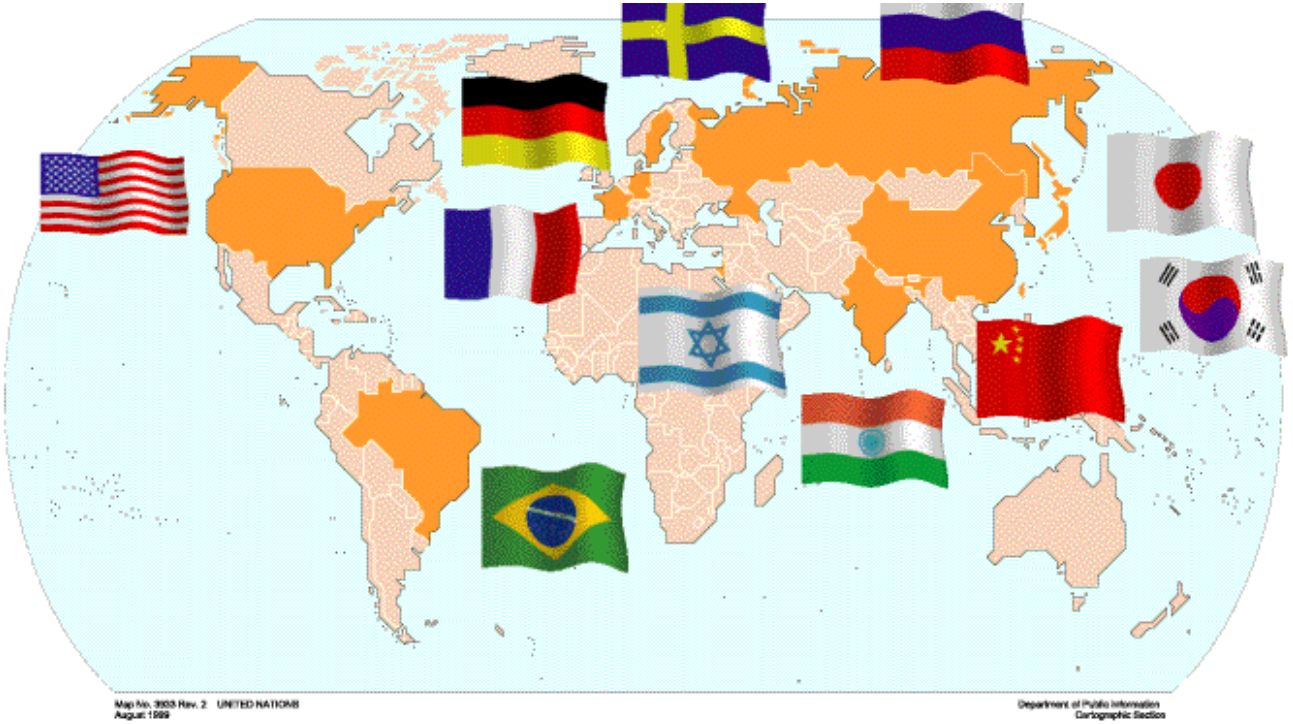
PHENIX OVERVIEW

W.A. Zajc
Columbia University
for the PHENIX Collaboration

PHENIX



Jniversity of São Paulo, São Paulo, Brazil
Academia Sinica, Taipei 11529, China
China Institute of Atomic Energy (CIAE), Beijing, P. R. China
Laboratoire de Physique Corpusculaire (LPC), Universite de Clermont-Ferrand, 63170 Aubiere, Clermont-Ferrand, France
Dapnia, CEA Saclay, Bat. 703, F-91191, Gif-sur-Yvette, France
IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, BP1, F-91406, Orsay, France
LPNHE-Palaiseau, Ecole Polytechnique, CNRS-IN2P3, Route de Saclay, F-91128, Palaiseau, France
SUBATECH, Ecole des Mines at Nantes, F-44307 Nantes, France
Jniversity of Muenster, Muenster, Germany
Banaras Hindu University,Banaras, India
Bhabha Atomic Research Centre (BARC),Bombay, India
Weizmann Institute, Rehovot, Israel
Center for Nuclear Study (CNS-Tokyo), University of Tokyo, Tanashi, Tokyo 188, Japan
Hiroshima University, Higashi-Hiroshima 739, Japan
KEK, Institute for High Energy Physics,Tsukuba, Japan
Kyoto University, Kyoto, Japan
Nagasaki Institute of Applied Science, Nagasaki-shi, Nagasaki, Japan
RIKEN, Institute for Physical and Chemical Research, Hirosawa, Wako, Japan
Jniversity of Tokyo, Bunkyo-ku, Tokyo 113, Japan
Tokyo Institute of Technology, Ohokayama, Meguro, Tokyo, Japan
Jniversity of Tsukuba, Tsukuba, Japan
Waseda University, Tokyo, Japan

Cyclotron Application Laboratory, KAERI, Seoul, South Korea
Kangnung National University, Kangnung 210-702, South Korea
Korea University, Seoul, 136-701, Korea
Myong Ji University, Yongin City 449-728, Korea
System Electronics Laboratory, Seoul National University, Seoul, South Korea
Yonsei University, Seoul 120-749, KOREA
Institute of High Energy Physics (IHEP-Protvino or Serpukhov), Protovino, Rus
Joint Institute for Nuclear Research (JINR-Dubna), Dubna, Russia
Kurchatov Institute, Moscow, Russia
PNPI: St. Petersburg Nuclear Physics Institute, Gatchina, Leningrad, Russia
Lund University, Lund, Sweden
Abilene Christian University, Abilene, Texas, USA
Brookhaven National Laboratory (BNL), Upton, NY 11973
University of California - Riverside (UCR), Riverside, CA 92521, USA
Columbia University, Nevis Laboratories, Irvington, NY 10533, USA
Florida State University (FSU), Tallahassee, FL 32306, USA
Georgia State University (GSU), Atlanta, GA, 30303, USA
Iowa State University (ISU) and Ames Laboratory, Ames, IA 50011, USA
LANL: Los Alamos National Laboratory, Los Alamos, NM 87545, USA
LLNL: Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
University of New Mexico, Albuquerque, New Mexico, USA
New Mexico State University, Las Cruces, New Mexico, USA
Department of Chemistry, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA

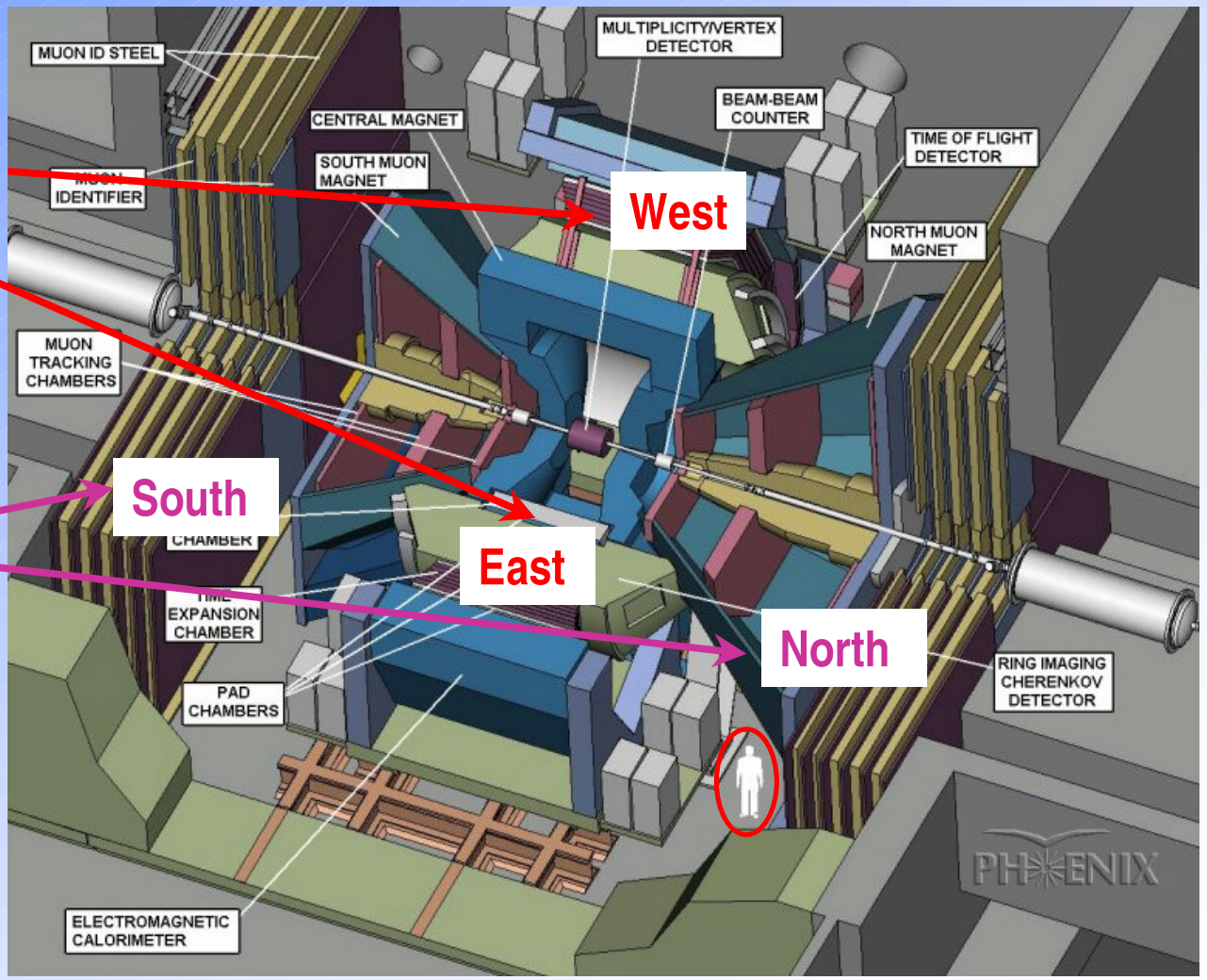
What is PHENIX?

- Pioneering High Energy Nuclear Interaction eXperiment
- Goals:
  - Broadest possible study of A-A, p-A, p-p collisions to
    - Study nuclear matter under extreme conditions
    - Using a wide variety of probes sensitive to all timescales
    - Study systematic variations with species and energy
  - Measure spin structure of the nucleon

