Lecture II

Jet quenching in high-energy heavy-ion collisions

International School QGP & HIC

Torino, Dec. 8th - 13th 2008

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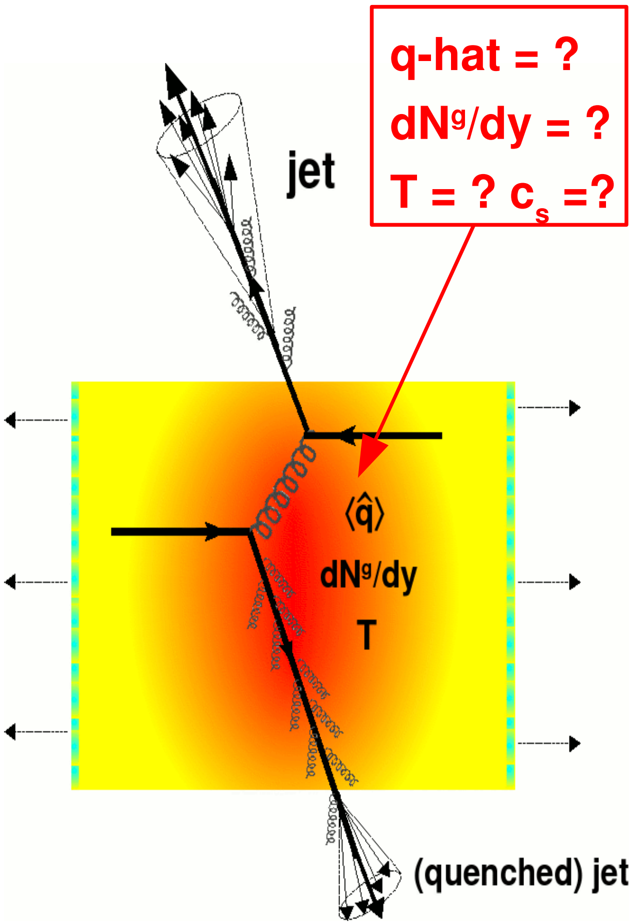
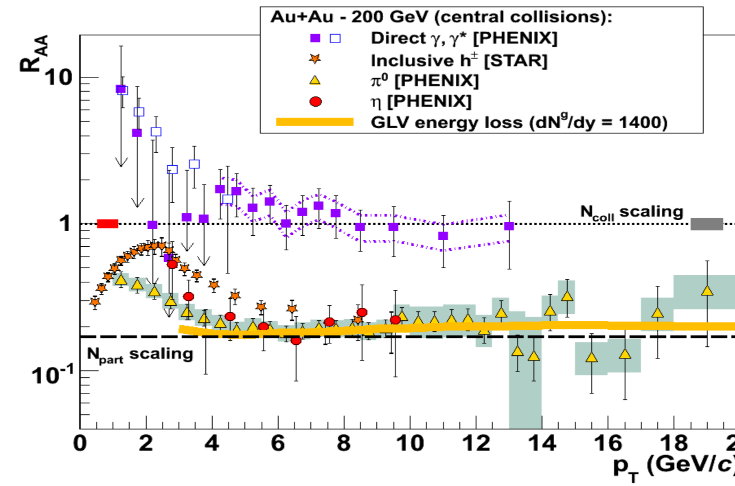
Massachusetts Institute of Technology

Lectures overview

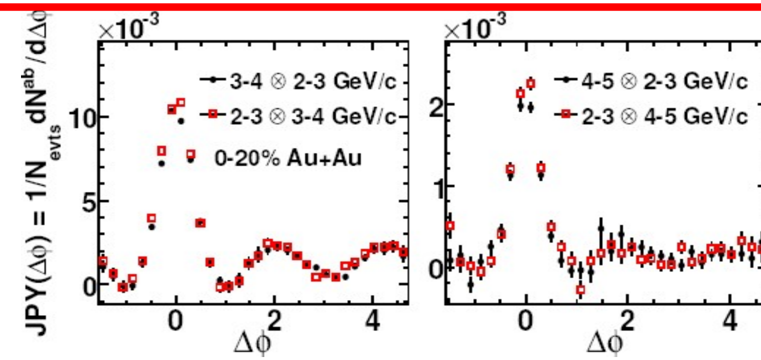


Hot/dense QCD matter properties via "jet quenching"

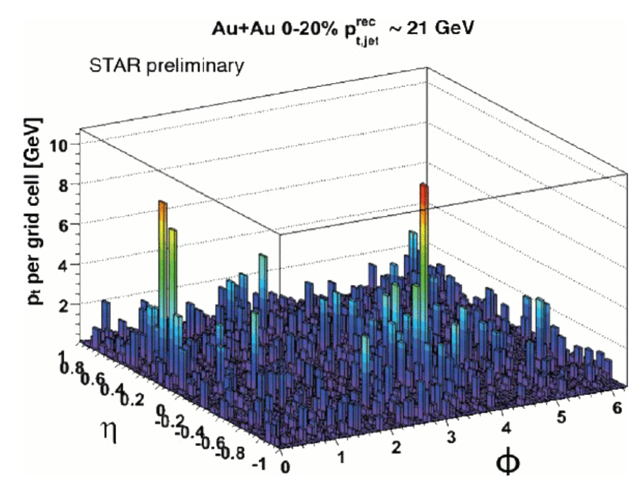
- Suppressed high-p_T hadron spectra:



- Modified high-p_T dihadron $\Delta\phi$-η correlations:



- Full jet reco, γ-jet, modified Fragm. Functions:



Plan of lectures

1st

0. Introduction: QCD matter, Heavy-ions, jet-quenching

1. High-p_T leading hadron suppression:

- pQCD factorization, quenching factor (R_{AA}): QGP q-hat, dN^g/dy
- $R_{AA}(p_T,\sqrt{s},cent,L,C_R,m_q)$: data vs parton energy loss models

2nd

2. High-p_T dihadron correlations

- Away-side suppression: QGP q-hat
- Away-side splitting: QGP speed-of-sound(?)

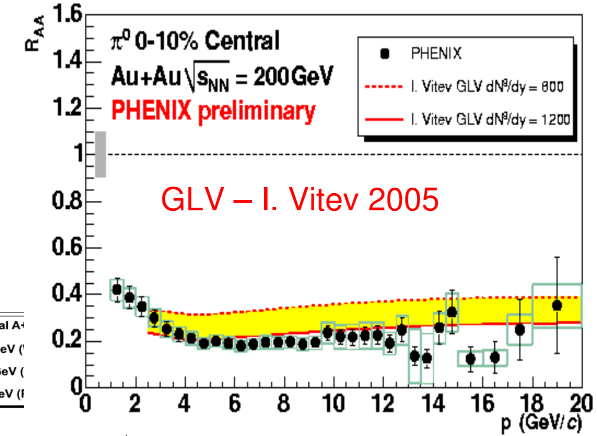
3rd

3. Full jet measurements:

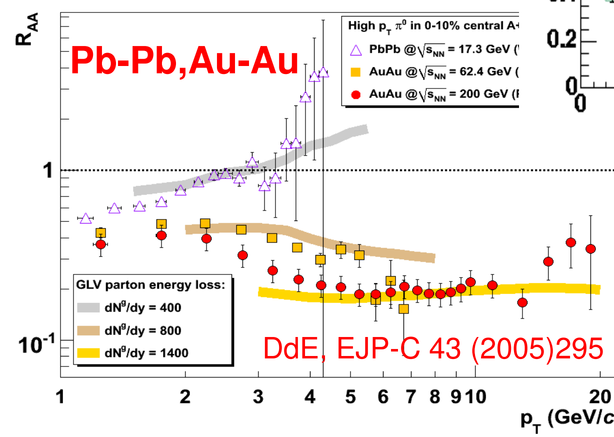
- Reconstruction: Clustering algo, bckgd subtraction, corrections
- γ -jet: medium Fragmentation-Functions: QGP q-hat

I. High-p_T leading hadron spectra

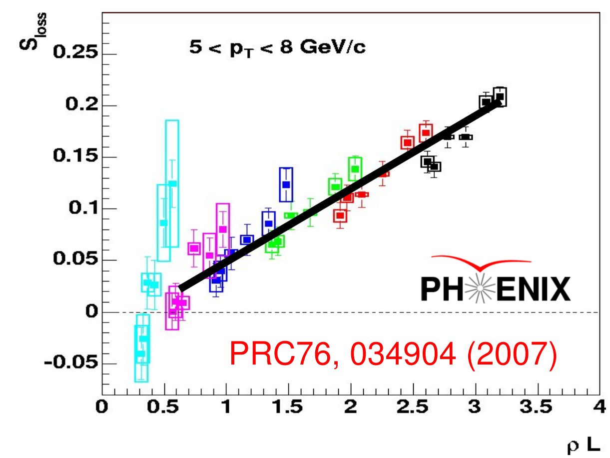
High p_T suppression vs. parton energy loss models



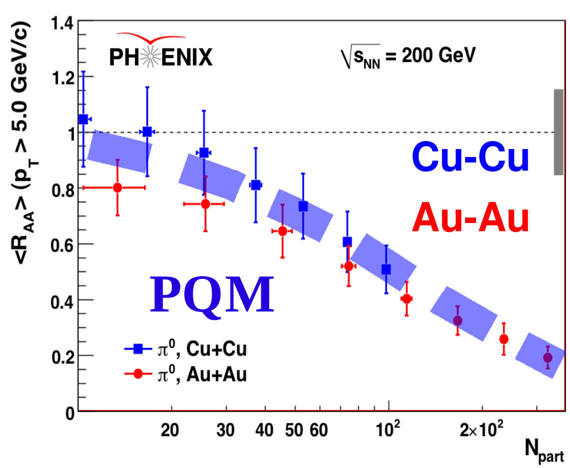
- ✔ Flat $R_{AA}(p_T)$: $\Delta E_{rad}^{LPM} \approx \alpha_s C_R \hat{q} L^2 \ln(E/(\hat{q}L))$



- ✔ $R_{AA}(\sqrt{s})$: $\Delta E \propto \alpha_S^3 C_R \frac{1}{A_\perp} \frac{dN^g}{dy} L$



- ✔ E_{loss} path-length ∝ L^2 (static), L (expanding):



- ✔ Centrality:
  $\log(R_{AA}) \propto N_{part}^{-2/3}$

High p_T suppression (V): non-Abelian nature ✔

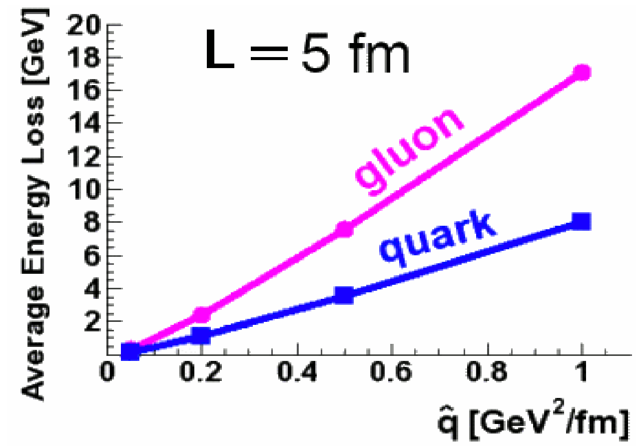
- Gluons radiate ×2 more than quarks:

$$\langle \Delta E \rangle \propto \alpha_S C_R \langle \hat{q} \rangle L^2$$

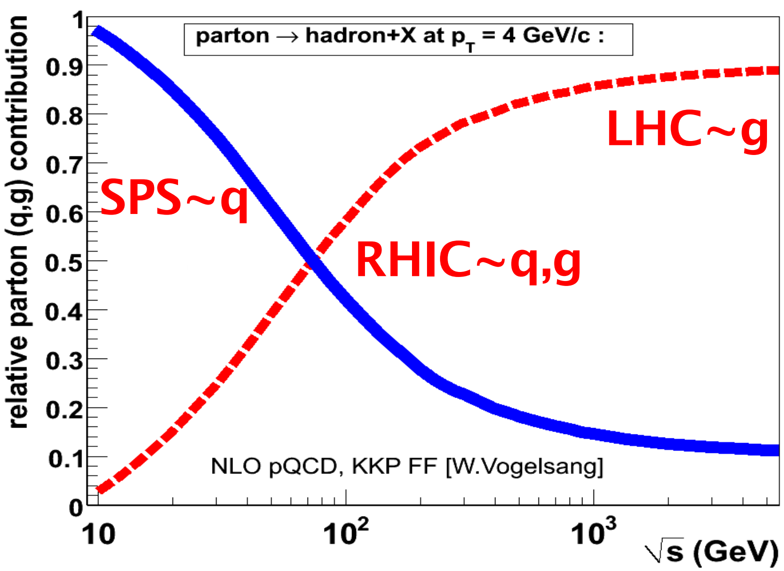
Gluon: $C_A = N_c = 3$

Quark: $C_F = (N_c^2-1)/2N_c = 4/3$

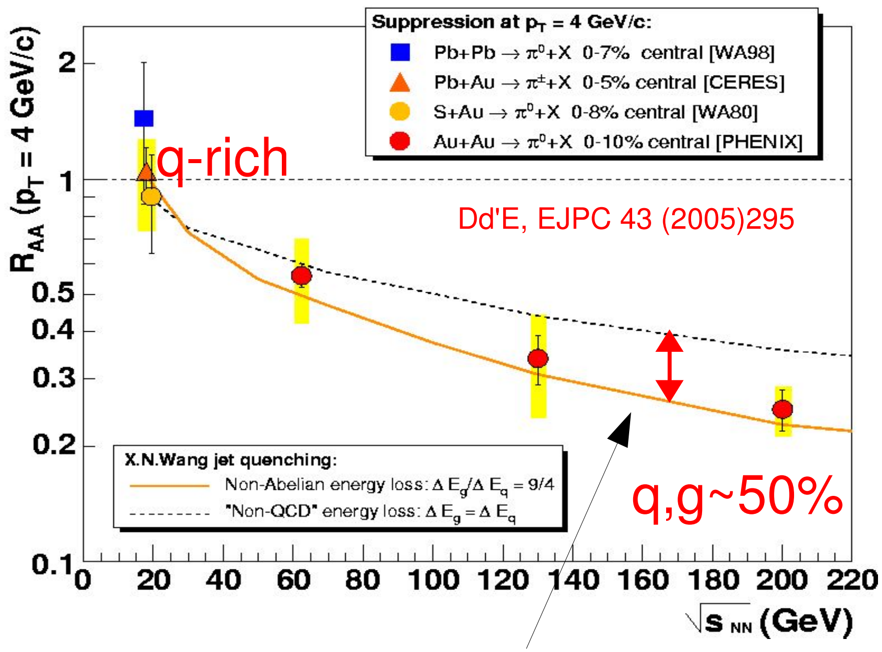
} $C_A / C_F = 2.25$



- TEST 1: Increase √s & at fixed p_T ⇒ access lower $x \sim 2p_T/\sqrt{s}$ ⇒ larger gluon fraction ⇒ increased quenching



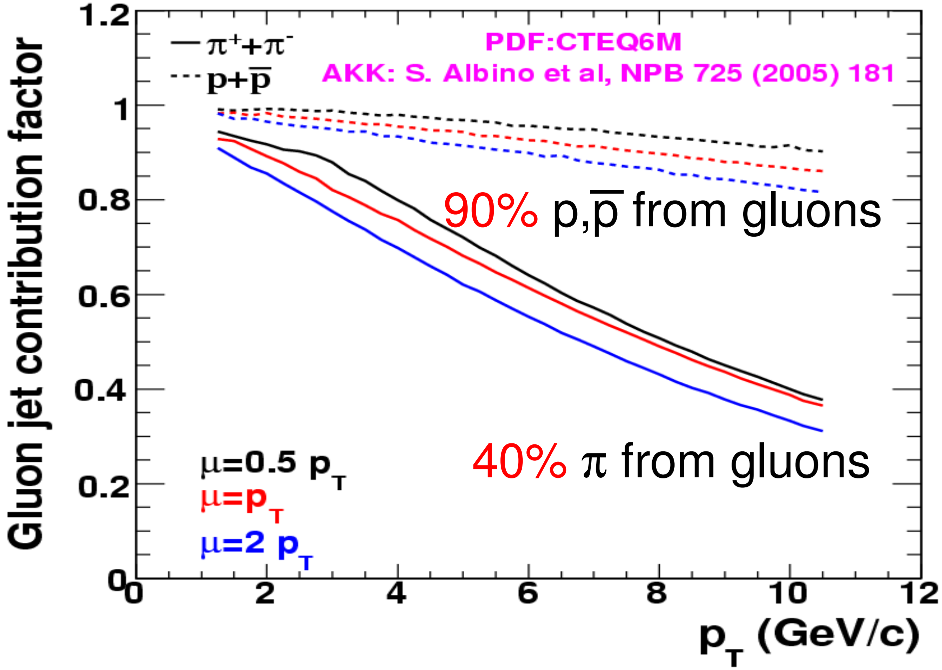
p_T = 5 GeV/c, √s = 10-5500 GeV



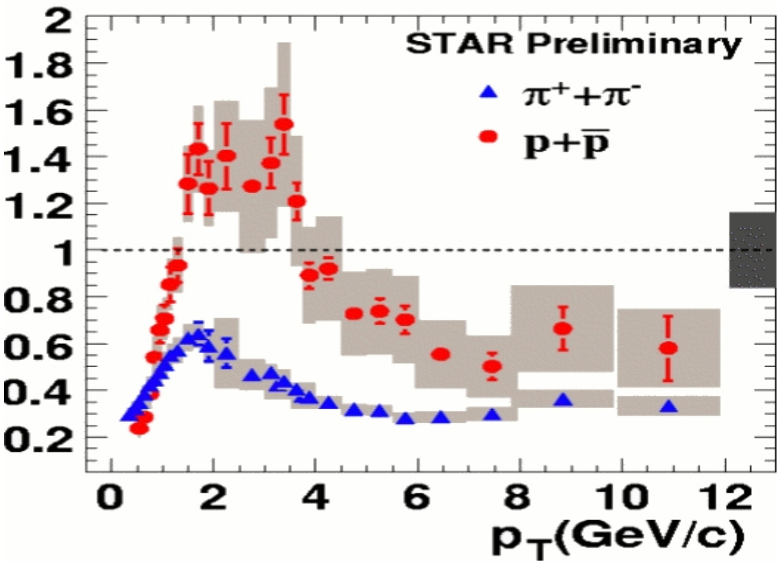
Non-Abelian energy loss model preferred over "non-QCD" ($q_{loss} = g_{loss}$)

High p_T suppression (V): non-Abelian nature ✔?

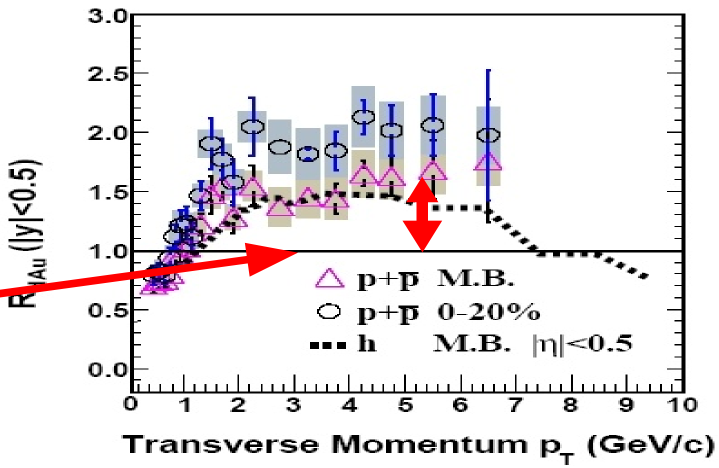
- TEST 2: ~90% high-p_T (anti)protons from gluon-fragmentation
  ⇒ increased p over π quenching ?



- But similar π,p suppression ?! no apparent stronger gluon energy loss ?



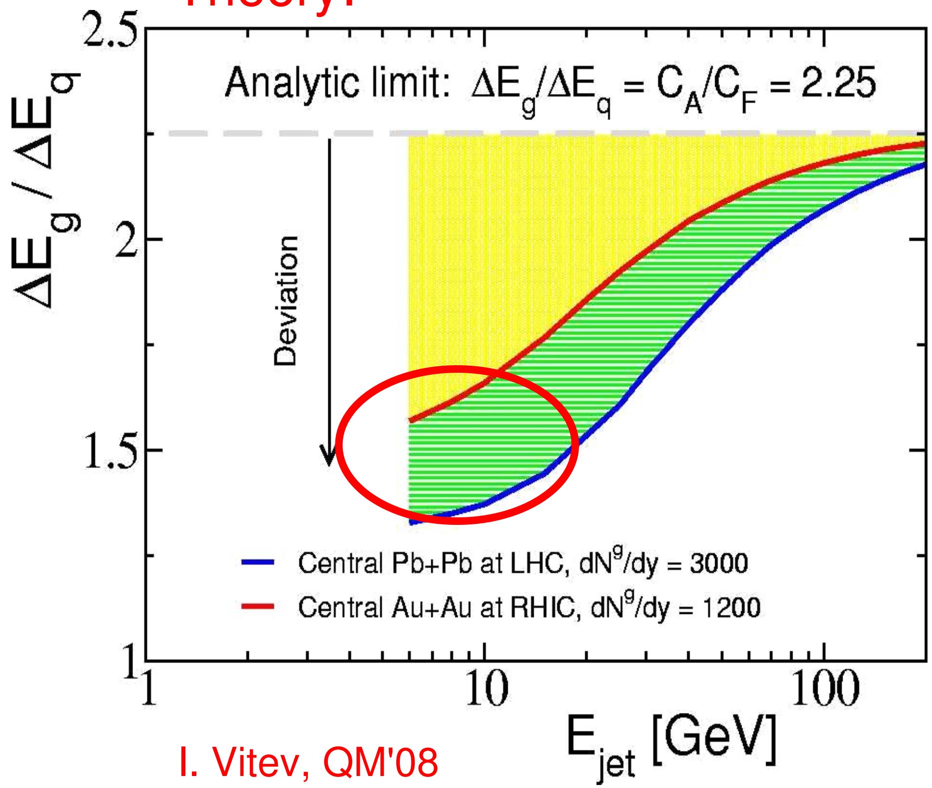
- Yet, (anti)proton production not well "calibrated": enhanced in d-Au (extra non-pQCD mechanism ?)



High p_T suppression (V): non-Abelian nature ✔

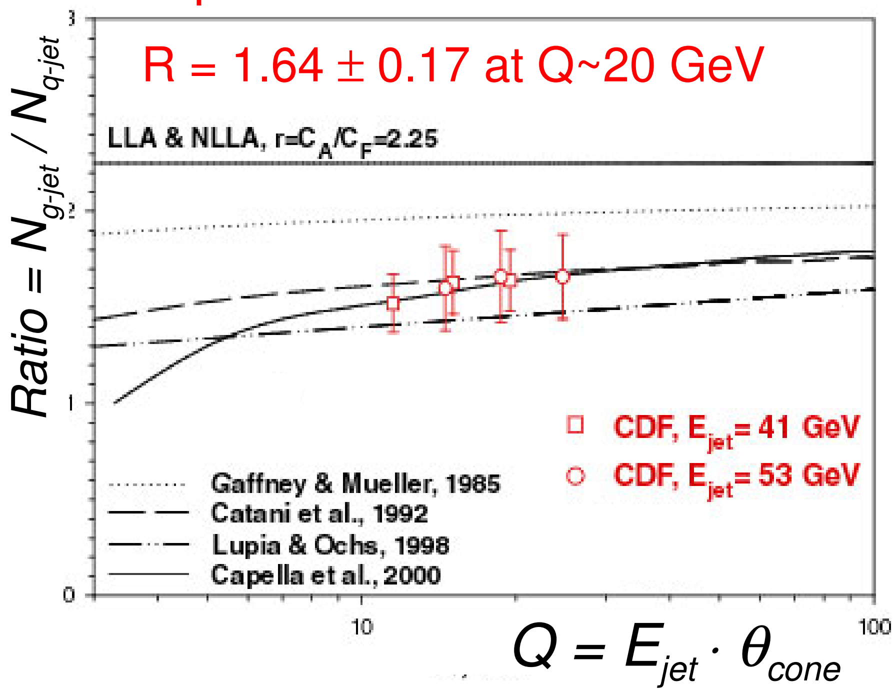
- Besides ... gluons radiate 2.25 times more than quarks only asymptotically ...

Theory:



I. Vitev, QM'08

Experiment:

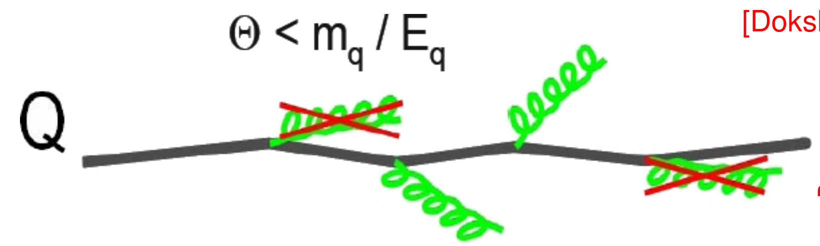


Latest LEP (OPAL) result:
r = 1.51±0.04 at Q~90 GeV

- Effectively: $\Delta E_g/\Delta E_q$~1.5   RHIC results do **not** disprove the colour-factor dependence of high-p_T suppression (if anything, the $\sqrt{s}$-dependence supports it ...)

High p_T suppression (VI): Heavy-quark mass effect ?

- Theory: Massive quarks cannot radiate gluons at low angles
  (causality requirement: since $v_Q<c$)

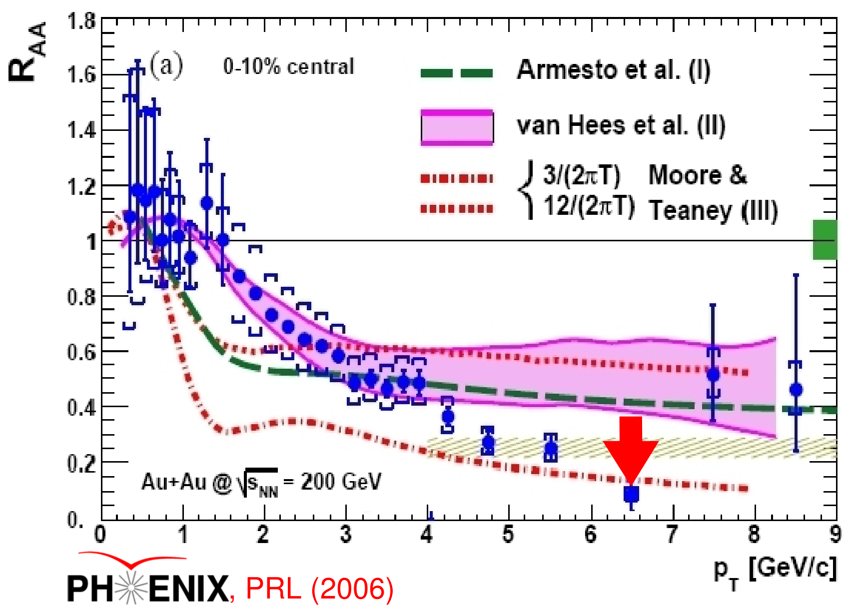


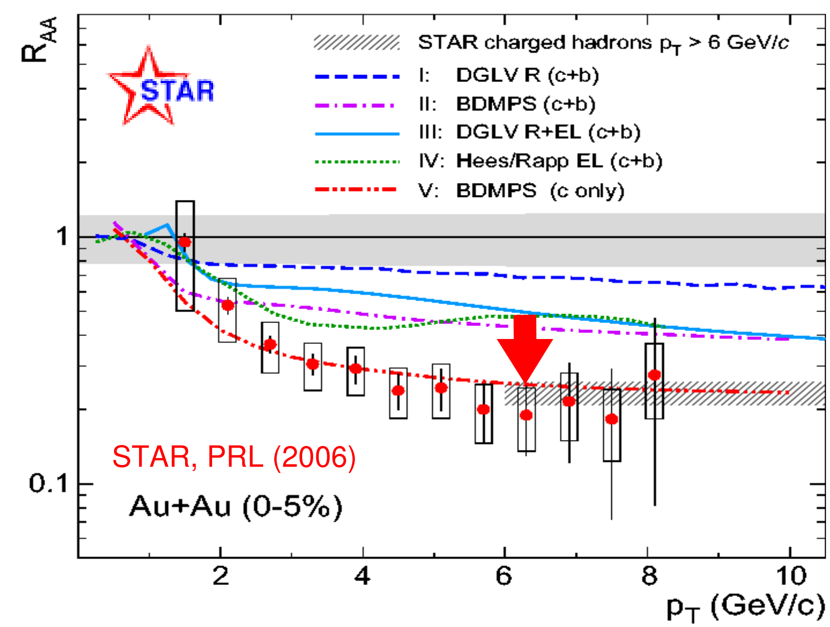
[Dokshitzer & Kharzeev]

"dead-cone"

⇒ Heavy-Q lose less energy than light-q ($\Delta E_{loss} \sim M/m_D$): ~25%(~75%) less for c,b

- Experiment: High-p_T $e^{\pm}$ from heavy-quark decays as suppressed as pions: R_{AA}~0.2 above ~6 GeV/c !





