Low masses in the ALICE muon spectrometer

- Low masses and chiral symmetry
- Low masses in ALICE

Wuhan workshop – May 2008 – Fabien Nendaz

What are the low masses ?

Resonance	ρ	ω	ϕ	J/ψ	Υ
Mass (MeV/c^2)	770	782	1020	3097	9460
Width (MeV/c^2)	150	8.4	4.4	0.087	0.052
$c\tau$ (fm)	1.3	23.4	45	2268	3752
BR $\mu^+ \mu^-$ (%)	$4.6\ 10^{-3}$	$9.0\ 10^{-3}$	$2.9\ 10^{-2}$	5.9	2.5

- Very short mean lifetime

  $\tau_{\rho} << \tau_{QGP} \sim 10$ fm $< \tau_{\omega,\phi} << \tau_{J/\psi,\Upsilon}$

- Small B.R. in dimuon, but important production :

  $N_{\mu\mu}$ (low masses) ~ $N_{\mu\mu}$ (J/ψ)

Physics motivations

- Formation of a QGP leads to a general strangeness enhancement .
  - Study of the ϕ $(s\bar{s})$ production rate.

- Chiral symmetry restoration
  - Study of the ρ spectral function.

The chiral symmetry

$$\mathcal{L}_{QCD} = -\frac{1}{4} G_a^{\mu\nu} G^a_{\mu\nu} + i\bar{u}\gamma^\mu D_\mu u + i\bar{d}\gamma^\mu D_\mu d - m_u \bar{u}u - m_d \bar{d}d + \ldots$$

$$\psi = \begin{pmatrix} u \\ d \end{pmatrix}$$

If we do not take into account the gluons and the heavier quarks :

$$\mathcal{L} = i\bar{\psi}\gamma^\mu \partial_\mu \psi - \frac{m_u + m_d}{2}\bar{\psi}\psi - \frac{m_u - m_d}{2}\bar{\psi}\tau_3\psi$$

$$m_u, m_d \approx 1{,}5 - 7\ MeV << \Lambda_{QCD} \approx 1\ GeV$$

$$\mathcal{L} = i\bar{\psi}\gamma^\mu \partial_\mu \psi$$

The chiral symmetry (II)

$$\mathcal{L} = i\overline{\psi}\gamma^{\mu}\partial_{\mu}\psi$$
$$= i\overline{\psi}_L\gamma^{\mu}\partial_{\mu}\psi_L + i\overline{\psi}_R\gamma^{\mu}\partial_{\mu}\psi_R$$

Left and right chiralities transform separately $\left(SU(2)_L \otimes SU(2)_R\right)$

↔ The Lagrangian is invariant under chiral transformations :

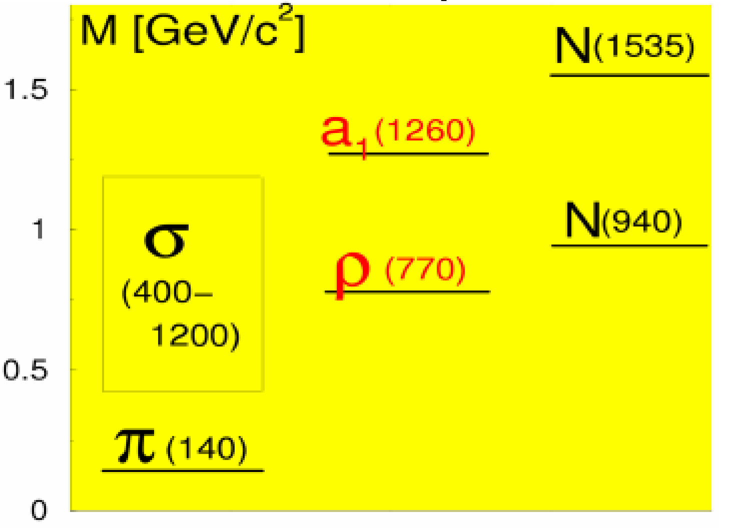
$$\psi_L \rightarrow e^{i\vec{\sigma}\cdot\vec{\varepsilon}_L/2}\psi_L$$
$$\psi_R \rightarrow e^{i\vec{\sigma}\cdot\vec{\varepsilon}_R/2}\psi_R$$

⇒ The QCD presents the chiral symmetry (in the light quarks limit).

Chiral partners

- Consequence of the chiral symmetry :
  - Each particle has a chiral partner with same spin and opposite parity.

$$\Pi(0^-) \leftrightarrow \sigma(0^+)$$
$$\rho(1^-) \leftrightarrow a_1(1^+)$$
$$N(940)(1/2^+) \leftrightarrow N(1535)(1/2^-)$$

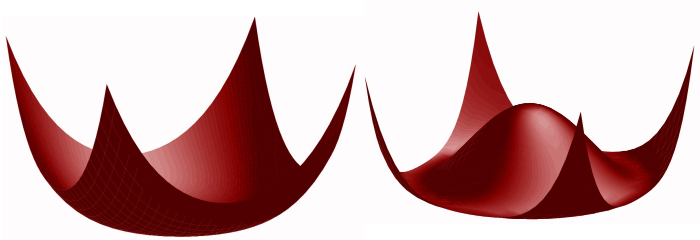


If chiral symmetry was realized then chiral partner would have the same mass. This is not the case.

$\Rightarrow$ Chiral symmetry is broken

Chiral symmetry breaking

- Chiral symmetry is spontaneously broken :
  - $\mathbf{L}_{QCD}$ is chiral symmetric, but
  - the vacuum is not (~ Higgs mechanism).



