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

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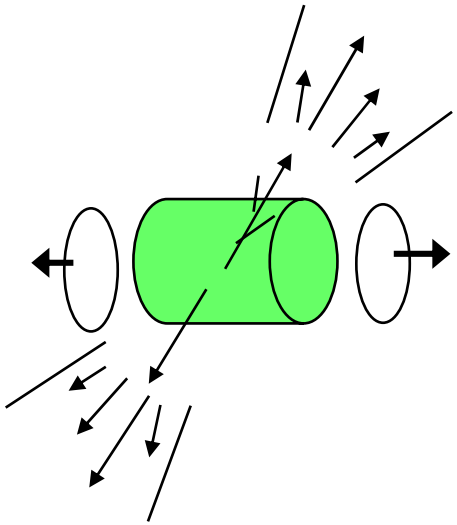
for the PHENIX Collaboration

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

Two themes

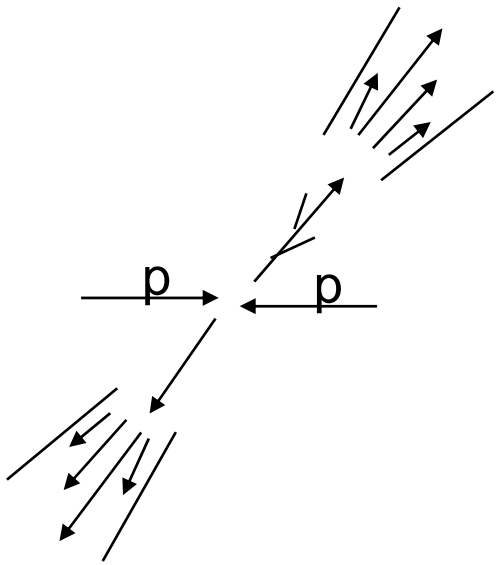
- how are jets affected by passing through a QGP ?
- how does QGP respond to the impact of a high-pt parton?

Relativistic Heavy-Ion Collisions:



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

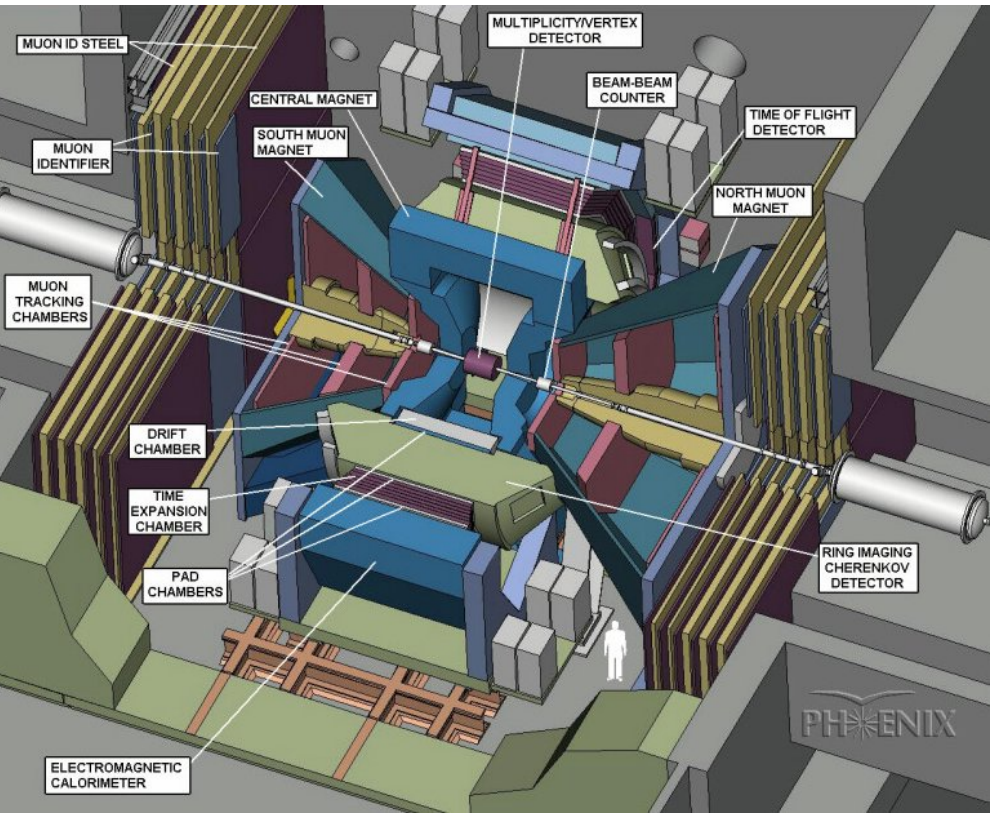
Hard-scattering process during QGP formation
$\Rightarrow$ high-pt partons travel through QGP



Compare with p+p as baseline

Differences => info on QGP

PHENIX Experiment at RHIC



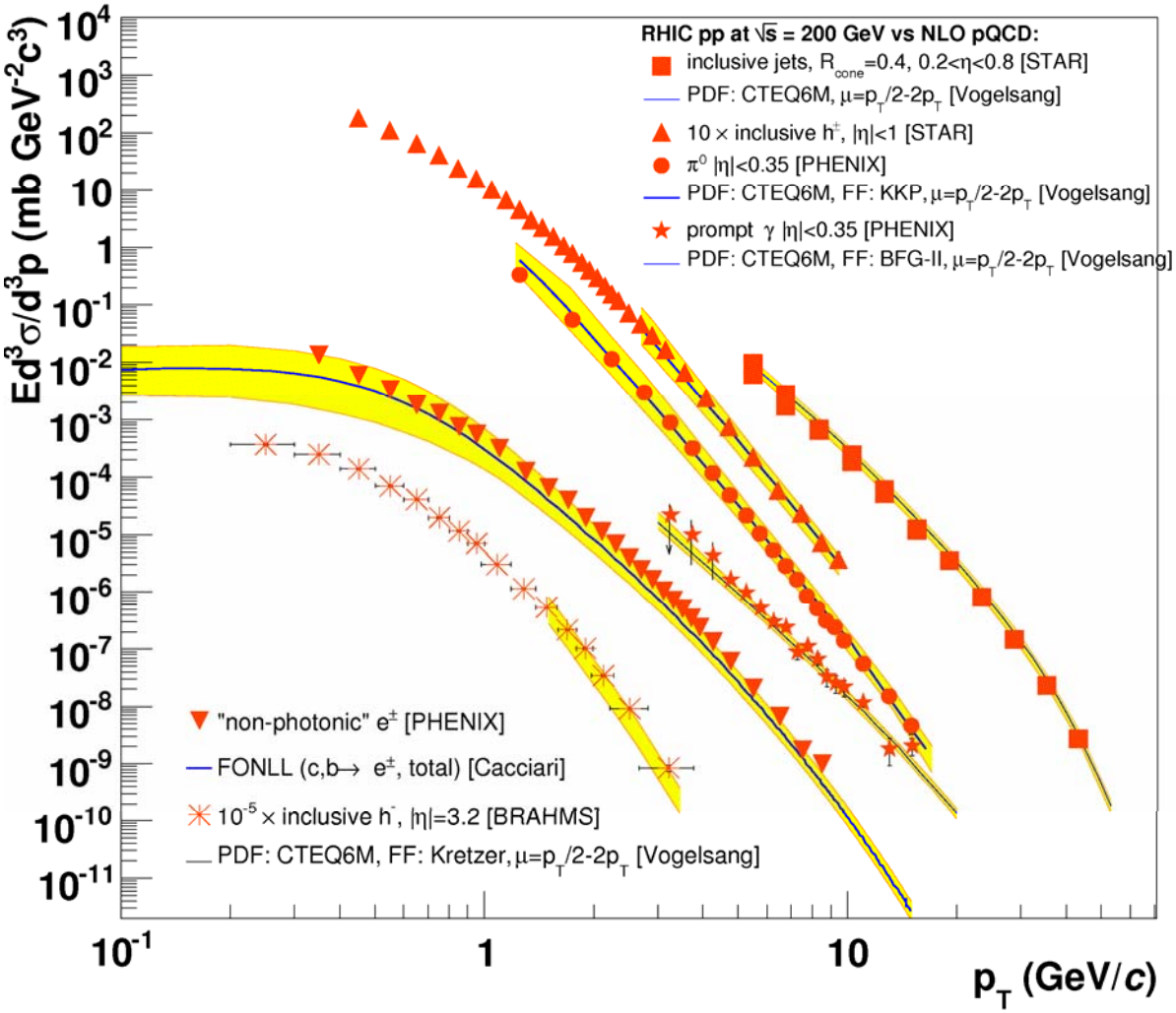
- In operation since 2000
- Designed for penetrating probes to characterize QGP

Focus on mid-rapidity arms

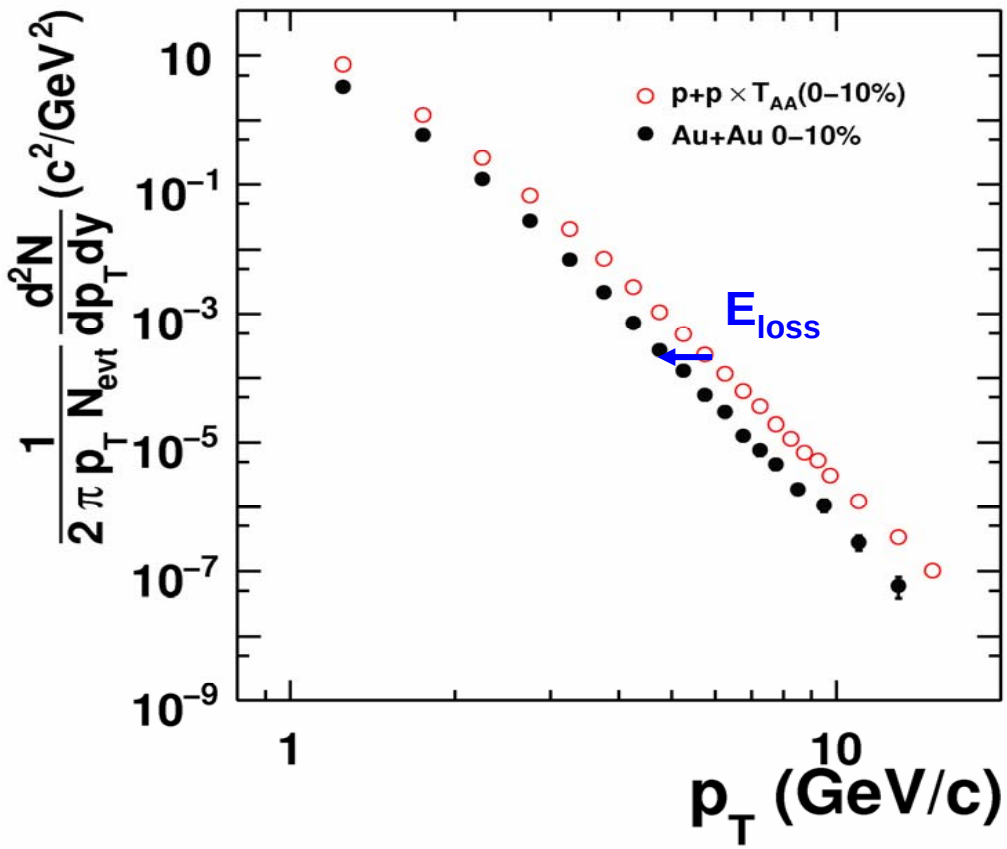
Charged tracking + Calorimetry => photons, π^0…+ J/ψ,…

