Dilepton production at intermediate energies with in-medium spectral functions of vector mesons

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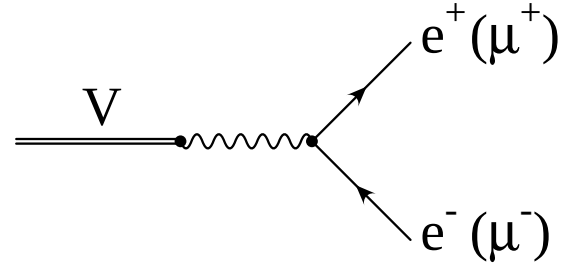
Content

- Elementary sources for e^+e^- production
  - Meson decays to e^+e^-
  - Nucleon resonance decays to e^+e^-
- In-medium spectral functions of ρ and ω
- Application to C+C@2.0 AGeV
  - Various in-medium scenarios vs. HADES data
- Summary and Conclusions

Elementary sources for e^+e^- production

Mesonic decays



Dilepton decays of pseudoscalar (π,η,$\eta\prime$)

and vector (ρ, ω, ϕ) mesons

$$d\Gamma^{(\mathcal{M}\to Xe^+e^-)} = d\Gamma^{(\mathcal{M}\to X\gamma^\star)} M\Gamma^{(\gamma^\star\to e^+e^-)} \frac{dM^2}{\pi M^4}$$

$$M\Gamma^{(\gamma^\star\to e^+e^-)} = \frac{\alpha}{3}\left(M^2+2m_e^2\right)\sqrt{1-\frac{4m_e^2}{M^2}}$$

direct decays : $\mathcal{M}\to e^+e^-$

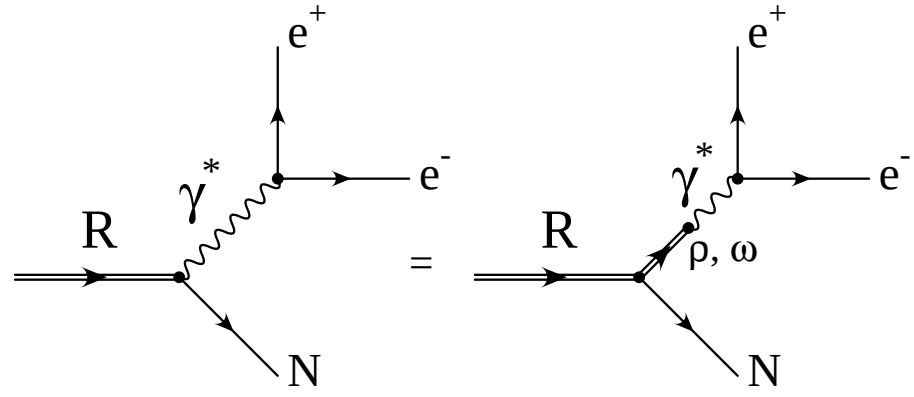
Dalitz decays : $\mathcal{M}\to \pi e^+e^-, \gamma e^+e^-, \ldots$

4-body decays : $\mathcal{M}\to \pi\pi e^+e^-$

A.Faessler, C.Fuchs and M.I.Krivoruchenko, **PRC61**(2000)035206

Resonance decays

$R \to N e^+ e^-$ decays of nucleon resonances $R = \Delta, N^\star$ with mass μ below 2 GeV and spin $J \leq \frac{7}{2}$



Vector meson dominance (VMD)

$$d\Gamma^{(R\to N e^+ e^-)} = d\Gamma^{(R\to N\gamma^\star)} M\Gamma^{(\gamma^\star\to e^+e^-)} \frac{dM^2}{\pi M^4}$$

$$d\Gamma^{(R\to N\gamma^\star)} \propto l.c. \left\{ |G_M|^2, |G_E|^2, |G_C|^2 \right\}_{c(\mu, m_N, M; l)}$$

decay modes: $\Delta \to N\rho; N^\star \to N\rho, \omega$

problems of VMD

- inconsistency between resonance meson decay and photoproduction data
- wrong asymptotics for the form factors

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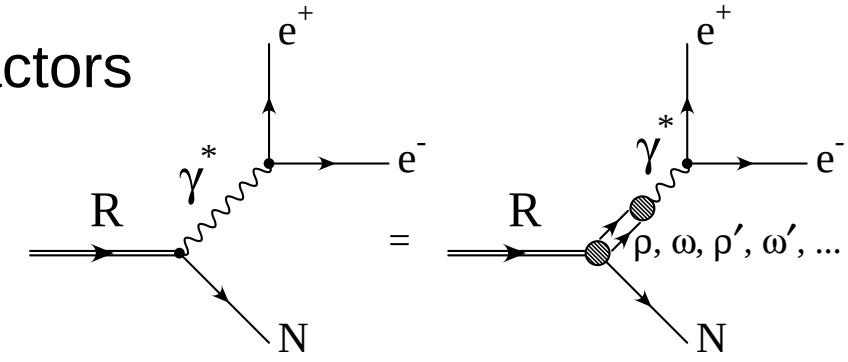


