Results on Au+Au collisions at 130 and 200AGeV from the PHENIX experiment

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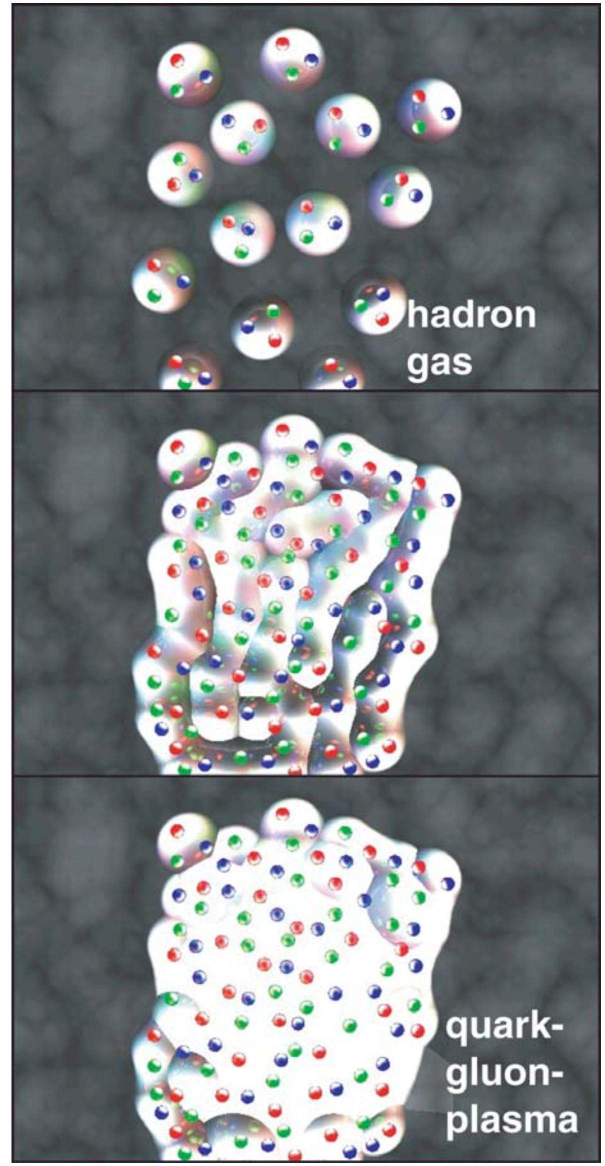
Outline

- introduction
  - motivation
  - experimental setup
- global observables:
  - E_T
  - multiplicity
- hadron production
  - identified particles: spectra, mean p_T, dN/dy
  - high p_T neutral pion production
  - particle ratios
- azimuthal correlations
  - elliptic flow
  - jets
- electromagnetic probes
  - direct photons
  - single electrons
  - J/ψ production
- conclusions

The Search for the Quark-Gluon-Plasma

- two phases of strongly interacting matter
  - ordinary hadronic matter
  - quark-gluon-plasma
    - » deconfinement
    - » chiral symmetry restoration
- fundamental understanding of QCD!
- achievable in
  - big bang
  - neutron stars
  - high energy nuclear reactions



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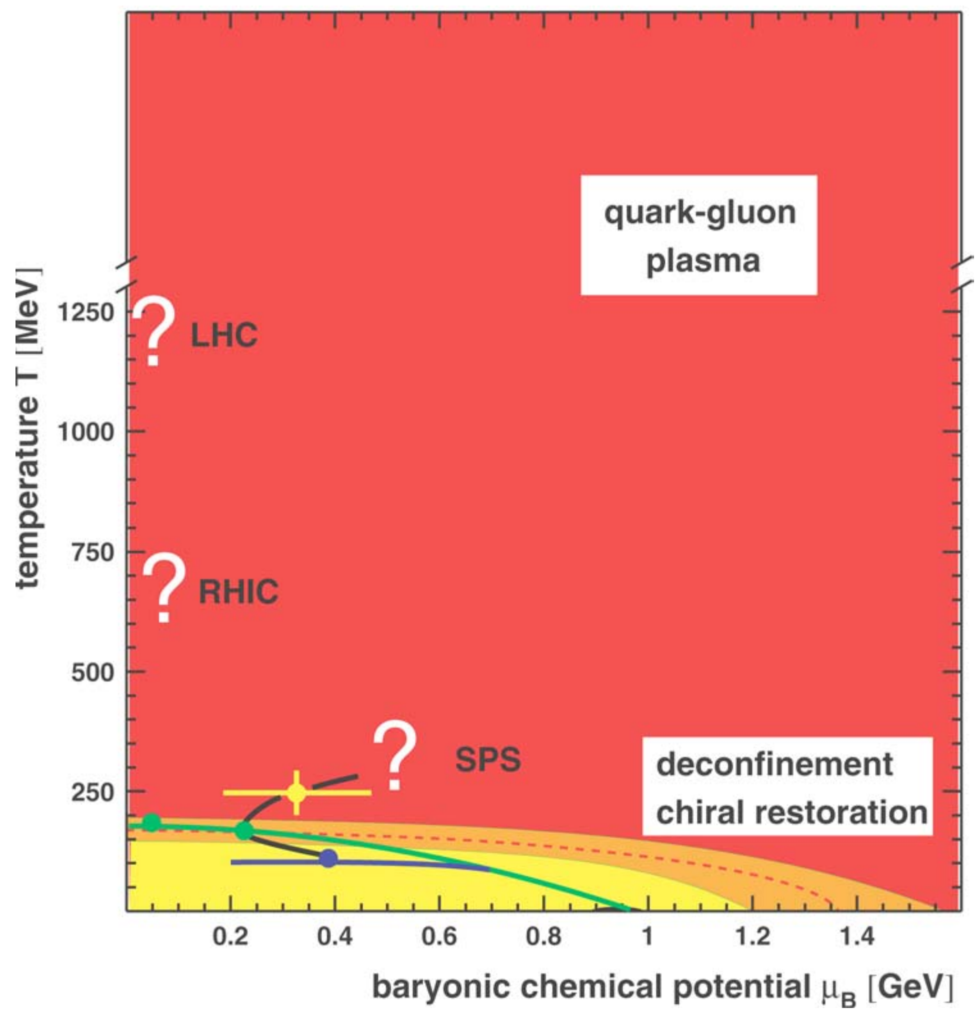
Phase Diagram of Strongly Interacting Matter

- circumstantial evidence for new phase of matter at SPS
  - dominated by hadronic phase
- experiments at RHIC (200 GeV)
  - higher energy density and temperature in the initial state
  - longer lifetime of possible QGP phase
  - theoretically easier
  - new observables
    - » jets
    - » heavy quarks



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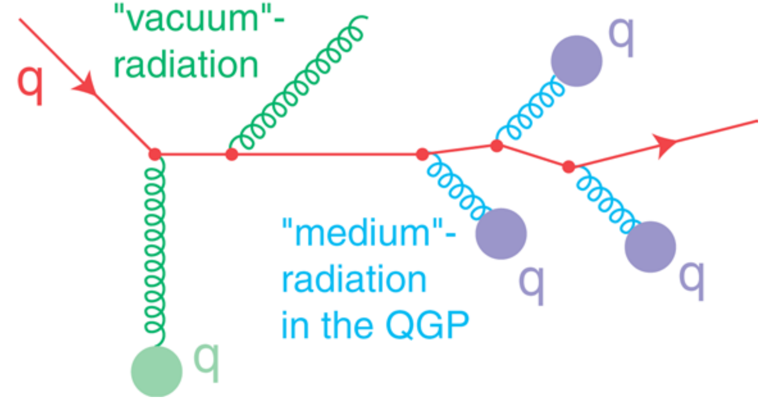
QGP Signatures



- many fascinating hints for new “state of matter” at SPS
  - J/ψ suppression
  - strangeness enhancement
  - direct photon emission
  - di-electron anomaly
  - ...
- opportunities at RHIC
  - clearer signatures
    - » larger ε and T
  - new domains
    - » hard scattering important
    - » jet quenching as signature

- jet quenching
  - parton energy loss in hot, dense matter
    - » medium induced gluon radiation
  - non-linear ($\Delta E \propto L^2$)
    - » interference, multiple scattering
  - sensitive to deconfinement!?
  - reduced particle yield at high p_T
  - disappearance of jet structures

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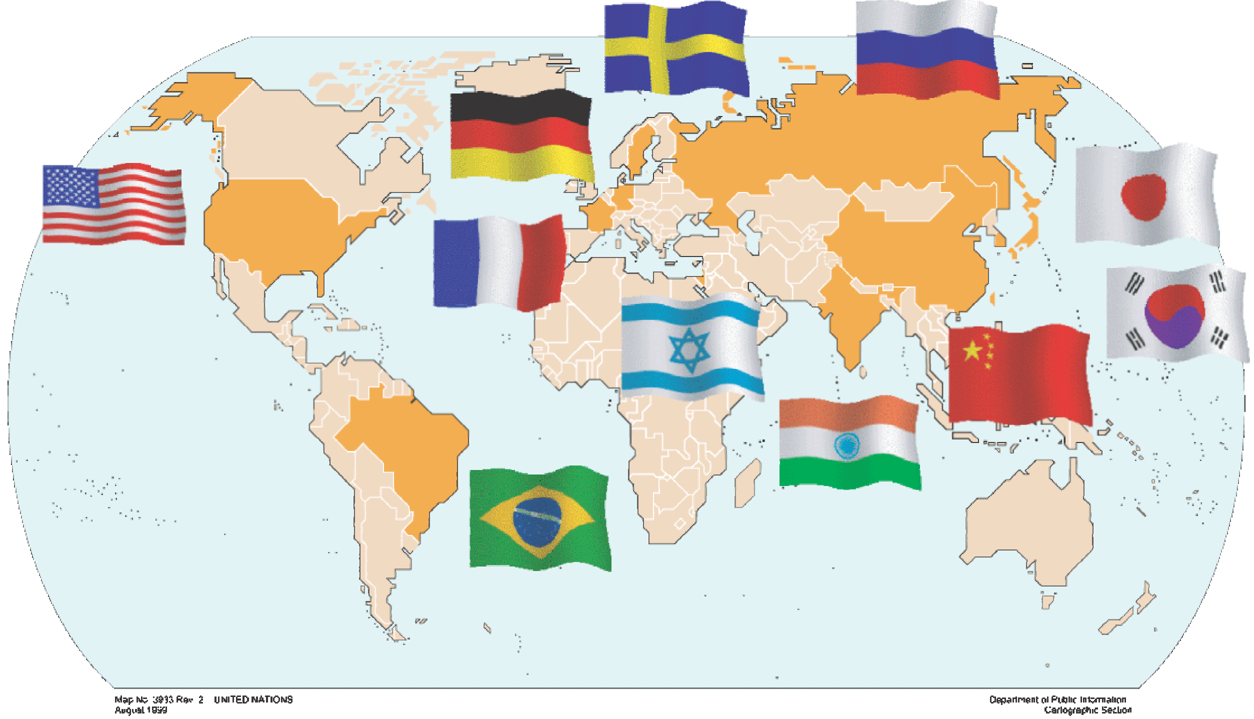

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The PHENIX Experiment

- PHENIX = Pioneering High Energy Nuclear Interaction eXperiment
- study of nuclear matter under extreme conditions (quark-gluon-plasma)
  - nuclear reactions at the highest available beam energies
    - » Au+Au at 200 AGeV
- a multitude of observables
  - focus on penetrating probes (γ, e^+e^-,$\mu^+\mu^-$)
    - » sensitive to early phase
  - identified hadrons at high p_T
  - global variables, flow, interferometry, fluctuations,...
- future: measurement of the spin structure of the proton
  - polarized proton beams
  - e.g. measurement of the polarized gluon structure functions
    - » quark-gluon-Compton-scattering

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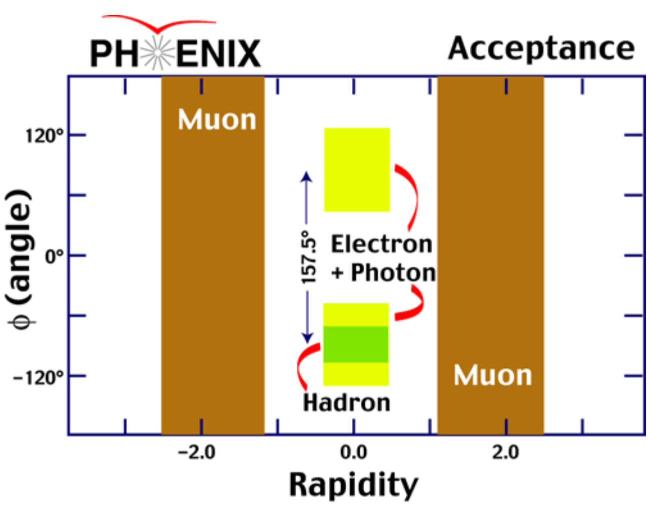
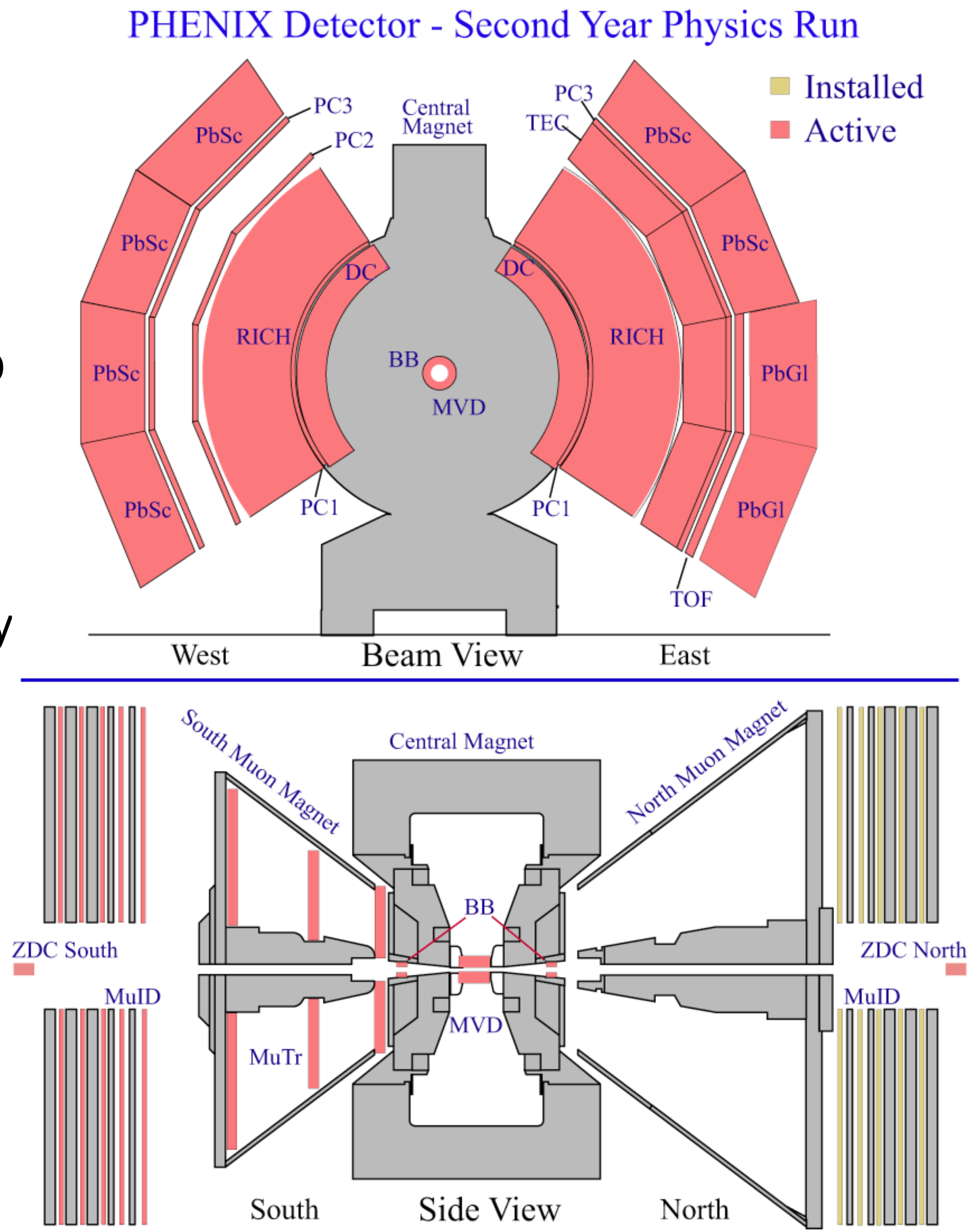
Experimental Setup

