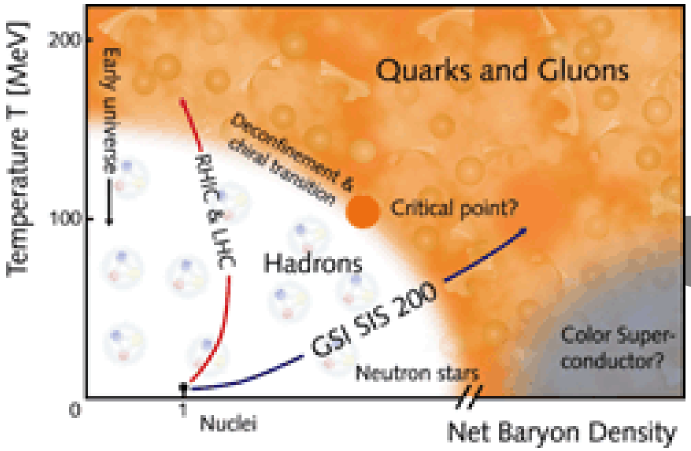
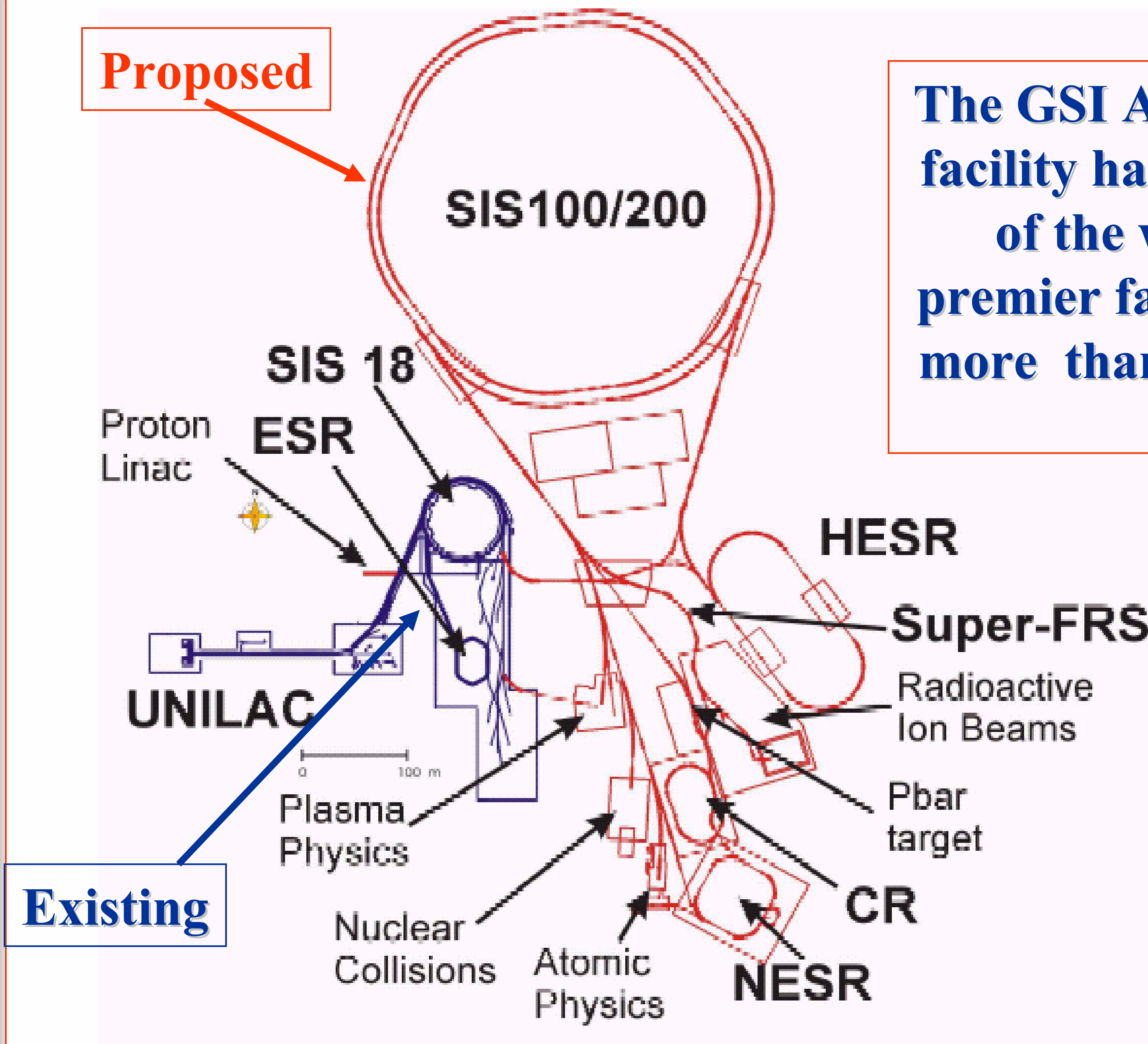
Compressed Baryonic Matter at the AGS: A Review !!



Roy A. Lacey
(SUNY Stony Brook)



The GSI Accelerator facility has been one of the world's premier facilities for more than 25 years.

Disclaimer

A Diverse Range of Experimental Programs have been Carried out at the AGS

AGS Expts.
E802/866
E810/891
E814/877
E864
E895
E917

p+A, Si+A, Au+A
2 – 18 AGeV
1986 - 14.6 AGeV/c Si
1992 – 11.0 AGeV/c Au

More than 200 pubs

Only a Selection of the full range of Experimental Results will be covered.

Outline

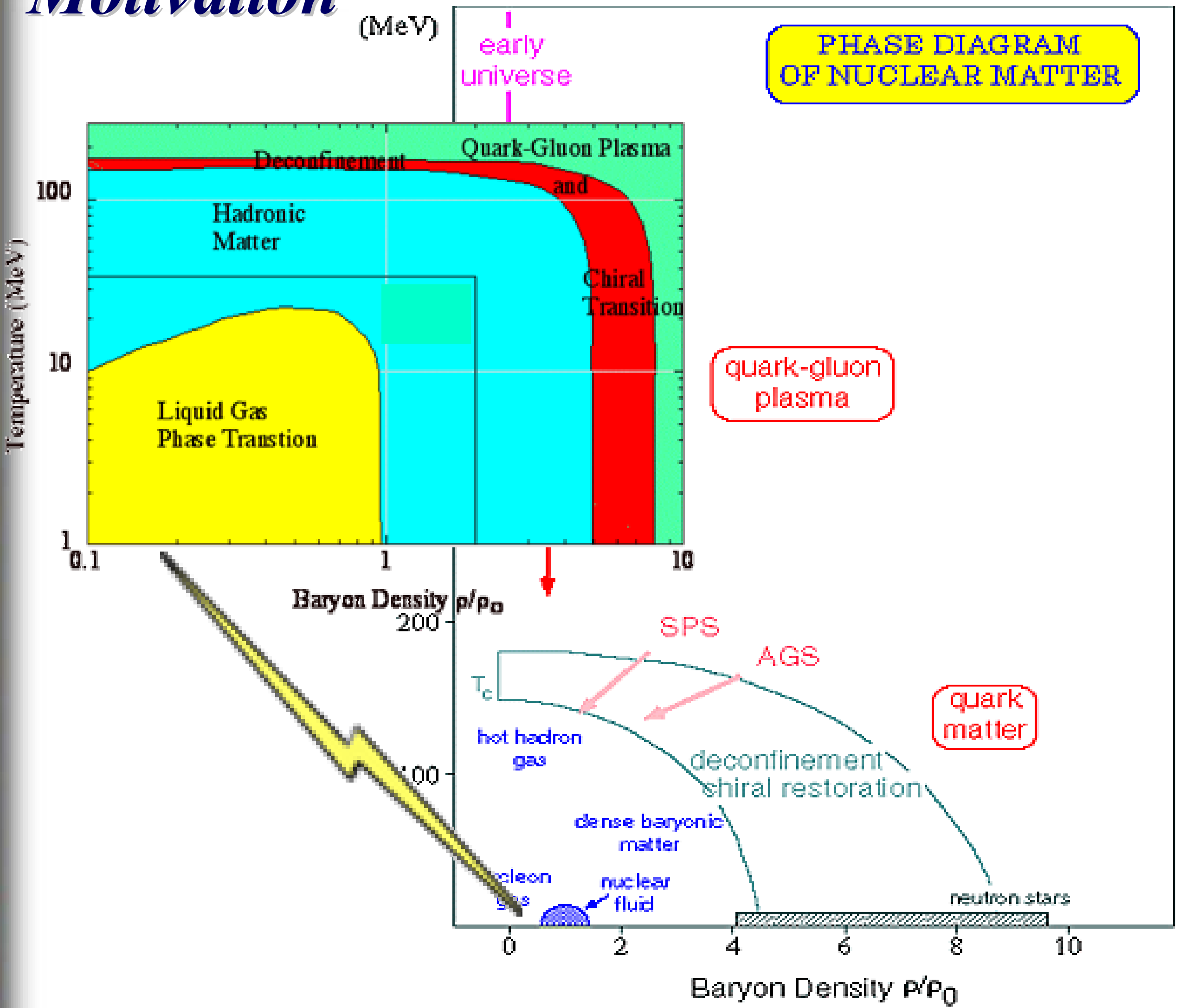
Motivation

Results & Implications

- Global Observables
- Rapidity Distributions & Stopping
- HBT
- Flow
- Particle Production

Summary

Motivation



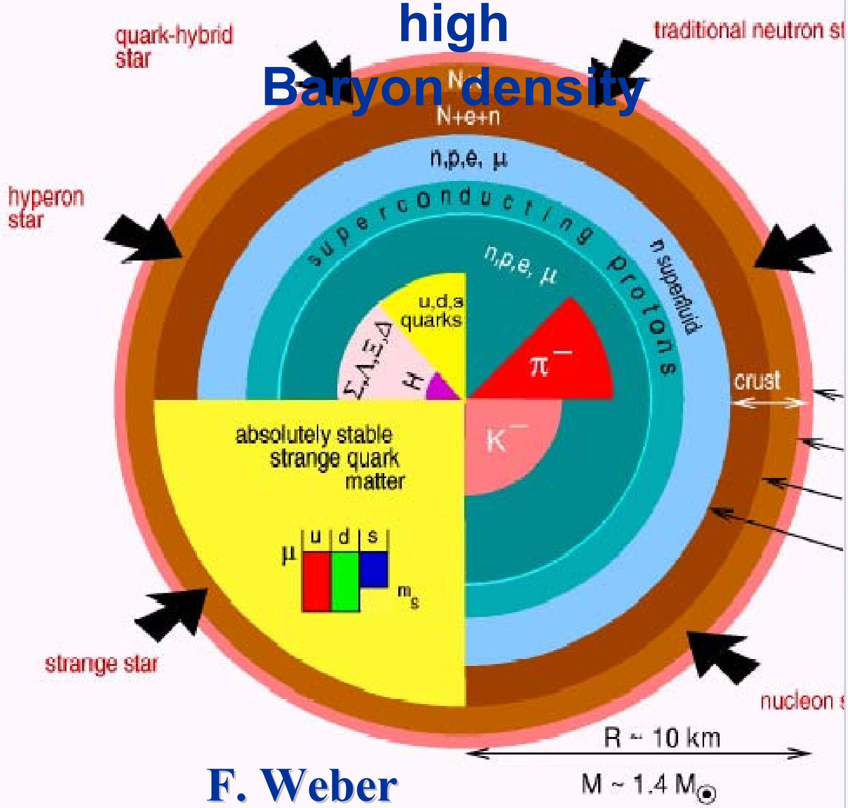
Particular Focus

Identification and Study of the LGP and QGP

The Notion of a Phase Diagram for Nuclear Matter is Pervasive

Motivation – High Density Nuclear Matter

Various competing forms of
matter are predicted at high
Baryon density



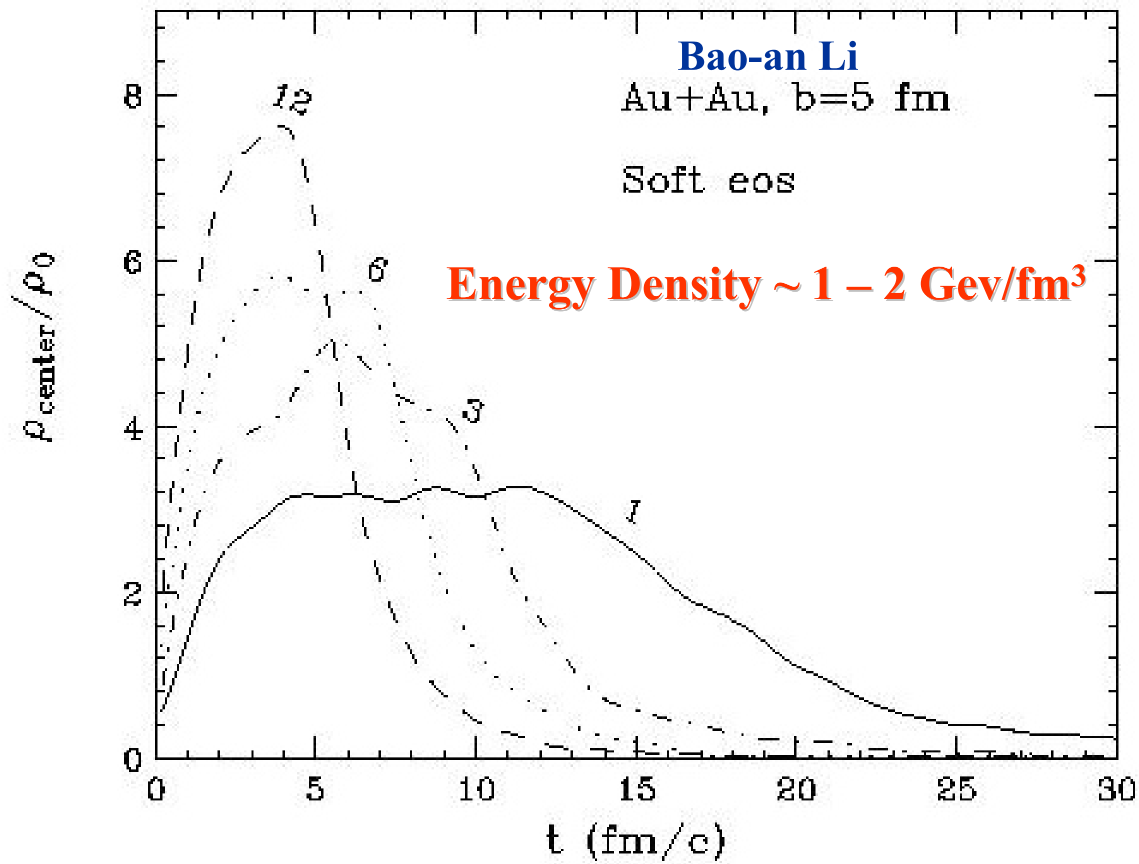
F. Weber

!! Crucial Information !!

- Property of Hadrons in Dense nuclear Medium
- Phase transition to Quark Gluon Matter at high baryon density
- Nuclear Equation of State at high baryon Densities

Motivation

Why Study Heavy Ion Reactions at the AGS ?

