HADES – STATUS

Joachim Stroth

RHIC-BES and Beyond, Remote

August 16–17, 2021

AGENDA

The HADES FAIR Phase-0 Program

Strangeness Phenomenology

Thermal Radiation

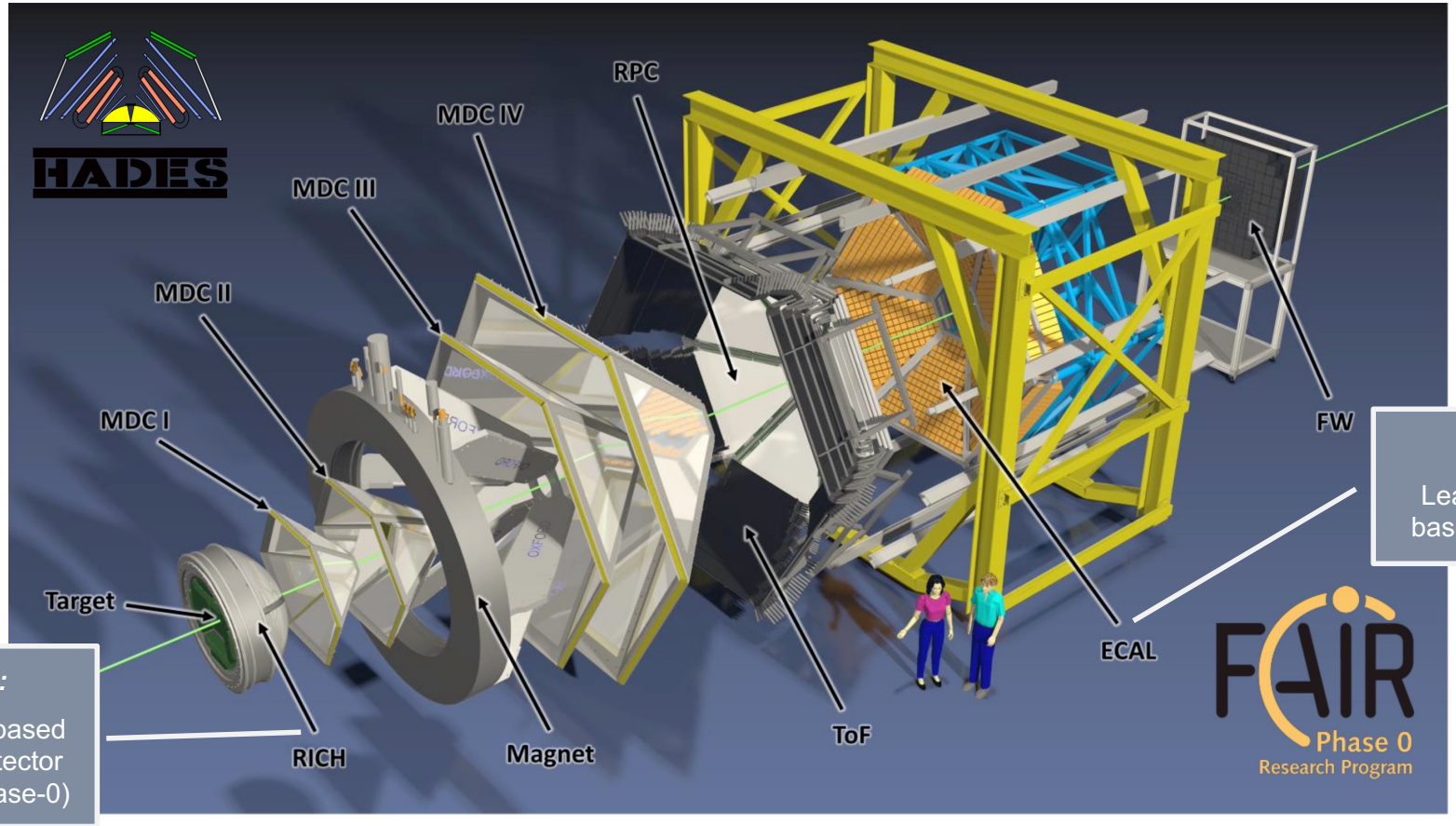
Meson Baryon Coupling

Near Future

FAIR PHASE-0 PROGRAM

HADES as FAIR Phase-0 Detector

Strategy: Operate HADES at SIS18 as long as dedicated program (i.e. π beam) is not completed



new:

Lead-glass based ECAL

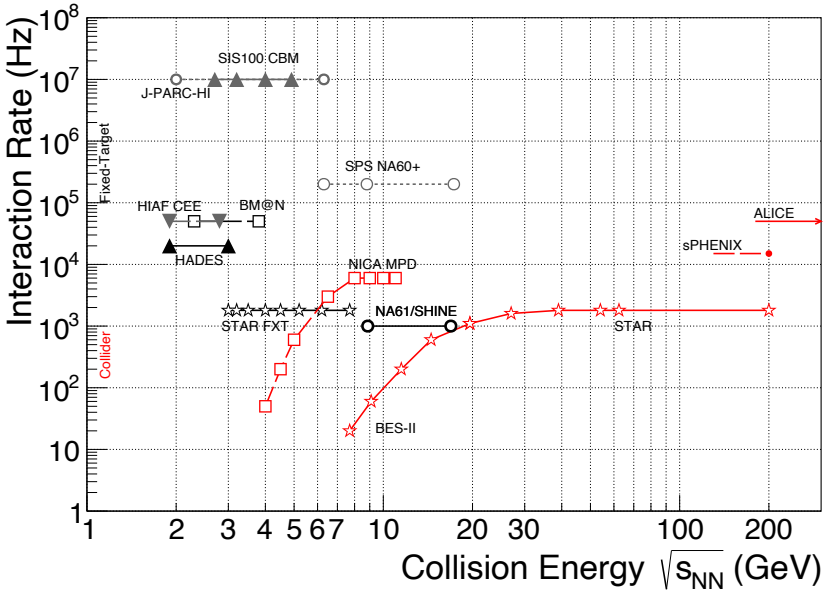
new:

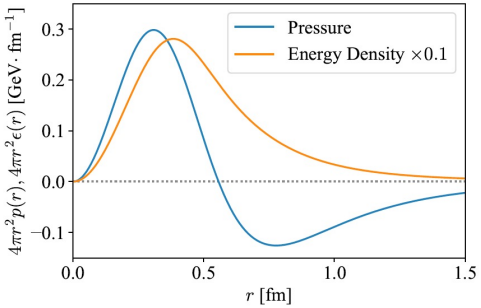
MAPMT based photo detector (CBM Phase-0)