- two central detector arms
  - charged particle tracking and PID
  - EM calorimetry
- two muon arms
  - muon tracking and ID
- global detectors (trigger, centrality vertex)
  - » Beam-Beam-Counter
  - » Zero-Degree-Calorimeter





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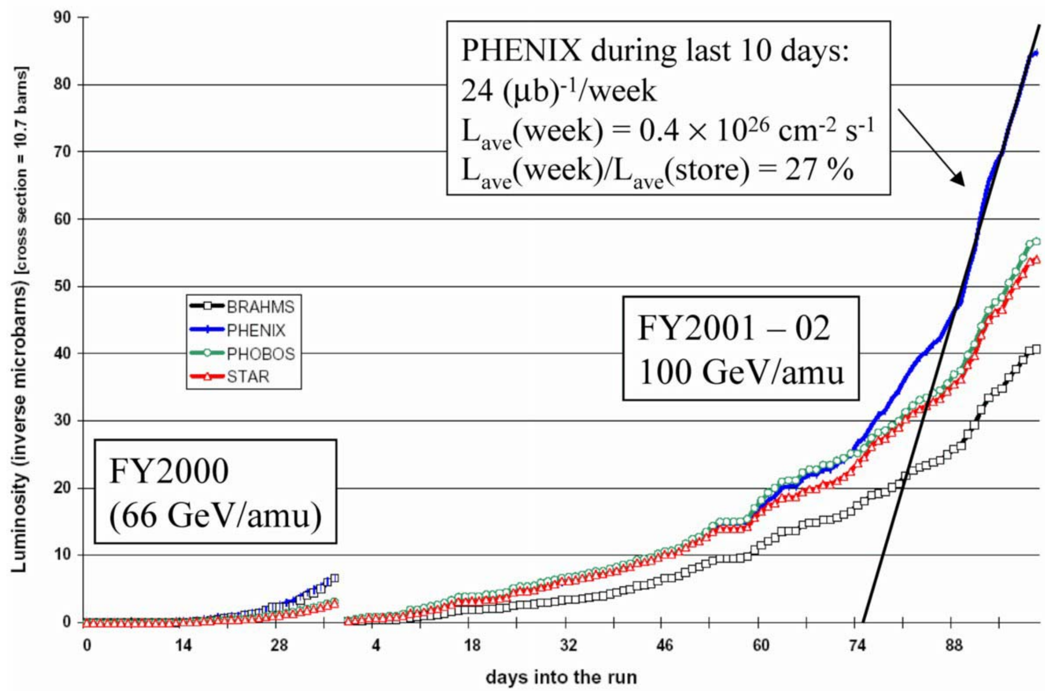
PHENIX – Run II

- Au-Au at E_{cm} = 200 GeV
  - RHIC delivered 42 μb^{-1} to PHENIX
  - "minimum bias" and Level-2 triggers: 24 μb^{-1}
- Proton-Proton at E_{cm} = 200 GeV
  - RHIC delivered 700 nb^{-1} to PHENIX
  - "minimum bias" and Level-1 triggers 150 nb^{-1}



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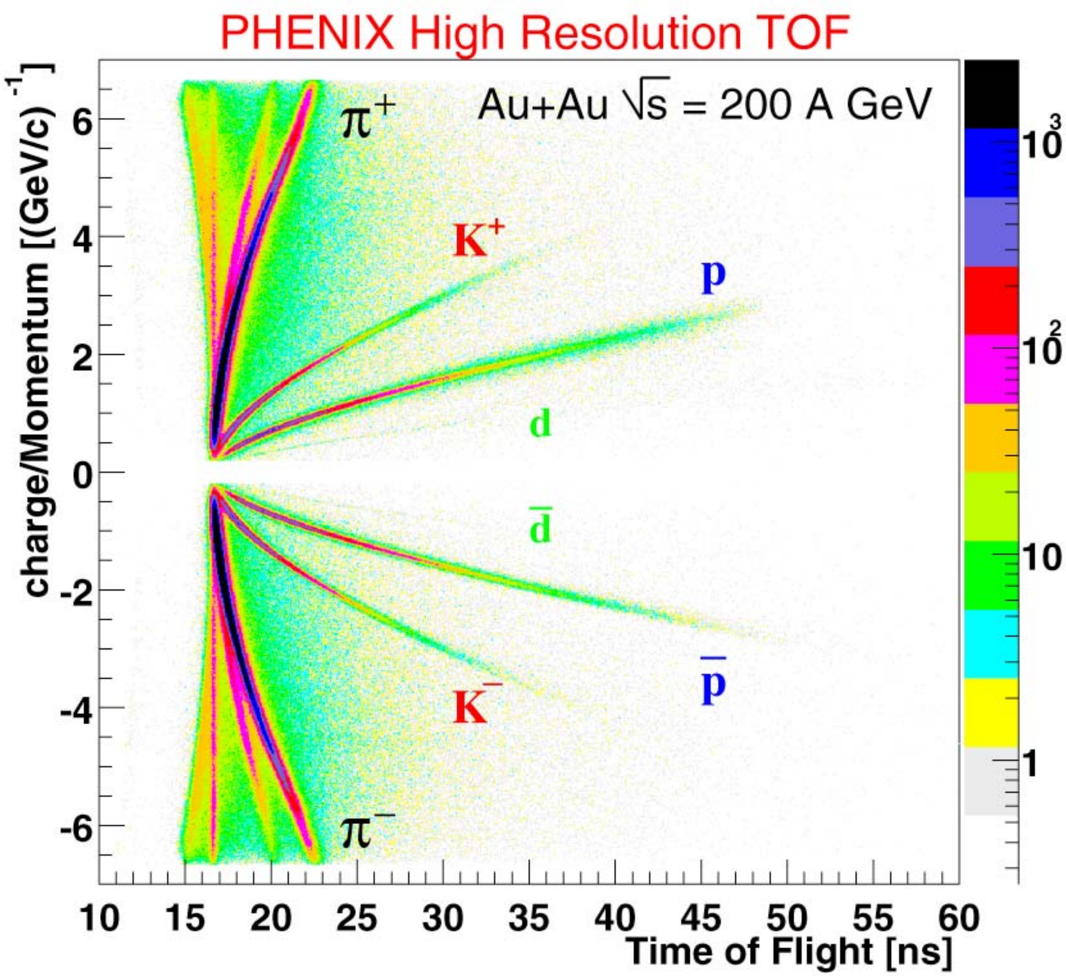
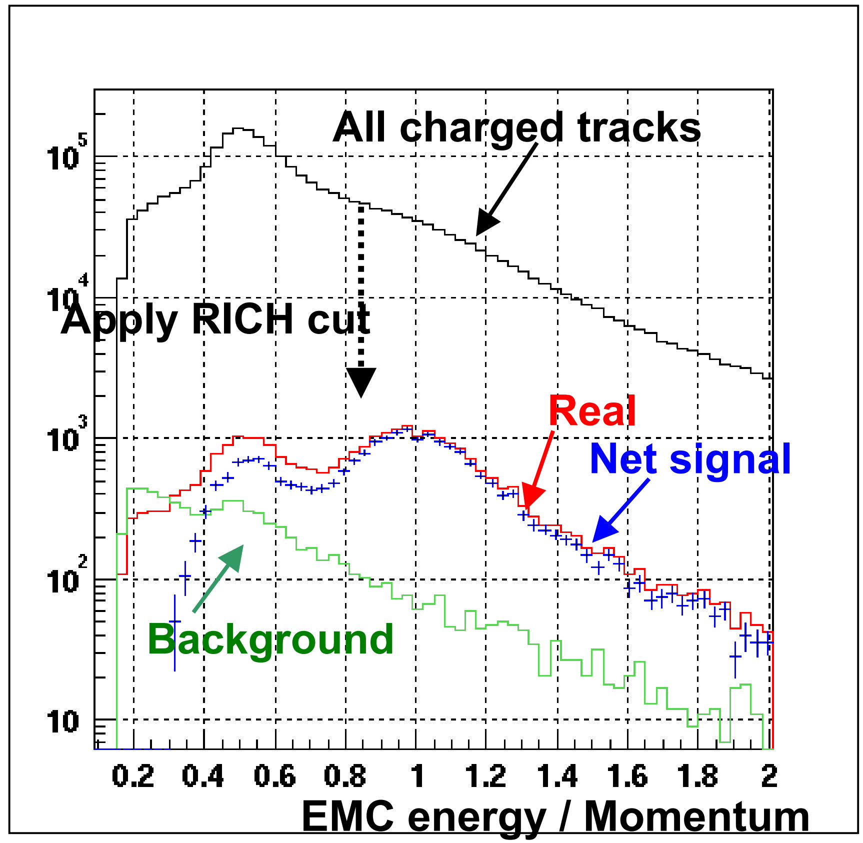
Excellent Particle Identification

- Hadron ID in TOF
- Electron ID in RICH and EMCal





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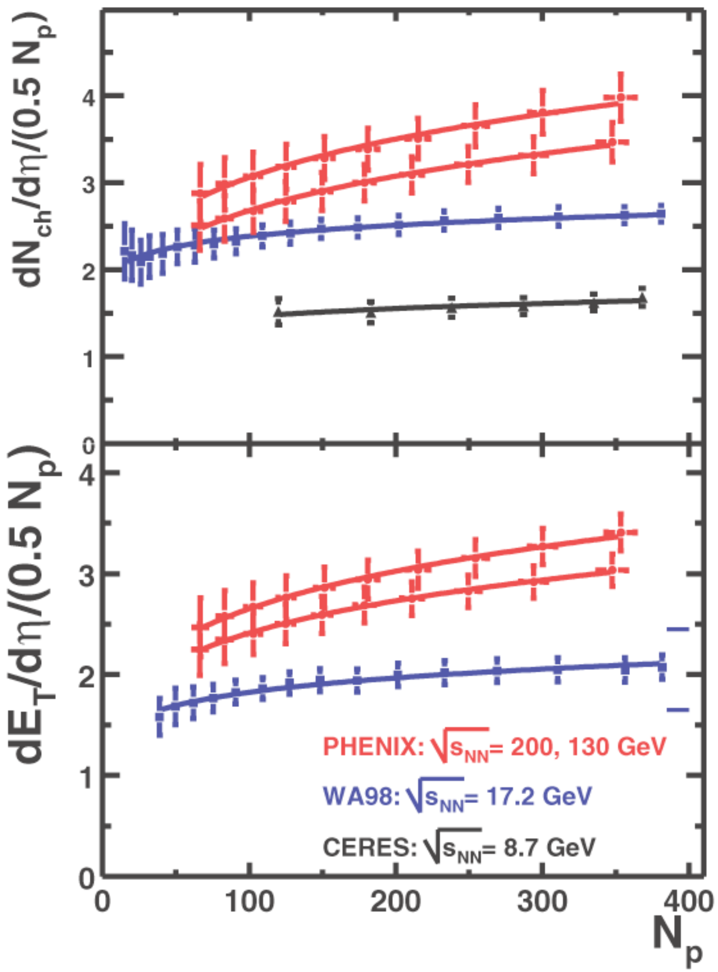
Global Variables



- charged multiplicity and transverse energy significantly higher at RHIC compared to SPS
- weak centrality dependence of N_{ch}/N_{part} and E_T/N_{part}
- energy density in 2% most central collisions

$$\varepsilon = \frac{1}{\pi R^2 \tau_0} \cdot \frac{dE_T}{d\eta}$$

$$\approx 5.5\,\text{GeV}/\text{fm}^3 \Big/ \left(\frac{\tau_0}{\text{fm}/c}\right)$$

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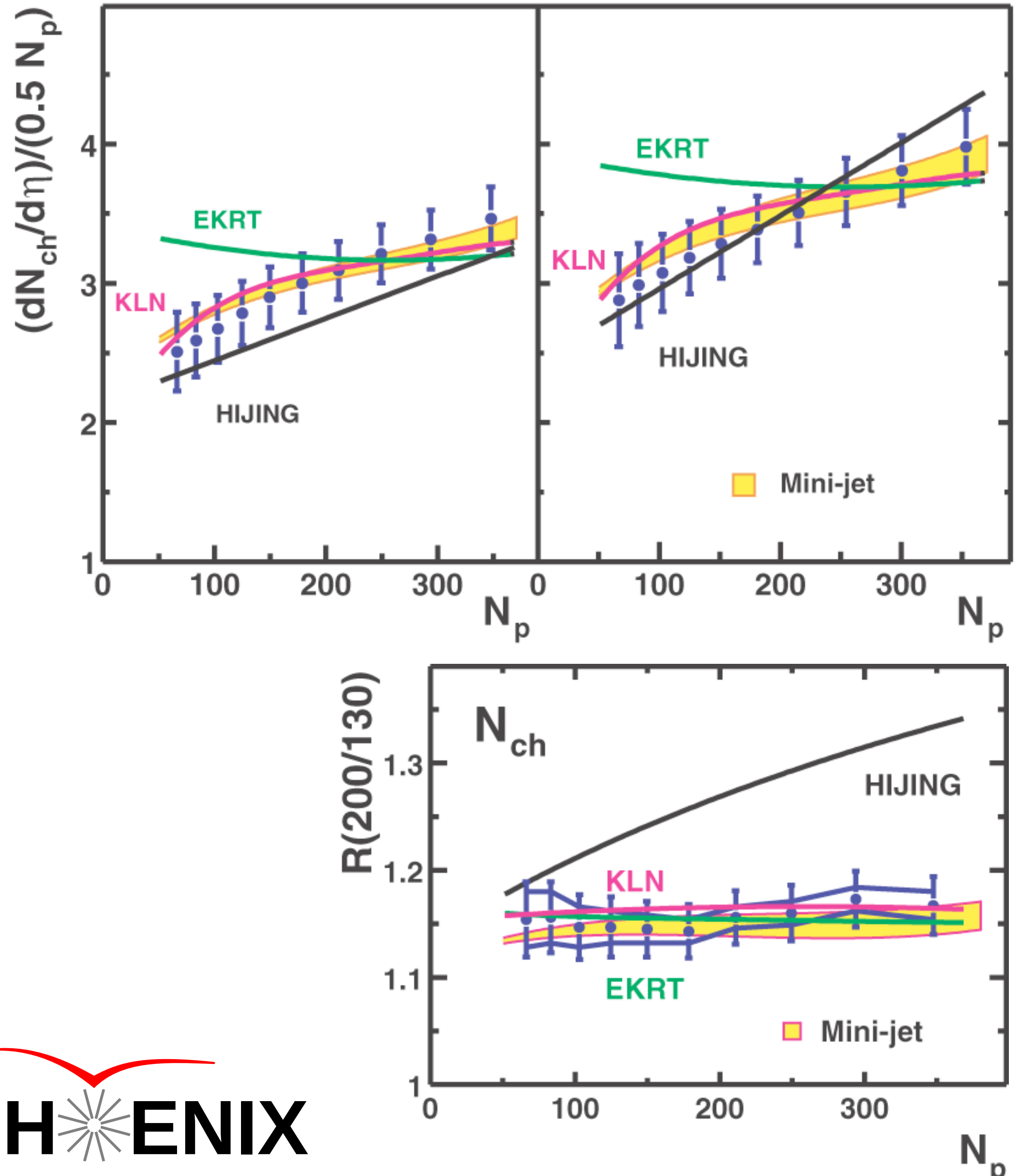
N_{ch} Model Comparison



