Dilepton and strangeness production studied with HADES

Romain Holzmann, GSI Helmholzzentrum für Schwerionenforschung,
for the HADES collaboration

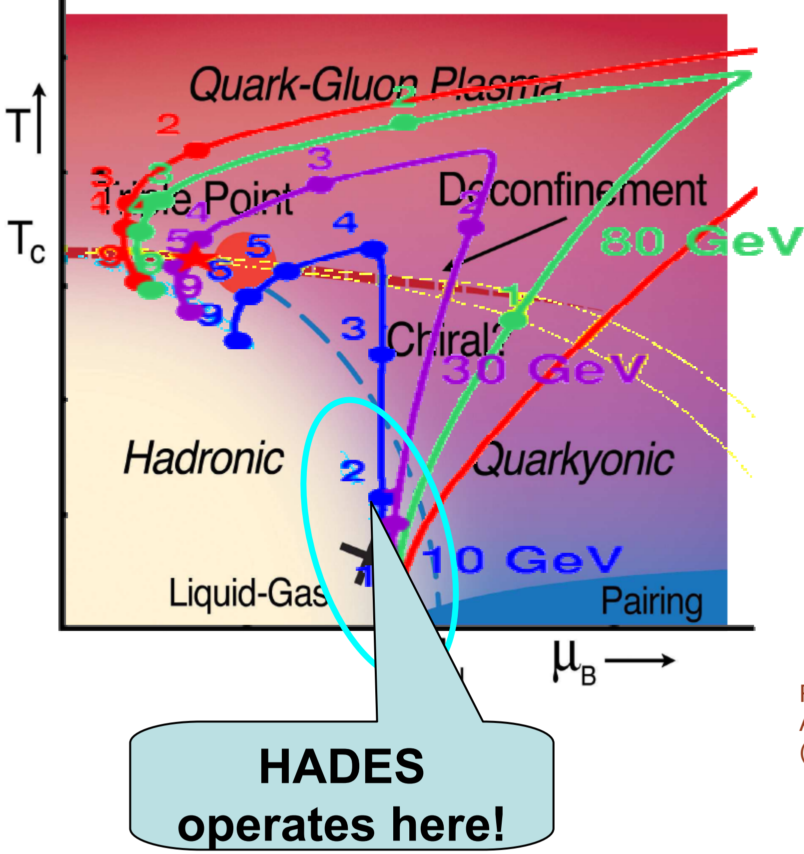
- Probing hadronic matter with HADES:
  dileptons and **strangeness**
- e^+e^- pairs - from N+N to A+A
- HADES, a strangeness detector
- The future: short- and mid-term projects

CBM Physics Workshop, April 2010

HADES

Exploring the phase diagram at high μ_B

Andronic et al. in arXiv:0911.4806v3



Probing nuclear matter at SIS:

- densities: $\rho_{max}/\rho_0 \cong 2 - 3$
- temperature: $T \cong 50 - 100$ MeV

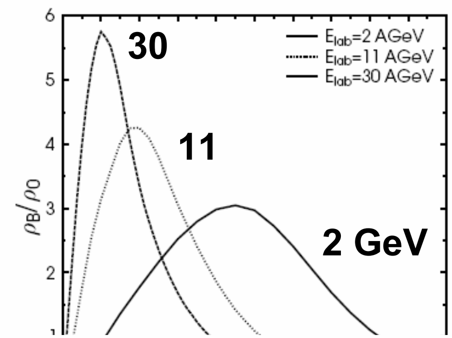
→ System stays above ground state density for $\tau \cong 10 - 15$ fm/c

A

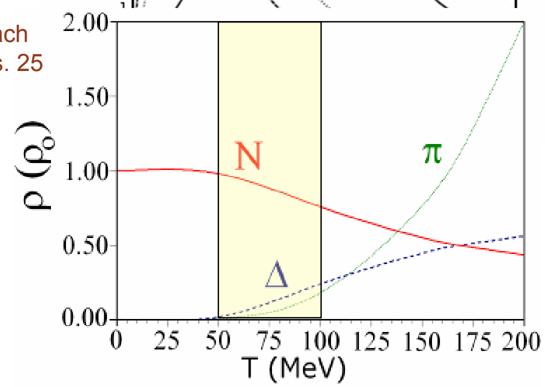
atter”:

ns

S. Vogel et al. Phys. Rev. C78 044909 (2008)

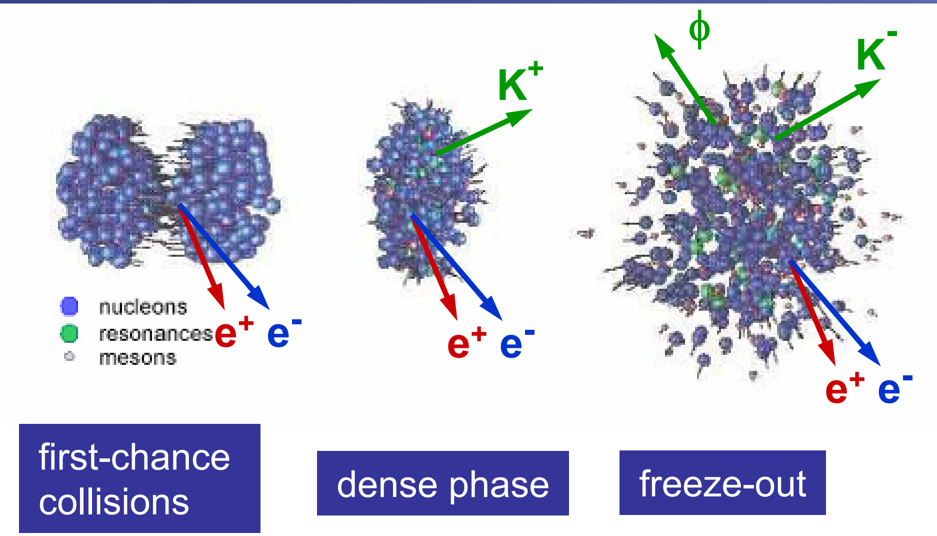


Rapp & Wambach Adv. Nucl. Phys. 25 (2000)

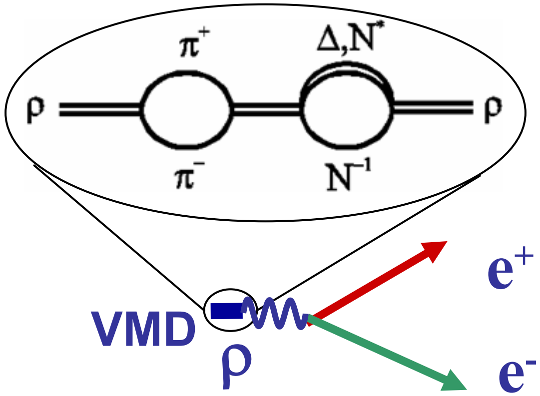


Radiation from hot and dense hadronic matter

HADES



- Study hot and dense hadronic matter
- Are there new forms of matter ?
- Properties of hadrons in matter ?



- The dilepton signal contains contributions from throughout the collision, incl. radiation from the early phase.

➔ Probes the electromagnetic structure of dense/hot hadronic (or partonic) matter.

→ in-medium spectral functions

→ emissivity of hadronic matter

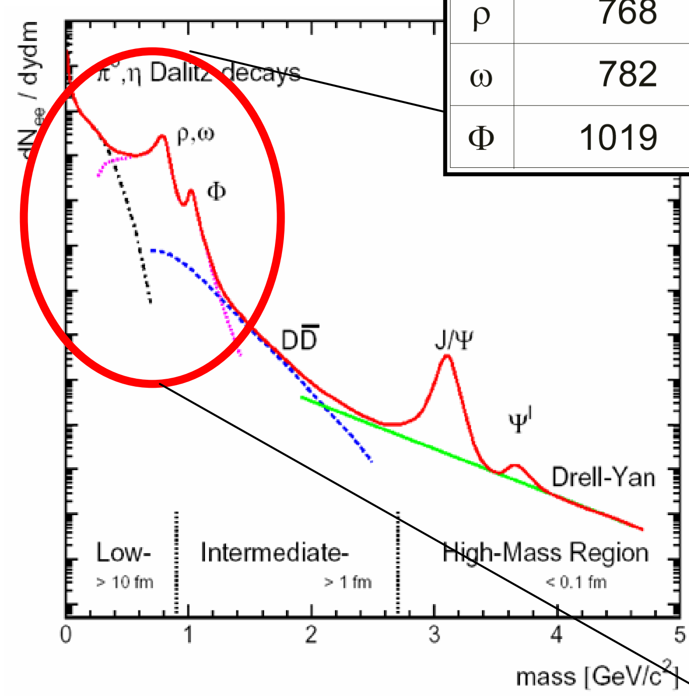
→ need to unfold collision dynamics

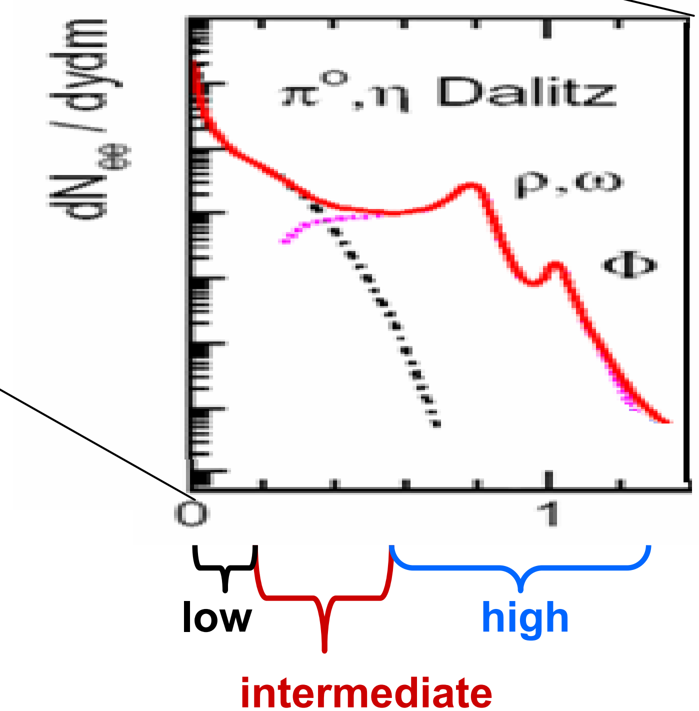
Dileptons: a penetrating, but rare probe

HADES

accessible at SIS18

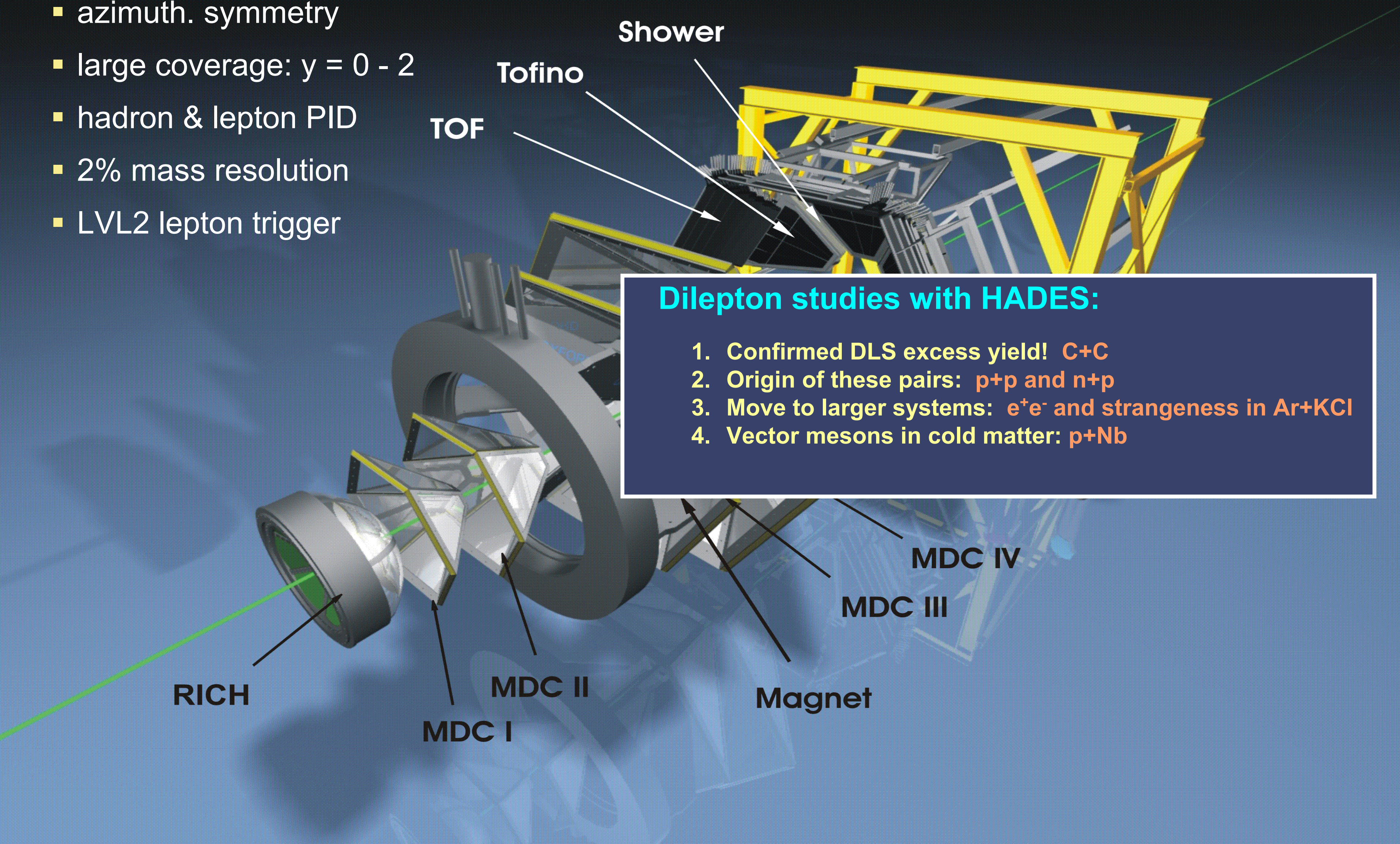
	mass [MeV/c^2]	$c\tau$ [fm]	dominating decay	e^+e^- branching ratio
ρ	768	1.3	$\pi\pi$	4.4×10^{-5}
ω	782	23.4	$\pi^+\pi^-\pi^0$	7.2×10^{-5}
Φ	1019	44.4	K^+K^-	3.1×10^{-4}





The HADES experiment at GSI

- azimuth. symmetry
- large coverage: y = 0 - 2
- hadron & lepton PID
- 2% mass resolution
- LVL2 lepton trigger



