EXPLORING THE HIGH μ_B REGION OF THE QCD PHASE DIAGRAM WITH HADES

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42nd International School on Nuclear Physics

QCD under extreme conditions - from heavy-ion collisions to the phase diagram

September 16 – 22, 2021

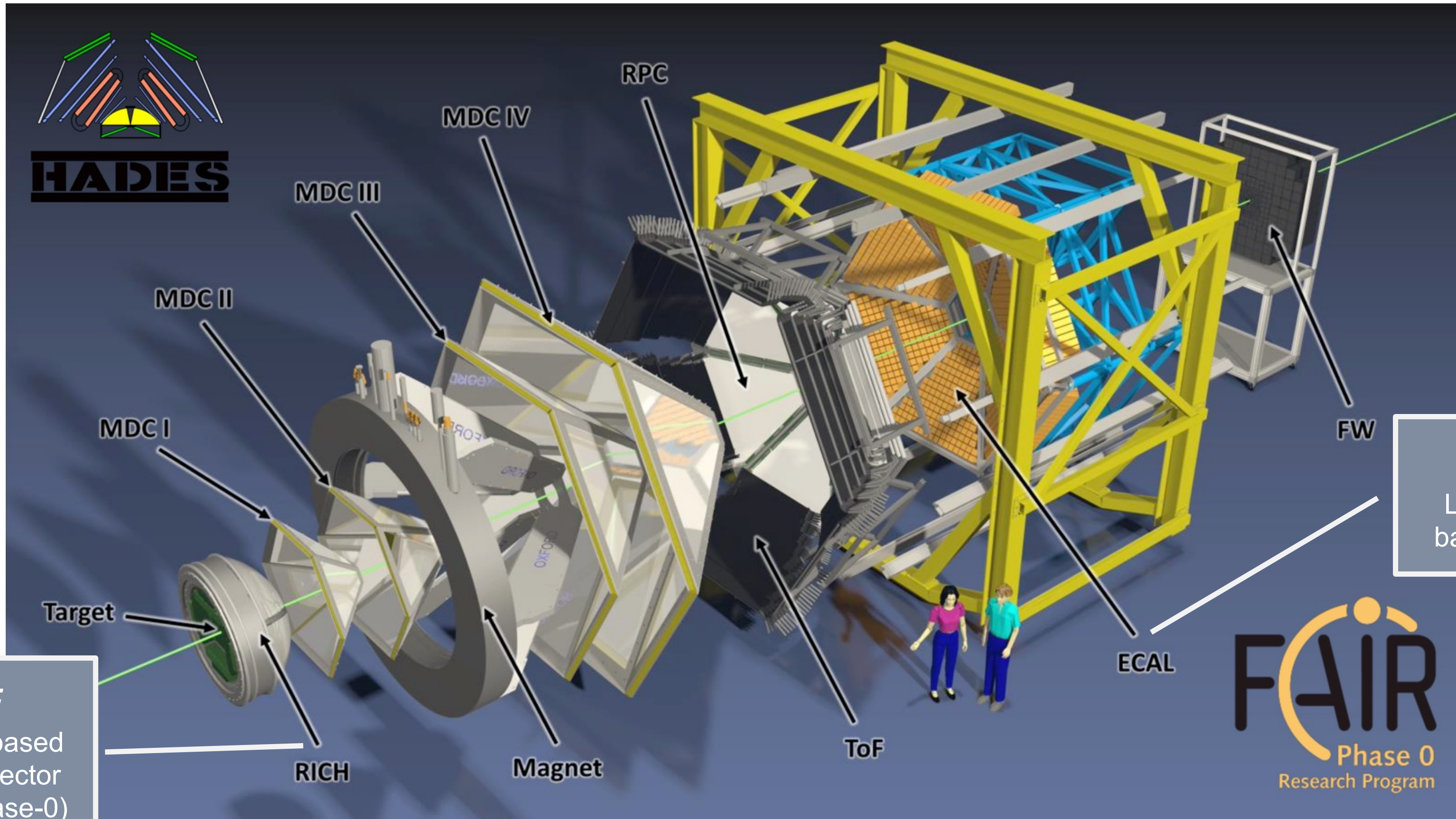
HFHF
Helmholtz Forschungsakademie Hessen für FAIR

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

GSI

HADES as FAIR Phase-0 Detector

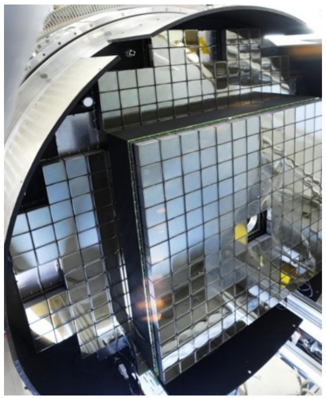
Large acceptance DiElectron Spectrometer – several upgrades since 2002

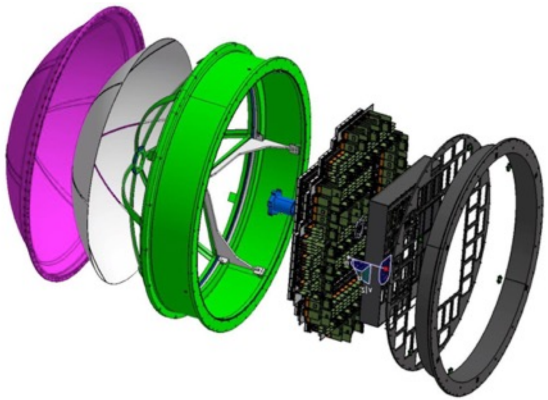


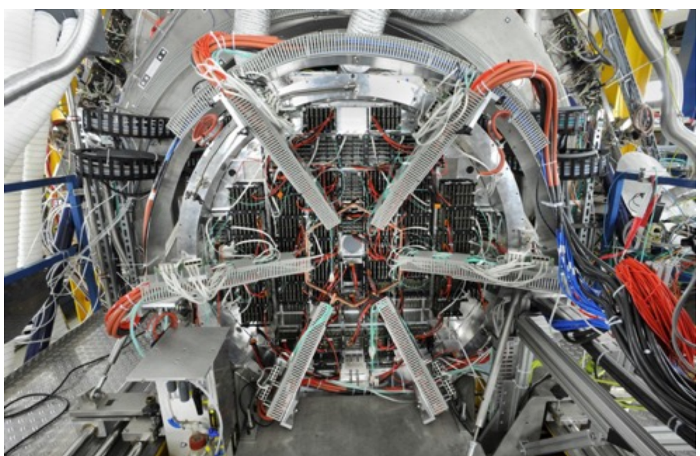
new:
Lead-glass based ECAL

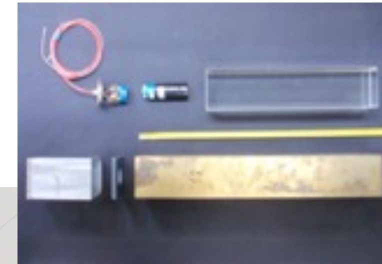
new:
MAPMT based photo detector (CBM Phase-0)

HADES Phase-0 detectors: MAPMT RICH – ECAL

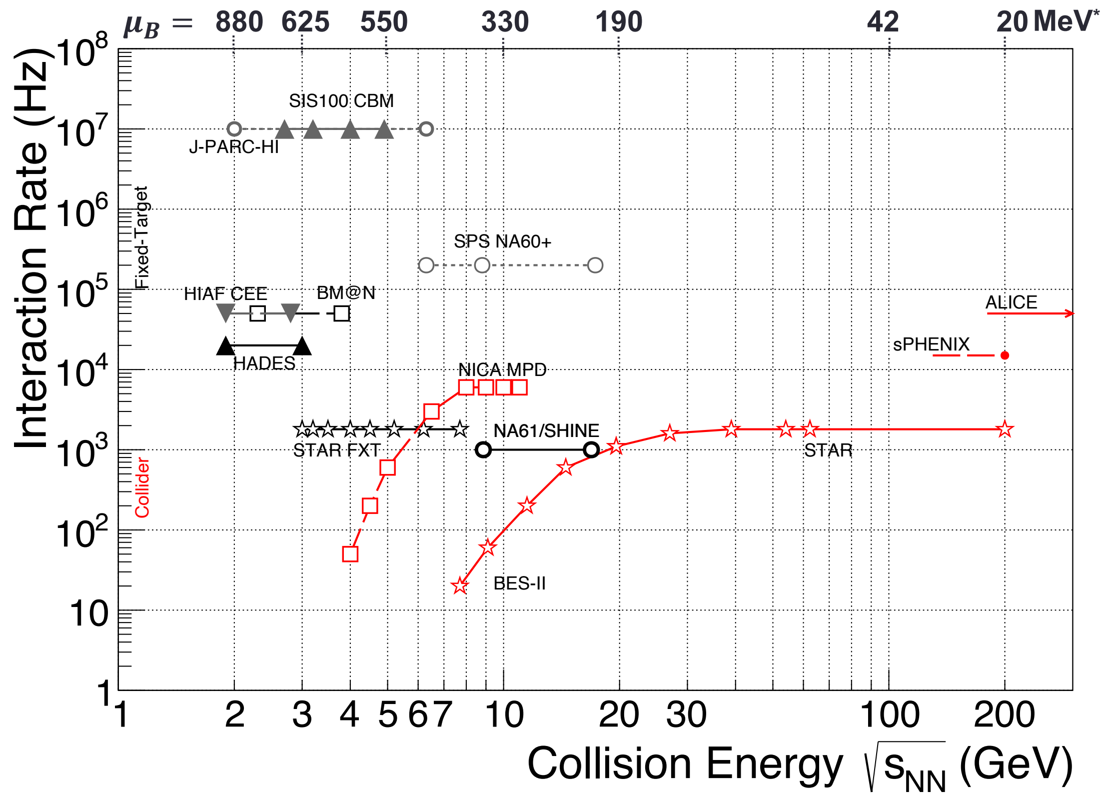






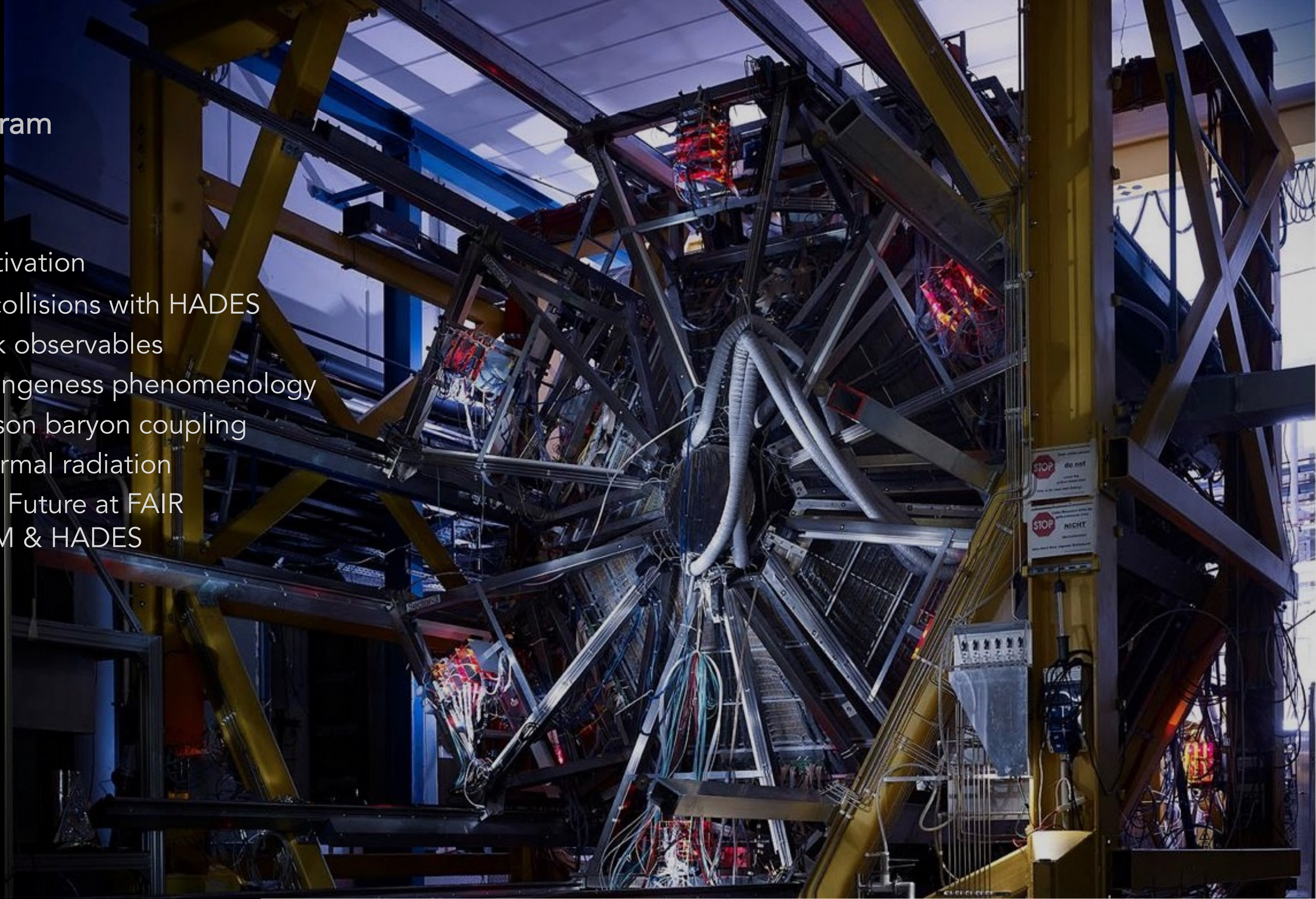


Exploring the QCD phase diagram at high μ_B

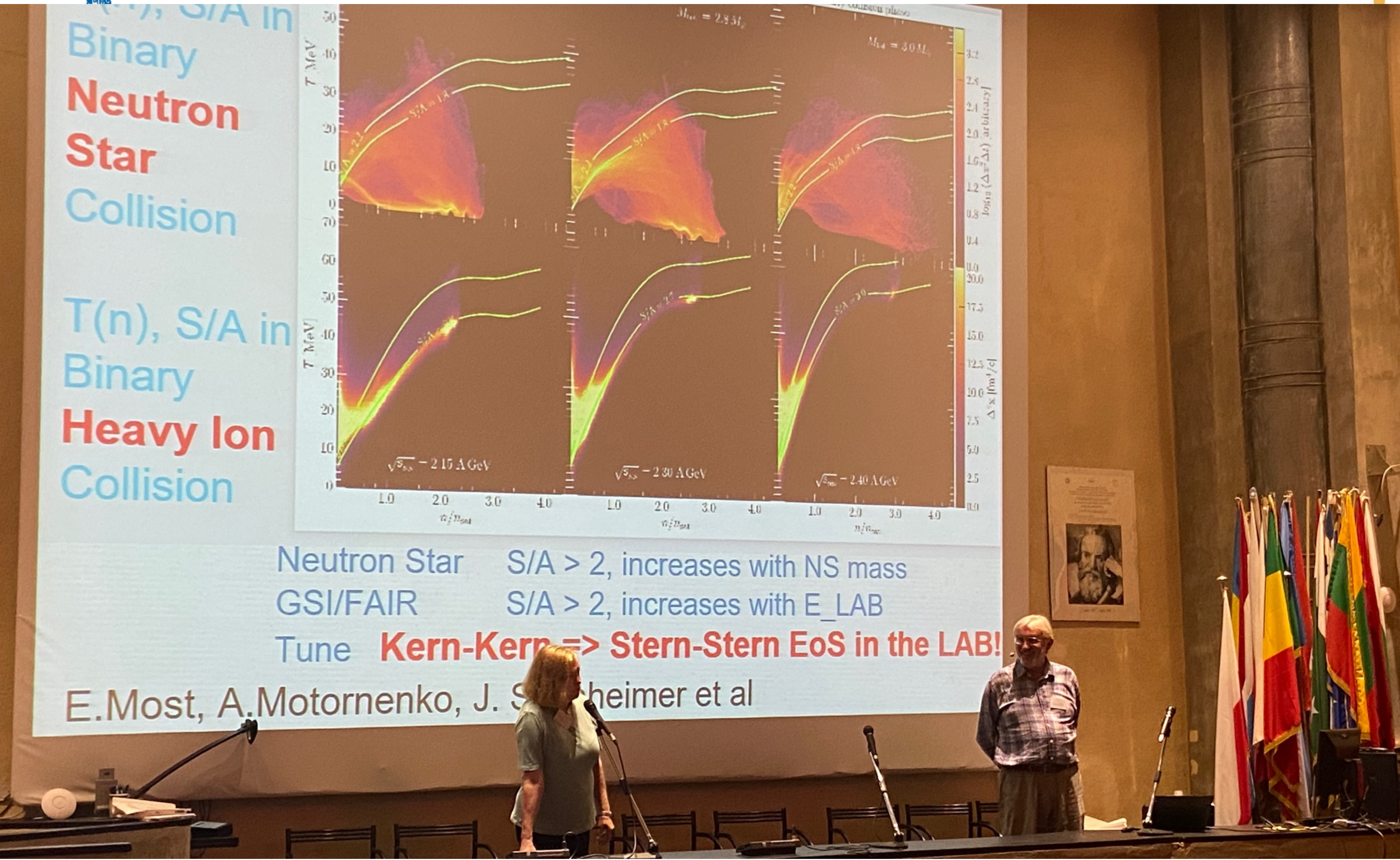


T. Galatyuk, Nucl.Phys. A982 (2019), update 2021 and CBM, EPJA 53 3 (2017) 60
*A. Andronic et al. Phys.Lett.B 678 (2009) 516 and 673 (2009) 142

