Characterizing the new state of strongly interacting quark-gluon matter discovered at RHIC

 

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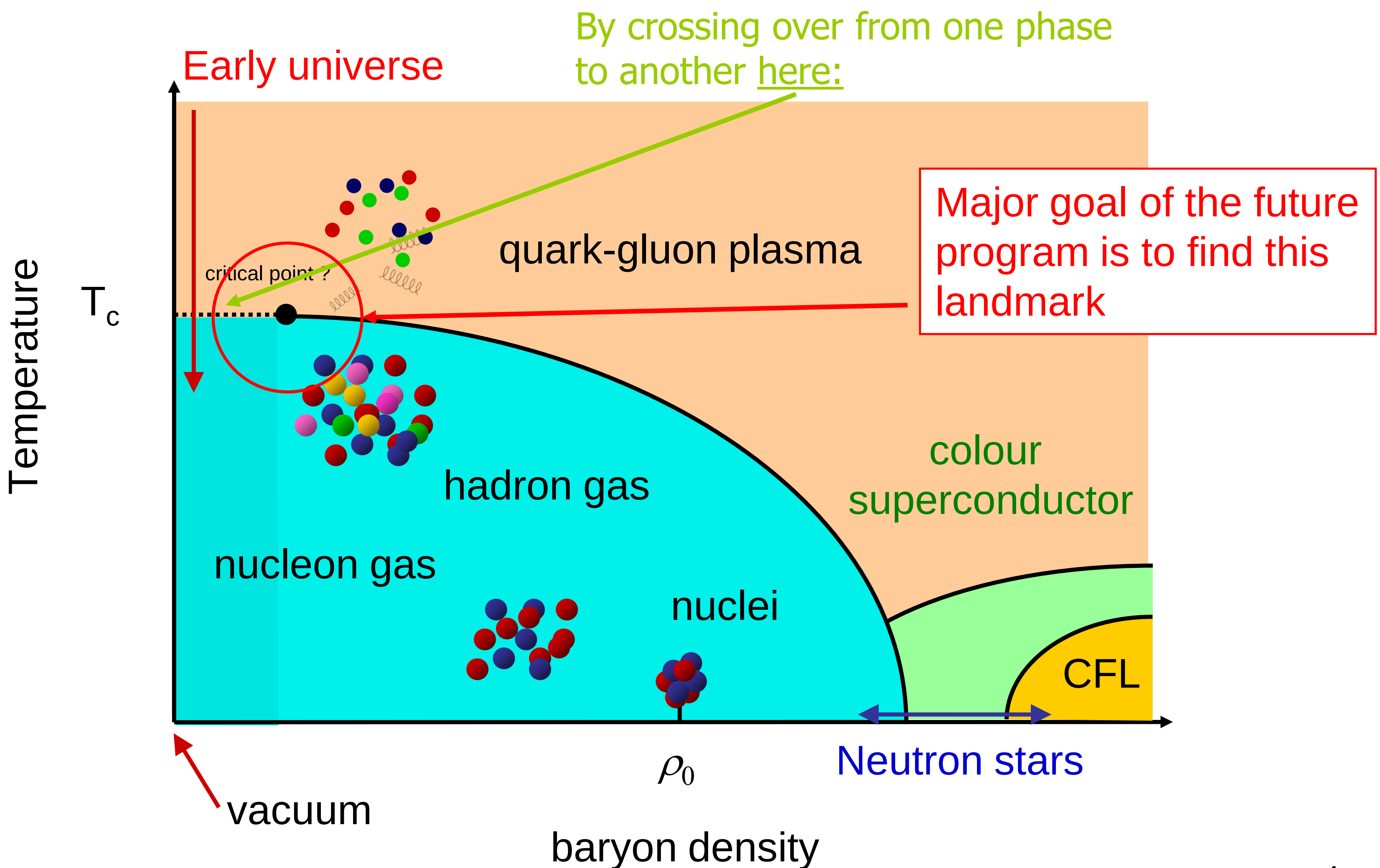
Plan of this lecture

- Overview of physics and experimental tools at RHIC
- Experimental results to date
  - Collective Flow
  - Hard Probes
  - Additional supporting evidence
- New physics coming in the future
- Conclusions

The Science of RHIC

- RHIC's original science mission:
  - Discovery of a new state of matter (quark-gluon plasma) in central heavy ion collisions (✓)
  - Detailed unfolding of the spin structure of the nucleon
- "Value added" physics:
  - Low x structure of hadrons
  - Fundamental tests of QCD
  - Search for new exotics
    - Forward inclusive spectra and correlations
    - Tagged forward proton studies
    - Ultra-peripheral collisions

The inspiration for the RHIC voyage of discovery: belief that under the right conditions, it is possible to "melt" protons and neutrons into their constituents



What are the phases of QCD Matter?

What we expected: lattice QCD at finite temperature

The nature of the transition?

The most realistic lattice calculations suggest there are no discontinuities in thermodynamic properties for the conditions at RHIC (i.e., no 1st- or 2nd-order phase transition), but that there is a smooth crossover transition with a rapid evolution vs. temperature near $T_c \approx 160 - 170$ MeV

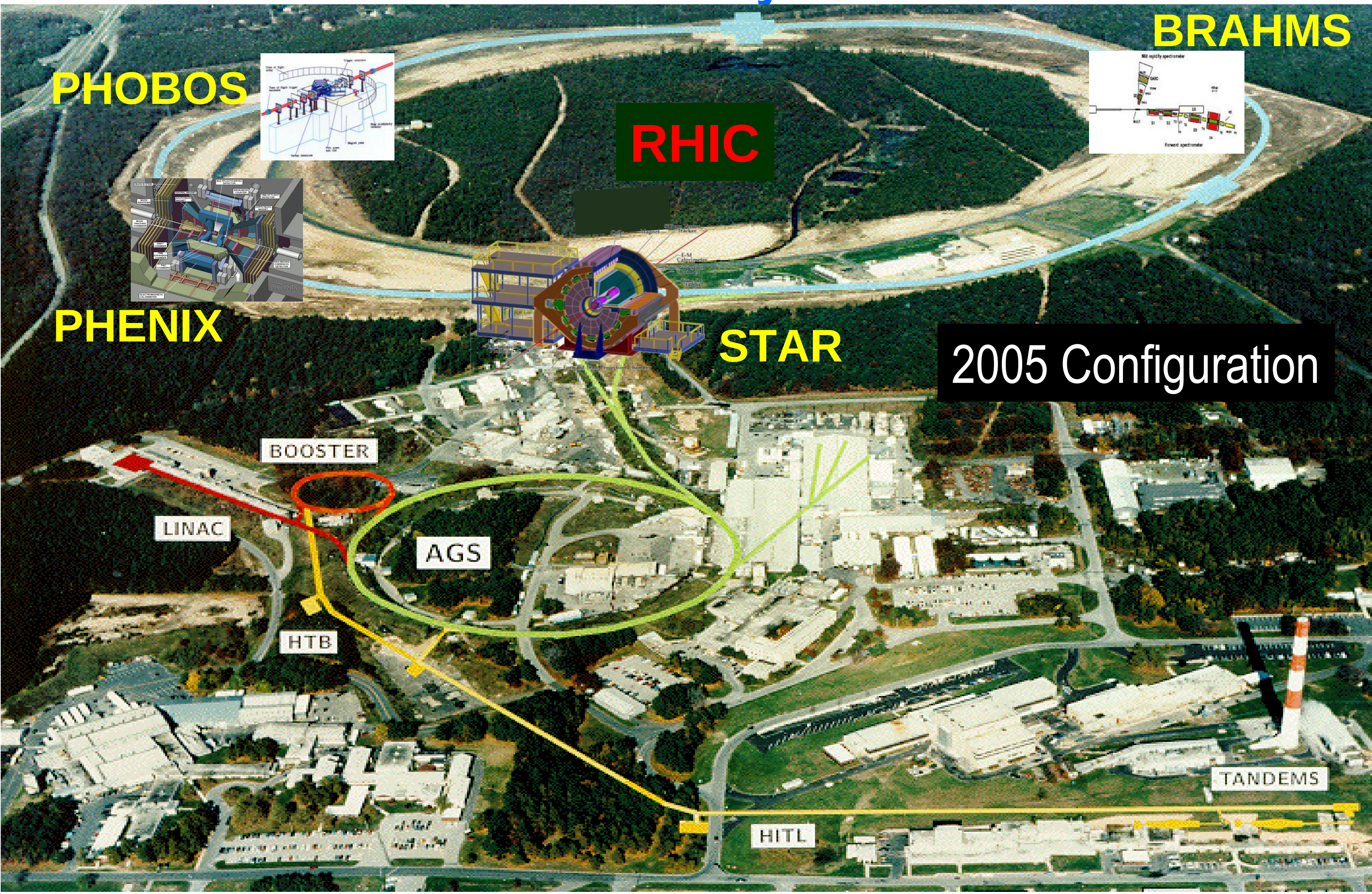
s (Stefan-

nn limit)

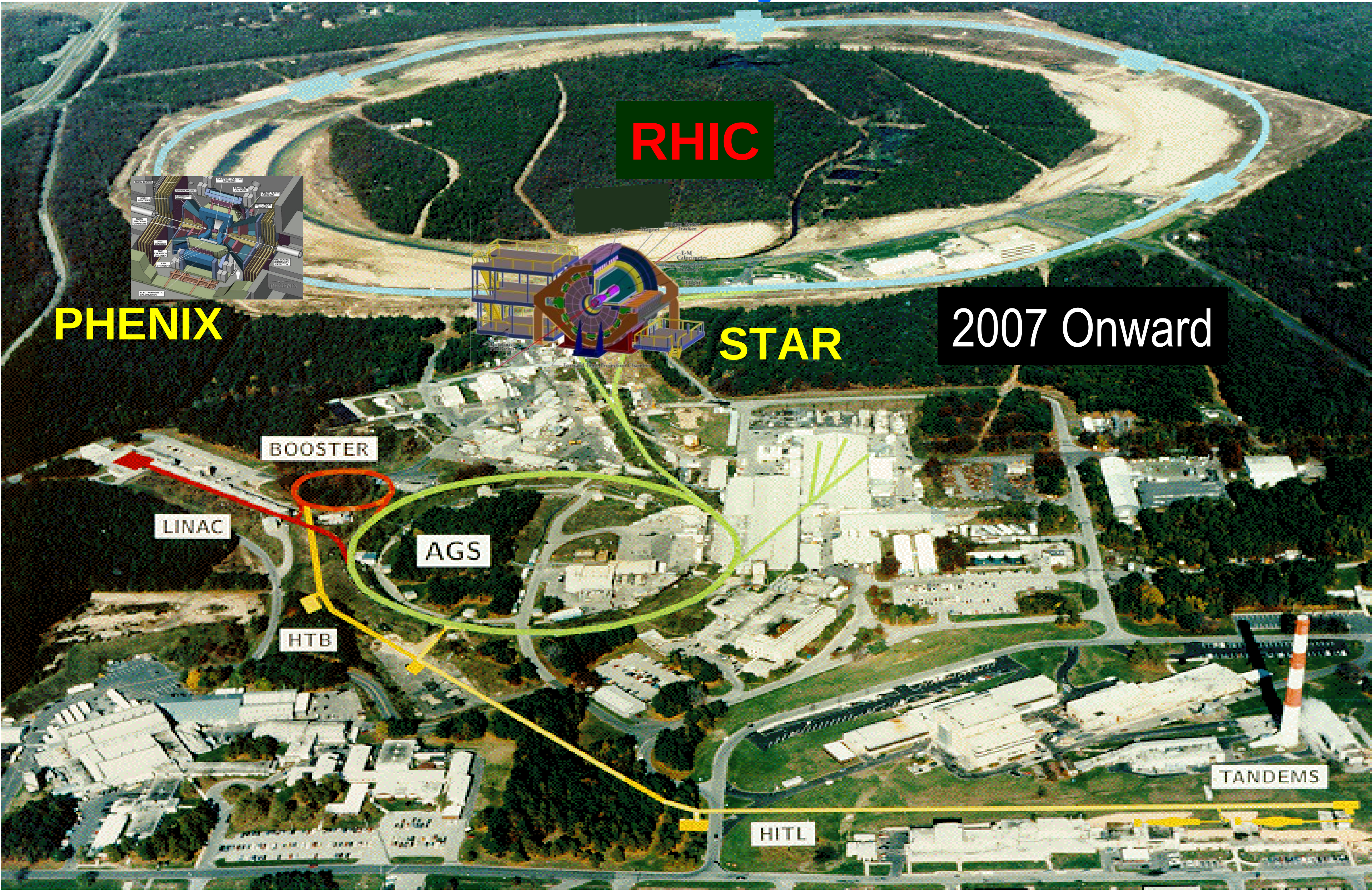
Critical energy density: $\varepsilon_C = (6 \pm 2) T_C^4$

$T_C \sim 175$ MeV $\Rightarrow \varepsilon_C \sim 1$ GeV/fm^3

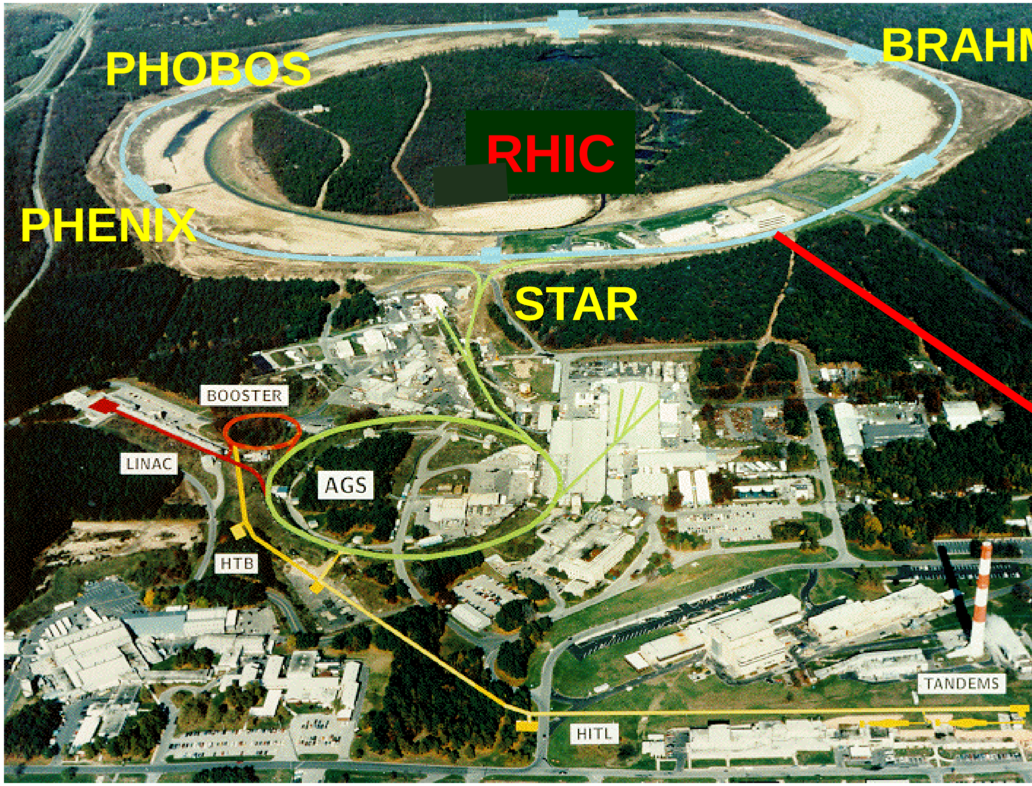
Relativistic Heavy Ion Collider



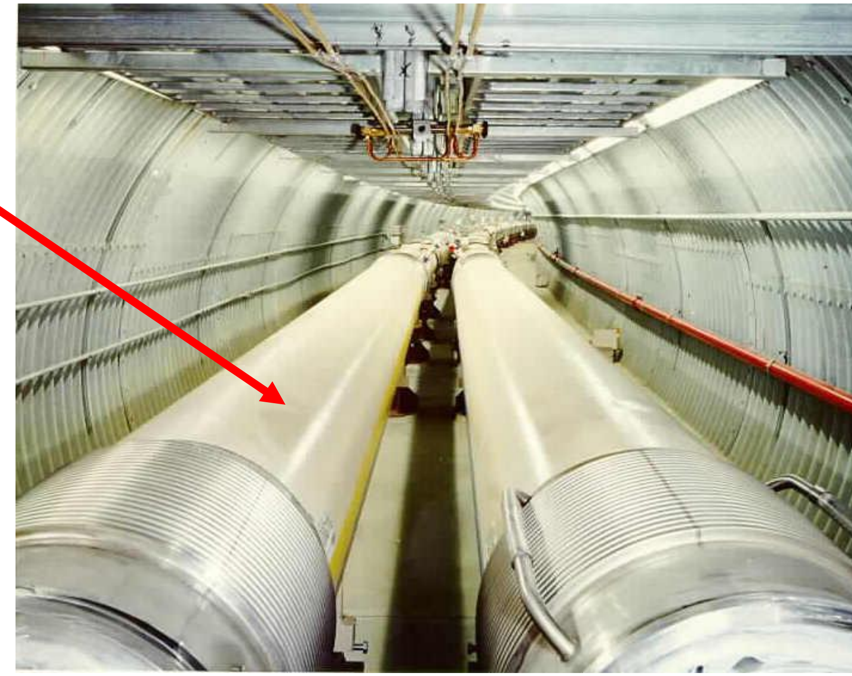
Relativistic Heavy Ion Collider



Relativistic Heavy Ion Collider



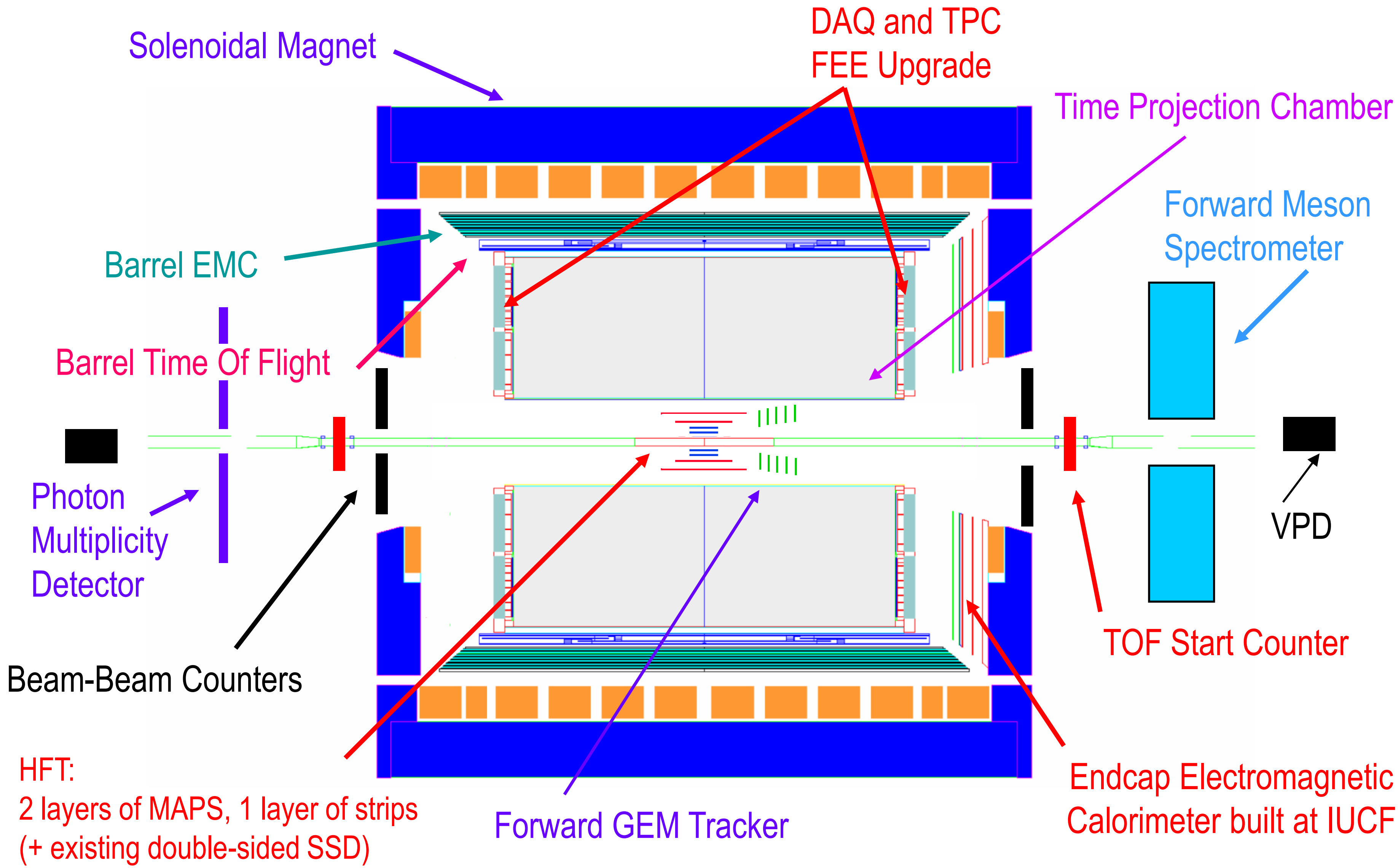
Two Concentric Superconducting Rings



Ions: A = 1 ~ 200, $\vec{p}\vec{p}$, pA, AA, AB

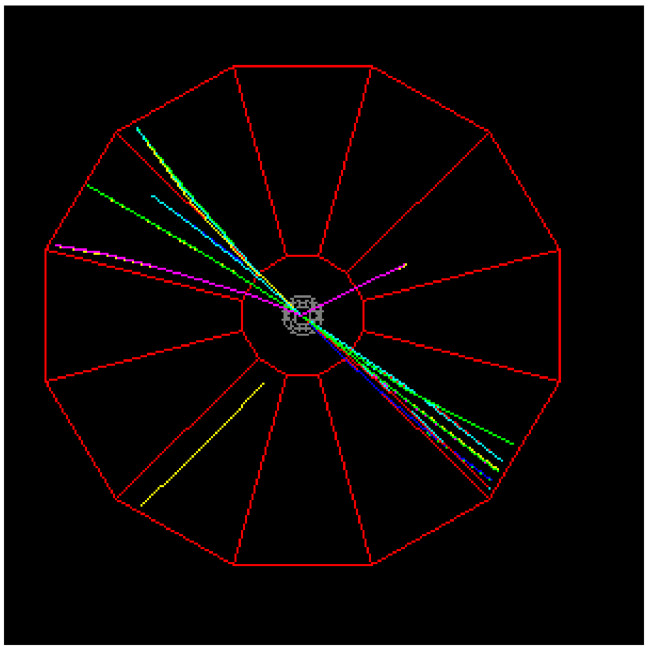
Design Performance	Au + Au	(Now)	p + p	(Now @ 200)
Max $\sqrt{s_{nn}}$	200 GeV		500 GeV	
L [cm^{-2} s^{-1}]	2×10^{26}	(3.6×10^{27})	1.4×10^{31}	(3.5×10^{31})
Interaction rates	1.4 khz	(~ 36 khz)	300 khz	(~ 750 khz)

