STRANGE PARTICLE PRODUCTION IN A SINGLE-FREEZE-OUT MODEL

W. Florkowski [1,2], W. Broniowski [1]

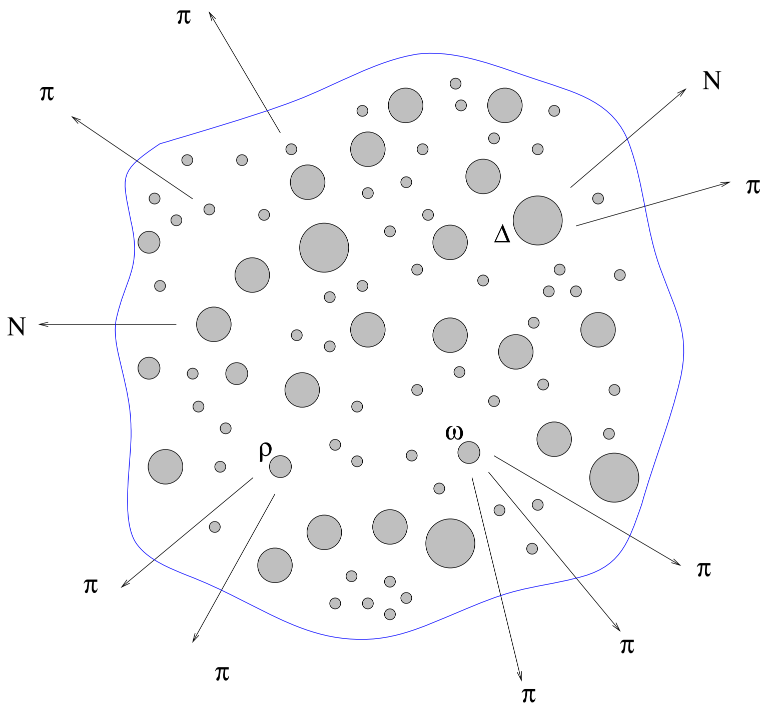
[1] The Henryk Niewodniczański Institute of Nuclear Physics, Kraków, Poland
[2] Institute of Physics, Świętokrzyska Academy, Kielce, Poland

VIIIth International Conference on Strangeness in Quark Matter,
Cape Town, SOUTH AFRICA, 2004

main topic of this talk: transverse-momentum spectra and elliptic flow of multistrange particles produced at RHIC

Thermal model

Koppe (1948), Fermi (1950), Landau, Hagedorn, Rafelski, Letessier, Torrieri, Bjorken, Gorenstein, Gaździcki, Sinyukov, Kostyuk, Heinz, Sollfrank, Braun-Munzinger, Stachel, Redlich, Csörgő, Lörstad, Becattini, Cleymans, Wheaton



$$\sim e^{-(E-\mu)/T}$$

our variant

WB + WF, **PRL 87 (2001) 272302** ($p_\perp$ spectra of pions, kaons, and protons)
WB + WF, **PRC 65 (2002) 064905** ($p_\perp$ spectra of strange particles)
WB + WF + Anna Baran, **AIP 660** (HBT radii and v_2)
WB + WF + Brigitte Hiller, **PRC 68 (2003) 034911** (pion invariant-mass distributions)
Piotr Bożek + WB + WF, **Heavy-Ion Physics (2004)** (pion balance functions)

single freeze-out model

1. $T_{\rm chem} = T_{\rm kin} \equiv T$
2. Complete treatment of resonances
3. Special choice of the freeze-out hypersurface, $\tau = \sqrt{t^2 - x^2 - y^2 - z^2} = \text{const}$
4. Only 4 parameters: T,μ_B (fixed by the ratios of the particle abundances), invariant time at freeze-out τ (controls the overall normalization), transverse size $\rho_{\rm max}$ ($\rho_{\rm max}/\tau$ controls the slopes of the $p_\perp$ spectra)
5. Hubble-like flow, $u^\mu = \frac{x^\mu}{\tau} = \frac{t}{\tau}(1, \frac{x}{t}, \frac{y}{t}, \frac{z}{t})$

definition of the hypersurface not unique! – see papers by Rafelski and Torrieri

the choice $t =$ const, á la Blast-Wave, also possible

Ratios ⟶ Transverse-momentum spectra

initial step: standard analysis of the particle ratios gives T and μ_B (relative normalization), later τ and $\rho_{\max}$ fitted from the spectra (absolute normalization and shape)

recent developments: SHARE - Statistical Hadronization with Resonances, Cracow - Arizona Collaboration supported by the NATO grant, nucl-th/0404083, submitted to Communications in Physics Computing

G. Torrieri, W. Broniowski, J. Letessier, J. Rafelski, and WF

a set of programs in Fortran and Mathematica devoted to the statistical analysis of the ratios of hadron resonances, offered for the community via our web page:

www.physics.arizona.edu/ torrieri/share/share.html

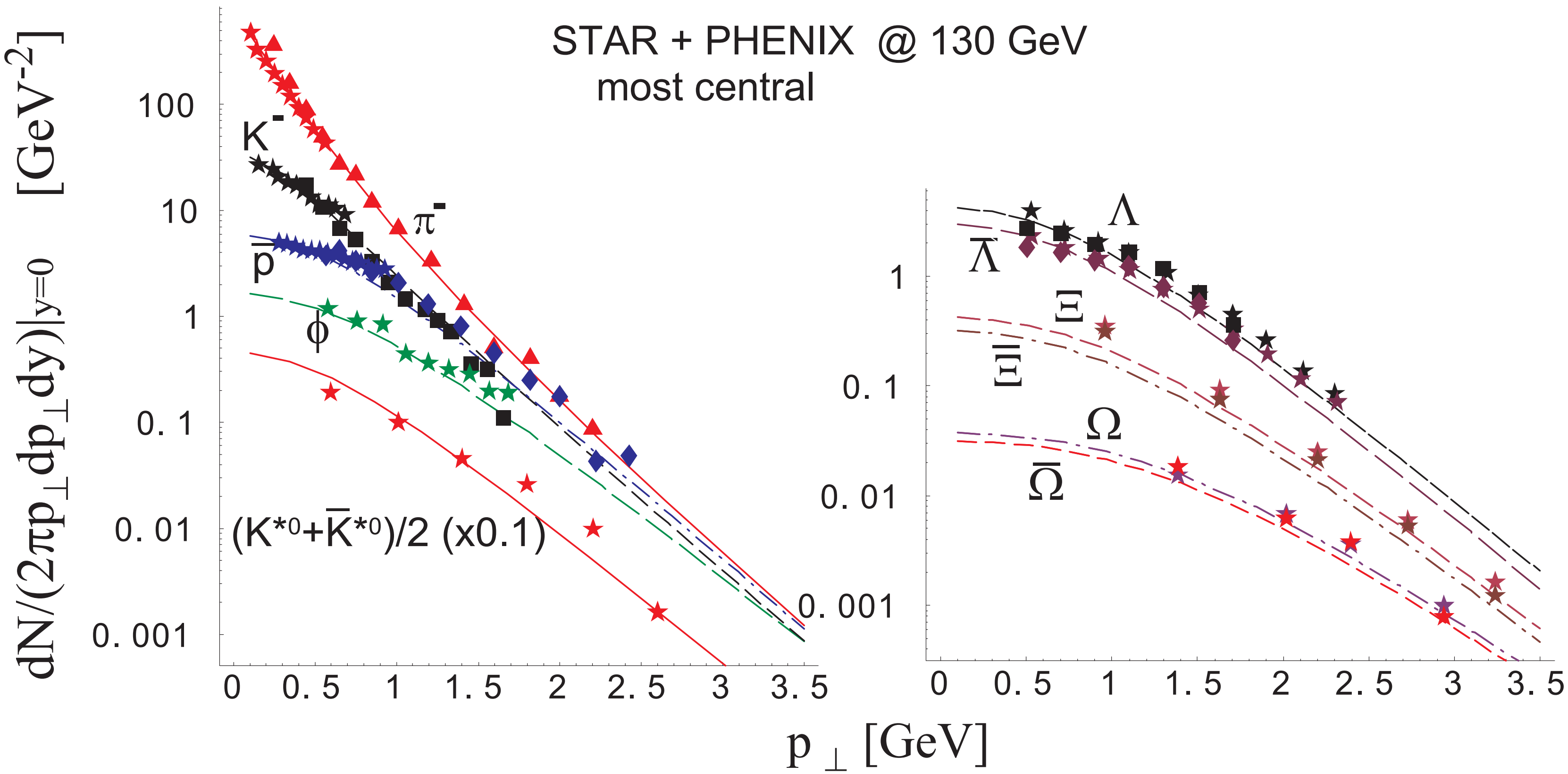
alternative approach: THERMUS - a thermal model package for ROOT

S. Wheaton and J. Cleymans, hep-ph/0407174

2 thermal parameters fitted from particle ratios

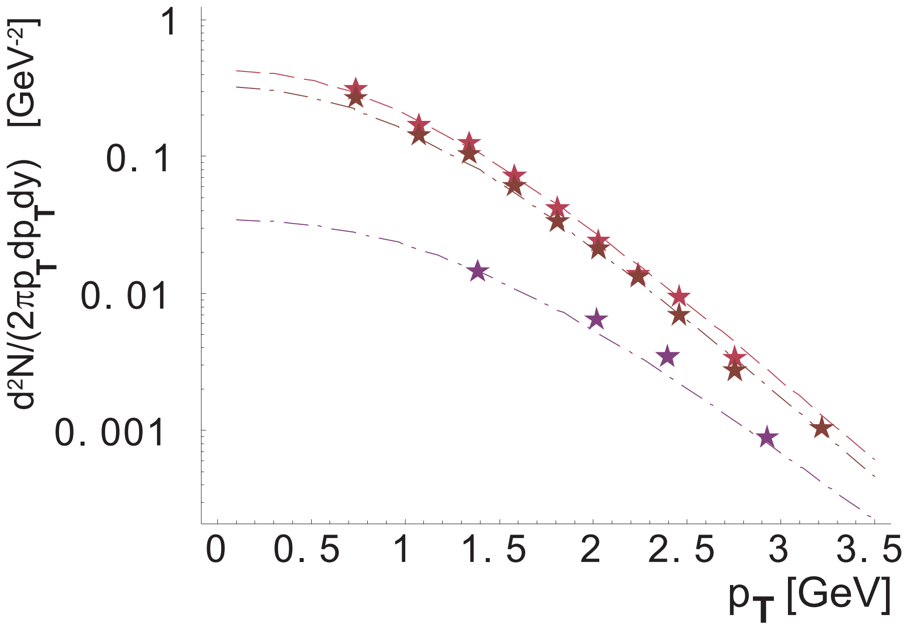
T [MeV] $= 165 \pm 7$, μ_B [MeV] $= 41 \pm 5$, @ 130 GeV
T [MeV] $= 166 \pm 5$, μ_B [MeV] $= 29 \pm 4$, @ 200 GeV

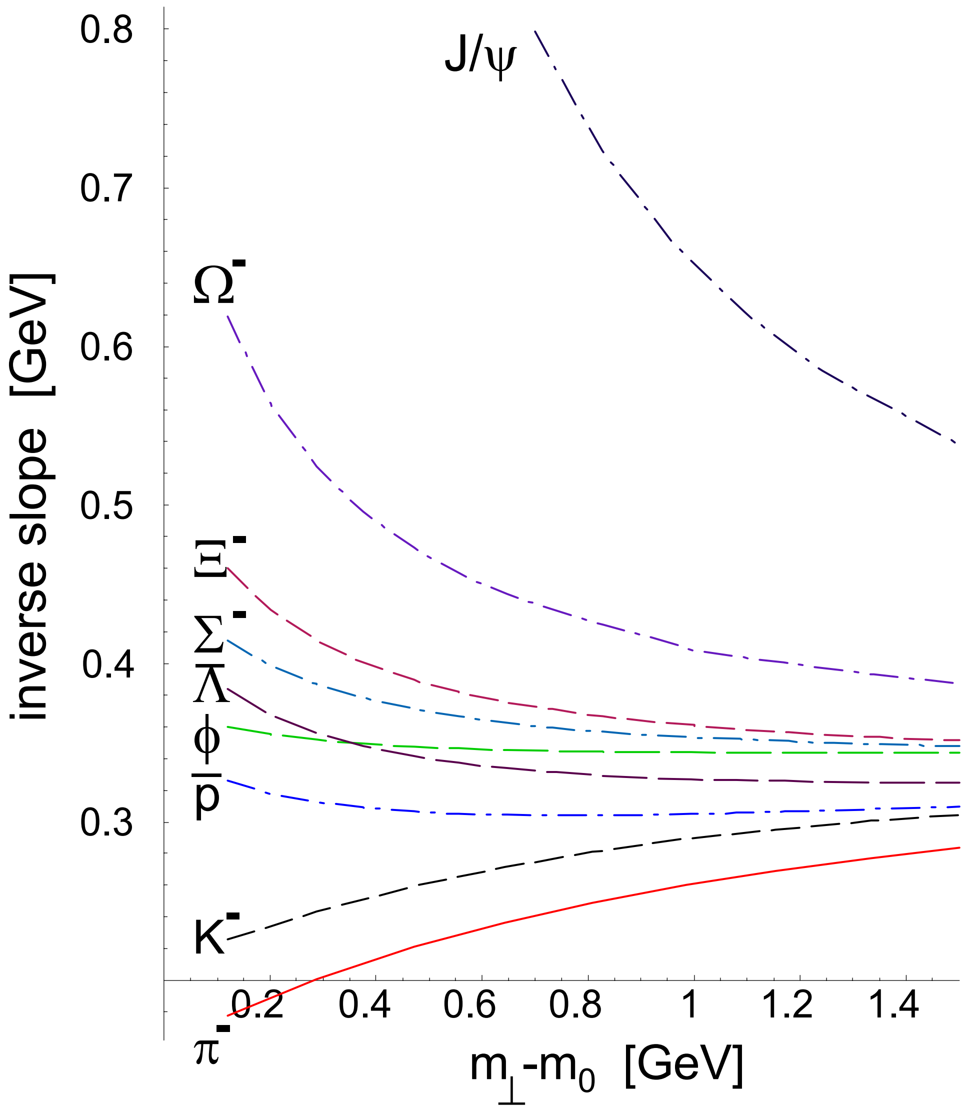
2 geometric parameters fitted from the spectra of $\pi^{\pm}, K^{\pm}, p$, and $\bar{p}$



