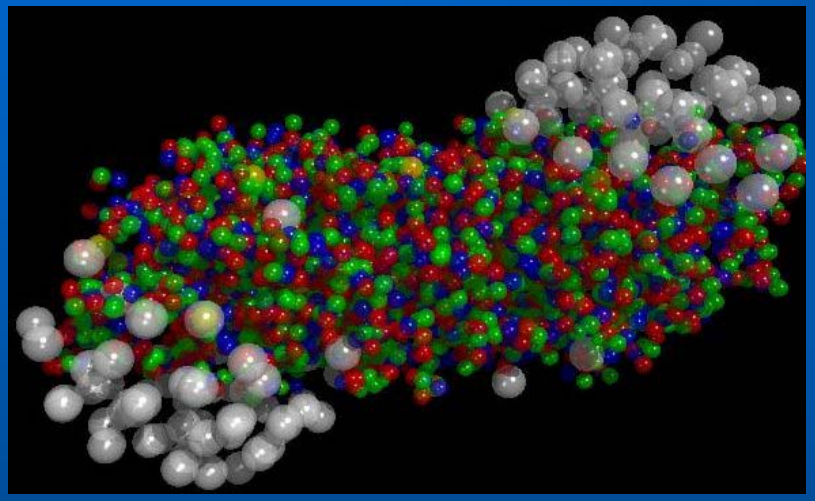
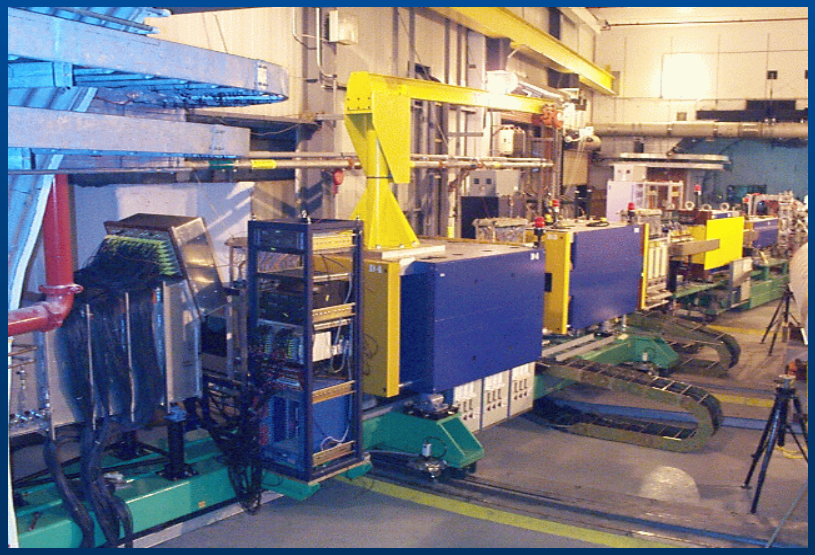
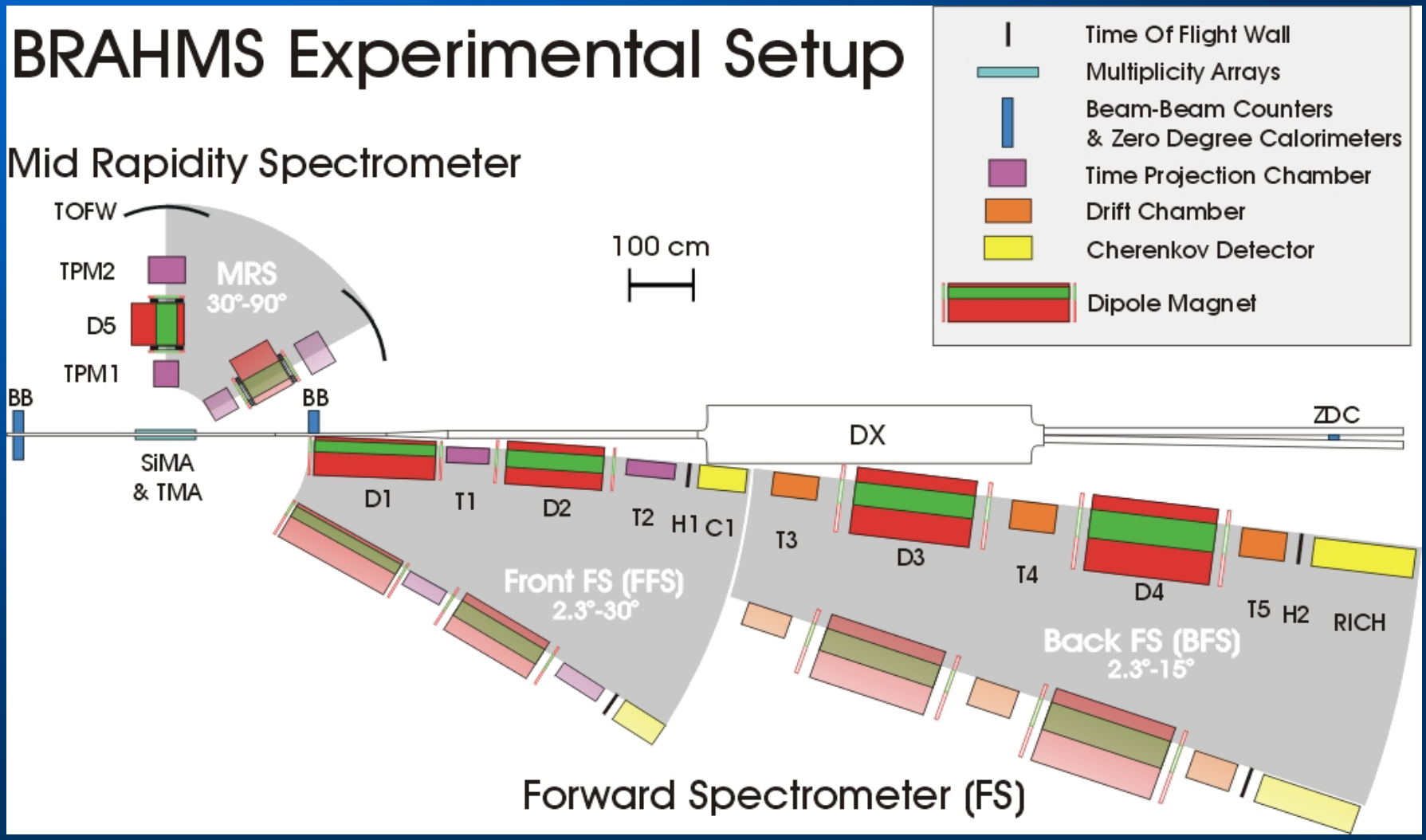
# Forward and high pt physics at RHIC with BRAHMS



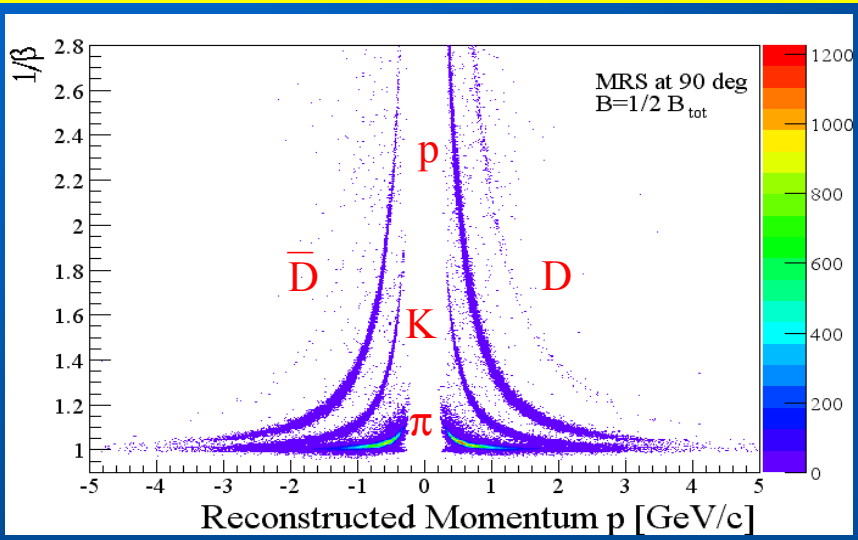


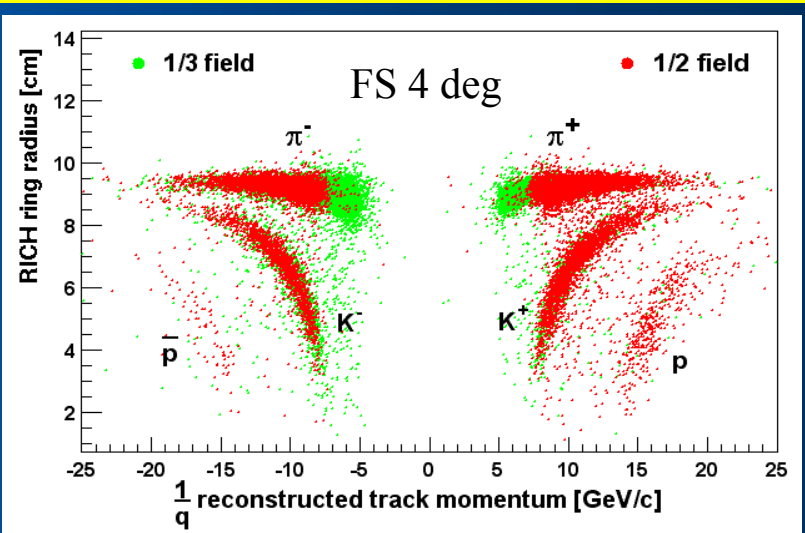
- Stopping in Au+Au at $\sqrt{s}$=200, 62.4 GeV
- Rapidity dependence of high pt suppression of hadrons at $\sqrt{s}$=200 GeV
  - Au+Au and d+Au at $\eta$=0
  - Au+Au at $\eta$=2.2, 3.2
  - d+Au at $\eta$= 0 to 3.2 (CGC?)
- Energy dependence of high pt suppression of hadrons at $\sqrt{s}$=62.4 GeV in Au+Au at $\eta$= 0, 1
- Flavor dependence in Au+Au and d+Au
- Rapidity dependence of particle production in p+p collisions

