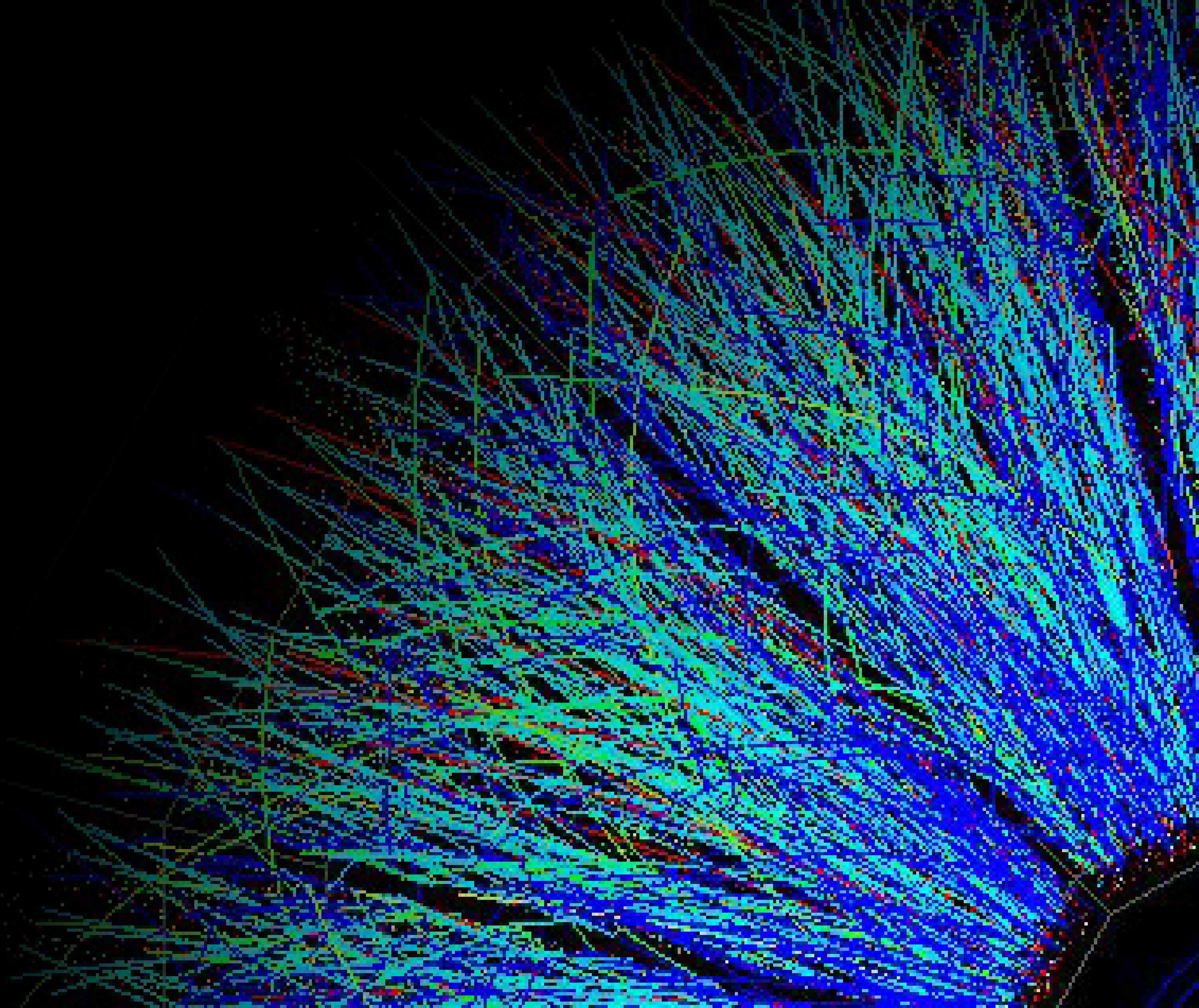
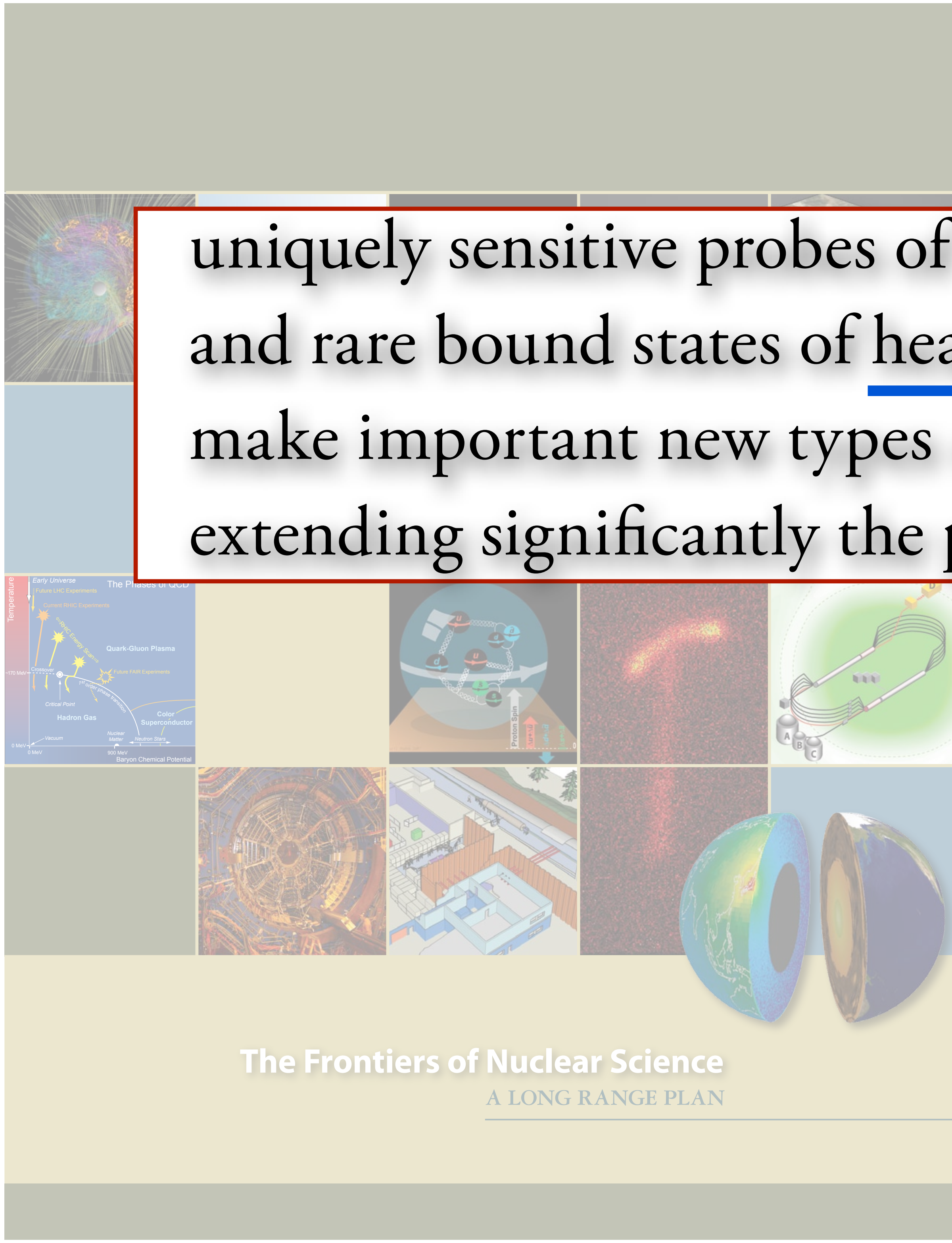
Future of Hard Probes at RHIC

Anne Sickles
BNL



2007 Long Range Plan



RECOMMENDATION IV

The experiments at the Relativistic Heavy Ion Collider have discovered a new state of matter at extreme temperature and density—a

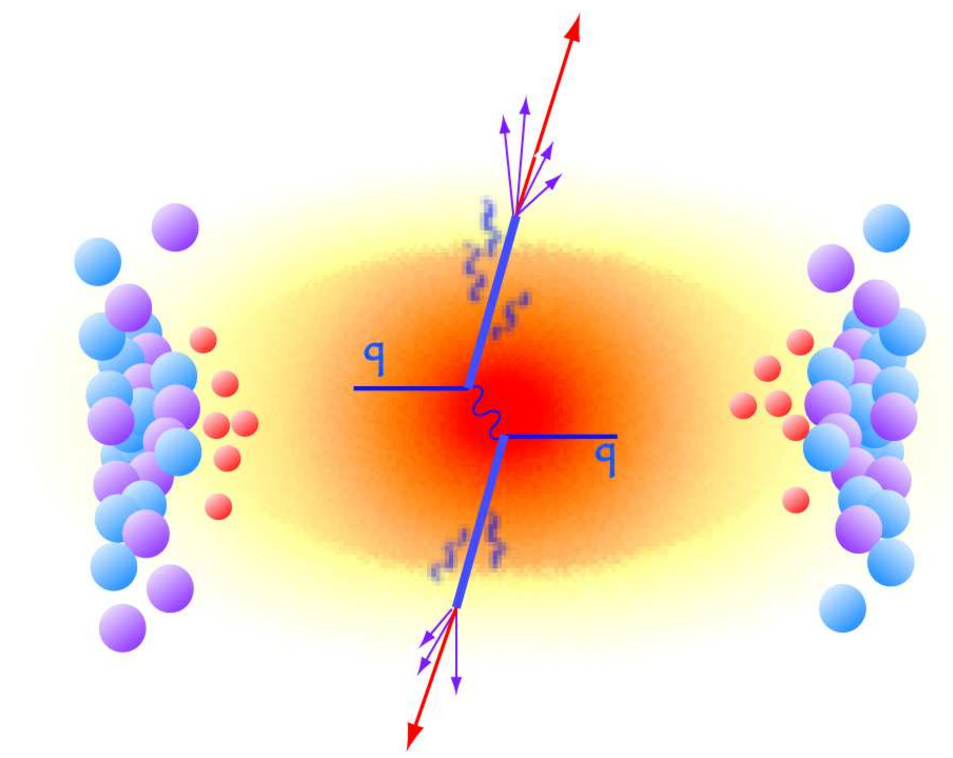
uniquely sensitive probes of the plasma such as energetic jets and rare bound states of heavy quarks. The detector upgrades make important new types of measurements possible while extending significantly the physics reach of the experiments.

The major discoveries in the first five years at RHIC must be followed by a broad, quantitative study of the fundamental properties of the quark-gluon plasma. This can be accomplished through a 10-fold increase in collision rate, detector upgrades, and advances in theory. The RHIC II luminosity upgrade, using beam cooling, enables measurements using uniquely sensitive probes of the plasma such as energetic jets and rare bound states of heavy quarks. The detector upgrades make important new types of measurements possible while extending significantly the physics reach of the experiments. Achieving a quantitative understanding of the quark-gluon plasma also requires new investments in modeling of heavy-ion collisions, in analytic approaches, and in large-scale computing.

Hard Probes at RHIC

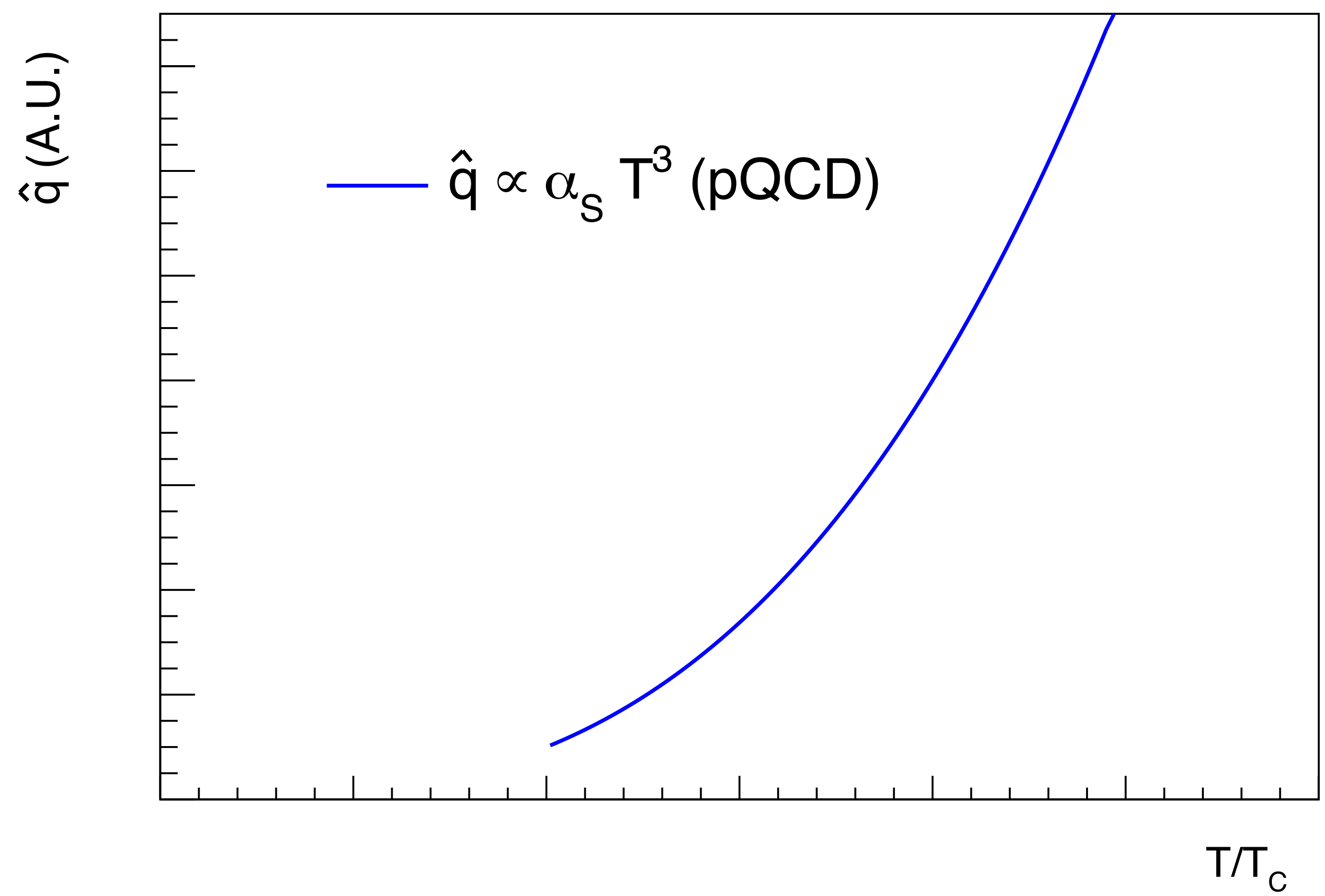
goal: quantify properties of QGP as a function of temperature

