Results from the PHENIX Experiment at RHIC

Nuclear Physics Spring Meeting, Münster

Klaus Reygers
University of Münster
for the PHENIX collaboration

Overview

- First PHENIX run in year 2000:

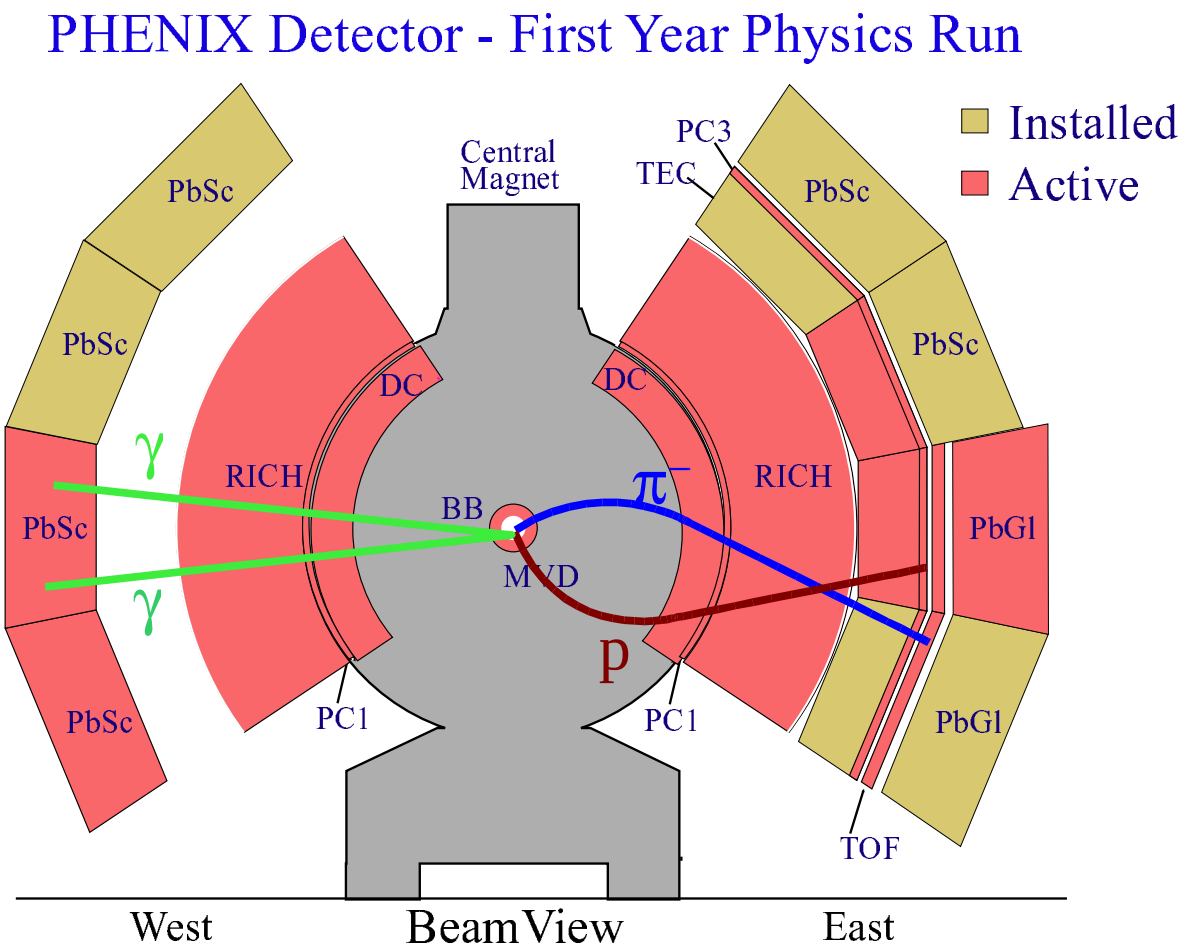
$$\text{Au+Au at } \sqrt{s_{nn}} = 130\,\text{GeV}$$

- $3.5 \cdot 10^6$ minimum bias events measured
- Selection of results in this talk
  - Transverse Energy
  - Elliptic Flow
  - Identified Hadron Spectra
  - Hadron Production at high p_T
  - Single Electron Production

Relativistic Heavy Ion Collider

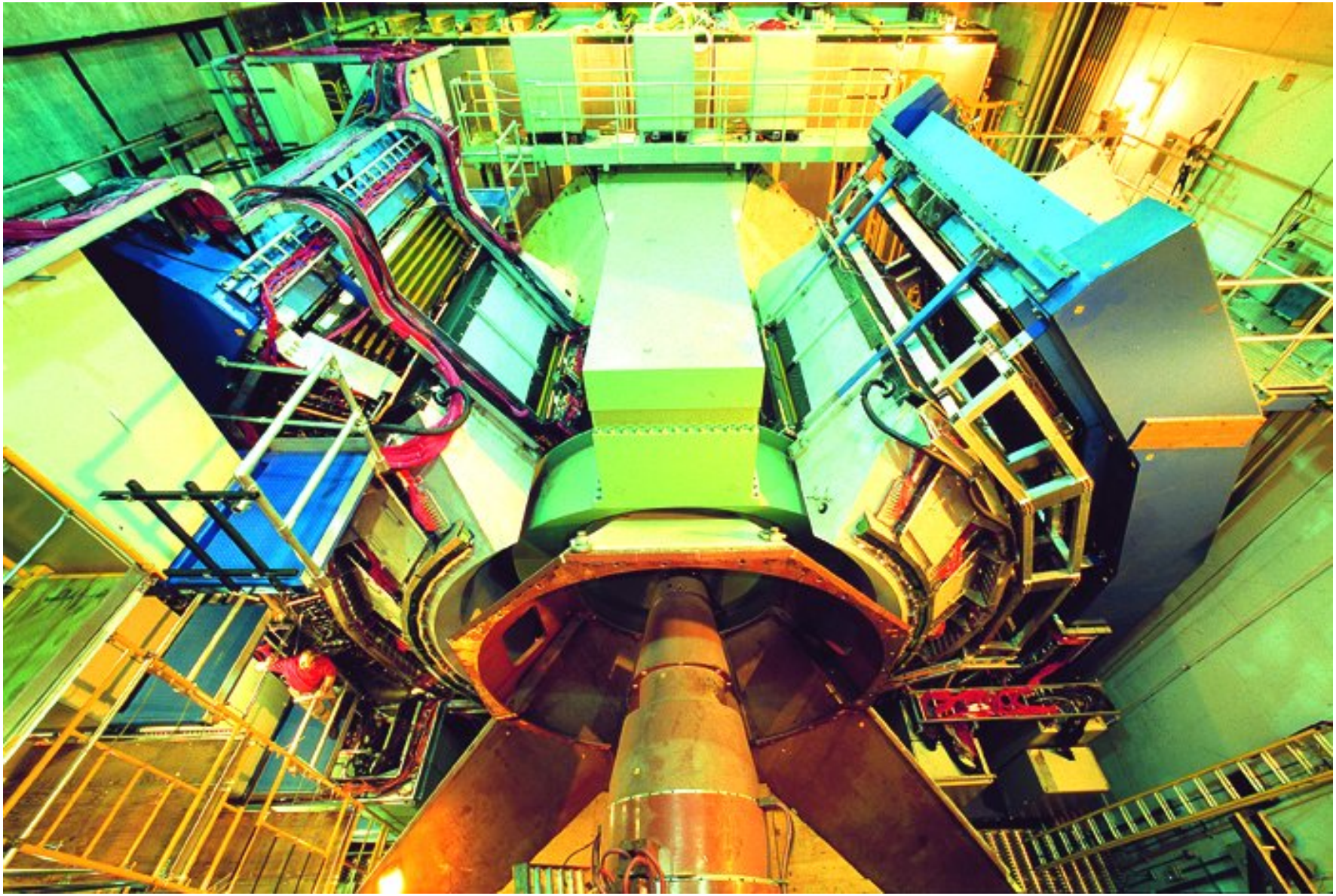
RHIC at the Brookhaven National Laboratory

