# Relativistic Heavy Ion Physics and the OSG

T. Hallman

OSG All Hands Consortium Meeting, 3-6 March 2008

Friday Center, Chapel Hill, NC

# The Nuclear Physics Players in OSG (at least ones I know about): ALICE at CERN, STAR at RHIC/BNL, GLUEX at JLAB

I will discuss examples of relativistic heavy ion physics (based on STAR experience) for which OSG developments are essential

The physics measurements made by ALICE and STAR experiments are rather similar with respect to their fundamental character:

- non-triggered probes of bulk properties (spectra, correlations, fluctuations, low $p_T$ di-leptons, vector mesons ($\rho$, $\phi$) etc.
- triggered rare probes such as jets, direct photons, quarkonia

The first category provides the most significant challenge due to the volume of experimental data and embedding required

# The Science of STAR at RHIC

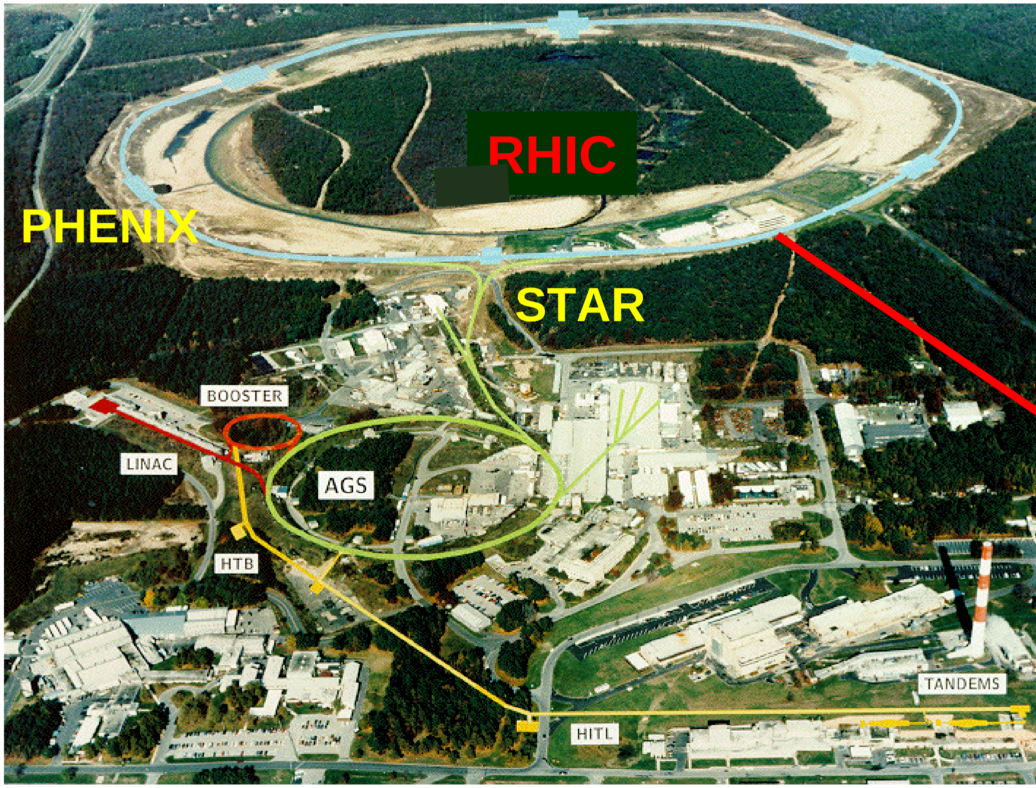
- RHIC's original science mission:
  - Discovery of a new state of matter (quark-gluon plasma) in central heavy ion collisions ( ✓)
  - Detailed unfolding of the spin structure of the nucleon
- "Value added" physics:
  - Low x structure of hadrons
  - Fundamental tests of QCD
  - Search for new exotics

