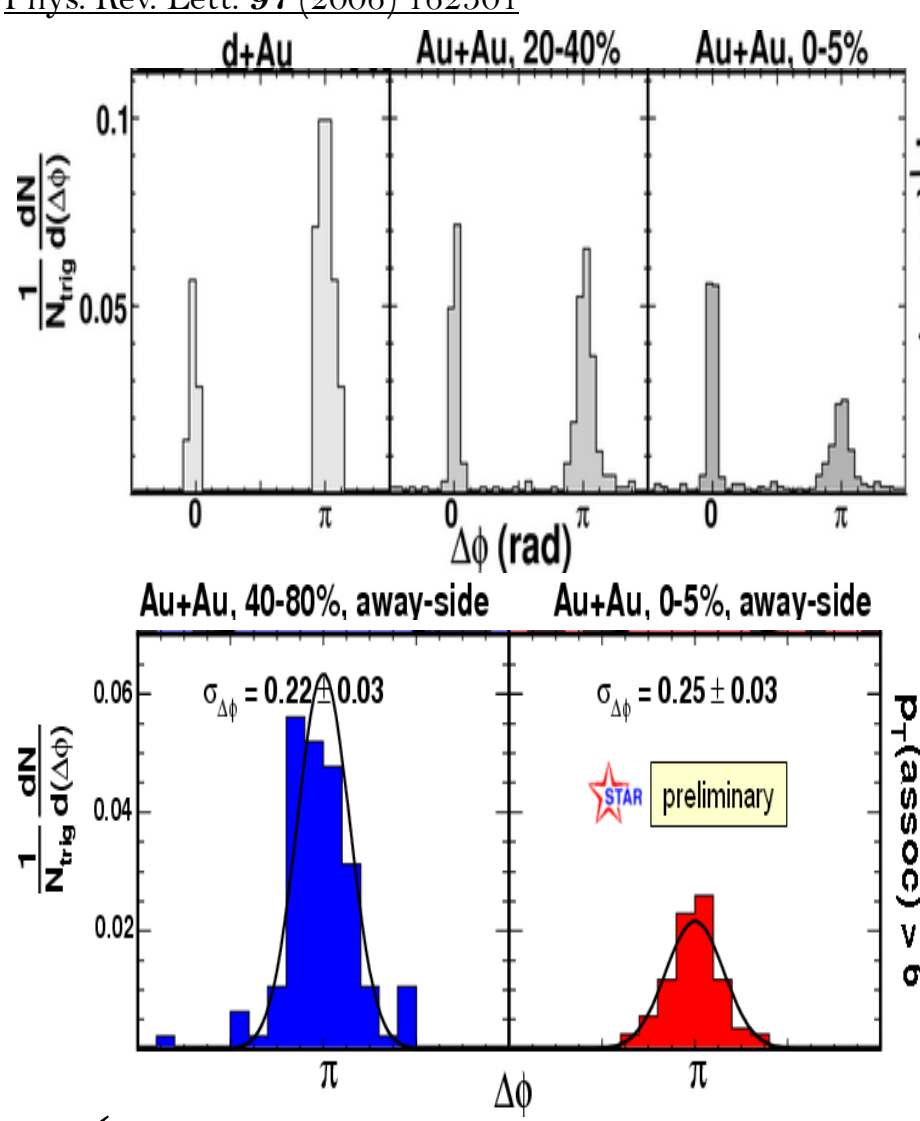


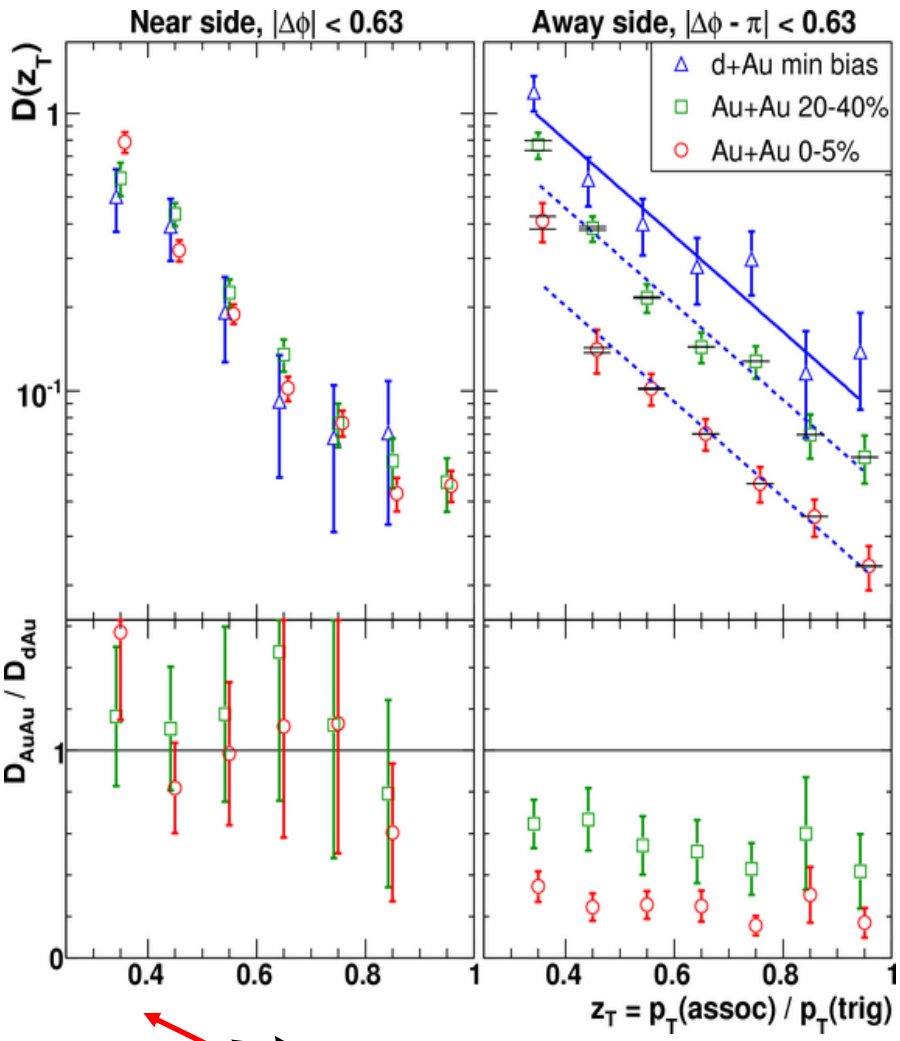


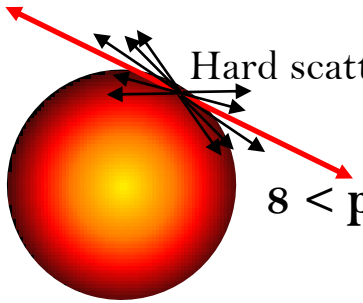
- AA collision is not simple incoherent superposition of NA collisions.
- NA collisions resembles NN collisions except for "Cronin effect"
- Hadron suppression and di-jet suppression at mid rapidity is final state effect
- di-jet suppression at higher p_T?