HIJING
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PRL 86, 3498 (2001)

EKRT
K.J.Eskola et al,
Nucl Phys. B570, 379 and
Phys.Lett. B 497, 39 (2001)

KLN
D.Kharzeev and M. Nardi,
Phys.Lett. B503, 121 (2001)
D.Kharzeev and E.Levin,
Phys.Lett. B523, 79 (2001)

Mini-jet
S.Li and X.N.Wang
Phys.Lett.B527:85-91 (2002)

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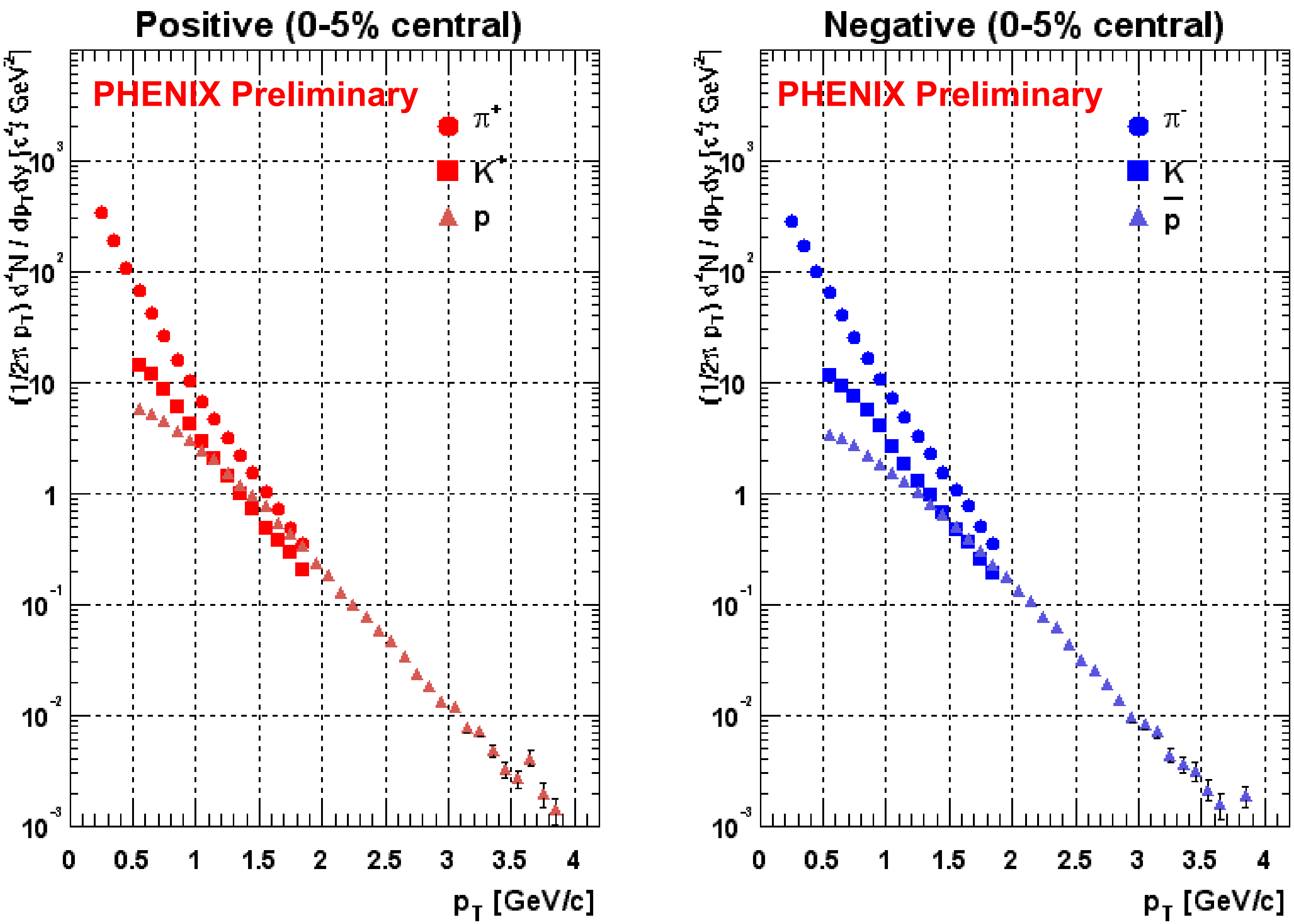
Identified Charged Hadron Spectra



- identified hadrons over large p_T-range
- protons ≈ pions at 2 GeV/c

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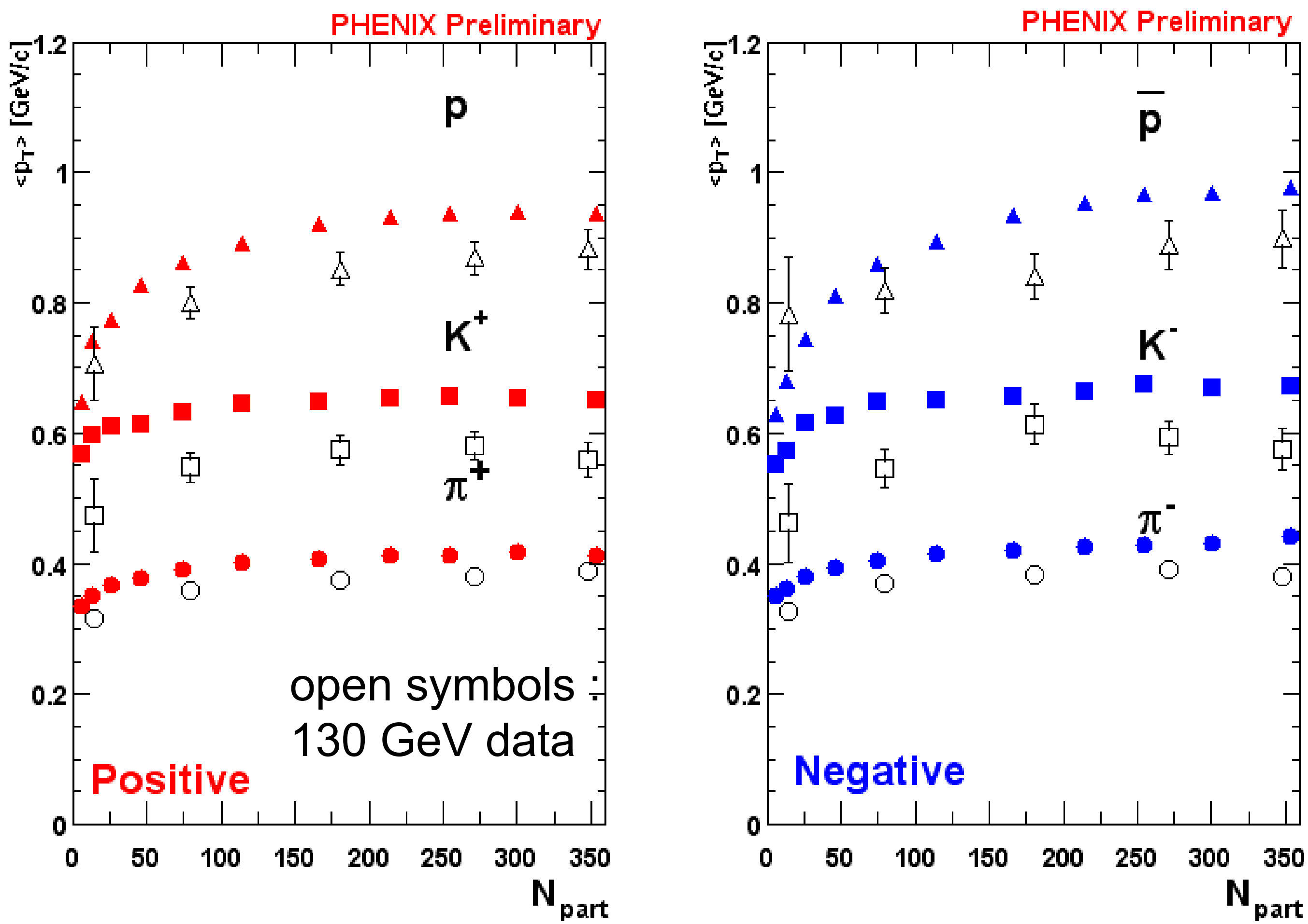
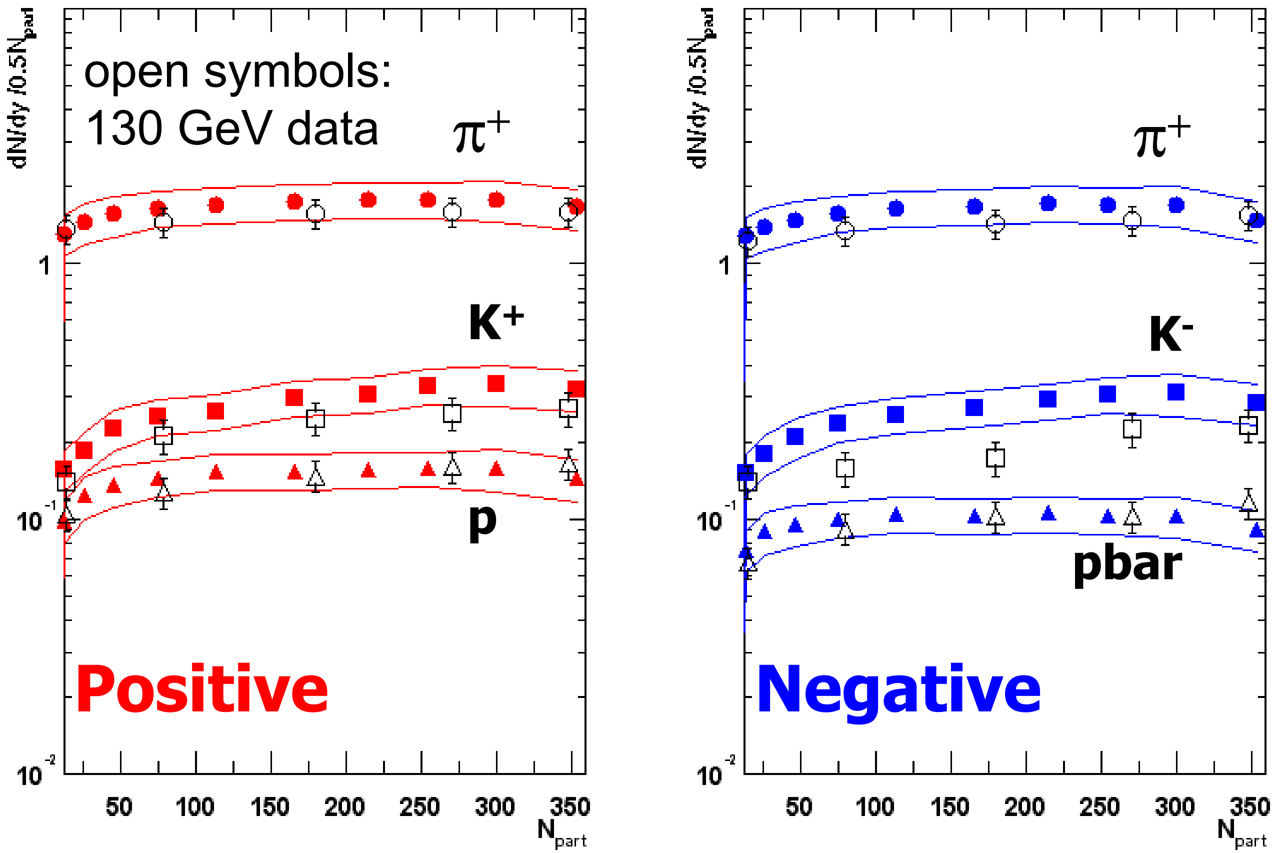
Mean Transverse Momentum



- increase for peripheral collisions and saturation for central
- values and increase larger for heavier particles
  - collective transverse flow?

