Dilepton Production with UrQMD at SIS Energies

Stephan Endres

Frankfurt Institute for Advanced Studies
ITP Uni Frankfurt

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H-QM Helmholtz Research School Quark Matter Studies

HGS-HIRe for FAIR

Overview

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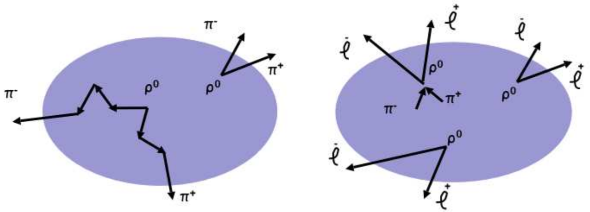
Why Dileptons...?

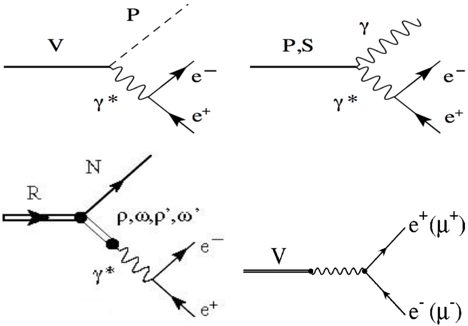
- Dileptons represent a clean and penetrating probe of hot and dense nuclear matter
- Once produced they do not interact with the surrounding matter
- Aim of studies
  $\Rightarrow$ In-medium modification of vector meson properties
  $\Rightarrow$ Chiral symmetry restoration



Dilepton sources in UrQMD

- Dalitz Decays
  $\Rightarrow \pi^0, \eta, \eta', \omega, \Delta$
  $\mathrm{P} \rightarrow \gamma + e^+e^-$
  $\mathrm{V} \rightarrow \mathrm{P} + e^+e^-$
  $\Delta \rightarrow \mathrm{N} + e^+e^-$

- Direct Decays
  $\Rightarrow \rho^0, \omega, \phi$



Resonances and Branching Ratios in UrQMD

- Two processes possible in UrQMD
  Collisions
  (e.g. $\pi\pi \rightarrow \rho$)
  Resonance decays
  (e.g. $N^* \rightarrow N + \rho$)
- At SIS energies, the resonance excitation and decay is dominant
- Branching ratios are in accordance with PDG

Resonance	Mass	Width	$N\pi$	$N\eta$	$N\omega$	$N\varrho$
N^*_{1440}	1.440	350	0.65			
N^*_{1520}	1.515	120	0.60			0.15
N^*_{1535}	1.550	140	0.60	0.30		
N^*_{1650}	1.645	160	0.60	0.06		0.06
N^*_{1675}	1.675	140	0.40			
N^*_{1680}	1.680	140	0.60			0.10
N^*_{1700}	1.730	150	0.05			0.20
N^*_{1710}	1.710	500	0.16	0.15		0.05
N^*_{1720}	1.720	550	0.10			0.73
N^*_{1900}	1.850	350	0.30	0.14	0.39	0.15
N^*_{1990}	1.950	500	0.12			0.43
N^*_{2080}	2.000	550	0.42	0.04	0.15	0.12
N^*_{2190}	2.150	470	0.29			0.24
N^*_{2220}	2.220	550	0.29		0.05	0.22
N^*_{2250}	2.250	470	0.18			0.25
Δ_{1232}	1.232	115	1.00			
Δ^*_{1600}	1.700	350	0.10			
Δ^*_{1620}	1.675	160	0.15			0.05
Δ^*_{1700}	1.750	350	0.20			0.25
Δ^*_{1900}	1.840	260	0.25			0.25
Δ^*_{1905}	1.880	350	0.18			0.80
Δ^*_{1910}	1.900	250	0.30			0.10
Δ^*_{1920}	1.920	200	0.27			
Δ^*_{1930}	1.970	350	0.15			0.22
Δ^*_{1950}	1.990	350	0.38			0.08

