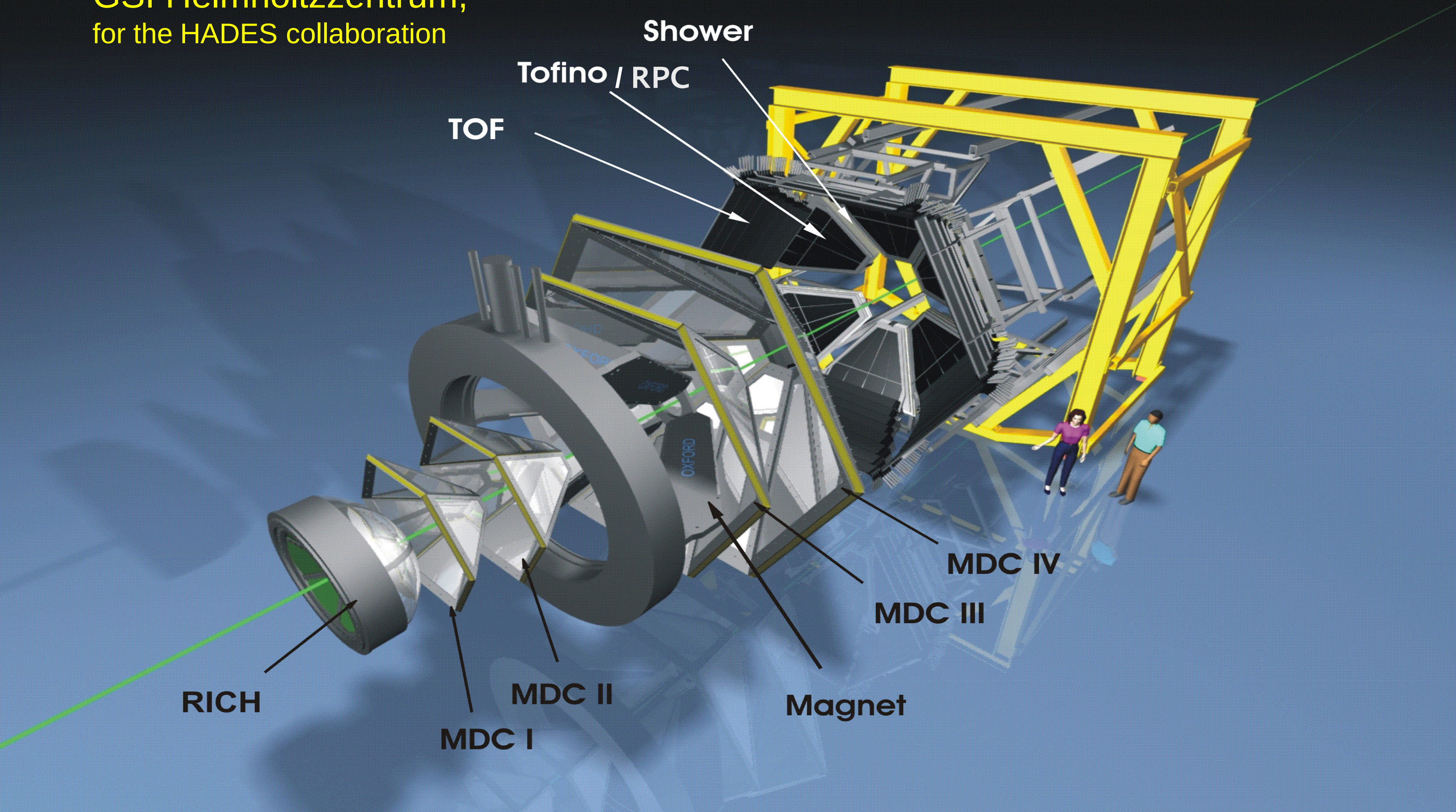
The HADES Experiment at GSI: an Update

Romain Holzmann,
GSI Helmholtzzentrum,
for the HADES collaboration

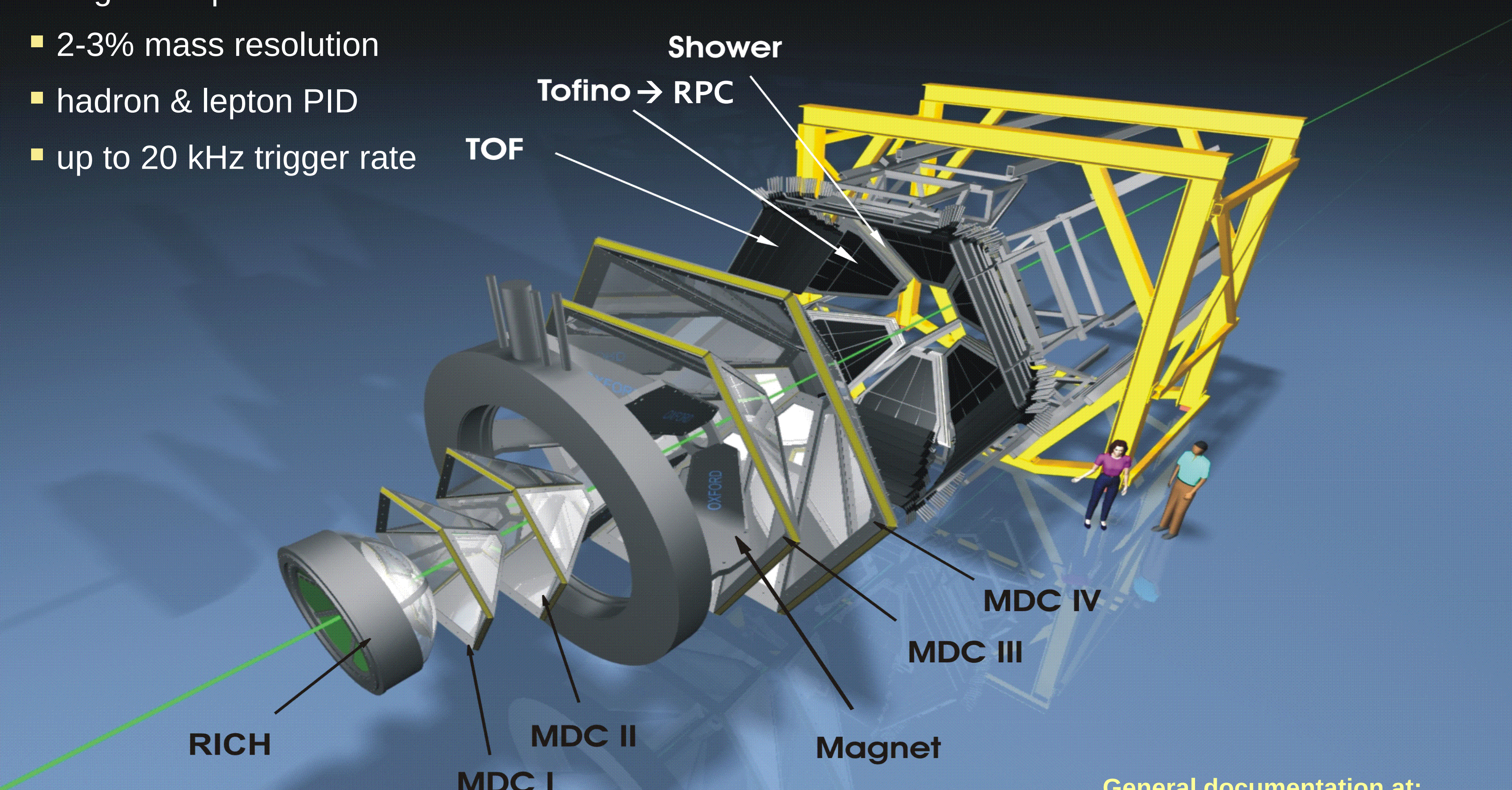


54th International Winter Meeting on Nuclear Physics, Bormio 2016

The HADES detector

High Acceptance DiElectron Spectrometer

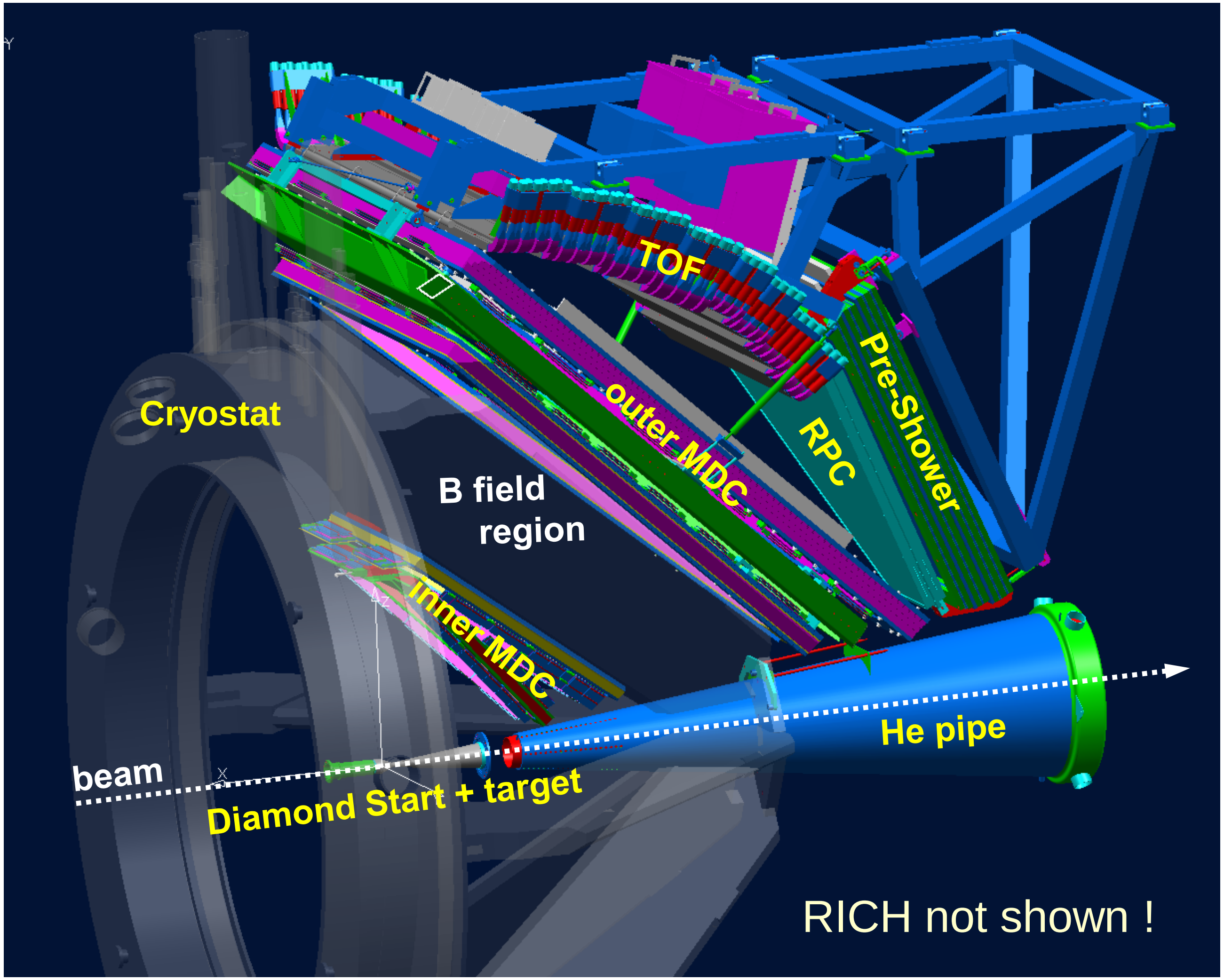
- large acceptance
- 2-3% mass resolution
- hadron & lepton PID
- up to 20 kHz trigger rate



General documentation at:
http://www-hades.gsi.de

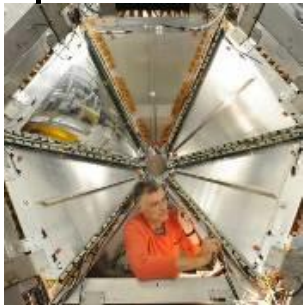
Technical layout of HADES

1 out of 6 HADES sectors



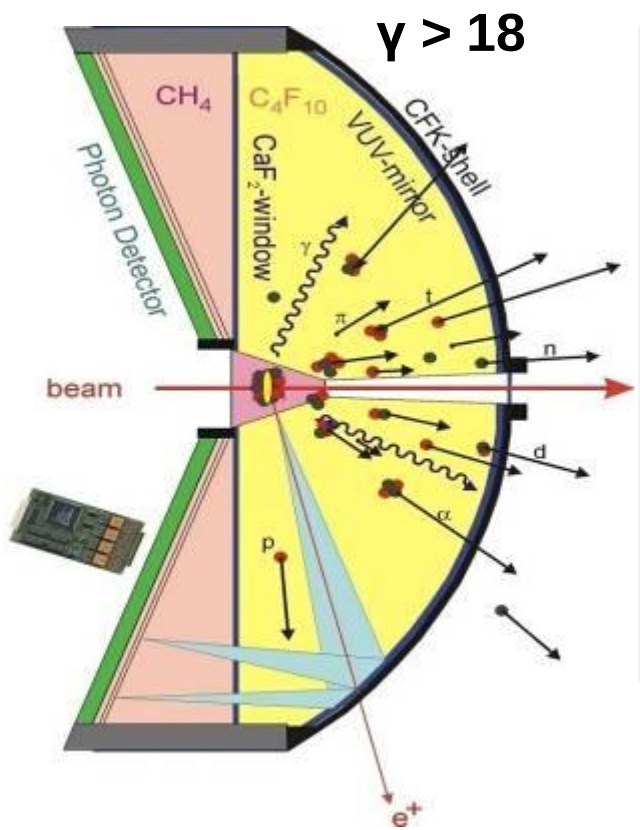
hadron-blind RICH

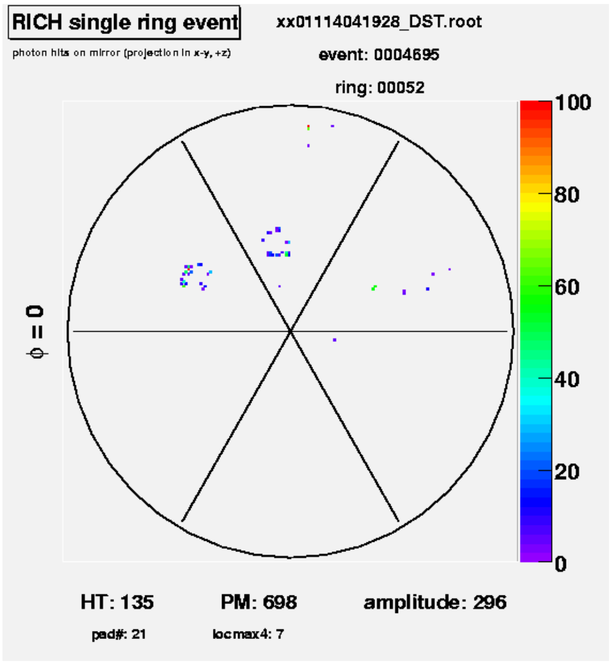
4 planes of MDC

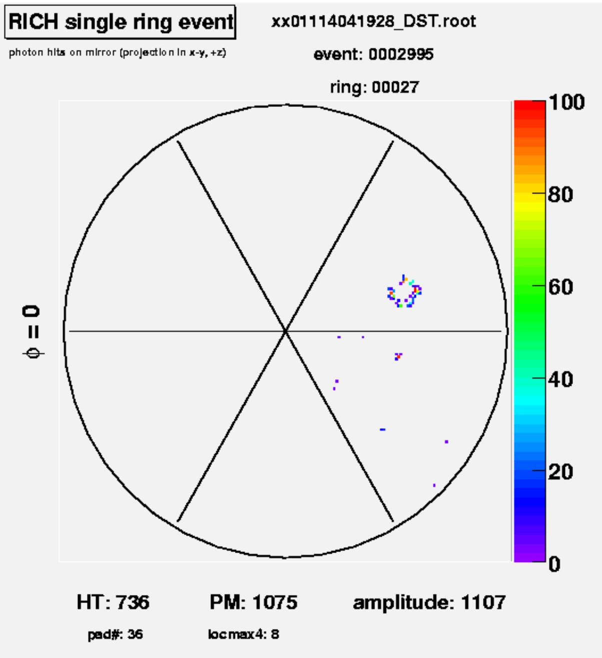


Forward Wall

The RICH: excellent lepton ID

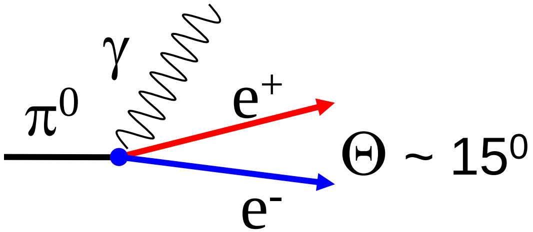


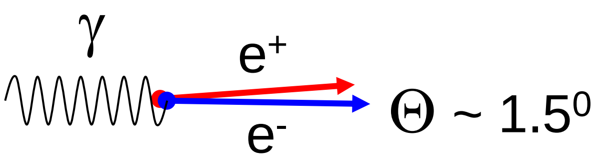




π^0 Dalitz pair

γ conversion pair



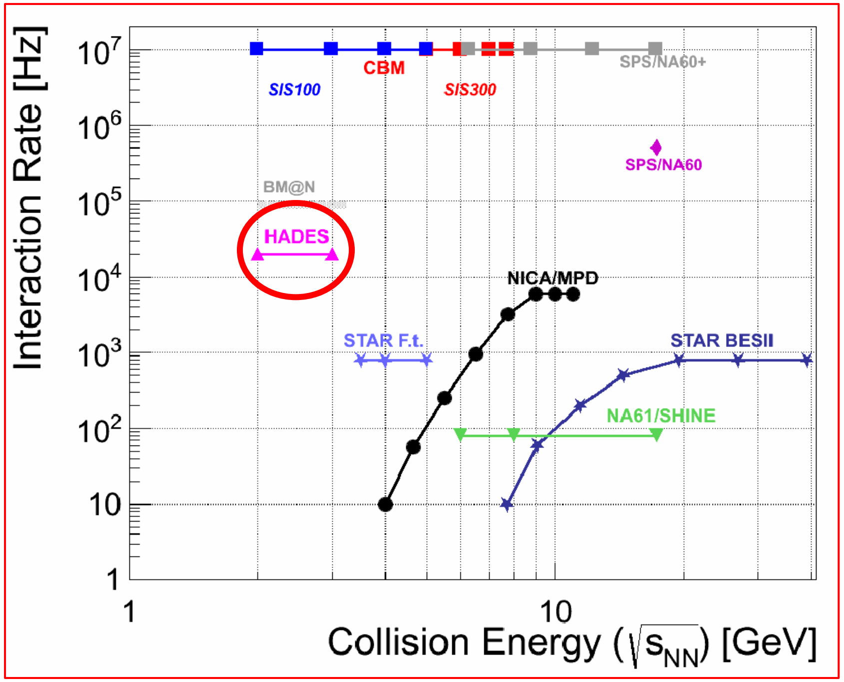


HADES operation at SIS18

2002 – 2009: light A+A, p+p, n+p, p+A

2011 – 2014: Au+Au, π-induced reactions

2018 – FAIR start: hight-statistics π+p & π+A, p+A and A+A



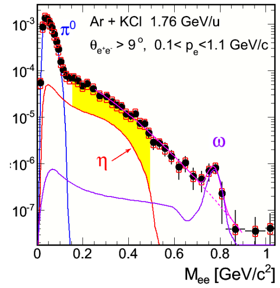
Rate capabilities of HI expts at low & moderate c.m. energy

➔ HADES is very competitive!

(compiled by T. Galatyuk)

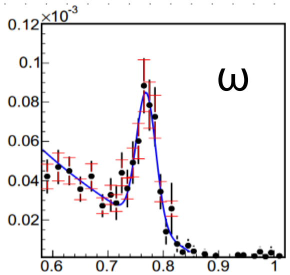
Physics we are after with HADES

- Particle production in heavy-ion collisions (also p+A)
  - Properties of compressed nuclear matter; explore its phase diagram
    - dilepton emission
    - (multi)strangeness production
    - femtoscopy ➔ see Thu afternoon talk by Oliver Arnold
    - global events characteristics (flow, flucs.)
  - ➢ **systematic investigation dilepton & strangeness production in A+A, p+A and π+A** (at $n/n_0 \approx$ 1-3) + event characterization



- Hadron spectroscopy
  - Elementary production mechanisms
    - coupling of ρ and ω to N*
    - isospin effects: σ_{pn} vs. σ_{pp}
    - strangeness production (ϕ, K, Σ, Λ, Ξ)

  → needed to model p+A & A+A
  - ➢ **systematic dilepton & hadron spectroscopy in pp, pn and πp** (i.e. in vacuum)



The HADES Collaboration

Cyprus:
Department of Physics, University of Cyprus

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

France:
IPN Orsay, CNRS/IN2P3,
Université Paris-Sud

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

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Laboratori Nazionali del Sud

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Jagiellonian University of Cracow

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

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JINR, Dubna
ITEP, Moscow

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

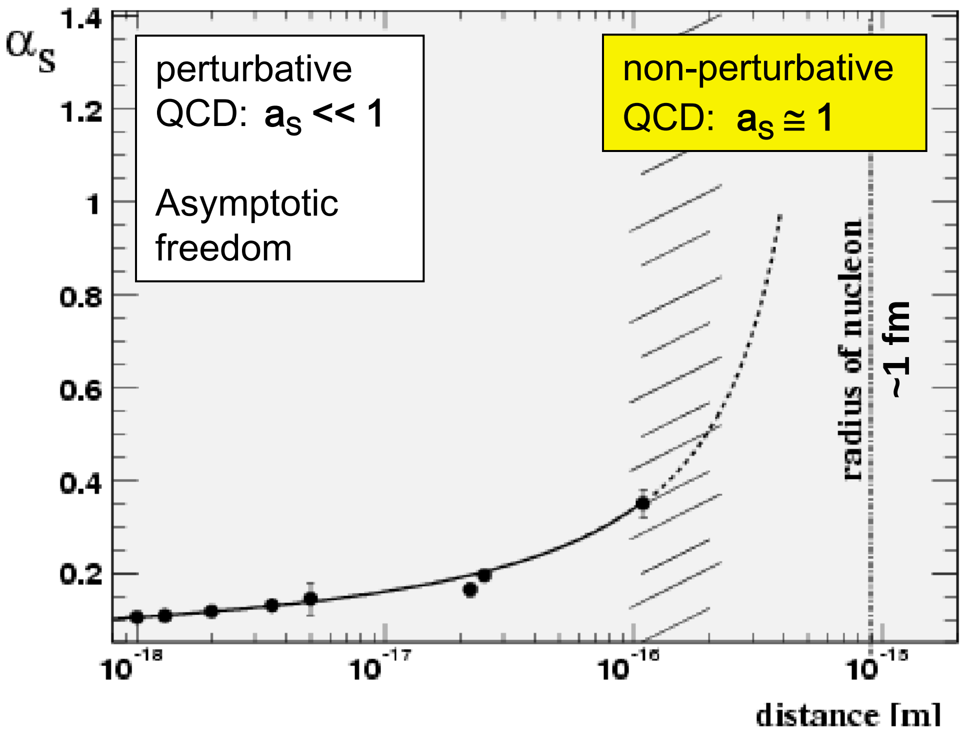
Slovakia:
Bratislava Univ.

