Resonance production in a thermal model

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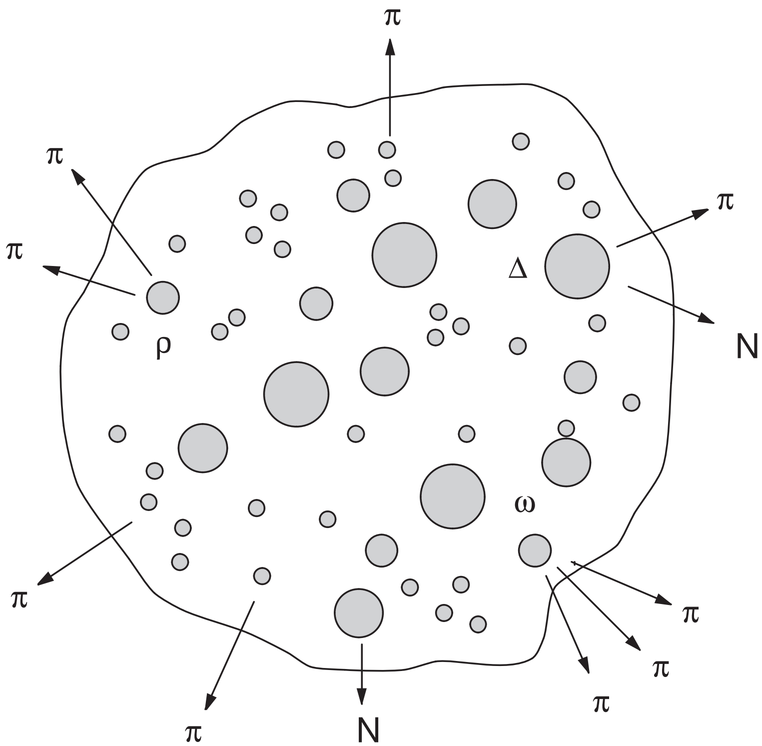
ISMD 2003, Cracow



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

This is not the

Cracow model

Thermal model

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

WB + WF, PRL 87 (2001) 272302; PRC 65 (2002) 064905 (our variant)
WB + A. Baran + WF, Acta Phys. Pol. B33 (2002) 4235 (review)
WB + WF + B. Hiller, **nucl-th/0306034**

1. $T_{\rm chem} = T_{\rm kin} \equiv T$, single freeze-out (short $\Delta\tau$, Appelshäuser, Lisa)

2. Complete treatment of resonances

3. Assumed freezeout hypersurface

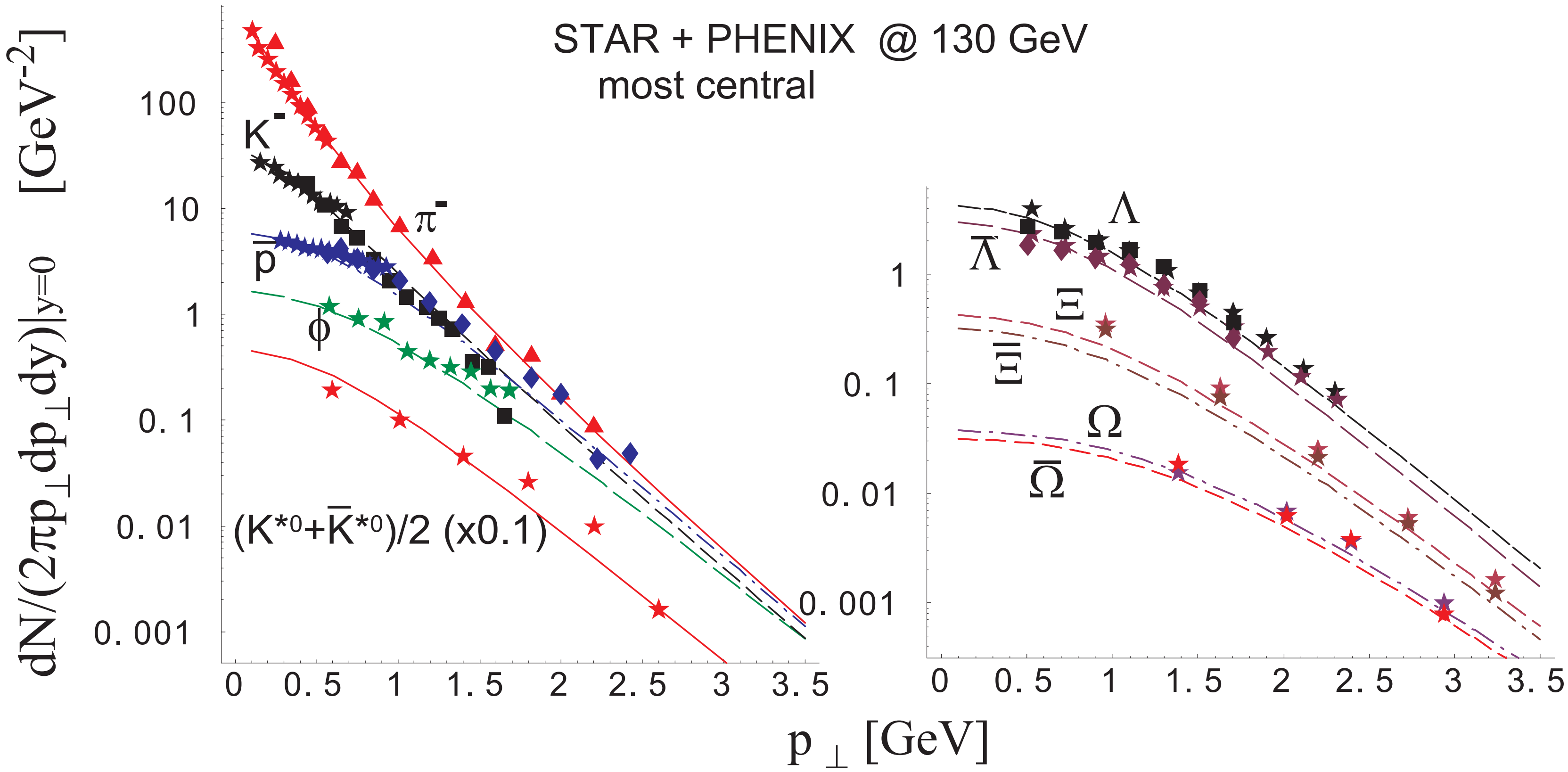
4. 4 parameters: T,μ_B (fixed by the ratios of the particle abundances), invariant time at freeze-out τ (controls the overall normalization), transverse size $\rho_{\max}$ ($\rho_{\max}/\tau$ controls the slopes of the $p_\perp$ spectra)

