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High p_T Physics in the $Au + Au$ Program with the STAR Experiment at RHIC

$\rightarrow$ Search for the Quark-Gluon Plasma

$\rightarrow$ Concentrate on First Year

Will Cover:

- Introduction
- Detector
- High p_T Measurements
- Summary & Future

RHIC

RHIC will provide collisions of ions from p to Au at $\sqrt{s}$ up to $500\ \mathrm{GeV}$ (p beams) and $200\ \mathrm{GeV}$ (Au beams)

Year 1: expect 10% of design luminosity by end of year
$\rightarrow$ run $AuAu$ collisions
$\rightarrow$ possible beam or energy change (pp, $SiSi$?)

Year 2: expect full design luminosity by end of year
$L = 2 \cdot 10^{26}\ \mathrm{cm}^{-2}/\mathrm{s}^{-1}$
$\longrightarrow \approx$ 2000 collisions/sec

STAR Physics Program

Why Study High p_T Production?

· Large momentum transfer - probe small distances
$\Rightarrow$ looking at earliest time after collisions

· high p_T partons travel thru dense matter and lose energy

· fragment outside collision zone - retain information during hadronization

· At RHIC energies ($\sqrt{s} = 200$ GeV), can make predictions using QCD + addition of known nuclear effects (initial k_T, structure function modification)

Search for Quark Gluon Plasma (QGP)

Look for changes compared to expectations:

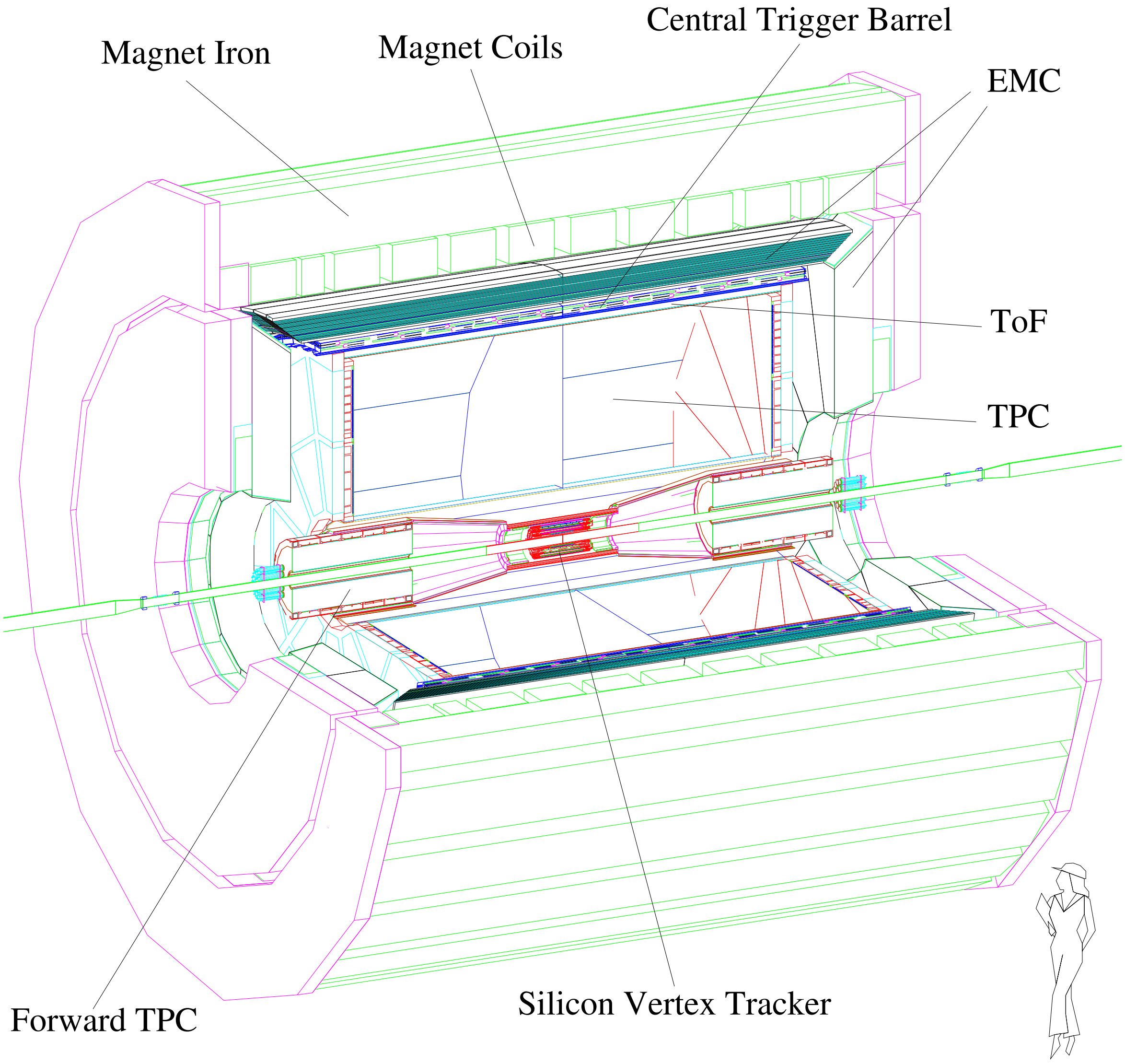
$\longrightarrow$ changes in jet fragmentation

- jet quenching due to parton dE/dX energy loss
  - softening of p_T spectum

$\longrightarrow$ changes in jet profiles

- total energy in jet should remain constant, but distribution inside may change

STAR Detector



STAR Detector

high p_T measurements of:

$\circ$ inclusive charged particles (h^+, h^-) to high $p_T \rightarrow$ TPC

$\circ$ charged particle ID to $\approx 3 - 5$ GeV $\rightarrow$ RICH

$\circ$ single neutral hadrons $(\pi^0) \rightarrow$ EMC

$\cdot$ $e, \gamma \rightarrow$ EMC + TPC

$\cdot$ jets and/or leading particles $\rightarrow$ EMC + tracking

Triggers:

L0: hardware multiplicity trigger

L3: software, ready in Year2?
- needed for J/ψ & enhances range of high p_T

Rates:

- Max Central Collision Rate ≈ 100 Hz
  ($\approx 5\%$ of collisons are central)
- DAQ rate to tape ≈ 1 Hz

High p_T Charged Hadron Production from pp Collisions

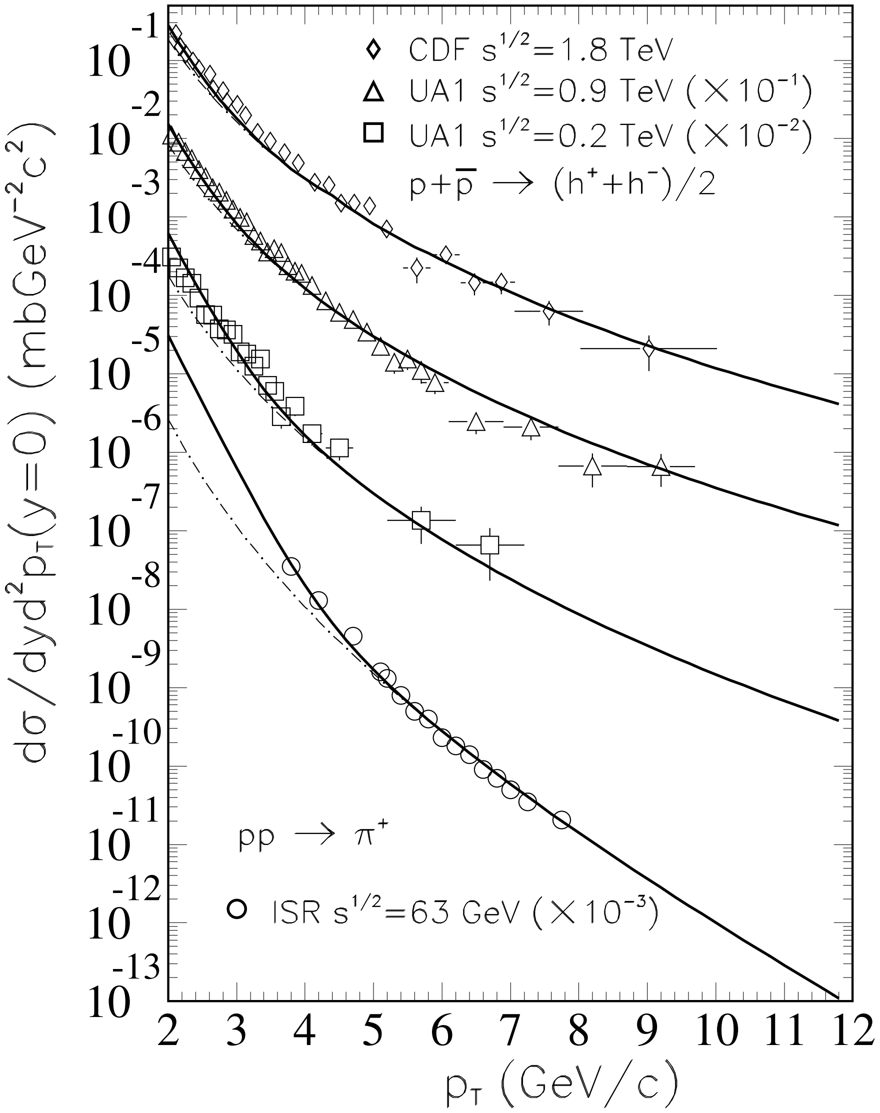


Figure 1: From pQCD calculation - Wang, Phys Rev **C58** (1998)2321.

