
Hadronic final states and their correlations in pp and heavy ion collisions

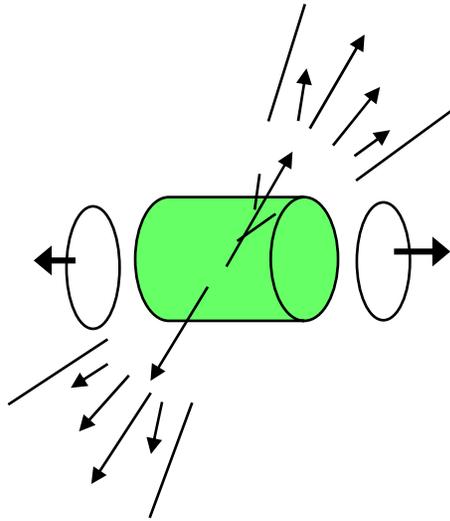
C.A. Ogilvie, Iowa State University
for the PHENIX Collaboration

Using jets to probe the Quark-Gluon Plasma (QGP)

Two themes

- how are jets affected by passing through a QGP ?
- how does QGP respond to the impact of a high-pt parton?

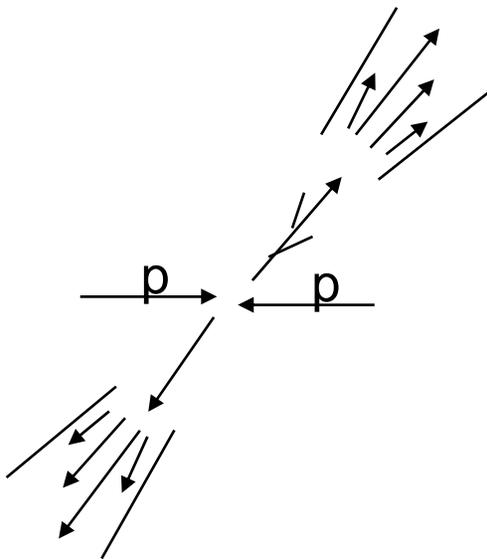
Relativistic Heavy-Ion Collisions:



Energy deposited during collision
of Au+Au at $\sqrt{s_{NN}}=200$ GeV
 \Rightarrow Formation of hot, dense QGP

Hard-scattering process
during QGP formation

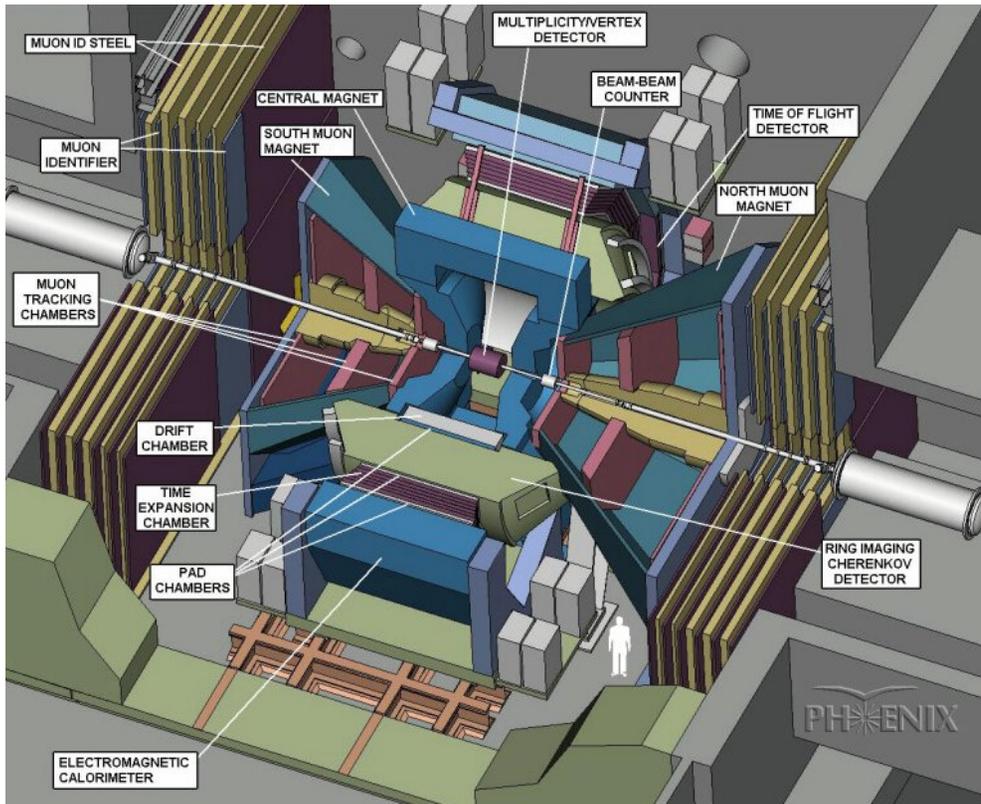
\Rightarrow high-pt partons travel through QGP



Compare with p+p as baseline

Differences \Rightarrow info on QGP

PHENIX Experiment at RHIC



- In operation since 2000
- Designed for penetrating probes to characterize QGP

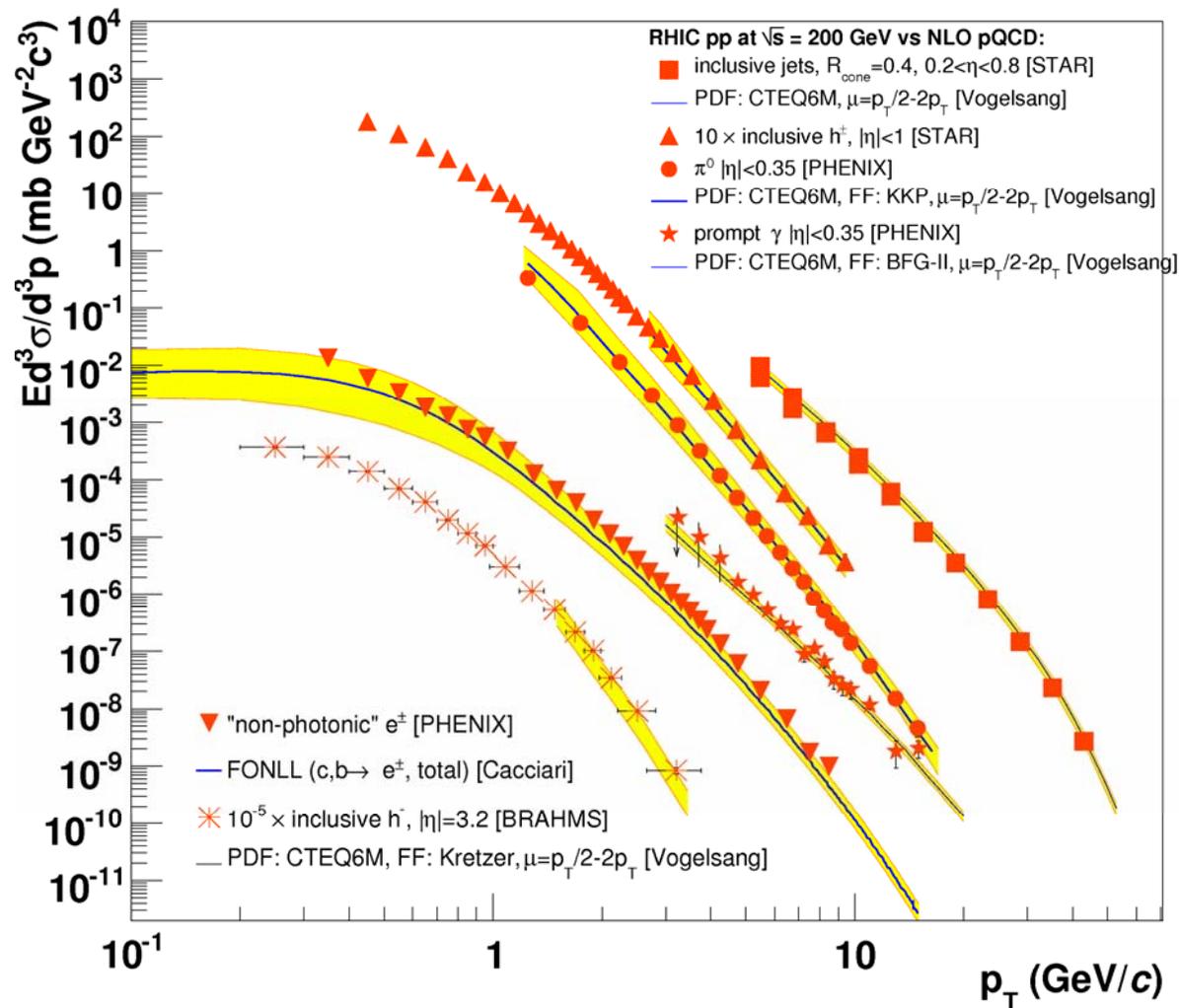
Focus on mid-rapidity arms

Charged tracking +
Calorimetry => photons, π^0 ... +
 J/ψ , ...

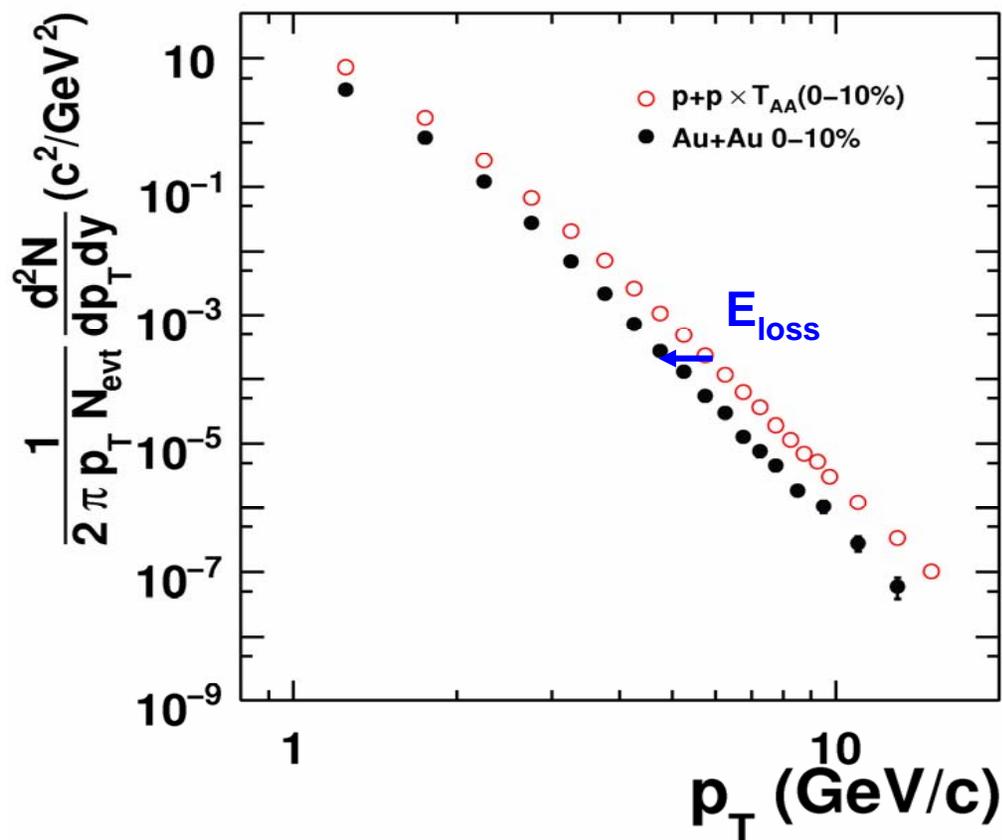
$\sqrt{s}=200 \text{ GeV}, p+p \Rightarrow x$