5. Hubble-like flow, $u^\mu = x^\mu/\tau$

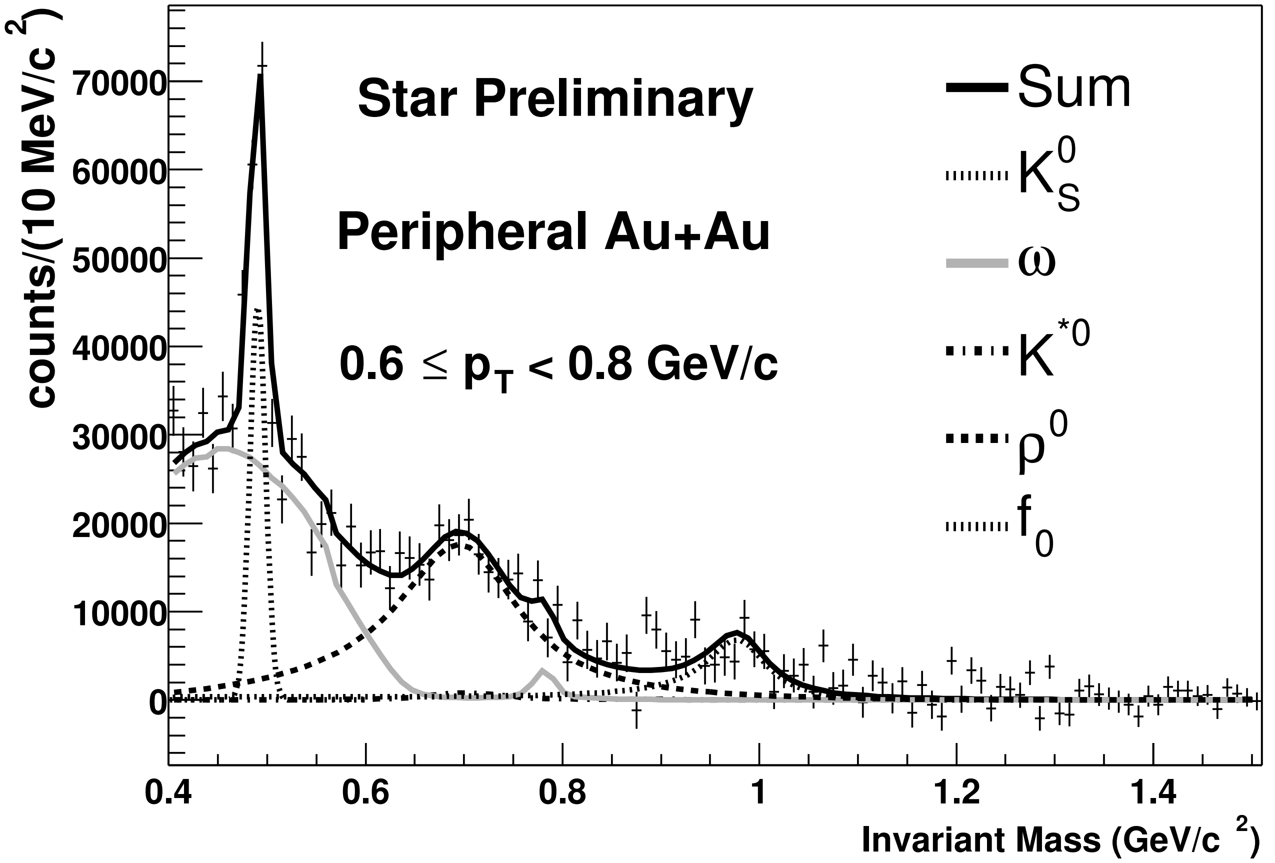
$\sim$ Buda-Lund

Particle ratios @ 130 and 200 GeV $\rightarrow$

T [MeV]	165 ± 7	160 ± 5
μ_B [MeV]	41 ± 5	26 ± 4
μ_S [MeV]	9	5
μ_I [MeV]	-1	-1
χ^2/DOF	1.0	1.5



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



Can we explain this in the thermal model?

