

PHENIX highlights

Y. Akiba

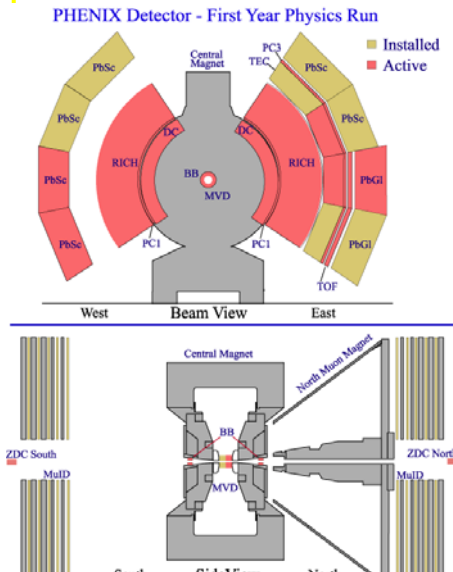
For PHENIX Collaboration

2004/06/02 NSAC Review

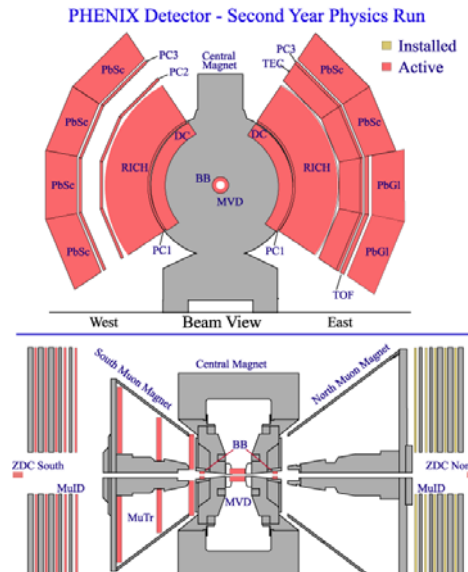
Run-1 to Run-4 Capsule History

Run	Year	Species	$s^{1/2}$ [GeV]	$\int Ldt$	N_{tot}	p-p Equivalent	Data Size
01	2000	Au+Au	130	$1 \mu b^{-1}$	10M	$0.04 pb^{-1}$	3 TB
02	2001/2002	Au+Au	200	$24 \mu b^{-1}$	170M	$1.0 pb^{-1}$	10 TB
		p+p	200	$0.15 pb^{-1}$	3.7G	$0.15 pb^{-1}$	20 TB
03	2002/2003	d+Au	200	$2.74 nb^{-1}$	5.5G	$1.1 pb^{-1}$	46 TB
		p+p	200	$0.35 pb^{-1}$	6.6G	$0.35 pb^{-1}$	35 TB
04	2003/2004	Au+Au	200	$241 \mu b^{-1}$	1.5G	$10.0 pb^{-1}$	270 TB
		Au+Au	62	$9 \mu b^{-1}$	58M	$0.36 pb^{-1}$	10 TB

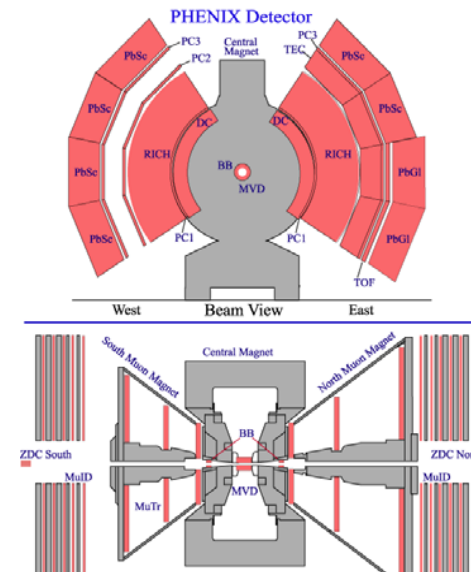
Run-1



Run-2



Run-3



Published results

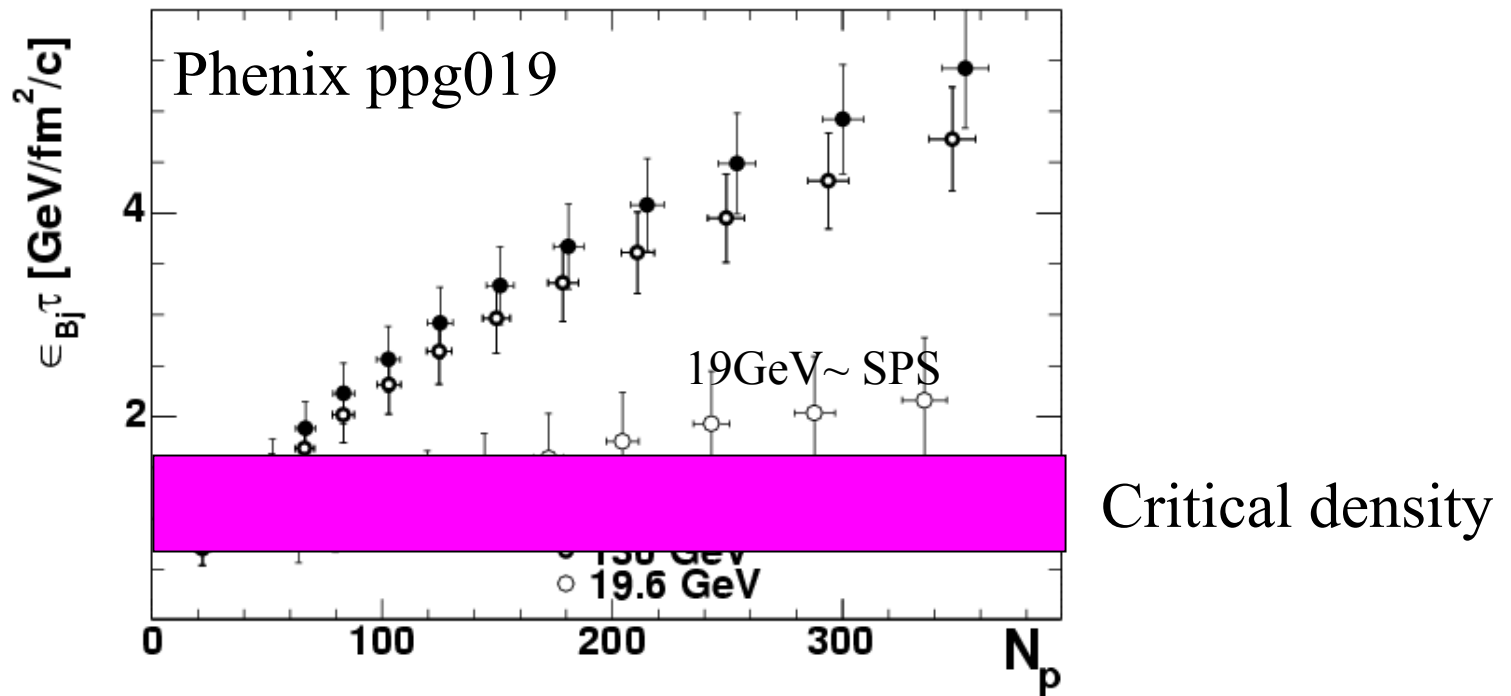
- 25 Publications to date
- 15 PRL + 5 PRC +1 PLB published
- 1 PRL accepted, 3 PRL in review
- 3 papers with 100+ citations
 - *First Measurement* of multiplicity vs centrality in Au+Au at 130 GeV
 - *Discovery* of high pT suppression in Au+Au at 130 GeV
 - *Discovery* of anomalous p/ π ratio at high pt through systematic study of π /K/p spectra in Au+Au at 130 GeV
- 6 more papers with 50+ citations
 - *First Measurement* of E_T at 130GeV
 - *First measurement* of charm at RHIC at 130 GeV
 - *Extention* of the suppression measurement of high p_T π^0 at 200 GeV
 - *Co-discovery* of absence of suppression in d+Au at 200 GeV
 - Measurement of HBT in extended p_T range at 130 GeV
 - Measurement of Λ and anti- Λ at 130 GeV
- More than 1200 citations total
- ~20 more papers in pipeline, including
 - *First measurement* of direct photon in Au+Au collisions
 - *First measurement* of jet correlation with leading baryon in Au+Au collisions at 200 GeV

