Vector mesons in nuclear matter

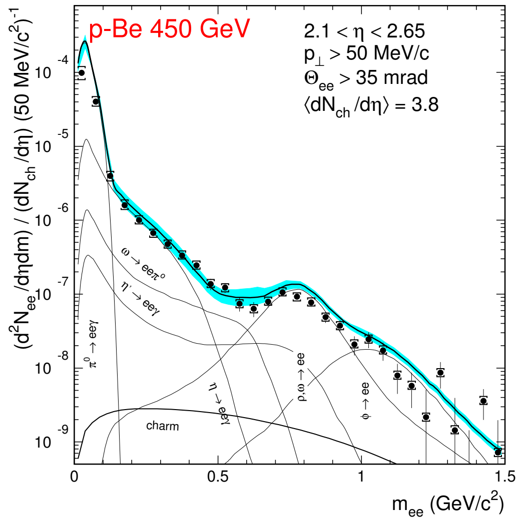
Gy. Wolf,
KFKI RMKI, Budapest
In collaboration with M. Lutz, B. Friman, F. Weber, B. Kämpfer,
O. Pavlenko

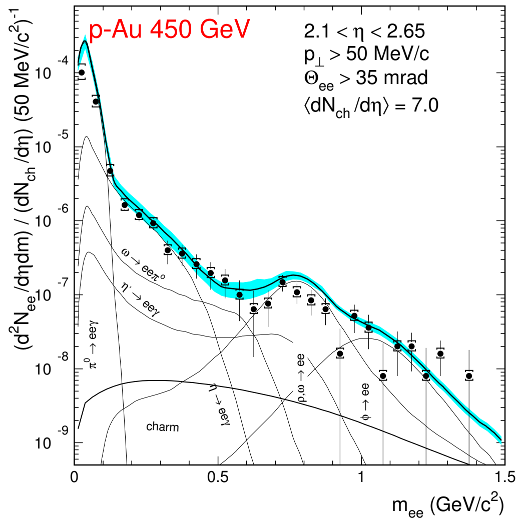
- Why vector mesons?
- Spectral function of vector mesons in matter
- Neutron star properties
- Dilepton spectra
- Summary

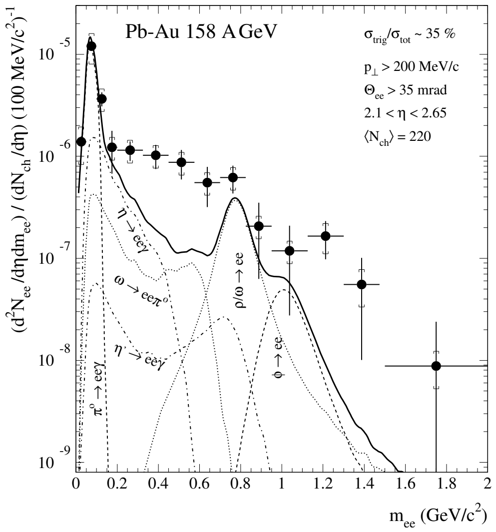
Why vector mesons?

- directly accessible by e^+e^- measurements
  dileptons escape almost undistorted
  $\Rightarrow$ Lepton pair carries information on ρ/ω properties in hot/dense matter
- low mass dilepton yield (CERES and DLS data) to be explained
  simulations: vector mesons are produced at
  $\rho/\rho_0 \sim 0.8 - 3, \quad T \sim 80 - 140 MeV$
- neutron star properties
  nuclear force - mediated by vector mesons - may change in dense matter
- possible tools for studying chiral restoration
  vector meson correlators

