First Results
from PHENIX experiment at RHIC

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Charged Multiplicity

Iowa State University

for the PHENIX Collaboration

Outline

- **PHENIX**
- **Global Measurements**
  - Transverse Energy
  - Flow
- **Identified Hadron Spectra**
- **High pT Spectra**
- **Pizero**
- **Outlook for Run 2**

What is PHENIX?

A strongly international venture:

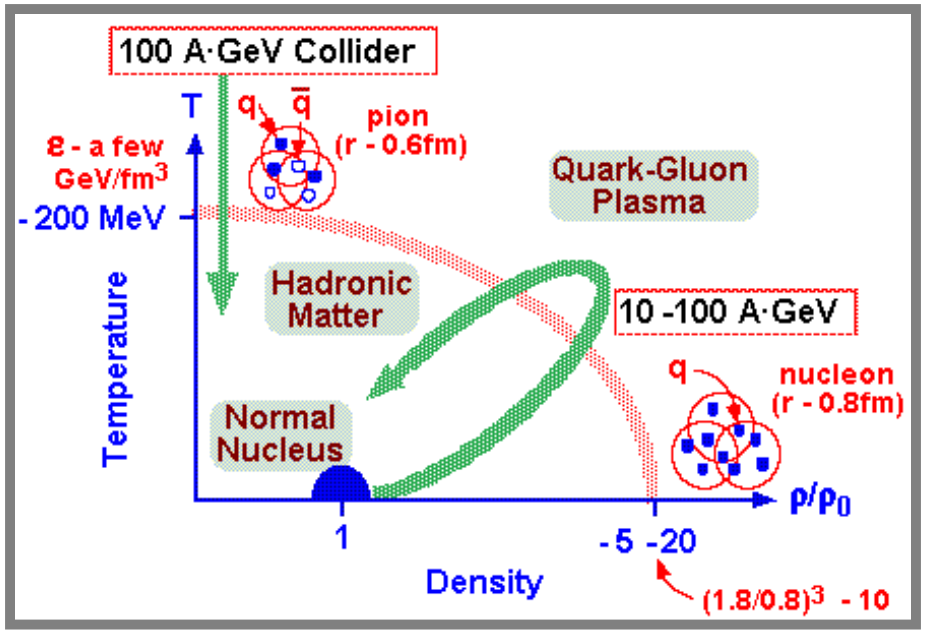
Brazil, China, France, Germany, India, Israel, Japan, South Korea, Russia, Sweden, United States

➔11 Nations

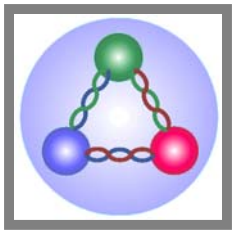
➔51 Institutions

➔~450 Collaborators

PHENIX Goals



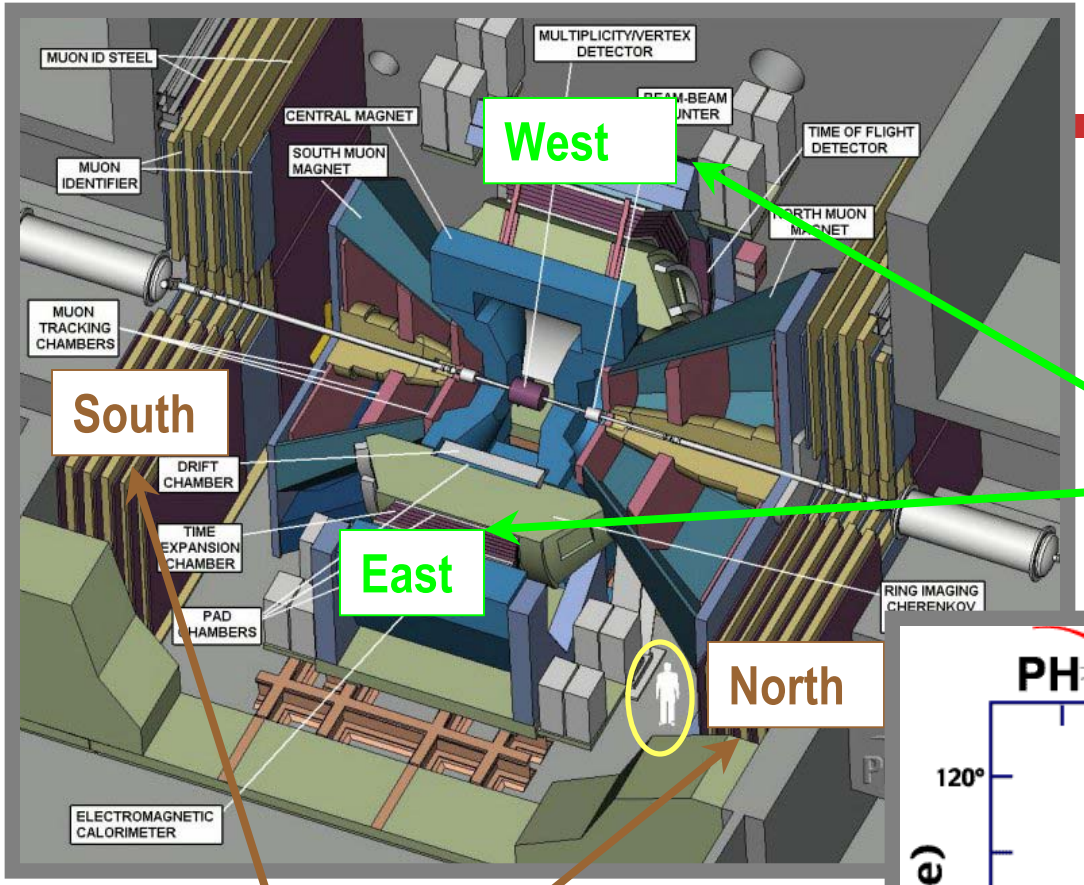
- Broadest possible study of A-A, p-A, p-p collisions to
  - Study nuclear matter under extreme conditions
  - Study systematic variations with species and energy



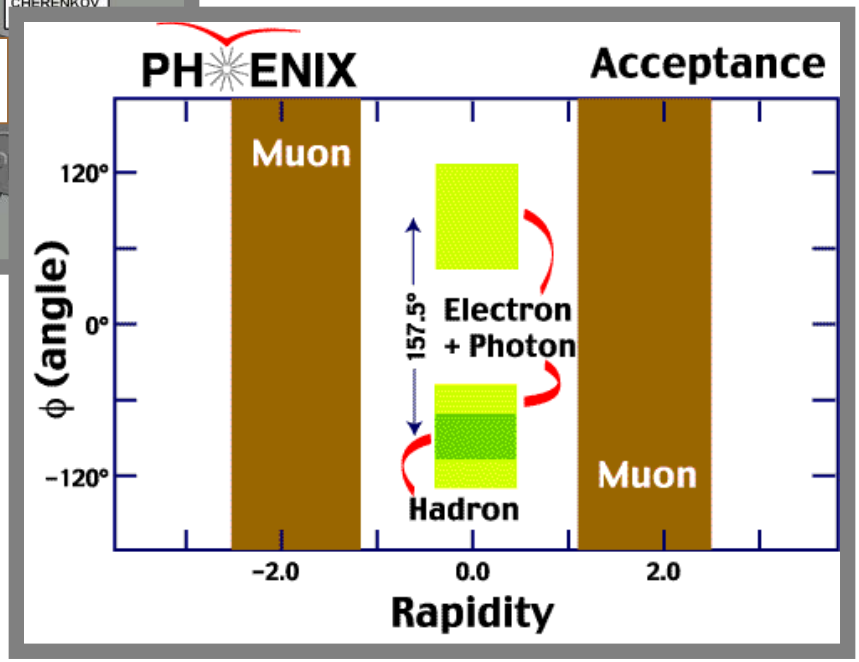
- Measure spin structure of the nucleon

➔ **These two programs have produced a detector with unparalleled capabilities**

PHENIX Detector

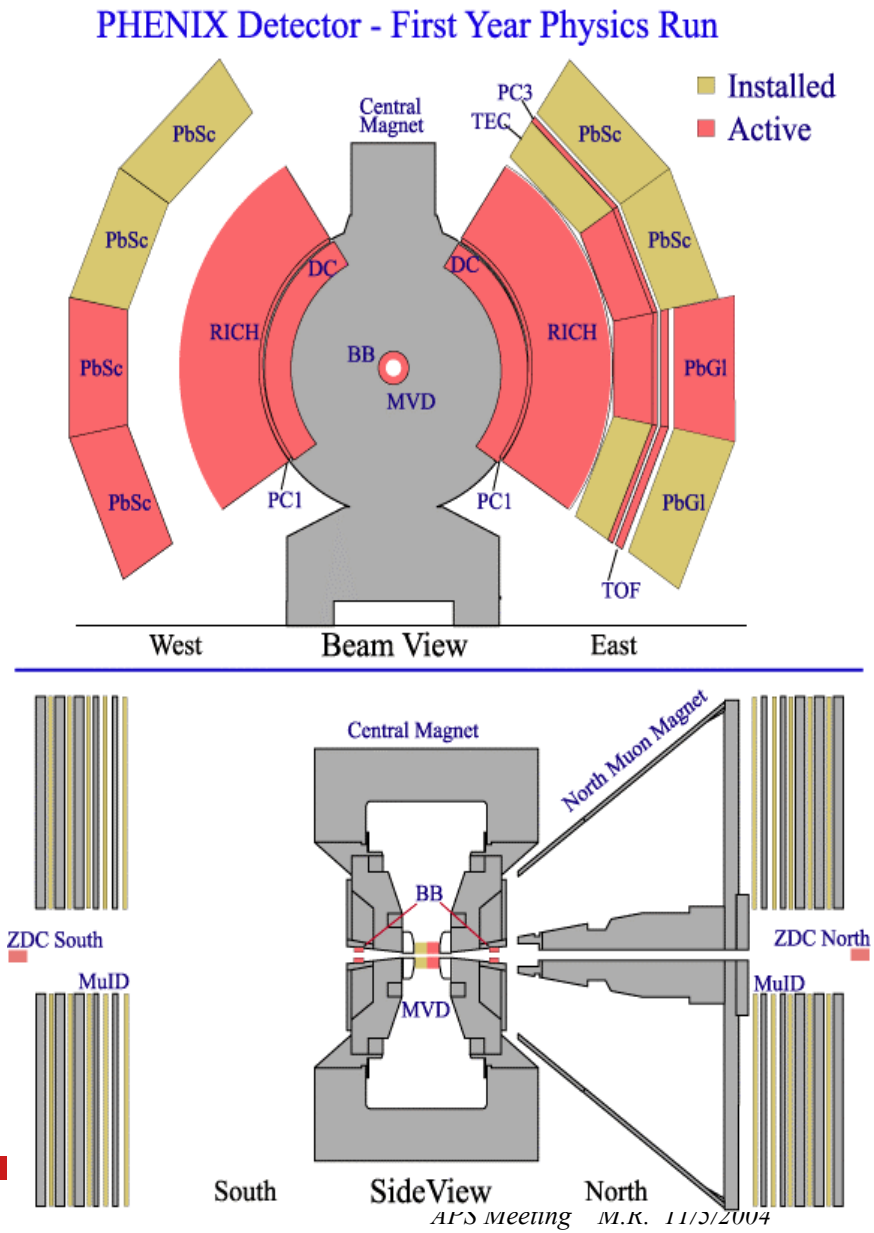


- 3 global detectors (centrality)
- 2 central spectrometers
- 2 forward spectrometers



Run-1 Configuration

- **Two central arms**
  - Mechanically ~ complete
  - Roughly half of aperture instrumented
- **Global detectors**
  - Zero-degree Calorimeters (ZDCs)
  - Beam-Beam Counters (BBCs)
  - Multiplicity and Vertex Detector (MVD, engineering run)



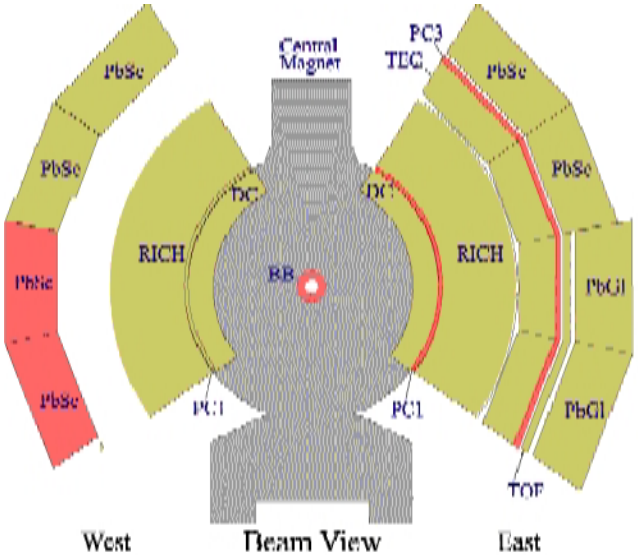
➔ **First Collisions on June 15, 2000**

➔ **Recorded 5M minimum bias events**

Global Event Characteristics

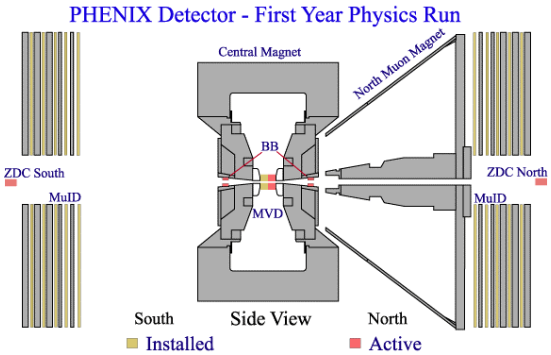
What?

