Vector Mesons in Cold Nuclear Matter with the GiBUU Transport Model

Janus Weil, Kai Gallmeister, Ulrich Mosel

Institut für Theoretische Physik, JLU Giessen

Mini-Workshop on
Vector Mesons in Cold Nuclear Matter
GSI, Darmstadt, 18.04.2011

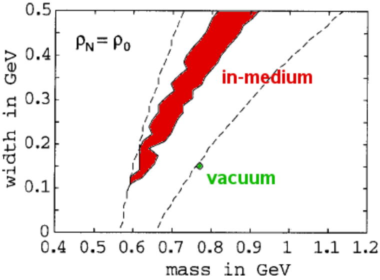
HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

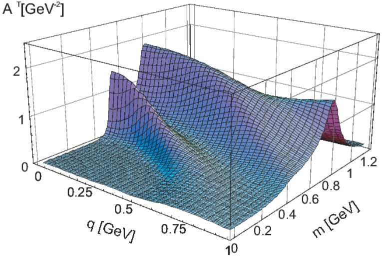
Outline

1. motivation: in-medium physics
2. the GiBUU transport model
3. dileptons from HADES:
   p + p @ 1.25 GeV
   p + p @ 3.5 GeV
   p + Nb @ 3.5 GeV
4. conclusions

Motivation: Hadrons in Medium

- how do vector mesons behave inside a hadronic medium?
- Hatsuda/Lee: mass shift $m_V^*(\rho)/m_V \approx 1 - \alpha(\rho/\rho_0)$, $\alpha \approx 0.16 \pm 0.06$
- 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

- BUU-type hadronic transport model
- unified framework for various types of reactions (pA, πA, γA, eA, νA, AA) and observables
- modular and well-documented Fortran code (F95/2003)
- collaborative effort, version control via Subversion
- publicly available releases (open source)
- http://gibuu.physik.uni-giessen.de

GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

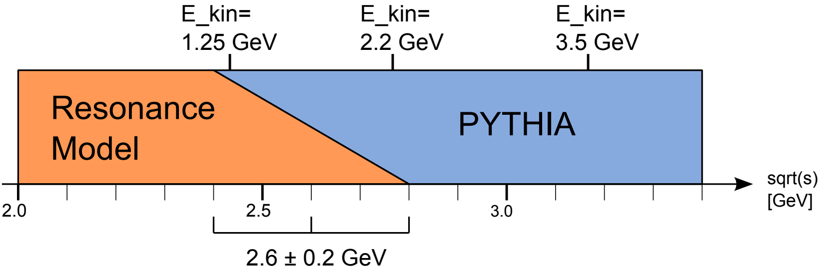
The BUU Equation

- BUU equation describes space-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, "off-shell potential"
- collision term I_{coll}:
  - decays and scattering processes (2- and 3-body)
  - depends on all $f_i \Rightarrow$ coupled-channel problem
  - low energy: resonance model energy: PYTHIA
- model includes 61 baryons and 21 mesons
- solve numerically via test-particle method:
  $f = \sum_i \delta(\vec{r} - \vec{r}_i)\delta(p - p_i)$

GiBUU: Collision Term



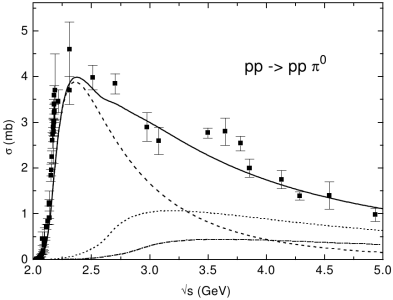
<u>Resonance Model:</u>

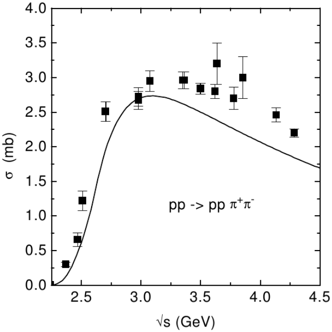
- Teis et al.
- all processes go via Res. prod.
- $NN \to NR$
- $R \to \pi N / 2\pi N / \eta N / \rho N$

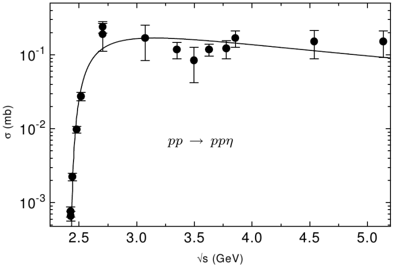
<u>PYTHIA:</u>

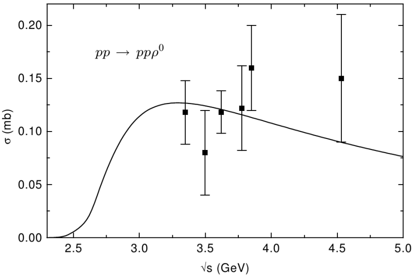
- Lund String Model
- high energy event generator
- few GeV up to TeV region
- only non-strange res.: Δ

Resonance Model (Teis)