➡ These two programs have produced a detector with unparalleled capabilities

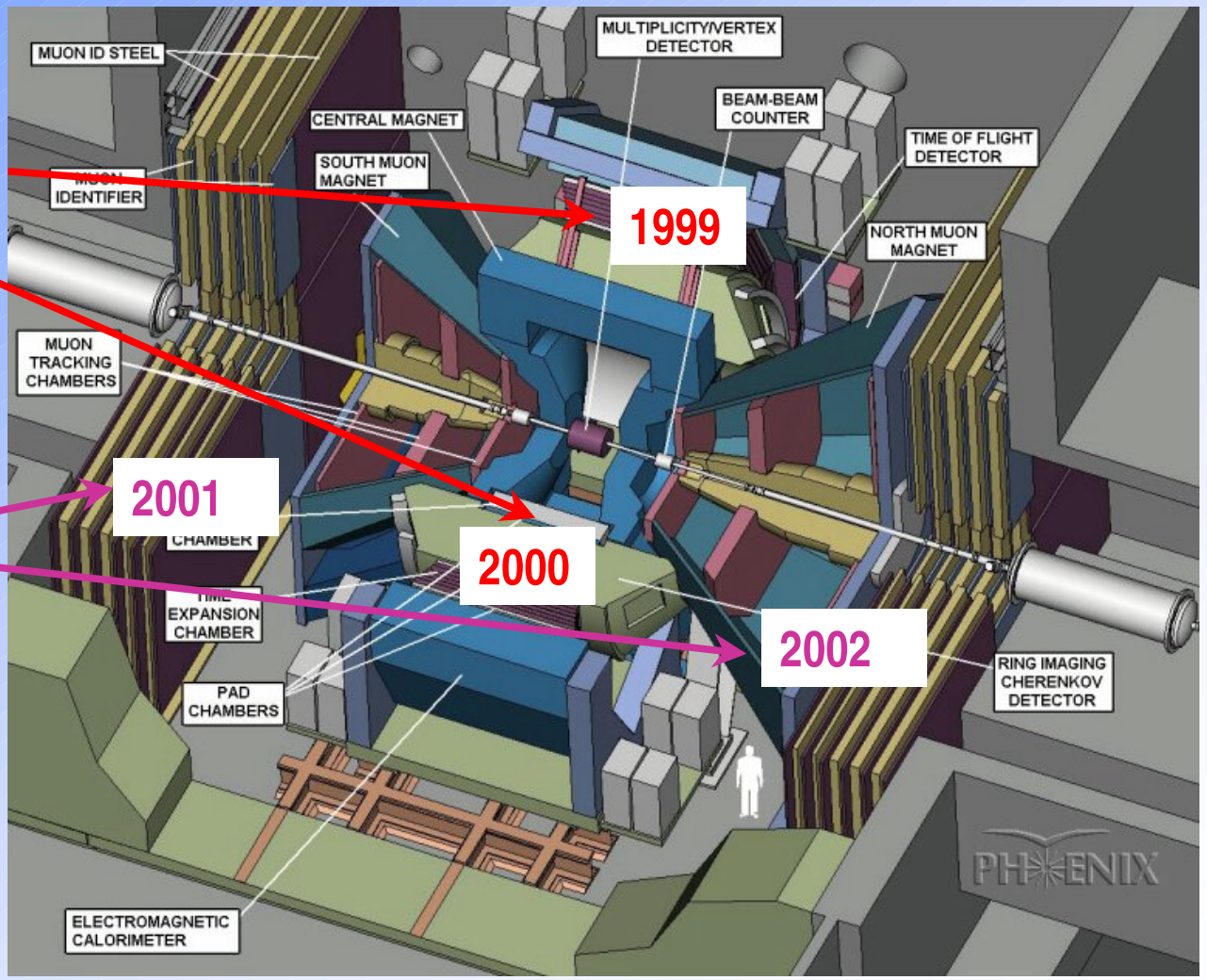
PHENIX at RHIC

- 2 central spectrometers
- 2 forward spectrometers
- 3 global detectors



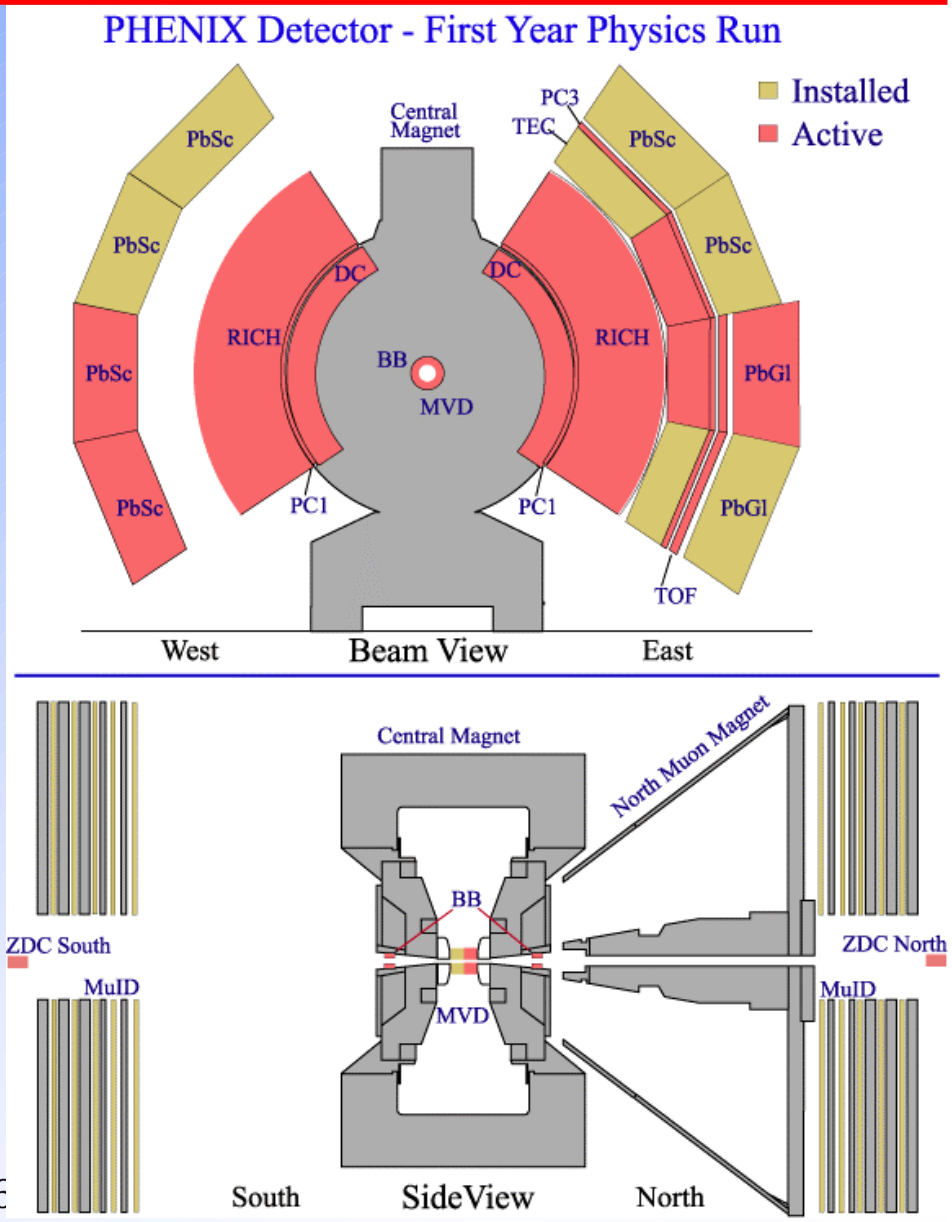
Schedule

- 2 central spectrometers
- 2 forward spectrometers
- 3 global detectors



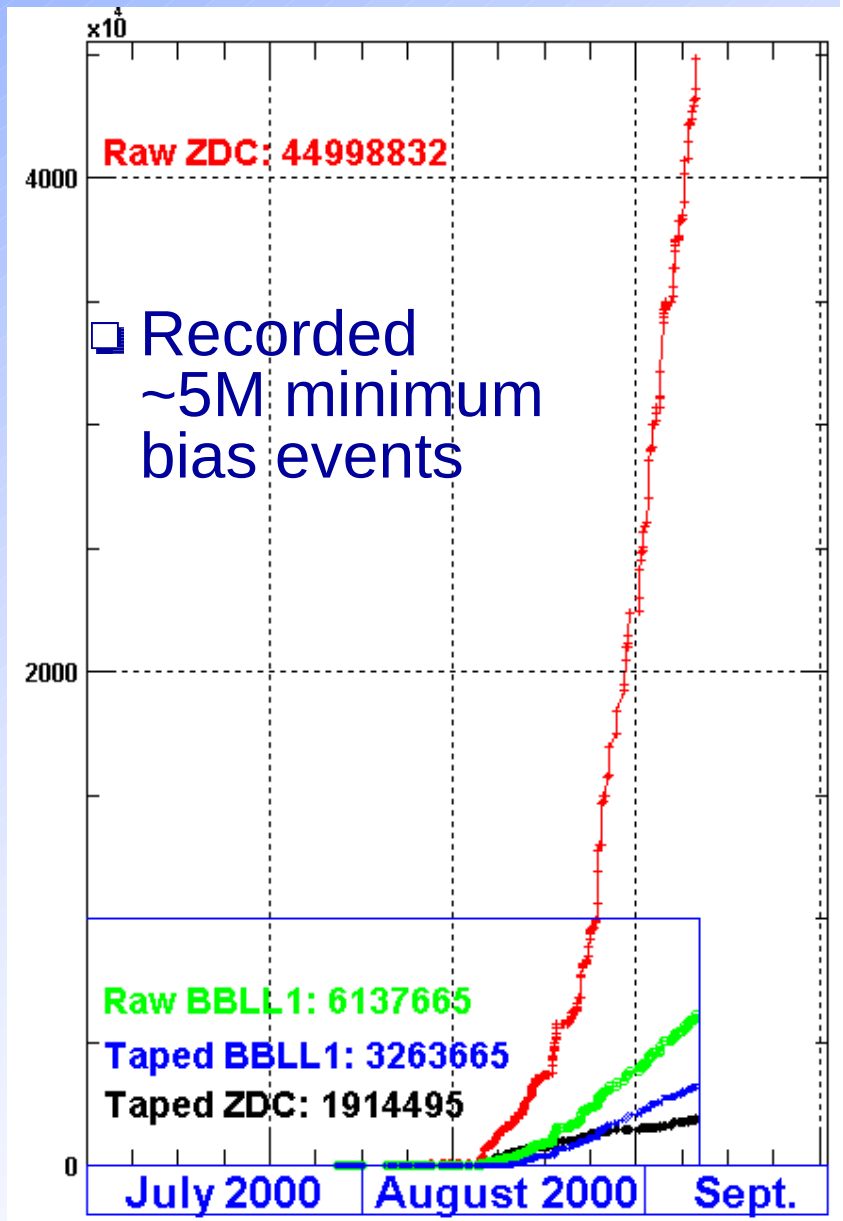
Run-1 Configuration

- 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)



Run-1 Accomplishments

- First collisions:15-Jun-00
- Last collisions: 04-Sep-00
- During this period:
  - Commissioned
    - Zero-Degree Calorimeters
    - Beam-Beam Counters
    - Multiplicity and Vertex Counter
    - Drift Chambers
    - Pad Chambers
    - Ring Imaging Cerenkov Counter
    - Time Expansion Chamber
    - Time-of-Flight Counters
    - Electromagnetic Calorimeter
    - Muon Identifier
    - Minimum Bias Triggers
    - Data Acquisition System



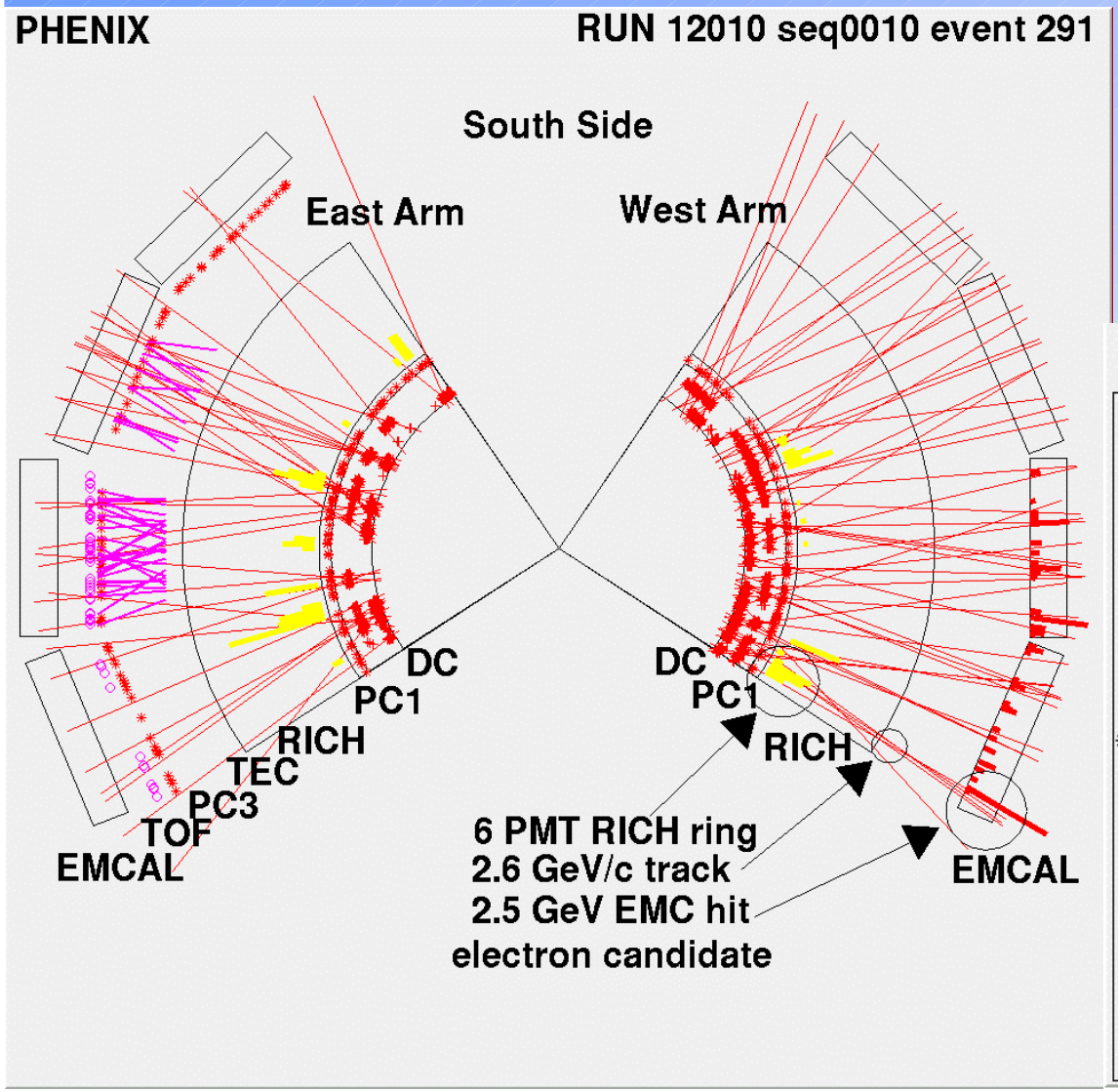
- Recorded ~5M minimum bias events

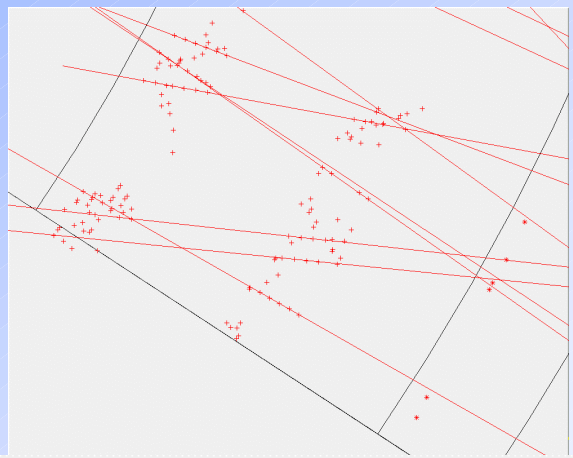
Relevant Posters

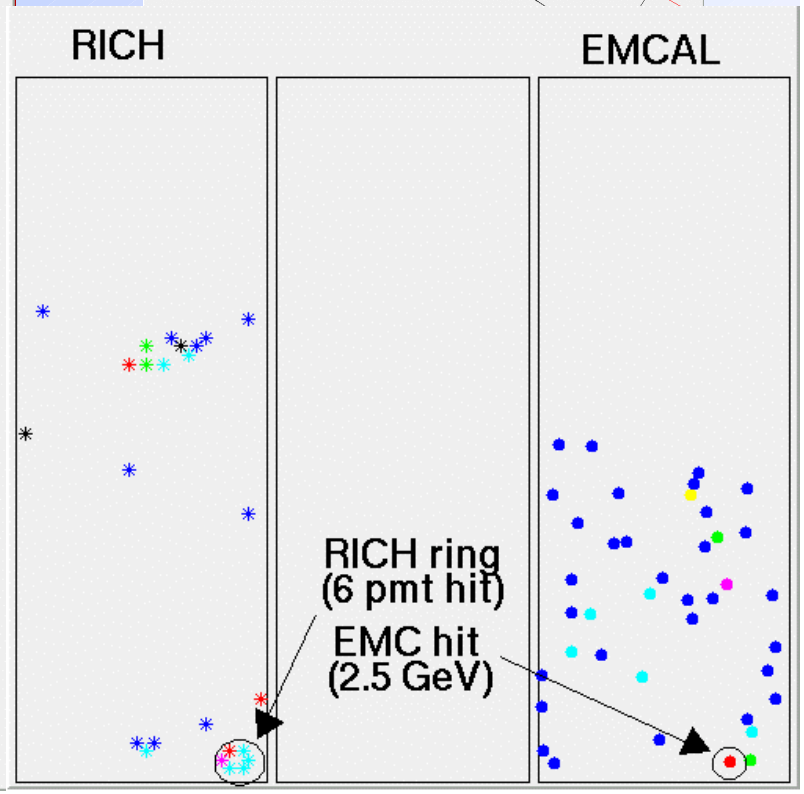
- P201 S. Adler The PHENIX Timing System
- P205 S. Botelho The PHENIX Time Expansion Chamber at RHIC
- P208 M. Chiu The PHENIX Data Acquisition System
- P211 L. Ewell The PHENIX Online Computing System
- P212 S.V. Greene The Design and Performance of the PHENIX Pad Chambers
- P213 A. Hansen The PHENIX Multiplicity Vertex Detector
- P214 A. Hoover, M. Liu The PHENIX South Muon Tracking System
- P215 J. Lajoie The PHENIX Muon Identifier Local Level-1 Trigger System
- P217 Y. Mao The PHENIX Muon Identifier Subsystem
- P219 Y. Miake Performance of the Time-of-Flight Counter in PHENIX
- P221 G. Mishra The PHENIX Event Builder
- P222 P. Nilsson The Readout System for the PHENIX Pad Chambers
- P223 E. O'Brien Charged Particle Tracking in PHENIX
- P226 T. Sakaguchi Performance of the PHENIX Ring Imaging Cherenkov Detector
- P229 T. Sugitate Performance of the Beam-Beam Counter in PHENIX
- P230 H. Torii Performance of the PHENIX EM Calorimeter in PHENIX

All sub-systems in concert

High p_T electrons in PHENIX:

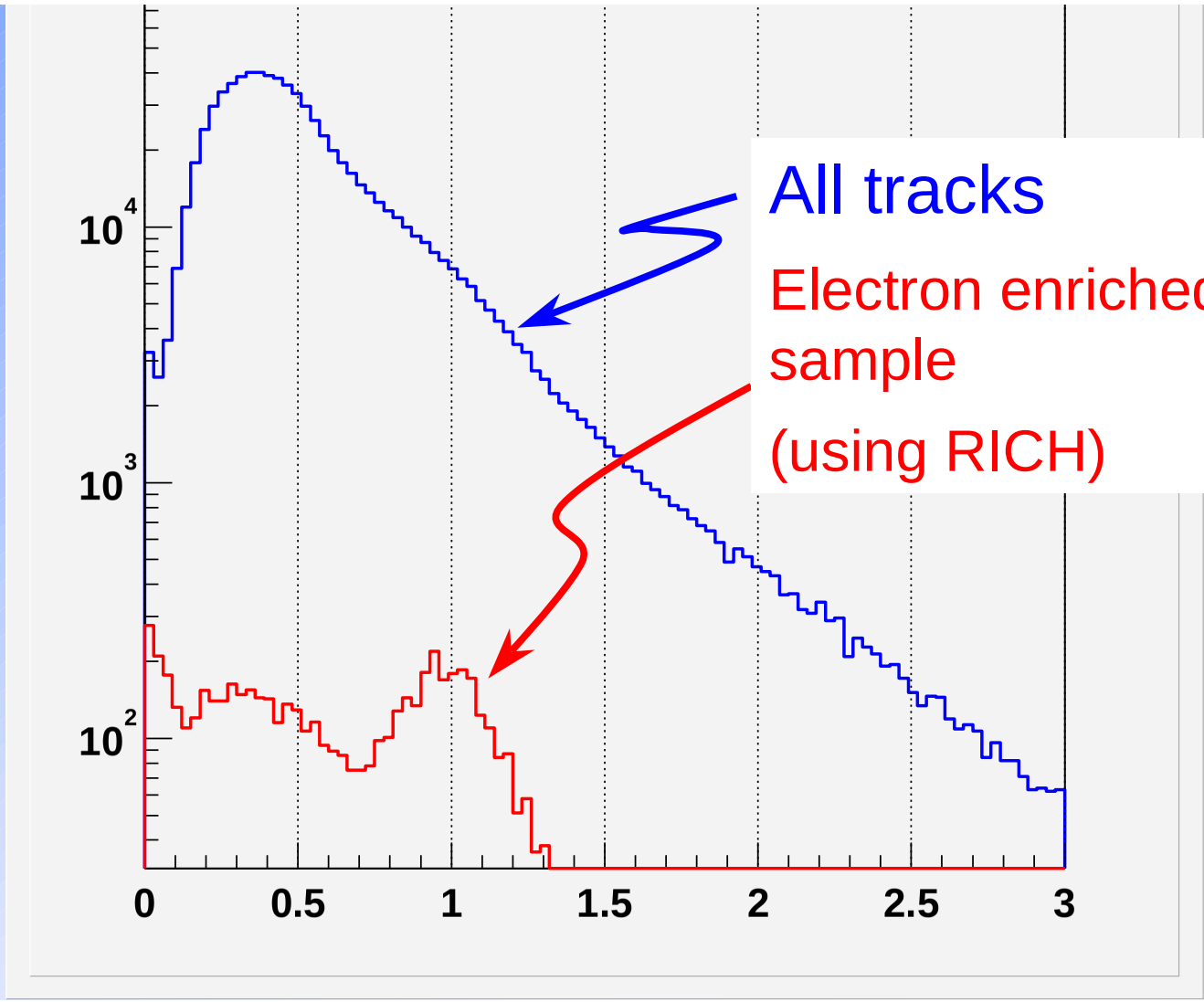






Identifying Electrons

E/p matching for p>0.5 GeV/c tracks



Run-1 Results

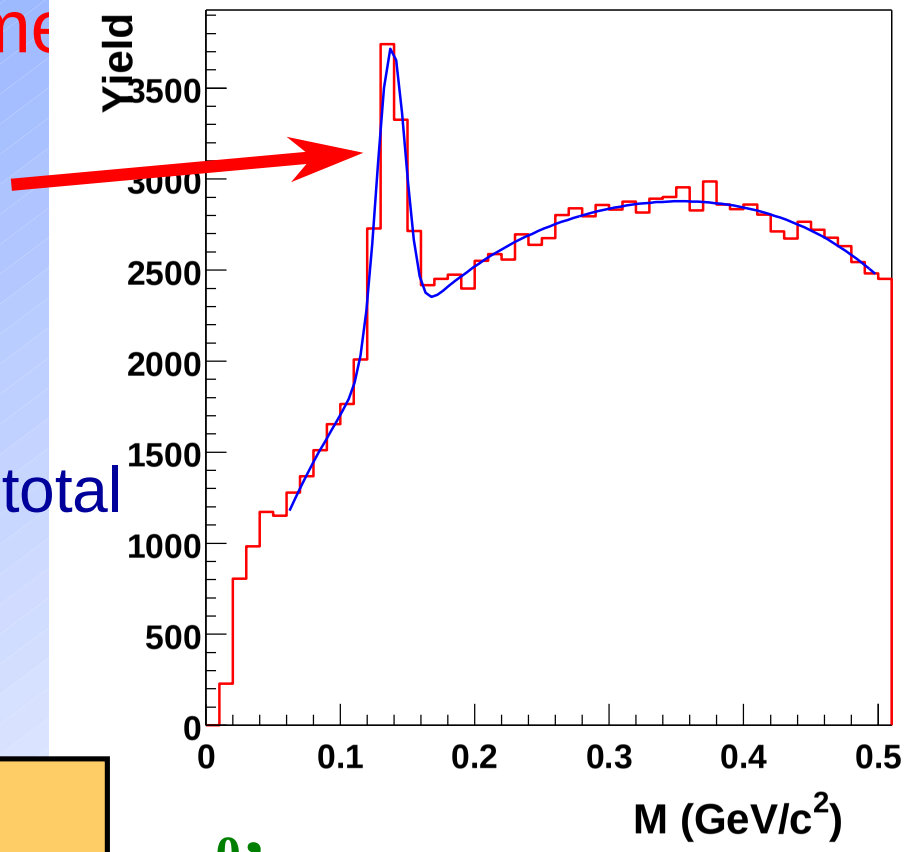
- Global Event Features
  - Transverse Energy
  - Charged Multiplicity
  - Elliptic Flow
- Identified Particles
  - Hadrons
    - $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$
    - π^{o}'s
    - $\pi^{\pm}\pi^{\pm}$ HBT
  - Electrons
- Studied versus
  - Centrality
  - Number of participants

All results presented are for Au-Au collisions at $\sqrt{s_{NN}} = 130$ GeV

Energy Measurements

- Measured with "electromagnetic" calorime
  - Superb E-M calorimeter
  - With a well-understood response to soft charged hadrons
  - ➡Reliable measurement of total transverse energy

$E_T = (1.17 \pm 0.05)\, E_{EMCal}$



π^0's

p_T>2 GeV, asym<0.8

Parallel Session I

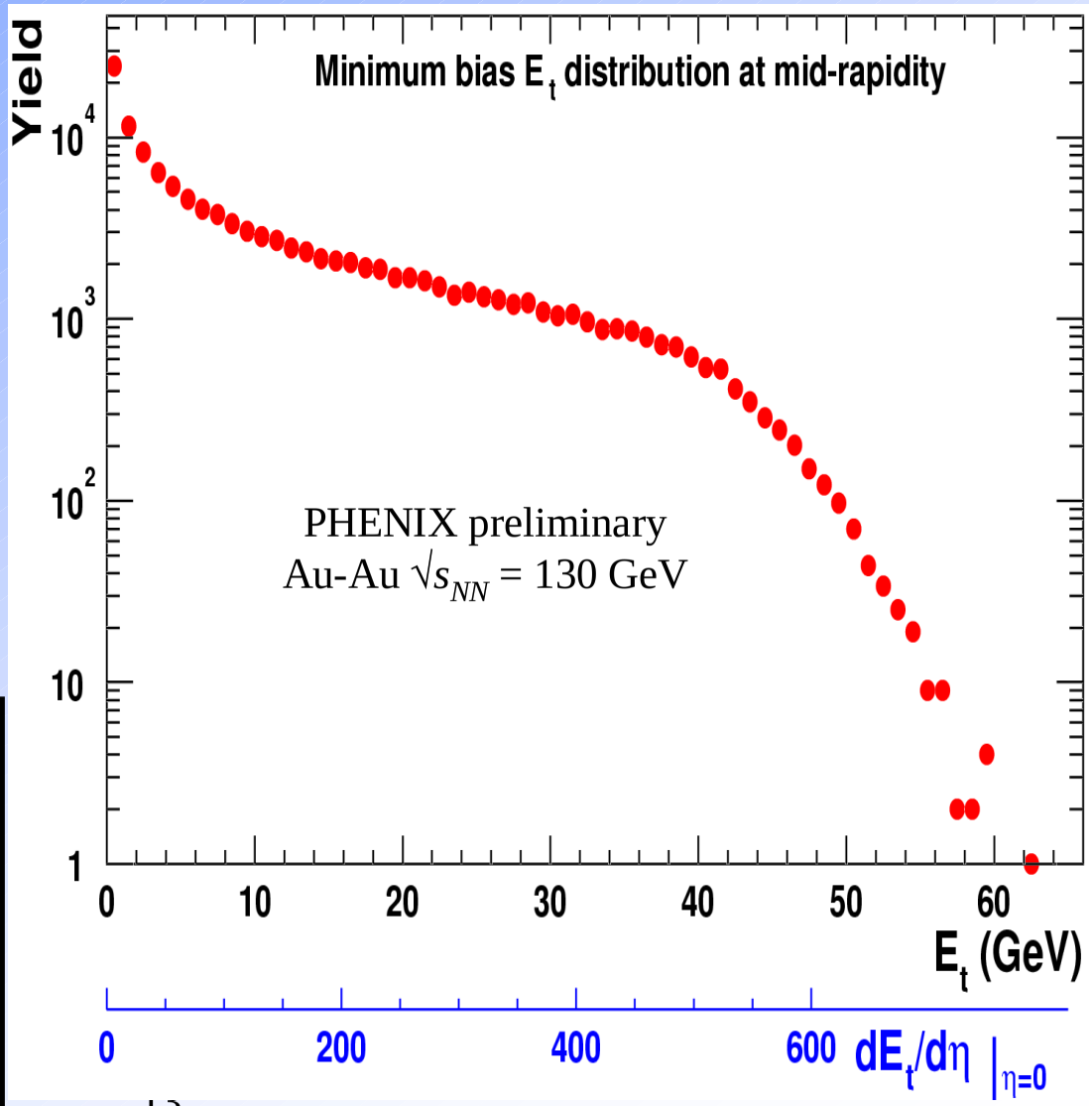
S. White: *Calorimetry and Global Event Characterization in PHENIX*

Transverse Energy Distribution

- Measured for
  - $|\eta| < 0.35$
  - $\Delta\phi = 45^o$
  - Minimum bias
    ~ 92% of $\sigma_{GEOM} = 7.2b$
- Studied versus
  - Charged multiplicity
  - Number of participants

Poster Session

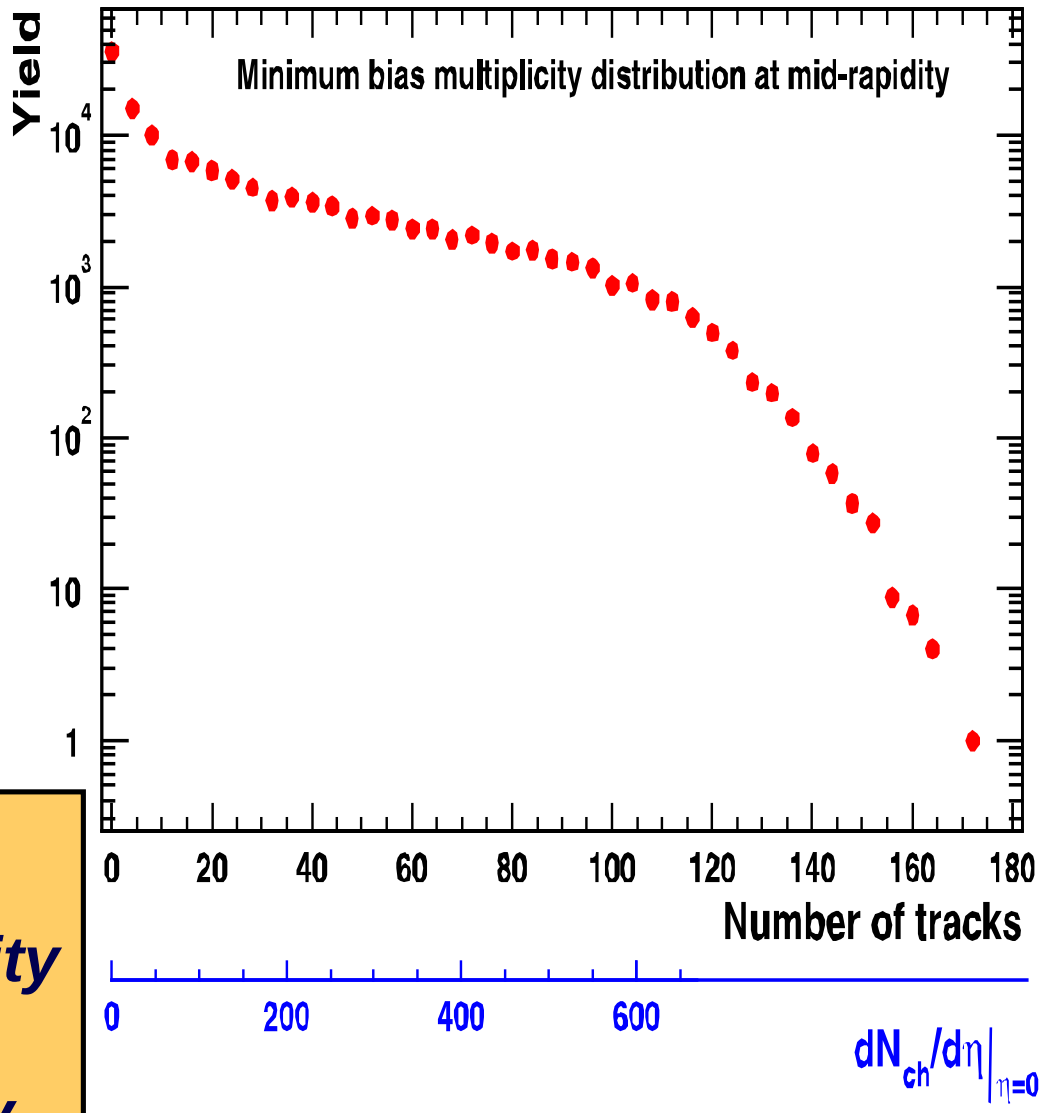
S. Bazilevsky:
Transverse Energy Measurements with the PHENIX detector at RHIC



Charged Multiplicity

- Measured for
  - $|\eta| < 0.35$
  - $\Delta\phi = 90^o$
  - Minimum bias
    ~ 92% of $\sigma_{GEOM} = 7.2b$
- Studied versus
  Number of participants

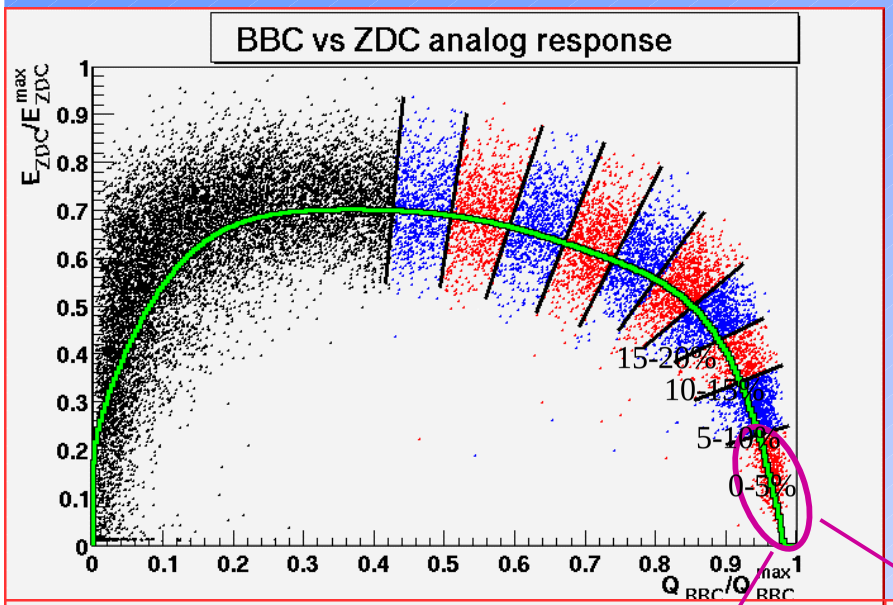
(nucl-ex/0012008)



Wednesday Plenary Session

A. Milov: *Charged multiplicity and Transverse Energy in Au-Au Collisions at 130 Gev*

Determining N(participants)



