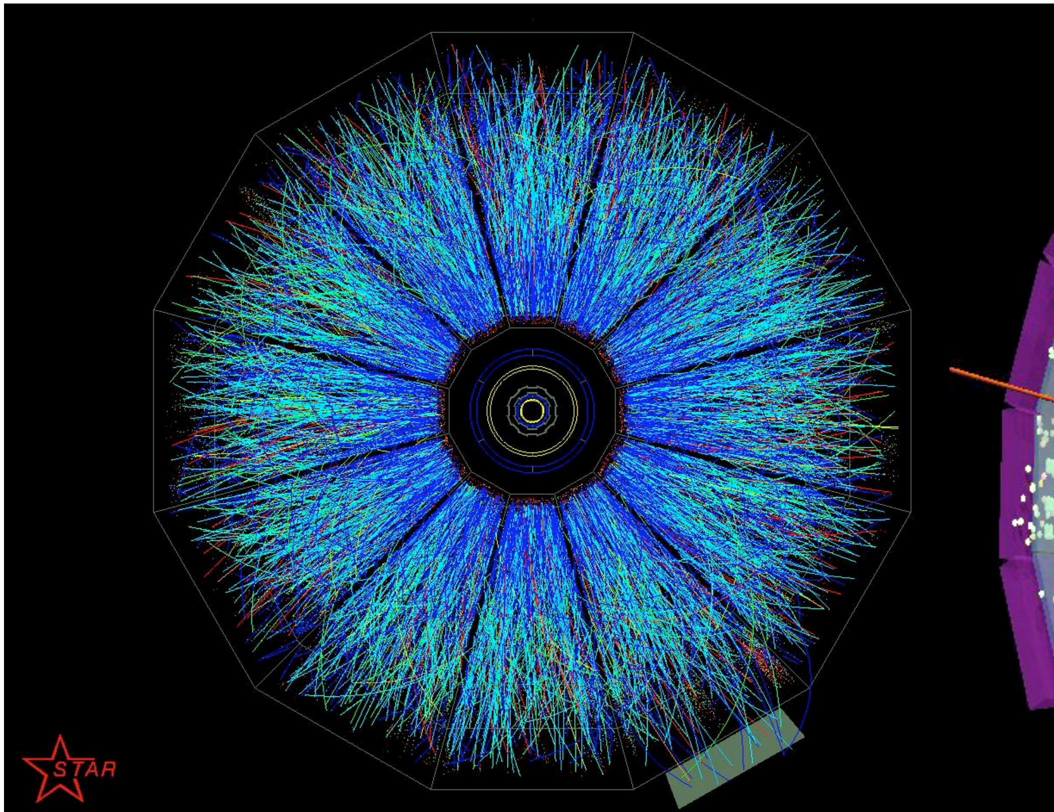
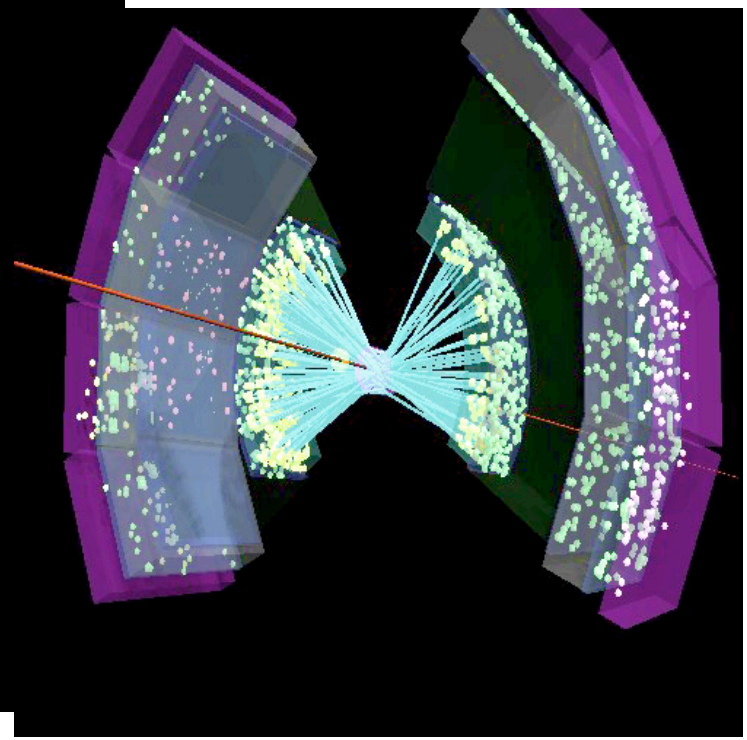
RHIC Heavy Ion Program (in the Next Decade)





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Introduction

- Critical point search
  - Beam energies 7.7-39 (Starting next year)
  - Lower beam energies after low-E electron cooling (≥ 2014)
- Luminous beams with stochastic cooling
  - Stochastic cooling ramp-up 2010-2014 (mostly by 2012)
- Charming physics with vertex upgrades
  - PHENIX: 2011
  - STAR: prototypes beginning 2011, full installation 2013

Key Physics Questions:

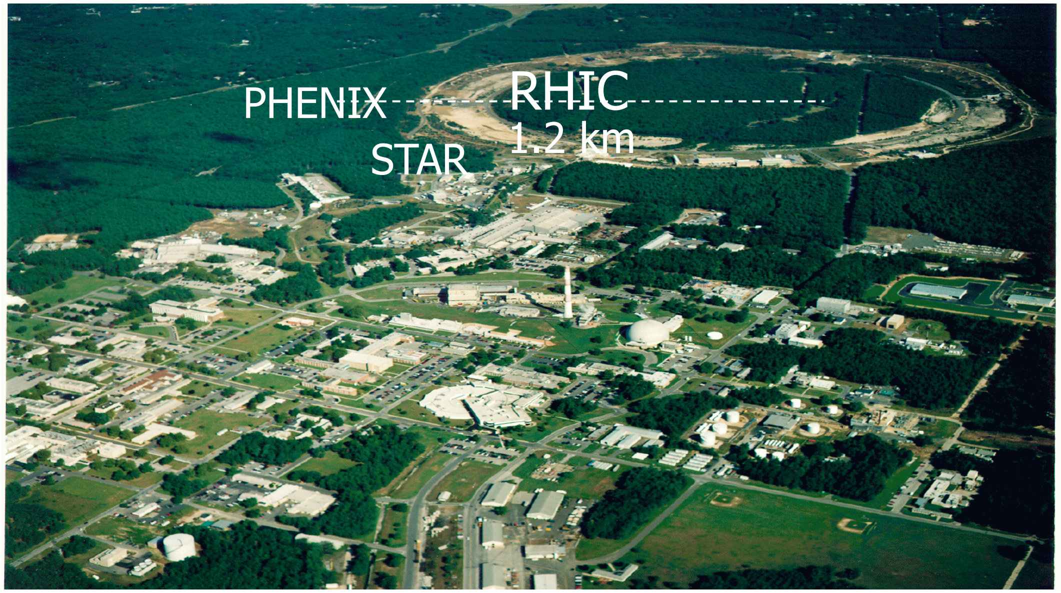
What are the landmarks on the QCD phase diagram?

What is the mechanism for QCD energy loss?

What are the quantitative properties of the QCD matter produced at RHIC?

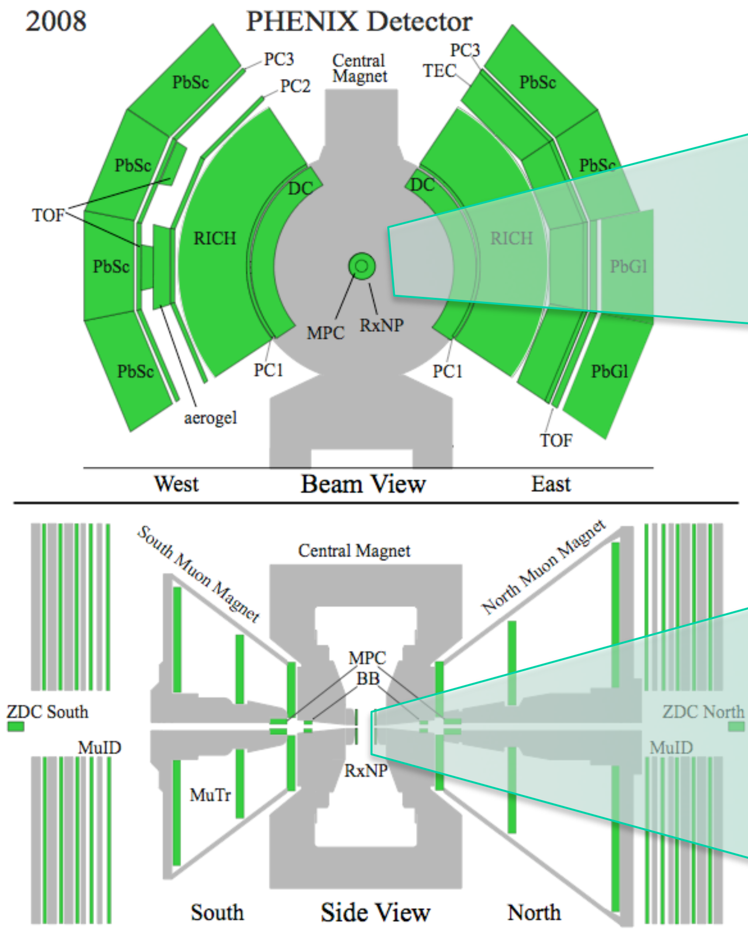
RHIC: A flexible accelerator

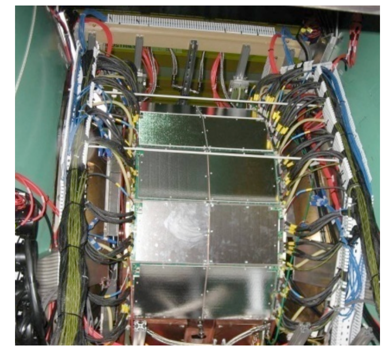
- Flexibility is key to understanding complicated systems
  - Polarized protons, $\sqrt{s}$ = 10-500 GeV
  - Nuclei from d to Au, $\sqrt{s_{NN}}$ = 5-200 GeV
- Physics runs to date
  - Au+Au @ 9.2,20,62,130,200 GeV
  - Cu+Cu @ 20, 62, 200 GeV
  - Polarized p+p @ 200, 500 GeV
  - d+Au @ 200 GeV
- Future reach
  - Increase A to Uranium
  - Scan in $\sqrt{s}$ to 5 GeV
  - Increase Luminosity x10