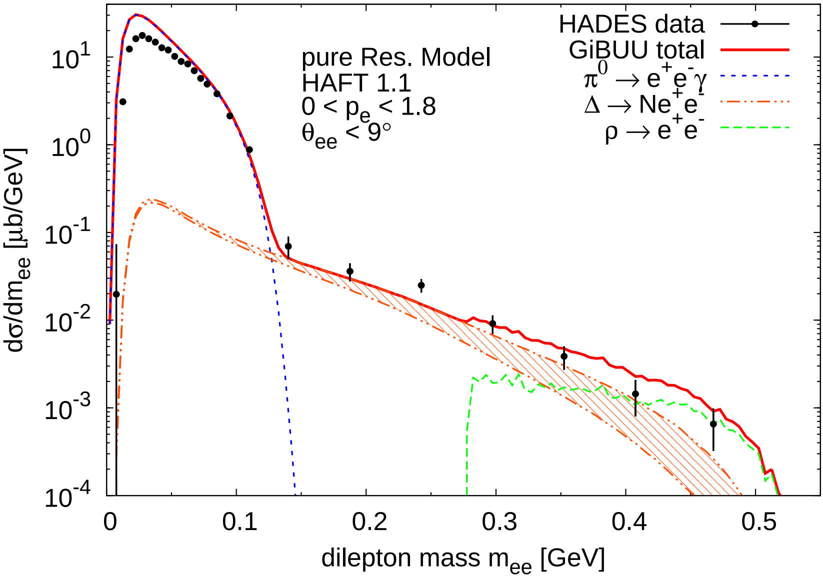




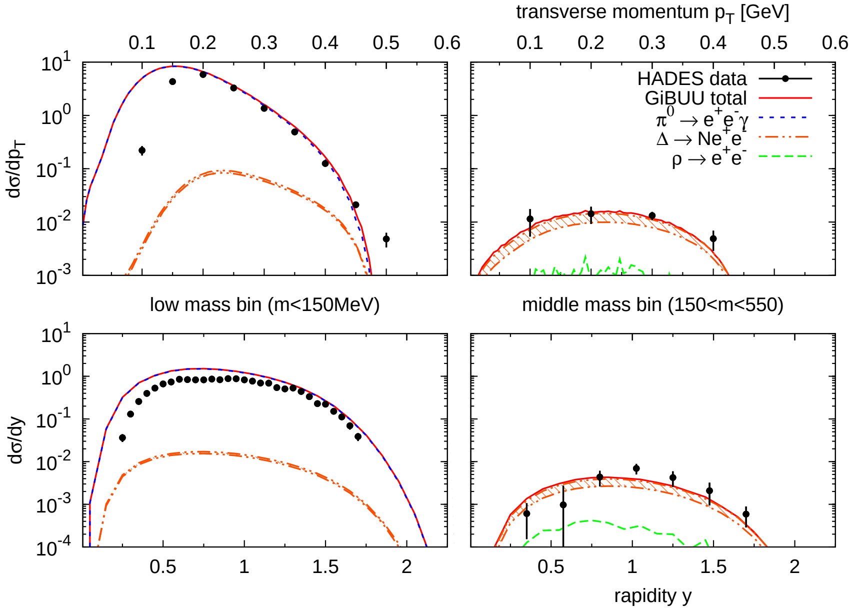


p + p @ 1.25 GeV

p+p @ 1.25 GeV, mass spectrum

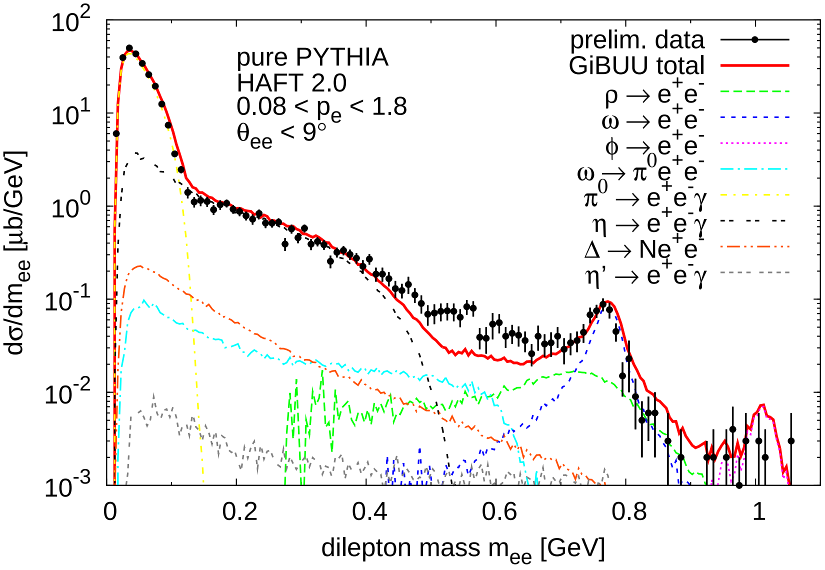


p+p @ 1.25 GeV, p_T and rap. spectra

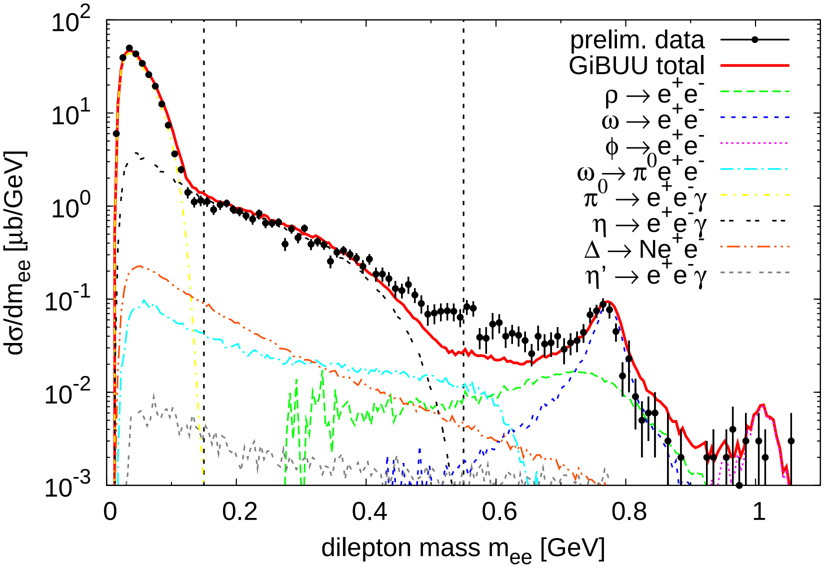


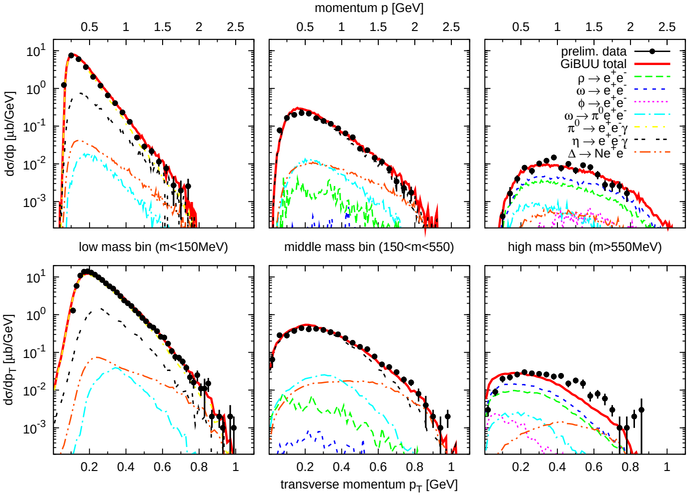
p + p @ 3.5 GeV

p+p @ 3.5 GeV, mass spectrum