- hard probes created only at the earliest stages of the collision
  - sensitive to highest collision temperatures
  - sensitive to entire lifetime of collision
  - theoretically calculable & measurable in reference systems (pp & dAu)



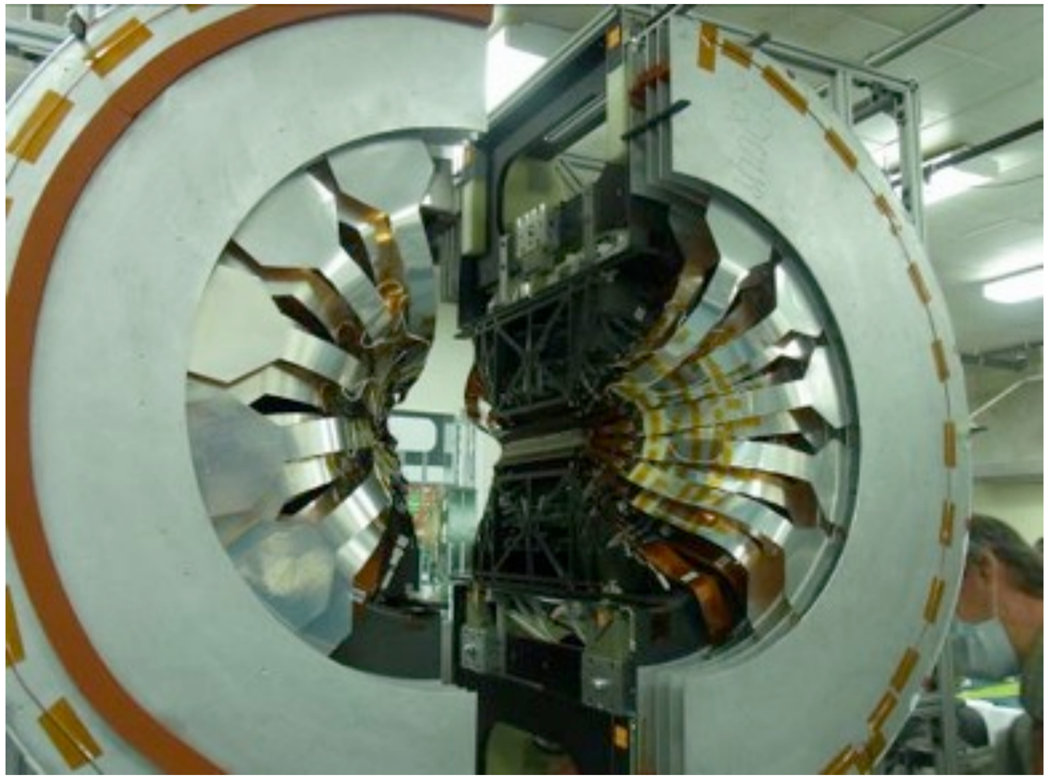
example: jet quenching

strongest quenching at the highest temperature in the collision

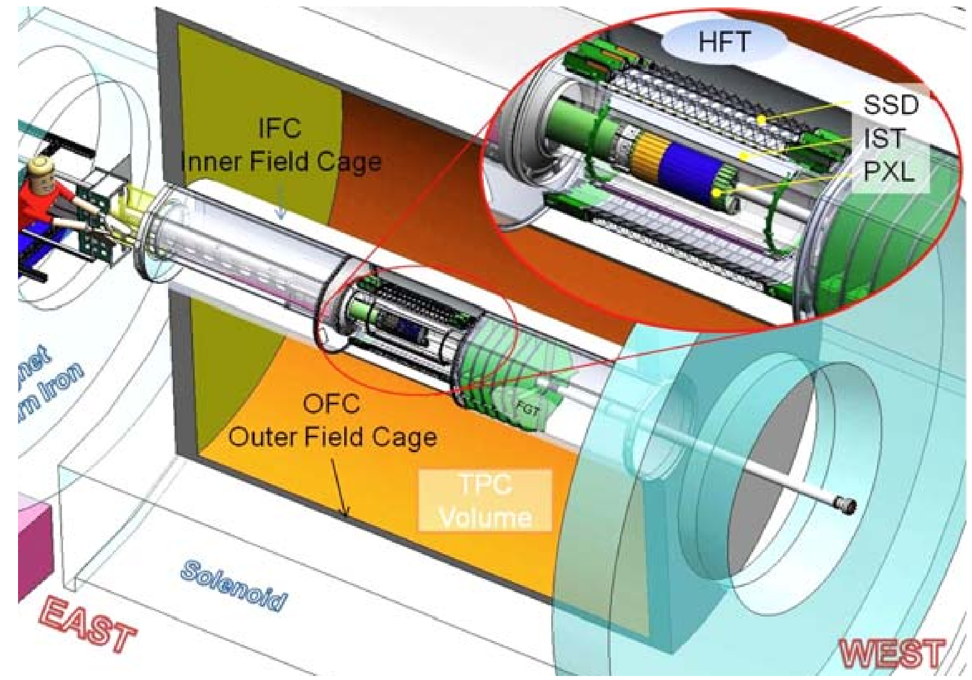


q(T) change the initial collision temperature by changing the collision energy

Investment in New Detectors

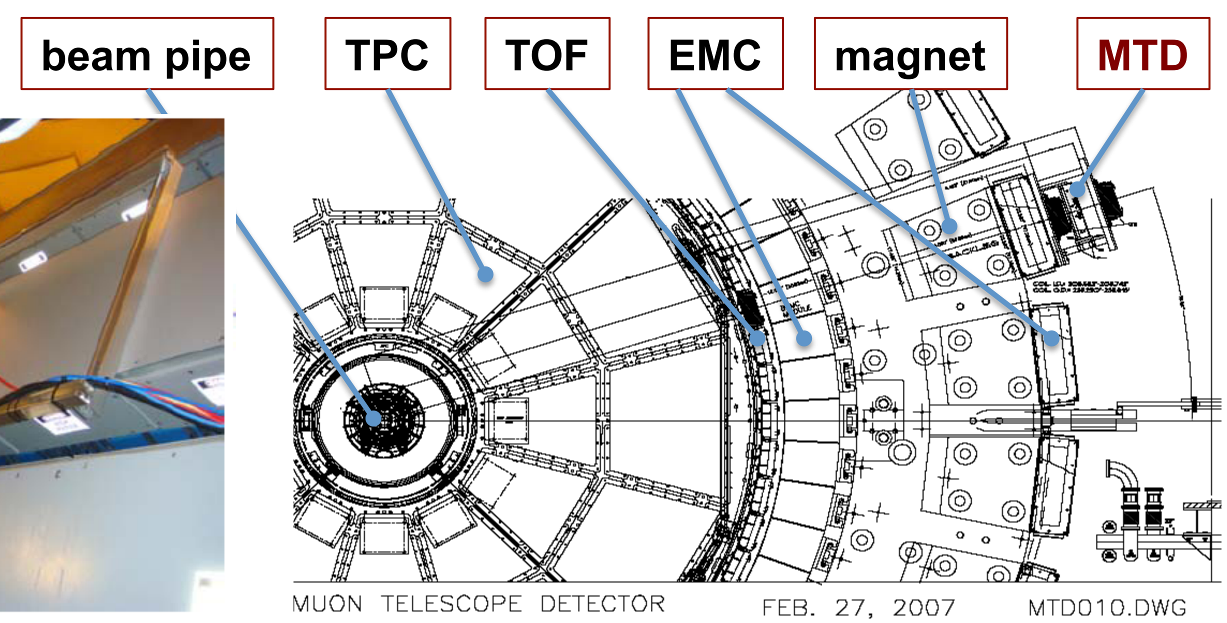


PHENIX (F)VTX
first data Run11&12



STAR HFT
projected
first data Run14

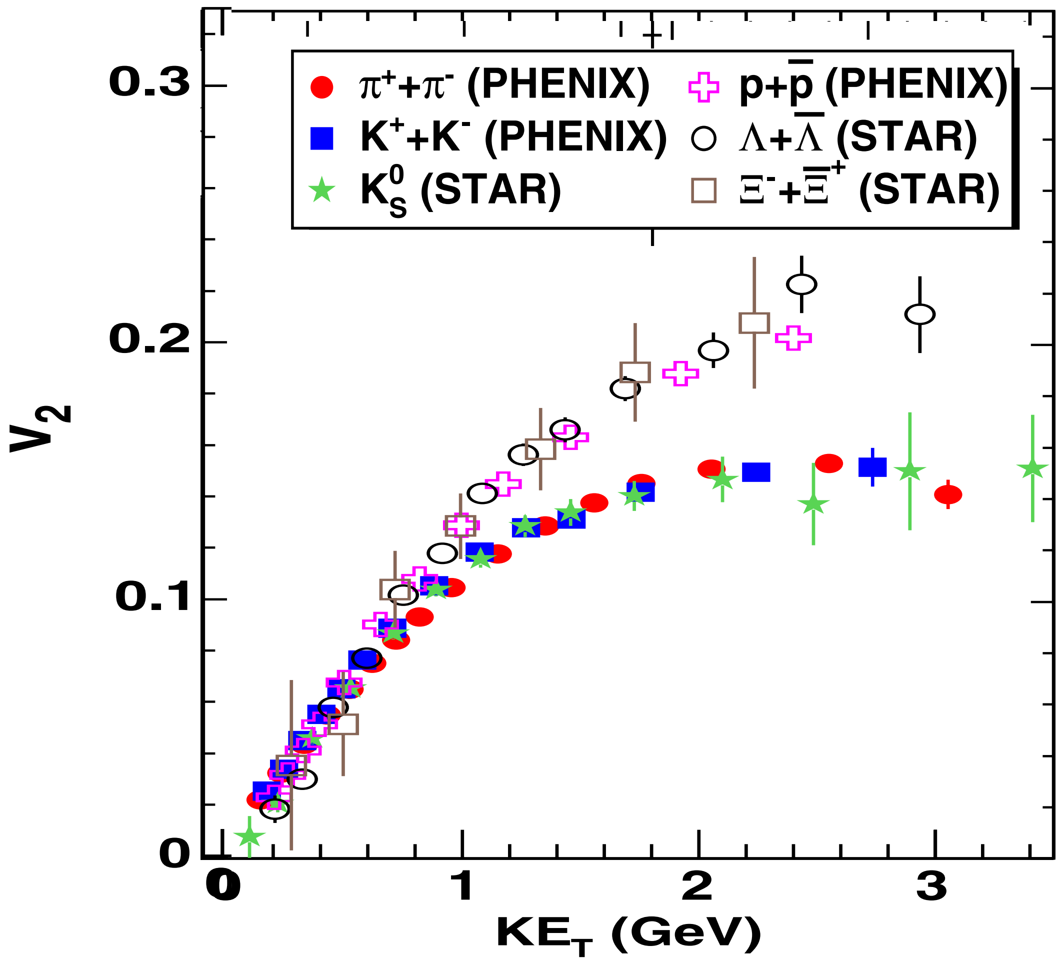
STAR MTD
partially installed Run13
fully installed Run14

