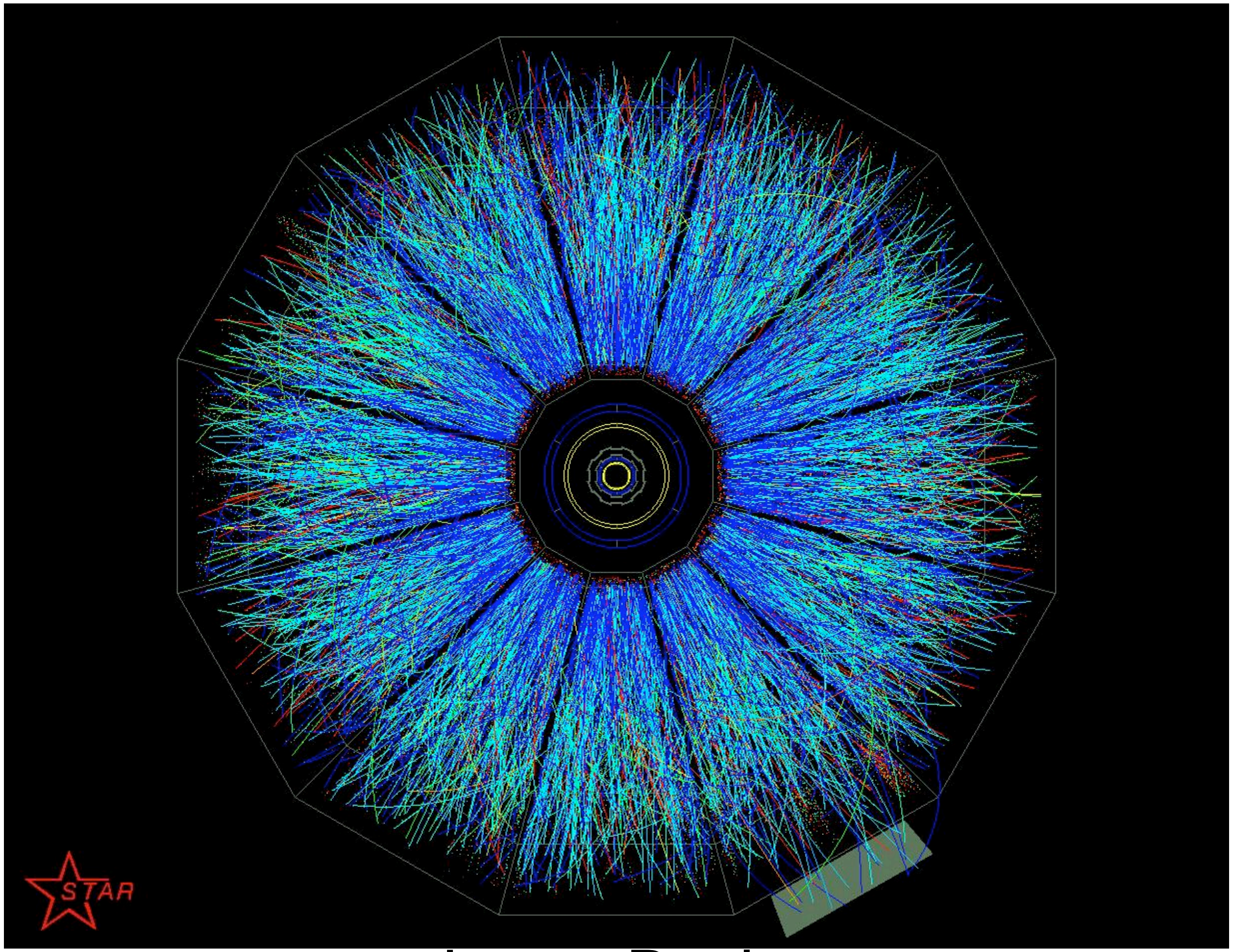
# Recent Results from STAR



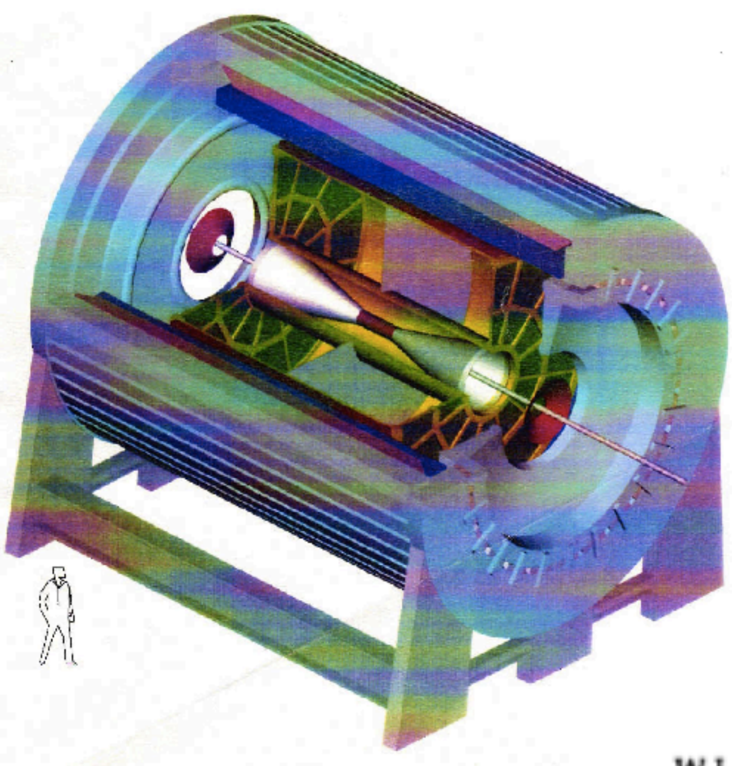

James Dunlop

Brookhaven National Laboratory

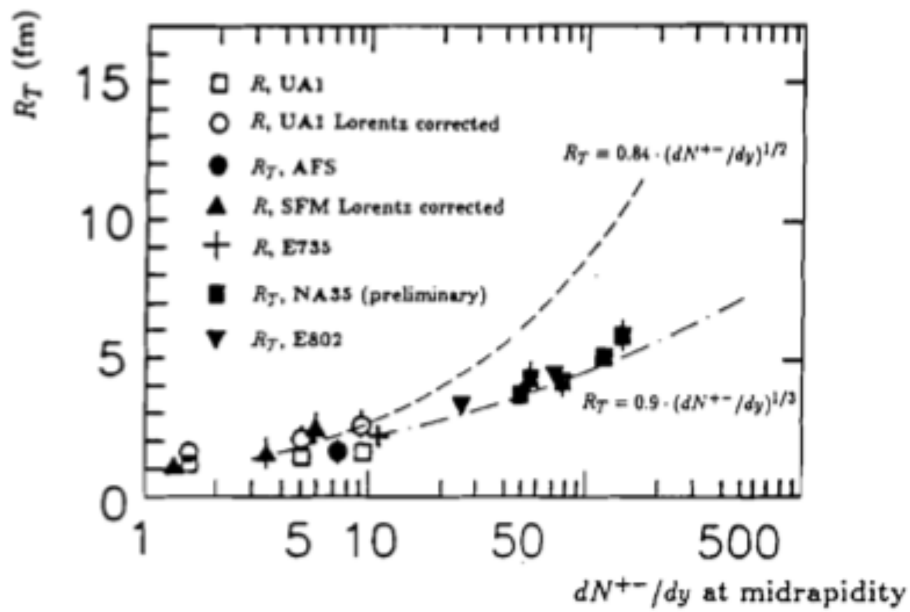
# STAR: The Beginning

STAR

Conceptual Design Report



The STAR Collaboration



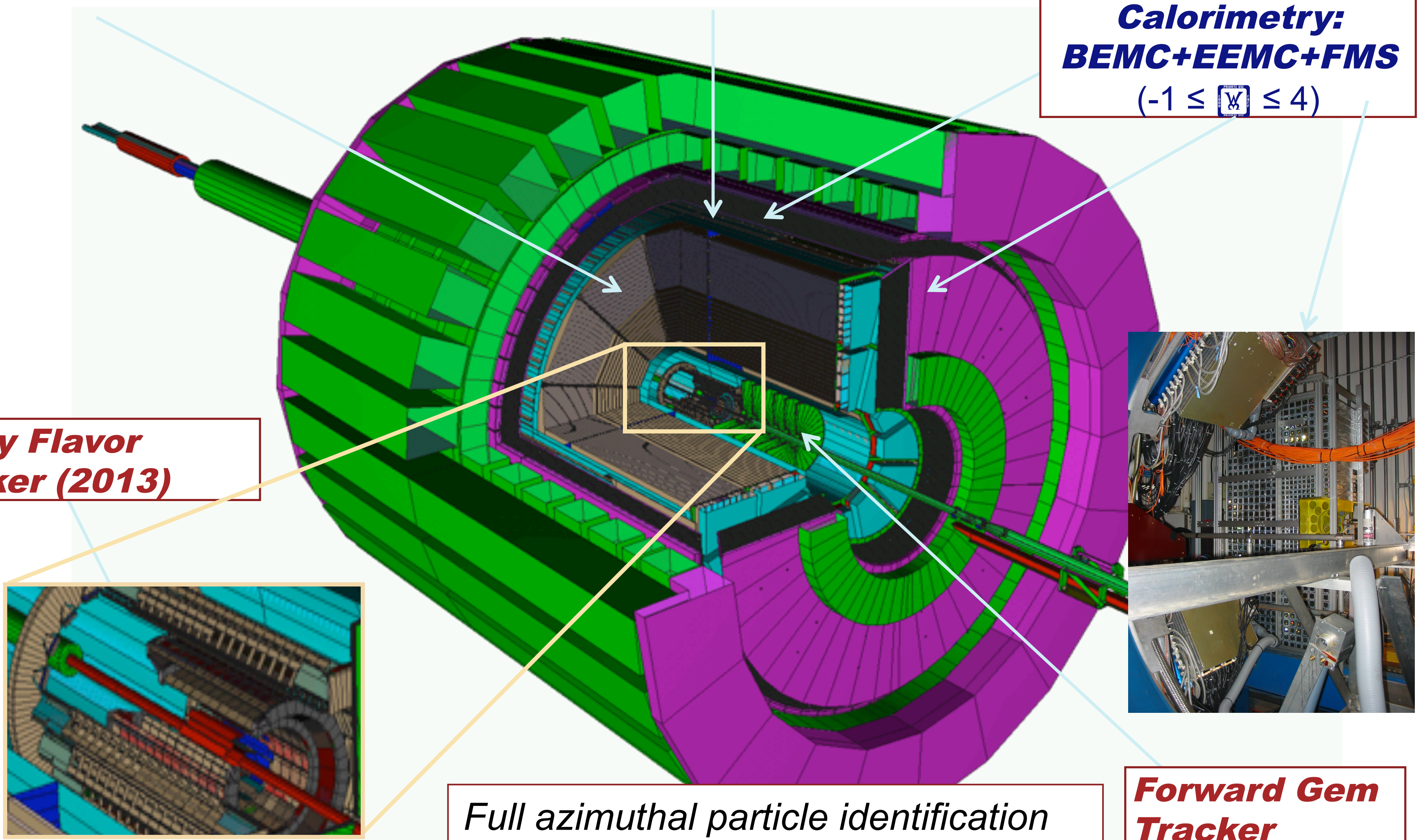

W.J. Braithwaite, J.G. Cramer, D. Prindle, T.A. Trainor, and X.-Z. Zhu
*University of Washington, Seattle, Washington 98195, U.S.A.*