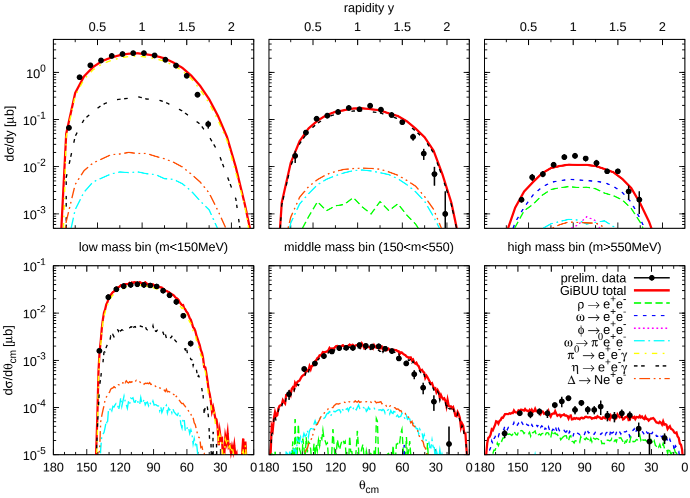
p+p @ 3.5 GeV, mass spectrum





- perfect agreement (with slight Pythia adjustment)
- problems only in high mass bin

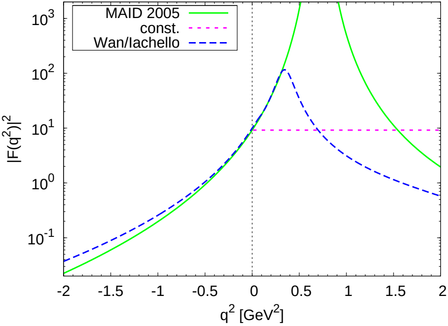
p+p @ 3.5 GeV, rap. and θ_{cm} spectra



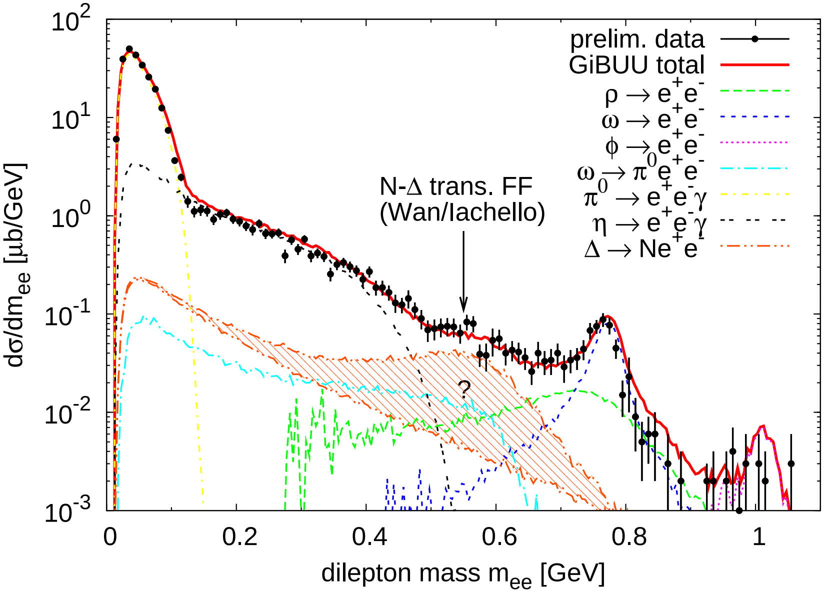
- discrepancy at forward angles
- filtering problem?!?