Dalitz Decays

- Dalitz decays can be decomposed into the corresponding decays into a virtual photon and the subsequent decay of the photon via electromagnetic conversion

$$\frac{d\Gamma}{dM^2} = \Gamma_{P\to\gamma\gamma*, V\to P\gamma*} \frac{1}{\pi M^4} M\Gamma_{\gamma*\to ee}$$

- Internal conversion probability of the photon

$$M\Gamma_{\gamma*\to ee} = \frac{\alpha}{3} M^2 \sqrt{1 - \frac{4m_e^2}{M^2}} \left(1 + \frac{2m_e^2}{M^2}\right)$$

Dalitz Decays

- The widths $\Gamma_{P\to\gamma\gamma^*}$ and $\Gamma_{V\to P\gamma^*}$ can be related to corresponding radiative widths

$$\Gamma_{P\to\gamma\gamma^*} = 2\Gamma_{P\to 2\gamma}\left(1-\frac{M^2}{m_p^2}\right)^3 \left|F_{P\gamma\gamma^*}(M^2)\right|^2$$

$$\Gamma_{V\to P\gamma^*} = 2\Gamma_{V\to P\gamma}\left[\left(1+\frac{M^2}{m_V^2-m_p^2}\right)^2-\left(\frac{2m_V M}{m_V^2-m_p^2}\right)^2\right]^{3/2} \cdot \left|F_{VP\gamma^*}(M^2)\right|^2$$

Form Factors & Direct Decays

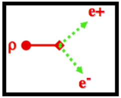
- For the Delta Dalitz decay we use the parametrization given by Wolf, with a modified coupling to fit the radiative decay width [G. Wolf et al., Nucl. Phys. A517, 615 (1990)]
- Form factors for the Dalitz decays are obtained from the vector-meson dominance model (VMD). We use the parametrizations by Landsberg and Li/Ko/Brown/Sorge

  [L.G. Landsberg, Phys.Rept.128, 301 (1985); C.M. Ko et al., Nucl.Phys. A610, 342C (1996)]
- The width for the direct decay of a vector meson V to a dilepton pair varies with the dilepton mass like M^{-3}

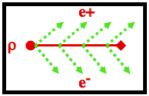
$$\Gamma_{V\to ee}(M) = \frac{\Gamma_{V\to ee}(m_V)}{m_V} \frac{m_V^4}{M^3} \sqrt{1 - \frac{4m_e^2}{M^2}} (1 + \frac{2m_e^2}{M^2})$$

Time Integration Method (Shining)

"Real"



"Virtual" / Time Integration



- *Assumption*: Resonance can continuously emit dileptons over its whole lifetime
- Integration of the dilepton emission rate over time
- Shining in UrQMD applied for Δ, ρ, ω, ϕ and η'
- Collisional broadening of each individual parent resonance is taken into account here

$$\frac{dN_{ee}}{dM} = \frac{\Delta N_{ee}}{\Delta M} = \sum_{j=1}^{N_{\Delta M}} \int_{t_i^j}^{t_f^j} \frac{dt}{\gamma} \frac{\Gamma_{ee}(M)}{\Delta M}$$

$\Delta(1232)$ Resonance in UrQMD

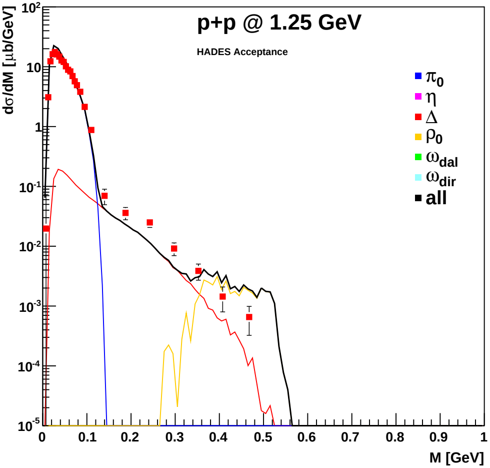
- In previous calculations it was seen, that the Delta Dalitz contribution was quite high
- As we do a shining that integrates over the lifetime of the resonances, it might be related to the resonance width
- In UrQMD mass dependent widths are used, but the lifetime is mass-independent $\tau{=}1/\Gamma(m_{pole})$ to avoid unphysically high lifetimes for low masses