Correlations at mid rapidity "higher pt"

Phys. Rev. Lett. **97** (2006) 162301





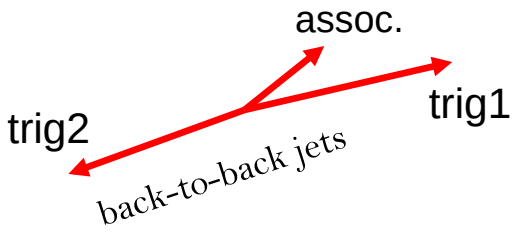


$8 < p_T^{trig} < 15$ GeV/C

✓ Are these tangential emission/non interacting jets "punch through"?

Di-jet trigger

Preprint: arXiv1102.2669



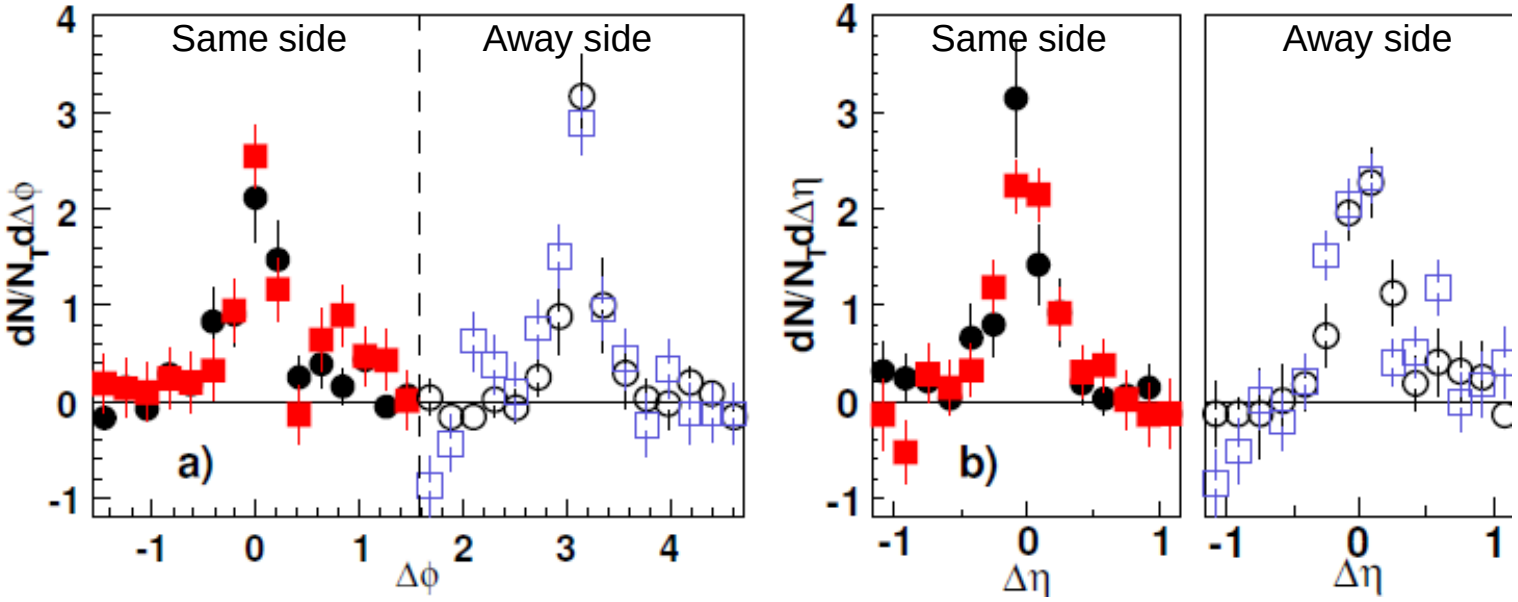
trig1: $5 < p_T^{trig1} < 10$ GeV/c

trig2: $4 < p_T^{trig2} < p_T^{trig1}$

(back-to-back, $|\phi_{trig1} - \phi_{trig2}| \leq \pi \pm 0.2$)

assoc: $1.5\ \mathrm{GeV}/c < p_T^{\mathrm{assoc}} < p_T^{\mathrm{trig1}}$

200 GeV Au+Au (squares) and d+Au (circles)

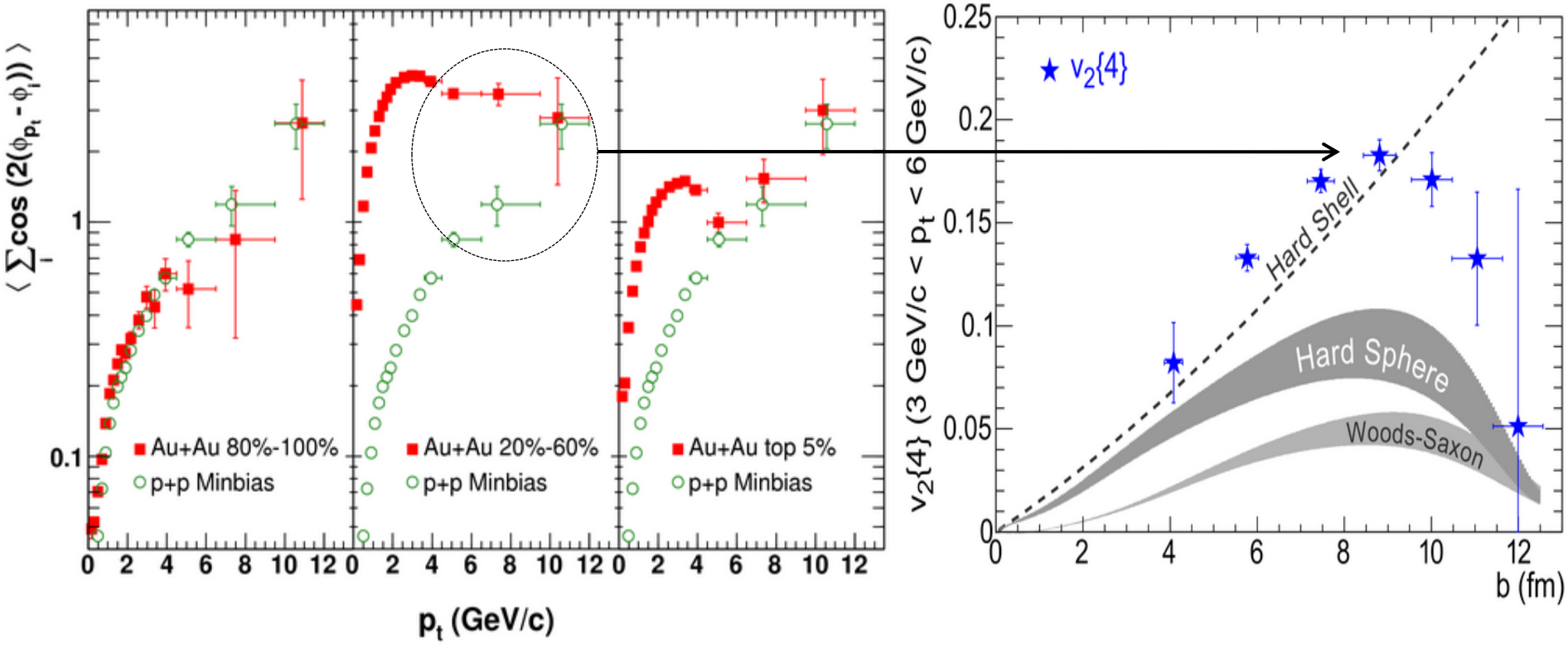


Similar away and near sides for AuAu and dAu

✓ Are these tangential emission/non interacting jets "punch through"?