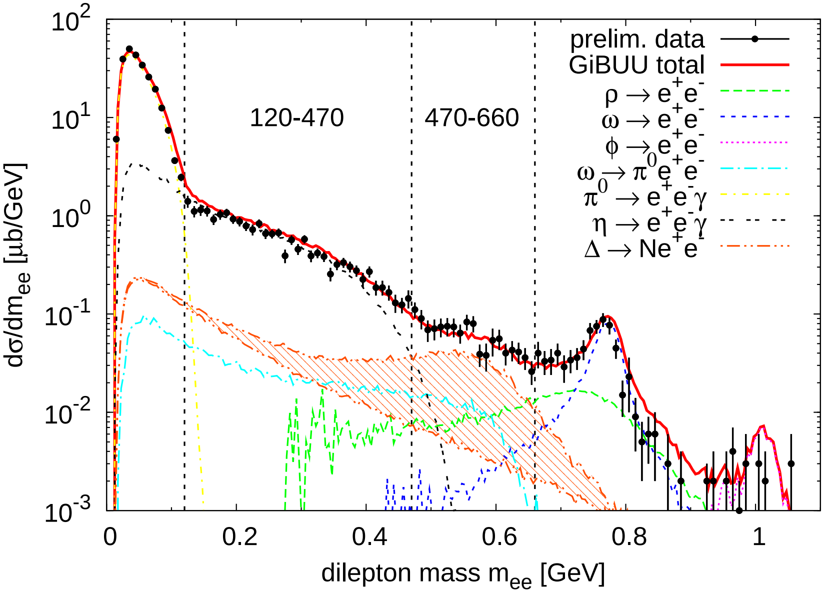
Δ Dalitz decay

- transition form factor $\Delta \to N\gamma^*$
  - 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)
  $F \sim (1 - \gamma e^{i\theta} q^2)^{-2} \cdot F_\rho(q^2)$



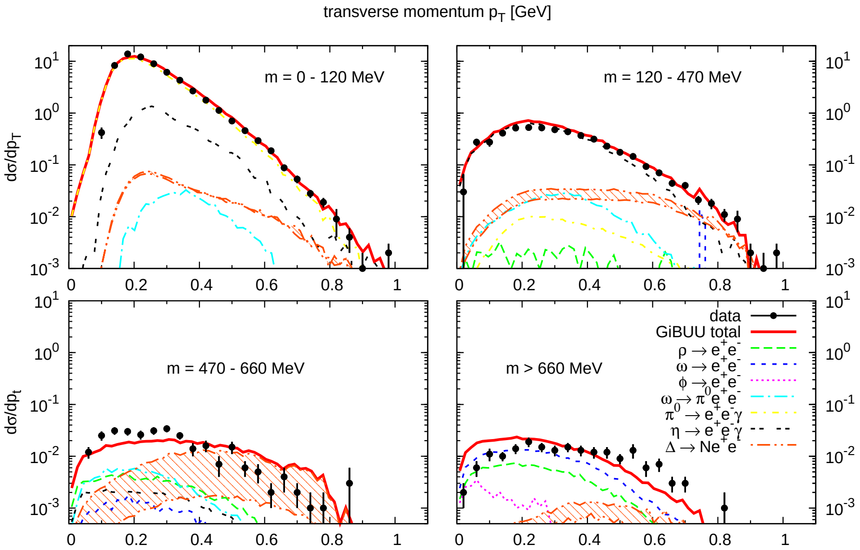
MASS SPECTRUM WITH Δ FORM FACTOR



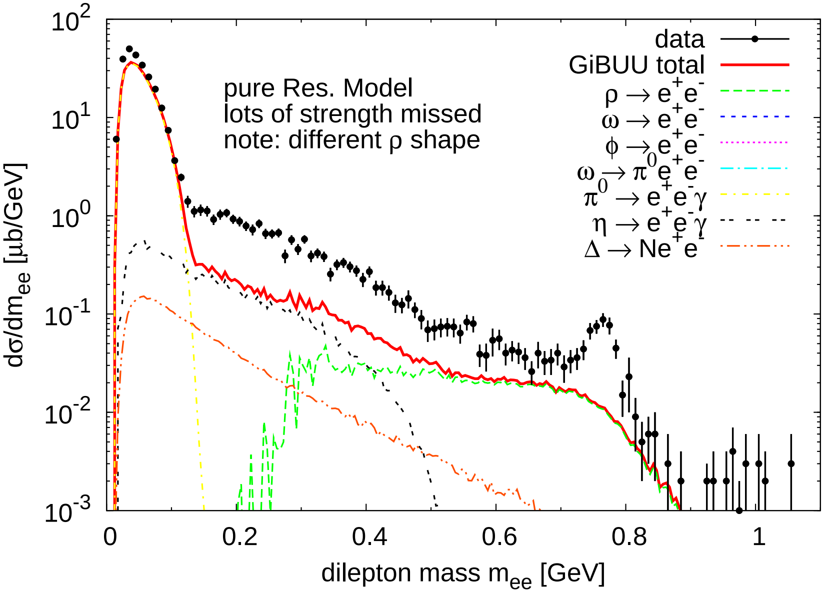


prelim. data
GiBUU total
ρ → e+e-
ω → e+e-
φ → e+e-
ω → π0e+e-
π0 → e+e-γ
η → e+e-γ
Δ → Ne+e-
120-470
470-660
dσ/dmee [μb/GeV]
dilepton mass mee [GeV]
10-3
10-2
10-1
100
101
102
0
0.2
0.4
0.6
0.8
1