→ Now: We use mass-dependent (partial) width for all masses higher than the pole mass to calculate τ:

$$\Gamma_{\mathrm{i,j}}(\mathrm{M}) = \Gamma^{\mathrm{i,j}}_{\mathrm{pole}} \frac{\mathrm{M_{pole}}}{\mathrm{M}} \left[\frac{\langle p_{i,j}(M) \rangle}{\langle p_{i,j}(M_{pole}) \rangle} \right]^{2l+1} \frac{1.2}{1 + 0.2 \left[\frac{\langle p_{i,j}(M) \rangle}{\langle p_{i,j}(M_{pole}) \rangle} \right]^{2l}}$$

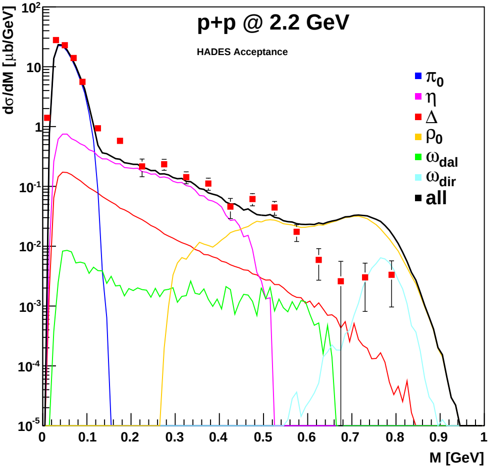
p + p @ 1.25 GeV

- $E_{lab} = 1.25$ GeV just below η threshold
- Small sub-threshold contribution from ρ expected
- Good agreement with data at low masses
- Too many dileptons from 0.3 GeV on $\rightarrow$ especially ρ^0

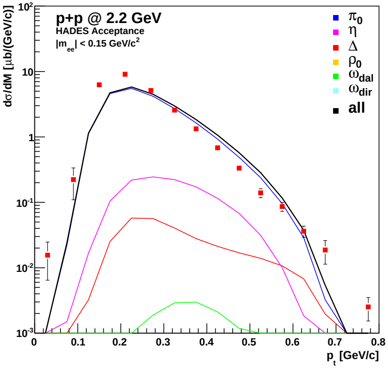


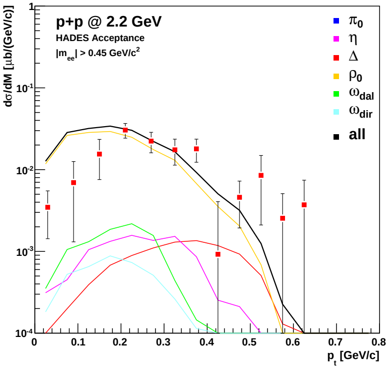
p + p @ 2.2 GeV

- Above η threshold, energy sufficient to reach pole mass of ω and ρ
- Overestimation of ρ contribution even larger than at 1.25 GeV



p_t Spectra for p + p @ 2.2 GeV

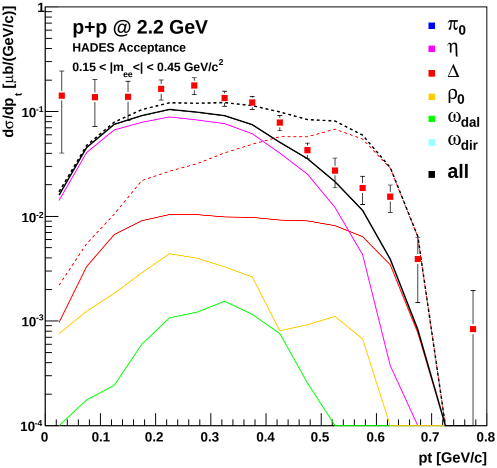




- p_t spectra are described well, especially in the low mass region dominated by the π^0 Dalitz decay
- We again see an overestimation of the ρ meson contribution