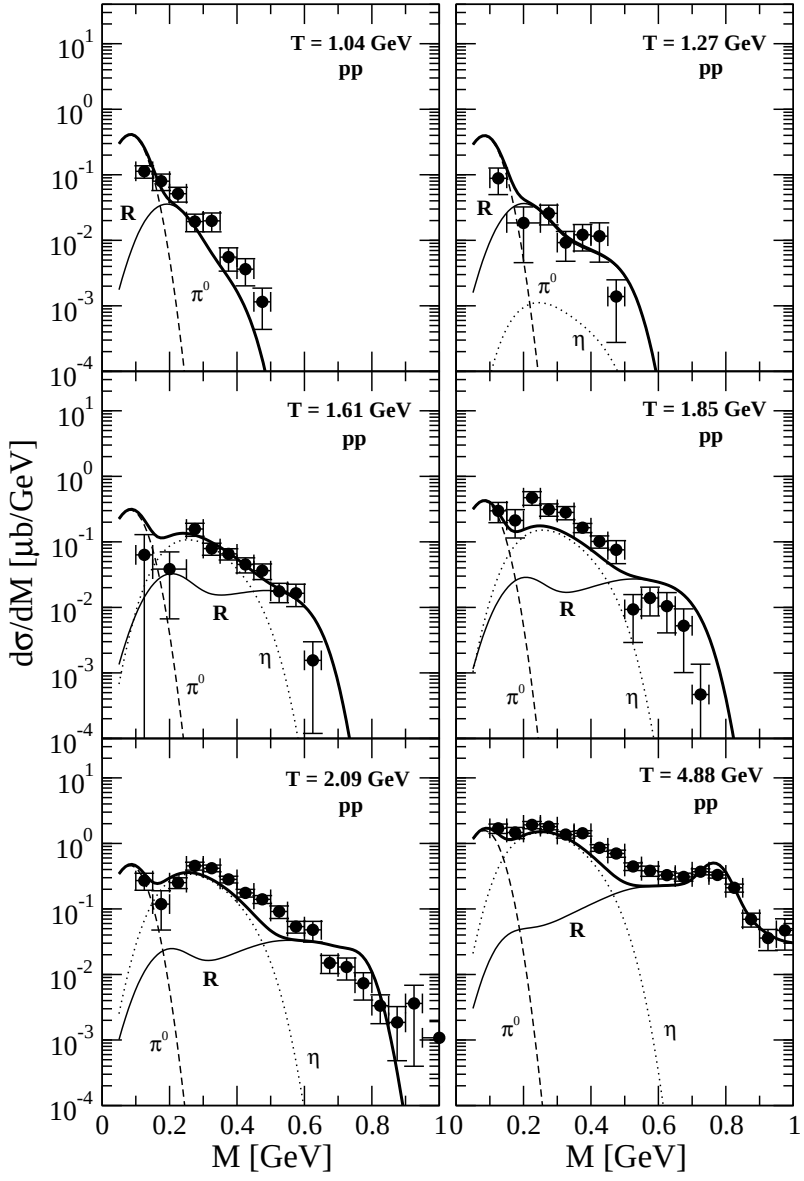
$\Rightarrow$ **Extended VMD**

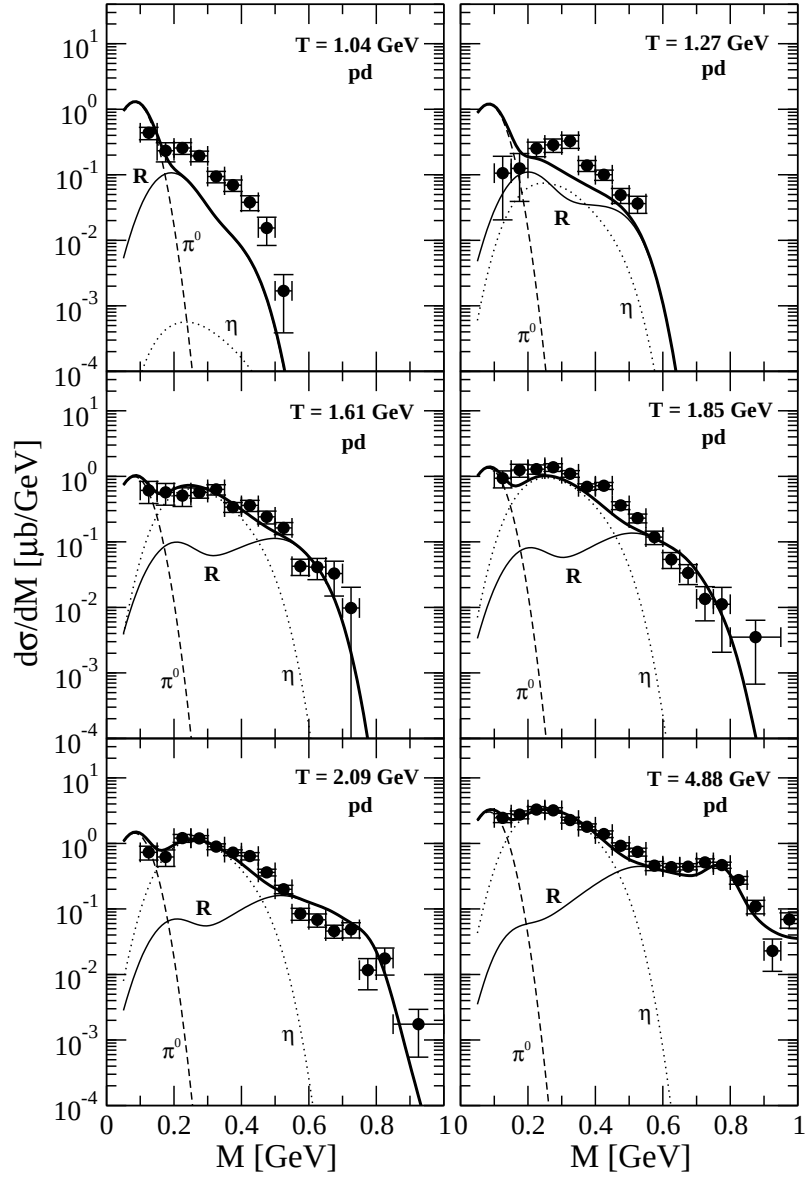
ASSUMPTION: interference between ρ and ρ', ρ'', . . . , in radiative processes