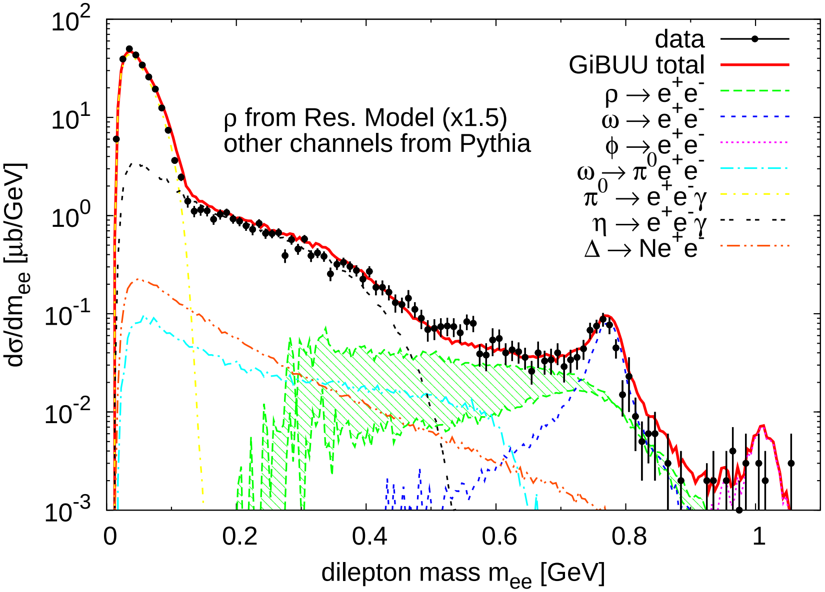
p_T SPECTRA WITH Δ FORM FACTOR



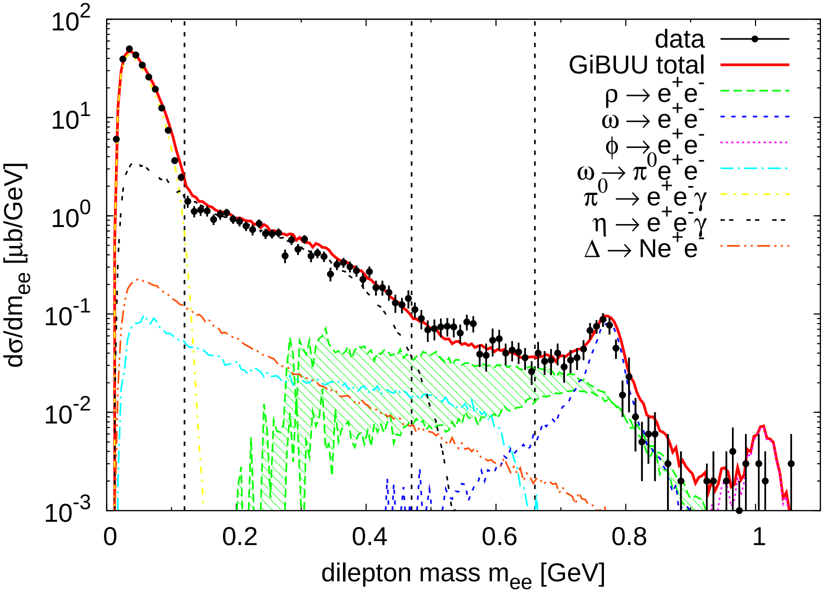
p + p @ 3.5 GeV via Res. Model



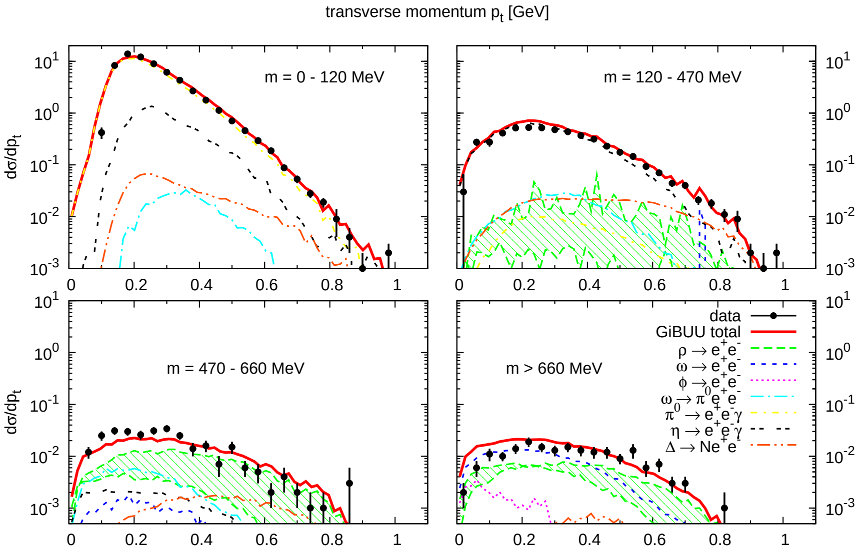
"Mixed Signals"



“Mixed Signals”