√s=200 GeV, p+p => x
NLO QCD agrees well with data

D. d'Enterria
nucl-ex/0611012



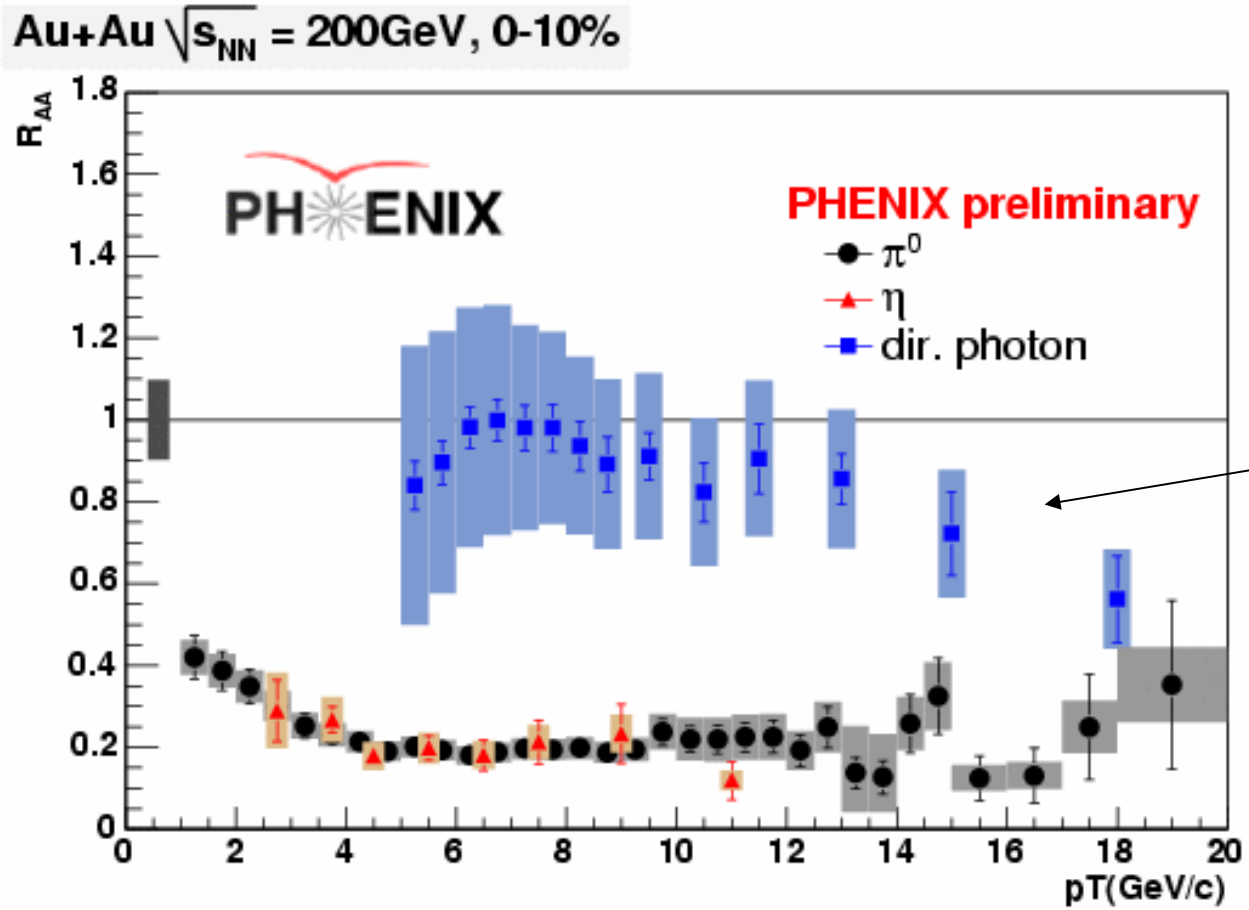
Partons lose energy as they travel through QGP



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

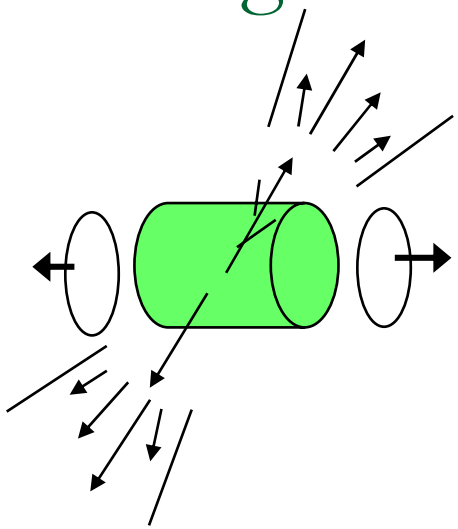
Ratio of (Au+Au)/(scaled p+p spectra)

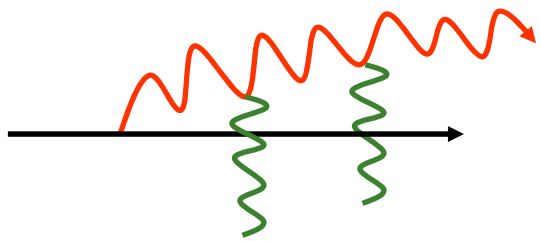


Drop possibly due to isospin difference p+p and A+A

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

Induced gluon radiation





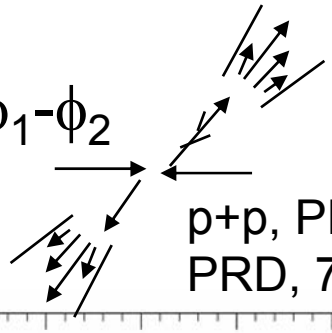
During gluon formation time,
parton may have multiple interactions
=> impressive, subtle calculations

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

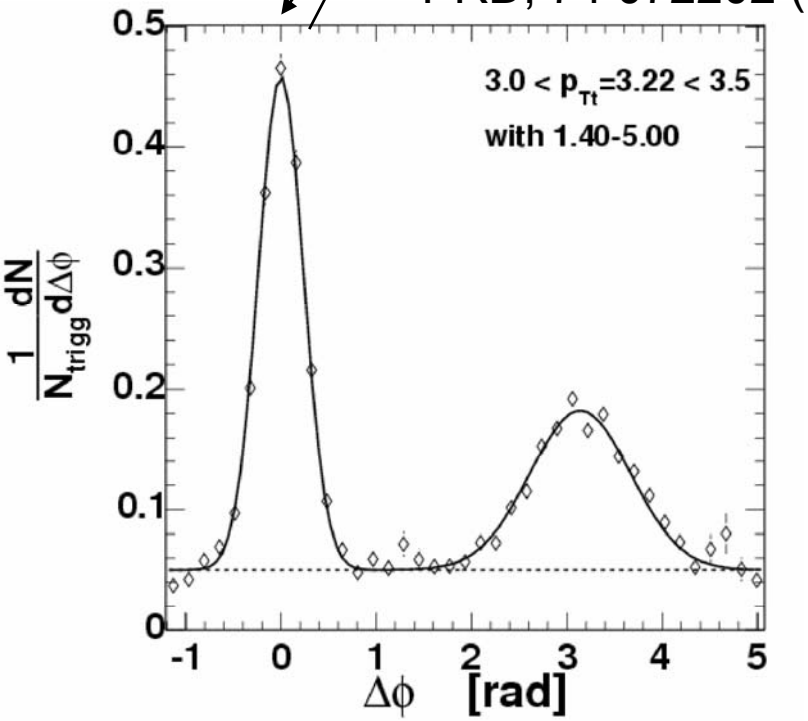
- Magnitude of energy-loss depends on
  - QGP density and how gluon-radiation is modeled
- What is the fate of this radiation ?
  - Broaden width of correlated particles ?
  - Or thermalize with the QGP ?