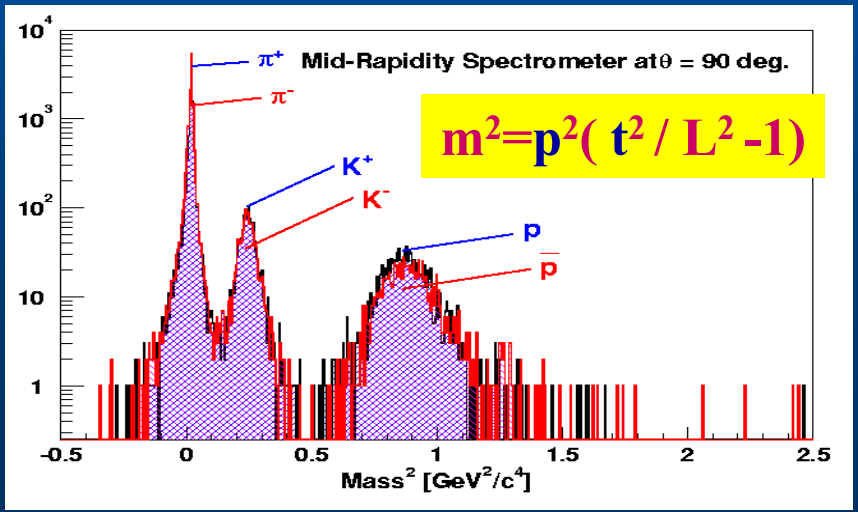
# The BRAHMS experiment

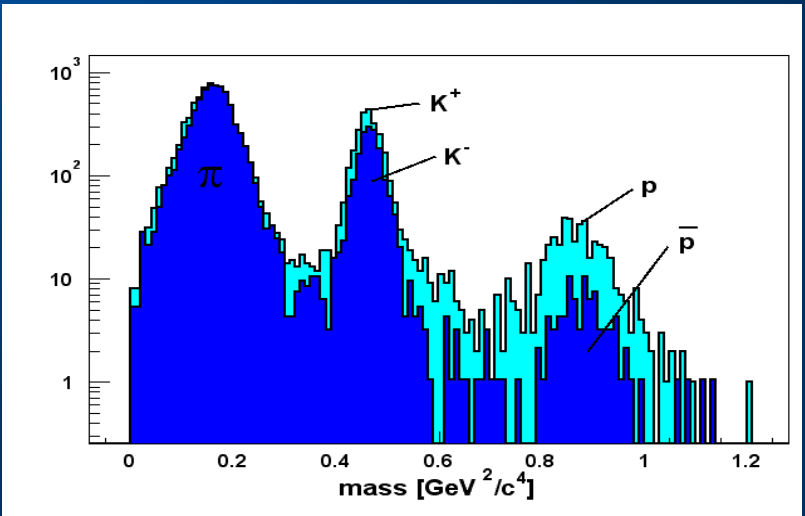


# Excellent Hadron Identification by TOF and RICH

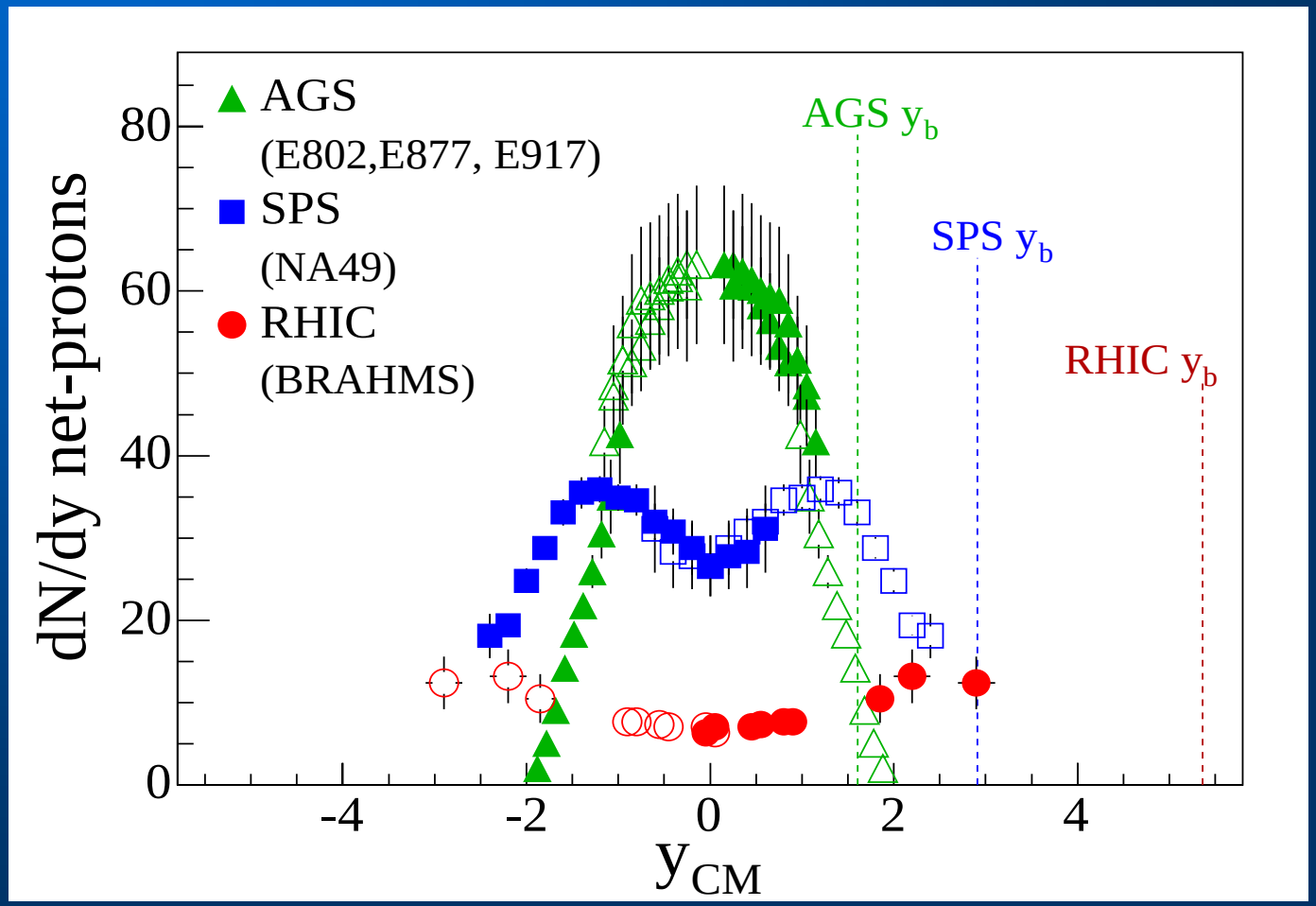


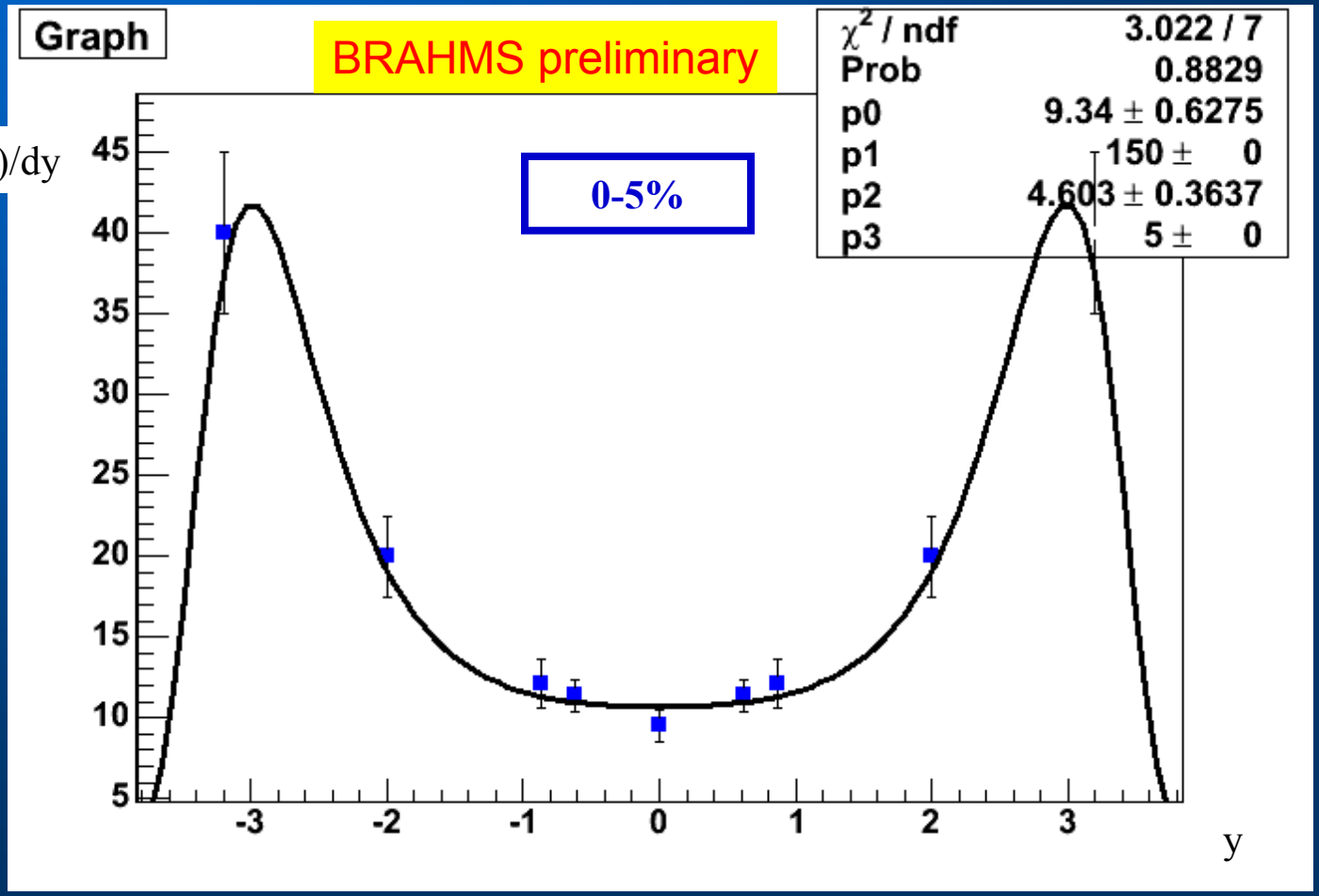



# Transparency and beam energy loss at RHIC

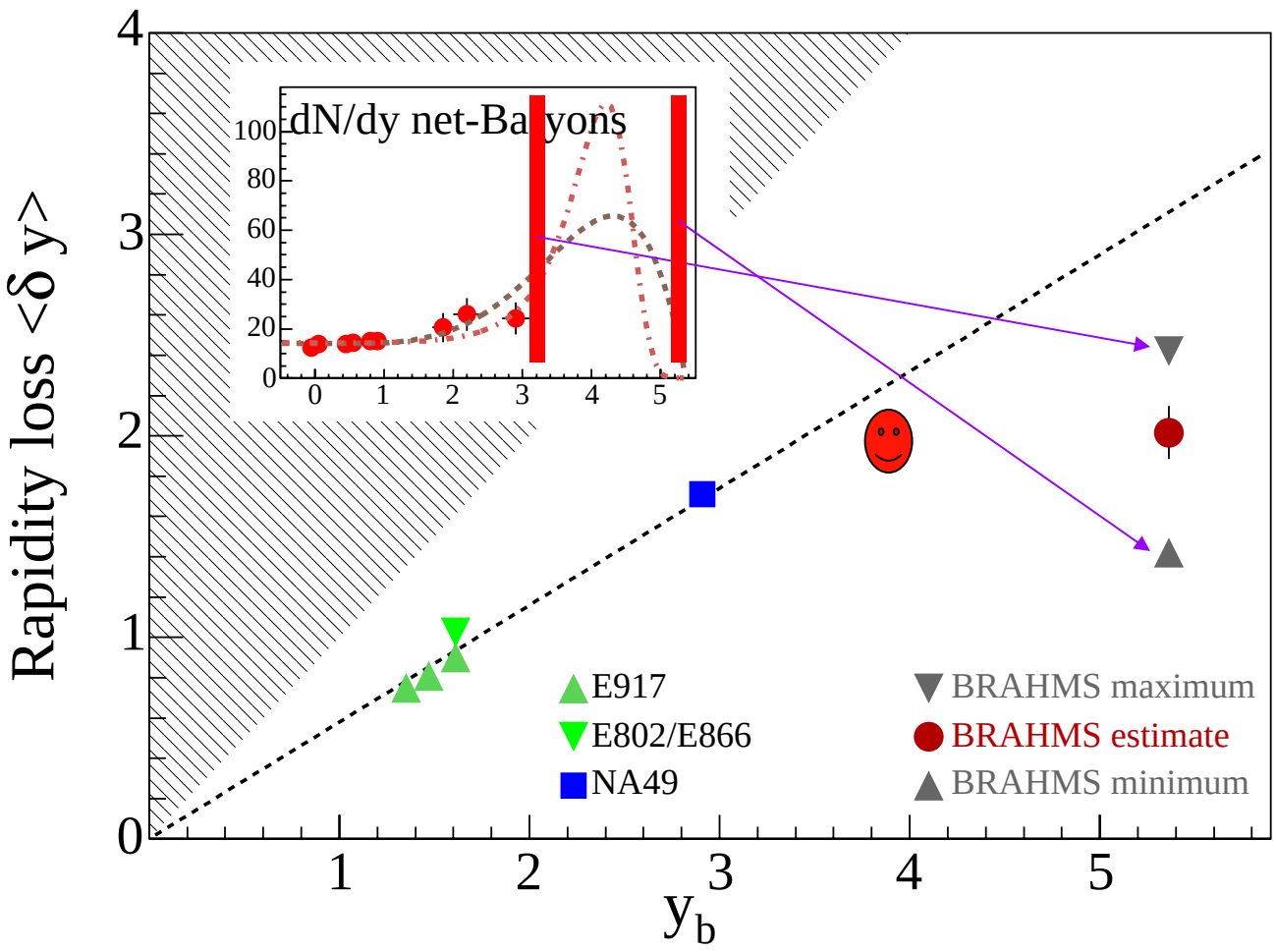



BRAHMS PRL **93** (2004) 102301

# Net Protons at 62.4 GeV



# Rapidity and energy loss at RHIC




**Relative rapidity loss :**

**$35\% < \Delta y/y_b < 44\%$**

**Rapidity loss saturates!**

**But Energy loss increases strongly**

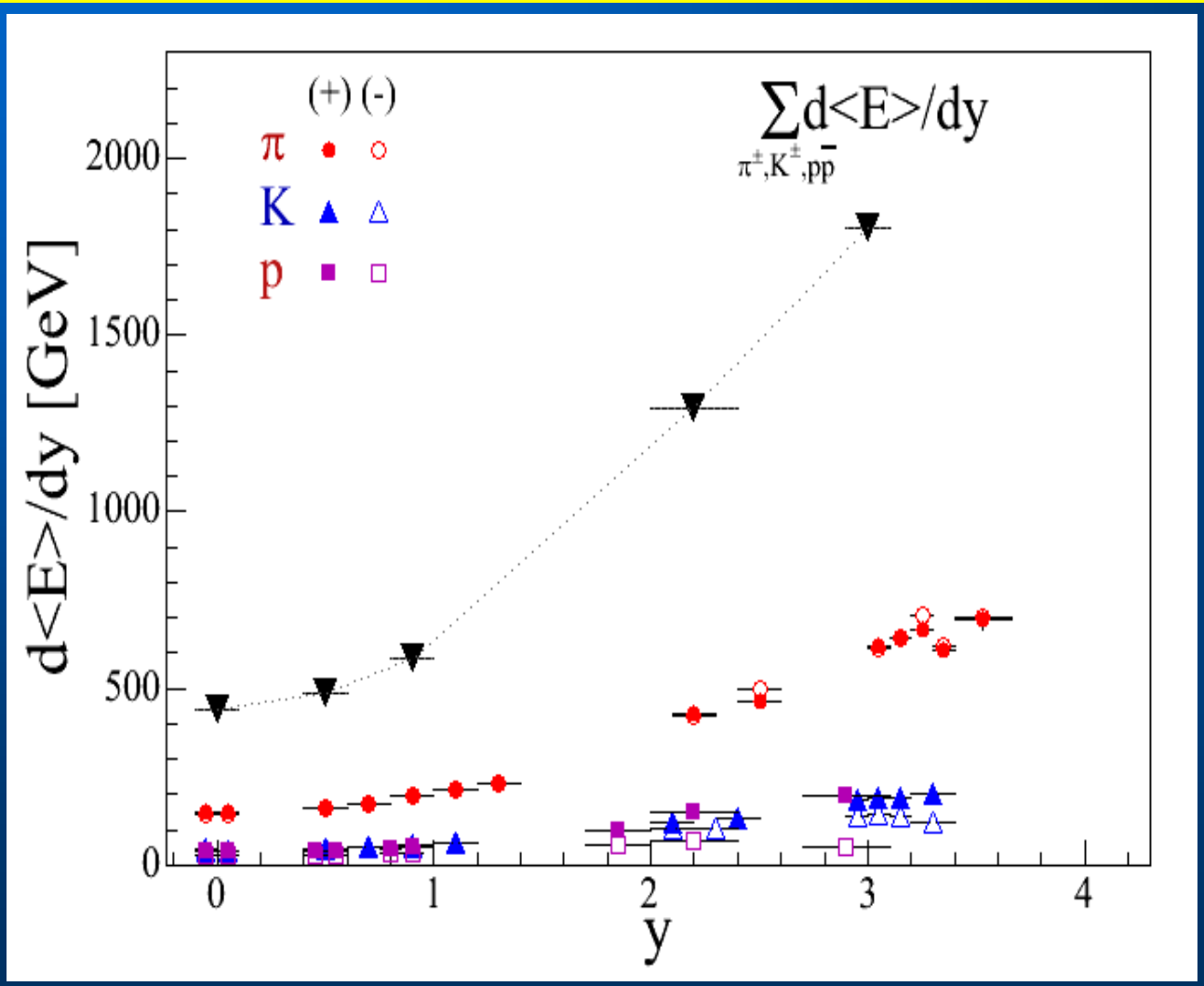
**$dE_{(baryon)}=75GeV$**

**$\Delta E(tot)=26TeV$**

**Out of available**

**35 TeV**

# Total relativistic energy

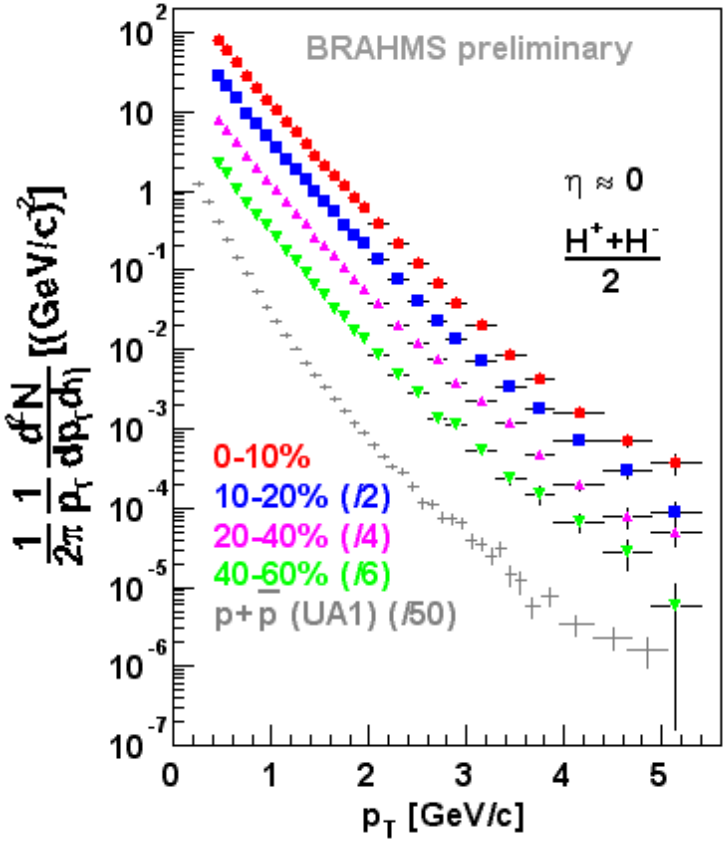



$E = m_t \cosh(y)$

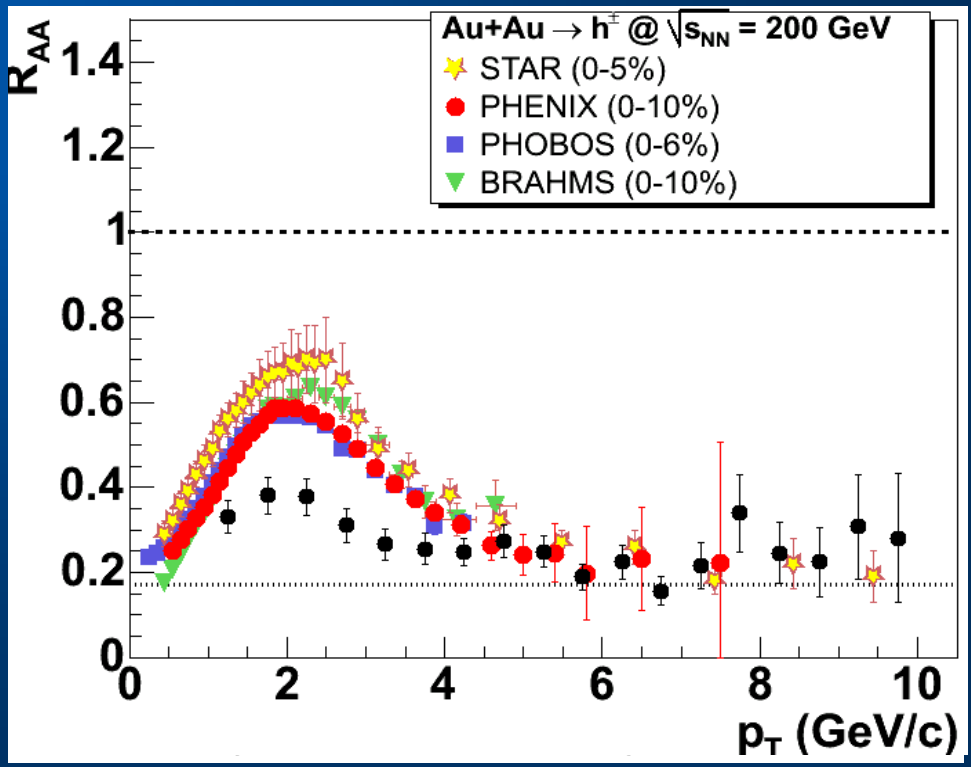
$m_t=(p_t^2+m^2)^{1/2}$

**Produced particles in -3<y<+3 carry about 9 TeV of total energy**

# The smoking gun of QGP?
# Jet Quenching, high pt suppression.



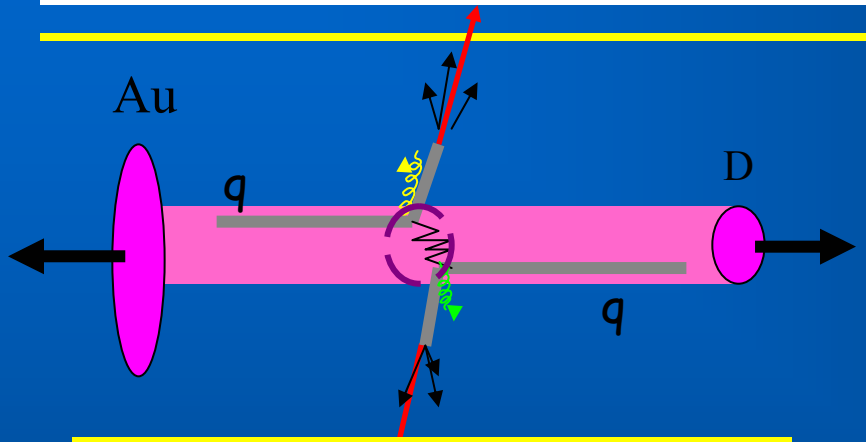

