Thermal model at RHIC

WB + W. Florkowski + A. Baran

The H. Niewodniczański Institute of Nuclear Physics

BRAHMS Collaboration Meeting - Physics Day
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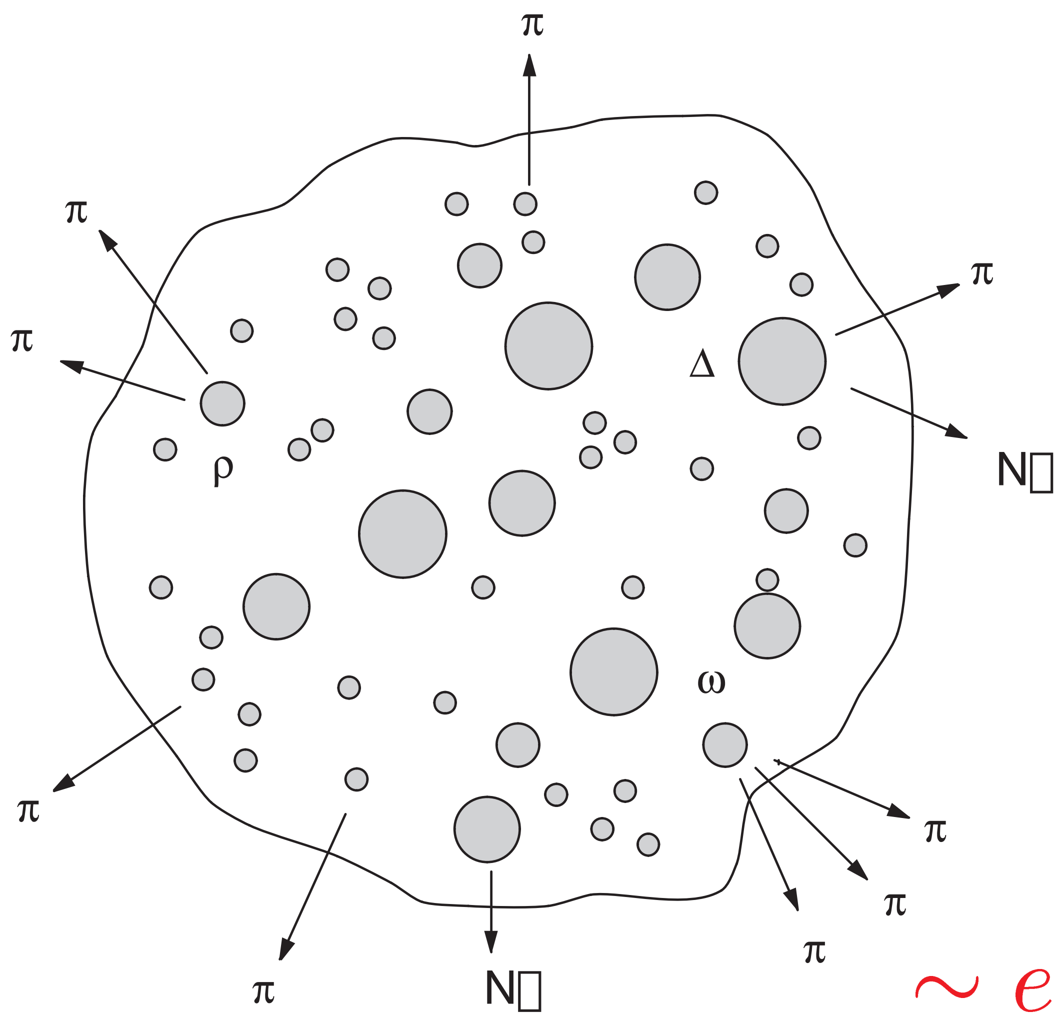


$$\sim e^{-(E-\mu)/T}$$

Thermal model

Koppe (1948), Fermi (1950), Landau, Hagedorn, Rafelski, Bjorken, Gorenstein, Gaździcki, Heinz, Braun-Munzinger, Stachel, Redlich, Magestro, Csörgő, Becattini, Cleymans, Letessier,...

WB+WF, Phys. Rev. Lett. 87:272302, 2001; Phys. Rev. C65:064905, 2002 (the model @ 130 GeV)
WB + A. Baran + WF, Acta Phys. Polon. B33:4235, 2002 (review)
A. Baran + WB + WF, nucl-th/0305075 (spectra @ 200 GeV)

- $T_{\rm chem} = T_{\rm kin} \equiv T$ (single freeze-out)
- Complete treatment of resonances
- Expansion
- 4 parameters: T,μ_B (fixed by the ratios of the particle abundances), τ (controls the overall normalization), $\rho_{\rm max}$ (transverse size), the ratio $\rho_{\rm max}/\tau$ (controls the slopes of the $p_\perp$ spectra)
- Hubble-like flow, $u^\mu = x^\mu/\tau$

(not unique)