- Radiative energy loss fails !?

High p_T suppression (VI): Heavy-quark mass effect ✔

"Heavy-quark puzzle" EXPLANATIONS ...

☹ Less B-mesons ? No. B/(D+B)~50% (preliminary PHENIX & STAR data)

😐 Extra quench from elastic Eloss: Likely. E_{coll} not negligible for slower heavy-Q

😐 Strongly-coupled QGP: Larger heavy-quark diffusion coeff. (AdS/CFT)

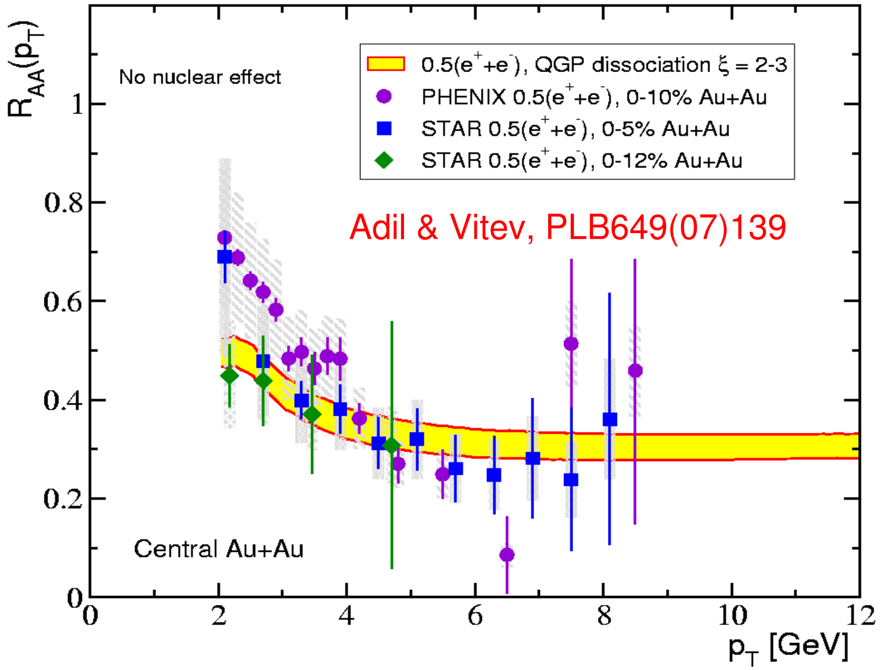
😐 Coalescence of c-quarks from mesons into baryons (with reduced $e^{\pm}$ BR) ?

☺ Very short D,B formation time O(1 fm/c) !

$\tau_{form} \sim (zp_p/m_h)/(1+\gamma_p) \sim$ 0.4-1.6 fm (*)

Heavy-quarks don't fragment
in vacuum but in the plasma (*) !

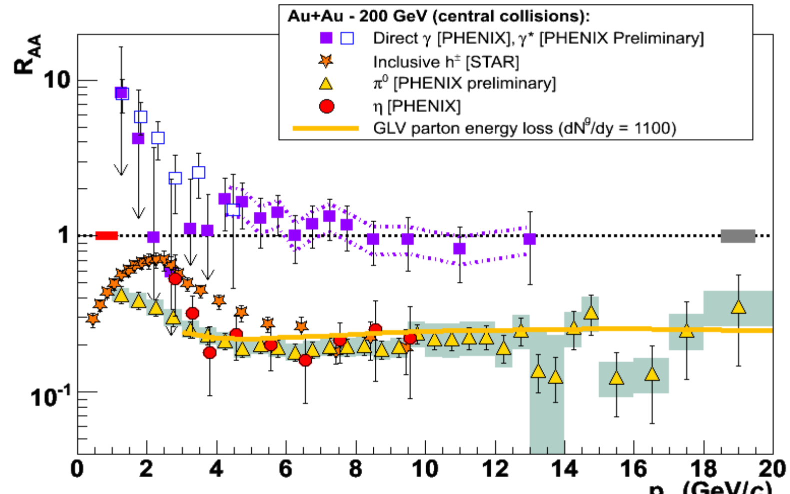
Parton-meson dissociation



(*) Note extra Lorentz boost: γ = E/m~3-10

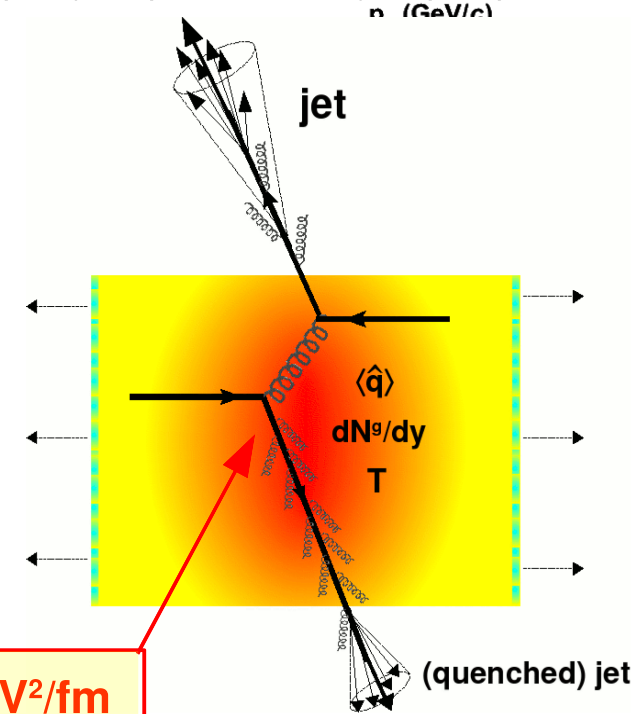
High-p_T leading hadron suppression: summary

■ High-p_T hadron suppression:



■ Validation pQCD E_{loss} models:

$R_{AA}(p_T,\sqrt{s},cent,L,C_R,m_q)$ ~ OK

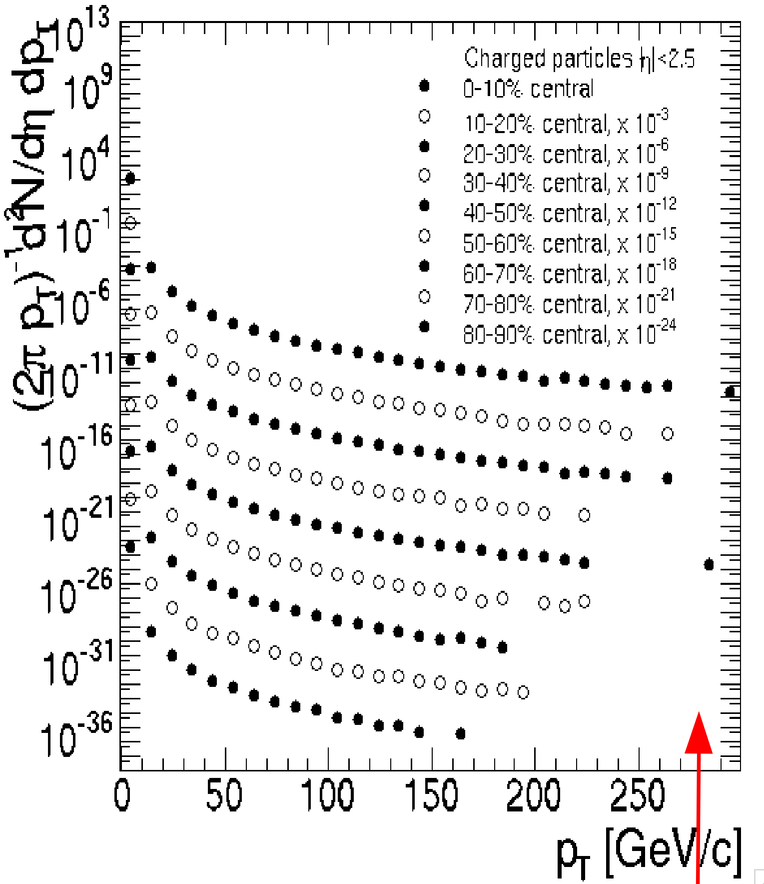


■ Hot/dense QCD matter tomography:

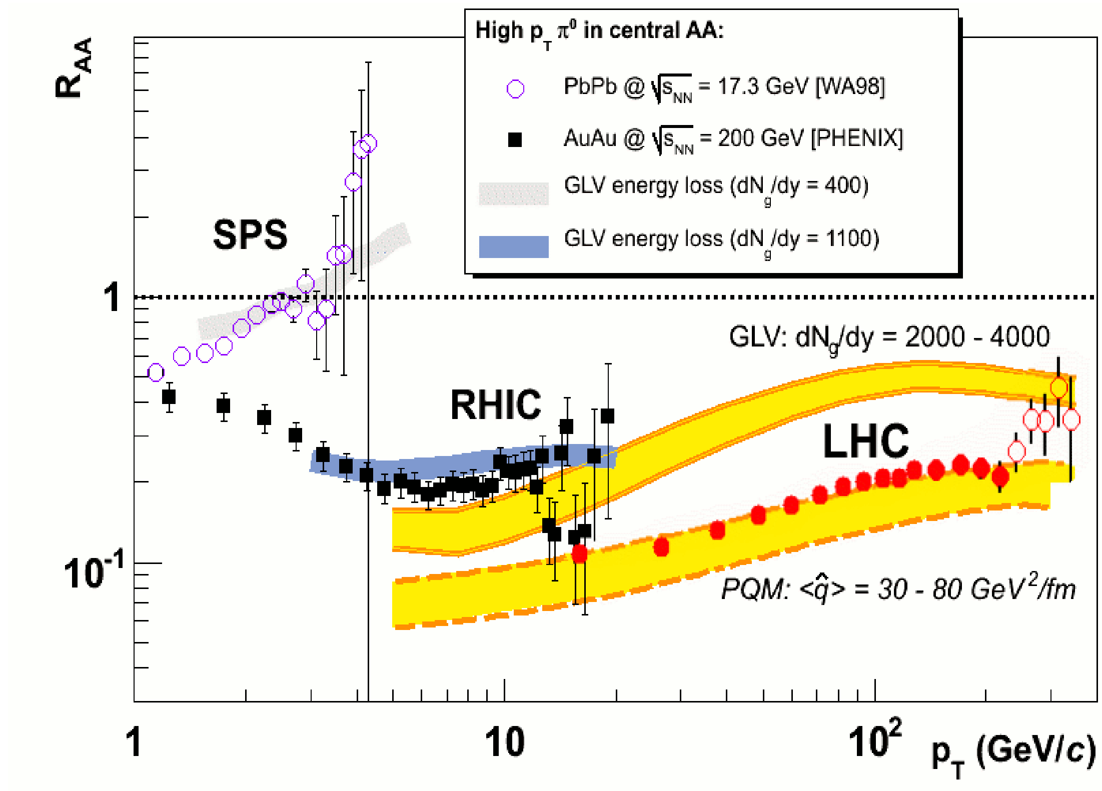
$\hat{q}$ ~13 GeV²/fm
dN^g/dy = 1400
T~0.4 GeV

High p_T suppression: outlook (CMS @ LHC)

- Physics reach (Pb-Pb @ 5.5 TeV, 0.5 nb^{-1}, HLT): spectra, R_{AA}



p_T~300 GeV/c

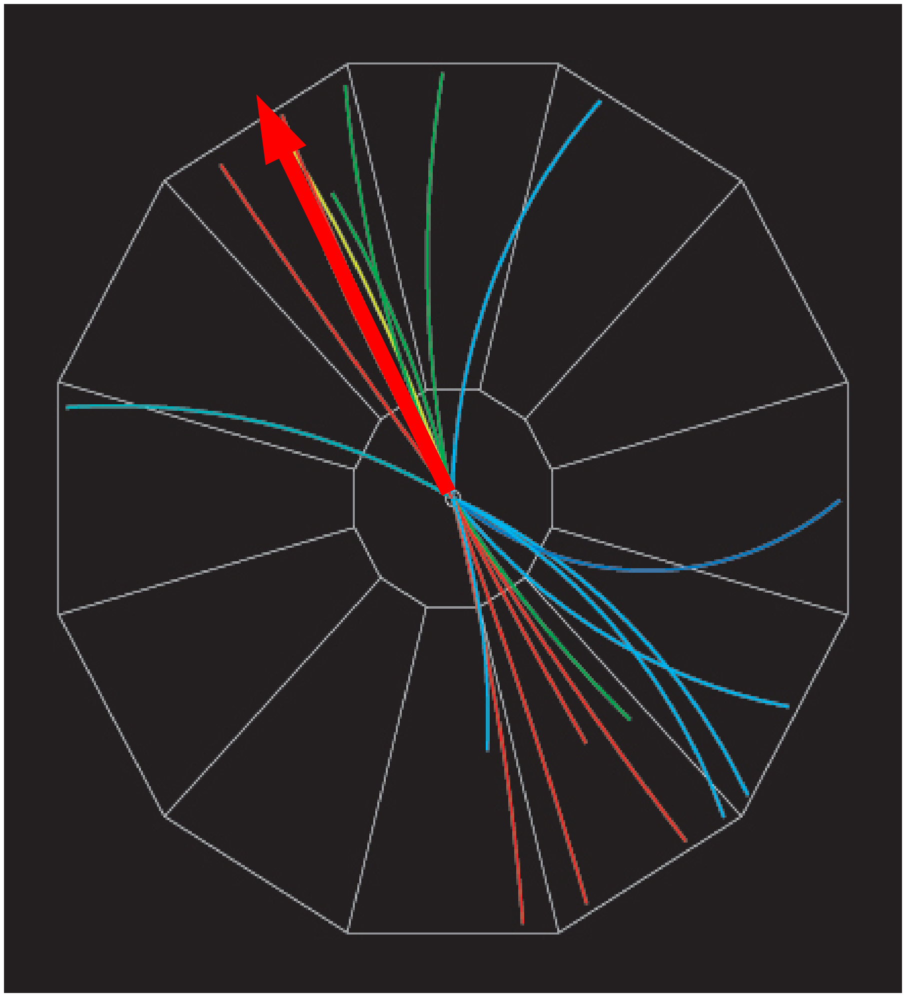


- R_{AA} at the LHC not independent of p_T: more sensitivity to energy loss distribution

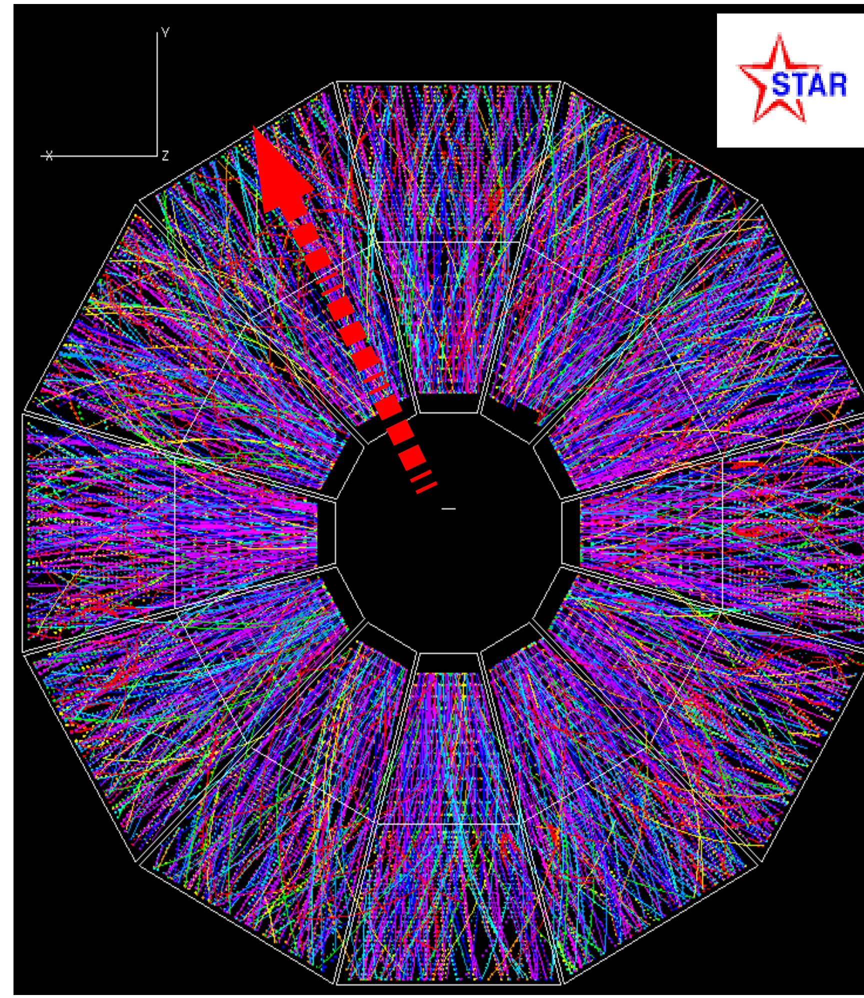
(Slower rise in BDMPS than in GLV)

II. High-p_T di-hadron η-ϕ correlations

Jet quenching via high-p_T leading hadrons

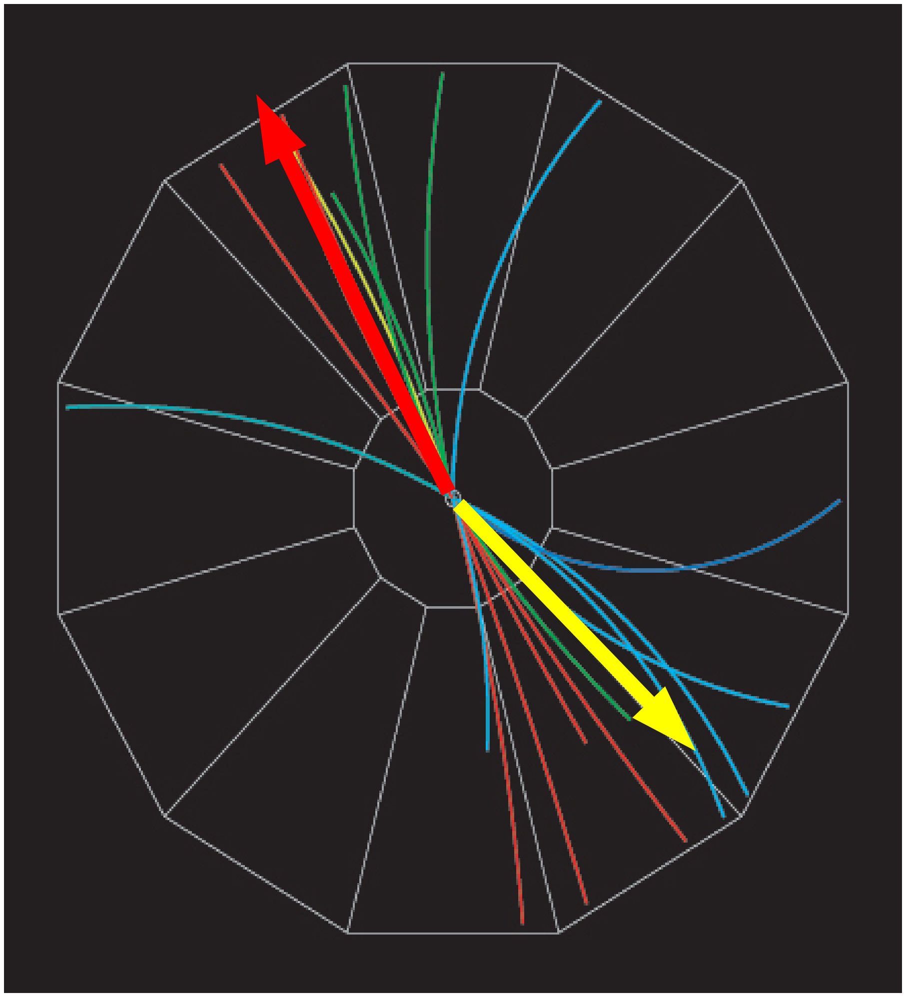


$p+p \rightarrow jet+jet$ [$\sqrt{s}$ = 200 GeV]

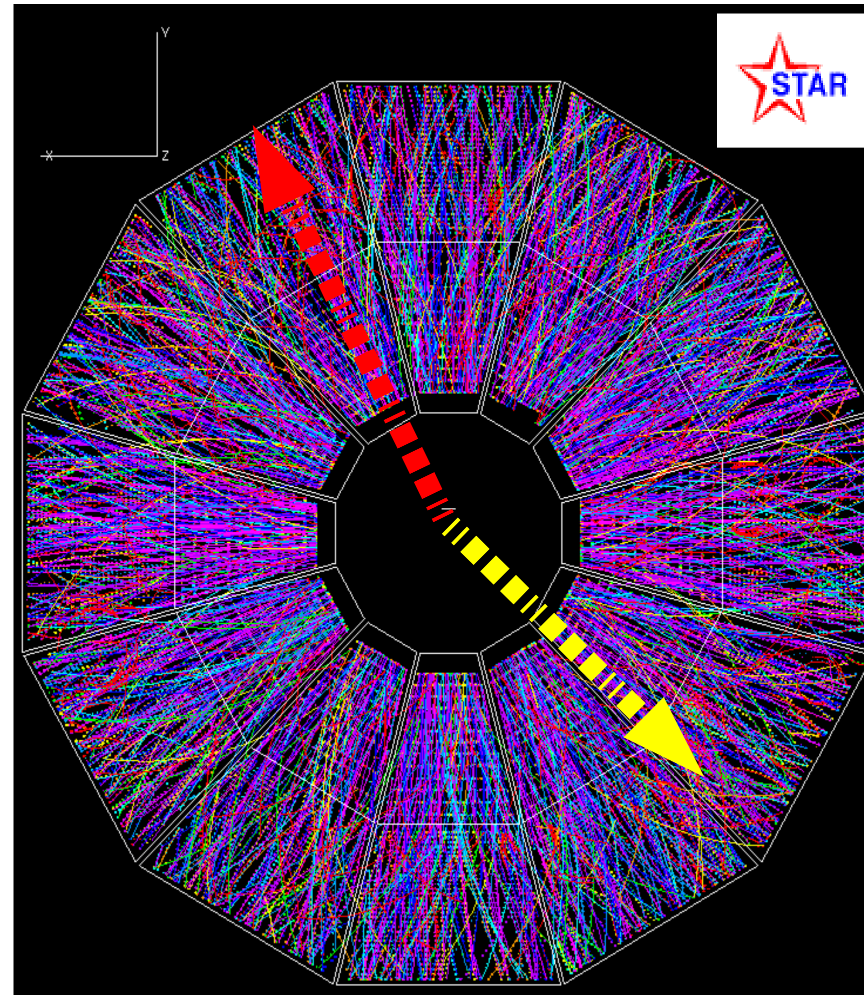


Au+Au $\rightarrow$ X [$\sqrt{s_{NN}}$ = 200 GeV]

Jet quenching via high-p_T dihadron ϕ correlations

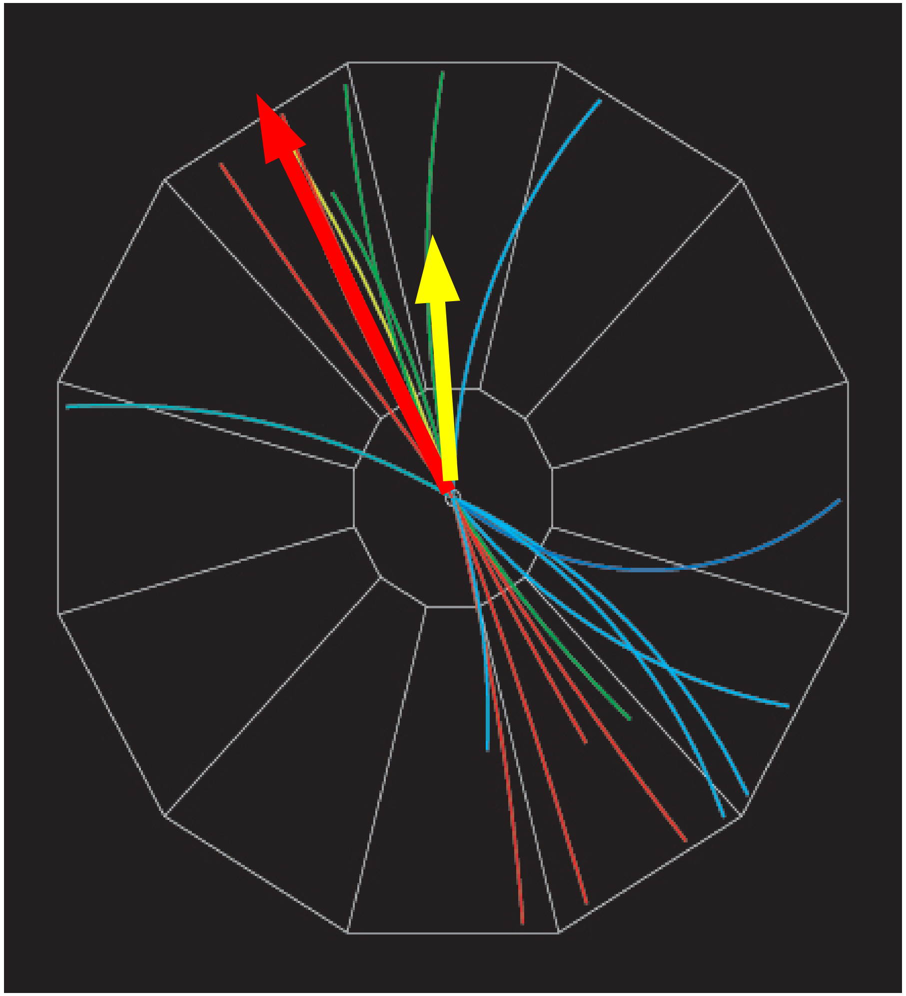


p+p $\rightarrow$jet+jet [$\sqrt{s}$ = 200 GeV]

