Latest Results from HADES

QCD matter: dense and hot
Hirschegg, Austria, January 17 - 22, 2016

Joachim Stroth, Goethe-University Frankfurt / GSI

Challenges for Nuclear Physics at the Turn of the Centuries

T.D. Lee, NN-Conference 1992 in Kanazawa, Japan

MISSING SYMMETRIES, UNSEEN QUARKS AND THE PHYSICAL VACUUM

T. D. Lee

Columbia University, New York, N.Y. 10027

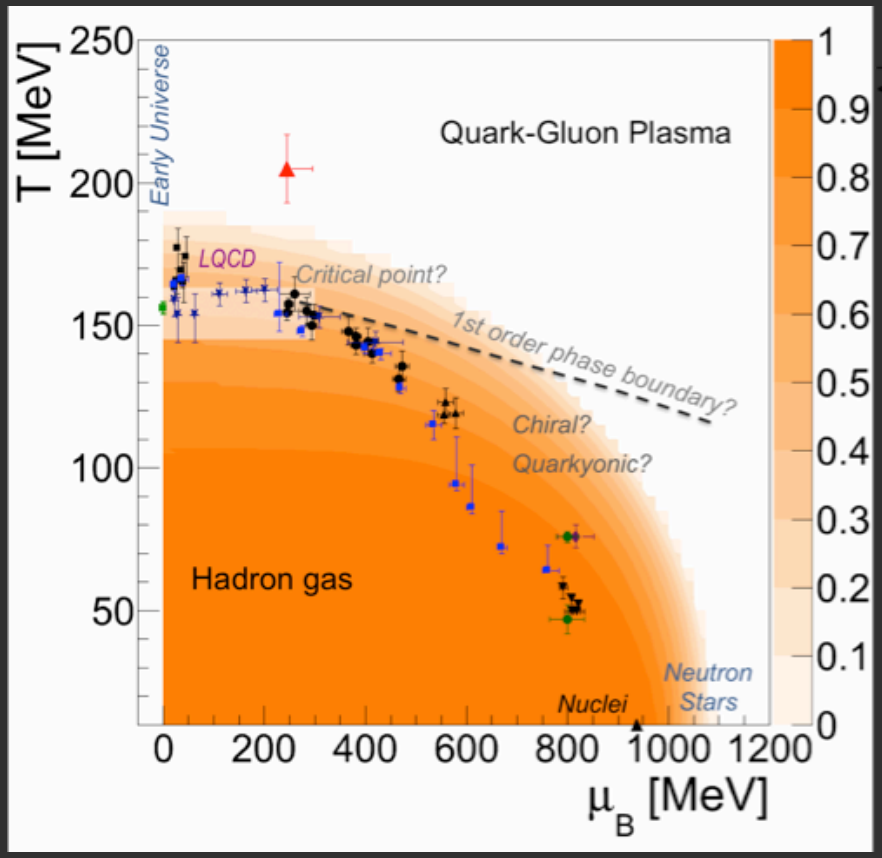
The two outstanding puzzles that confront us today are:

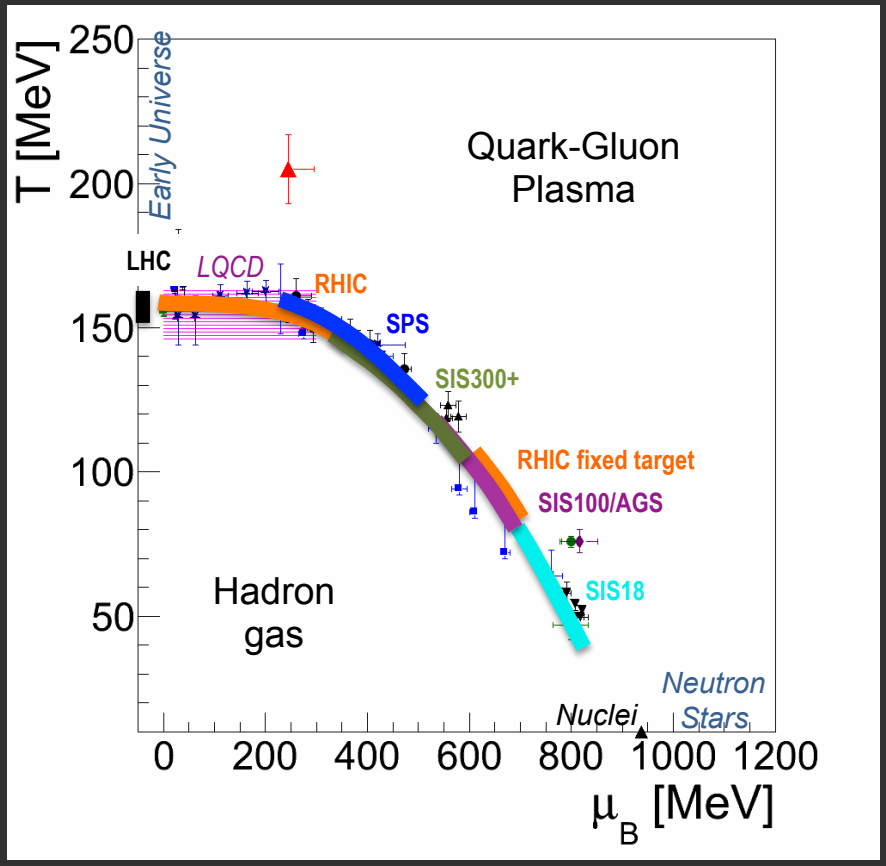
i) **Missing symmetries** - All present theories are based on symmetry, but most symmetry quantum numbers are *not* conserved.

ii) **Unseen quarks** - All hadrons are made of quarks; yet, no individual quark can be seen.

- Understand the formation of matter out of its elementary building blocks from first principles.
- Explore the phase structure of strongly interacting matter (QGP, NS-EOS, ...)

Experimental Approach to QCD Phases





LQCD: Z. Fodor et al., hep-lat/0402006
Condensate: B.J. Schaefer and J. Wambach, private communication
HADES data: M. Lorenz et al., Nucl. Phys. A (2014) QM14
A. Andronic et al., Nucl. Phys. A 837 (2010) 65
J. Cleymans et al. , Phys. Rev. C 60 (1999) 054908

Agenda

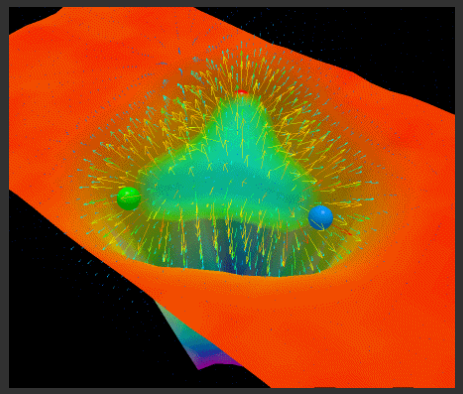
- Introduction
- Emissivity of baryons
- Dielectrons from cold and dense matter
- Strangeness production and propagation
- Outlook

Cloudy Bag Model (for the nucleon)

Chirally restored valence quarks surrounded by a cloud of virtual pions (G. Brown and M. Rho, 1979)

- $R_{bag} = 0.82$ fm → bags touch at $\rho \approx 3\,\rho_0$

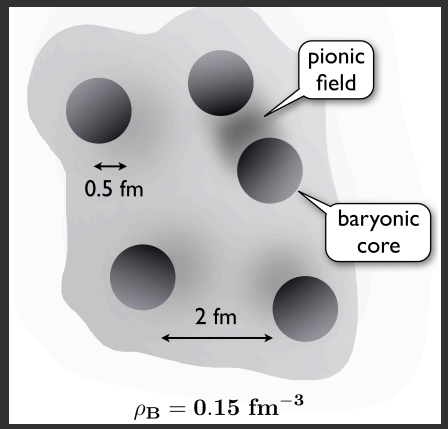
An old model but very instrumental in planning experiments (A.W. Thomas, MENU 2013)

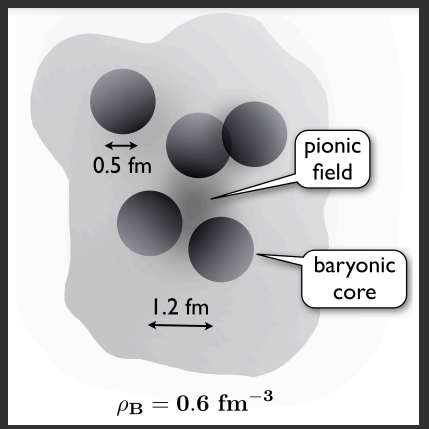


Lattice-QCD vacuum action on the presence of static quarks!

http://www.physics.adelaide.edu.au/theory/staff/leinweber

- Not much guidance yet from lQCD at finite μ_B!





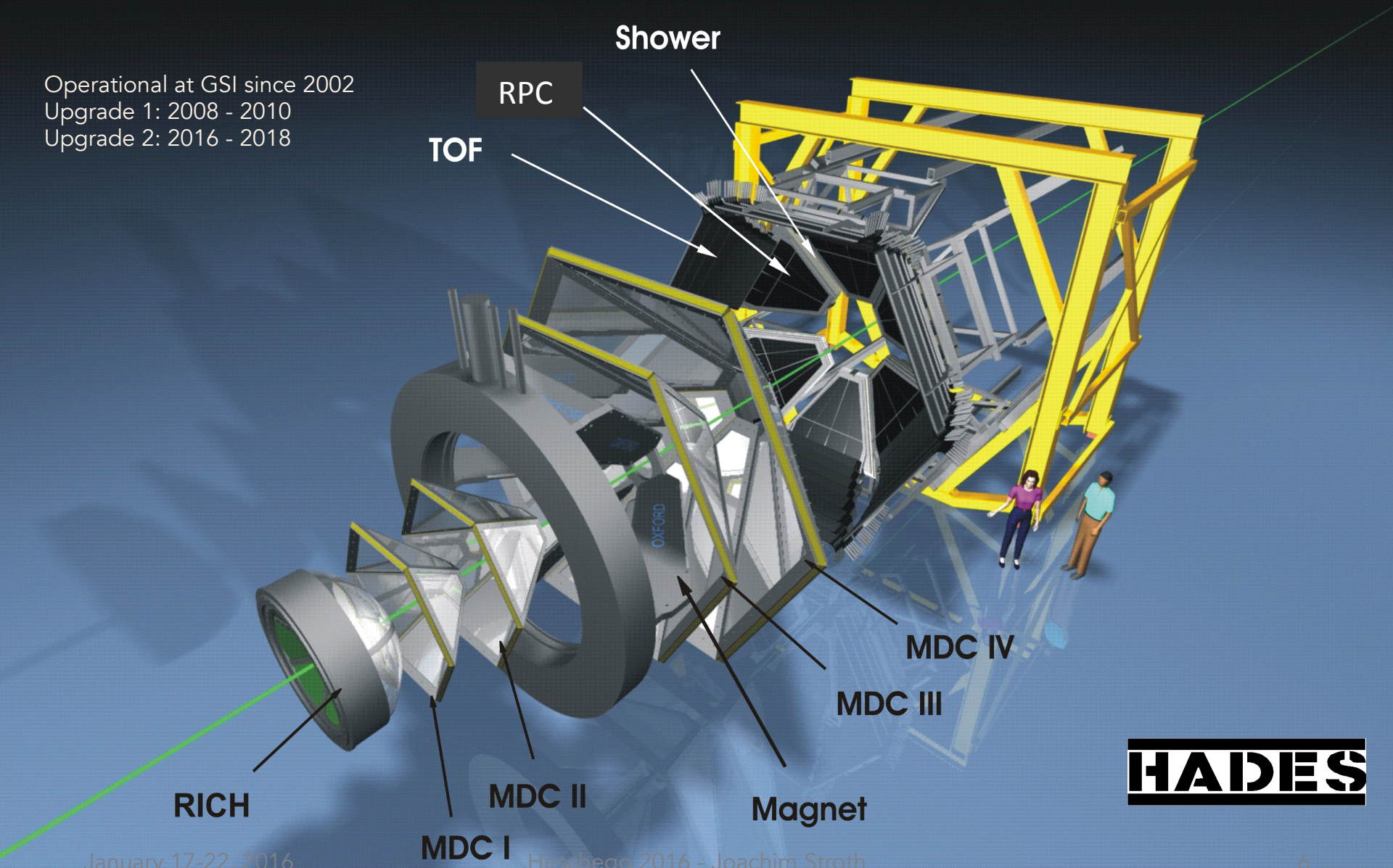
Nuclear matter from in-medium Chiral Perturbation Theory!