Program

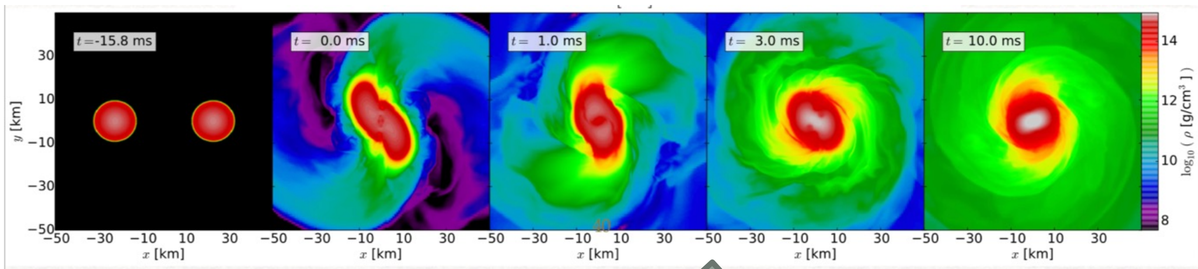


- Motivation
- HI collisions with HADES
- Bulk observables
- Strangeness phenomenology
- Meson baryon coupling
- Thermal radiation
- The Future at FAIR
  CBM & HADES



T(n), S/A in
Binary
Neutron
Star
Collision
T(n), S/A in
Binary
Heavy Ion
Collision
Neutron Star S/A > 2, increases with NS mass
GSI/FAIR S/A > 2, increases with E_LAB
Tune Kern-Kern => Stern-Stern EoS in the LAB!
E.Most, A.Motornenko, J. S heimer et al

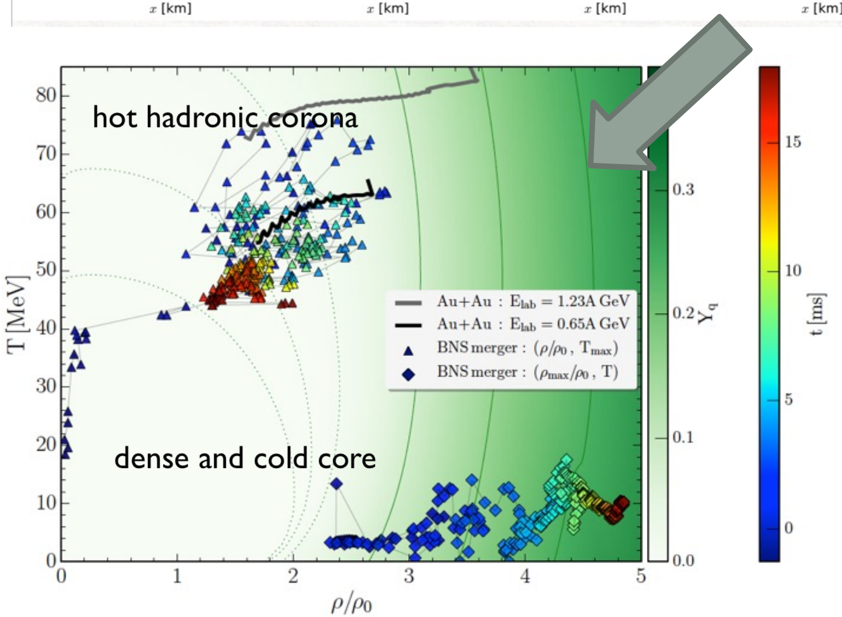
Heavy-ion collisions and neutron star merger



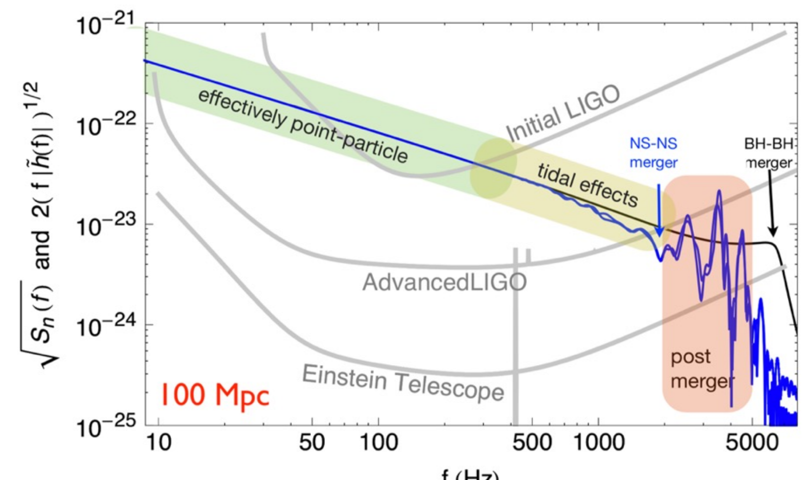
Gravitational wave signal can probe the dense EOS during "ring down" if frequencies in kHZ range are detected.

Moderately dense but hot medium in the surface region of the merger.

HIC observables!?



M. Hanauske, J. Steinheimer (priv. com.)
L. Rezzolla et al. arXiv:1807.03684

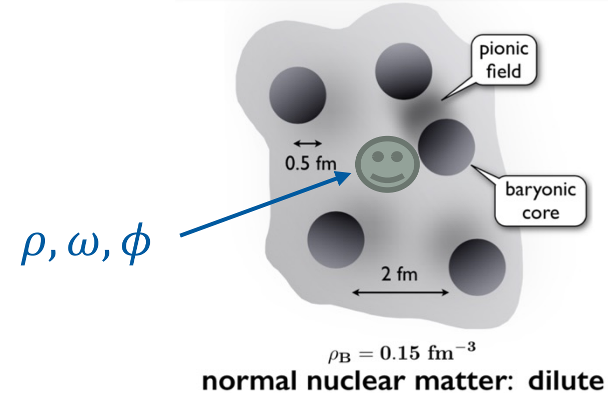


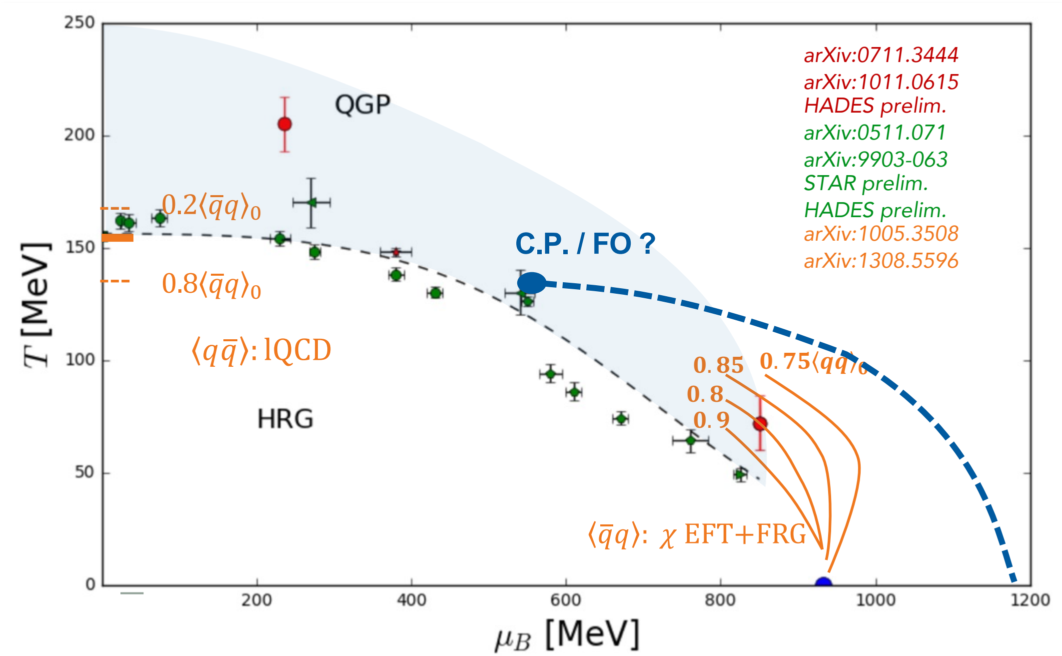
H. Stöcker courtesy Jocelyn Read

The HADES mission

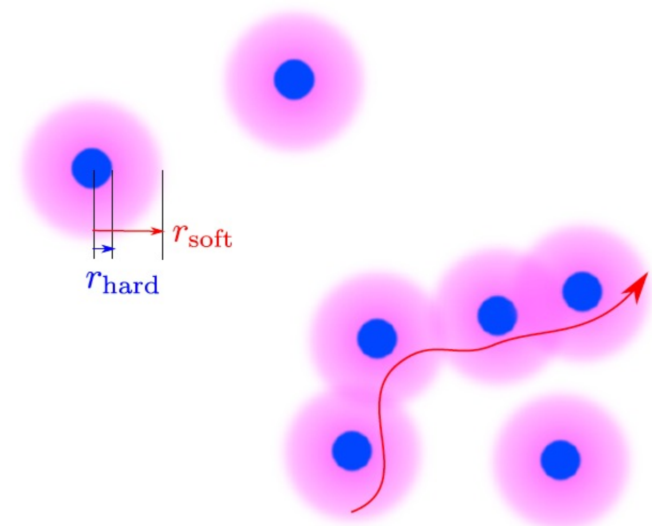
Characterize the microscopic properties of compressed baryonic matter

- From medium modifications to novel phases of QCD matter
- Dynamics of meson baryon coupling





JS, JPS Conf.Proc. 26 (2019) 011013



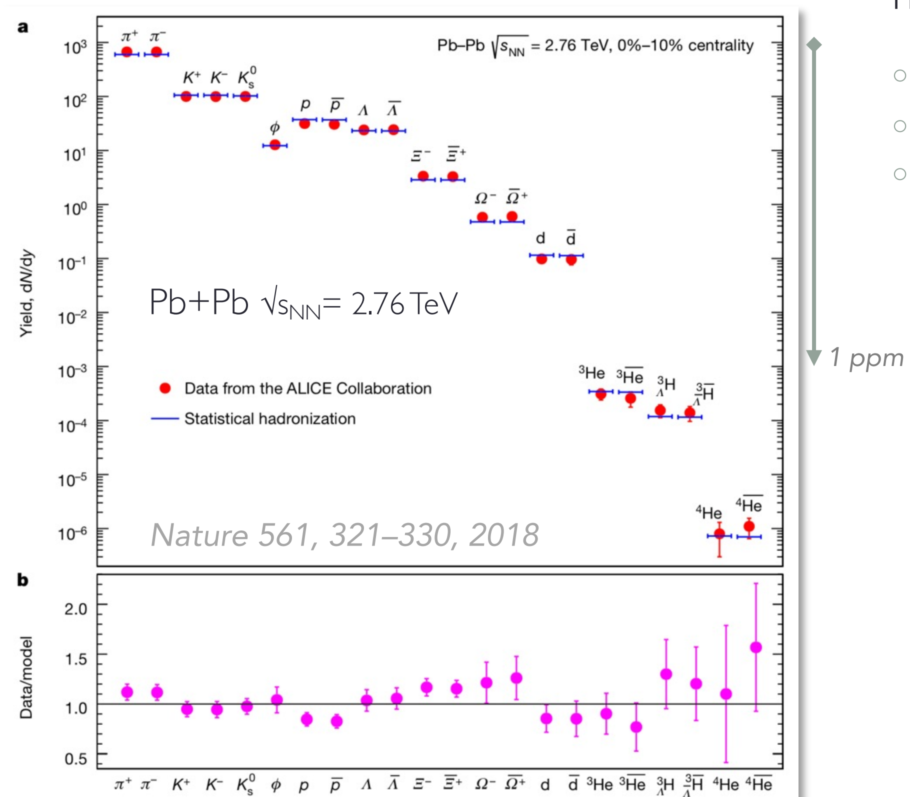
K. Fukushima, T. Kojo, W. Weise; arXiv:2008.08436v2
(also G. Baym, QNP2018)

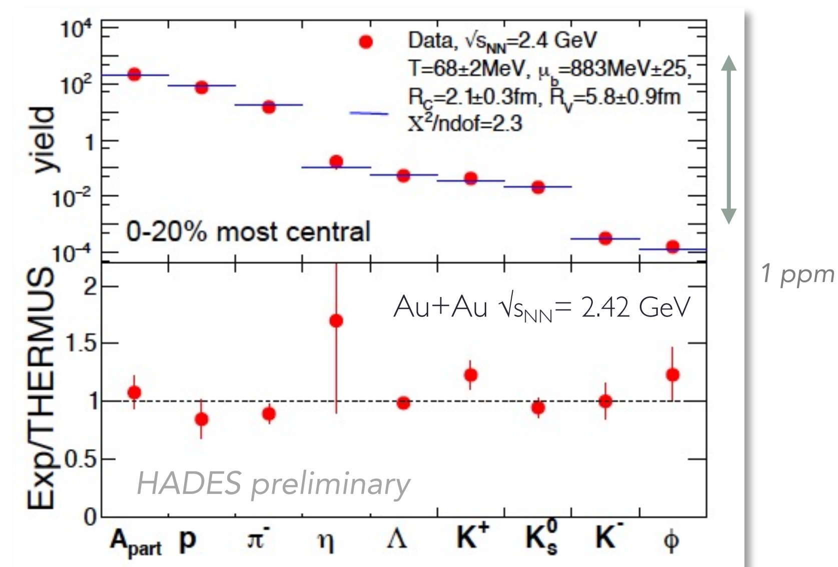
Freeze-out conditions from SIS18 to LHC

ALICE ($\sqrt{s} = 2.76\ A$TeV): $\boldsymbol{T_{ch} = 156.5\ (1.5); \mu_B = 0.7\ (3.8)}$

HADES ($\sqrt{s} = 2.42\ A$GeV): $\boldsymbol{T_{ch} = 68.2\ (1.5); \mu_B = 883\ (25\ )\ (?)}$

- Factor 1000 in beam energy / factor ~2 in temperature
- Strangeness canonical treatment at low beam energies!
- Calculation carried out with vacuum masses!