The (evolving) STAR detector

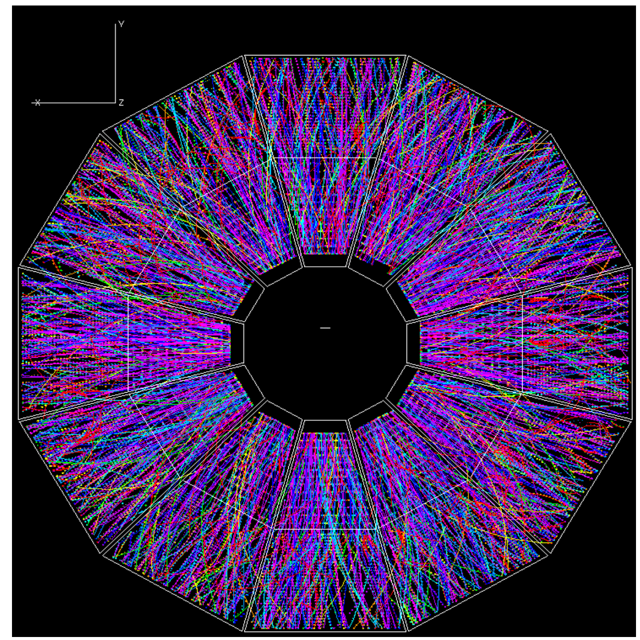


From p+p to Au+Au in the STAR TPC

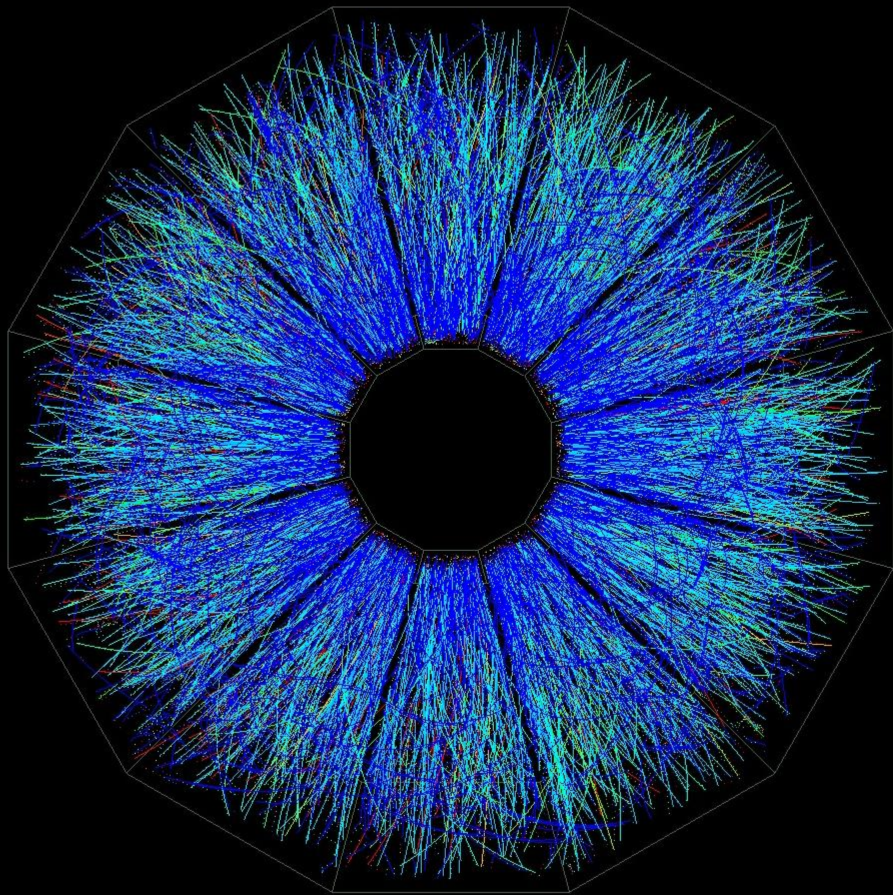
p+p →jet+jet
(STAR@RHIC)



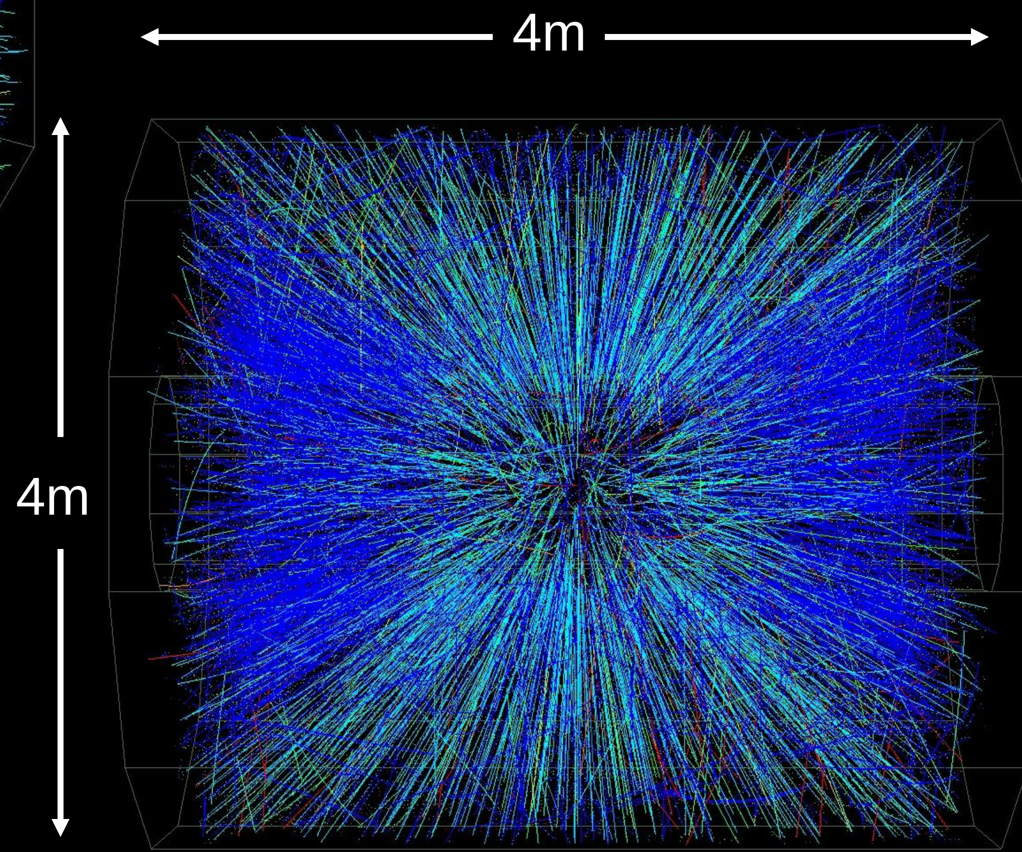
Au+Au → X
(STAR@RHIC)



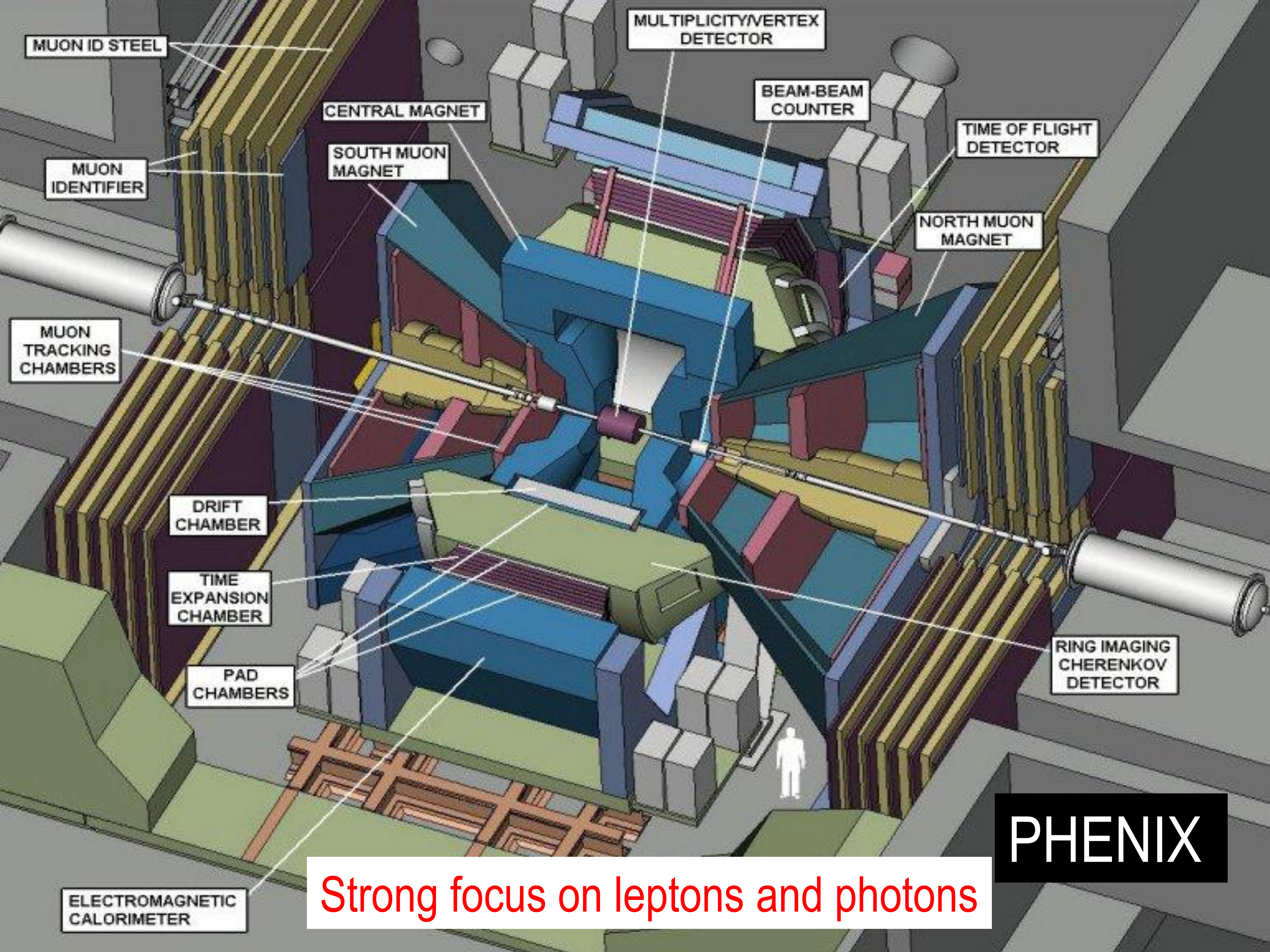
Au on Au Event at CM Energy ~ 130 A-GeV



Central Event



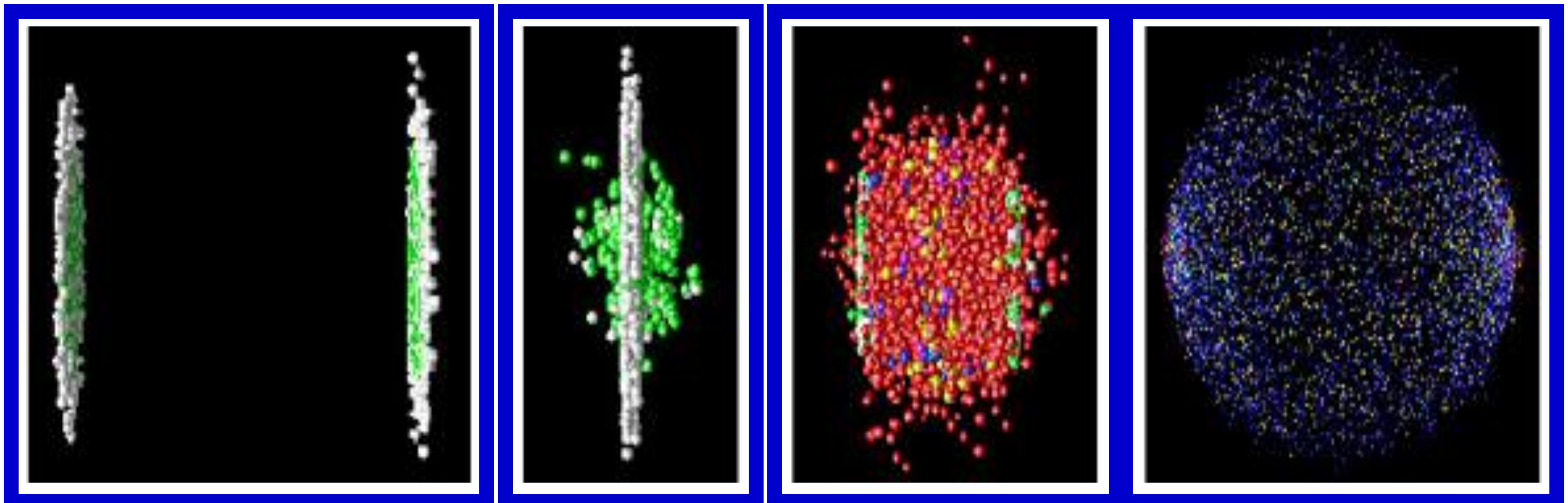
color code ⇒ energy loss



MUON ID STEEL
MULTIPLICITY/VERTEX DETECTOR
BEAM-BEAM COUNTER
CENTRAL MAGNET
TIME OF FLIGHT DETECTOR
MUON IDENTIFIER
SOUTH MUON MAGNET
NORTH MUON MAGNET
MUON TRACKING CHAMBERS
DRIFT CHAMBER
TIME EXPANSION CHAMBER
PAD CHAMBERS
RING IMAGING CHERENKOV DETECTOR
ELECTROMAGNETIC CALORIMETER
PHENIX
Strong focus on leptons and photons

Time line of a relativistic heavy ion collision

1 2 3 4



Two thin disk
quarks and gl
approach

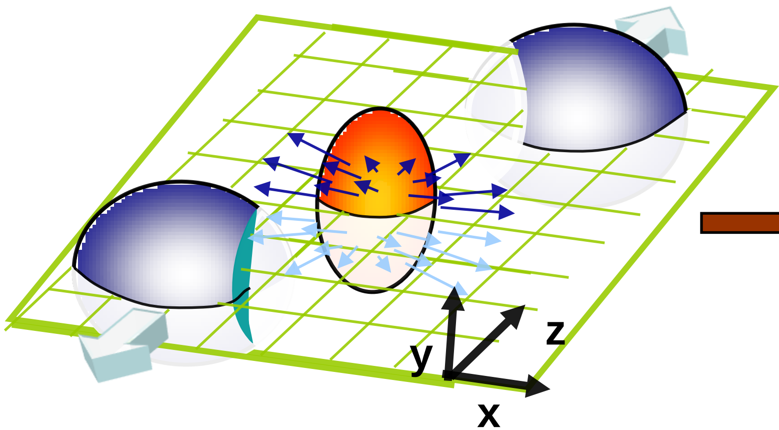
Initial collisi
products of
scattering cr

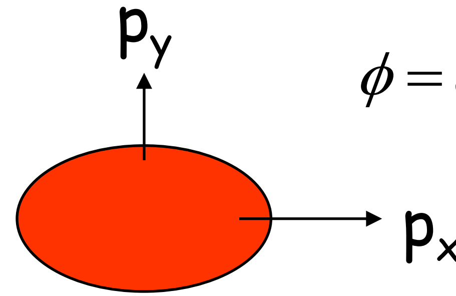
Dense partonic
medium
The QGP?
The sQGP?
A “perfect liquid”?

Hadron gas phase

What discoveries has the first phase at RHIC yielded?

Collective motion: "elliptic flow"





$$\phi = \text{atan}\frac{p_y}{p_x}$$

$$\varepsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$

Initial coordinate-space anisotropy

$$v_2 = \left\langle \frac{p_x^{\ 2} - p_y^{\ 2}}{p_x^{\ 2} + p_y^{\ 2}} \right\rangle$$

Final momentum-space anisotropy

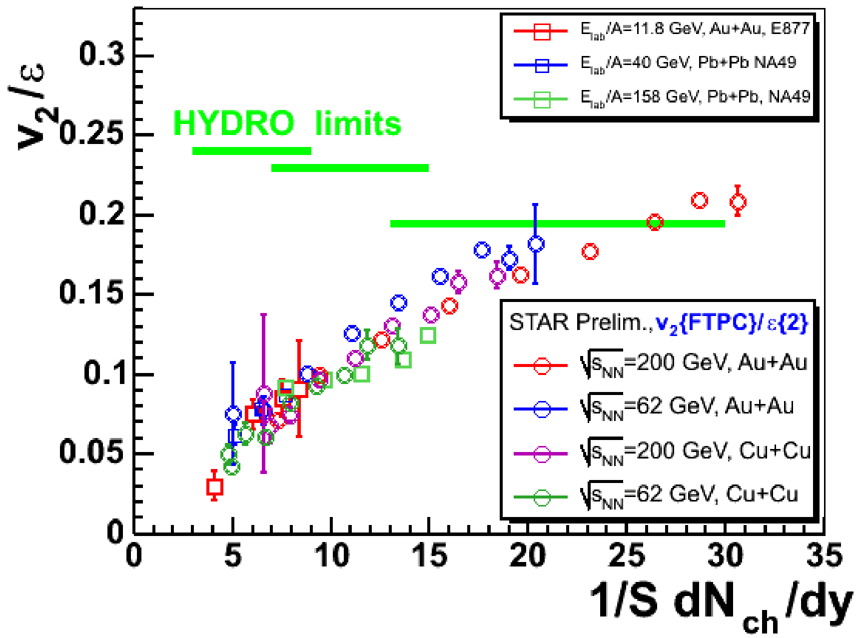
$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos[2(\phi - \Psi_R)] + 2v_4 \cos[4(\phi - \Psi_R)] + \ldots$$

Elliptic flow establishes there is strongly interacting matter at t ~ 0

Is there elliptic flow at RHIC?

Yes! First time hydrodynamics without any viscosity describes heavy ion reactions.

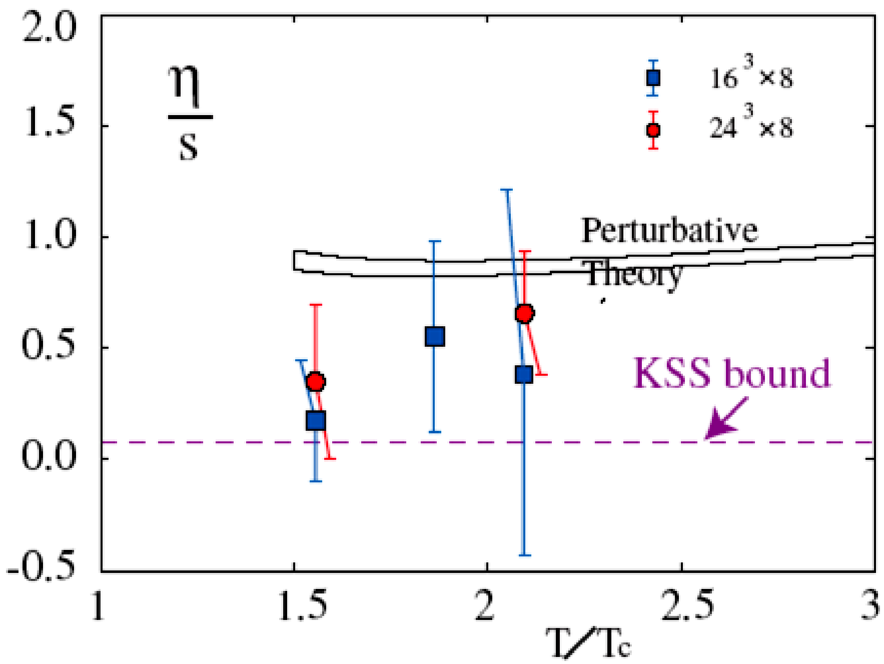
- Hydrodynamic calculations ass and near-zero viscosity reprod p_T ~ 1.5 GeV/c
- Same calculations fit the radial
- Elliptic flow saturates the hydr
- Very rapid thermalization, very
- A perfect fluid?



Thermalization time τ < 1 fm/c and ε = 20 GeV/fm^3

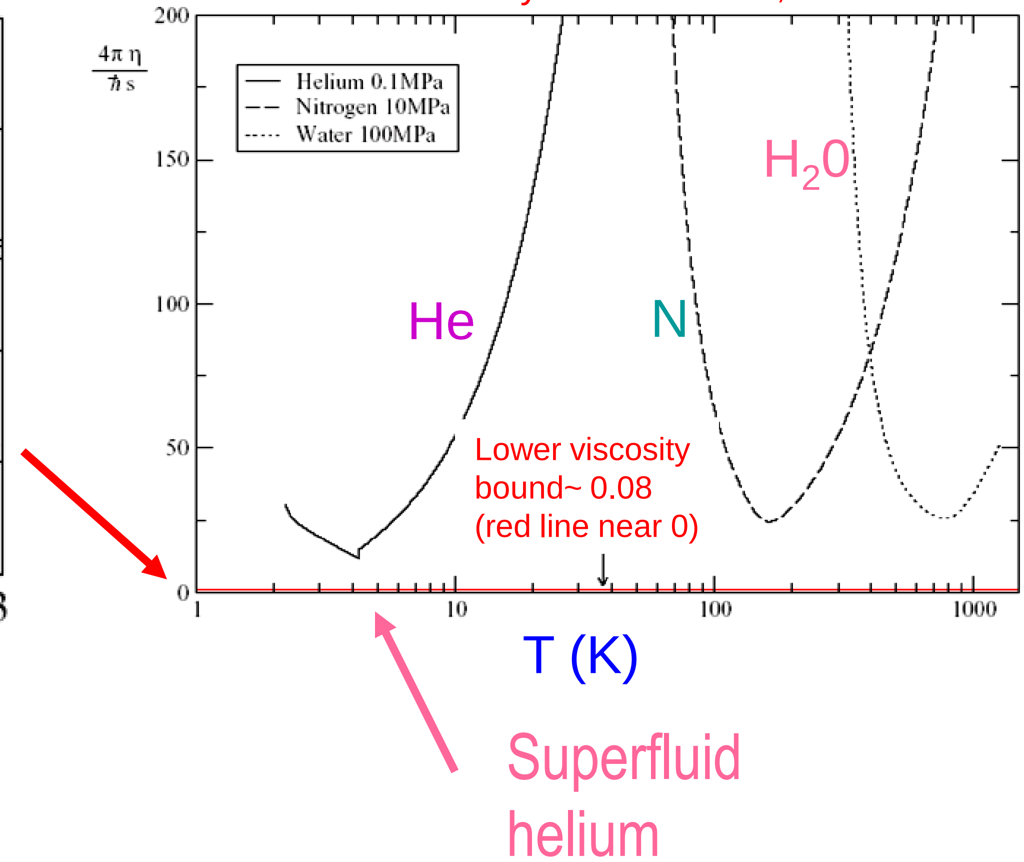
What is the viscosity?
How perfect is our liquid?

A. Nakamura and S. Sakai,
hep-lat/0406009

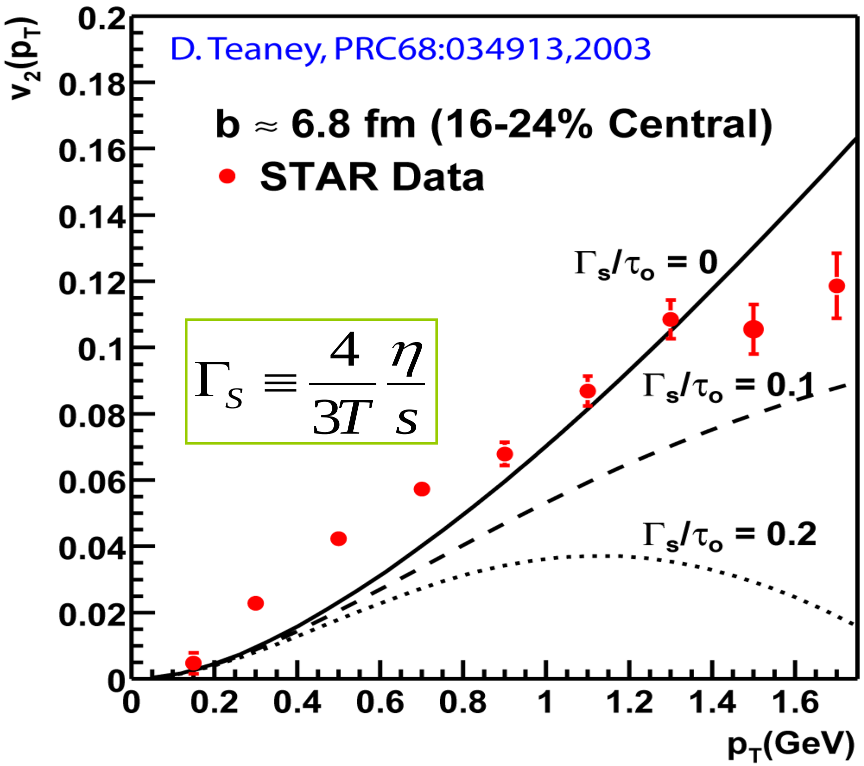


$\eta/s \div \hbar/4\pi$

Kovtun, Son, Starinets,
Phys. Rev. Lett 94, 2005



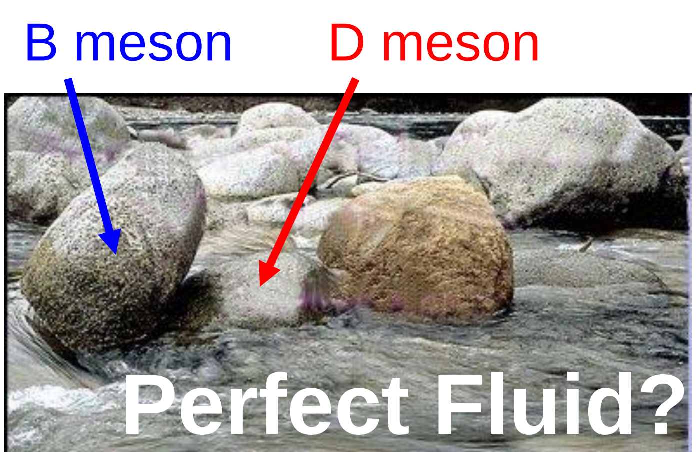
How to Quantify η/s at RHIC?