PHENIX White paper

- We are making assessment of our achievement in the first 4 years of RHIC/PHENIX
- White Paper Writing Group
 - Charge: Assessing the current PHENIX (and RHIC) data set and its implication for the discovery of a new state of matter
 - Members:
Y. Akiba (chair), S. Bathe (secretary), B. Cole, S. Esumi, B. Jacak, J. Nagle, C. Ogilvie, R. Seto, P. Stankus, M. Tannenbaum, I. Tserruya
- We are evaluating the implication of the data in terms of
 - Evidences for high density matter formation
 - Evidences for thermalisation
 - Hadronisation process --- evidence for recombination?
 - and*
 - Evidence for QGP formation

$dE_T/d\eta$ and Bjorken Energy density

Bjorken energy density is a bench mark of the energy density achieved in heavy ion collisions.

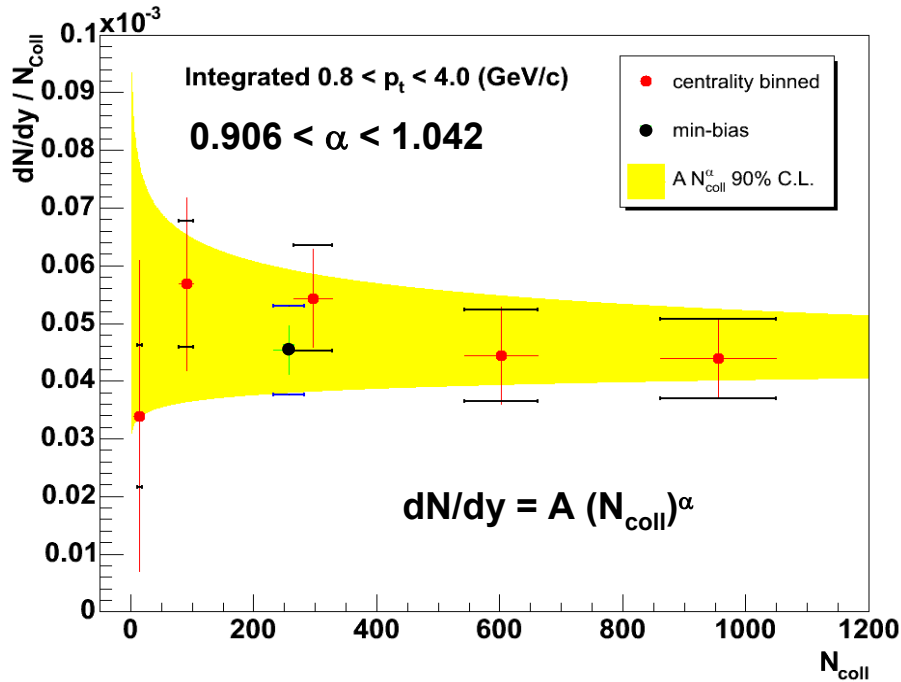


- Bjorken energy density measured by PHENIX is 5.5 GeV/fm³ for $\tau_0=1$ fm/c. this is more than twice of the value at SPS (after proper corrections)
- $\epsilon_{Bj} \gg 1$ GeV/fm³ ($\sim \epsilon_{crit}$) at RHIC except for the most peripheral collisions.
- Formation time $\tau > 2R/\gamma = 0.14$ fm/c at RHIC (1.7 fm/c at SPS)