Use combination of

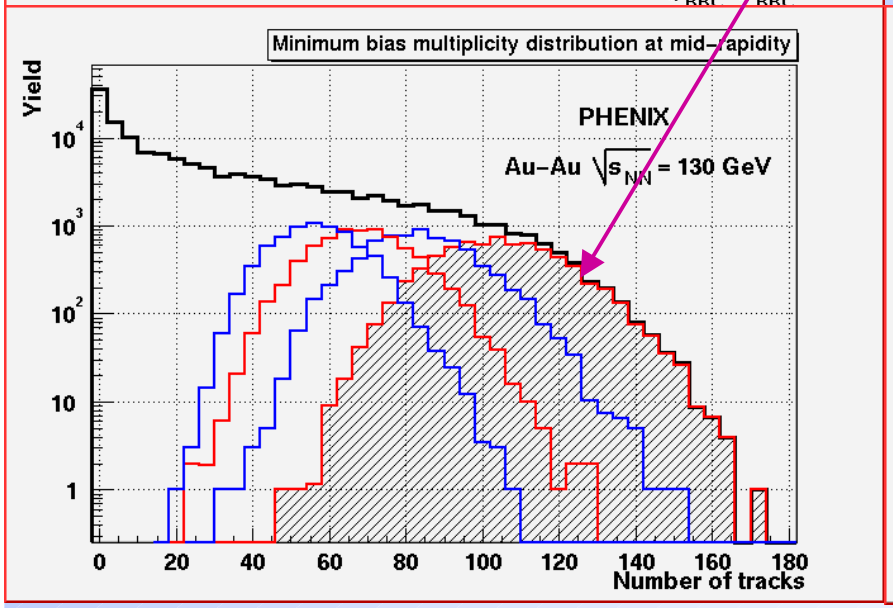
- Zero Degree Calorimeters
- Beam-Beam Counters

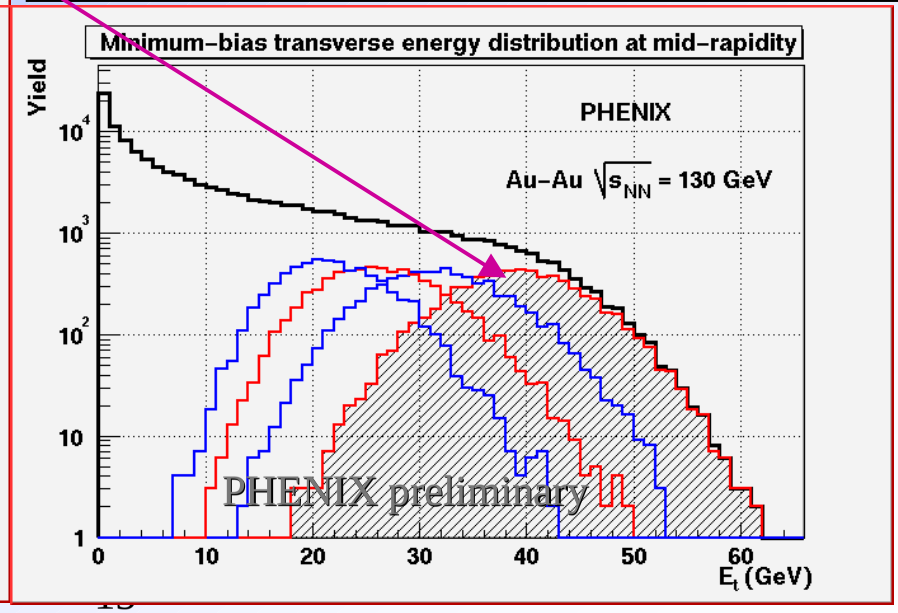
to define centrality classes

- Glauber modeling

to extract N-participants

A. Denisov: **Common Event Characterization in the RHIC Experiments**

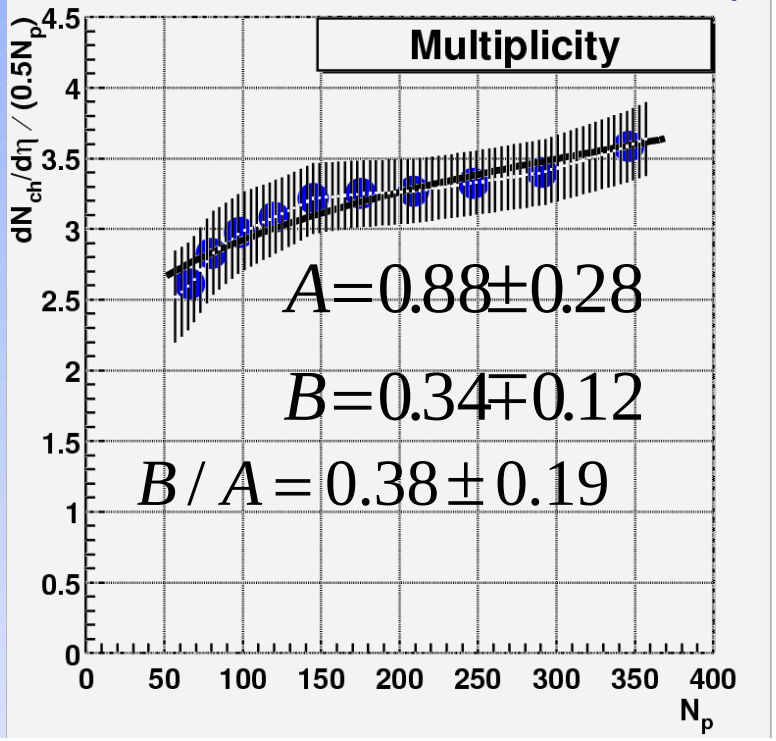


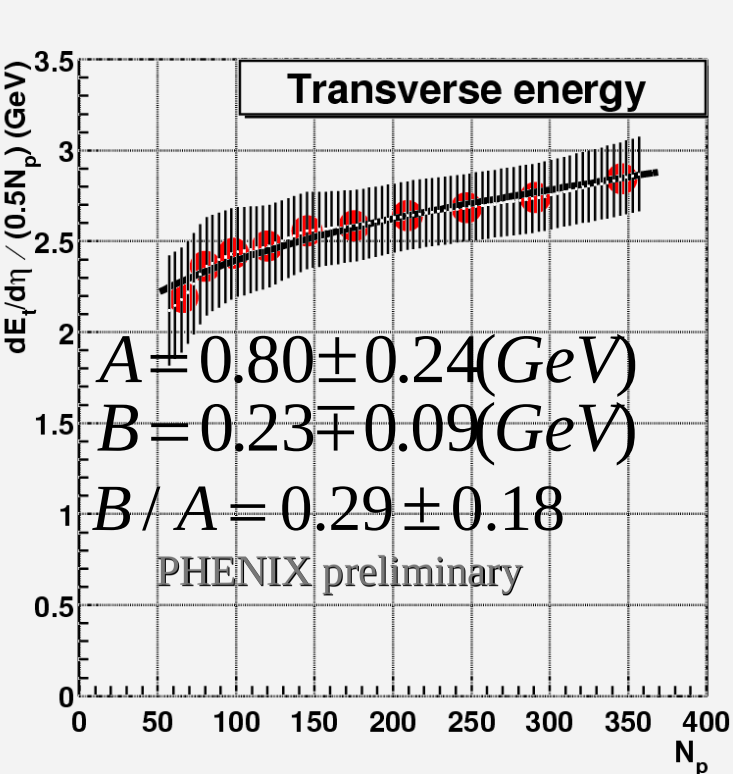


Results

- Excellent consistency between two analyses
- Yields grow significantly faster than Nparticipants
- Evidence for term ~ Ncollisions
  - Qualitatively consistent with HIJING
  - Inconsistent with some saturation models
  - Hard processes increase with centrality (30% mid-central to ~50% most central)

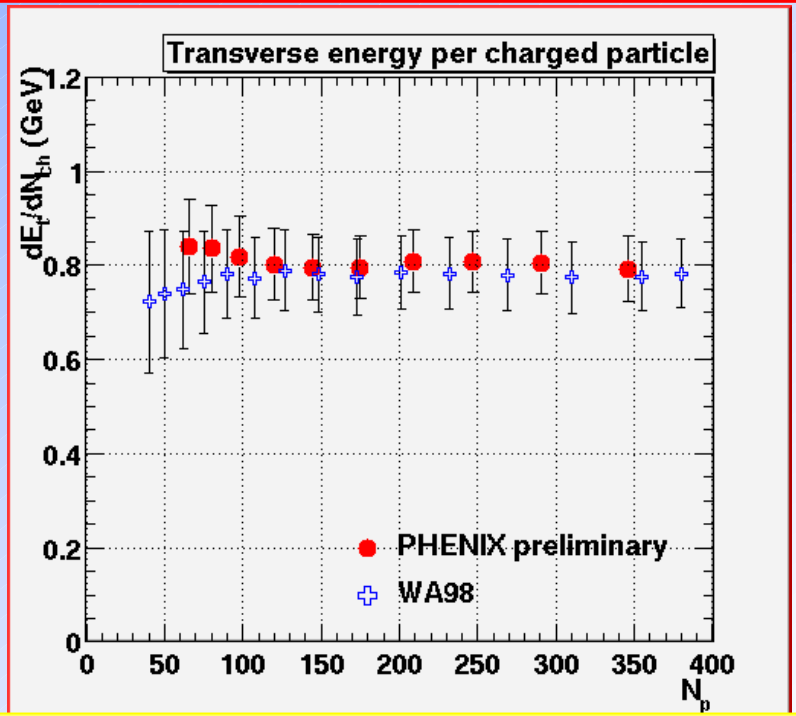
$$dX/d\eta\big|_{\eta=0} = A \times N_{part} + B \times N_{coll}$$





Comparisons

- E_T to Charged
  - PHENIX: independent of Npart
  - Same trend and value as WA98
- Energy densities
  - *Assume* same τ, ~ same R_T
  - Bjorken ansatz then implies ~50% greater energy density than at CERN SPS
- $(\text{Npart})^{\alpha}$ scaling
  - Larger than at CERN SPS
  - Increase role of hard scattering



dE_t/dN_{ch} **independent of** N_{par}

α-value	Multiplicity	E_T
PHENIX	1.16 ± 0.04	$\mathbf{1.13 \pm 0.05}$
WA98	1.07 ± 0.04	1.08 ± 0.06
WA97	1.05 ± 0.05	

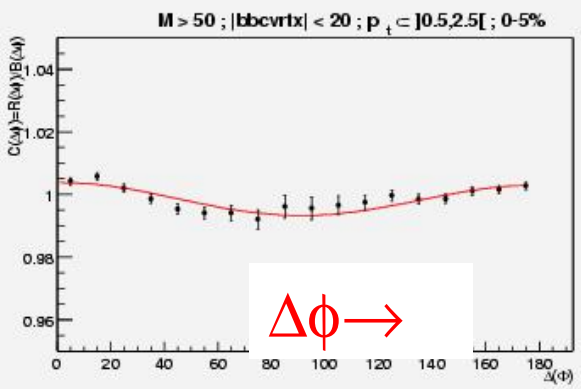
Elliptic Flow

- Determine via a correlation function method

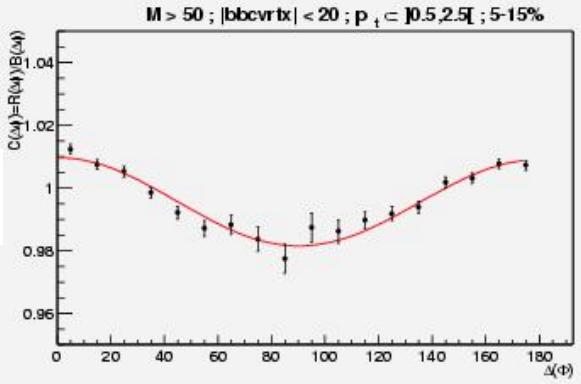
$$C(\Delta\phi) = \frac{R(\Delta\phi)}{B(\Delta\phi)}$$

- Study versus
  - Centrality
  - p_T (next slide)