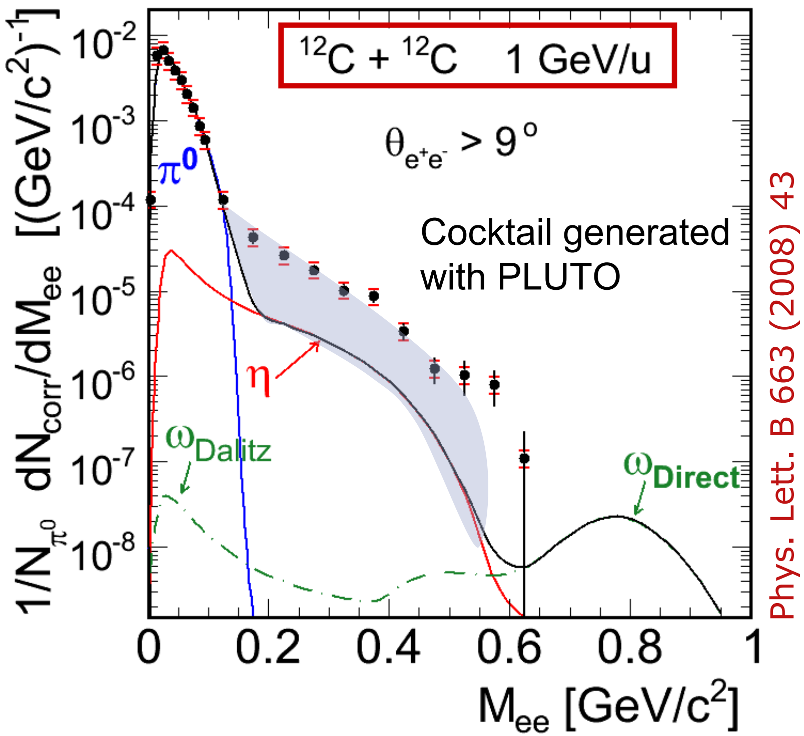
Dilepton studies with HADES:

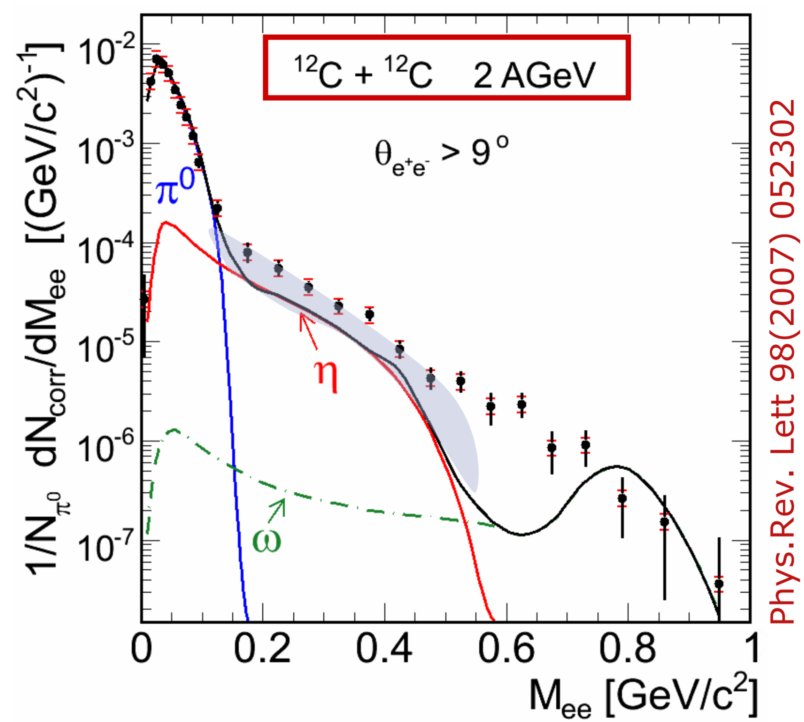
1. Confirmed DLS excess yield! C+C
2. Origin of these pairs: p+p and n+p
3. Move to larger systems: e^+e^- and strangeness in Ar+KCl
4. Vector mesons in cold matter: p+Nb

1) Inclusive e^+e^- production in C+C

HADES

Efficiency-corrected di-electron spectra, normalized to the number of neutral pions:



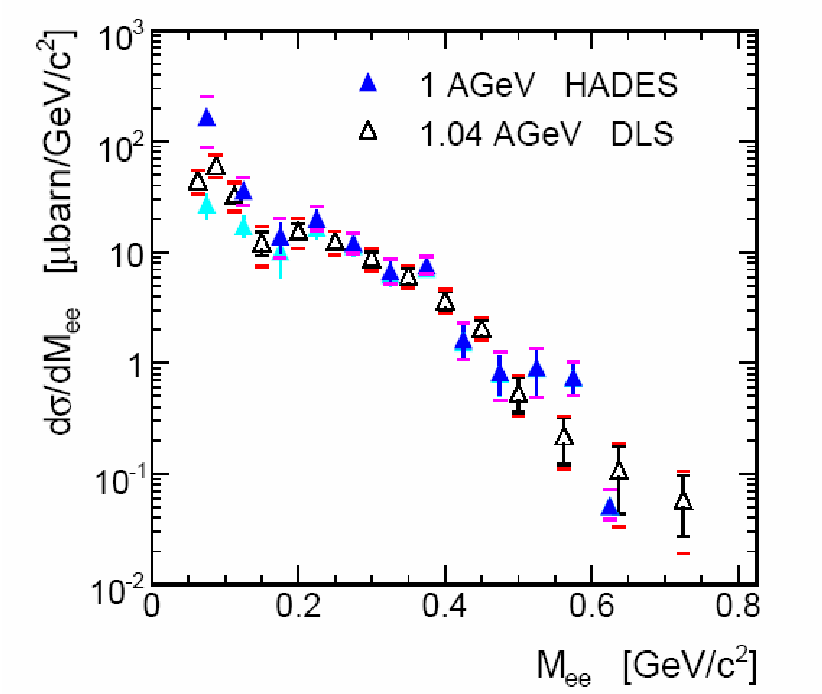


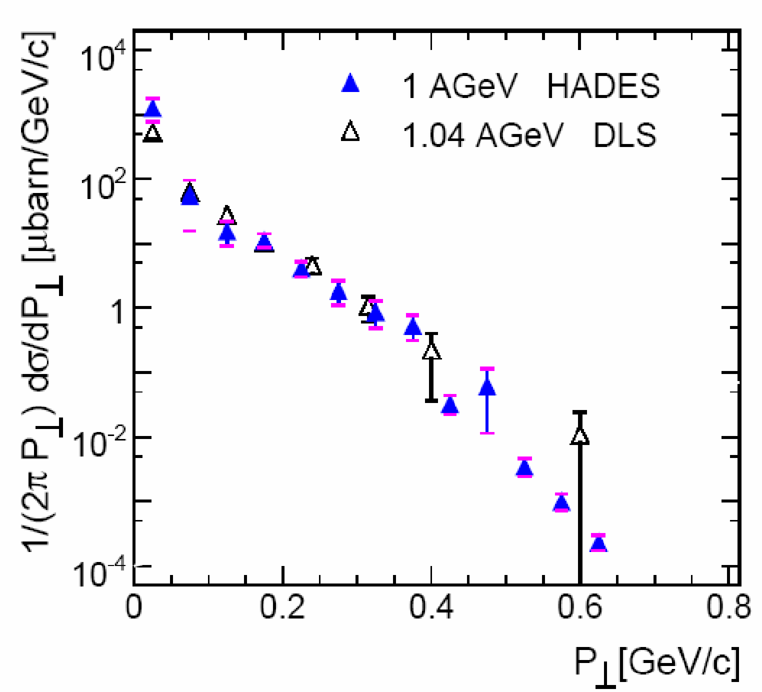
- Checking on DLS: Is there excess e+e- yield?
- How does the excess evolve with bombarding energy?
- And with system size? – or – Is there physics beyond free NN?

HADES vs. DLS: a direct comparison

HADES

Project HADES data into DLS acceptance and compare …





DLS Data: R.J. Porter et al.: PRL 79 (1997) 1229

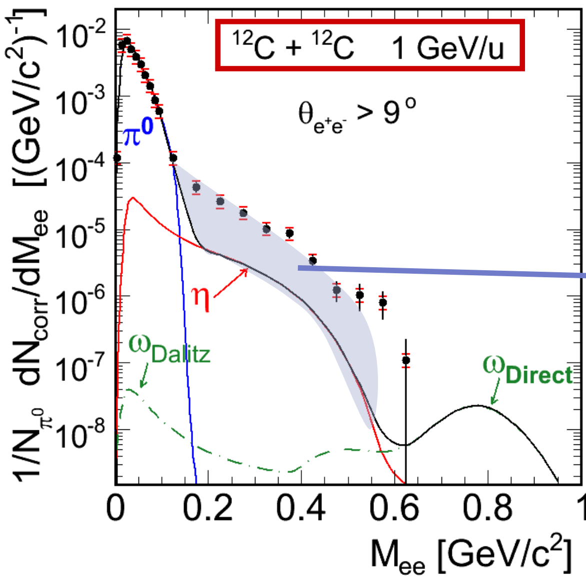
J. Carroll at

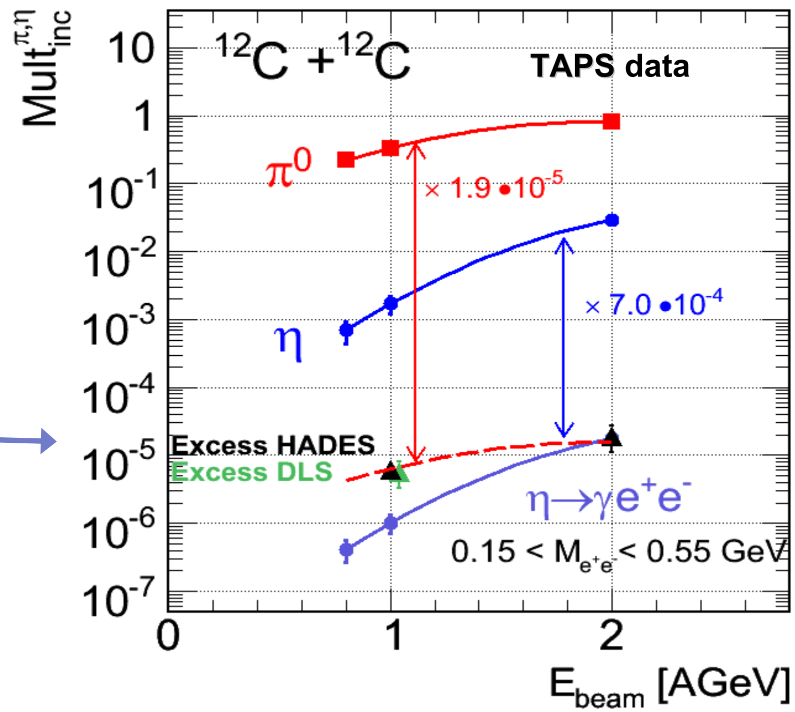
International Workshop on Soft Dilepton Production
August 20-22,1997, LBNL

→ HADES and DLS data agree !

The pair "excess" in C+C quantified

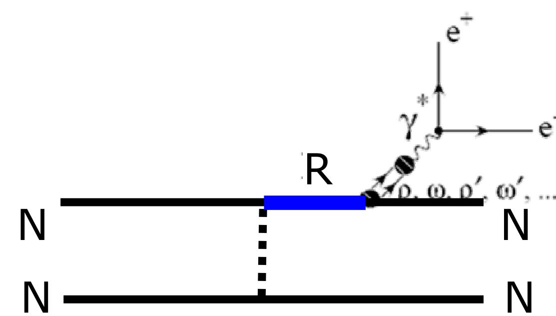
Excess pair yield over cocktail of long-lived sources vs. E_{beam}:





Enhancement scales like M_π

➔ Hinting at Δ resonance decays and/or NN bremsstrahlung!

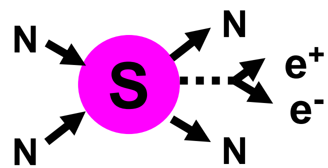


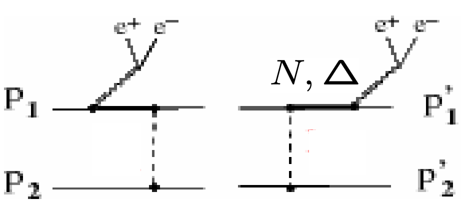
2) Virtual photons from free NN collisions

HADES

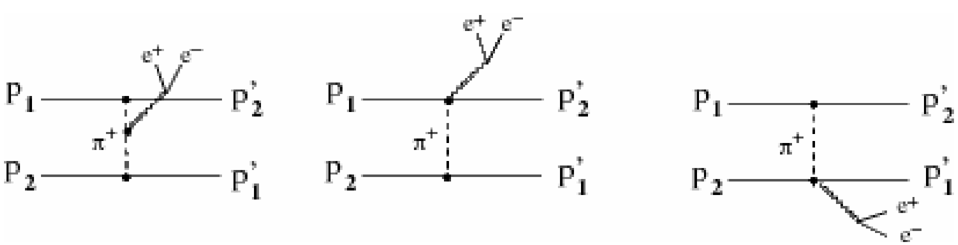
Measured 1.25 GeV/u p+p and d+p

- Check vs. microscopic calculations of NN processes
- Compare NN with C+C

Typical OBE diagrams for  **:**

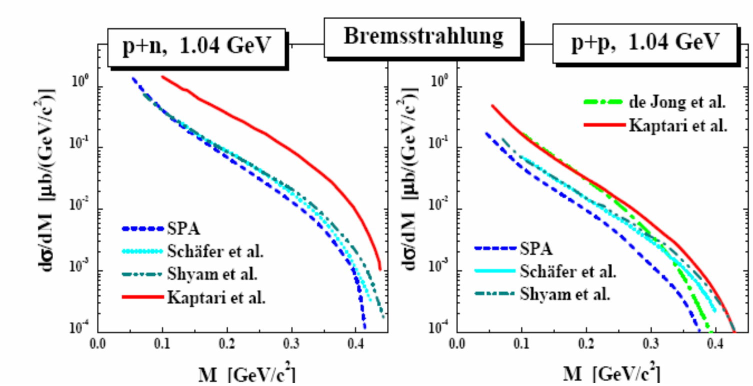


+ ISI + FSI



exchange terms

contact terms

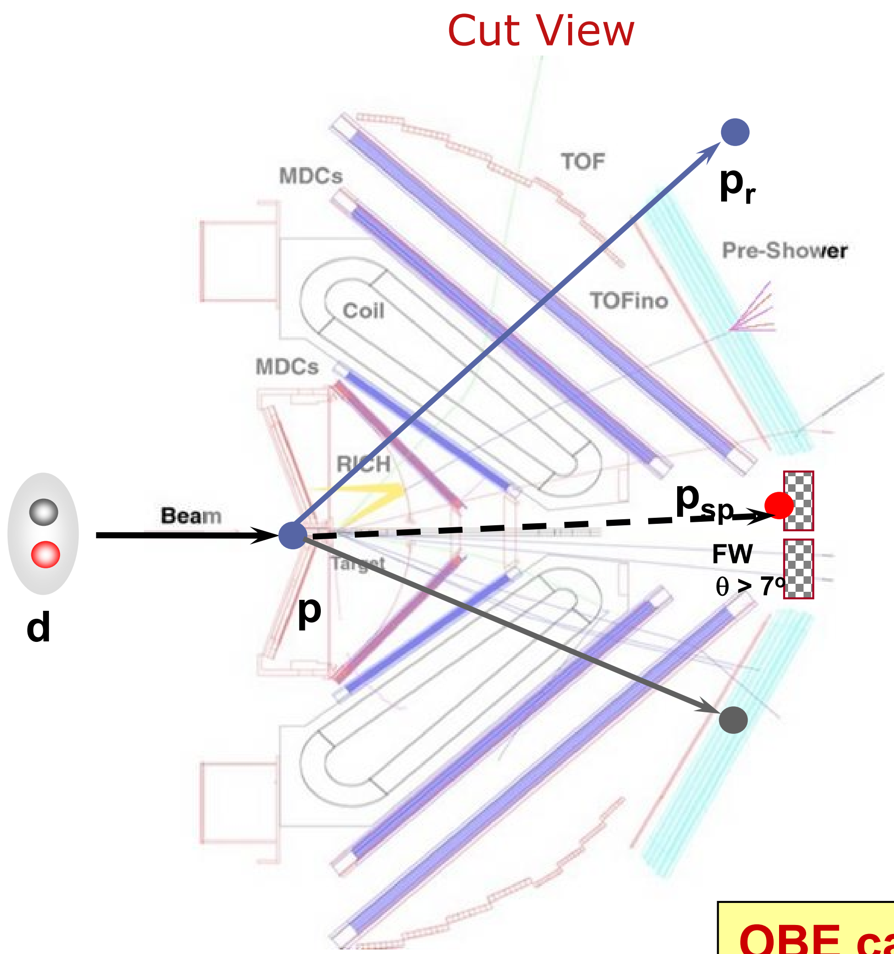


Compilation by E.L Bratkovskaya & W. Cassing in Nucl.Phys A 807, 214 (2008).