18 institutions
120+ members

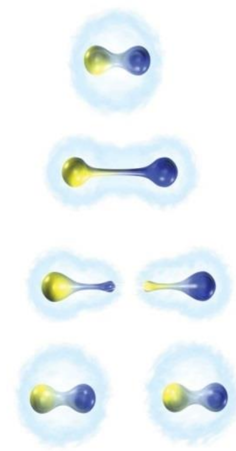
Hadron masses in the medium

QCD: running coupling constant α_s

Strong interaction coupling strength



Quarks are confined!



$$V(r) = -\frac{4\alpha_s \hbar c}{3r} + Kr$$

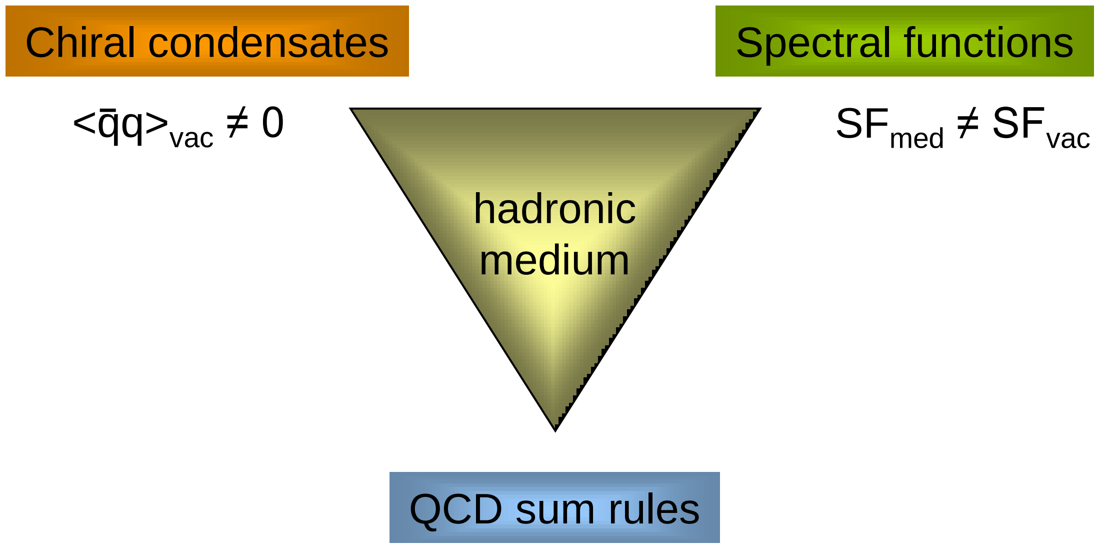
At low energy, the QCD lagrangian cannot be handled perturbatively, we have to

- fall back on models (e.g. χPTH)
- solve on the lattice (LQCD)
- explore symmetries of $\mathbf{L}_{QCD}$
  e.g. broken chiral symmetry

Setting the stage: non-perturbative QCD

Arguments for in-medium modifications of hadrons are based on …

… chiral symmetry restoration … hadronic many-body theories

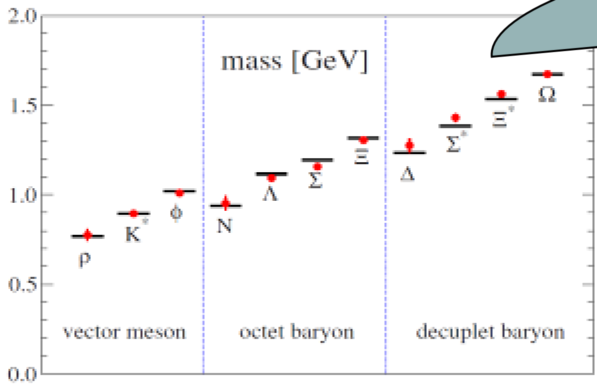


… relate condensates and spectral functions.

Recent reviews of the field:
Leupold, Metag & Mosel, Int. J. Mod. Phys. E19 (2010)
Hayano & Hatsuda, Rev. Mod. Phys. 82 (2010)

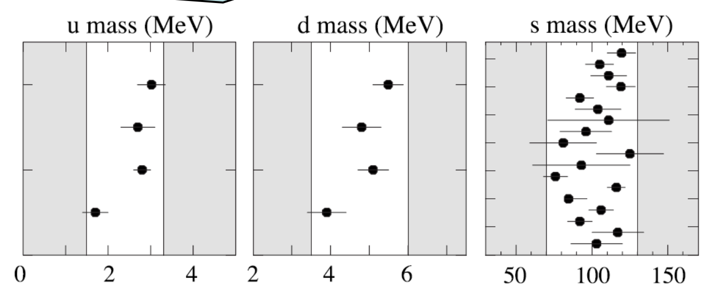
Mass generated by breaking QCD chiral symmetry

Model calculations, e.g. Lattice QCD, adjusted to exp. hadron spectrum

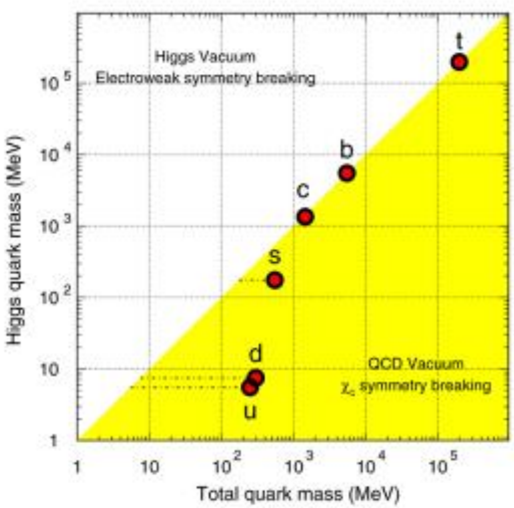


Aoki et al., **PRD 79 (2009)** …

PDG 2010



Current quark masses



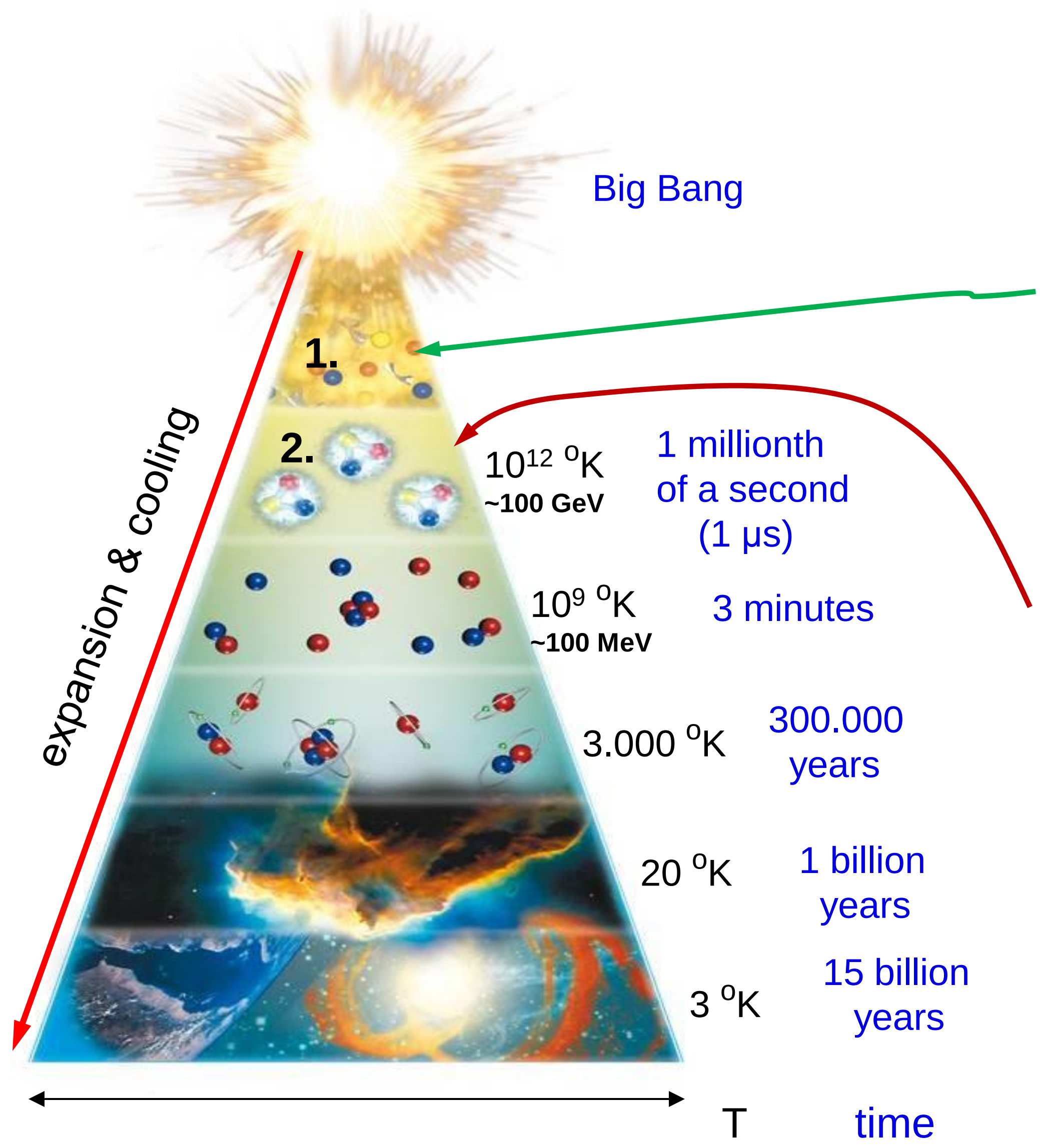
Zhu et al.,
PLB 647 (2007) 366

Constituent quark mass:

$$M_{quark} = \underbrace{M_{weak}}_{\text{Higgs mechanism}} + \underbrace{M_{strong}}_{\text{spontaneous } \chi \text{ sym. breaking } \rightarrow \langle \bar{q}q \rangle \neq 0}$$

➔ 99% of the observed large hadron masses are dynamically generated!

Evolution of the universe & mass generation



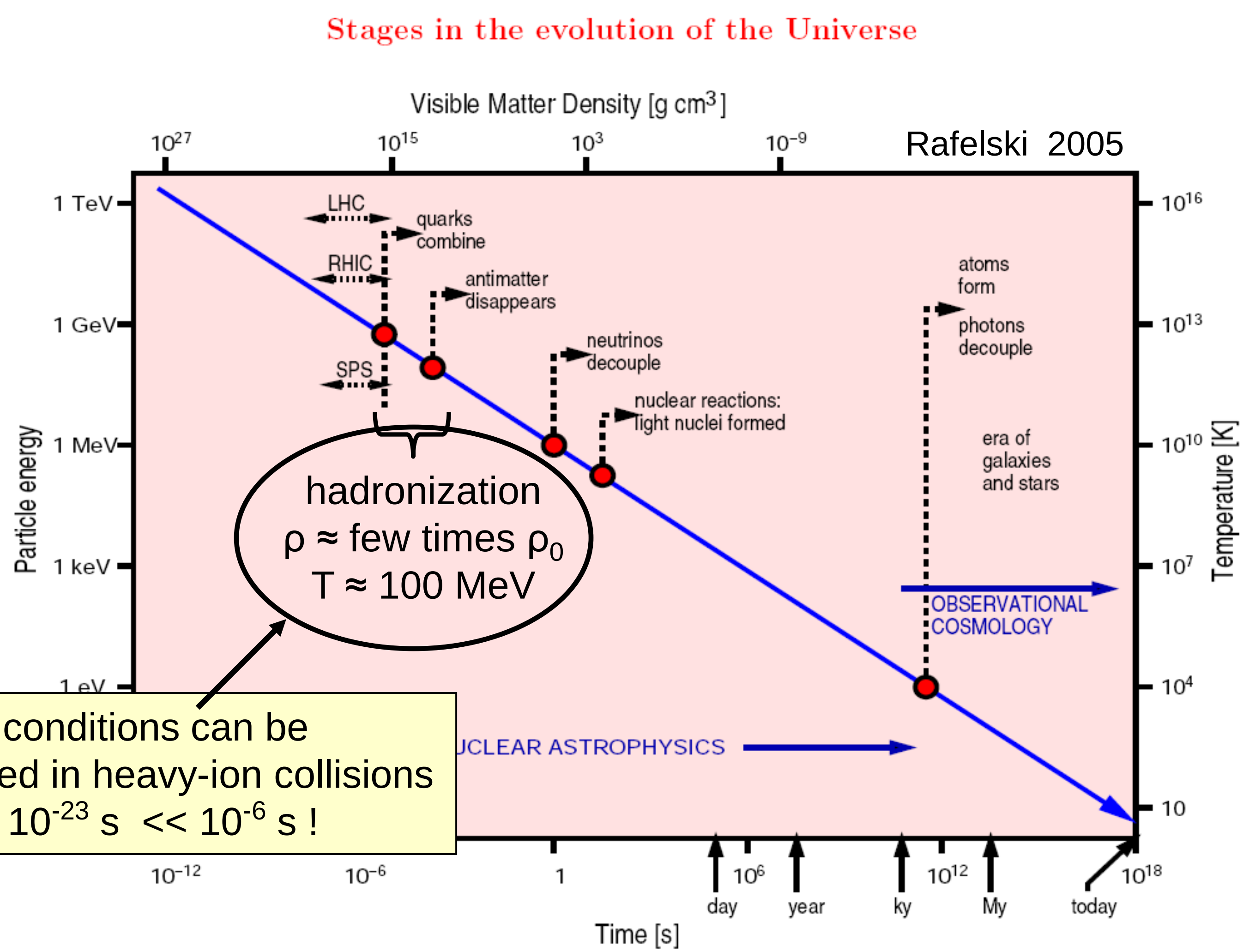
Two steps in mass generation:

1. Electro-weak transition
   (Higgs mechanism)
   - ► weak mass = current mass
2. Chiral transition
   (hadronization)
   - ► strong mass

We observe the constituent mass:

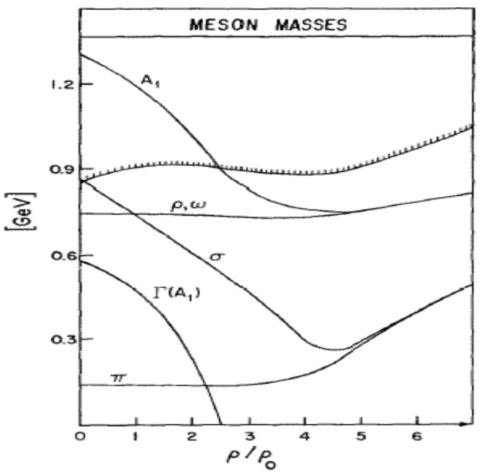
$$\mathbf{M = M_w + M_s}$$

Evolution of the universe

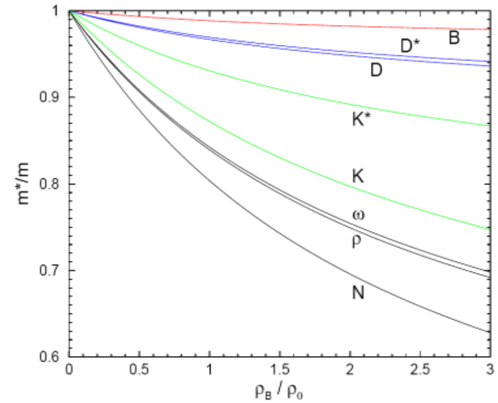


Such conditions can be realized in heavy-ion collisions $t_{reac} \approx 10^{-23}$ s $<< 10^{-6}$ s !

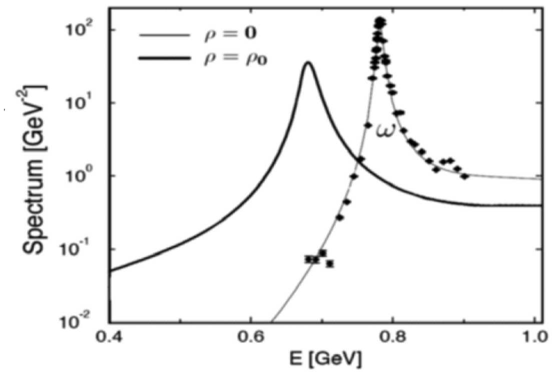
In-medium masses: a cornucopia of models



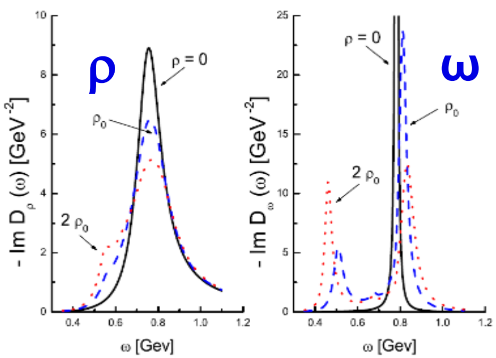
Nambu Jona-Lasinio model
Bernard & Meißner NPA 489 (1988) 647



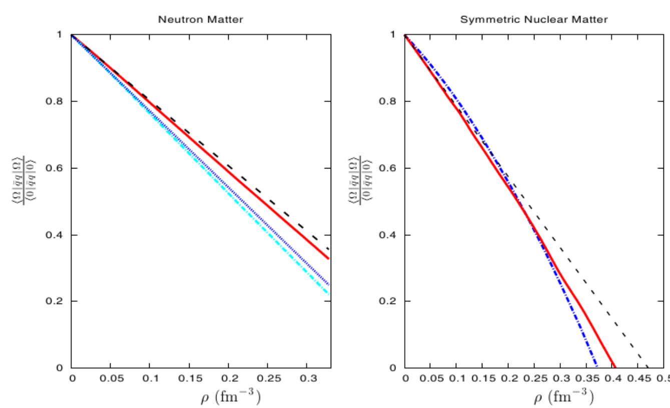
Quark-Meson Coupling model
Saito et al. PRC55 (1997) 2637



Effective Lagrangian model
Klingl et al. NPA 650 (1999) 299
and for ϕ in PLB 431 (1998) 254



Coupled-channels approach
M. Lutz et al. NPA 706 (2002) 431



Chiral power counting model
Lacour, Oller & Meißner J Phys G37 (2010) 125002

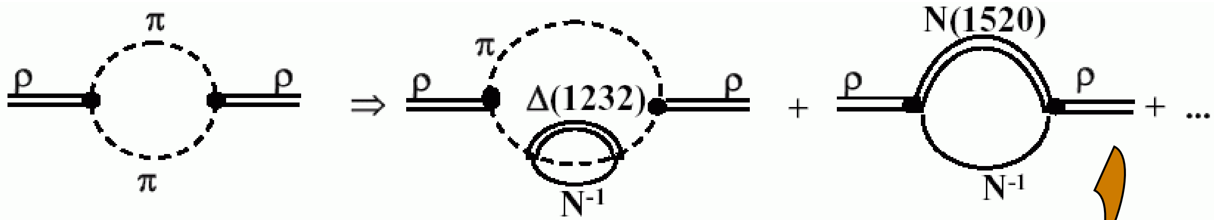
… and quite a few more !

Vector meson spectral function in HMBT

ρ in vacuum

ρ in baryonic medium modified by coupling to resonance-hole states

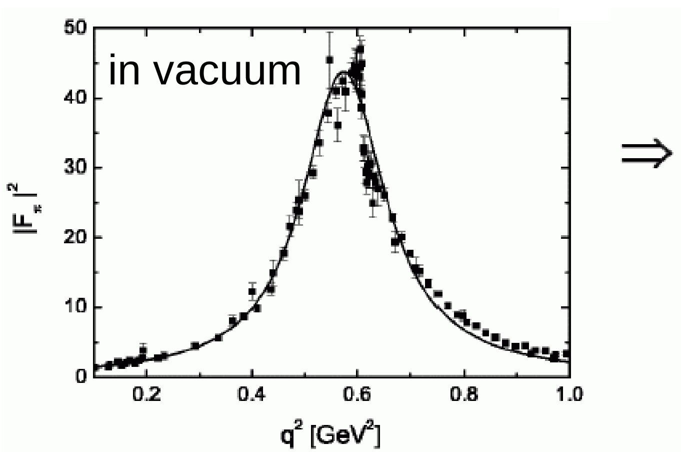
Hadronic Many-Body Theory:
Rapp & Wambach
Adv Nucl Phys 25 (2000) 1



propagator: $D = \frac{1}{p^2 - m^2 - \Pi_{vac}}$ $\Rightarrow$ $D = \frac{1}{p^2 - m^2 - \Pi_{vac} - \Pi_{med}}$

spectral function: $= \frac{1}{\pi} \, Im \, D$

for p>0



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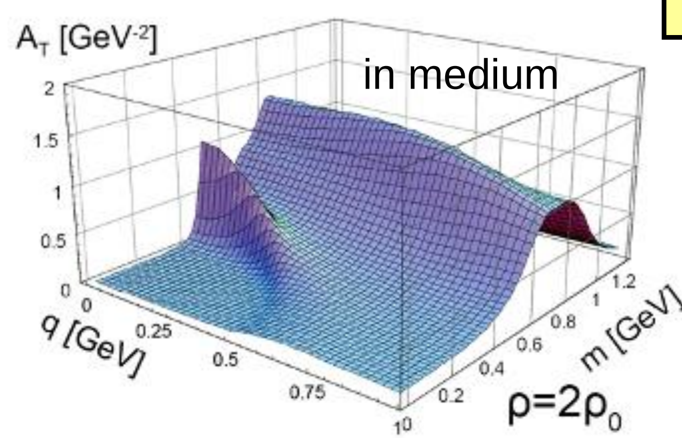


Leupold, Mosel, Post et al.
NPA 741 (2004) 81; NPA 780 (2006) 187

QCD sum rules connect both worlds

However, $\langle q\bar{q} \rangle$ is not an observable !!