$\Rightarrow$ include excited ρ', ω', ρ'', . . . , states in the transition form factors

M.I.Krivoruchenko, B.Martemyanov, A.Faessler and C.Fuchs, **AP296**(2002)299

eVMD vs. $pp \to e^+e^-X$ and $pd \to e^+e^-X$





K.Shekhter, C.Fuchs *et al.*, **PRC68**(2003)014904

Heavy Ion Collisions

Transport model: **Quantum Molecular Dynamics**

Tübingen RQMD:

- all R with mass below 2 GeV included
- included baryon-baryon collisions:

  all elastic channels

  inelastic channels $NN \to NN^\star$, $NN \to N\Delta^\star$, $NN \to \Delta N^\star$,

  $$NN \to \Delta\Delta^\star,\ NR \to NR'$$
- included pion-absorption $\rightleftharpoons$ resonance-decay channels:

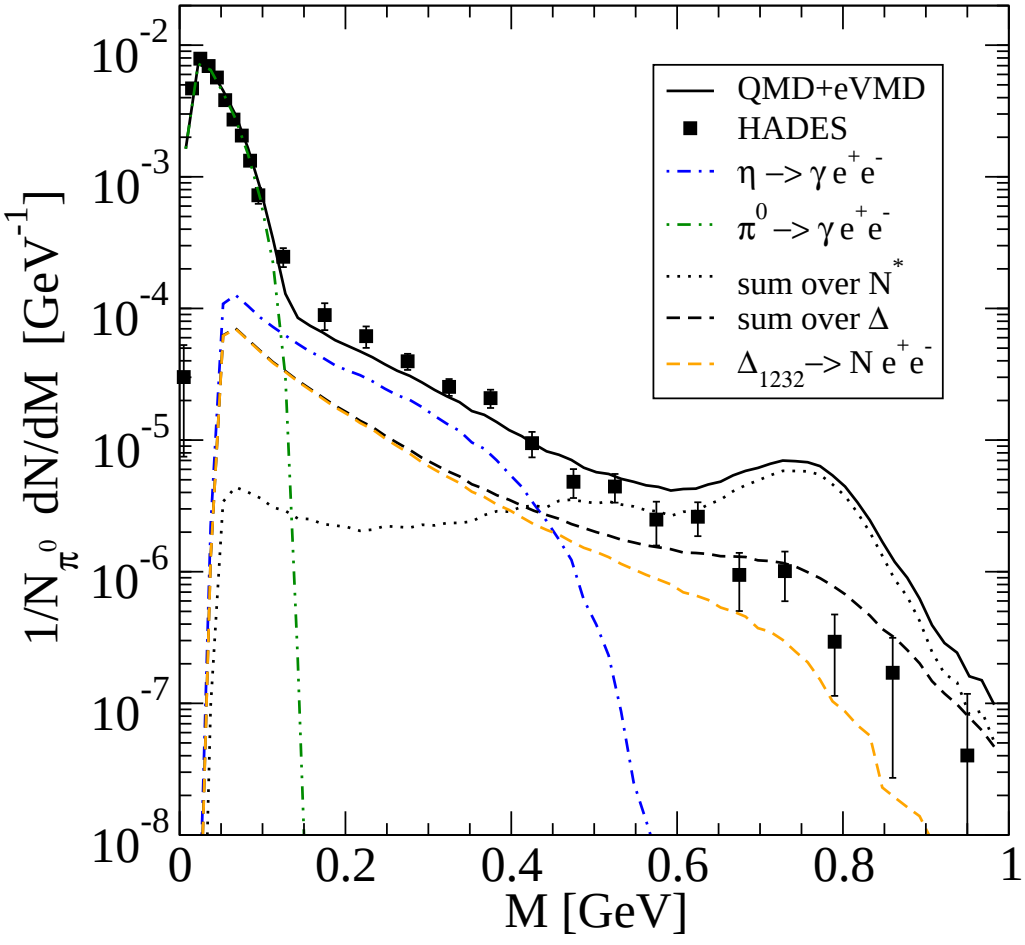
  $\Delta \rightleftharpoons N\pi$, $\Delta^\star \rightleftharpoons \Delta\pi$, $\Delta^\star \rightleftharpoons N_{1440}\pi$, $N^\star \rightleftharpoons N\pi$,

  $N^\star \rightleftharpoons N\pi\pi$, $(N^\star \rightleftharpoons \Delta\pi,\ N^\star \rightleftharpoons N_{1440})$
- included η absorption via $N^*(1535)$

  η production cross sections in C+C consistent with results from TAPS

eVMD+RQMD: K.Shekhter *et al.*,**PRC68**; M.D.Cozma *et al.*,**PLB640**.

Vacuum eVMD vs. HADES



In-medium effects necessary!