$$R_{AA} = \frac{d^2N / dp_T d\eta}{\left(\langle N_{bin} \rangle / \sigma_{inel}^{NN}\right) d^2\sigma^{NN} / dp_T d\eta}$$




Soft

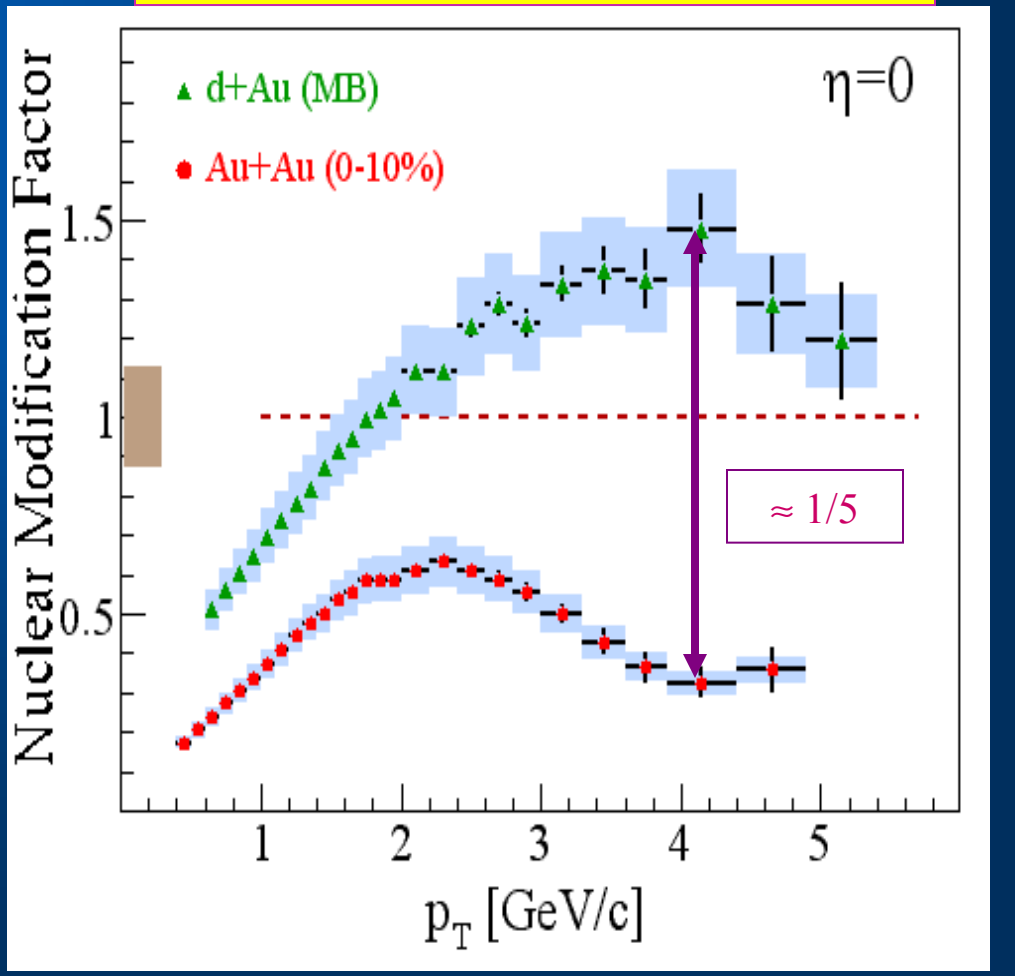
Hard (jets)

# Test: Absence of suppression at midrapidity in d+Au?

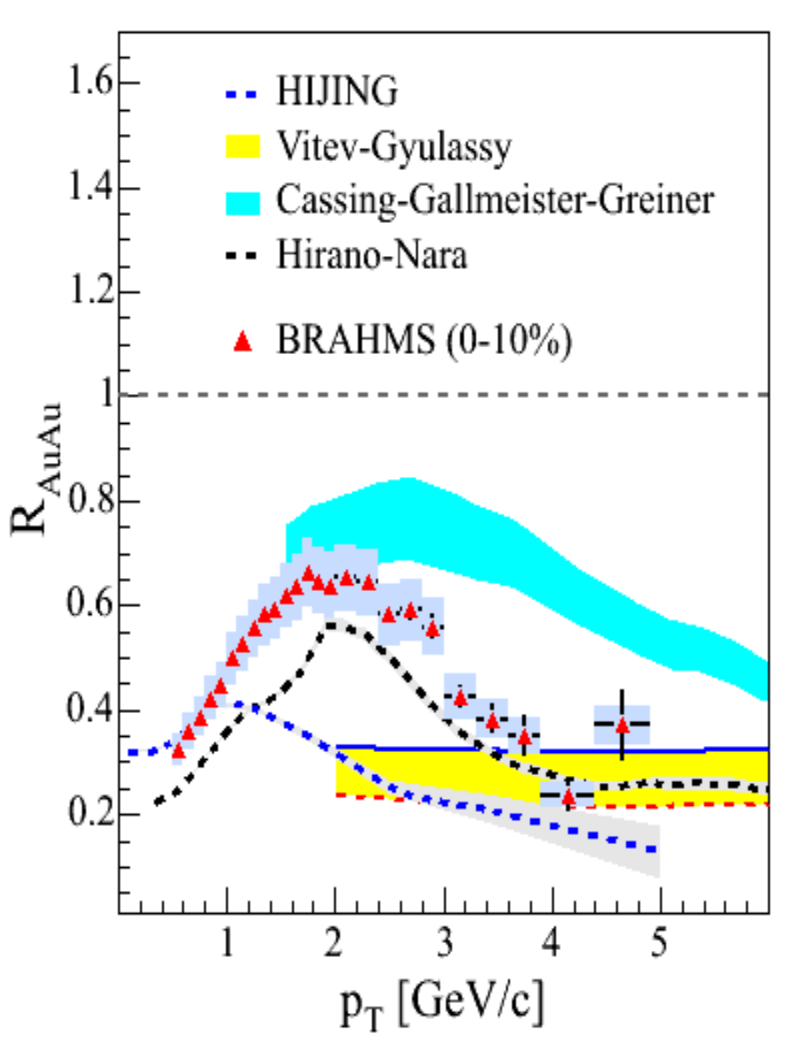



**Absence of high pt suppression at midrapidity rules out initial state effects .**


**PRL 91 (2003) 072305**



# What does theory have to say?



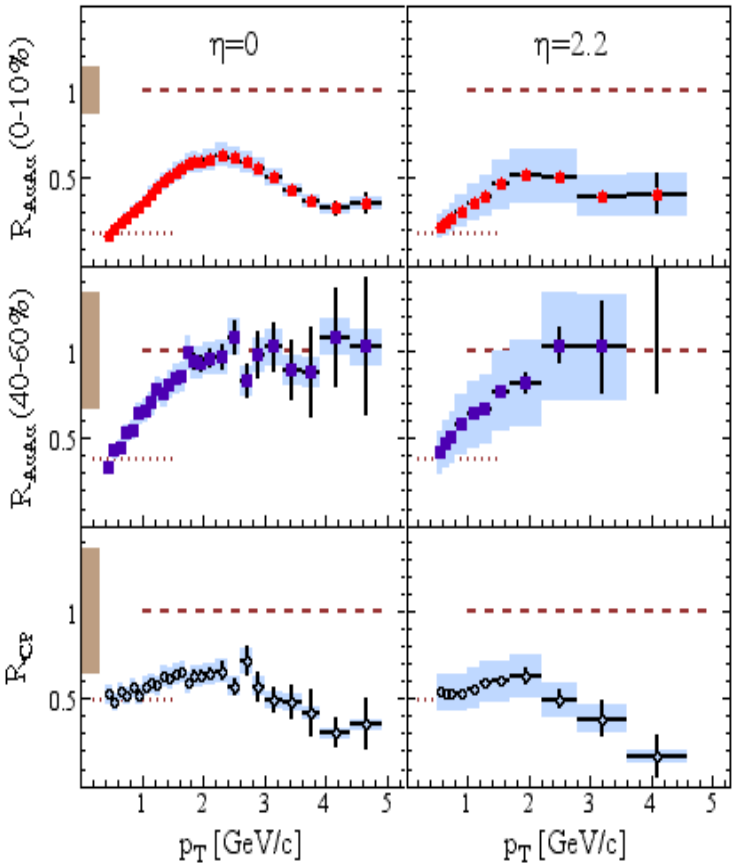

HIJING: pQCD (hard) + strings (soft), shadowing, very schematic jet quenching (1992)

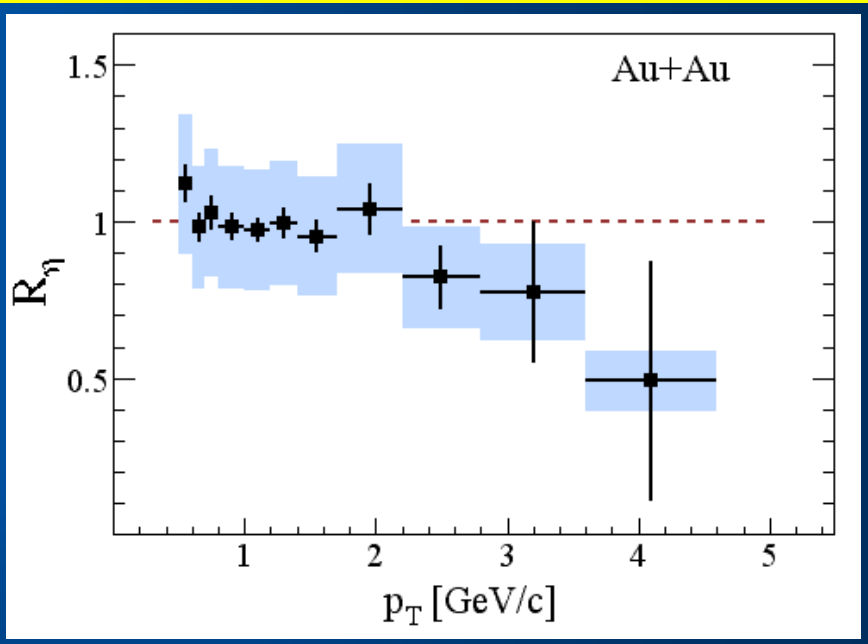
Vitev-Gyulassy: pQCD (hard), no soft Cronin $k_T$ broadening, shadowing and (GLV) jet quenching

Cassing et al: pQCD (hard) + strings (soft) $k_T$ broadening, shadowing and energy loss (pre-hadronic and hadronic)

Hirano-Nara: pQCD (hard) + hydro (soft) Cronin $k_T$ broadening, shadowing and (GLV) jet quenching

# High pt suppression persists at forward rapidity




**Large high pt suppression also at forward rapidity.**

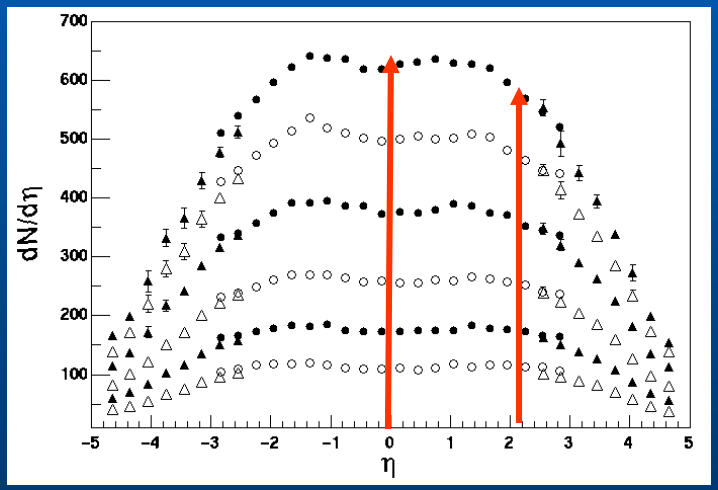
**Longitudinally extended medium, boost invariance, CGC or …?**