NLO QCD agrees well with data

D. d'Enterria
nucl-ex/0611012



Partons lose energy as they travel through QGP

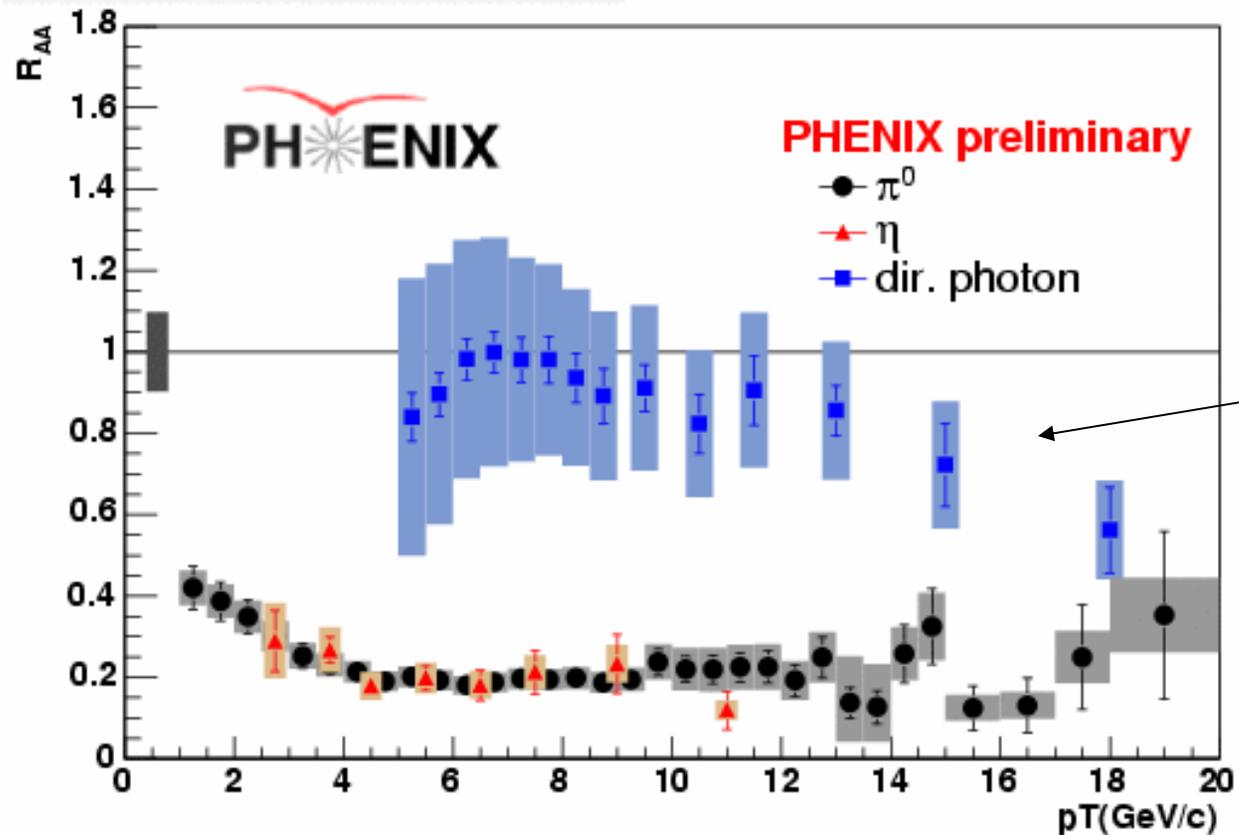


π^0 spectra at $\sqrt{s}=200$ GeV
nucl-ex/0611007
PHENIX

- p+p cross-section scaled by parton-flux in Au+Au
- Fewer high-pt π^0 in Au+Au
 - Energy-lost by parton => info on density of QGP

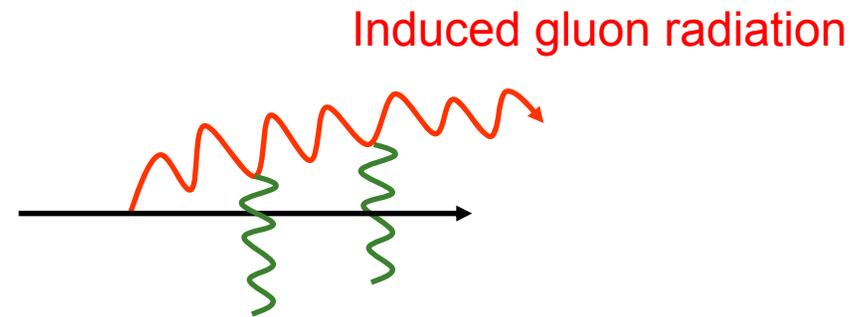
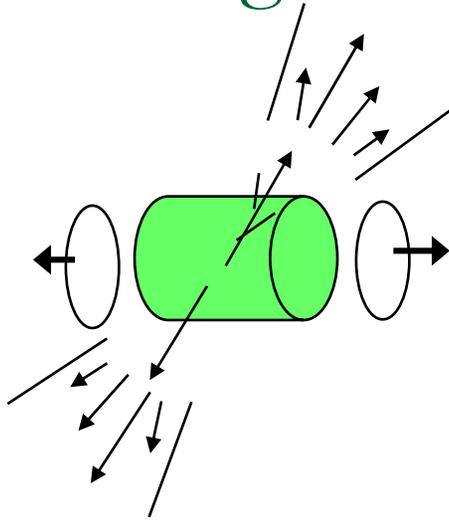
Ratio of (Au+Au)/(scaled p+p spectra)

Au+Au $\sqrt{s_{NN}} = 200\text{GeV}$, 0-10%



- Mesons suppressed $\times 5 \rightarrow$ energy-lost in QGP
- γ scale with parton flux

Induced gluon radiation



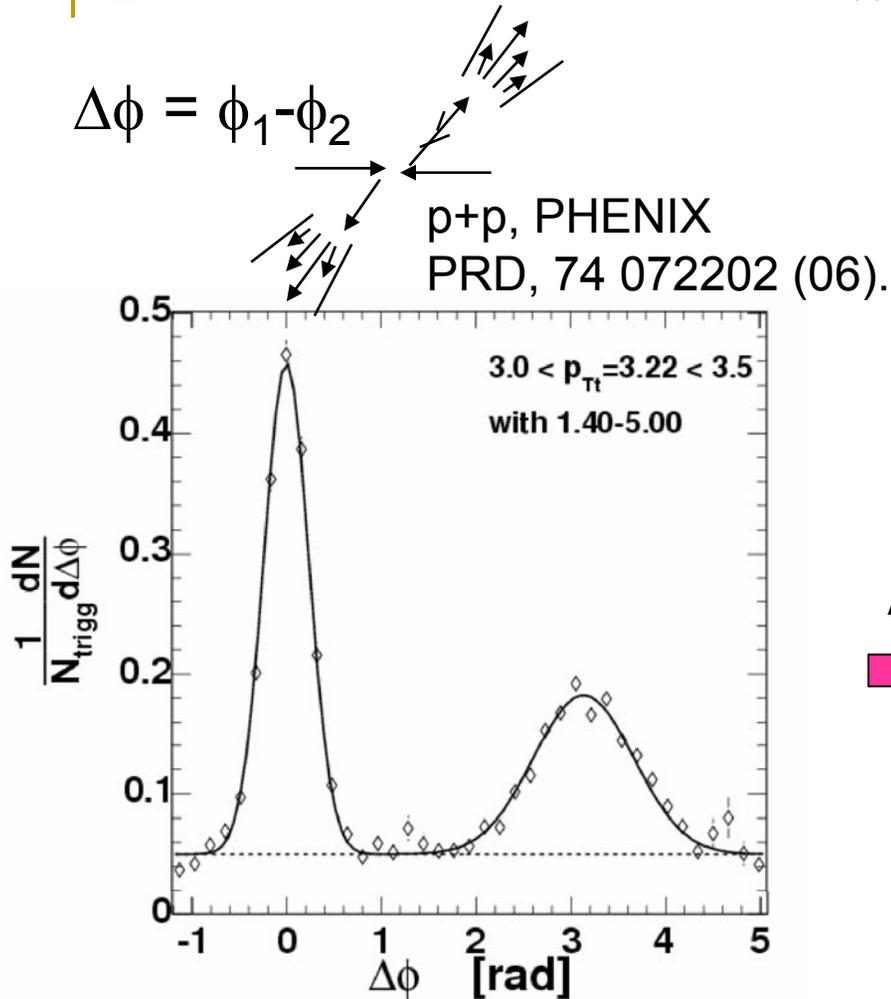
During gluon formation time,
parton may have multiple interactions
=> impressive, subtle calculations

M.Gyulassy et al., Phys.Lett.B526 (2002)