# STAR: A Correlation Machine

***Tracking: TPC***

***Particle ID: TOF***

***Electromagnetic Calorimetry: BEMC+EEMC+FMS***
($-1 \le \eta \le 4$)

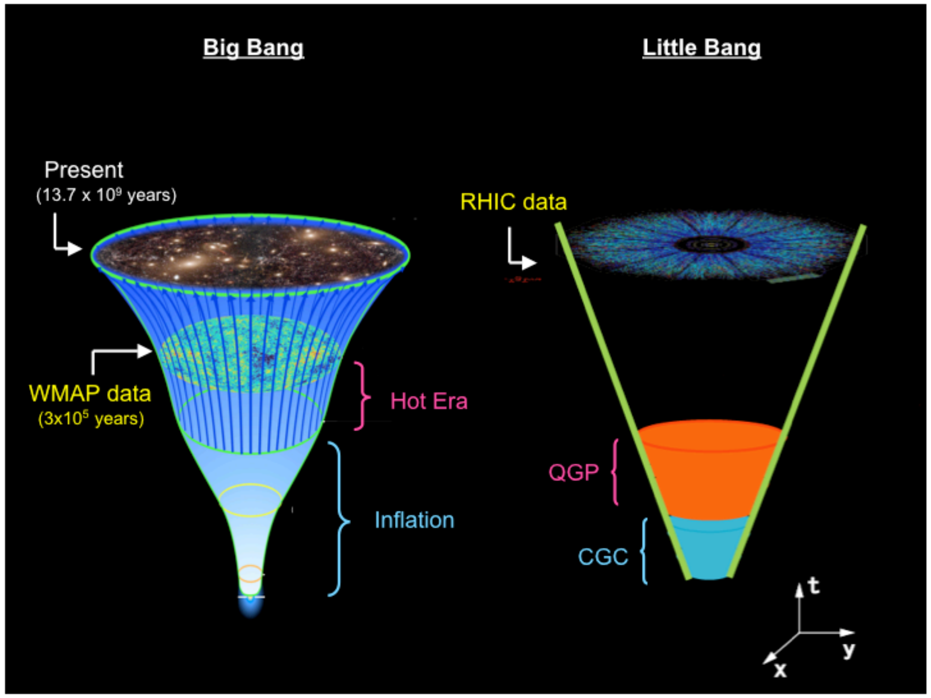


***Heavy Flavor Tracker (2013)***

***Forward Gem Tracker (2011)***

*Full azimuthal particle identification over a broad range in pseudorapidity*

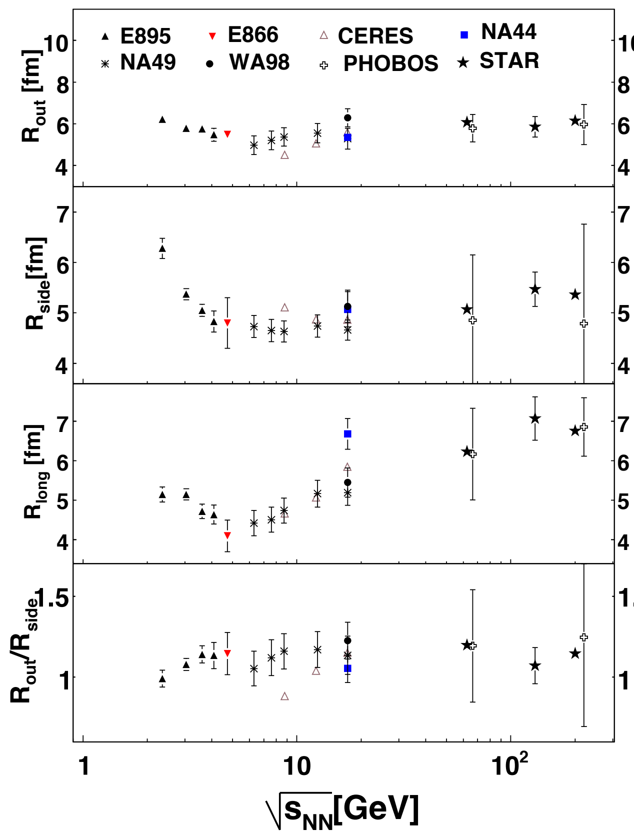
# Correlations

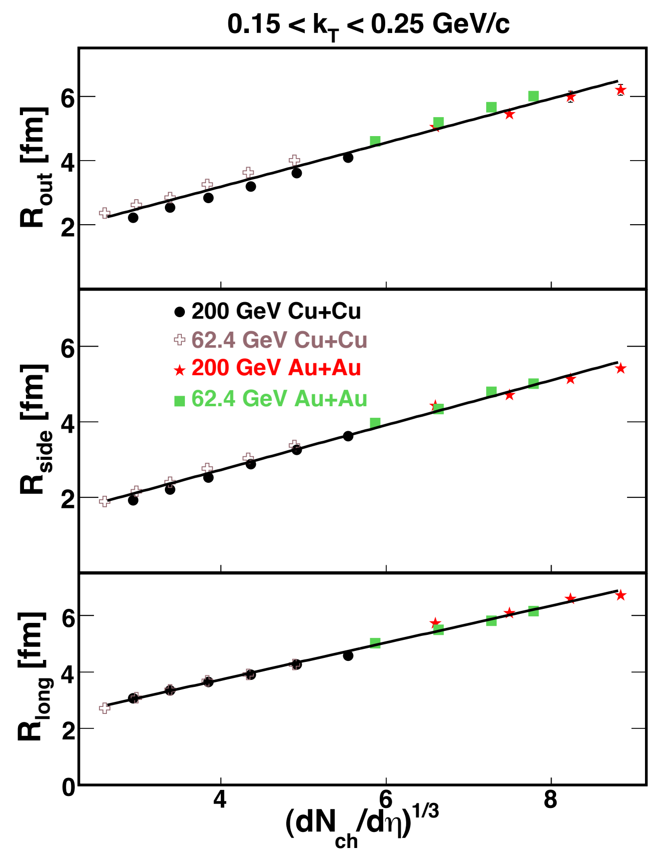



- WMAP: $10^{-5}$ level
  - One sample
  - Only photons
  - Well-defined separation of sources
- RHIC: $10^{-1}$ to $10^{-3}$ level
  - Multiple samples
  - Multiple probes
  - Separation of sources still under active investigation