Base line: Ncoll Scaling

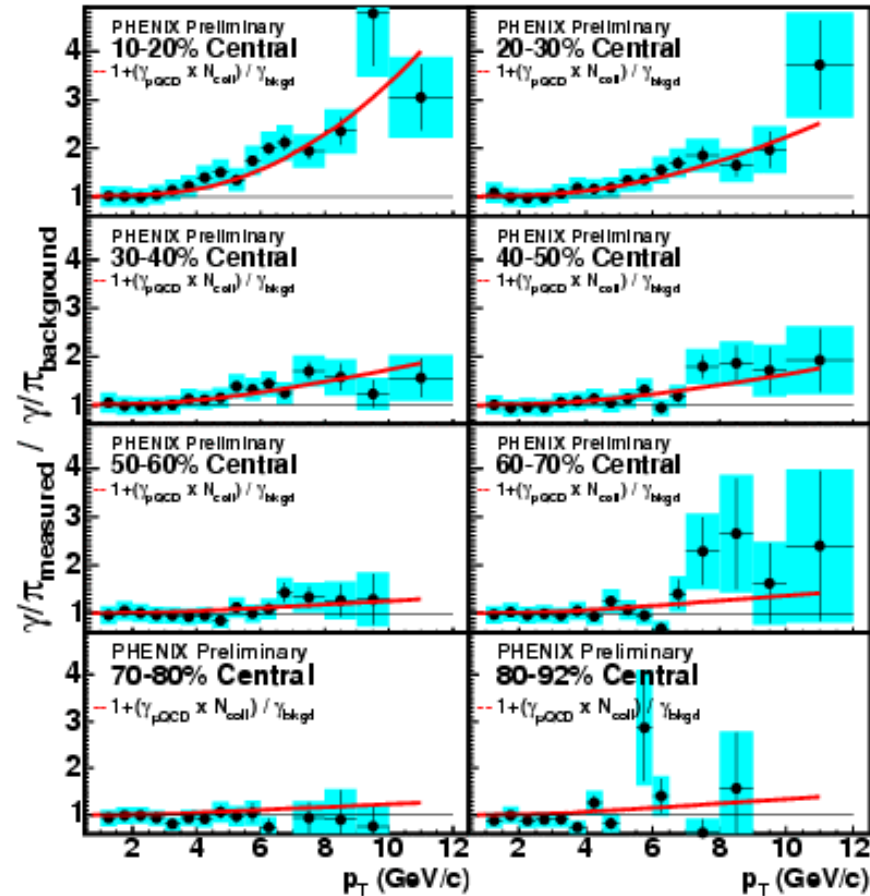
Charm yield scales with Ncoll

Electron from charm decay in Au+Au @200 GeV



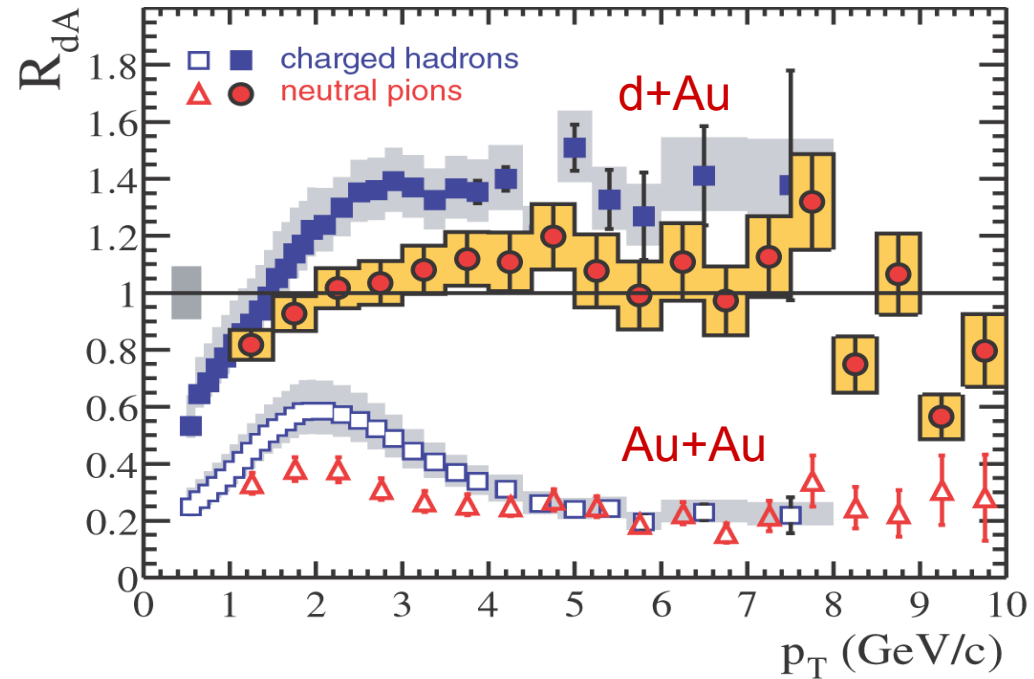
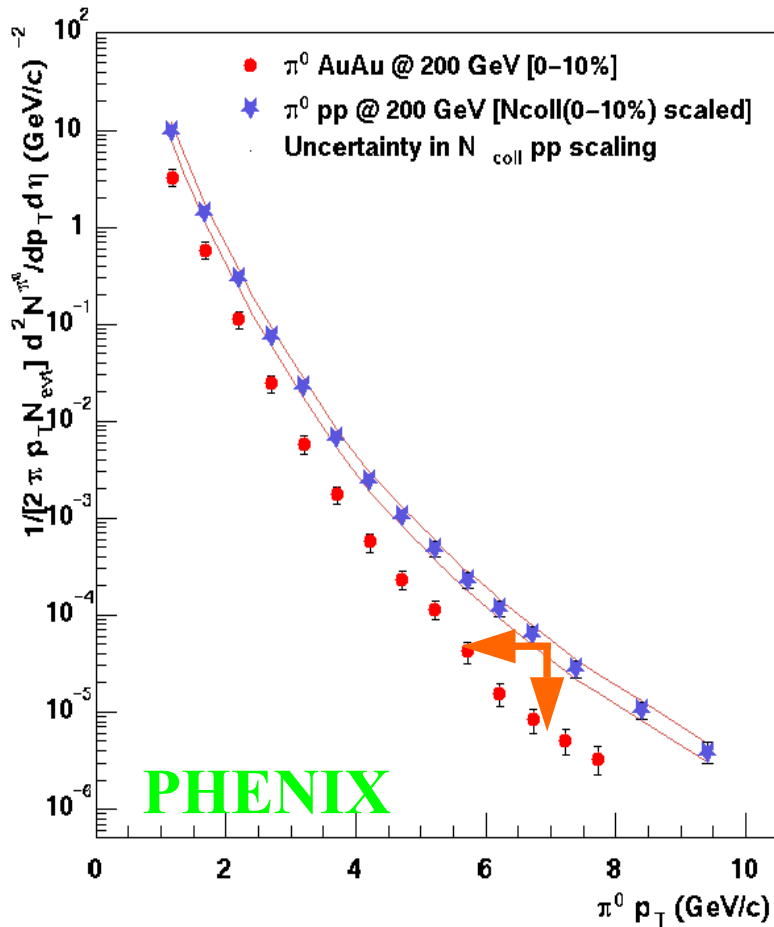
Direct photon scales with Ncoll

Direct γ from Au+Au @200GeV



- PHENIX data show that the yield of point-like process with little final state effect scales with Ncoll, as expected

Jet quenching --- Formation of dense matter



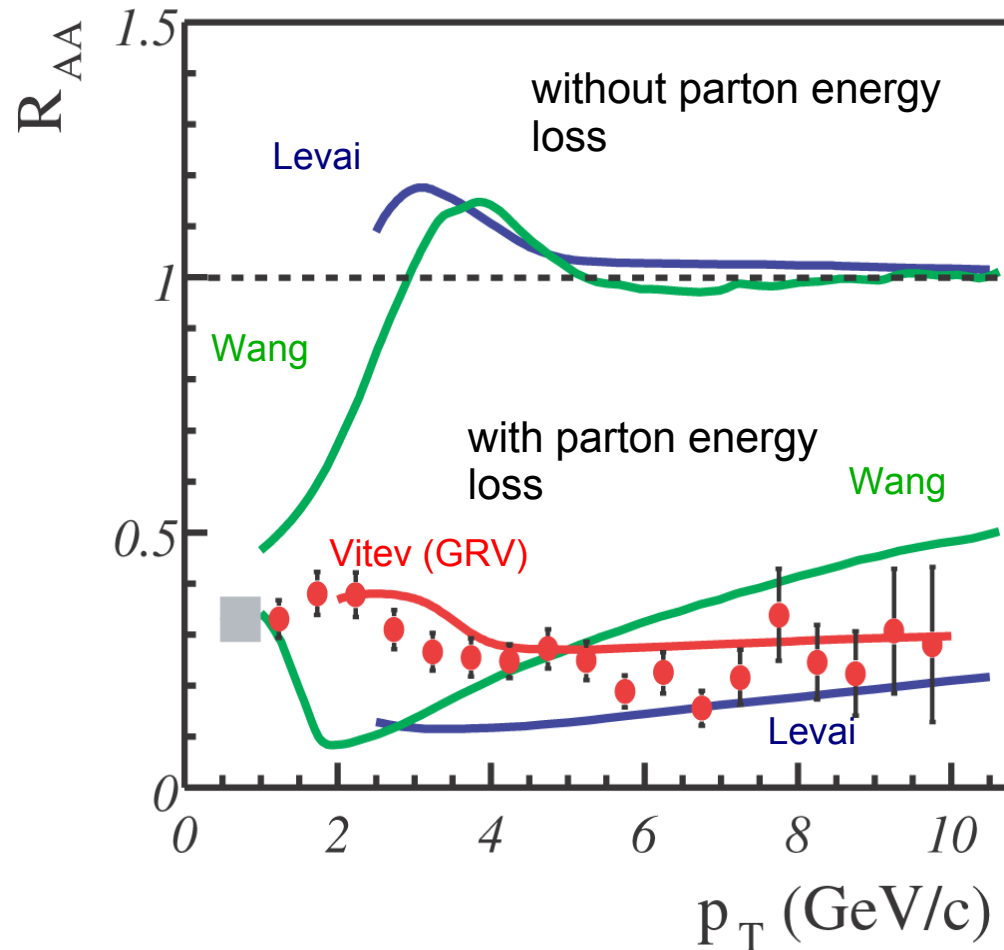
- **Discovery** of high p_T suppression in Au+Au collision
 - **(Co-)discovery** of absence of suppression in d+Au
 - The effect is attributed to parton energy loss in the dense matter
- Very strong evidence of *formation of a dense matter* at RHIC!