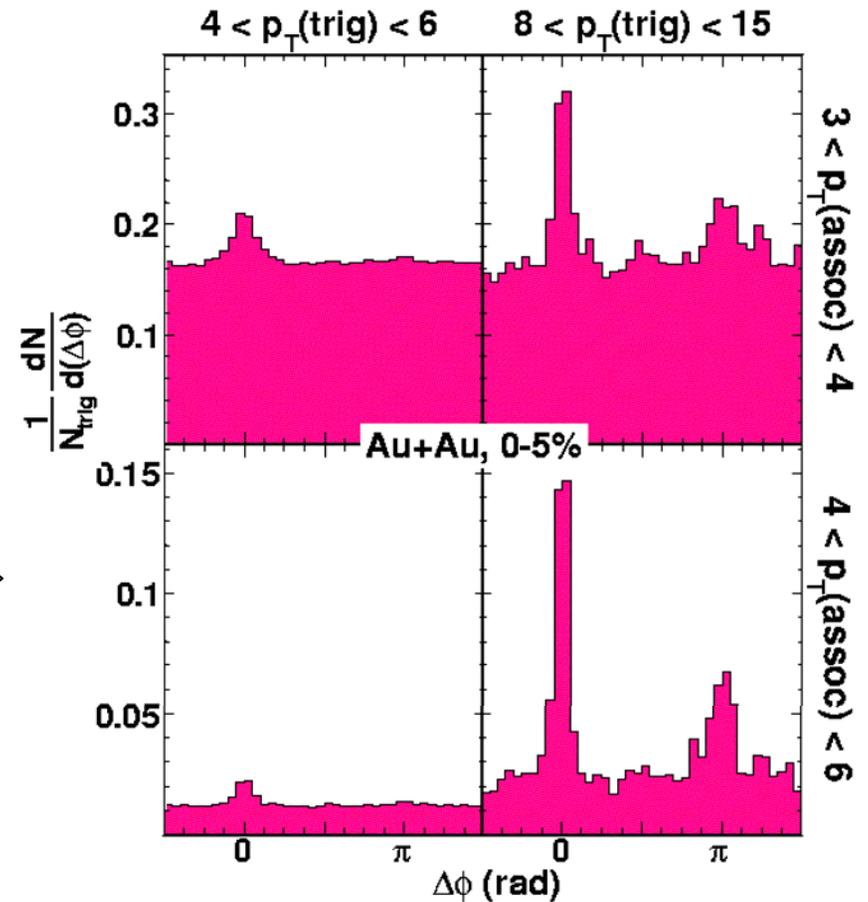
- Magnitude of energy-loss depends on
 - QGP density and how gluon-radiation is modeled
- What is the fate of this radiation ?
 - Broaden width of correlated particles ?
 - Or thermalize with the QGP ?

Particles correlated with high-pt trigger

STAR

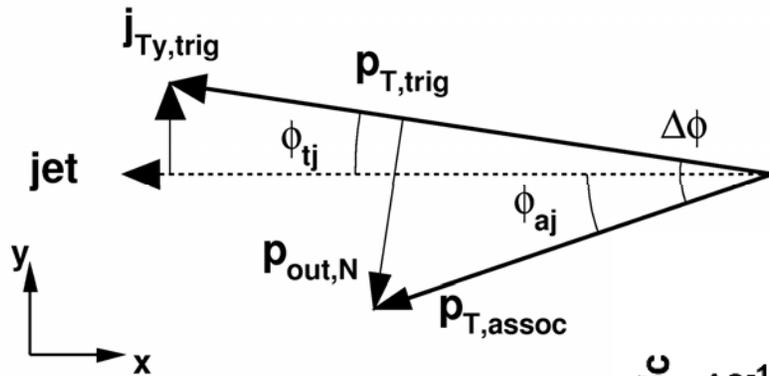


A+A
→

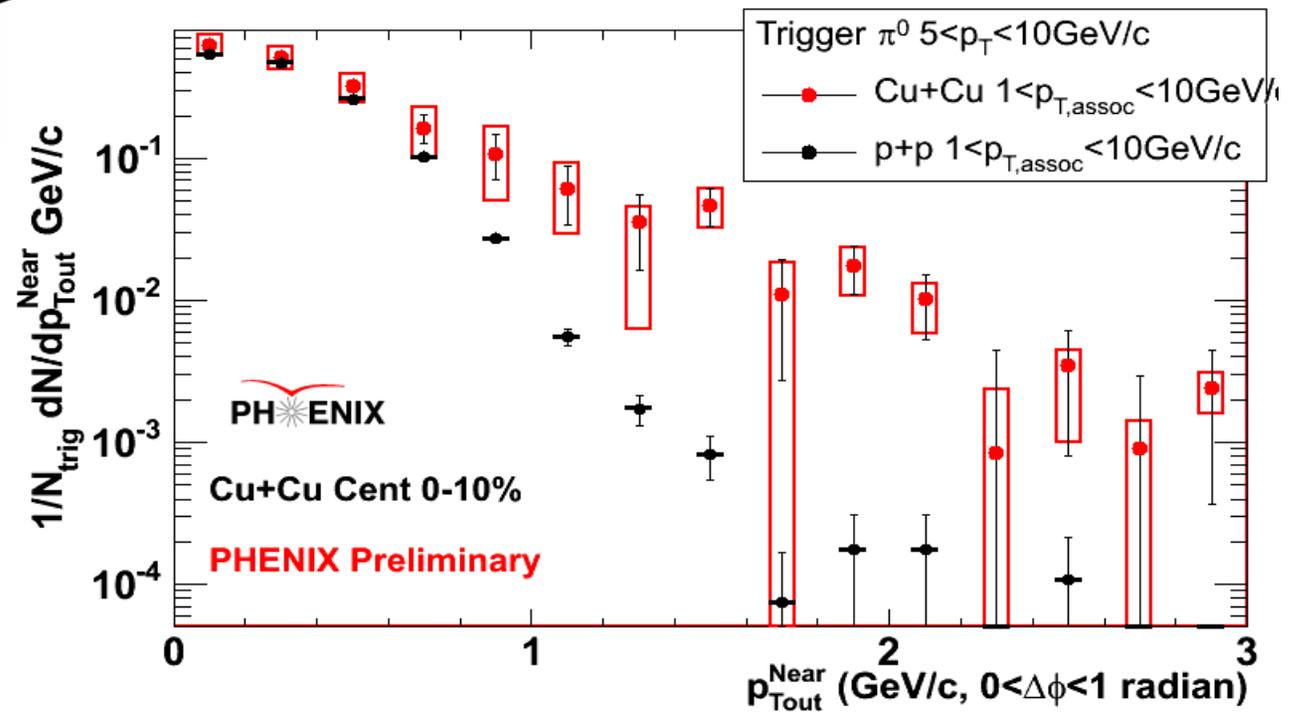


- Correlation survives high-multiplicity environment of A+A

Near-side correlation

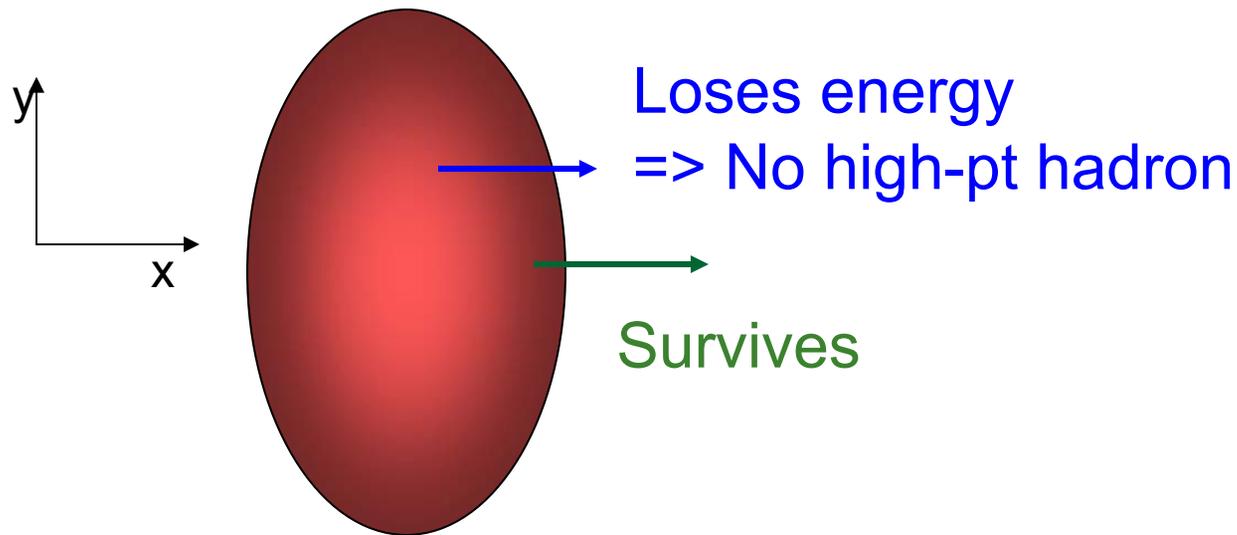


P_{out} is transverse momentum of 2nd wrt high-pt trigger particle



- Jets broader in **Cu+Cu** than p+p
 - Fragmentation of induced gluon radiation?

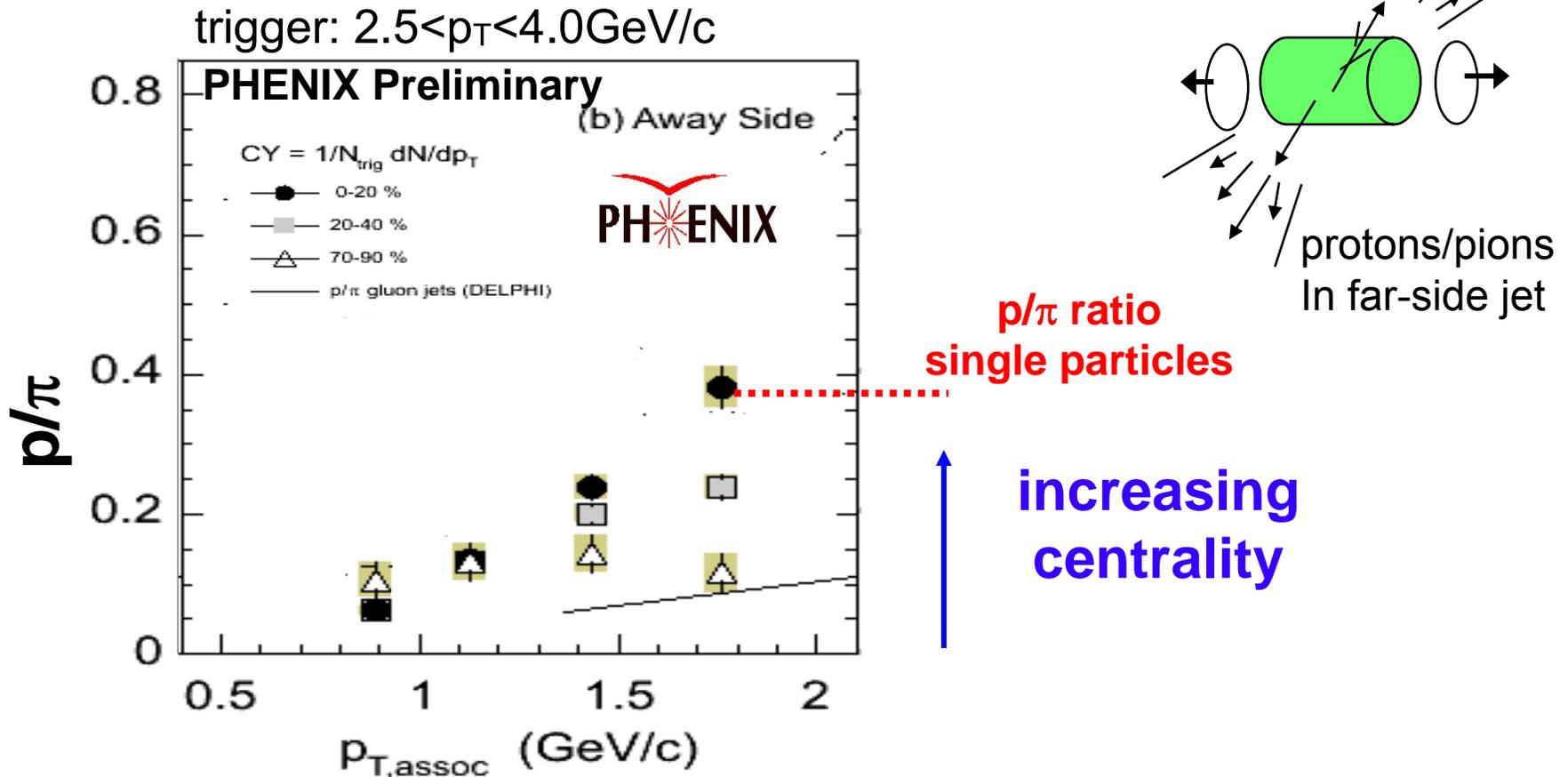
Hard-scattering locations biased to surface