- Overview of conditions prevailing in collision
- Check of participant-nucleon scaling
- Estimate the energy density

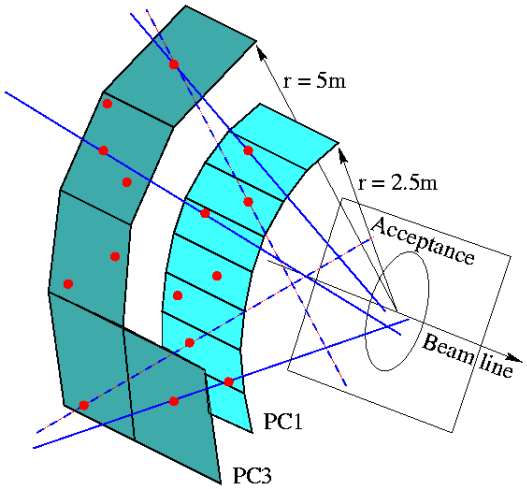


How?

- Zero Degree Calorimeters form trigger for "softest" collisions
- Beam-Beam counters
  - ✔ tag 92% of strong interactions
  - ✔ impose our chosen z-limits on interaction diamond
  - ✔ provide time-zero
- Pad Chambers count charged particles
- EMCalorimeter measures energy deposited



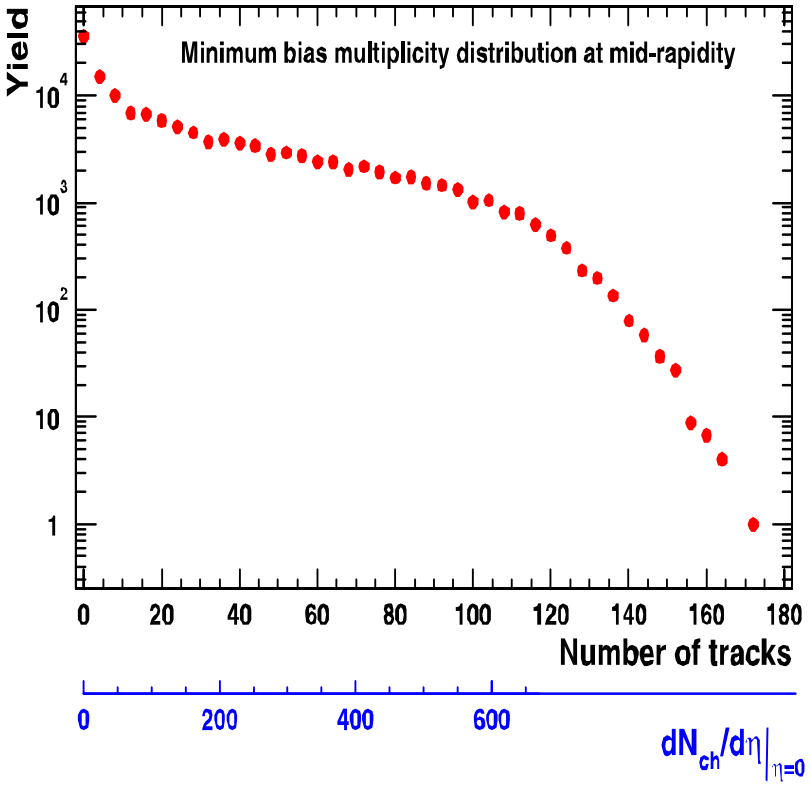
Charged Multiplicity



- **Procedure:**

  count tracks on a statistical basis, no explicit track reconstruction

- **Measured for**
  - $|\eta| < 0.35$
  - $\Delta\phi = 90°$
  - Minimum bias
    $\sim$ 92% of $\sigma_{GEOM} = 7.2b$

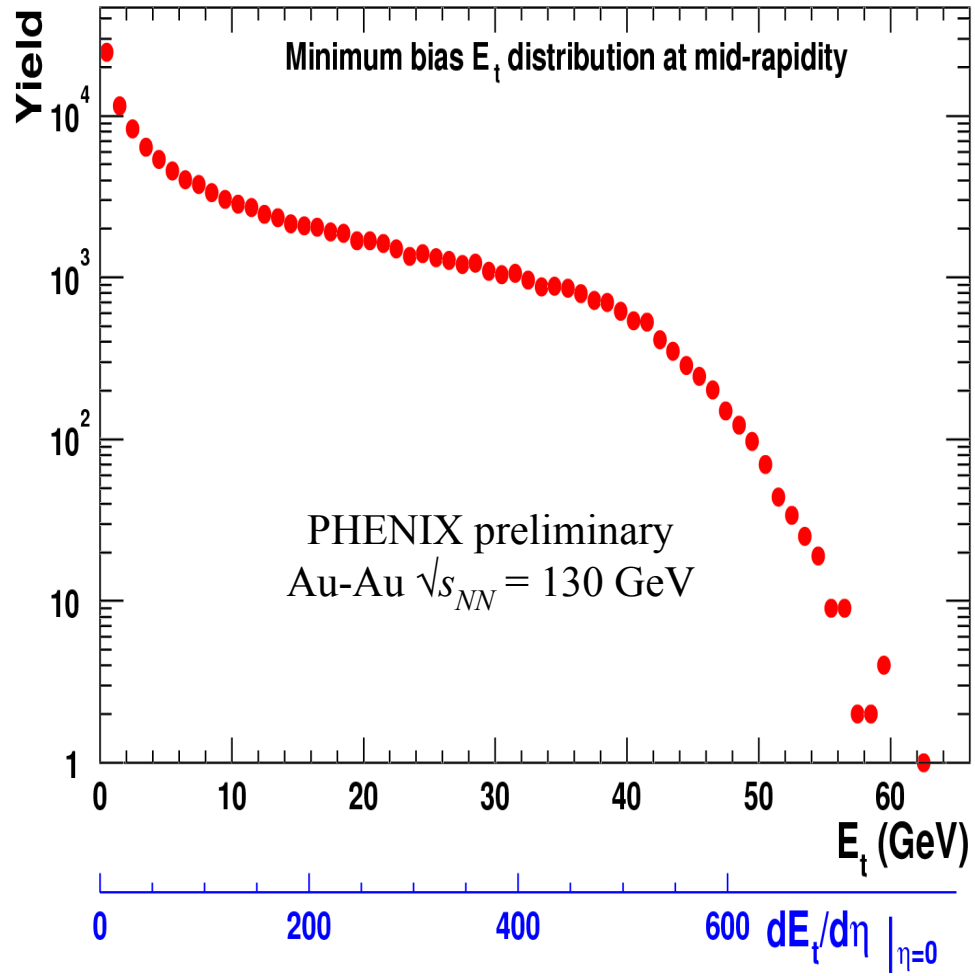


Phys. Rev. Lett. 86, 3500 (2001)

Transverse Energy Distribution

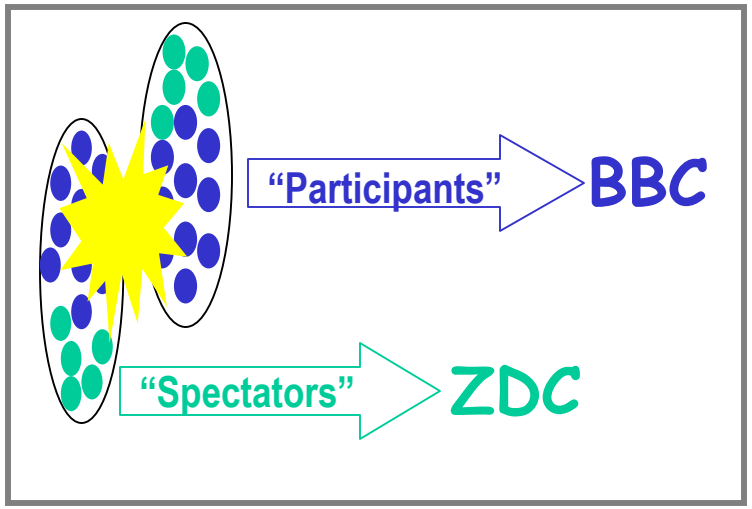
Measured for:

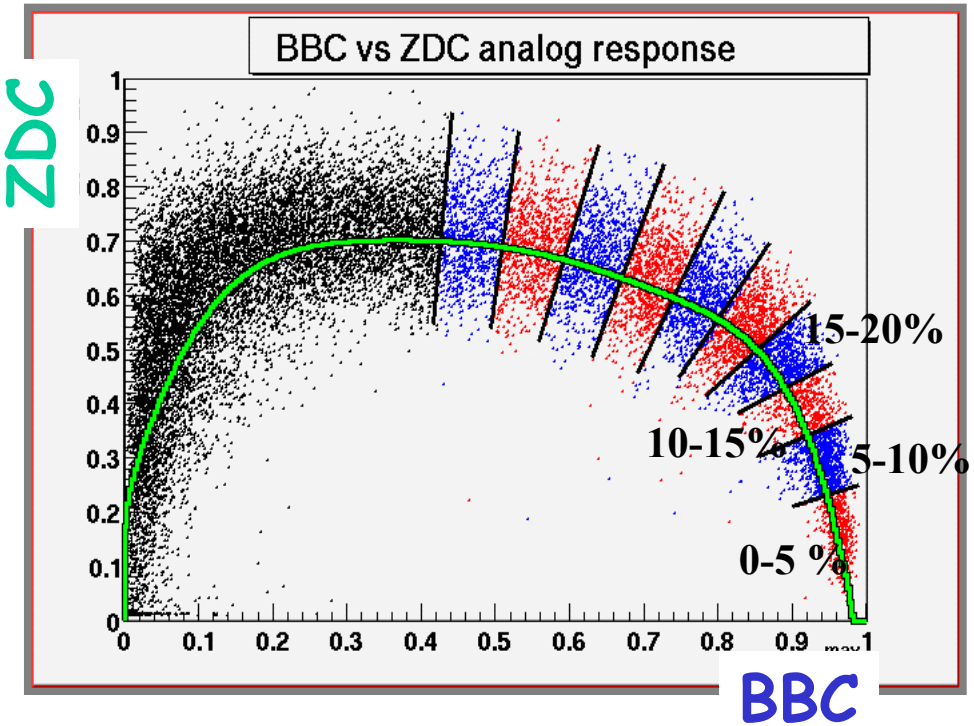
- $|\eta| < 0.35$
- $\Delta\phi = 45°$
- **Minimum bias**
  ~ 92% of σ_{GEOM} = 7.2b



Nucl-exp 0104015
submitted to Phys. Rev. Lett.

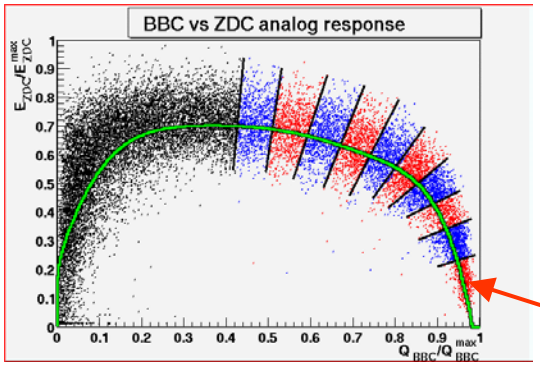
Measuring Centrality

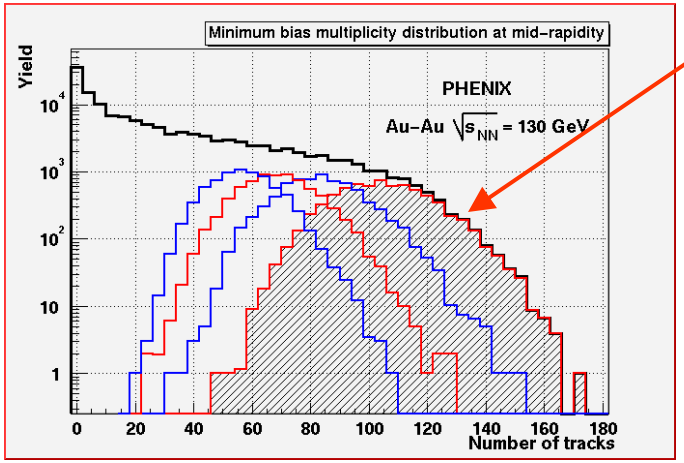




- **Zero Degree Calorimeters (ZDC) are sensitive to spectator neutrons**
- **Using a combination of the ZDC's and BBC's we can define Centrality Classes**

From Centrality to N_{binary} Collisions and $N_{participants}$





Use Glauber modeling to extract $N_{participants}$ and N_{binary} Collisions

Centrality	Collisions	Participants
0-5%	945 ± 15%	347 ± 15%
5-15%	673 ± 15%	271 ± 15%
15-30%	383 ± 15%	178 ± 15%
30-60%	123 ± 15%	76 ± 15%
60-80%	19 ± 60%	19 ± 60%
80-92%	3.7 ± 60%	5 ± 60%