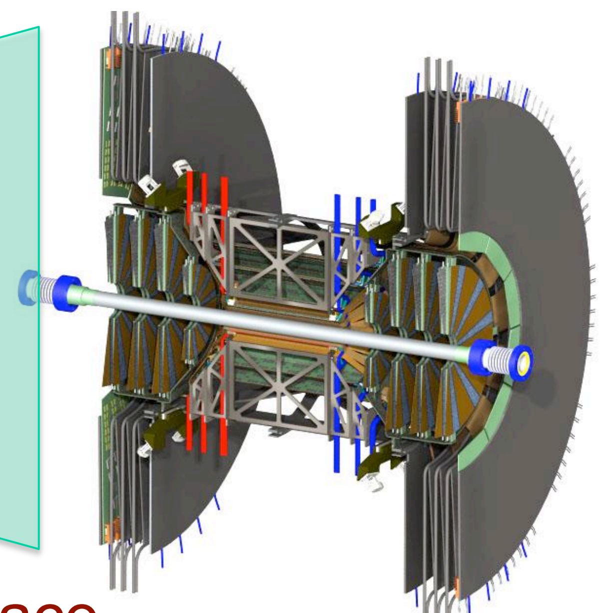
PHENIX: Precision ID

Now: Hadron Blind Detector



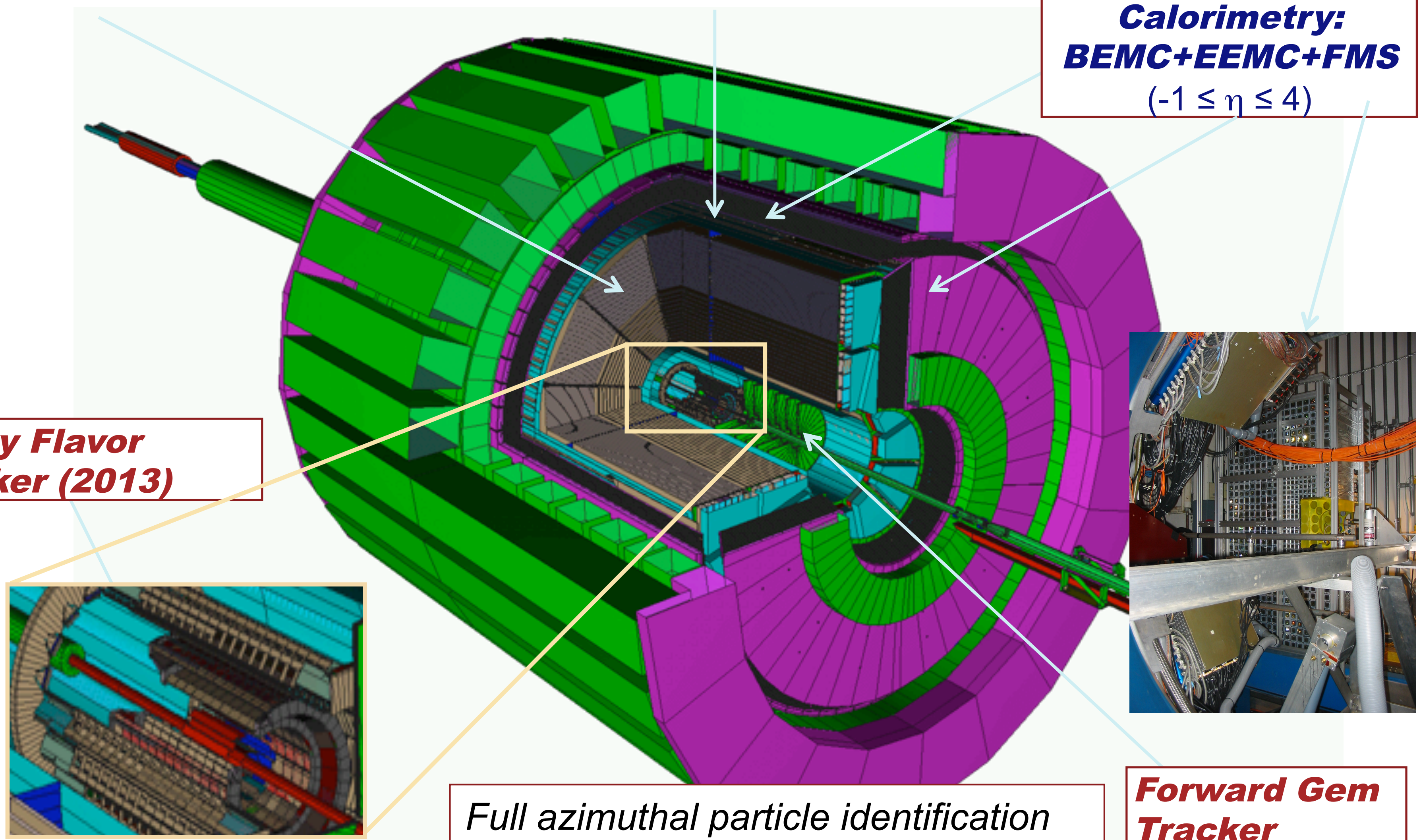


2011: Silicon Vertexing



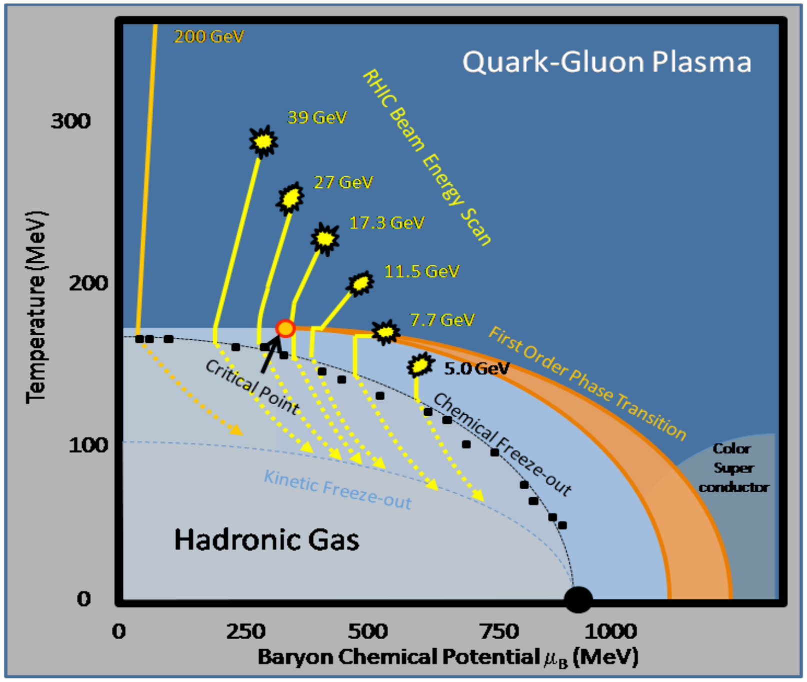
Precision ID in a selected range of phase space

STAR: A Correlation Machine



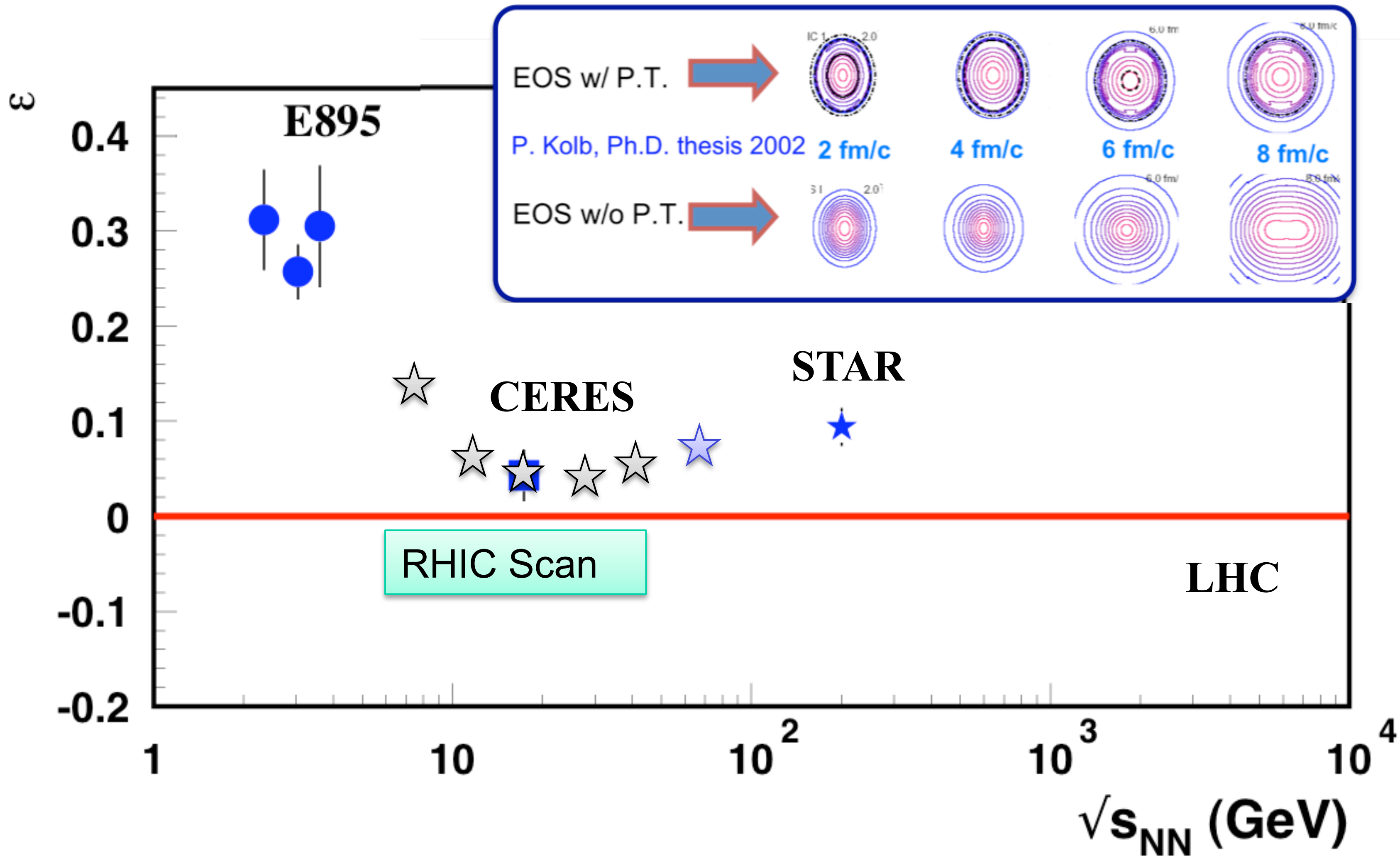
Full azimuthal particle identification over a broad range in pseudorapidity

Strategy: Critical Point Search



- 1^{st} order phase transition: bracket location of the Critical Point
  - Hydrodynamics: v_1, v_2, azimuthally sensitive HBT for EOS softest point
- Direct signatures of Critical Point via enhanced fluctuations
  - Large-acceptance identified particle fluctuations and correlations

