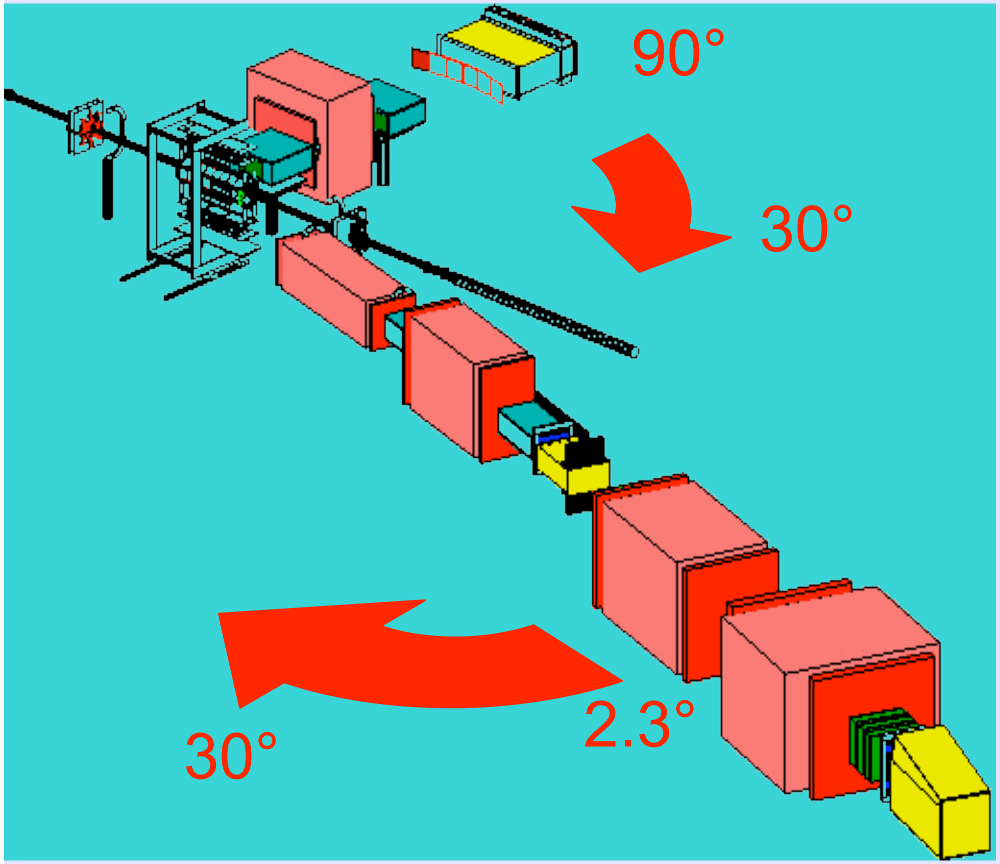
The BRAHMS HI and Spin Programs



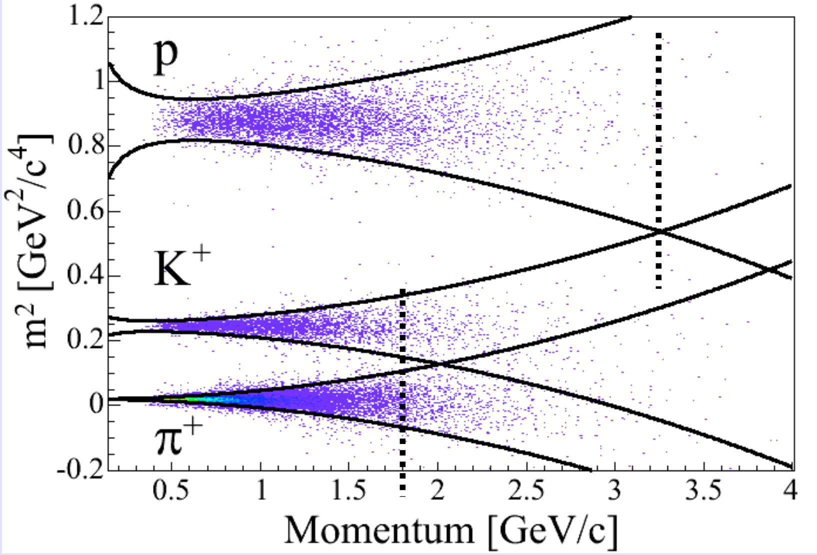
Broad **RA**nge **H**adron
Magnetic **S**pectrometers

S. J. Sanders
U. Kansas

Particle Identification

TIME-OF-FLIGHT

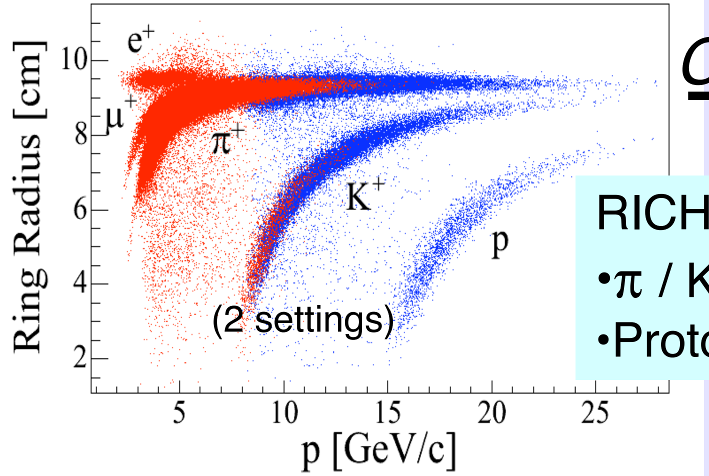
$$m^2 = p^2\left(\frac{c^2 TOF^2}{L^2} - 1\right)$$



Particle Separation: p_{max} (2σ cut)=

2σ cut	MRS TOFW	MRS TOFW2	FS TOF1	FS TOF2
π / K	2.0 GeV/c	2.4 GeV/c	3.0 GeV/c	4.5 GeV/c
K / p	3.5 GeV/c	4.0 GeV/c	5.5 GeV/c	7.5 GeV/c

CHERENKOV

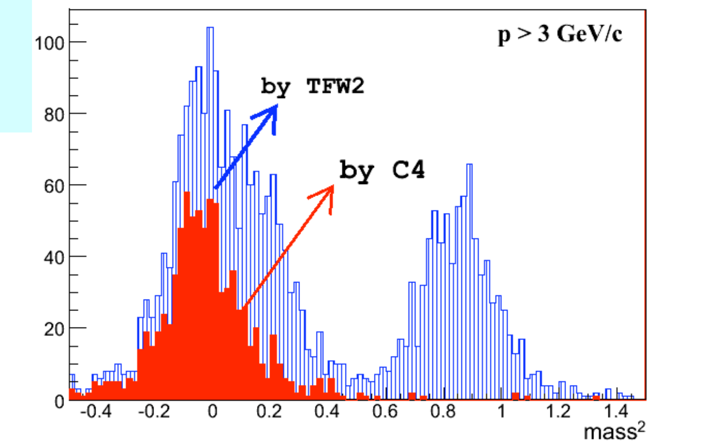


RICH (FS):

- π / K separation 20 GeV/c
- Proton ID up to 35 GeV/c

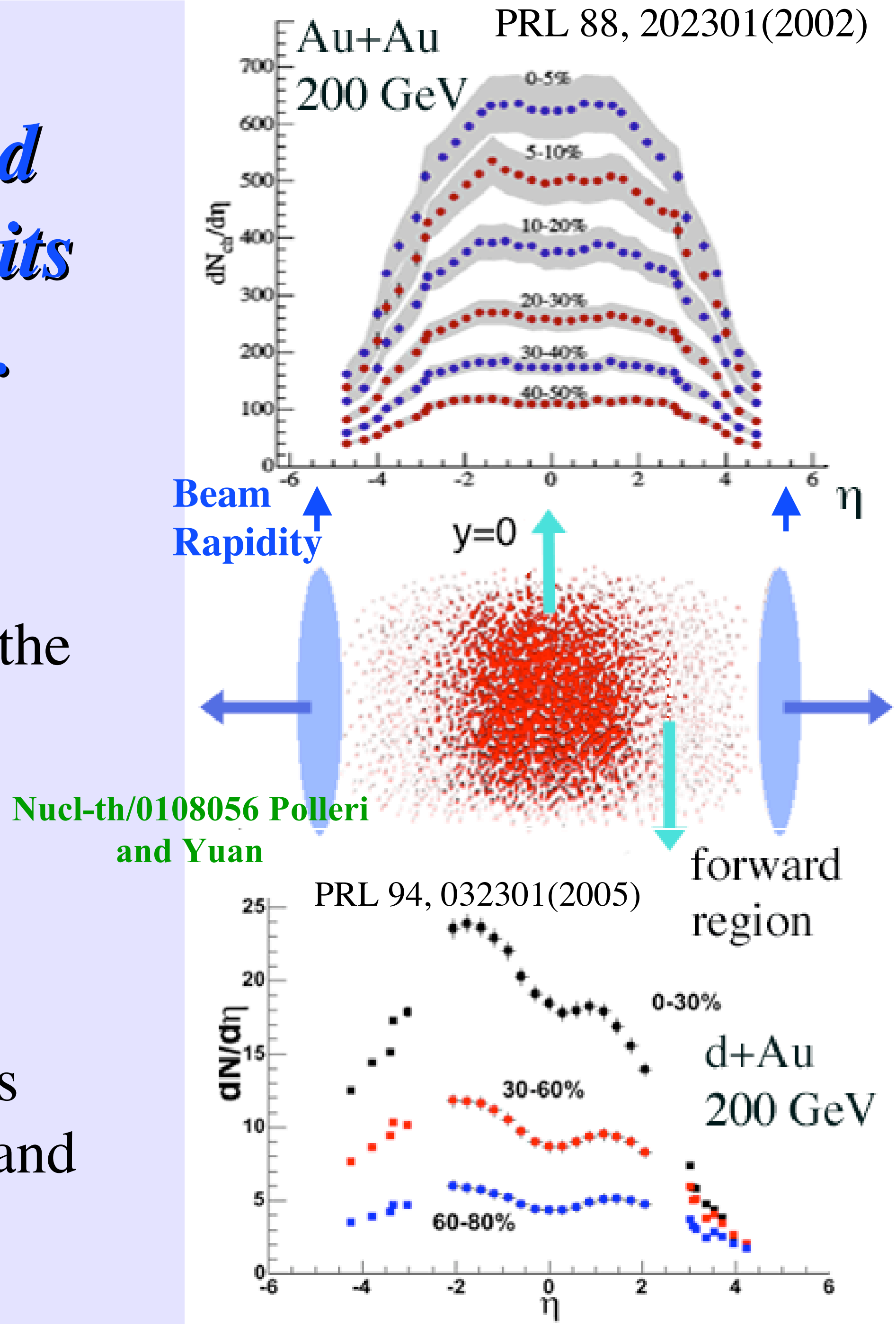
C4 Threshold (MRS):