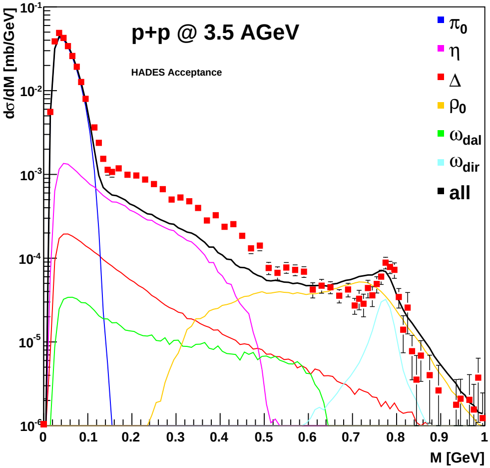
p_t Spectra for p + p @ 2.2 GeV

- Dashed lines = mass-independent Δ lifetime → Now no overshooting of data points by high p_t Deltas
- In the intermediate mass region we see the eta contribution too low compared to the data

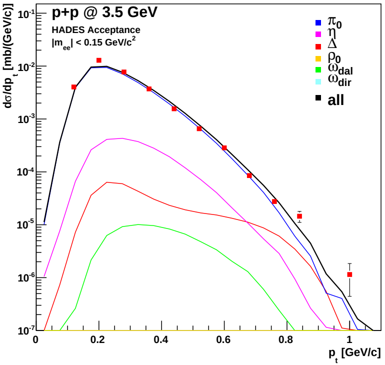


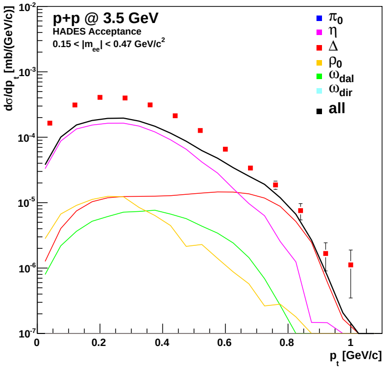
p + p @ 3.5 GeV

- Here the UrQMD result for ρ contribution is in accordance with the data
- However, we get too little dileptons in the intermediate mass region



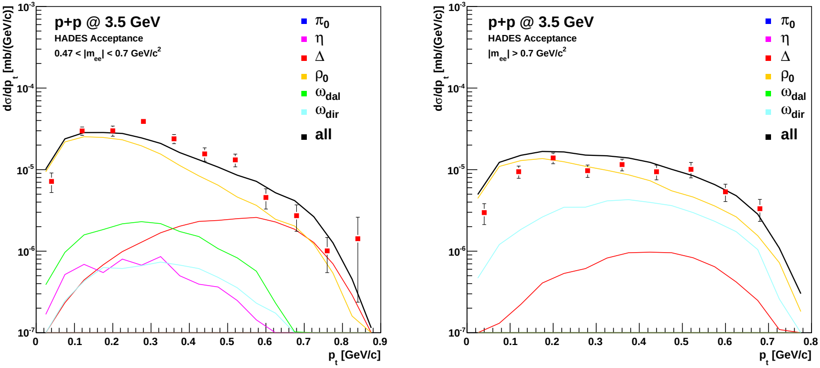
p_t Spectra for p + p @ 3.5 GeV





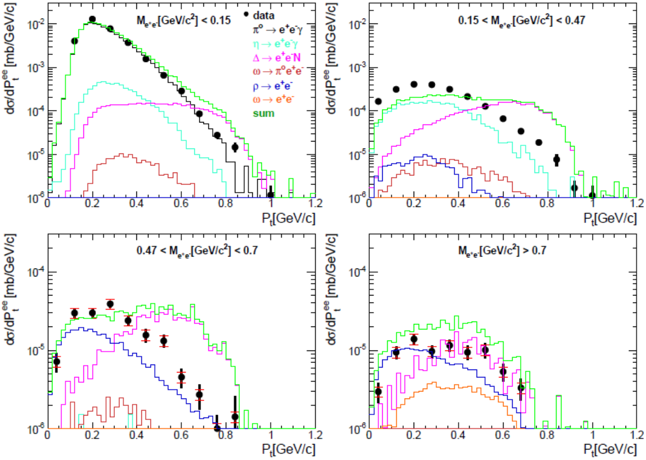
- p_t spectra are described well, especially in the low mass region dominated by the π^0 Dalitz decay
- η dominated intermediate mass region too low in UrQMD results

p_t Spectra for p + p @ 3.5 GeV



- p_t spectra are described well also for the high mass region
- The ρ meson contribution fits the data at 3.5 GeV

Previous p_t Spectra for p + p @ 3.5 GeV



- For comparison: p_t spectra without mass-dependent Δ lifetime overshoop the data!