- Order parameter of the chiral symmetry :

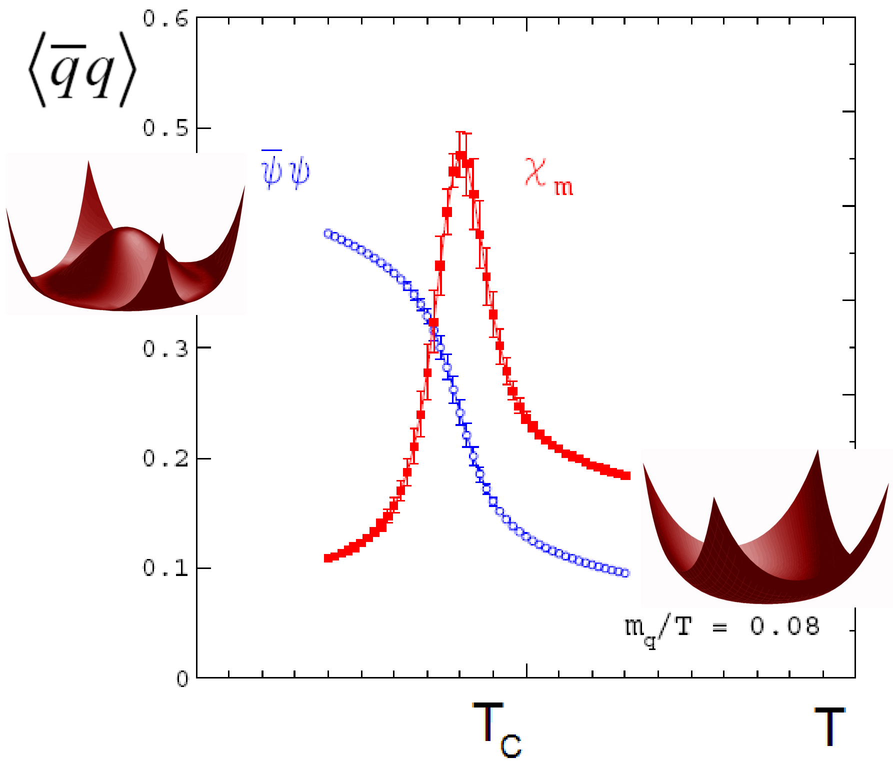
  the quark condensate : $\langle \bar{q}q \rangle = \frac{1}{2} \langle \bar{q}_R q_L + \bar{q}_L q_R \rangle$

- In the QCD vacuum :

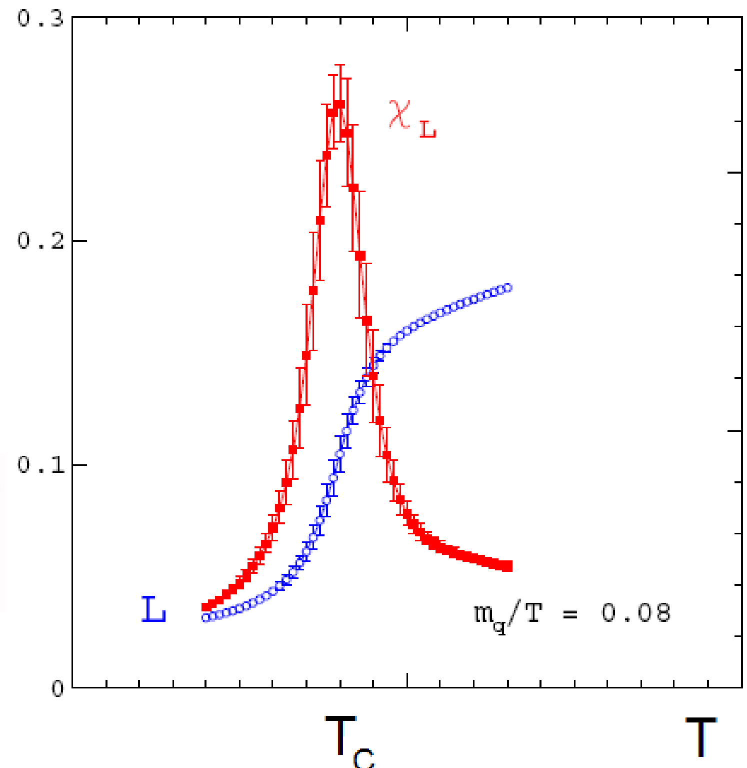
$$\langle \bar{q}q \rangle_0 \approx -(240 MeV)^3$$

(measured from the decay of the pions)