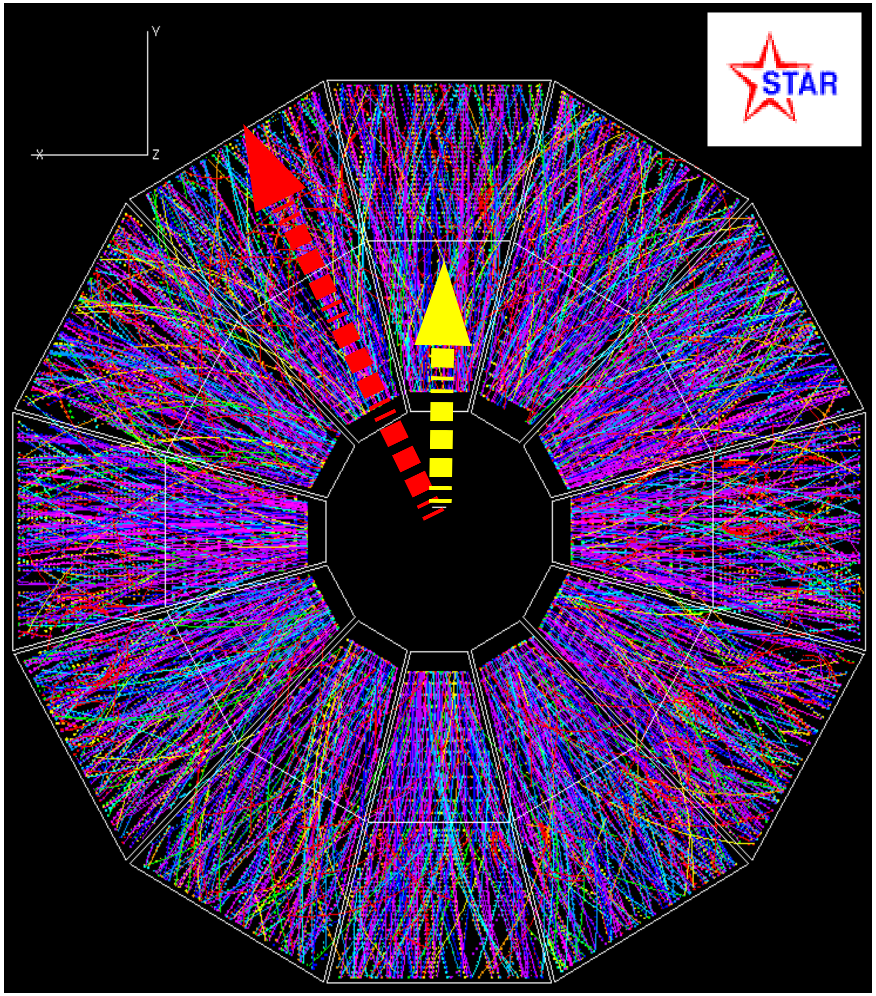


Au+Au $\rightarrow$ X [$\sqrt{s_{NN}}$ = 200 GeV]

Jet quenching via high-p_T dihadron ϕ correlations



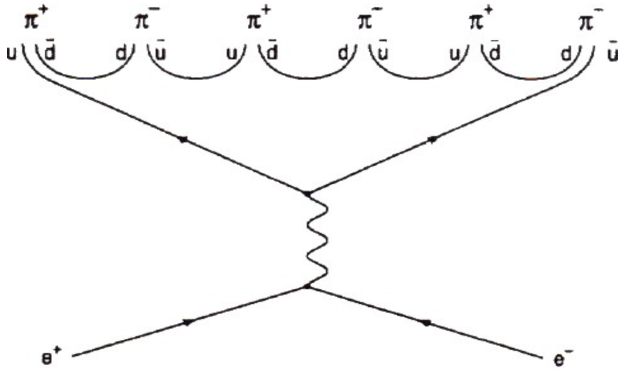
p+p →jet+jet [√s = 200 GeV]



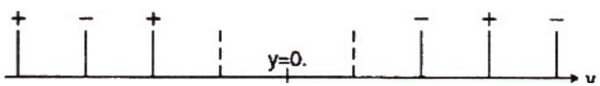
Au+Au → X [$\sqrt{s_{NN}}$ = 200 GeV]

Jet fragmentation: azimuthal charge ordering

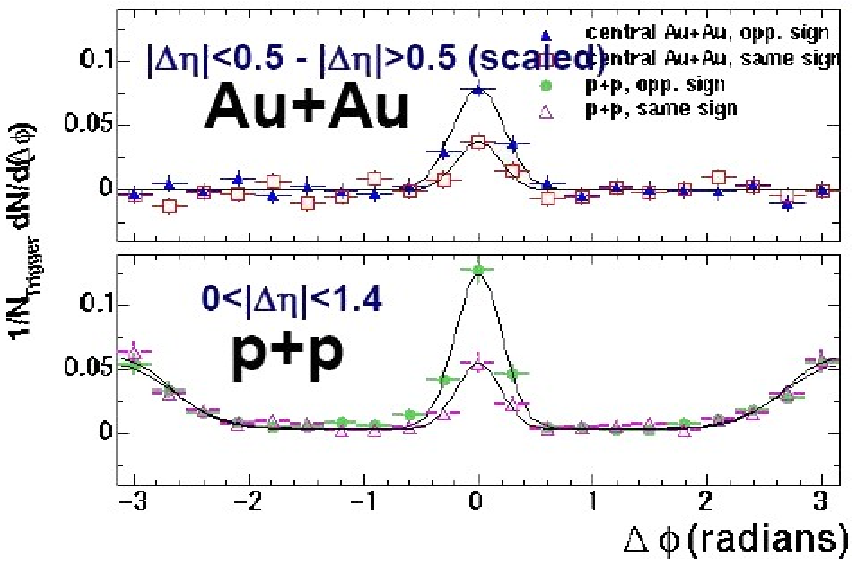
- Strong dynamical charge correlations are expected in jet fragmentation:



Ref: PLB 407 (1997) 174.



System	(+-)/(++ & --)
p+p	2.7+-0.6
0-10% Au+Au	2.4+-0.6
Jetset	2.6+-0.7



STAR, PRL , (2002)

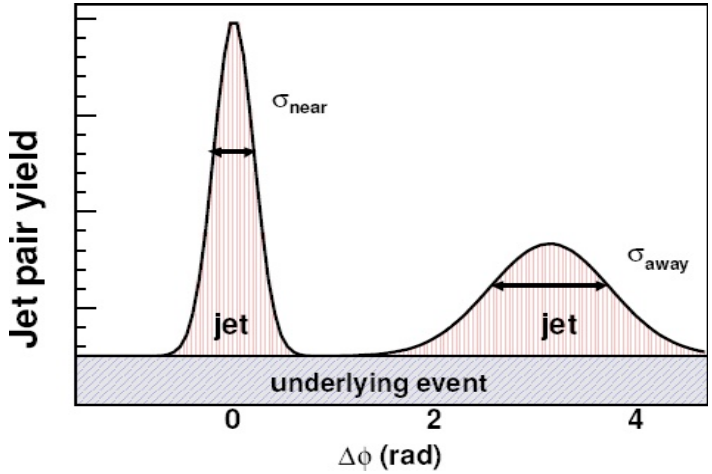
- Compare ++ and -- correlations to +-

- Similar charge ordering observed in pp, AuAu & jet-fragmentation MC.

p_T > 4 GeV/c: same hadron production mechanism in central Au-Au & pp

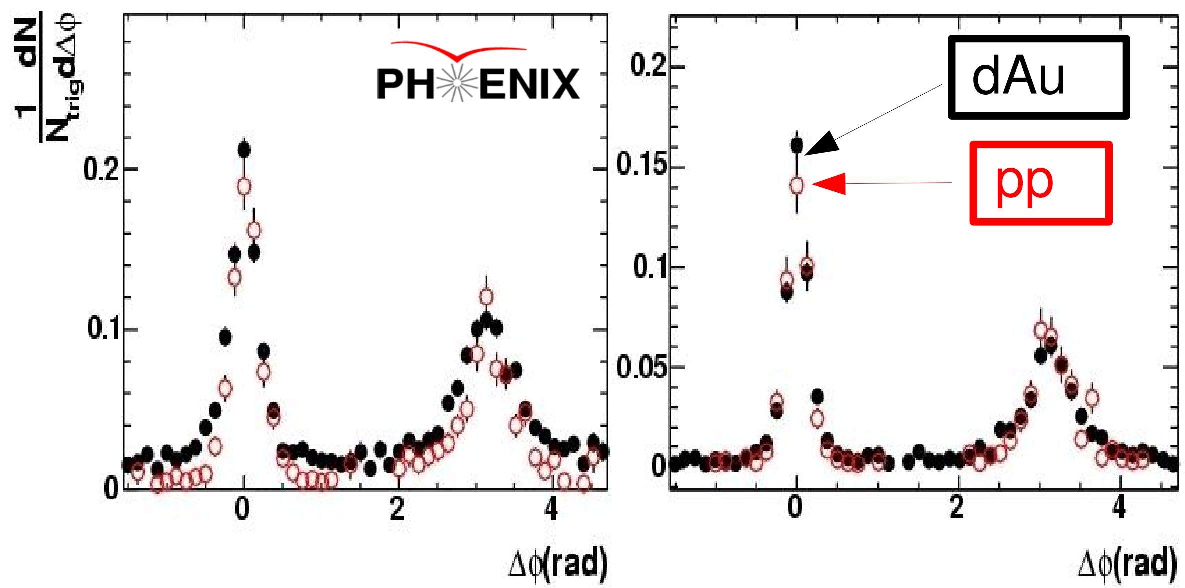
Dijets via di-hadron Δφ correlations: pp, dAu

- Study dijet events "statistically": via typical back-to-back azimuthal correlations of produced hadron pairs ($h^{\pm -} - h^{\pm}$, $\pi^{0,\pm} - h^{\pm}$):



- Trigger: highest p_T (leading) hadron.
- Associated Δφ distribution (e.g. "assorted": $2\ \text{GeV}/c < p_T^{assoc} < p_T^{trigger}$)

$$\frac{1}{N_{trig}}\frac{dN}{d\Delta\phi} = \frac{1}{N_{trig}}\frac{N_{cor}(\Delta\phi)}{N_{mix}(\Delta\phi)}$$



p_T^{assoc} = 2-3 GeV/c

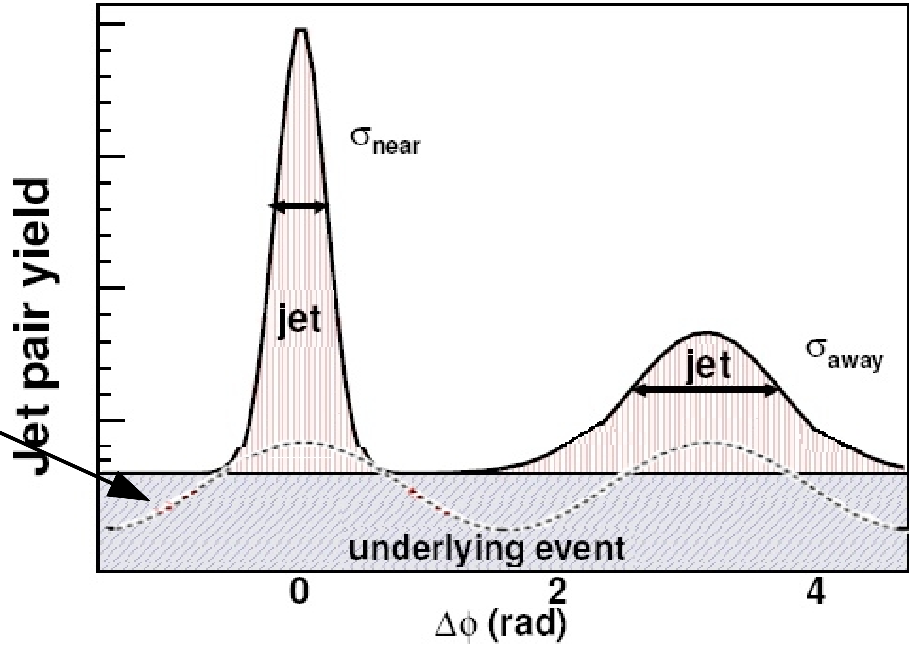
p_T^{assoc} = 3-5 GeV/c

- Clear near-side (Δφ ~ 0) and away-side (Δφ ~ π) jet signals:

Dijets via di-hadron Δϕ correlations: AuAu

- Au-Au: - trigger hadron: usually from parton at surface
  - away-side hadron: from quenched parton

- Same analysis as in pp, dAu but:
  - larger underlying event
  - elliptic flow subtraction



- I_{AA} = "suppression factor" of strength of away-side associated yields:

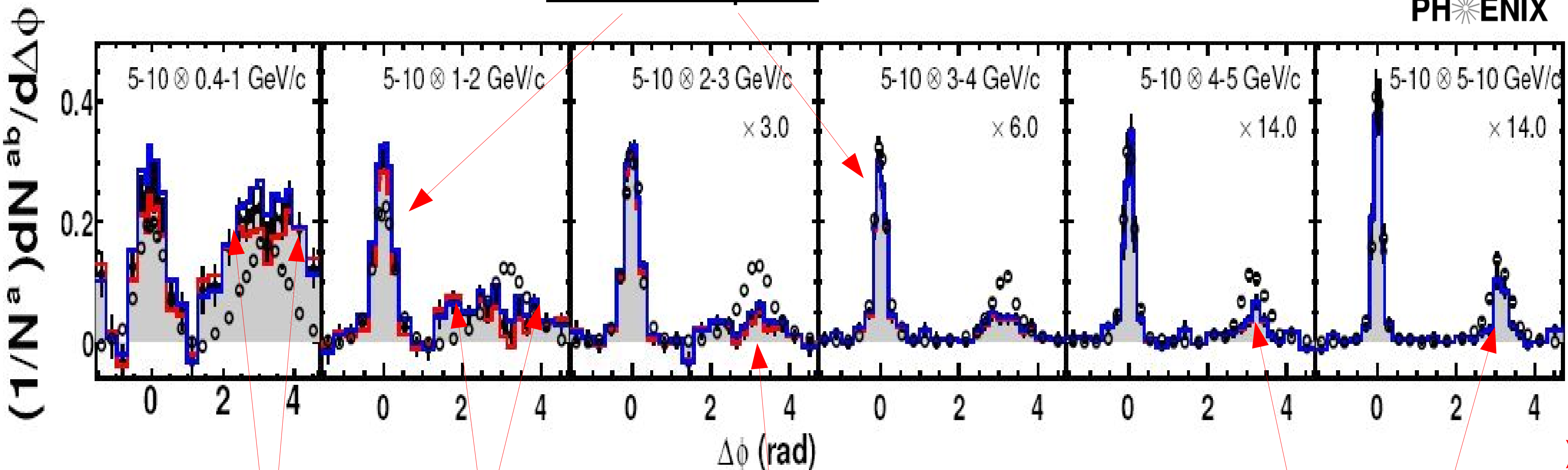
$$D^{away}_{pp(AA)} = \int_{p^{trig}_{T,min}}^{p^{trig}_{T,max}} dp_{T,1} \int_{p^{assoc}_{T,min}}^{p^{assoc}_{T,max}} dp_{T,2} \int_{away\,side} d\Delta\phi \, \frac{d^3\sigma^{h_1 h_2}_{pp(AA)}/dp_{T,1}dp_{T,2}d\Delta\phi}{d\sigma^{h_1}_{pp(AA)}/dp_{T,1}}$$

$$I_{AA} = \frac{D_{AA}(z_T, p_T^{\rm trig})}{D_{pp}(z_T, p_T^{\rm trig})}$$

Dijets via dihadron Δφ correlations: central AuAu

- Strongly distorted back-to-back Δ φ correlations at intermediate p_T's :

Near-side peak: ~unmodified



Away-side:

broadening softening at low p_T

"splitting" at intermediate p_T

"disappearance" at semi-hard p_T

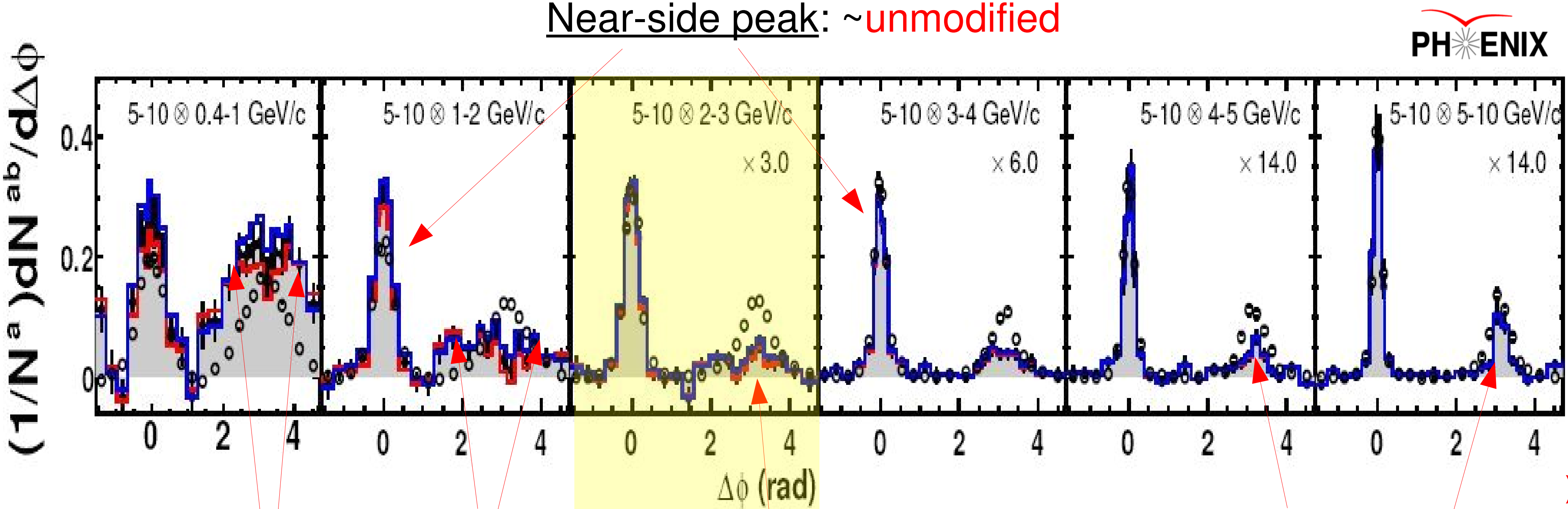
"punch-through" at high p_T

PRC78, 014901 (2008)

Dijets via dihadron Δϕ correlations: central AuAu

- Strongly distorted back-to-back Δ ϕ correlations at intermediate p_T's :

Near-side peak: ~unmodified



Away-side:

broadening

softening at low p_T

"splitting" at mid p_T

"disappearance" at semi-hard p_T

"punch-through" at high p_T

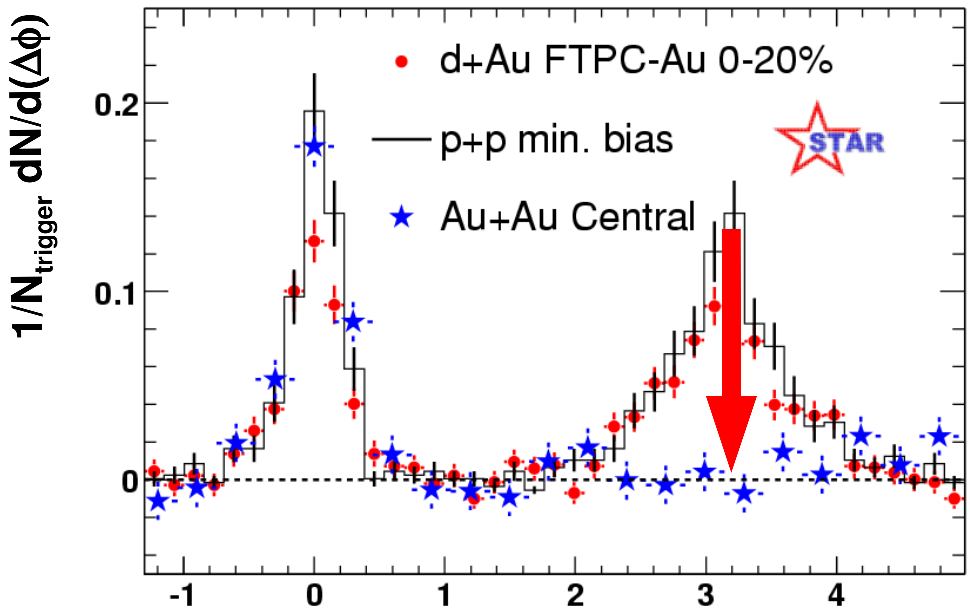
PRC78, 014901 (2008)

AuAu dihadron Δφ correlations: semi-hard

- Away-side peak disappears: "monojet"- like topology:

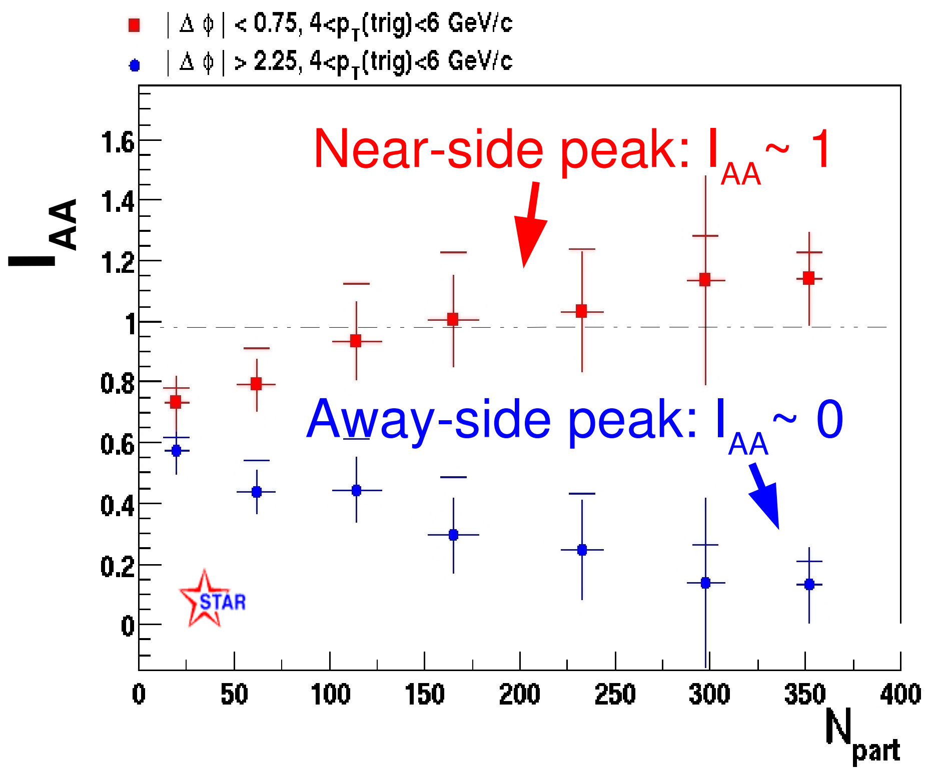
$p_{T\,trigg}$ = 4 – 6 GeV/c

p_{Tassoc} > 2 GeV/c



STAR, PRL90, 082302 (03)

- Associated azimuthal yield strengths (pp/AA) vs centrality :



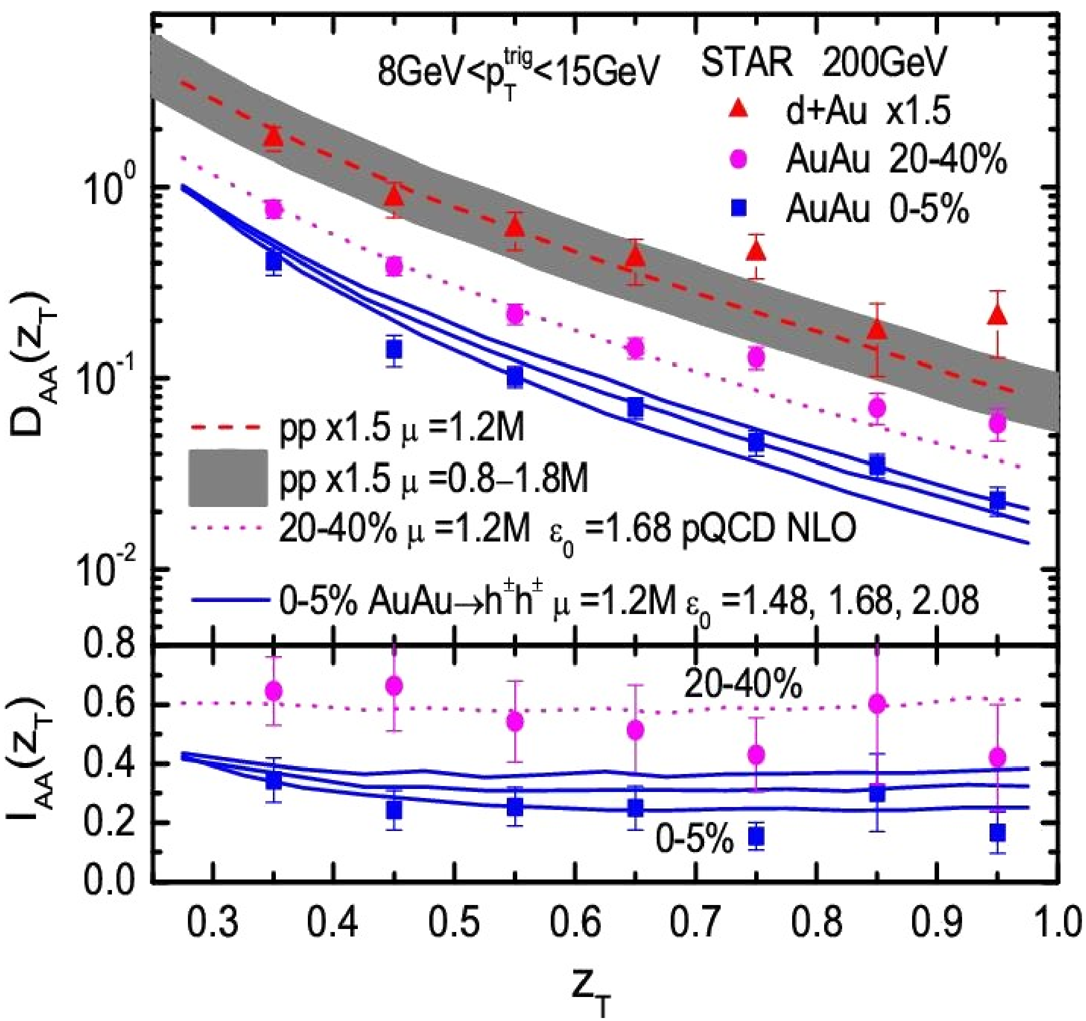
$$I_{AA} = \frac{D_{AA}(z_T, p_T^{\rm trig})}{D_{pp}(z_T, p_T^{\rm trig})}$$