comparison of our predictions from (2001) with the finally published data, STAR Collaboration, Multi-Strange Baryon Production in Au-Au Collisions at $\sqrt{s_{NN}} = 130$ GeV, J. Adams et al., Phys. Rev. Lett. 92, 182301 (2004)

spectra of Ξ and $\Omega + \bar{\Omega}$



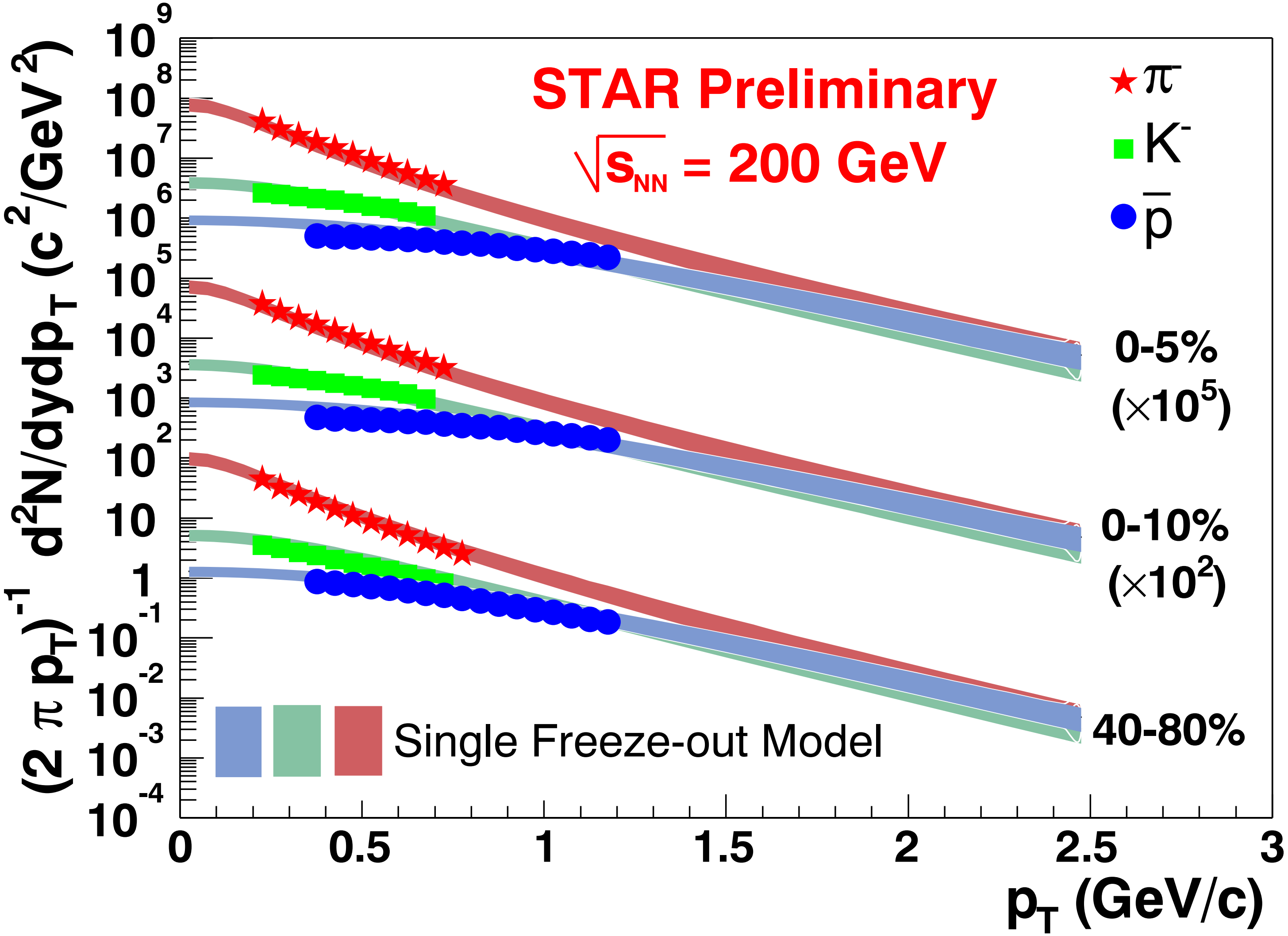


inverse slope [GeV]
0.8
0.7
0.6
0.5
0.4
0.3
J/ψ
Ω⁻
Ξ⁻
Σ⁻
Λ
φ
p̄
K⁻
π⁻
0.2
0.4
0.6
0.8
1
1.2
1.4
m⊥-m0 [GeV]