The Roper Resonance

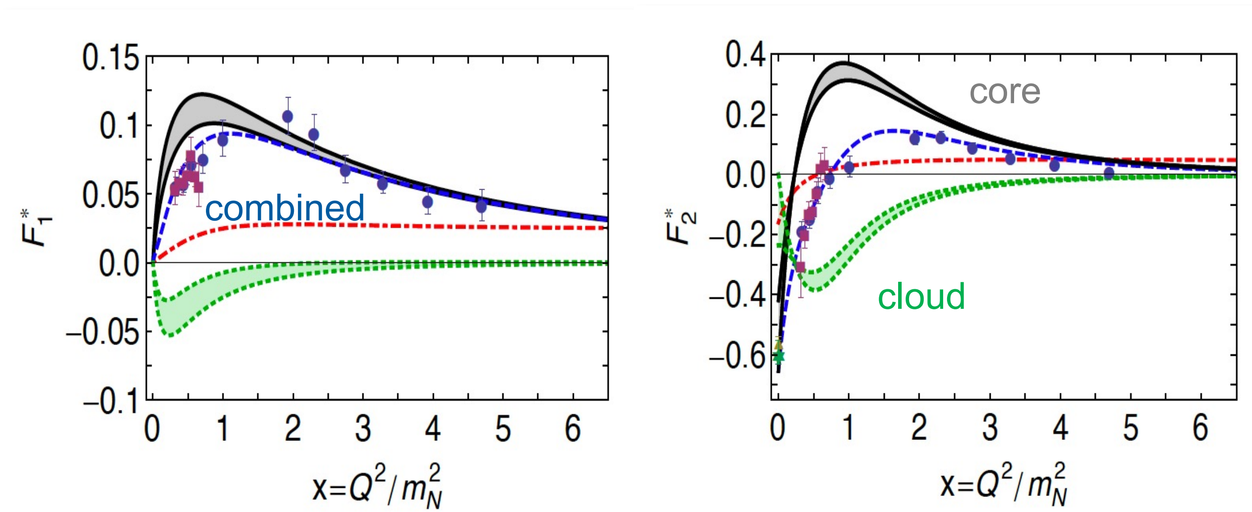
- The second lowest (in mass) excitation of the nucleon is the Roper resonance.
- In constituent quark model first radial excitation of the nucleon, but too low mass.

$$A_{1/2}(Q^2) = c(Q^2)[F_1^*(Q^2) + F_2^*(Q^2)]$$

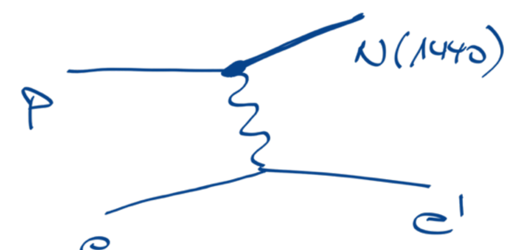
$$S_{1/2}(Q^2) = \frac{q_{\text{CMS}}}{\sqrt{2}} c(Q^2) \left[\frac{F_1^*(Q^2) m_{fi}}{Q^2} + \frac{F_2^*(Q^2)}{m_{fi}}\right]$$

The transition form factors measured at CLAS (JLAB) in the space-like region reveal a particular structure:

- Radially excited dressed-quark core with a "strongly bound pion" in the cloud.



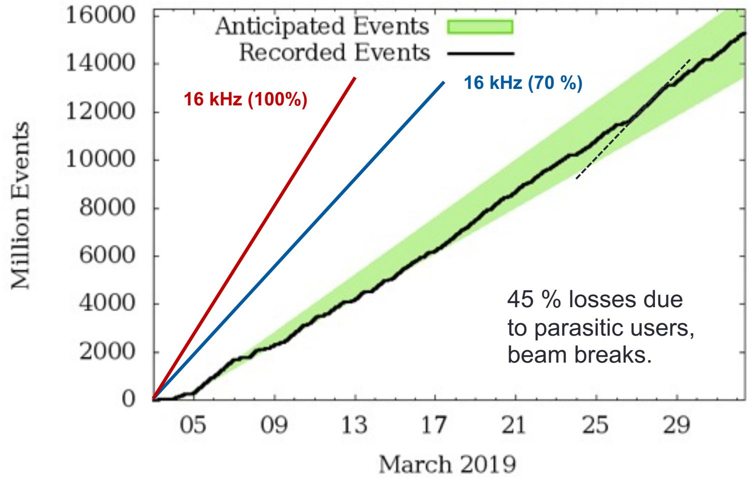
$$N(1440)\ \ I(J^P) = \frac{1}{2}\left(\frac{1}{2}^+\right)$$

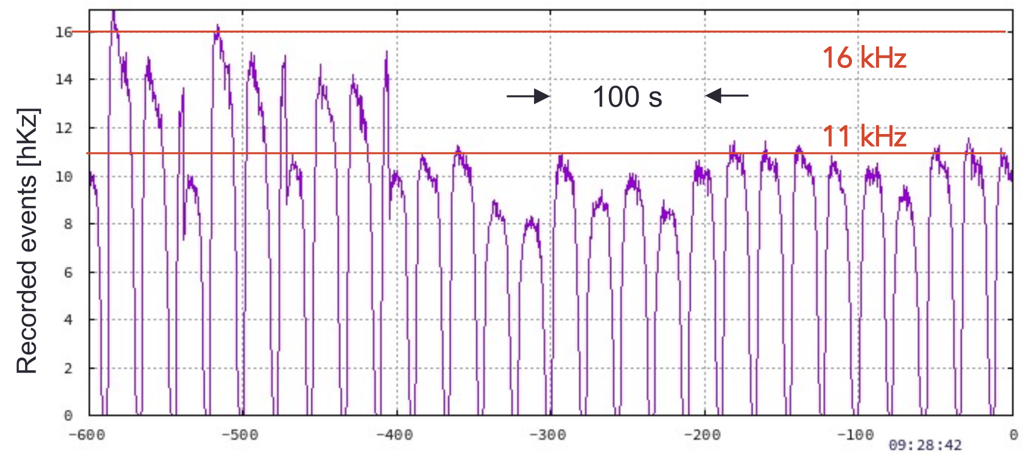


C. Roberts, V. Burkert; arXiv:1710.02549v1

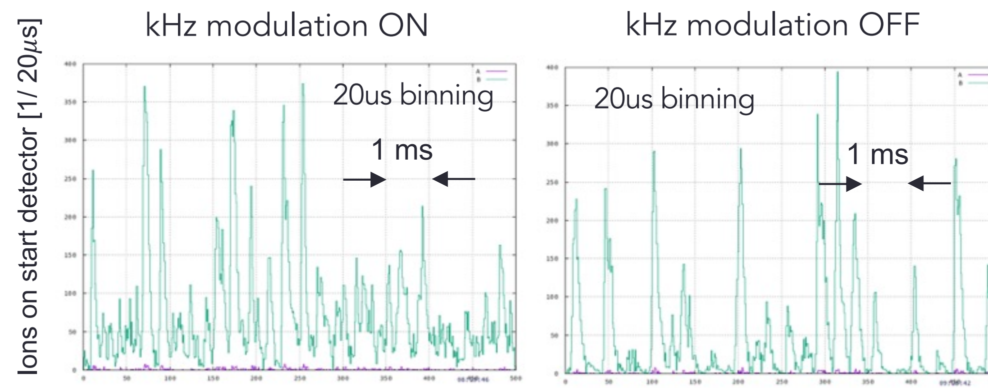
HI COLLISIONS WITH HADES

Ag+Ag ($\sqrt{s} = 2.55\, A$ GeV)





Quadrupole modulation – influence on HADES event rate



Room for optimization of data taking rate:

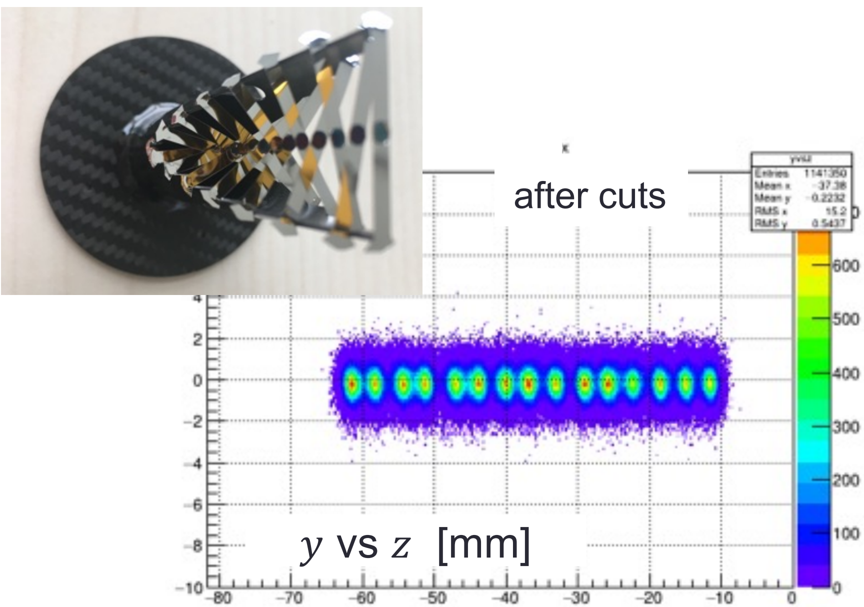
- Spill duty-factor
  - Feed-back system in preparation
- Spill micro-structure
  - Idle time
  - Pile up

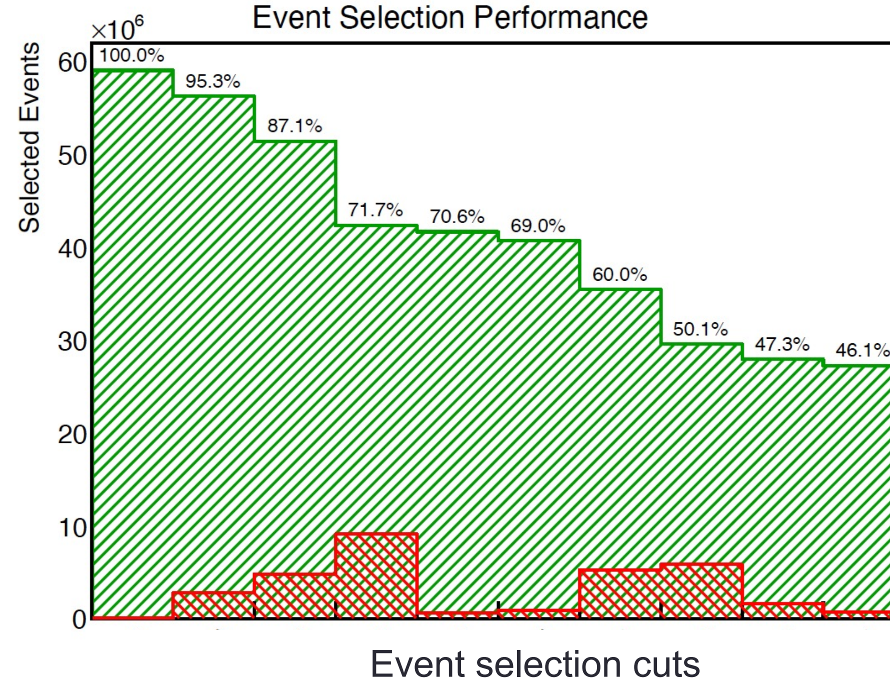
R. Singh, P. Forck, S. Sorge; arXiv:1904-09195

Ag+Ag – offline analysis / event cleaning

From recorded to clean events - reasons for losses:

- Reactions outside the target stack
- Pile-up events
- T0 inefficiency

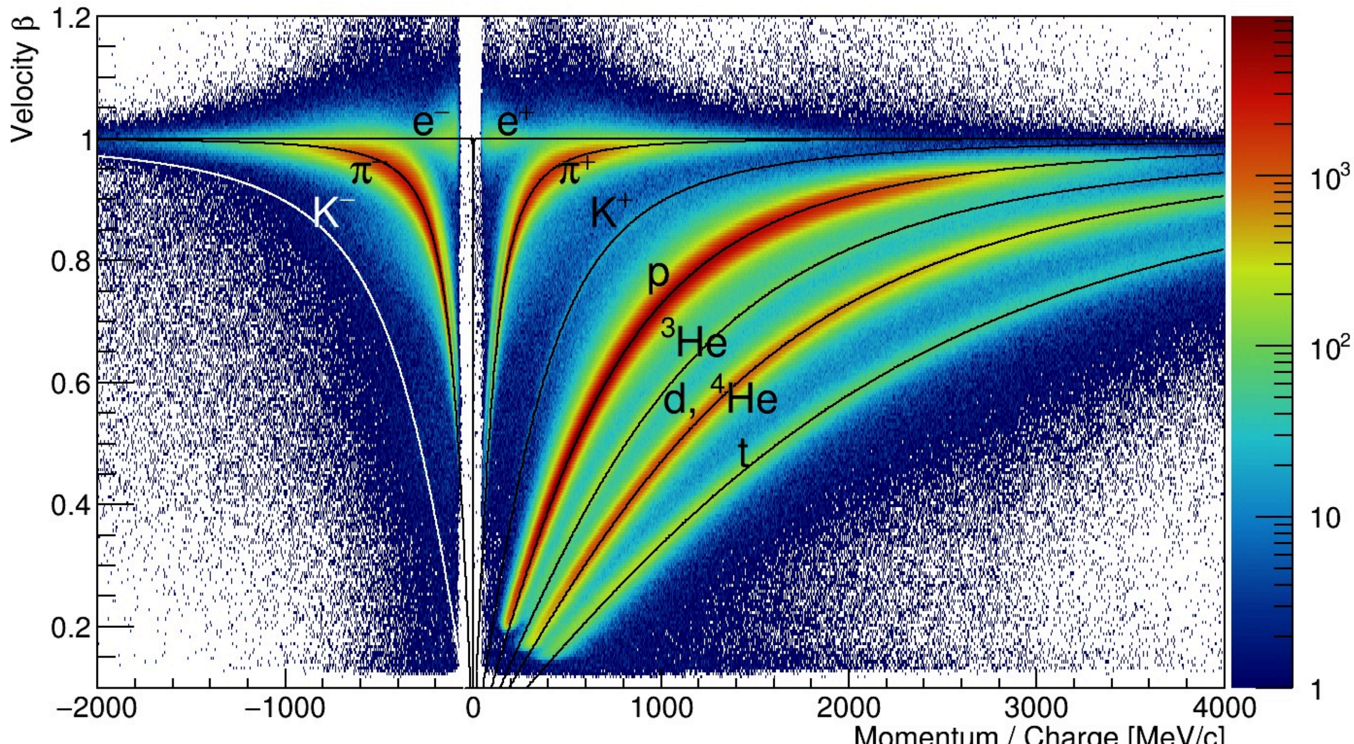




Removed events dominantly suffering pile-up (> 50%)

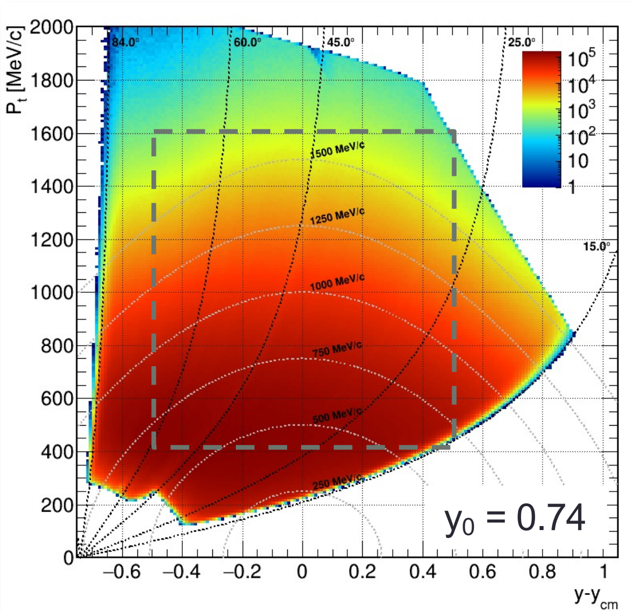
Particle identification

Time-of-flight (β)
+ dE/dx (Kaons, light nuclei)
+ Cherenkov rings (electrons / positrons)



BULK OBSERVABLES

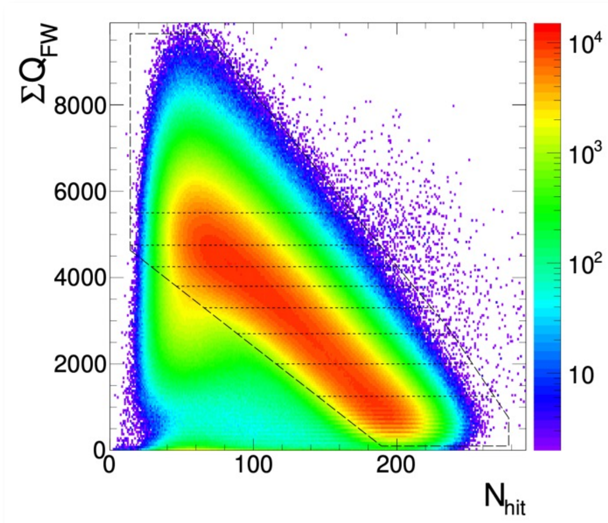
E-b-E Proton Distributions from $Au + Au \sqrt{s} = 2.42$ AGeV



HADES $y - p_t$ coverage for protons

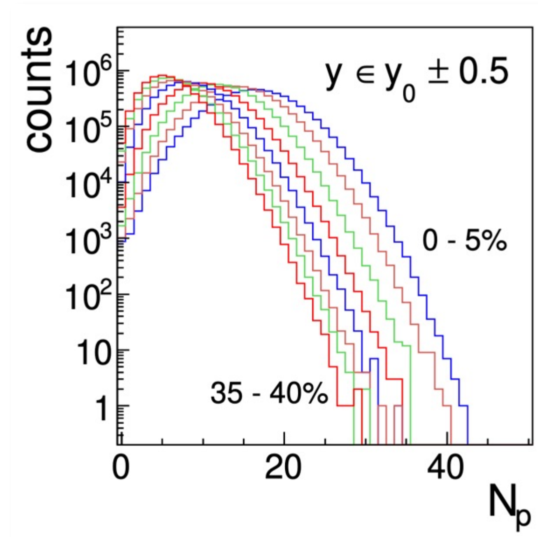
Purity < 0.999, use β and dE/dx

Useful acceptance $y = y_0 \pm 0.5$



Centrality is derived from the dE/dx signal in the forward hodoscope Σ_Q.