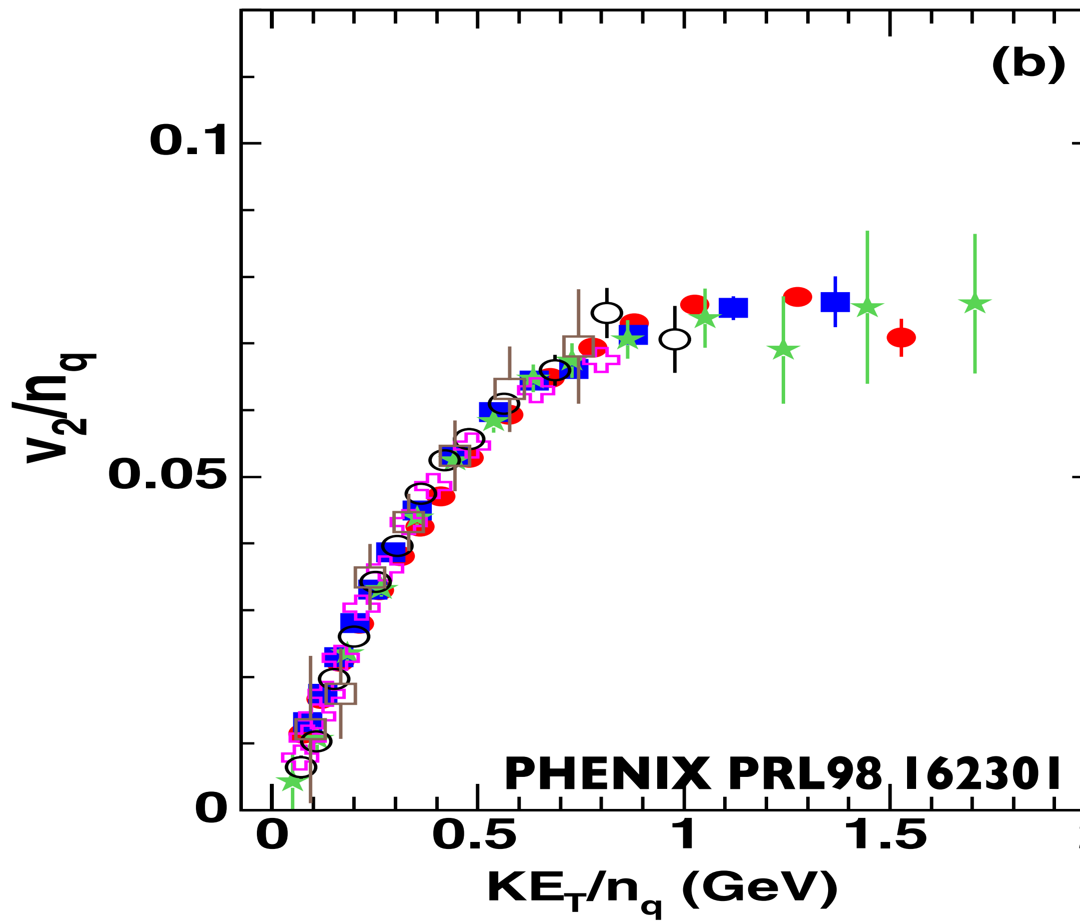


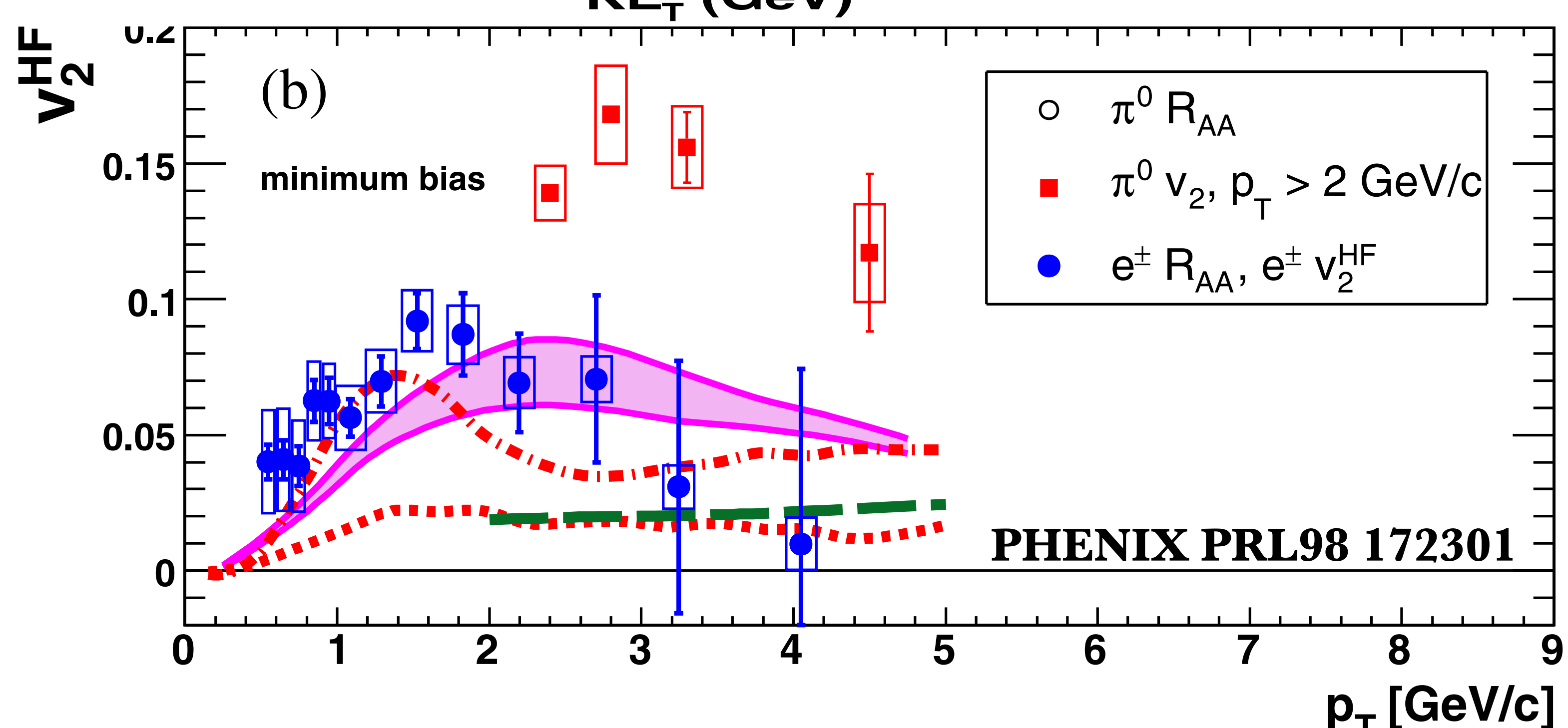
how are charm quarks
incorporated into the QGP?

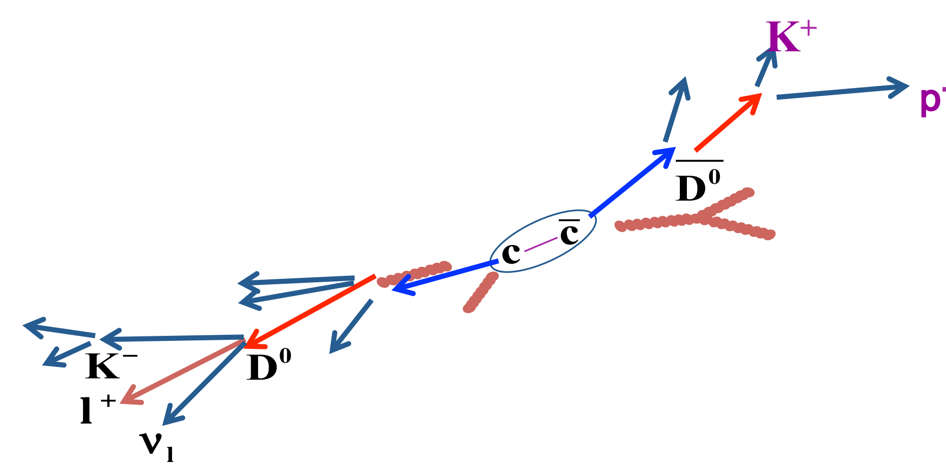
is charm part of the bulk matter?

recombination





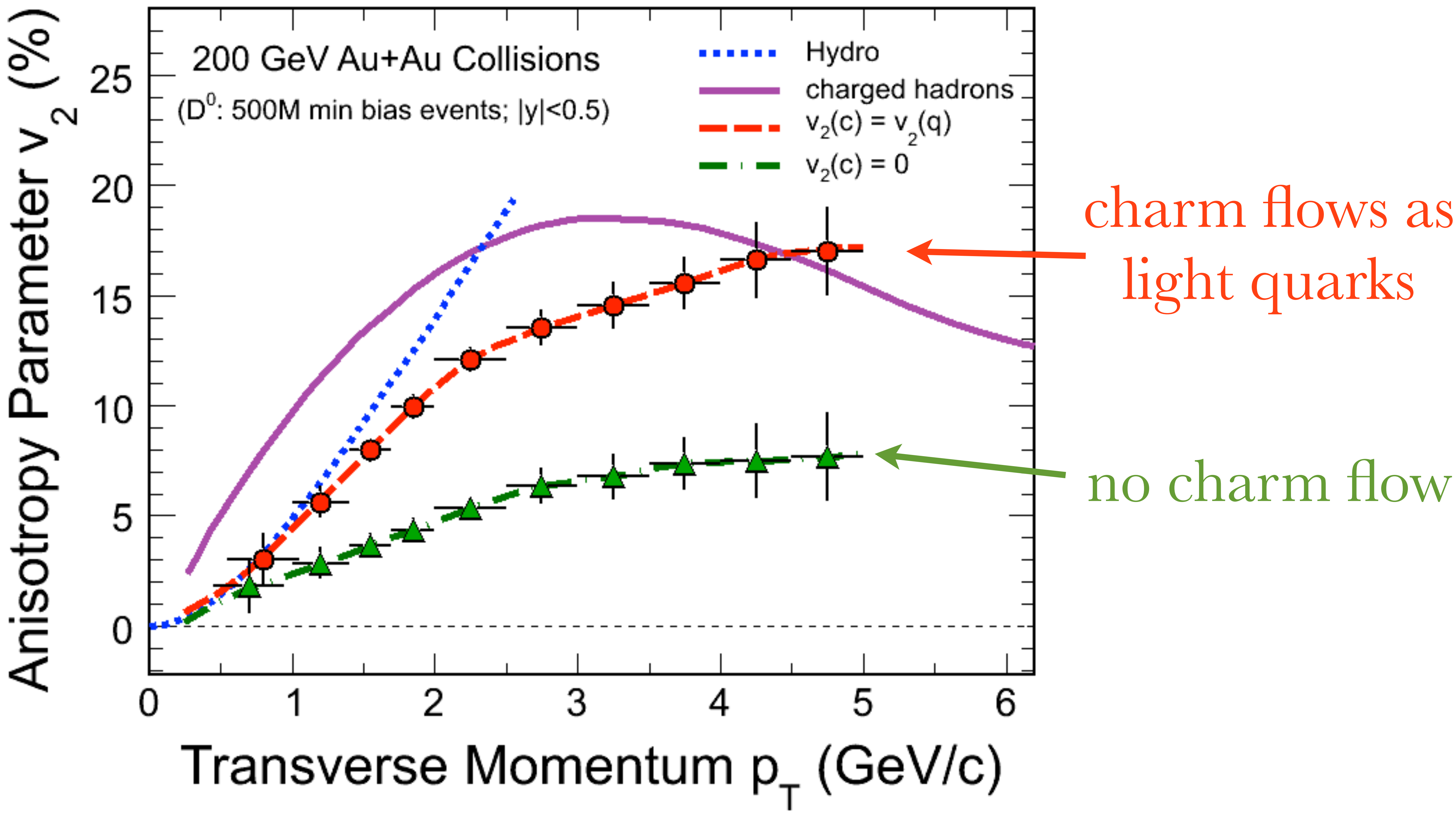




do charm mesons flow with the light quarks?

D mesons with HFT

- FY14, 10 weeks AuAu



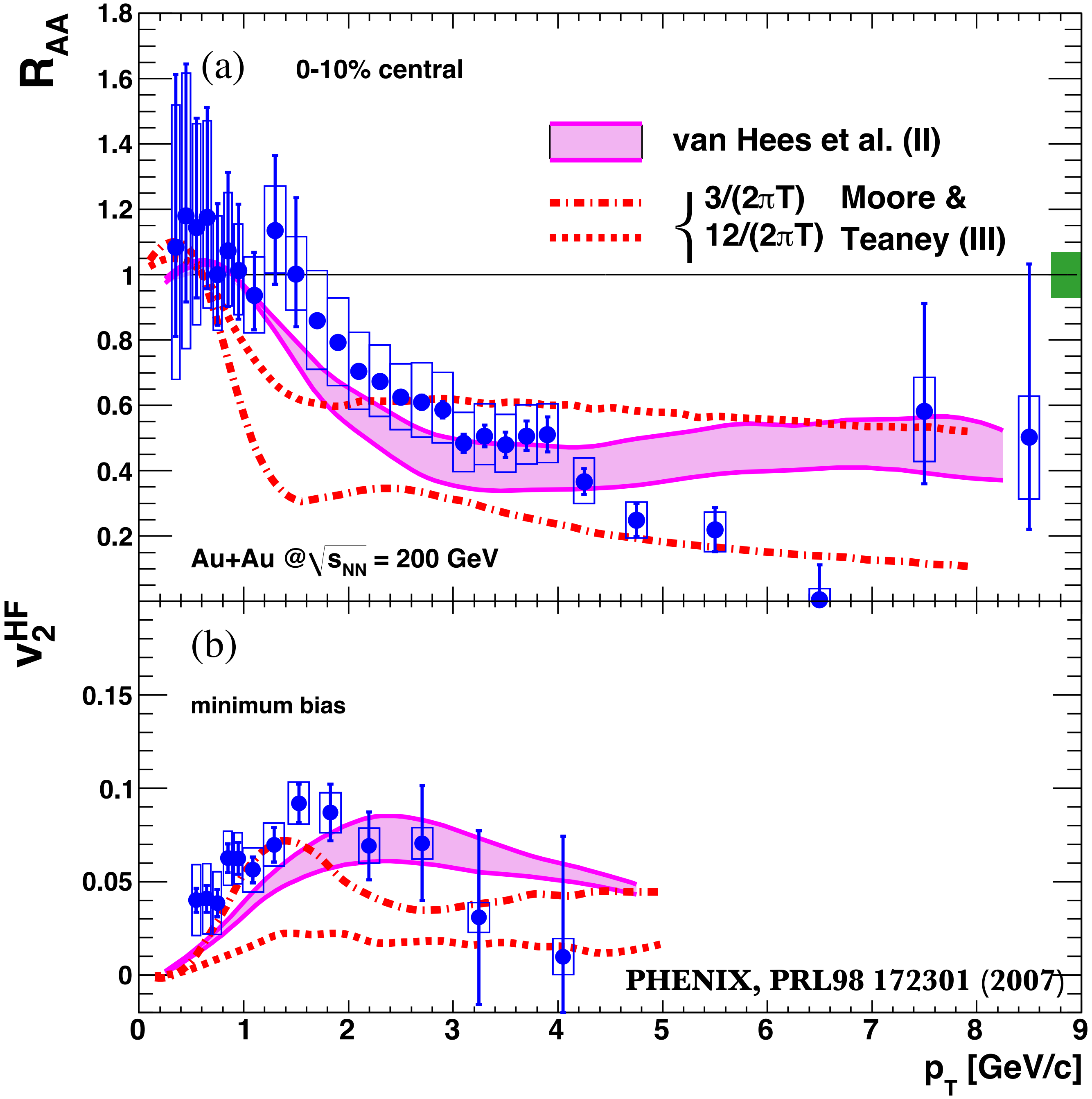
will determine if charm mesons follow same v2 scaling as light & strange hadrons