Pseudorapidity Density



- weak centrality dependence of $(N_X/dy)/N_{part}$
- behavior similar for 130 and 200 GeV

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Suppression of Hadron Production

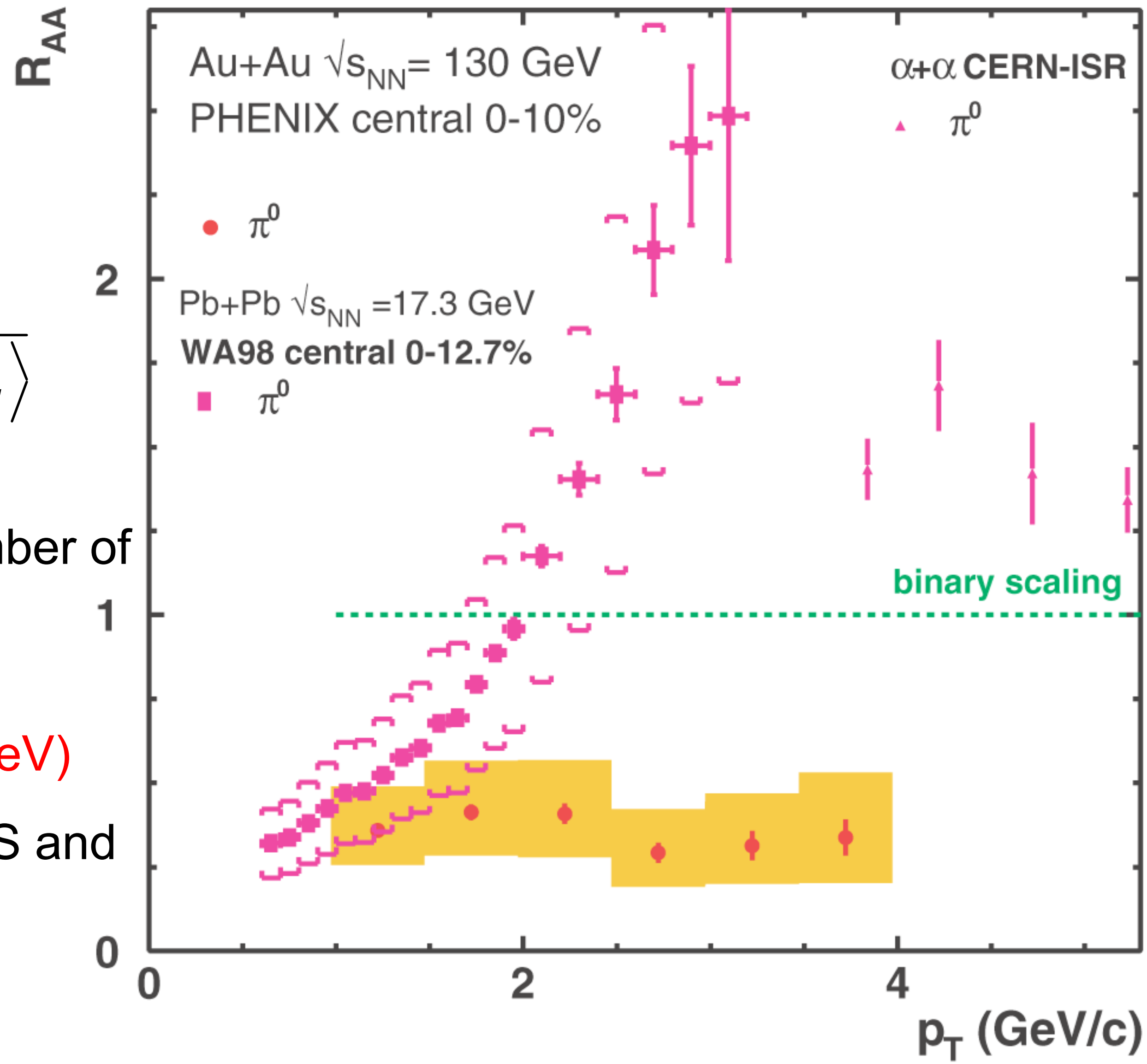
M.M. Aggarwal et al., Eur.Phys.J.C 23, 225-236, 2002

K. Adcox et al. , Phys. Rev. Lett. 88, 22301 (2002)

- ratio of p_T-spectra
  - AA central / pp

$$R_{AA} \equiv \frac{d^2N^{AA}/dydp_T}{d^2N^{pp}/dydp_T \cdot \langle N_{coll}^{AA} \rangle}$$

- R_{AA} =1 for scaling with number of binary collisions
- $R_{AA} < 1$ for central Au+Au reactions at RHIC (130 AGeV)
- $R_{AA} > 1$ for reactions at SPS and ISR



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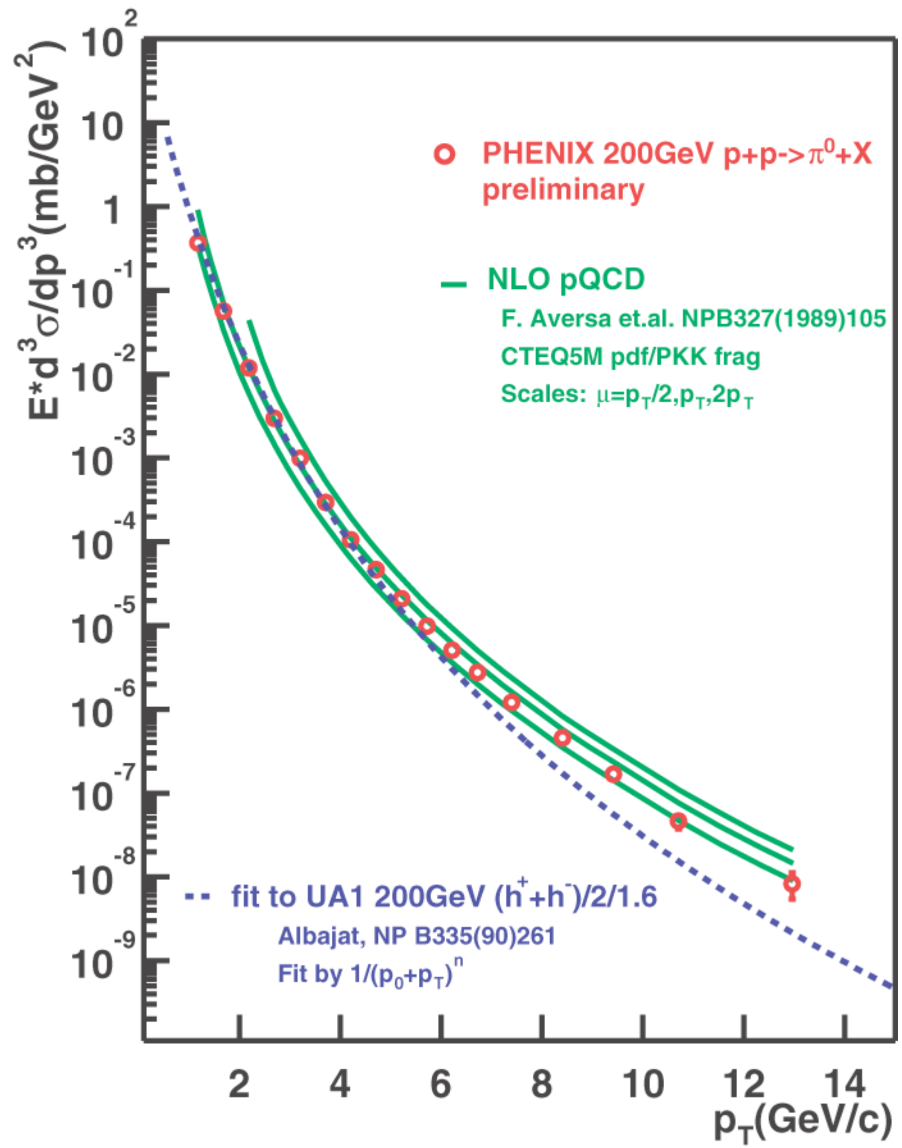
The Reference: Spectra in pp at 200 GeV

- measurement of neutral pion spectra in pp
  - reference for AA
    - » same detector, same systematics as AA
- consistent with pQCD calculations



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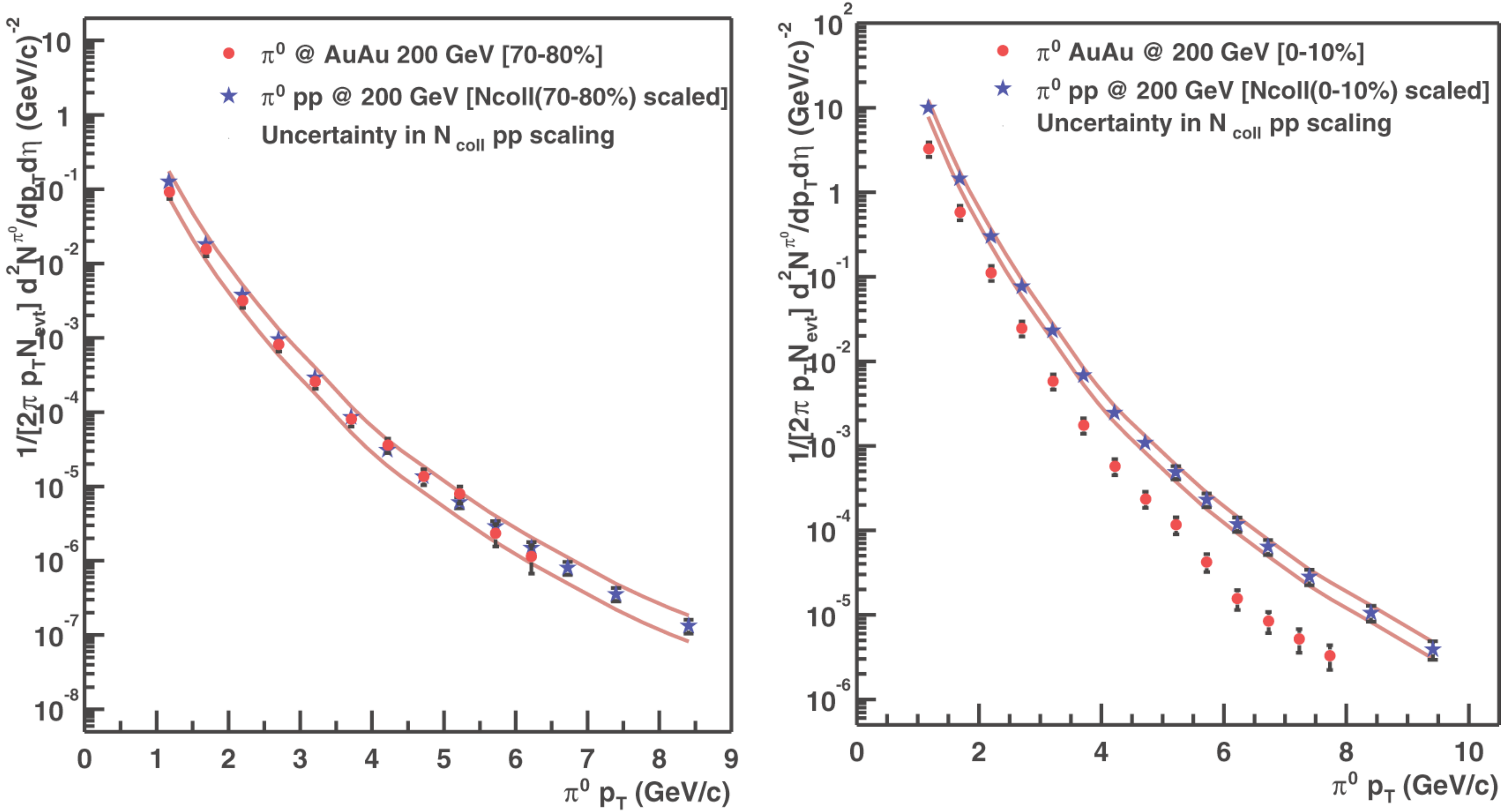
Neutral Pion Spectra in Au+Au at 200GeV



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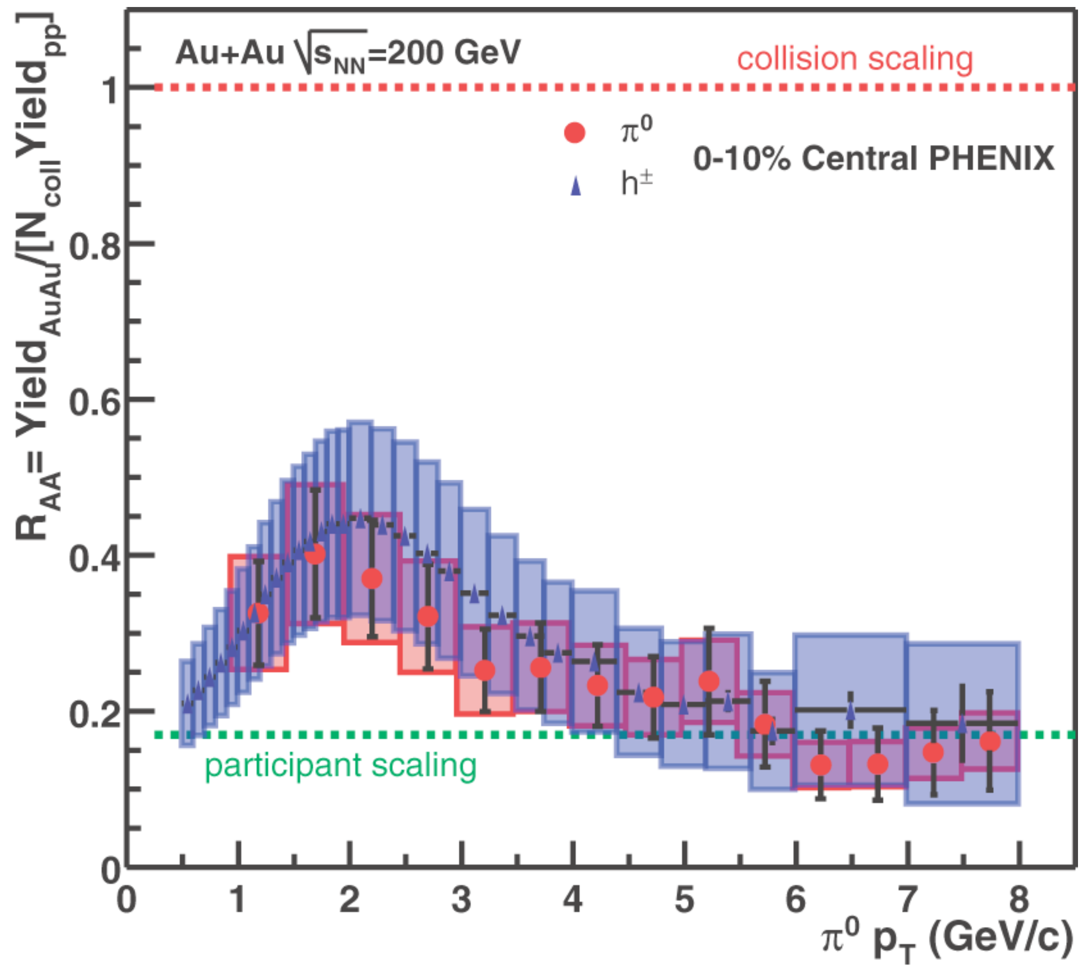
Suppression in Hadron Spectra – The Nuclear Modification Factor

- nuclear modification factor
  - p_T-spectra for AA-central/pp

$$R_{AA} \equiv \frac{d^2N^{AA}/dydp_T}{d^2N^{pp}/dydp_T \cdot \langle N_{coll}^{AA} \rangle}$$

- strong suppression in π^0:
  - decreasing with p_T
  - factor 6 at p_T = 6-8 GeV/c
- similar suppression in charged hadrons
  - R_{AA} slightly higher at intermediate p_T?