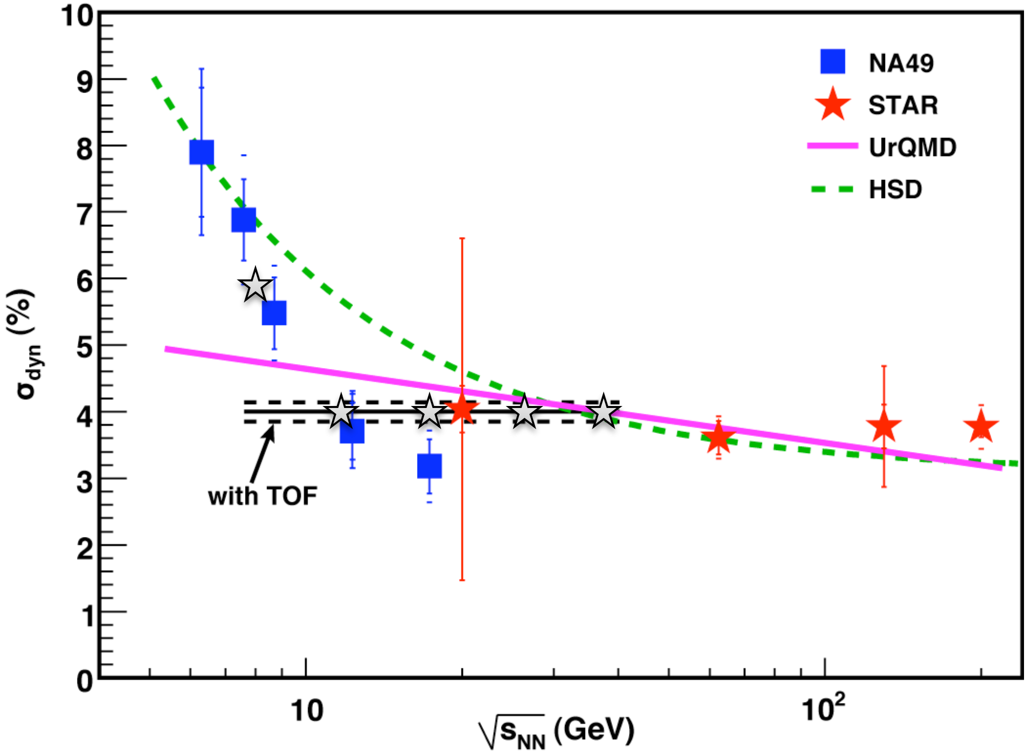
1st order: HBT vs Reaction Plane



Non-monotonic behavior would indicate a softest point: 1st order

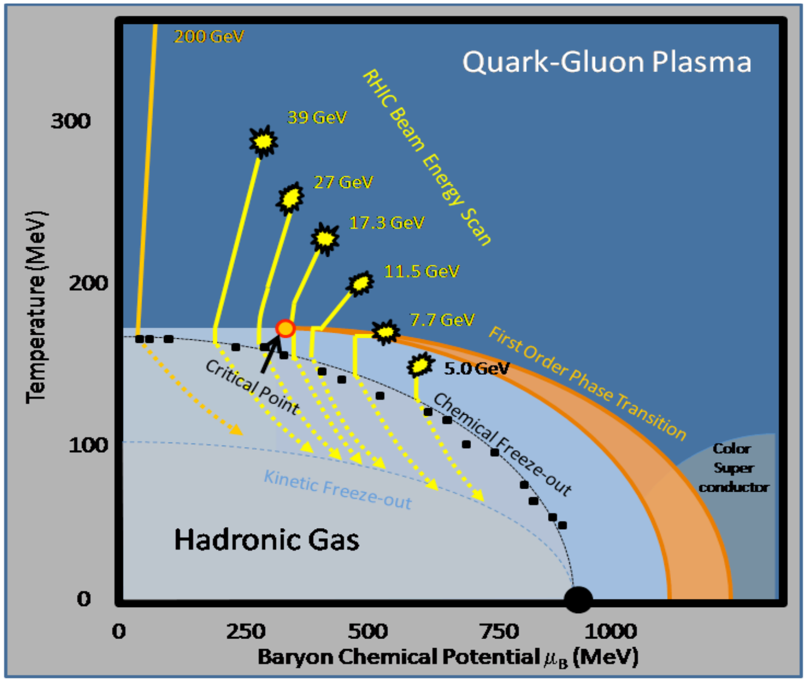
Identified particle fluctuations

$(K^{+}+K^{-})/$
$(\pi^{+}+\pi^{-})$



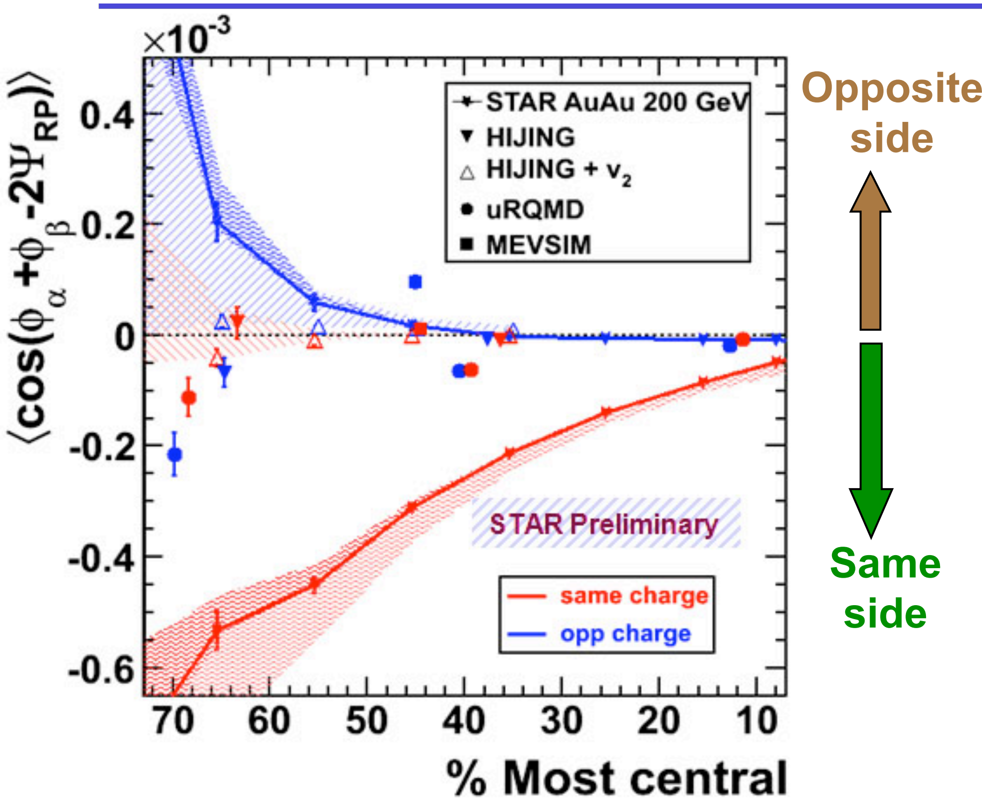
- Example: K/π fluctuations
  - Rise in NA49 data not explained by models
- STAR: Full PID, large acceptance uniform over $\sqrt{s_{NN}}$
- Unprecedently accurate and differential measurements possible

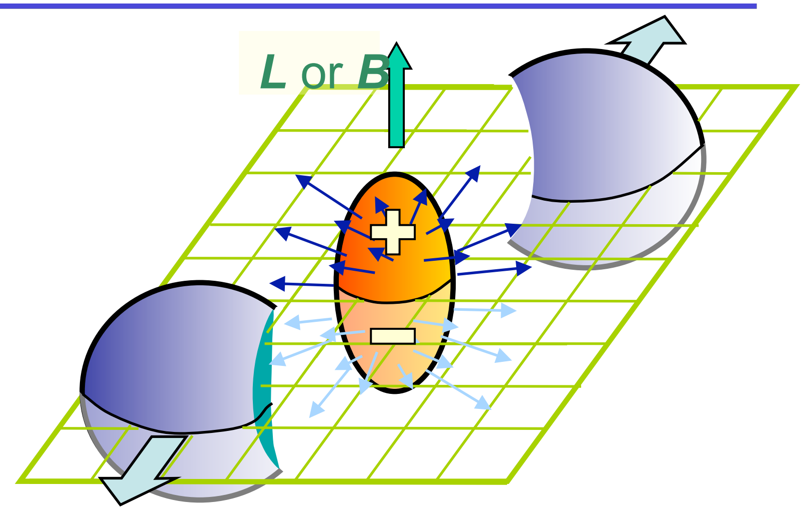
Turn-off of QGP Signatures



- Search for onset of signatures of new phenomena discovered at highest RHIC energy
  - Number of constituent quark scaling in v_2: partonic collectivity
  - Hadron suppression: opacity
  - “Ridge”: pair correlations extended in pseudorapidity
  - Local parity violation

Local Parity Violation





Requirements:

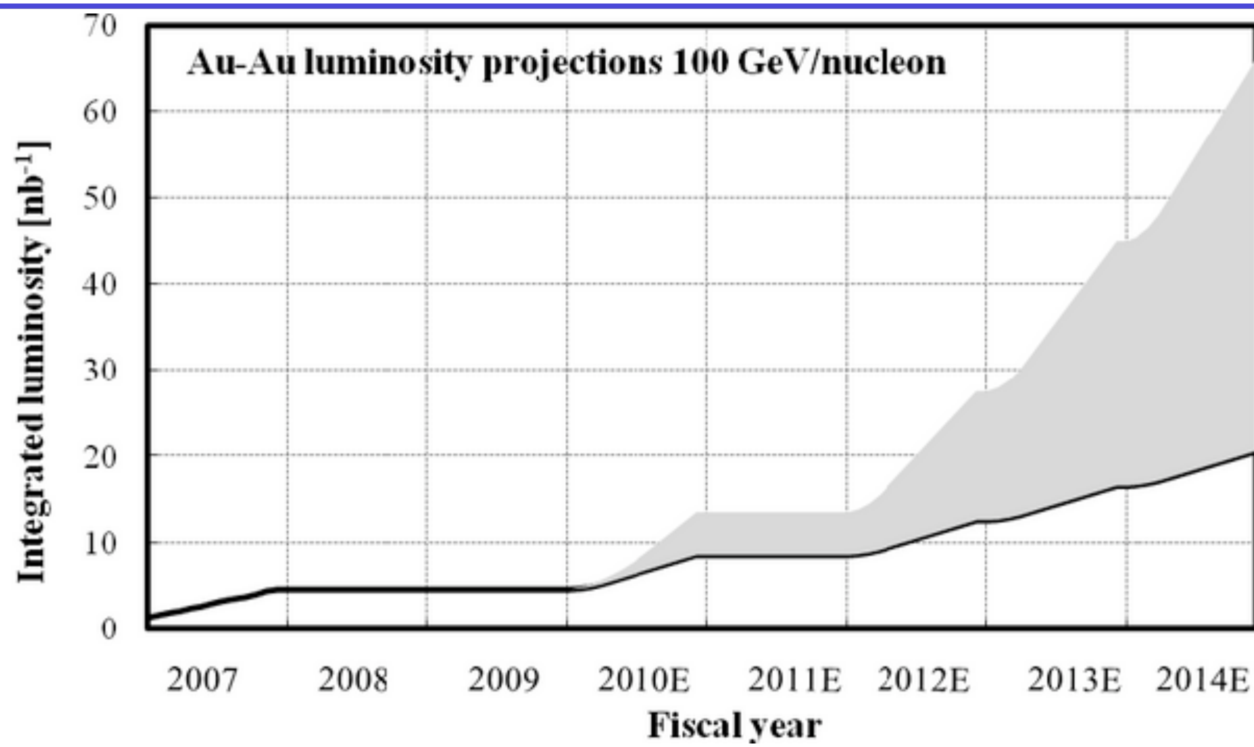
Large Magnetic Field from initial L

Chiral symmetry restoration

Deconfinement

- Signature consistent with local parity violation at 200, 62 GeV
  - Measure Parity Even so potential contamination
    - No background found to date that can mimic effect
    - Background (and magnetic field) expected to change with energy
- Program: vary energy, vary species (isobars?) to test behavior