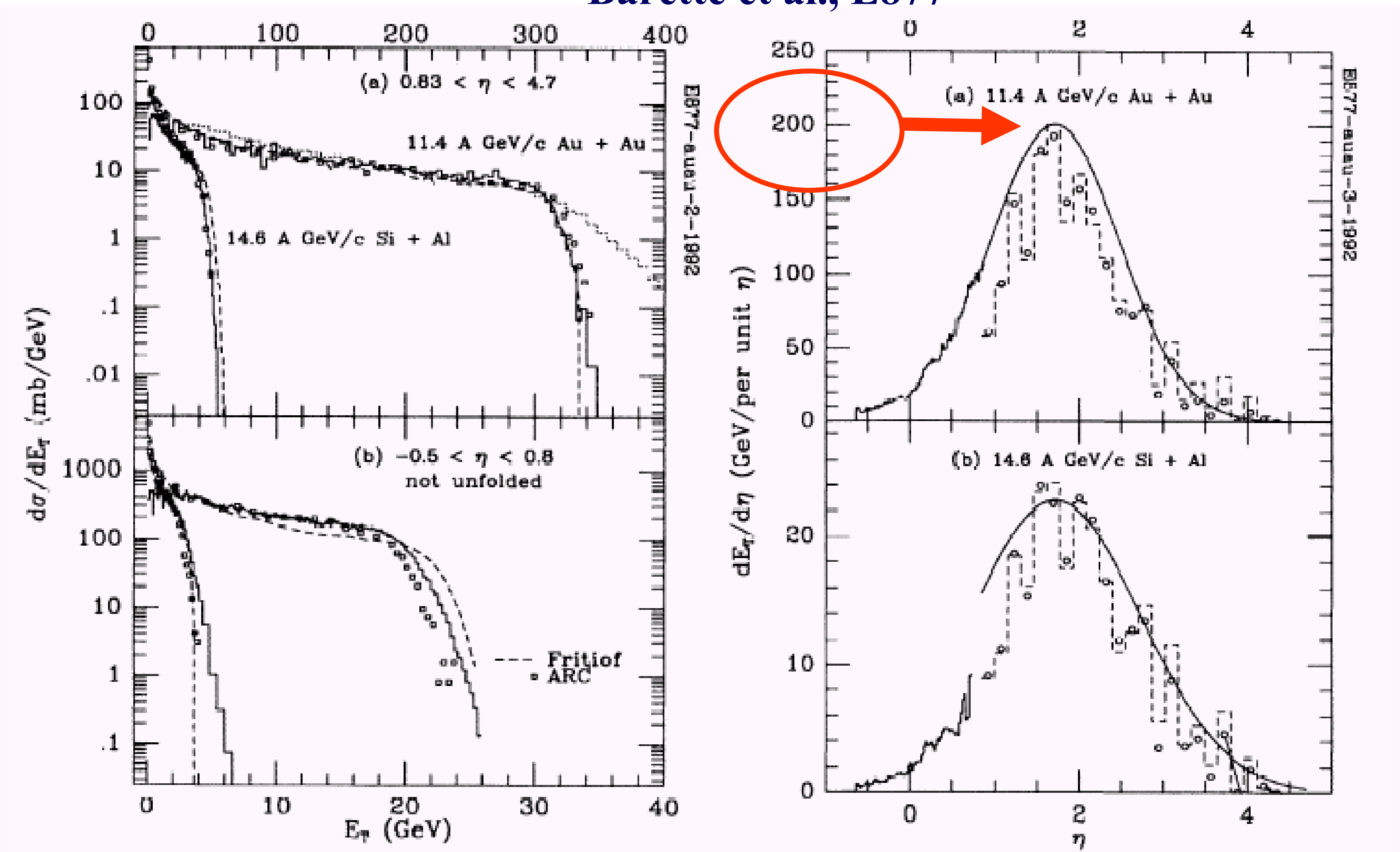


Compressed Baryonic Matter is Produced at the AGS

In an Interesting Region of the Phase Diagram ?

Global Observables

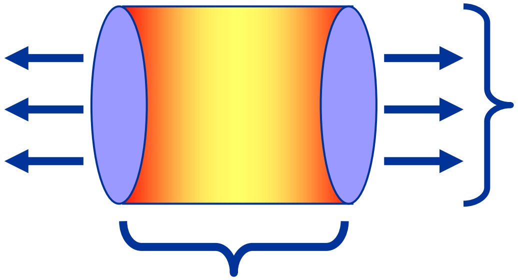
Barette et al., E877



$N_c \sim 450$ for central collisions

Substantial Pseudorapidity Densities are achieved

Energy Density



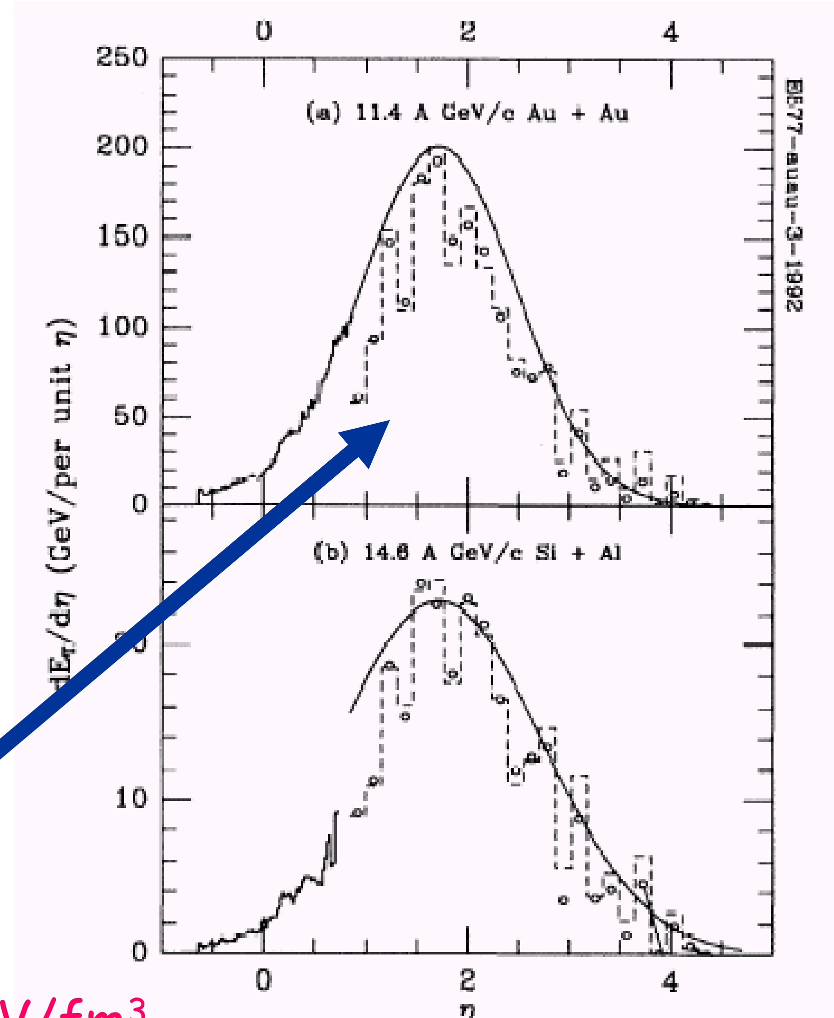
$$\varepsilon_{Bj} = \frac{1}{\pi R^2}\frac{1}{\tau_0}\frac{dE_T}{dy}$$

~6.5 fm

time to thermalize the system (τ_0 ~ 1 fm/c)

$\varepsilon_{Bjorken}$ ~ 1.3 GeV/fm^3

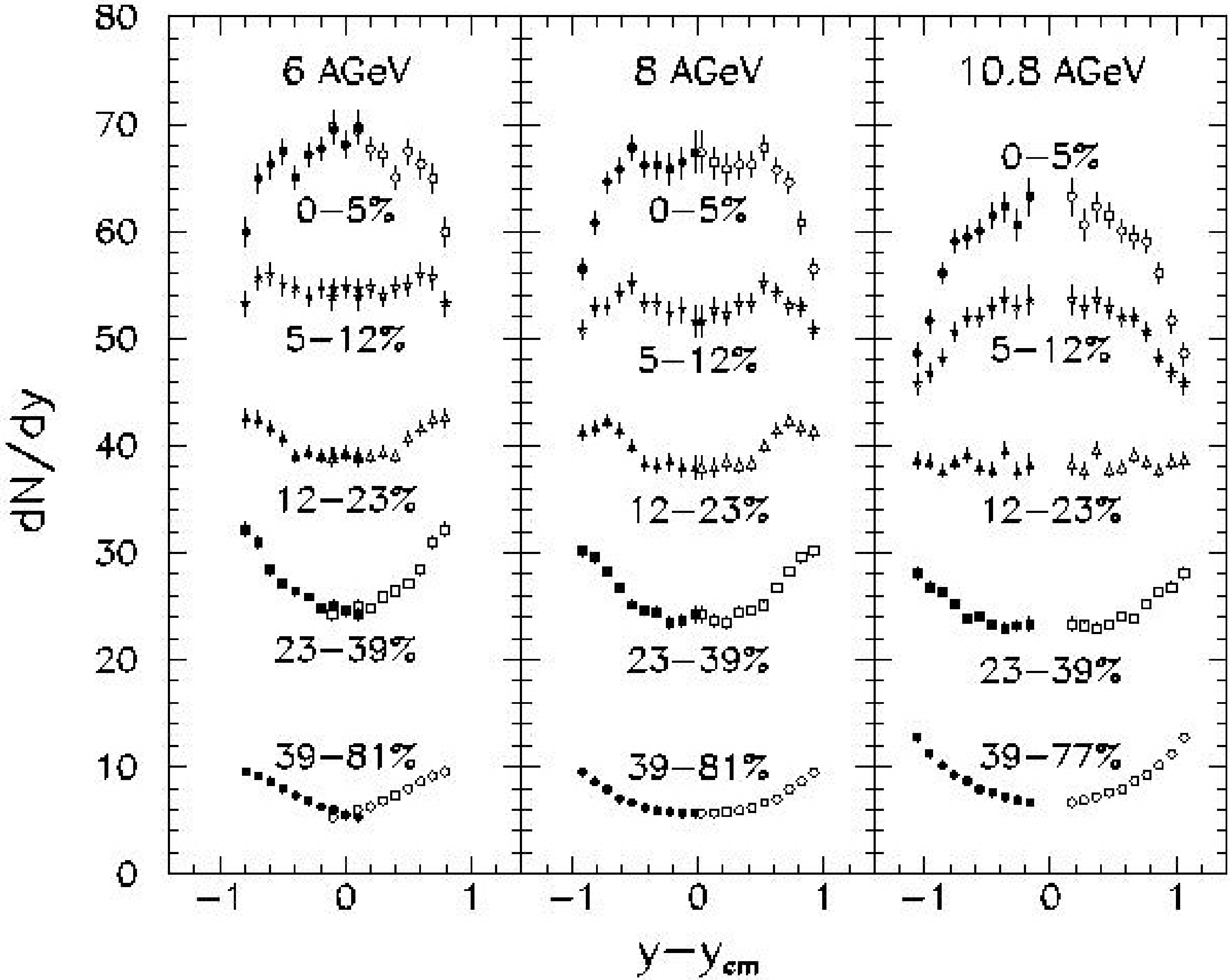
Critical Energy Density ~ 1-1.5 GeV/fm^3



Barette et al., E877

Large Energy Density → pressure gradients & Expansion

Rapidity Distributions and Baryon Stopping

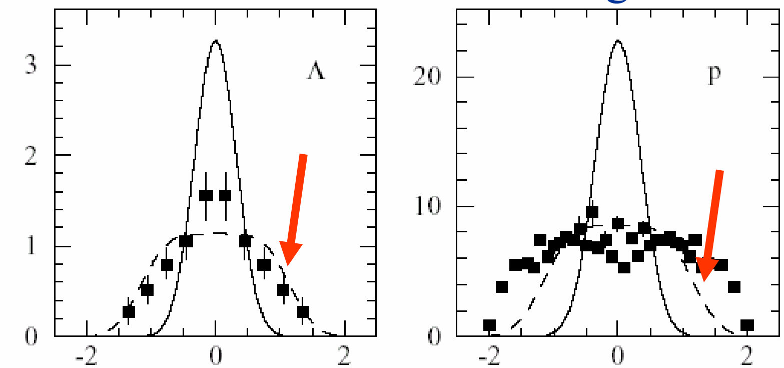


Holzman et. al E917

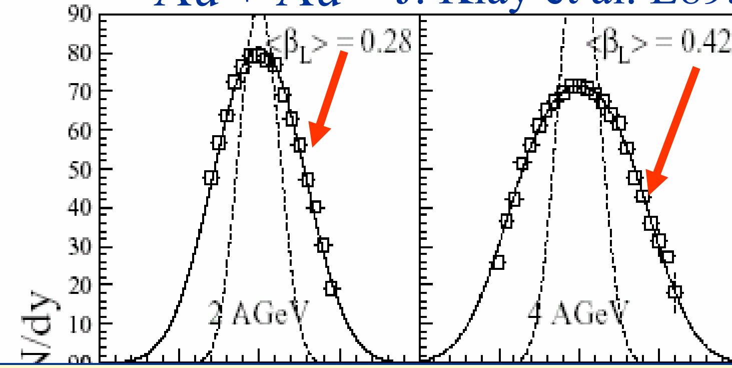
Significant Stopping is achieved in central collisions at the AGS

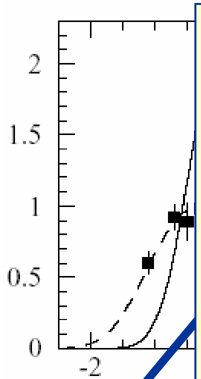
Rapidity Distributions and Baryon Stopping

Si + Al Braun-Munzinger et al.