CERES data







G. Agakichiev *et al.*

Eur. Phys. J. C4 (1998) 231

G. Agakichiev *et al.*

Phys. Lett. B422 (1998) 405

Self energy of vector mesons

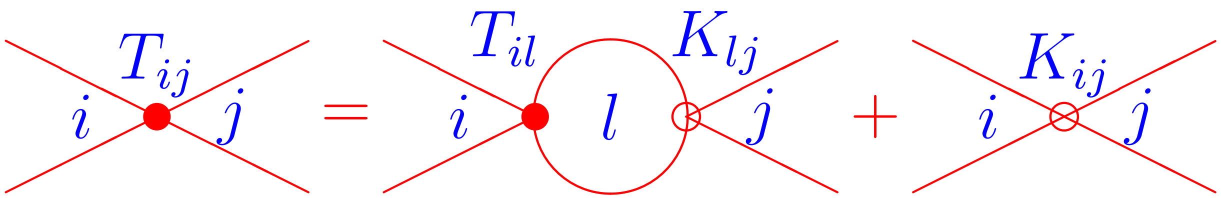
- low density expansion
  $\langle n.m.|\mathcal{O}|n.m.\rangle = \langle 0|\mathcal{O}|0\rangle + \rho\langle N|\mathcal{O}|N\rangle$
- Modification of vector mesons in nuclear matter (after LSZ reduction)

  $\Delta\Pi = -4\pi\rho(1 + \frac{m_V}{m_N})\langle NV|NV\rangle$
  $\langle NV|NV\rangle$: vector mesons' forward scattering amplitude off the nucleon
- goal: $T_{\omega N\rightarrow\omega N}$ and $T_{\rho N\rightarrow\rho N}$
  - not measurable
  - measurable: $T_{\pi N\rightarrow VN}$ and $T_{\pi N\rightarrow\pi N}$

$\Rightarrow$ coupled channels

Coupled channel approach

- Bethe-Salpeter equation



- channels:

  $\boldsymbol{\pi N, \rho N, \omega N, \eta N, \pi\Delta, \eta\Delta, K\Lambda, K\Sigma}$

- partial wave expansion:

  $\boldsymbol{\rho N, \omega N}$ in s-wave so:

  S11:$\boldsymbol{\pi N, \rho N, \omega N, \eta N, \pi\Delta, K\Lambda, K\Sigma}$

  S31:$\boldsymbol{\pi N, \rho N, \pi\Delta, K\Sigma}$

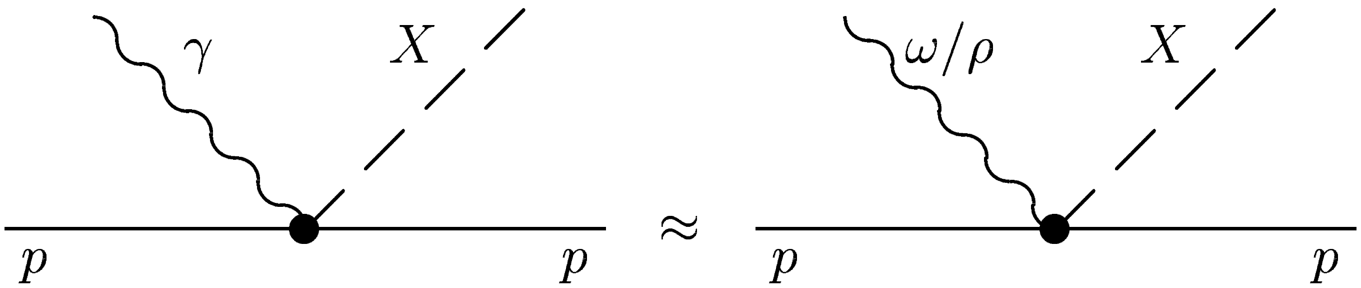
  D13:$\boldsymbol{\pi N, \rho N, \omega N, \pi\Delta}$