Shows that pQCD predictions are accurate at RHIC energies for nucleon-nucleon collisions

Prediction for Ratio $Au + Au$ to pp inclusive hadron spectra

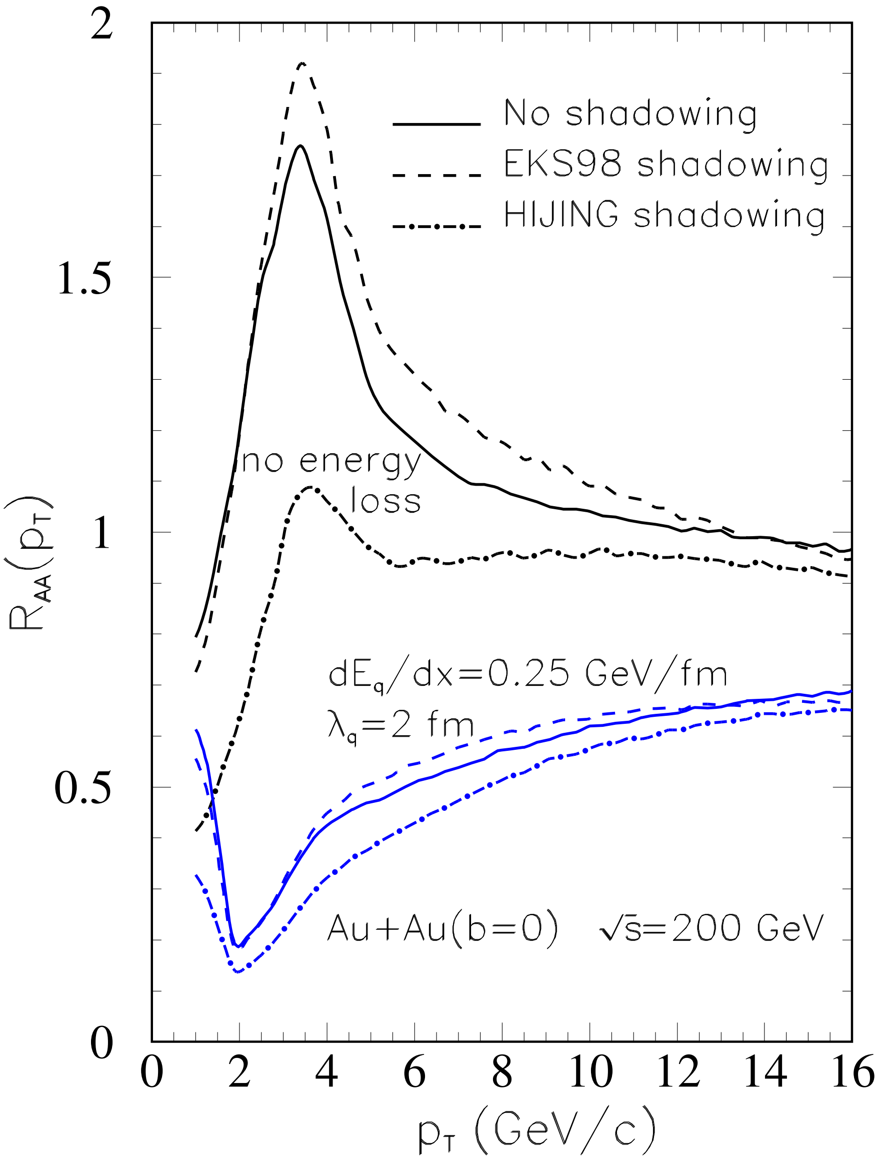


Figure 2: pQCD prediction of ratio of hadron spectra in central $Au + Au$ to pp collisions at $\sqrt{s} = 200$ GeV vs p_T. Nuclear effects included. Effects of different parameterizations of modification of gluon distribution (shadowing) and parton energy loss shown. Wang, nucl-th/9812021.

Looking for suppression of spectra at large p_T due to parton energy loss (jet quenching).

Prediction for Charged Particle Multiplicity in $Au + Au$

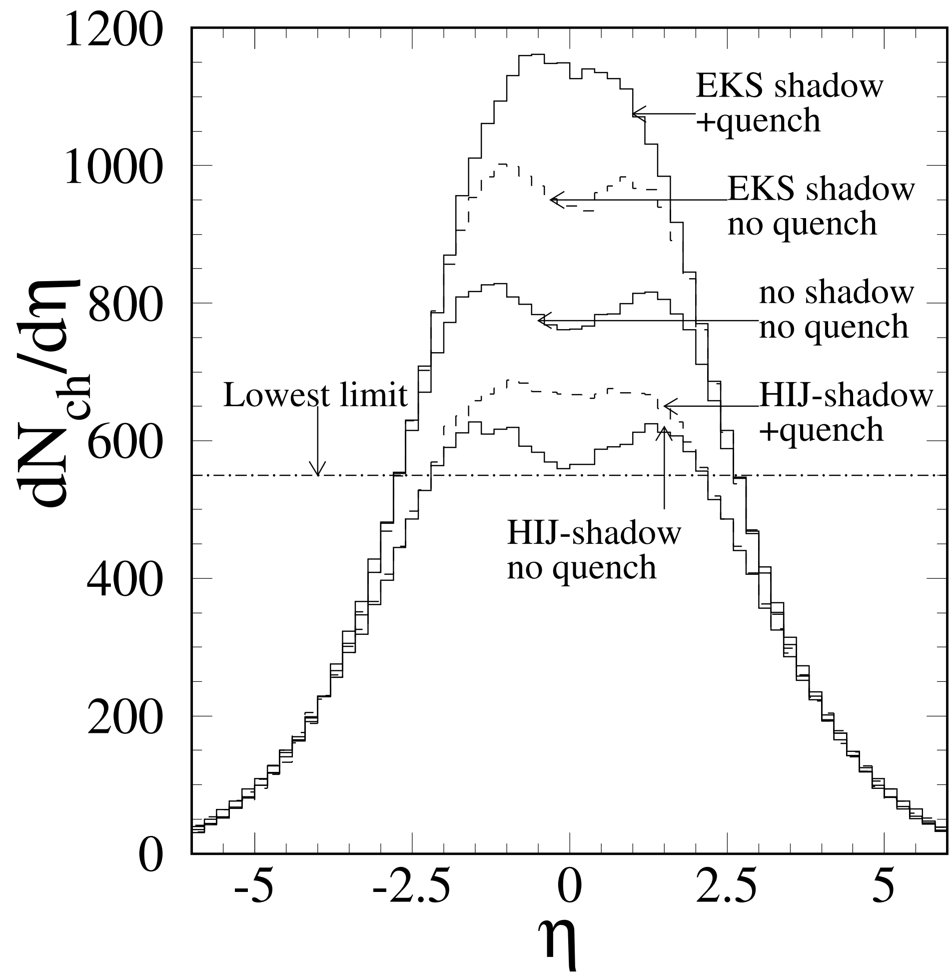


Figure 3: Multiplicity in central $Au + Au$ collisions vs η from pQCD prediction. Nuclear effects included. Effects of different parameterizations of modification of gluon distribution (shadowing) and parton energy loss ($dE/dx = 1\ \mathrm{GeV/fm}$) shown. Wang, nucl-th/9907090.

Looking for change in multiplicity vs η due to parton energy loss.