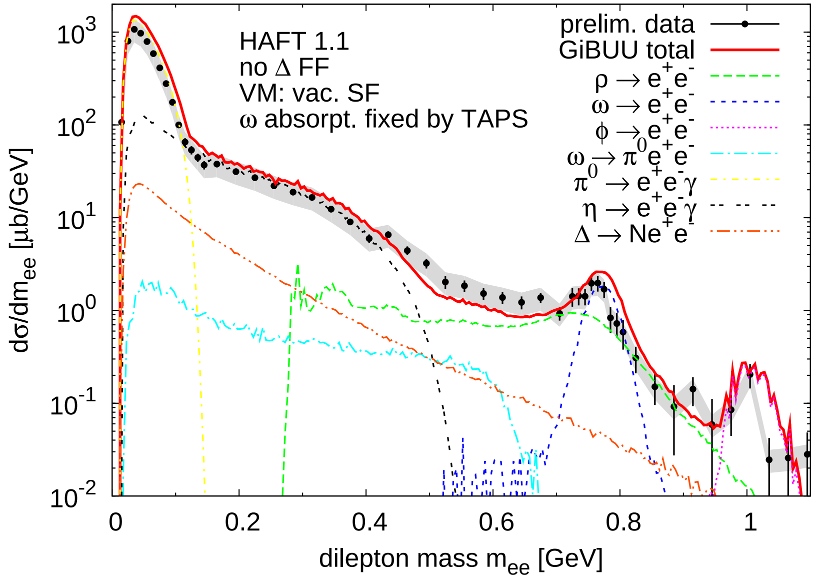
"Mixed" p_T Spectra



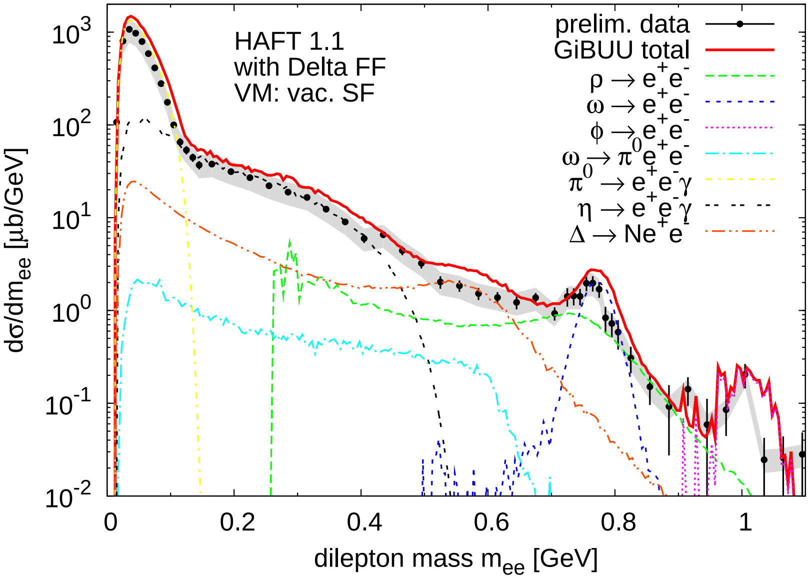
p + Nb @ 3.5 GeV

Next Step: p+Nb@3.5 GeV

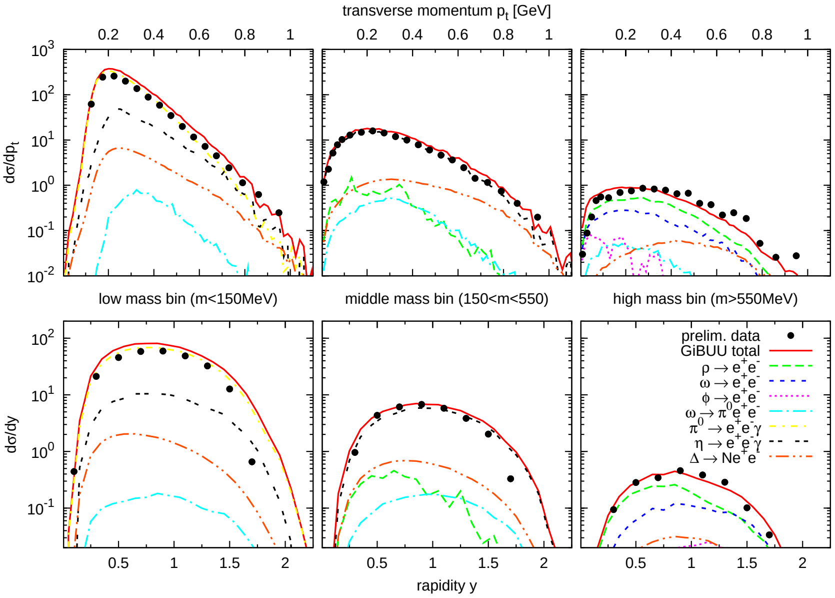
- cocktail composition basically fixed by p+p
  (elementary cross sections, branching ratios, form factors, ...)
- use p+p as a base line for p+Nb
- additional medium effects:
  1) FSI, absorption, rescattering
  2) secondary production processes
  3) modified spectral functions
- vector mesons in medium:
  ρ: sensitive to direct modification of mass spectrum?
  ω/ϕ: transparency ratio / absorption
- unfortunately p+p still leaves us with some uncertainties ...


HAFT 1.1
no Δ FF
VM: vac. SF
ω absorpt. fixed by TAPS
prelim. data
GiBUU total
ρ → e+e-
ω → e+e-
φ → e+e-
ω → π0e+e-
π0 → e+e-γ
η → e+e-γ
Δ → Ne+e-
dσ/dmee [μb/GeV]
dilepton mass mee [GeV]
10^3
10^2
10^1
10^0
10^-1
10^-2
0
0.2
0.4
0.6
0.8
1

p+Nb@3.5 GeV, mass spectrum



p+Nb@3.5 GeV, p_T and rap.