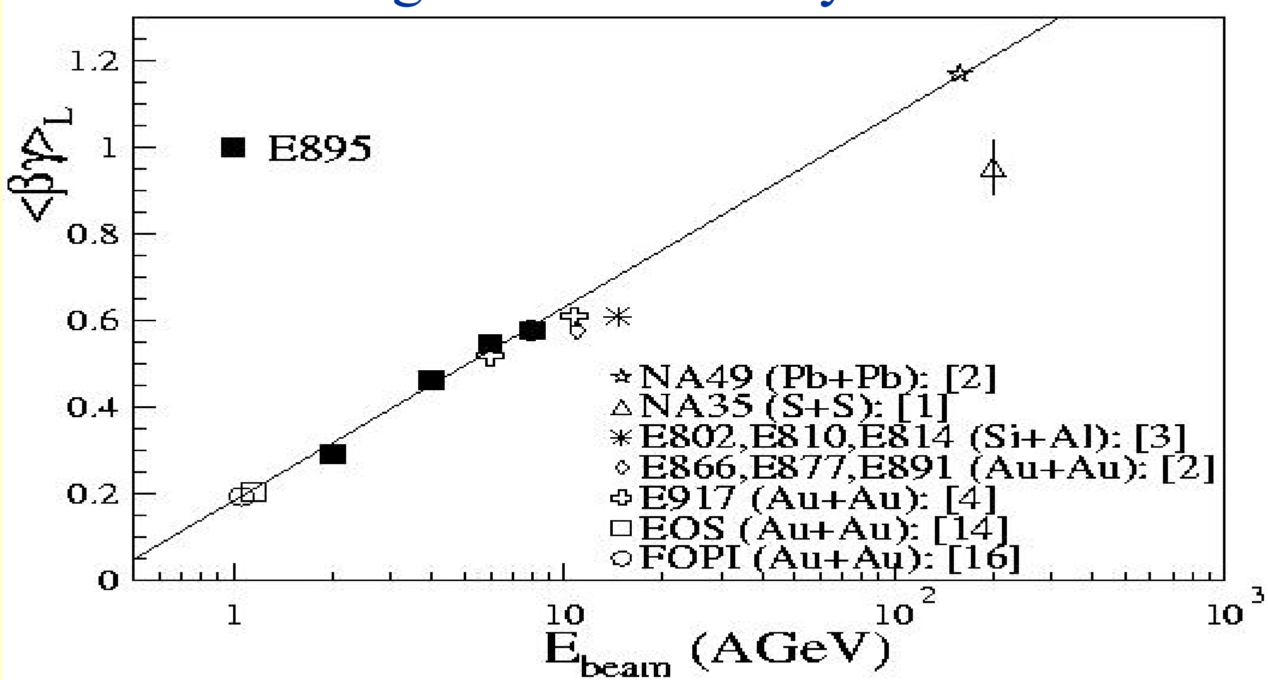
Au + Au J. Klay et al. E895





$\frac{dN}{dy} \propto T$

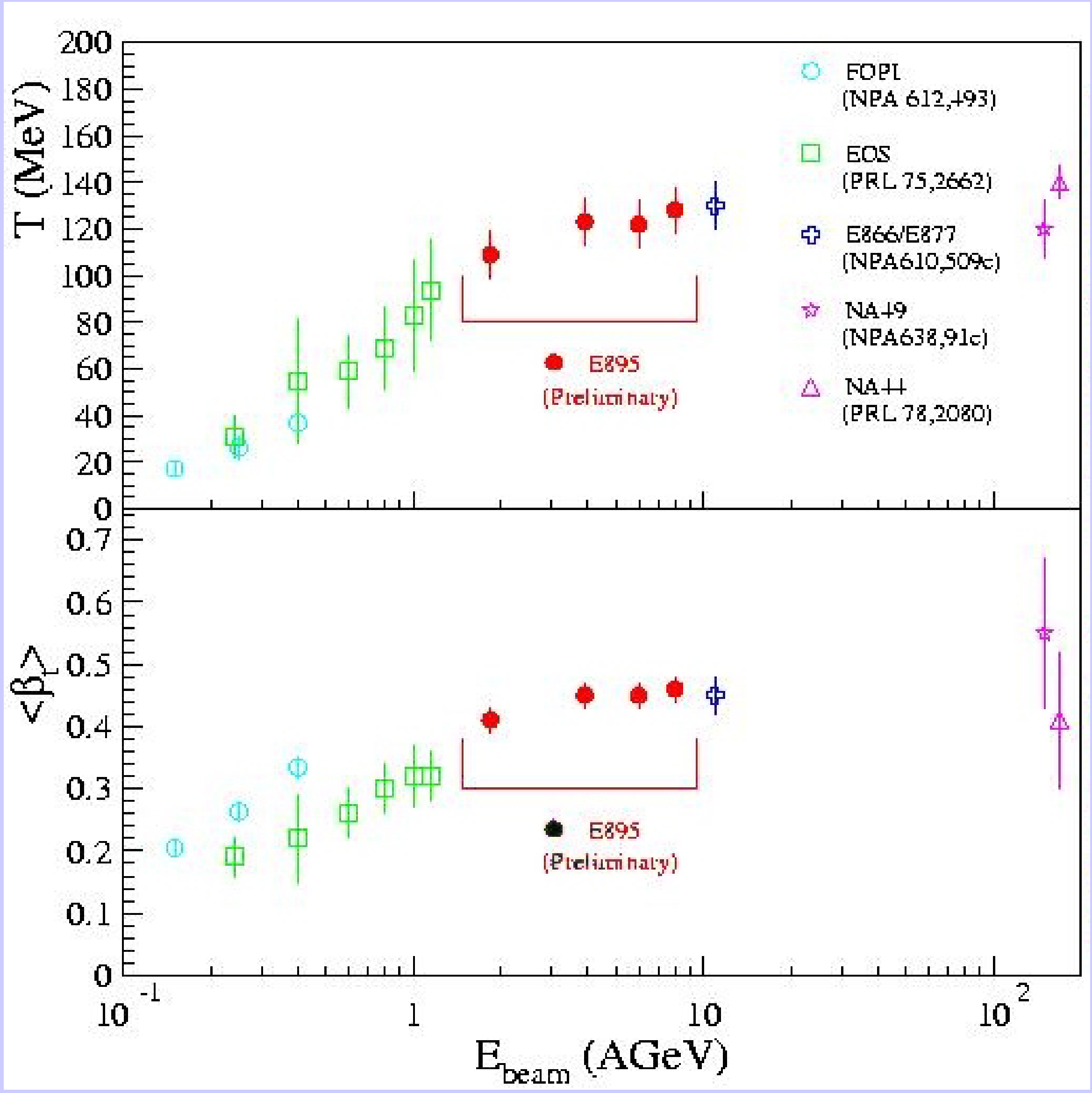
Longitudinal Flow Systematics



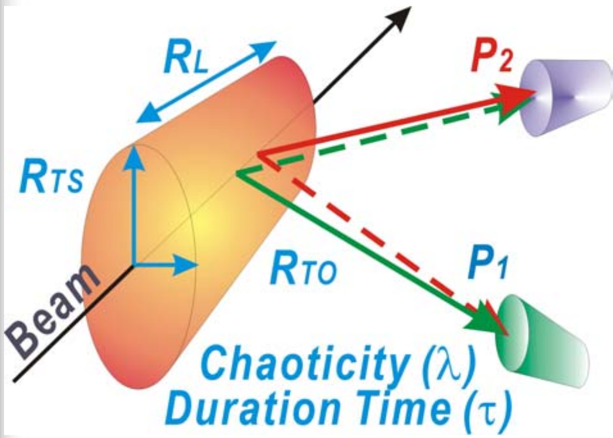
Stony Brook

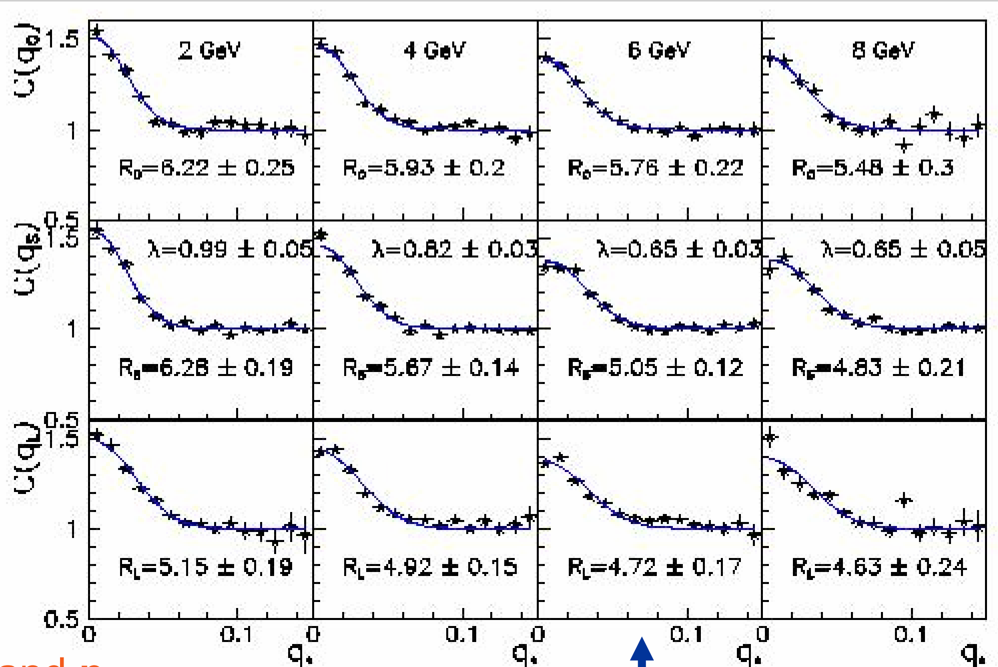
Radial Flow

Significant Transverse Expansion



HBT





Probability to detect 2 particles at $\mathbf{p}_1$ and $\mathbf{p}_2$,

$$C_2 = \int d^4x_1 d^4x_2 |\psi_{12}|^2 \rho(x_1)\rho(x_2)$$

$$\rho(\vec{r},t) = \exp\left(-\frac{r_L^2}{2R_L^2} - \frac{r_{TS}^2}{2R_{TS}^2} - \frac{r_{TO}^2}{2R_{TO}^2} - \frac{t^2}{2\tau^2}\right)$$

$$C_2 = 1 + \lambda \exp\left(-q_L^2 R_L^2 - q_{TS}^2 R_{TS}^2 - q_{TO}^2 R_{TO}^2 - \Delta E^2 \tau^2\right)$$

$$C_2^{exp} = \frac{\dfrac{d^2\sigma}{dp_1 dp_2}}{\dfrac{d\sigma}{dp_1} \times \dfrac{d\sigma}{dp_2}}$$

In the Longitudinal CMS, where $(\mathbf{p}_1+\mathbf{p}_2)_{beam} = 0$,

$$C_2 = 1 + \lambda \exp\left[-q_L^2 R_L^2 - q_{TS}^2 R_{TS}^2 - q_{TO}^2 \left(R_{TO}^2 + \beta_{\pi\pi}^2 \tau^2\right)\right]$$

$\rightarrow R_{TO}^{exp}$

$$\tau^2 \approx \frac{\left(R_{TO}^{exp}\right)^2 - \left(R_{TS}^{exp}\right)^2}{\beta_{\pi\pi}^2}$$

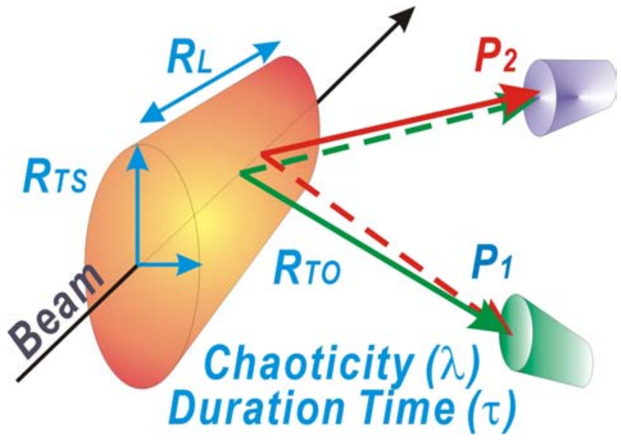
Observables

3 radii: $R_L, R_{TS}, R_{TO}^{exp} = \sqrt{R_{TO}^2 + \beta_{\pi\pi}^2 \tau^2}$

duration time: τ

chaoticity: λ

HBT



$$C_2 = 1 + \lambda \exp\left[-q_L^2 R_L^2 - q_{TS}^2 R_{TS}^2 - q_{TO}^2 \left(R_{TO}^2 + \beta_{\pi\pi}^2 \tau^2\right)\right]$$

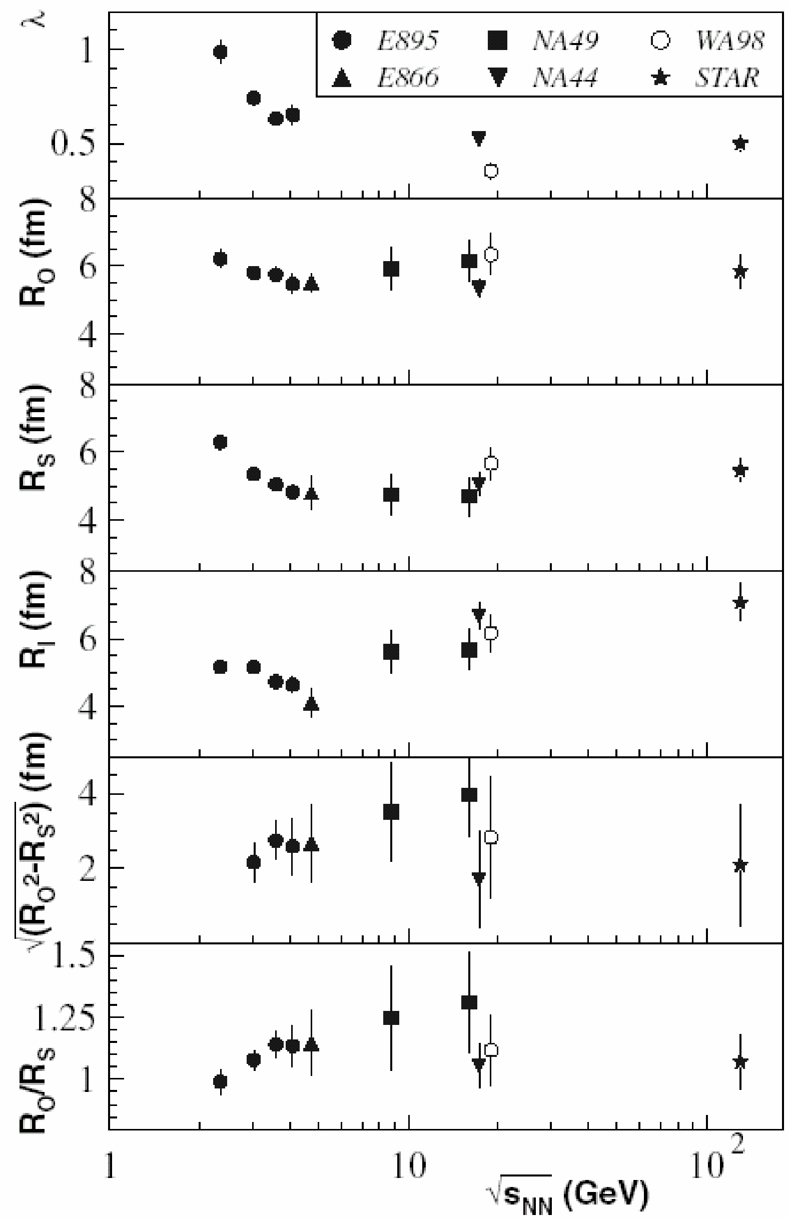
$\left(R_{TO}^2 + \beta_{\pi\pi}^2 \tau^2\right) \rightarrow R_{TO}^{exp}$

$$\tau^2 \approx \frac{\left(R_{TO}^{exp}\right)^2 - \left(R_{TS}^{exp}\right)^2}{\beta_{\pi\pi}^2}$$