Particles correlated with high-pt trigger

$\Delta\phi = \phi_1 - \phi_2$

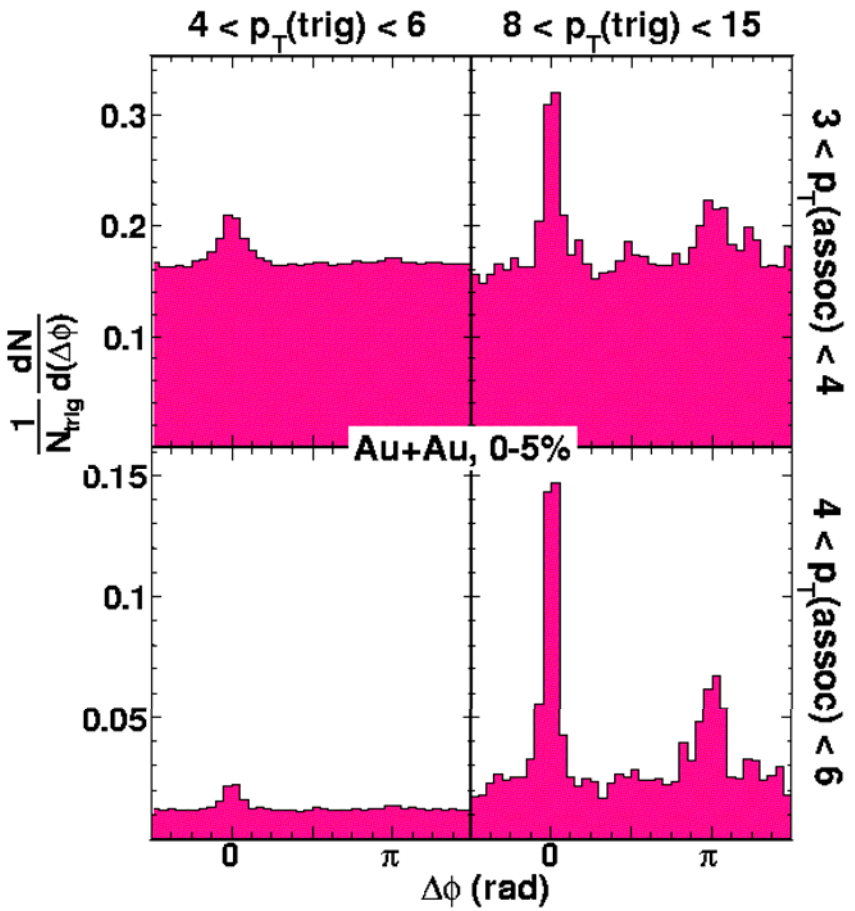


p+p, PHENIX
PRD, 74 072202 (06).



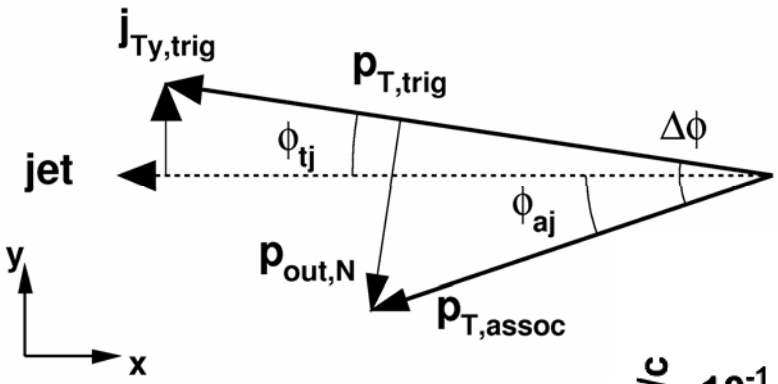
A+A

STAR

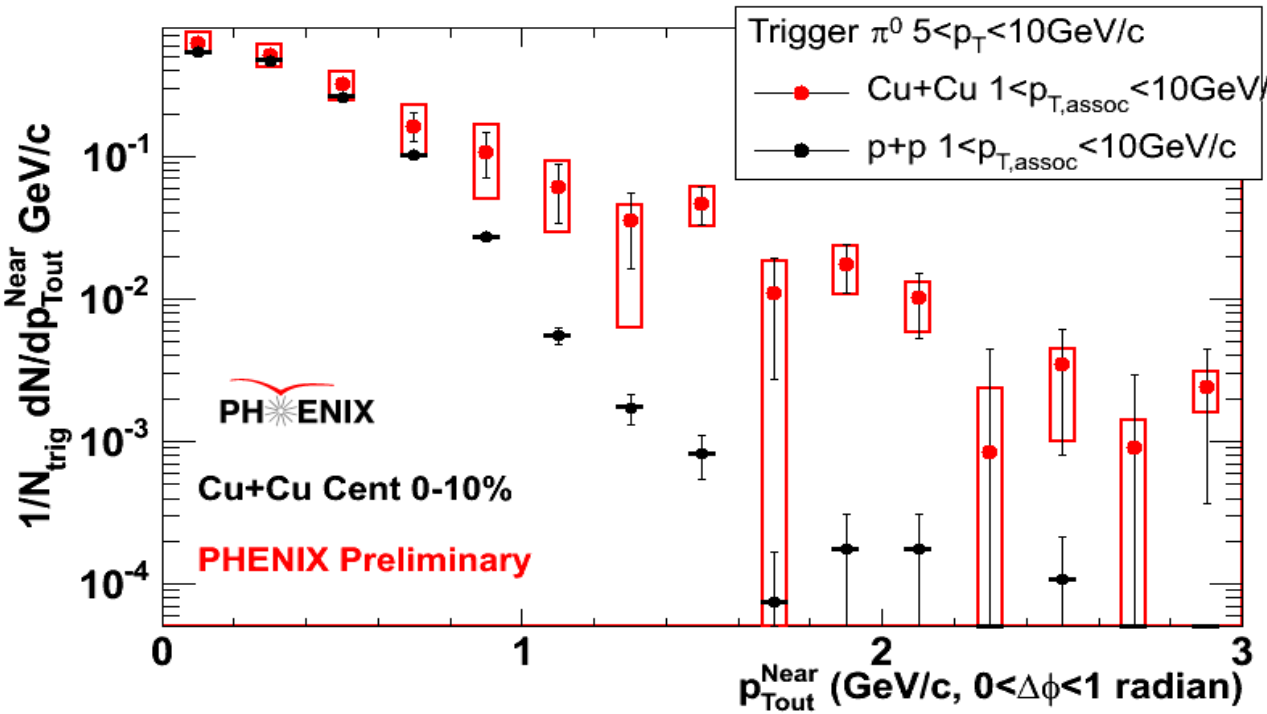


- Correlation survives high-multiplicity environment of A+A

Near-side correlation

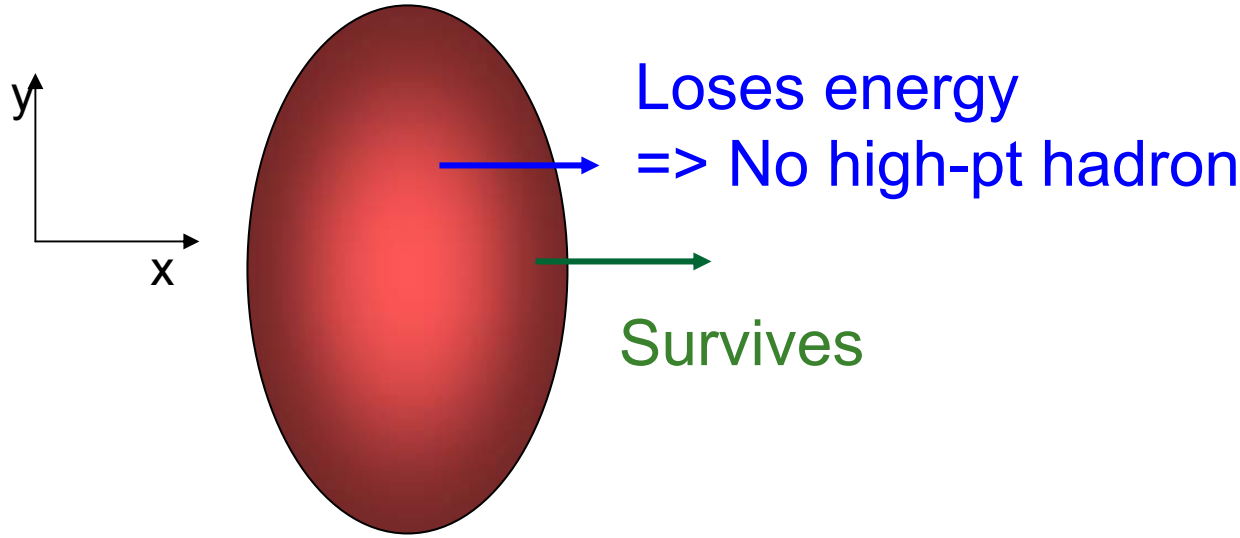


P_{out} is transverse momentum of 2nd wrt high-pt trigger particle



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

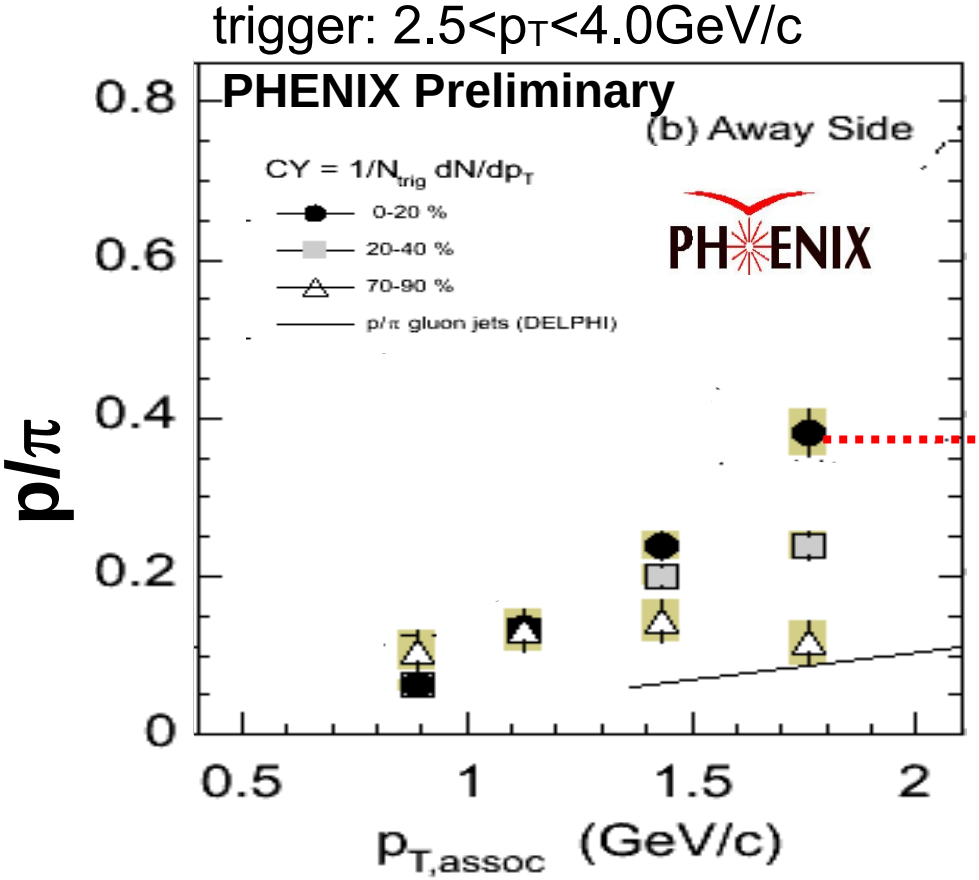
Hard-scattering locations biased to surface

