In-Medium Properties of Vector Mesons in a Transport Approach

Janus Weil, Ulrich Mosel

Institut für Theoretische Physik, JLU Giessen

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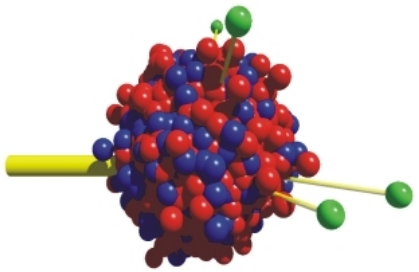
Outline

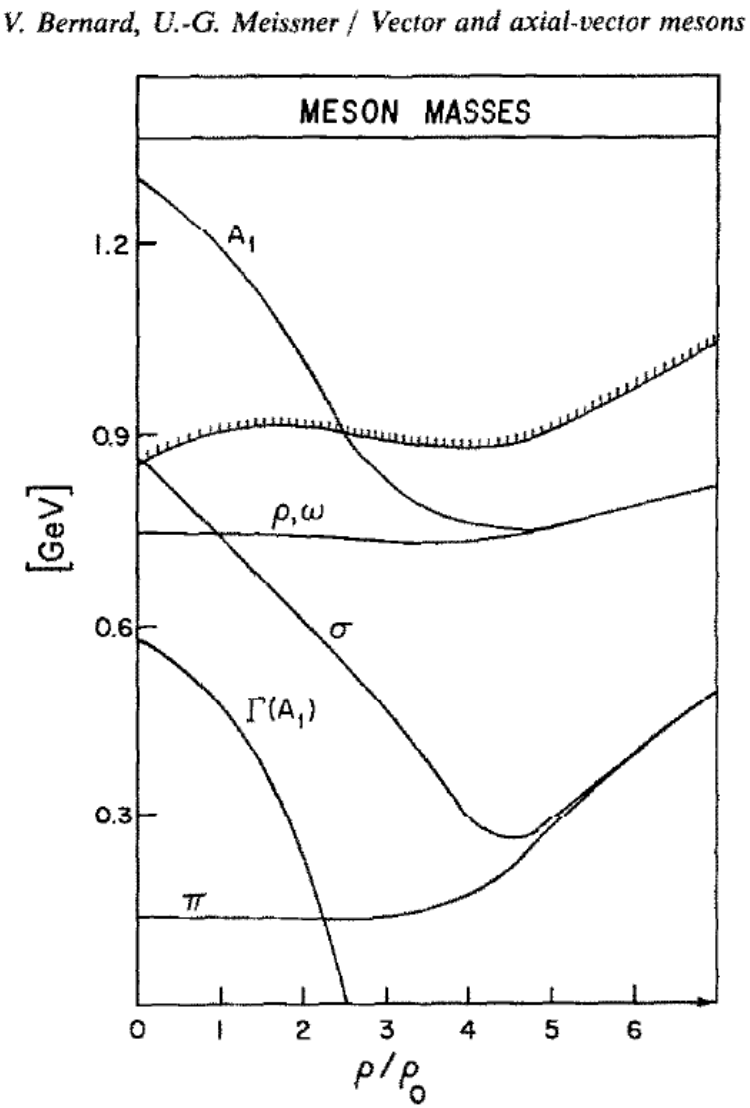
1. motivation: in-medium physics
2. the GiBUU transport model
3. dileptons from HADES:
   p + p @ 3.5 GeV
   p + Nb @ 3.5 GeV
4. conclusions/outlook



[not covered here: photoproduction of omega mesons on nuclei as measured by CB/TAPS, cf. arXiv:1008.4520]

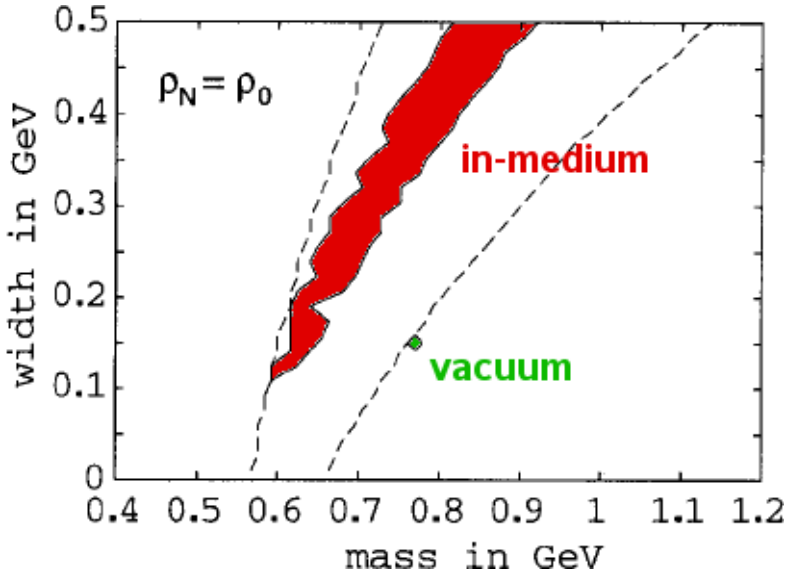
Motivation: Hadrons in Medium

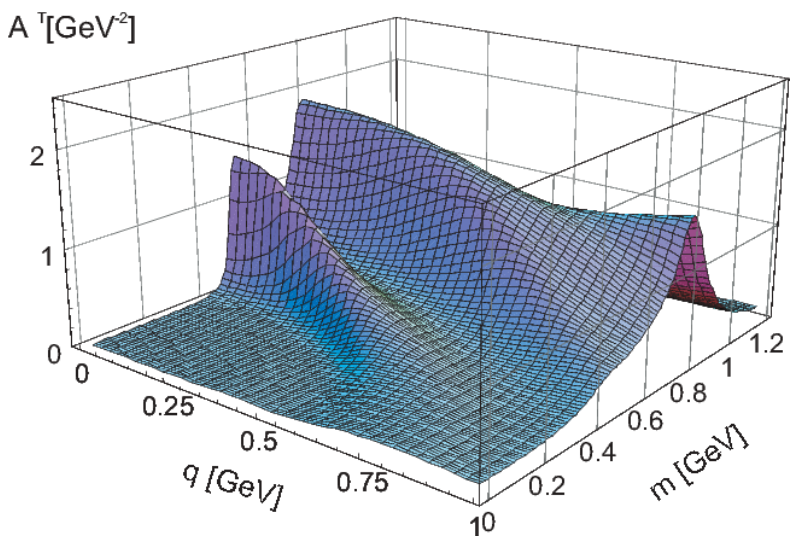
- how do vector mesons behave inside a hadronic medium?
- major prediction: mass shift $\leftrightarrow$ (partial) restoration of chiral symmetry in medium
- Brown/Rho (eff. Lagrang. approach): $m_V^*(\rho_0)/m_V \approx 0.8$
- Hatsuda/Lee (using QCD sum rules, neglecting width): $m_V^*(\rho)/m_V \approx 1 - \alpha(\rho/\rho_0)$, $\alpha \approx 0.16 \pm 0.06$