(positions of resonances, high vs. low M - yet another thermometer)

The phase-shift formula for the density of resonances

Beth,Uhlenbeck (1937); Dashen, Ma, Bernstein, Rajaraman; **Weinhold**, Friman, Nörenberg; **WB,WF,B. Hiller, nucl-th/0306034**; Pratt, Bauer, nucl-th/0308087

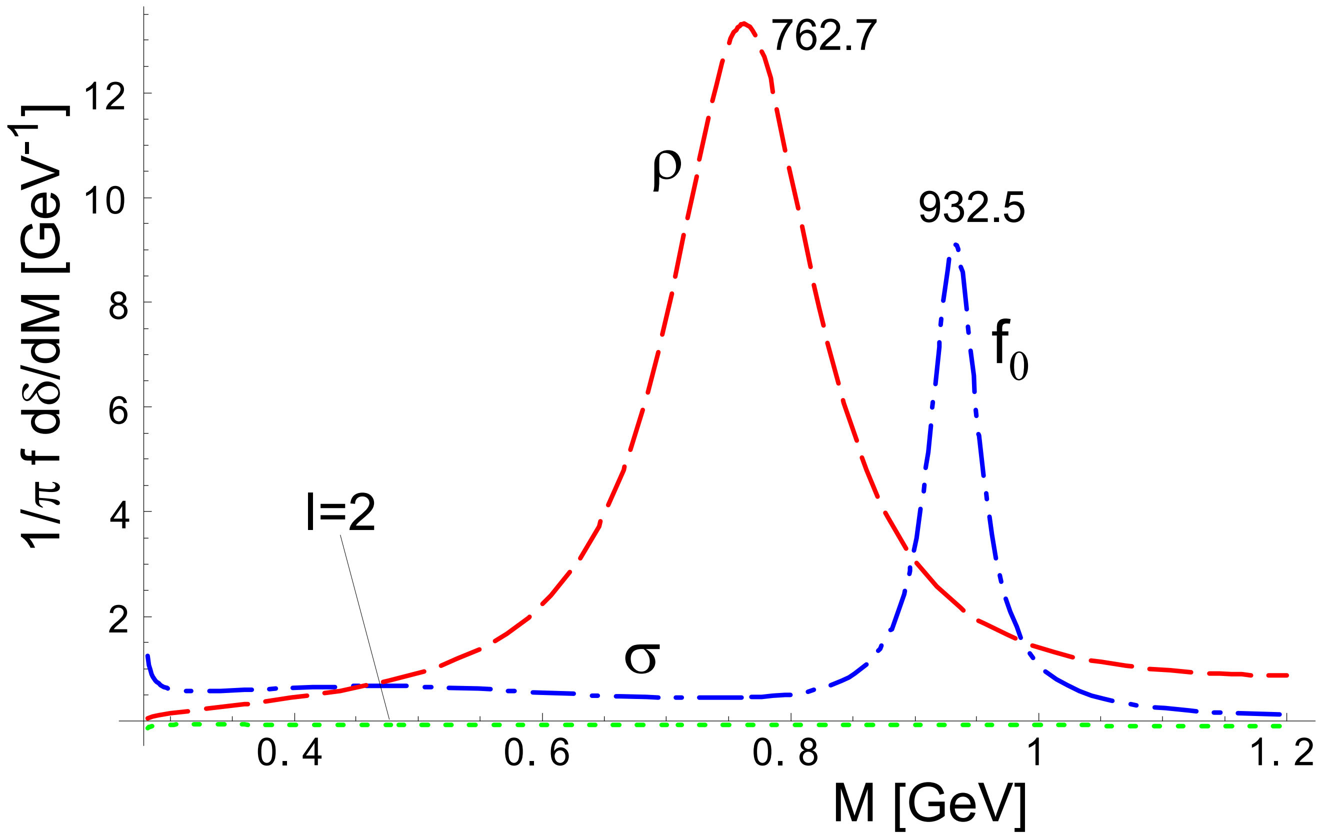
$$\frac{dn}{dM} = f \int \frac{d^3p}{(2\pi)^3} \frac{d\delta_{12}(M)}{\pi dM} \frac{1}{\exp\left(\frac{\sqrt{M^2+\boldsymbol{p}^2}}{T}\right) \pm 1}$$

In some works the spectral function of the resonance is used *ad hoc* as the weight, 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