# Hanbury-Brown Twiss Correlations

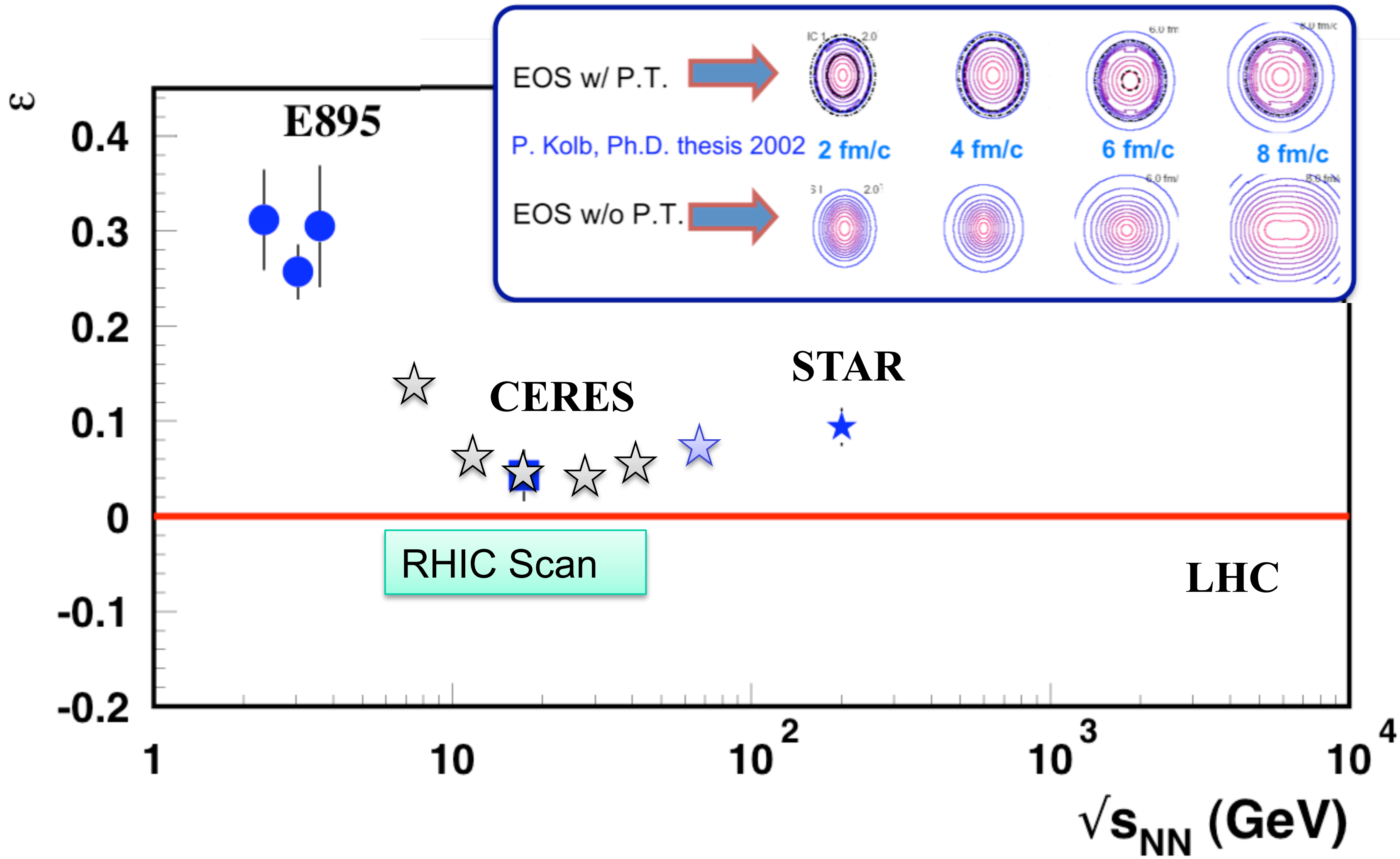
STAR: arXiv:0903.1296



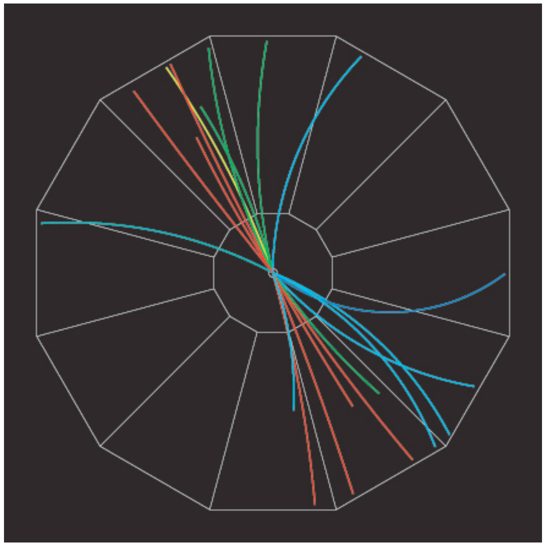

- 25 years of study have led to smooth systematics
- Smoothness still extremely “puzzling”
  - Competition of many small factors? Pratt
  - Distorted Wave Emission Functions? Cramer and Miller, nucl-th/0507004

# $1^{st}$ order: HBT vs Reaction Plane




Non-monotonic behavior would indicate a softest point: $1^{st}$ order

# The Promise of Jet Tomography



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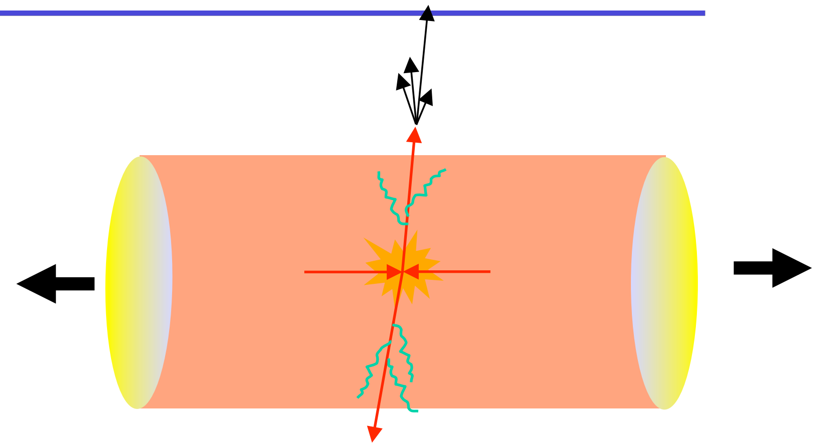

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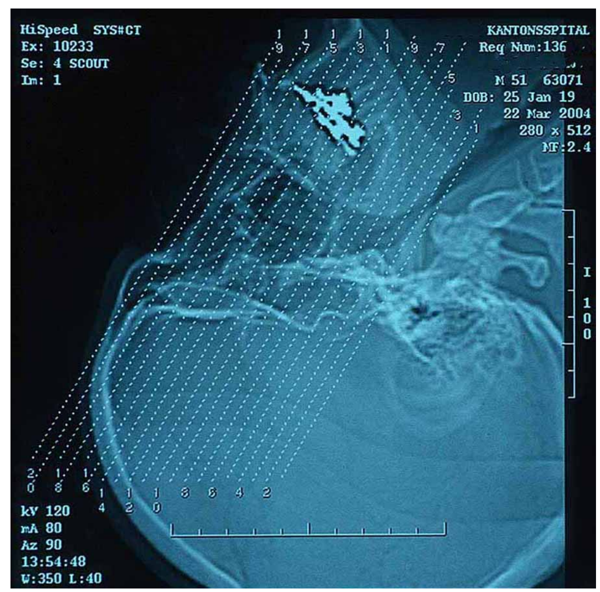
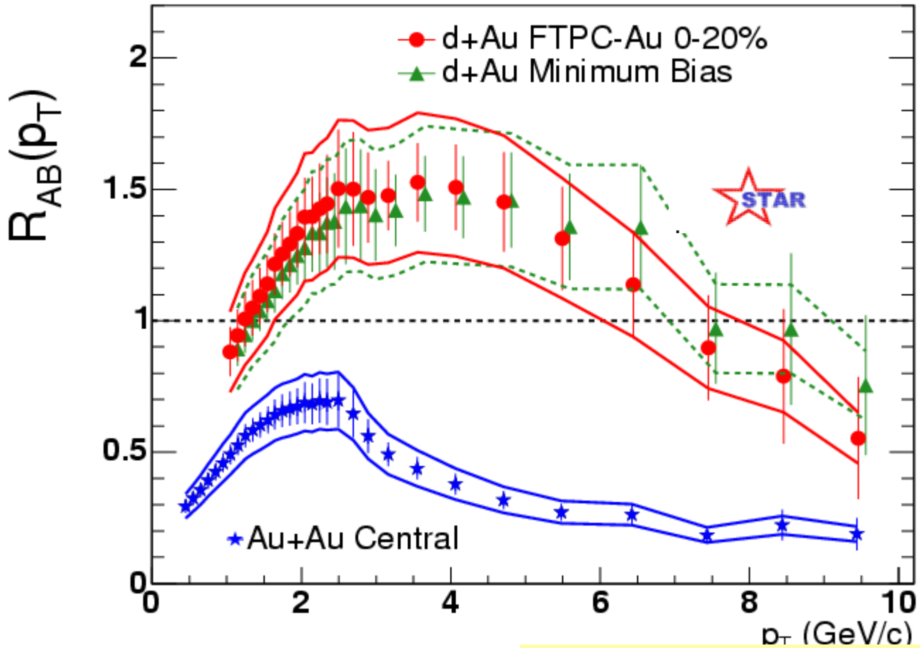
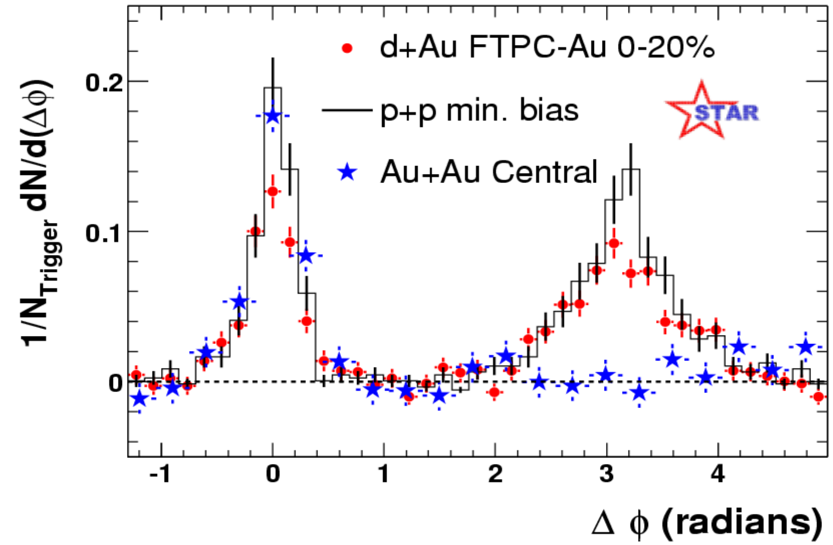



- Simplest way to establish the properties of a system
  - Calibrated probe
  - Calibrated interaction
  - Suppression pattern tells about density profile
- Heavy ion collisions
  - Hard processes serve as calibrated probe
  - Suppression provides density measure

# Application to Heavy Ion Collisions: Initial Results




*PHENIX: Phys. Rev. Lett. 91 (2003) 072301*
*STAR: Phys. Rev. Lett. 91 (2003) 072304*
*PHOBOS: Phys. Rev. Lett. 91 (2003) 072302*
*BRAHMS: Phys. Rev. Lett. 91 (2003) 072303*

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

Binary collision scaling p+p reference

Strong suppression in Au+Au collisions, no suppresion in d+Au:

Effect is due to interactions between the probe and the medium

Established use as a probe of the density of the medium

Conclusion (at the time): medium is dense (50-100x nuclear matter density)

# Where does the energy go?

- Lower the associated $p_T$ to search for radiated energy
- Additional energy at low $p_T$ BUT no longer collimated into jets

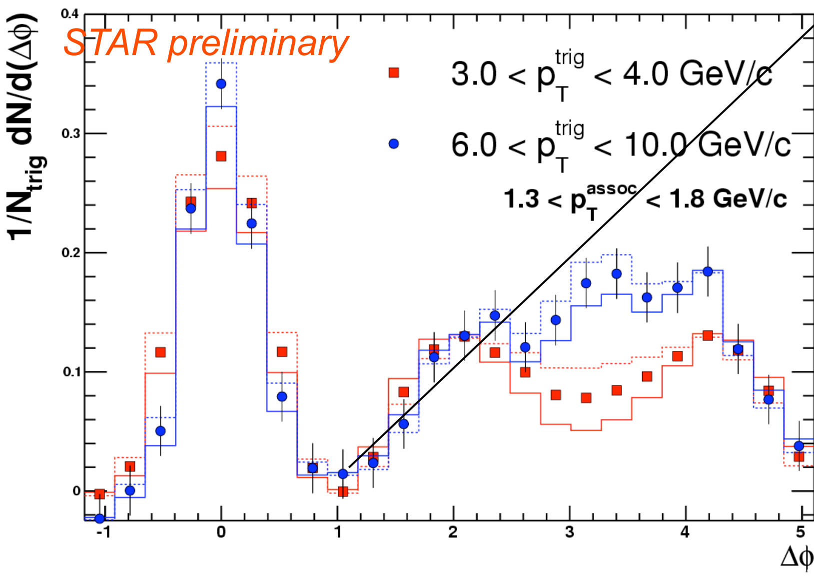
  Active area: additional handles on the properties of the medium?