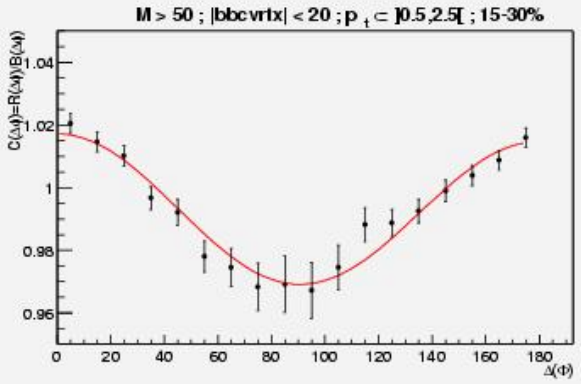
0-5%



5-15%



15-30%

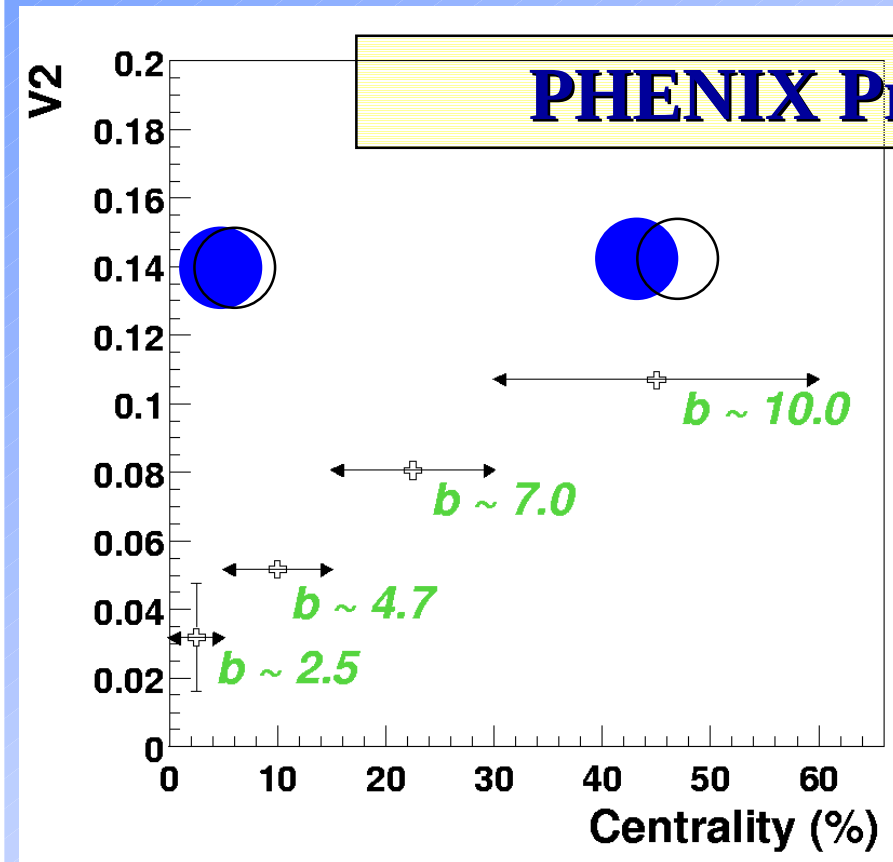


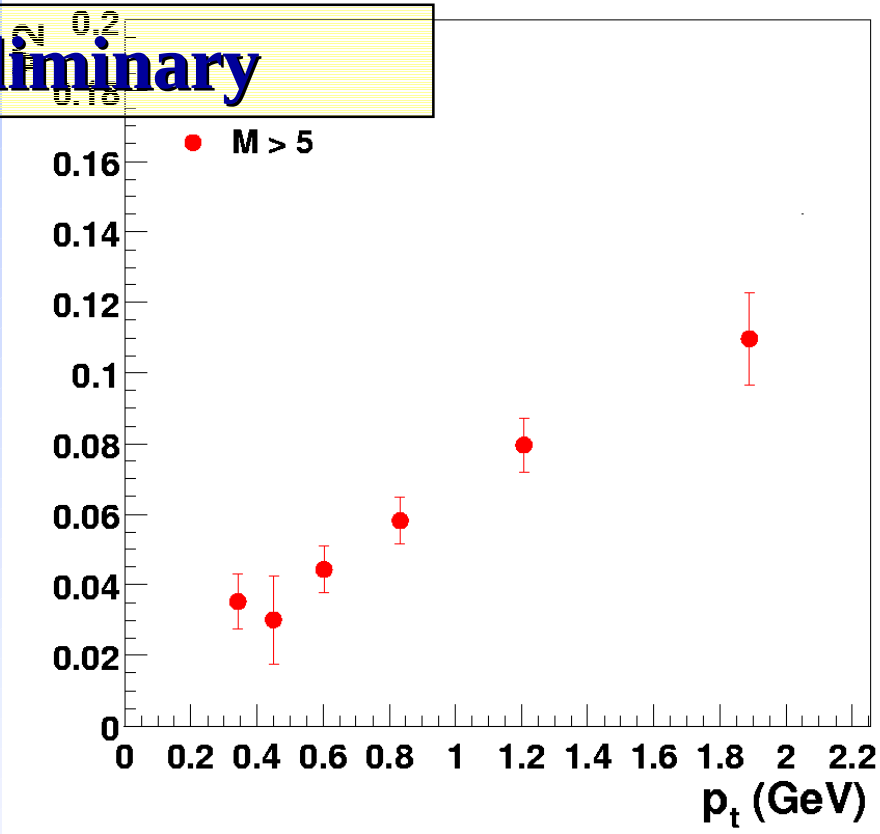
Elliptic Flow

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

Wednesday. Parallel Session II

R. Lacey: ***Elliptic Flow Measurements with the PHENIX Detector System***





Summary 1

Systematic study versus Nparticipants

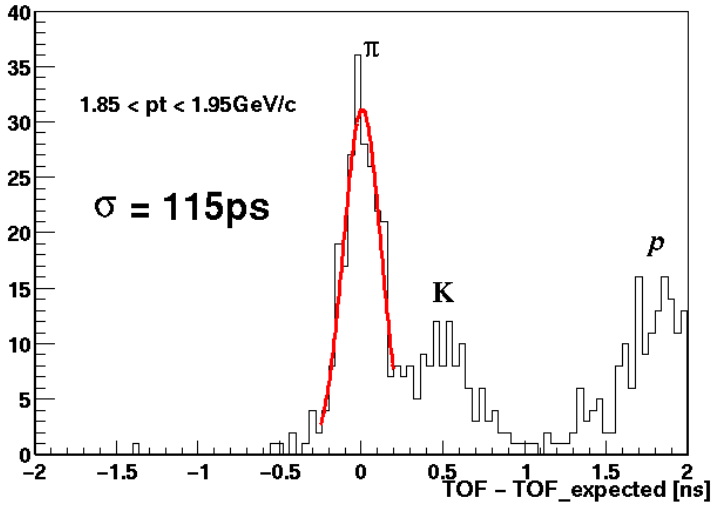
- Evidence for role of Ncollision term
- Larger α values than at CERN SPS
- Energy density ~ 1.5 x value at CERN SPS
- Observation of significant elliptic flow

Hadron Identification

Combined

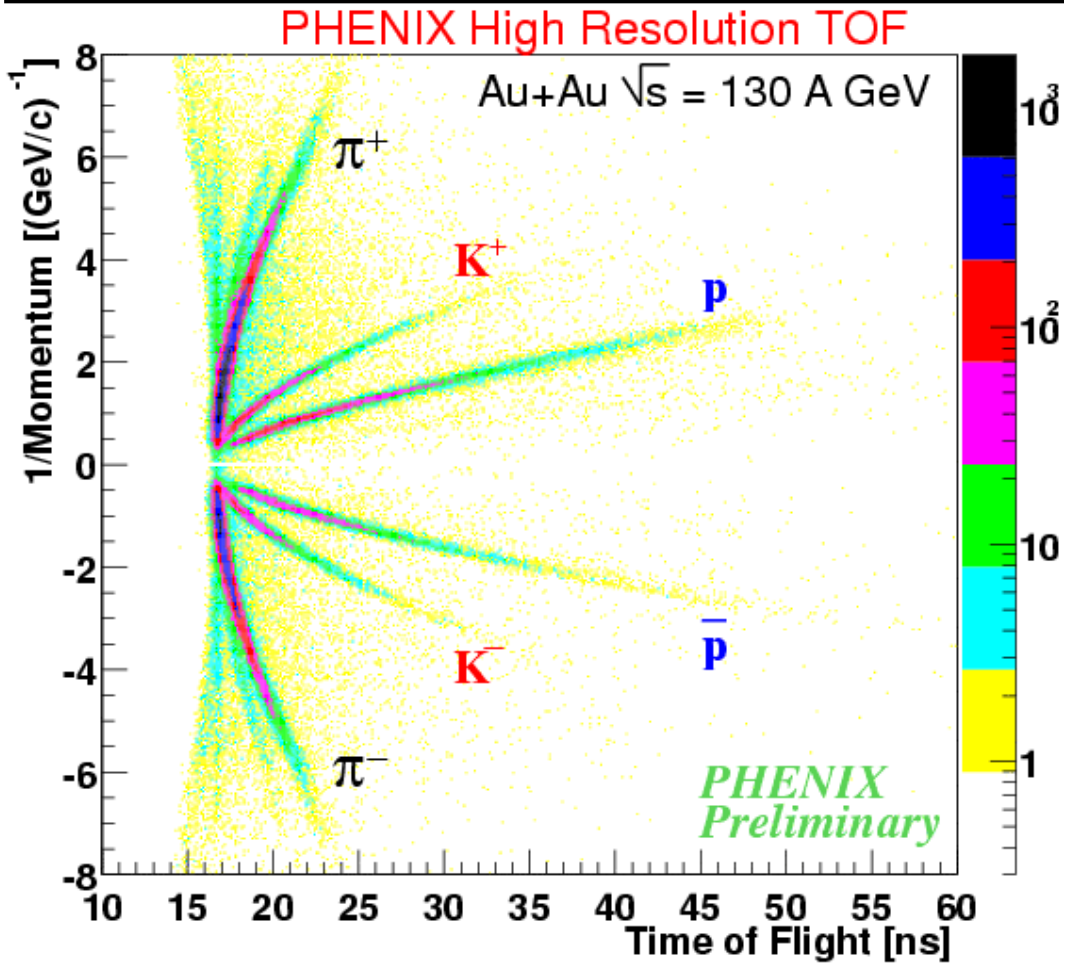
- Tracking
- Beam-Beam Counter
- Time-of-Flight array

provides excellent hadron identification over broad momentum band:



Tuesday, Parallel Session I

H. Hamagaki: Particle identification capability of the PHENIX experiment

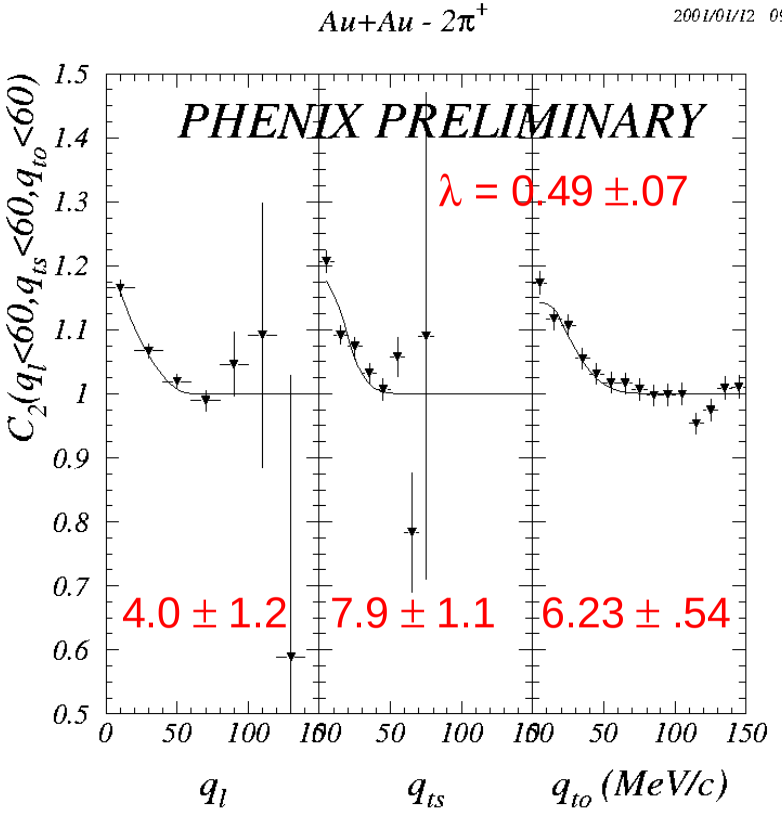


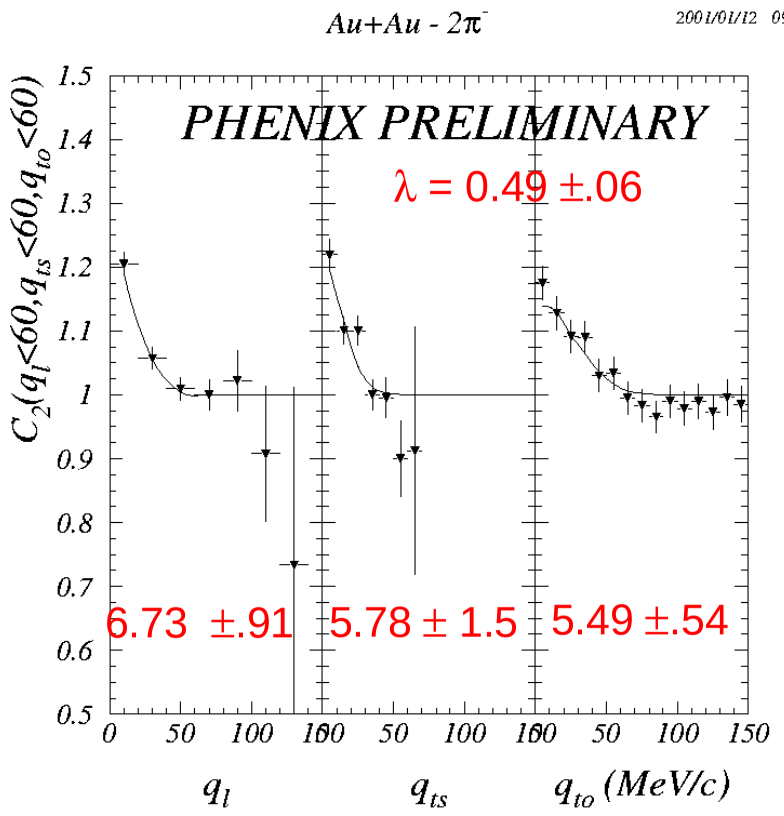
HBT

- A proof-of-principle analysis:
  - ~20% most central events
  - Full Coulomb correction
  - No evidence for large expansion

Friday, Parallel Session III

S.C. Johnson: ***First Results on Two-Particle Correlations Determined by the PHENIX Experiment at RHIC***