PHENIX Setup

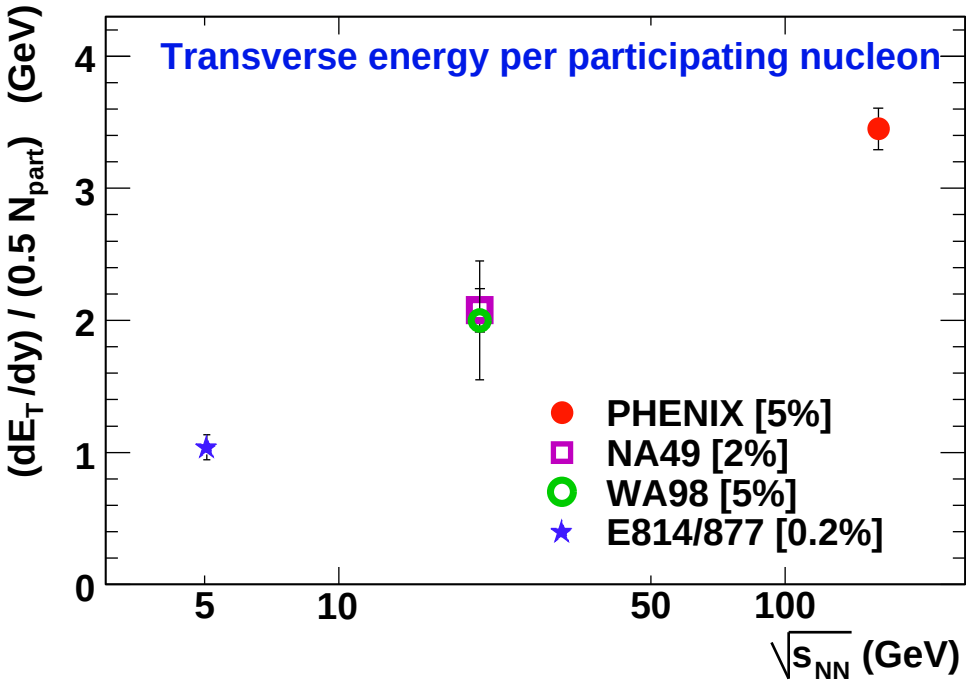


- Particle Tracking
  - Drift Chamber (DC)
  - Pad Chamber (PC)
- Charged Particle ID
  - Time of Flight (TOF) detector (start signal from BBC)
- π^0 (via $\pi^0 \rightarrow \gamma\,\gamma$)
  - lead glass (PbGl)
  - lead scintillator (PbSc)
- Electron ID
  - Ring Imaging Cherenkov Detector (RICH)

PHENIX



Transverse Energy



talk by
Christian Klein−Bösing

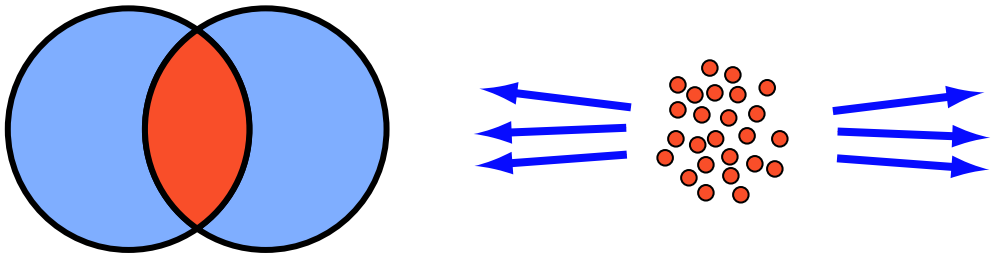
- 2% most central Au+Au:

$$dE_T/dy = 688^{+31}_{-46}\,\mathrm{GeV}$$

- ≈60% increase over CERN SPS value (NA49, WA98)
- Bjorken energy density estimate:
  - $\varepsilon_{Bj} \cdot \tau_0 \approx 4.6\,\mathrm{GeV/fm^3} \cdot \mathrm{fm}/c$
- ε possibly much higher, estimates are in the range
  - $3\,\mathrm{GeV/fm^3} < \varepsilon < 20-100\,\mathrm{GeV/fm^3}$

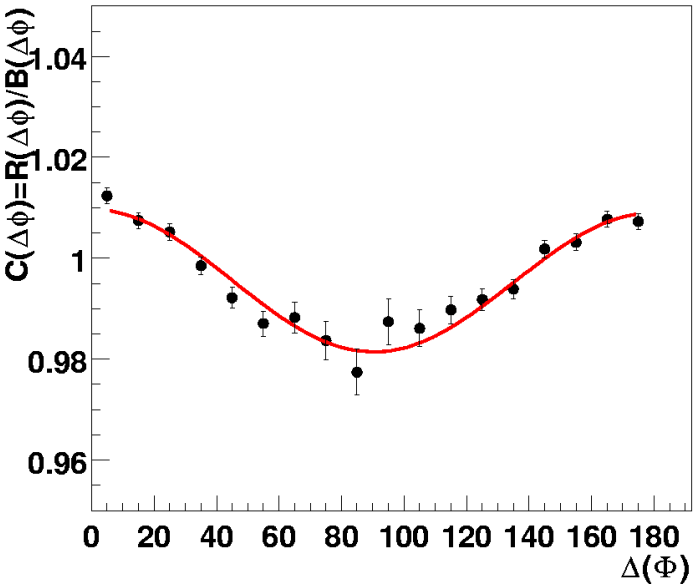
Elliptic Flow

- Question:
  Does the fireball behave collectively ?
  - Study particle flow in the transverse plane



- Limited detector acceptance: event−mixing

$$C(\Delta\phi) = \frac{\Delta\phi(\text{real})}{\Delta\phi(\text{mixed events})}$$

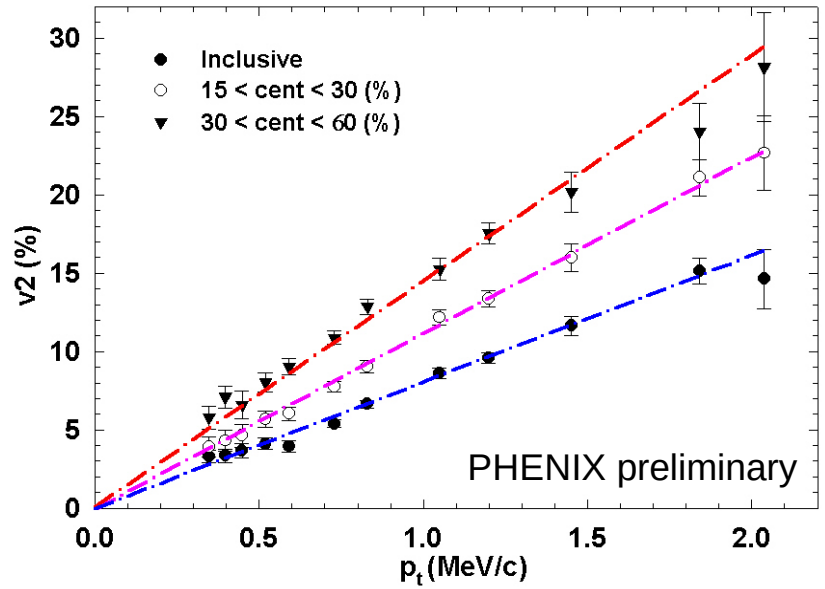


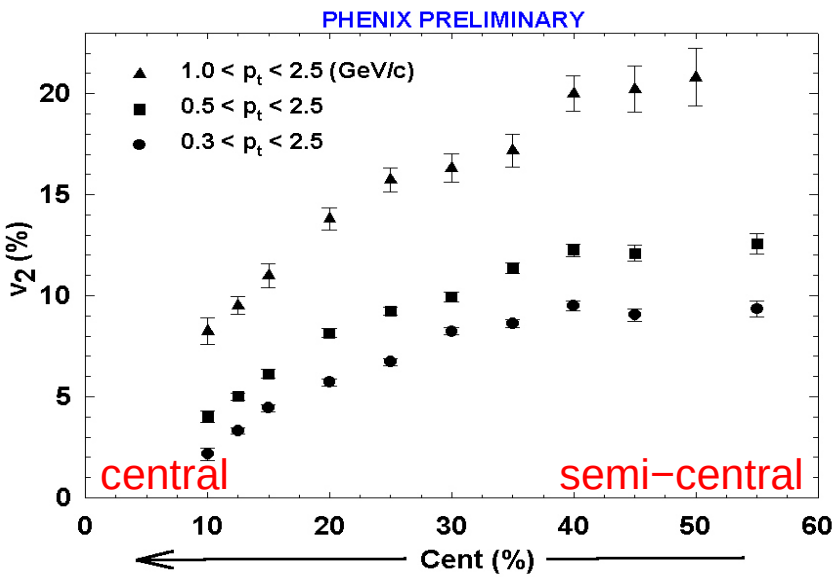
- Flow signal studied via 2−particle $\Delta\phi$ correlations
  - reaction plane determination circumvented

$$\frac{dN}{d(\Delta\phi)} \propto 1 + 2\,v_1^2 \cos(\Delta\phi) + 2\,v_2^2 \cos(2\Delta\phi)$$