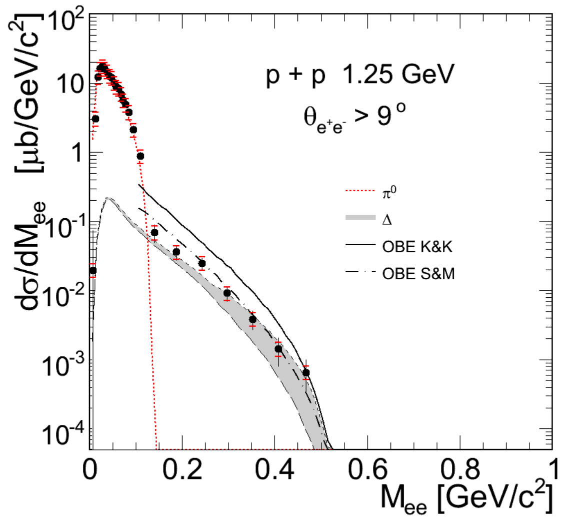
Main active players:

Kaptari & Kämpfer, Mosel & Shyam

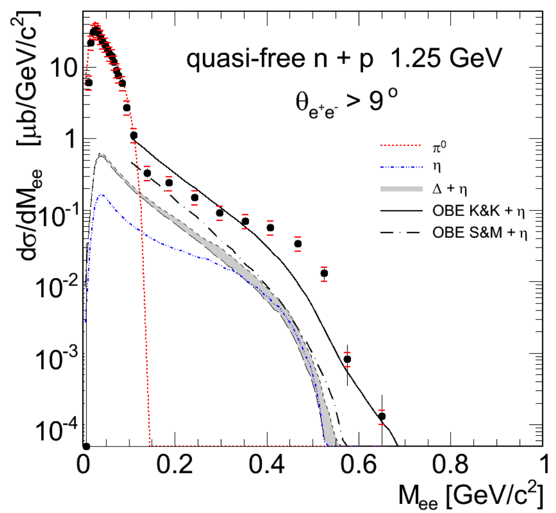
Tagging quasi-free np reactions in HADES



p+p:



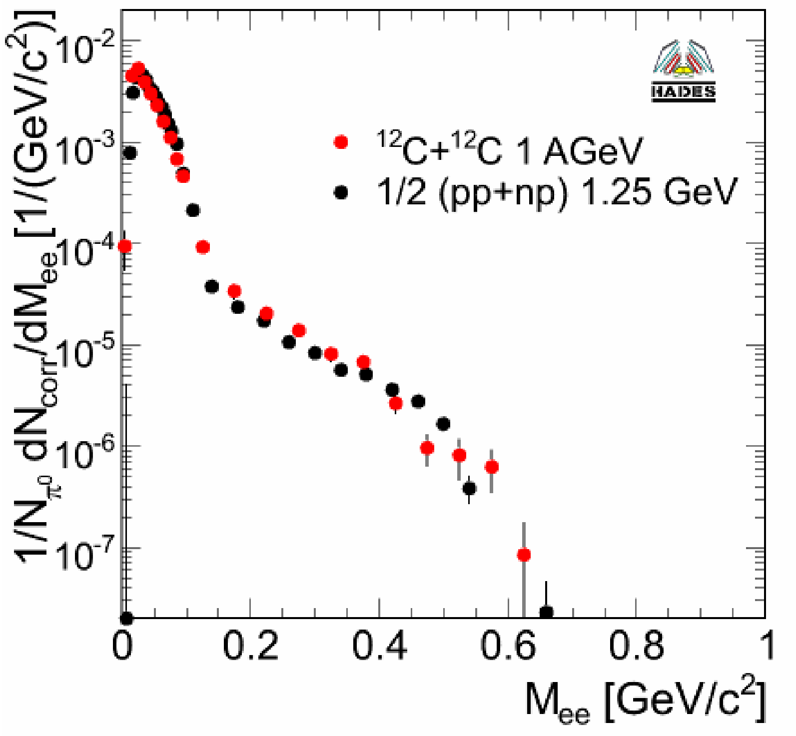
d+p: quasi-free np



OBE calculations reproduce pp, but not (yet) np !

Comparing C+C data with N+N data

Comparison of C+C data to average of pp and np collisions:

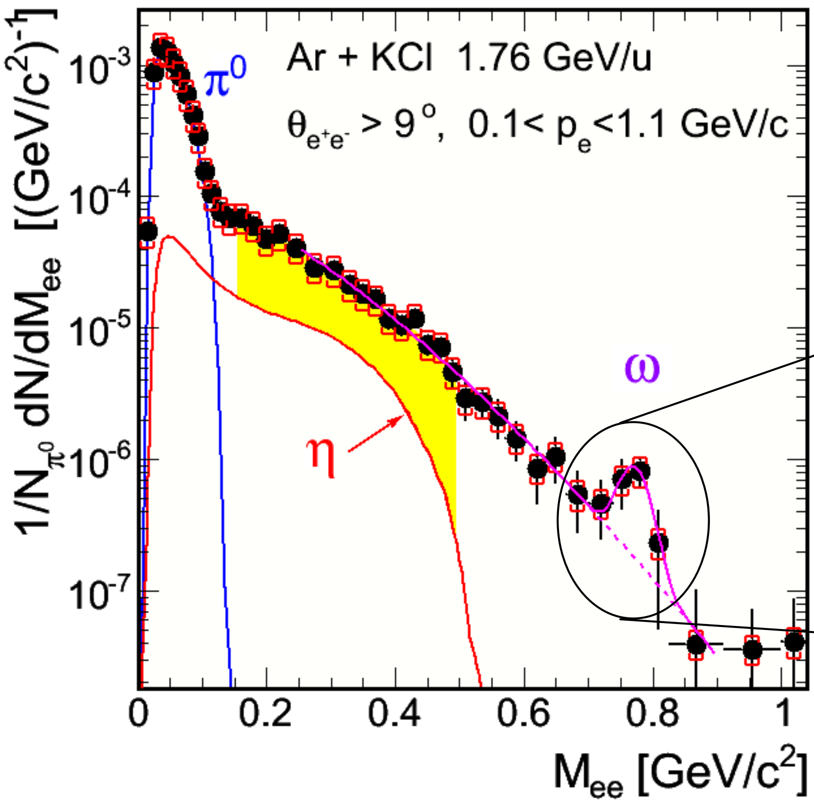


- C+C data reproduced (within 20%) by superposition of NN interactions
- Pair "excess" observed in C+C data can be traced back to enhanced pair production in n+p collisions
- How about yet heavier systems?

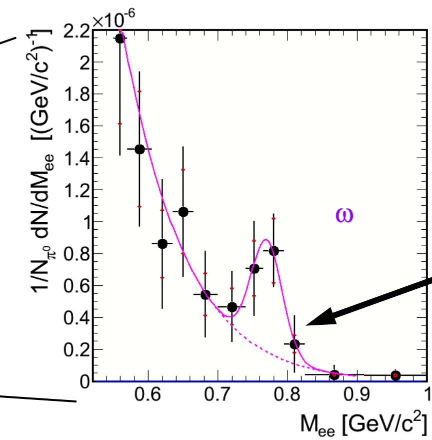
All normalized to N_π

3) Moving on to heavier systems: Ar+KCl

HADES



- Again, strong overshoot above the trivial cocktail!
- First ω peak seen at SIS energies!

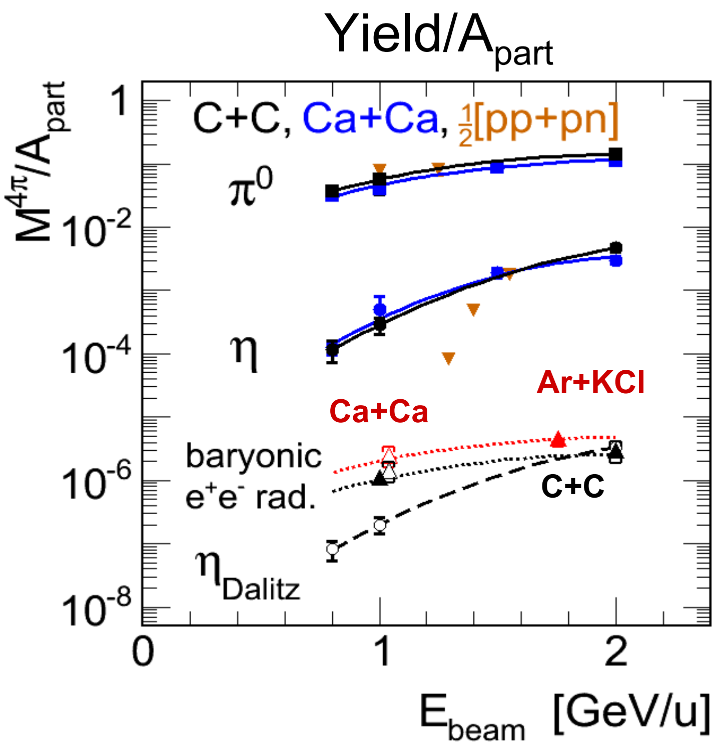


~ 40 counts

► $M_{LVL1}(\omega) = (6.7 \pm 2.7) \cdot 10^{-3}$

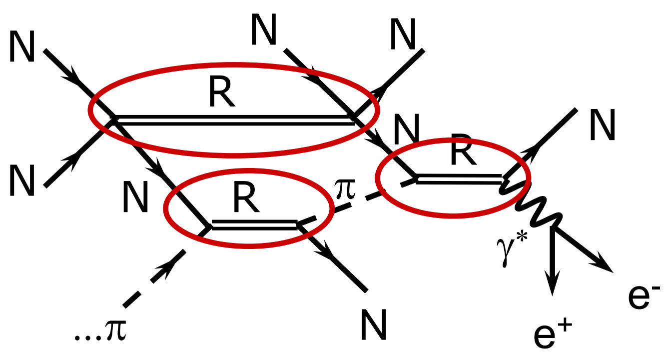
"Excess" vs. beam energy and system size

HADES



- baryonic contrib. in Ar+KCl >> C+C
- scales with E_{beam} like π production
- scales with A_{part} stronger than linear

➔ **≈ $\langle A_{part} \rangle^{1.4}$**



► multistep processes!

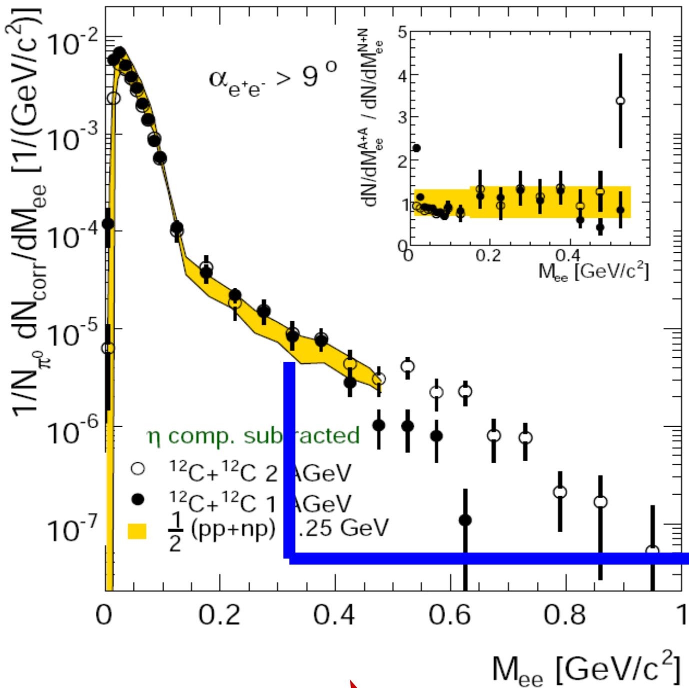
π^0 and η from TAPS ■
(min. bias)

e⁺e⁻ continuum pairs :
HADES ▲ ▲ (LVL1)
DLS △ △ (min. bias)

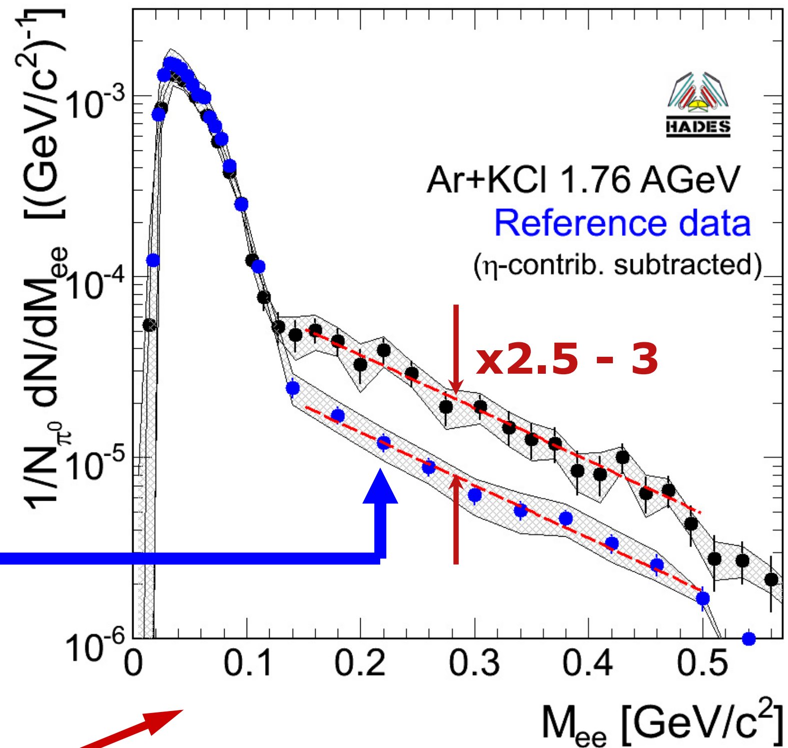
Preparing a "reference" for A+A

HADES

Definition of a **"reference"** based on pp and np data:



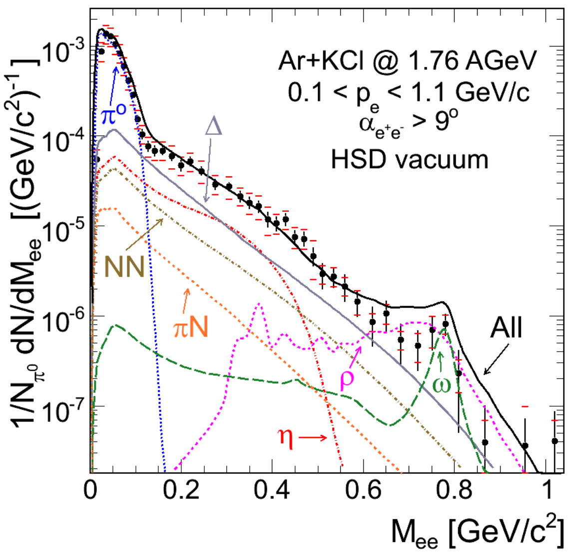
Compare excess over η in Ar+KCl with excess over η in reference



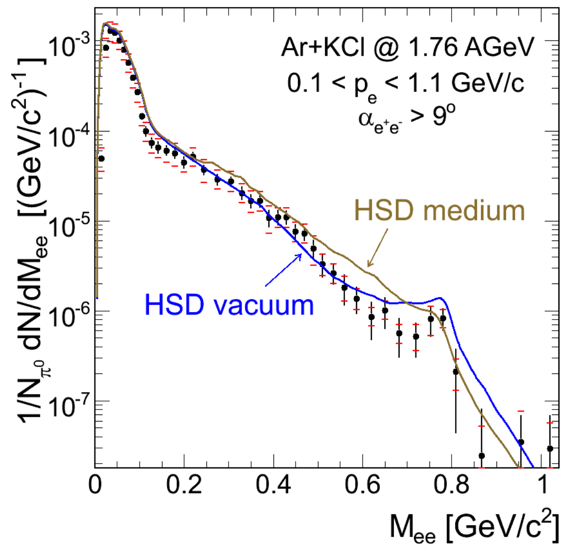
- **η contributions subtracted !**
- **yield normalized to M(π⁰)** ►► **Excess over free NN!**

Transport model predictions for Ar+KCl

vacuum calculation



vacuum vs. in-medium

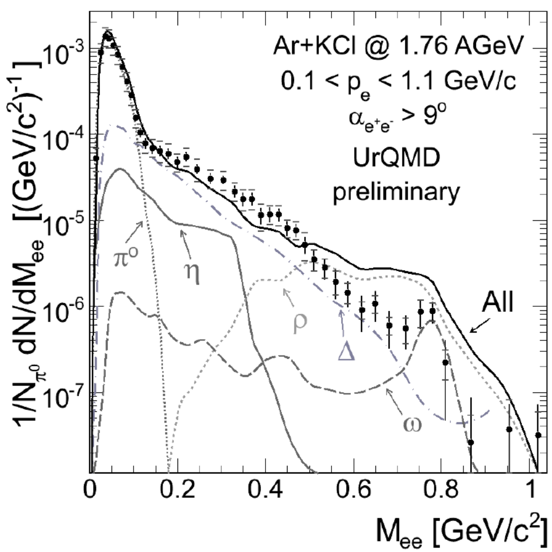


HSD model (status 2008)

E.L. Bratkovskaya, W. Cassing,
Nucl.Phys.A 807 (2008) 214 -250

UrQMD model

K. Schmidt et al.
arXiv 0811:4073v2

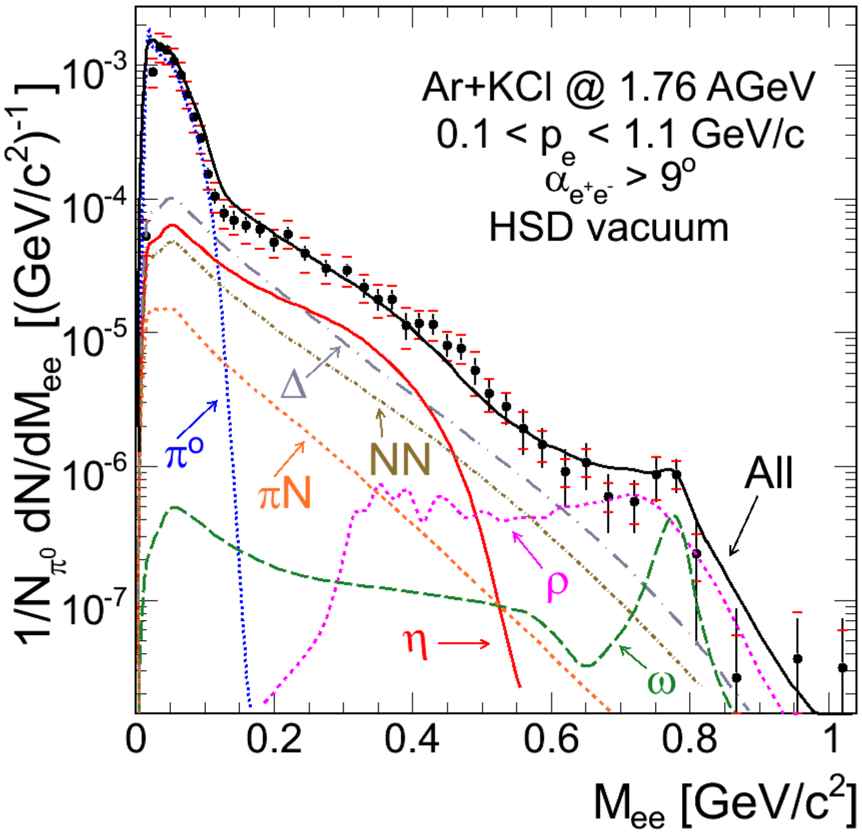


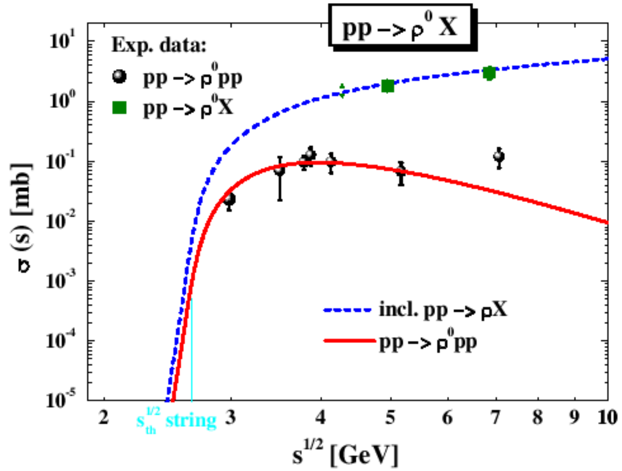
Transport models do

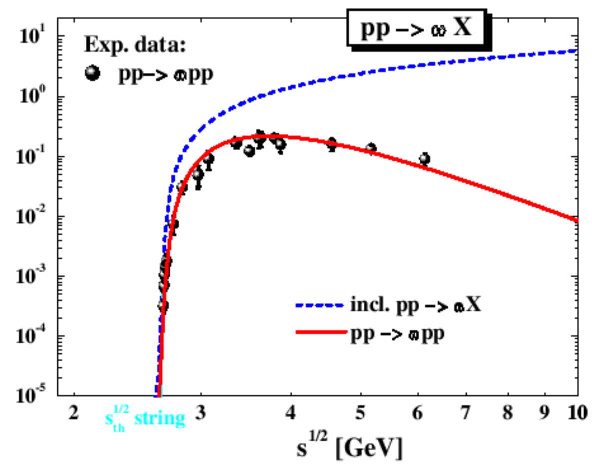
- fine for M_{ee}< 0.6 GeV
- overshoot ω/ρ peak

➔ Are in-medium effects needed?
Not clear yet…

Ar+KCl in HSD (Nov09 release)







retuned

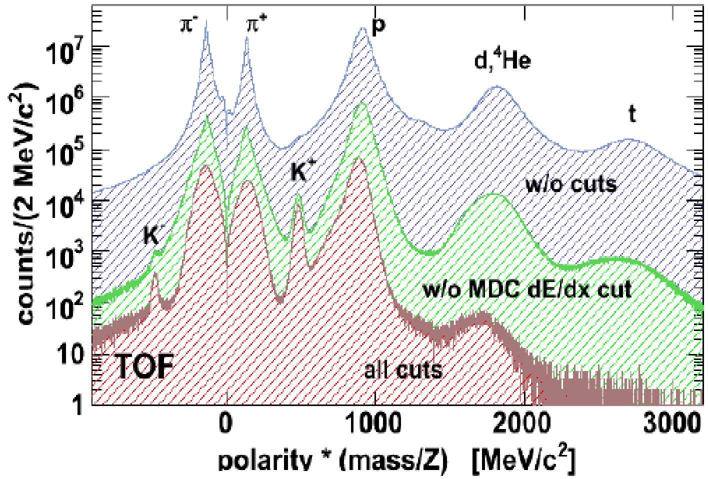
- $M_\omega/M_{\pi 0}$ = 0.0019 (exp = 0.0020)
- for M>0.65 GeV: ω+ρ = 70%

Strange, stranger, strangeness!

HADES

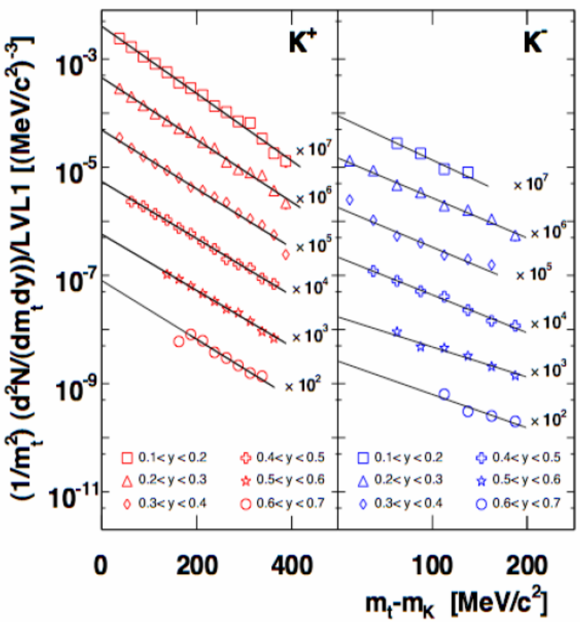
HADES has

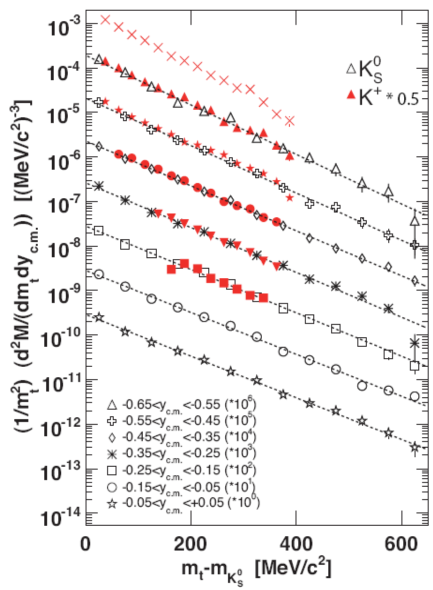
- high mom resolution
- high acceptance
- good particle ID
- vertexing

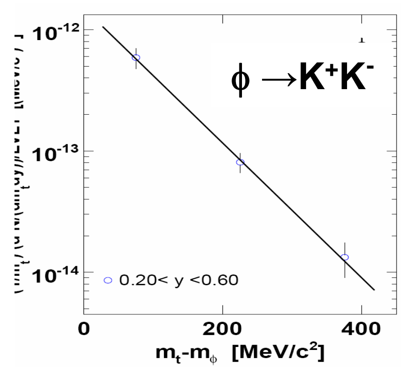


1.76 GeV/u Ar+KCl

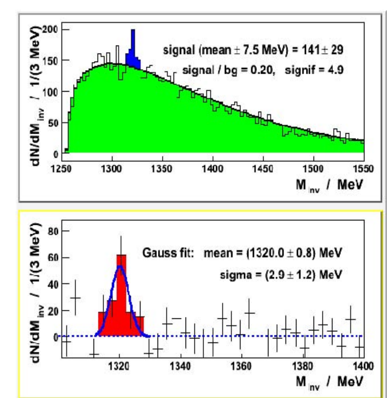
PID based on dE/dx and TOF







$\Xi^- \rightarrow \Lambda\pi^-$



+ more in N+N

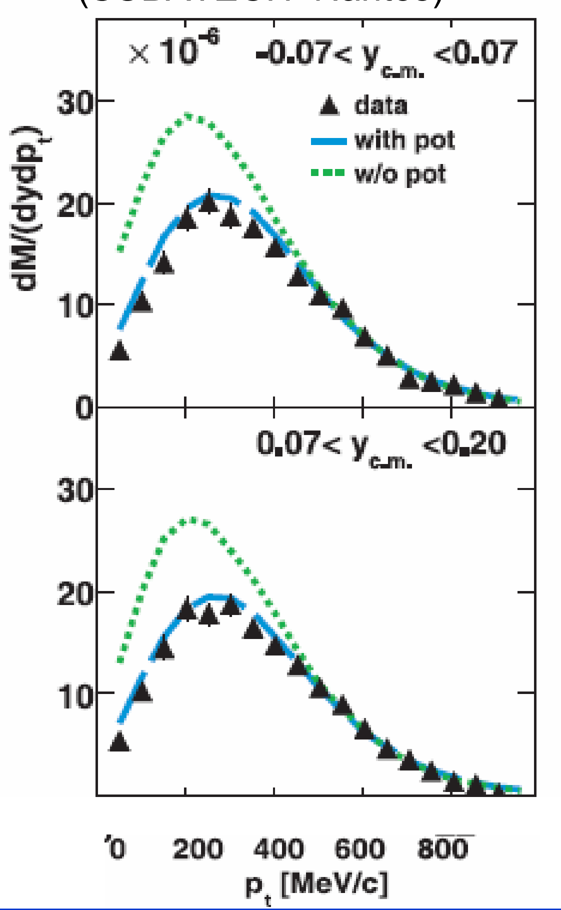
e.g. Λ(1405), Σ(1385)

Kaon ($K^{0,+}$) in-medium potential

HADES

Ar+KCl data vs. IQMD

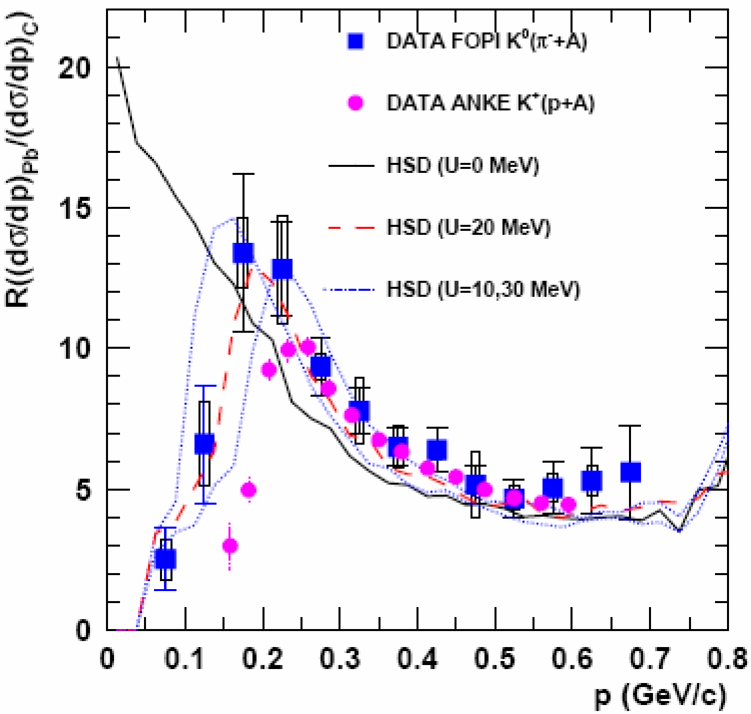
(SUBATECH Nantes)



consistent with V_0 = 39 MeV at $\rho = \rho_0$

extrapolation from high density to ρ_0 (IQMD)