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

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

$d\delta_{\pi\pi}(M)/dM$ from experiment

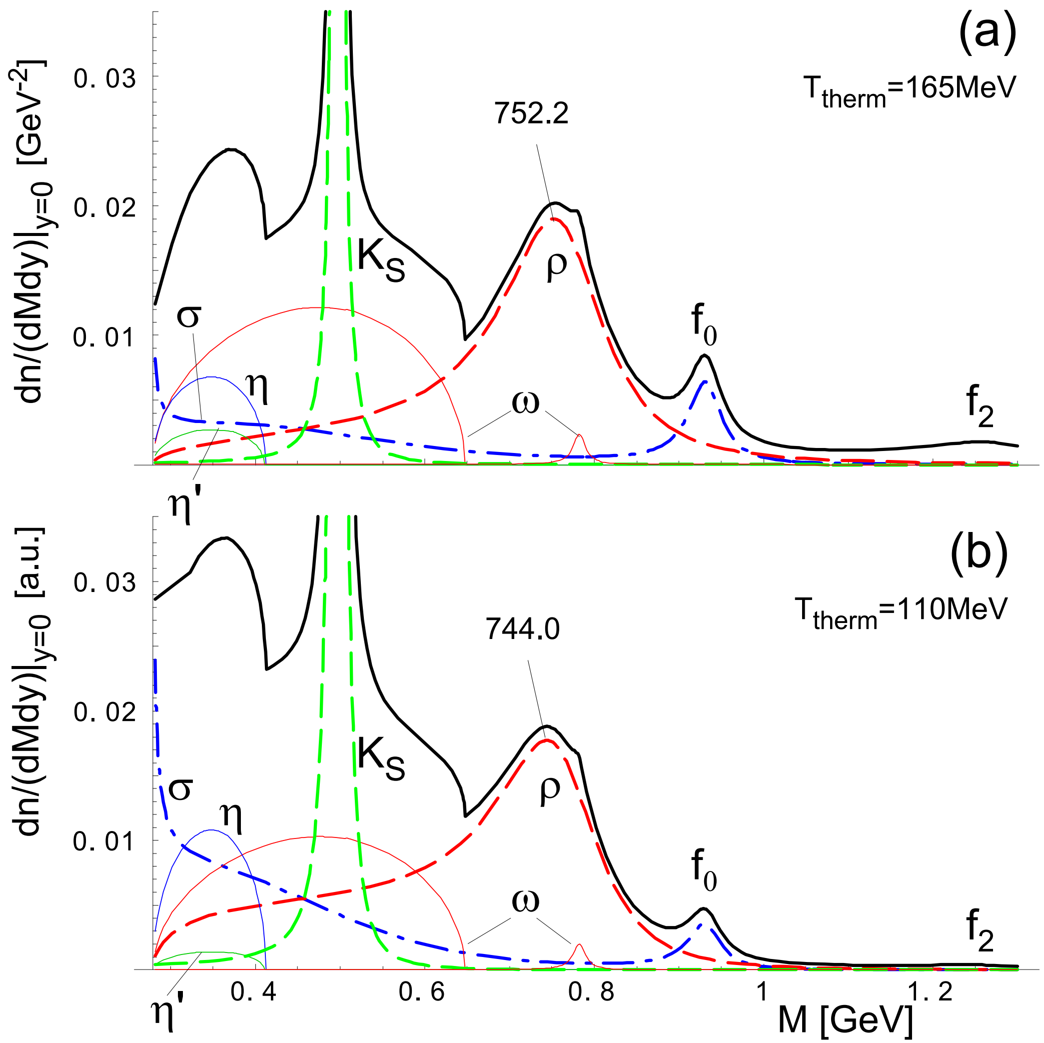


Small contribution from σ, negative and tiny contribution from $I = 2$, peaks slightly shifted to lower M

Warm-up calculation - static source

We compute the spectra at mid-rapidity, hence

$$\left.\frac{dn}{dM\,dy}\right|_{y=0} = \sum_i f_i \int_{p_\perp^{\rm low}}^{p_\perp^{\rm high}} \frac{p_\perp\, dp_\perp}{(2\pi)^2} \frac{d\delta_i(M)}{\pi\, dM} \frac{\sqrt{M^2+p_\perp^2}}{\exp\left(\frac{\sqrt{M^2+\boldsymbol{p}_\perp{}^2}}{T}\right)-1}$$