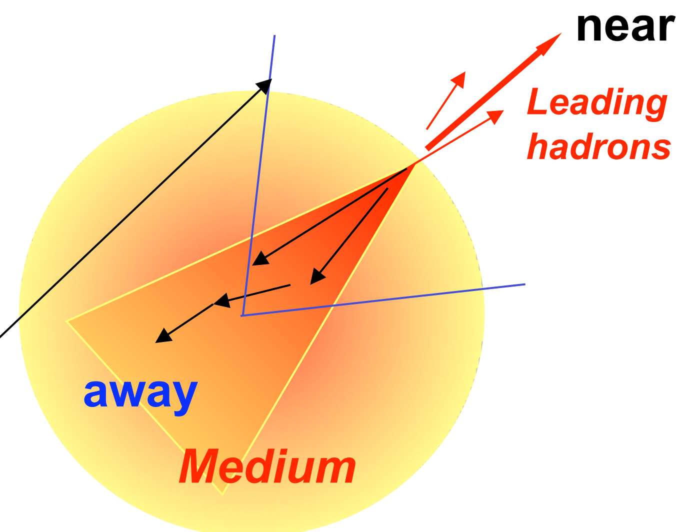
  Mach shocks, Cherenkov cones …

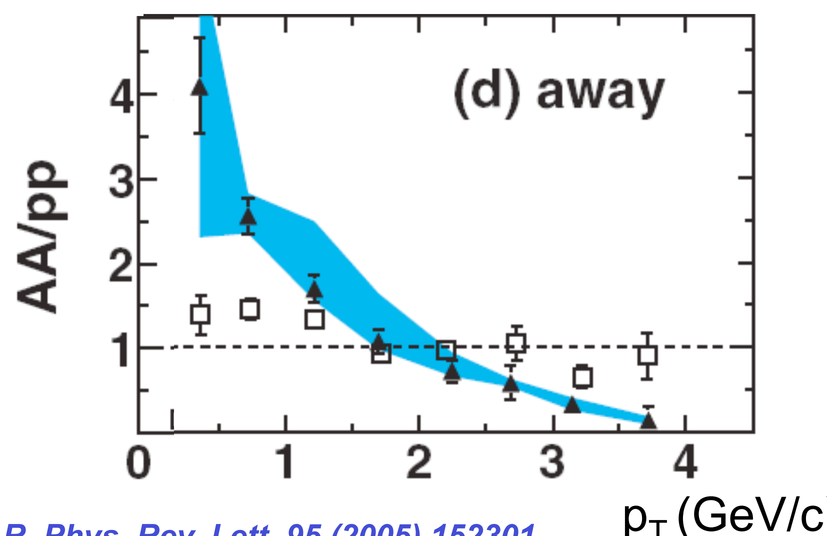
e.g. Renk and Ruppert, Phys. Rev. C 73 (2006) 011901

OR: an issue in technique? $v_2$ subtraction

0-12% 200 GeV Au+Au




*M. Horner, QM2006*

*STAR, Phys. Rev. Lett. 95 (2005) 152301*

# The Ridge: Dh-Df Correlations

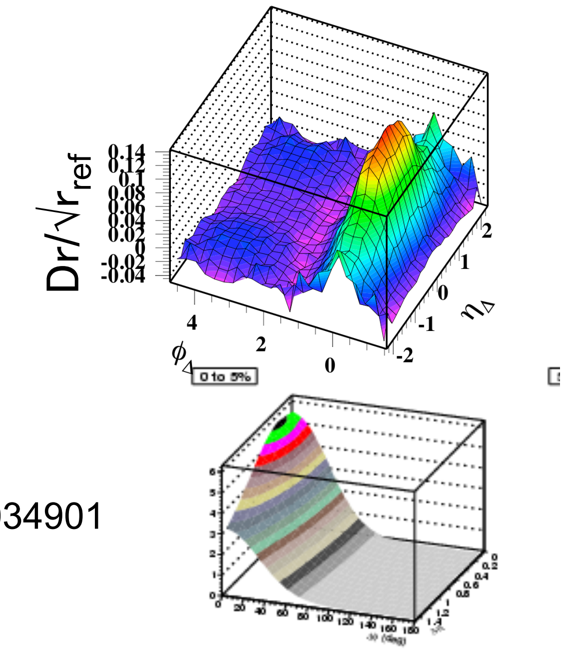
- **In Au+Au: broadening of the near-side correlation in**
- **Seen in multiple analyses**
  - **Number correlations at low $p_T$**
    - **PRC73 (2006) 064907**
  - **$P_T$ correlations at low $p_T$, for multiple energies**
    - **Major source of $p_T$ fluctuations**
    - **J. Phys. G 32, L37 (2006)**
    - **J. Phys. G 34, 451 (2007)**
  - **Number correlations at intermediate $p_T$**
    - **PRC 75, 034901 (2007)**
  - **Number correlations with trigger particles up to 8 GeV/c**
    - **ArXiv:0909.0191v1**

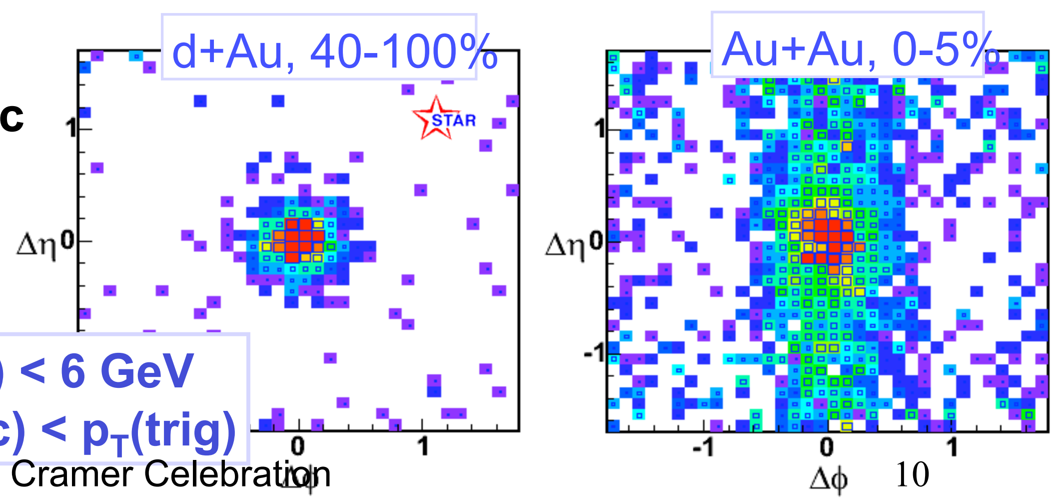
**Physical origin still not definitively established**

Phys. Rev. C73 (2006) 064907

mid-central Au+Au
$p_t$ < 2 GeV

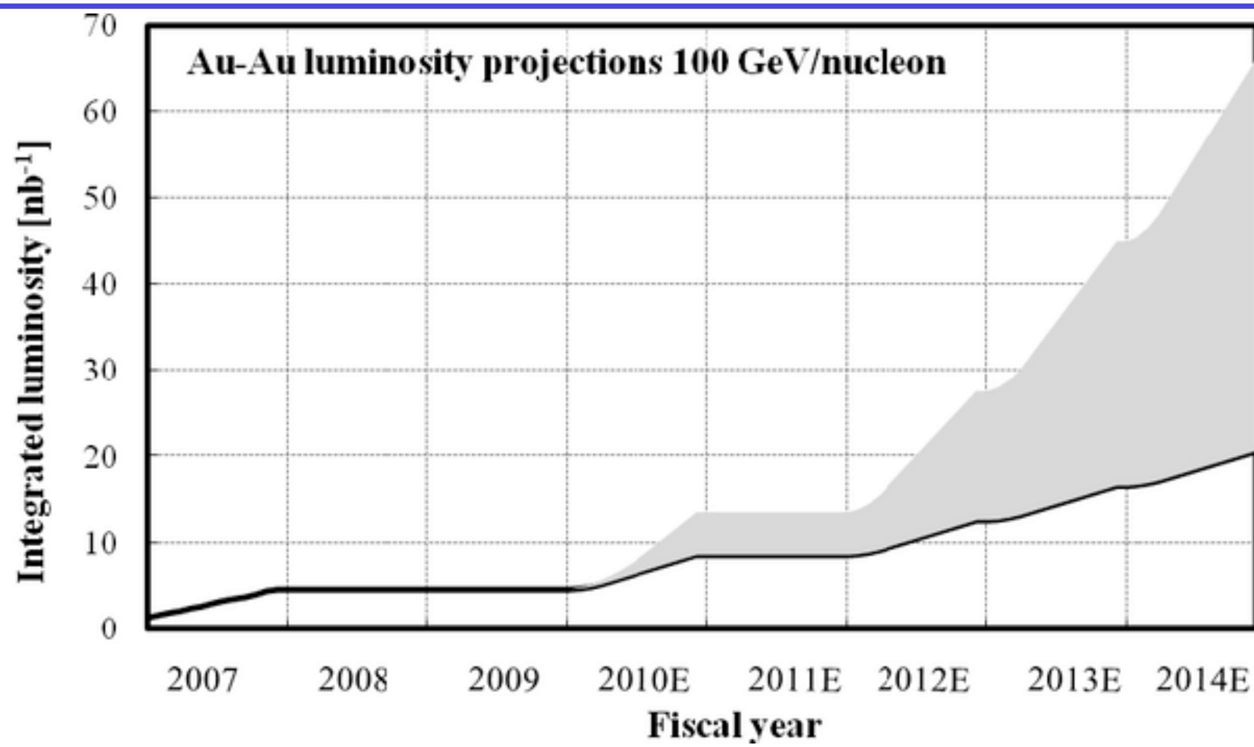
0.8< $p_t$ < 4 GeV
STAR PRC 75(2007) 034901