Motivation II

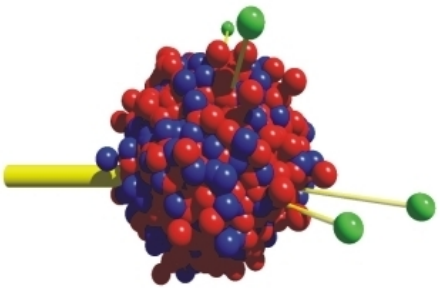
- other effects: collisional broadening, resonance structures, ...
- collisional broadening (LDA): $\Gamma_{coll} = \rho < v_{rel} \sigma_{VN} >$
- extended sum-rule analysis by Leupold/Peters/Mosel, including finite width (NPA 628, 1998)
- coupling to resonances can introduce additional structures in the spectral function (Post, 2003)





The GiBUU Transport Model

- semi-classical hadronic transport model
- unified framework for various types of reactions (γA, eA, νA, pA, πA, AA) and observables
- modular and flexible Fortran code base
- version control (svn): collaboration & reproducibility
- publicly available releases (open source)
- http://gibuu.physik.uni-giessen.de



GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

The BUU equation

- BUU equation describes time evolution of phase space density $f_i(\vec{r}, t, \vec{p})$ for each particle species i ($i = N, \Delta, \pi, \rho, ...$):

$$\left(\partial_t + (\nabla_{\vec{p}} H_i)\nabla_{\vec{r}} - (\nabla_{\vec{r}} H_i)\nabla_{\vec{p}}\right) f_i(\vec{r}, t, \vec{p}) = I_{coll}[f_i, f_j, ...]$$

- Hamiltonian H_i:
  - hadronic mean fields, Coulomb potential
  - "off-shell potential"
- collision term I_{coll}:
  - depends on all $f_i \Rightarrow$ coupled-channel problem
  - decays and scattering processes (2- and 3-body)
  - low energy: resonance model
  - high energy: string model PYTHIA (above 2.2/2.6 GeV)

In-Medium Effects

Mass Shifts

- incorporated as simple scalar potential: $m^* = m + S(\rho)$

Collisional Broadening

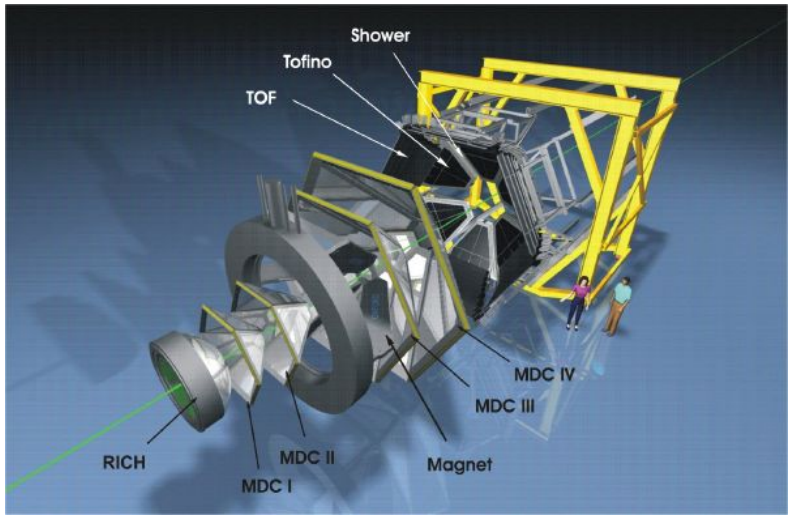
- in medium: $\Gamma_{tot} = \Gamma_{vac} + \Gamma_{coll}$
- $\Gamma_{coll} = \rho \langle v_{rel} \sigma_{VN} \rangle$ (low density approx. in lab frame)
- contributing processes: $VN \to \pi N, \pi\pi N, R, ...$
- in practice: use $\Gamma_{coll}(\rho)$ [no momentum dependence]

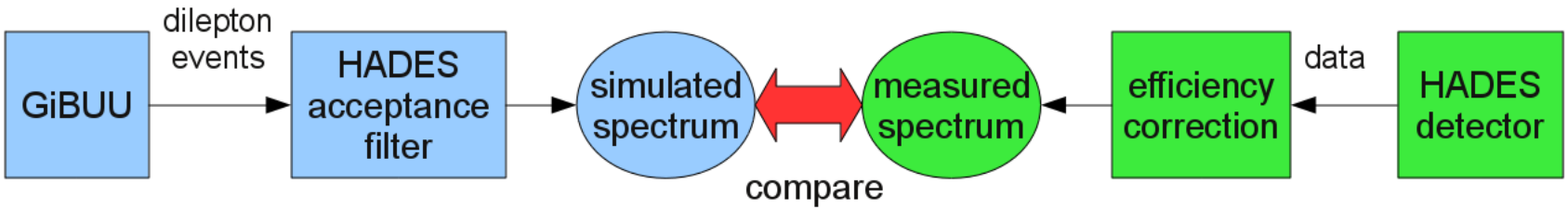
Off-Shell Transport

- density-dependent spectral functions need to be handled consistently
- smooth transition from in-medium to vacuum distribution