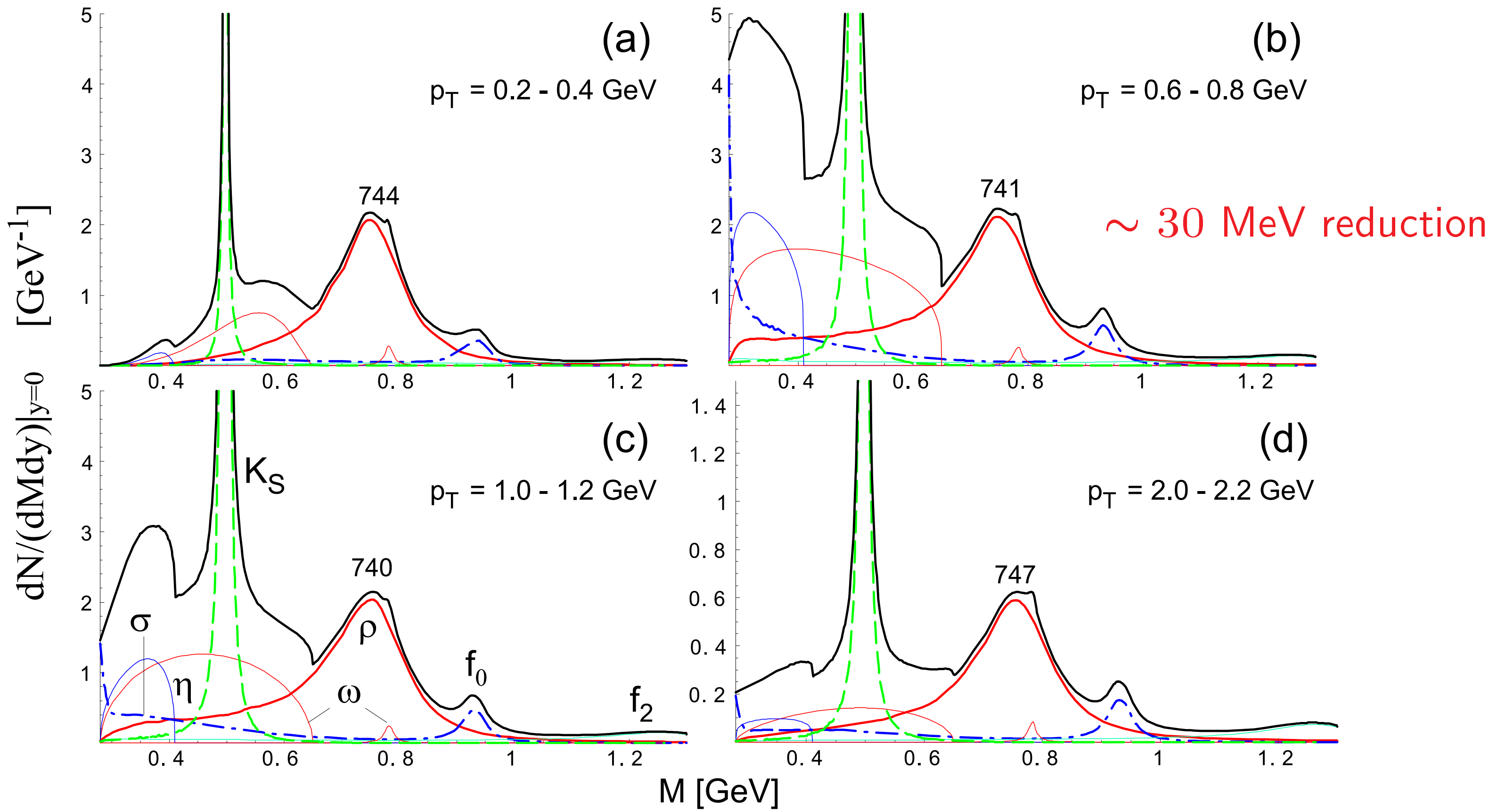


flat

steep

Cuts/flow + feeding from resonances

Flow has no effect on the invariant mass of a pair of particles produced in a resonance decay, since the quantity is Lorentz-invariant. Neverthelss, it affects the results since the kinematic cuts in an obvious manner break this invariance



The invariant $\pi^+\pi^-$ mass spectra in the single-freeze-out model for four sample bins in the trasverse momentum of the pair, p_T, plotted as a function of M. η indicates $\eta + \eta'$. All kinematic cuts of the STAR experiment are incorporated

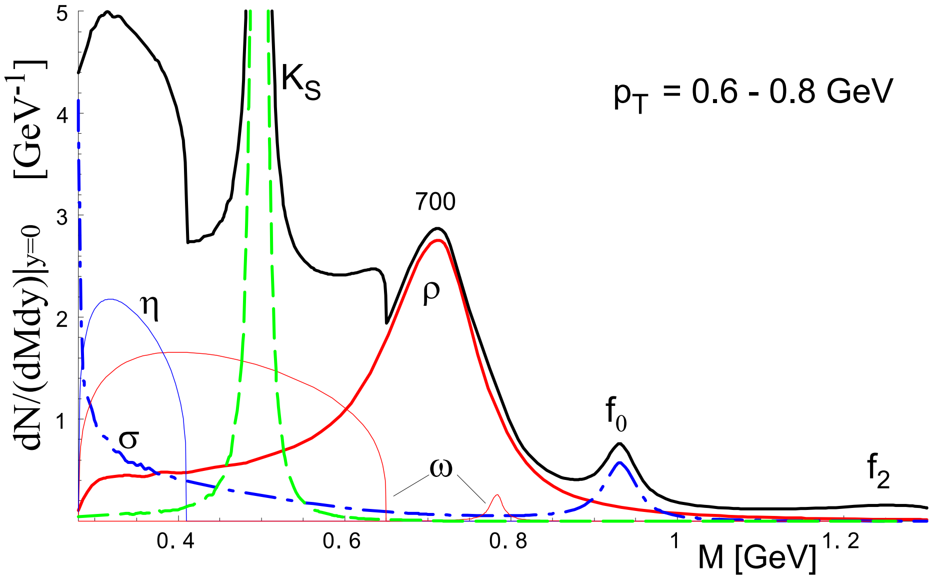
Resonanse decays

The calculation leads to the following enhancement factors coming from the decays of higher resonances: $d_{K_S} = 1.98$, $d_\eta = 1.74$, $d_\sigma = 1.13$, $d_\rho = 1.42$, $d_\omega = 1.43$, $d_{\eta'} = 1.08$, $d_{f_0} = 1.01$, and $d_{f_2} = 1.28$. Thus, the effects is strongest for light particles, K_S, η, ρ, and ω, while it is weaker for the heavier η' and scalar mesons.

Full model, with feeding from higher resonances and flow/cuts at $T = 165$ MeV is similar to the naive model at $T = 110$ MeV !

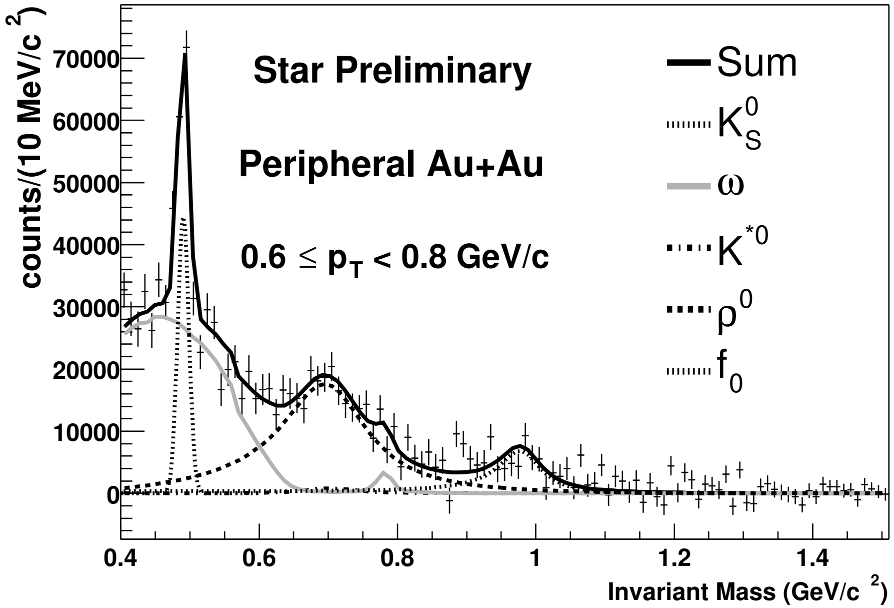
Medium effects?