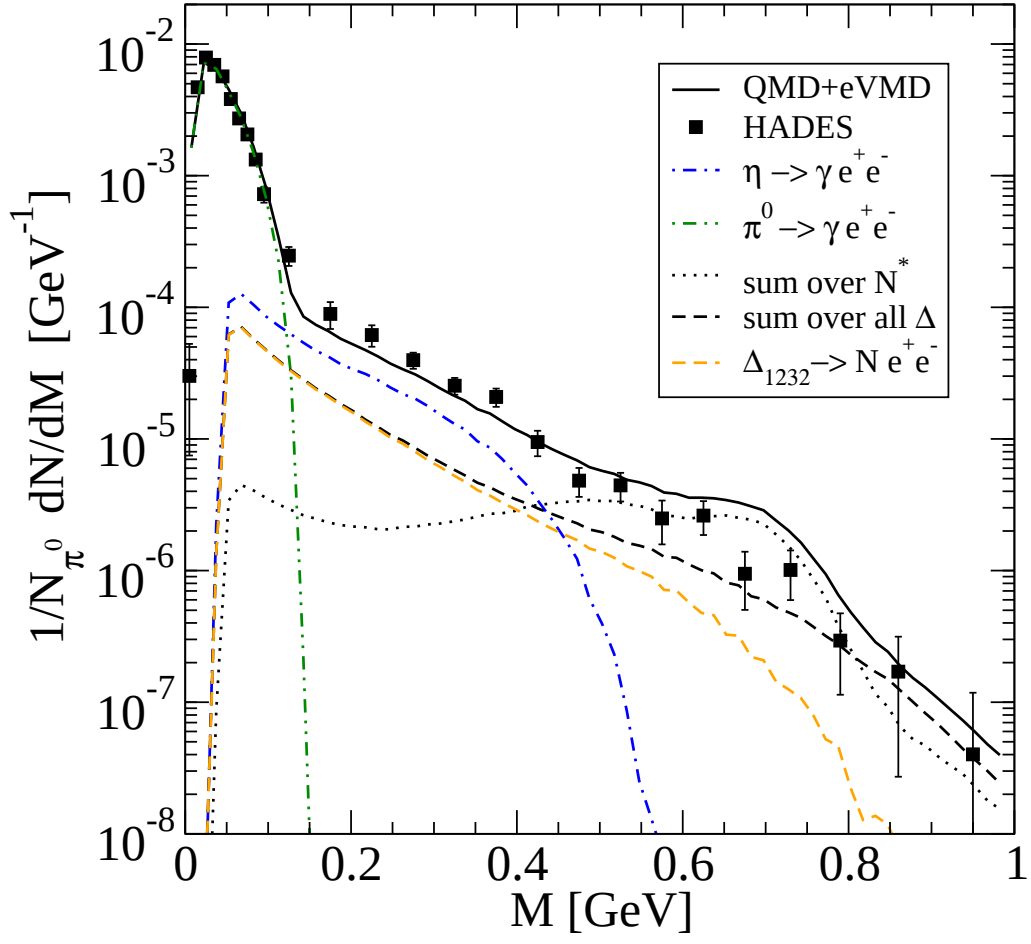
Exp. data: G. Agakichiev et al., PRL **98**, 052302 (2007)

"schematic" in-medium scenario

- $\Gamma_V^{\rm tot} = \Gamma_V^{\rm vac} + \rho/\rho_0 \Gamma_V^{\rm coll}$ with

  $\Gamma_\omega^{\rm tot}(\rho_0)$ = 125 MeV,

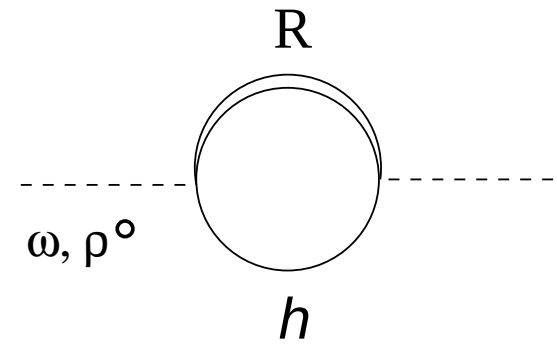
  $\Gamma_\rho^{\rm tot}(\rho_0)$ = 250 MeV



In-medium spectral functions

- **Self-energy**

$$\Sigma_N = -\int A_{VN}\, 2\cdot 2 \frac{d^3p_N}{2E(2\pi)^3} \quad \sim$$



$$A_{VN} = -\sum_R \frac{(2J_R+1)}{2\cdot 3}\frac{8\pi s}{k}\frac{\Gamma_{RNV}(s)}{s - M_R^2 + i\sqrt{s}\Gamma_R^{tot}(s)} \qquad \left(n_B = \frac{2}{3\pi^2}p_F^3\right)$$

$$\Gamma_{RNV}(s) = \frac{k}{8\pi s}\frac{\overbrace{2(A_{3/2}^2 + A_{1/2}^2 + S_{1/2}^2)}^{\Sigma_N^T\ ,\ \Sigma_N^L}}{(2J_R+1)} \qquad \Sigma_N = \frac{2\Sigma_N^T + \Sigma_N^L}{3}$$