- **QCD sum rules** provide a link between hadronic observables and condensates:
  Hatsuda & Lee, PRC 46 (1992) R34; Leupold & Mosel, PRC 58 (1998) 2939

$$\frac{Q^2}{24\pi^2}\int ds \frac{R(s)}{\left(s+Q^2\right)^2} = \frac{1}{16\pi^2}\left(1+\frac{\alpha_s}{\pi}\right)+\frac{1}{Q^4}\left[m_q\langle\bar{q}q\rangle+\frac{1}{24}\left\langle\frac{\alpha_s}{\pi}G^2\right\rangle\right] + \text{higher order terms}$$

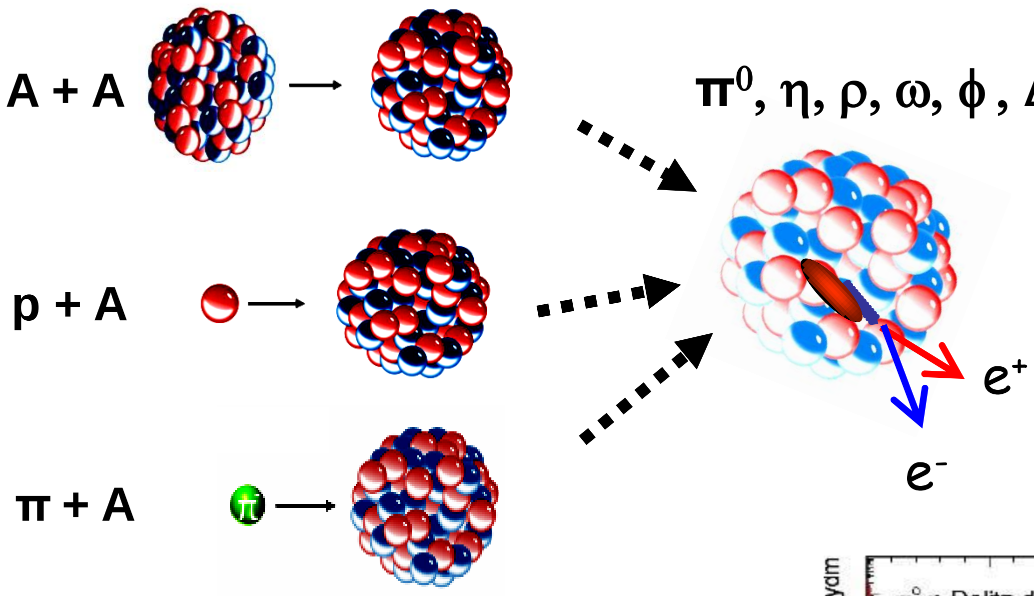
hadronic spectral function: $R(s) \sim F^2 \frac{1}{\pi}\frac{\sqrt{s}\,\Gamma(s)}{\left(s-M_\rho{}^2\right)^2+s\left(\Gamma(s)\right)^2}$

- Chiral condensate is related to integral over hadronic spectral functions only
  $\rightarrow$ spectral function are constrained, but not fully determined

$\Rightarrow$ **Models are still needed for specific predictions of hadron properties !!**

Experimental access to in-medium effects

e^+e^- spectroscopy of hadronic matter



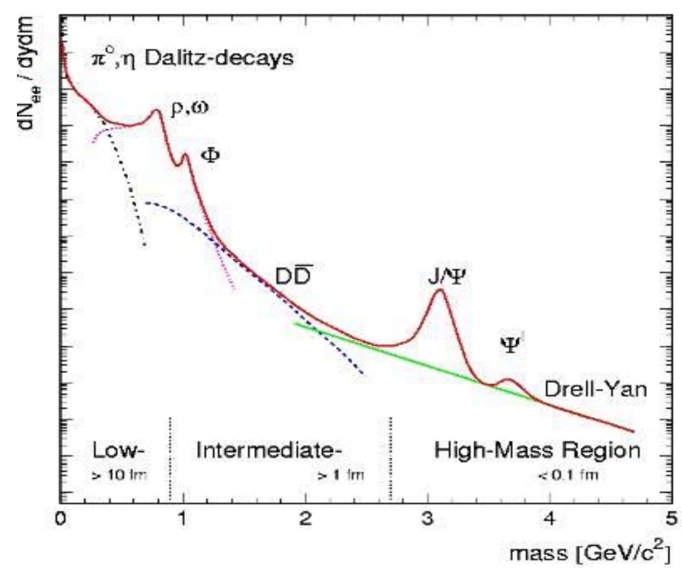
π^0, η, ρ, ω, ϕ , Δ, N*...

Modus operandi:

1. produce hadron
2. let decay into leptons
3. detect products
4. reconstruct inv mass

Pair invariant mass:

$$M_{ee} = \sqrt{(p_1 + p_2)^2}$$



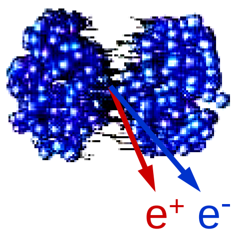
Dileptons from nucleus-nucleus collisions

(in few GeV/u regime)

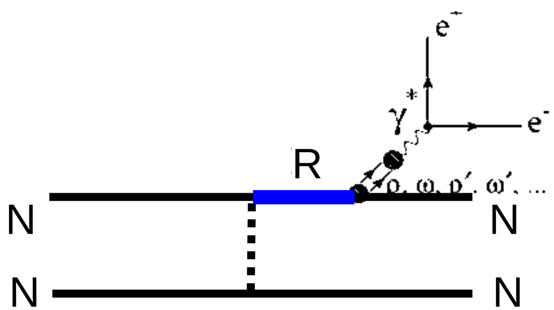
Au+Au collision:

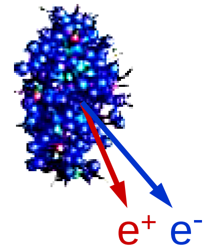
collision lasts in total <100 fm/c
dense phase ≈15 fm/c

time

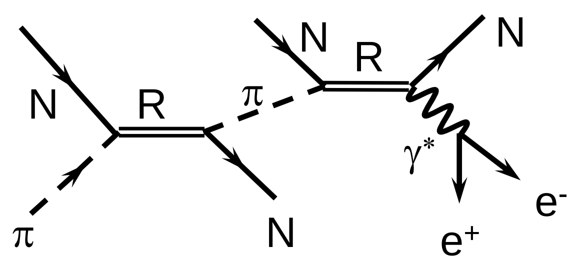


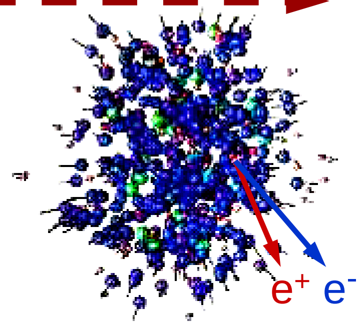
First-chance NN collisions



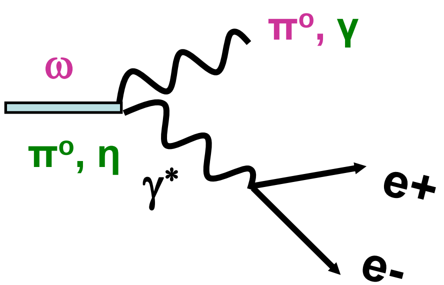


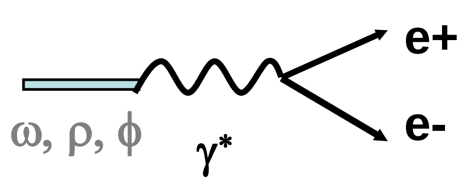
Hot and dense phase
multistep production
of resonances and mesons





Freeze–out
decays of (long-lived)
states: π^0, η, ω

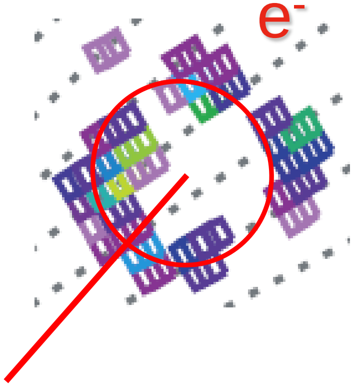




Observed dilepton yields are integrated over full duration !

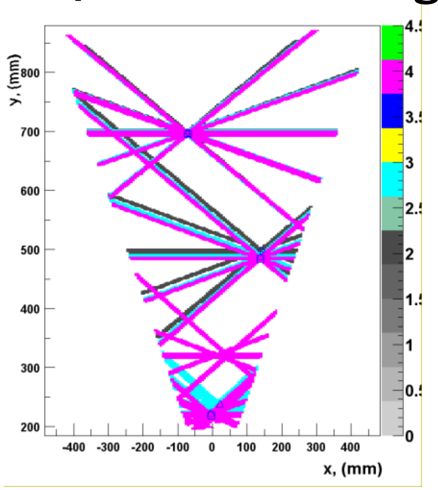
Electron/positron identification in HADES

RICH pattern



+

MDC hit finder & hit/track matching



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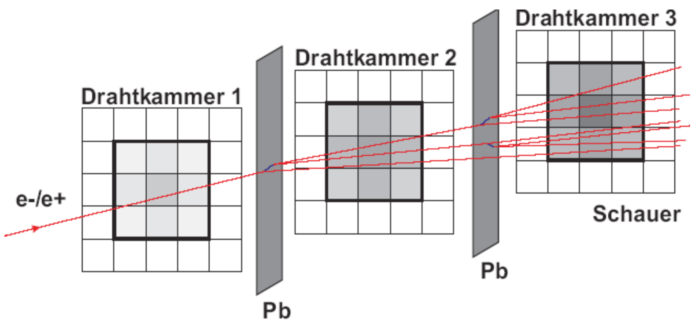
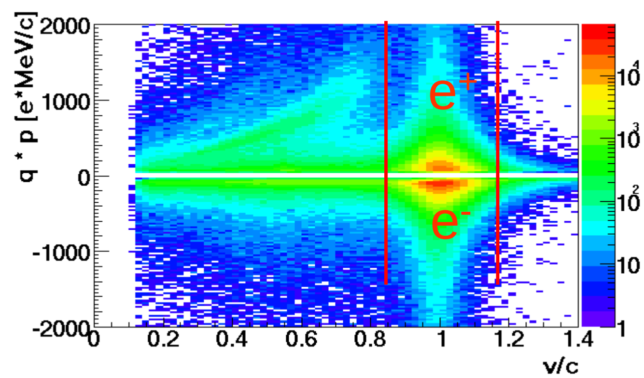
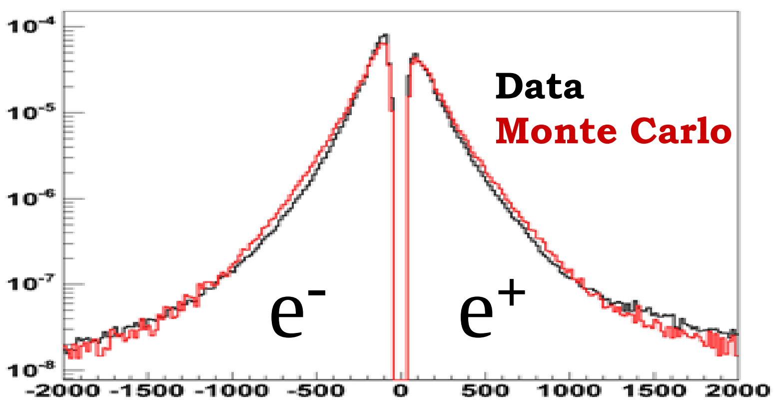
Pre-Shower condition



velocity vs. momentum

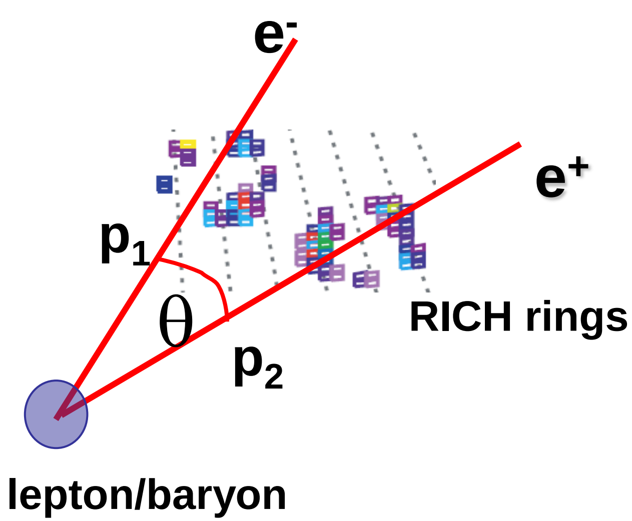




Momentum * charge [MeV/C]

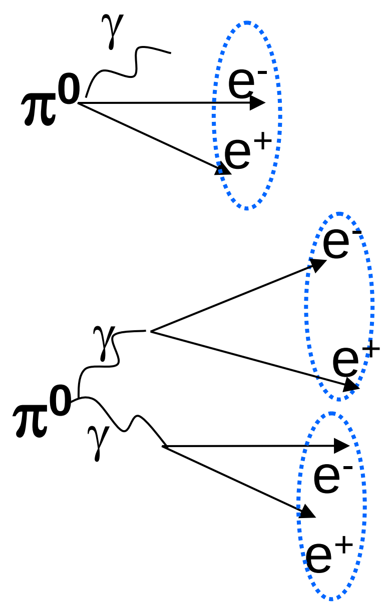
Lepton pair reconstruction

Pair reconstruction



$$M_{inv} = 2 \cdot \sin(\Theta/2)\sqrt{p_1 p_2}$$

Correlated pairs:

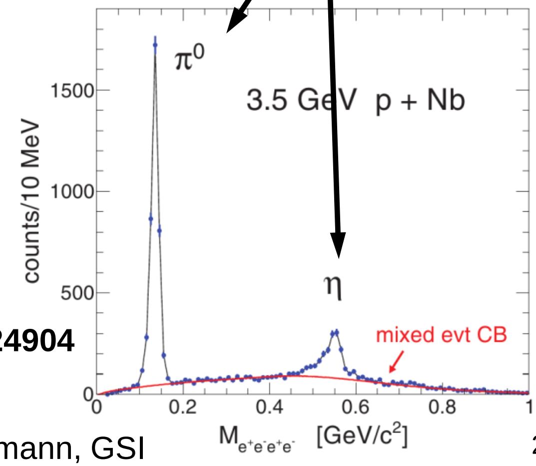


Dalitz decay

2-photon decay
+ conversion

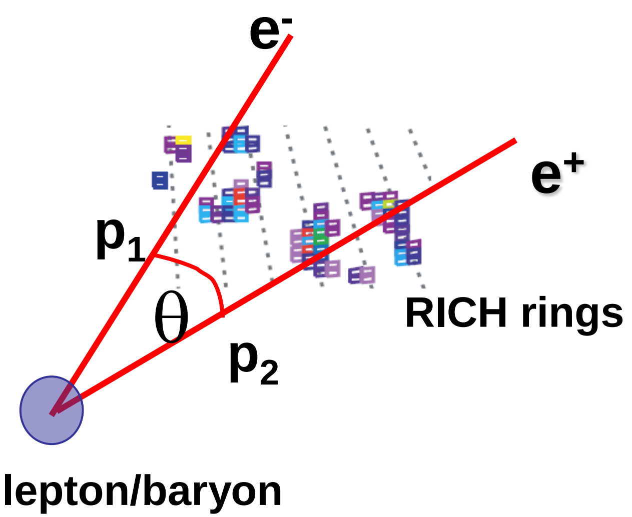
2-photon
calorimetry
in HADES

PRC 88 (2013) 024904

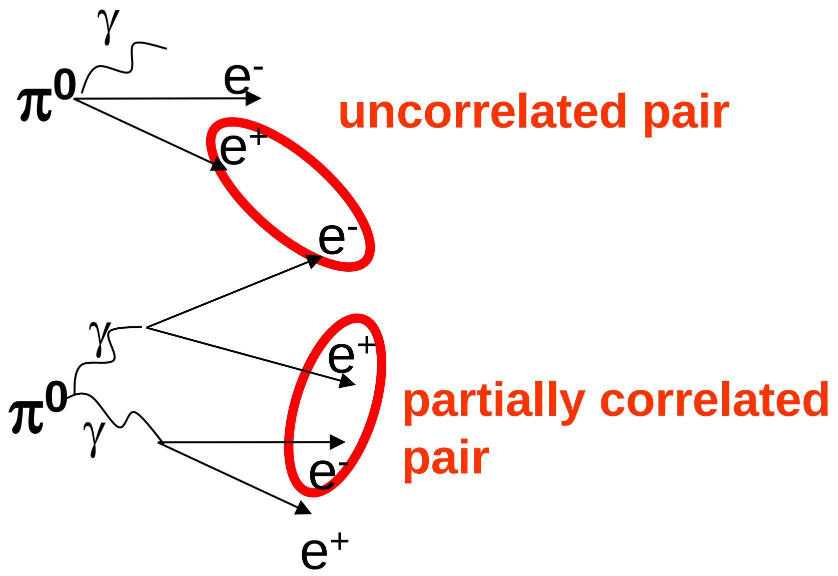


Lepton pair reconstruction

Pair reconstruction



$$M_{inv} = 2 \cdot \sin(\Theta/2)\sqrt{p_1 p_2}$$

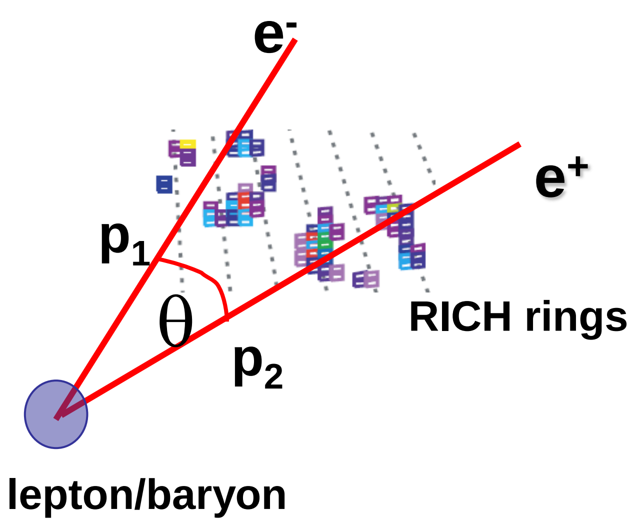


➔ Need soffisticated methods, combining event-mixing and like-sign averages, to subtract this combinatorial background!

$$N_{CB} \propto N_{\pi^0}^2$$

Lepton pair reconstruction

Pair reconstruction



$$M_{inv} = 2 \cdot \sin(\Theta/2)\sqrt{p_1 p_2}$$

Combinatorial background subtraction

From:

- like-sign pairs
- event mixing

$$CB = 2\sqrt{N_{e+e+} N_{e-e-}}$$

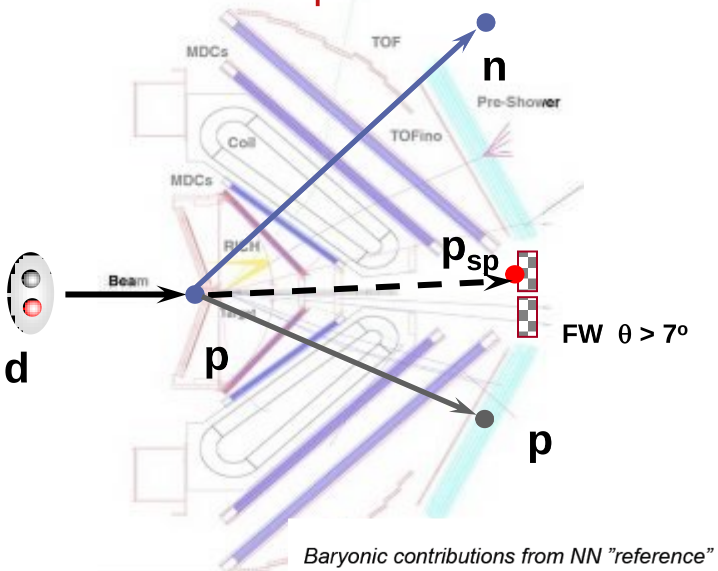
Signal:

$$S_{+-} = N_{e+e-} - k\, CB_{+-}$$

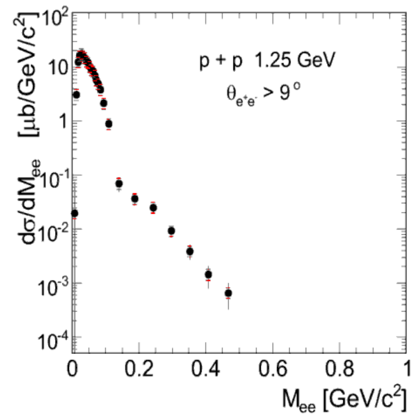
k corrects for charge-asymetries

p+p vs. n+p: Strong isospin effects

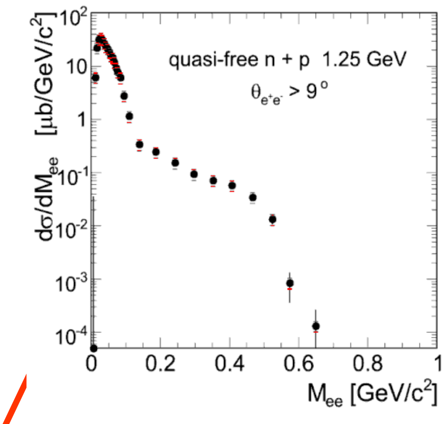
Tagging quasi-free np collisions in 2.5 GeV dp reactions:



1.25 GeV p+p:

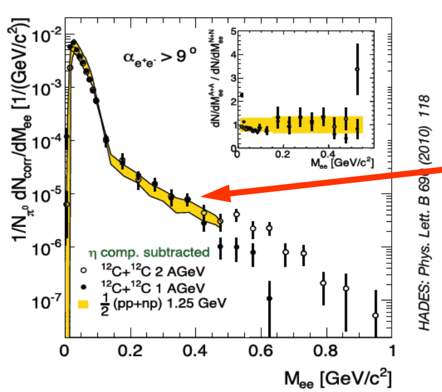


d+p: quasi-free np



Agakishiev et al., PLB 690 (2010) 118

Baryonic contributions from NN "reference"