Diffusion of Charm

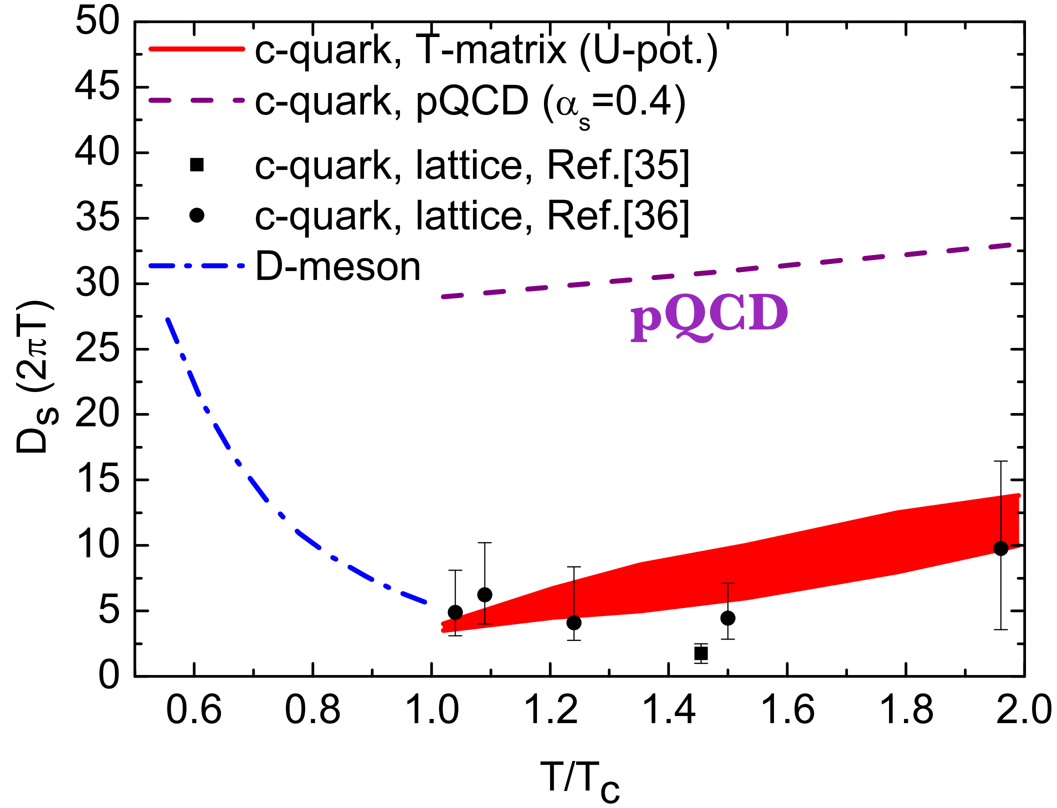
"quantitative measure of their coupling to thermalized light quarks and gluons"

He, Fries & Rapp, 1204.4442

$D_{HQ} \sim$ a few $\cdot\ (2\pi T)$



data far from pQCD expectation, but qualitatively consistent with lattice & Langevin based models

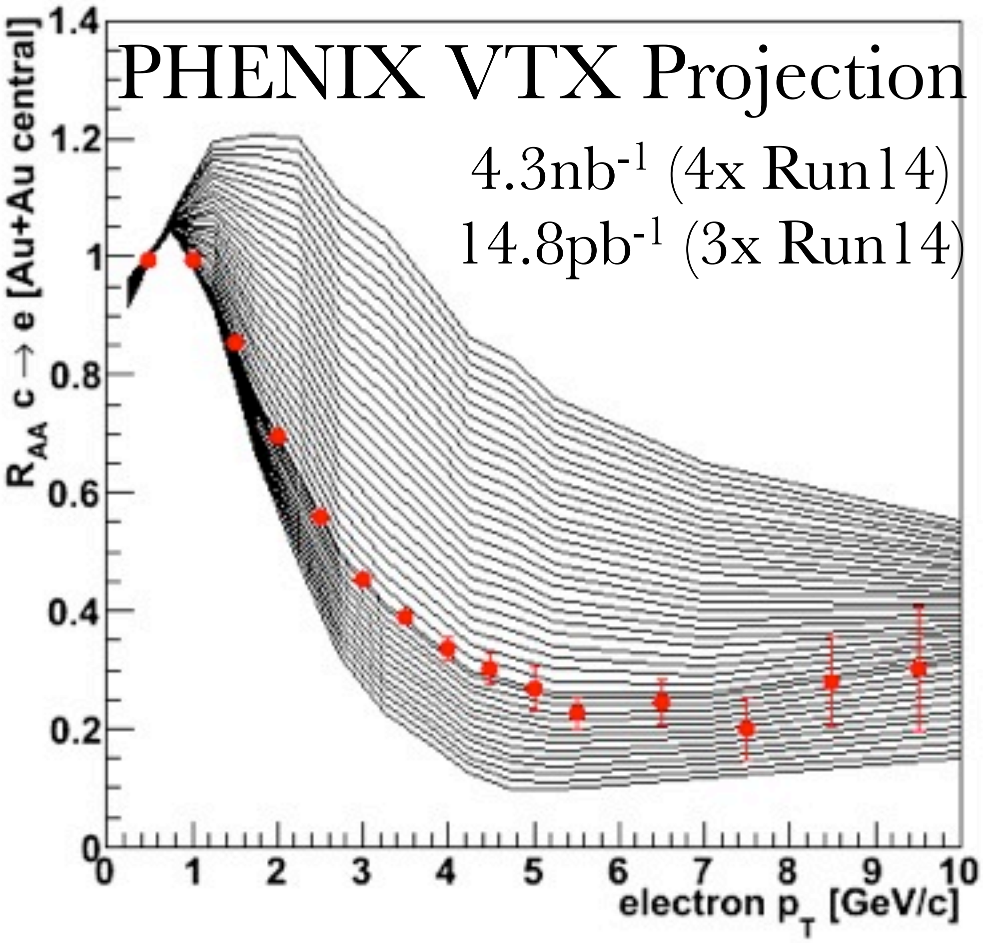


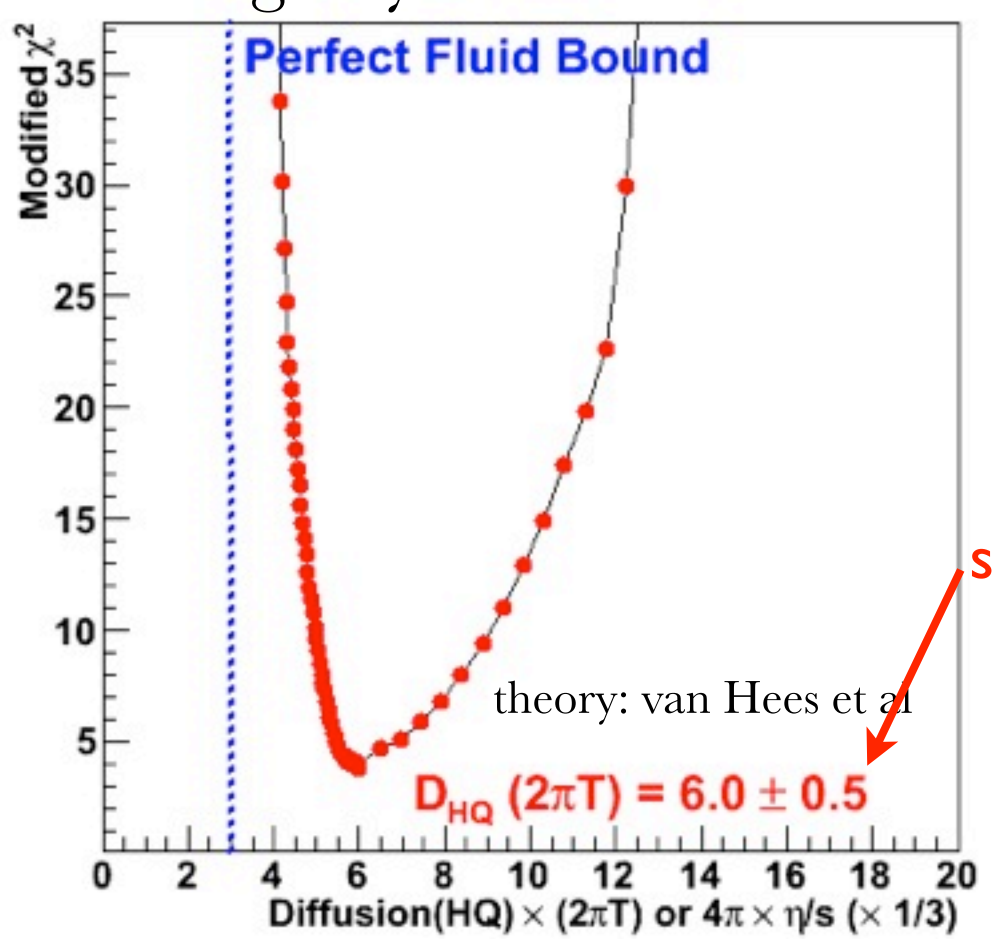
He, Fries & Rapp, 1204.4442

Diffusion of Charm

- D_{HQ} is related to η/s: **$D_{HQ} \cdot 2\pi T = 3\ (4\pi\eta/s)$**
- very different systematics
- need pA to quantify baseline
- is there consistency in η/s with flow measurements?
  - if not, why not?