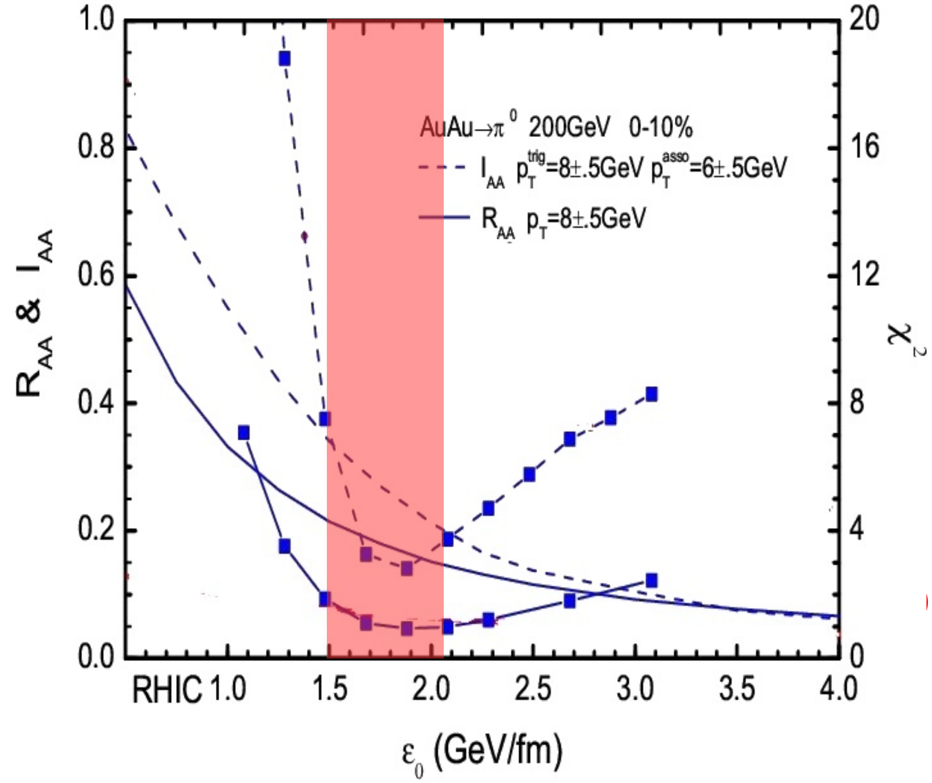
High p_T di-hadron correlations ⇒ QCD medium properties

- I_{AA} ratio of "pseudo-FFs" provides valuable extra constraint on medium properties:

$$I_{AA} = \frac{D_{AA}(z_T, p_T^{\rm trig})}{D_{pp}(z_T, p_T^{\rm trig})}$$

STAR



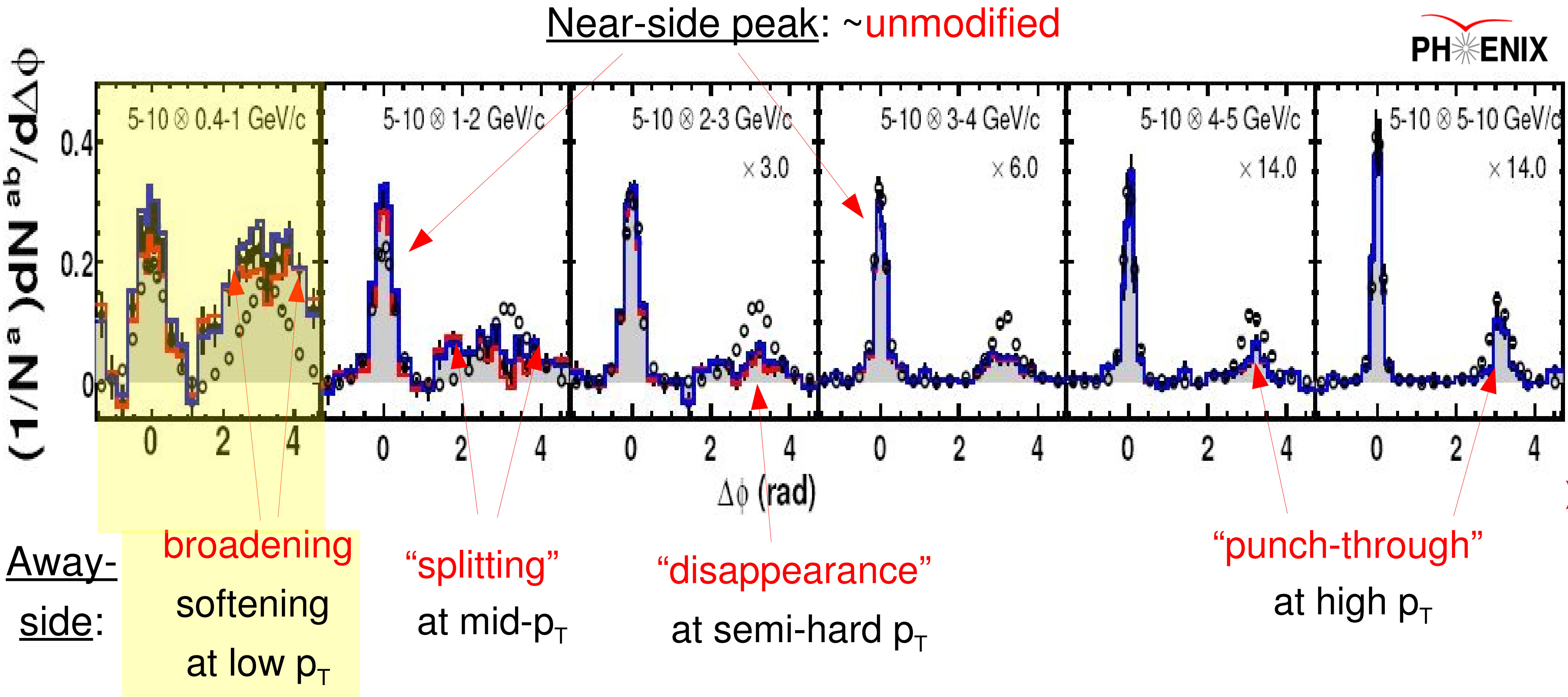


ε_0 = 1.5-2.1 GeV/fm

H-Z Zhang et al., PRL98(2007)212301

Dijets via dihadron Δφ correlations: central AuAu

- Strongly distorted back-to-back $\Delta\phi$ correlations at intermediate p_T's :



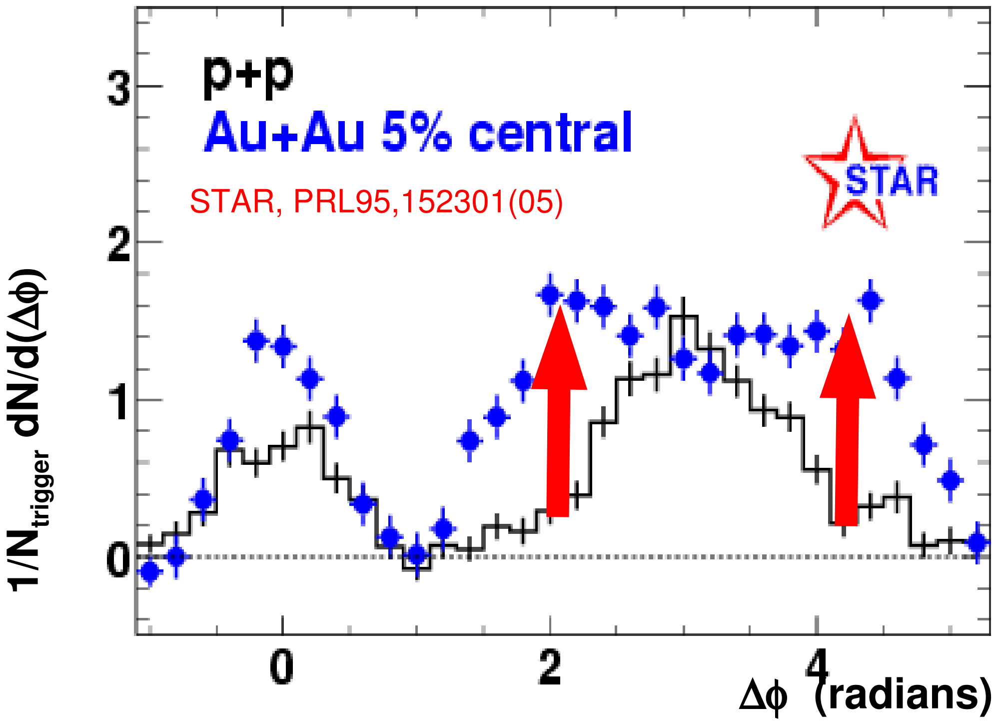
PRC78, 014901 (2008)

AuAu dihadron $\Delta\phi$ correlations: low-p_T

- "Jet remnants" reappear at low p_T as a broader/softened structure:

$p_{T\,trigg}$ = 4 – 6 GeV/c

$p_{T\,assoc}$ = 0.15 – 4 GeV/c



- Soft p_T "jet remnants" are "thermalized" ($\langle p_T\rangle \sim \langle p_T^{bulk}\rangle$):

$\langle p_T\rangle$ away-side hadrons (p-p) ~ 1. GeV/c

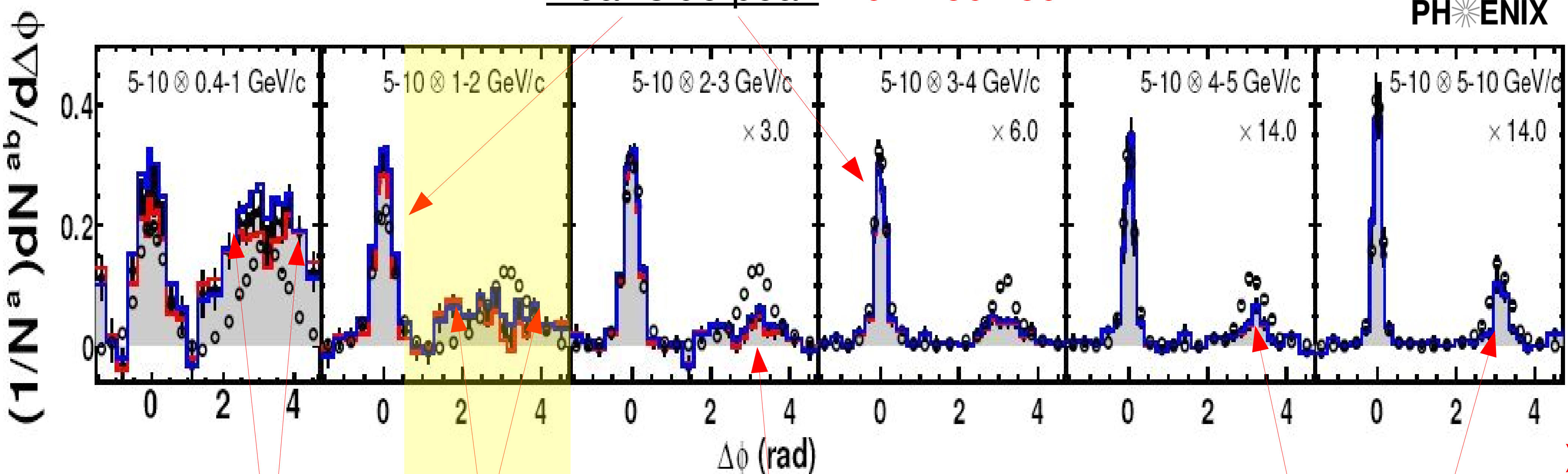
$\langle p_T\rangle$ away-side hadrons (Au-Au) ~ 0.7 GeV/c

$\langle p_T\rangle$ inclusive hadrons (Au-Au): ~0.6 GeV/c

Dijets via dihadron Δφ correlations: central AuAu

- Strongly distorted back-to-back $\Delta\phi$ correlations at intermediate p_T's :

Near-side peak: ~unmodified



Away-side:

broadening softening at low p_T

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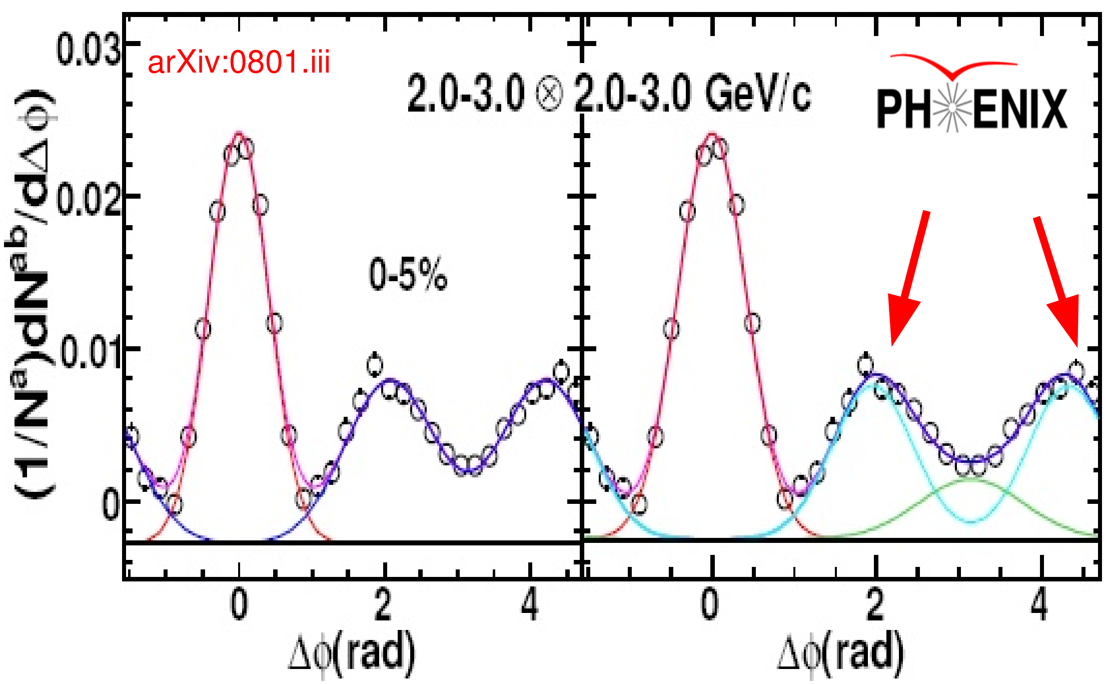
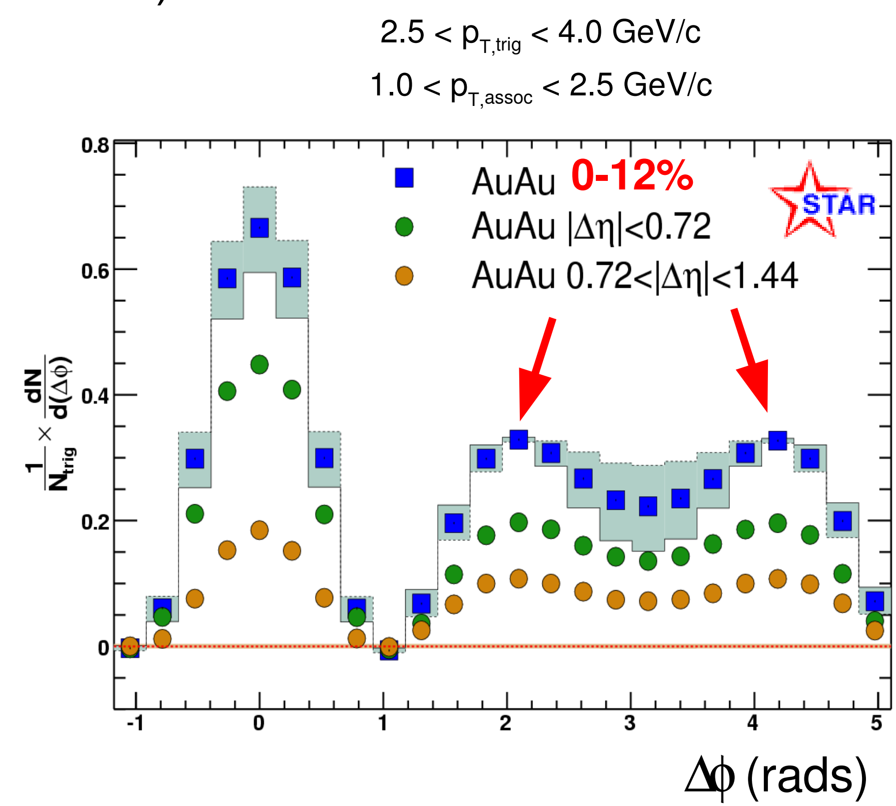
"punch-through" at high p_T

PRC78, 014901 (2008)

AuAu dihadron $\Delta\phi$ correlations: mid-p_T splitting (I)

- Strongly modified away-side $\Delta\phi$ correlations at intermediate p_T's :
  - (1) Away-side "dip" at $\Delta\phi\pi$
  - (2) Excess of activity ("double peak", "shoulders") at:



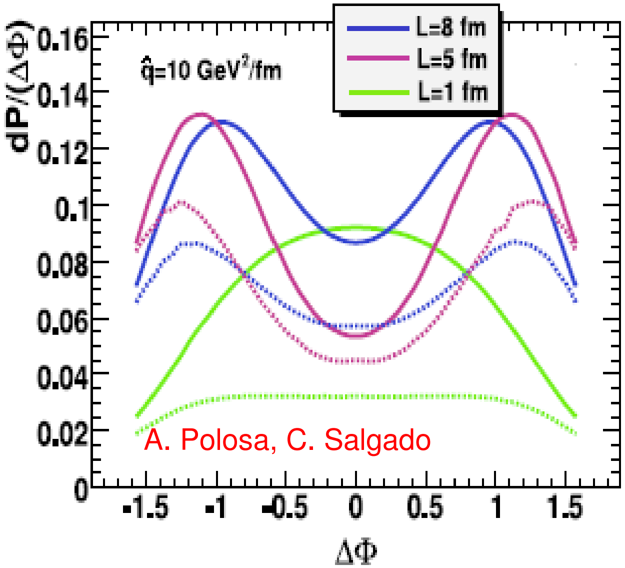


$\Delta\phi\pi$ $\pm$1.2 rad

$\Delta\phi\pi$ $\pm$1.3 rad

AuAu dihadron $\Delta\phi$ correlations: mid-p_T splitting (II)

- Large angle gluon rad.

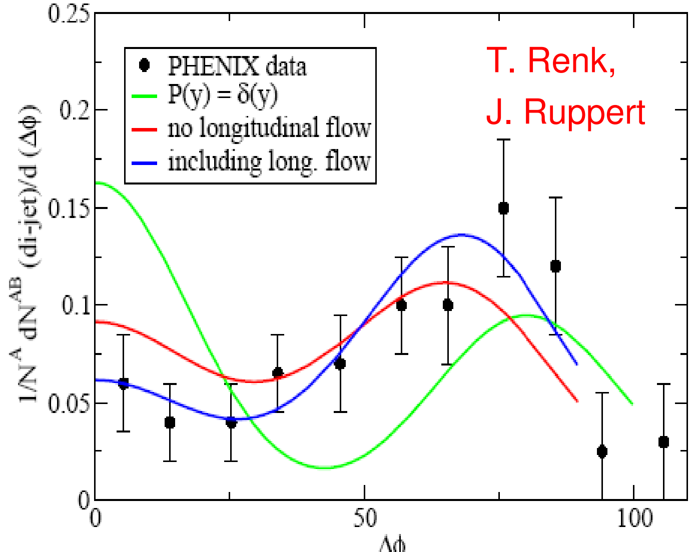


Also: Vitev, Phys. Lett. B630 (2005)

Quenched-jet scatters through medium radiates large-angle gluon ("Mercedes" topology)

- But also: deflected jets ...

- Mach cone

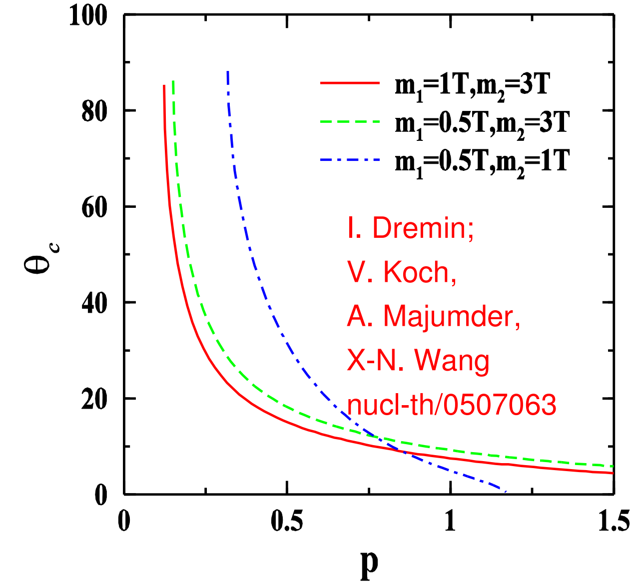


hep-ph/0411315 Casalderrey,Shuryak,Teaney
nucl-th/0406018 Stoecker
hep-ph/0503158 Muller,Ruppert
nucl-th/0503028 A. K. Chaudhuri

Supersonic-jet ($v>v_s$) generates sonic-boom while propagating thru medium. Speed-of-sound accessible:

$$\cos\theta_M = c_s$$

- Cerenkov radiation

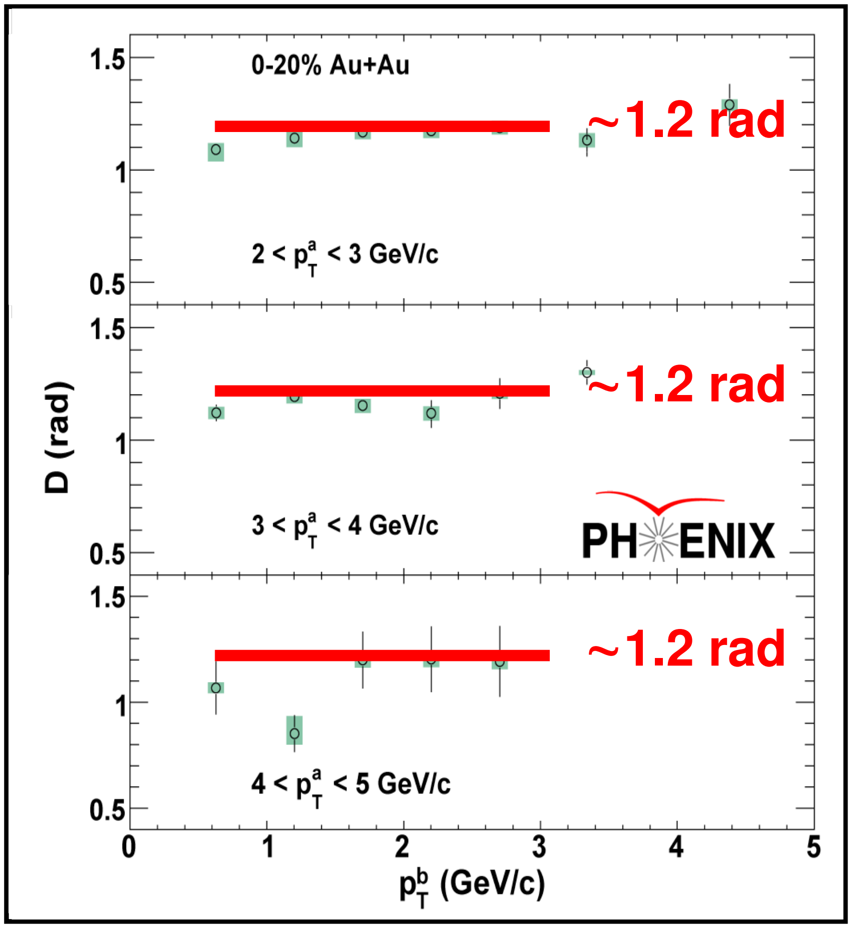


Quenched-jet radiates at Cerenkov gluons when traversing medium at v > c. Gluon dielectric coeffic. :

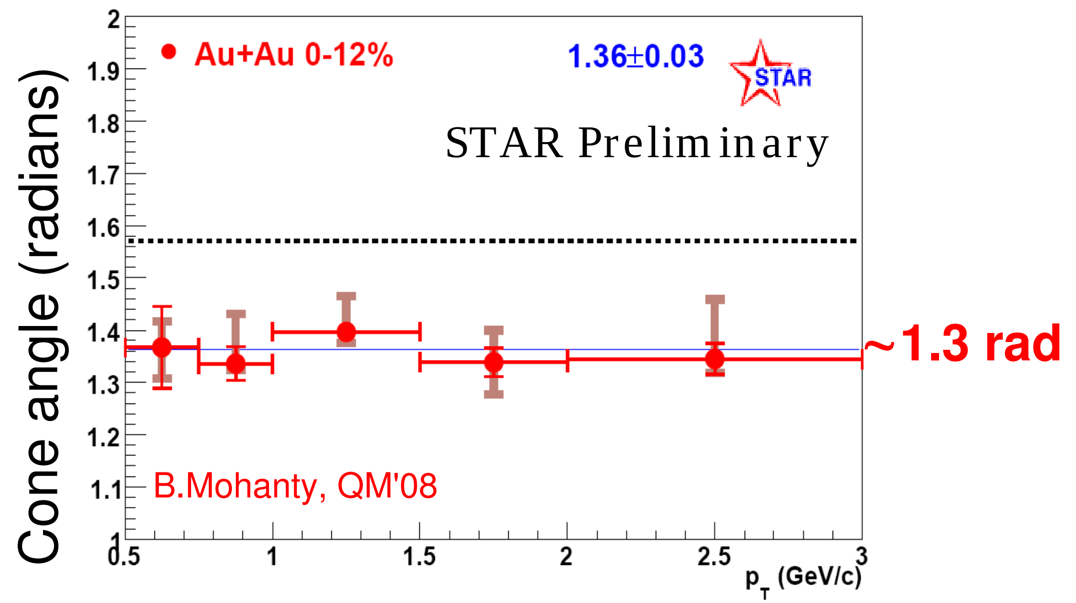
$$\cos(\theta_c) \approx \frac{1}{\sqrt{\varepsilon}} \approx \frac{1}{n}$$

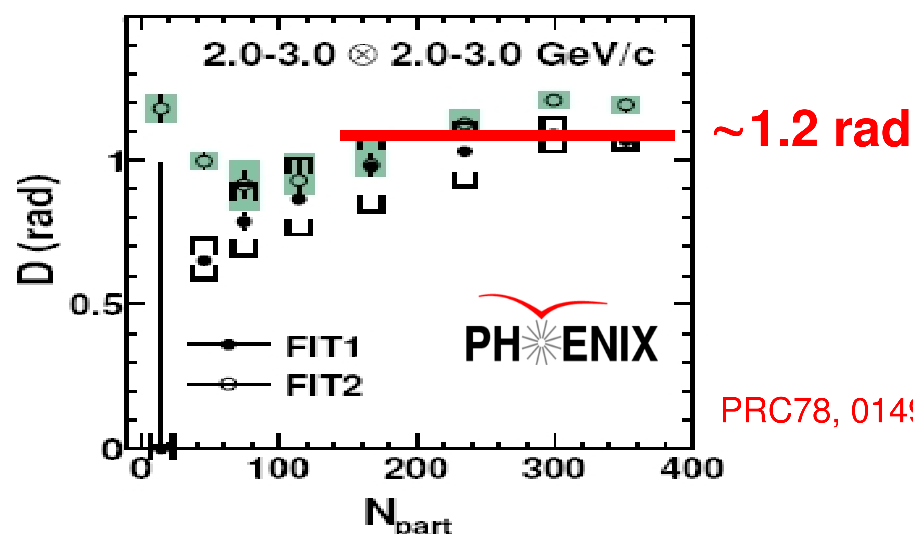
AuAu dihadron Δφ correlations: mid-p_T splitting (III)