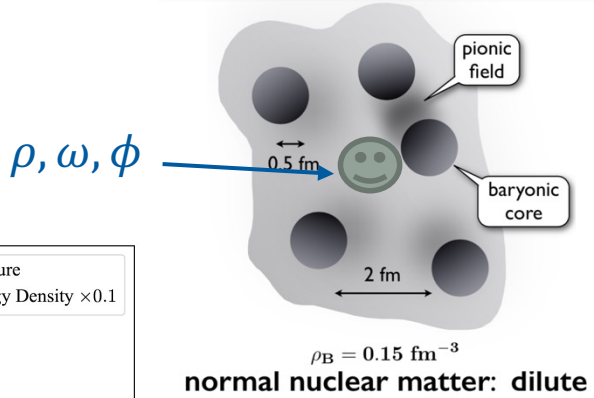
The HADES mission

Characterize the microscopic properties of compressed baryonic matter

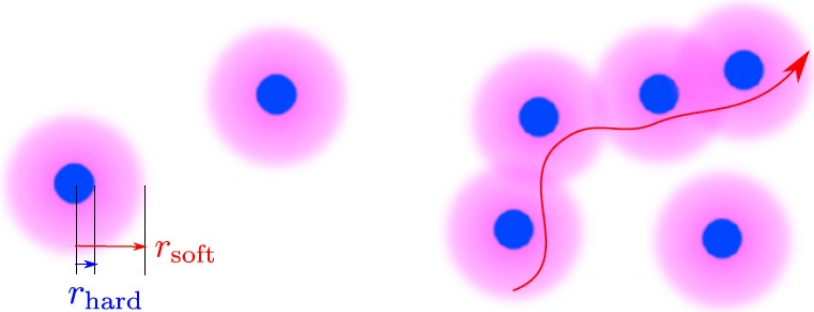
- From medium modifications to novel phases of QCD matter
- Dynamics of meson baryon coupling







W. Weise, QNP2018



T. Galatyuk, Nucl.Phys. A982 (2019), update 2021 and CBM, EPJA 53 3 (2017) 60

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

HADES during FAIR Phase-0

15 Billion events Ag+Ag taken in 2019, the only 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 (Ξ^- (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 pN 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 LH_2 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.

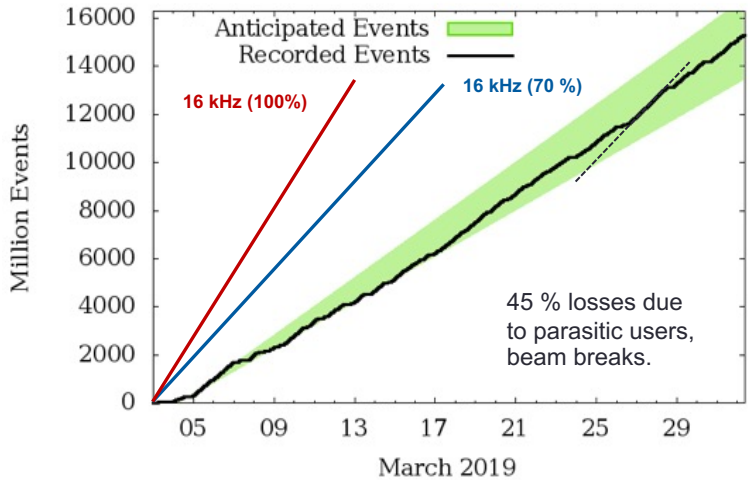
Below is an executive summary of the proposed study with proton beam using the HADES spectrometer combined with the new forward detection system.

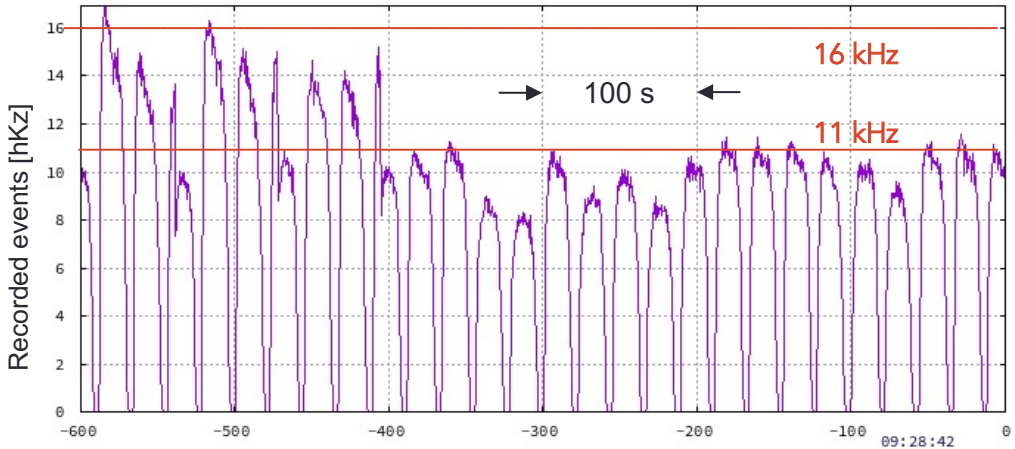
This is a new experiment proposal.
We request 106 shifts.

not granted yet

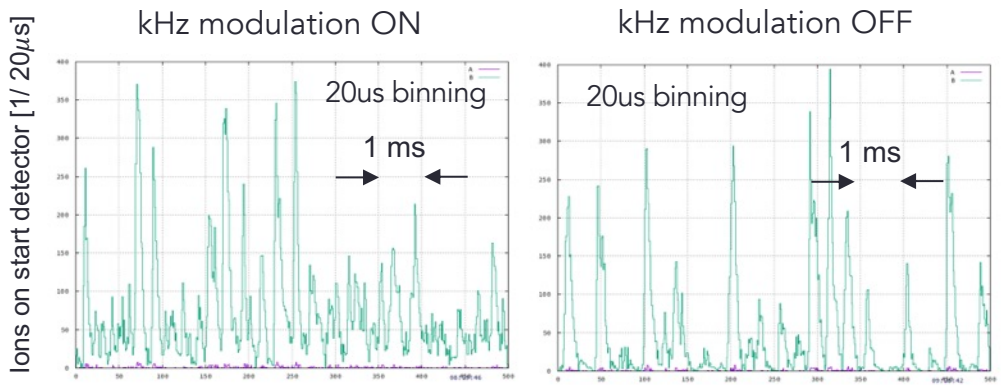
Strategic G-PAC meeting planned for December 9–10, 2021.