To **survive** energy-loss to produce a high-pt trigger production points are biased towards surface

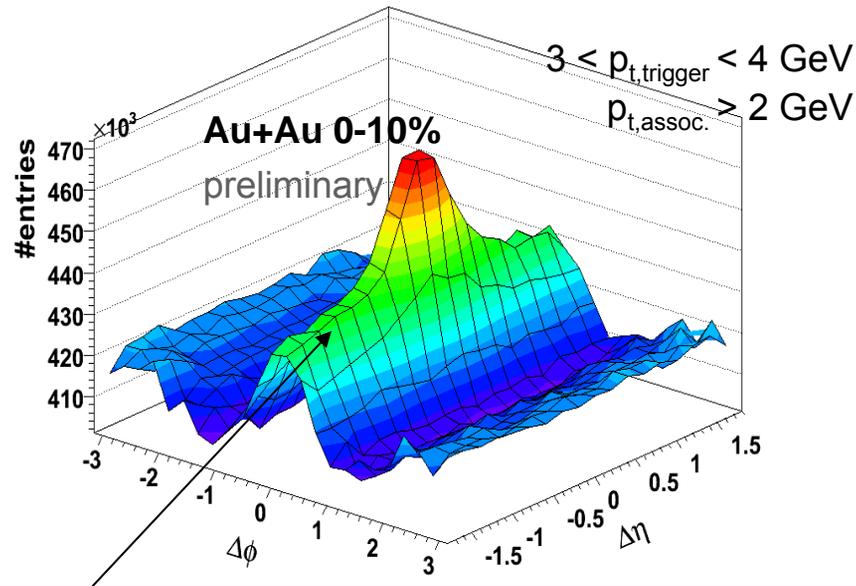
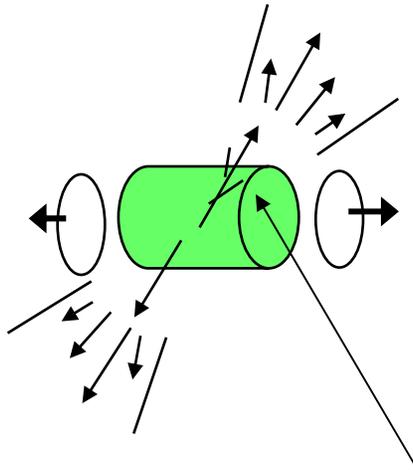
- Back-to-back partner parton travels through more QGP
 - Far-side may provide more information

Particle composition of far-side jet

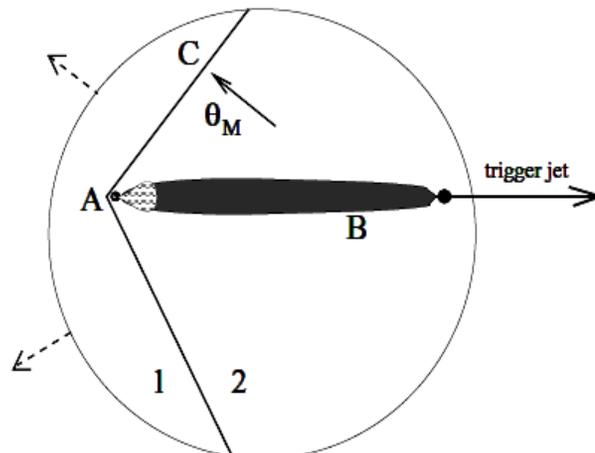


- Particle composition close to e^+e^- data in peripheral A+A
- Increases with more central collisions
 - jet takes on more and more of medium's characteristics

Response of medium to passage of high-pt parton



- Near-side, generation of ridge => strength large $\Delta\eta$ (STAR talk)
- Far-side: does super-sonic parton generate a mach-cone ?

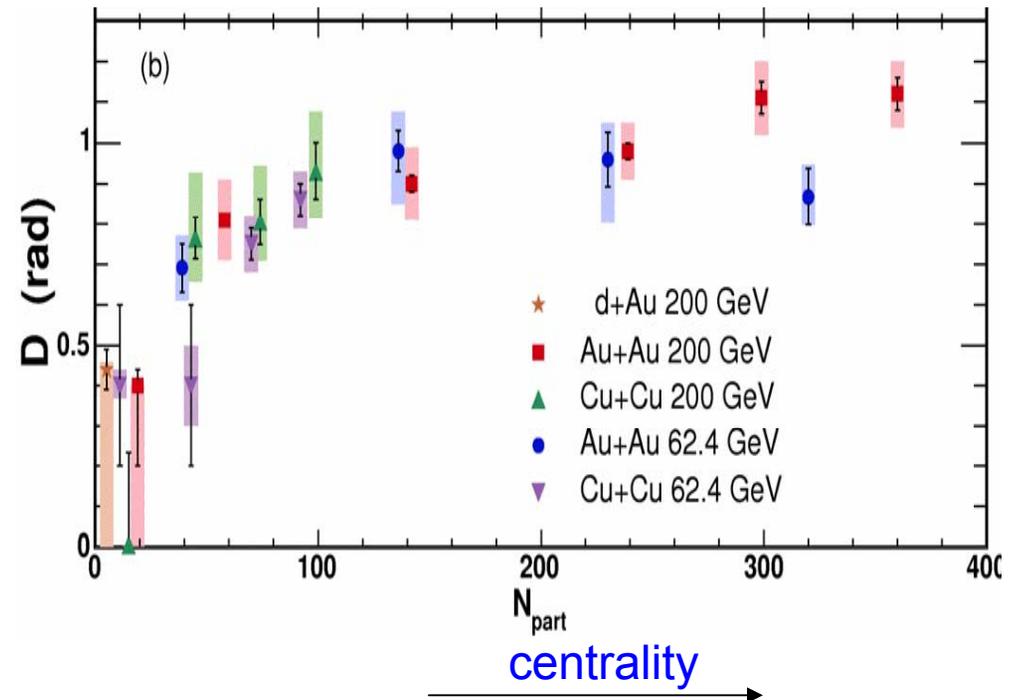
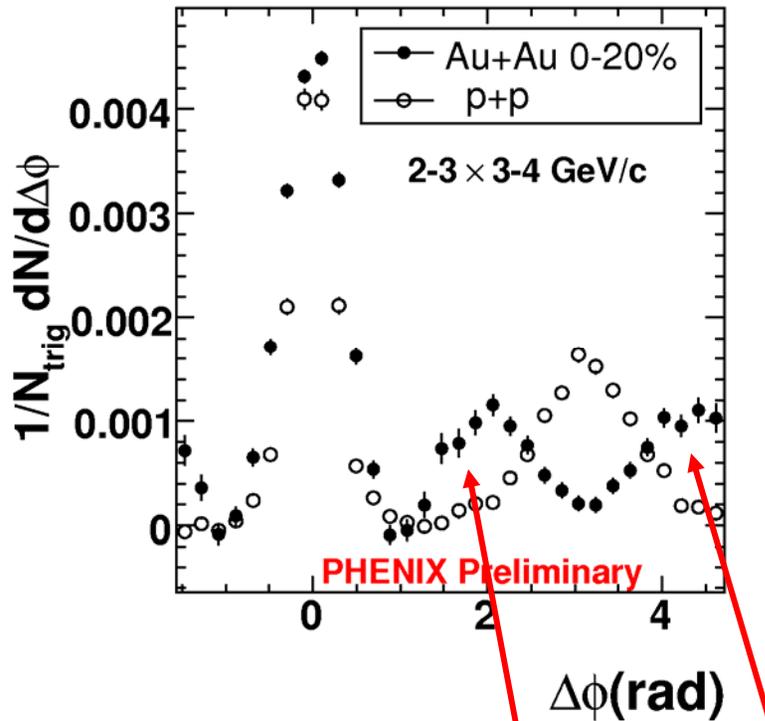


hep-ph/0410067;
H.Stocker...
Jorge Casalduerry-Solana

Far-side Production of Particles

PHENIX preliminary
nucl-ex/0611019

$1 < p_{t,ass} < 2.5 < p_{t,trig} < 4 \text{ GeV}/c$



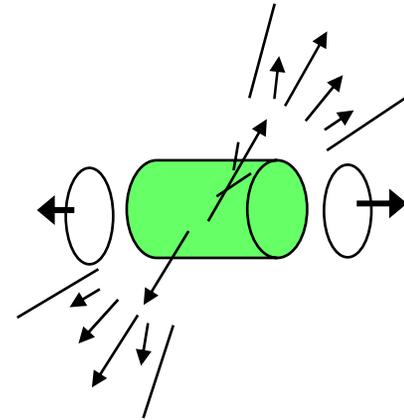
Observation of particles produced
~1 radian away from back-to-back!