Γ_S = sound attenuation length
(~ mean free path)

For reasonable T (~ $2T_C$) and τ (~ 1 fm/c) data suggest η/s << 0.3

- Ultimately Needed:
  - Continued progress on viscous relativistic hydrodynamic theory
  - Radial, directed, elliptic flow measurements for several identified hadron species. Particularly valuable:
    - Multi-strange hadrons φ, Ξ, Ω (reduced coupling to hadron gas phase) to determine viscous effects in the hadronic phase
    - D mesons (establish thermalization time scale)

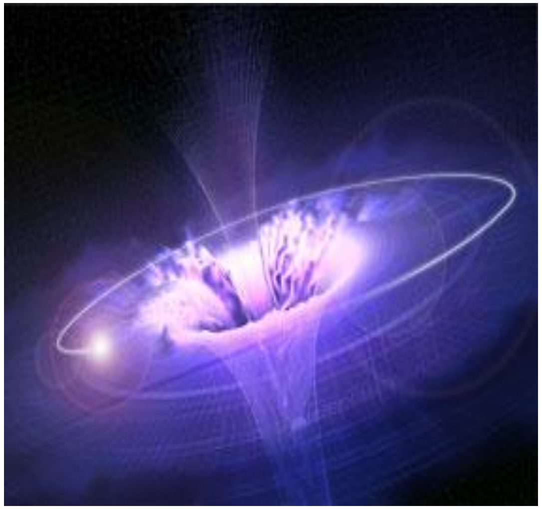


String Theory ?

What could this have to do with our physics?

The Maldacena duality, know also as AdS/CFT correspondence, has opened a way to study the strong coupling limit using classical gravity where it is difficult even with lattice Quantum Chromodynamics.

It has been postulated that there is a universal lower viscosity bound for all strongly coupled systems, as determined in this dual gravitational system.



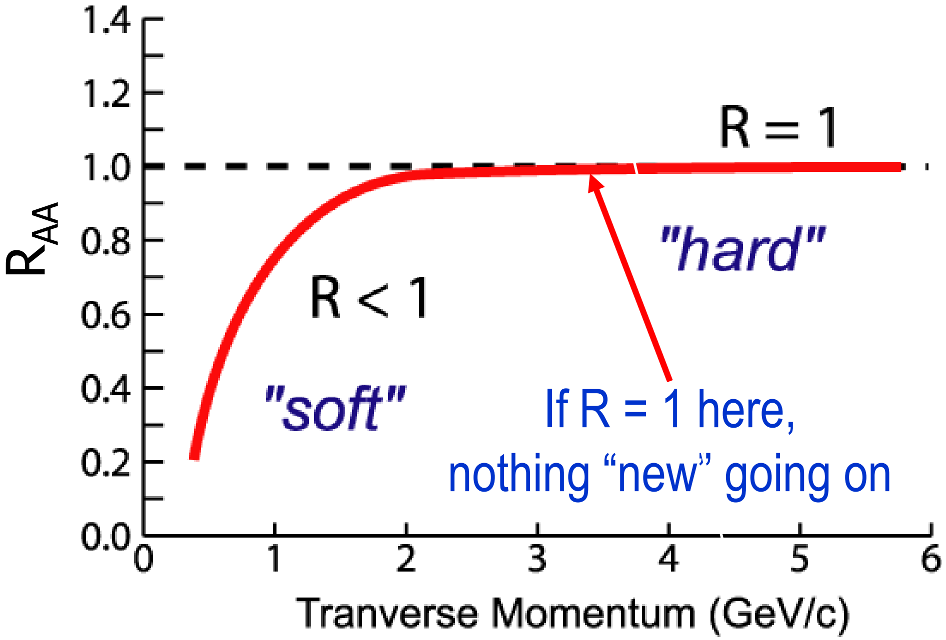
A second discovery: jet quenching

An "inclusive" measure:
the "Nuclear Modification Factor:"

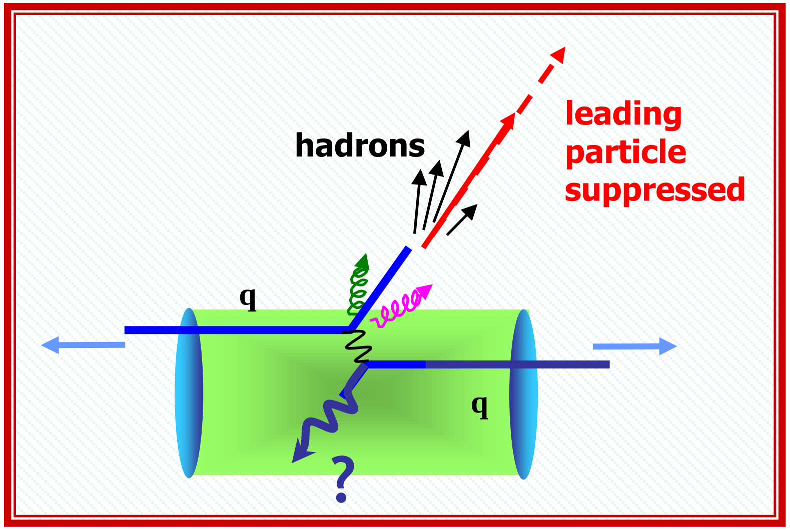
$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{NN}/dp_T d\eta}$$

$<N_{binary}>/\sigma_{inel}^{p+p}$

nucleon-nucleon cross section



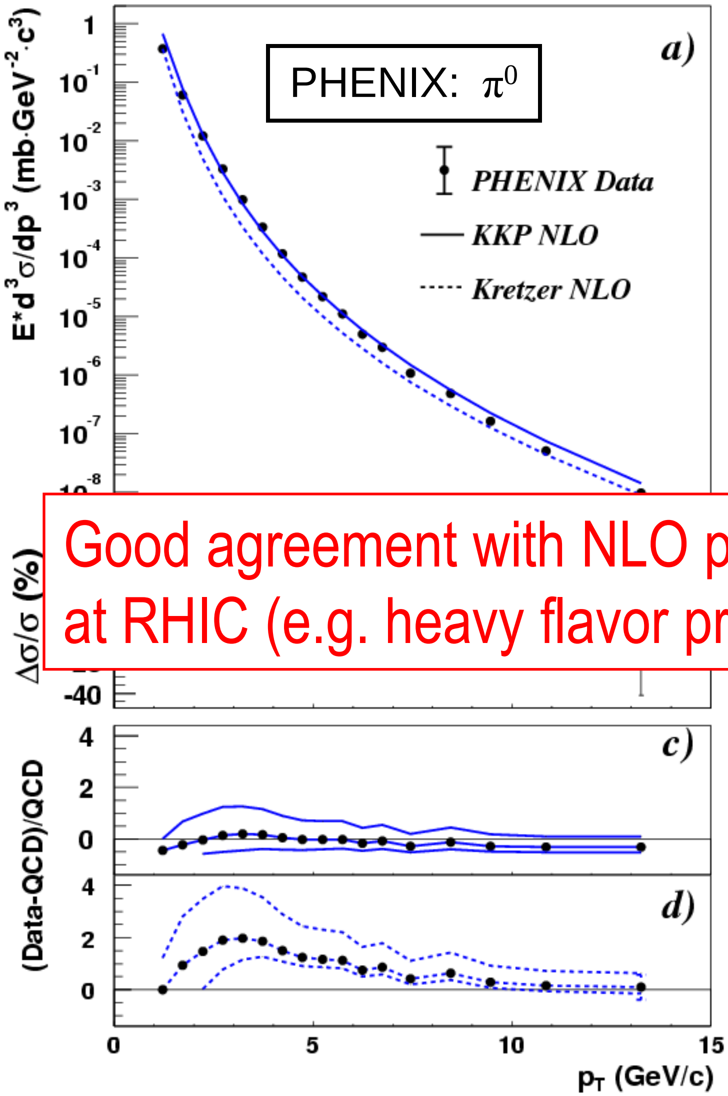
A second test: back-to-back correlations from di-jets jets



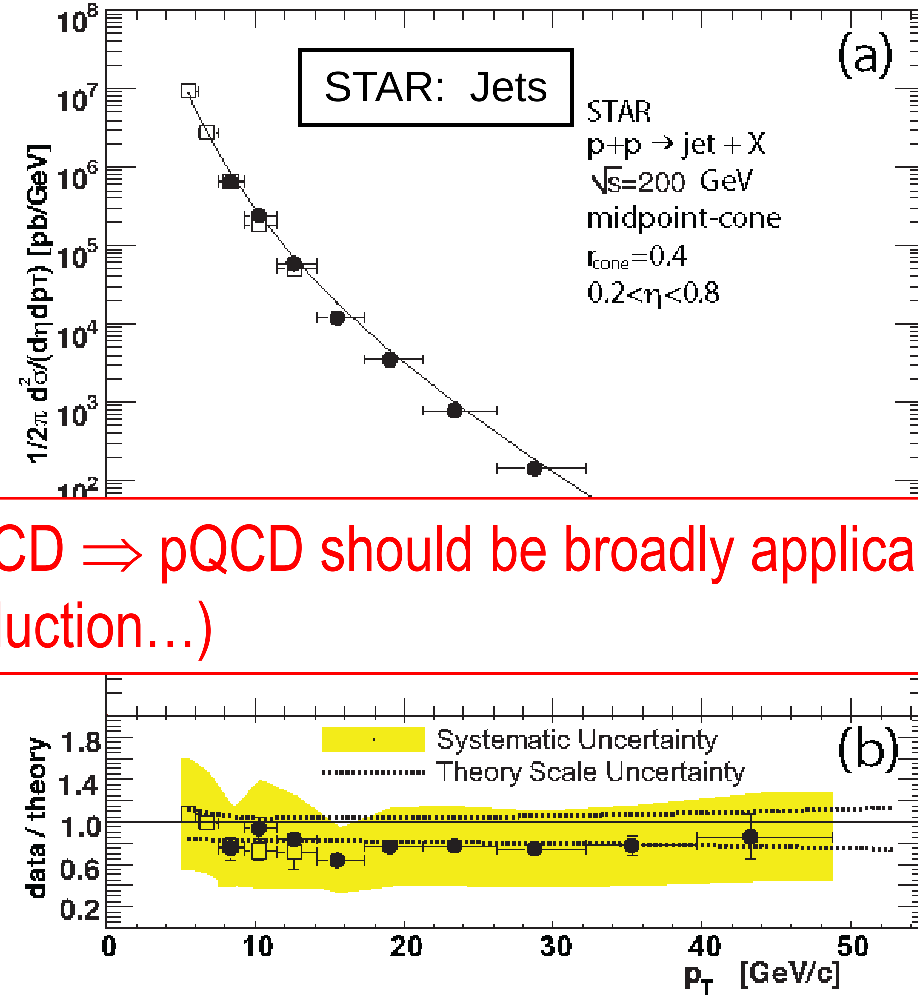
Will our calibrated penetrating probe go through the same way?
-- or will it be quenched ? --

Hard scattering at RHIC and NLO pQCD

PRL 91, 241803



hep-ex/0608030



Good agreement with NLO pQCD ⇒ pQCD should be broadly applicable at RHIC (e.g. heavy flavor production…)

In central Au+Au collisions something dramatically new occurs: jet quenching

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{NN}/dp_T d\eta}$$

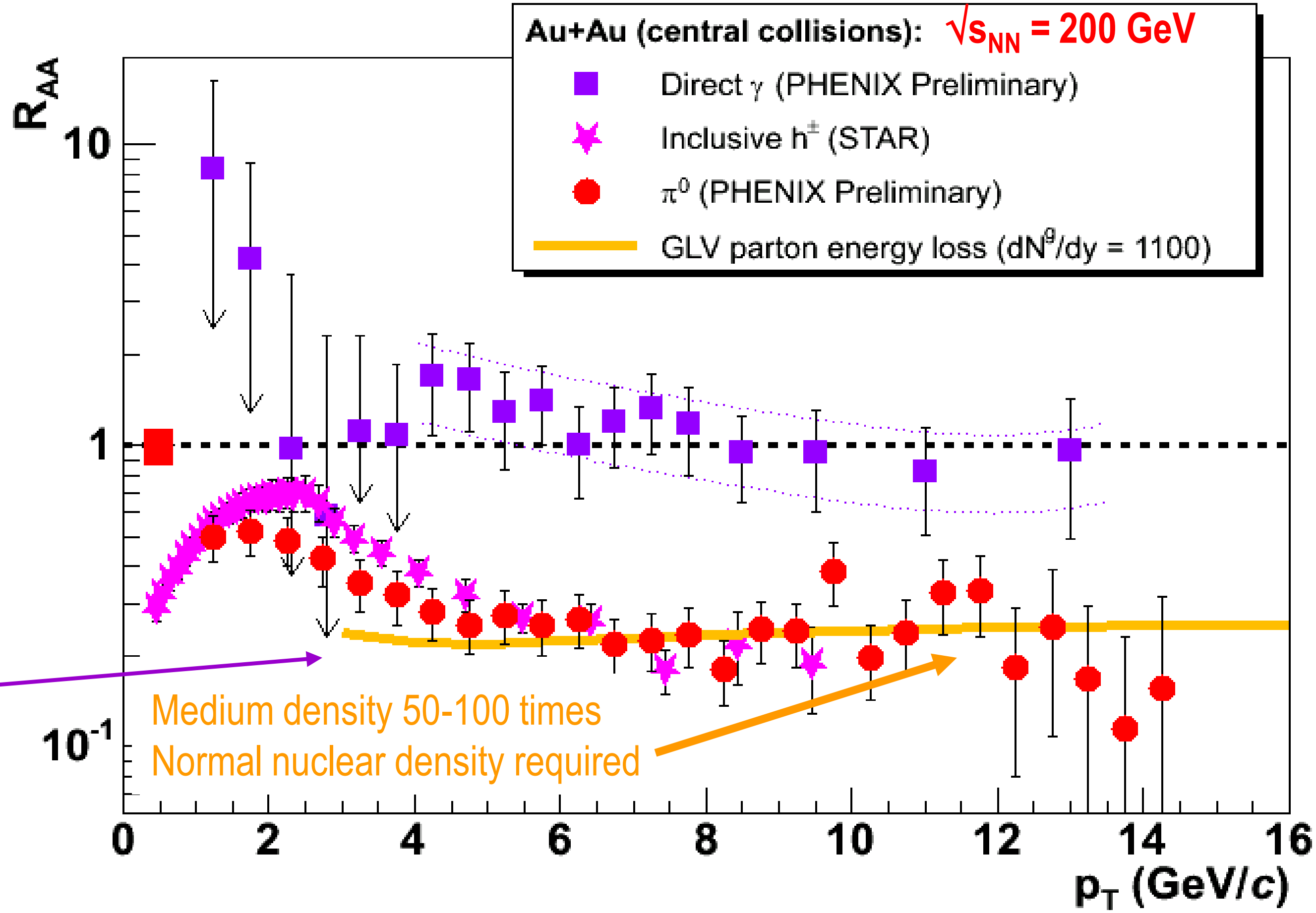
← Nuclear Modification Factor

Binary collision scaling

Particles which are made up from colored quarks and gluons are strongly suppressed

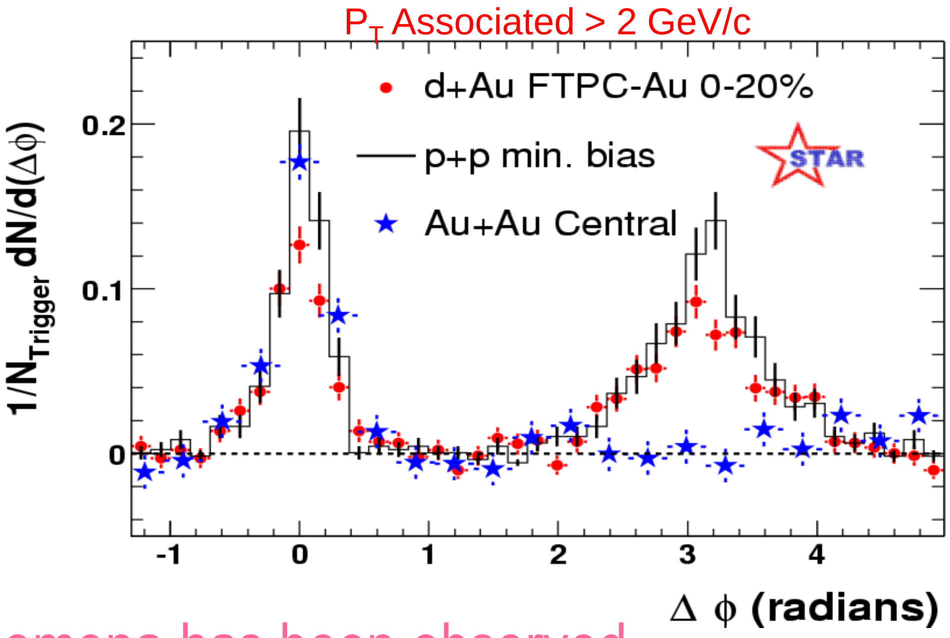
Direct photons are not

The contsant level of suppression indicates the effect occurs before the final particles are made (hadronization)



Jet quenching at RHIC

The effect is seen even more dramatically in di-hadron correlations: recoiling jets are strongly modified due to quenching



Unequivocally, a new phenomena has been observed

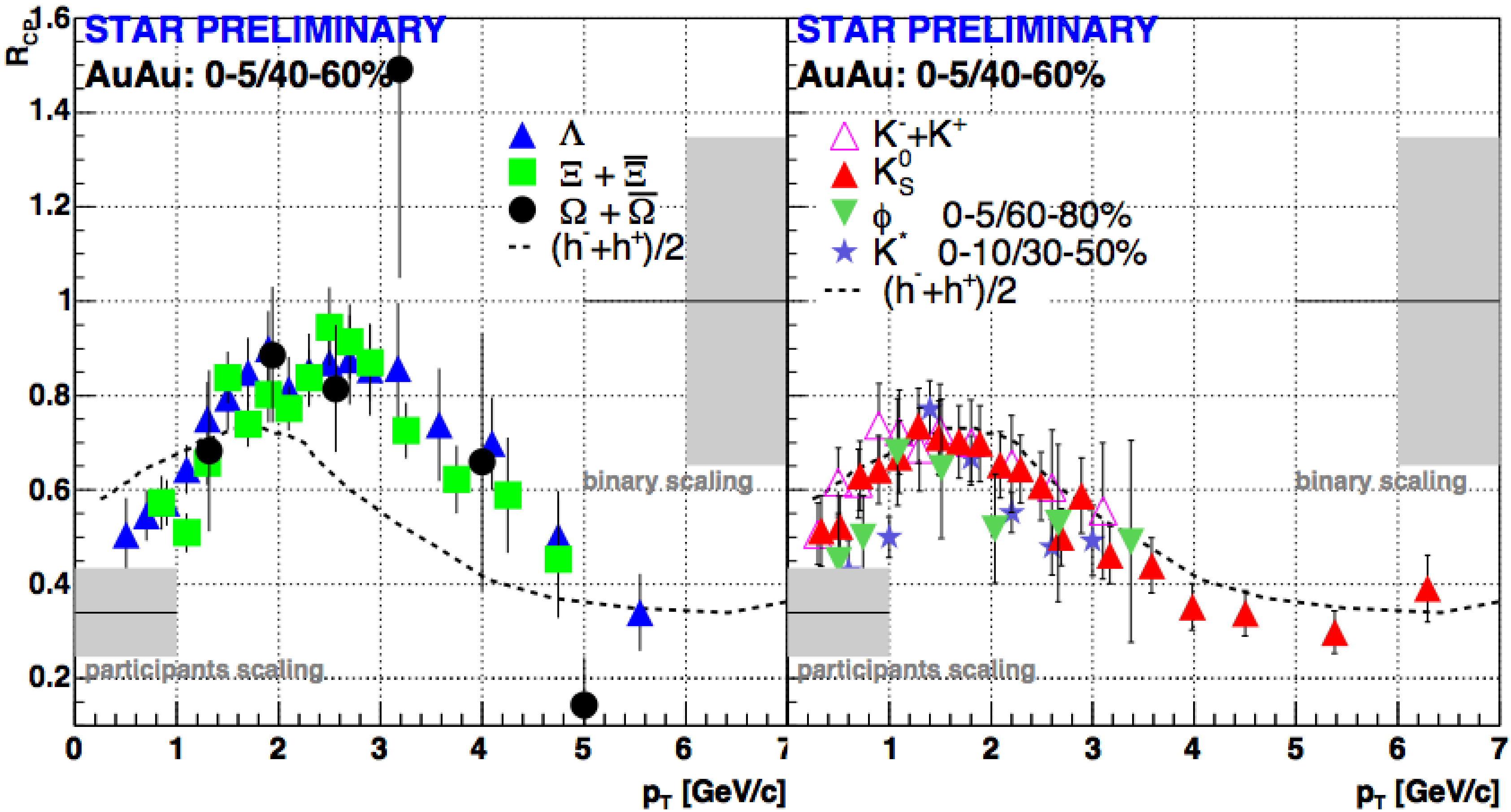
- In central Au+Au collisions:

Not everything is understood:

Electrons from the semi-leptonic decay of charm + bottom appear as suppressed as particles containing light quarks. That raises new questions

But evidence for jet quenching in some new form of opaque matter is unequivocal

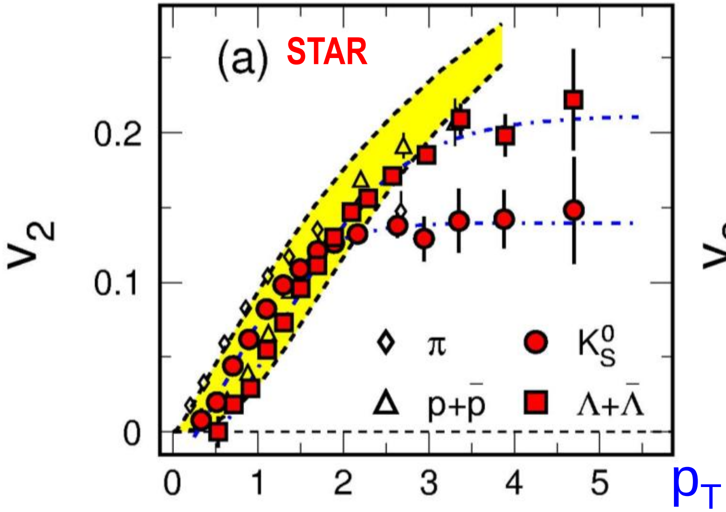
Additional evidence from something that was not predicted