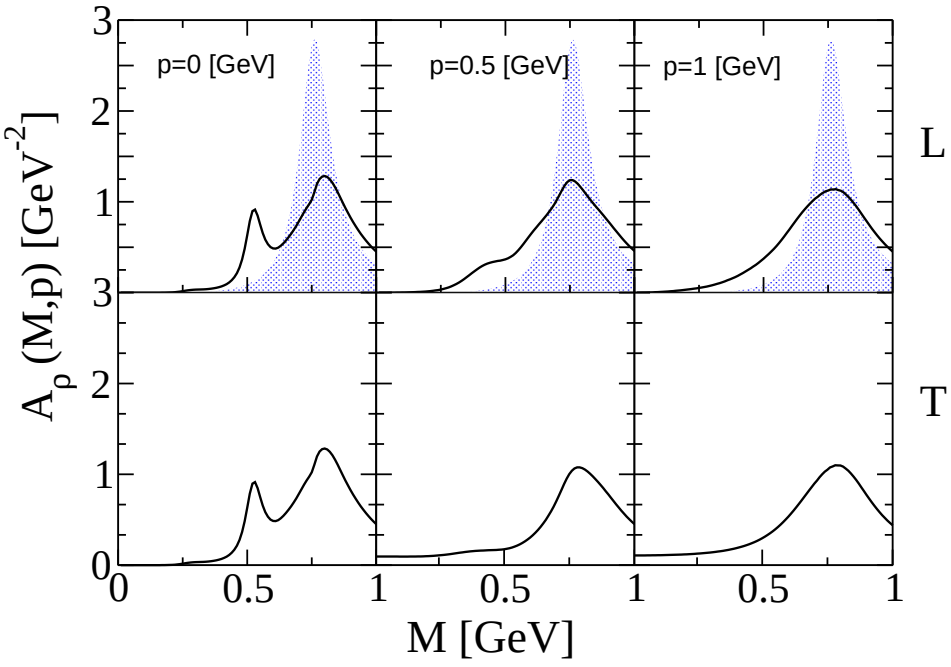
$$\boxed{\Sigma = \Sigma_N + \Sigma_0} \qquad \Sigma_0 = -im_\rho \Gamma_V^{tot}(m)$$

Included R: $N^*(1535)$, $N^*(1650)$, $N^*(1520)$, $N^*(1440)$, $N^*(1720)$, $N^*(1680)$, $\Delta(1620)$, $\Delta(1700)$, $\Delta(1232)$, $\Delta(1905)$, $\Delta(1950)$

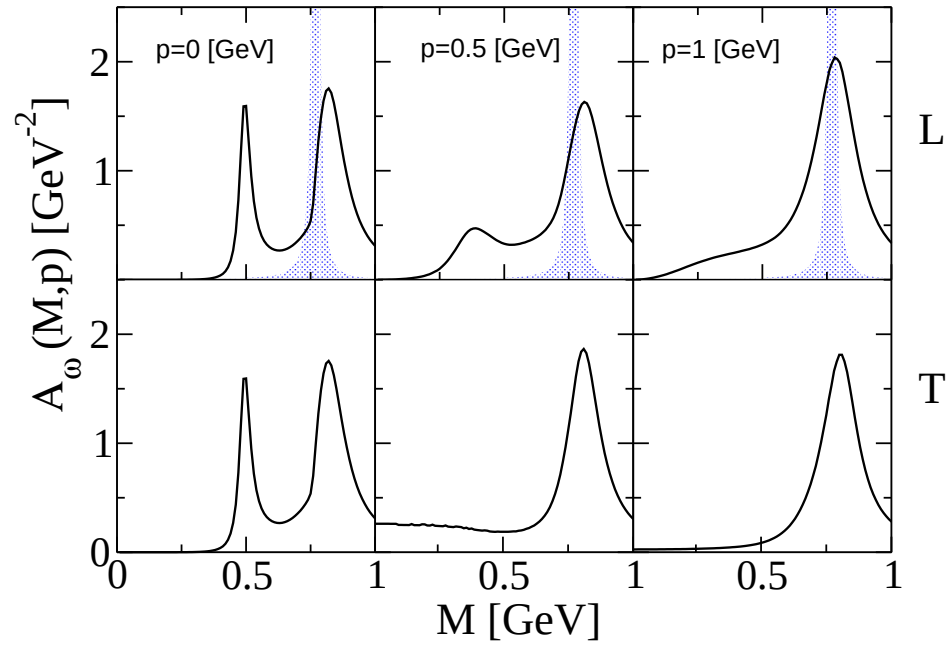
ρ/ω-meson spectral function

$$A_{\rho/\omega}(p, n_B) = -\frac{1}{\pi}\,\mathrm{Im}\left\{\frac{1}{p^2 - m^2_{\rho/\omega} - \Sigma(p, n_B)}\right\} \qquad (p^2 = M^2)$$

ρ-meson $\rho = \rho_0$



ω-meson $\rho = \rho_0$

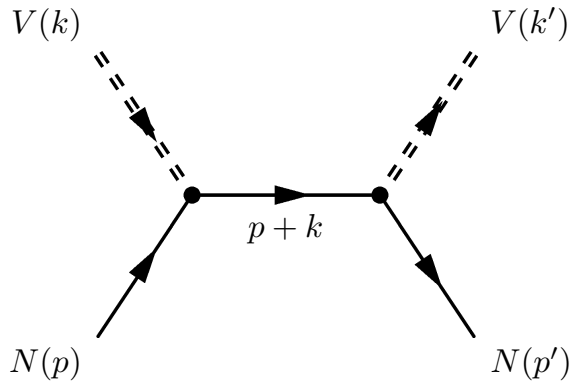


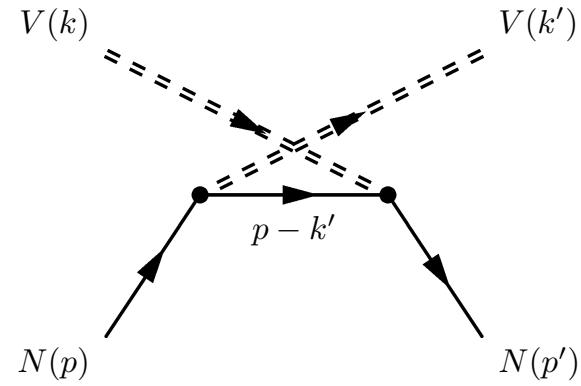
ρ: **Peak at $M\sim$ 0.5 GeV** due to coupling to $N^*(1520)N^{-1}$ state