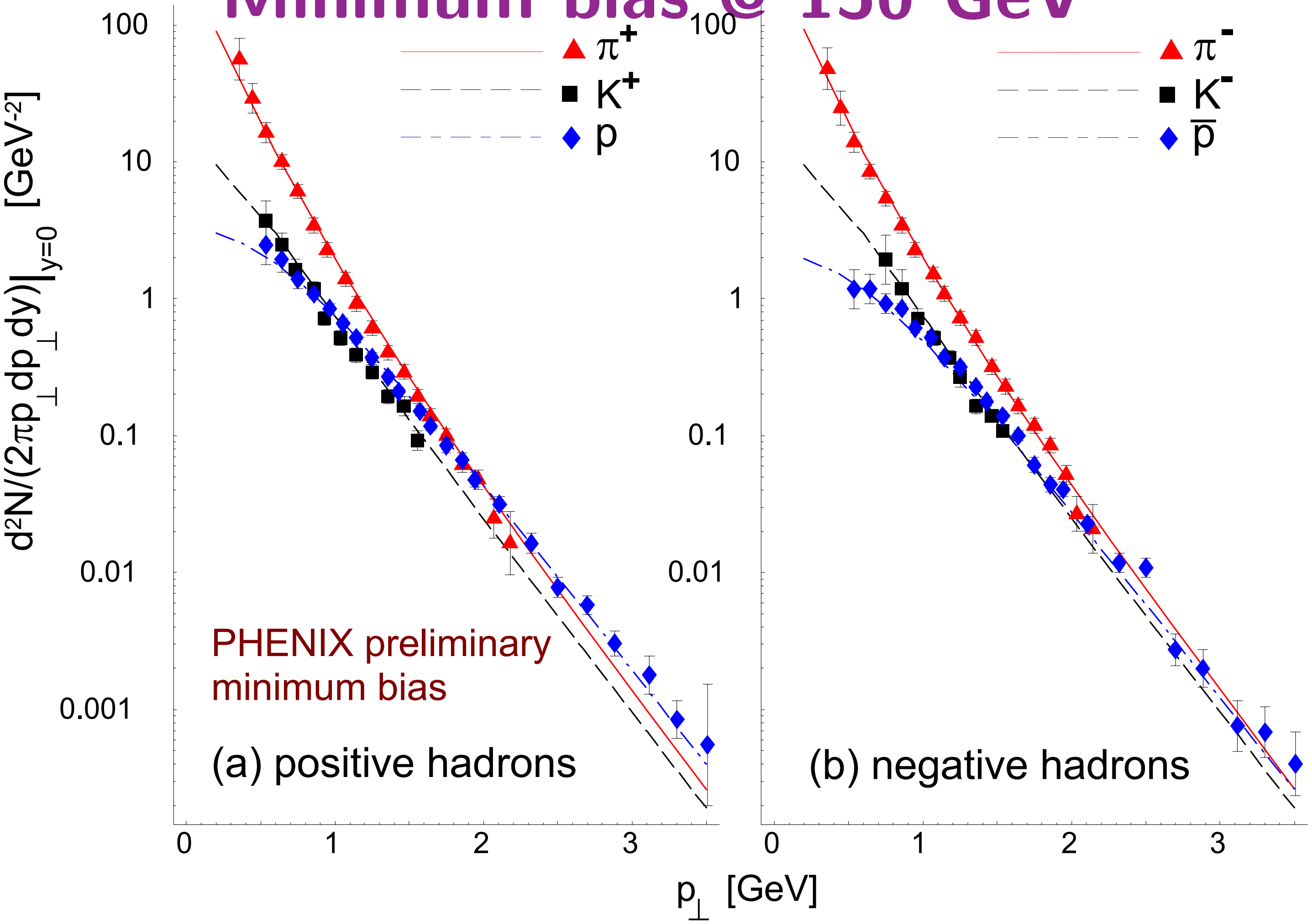
Particle ratios @ 200 GeV

Fitted thermal parameters

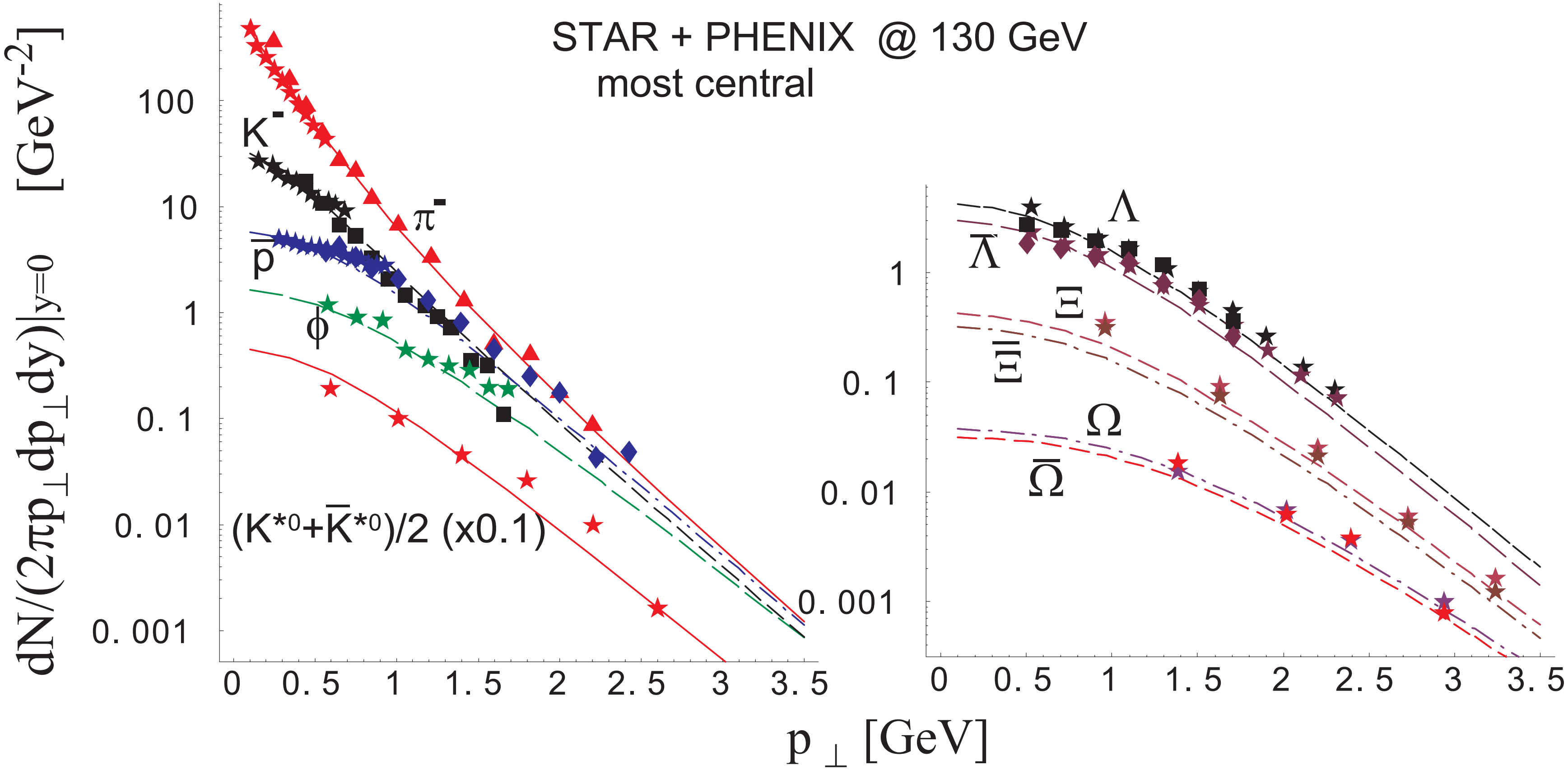
T [MeV]	160 ± 5
μ_B [MeV]	26 ± 4
μ_S [MeV]	5
μ_I [MeV]	-1
χ^2/n	1.5

Ratios used in the thermal analysis		
π^-/π^+	1.015	$1.025 \pm 0.006 \pm 0.018$ (0-12%) $1.02 \pm 0.02 \pm 0.10$ (0-5%)
K^-/K^+	0.95	$0.95 \pm 0.03 \pm 0.03$ (0-12%) $0.92 \pm 0.03 \pm 0.10$ (0-5%)
$\overline{p}/p$	0.74	$0.73 \pm 0.02 \pm 0.03$ (0-12%) $0.70 \pm 0.04 \pm 0.10$ (0-5%) 0.78 ± 0.05 (0-5%)
$\overline{p}/\pi^-$	0.089	0.083 ± 0.015 (0-5%)
K^-/π^-	0.174	0.156 ± 0.020 (0-5%)
$\Omega/h^- \times 10^3$	0.841	$0.887 \pm 0.111 \pm 0.133$ (0-10%)
$\overline{\Omega}/h^- \times 10^3$	0.740	$0.935 \pm 0.105 \pm 0.140$ (0-10%)
$K^*(892)/\pi^-$	0.055	$0.030 \pm 0.004 \pm 0.007$ (0-20%)
$K^*(892)/K^-$	0.32	$0.19 \pm 0.02 \pm 0.05$ (0-20%)
$\phi/K^*(892)$	0.44	$0.63 \pm 0.10 \pm 0.16$ (0-20%)