π^0 Production from nucleus-nucleus Collisions - Data & Predictions

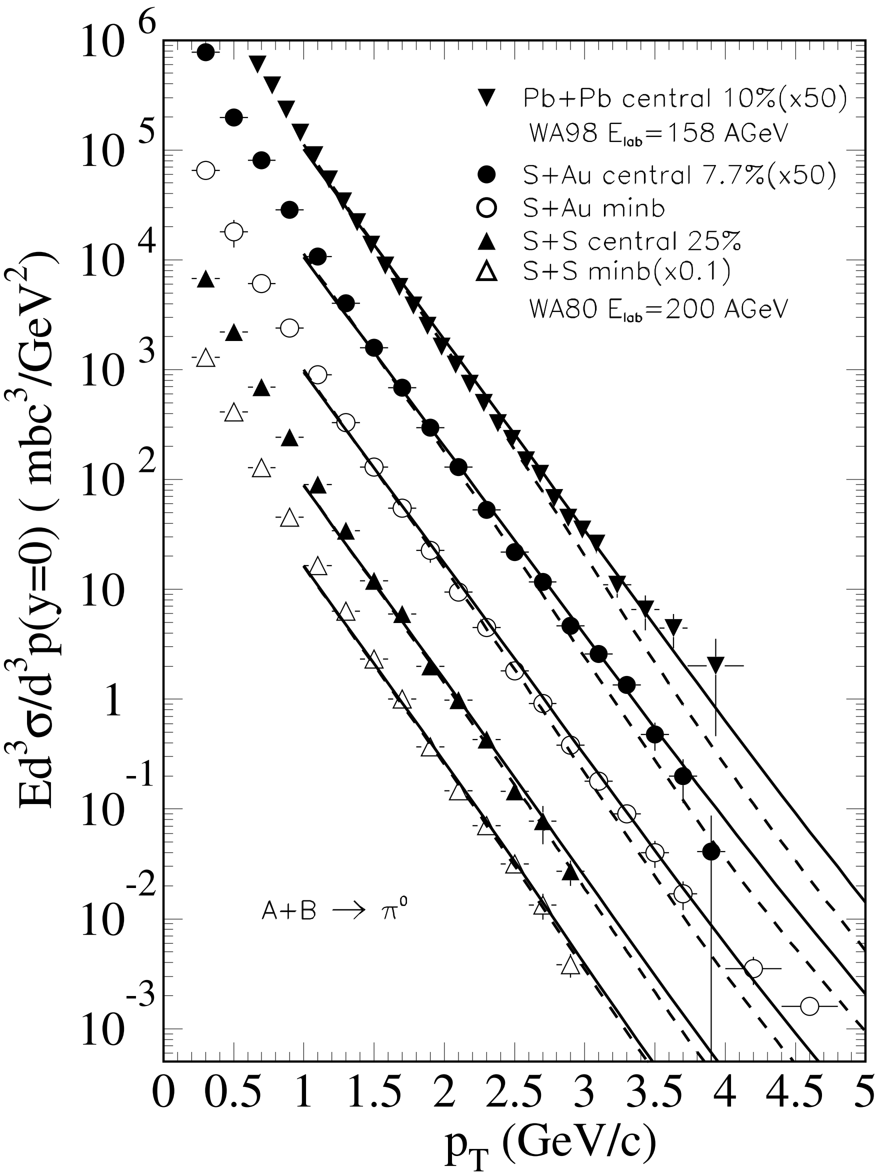


Figure 4: Production of π^0 at CERN SPS compared to pQCD with nuclear effects added. Predictions shown with and without nuclear modification of parton distributions. No parton energy loss added. Wang, nucl-th/9907093.

At SPS energies, pQCD predictions for $A + B$ interactions w/o parton energy loss match data well. Deviations at RHIC will be striking evidence of QGP formation.

Basic Program using High p_T production

$\longrightarrow$ Measure hadron production and compare to predictions using pQCD with nuclear modifications of structure functions, initial k_T, k_T broadening, modifications of gluon distributions ... all known nuclear effects

$\longrightarrow$ Look for differences from predicted expectations with and without added parton energy loss

$\longrightarrow$ To fully untangle contributions from known nuclear effects, must use pp and pA data as baseline measurements

$\longrightarrow$ In the meantime ... to see effects of dense environment, measure production relative to

- how much dense matter it's gone thru (i.e. centrality)
- different types of beams: AuAu, SiSi ... pp
- different beam energies

Lots of measurements that could indicate QGP formation in first year of data!

π^0 Spectra

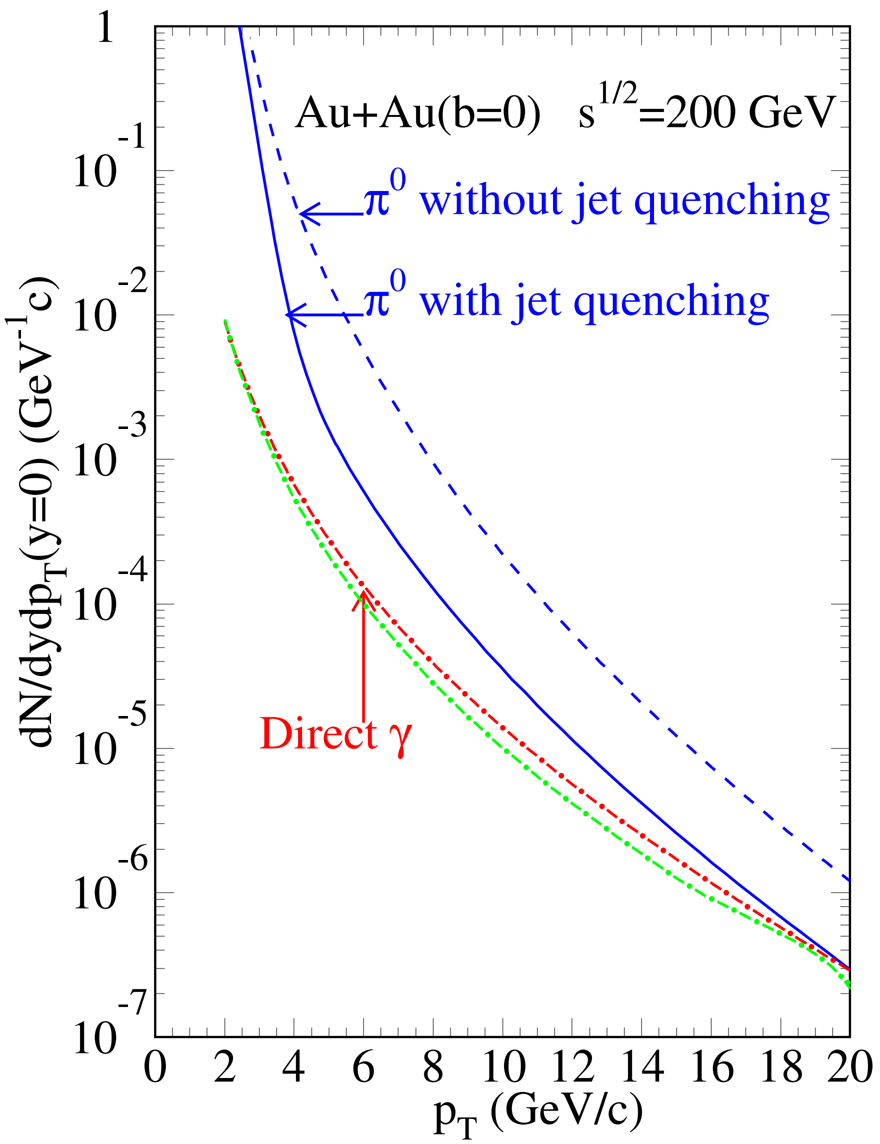


Figure 5: pQCD calculation of inclusive p_T distribution from $Au + Au$ collisions with nuclear effects included. Parton energy loss of $\mathrm{dE_q/dx} = 1\ \mathrm{GeV/fm}$ and mean-free path $\lambda_q = 1\ \mathrm{fm}$ assumed. Wang, Phys. Rev. **C58** (1998) 2321.

$\longrightarrow$ Year1 measurement using EMC:
expect $\approx 2500(25)$ events at $p_T = 5(10)$ GeV

$\longrightarrow$ Also h^+, h^- production using TPC,
as function of centrality

Charged Hadron Ratios

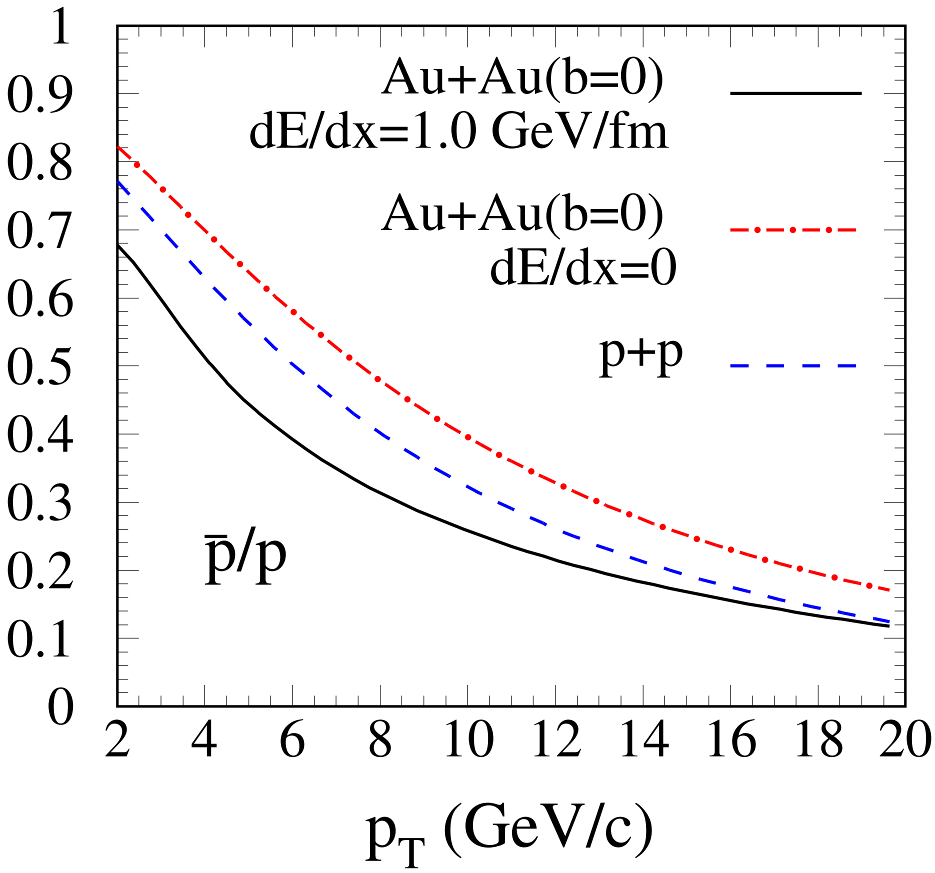


Figure 6: Ratio of $\bar{p}/p$ production vs. p_T from $Au + Au$ collisions. The pQCD predictions with nuclear effects included are shown with and without parton energy loss. Wang, Phys. Rev. **C58** (1998) 2321.