Correlations w.r.t reaction plane

Phys. Rev. Lett. **93** (2004) 252301



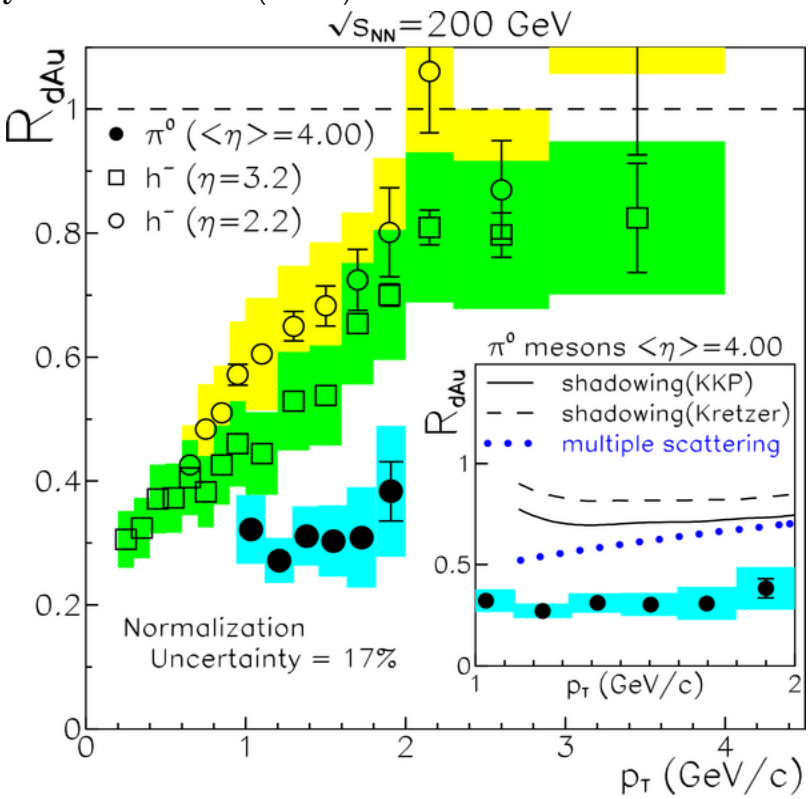
v_2 at high p_T is finite positive!

Jet quenching : energy loss dependence of path length

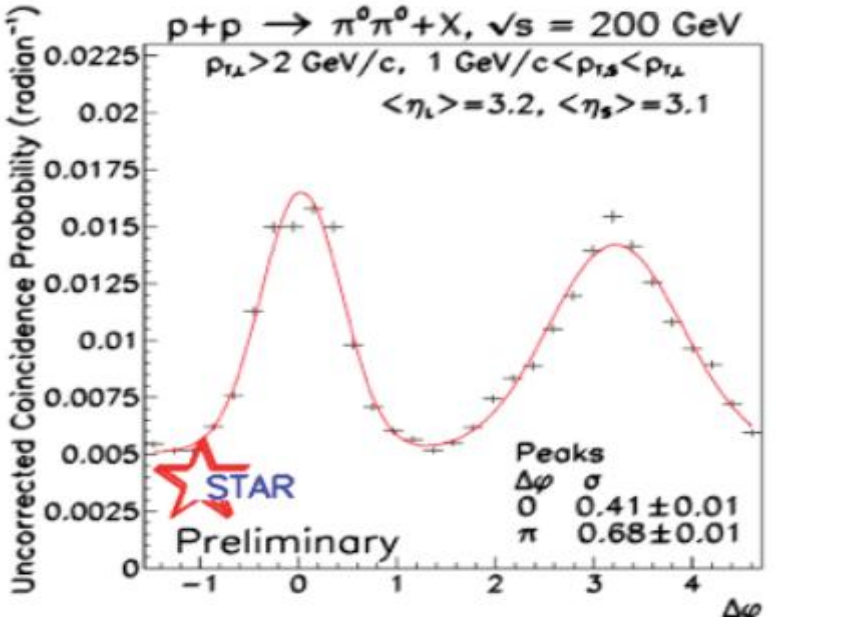
- The measured value of elliptic flow at high p_T is larger than the possible value from surface emission scenario.

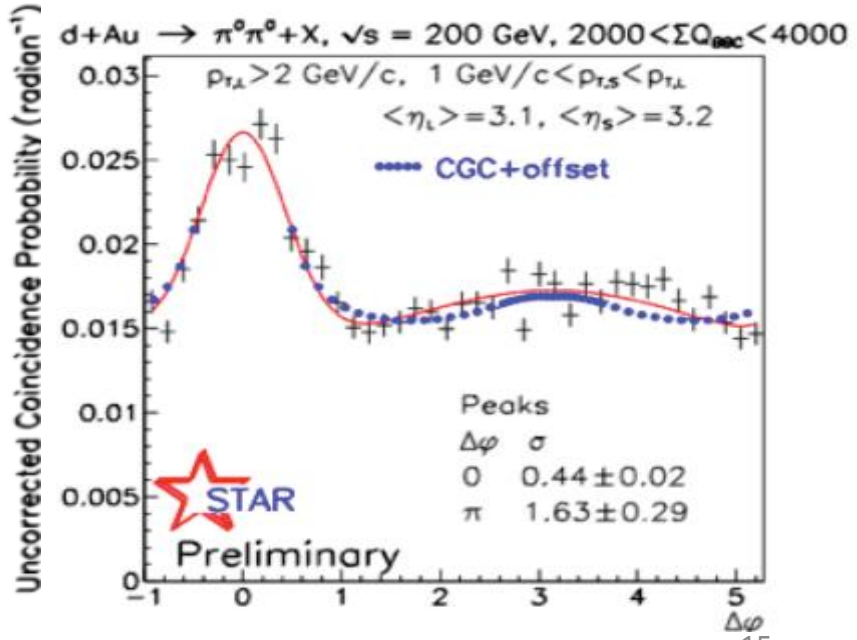
Spectra and correlations at forward rapidity

Phys. Rev. Lett. **97** (2006) 152302



π^0 spectra in pp and dAu collisions checked against pQCD and then R_{dAu} is obtained





- Charged particles and π^0 are suppressed in the forward direction
- Consistent with saturation at low x

⟶ mono-jet

" qualitatively consistent with CGC"