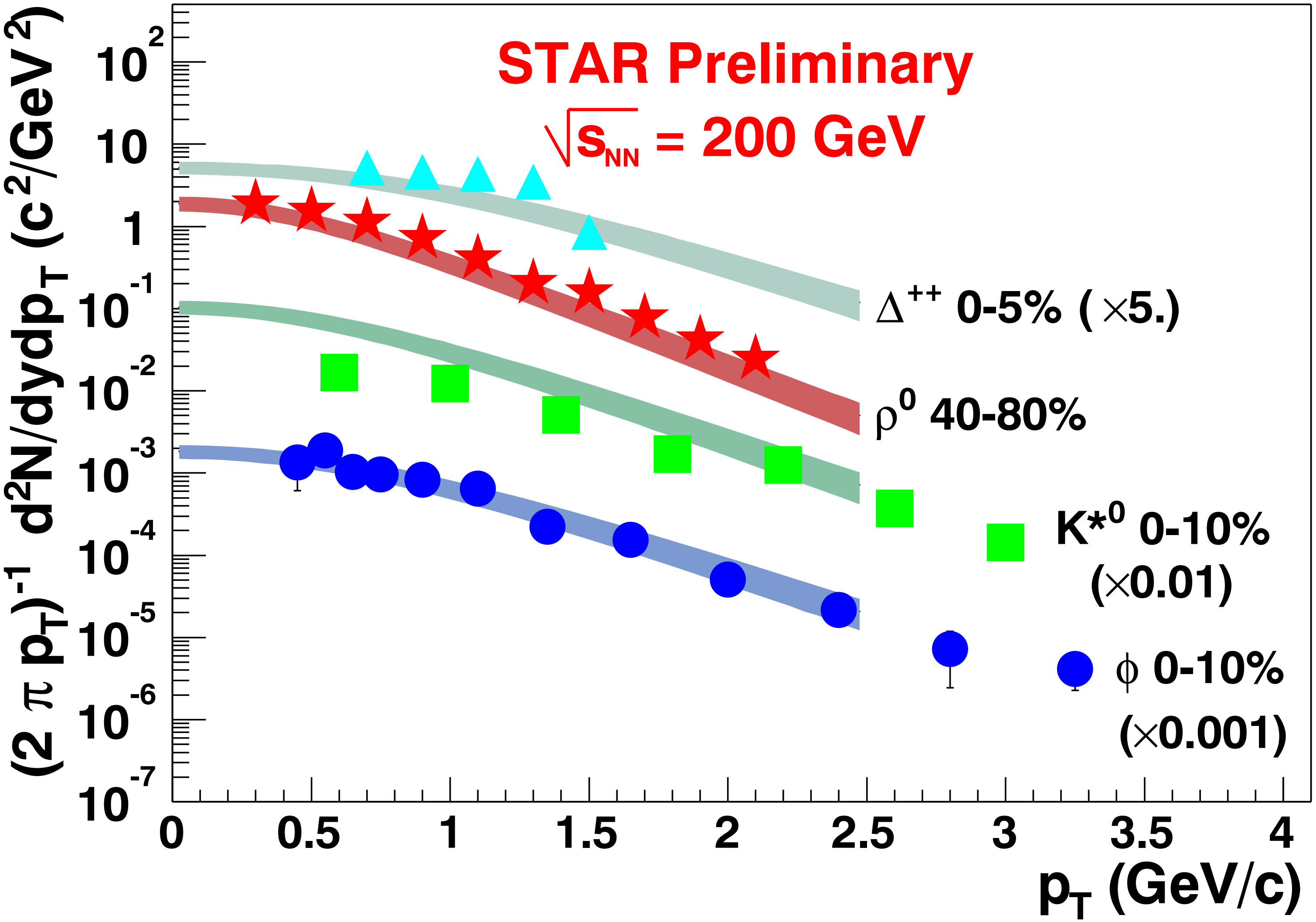
130 ⟶ 200 GeV

STAR spectra vs. single freeze-out model

compiled by Patricia Fachini



compiled by Patricia Fachini

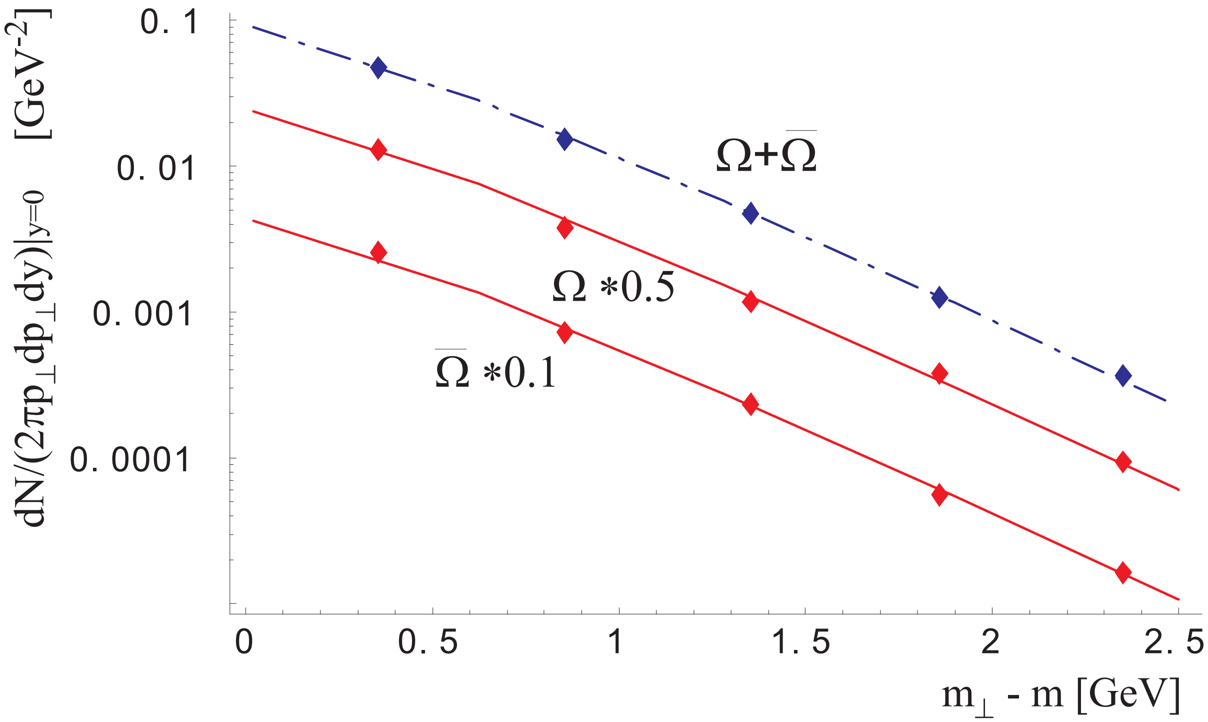


Ratios including resonances

	$m^*_\rho = 770$ MeV	$m^*_\rho = 700$ MeV	Experiment
T [MeV]	$T = 165.6 \pm 4.5$	$T = 167.6 \pm 4.6$	
μ_B [MeV]	$\mu_B = 28.5 \pm 3.7$	$\mu_B = 28.9 \pm 3.8$	
η/π^-	0.120 ± 0.001	0.112 ± 0.001	
ρ^0/π^-	0.114 ± 0.002	0.135 ± 0.001	0.183 ± 0.028 (40-80%)
ω/π^-	0.108 ± 0.002	0.102 ± 0.002	
$K^*(892)/\pi^-$	0.057 ± 0.002	0.054 ± 0.002	
ϕ/π^-	0.025 ± 0.001	0.024 ± 0.001	
η'/π^-	0.0121 ± 0.0004	0.0115 ± 0.0003	
$f_0(980)/\pi^-$	0.0102 ± 0.0003	0.0097 ± 0.0003	0.042 ± 0.021 (40-80%)
$K^*(892)/K^-$	0.33 ± 0.01	0.33 ± 0.01	0.205 ± 0.033 (0-10%) 0.219 ± 0.040 (10-30%) 0.255 ± 0.046 (30-50%) 0.269 ± 0.047 (50-80%)
$\Lambda(1520)/\Lambda$	0.061 ± 0.002	0.062 ± 0.002	0.022 ± 0.010 (0-7%) 0.025 ± 0.021 (40-60%) 0.062 ± 0.027 (60-80%)
$\Sigma(1385)/\Sigma$	0.484 ± 0.004	0.485 ± 0.004	

see talk about the resonance production by Christina Markert on Sunday

Ω spectra from STAR @ 200 GeV