J.W. Holt, M. Rho, W. Weise arXiv1411.6681 (Phys. Rep. 2015)

- Provides prediction for chiral order parameter a.f.o. baryon density
- Possibility to connect CBM/HADES measurements to neutron star core matter EOS

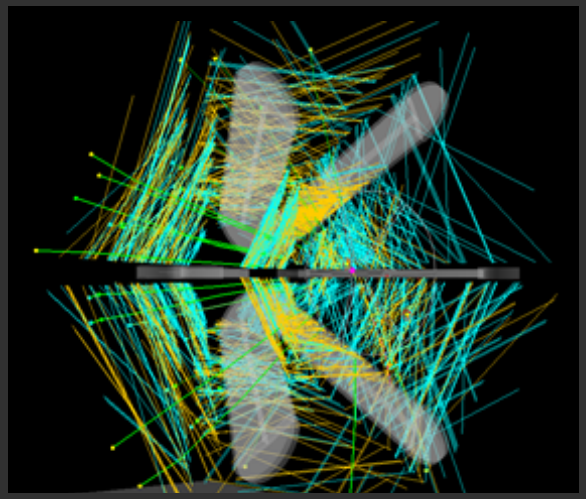
The HADES experiment @ GSI

Operational at GSI since 2002
Upgrade 1: 2008 - 2010
Upgrade 2: 2016 - 2018

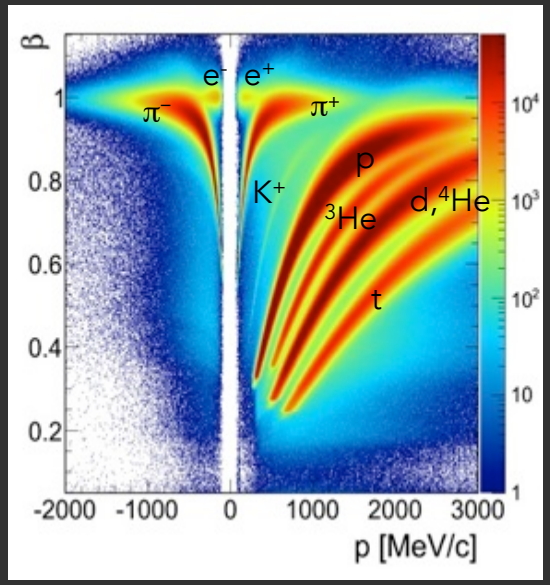


Hades Event Reconstruction

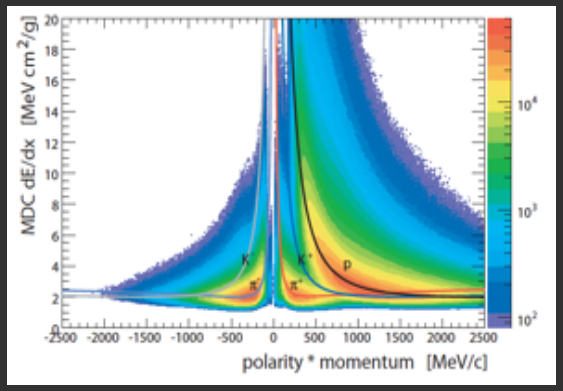
Fired wires in the drift chambers



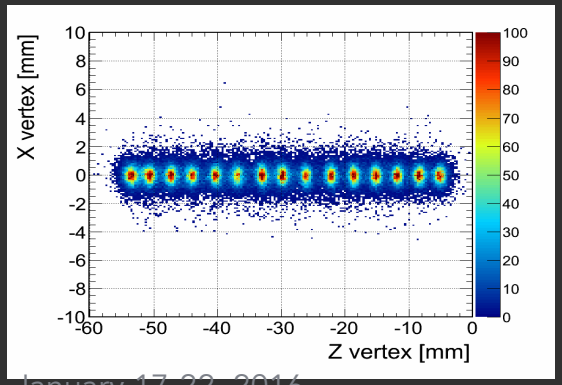
Velocity vs. momentum



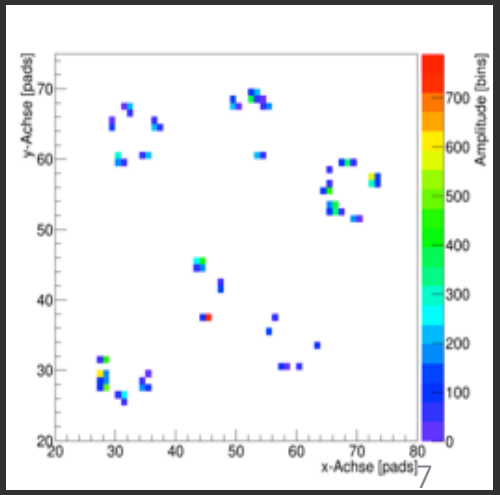
dE/dx in the MDC and ToF



Vertex reconstruction



RICH rings

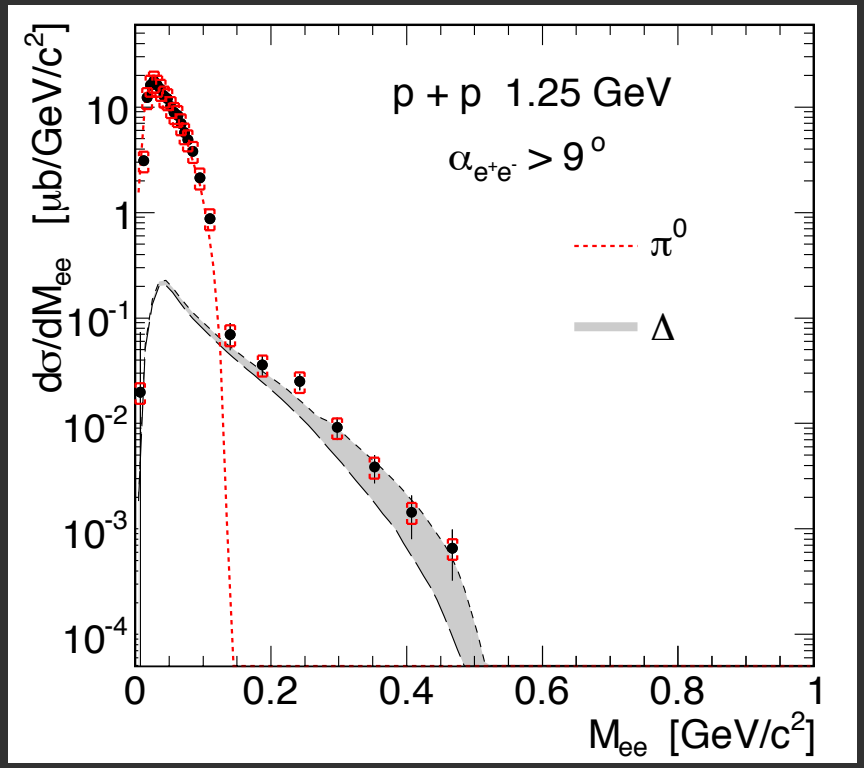


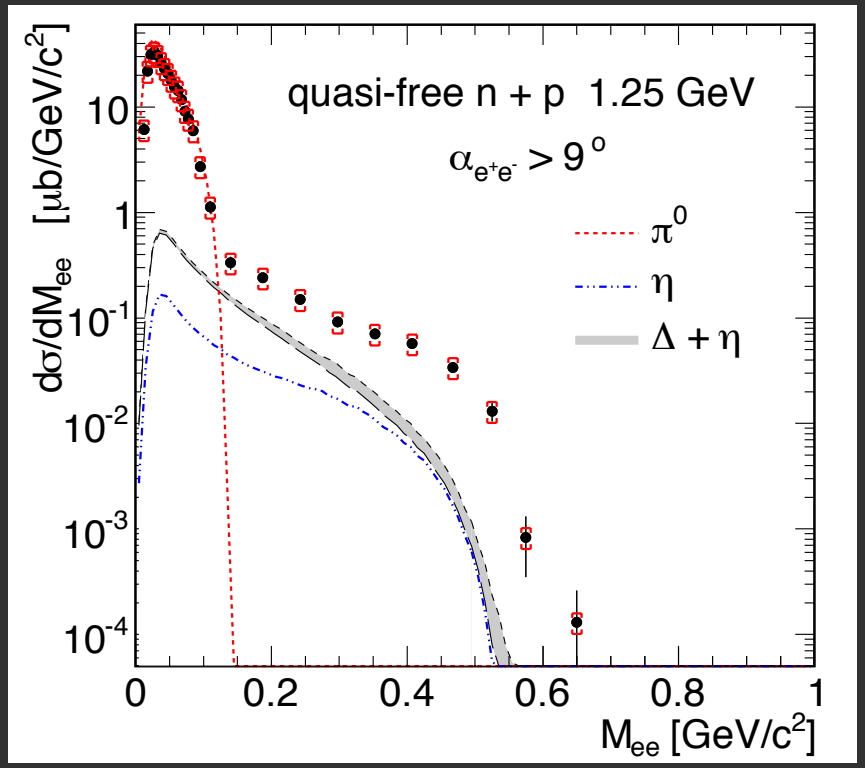
EMISSIVITY OF BARYONS

e^+e^- Pairs from pp and np Reactions (HADES)

Energy below free η prduction threshold

- Remarkable isospin effect
- Beam energy dependence observed
- Two assumptions for the Δ-Dalitz decay form factor



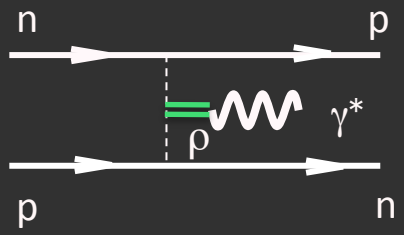


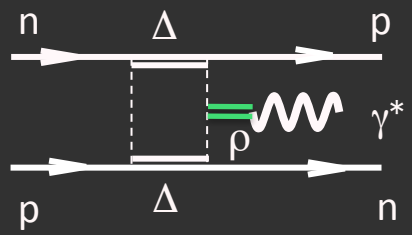
HADES collaboration (PLB 690, 2010)

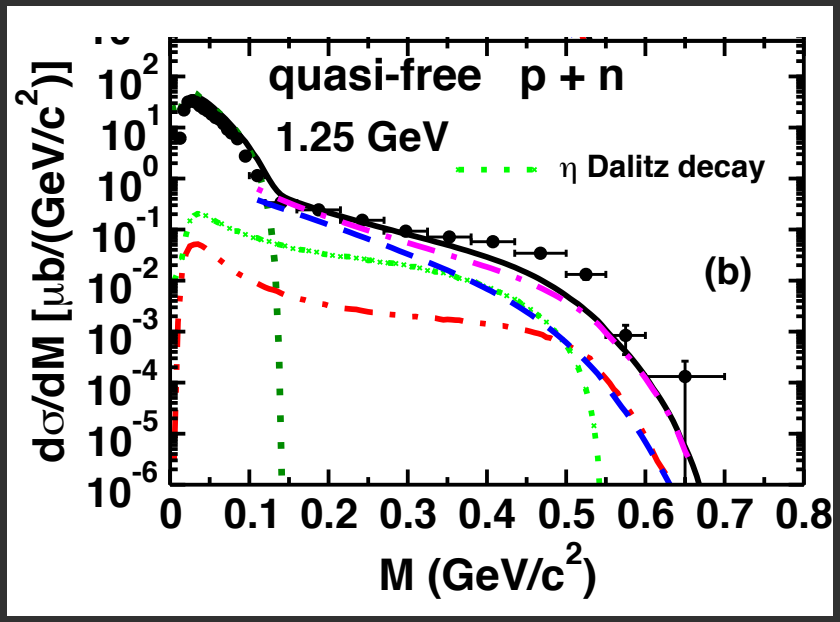
Theoretical Interpretation of the "Isospin Effect"

- Radiation from the internal line yields enhanced emission at high invariant masses.