Suppression --- parton energy loss?

- Among the models in the market, the gluon radiation energy loss model by GRV explain the data very well.
- Models without energy losses are excluded
- The flat R_{AA} of the data excludes constant energy loss
- Need systematic error in theory curve
- The much higher p_T reach (~ 20 GeV/c) in RUN4 will further constraint the models

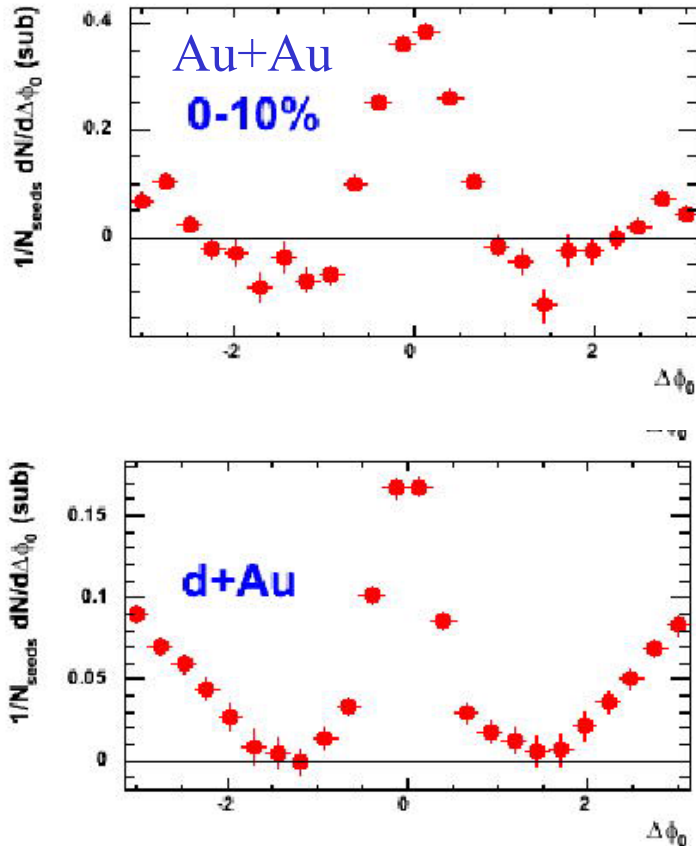
Comparison to model calculations with and without parton energy loss:

Au+Au at $\sqrt{s_{NN}} = 200$ GeV

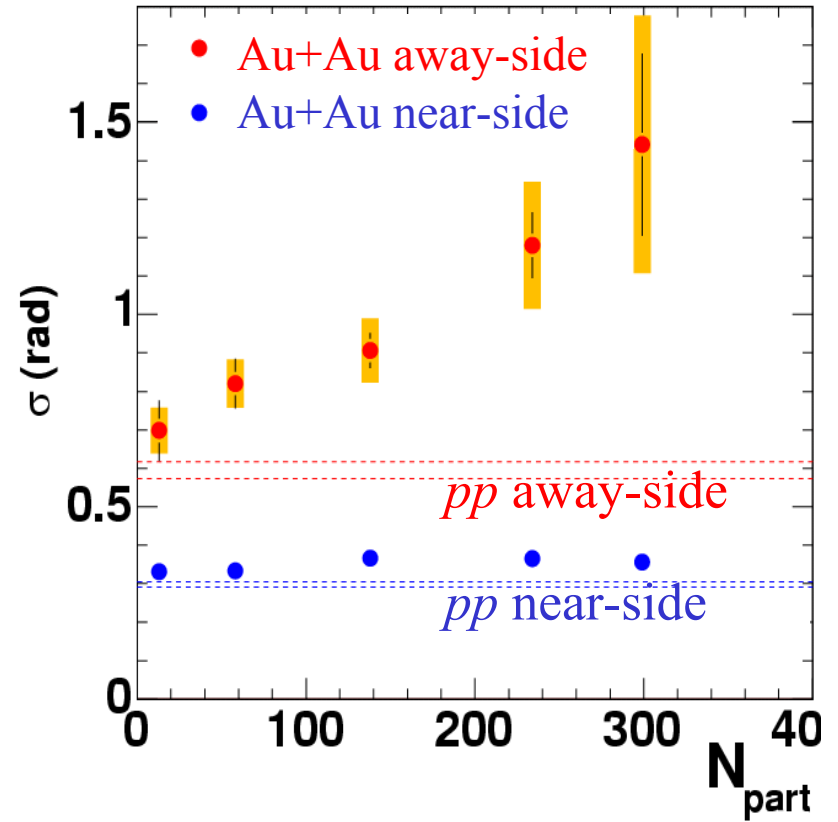


Evidence for Jets

Two particle correlation from Jets



Au+Au jet width

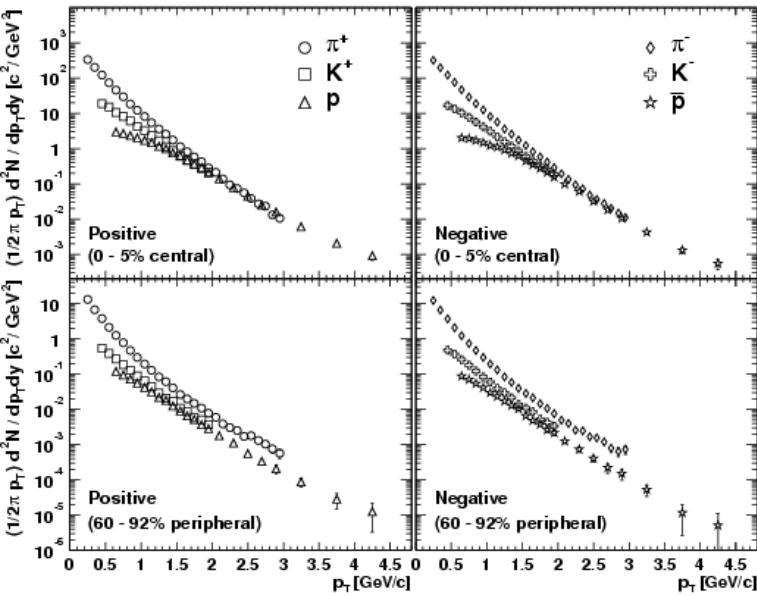


- Two particle correlation shows jet-like structure in p+p, d+Au and Au+Au
- This is the direct evidence that the origin of high p_T particles are jets
- The width of away-side jet increase in central Au+Au collision, while the width of the near-side jet remain unchanged