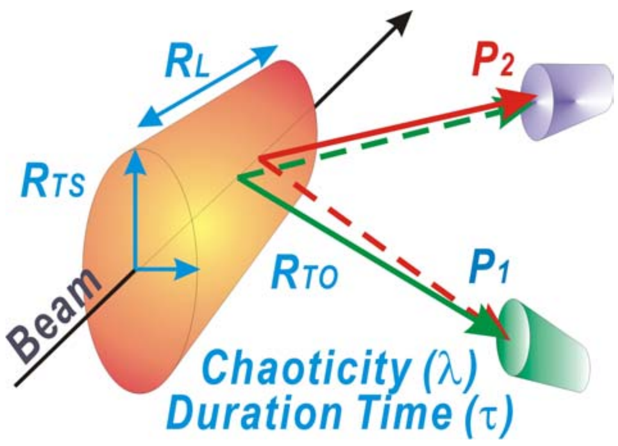
$$V \sim 2600\ fm^3 \quad (2X\ Au)$$

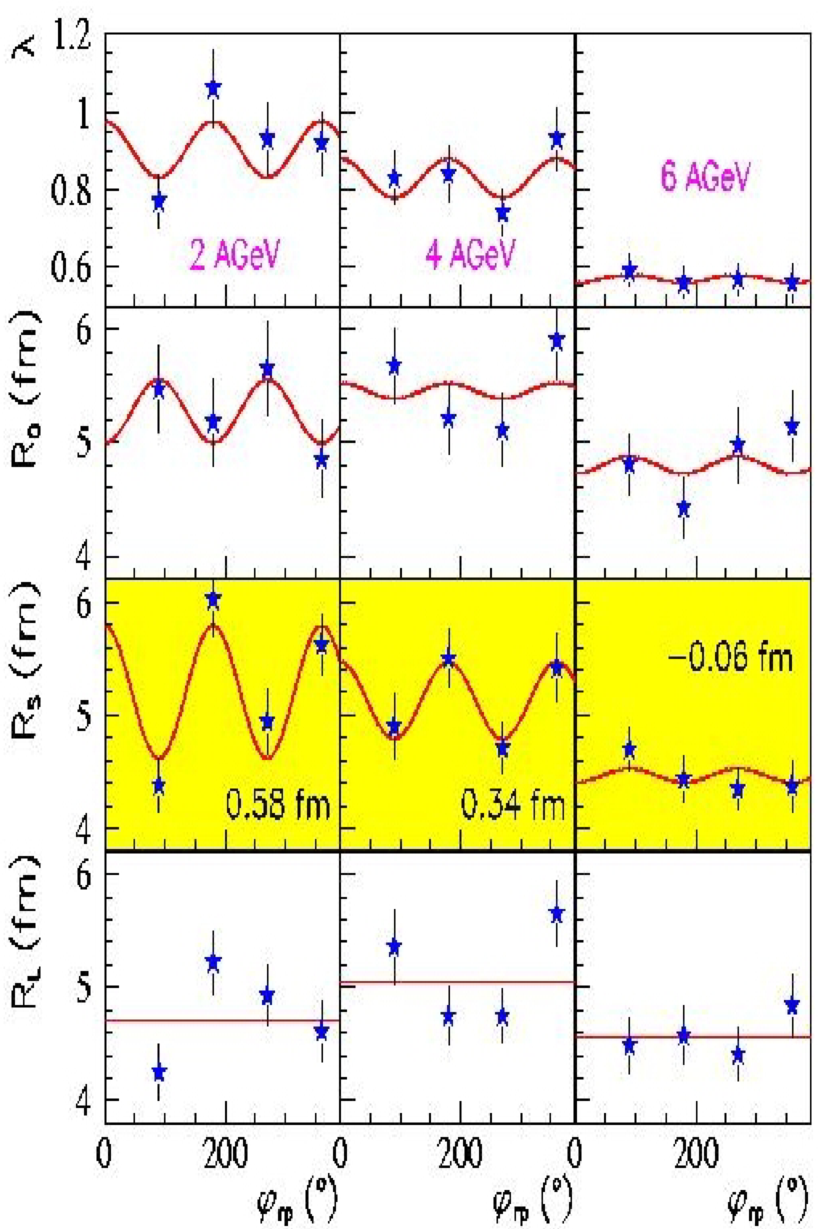
$$\rho \sim 0.12/fm^3$$

Stachel et al.