quantifies elliptic flow

Elliptic Flow: v_2 vs. p_T and Centrality

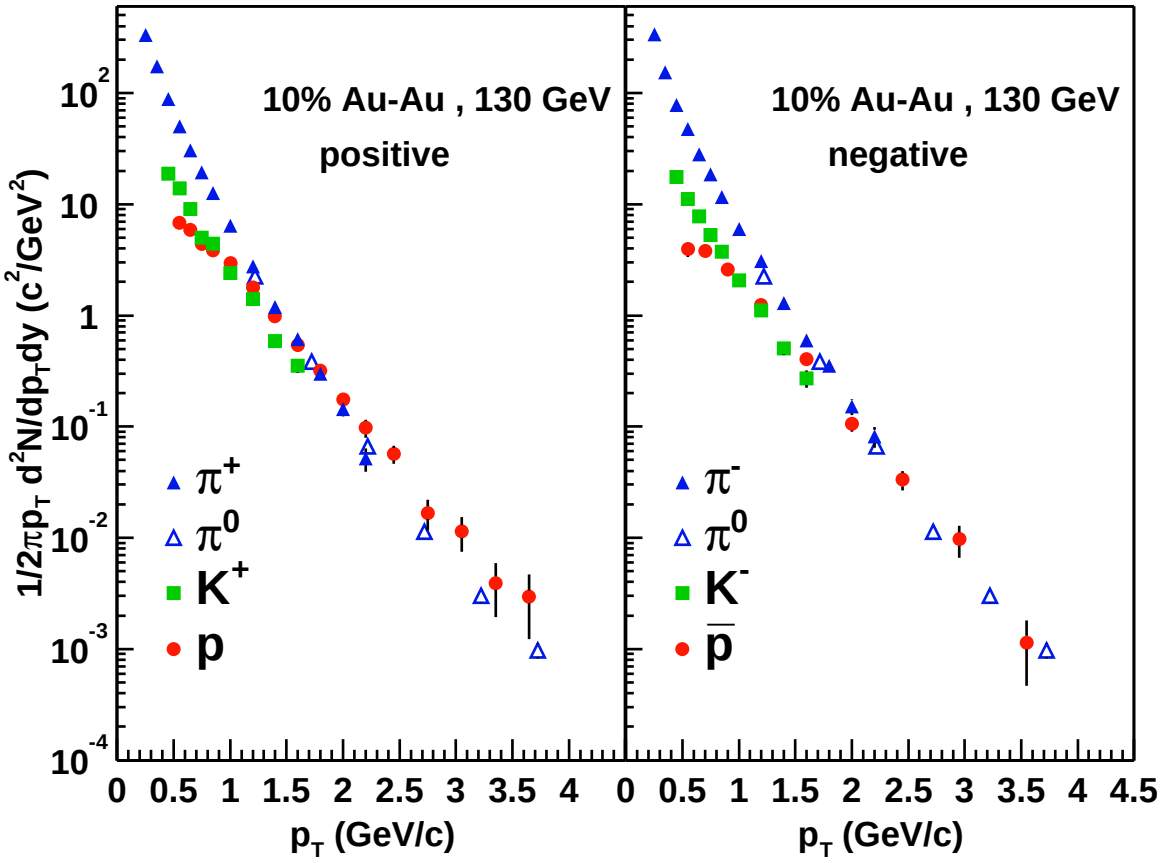




- v_2 increases with p_T
- v_2 decreases from semi−central to central reactions

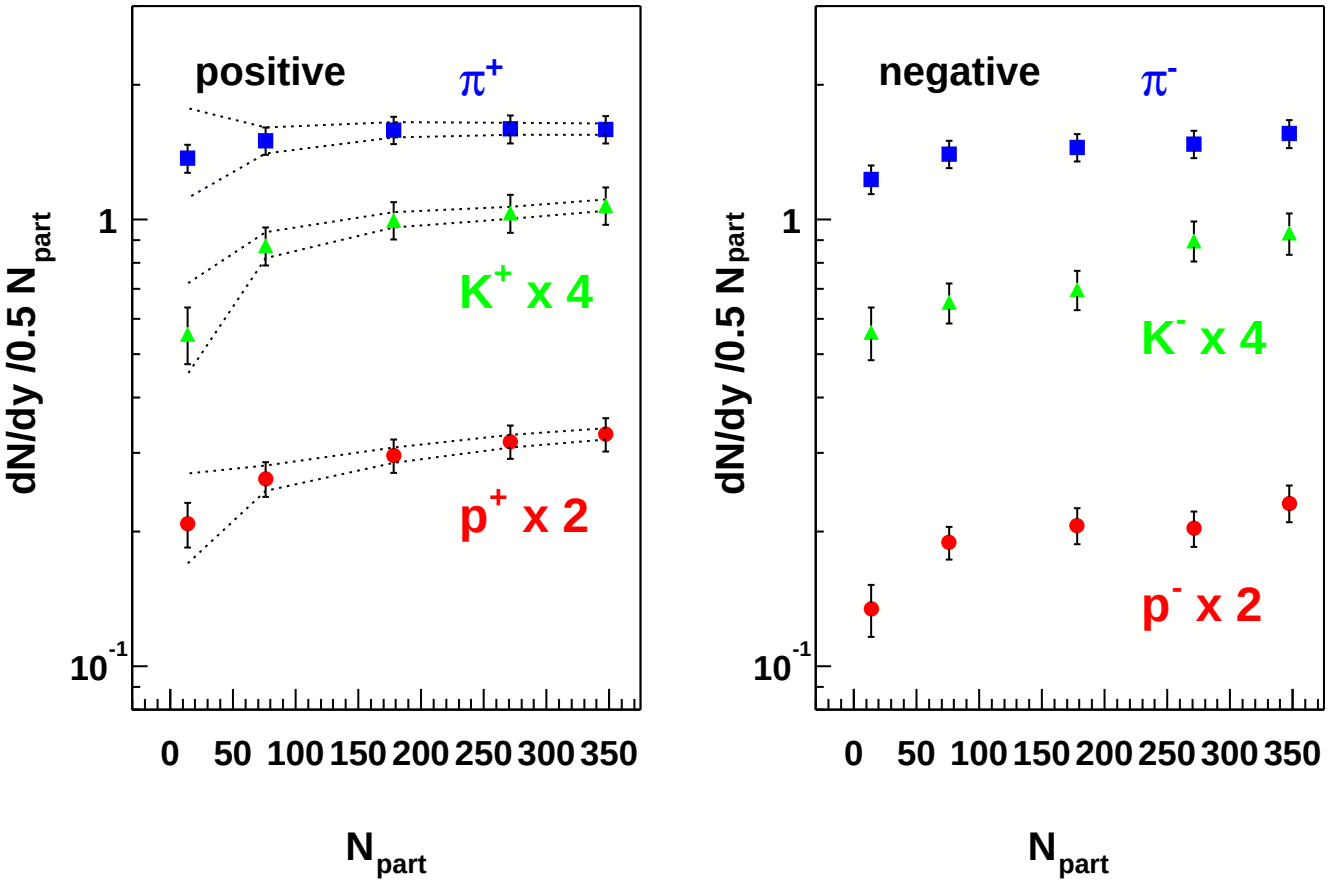
- Conclusions:
  - A+A ≠ simple superposition of parton−parton scatterings
  - Strong interaction among quarks and gluons in the fireball required in theoretical description of elliptic flow (e.g. in hydrodynamical models)

Identified Hadron Spectra



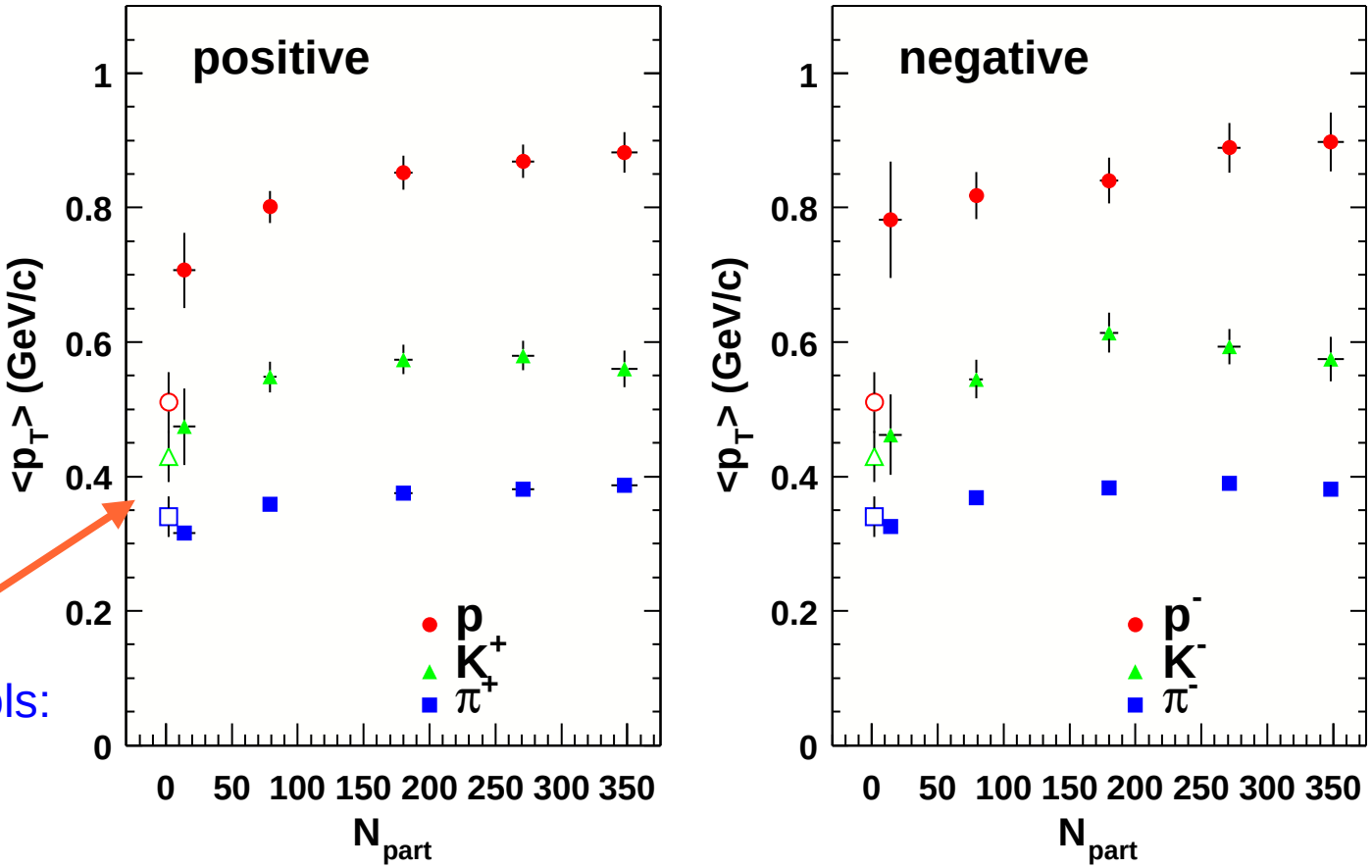
- good agreement between charged and neutral pions
- protons and anti−proton above pion yield at high p_T (never observed before in p+p or A+A)

