R_{CP} Measurement with Hadron Decay Muons in Au+Au Collisions at $\sqrt{s_{NN}}$=200 GeV

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For the PHENIX Collaboration

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- Physics motivation
  - from p+p to Au+Au
- PHENIX Experiment
- Muons from hadron decay
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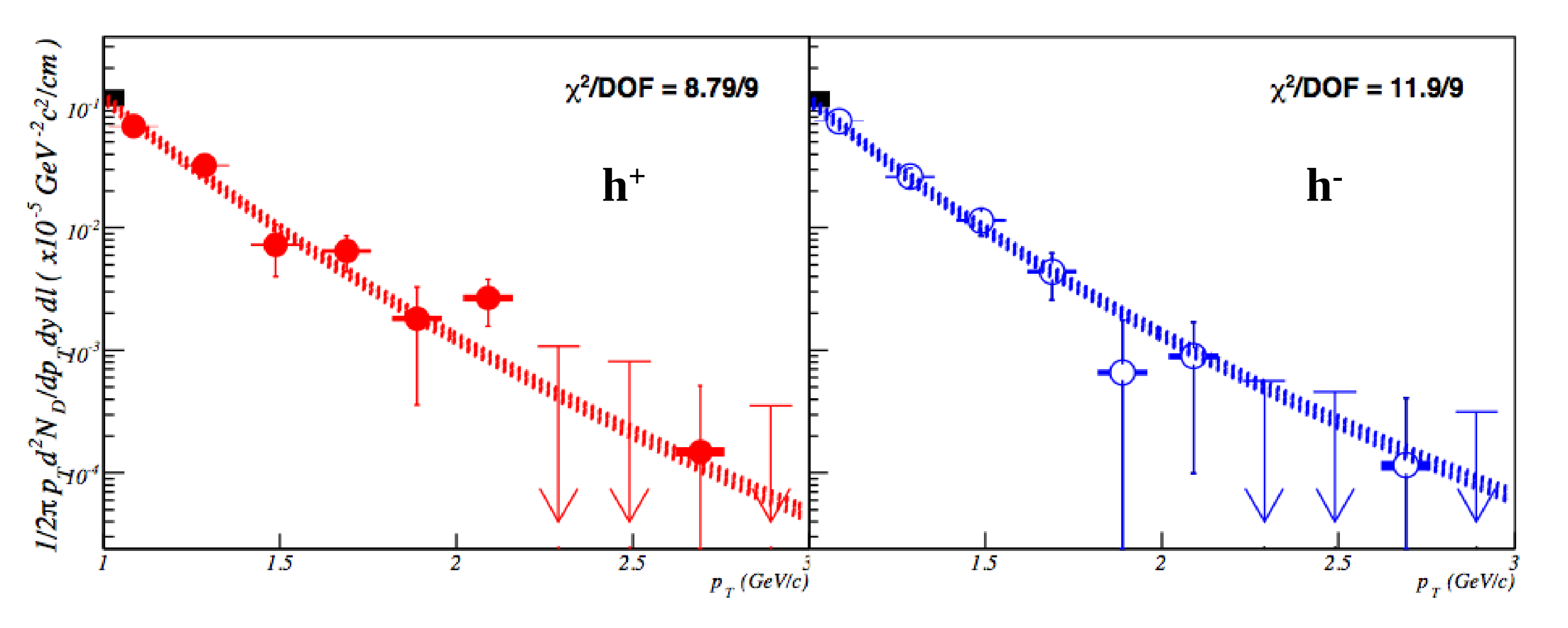
PHENIX single muon physics

- Study particle production in (polarized) pp, pA and AA collisions at forward (backward) rapidity
  - Light hadrons: How dense is the matter? channel)
  - Heavy flavor: How strongly coupled is the matter? nnel)
- Probe nuclear medium effects:
  - Normal nuclear medium (dAu)
  - Hot and dense nuclear medium (AuAu)
- SPIN measurement: gluon polarization

Physics motivation - from p+p to Au+Au

- p+p collision
  - Provide baseline reference for heavy-ion measurements
  - Test of pQCD
- p+A collision (d+Au at RHIC)
  - Probe Initial-State Effects / Normal nuclear medium(Cold nuclear medium) effect
  - Shadowing / saturation @ low x_A
  - p_T broadening / energy loss
  - Modifications of baryon production
- Au+Au collision
  - Hot and dense nuclear medium
  - QGP / phase transition to the new state of matter
- Cu+Cu collision
  - can give much better N_{part} and N_{coll} precision
  - RHIC provided Cu+Cu collisions at $\sqrt{S_{NN}}$=200, 62, 22 GeV

Light hadron's Differential multiplicity in p+p

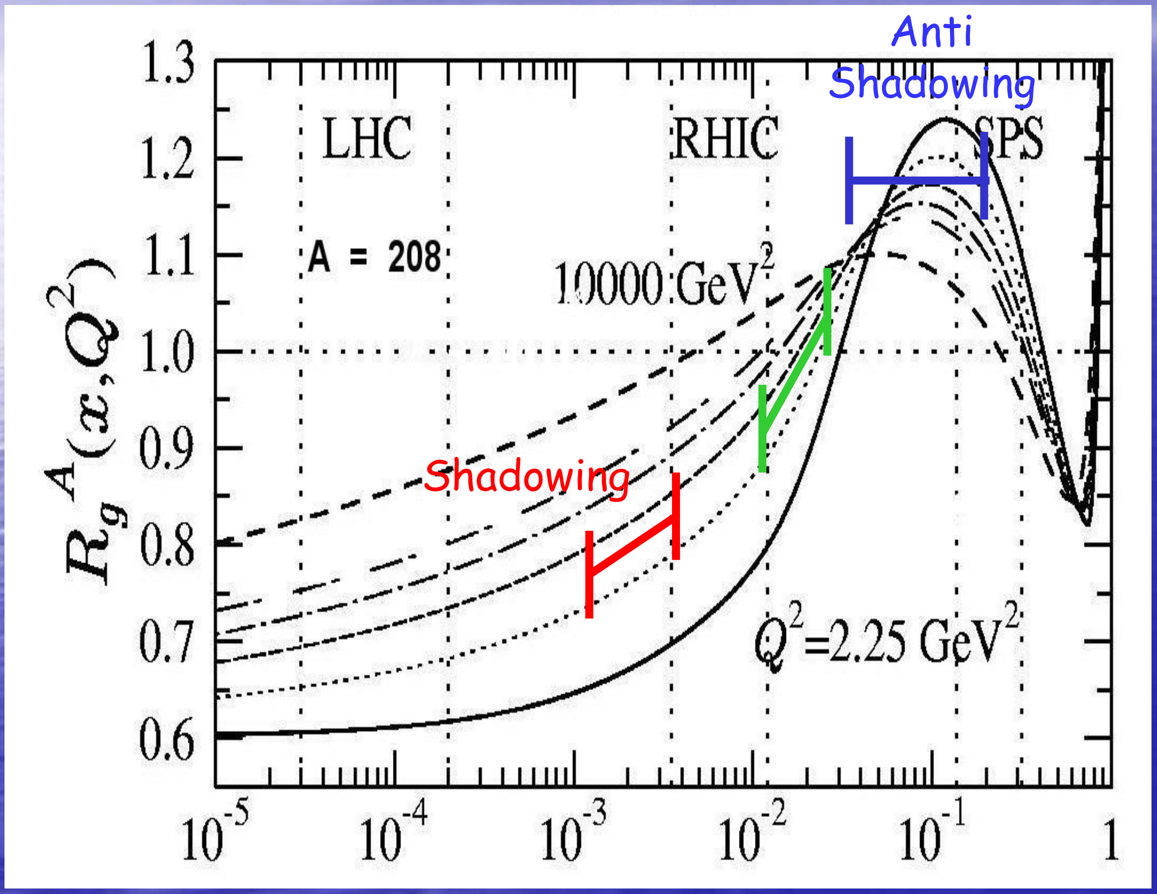


hep-ex/0609032

- PHENIX Run2 p+p data – hadron decay muons
- Provide baseline reference for d+Au / Au+Au measurement

Physics Motivation – d+Au

gluons in Pb / gluons in p



X

From Eskola, Kolhinen, Vogt
Nucl. Phys. A696 (2001) 729-746.

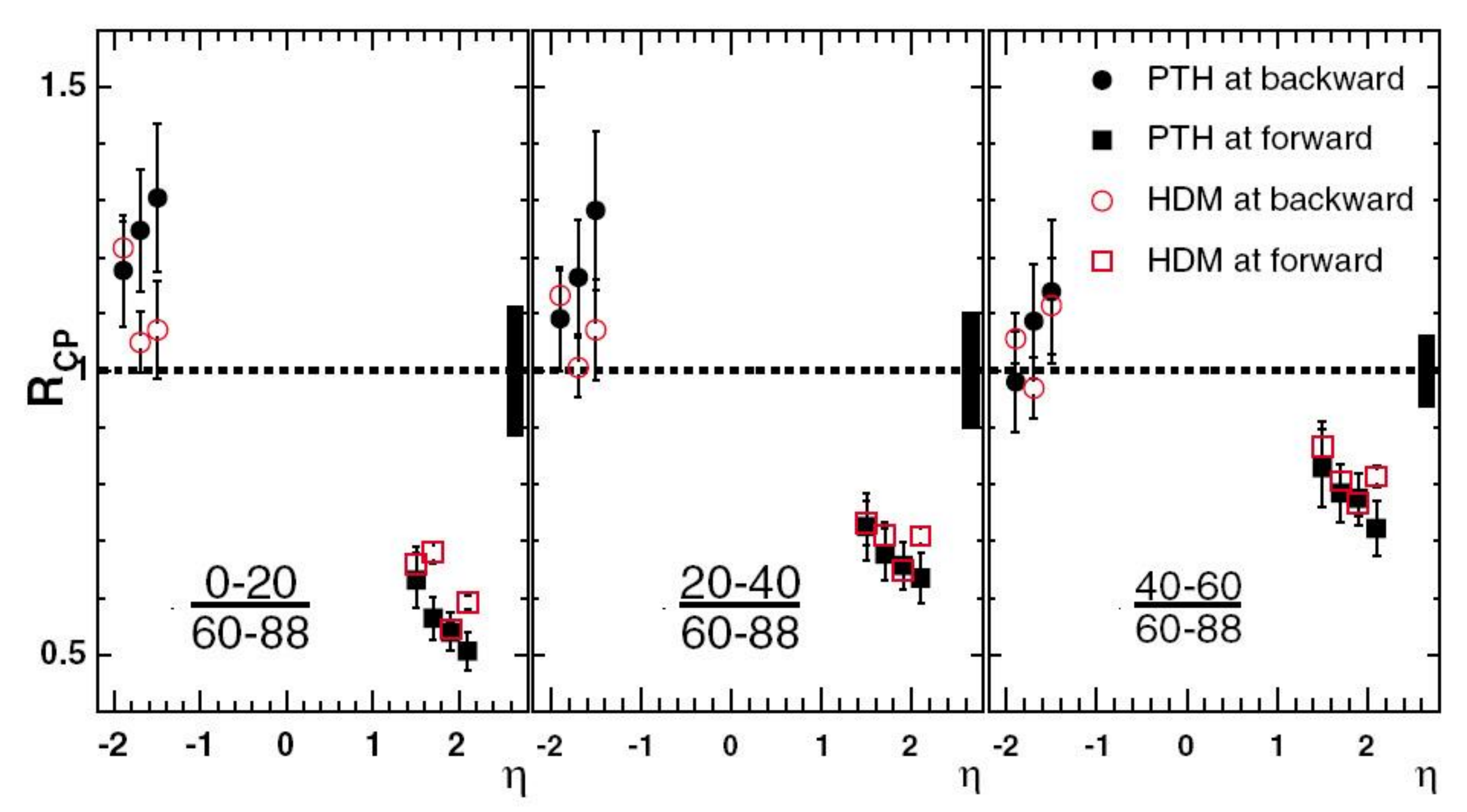
Three rapidity ranges probe different momentum fraction of Au partons

PHENIX North arm (y > 1.2) :
small X ~ 0.003
Shadowing/suppression regime

PHENIX Central arm (y ~ 0) :
intermediate X ~ 0.020

PHENIX South arm (y < -1.2) :
large X ~ 0.090
Anti-shadowing/Cronin regime

R_{CP} in d+Au Collisions - PHENIX

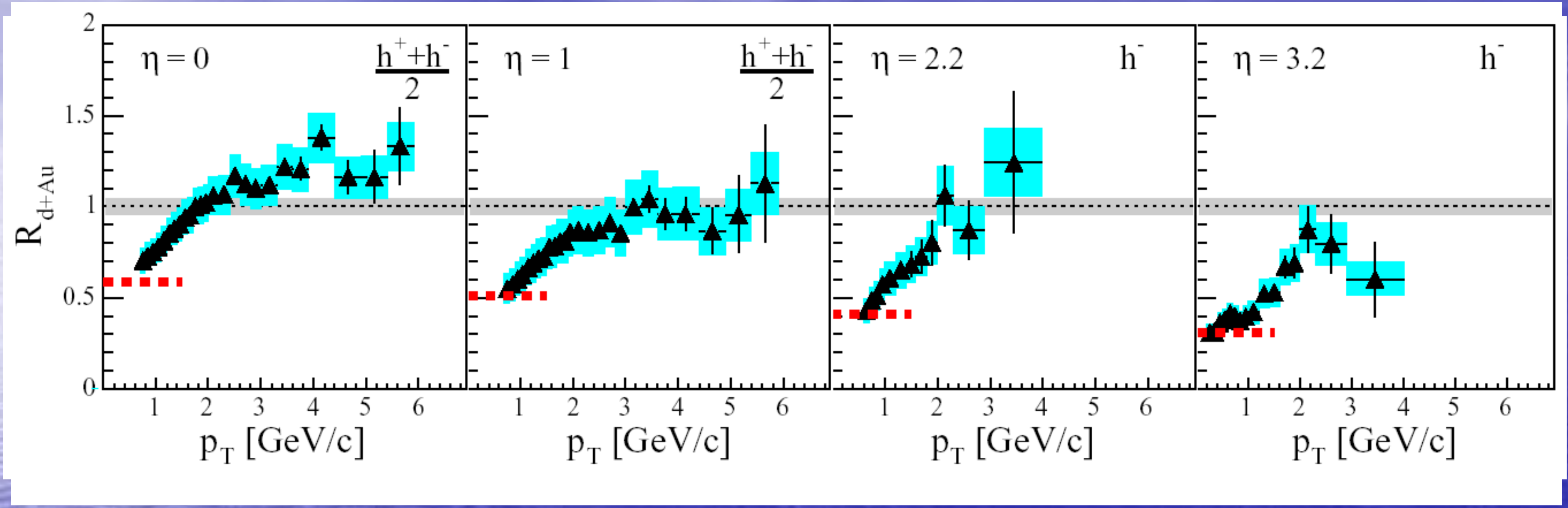


PHENIX - Phys. Rev. Lett. 94, 082302 (2005)

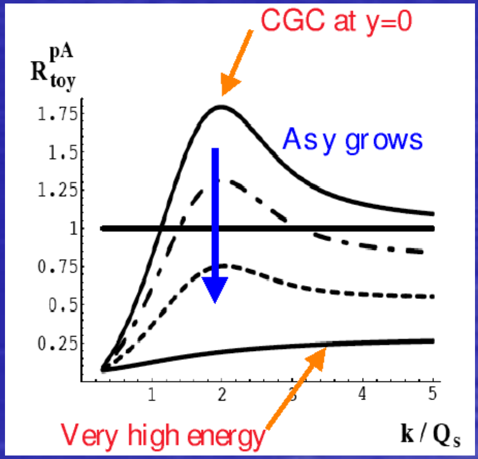
d direction → ← **Au direction**

R_{dAu} in d+Au Collisions

Brahms PRL 93 (2004)



D. Kharzeev hep-ph/0307037



Cronin-like enhancement at η =0

Clear suppression as η changes from 0 to 3.2

Measurements very consistent with initial-state effects estimated by CGC.

