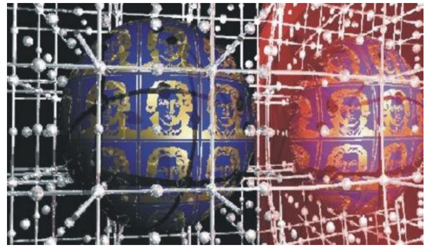
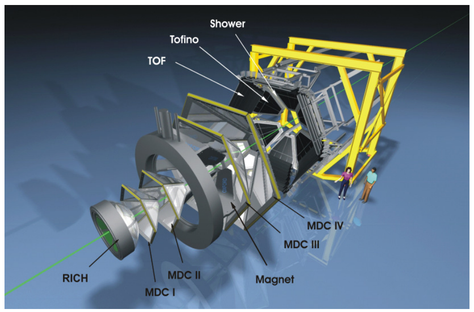
GOETHE UNIVERSITÄT FRANKFURT AM MAIN



Dilepton production and off-shell transport dynamics at SIS energies

Elena Bratkovskaya

Institut für Theoretische Physik, Uni. Frankfurt



12 August 2009, EMMI Workshop on 'Virtual Bremsstrahlung and HADES'
Uni. Frankfurt

Applicability of transport approaches and viscous hydro

The ratio of shear viscosity to entropy density η/s defines the applicability of many-body approaches !

Recall: ideal hydro: $\eta/s = 0$!

Validity of transport approaches (in 2PI approximation):

a) **classically:** $\lambda > d$

mean-free path λ must be larger than the average distance $d = \rho^{-1/3}$ of the `degrees of freedom` (hadrons or partons)

for gluons (e.g. C. Greiner et al.) : $\lambda > d = \rho^{-1/3} = \pi^{2/3} /(16^{1/3}\ T)$

using $\eta/s = 4/15\ T\ \lambda$ → $\eta/s > 0.22$

b) **quantum mechanics:** $\Gamma < E/2$

width of quasi-particles Γ must be less than about half the quasi-particle energy $E = (p^2+M^2)^{1/2}$

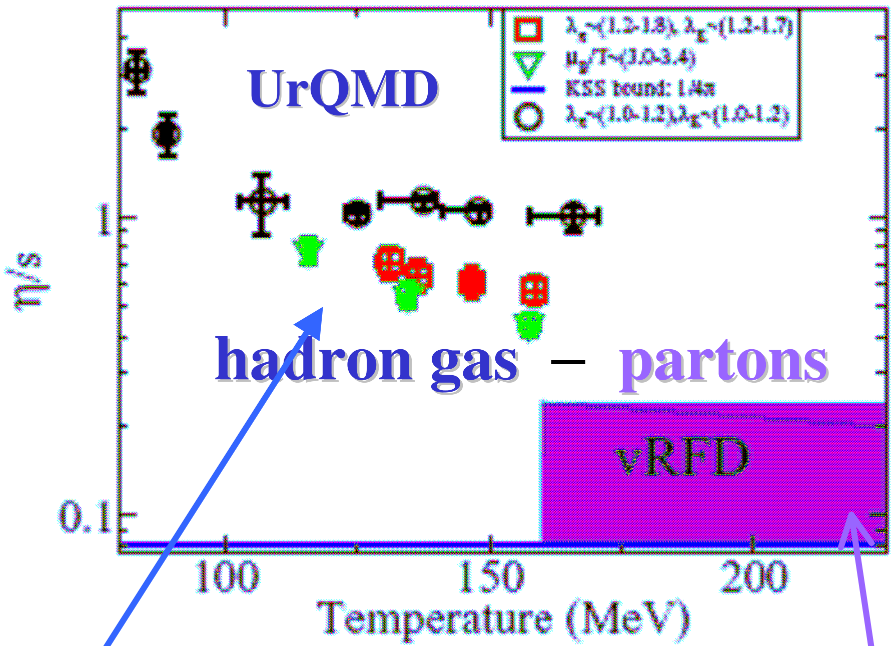
(Juchem, Cassing, Greiner 2003) : average energy $\langle E \rangle = (M^2+(3T)^2)^{1/2}$

→ for M=0: $\eta/s > 0.18$ (η/s is even lower for $M > 2T$ as in PHSD!)

PHSD: W. Cassing, E. B., PRC 78 (2008) 034919; arXiv:0907.5331 [nucl-th]

What do we know about η/s?

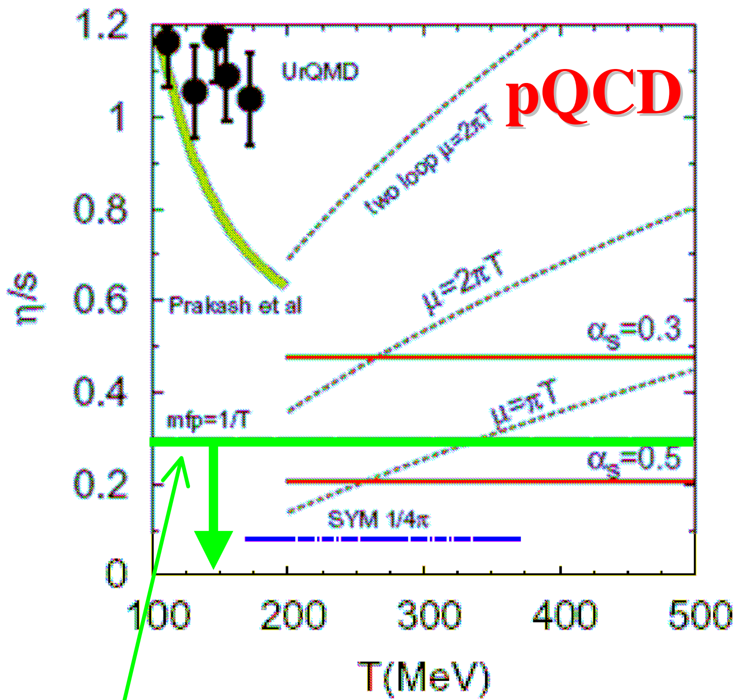
N. Demir, S.A. Bass : PRL 102 (09) 172302



In hadronic phase: η/s > 0.5
➔ transport is valid!