    Forward inclusive spectra and correlations

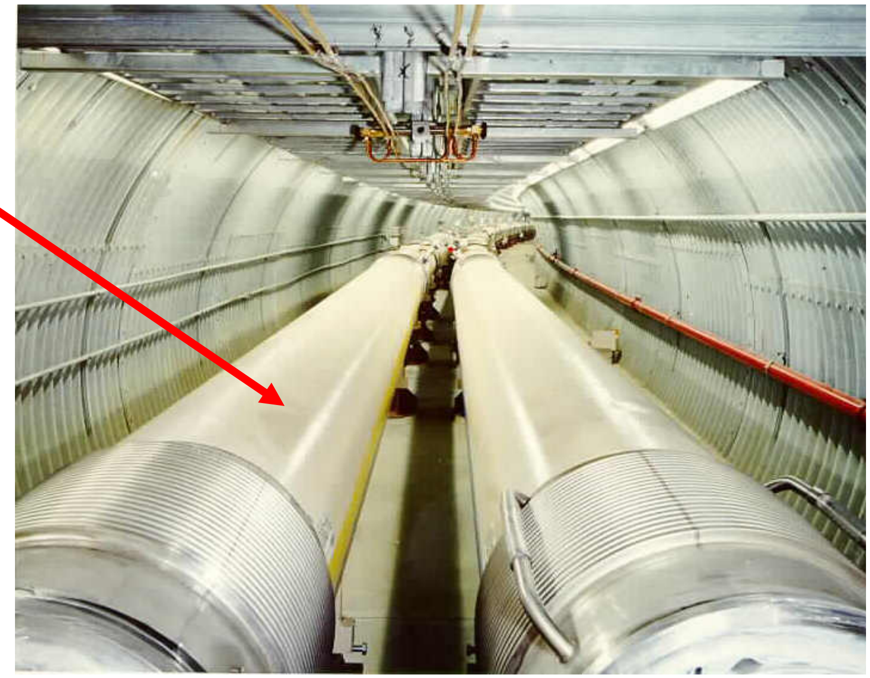
    Tagged forward proton studies

    Ultra-peripheral collisions

# Relativistic Heavy Ion Collider



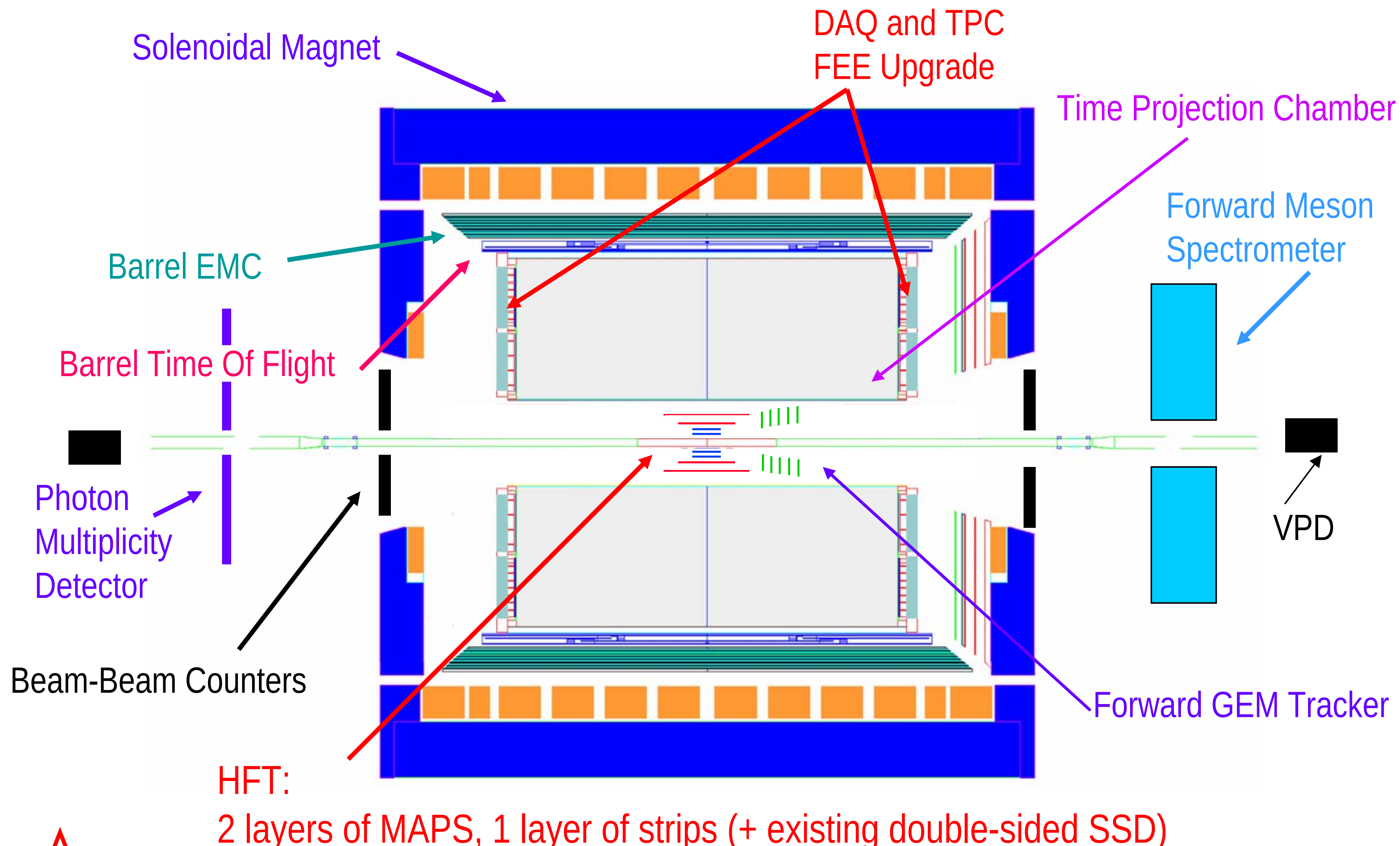

**Two Concentric Superconducting Rings**



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

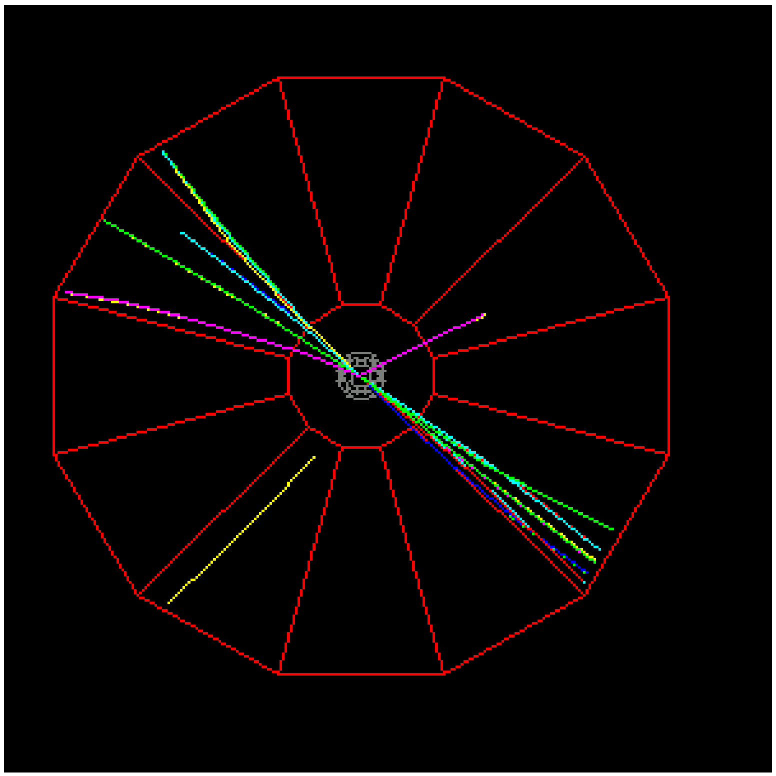
| Design Performance | Au + Au | (Now) | p + p | (Now @ 200) |
|---|---|---|---|---|
| **Max $\sqrt{s_{nn}}$** | **200 GeV** | | **500 GeV** | |
| **L [$cm^{-2}\ s^{-1}$]** | **2 x $10^{26}$** | (3.6 x $10^{27}$) | 1.4 x $10^{31}$ | (**3.5** x $10^{31}$) |
| **Interaction rates** | **1.4 khz** | (~ 36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

# The STAR Detector

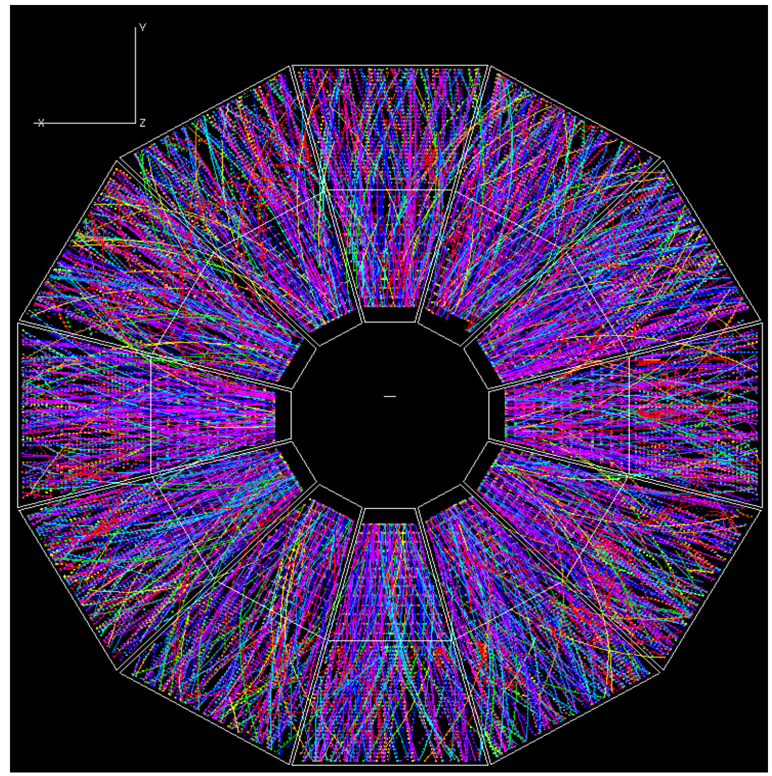


# From p+p to Au+Au in the STAR TPC

p+p →jet+jet
(STAR@RHIC)



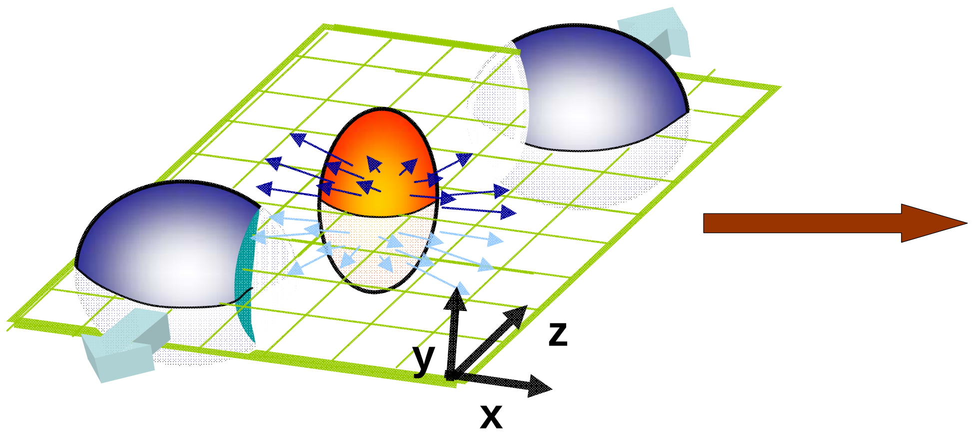
Au+Au → X
(STAR@RHIC)

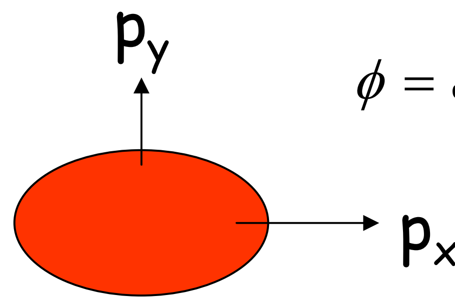


# Relativistic heavy ion physics: a different kind of high energy physics

| High Energy | Relativistic Heavy Ion Physics |
|---|---|
| $4\pi$ hermetic detector with comprehensive PID and extensive calibration out to very high $p_T$ | $2\pi$ acceptance with reasonably large $\eta$ bite around mid-rapidity very good PID out to moderately high $p_T$ |
| Search for new particle(s) expected to have very low cross section (e.g. $\sigma_{T\text{-}Tbar} \sim 5$ pb,1.8 TeV) | relatively high cross section "rare" probes ($\sigma_{J/\psi} \sim 3\ \mu$b, 200 GeV) |
| Multiple, well defined yet complex triggered final states to search for in very large data volume | highly complex hadronic final state in which "rare" probes are embedded, from which correlations and fluctuations must be fished out |
| Requires extensive simulation with precise detector response | Requires extensive embedding with realistic detector response |