Physics Motivation – Au+Au

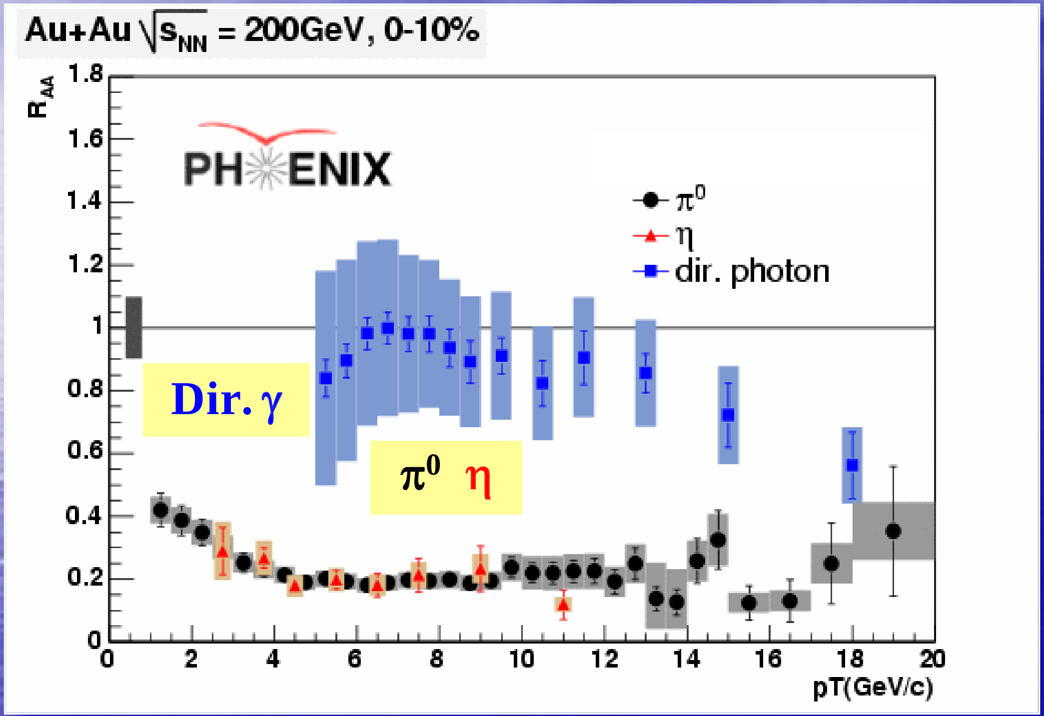
R_{CP}: Ratio between the central and peripheral yields scaled by the number of binary collisions, where it is assumed that peripheral is similar to pp

- Two different effects can be expected (vs eta)
  1. Low energy density(less energy loss) could make R_{CP} high
  2. New regime of parton physics at low-x(CGC).
     - Gluon saturation at low-x has been predicted to suppress hadronic yields
     - For Au+Au collisions, $R_{CP} \ll 1$ can be expected
- PHENIX can measure R_{CP} with mesons

R_{CP} measurement

- Advantage: a lot of detector systematics cancel.
- Disadvantage: most peripheral bin of 60-93% still corresponds to 14~15 collisions and not all nuclear effects might be eliminated.

Light quark p_T suppression



Phys. Rev. Lett. 91, 072301 (2003)

Nuclear modification factor:

$$R_{AA}(p_T) = \frac{\frac{dN^{AA}}{dp_T}}{\frac{T_{AA}\, d\sigma^{pp}_{inel}}{dp_T}}$$

Suppression, $R_{AA} << 1$, indicates strong coupling of quarks to the produced medium.

Photons not suppressed by the medium

Mesons suppressed by medium by factor of ~5

The PHENIX detector

- Optimized for lepton measurements

□ Electrons - central arms :

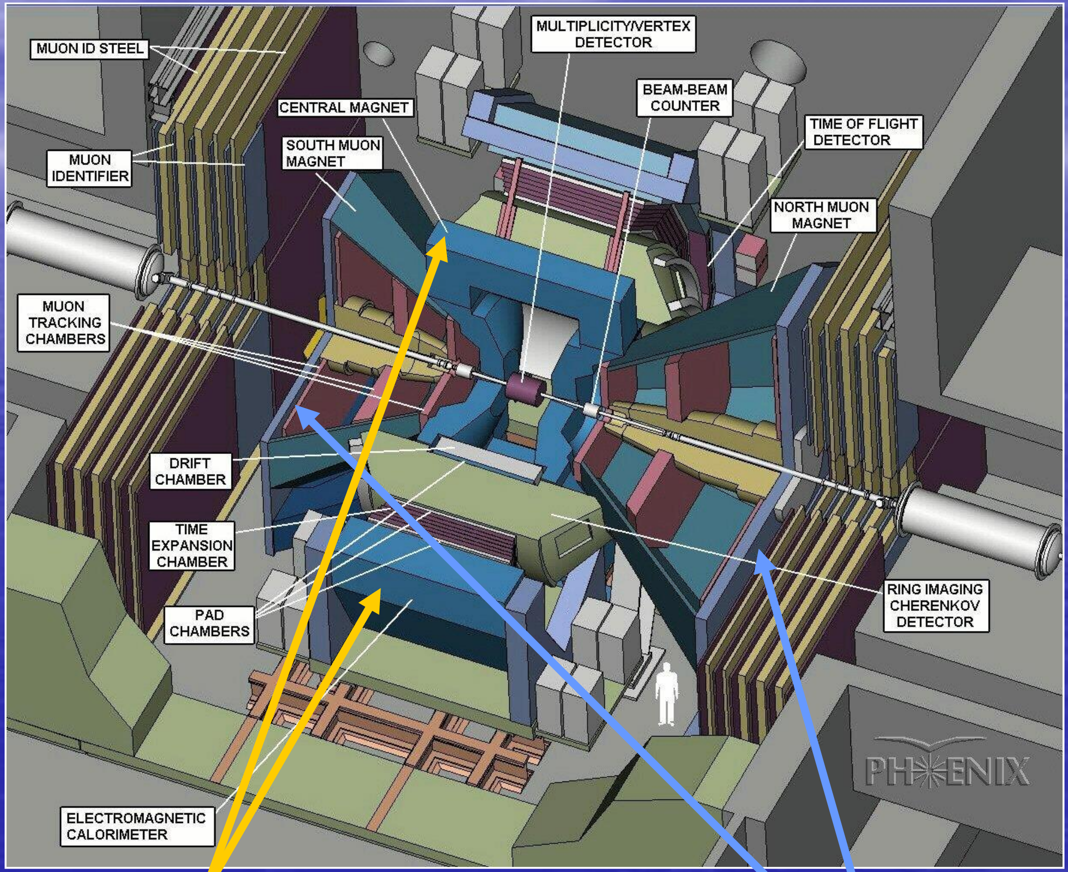
$|\eta| \leq 0.35$

$p \geq 0.2$ GeV/c

□ Muons - forward arms :