π+A & p+A data (FOPI & ANKE)



consistent with V_0 = 20±5 MeV at $\rho = \rho_0$

extrapolation from low density to ρ_0 (HSD)

Needs further studies! e.g. flow…

ϕ/ω ratio: OZI in Ar+KCl vs. NN

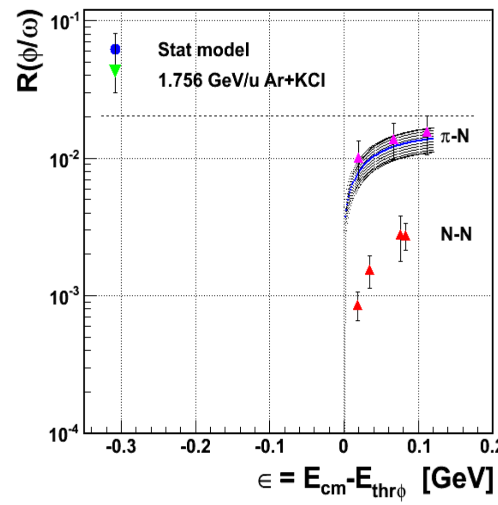
HADES

Using yields from

- $\phi \to K^+K^-$: $(2.6 \pm 0.7) \cdot 10^{-4}$
- $\omega \to e^+e^-$: $(6.7 \pm 2.7) \cdot 10^{-3}$

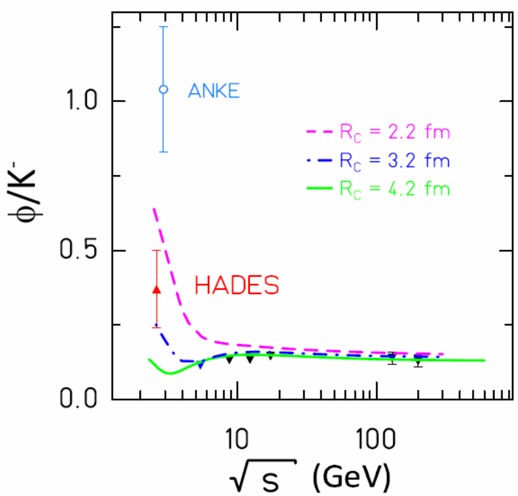
▶ $$R_{\phi/\omega} = 0.043^{+0.038}_{-0.013}$$

>> $R_{\phi/\omega}$ in NN and πN reactions !



>> OZI allowed

Yet can be described in a statistical model (THERMUS):



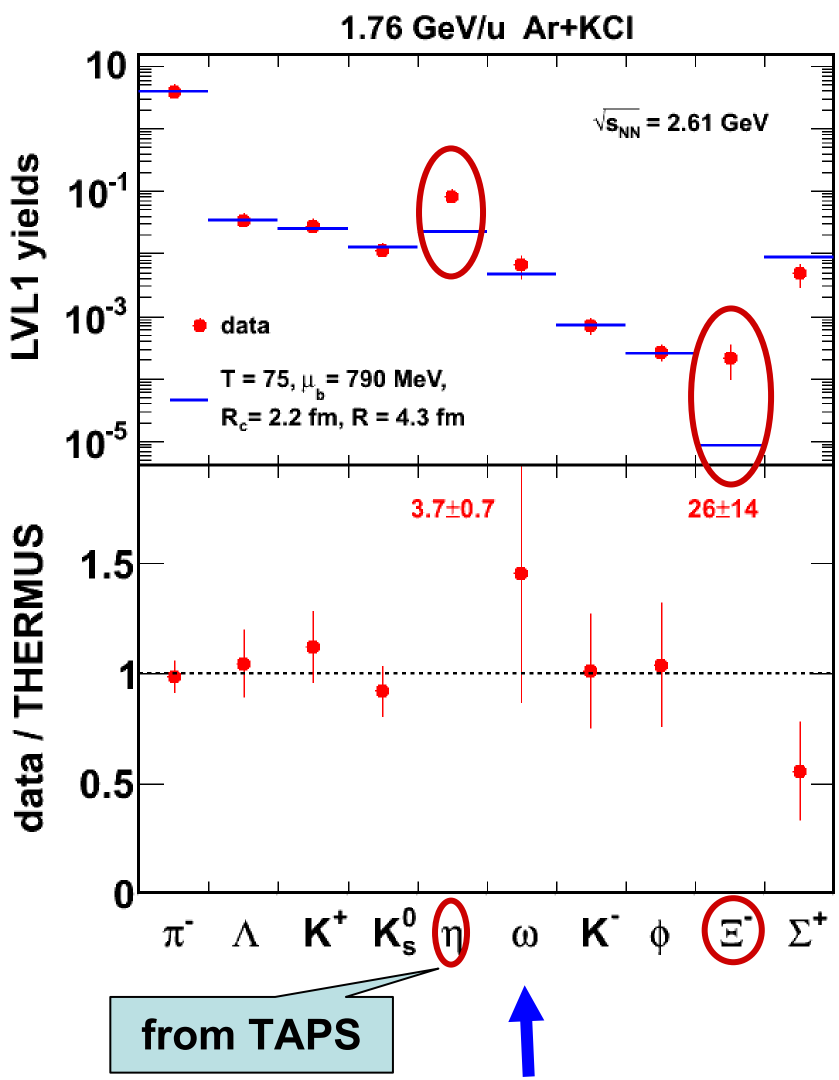
Comparison with a statistical model

HADES

THERMUS calculation

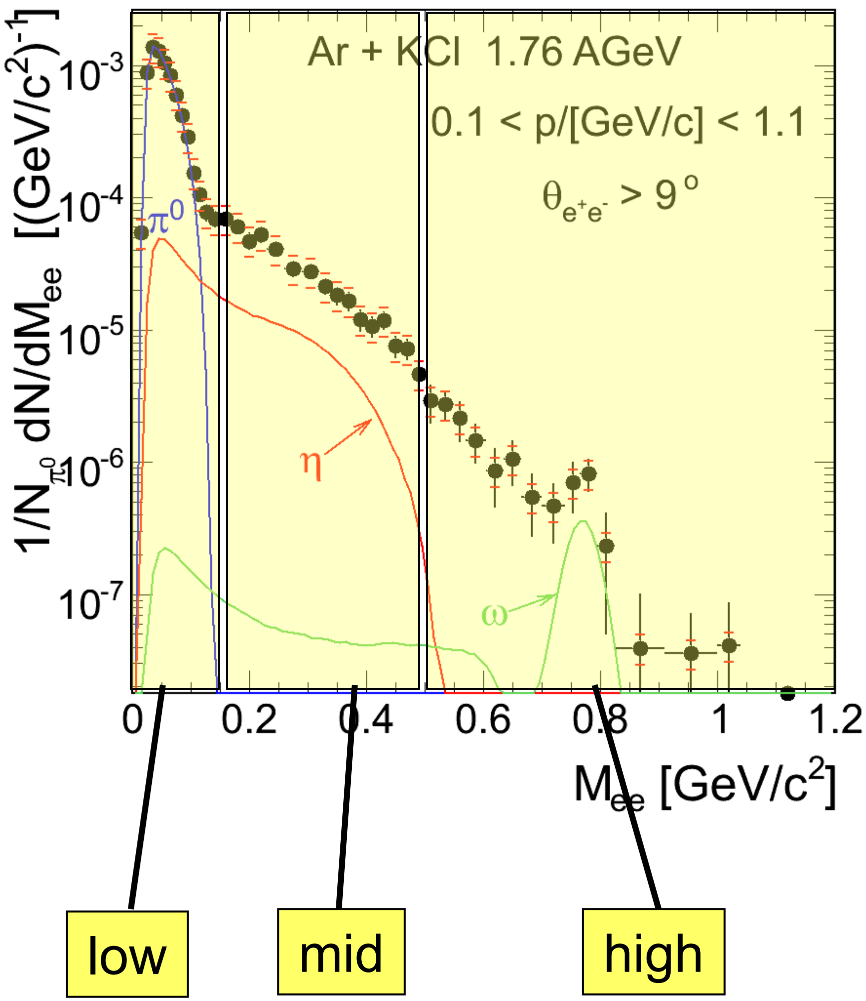
(T, μ_B and R_C fit to HADES data)

ω and ϕ described in statistical model, but…



Definition of mass slices for dN/dm_t

HADES



mostly 3-body !

mostly 2-body ?

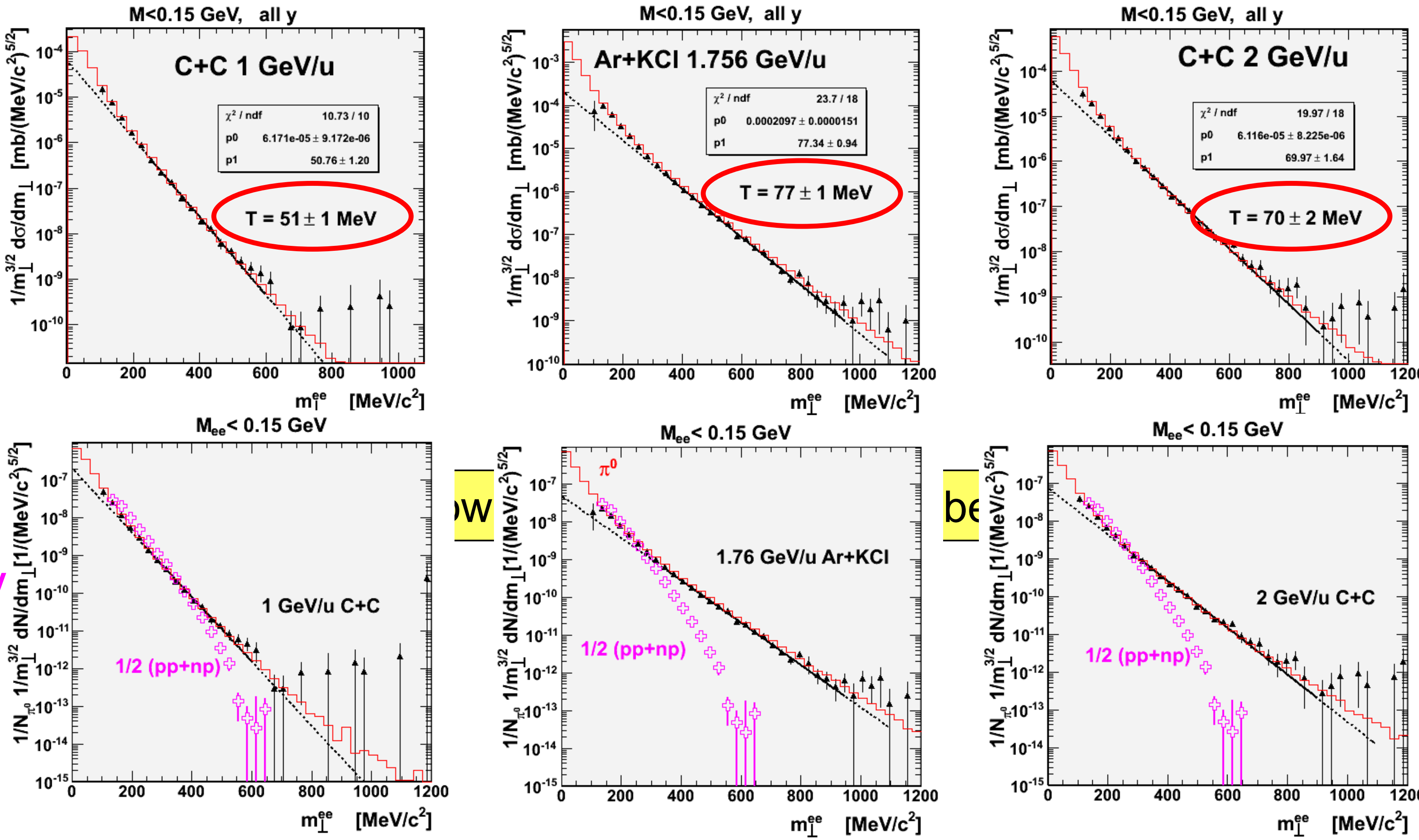
Transverse-mass spectra: M_{ee}< 0.15 GeV

(efficiency **and** acceptance corrected)

HADES

A+A

A+A
vs.
1.25 GeV
N+N

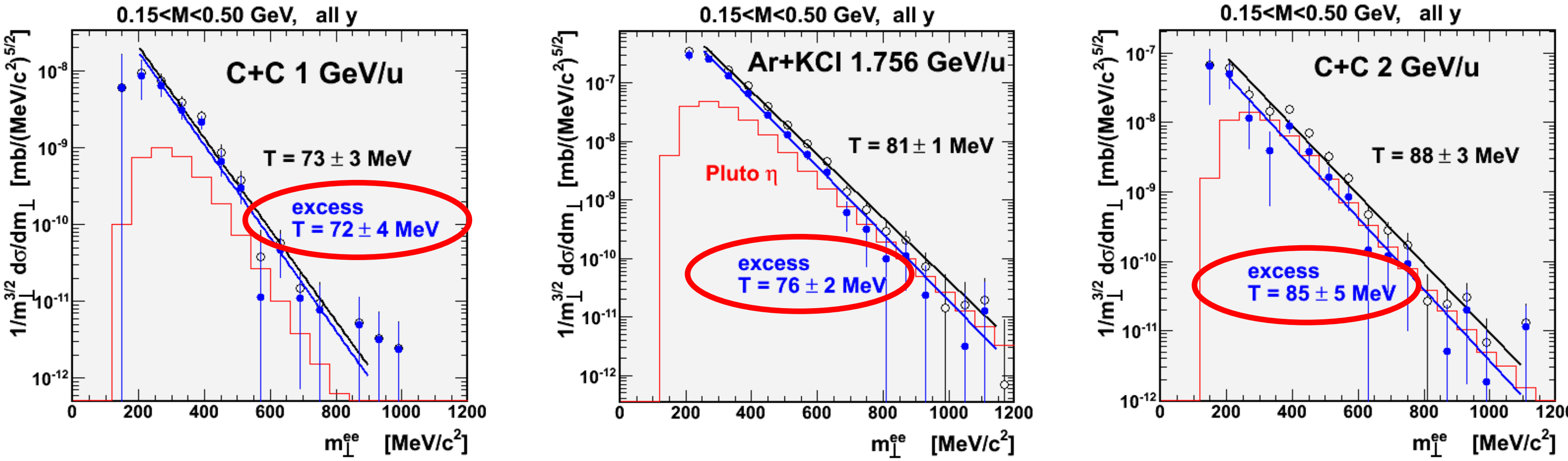


▶ 1.25 GeV/u NN reference

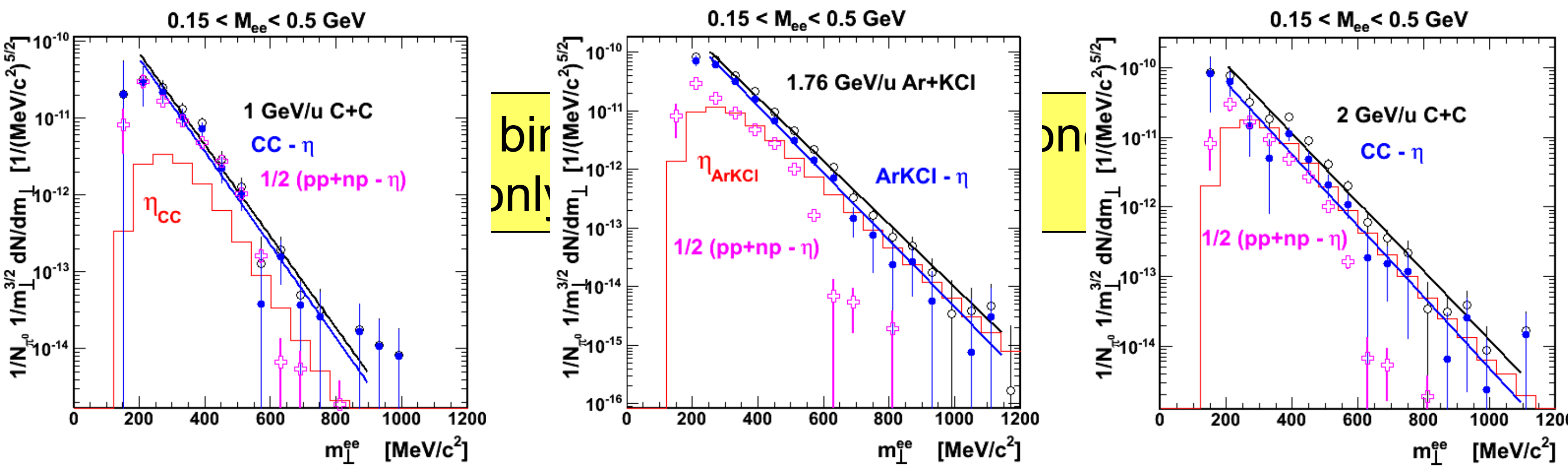
Transverse mass: 0.15 < M_{ee} < 0.50 GeV