- π / K separation 9 GeV/c



BRAHMS studies the properties of the produced medium as a function of its longitudinal expansion…

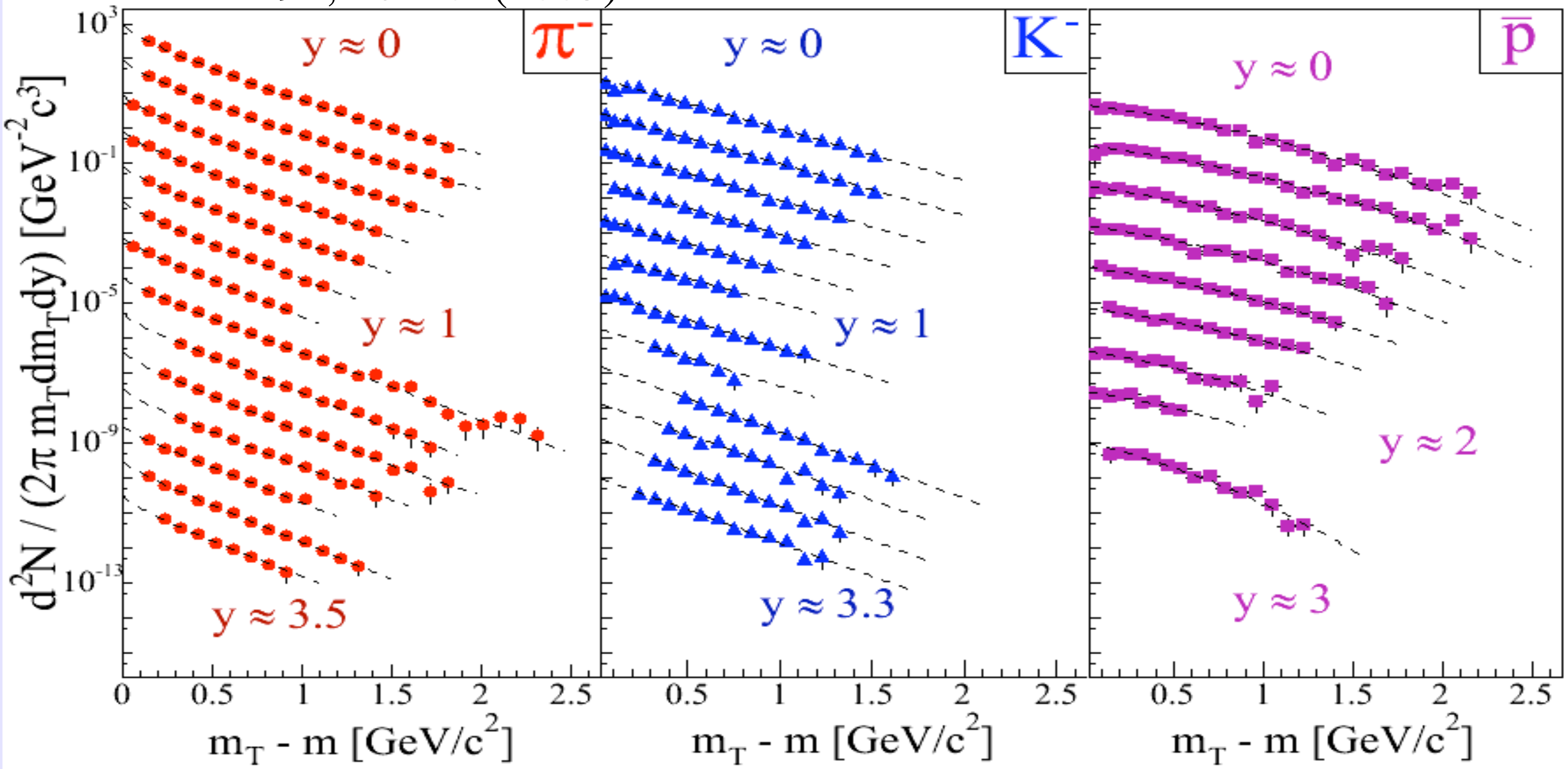
- What is the energy available for particle production?
- What is the longitudinal extent of the created medium?
- How does the “chemistry” of the medium change with rapidity?
- Are small-x effects (saturation) evident in the forward direction?
- Are there characteristic differences seen at large rapidity between AA and pp collisions?



Particle Spectra (200 GeV Au+Au)

5% central

PRL 94, 162301(2005)



Pions: power law $A\left(1+\frac{p_T}{p_0}\right)^{-n}$

Kaons: exponential $A\exp\left(-\frac{m_T-m}{T}\right)$

Protons: Gaussian $A\exp\left[-\frac{p_T^2}{2\sigma^2}\right]$

Energy Balance
(200 GeV Au+Au)

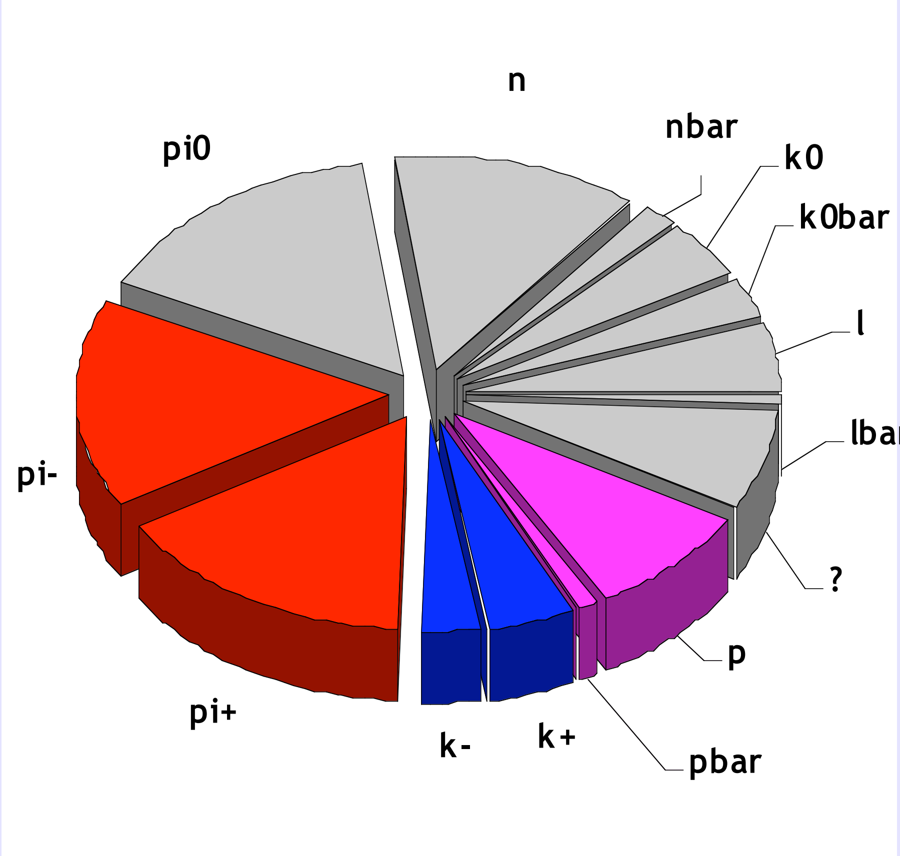
Energy (in GeV)

p	: 3108	π^0	: 6004
$\bar{p}$	: 428	n	: 3729
K^+	: 1628	$\bar{n}$	: 513
K^-	: 1093	K^0	: 1628
$\pi+$	: 5888	$\bar{K}^0$	: 1093
$\pi-$	: 6117	Λ	: 1879
		$\bar{\Lambda}$	: 342

sum: 33.4 TeV

produced: 24.8TeV

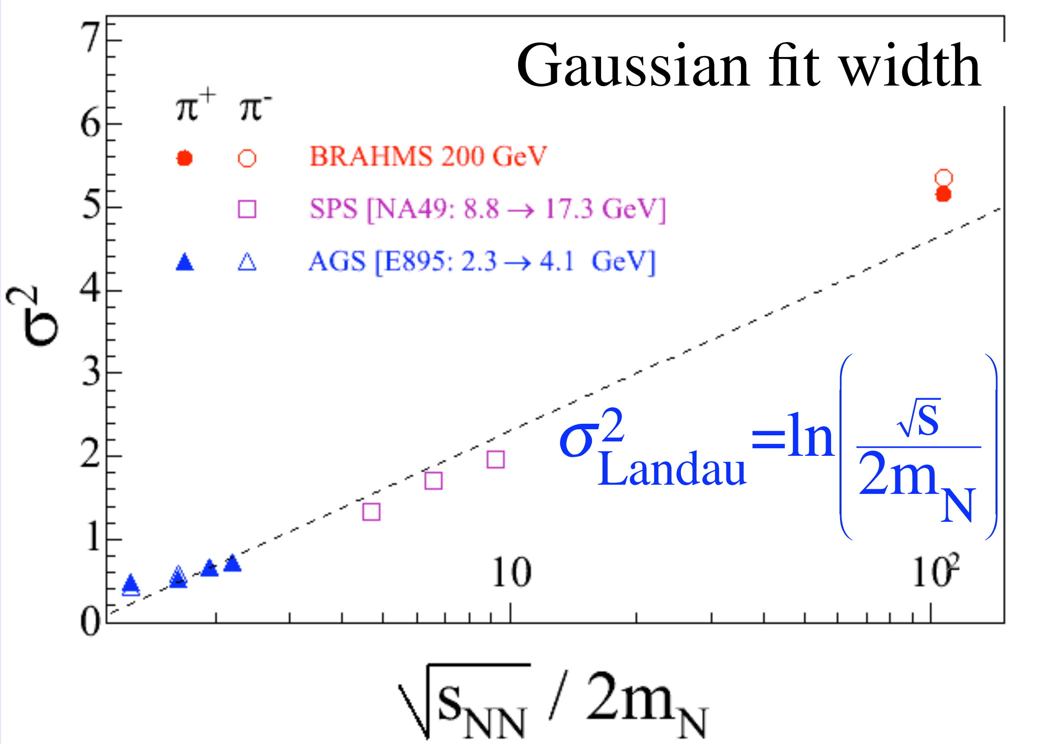
$$E_{total} = \sum_{species}\left[\int \frac{dN}{dy}\langle m_T\rangle \cosh(y)\, dy\right]$$



Starting with ≈35 TeV ($E_{beam}\times N_{part}$), ≈25 TeV carried away by produced particles.