Fit with 2 Gaussians, each D radians away from π
D scales with system size

=> emission consistent with medium's response to jet

Future/Starting Directions (I)

- Energy-loss of **charm+beauty** quarks
 - Predicted to lose less energy
 - Less gluon radiation
 - larger interference during multiple-scattering
 - dead-cone effect
- **Challenge for models**
 - If they reproduce both pion and charm energy-loss
 - Confidence in how gluon radiation is modeled



Non-photonic electrons \rightarrow charm (+ beauty) in p+p

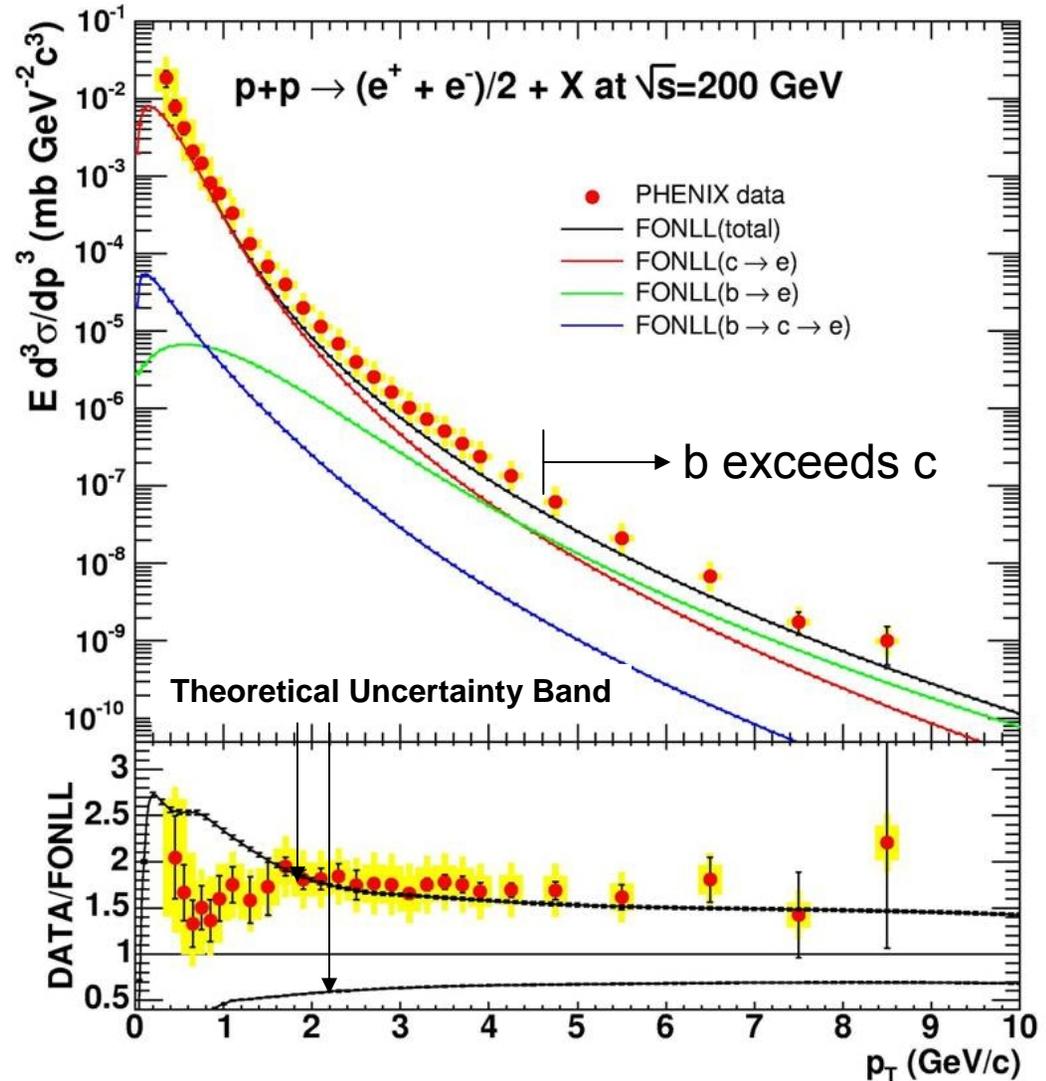
PHENIX
PRL97,252002

Ratio:

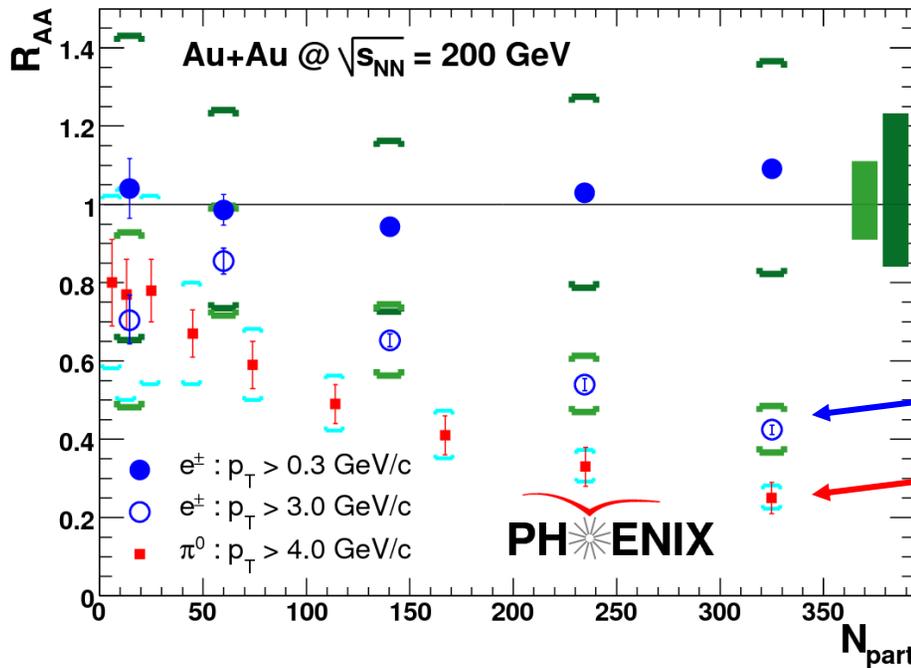
1.71 ± 0.02 (stat) ± 0.18 (sys)
($0.3 < p_T < 9.0$ GeV/c)

Details

D. Hornback talk
yesterday



Suppression of heavy-quark spectra in A+A



PHENIX
nucl-ex/0611018
PRL in press

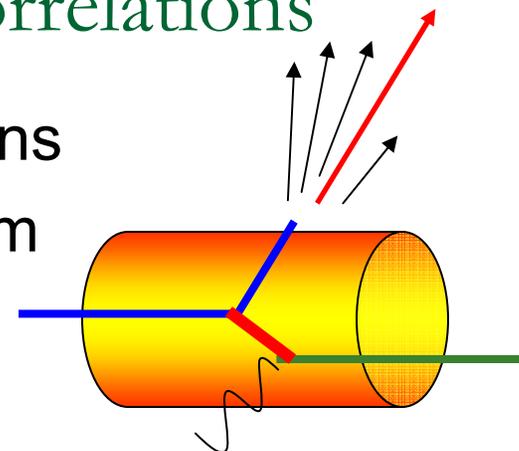
Suppression of e , $p_T > 3.0$ GeV/c
Slightly smaller than light quarks

Challenge for models to reproduce both light, heavy-q E_{loss}

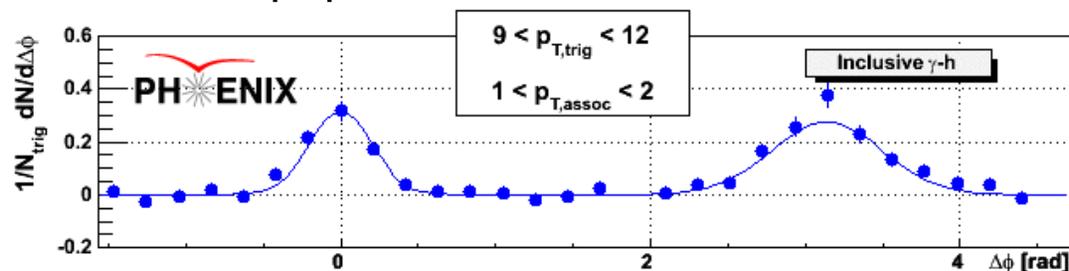
Expt. need to increase statistics, reduce systematics
silicon upgrade=> displaced vertices

Future/Starting Directions (II): γ -h correlations

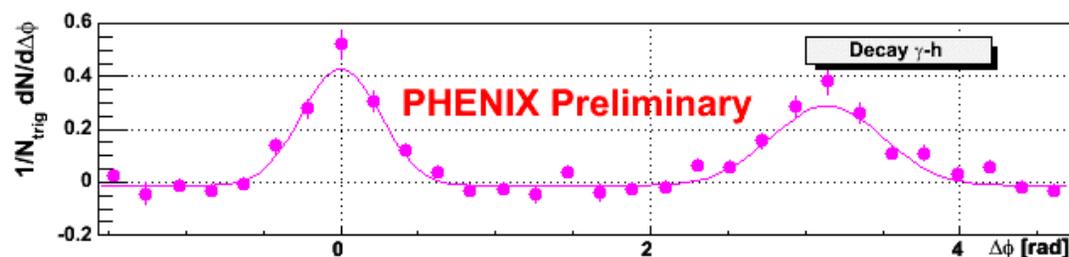
- Tag the energy of the jet with direct-photons
 - Back-to-back hadrons probe the medium