Chiral symmetry restoration



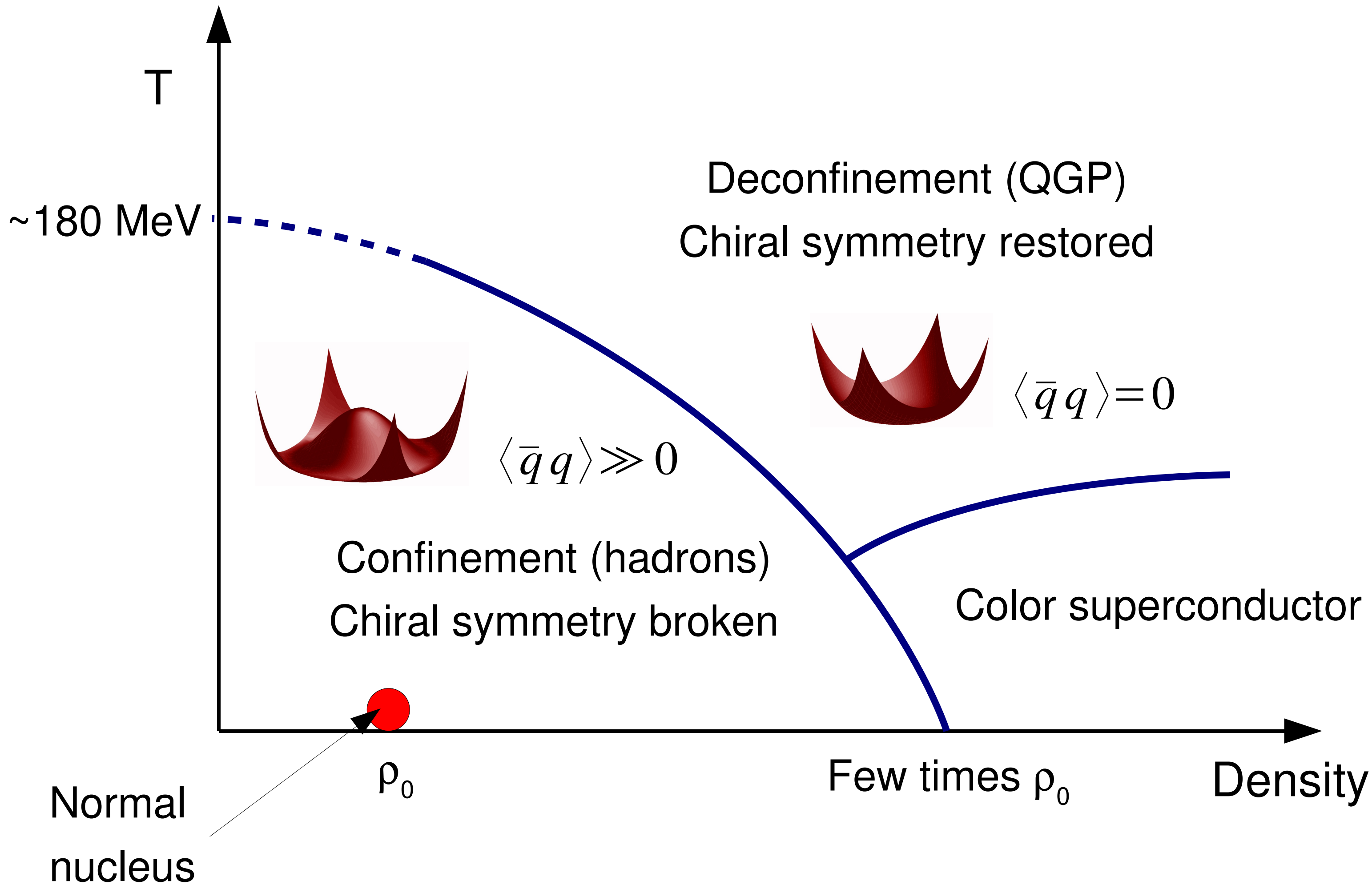
Order parameter of the chiral symmetry



Order parameter of the confinement

- Lattice QCD calculation show a drop of the quark condensate value when $T=T_C$-> phase transition: chiral symmetry restoration
- T_C(chiral)=T_C(deconfinement) !

Phase diagram



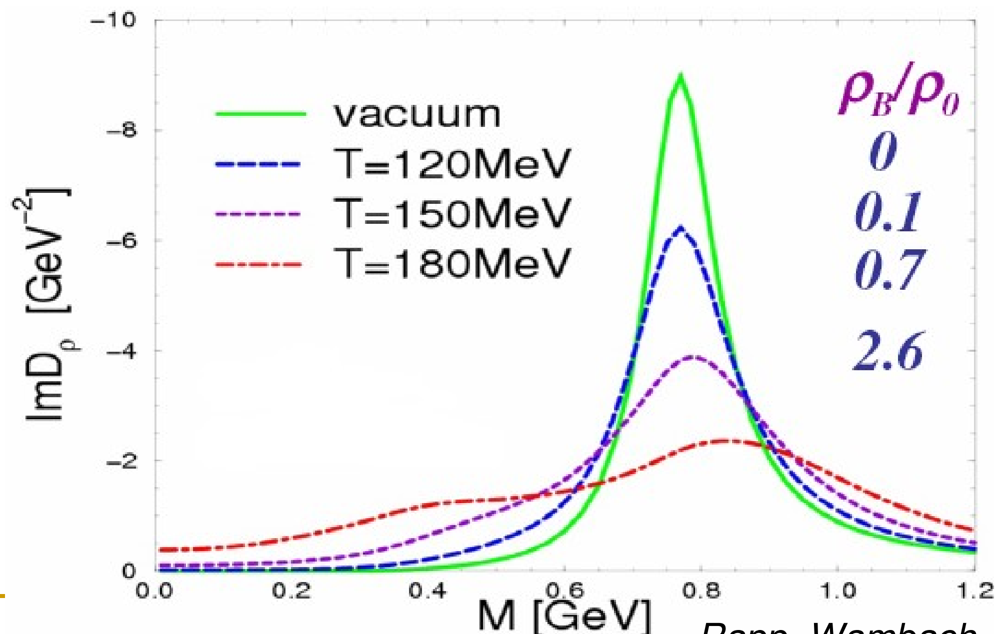
Consequences on the ρ spectrum

- When the temperature increases, the chiral symmetry restoration induces a mixing between chiral partners.
  - For example ρ and a_1.

- The ρ spectral function in a hot and dense medium has been calculated.

- Prediction :

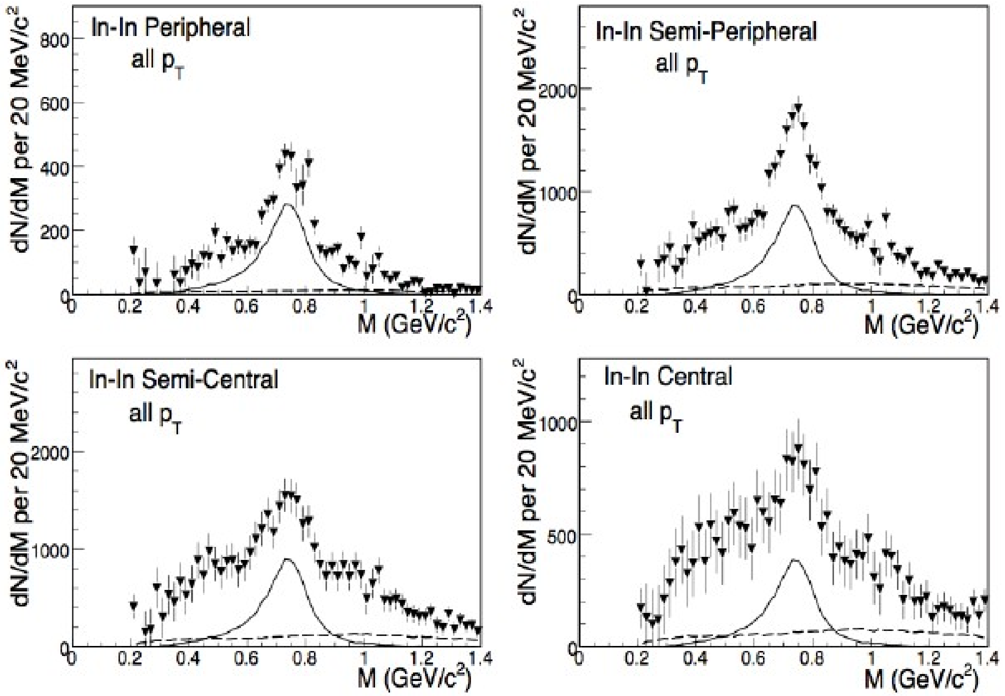
  Broadening of the spectral function with the increase of the temperature and density.



Rapp, Wambach

Experimental results : NA60

NA60 at SPS measured the rho spectral function in In-In collisions.