Possible to measure $\bar{p}/p$ ratio at high p_T (also K's, π's) with RICH in Year 1. Using TPC, can measure h^+/h^- ratio. Sensitive to both difference in fragmentation (g,q) and parton energy loss in high energy density environment.

Other High p_T Probes

∘ Jet Properties

- ⋆ sphericity of event
- ⋆ angular correlations
  - - near side (jet profiles)
  - - away side (jet quenching)

∘ Particle Production - first year and future

- ⋆ Λ, J/ψ at high p_T
- ⋆ direct γ's - sensitive to gluon distributions; don't interact with strongly with hadronic matter
- ⋆ leading particle distributions $\rightarrow$ may be easier/cleaner to measure than jets
- ⋆ jet production - more difficult due to large underlying event energies at RHIC
- ⋆ γ+jet events; tag the γ and measure jet

Summary

High p_T Physics at STAR in First Year:

$\star$ inclusive charged hadron production

- p_T spectra
  $\longrightarrow$ as function of centrality, beam type, energy
- ratio h^+/h^-
- multiplicity vs. η

$\star$ identified particle production ratios ($\bar{p}/p$ ...) vs p_T

$\star$ π^0 production p_T spectra

$\star$ angular correlations

- Looking forward to Data in 2000

- Many new exciting & unexpected(?) results!!

STAR Detector

STAR has full azimuthal coverage and large η range. Heart of detector is TPC & 0.5 Tesla solenoidal magnet.

- TPC:
  - tracking and individual track PID
  - $|\eta| < 1.7$, $\Delta\phi = 2\pi$
  - momentum resolution: $\sigma_p/p \leq 1\%$ for $p < 5$ GeV
- RICH:
  - limited angular coverage
  - $0 < \eta < 0.3$, $\Delta\phi \approx 20°$
  - extends PID to $\approx 3 - 5$ GeV
- SVT:
  - vertex tracking, PID
- FTPC:
  - $2.4 < |\eta| < 4.0$
  - 1 side in first year
- EMC:
  - Pb-scintillator sampling EM calorimeter, + preshower & shower max detector
  - segmentation 0.05×0.05 in $\Delta\eta \times \Delta\phi$
  - resolution $\approx 15\%/\sqrt{E}$
  - 4800 projective towers
  - 36,000 shower max pads at $5X_\circ$
  - barrel: $|\eta| < 1$, $\Delta\phi = 2\pi$ (10% in Year1 $+30\%$ added each year)
  - endcap: $1.05 < \eta < 2$, $\Delta\phi = 2\pi$ ($>$ Year2)

TPC Momentum Resolution

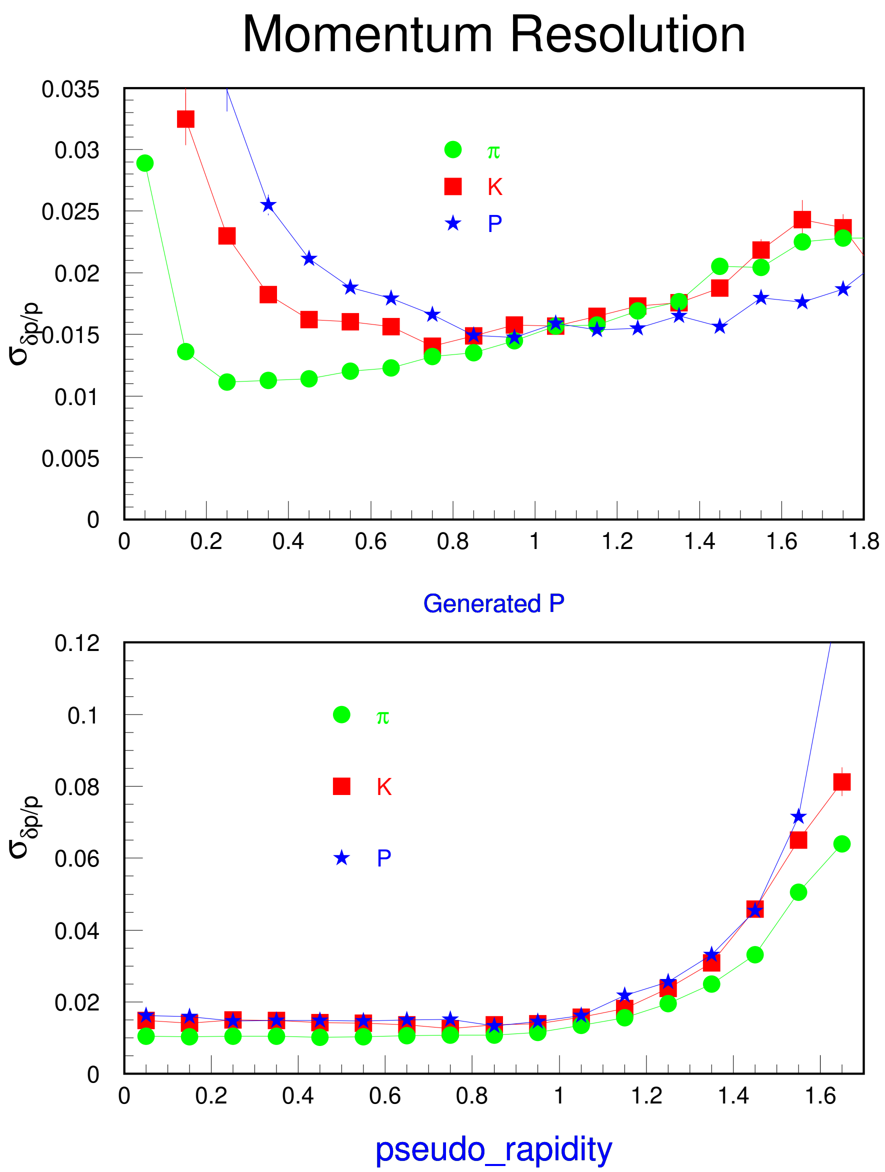


Figure 7: TPC Momentum Resolution vs momentum and η.

TPC Momentum Resolution

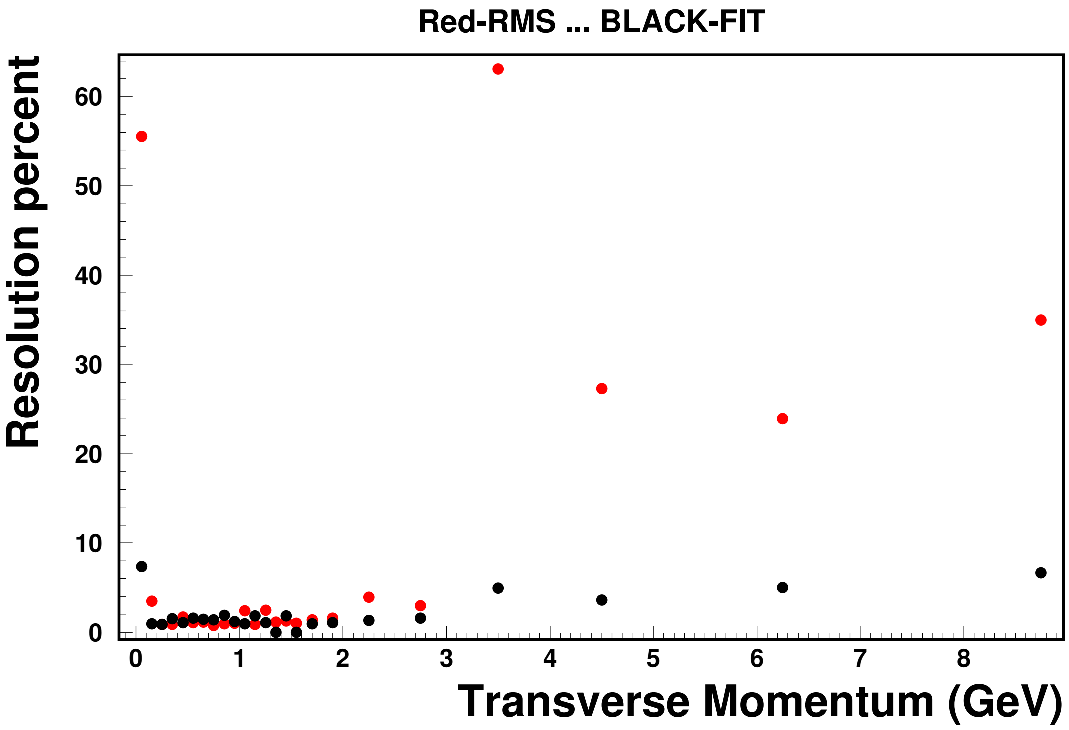


Figure 8: TPC Momentum Resolution vs p_T.