in partonic phase: η/s < 0.3

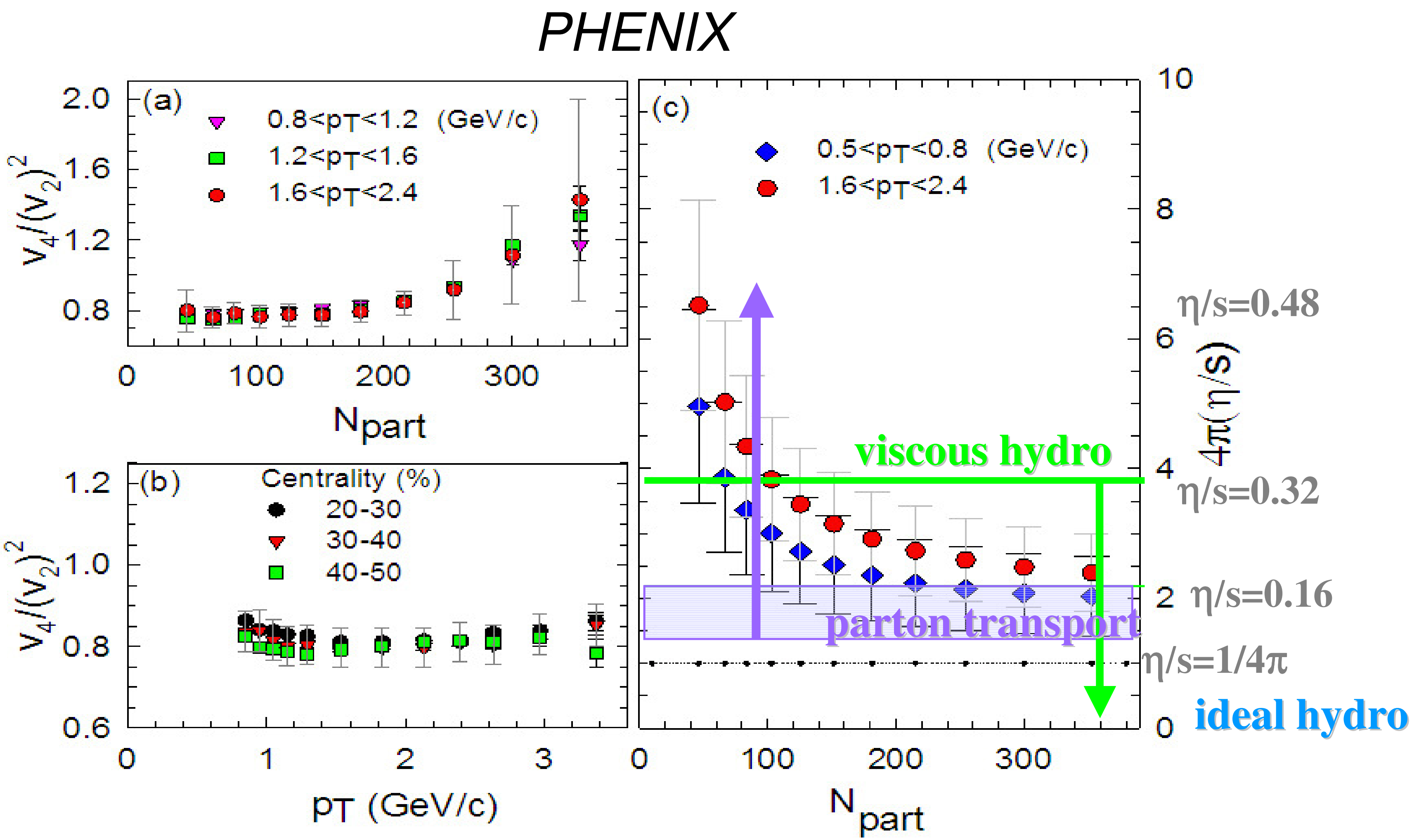
D. Teaney: nucl-th / 0905.2433



D. Teaney: dissipative (viscous) hydro works for η/s < 0.3 !

… What the experiment tells us about η/s at RHIC?

Experimental situation in Au+Au at RHIC

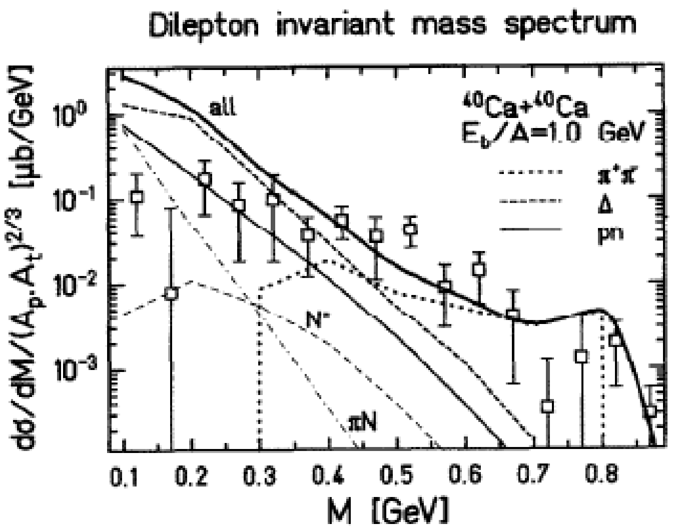


→The off-shell transport - with parton-hadron degrees of freedom – is valid at least up to RHIC energies !

Data from R. Lacey: CBM Workshop, March 2009

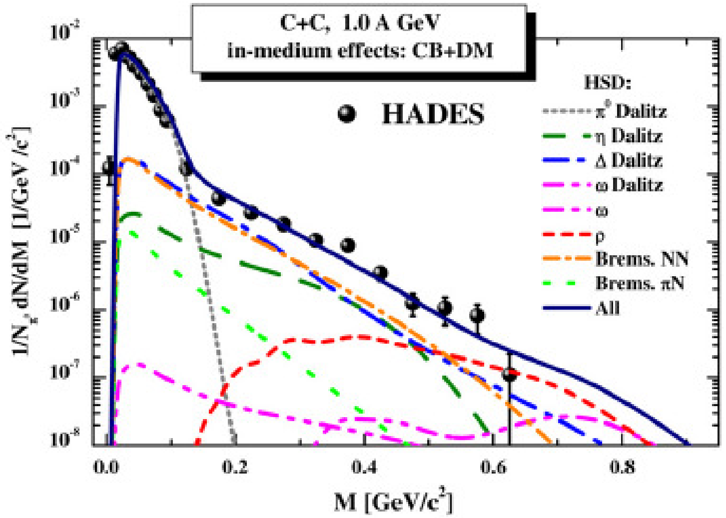
‚History‘ of dilepton cocktails

Gy. Wolf et al., Nucl. Phys. A517 (1990) 615 [Similar to : C.M. Ko et al., NPA 512 (1990) 772]



BUU:
- first calculation of dilepton production in heavy-ion collisions within a transport model
- implementation of the basic dilepton channels
- time integration (‚shining‘) method
- discussion of in-medium effects

E.B., W. Cassing, Nucl. Phys. A807 (2008) 214



HSD :
- … +
- off-shell transport dynamics
- dynamical treatment of resonances with broad spectral functions
- in-medium effects (dropping mass, collisional broadening)

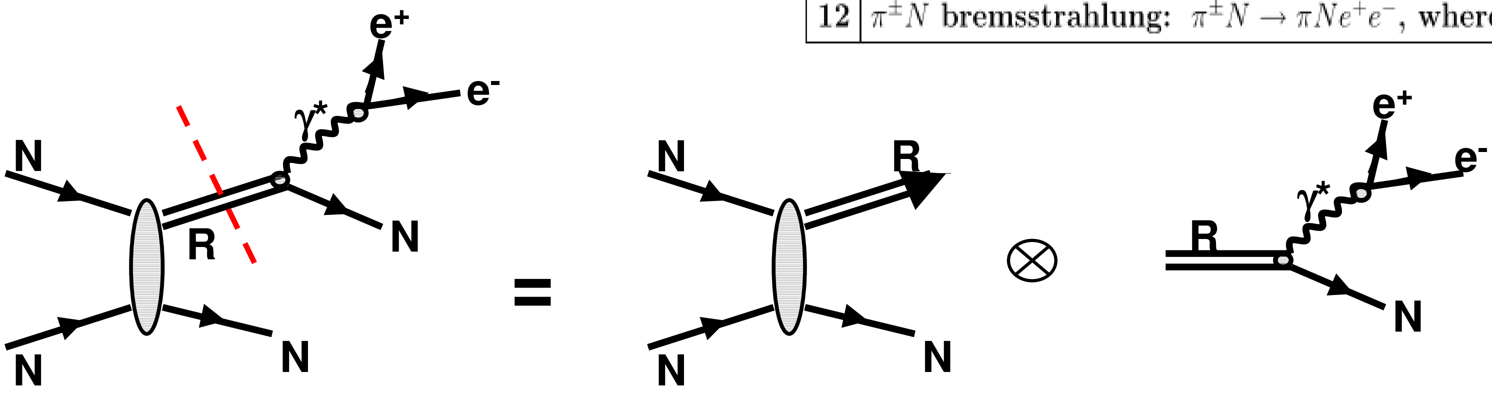
Dilepton cocktail in HSD

- All particles decaying to dileptons are first produced in BB, mB or mm collisions