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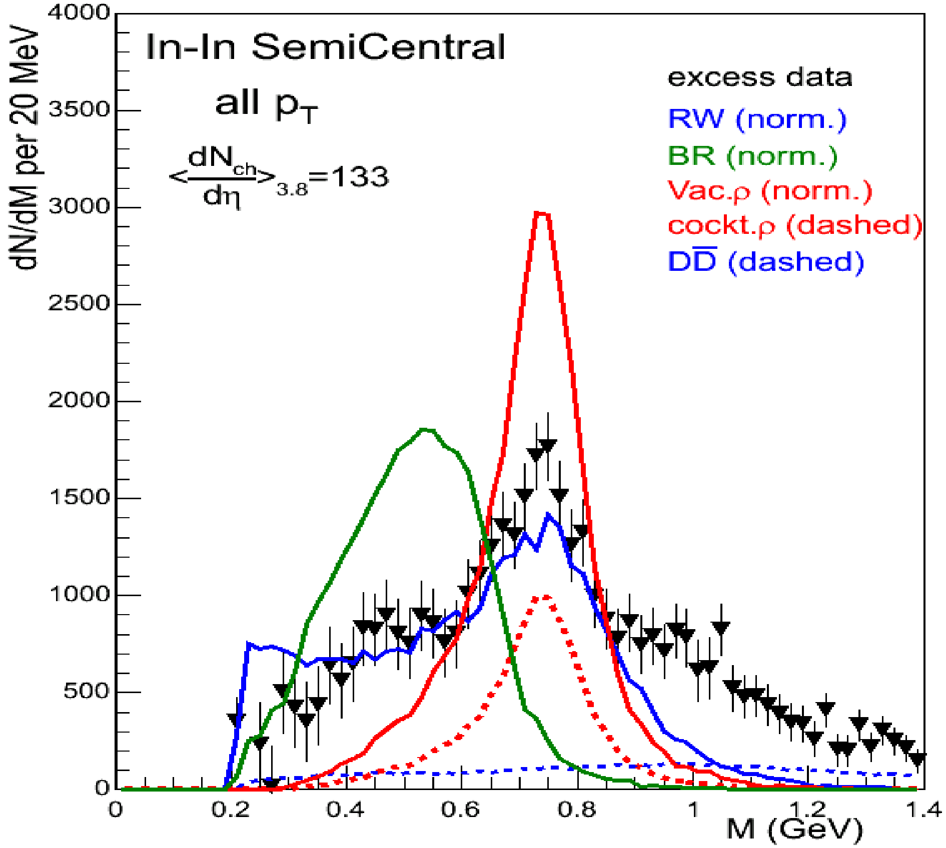
- Net excess peaked at M_ρ, increasing with the centrality. Explained by $\pi\pi \rightarrow \rho \rightarrow \mu^+\mu^-$
- Broadening with the centrality. Explained by in medium effects.

Theory vs NA60



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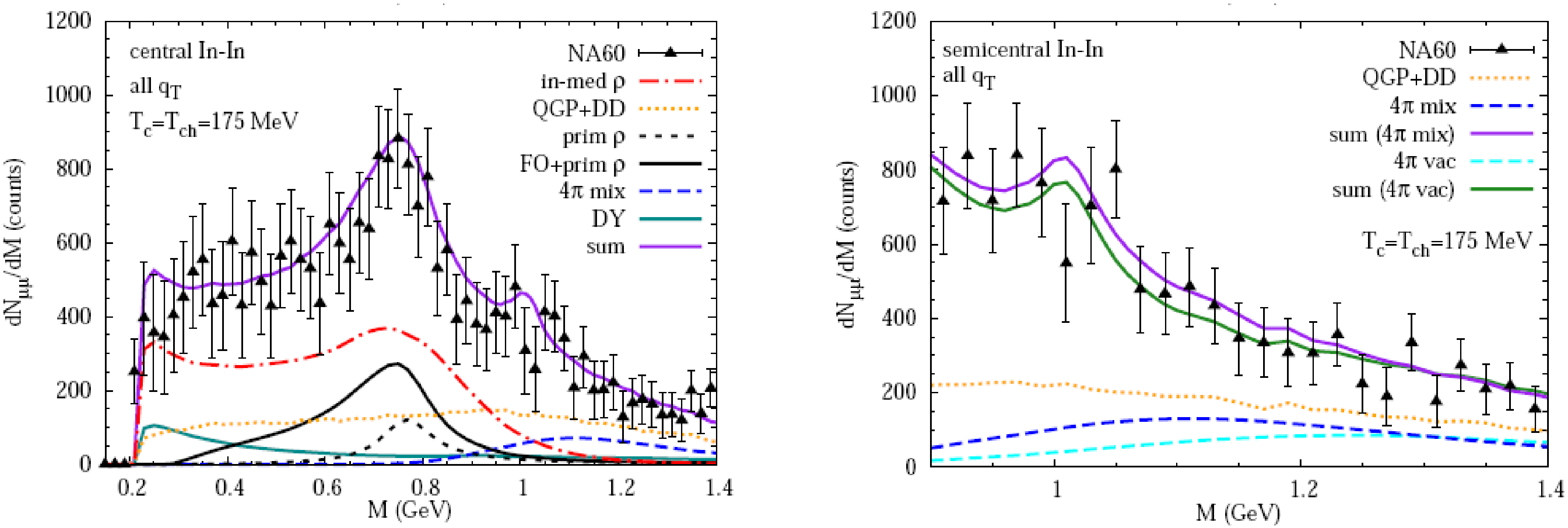
The scenario of a rho spectrum broadening describes the data.

The scenarios of unmodified rho (red) and of mass variation (green) are not observed.