C. Suire, QM2002

Elliptic flow

WB + WF + Anna Baran, Proceedings of the Coimbra Workshop on Hadron Physics, nucl-th/0212053, AIP 660

Ph. D. Thesis by Anna Baran, to be published

when the nuclei collide at non-zero impact parameter, $b \neq 0$, the momentum distribution of the produced particles carries azimuthal asymmetry

$$\left.\frac{dN}{d^2p_\perp dy}\right|_{y=0} = \left.\frac{dN}{2\pi p_\perp dp_\perp dy}\right|_{y=0} (1 + 2\, v_2\, \cos 2\phi + 2\, v_4\, \cos 4\phi + \ldots)$$

experimentally determined centrality may be used to determine b from the geometric formula

$$c \simeq \frac{b^2}{(2R)^2}$$

eccentricity is obtained from the measured values of $R_{\rm side}(\phi)$, STAR Collaboration, nucl-ex/0301005

$$\epsilon = \frac{\langle y\rangle^2 - \langle x\rangle^2}{\langle y\rangle^2 + \langle x\rangle^2}$$

modification of the freeze-out hypersurface (almond shape)

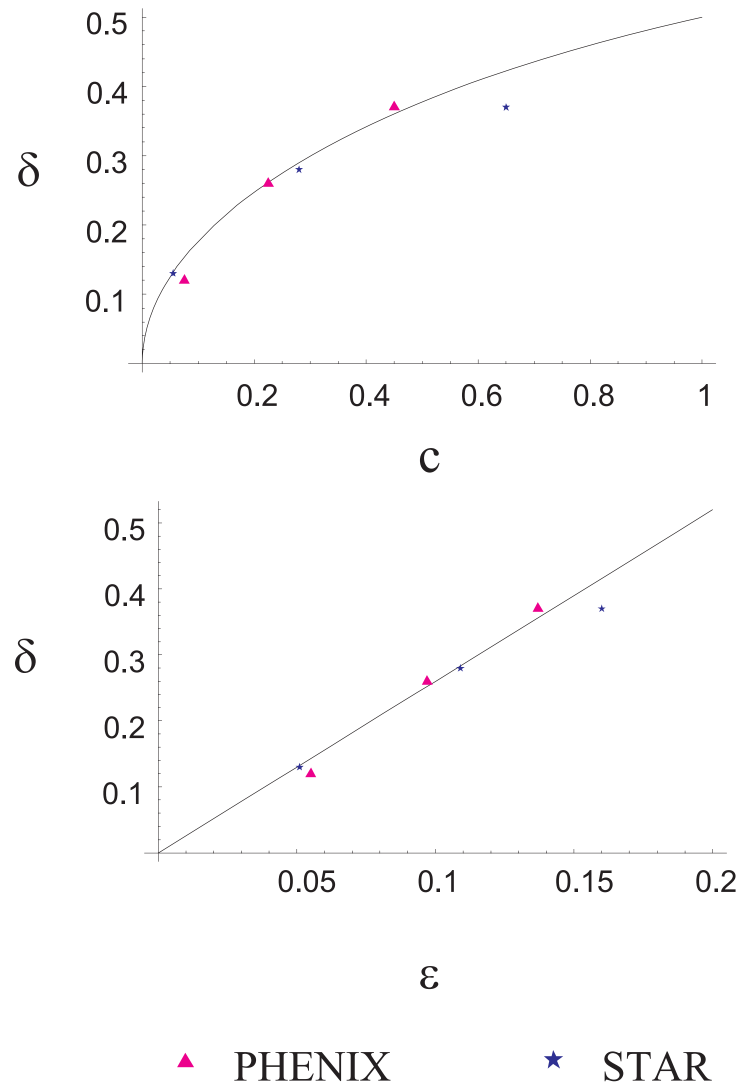
$$\begin{aligned} r_x &= \rho_{\max}\sqrt{1-\epsilon}\,\cos\phi \\ r_y &= \rho_{\max}\sqrt{1+\epsilon}\,\sin\phi \end{aligned}$$

modification of the flow profile (stronger in-plane)