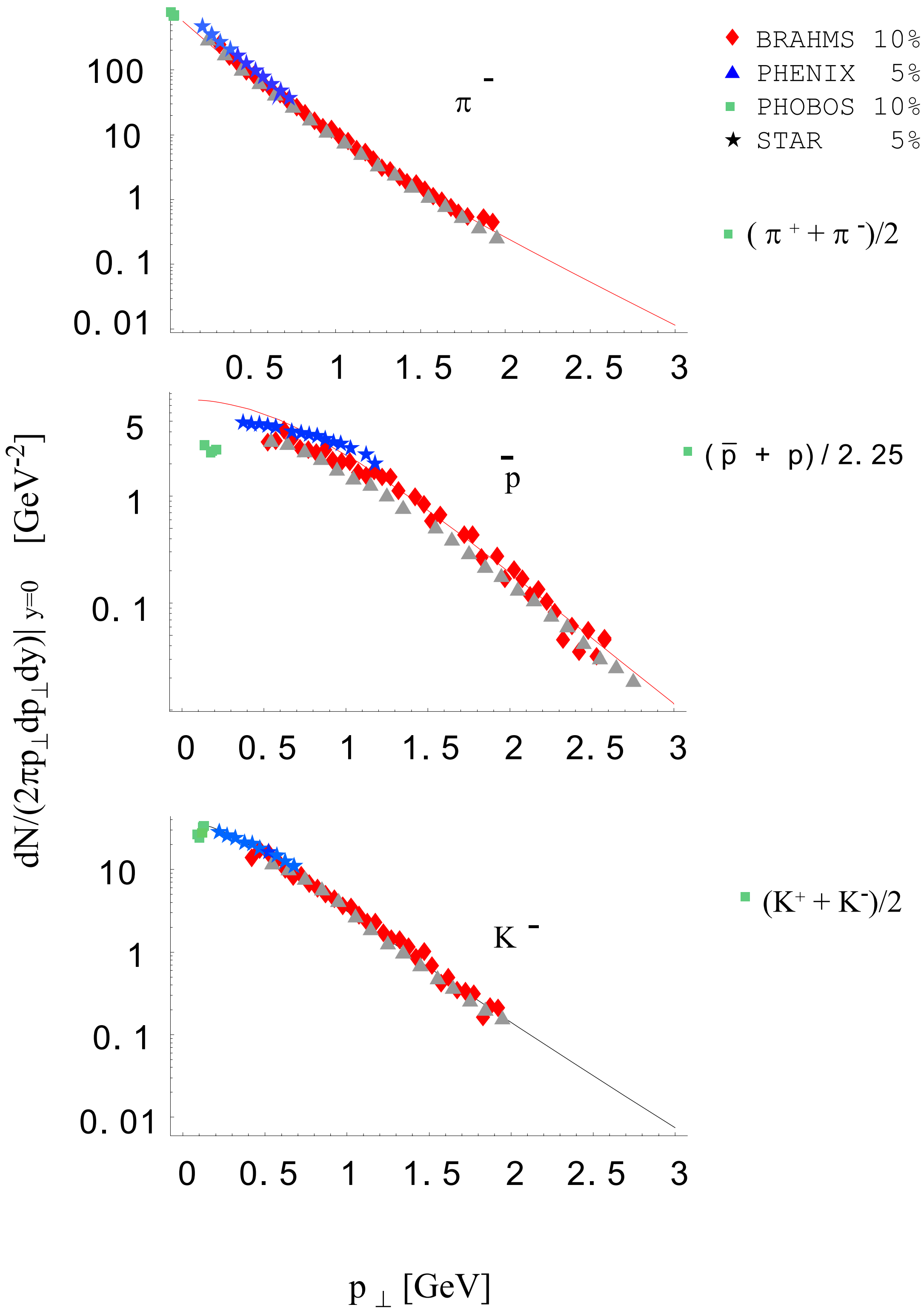
Minimum bias @ 130 GeV



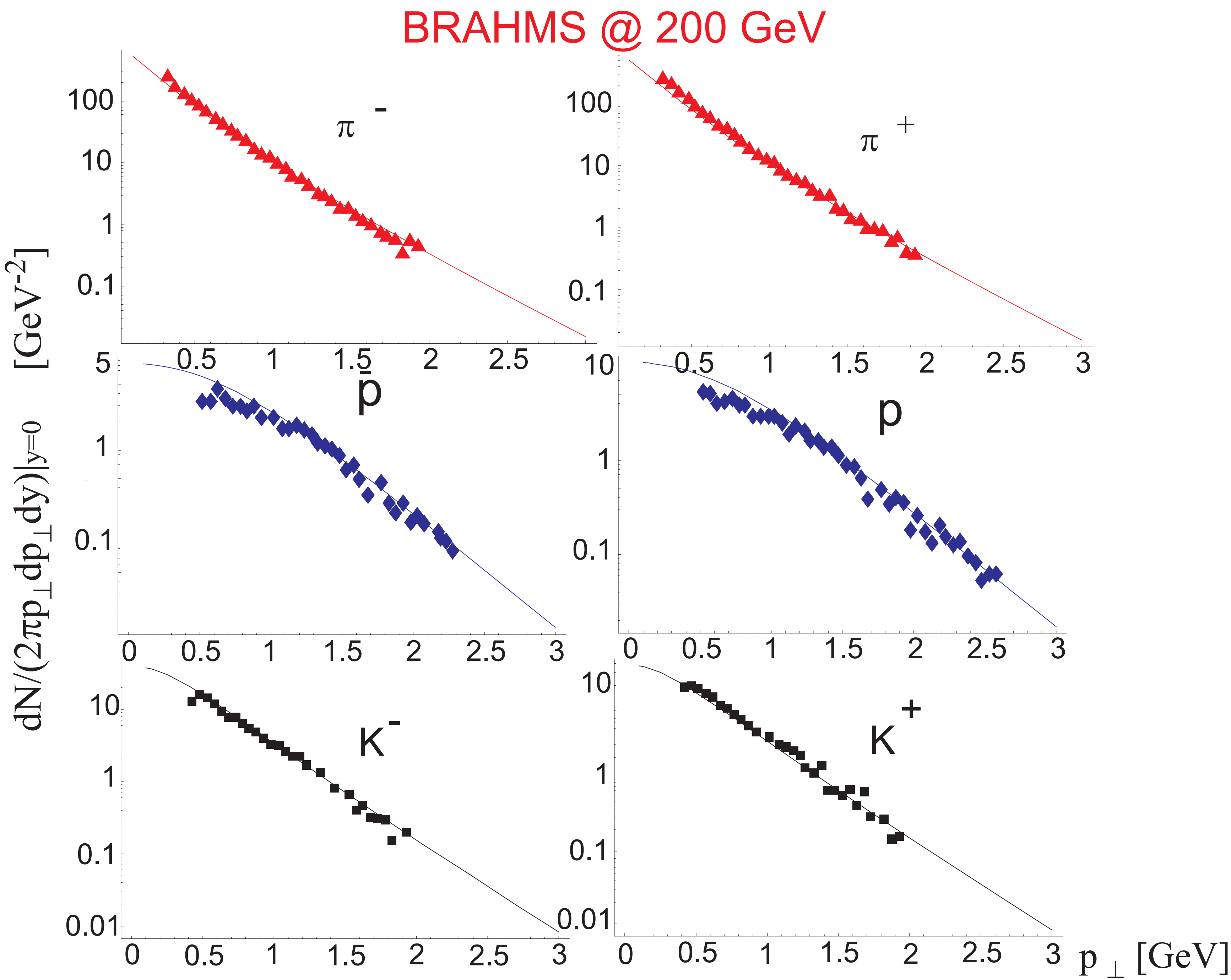
Most central @ 130 GeV

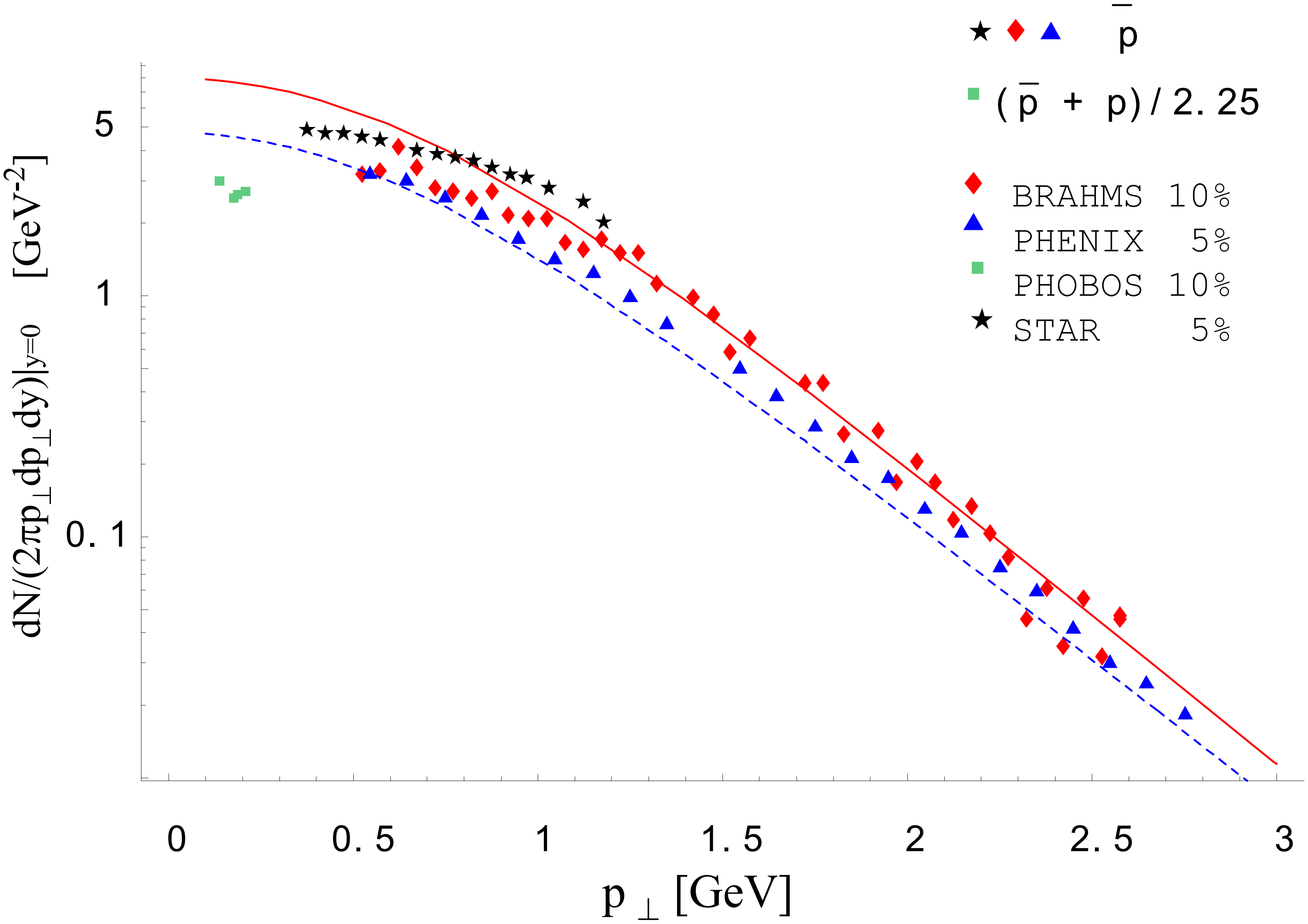


From now on all for 200 GeV !

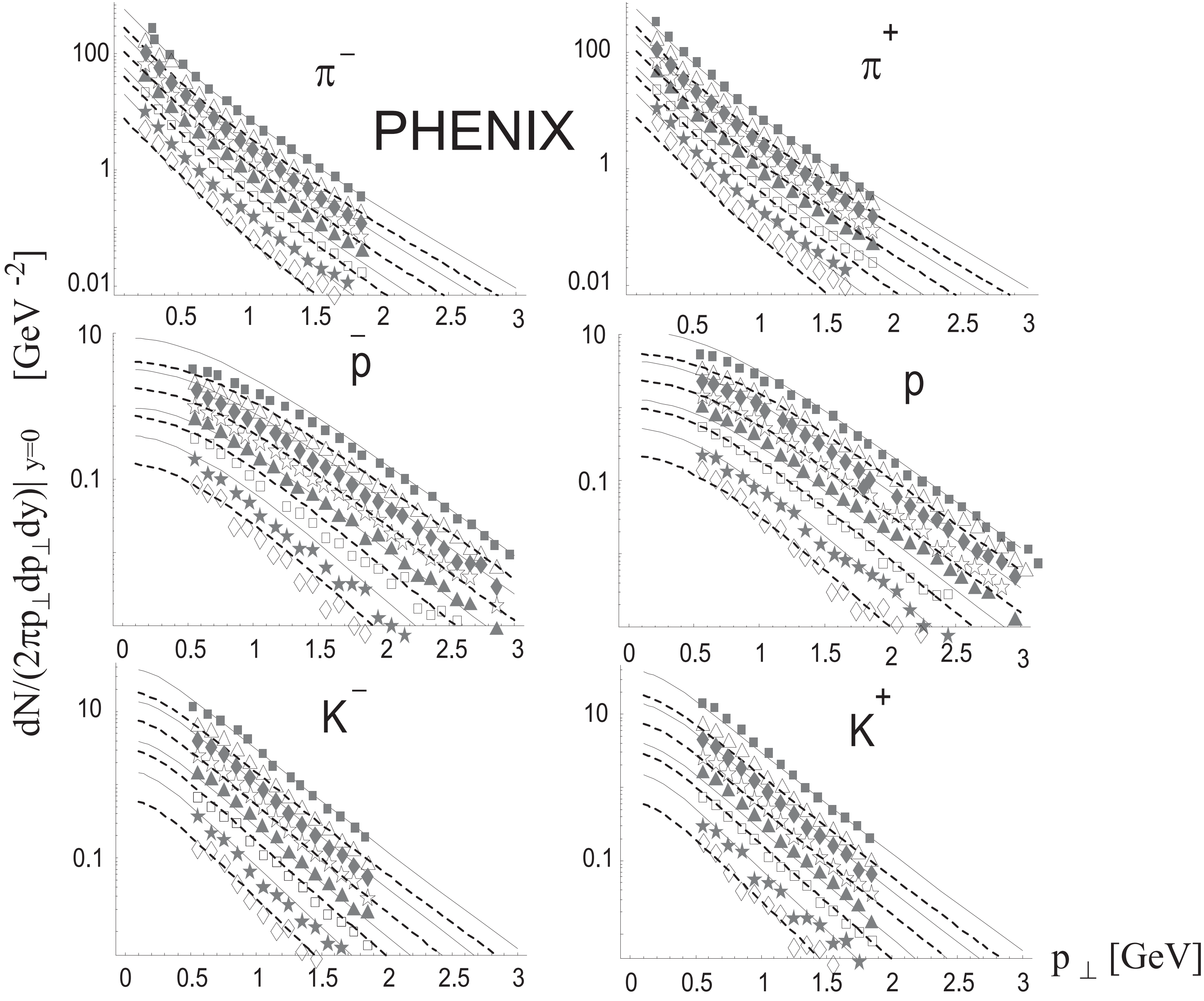


BRAHMS 10%
PHENIX 5%
PHOBOS 10%
STAR 5%
π -
(π + + π -)/2
p̄
(p̄ + p) / 2. 25
K -
(K+ + K-)/2
dN/(2πp⊥dp⊥dy)| y=0 [GeV-2]
p ⊥ [GeV]