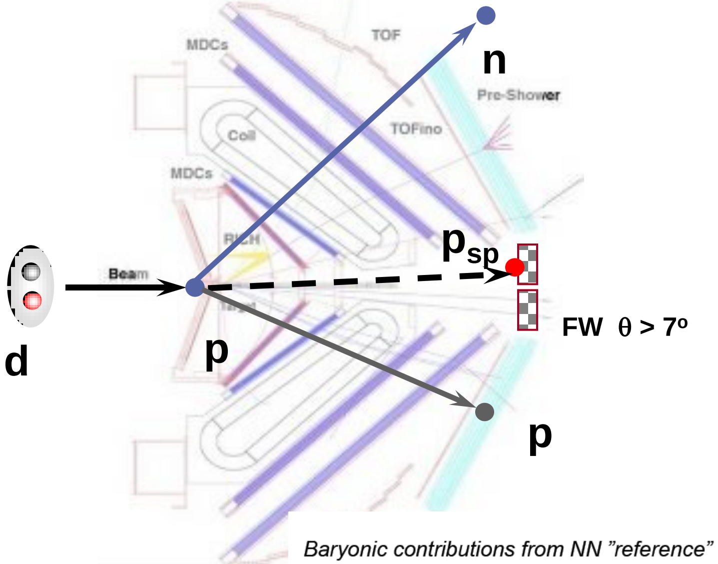


Reference for A+A:

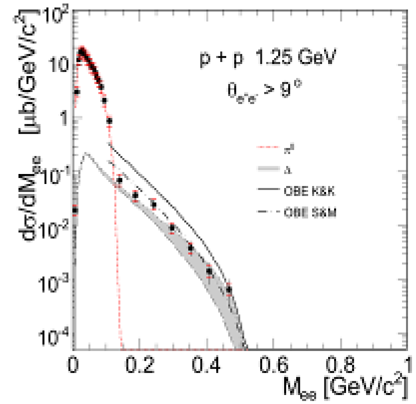
½ (pp+np) ≈ C+C

p+p vs. n+p: Strong isospin effects

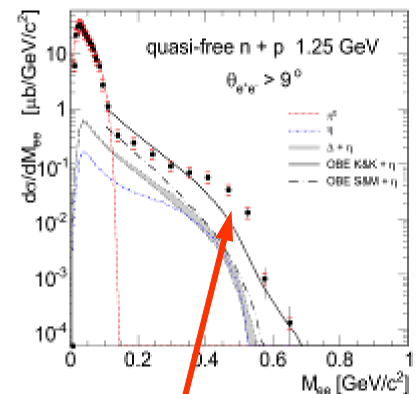
Tagging quasi-free np collisions in 2.5 GeV dp reactions:



1.25 GeV p+p:



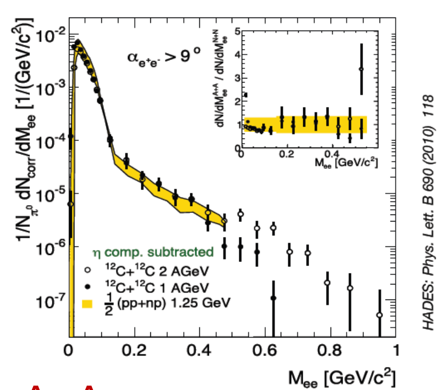
d+p: quasi-free np

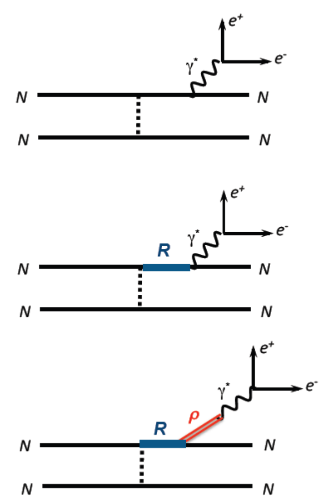


Agakishiev et al., PLB 690 (2010) 118

C+C = (pp+np)/2

Baryonic contributions from NN "reference"



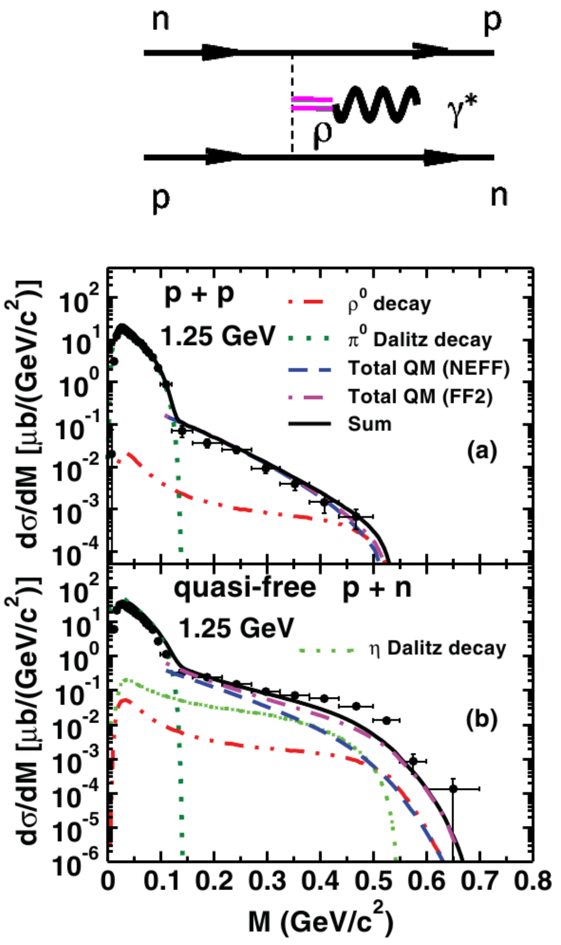


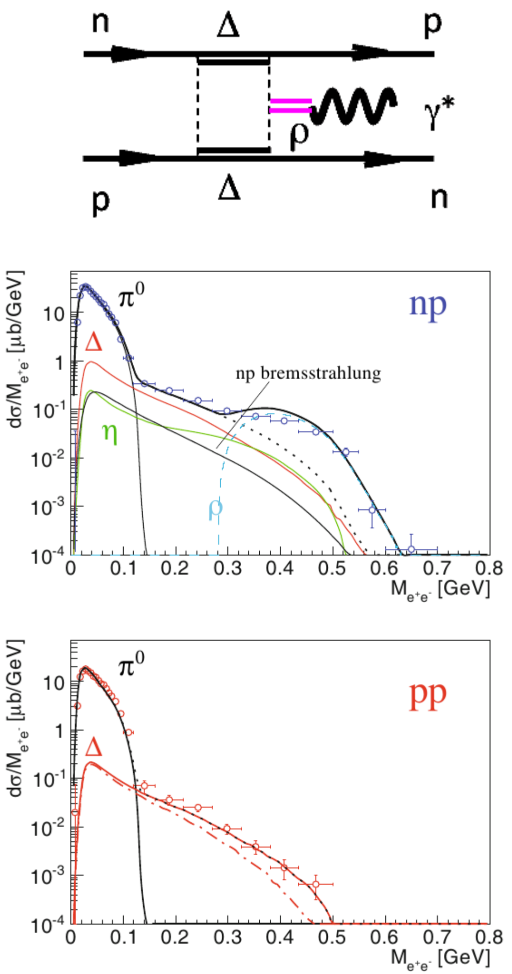
R = Δ, N*

OBE calculations describe pp, but np needs more!

➔ reference for A+A

Adding higher-order diagrams helps



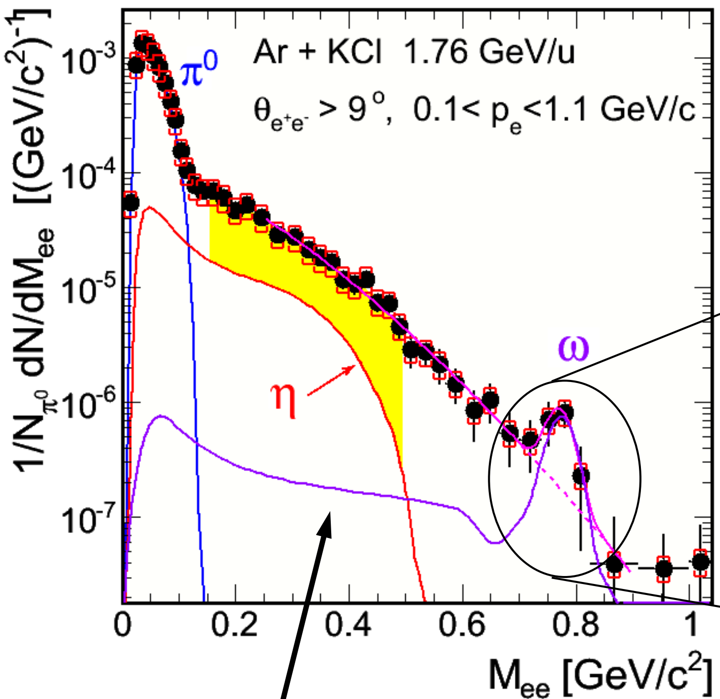


Shyam & Mosel., **PRC 82 (2010) 062201**

Bashkanov & Clemens, **EPJA 50 (2014) 107**

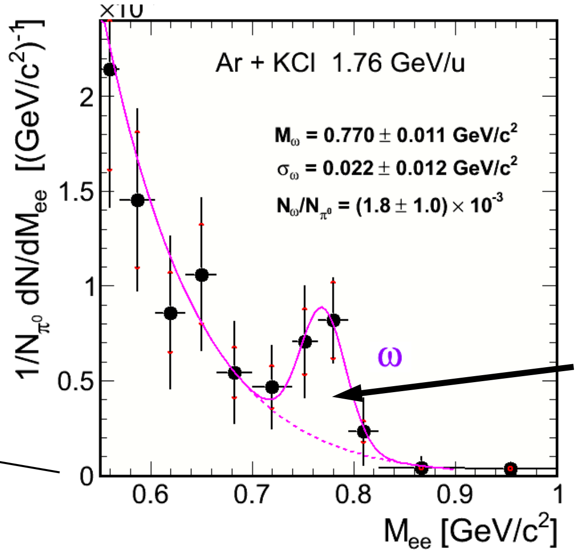
e^+e^- excess in 1.76 GeV/u Ar+KCl

Agakishiev et al., **PRC 84 (2011) 014902**



Cocktail of long-lived sources: π^0, η, and ω

- Strong overshoot above the cocktail of long-lived sources!
- First ω peak seen at SIS energies!



~ 40 counts

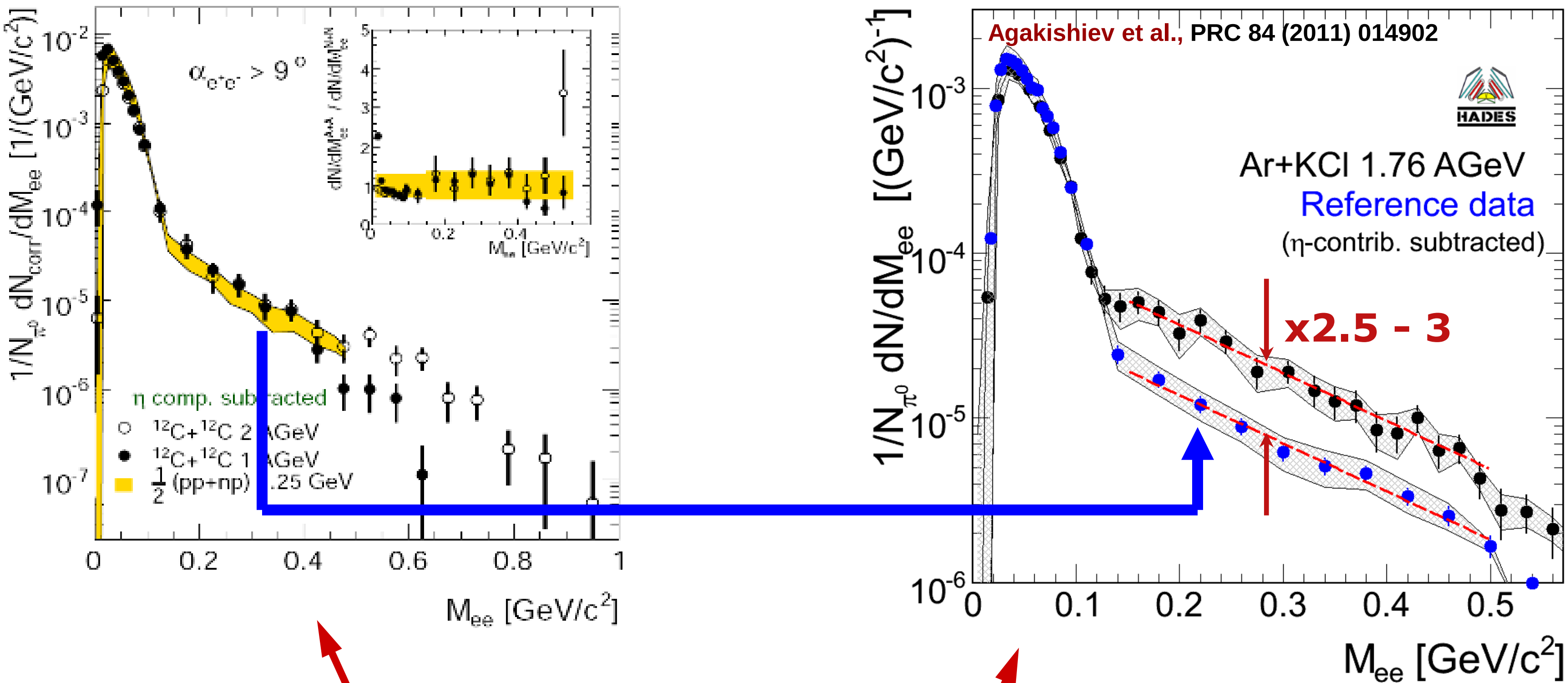
▶ $M_{LVL1}(\omega) = (6.5 \pm 2.8) \cdot 10^{-3}$

±20 % sys.

Comparing “N+N reference” with A+A

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(π^0)

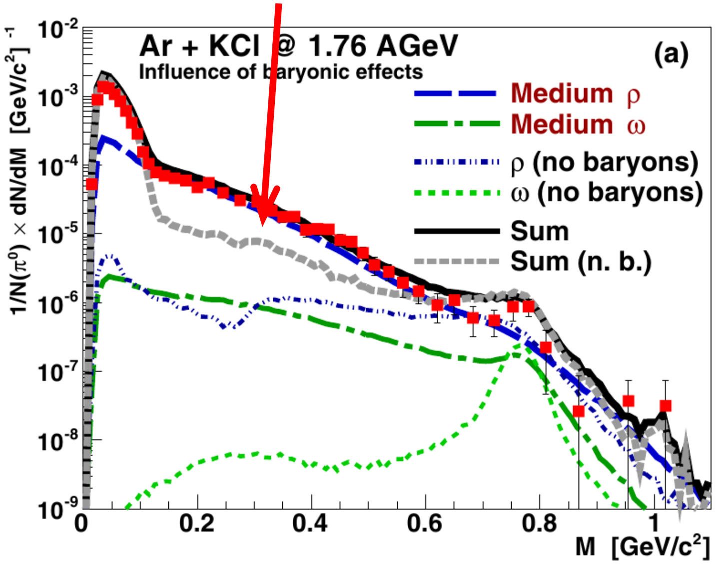
►► **Strong excess over free N+N already in Ar+KCl !**

HADES vs. “coarse-grained” UrQMD transport

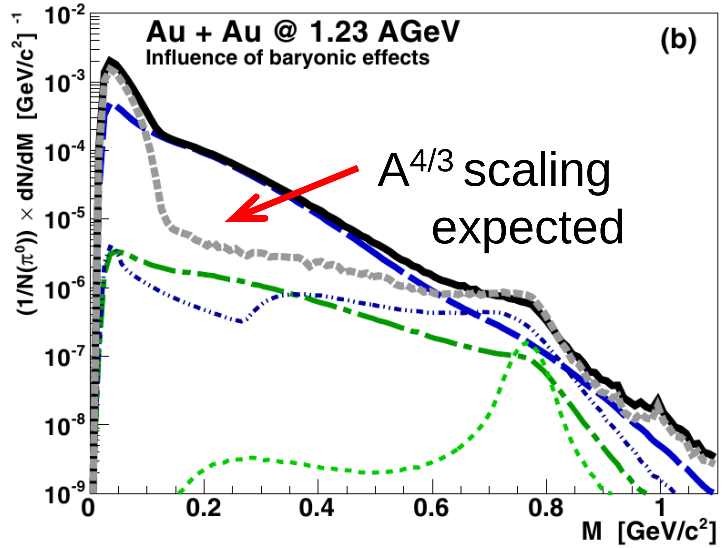
Endres, van Hees, Weil & Bleicher, PRC 92 (2015) 014911

1) Average over many UrQMD transport events
2) Determine local temperature & density in a grid of space-time cells
3) Use HMBT ρ & ω spectral functions to compute EM emission rates
4) Sum up all cells ➔ **thermal dilepton radiation**
5) Add freeze-out contributions ➔ non-thermal part

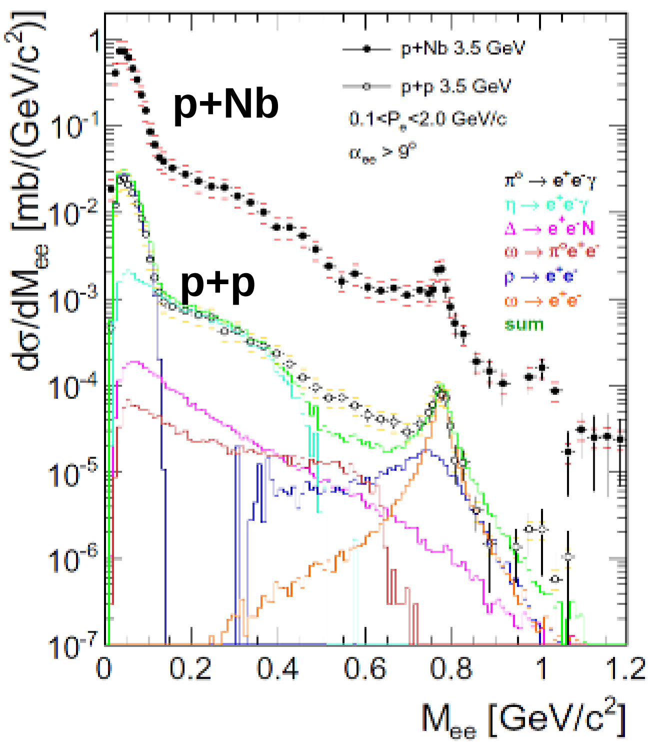
in medium thermal e^+e^- radiation



Prediction for Au+Au:



ρ/ω from p+Nb vs. p+p at 3.5 GeV



Agakishiev et al. (HADES),
PLB 715 (2012) 304

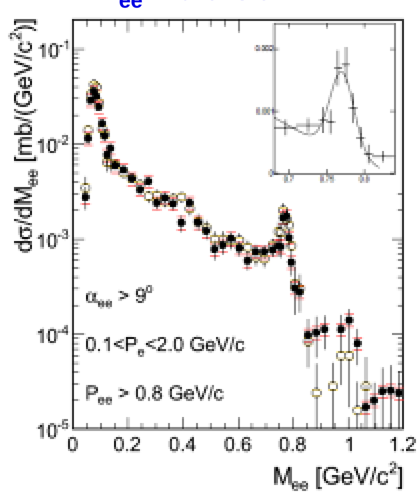
HADES: 3.5 GeV p + Nb vs. p + p

(good acceptance for low-momentum pairs !)

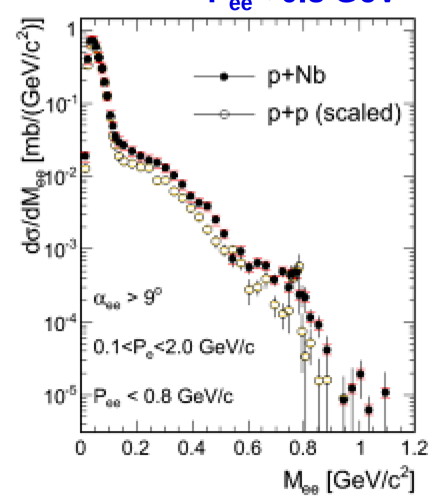
for p_{e+e-}< 0.8 GeV/c strong excess over pp:

►Slow pairs show strong in-medium effects

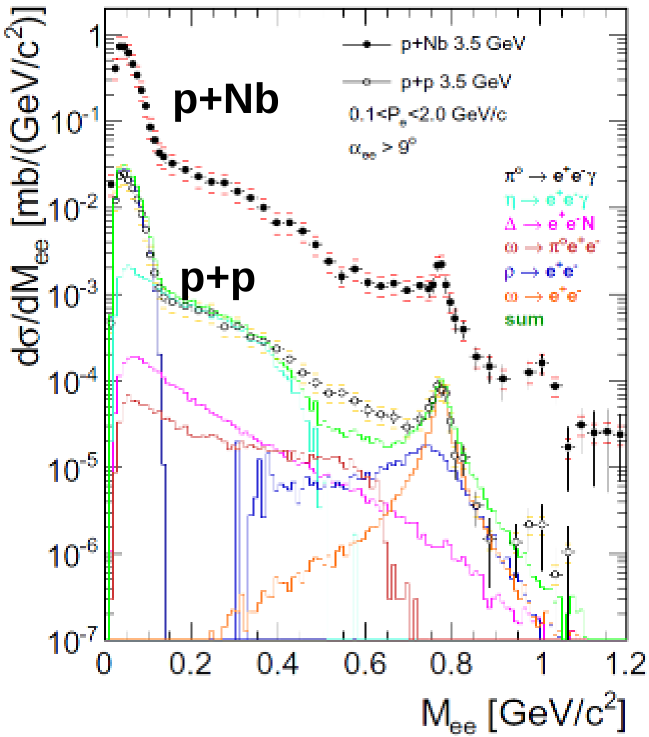
P_{ee} > 0.8 GeV



P_{ee}< 0.8 GeV



ρ/ω from p+Nb vs. p+p at 3.5 GeV

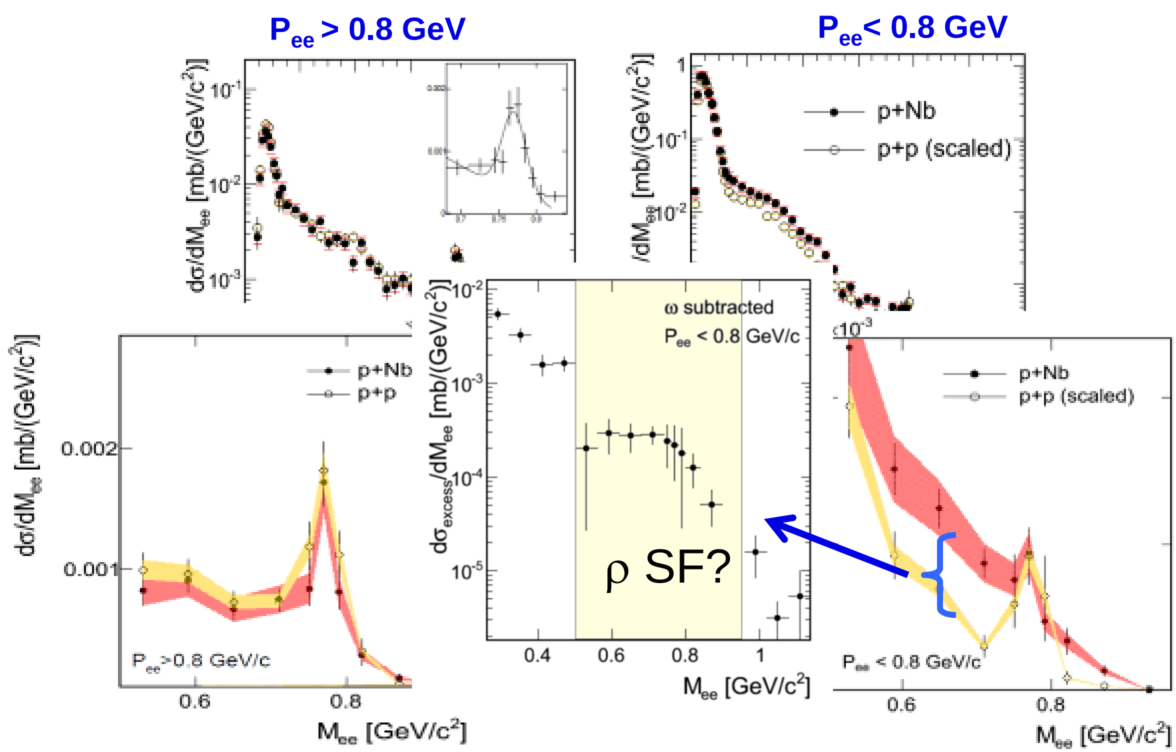


HADES: 3.5 GeV p + Nb vs. p + p

(good acceptance for low-momentum pairs !)