  D33:$\boldsymbol{\pi N, \rho N, \pi\Delta, \eta\Delta}$

Photon induced meson production

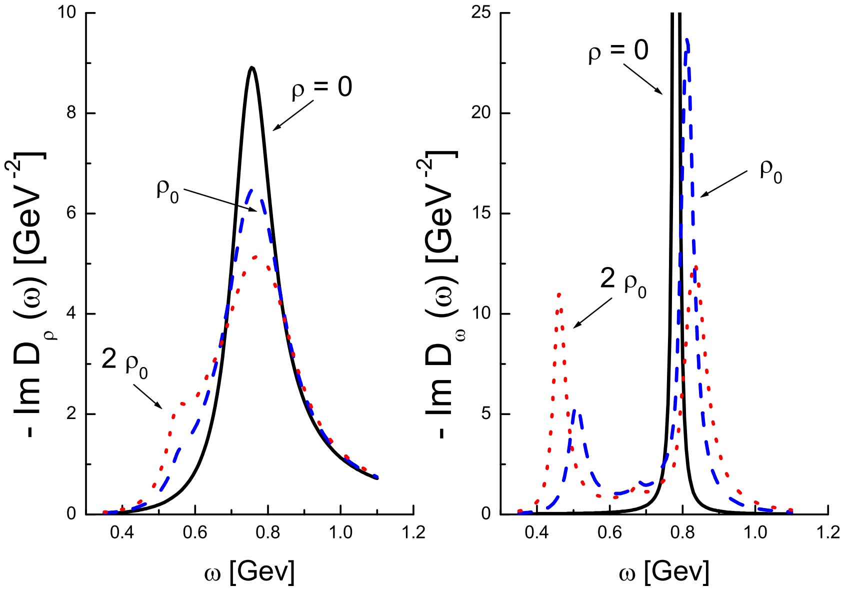
generalized vector meson dominance assumption:

$$\mathcal{M}^{IJ}_{\gamma N \to X} = a^J \mathcal{M}^{IJ}_{\omega N \to X} + b^J \mathcal{M}^{IJ}_{\rho N \to X}$$



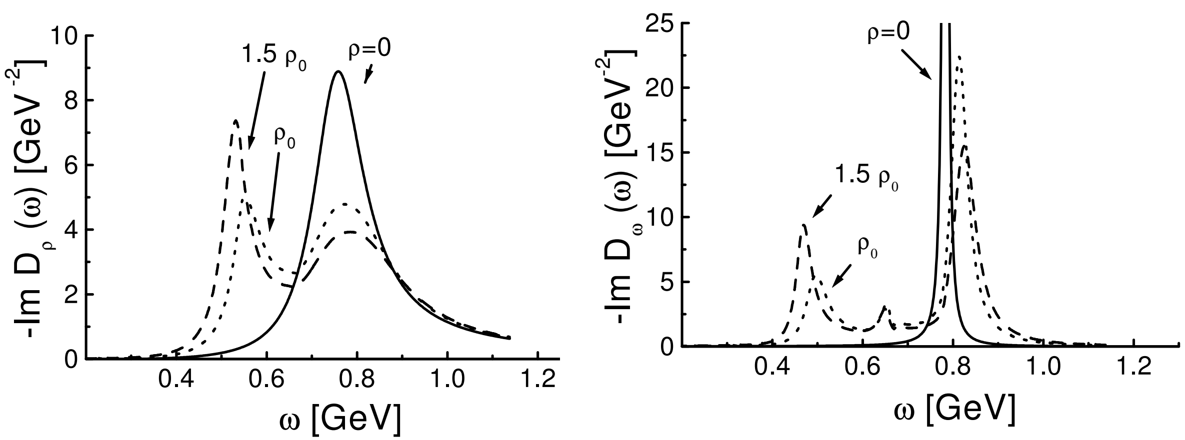
+ vector meson amplitudes tested below threshold
- interference of the vector meson amplitudes
  $\Rightarrow$ relative signs can be fixed (needed for dilepton production)

Vector mesons in nuclear matter



M. Lutz, Gy. Wolf, B. Friman; Nucl Phys. A706 (2002) 431.

our old results:



Neutron star properties

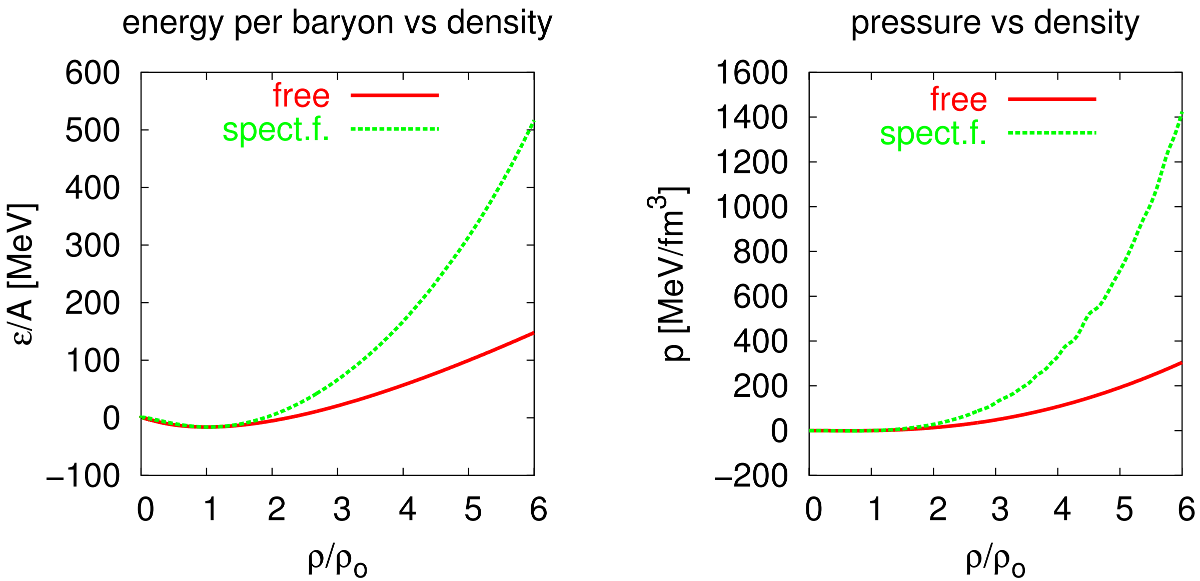
Lagrangian for nucleon, ω, ρ and σ-mesons

$$\begin{aligned}\mathcal{L} \;=\; & \bar{\Psi}\gamma^\mu(i\partial_\mu - g_\omega\omega_\mu)\Psi - \bar{\Psi}(m_N - g_\sigma\sigma)\Psi \\ & -\frac{1}{4}(\partial^\nu\omega^\mu - \partial^\mu\omega^\nu)(\partial_\nu\omega_\mu - \partial_\mu\omega_\nu) + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu \\ & +\frac{1}{2}(\partial_\nu\sigma\partial^\nu\sigma - m_\sigma^2\sigma^2) - \frac{1}{3}bm_N(g_\sigma\sigma)^3 - \frac{1}{4}c(g_\sigma\sigma)^4 \\ & -\frac{1}{4}(\partial^\nu\rho^\mu - \partial^\mu\rho^\nu)(\partial_\nu\rho_\mu - \partial_\mu\rho_\nu) + \frac{1}{2}m_\rho^2\rho_\mu\rho^\mu \\ & -g_\rho\rho_\nu(\frac{1}{2}\bar{\Psi}\gamma^\nu\tau\Psi + \rho_\mu \times (\partial^\nu\rho^\mu - \partial^\mu\rho^\nu) + 2g_\rho(\rho^\nu \times \rho^\mu) \times \rho_\mu)\end{aligned}$$