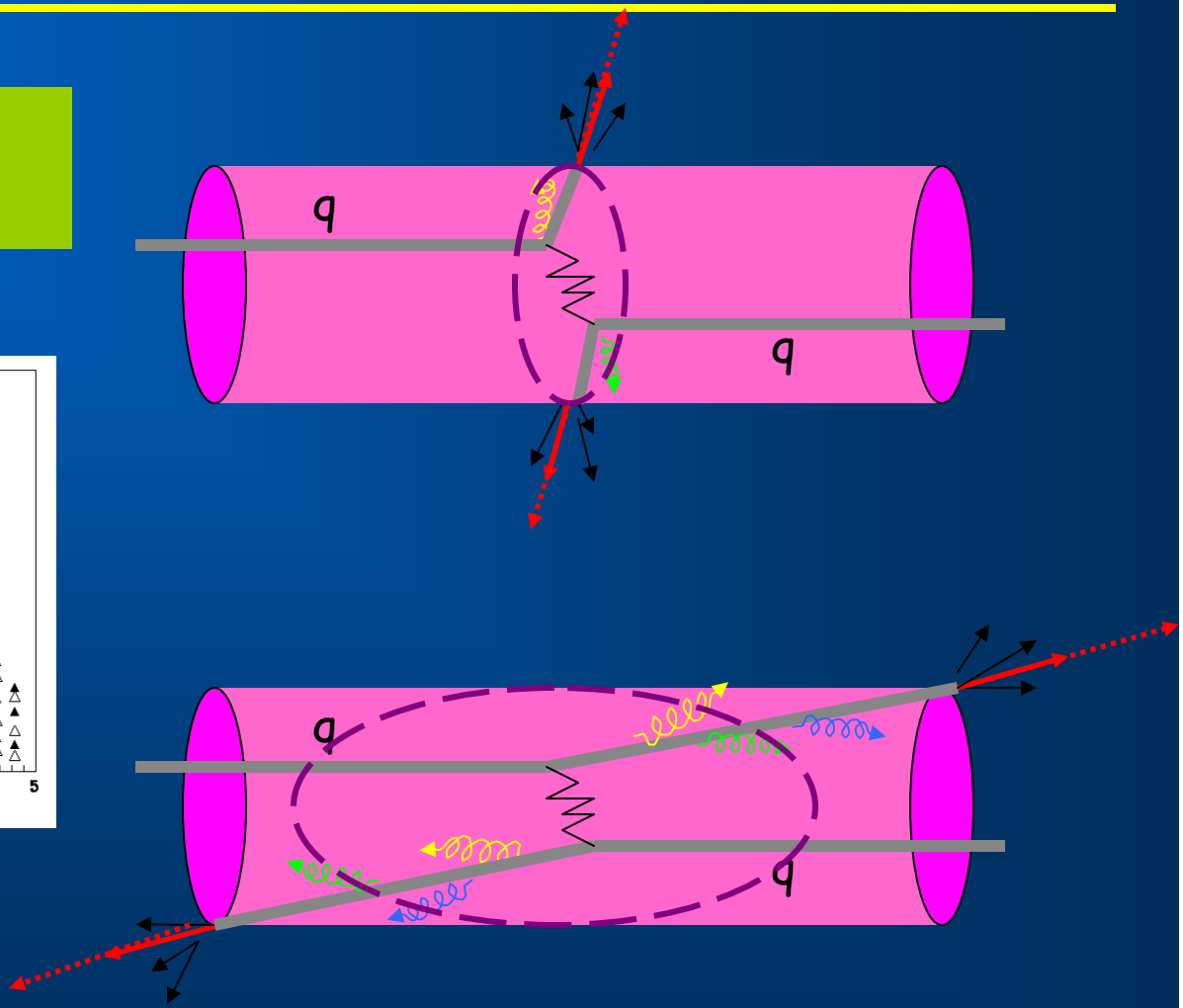
**Not quantitatively understood.**

# Energy loss by stimulated gluon emission in QGP ?

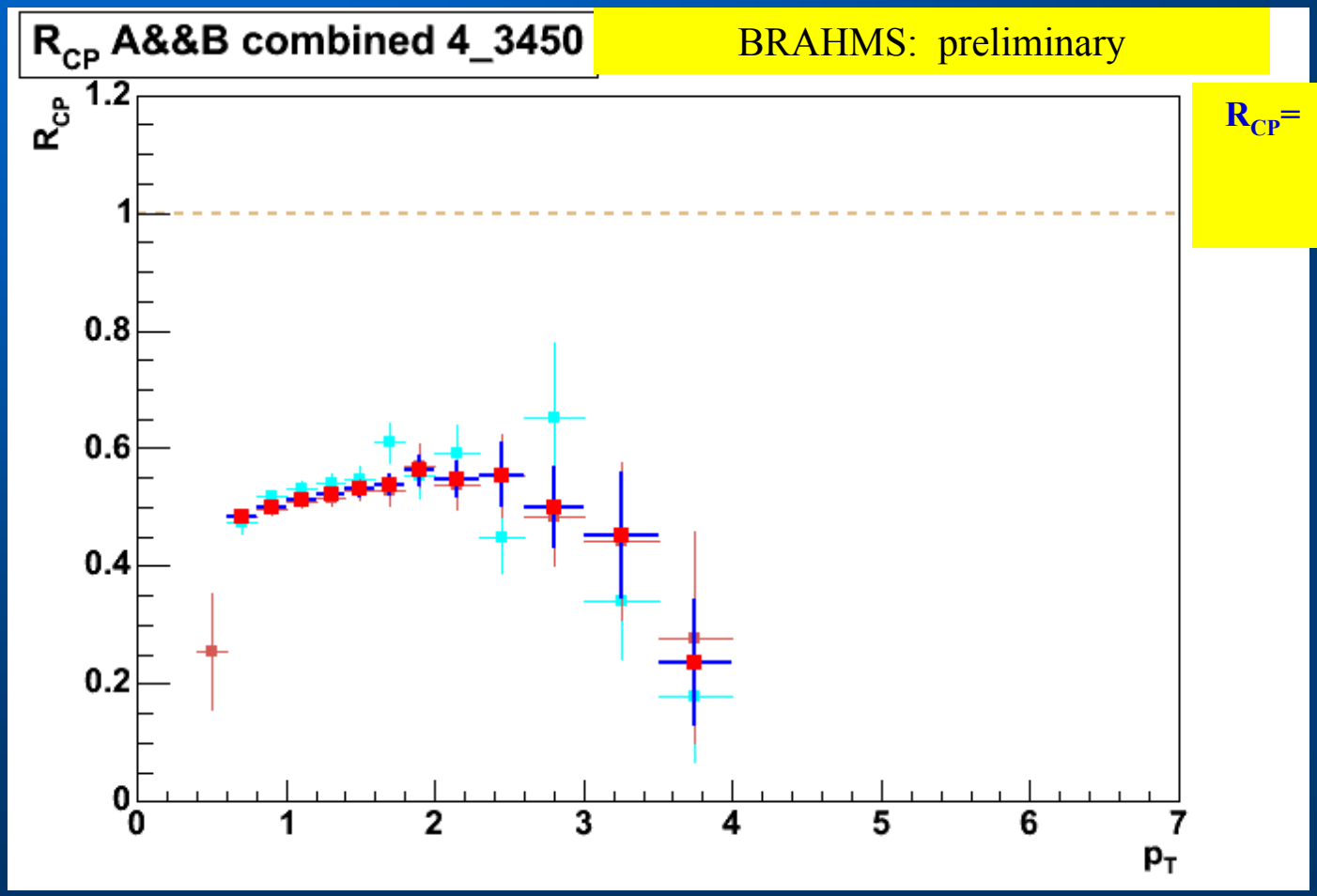

$$\text{QCD: } \langle \Delta E \rangle \propto \int \rho^g \ln(1/L)\, dz$$

$$\propto \langle L^2 \rangle$$



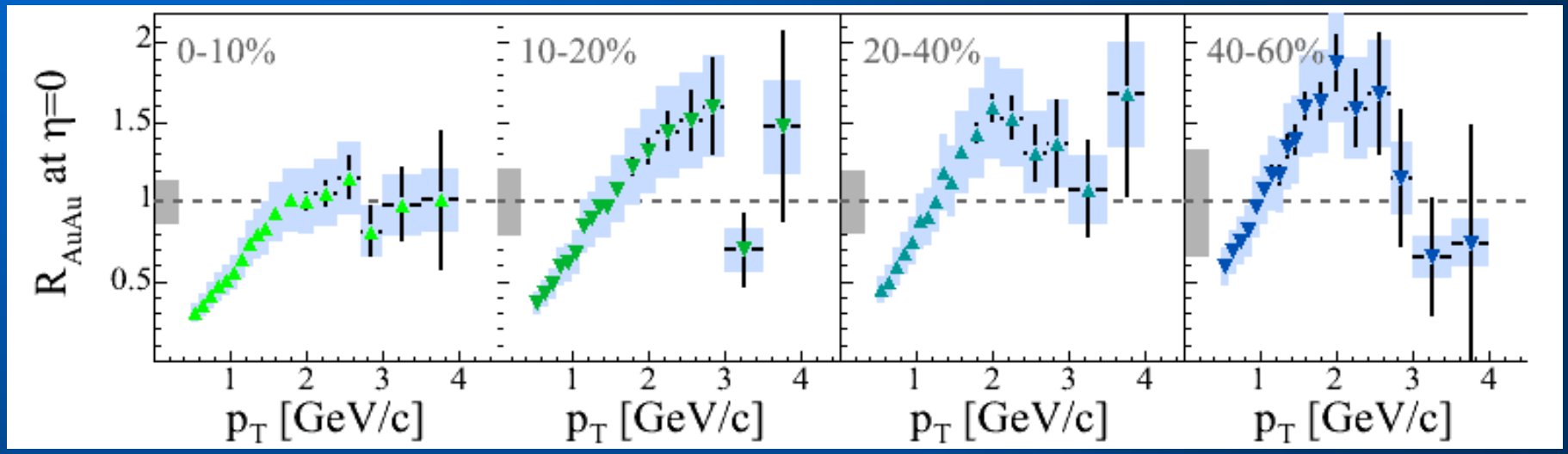
# $R_{AuAu}$ for hadrons at η=3.2 (4degrees) RHIC run IV

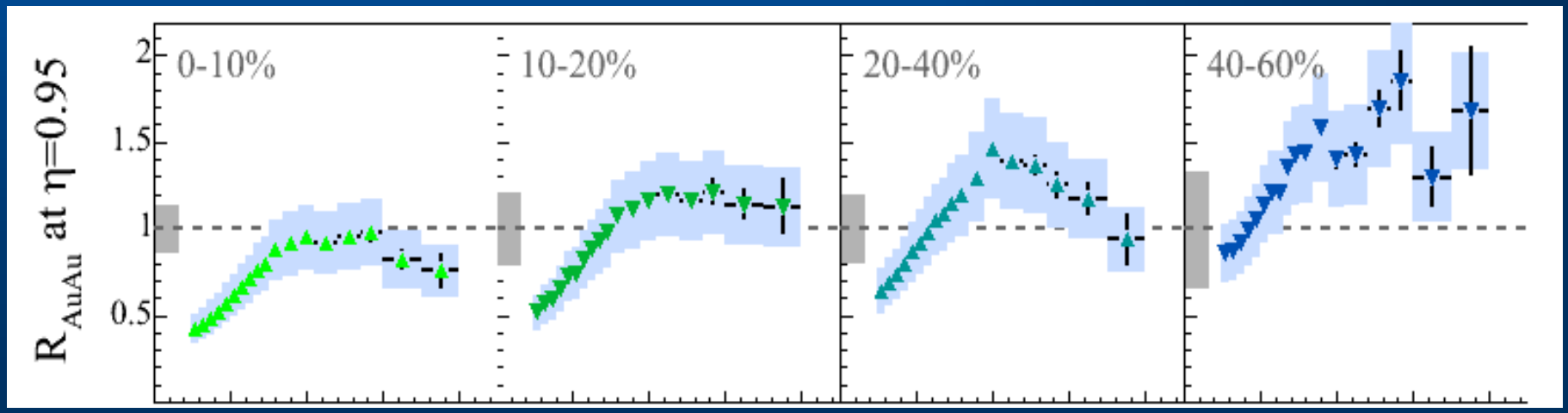



$R_{CP}$= RdAu (0-20%) / (60-80%) / RdAu (30-50%) / (60-80%)

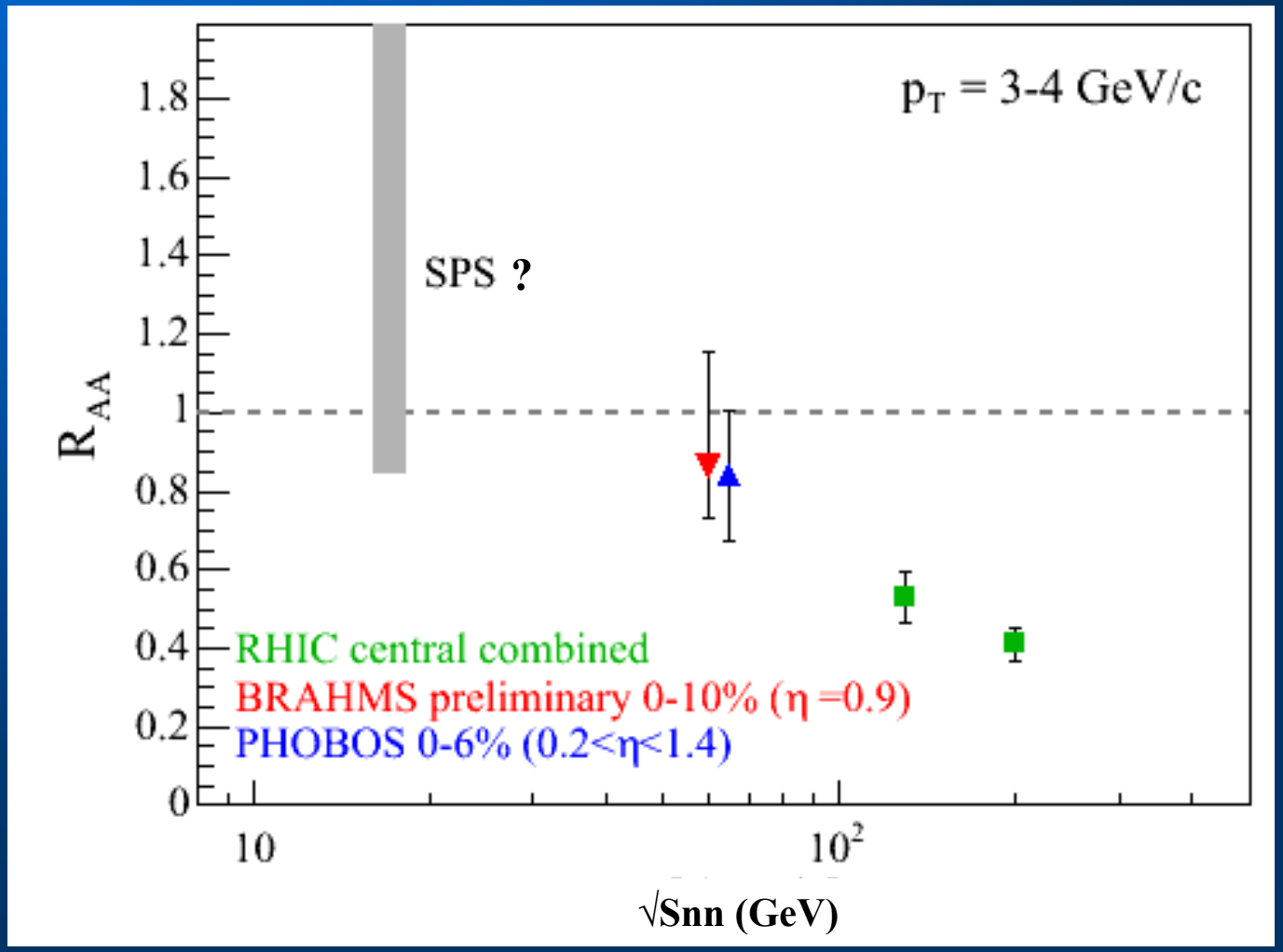
RCP indicates strong high pt suppression at very forward rapidities in Au+Au