for $p_{e+e-} < 0.8$ GeV/c strong excess over pp:

► Slow pairs show strong in-medium effects

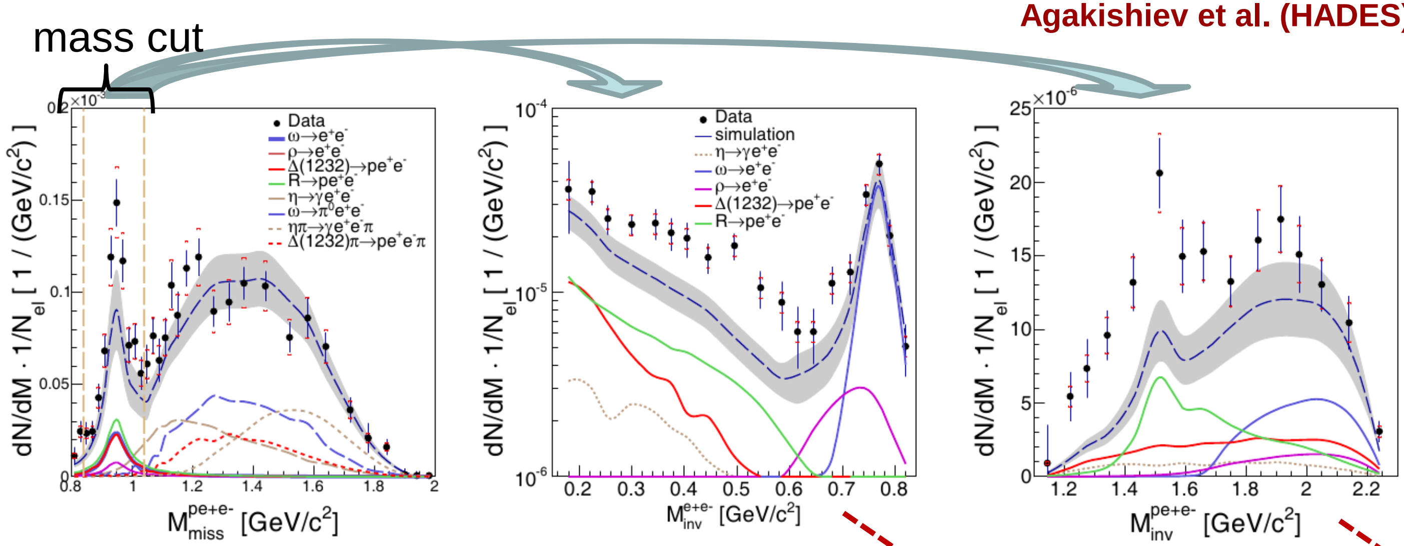


Agakishiev et al. (HADES), PLB 715 (2012) 304

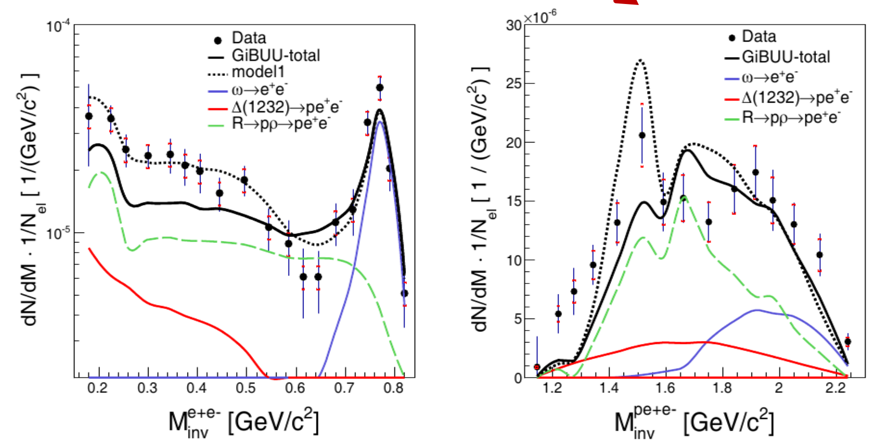
Exclusive reactions: Disentangling resonances

Exclusive measurement of 3.5 GeV $pp \rightarrow pN^* \rightarrow pp\, e^+e^-$

Agakishiev et al. (HADES), EPJA 50 (2014) 82



With enhanced **N*(1520) → Nρ**:

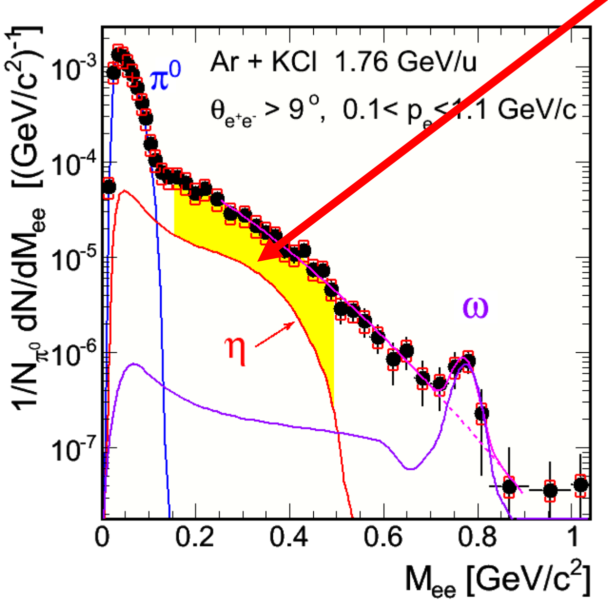


► Global (PWA) fits constrain the contributing baryon resonances

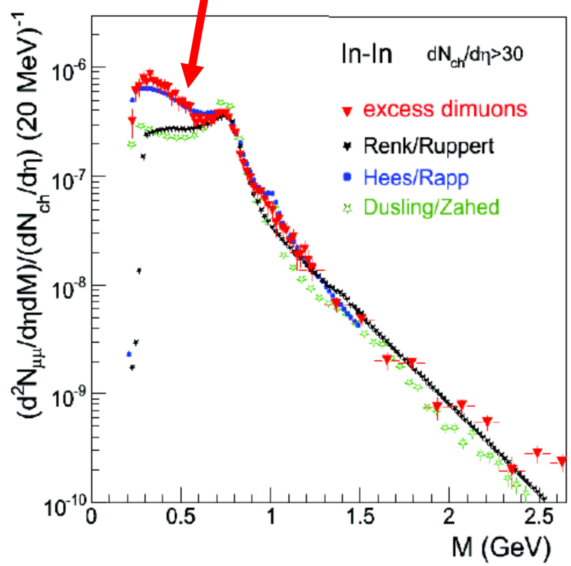
The ubiquitous dilepton excess yield in HIC

Low-mass dilepton excess present at **all** energies

SIS (HADES)

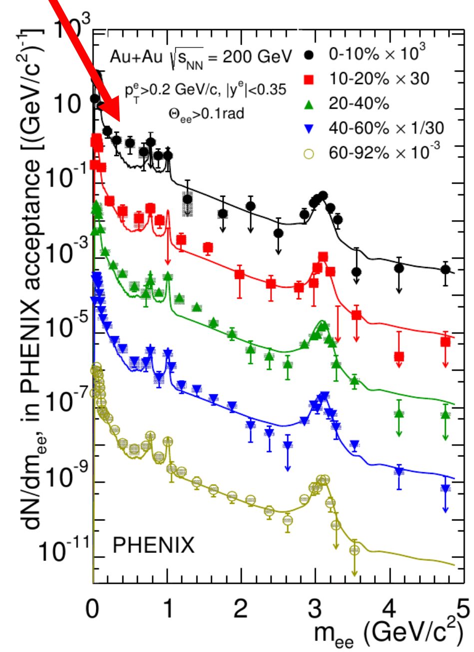


SPS (NA60)



RHIC (PHENIX)

arXiv:1509.04667

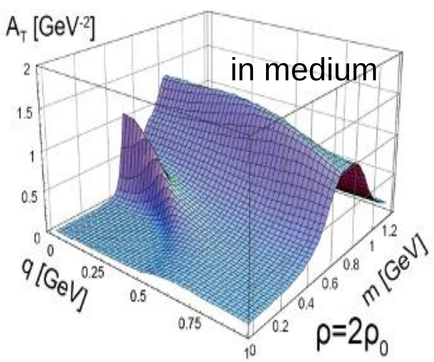


► Coarse-grained transport + in-medium spectral functions provides a quantitative description of the excess!

STAR: **PRC 92 (2015) 024912**

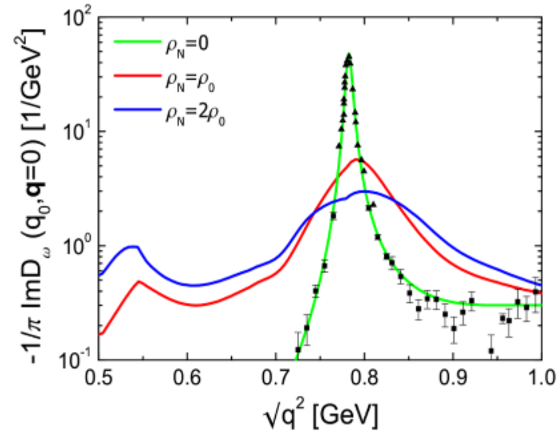
HMBT vs. chiral symmetry restoration

ρ spectral function



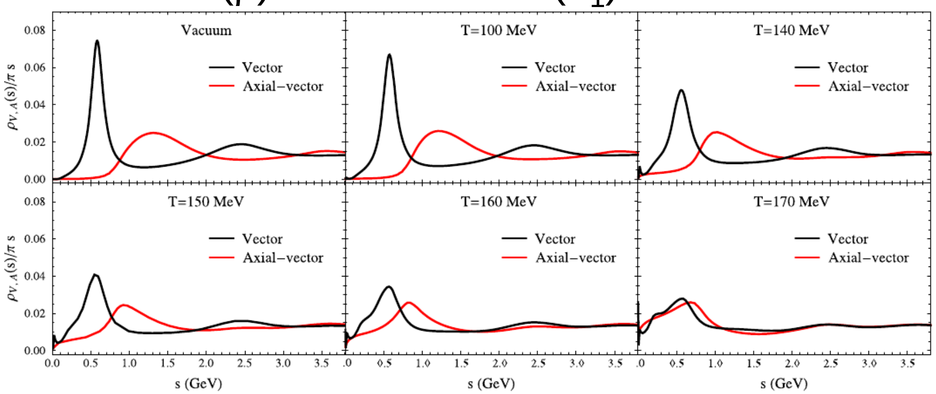
Leupold, Mosel, Post et al.
NPA 741 (2004) 81

ω spectral function



Mühlich, Leupold & Mosel,
NPA 780 (2006) 187

vector (ρ) & axial vector (a_1) vs. T



Hohler & Rapp,
PLB 731 (2014) 103

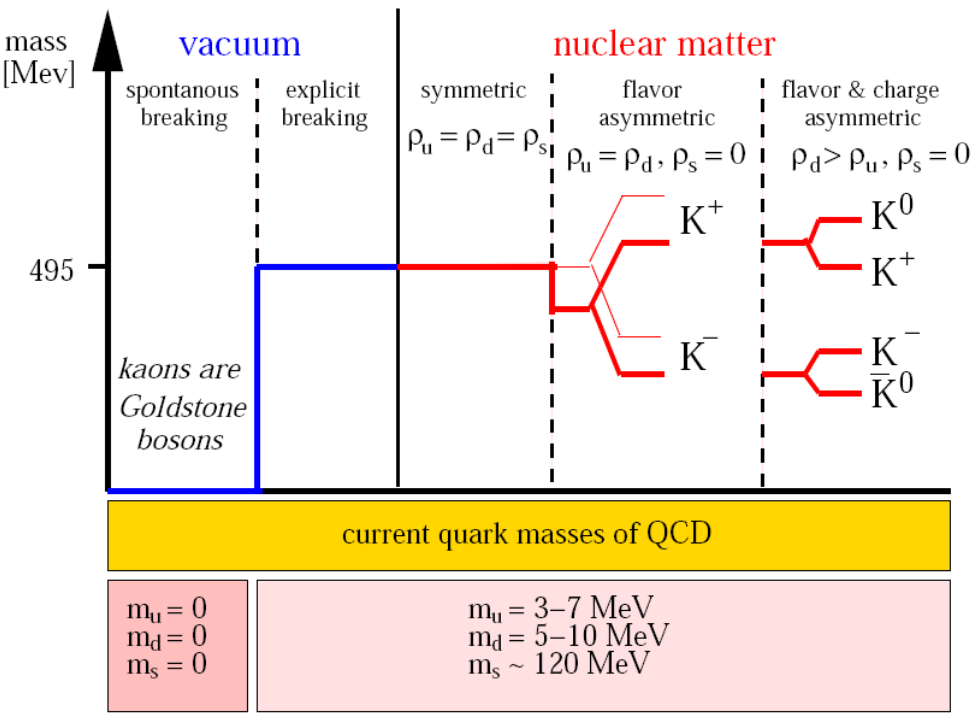
At high T, hadronic many-body theory is consistent with chiral symmetry Restoration by fullfilling the Weinberg sum rules.

Argument needs to be extended to finite densities …

Strangeness production in few-GeV HIC

Kaons in the medium

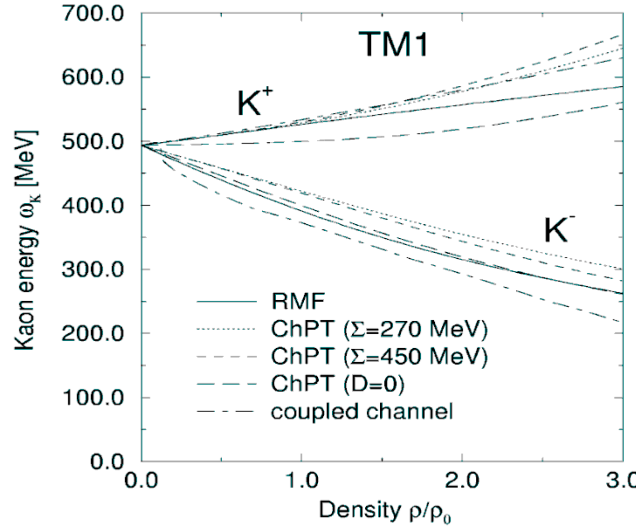
Kaons and chiral symmetry:



Dispersion relation:

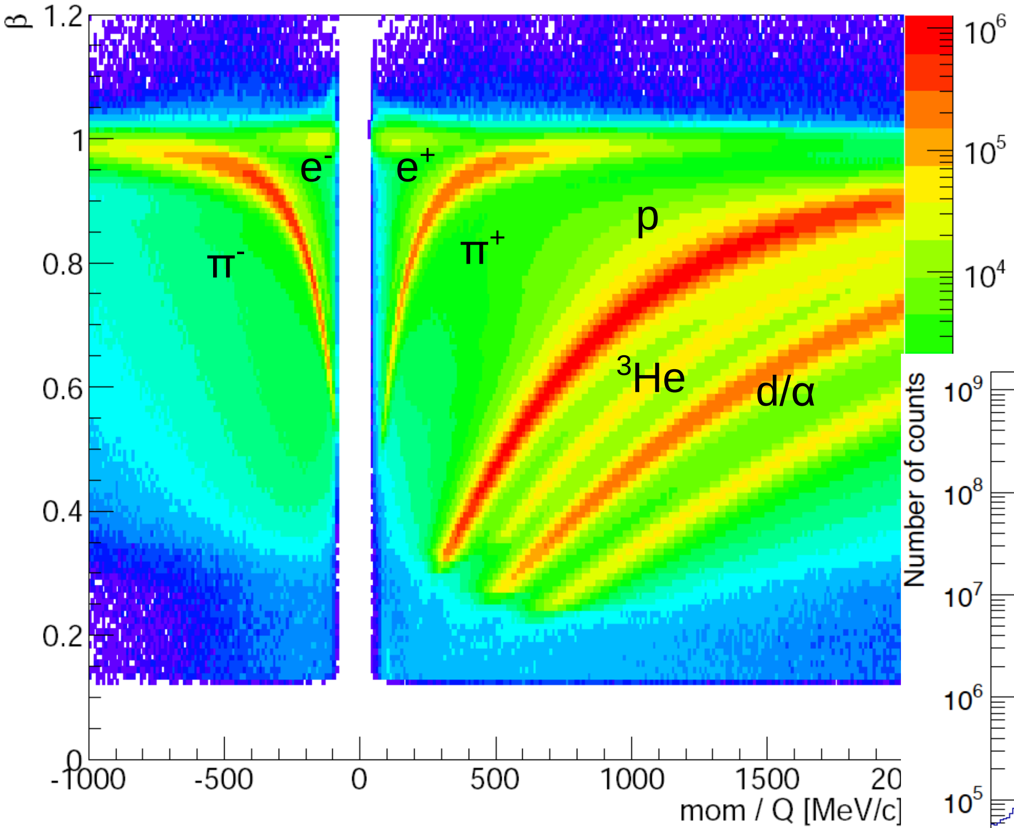
$$\omega_{K^\pm}(\vec{k},\rho_N) = \left[m_K^2 + \vec{k}^2 - \frac{\Sigma_{KN}}{f^2}\rho_S + \left(\frac{3\rho_N}{8f^2}\right)^2 \right]^{\frac{1}{2}} \pm \frac{3\rho_N}{8f^2}$$

$$\omega_{K^\pm}(\vec{k},\rho_N) = \left(m_K^{*2} + \vec{k}^2\right)^{\frac{1}{2}} = U_S \pm U_V + \left(m_K^2 + \vec{k}^2\right)^{\frac{1}{2}}$$



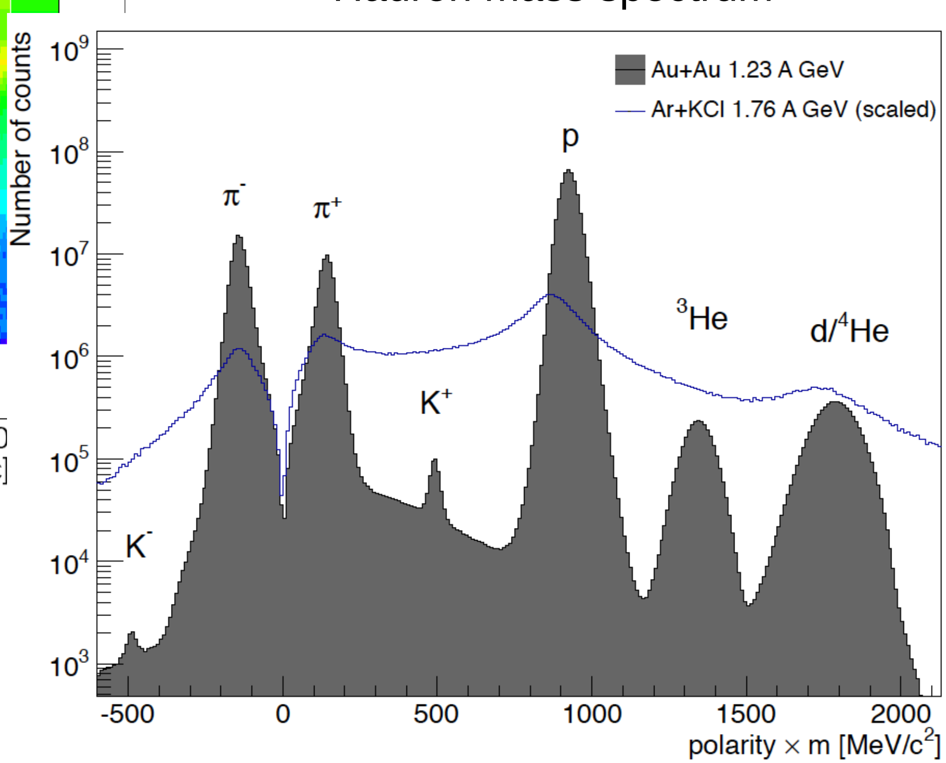
D.B. Kaplan et al., **PLB 175 (1986) 57**
G.E Brown et al., **NPA 567 (1994) 937**
T. Waas et al., **PLB 379 (1996) 34**
J. Schaffner-Bielich et al., **NPA 625 (1997) 325**
G. Mao et al., **PRC 59 (1999) 3381**