TPC,RICH PID Ranges

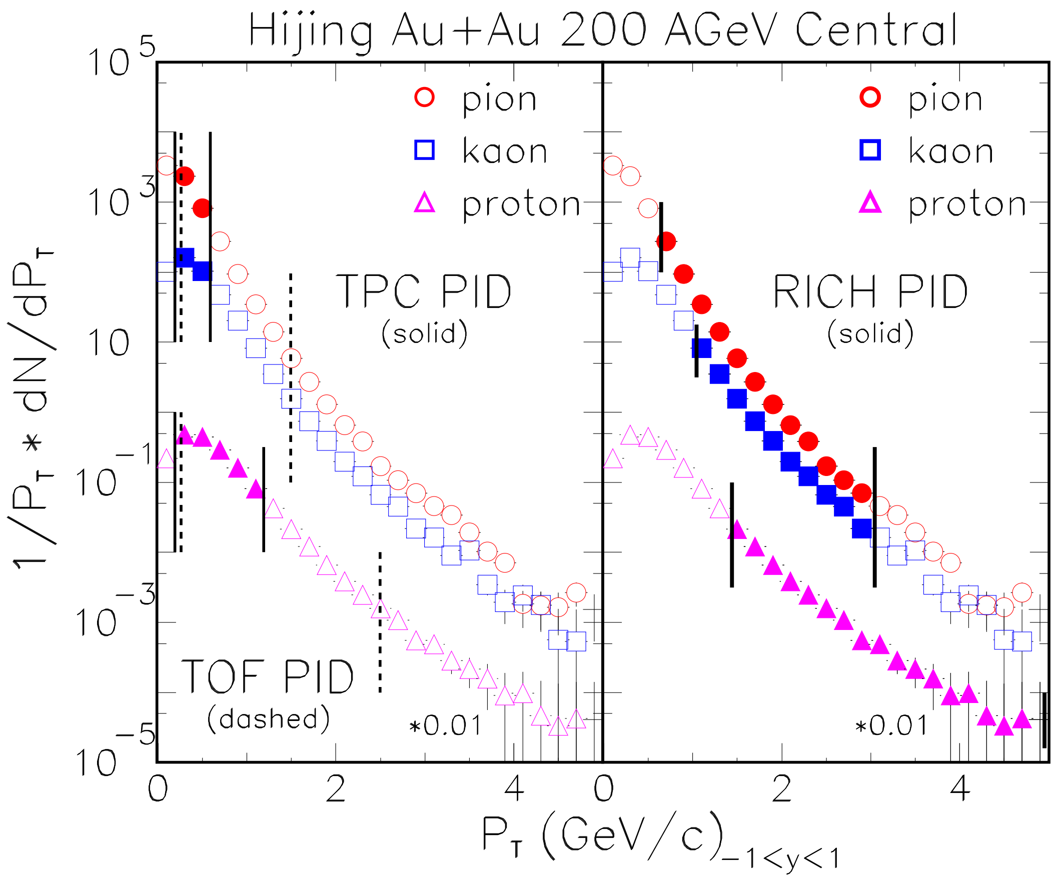


Figure 9: TPC, RICH PID ranges vs. p_T

Acceptance for π

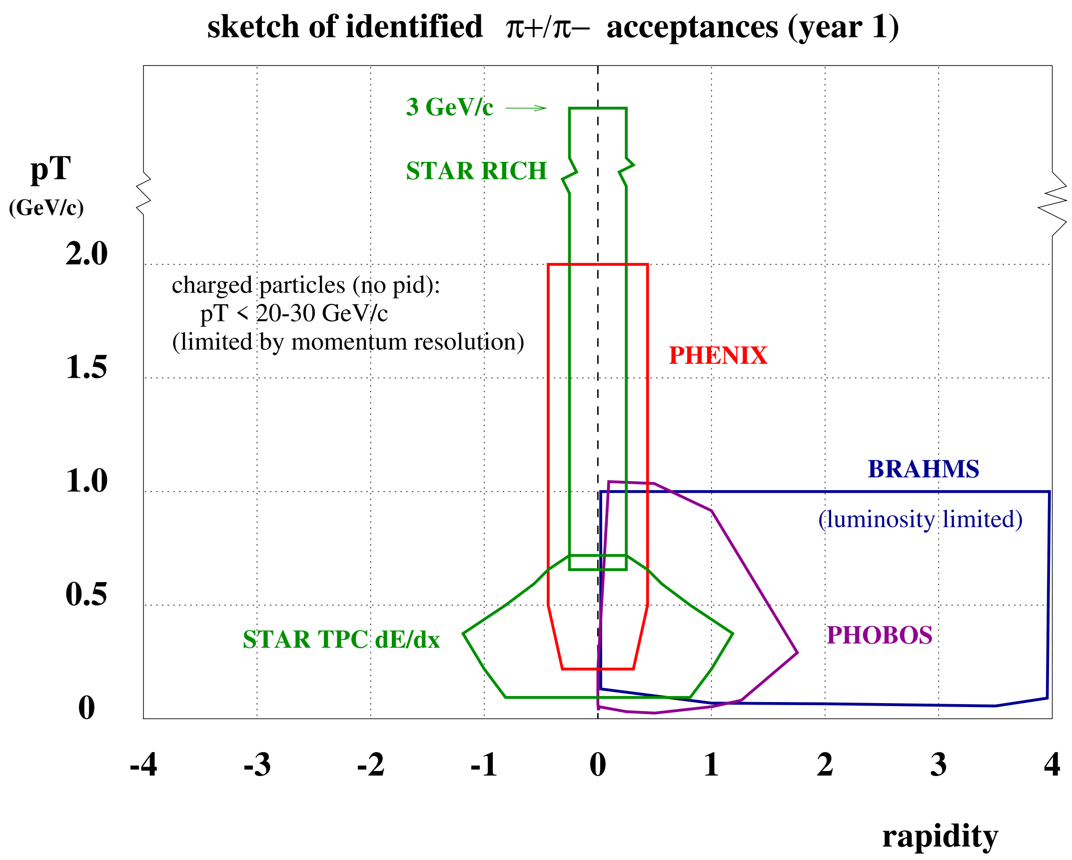


Figure 10: π acceptance range

Acceptance for K

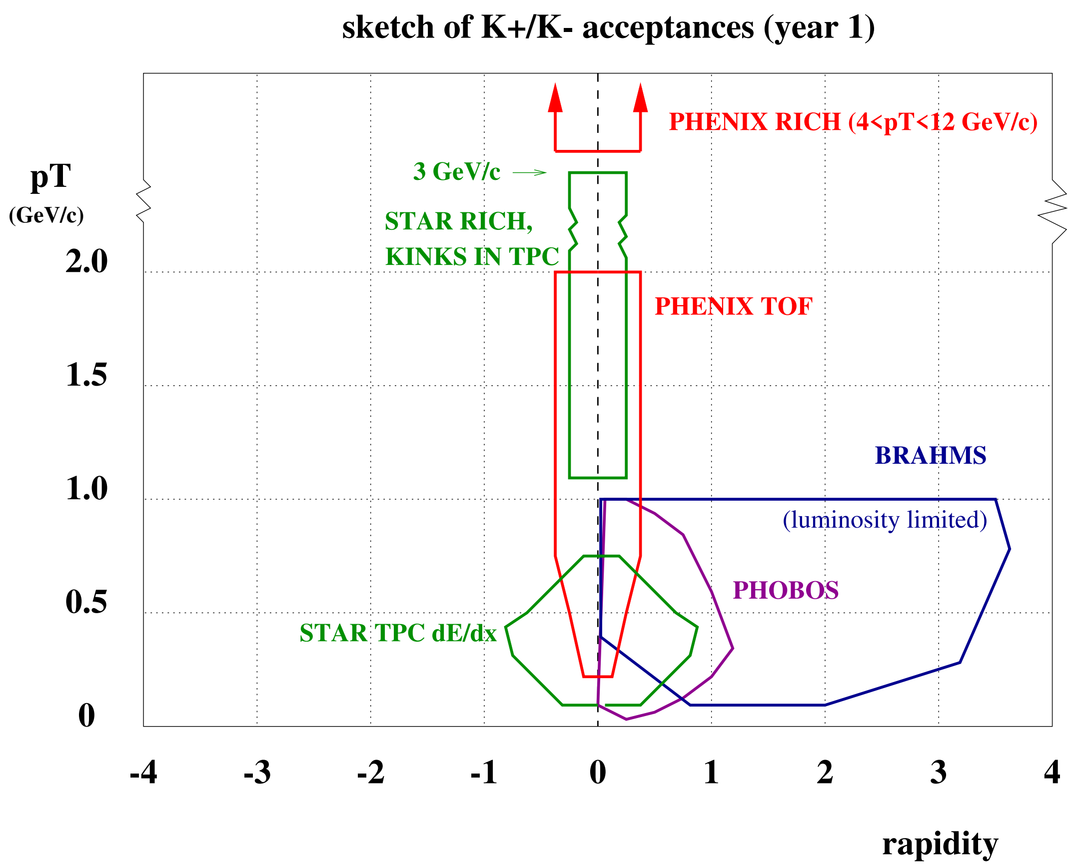


Figure 11: K acceptance range

Acceptance for p

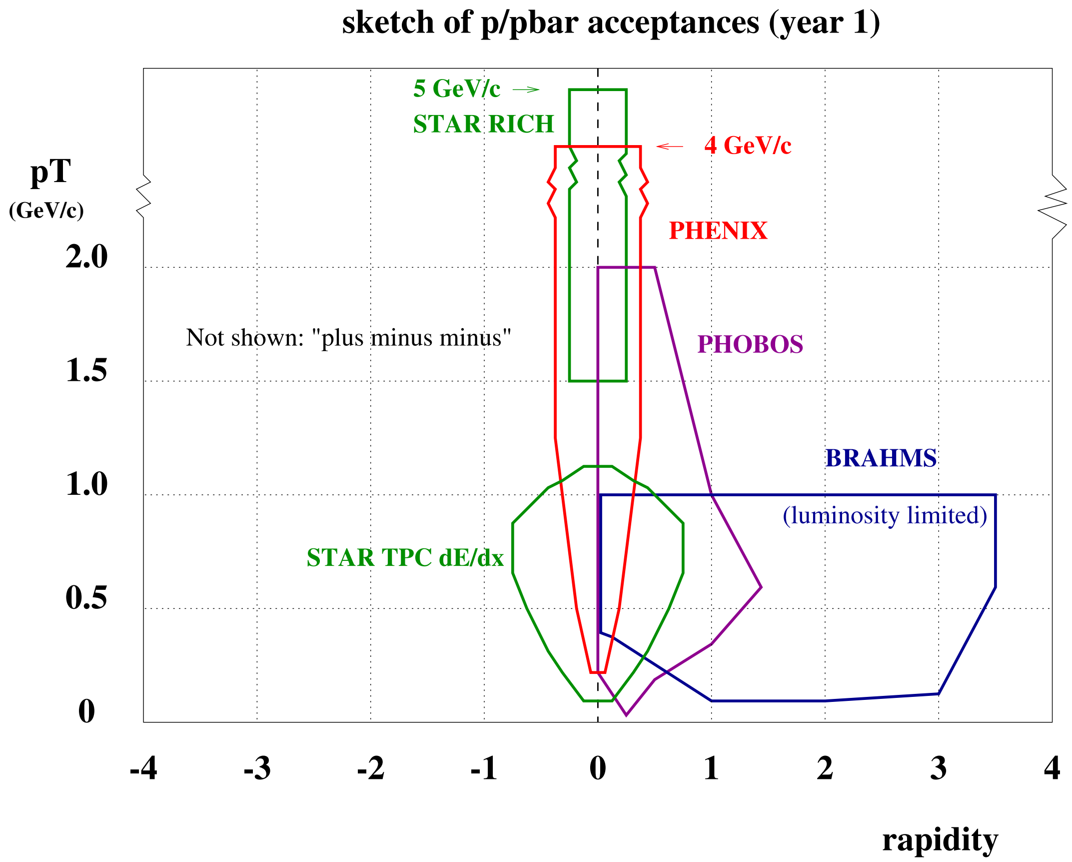


Figure 12: p acceptance range

Partons in High Energy Density Environment

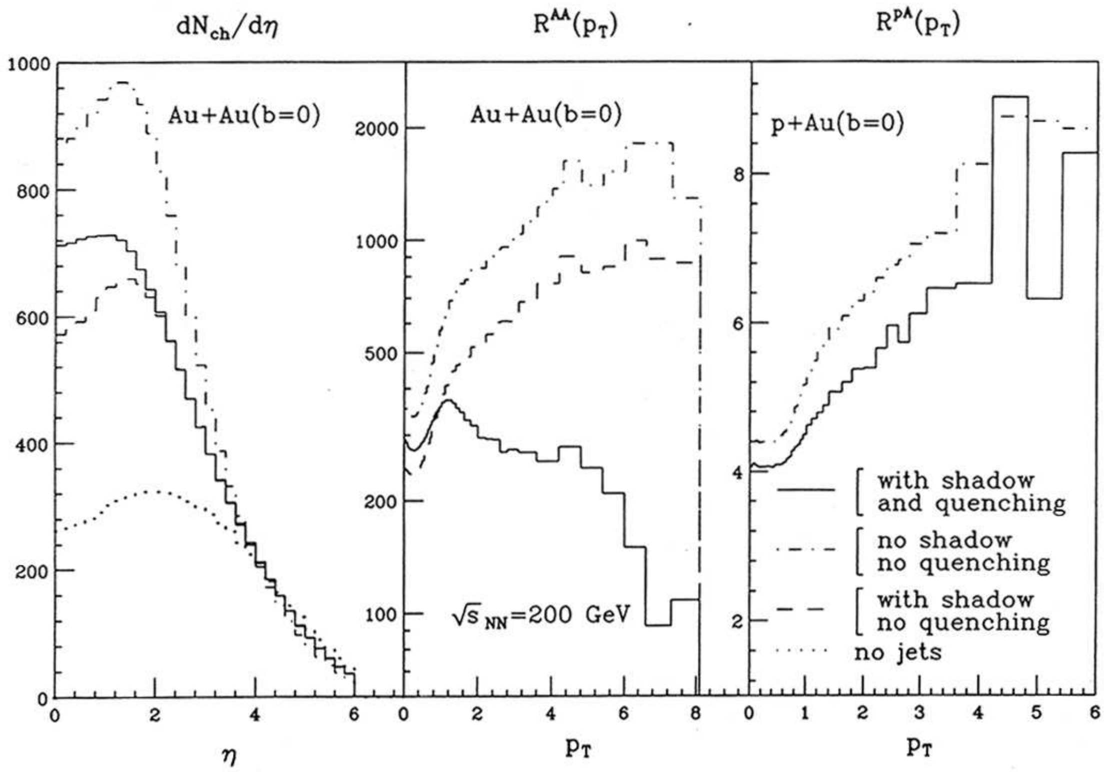


Figure 13: Inclusive charged particle spectra (HIJING) dependence on mini-jet production. R