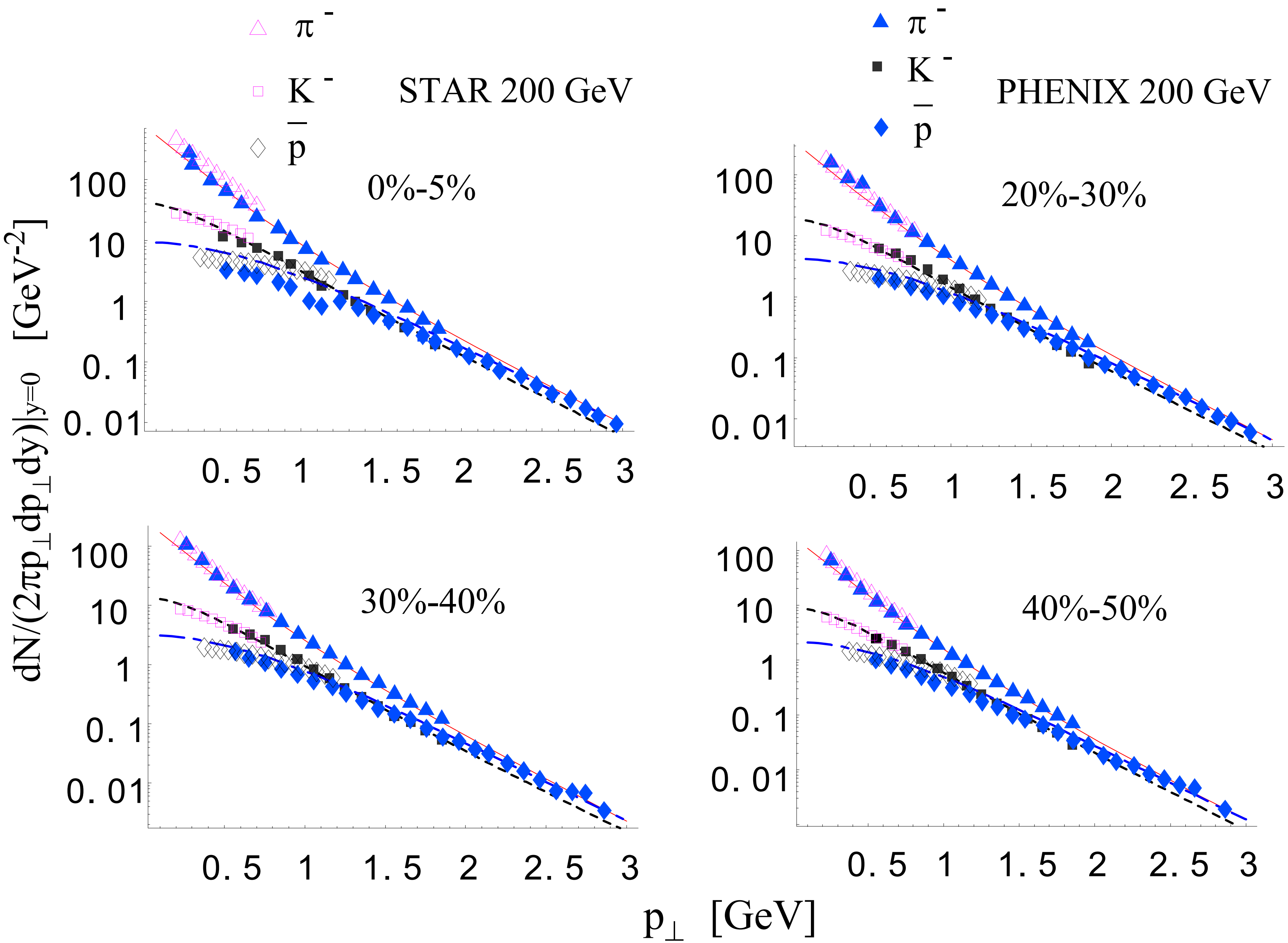

BRAHMS @ 200 GeV
dN/(2πp⊥dp⊥dy)|y=0 [GeV-2]
π -
π +
p̄
p
K-
K+
p ⊥ [GeV]



5
1
0. 1
0
0. 5
1
1. 5
2
2. 5
3
$dN/(2\pi p_\perp dp_\perp dy)|_{y=0}$ [GeV^{-2}]
$p_\perp$ [GeV]
$\bar{p}$
$(\bar{p} + p)/2.25$
BRAHMS 10%
PHENIX 5%
PHOBOS 10%
STAR 5%

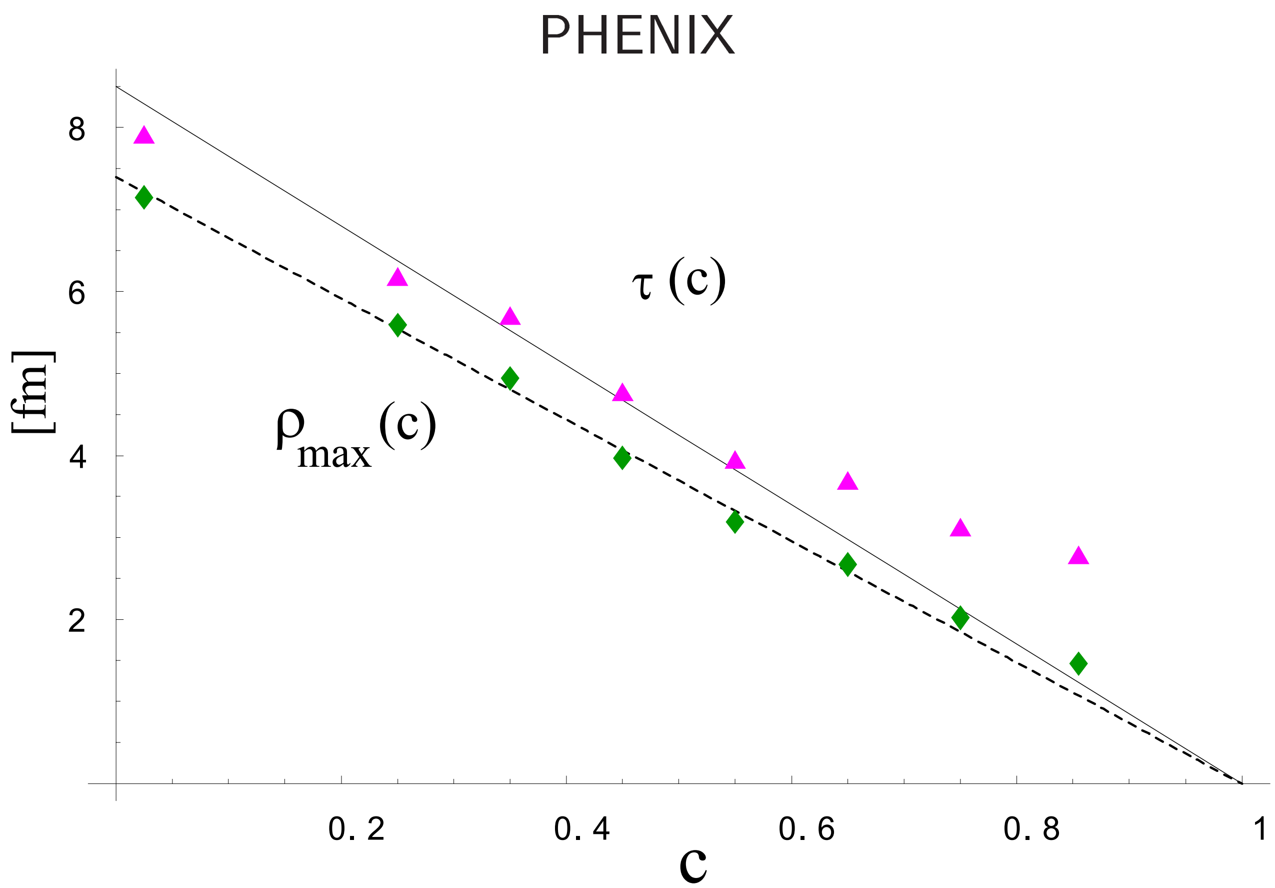


PHENIX
π⁻
π⁺
p̄
p
K⁻
K⁺
dN/(2πp⊥dp⊥dy)| y=0 [GeV -2]
p ⊥ [GeV]

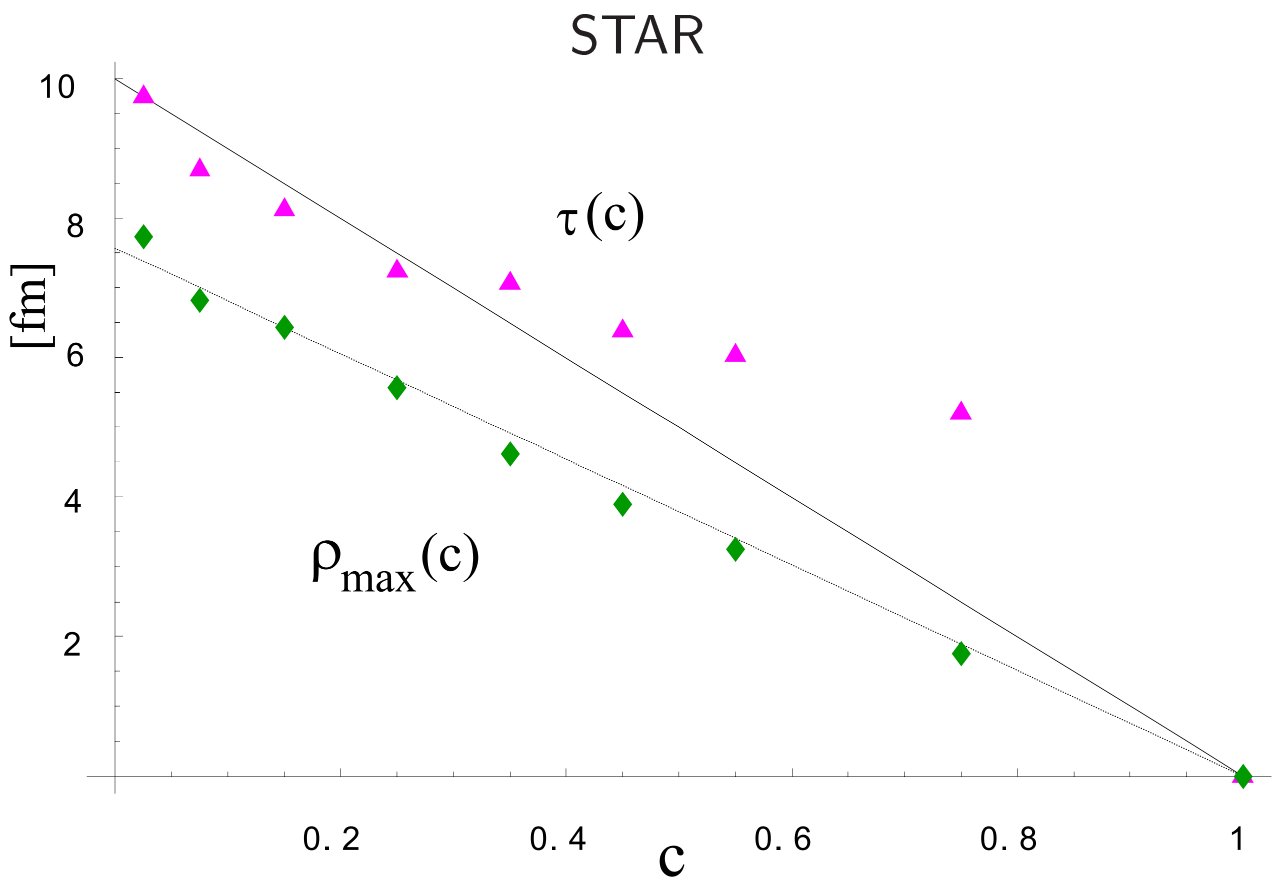


π -
K -
p̄
STAR 200 GeV
π -
K -
p̄
PHENIX 200 GeV
0%-5%
20%-30%
30%-40%
40%-50%
100
10
1
0. 1
0. 01
0. 5
1
1. 5
2
2. 5
3
dN/(2πp⊥dp⊥dy)|y=0 [GeV-2]
p⊥ [GeV]

	c [%]	τ [fm] (norm)	$\rho_{\rm max}$ [fm]	$\langle\beta_\perp\rangle$ (slope)
ALL	$0-5/10$	7.58 ± 0.32	7.27 ± 0.12	0.52 ± 0.02
BRAHMS	10	7.68 ± 0.19	7.46 ± 0.05	0.52 ± 0.01
STAR	$0-5$	9.74 ± 1.57	7.74 ± 0.68	0.45 ± 0.08
	$5-10$	8.69 ± 1.39	7.18 ± 0.64	0.47 ± 0.08
	$10-20$	8.12 ± 1.31	6.44 ± 0.57	0.45 ± 0.08
	$20-30$	7.24 ± 1.18	5.57 ± 0.50	0.44 ± 0.08
	$30-40$	7.07 ± 1.17	4.63 ± 0.39	0.39 ± 0.08
	$40-50$	6.38 ± 1.02	3.91 ± 0.33	0.37 ± 0.07
	$50-60$	6.19 ± 1.09	3.25 ± 0.28	0.32 ± 0.07
	$70-80$	5.48 ± 0.81	4.03 ± 0.10	0.43 ± 0.06
PHENIX	$0-5$	7.86 ± 0.38	7.15 ± 0.13	0.50 ± 0.02
	$20-30$	6.14 ± 0.32	5.62 ± 0.11	0.50 ± 0.02
	$30-40$	5.73 ± 0.16	4.95 ± 0.05	0.48 ± 0.01
	$40-50$	4.75 ± 0.28	3.96 ± 0.09	0.47 ± 0.03
	$50-60$	3.91 ± 0.23	3.12 ± 0.07	0.45 ± 0.03
	$60-70$	3.67 ± 0.12	2.67 ± 0.03	0.42 ± 0.01
	$70-80$	3.09 ± 0.11	2.02 ± 0.02	0.39 ± 0.01
	$80-91$	2.76 ± 0.20	1.43 ± 0.03	0.32 ± 0.03