$1.2 < |\eta| < 2.4$

$p \geq 2$ GeV/c

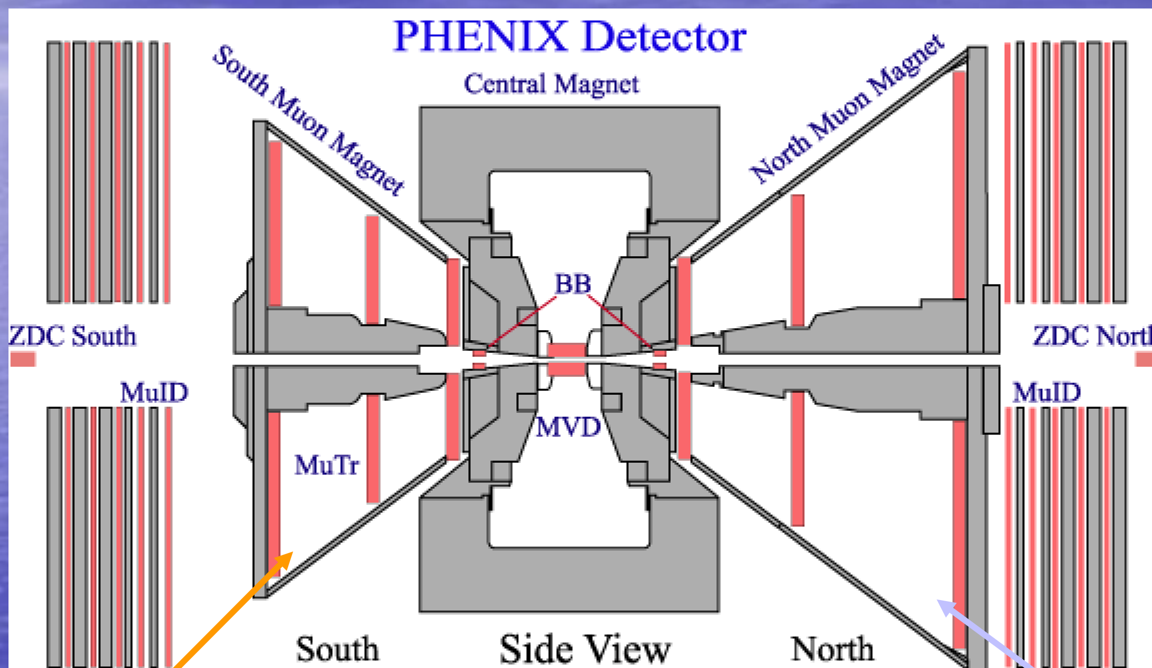


two central electron/photon/hadron spectrometers

two forward muon spectrometers

The PHENIX Detector

Au Au

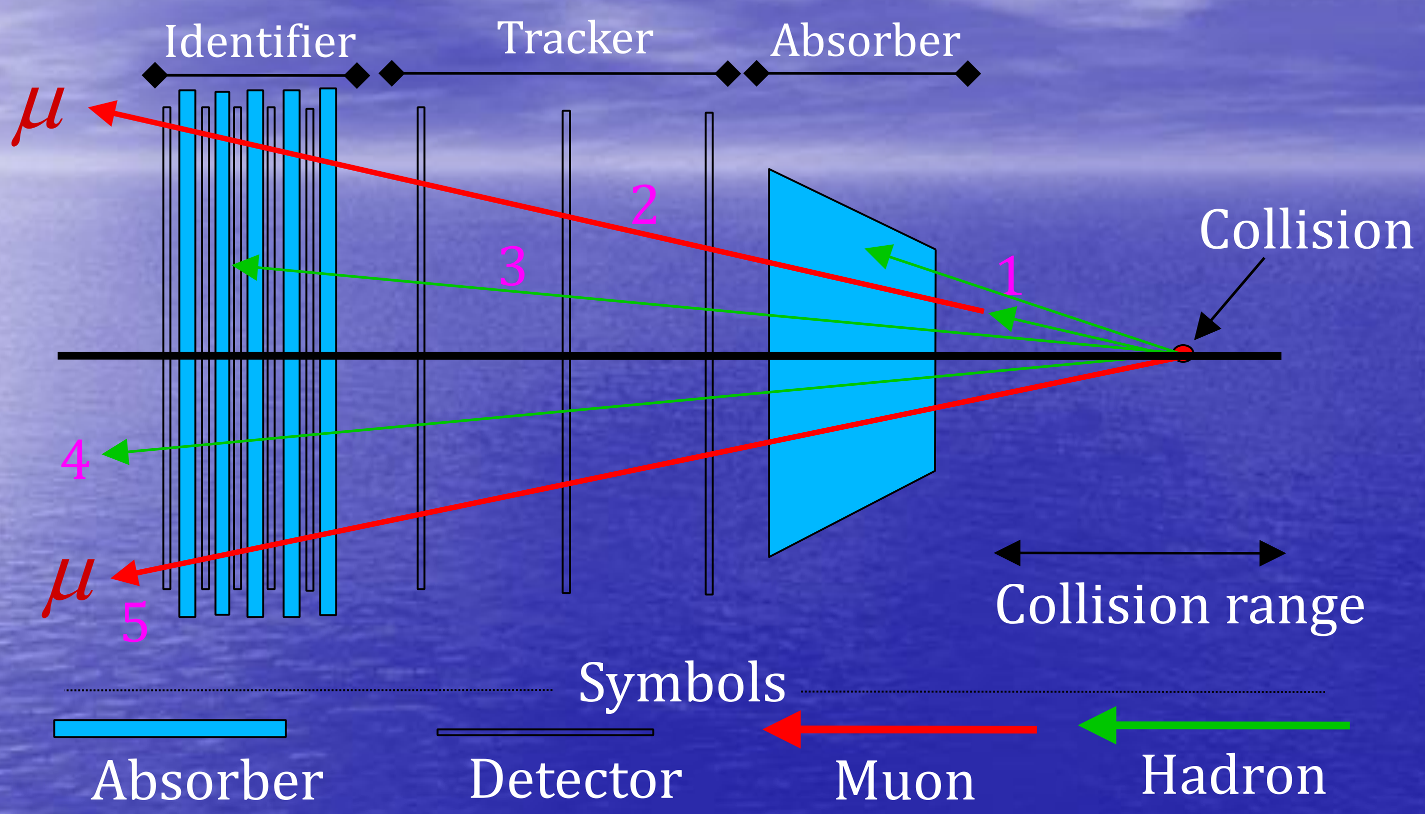


South Muon arm : $-2.2 < \eta < -1.2$

North Muon arm : $1.2 < \eta < 2.4$

241 mb^{-1} Au+Au data at $\sqrt{s_{NN}}$=200 GeV at 2004~2005 RHIC Run4

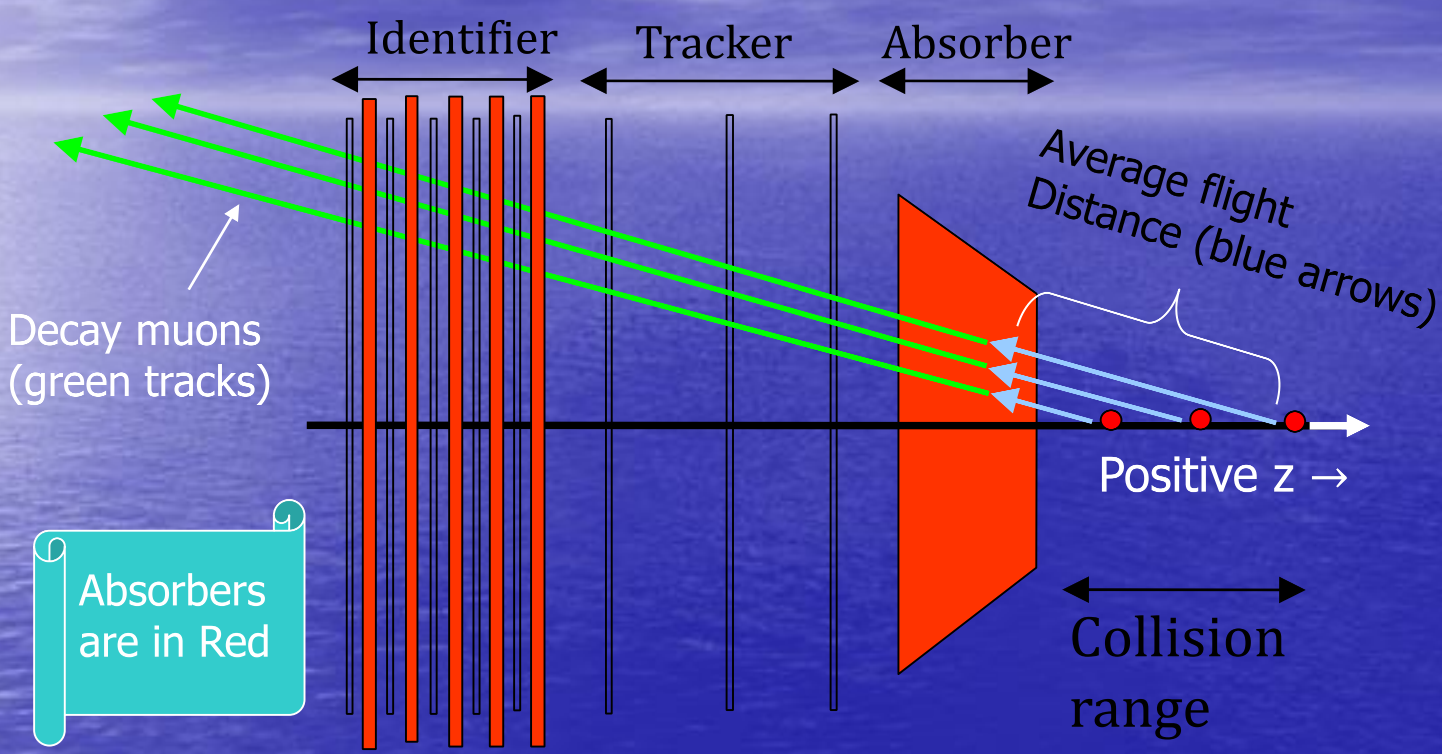
Major Sources of Inclusive Tracks



1 : Hadrons, interacting and absorbed (98%)
2 : Charged π/K's, "decaying" before absorber (≤1%)
3 : Hadrons, penetrating and interacting ("stopped")
4 : Hadrons, "punch-through"
5 : Prompt muons, heavy flavour decay

Item 2 is desired signal and rest of them are background in this analysis

Identification of muons from hadronic decay

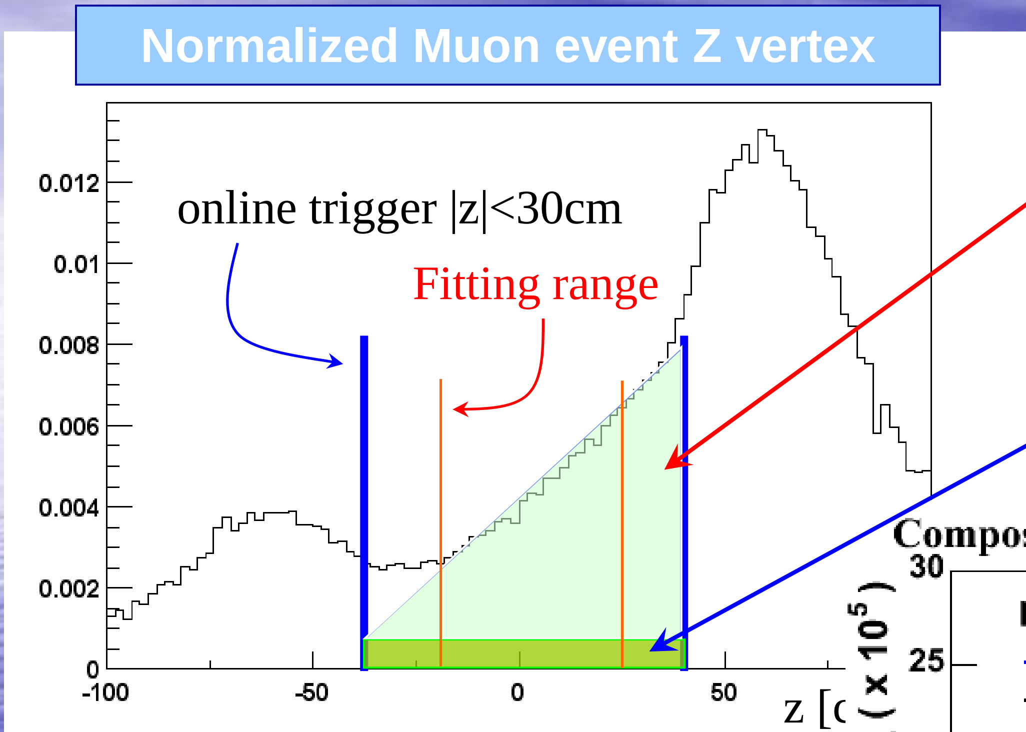


$$P_{decay}(p,L) = 1 - e^{-\frac{L \cdot m}{\tau \cdot p}}$$

The yield of decay muons depends on the collision location linearly.

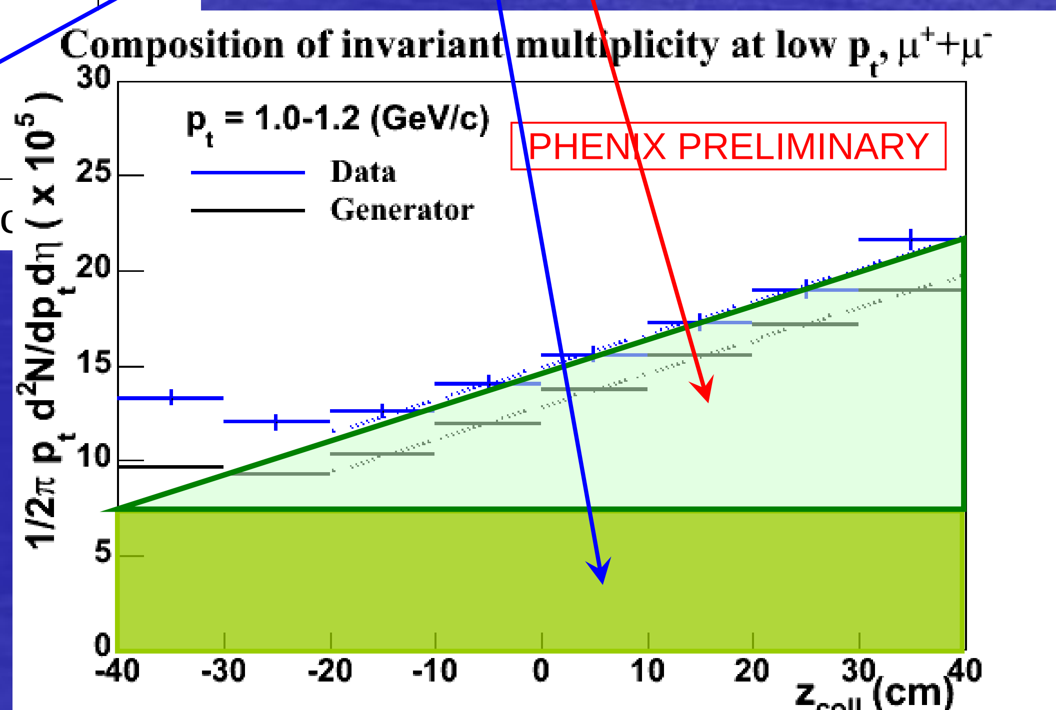
where, L is distance from the collision point to the absorber

Z vertex Dependence



Decay muons

Prompt muons(haevy flavor decay)
punch through hadrons

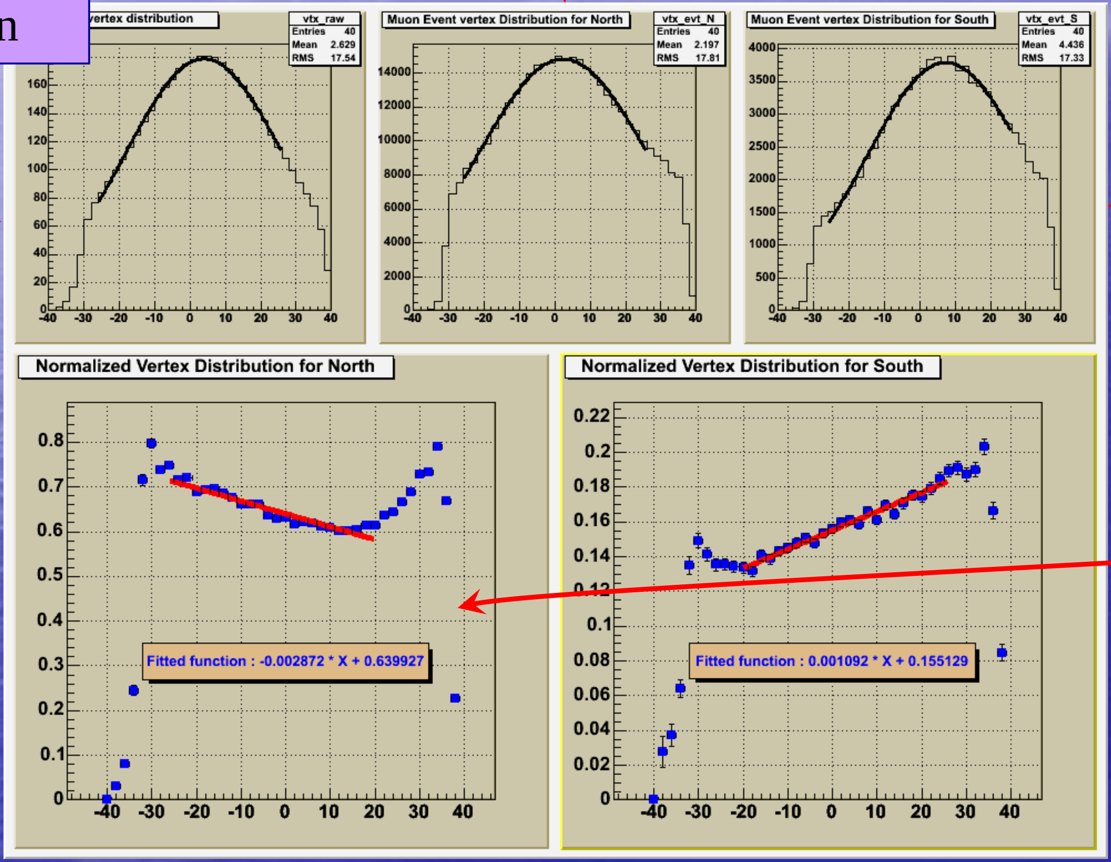


- Linear shape of ***z*** vertex slope because $c\tau\gamma$~100 [m].
- π/K decay μ dominates single muons.
- Prompt μ or punch through background has no vertex dependent.