is ratio of nucleus-nucleus collisions to *pp* collisions. Gyulassy & Wang, PRL **68** (1992) 1480.

Heavy Ion vs. pp Interactions

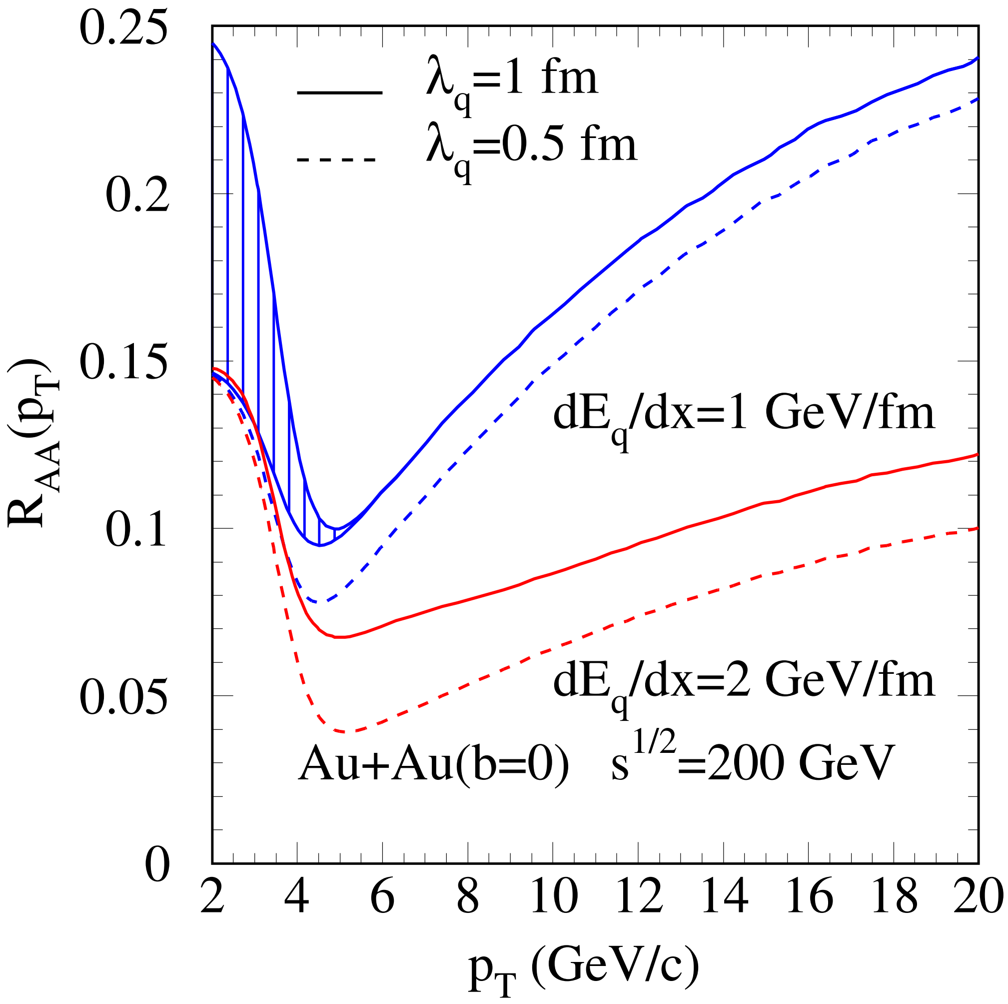


Figure 14: pQCD calculation showing ratio of charged particle P_T spectrum in central AuAu vs. pp at $\sqrt{s}$ = 200 GeV,normalized to effective total number NN collisions in a central AA collision (this is effectively the suppression). If nuclear effects (shadowing & jet quenching) are not taken into account, ratio $\approx$ 1 at large P_T. Wang, Phys. Rev. **C58**(1998)2321.