# A concept essential to understand the next slides: "elliptic flow"




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

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

**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 <u>matter</u> very early

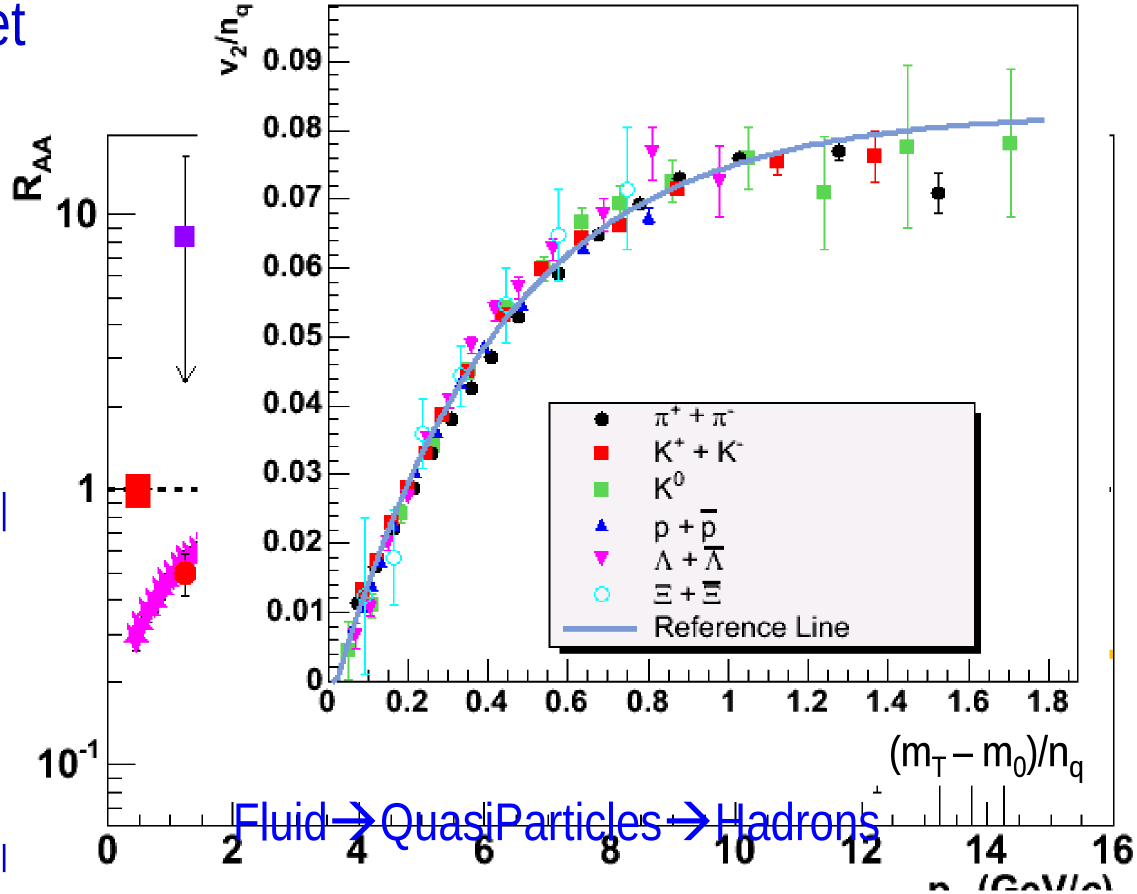
# The starting point: what we have discovered thus far

The hottest, densest matter yet examined in the laboratory

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

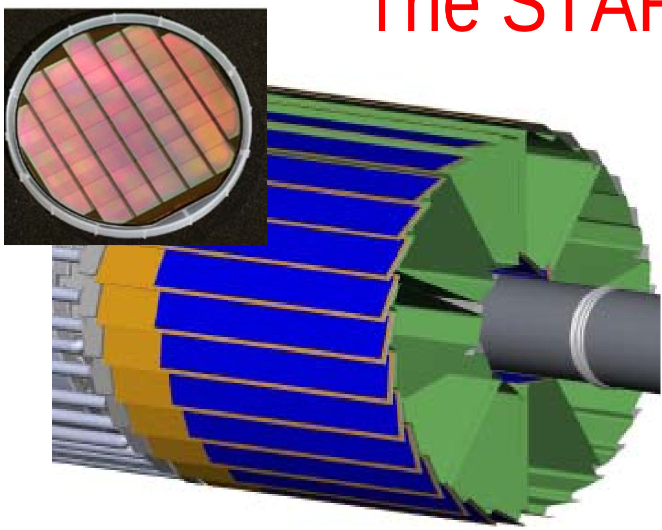
It appears to flow as a relativistic quantum liquid with viscosity to entro[p
density ratio lower than any other known liquid

It produces copious mesons and baryons with yield ratios and flow properties that suggest their formatio[n




These discoveries have all been made with light quark hadrons. They have raised new questions which require extension to heavy quark mesons and baryons. That drives the need for order of magnitude larger data sets