HADES performance: particle ID



Hadron pid based on
- ToF
- Momentum
- dE/dx

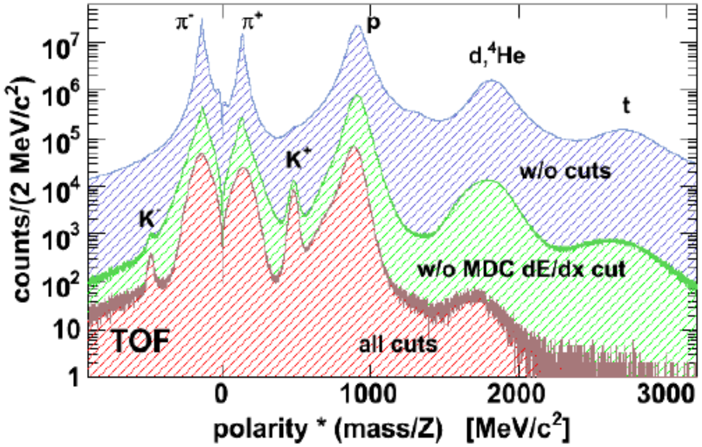
Hadron mass spectrum



Strangeness production in Ar+KCl

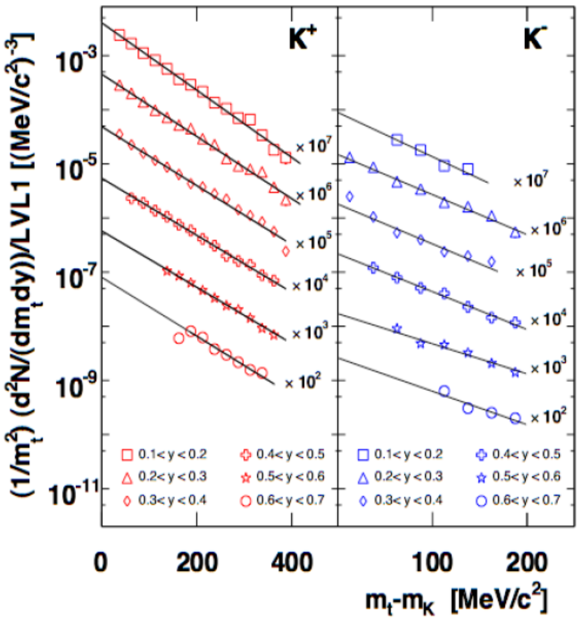
HADES has

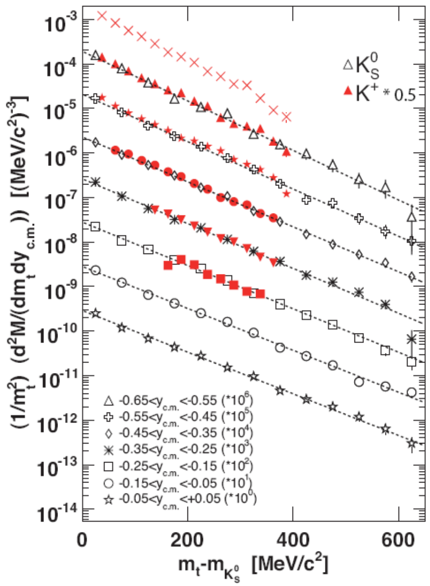
- high mom resolution
- high acceptance
- good particle ID
- vertexing

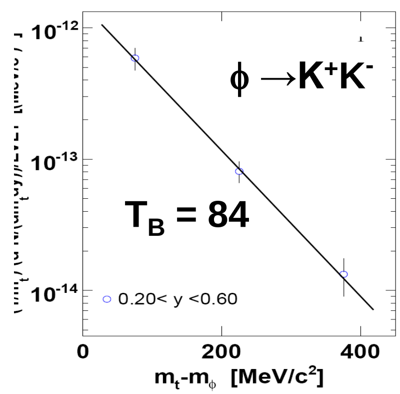


1.76 GeV/u Ar+KCl

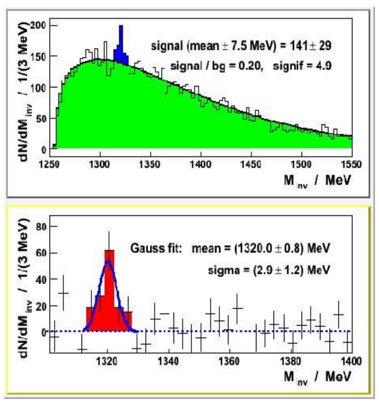
PID based on dE/dx and TOF





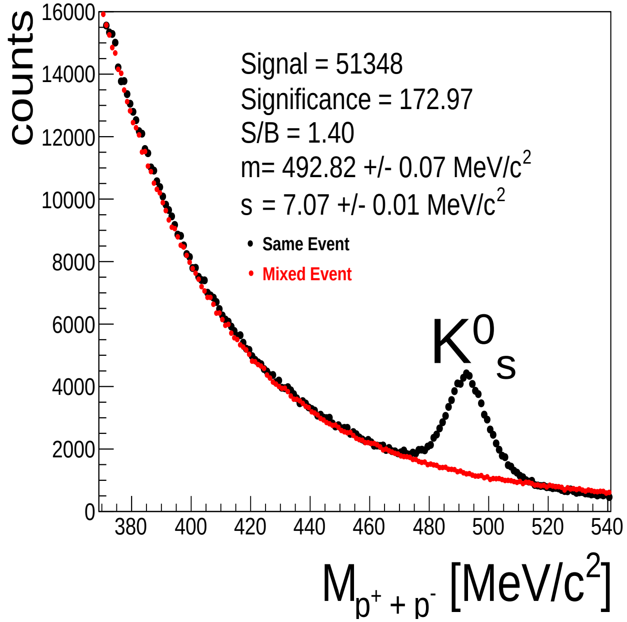


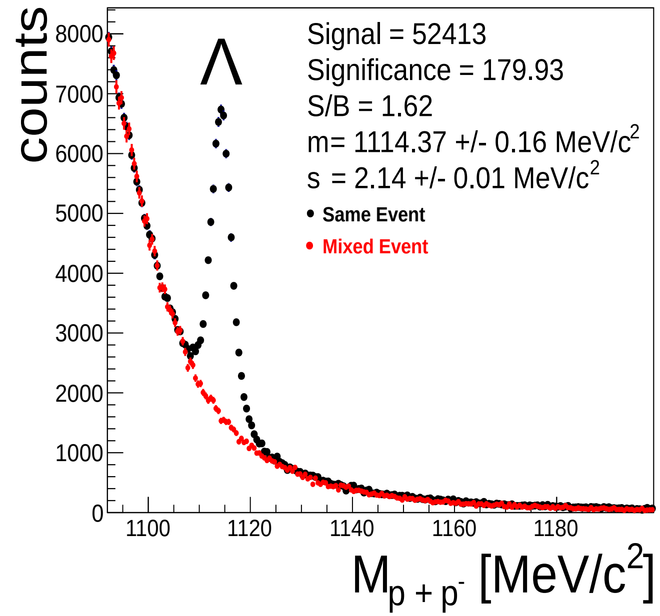
$\Xi^- \rightarrow \Lambda\pi^-$



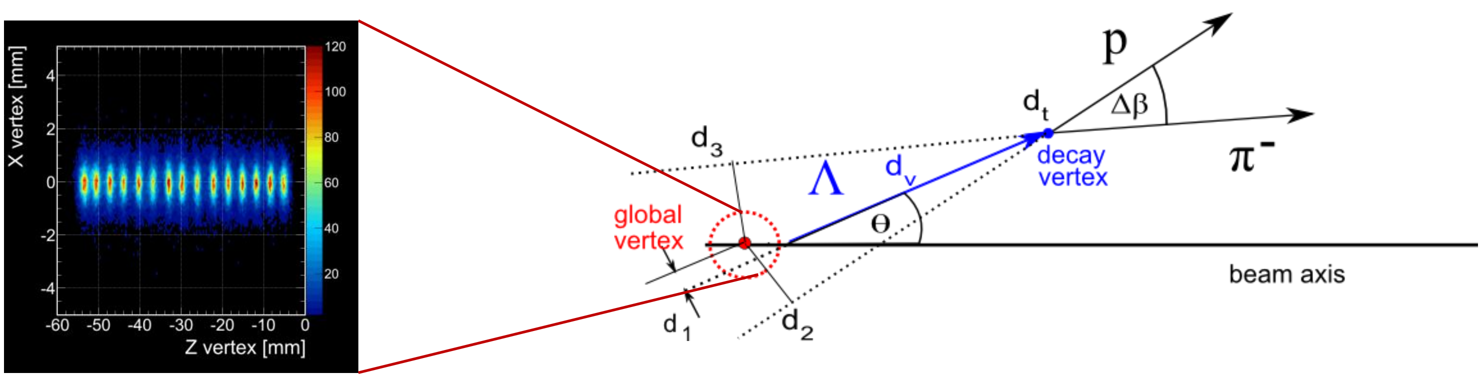
PRC 80 (2009) 025209
PRL 103 (2009) 132310
PRC 82 (2010) 021901
EPJA 44 (2010) etc.

HADES performance: weak decays



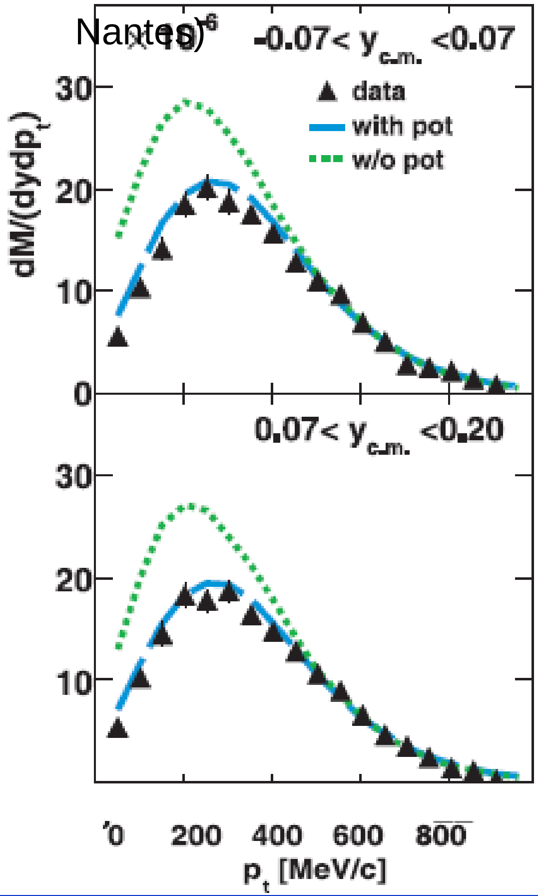


event
vertex



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

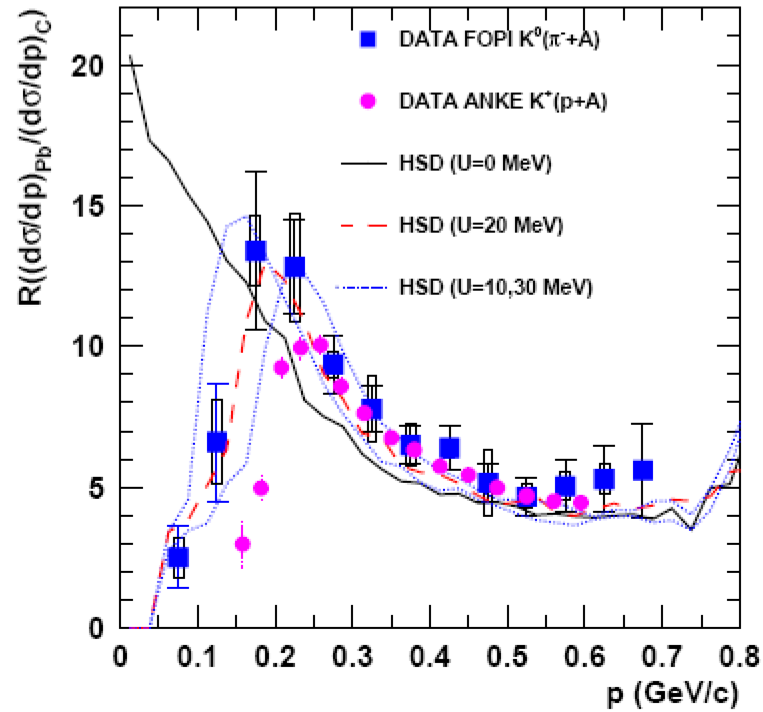
HADES Ar+KCl data
vs. IQMD (SUBATECH
Nantes)



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)



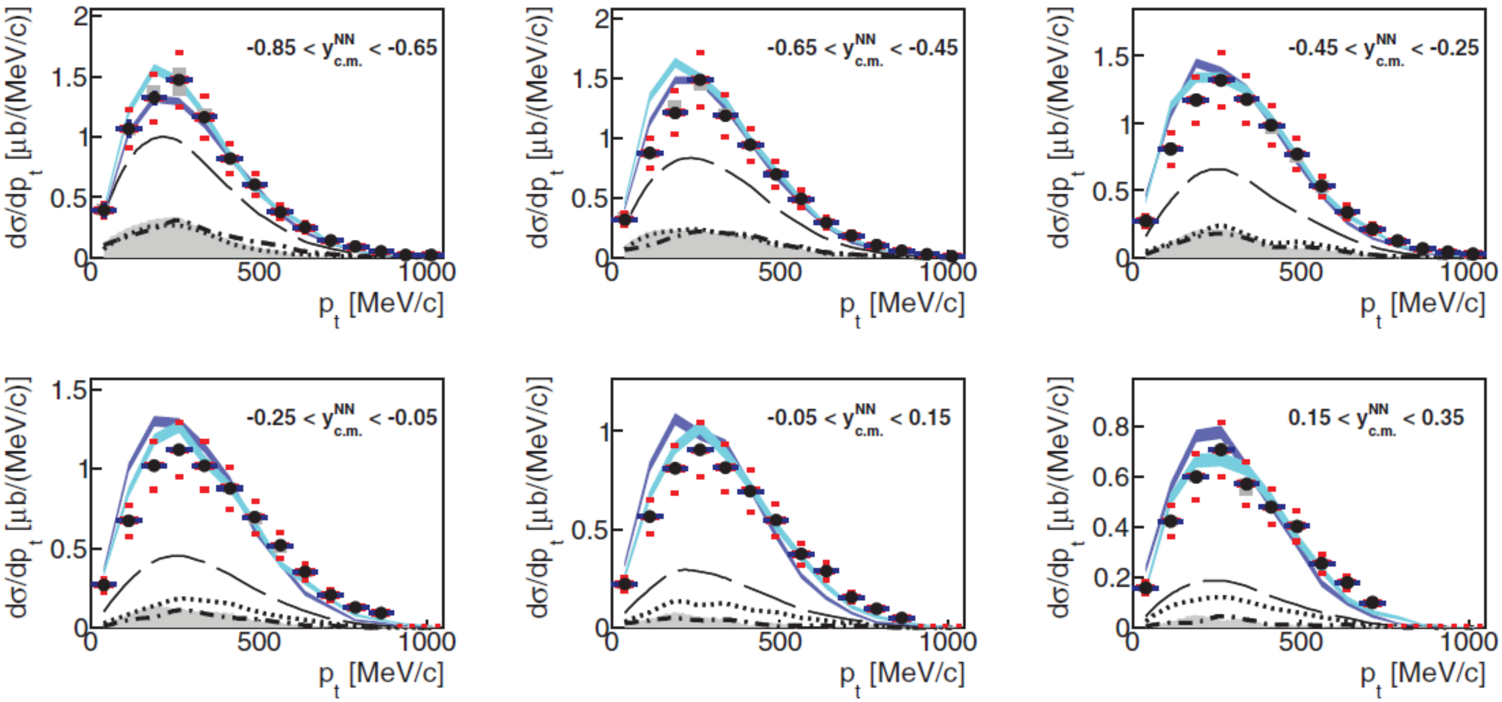
consistent with V_0 = 20±5 MeV at $\rho=\rho_0$

extrapolation from low density to ρ_0 (HSD)

K^0 in-medium potential in p+Nb

HADES p+Nb data vs. GiBUU (Gießen, Frankfurt)

PRC 90 (2014) 054906



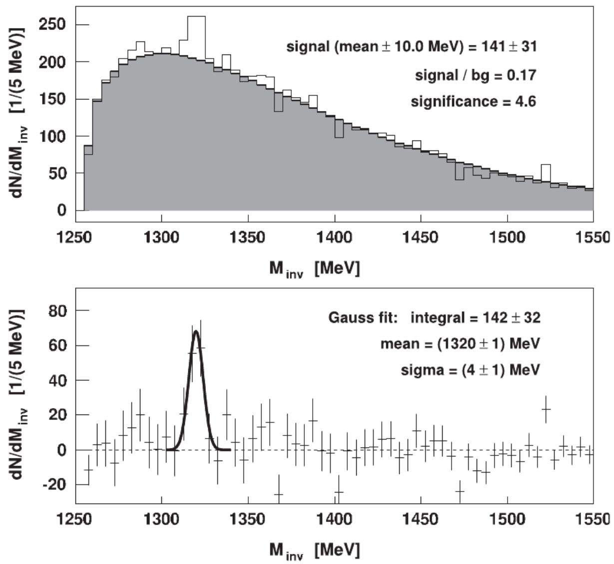
consistent with V_0 = 35 MeV at $\rho=\rho_0$
kaon repulsive potential from chiral perturbation theory

HADES: Far subthreshold Ξ^- production

Reconstuct Ξ^- in off-vertex $\Xi^- \rightarrow \Lambda\pi^- \rightarrow p\,\pi^-\,\pi^-$ decays:

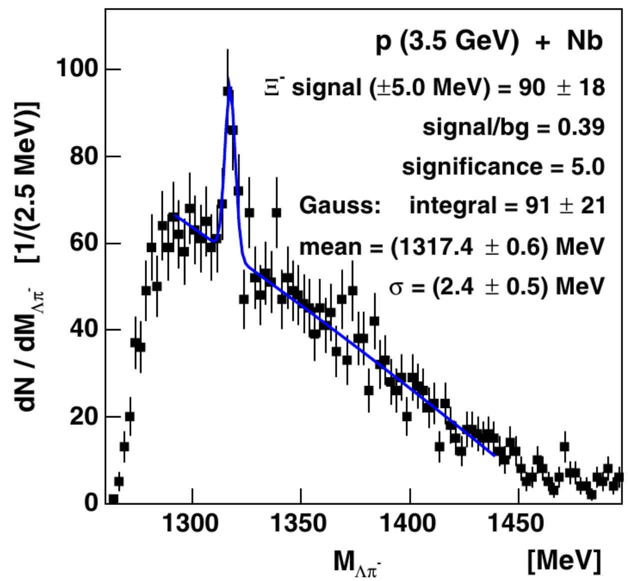
1.756 GeV/u Ar + KCl

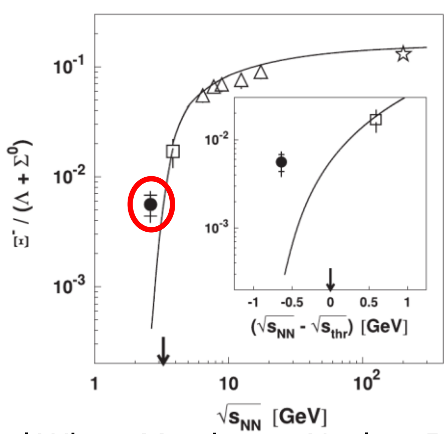
PRL 103 (2009) 132301



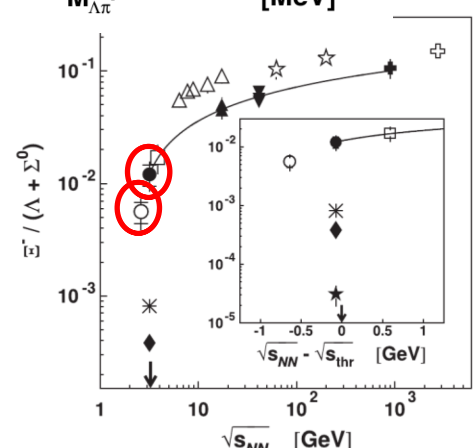
3.5 GeV p + Nb

PRL 114 (2015) 212301





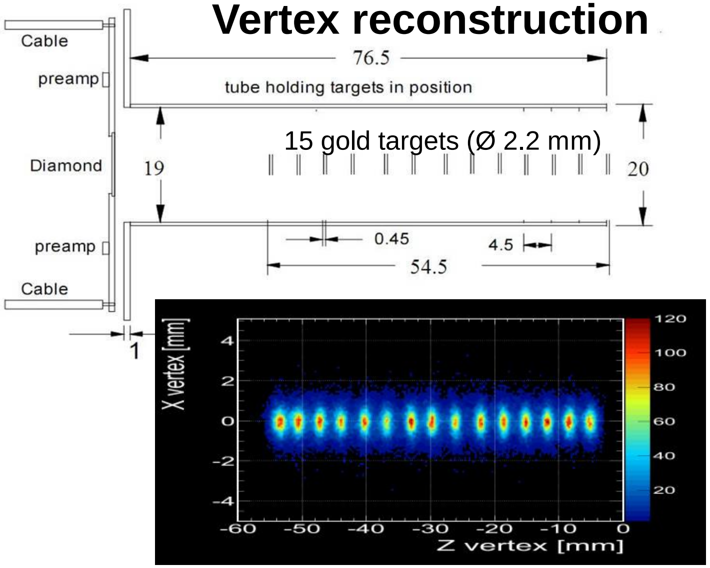
>10-fold enhanced over various model calculation!

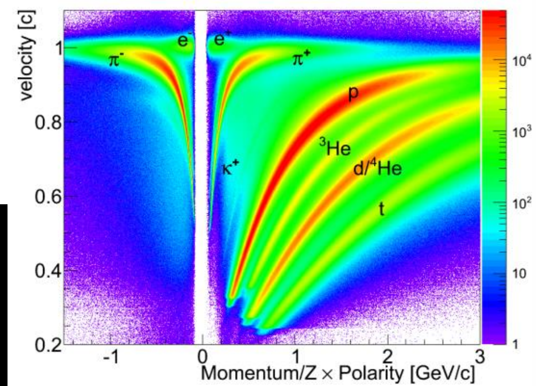


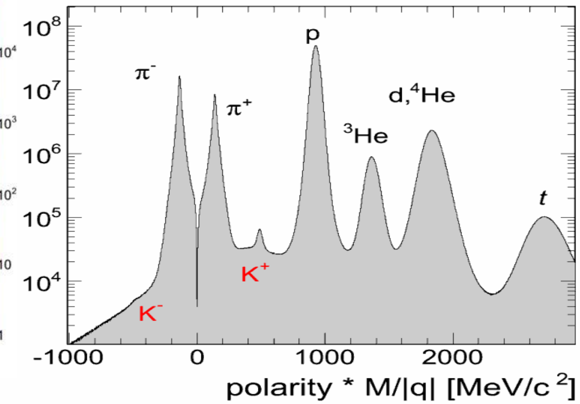
1.23 GeV/u Au + Au: strangeness production

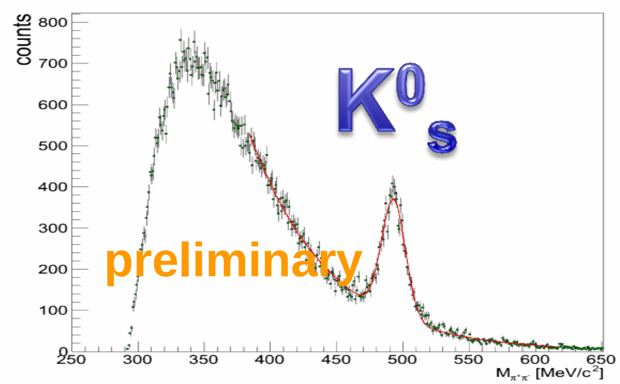
Strangeness production

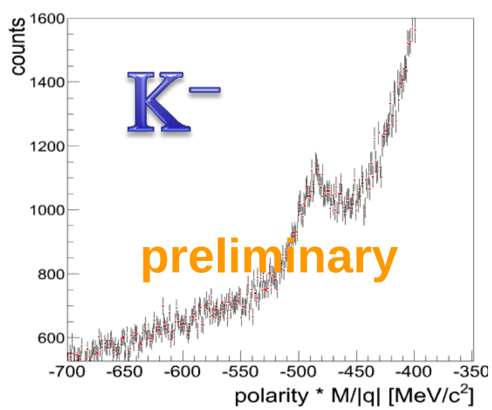
Vertex reconstruction

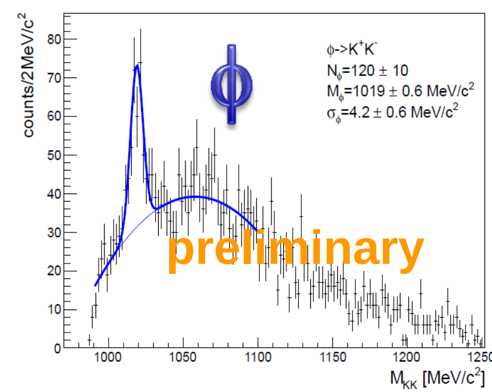












First measurement at such low beam energy !