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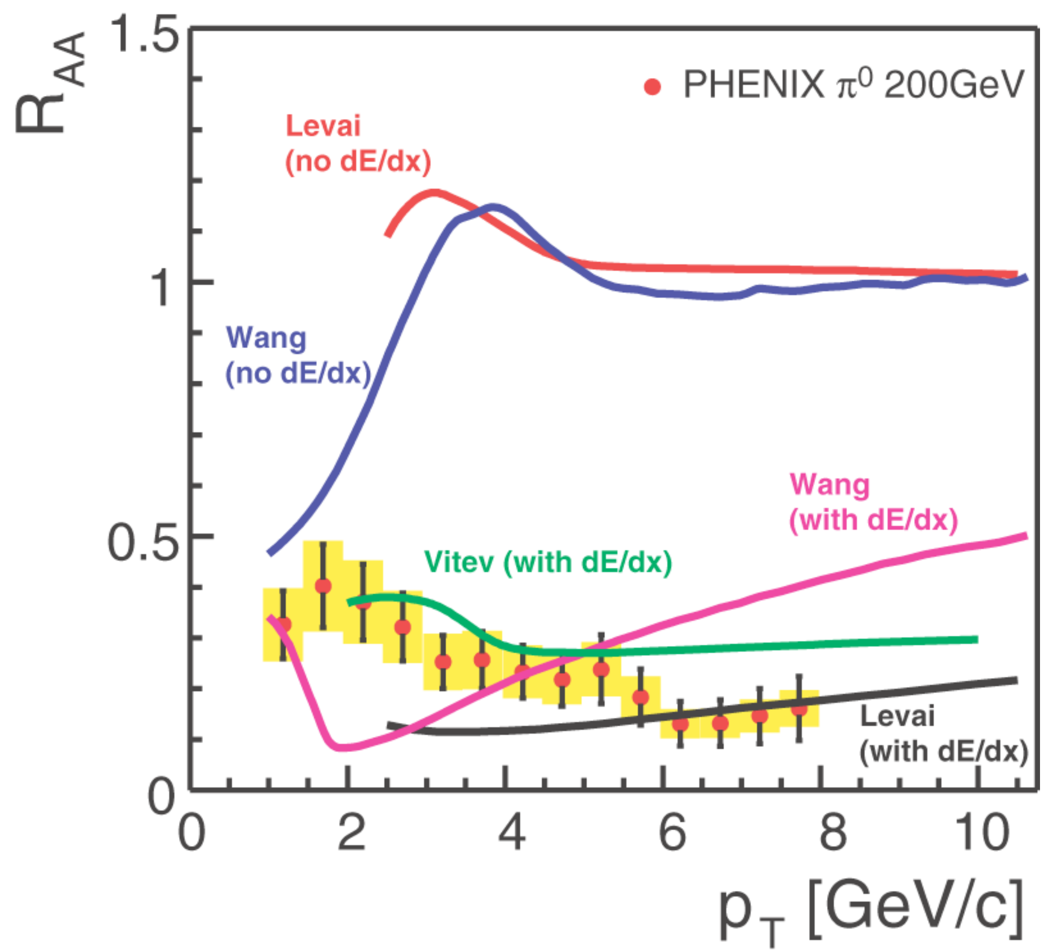
High p_T Neutral Pion Suppression – Comparison To Theory

- pQCD calculations:
  - P. Levai, Nucl.Phys.A698 (2002) 631
  - X.N. Wang, Phys.Rev.C61 (200) 064910
  - I. Vitev, talk at QM2002
- so far suppression not described by theories
  - calculations without energy loss completely off
  - energy loss calculations show different p_T dependence



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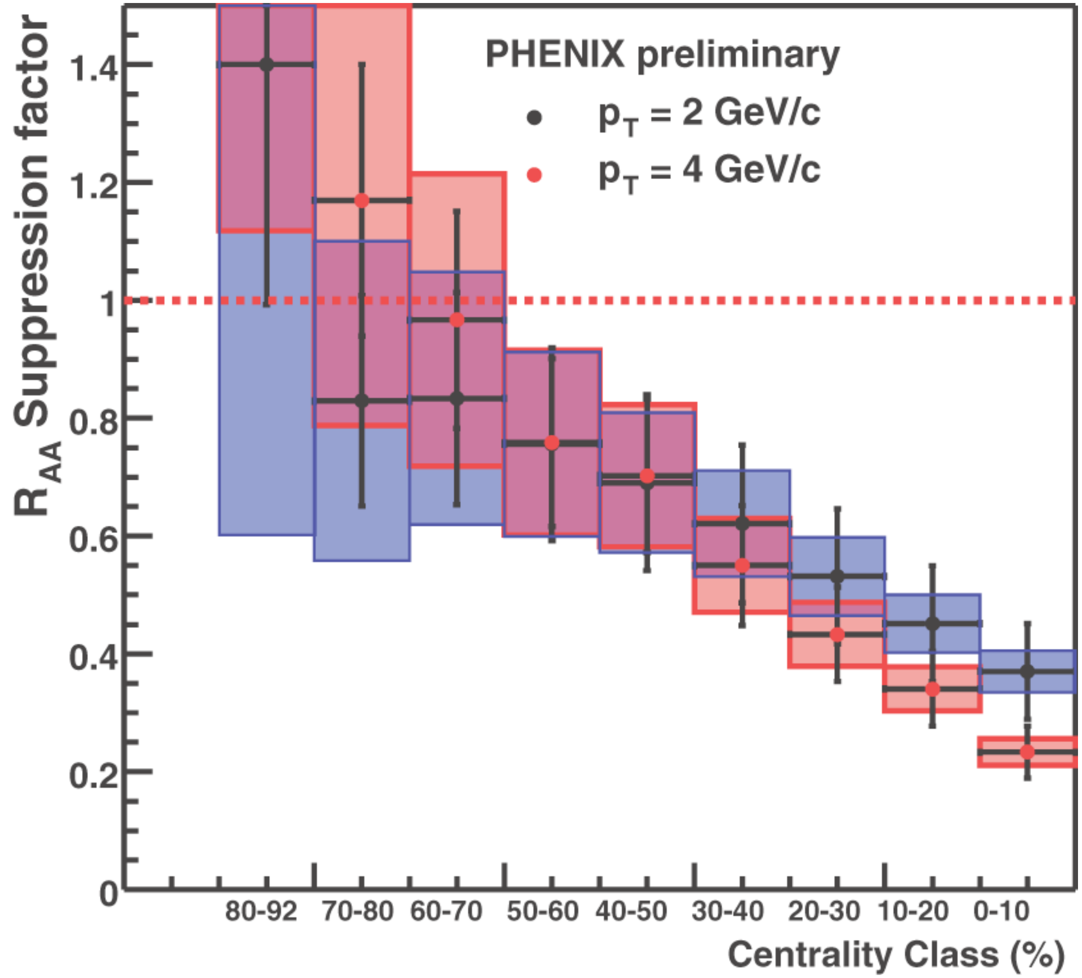
Centrality Dependence of Suppression

- R_{AA} for neutral pions as a function of centrality
  - gradual decrease
  - stronger decrease for higher p_T
- no threshold effect
  - surface-to-volume?
    - » high p_T particle emission only from surface?



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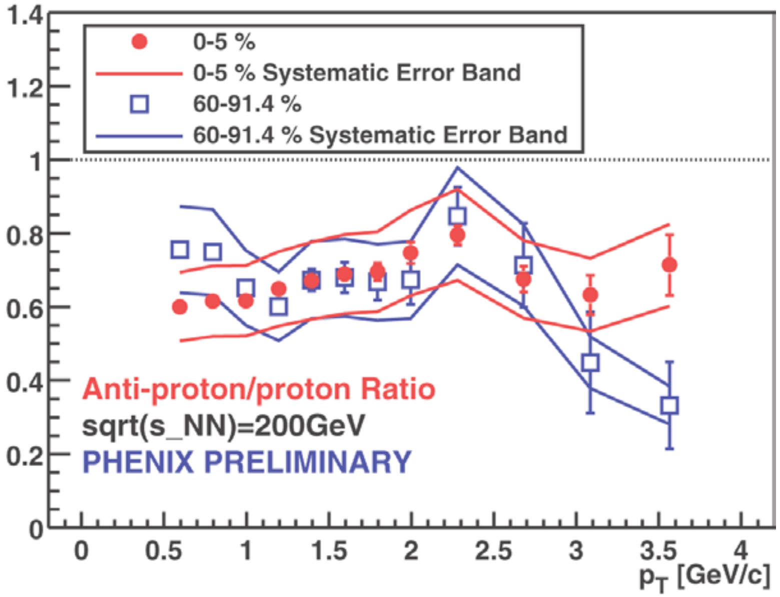
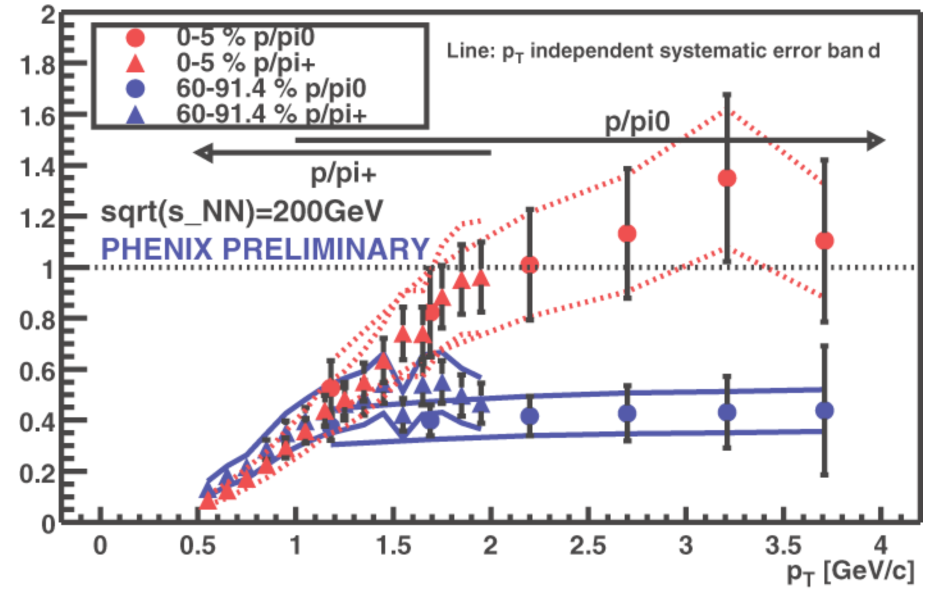
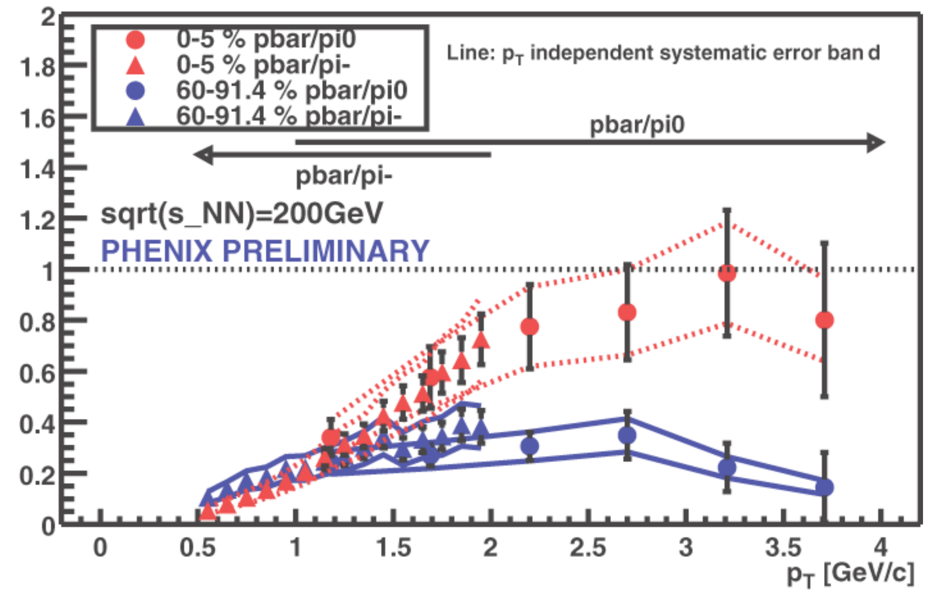
Chemical Composition at High p_T

- p/π and $\bar{p}/\pi$ ratios ≈1 for p_T = 3 GeV/c in central collisions
- $\bar{p}/p$ ratio decreasing at high p_T?
  - also in central collisions?







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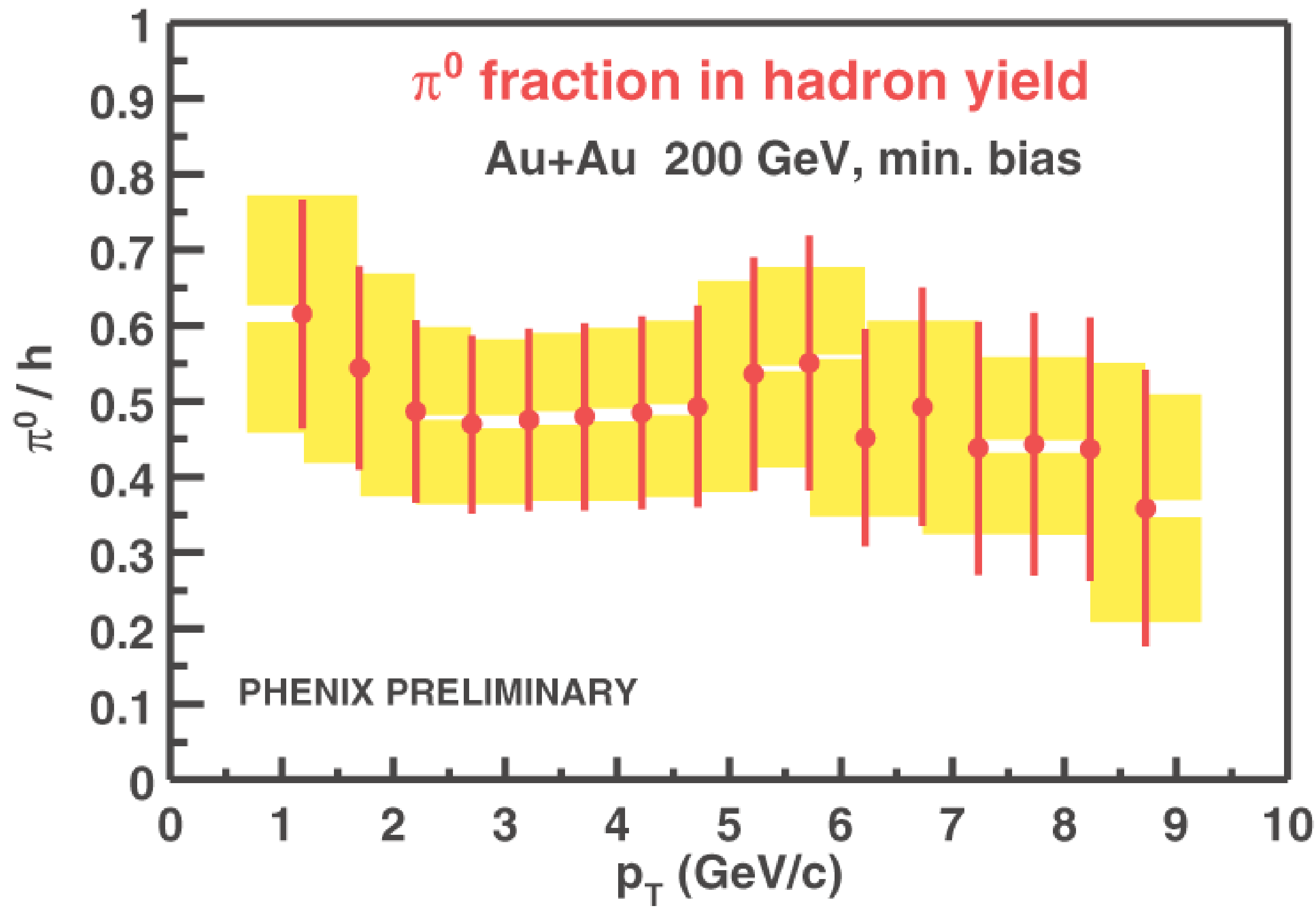
Chemical Composition at High p_T

- ratio $\pi/h \approx 0.5$ in min.bias
  - similar in central reactions
- important baryon and/or kaon contribution out to p_T = 9 GeV/c?
  - different from pQCD expectations?