Bjorken vs. Landau

PRL 94, 162301(2005)



Bjorken:

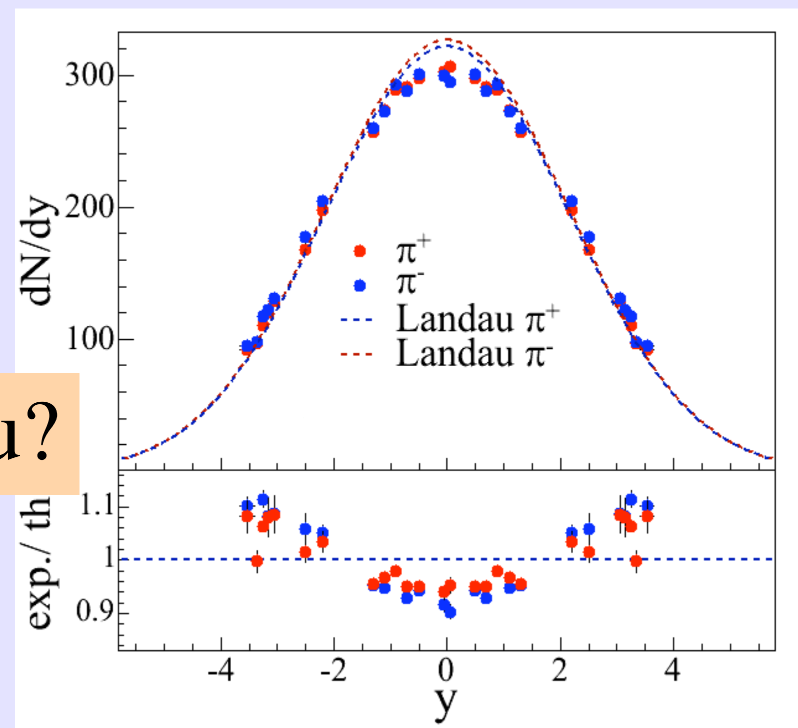
Boost invariance of central region.

Landau:

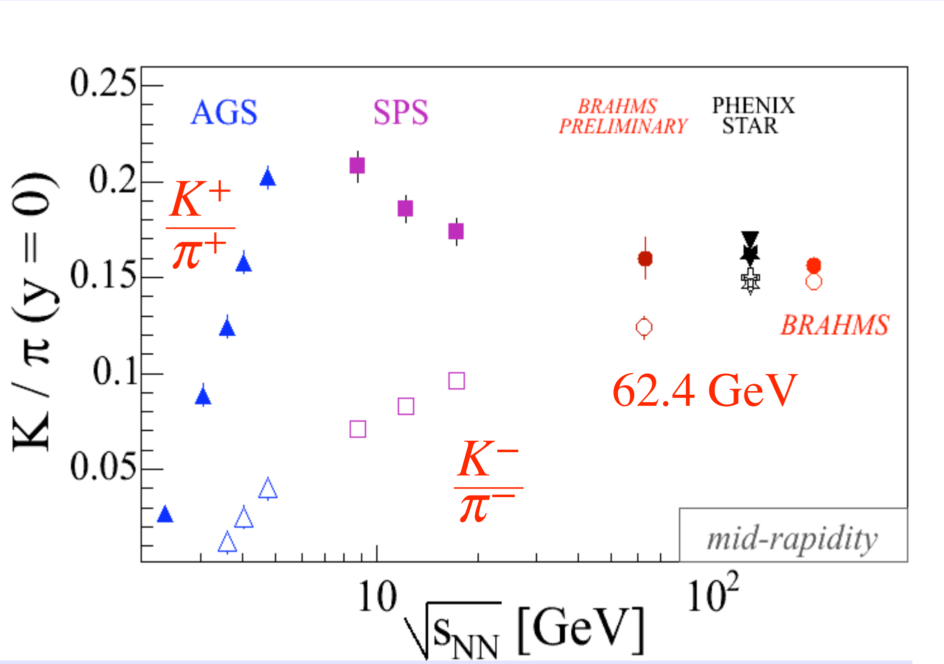
Isentropic expansion of 3D relativistic pion gas.

P.Carruthers, M.Duong-van, PRD **8**, 859 (1973).

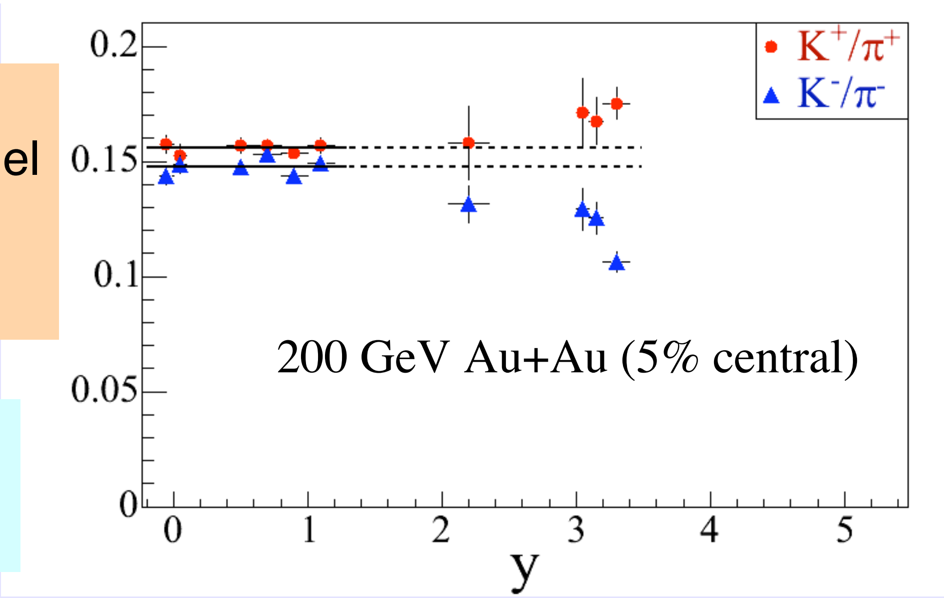
|y|<1 plateau?



K/π Ratios



PRL 94, 162301(2005)



Y < 1 : consistent with Hadron Gas Stat. Model

K^+/π^+ : 15.6 ± 0.1 % (stat)

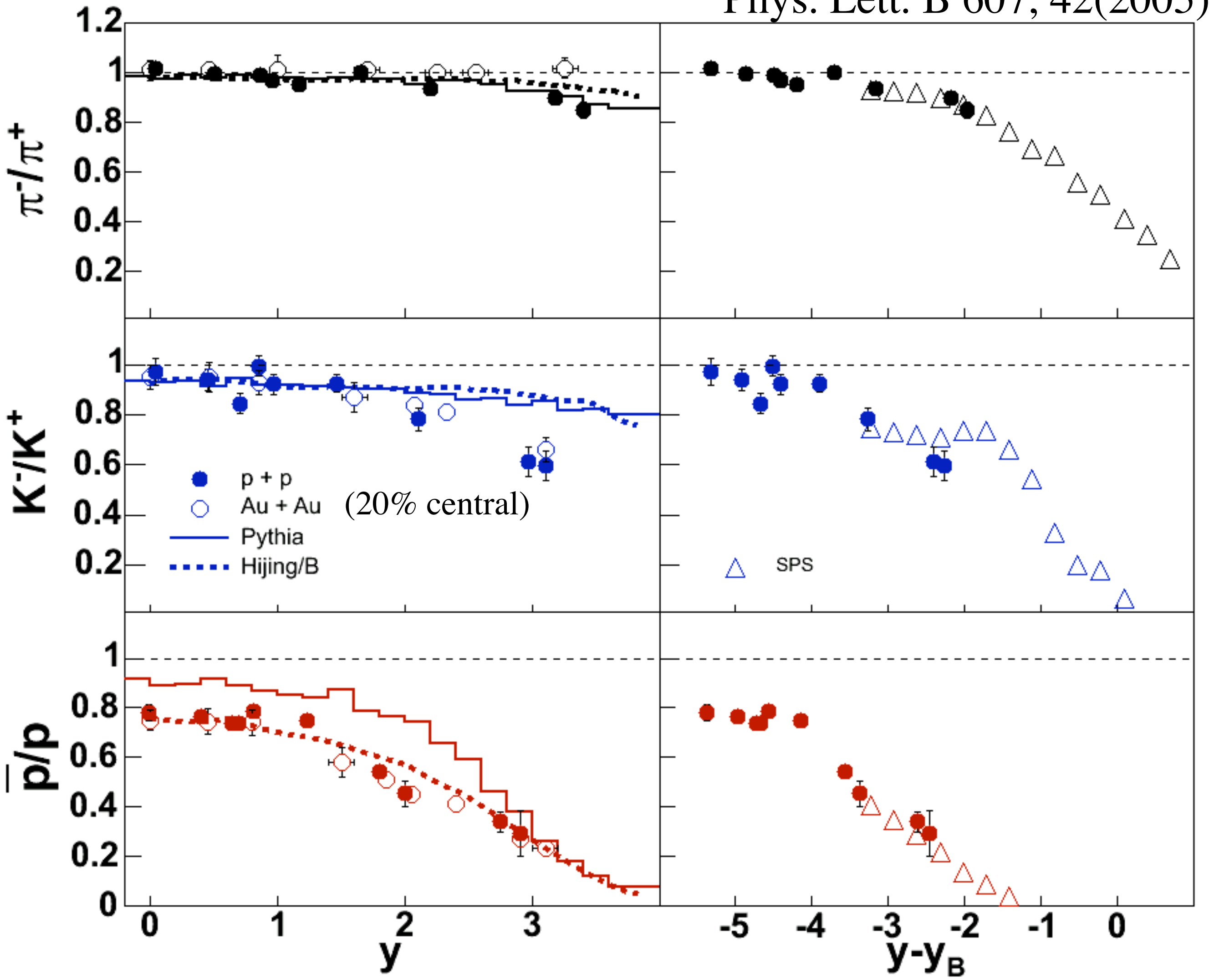
K^-/π^- : 14.7 ± 0.1 % (stat)

[Phys. Lett. B 518 (2001) 41]

Is forward BRAHMS at 62.4 GeV going to approach SPS?