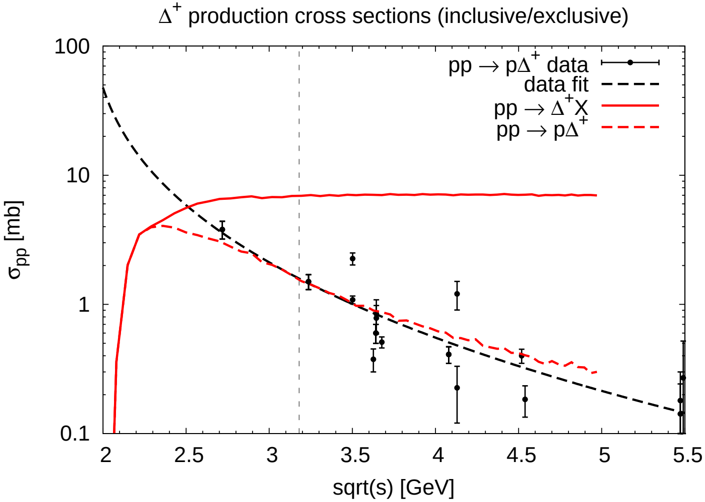


Conclusions

1. p + p @ 1.25 GeV:
   - reasonable agreement with data
   - some trouble with filters/cuts?
2. p + p @ 3.5 GeV:
   - very good agreement with data
   - only puzzle: intermediate mass gap
   - Δ Dalitz form factor
   - ρ production via resonances
3. p + Nb @ 3.5 GeV:
   - discrepancy in pi0 channel
   - normalization issue?
   - check pion spectra!
   - no conclusions on VN in medium yet
4. C + C / Ar + KCl:
   - stay tuned!

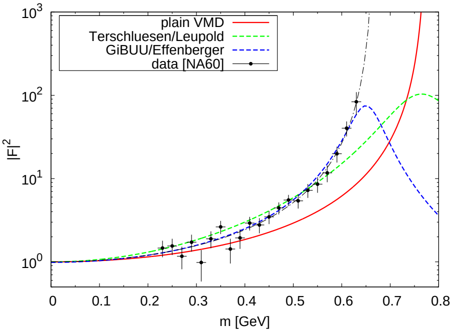
Back-Up Slides

Delta cross section

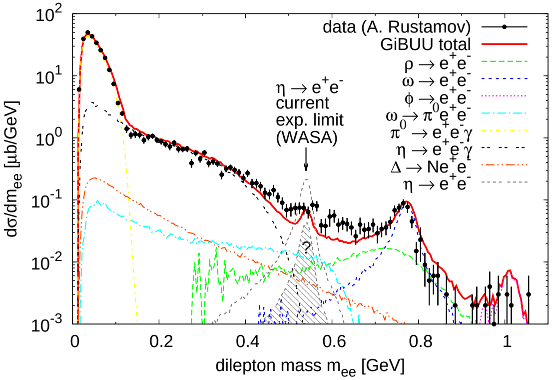


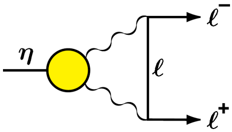
ω Dalitz decay: $\omega \to \pi^0 e^+ e^-$

- inclusive ω production cross section fixed by $\omega \to e^+e^-$, BR($\omega \to e^+e^-$) well known: $7.2 \cdot 10^{-5}$
- ω Dalitz branching also well known
- form factor fixed by NA60 data (Arnaldi et al., PLB 677)

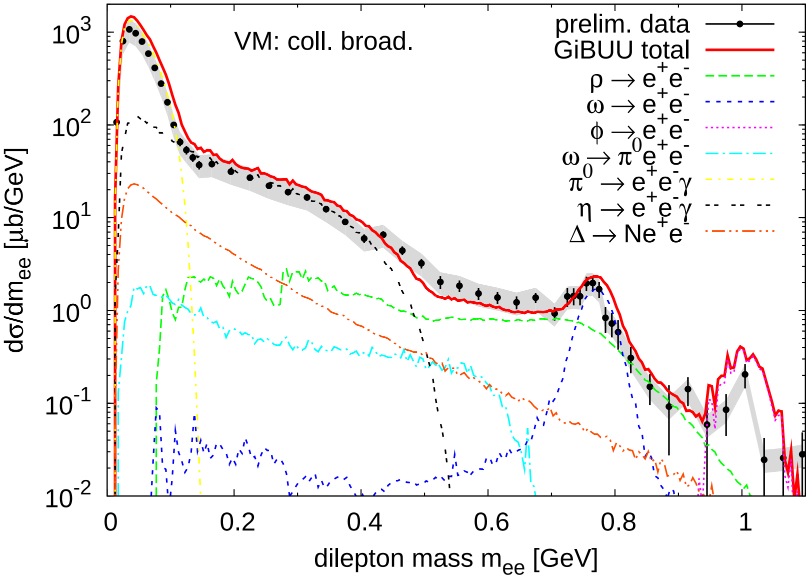


- exp. upper limit (WASA, Berlowski et al., PRD 77, 2008): $\mathrm{BR}(\eta \to e^+e^-) < 2.7 \cdot 10^{-5}$
- HADES might be able to push down this limit ...
- theor. prediction (Browder et al., PRD 56, 1997): $\mathrm{BR}(\eta \to e^+e^-) \approx 10^{-9}$