FY15: additional AuAu & pp running beyond FY14

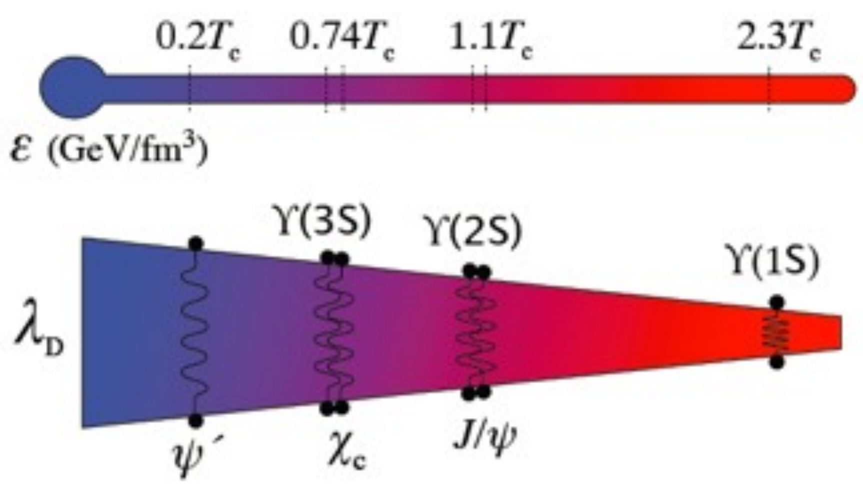


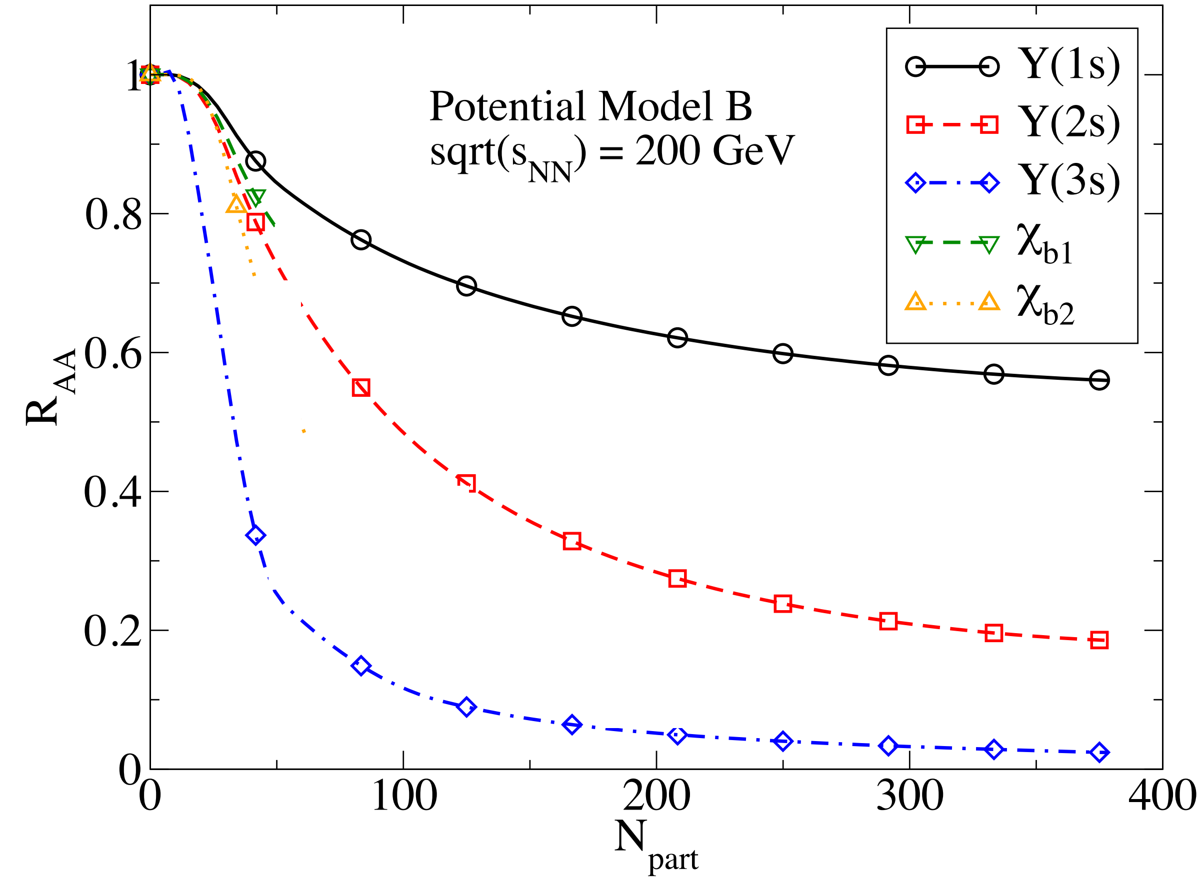


10% precision similar to goal on η/s from flow measurements

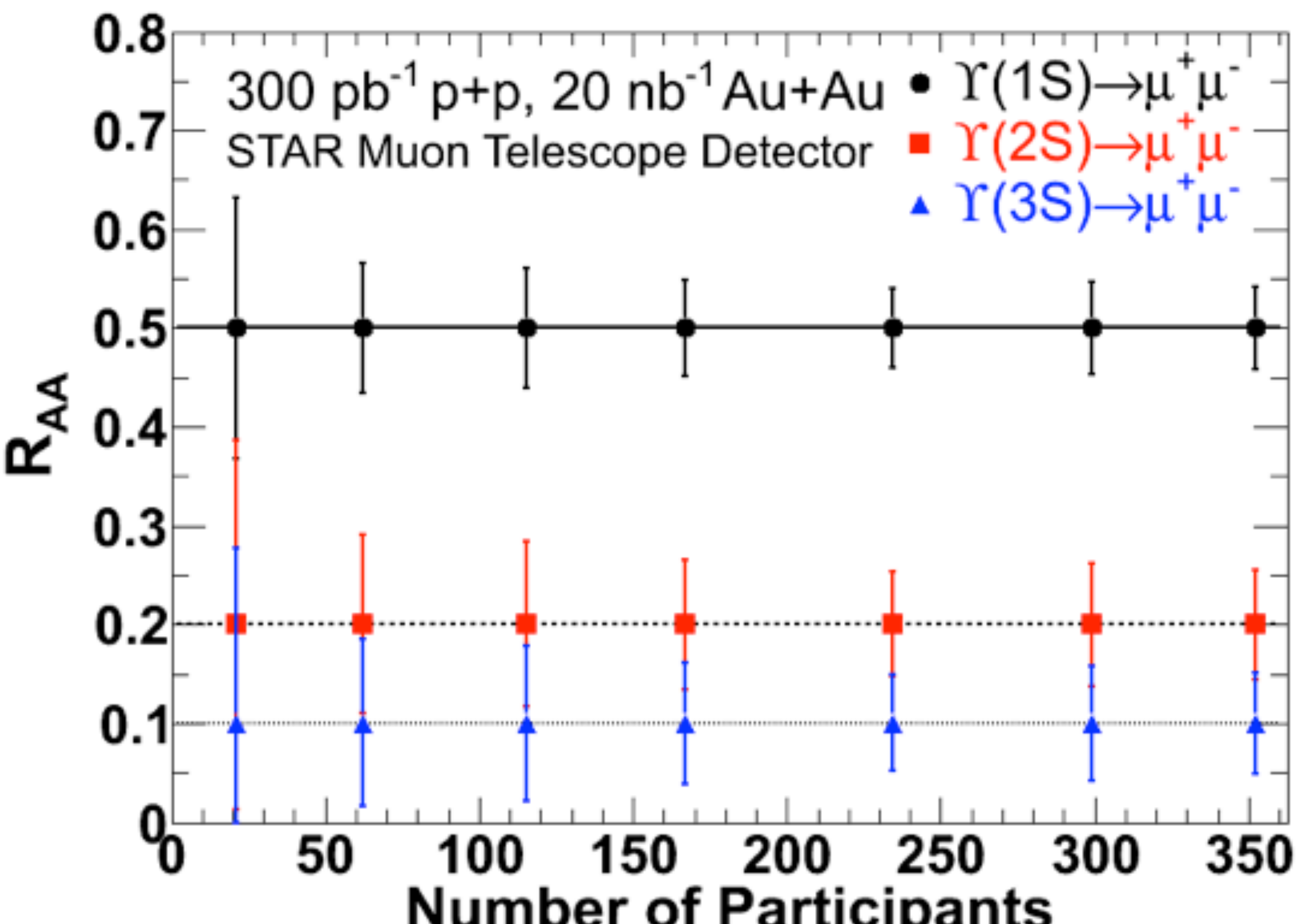
bottomonium states

Upsilons





Strickland & Bazow: 1112.2761

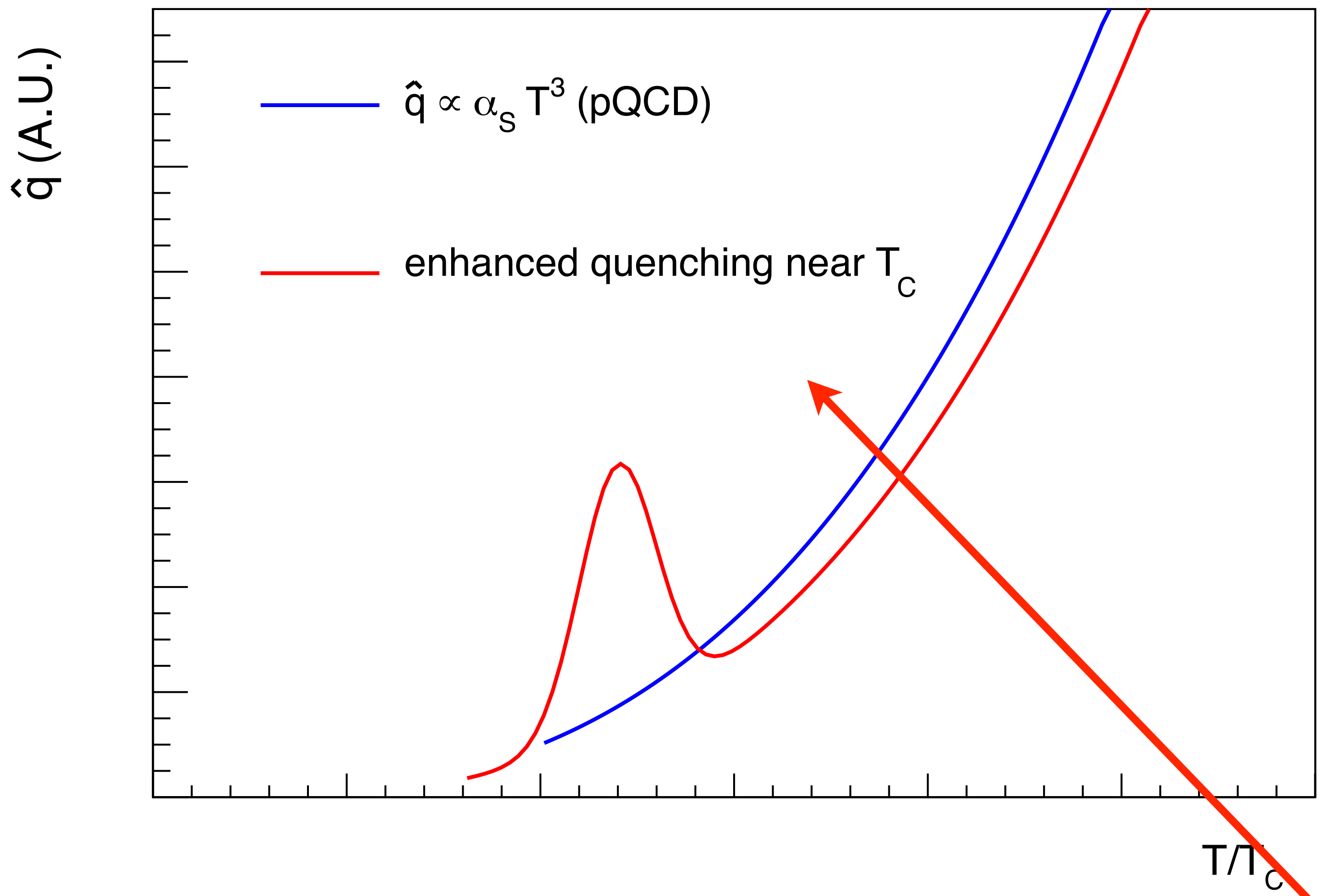


FY16: substantial pp running time required for reference data

pA data also required for baseline cold nuclear matter effects

jet quenching at RHIC

stronger coupling in RHIC regime?



in pQCD, jet quenching strongest at highest collision temperatures

- evidence from RHIC & LHC data that coupling is actually stronger at RHIC

PRL **102,** 202302 (2009) PHYSICAL REVIEW LETTERS week ending 22 MAY 2009

Angular Dependence of Jet Quenching Indicates Its Strong Enhancement near the QCD Phase Transition

Jinfeng Liao[1,2,*] and Edward Shuryak[1,†]

see also: Horowitz & Gyulassy 1104.4958, Buzzatti & Gyulassy 1106.3061, Zakharov 1105.2028...

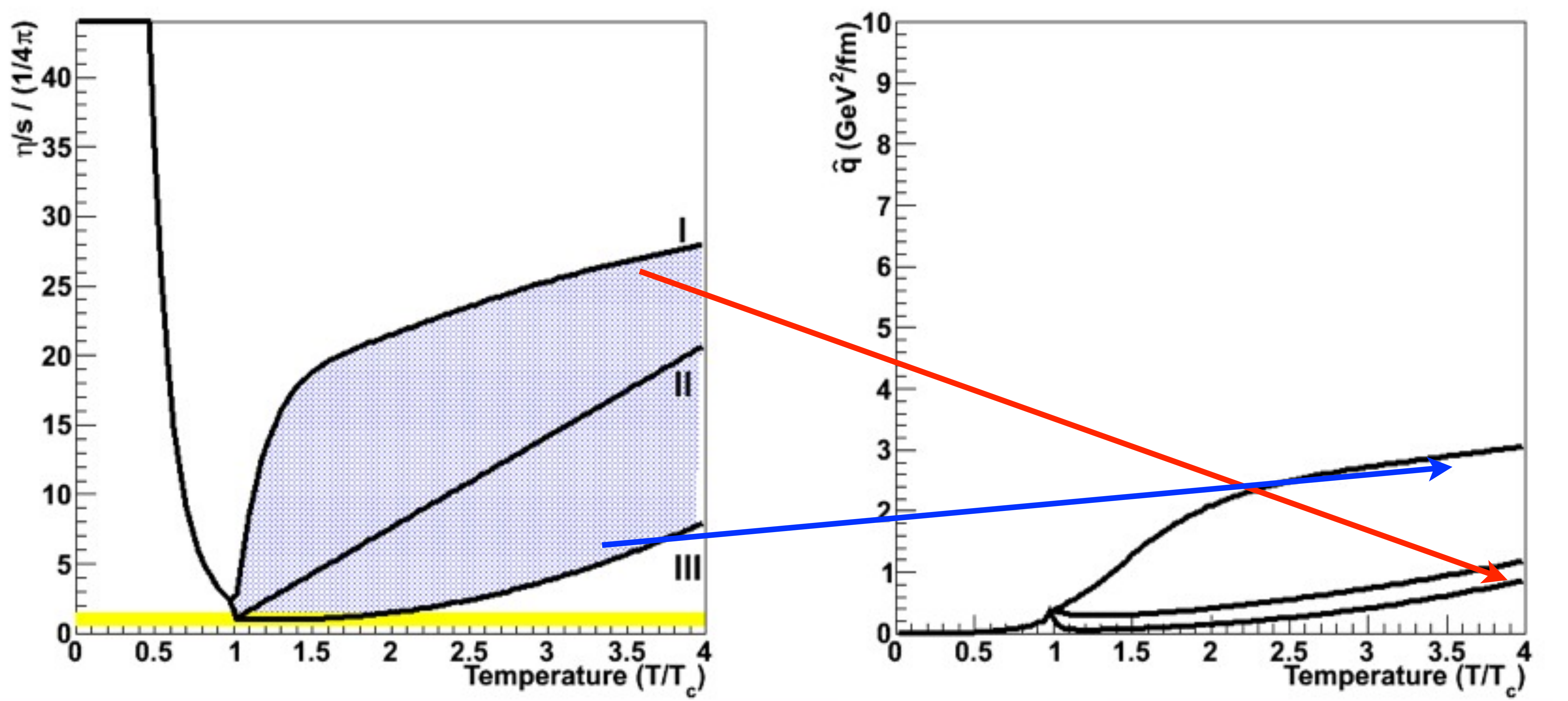
connecting η/s & jet quenching

PRL **99,** 192301 (2007) PHYSICAL REVIEW LETTERS week ending 9 NOVEMBER 2007

Small Shear Viscosity of a Quark-Gluon Plasma Implies Strong Jet Quenching

Abhijit Majumder,[1] Berndt Müller,[1] and Xin-Nian Wang[2]

at weak coupling: $\frac{\eta}{s} = 1.25\frac{T^3}{\hat{q}}$ at strong coupling: $\frac{T^3}{\hat{q}} \ll \frac{\eta}{s}$