$$\mathbf{BB \to RX}$$
$$\mathbf{mB \to RX}$$
$$\mathbf{R \to e^+e^-X}$$
$$\mathbf{R \to mX,\ m \to e^+e^-X}$$
$$\mathbf{R \to R'X,\ R' \to e^+e^-X}$$

i	Dilepton channel	electromagnetic decays
1	Dalitz decay of π^0:	$\pi^0 \to \gamma e^+e^-$
2	Dalitz decay of η:	$\eta \to \gamma e^+e^-$ (or $\mu^+\mu^-$)
3	Dalitz decay of ω:	$\omega \to \pi^0 e^+e^-$
4	Dalitz decay of Δ:	$\Delta \to Ne^+e^-$
5	direct decay of ω:	$\omega \to e^+e^-$
6	direct decay of ρ:	$\rho \to e^+e^-$
7	direct decay of ϕ:	$\phi \to e^+e^-$
8	direct decay of J/Ψ:	$J/\Psi \to e^+e^-$
9	direct decay of Ψ':	$\Psi' \to e^+e^-$
10	Dalitz decay of η':	$\eta' \to \gamma e^+e^-$
11	pn bremsstrahlung:	$pn \to pne^+e^-$
12	$\pi^\pm N$ bremsstrahlung:	$\pi^\pm N \to \pi Ne^+e^-$, where $N = p$ or n

- ‚Factorization' of diagrams in the transport approach:



- The dilepton spectra are calculated perturbatively with the time integration method.

Zoom: Dilepton channels

electromagnetic decays → under control!

i	Dilepton channel	
1	Dalitz decay of π^0:	$\pi^0 \to \gamma e^+e^-$
2	Dalitz decay of η:	$\eta \to \gamma e^+e^-$ (or $\mu^+\mu^-$)
3	Dalitz decay of ω:	$\omega \to \pi^0 e^+e^-$
4	Dalitz decay of Δ:	$\Delta \to N e^+e^-$
5	direct decay of ω:	$\omega \to e^+e^-$
6	direct decay of ρ:	$\rho \to e^+e^-$
7	direct decay of ϕ:	$\phi \to e^+e^-$
8	~~direct decay of J/Ψ:~~	~~$J/\Psi \to e^+e^-$~~
9	~~direct decay of Ψ':~~	~~$\Psi' \to e^+e^-$~~
10	~~Dalitz decay of η':~~	~~$\eta' \to \gamma e^+e^-$~~
11	pn bremsstrahlung:	$pn \to pne^+e^-$
12	$\pi^\pm N$ bremsstrahlung:	$\pi^\pm N \to \pi N e^+e^-$, where $N = p$ or n

(rows 1–7:) **π,η,Δ,ω,ρ,φ,... production – can be controlled by N+N and π+N exp. data**

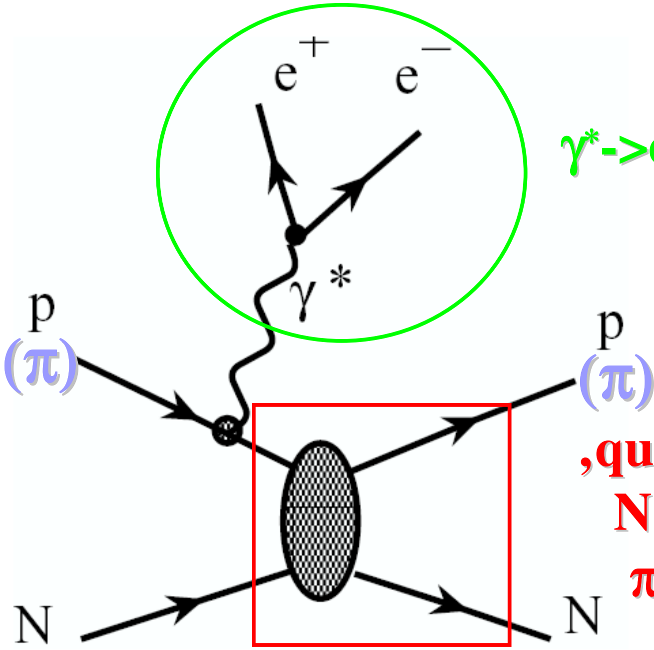
(rows 8–10:) **not for HADES**

NN, πN bremsstrahlung = ‚background' radiation - hard to control by exp. data!

→ reliable theoretical model for NN and πN bremsstrahlung is needed!

NN and πN bremsstrahlung - SPA

Soft-Photon-Approximation (SPA):
N N –> N N e^+e^- (or π N –>π N e^+e^-)



‚quasi- elastic'
N N -> N N
π N -> π N

Phase-space corrected soft-photon cross section:

$$\frac{d\sigma}{dy\,d^2q_T\,dM} = \frac{\alpha^2}{6\pi^2}\frac{\bar\sigma(s)}{M q_0^2}\frac{R_2(s_2)}{R_2(s)}$$

$$R_2(s) = \sqrt{1-(m_1+m_2)^2/s}$$

$$s_2 = s + M^2 - 2q_0\sqrt{s}$$

$$\bar\sigma(s) = \frac{s-(m_1+m_2)^2}{2m_1^2}\,\sigma(s)$$

‚off-shell' correction factor

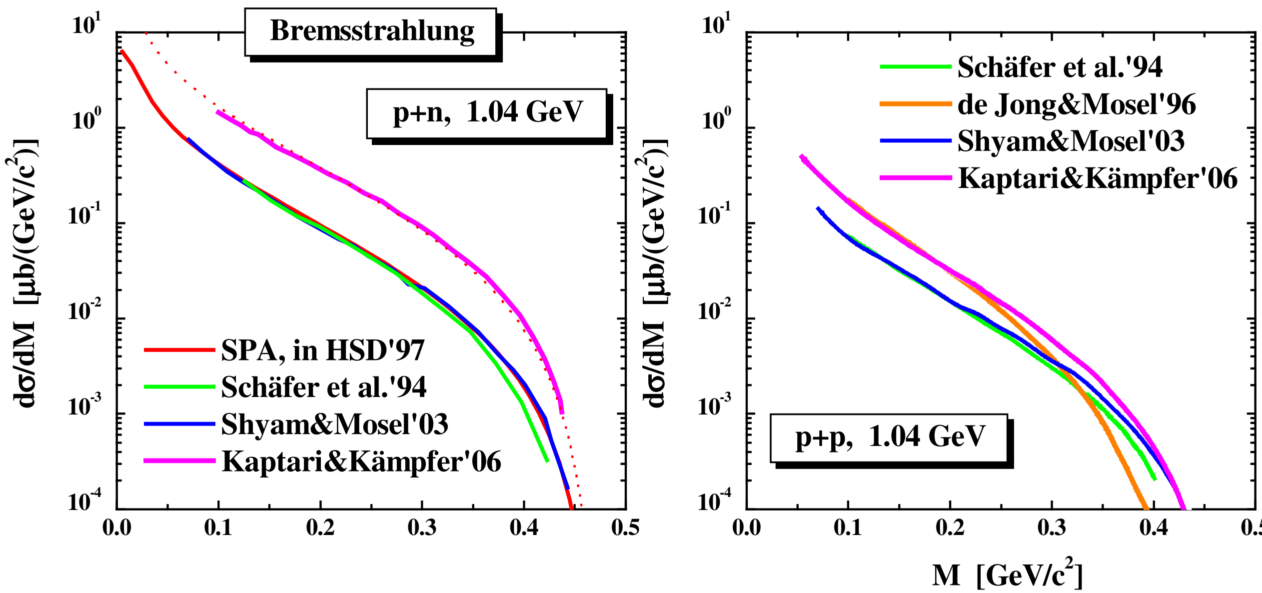
elastic $\sigma(s)$ NN (πN)