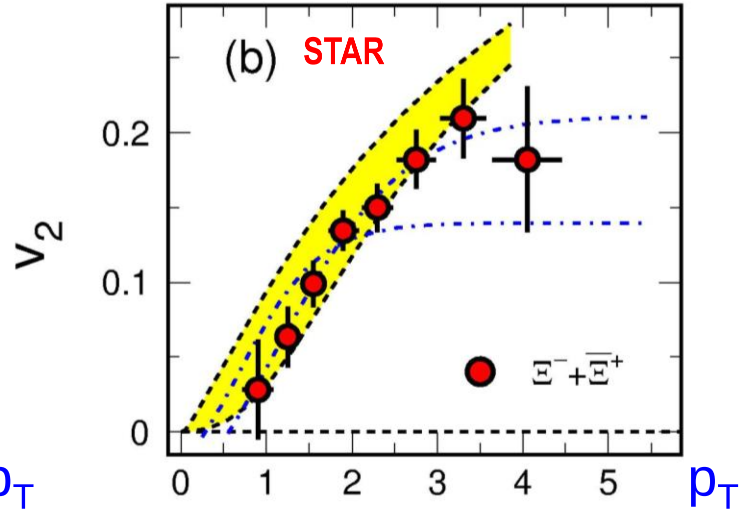


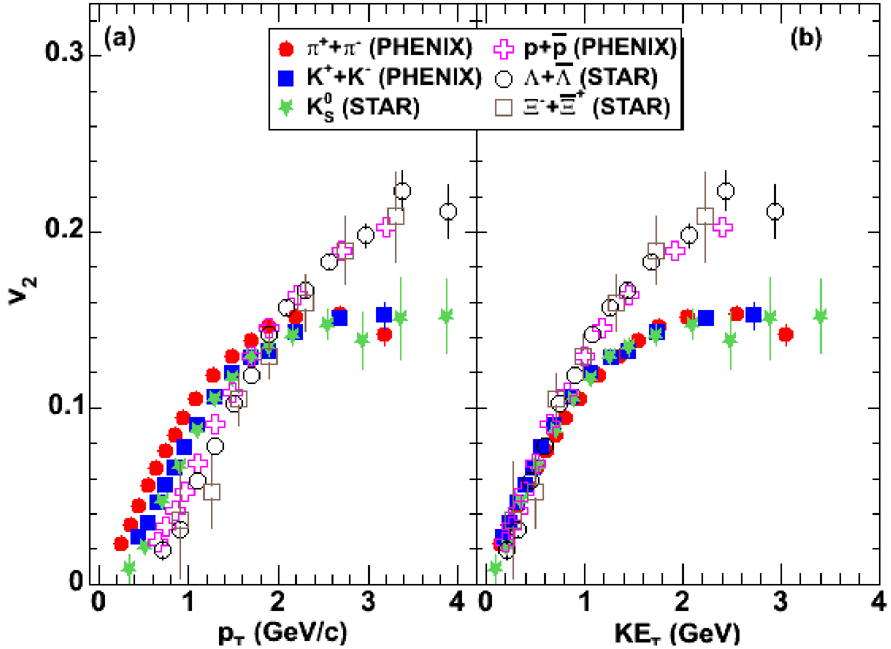
The mesons (quark-antiquark) and the baryons (3 quarks) exhibit two distinct behaviors below transverse momenta of ~ 6 GeV/c

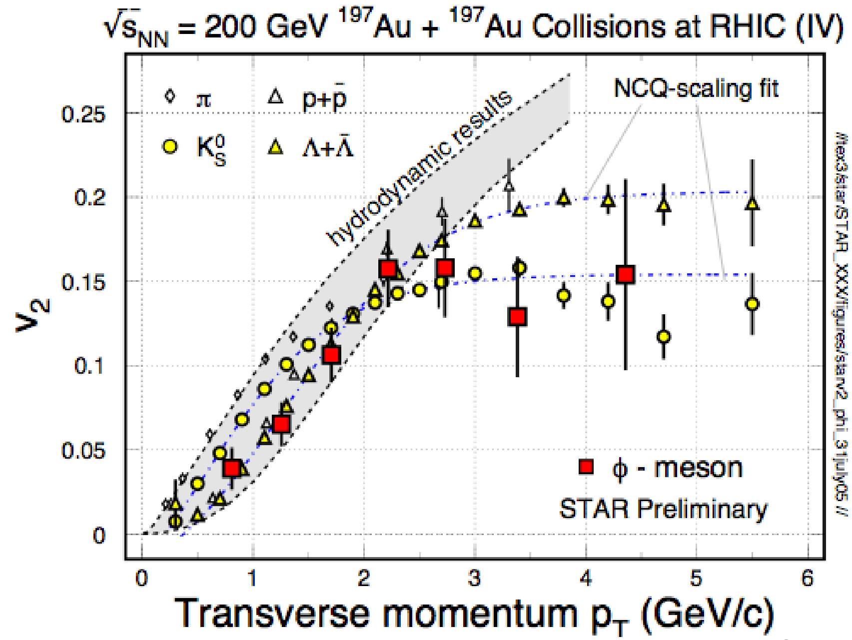
(K*, ϕ which are as heavy as the proton follow the mesons !)

Same "splitting" of mesons/baryons if you look at elliptic flow

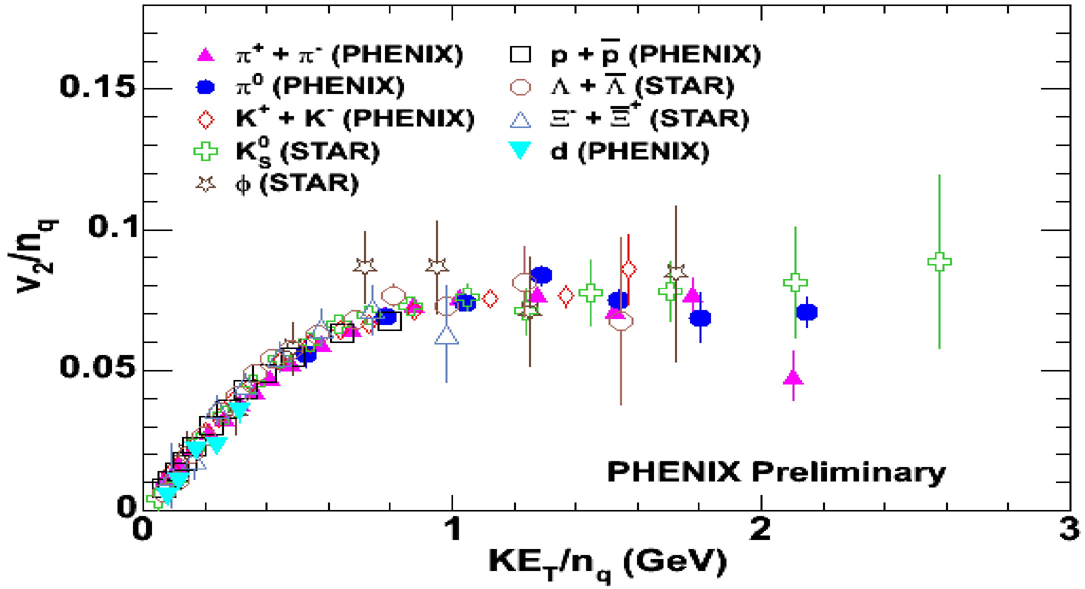


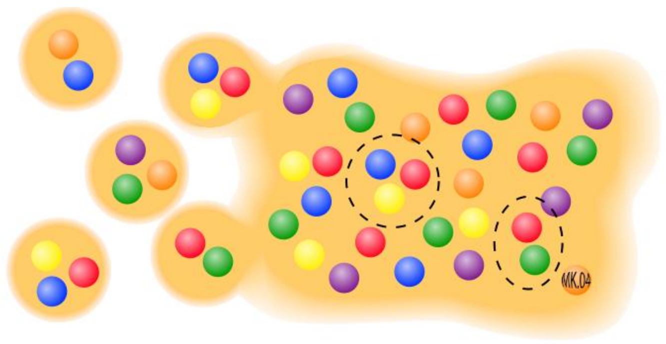






What if quarks coalesce to make hadrons?





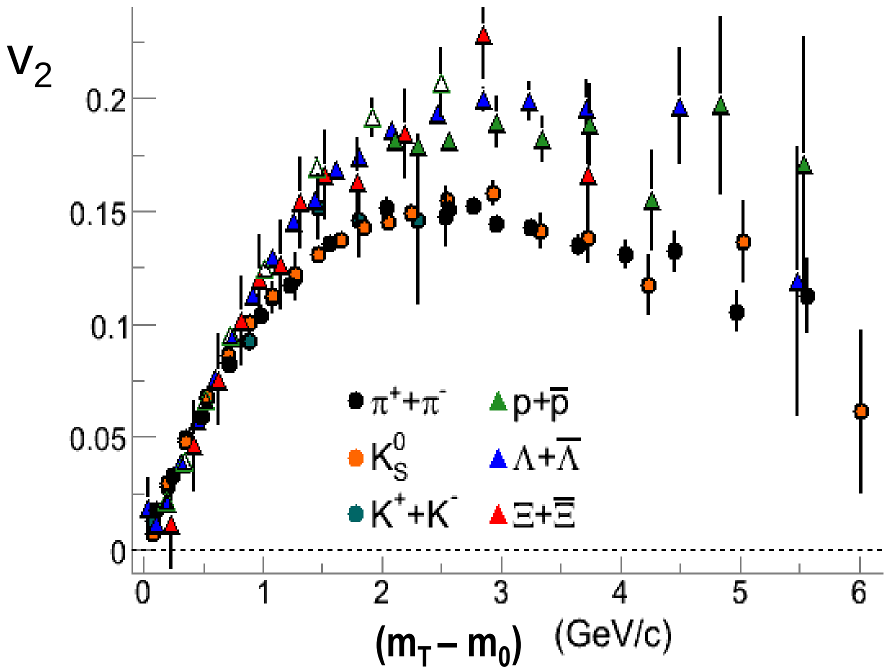
$$\frac{dN}{d\phi} \propto \left[1 + 2v_2(p_T)\cos(2\phi) + \cdots\right]$$

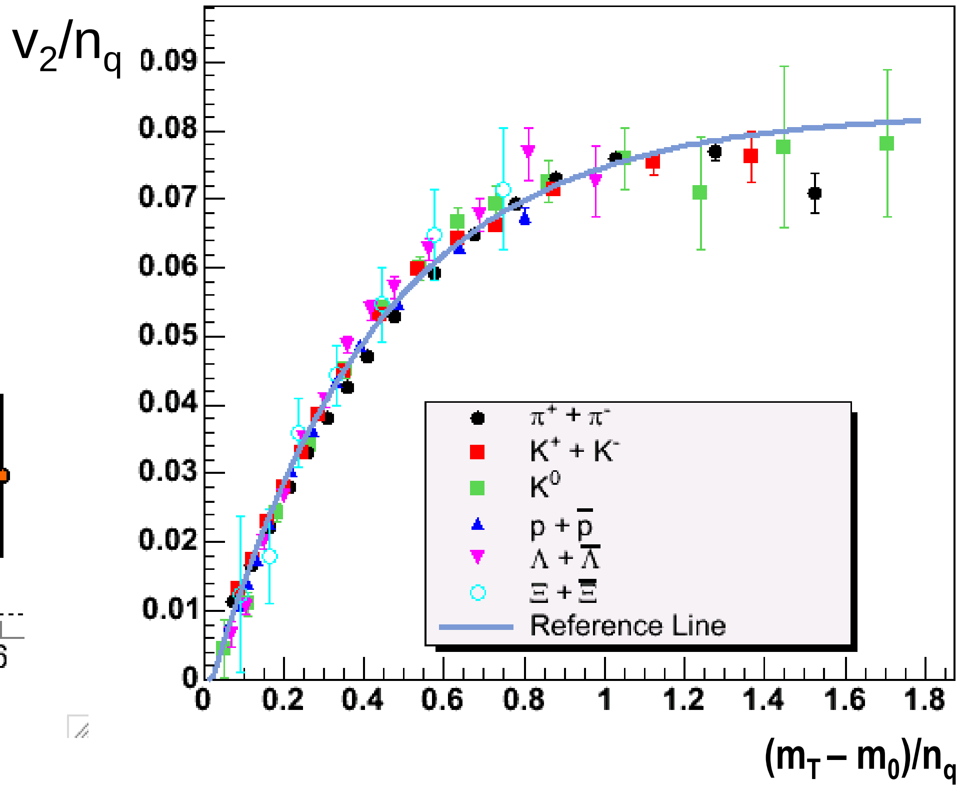
$$= \left[1 + 2v_2^q(p_T^q)\cos(2\phi) + \cdots\right]^{n_q}$$

$$\approx 1 + 2n_q v_2^q\left(\frac{p_T}{n_q}\right)\cos(2\phi) + \cdots$$

- v_2 obeys constituent quark scaling
  - Hadronization through **coalescence**
  - Evidence for **flowing quarks**

A remarkable scaling of the “fine structure” of elliptic flow is observed



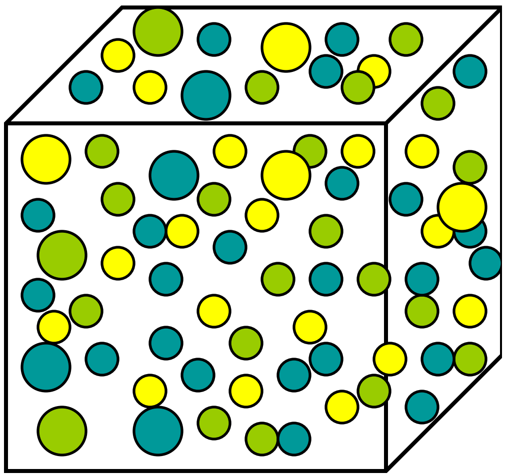


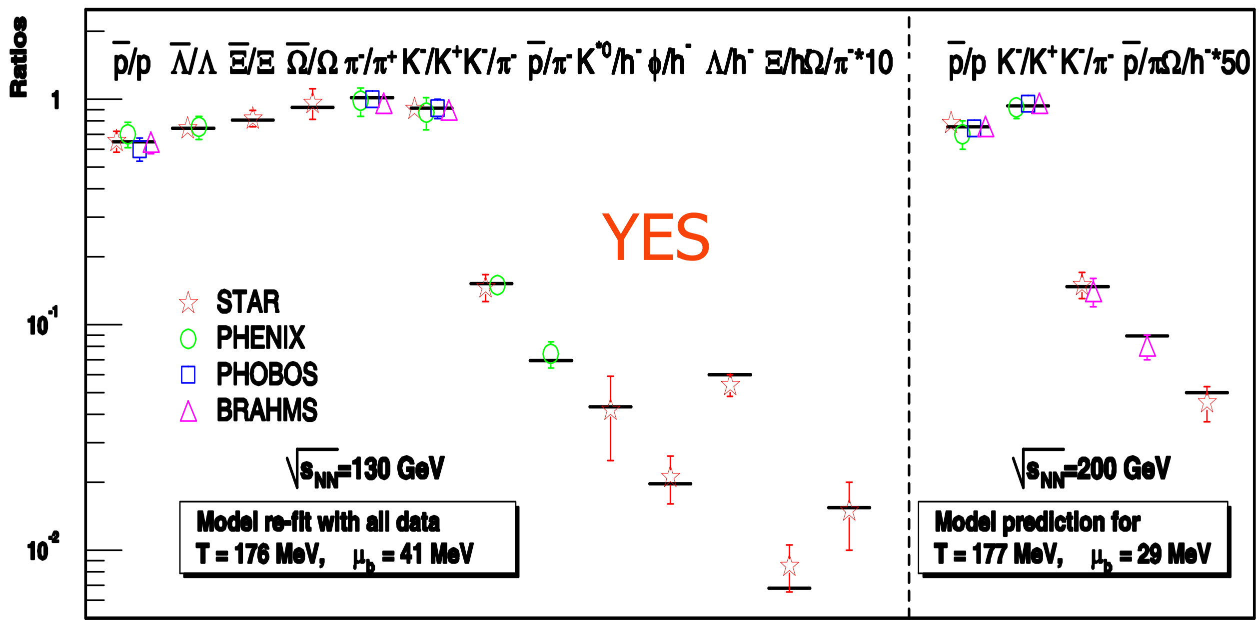
Fluid→QuasiParticles→Hadrons

Evidence for fluid breaking up into quasi-particles with quantum numbers of quarks before hadrons

Supporting Evidence :

For a thermalized system of quarks (describable by thermodynamic properties such as temperature and chemical potential) then the ratios of the yields of particles distilled (hadronized) out of this quark soup should be predictable by statistical thermodynamics. Is it?





Horizontal bars are the prediction, points are data

pT-integrated particle yield ratios in central Au+Au collisions consistent with Grand Canonical Stat. distribution @ Tch = (160 ± 10) MeV, $\mu B \approx 25$ MeV, across u, d and s quark sectors. Inferred Temp. consistent with Tcrit (LQCD) $\Rightarrow$ phase transition

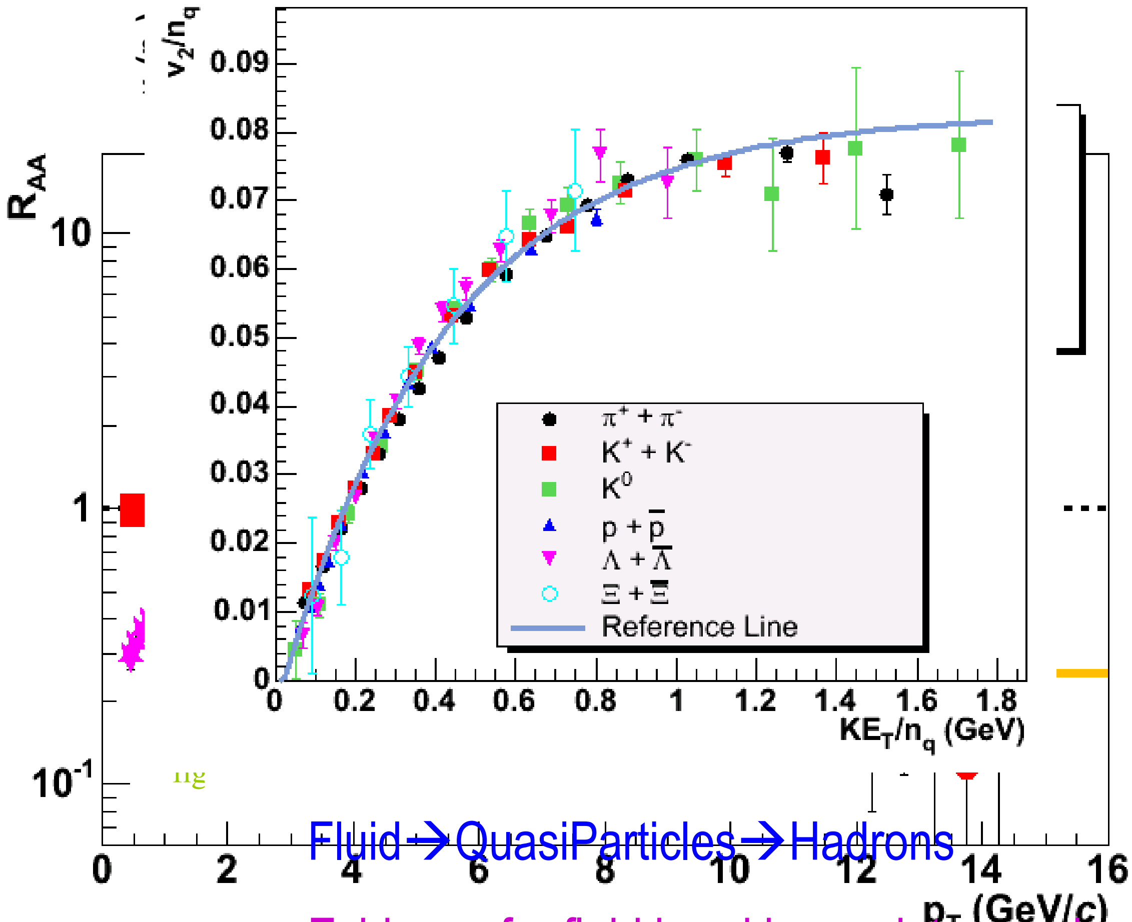
Three major discoveries at RHIC which point unequivocally to a new state of strongly interacting quark-gluon matter

The hottest, densest matter yet examined in the laboratory

It is highly opaque to colored probes– quarks and gluons – but not to photons

It flows as a relativistic quantum liquid with minimal shear viscosity

It produces copious mesons and baryons with yield ratios and flow properties that suggest their forma[tion] via coalescence of valence quark[s] from a hot thermal bath.



Fluid→QuasiParticles→Hadrons

Evidence for fluid breaking up into quasi-particles with quantum numbers of quarks before hadrons

For reasonable T (~ $2T_C$) and τ (~ 1 fm/c) data suggest $\eta/s << 0.3$

These phenomena were not observed at the SPS (some were not even predicted) and they constitute important new discoveries

Are we done?

No, only just begun

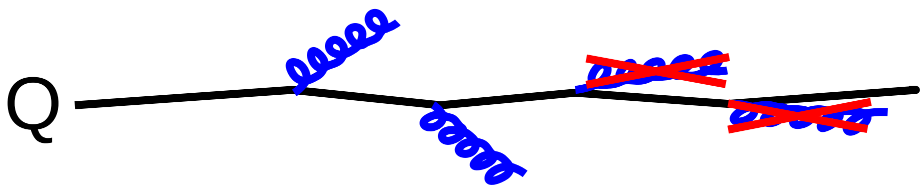
New questions have emerged from exploring this terra incognita

A new puzzle which emerges:

Initially there was a reasonably strong consensus that the suppression was basically understood: radiative energy loss in a medium 50-100 times normal nuclear matter density

Then these measurements were extended to the heavy quark sector (c, b) by studying suppression of electrons from their semi-leptonic decays

Heavy quark energy loss



Dokshitzer, Khoze, Troyan, JPG 17 (1991) 1602.
Dokshitzer and Kharzeev, PLB 519 (2001) 199.

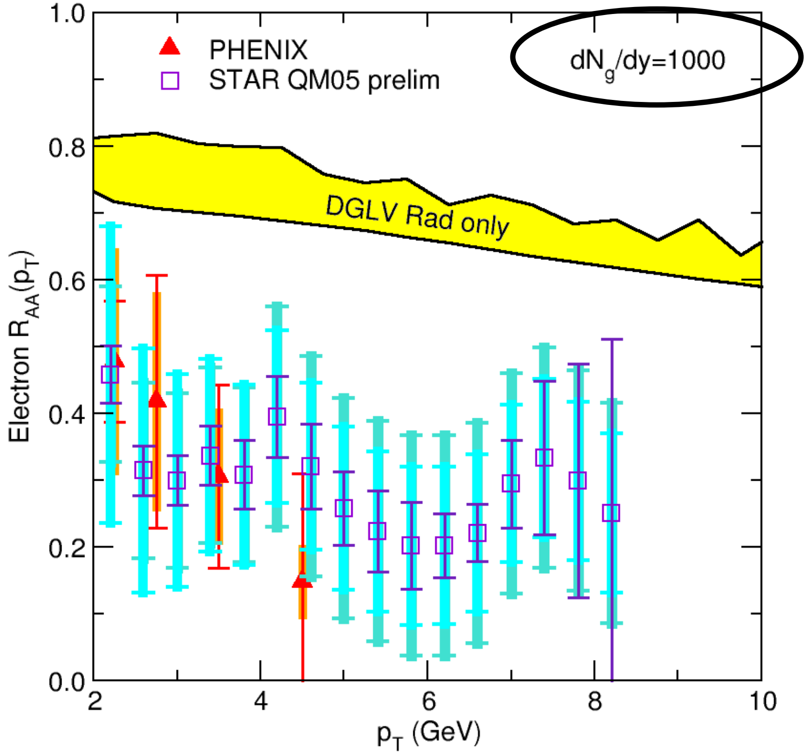
- In vacuum, gluon radiation suppressed at $\theta < m_Q/E_Q$
- “dead cone” effect: heavy quarks fragment hard into heavy mesons

Dead cone also implies lower heavy quark energy loss in matter: (Dokshitzer-Kharzeev, 2001)

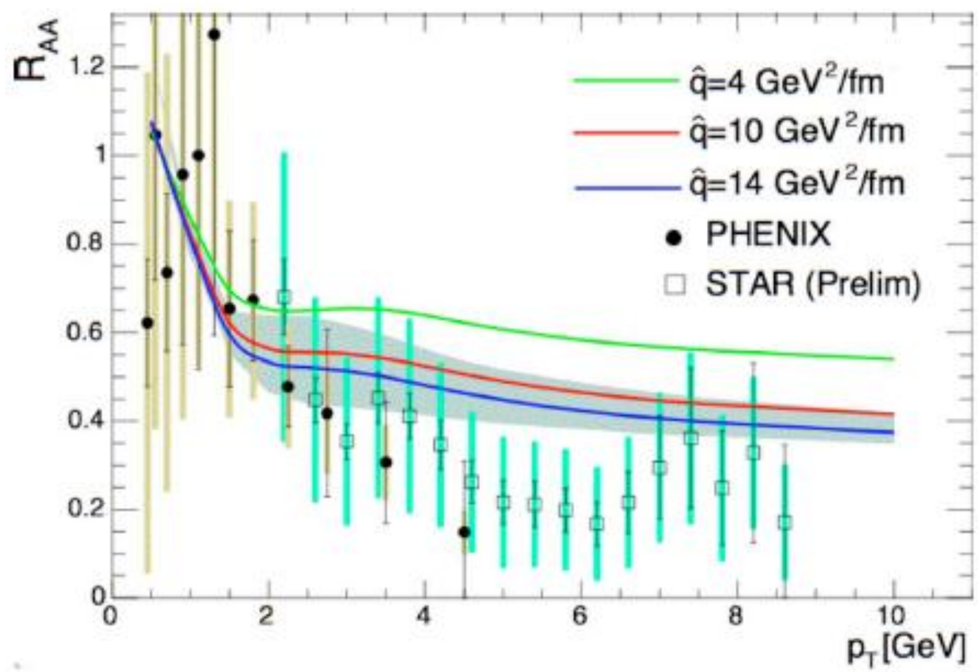
$$\omega \frac{\mathrm{d}I}{\mathrm{d}\omega}\bigg|_{HEAVY} = \frac{\omega \frac{\mathrm{d}I}{\mathrm{d}\omega}\Big|_{LIGHT}}{\left(1+\left(\frac{m_Q}{E_Q}\right)^2 \frac{1}{\theta^2}\right)^2}$$

Heavy flavor suppression via b,c → e+X

S.Wicks et al., nucl-th/0512076



Armesto et al., Phys.Lett.B637:362-366,2006



R_{AA}(non-photonic electrons) ~ 0.2 ~ $R_{AA}(\pi^0)$!!