HBT – Reaction plane Dependence



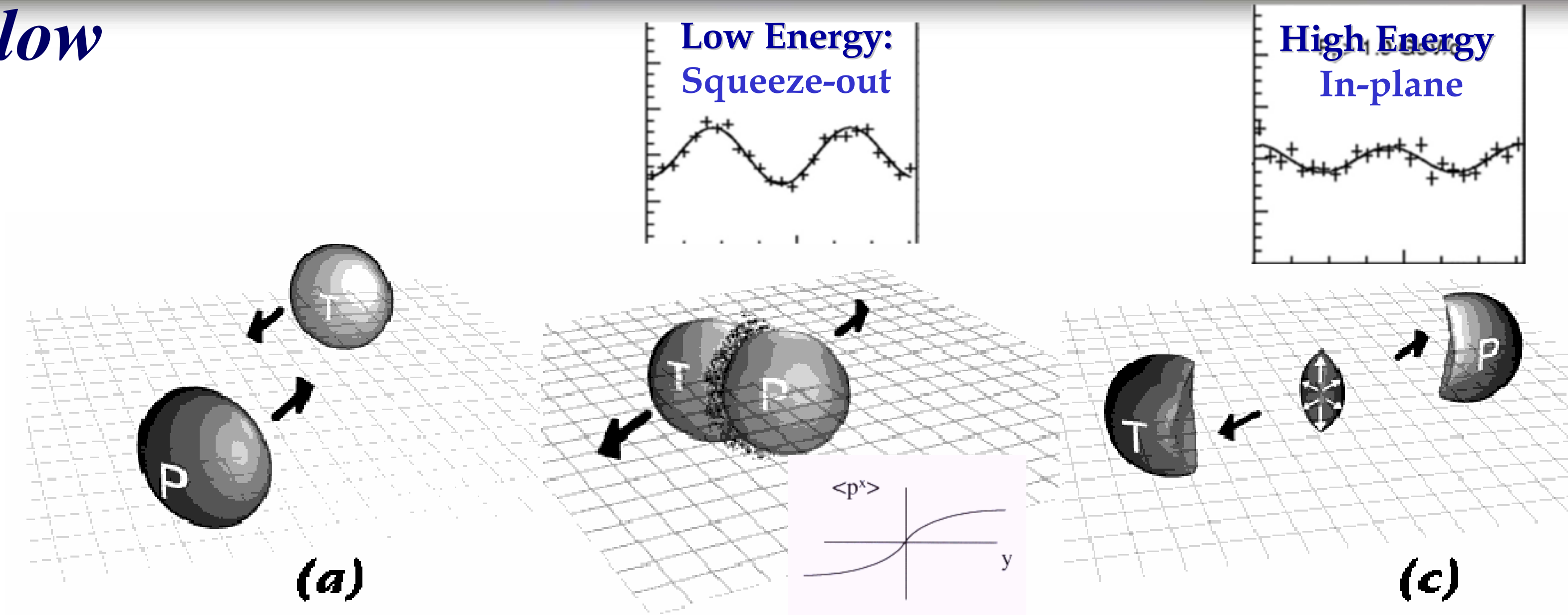


Rout < Rside

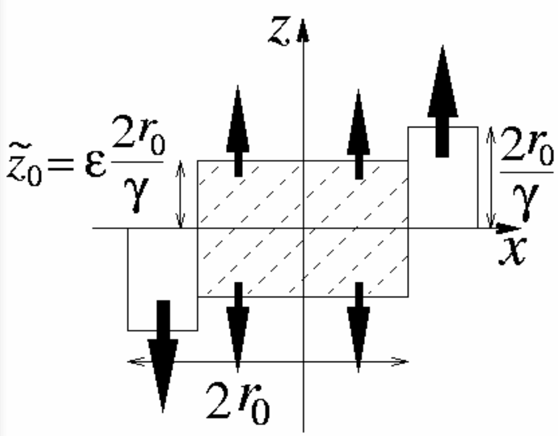
Initial Overlap

=> Shape at freeze-out

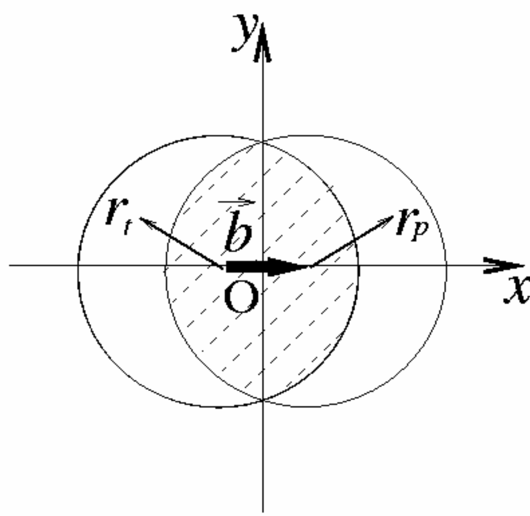
Flow



Pressure Gradients Drive Transverse and Elliptic flow



Reaction Plane

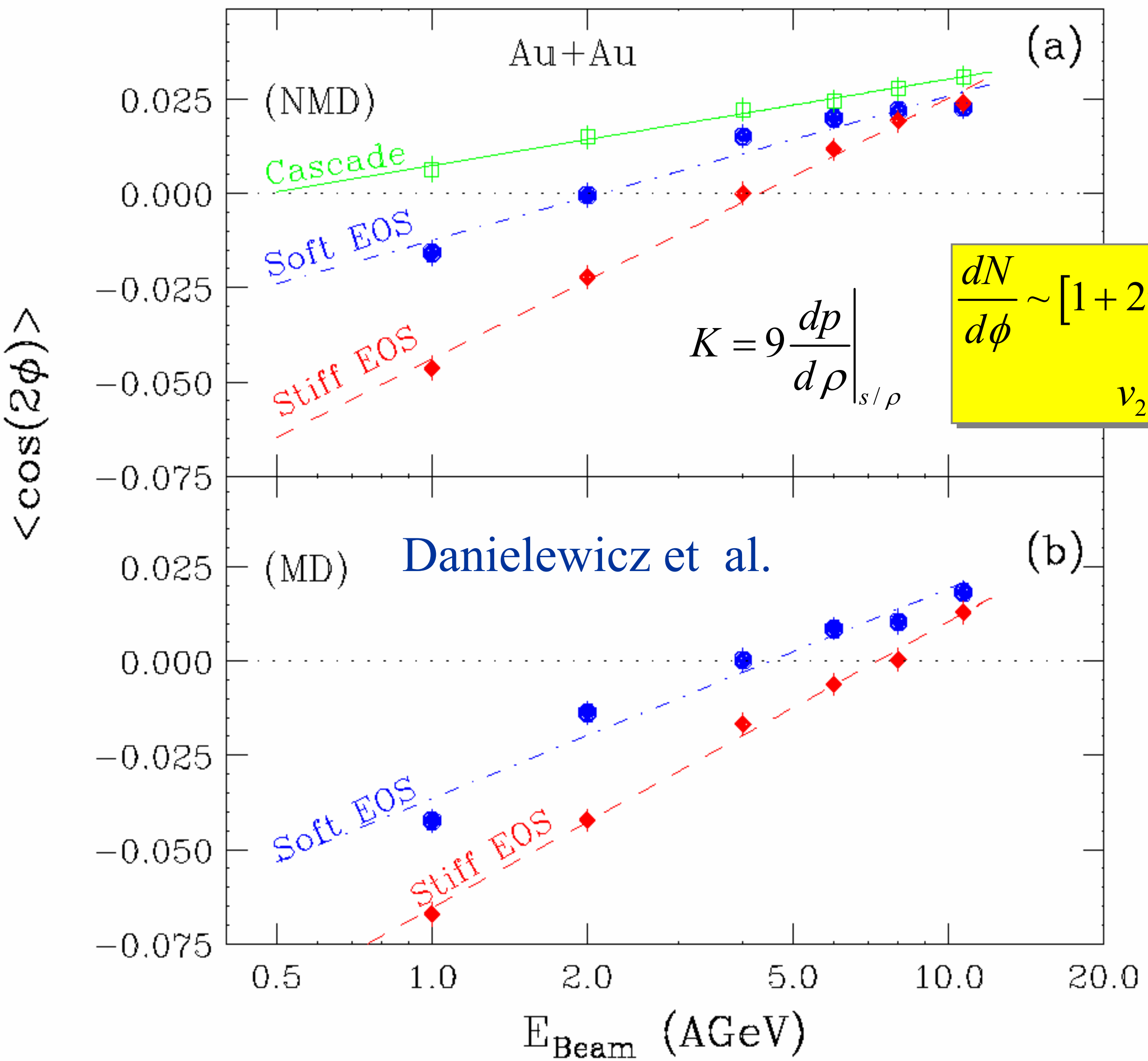


Transverse Plane

$$t_{expan} \sim \frac{R}{c_S}$$

$$t_{pass} \sim \frac{2R}{\gamma_0 v_0}$$

$$\frac{dN}{d\phi} \sim \left[1 + 2v_1 \cos(\phi) + 2v_2 \cos(2\phi)\right]$$

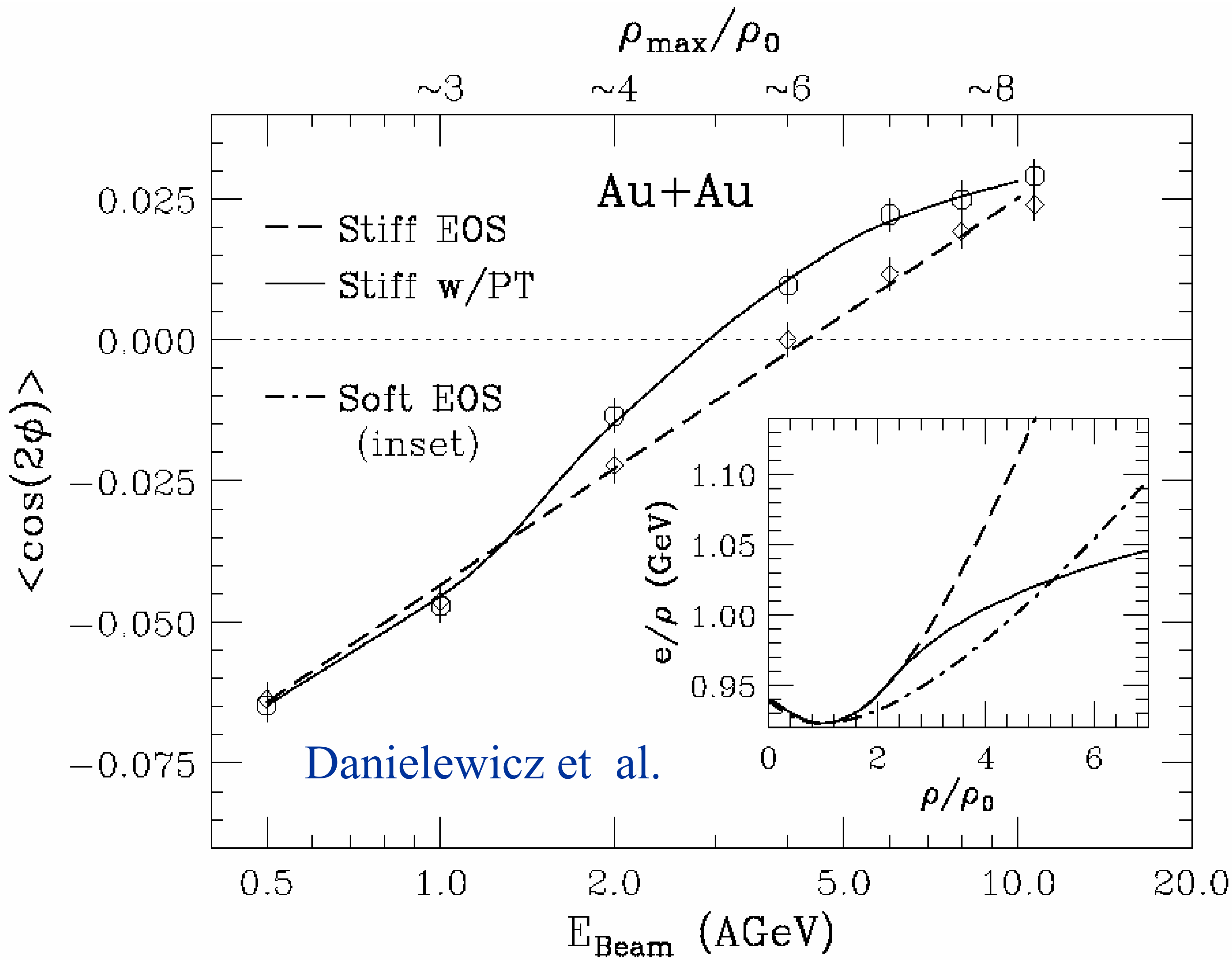


$$K = 9 \frac{dp}{d\rho}\bigg|_{s/\rho}$$

$$\frac{dN}{d\phi} \sim \left[1 + 2v_1\cos(\phi) + 2v_2\cos(2\phi)\right]$$

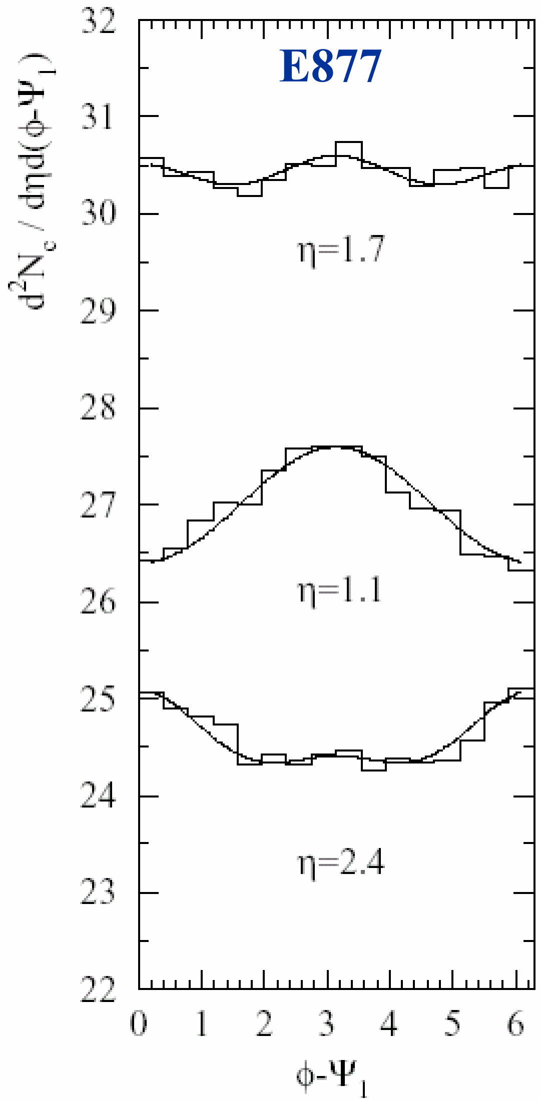
$$v_2 = \langle \cos(2\phi) \rangle$$

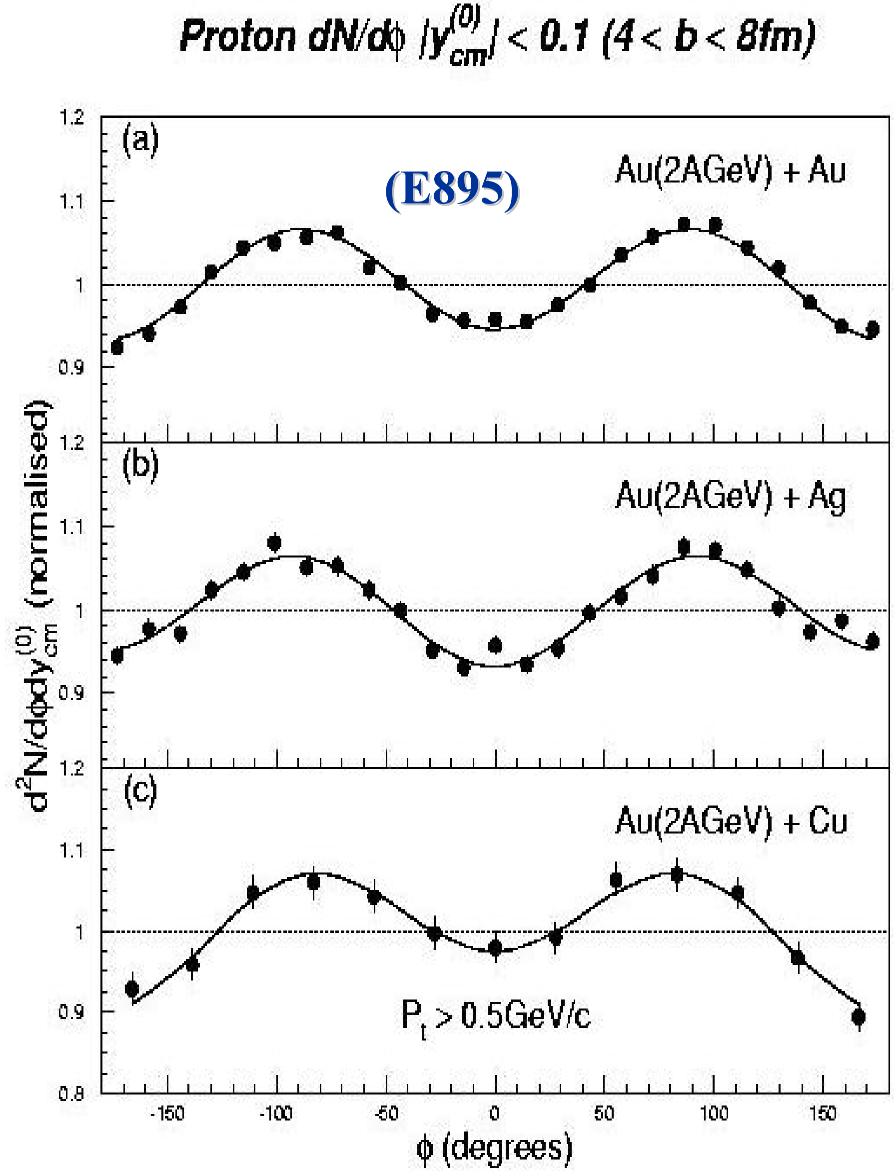
V_2 is sensitive to the EOS

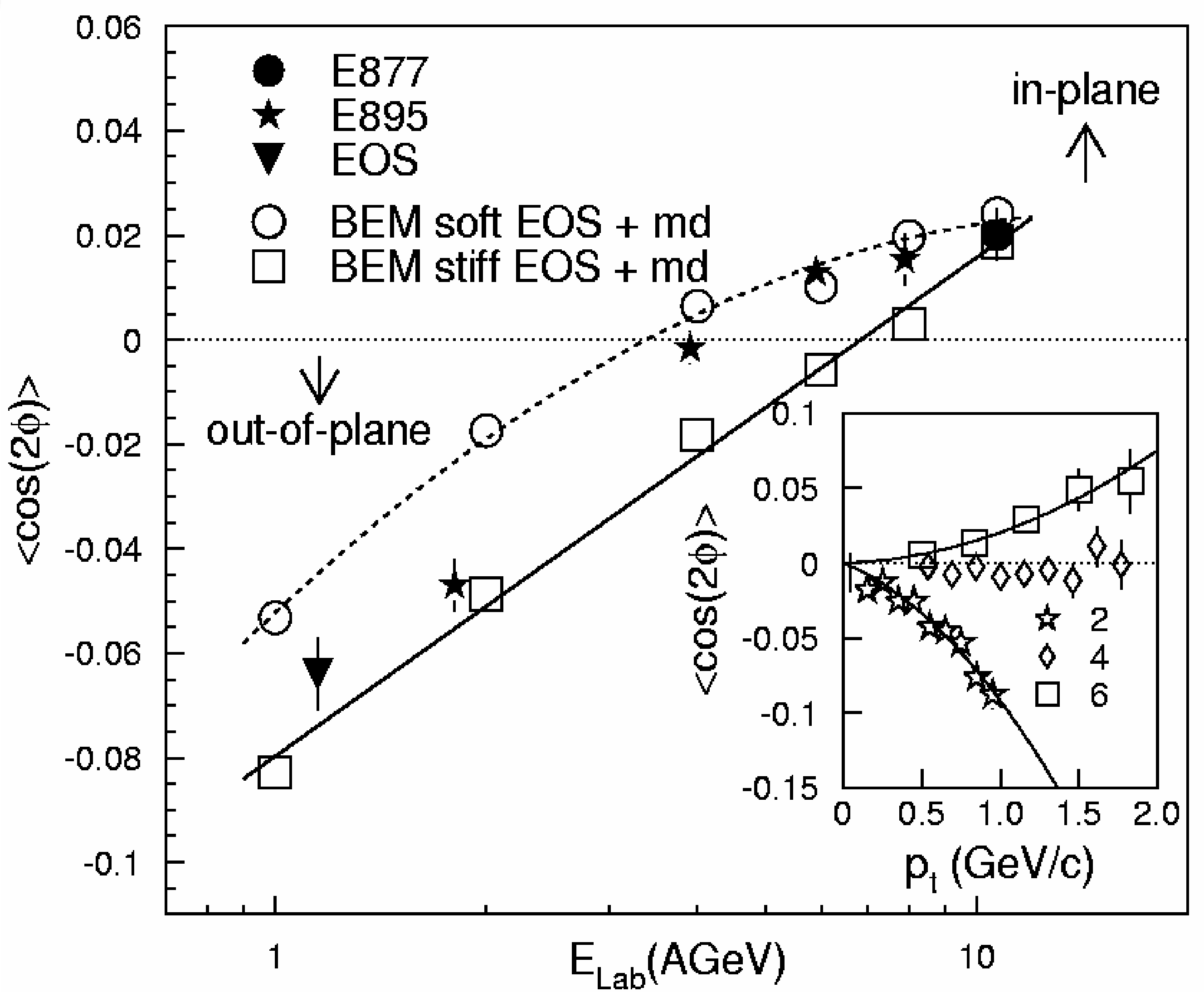


V_2 is sensitive to the Phase Transition

Flow


E877
η=1.7
η=1.1
η=2.4
d²N_c / dηd(φ-Ψ_1)
φ-Ψ_1

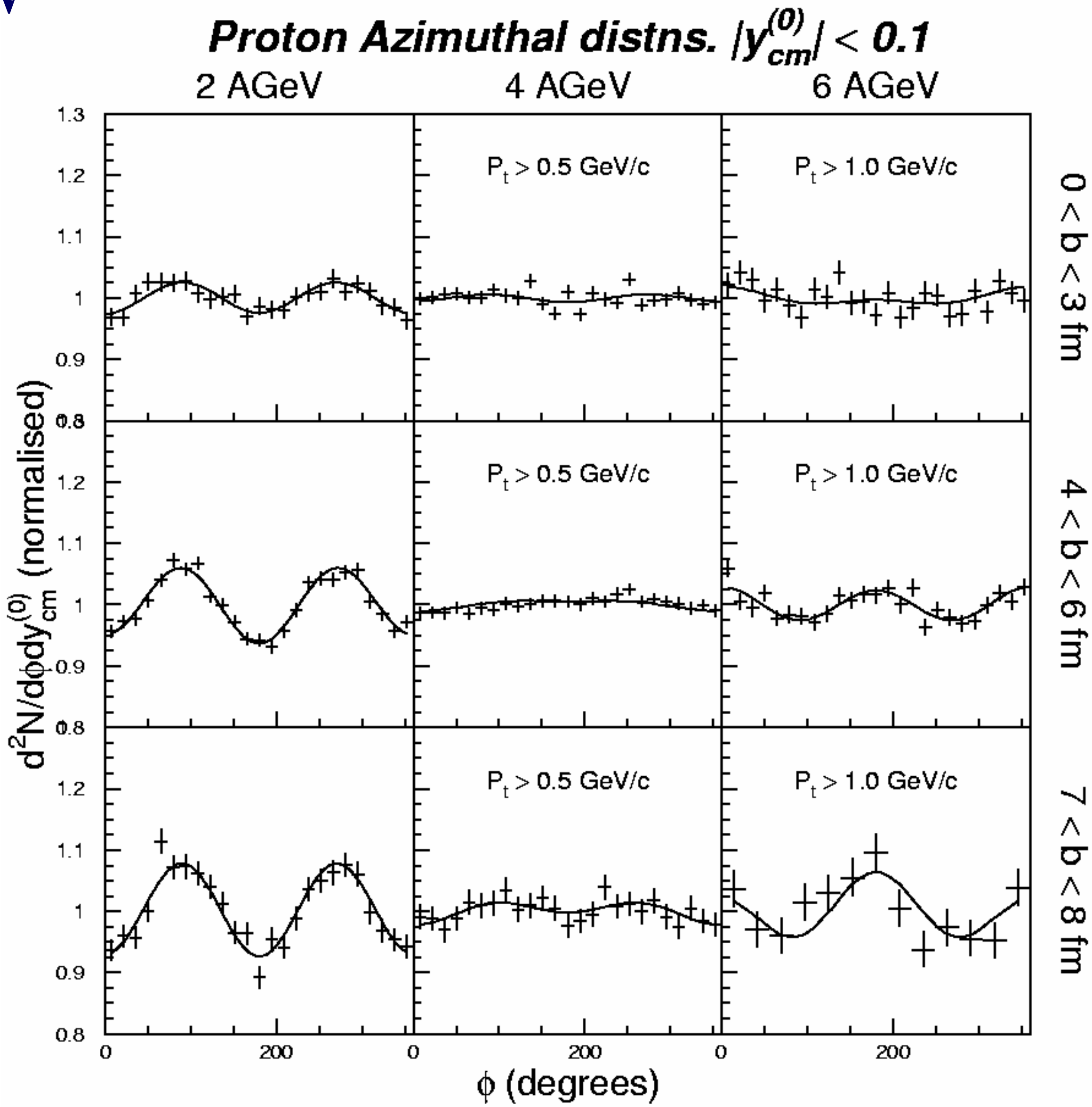

Proton dN/dφ |y_cm^(0)| < 0.1 (4 < b < 8fm)
(E895)
(a)
Au(2AGeV) + Au
(b)
Au(2AGeV) + Ag
(c)
Au(2AGeV) + Cu
P_t > 0.5GeV/c
d²N/dφdy_cm^(0) (normalised)
φ (degrees)