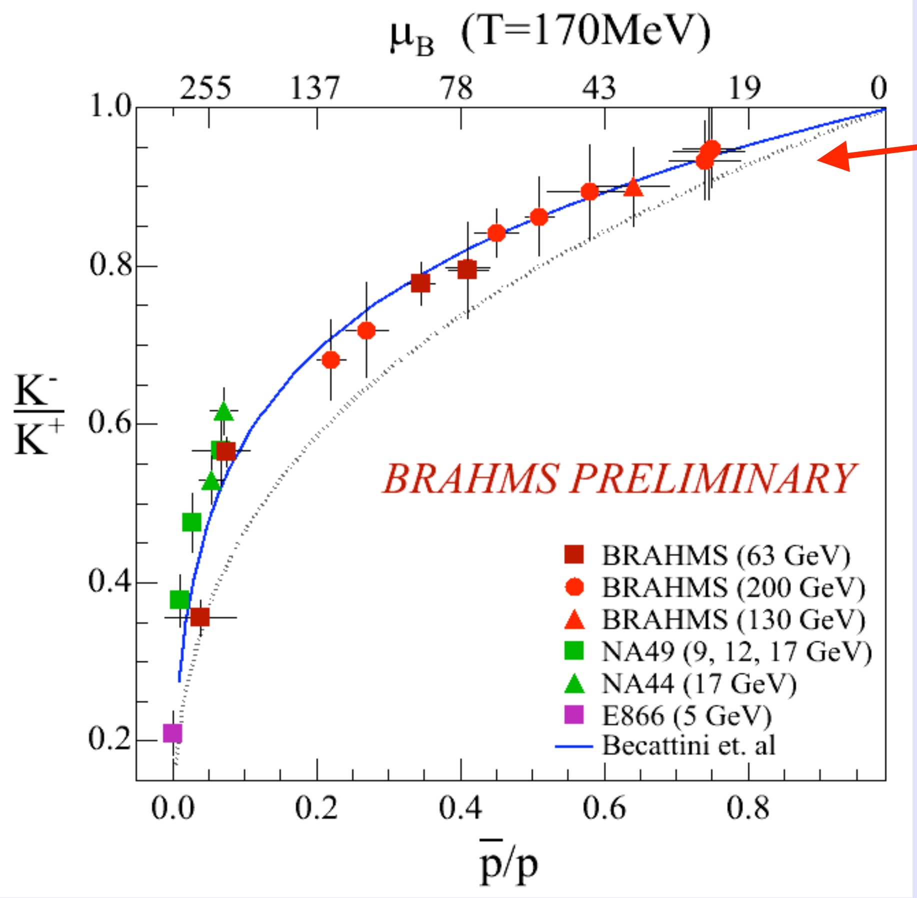
BRAHMS particle ratios
Au+Au and pp compared (200 GeV)

Phys. Lett. B 607, 42(2005)



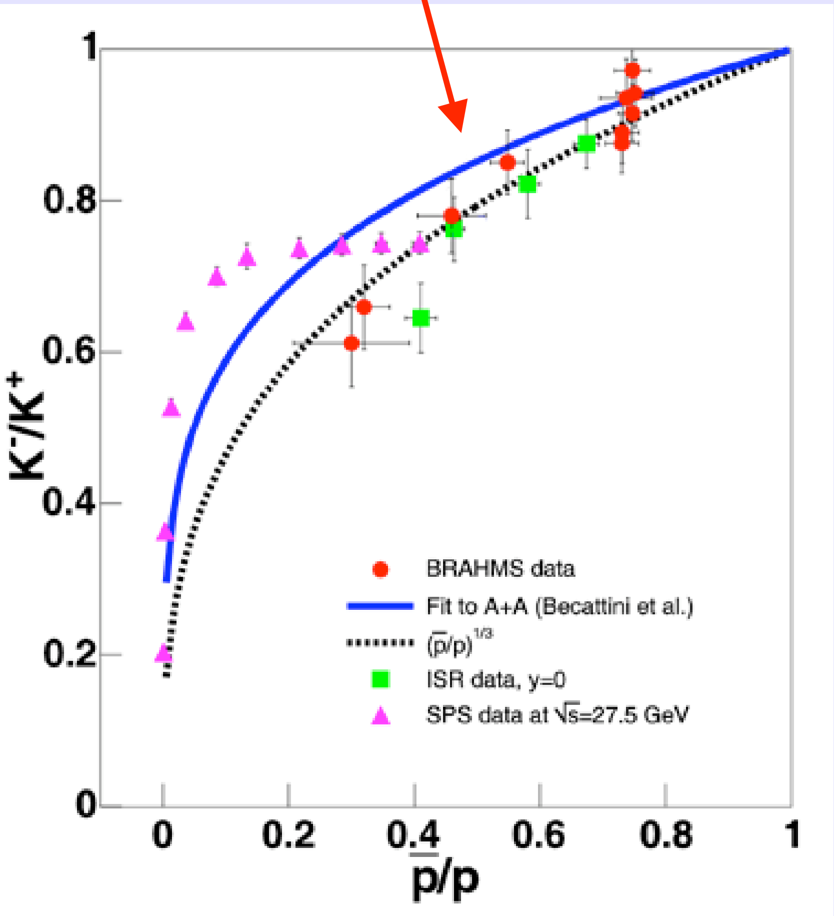
AuAu ≈ pp

Particle Ratios (AuAu and pp) continued…



Heavy ion

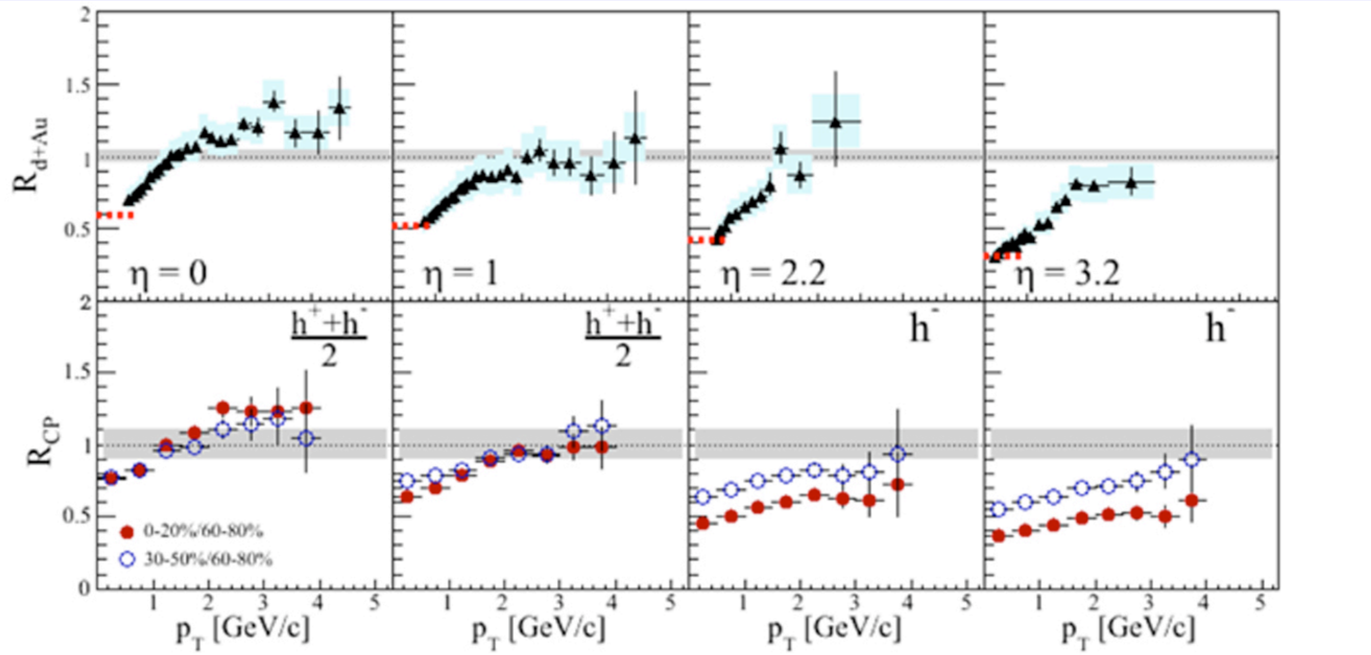
pp



$$\frac{K^-}{K^+} = e^{2\mu_S/T} e^{-2\mu_q/T} = e^{2\mu_S/T}\left(\frac{\bar{p}}{p}\right)^{1/3}$$

d+Au at 200 GeV. Initial state effects at forward rapidity? R_{dAu} and R_{cp}

PRL 93, 242303(2004)