# The STAR Heavy Flavor Tracker

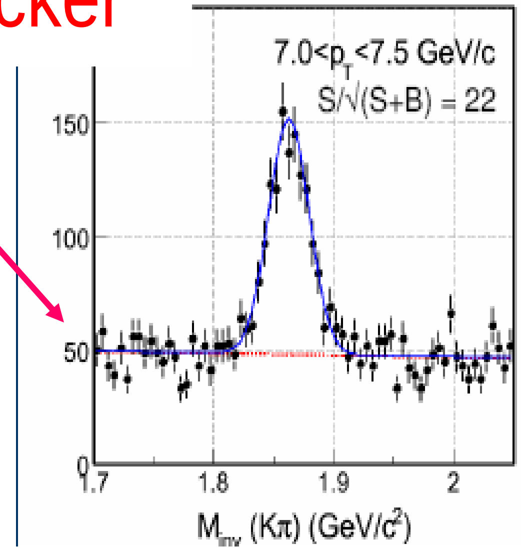


100M central Au+Au

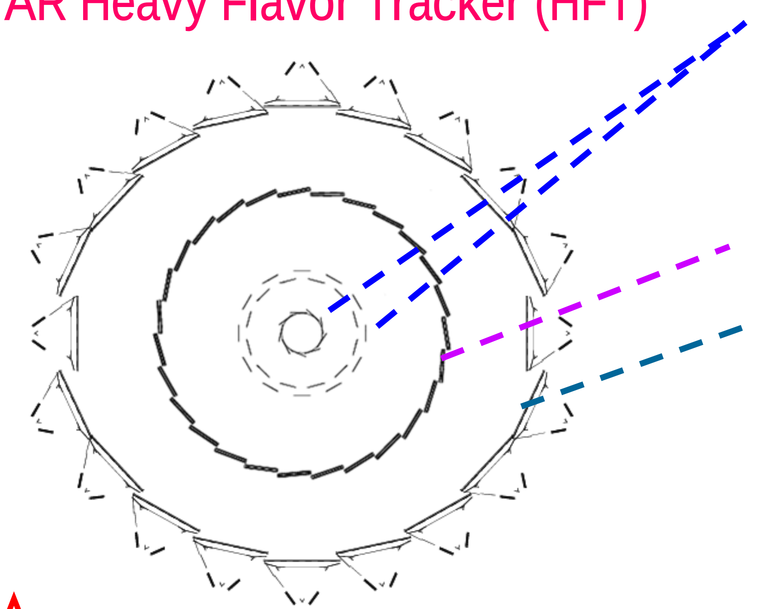
$D^0 + \overline{D^0}$, RHIC II

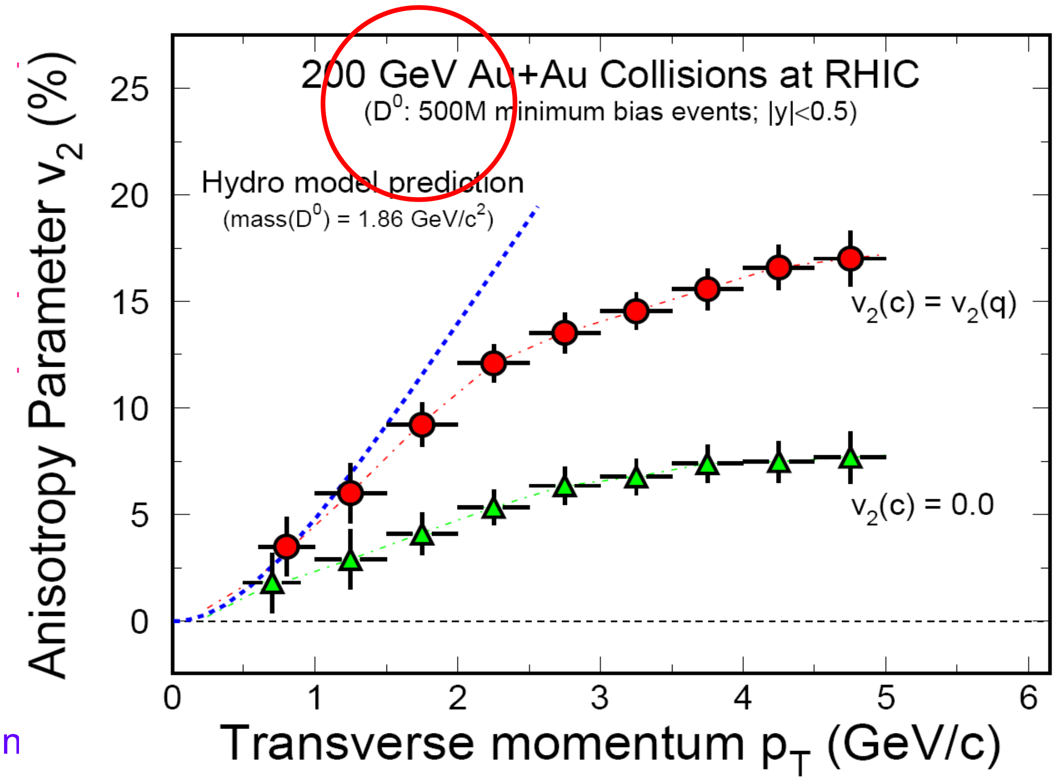
Topological PID

pileup included



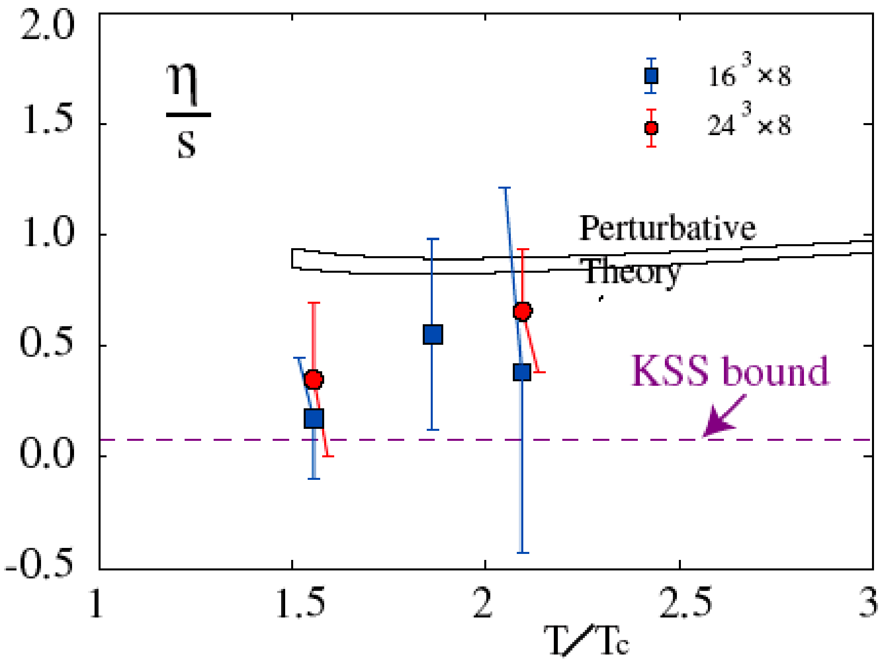

STAR Heavy Flavor Tracker (HFT)





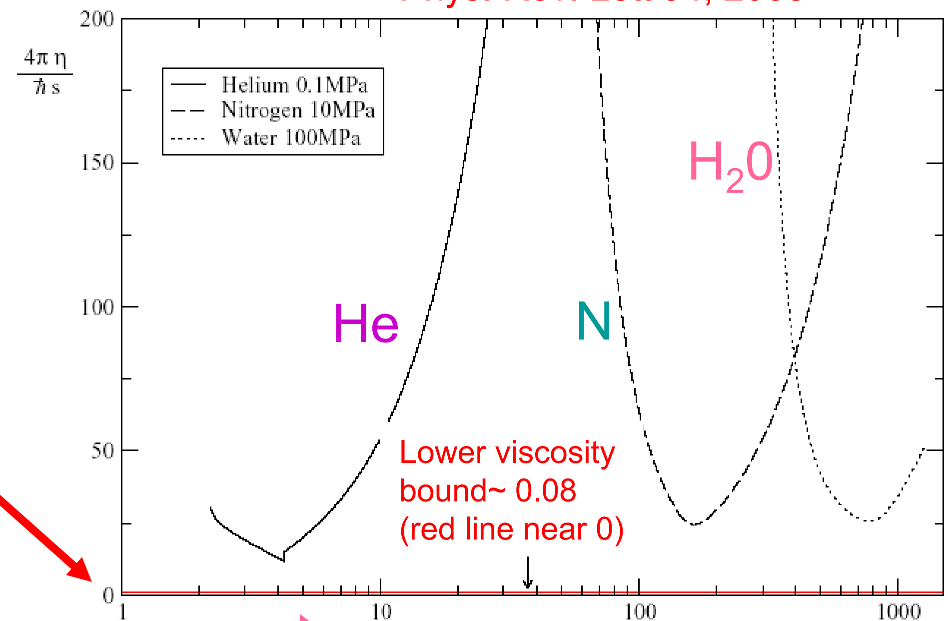
# What is the viscosity?
# How perfect is our liquid?

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




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

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

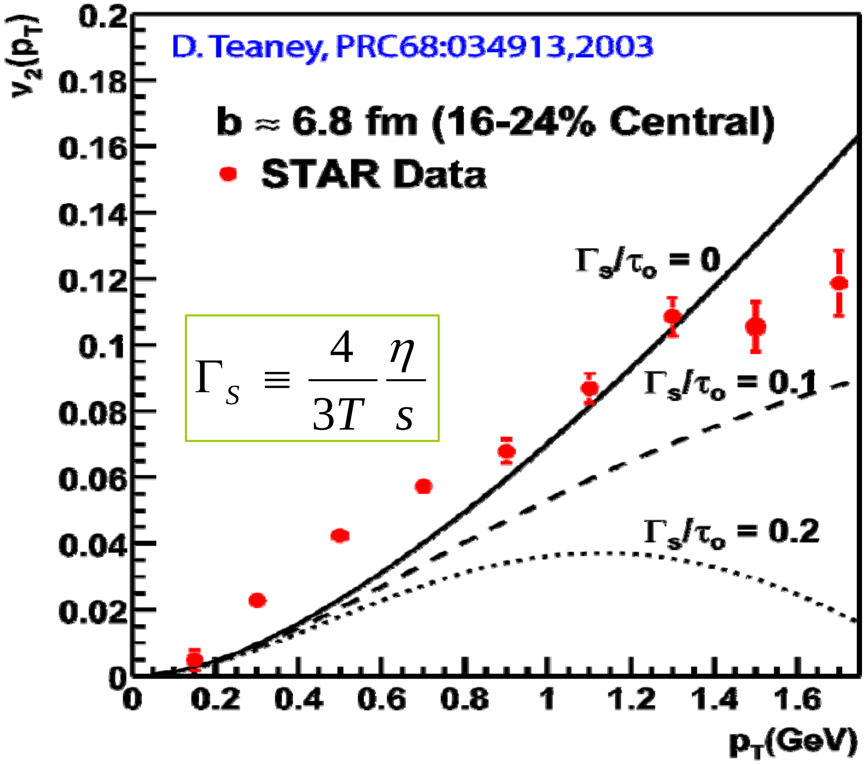



T (K)