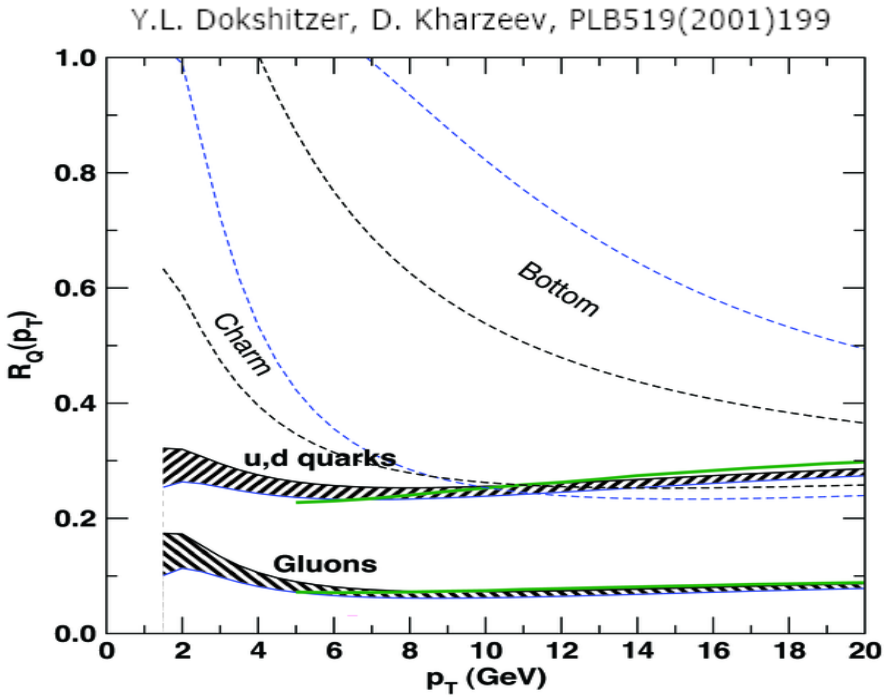
Group I

Questions	Midη	Forwardη	Measurements	Remarks
Is AA collision an incoherent superposition of NN/NA collisions?	**No**	?	Spectra and two/multi particle correlations in η and Φ and correlations w.r.t reaction plane	**Final state effect**, surface bias emission?, inconsistency with v_2? non-interacting jets?, ridge?
Does NA collisions resemble NN collisions?	**Yes except for Cronin effect**	**No**	Spectra and two particle correlations in η and Φ	**Onset of saturation at forward rapidity**
What is the role of the precursor state, the proposed CGC, if it exists?	?	**Onset of saturation**	Spectra and two particle correlations in Φ	**Onset of saturation at forward rapidity**, CGC?

Group II

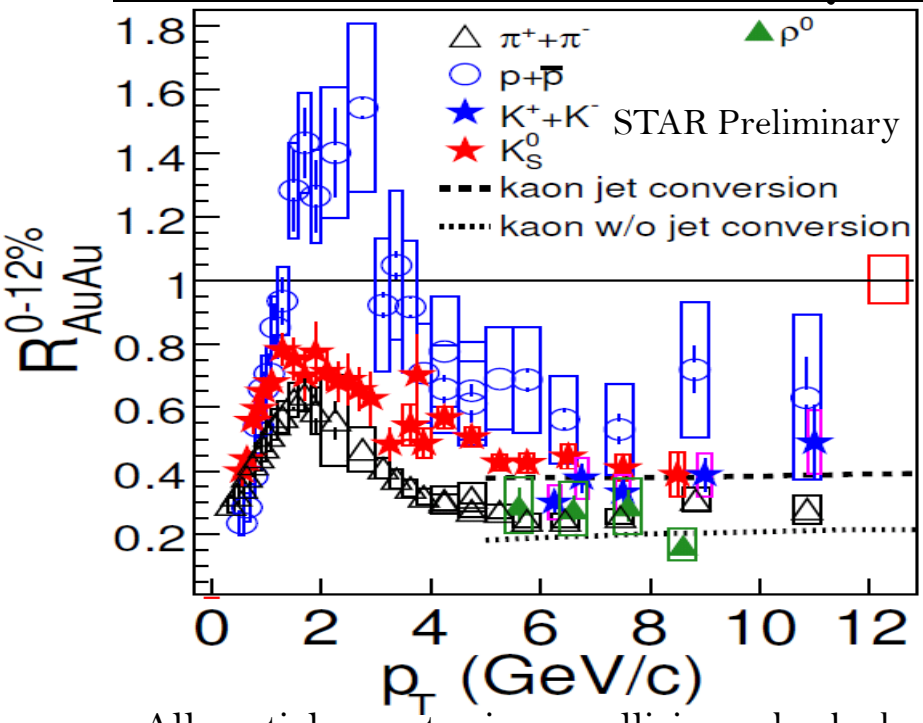
- Hadron suppression: Hadronic absorption and/or partonic energy loss?
  - ✓ Hadronic or partonic order?

- What is the mechanism of energy loss (radiative/elastic)?
  - ✓ Heavy and light quarks



- What is the functional form of energy loss (E,L,C_R,f) ?
  - ✓ Access to the underlying scale "partonic level"

Hadronic and/or partonic suppressions

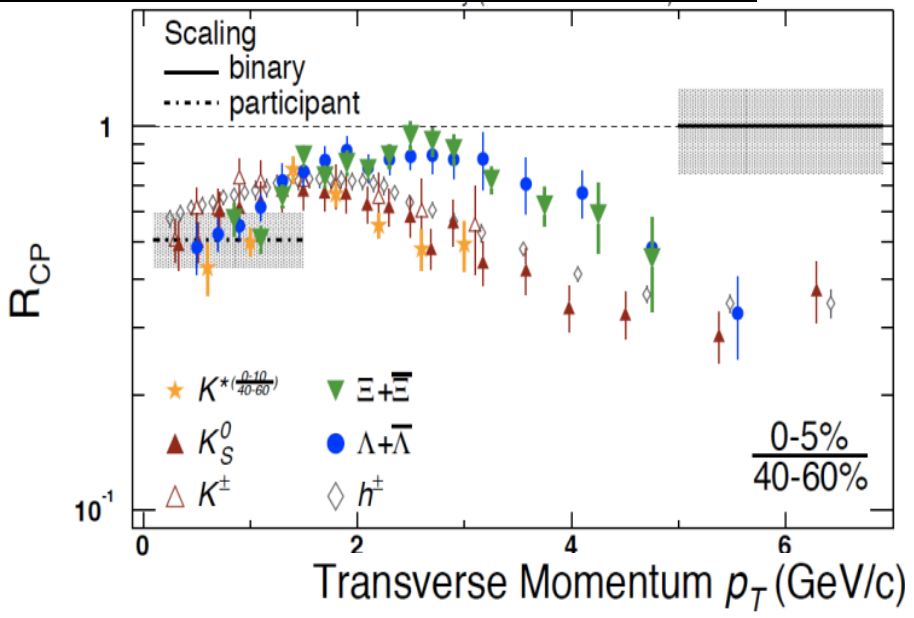


All particle spectra in pp collisions checked against pQCD and then R_{AA} is obtained