Theory vs NA60, latest results



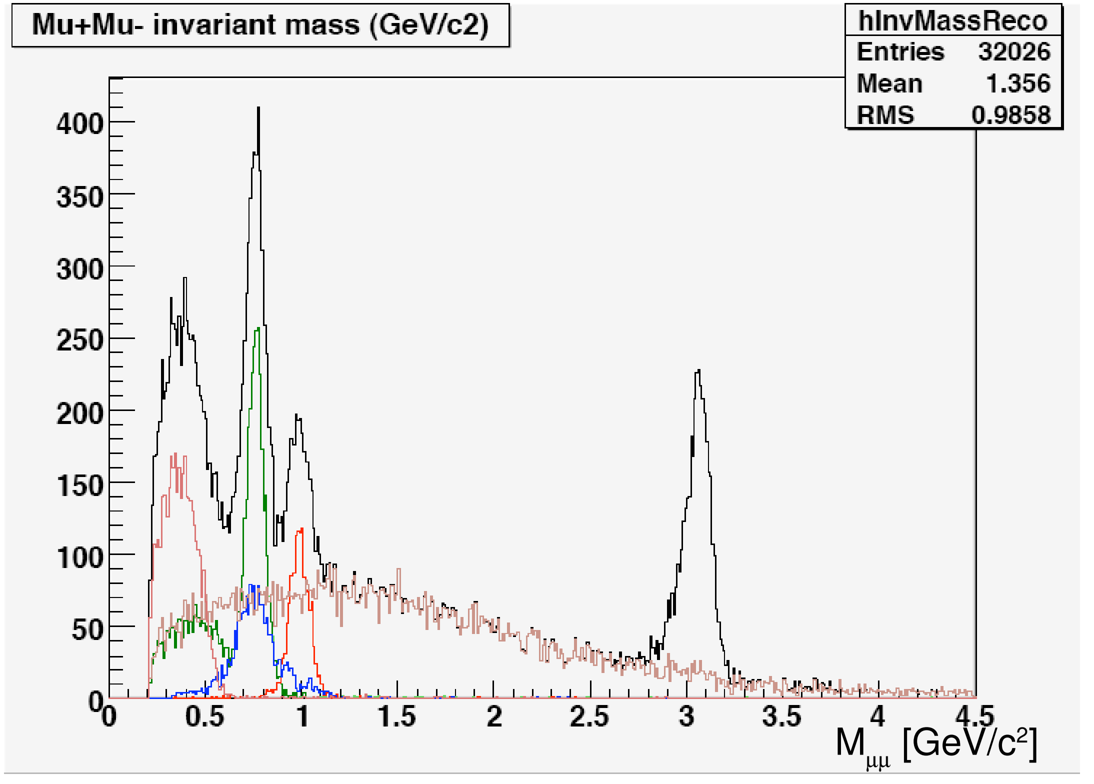
Van Hess, Rapp 04/08

Recent calculations reproduce well the data in all mass range (left panel)
→ In medium effects are well understood.

Direct chiral mixing has a too small effect to be proven (right panel)
→ perhaps in ALICE ?

Prediction for ALICE

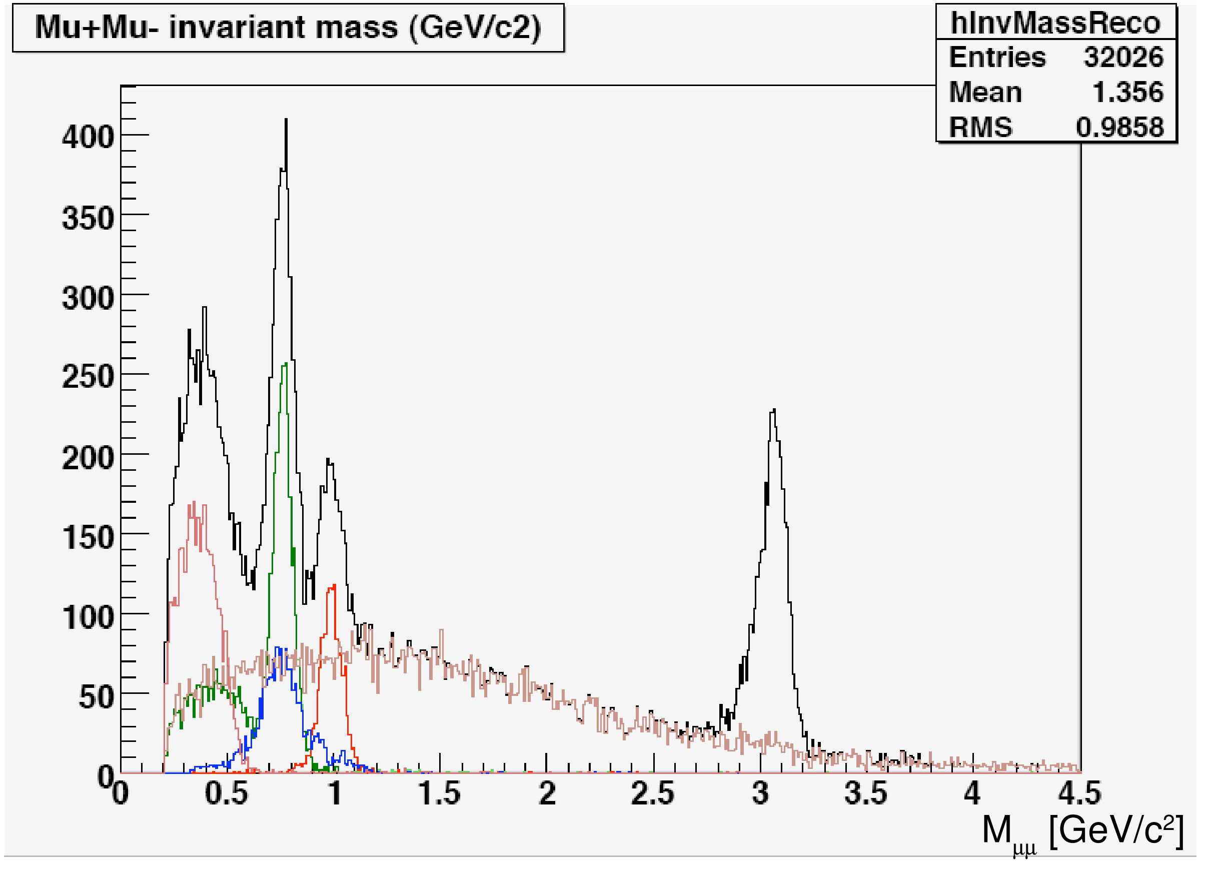
ALICE: pp



Expected signal in the ALICE dimuon spectrometer, without the uncorrelated background (~50000 pp events of PDC06, p_T cut at 0.5 GeV/c).

Contributions of the rho (blue), omega (green), phi (red), eta (dark red) and open c/b (brown).

ALICE: pp (II)



With uncorrelated background (fast simulations for 1 month of data taking).

The signal over noise ratio is still good (S/B ~ 0.3 - 1).