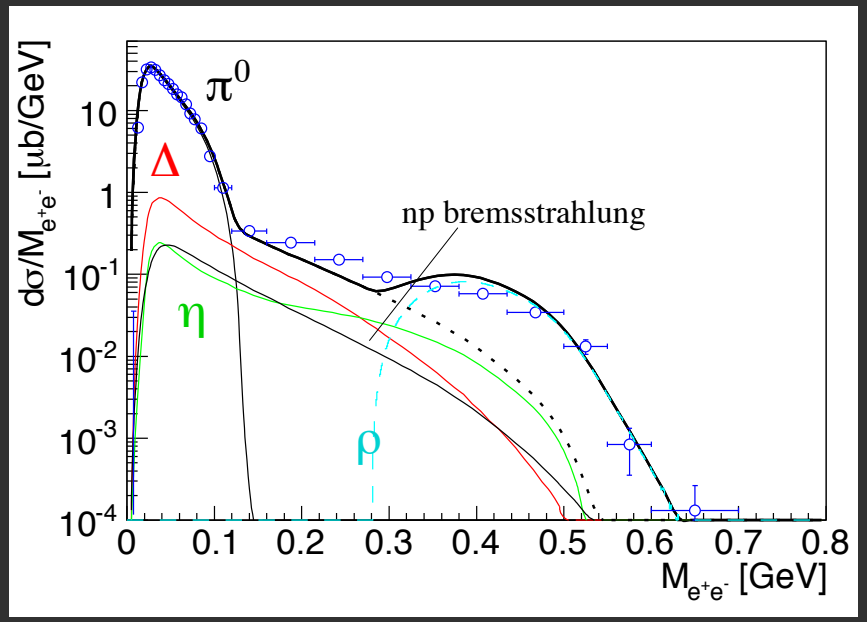
➛ can be understood as off-shell (cloud cloud) π π collision!







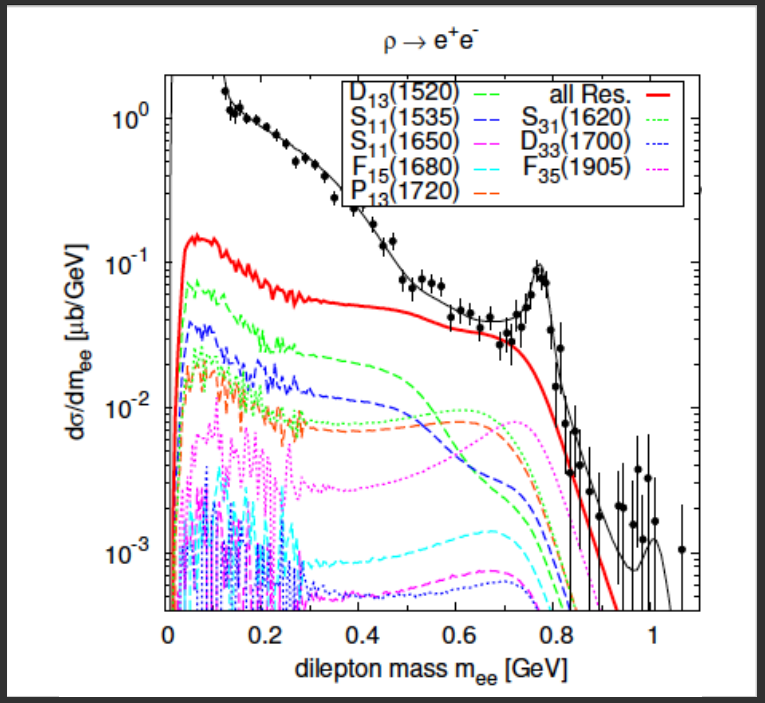
R. Shyam, U. Mosel [arXiv:1003.3343]



M. Bashkanov, H. Clement [arXiv:1312.2810]

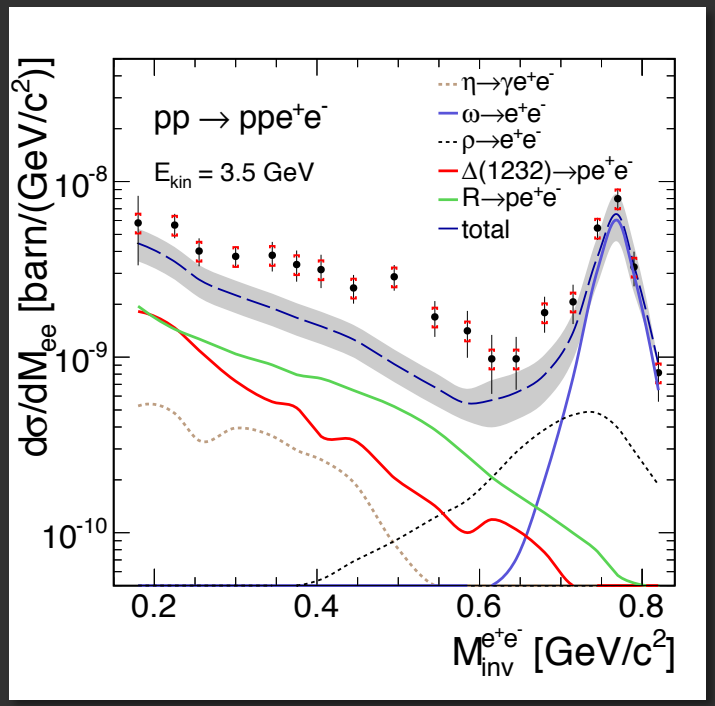
Dielectrons from p+p collisions @ 3.5 GeV

- GiBUU calculation with intermediate ρ mesons R ➛ Nρ ➛N e^+e^-
- Resonance population from "educated guess"



J. Weil et al., Eur. Phys. J. A 48 (2012) 111

- Exclusive dielectron spectrum
- Dalitz decays strongly suppressed
- pure QED from factor for R-decays



HADES: Eur. Phys. J. A (2014) 50: 82

π-beam run in 2014

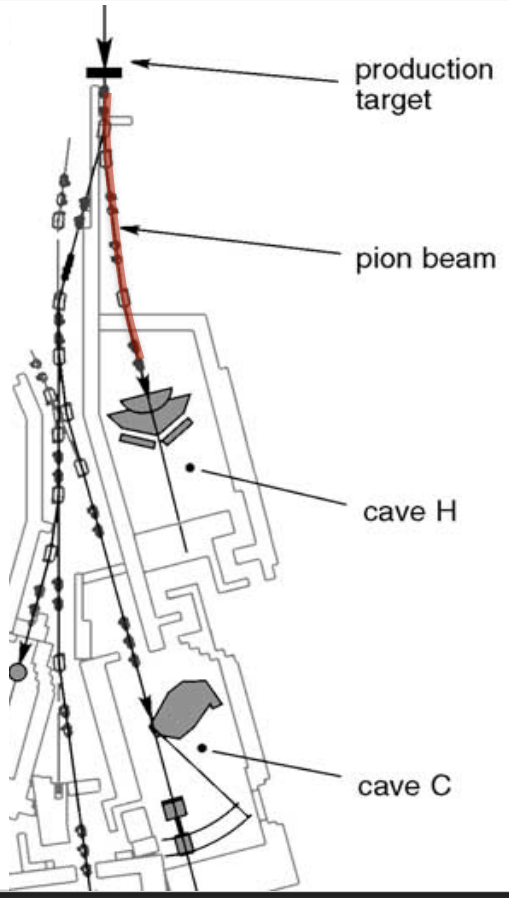
- Physics with πN experiments:
  - Resonance-Dalitz decays
  - Special interest on sub-threshold vector meson production
  - In-medium effects (strange and vector mesons)
- Pion beam
  - Momentum: 0.6 < p < 2 GeV/c
  - Pion tracking with two double-sided silicon strip detectors in the beam line
  - Improved conditions in 2018 due to FAIR upgrade