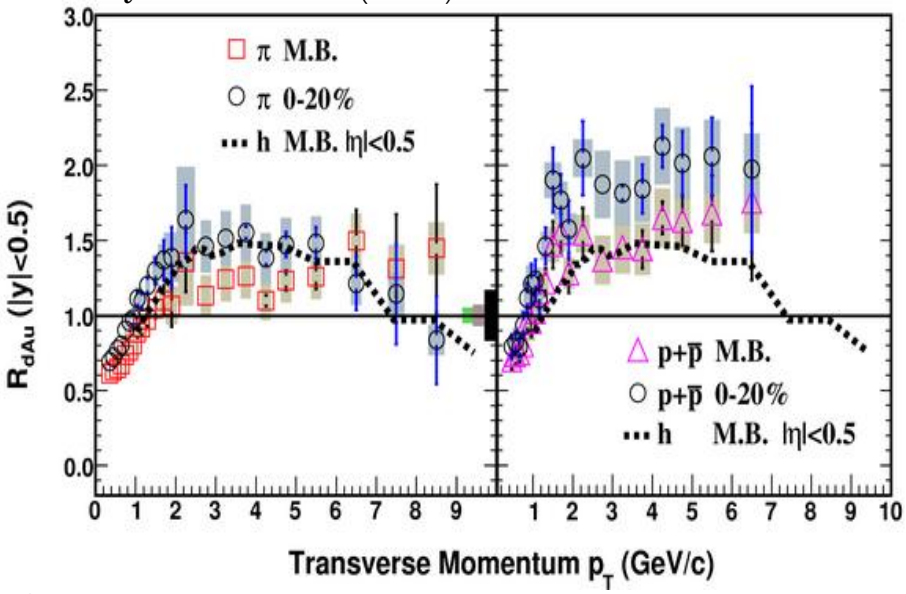
$R_{AA}(p+\bar{p}) \sim R_{AA}(K) \sim R_{AA}(\pi) \sim R_{AA}(\rho)$

Neither unique hadronic order, nor partonic order over the entire range, only quark number order in AuAu and dAu at intermediate p_T

✓ Different production mechanisms, different formation time for different particles.