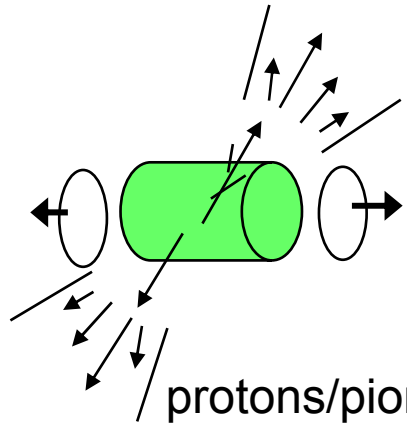


To survive energy-loss to produce a high-pt trigger production points are biased towards surface

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

Particle composition of far-side jet





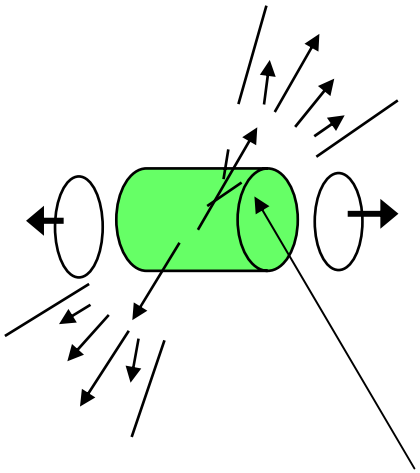
protons/pions
In far-side jet

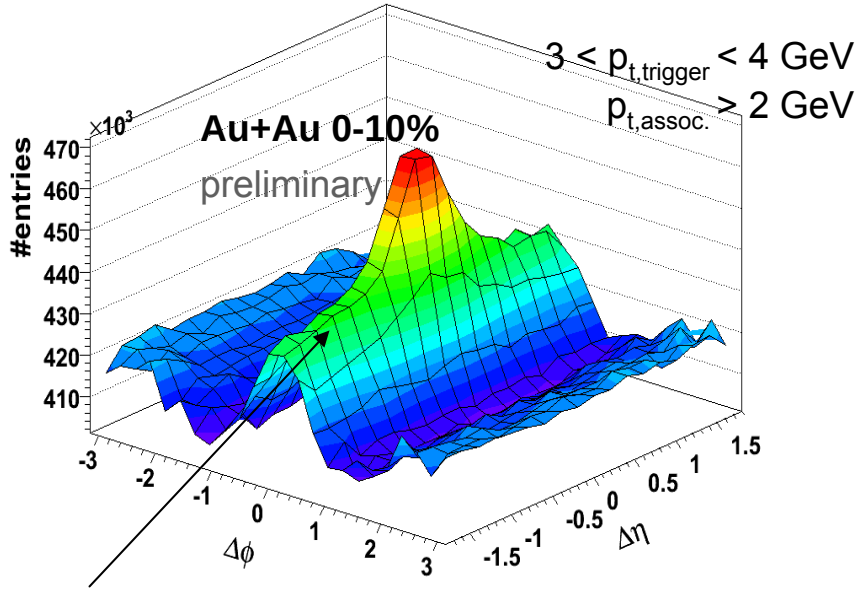
p/π ratio single particles

increasing centrality

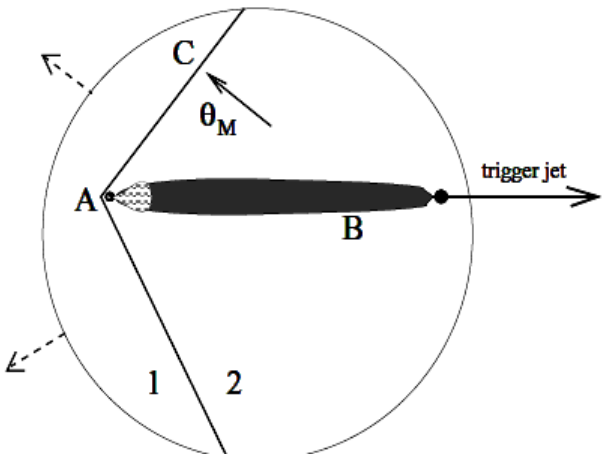
- Particle composition close to e^+e^- data in peripheral A+A
- Increases with more central collisions
  - jet takes on more and more of medium's characteristics

Response of medium to passage of high-pt parton





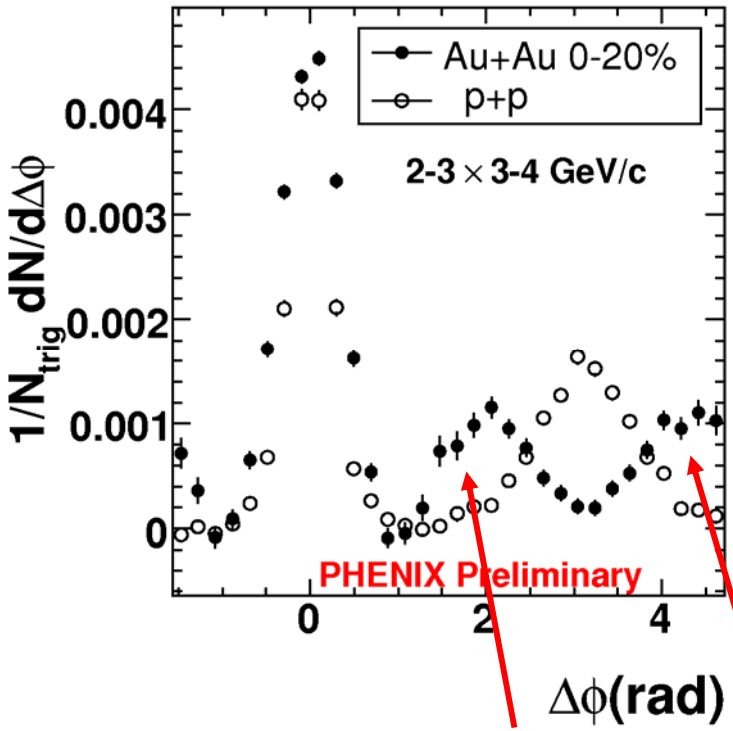
- Near-side, generation of ridge => strength large $\Delta\eta$ (STAR talk)
- Far-side: does super-sonic parton generate a mach-cone ?

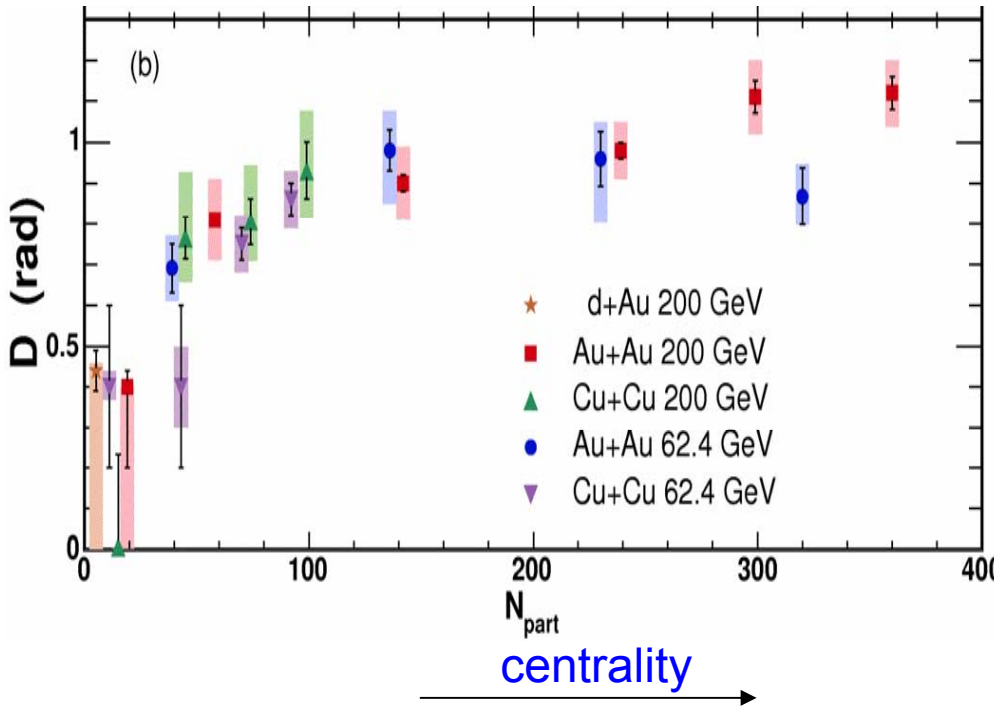


hep-ph/0410067;
H.Stocker…
Jorge Casalderry-Solana

Far-side Production of Particles

PHENIX preliminary
nucl-ex/0611019
$1<p_{t,ass}<2.5<p_{t,trig}<4$ GeV/c

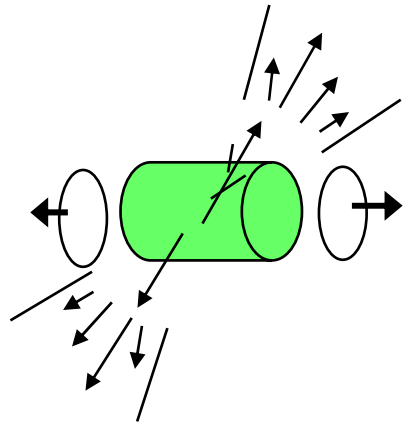




Observation of particles produced
~1 radian away from back-to-back!