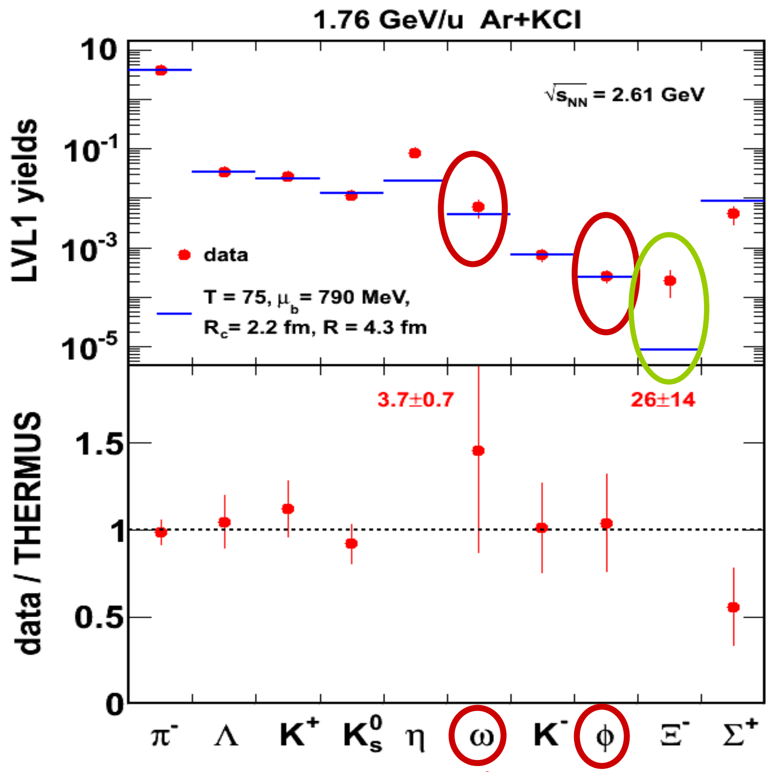
Comparison with statistical hadronization models

THERMUS
statistical model

T, μ_B and R_C
fitted to HADES yields
in particular from

$\omega \rightarrow e^+e^-$
$\phi \rightarrow K^+K^-$

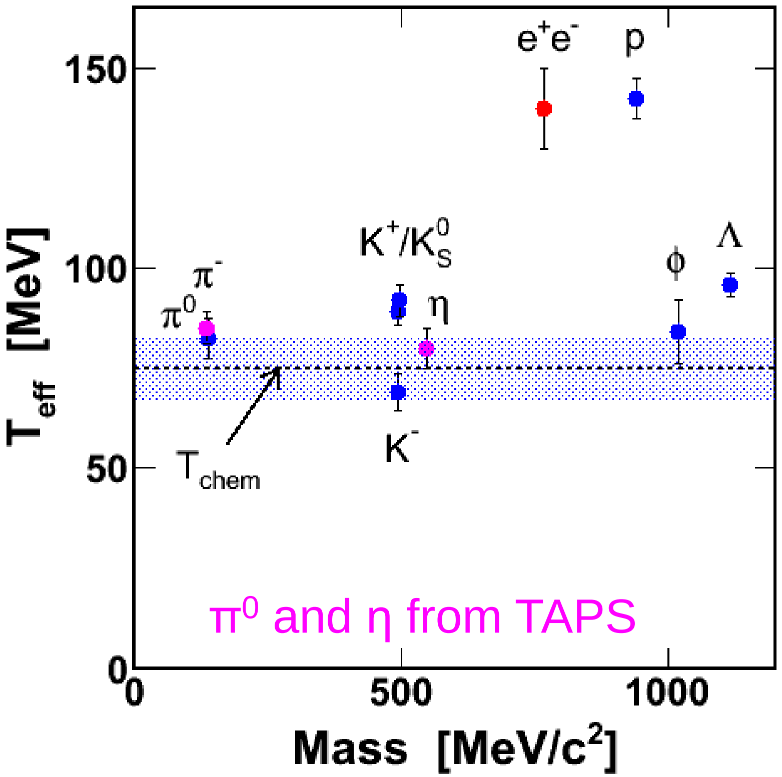
$\Xi^- \rightarrow \Lambda\pi^-$

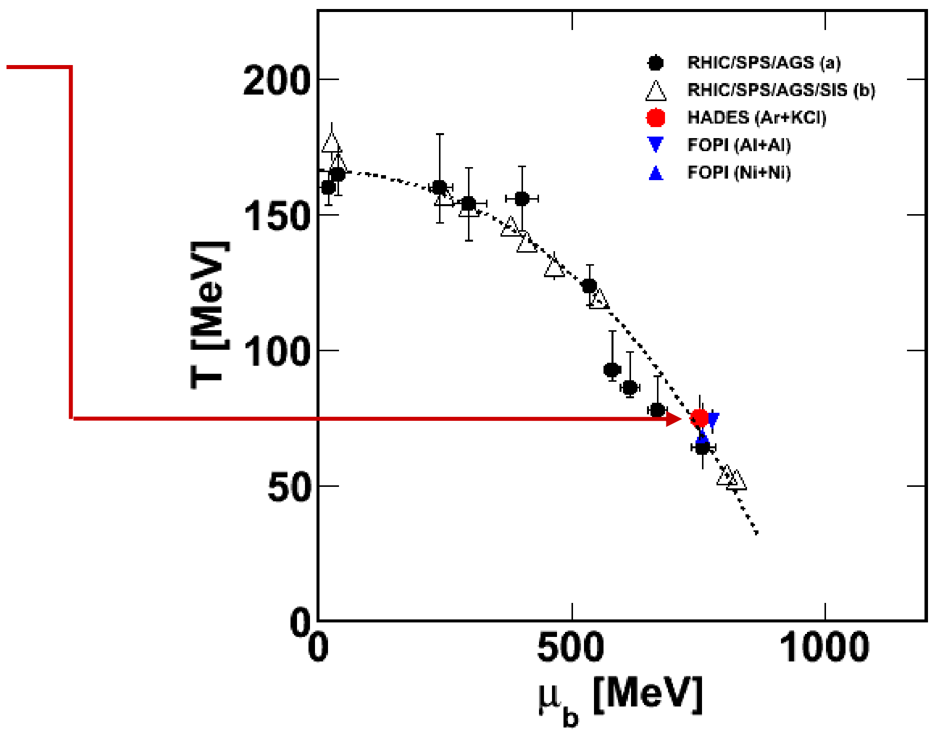


Ξ^- yield missed by
> order of magnitude !

Vector meson yields
(ω and ϕ) are described
well by THERMUS.

Kinetic vs. thermal freeze-out at 1.756 GeV/u





Pion-induced reactions: π + p and π + A

Secondary π^+ and π^- beams of $\approx 10^6$/s now available

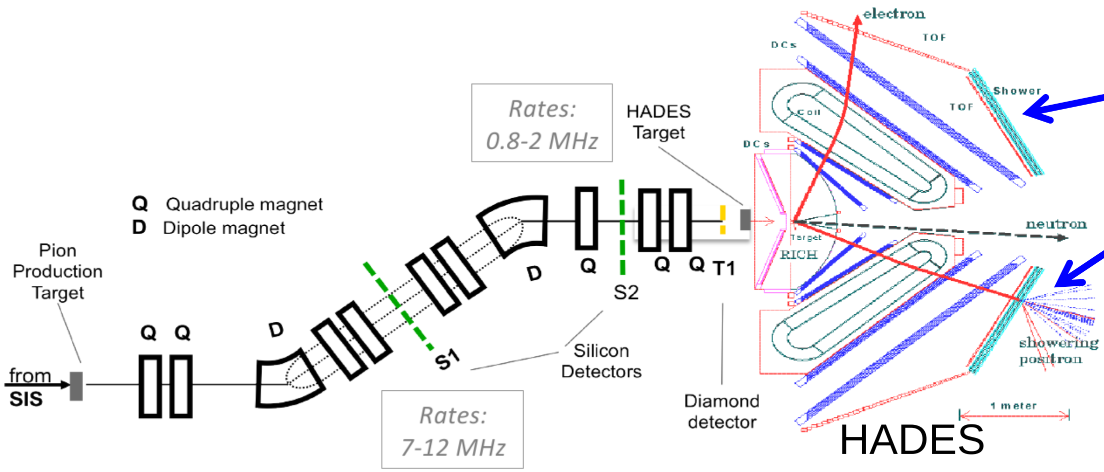
First runs done in 2014.

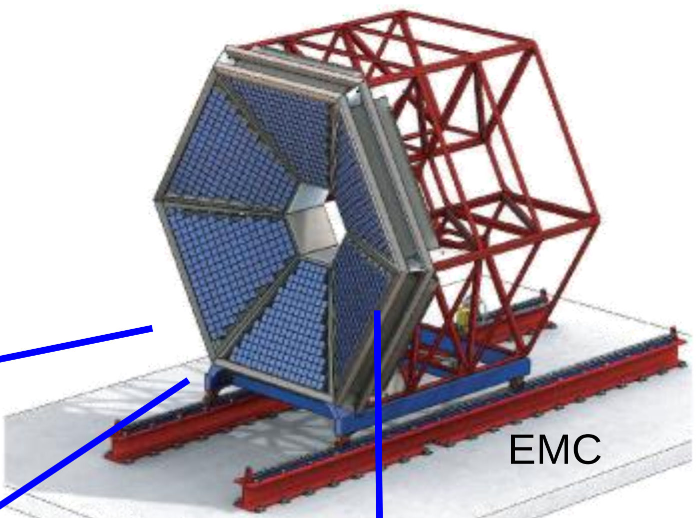
Leadglass EM calorimeter to be added in 2017/18.

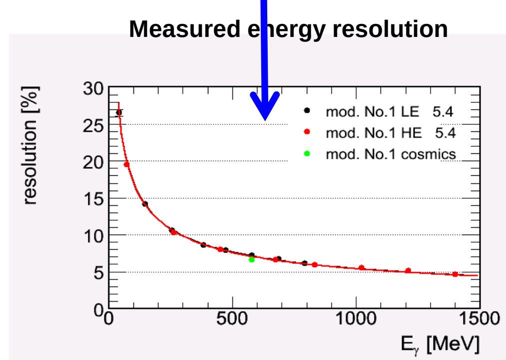
► wealth of physics topics accessible:

- coupling of ρ and ω to N*
- strangeness production (ϕ, K, Σ, Λ, Ξ^-)
- time-like form factors of ω, ϕ, Δ, Σ^0 and Λ
- π + A vs. π + p

► complement existing sparse data base
→ appropriate for a PWA







magnetic separation & Si pion tracker CERBEROS

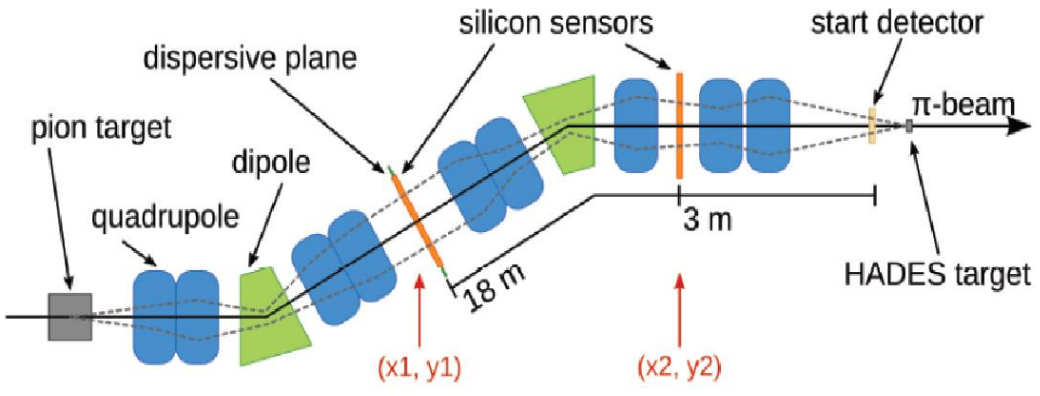
Outlook: the HADES roadmap: 2016 → 2020+

- **2016**: finalize Au+Au 1.23 GeV/u data analysis
- **2017-18**: finalize pion beam data analysis
- **2016-18**: upgrade HADES: add leadglass EM calorimeter, add strawtube tracker, replace RICH photon detector
- **2018-20**: hi-stat pion beam, p+A and A+A runs
- **2020/21**: move HADES to SIS100
- **>2021**: first beams from SIS100

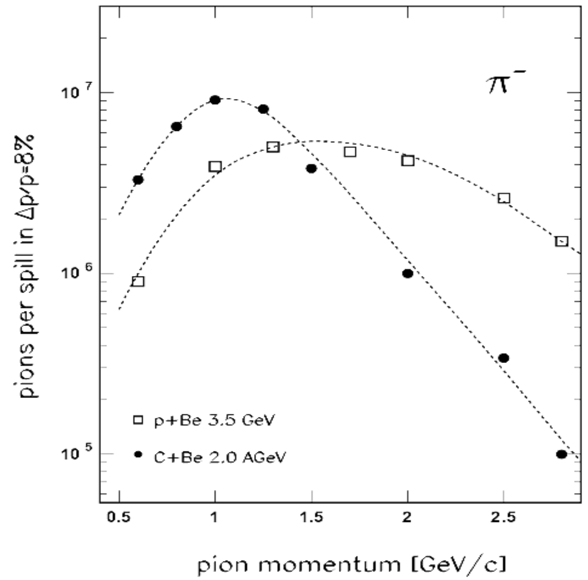
Leftovers

π-N reactions

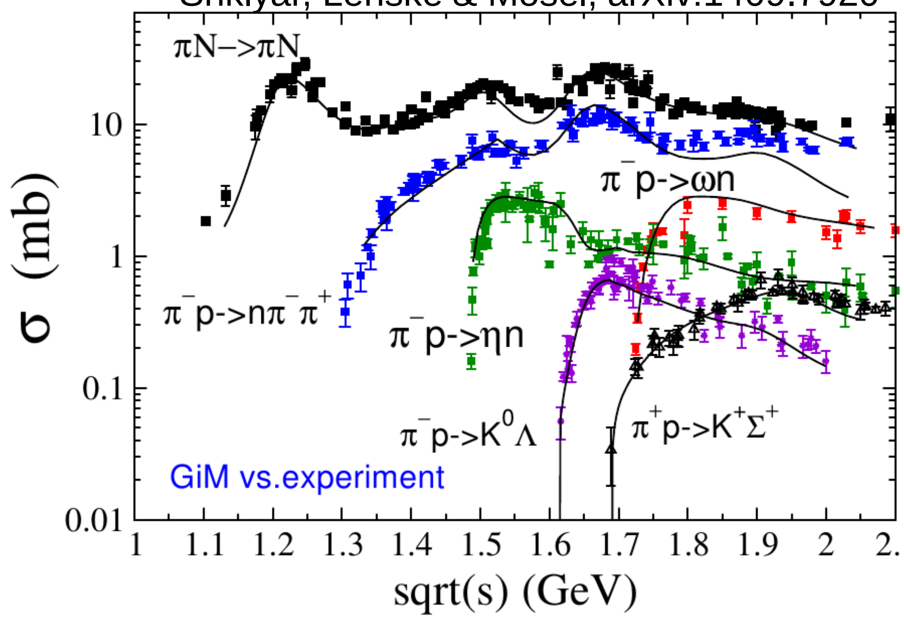
pion-beam chicane @ GSI



expected pion rates on target

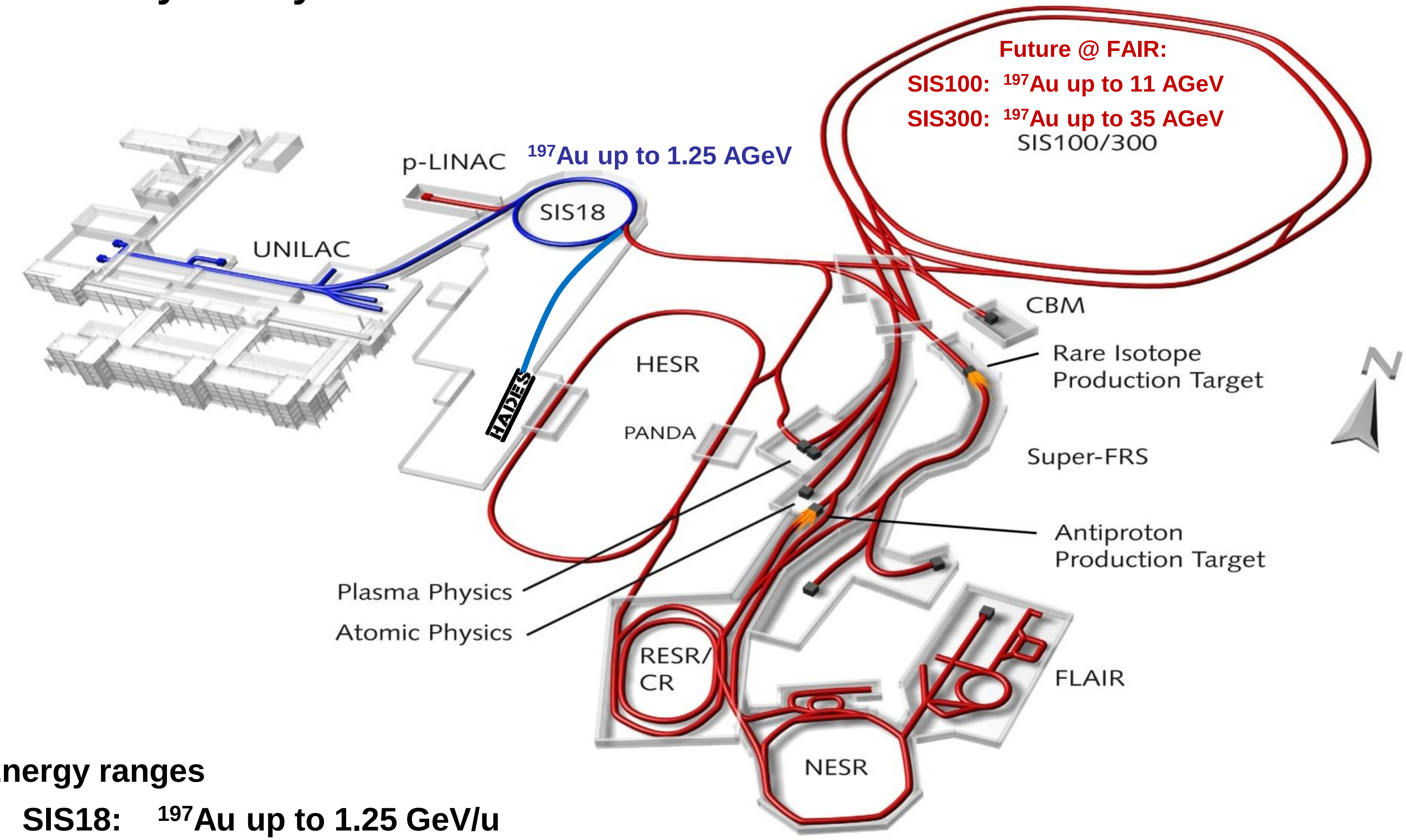


Shklyar, Lenske & Mosel, arXiv:1409.7920



The FAIR project at GSI

SIS heavy-ion synchrotrons at GSI Darmstadt



Energy ranges

- **SIS18: ^{197}Au up to 1.25 GeV/u**
- **SIS100: ^{197}Au up to 11 GeV/u - future HADES/CBM**
- **SIS300: ^{197}Au up to 35 GeV/u - future CBM**

HADES at the future FAIR facility

SIS100 (>2020):

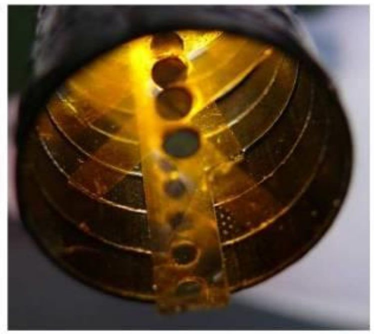
p+A at 15 GeV
A+A at 8 GeV/u

FAIR construction site 2015

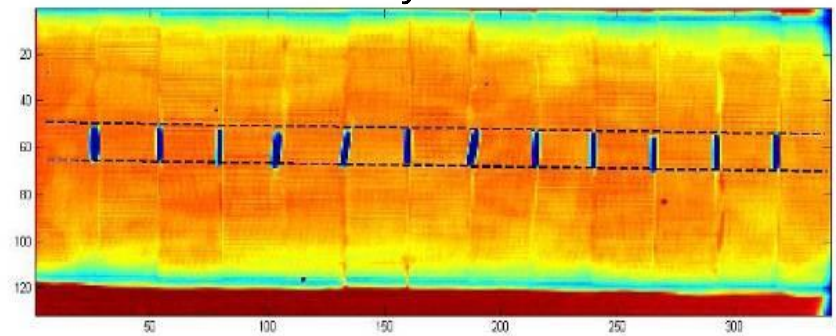
HADES segmented targets

3.5 GeV p+Nb:

- ^{93}Nb material
- 12 discs of Ø = 1.25 mm
- Δz = 4.5 mm
- 2.8% interaction prob.