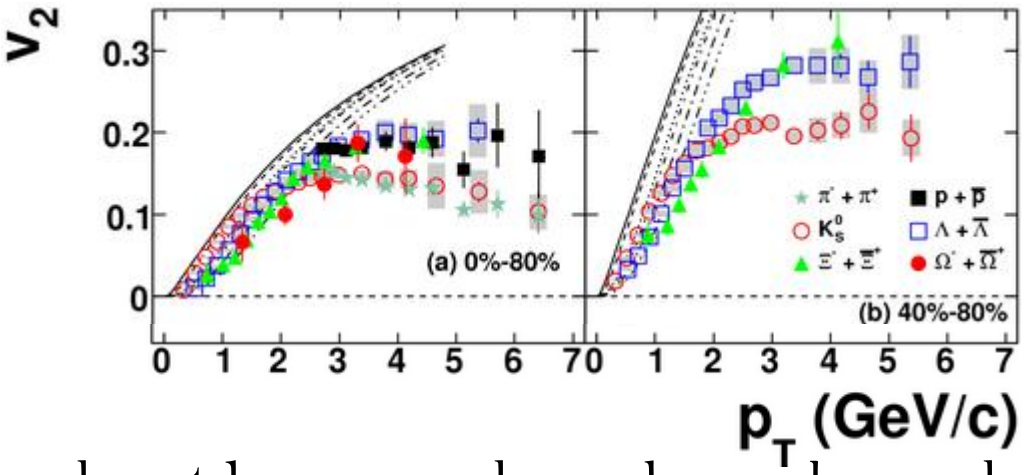


Phys. Lett. B **637** (2006) 161



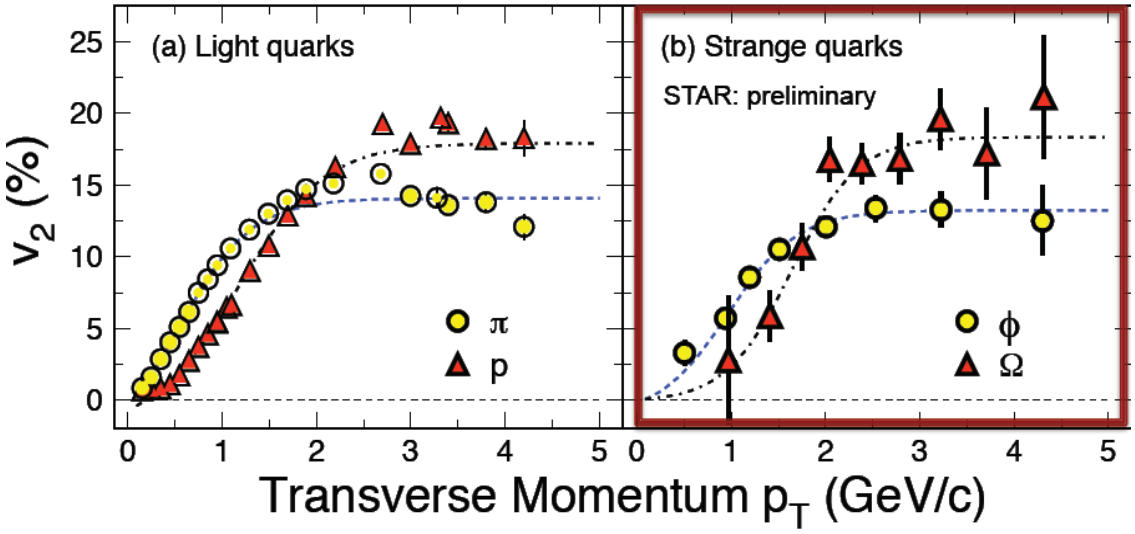
Hadronic and/or partonic collectivity

Phys. Rev. C **77** (2008) 54901



✓ Hadronic order at low p_T and quark number order at intermediate p_T

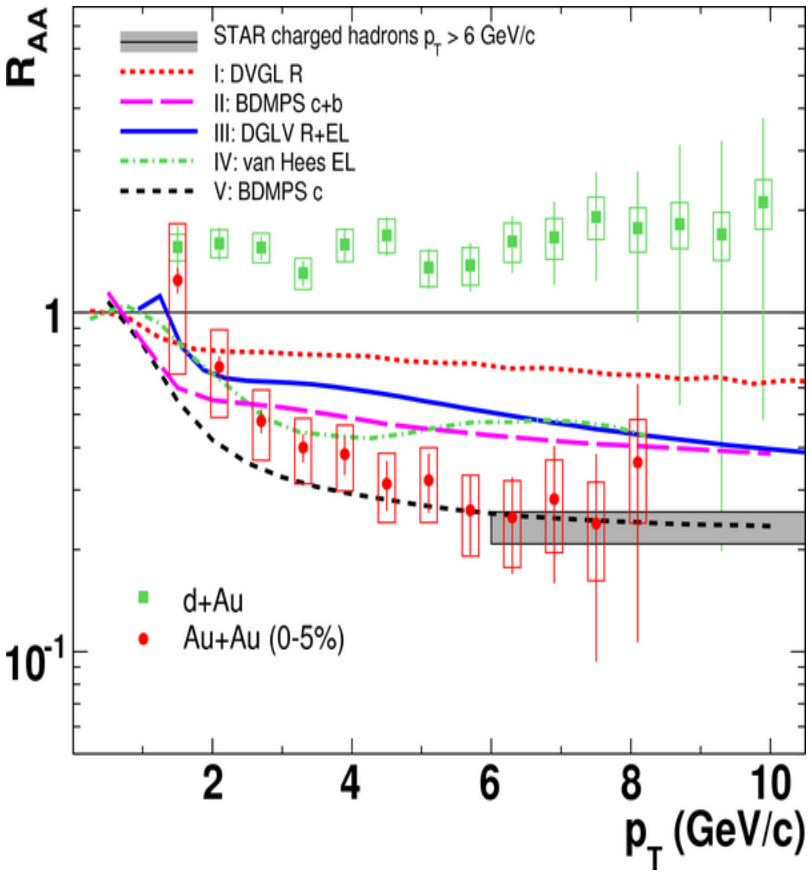
➢ Scaling with quark number suggests partonic collectivity



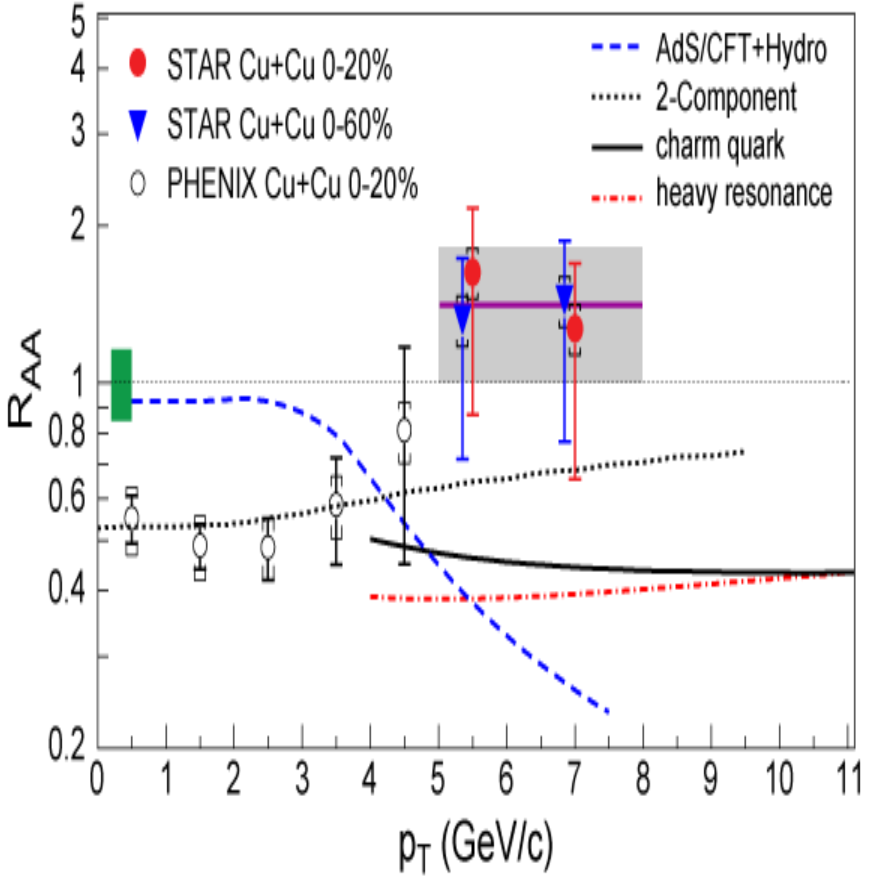
✓ Light and s-quark have similar v_2 ⟶ pre-hadronic collectivity

Inelastic and/or elastic energy loss

Phys. Rev. Lett. **98** (2007) 192301



Phys. Rev. C **80** (2009) 41902



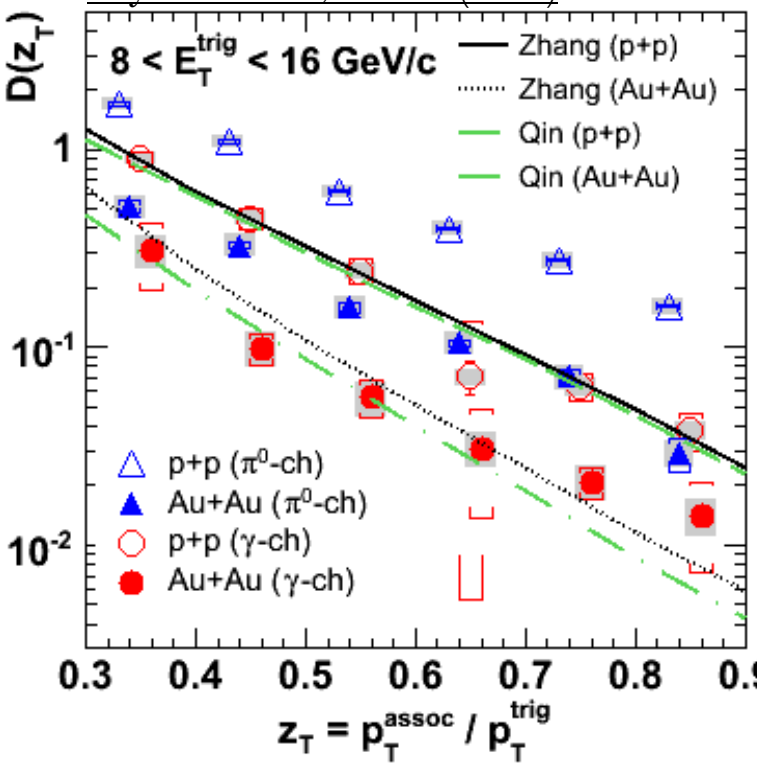
✓ Unexpected level of suppression for non-photonic electrons, Collisional energy loss? Bottom contributions? Requires direct measurements for c- and b- hadrons