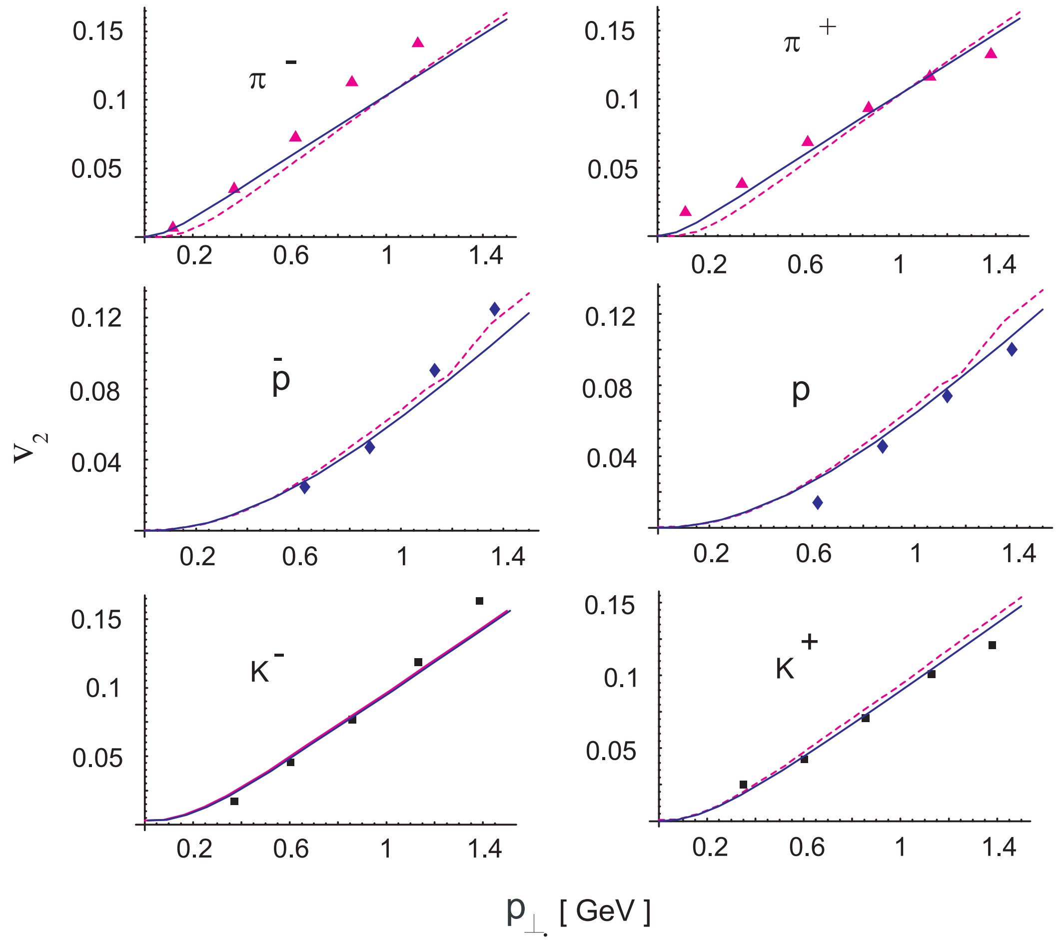
$$\begin{aligned} u_x &= \frac{r_x}{N}\sqrt{1+\delta}\,\cos\phi \\ u_y &= \frac{r_y}{N}\sqrt{1-\delta}\,\sin\phi \\ u_z &= \frac{r_z}{N} \\ u_t &= \frac{t}{N} \end{aligned}$$

N obtained from the normalization condition $u^\mu u_\mu = 1$

results of the fit procedure of v_2 for pions, kaons, and protons

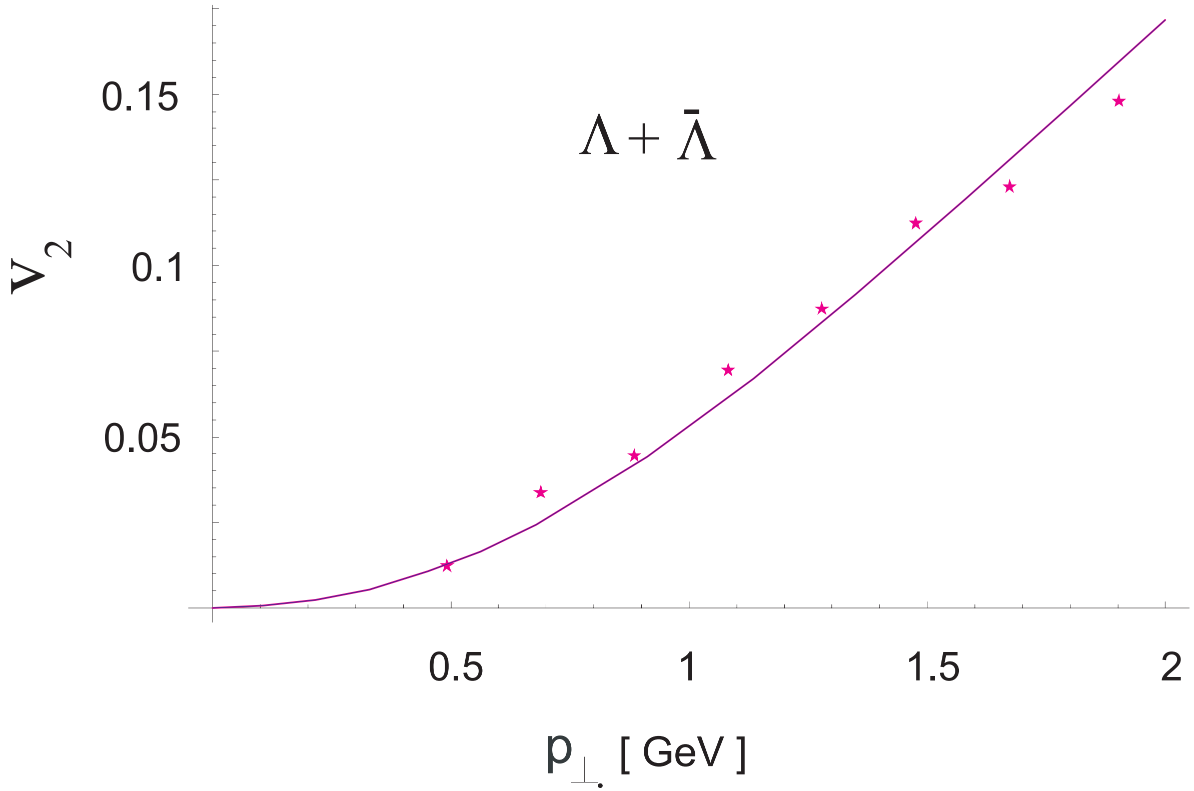


preliminary minimum bias data from PHENIX @ 200 GeV
S. A. Voloshin, Nucl. Phys. **A715** (2003) 379c