Normalized Vertex Distribution

MB raw vertex distribution

Muon event vertex distribution



Normalized vertex distribution

Normalized vertex distribution can be fit with a linear function : $\alpha \cdot z + \beta$

Decay muon Rcp measurement

$$R_{CP} = \frac{\frac{1}{N_{binary}^{central}}\left(\frac{d^2N}{d\eta dp_T}\right)^{central}}{\frac{1}{N_{binary}^{peripheral}}\left(\frac{d^2N}{d\eta dp_T}\right)^{periperal}}$$

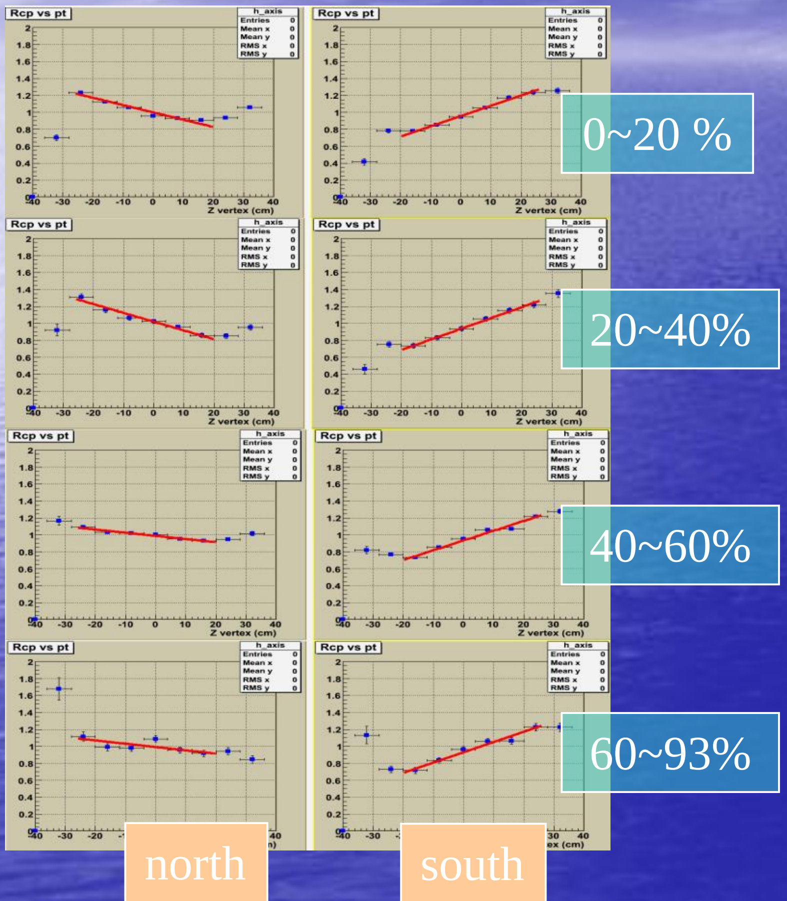
The normalized muon event vertex distribution ：

$$\frac{1}{N_{measured}^{MB}(Z)}\frac{d^3N(Z,\eta,P_T^{\mu^\pm})}{dP_T^{\mu^\pm}d\eta dZ} \approx \{\alpha(P_T,\eta)\cdot(Z-Z_{eff}^0)+\beta(P_T,\eta)\}$$

Decay muons R_{CP}：

$$R_{CP}^{decay}(p_T,\eta) = \frac{\alpha^{central}(p_T,\eta)\cdot\varepsilon_{reco}^{peripheral} / N_{binary}^{Central}}{\alpha^{peripheral}(p_T,\eta)\cdot\varepsilon_{reco}^{central} / N_{binary}^{Peripheral}}$$

Decay slope measurement



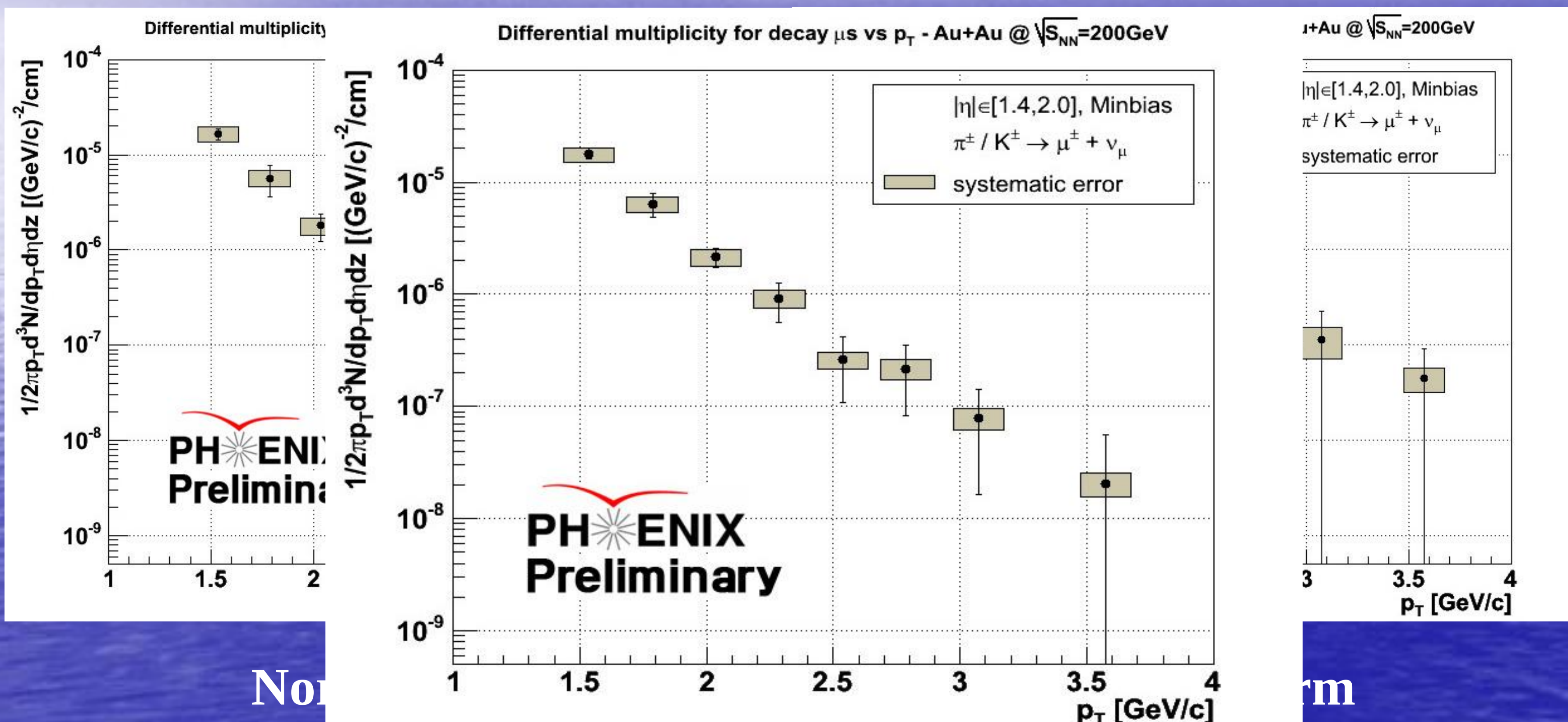
1.2 < η < 2.2,
1.5 < P_T < 2.0

- decay slope should be measured on every centrality, P_T and eta bins
- north and south arm show opposite slope
- decay slope corresponds to $\frac{d^2N}{dP_T d\eta}$
- (efficiency corrected) decay slope ratio between central and peripheral bins is R_{CP}

centrality

Event centrality was measured by BBC and ZDC correlation. Number of binary collisions was calculated by Glauber model

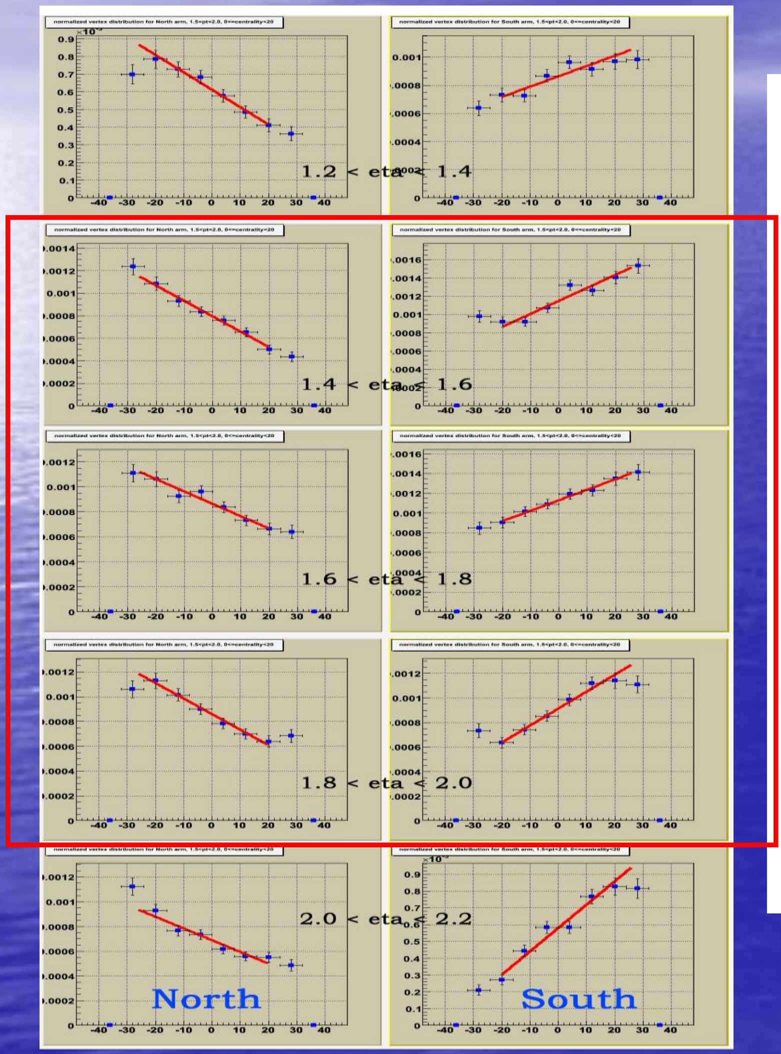
Differntial multiplicity (vs P_T)

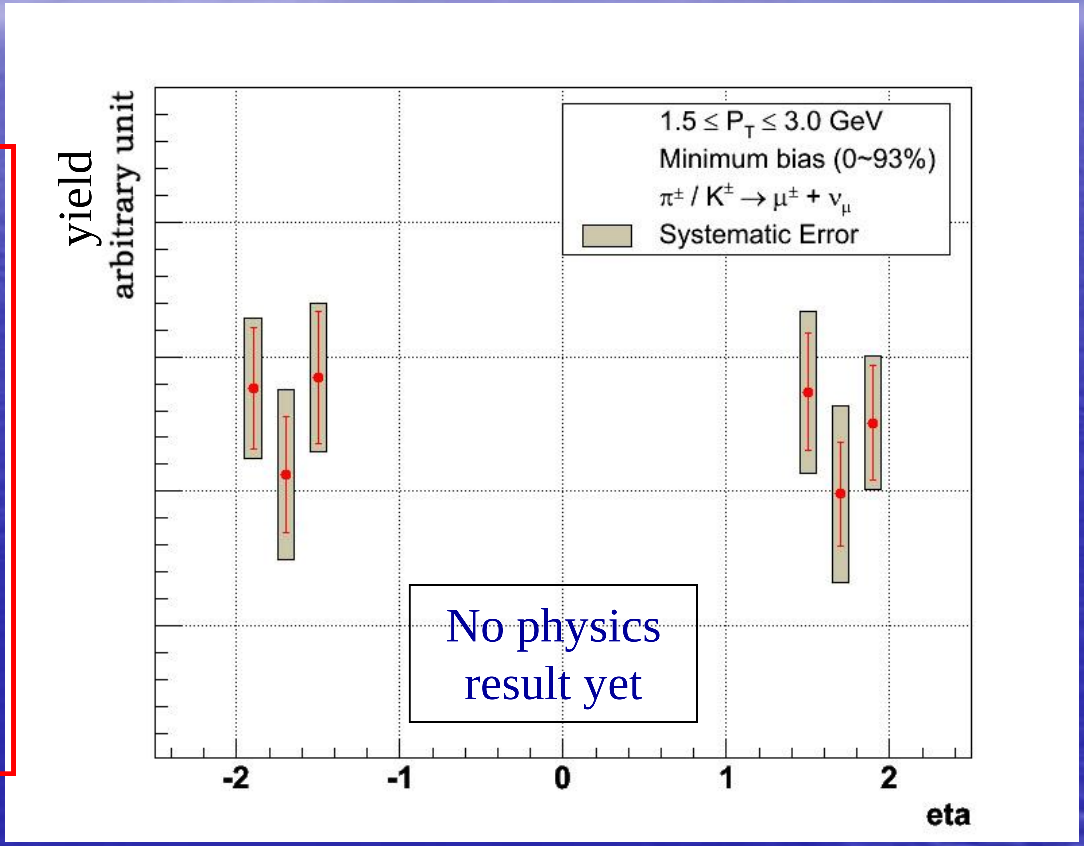


Nor … rm

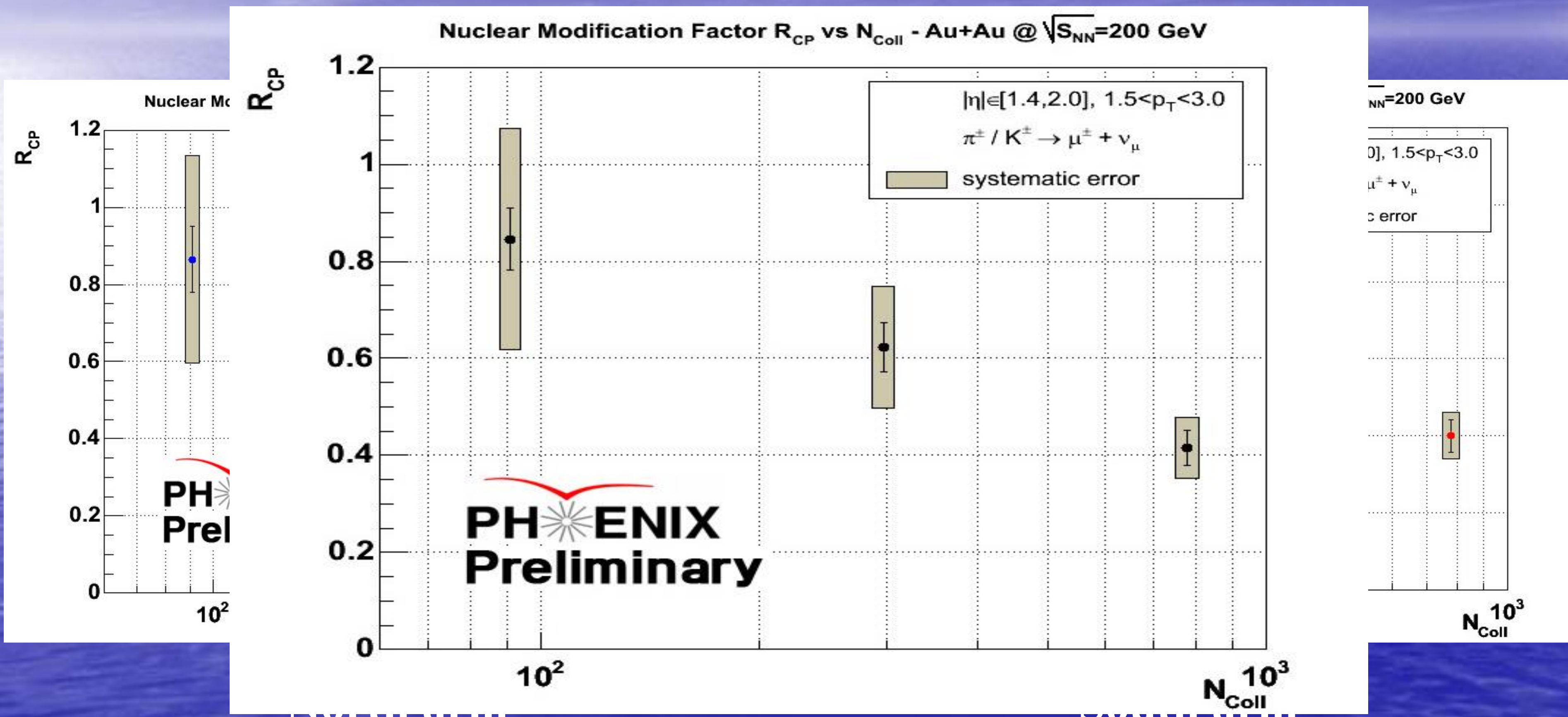
Our approach works fine for both arm!!