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





Quadrupole modulation – influence on HADES event rate



Room for optimization of data taking rate:

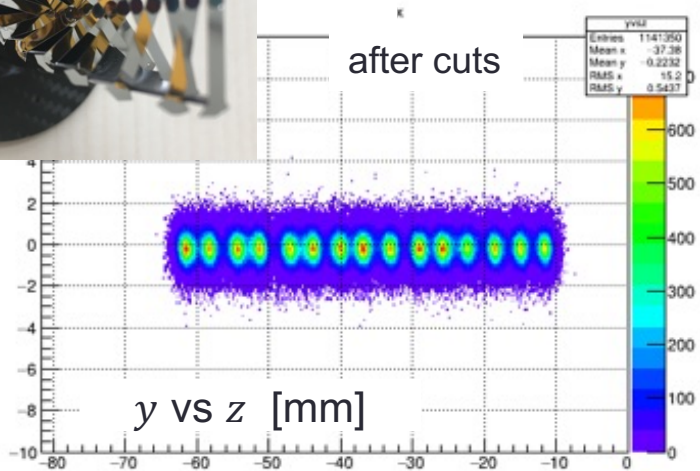
- Spill duty-factor
  - Feed-back system in preparation
- Spill micro-structure
  - Idle time
  - Pile up

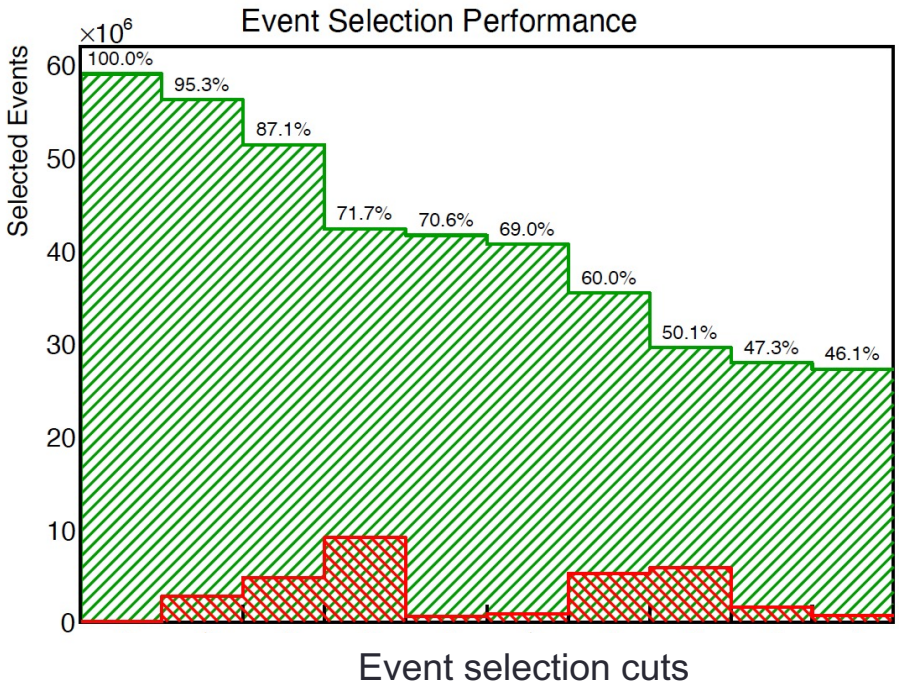
R. Singh, P. Forck, S. Sorge; arXiv:1904-09195

Ag+Ag – offline analysis / event cleaning

From recorded to clean events - reasons for losses:

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

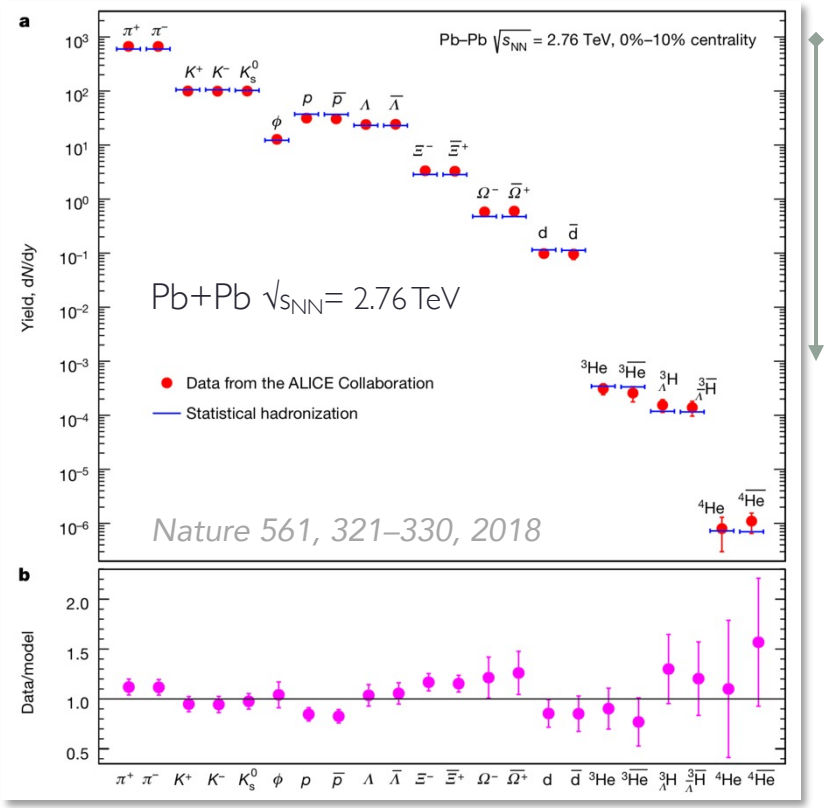




Removed events dominantly suffering pile-up (> 50%)

STRANGENESS PHENOMENOLOGY

Freeze-out conditions from SIS18 to LHC

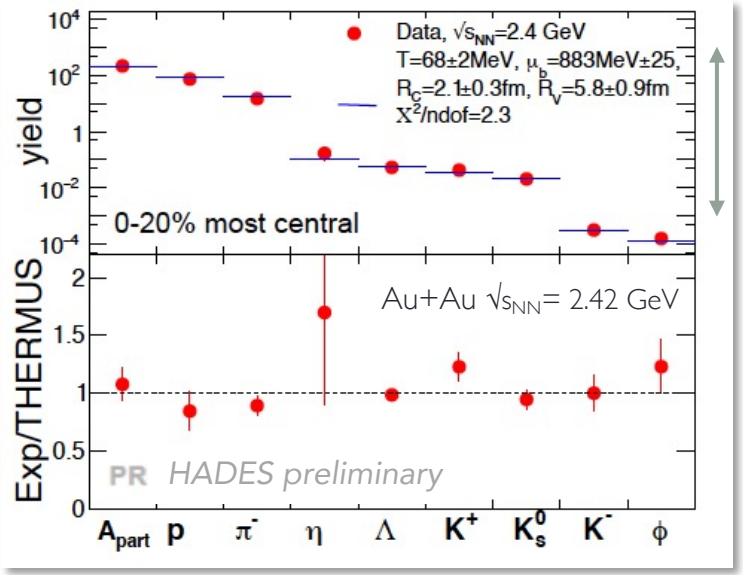


1 ppm

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

HADES ($\sqrt{s} = 2.4\ A\text{GeV}$): $\boldsymbol{T_{ch} = 68.2\ (1.5);\ \mu_B = 883\ (25)}$