Luminosity progression to the fb^{-1} era

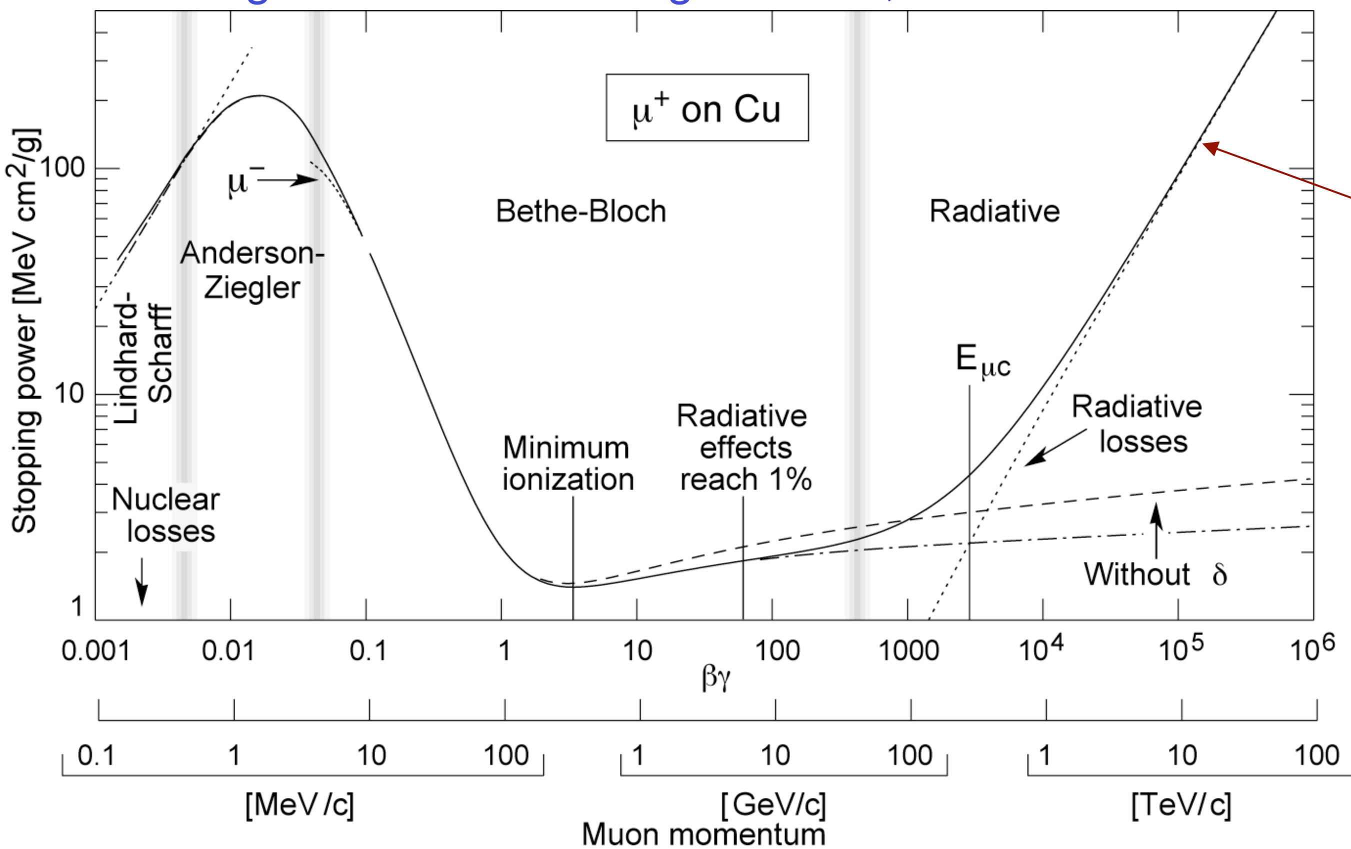


$26\ nb^{-1} * 197 * 197 =$
$1\ fb^{-1}$ pp equivalent

Stochastic cooling: order of magnitude increase in luminosity for rare probes

Mechanisms for Energy Loss

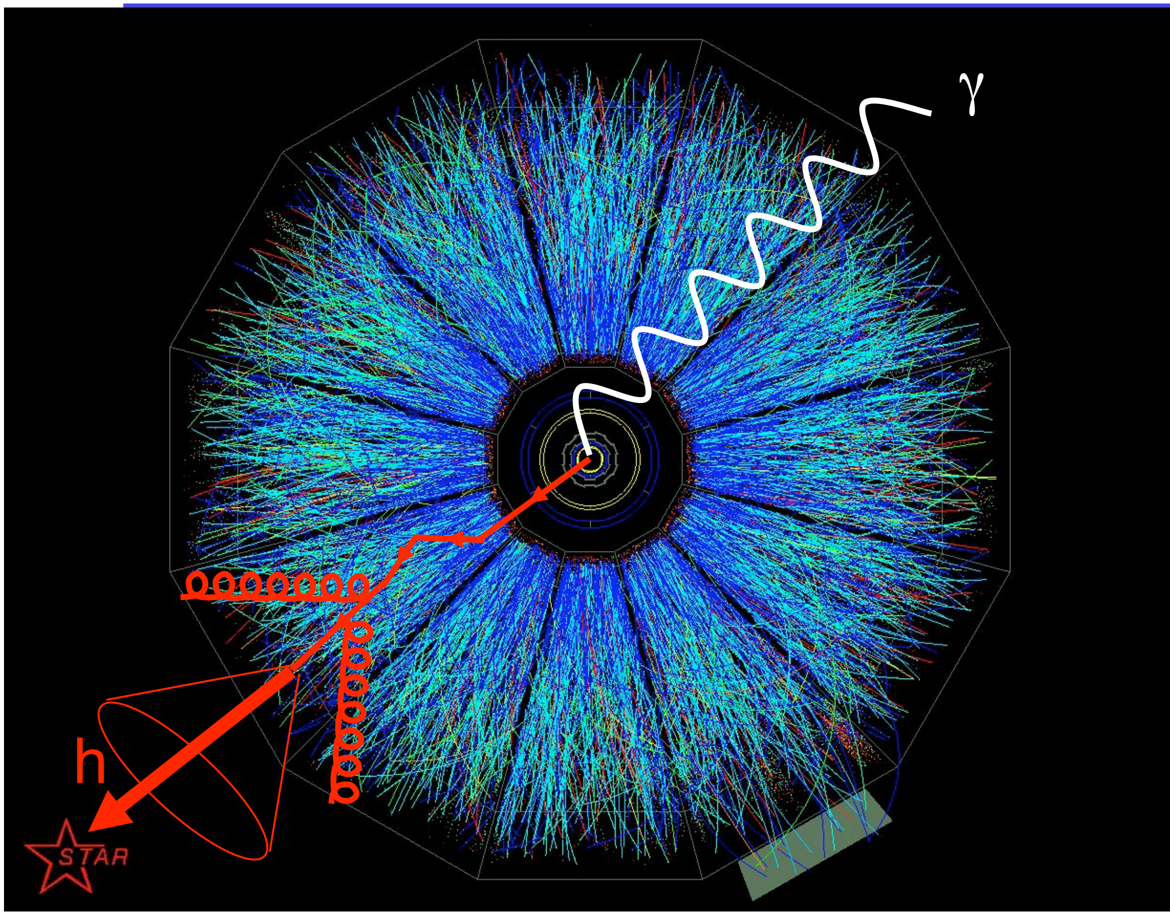
"Passage of Particles through Matter", Particle Data Book

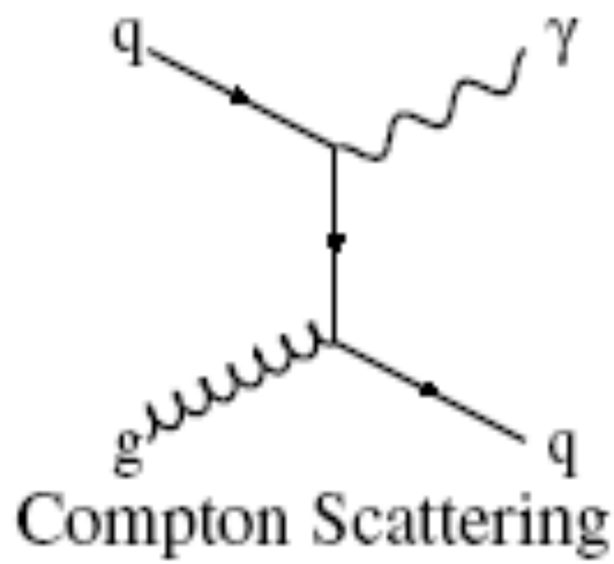


Bremsstrahlung
Radiative dE/dx

- QED: different momenta, different mechanisms
- Just beginning the exploration of this space in QCD

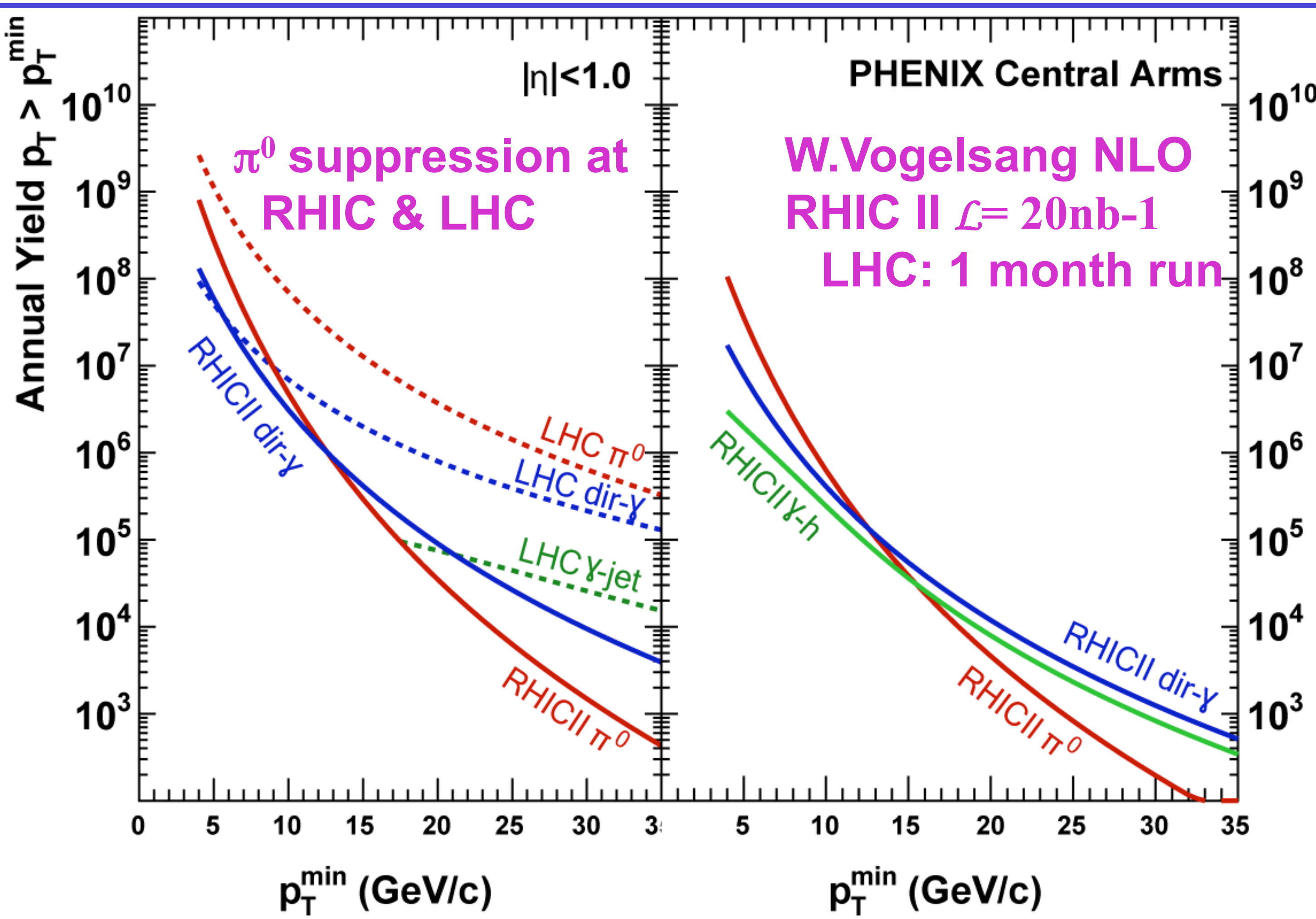
γ-Jet: Golden Probe of QCD Energy Loss





- γ emerges unscathed from the medium
  - Probes deeply into the medium: different surface bias from hadron, dihadron
  - Fully reconstructed kinematics: measure real fragmentation function D(z)

γ-Jet: RHIC is clean

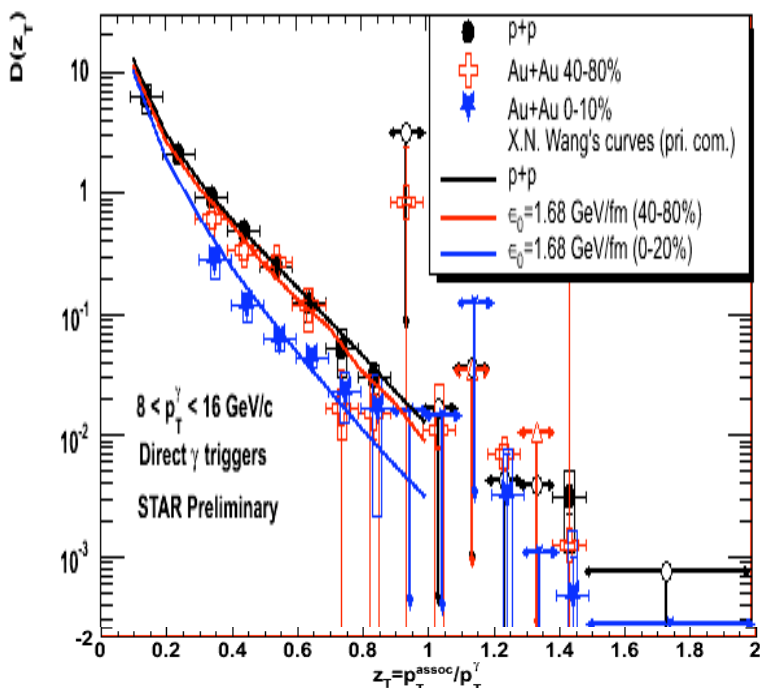


RHIC: Clean separation of γ from π^0 for p_T>~10 GeV

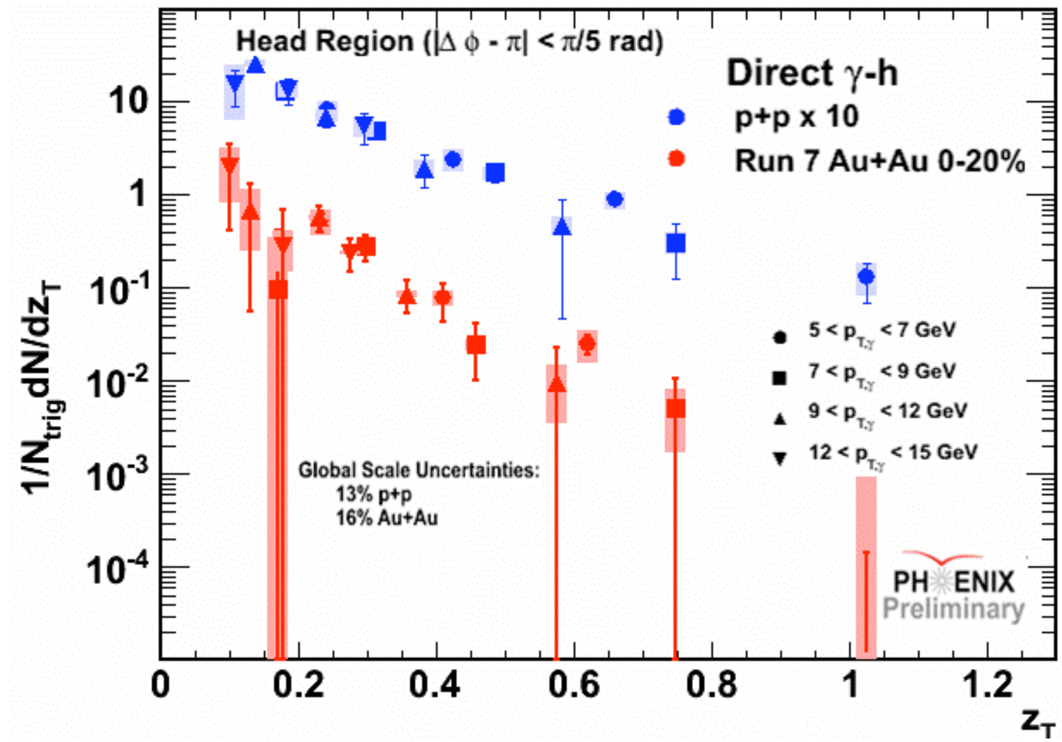
Fragmentation contribution also expected to be small