Decay slope measurement(vs eta)





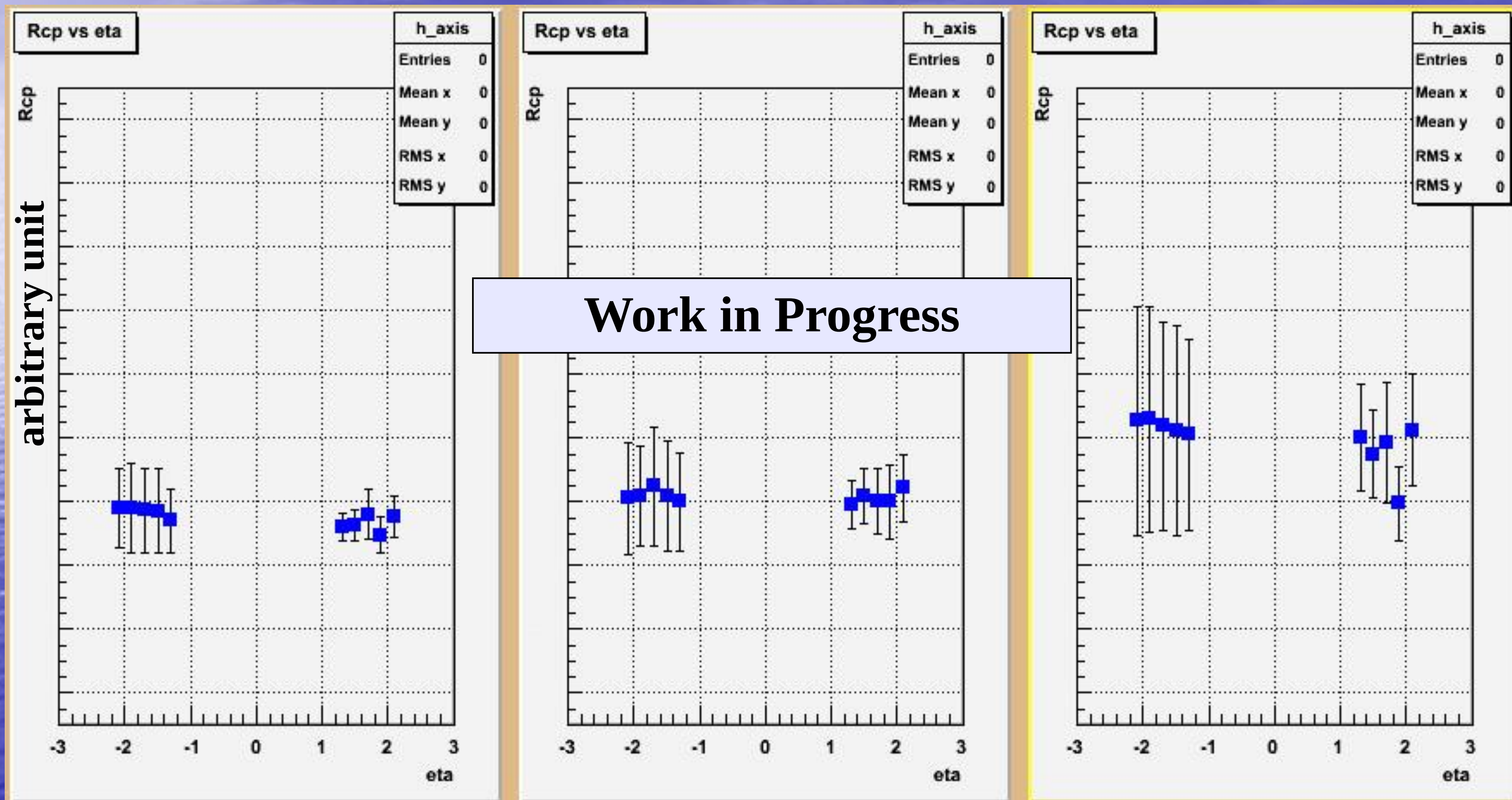
R_{CP} vs Number of Binary Collisions



Peripheral ⟷ Central

R_{CP} vs η

arbitrary unit

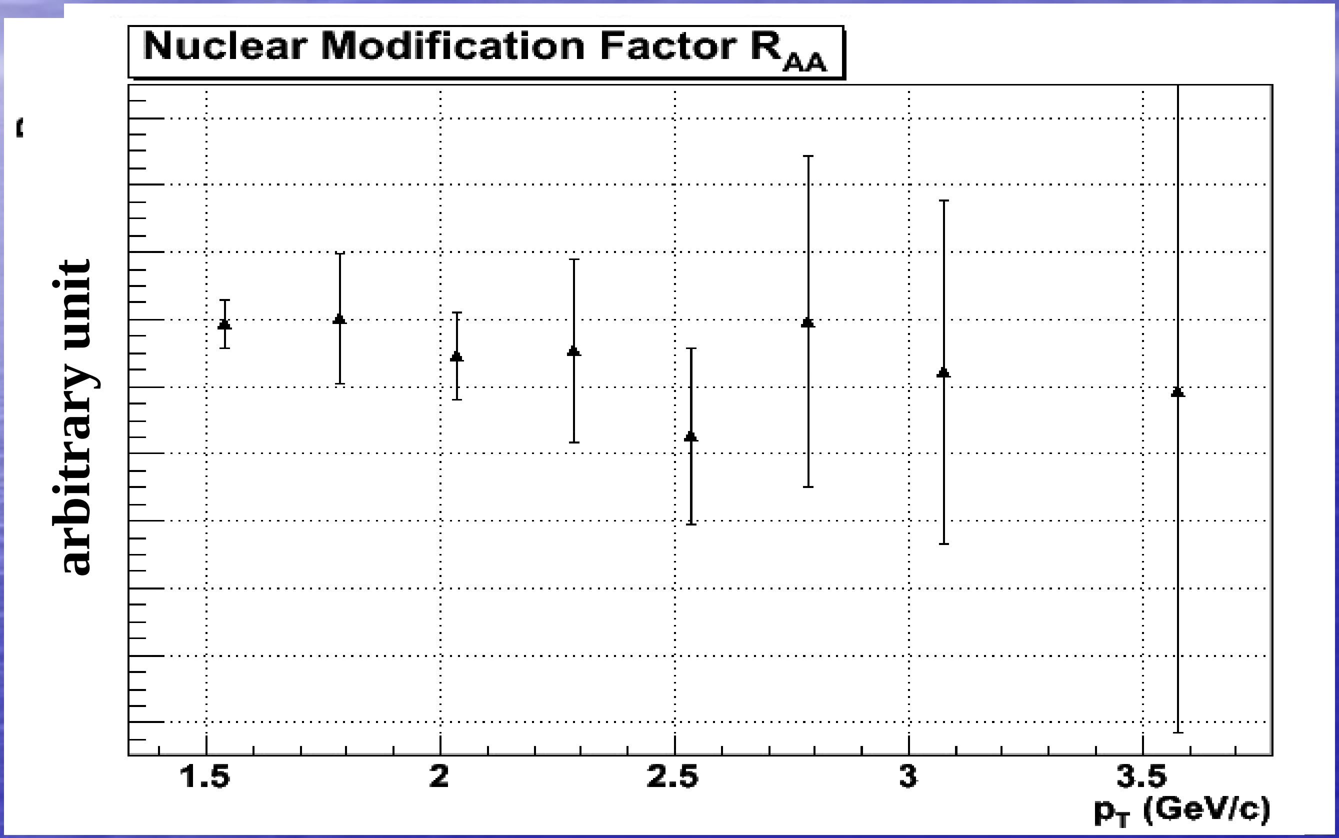


Work in Progress

Central

Peripheral

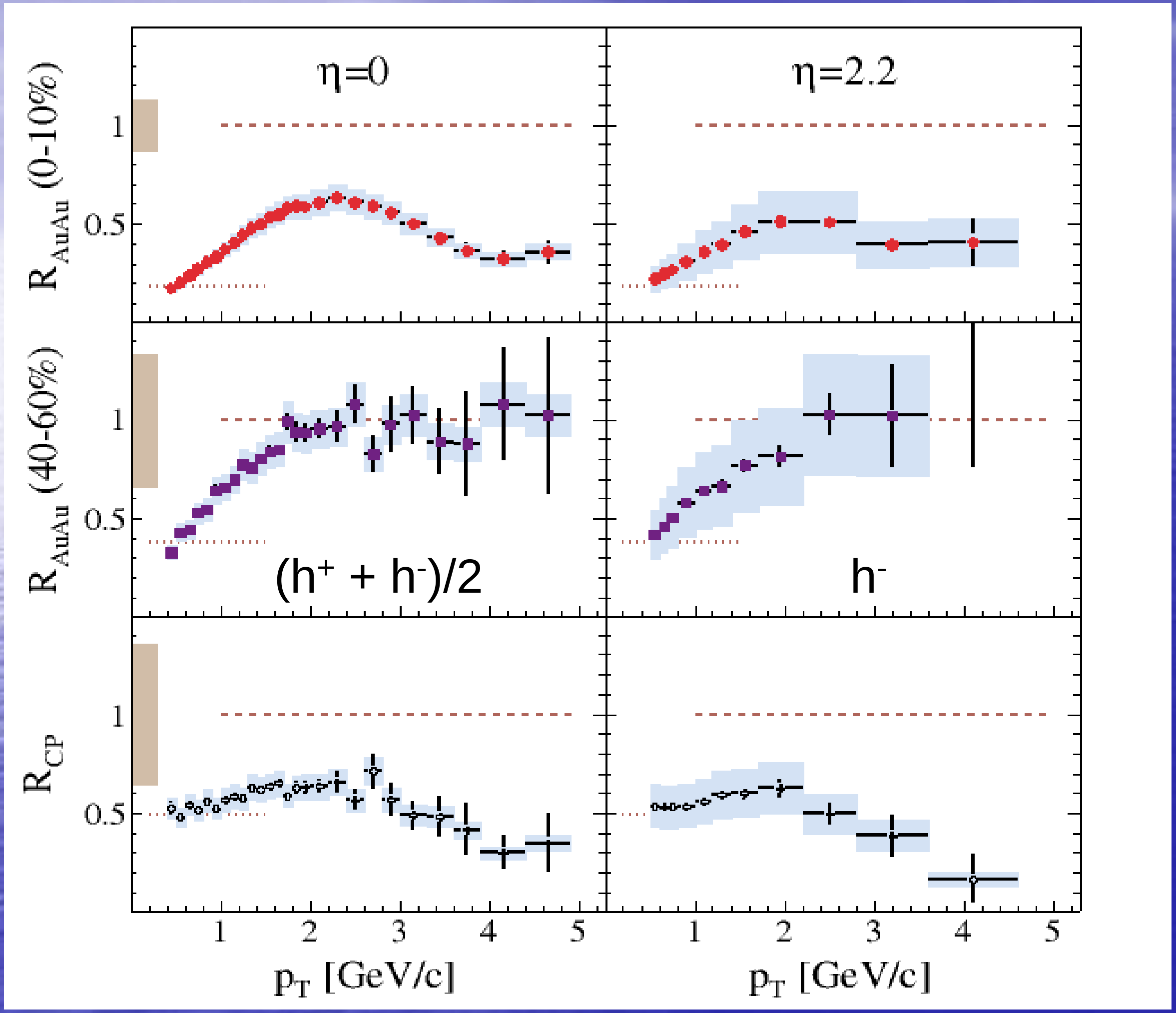
R_{CP} / R_{AA} vs p_T



Statistical error bar only

Work in progress

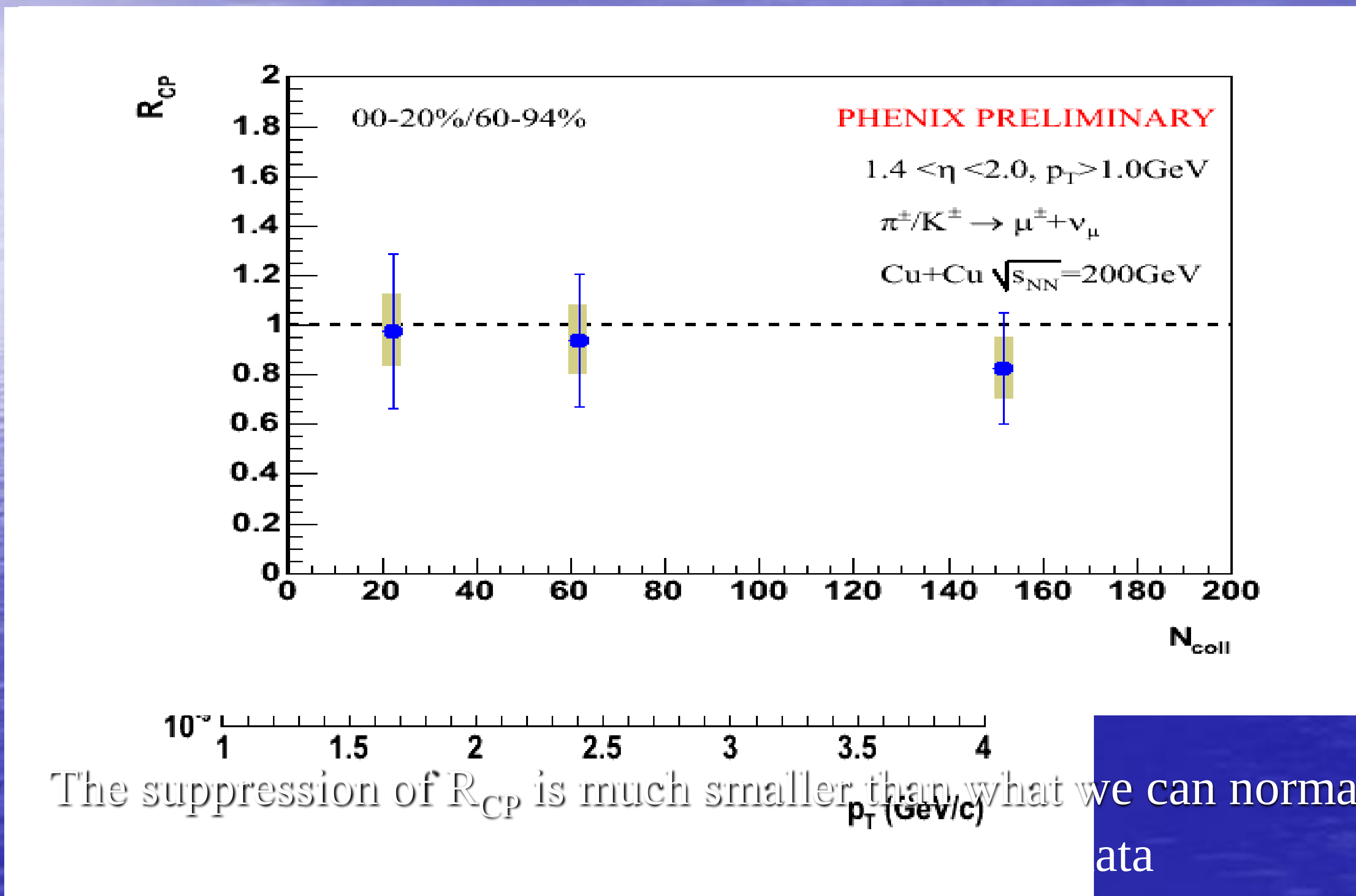
R_{AuAu} and R_{CP} from Brahms



Brahms PRL 91(2003)

- Low pT part scale with the number of participants (soft collisions)
- strong suppression in central collisions (f. 4)
- the suppression can not be explained by hadronic energy loss
- similar behavior at η 0 and 2.2 → Rapidity distribution will not change as a function of centrality.
- R_{CP} similar to R_{AA} (no medium effect in semi-peripheral colls.)

PHENIX Cu+Cu results



- The suppression of R_{CP} is much smaller than what we can normally expect
- ata
- Cronin effect might affect a lot

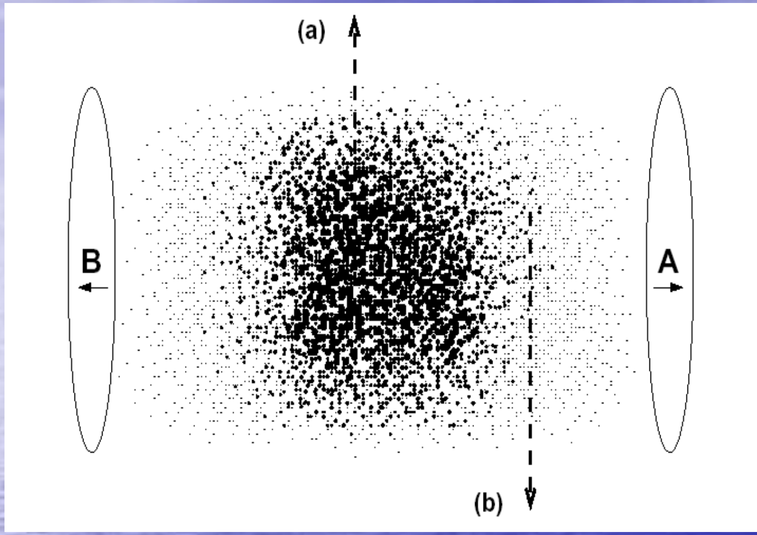
Summary / Outlook