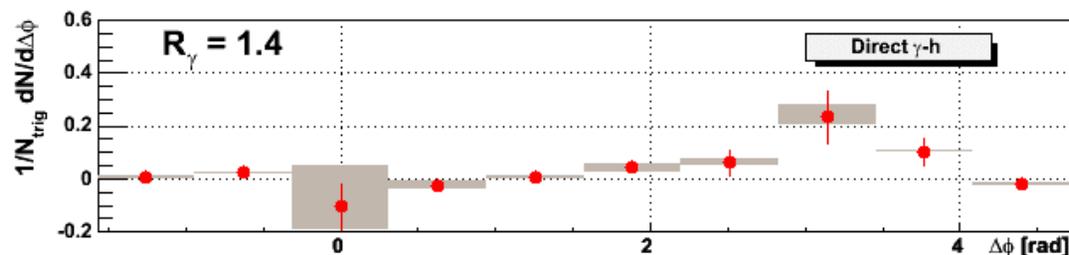
p+p collisions at 200 GeV



1 Inclusive γ -h

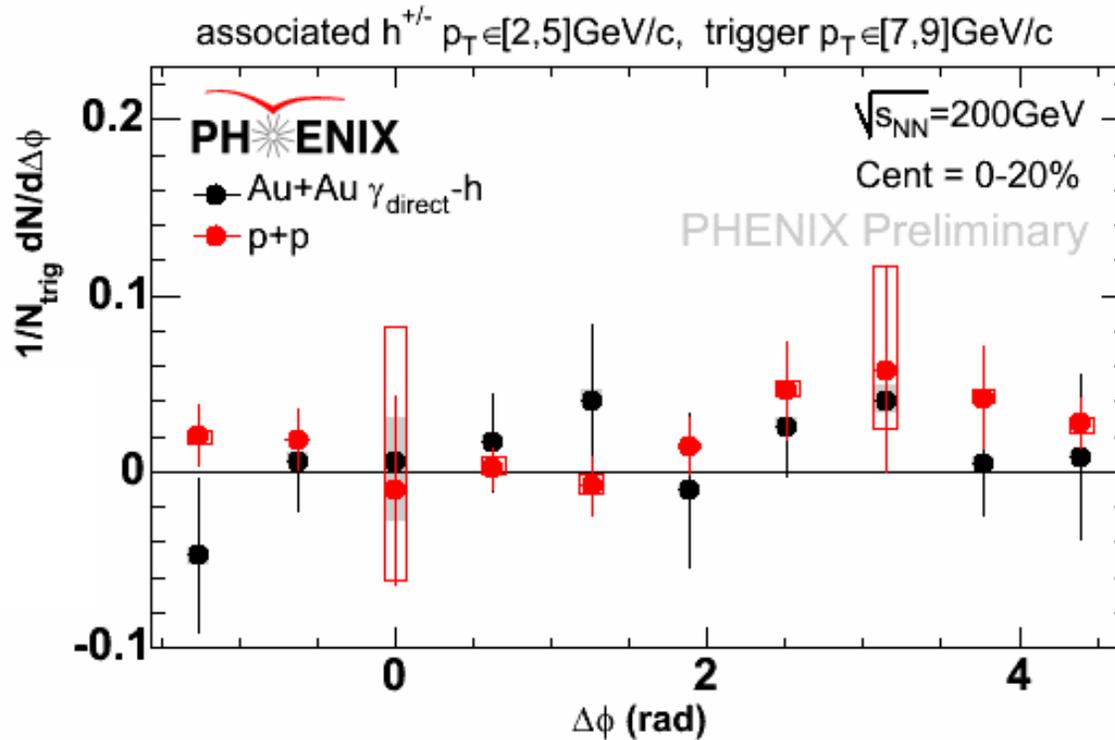


2 Decay γ -h contribution
(via π^0 -hadron)



3 Direct γ -h !

γ -h correlations in A+A



- Need more luminosity
 - Current run, RHIC-II upgrade

Conclusions: Two themes

- How are jets affected by passing through a QGP ?
 - Lose energy
 - Radiated gluons increase width of jet
 - Heavy-quarks lose slightly less energy than light quarks
- How does QGP respond to the impact of a high-pt parton?
 - Observation of particles ~ 1 radian from back-to-back
 - Possible origins, Mach cone....
- Future: Map out properties of plasma: density, dynamics
 - Energy-loss of charm \leq vary induced radiation
 - Use direct γ to tag energy of jet

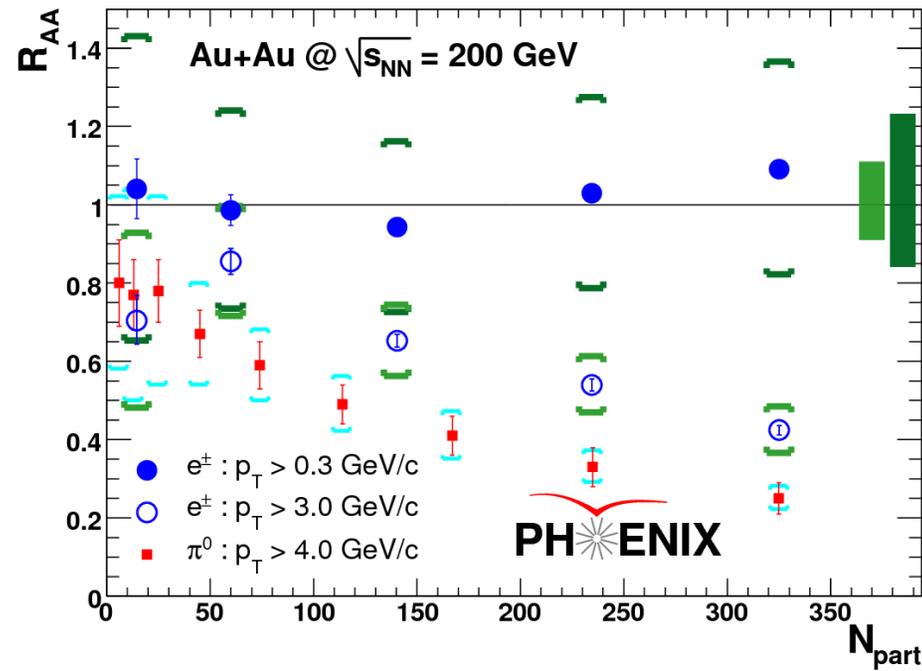
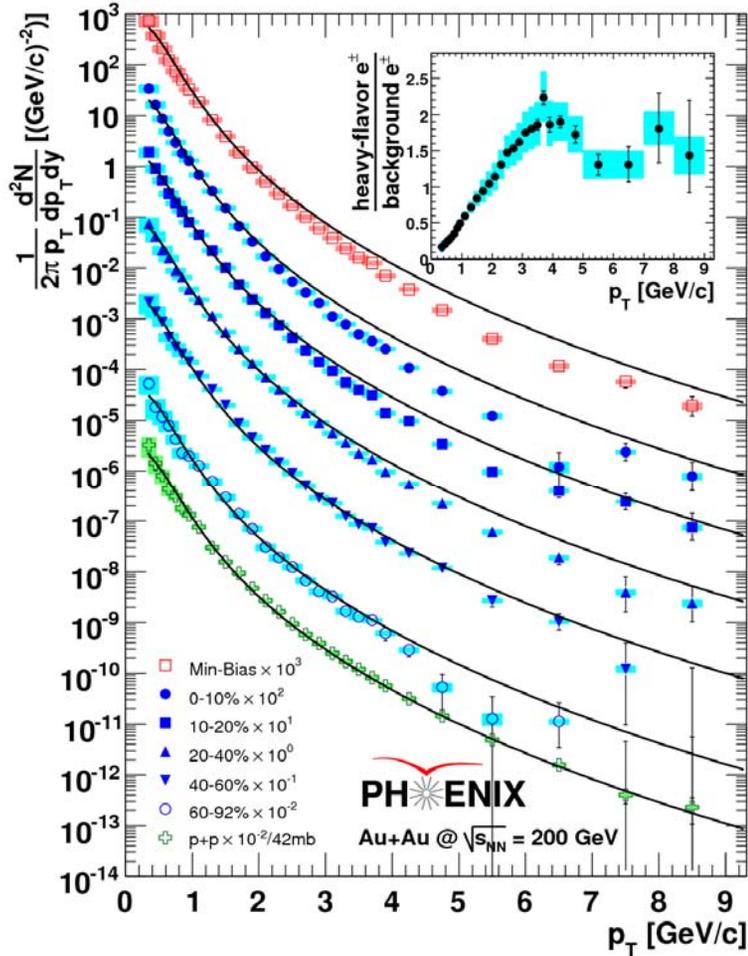
Thanks!



Backup

Suppression of heavy-quark spectra in A+A

Suppression in $p_T > 3.0$ GeV/c,
Slightly smaller than for light quarks.