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



1 ppm

Alternativ fit for Au+Au using yields of light nulcei

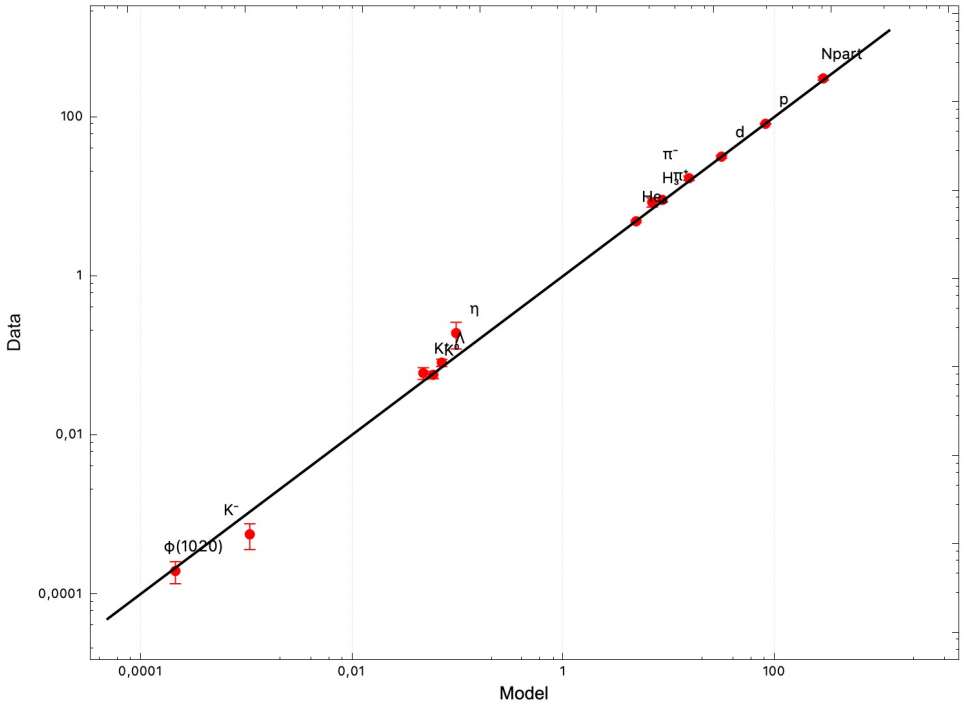
Thermal-FIST

V. Vovchenko et al.
*Computer Physics Communications **244**, 295 (2019)*

Result for:
Strangeness-canonical, ideal HRG,
const. Breit-Wigner, Boltzmann

chi2/dof = 15.6383/8 = 1.95479

Extracted parameters:
T[MeV] = 63.7962 +- 0.763072
R[fm] = 9.85896 +- 0.131778
V[fm3] = 4014.05 +- 160.959
Rc[fm] = 3.22828 +- 0.191601
Vc[fm3] = 140.929 +- 25.0929
muB[MeV] = 782.166 +- 1.81427
muQ[MeV] = -17.3872 (FIXED)
gammaq = 1 (FIXED)
gammaS = 1 (FIXED)



Universal strangeness centrality dependence

Strangeness production at SIS18 energies enabled by medium-effects

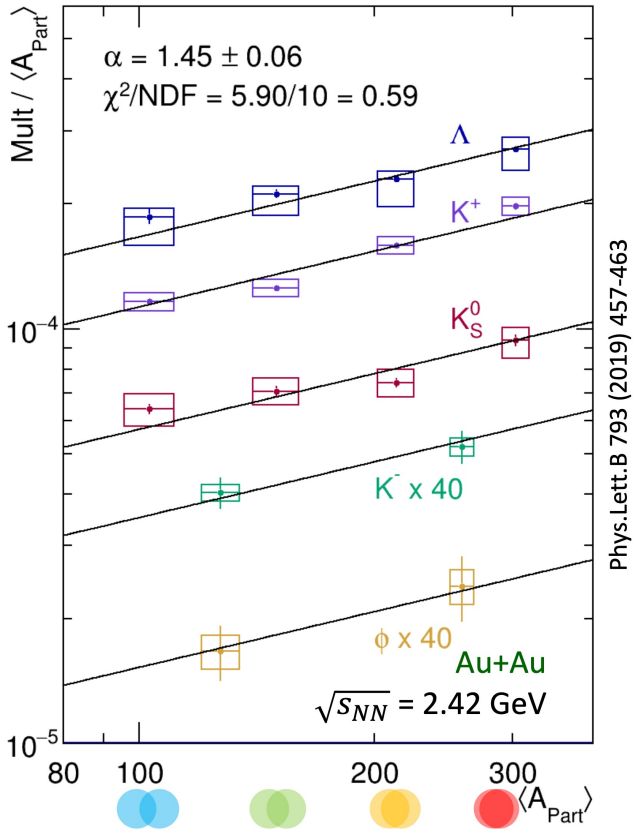
Suggests density-dependence of production

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

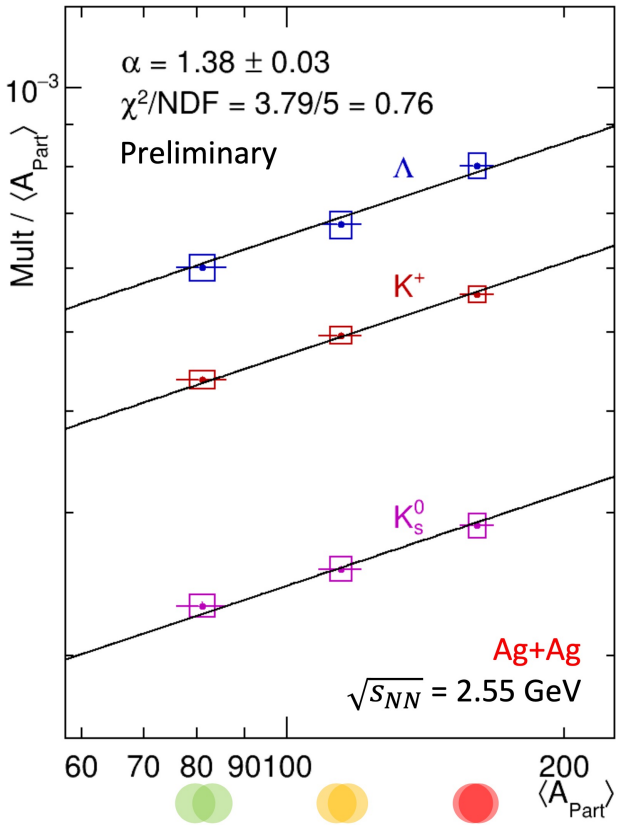
$NN \rightarrow NNK^{+}K^{-}$: $\sqrt{s} = 2.9$ GeV