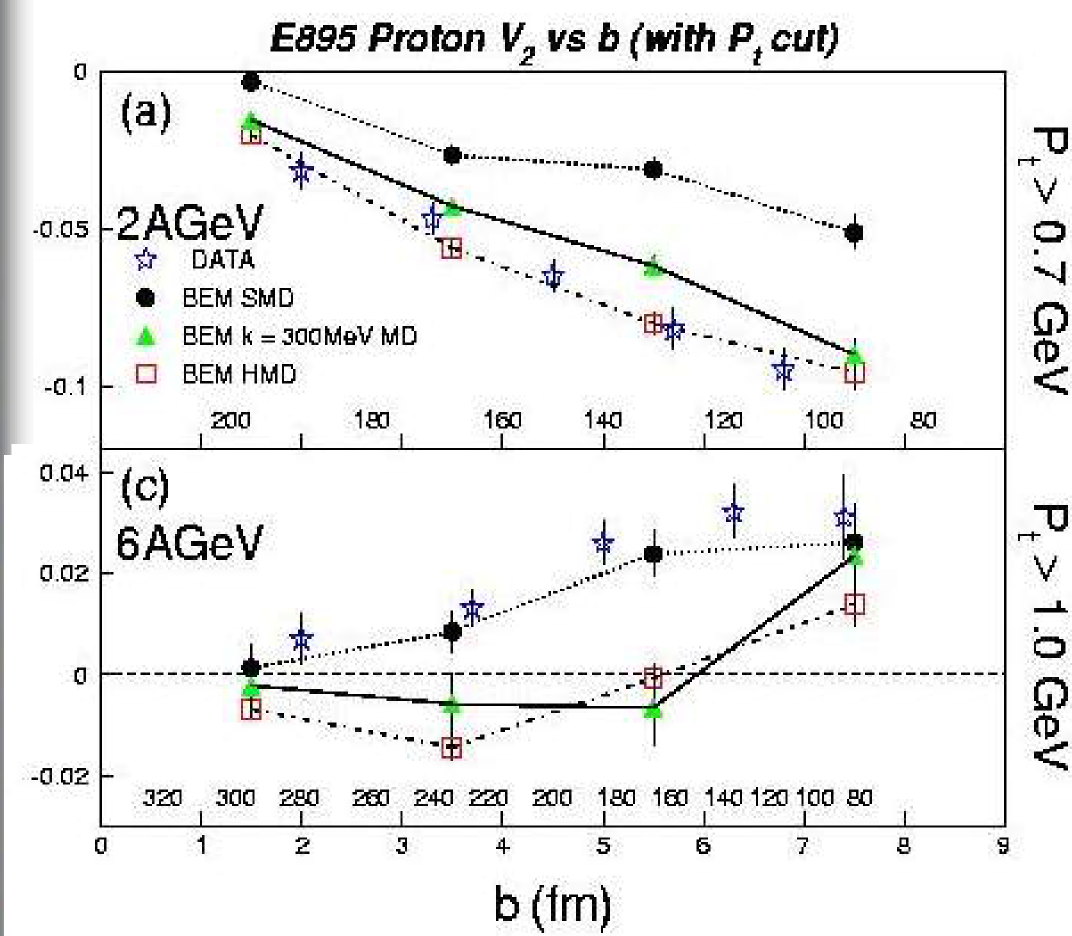


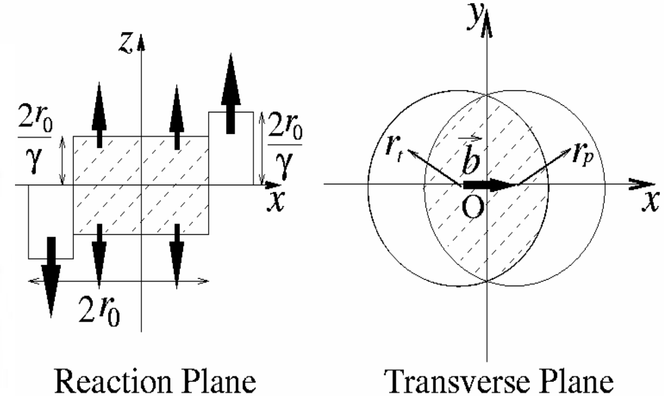
Good Agreement with theory, Softening of EOS

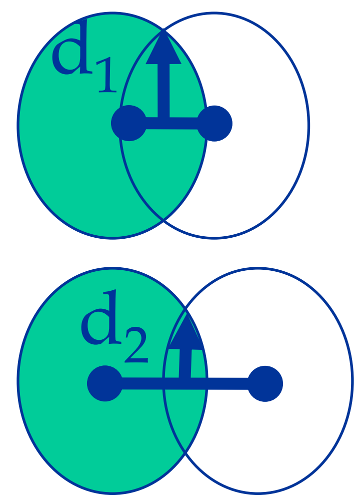
Differential Flow

Differential Measurements (E895)









$$t_{pass} \sim \frac{2R}{\gamma_0 v_0}$$

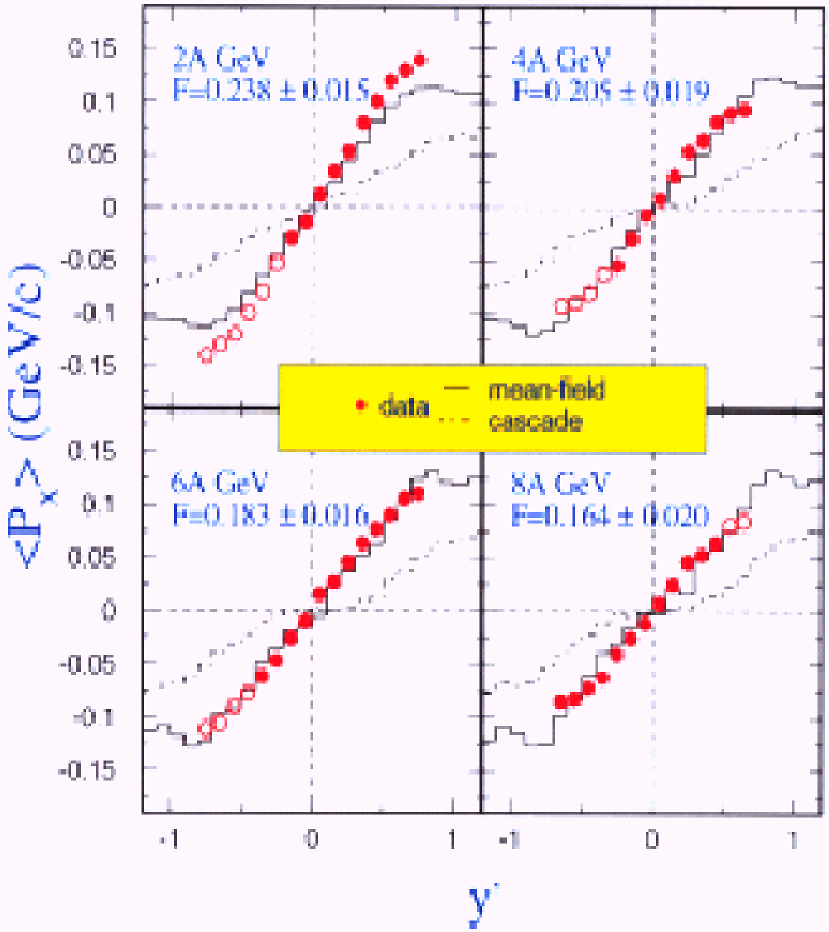
$$t_{expan} \sim \frac{d_1}{c_S}$$

$$t_{expan} \sim \frac{d_2}{c_S}$$

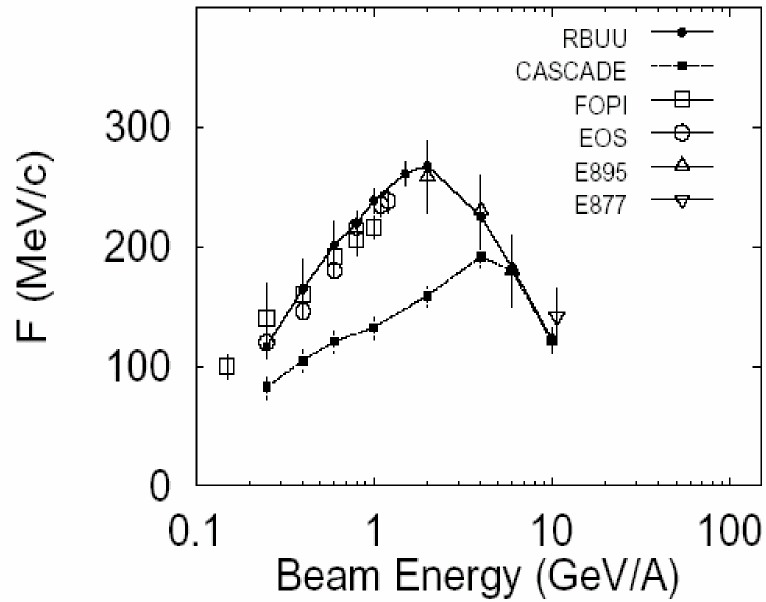
- **Differential Elliptic Flow Studies Provide Important Additional Insights on the EOS**

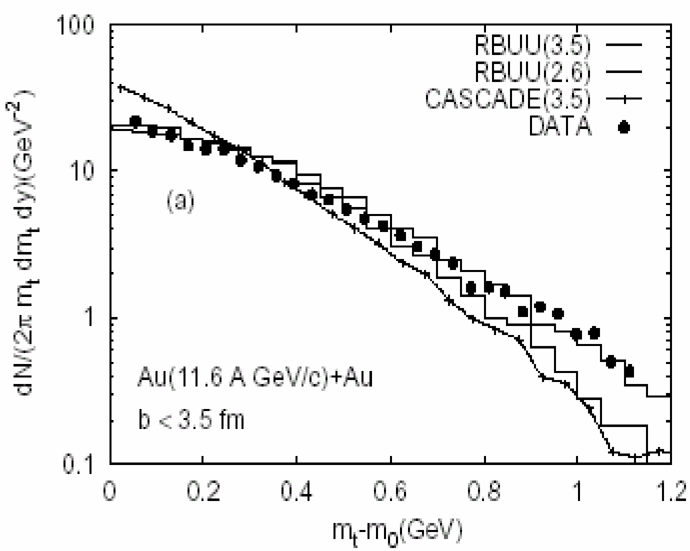
Stony Brook

H. Liu E895



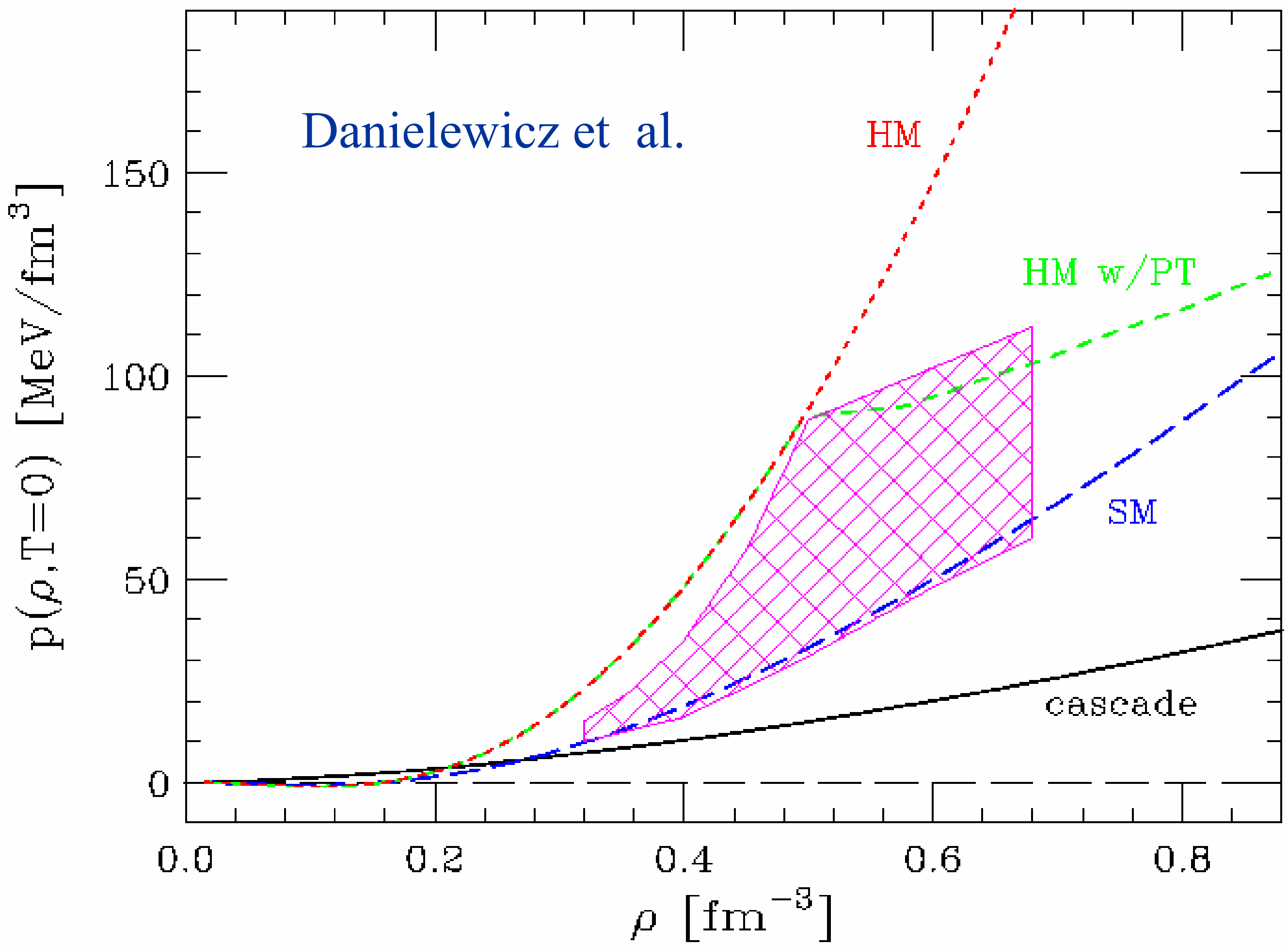
Sahu et al.