Charged Hadron Ratios

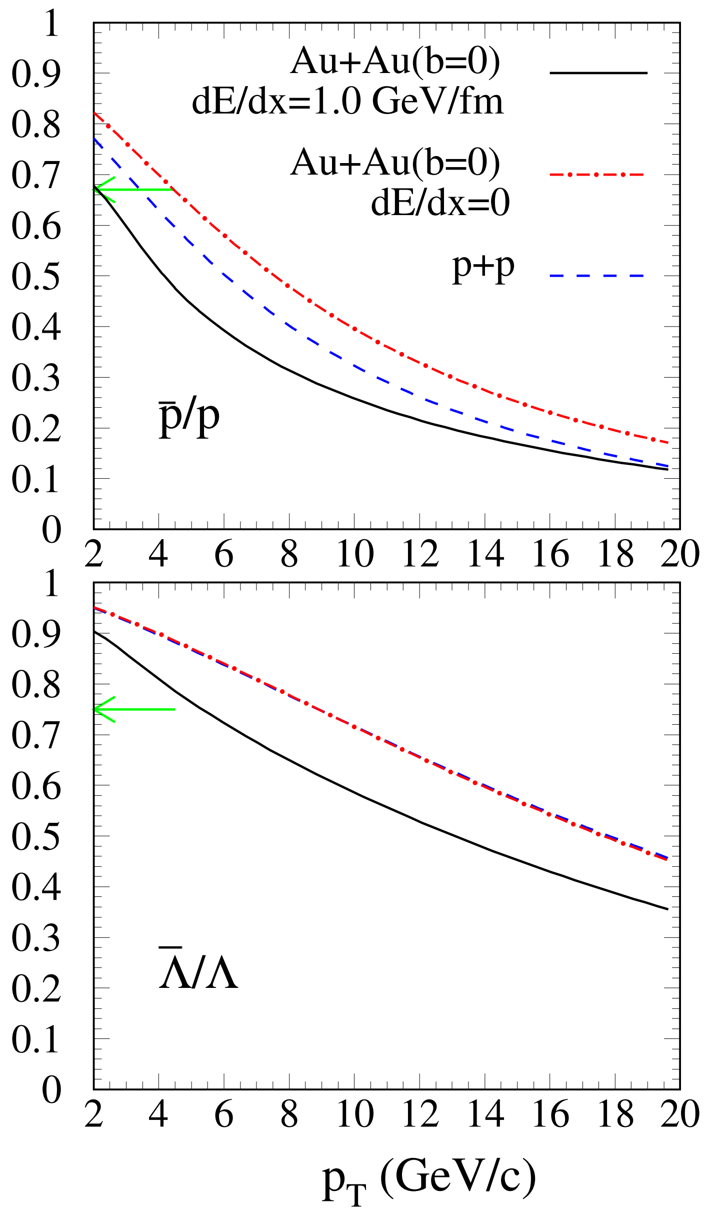
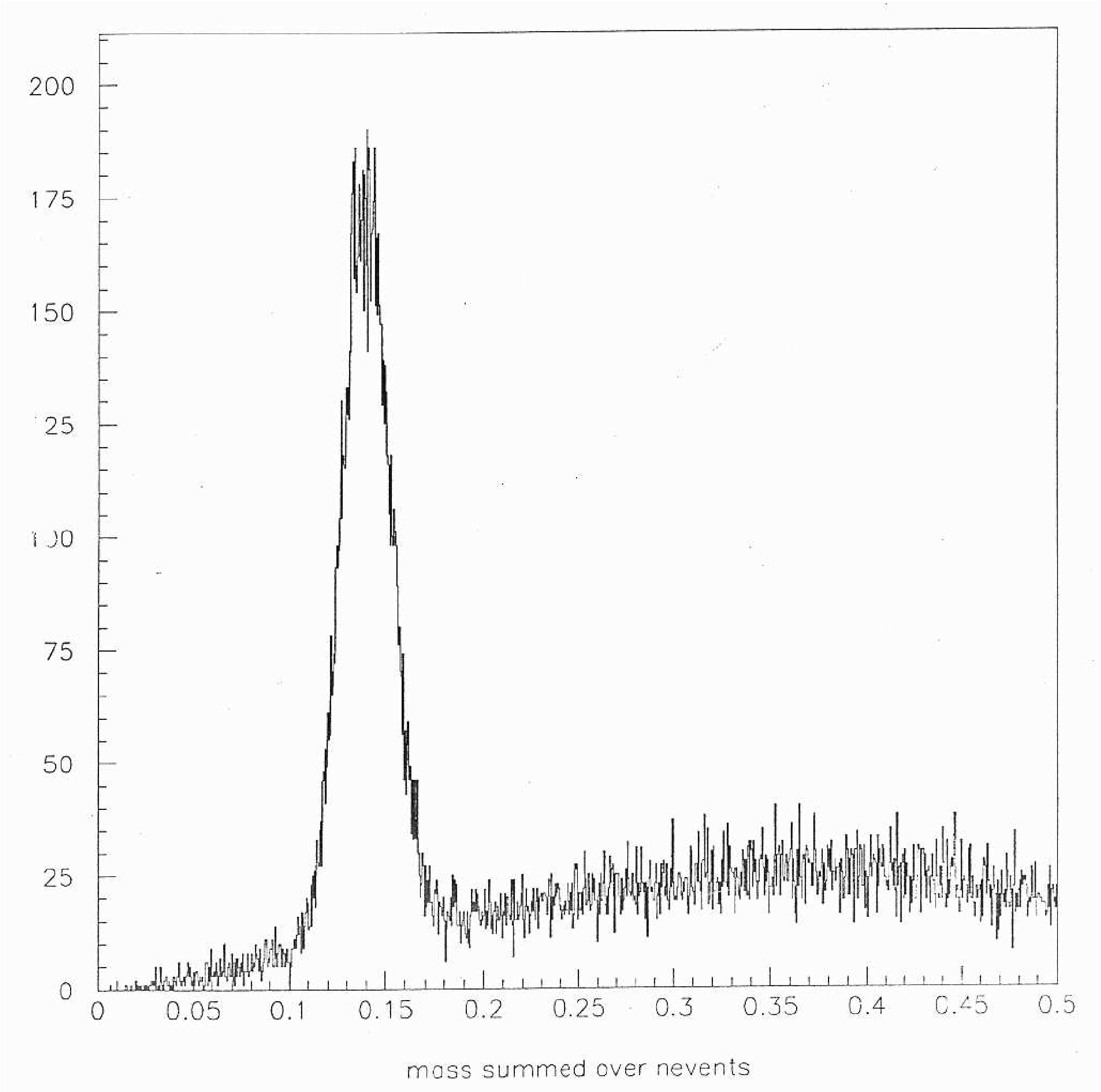


Figure 15: Ratio of charged hadron production vs. p_T with different energy loss schemes. From pQCD calculation by Wang, Phys. Rev.**C58**(1998)2321.

Possible to measure $\bar{p}/p$ ratio at high p_T with RICH detector in Year 1.
Sensitive to both difference in fragmentation and energy loss in high energy density environment.

STAR: $\pi^0 \rightarrow \gamma\gamma$ mass peak - Year1 Statistics



$\longrightarrow$ Year1 measurement using EMC:
expect $\approx 2500, 25$ events at $P_T = 5, 10$ GeV (T. Cormier)