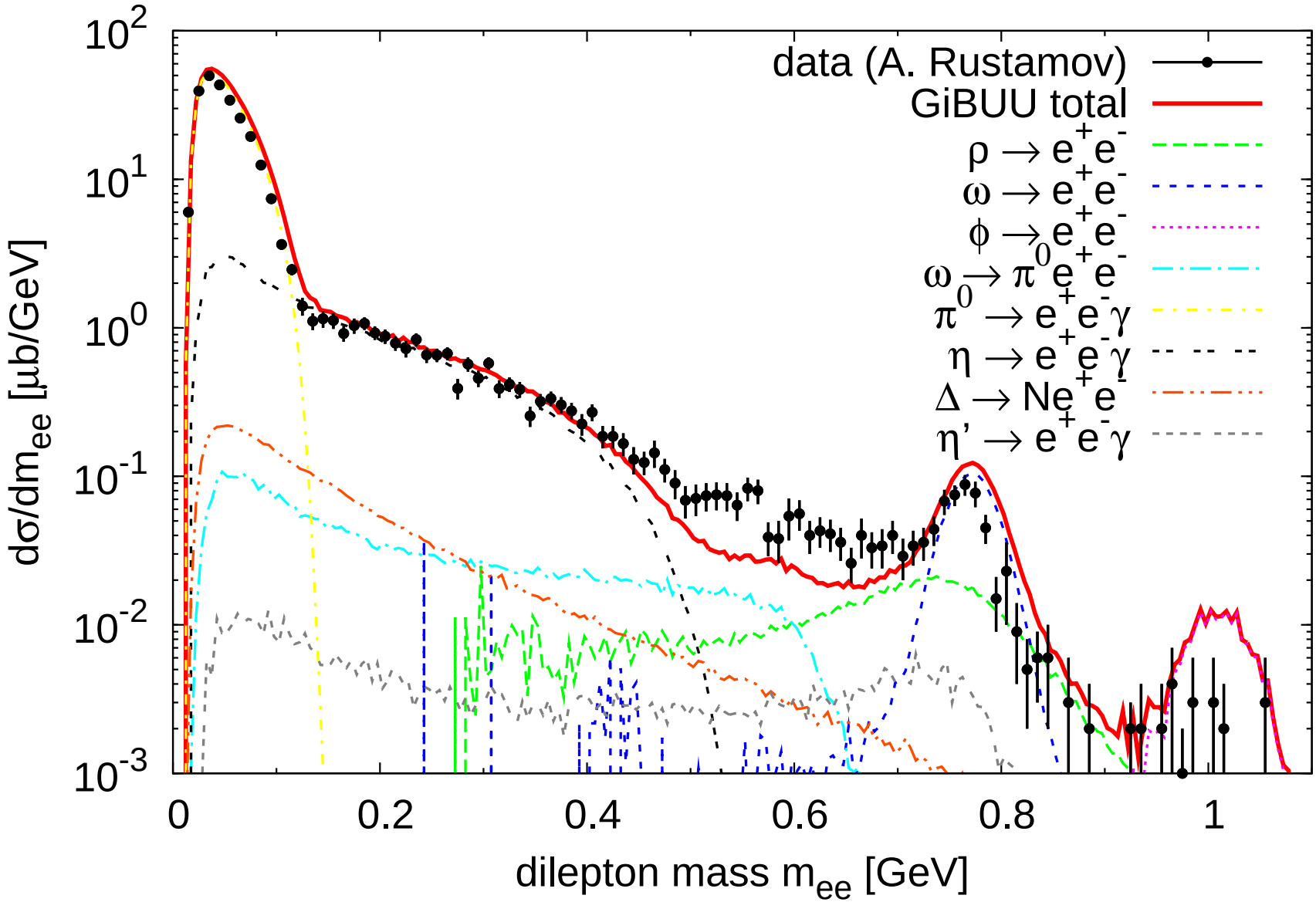
The HADES detector at GSI

- "High Acceptance Di-Electron Spectrometer"
- pp, pA, AA $\rightarrow e^+e^-X$
  $\Rightarrow$ p+p@3.5GeV
  $\Rightarrow$ p+Nb@3.5GeV
- mass resolution: $\sim$ 15 MeV
- polar angle: $15^\circ < \theta < 85^\circ$
- opening angle cut: $\theta_{ee} > 9^\circ$





p+p @ 3.5 GeV, mass spectrum



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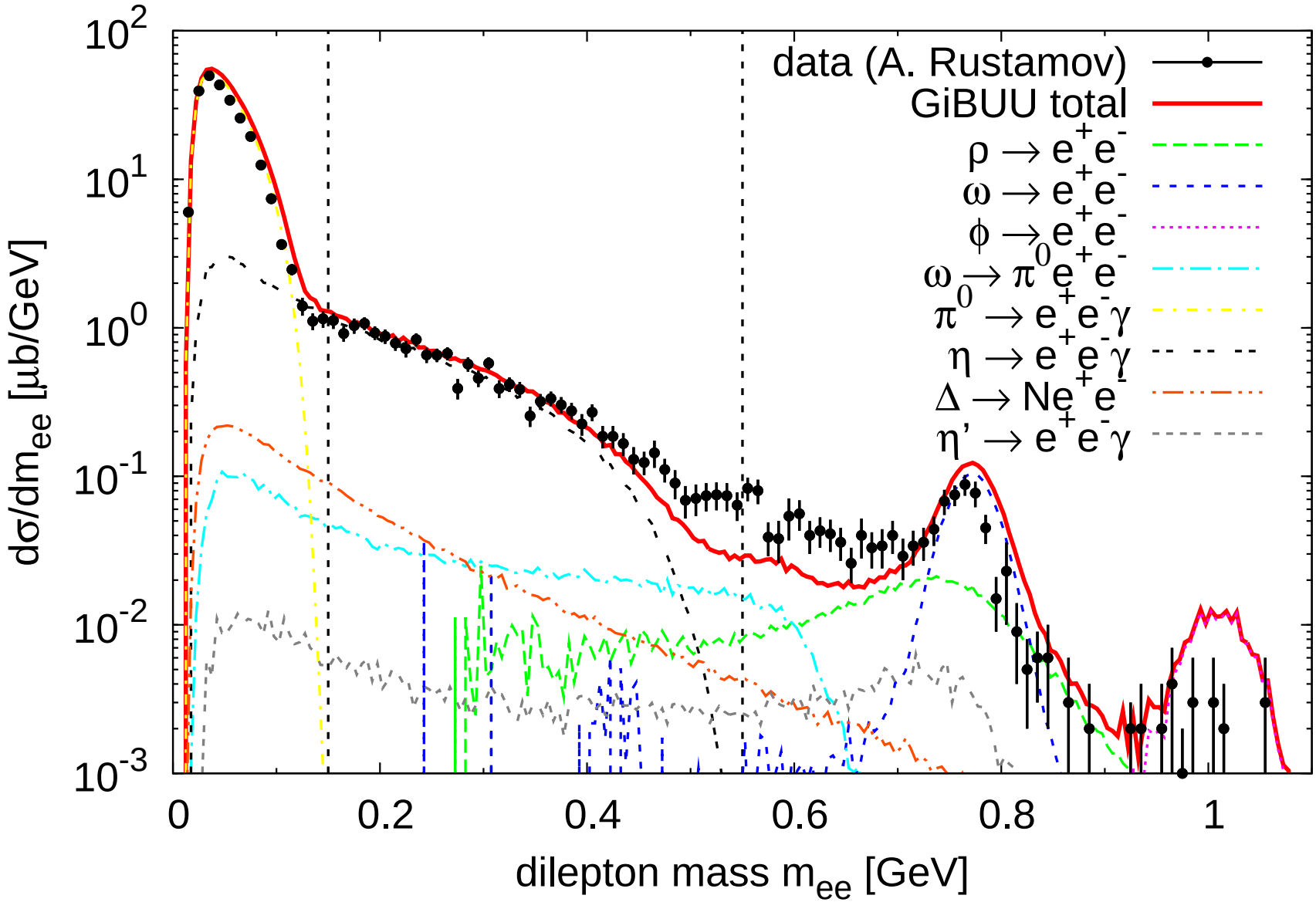
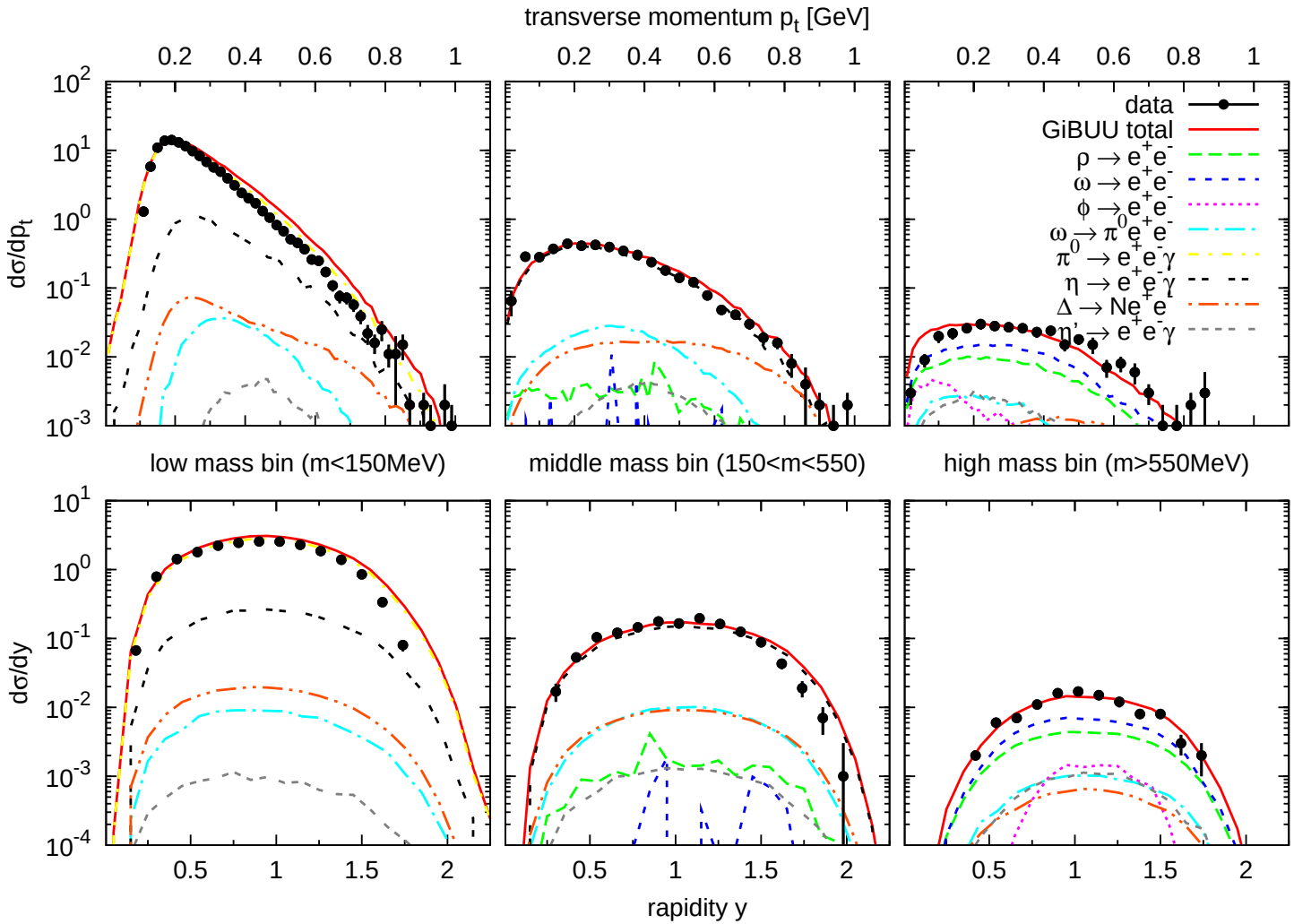