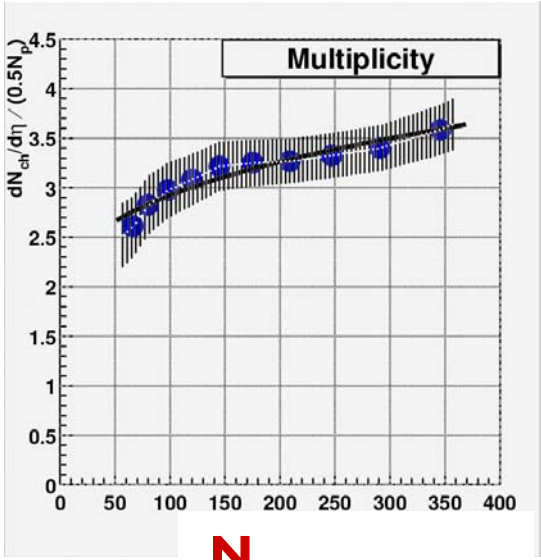
Multiplicity and Transverse Energy vs $N_{participants}$

- **Excellent consistency between two analyses**
- **Yields grow significantly faster than Nparticipants**
- **Evidence for term ~ Ncollisions**

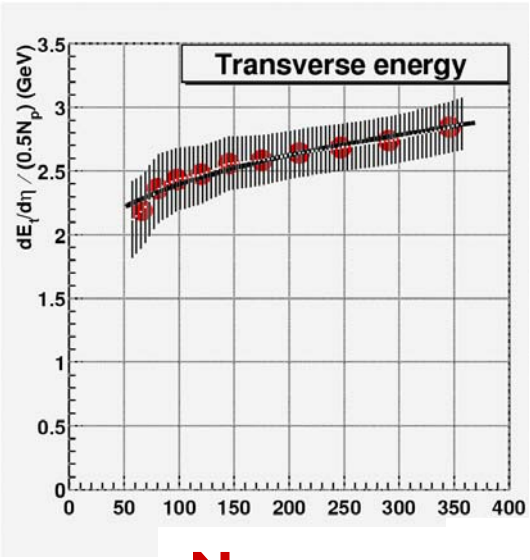
$$dX/d\eta\big|_{\eta=0} = A \times N_{part} + B \times N_{coll}$$

X	A	B
Multiplicity	**0.88 ± 0.28**	**0.34 ∓ 0.12**
Transverse Energy	**0.80 ± 0.24**	**0.23 ∓ 0.09**

- Qualitatively consistent with HIJING
- Inconsistent with some saturation models



$N_{participants}$



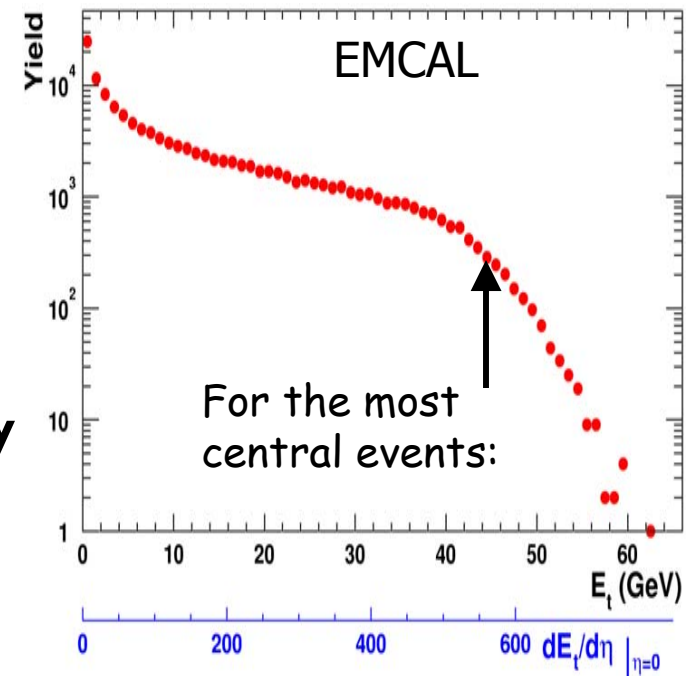
$N_{participants}$

Determining Energy Density

Transverse Energy for 2% most central events:

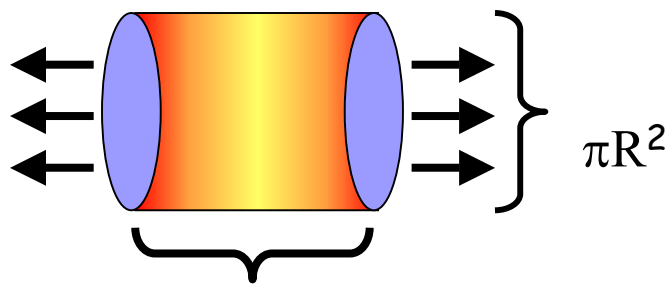
SPS $dE_T/d\eta\big|_{\eta=0} = 405 \;\; GeV$

RHIC $dE_T/d\eta\big|_{\eta=0} = 578 \;\; GeV \pm {}^{26}_{39}$



Bjorken formula for thermalized energy density

$$\varepsilon_{Bj} = \frac{1}{\pi R^2}\frac{1}{\tau_0}\frac{dE_T}{dy}$$

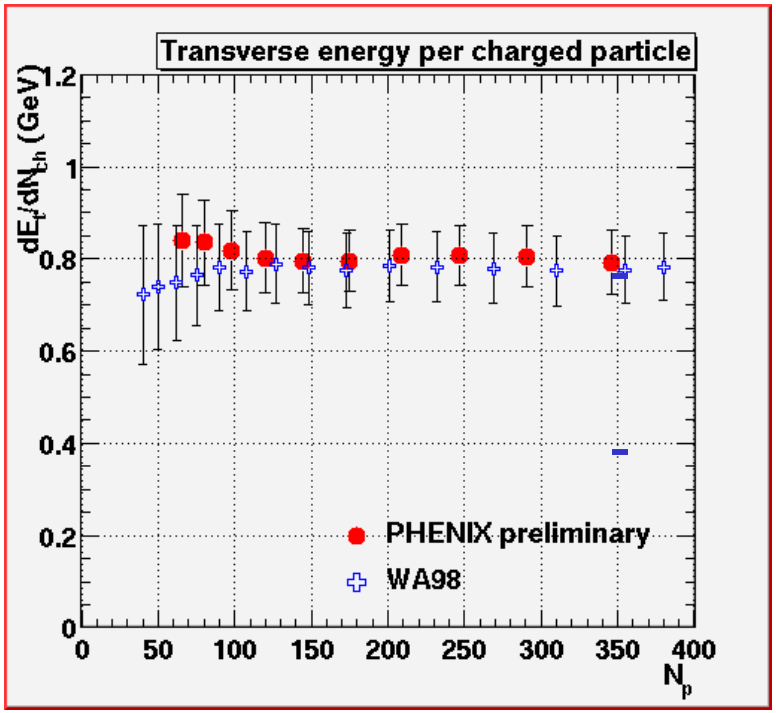


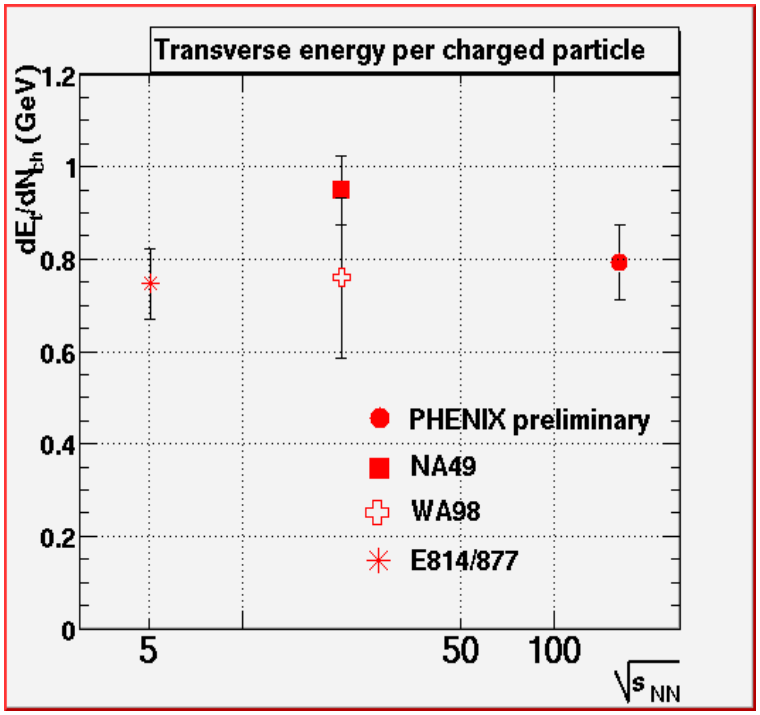
$$dz = \tau_0 dy$$

Assume same τ_0, ~ same R then:

~70% greater energy density than at CERN SPS → $\varepsilon_{Bjorken}$ ~ 5.0 GeV/fm^3

ET per charged particle





Independent of N_{part}

Independent of $\sqrt{s_{NN}}$

→ Additional energy density at RHIC is achieved with increased particle production

Elliptic Flow

Determine via a correlation function method

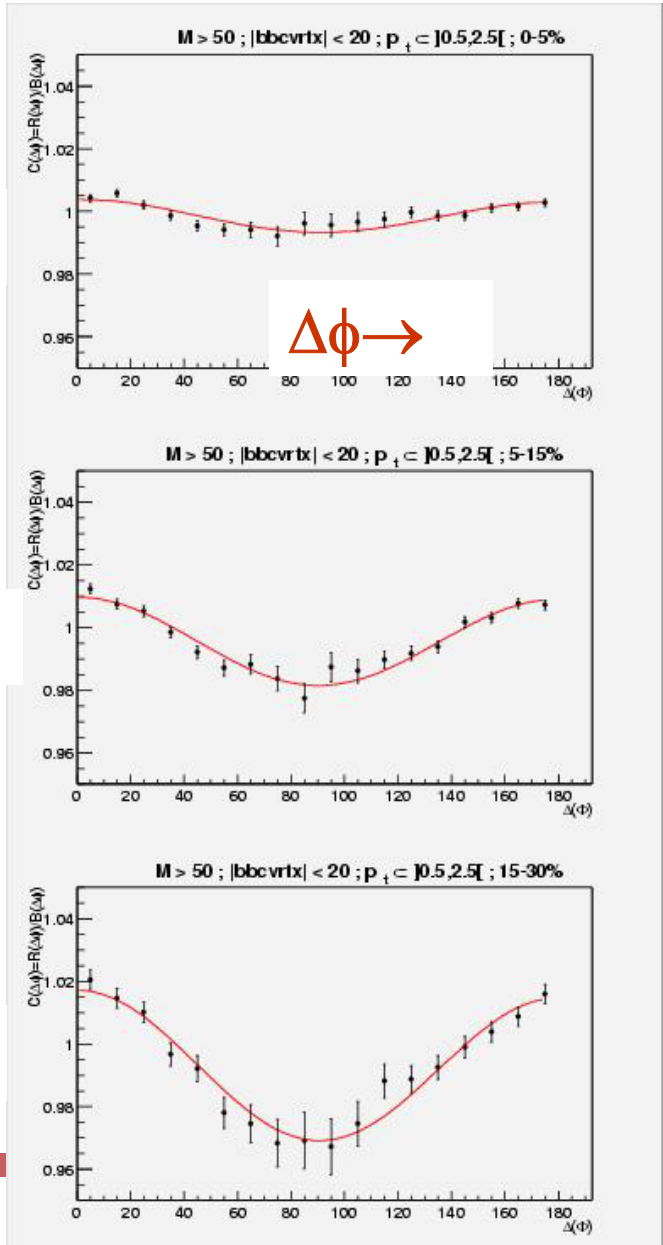
$$C(\Delta\phi) = \frac{R(\Delta\phi)}{B(\Delta\phi)}$$