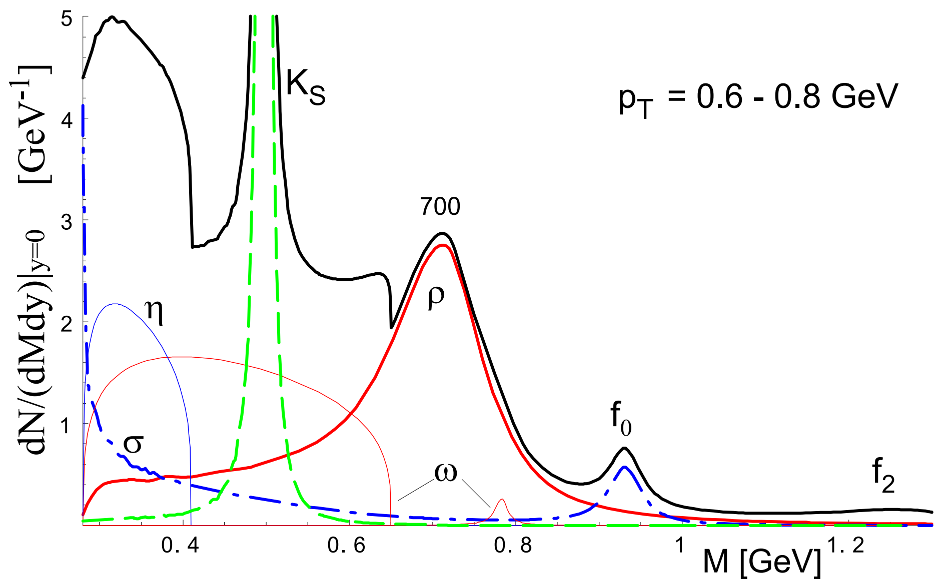
Is the position of ρ lower than in the vacuum (or other effects)?



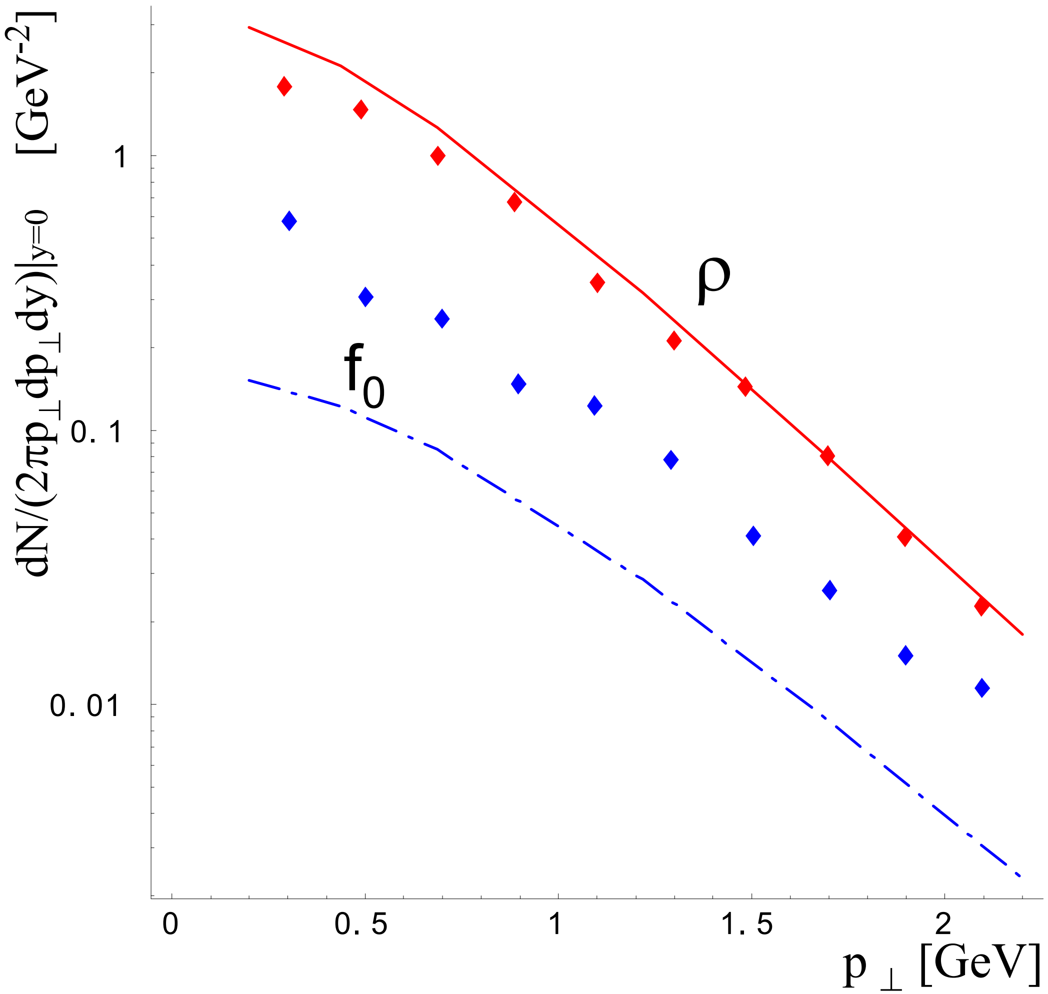
Our model + position of ρ shifted down from the vacuum value by 9%