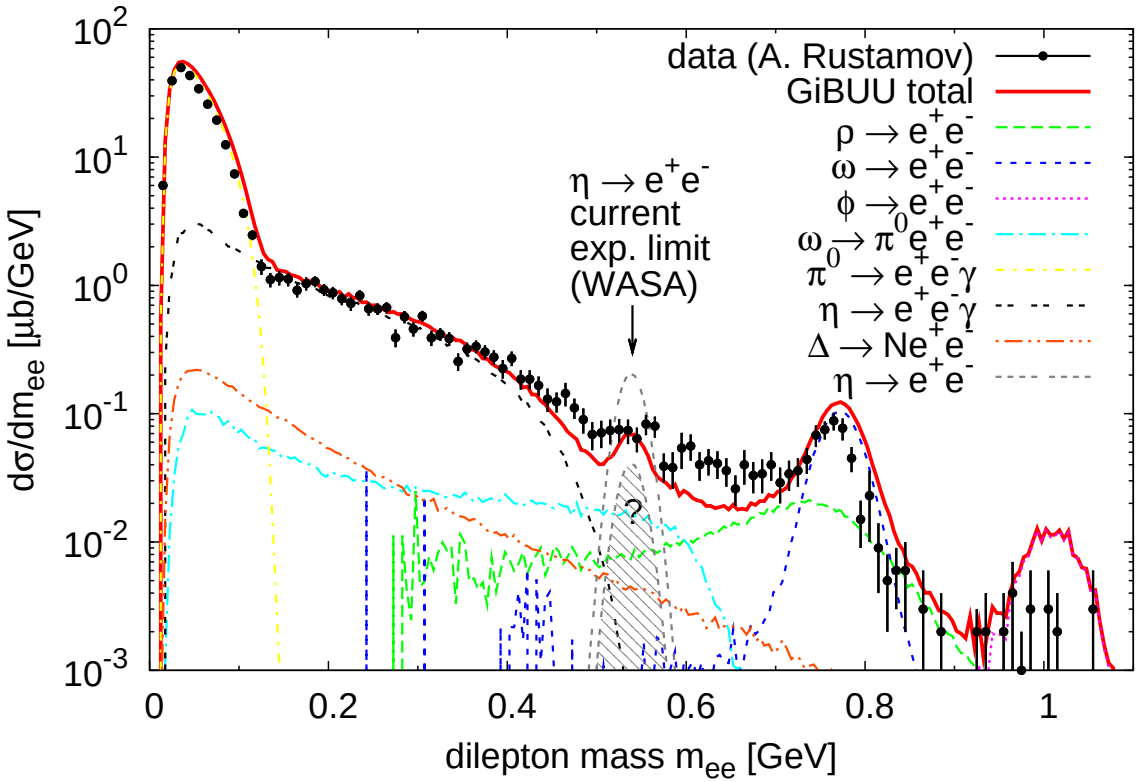
p+p @ 3.5 GeV, p_T and rap. spectra

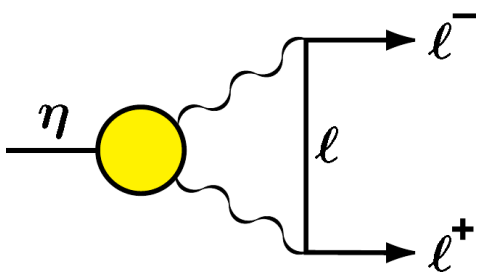


- good overall agreement, consistent with mass spectrum
- discrepancies: due to filtering effects or real physics?

