COMPARISON OF HADRONIC RESCATTERING CALCULATIONS OF ELLIPTIC FLOW AND HBT WITH MEASUREMENTS FROM RHIC

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OUTLINE

1) RESCATTERING CALCULATION

2) RESULTS FOR RADIAL AND ELLIPTIC FLOW

3) RESULTS FOR HBT

→ MOTIVATION ←

HOW FAR CAN ONE GET WITH A "PURE" (NAÏEVE) HADRONIC RESCATTERING SENARIO ??

RESCATTERING CALCULATION

USE HERMANN-BERTSCH METHOD FOR ISOSPIN-AVERAGED "PION-GAS" CALCULATION (PRC 51 (1995)), BUT INCLUDE BARYONS

→ $\pi, \rho, \omega, \eta, \eta', K, K^*, \phi, N, \Delta, \Lambda$

⇒ <u>INITIAL STATE</u> + <u>RESCATTERING</u> → <u>FREEZEOUT</u>

* <u>INITIAL STATE</u>:

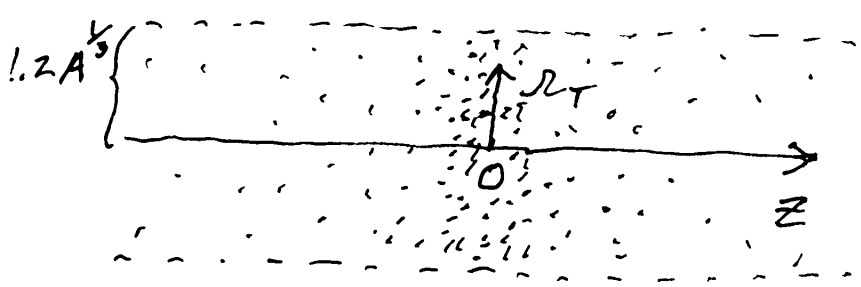
T = TEMPERATURE PARAMETER

$$\frac{1}{m_T}\frac{d^2N}{dm_T\,dy} \propto \frac{m_T}{e^{m_T/T} \pm 1}\, f(y)$$

RAPIDITY WIDTH

WHERE $f(y) = \begin{cases} e^{-y^2/2\sigma_i^2}, & i = \pi, K, \rho, \ldots \text{ (MESONS)} \\ \text{"FLAT" OR "PEAKED"}, & \text{BARYONS} \end{cases}$

→ GEOMETRY:



$\frac{dN}{dr_T}$ → PROJECTED SPHERE IN $b=0$ CA

$z = \tau_{HAD} \sinh(y)$

$t = \tau_{HAD} \cosh(y)$

PROPER TIME FOR HADRONIZATION

→ MULTIPLICITIES:

CHOOSE $\langle m \rangle_i$ TO EVOLE TO EXPERIMENTAL $\langle \pi \rangle$, $\langle K \rangle$, $\langle P \rangle$

(USE HELIOS p+p DATA TO HELP SET INITIAL RESONANCE FRACTIONS)

* <u>RESCATTERING</u>:

"TUNE" $\underline{T}$, $\underline{\sigma}$, $\underline{\tau_{HAD}}$ ⟸ ADJUSTABLE PARAMETERS

	(158 GeV Pb+Pb) SPS	(130 GeV Au+Au) RHIC
T (MeV)	220	300
τ_{HAD} (FM/c)	1	1
σ	1.2	2.4

v_2 elliptic flow

radial flow

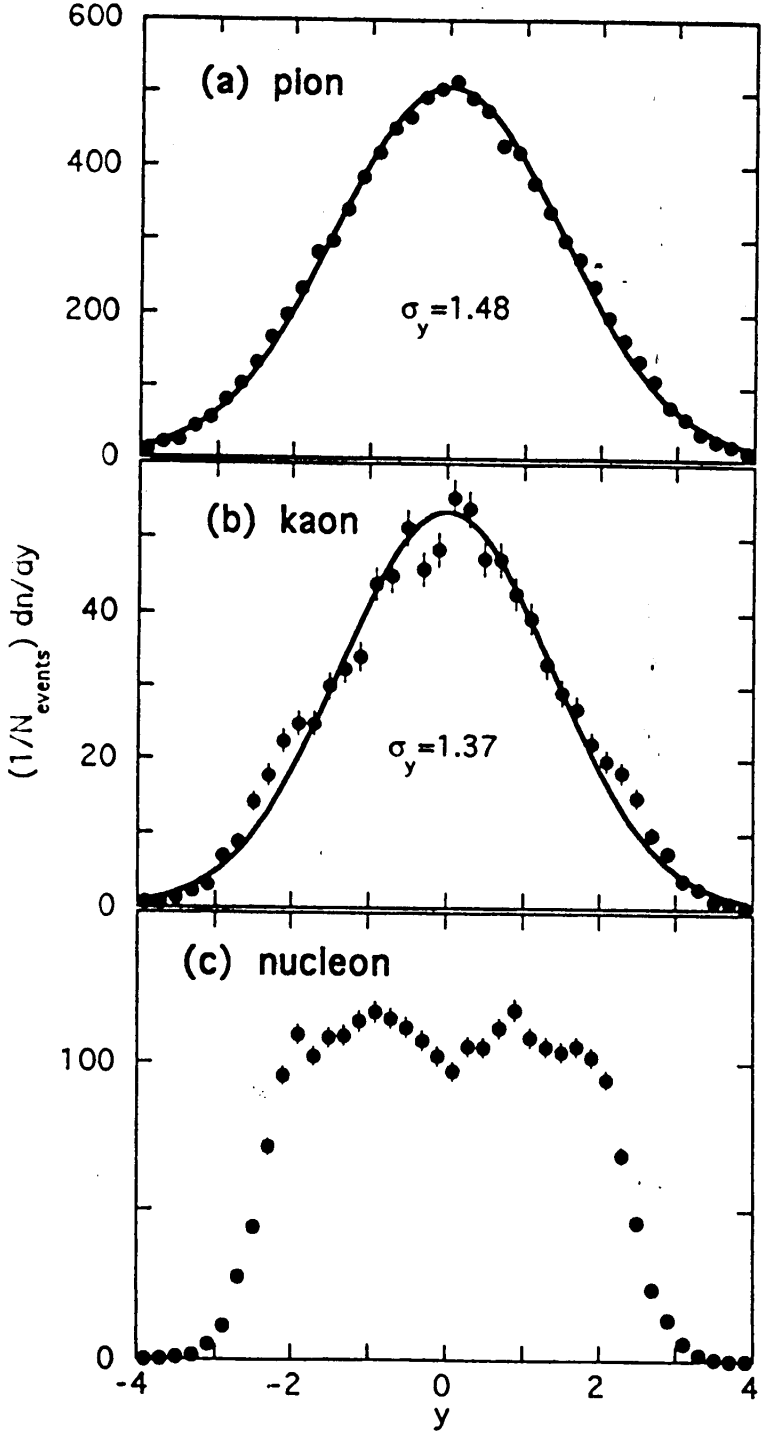


FIG. 5. Freeze-out rapidity distributions for (a) pions, (b) kaons, and (c) nucleons from the rescattering calculation. Fits to Eq. (2) for

PRC57(98)