- **key: independently measure BOTH qhat(T) & η/s(T)**

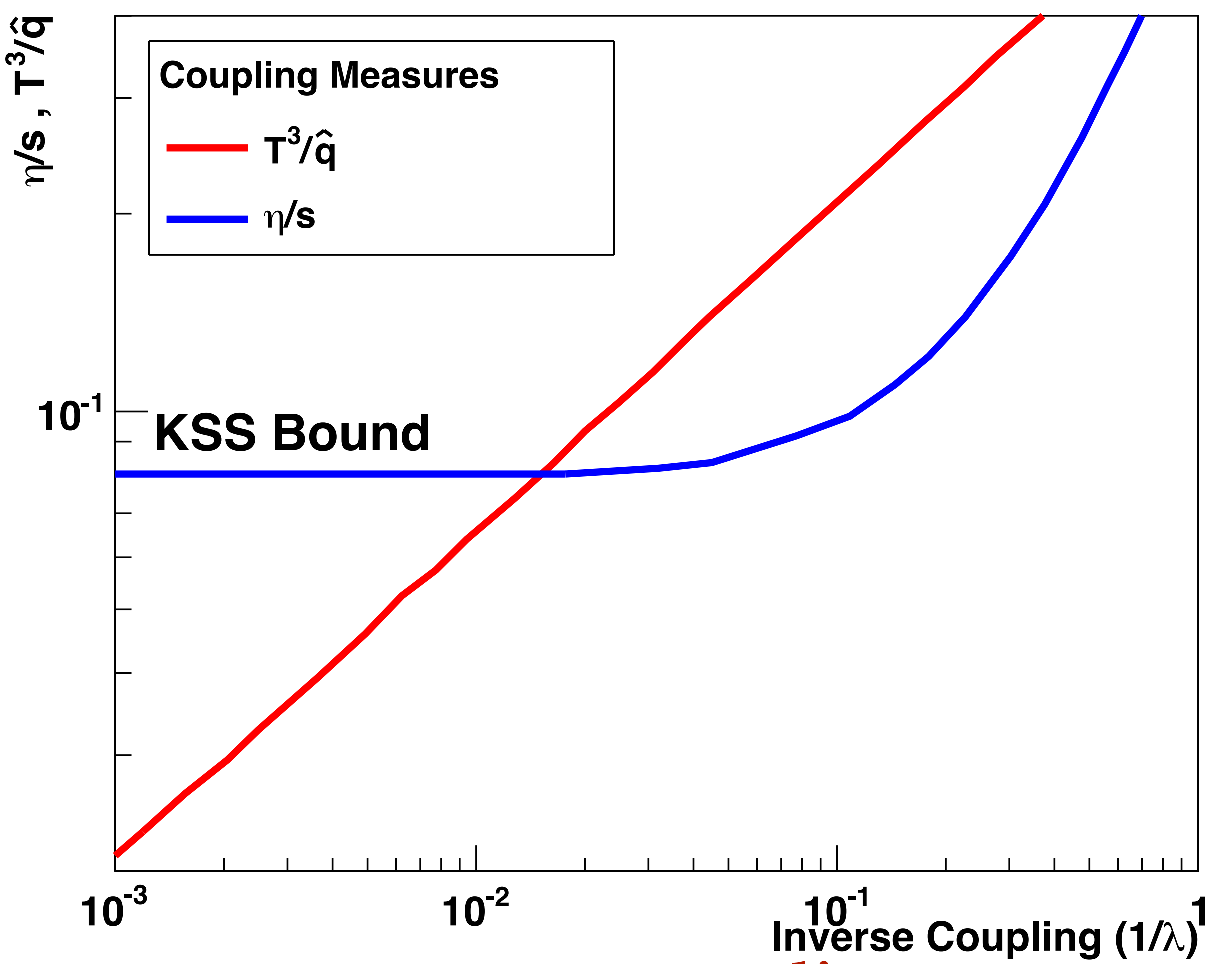
at strong coupling

PRL **99,** 192301 (2007) PHYSICAL REVIEW LETTERS week ending 9 NOVEMBER 2007

Small Shear Viscosity of a Quark-Gluon Plasma Implies Strong Jet Quenching

Abhijit Majumder,[1] Berndt Müller,[1] and Xin-Nian Wang[2]

- at strong coupling qhat/T^3 is a better measure of the coupling (λ) than η/s

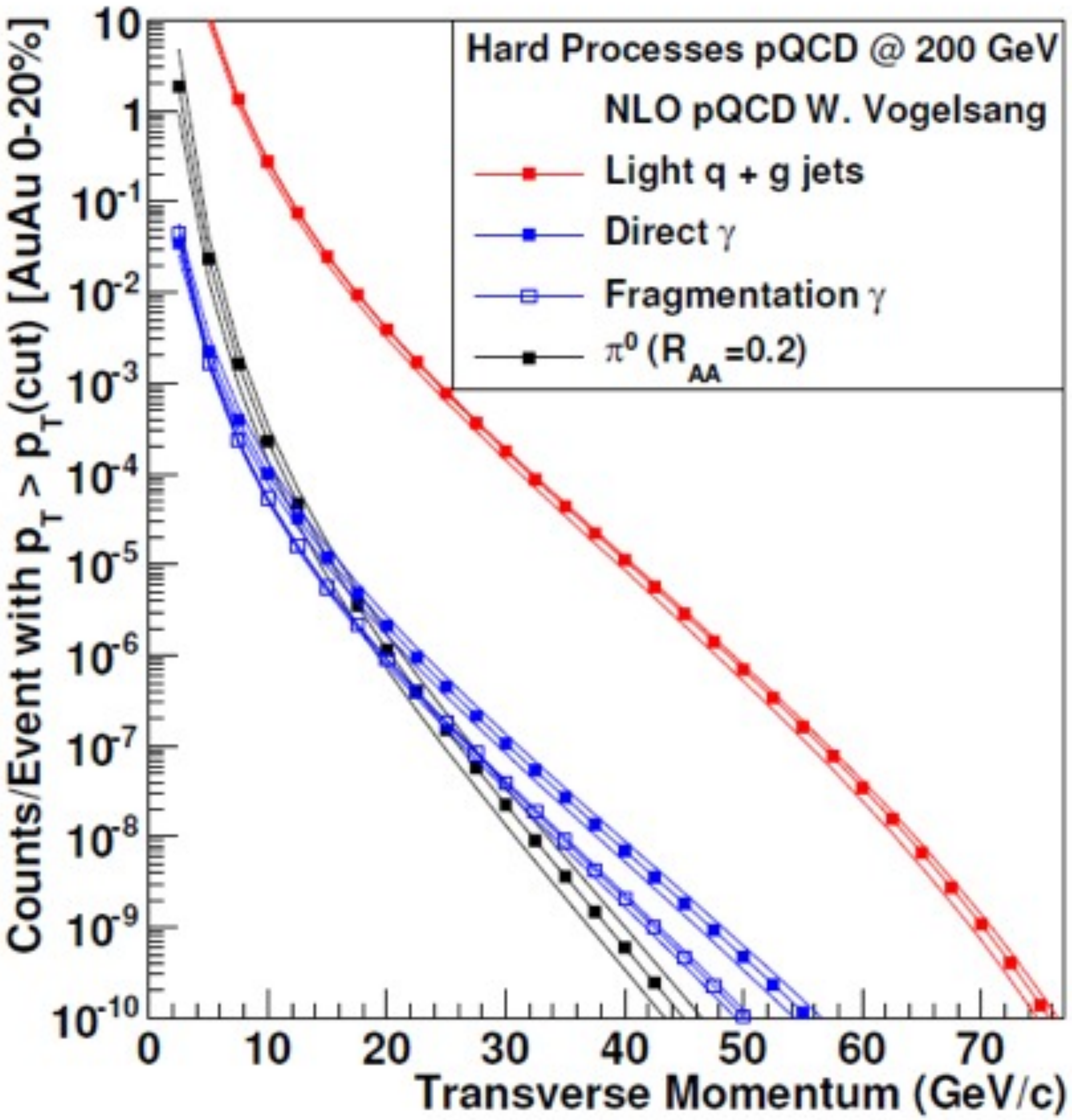


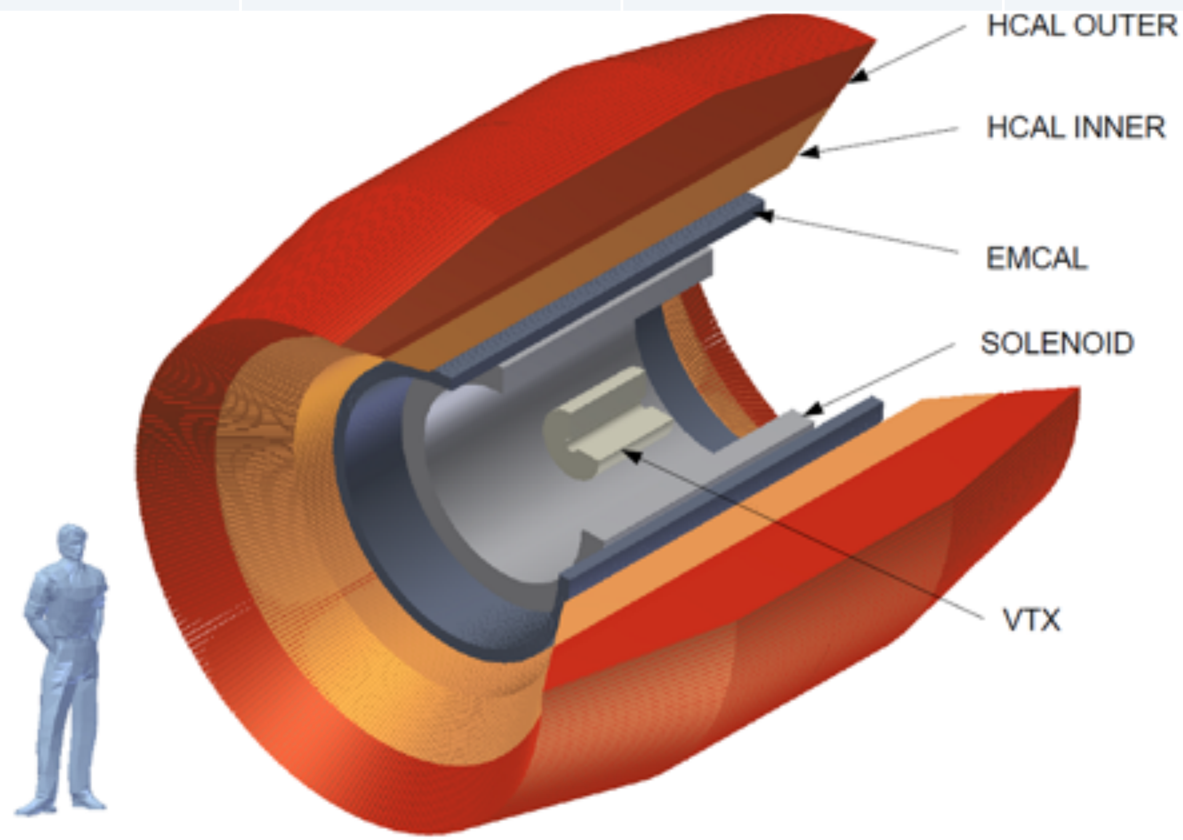
stronger coupling

jets at RHIC temperatures extremely interesting!

calorimetric jet detection at RHIC

	Au+Au (central 20%)	p+p	d+Au
>20GeV	10^7 jets 10^4 photons	10^6 jets 10^3 photons	10^7 jets 10^4 photons
>30GeV	10^6 jets 10^3 photons	10^5 jets 10^2 photons	10^6 jets 10^3 photons
>40GeV	10^5 jets	10^4 jets	10^5 jets
>50GeV	10^4 jets	10^3 jets	10^4 jets