Data can be explained with a single slope:

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



Phys.Lett.B 793 (2019) 457-463

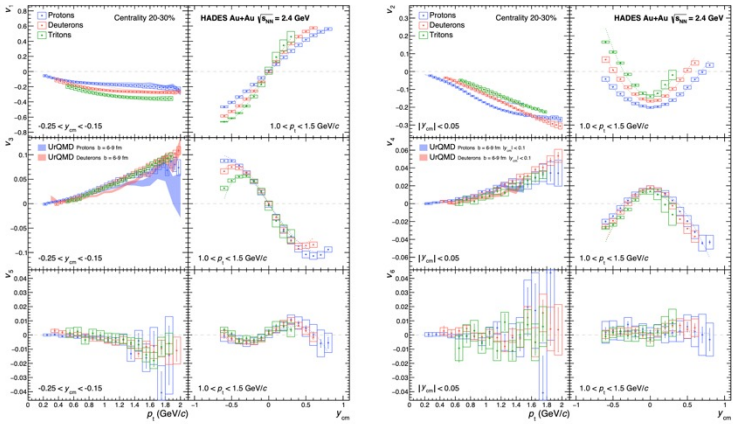


Higher-order flow components

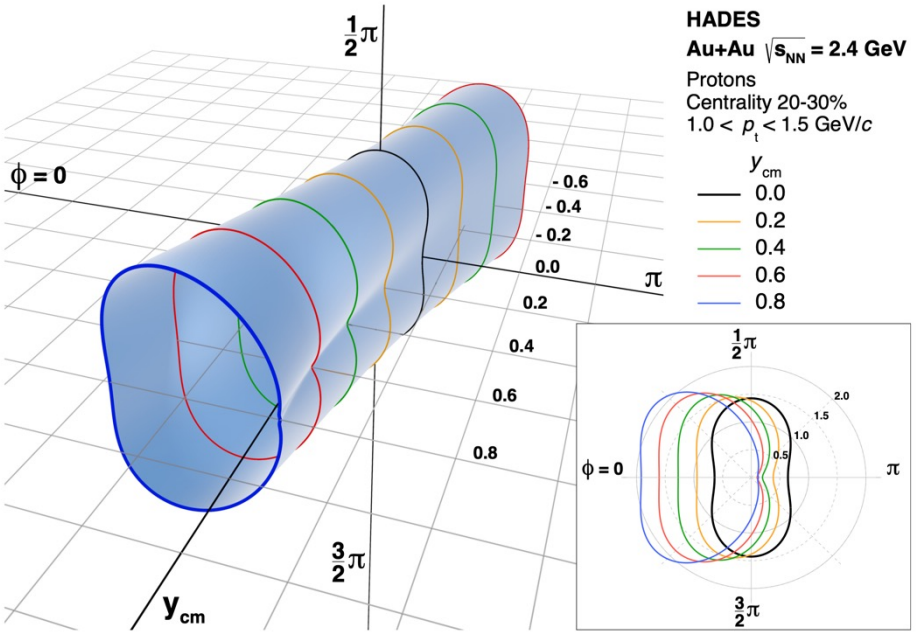
The collective motion (flow) of protons, deuterons and tritons shows a distinct pattern which encodes properties of the fireball (e.g. equation-of-state)

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



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

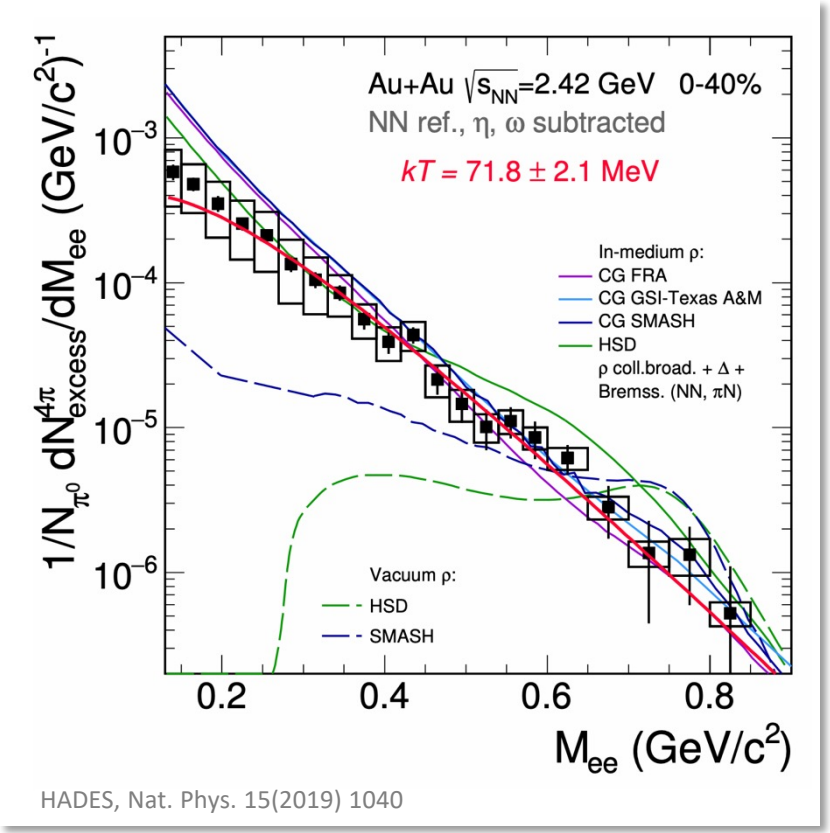


HADES, Phys. Rev. Lett. 125 (2020)