RESCATTERING MODEL → SPS Pb+Pb

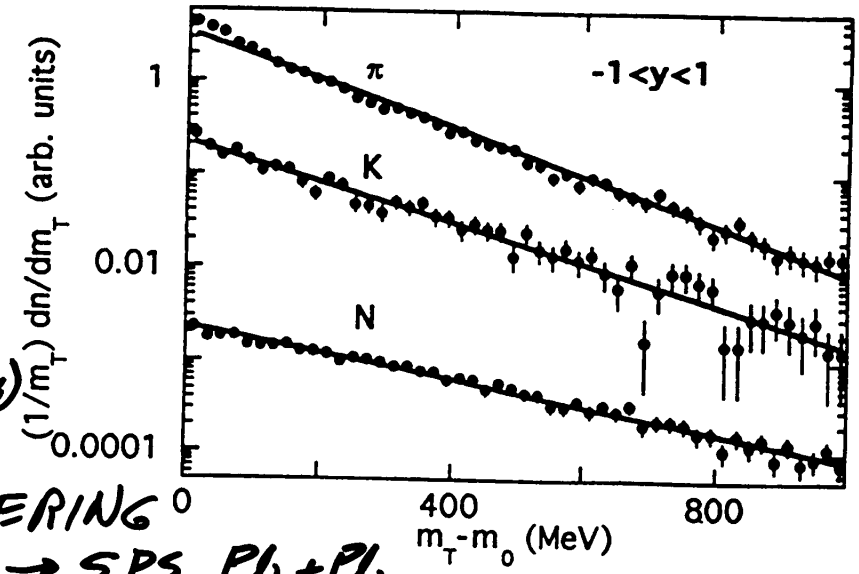


FIG. 6. m_T distributions at freeze-out from the rescattering calculation for pions, kaons, and nucleons at midrapidity. Normalizations are arbitrary. Fits to Eq. (1) are also shown.

T=220 MeV

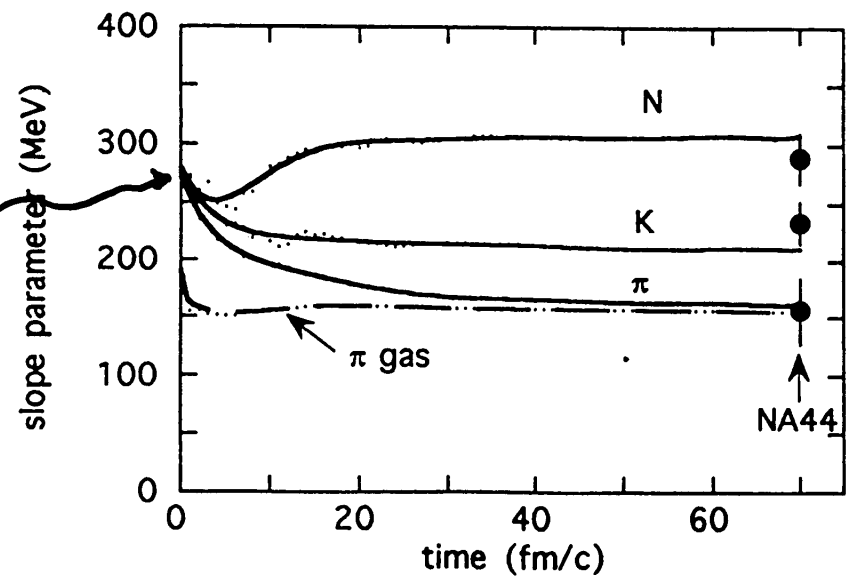
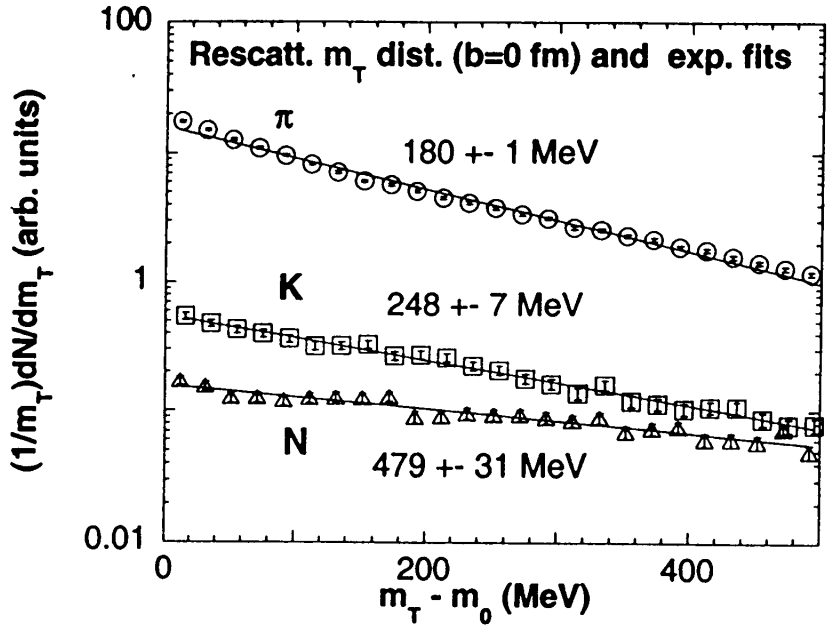


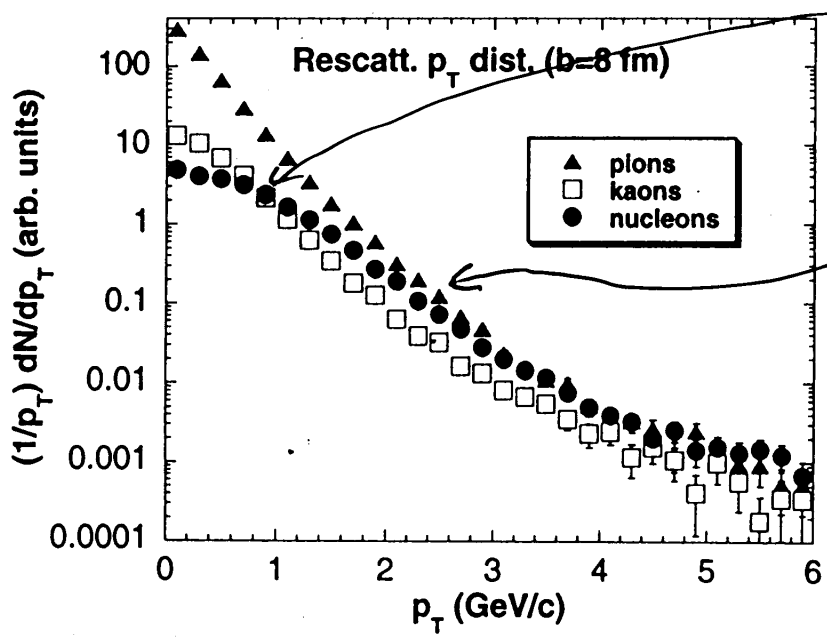
FIG. 7. Time evolution of the slope parameters in the rescattering calculation for a full calculation (solid lines) and for a "pion gas" calculation (dashed line). Experimental freeze-out slope pa-

130 GeV Au + Au RESCATT. CALC.



STAR
↓
190 ± 10 MeV
300 ± 30 MeV
565 ± 50 MeV

FIG. 2: Transverse mass distributions from the rescattering model. The lines are exponential fits to the distributions and the slope parameters are shown.



K–N crossing ~ 1 GeV/c

π–N merging for p_T > 2 GeV/c

Same as seen in PHENIX for minimum bias data!

FIG. 3: Transverse momentum distributions for pions, kaons, and nucleons from a $b = 8$ fm rescattering calculation.