- **Study versus**
  - **Centrality**
  - **p_T (next slide)**

0-5%

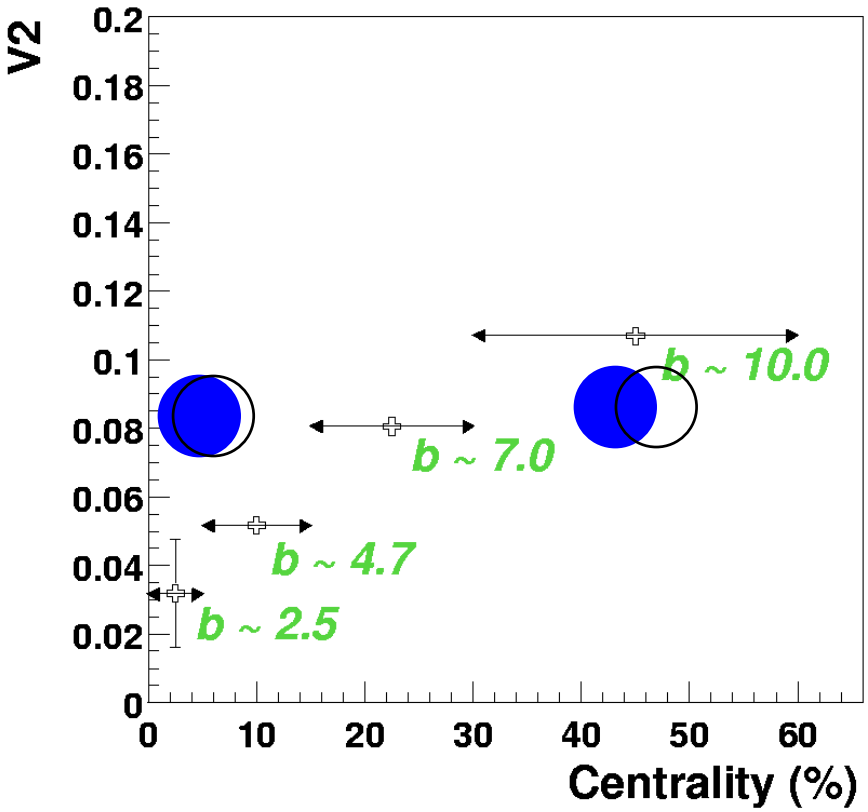
5-15%

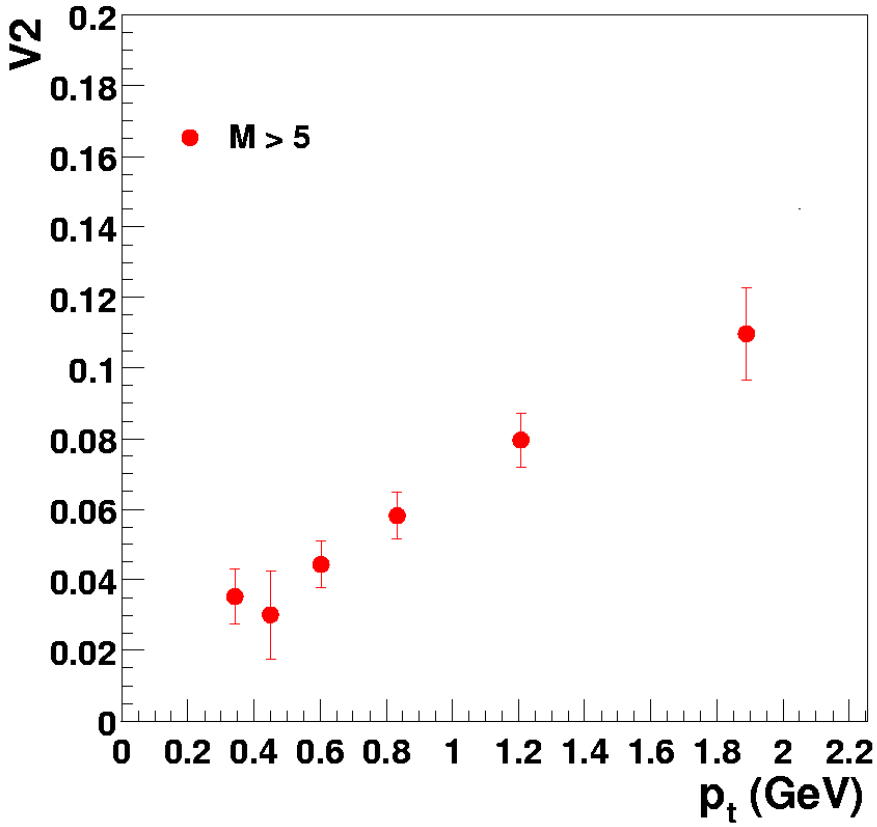
15-30%



Elliptic Flow

- **Extract v_2's from $C(\Delta\phi)$**
- **Qualitative trends consistent with STAR results**





Global Summary

Systematic study versus Nparticipants

- Evidence for role of Ncollision term
- Energy density at least ~ 1.7 x value at CERN SPS
- Observation of significant elliptic flow indicating the system is interacting

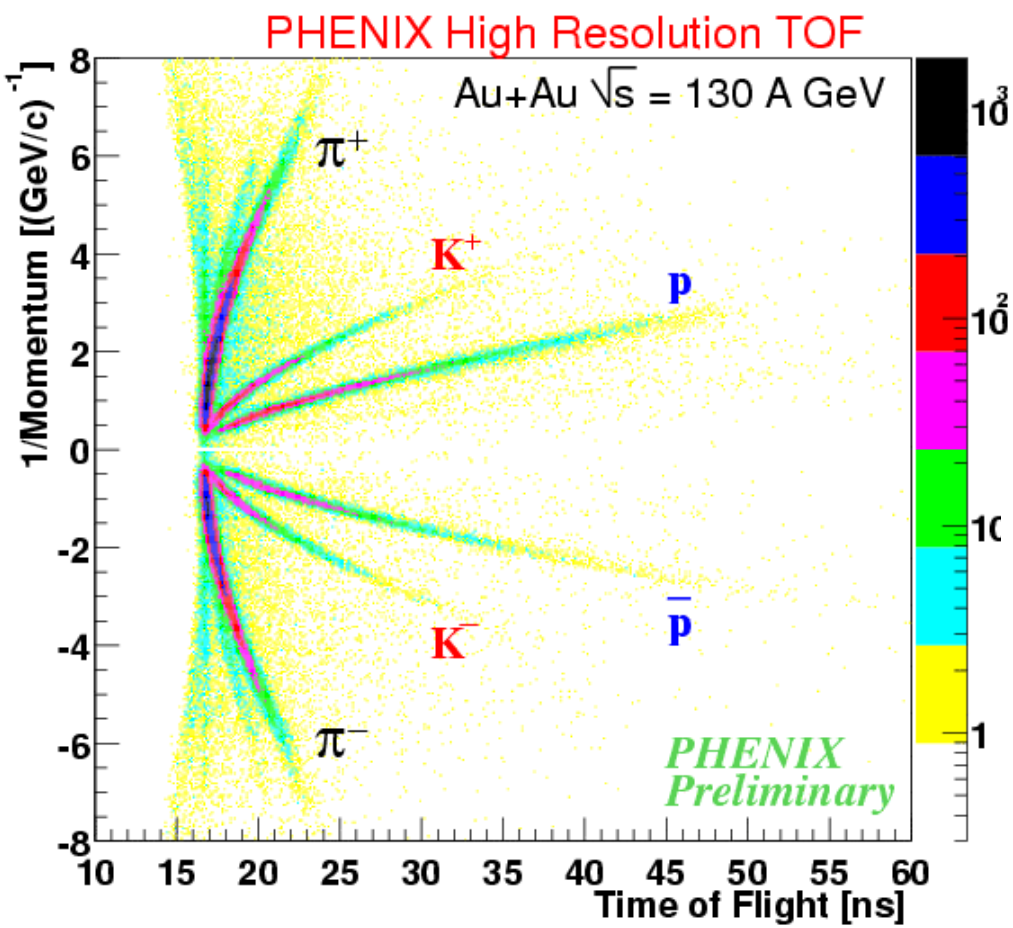
J12.007, "PHENIX particle multiplicity compared to the predictions from various event generator models", Indrani Ojha

Q12.009, "Net Charge Fluctuations at Mid-rapidity in Au+Au Collisions at sqrt s_nn = 130 GeV", Henrik Tydesjo

Q12.011, "Event-by-event fluctuations in the mean transverse momentum of charged particles produced in Au+Au Collisions in the PHENIX Experiment at RHIC", Jeffery T. Mitchell

Q12.013, "Wavelet Analysis In Search Of Disoriented Chiral Condensate in Au + Au Collisions at sqrt s = 130 A GeV in the PHENIX Experiment at RHIC", Tarun kanti Ghosh

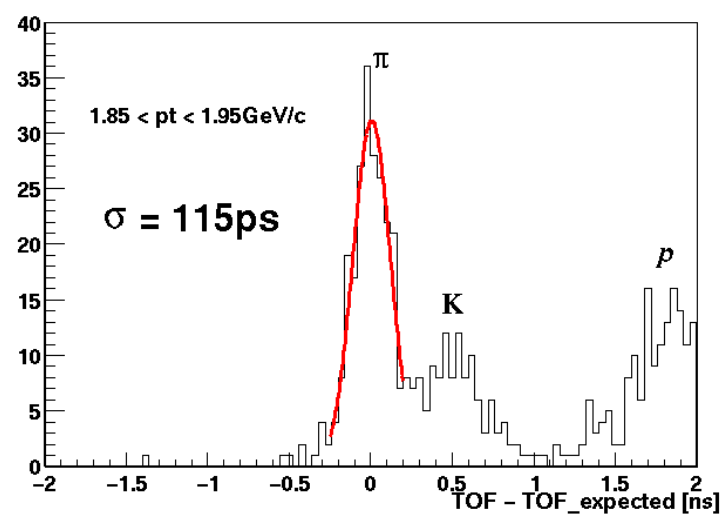
Hadron Identification



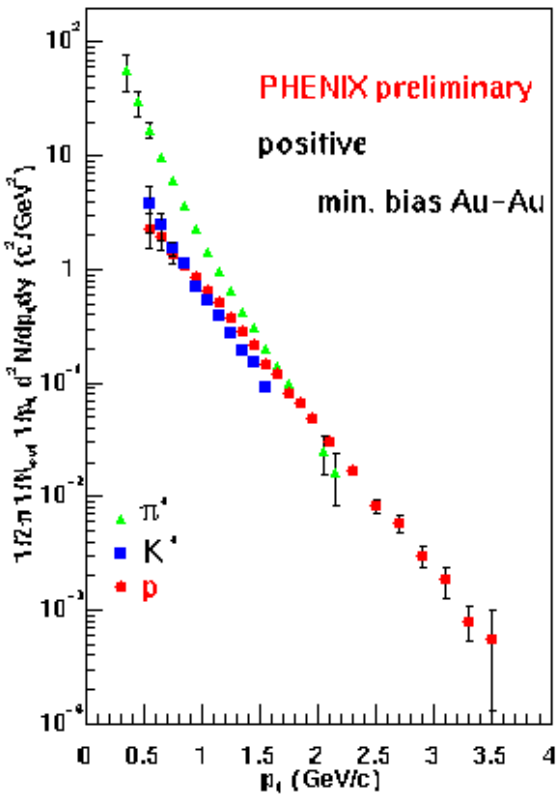
Combined

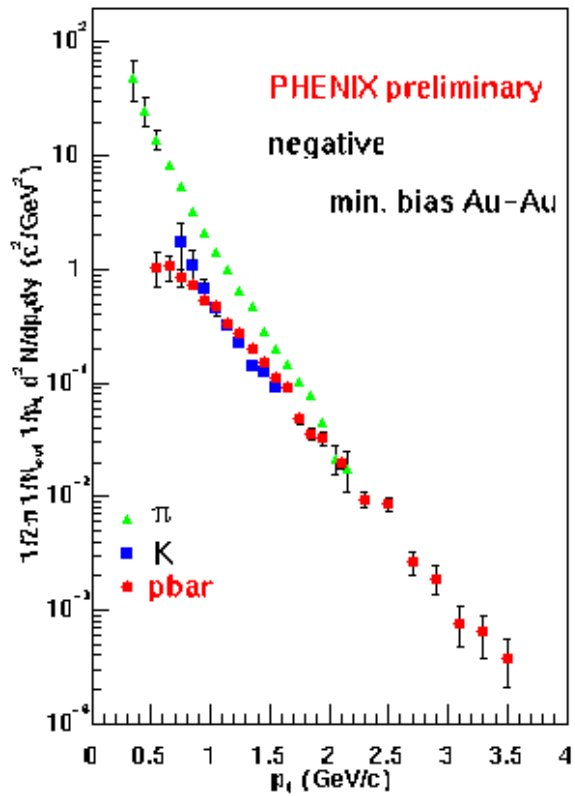
- **Tracking**
- **Beam-Beam Counter**
- **Time-of-Flight array**

provides excellent hadron identification over broad momentum band:

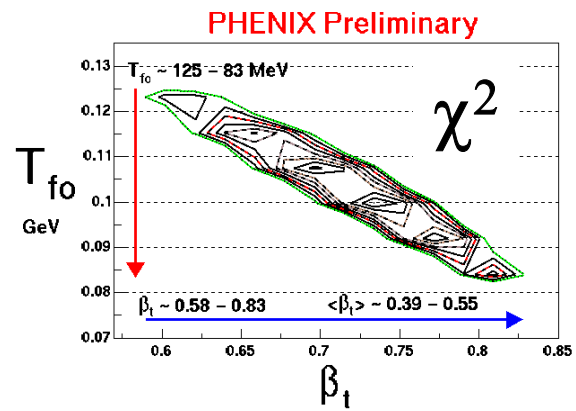


Identified Particle Spectra





Fit π, K, p spectra to obtain expansion velocity and freeze-out temperature.