γ-Hadron Correlations: First Peek

STAR: Hamed, QM2009



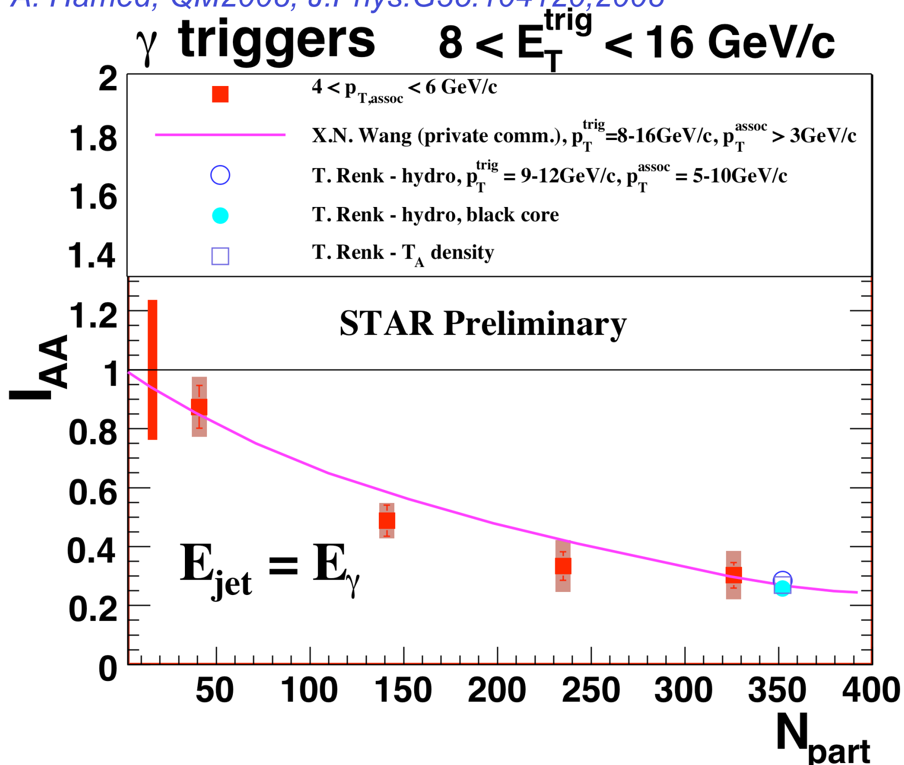
PHENIX: arXiv:0903.3399



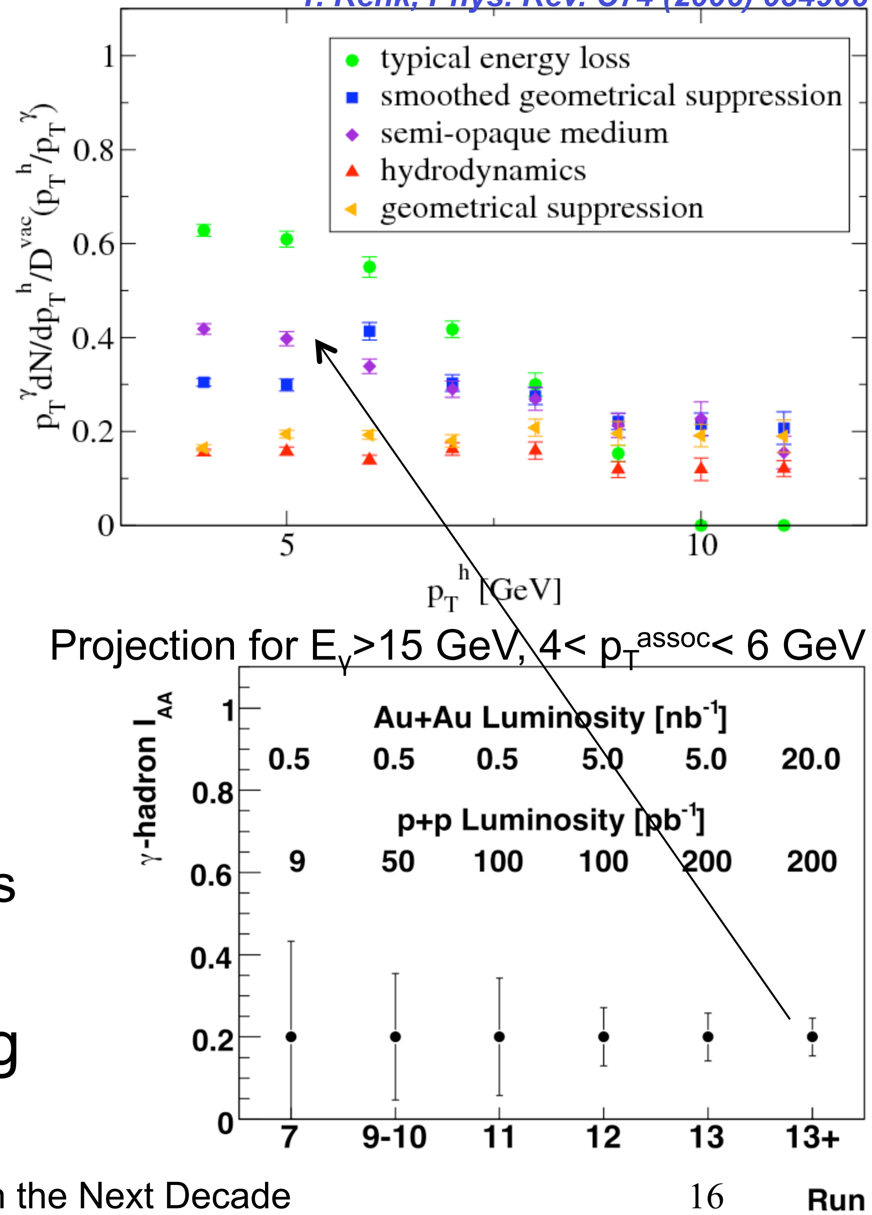
Both STAR and PHENIX have made first measurements in both Au+Au and p+p

γ-Hadron Correlations: need for precision

A. Hamed, QM2008, J.Phys.G35:104120,2008

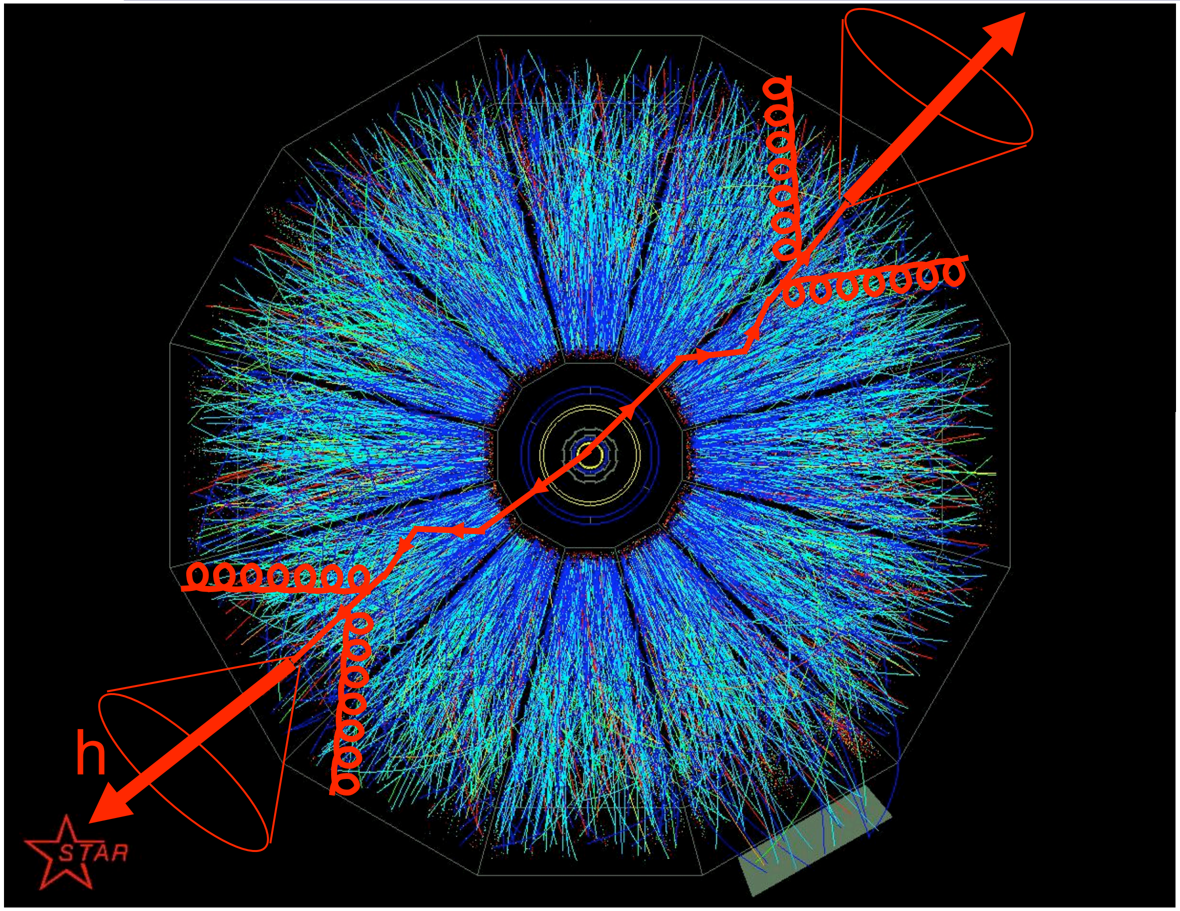


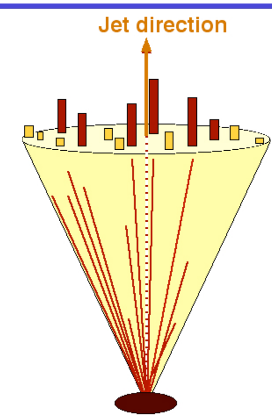
T. Renk, Phys. Rev. C74 (2006) 034906

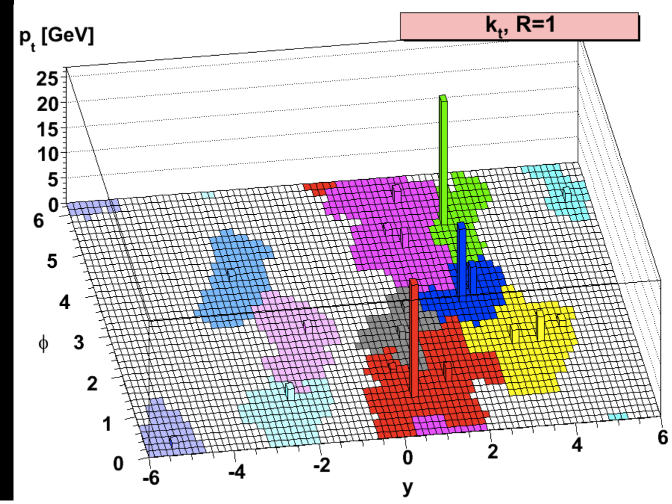


- First measurements made
  - Agree with theory within uncertainties
  - Higher precision needed
- Major progress possible in coming years with RHIC II

Jets







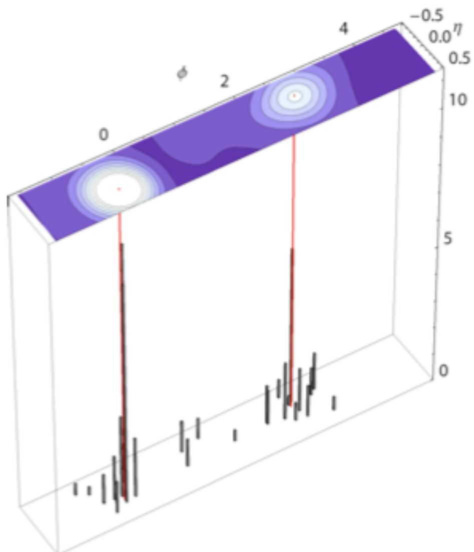
Jet reconstruction: another way to constrain hard kinematics

- Positive: large cross-section, so large p_T reach
- Negative: large backgrounds, limited E resolution