Flattening out of $\frac{dN}{d\eta}$ near $\eta = 0$ due to transformation of Gaussian $\frac{dN}{dy} \rightarrow \frac{dN}{d\eta}$

$\rightarrow$ Flattening seen in PHOBOS

130 GeV Au + Au RESCATTERING CALC.

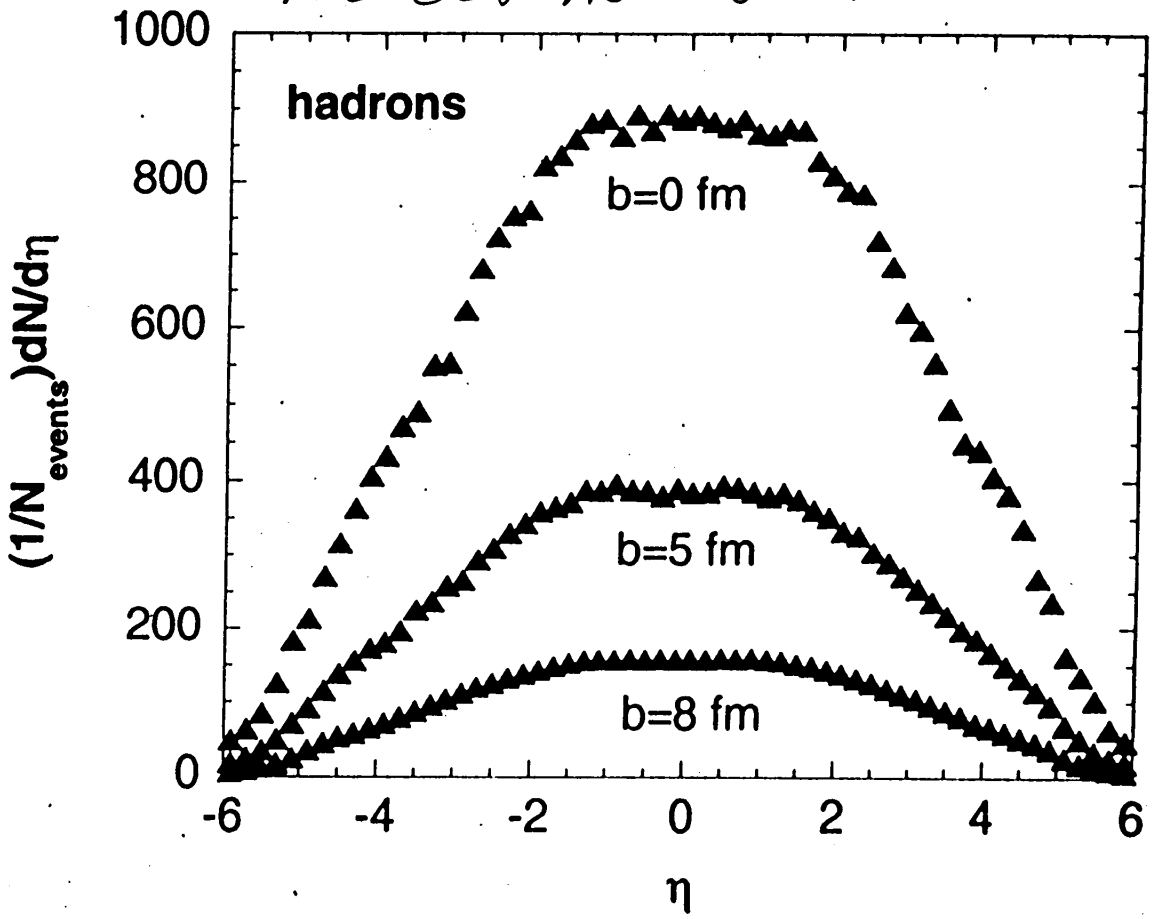
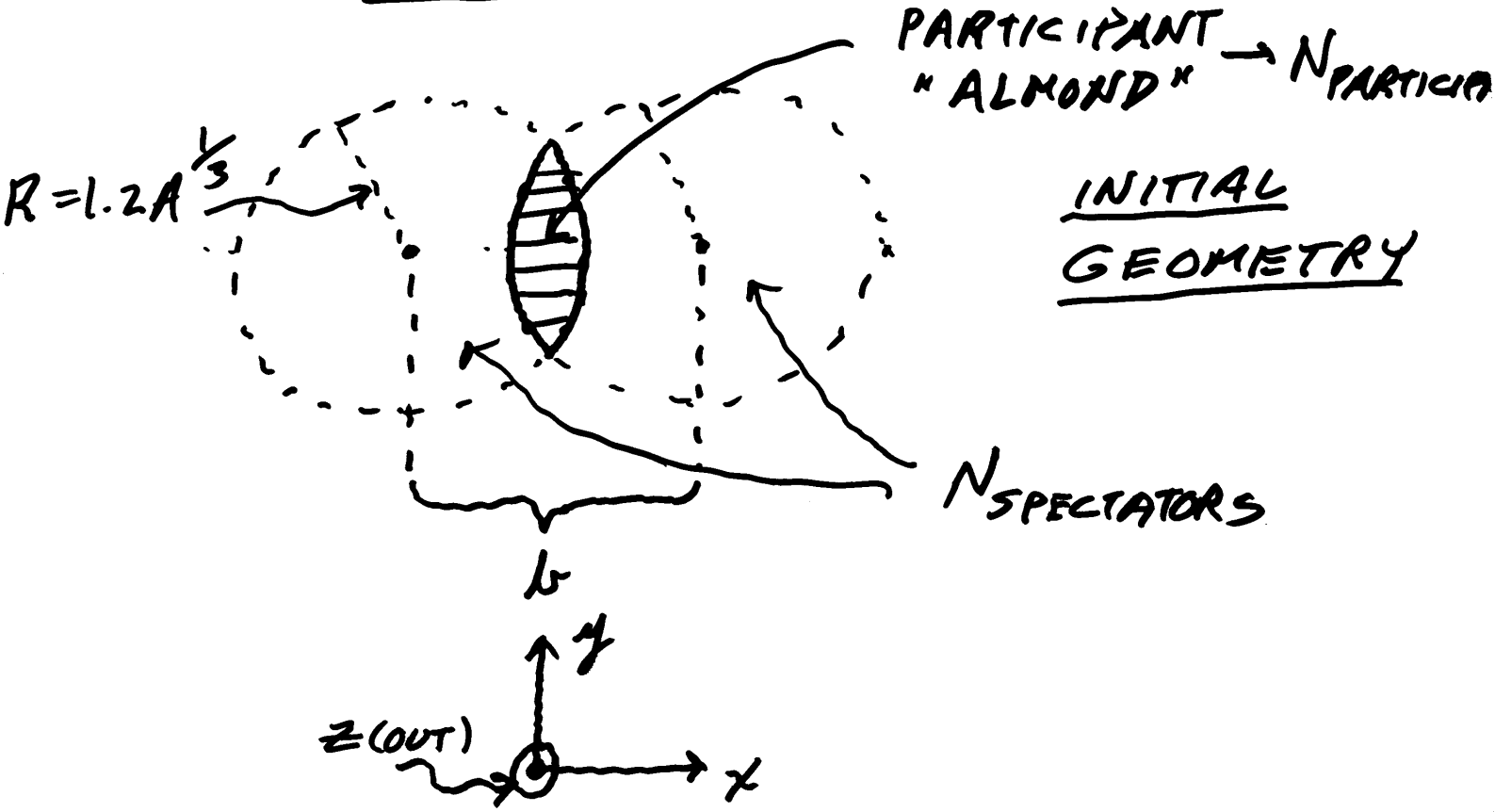


FIG. 1: Pseudorapidity distributions summed over pions, kaons, and nucleons from rescattering calculations for $b = 0, 5$, and 8 fm.