# $R_{AuAu}$ @ 62.4 GeV
# η=0 and η=0.95

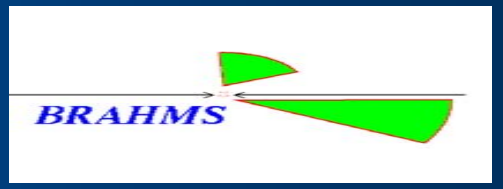


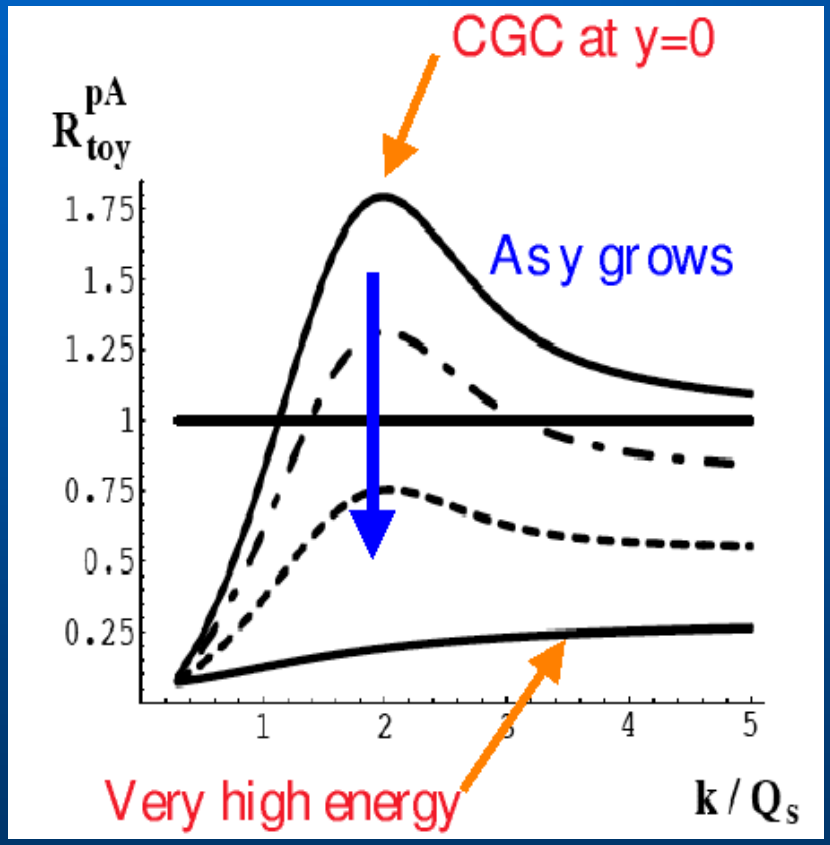



# No sudden transition…..

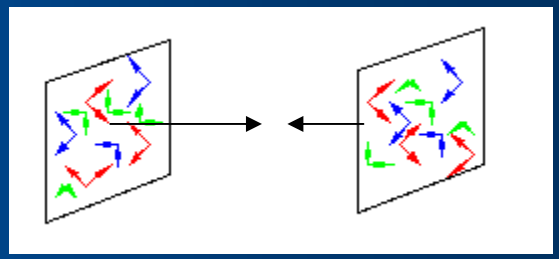


# Color Glass Condensate
# The fundamental state of the colliding nuclei?



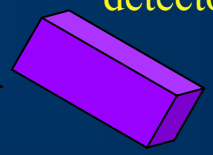




X= p(parton) /p(nucleon)

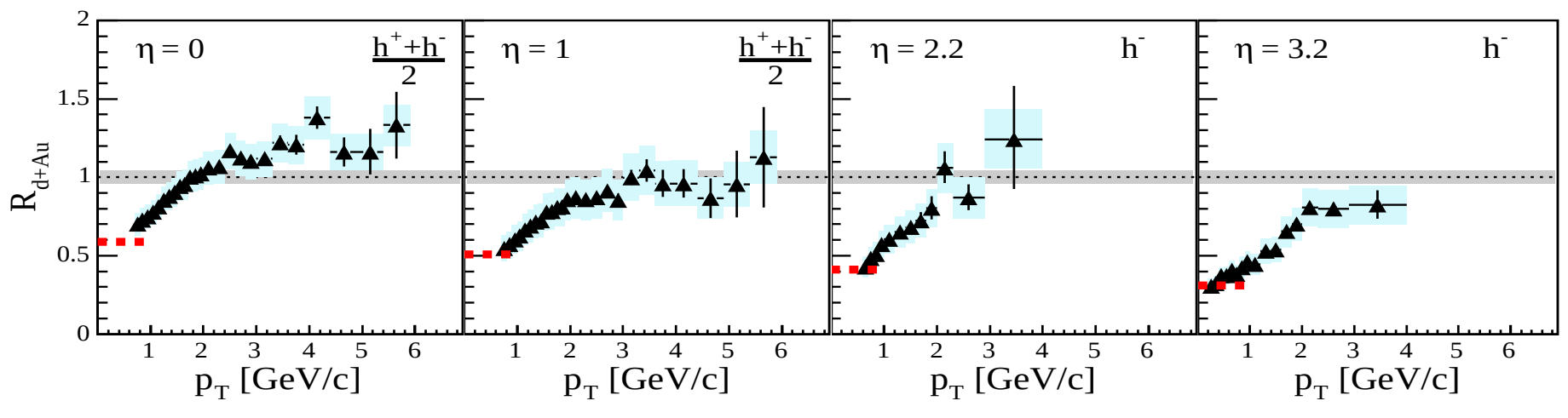



**Measure at large y on D side:**

**Probes small x in Au**

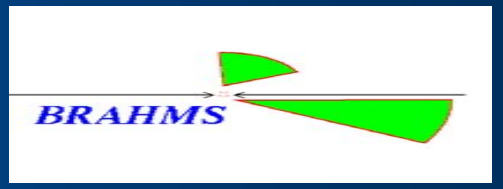


# Color Glass Condensate in d+Au collisions?

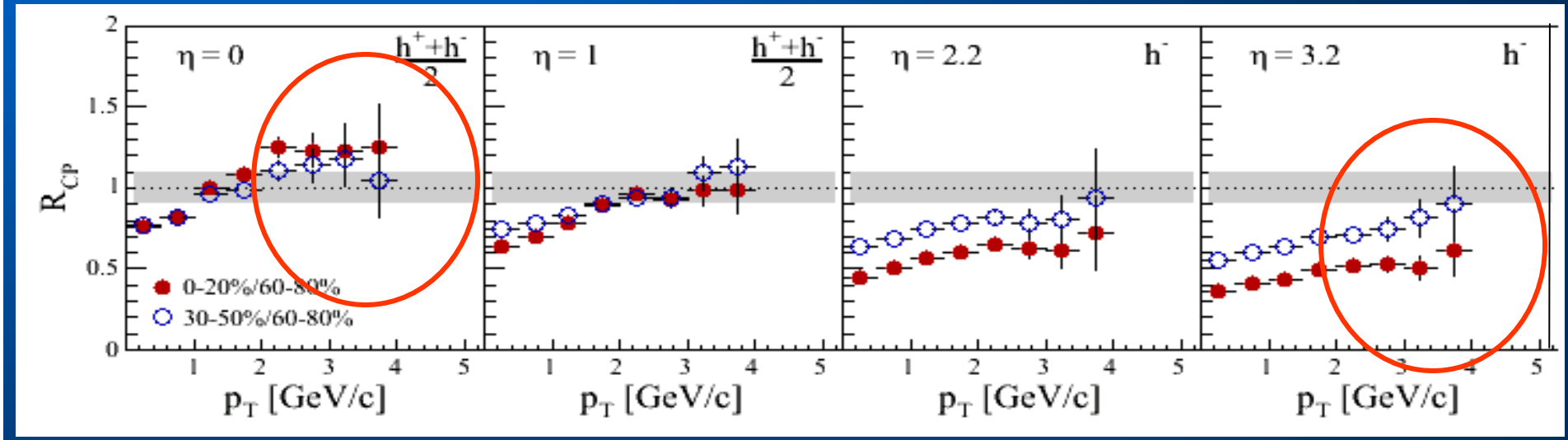



**BRAHMS accepted PRL nucl-ex / 0403005**

# Centrality dependence … in d+Au



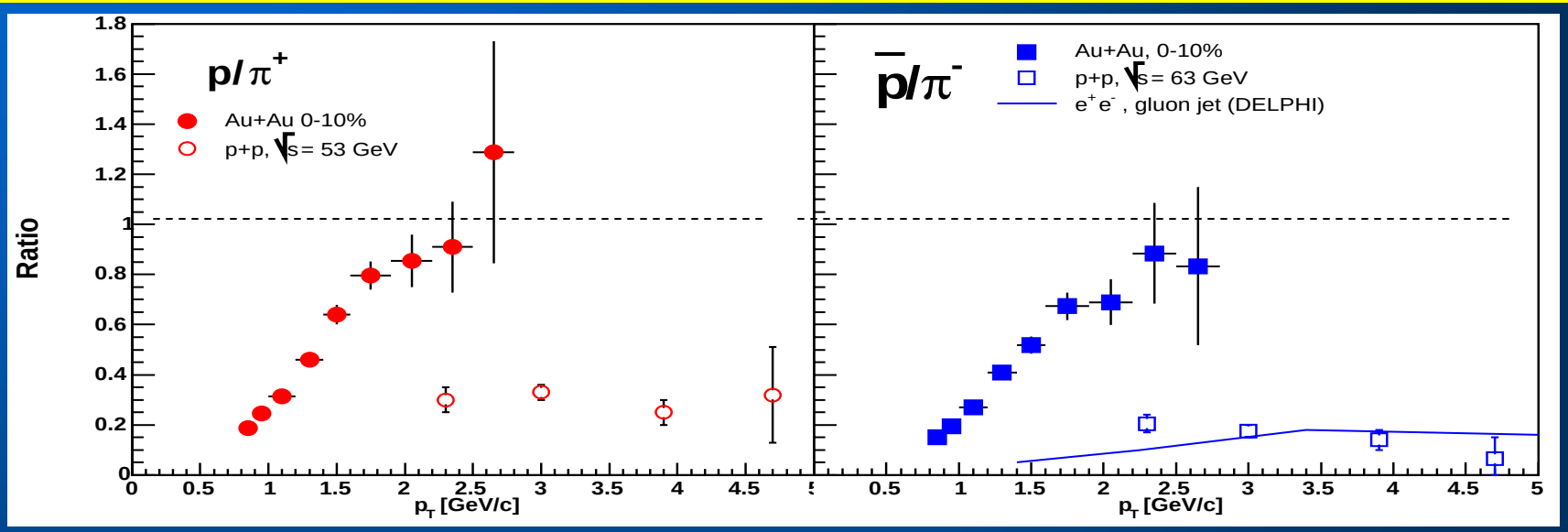

$$R_{CP} = \frac{\text{RdAu (0-20\%) / (60-80\%)}}{\text{RdAu (30-50\%) / (60-80\%)}}$$