- Splitting angle $\Delta\phi$ π ± 1.2 rad doesn't vary much in wide p_T & centrality range: inconsistent with Cerenkov ? (θ_C decreases with speed of parton)



M.McCumber, QM'08





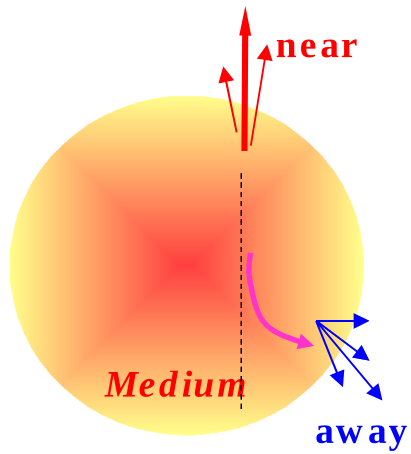
PRC78, 014901 (2008)

AuAu 3-particle Δφ correlations: mid-p_T splitting (I)

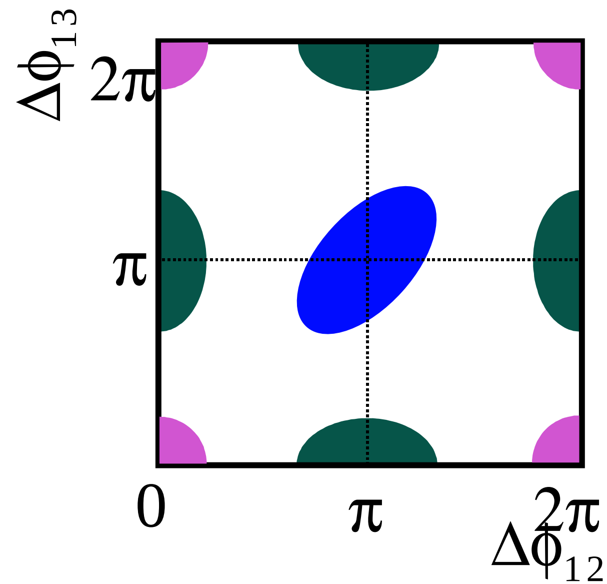
[M.v Leeuwen, QM06]

- 3-particle Δφ–Δφ help discriminate among various physics mechanisms:

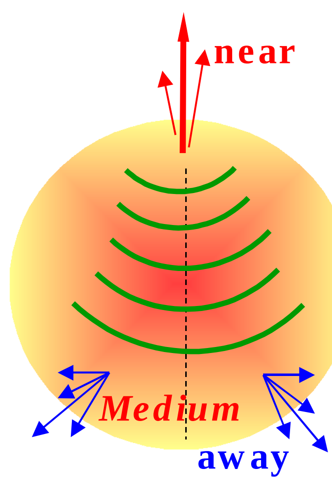
Event-by-event deflection of jets



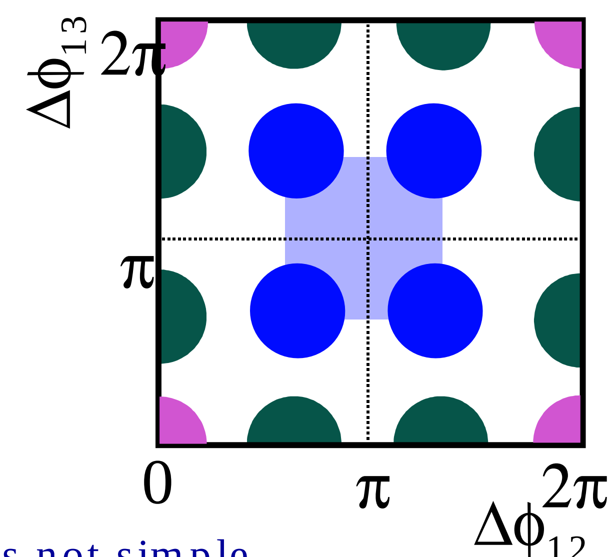
deflected jets



Cone-like structure in each event



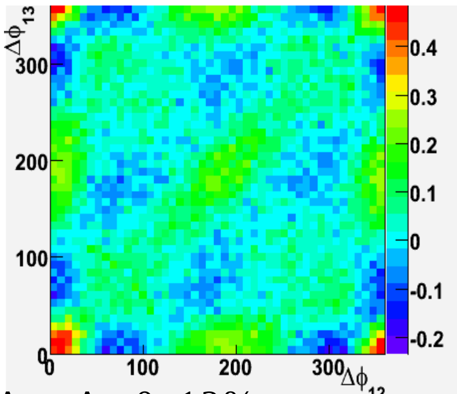
Mach cone



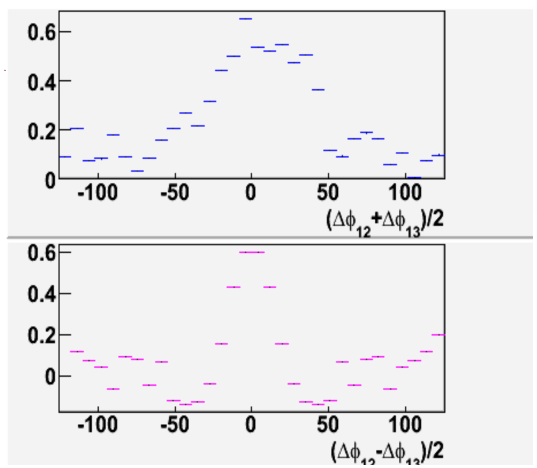
However: Large backgrounds, background shapes not simple

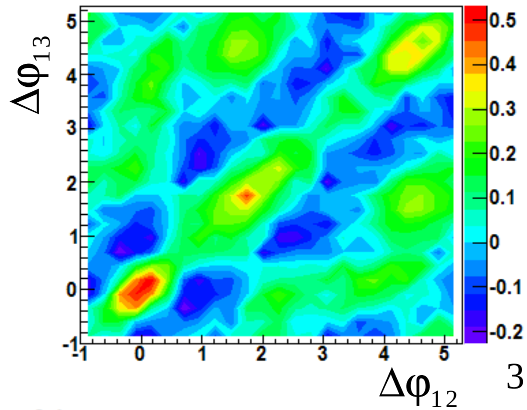
AuAu 3-particle Δϕ correlations: mid-p_T splitting (II)

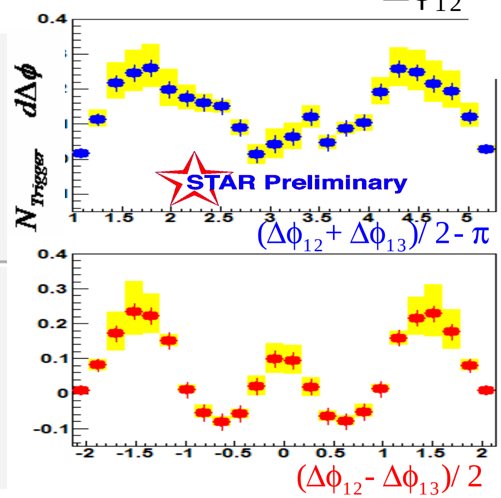
C. Pruneau, J. Ulery



Au+Au 0-12%

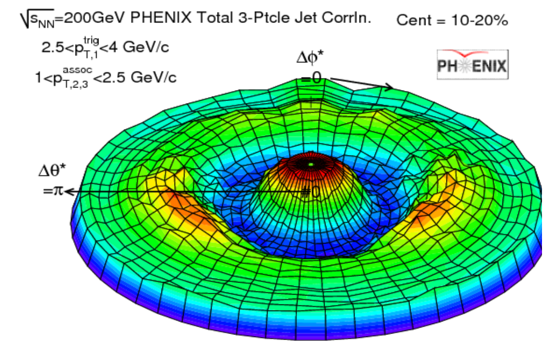




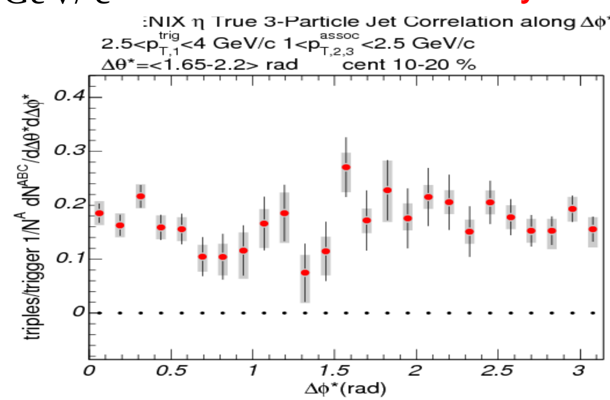


$3 < p_{T,trig} < 4$ GeV/c
$1 < p_{T,assoc} < 2$ GeV/c

C. Zhang, N. Ajitanand



PHENIX Preliminary



Cumulant analysis:
Model-independent
Non-zero 3-particle structure

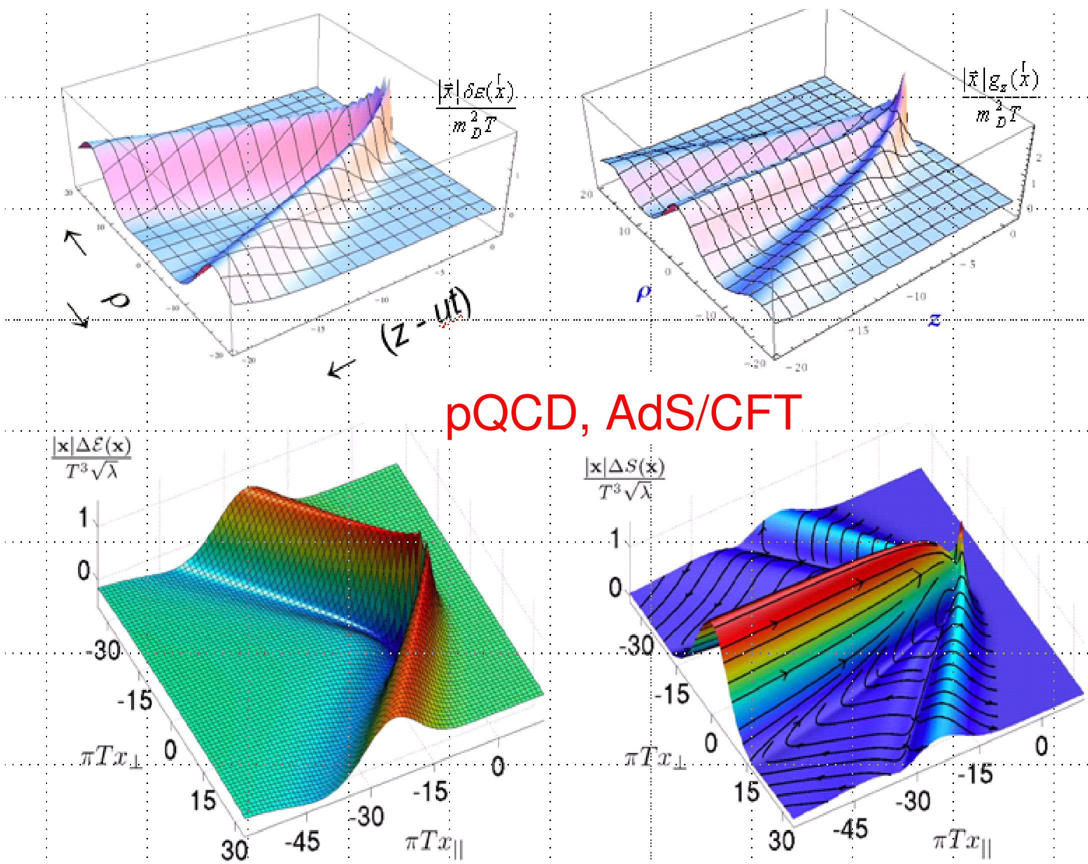
Jet+background analysis:
Model-dependent, more sensitive
Off-diagonal peaks consistent
with conical emission

(Different coordinates)
No ‘deflected-jet peak’
consistent with conical emission

Cone-like emission favoured

AuAu dihadron Δφ corrs: splitting = Mach cone ?

- Supersonic (quenched) jet can generates Mach shock-boom in medium.
- Speed-of-sound accessible: $\cos\theta_M = c_s$



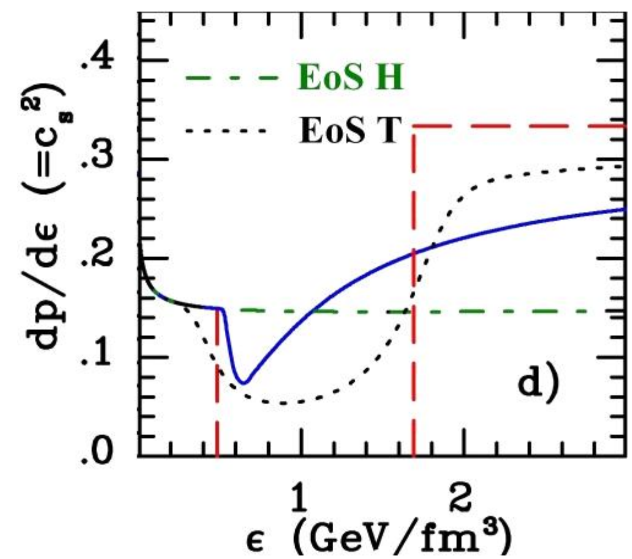
pQCD, AdS/CFT

u = 0.99955 c

R.B. Neufeld (preliminary)

Chesler & Yaffe arXiv:0712.0050

u = 0.75 c



(time-averaged)

$$\langle c_s \rangle = \frac{1}{\tau_f}\int d\tau c_s(\tau) \sim 0.33$$

θ_{theory} = arccos(‹c_s›) ~ 1.2 rad

- Yet, unclear if signal survives at final hadronic state ...

High p_T dihadron correlations: summary

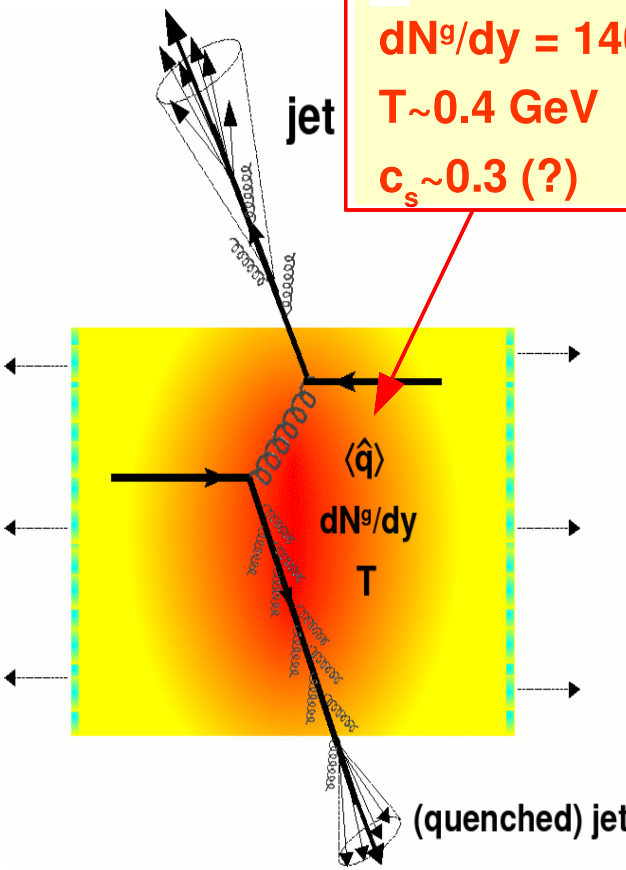
- High-p_T 2-,3- hadron ϕ correlations: access medium-modified dijets
- Jet-like correlations clearly present: near-side shape, charge ordering
- Away-side associated hadrons strongly modified:
  - Low p_T: yield strongly enhanced, softened & broadened
  - Mid-p_T: double-peak structure with conical-like emission at ~1.2 rad

    If Mach-cone: possibility to access QGP speed-of-sound c_s~0.3
  - Semi-hard p_T: away-side peak strongly suppressed.

    I_{AA} described by parton energy-loss models: ε_0 = 1.5-2.1 GeV/fm
  - High-p_T (p_T~8 GeV/c): away-side peak reappears ("punchthrough")
- Rich phenomena at intermediate p_T: Interesting connections to collective medium response to hard partons (speed of sound, index of refraction, ...) but theory-data comparison challenging.

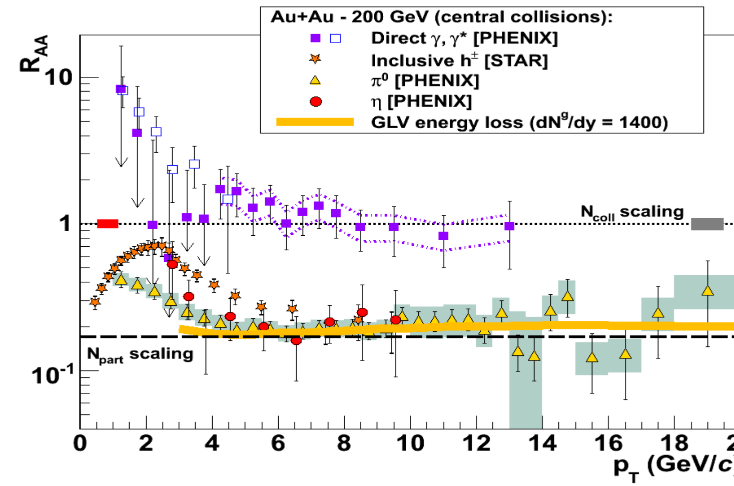
Lectures overview

$\hat{q}$ ~13 GeV²/fm
dN^g/dy = 1400
T~0.4 GeV
c_s~0.3 (?)

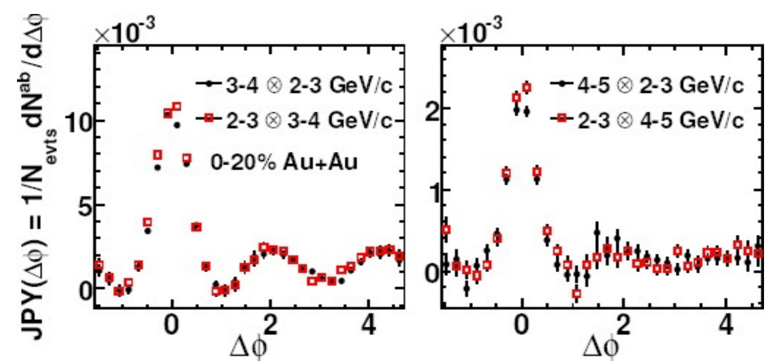


Hot/dense QCD matter properties via "jet quenching"

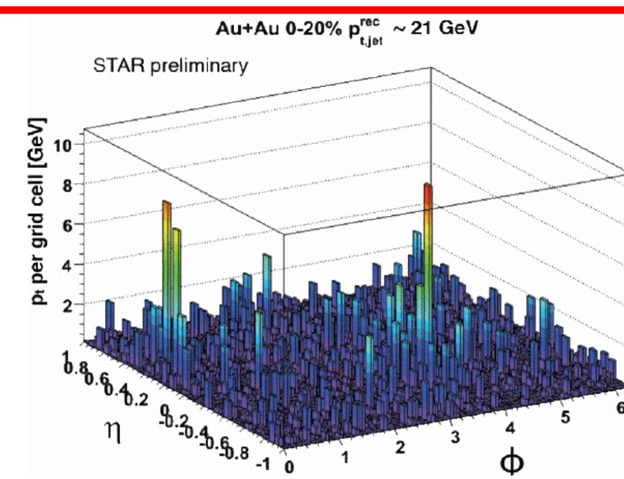
- Suppressed high-p_T hadron spectra:



- Modified high-p_T dihadron Δφ-η correlations:



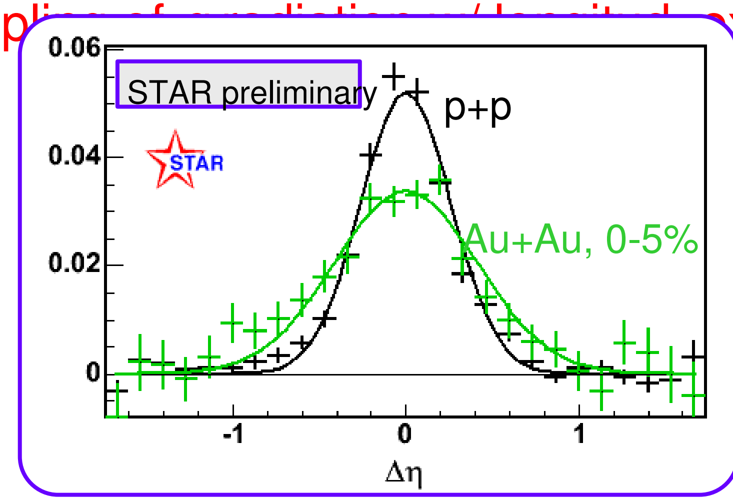
- Full jet reco, γ-jet, modified Fragm. Functions:

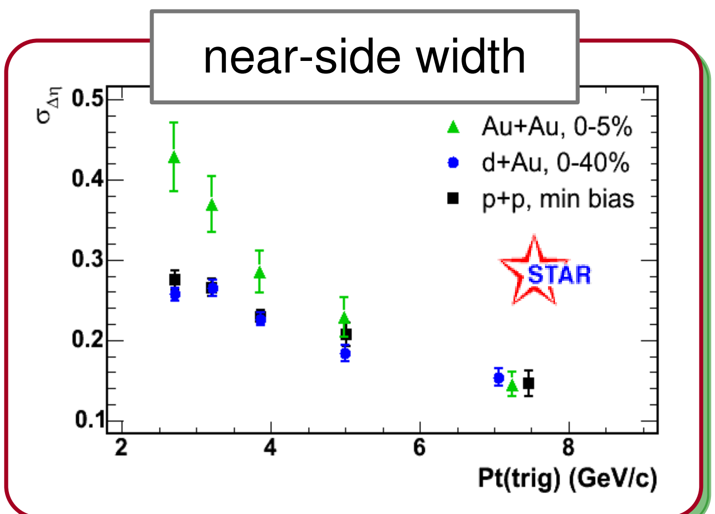


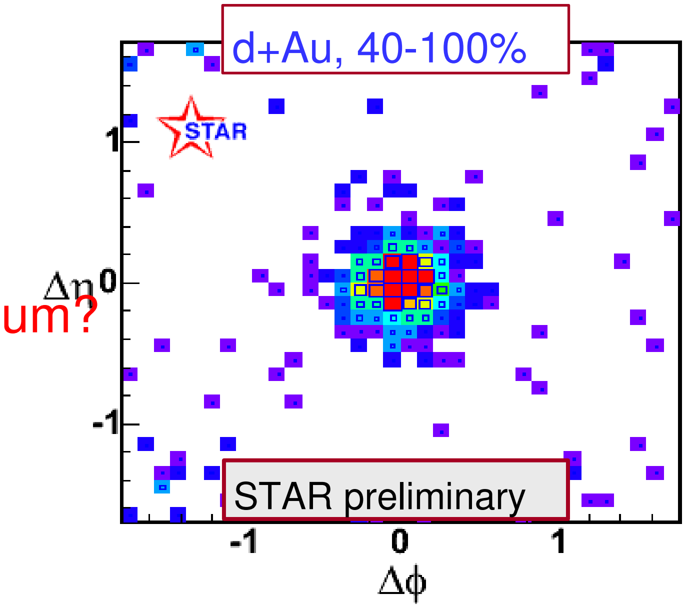
Backup slides

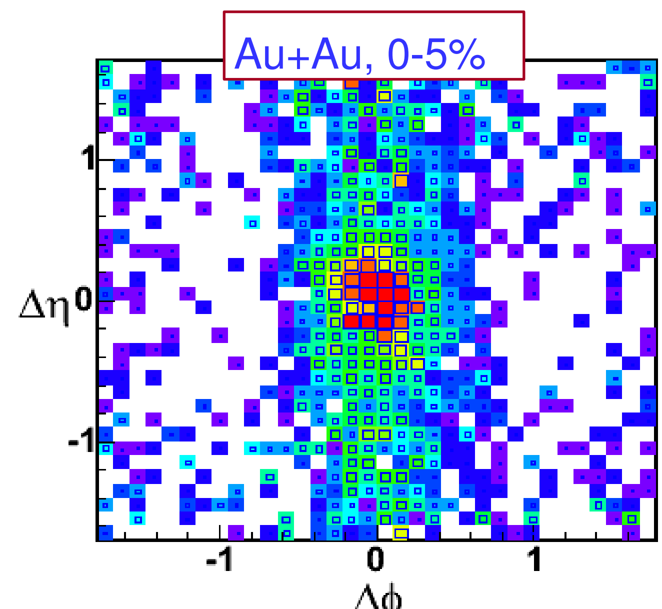
Dihadron Δη correlations: AuAu (200 GeV)

- Significant broadening of pseudo-rapidity correlations in AuAu compared to pp,dAu. (“stretching” of jet cone along η).
- Coupl… xpanding medium?