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)



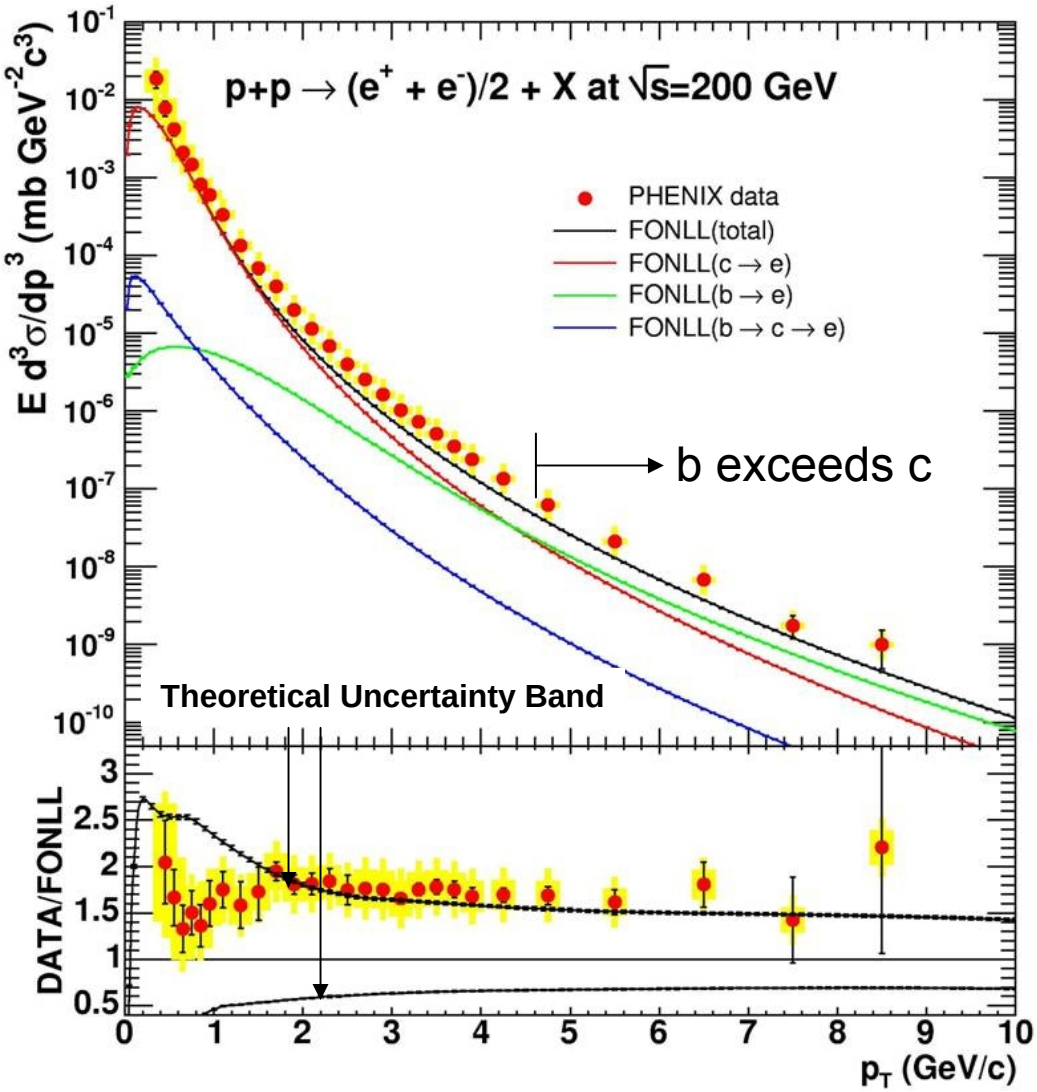
- Energy-loss of charm+beauty quarks
  - Predicted to lose less energy
  - Less gluon radiation
    - larger interference during multiple-scattering
      - dead-cone effect
- Challenge for models
  - If they reproduce both pion and charm energy-loss
    - Confidence in how gluon radiation is modeled

Non-photonic electrons → charm (+ beauty) in p+p

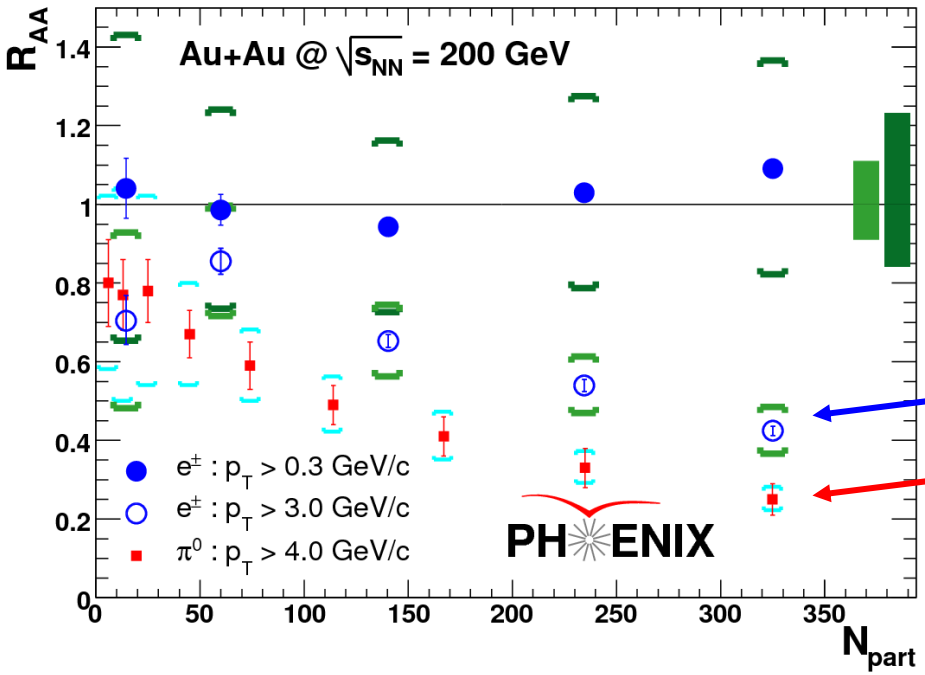
PHENIX
PRL97,252002

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

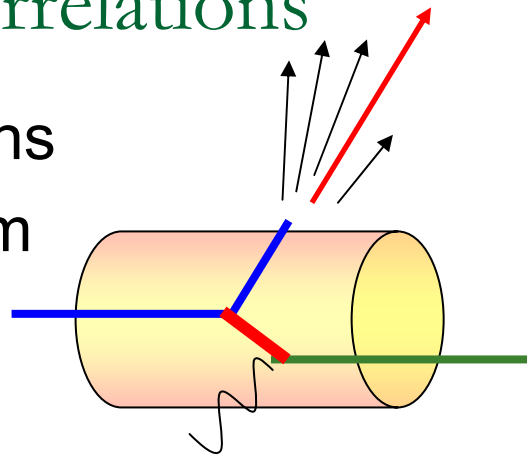
Suppression of e, p_T>3.0 GeV/c
Slightly smaller than light quarks

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

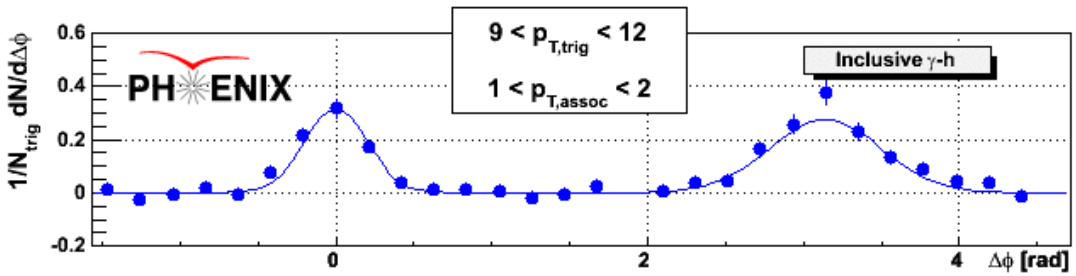
Expt. need to increase statistics, reduce systematics
silicon upgrade=> displaced vertices

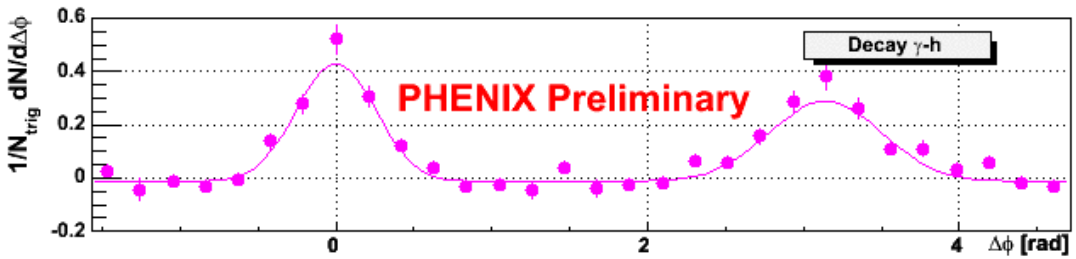
Future/Starting Directions (II): γ-h correlations

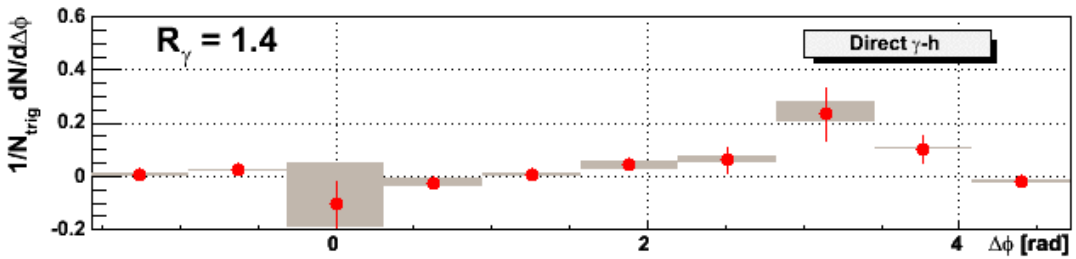
- Tag the energy of the jet with direct-photons
  - Back-to-back hadrons probe the medium