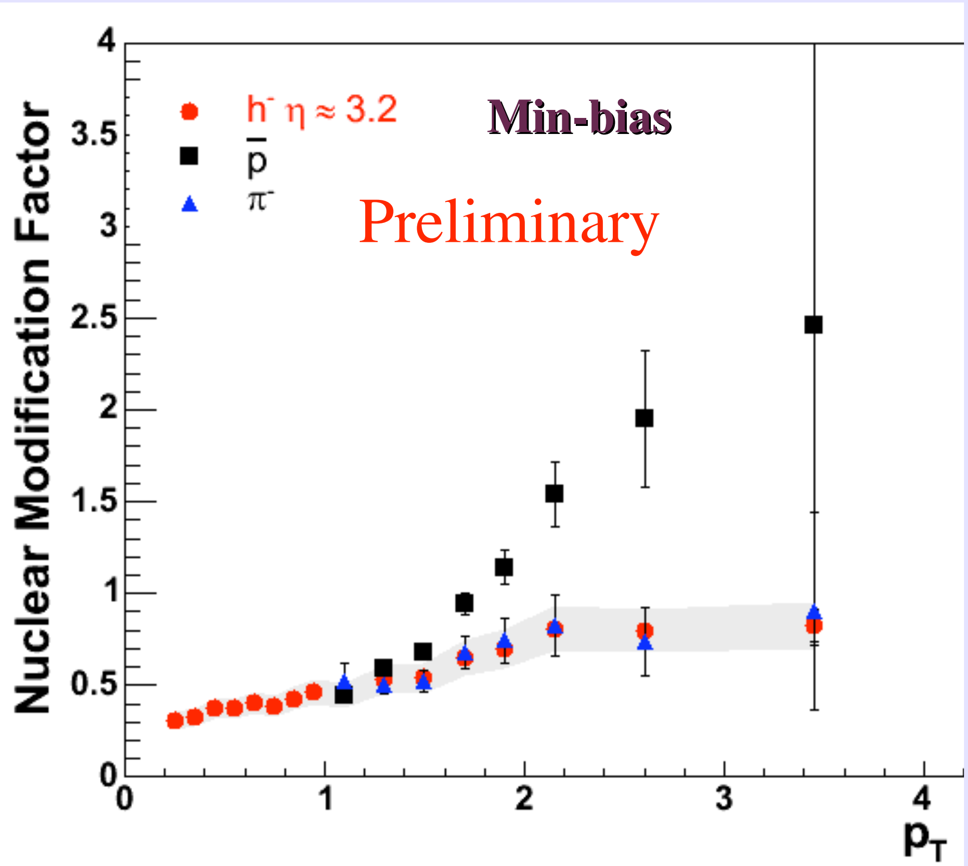


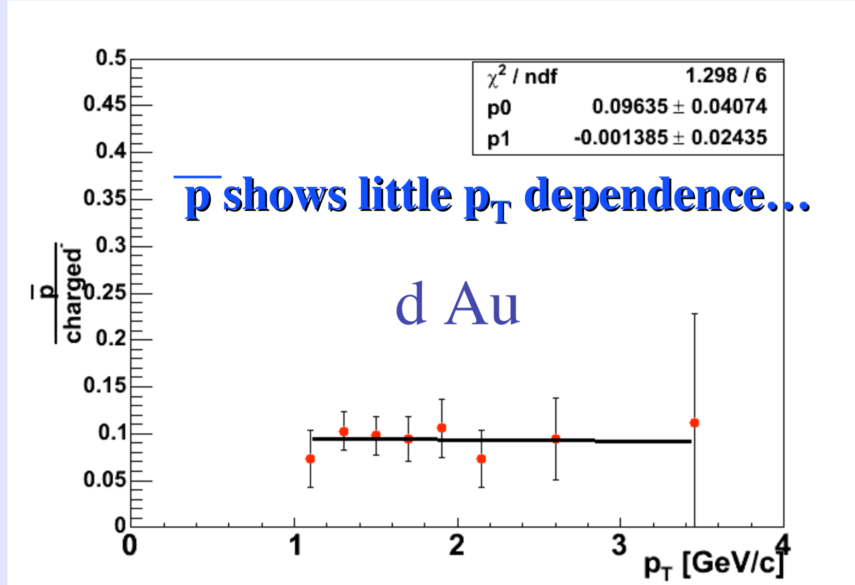
Both saturation and recombination models can reproduce behavior!

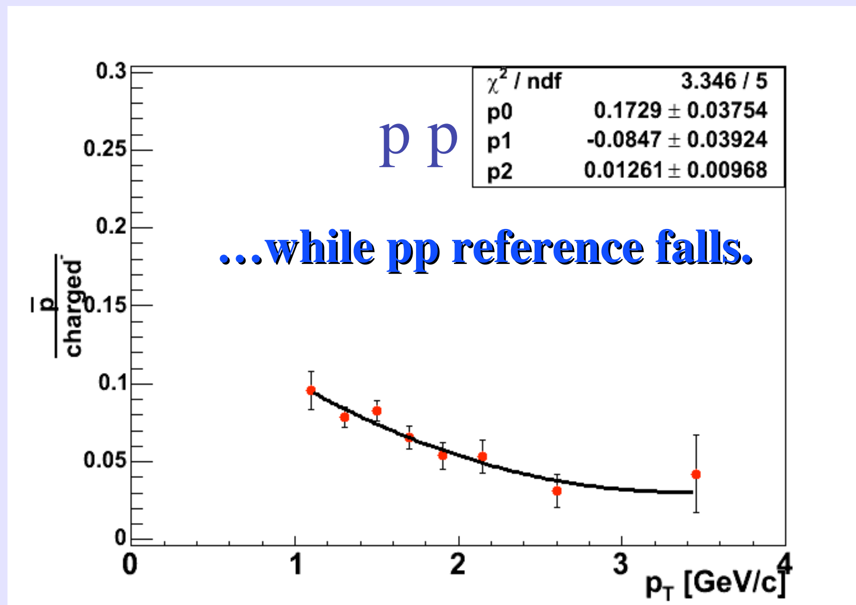
$$R_{dAu} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dp_T d\eta (d+Au)}{dN/dp_T d\eta (pp)}$$

$$R_{CP} = \frac{\langle N_{coll}^{peripheral} \rangle}{\langle N_{coll}^{central} \rangle} \frac{dN/dp_T d\eta (central)}{dN/dp_T d\eta (peripheral)}$$

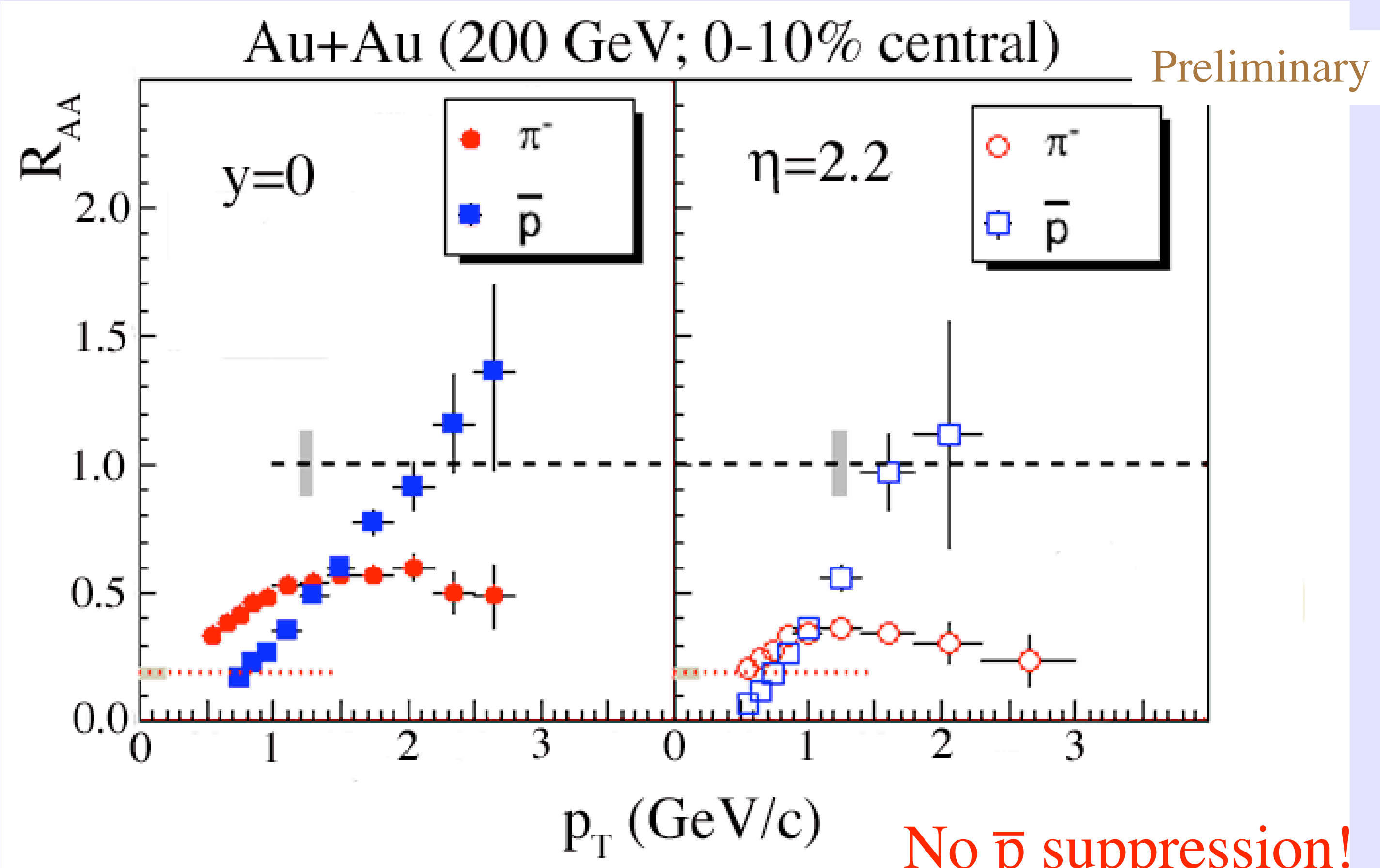
R_{dAu} rises faster for pbar than π-





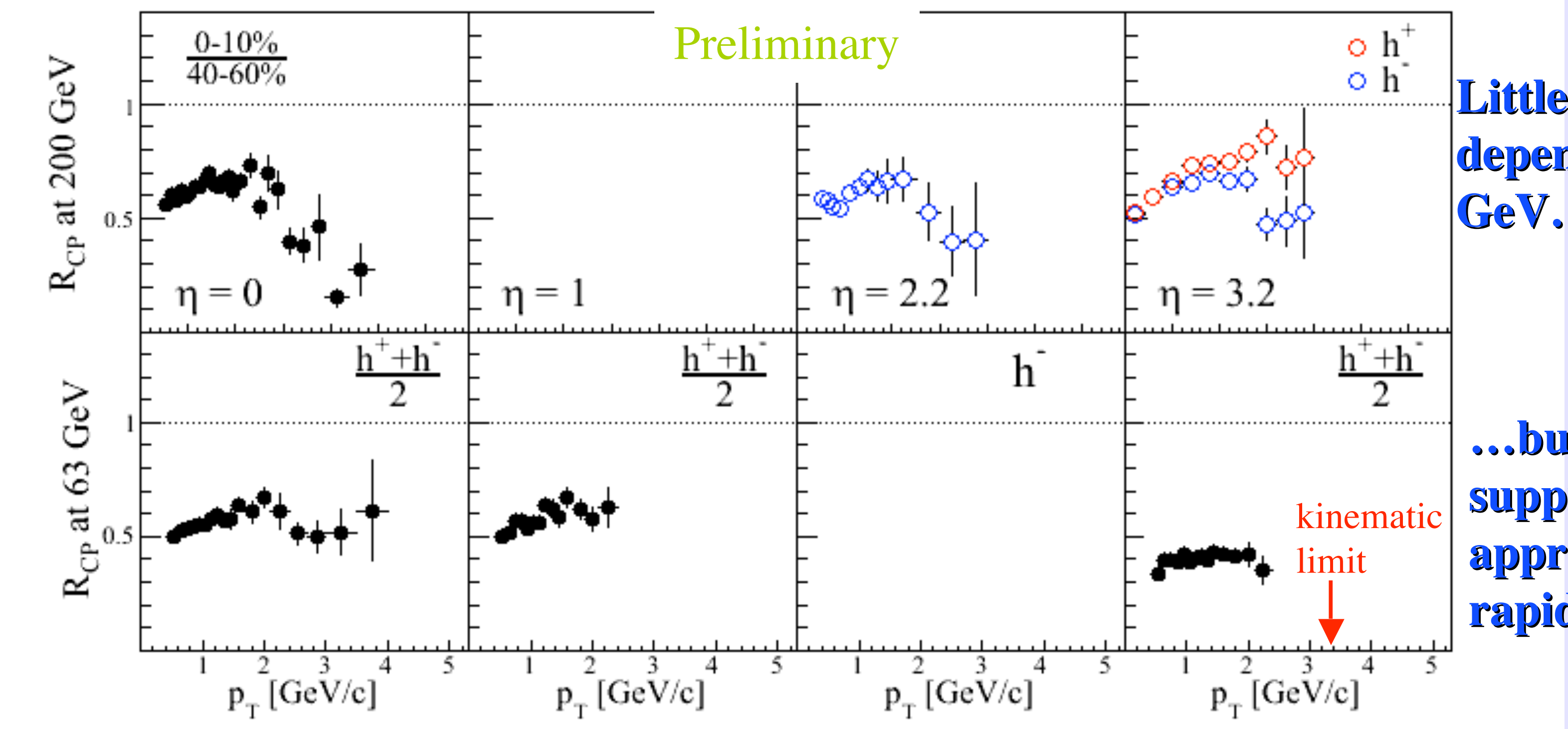


What about forward Au+Au? Identified particle R_{AA}.