β_T : 0.6- 0.8

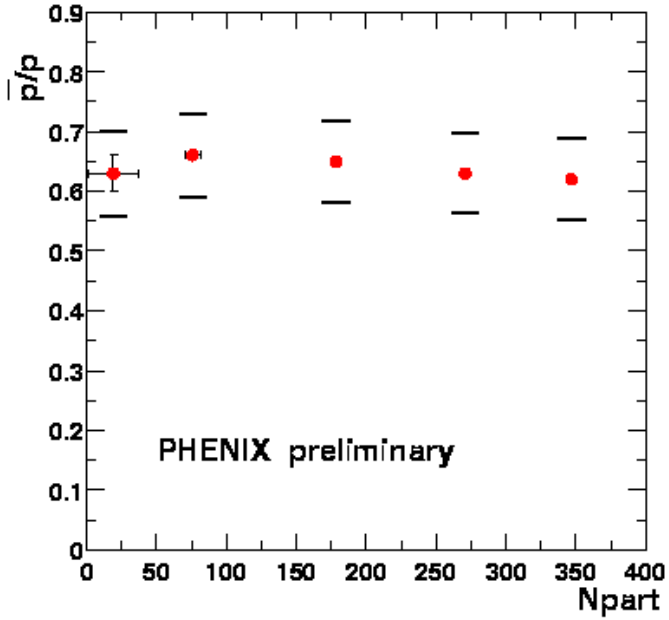
$<\beta_T>$: 0.4 - 0.6

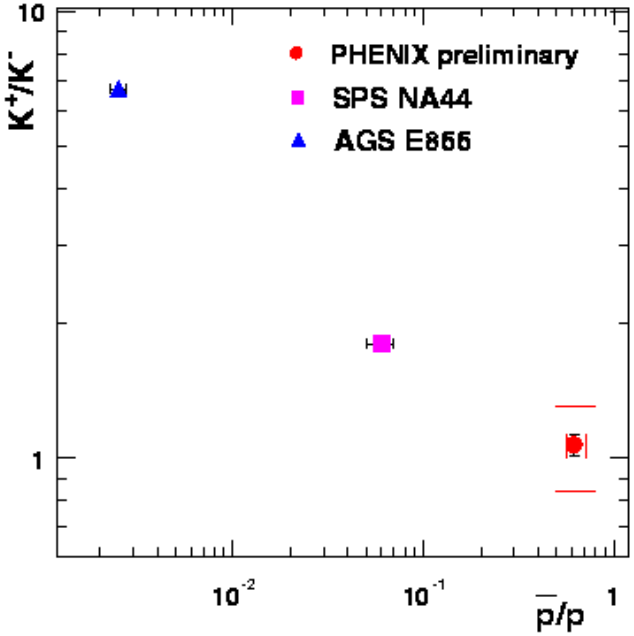
T_{fo}: 125-83 MeV

Hadron yields

Anti-proton/proton studied over broad p_T range

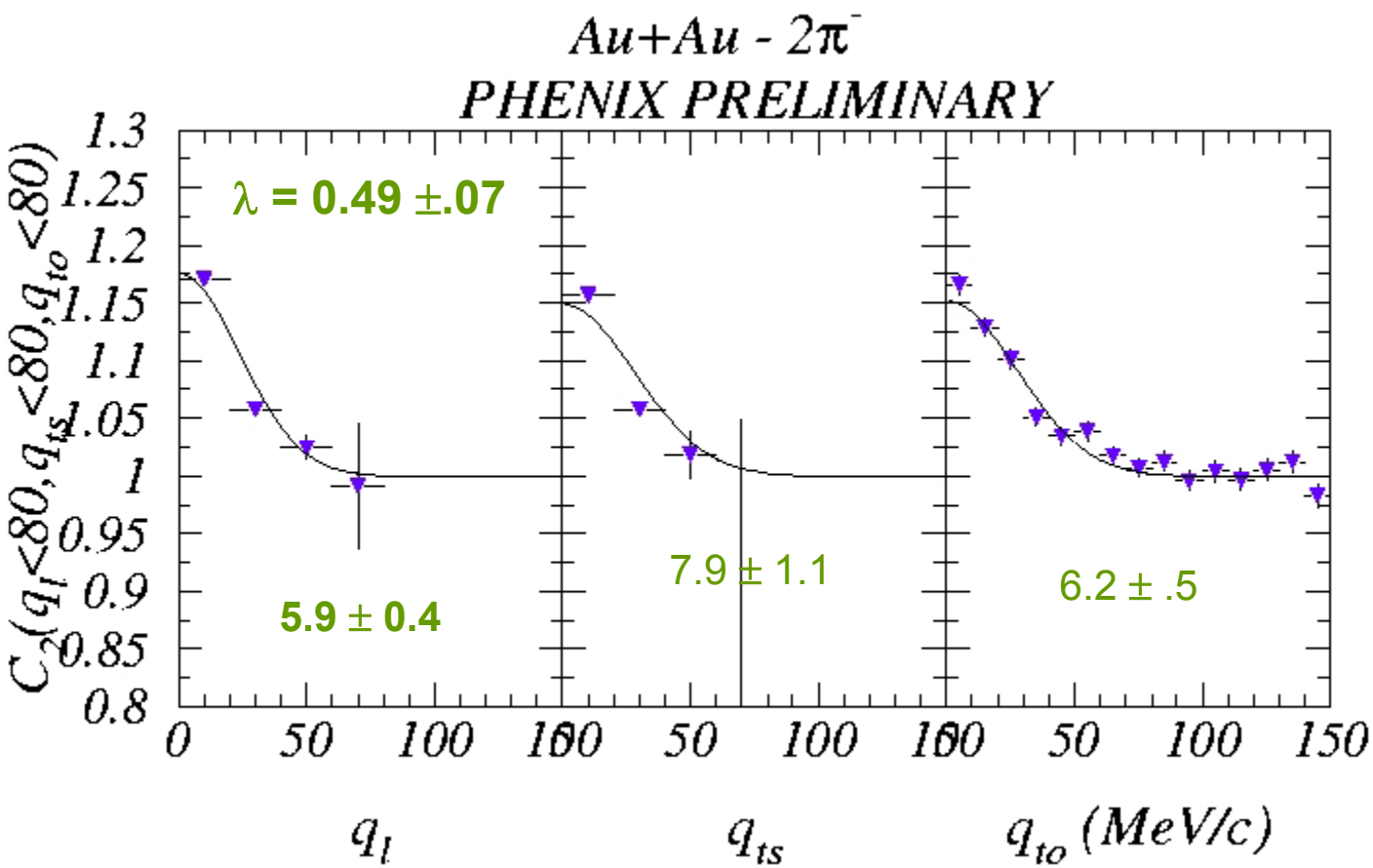
- Weak centrality dependence
- Similar data available for K^+/K^-, $\pi^+\pi^-$
- Dramatic increase of $\bar{p}/p$ as a function of collision energy





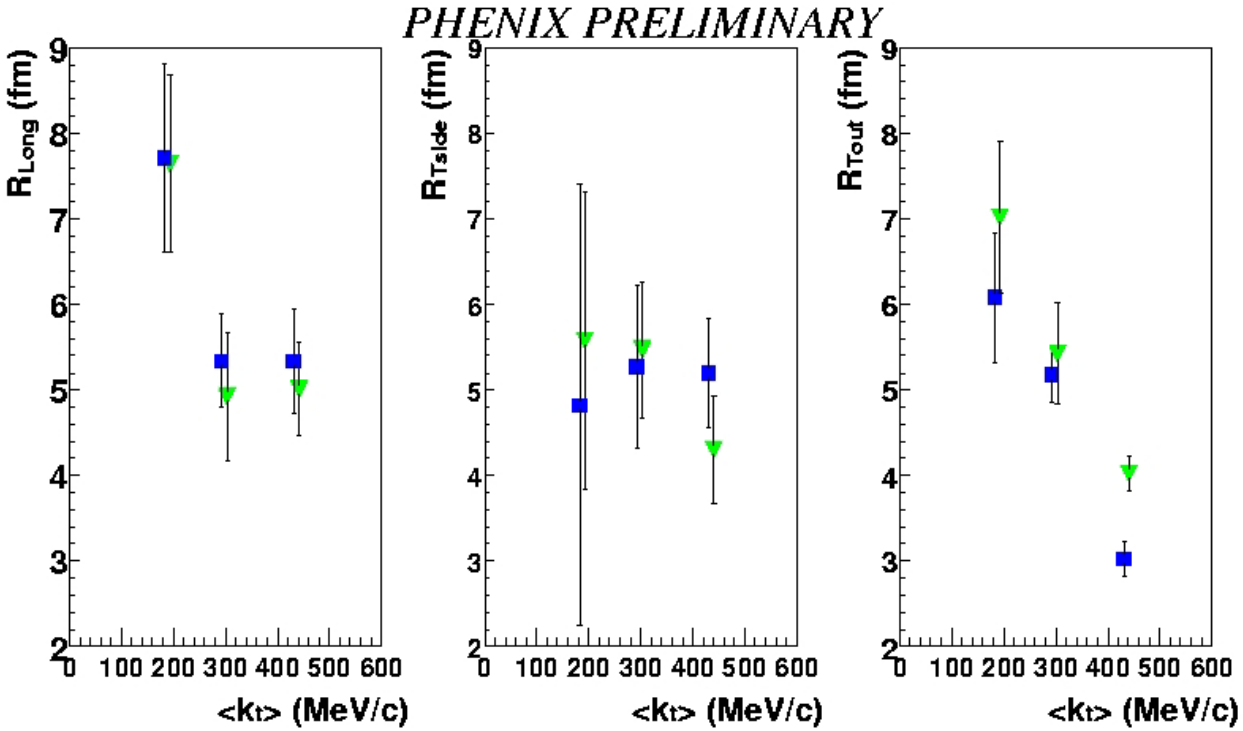
HBT

- Full Coulomb correction
- No evidence of large sources



HBT k_T Dependence

- Mild, if any, R_{long} dependence on k_T
- Strong R_{out} dependence on k_T



Identified Charged Hadron Summary

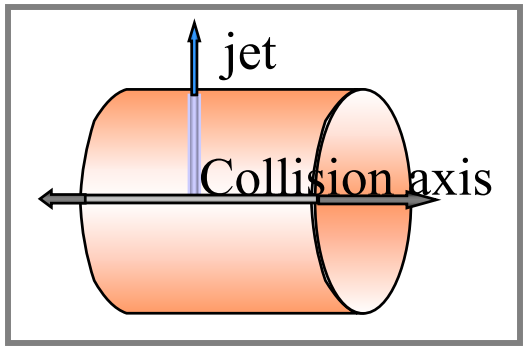
- **Clean π/K/p identification over broad momentum range**

- **Systematic study of spectra**
  - Measured radial flow parameters $\beta_t \sim 0.6 - 0.8$
  - Anti-proton/proton ratio ~ constant with Nparticipants
  - Anti-proton/proton, K+/K- consistent with much lower net baryon density than previous results at lower energy
  - For the first time in heavy ion collisions, more baryons are pair-produced than brought in from initial state

- **2-pion HBT parameters obtained**
  - not large source sizes

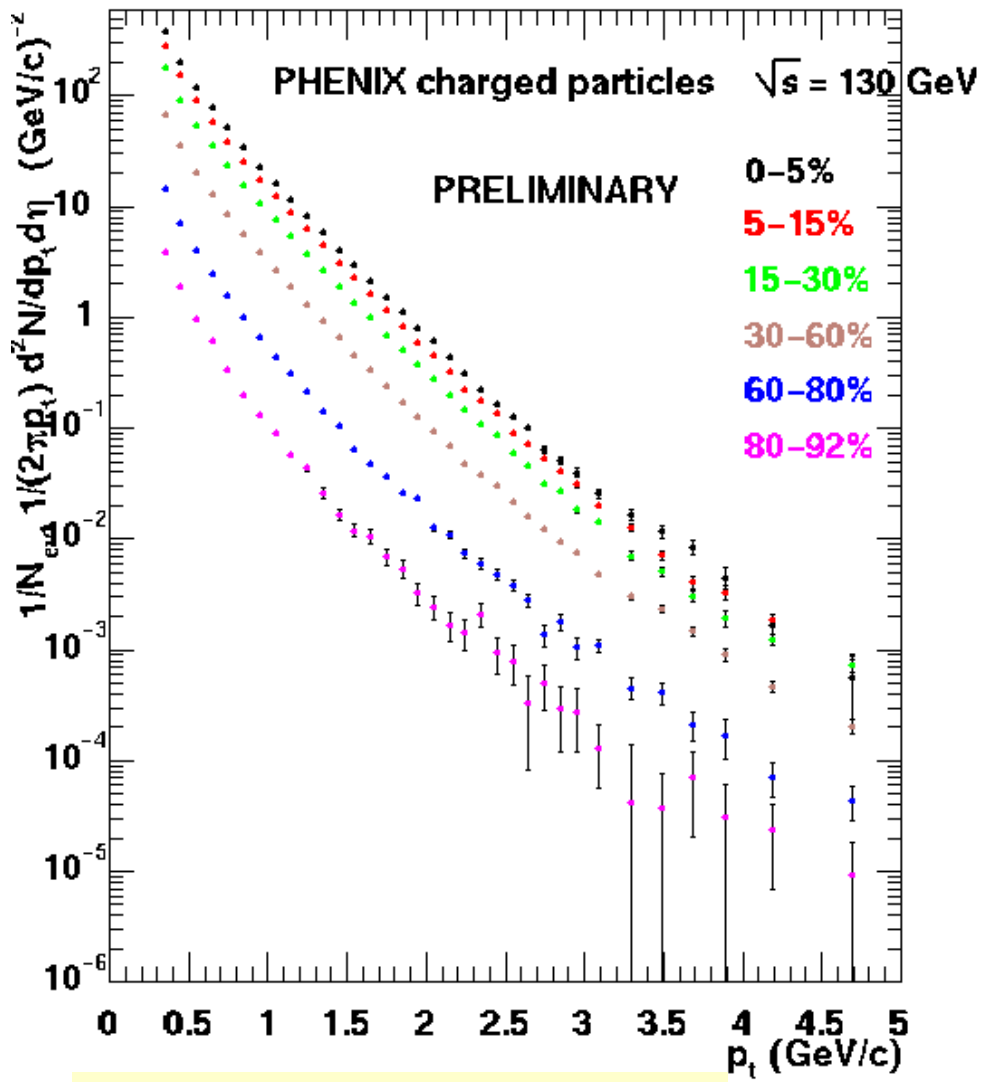
J12.006, "Radial Flow", Jane Burward-Hoy