[D. Magestro, HP'04]

$3 < p_T(\text{trig}) < 6$ GeV

$2 < p_T(\text{assoc}) < p_T(\text{trig})$

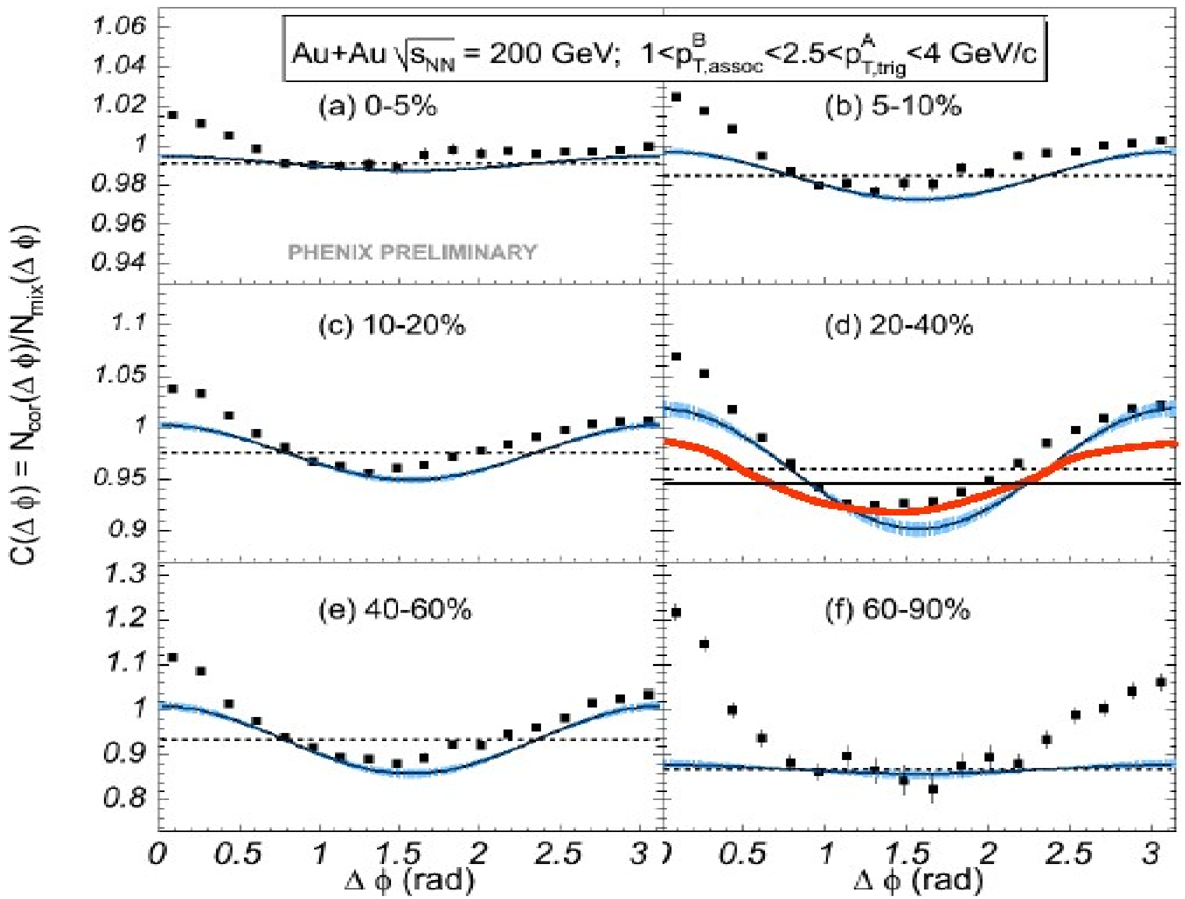
Dijets via dihadron Δϕ correlations: central AuAu

- Same $dN_{pair}/d\phi$ analysis as in pp (dAu) but 2 extra complications:

  (1) Increased underlying event background

  (2) Collective elliptic flow (harmonic) contribution

$$\overbrace{C(\Delta\phi)}^{\text{Correlation Function}} = a_0\left[\overbrace{H(\Delta\phi)}^{\text{Harmonic}} + \overbrace{J(\Delta\phi)}^{\text{Jet Function}}\right]$$



PHENIX

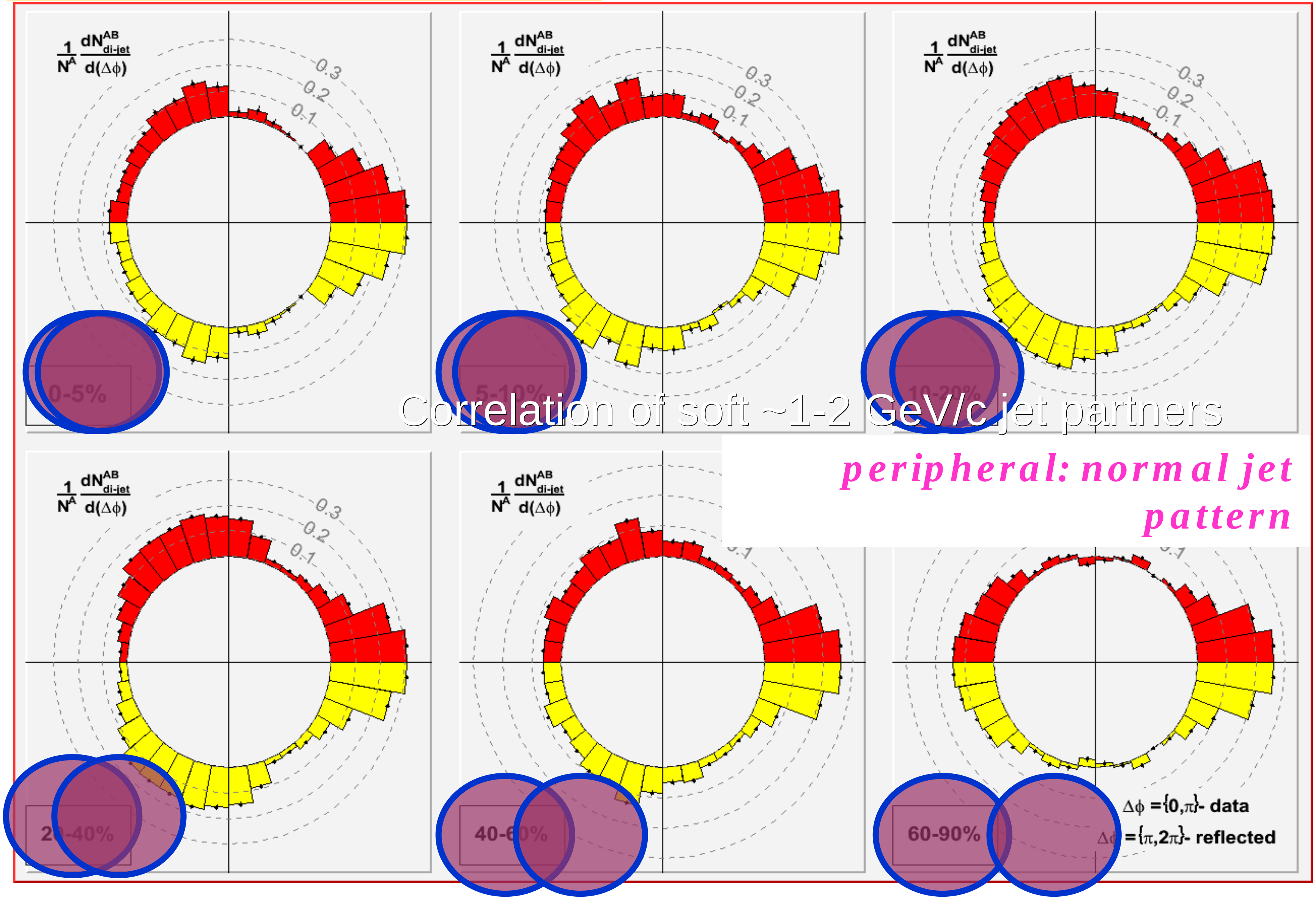
Ajitanand, ICPAQGP'04 and nucl-ex/0501025

- Delicate subtraction procedure (esp. in finite acceptances).

Dihadron Δφ correlations: AuAu away-side splitting

Emergence of a Volcano Shape

PHENIX (nucl-ex/0507004)



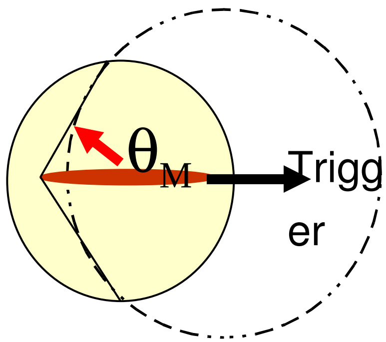
Correlation of soft ~1-2 GeV/c jet partners

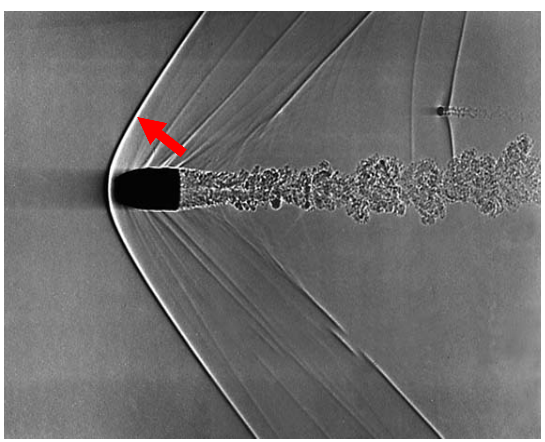
peripheral: normal jet pattern

Dihadron Δφ correlations: splitting

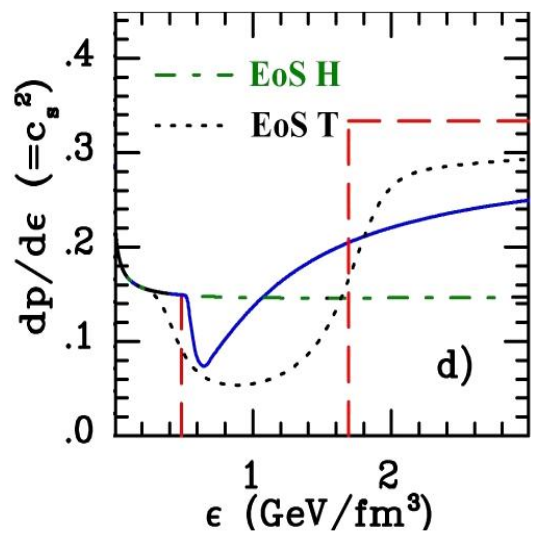
- Double peak structure at $\pi \pm 1.2$ rad reminiscent of Mach wave conical shock ("sonic boom") in medium ⇒ speed of sound accessible

Mach cone: $\cos\theta_M = c_s$





$\langle c_s \rangle = \frac{1}{\tau_f}\int d\tau\, c_s(\tau) \sim 0.33$ (time-averaged)



→ QGP ($c_s \sim 1/\sqrt{3}$)

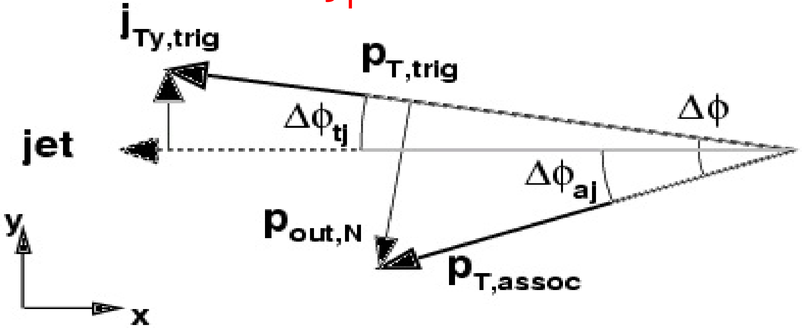
→ HRG ($c_s \sim \sqrt{0.2}$)

→ phase transition ($c_s \sim 0.$)

$\theta = \arccos(\langle c_s \rangle) \sim 1.2$ rad ~ θ_{exp}

Jet properties from dihadron correlations

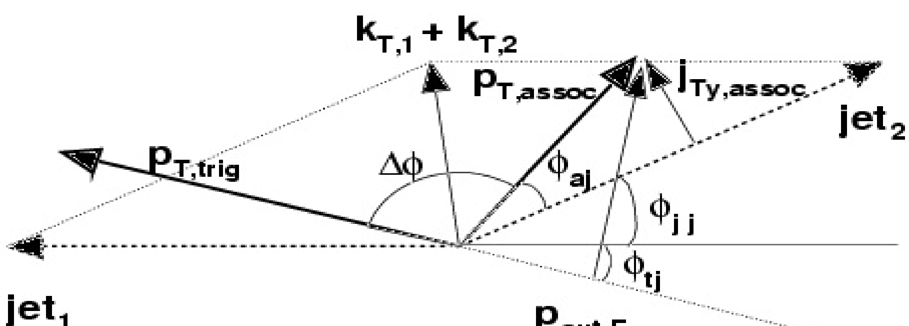
- Jet "width" j_T :



[*]

$$\langle j_{T_y}\rangle_{RMS} \simeq \frac{\sigma_N \langle p_{T,asso}\rangle}{\sqrt{1+\langle x_h^2\rangle}} \simeq \sigma_N \frac{\langle p_{T,trig}\rangle\langle p_{T,asso}\rangle}{\sqrt{\langle p_{T,trig}\rangle^2+\langle p_{T,asso}\rangle^2}}$$

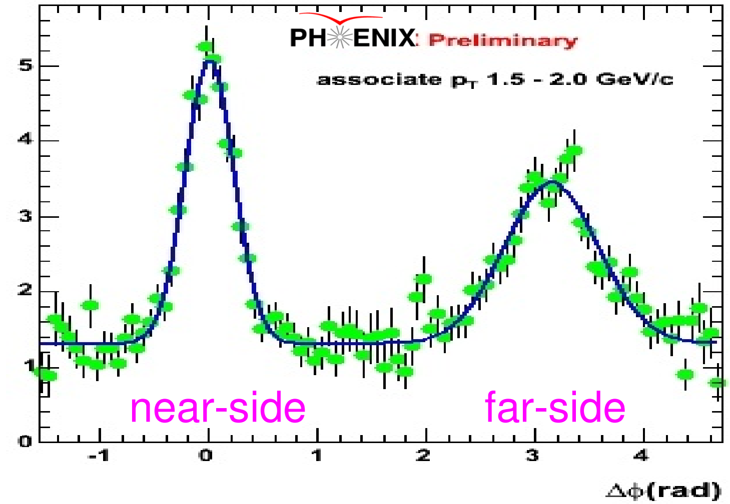
where $x_h = p_{T,asso}/p_{T,trig}$



[**]

$$\langle k_{Ty} z_{trig}\rangle_{RMS} = \frac{1}{\sqrt{2\langle x_h^2\rangle}}\sqrt{\langle p_{T,assoc}\rangle^2 \sin^2\sigma_F - (1+\langle x_h^2\rangle)\langle j_{T_y}\rangle^2_{RMS}}$$

(1) 2-hadron correlation function:



$$\frac{1}{N_{trig}}\frac{dN}{d\Delta\phi} = B + \frac{Yield_N}{\sqrt{2\pi}\sigma_N} e^{\frac{-\Delta\phi^2}{2\sigma_N^2}} + \frac{Yield_F}{\sqrt{2\pi}\sigma_F} e^{\frac{-(\Delta\phi-\pi)^2}{2\sigma_F^2}}$$

(2) Fit to 2-gaussians:

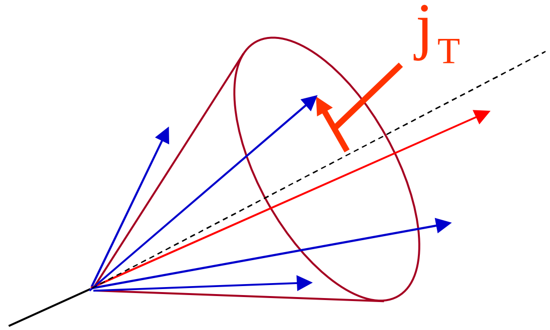
$\Rightarrow$ near-side σ_N, far-side σ_F widths

(3) Extraction of j_T, k_T from σ_N, σ_F via [*], [**] (and dN/dx_E from $Yield_{N,F}$)

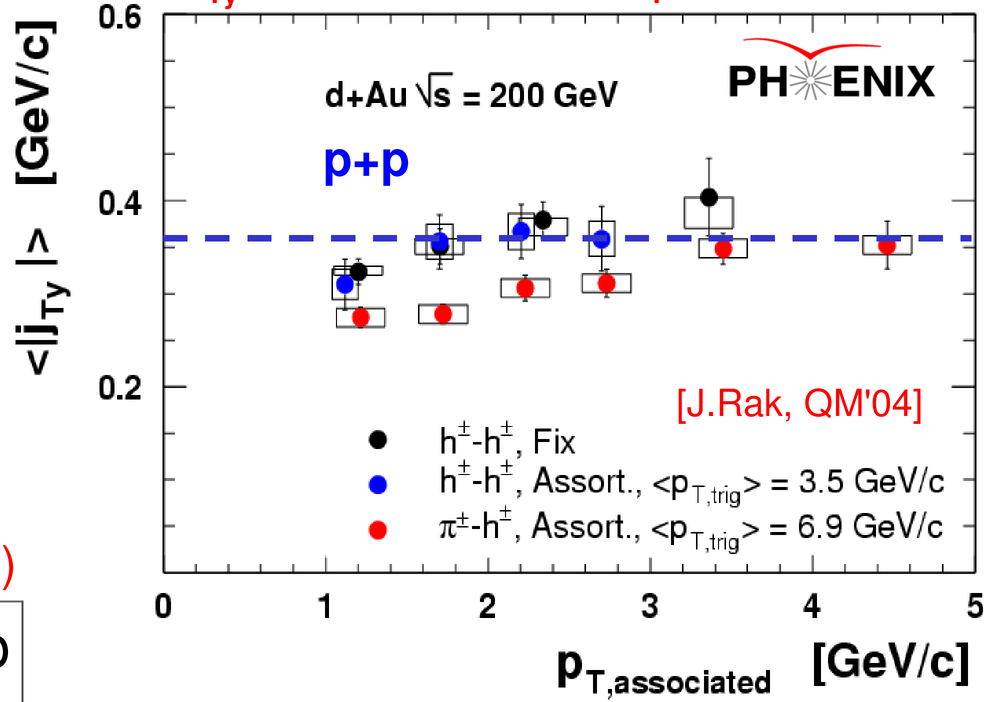
[details in J.Jia, nucl-ex/0409024]

Mean transverse momentum of jet hadrons (j_T): pp, dAu

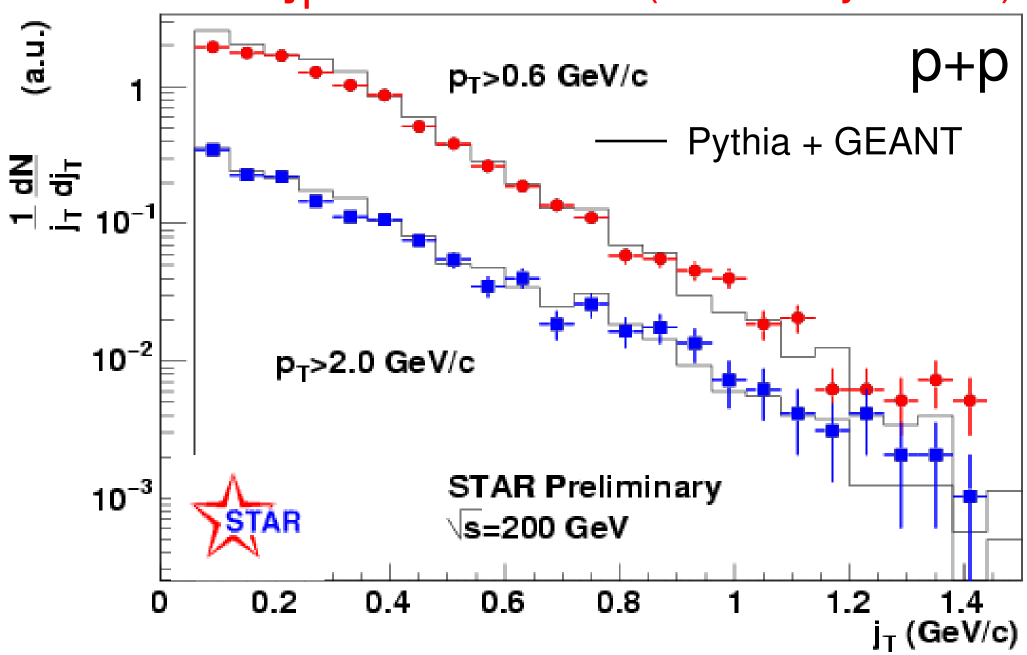
- Jet (near-angle) "width" j_T :



$< j_{Ty} >$ ~350 MeV/c ≡ $< j_T >$ ~ 500 MeV/c



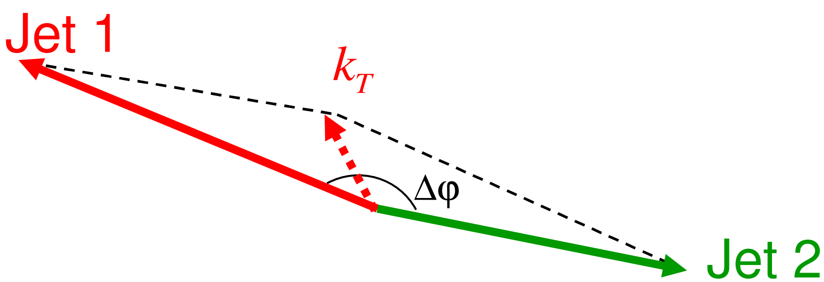
$< j_T >$ ~ 500 MeV/c (from full jet reco)

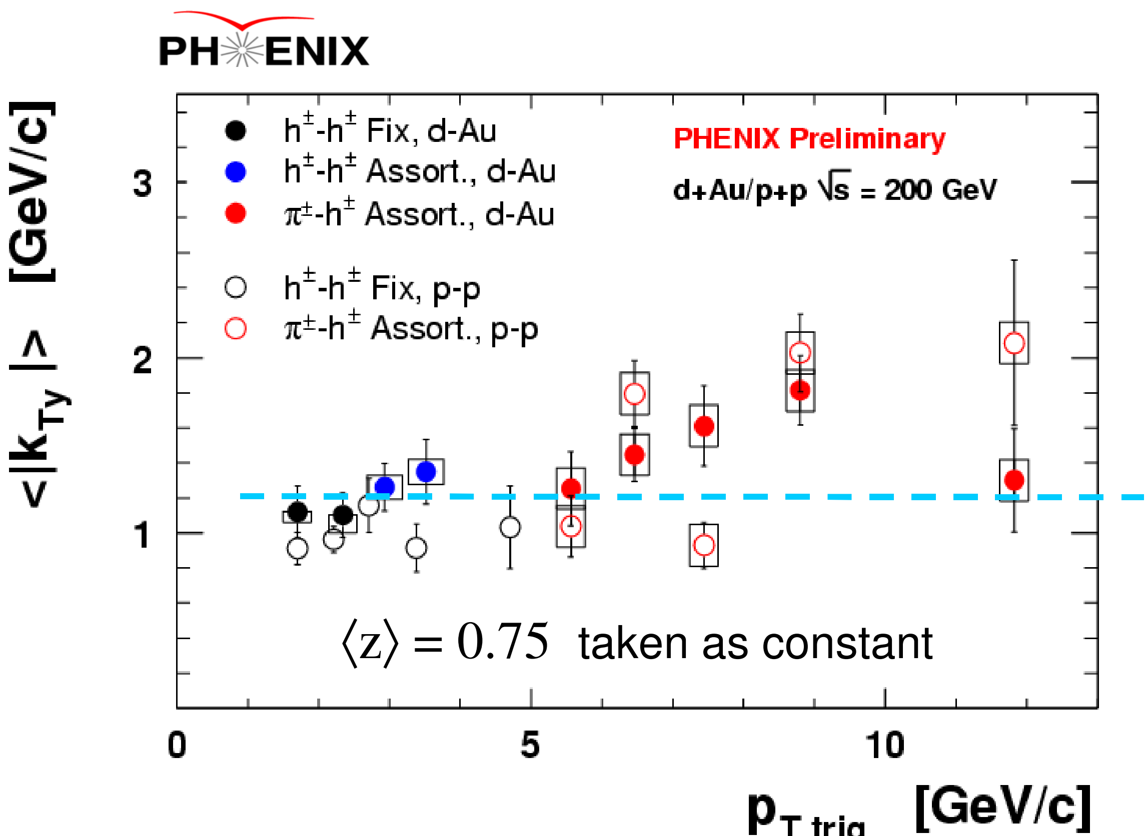


- $< j_T >$ ~ 500 MeV/c: Agreement between RHIC and ISR data.
- No apparent difference between dAu and pp.
- Fragmentation not affected by cold QCD medium.

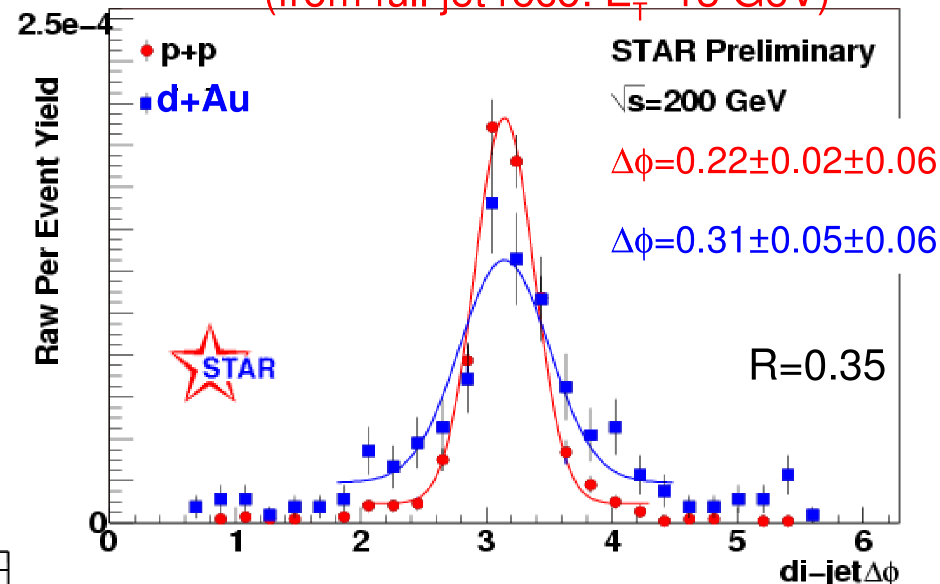
Di-jet acoplanarity (intrinsic k_T) : pp, dAu

- Intrinsic k_T (di-jet acoplanarity):





(from full jet reco: E_T~13 GeV)



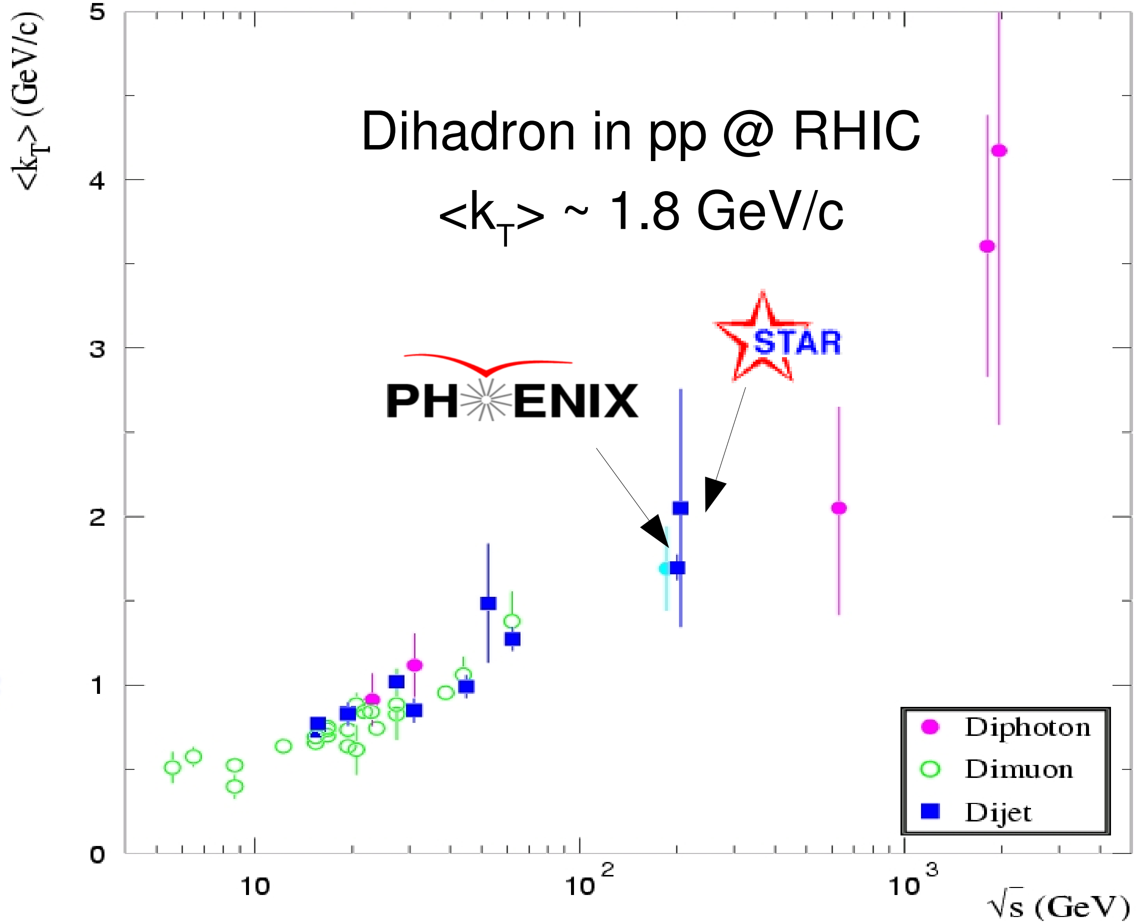
- Non-negligible pp **k_T broadening**: **$\langle k_{Ty}\rangle$ ~ 1.1 GeV/c** (not observed in high p_T spectra $\langle k_T\rangle_{pair} \neq \langle k_T\rangle_{incl}$)
- Non-null (but small) dAu