SPA implementation in HSD:
e^+e^- production in elastic NN (πN) collisions with probability:

$$\frac{dP(s, M, \vec q)}{dM\,d\vec q} = \frac{d\sigma(s, M, \vec q)}{dM\,d\vec q}\cdot\frac{1}{\sigma^{elast}_{NN(\pi N)}}$$

(as in Gy. Wolf et al., NPA517 (1990) 615)

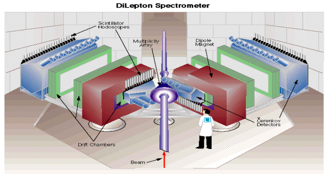
Bremsstrahlung – a new view on an ‚old‘ story



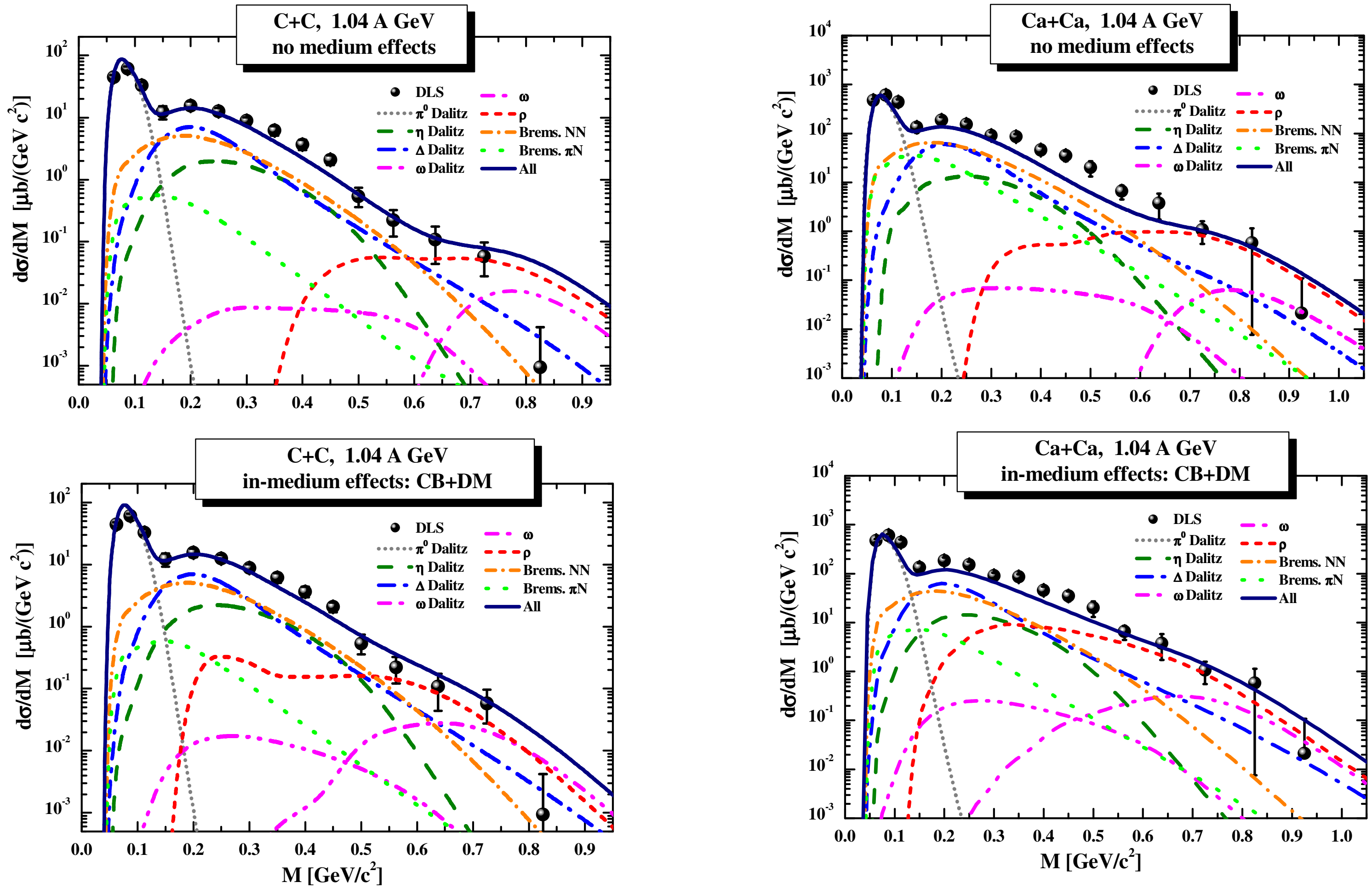
New OBE-model (Kaptari&Kämpfer, NPA 764 (2006) 338):

- pn bremstrahlung is larger by a factor of 4 than it has been calculated before (and used in transport calculations before)!
- pp bremstrahlung is smaller than pn, however, not zero; consistent with the 1996 calculations from F. de Jong in a T-matrix approach

2007 ‚DLS puzzle‘ : Experimentally: HADES = DLS !
Theory: the DLS puzzle is solved by accounting for a larger pn bremsstrahlung !