Centrality Dependence of Yields



- Yield/N_{part} increases for all particle species
- relative rise for kaons and protons stronger than for pions

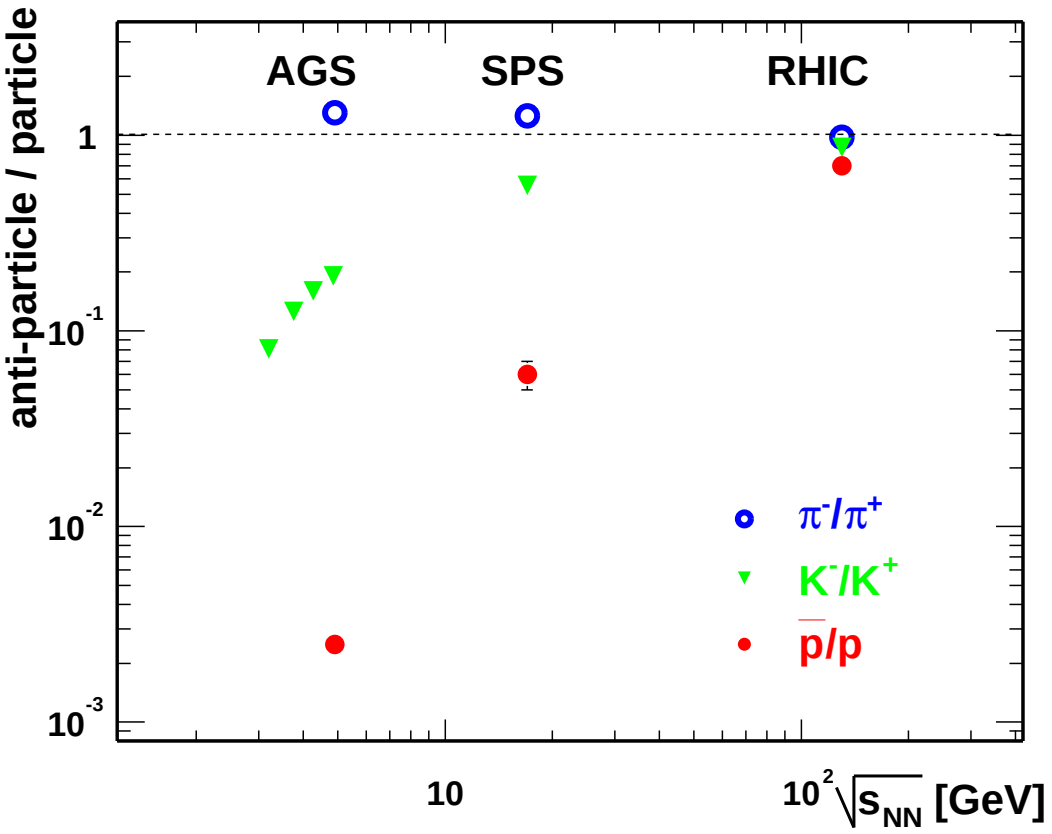
Centrality Dependence of $\langle p_T \rangle$



open symbols:
$\langle p_T \rangle$ in p+p

- $\langle p_T \rangle$ increases with N_{part} and particle mass
- this is consistent with expectation from radial flow

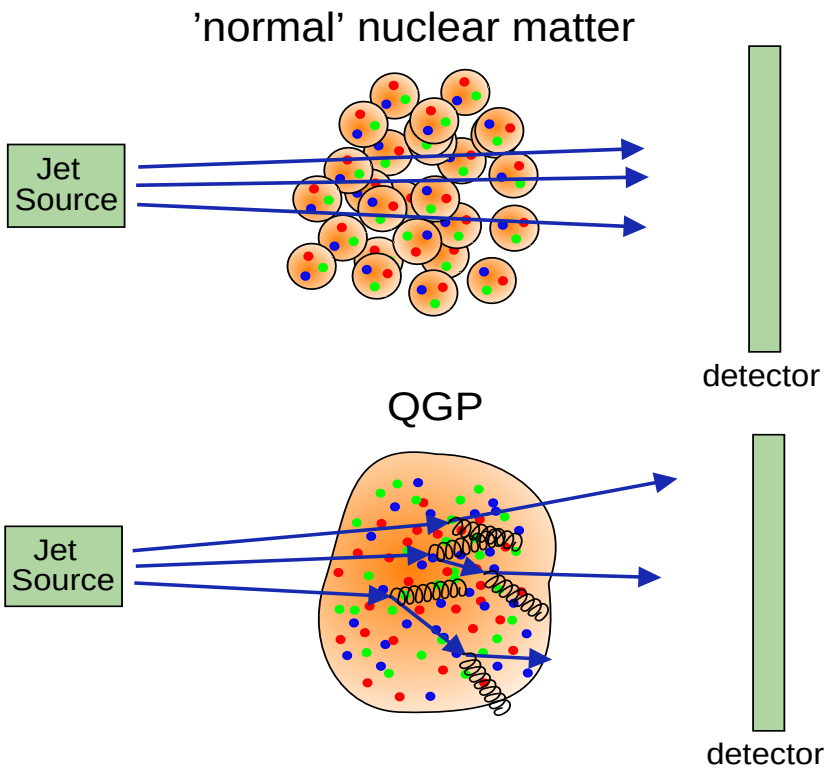
Particle Ratios at Midrapidity



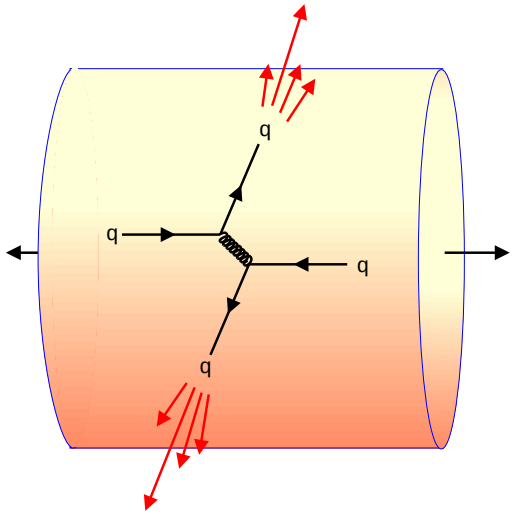
- Anti−particle / particle ratios at RHIC closer to unity than at SPS and AGS
- RHIC: $\bar{p}/p = 0.70 \pm 0.02 \pm 0.08$
- Net baryon density (baryons − anti-baryons) in central collisions ≈1/3 of SPS value:
  - RHIC: $(dN/dy)_{y=0} = (p - \bar{p}) \cdot A/Z \approx 21.4$
  - SPS: $(dN/dy)_{y=0} = (p - \bar{p}) \cdot A/Z \approx 68$

High−p_T Particle Production

- Potential QGP signal: energy loss of fast partons
- Jet−Tomography:

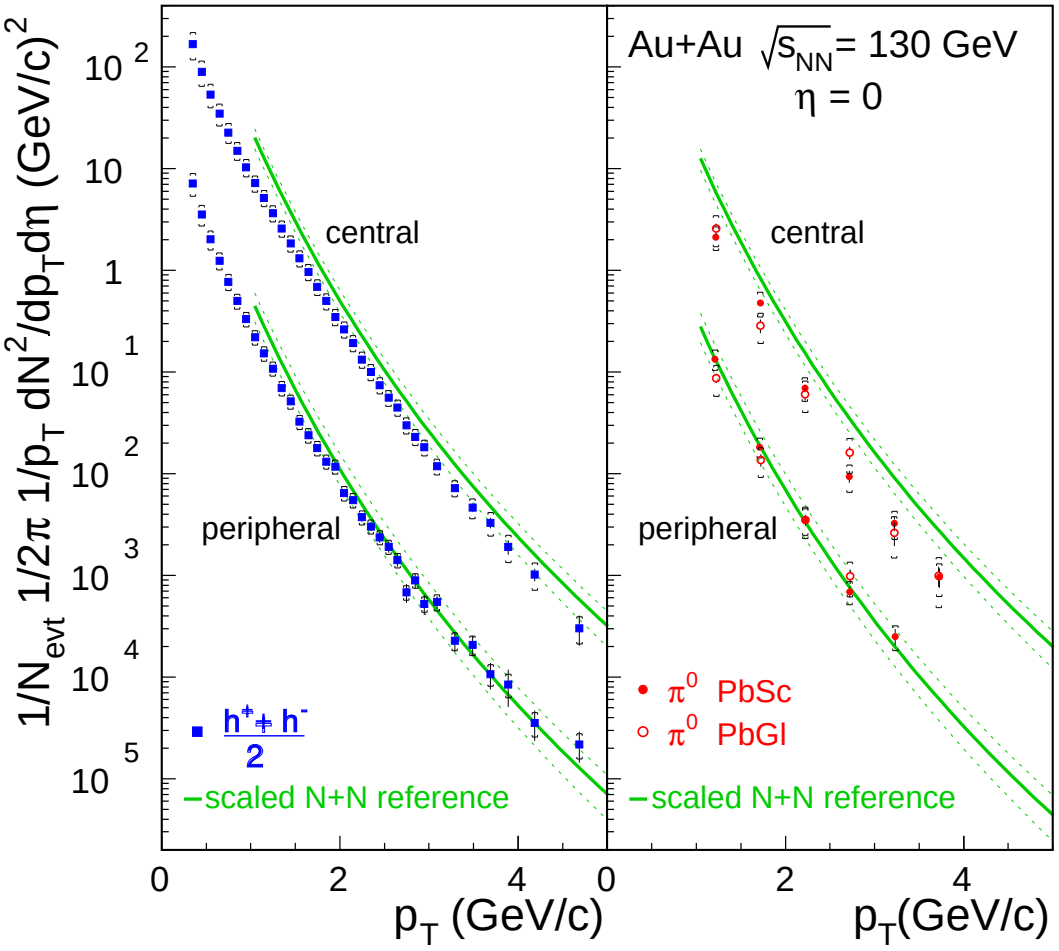


- Hard partons created in early phase of a A+A reaction, well before possible QGP formation



- Jets not directly observable due to huge soft particle background
- Search for modifications of single particle yields at high p_T

Charged Hadron and π^0 p_T −Spectra



talk on neutral pions by Stefan Bathe

- π^0−spectra:
  - Internal cross check: PbGl and PbSc data analyzed independently by two different teams
  - Very good agreement
- n+n reference: interpolated to $\sqrt{s}$=130 GeV from existing proton−(anti)proton data
- number of inel. nucleon−nucleon collisions in Au+Au from Glauber calculation
  - N_{coll} (central) = 905 ± 96
  - N_{coll} (peripheral) = 20 ± 6

Nuclear Modification Factor

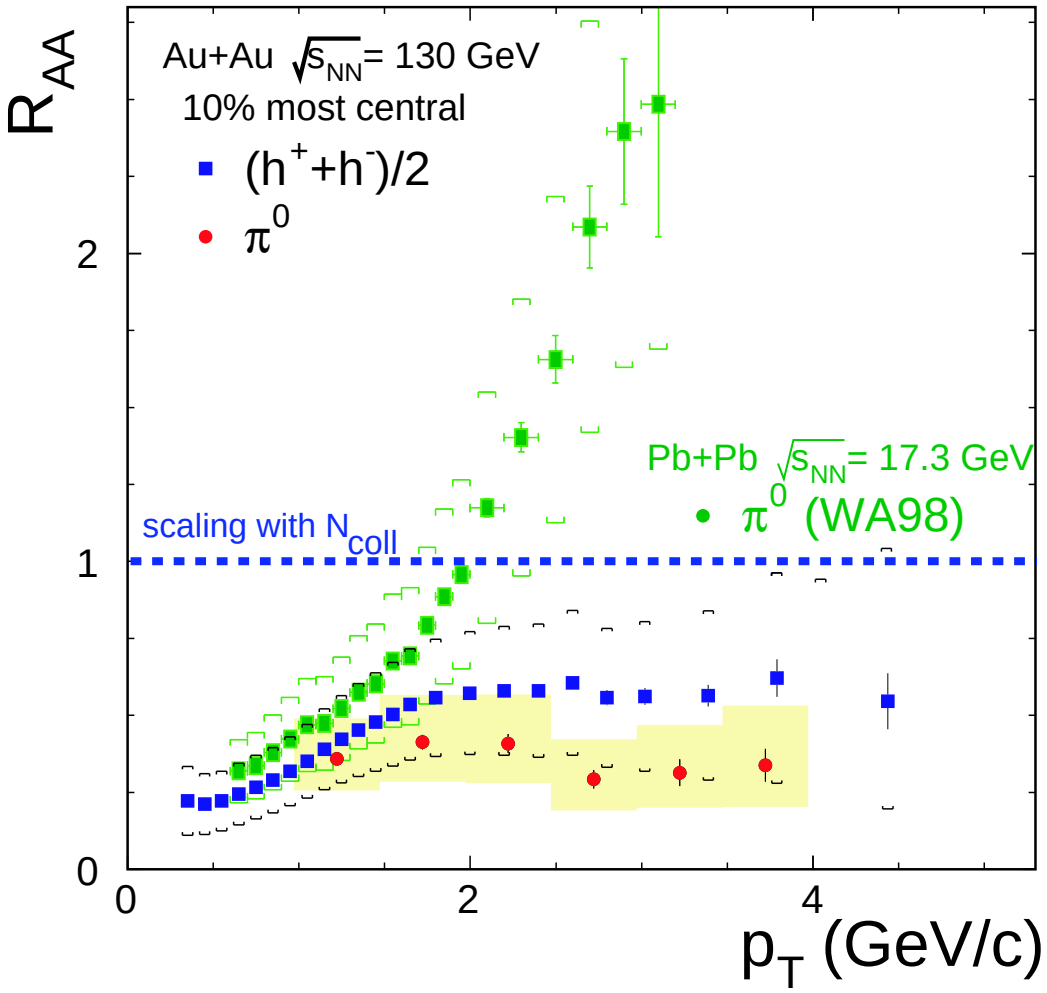
$$R_{AB} = \frac{\frac{d\sigma}{dp_T}(A+B)}{\left[\int d^2b\, T_{AB}(\vec{b})\right] \times \frac{d\sigma}{dp_T}(p+p)} = \frac{\frac{dN}{dp_T}(A+B)}{N_{coll}^{nn} \times \frac{dN}{dp_T}(p+p)}$$

$A \cdot B$ for min. bias reactions

inel. nucleon−nucleon collisions

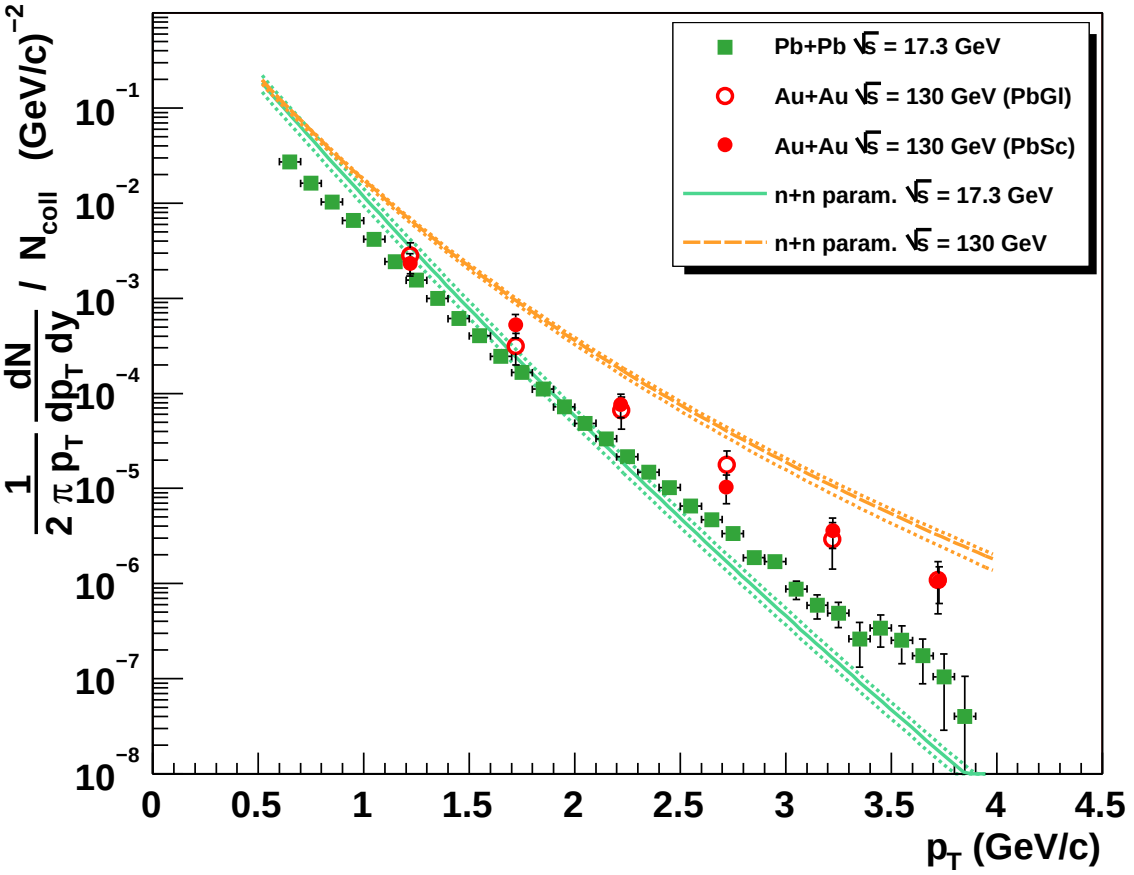
- Expectation in the absence of any nuclear effects: $R_{AB} = 1$ (*point−like scaling*)
- this ignores expected nuclear modifications like
  - initial state multiple parton scattering (Cronin effect)
  - change of the parton distribution function at small *x* (shadowing) (expected to be a 10% effect at maximum)