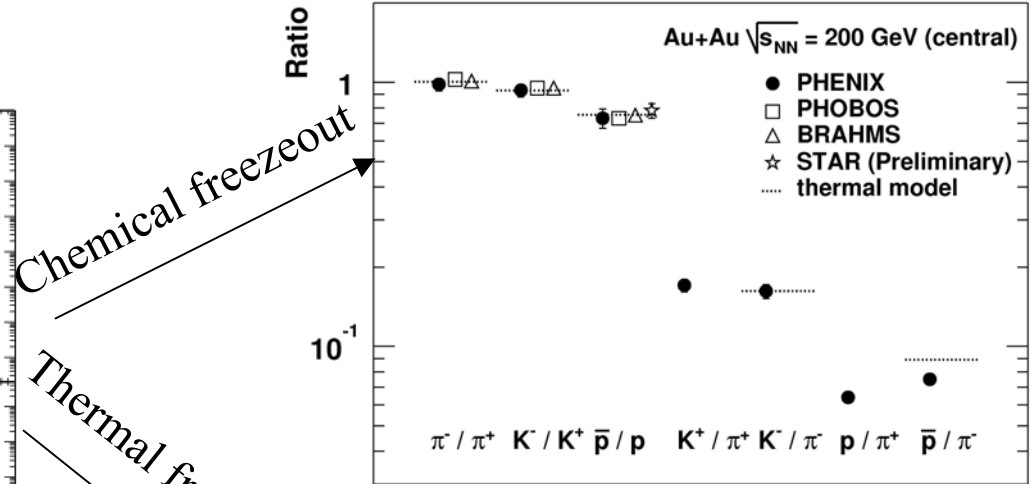
Particle composition and spectra

Evidence for thermalized final state

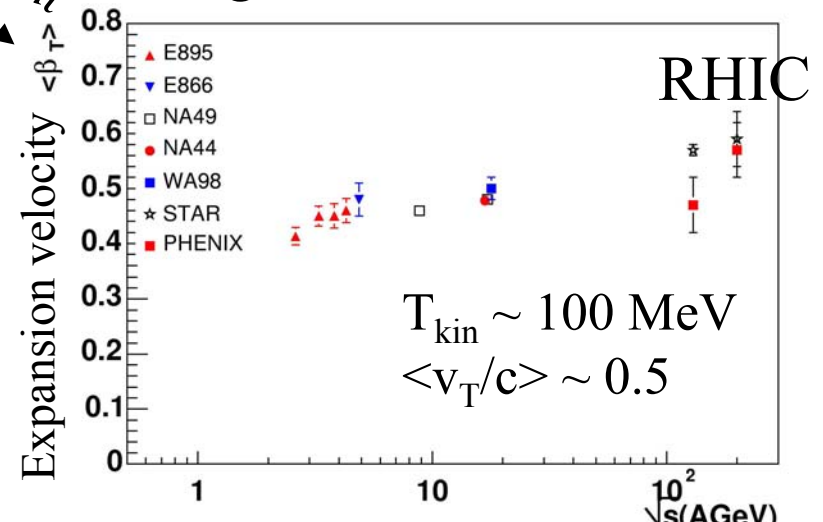
$\pi/K/p$ measurement in a
Broad pt range



Stat. model fit: $T_{ch} \sim 170 \text{ MeV}$, $\gamma_s \sim 1$
Strangeness saturation at RHIC?



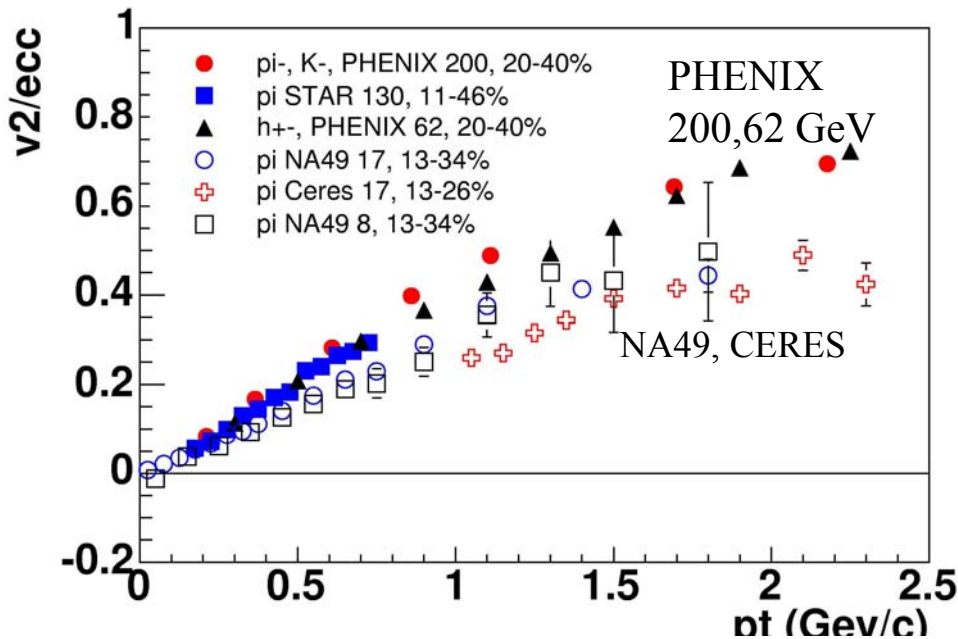
stronger radial flow at RHIC?



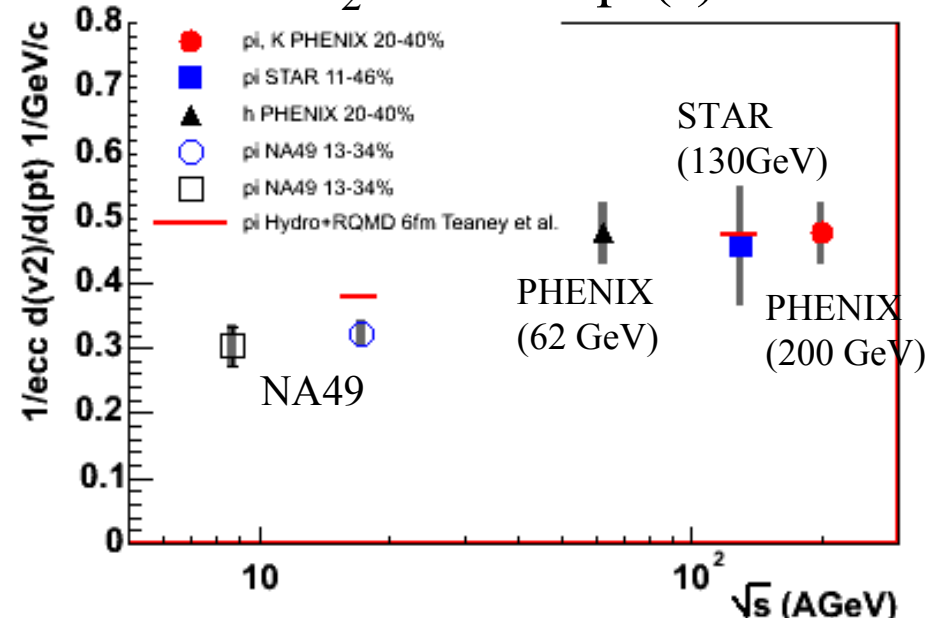
- Hadron spectra and hadron ratios provides evidence for thermalisation at chemical and kinetic freeze-out
- This conclusion is strongly model dependent.