STAR vs. thermal model





$p_\perp$ spectra of resonances

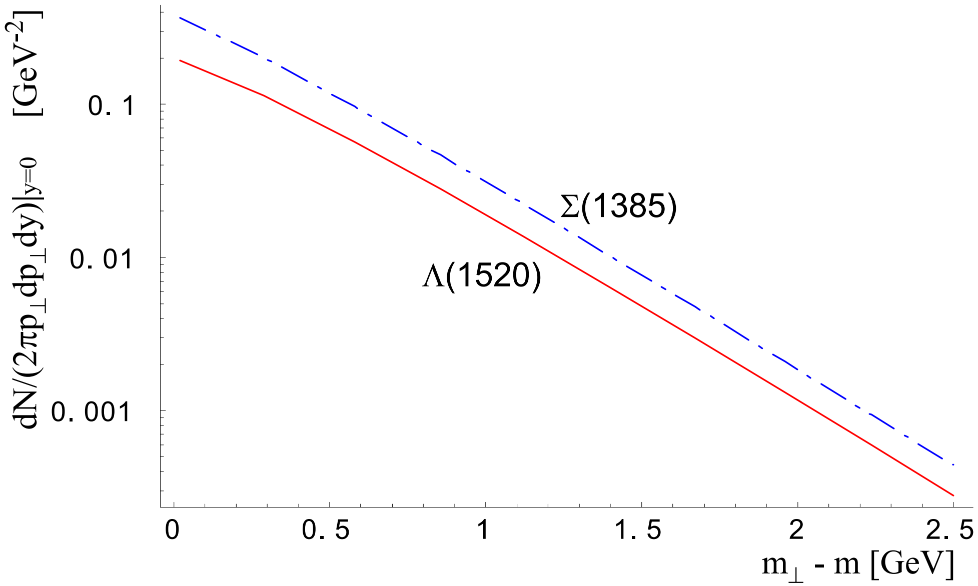


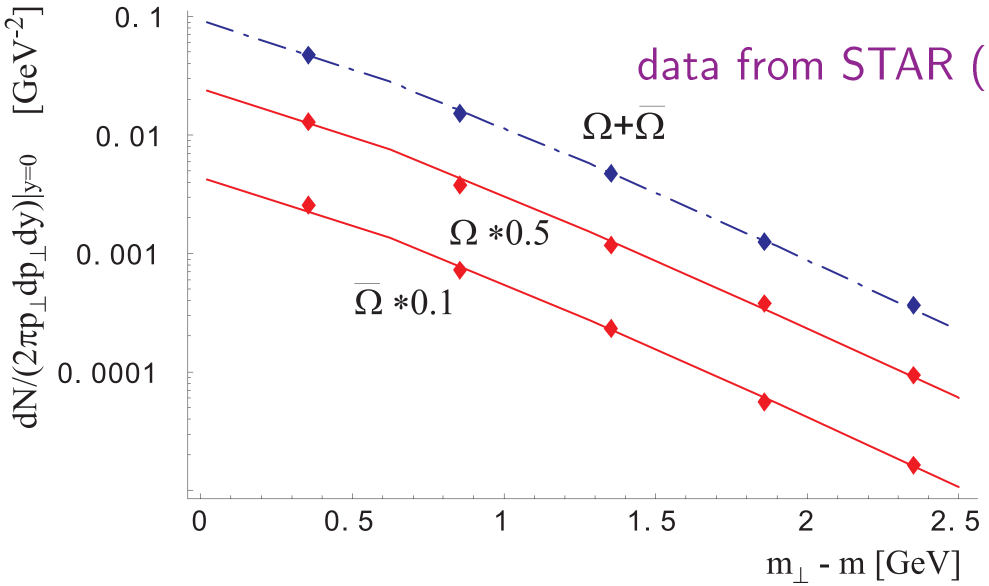
For f_0 experiment $>$ thermal model!