HADES

A+A



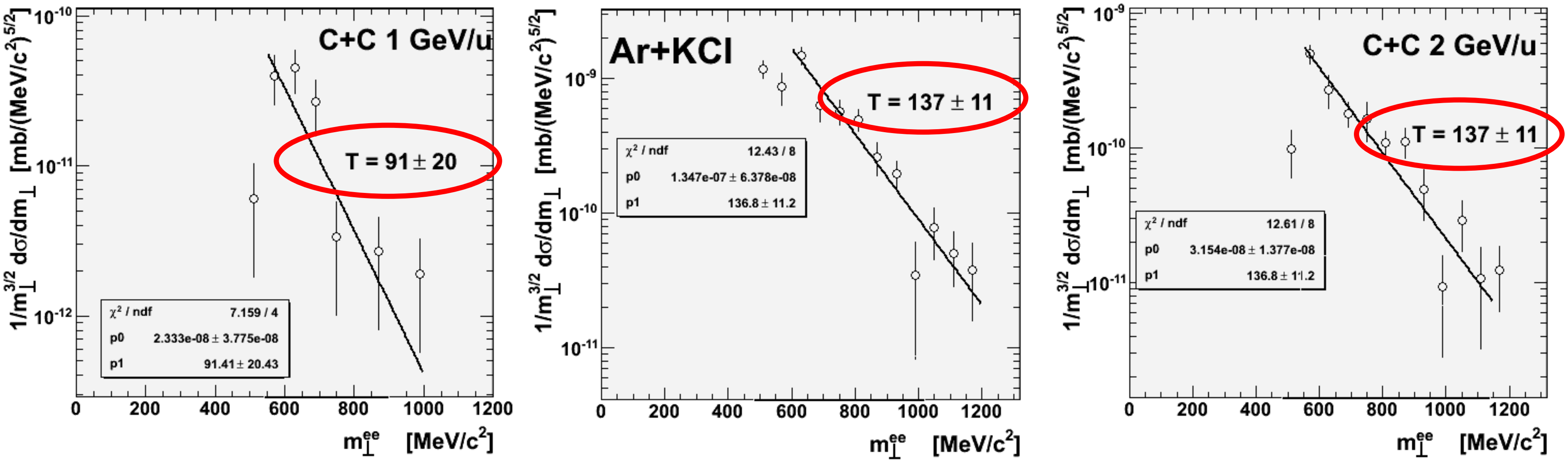
A+A
vs.
1.25 GeV
N+N



► 1.25 GeV/u NN reference … ?

Transverse mass: M_{ee} > 0.50 GeV

HADES

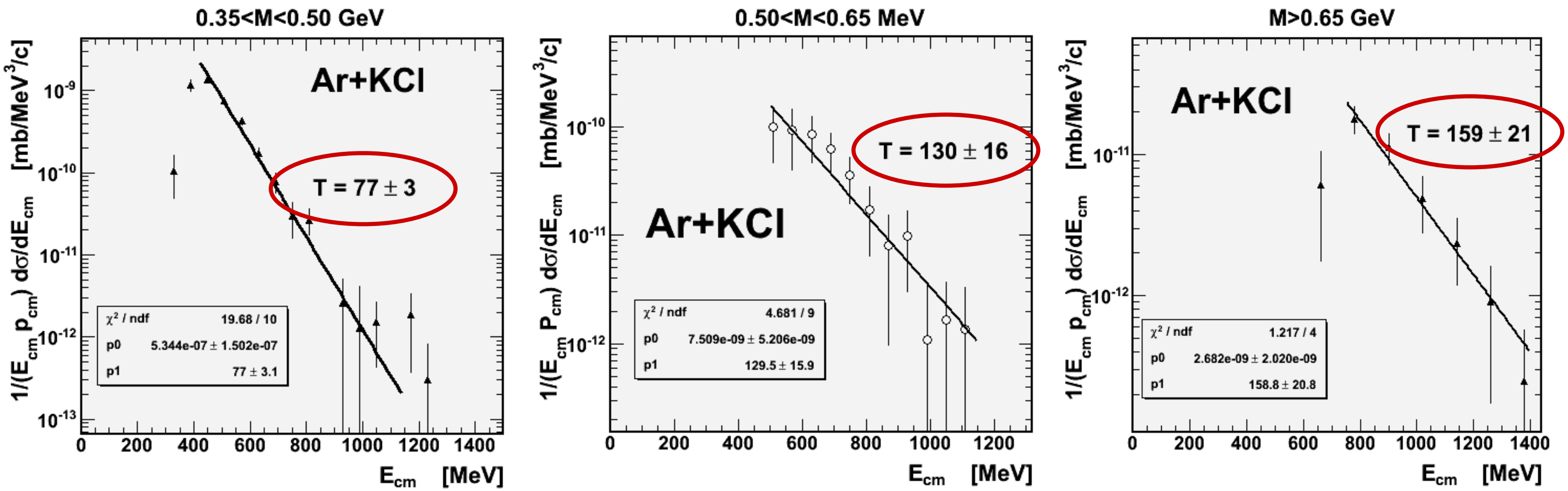


► Large slopes: $T_{ee} >> T_{chem}$ = 75 MeV

More mass cuts in ArKCl…

HADES

M_{ee} = 0.35 – 0.50 0.50 – 0.65 >0.65 GeV

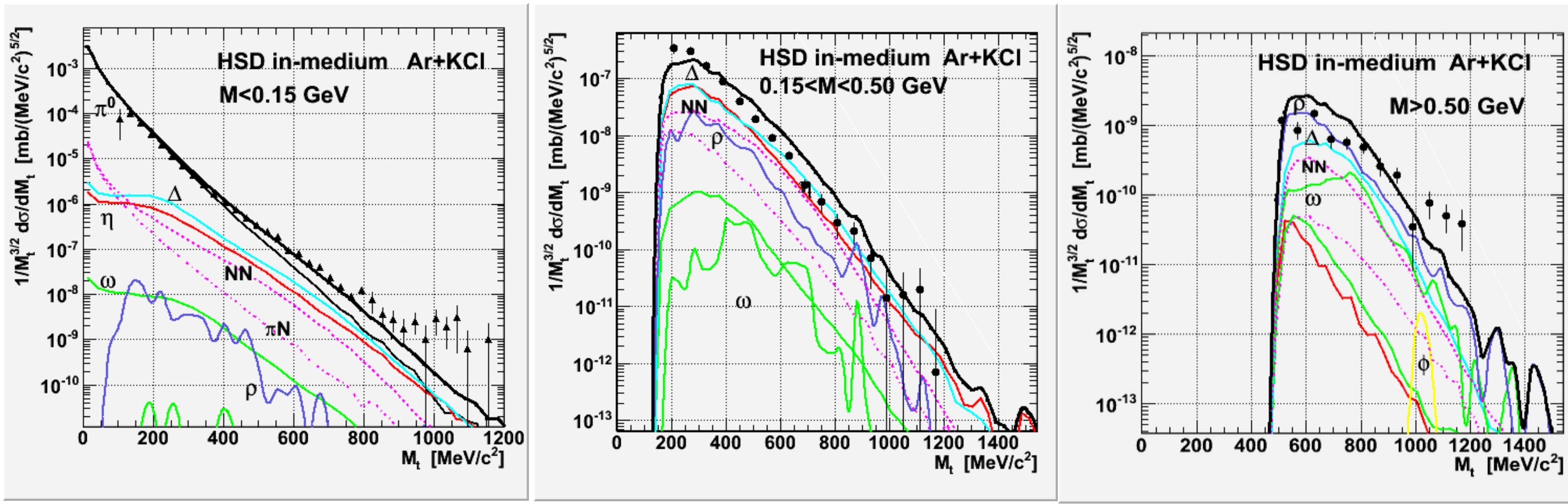


3-body (!) → 2-body (?) decays

Comparison with in-medium HSD

HADES

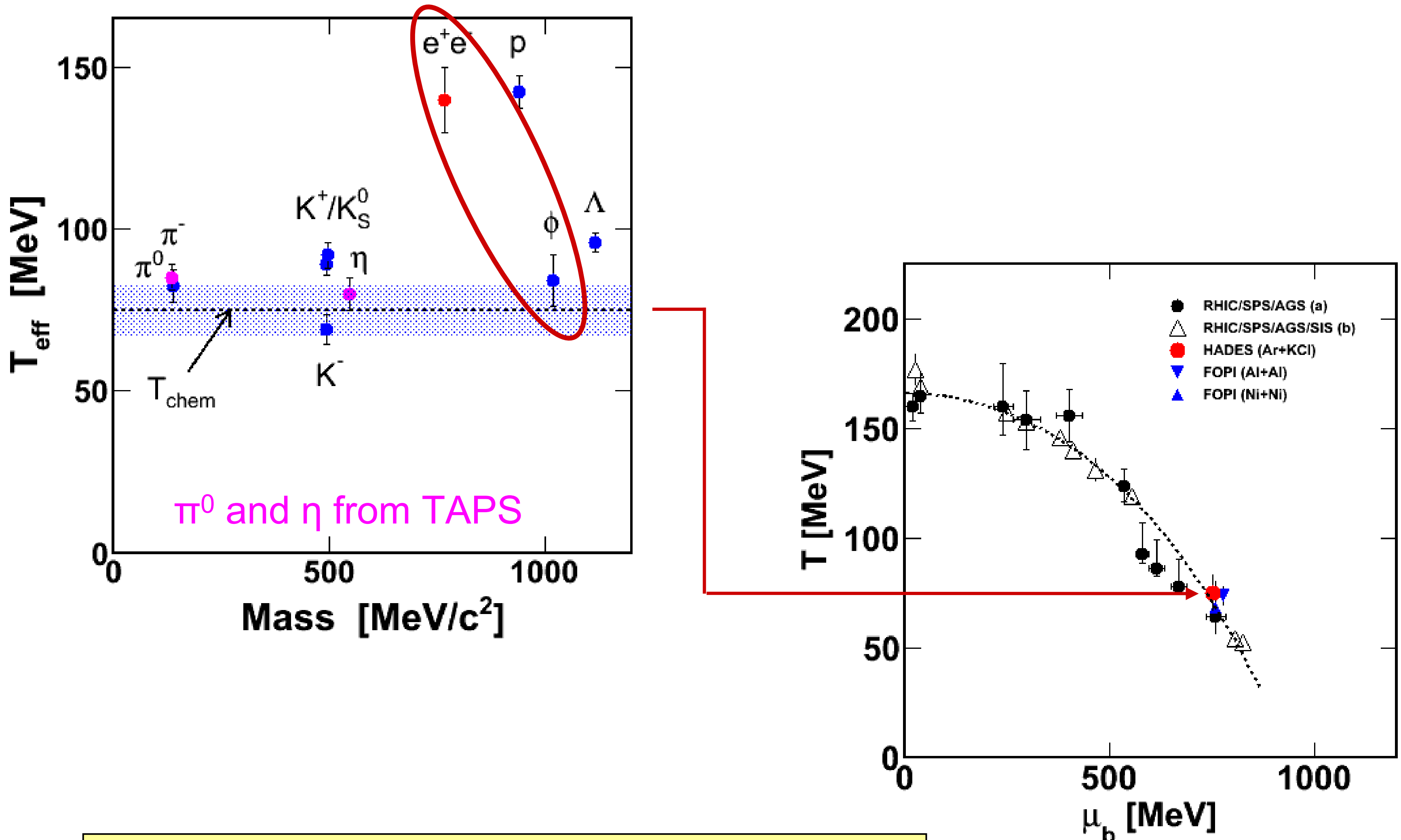
HSD vs. Ar+KCl at 1.76 GeV/u



- low-mass bin is well described, except for m_t >800 MeV
- at mid-mass, slope is fine, but no selectivity
- high-mass slope reproduced by neither **ρ/ω,** nor **Δ** !

Systematics of slopes at 1.76 GeV/u

HADES

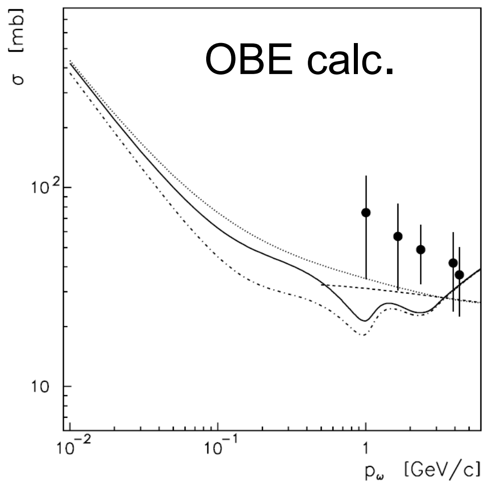


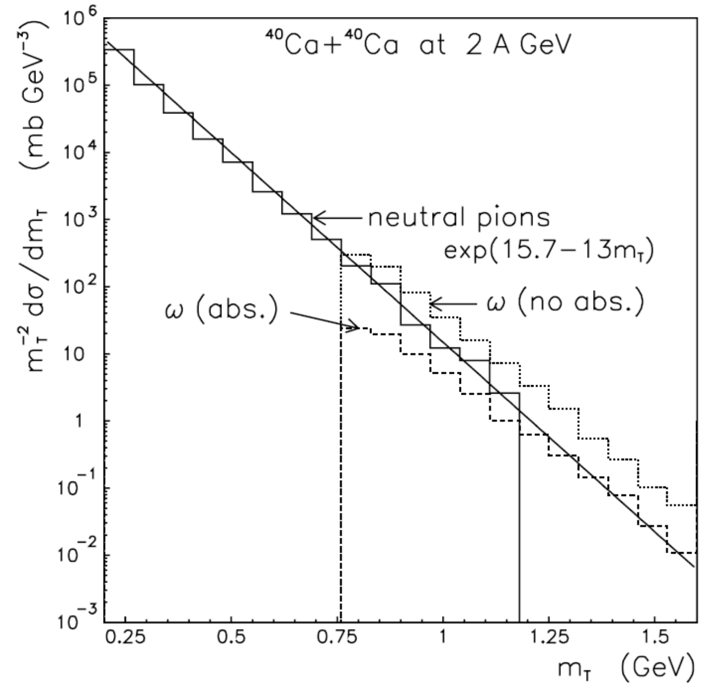
Why are slopes of ρ/ω and ϕ so different ?