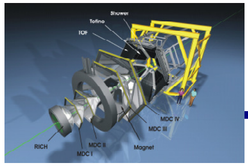


HSD: Dileptons from A+A at 1 A GeV - DLS

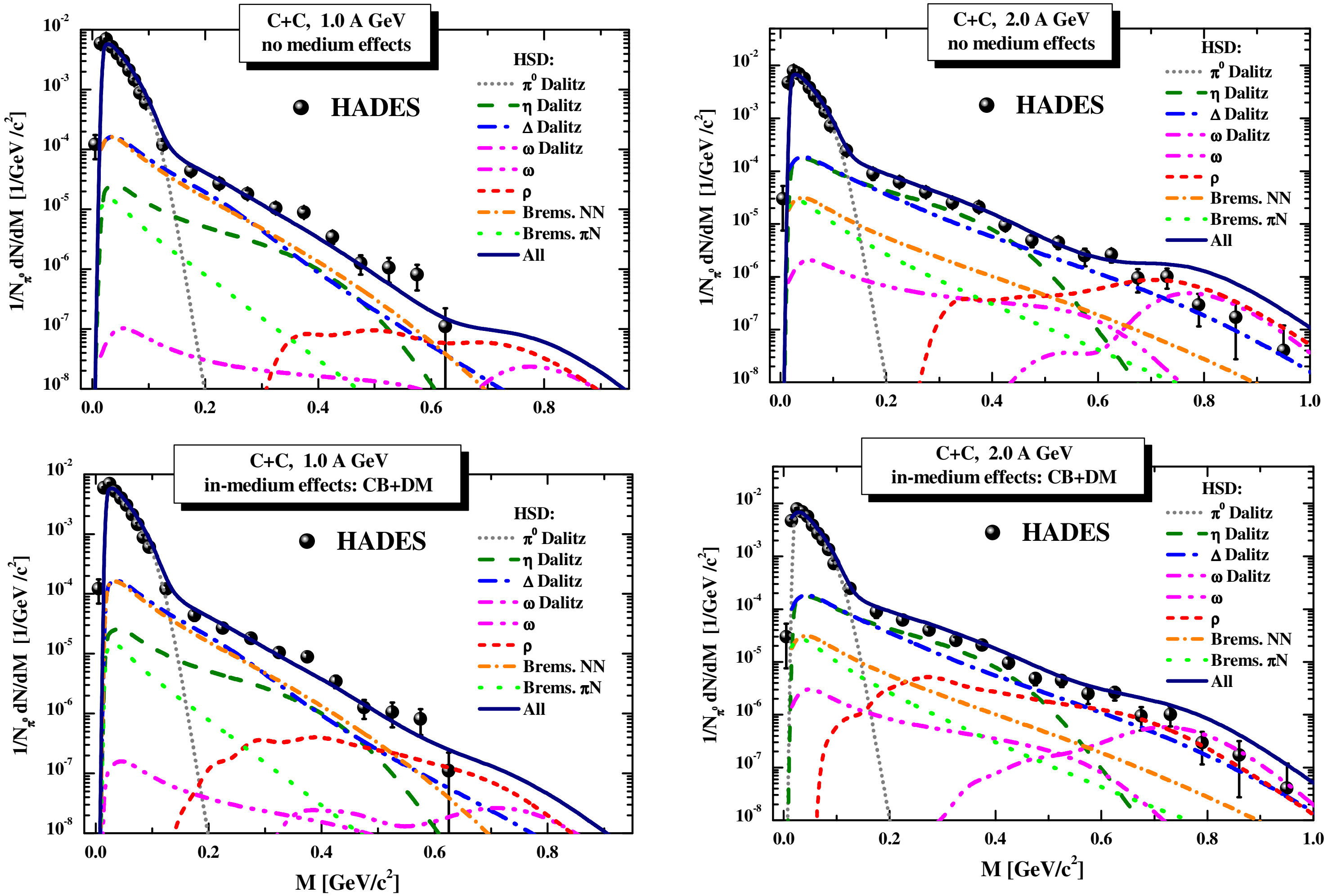


• bremsstrahlung and Δ-Dalitz are the dominant contributions in A+A for 0.15 < M < 0.55 GeV at 1 A GeV !

E.B., Cassing, NPA807 (2008) 214

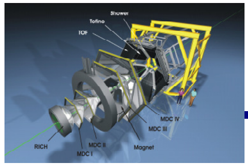


HSD: Dileptons from C+C at 1 and 2 A GeV - HADES

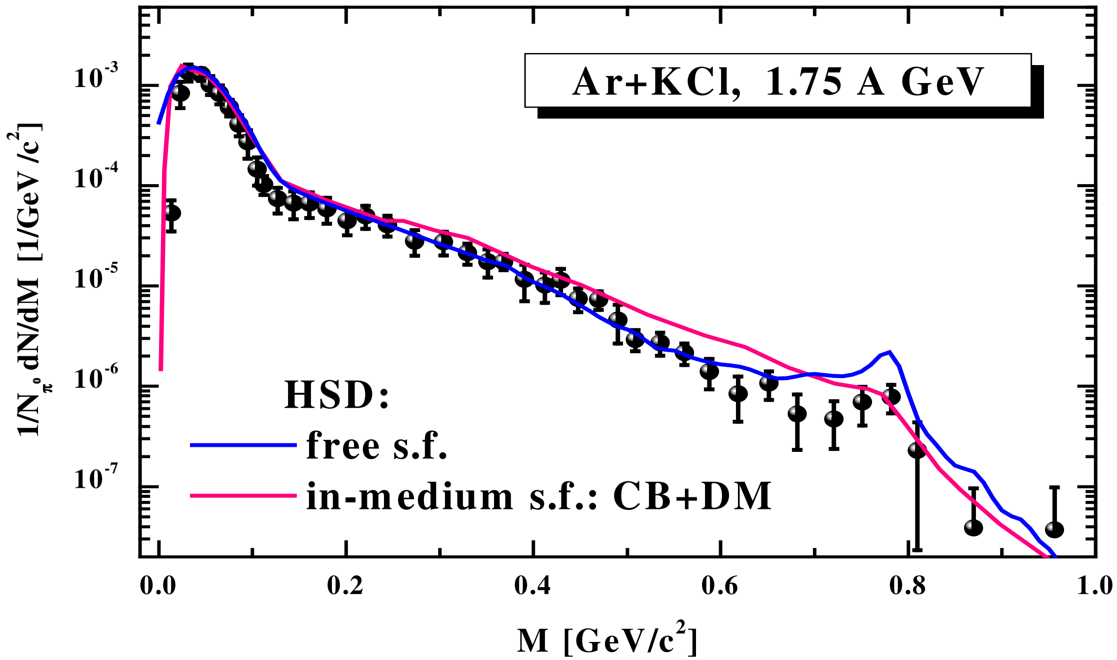


- HADES data show exponentially decreasing mass spectra
- Data are better described by in-medium scenarios with collisional broadening
- In-medium effects are more pronounced for heavy systems such as Au+Au

E.B., Cassing, NPA807 (2008) 214



HSD: Dileptons from Ar+KCl at 1.75 A GeV - HADES



HSD by
Filip Krizek

- preliminary HADES data show a peak structure at M~0.78 GeV
- HSD overestimates yield at M~0.5-0.8 GeV for the in-medium as well as for free scenarios

➔ no medium effects observed ?! NO !!!

⇒ Indication that the ρ-meson production cross section from NN closer to threshold is overestimated in HSD ☹

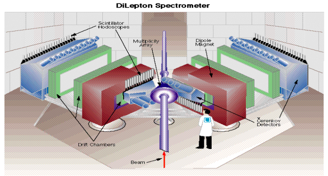
- In-medium effects are more pronounced for heavy systems such as Ar+KCl
- The peak at M~0.78 GeV relates to ω/ρ mesons decaying in vacuum