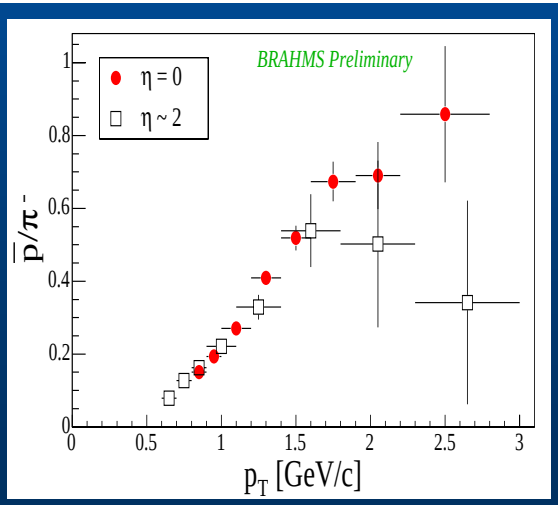



**Most central to peripheral ratio is most enhanced at midrapidity and most suppressed at forward rapidity**

**This centrality inversion is consistent with the CGC model.**

# 'High pt' spectra are different for baryons and mesons in Au+Au



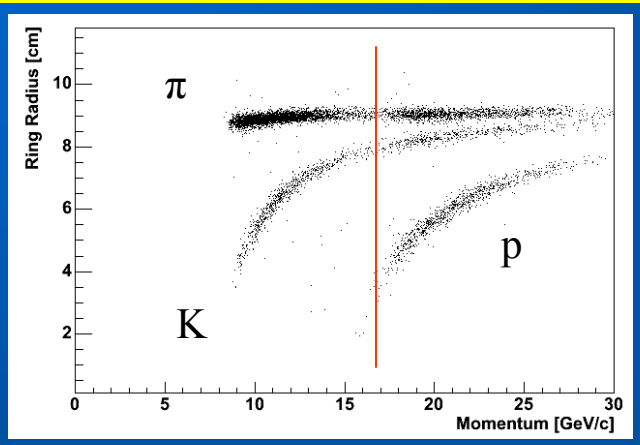




**Very different from p+p and $e^+$+$e^-$**

**Hadronic flow or partonic mechanism?**

**Qualitative agreement with parton recombination models, but need results from run IV for higher pt**

# How does it look in d+Au ?
# Identified hadrons at 4 degrees (η=3.2)

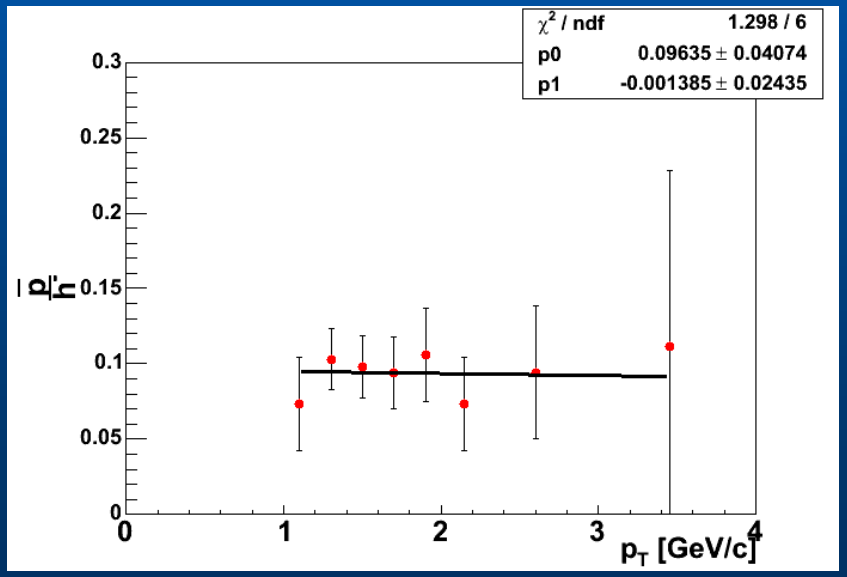


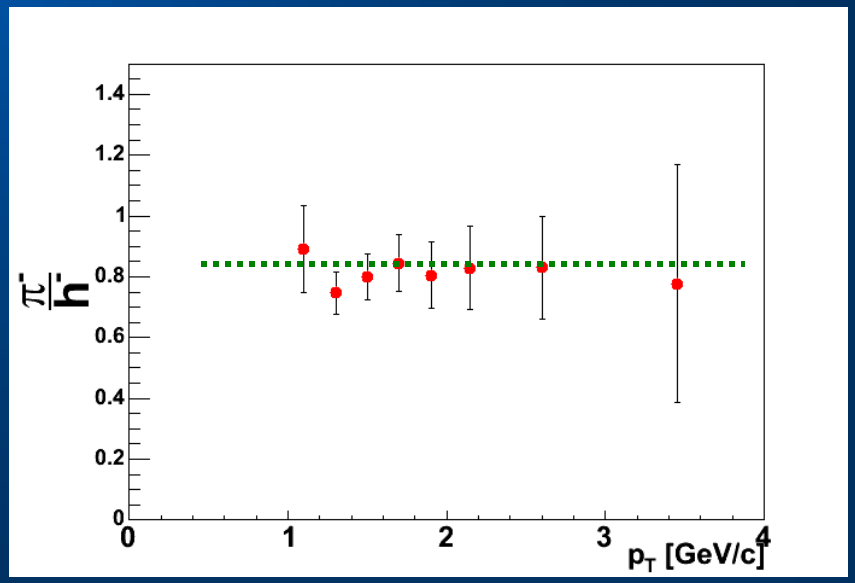

PID with RICH

**At eta= 3.2**

**P-bar : 10%**

**Π- : 80%**



# $R_{dAu}$ at η=3.2
# (min.bias) Baryon meson difference in d+Au

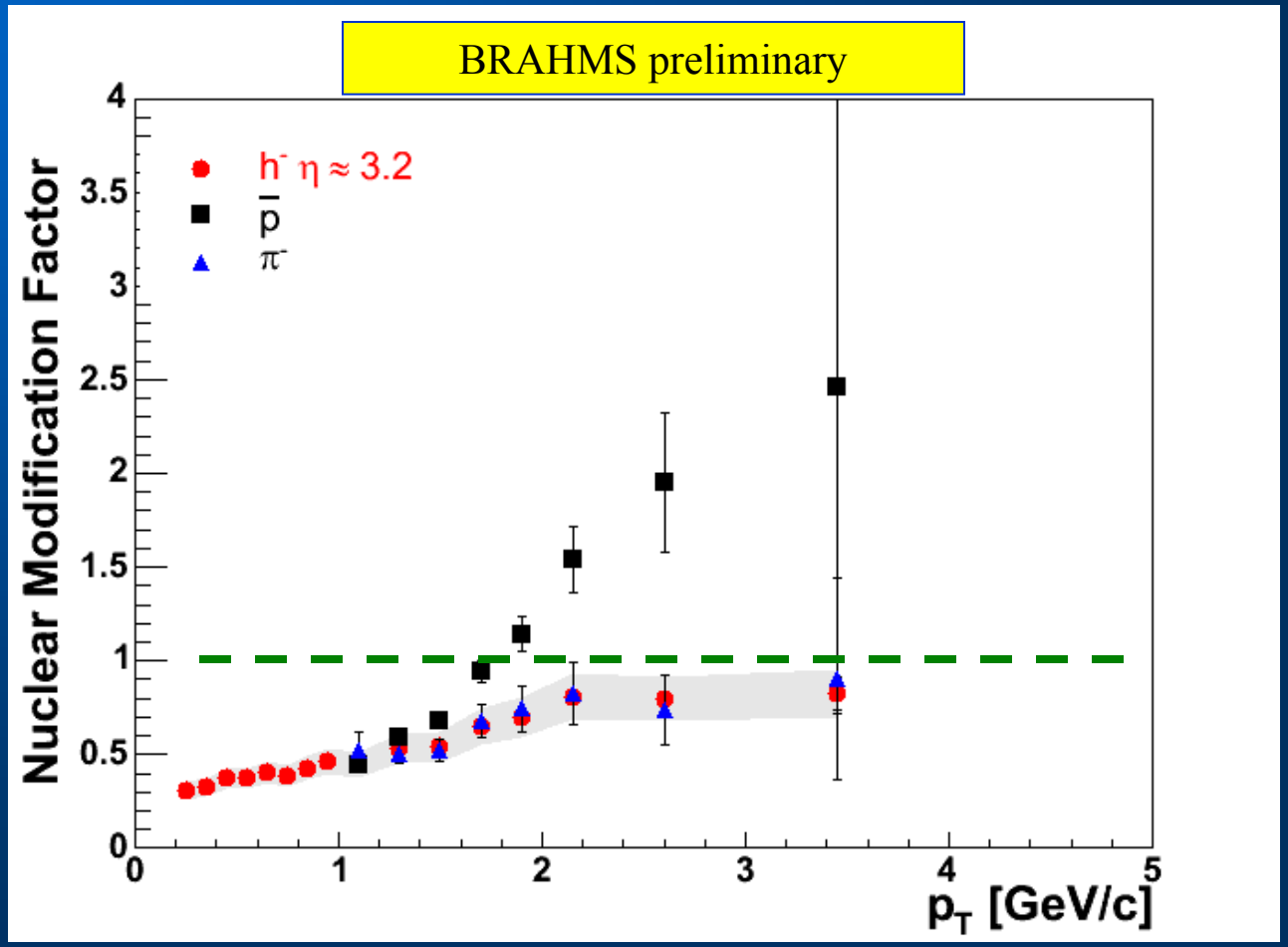
**Strong Difference between mesons (pions) and Baryons (anti-p) persists at forward rapidity**

**in d+Au collisions**

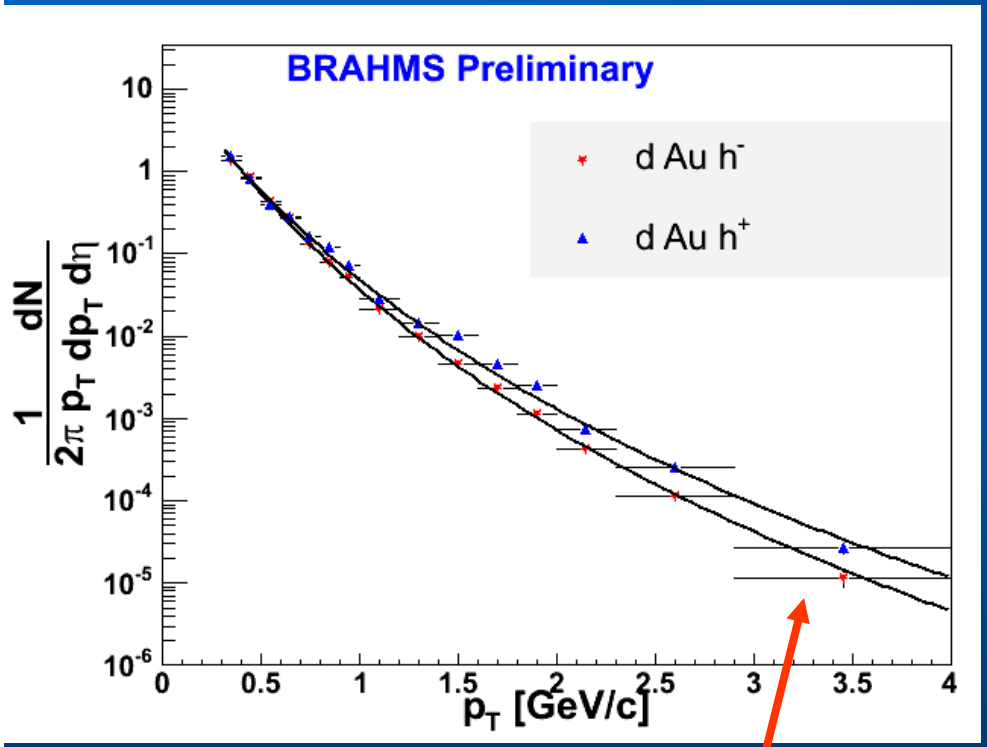
**Flow?**

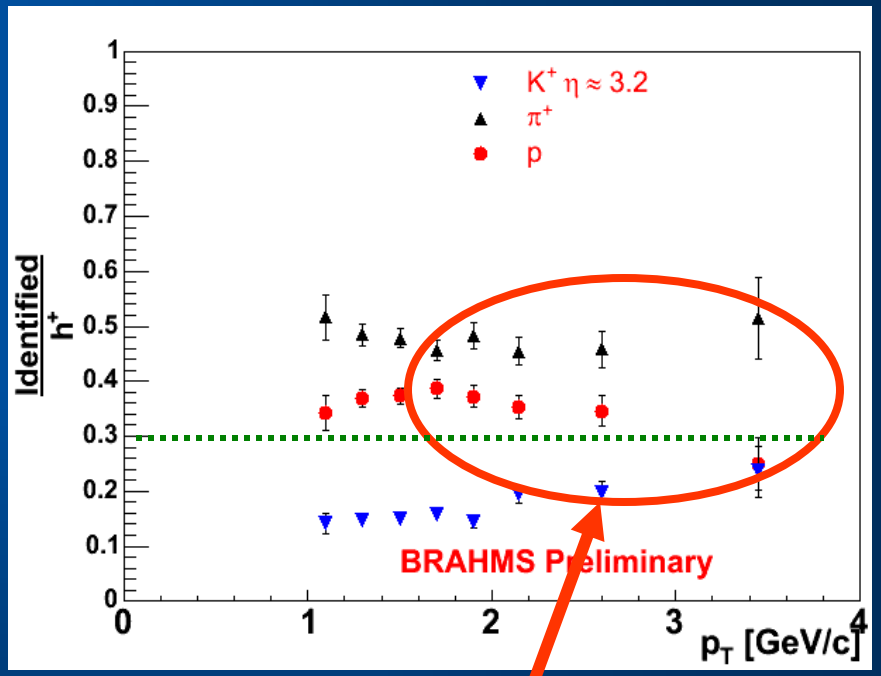
**Isospin?**

**Need to understand**



# The hadron spectrum for d+Au at η=3.2



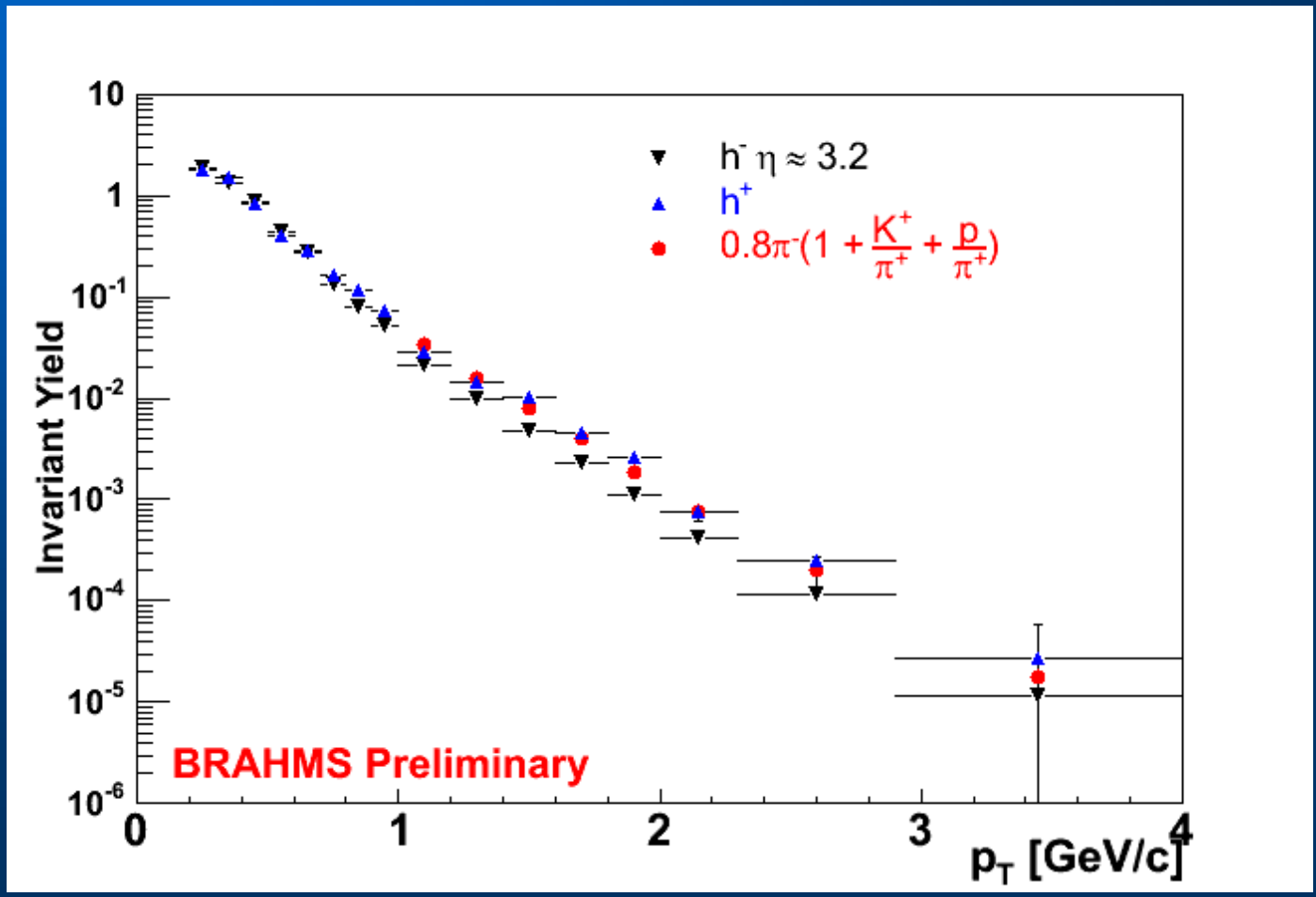




Excess of h+ over h-

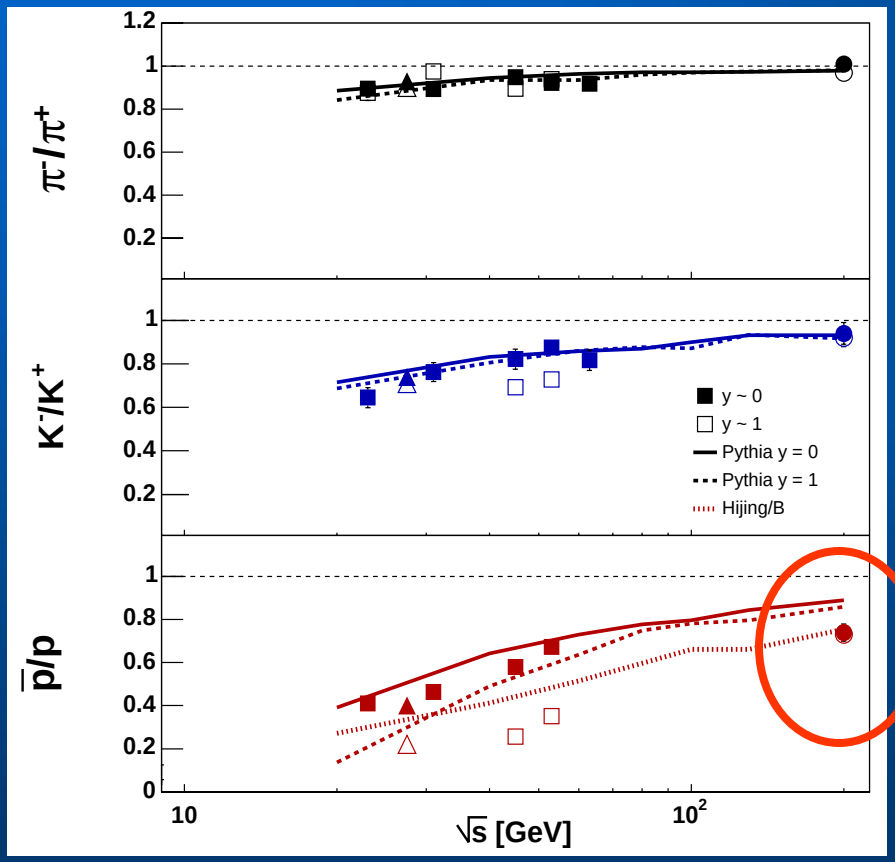
But many protons at forward rapidity

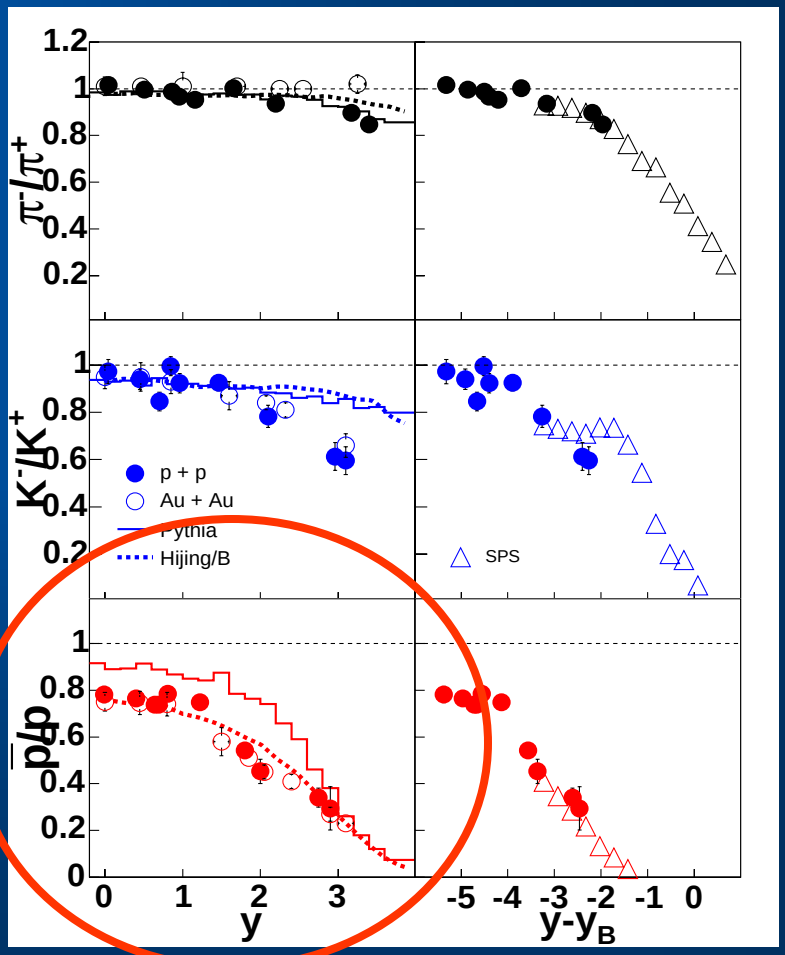
# Difference understandable from relative abundances