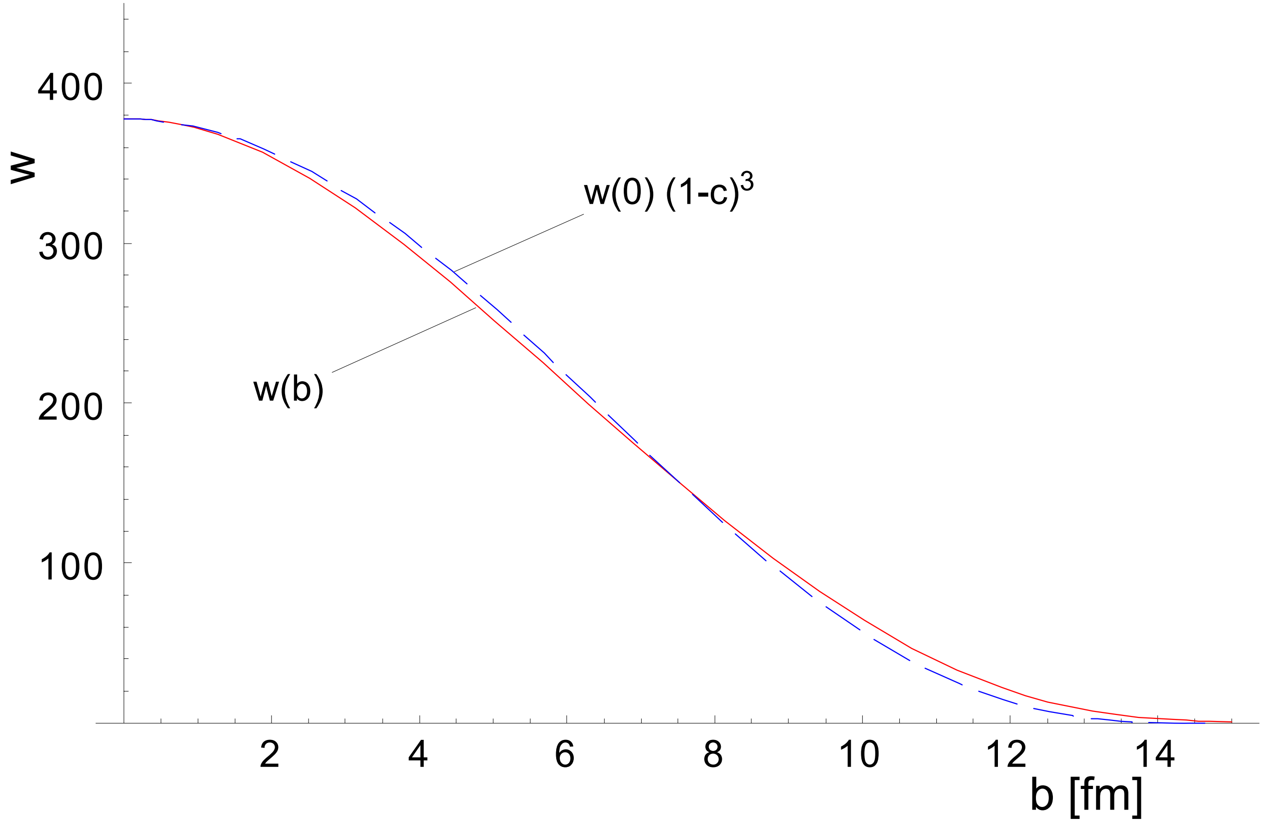
PHENIX
τ (c)
ρmax (c)
[fm]
8
6
4
2
0.2
0.4
0.6
0.8
1
c



STAR
10
8
6
4
2
[fm]
τ(c)
ρmax(c)
0. 2
0. 4
0. 6
0. 8
1
c

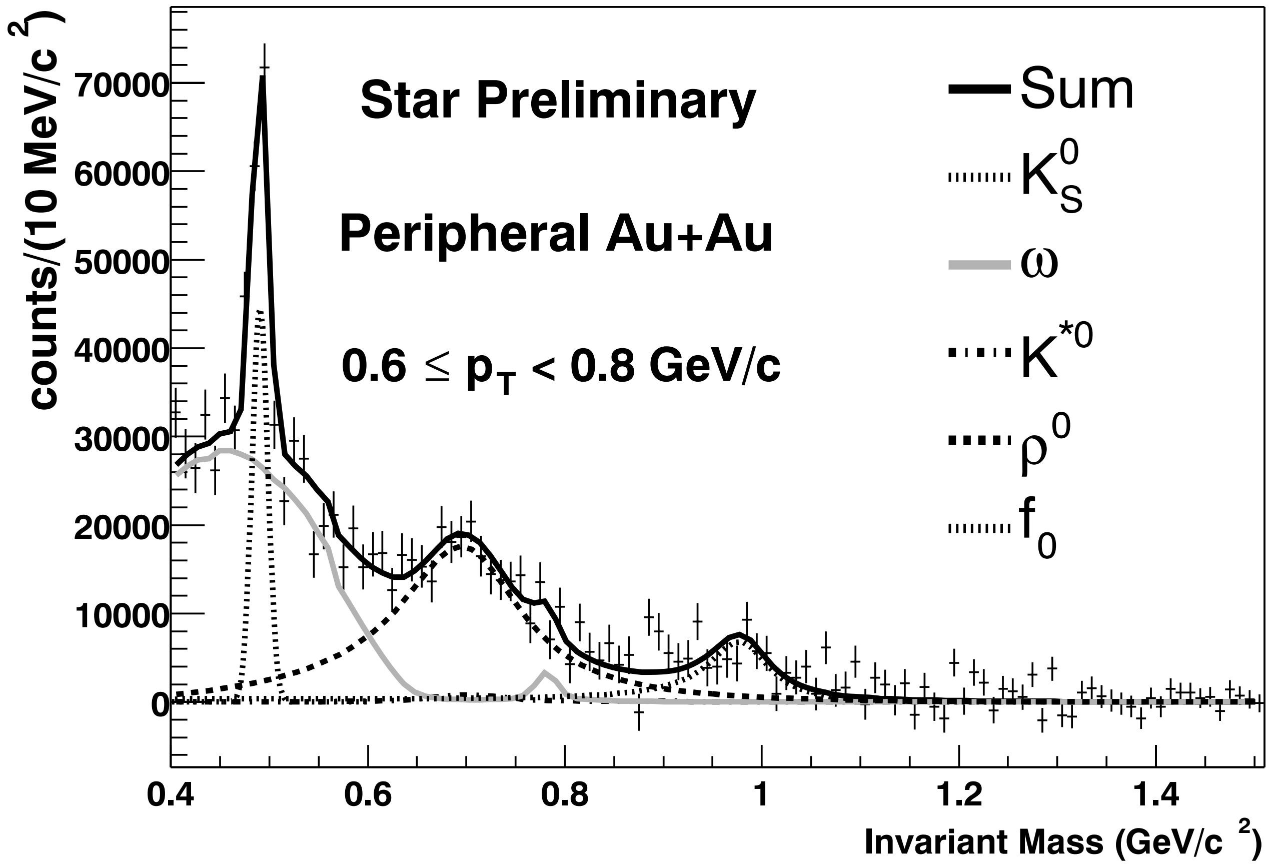
$$c = \frac{\pi b^2}{\sigma_{\mathrm{inel}}^{\mathrm{tot}}} \simeq \frac{b^2}{(R_1 + R_2)^2}$$

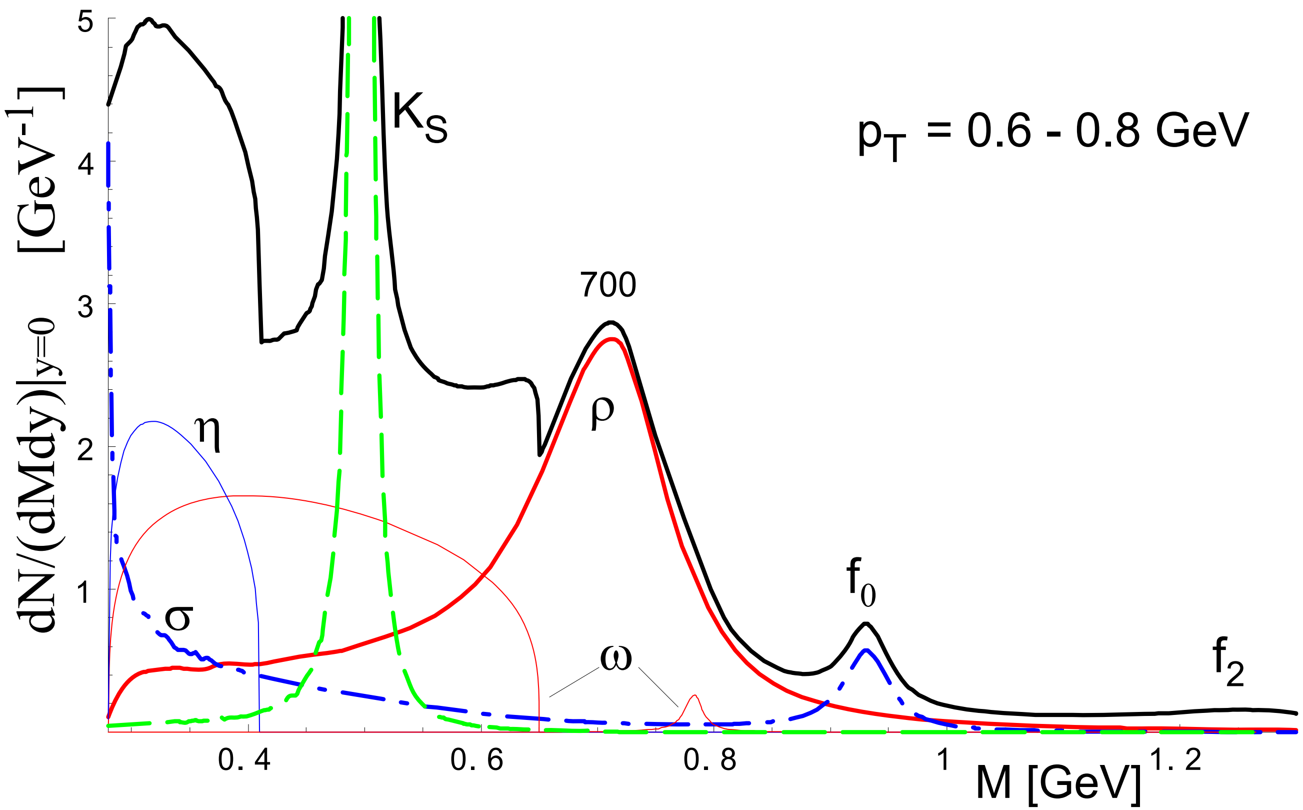
(WB+WF, Phys.Rev.C65:024905,2002)