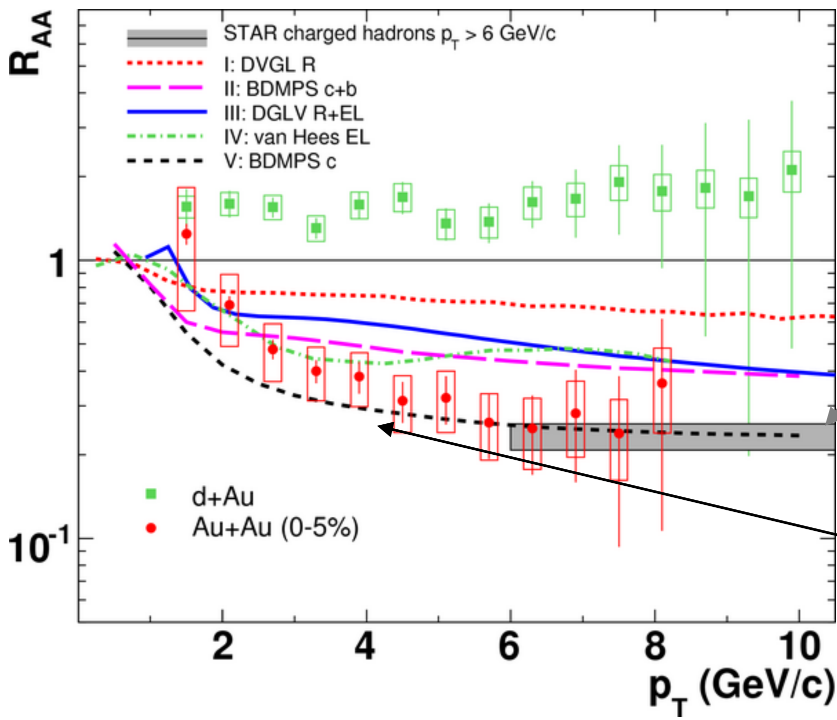
Gluon density/qhat constrained by light quark supression+entropy density (multiplicity)

⇒ under-predicts electron suppression

⇒ charm vs beauty? elastic energy loss? …?

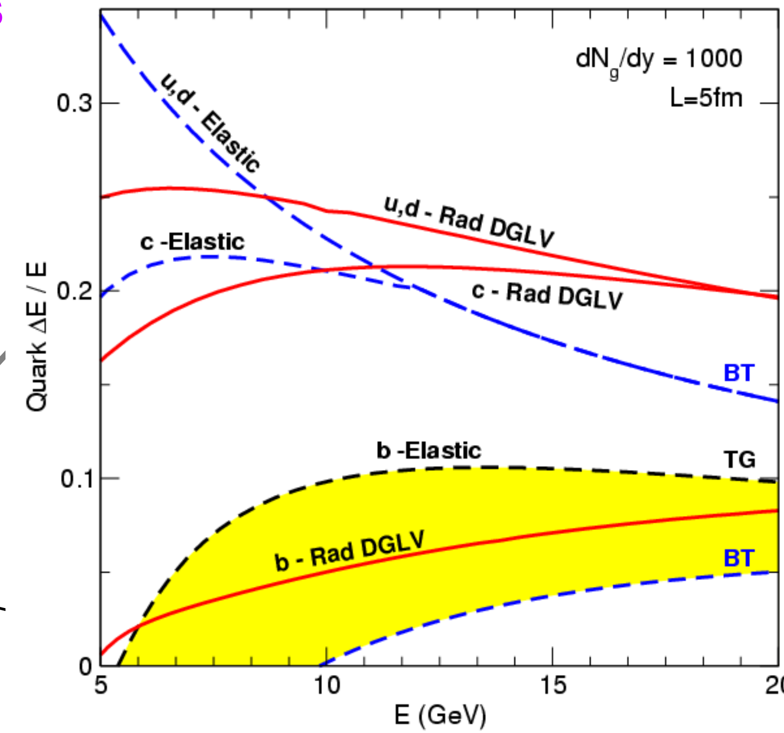
Surprising results on suppression of High-p_T Charm via Electrons

Ratio of charm spectra in Au+Au to p+p normalized by No. of binary collisions & comparison with models of pQCD energy loss primarily based on radiation of gluons



Results caused a shift of paradigm on importance of collisional energy loss

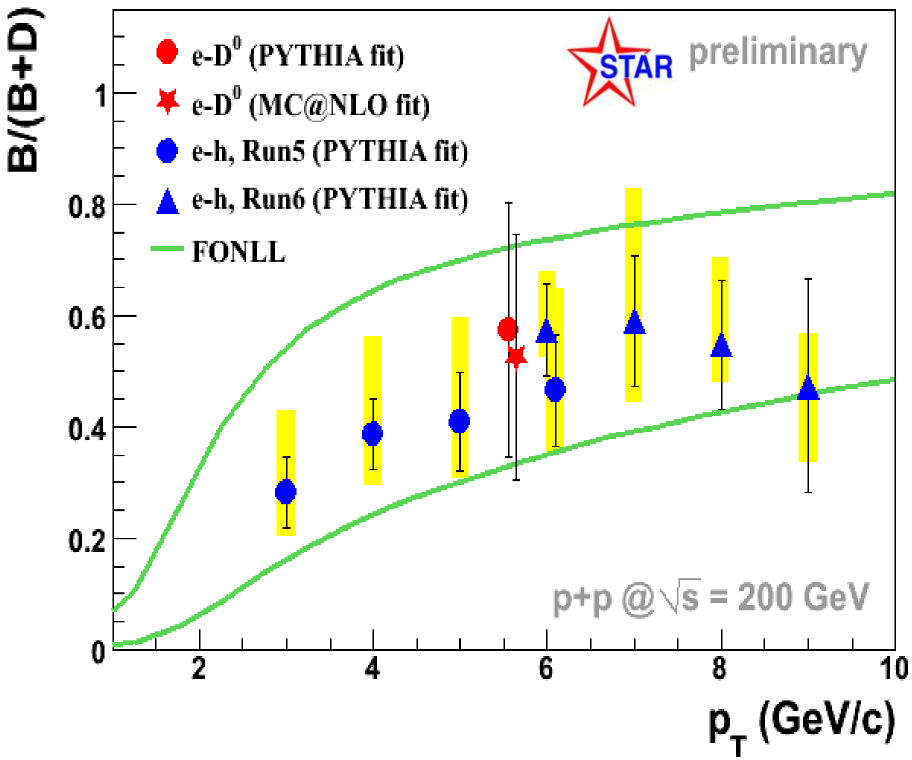
S.Wicks et al., nucl-th/0512076



- Measurement of non-photonic electrons from semileptonic D decays show substantial suppression in central Au+Au collisions comparable to that from light mesons
- Describing the suppression is difficult for models→ theory paradigm shift on radiative energy loss, collisional E-loss, fragmentation and dissociation in medium?
- Energy loss models need to be revisited!

Insight from heavy flavor correlations in p+p

All measurements in p+p at sqrt(s) = 200 GeV



In p+p collisions:

- The B contribution to non-photonic electrons is sizeable based on e-hadron and e-D meson correlations

Taken together with suppression of non-photonic electrons in Au+Au, this suggests significant suppression of non-photonic electrons from bottom in the medium

This may be hinting our paradigm needs to change

Possible example of paradigm shift at RHIC

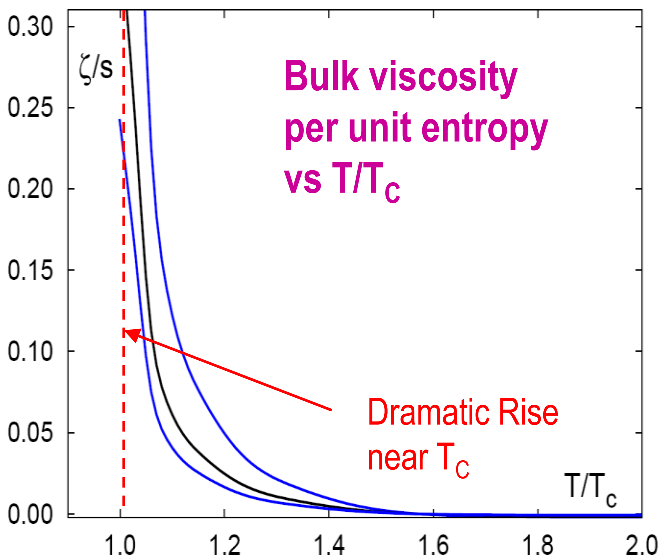
- From Dmitri Kharzeev on pQCD energy loss: "if it is really true that bottom is suppressed, there's just no way.."

First glimpses of a new paradigm?

BNL-NT-07/47
RBRC-703

Universal properties of bulk viscosity near the QCD phase transition

Frithjof Karsch[a], Dmitri Kharzeev[a] and Kirill Tuchin[b,c]



arXiv:0711.0914v1 [hep-ph] 6 Nov 2007

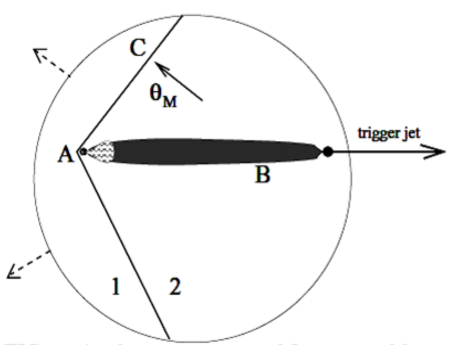
Bulk viscosity of hot qgp in the presence of light quarks from lattice data on QCD equation of state

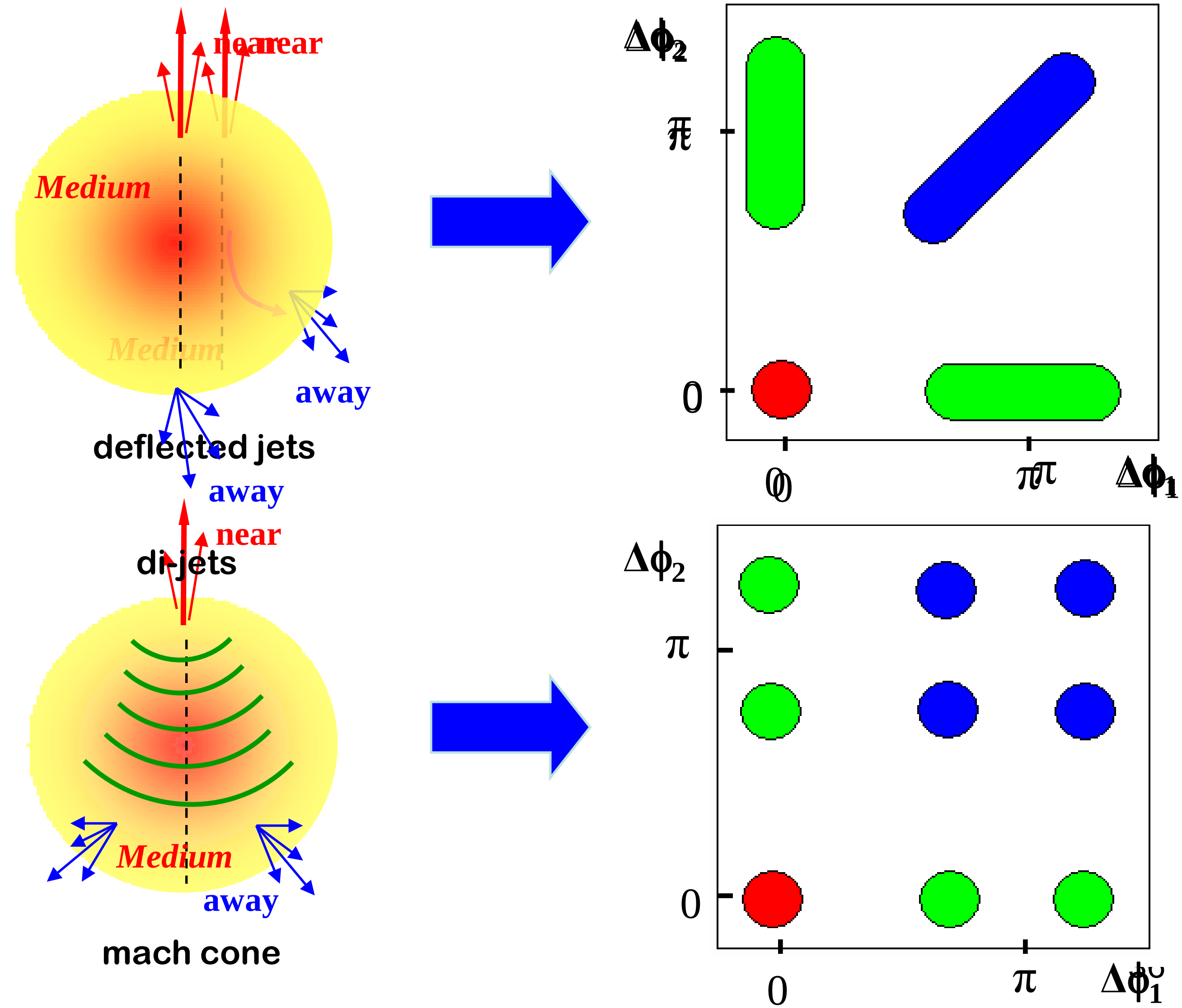
- Large Bulk Viscosity →
  - strong coupling between dilatational modes and internal degrees of freedom
  - Production of large number of soft partons
  - Screening of color charge of pre-existing quarks and gluons
  - Soft statistical hadronization
  - Decrease in $\langle p_T \rangle$ and increase of M due to rapid increase in entropy and associated quenching of transverse hydro expansion

(Observed effect for ^{3}He)

A possible collective mode of excitation

Using 3-particle correlation to discriminate different physical mechanisms.



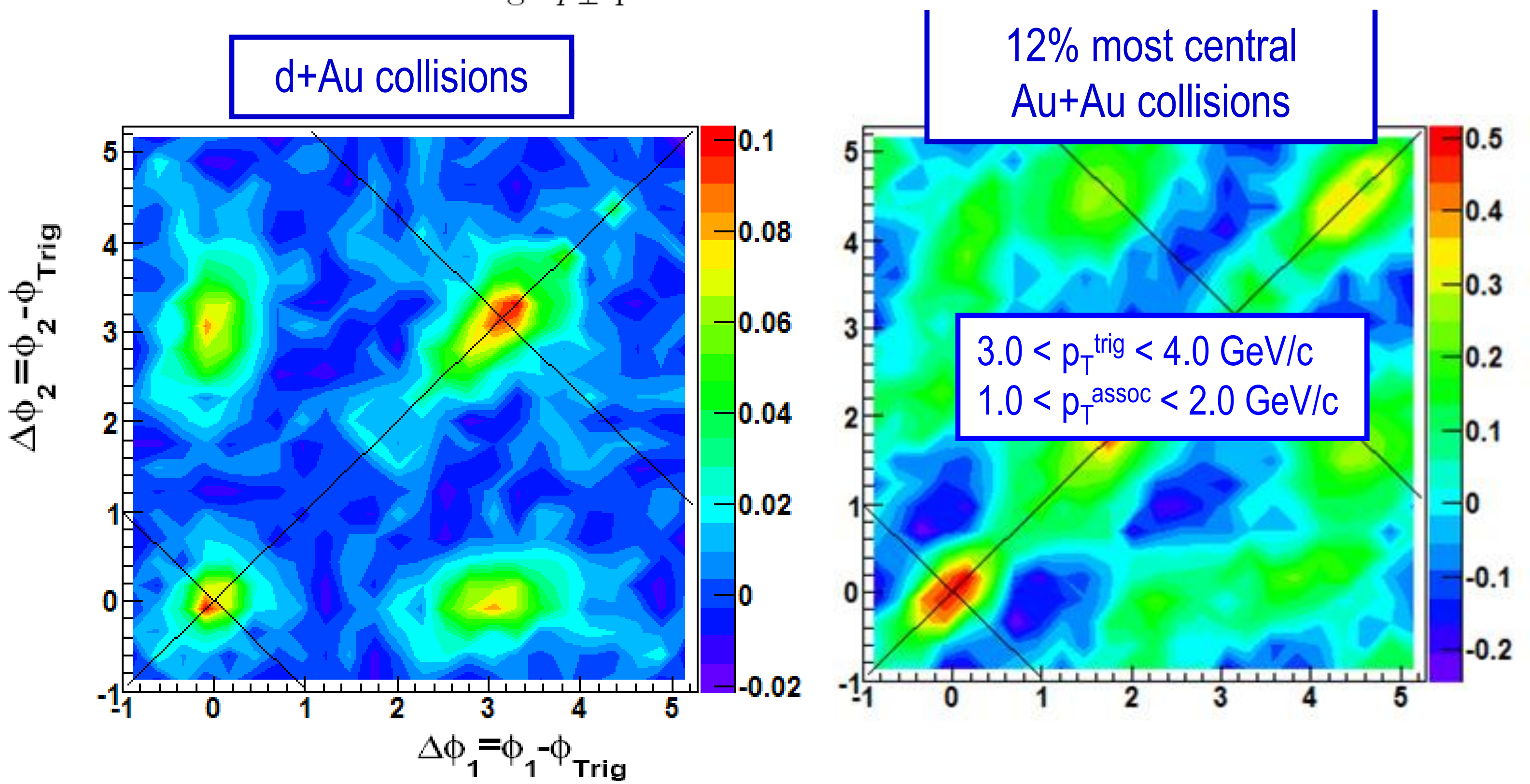


The experimental evidence

Indications of Conical Emission of Charged Hadrons at RHIC

arXiv:0805.0622v1 [nucl-ex] 6 May 2008

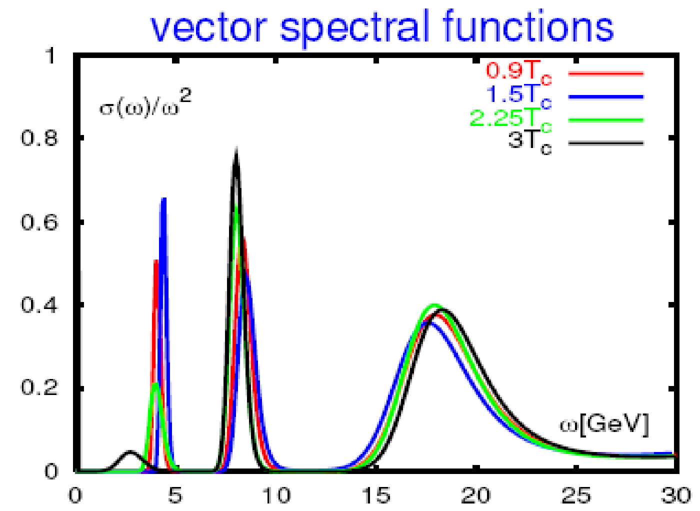
..... Distinct peaks at $\theta=1.38\pm0.02(\text{stat})\pm0.06(\text{syst.})$ from π are observed on the away side in central Au+Au collisions, with correlated hadron pairs far apart, symmetric about π, as well as close together. These structures are evidence of conical emission of hadrons correlated with high $p_\perp$ particles.



Future tools

Deconfinement and color screening?

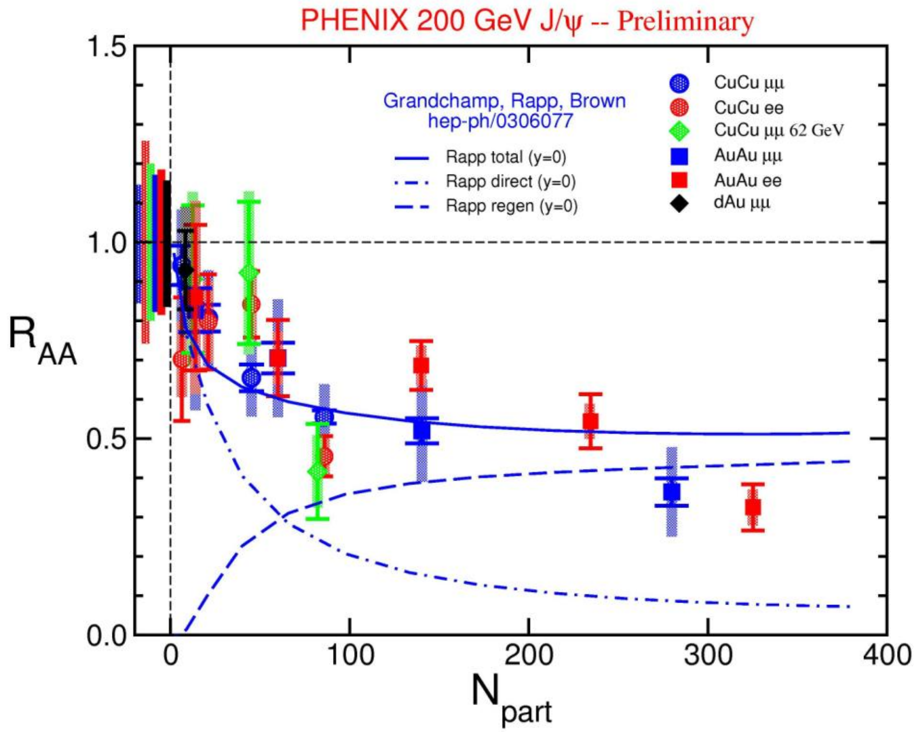
- Classic proposal: quarkonium suppression by color screening.
- Lattice QCD calculations tell us the world is more complicated than we thought! Quarkonium resonances should persist above T_c.
- Hierarchy of melting:

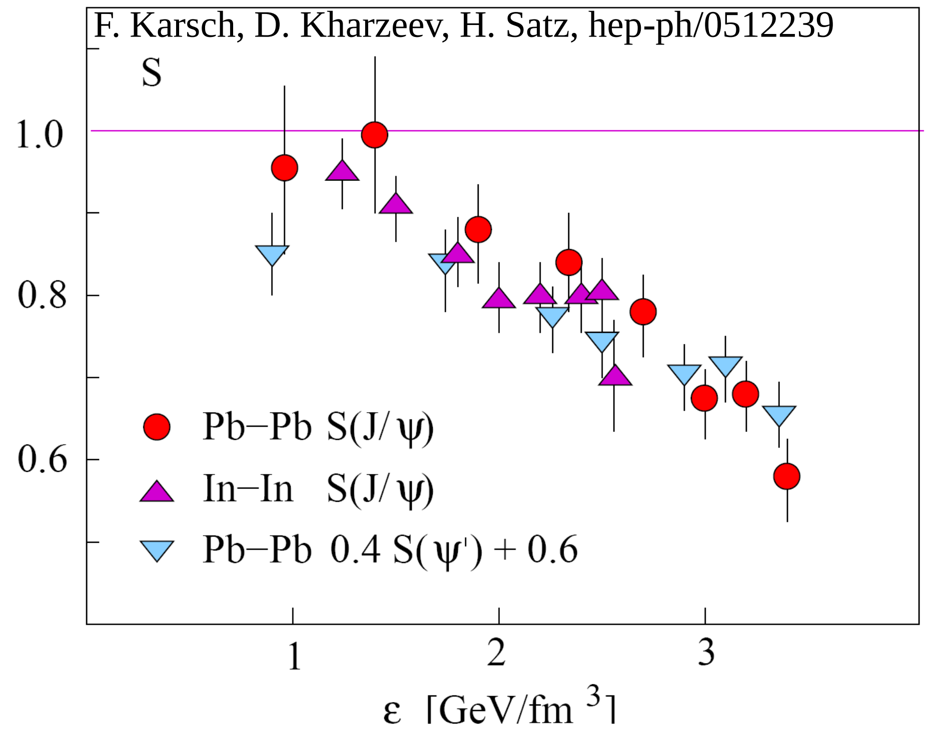


State	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.10	< 1.76	1.60	1.19	1.17

- Also recombination: $c + \bar{c} \rightarrow J/\psi$

Current status





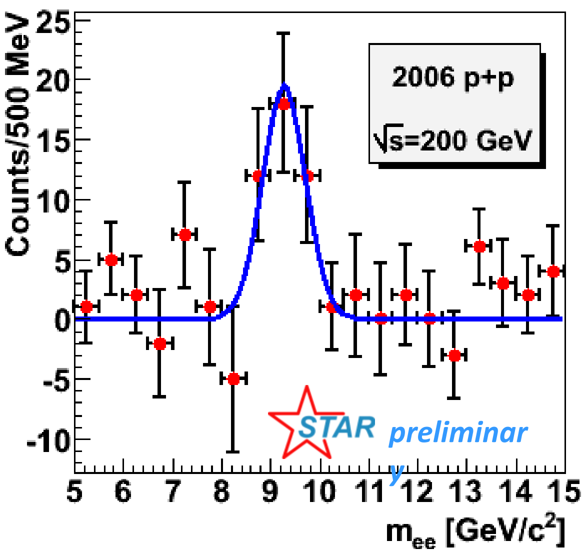
- Suppression + regeneration describes PHENIX results well
- Sequential melting also works if you assume the *J/ψ* doesn't melt

How to discriminate?