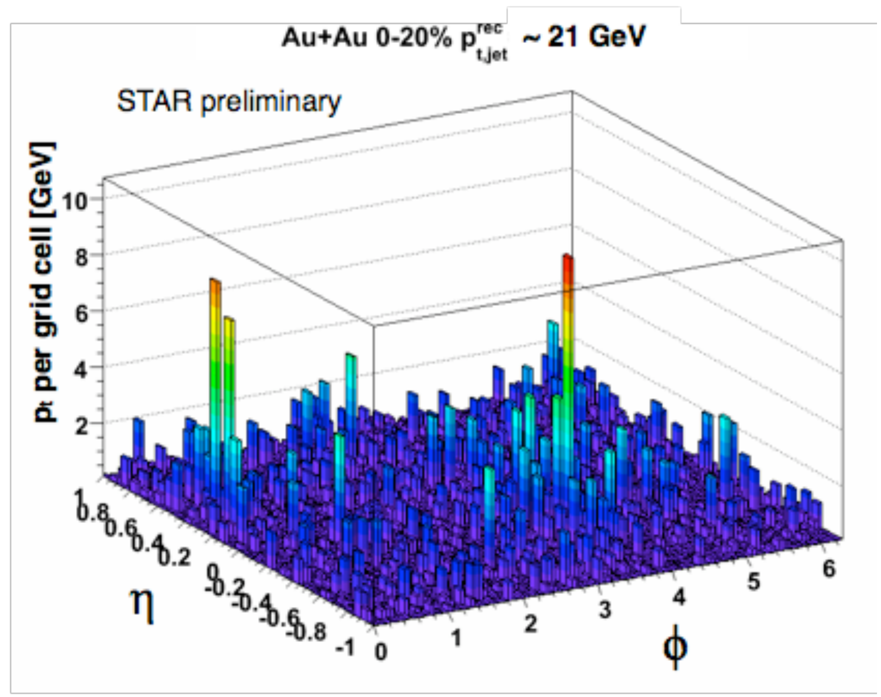
Jets in Au+Au: Results so Far

PHENIX, Quark Matter 2009

STAR, Quark Matter 2009



Run 150513, event 277518
19–20% centrality
24.3 GeV/*c* and 10.3 GeV/*c* dijet



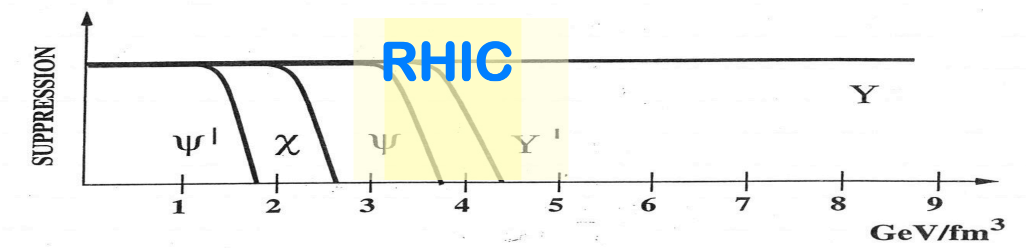
Beginning results from 2007 indicative, but in no way final word

- Beginning application of FastJet… to handle large background

Orders of magnitude more luminosity available by Run 14

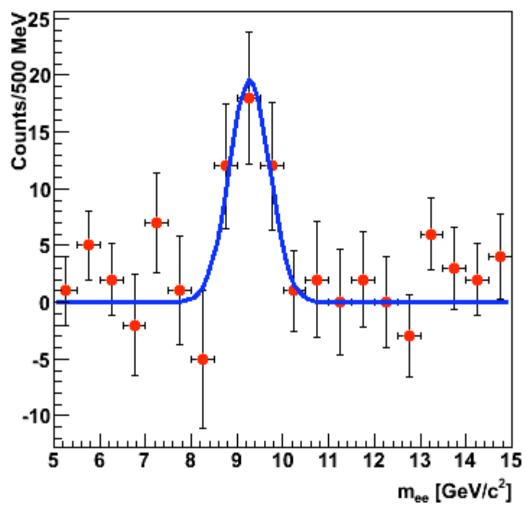
- Issue: effective triggers to sample luminosity w/o physics bias

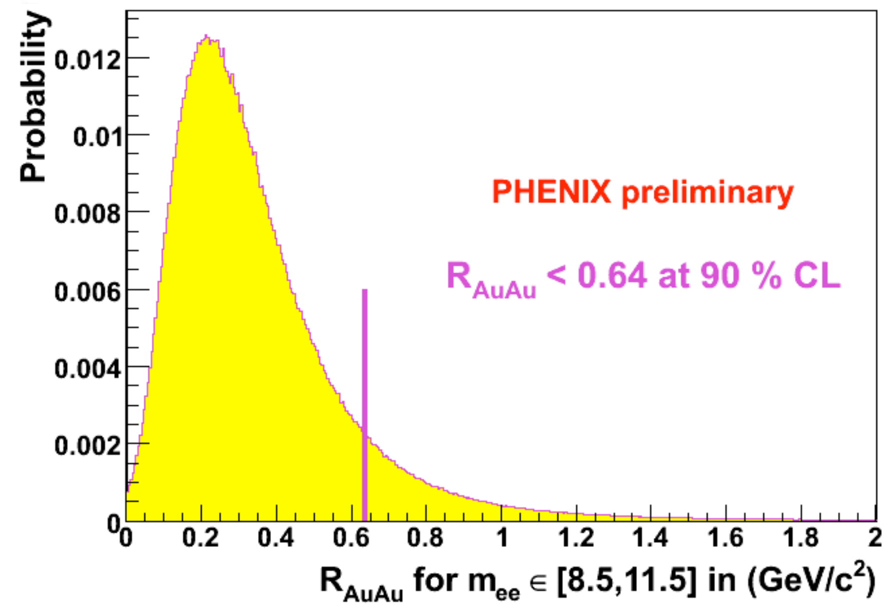
Quarkonium: Upsilon



Proof of principle: STAR p+p 2006

Upsilon(1S+2S+3S)→e^+e^-



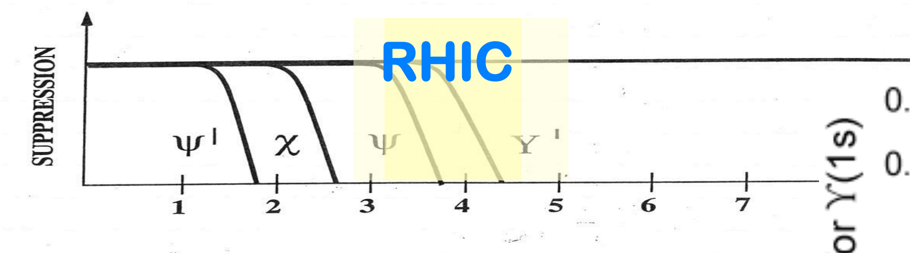


Sequential dissociation of quarkonia to measure energy density of plasma

Both STAR and PHENIX have made first measurements

PHENIX: (1S+2S+3S) R_{AA}<0.64 at 90% CL; need to separate states

Quarkonium in the fb^{-1} era: Upsilon



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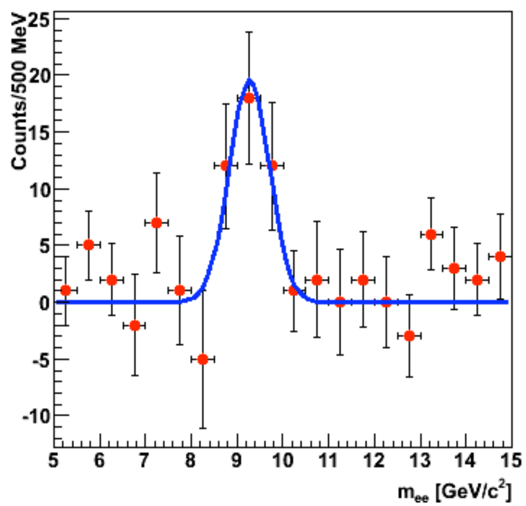
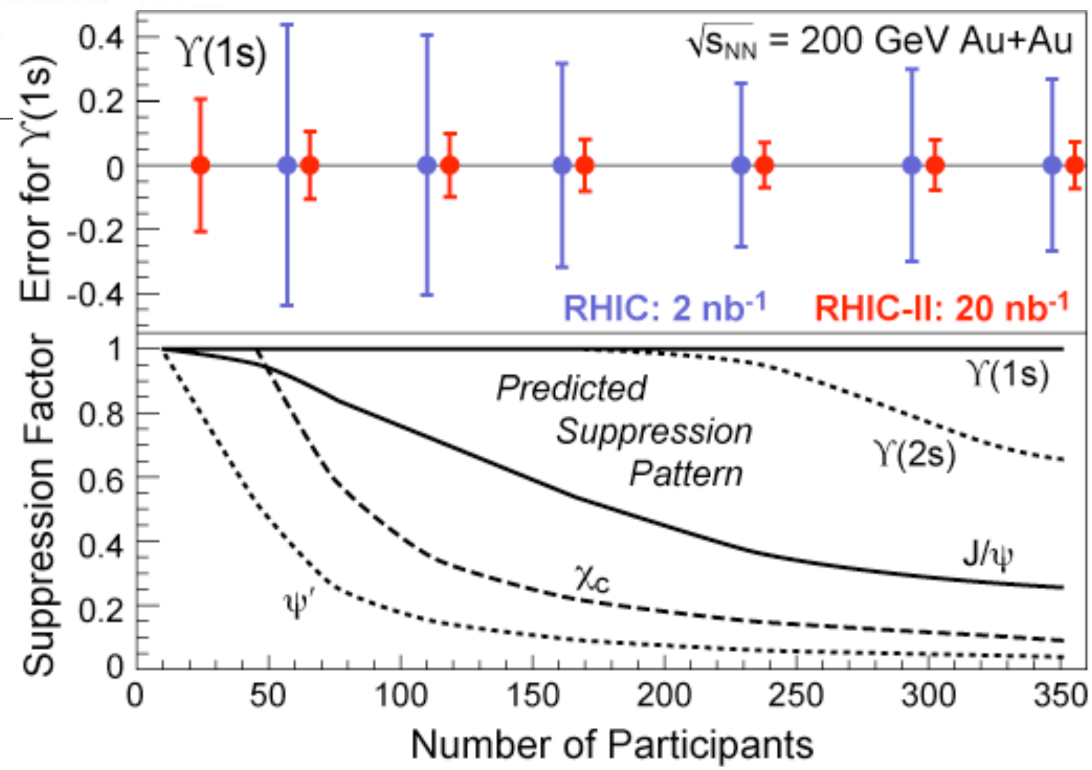




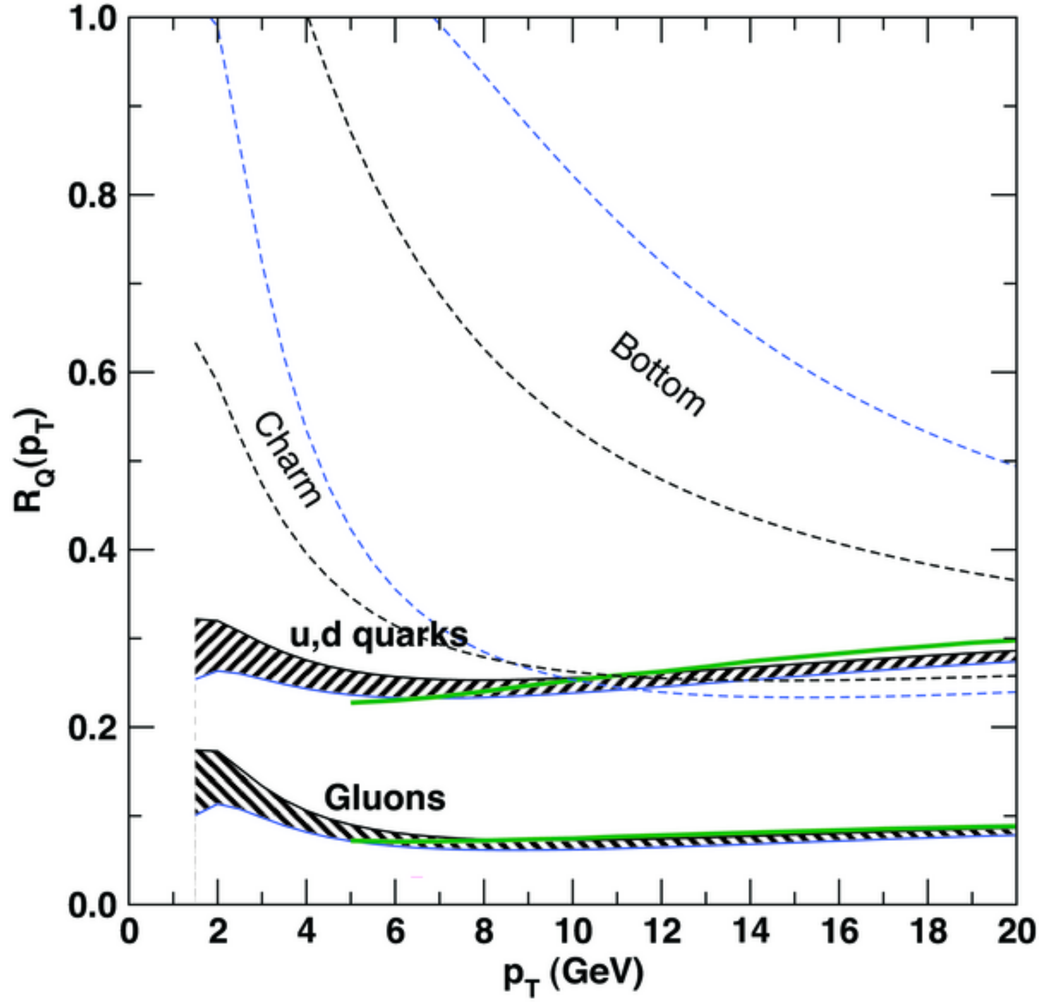
Sequential dissociation of quarkonia to measure energy density of plasma