Primary beam:
10^{11} N (2 AGeV) /spill

SIS fast ramping

Spill: 4s cycle

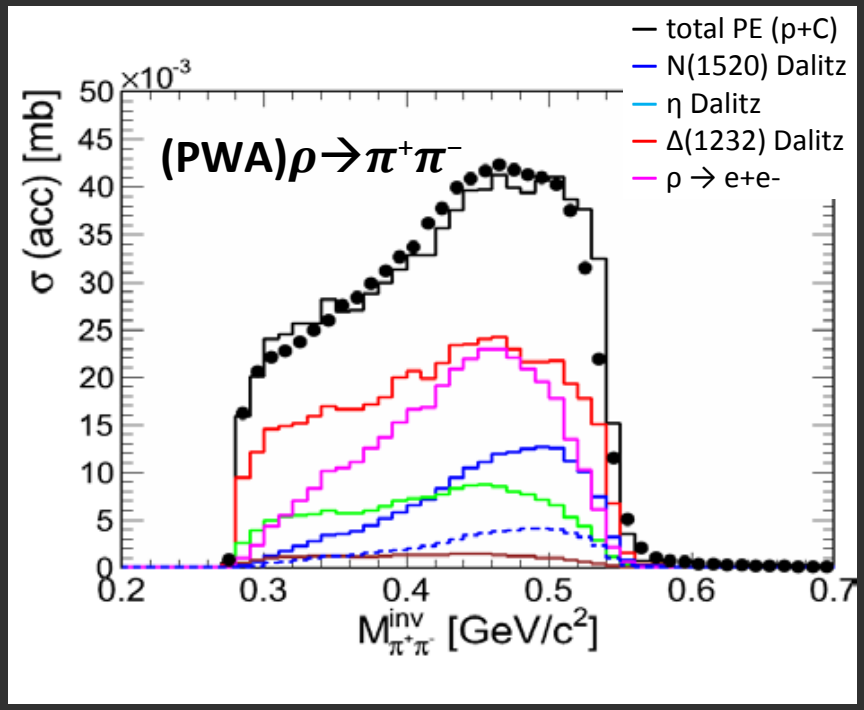
Secondary π beam:
10^{6} π/spill

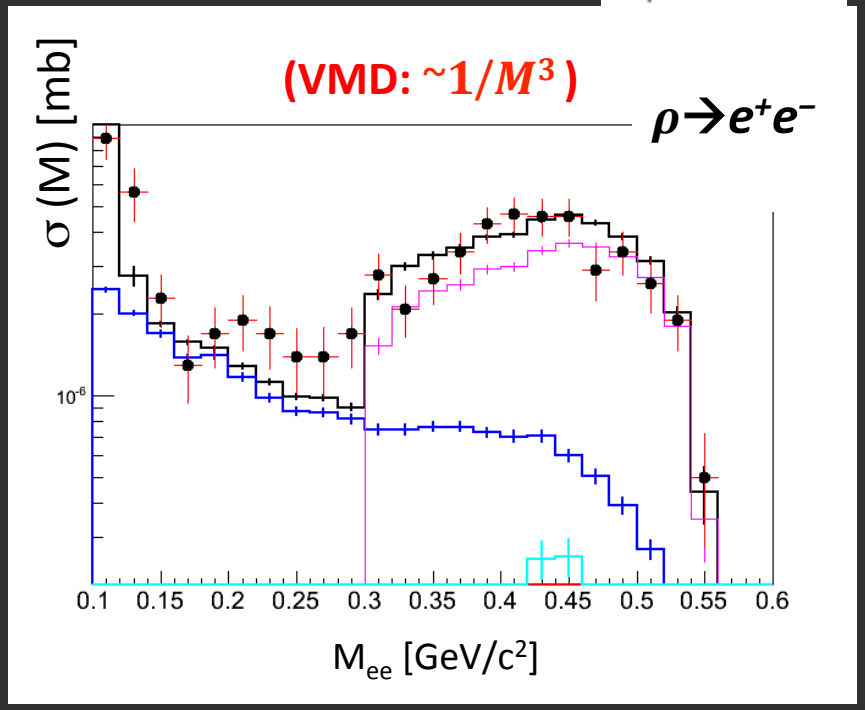


Exclusive Reconstr. of $\pi N \rightarrow N e^+e^-$ Reactions

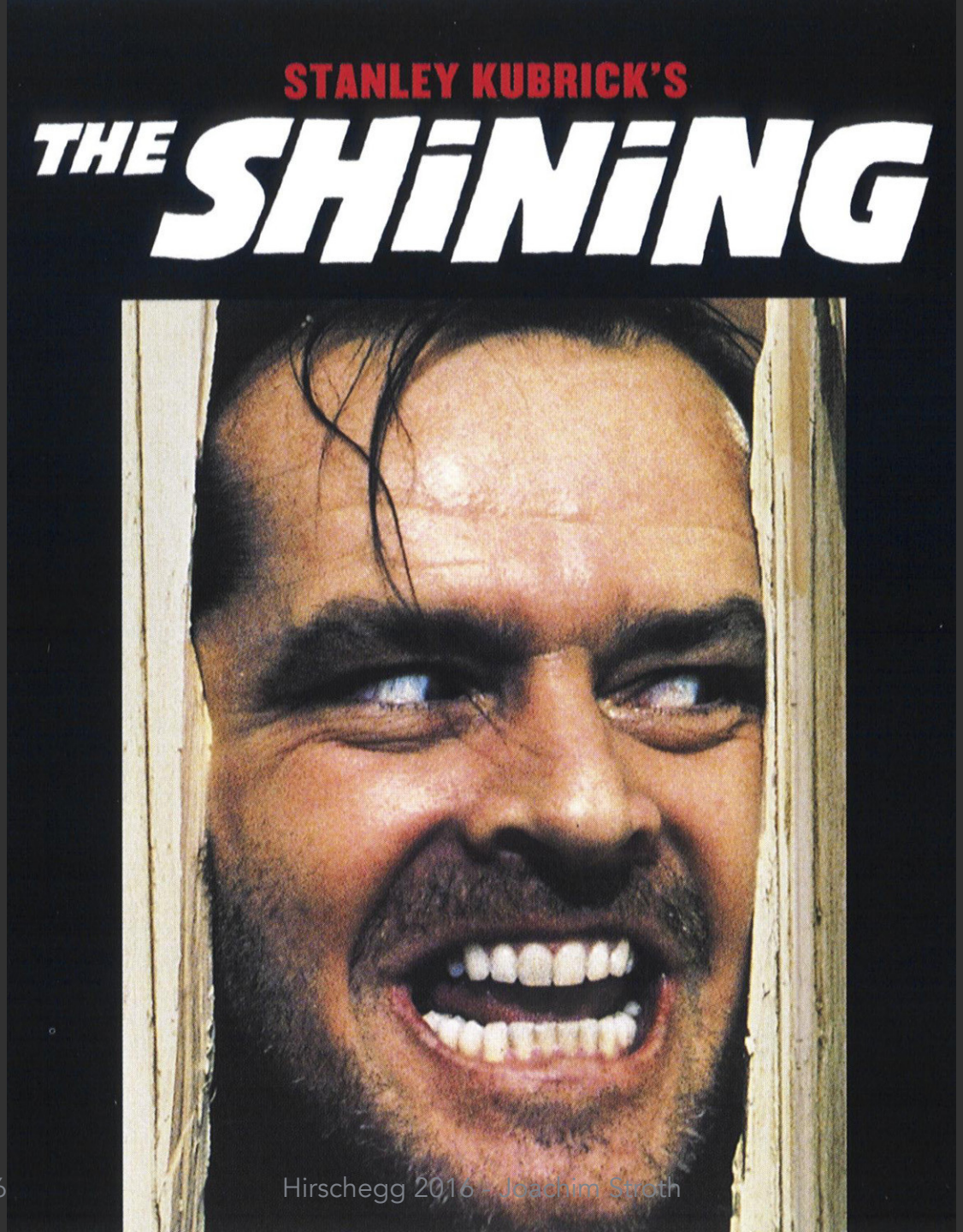
- π^- momentum tuned to second resonance region (0.7 Gev/c)
- Resonance decomposition of 2-π channel from PWA
- No further normalization for "predicted" dielectron yirld

preliminary





DIELECTRONS FROM DENSE MATTER

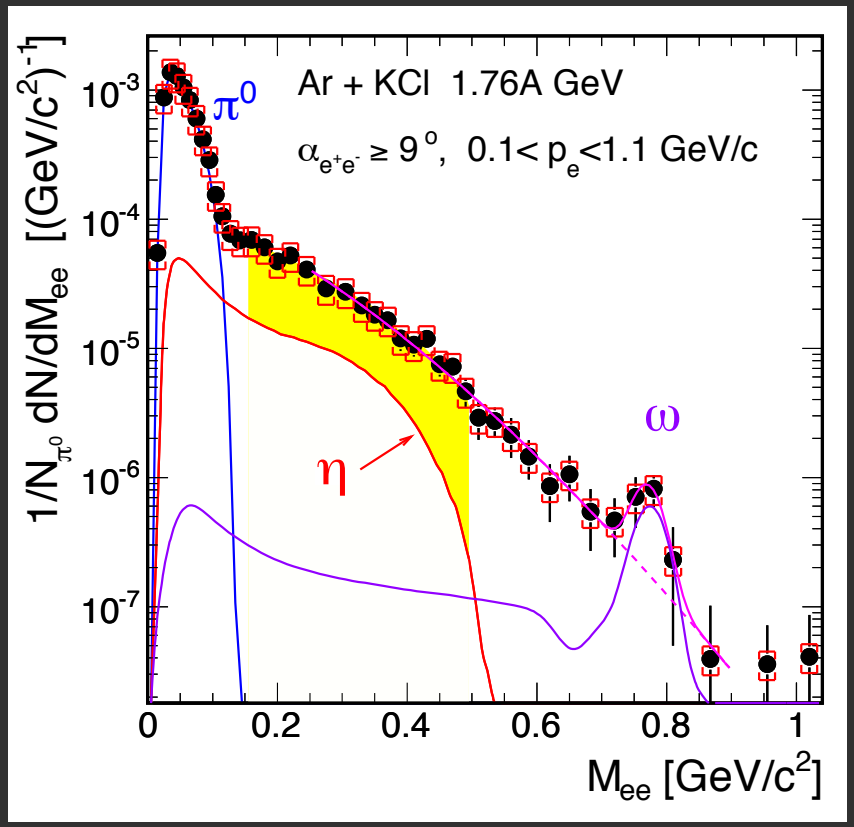

STANLEY KUBRICK'S
THE SHINING

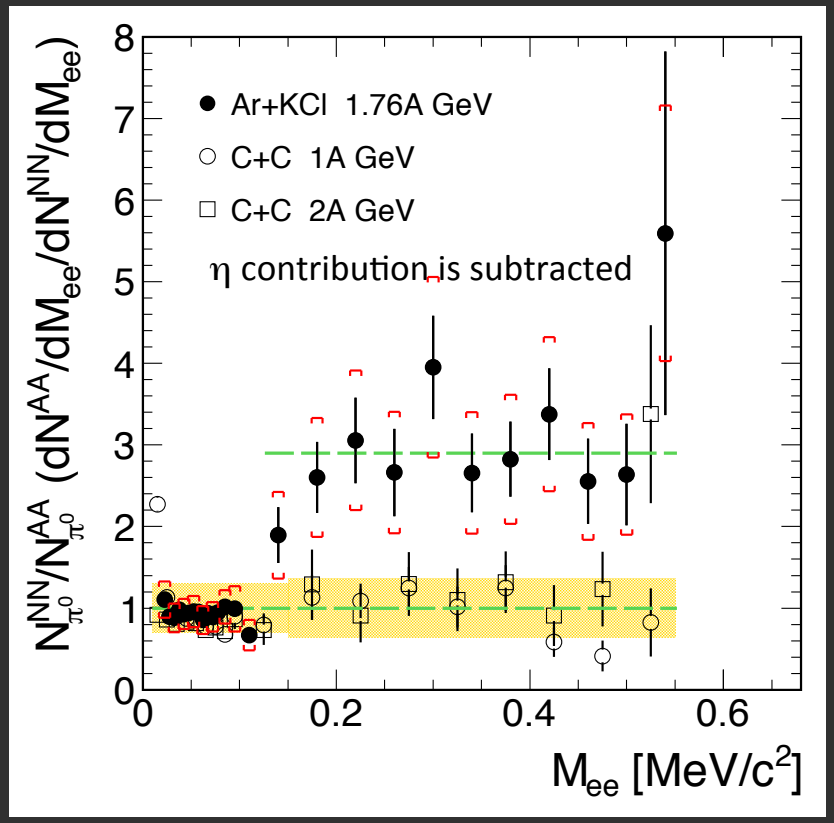
e^+e^- pairs from Ar+KCl at 1.76 GeV/u

First observation of ω mesons in HI collisions at these low energies.

„True" excess (~factor 3)