$b > 0$ CALCULATIONS



FOR PARTICLE MULTIPLICITIES, SCALE $\langle m_{b=0} \rangle_i$:

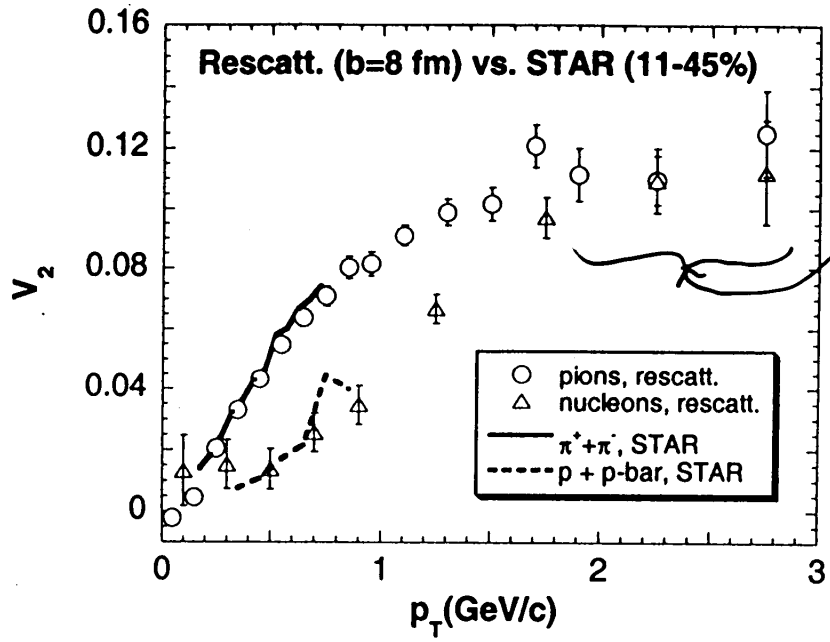
$$\langle m_b \rangle_i = \frac{N_{PARTICIPANTS}}{N_{PARTICIPANTS} + N_{SPECTATORS}} \langle m_{b=0} \rangle_i$$

CALCULATE FOR $b = 5$ fm, 8 fm

ELLIPTIC FLOW VARIABLE:

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

WHERE $\phi = \tan^{-1} \frac{P_y}{P_x}$



Flattening out of v_2 at high p_T as seen in STAR and PHENIX minimum bias hadron data

FIG. 4: Calculations of v_2 from the rescattering model for $b = 8$ fm for pions and nucleons compared with STAR measurements at 11-45% centrality. The plotted points with error bars are the rescattering calculations and the lines show the trends of the STAR measurements. Average errors on the STAR measurements are ≤ 0.002 for pions and 0.006 for protons+antiprotons.

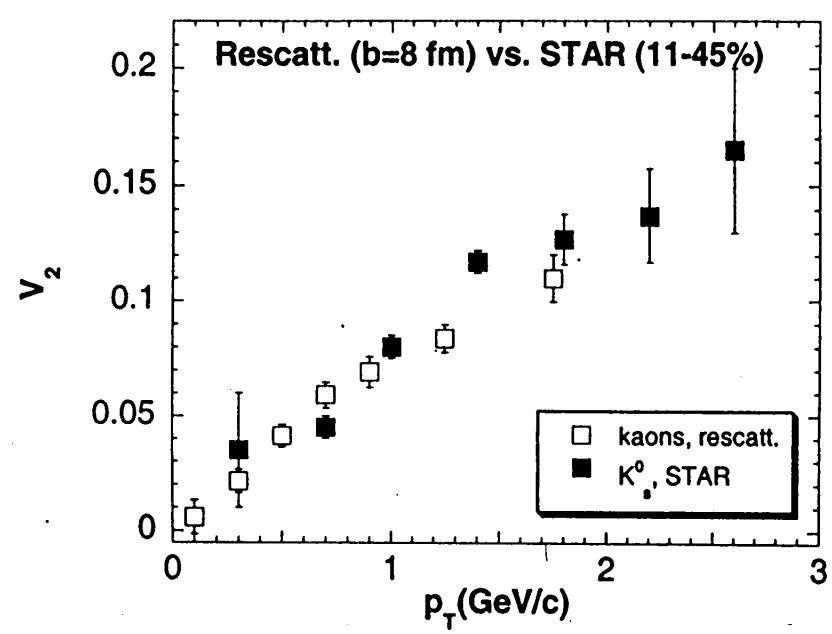


FIG. 5: Calculation of v_2 from the rescattering model for kaons at $b = 8$ fm compared with STAR measurements for $K^0{}_s$ at 11-45% centrality.

HBT RESCATTERING CALCULATION

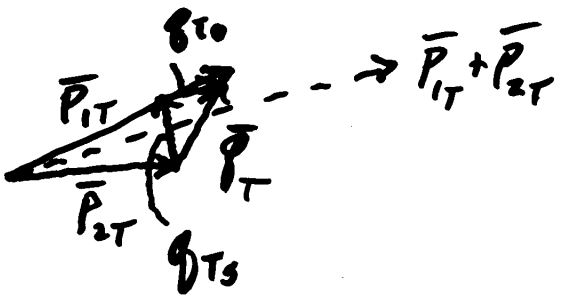
FOR HBT, IMPOSE SYMMETRIZATION ON PION PAIRS $\begin{cases} \bar{r}_i, t_i, \bar{p}_i, m_i \\ \bar{r}_j, t_j, \bar{p}_j, m_j \end{cases}$

$$W(ij) = 1 + \cos\left[(\bar{p}_i - \bar{p}_j)\cdot(\bar{r}_i - \bar{r}_j) - (E_i - E_j)(t_i - t_j)\right]$$

BIN WEIGHTED PAIRS TO FORM CORRELATION FUNCTI

$$C(\bar{q}) = \frac{\sum_{ij(\bar{q})} \frac{dN}{d\bar{p}_i}\frac{dN}{d\bar{p}_j} W(ij)}{\sum_{ij(\bar{q})} \frac{dN}{d\bar{p}_i}\frac{dN}{d\bar{p}_j}}, \quad \bar{q} \equiv \bar{p}_i - \bar{p}_j$$

USE BERTSCH–PRATT VARIABLES (LCMS



$q_{T_{OUT}}, q_{T_{SIDE}}, q_L$

FIT $C(\bar{q})$ WITH GAUSSIAN

$$C_G(\bar{q}) = A\left(1 + \lambda e^{-q_{T_S}^2 R_{T_S}^2 - q_{T_O}^2 R_{T_O}^2 - q_L^2 R_L^2}\right)$$