**3 < $p_T$(trig) < 6 GeV**
**2 < $p_T$(assoc) < $p_T$(trig)**

# Luminosity progression to the $fb^{-1}$ era

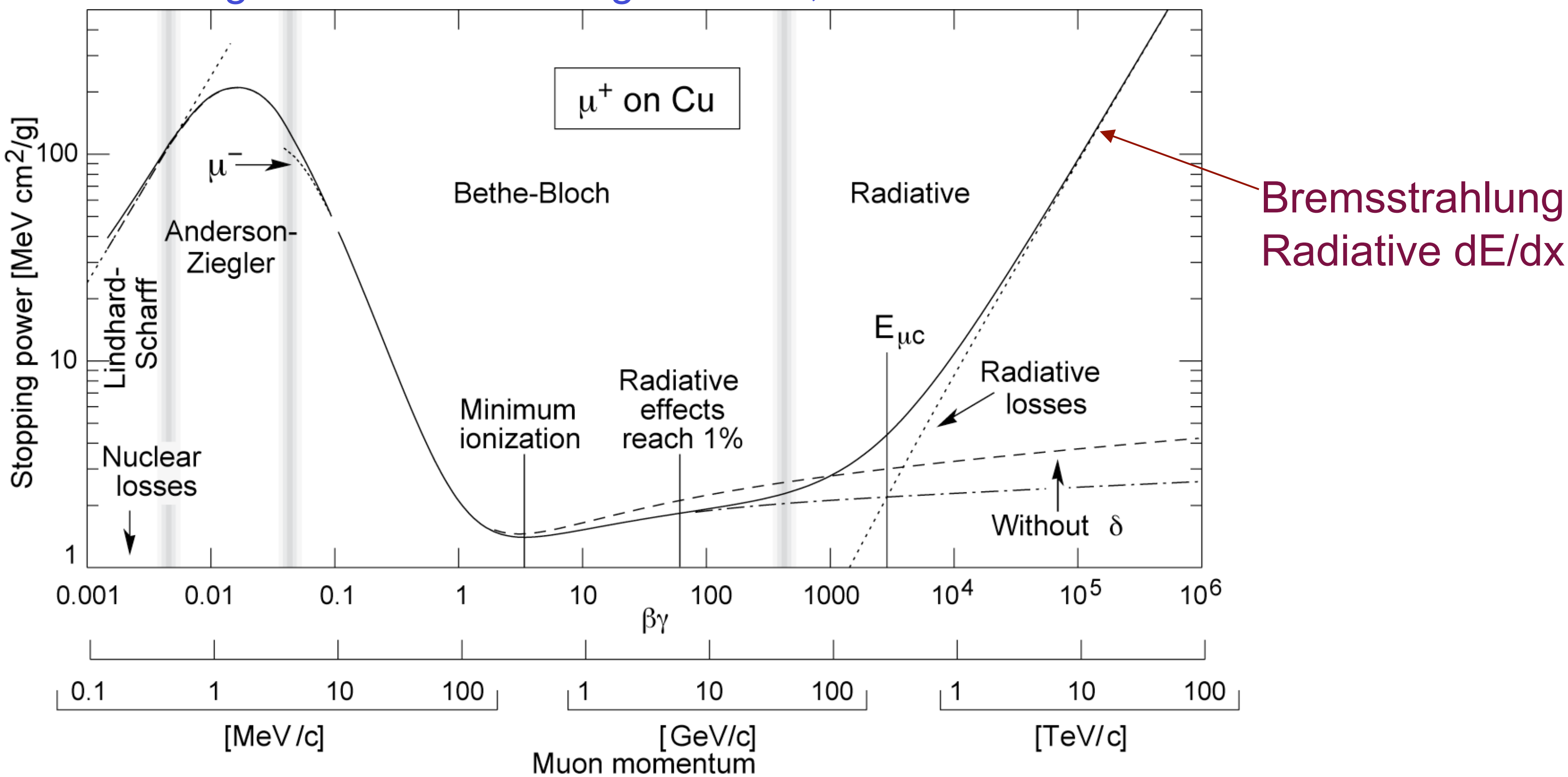



26 $nb^{-1}$*197*197 =
1 $fb^{-1}$ pp equivalent

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

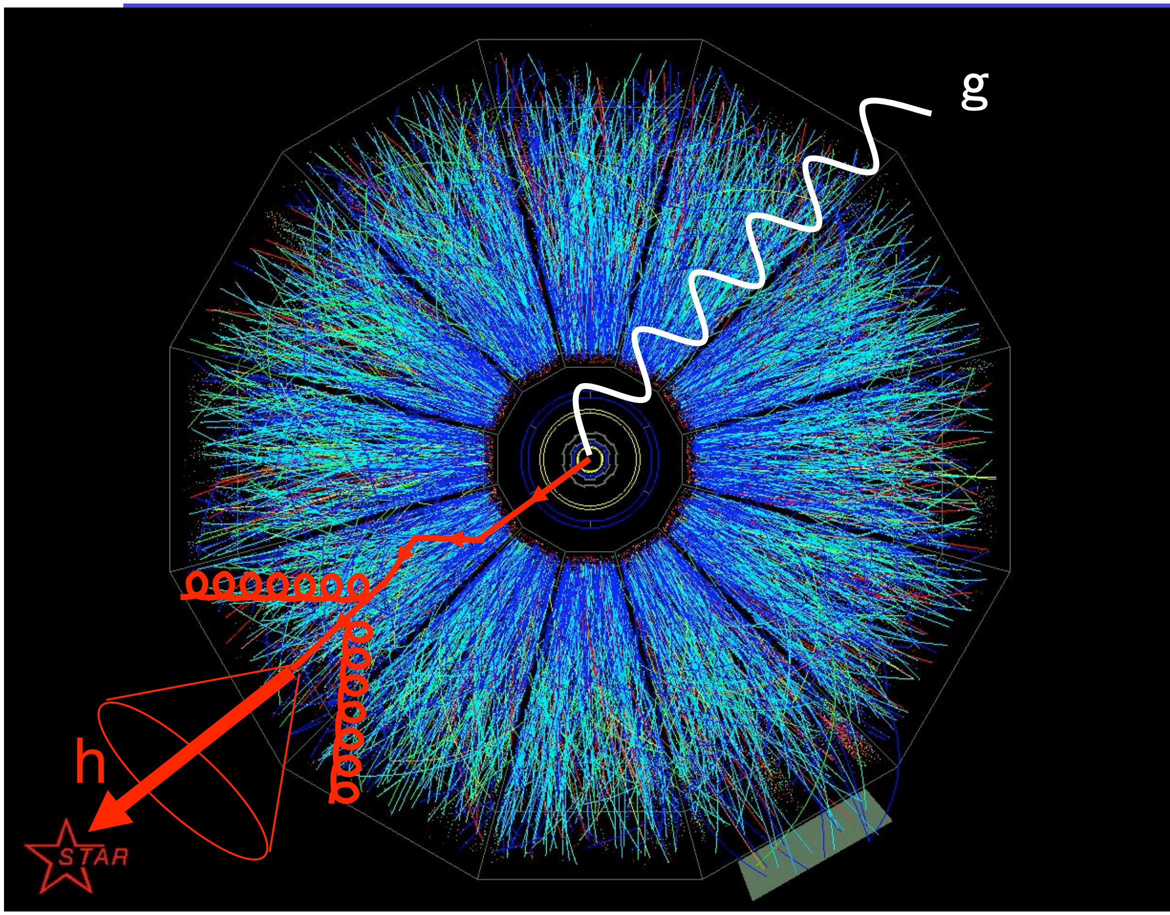
# Mechanisms for Energy Loss

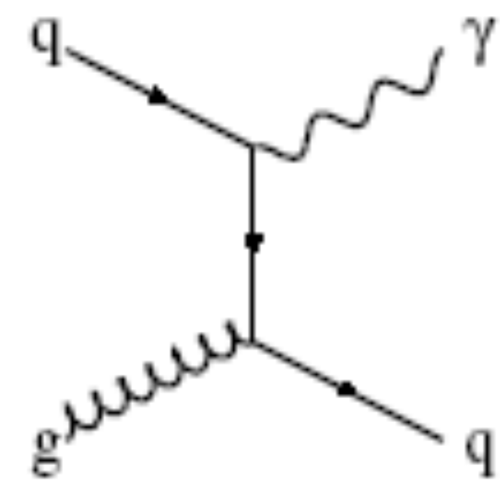
"Passage of Particles through Matter", Particle Data Book