The number of wounded nucleons, $w(b)$ (solid line) and the approximating function $w(0)(1-c(b))^3$ (dashed line), plotted as functions of the impact parameter b. Since the multiplicity of hadrons produced in our model is proportional to $(1-c(b))^3$ at moderate values of c, the model conforms to the wounded-nucleon scaling.

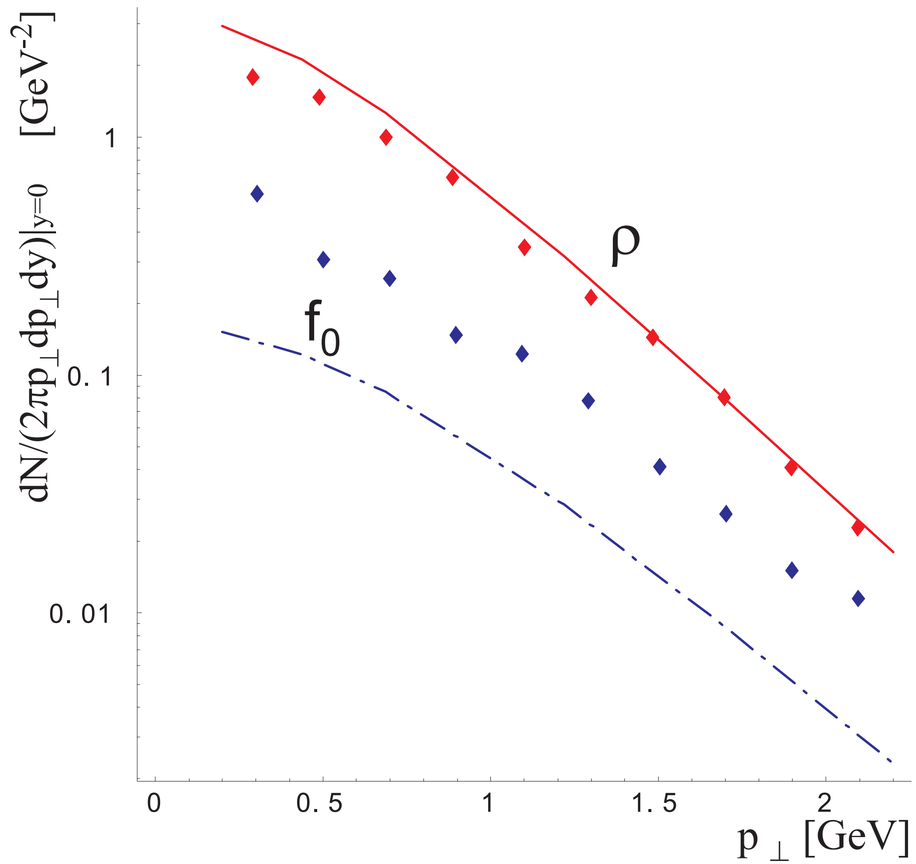
$\pi^+\pi^-$ pairs from STAR (P. Fachini)





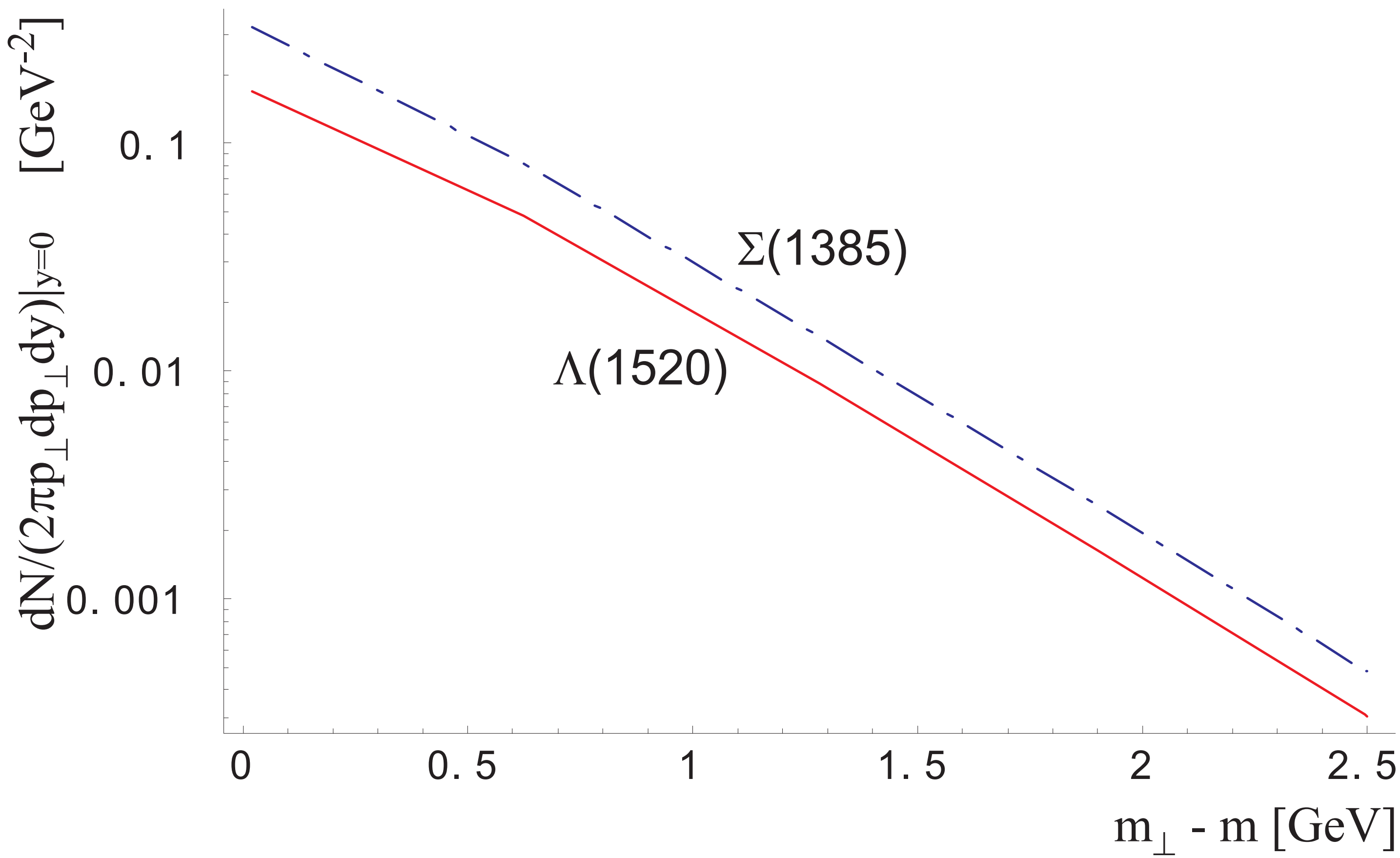
Our model + position of ρ shifted down from the vacuum value by 9% !