DIRECT η DECAY: $\eta \to e^+e^-$

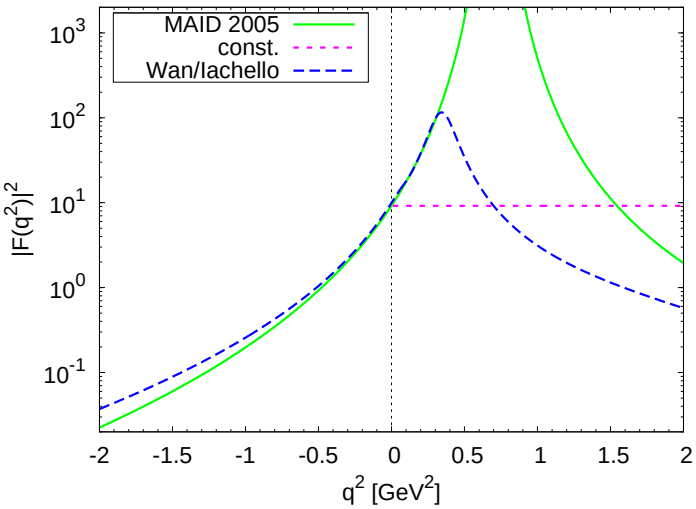
- exp. upper limit (WASA, Berlowski et al., PRD 77, 2008): $\mathrm{BR}(\eta \to e^+e^-) < 2.7 \cdot 10^{-5}$
- HADES might be able to push down this limit ...
- theor. prediction (Browder et al., PRD 56, 1997): $\mathrm{BR}(\eta \to e^+e^-) \approx 10^{-9}$

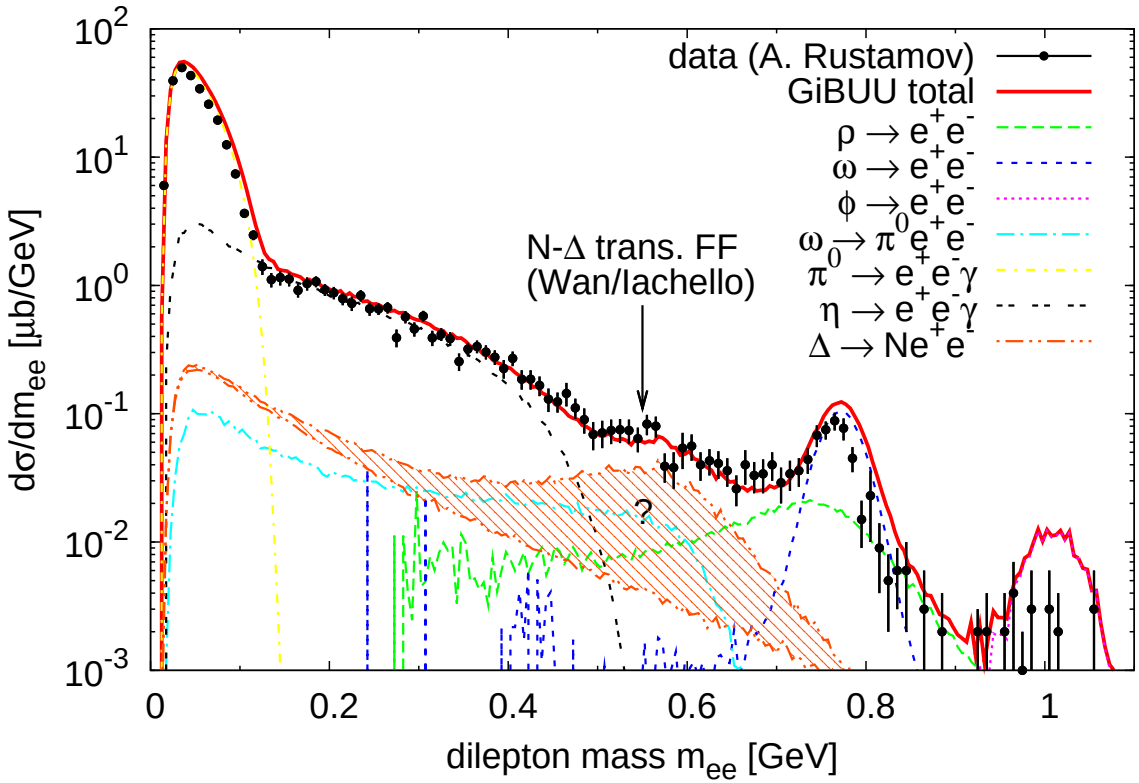




Δ Dalitz decay

- transition form factor $\Delta \rightarrow N\gamma^*$
  - space-like region: data from electroproduction
  - basically unknown in time-like region (no data)
- best available guess for time-like region:
  two-component quark model (Wan/Iachello, IJMP A20, 2005)
  $F \sim (1 - \gamma e^{i\theta} q^2)^{-2} \cdot F_\rho(q^2)$