Good start, but needs full luminosity of RHIC II to be definitive

Heavy Quark Motivation: Grey Probes

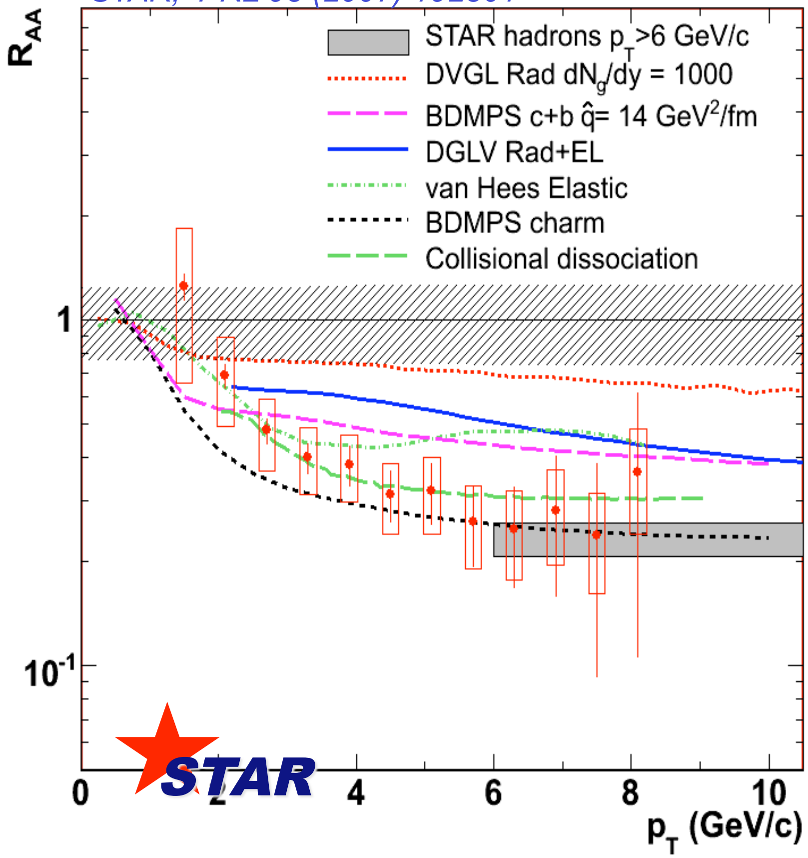
- Problem: interaction with the medium so strong that information lost: “Black”
- Significant differences between predicted R_{AA}, depending on the probe
- Experimental possibility: recover sensitivity to properties of the medium by varying probe

Wicks et al, Nucl. Phys. A784 (2007) 426

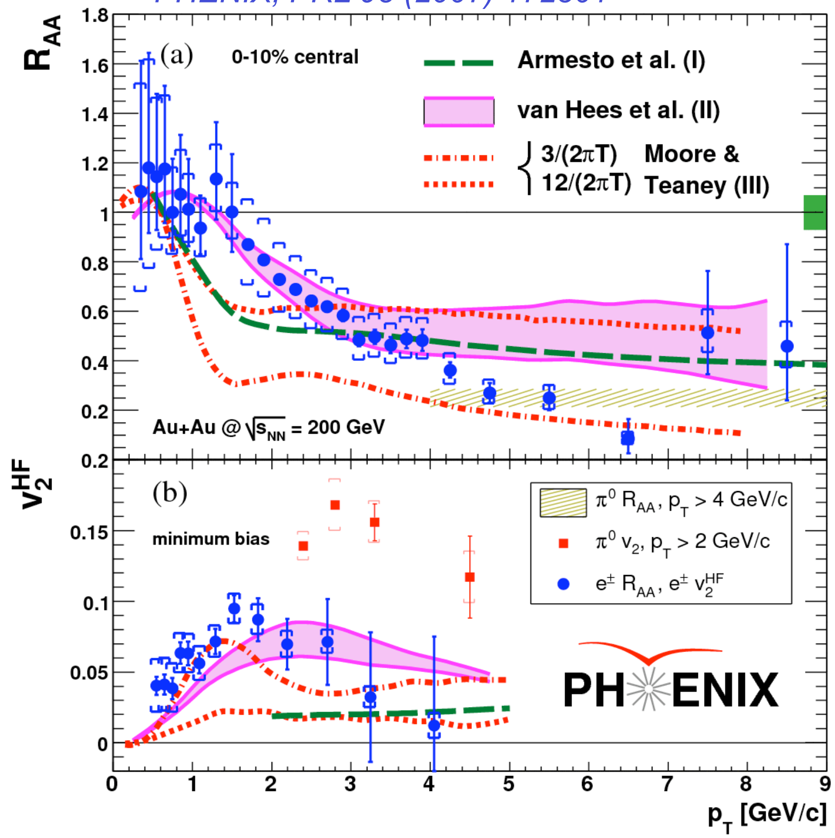


Charm/Beauty: No shade of gray

STAR, PRL 98 (2007) 192301



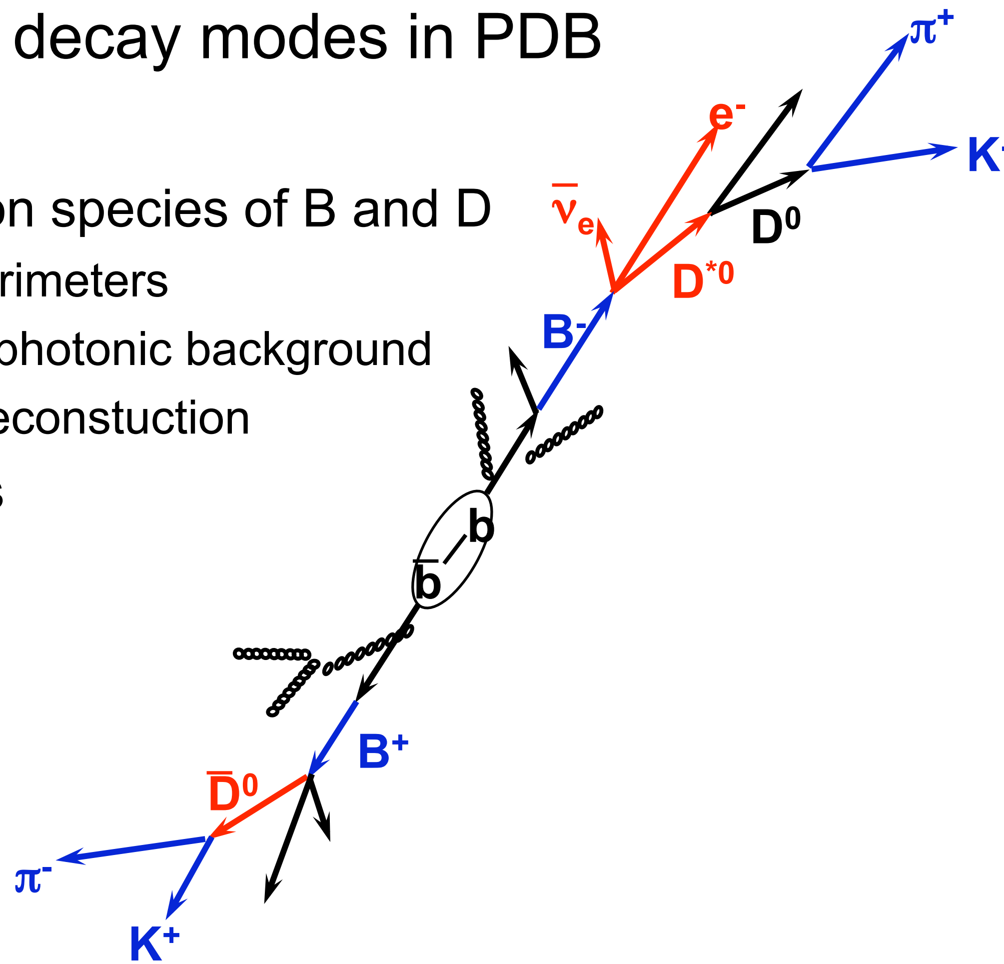
PHENIX, PRL 98 (2007) 172301



- Strong suppression and flow of non-photonic electrons
- Study mechanism of energy loss (especially B)
- Study thermalization and transport properties (esp. low p_T D)

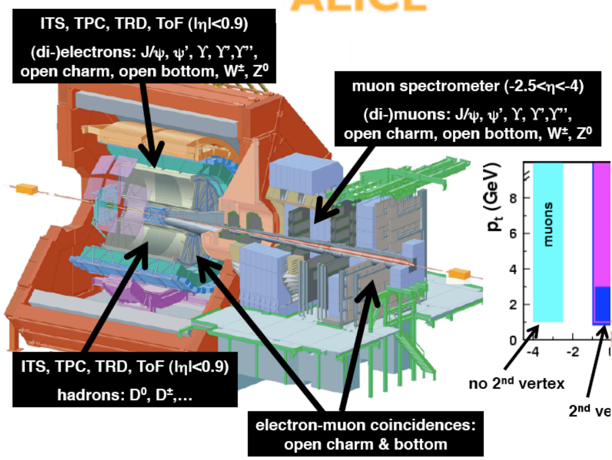
Measurement: a wealth of decay

- 4 pages D^0, 10 pages of B^+ decay modes in PDB
- Most promising modes:
  - Leptons: B.R. ~10% per lepton species of B and D
    - Electrons: triggerable in calorimeters
    - Muons: no Bremsstrahlung, photonic background
    - Neither have full kinematic reconstuction
  - Pure hadronic: full kinematics
    - $D \to K\pi$, $D^* \to K\pi\pi$
    - Not easily triggerable
  - $B \to J/\Psi + X$
    - Clean from D contamination
    - B.R. ~1%, triggerable

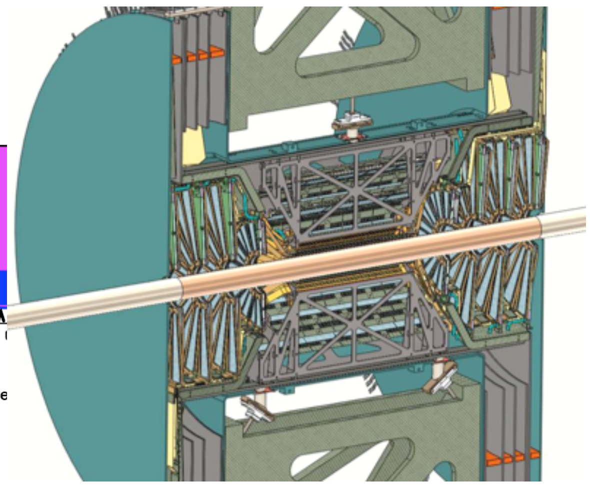


Outlook: Precision Vertexing

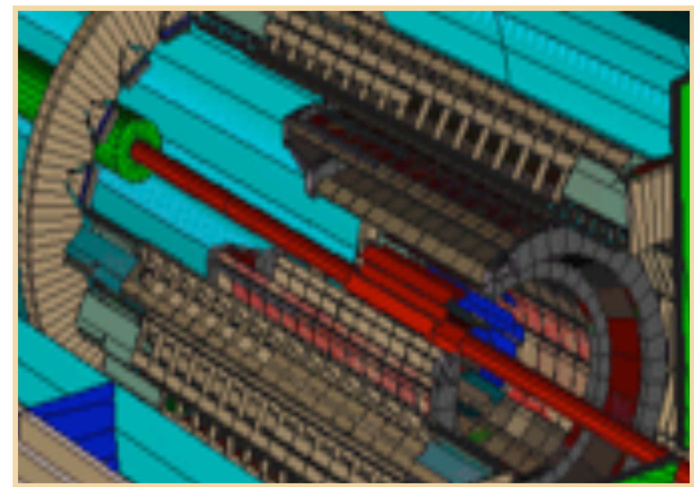
ALICE



PHENIX VTX



STAR Heavy Flavor Tracker



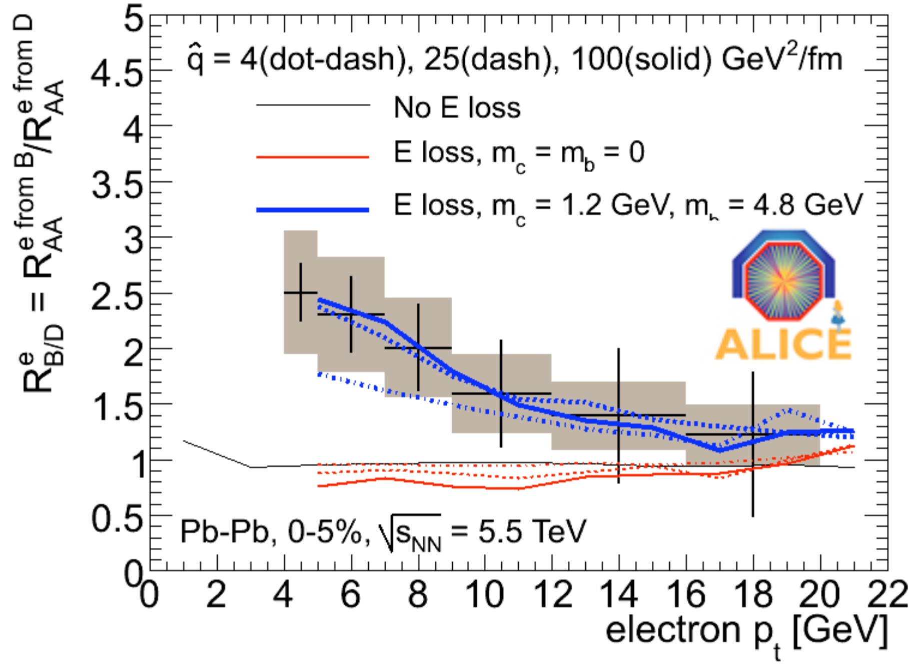
Entering prime years for heavy flavor with precision vertexing