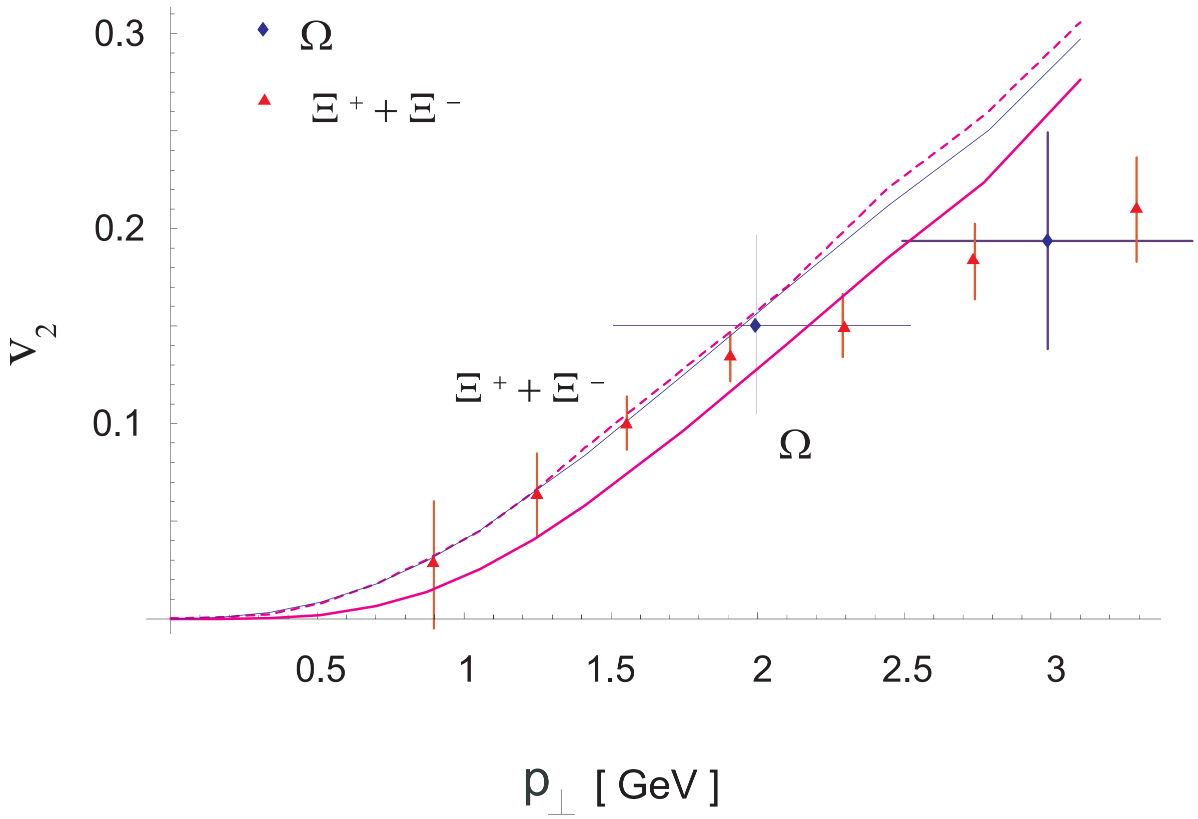
single-freeze-out model fit: $T = 165$ MeV, $\mu_B = 26$ MeV (from the ratios), $\tau = 4.04$ fm, $\rho_{\max} = 3.70$ fm (from the spectra), $\epsilon = 0.13$, $\delta = 0.25$ (from v_2)

minimum bias (0-80%) data from STAR @ 200 GeV, PRL 92 (2004) 052302



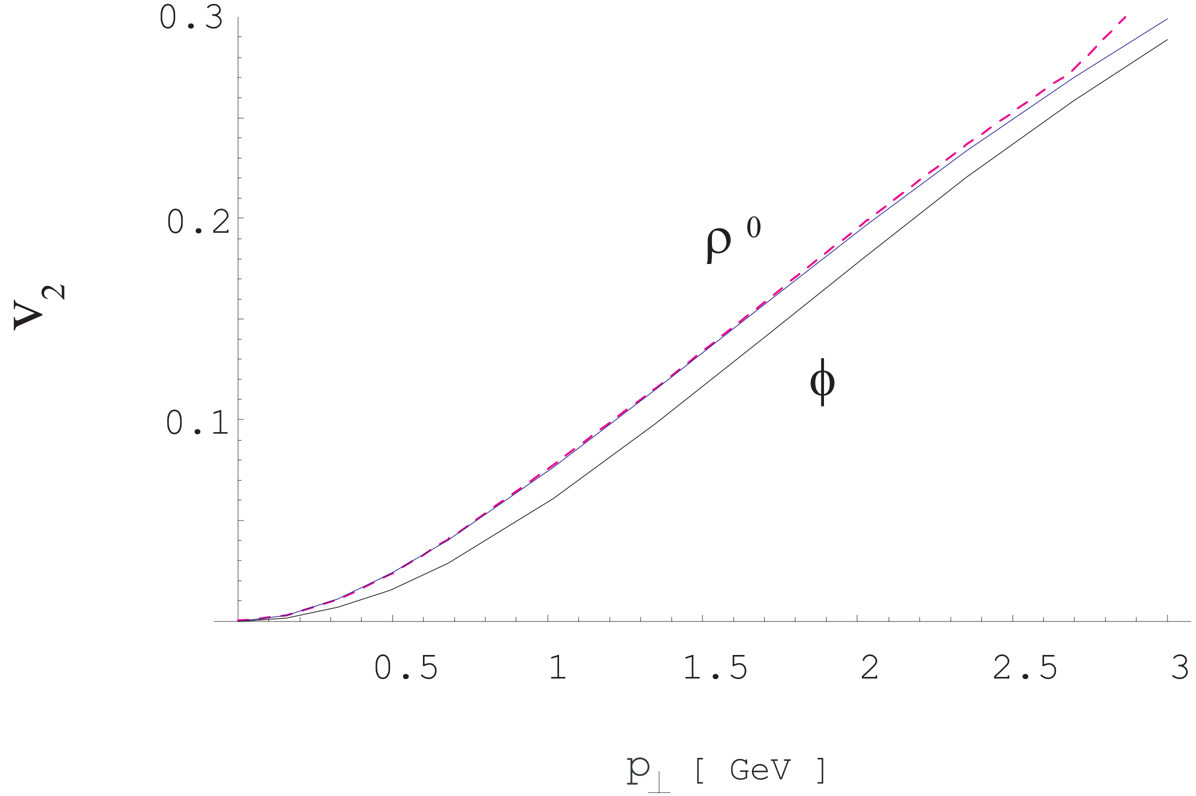
model parameters as above

the first measurement of the elliptic flow for multistrange baryons, J. Castillo, contribution to QM04, J. Phys. G30 (2004) S1207



model parameters as above

again with the same parameters predictions for ρ and ϕ



Summary

1. Production of strange particles is well described in a thermal model with single freeze-out

2. Thermodynamic parameters are determined from the ratios of hadron abundances, whereas the expansion parameters are determined from the spectra of pions, kaons, and protons. Then, the predictions about the transverse-momentum spectra and v_2 are made for strange particles