Loose cut on spectrometer activity to suppress peripheral reactions.



Analysis based on $1.6 \cdot 10^8$ evts.

Divided into eight centrality classes:

30-40%, 20-30%, 10-20%, and 0-10%

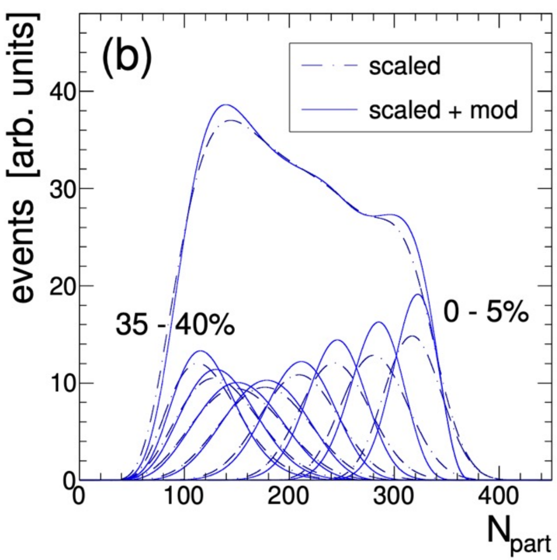
HADES Phys.Rev.C 102 (2020) 2, 024914

Corrections applied to the data

Volume fluctuations

- Corecctions of proton cumulants based on "volume cumulants" derived from N_{hit} distributions in N2LO.

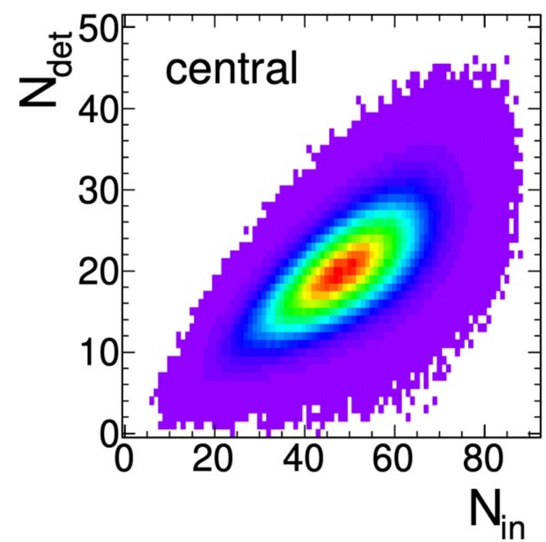
V. Skokov et al. Phys.Rev.C 88, 034911 (2013)
PBM et al. Nucl.Phys.A 960, 114 (2017)



Detector response

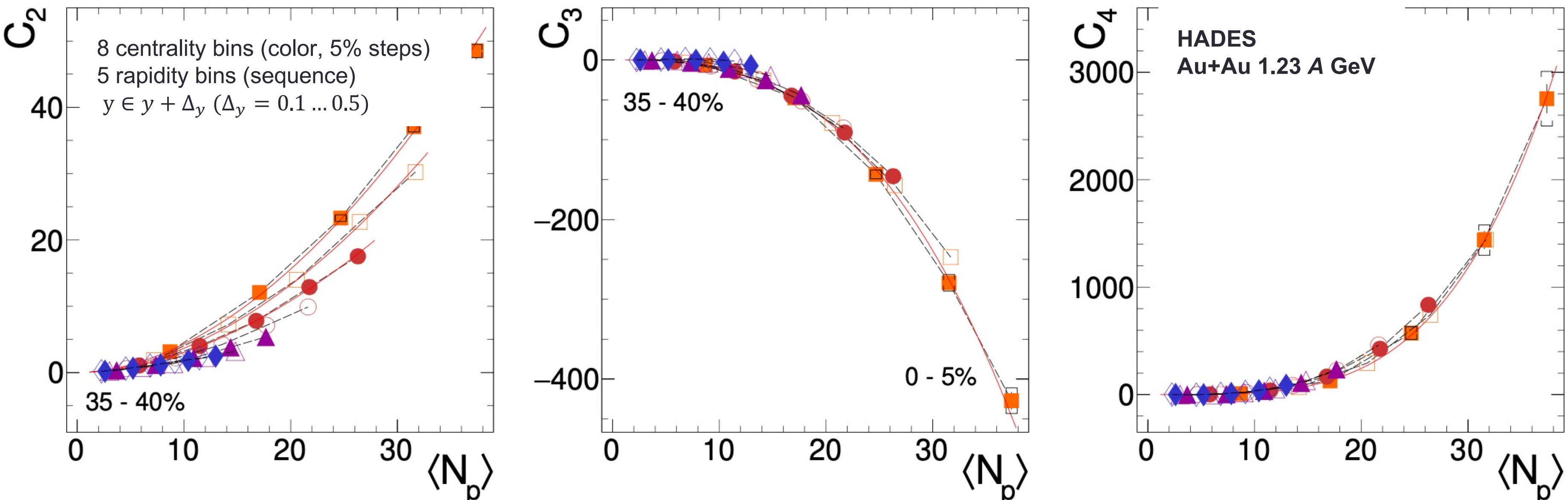
- Studied with the HADES simulation package
- Corrected using factorial moment method

M. Kitazawa, Phys. Rev. C 93, 044911 (2016).
T. Nonaka et al., Phys. Rev. C 95, 064912 (2017).



HADES Phys.Rev.C 102 (2020) 2, 024914

$\langle N_p \rangle$ scaling of factorial cumulants C_n



$C_2 \propto \langle N_p \rangle^\alpha$ $\alpha = 1.86 \pm 0.04$

$C_3 \propto \langle N_p \rangle^\alpha$ $\alpha = 2.84 \pm 0.05$

$C_4 \propto \langle N_p \rangle^\alpha$ $\alpha = 3.89 \pm 0.14$

$C_1 = K_1$
$C_2 = K_2 - K_1$
$C_3 = K_3 - 3K_2 + 2K_1$
$C_4 = K_4 - 6K_3 - 11K_2 + 6K_1$
K_n: cumulants
C_n: factorial cumulants/correlator

$\alpha \simeq n \rightarrow$ signature of rather long-range correlation ($\Delta y_{corr} > \Delta_y$)

B. Ling, M.A. Stephanov; Phys.Rev:C 93, 034519

HADES Phys.Rev.C 102 (2020) 2, 024914

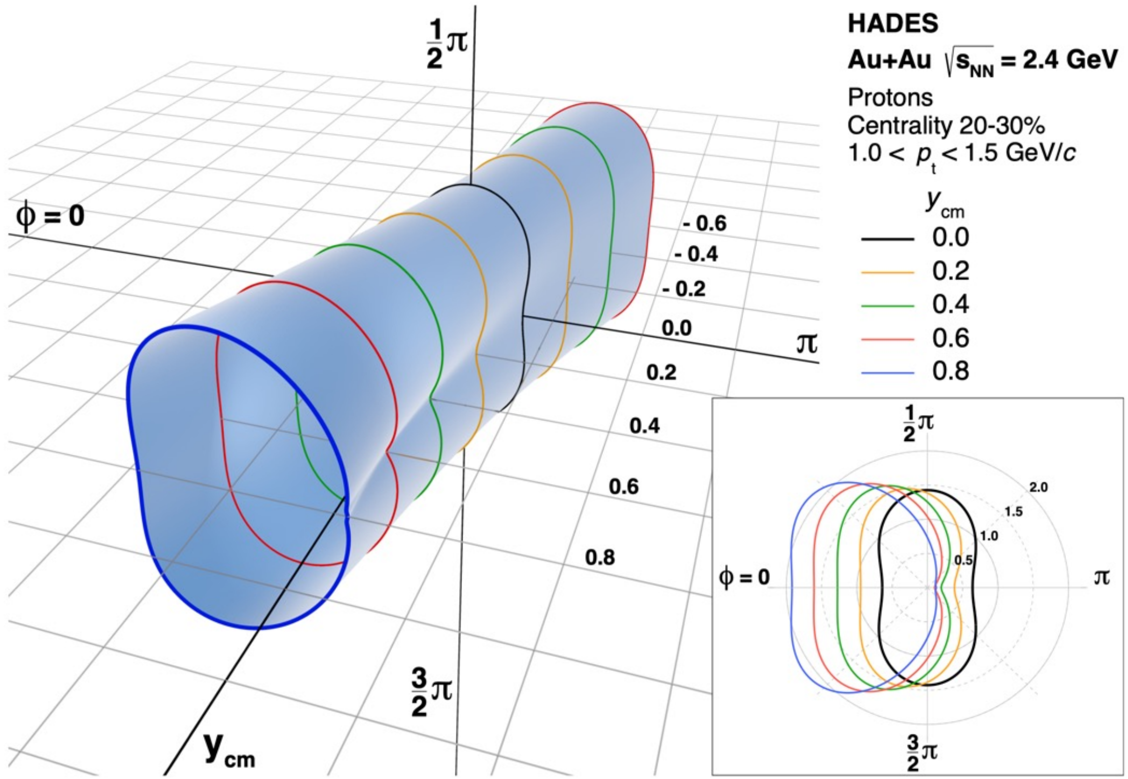
Proton higher-order flow components ($Au + Au\ \sqrt{s} = 2.42$ AGeV)

The collective motion (flow) of protons, deuterons and tritons shows a distinct pattern which encodes properties of the fireball (e.g. equation-of-state).

Hillmann, Steinheimer et al., J.Phys.G 45 (2018)

The flow is encoded in the transverse mass spectra and in the angular variation of the yields.

$$\frac{dN}{d\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\varphi - \Psi_n))$$



HADES, Phys. Rev. Lett. 125 (2020)

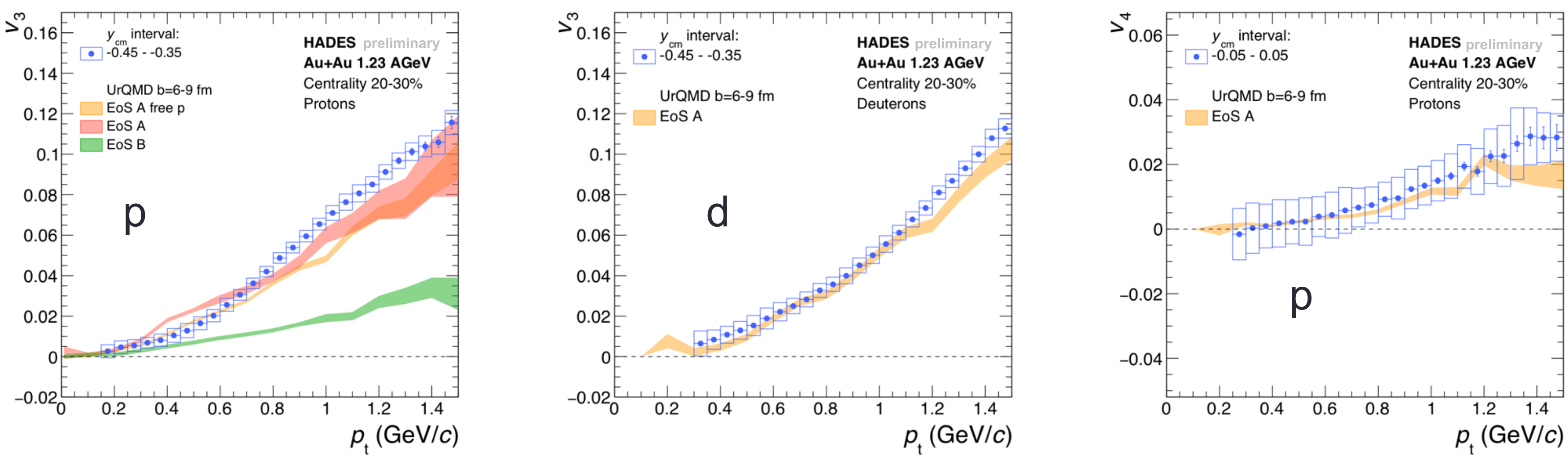
Sensitivity to the EoS: $v_3\{\Psi_{RP}\}$ and $v_4\{\Psi_{RP}\}$

UrQMD with Skyrm potential

$$V_{Sk} = \alpha \cdot \left(\frac{\rho_{int}}{\rho_0}\right) + \beta \cdot \left(\frac{\rho_{int}}{\rho_0}\right)^{\gamma}$$

– EOS A + coalescence in space and momentum

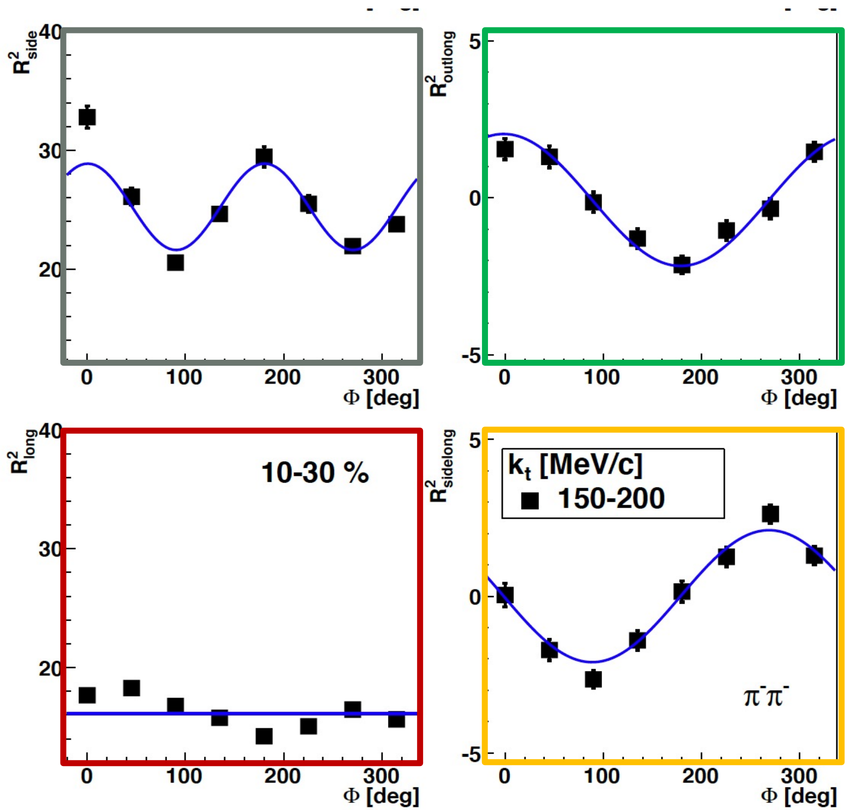
EOS	A	B
α (MeV)	-124	-356
β (MeV)	71	303
γ	2	1.17



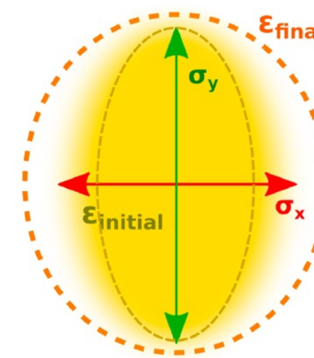
"… this ansatz provides a very good description of the measured deuteron flow data, if a hard equation of state is used …"