Complementary capabilities and systems

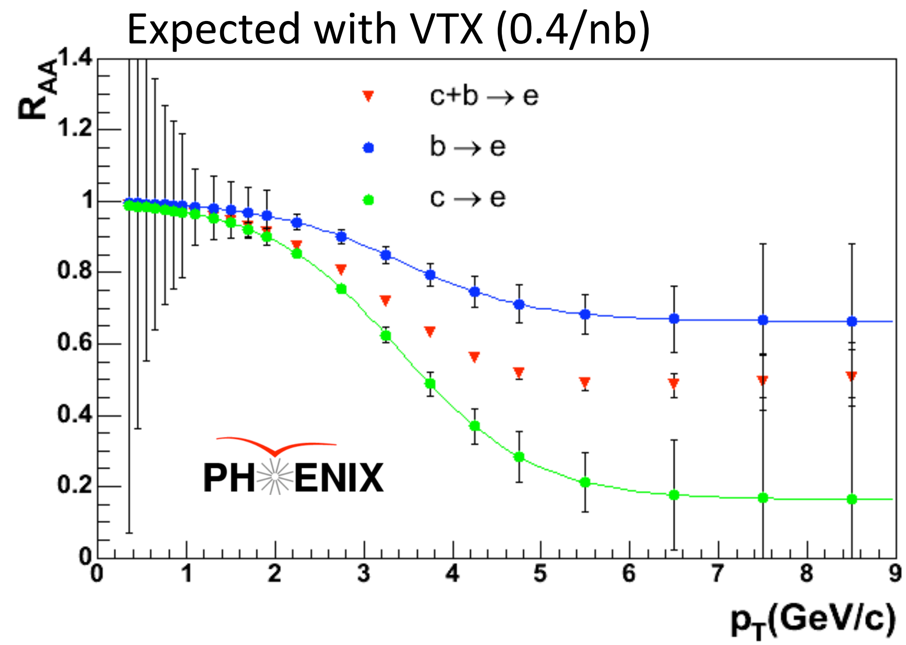
- ALICE: LHC, where c becomes a “light” quark
- PHENIX: Focus on electrons and muons
- STAR: Focus on fully reconstructed kinematics

Separating Charm from Beauty

ALICE Projections

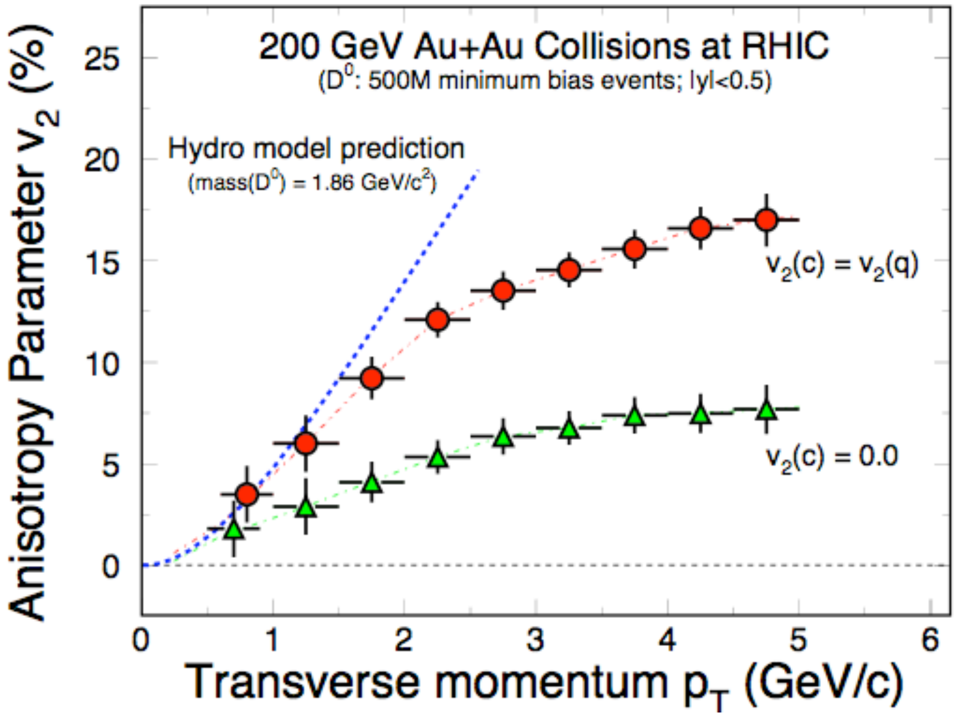


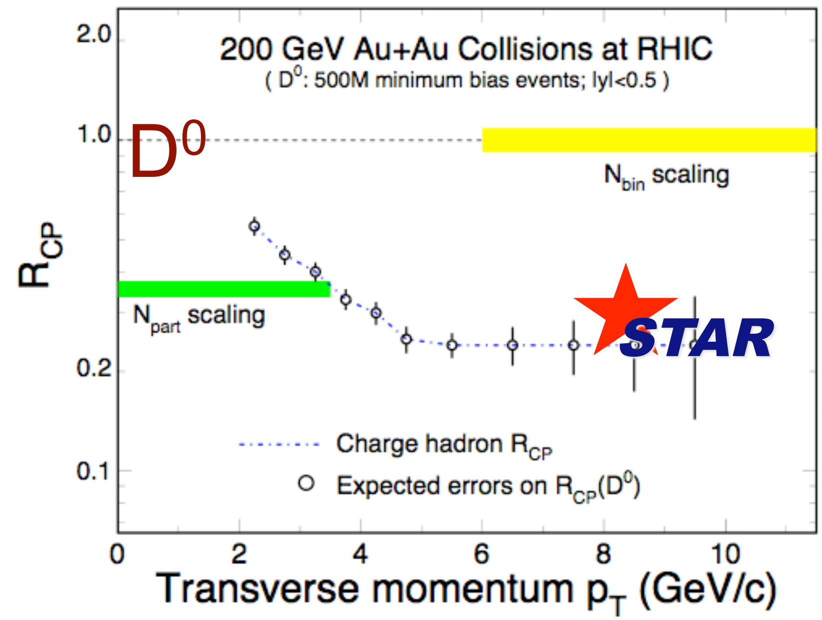
PHENIX Projection

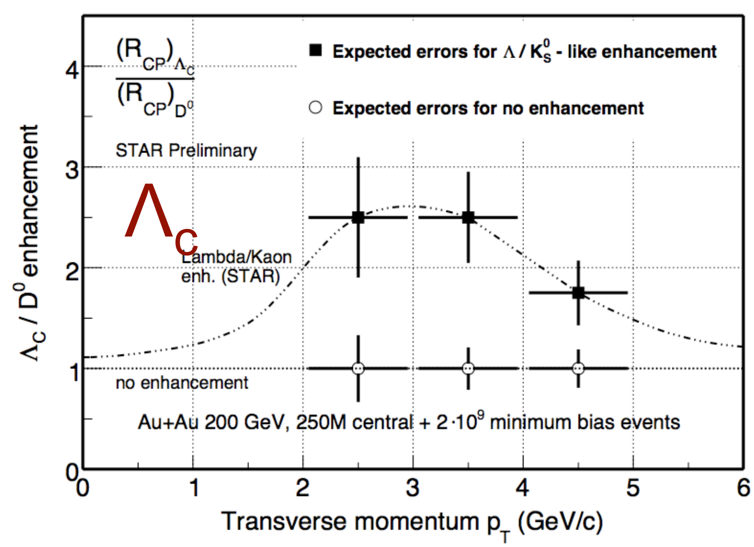


- At ALICE, c a "light quark", e_B/e_C sensitive to B energy loss
- PHENIX VTX: built to isolate e_B from e_D
- Clean measurements of beauty quenching will be possible

Open Charm with the STAR HFT







- Direct reconstruction with full kinematic information
- Only possible for charm:
  - D^+, D^0, Λ_c
- No ambiguities

Conclusion

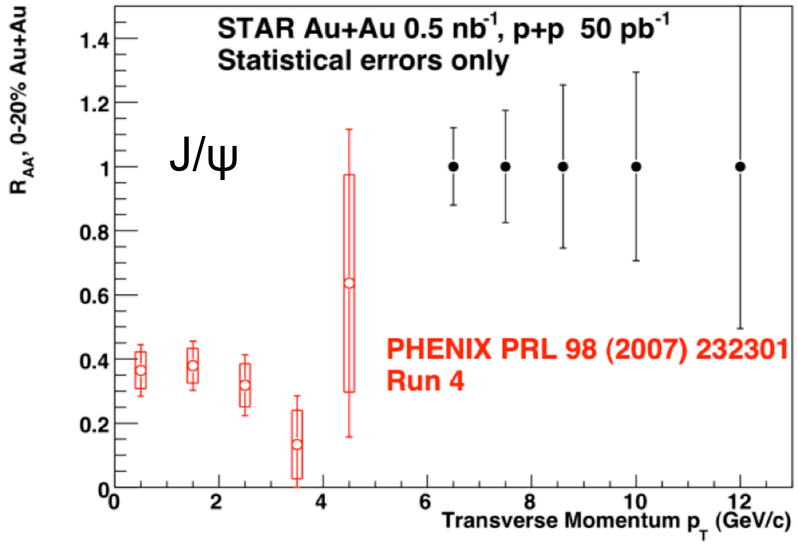
Key Physics Questions:

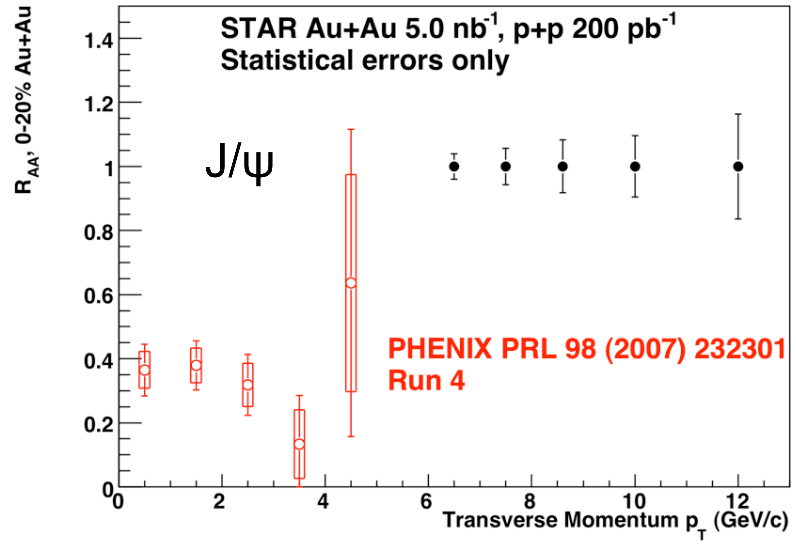
- What are the landmarks on the QCD phase diagram?
- What is the mechanism for QCD energy loss?
- What are the quantitative properties of the QCD matter produced at RHIC?

RHIC is well-positioned to provide answers to these questions over the next decade with

- Critical point search
- Luminous beams (Jets, γ-jet, Quarkonia)
- Charming and beautiful suppression and flow

Quarkonia: High Pt J/ψ





- Test mechanism of J/ψ production
  - J/ψ only hadron with R_{AA} = 1?
- Start of high precision with Run 10
  - expect ~2 nb^{-1}
- Precision measurements later in the decade after full stochastic cooling