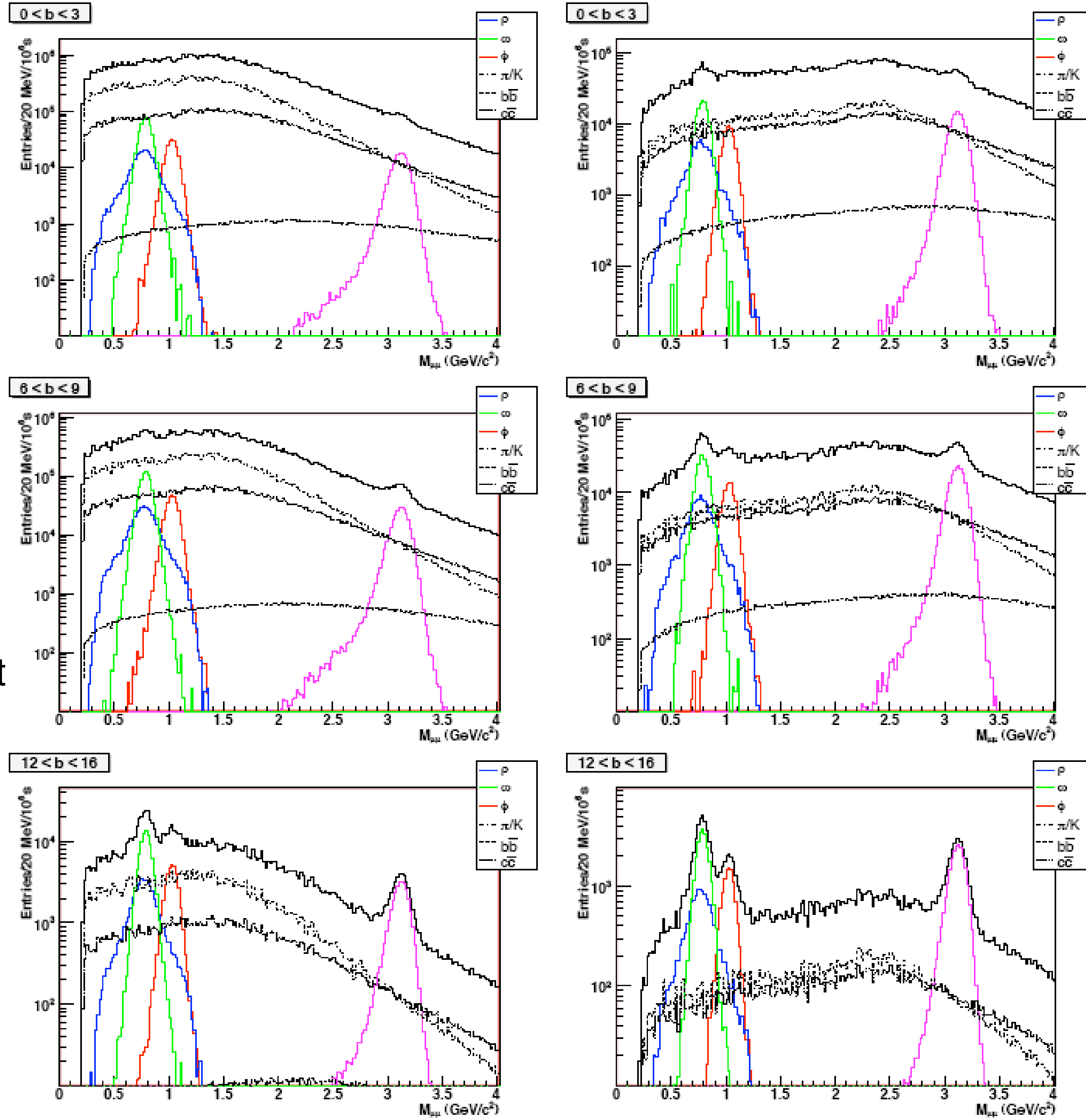
Pb-Pb

Fast simulations, for $p_T > 0.5$ GeV (left) and $p_T > 1$ GeV (right),

for 3 different centralities

Very important background (especially at low p_T).

Problem : in medium effects more important at low p_T.



Signal over background ratio in Pb-Pb

For one month of data taking :

Meson	b range (fm)	S[$\times10^3$]	B[$\times10^3$]	S/B	Significance
ρ	0 - 3	255	16703	0.02	62
	6 - 9	381	9672	0.04	120
	12 - 16	41	167	0.25	92
,ω	0 - 3	503	8485	0.06	168
	6 - 9	755	5178	0.15	310
	12 - 16	82	89	0.92	199
ϕ	0 - 3	210	10668	0.02	64
	6 - 9	323	6125	0.05	127
	12 - 16	34	112	0.31	91

S/B are small, but significance is high thanks to high statistics.

Conclusions

- Low masses dimuons are important for the study of chiral symmetry.
- This study is possible in ALICE, thanks to very high statistics.
- But : an important work on the signal extraction will be necessary.

Backup

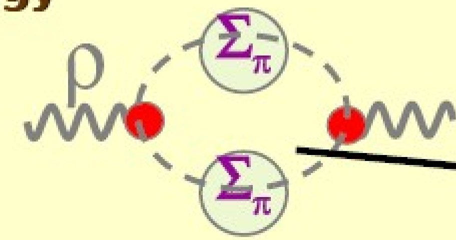
e. Many body approach *(R. Rapp, J. Wambach, G. C)*

ρ propagator

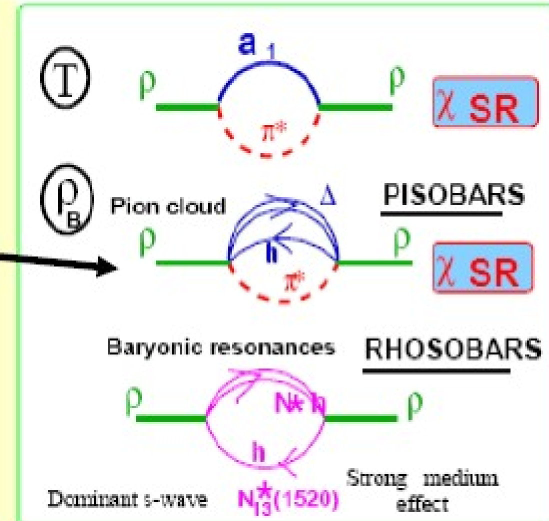
$$D_\rho(M, \vec{q}, \mu_{B,T}) = \left(M^2 - m_\rho^2 - \Sigma_{\rho\pi\pi} - \Sigma_{\rho B} - \Sigma_{\rho M}\right)^{-1}$$