3. Single freeze-out model yields $R_{\rm out}/R_{\rm side} \approx 1$, and describes well pion invariant masses and balance functions

Back-up slides

The phase-shift formula for the density of resonances

Beth,Uhlenbeck (1937); Dashen, Ma, Bernstein, Rajaraman; **Weinhold, Friman, Nörenberg**; WB+WF+BH, PRC 68 (2003) 034911; Pratt, Bauer, nucl-th/0308087

$$\frac{dn}{dM} = f \int \frac{d^3p}{(2\pi)^3} \frac{d\delta_{12}(M)}{\pi dM} \frac{1}{\exp\left(\frac{\sqrt{M^2+\boldsymbol{p}^2}}{T}\right) \pm 1}$$

In some works the spectral function of the resonance is used instead of the derivative of the phase shift. For narrow resonances this does not make a difference, since then $d\delta_{12}(M)/dM \simeq \pi\delta(M - m_R)$, and

$$n^{\text{narrow}} = f \int \frac{d^3p}{(2\pi)^3} \frac{1}{\exp\left(\frac{\sqrt{m_R^2+\boldsymbol{p}^2}}{T}\right) \pm 1}$$

For wide resonances, or for effects of tails, the difference between the correct formula and the one with the spectral function is significant

Concept of the balance functions

S. Bass, P. Danielewicz, and S. Pratt, PRL 85 (2000) 2689

$$B(\delta, Y) = \frac{1}{2}\left\{ \frac{\langle N_{+-}(\delta)\rangle - \langle N_{++}(\delta)\rangle}{\langle N_{+}\rangle} + \frac{\langle N_{-+}(\delta)\rangle - \langle N_{--}(\delta)\rangle}{\langle N_{-}\rangle} \right\}$$

N_{+-} and N_{-+} numbers of the unlike-sign pairs

N_{++} and N_{--} numbers of the like-sign pairs

two members of a pair fall into the rapidity window Y, their relative rapidity is

$$\delta = \Delta y = |y_2 - y_1|$$

N_{+} (N_{-}) number of positive (negative) particles in the interval Y

Two contributions for the $\pi^+\pi^-$ balance function

1) RESONANCE CONTRIBUTION (R) is determined by the decays of neutral hadronic resonances which have a $\pi^+\pi^-$ pair in the final state

$$K_S,\ \eta,\ \eta',\ \rho^0,\ \omega,\ \sigma,\ f_0$$

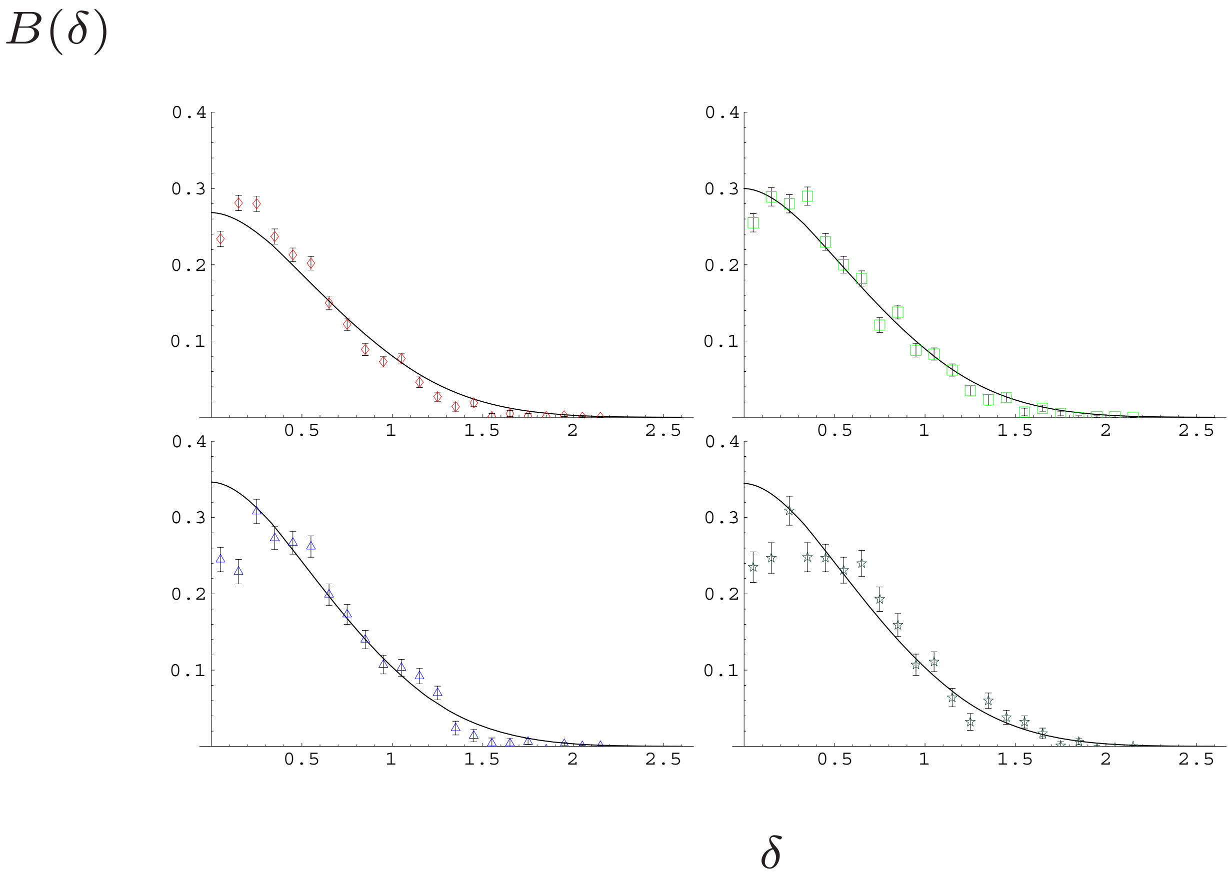
2) NON-RESONANCE CONTRIBUTION (NR) other possible correlations among the charged pions

   in our approach the non-resonance two-particle distribution is determined by the local relative thermal momenta of particles

The pion balance function is constructed as a sum of the two terms

$$B(\delta, Y) = B_{\mathrm{R}}(\delta, Y) + B_{\mathrm{NR}}(\delta, Y)$$

Fit to the STAR data



four different centralities: 0-10%, 10-40%, 40-70%, 70-96%

rescaling factors: 0.40, 0.44, 0.51, 0.51 (χ^2 fits)

poor man's way of taking into account the detector efficiency