Superfluid
helium

KSS bound:
strongly coupled SUSY QCD = classical supergravity

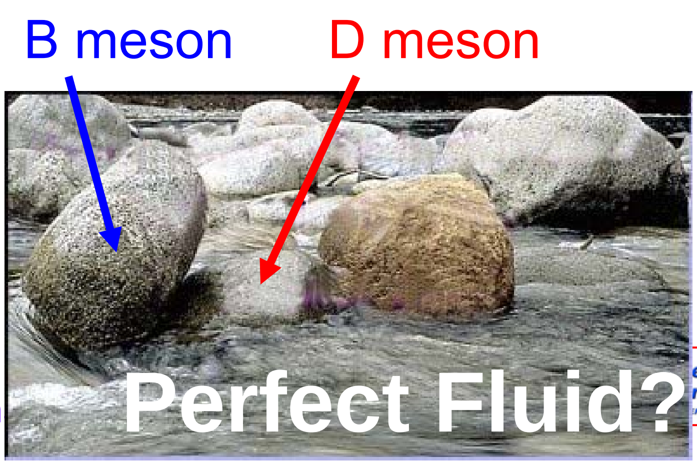
# How to Quantify η/s at RHIC?




$\Gamma_S$ = 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)

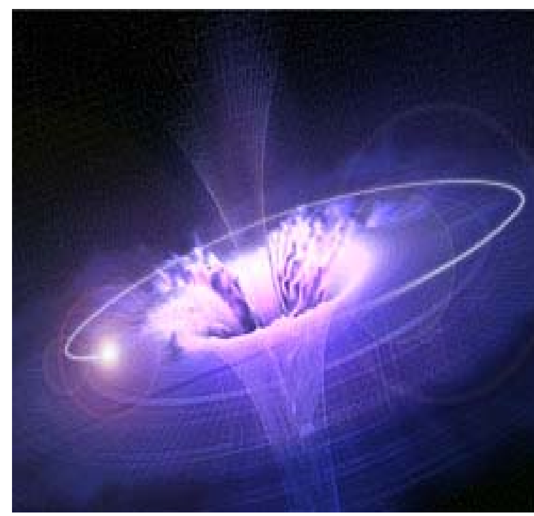


# String Theory ?

What could this have to do with our physics?

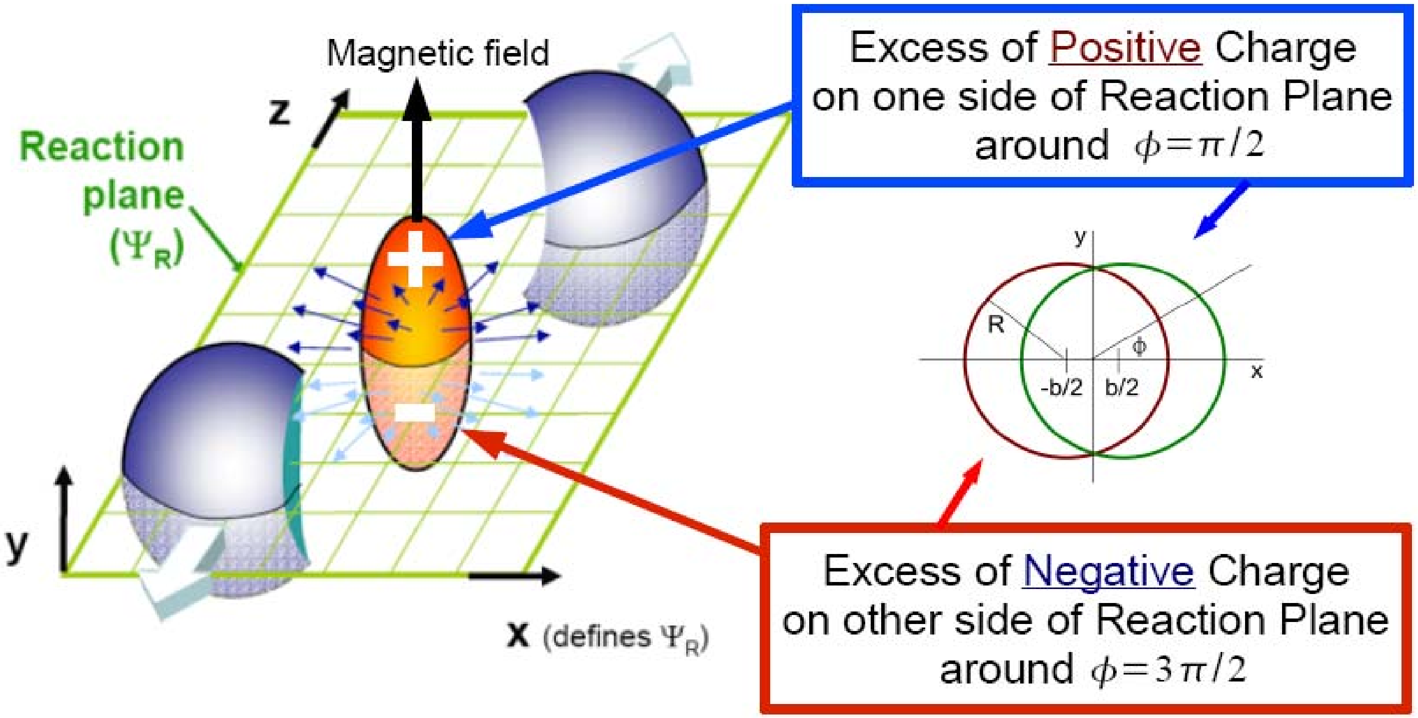
The Maldacena duality, know also as AdS/CFT correspondence, has opened a way to study the strong coupling limit using classical gravity where it is difficult even with lattice Quantum Chromodynamics.

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



# The Chiral Magnetic Effect in Heavy Ion Collisions

*Event by event P- and CP-violation*




Result potentially has important cosmological implications (e.g. matter/anti-matter asymmetry in the universe) OSG type capability needed to “get to the bottom of it”

# Some numbers which indicate the challenge

In Run 7, STAR acquired about 75M min-bias events. This dataset will take ~10 months to analyze (~ 830 Tb, raw + reconstructed). The future outlook:

| | |
|---|---|
| Run 8: | 370 Mevts |
| Run 9: | 700 Mevts |
| Run10: | 1200 Mevts |
| Run11: | 1700 Mevts |
| Run12: | 1700 Mevts |

Increase occasioned by DAQ upgrade in 2009 which will increase bandwidth by an order of magnitude

(caution: "richness factor" not constant due to different beams this does not include simulation needs, only real data processing

— by any measure this is a huge challenge

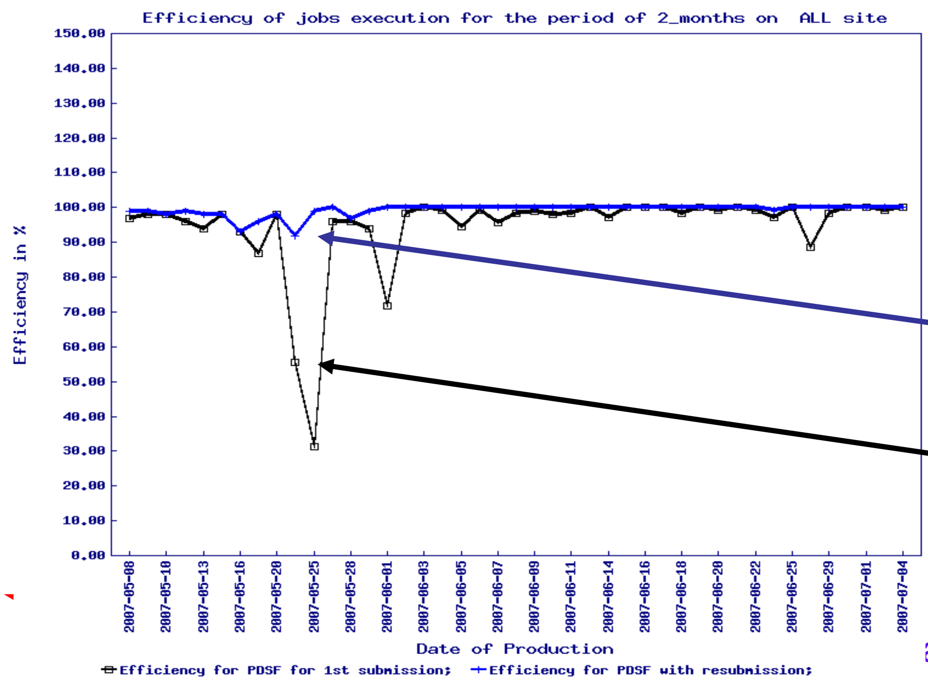
- Strategy
  - Move all simulation production and a significant amount of real-data processing to the GRID.
  - Utilize OSG to distribute grid middleware components with documentation to STAR sites
  - An example: utilize BestMan SRM service (server) to deploy file transfer service components to remote sites, as a component of a standard OSG installation. (Implies STAR 'operational