From A+A to N+N reactions and backward

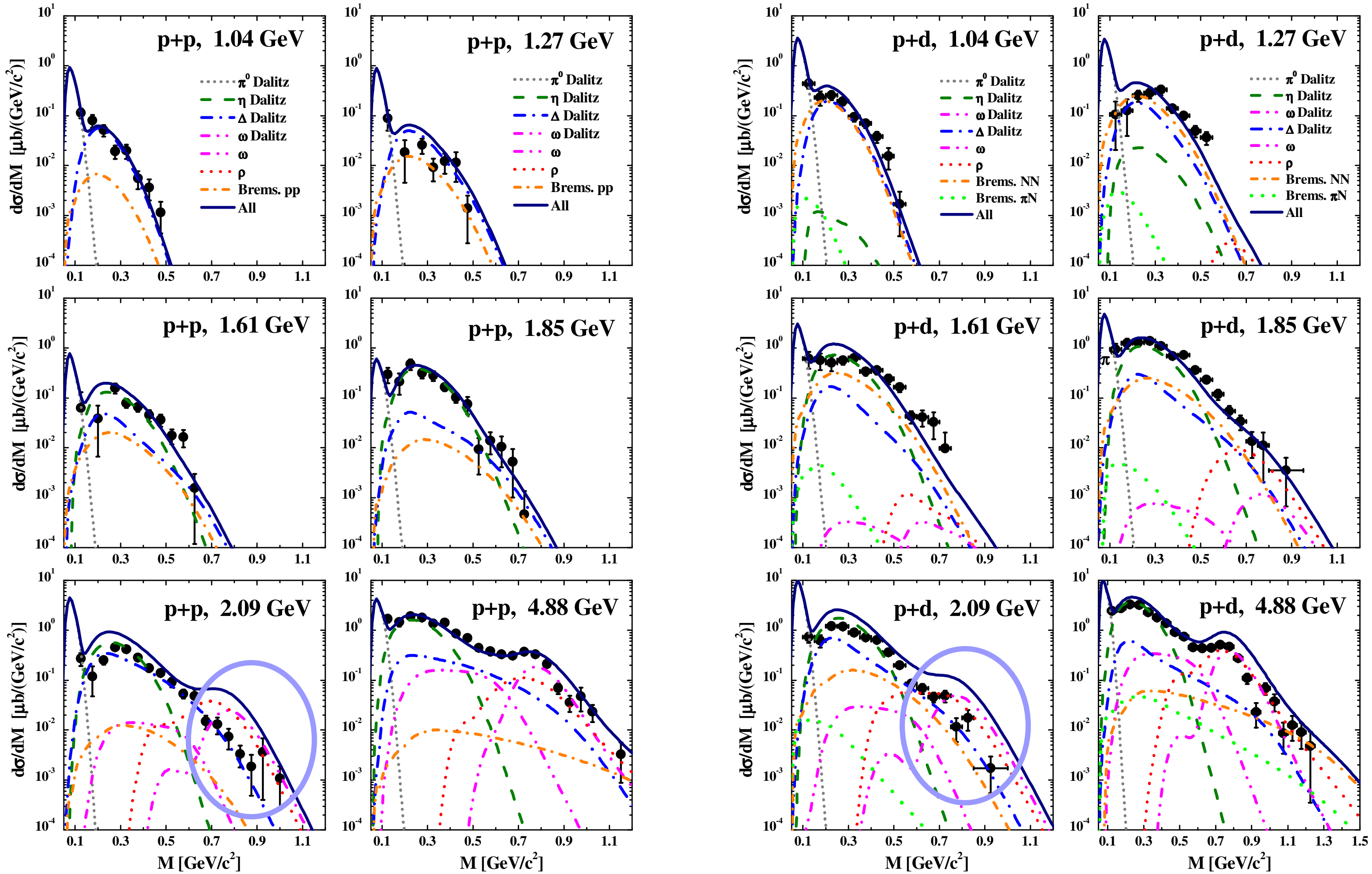
- ❑ Does Δ Dalitz and NN Bremsstrahlung explain the excess?

- ❑ Control on vector meson production cross sections at threshold!

→ verification in NN collisions is needed



HSD: Dileptons from p+p and p+d - DLS



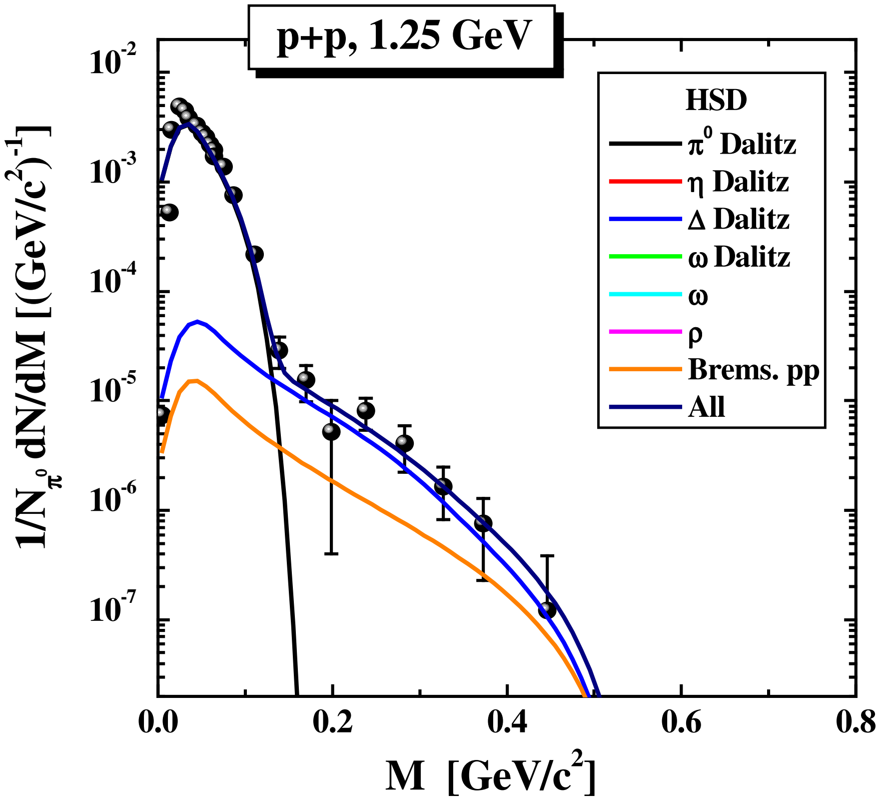
- **bremsstrahlung** is one of the dominant contributions in p+d for 0.15 < M < 0.55 GeV at ~1-1.5 A GeV

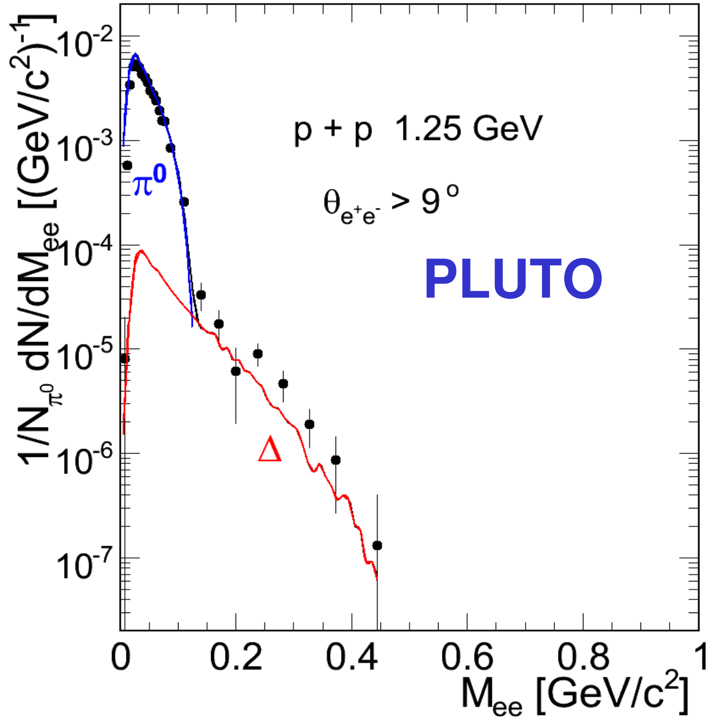
pp, pn (pd) reactions

- DLS data (low statistics and mass resolution) do not allow for definite conclusions