ρ self-energy

$\Sigma_{\rho\pi\pi} =$



$\Sigma_{\rho B,M} =$



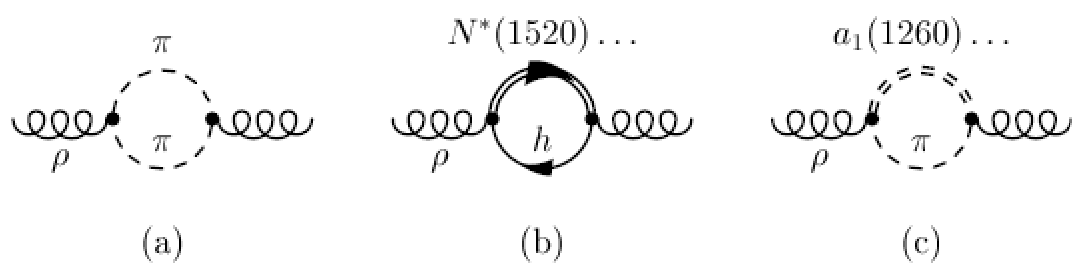
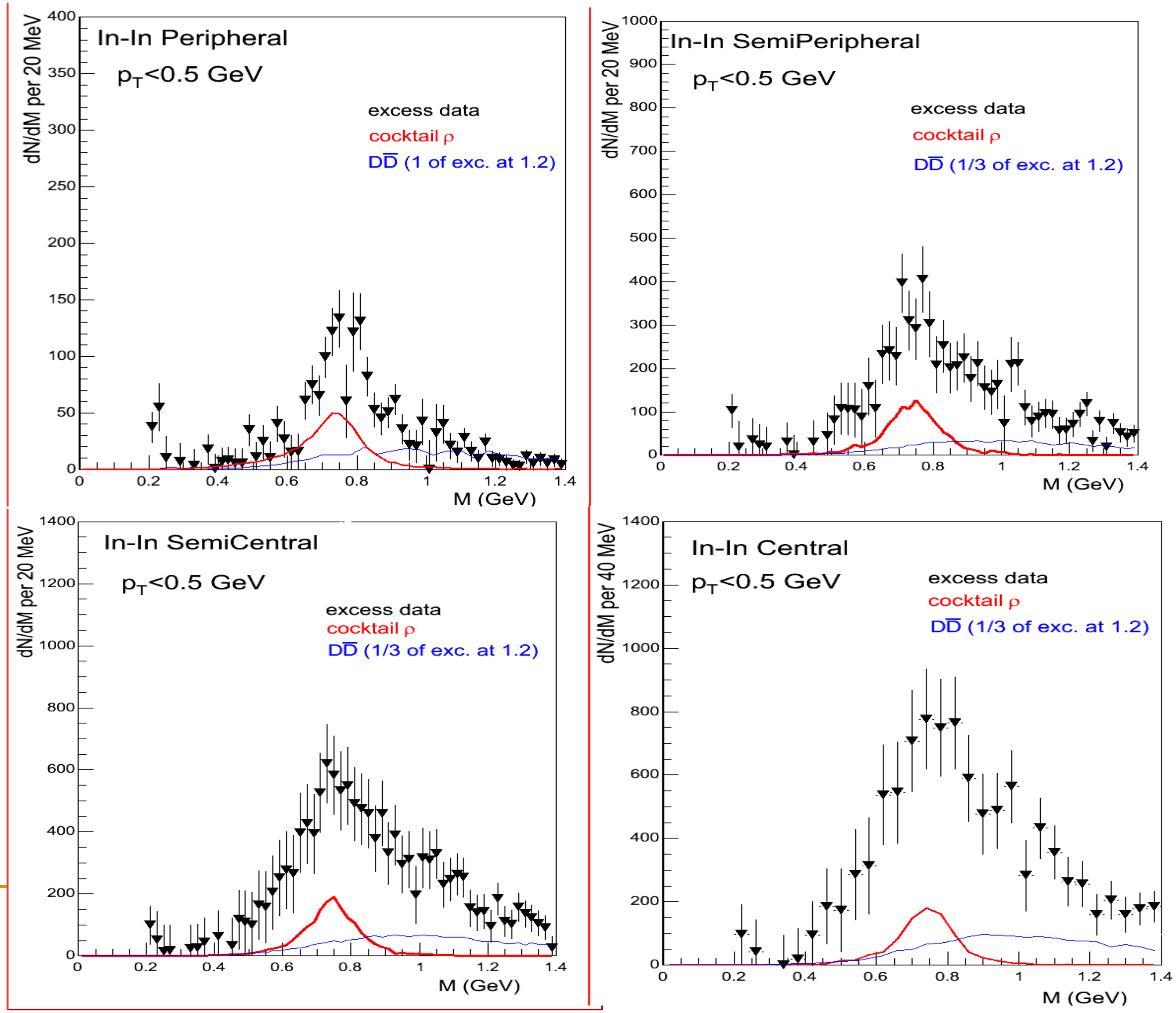