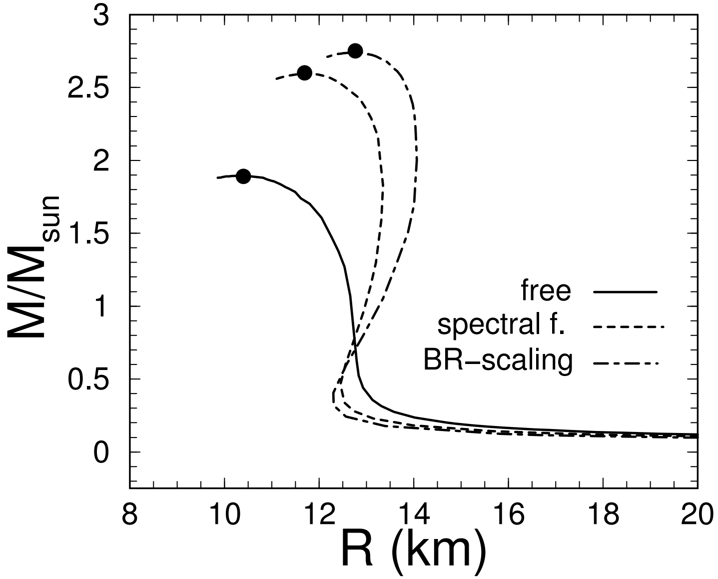
+ mean field approximation

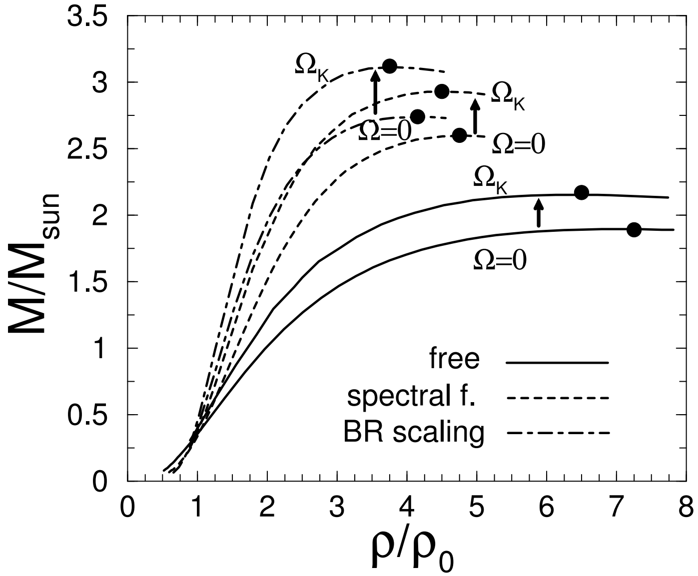
EOS of neutron stars

- In the mean field energy and pressure the vektor meson part always proportional g_v^2/m_v^2.
- $g_v^2/m_v^2 \longrightarrow \int g_v^2/s f(s) ds$
- EOS is stiffer