It is fair to say that these developments are central to the future STAR scientific program, which will become "Grid (OSG) limited" within 1-2 years

# Proof of Principle Initial Successes and Benefits from OSG

- Year 1 OSG Milestone for STAR: ✓
  - Migration of 80% or more of the simulation production to OSG based operation

A specific example: Pythia+GEANT simulations to reduce the systematic uncertainties on jet and $\pi^0$ trigger and reconstruction biases already being performed on the GRID




Efficiency of job execution via OSG infrastructure.

After resubmission

Before resubmission.

# ALICE has a similar plan

ALICE: already uses a distributed computing model, and has written its own interface (AliEn for ALICE Environment) that is already in use.

However, there is interest in replacing this with an interface to the OSG would have several advantages:

- provide a more stable software environment
- allow greater integration of ALICE computing with US Open Science Grid development

From the ALICE-USA computing plan:

…A second area of focus concerns the development of grid middle-ware tools that will allow the Alien software to connect to the Open Science Grid. Connecting to the standard grid interface of the US science community will provide a stable platform for managing the US computing resources within ALICE and allow the ALICE-USA collaboration to make contact with the larger grid computing community in the US. We estimate that approximately one FTE-year of effort will be required

# Conclusions

- The is truly compelling nuclear science program internationally for which OSG is an enabling development which is critical
- Continued aggressive progress is necessary to avoid compelling science in this field from becoming “GRID (OSG) limited”

# Near term plans

- We MUST prepare for real data production on OSG
  - And take ANY shortcut necessary to accomplish it BY 2009
    - onset of DAQ1000, one order of magnitude higher data acquisition rate than today will require additional resources for real-data processing
    - Virtualization appears to us as one development helping to easily deploy & run a 2 Million line framework (software) for data mining
  - UCM job tracking (SBIR with Tech-X) is maturing
    - Essential to engage discussion on integration – we MUST monitor our application

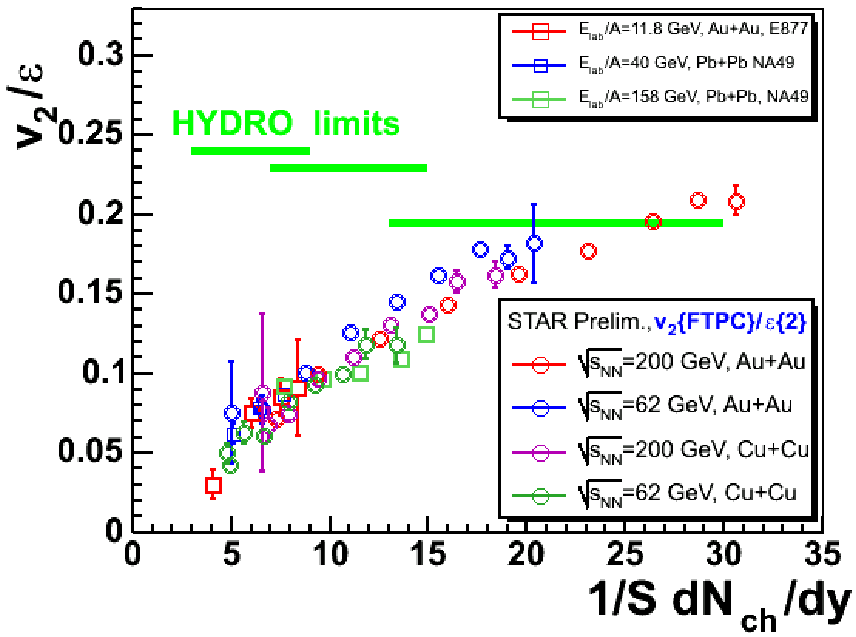
- We have to consolidate our sites
  - More resources are available in STAR but not-fully used (BHAM, UIC for example)
    - We will ramp up in infrastructure support to achieve this
    - We hope leveraging OSG efforts in the US (UIC for example)
  - We have efforts in integrating Mac OS-X resources from MIT
    - Initial work was uniquely started in STAR
    - Is there a path forward? Depends on priorities …

# Backup Slides

# Is there elliptic flow at RHIC?

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

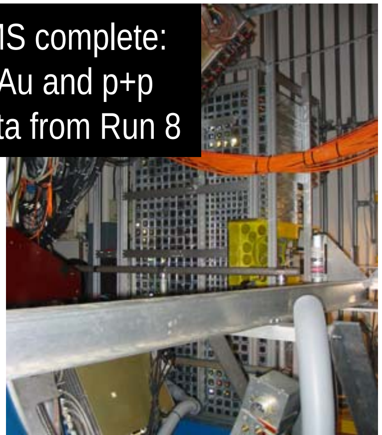
- Hydrodynamic calculations assuming a latt
  reproduce the mass splitting well up to $p_T$ ~
- Same calculations fit the radial flow data si
- Elliptic flow saturates the hydrodynamic lim
- Very rapid thermalization, very strong inter
- A perfect fluid?




Thermalization time $\tau < 1$ fm/c and $\varepsilon = 20$ GeV/fm$^3$

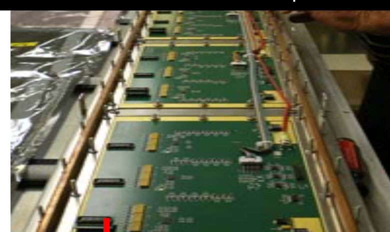
# STAR/RHIC Upgrades: The Big Picture

FMS complete:
d+Au and p+p
data from Run 8

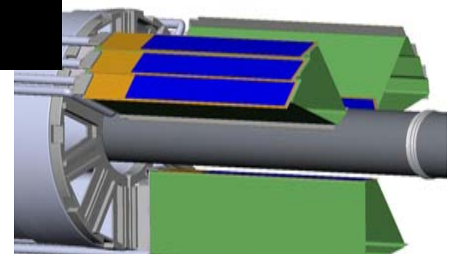


DOE investment ~ $400k

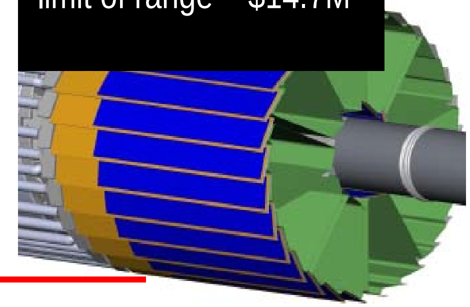
TOF complete:
PID information for > 95% of kaons and protons in the STAR acceptance
Clean $e^{\pm}$ ID down to 0.2 GeV/c
DOE investment ~ $4900k
Chinese investment ~ $2700k



HFT partial implementation



HFT complete
full topological PID for c, b mesons
DOE investment : upper limit of range ~ $14.7M