➢ The HADES „Delta" clock

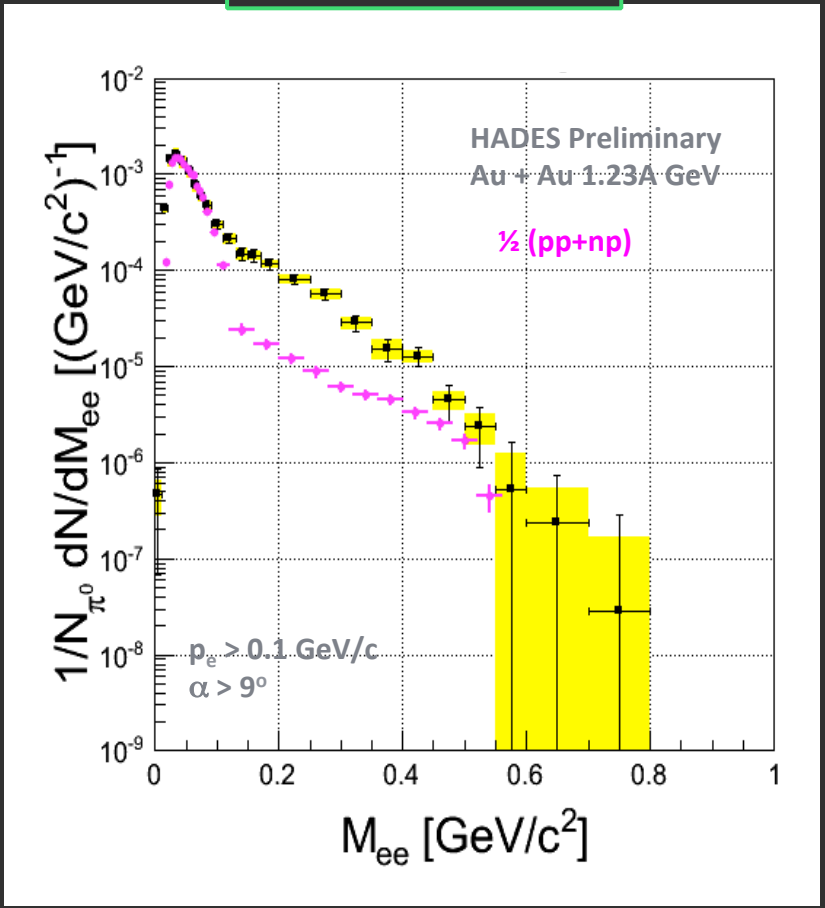




HADES , Nucl.Phys.A830:483C,2009

Virtual photon emission in Au+Au collisions

preliminary

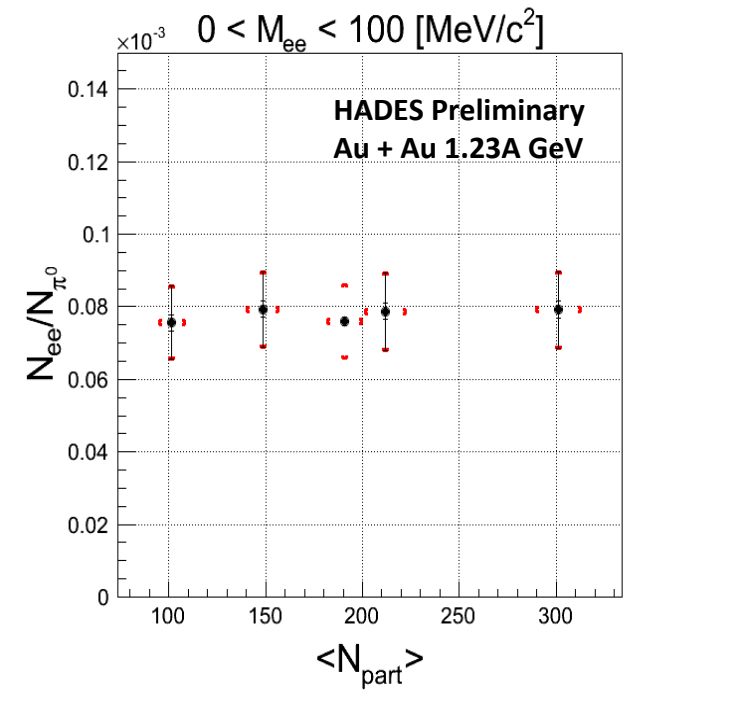


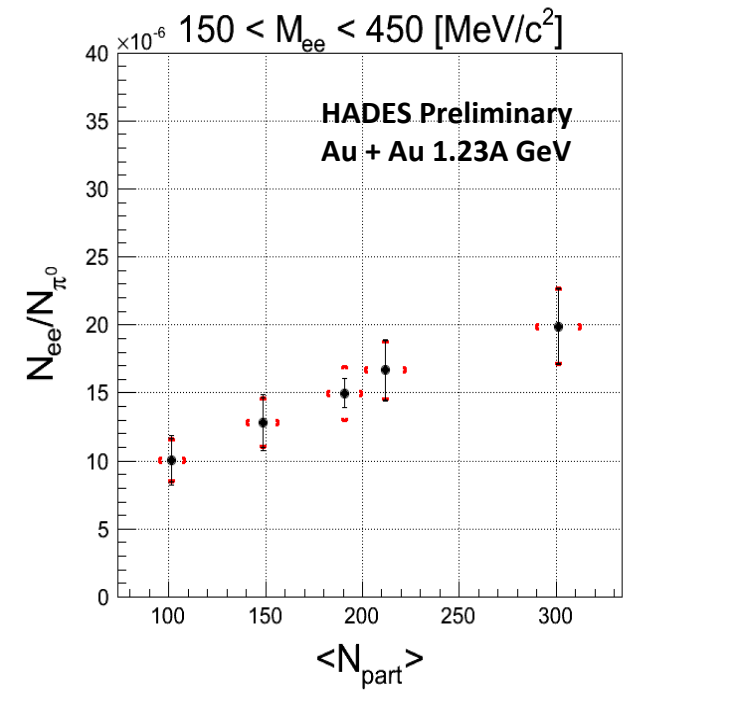
- Corrected for efficiency, not for acceptance
- Normalized to the number of produced π^0
- Almost exponential spectrum up to VM region!
- Increase of low-mass yield reflects the number of Δ's/ N*'s regenerated in fireball
  → HADES "R-clock"

HADES, in preparation

Centrality Dependence of Excess

preliminary





HADES, in preparation

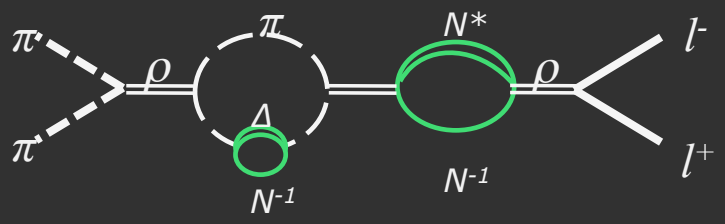
Excess yield scales with system size like $A_{part}^{1.4}$

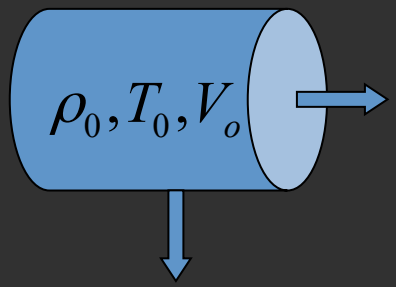
- Ar+KCl: 34% most central collisions (A_{part}=38)
- Au+Au: 40% most central collisions (A_{part}=187)

Dilepton Rates From Theory

- Thermal dilepton rates ...

$$\frac{d^3N}{dMdydp_t} \equiv \int_{t=0}^{\infty} \frac{d^4\varepsilon}{d\mathbf{p}} \left[T(\mathbf{x}), \mu_B(\mathbf{x}), \vec{v}_{coll}(\mathbf{x}), .. \right] d\mathbf{x}$$





isentropic expansion

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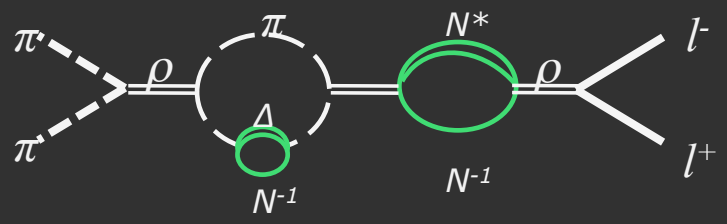
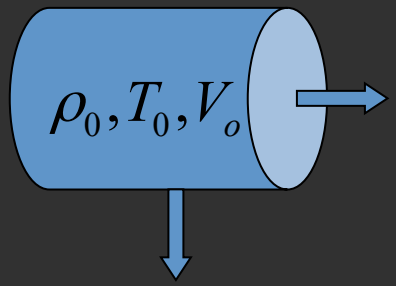
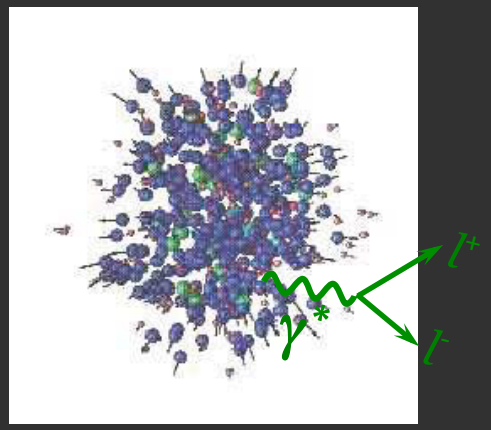




isentropic expansion

- ... or from transport with "shining"



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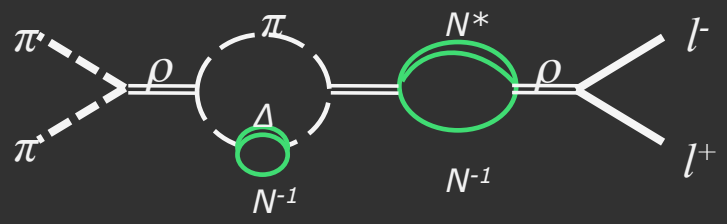

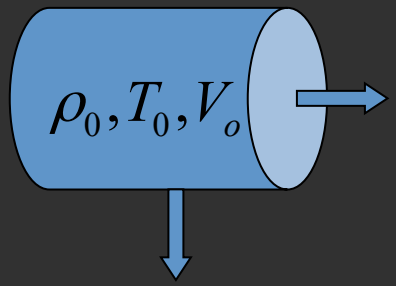

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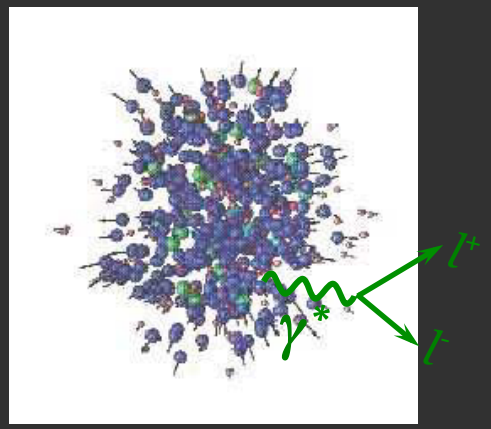
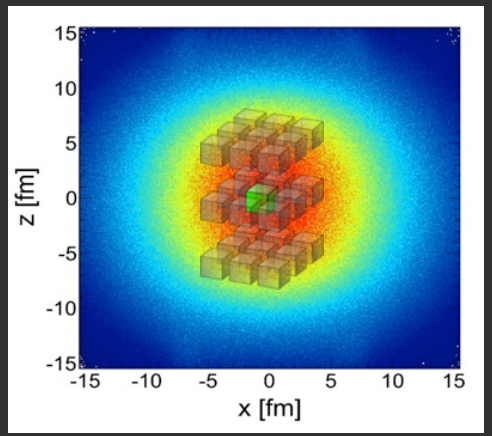


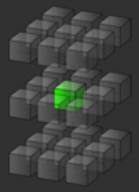
- ....or combined!

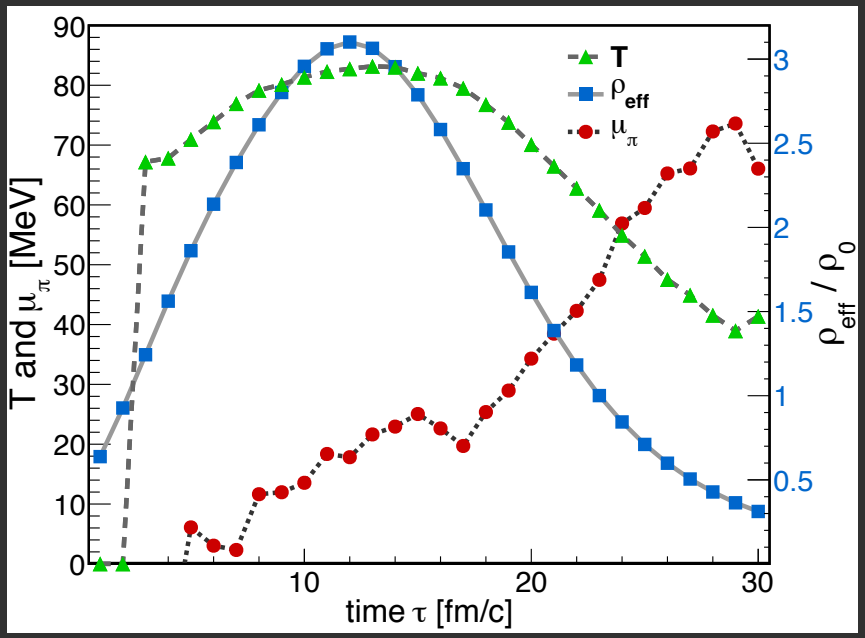


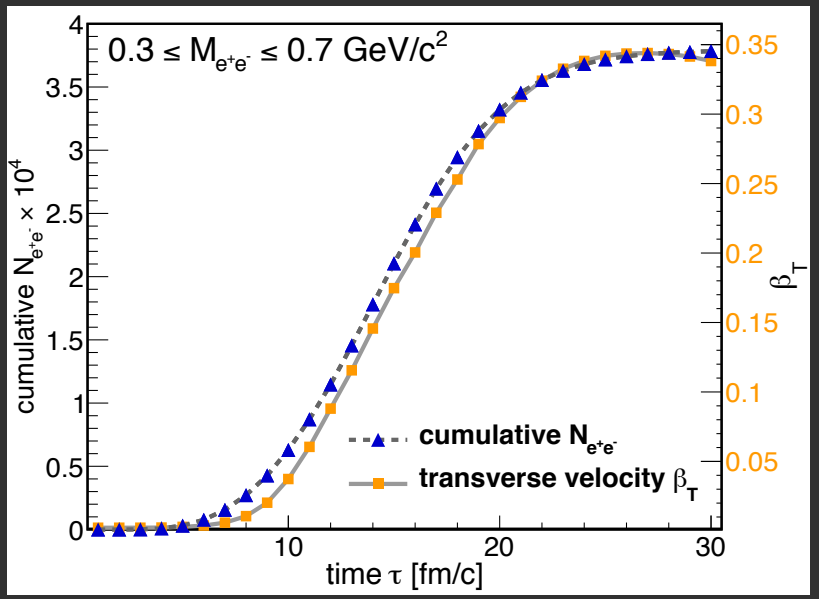
Emission Profile

Density and temperature evolution of a inner cube with volume 7^3 fm^3.