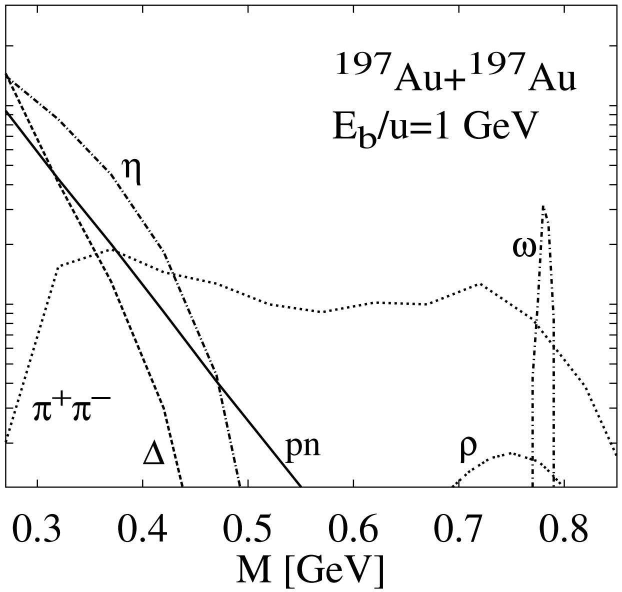


Effects on neutron stars



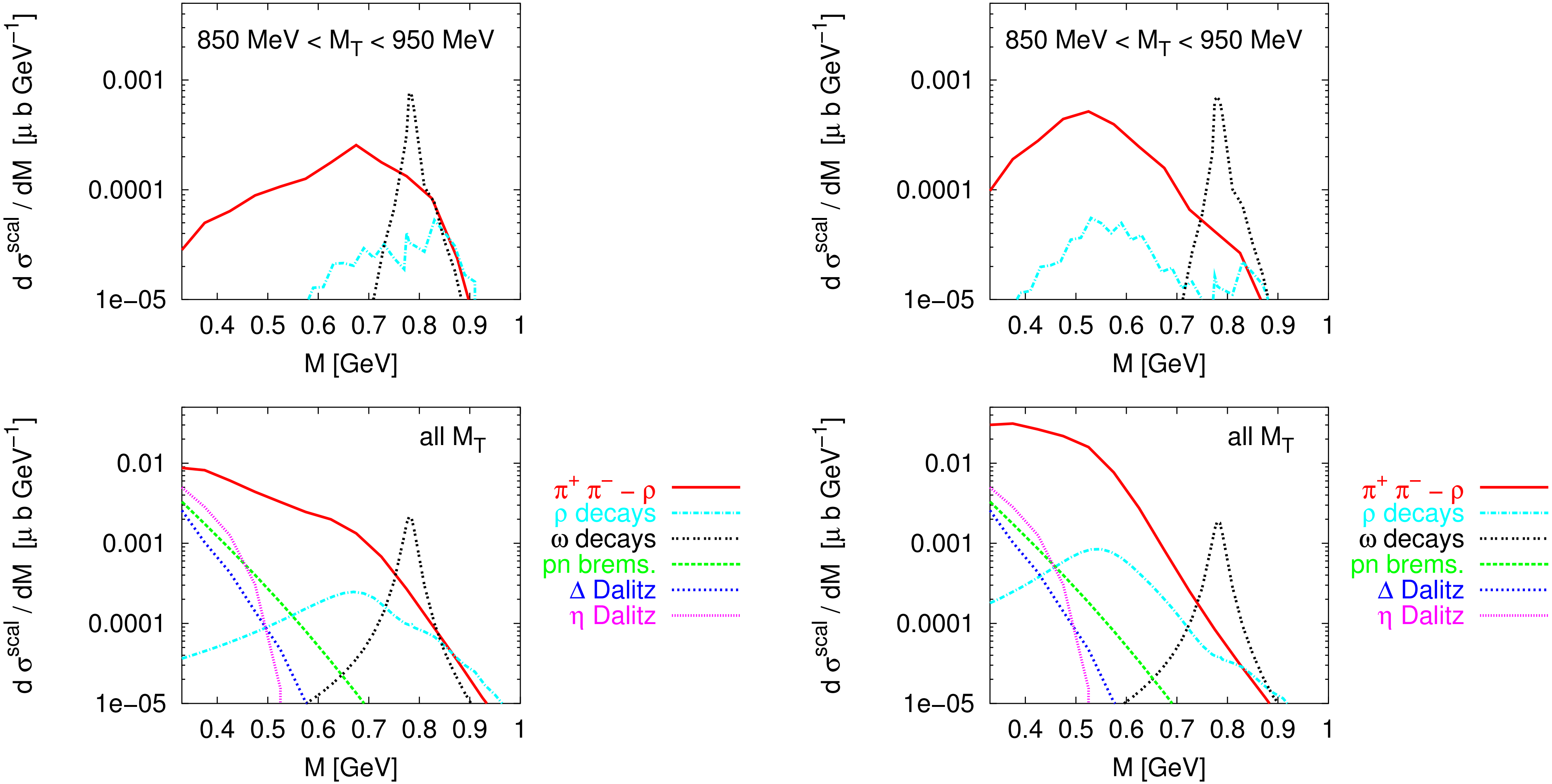


Vector mesons in the dilepton spectra



- vector mesons dominate above 500 MeV
- $\frac{d\sigma}{dM} \sim f_{SB}(T,E) f_{SF}(M)$
- invariant mass spectra at fixed $m_t \longrightarrow \frac{d\sigma}{dM} \sim f_{SF}(M)$