- Compare model predictions to measurements of:
  - *J*/ψ spectrum modifications vs. rapidity and beam energy
  - *J*/ψ elliptic flow
- Need ψ’ and χ_c measurements, both as inputs to the model calculations and to provide direct evidence for melting
- Need bottomonium (separated 1s,2s,3s), where the expected effects are quite different from charmonium
- These measurements require upgraded detector capabilities and higher “RHIC II” luminosity

A future test of color screening in the plasma: Bottomonium (ϒ)

First ϒ measurement

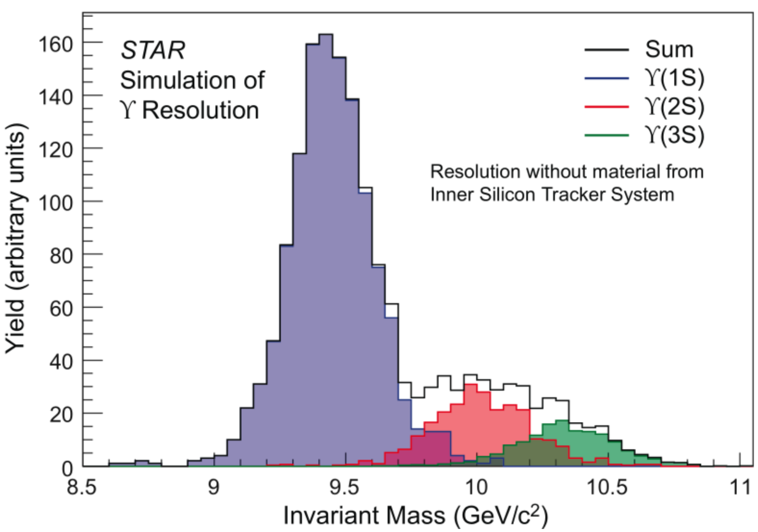


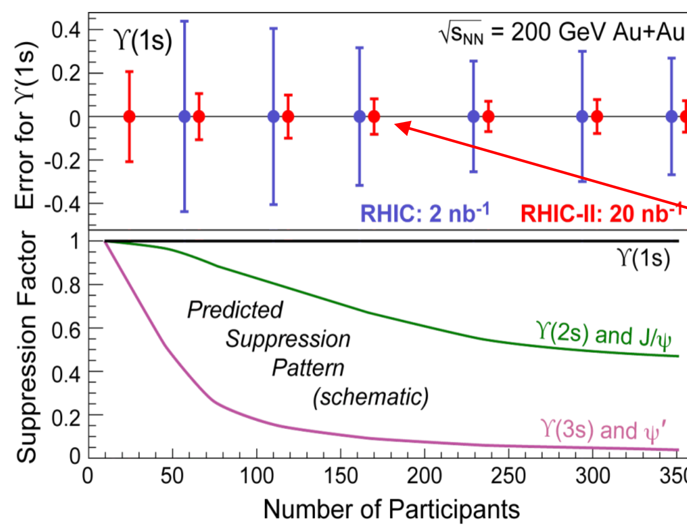
The ϒ, ϒ', ϒ'' should behave differently than the J/Ψ

- ϒ(1S) no melting at RHIC ⇒ standard candle
- ϒ(2S) likely to melt at RHIC (analog J/ψ)
- ϒ(3S) melts at RHIC (analog ψ')

Features

- co-mover absorption negligible
- recombination negligible at RHIC





ϒ→e⁺e⁻:
T. Ullrich et al

Statistical precision Expected with RHIC II luminosity

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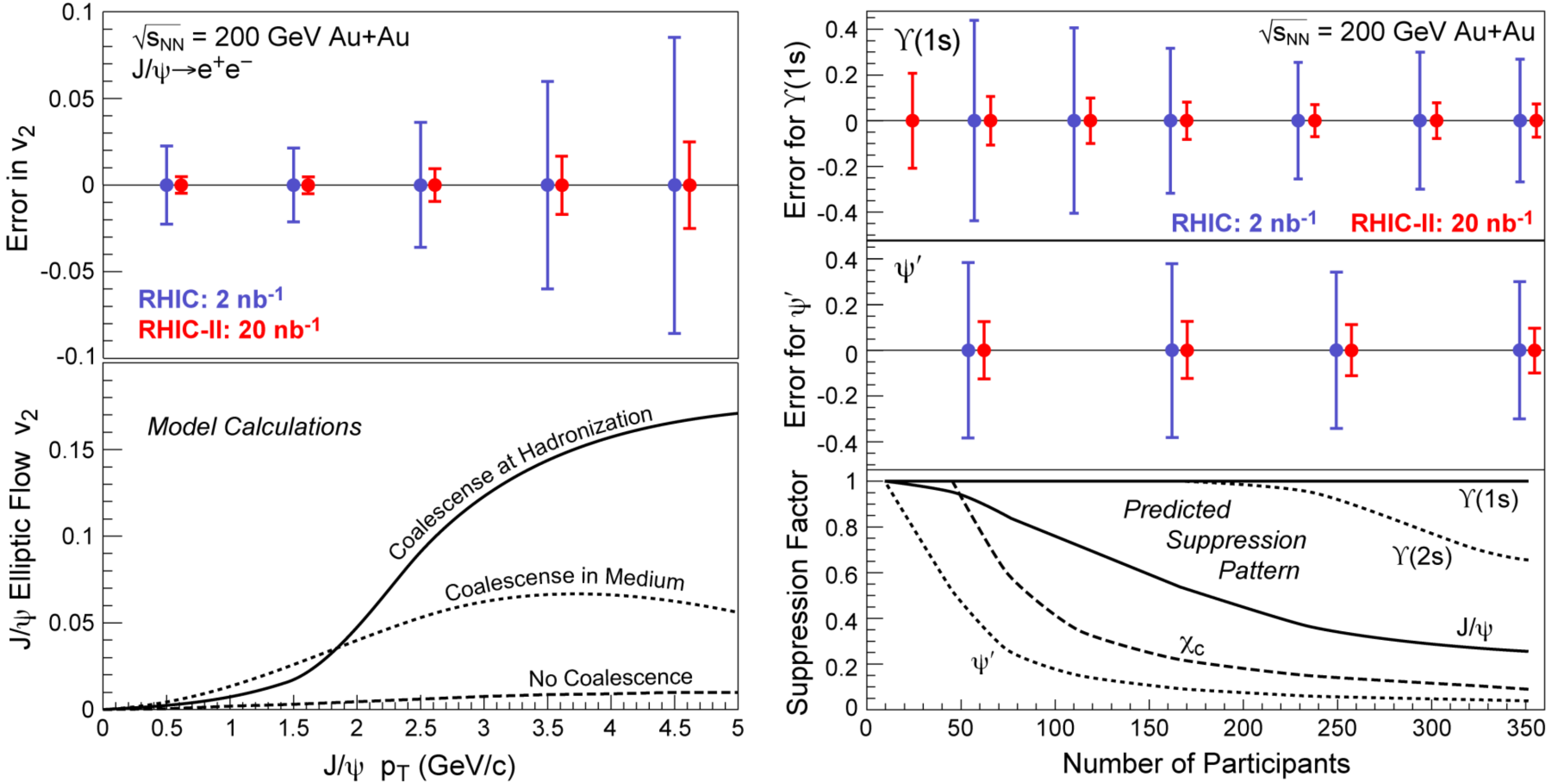
RHIC-II Science Goals: Quantifying Properties of the Perfect Liquid

Enhanced luminosity (by 2012) + detector upgrades will enable rare probe studies of quarkonium (*qqbar* systems) yield & flow, sensitive to color screen-ing (deconfinement) and parton equilibration/coalescence in the QGP.



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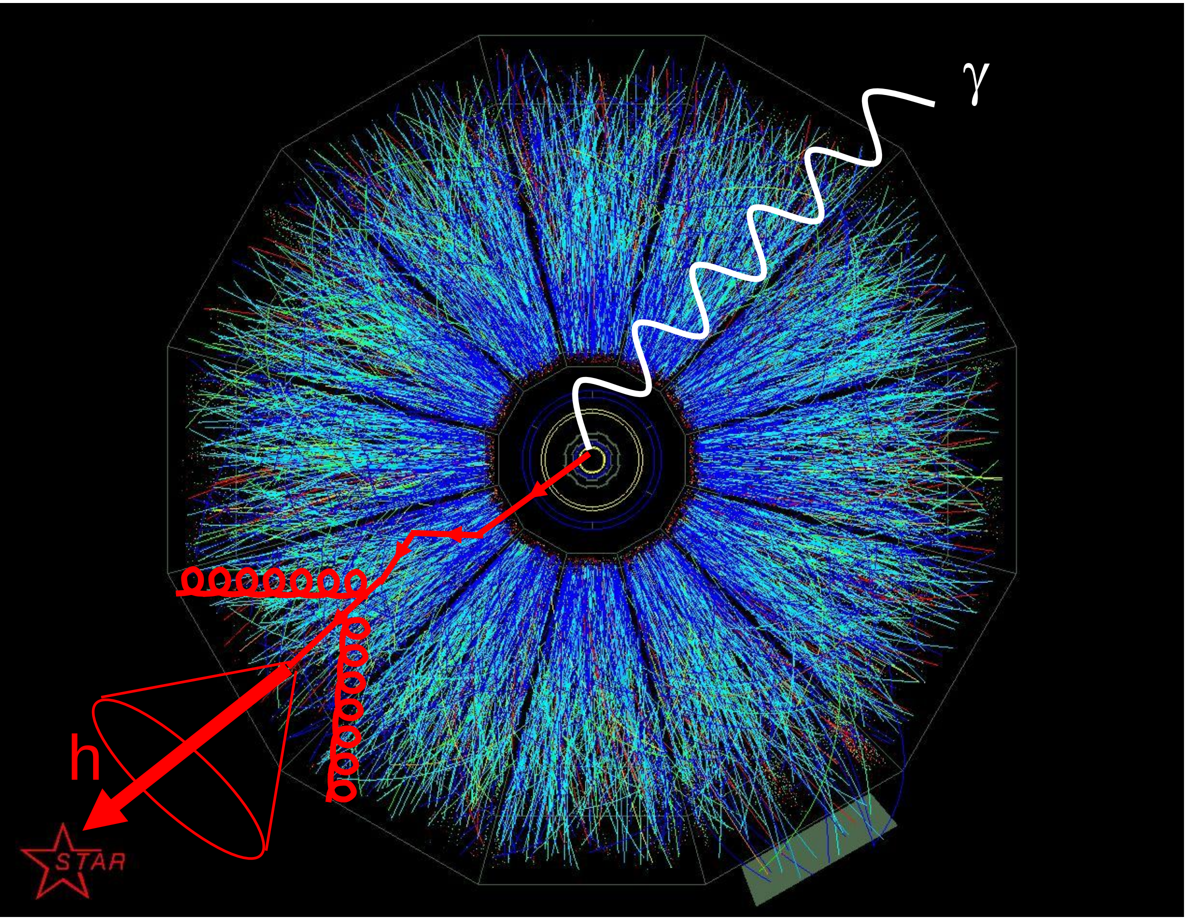
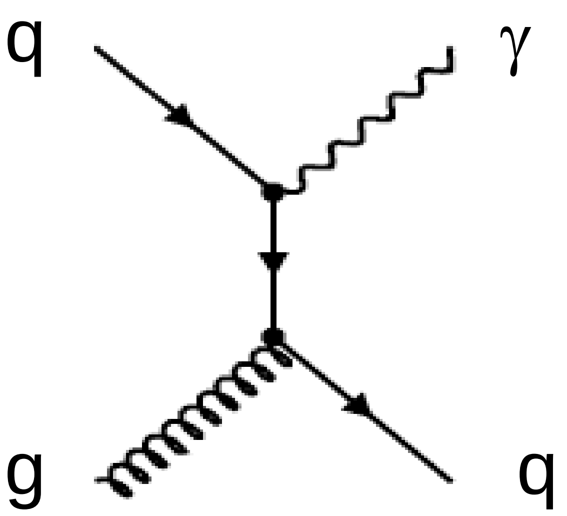
γ-Jet: Golden Probe of QCD Energy Loss

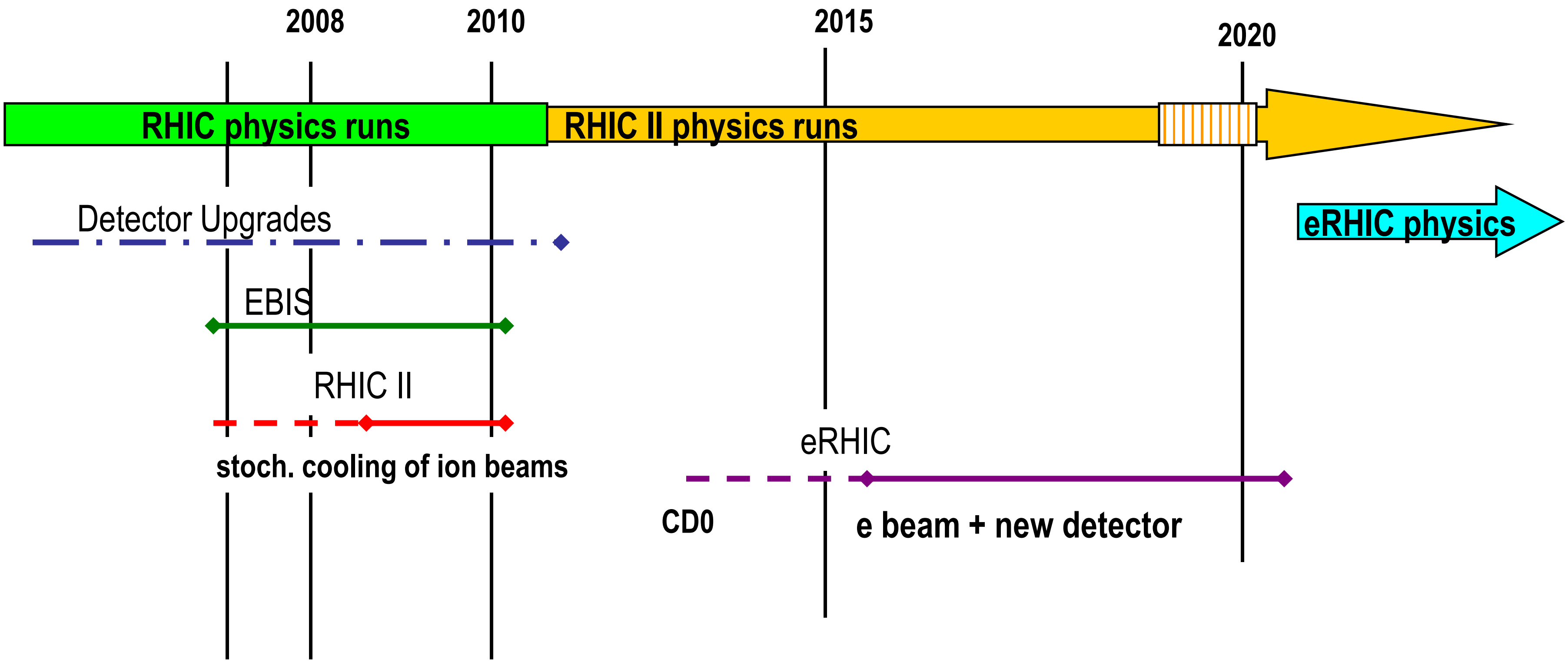




QCD analog of Compton Scattering

- γ emerges unscathed from the medium
  - This probe is valuable for comparison with di-hadron correlations
  - It provides fully reconstructed kinematics: measure real fragmentation function D(z)

A Long Term (Evolving) Strategic View for RHIC



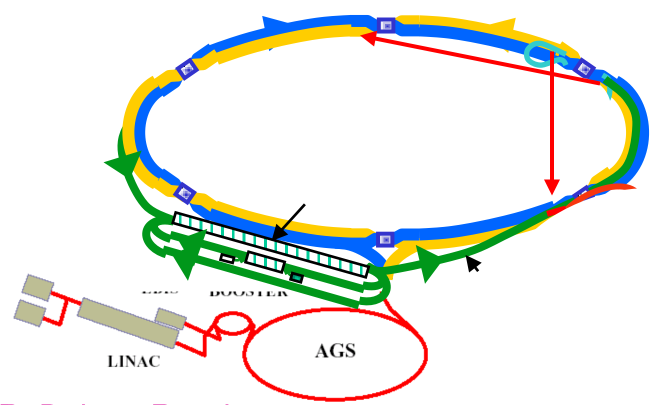
Legend:

- - - - - - - - *R&D*

◆———◆ ***Construction***

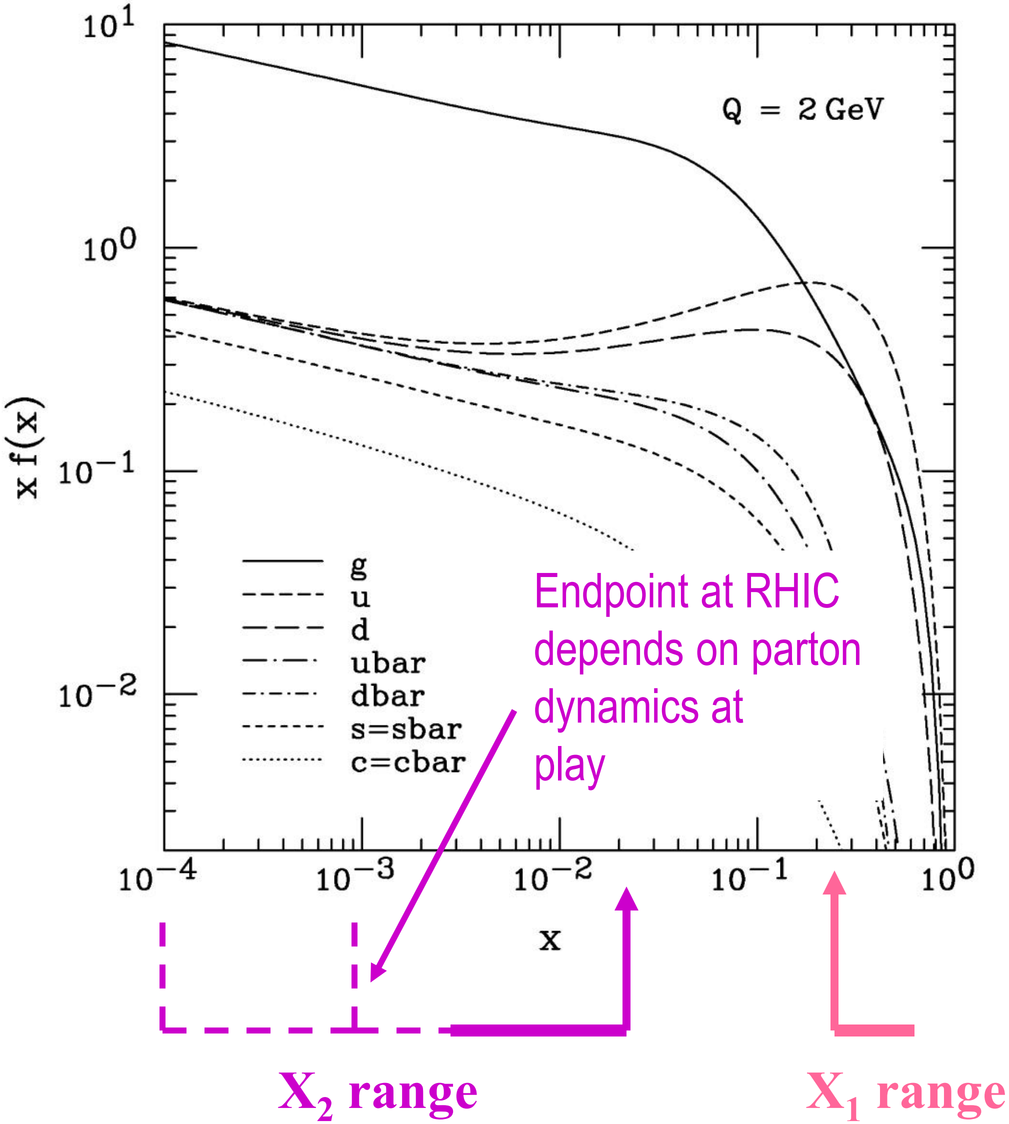
— · — · — · —◆ ***Multiple small projects***

CD0: DOE Critical Decision, mission need



And then, there is the question of the initial conditions

What are the initial-state parton distribution functions and how they effect the time it takes to thermalize



Measurements needed at high rapidity to set the dominant parton type:

Projectile (x_1 ~1) mostly valence quarks.

Target (x_2<0.01) mainly gluons.

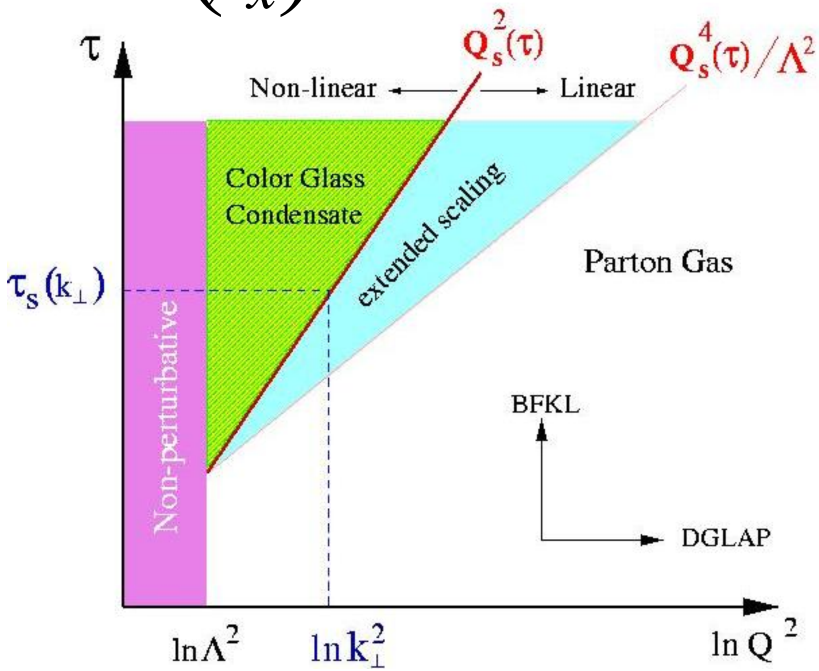
Sensitive to $x_g \sim 10^{-3}$ in pQCD picture

Sensitive to $x_g \sim 10^{-4}$ in CGC picture

- Question
  - At low-x in the previous plot, the gluon distribution continues to grow exponentially
  - But, it can not grow indefinitely without bound
  - What happens at when x becomes very small ?