p+p collisions at 200 GeV

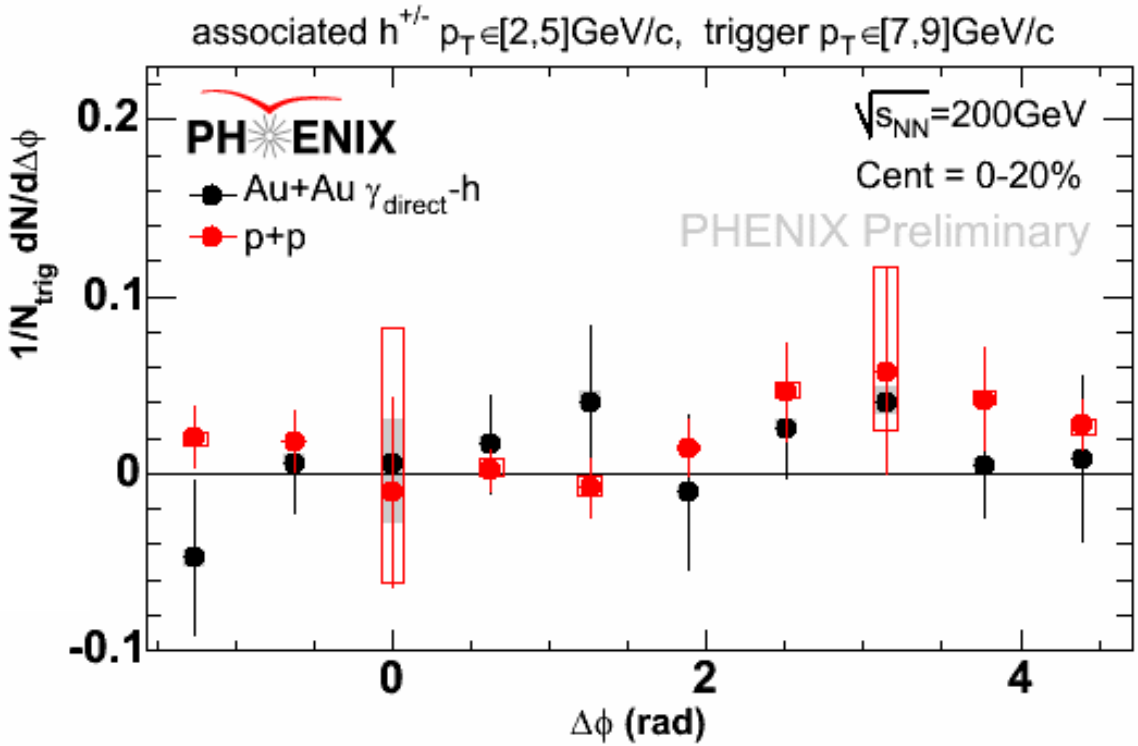






1. Inclusive γ-h
2. Decay γ-h contribution (via π^0-hadron)
3. Direct γ-h !

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

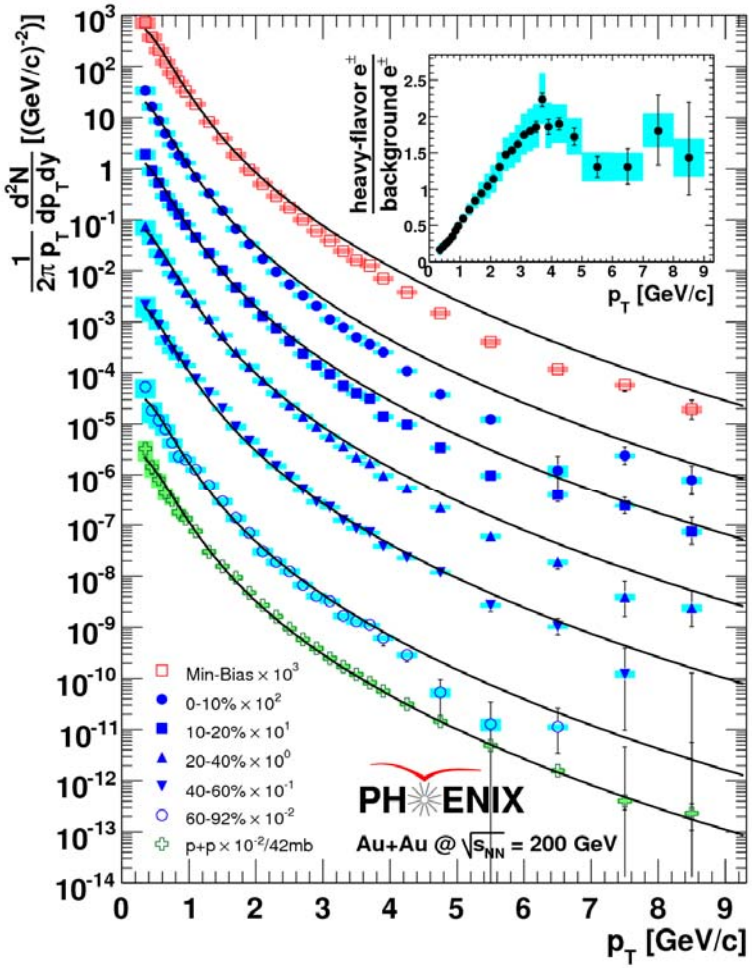
- How does QGP respond to the impact of a high-pt parton?
  - Observation of particles ~ 1 radian from back-to-back
  - Possible origins, Mach cone….

- Future: Map out properties of plasma: density, dynamics
  - Energy-loss of charm <= vary induced radiation
  - Use direct γ to tag energy of jet

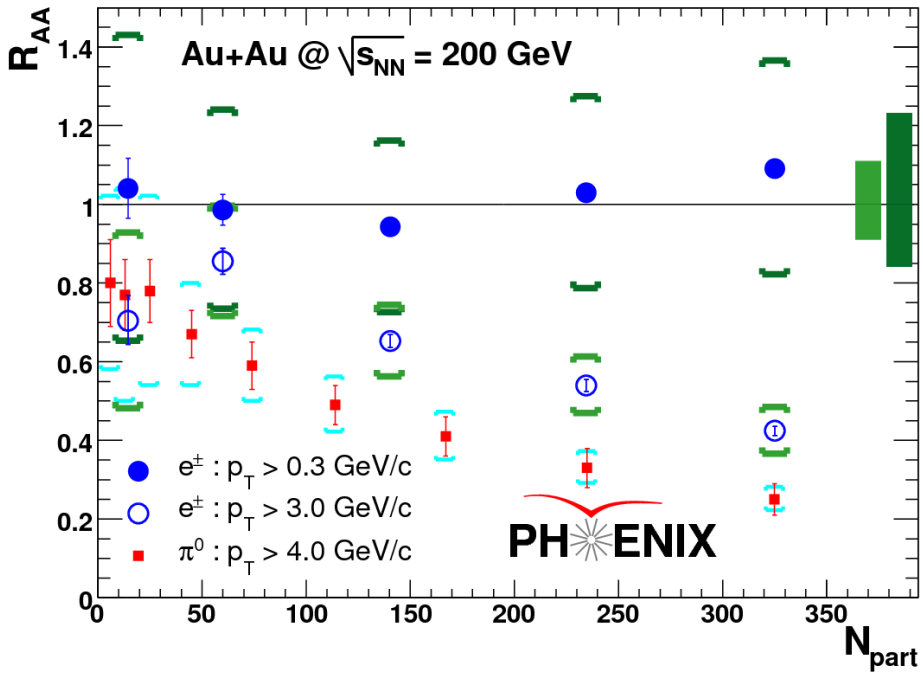
Thanks!

Backup

Suppression of heavy-quark spectra in A+A



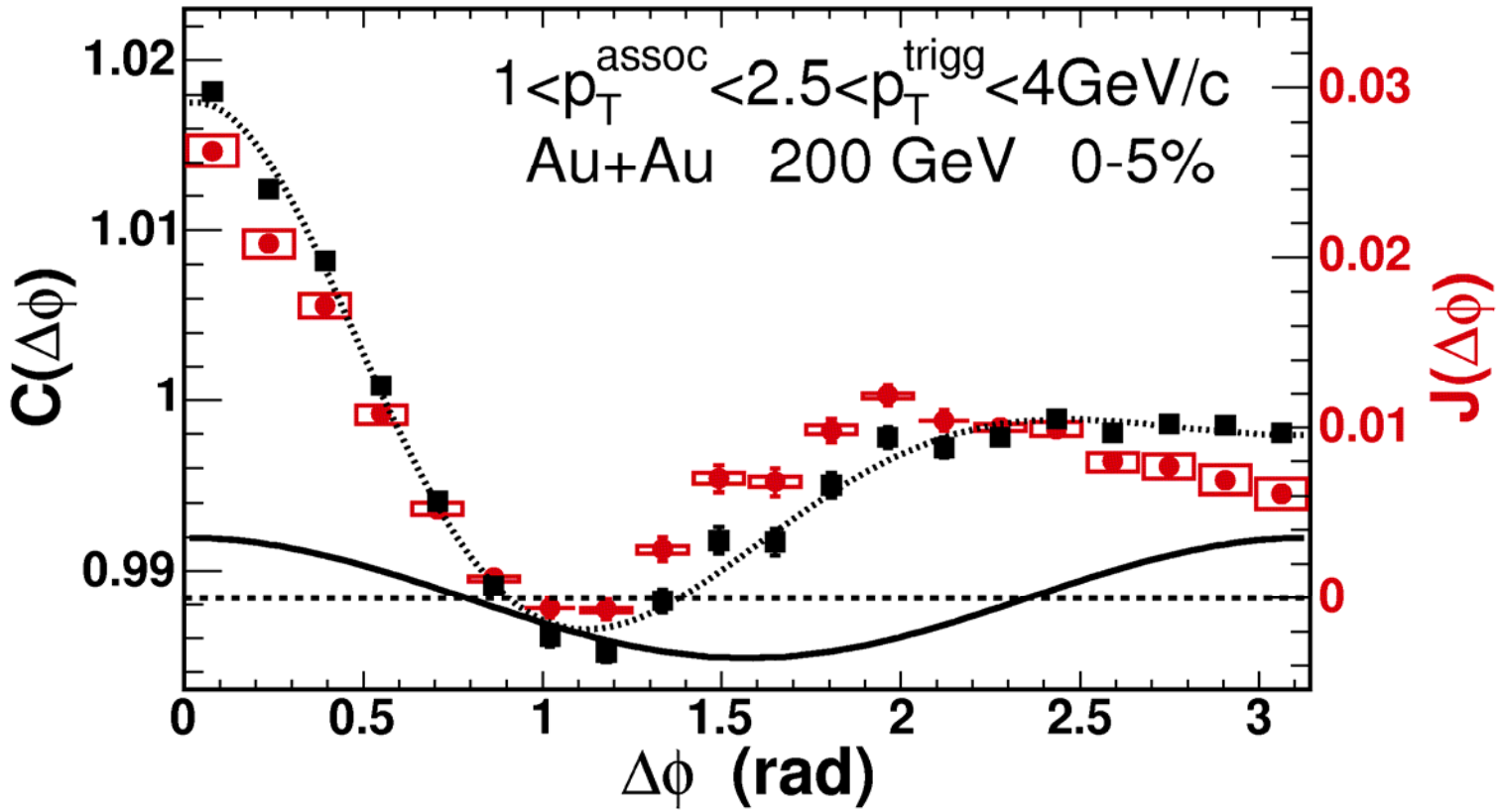
Suppression in p_T>3.0 GeV/c,
Slightly smaller than for light quarks.