No $\bar{p}$ suppression!

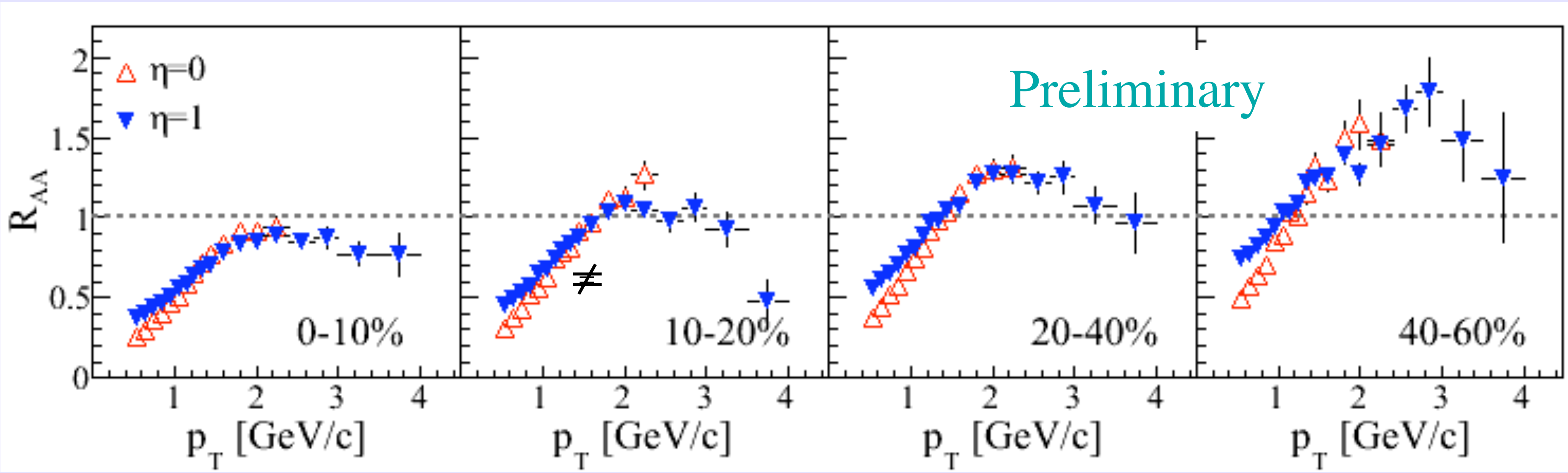
What about forward Au+Au? (cont.) *R_{cp} (AuAu)*



Little η dependence at 200 GeV…

…but greater suppression approaching beam rapidity at 63 GeV.

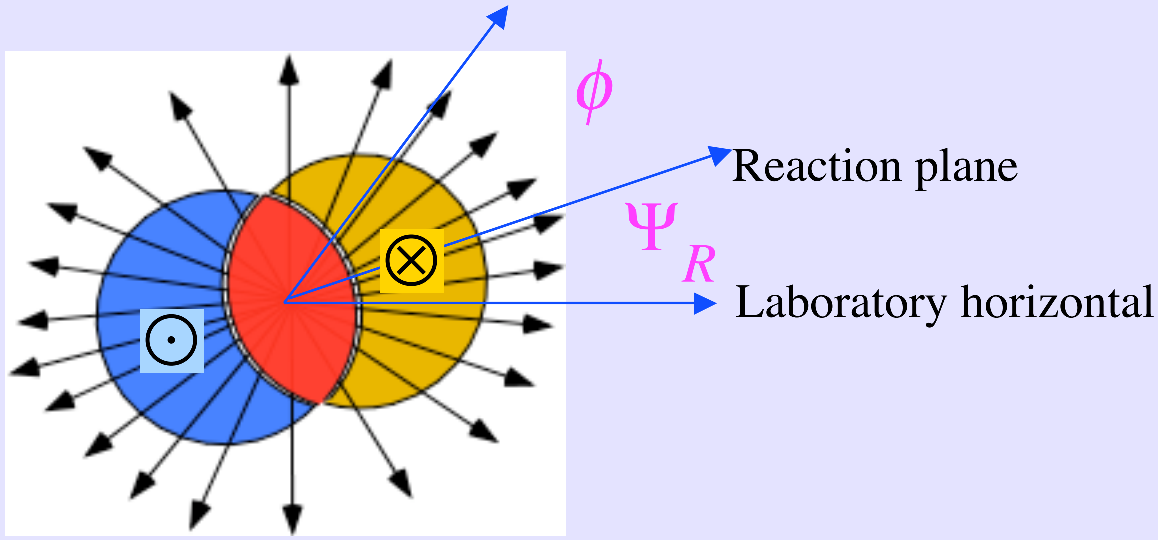
R_{AA}(62.4 GeV Au+Au)



(pp reference is based on ISR collider data)

Peripheral Au+Au is not pp!

Azimuthal (Elliptic) Flow

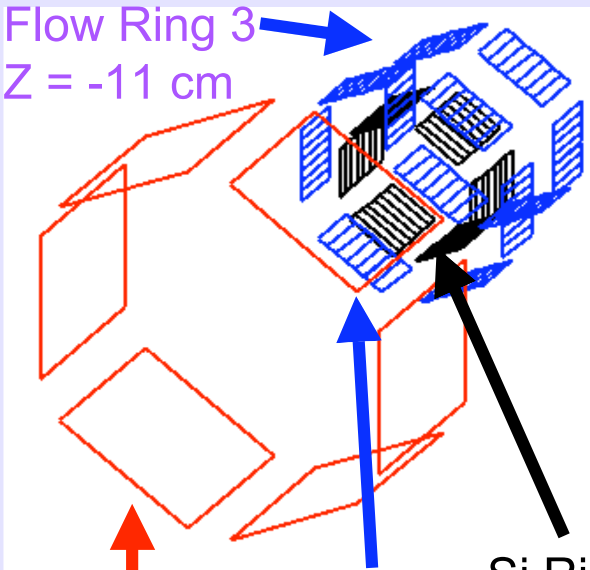


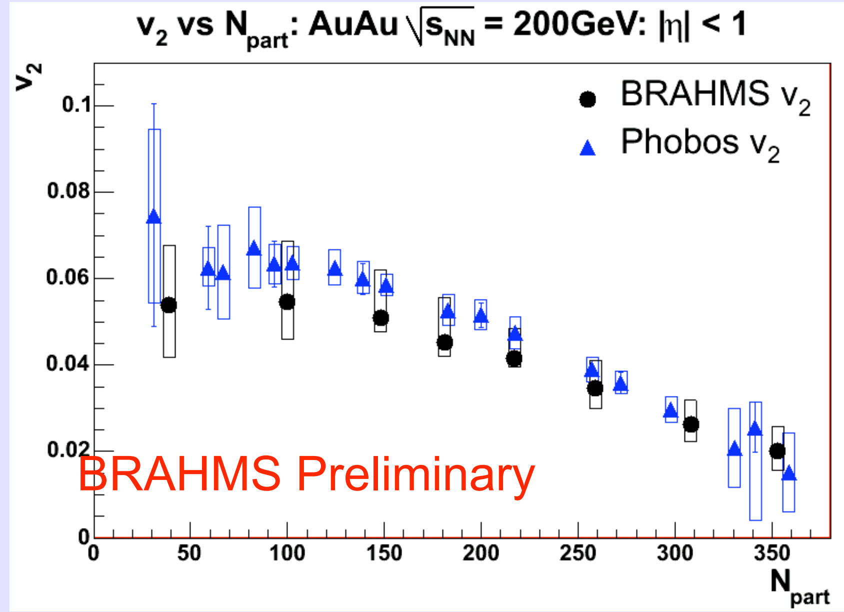
An asymmetric reaction region leads to asymmetric particle production:

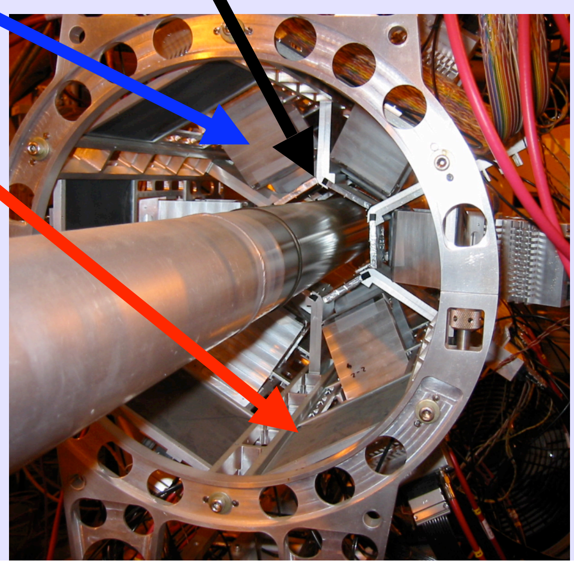
$$\frac{dN'}{d(\phi-\Psi_R)} = A\left(1+\sum_n 2v_n \cos[n(\phi-\Psi_R)]\right)$$

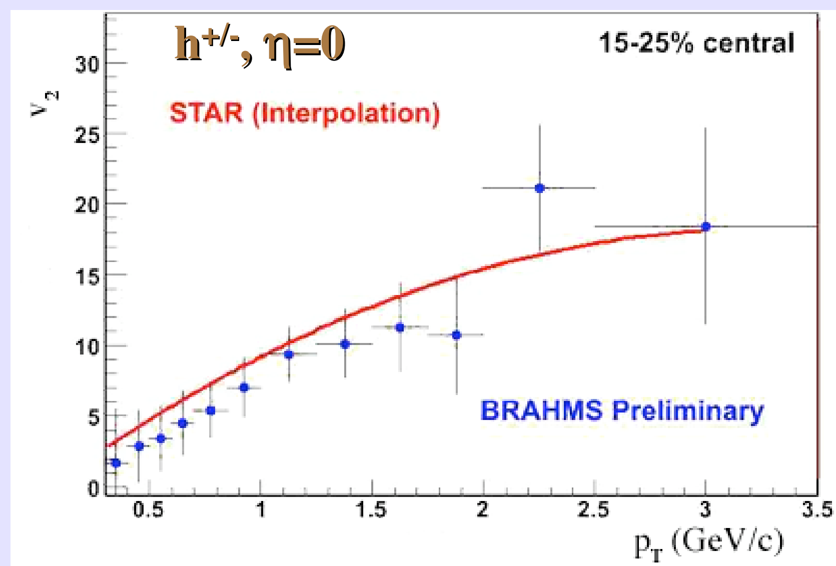
What happens at forward rapidity?