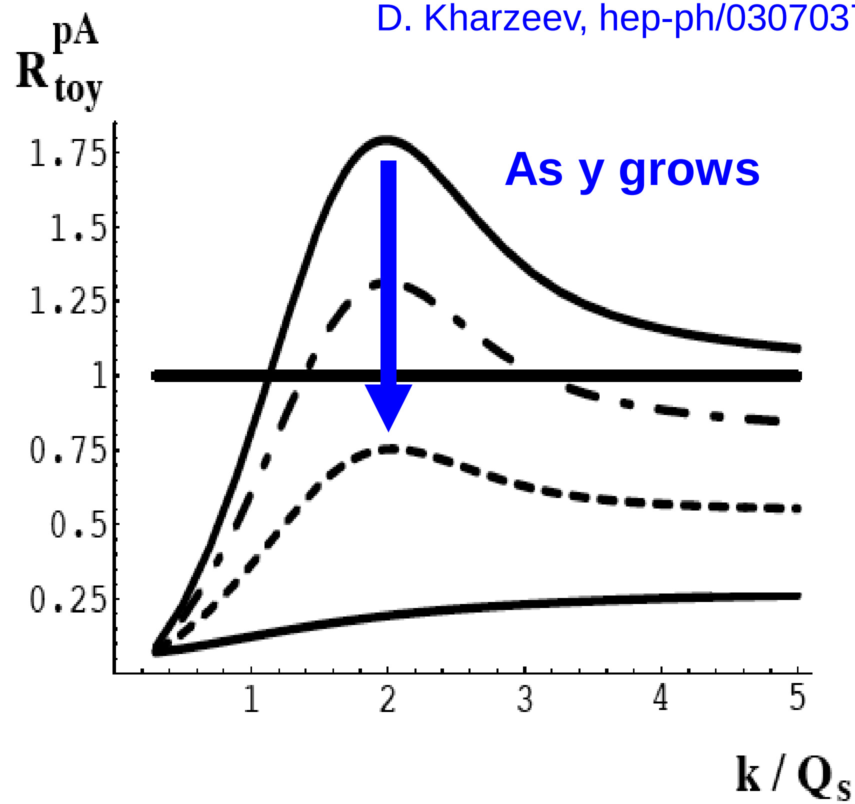
Attempt at a semi-classical, effective field approach: conceptual expectation for a Color Glass Condensate

$\tau = \ln\left(1/x\right)$ τ related to rapidity of produced hadrons.



Iancu and Venugopalan, hep-ph/0303204

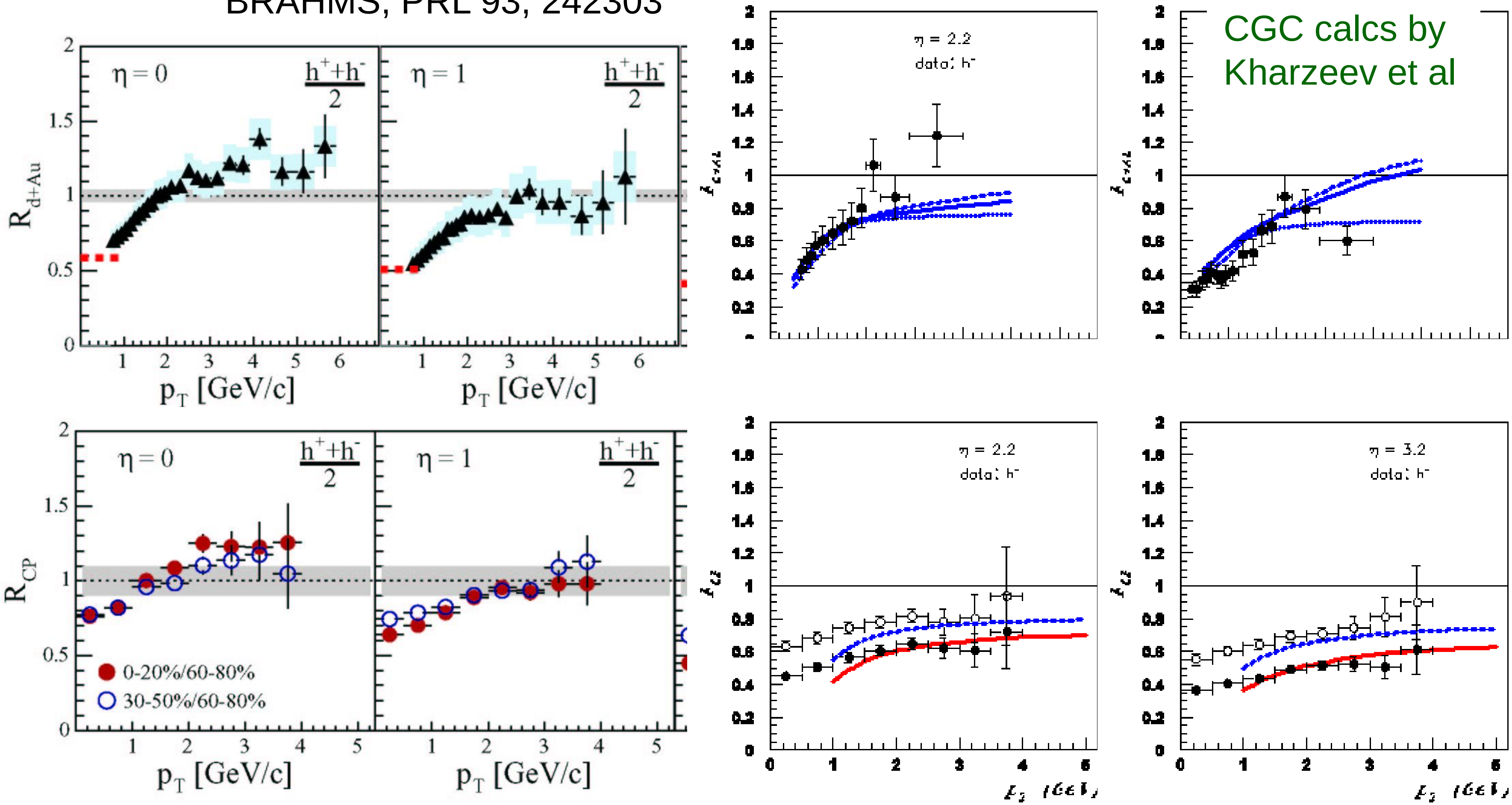
D. Kharzeev, hep-ph/0307037



Is there evidence for **gluon saturation at RHIC energies**?

Forward particle production in d+Au collisions

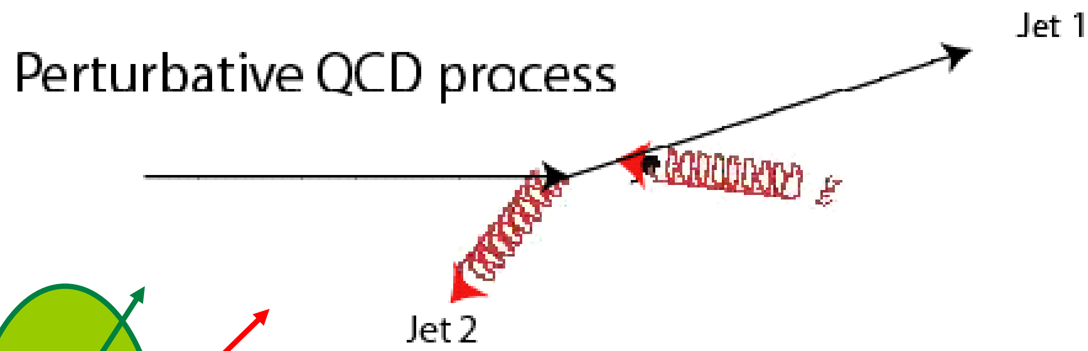
BRAHMS, PRL 93, 242303



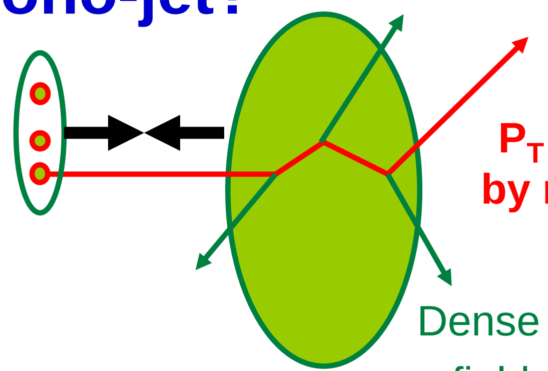
- Sizable suppression of charged hadron yield in forward d+Au
- Evidence for a saturated gluon field in the Au nucleus?
- Several other mechanisms have also been proposed

Correlations will provide a more sensitive probe

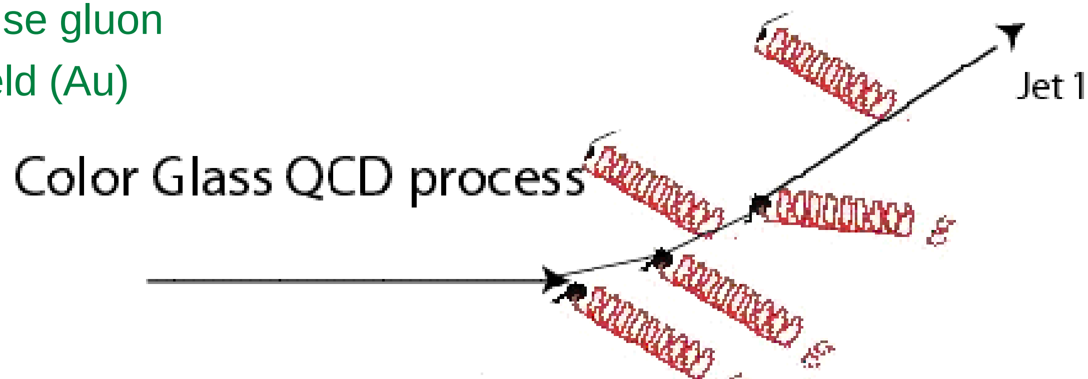
p+p: **Di-jet**



d+Au: **Mono-jet?**



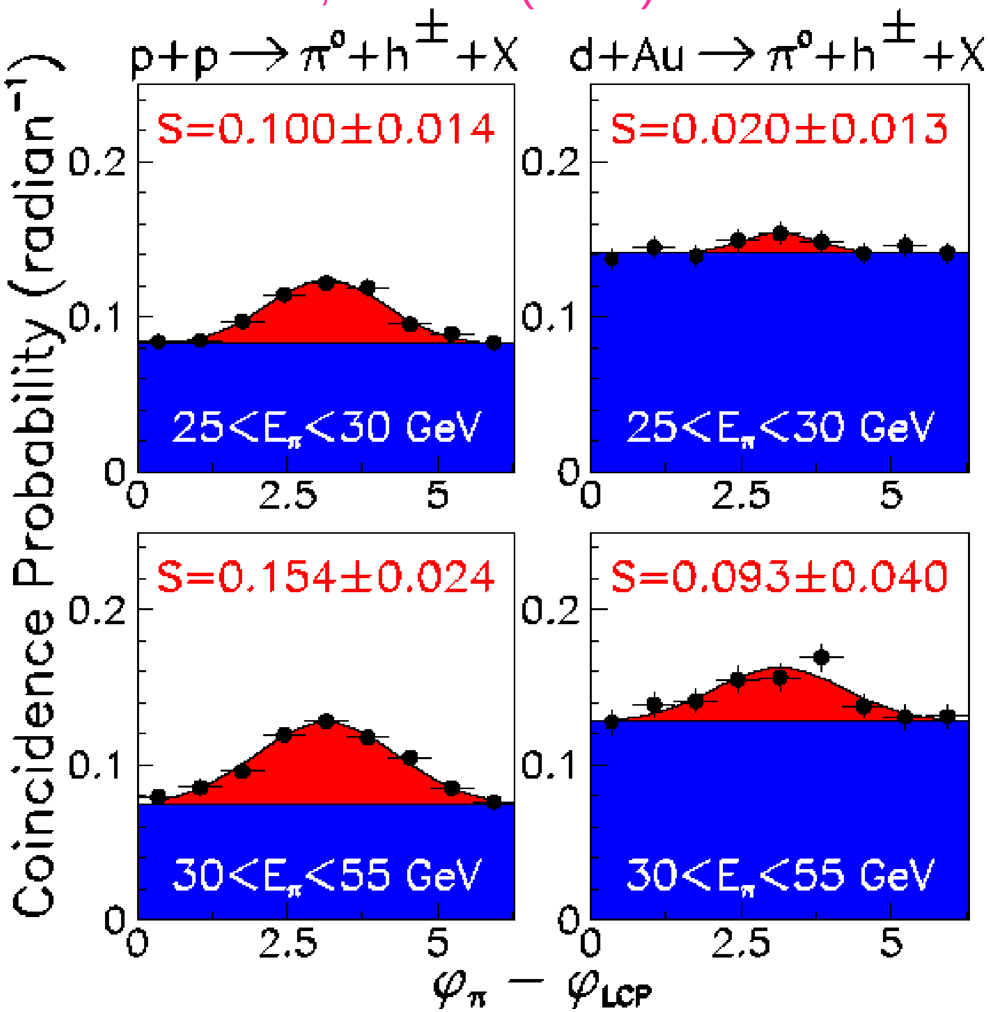
Kharzeev, Levin, McLerran gives physics picture (NPA748, 627)



Color glass condensate predicts that the back-to-back correlation from p+p should be suppressed

An initial glimpse: correlations in d+Au

PRL 97, 152302 (2006)



$\langle p_{T,\pi} \rangle \sim$ 1.0 GeV/c

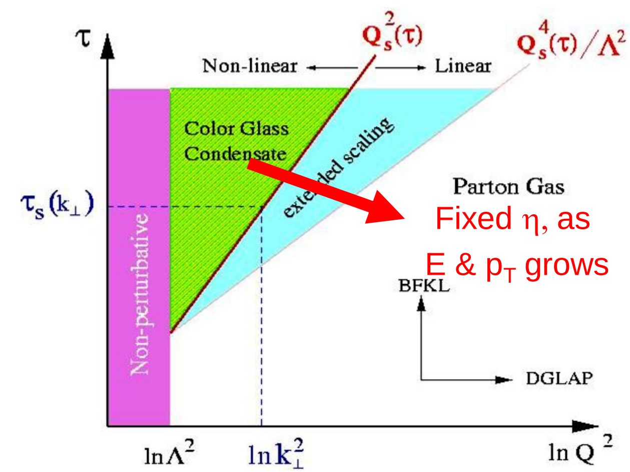
$\langle p_{T,\pi} \rangle \sim$ 1.3 GeV/c

π^0: $|\langle\eta\rangle| = 4.0$

h : $|\eta| < 0.75$; $p_T > 0.5$ GeV/c

- are suppressed at small $\langle x_F \rangle$ and $\langle p_{T,\pi} \rangle$

consistent with CGC picture



- are similar in d+Au and p+p at larger $\langle x_F \rangle$ and $\langle p_{T,\pi} \rangle$

As expected by HIJING

Ultimately, to study the low-x gluon distribution in heavy nuclei properly, a new Electron-Ion Collider (EIC) is needed (BNL + TJNAF)

What has been found: 3^+ new discoveries

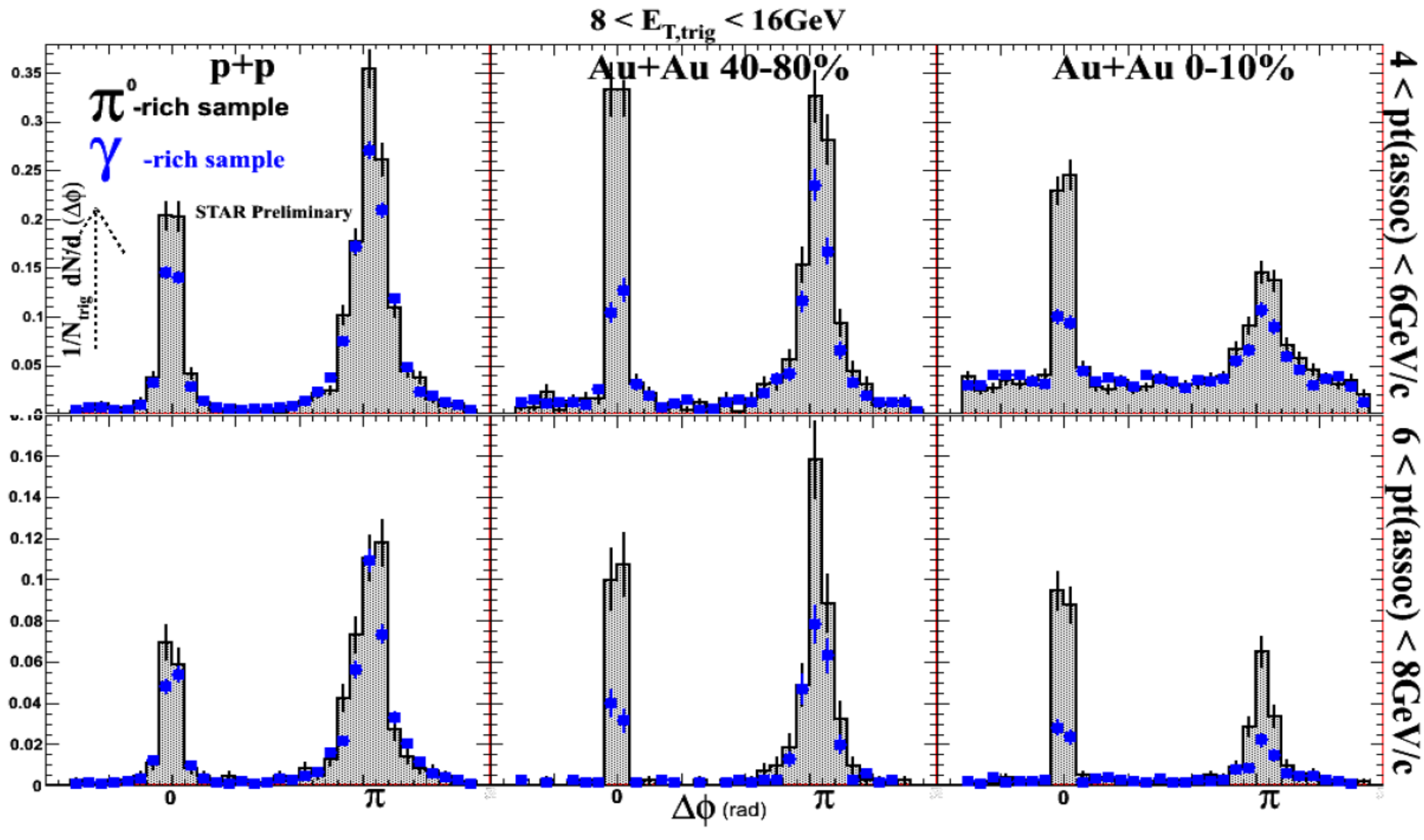
- Enormous collective motion of the medium, consistent with near-zero viscosity hydrodynamic behavior
  - Very fast thermalization
  - A “perfect liquid”
- Jet quenching in the dense matter
  - Densities up to 100 times cold nuclear matter and 15 times the critical density from lattice calculations
- Anomalous production of baryons relative to mesons
  - Strongly enhanced yields of baryons relative to mesons
  - Scaling of yields and collective motion with the number of valence quarks
  - Hadrons form by constituent quark coalescence
- Indications of gluon saturation in heavy nuclei
  - Relatively low multiplicities in Au+Au collisions
  - Suppressed particle production in d+Au collisions

New scientific questions

- What is the mechanism of the unexpectedly fast thermal equilibration?
- What is the initial temperature and thermal evolution of the produced matter?
- What is the energy density and equation of state of the medium?
- What is the viscosity of the produced matter?
- Is there direct evidence for deconfinement, color screening, and a partonic nature of the hot, dense medium? What is the screening length?
- Can we directly observe a QCD phase transition? Where is the QCD critical point?
- Is chiral symmetry restored, as predicted by QCD?
- How does the new form of matter hadronize at the phase transition?

These are the topics of RHIC II……

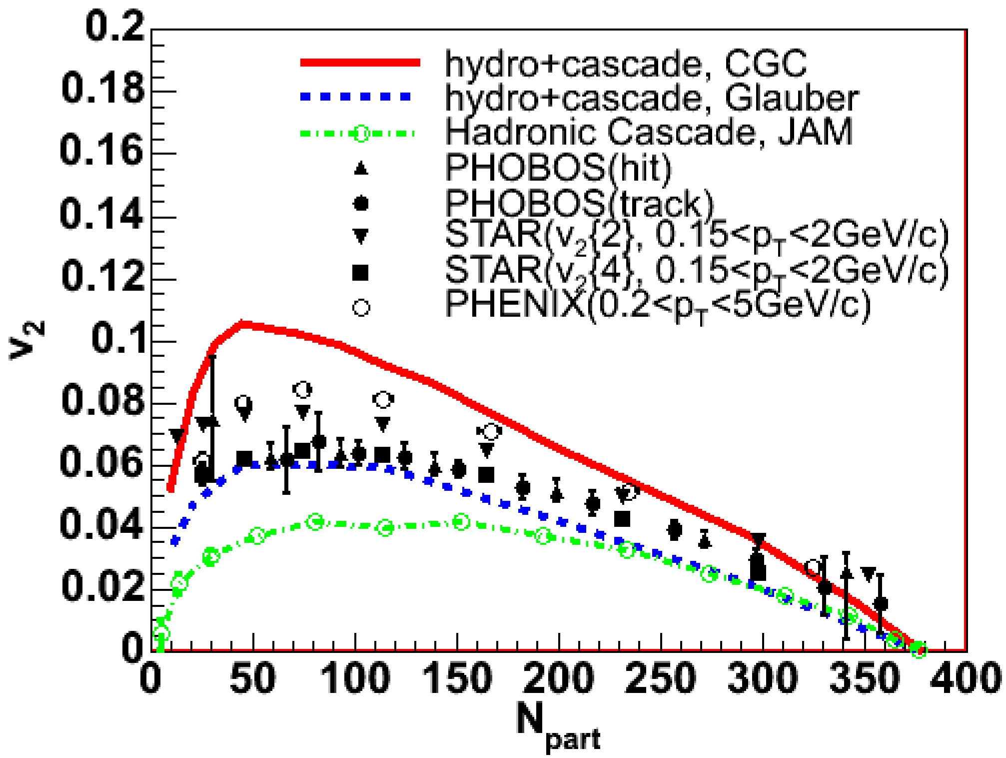
First results on high-p_T di-hadron,γ-hadron correlations

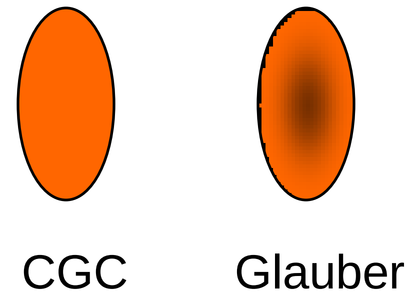


First steps to precision study with high luminosity at RHIC

Relevance of the answer to the QGP: v_2 and the hydro limit—Glauber vs Color Glass Condensate

Hirano et al, PLB 636, 299





CGC: Treats the nucleus as a saturated gluon field

Effects initial eccentricity of the overlap zone

- Do we have Glauber matter distribution + perfect liquid, or Color Glass Condensate distribution + viscous matter?
- Understanding the initial state is **crucial to understand what we are seeing in the final state**

In fact there is a strong coupling to understanding the story at mid-rapidity:

Answers are (urgenetly) needed to:

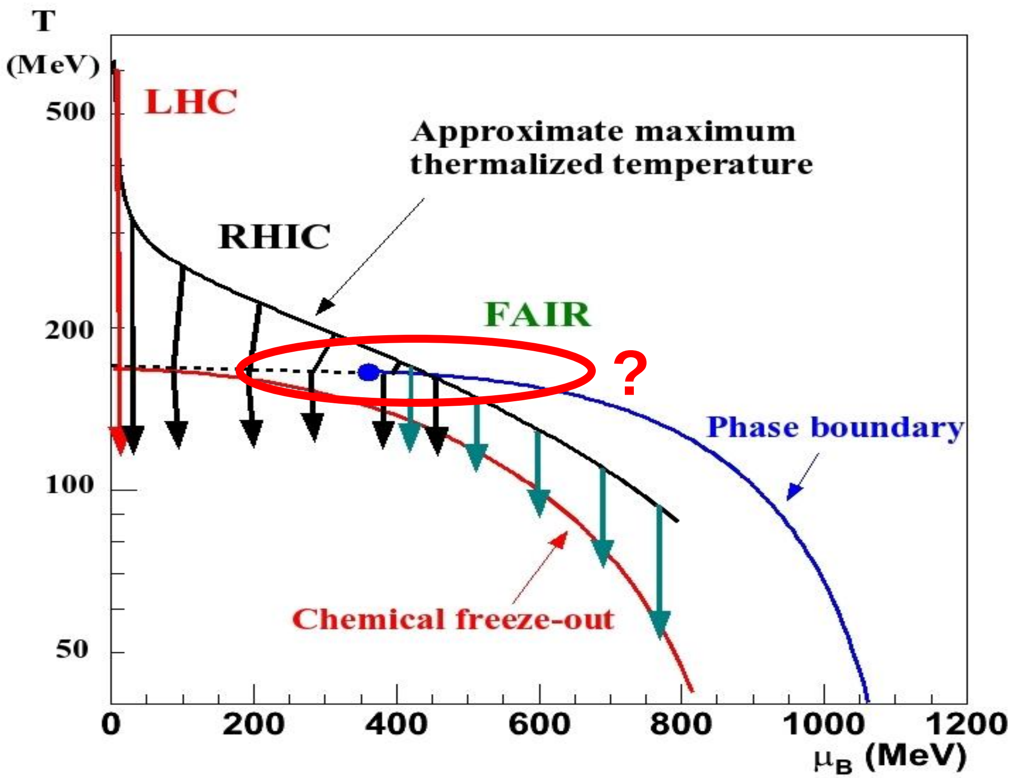
Understand the initial state conditions for relativistic heavy nuclei at RHIC and confirm our understanding of multiplicities and rapidity dependence

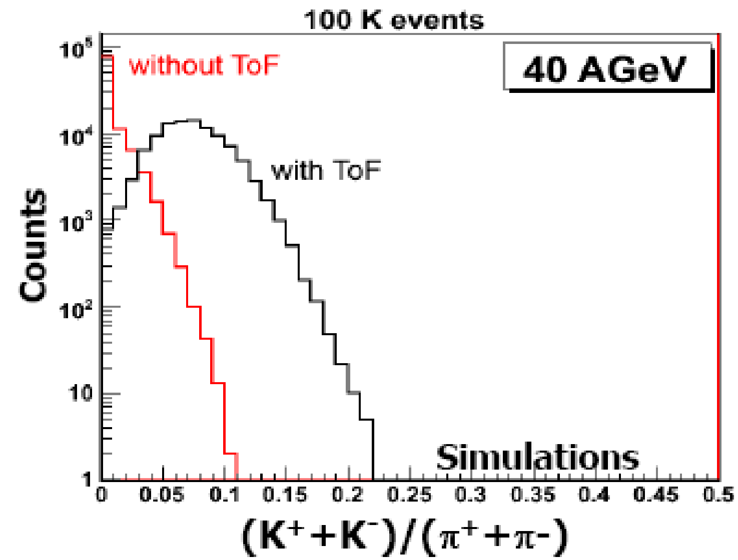
Understand how thermalization appears to be established so quickly at RHIC

Understand whether we have really reached the hydro limit for v_2

Understand mid-rapidity particle production at the LHC in the future

Where is the QCD critical point?