$h+ = 0.8h-( 1 + p/\pi+ + K/\pi+)$



# p+p at 200GeV
# Particle ratios vs rapidity

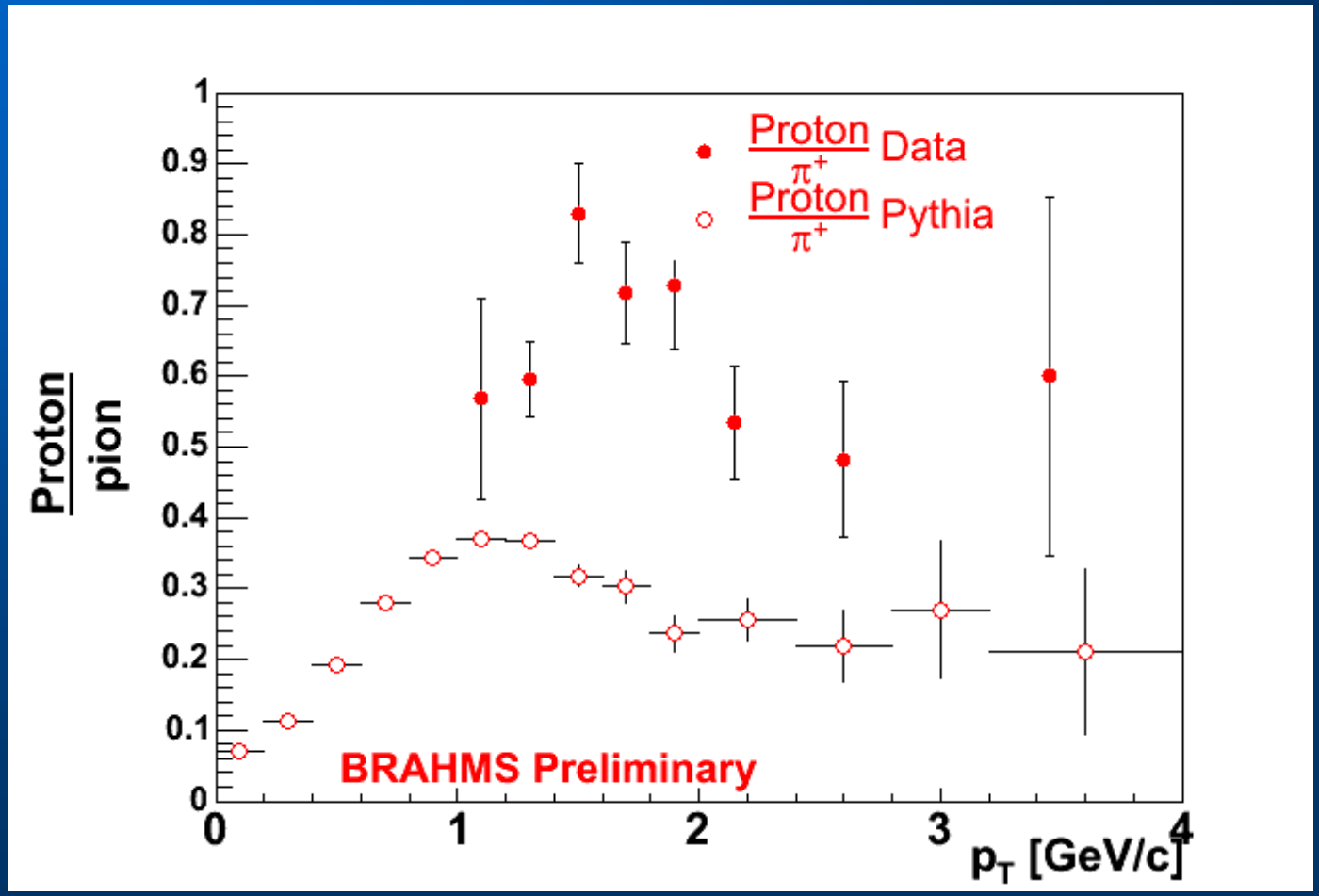


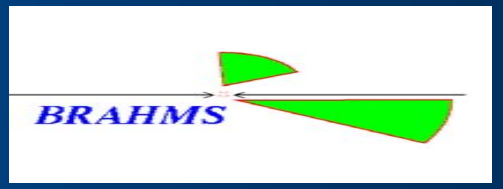

PYTHIA misses 200GeV protons

BRAHMS, nucl-ex/0409002, Submitted to Phys. Lett. B (2004)

# Proton/pion in p+p at η=3.2 vs. Pythia (vs. 6.303)

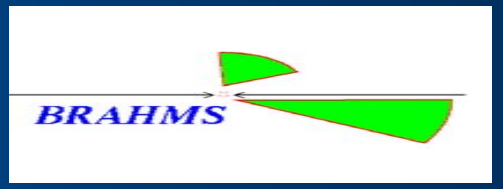


# Summary

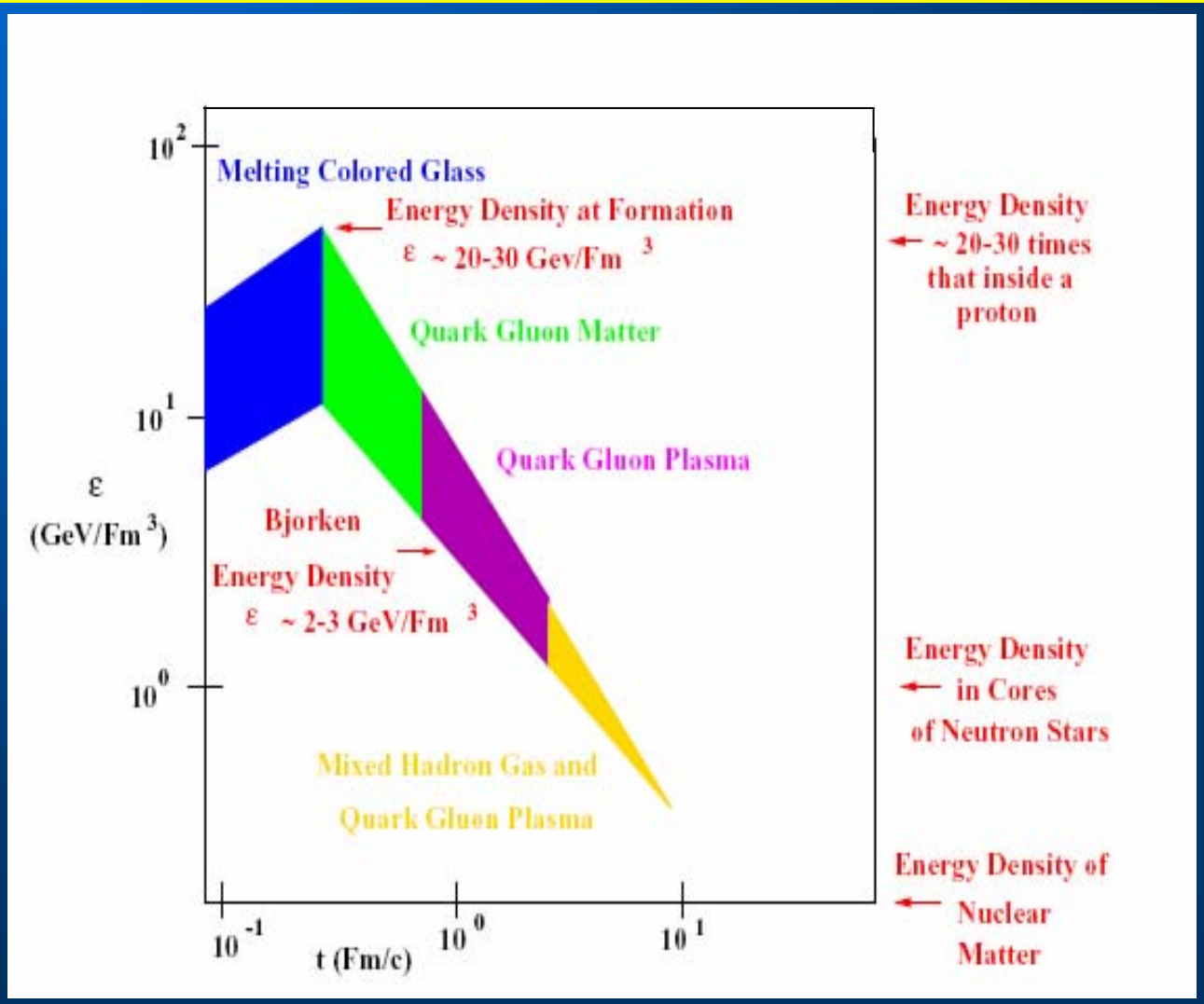



- Large high pt suppression at midrapidity in Au+Au. Gluon radiation energy loss?
- No suppression in d+Au => no initial state effects. Large effect (factor 5).
- Strong high pt suppression in Au+Au persists at forward rapidities- need quantitative understanding.
- Reduced high pt suppression in Au+Au at 62.4 GeV
- Decrease in R(dAU) from η=0 to η=3.2 and centrality dependence inversion. Consistency with CGC picture.
- Baryon/mesons difference sseen at midrapidty in Au+Au is also present in d+Au at forward rapidity.
- Pythia does not reproduce protons in p+p.
- === > BRAHMS whitepaper on RHIC discoveries: Nucl-ex/0410020, subm. Nucl. Phys. A

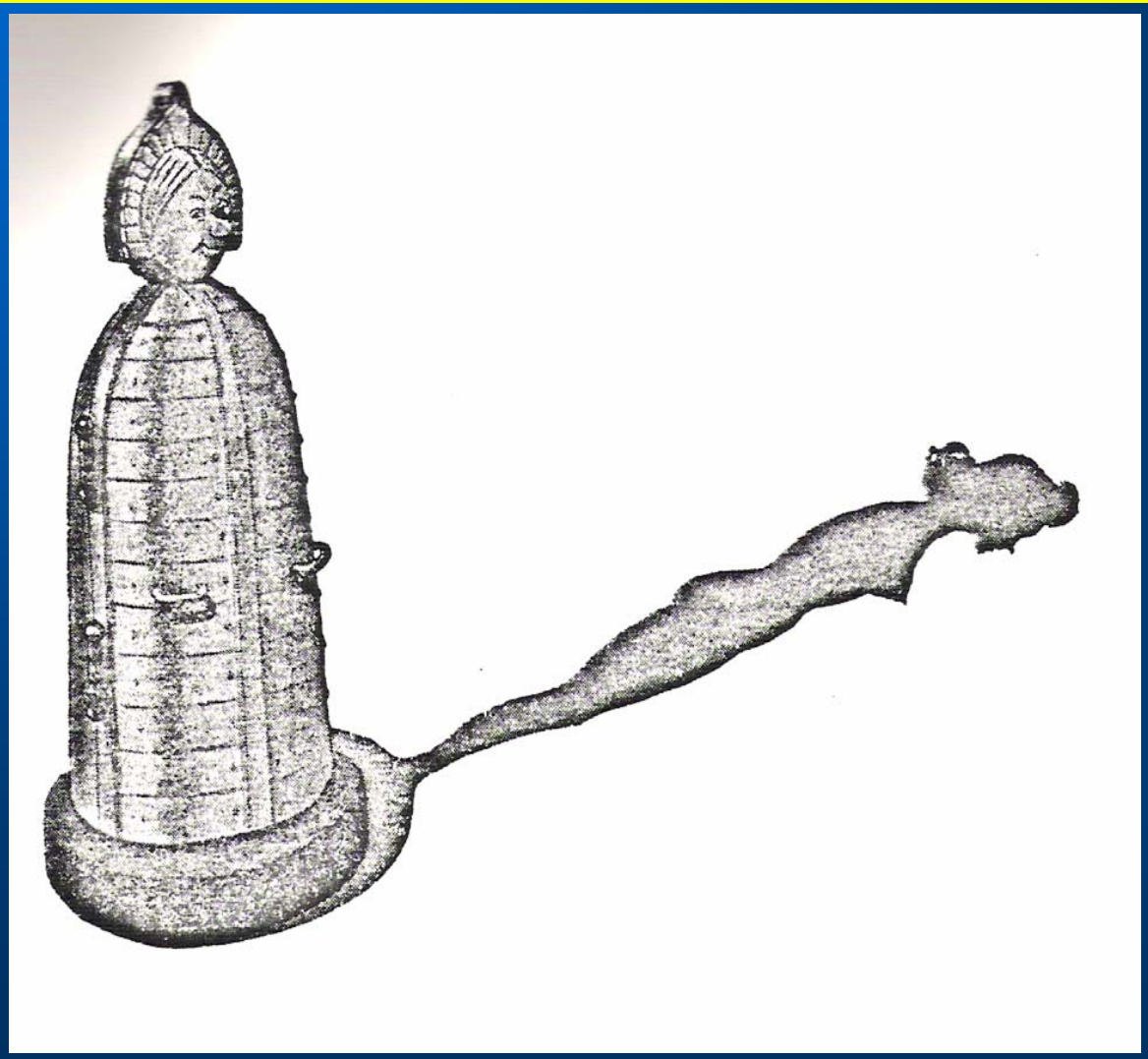
# Extra material



# Is a unified picture emerging?



# New Physics?



# BRAHMS
# Intl. collaboration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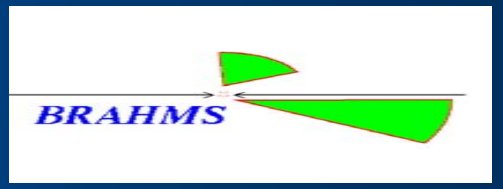
## At lower energy the opposite is seen : High pt *enhancement*