ω: **Peak at $M\sim$ 0.5 GeV** due to coupling to $N^*(1535)N^{-1}$ state

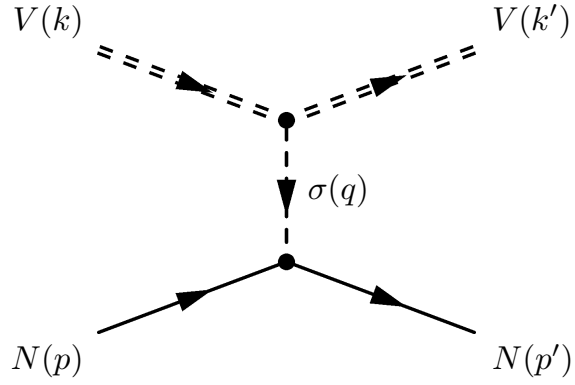
Non-resonant contributions

- Compton scattering contribution





- σ-exchange contribution

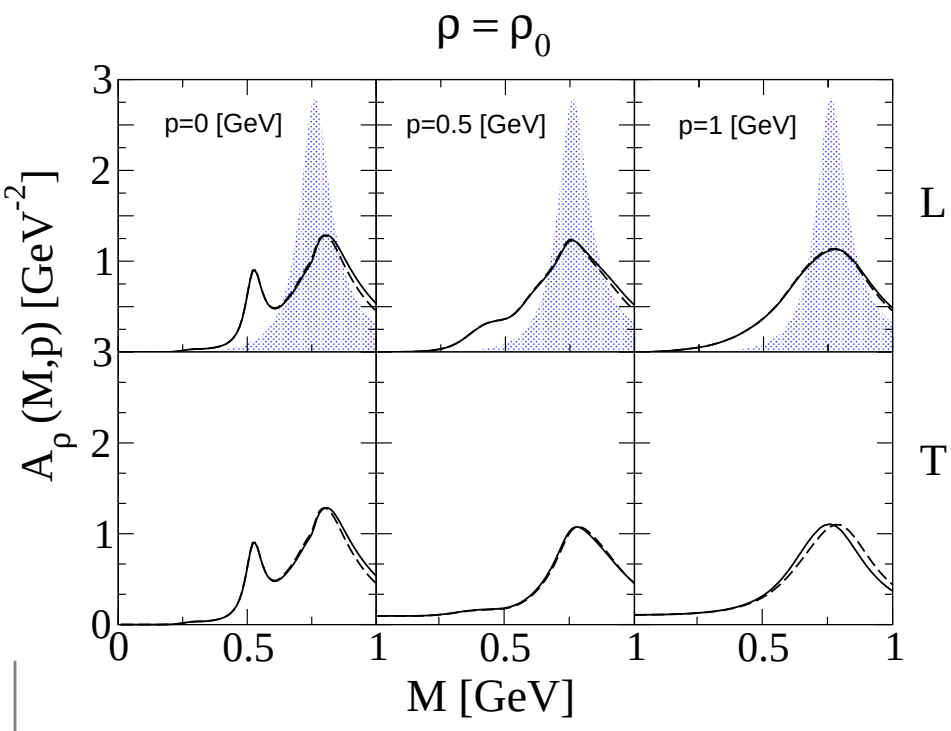


ρ/ω-meson spectral function

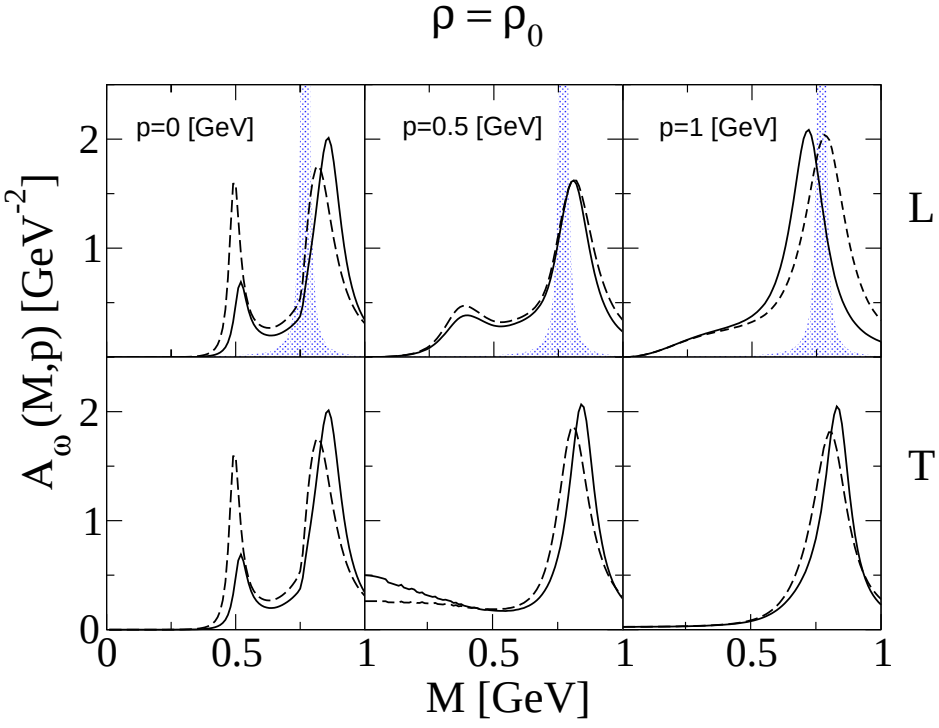
– – $\Sigma_0 + \Sigma^{\mathrm{Res}}$

— $\Sigma_0 + \Sigma^{\mathrm{Res}} + \Sigma^{\mathrm{Compt}} + \Sigma^{\sigma-\mathrm{exch}}$