[P. Hillmann, J. Steinheimer, M. Bleicher, J.Phys G45 (2018) 085101]

3-D HBT ($\pi\pi$) image of collision zone



- Identical particle correlations from Au-Au collisions, a.f.o. relative event-plane angle Φ and pair momentum. *(U.A. Wiedemann; Phys.Rev.C 57, 266 (1998), U.A. Wiedemann, U. Heinz; Phys.Rep. 319, 145 (1999))*
- Size modulations available for 6 bins in pair momentum.
- Initial (nuclear overlap) eccentricity is relaxed at freeze-out $\epsilon_{\text{initial}} > \epsilon_{\text{final}}$.
- Correlation volume ~ 2200 fm^3 at vanishing transverse momentum.



$$R^2_{ij} = \begin{pmatrix} R^2_o & R^2_{os} & R^2_{ol} \\ R^2_{os} & R^2_s & R^2_{sl} \\ R^2_{ol} & R^2_{sl} & R^2_l \end{pmatrix}$$

$\Phi = \angle yb$ *(long axis and impact parameter)*

HADES, Eur. Phys. J. A 56, 140 (2020)

STRANGENESS PHENOMENOLOGY

Universal strangeness centrality dependence

Strangeness production at SIS18 energies enabled by medium-effects

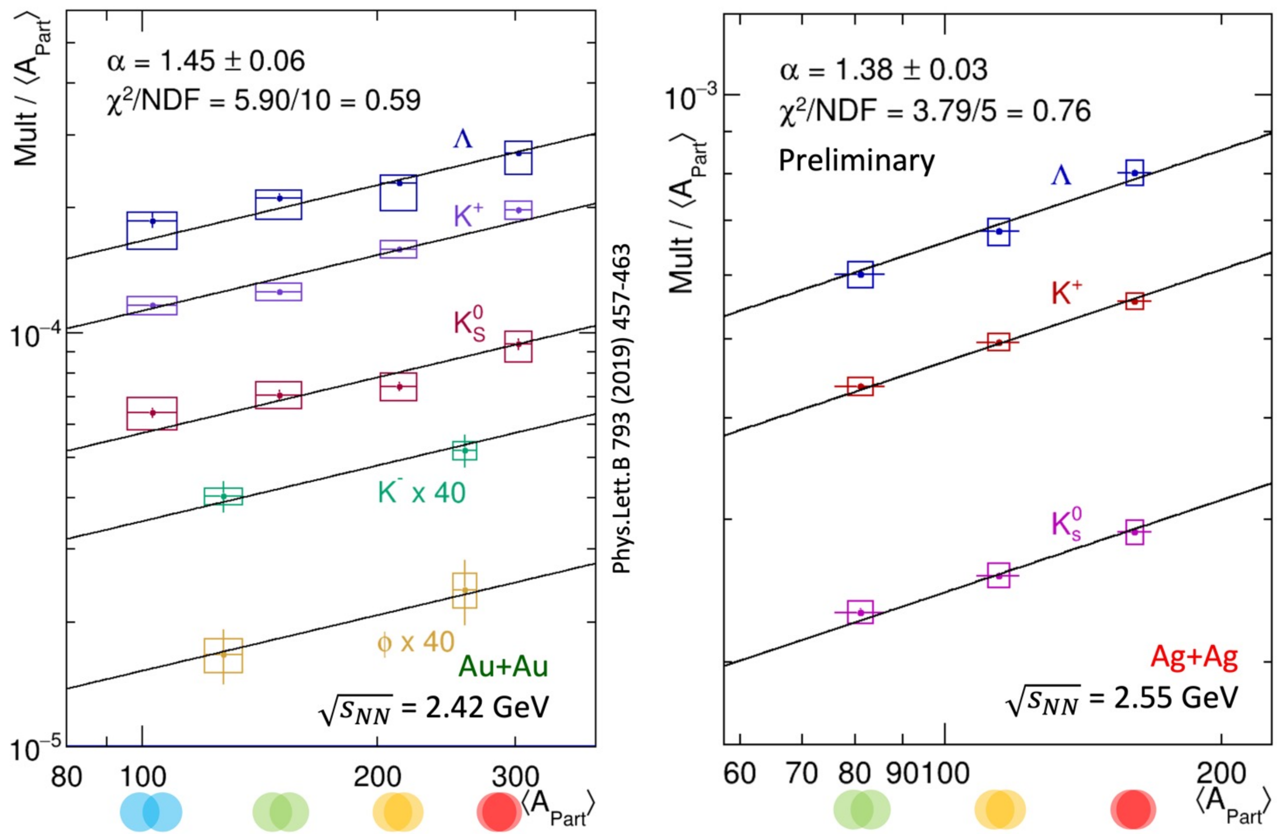
Suggests density-dependence of production

$NN \rightarrow N\Lambda K^+$: $\sqrt{s} = 2.5$ GeV

$NN \rightarrow NNK^+K^-$: $\sqrt{s} = 2.9$ GeV

Data can be explained with a single slope:

$$M_i \propto \langle A_{\text{part}} \rangle^{\alpha}.$$



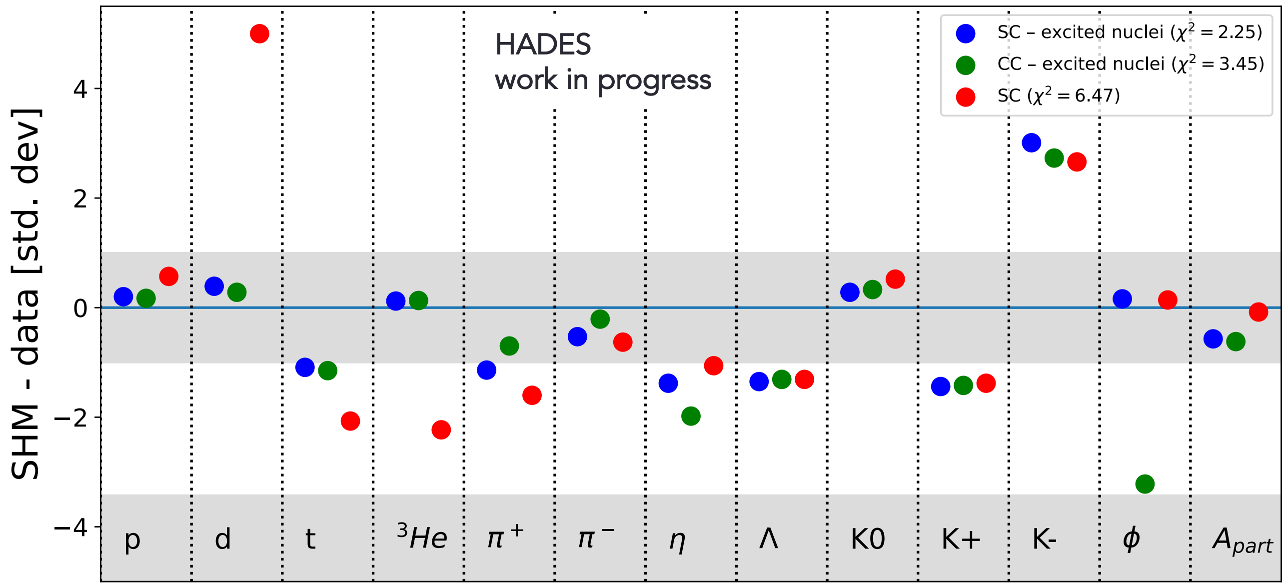
Refined fits including light nuclei

https://github.com/vlvovch/Thermal-FIST (V. Vovchenko, HS)
Comput. Phys. Commun. 244, 295 (2019), 1901.05249 [nucl-th])

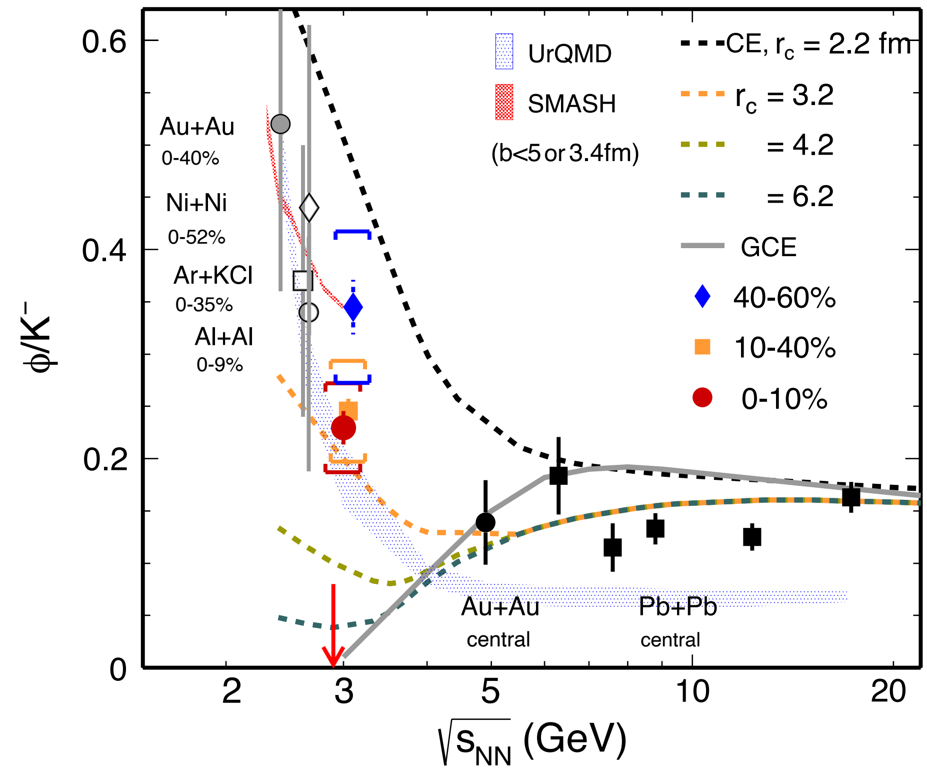
A: strangeness canonical, excited nuclear states
B: strangeness canonical, w/o excited nuclear st.
C: grand canonical, excited nuclear states

all non-interacting gas, const. Breit-Wigner width

	A	B	C
T [MeV]	64.0 ± 1.2	66.2 ± 0.7	64.2 ± 1.1
μ_B [MeV]	783 ± 2.5	801 ± 1.5	782 ± 2.5
R [fm]	9.9 ± 0.2	8.7 ± 0.14	9.9 ± 0.17
R_c [fm]	3.39 ± 0.4	2.68 ± 0.14	–
γ_s	1	1	0.056 ± 0.007
χ^2	2.5	6.5	3.5



Canonical suppression of strangeness production (?)

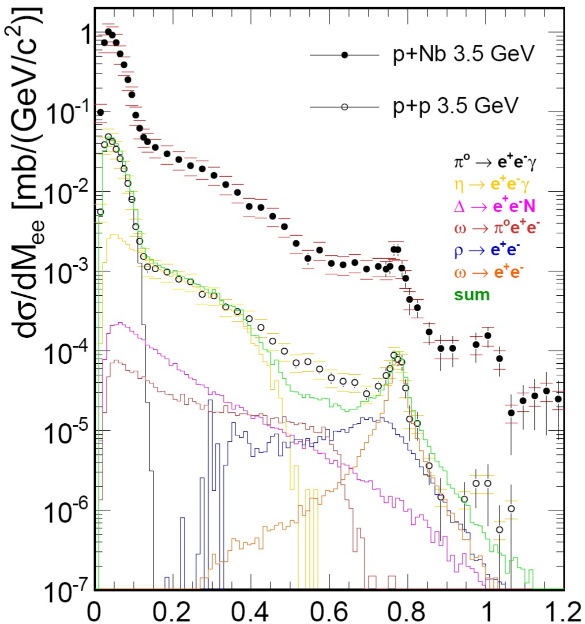


G.N. Xie for STAR 2108.05424 [nucl-ex]

MESON BARYON COUPLING

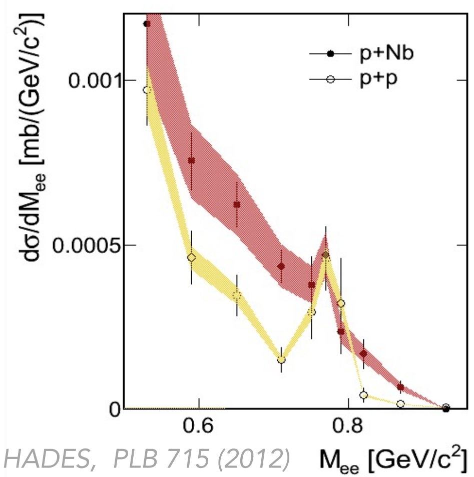
Vector mesons in (cold) matter

- Line shape measurement notoriously difficult
- In Au+Au ω multiplicity ~ 10^{-2}
- Γ_{ee}/Γ_{tot}~ 5 $\times 10^{-5}$



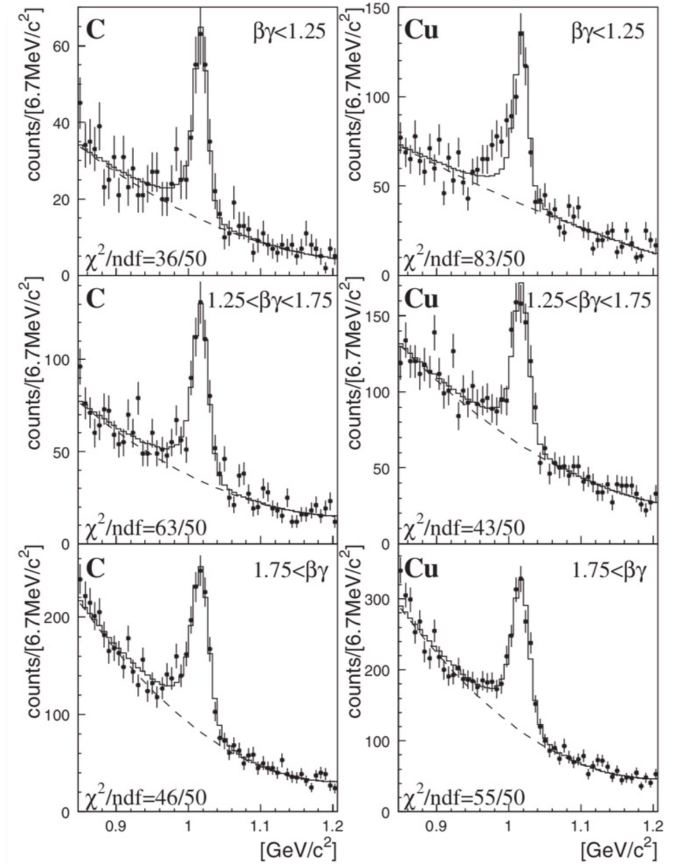
HADES, PLB 715 (2012)

HADES (ω)



HADES, PLB 715 (2012)

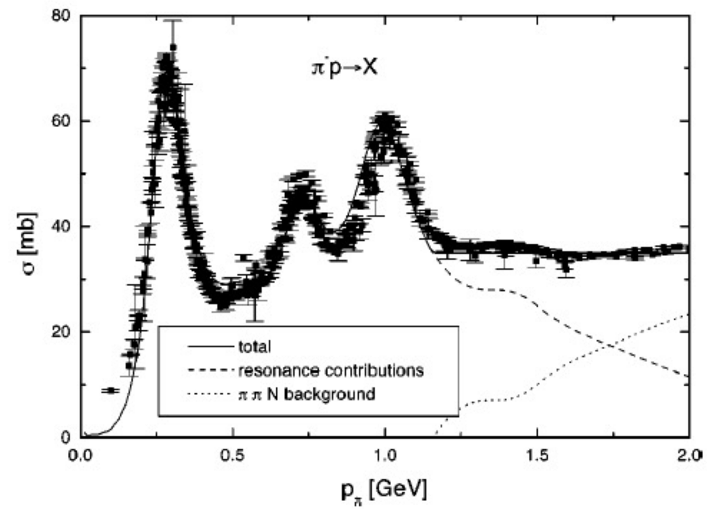
KEK-PS E325 (ϕ)