Momentum-dependant ω reabsorption

- $\omega N \rightarrow \pi N$
- $\omega N \rightarrow \pi\,\pi\,N$
- $\omega N \rightarrow \rho N$
- etc.

Lykasov et al. HSD calculation
EJP A6 (1999) 71





Large absorption cross sections (>50 mbarn) are supported by transparency ratio (T_A) measurements in ω photoproduction

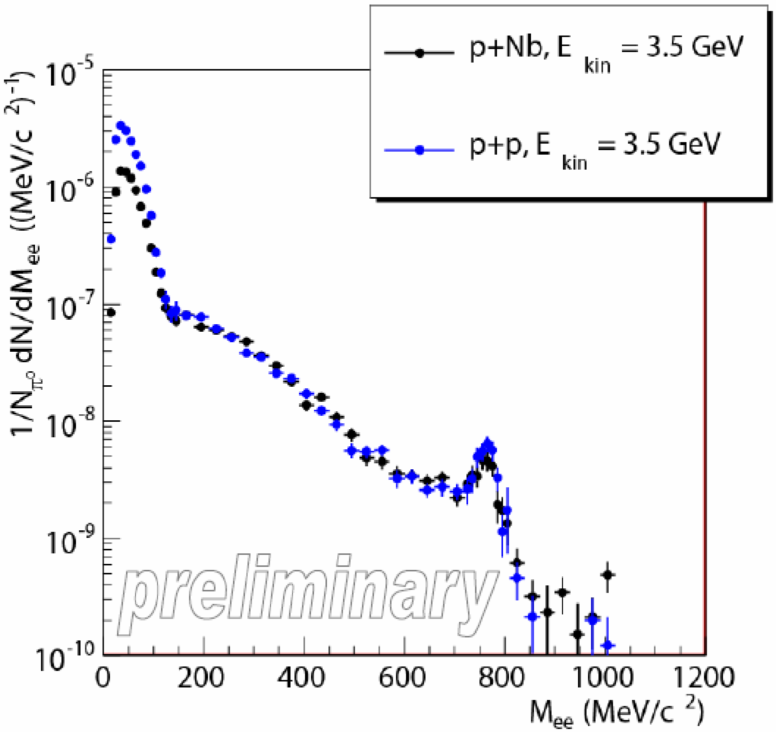
(at MAMI C and ELSA)

m_t slope: 77 MeV → 130 MeV

Also: slope(ω) >> slope(ϕ)

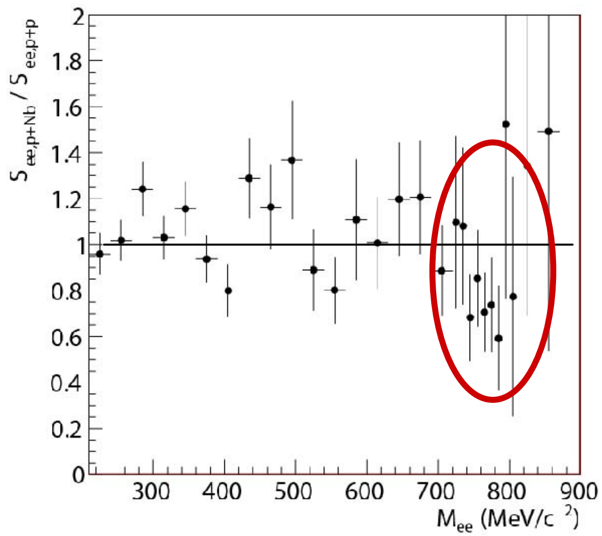
4) ω in cold nuclear matter: p+Nb vs. p+p

- Do p+p to have "in-vacuum" reference
- Do p+Nb and compare with p+p
- However, from photoproduction data, ω is known to be broadened (x16) in the medium ► use transparency ratio T_A!



N_{ee} normalized to respective π yield

On-going analysis…



Ratio p+Nb / p+p

5) HADES next runs at SIS18

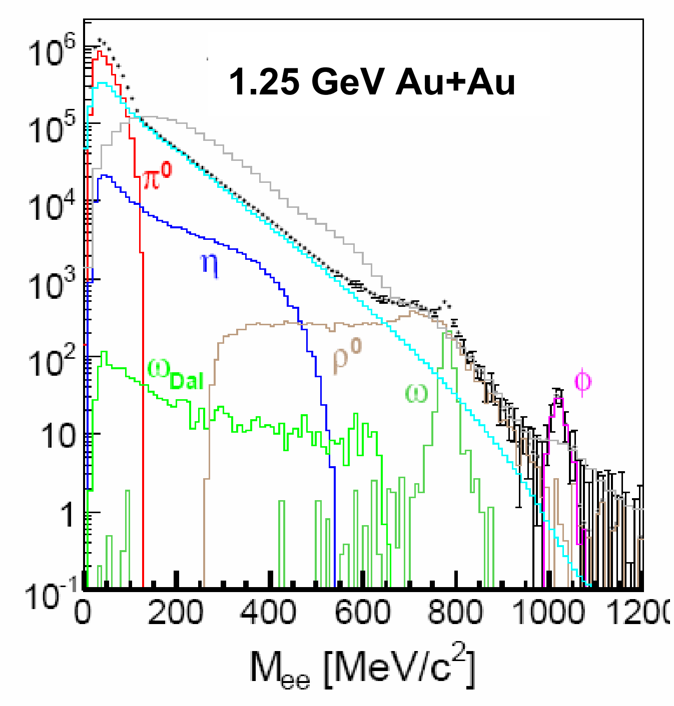
HADES

HADES upgrade nearly completed

- new MDC inner tracking plane
- new RPC timing detectors
- new and faster readout electronics
- Forward Wall installed

► **Getting ready for Au run in fall 2010**

Simulated counts for 4 weeks beam



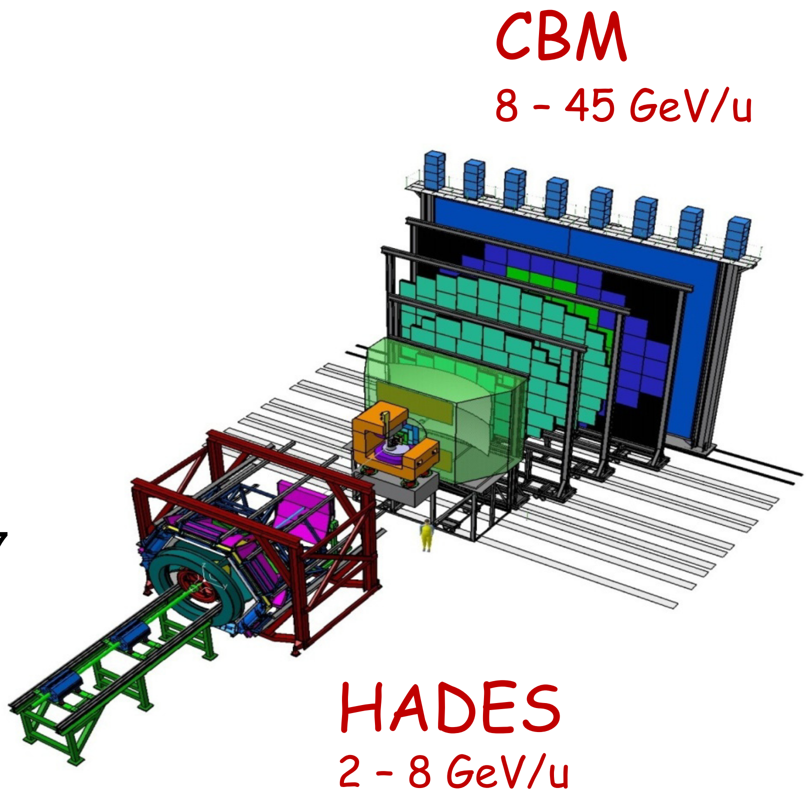
Expected pair rates/day

	AuAu 1.25 GeV/u	NiNi 1.93 GeV/u	AgAg 1.65 GeV/u	ArKCl (data) 1.76 GeV/u
LVL1/s	10^4	10^4	10^4	$2.5\cdot10^3$
P(excess$\rightarrow e^+e^-$)	$1.6\cdot10^{-3}$	$5.0\cdot10^{-4}$	$9.0\cdot10^{-4}$	$1.6\cdot10^{-4}$
Acc * Eff	0.04	0.04	0.04	0.04
Pairs/day	27600	8640	15500	690
P($\eta \rightarrow e^+e^-$)	$1.4\cdot10^{-3}$	$1.8\cdot10^{-3}$	$2.2\cdot10^{-3}$	$5.0\cdot10^{-4}$
Acc * Eff($m_{e+e-} > 0.15$)	0.0053	0.0053	0.0053	0.0053
Pairs/day($m_{e+e-} > 0.15$)	3200	4120	5030	290
P($\omega \rightarrow e^+e^-$)	$8.7\cdot10^{-7}$	$1.2\cdot10^{-6}$	$1.8\cdot10^{-6}$	$5.0\cdot10^{-7}$
Acc * Eff	0.05	0.05	0.05	0.03
Pairs/day	20	26	40	2
P($\rho \rightarrow e^+e^-$)	$2.2\cdot10^{-5}$	$1.2\cdot10^{-5}$	$2.0\cdot10^{-5}$	-
Acc * Eff	0.05	0.05	0.05	0.03
Pairs/day	480	260	430	-
P($\phi \rightarrow e^+e^-$)	$1.4\cdot10^{-7}$	$2.0\cdot10^{-7}$	$2.2\cdot10^{-7}$	$7.8\cdot10^{-8}$
Acc * Eff	0.05	0.05	0.05	0.03
Pairs/day	3	4	5	<0.25

+ plenty of strangeness!

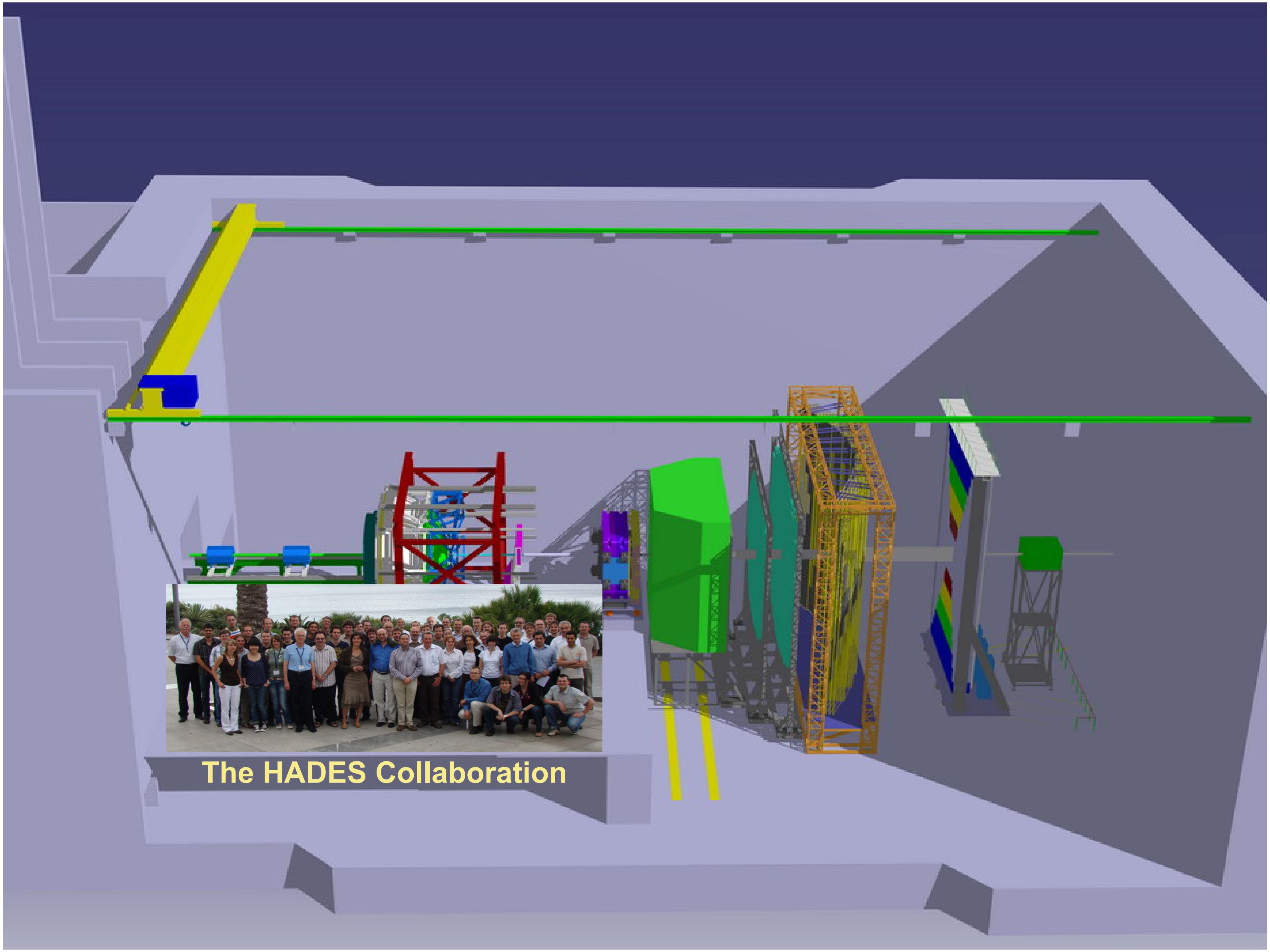
Conclusions and outlook

- Understanding pp and np is essential for A+A
- In Ar+KCl onset of “medium” effects
  - strong baryonic contribution to e^+e^-
  - first observation of vector mesons
- 2nd focus on strangeness
- Upgraded HADES will investigate
  - heavy systems up to Au+Au
  - πN and πA reactions
  - + strong strangeness program
- Move to SIS100 planned for 2016/17



2016: HADES goes underground

HADES



The HADES Collaboration on tour

Cyprus:
Department of Physics, University of Cyprus

Czech Republic:
Nuclear Physics Institute, Academy of Sciences of Czech Republic

France:
IPN (UMR 8608), Université Paris Sud

Germany:
GSI, Darmstadt
FZ Dresden-Rossendorf
IKF, Goethe-Universität Frankfurt
II.PI, Justus Liebig Universität Giessen
PD E12, Technische Universität München

Italy:
Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud
Istituto Nazionale di Fisica Nucleare, Sezione di Milano