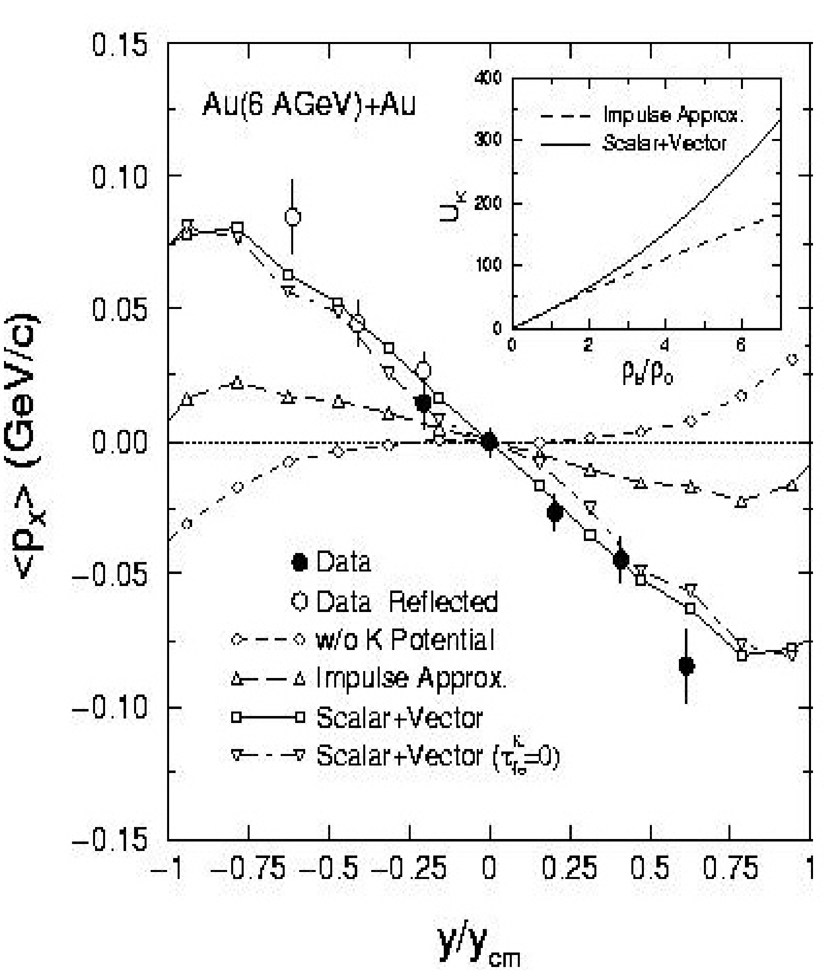
Good Agreement with calculation which assumes p dependent meanfield

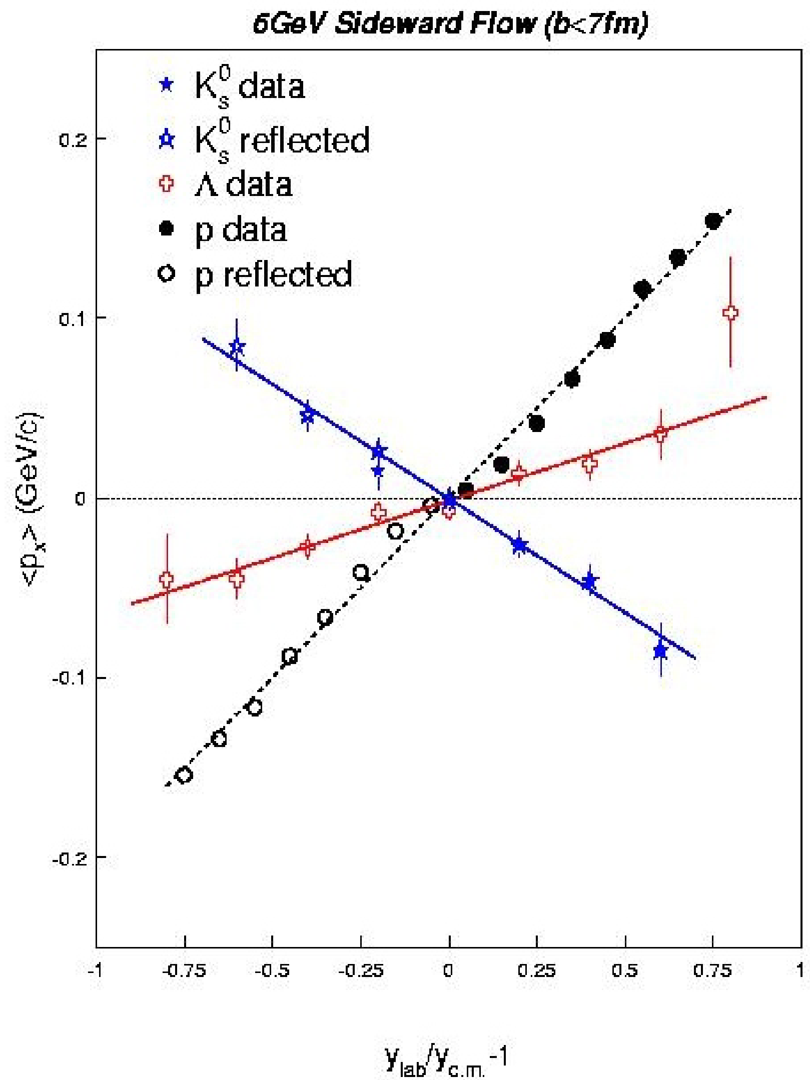
Flow



New constraints for the EOS achieved

Flow of Produced Particles





Clear Evidence for in-medium potential

Particle Production

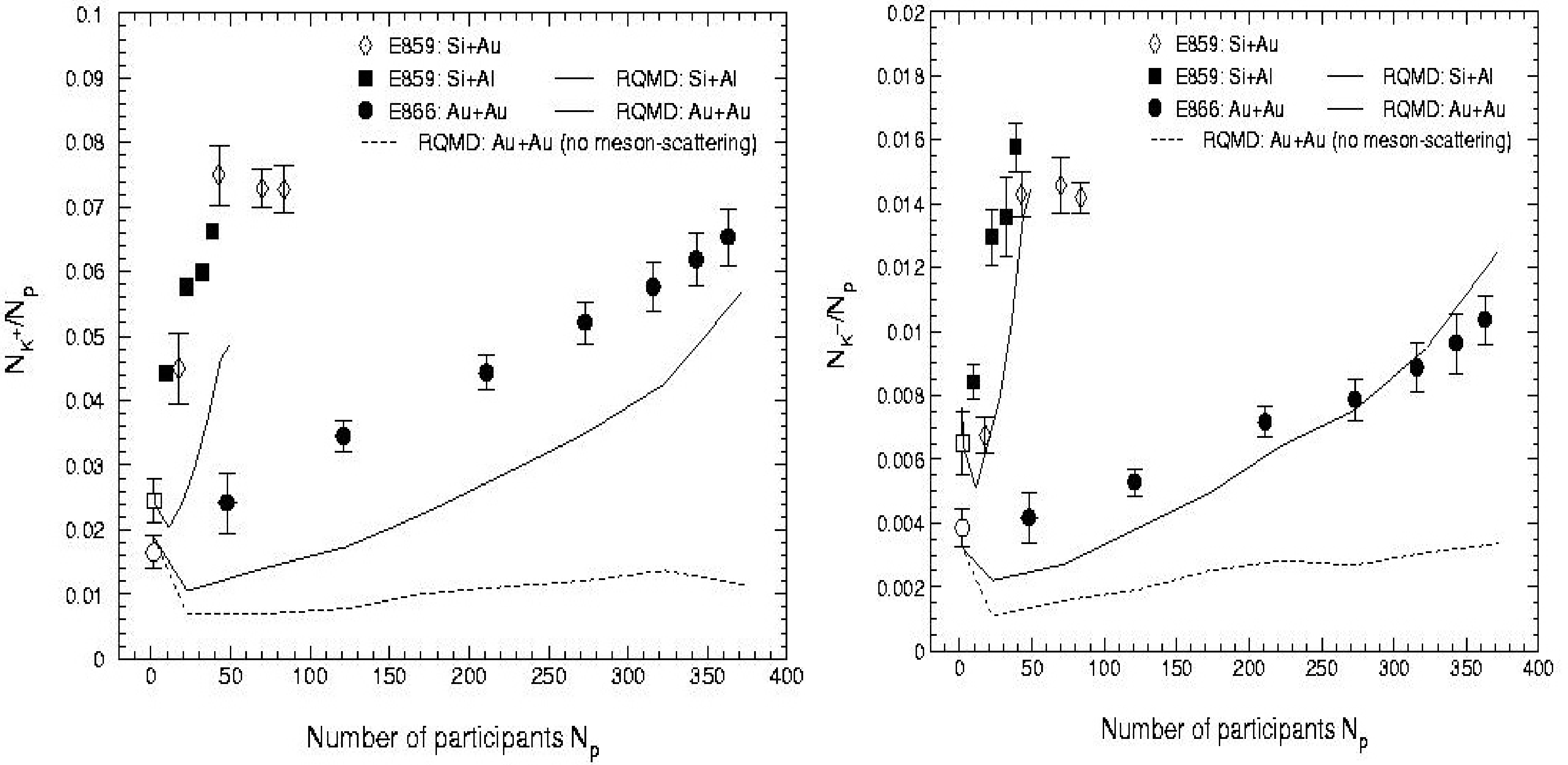
OF Particular Interest

- Enhancement in Strangeness Production
- Enhancement in the ratio Antihyperon/Antibaryon

→ **Probes for the QGP**

Particle Production

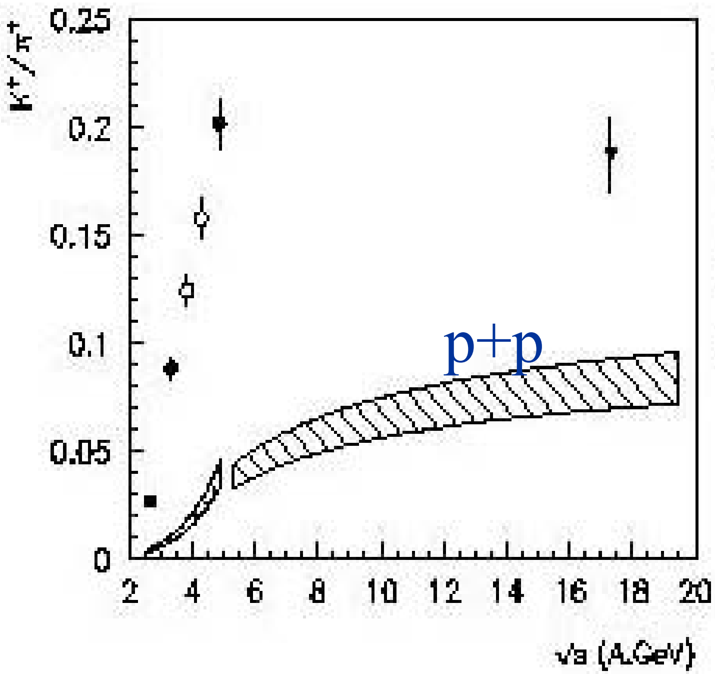
F. Wang

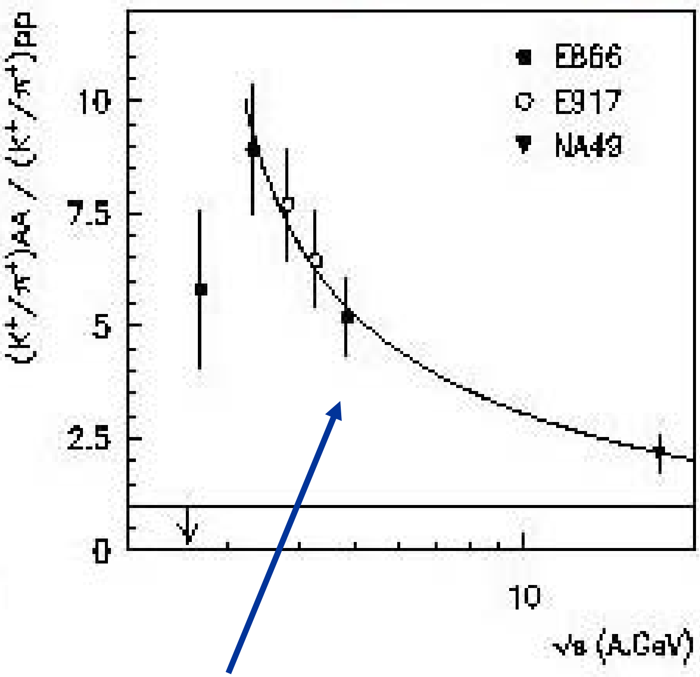


Yields Increase from Peripheral to Central Collisions
-- Consistent With Multiple Collisions per participant