Charged p_T Spectra



- Partons are expected to lose energy via gluon radiation while traversing a quark gluon plasma
- Hadrons with Pt > 1 GeV are expected to be from jet fragmentation

➡ **Study systematic trends in high p_T production with charged particles**

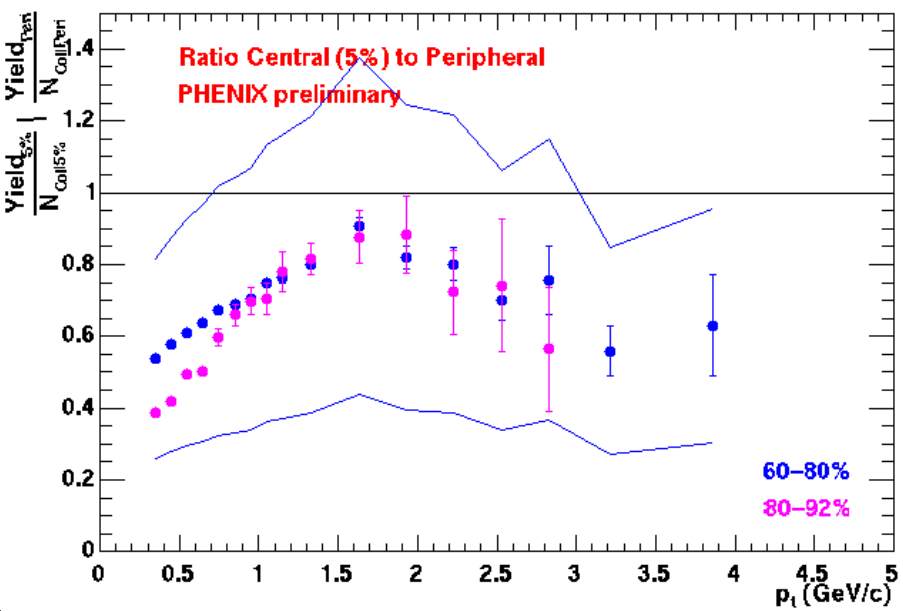


Data span 1-5 GeV

Central vs. Peripheral Yields

- **Can study relative yields within the data set:**
  - Compare central to peripheral spectra vs. p_T
  - Scale by the average number of collisions

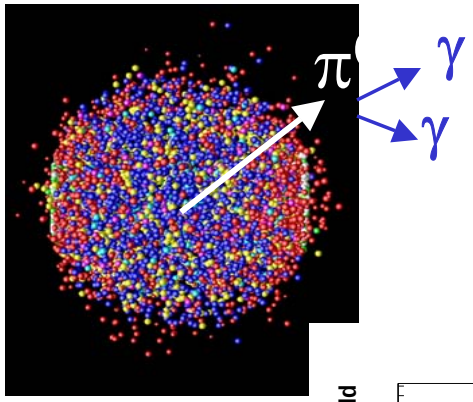
Blue Lines represent estimates for systematic error on N Collisions

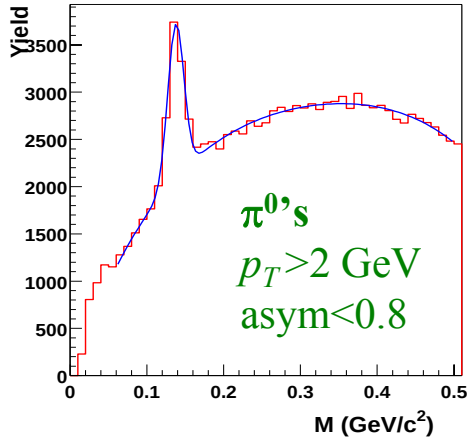


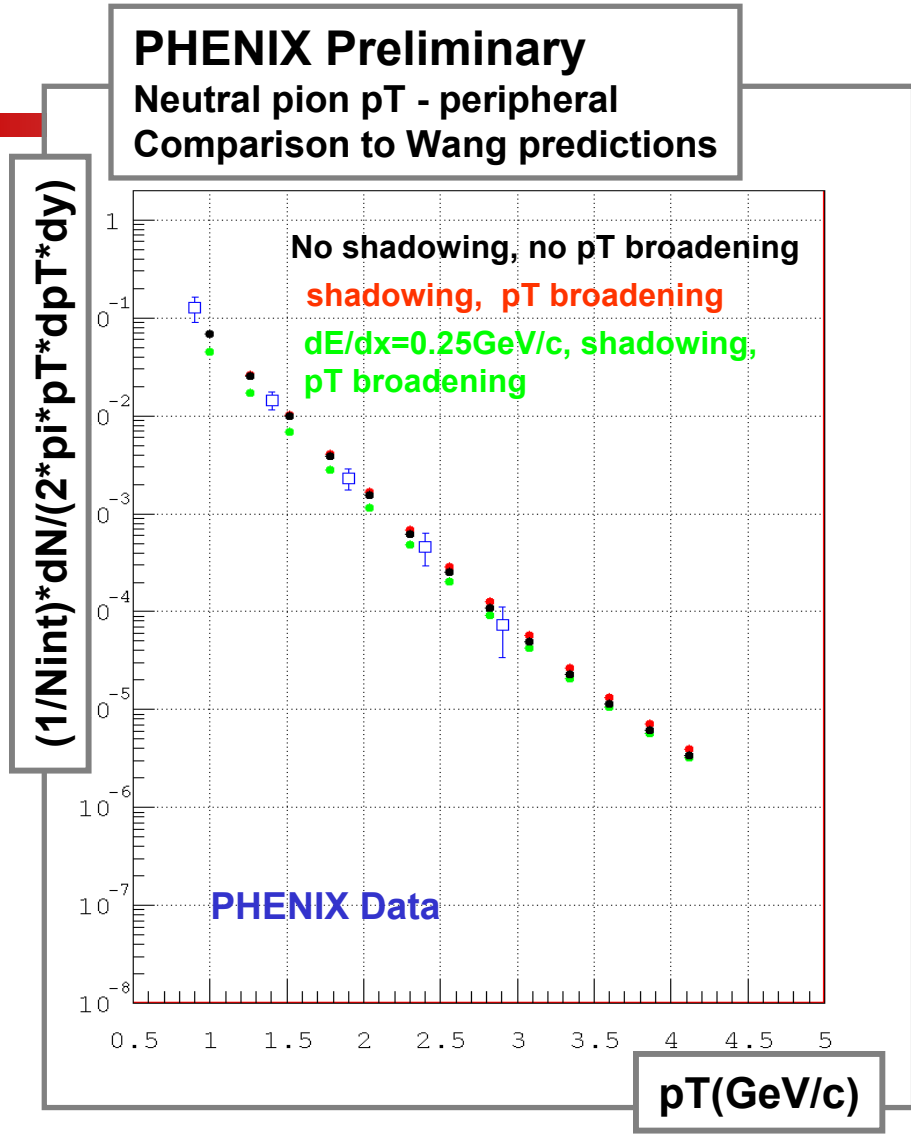
$$\text{Ratio} = \frac{\text{Yield(Central)} / \langle N_{COLL}(\text{Central})}{\text{Yield(Peripheral)} / \langle N_{COLL}(\text{Peripheral})\rangle}$$

- Ratio unity if yields scale as number of collisions
- Ratio found to be less than 1, decreasing for $p_T > 2$ GeV/c

π^0 Spectra







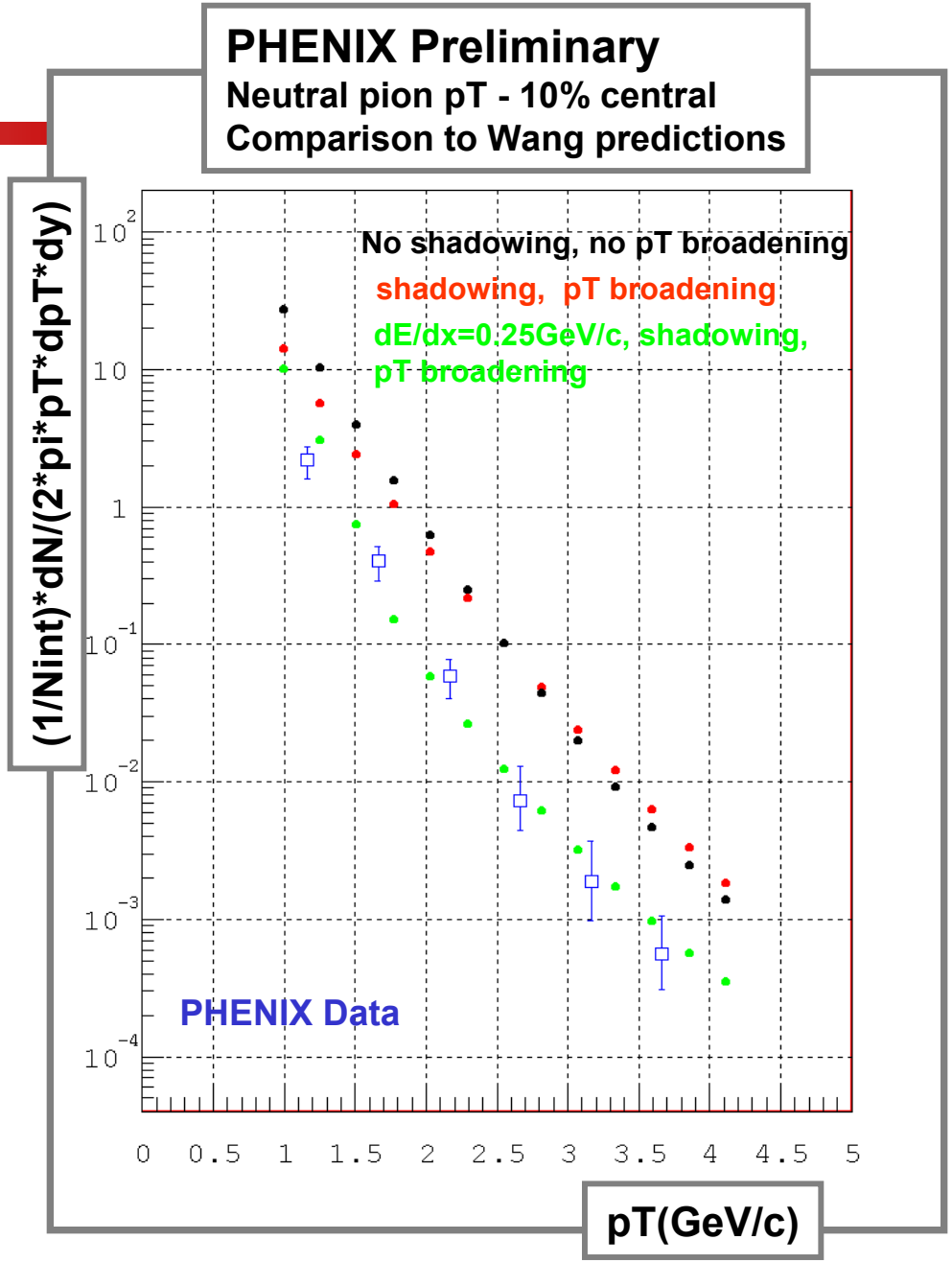
- **Yields of π^0's have been extracted for peripheral data set**
  - Data span 1-4 GeV/c
  - Well-described by X.N. Wang "no quenching" predictions