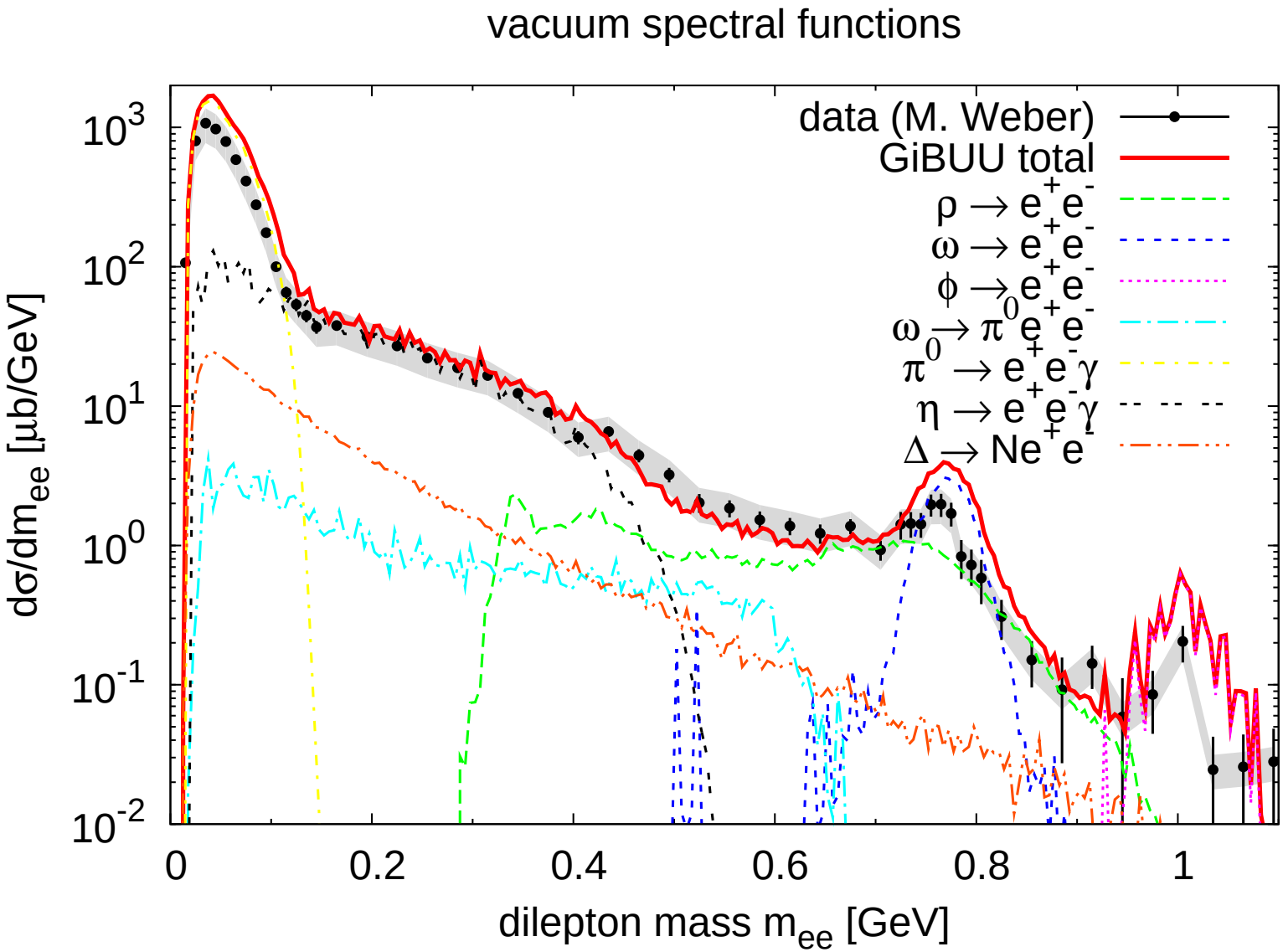




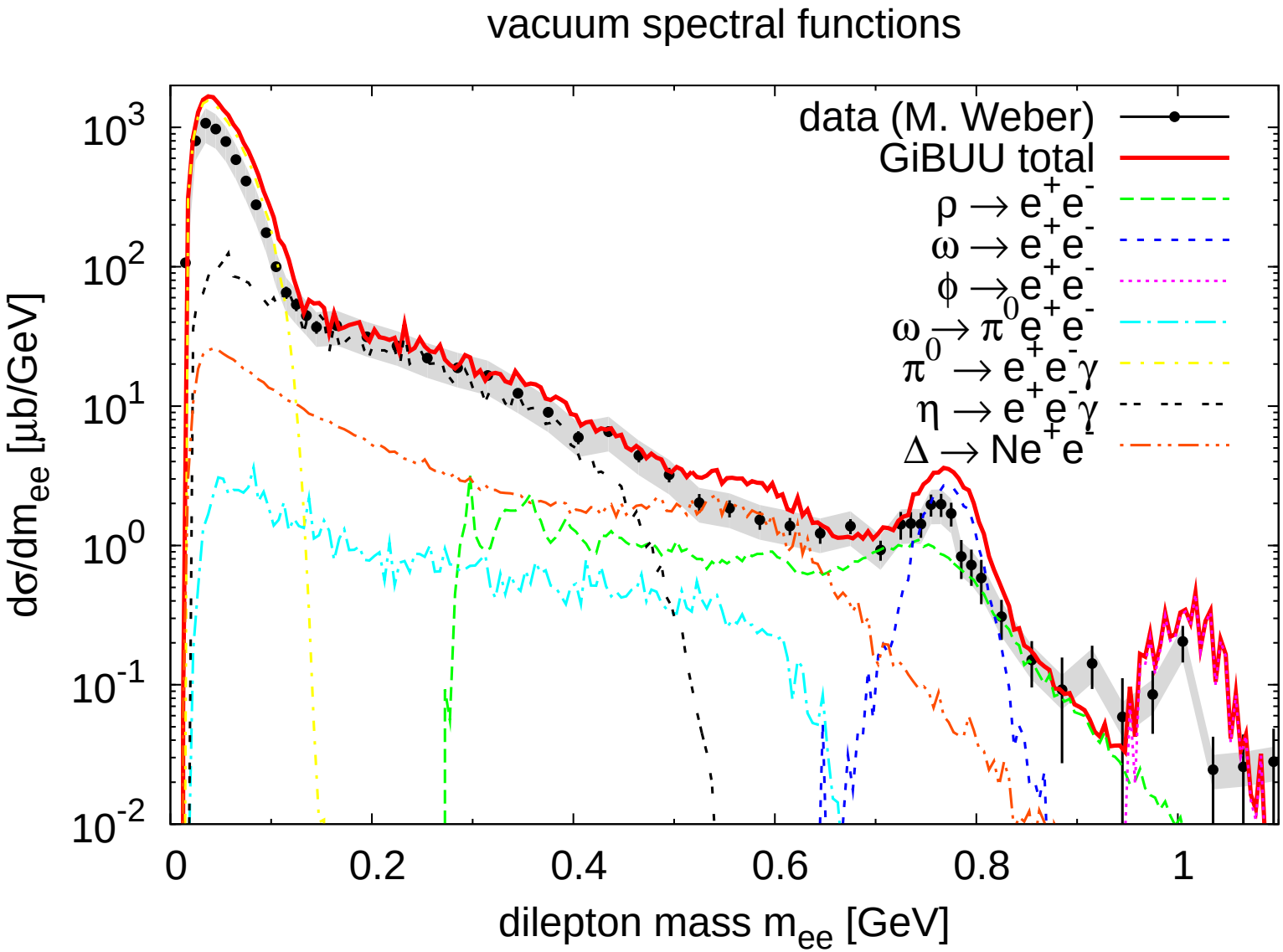
Next Step: p+Nb@3.5 GeV

- fixed by p+p: elementary cross sections, branching ratios, form factors
- once we can reasonably describe p+p@3.5GeV:
  use p+p as a base line
- additional medium effects in p+A:
  1) FSI, absorption, rescattering
  2) modified spectral functions
- ρ: sensitive to direct modification of mass spectrum?
- ω/ϕ: transparency ratio / absorption
- unfortunately p+p still leaves us with some uncertainties ...