ρ-meson

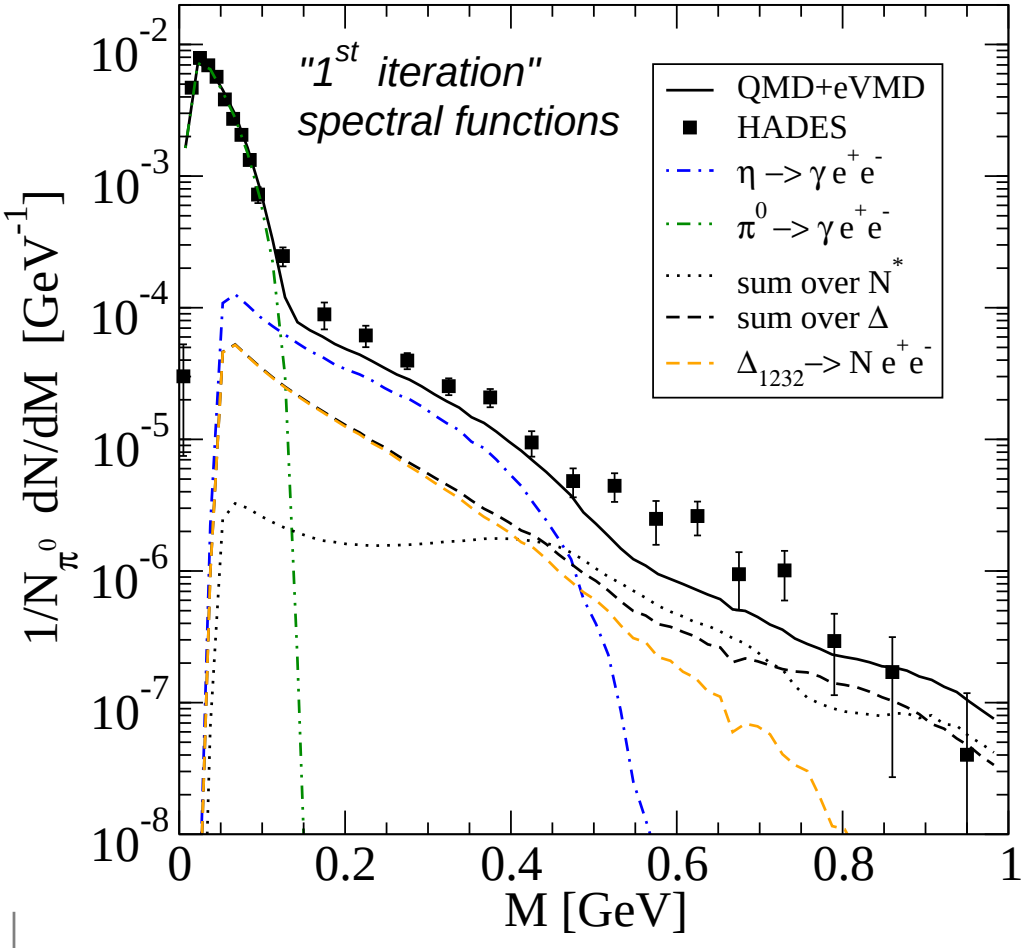


ω-meson



Application to C+C@2.0 AGeV

"microscopic" in-medium scenario



- no free parameters
- **unified** description of V and e^+e^- production & in-medium modifications