R_{AA} at SPS and RHIC



- SPS
  - $R_{AA} > 1$ for $p_T > 2$ GeV/c
  - in line with expectation from Cronin effect
- RHIC
  - **$R_{AA} < 1$** in the entire p_T range

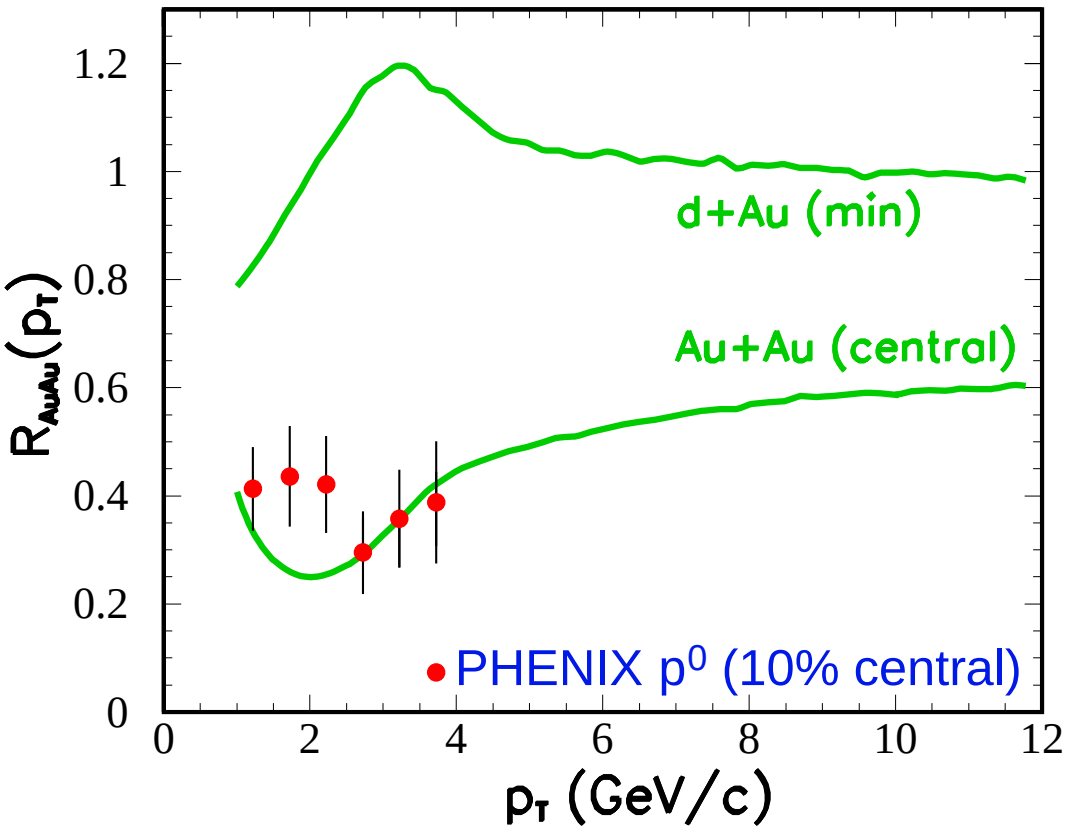
Direct Comparison of π^0 p_T–Spectra at SPS and RHIC



- $\sqrt{s}$=17.3 GeV → $\sqrt{s}$=130 GeV:

  Change in n+n spectrum much stronger than change in A+A spectrum

One Possible Explanation: Jet Quenching



E. Wang, X.N. Wang, hep−ph/0202105

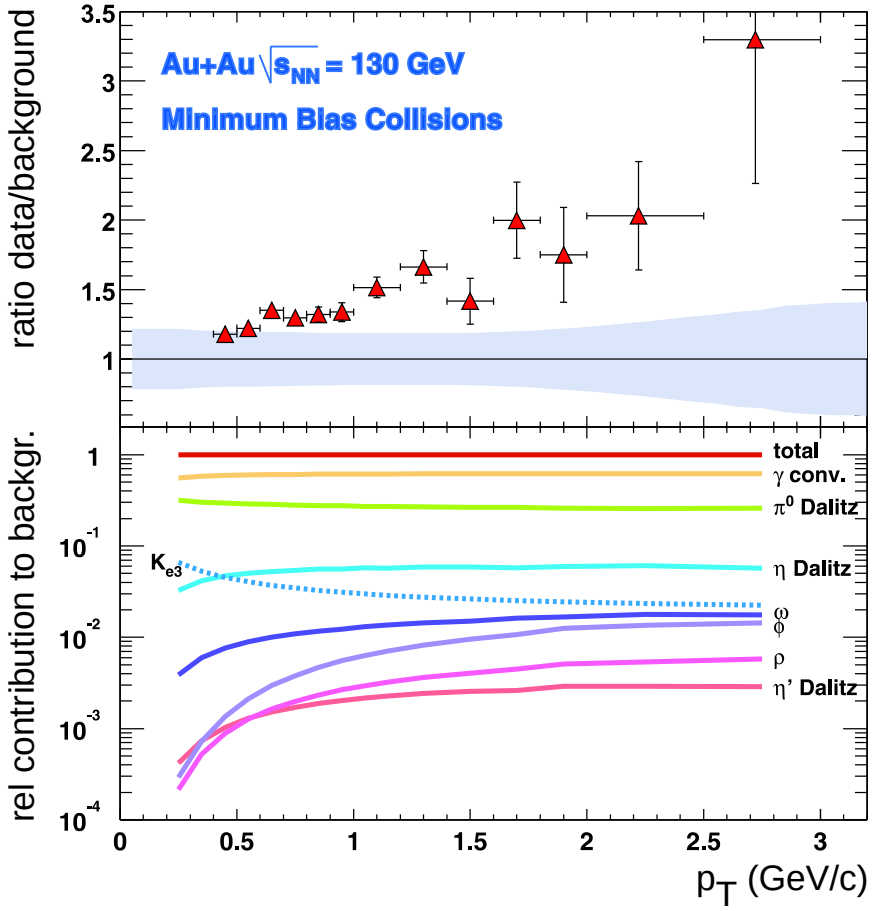
- pQCD based model including
  - Cronin−effect
  - shadowing
- Extracted energy loss for a 10 GeV quark equivalent to $dE/dX \approx 7.3$ GeV/fm in a static medium
- Significantly higher energy loss (> factor 10) than in cold nuclear matter