π^0 Spectra - Central

Inconsistent with scenarios without dE/dx loss

Not inconsistent with energy loss

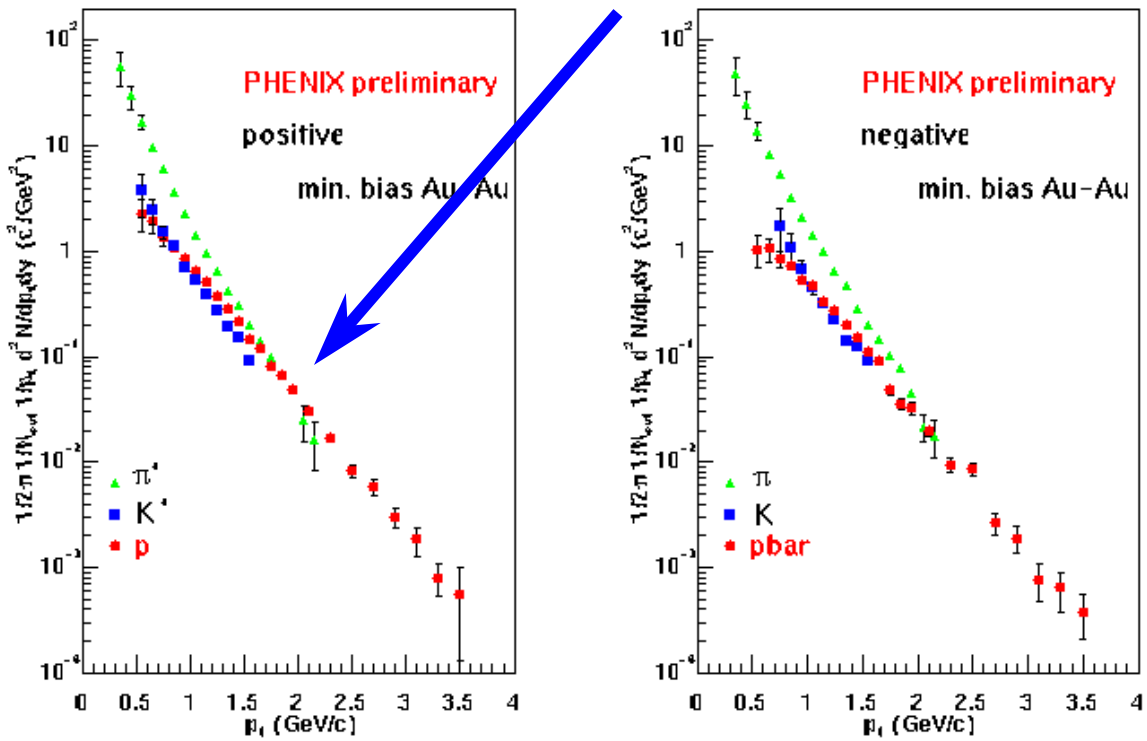
<dE/dx>=0.25 GeV/fm



Composition at high p_T

Possible complication in comparisons of neutral and charged yields:

Particle composition is observed to be a strong function of p_T



Neutral and Charged Particle Spectra Summary

Systematic study of p_T spectra for

- Charged particles
- π^0''s

versus centrality show

- Charged particles show hint of deficit, at 1σ level, in central-peripheral collisions comparison
- π^0''s show good agreement for peripheral collisions with predictions from hard scattering
- π^0''s show deficit in more central collisions in comparison with models without energy loss

J12.010, "Measurement of Neutral Pion Correlations with the PHENIX Electromagnetic Calorimeter", Mike Heffner

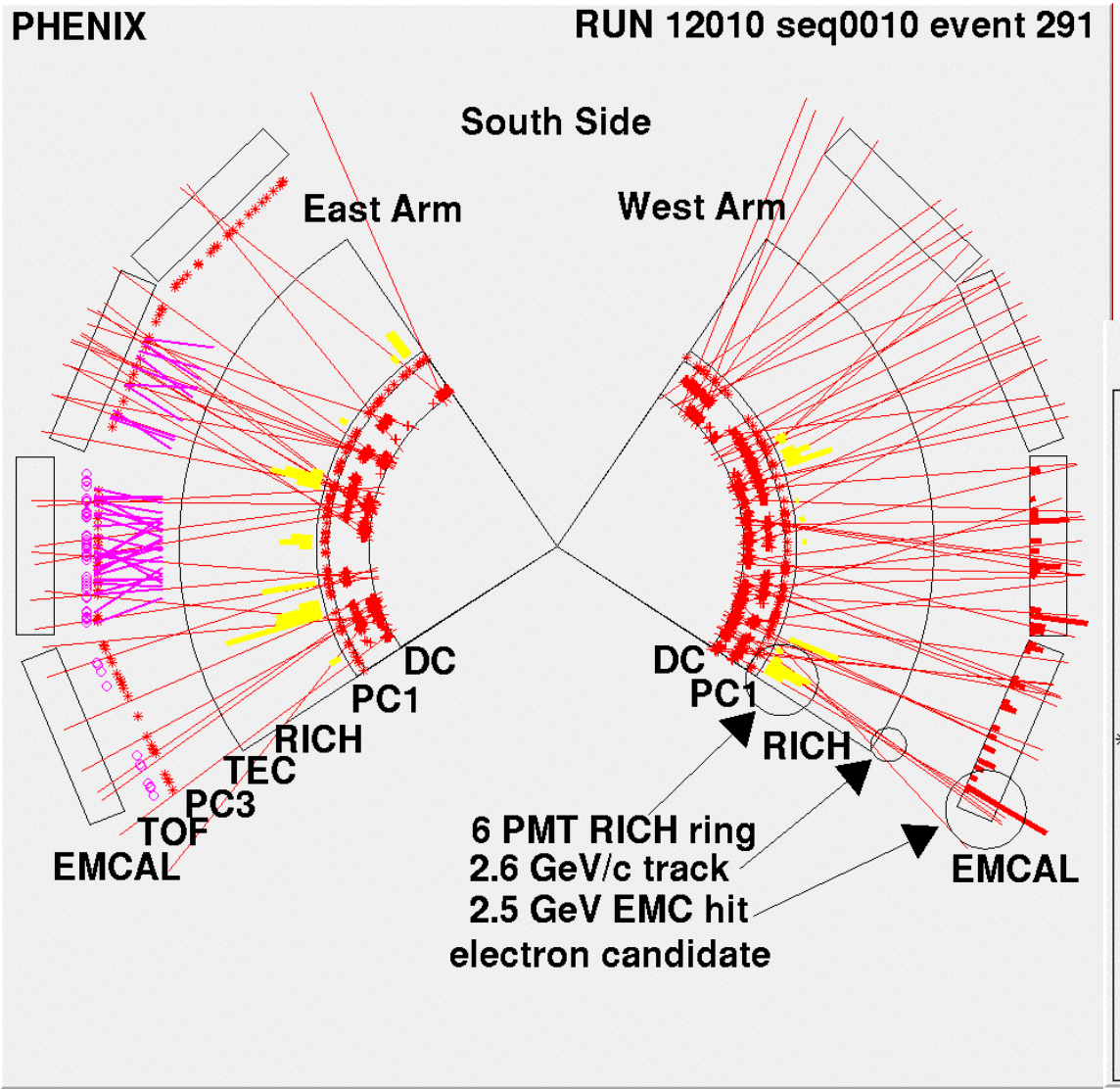
Q12.004, "spectra of high momentum charged particles", Jiangyong Jia

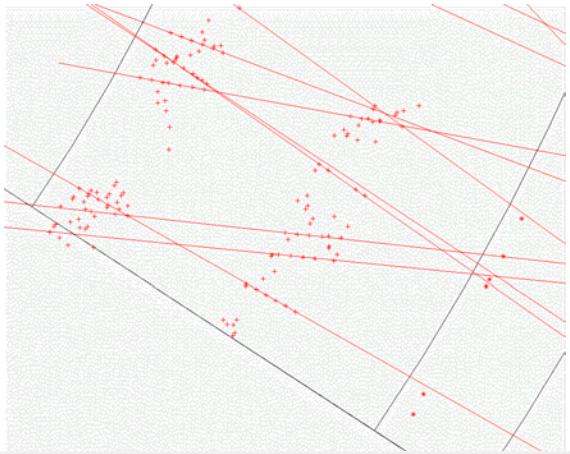
Q12.005, "Angular Correlations at High-pt", Craig Ogilvie

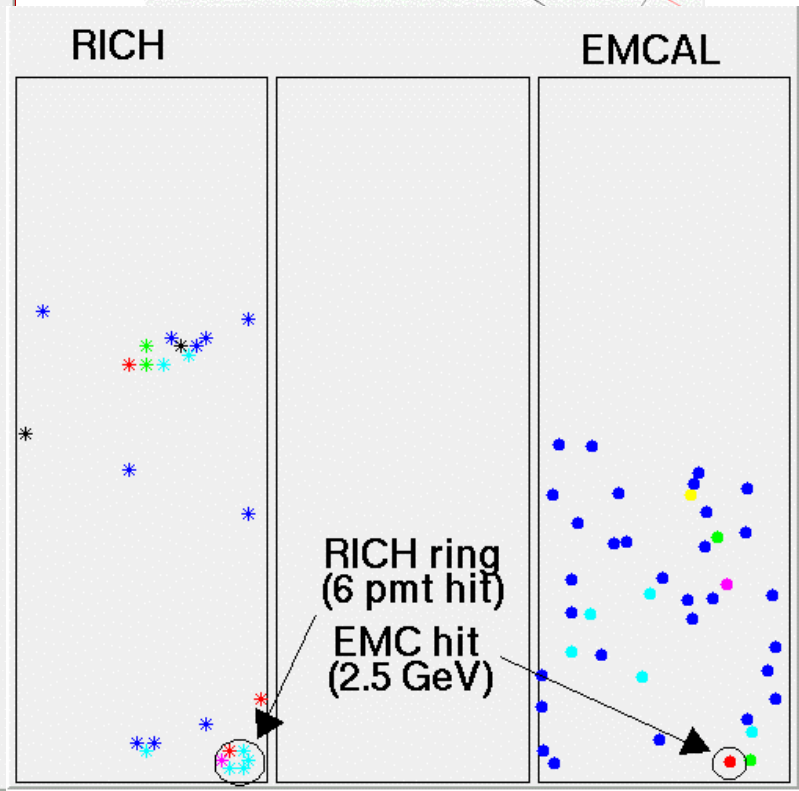
Q12.006, " Back to Back Photon Correlations in PHENIX", Mickey Chiu

All sub-systems in concert: electrons in PHENIX

➔ **Clean results using full array of PHENIX tracking, PID and calorimetry**

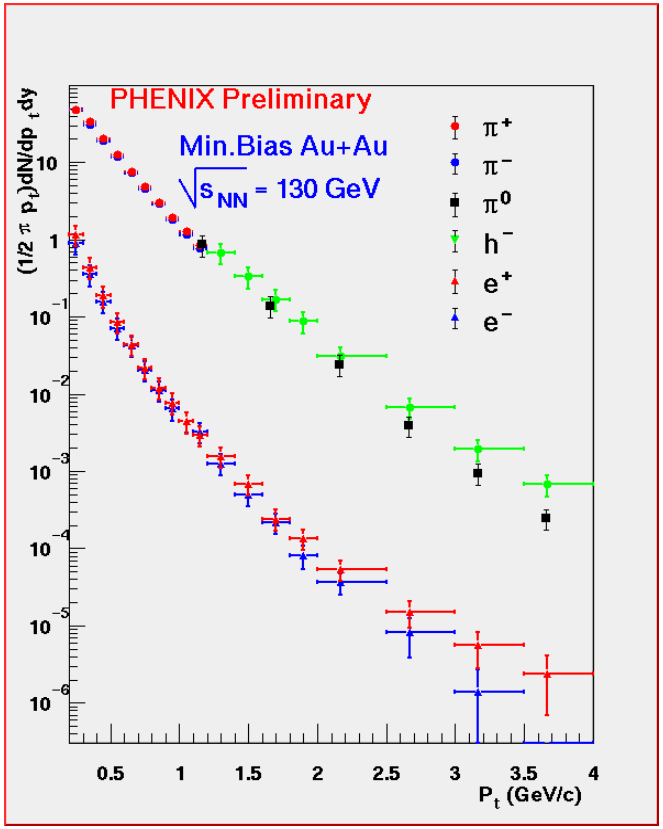




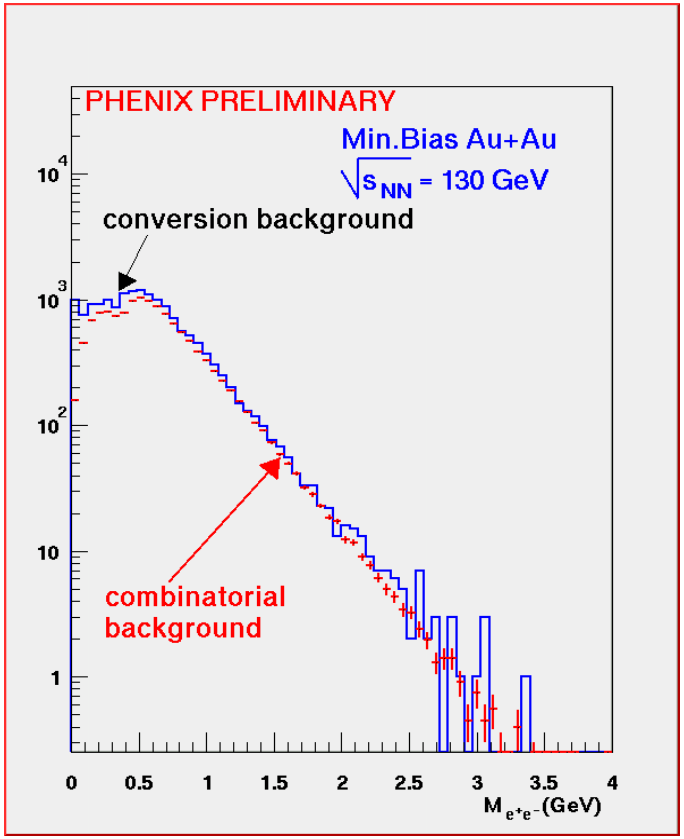


Electron Spectra

- **Ultimate goal is to Understanding physics signals:**
  - Semi-leptonic D and B decays
  - Direct photon (conversions)
  - M(e+e-) spectrum