Elliptic Flow --- evidence for rapid thermalisation

Elliptic flow vs pT



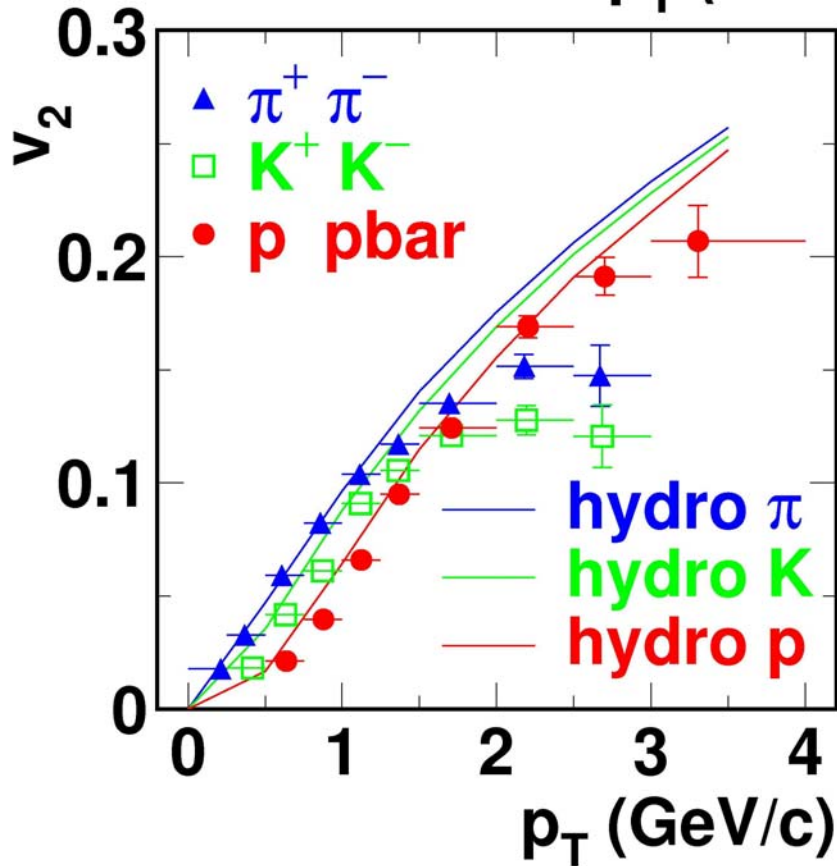
v₂/ecc vs sqrt(s)



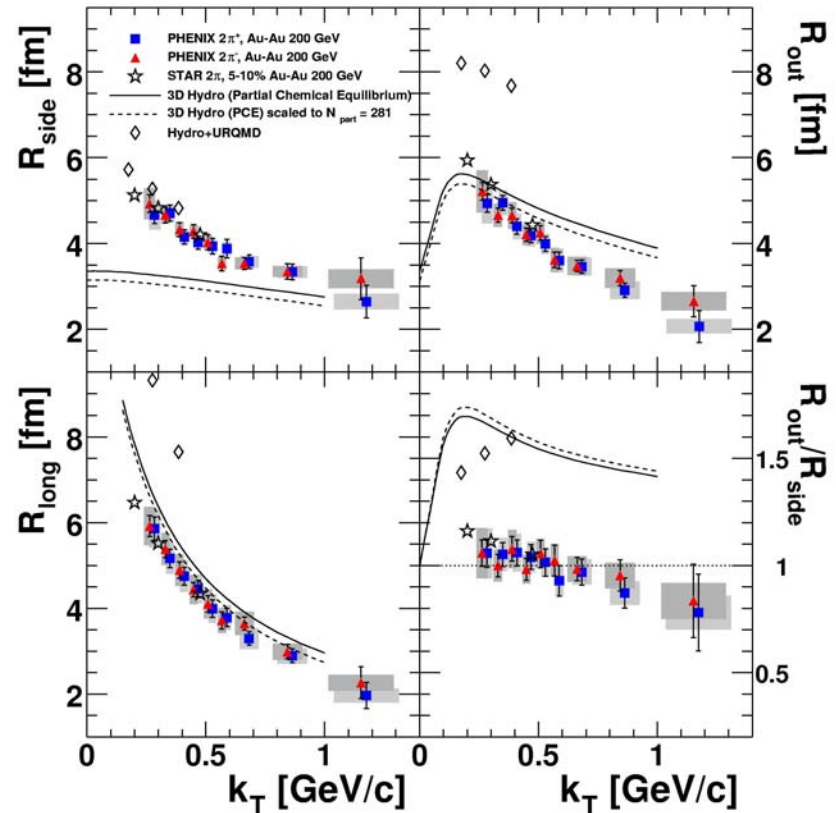
- A very strong elliptic flow is observed at RHIC
- Elliptic Flow is stronger in RHIC energy than in lower energies, and it is close to “hydrodynamic limit”
- Strong elliptic flow is considered as a strong evidence for *rapid thermalisation* of matter created in the collision.