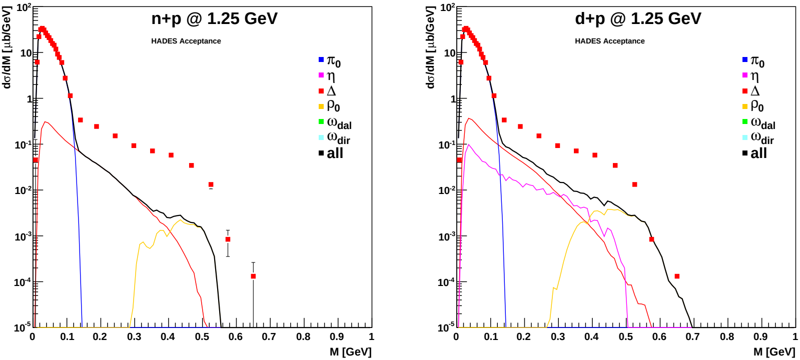
[G. Akakishiev et al., Eur.Phys.J. A48 (2012) 64]

n + p @ 1.25 GeV

- Deuteron beam with 1.25AGeV has been used by HADES besides p+p
- Trigger on forward-going protons in order to select the (quasi-free) np collisions
- Fermi motion of the bound nucleons in the deuteron leads to a smearing of the NN collision energy $\rightarrow$ reaching above η-production threshold

$\Rightarrow$ One can not easily compare data with pure n+p simulations

n + p @ 1.25 GeV



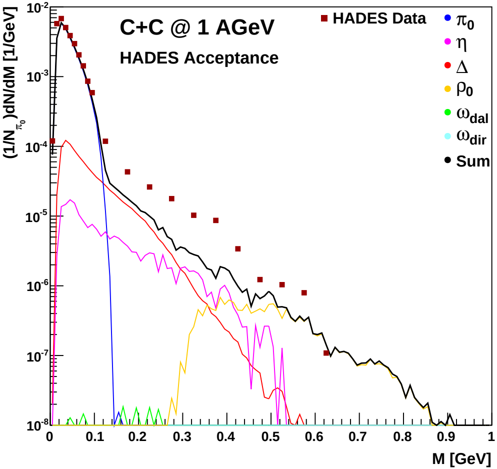
- η and more ρ are produced in d+p, compared to n+p
- However, even for d+p the Yield is underestimated by a factor of about 5 to 10

Study of A+A collisions

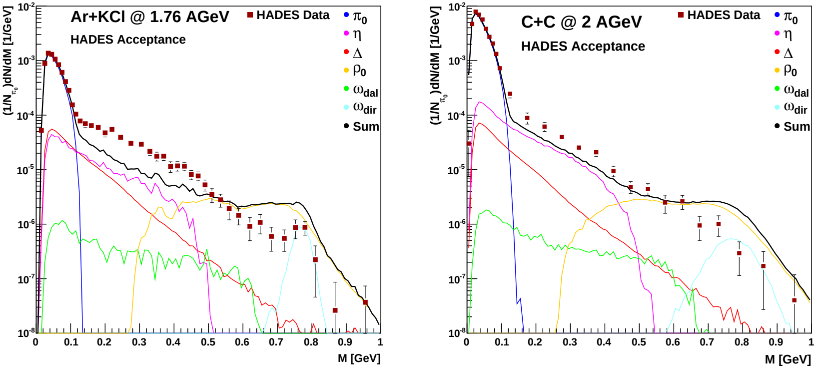
- In nucleus-nucleus collisions, additional effects compared to pp are expected
  - Fermi Momentum
  - Not only p+p, but also p+n and n+n collisions
  - Secondary interactions, depending on system size and energy
- Vector meson spectral functions may be changed in the medium
  - Shift of the pole mass (of the ρ)
  - Resonance melting in the medium
- In UrQMD, no such in-medium effects are implemented