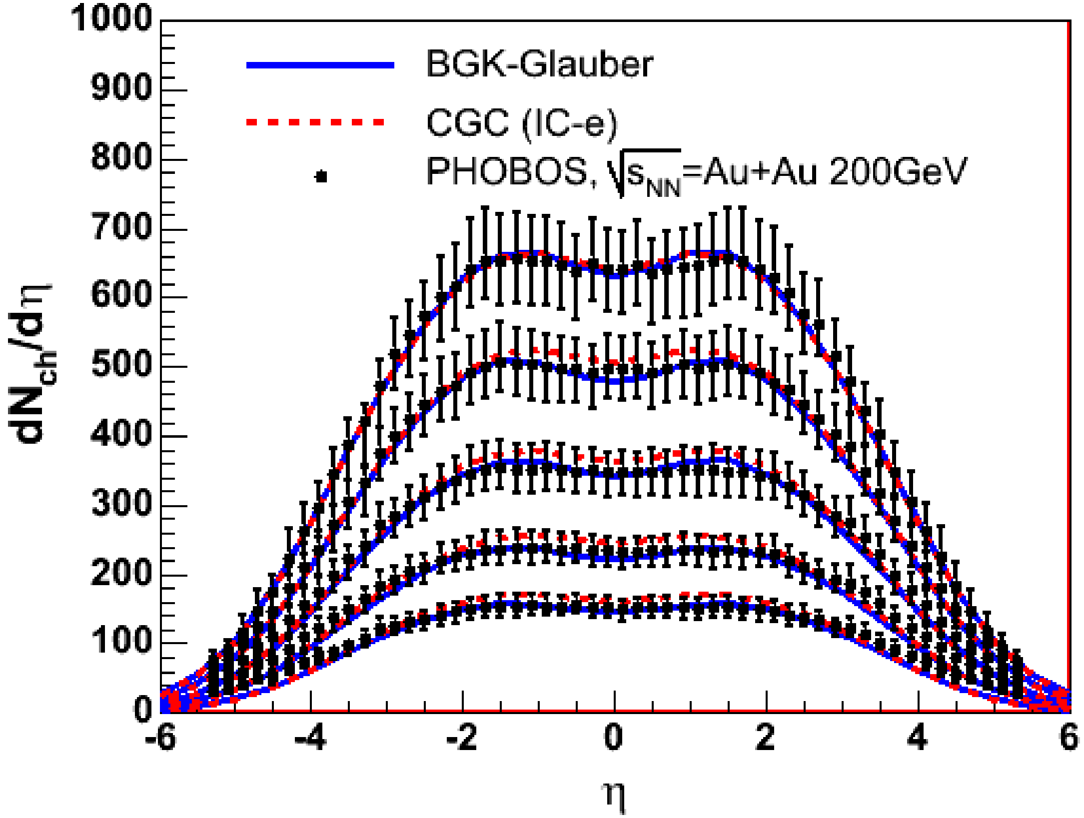




A possible signature:
event-by-event K/π fluctuations.
Needs large-acceptance PID.

- The “landmark” on the QCD phase diagram!
- Lattice calculations: between μ_B of <~200 and >~700 MeV.
- RHIC can find it if μ_B < 500 MeV
- Need detailed study of many different collision energies
- Significant advantage of RHIC: with collider detectors, most systematic effects are constant with beam energy
- Low energy electron cooling would greatly increase the luminosity

Particle multiplicity vs. pseudorapidity



- Multiplicities well described by Color Glass Condensate model
- Evidence for saturated gluon fields in the Au nucleus?

In principle, there is a lot of information needed to understand High p_T Particle Production in A+A Collisions

(According to pQCD…)

$$\frac{dN^h_{AB}}{dy d^2 p_T} = K \sum_{abcd} \int dx_a dx_b \int d^2\mathbf{k}_a d^2\mathbf{k}_b$$

$$\times f_{a/A}(x_a, Q^2) f_{b/B}(x_b, Q^2)$$ **Parton Distribution Functions**

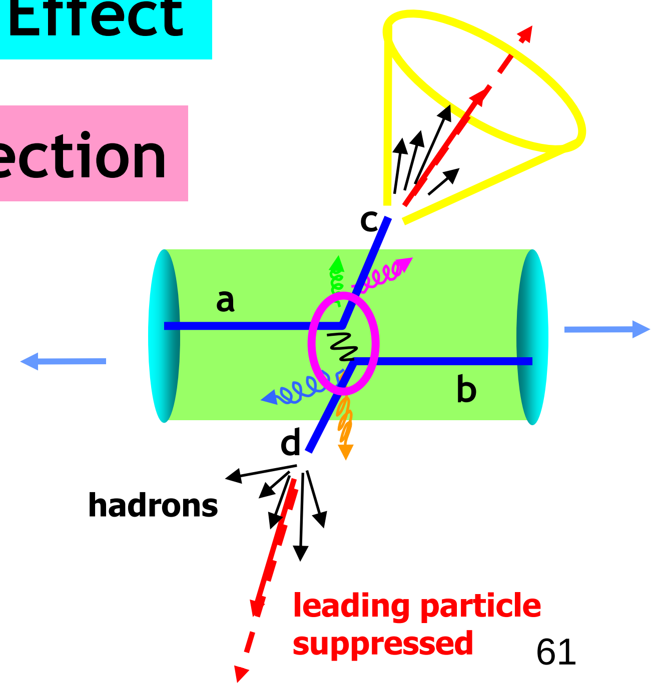
$$\times g(\mathbf{k}_a) g(\mathbf{k}_b)$$ **Intrinsic k_T , Cronin Effect**

$$\times S_A(x_a, Q_a^2) S_B(x_b, Q_b^2)$$ **Shadowing, EMC Effect**

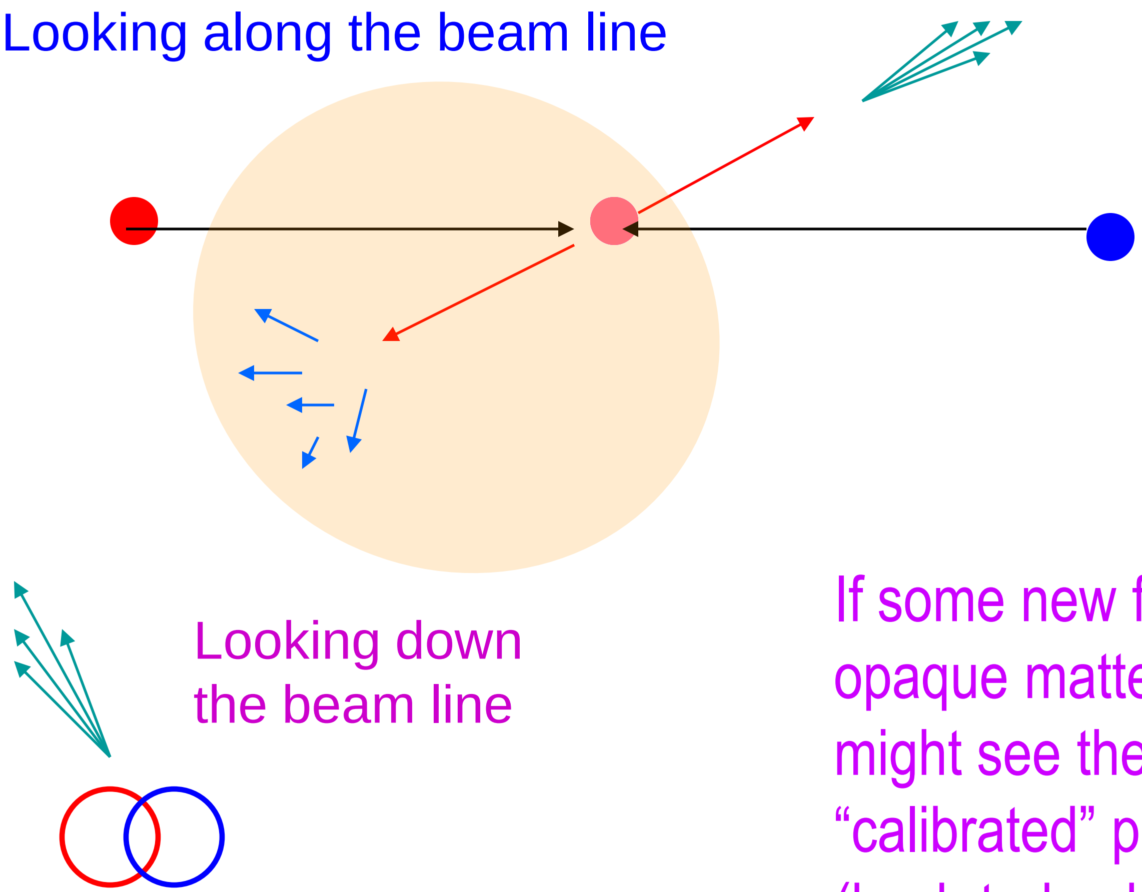
$$\times \frac{d\sigma}{d\hat{t}}(ab \to cd)$$ **Hard-scattering cross-section**

$$\times \int_0^1 d\varepsilon P(\varepsilon) \frac{z_c^*}{z_c}$$ **Partonic Energy Loss**

$$\frac{D^0_{h/c}(z_c^*, Q_c^2)}{\pi z_c}$$ **Fragmentation Function**



But using our calibrated probe we can try something simpler to start

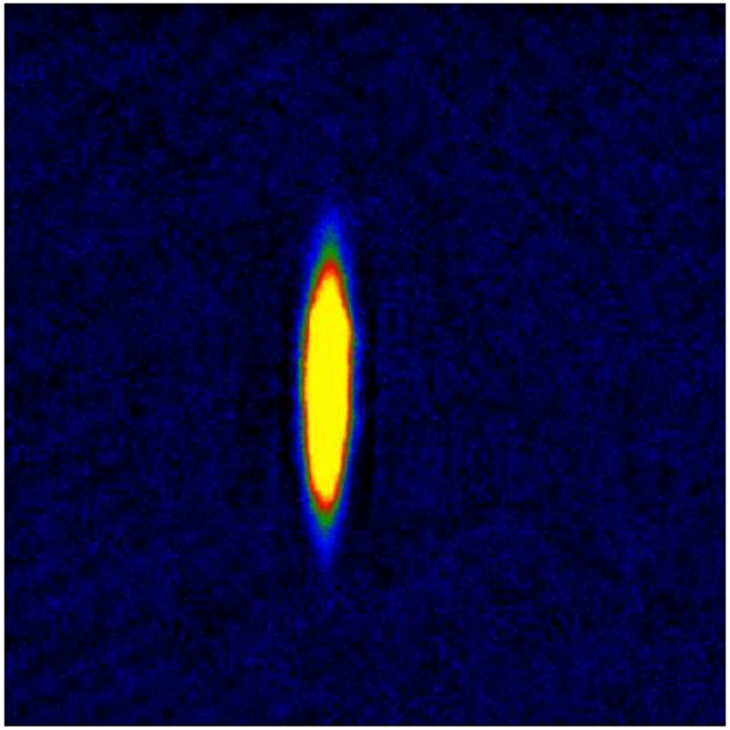


If some new form of dense, opaque matter is formed, we might see the effects on our “calibrated” probe (back-to-back correlation)

Gas of weakly/strongly interacting Li atoms

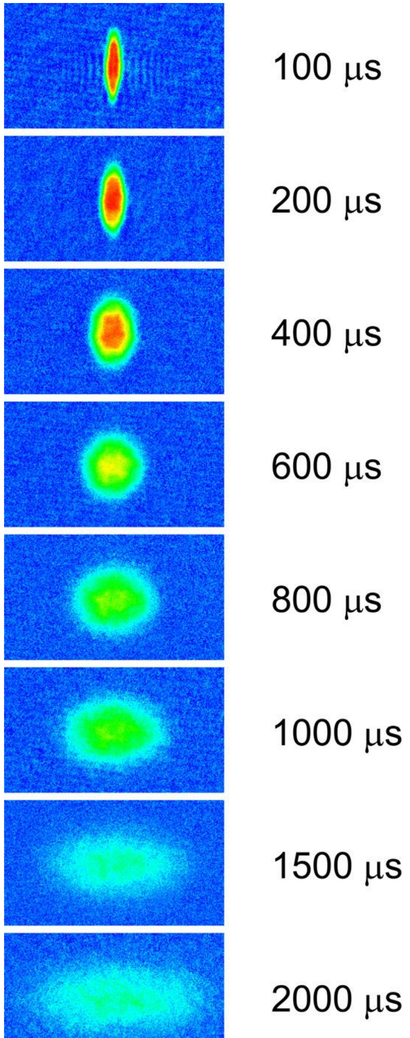
M. Gehm et al, Science 298, 2179

– excite Feshbach resonance



weakly coupled

strongly coupled



The next step for one of the detectors

Full prototype TPC sector now in operation and working flawlessly

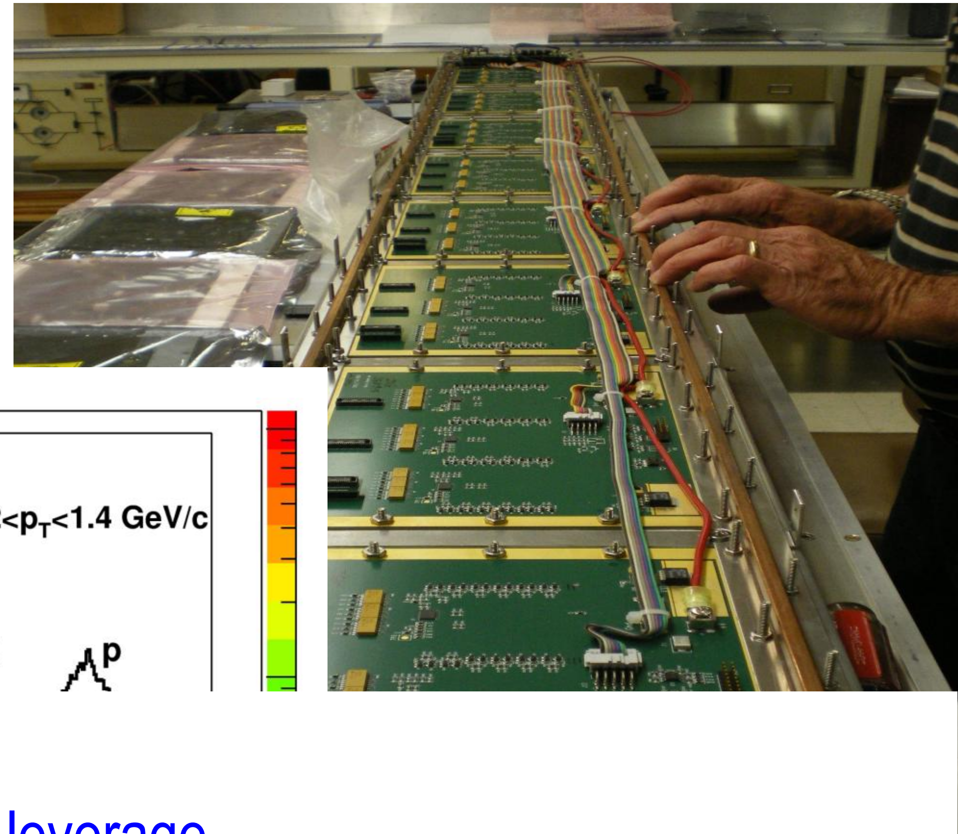
Collaboration Plan:

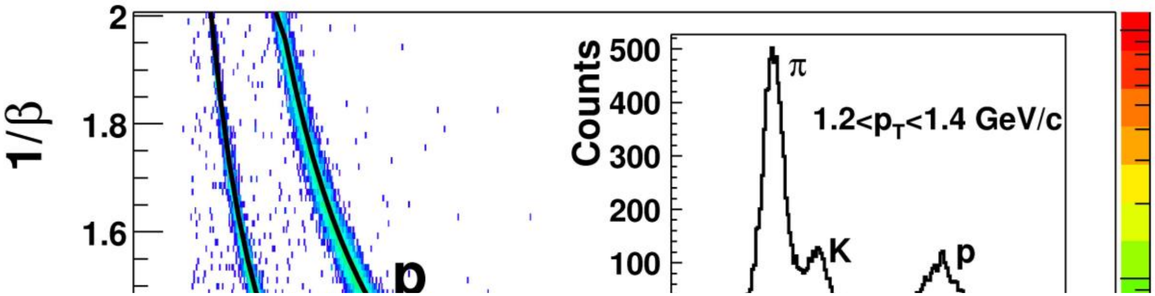
Increase of DAQ rate to1000 times design by Run 9 leveraging CERN/ALICE Altro chip development (thank you)

Construction of HFT in time for full operation in Run 12 (Fall 2011)

Five "final item" mrpc trays in place and in the STAR data stream now

- PID information for > 95% of kaons and protons in the STAR acceptance





Collaboration plan

120 trays of MRPC modules which leverage

MRPC development at CERN (Crispin Williams et al)

Development of HPTDC Chip

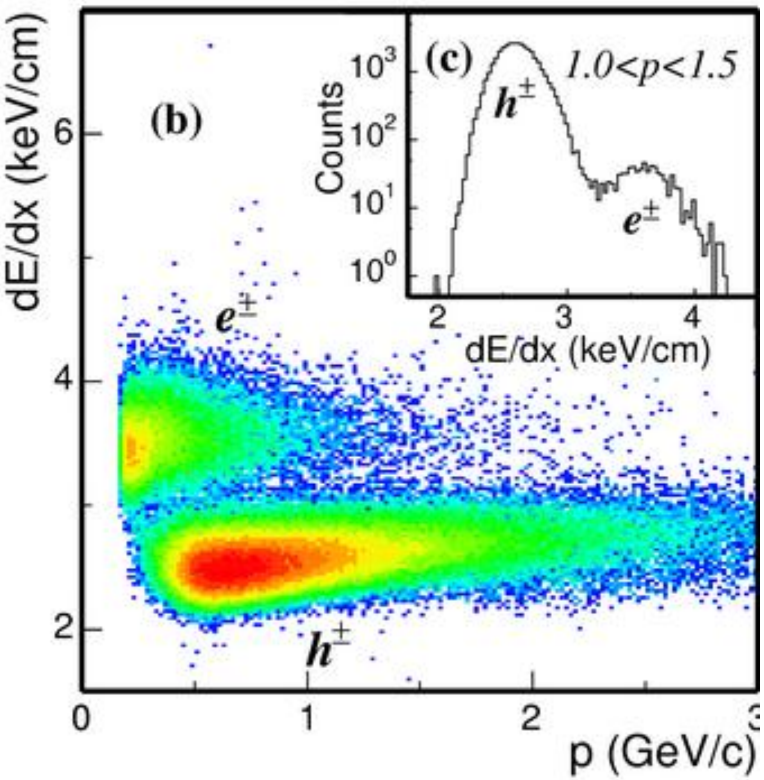
MRPC tech transfer and construction (contributed) in China

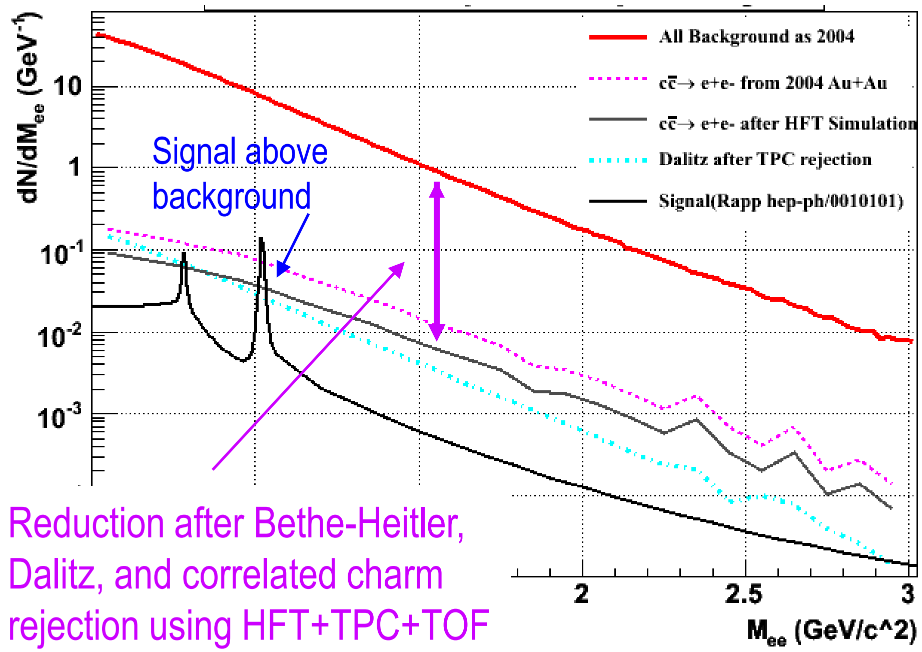
} Thanks

Fully complete in time for run 10 (fall 2009)

Future di-lepton program to study in-medium effects

BNL-developed technique: dE/dx for β = 1 particles (TOF)





Projected e^+e^-: yields for 200M central Au+Au events

Detectors	ω	ϕ
TPC+TOF+HFT	20K	6K

- Initiate and develop electron PID with TPC+TOF
- Utilize either low material (pre-HFT) or HFT
- Develop di-lepton program at STAR with resonance techniques + electron PID
- Statistics comparable to NA60