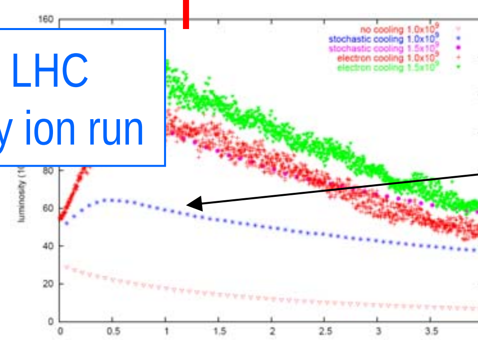


| | | |
|---|---|---|
| 1st priority | STAR/RHIC Upgrades: The Big Picture | Au+Au |
| 2cnd config | | p+p ,500 |

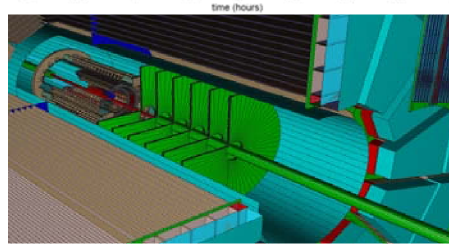
FY08 FY09 FY10 FY11 FY12 FY13 FY14 FY15

Planned LHC
1st heavy ion run

DAQ1000 complete
Immediate improvement of 300% in sampled luminosity for rare probes (e.g. jets in p+p)
DOE investment ~ $1900k



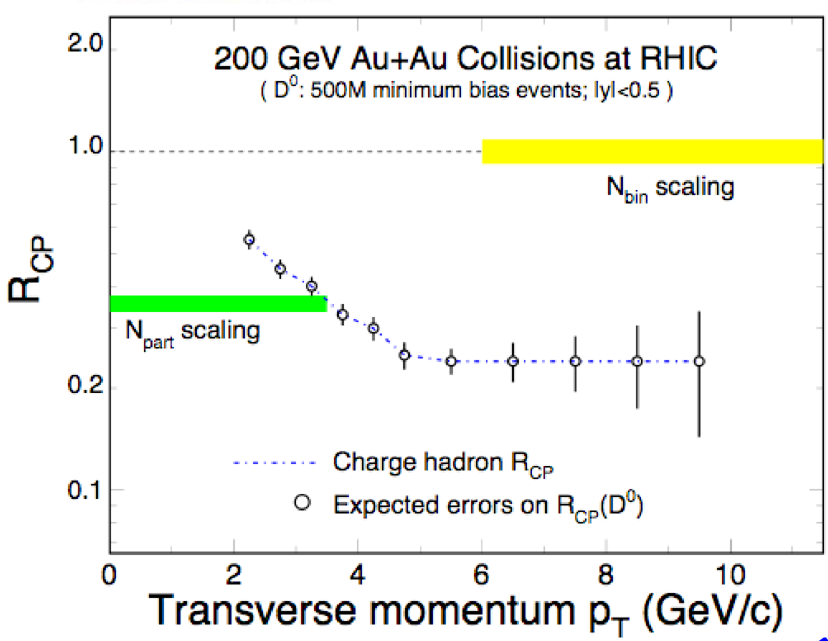
Increase in Au+Au luminosity to $50 \times 10^{27}$ $cm^{-2}$ $sec^{-1}$
U+U available from EBIS
DOE investment ~ $7M



FGT complete:
Accurate charge sign determination for W's, DOE investment ~ $1900k

STAR

# The HFT

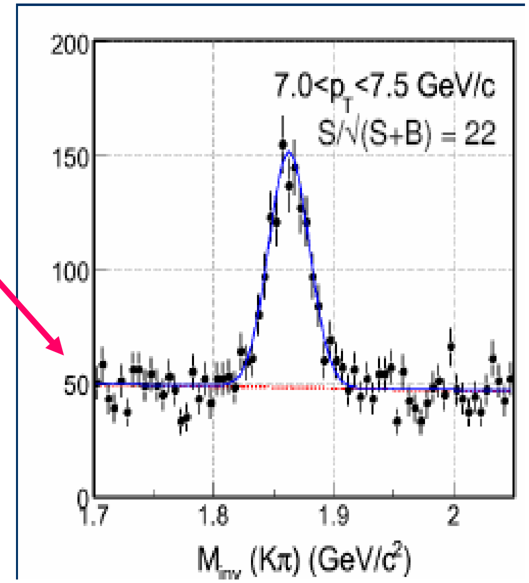


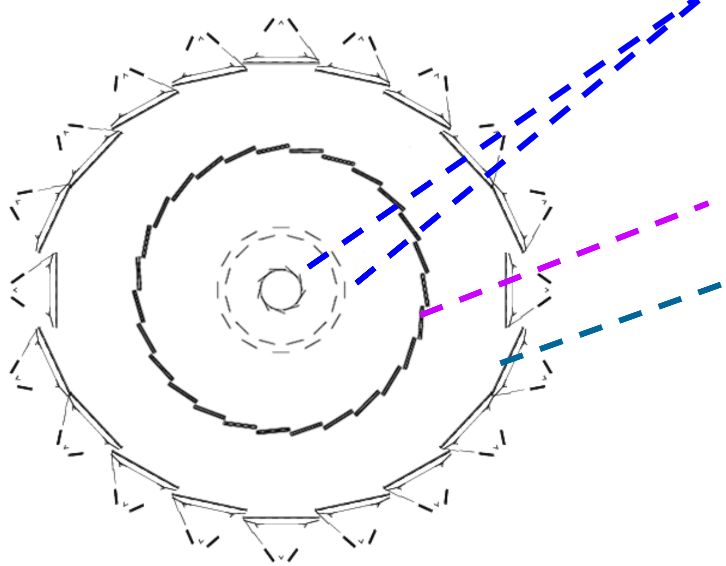

100M central Au+Au

$D^0 + \overline{D^0}$, RHIC II

Topological PID

pileup included



- 2-layer Active Pixel Sensors: 30 μm pitch
  thickness— $x/x_0 \sim 0.28\%$ per layer
  2.5cm inner radius; 200μs integration
- 1-layer* Si strips
- SSD: $x/x_0 \sim 1\%$