Particle Production

Phys.Lett. B476, (2000) 1-8
Phys.Rev. C61, (2000) 031901

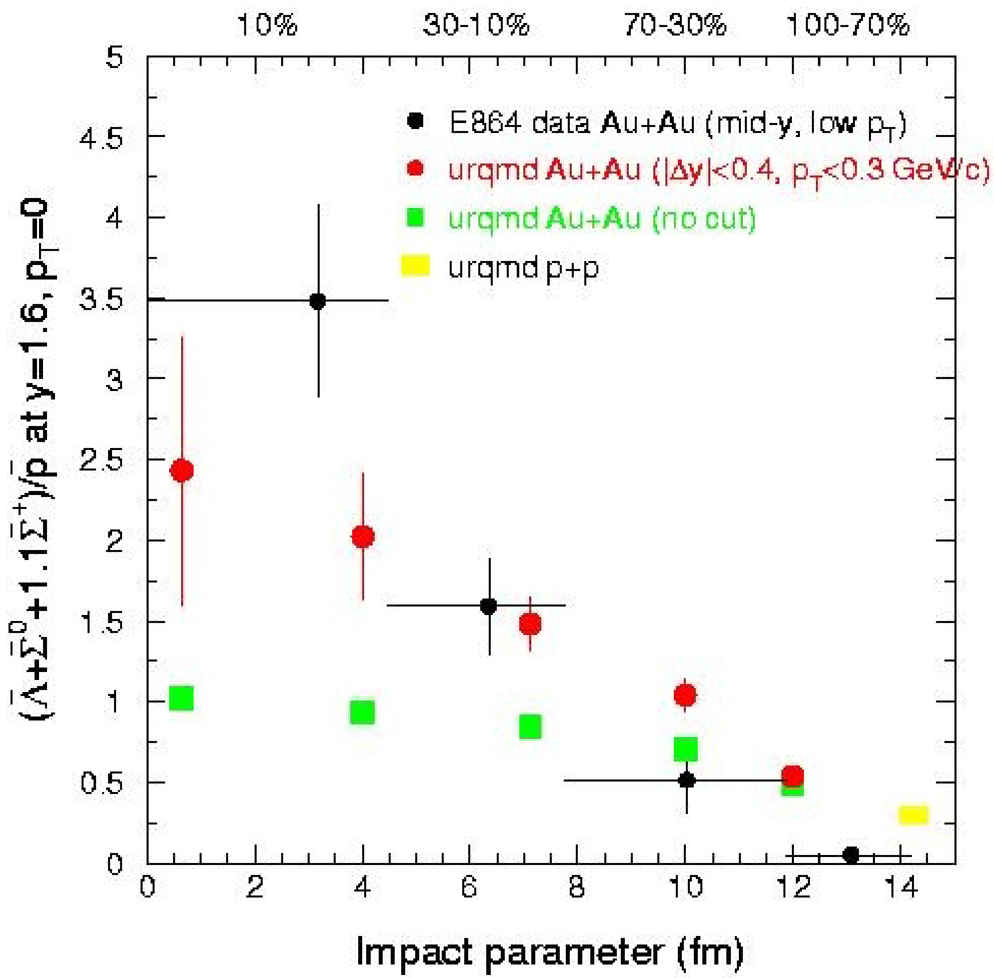




Ratio increases with beam energy… possible maximum

Smooth Decrease in enhancement

Particle Production

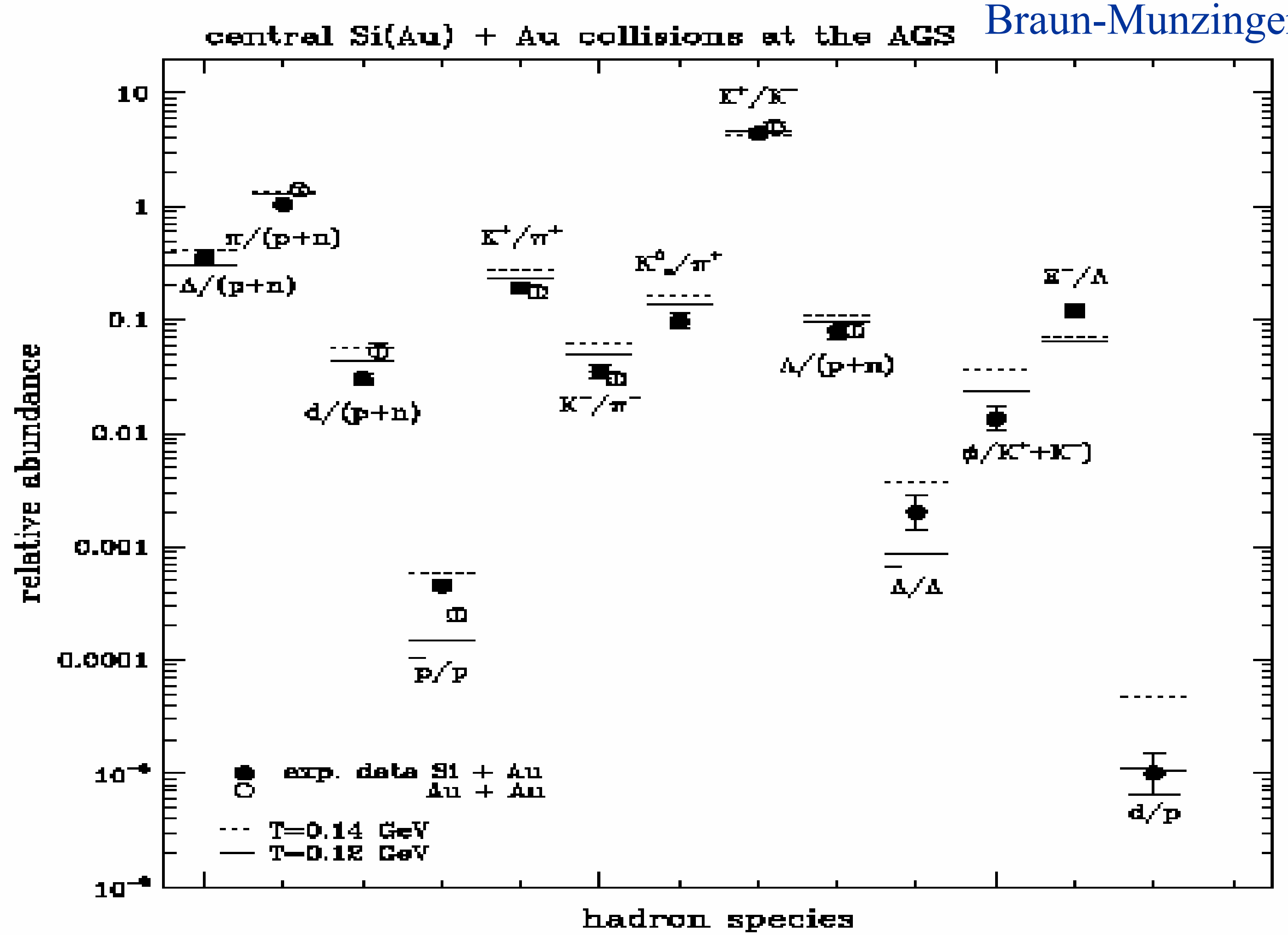


Ratio Increase from Peripheral to Central Collisions

-- Reasonable agreement with model calculations

Particle Production

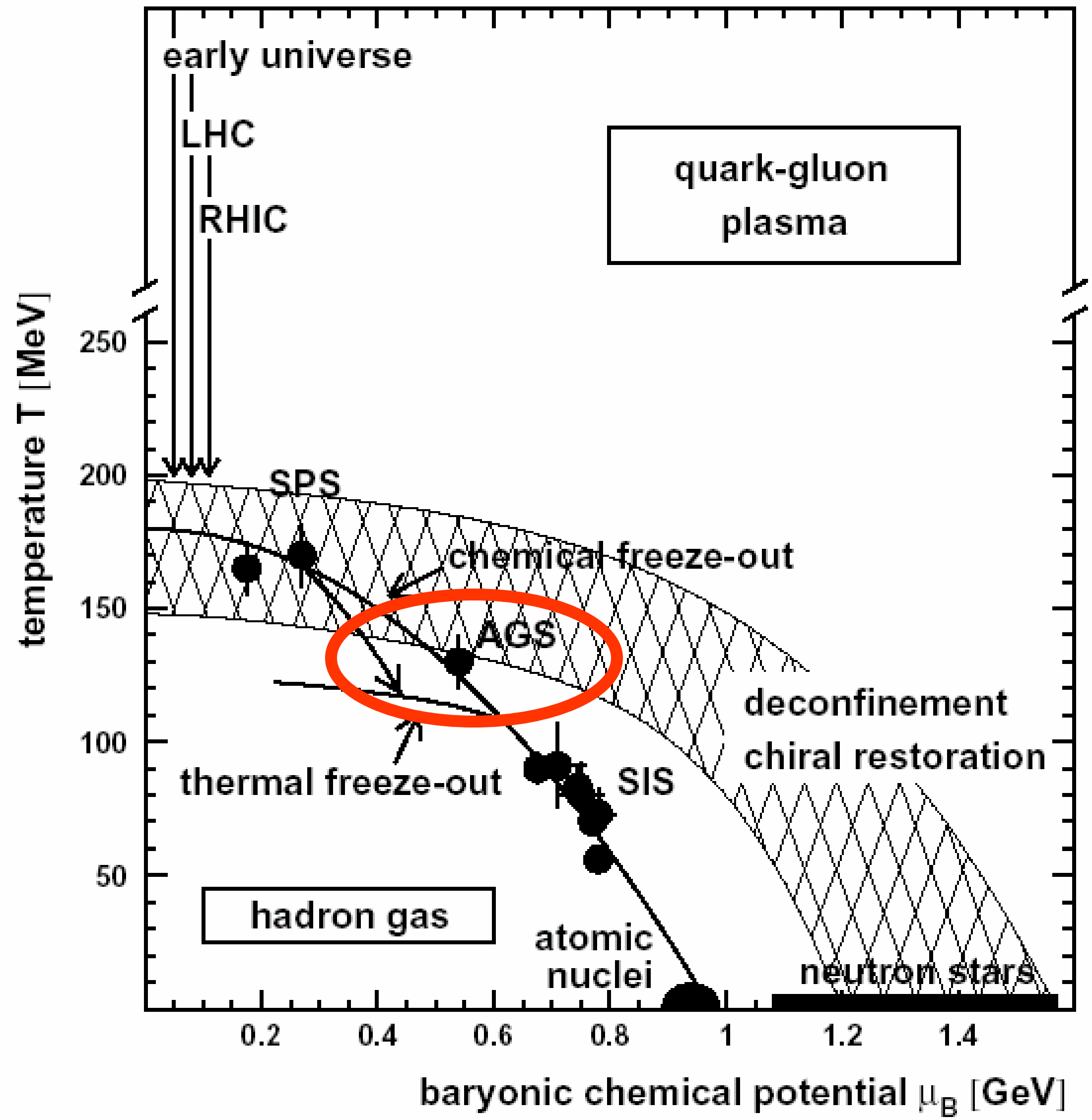
Braun-Munzinger et al.



Remarkable Agreement with Predictions of Thermal model

$\Rightarrow \mu_B$ & T

Stachel et al.



Stony Brook

Summary

Compressed Baryonic Matter is Produced With Significant Energy Density at the AGS.

- **The study of this matter has provided a wealth of insights**
- **Further Studies are Required for a more complete understanding as well as further mapping of the phase diagram**

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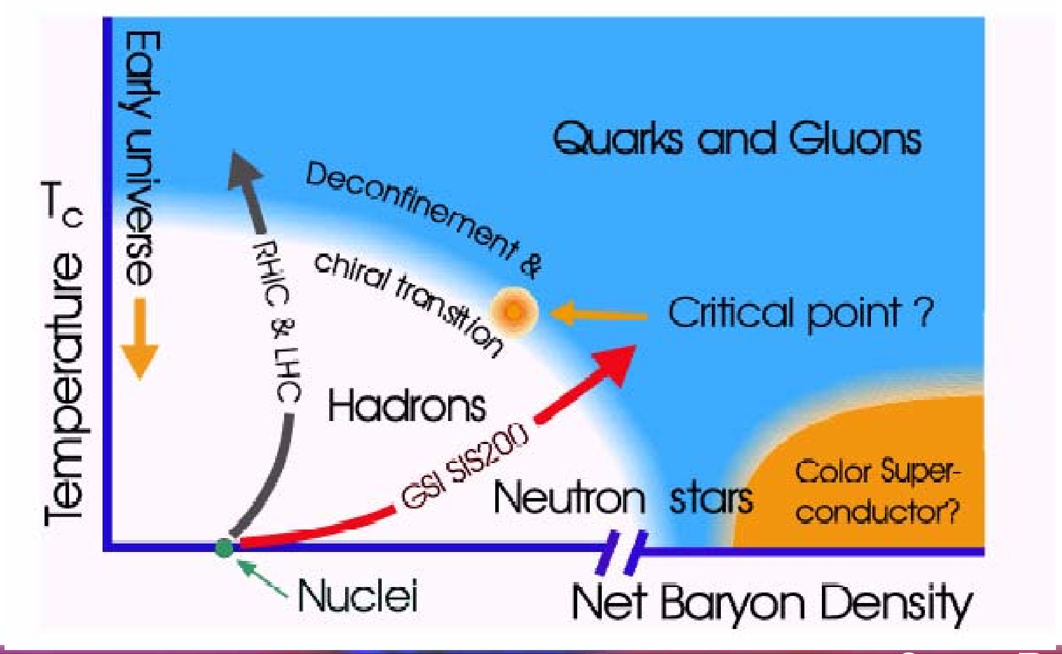
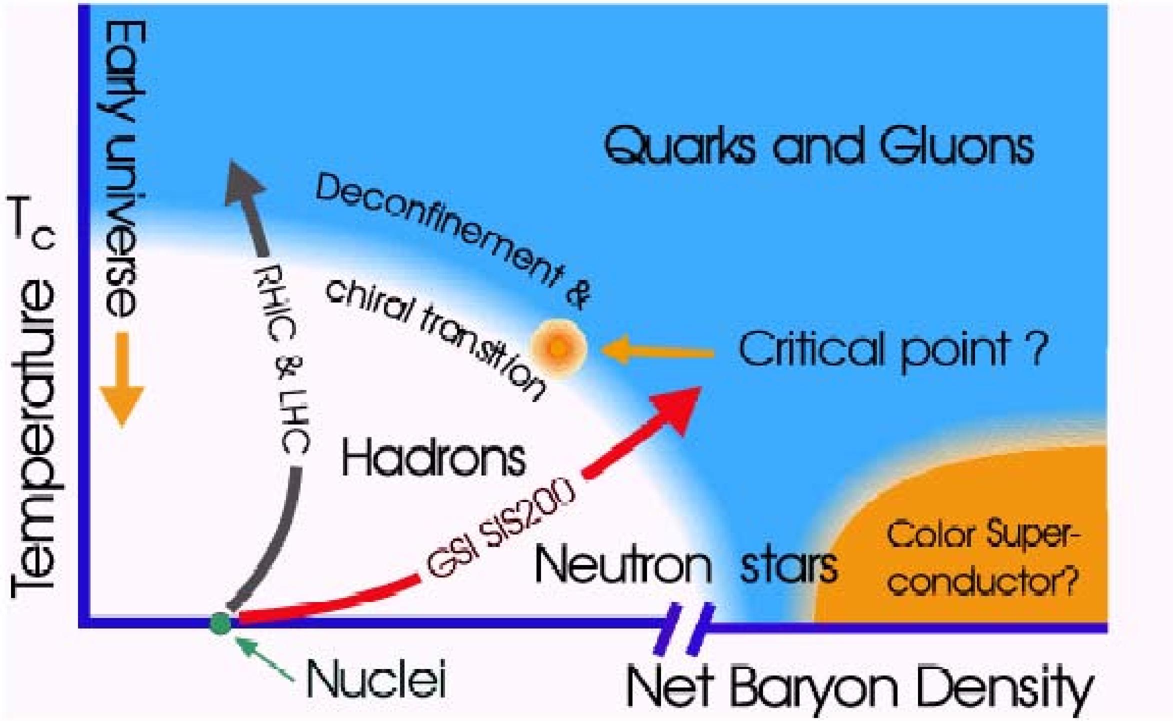
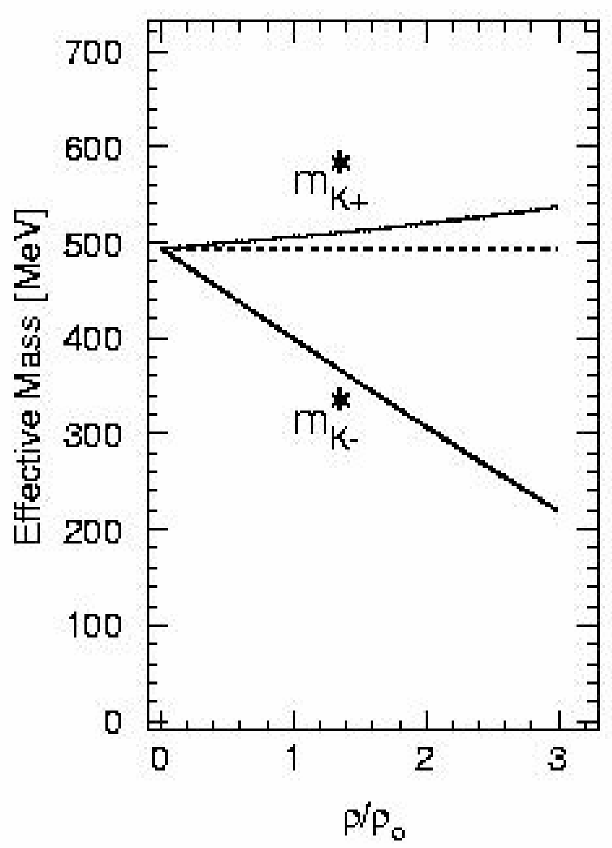




New constraints for the EOS achieved

Motivation – Strange Particles



K^- & $\overline{K^0}$ → attractive Interaction

K^+ & K^0 → Repulsive Interaction

-→ Consequences for Flow

In QGP

$$gg \rightarrow s\bar{s}$$

Production in hadronic gas

→ pairs of strange hadrons with increased threshold

→ Strangeness Enhancement

The Production and Propagation of Strange Hadrons constitutes an Important Probe