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

THERMAL RADIATION

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

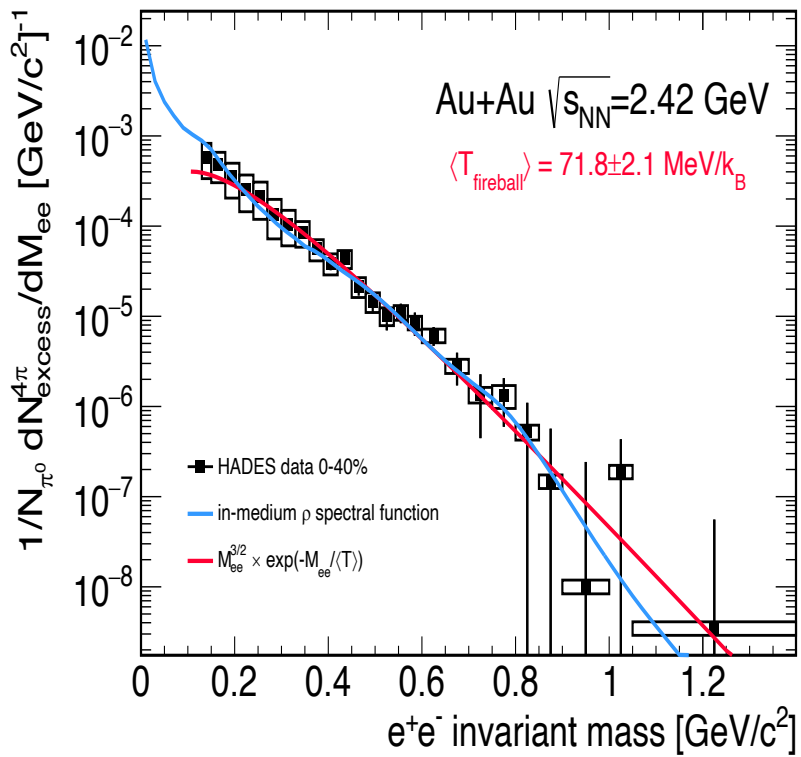


HADES, Nat. Phys. 15(2019) 1040

- 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

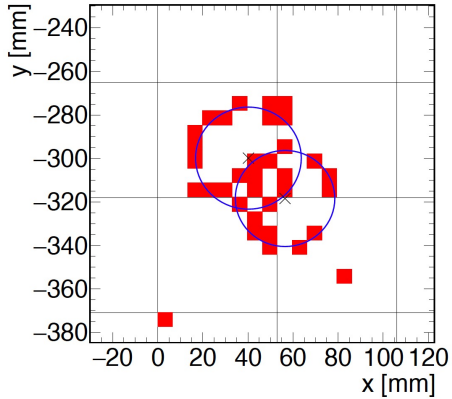
- Coarse-grained UrQMD[3]
  - Thermal emissivity with in-medium propagator [4]
  - $\rho - a_1$ chiral mixing[5] (not measured so far)
  - Finer grid for calculation of emissivities at high μ_B and moderate T.

(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

Di-electron results Ag+Ag ($\sqrt{s} = 2.55\ A$ GeV)

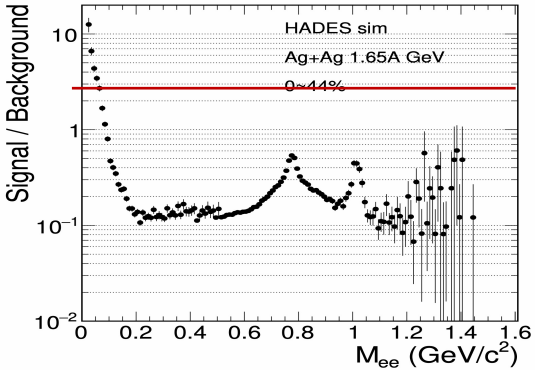
New CBM-type Photo Camera provides significant improvement:

- 180.000 signal pairs above π^0 Dalitz region
- First measurement of dilepton yield beyond vector meson mass region for low energies
- Short run (3 days) Ag+Ag with 18.000 signal pairs above π^0 Dalitz

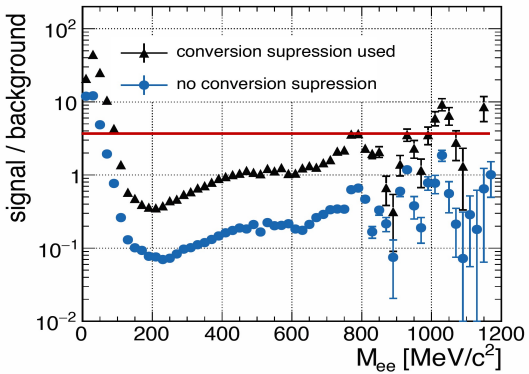


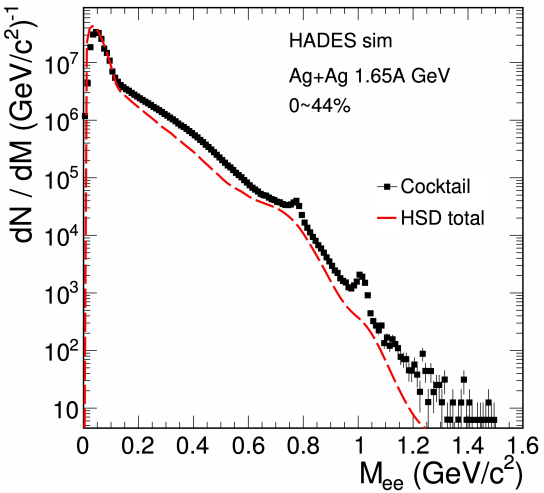
- Factor of 3 better electron identification efficiency

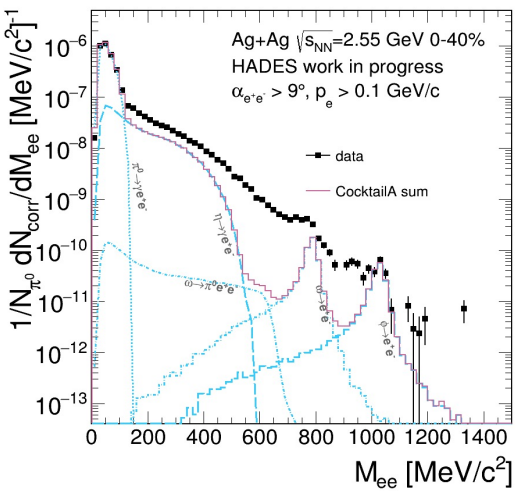
proposal (simulation)



current analysis status





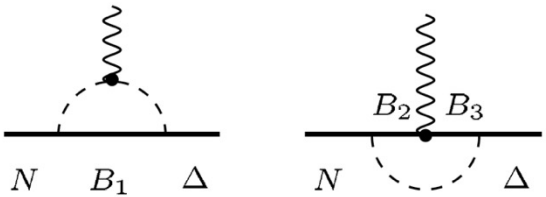


MESON BARYON COUPLING

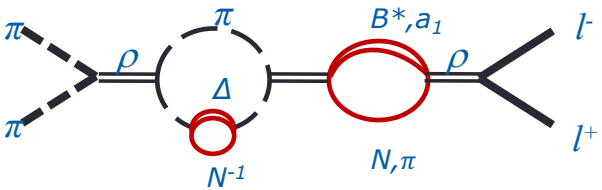
Pion cloud effect in Δ(1323)