$\Rightarrow$ GET λ, R_{T_S}, R_{T_O}, R_L

RESCATTERING MODEL
SPS Pb + Pb

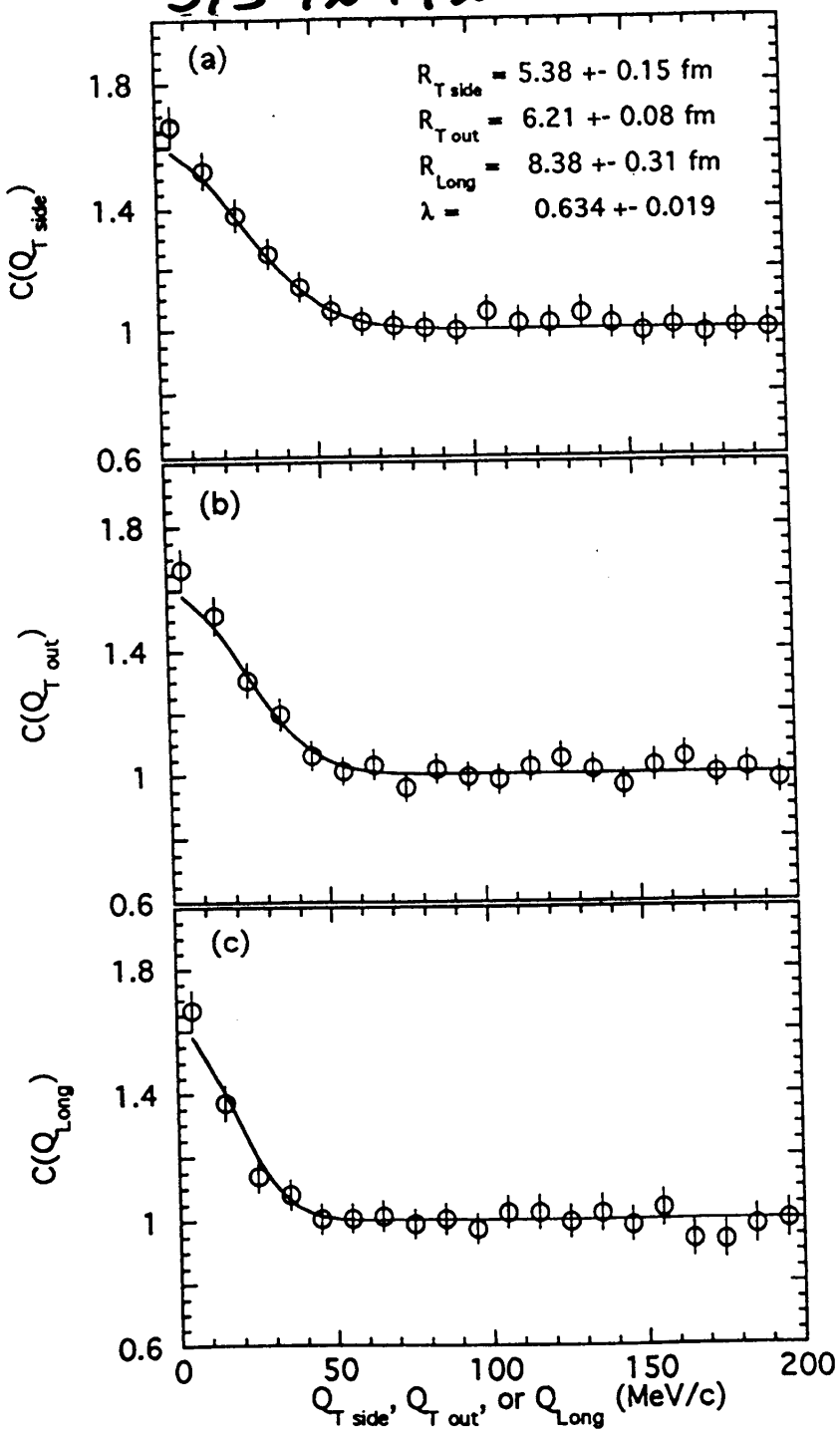


FIG. 8. Projections of the three-dimensional two-pion correla-

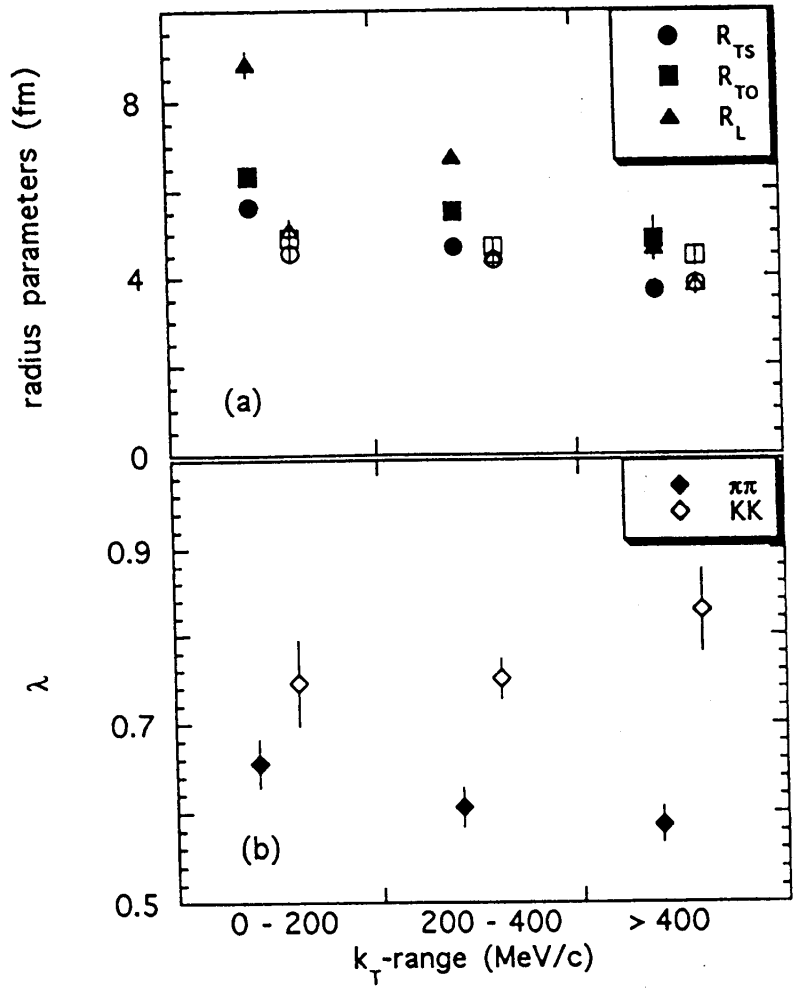


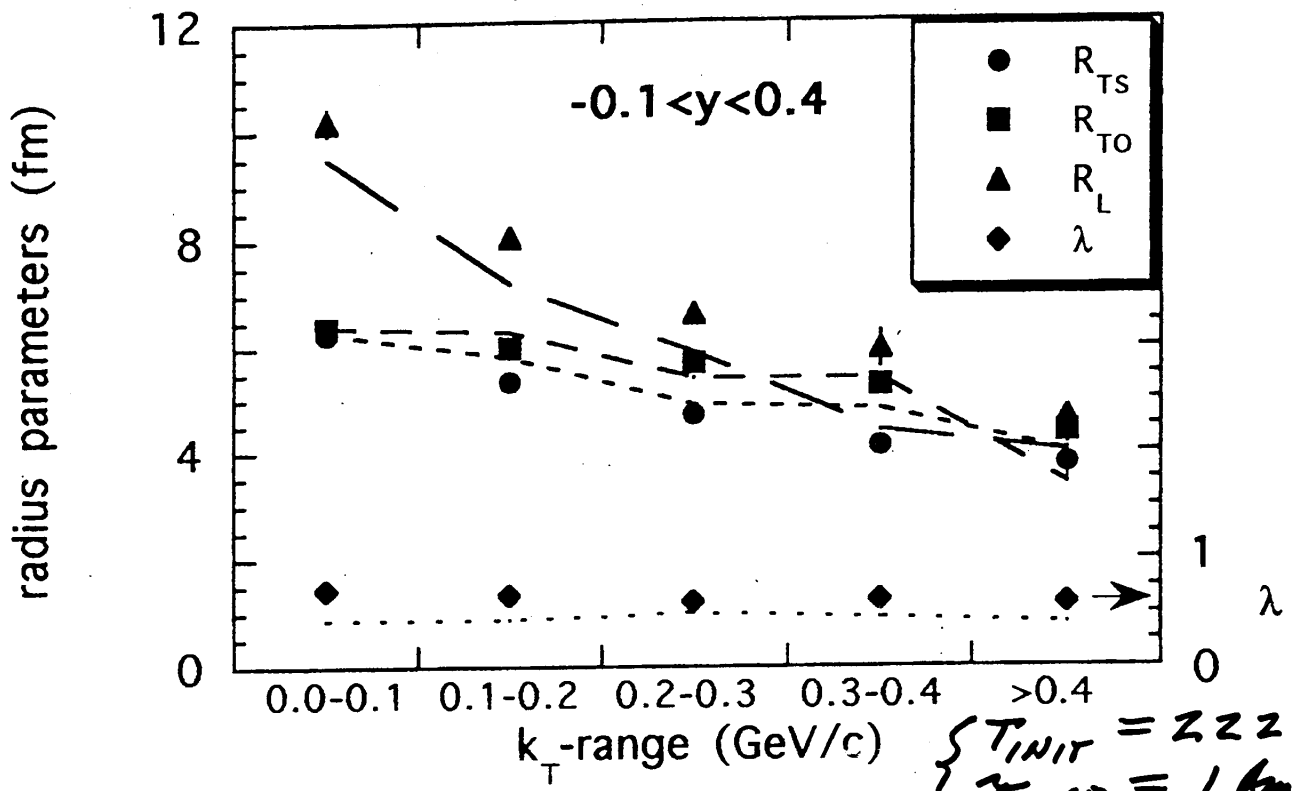
FIG. 9. k_T dependences of pion (solid symbols) and kaon (open symbols) (a) radius and (b) λ parameters extracted at midrapidity $(-1<y<1)$ from the present rescattering calculation.