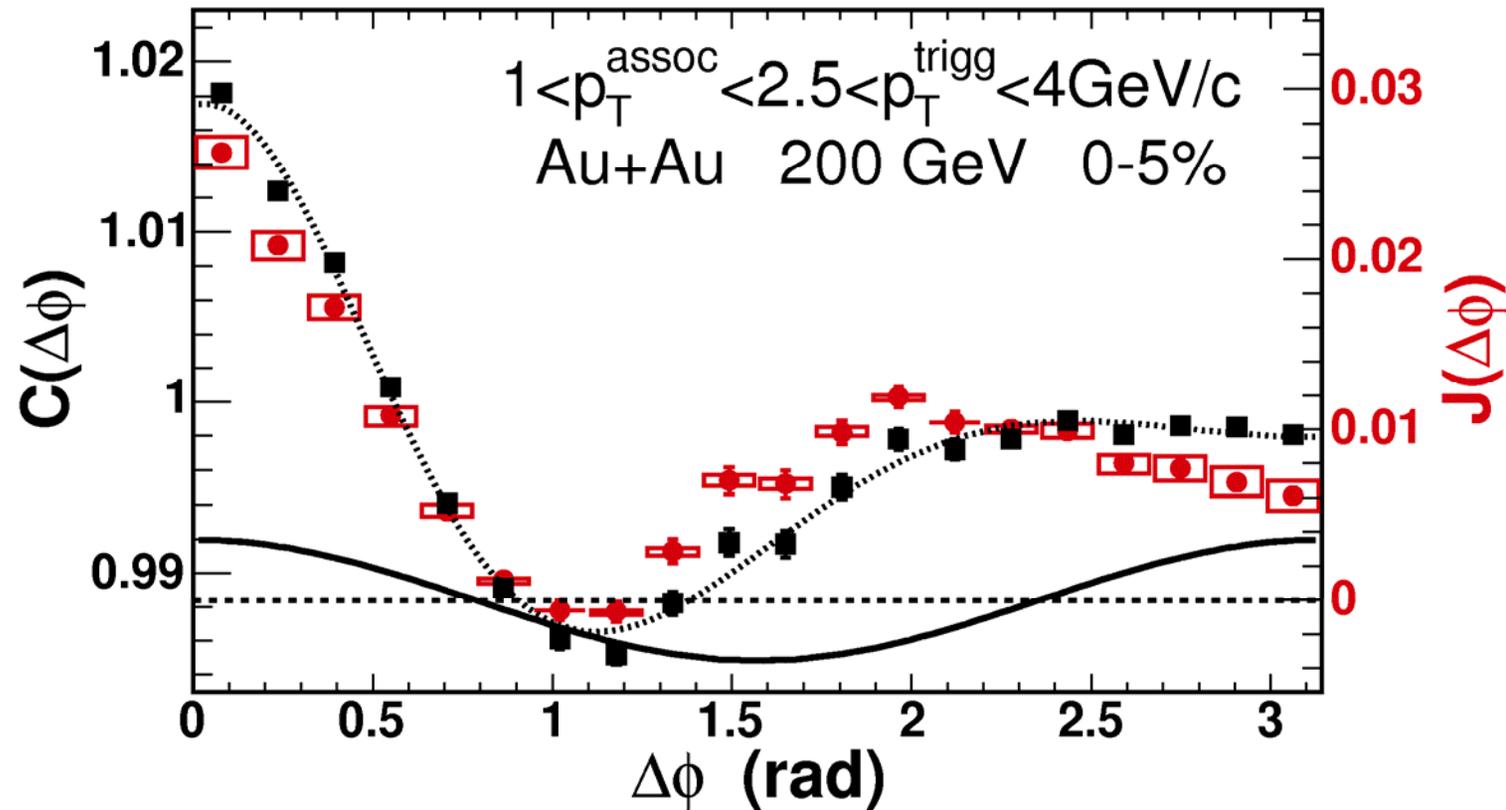


nucl-ex/0611018

PRL in press

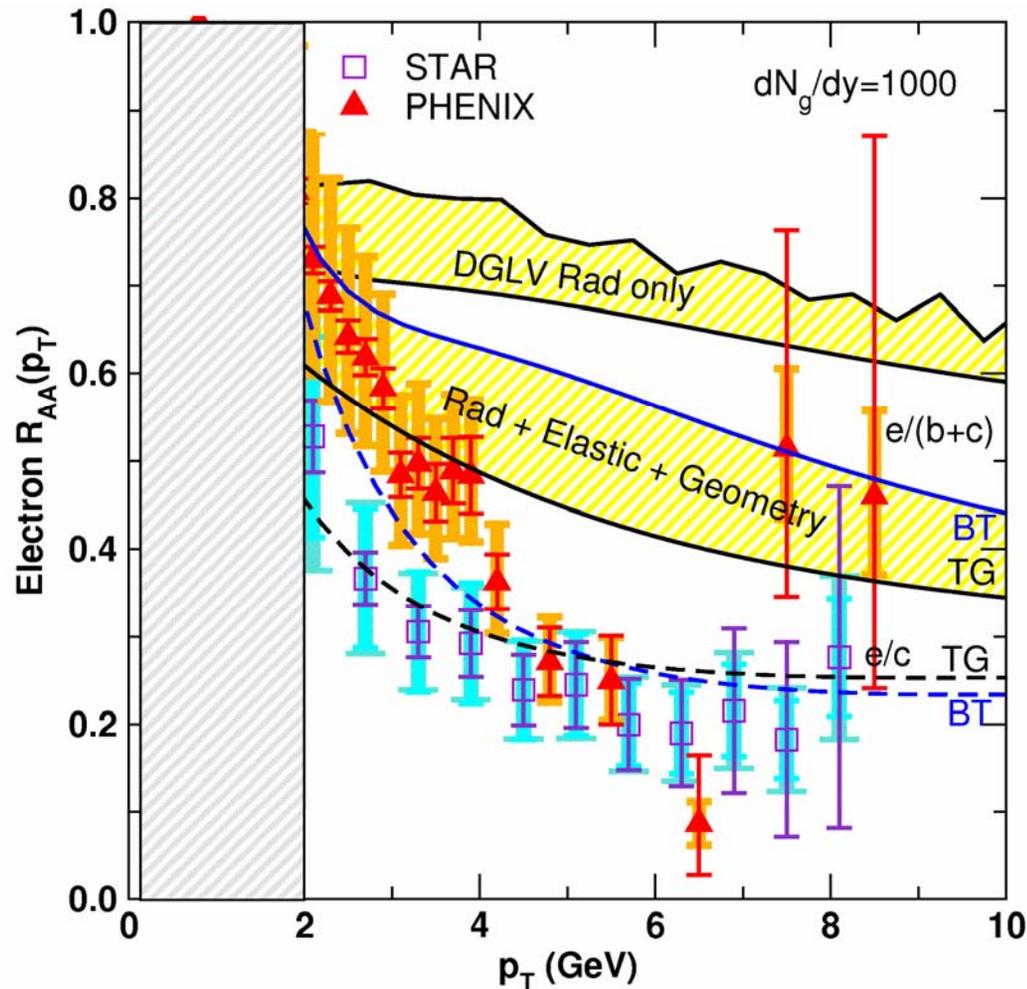
Need to increase statistics, reduce systematics
silicon upgrade => displaced vertices

Elliptic flow provides a background correlation



- Variation of v_2 values => dominant source of systematic error

Radiation energy-loss + collision energy-loss



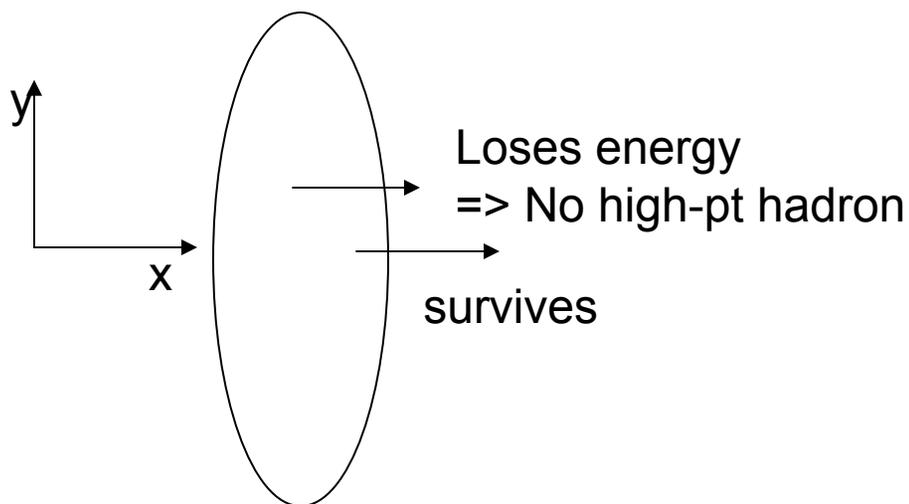
Wicks et al.
nucl-th/0512076

Both mechanisms
are important for
heavy quarks

But still can't reproduce
suppression in data

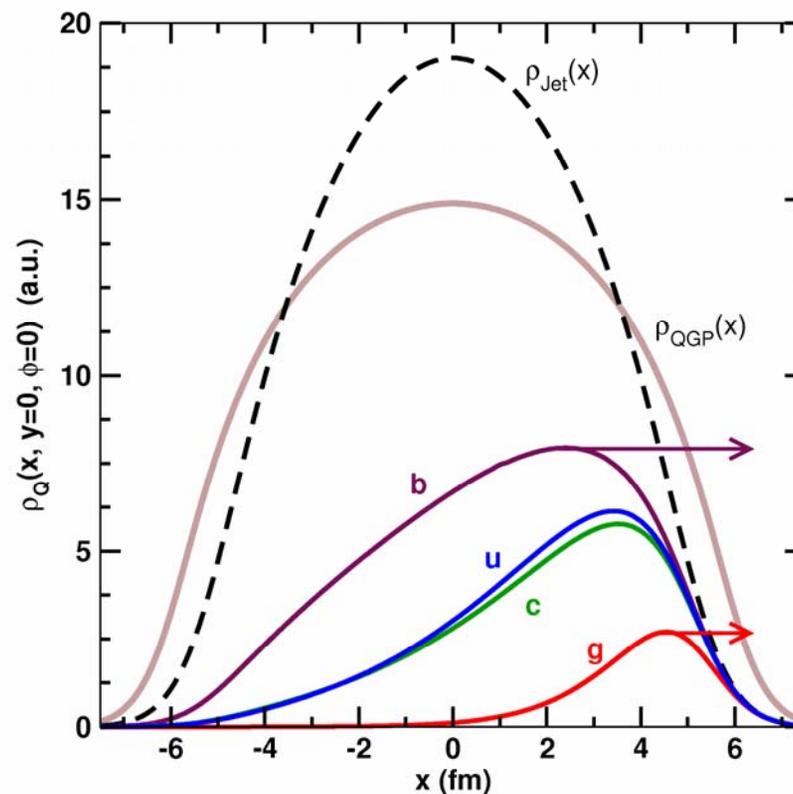
This calculation reproduces
 π^0 suppression

Hard-scattering locations biased to surface



Scattering locations  that survive energy-loss to produce a high-pt trigger are biased towards surface