nucl-ex/0611018
PRL in press

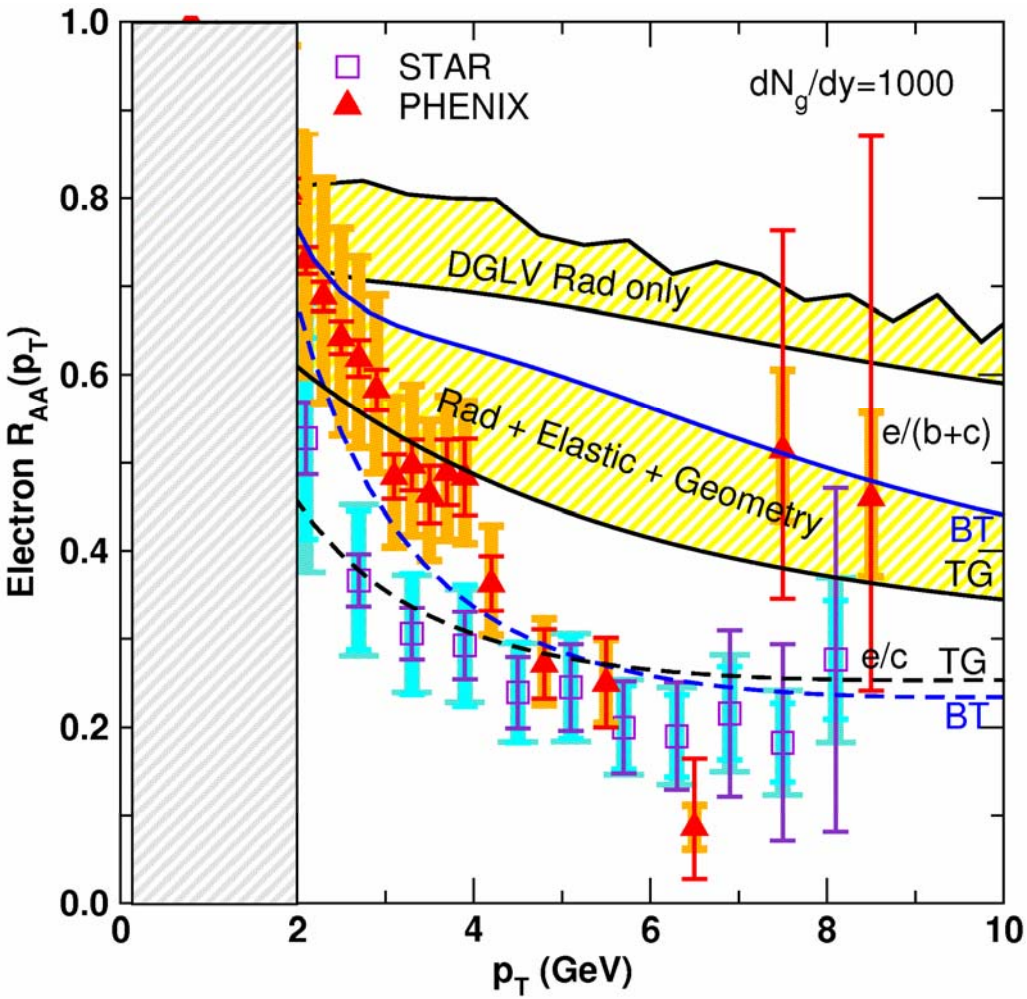
Need to increase statistics, reduce systematics
silicon upgrade=> displaced vertices

Elliptic flow provides a background correlation



- Variation of v2 values => dominant source of systematic error

Radiation energy-loss + collision energy-loss



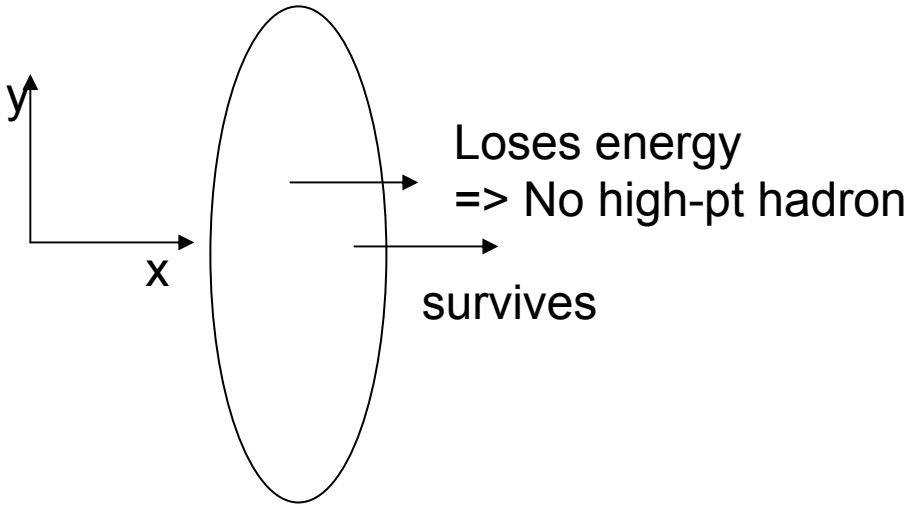
Wicks et al.
nucl-th/0512076

Both mechanisms are important for heavy quarks

But still can't reproduce suppression in data

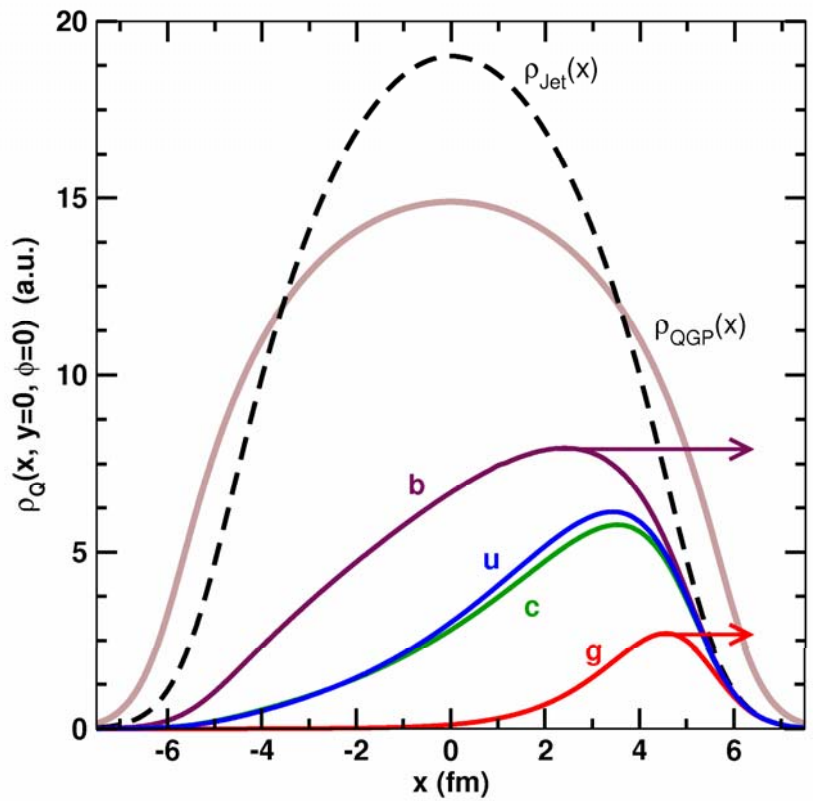
This calculation reproduces π^0 suppression

Hard-scattering locations biased to surface



Wicks et al.
nucl-th/0512076

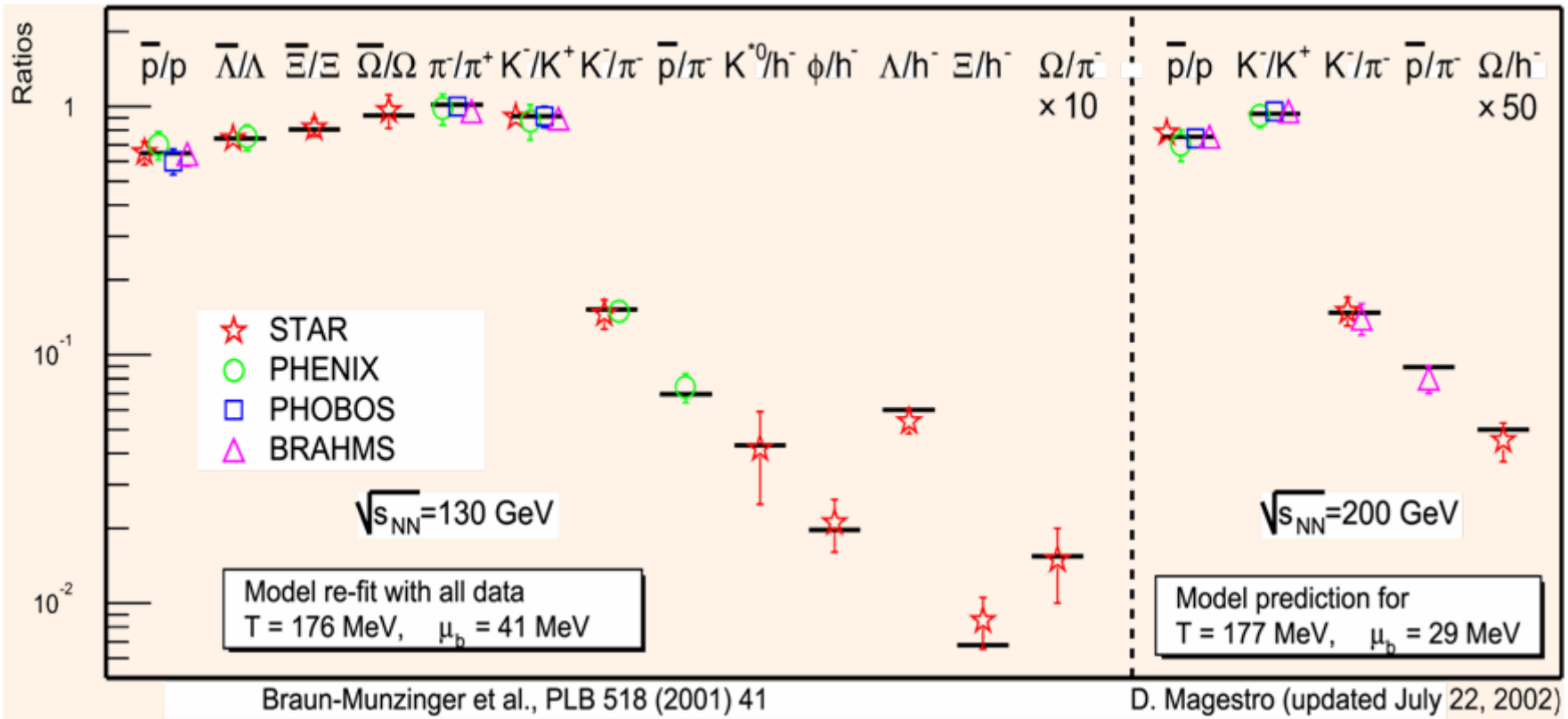
Scattering locations
that survive energy-loss
to produce a high-pt trigger
are biased towards surface