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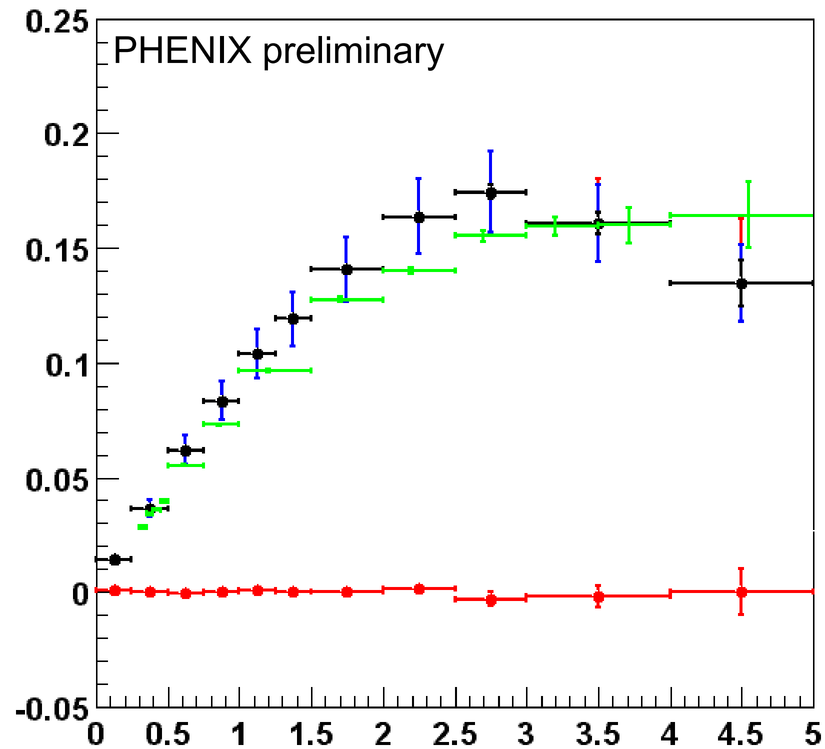
Elliptic Flow in Minimum Bias Au+Au at 200 AGeV

- azimuthal asymmetry in particle emission
  - strong effect due to pressure gradient (hydrodynamic flow)
- flow saturates for p_T > 3 GeV/c
  - asymmetry in hard scattered particles
  - asymmetric jet quenching?



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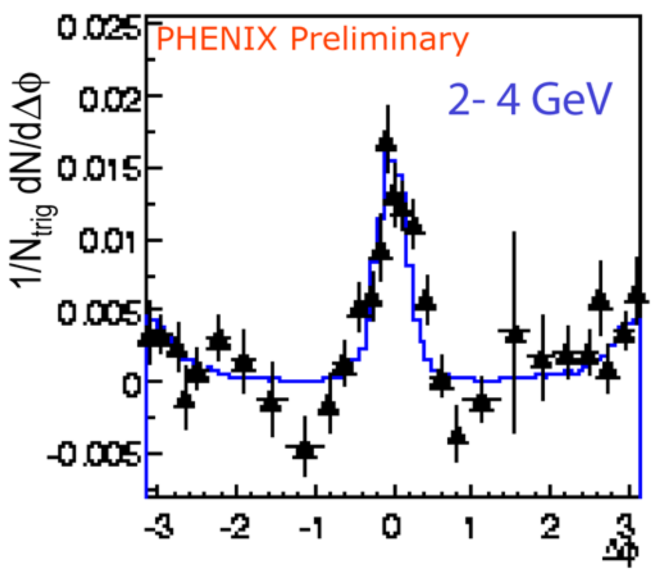
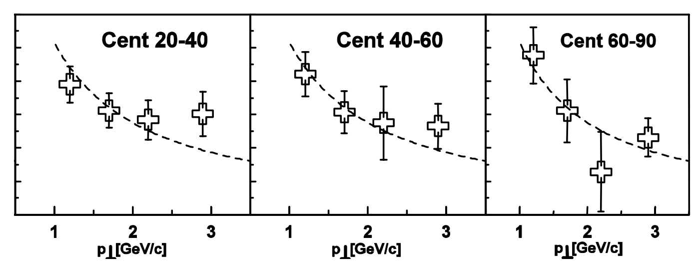
Jet Evidence in Azimuthal Correlations at RHIC

- correlation of charged tracks with γ (π^0) in triggered events
  - trigger particle p_T > 2.5 GeV/c
  - $\Delta\phi$ distribution for p_T = 2-4 GeV/c
- signature of jets in Au+Au
  - consistent with PYTHIA calculations and p+p data

- similar correlations between pairs of charged particles
- fit of jet signal with Gaussian
  - width decreases as a function of p_T
  - transverse momentum relative to jet axis consistent with expectation for jet fragmentation





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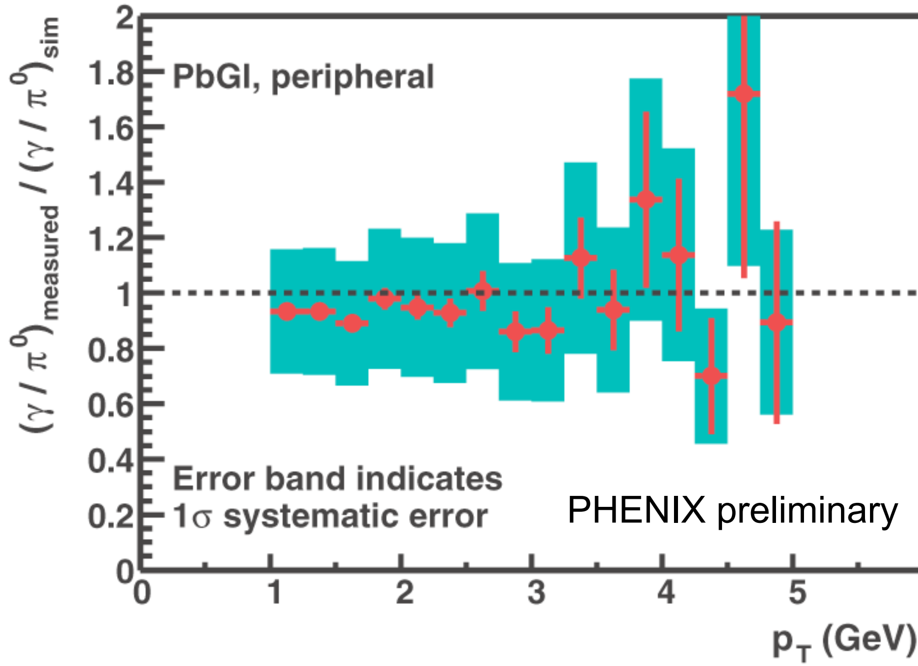
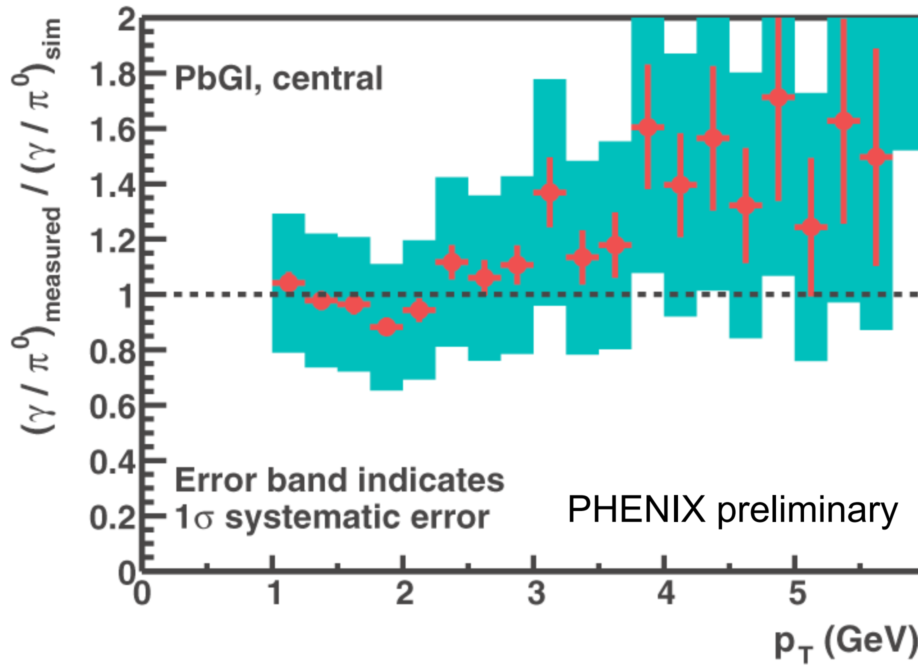
Photon Measurements

- direct photon analysis in PHENIX
  - search for thermal photons
  - prompt photons as “calibration” for high p_T hadron production
- no significant excess over hadron decays observed
  - promising results
  - important: redundancy of PHENIX
    - photon measurements in two different EMCal detectors and via conversion
    - two calorimeters yield c onsistent results
    - conversion method under study
  - significantly reduced systematic errors in the future





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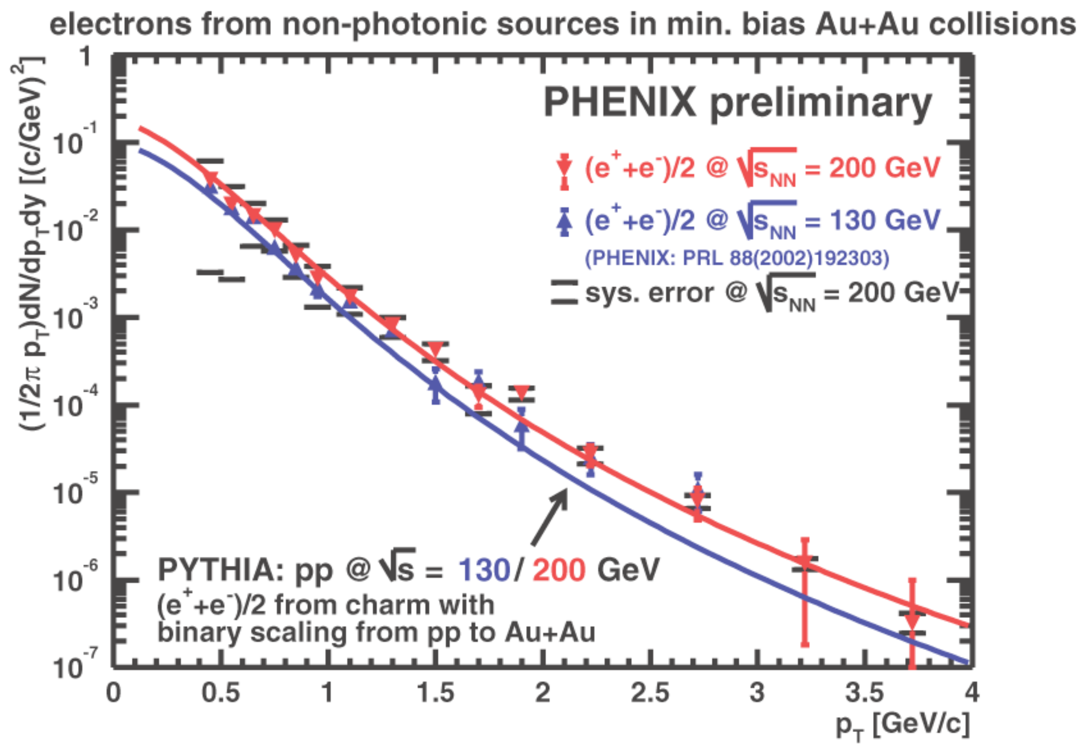
Single Electron Spectra

- electron measurements in PHENIX
  - tracking in Drift- and Pad-Chambers
  - identification in RICH and EM-calorimeter
- subtraction of background
  - photon conversions from mesons and π^0-Dalitz dominant
    - pions measured in the same experiment!
    - identification of photonic sources by converter method
- physics signal?
  - main source: open charm?

- yield and spectral shape consistent with PYTHIA calculation
- scaling with binary collisions
  - little energy loss?



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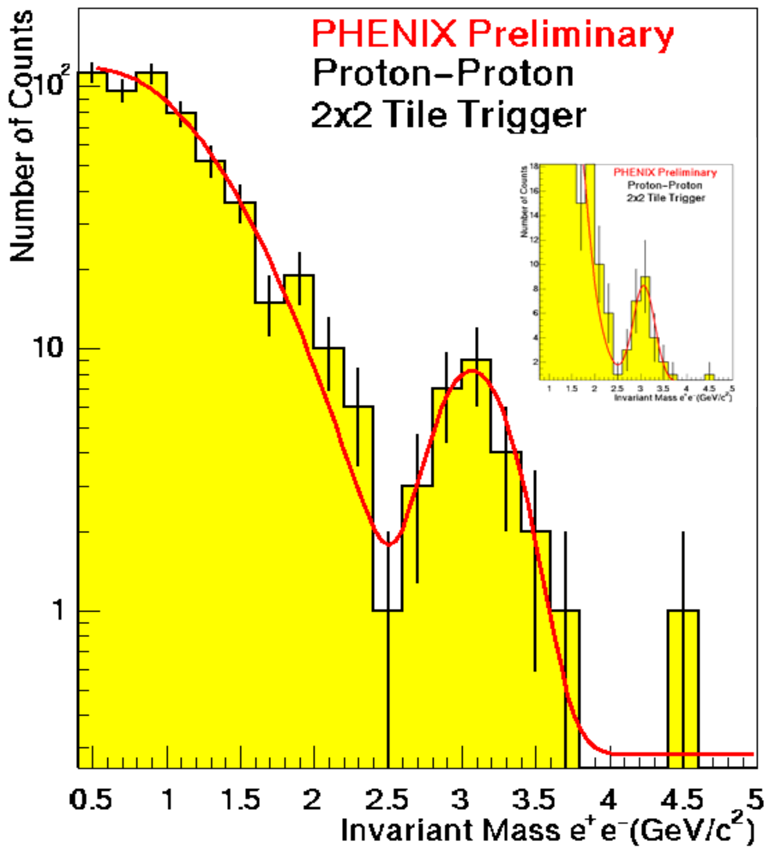
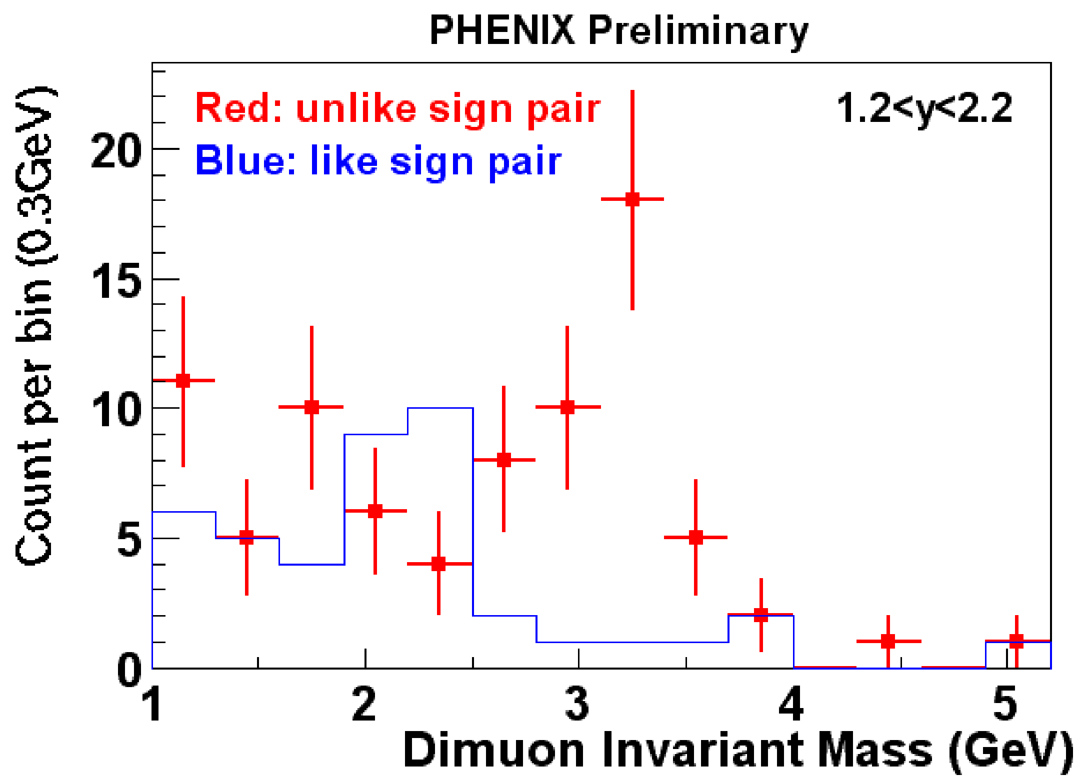
J/ψ in p+p Collisions