➢ J/ψ yield is consistent with no suppression at high p_T

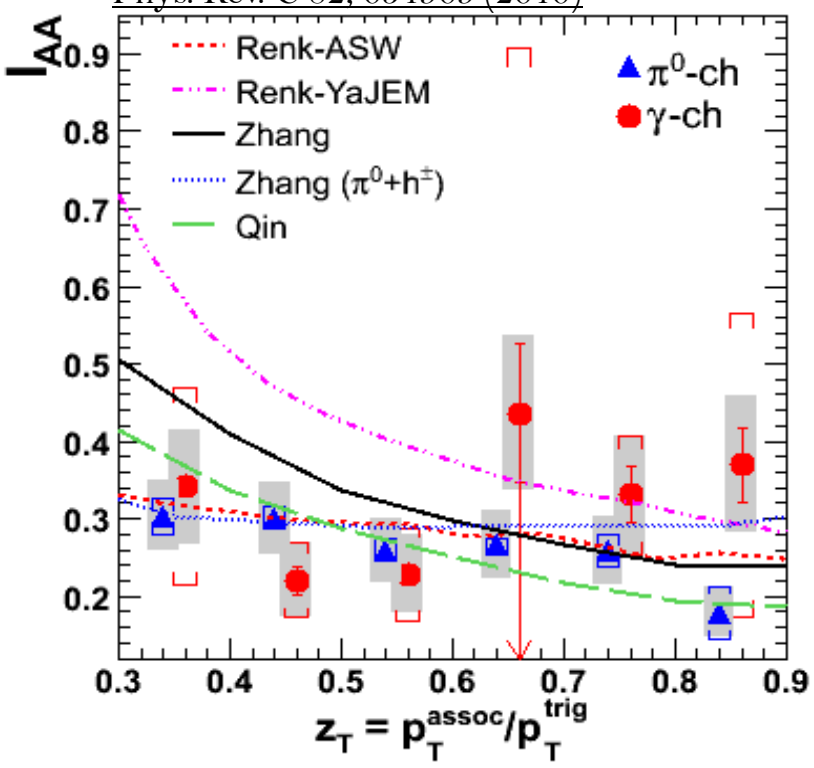
STAR is capable to do a lot more "Jaro's talk"

Functional form of energy loss

Phys. Rev. C 82, 034909 (2010)



Phys. Rev. C 82, 034909 (2010)

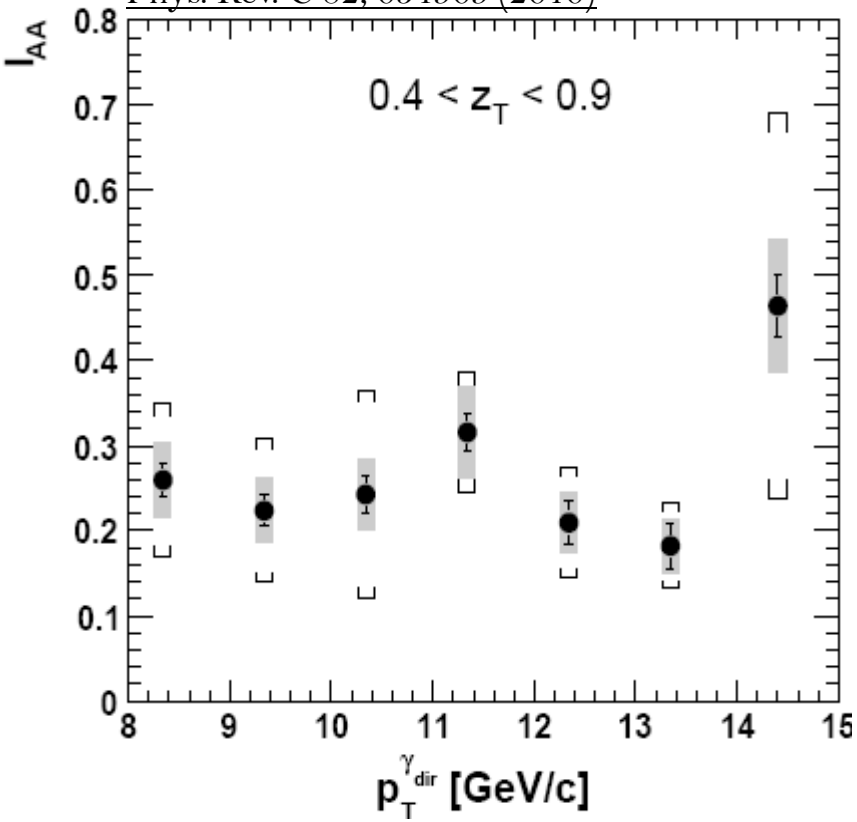


✓ Associated yields in p+p and Au+Au are well described by theoretical models.

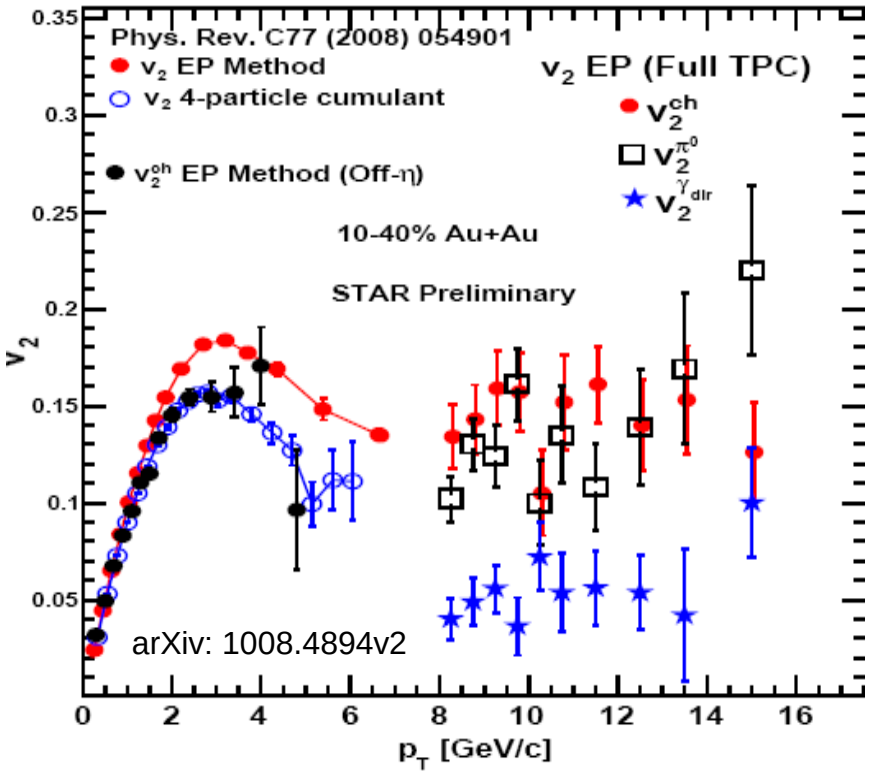
- similar level and pattern of suppression
- Effect of fluctuations in energy loss dominates over the effect of geometry?!
- Energy loss dependence of parton initial energy smeared out the expected differences?!