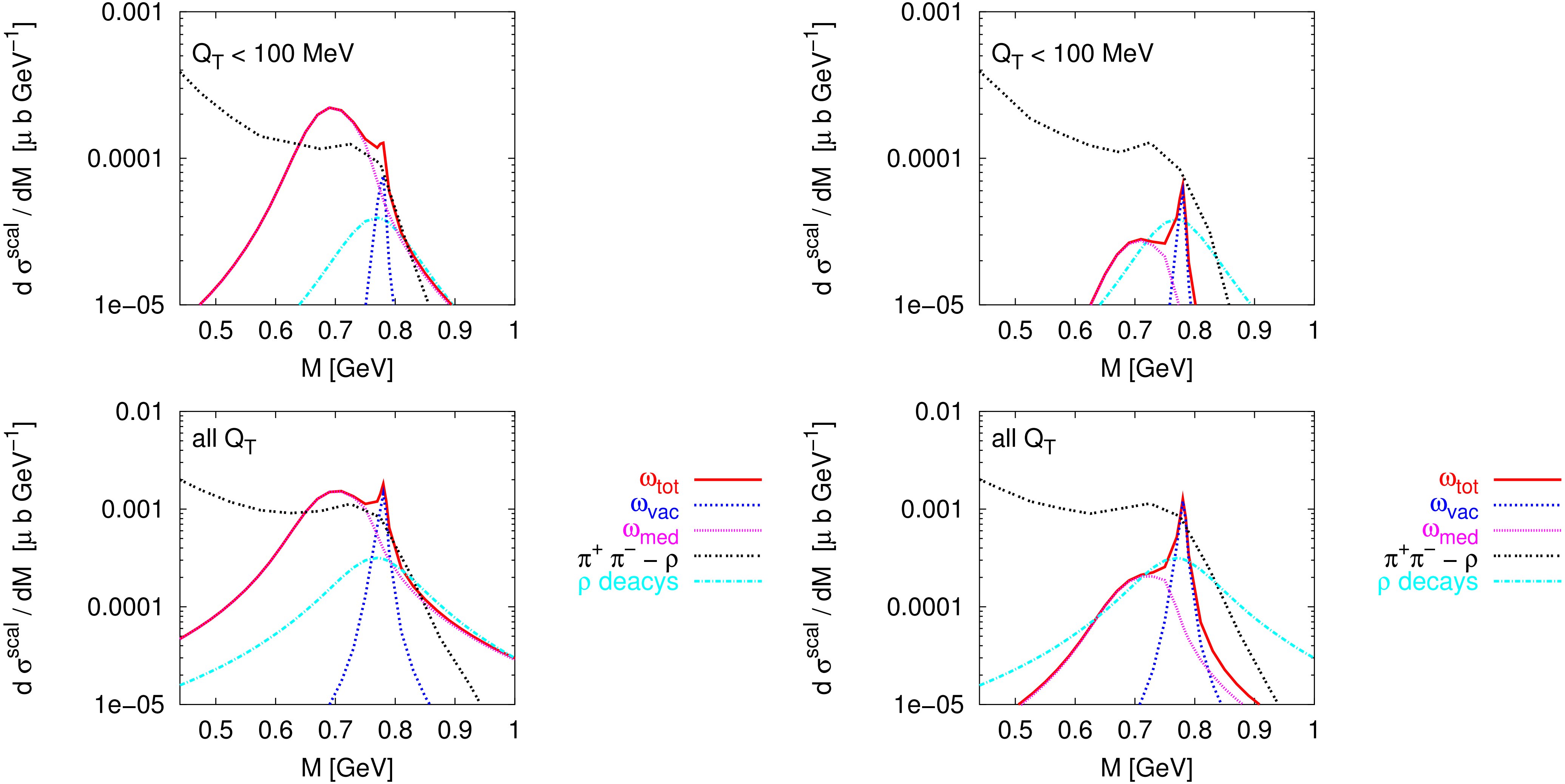
Vector mesons modification in the dilepton spectra



a) ρ- and ω-width multiplied by a factor 3

b) additional ρ-mass shift of 150 MeV

Vector mesons modification in the dilepton spectra



$\Gamma_\omega = \Gamma_{\omega_o} + 50\, MeV \times \rho/\rho_o \qquad m_\omega = m_{\omega_o} - 70\, MeV \times \rho/\rho_o$

a) fixed branching ratio

b) fixed em width

Gy. Wolf, O.P. Pavlenko, B. Kaempfer; nucl-th/0306029

Summary

- vector meson modification is not mass shift, or broadening, but resonance-hole excitations in the spectral function
- vector meson modifications may have an effect on neutron star structure
- difficult to observe the modifications in the dilepton mass spectra, better to use additional kinematical cuts, like m_t or p_t.
- include the vector meson propagation with their spectral function
- use realistic spectral functions