Single Electrons

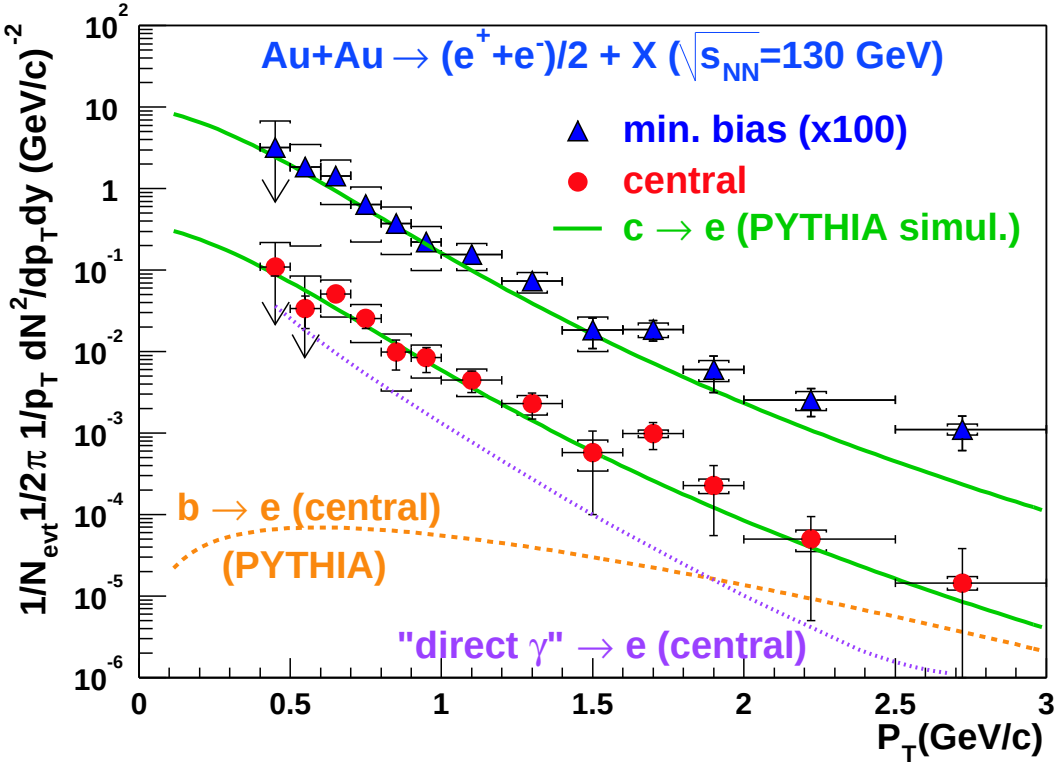
- Single electrons:
  a tool to study *c*− and *b*−quark production
  ($c \rightarrow e$+X, b $\rightarrow e$+X)

- Important for the understanding of
  - shadowing
  - quark energy loss
  - J/Ψ suppression

- Various sources of expected electrons need to be taken into account:



Background−Subtracted Electron Spectrum



PYTHIA simulation for p+p is scaled by N_{coll}

- Extracted charm cross section per nucleon−nucleon collision (10% central Au+Au):

$$\sigma_{c\bar{c}} = 380\,\mu\mathrm{b} \pm 60\,\mu\mathrm{b}\,(stat) \pm 200\,(syst.)\,\mu\mathrm{b}$$

- Result consistent with scaled p+p results from
  - PYTHIA (tuned to describe lower energy data)
  - next−to−leading order QCD calculation
- No hints of nuclear modifications

Summary

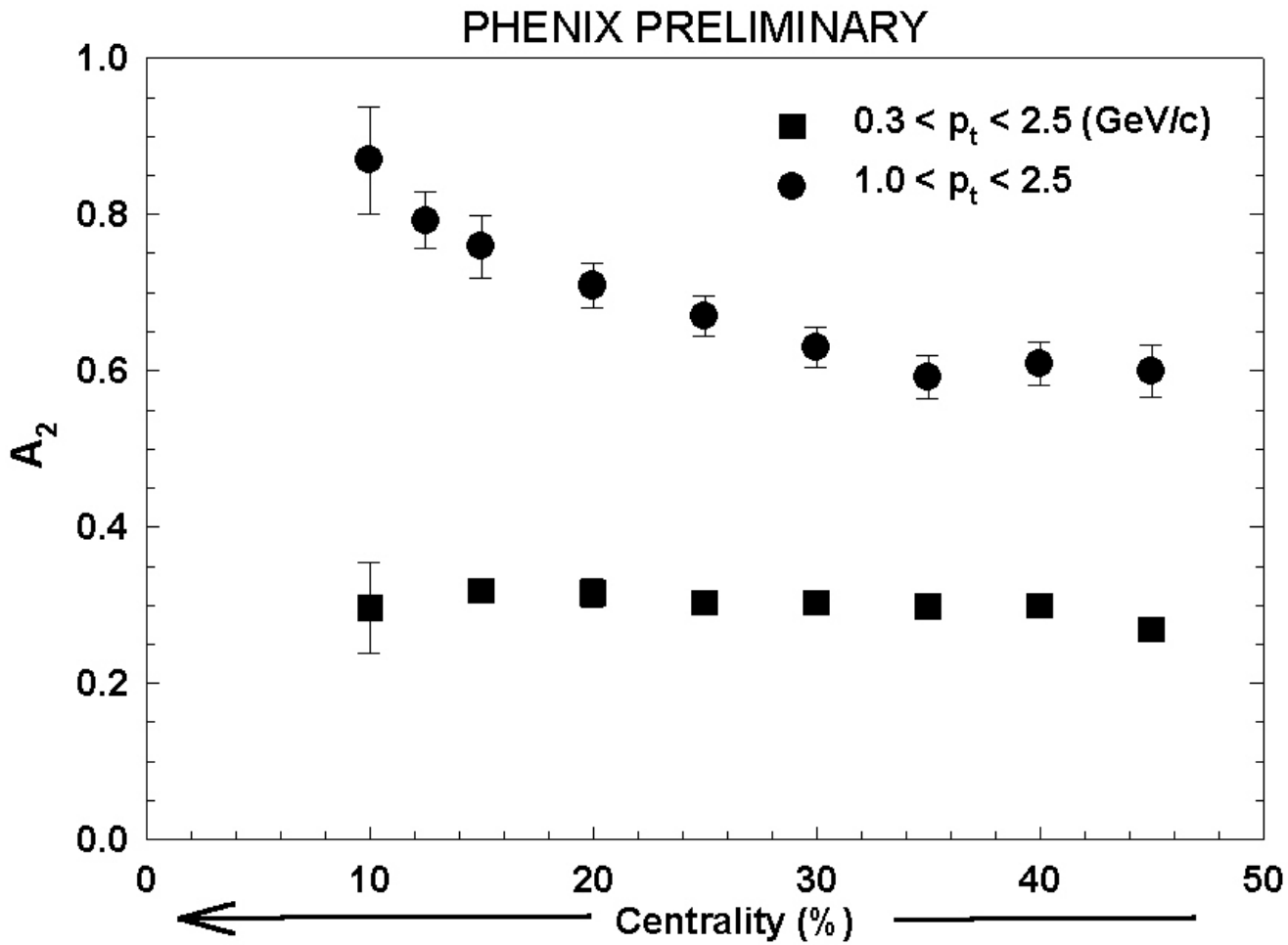
- E_T:
  Energy densities in Au+Au at RHIC significantly higher than at CERN SPS

- High p_T particle production:
  Suppression of high p_T hadrons in central Au+Au relative to scaled p+p reference

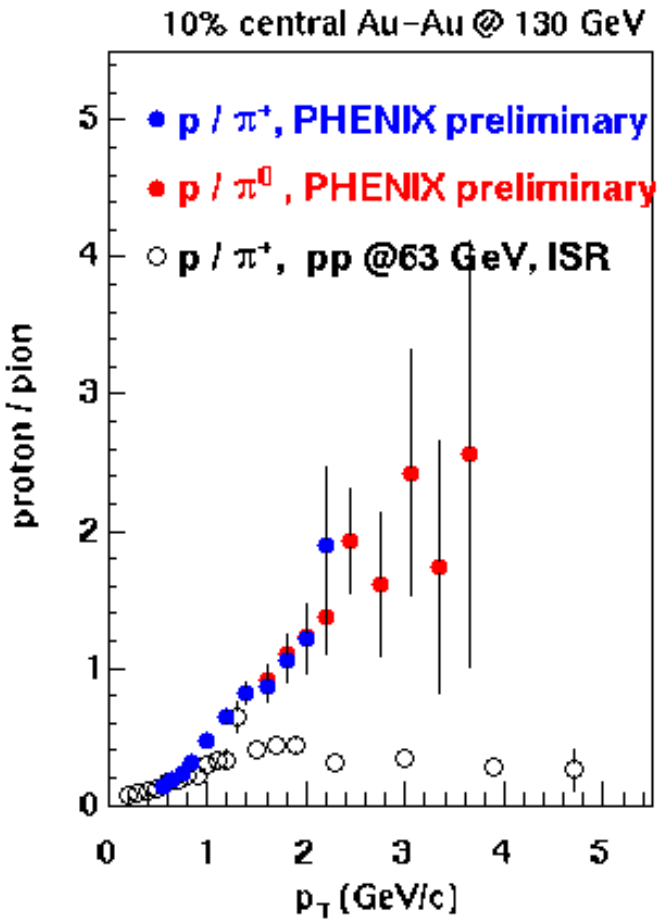
- Single Electrons:
  Charm cross section in line with PYTHIA and NLO QCD calculation