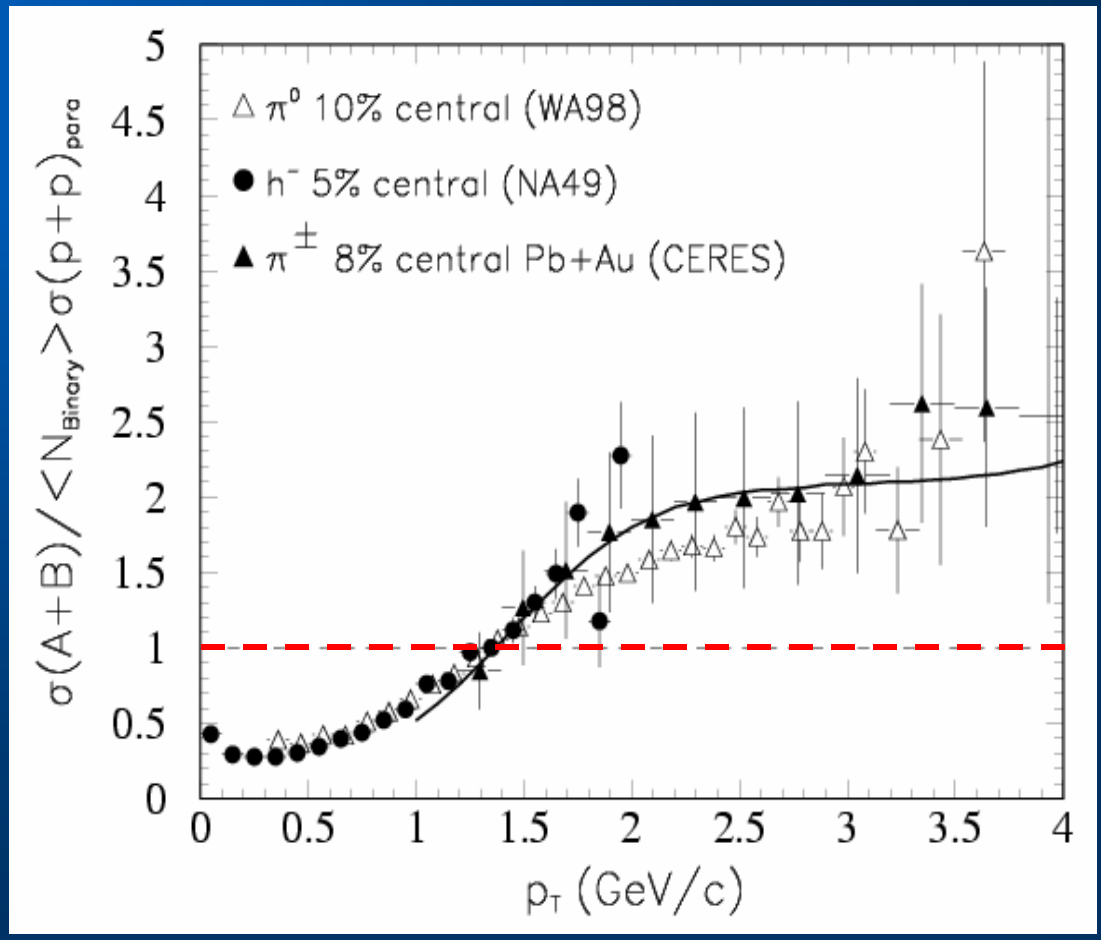

**CERN- SPS**

**($\sqrt{s_{nn}}$=17 GeV)**

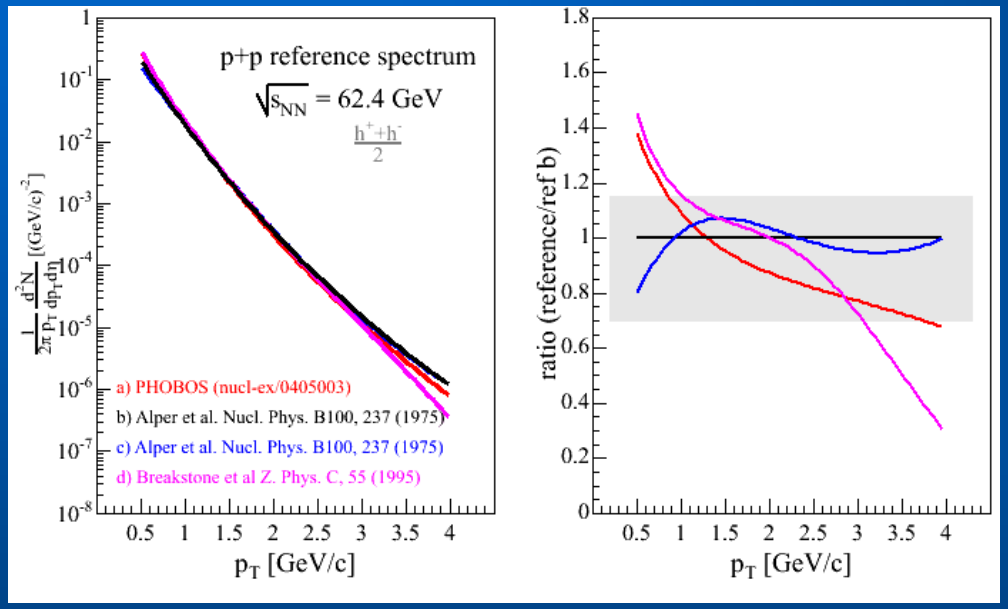
**High p_t enhancement seen when compared to p+p scaled by N_binary.**

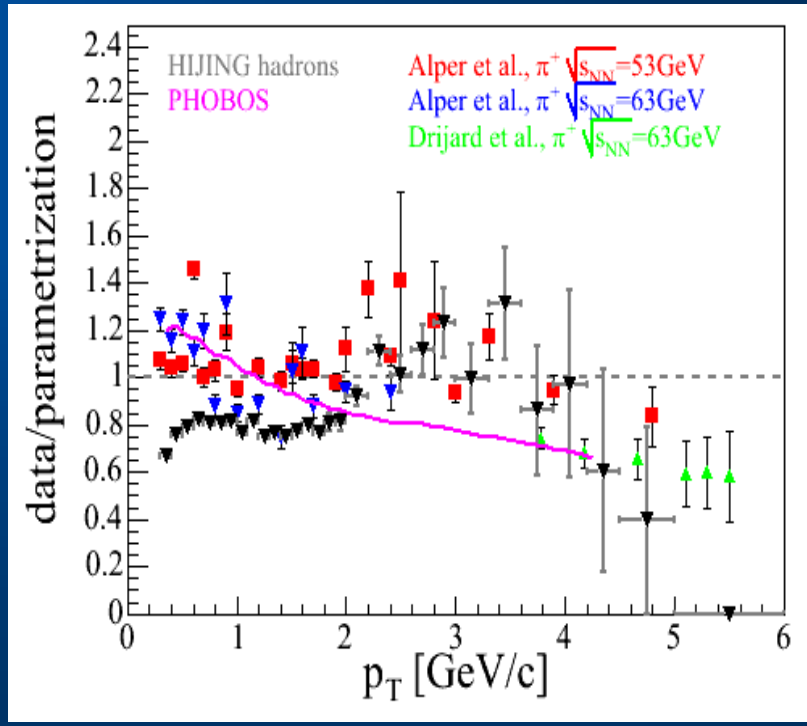
**Cronin effect:**

**quark mult scattering**

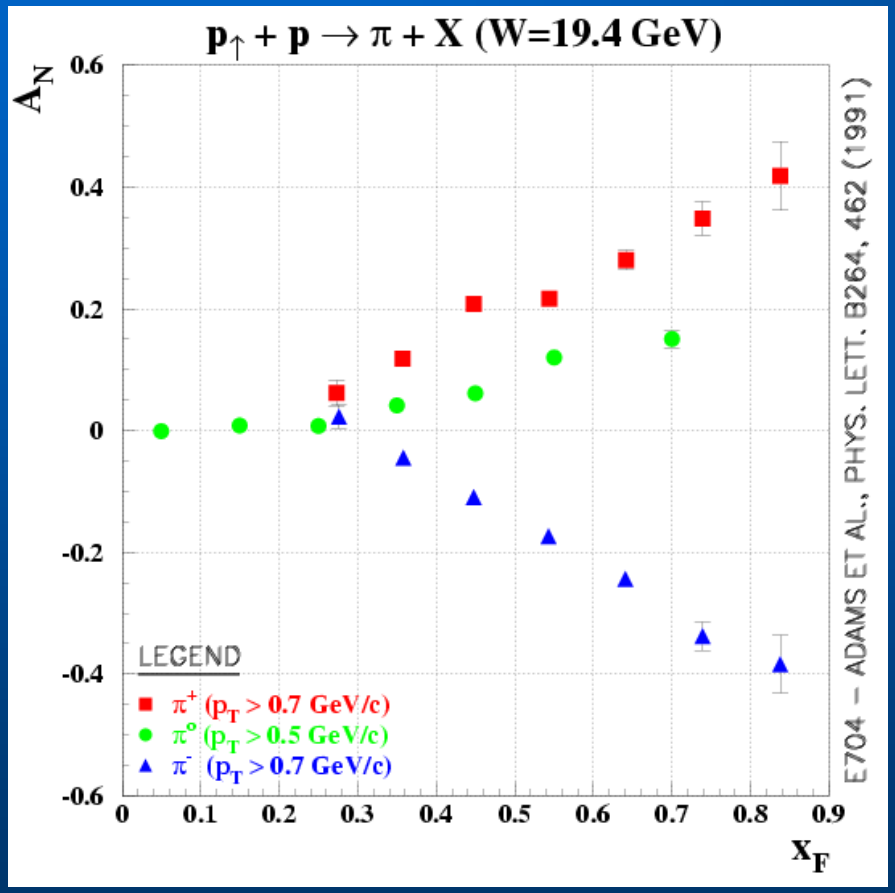


# p+p reference at 62.4 GeV: a problem

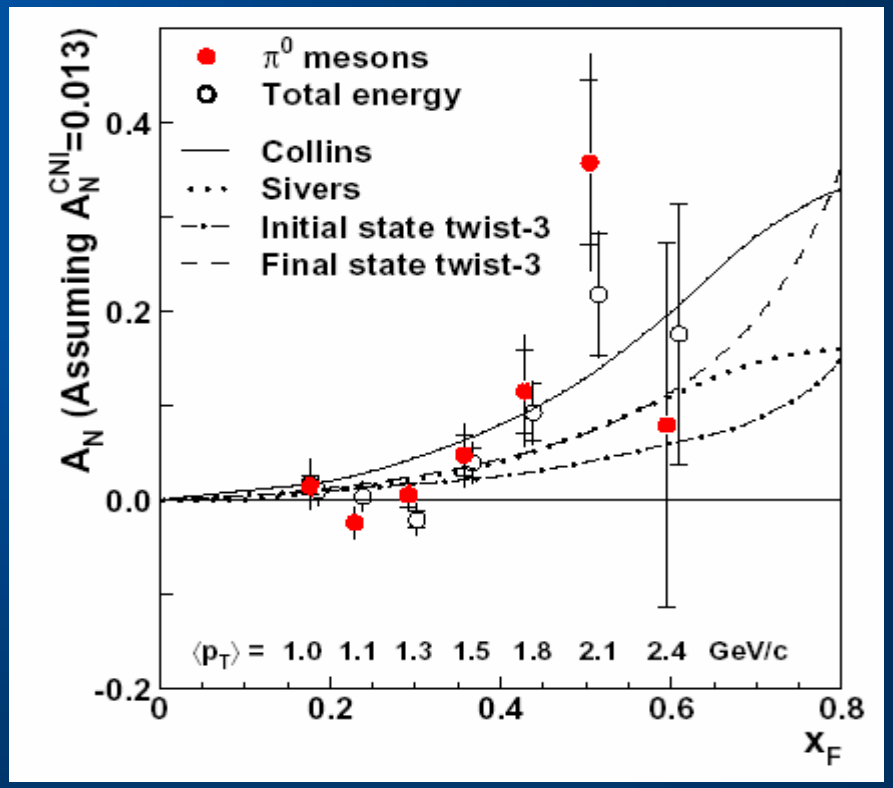


# Transverse spin asymmetry for pions using polarized p+p collisions




$A_N = (s+ - s-) / (s+ + s-)$




D.L.Adams (E704) Phys.Lett B264,462(1991); Phys.ReV D53, 4747 (1996). **FNAL704**

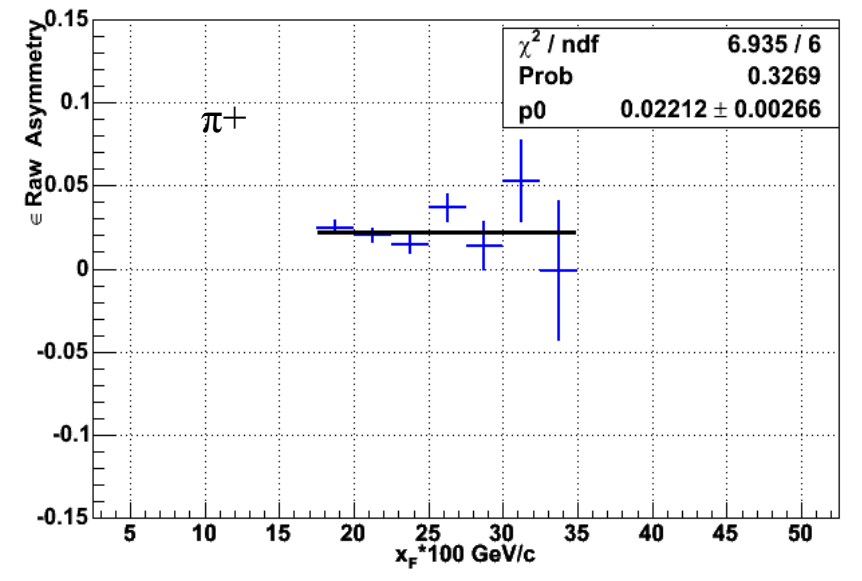
**STAR PRL 92,06230(2004)**

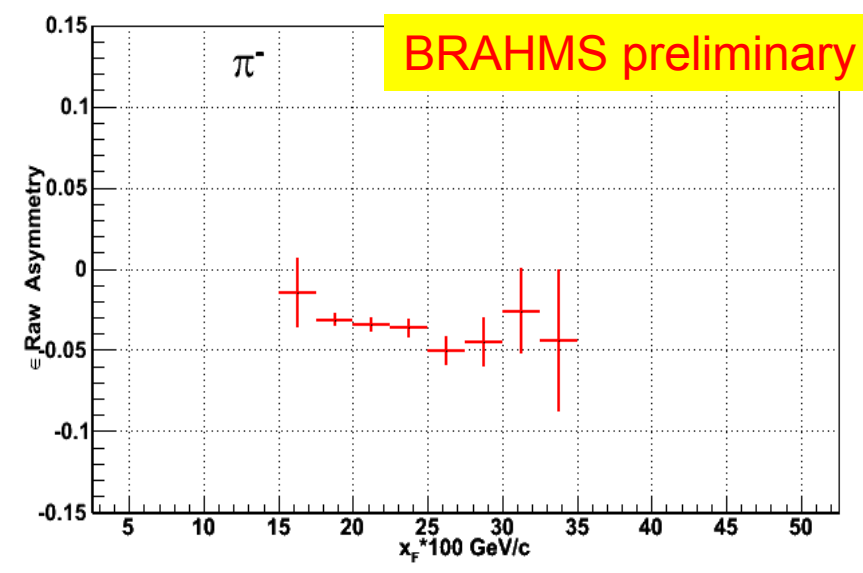
# First results at high XF

$A_N = \varepsilon / P$ P=0.40 - 0.45

$\varepsilon = (N+/L+ - N-/L-) / (N+/L+ + N-/L-)$

$= (N+ - L*N-) / (N+ + L*N-)$ with $L = L+ / L-$




< ε >~ +0.022

⇒ $A_N$ = +0.05 +- 0.005 +- [0.015]

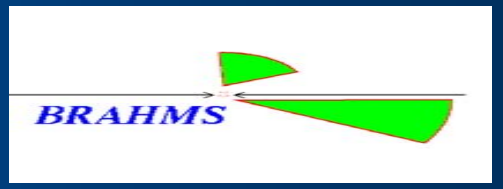
0.17 < xF < 0.32

<ε >~ -0.035

⇒ $A_N$ = -0.08 +- 0.005 +- [0.015]

0.17 < xF < 0.32

# BRAHMS whitepaper on RHIC discoveries




**Conclusion:**

…

There is no doubt that the experiments at RHIC have revealed a plethora of new phenomena that for the most part have come as a surprise. In this sense it is clear that the matter that is created at RHIC differs from anything that has been seen before. What name to give it must await our deeper understanding of this matter.

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