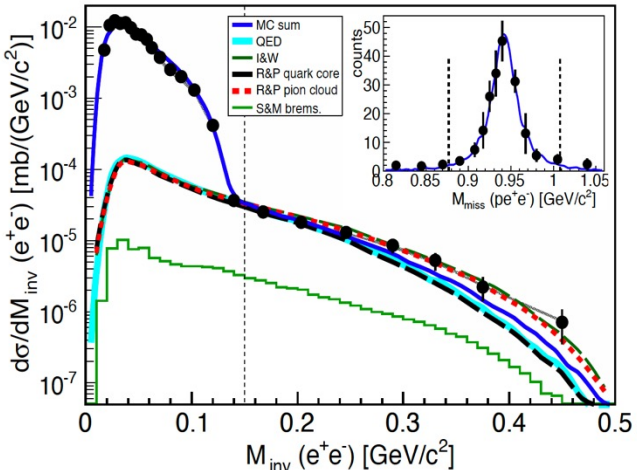
- Exclusive dielectron production in p+p collisions.
- Effect of the pion cloud observed in the time-like electromagnetic transition formafactor (off-shell ρ meson).

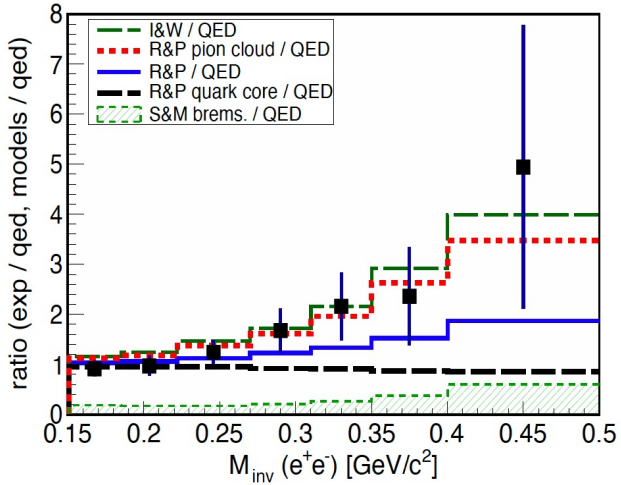
Peña, Ramalho; arXiv-1205-2575
Peña, Ramalho + GiBUU.; arXiv-1512-03764



- Moderate contribution to the in-medium propagator



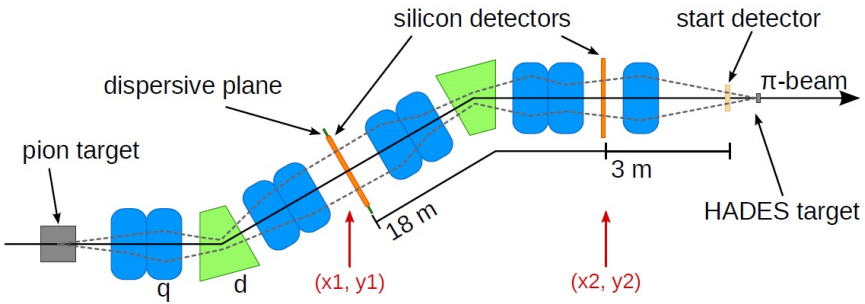


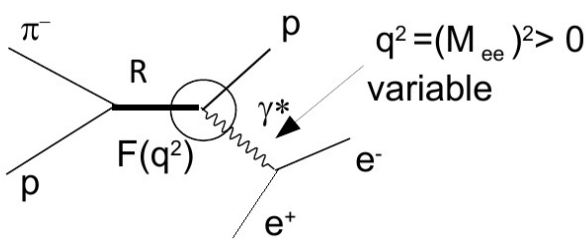


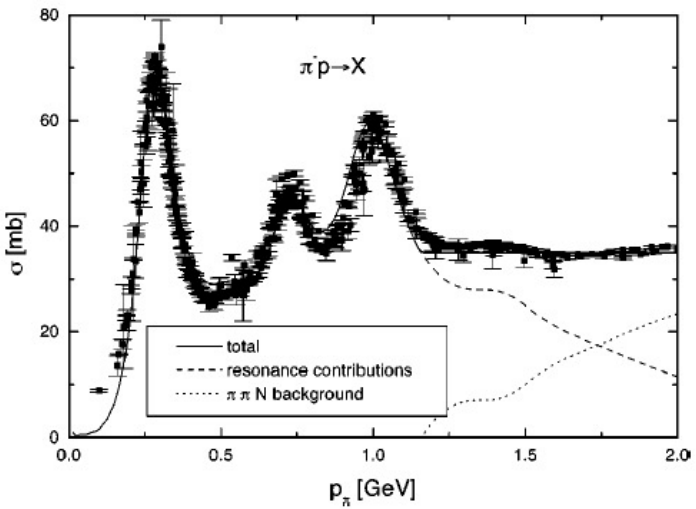
HADES: arXiv:1404.2136 [nucl-th]

THE HADES Pion Beam Facility

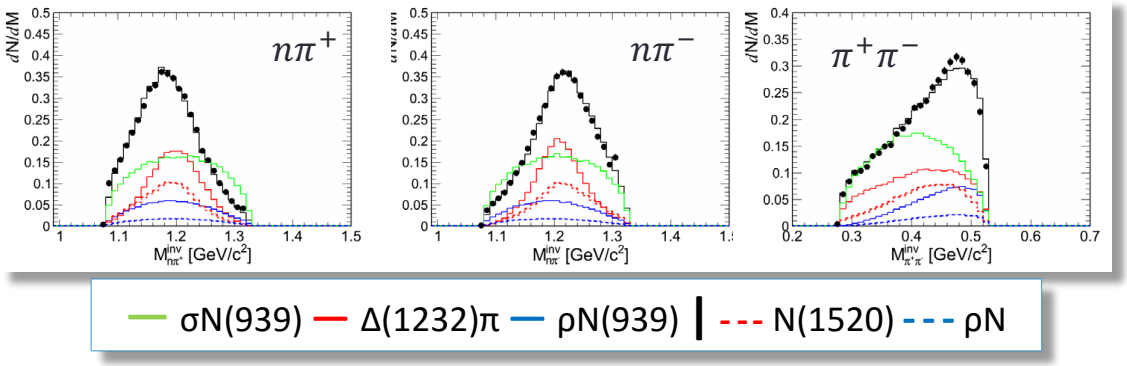
- A production target 40 m upstream the experiment target position allows production of secondary beams
- Direct excitation of baryon resonance
- Combination with dilepton spectrometer world-wide unique