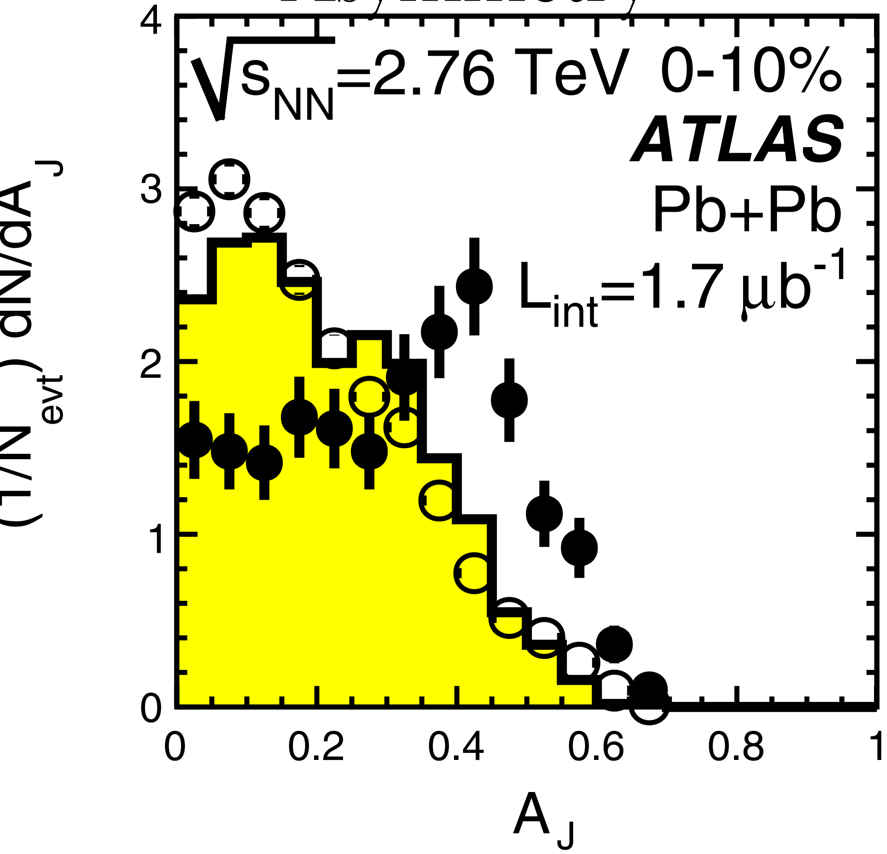


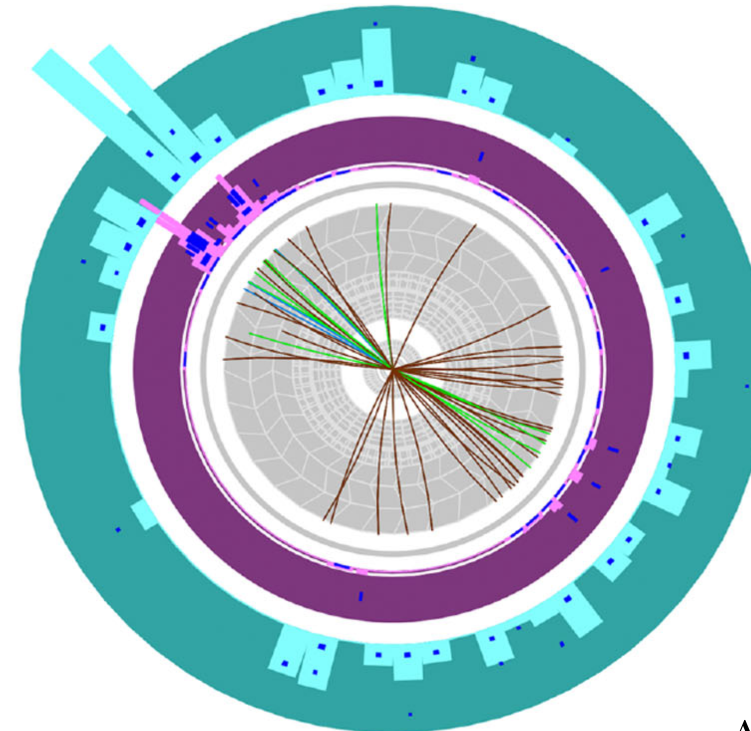


proposal:1207.6378

Constraining Effective Coupling

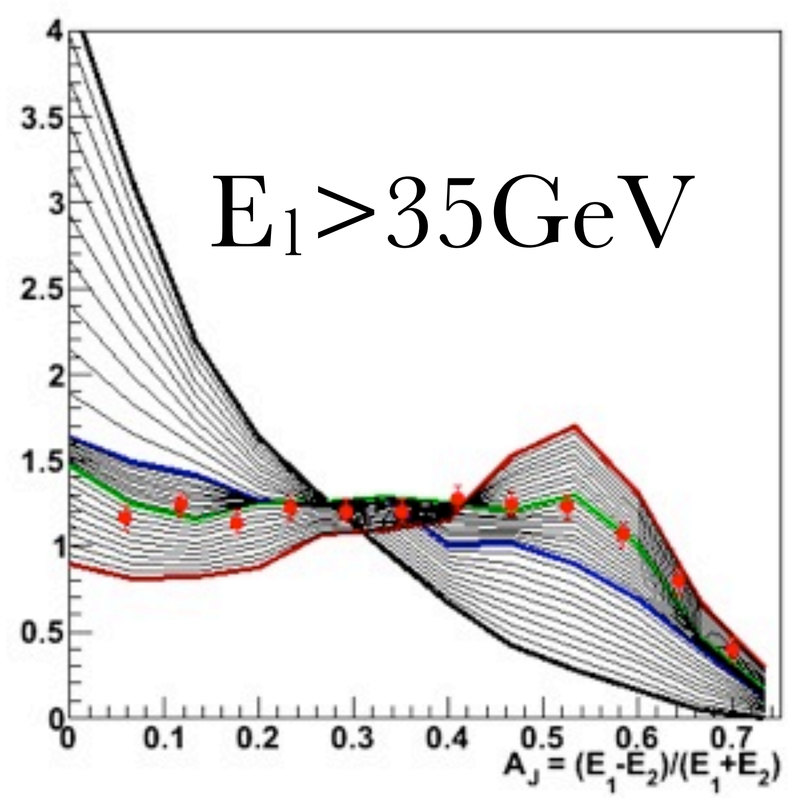
Di-Jet Energy Asymmetry

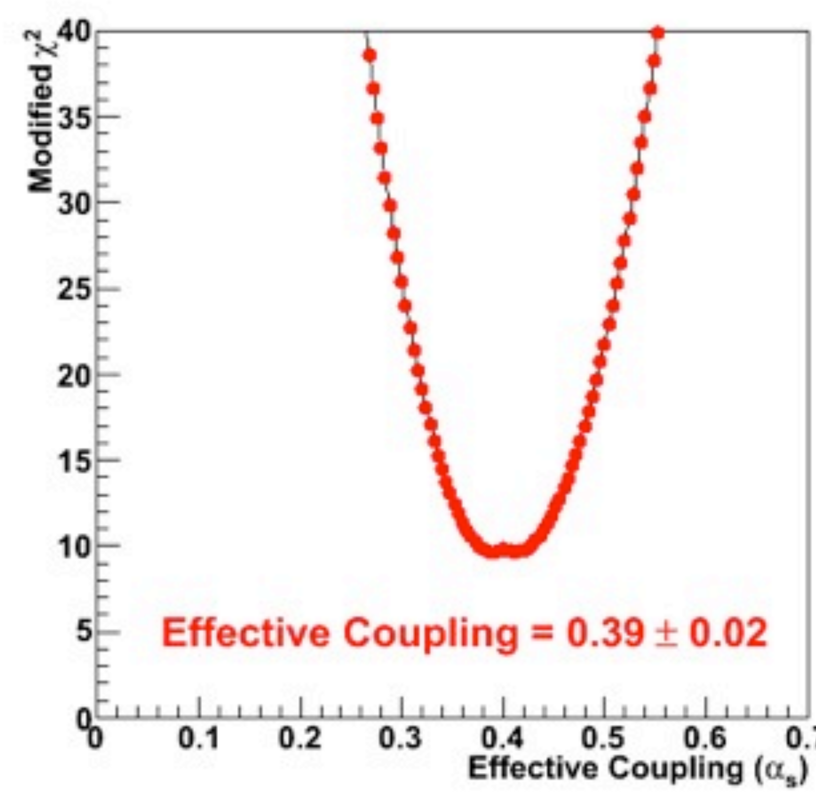




ATLAS PRL105 252303

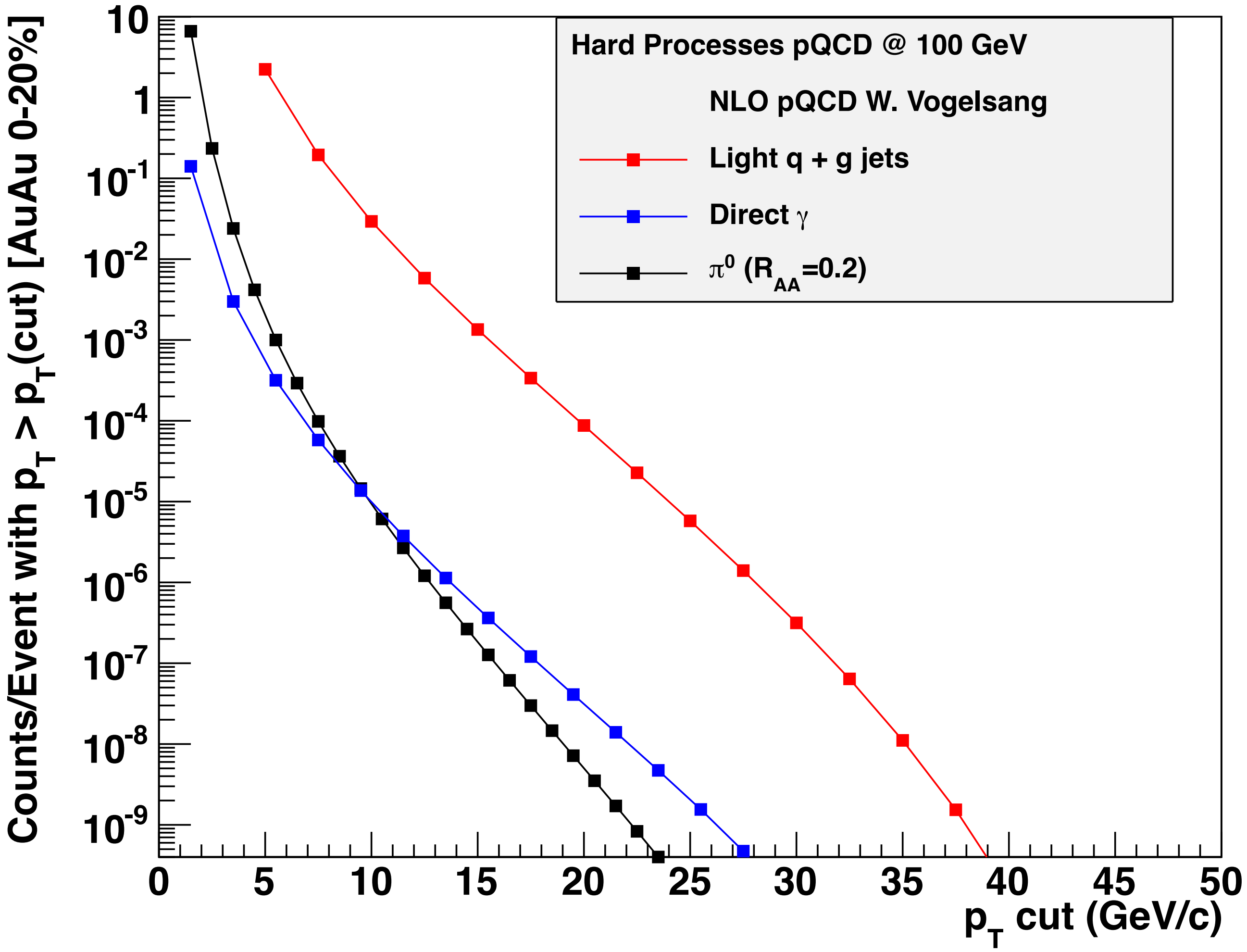
sPHENIX Projection
FY19
20 weeks AuAu

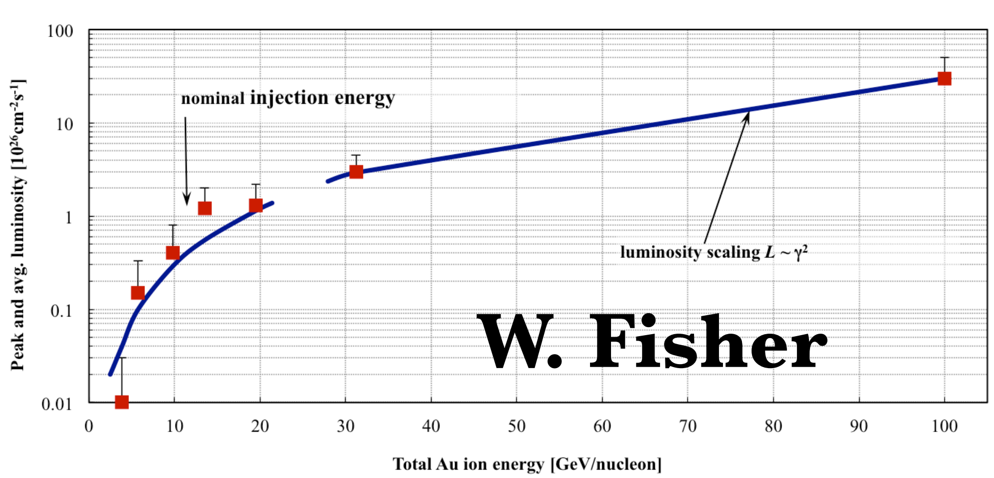


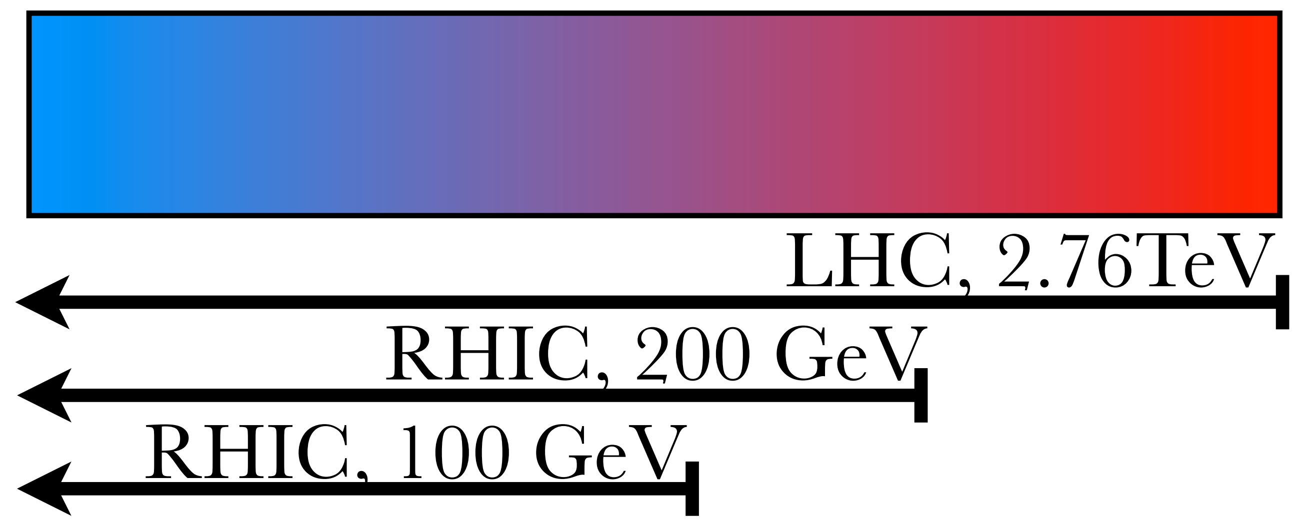


calculation: Coleman-Smith

jet measurements @ $\sqrt{s_{NN}}$ = 100GeV



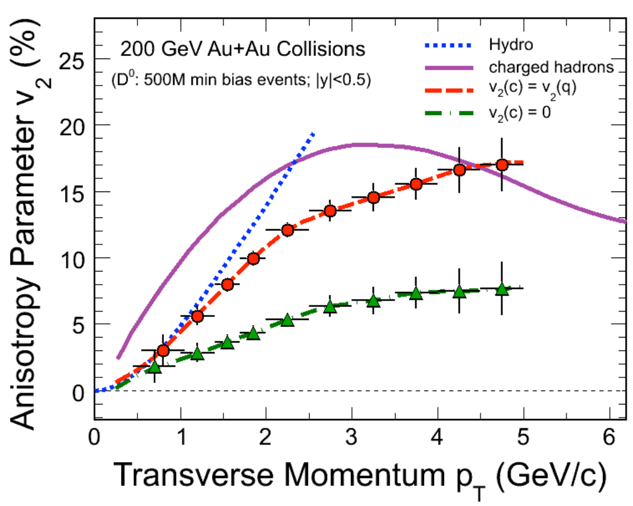


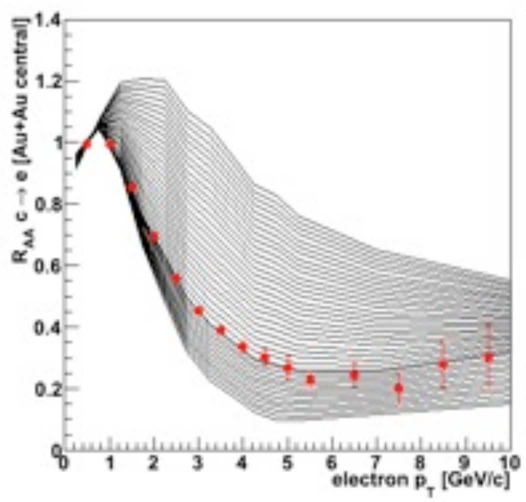


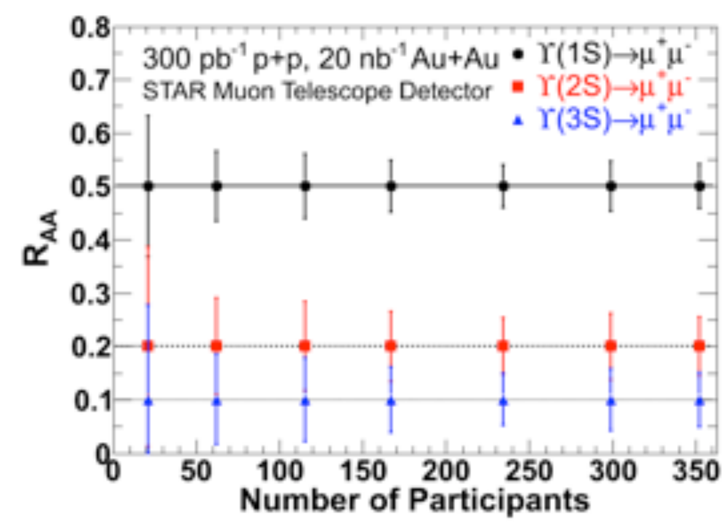
- 2B central AuAu events / 20 week run
- →10^5 jets > 20GeV
- rates include RHIC luminosity scaling with beam energy
- working to determine lowest energy feasible for jet measurements

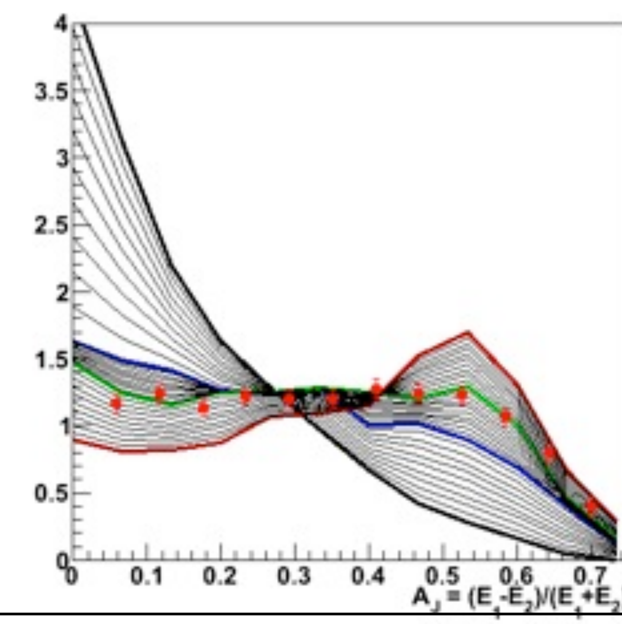
Hard Probes at RHIC

- measure the temperature dependence of transport properties by varying the collision energy
- interconnections between QGP properties enables a coherent understanding of QGP









I've highlighted new measurements enabled by upgraded detectors
additionally dramatic improvements in understanding to be gained by huge increase in statistical precision of existing measurements

RHIC luminosity, detector upgrades and robust theoretical models enable a rich era of hard probes physics at RHIC!

extras

LHC timeline

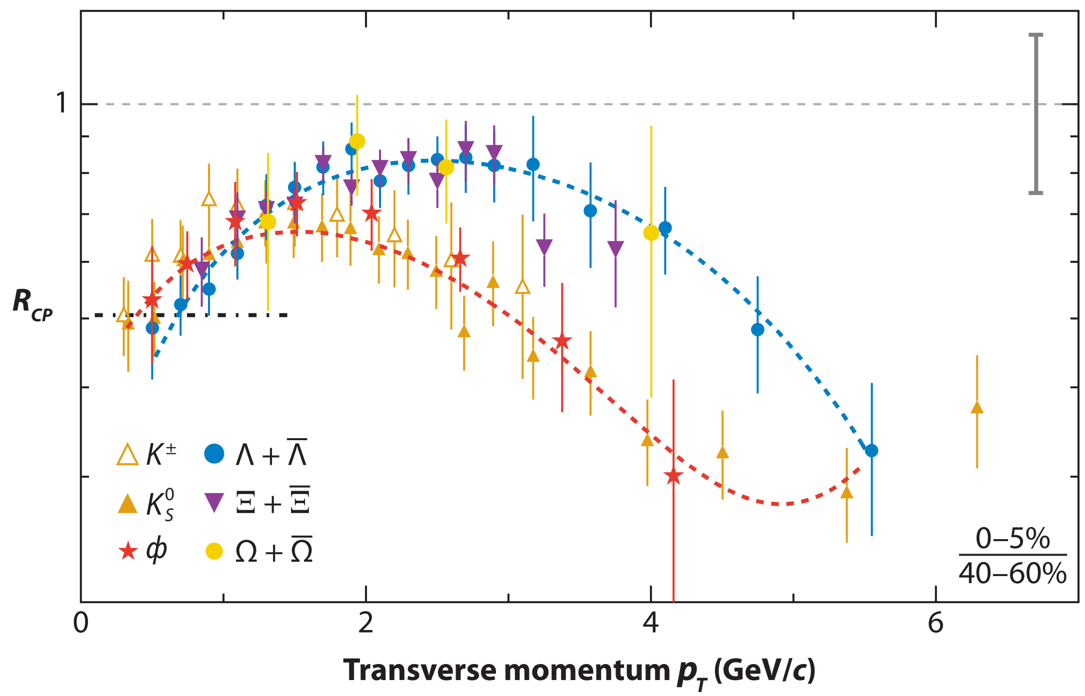
LHC Heavy-Ion Programme to 2022

2013-14		Long shutdown LS1, increase *E*
2015-16	**Pb-Pb**	Design luminosity+, ~ 250 μb^{-1}/year
2017	**p-Pb *or* Pb-Pb**	P-Pb to enhance 2015-16 data. Energy? Pb-Pb if μb^{-1} still needed
2018		LS2: install DS collimators around ALICE to protect magnets (ALICE upgrade for 6 × design luminosity)
2019	**Pb-Pb**	Beyond design luminosity … as far as we can. Reduce bunch spacing?
2020	**p-Pb**	
2021	**Ar-Ar**	Intensity to be seen from injector commissioning for SPS fixed target. Demanding collimation requirements.
2022		LS3, upgrades ?? Stochastic cooling ??

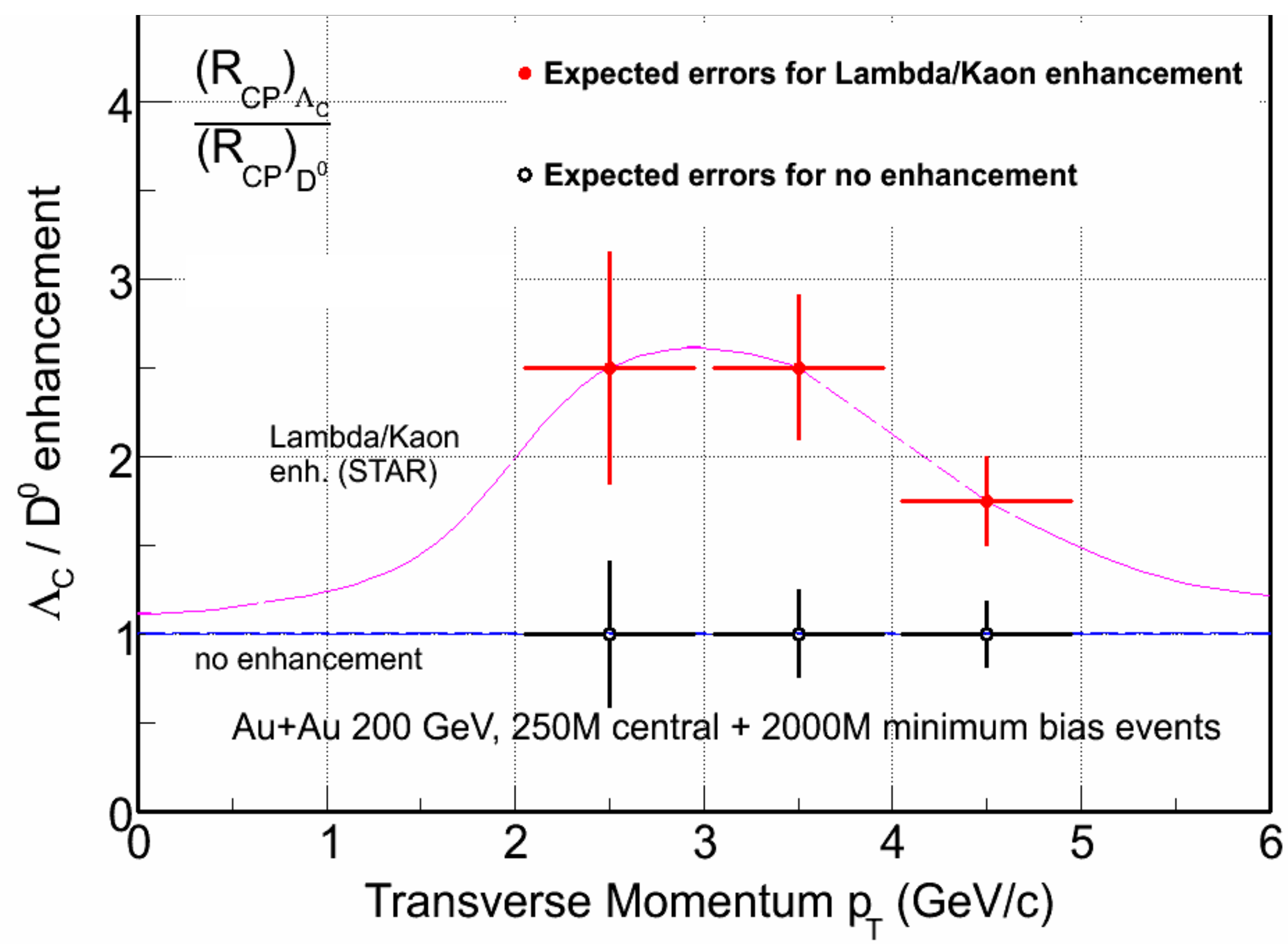
J.M. Jowett,Town Meeting "Relativistic Heavy Ion Collisions", CERN, 29/6/2012 26

does charm coalesce?

FY16, additional AuAu running 25 weeks



HFT Projections