BRAHMS Azimuthal Flow



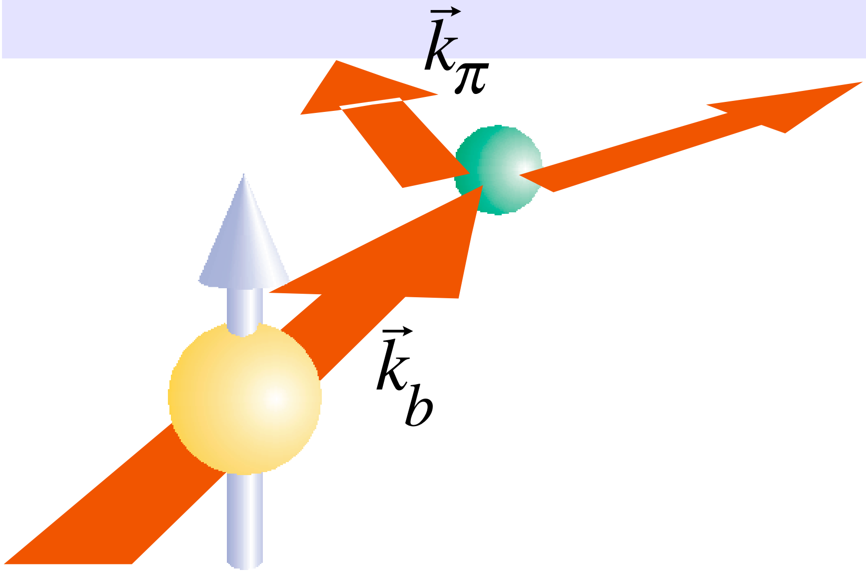






Identified particle $v_2(p_T)$ over an extended η range, $0<\eta<3.2$, will be presented at QM2005…

Single Transverse Spin Asymmetry



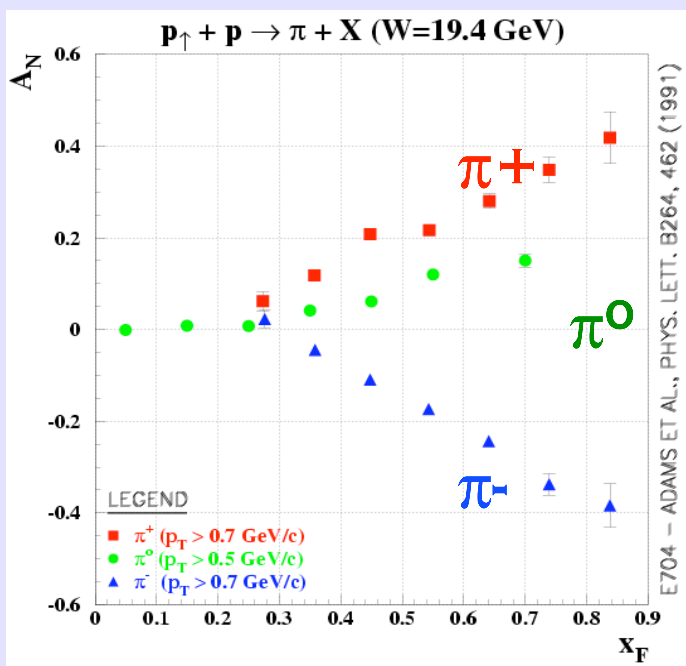
$A_n = (\sigma^+ - \sigma^-) / (\sigma^+ + \sigma^-)$

With spin direction defined by $\vec{k}_b \times \vec{k}_\pi$

Early pQCD calculations predicted effect to be small.

Low energy data (FNAL E704) show clear differences between π^{+-} and π^0.

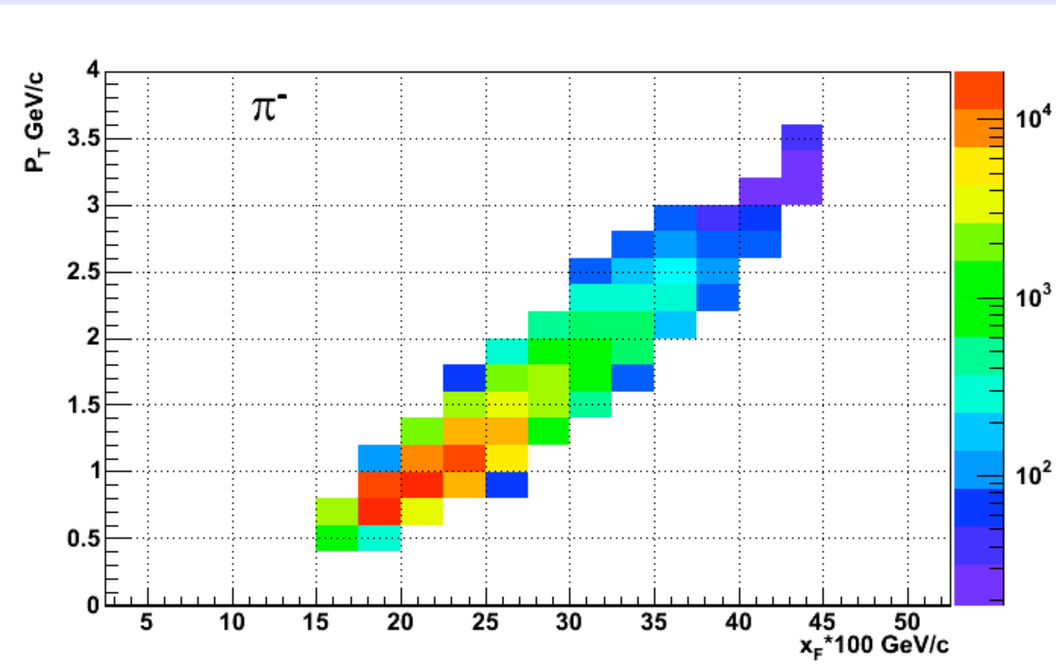
D.L.Adams (E704) Phys.Lett B264,462(1991); Phys.ReV D53, 4747 (1996).



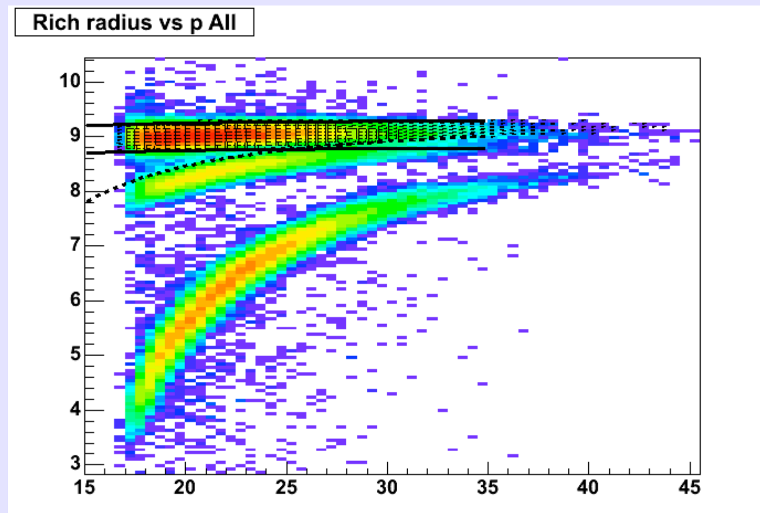
Several models:
- Sivers effect (initial state).
- Collins effect (final state).
- Qui and Sterman (twist-3 pQCD)

Kinematic Variables and Measurement

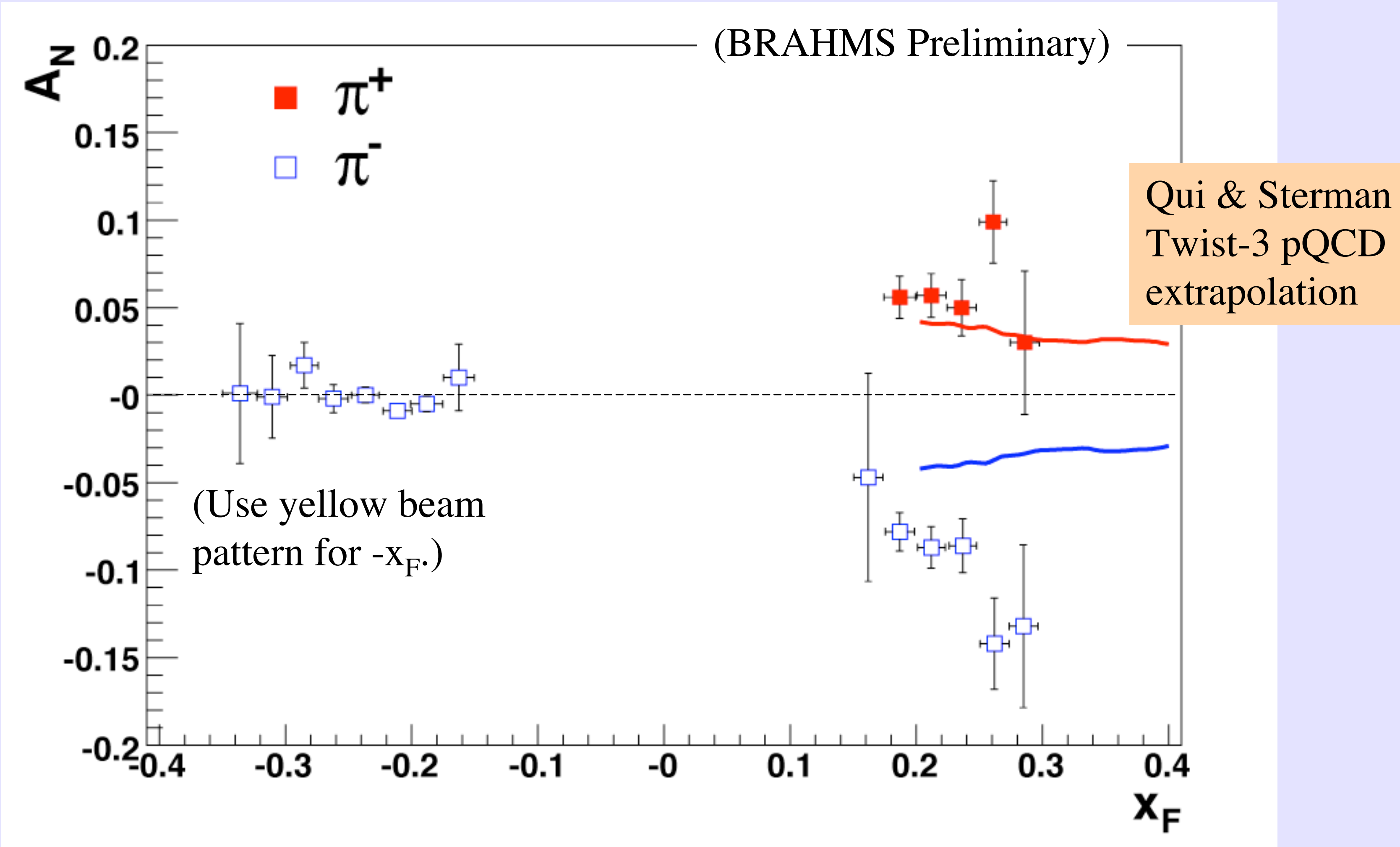
- The kinematic variables of interest are Feynman x (x_F) and p_T.
- Shown is the BRAHMS acceptance for the data taken at $\theta = 2.3^o$ and the maximum field setting (7.2 Tm).