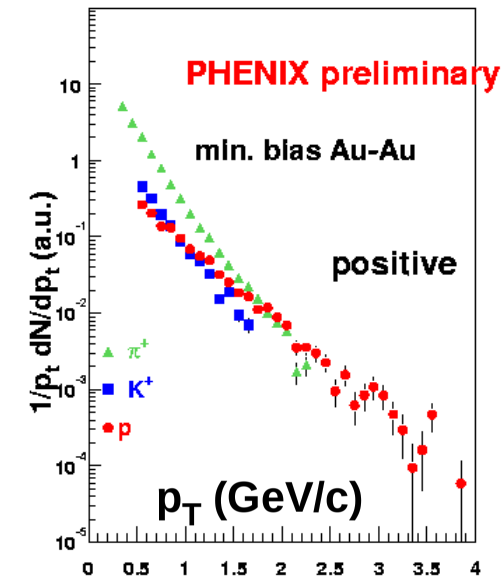
Identified Particle Spectra

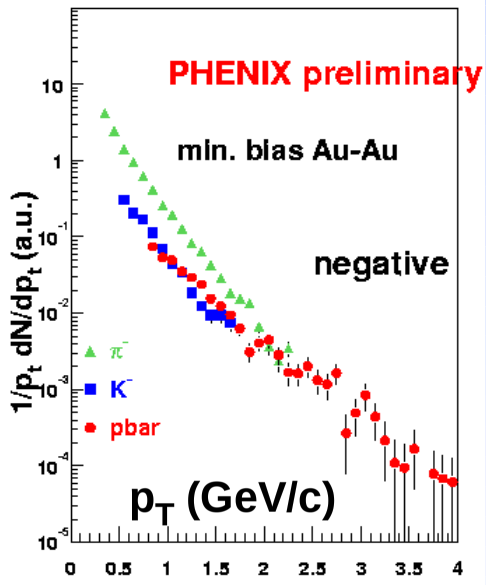
Fit π, K, p spectra to obtain

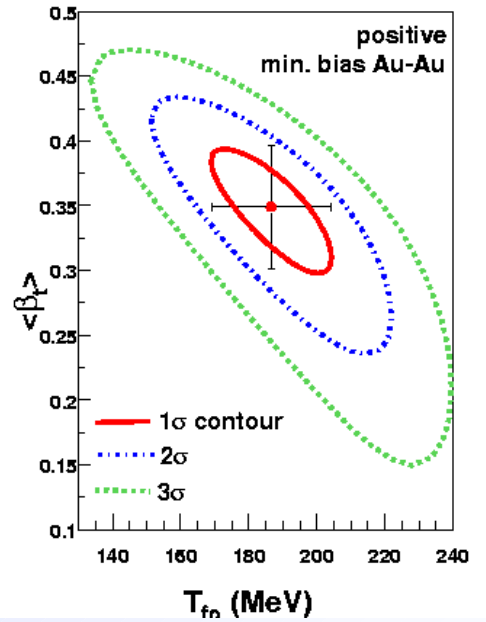
$\langle\beta_T\rangle \sim 0.35$

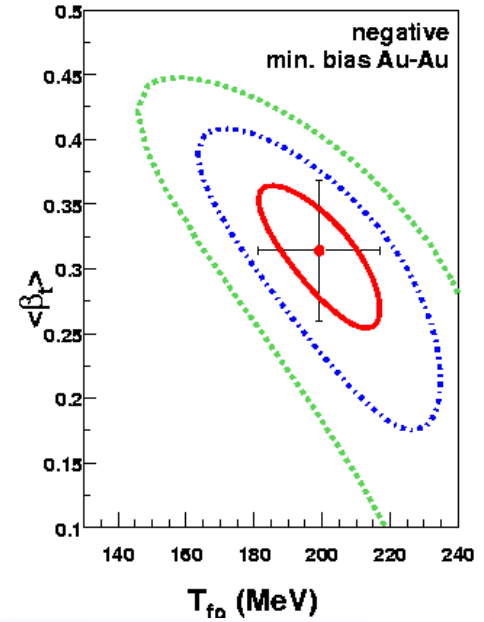
$T_{fo} \sim 180\text{-}200$ MeV

Systematic errors: to be determined









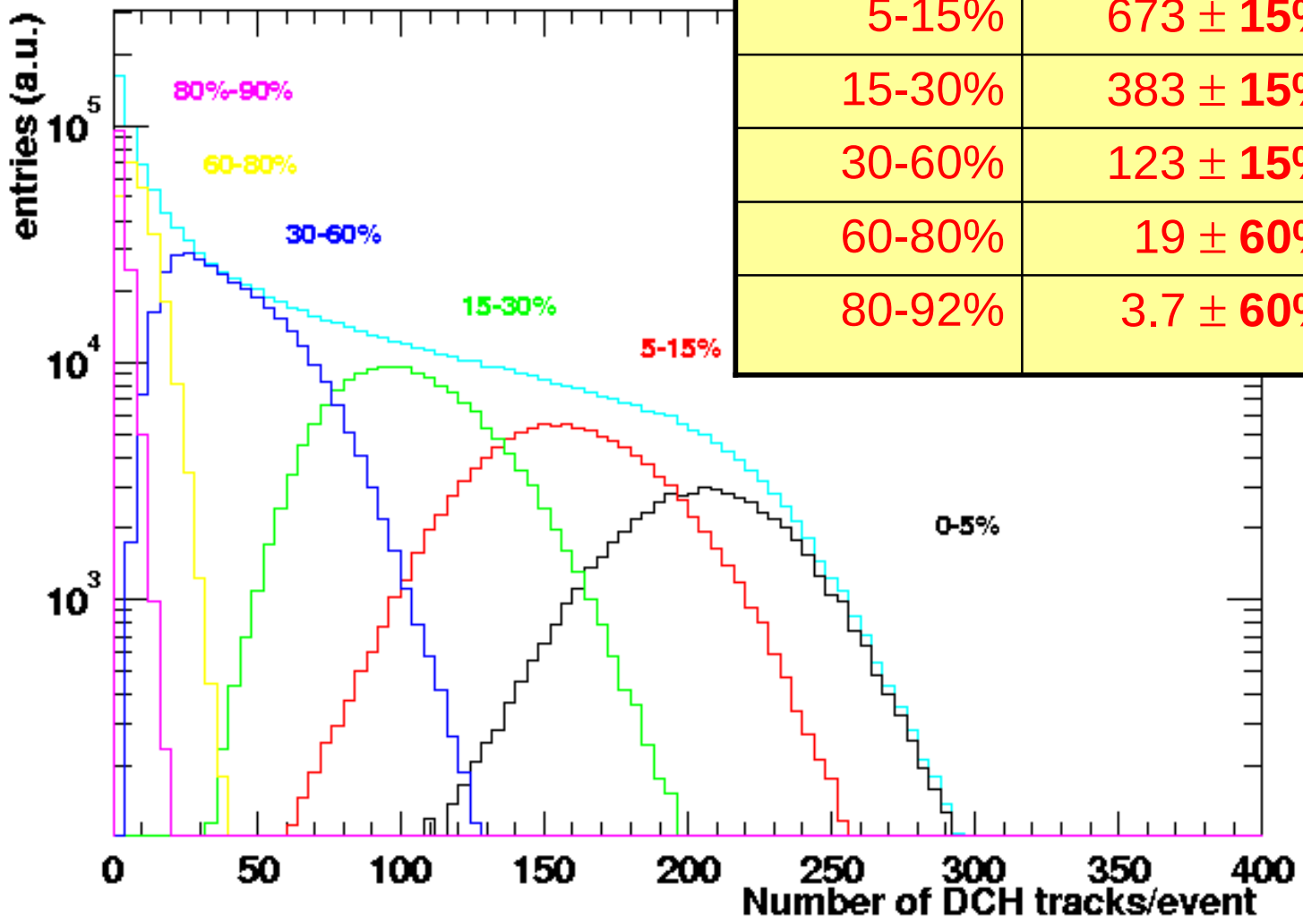
Wednesday, Parallel Session II

J. Velkovska: *p_T spectra of identified hadrons measured with the PHENIX experiment*

Centrality Selections

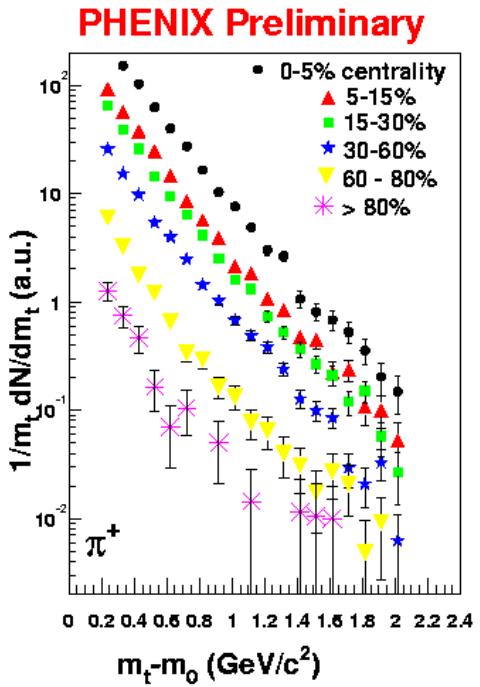
Conversion to Ncollisions and Nparticpants

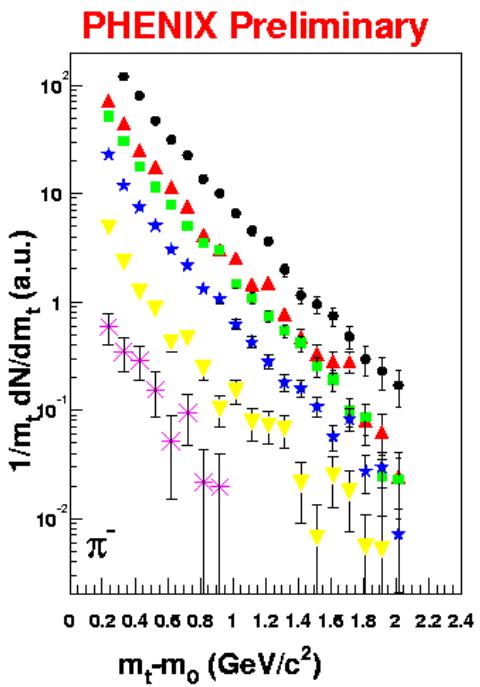
Centrality	Collisions	Participants
0-5%	945 ± **15%**	347 ± **15%**
5-15%	673 ± **15%**	271 ± **15%**
15-30%	383 ± **15%**	178 ± **15%**
30-60%	123 ± **15%**	76 ± **15%**
60-80%	19 ± **60%**	19 ± **60%**
80-92%	3.7 ± **60%**	5 ± **60%**

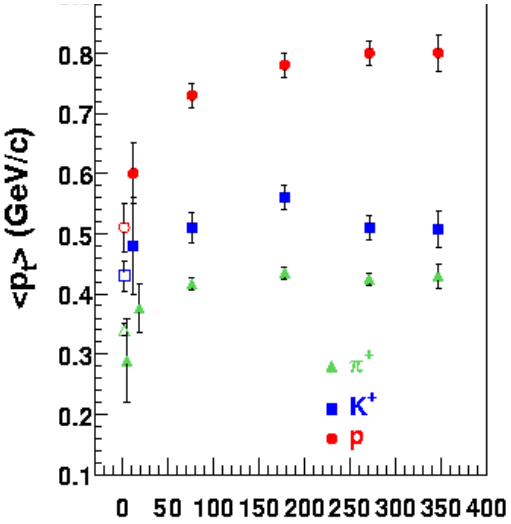


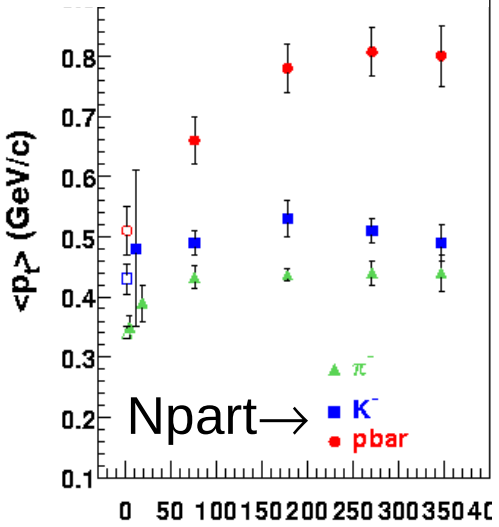
Identified Spectra vs. Participants

- Study identified spectra versus number of participants
- Characterize with $\langle p_T \rangle$ rather than local slopes
- Find
  - π, K ~ flat with Npart
  - Larger dependence for p and anti-proton
  - Structure confined to low values of Npart
  - Good agreement at low Npart with inferred values for p-p collisions









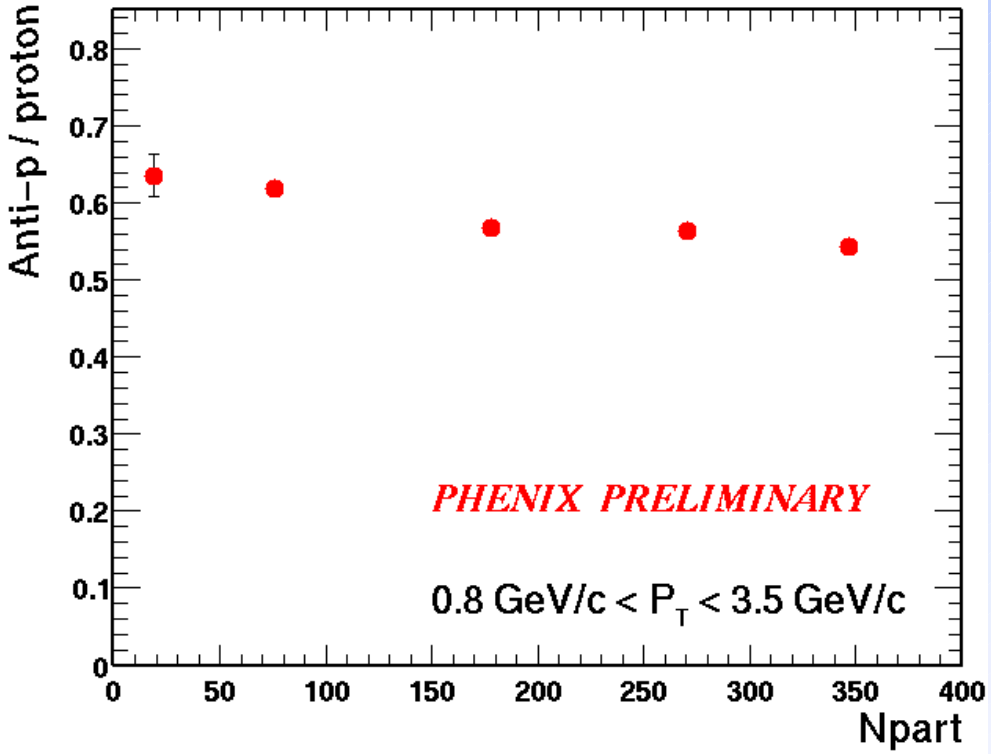
Hadron yields

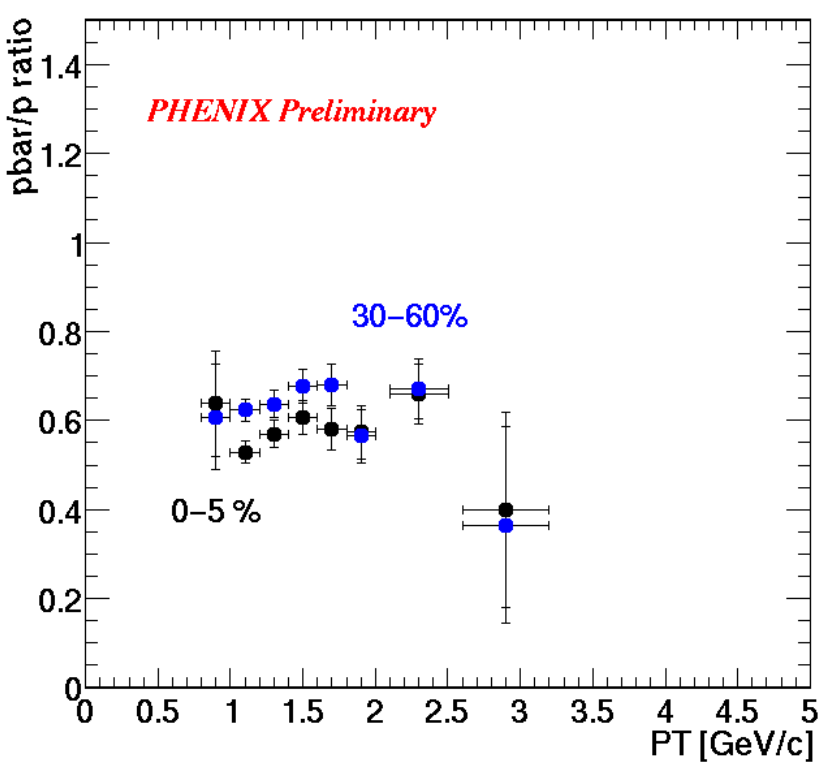
Anti-proton/proton studied over broad p_T range

- Little or no p_T dependence
- Weak centrality dependence
- Similar data available for K^+/K^-, $K^{\pm}/\pi^{\pm}$

Friday, Parallel Session III

H. Ohnishi: *Particle ratios in PHENIX at RHIC*





Summary 2

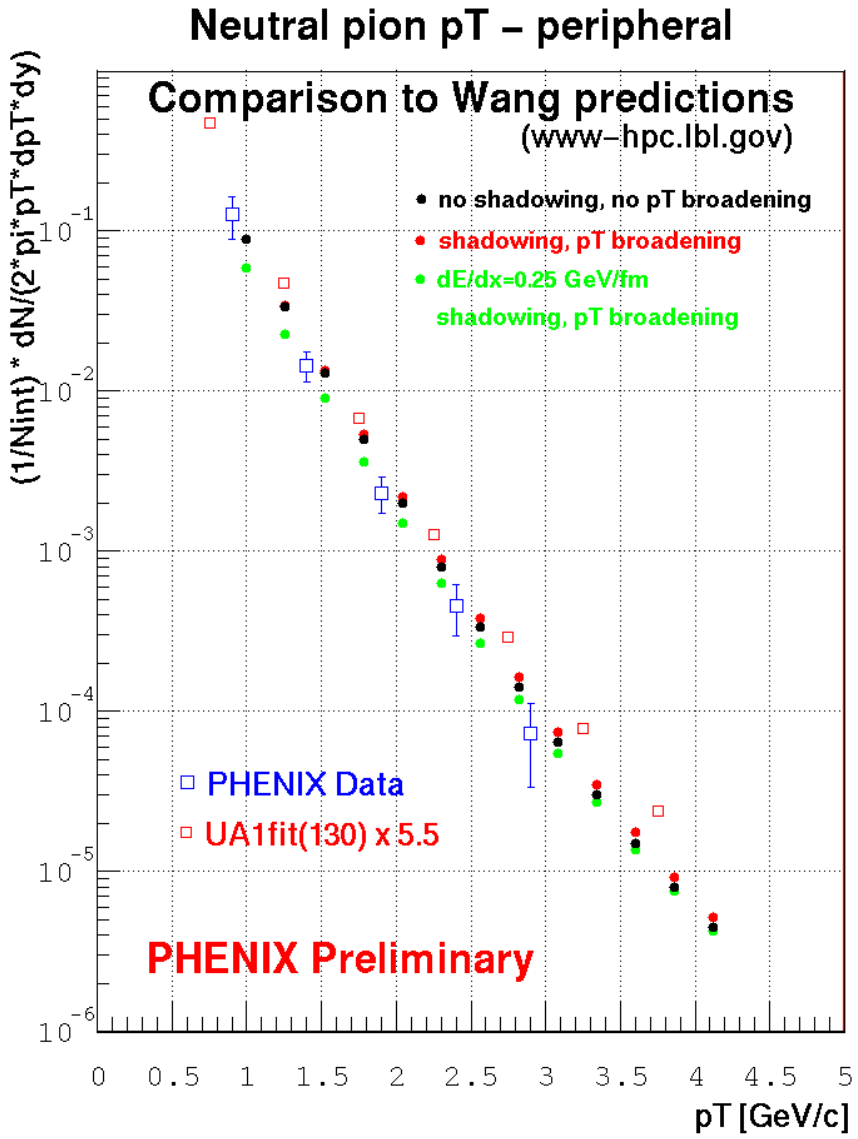
- Clean π/K/p identification over broad momentum range
- 2-pion HBT parameters obtained