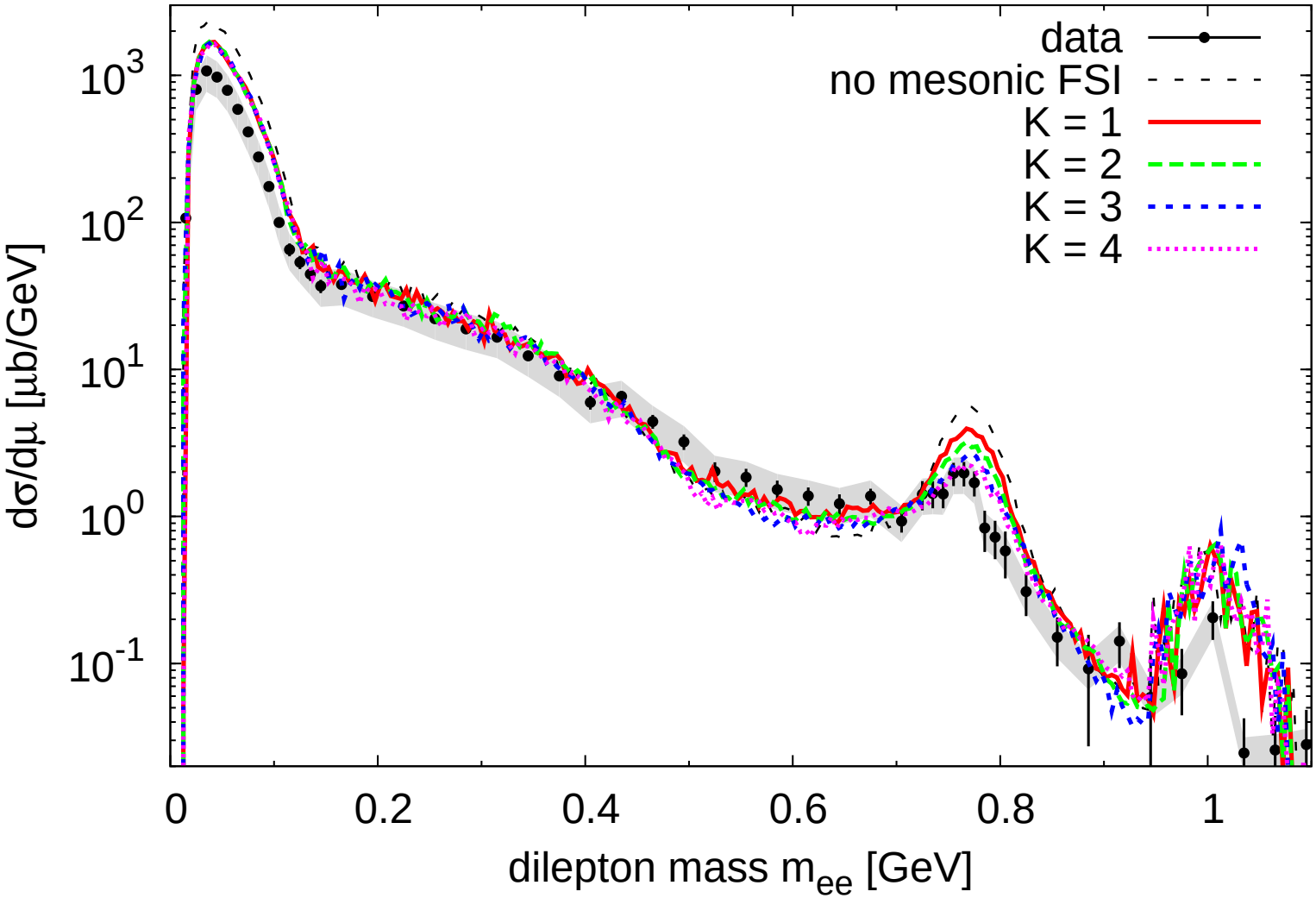
p+Nb@3.5 GeV (no Delta FF)



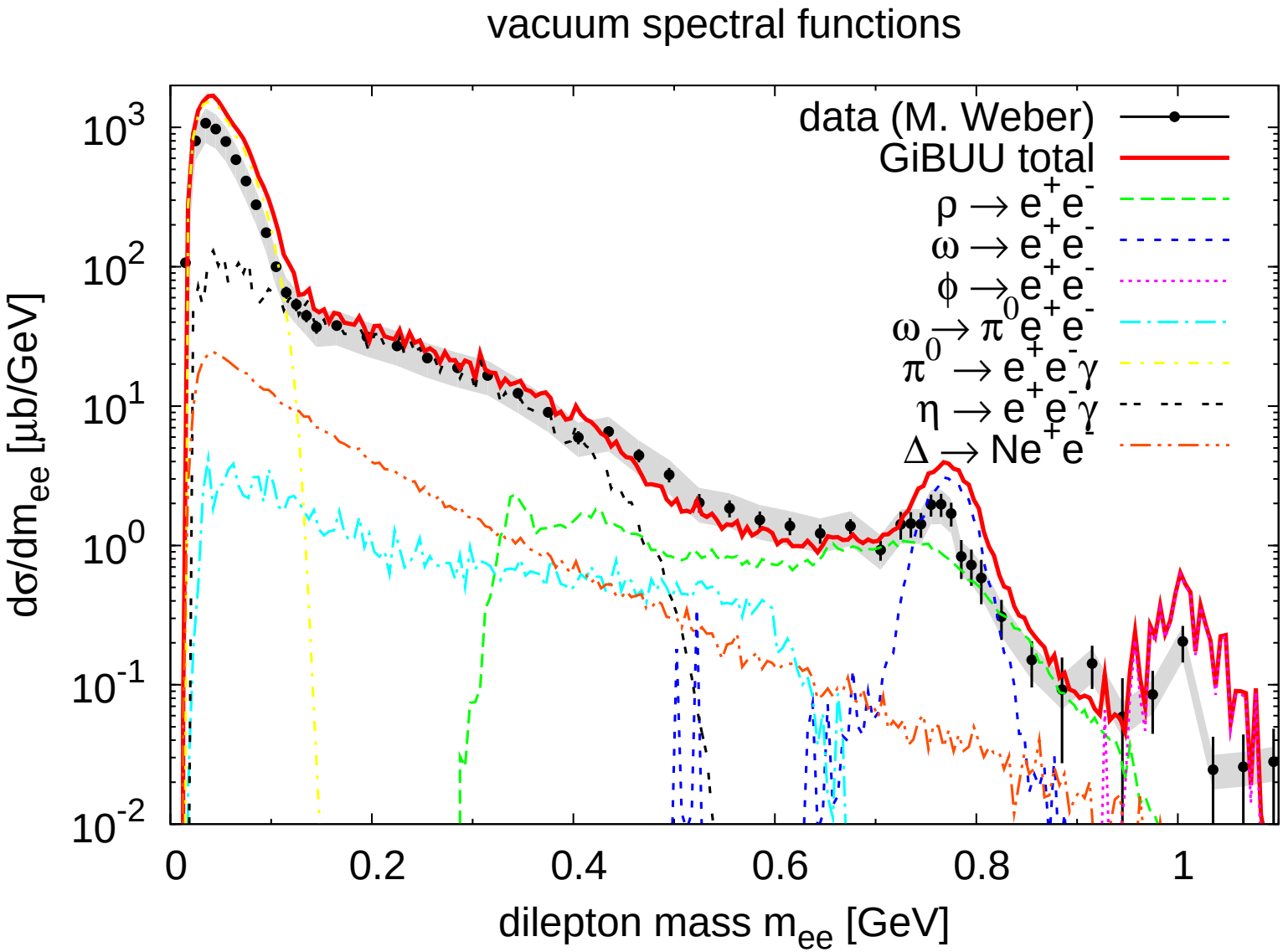
p+Nb@3.5 GeV (with Delta FF)