	$m_\rho^* = 770$ 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	

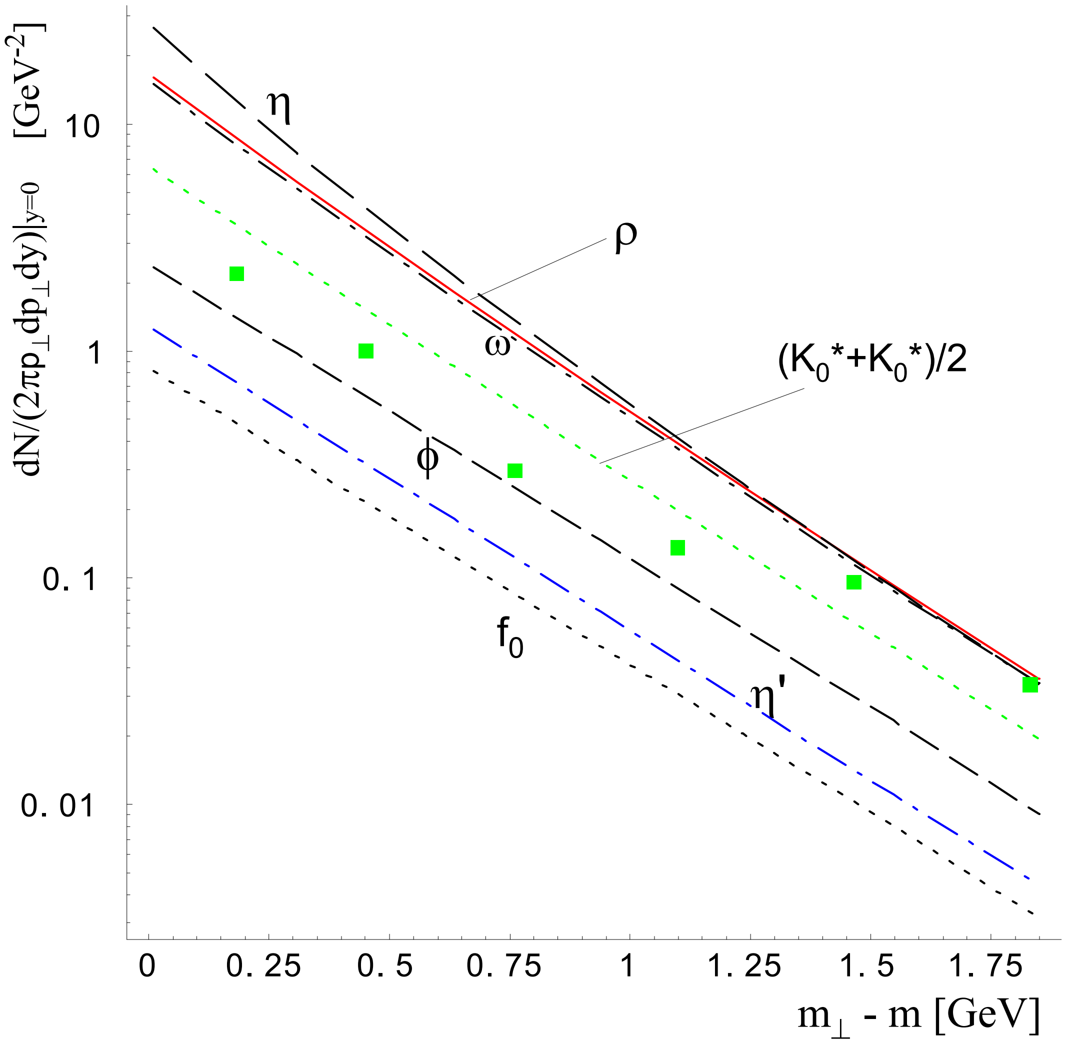
Model underpredicts ρ and f_0 with $T = 165$ MeV. Lower T would imply even less resonances!

Predictions





data from STAR (C. Suire, QM2002)


dN/(2πp⊥dp⊥dy)|y=0 [GeV-2]
10
1
0. 1
0. 01
0
0. 25
0. 5
0. 75
1
1. 25
1. 5
1. 75
m⊥ - m [GeV]
η
ρ
ω
(K0*+K0*)/2
φ
f0
η'

Summary

1. Shape of the $\pi\pi$ "spectral line" - new thermometer
2. Derivative of phase shift, not the spectral density as weight
3. Single freeze-out works, it gives similar results at 165MeV to the naive calculation at 110MeV
4. Konematic cuts and flow important, resonance decays important
5. Not possible to place the rho peak at the experimental value (medium effects?, other effects?)
6. Measure, please, the $\pi\pi$ spectra for most central events!

Back-up slides

The STAR cuts

The cuts in the STAR analysis of the $\pi^+\pi^-$ invariant-mass spectra have the following form (Fachini):

$$\begin{aligned} &|y_\pi| \leq 1, \\ &|\eta_\pi| \leq 0.8, \\ &0.2 \text{ GeV} \leq p_\pi^\perp \leq 2.2 \text{ GeV}, \end{aligned} \tag{1}$$

while the bins in $p_T \equiv |\boldsymbol{p}_\pi^\perp + \boldsymbol{p}_\pi^\perp|$ start from the range $0.2 - 0.4$ GeV, and step up by 0.2 GeV until $2 - 2.4$ GeV.

Resonanse decays

The calculation leads to the following enhancement factors coming from the decays of higher resonances: $d_{K_S} = 1.98$, $d_\eta = 1.74$, $d_\sigma = 1.13$, $d_\rho = 1.42$, $d_\omega = 1.43$, $d_{\eta'} = 1.08$, $d_{f_0} = 1.01$, and $d_{f_2} = 1.28$. Thus, the effects is strongest for light particles, K_S, η, ρ, and ω, while it is weaker for the heavier η' and scalar mesons.

Lowering the ρ mass

In order to show how the medium modifications will show up in the $\pi^+\pi^-$ spectrum, we have scaled the $\pi\pi$ phase shift in the ρ channel, according to the simple law

$$\delta_1^1(M)_{\mathrm{scaled}} = \delta_1^1(s^{-1}M)_{\mathrm{vacuum}}, \qquad (2)$$

Phase shift vs. spectral density