- similar measurement at LHC doesn't come until ALICE ITS Upgrade

2013 & 2014 RHIC Running

PAC Reommendations: June 2012

For Run 13 the PAC recommends the following (*in order of priority*):

1. Running with polarized proton collisions at 500 GeV to provide an integrated luminosity of 750 pb^{-1} at an average polarization of 55%.
2. Depending on the amount of running time remaining after priority #1
   a. If less than 3 weeks remain, a week of 200 GeV Au+Au collisions.
   b. If at least 3 weeks of running time remain, 3 weeks of 15 GeV Au+Au collisions.
3. 8 days of 62 GeV p+p collisions.
4. At the discretion of the ALD, 4 days of low-luminosity running to accomplish the pp2pp goals.

For Run 14 the PAC recommends the following (*in order of priority*)

1. 8-10 weeks of 200 GeV Au+Au collisions.
2. 4-5 weeks of 200 GeV polarized proton collisions.
3. For any remaining time, 200 GeV d+Au collisions.

Timeline for RHIC's Next Decade

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 500 GeV $\vec{p}+\vec{p}$ • 15 GeV Au+Au	• Sea antiquark and gluon polarization • QCD critical point search	• Electron lenses • upgraded pol'd source • STAR HFT
2014	• 200 GeV Au+Au and baseline data via 200 GeV p+p (needed for new det. subsystems)	• Heavy flavor flow, energy loss, thermalization, etc. • quarkonium studies	• 56 MHz SRF • full HFT • STAR Muon Telescope Detector • PHENIX Muon Piston Calorimeter Extension (MPC-EX)
2015-2017	• High stat. Au+Au at 200 and ~40 GeV • U+U/Cu+Au at 1-2 energies • 200 GeV p+A • 500 GeV $\vec{p}+\vec{p}$	• Extract $\eta/s(T_{min})$ + constrain initial quantum fluctuations • further heavy flavor studies • sphaleron tests @ $\mu_B \neq 0$ • gluon densities & saturation • finish p+p W prod'n	• Coherent Electron Cooling (CeC) test • Low-energy electron cooling • STAR inner TPC pad row upgrade
2018-2021	• 5-20 GeV Au+Au (E scan phase 2) • long 200 GeV + 1-2 lower $\sqrt{s}$ Au+Au w/ upgraded dets. • baseline data @ 200 GeV and lower $\sqrt{s}$ • 500 GeV $\vec{p}+\vec{p}$ • 200 GeV $\vec{p}+A$	• x10 sens. increase to QCD critical point and deconfinement onset • jet, di-jet, γ-jet quenching probes of E-loss mechanism • color screening for different $q\bar{q}$ states • transverse spin asyms. Drell-Yan & gluon saturation	• sPHENIX • forward physics upgrades