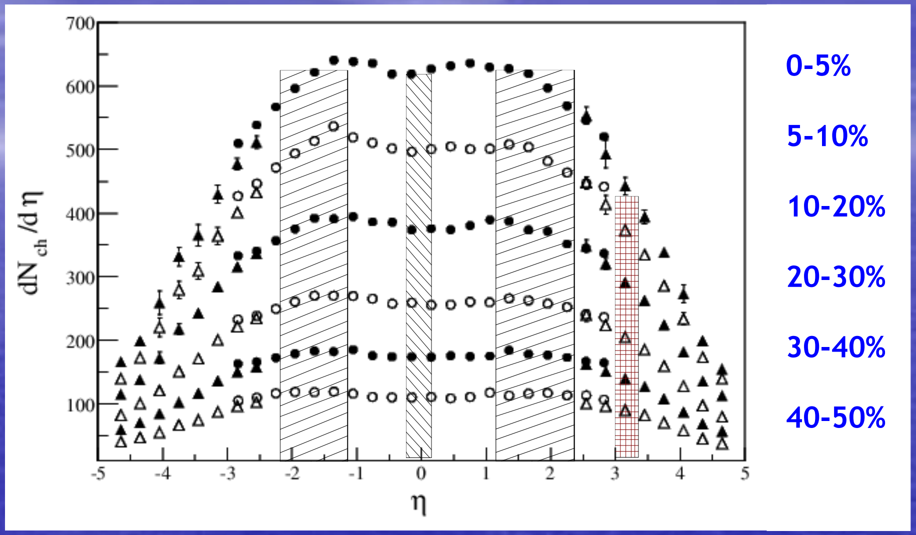
- R_{CP} measurement in Au+Au collision is important issue to understand nuclear effects
- Suppression at forward rapidity/enhancement at backward rapidity in d+Au system
- Strong suppression in central Au+Au collision
- Suppression in Au+Au – strong coupling of quarks to the produced medium
- No big change of NMF with eta in Au+Au
- PHENIX Run4 Au+Au full data set will be served in two months
- New p+p results with much higher statistics(factor of 100) will be come out in a near future(RHIC run5)

Backup Slides

Going to higher η in Gold-Gold

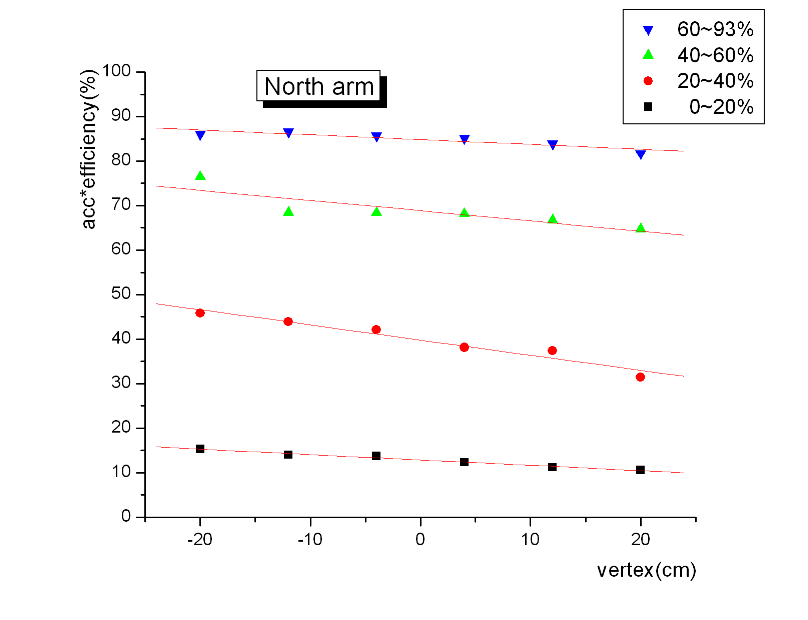
Polleri and Yuan (nucl-th/0108056)

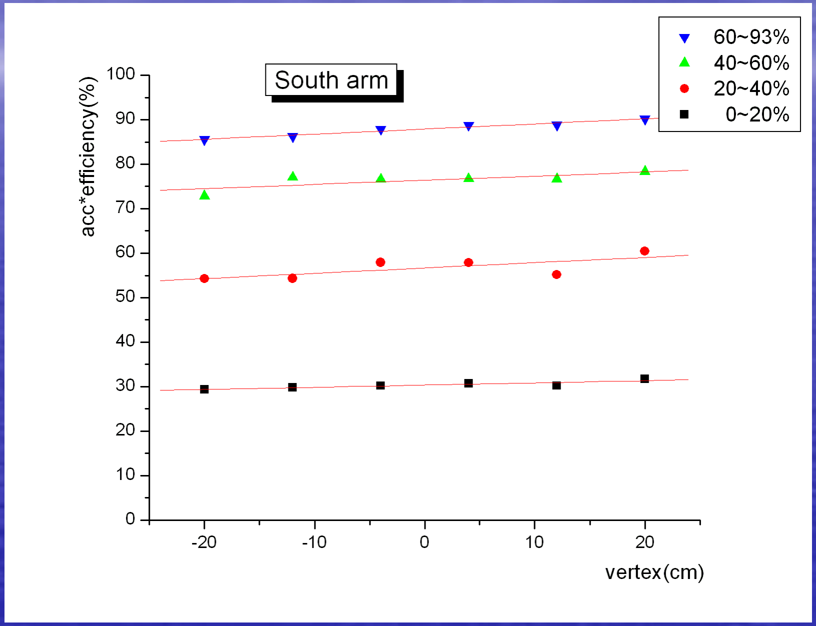




Higher rapidities
- means smaller medium density => less supression
- jet-quenching in longitudinally expanded source
- Nch|η =2.0 < Nch| η =0
- initial and final-state effects have different dependence on rapidity; final-state effects are maximal at mid-rapidity whereas initial-state effects are enhanced in forward region