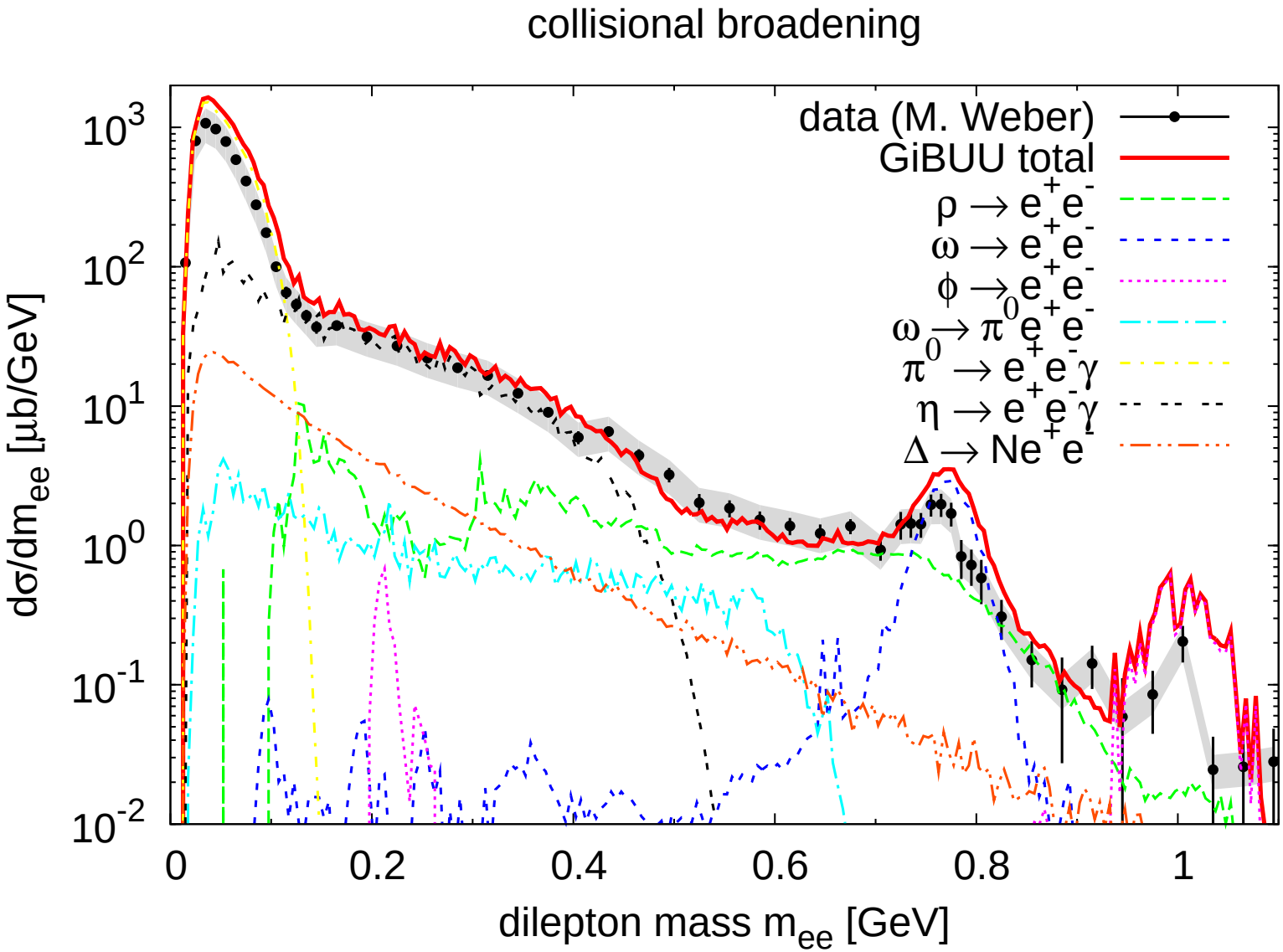
p+Nb@3.5 GeV, omega absorption



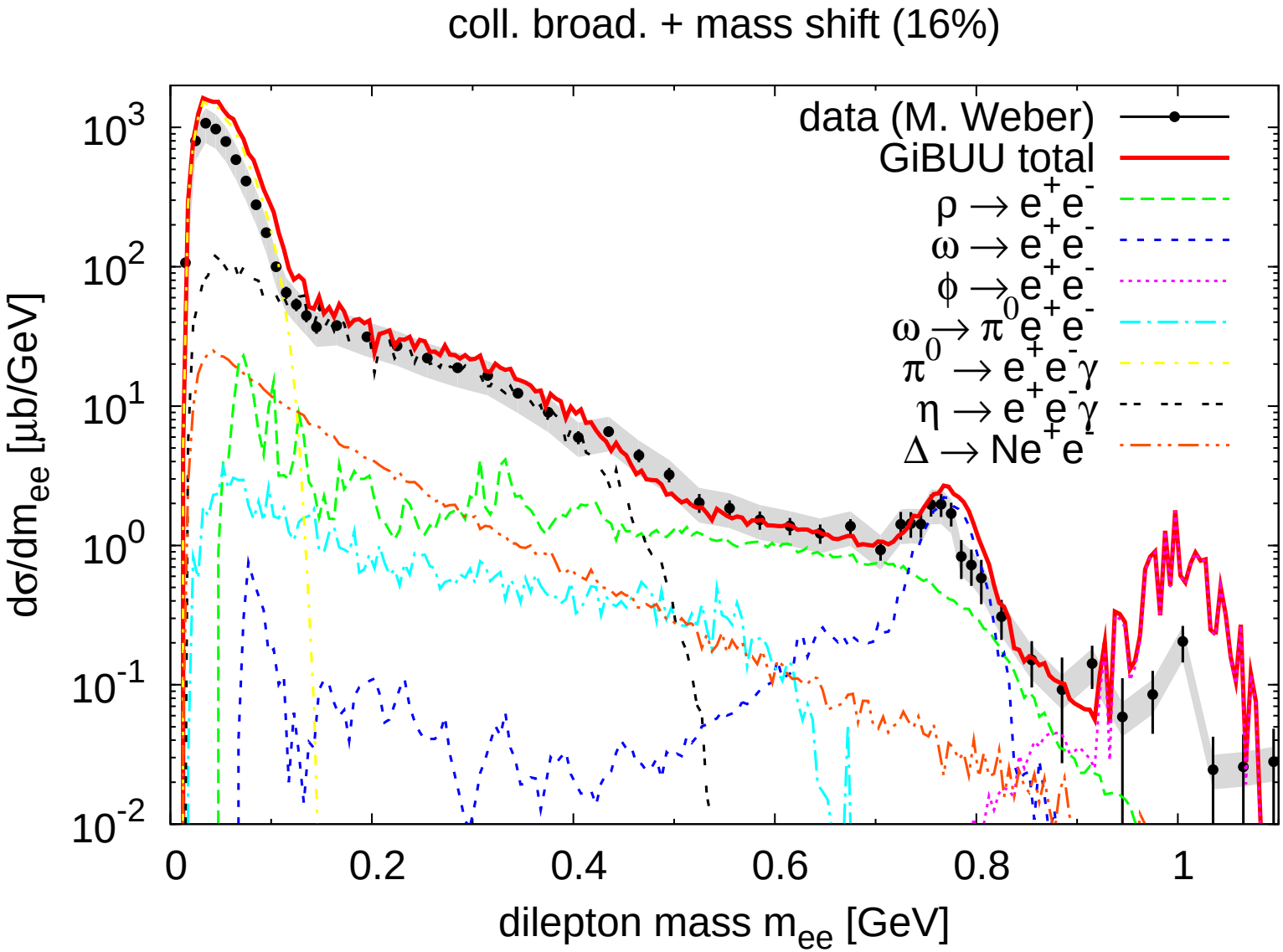
p+Nb@3.5 GeV, mass spectrum



p+Nb@3.5 GeV, mass spectrum



p+Nb@3.5 GeV, mass spectrum



Conclusions/Outlook

1. VM properties in (cold) nuclear matter: a challenging problem!
2. GiBUU: a valuable tool to study in-medium physics
3. HADES: we need to understand elementary reactions before we can draw hard conclusions on p+A and A+A
4. future work: Ar+KCl @ 1.76 AGeV