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

# g-Jet: Golden Probe of QCD Energy Loss

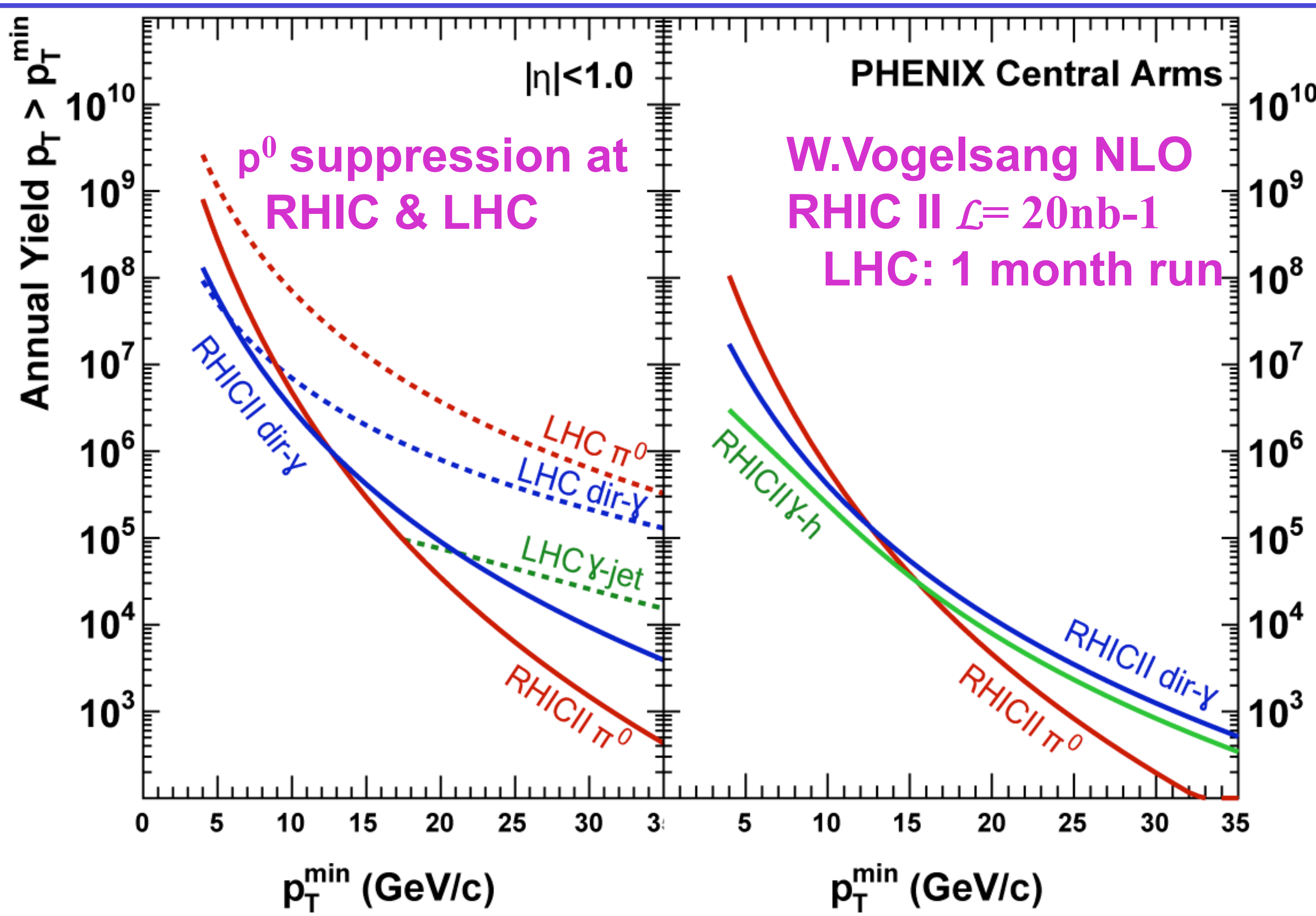



Compton Scattering

- g 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

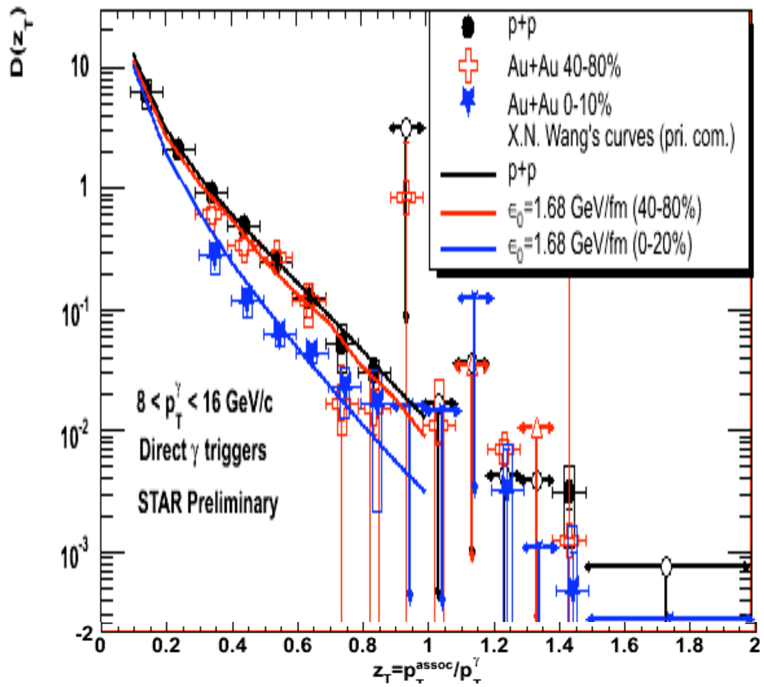



RHIC: Clean separation of g from p0 for $p_T$>~10 GeV

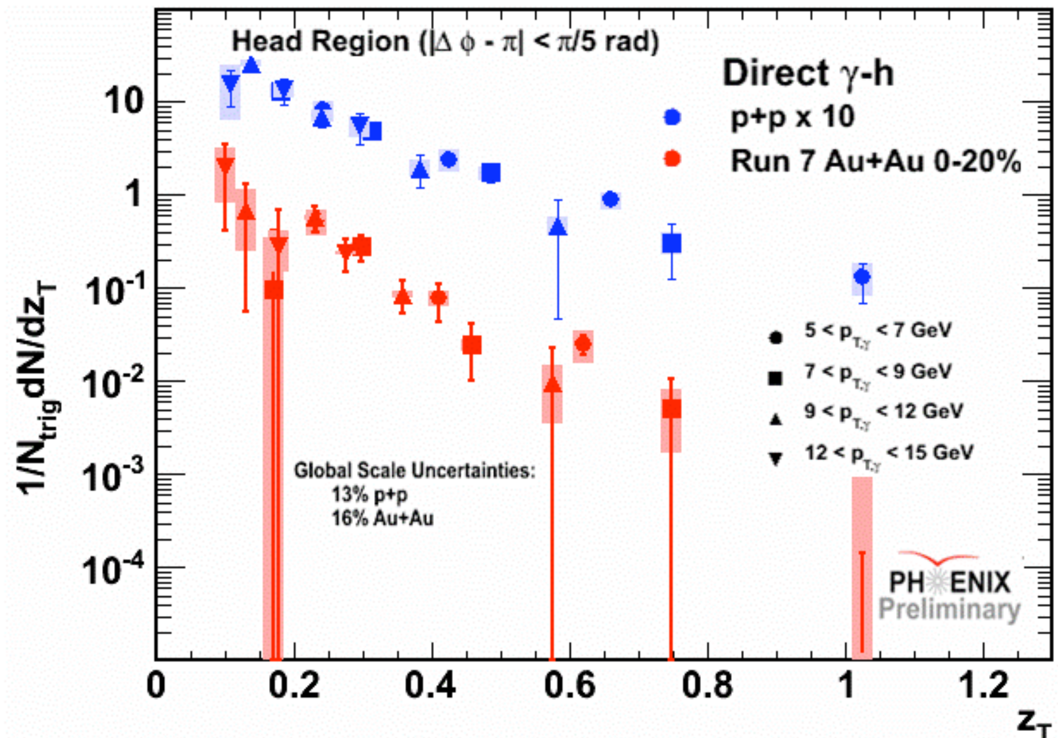
Fragmentation contribution also expected to be small