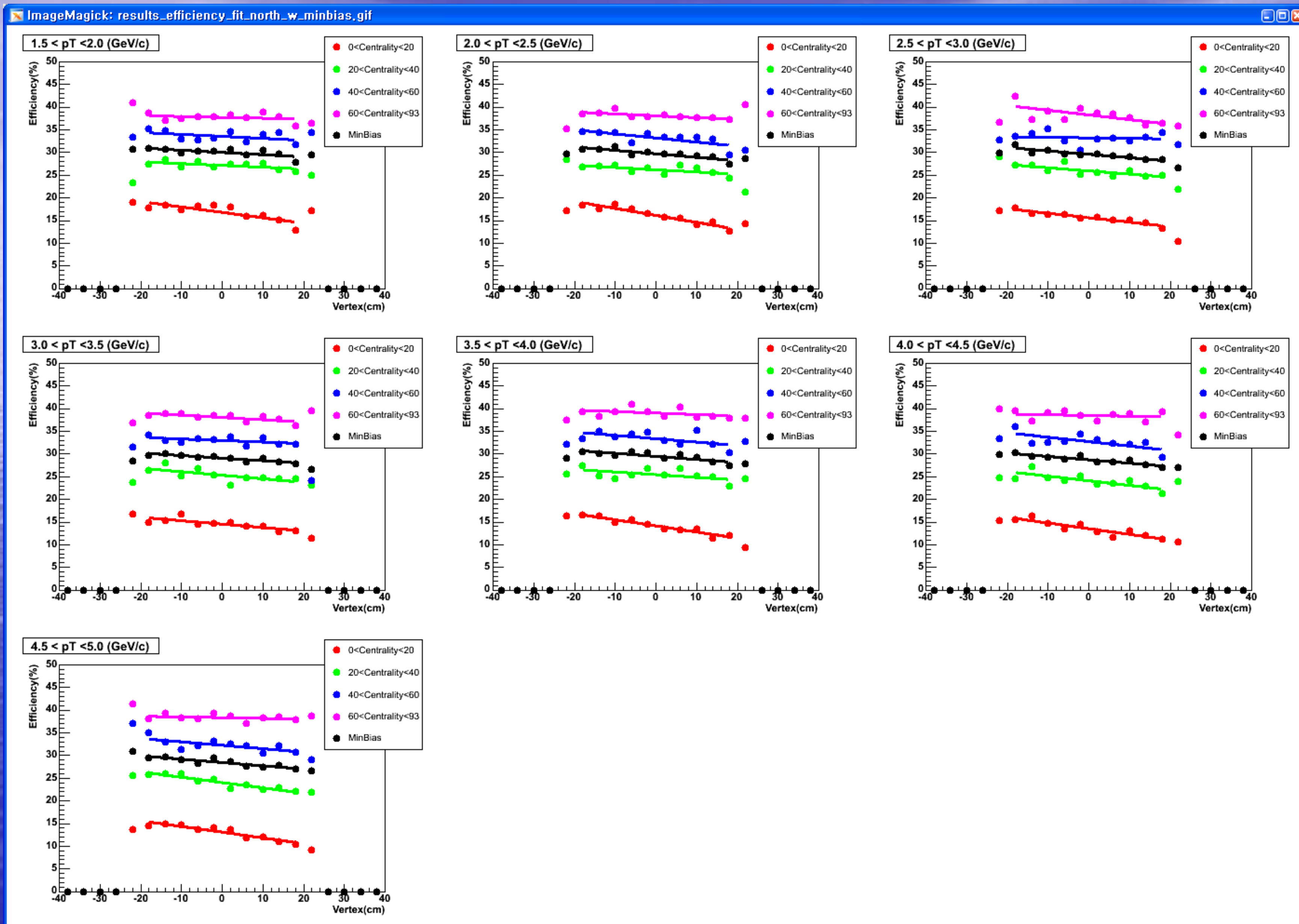
Efficiency Correction



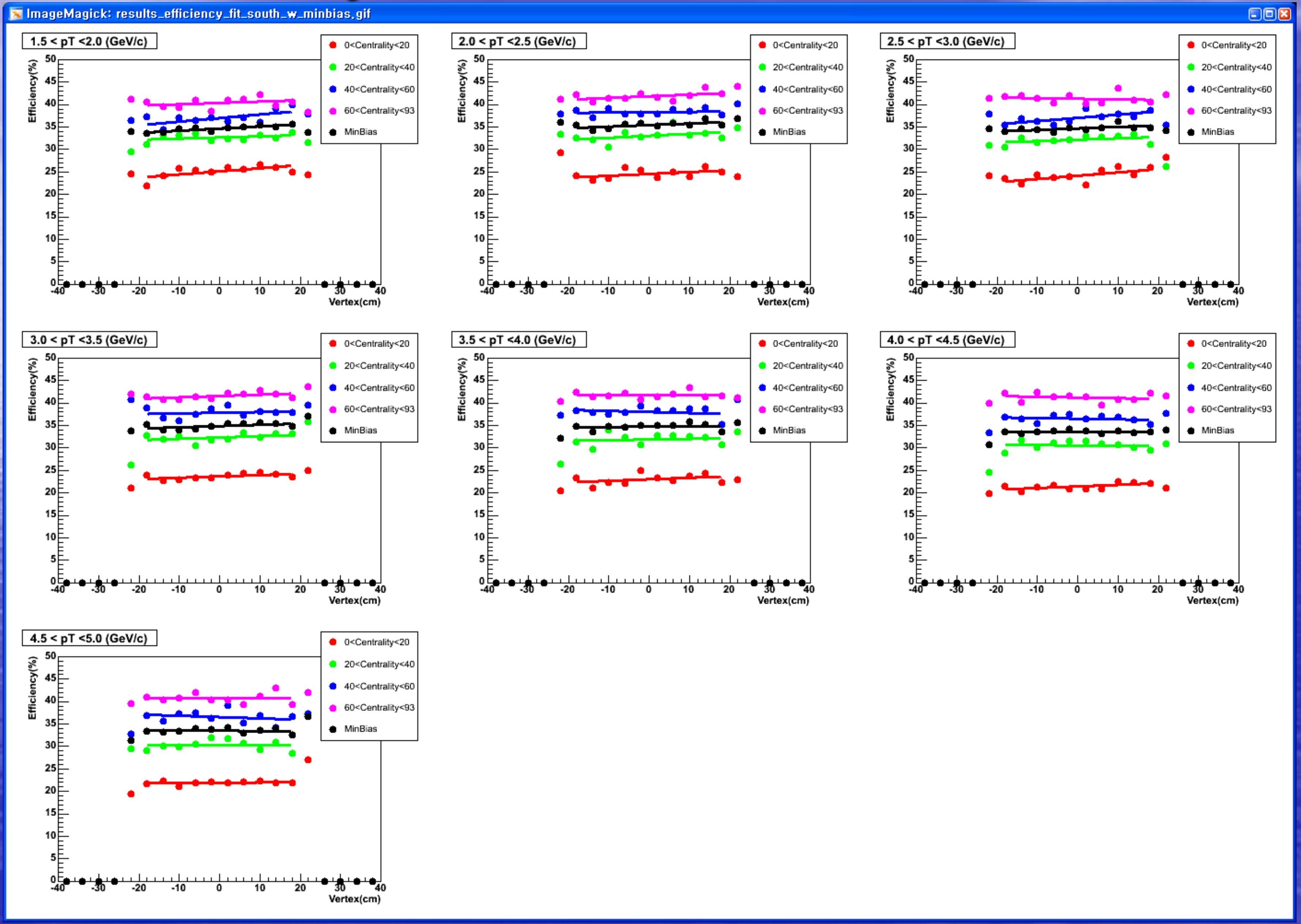


- Efficiency can be calculated by embedding method (simulation + real data)
- Efficiency decrease as vertex goes to the detector
  - opening angle varies as a function of vertex
  - acceptance and multiplicity can change
  - combinatorial background
- Vertex bin by bin correction needed

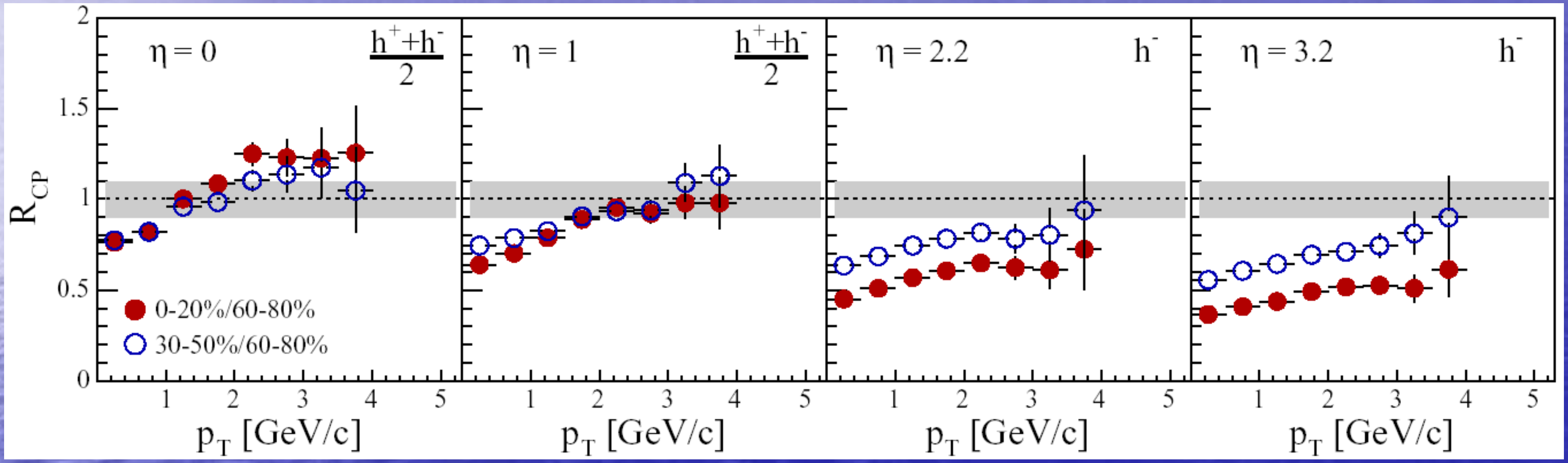
Efficiency – North arm



Efficiency – South arm



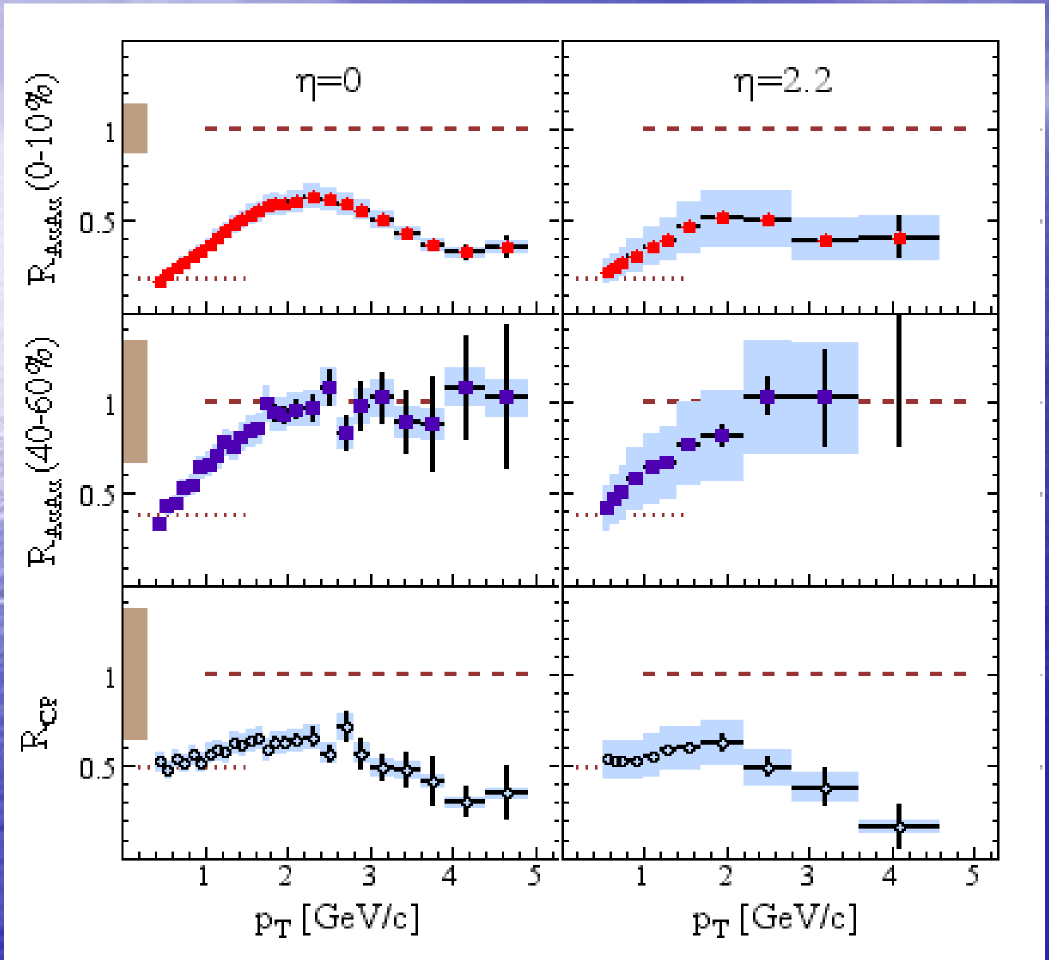
R_{CP} on d+Au collisions - BRAHMS



Change of R_{CP} from mid- to forward rapidities is stronger for central collisions than for semi-peripheral collisions

High pt suppression

Brahms PRL 91(2003)



- approximate binary scaling in semi-peripheral collisions

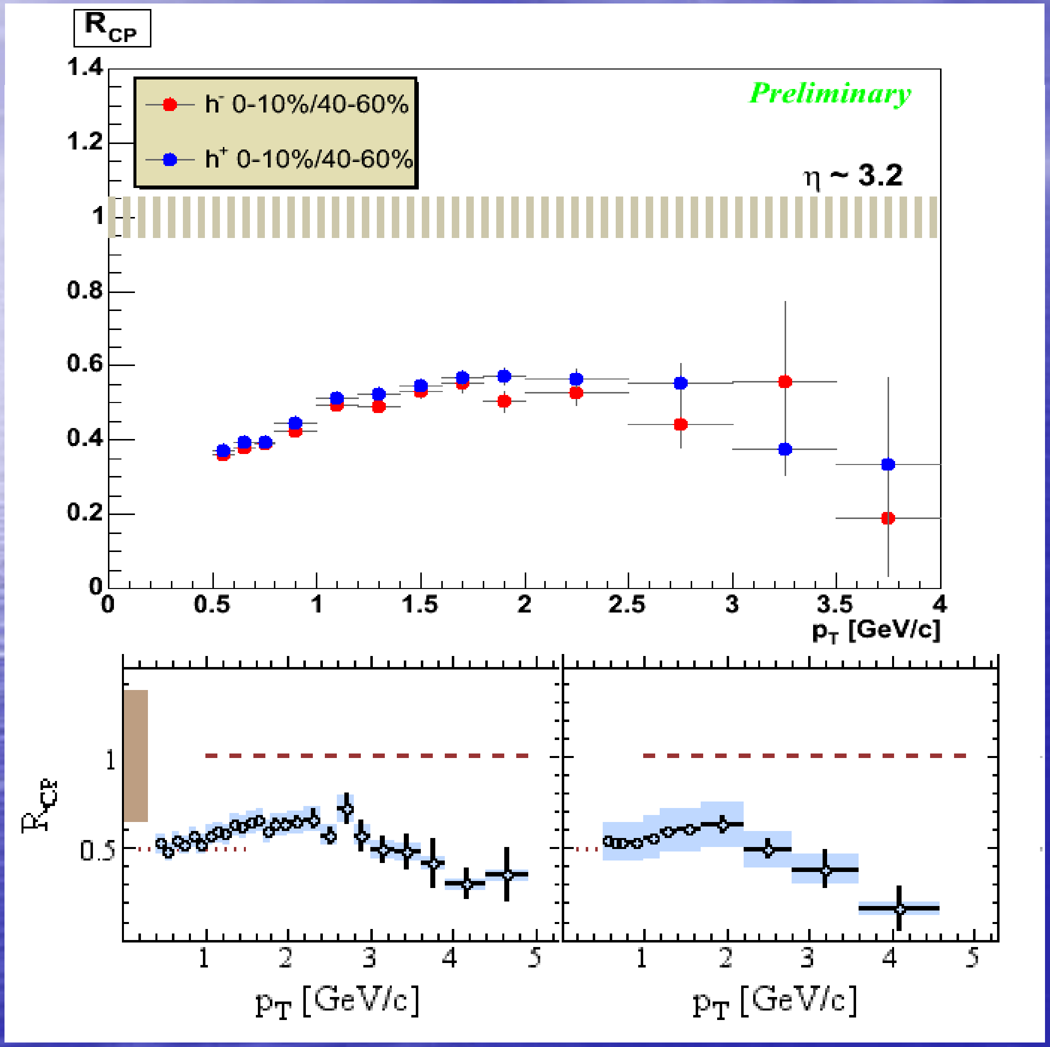
- strong suppression in central collisions (f. 4)

- similar behaviour at η 0 and 2.2 -> source extended to η ~2
- longitudinal expansion at y >0

- Rcp similar to Raa (no medium effect in semi-peripheral colls.)