- new (good quality) HADES data on pp, pn (pd) reactions for different energies provide an independant check for the elementary channels involved in A+A

pp @ 1.25GeV : new HADES data



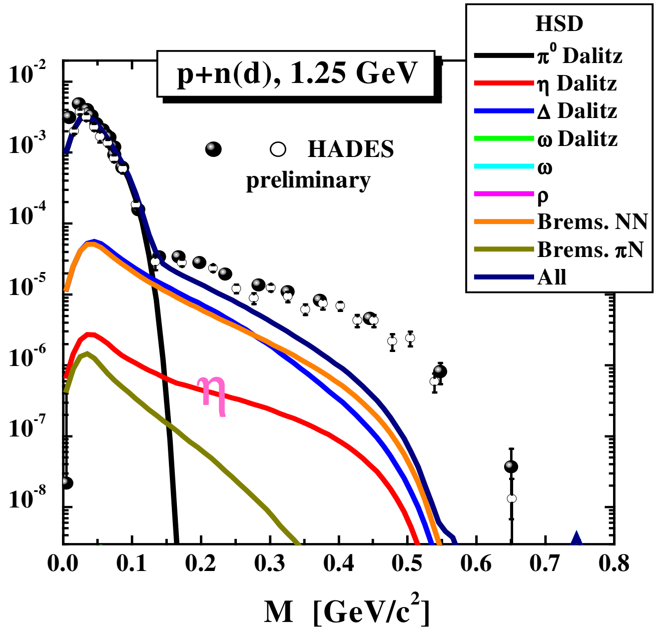


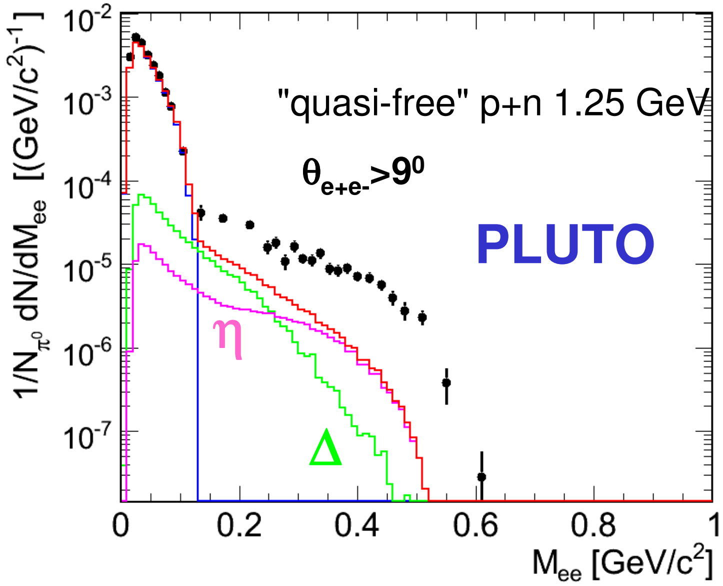
✓ Δ-Dalitz decay is the dominant channel (HSD consistent with PLUTO)

✓ HSD predictions: good description of new HADES data for p+p!

E.L.B. &W. Cassing, NPA 807 (2008) 214

Quasi-free pn (pd) reaction: HADES data @ 1.25 GeV





HSD predictions underestimate the HADES p+n (quasi-free) data at 1.25 GeV:

1) 0.2<M<0.55 GeV:

η-Dalitz decay is by a factor of ~10 is larger in PLUTO than in HSD since the channels $d + p \to p_{spec} + d + \eta$ ('quasi-free' η-production - dominant at 1.25GeV!) and $p + n \to d + \eta$ were NOT taken into account before!

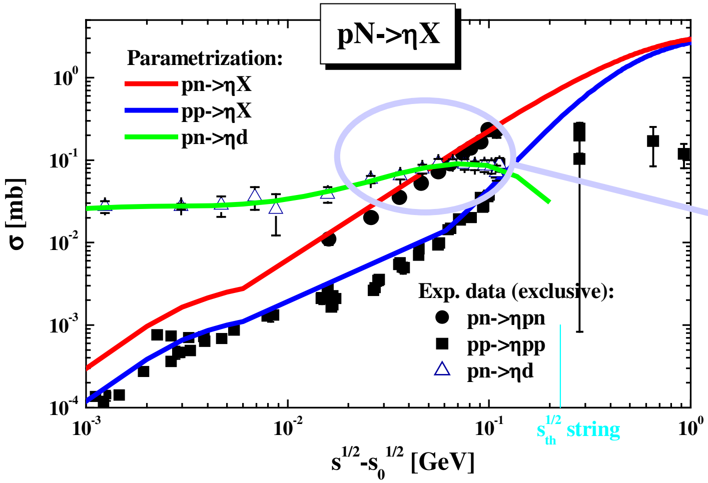
Note: these channels have NO impact for heavy-ion reactions and even for p+d results at higher energies!

*In HSD: p+d = p + (p&n)-with Fermi motion according to the Paris deuteron wave function

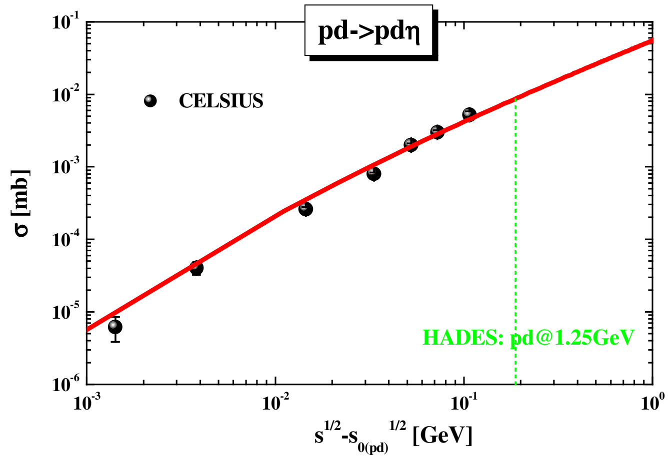
Quasi-free pn (pd) @ 1.25 GeV: η-channel

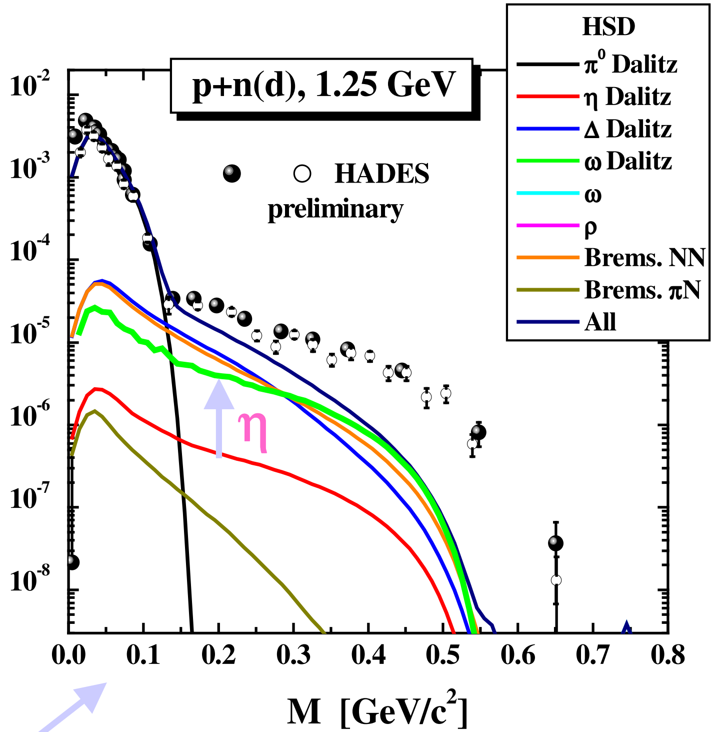
Add the following channels:

1) $p + n \rightarrow d + \eta$



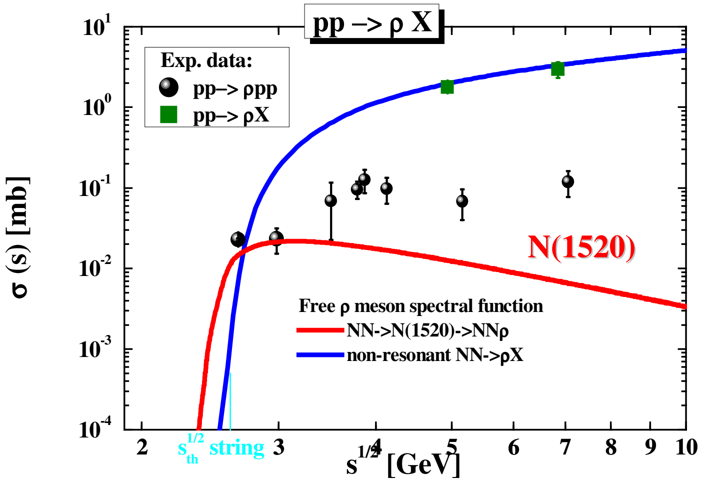
2) $d + p \rightarrow p_{spec} + d + \eta$

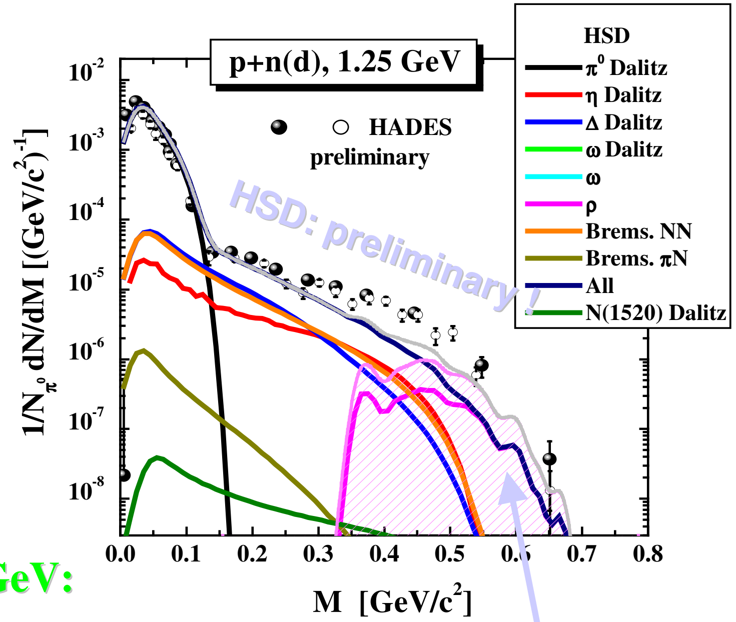


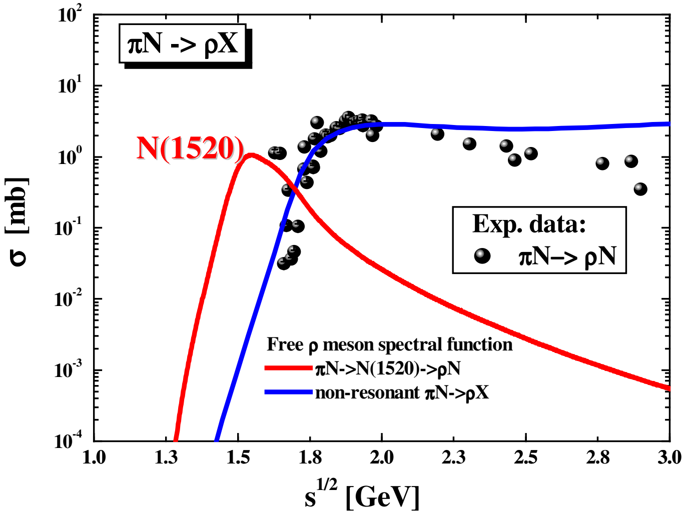


Now HSD agrees with PLUTO on the η- Dalitz decay!

Quasi-free pn (pd) @ 1.25 GeV: N(1520) ?!

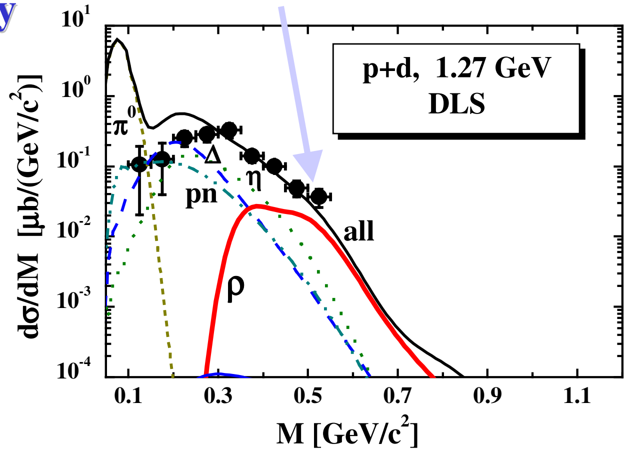






2) M > 0.45 GeV:

HSD very(!) preliminary result for p+d @1.25 GeV shows that the missing yield might be only PARTLY (!) attributed to subthreshold ρ–production via N(1520) excitation and decay



Similar to our NPA686 (2001) 568

Model for N(1520): according to Peters et al., NPA632 (1998) 109

Summary I

Transport models give reliable results for A+A ONLY with
reliable initial input, i.e. if the elementary reactions are under control

=> REQUESTS:

cross sections for elementary channels:		experim. information
baryon-baryon	→	p+p, p+A reactions
meson-baryon	→	π+p, π+A reactions
meson-meson (for higher energies)		

Warnings:

- isospin dependence of cross sections is important, too!
- additional complication due to coherence effects in p+d reactions !

Similar ‚problems' with π+d reactions !

Summary II: physics key issues

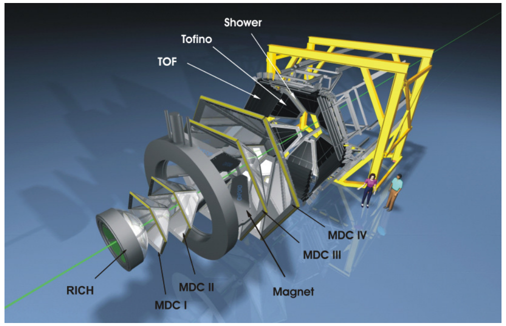
A+A, p+A, π+A reactions:

- in-medium effects - collisional broadening and dropping mass of the vector mesons (ρ,ω,φ)
- study of the mesonic and baryonic resonance dynamics

impact on A+A

p+p(n), π+p(n) reactions:

- control on different elementary channels
- study of the baryon resonance dynamics near threshold
- quantum interference of ρ^0 and ω-mesons at low energies (?)



Thanks to

HADES collegues:

Yvonne, Gosia, Romain, Piotr, Joachim, Tatyana, Volker, Beatrice, Filip, …

+ Wolfgang