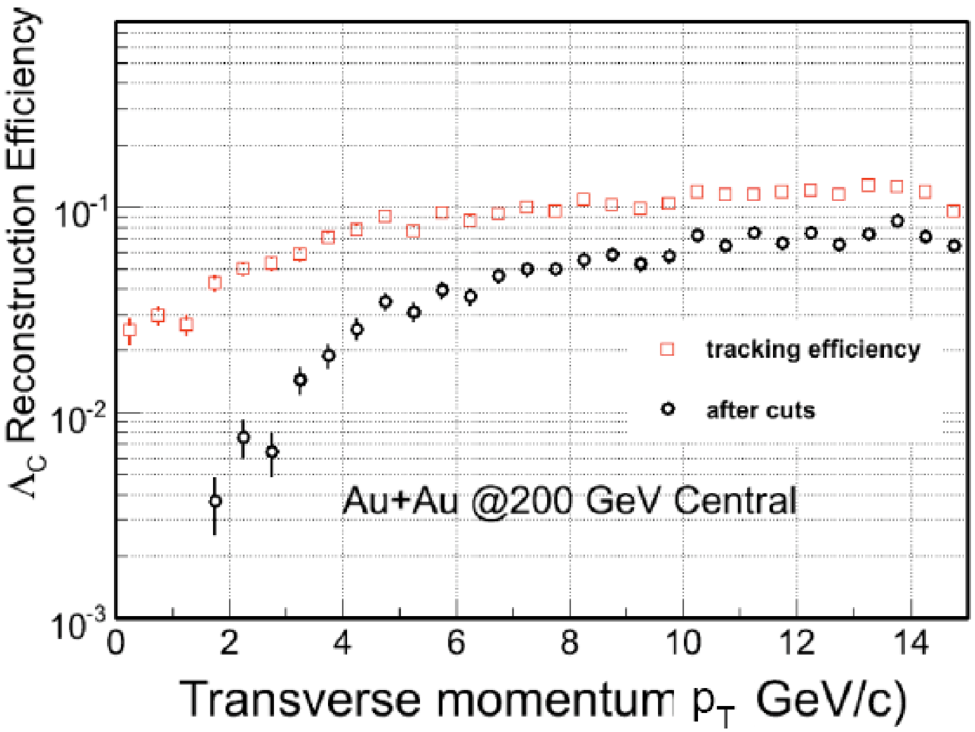
$|\eta| \leq 1$

$p_T > 0.5$ GeV/c: e, $D^{0,\pm,s,*}$, $\Lambda_c$, B…

D-D correlation functions

# The HFT will open the (3-body) charm & bottom hadron sector

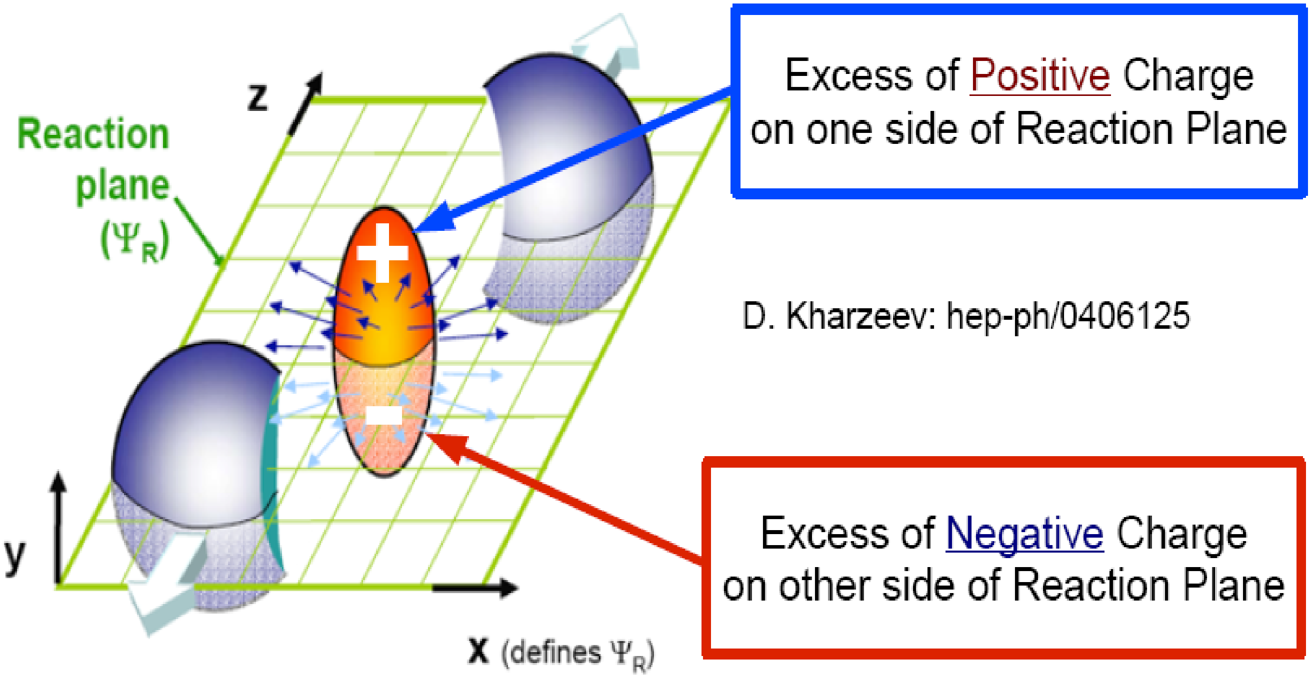
$\Lambda_c \rightarrow pK^-\pi^+$ M = 2.286 GeV/$c^2$ cτ = 60 μm




Simulations of the most challenging 3-body decays are encouraging so far

This capability, which will be provided uniquely at RHIC by the HFT, is crucial for determining whether the baryon/meson anomaly extends to heavy quark hadrons

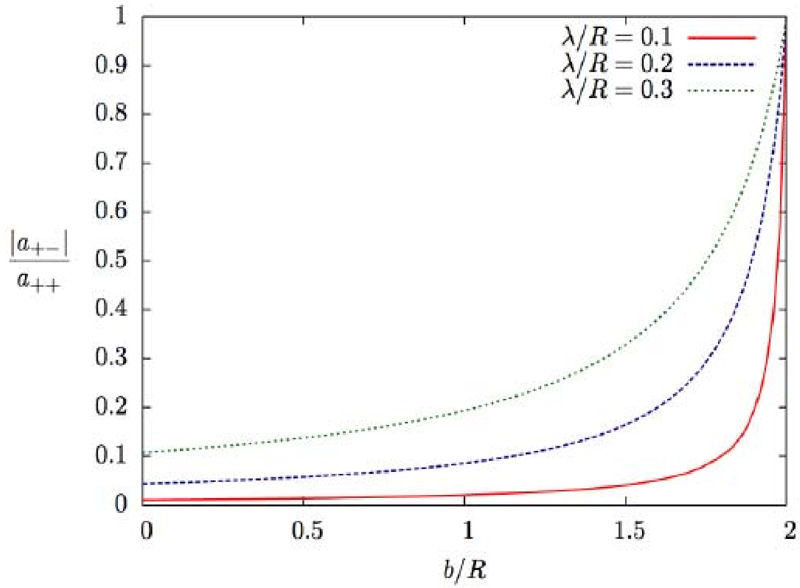
# Implications of CP-violating transitions in hot quark matter on heavy ion collisions




Harmen Warringa, BNL

Based on work with Dima Kharzeev and Larry McLerran arXiv:0711.0950

# Suppression of +/- correlations



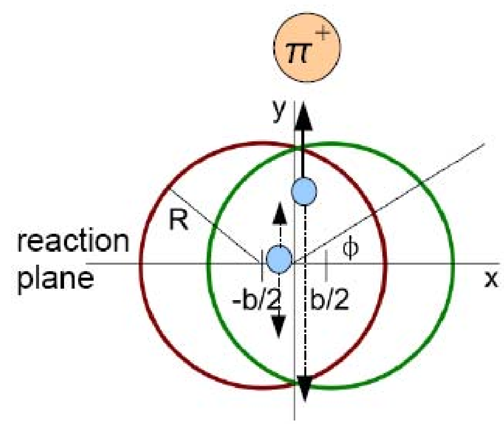

A possible result of the Chiral Magnetic Effect

Suppression of correlations

between positively charged particles on one side and

negatively charged particles on other side of reaction plane

due to screening.



# Longer term needs

- Requirements driven by demanding data processing
  - https://twiki.grid.iu.edu/twiki/bin/view/UserGroup/VOApplicationsRequirements#STAR
  - We will need to efficiently share resources
    - Concerned about what happens when LHC has ramped up data taking.
    - Will there be any cycles left to be had?

- Additional
  - STAR is expanding its pool of sites
    - Interest in sites possibly shared by EGEE - OSG interoperability (especially China)
    - Hoping for help from OSG to understand policy as well as technology issues.
  - We believe virtualization is “a” path forward to
    - Simple deployment of experimental software
    - Allowing experimental software developer’s team to concentrate on science and a minimal OS version support
    - Globus workload management needed

# Near term plans

- We hoped to push for a NP extension to OSG – motivations were
  - Nuclear Physics experiments use distributed grid systems for their data distribution, processing and analysis. Access to and use of storage is of key importance.
  - Through interfacing to and using OSG software and infrastructure the NP experiments will have more effective and common infrastructures.
  - By better supporting the Nuclear Physics Community OSG will have broader impact and be more generally useful.
  - The OSG deliverables are driven by its stakeholders and are effort limited

- Activities – Both were assumed to leverage OSG staff efforts
  - Scalla/XROOTD based Storage Element
    - Both STAR and Alice have been precursor of its use in production mode
  - Policy based Data Replication Service
    - Leveraging existing CEDPS activity
- Status
  - Unclear where the OSG management can help - No news from the agency
  - Further delays in our science deliverables ?

# Continued Challenges

- STAR biggest issues is real-data production
  - Orders of magnitude more demanding
  - We are NOT in a position to make this work.
    - Cyber infrastructure (network speed) slow
    - SRM past "delays" had severe consequences on program
    - Lack of components to monitor at application level is an issue for us with 10 year's data production experience

- OSG has started to help in this area:
  - Troubleshooting of data transfer
    - OSG team involved and helped with communication, follow-ups, independent tests and checks
    - Wayne Betts (STAR) a key resource – cross collaboration worked well ; mutual benefits
  - Grid Operation Center (GOC) a useful structure
    - Keep a "watch" on our global infrastructure via suite of tests
      - This helps address the remaining infrastructure instabilities to some (large) extent
      - Local workforce is needed ALWAYS
    - We view GOC and distributed responsibility as a plus