  No evidence for large expansion
- Systematic study of spectra vs Nparticipants
  - "Early" onset of trends vs. Nparticipants
  - Anti-proton/proton ratio ~ constant with both Nparticipants and p_T
  - Anti-proton/proton, K+/K- consistent with much lower net baryon density than previous results at lower energy

π^0 Spectra

- Yields of π^0's have been extracted for minimum bias, peripheral and central data sets

- For 75-92% most-peripheral sample
  - Data span 1-3 GeV/c
  - Well-described by scaling inferred p-p distribution by <Ncollisions> = 5.5
  - Well-described by X.N. Wang "no quenching" predictions

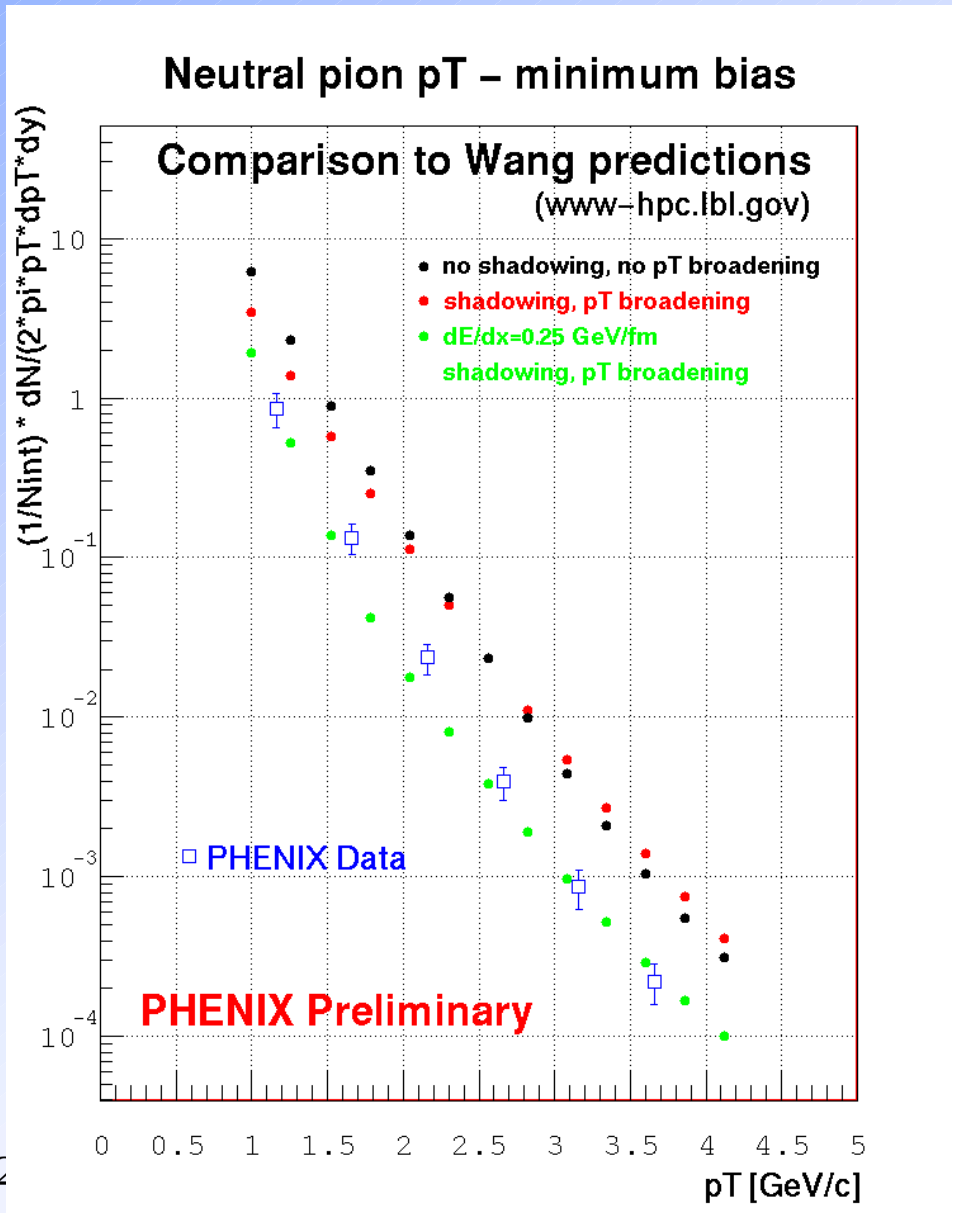


π^0 Spectra

- Minimum bias data fall below yields inferred from A^2 scaling of hard phenomena
- Trend continues for central collisions
- Details:

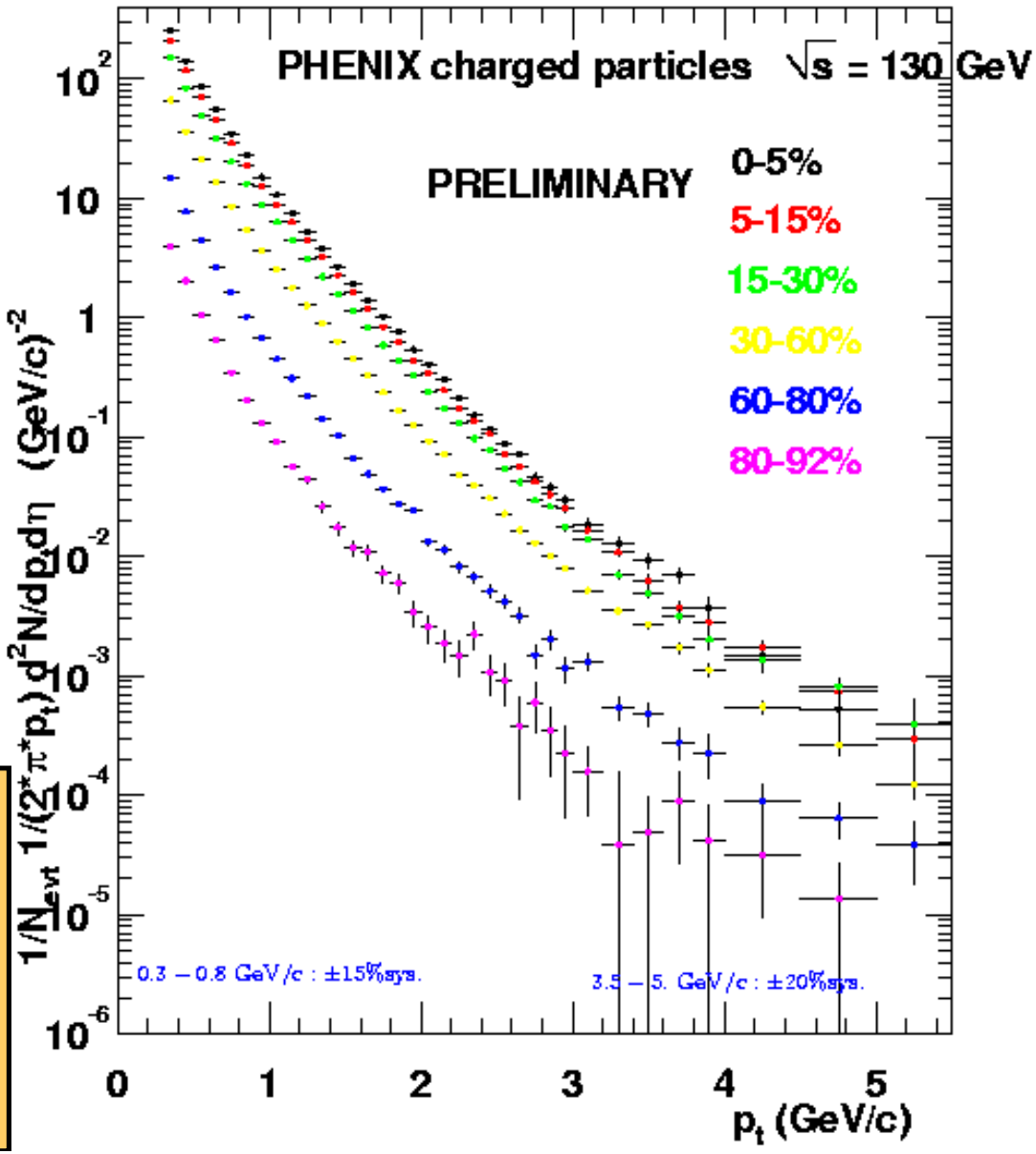
Thursday Plenary Session

G. David: *Neutral Pion Distributions at RHIC*



Charged p_T Spectra

- Systematic trends in high p_T production also studied with charged particles
  - Much greater statistics
  - Different systematics

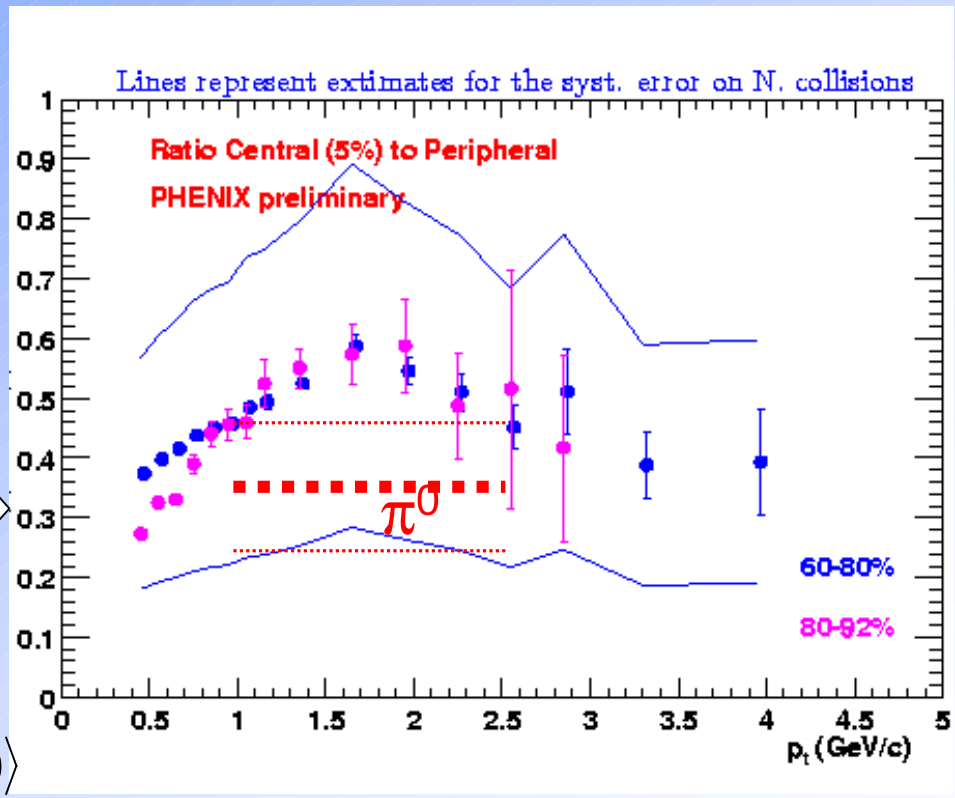


Wednesday, Parallel Session II

F. Messer: ***Spectra and angular correlation of high momentum charged particles in PHENIX.***

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

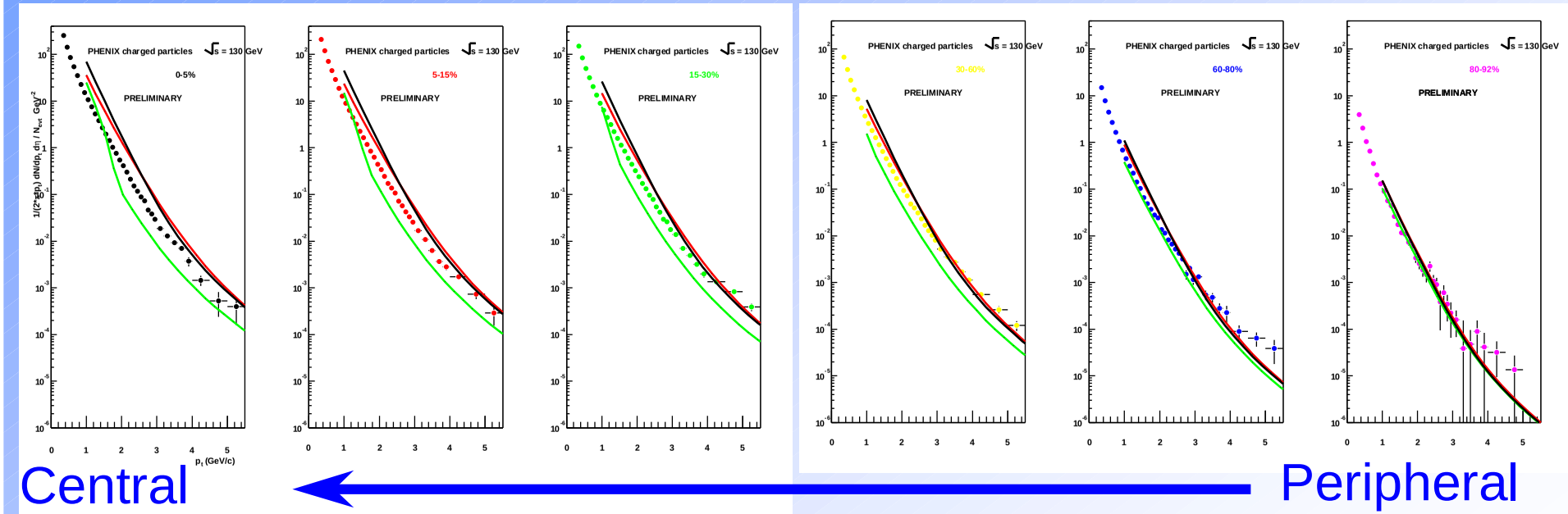


$$\text{Ratio} = \frac{\text{Yield(Central)} / \langle N_{COLL}(\text{Central}) \rangle}{\text{Yield(Peripheral)} / \langle N_{COLL}(\text{Peripheral}) \rangle}$$

- Ratio unity if yields scale as number of collisions
- Ratio found to be less than 1, decreasing for $p_T > 2$ GeV/c
- Same is observed in π^0 analysis (very different sytematics)

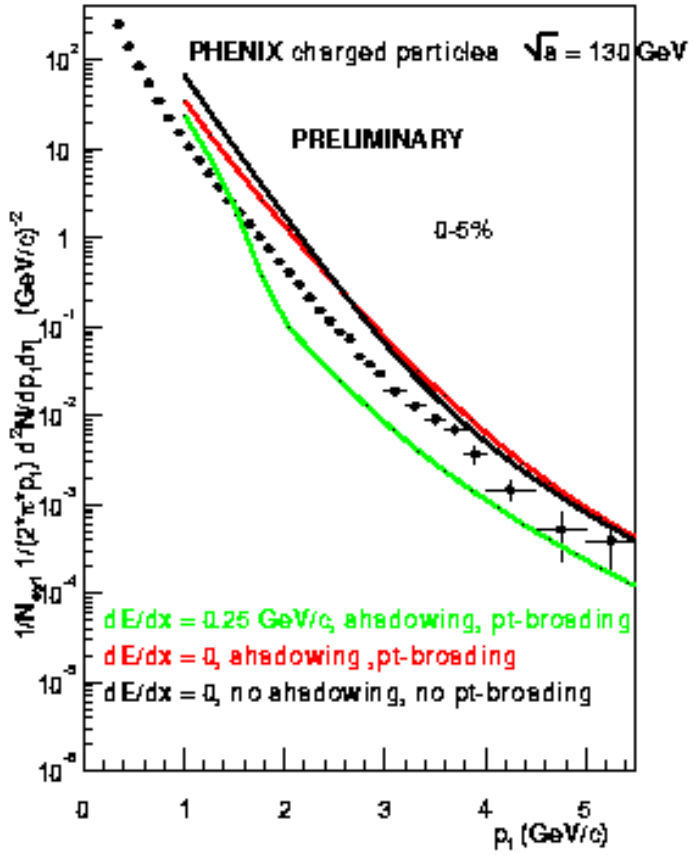
Comparison to Theory (I)