$\langle k_T\rangle_{nuclear}$ $\langle k_T^2\rangle_{dAu} = \langle k_T^2\rangle_{pp} + \langle k_T^2\rangle_{nuclear}$

(constraints models of multiple scattering in cold nuclear medium)

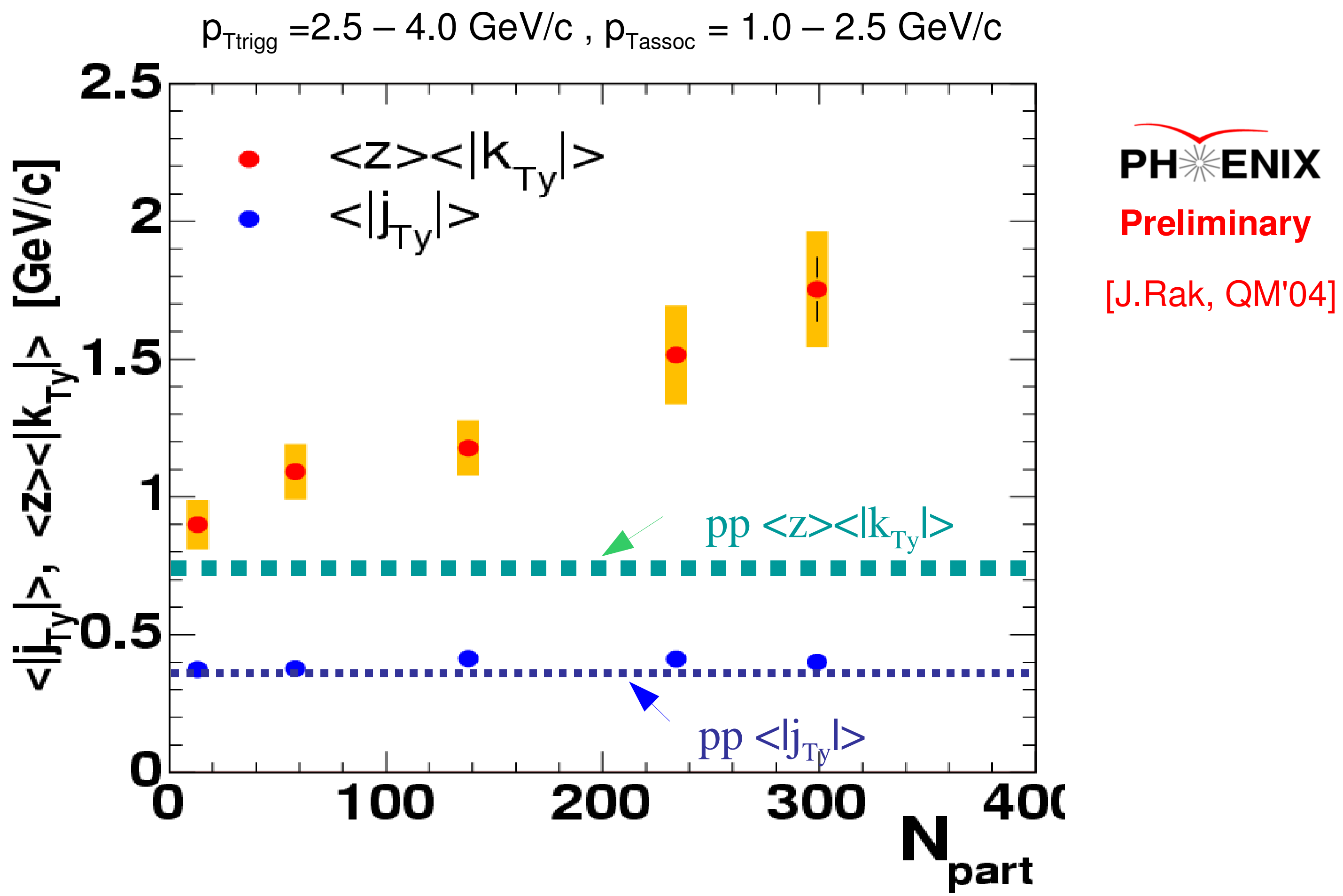
Di-jet acoplanarity (intrinsic k_T): Excitation function (pp)

- sqrt(s)-dependence of $<k_T>_{pair}$:



Jet properties (j_T, k_T): AuAu (200 GeV)

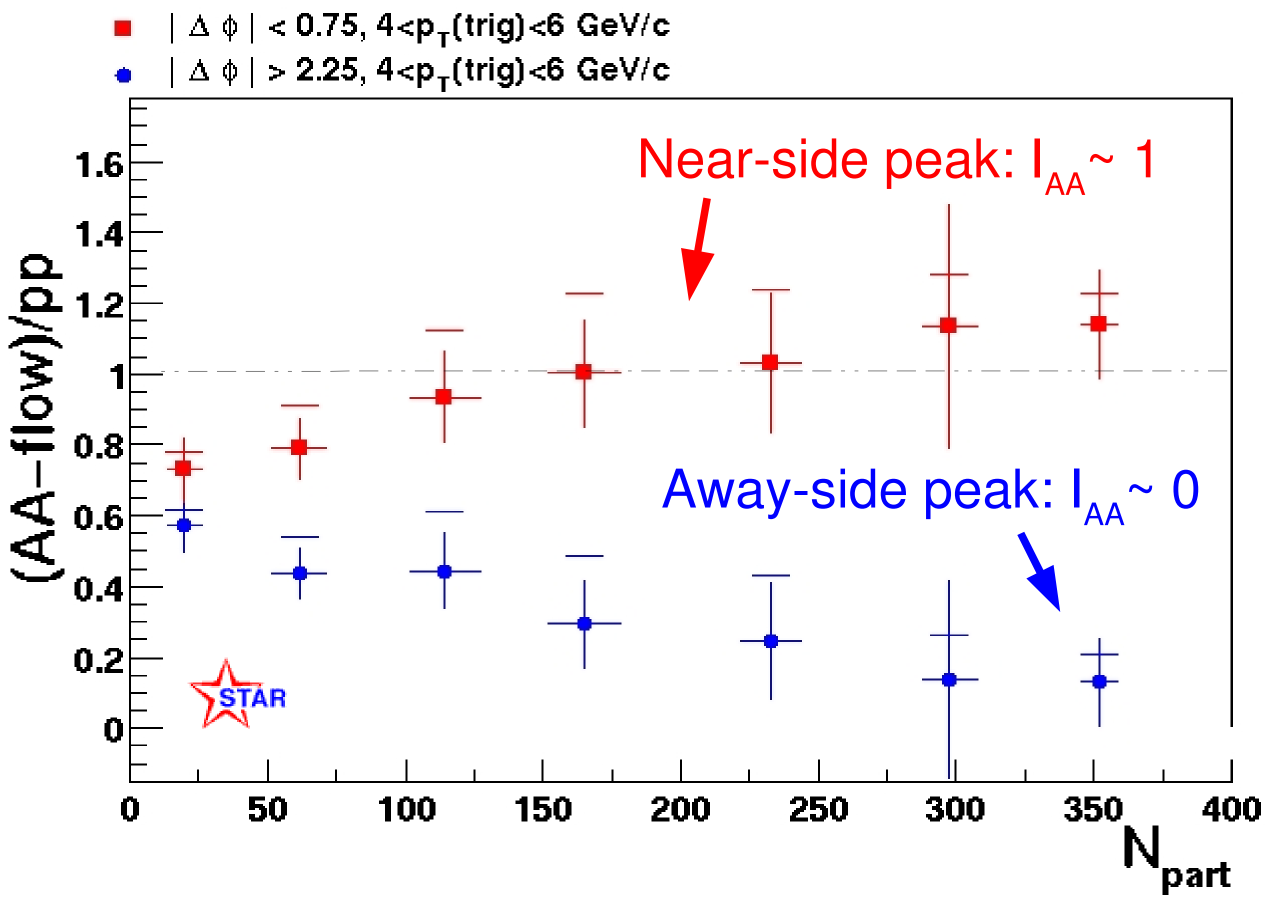
- Centrality dependence of $\langle |j_{Ty}| \rangle$ and $\langle z \rangle \langle |k_{Ty}| \rangle$ in Au+Au:



Dijets via dihadron azimuthal correlations: AuAu (200 GeV)

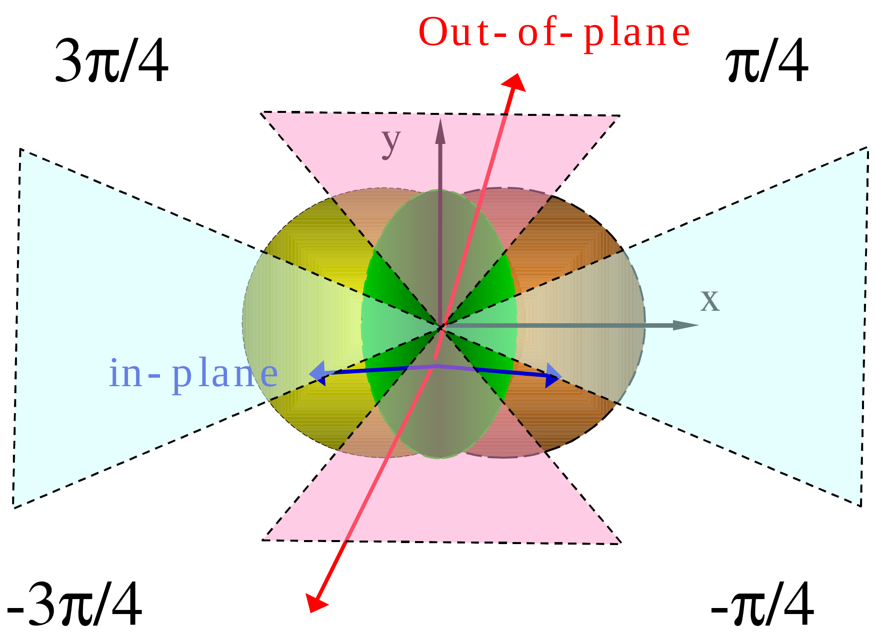
- Centrality dependence of near- and away- side correlations "strengths":

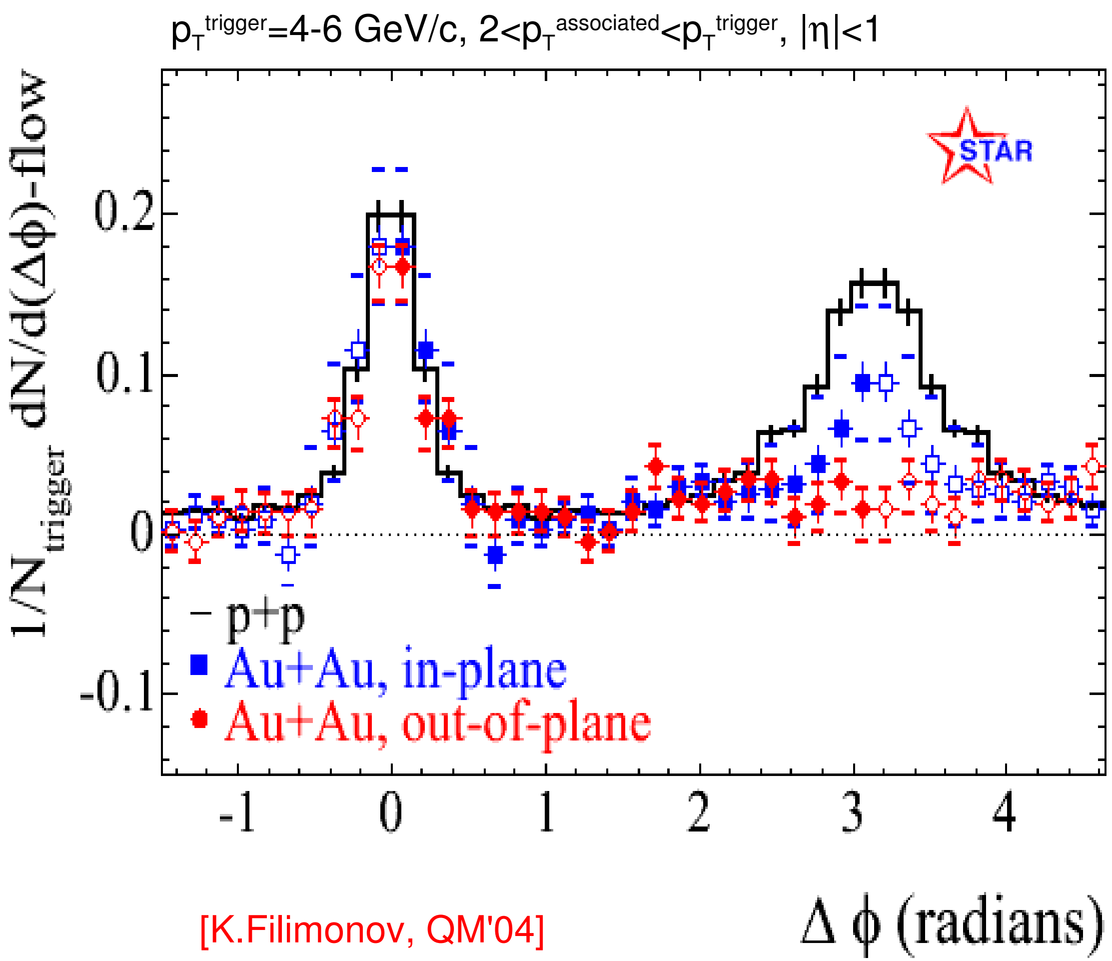
$$I_{AA}(\Delta\phi_1, \Delta\phi_2) = \frac{\int_{\Delta\phi_1}^{\Delta\phi_2} d(\Delta\phi)[D^{\mathrm{AuAu}} - B(1 + 2v_2^2\cos(2\Delta\phi))]}{\int_{\Delta\phi_1}^{\Delta\phi_2} d(\Delta\phi) D^{\mathrm{pp}}}$$



STAR, PRL90, 082302 (2003)

Reaction-plane dependence of away-side dissapeareance





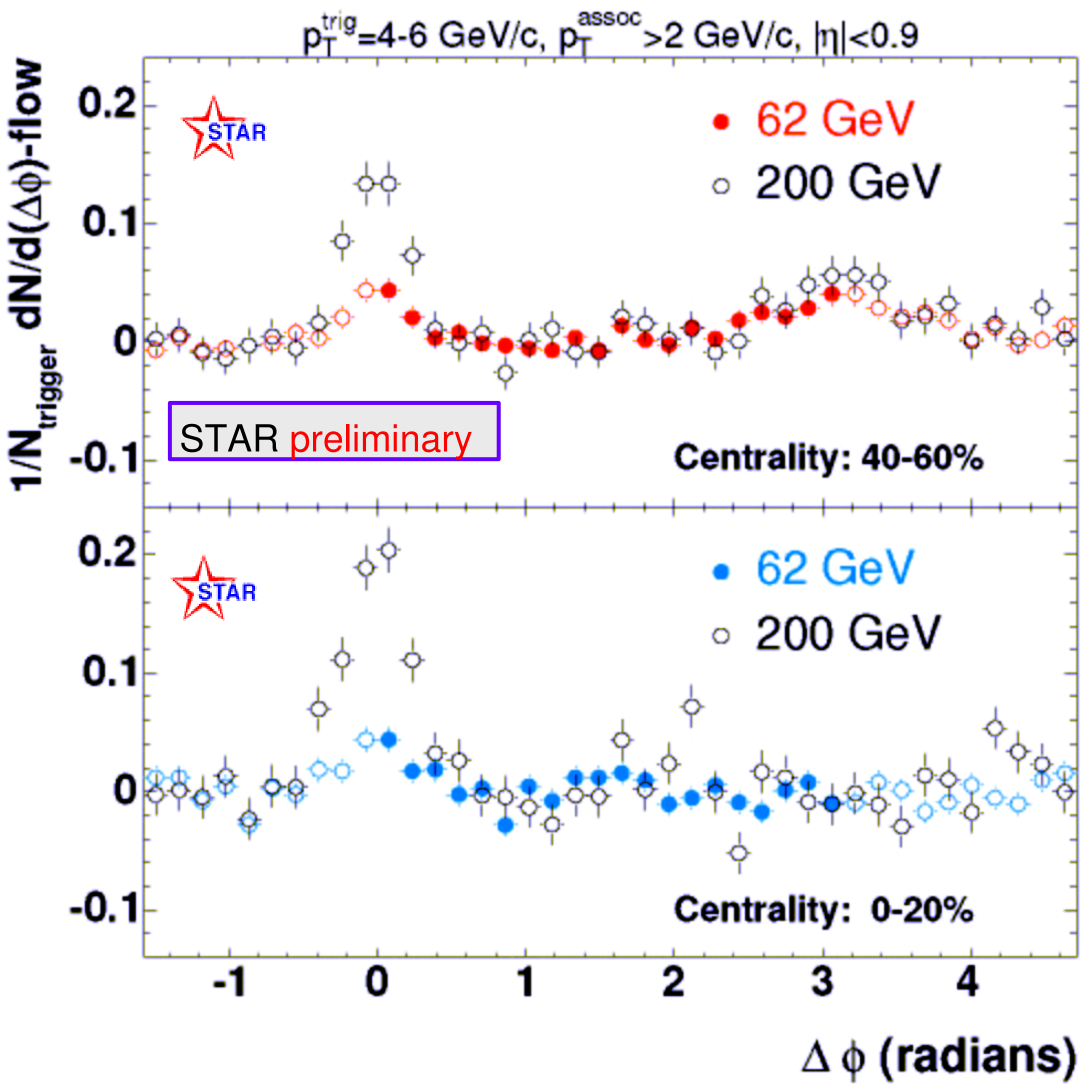
[K.Filimonov, QM'04]

Back-to-back suppression out-of-plane stronger than in-plane
(consistent with increasing energy loss in larger path-length)

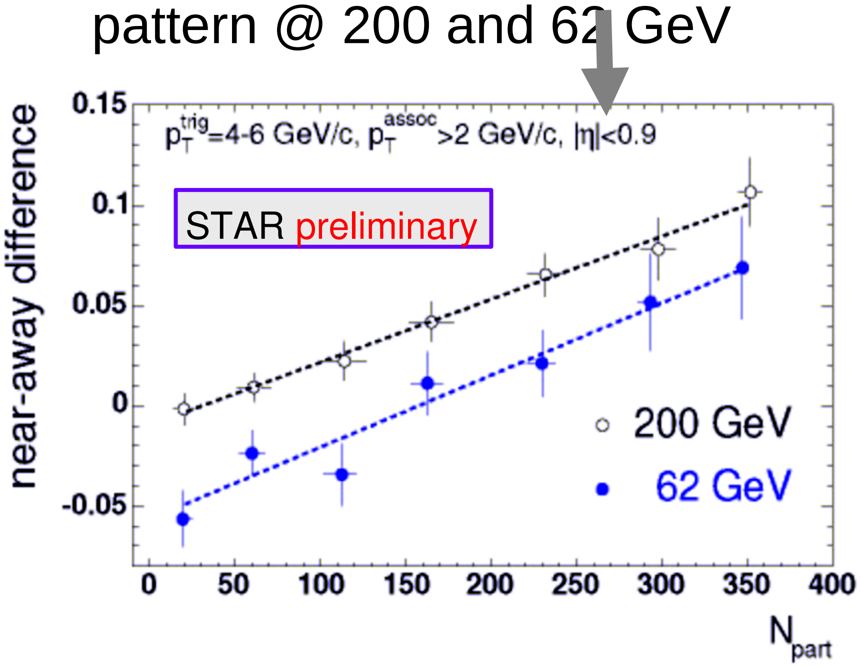
Constraints on path-length dependence of partonic "absorption"

Dihadron azimuthal correlations: AuAu (62 GeV)

- Away-side disappearance also at 62 GeV (statistics limited):



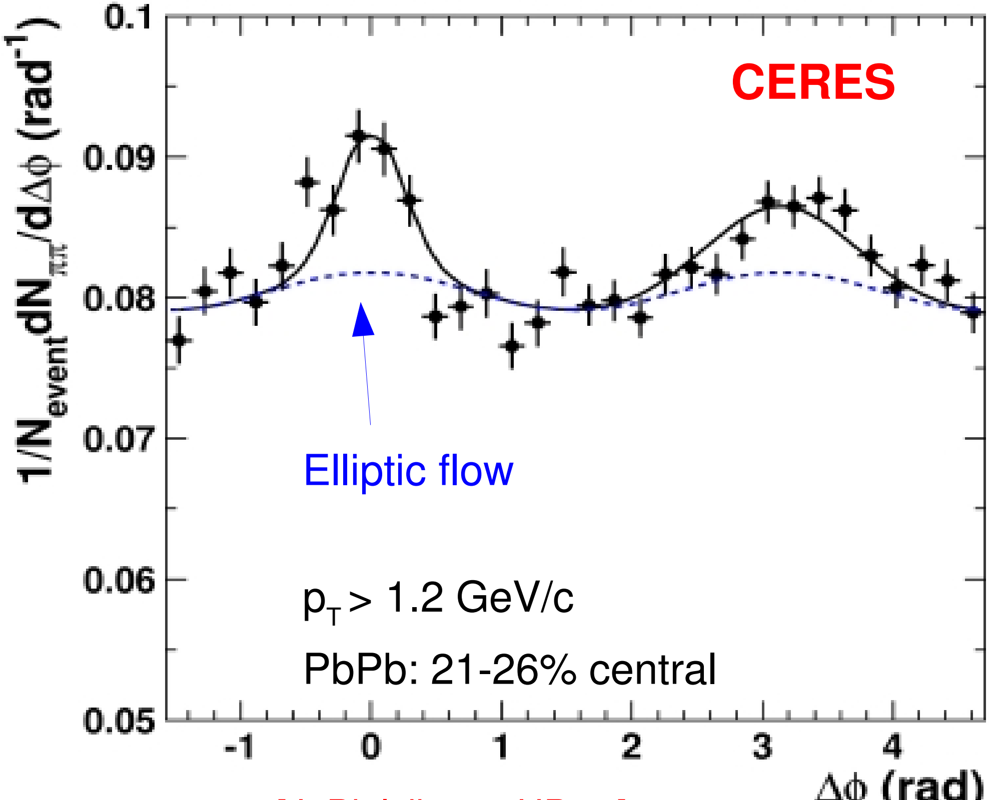
- [near side] [away side]diff. indicates similar suppression pattern @ 200 and 62 GeV



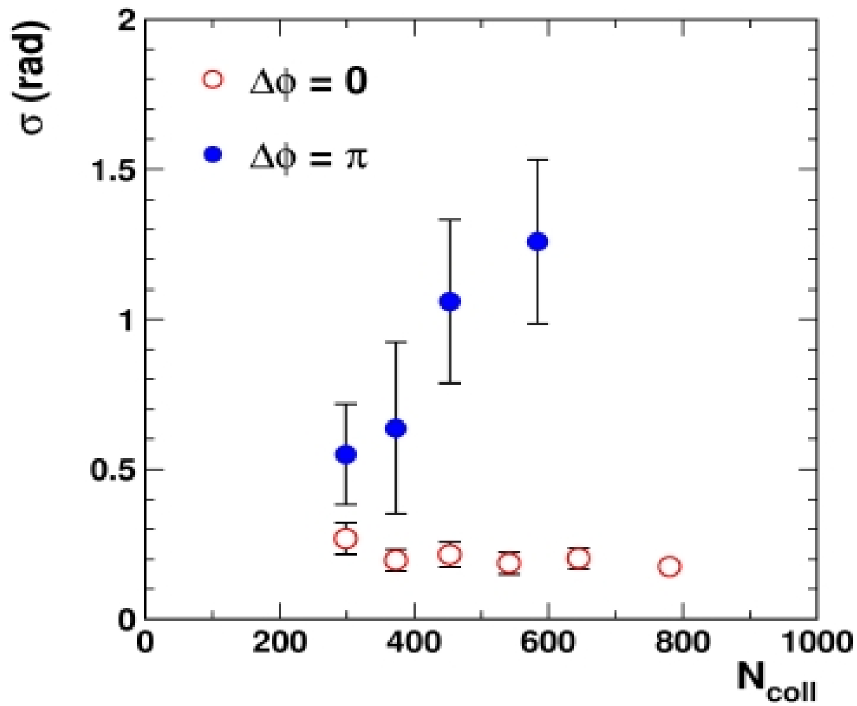
[D. Magestro, HP'04]

Dihadron azimuthal correlations: PbPb (17 GeV)

- Large broadening of away-side correlations seen in di-pion azimuthal correlations at CERN-SPS:

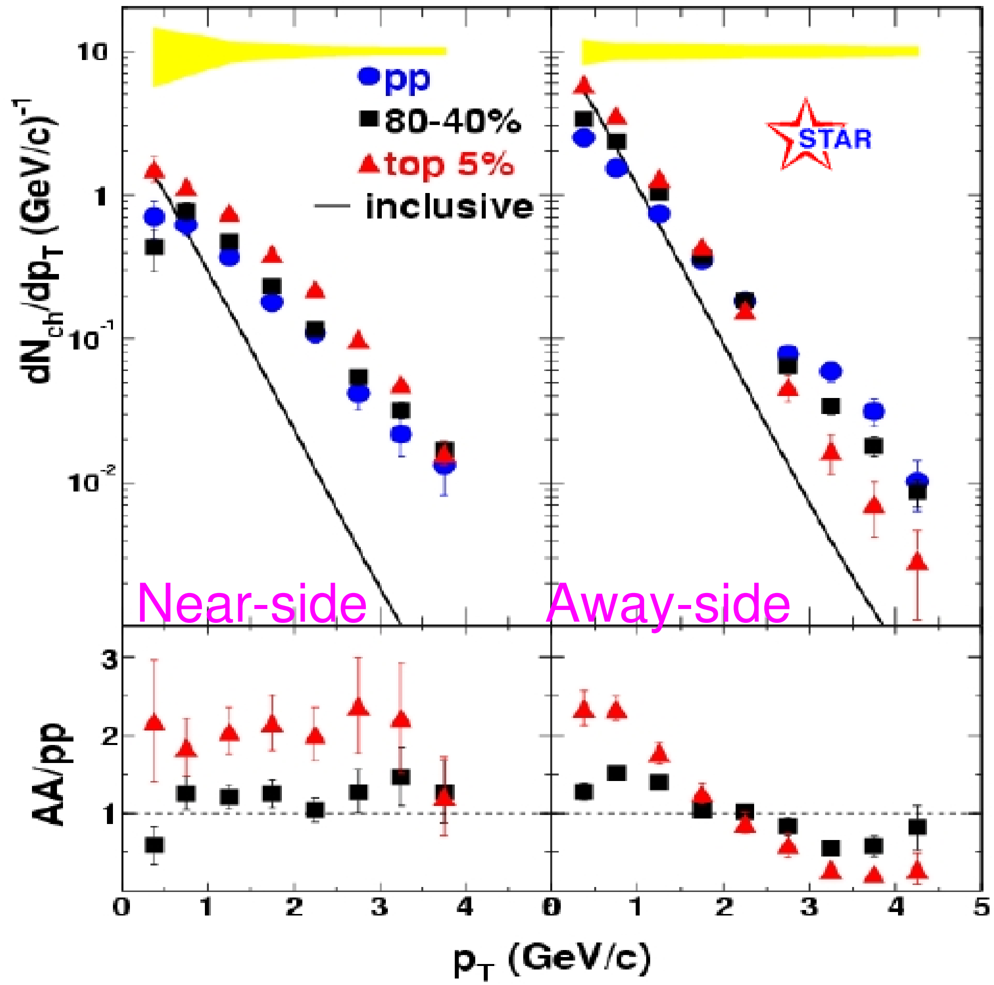


[J. Bielcikova, HP'04]