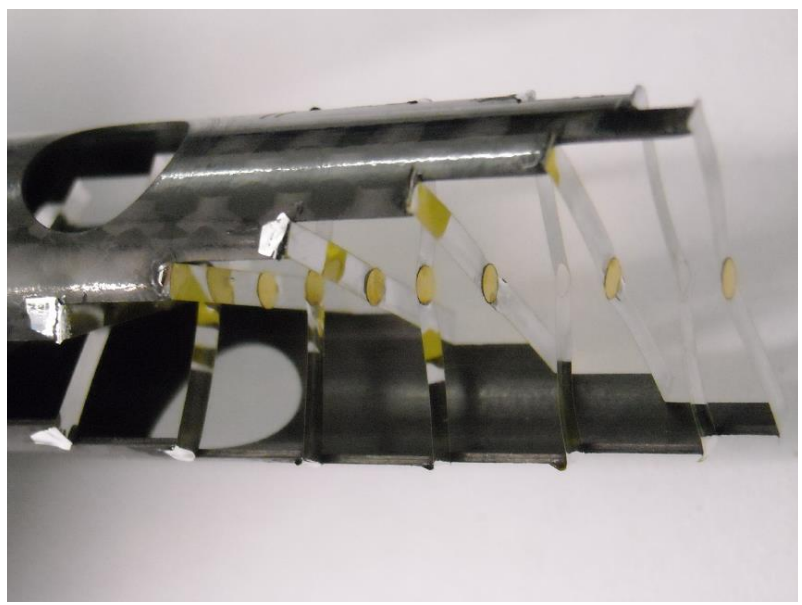
X-ray view



~ 55 mm

1.23 GeV Au+Au:

- ^{197}Au material
- 15 discs of Ø = 2.2 mm
- Δz = 3.6 mm
- 2.0% interaction prob.
- very low material budget

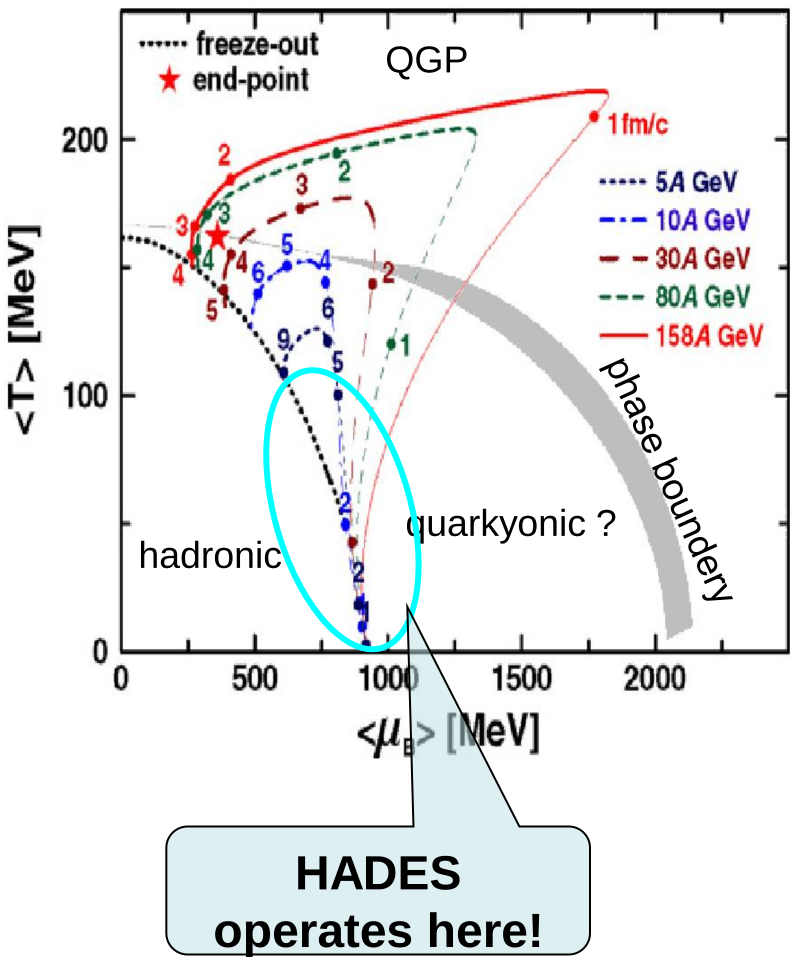


Kindler et al.,
NIM A 655 (2011) 95

HIC at GeV energies: moderate T & high μ_B

Quarkyonic matter: **Andronic et al., NPA 837 (2010) 65**

Trajectories: **Ivanov et al., PRC 73 (2006) 044904**



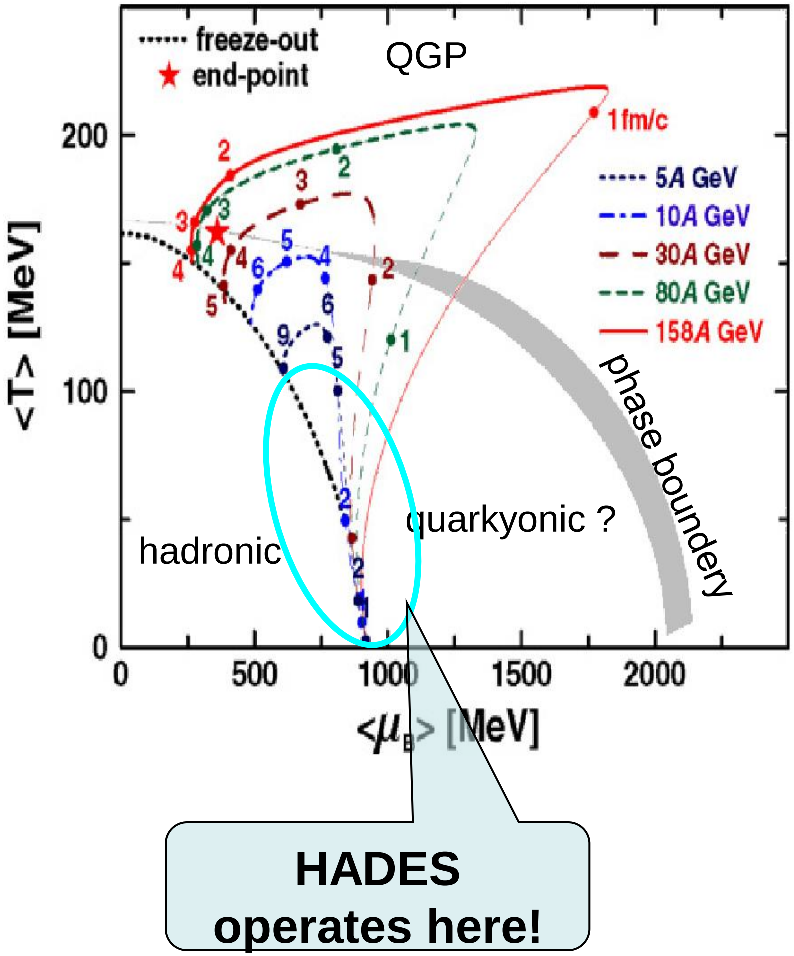
Probing nuclear matter at SIS:

- density: $n_{max}/\nu_0 \cong 2 - 3$
- temperature: $T \cong 50 - 100$ MeV
- baryon resonances matter

The few GeV/u regime: moderate T & high μ_B

Quarkyonic matter: Andronic et al., NPA 837 (2010) 65

Trajectories: Ivanov et al., PRC 73 (2006) 044904



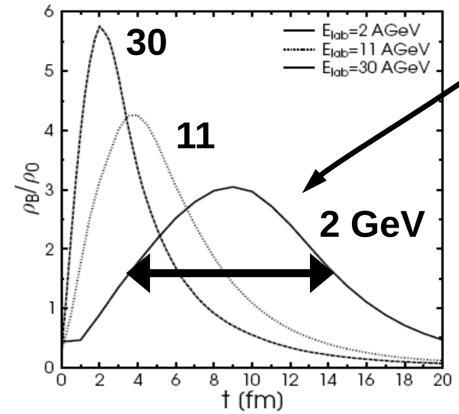
Probing nuclear matter at SIS:

- density: $n_{max}/\nu_0 \cong 2 - 3$
- temperature: $T \cong 50 - 100$ MeV
- baryon resonance matter

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

S. Vogel et al.
PRC 78 (2008) 044909

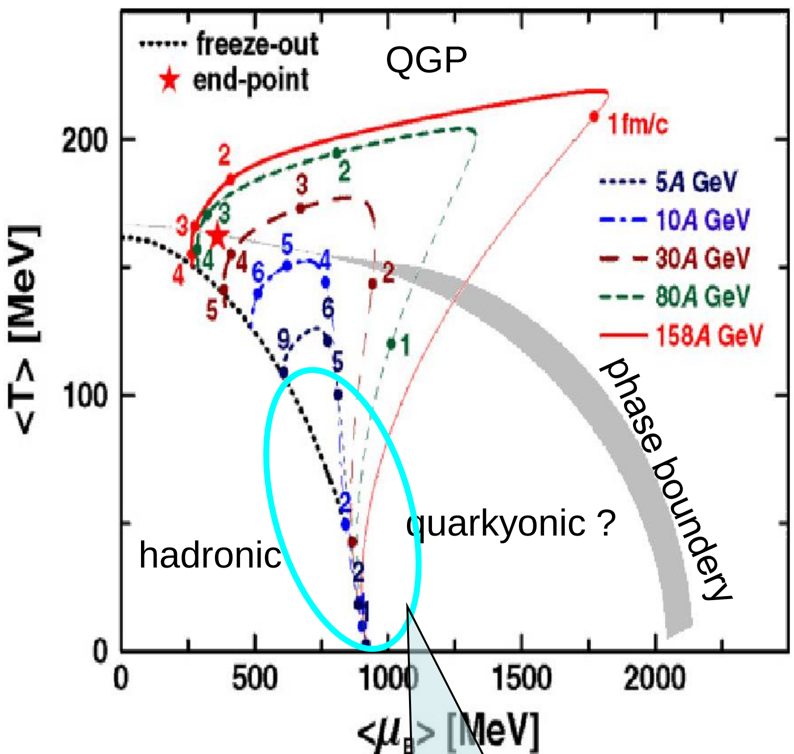
UrQMD
Au+Au



The few GeV/u regime: moderate T & high μ_B

Quarkyonic matter: **Andronic et al.,** NPA 837 (2010) 65

Trajectories: **Ivanov et al.,** PRC 73 (2006) 044904



HADES operates here!

Probing nuclear matter at SIS:

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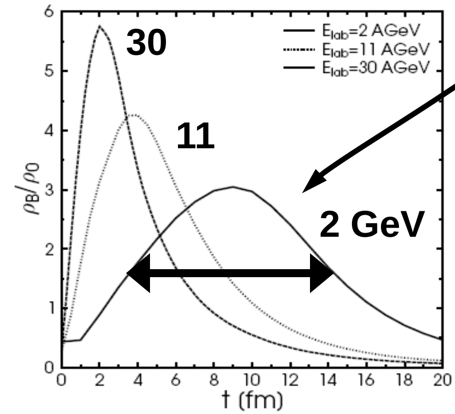
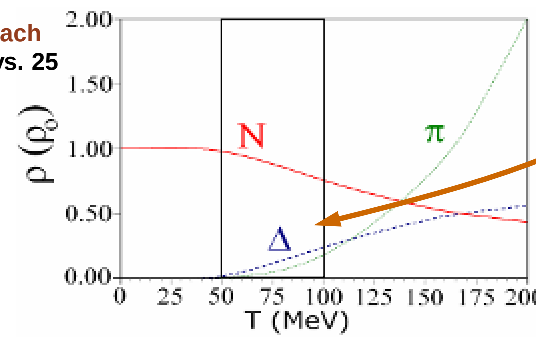
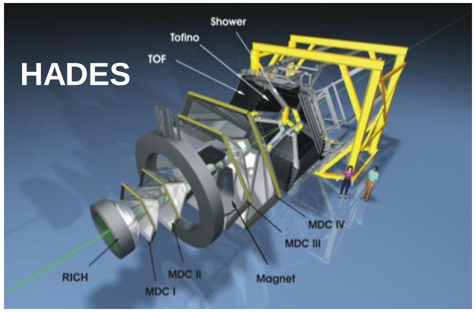


Rapp & Wambach
Adv. Nucl. Phys. 25 (2000) 1

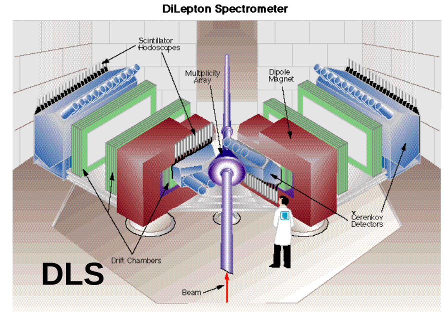
thermal model at $n=n_0$



HADES confirms DLS

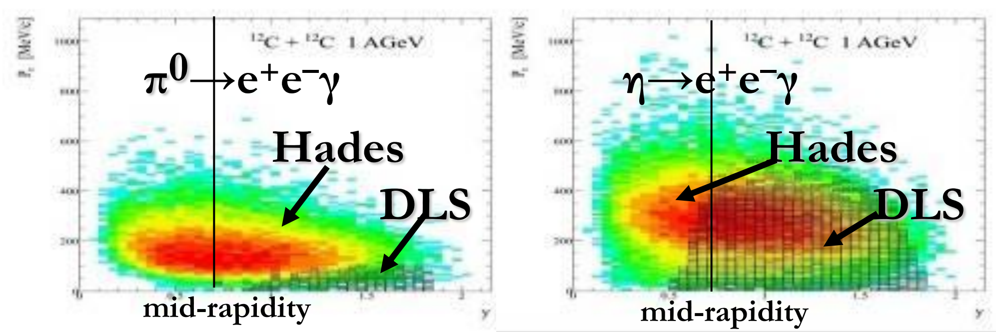


vs.



DLS at the Bevalac (1987 – 1993)

DLZ puzzle: strong excess yield

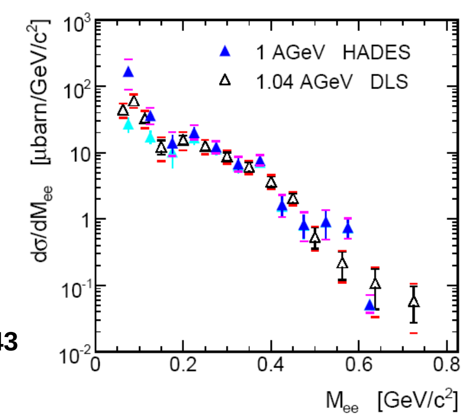


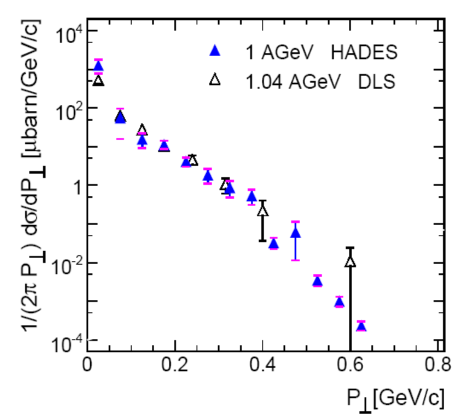
► π^0, η acceptance
HADES >> DLS

► HADES **fully confirmed** highly controversial DLS findings in C+C !

DLS: Porter et al., PRL 79 (1997) 1229

HADES: Agakishiev et al., PLB 663 (2008) 43



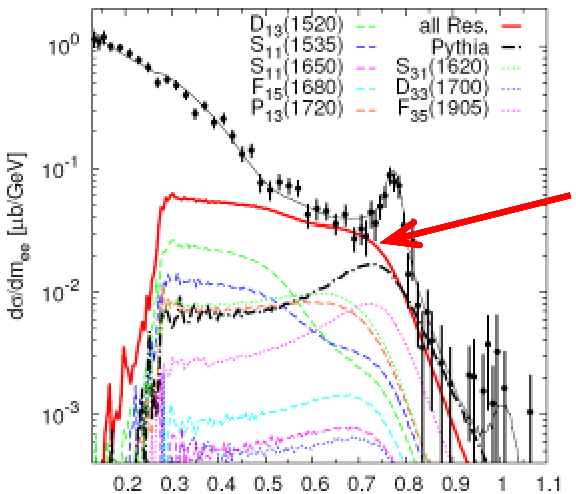


HADES vs. GiBUU transport calculations

GiBUU: Weil, van Hees & Mosel, **EPJA 48 (2012) 111**

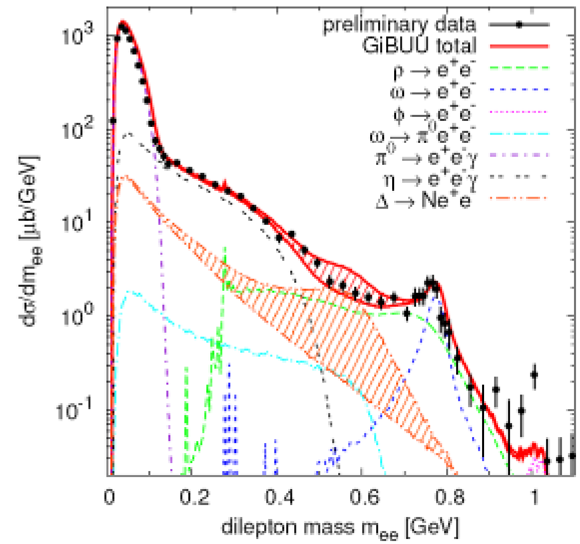
Decays of N* resonances
strongly enhance the $\rho \to e^+e^-$ channel:

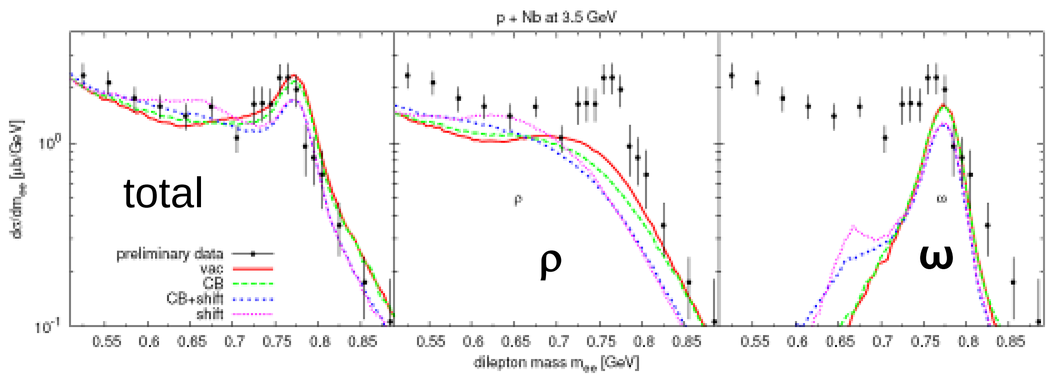
3.5 GeV p+p



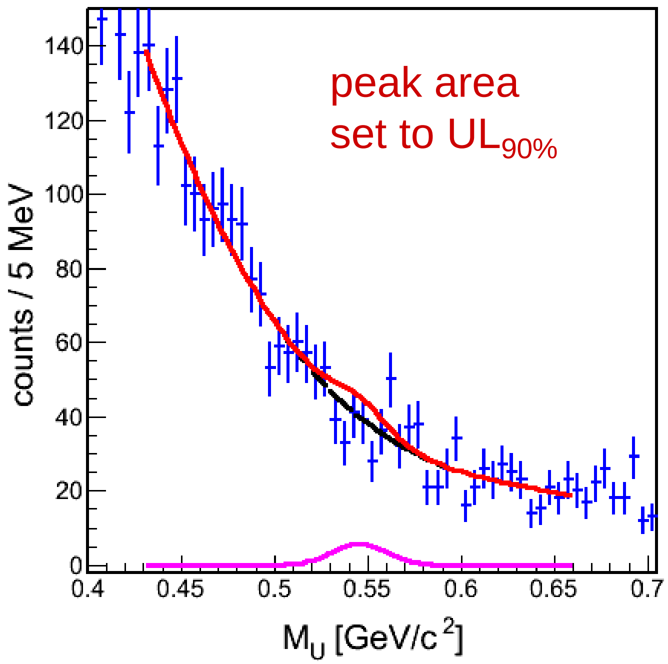
$\rho \to e^+e^-$

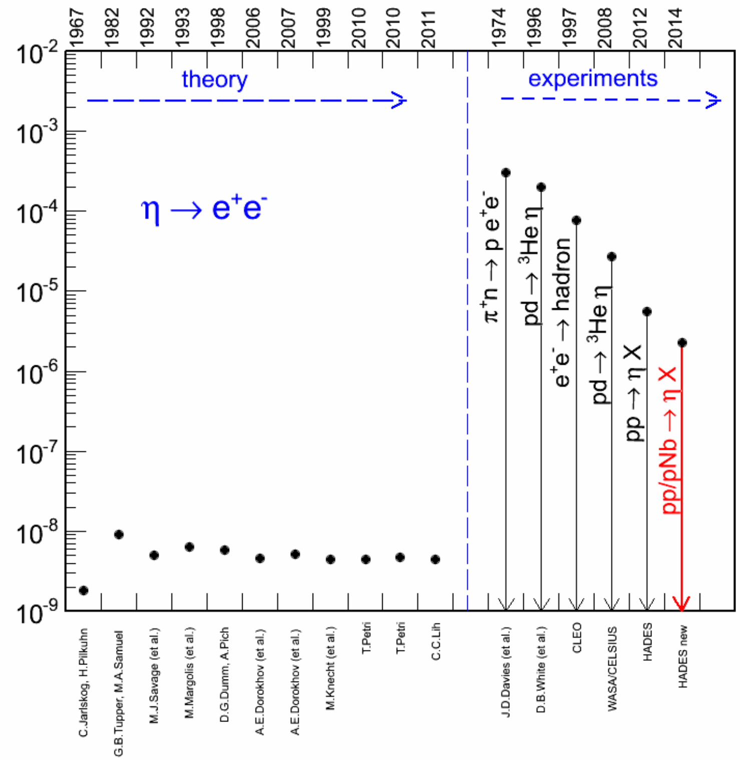
3.5 GeV p+Nb





Bonus track: UL on $\eta \rightarrow e^+e^-$ decay





$BR_{\eta \rightarrow e+e-}$ **< 2.5×10^{-6} at 90% CL**

HADES: Phys. Lett. B 731 (2014) 265

➔ Still far above QCD inspired theoretical expectations: BR≃ 5×10^{-9}