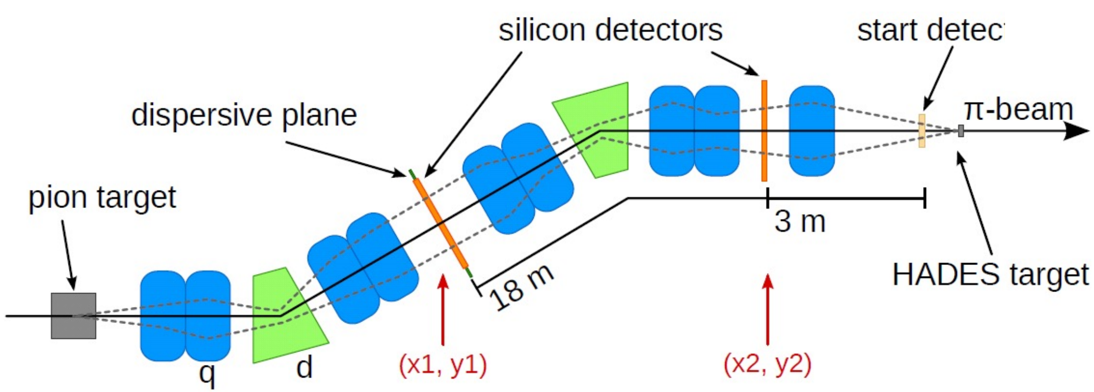


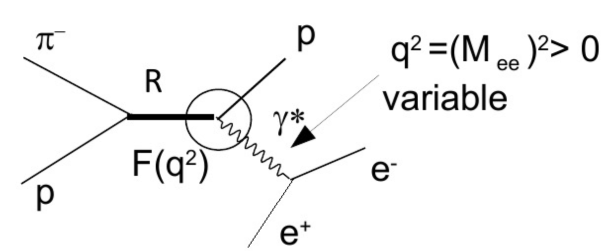
KEK-PS E325, PRL 98, 042501 (2007)

The HADES Pion Beam Facility

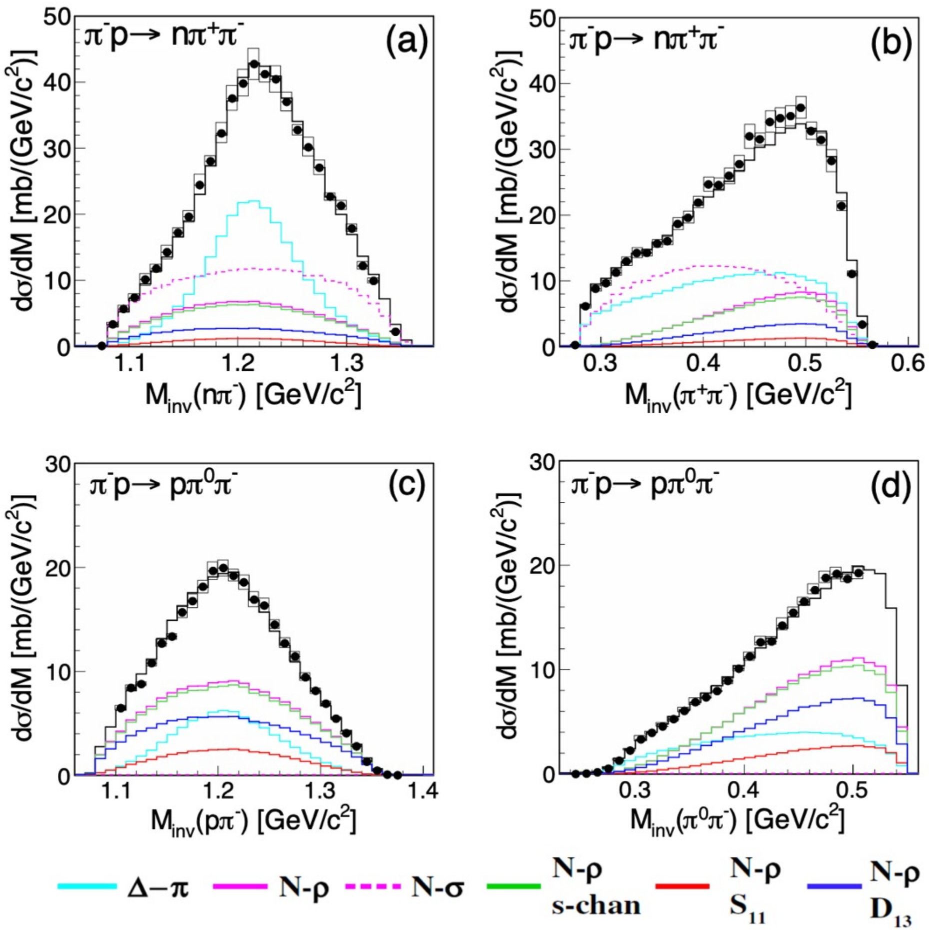
- Production target 40 m upstream the experiment target position allows production of secondary beams
- Direct excitation of baryon resonance
- Combination with dilepton spectrometer world-wide unique







Extraction of partial waves from two-pion channel



- p_π = [656, 690, 748, 800] MeV

- $\pi^- + p \rightarrow \pi^- + \pi^+ + n$
  - Hadronic final states used in PWA
  - (Bonn/Gatchina code)
  - Use invariant masses and angular distribution.

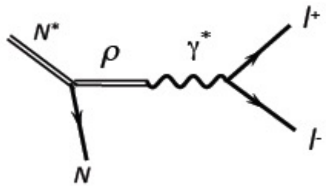
- $\pi^- + p \rightarrow e^- + e^+ + n$
  - Prediction for dilepton invariant mass assuming strict VMD.
  - Two-component model.

HADES Phys.Rev.C 102 (2020) 2, 024001.

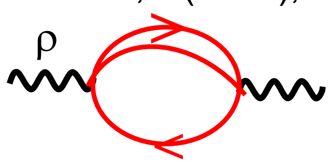
$\pi^- + p \rightarrow e^+e^- + n$

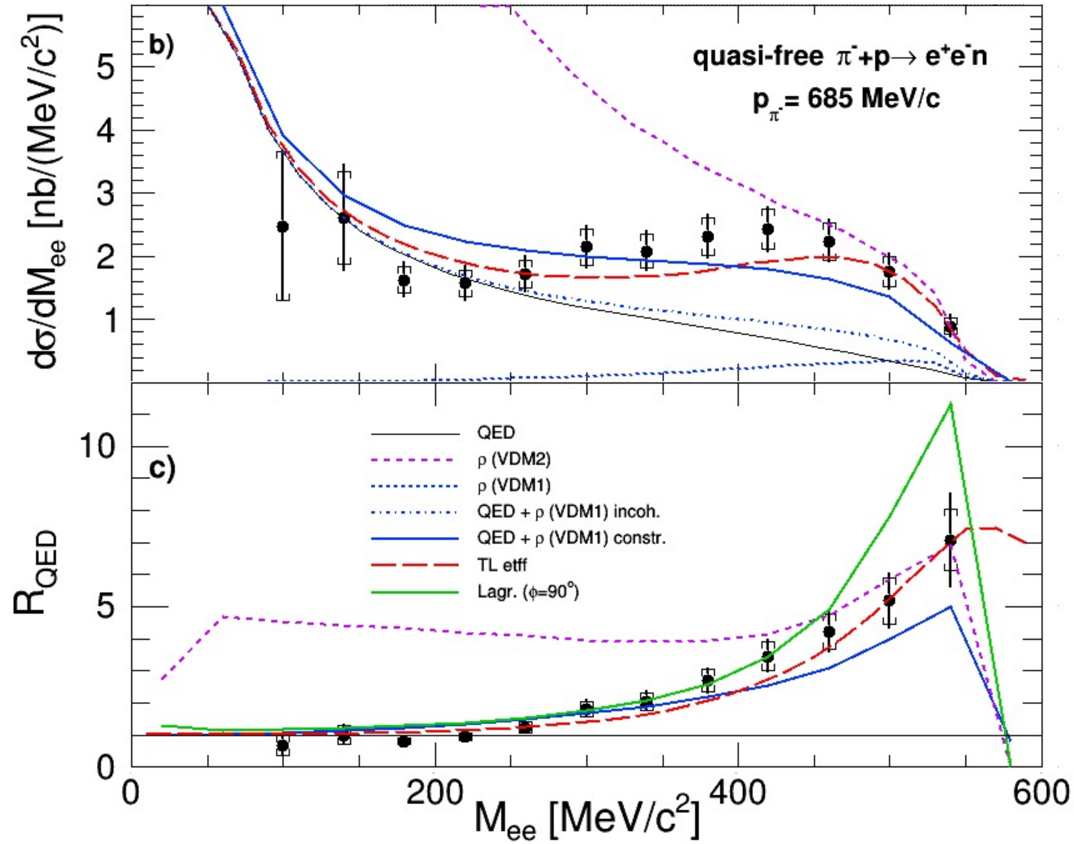
Effective transition form factor (time-like) extracted by subtracting QED expectation.

R-Dalitz decay:



Baryonic contribution to in-medium ρ selfenergy

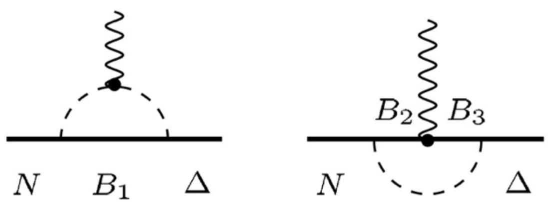




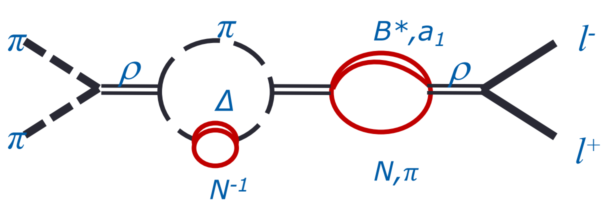
Pion cloud effect in Δ(1323)

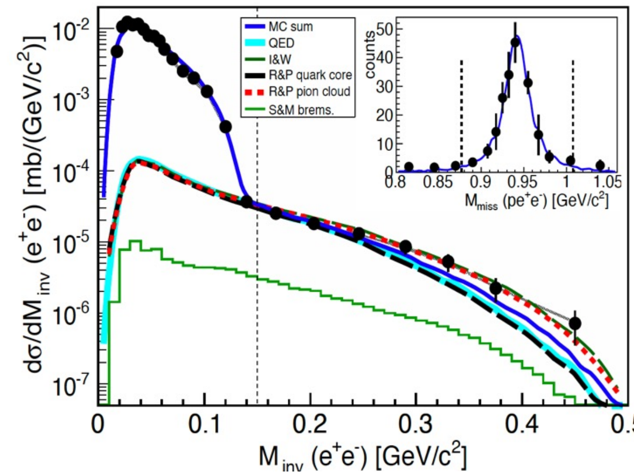
- Exclusive dielectron production in p+p collisions.
- Effect of the pion cloud observed in the time-like electromagnetic transition formafactor (off-shell ρ meson).

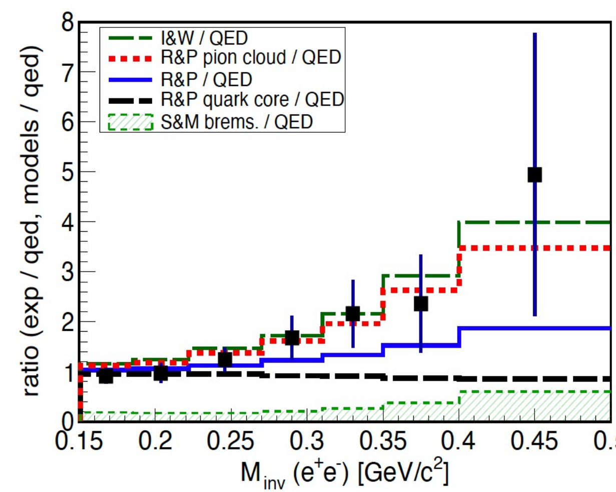
Peña, Ramalho; arXiv-1205-2575
Peña, Ramalho + GiBUU.; arXiv-1512-03764



- Moderate contribution to the in-medium propagator







HADES: arXiv:1404.2136 [nucl-th]

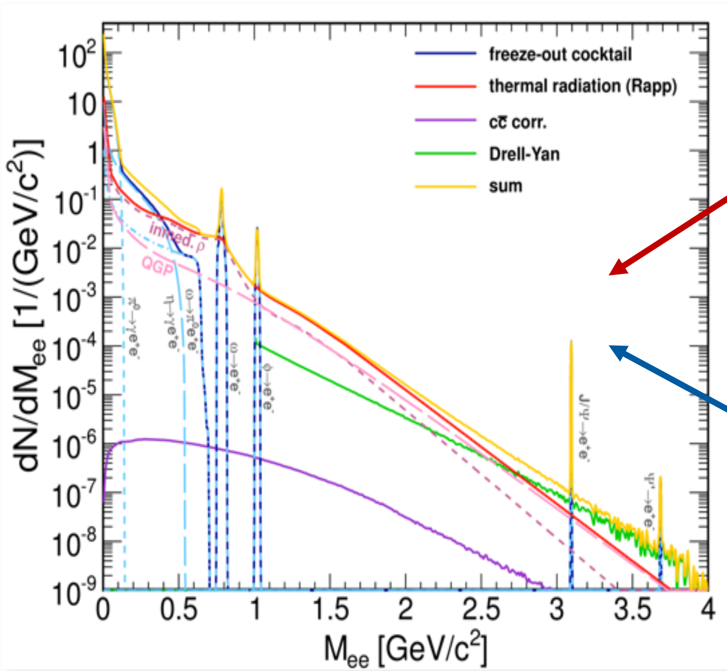
THERMAL RADIATION

Theoretical approaches to medium radiation

Medium (excess) radiation from *Thermal Emission Rates (ϵ)* ("standard candle"):

$$\frac{d^4N}{dMdydp_t d\alpha} = \int \frac{\alpha^2}{\pi^3 M^2} L(M^2) f_B(q\cdot u;\ T)\ \mathrm{Im}\Pi_{\mathrm{EM}}[M,q;T,\mu_B]\, d\boldsymbol{x}$$

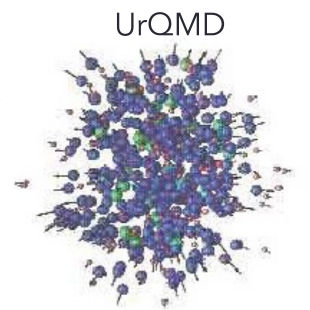
$$\equiv \int \frac{d^4\epsilon}{d\boldsymbol{q}} [T(\boldsymbol{x}),\mu_B(\boldsymbol{x}),\vec{v}(\boldsymbol{x})]\, d\boldsymbol{x}$$



F. Seck, MSc 2015

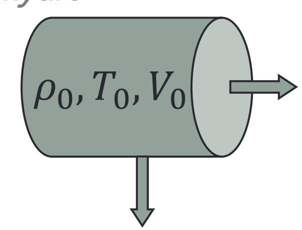
shining

coarse graining



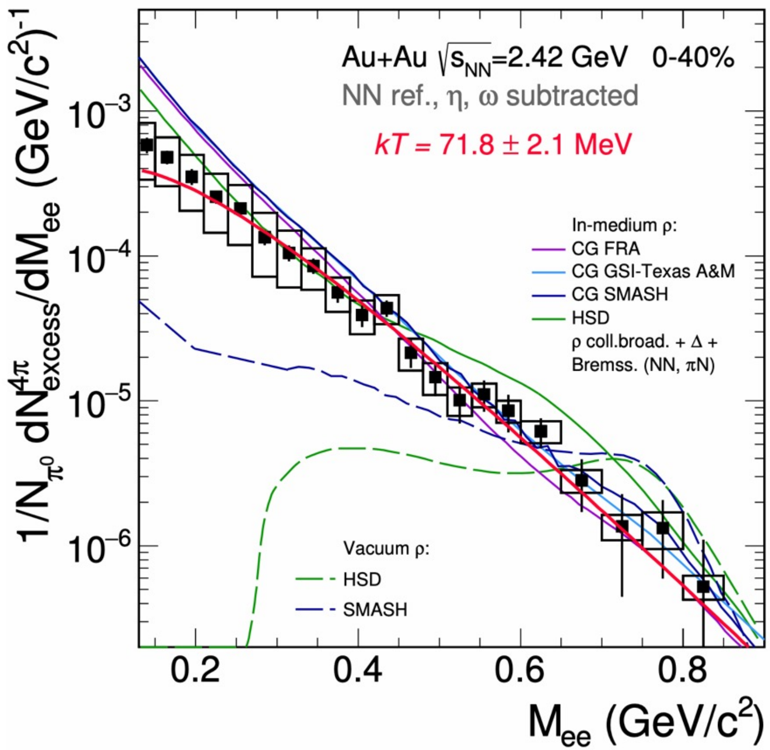
or

isentropic expansion, hydro



Dilepton emission from *Microscopic Transport.*

Thermal dileptons Au+Au ($\sqrt{s} = 2.4\,A$ GeV)