fit with Eq. (9) has also been superimposed onto the Monte Carlo points, the extracted pion source parameters being displayed in the figure. The pion acceptance used for the calculation of this correlation function was $-1<y<1$ and $p_T<400$ MeV/c, leading to an average k_T ($k_T=|\mathbf{p}_{T_1}+\mathbf{p}_{T_2}|/2$) of about 140 MeV/$c$. The main difference between these source parameters and ones extracted from rescattering cal-

RESCATTERING VS. NA49

→ 160 GeV/n Pb + Pb

HUMANIC, PRC57 (1998)



T_{INIT} = 222 MeV
τ_{HAD} = 1 fm/c

FIG. 11. Comparisons between calculations and NA49 measurements of the k_T dependence of the pion source parameters. The trends of the NA49 measurements are indicated by the dashed lines, which have similar identifications as in Fig. 10.

H. APPELSHÄUSER, PH.D. THESIS (1996)

dences of pion and kaon source parameters extracted at midrapidity ($-1<y<1$) from the present rescattering calculation for central Pb+Pb collisions. Looking at the radius parameters first, there is a general trend for these parameters to decrease with increasing average k_T which is rather strong in the case of pions and weaker for kaons. Comparing the pion and kaon radius parameters at low k_T, the most striking difference seen between them is $R_{\rm long}$ is significantly larger

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of about 140 MeV/c. The main difference between these source parameters and ones extracted from rescattering calculations without resonances [5] is seen in the λ parameter: without resonances $\lambda \approx 1$ and with resonances $\lambda < 1$, in this case about 0.6. As has been pointed out previously [6], this reduction in λ is mainly due to the presence of long-lived resonances (e.g., η and η'). Figure 9 shows the k_T depen-

PRC 57 (98) RESCATTERING MODEL
SPS Pb + Pb

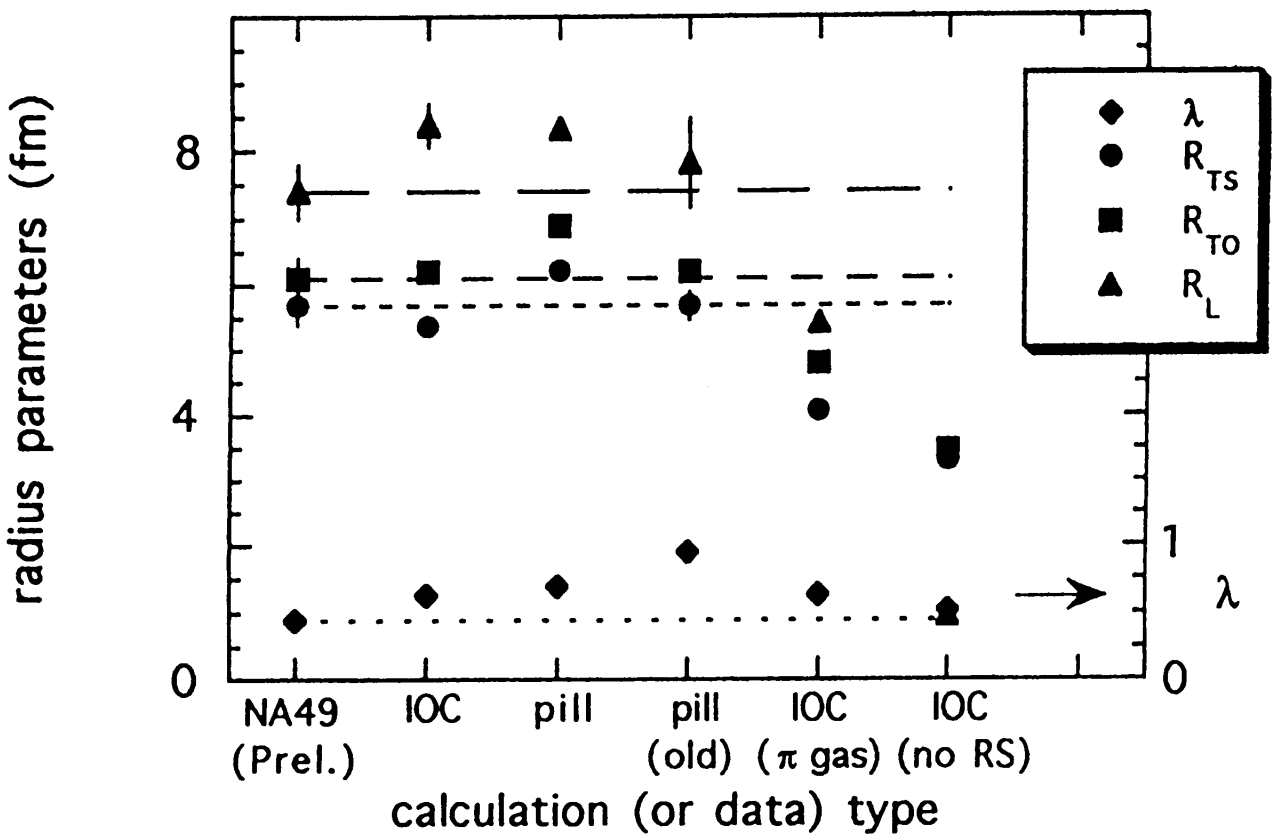


FIG. 10. Comparison between preliminary NA49 experimental pion interferometry results for Pb+Pb for the same average k_T and y range as used in Fig. 8 [10,11] and various rescattering model calculations. The dashed lines are projections of the experimental data points to allow an easier comparison with the calculations.