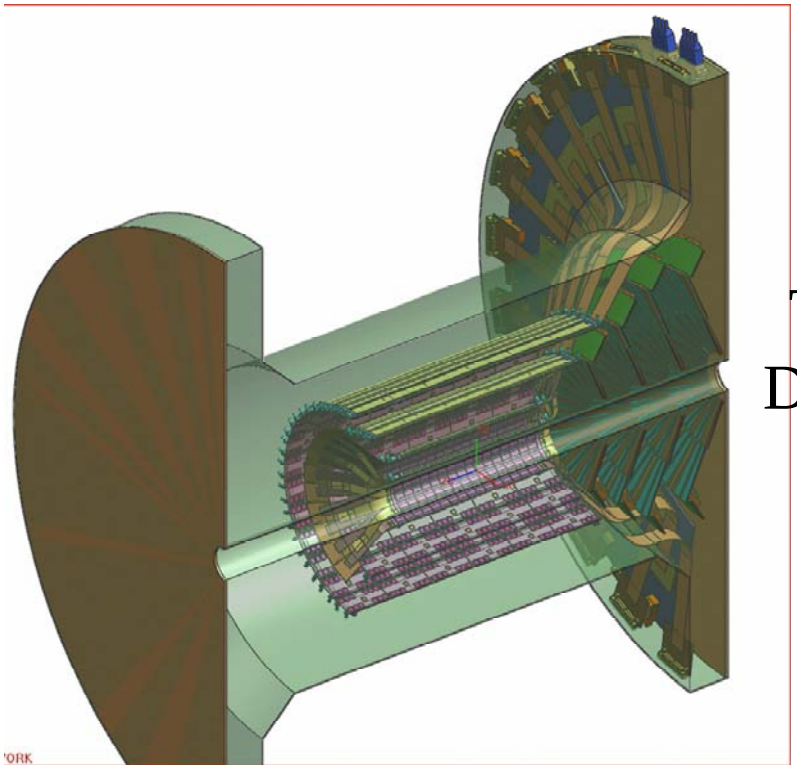
- Back-to-back partner parton travels through more QGP
  - Far-side may provide more information

Chemistry

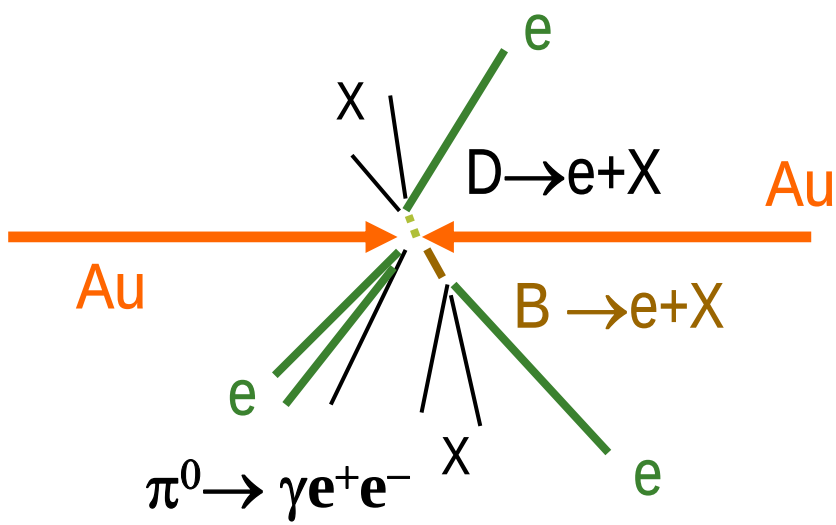
- Excellent description of particle ratios
- Consistent with lattice QCD $T_f = 175$ MeV



VTX Upgrade

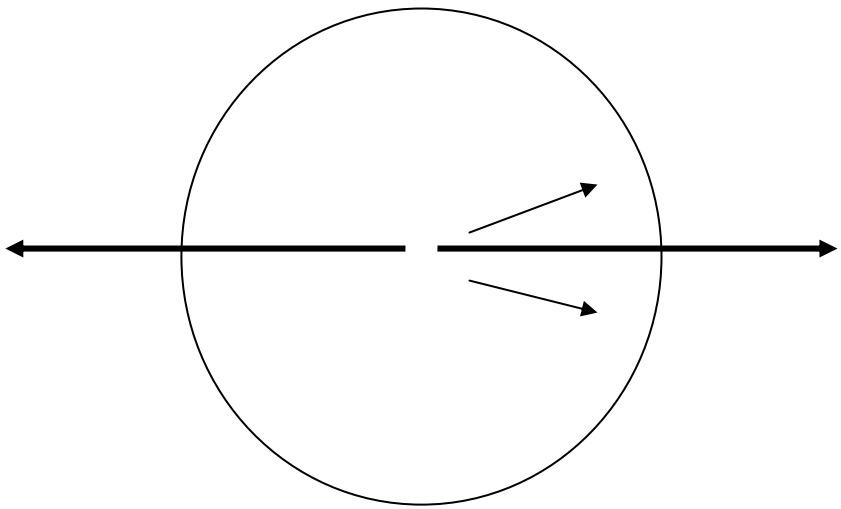


Two layers of silicon pixel detectors
Two layers of silicon strip detectors
Tracks extropolate back to collision vertex
Displaced vertices => charm (D), beauty (B)
Requires ~ 50 μm precision

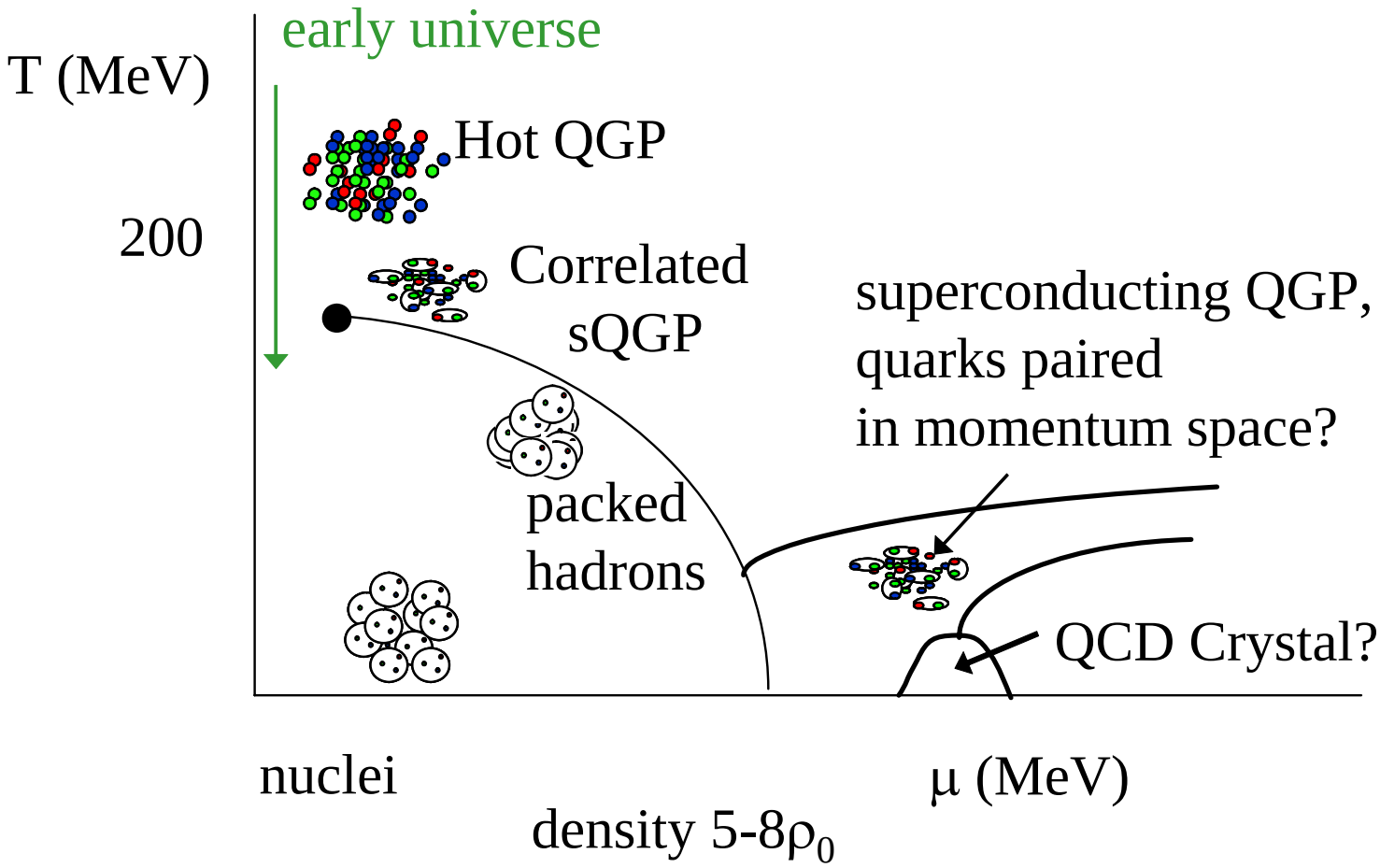


Mach-Cone on near-side?

- 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