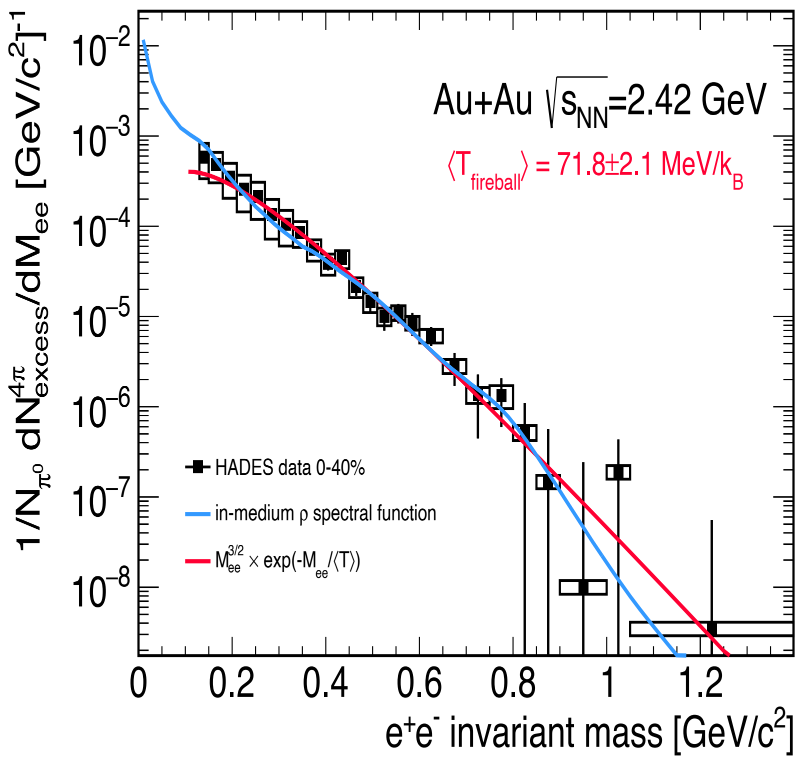


HADES, Nat. Phys. 15(2019) 1040

- Microscopic transport[(2)]:
  - Vacuum ρ spectral function and Δ regeneration
  - Explicit broadening and density dependent mass shift
- Coarse-grained UrQMD[(3)]
  - Thermal emissivity with in-medium propagator [(4)]
  - $\rho - a_1$ chiral mixing[(5)] (not measured so far)

(4) Rapp, van Hees; arXiv:1411.4612v
(2) E. Bratkovskaya;
(3) CG FRA Endres, van Hees, Bleicher; arXiv:1505.06131
CG GSI-TAMU; Galatyuk, Seck, et al. arXiv:1512.08688
(4) Rapp, Wambach, van Hees; arXiv:0901.3289
(5) Rapp, Hohler; arXiv:1311.2921v

Thermal dileptons Au+Au ($\sqrt{s} = 2.4\,A$ GeV)



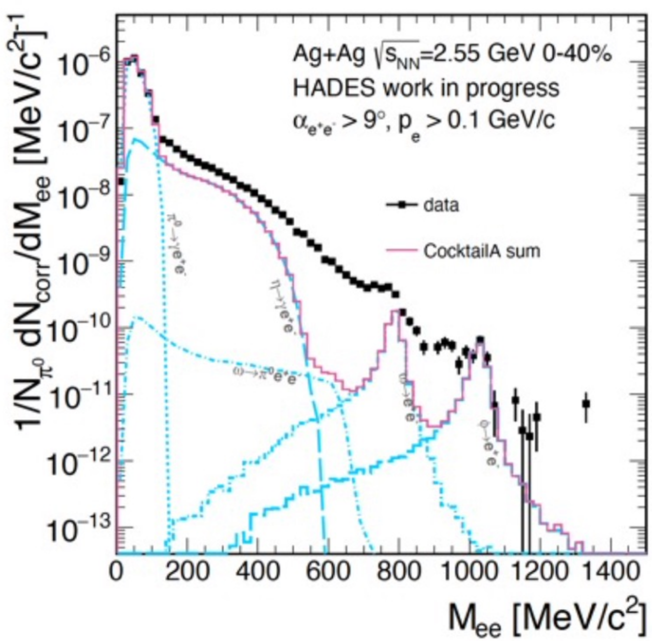
pub. in preparation

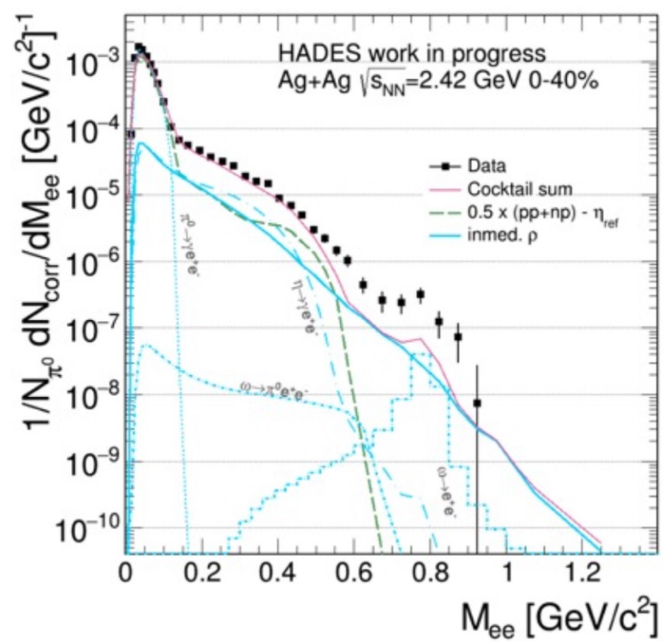
Coarse-grained UrQMD[3]

- Thermal emissivity with in-medium propagator [4]
- $\rho - a_1$ chiral mixing[5] (not measured so far)
- Finer grid for calculation of emissivities at high μ_B and moderate T.

(4) Rapp, van Hees; arXiv:1411.4612v
(2) E. Bratkovskaya;
(3) CG FRA Endres, van Hees, Bleicher; arXiv:1505.06131
CG GSI-TAMU; Galatyuk, Seck, et al. arXiv:1512.08688
(4) Rapp, Wambach, van Hees; arXiv:0901.3289
(5) Rapp, Hohler; arXiv:1311.2921v

Dileptons Ag+Ag ($\sqrt{s} = 2.4\,2,\ \ 2.55\,A\,\mathrm{GeV}$)





Reminder: Jan-Hendrik Otto, Friday evening

THE FUTURE

HADES during FAIR Phase-0

15 Billion events Ag+Ag taken in 2019, the only HADES Phase-0 run so far!

Au+Au BES < 1 A GeV

Searching for critical behavior and limitations of the universal freeze-out line

Au+Au collisions at 0.2A–0.8A GeV

The HADES Collaboration

HADES

Spokespersons: J. Stroth (j.stroth@gsi.de), P. Tlusty (tlusty@ujf.cas.cz)
GSI contact: J. Pietraszko (j.pietraszko@gsi.de)

Infrastructure: SIS18 and HADES cave

Beam: slow extraction
Au at 0.8A–0.6A–0.4A–0.2A GeV, 1.2×10^6 ions/s (flat top)
C at 0.8A–0.6A GeV, 3×10^6 ions/s (flat top)

Abstract

We will extend our exploration of the QCD phase diagram towards the location of the nuclear liquid-gas phase transition. Two longer Au+Au runs (30 shifts each) are dedicated to low-mass dielectron and strangeness production while two shorter Au+Au runs (9 shifts each) will focus on the most abundant (non-strange) particles only, suitable for event-by-event analysis of particle correlations and fluctuations as well as to extract temperature of the system at freeze-out. We aim at high statistics to enable (i) laboratory studies of the matter properties (Equation-of-State) in compact stellar objects and (ii) detection of measurable consequences of phase transition and critical point in the QCD phase diagram. Moreover, C+C collisions (6 shifts each) will be investigated to provide reference data.
In the following we elucidate the proposed studies using the HADES spectrometer.

This is a proposal for a new experiment

In total we request 94 shifts

50% granted
not scheduled yet
due to lack in beam time

EM transition form factors of hyperons

Production and Decay of Hyperons, and Inclusive Hadron and Dilepton Production

in p+p Reactions at 4.5 GeV

The HADES and
HADES-PANDA Collaborations

HADES

Spokespersons: J. Stroth (j.stroth@gsi.de), P. Tlusty (tlusty@ujf.cas.cz)
GSI contact: J. Pietraszko (j.pietraszko@gsi.de)

Infrastructure: SIS18, LH_2 target, HADES cave

Beam: protons at 4.5 GeV, beam intensity 7.5×10^7 p/s, slow extraction

Abstract

In this FAIR Phase-0 proposal, we request proton beam to perform a group of experiments mostly involving hyperons or hidden strangeness. This run group will make very effective and efficient use of the available beamtime since four investigations require the same beam/trigger conditions and improved detector set-up, thus they will be measured concurrently. This proposal addresses the following main physics topics: (1) Hyperon electromagnetic decays $Y \to \Lambda\gamma^*$ and $Y \to \Lambda\gamma$. (2) Hyperon hadronic decays. (3) Production of double strangeness ($\Xi^-(1321)$, $\Lambda\Lambda$) and hidden strangeness (ϕ). (4) Inclusive hadron and dilepton production as a reference for p+A and heavy-ion data. These measurements will provide first results in this energy region and an important benchmark for the future physics program at FAIR. The measurements of hyperon production and electromagnetic decays during Phase-0 are complementary to the Phase-1 studies at PANDA with antiproton-proton interactions, and will enable some PANDA detector systems to be setup and commissioned already now.
Below is a description of the proposed study with proton beam using the HADES spectrometer combined with the new forward detection system.

This is a new experiment proposal.

We request 84 shifts plus 4 shifts in a separate proposal for commissioning.

100 % granted
run scheduled for 2022

Cold matter effects including line shapes and SRC

Studying Medium Effects in Proton Induced Reactions

p+Ag reactions at 4.5 GeV

The HADES Collaboration

HADES

Spokespersons: J. Stroth (j.stroth@gsi.de), P. Tlusty (tlusty@ujf.cas.cz)
GSI contact: J. Pietraszko (j.pietraszko@gsi.de)
SRC part: T. Aumann (T.Aumann@gsi.de), O. Hen, E. Piasetzki

Infrastructure: SIS18, HADES cave, and
part of the NeuLAND detector to measure the recoil neutron

Beam: p at 4.5 GeV, beam intensity 4×10^6 protons/s, slow extraction

Abstract

We propose to investigate p+Ag reactions with an improved experimental set-up which enables measurements of charged particles emitted into the very forward hemisphere. Main physics topics are addressed: (i) dielectron production in the low and intermediate mass region; (ii) ω disappearance in "cold" nuclear matter; (iii) strangeness production and propagation in "cold" nuclear matter (comparison and constraints for thermal and transport models) (iv) $\Lambda - p$ scattering parameters and phase shifts; (v) understanding short-range correlations in nuclei; (vi) search for a dark photon in the dielectron channel. These results will provide an important reference for the future program at FAIR.
Below is an executive summary of the proposed study with proton beam using the HADES spectrometer combined with the new forward detection system.

This is a new experiment proposal.

We request 88 shifts.

not granted yet

Baryon resonances, meson baryon coupling in the 3rd resonance region

Baryon couplings to mesons and virtual photons in the third resonance region: vacuum and cold matter studies

Pion induced reactions on CH_2 and C, Ag targets

The HADES Collaboration

HADES

Spokespersons: J. Stroth (j.stroth@gsi.de), P. Tlusty (tlusty@ujf.cas.cz)
GSI contact: J. Pietraszko (j.pietraszko@gsi.de)

Infrastructure: SIS18, pion production target and HADES cave
Beam: Nitrogen at 2A GeV, maximum intensity, slow extraction

Abstract

We propose to use the GSI pion beam to provide information on baryon resonances in the third resonance region which is crucial for the understanding of the emissivity of dense and hot hadronic matter. This includes their couplings to mesons and virtual photons and their behavior in cold matter. First, differential cross sections for hadronic final states will be included in Partial Wave Analyses to extract various baryon-meson couplings, among which are ρN and ωN, with unprecedented precision. Second, the measurement of e^+e^- production off the nucleon, which is sensitive to the electromagnetic transition form factors of baryons in the time-like region, will probe the role of vector mesons (ρ, ω) herein. Finally, pion-nucleus data allow to investigate medium effects on vector mesons in cold nuclear matter. The whole data set constitutes an important input to understanding of the emissivity of dense and hot hadronic matter.

In 2017, we submitted a request for 93 shifts pion beam and got approved 40 A^- shifts, which could not be scheduled. This proposal is an update, and extension, of the 2017 proposal motivated by the results of the data analysis of previous experiments.

We request 143 shifts.

not granted yet

Iso-spin effects in dilepton production

Scrutinizing Iso-spin Effects in N+N Bremsstrahlung and Dibaryon d*(2380) Formation in n+p Collisions

A Beam Energy Scan for proton and neutron induced reactions on protons

The HADES Collaboration

HADES

Spokespersons: J. Stroth (j.stroth@gsi.de), P. Tlusty (tlusty@ujf.cas.cz)
GSI contact: J. Pietraszko (j.pietraszko@gsi.de)

Beam: d with kinetic energy of $T_d = 1.0, 1.13, 1, 25, 1.75$ A GeV, beam intensity 2×10^7 deuterons/s, slow extraction

Abstract

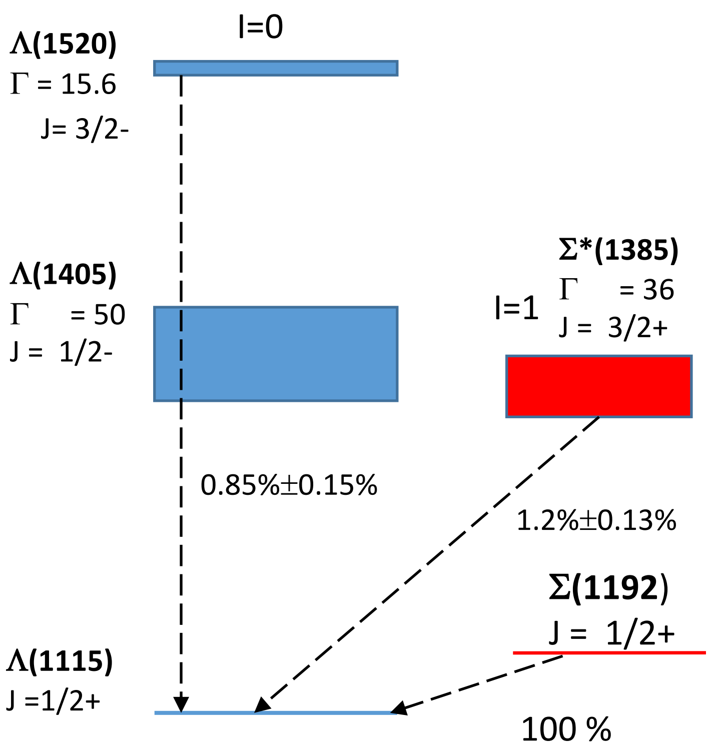
We propose to investigate p+p and quasi-free n+p reactions with deuterium beams on a LH2 target with an improved experimental set-up which enables measurements of charged particles emitted into the very forward hemisphere. Quasi-free p+p and n+p reactions will be disentangled by tagging the proton spectator from deuterium break-up in the new Forward Detector which covers almost complete (~ 98%) phase space for the spectator emission. The main goals of proposal are: (1) measurement of NN reference spectra for interpretation of medium effects in heavy-ion collisions in 1–2 AGeV energy range; (2) characterisation of dilepton production from baryonic sources in exclusive reaction channels (3) studies of isospin dependence of kaon (K^0,K^+) production close to the threshold and (4) di-baryon $M_{d^*} = 2380$ MeV ($I = 0$, $J^P = 3^+$) production in quasi-free n+p reactions. The results will also provide an important reference for the future heavy-ion program at FAIR.