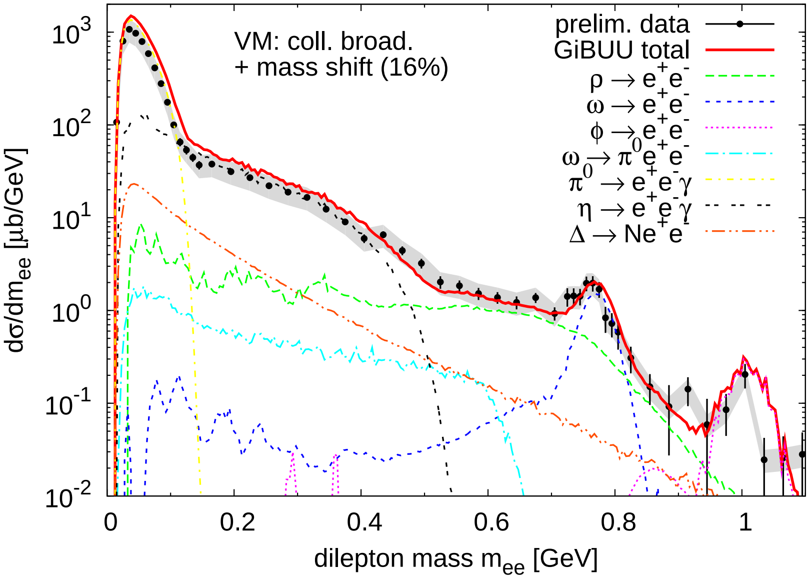


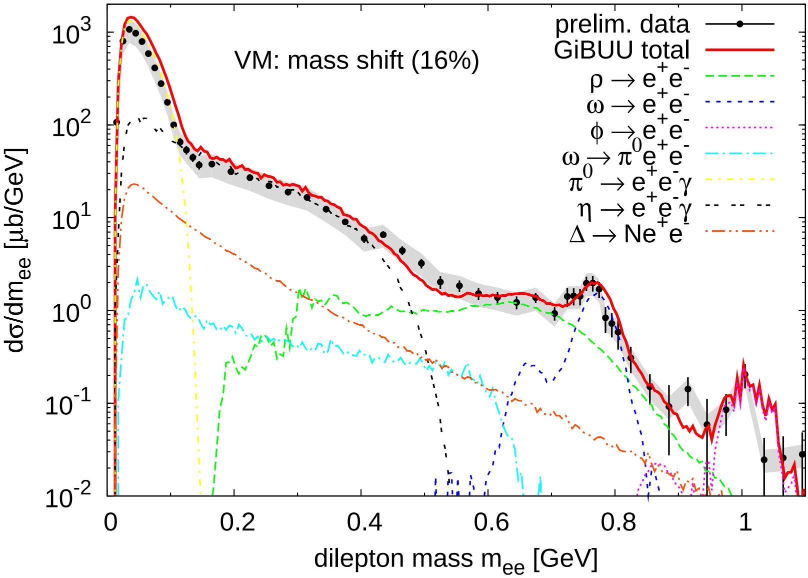


p+Nb@3.5 GeV, mass spectrum



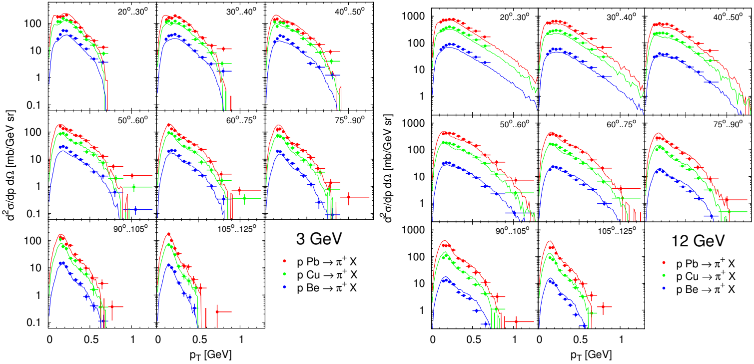
p+Nb@3.5 GeV, mass spectrum





prelim. data
GiBUU total
VM: mass shift (16%)
ρ → e+e-
ω → e+e-
φ → e+e-
ω → π0 e+e-
π0 → e+e- γ
η → e+e- γ
Δ → Ne+e-
dσ/dm_ee [μb/GeV]
dilepton mass m_ee [GeV]
10^3
10^2
10^1
10^0
10^-1
10^-2
0
0.2
0.4
0.6
0.8
1

- pions are important for normalization
- can serve as a cross check for dilepton spectra
- GiBUU nicely describes inclusive pion data by HARP (Gallmeister, NPA 826, 2009)



- off-shell EOM for test particles
  [Cassing/Juchem (NPA 665, 2000), Leupold (NPA 672, 2000)]:

$$
\begin{aligned}
\dot{\vec{r}}_i &= \frac{1}{1-C_i}\frac{1}{2E_i}\left[2\vec{p}_i + \frac{\partial}{\partial\vec{p}_i}Re(\Sigma_i) + \chi_i\frac{\partial\Gamma_i}{\partial\vec{p}_i}\right] , \\
\dot{\vec{p}}_i &= -\frac{1}{1-C_i}\frac{1}{2E_i}\left[\frac{\partial}{\partial\vec{r}_i}Re(\Sigma_i) + \chi_i\frac{\partial\Gamma_i}{\partial\vec{r}_i}\right] , \\
C_i &= \frac{1}{2E_i}\left[\frac{\partial}{\partial E_i}Re(\Sigma_i) + \chi_i\frac{\partial\Gamma_i}{\partial E_i}\right] , \\
\chi_i &= \frac{m_i^2 - M^2}{\Gamma_i} , \quad \frac{d\chi_i}{dt} = 0
\end{aligned}
$$

- incorporate density-dependent self energies Σ_i, $\Gamma_i \sim Im(\Sigma_i)$