- $J/\psi \rightarrow \square^{+} \square^{-}$



- $J/\psi \rightarrow \mu^{+} \mu^{-}$



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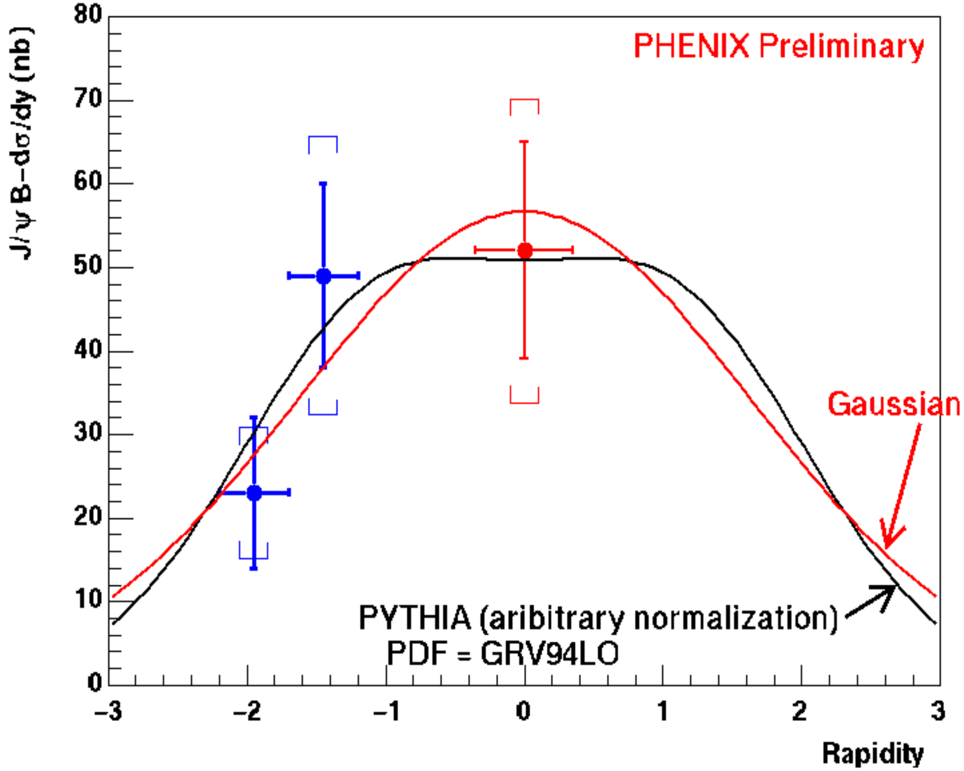
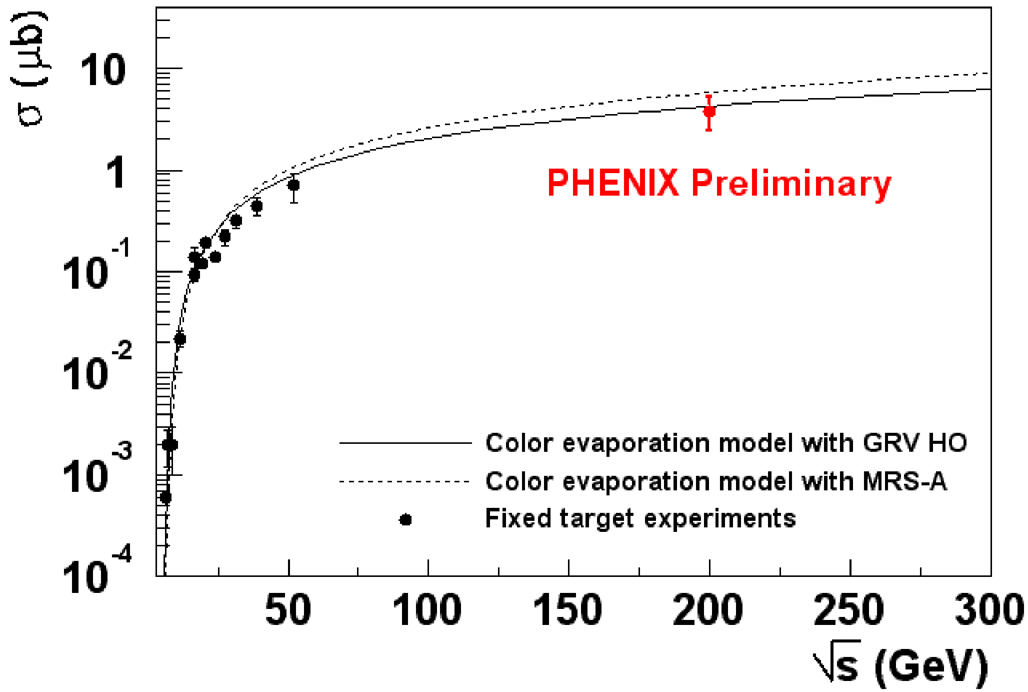
J/ψ Cross Section in p+p Collisions

- rapidity distribution



- energy dependence of total cross section



$$\sigma(pp \rightarrow J/\psi + X) = 3.8 \pm 0.6(stat) \pm 1.3(sys)\ \mu b$$

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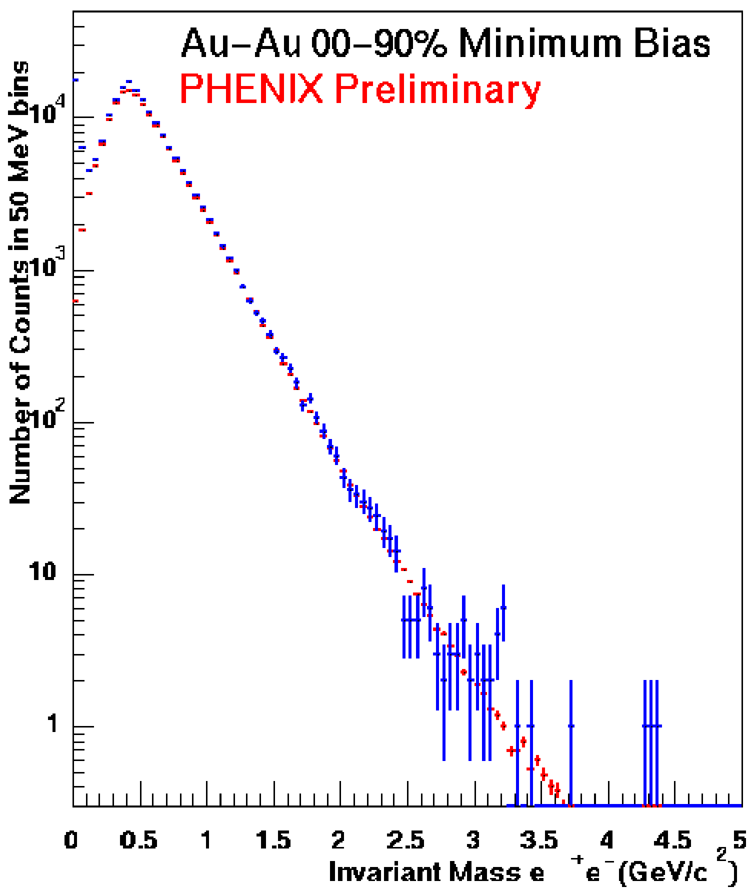
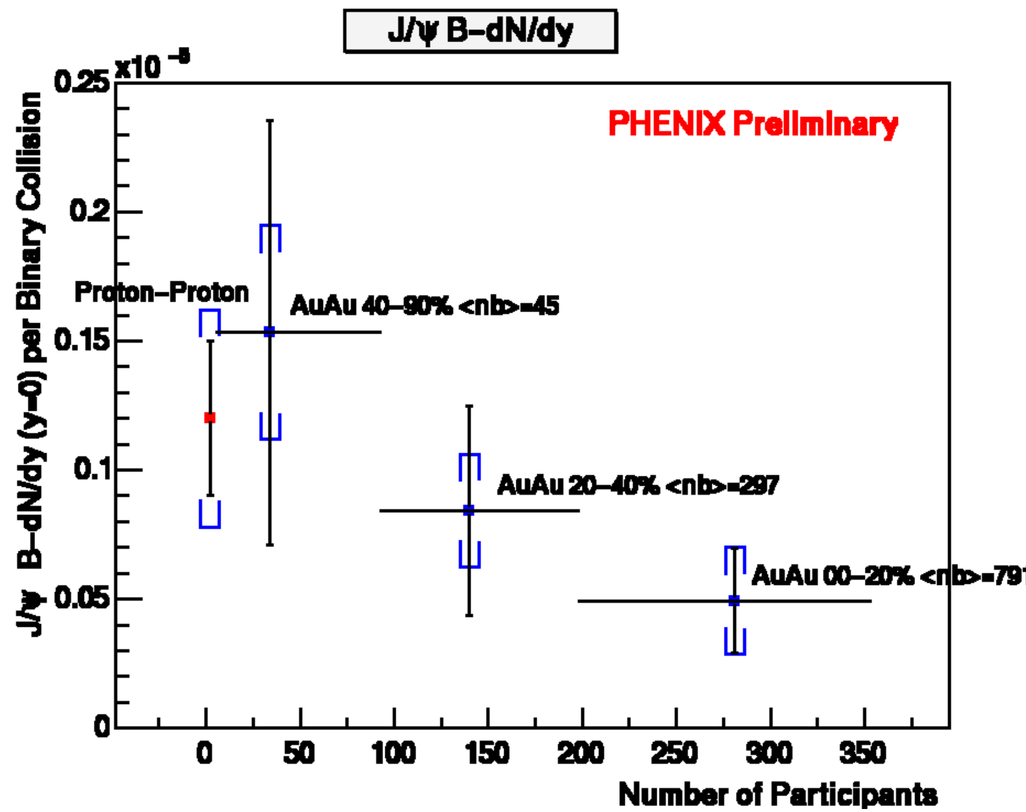
J/ψ in Au+Au Collisions



- centrality dependence
  - normalized to binary collisions



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Summary

- quenching of high p_T hadrons in central reactions established
  - neutral pions suppressed by 1/6 up to p_T = 8 GeV/c
  - suppression continuous in centrality (no threshold)
  - decreasing $\langle p_T \rangle$ at high p_T for charged hadrons
- chemical composition not (yet) jet-like
  - only ≈50% of hadrons are pions
  - role of baryons at high p_T (p/π, $\bar{p}/\pi$, $\bar{p}/p$)?
- saturation of v_2 for p_T > 3 GeV/c
  - hydrodynamics important for p_T < 3 GeV/c?
  - amount of v_2 from partial quenching?
- jets re-discovered in AA at RHIC
  - near-side correlation with trigger photon
  - most trigger particles (decay gamma) for p_T > 2.5GeV/c from jets?!

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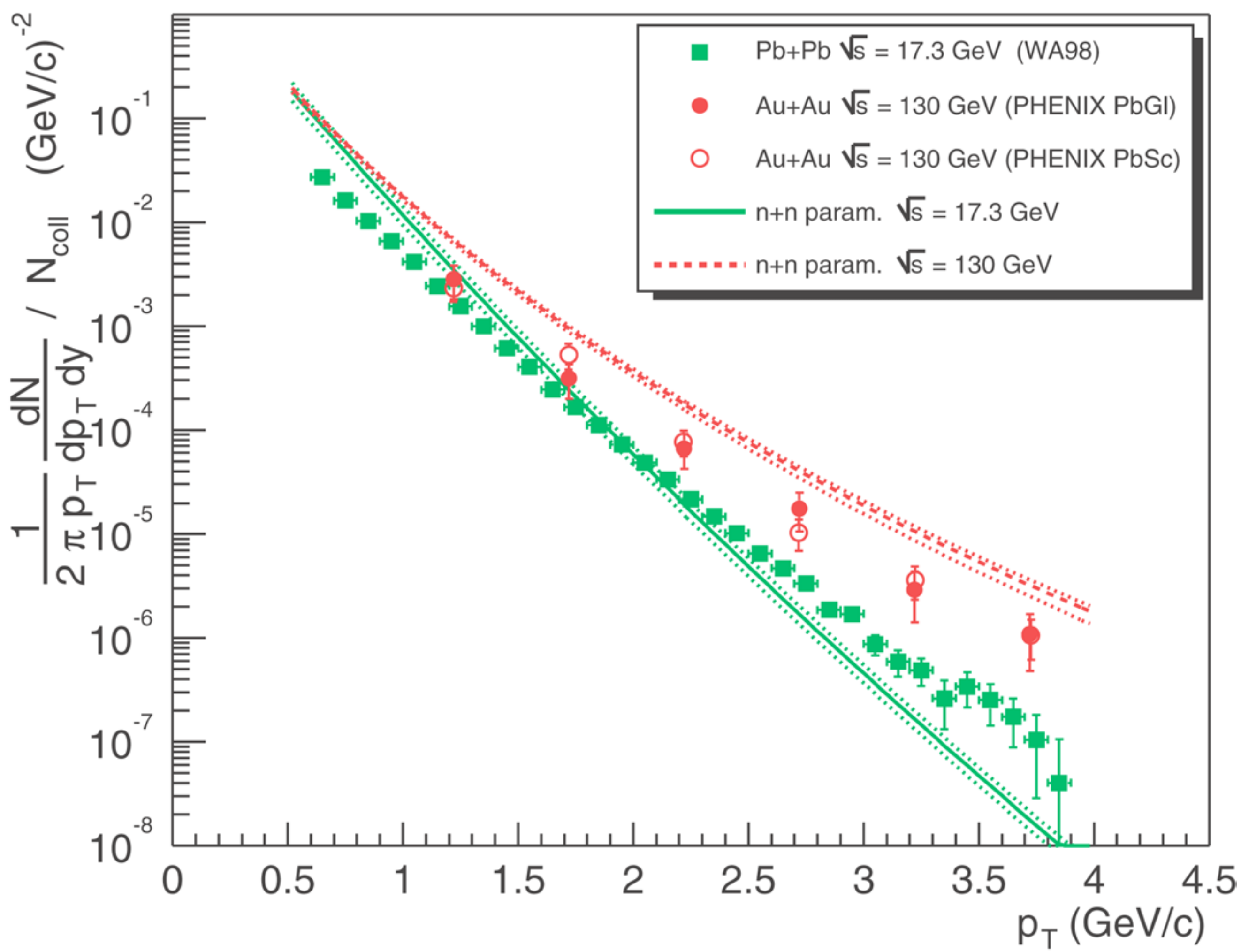
Summary 2

- promising first results for electromagnetic probes
  - direct photon analysis under way
  - single electrons consistent with charm predictions from pQCD
  - J/ψ cross section measured in p+p
  - J/ψ measured in Au+Au
  - eagerly waiting for higher luminosity
- many more results from hadrons and global observables
  - multiplicity
  - transverse energy
  - identified hadrons
  - elliptic flow
  - not discussed:
    - interferometry
    - fluctuations
    - production of Λ and deuterons
    - ...