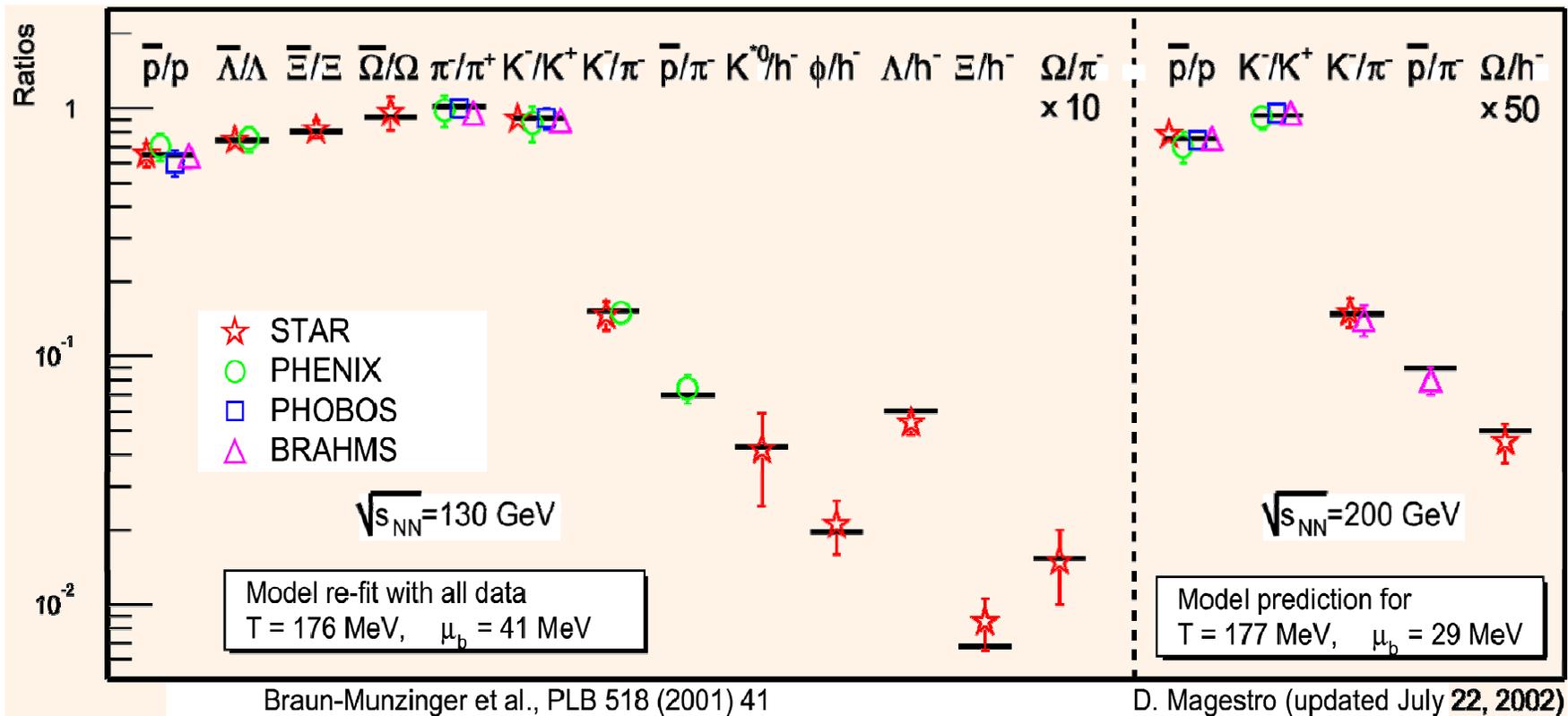
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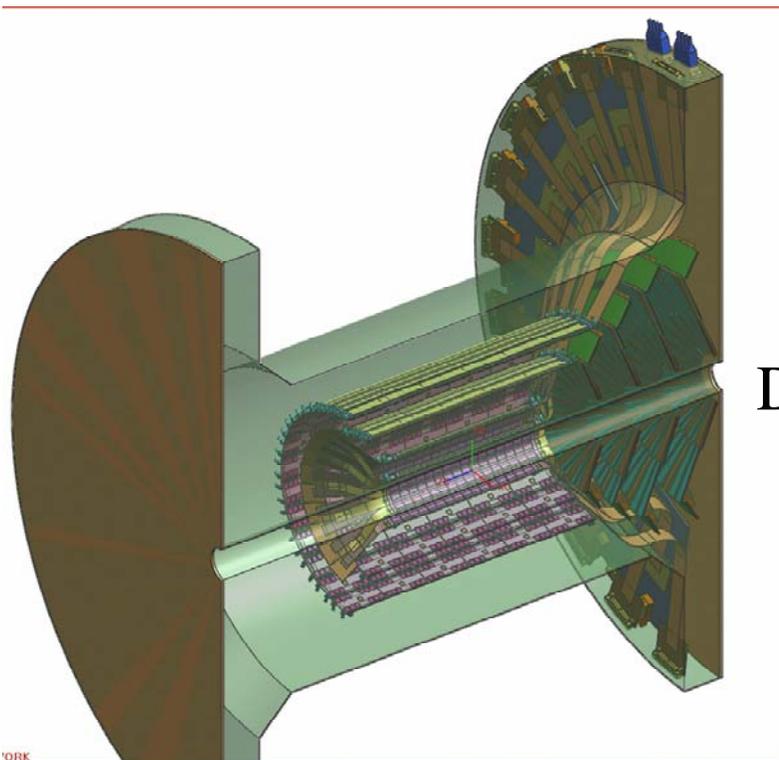
- Back-to-back partner parton travels through more QGP
- Far-side may provide more information

Chemistry

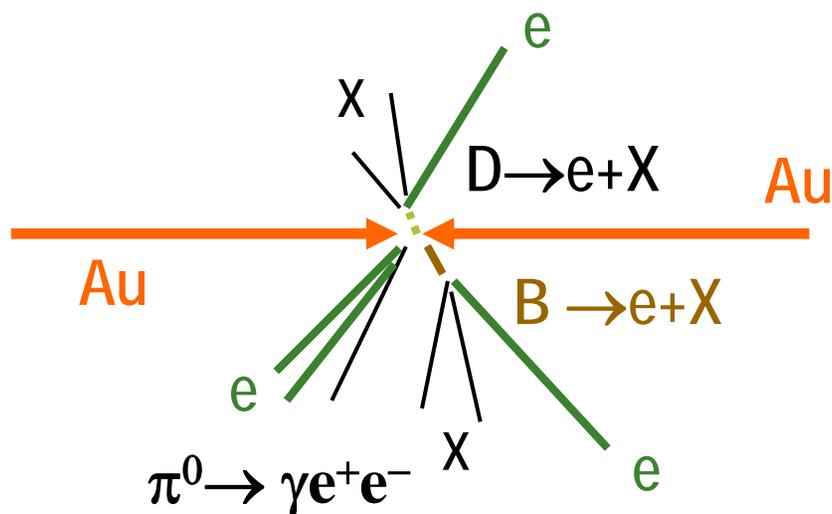
- Excellent description of particle ratios
- Consistent with lattice QCD $T_f = 175 \text{ MeV}$



VTX Upgrade

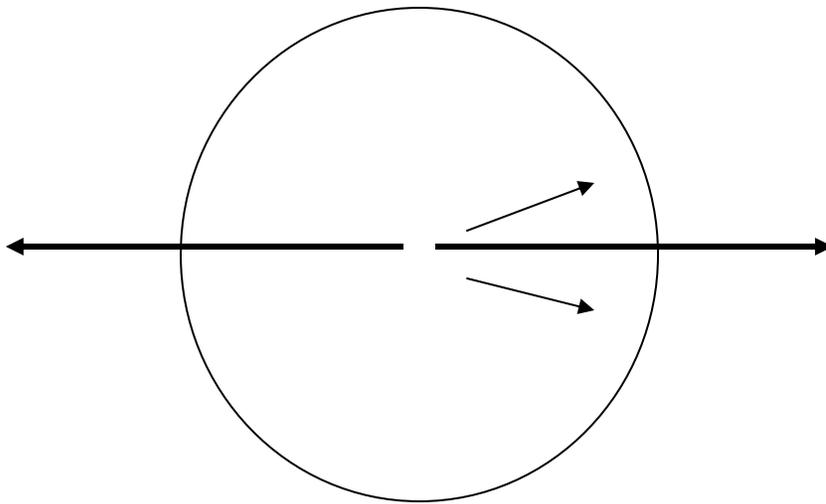


Two layers of silicon pixel detectors
Two layers of silicon strip detectors
Tracks extrapolate back to collision vertex
Displaced vertices => charm (D), beauty (B)
Requires $\sim 50 \mu\text{m}$ precision

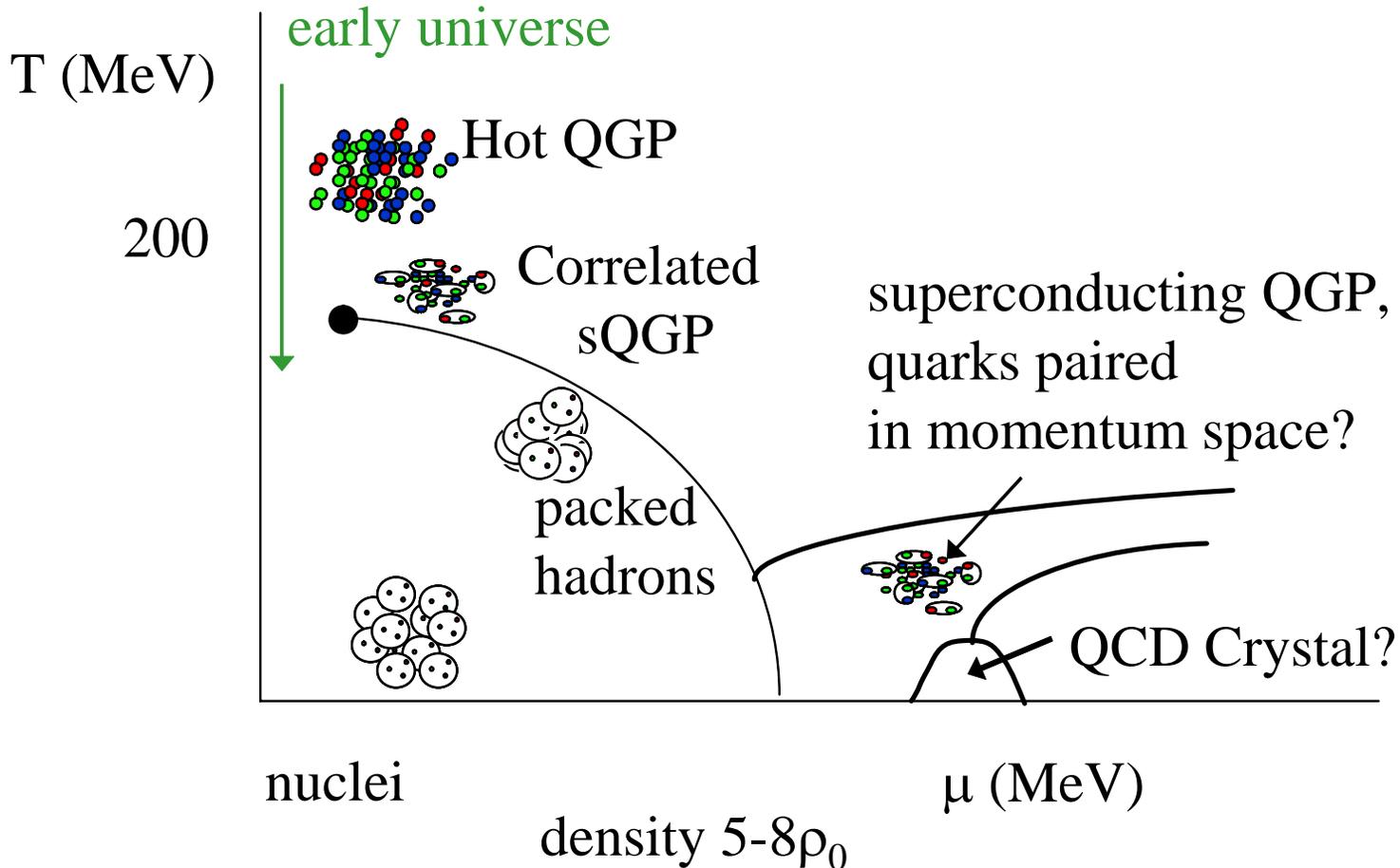


Mach-Cone on near-side?

- Should see some hint of possible Mach-cone in near-angle
- Move scattering locations to center
 - Require two high-pt back-to-back triggers
 - Correlate one of these with near-angle low-pt particles



Goal: Understand Phase Diagram of QCD



- Experimentally probe high-temp QGP at RHIC/LHC