- Au+Au collisions at 1.23 *A*GeV
- Average densities up to 3 ρ_0 reached
- Emission phase coincides with built-up of flow







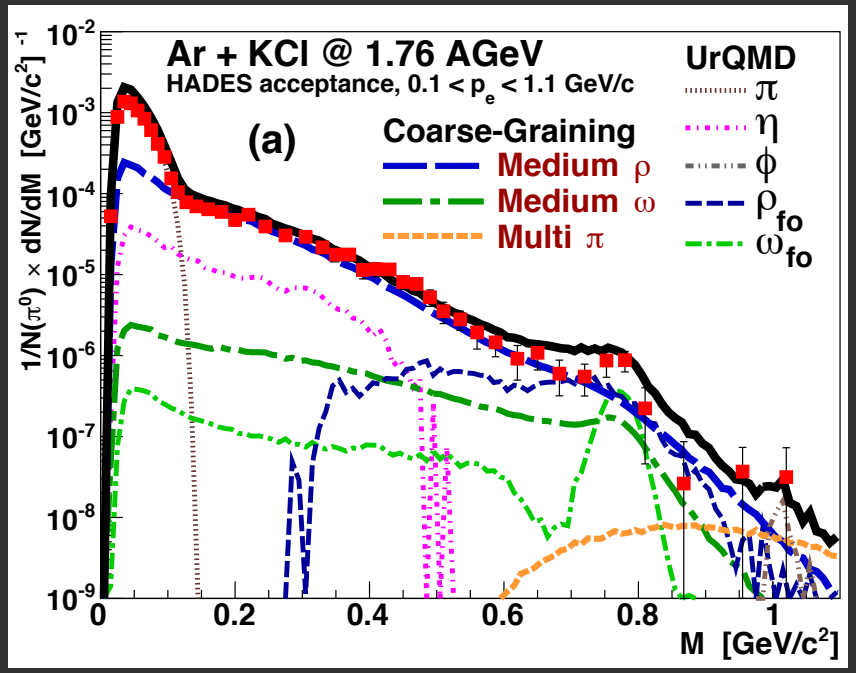
T. Galatyuk, F. Seck,, PH, RR, JS, arXiv:1512.08688

Low-mass Dilepton Excess

Cocktail plus rates from Coarse Grained UrQMD / Rapp/Wambach

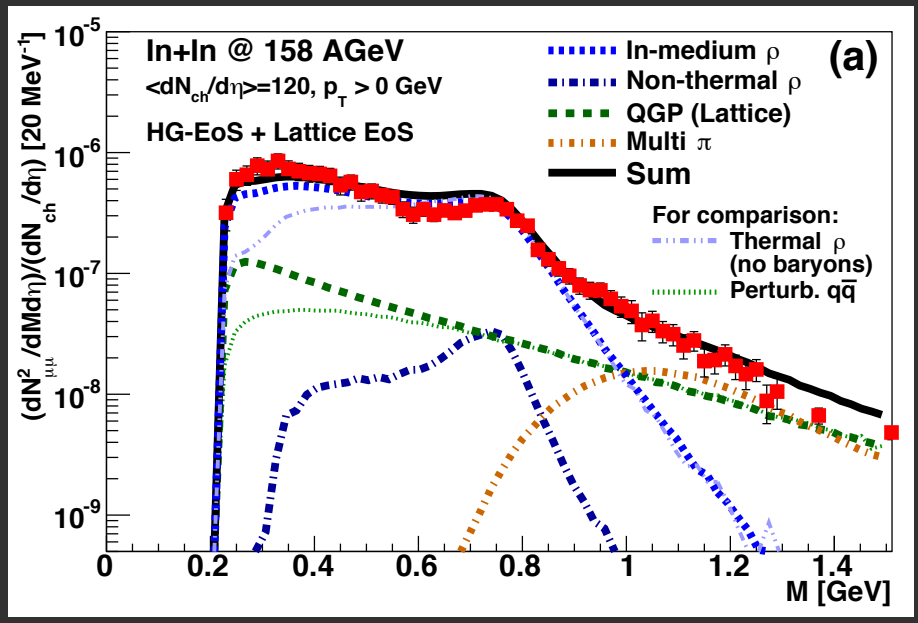
- Seems to describe data measured for 1.7 *A*GeV up to the highest energies (RHIC)
- But there are open questions:
  - ? Is the emissivity description complete → Constrain theory by π N reactions
  - ? How to properly describe the expansion → Compare to hadronic collective observables

HADES data



S. Endres_et al. UrQMD [arXiv:1505.06131]

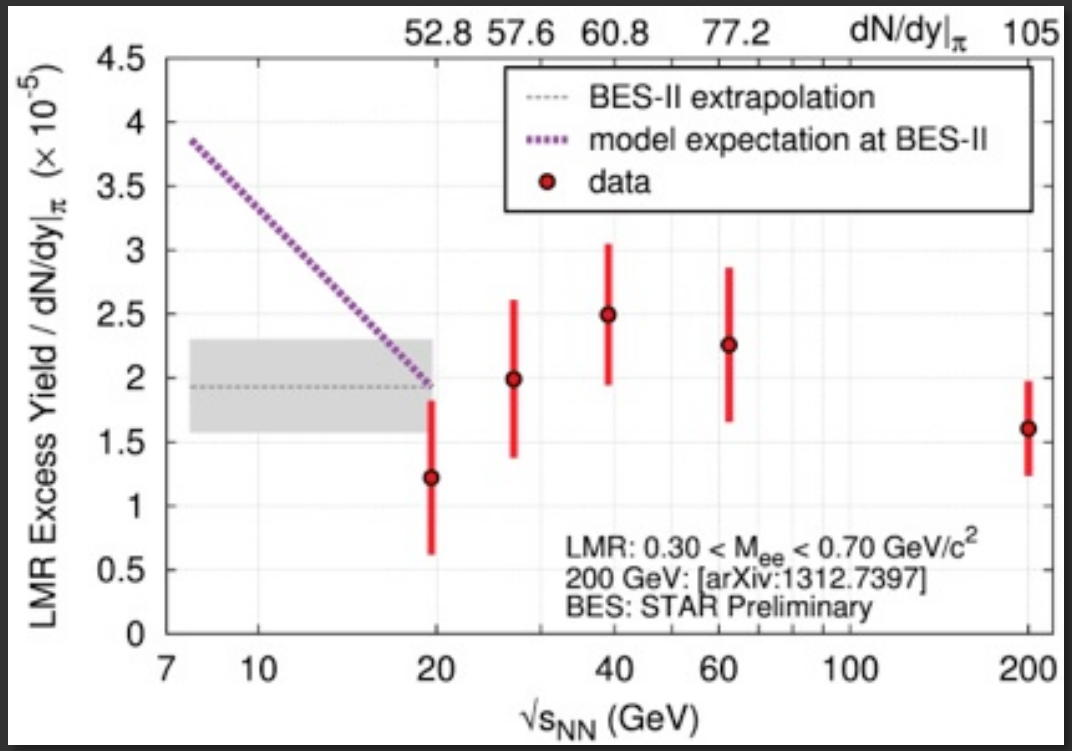
NA60 data



S. Endres et al. UrQMD [arXiv:1412.1965]

Excitation Function of Low-mass Yields

- The yield in the mass range $0.2 < M_{ee}/GeV < 0.7$ is very sensitive to the space-time evolution of the fireball.
- A first-order phase transition could give rise to non-monotonic behavior



STAR: P. Huck et al., Nucl.Phys. A931 (2014)

STRANGENESS PRODUCTION AND PROPAGATION

STRANGER THAN PARADISE

A NEW AMERICAN FILM

"...A very, very funny film which resists rational description as strongly as it resists pigeonholing."

Sheila Benson, Los Angeles Times

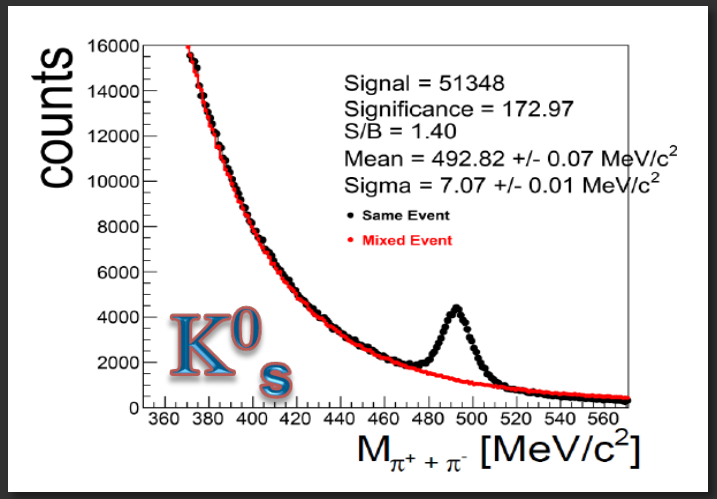
THE SAMUEL GOLDWYN COMPANY PRESENTS A FILM BY JIM JARMUSCH

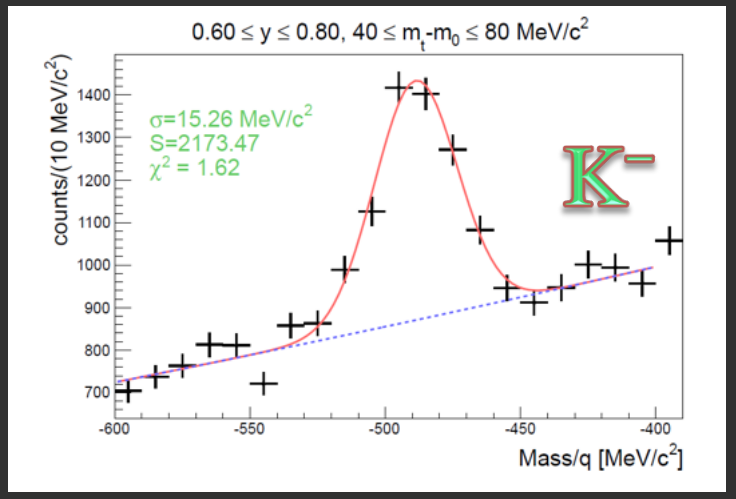
WITH JOHN LURIE ESZTER BALINT RICHARD EDSON