# γ-Hadron Correlations: First Peek

STAR: Hamed, QM2009




PHENIX: arXiv:0903.3399

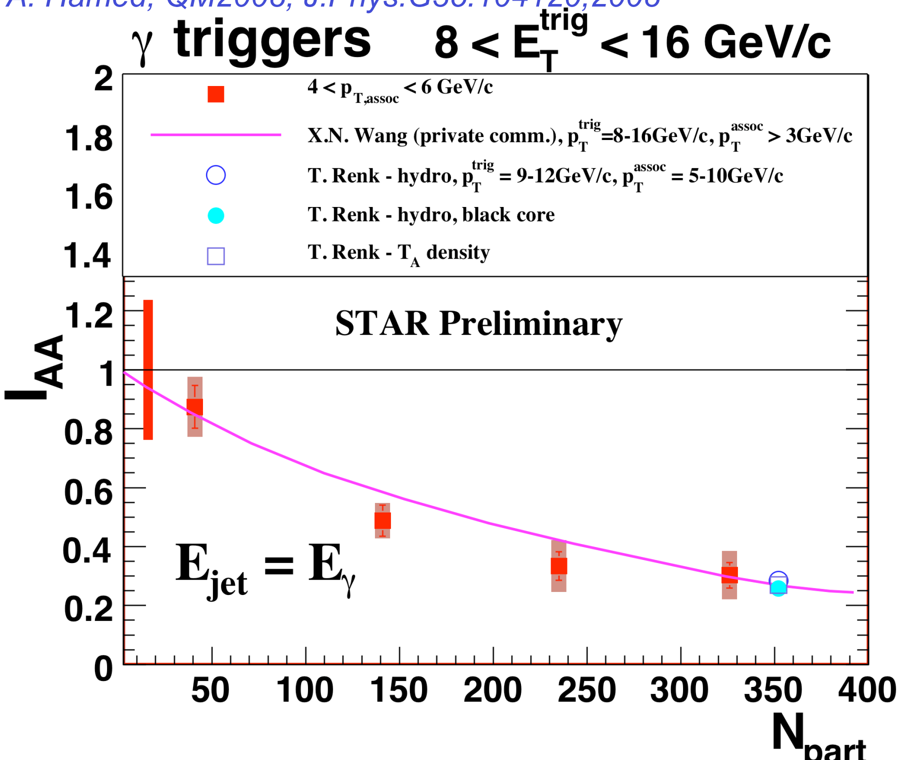


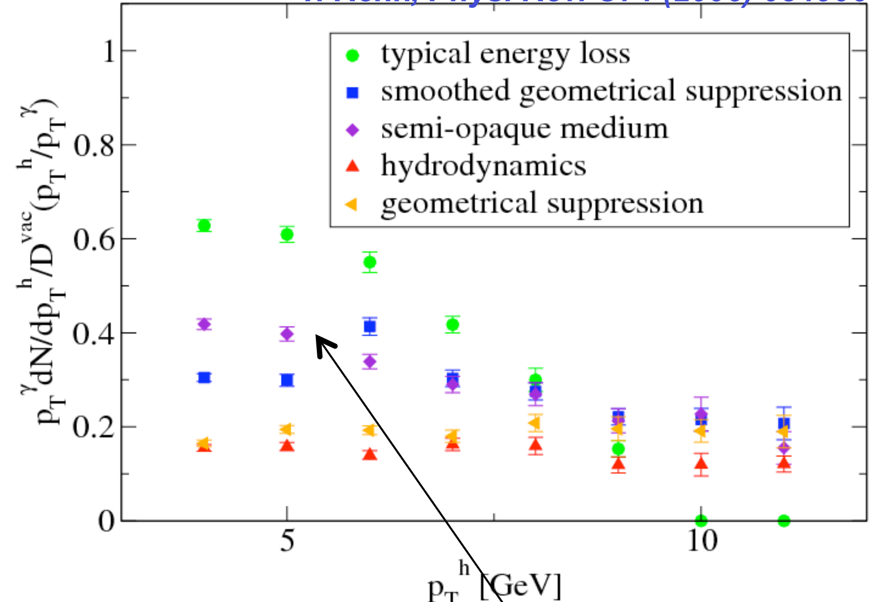

Both STAR and PHENIX have made first measurements in both Au+Au and p+p

# γ-Hadron Correlations: need for precision

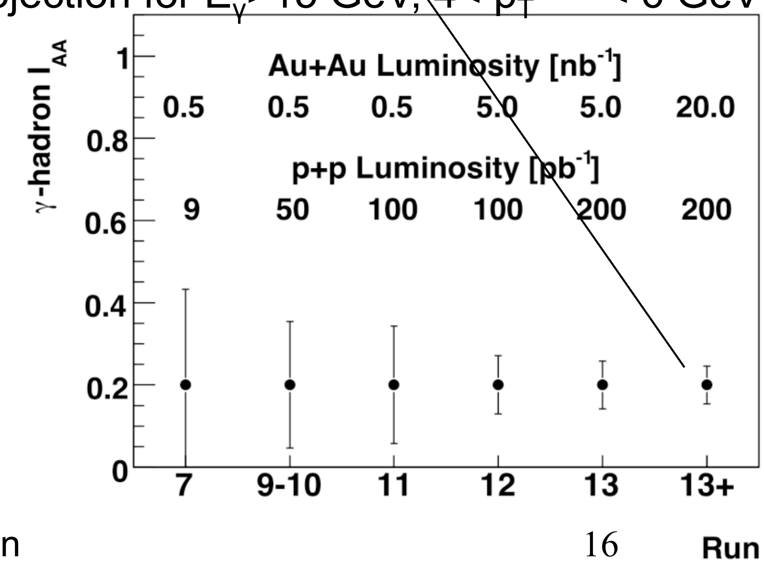
*A. Hamed, QM2008, J.Phys.G35:104120,2008*

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



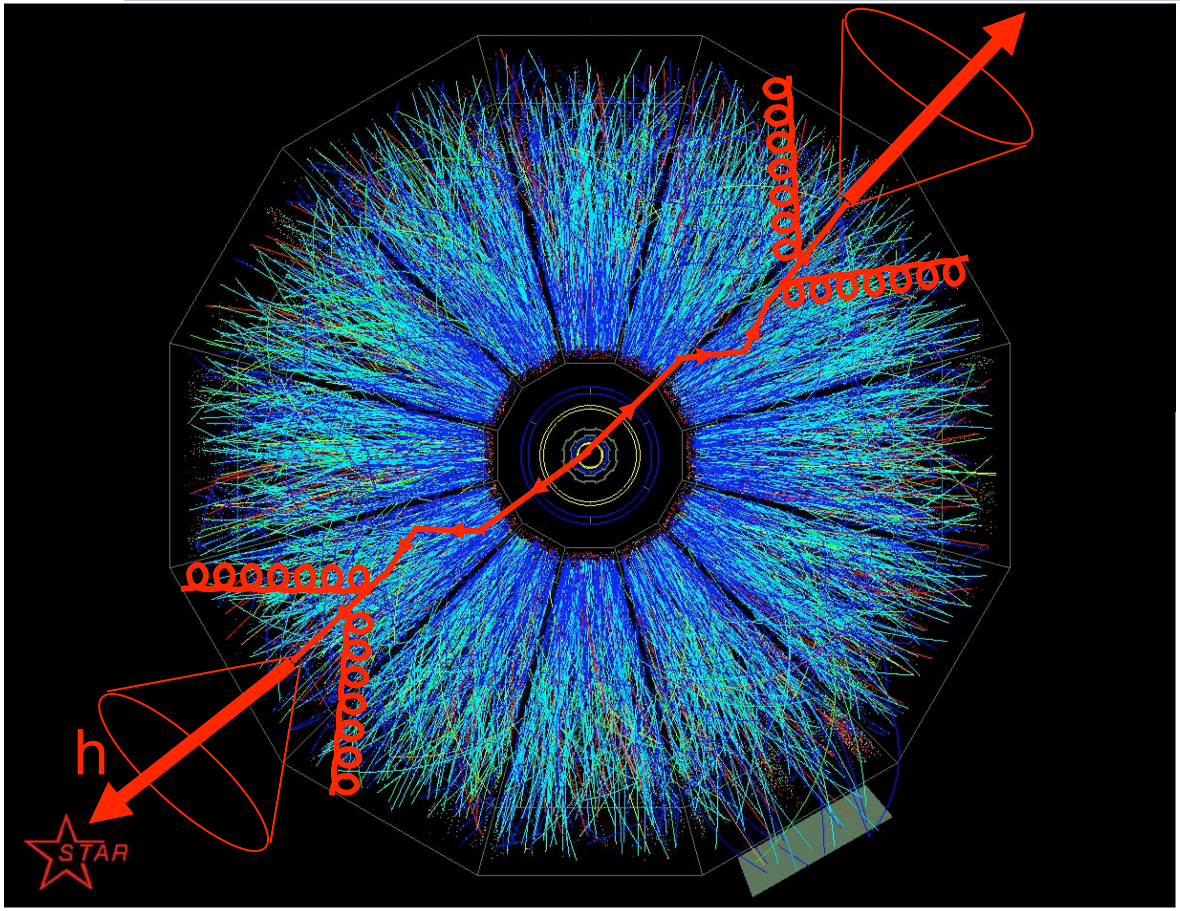



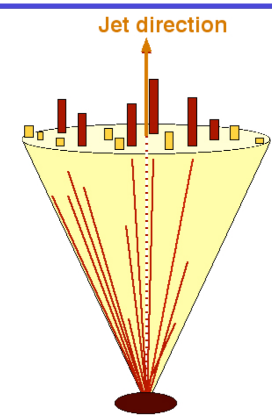

Projection for $E_\gamma$>15 GeV, 4< $p_T^{assoc}$< 6 GeV

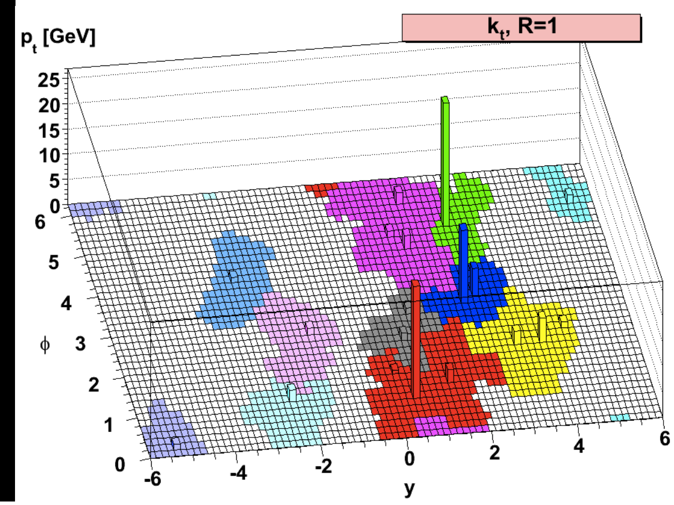



- First measurements made
  - Agree with theory within uncertainties
  - Higher precision needed
- Major progress possible in coming years with RHIC II