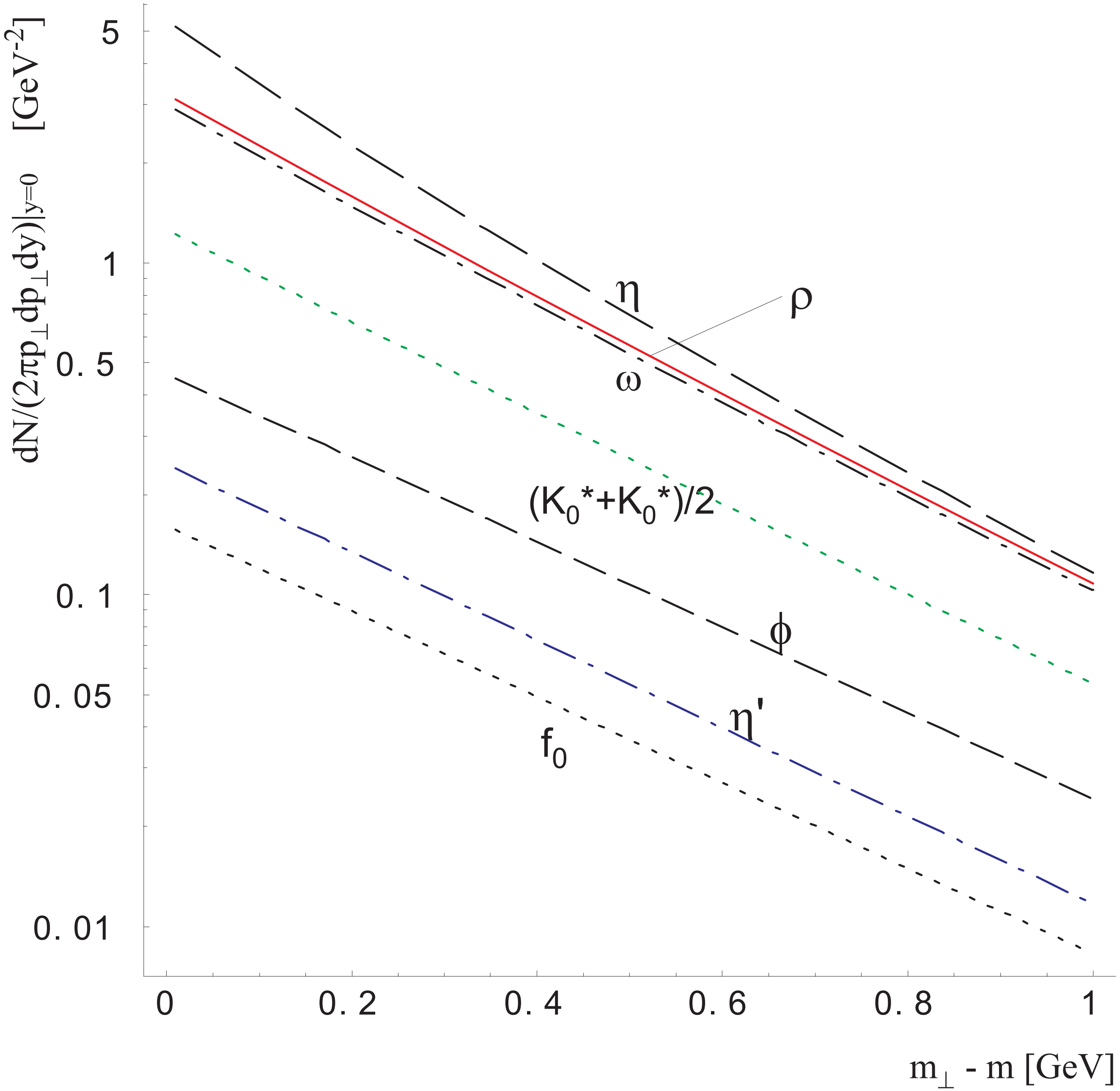
$p_\perp$ spectra of resonances



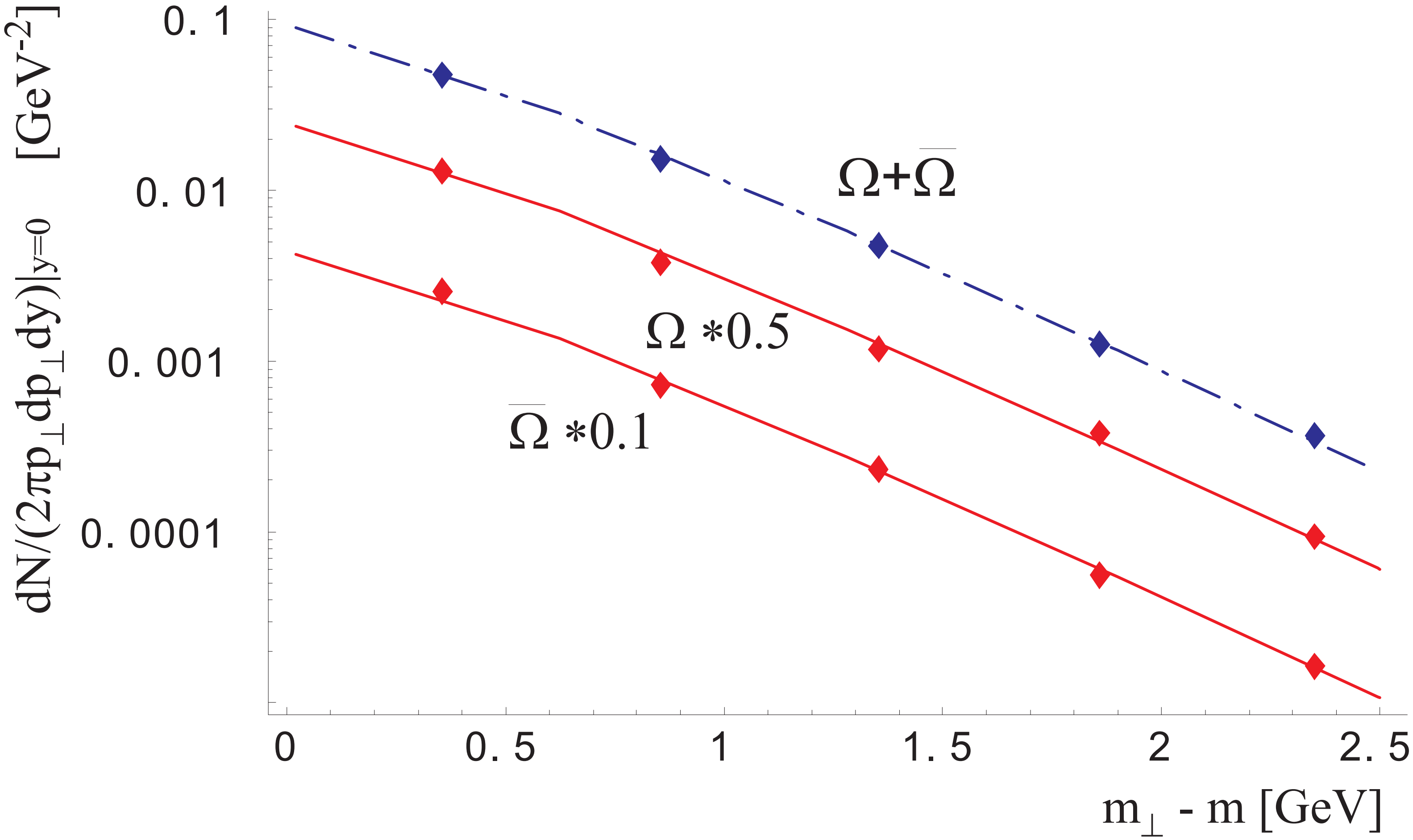
	$m_\rho^* = 770$ MeV	$m_\rho^* = 700$ MeV	Experiment
T [MeV] μ_B [MeV]	$T = 165.6 \pm 4.5$ $\mu_B = 28.5 \pm 3.7$	$T = 167.6 \pm 4.6$ $\mu_B = 28.9 \pm 3.8$	
$K^*(892)/\pi^-$	0.057 ± 0.002	0.054 ± 0.002	
$K^*(892)/K^-$	0.33 ± 0.01	0.33 ± 0.01	0.205 ± 0.033 (0-10%) 0.219 ± 0.040 (10-30%) 0.255 ± 0.046 (30-50%) 0.269 ± 0.047 (50-80%)
$\phi/K^*(892)$	0.446 ± 0.003	0.448 ± 0.002	0.595 ± 0.123 (0-10%) 0.633 ± 0.138 (10-30%) 0.584 ± 0.132 (30-50%) 0.528 ± 0.106 (50-80%)
ρ^0/π^-	0.118 ± 0.002	0.138 ± 0.001	0.178 ± 0.027 (40-80%)
$f_0(980)/\pi^-$	0.0102 ± 0.0003	0.0097 ± 0.0003	0.042 ± 0.021 (40-80%)
$\Lambda(1520)/\Lambda$	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	

Predictions



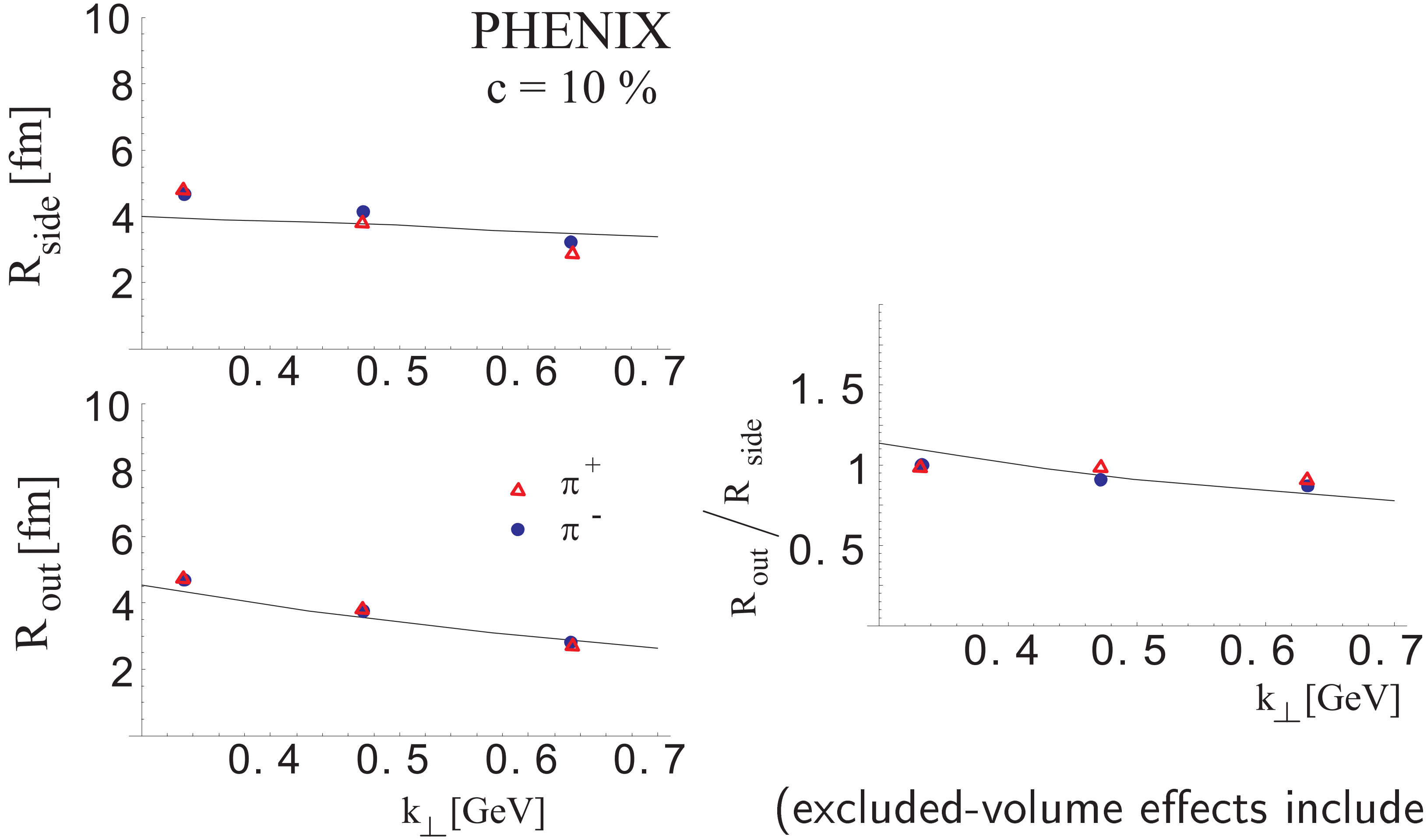


dN/(2πp⊥dp⊥dy)|y=0 [GeV-2]
5
1
0. 5
0. 1
0. 05
0. 01
0
0. 2
0. 4
0. 6
0. 8
1
m⊥ - m [GeV]
η
ρ
ω
(K0*+K0*)/2
φ
η'
f0



preliminary data from STAR (C. Suire, QM2002)