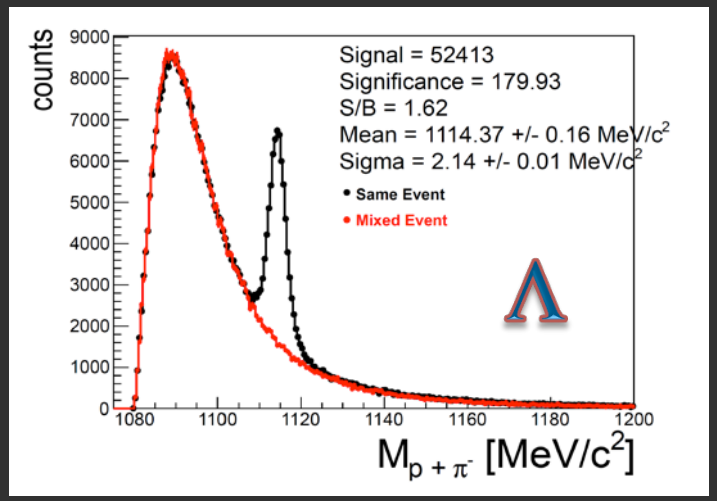
EXECUTIVE PRODUCER/OTTO GROKENBERGER PRODUCER/SARA DRIVER

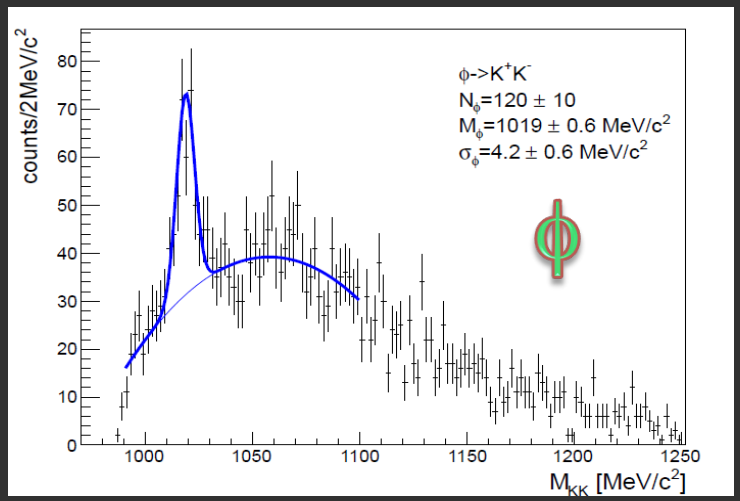
MUSIC/JOHN LURIE WRITER-DIRECTOR/JIM JARMUSCH

Reconstructed Strangeness in Au+Au @ 1.23AGeV



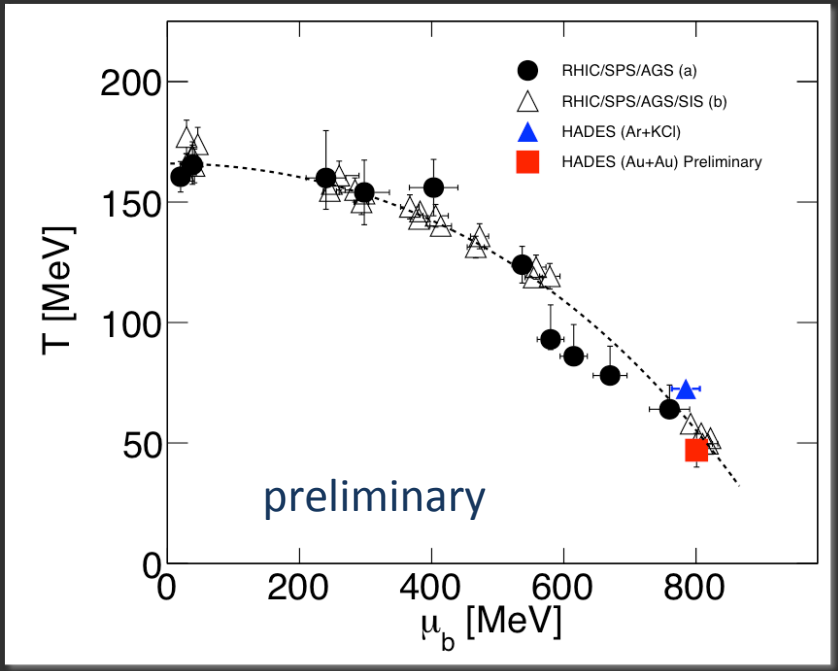


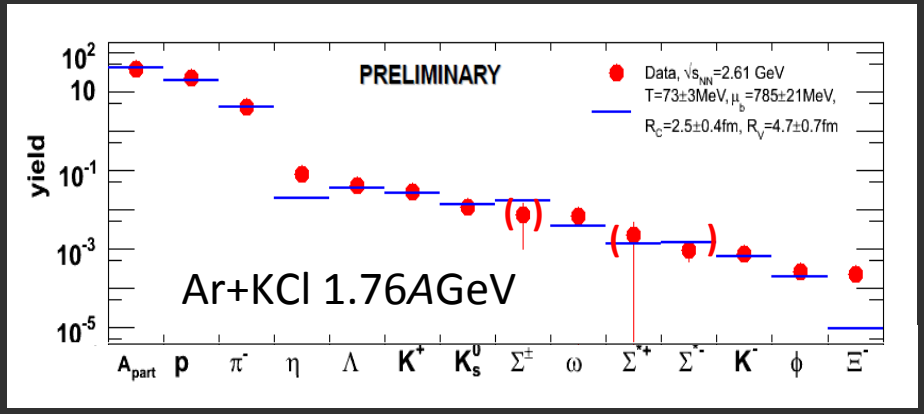


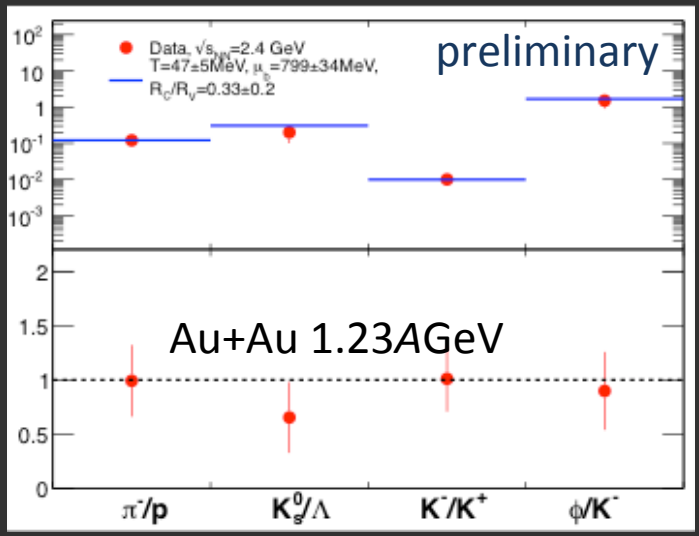


Hadron Production and SHM

Statistical "hadronization" also working at high m_B and low temperature!(?)







-- *THERMUS fit: J.Cleymans, J.Phys.G31(2005)S1069*

● *HADES Au+Au data at 1.25 AGeV PRELIMINARY,*

▲ *Ar+KCl: Phys.Rev.C80:025209,2009*

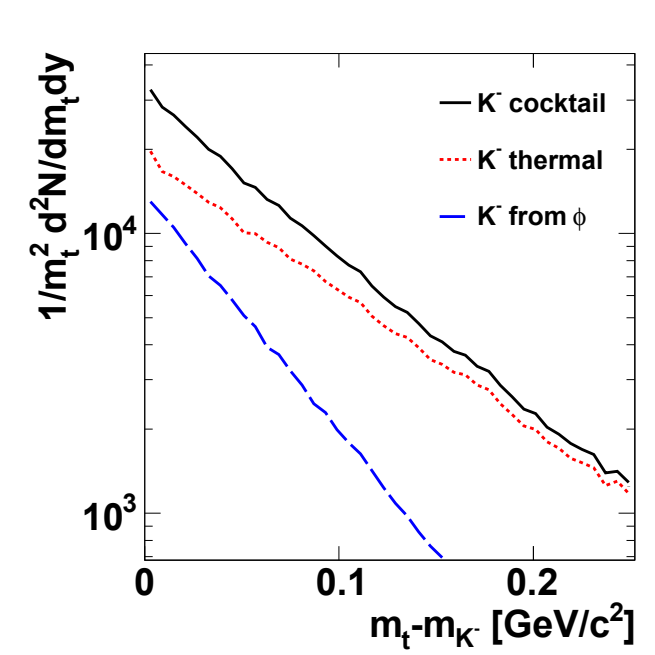
ϕ Decay as Source for K^-

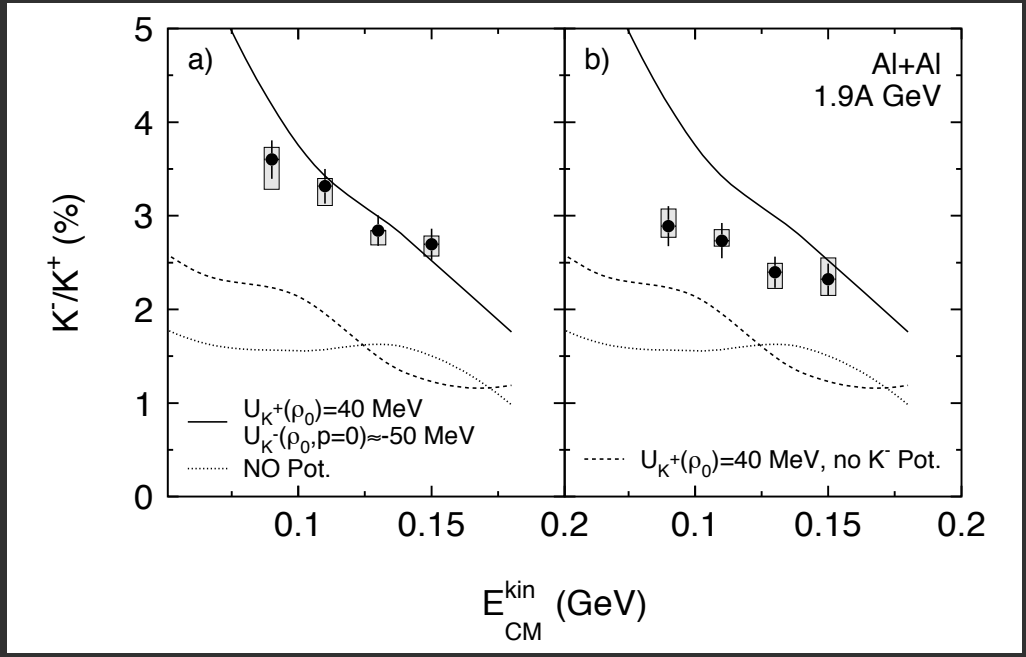
HADES (Ar+KCl 1.76 *A*GeV)

- K^- from ϕ decay shows substantially different slope
- T_{K-} (thermal) = 89 MeV
- T_{K+} (data) = 89±1±2MeV

FOPI

- K^-/K^+ ratio (a) corrected for ϕ decay (b)
- Compared to transport calculations (HSD) w. and w/o. potential
- "Temperatures" from Boltzmann fits not shown():
  - T_{K-}(thermal) = 89 ± 9 + 24 MeV
  - T_{K+}=109 ± 2(stat) + 6-13 (syst) MeV





M. Lorenz and HADES, PoS(BORMIO2010)038

FOPI collaboration, arXiv:1512.06988

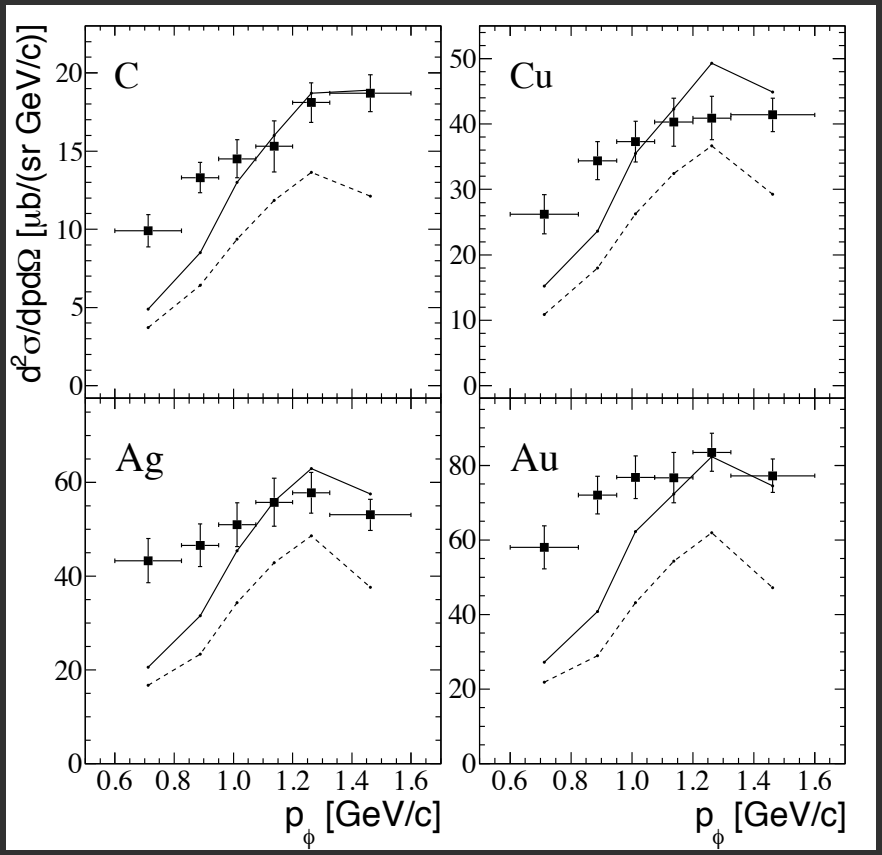
In-medium ϕ Propagation (ANKE)

ANKE reports an in-medium (cold matter) cross section for phi of 14 - 21 mb.