Poland:
Smoluchowski Institute of Physics, Jagiellonian University of Cracow

Portugal:
LIP-Laboratório de Instrumentação e Física Experimental de Partículas

Russia:
INR, Russian Academy of Science
Joint Institute of Nuclear Research
ITEP

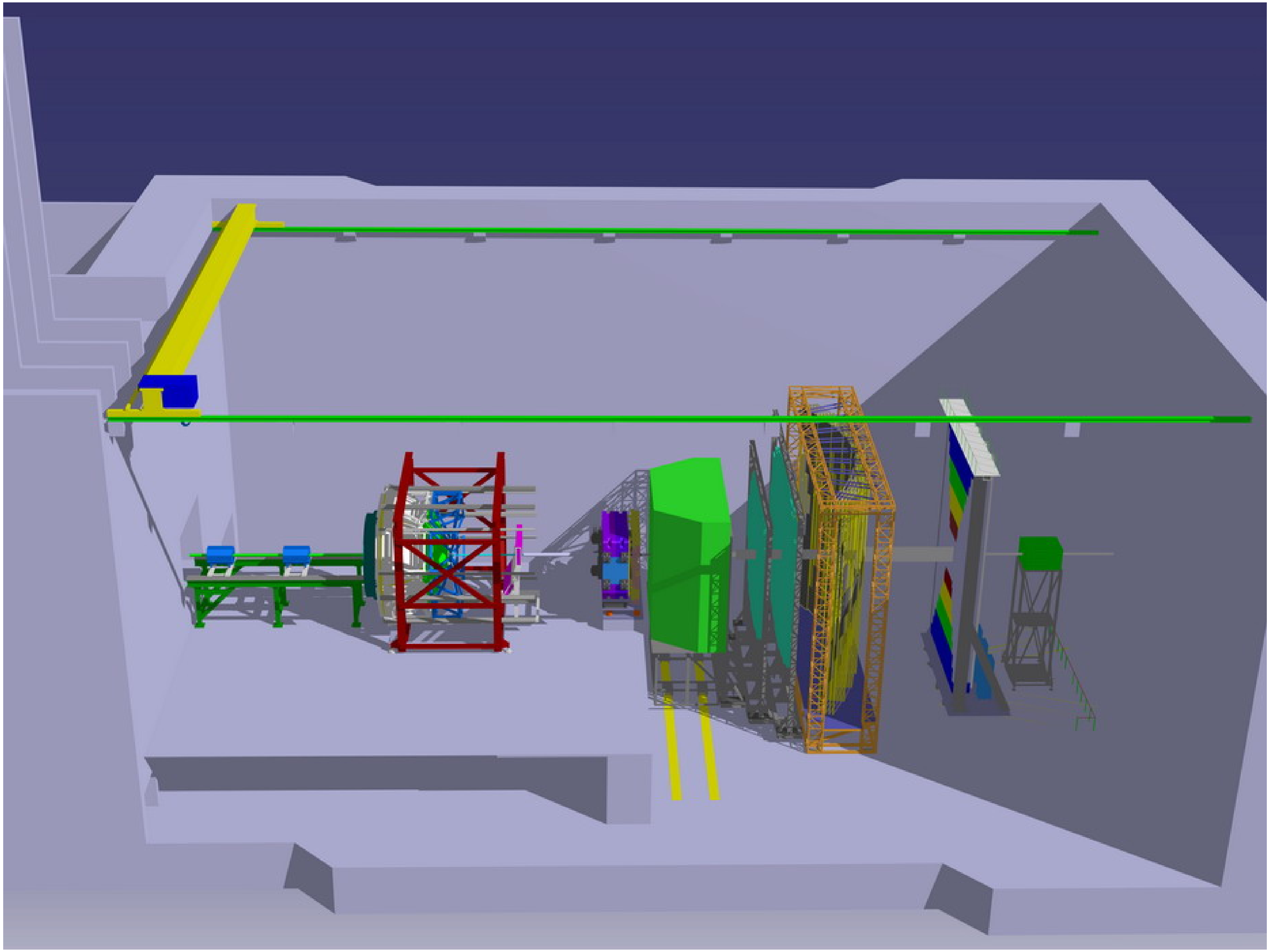
Spain:
Departamento de Física de Partículas, University of Santiago de Compostela
Instituto de Física Corpuscular, Universidad de Valencia-CSIC

17 institutions
120+ members

HADES

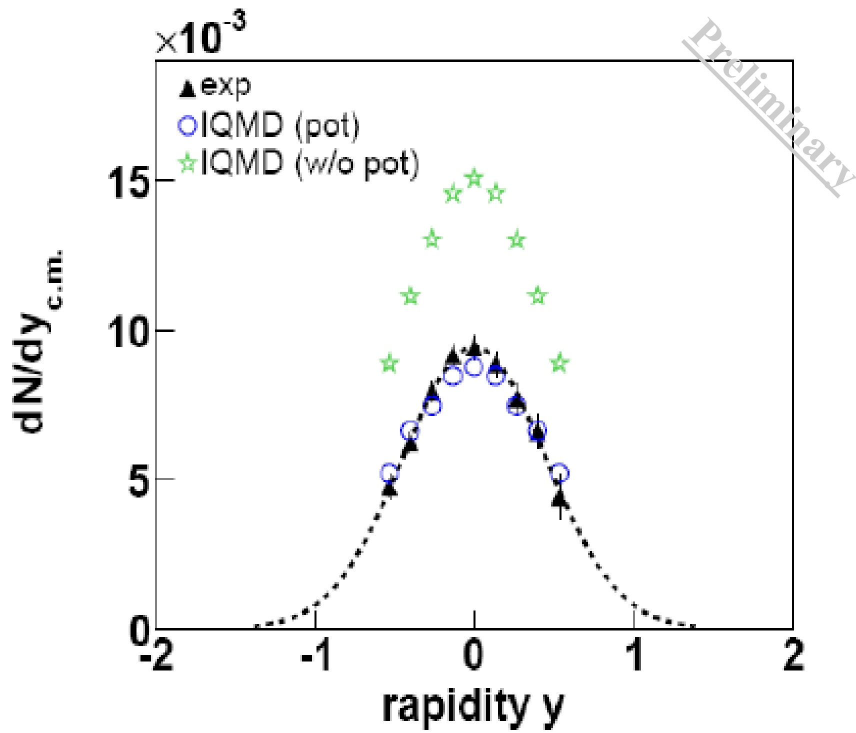
Cavalry to the rescue!

HADES in CBM cave (design by W. Niebur)

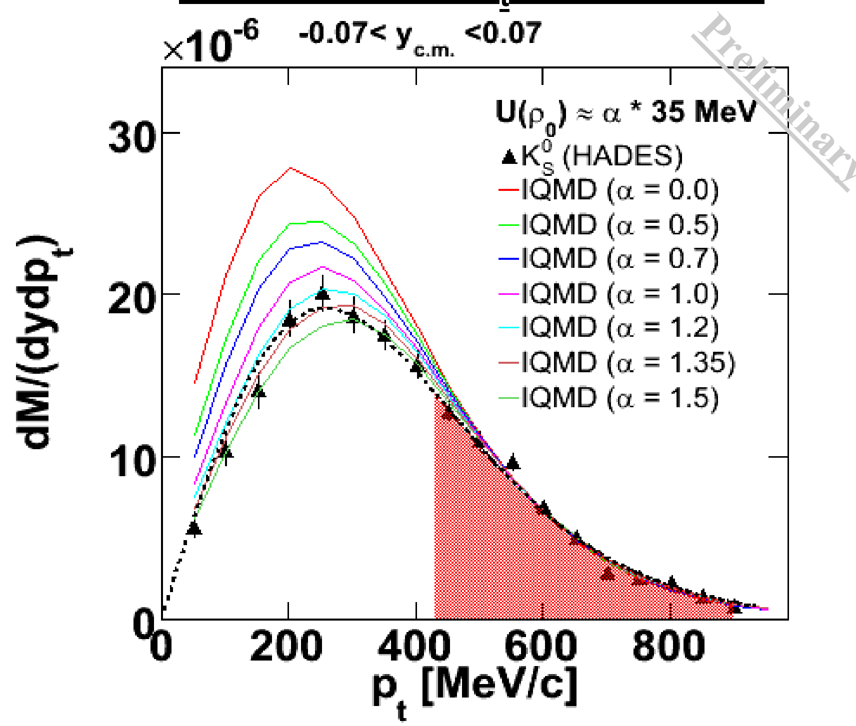


Neutral Kaon Prodcution and the IQMD Model

Absolute normalization (b < 6 fm)



Normalized to p_t > 450 MeV/c



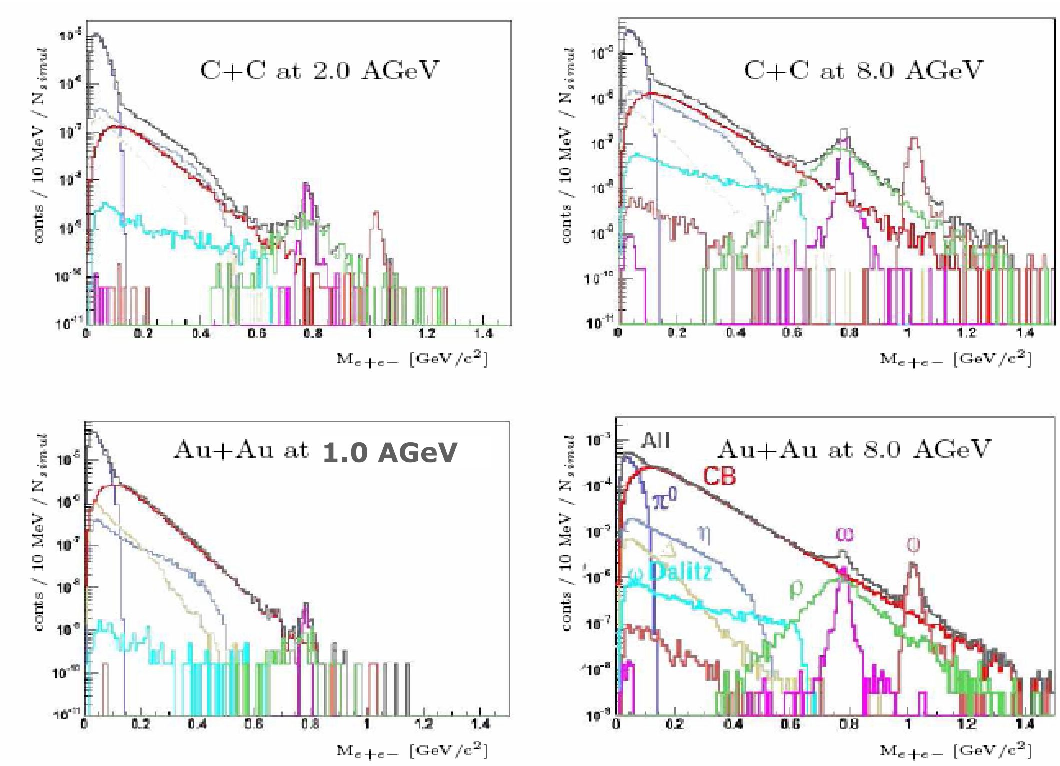
IQMD potential scan

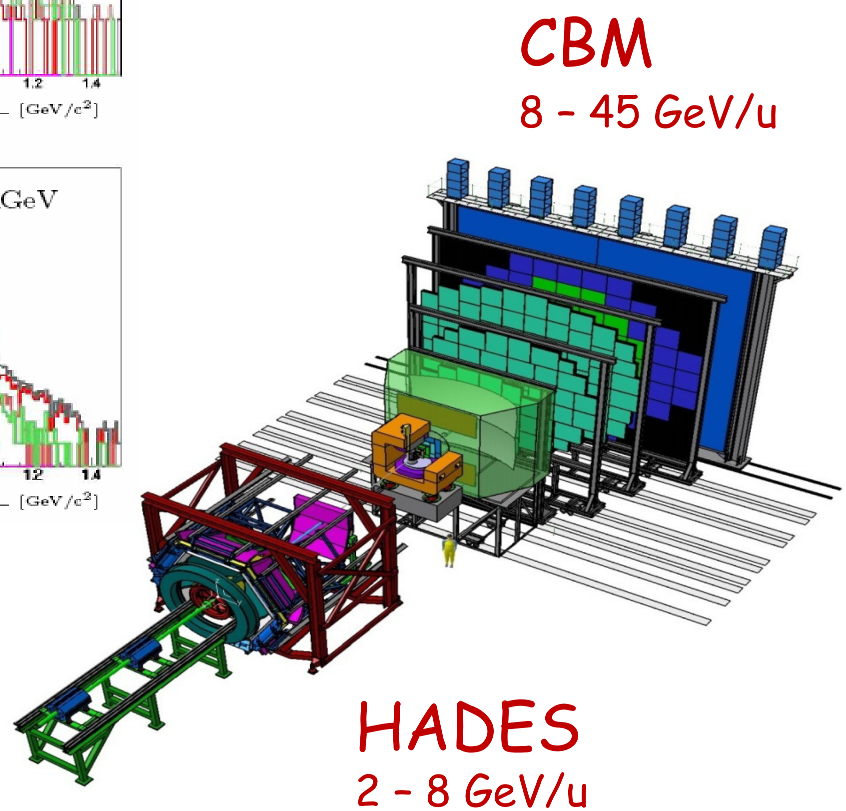
C.Hartnack, A.Schmah, L.Fabbietti

- An repulsive KN potential effects both the production yield (reduction) and the pt-slope (blue-shift) !
- Potential can be adjusted independently from systematic uncertainties in the yield.

6) HADES at SIS100: beyond the 2 GeV limit!

HADES





Simulations on-going …

Time table for move to CBM cave

HADES

Project / subproject / item	duration	I-III	IV-VI	VII-IX	X-XII	XIII-XV
		← shutdown of the SIS18				
Cave preparation	6 month					
Control room	1 month					
Computer room	1 month					
Service place for detectors	1 month					
Cooling infrastructure	3 months					
Air-conditions	3 months					
Power lines	3 months					
Beam line	13 months					
HADES transfer						
HADES disassembling	6 months					
Transport to the storage place	6 months					
Old supply lines disassembly	6 months					
Storage place	1 month					
N2 gas, vinyl pipes	1 month					
Foil tent	1 month					
Support fames for detectors	1 month					
Transport / installation in the new cave	6 months					
Mainframe transport/installation	1 month					
Supply lines installation	3 months					
Transport/installation of subsystems	6 months					
Magnet / beam line/ main frame alignment	1 month					
Magnet	3 months					
Preparation for transport	1 months					
Transport	2 weeks					
Installation	2 weeks					
Cryo supply	3 months					

Cost table

HADES

Project / subproject / item	cost	remarks
Cave design		
Control room	90,000.00 €	Separate room for HADES
Computer room (equipment only)	10,000.00 €	Shared with CBM, equipment only
Service room for detectors (equipment only)	10,000.00 €	Shared with CBM, equipment only
Cooling infrastructure in cave	130,000.00 €	Water cooling
Air-condition in control room	30,000.00 €	
Power lines in cave and control room	120,000.00 €	
Beam line	130,000.00 €	Beam focus on HADES target
HADES transfer		
HADES disassembly	0.00 €	
Storage place		
N2 gas, vinyl pipes	15,000.00 €	
Foil tent	5,000.00 €	
Support fames for detectors	25,000.00 €	
Transport / installation in the new cave		
Transport (mainframe, subsystems)	50,000.00 €	
Installation of subsystems	20,000.00 €	
Magnet / beam line/ main frame alignment	50,000.00 €	
Magnet		
Preparation for transport	15,000.00 €	
Transport	20,000.00 €	
Installation	50,000.00 €	
Cryogenic distribution system	150,000.00 €	FAIR cryo plant will be used
TOTAL	**920,000.00 €**	