Energy Dependence of p_T-spectra in pp and AA

- spectra in pp
  - strong variation with beam energy
  - "flattening" of spectra
  - power law
    - » influence of hard scattering
- spectra in AA
  - little variation with beam energy
  - almost exponential
    - » influence of thermal production?

K. Reygers et al., Hirschegg 2002



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Interlude: Thermalization and Hadron Spectra

- spectra of pions and (anti)protons
- description by hydrodynamical source
  - perfect description possible

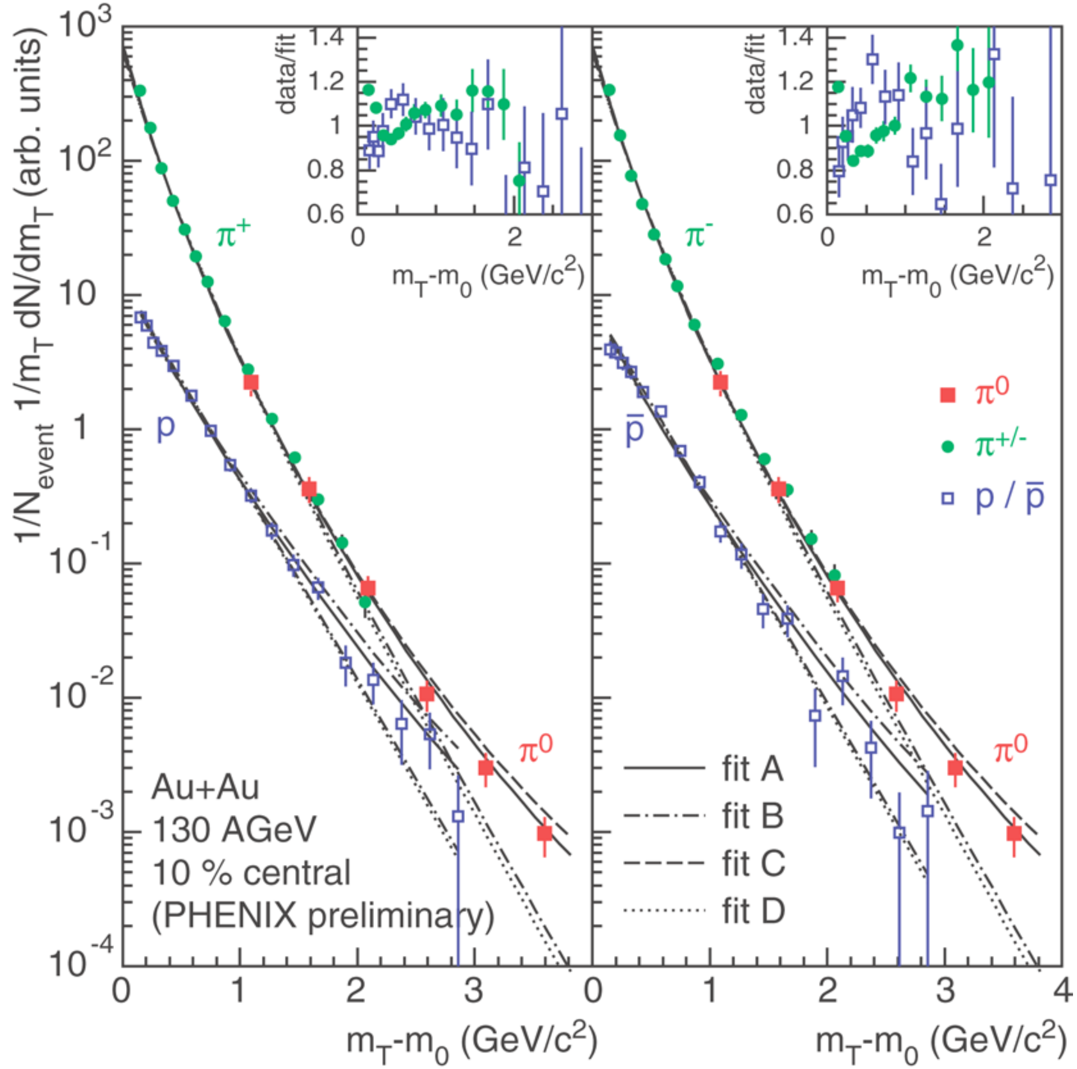
    T_{ch} = 172 ± 2 MeV

    μ_B = 37 ± 4 MeV

    T_{kin} = 123 ± 6 MeV

    $<\beta_T>$ = 0.45 ± 0.02
- doesn't explain suppression
  - need stronger suppression to account for additional hydrodynamic production

T.P., nucl-th/ 0207012



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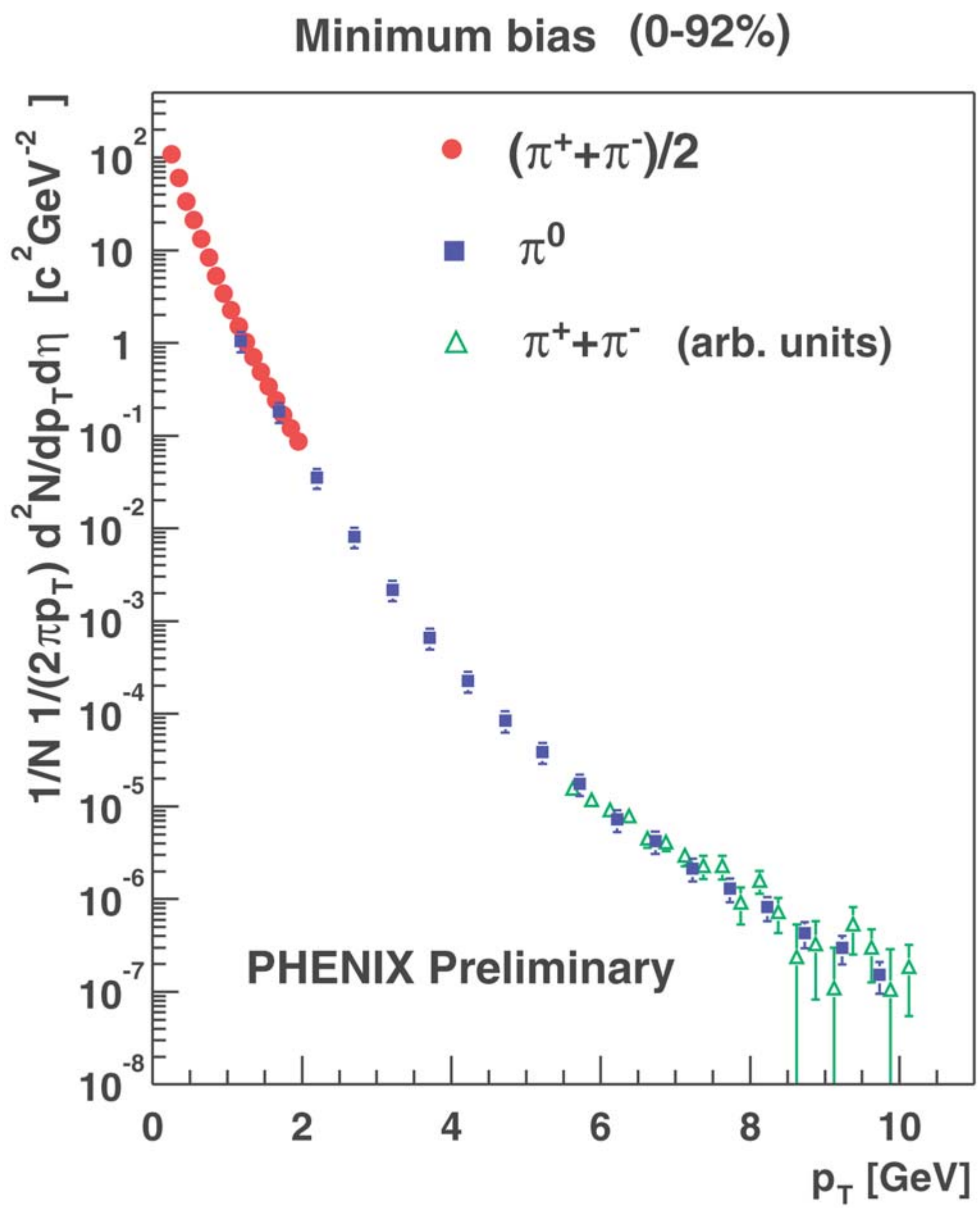
New Results at 200 GeV

- identified particles are best!
- PHENIX neutral pions at high p_T
- identified charged particles to come?



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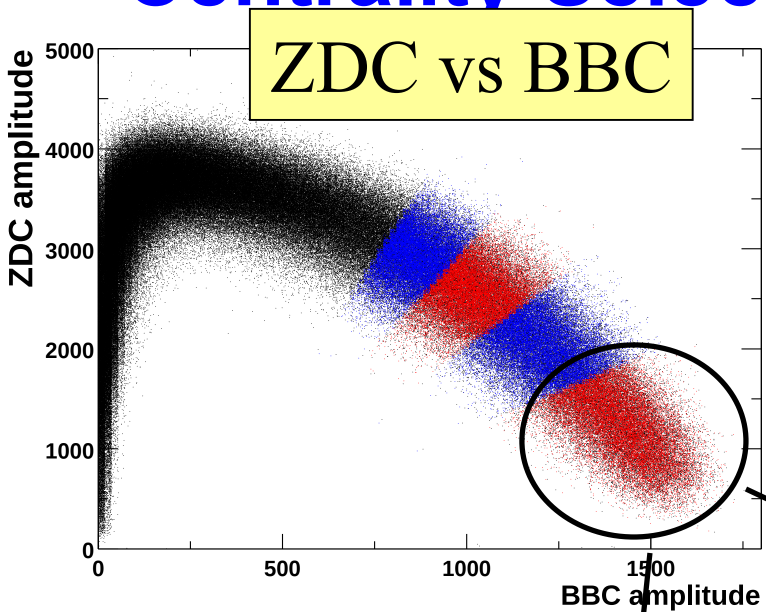
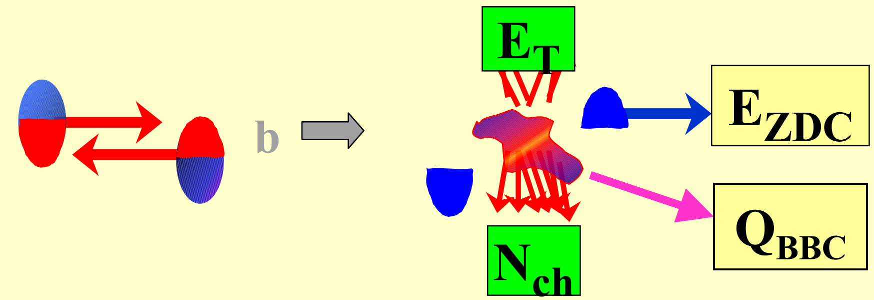
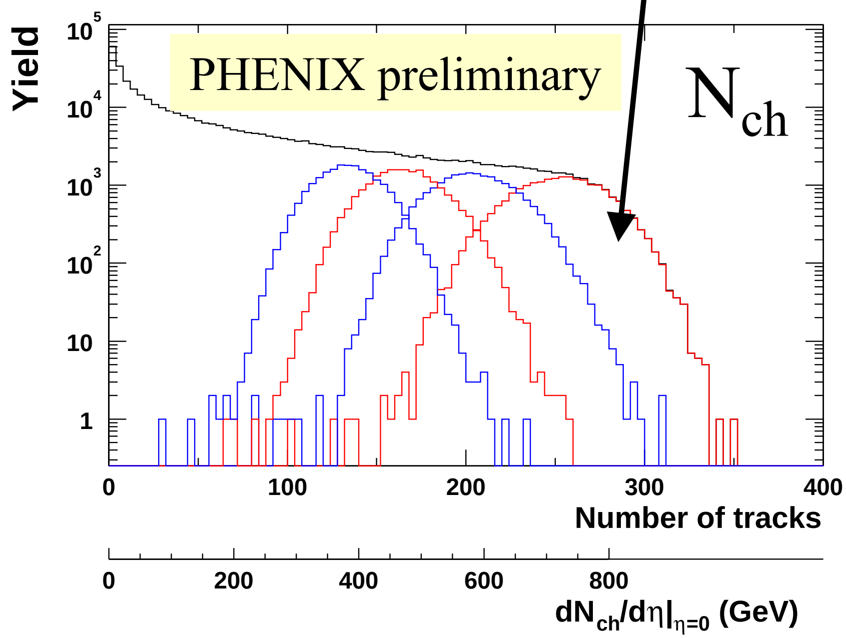
Centrality Selection

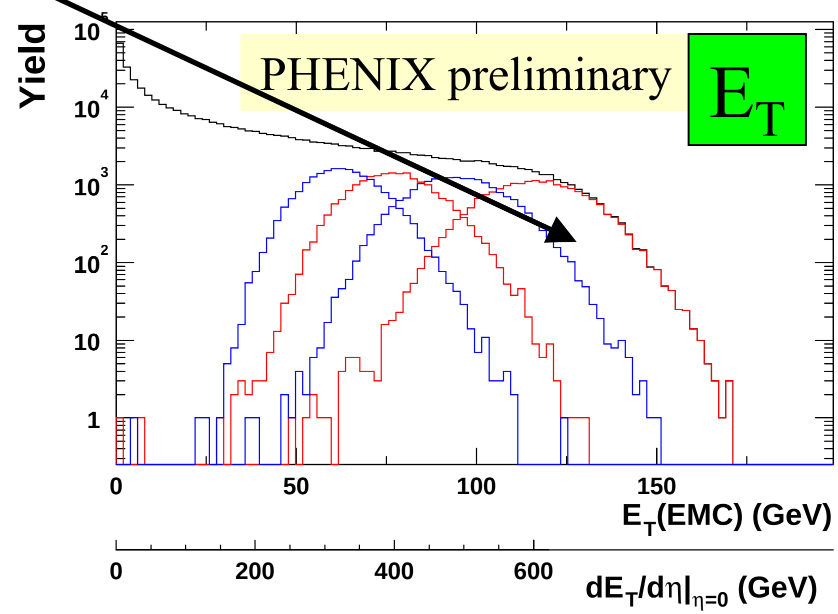


Define centrality classes: ZDC vs BBC



Extract N participants: Glauber model





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