Proton (2.83 GeV) induced production under forward angles (θ<9°).

The curves show:

- Model 1 (not shown)
  - Eikonal approx. by Valencia group using in-medium phi spectral function
- Model 2 (dashed)
  - As 1 but with different in-medium function
- Model 3 (solid)
  - BUU from Rossendorf
  - Has also an in-medium mass shift included



ANKE, arXiv:1201.3517v1

OUTLOOK

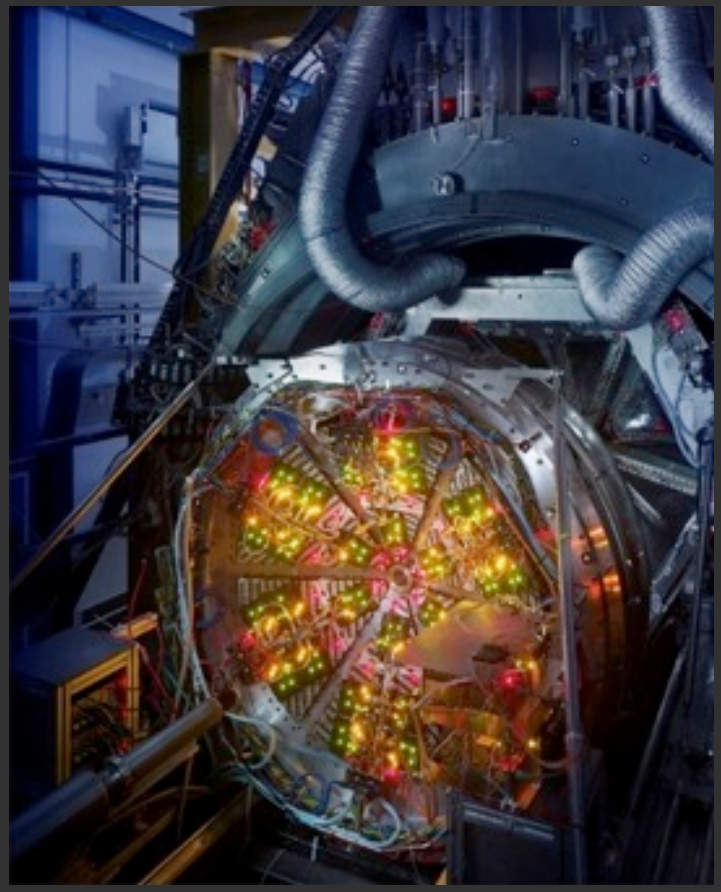
HADES run scenario at SIS18

Time line

- Upgrade program in 2016-2017 (no operation)
- Likely beam available from 2018 on (summer)
- Anticipated improved conditions
  - radiation protection
  - new slow extraction
  - improved intensities

Assume three long campaigns,i.e.:

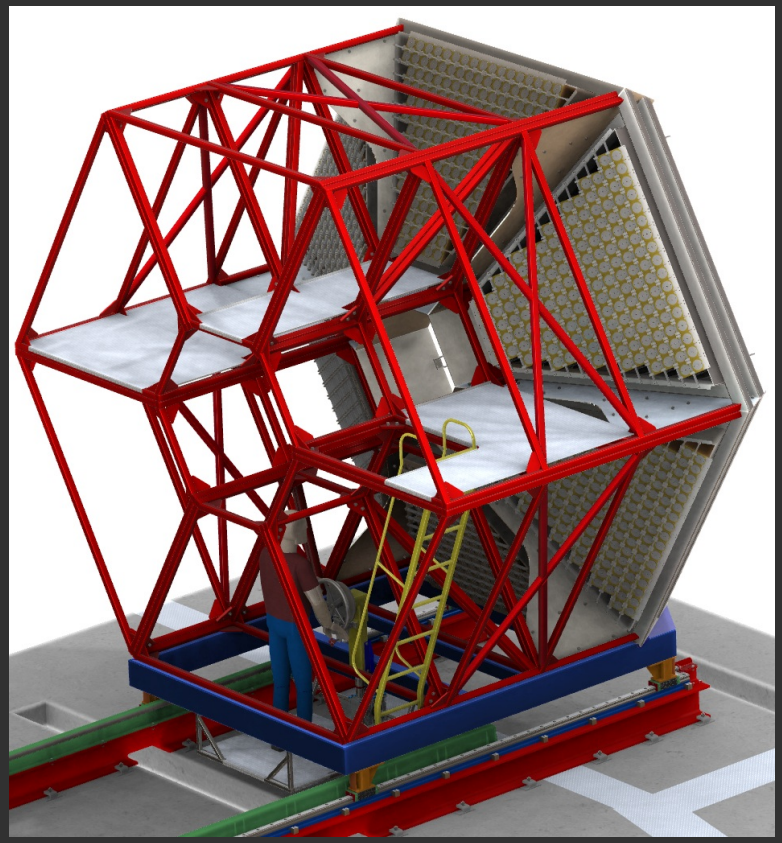
- π+PE/lH_2: baryon em transition form factors, baryonic resonances with strangeness
- p+A: strangeness/vector mesons in medium
- A+A: medium system at maximal energy



Ongoing Upgrade 2016-2018

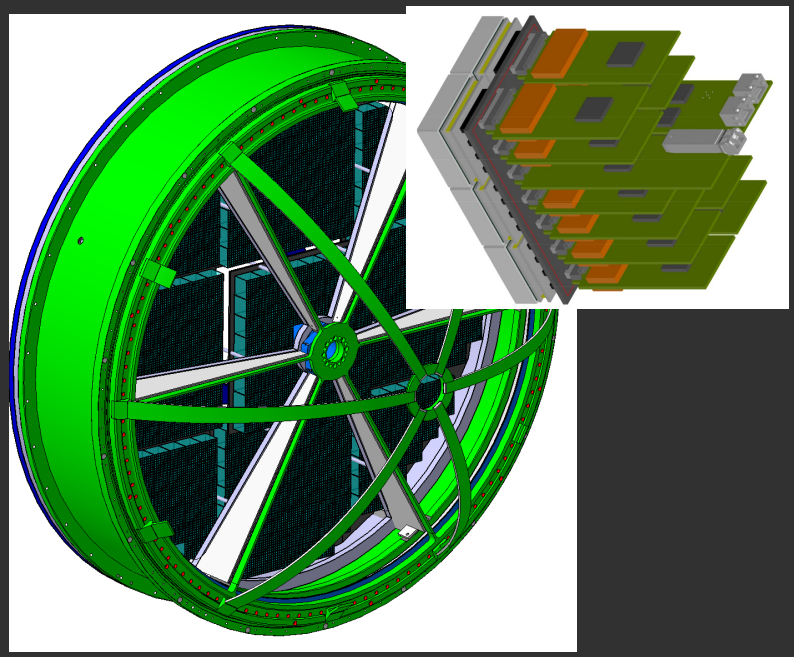
HADES ECAL

- Lead glass calorimeter (recycled OPAL crystals)
- Replaces pre-shower detector



MAPMT UV photon detector for HADES

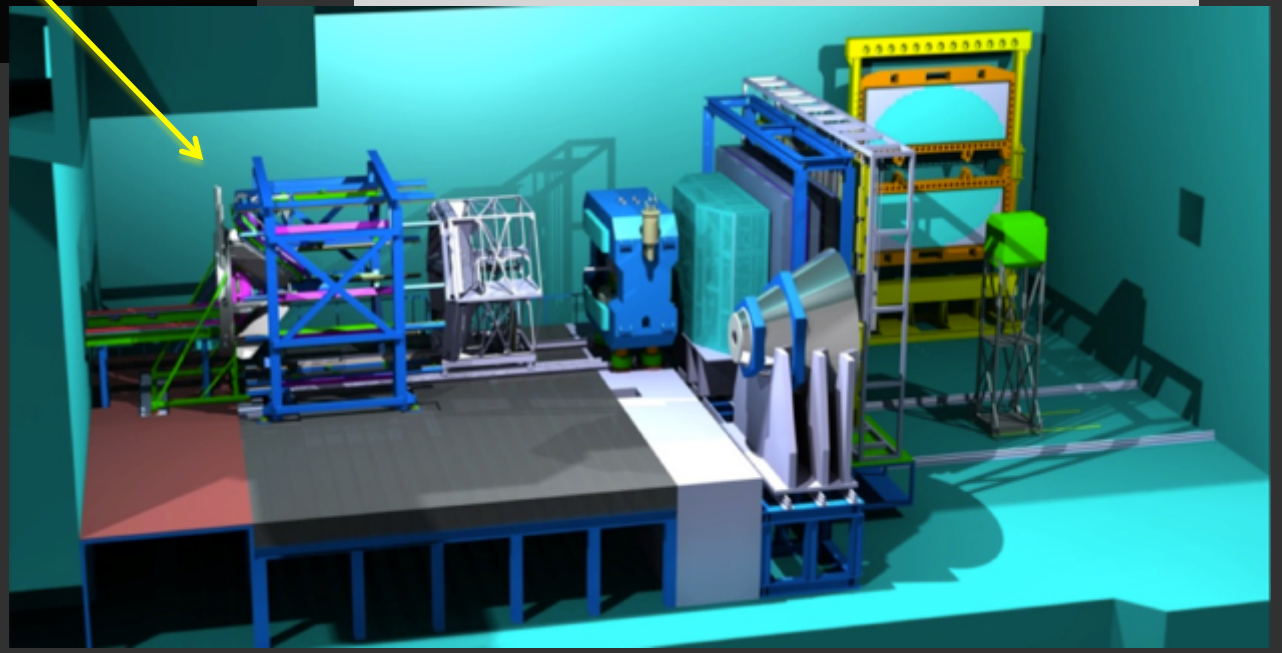
- Replaces aging solid CsI based UV photon detector
- Improves rate capability
- Joint development CBM and HADES
- Leaves the rest of the HADES-RICH untouched



The future at FAIR

Explore Compressed Baryonic Matter with rare and penetrating probes:

- **EOS** of (baryon) dense and hot QCD matter
- Search for **exotic quark matter** phases and rare strange matter
- Study the **limit of hadronic existence**



- Use high-acceptance **HADES** spectrometer for important reference measurements (cold-matter physics)

Summary

- HADES has collected high-quality data on dilepton emission from A+A and elementary collisions, including exclusive channels.
- Contributions from the dense/early phase are quite featureless.
  - strong broadening of in-medium states!(?)
- Interesting observations in strangeness production.
  - better statistics needed to make the case
- Next at SIS18: heavy collision systems and pion induced reactions.
- Bright future for the investigation of Compressed Baryonic Matter at FAIR.


The ERICE Honky Tonk Show
Thank you for your attention

The HADES collaboration

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