- the suppression can not be explained by hadronic energy loss

Rcp for Au+Au h+, h- at η ~ 3.2



Centrality bins using multiplicity in |η|<2

Glauber Model

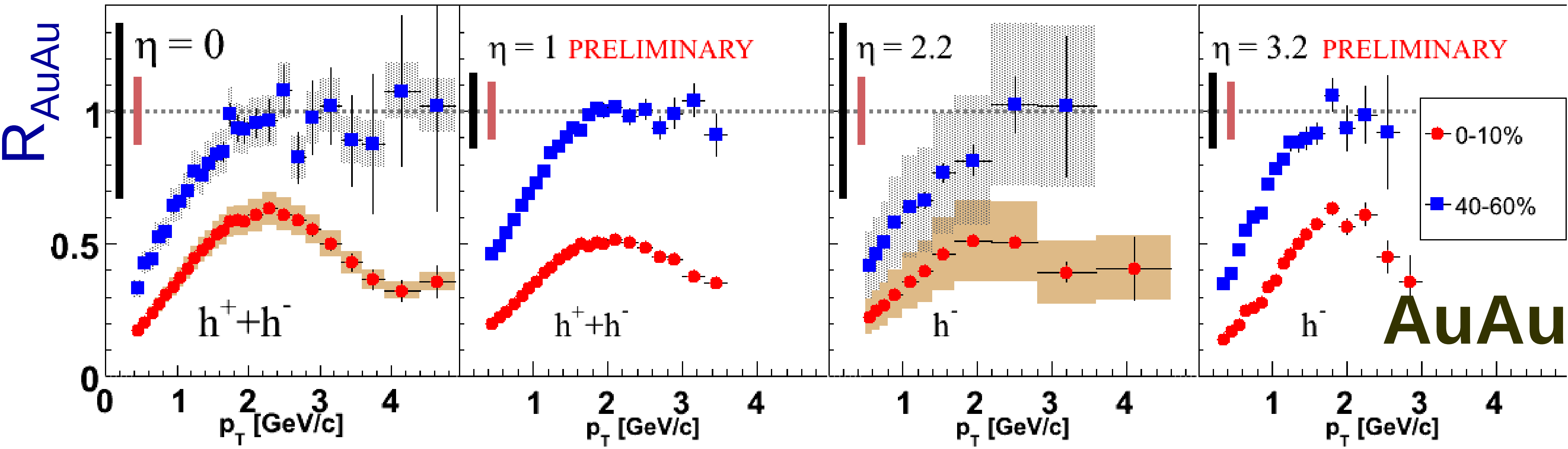
$\langle N_{coll} \rangle$ for 0-10% ~880

$\langle N_{coll} \rangle$ for 40-60% ~ 78

$\langle N_{coll} \rangle$ for 50-90% ~ 21

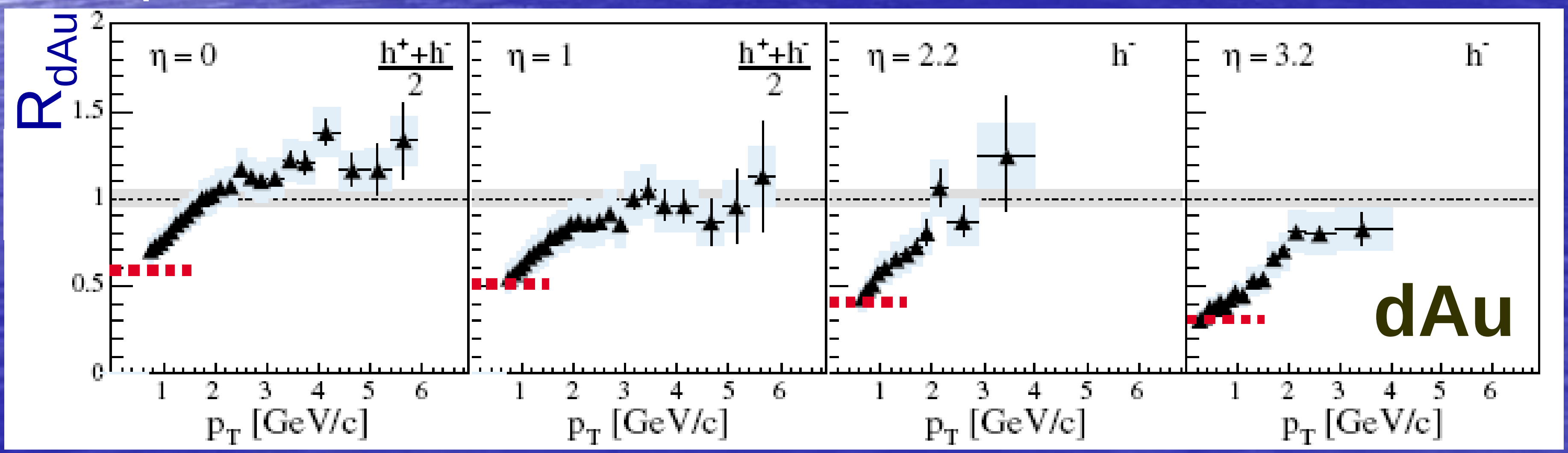
- **persistent over 3 units in η**
- **no strong η dependency**
- **room for initial-state effects**
- **analysis of Raa in progress**

Suppression at Forward Rapidities at 200 GeV

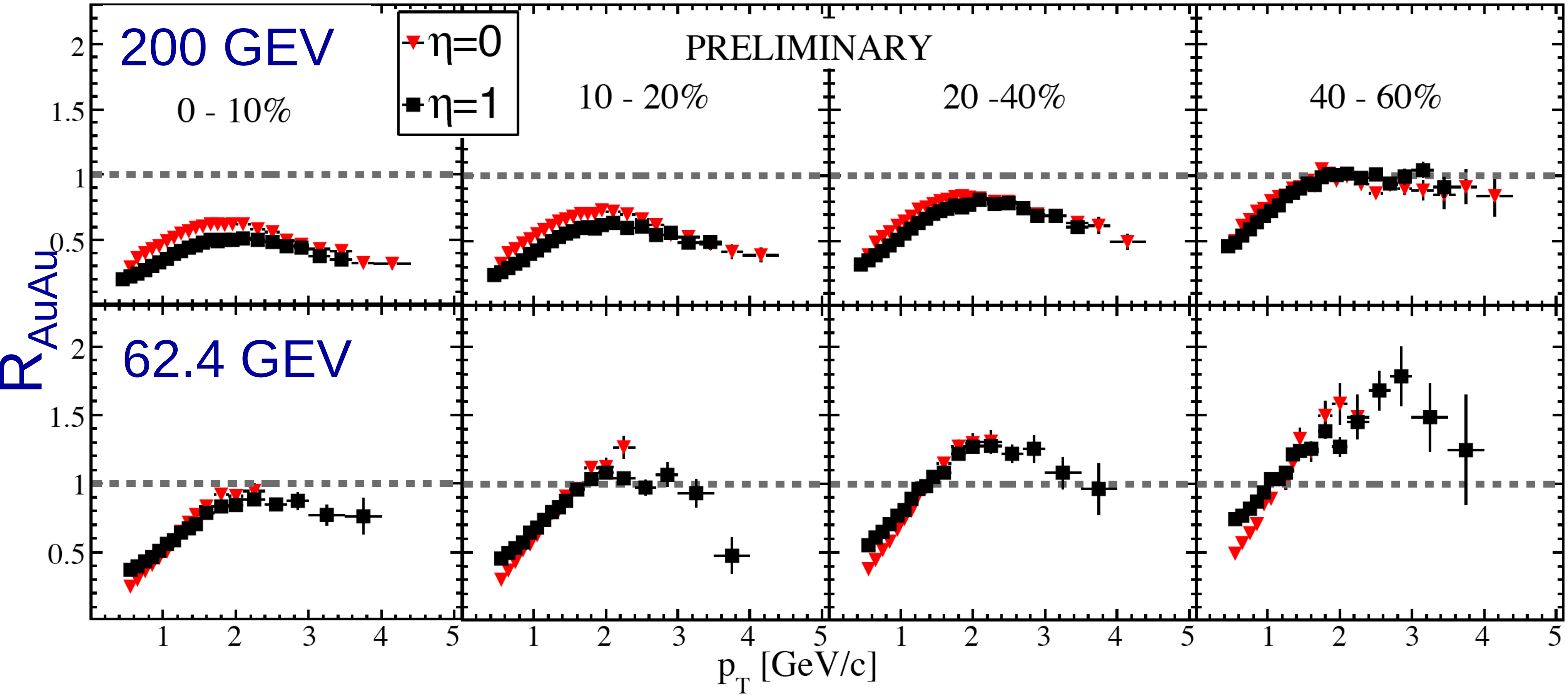


Charged Hadrons

$\eta = 0$ → $\eta = 3.2$



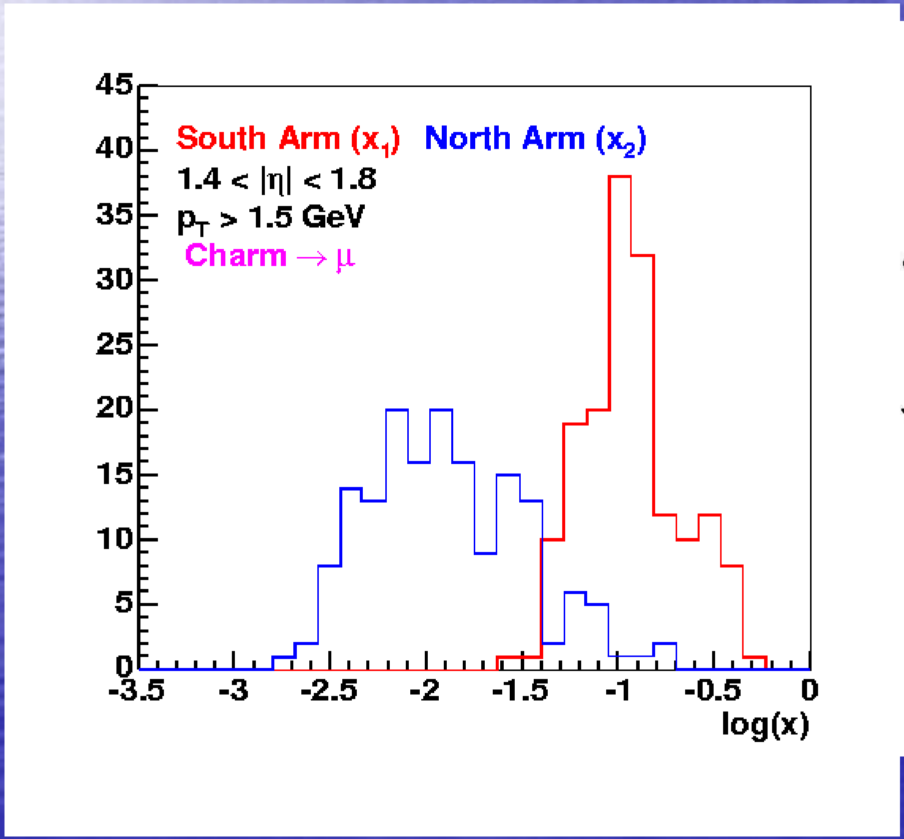
NMF Dependence on Centrality

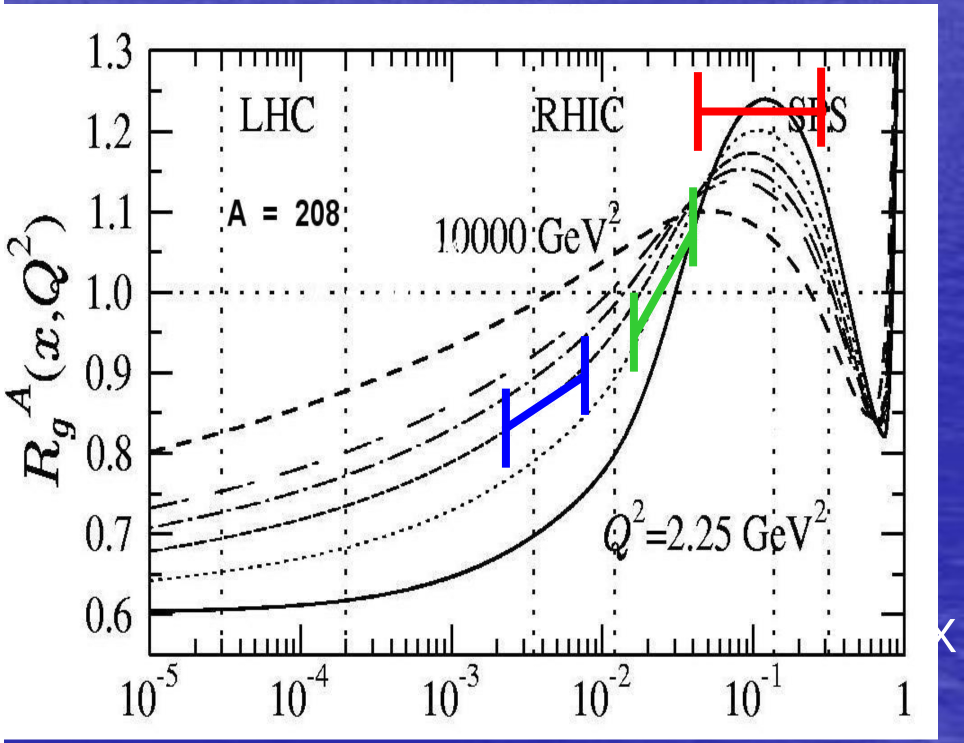


- The higher energy system begins to look more like pp collisions for less central events.
- The lower energy system shows Cronin enhancement similar to what is seen at SPS energies.

PHENIX muon arms "x" coverage

Particle production in the d direction (north) is sensitive to the small-x parton distribution in the Au nuclei; whereas in the gold (south) is sensitive to the large-x in Au





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Nucl. Phys. A696 (2001) 729-746.