Functional form of energy loss

Phys. Rev. C 82, 034909 (2010)



arXiv: 1008.4894v2



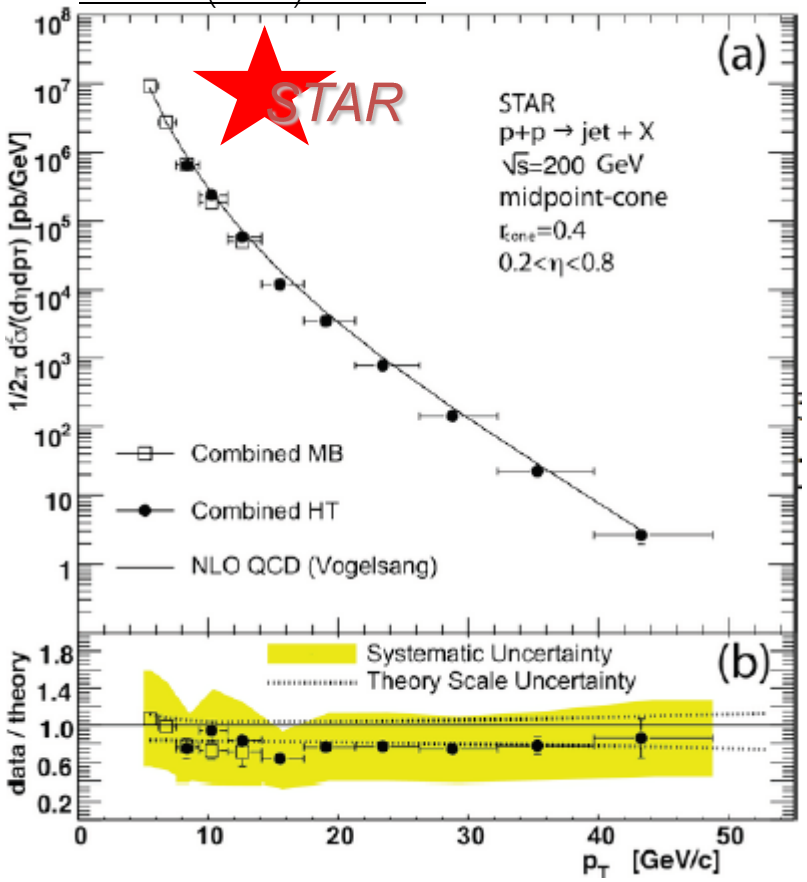
- The energy loss dependence on path length, color factor, and parton initial energy is not observed within the covered kinematic range

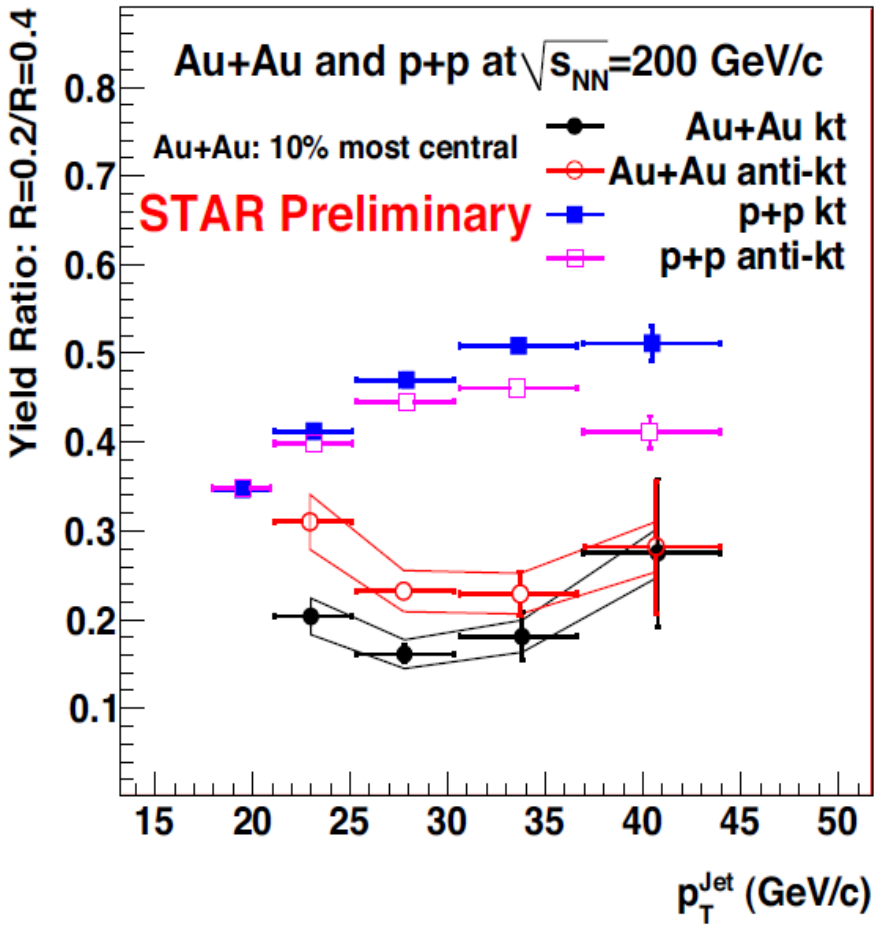
- $v_2^{\pi^0} \approx v_2^{ch} \approx 3 * v_2^{\gamma dir}$

Is it reaction plane bias, possible path length dependence of energy loss, and/or fragmentation photon contributions?

Functional form of energy loss

PRL 97 (2006) 252001





- Jet cross section at mid rapidity is consistent with NLO pQCD over many orders of magnitude
- Suggestive broadening of jets in AuAu collisions compared to jets in pp collisions

STAR is capable to do a lot more "Jan's talk"

Group II

Questions	Exp	Theory	Measurements	Remarks
Hadron suppression: Hadronic absorption and/or partonic energy loss?	**?**	**Partonic energy loss for light quark**	Spectra and correlations w.r.t reaction plane for many identified hadrons with different quarks contents	Th: suppression is too large to be described by hadronic absorption for light quarks. Exp: Neither hadronic nor partonic hierarchy, scaling with quark number at intermediate p_T
What is the mechanism of energy loss (radiative/elastic)?	**?**	**?**	Spectra, two particle correlations in Φ, and correlation w.r.t reaction plane for heavy quarks	Exp: Unexpected level of suppression for non-photonic electrons.
What is the functional form of energy loss (E,L,C_R,f) ?	?	**E, ln(E),√E, L^2,L,C_R,f**	Spectra and two particle correlations in Φ for direct photon spectra and jet-hadron correlation in Φ.	Exp: No strong dependence on E, L, C_R,f is observed

✘ For two particle correlations in Φ, and correlation w.r.t reaction plane for heavy quarks and jet-hadron correlation in Φ see Jaro's and Jan's talks respectively.

Summary

➢ Single hadron and di-jet analysis in NN, NA, and AA establish the final state effect in AA at mid η and the onset of saturation at forward η.

A particular focus of this talk was to discuss to what extent the high-p_T particles produced (STAR) can be taken as evidence for the RHIC paradigm of jet quenching "Parton traverses QDC medium (partonic matter) and loses energy".

Theory - experiment comparison seems to favor the partonic energy loss (light quarks) over the hadronic absorptions in partonic and/or hadronic matter.

The basic question

➢ Whether AA creates a medium long-lived and extend over sizable volume and reached the thermodynamics limit to have particular thermodynamic and transport properties.?!

is awaiting future measurements of more evident results and demanding theoretical progress