# Jets



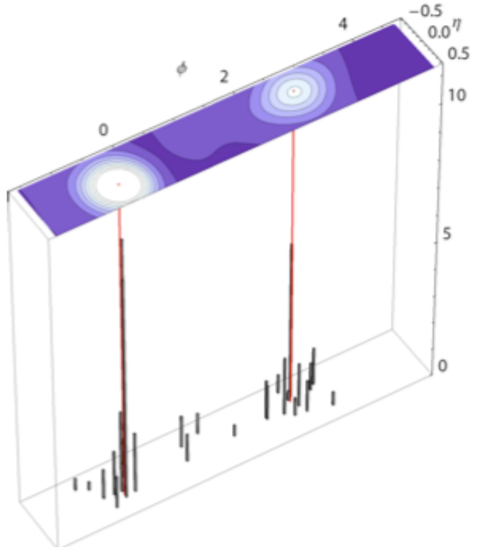




Jet reconstruction: another way to constrain hard kinematics

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

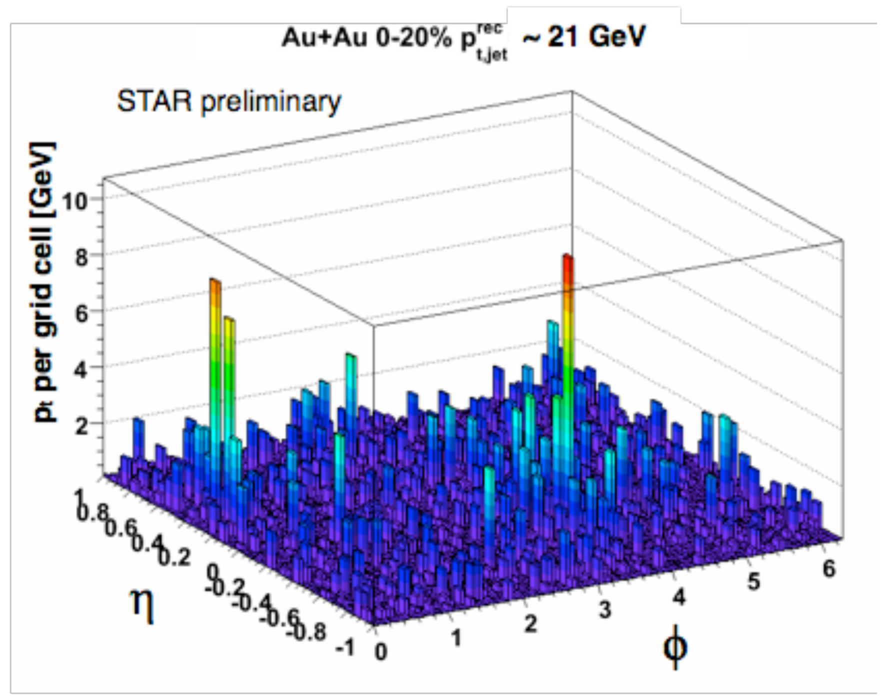
# Jets in Au+Au: Results so Far

PHENIX, Quark Matter 2009




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

STAR, Quark Matter 2009



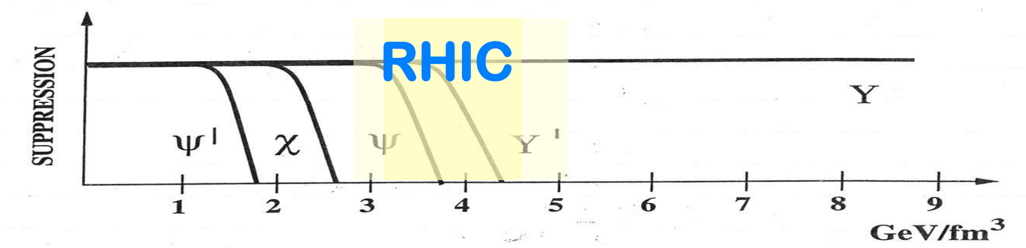

Beginning results from 2007 indicative, but in no way final word

Beginning application of FastJet… to handle large background

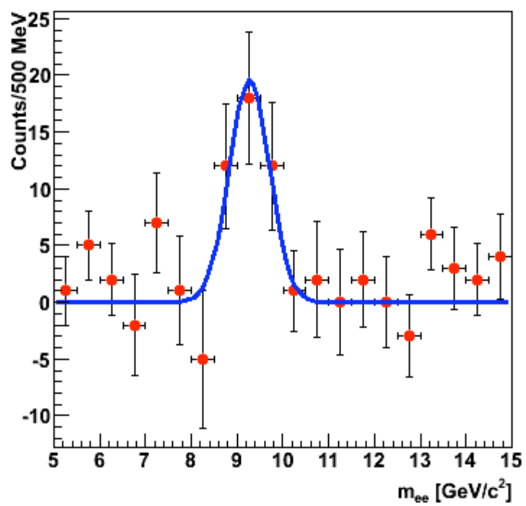
Orders of magnitude more luminosity available by Run 14

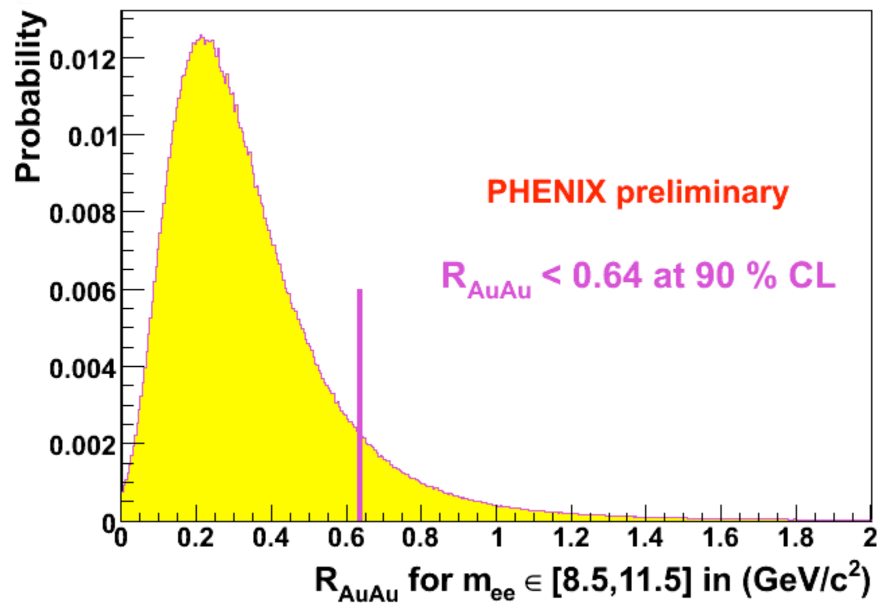
Issue: effective triggers to sample luminosity w/o physics bias

# Quarkonium: Upsilon




Proof of principle: STAR p+p 2006
Upsilon(1S+2S+3S)→$e^+e^-$



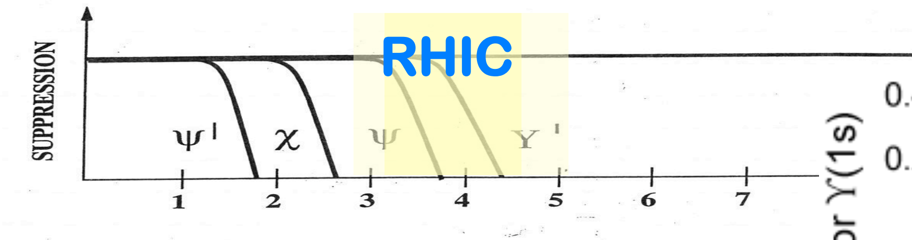




Sequential dissociation of quarkonia to measure energy density of plasma

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




Proof of principle: STAR p+p 2006
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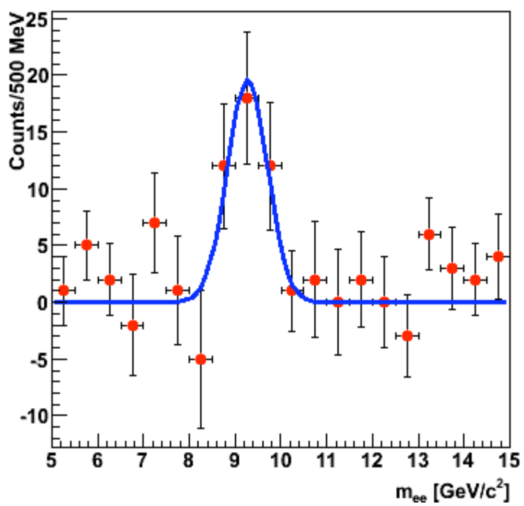


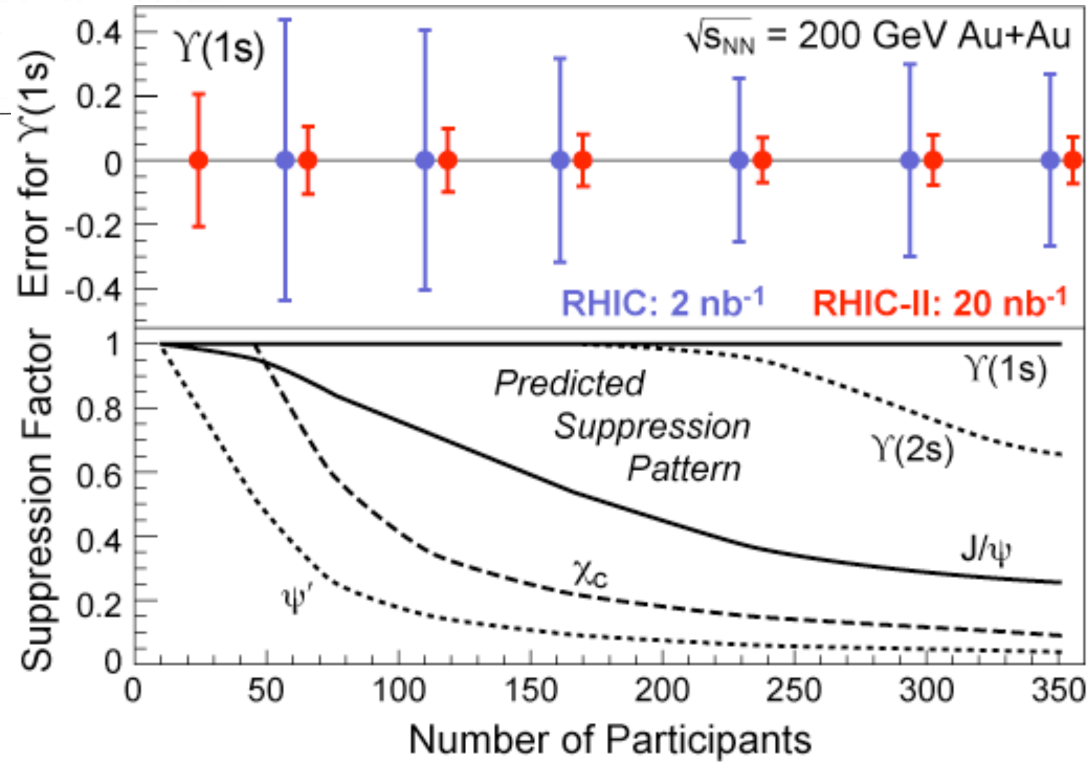


Sequential dissociation of quarkonia to measure energy density of plasma

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

# Summary

- STAR has evolved into the best machine in the world for correlation studies in heavy ion collisions

- Unresolved issues and opportunities in correlations
  - Is there a probe-able region that has a 1$^{st}$ order Phase Transition?
    - Hanbury-Brown Twiss correlations vs Reaction Plane and the Energy Scan
    - More in the next talk..
  - What is the physical origin of the ridge?
    - Particle Identification with TOF
  - What is the detailed mechanism for energy loss?
    - γ-hadron correlations, full jet reconstruction, and heavy flavor with luminosity and detector upgrades