(δp/p~1% at 22 GeV/c)

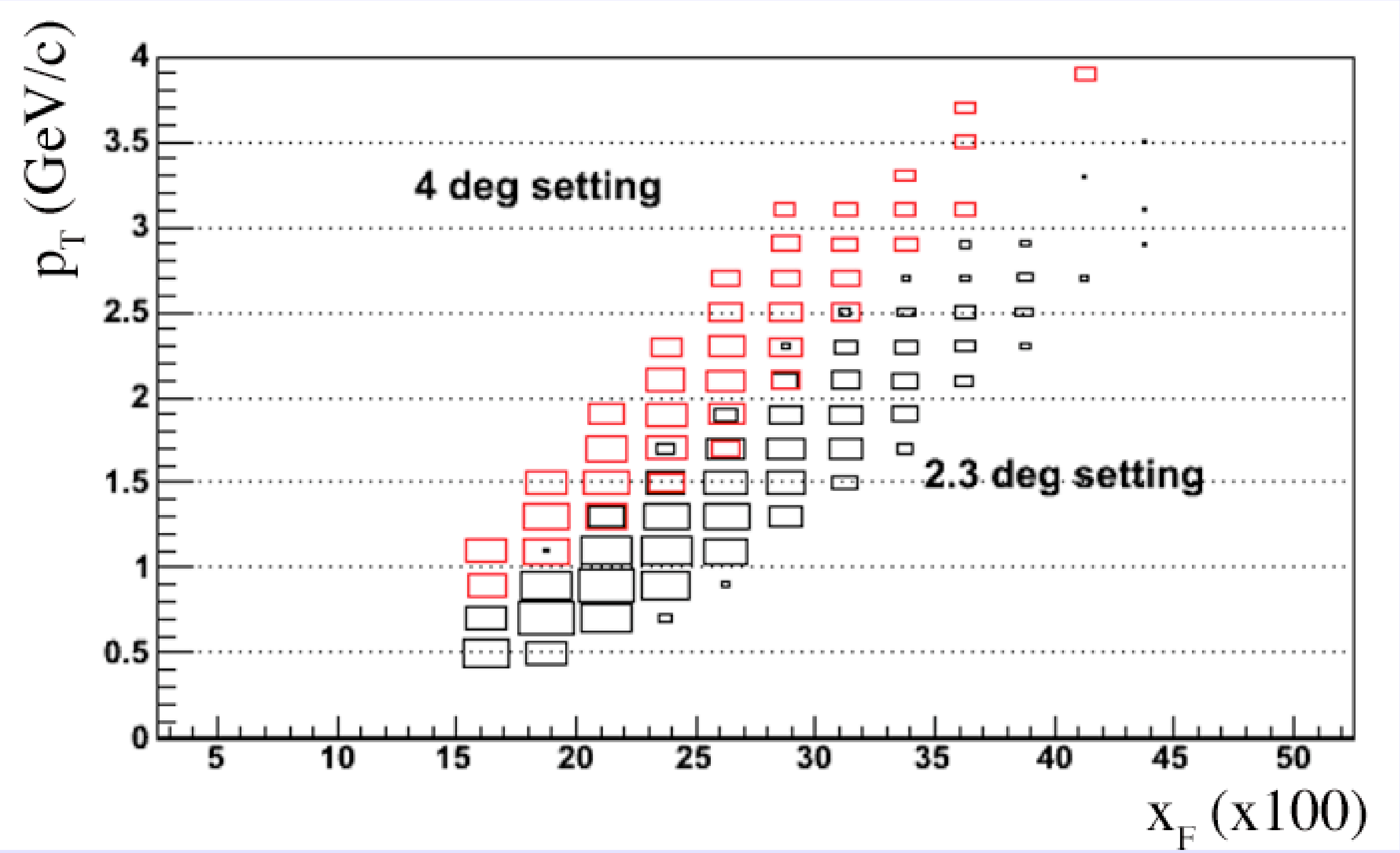


A_N for π^+ and π^- (2004 run)



Also find $A_N \approx 0$ for protons.

With 2005 pp data, BRAHMS will be able to explore p_T-x_F dependence…



Summary

•With a focus on the forward region, the BRAHMS heavy-ion program includes studies of a rich variety of topics:

- ✓Nuclear stopping and energy balance.
- ✓Low-x saturation effects. Relative importance of initial state (saturation) and final state (recombination, etc.) effects in the forward region.
- ✓Longitudinal extent of produced medium.
- ✓Nuclear chemistry of produced medium as a function of rapidity.
- ✓Radial and azimuthal flow.

•Initial state *vs*. final state questions of a very different type arise with the study of single transverse spin alignment of pions in polarized pp measurement. Extensive new results will become available with the analysis of the 2005 pp data.

The BRAHMS Collaboration

- 12 institutions-

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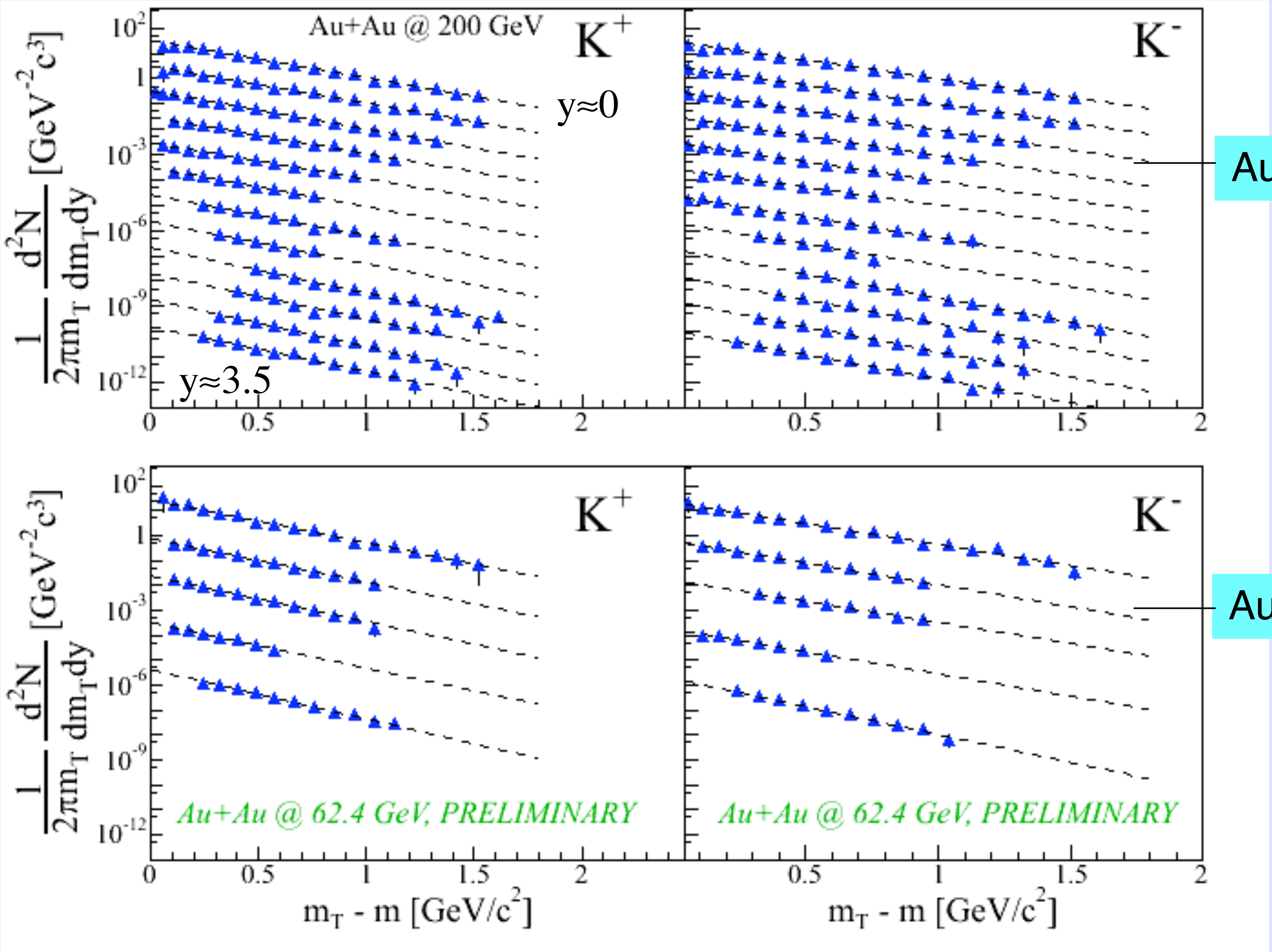
Strangeness—Kaon Spectra

Top 5% central collisions



AuAu 200 GeV

AuAu 63 GeV

Fit: exponential

$$A \exp\left(-\frac{m_T - m}{T}\right)$$