C + C @ 1 AGeV

- Here the ρ contribution fits quite well
- Underestimation below for energies above the pion peak
- Hardly any ω produced, η is relatively small

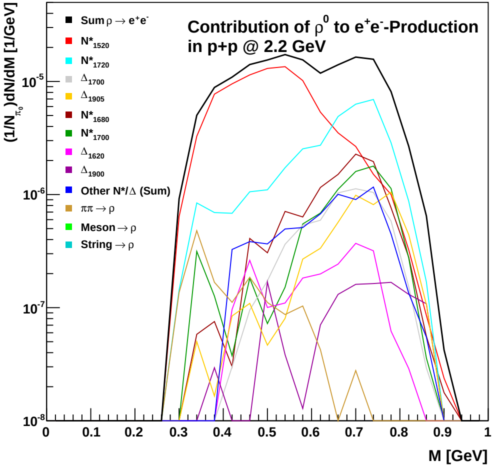


Ar + KCl @ 1.76 AGeV & C + C @ 2 AGeV



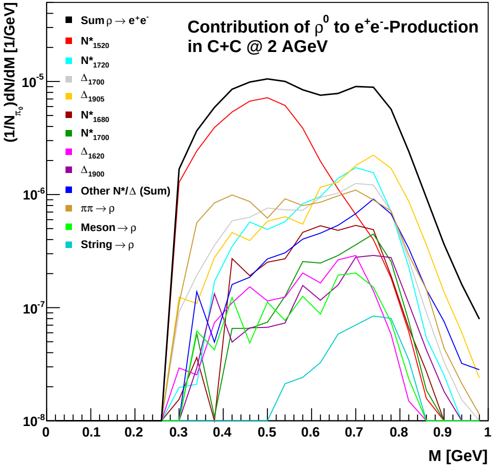
- As in elementary reactions, we get too many dileptons via the ρ^0 resonance, especially in the high-mass tail
- How are the ρ mesons produced?

ρ^0 Contribution



- Main contribution below pole mass by N^*_{1520} resonance
- For pole mass peak via Δ^*_{1720}, N^*_{1680} and N^*_{1700}
- Other sources negligible

ρ^0 Contribution

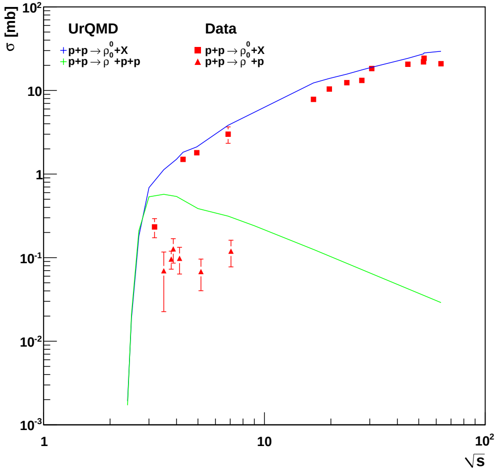


- Main contribution below pole mass again by N^*_{1520}
- For pole mass peak via N^*_{1720}, Δ^*_{1700} and Δ^*_{1905}
- $\pi\pi \rightarrow \rho$ makes up 10%

Why too many dileptons from ρ ?

- All HADES energies are close to thresholds
  - Cross-sections change rapidly with small energy differences
  - Are the cross-sections in order?
- Possible σ channel for a part of what we treat as a ρ?
- Do in-medium effects not included in UrQMD play a role ?
- Why do we see the large overestimation for invarinat masses above 700 GeV (pole mass)?