p_t spectra



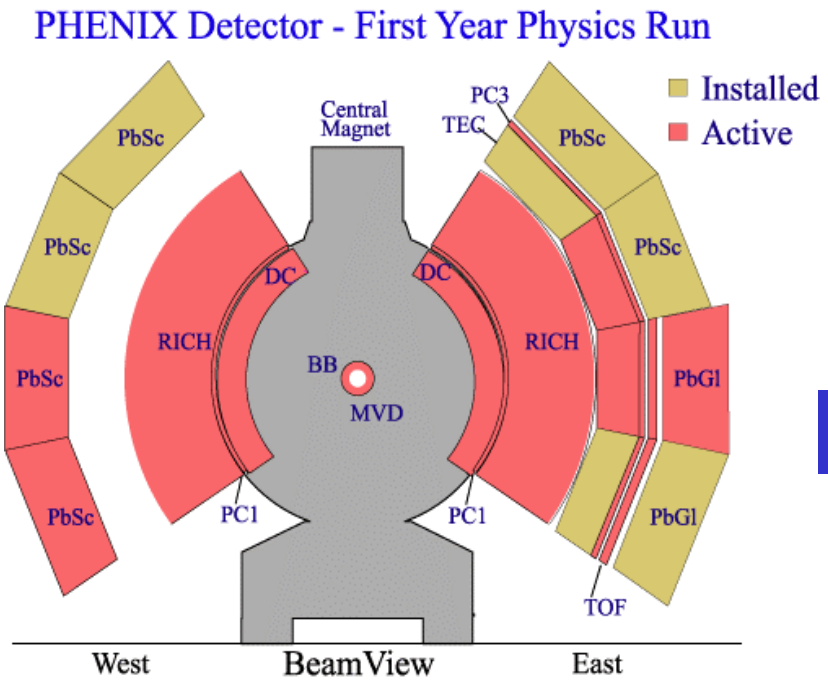
M_{e+e-} spectra

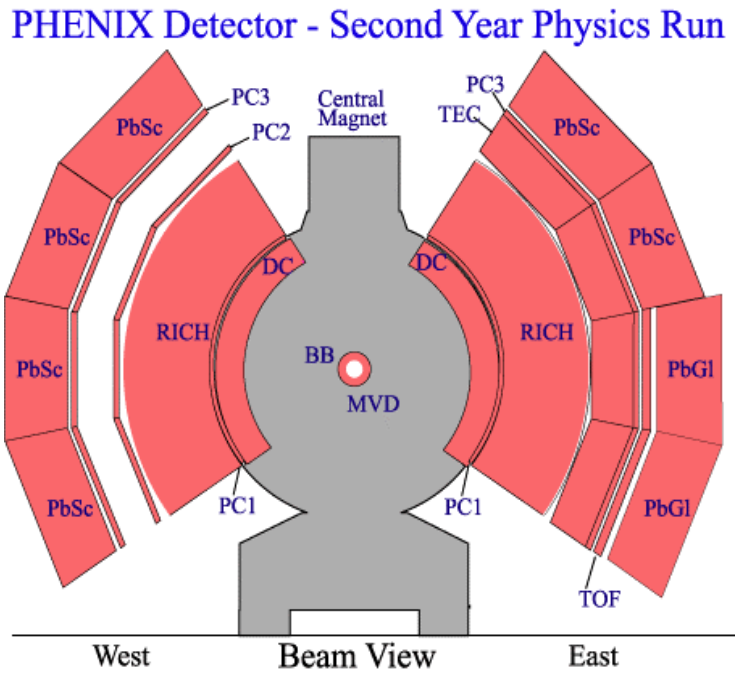
J12.008, "Electron Spectroscopy in Au+Au collisions at sqrt s =130A GeV with PHENIX", Ralf Averbeck

Near-future Outlook (I) - Run 2

Completion of Central Arms

➔ Significantly increased aperture

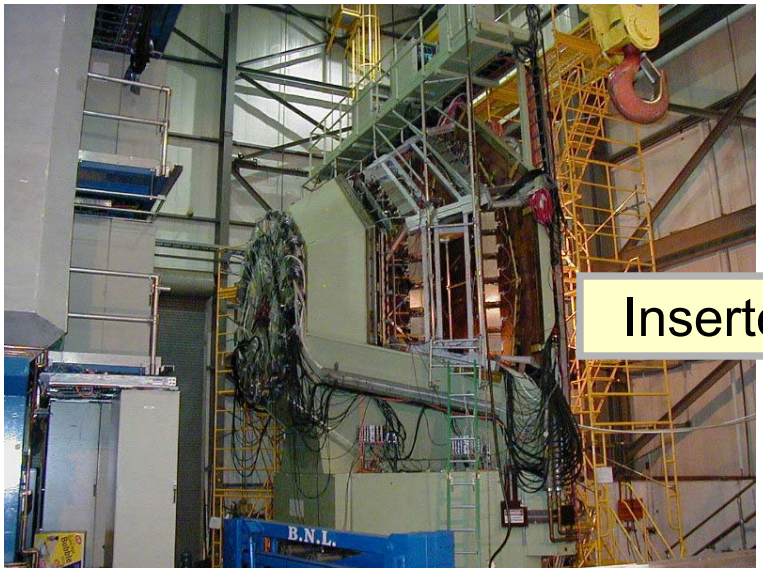




Near-future Outlook (II)

Addition of new capabilities

South Muon Arm ➔ Di-muon physics



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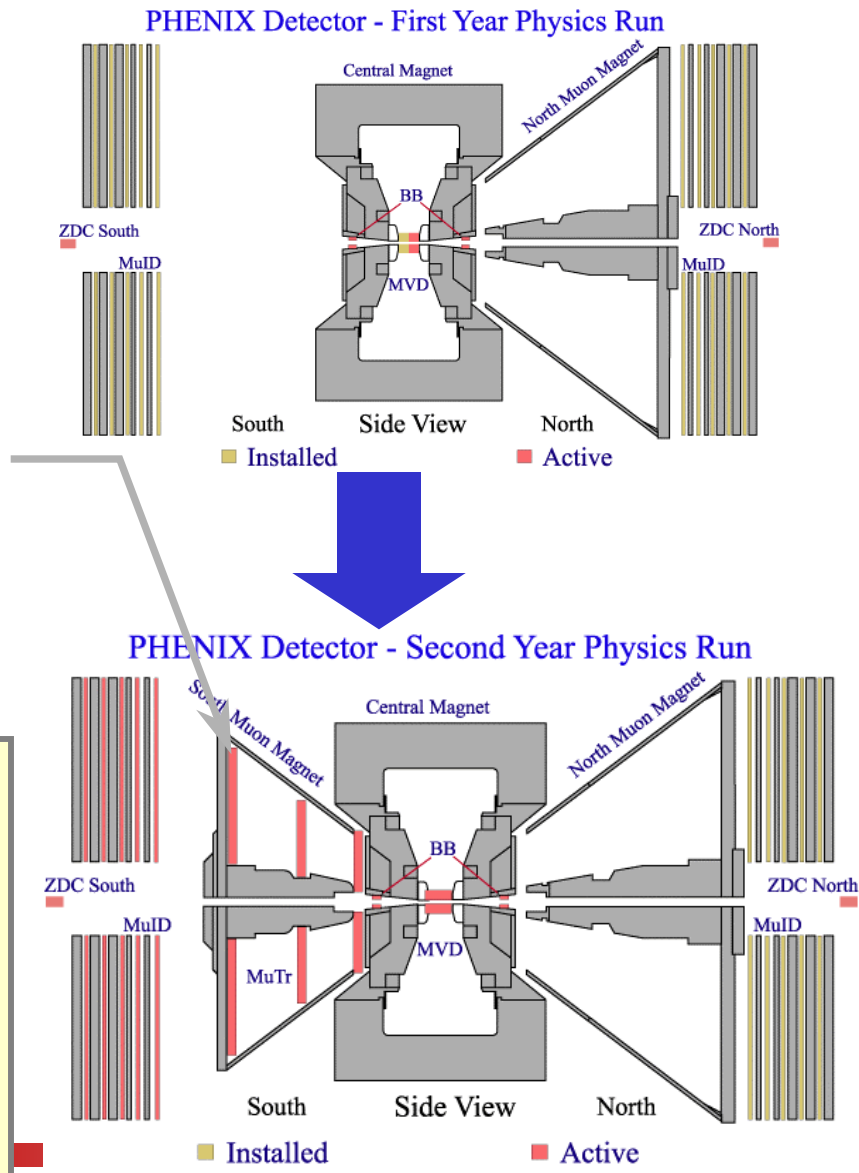


V10.003, "Status and Expectations of the Muon Tracking System of PHENIX", Rusty Towell

V10.004, "Muon Reconstruction and Particle Identification", Yajun Mao

V10.005, "Front-End Electronics in the Muon Tracking System of the PHENIX Experiment", Ming X. Liu

V10.006, "Readiness of the PHENIX Muon Identifier for Au+Au and Polarized p+p Collisions at RHIC", Hiroki Sato

V10.007, "The PHENIX Muon Identifier Front End Electronics", Andrew Glenn

V10.008, "The PHENIX Muon Arm Triggers", Jason Newby

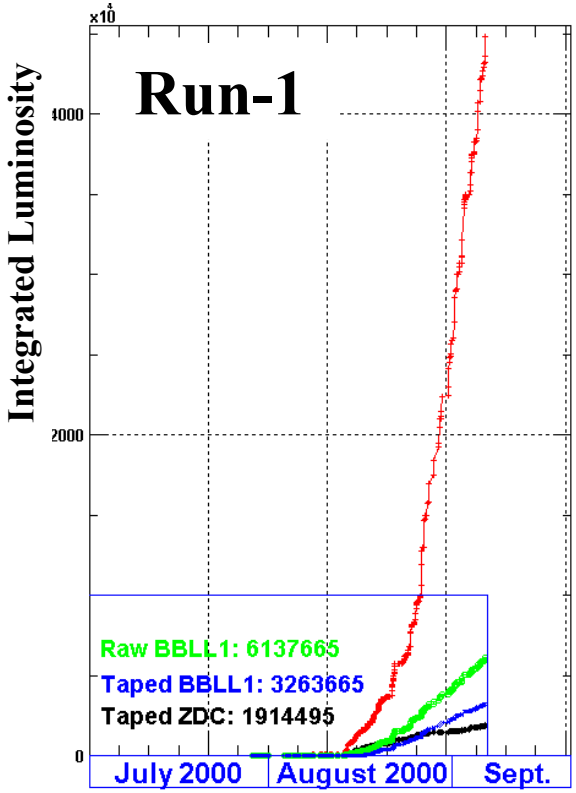
Near-future Outlook (III)

Upgraded

- Triggers
- Data Acquisition

V10.002, "The PHENIX Event Builder", Sean Kelly

The ~5M events recorded in Run-1 represent ~1 day of data-taking for RHIC+PHENIX in Run-2



Much more data in the upcoming run

➔ STAY TUNED!

Summary

PHENIX detector has provided outstanding data in first year of RHIC operations

- Measured
  - Charged multiplicity
  - Transverse energy
  - Elliptic flow
  - Identified particle spectra
  - HBT parameters
  - High p_T spectra
  - Inclusive electron spectrum …….
- Observed
  - Role of hard scattering
  - Intriguing systematics in high p_T particle yield

Ideally positioned to dramatically extend these results in the upcoming run using AA and pp Collisions!

TALK SLIDES END HERE

PHENIX TALKS at April APS Meeting

- J12.006 "Radial Flow", Jane Burward-Hoy
- J12.007 "PHENIX particle multiplicity compared to the predictions from various event generator models", Indrani Ojha
- J12.008, "Electron Spectroscopy in Au+Au collisions at sqrt s =130A GeV with PHENIX", Ralf Averbeck
- J12.010, "Measurement of Neutral Pion Correlations with the PHENIX Electromagnetic Calorimeter", Mike Heffner
- Q12.004, "spectra of high momentum charged particles", Jiangyong Jia
- Q12.005, "Angular Correlations at High-pt", Craig Ogilvie
- Q12.006, " Back to Back Photon Correlations in PHENIX", Mickey Chiu
- Q12.009, "Net Charge Fluctuations at Mid-rapidity in Au+Au Collisions at sqrt s_nn = 130 GeV", Henrik Tydesjo
- Q12.011, "Event-by-event fluctuations in the mean transverse momentum of charged particles produced in Au+Au Collisions in the PHENIX Experiment at RHIC", Jeffery T. Mitchell
- Q12.013, "Wavelet Analysis In Search Of Disoriented Chiral Condensate in Au + Au Collisions at sqrt s = 130 A GeV in the PHENIX Experiment at RHIC", Tarun kanti Ghosh
- V10.002, "The PHENIX Event Builder", Sean Kelly
- V10.003, "Status and Expectations of the Muon Tracking System of PHENIX", Rusty Towell
- V10.004, "Muon Reconstruction and Particle Identification", Yajun Mao
- V10.005, "Front-End Electronics in the Muon Tracking System of the PHENIX Experiment", Ming X. Liu
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- V10.007, "The PHENIX Muon Identifier Front End Electronics", Andrew Glenn
- V10.008, "The PHENIX Muon Arm Triggers", Jason Newby
- V10.009, "Studies on a Vertex Spectrometer for the PHENIX Experiment at RHIC", Johann M. Heuser