Success and failure of hydrodynamics

Success – v_2 of $\pi/K/p$



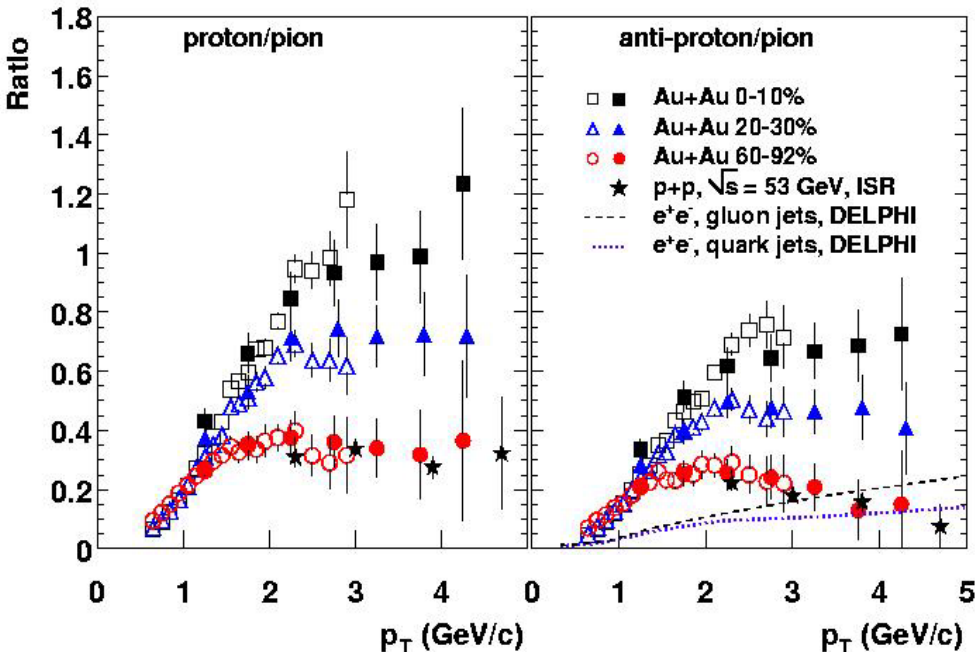
Failure --- HBT puzzle



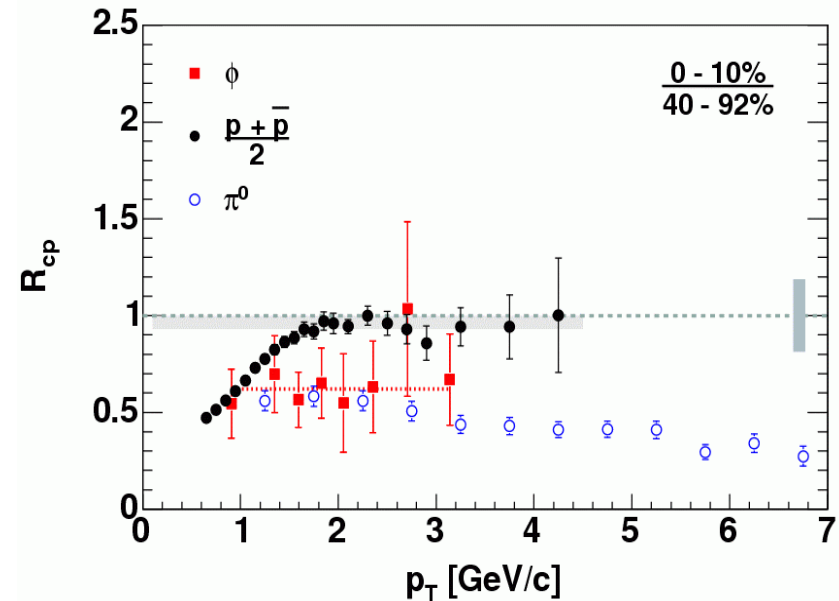
- Hydrodynamics model well reproduces v_2 of $\pi/K/p$ measured by PHENIX
- But it failed to reproduce the HBT measurement
- PHENIX data provides strong constraint on the models

Anomalous p/π ratio

Large p/π ratio in 2-4 GeV/c



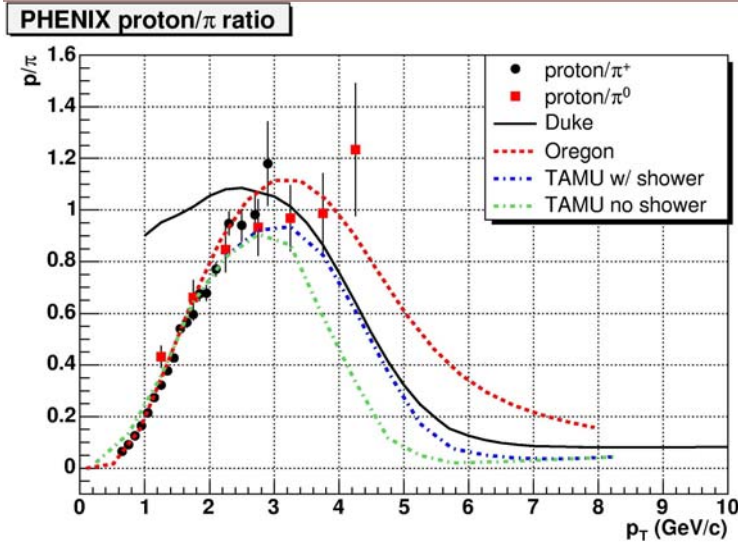
Proton scales with N_{coll}
Mesons don't



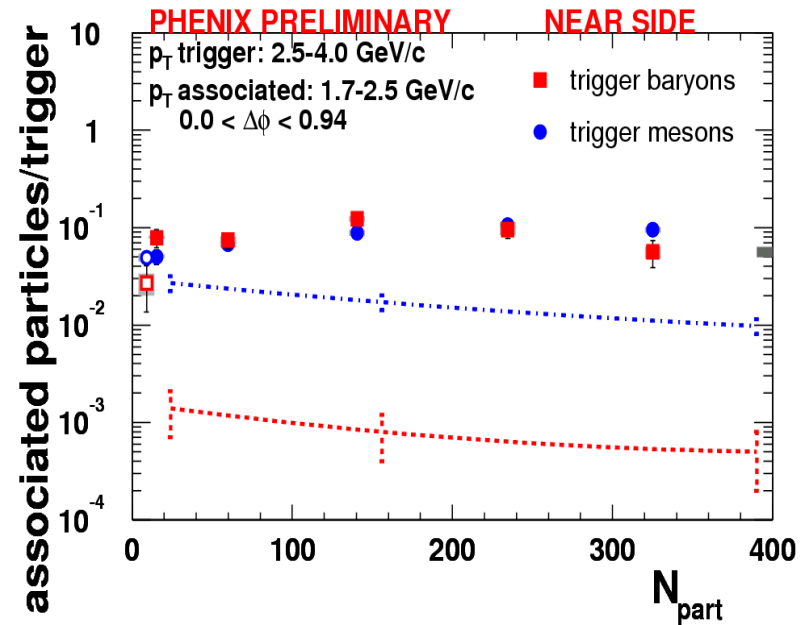
- Another discovery: anomalous p/π ratio in intermediate p_T (2 – 4 GeV/c)
- The large p/π ratio can not be explained by usual fragmentation mechanism
- The cause is not the mass --- ϕ behaves like pion, not like proton
- This surprising PHENIX data inspires “recombination models”

Is Recombination the answer?

Recomb. Models explain large p/π

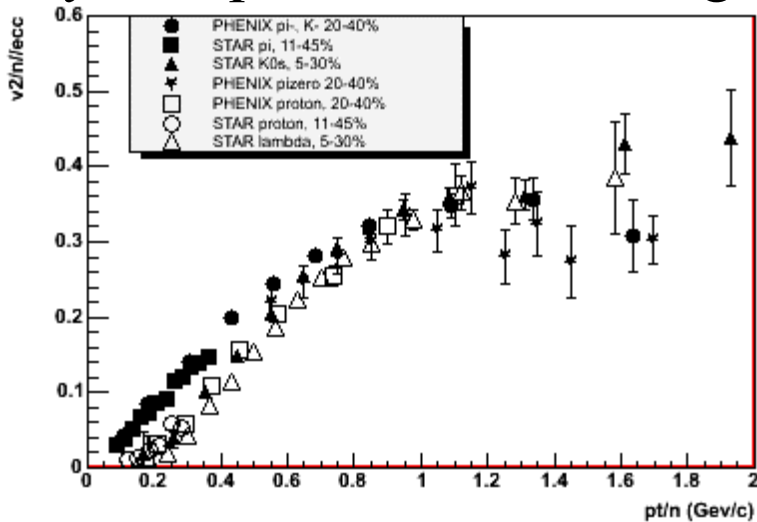


Leading baryons have jet-like correlation.



BUT

They also predict v_2/n scaling



Can any model explain all of these observations?