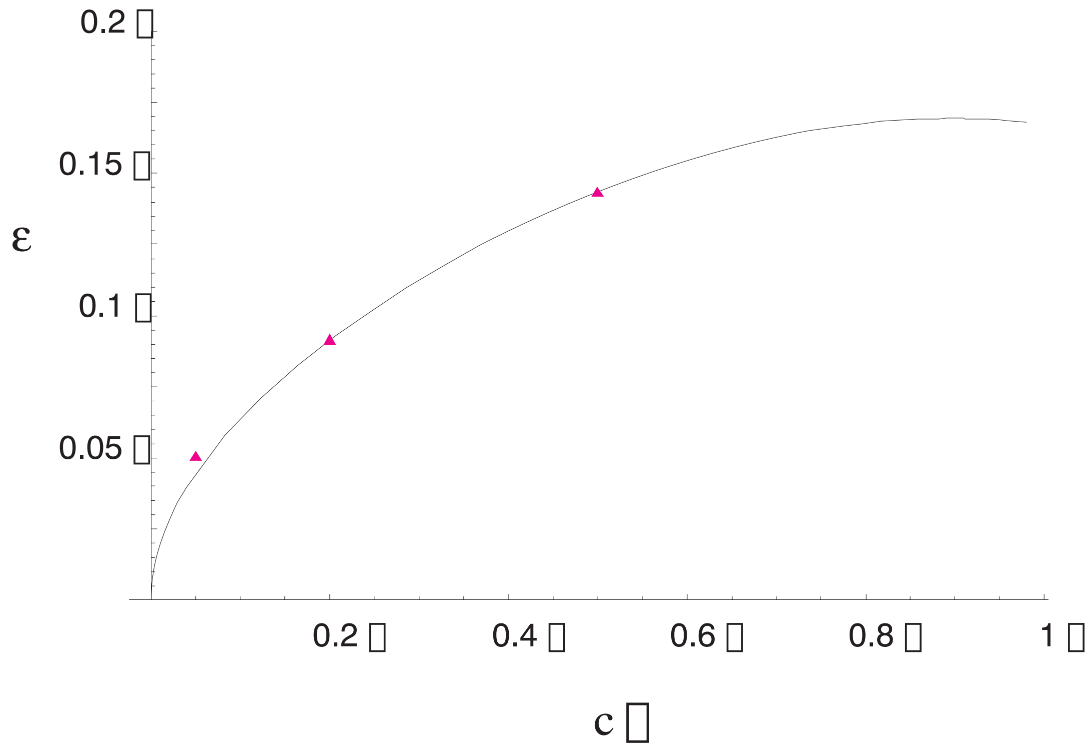
HBT correlation radii



(excluded-volume effects included)

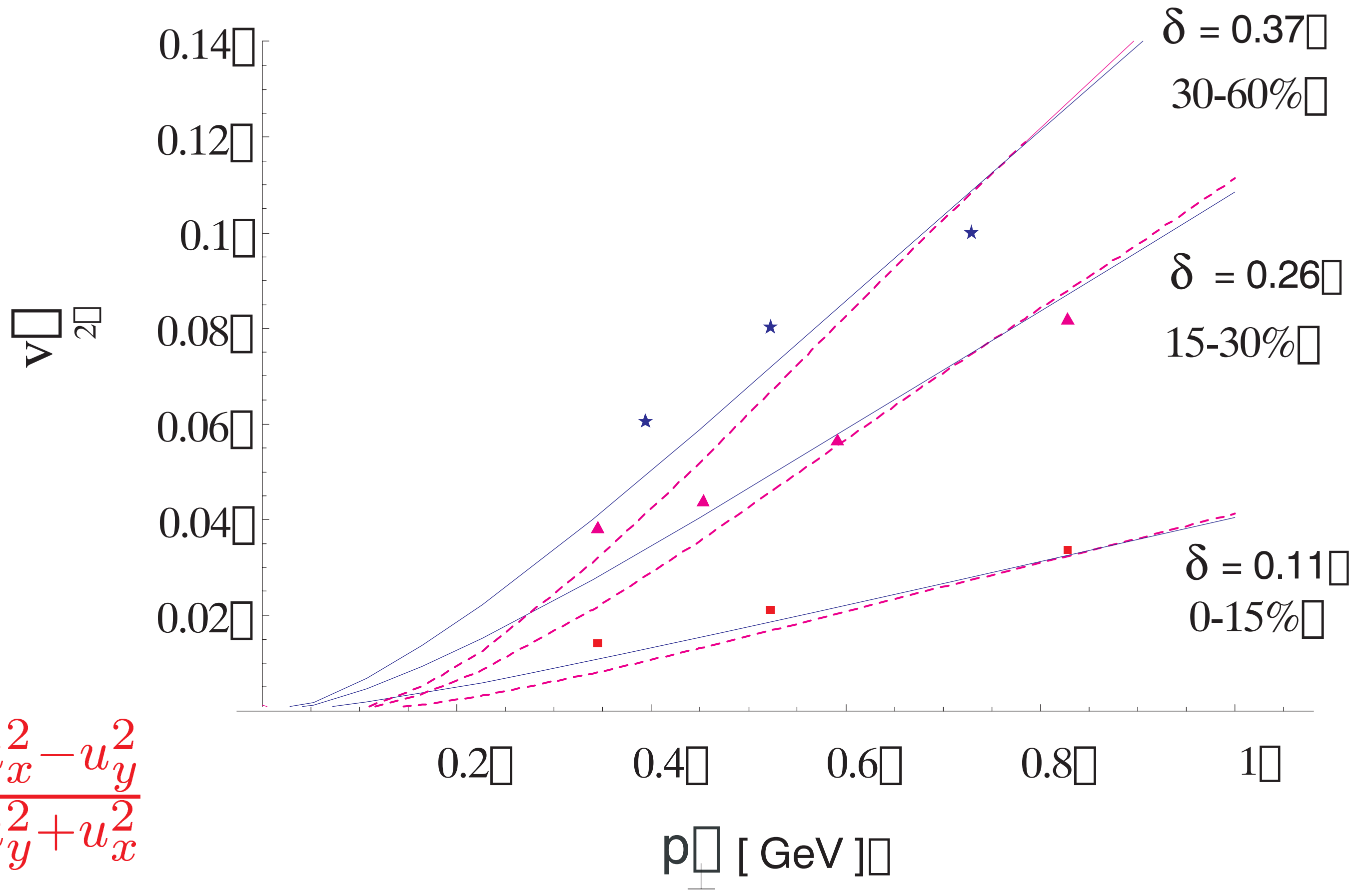
Azimuthal deformation vs. c

$$\varepsilon = \frac{R_y^2 - R_x^2}{R_y^2 + R_x^2},$$ elongated out of plane



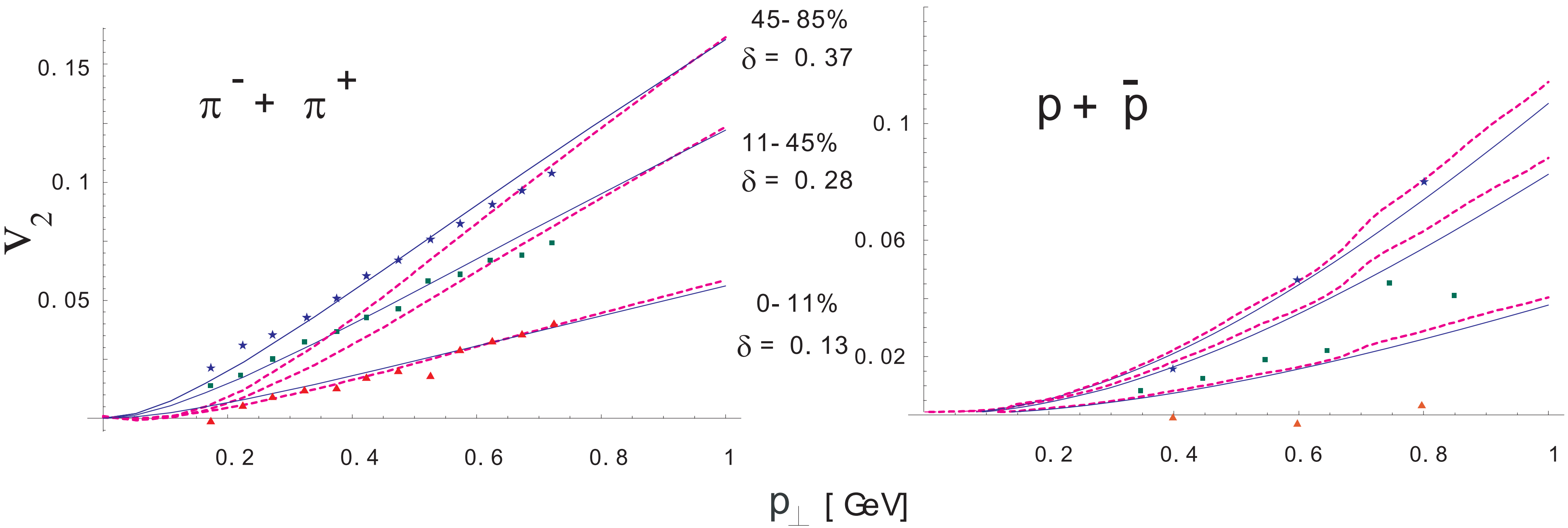
[data from STAR, M. Lisa, nucl-ex/0301005]

v_2, PHENIX @ 130 GeV



$$\delta = \frac{u_x^2 - u_y^2}{u_y^2 + u_x^2}$$

v_2, STAR @ 130 GeV



Summary

1. The thermal model with resonances works very well for the particle ratios at midrapidity
2. Single-freeze-out assumption (approximation) works!
3. Supplied with simple expansion, works impressively for p_T spectra at midrapidity, for various centralities c
4. Complies to the wounded-nucleon scaling at various c
5. Good for $p_\perp \leq\sim 2$ GeV
6. Predictive for resonances, invariant-mass correlations

7. Works very reasonably for the HBT radii, in particular $R_{\rm out}/R_{\rm side} \sim 1$

8. Works reasonably for the elliptic flow

9. Should therefore be treated seriously, at least as a very efficient parameterization of the data

10. Allows for the detection of shape and flow at the freeze-out, serves as constraint for more microscopic approaches

11. Why should the simple $e^{-(E-\mu)/T}$ work? There is very little time to achieve thermal equilibrium in the gas of hadrons (early freeze-out), statistical hadronization, ...