Below is an executive summary of the proposed study with proton beam using the HADES spectrometer combined with the new forward detection system.

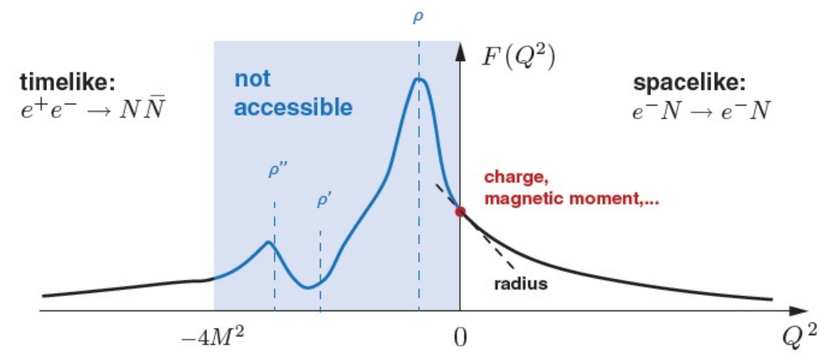
This is a new experiment proposal.
We request 106 shifts.

not granted yet

Hyperon Radiative Decays



CLAS PRD83 (2011) 072004, PRC71(2005) 054609



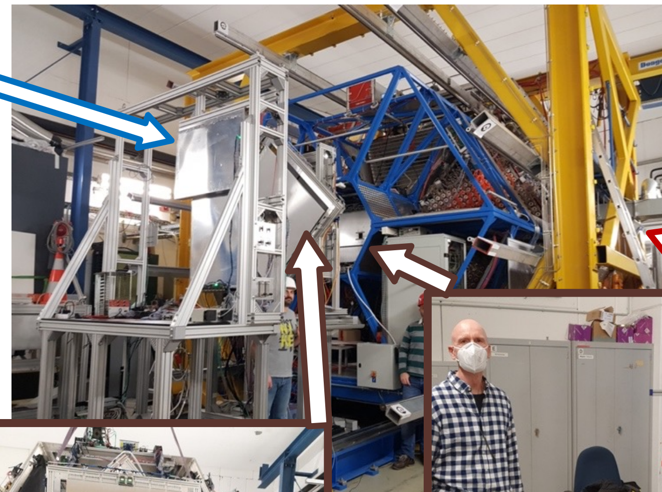
- Baryon excitation spectrum likely the result of a complex interactions of baryon core with meson cloud.
- Cloud in particular sensitive to soft perturbations (low-q)
- Baryons with strange (semi-heavy) quarks can add valuable extra information

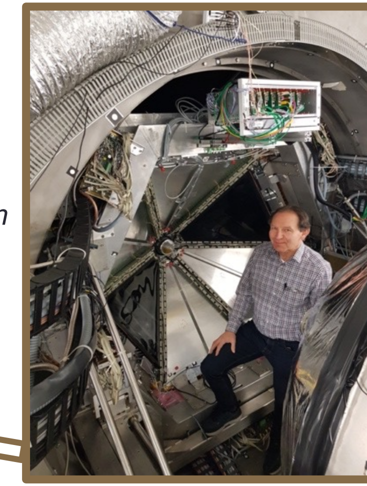
together with PANDA@HADES

The upgraded HADES detector (five new detector systems)

Improved physics performance through instrumentation of the very forward hemisphere using FAIR technology.

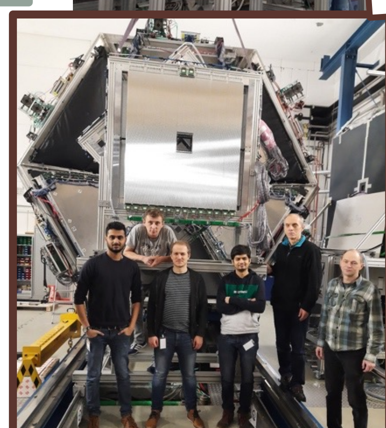
In particular important for the Hyperon Program.

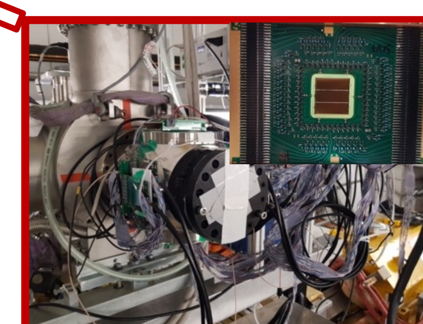




iTOF
TransFAIR, Jülich
- APD read-out
- Enhances trigger purity

Forward RPC
LIP Coimbra
- Based on R&D for neuLAND
- TRB3 read-out





STS2
Jagiellonian Univ.
- PANDA straw technology
- PANDA PASTTREC FEE chip

STS1
TransFAIR, Jülich
- PANDA straw technology
- PANDA PASTTREC FEE chip

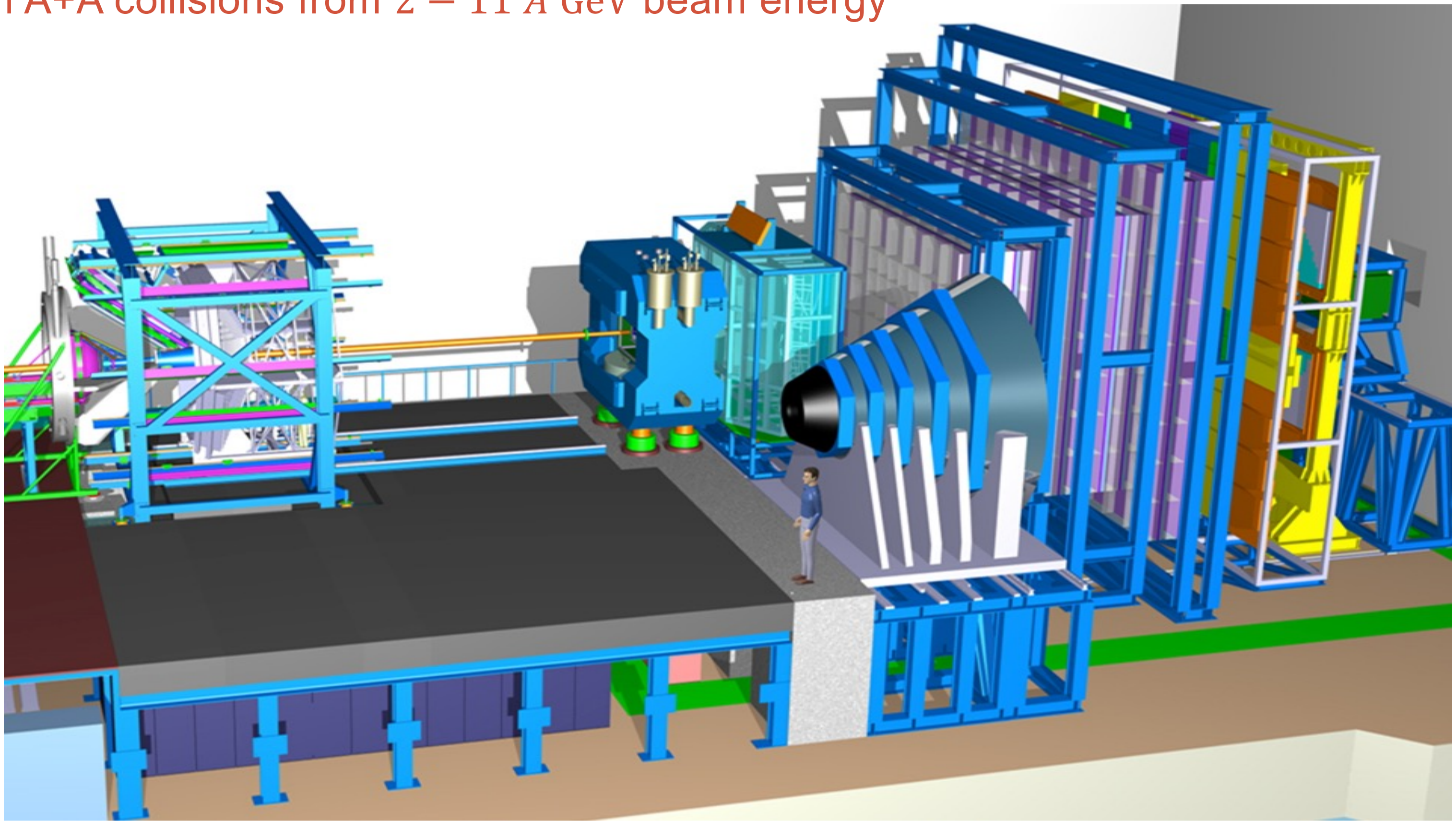
T0
GSI, TU Darmstadt
- LGAD technology
- In-beam detector

The Future at FAIR

Roof closing CBM cave

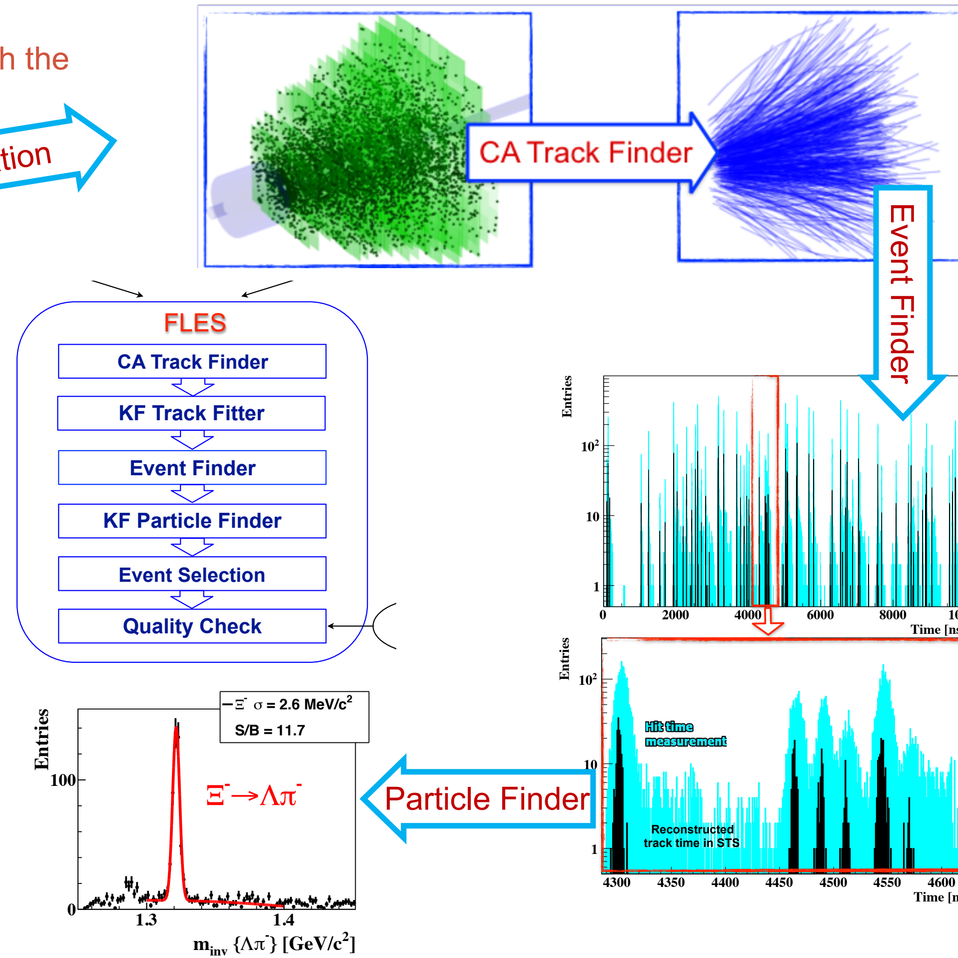
The CBM experiment

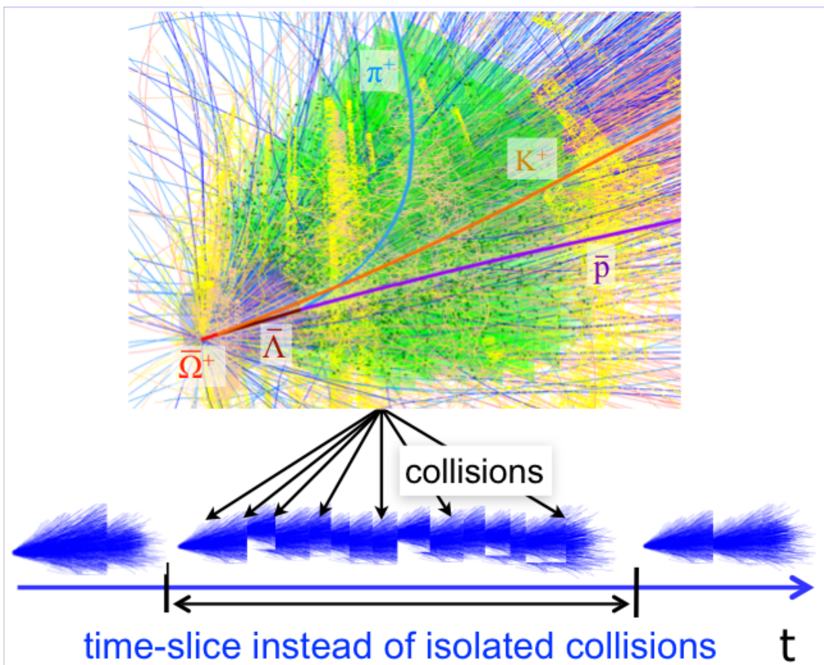
Systematic exploration of baryon dominated matter in A+A collisions from $2 - 11\ A\ \mathrm{GeV}$ beam energy



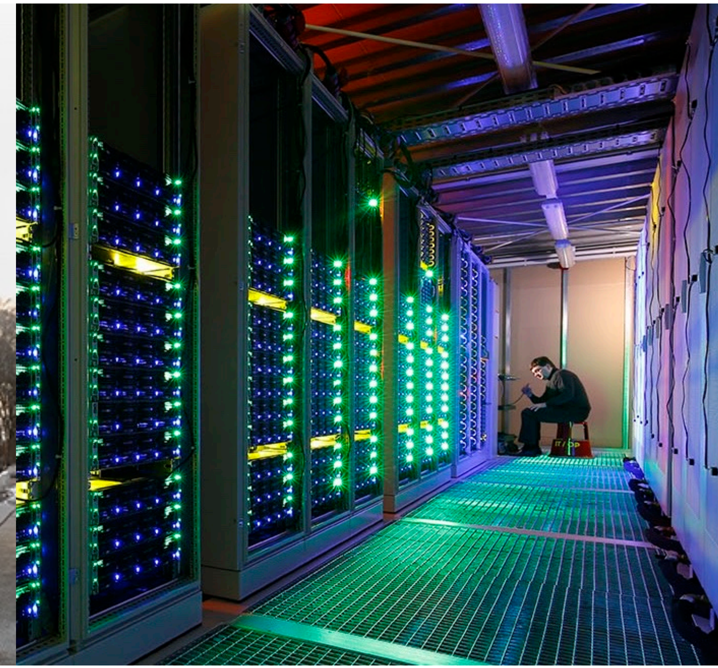
High-rate operation – FLES

Real-time event selection from free-streaming data with the First Level Event Selector (FLES).
Up tp 1 TB/s – fully inspected in real time





The Green Cube at GSI as FLES



Up to 40.000 processor cores forseen for event selection

Summary

- HADES aims at a comprehensive program during FAIR Phase-0
  - Au+Au BES
  - Cold matter studies
  - d, p, π beam induced „elementary" reactions
- Upgrades of the detector to enhance physics performance, in particular also for exclusive channels in proton induced reactions
- Strangeness production still not fully understood. Thermal description work reasonably well
- Very consistent picture of dilepton continuum
- Many data on multi-differential observables thanks to high statistics (Bayesian analysis)
- Progress will finally depend on available beam time and support from theory
- Prepare for BES with CBM & HADES

THANK YOU