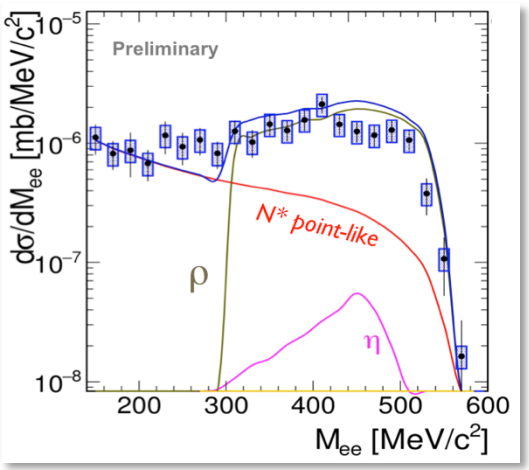
Electromagnetic TFF for baryons (N*)

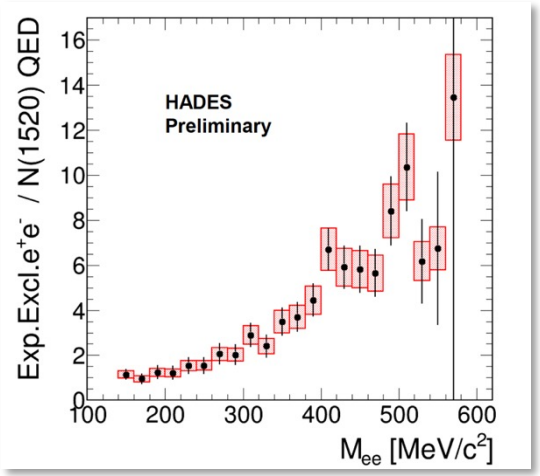


HADES pion beam experiment

- p_π = [656, 690, 748, 800] MeV

- $\pi^- + p \rightarrow \pi^- + \pi^+ + n$
  - Hadronic final states used in PWA (A. Sarantsev; BONN/GATCHINA)





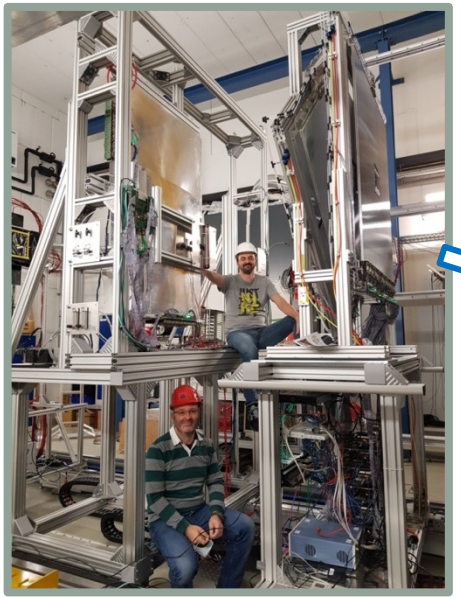
- $\pi^- + p \rightarrow e^- + e^+ + n$
  - Prediction for dilepton invariant mass assuming strict VMD.
  - Evidence for intermediate ρ propagation in both s- (baryon resonance) and t-channel.
  - EM TFF shows VDM-like rise

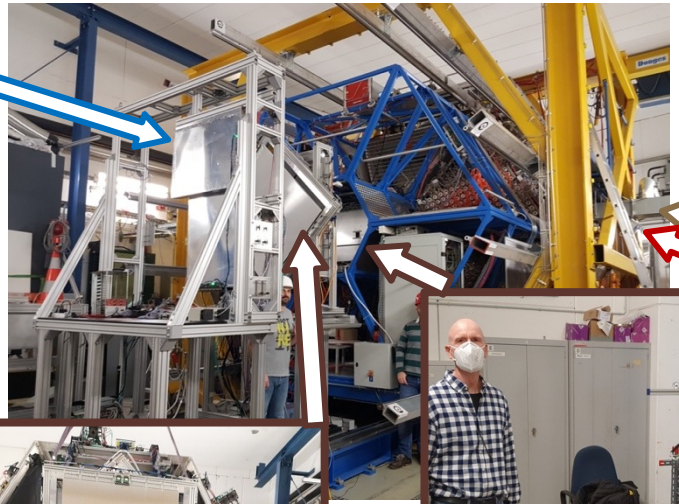
NEAR FUTURE

The upgraded HADES detector (five new detector systems)

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

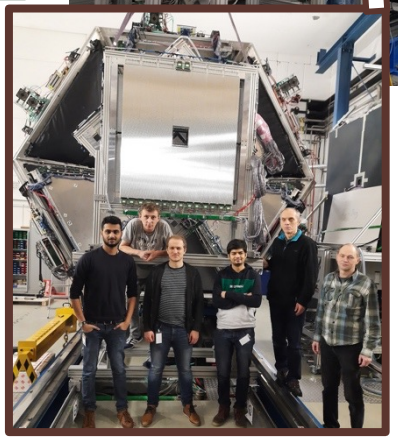
In particular important for the Hyperon Program.

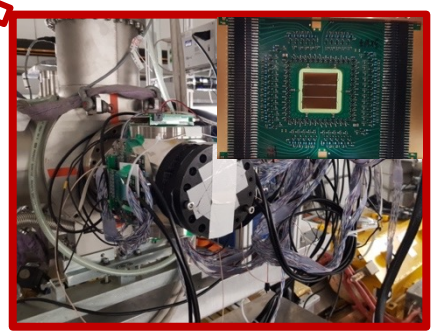




iTOF
TransFAIR, Jülich
- APD read-out
- Enhances trigger purity

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

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 well.
- Many data o multi-differential observables thanks to high statistics.
- Vector mesons valuable probe to monitor the properties of dense matter
- Strong in-medium modifications due to meson-baryon coupling
- Progress will finally depend on available beam time

The HADES Collaboration

HADES–XXXVIII, Collaboration Meeting at Dresden/Rossendorf, March 2020

THANK YOU