E.S., M.D.Cozma, A.Faessler, C.Fuchs *et al.*, **PRC**, in press

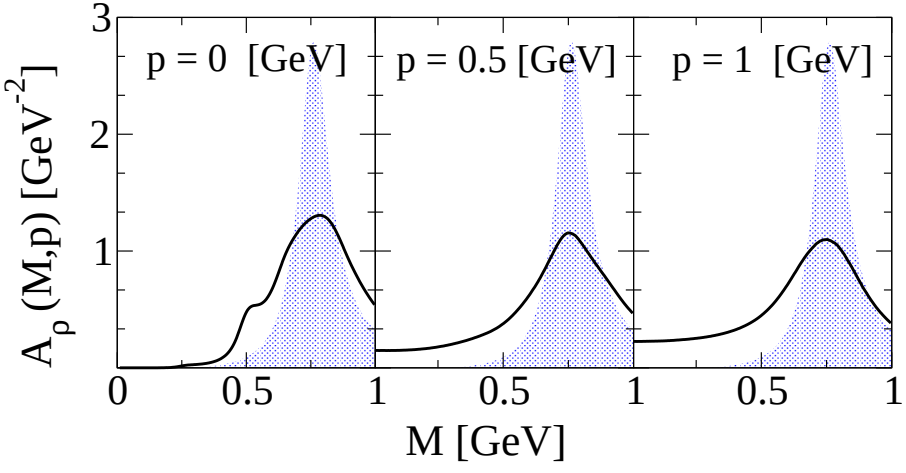
In-medium R: role of self-consistency

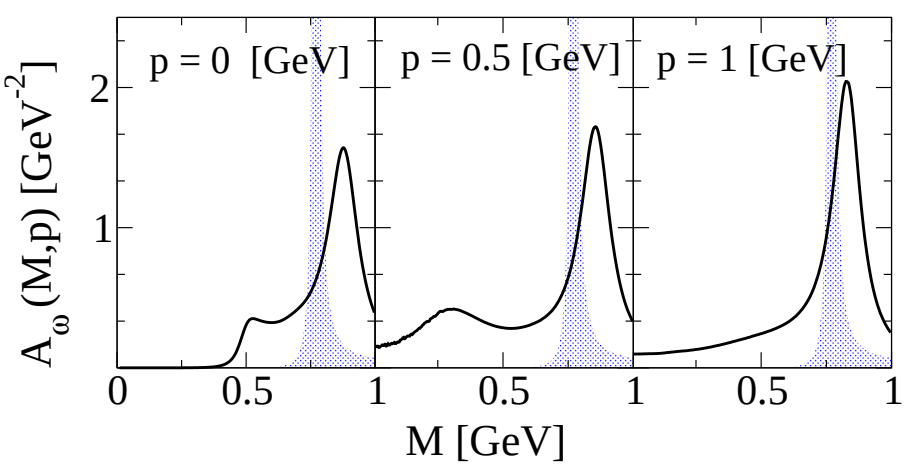
Accounting for

$$\Gamma_R^*(s,|\mathbf{p}_R|) = \Gamma_R^{\rm tot}(s) + \sum_V \int \Gamma_{RNV}(s,M)\Delta\mathcal{A}_V(M,|\mathbf{p}|)dM^2\,\frac{d\Omega}{4\pi}$$

in $$A_{VN} = -\sum_R \frac{(2J_R+1)}{2\cdot 3}\,\frac{8\pi s}{k}\,\frac{\Gamma_{RNV}(s)}{s-M_R^2+i\sqrt{s}\Gamma_R^{\rm tot}(s)}$$

and iterate up to convergence...





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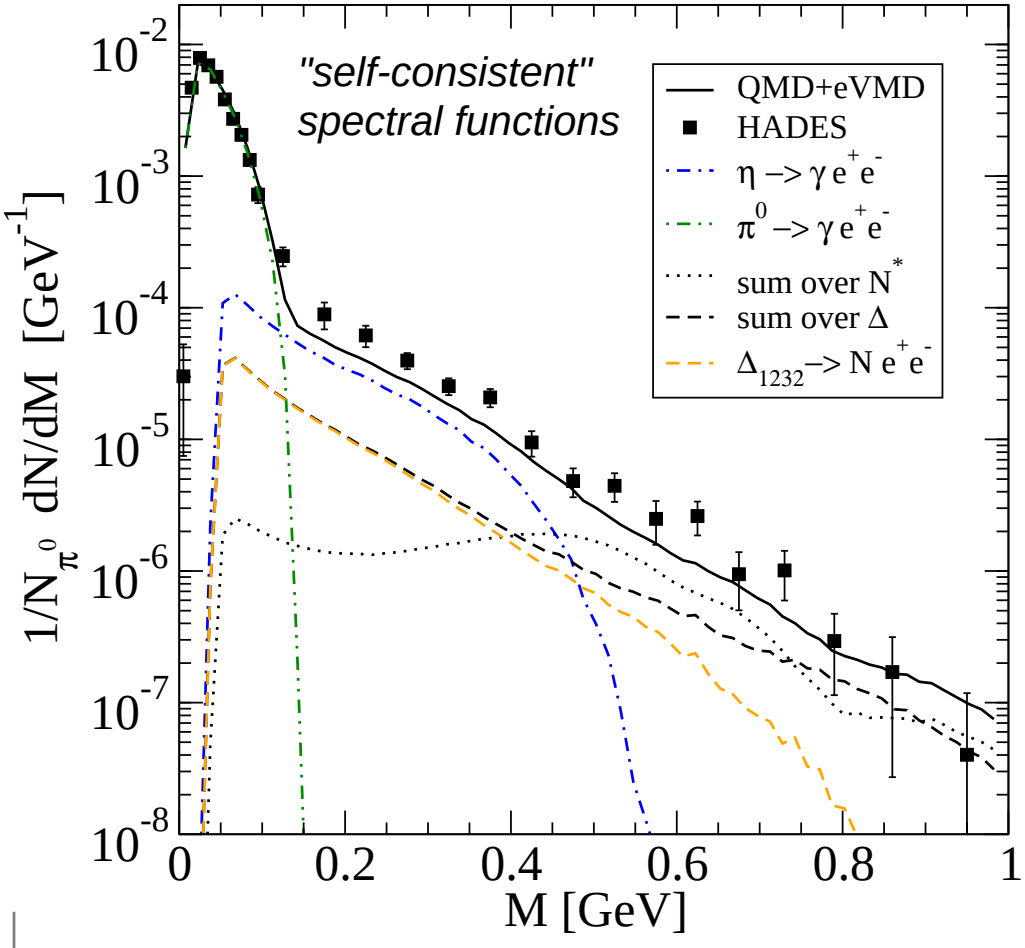

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Summary and Conclusions

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- Extention of standard VMD
  - correct asymptotics for the form factors
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- In-medium ρ and ω meson spectral functions
- Application to C+C@2.0 AGeV
  - Vacuum formulation fails: need for in-medium effects
  - HADES data favour strong modification of the VM properties
  - self-consistent iterative scheme gives reasonable description of the data in the region $0.45 \leq M \leq 0.75$ GeV

$\Rightarrow$ **inclusion of in-medium R properties important!**