J/ψ Production - Year 2 Statistics

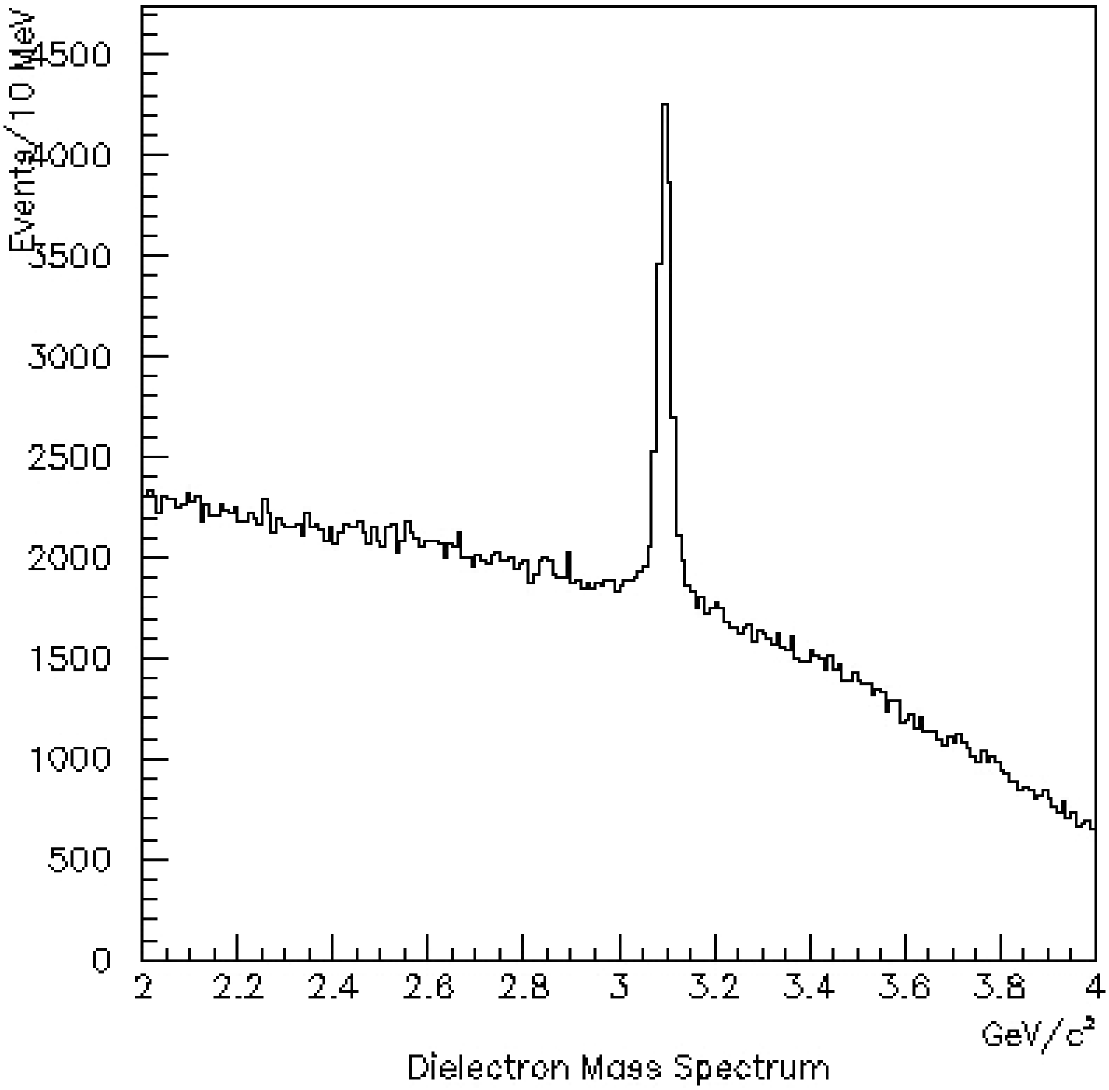


Figure 16: T. LeCompte

Year2 measurement (L3 trigger)
- simulation with all detector effects:
require $P_T > 1.5\,\mathrm{GeV}$, get $\approx 4 \times 10^4$ J/ψ's per year

π Production at SPS and RHIC

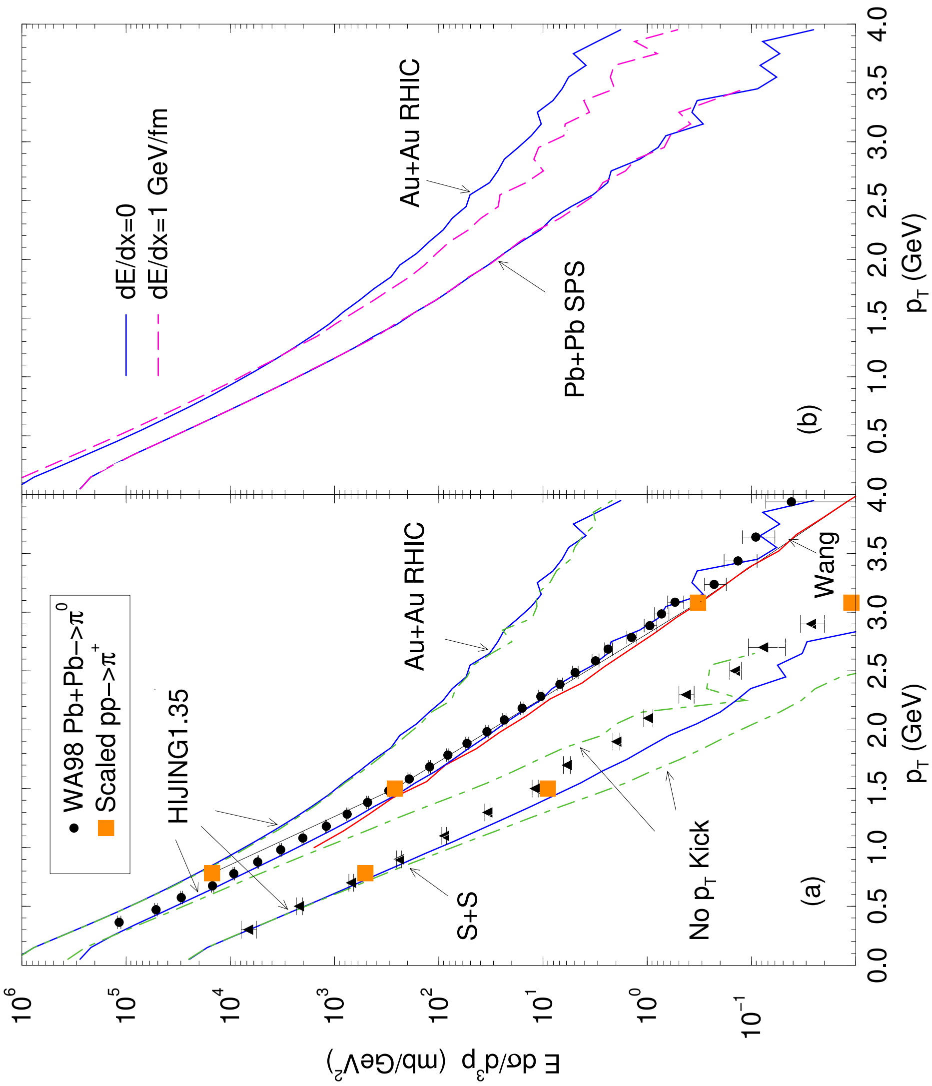


Figure 17: M. Gyulassy and P. Levai, Phys. Lett B442 (1998) 1.

Charged π production

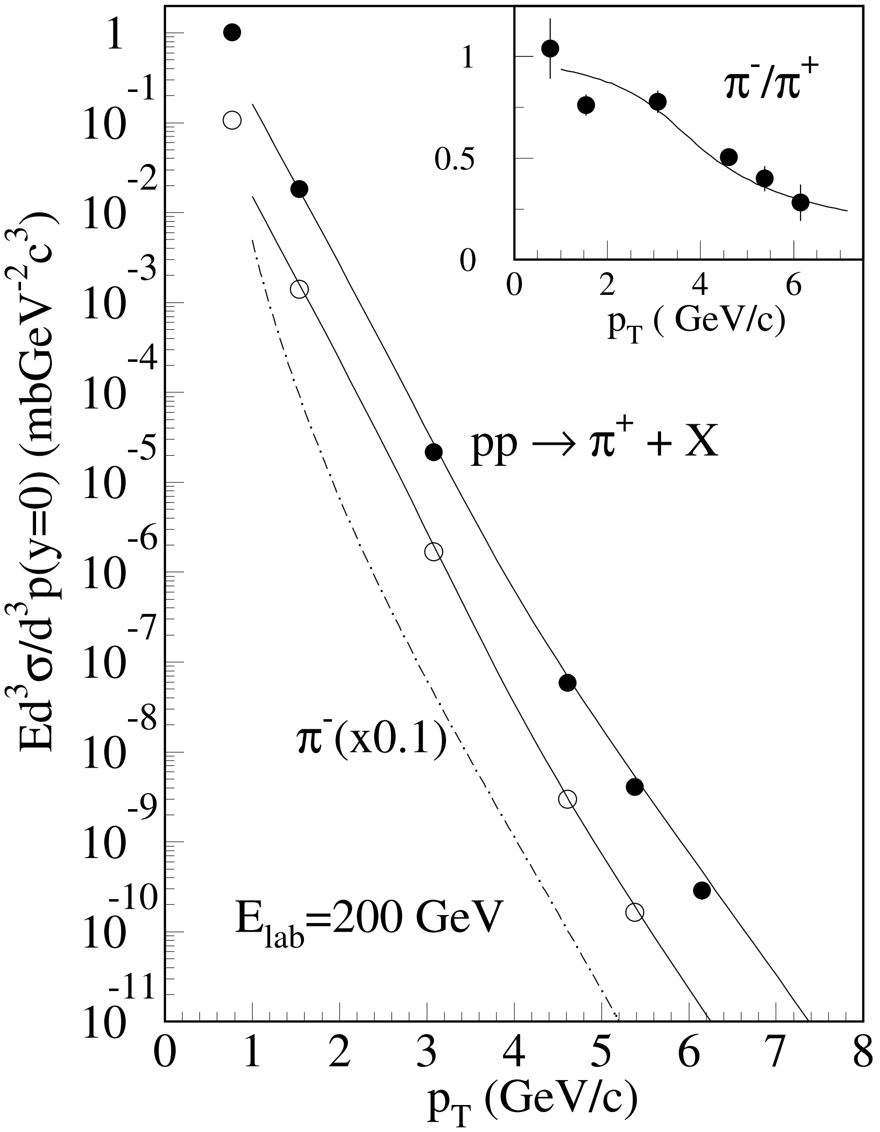


Figure 18: Inclusive π spectra compared to pQCD with and without intrinsic k_T added. Wang, nucl-th/9907093.

High p_T Program - Long Term

$\rightarrow$ In order to obtain full experimental results, we will need results from data sets (or obtain elsewhere):

$\star$ structure functions in the proton
  - pp data set, select $\gamma - jet$ final state

$\star$ nuclear shadowing (modification of structure functions)
  - pA data set, select $\gamma - jet$ final state

$\star$ jet fragmentation functions
  - pp data set
  - pA data set
  - AA data set

$\star$ measure AA production as a function of beam energy and centrality