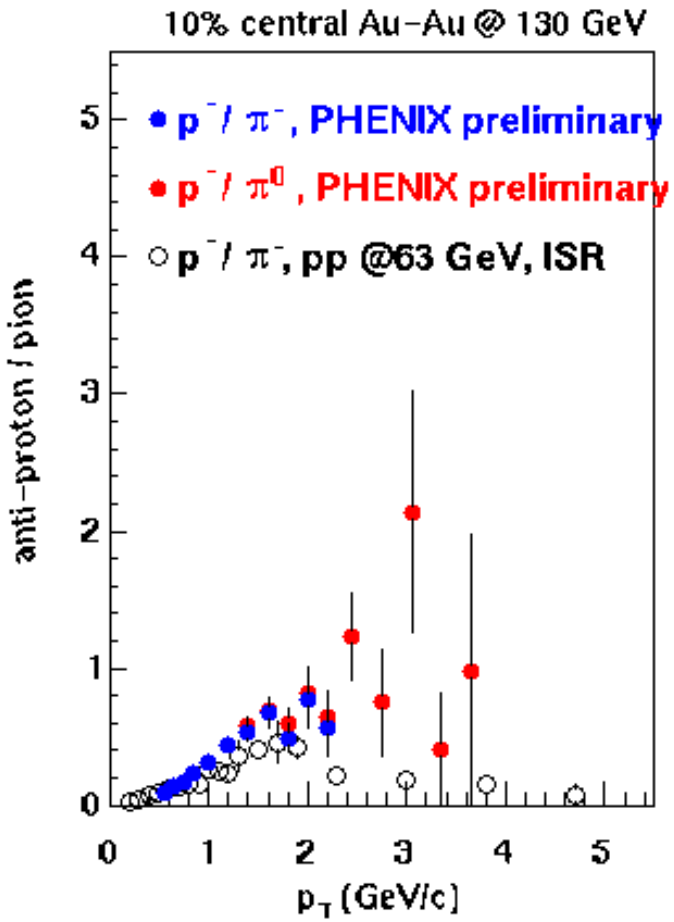
Extra Slides

Elliptic Flow: v_2 / ε

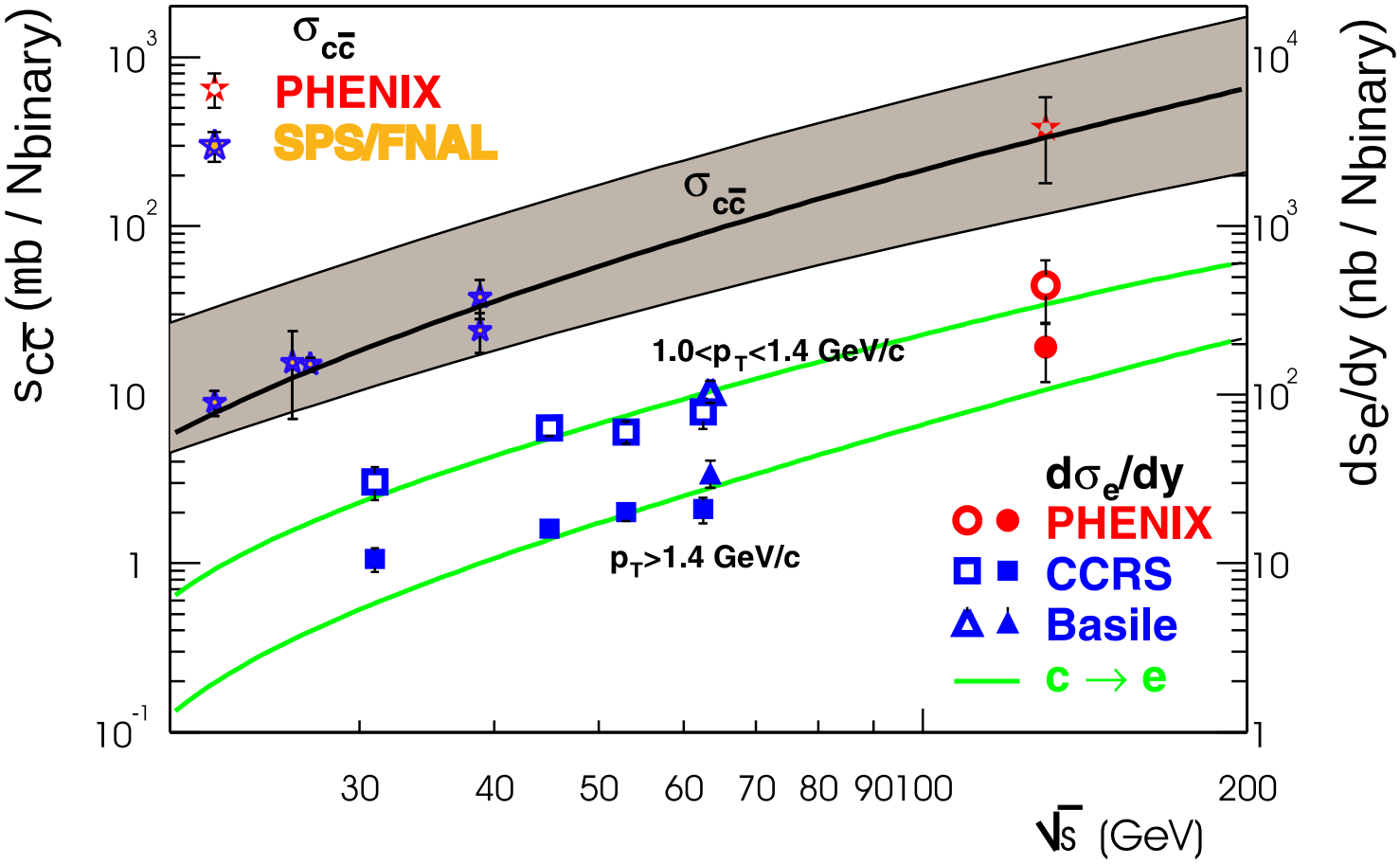


Nucleon To Pion Ratio

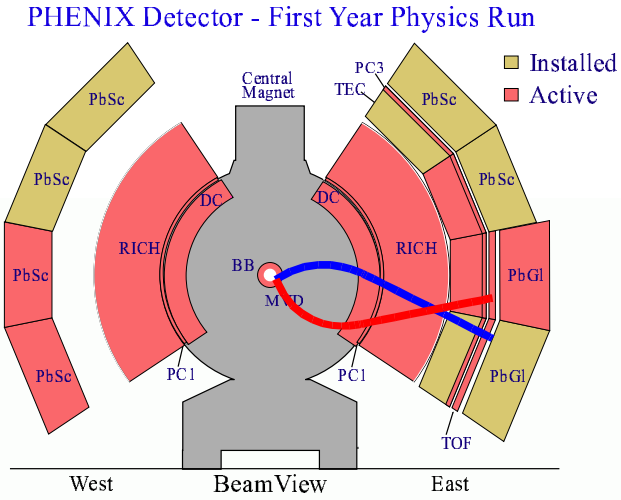


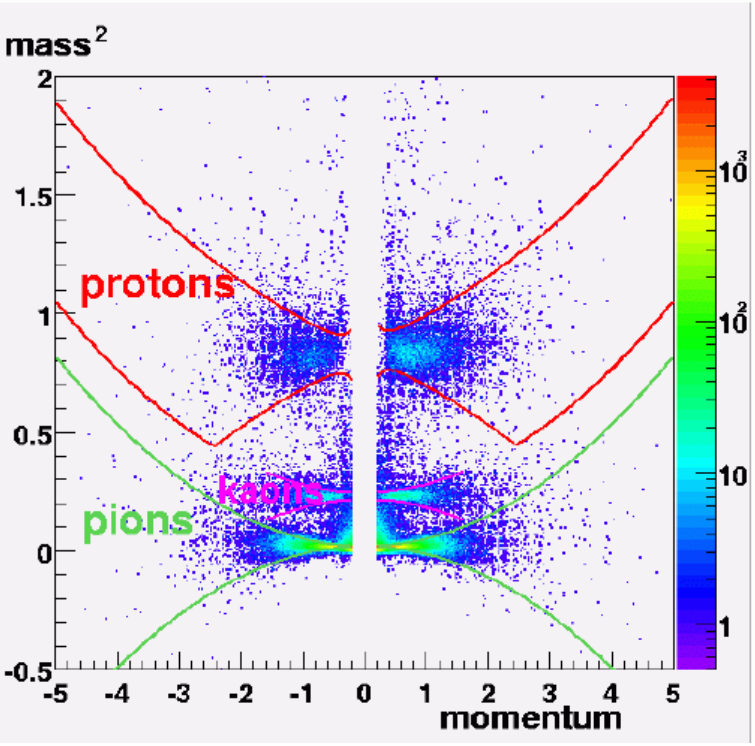


Charm Cross Section from PYTHIA and from a NLO QCD calculation



Identifying Charged Hadrons in PHENIX





- Drift Chamber resolution:

$$\sigma(p)/p \sim 0.6\% \oplus 3.6\% \, p$$

- TOF resolution:

115 ps

- Acceptance:
  - $\Delta\phi = 45°$
  - $\Delta\eta = 0.7$

Charged Multiplicity vs. √s