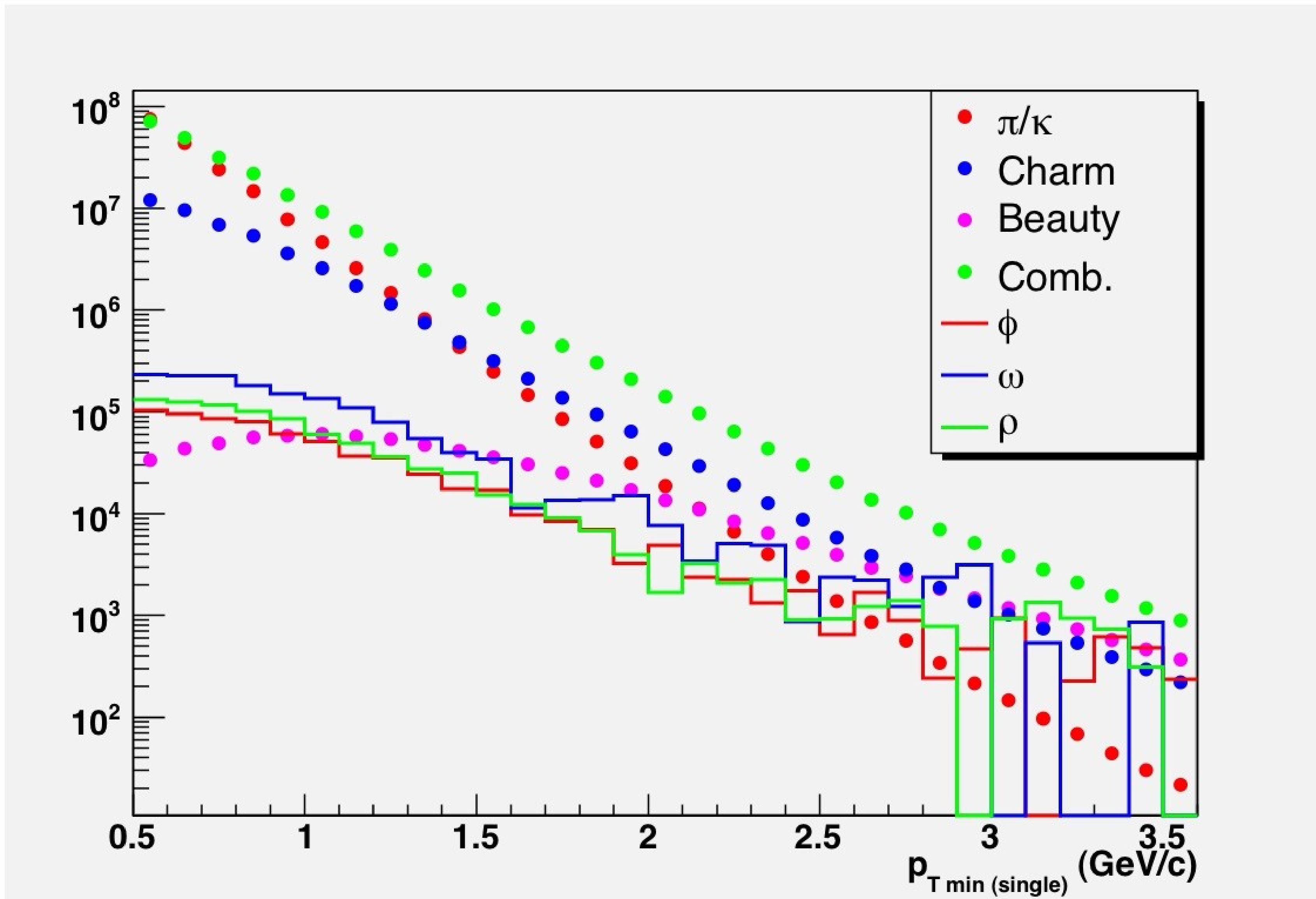
Figure 2: *Sources of medium effects induced by interactions of the ρ meson in hot and dense hadronic matter: (a) renormalization of its pion cloud due to modified pion propagators, and direct interactions of the ρ meson with (b) baryons and (c) mesons, typically approximated by baryon- and meson-resonance excitations [11, 12].*

Table 1.5: Idem as Table 1.5 using the "Low" p_T trigger condition ($p_T^{single} > 1$ GeV/c).

$p_T^{single} > 1$ GeV/c					
Meson	b range (fm)	S[$\times 10^3$]	B[$\times 10^3$]	S/B	Significance
ρ	0 - 3	67	861	0.08	70
	3 - 6	123	1058	0.12	114
	6 - 9	104	505	0.21	133
	9 - 12	50	106	0.47	128
	12 - 16	11	8	1.37	81
ω	0 - 3	137	458	0.30	178
	3 - 6	236	564	0.42	265
	6 - 9	206	267	0.77	300
	9 - 12	100	57	1.74	253
	12 - 16	23	4	5.40	140
φ	0 - 3	61	569	0.11	78
	3 - 6	109	710	0.15	121
	6 - 9	93	339	0.28	142
	9 - 12	45	72	0.63	133
	12 - 16	10	5	1.71	80

NA60, low pT


In-In Peripheral
pT<0.5 GeV
excess data
cocktail ρ
DD̄ (1 of exc. at 1.2)
dN/dM per 20 MeV
M (GeV)
In-In SemiPeripheral
pT<0.5 GeV
excess data
cocktail ρ
DD̄ (1/3 of exc. at 1.2)
dN/dM per 20 MeV
M (GeV)
In-In SemiCentral
pT<0.5 GeV
excess data
cocktail ρ
DD̄ (1/3 of exc. at 1.2)
dN/dM per 20 MeV
M (GeV)
In-In Central
pT<0.5 GeV
excess data
cocktail ρ
DD̄ (1/3 of exc. at 1.2)
dN/dM per 40 MeV
M (GeV)



10^8
10^7
10^6
10^5
10^4
10^3
10^2
0.5
1
1.5
2
2.5
3
3.5
p_T min (single) (GeV/c)
π/κ
Charm
Beauty
Comb.
φ
ω
ρ

Table 1.6: Expected resonance signal (S), background (B) yields (in unit of 10^3), signal-to-background ratio (S/B) and significance ($S/\sqrt{S+B}$) for ρ, ω and φ for five bins in p_T for the most central bin (0<b<3). For each column, the first number gives the result using the "Natural" p_T trigger cut ($p_T^{single} > 0.5$ GeV/c) and the number in parenthesis the result using the "Low" p_T trigger cut ($p_T^{single} > 1$ GeV/c).

Meson	p_T range (GeV/c)	S[$\times 10^3$]	B[$\times 10^3$]	S/B	$S/\sqrt{S+B}$
ρ	0 - 2	104 (0.4)	12142 (39)	0.01 (0.01)	30 (1.8)
	2 - 4	136 (49)	4243 (751)	0.03 (0.06)	65 (55)
	4 - 6	20 (15)	138 (58)	0.14 (0.27)	50 (57)
	6 - 8	3.7 (3.3)	13 (4.9)	0.29 (0.68)	29 (37)
	8 - 10	0.8 (0.7)	2.0 (0.7)	0.38 (1.02)	15 (19)
ω	0 - 2	210 (0.8)	6176 (24)	0.03 (0.03)	83 (4.9)
	2 - 4	274 (100)	2234 (398)	0.12 (0.25)	173 (142)
	4 - 6	42 (33)	74 (32)	0.56 (1.05)	122 (131)
	6 - 8	6.9 (6.4)	7.0 (2.7)	0.99 (2.39)	59 (67)
	8 - 10	1.5 (1.4)	1.1 (0.4)	1.39 (3.65)	29 (33)
φ	0 - 2	89 (0.9)	7487 (36)	0.01 (0.02)	32 (4.7)
	2 - 4	106 (43)	2213 (450)	0.05 (0.10)	69 (62)
	4 - 6	19 (15)	85 (36)	0.22 (0.42)	58 (67)
	6 - 8	2.9 (2.5)	8.1 (3.1)	0.36 (0.80)	28 (34)
	8 - 10	0.8 (0.7)	1.4 (0.5)	0.54 (1.51)	16 (21)