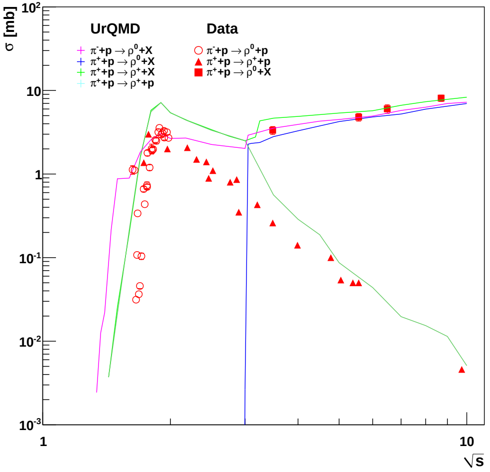
Cross-sections N+N $\rightarrow \rho^0$+X



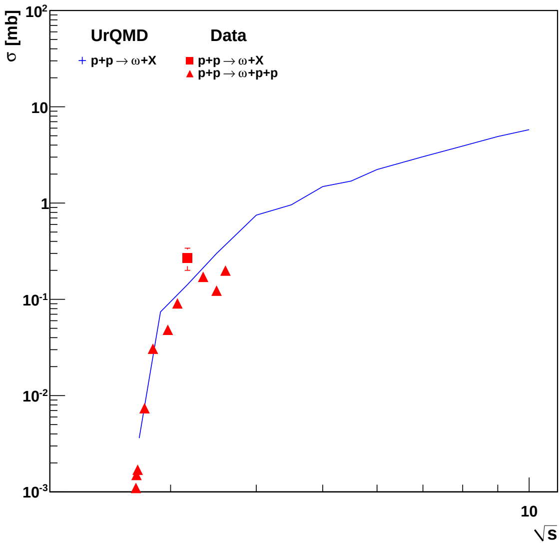
- Good description of inclusive cross-section for energies above HADES energies
- For energies near threshold, σ might be too high, as recent HADES measurement indicates

Cross-sections π+N $\rightarrow$ ρ+X

- ρ^+ production overestimated below $\sqrt{s} = 3$ GeV (but not relevant for dileptons)
- ρ^0 from UrQMD fits quite well to data, except for threshold region
- Does experiment just don't see these ρ which are significantly below pole mass?

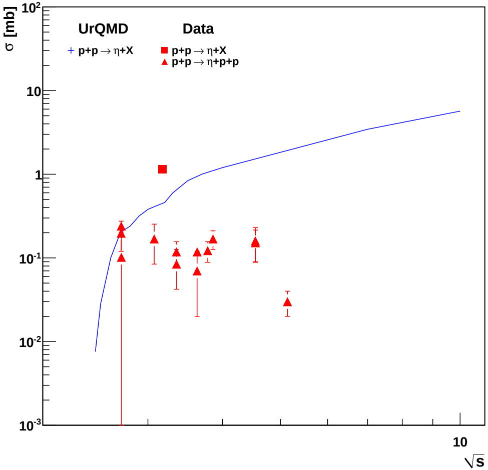


Cross-sections for ω meson



Cross-sections p+p $\rightarrow \eta$+X

- η inclusive production obvious under-estimated at HADES energies (as clear from dN/dM Spectra)
- Isospin asymmmetry taken into account
  - $\rightarrow$ *pn* cross-sections increased by a factor of 6 according to TAPS data



Summary on cross-sections

- Only few data are available, so more data would be good!
- In UrQMD the ρ **cross-section** close to the threshold seems to be too high while the η **cross-section** might be too low
- $\Rightarrow$ Problem must be related to $NN \rightarrow NN^*$ and $N\Delta^*$*production*

Next Steps

- Optimization of dilepton production in UrQMD, especially the ρ^0 and η channel
  - E.g. comparison with Manley's partial wave analysis

    [D.M. Manley et al., Phys.Rev. D45, 4003 (1992)]

- **Coarse graining** to be done for HADES energies
  - Take local temperature and baryon chemical potential as functions of space and time
  - Accumulate an ensemble of events and determine local variables via coarse graining

- Dilepton calculation with **hybrid model** (transport + hydro)
  - Previous work (Dimuons from NA60) by Elvira Santini

    [E. Santini et al., Phys.Rev. C84, 014901 (2011)]
  - Proceed with this work and calculate yields for RHIC and LHC energies