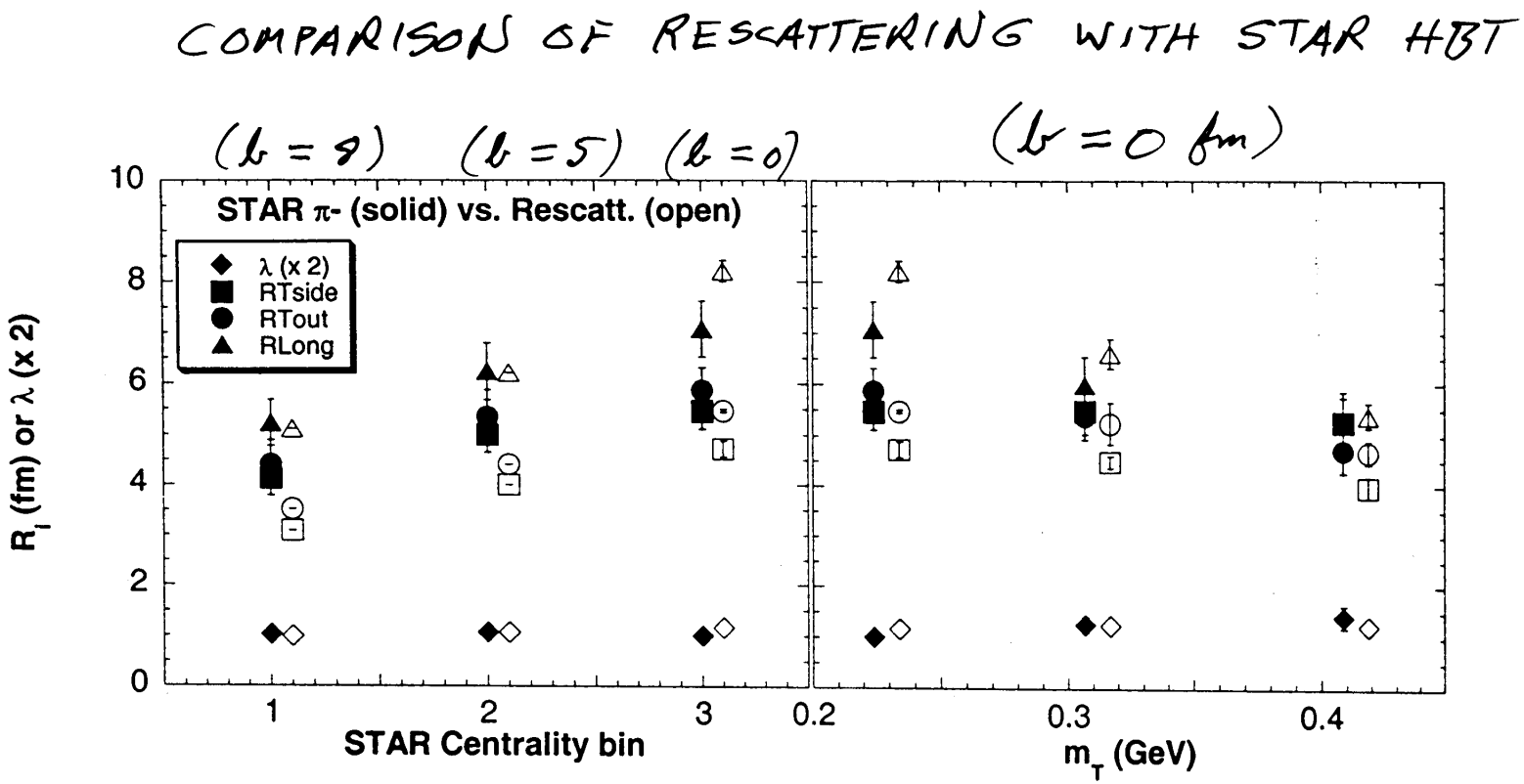
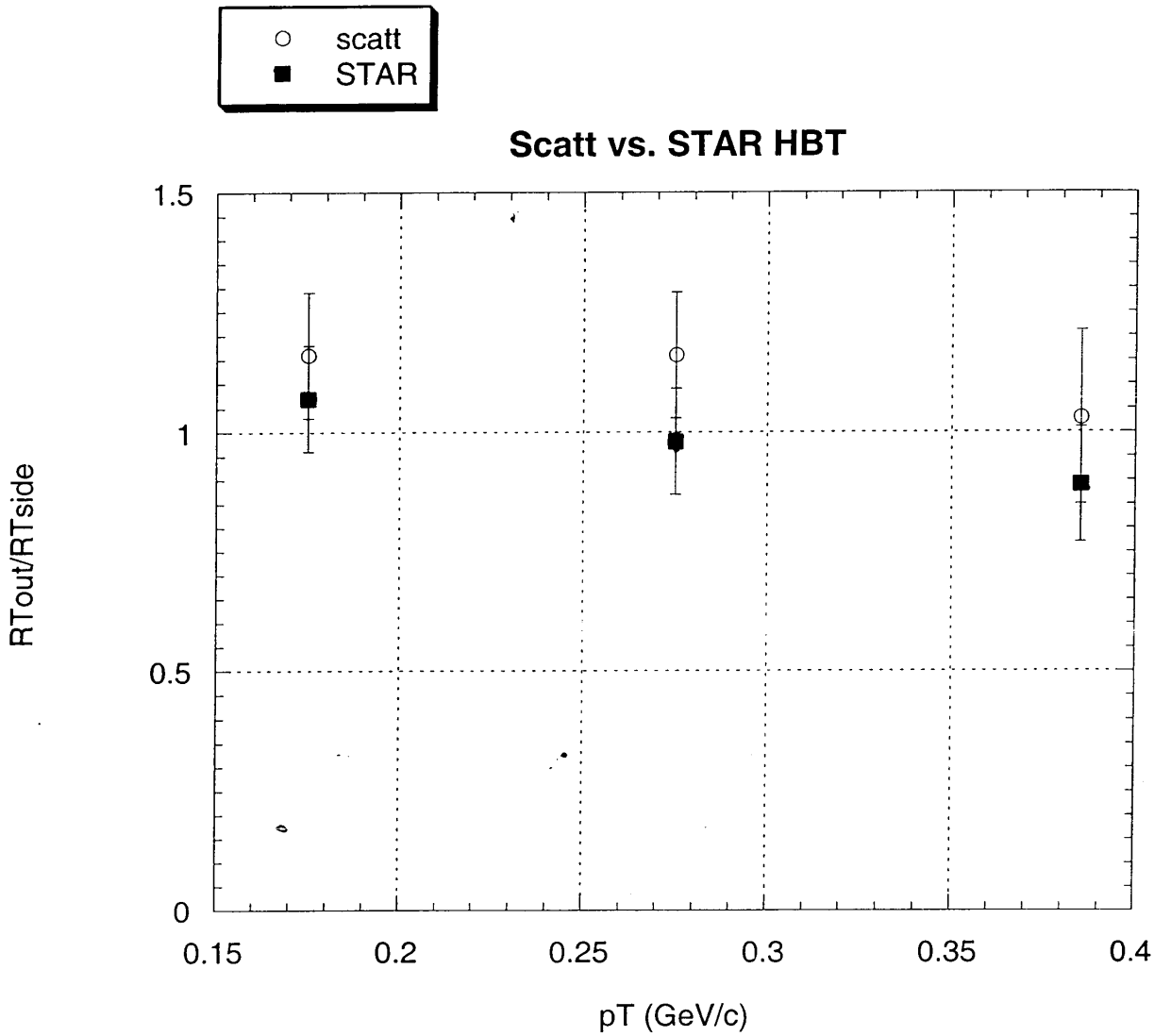


FIG. 3: Comparison of HBT source parameters from rescattering with STAR measurements as a function of centrality [illegible] (see text) and m_T. The STAR measurements are the solid symbols and the rescattering calculations are the open symbols. The errors on the STAR measurements are statistical+systematic.