Fragmentation functions : Central AuAu (200 GeV)

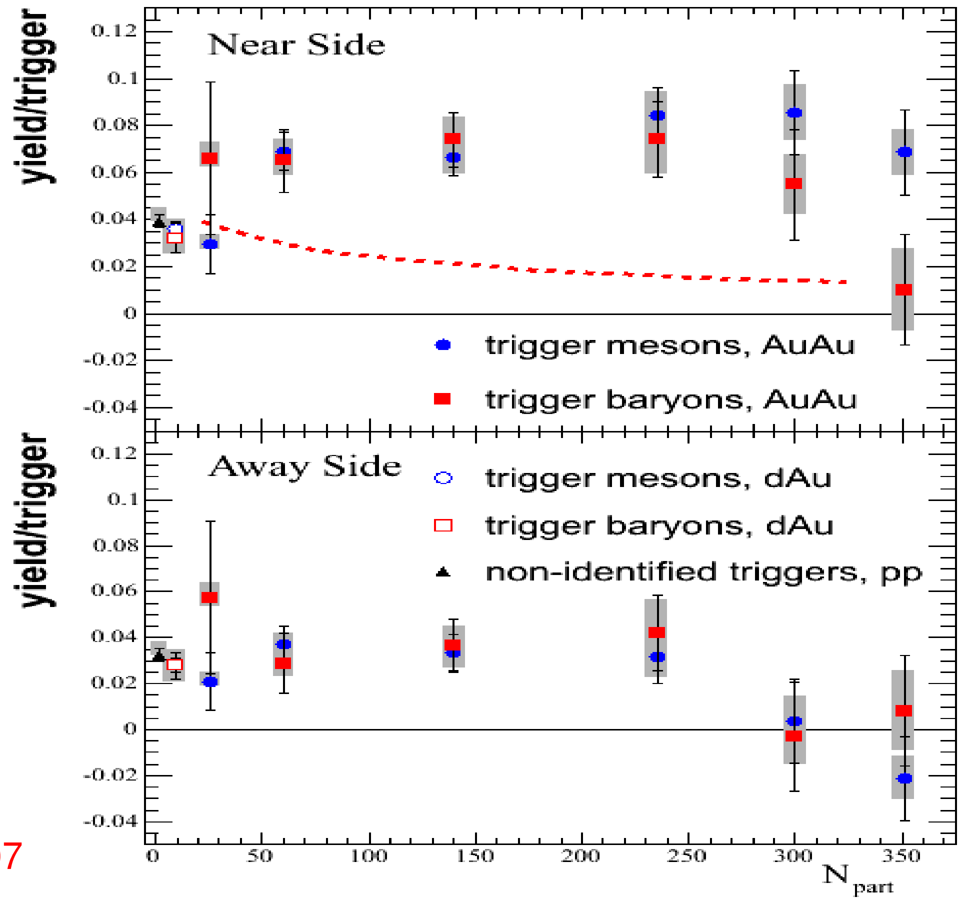
- Associated ($p_{T_{assoc}}$ = 0.15 – 4 GeV/c) near- and away- side hadron p_T spectra:



[F.Wang, QM'04]

Fragmentation functions : Central AuAu (200 GeV)

- Baryon-meson dependence of associated near- and away- side hadron p_T spectra:



$p_{T\,trigg}$ = 2.5 – 4 GeV/c

$p_{T\,assoc}$ = 1.7 – 2.5 GeV/c

Near-side

Away-side

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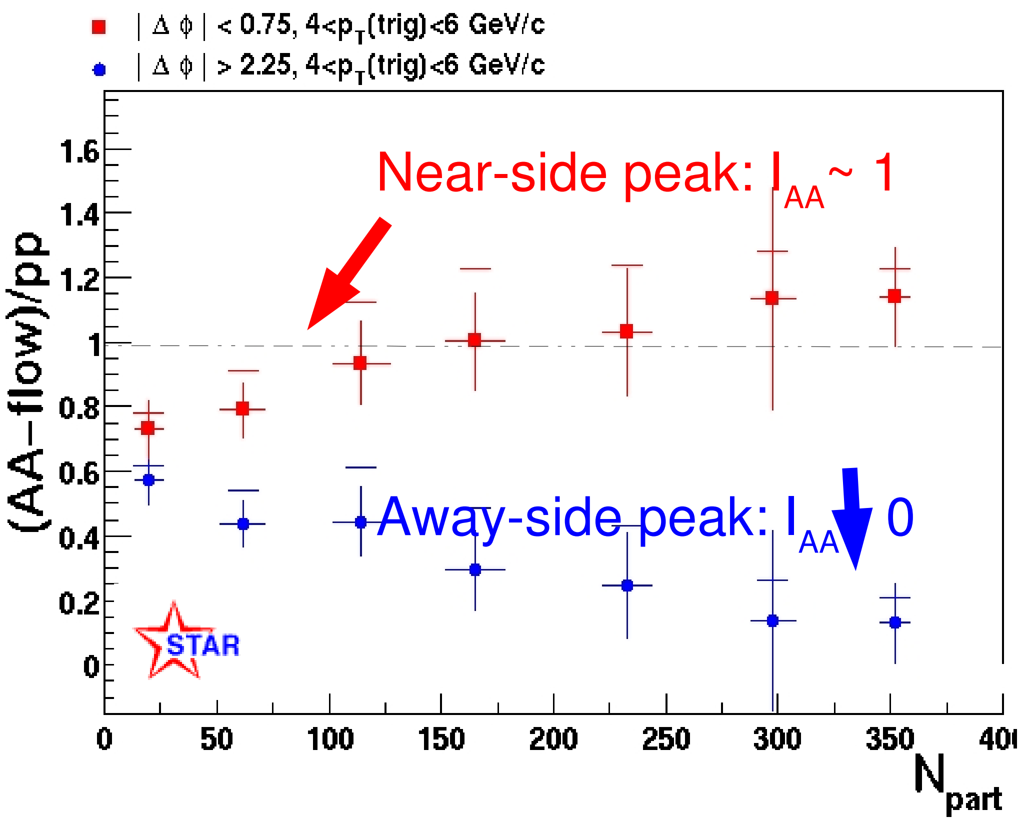
nucl-ex/0408007

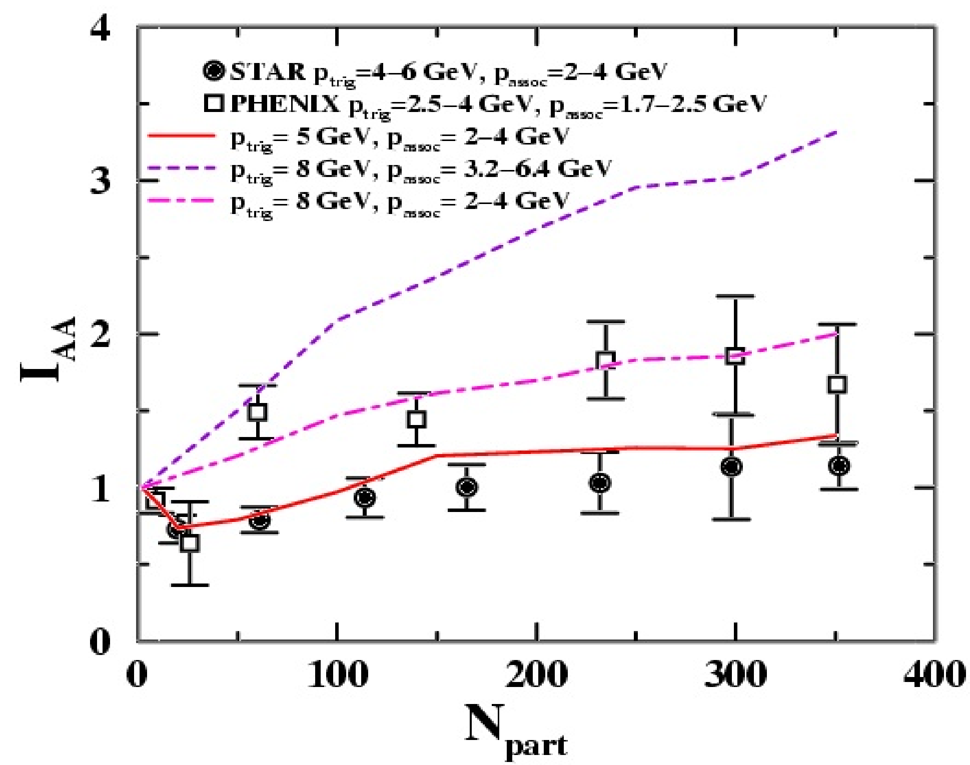
Dihadron azimuthal correlations: AuAu mono-jets

- Centrality dependence of near- and away- side correlations “strengths”:

$$I_{AA}(\Delta\phi_1, \Delta\phi_2) = \frac{\int_{\Delta\phi_1}^{\Delta\phi_2} d(\Delta\phi)[D^{\rm AuAu} - B(1 + 2v_2^2\cos(2\Delta\phi))]}{\int_{\Delta\phi_1}^{\Delta\phi_2} d(\Delta\phi) D^{\rm pp}}$$



STAR, PRL90, 082302 (2003)



[A.Majumder, nucl-th/041261]

Summary: Jet quenching at RHIC

- Results I: Leading hadron production in pp, dAu, AuAu @ RHIC:

  - Strong (factor ~5) high p_T suppression in central AuAu: p_T-, sqrt(s)- dependence consistent with parton energy loss in dense QCD medium (dN^g/dy~1100).

  - Reaction-plane dependence of the suppression provides additional constraints to the path-length dependence of the energy loss.

- Results II: Jet production in QCD vacuum (pp) & cold QCD medium (dAu):

  - Small differences on the extracted properties (j_T, k_T) of the jets emitted in pp & dAu

  - Relatively small initial state effects (multiple scattering) in cold nuclear matter.

- Results III: Jet production in a hot & dense QCD medium (AA):

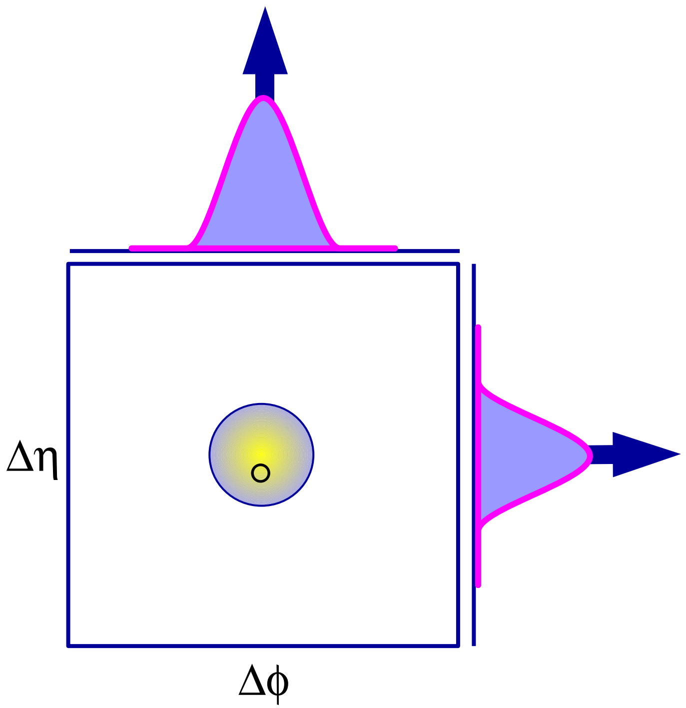
  - Away-side disappearance consistent with:

    (i) Mono-jet predictions due to high-energy parton absorption in dense QCD matter. (enhanced suppression following line of longest path).

    (ii) Large broadening of di-jet acoplanarity (k_T~3 GeV/c) due to multiple scattering of away-side parton in the medium. (Can we extract a transport coeffic. consistent w/

Cartoon summary : Jet-quenching at RHIC

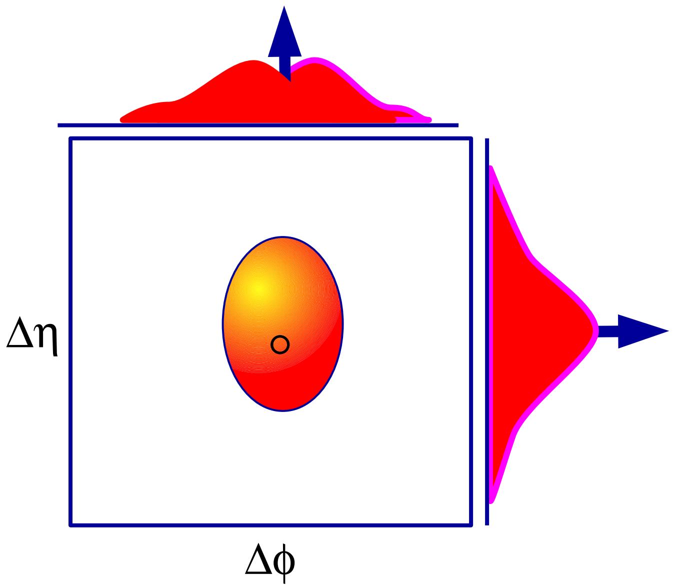
- Jet profile in pp (dAu) collisions:



Near-side width: <j_T> ~ 600 MeV/c

Dijet acoplanarity: <k_T> ~ 1.8 GeV/c

- Jet profile in AuAu central collisions:



Factor ~5 suppression of leading hadron.

(Increased) dijet acoplanarity: <k_T> ~ 3 GeV/c

"Thermalized" associated low p_T yields

Dijet broadening in eta.

Fragmentation functions : x_E distributions pp,dAu

- Away-side associated hadron p_T spectra:

$x_E \sim z/\langle z_{trig}\rangle$ represents away jet fragmentation z

$\langle z_{trig}\rangle = 0.85$ measured*

$\Rightarrow D^q_\pi(z) \sim e^{-6z}$

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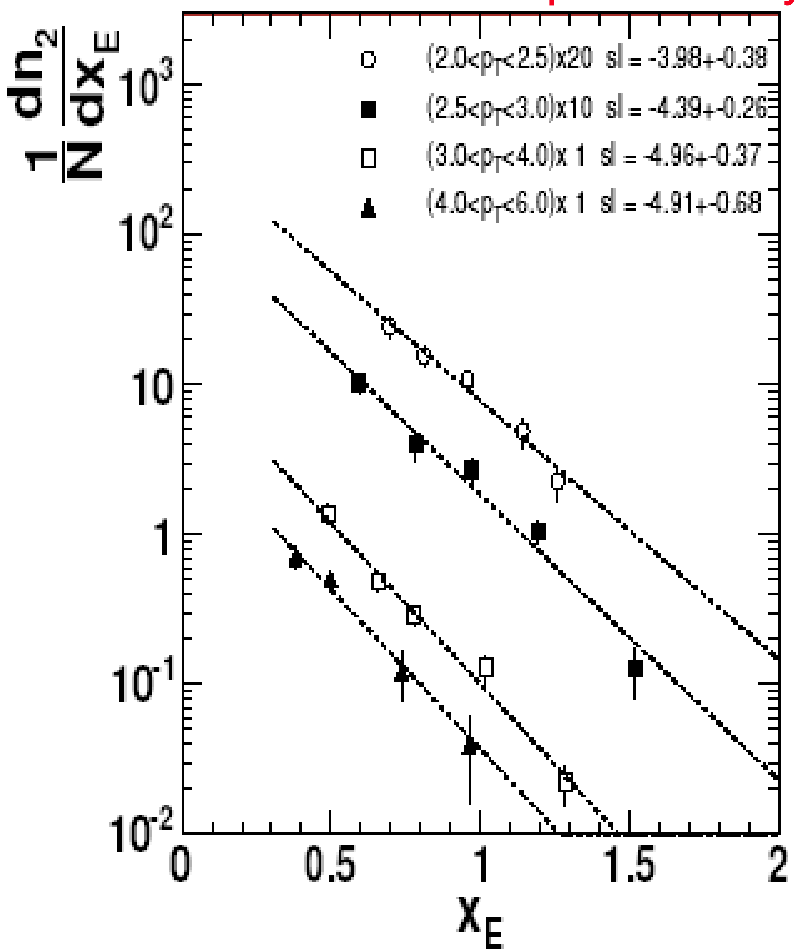

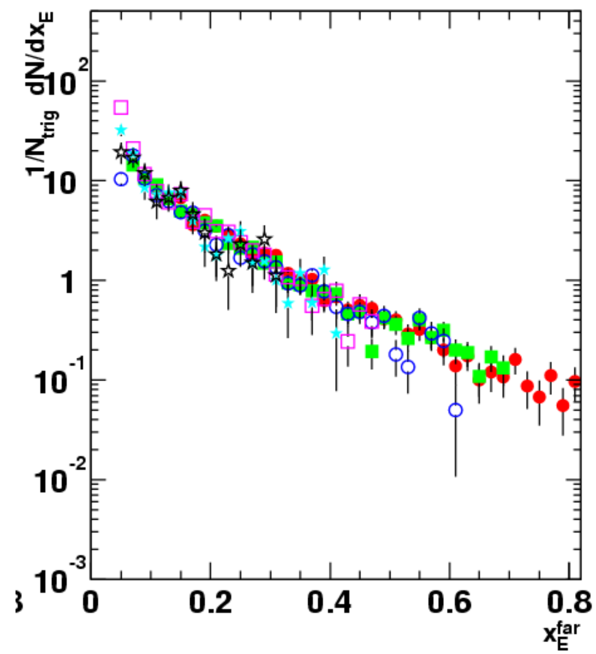

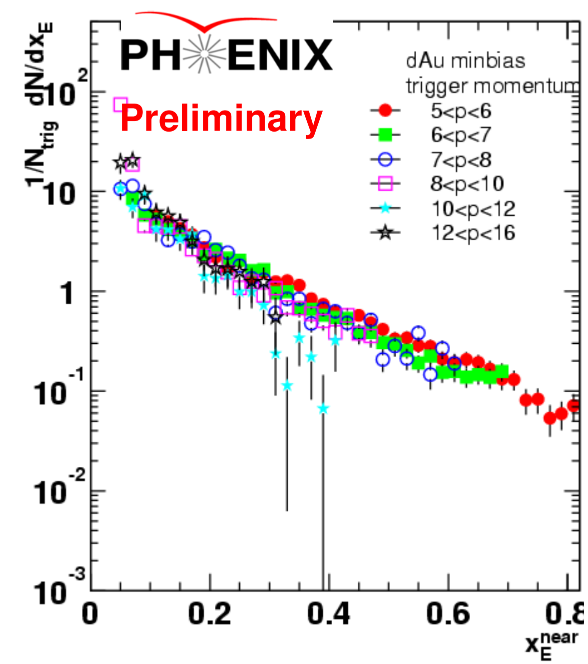

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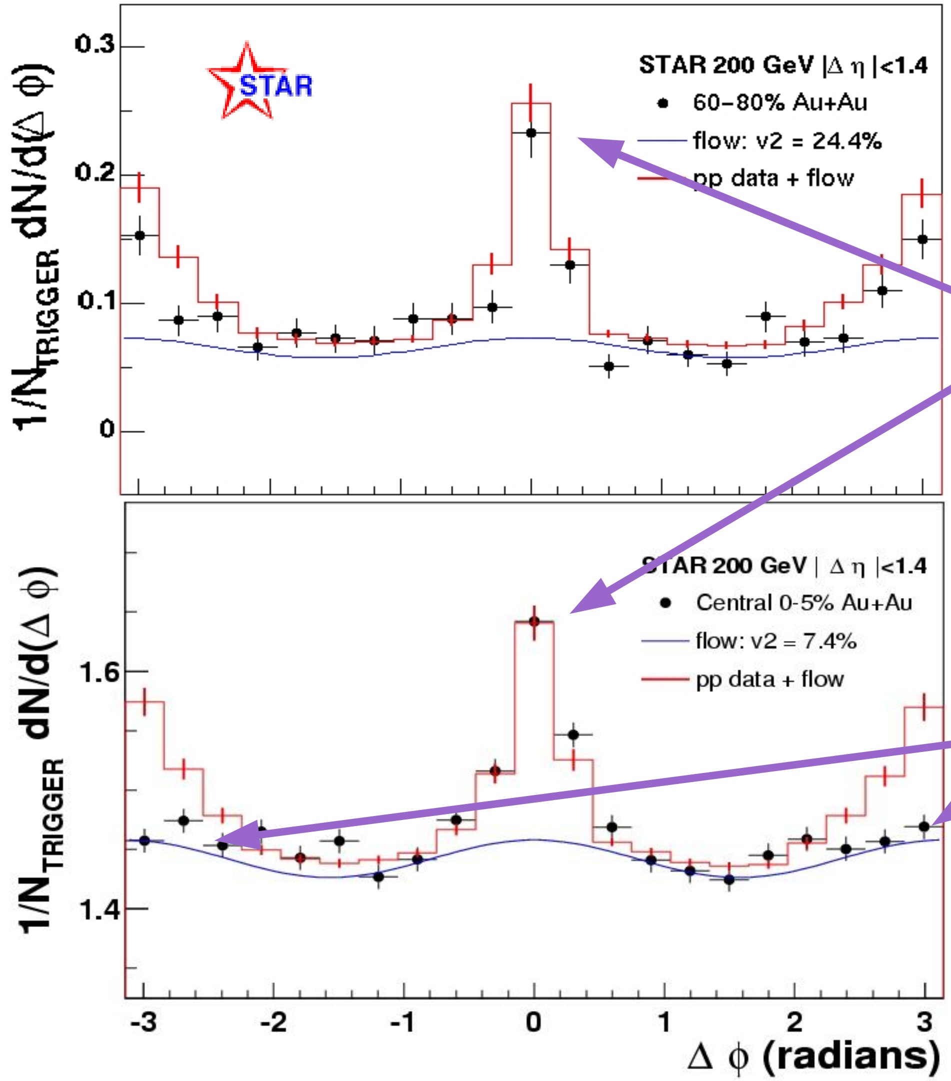
J. Jia

Dijets via dihadron azimuthal correlations: AuAu

- .. $dN_{pair}/d\Delta\phi$ for "trigger" (p_T > 4GeV/c) & associated (p_T = 2- 4 GeV/c) charg. hadrons:

Periph.:

Central:



Red histogram: p+p (+flow)
Black points: Au+Au
Blue curve: flow contribution

- Near-side peak: Au+Au = p+p.

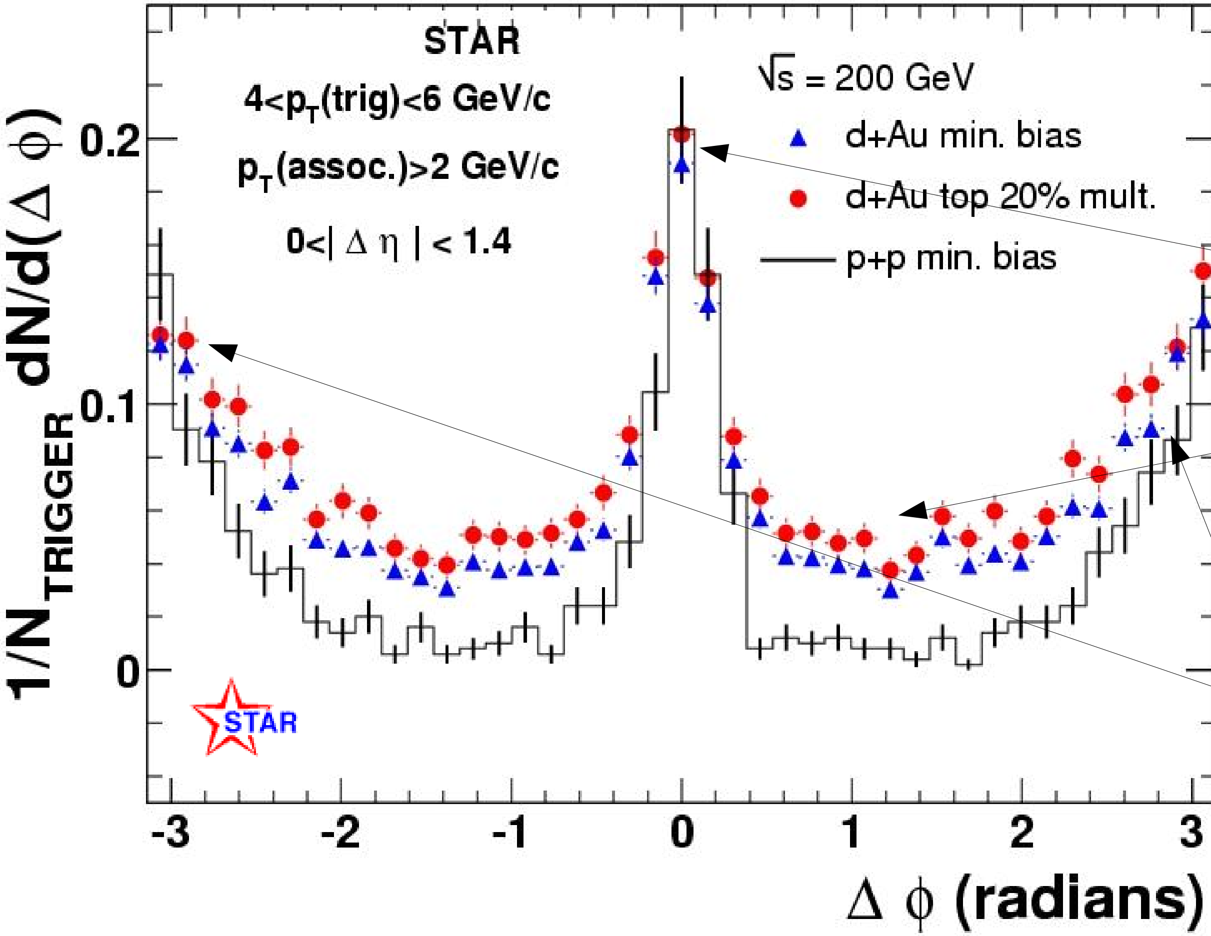
  Trigger hadrons (p_T > 4GeV/c) from jet fragmentation.

- Away-side peak: Au+Au << p+p

  Back-to-back jets suppressed ("mono-jet") in central Au+Au !

High p_T azimuthal correlations: jets in dAu, pp

- ..



- Near- side: d+Au correlation strength and width similar to p+p (& Au+Au)
- Increasing "underlying event": p+p<d+Au(m.bias)<d+A(central)
- Away-side: d+Au peak broadens but small centrality dependence

- Back-to-back jets do not disappear in central d+Au !