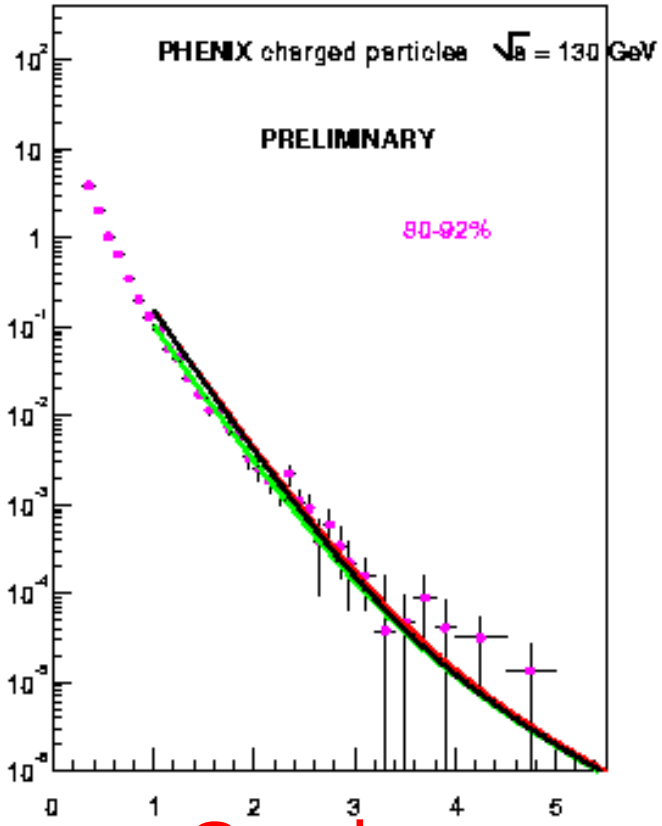
- Compare charged p_T spectra in each centrality slice to predictions from X.N. Wang:



(I know you can't read these figures!)

Comparison to Theory (II)



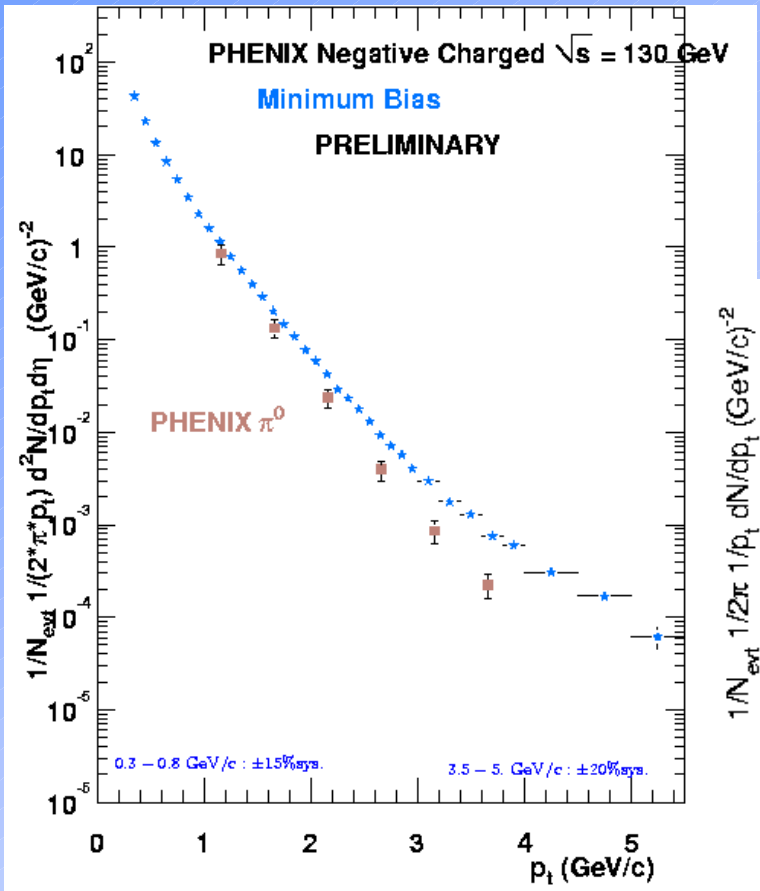


- Good agreement with peripheral
- Clear deficit with respect to "no shadowing, no quenching" calculations

Ref: X.-N. Wang, Phys. Rev. C61, 064910 (2000)
Ref: X.-N. Wang, nucl-th/0009019

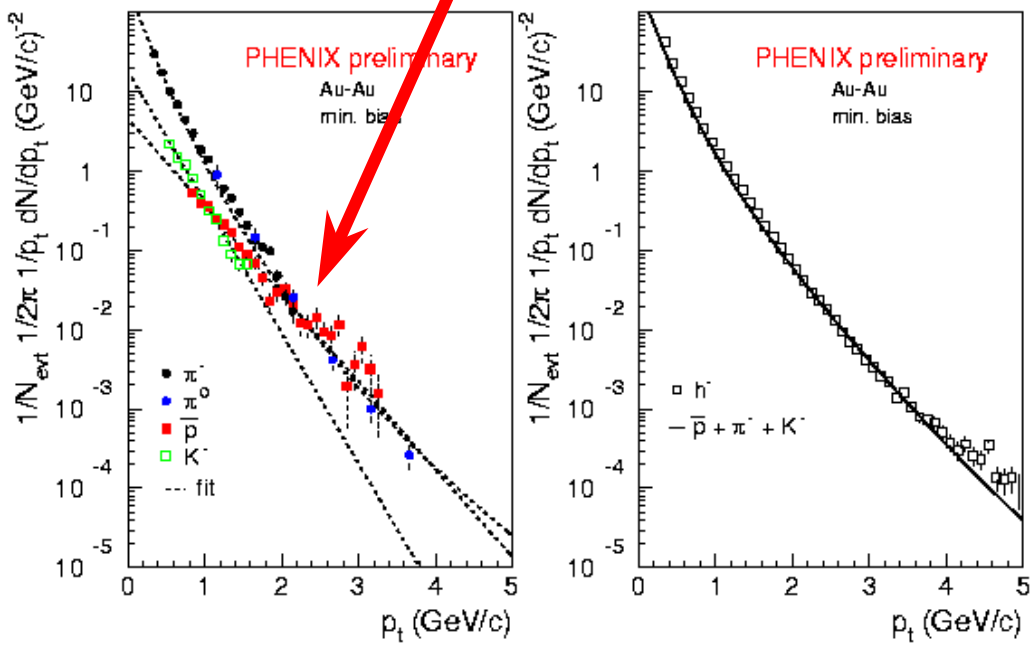
Composition at high p_T

Possible complication in comparisons of charged yields to theory:



Absolute Normalization : ±20%sys.

Particle composition is observed to be a strong function of p_T



Summary 3

Systematic study of p_T spectra for

- π^0's
- Charged particles

versus centrality show

- Good agreement for peripheral collisions with predictions from hard scattering
- Clear deficit in more central collisions
  - Data-to-data comparisons
  - Data-to-model comparisons
- Hints of particle composition effect in charged spectra

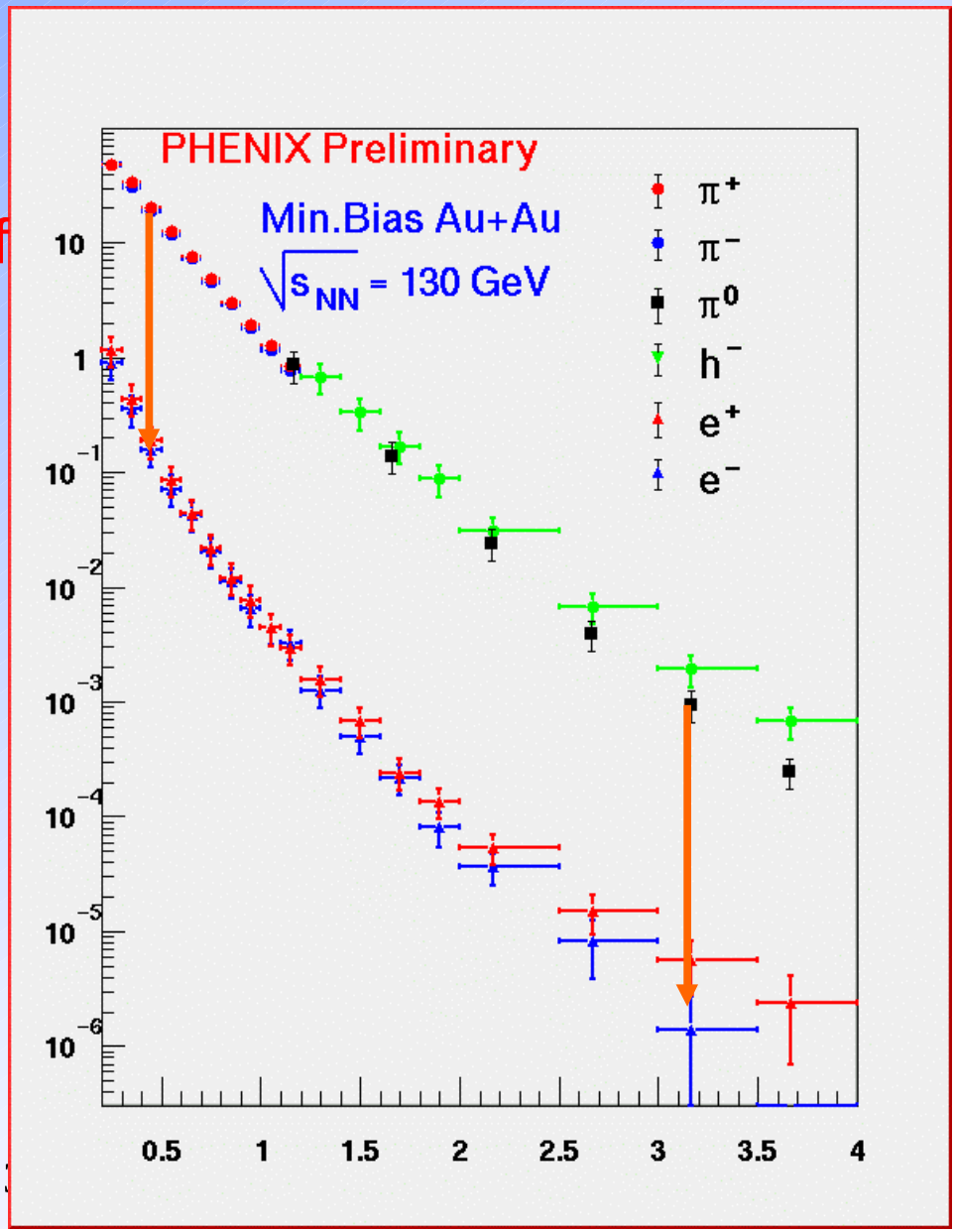
Electron Spectra

- Have begun detailed investigation of electron yields
- ➡ Clean results using full array of PHENIX tracking, PID and calorimetry
- Ultimate goals:

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

Friday Plenary Session

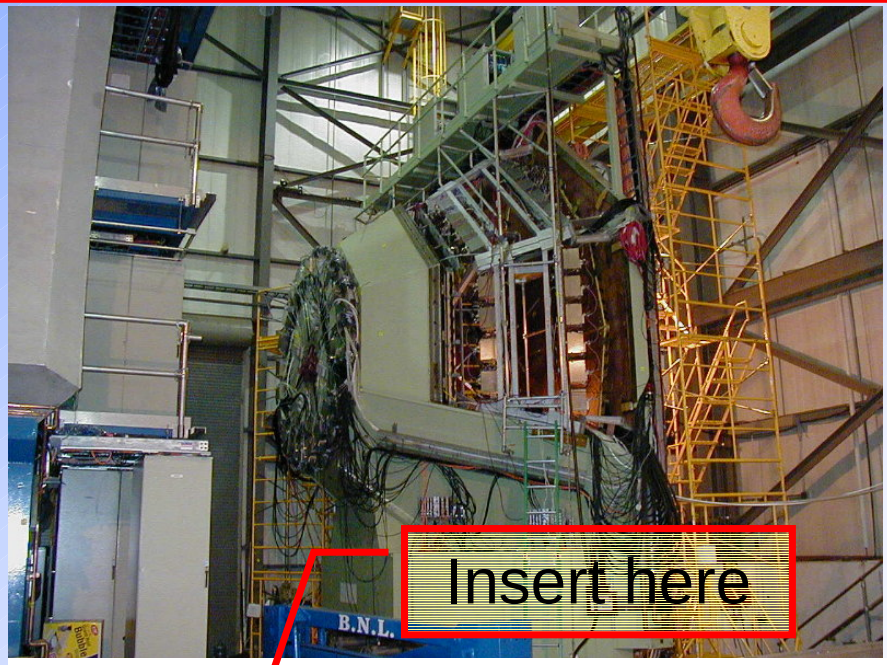
Y. Akiba: Electron Measurements *at RHIC*

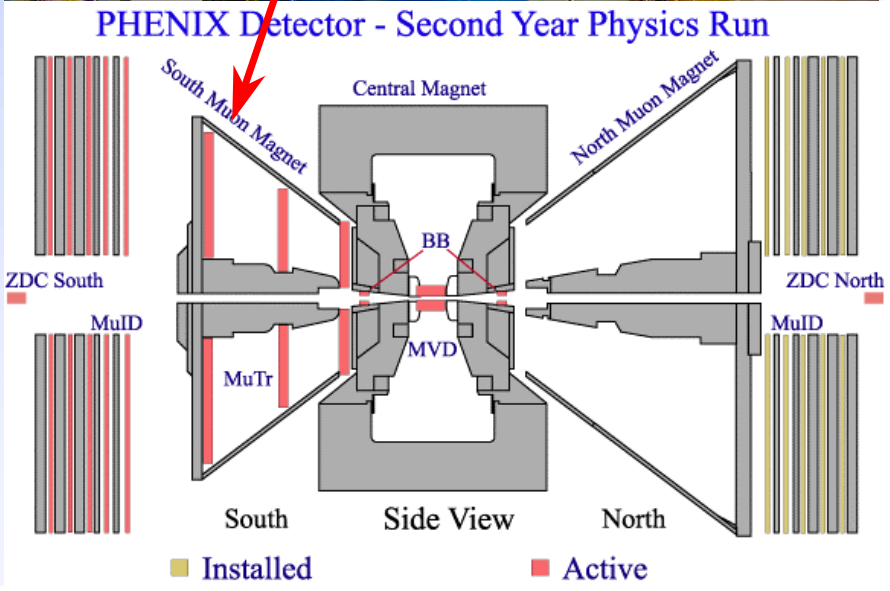


Shape of Things to Come

- Completion of Central Arms
  - ➡ Significantly increased aperture
- Addition of new capabilities
  - ❑ South Muon Arm
  - ❑ Di-muon physics
- Upgraded
  - ❑ Triggers
  - ❑ Data Acquisition

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





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
    - (more)
  - Observed
    - Role of hard scattering
    - Intriguing systematics in high p_T particle yield
- *Ideally positioned to dramatically extend these results in second year of RHIC running*