$b = 0$ RESCATTERING MODEL vs. STAR HBT (CENTRAL TRIGGER)



STAR HBT

● RESCATTERING MODEL

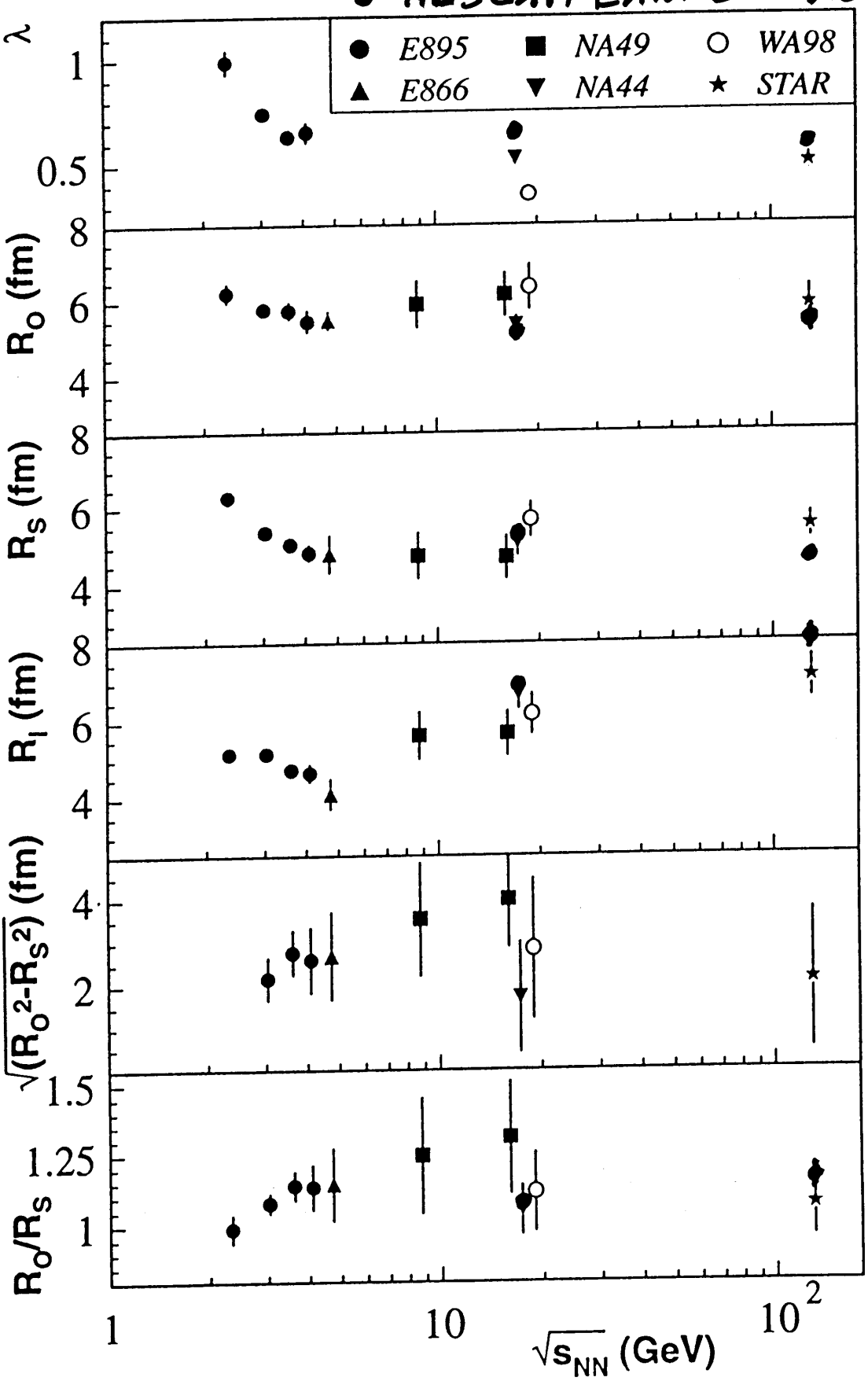


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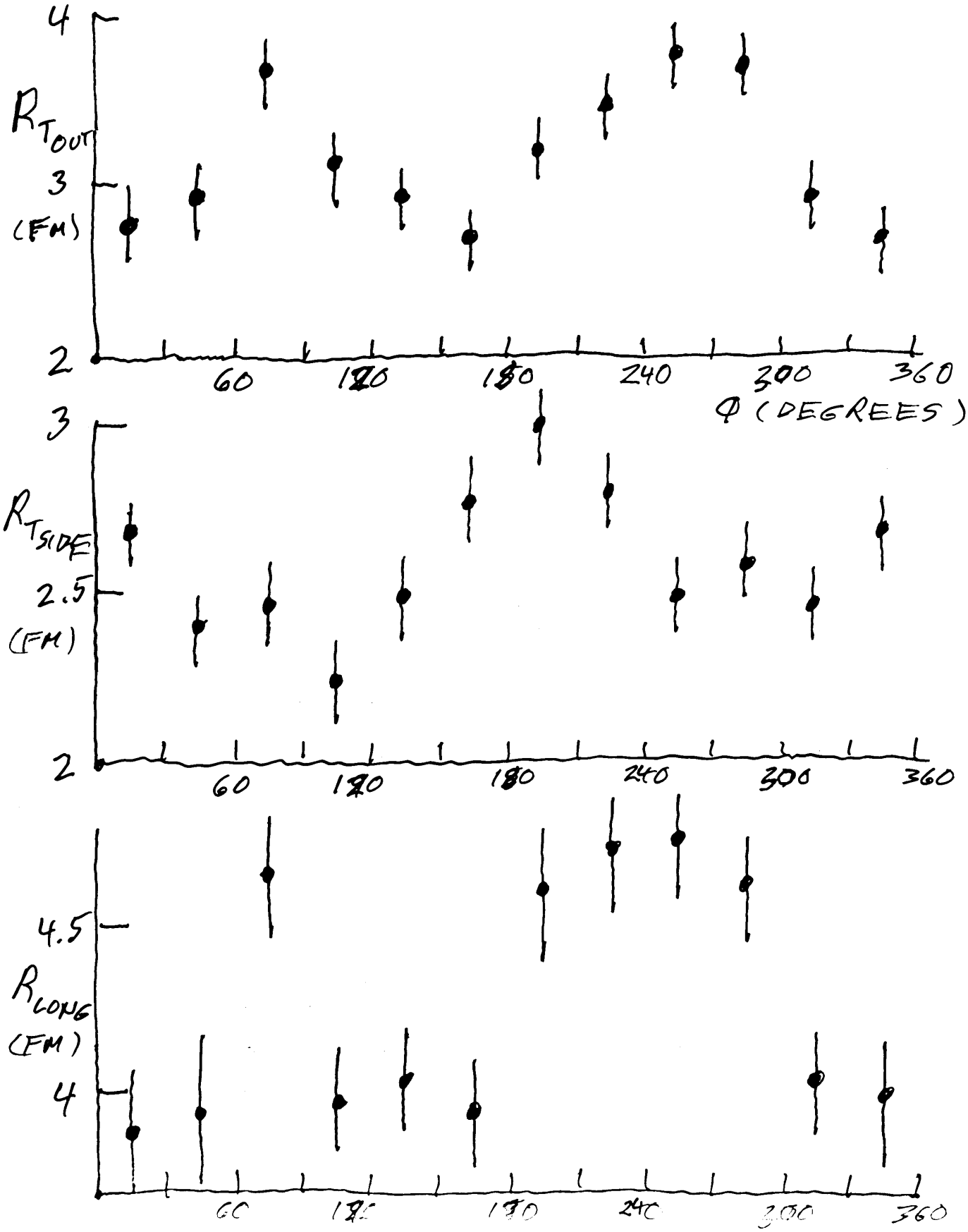
FIG. 3. The energy dependence of π^- HBT parameters for central Au/Au (Pb/Pb) collisions at midrapidity and $p_T \approx$

HBT VS. φ FROM RESCATTERING $b = 8$ FM

(FROM 2AM THIS MORNING CALCULATION) (RHIC 130 GeV



CONCLUSIONS

⇒ THE RESCATTERING MODEL DOES A GOOD JOB AT DESCRIBING

* RADIAL FLOW
* ELLIPTIC FLOW
* HBT

FOR RHIC $\sqrt{s} = 130$ GeV Au+Au DATA

⇒ SUGGESTS THE PRE-HADRON STATE OF THE COLLISION IS SHORT-LIVED ($\tau \sim 1$ FM/c) AND "HOT" ($T \sim 300$ MeV)