Summary

- Large amount of data have been collected and analyzed by PHENIX in the first four years of RHIC operation
- Evidence for high densities (high p_T suppression): *very strong*
(Control measurement of d+Au essential supporting piece of evidence)
- Evidence for bulk behavior (flow, thermalization): *strong*
- Anomalous p/π ratio and scaling of v_2 can be interpreted as recombination of quarks, but Jet correlation is a challenge to this class of models.
- What remains in the *discovery phase*
 - Experimental side:
 - J/ Ψ , energy loss of charm, charm flow, R_{AA} at higher p_T , detailed Jet tomography, direct photon, gamma+jet, thermal radiation, ...
 - Systematic study (Energy scan and species scan)
 - Theory side:
 - (Much) more robust *quantitative* understanding
 - Quantitative understanding of “failures” (e.g., HBT)

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China Institute of Atomic Energy, Beijing
Peking University, Beijing

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12 Countries; 57 Institutions; 460 Participants*

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*as of July 2002

Run-1 Publications

- “Centrality dependence of charged particle multiplicity in Au-Au collisions at $\sqrt{s_{NN}} = 130$ GeV”
PRL 86 (2001) 3500 100+
- “Measurement of the midrapidity transverse energy distribution from $\sqrt{s_{NN}} = 130$ GeV Au-Au collisions at RHIC”
PRL 87 (2001) 052301 50+
- “Suppression of hadrons with large transverse momentum in central Au-Au collisions at $\sqrt{s_{NN}} = 130$ GeV”
PRL 88, 022301 (2002) 100+
- “Centrality dependence of $\pi^{+/-}$, $K^{+/-}$, p and pbar production at RHIC”
PRL 88, 242301 (2002) 100+
- “Transverse mass dependence of the two-pion correlation for Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV”
PRL 88, 192302 (2002) 50+
- “Measurement of single electrons and implications for charm production in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV”
PRL 88, 192303 (2002) 50+
- "Net Charge Fluctuations in Au+Au Interactions at $\sqrt{s_{NN}} = 130$ GeV,"
PRL 89, 082301 (2002)
- "Event-by event fluctuations in Mean p_T and mean e_T in $\sqrt{s_{NN}} = 130$ GeV Au+Au Collisions"
PRC 66, 024901 (2002)
- "Flow Measurements via Two-particle Azimuthal Correlations in Au + Au Collisions at $\sqrt{s_{NN}} = 130$ GeV“
PRL 89, 212301 (2002)
- "Measurement of the lambda and lambda^bar particles in Au+Au Collisions at $\sqrt{s_{NN}} = 130$ GeV"
PRL 89, 092302 (2002) 50+
- "Centrality Dependence of the High p_T Charged Hadron Suppression in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV"
PLB561, 82 (2003)
- "Single Identified Hadron Spectra from $\sqrt{s_{NN}} = 130$ GeV Au+Au Collisions“
PRC 69, 024904(2004)

Run-2 and Run-3 Publications

RUN-2

- “Suppressed π^0 Production at Large Transverse Momentum in Central Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV”
PRL 91, 072301 (2003) 50+
- “Scaling Properties of Proton and Anti-proton Production in $\sqrt{s_{NN}} = 200$ GeV Au+Au Collisions”
PRL 91, 172301 (2003)
- “J/psi production from proton-proton collisions at $\sqrt{s} = 200$ GeV”
PRL92, 051802 (2004)
- “J/Psi Production in Au-Au Collisions at $\sqrt{s_{NN}} = 200$ GeV at the Relativistic Heavy Ion Collider”
PRC69, 014901 (2004)
- “Elliptic Flow of Identified Hadrons in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV”
PRL91, 182301 (2003)
- “Midrapidity Neutral Pion Production in Proton-Proton Collisions at $\sqrt{s} = 200$ GeV”
PRL91, 241803 (2003)
- “Identified Charged Particle Spectra and Yields in Au-Au Collisions at $\sqrt{s_{NN}} = 200$ GeV”
PRC 69, 034909 (2004)
- “High-pt Charged Hadron Suppression in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV”
PRC69, 034910 (2004)
- “Measurement of Non-Random Event-by-Event Fluctuation of Average Transverse Momentum in $\sqrt{s_{NN}} = 200$ GeV Au+Au and p+p collisions”
nucl-ex/0310005. Accepted for publication in PRL.
- “Bose-Einstein Correlations of Charged Pion Pairs in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV”
nucl-ex/0401003. Submitted to PRL
- “Deuteron and antideuteron production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV”
Submitted to PRL today

RUN-3

- “Absence of Suppression in Particle Production at Large Transverse Momentum in $\sqrt{s_{NN}} = 200$ GeV d+Au Collisions”,
PRL 91, 072303 (2003) 50+
- Double Helicity Asymmetry in Inclusive Mid-Rapidity p_0 Production for Polarized p+p Collisions at $\sqrt{s} = 200$ GeV
hep-ex/0404027, submitted to PRL

Accomplishments and Discoveries

- **First measurement** of the dependence of the charged particle pseudo-rapidity density and the transverse energy on the number of participants in Au+Au collisions at $\sqrt{s_{NN}}=130$ GeV.
- **Discovery** of high p_T suppression in π^0 and charged particle production in Au+Au collisions at $\sqrt{s_{NN}}=130$ GeV and a systematic study of the scaling properties of the suppression; **extension of these results to much higher transverse momenta** in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV
- **(Co)-Discovery** of absence of high p_T suppression in d+Au collisions at $s_{NN}=200\sim$ GeV.
- **Discovery** of the anomalously large proton and anti-proton yields at high transverse momentum in Au+Au collisions at $\sqrt{s_{NN}}=130$ GeV through the systematic study of π^\pm , K^\pm , p^\pm spectra; measurement of Λ and anti- Λ in Au+Au collisions at $\sqrt{s_{NN}}=130$ GeV ; study of the scaling properties of the proton and anti-proton yields in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV.
- **Measurement of HBT correlations** in $\pi^+ \pi^+$ and $\pi^- \pi^-$ pairs in Au+Au collisions at $\sqrt{s_{NN}}=130$ GeV , establishing the ``HBT puzzle" of $R_{OUT} \sim R_{SIDE}$ extends to high pair momentum; extension of these results to $\sqrt{s_{NN}}=200$ GeV
- **First measurement** of single electron spectra in Au+Au collisions at $\sqrt{s_{NN}}=130\sim$ GeV, suggesting that charm production scales with the number of binary collisions.
- **First measurement** of direct photon in Au+Au collisions at 200 GeV
- Sensitive measures of charge fluctuations and fluctuations in mean p_T and transverse energy per particle in Au+Au collisions at $\sqrt{s_{NN}}=130\sim$ GeV.
- Measurements of elliptic flow for charged particles from Au+Au collisions at $\sqrt{s_{NN}}=130\sim$ GeV and identified charged hadrons from Au+Au collisions at $\sqrt{s_{NN}}=200\sim$ GeV.
- Measurements of jet correlation in p+p, d+Au, and Au+Au collisions
- **First measurements** of jet correlation with particle identification in Au+Au collision
- Extensive study of hydrodynamic flow, particle yields, ratios and spectra from Au+Au collisions at $\sqrt{s_{NN}}=130$ GeV and 200 GeV.
- **First observation** of J/Ψ production in d+Au, and Au+Au collisions at $\sqrt{s_{NN}}=200\sim$ GeV.
- Measurement of crucial baseline data on π^0 spectra and J/Ψ production in p+p collisions at $\sqrt{s_{NN}}=200\sim$ GeV.
- **First measurement** of A_{LL} of π^0