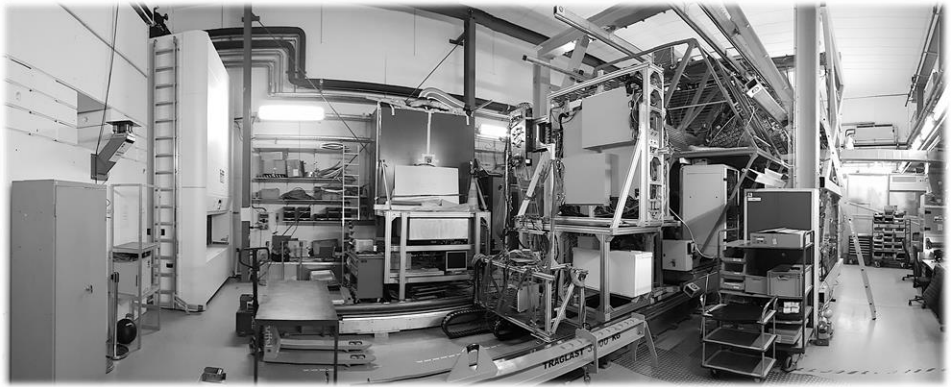
Perspectives with HADES

Status and long term vision

Jerzy Pietraszko for the HADES Collaboration

KHuK Annual Meeting 2022,
Physikzentrum Bad Honnef, Germany

December 8 – 10, 2022



HADES Mission

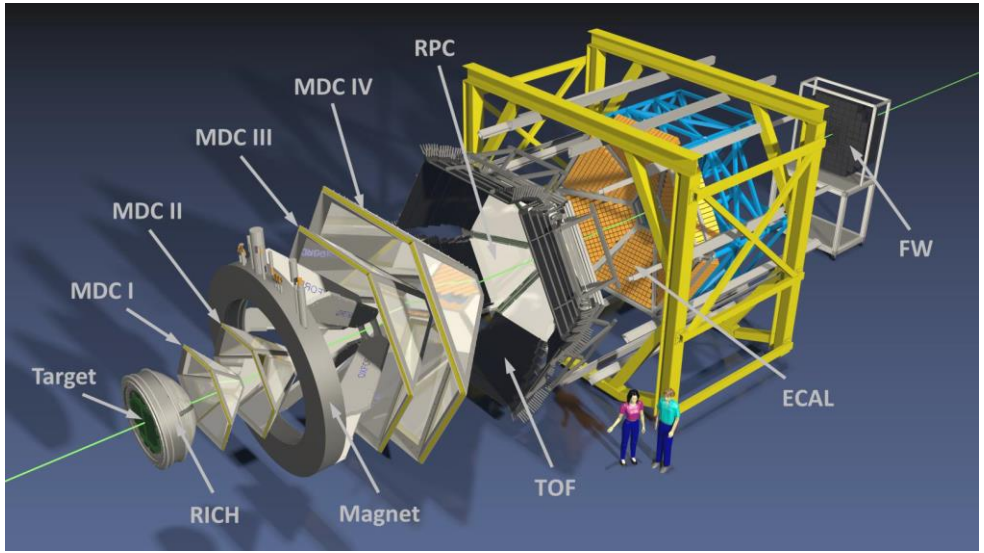
Study thermodynamic (bulk) and microscopic properties of QCD matter under extreme conditions
(akin to Neutron Star Merger matter) :

- Equation-of-state
  (phase structure, phase transitions)
- In-medium properties of hadrons
  (ρ “melting”, short-range-correlations)
- Structure of baryon excitations
  (time-like transition form factors)

Broad physics program:

- Part of the FAIR CBM pillar (BMBF FSP-T06)
- Cooperation with PANDA and NUSTAR-R3B

- Fixed target experiment at GSI (SIS18)
- Excellent hadron and dielectron identification
- SIS18 beams: proton, heavy-ion, secondary pion
- Uniqueness: GSI pion beam facility & dielectron detection

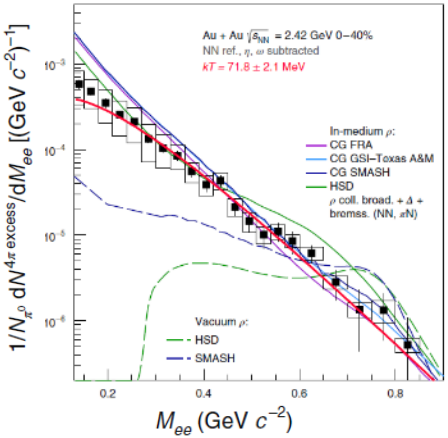


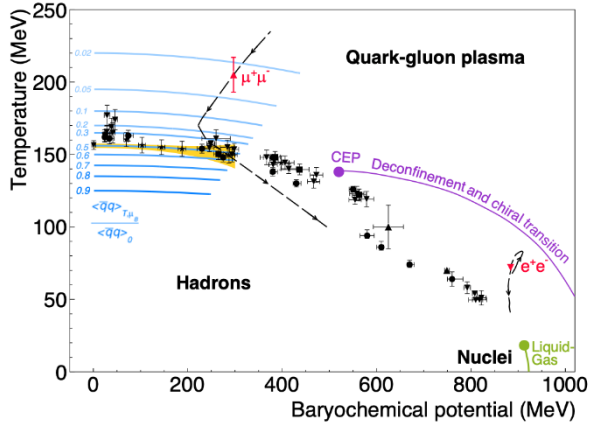
Probing Dense Baryon-rich Matter with Virtual Photons

Electromagnetic radiation from the fireball

- Thermal radiation from baryon-rich QCD matter at SIS18 energies
- Isolate excess radiation by subtracting conventional sources
- Near-exponential fall-off of dielectron excess yield
- Accurate “Thermometer” of the fireball

HADES, Nature Physics 15, pages 1040–1045 (2019)





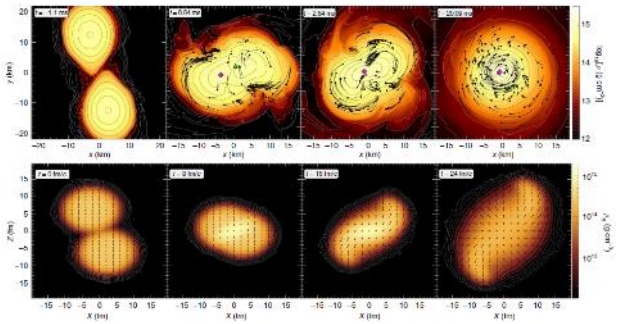
Similarity to a binary neutron star merger

- A heated shell with T of 50-80 MeV and densities of $2\varrho_0$ are predicted
- Consistent with obtained T and ϱ of fireball

Simulated density profile of:

binary neutron star merger

Au+Au collision at 2.4 GeV



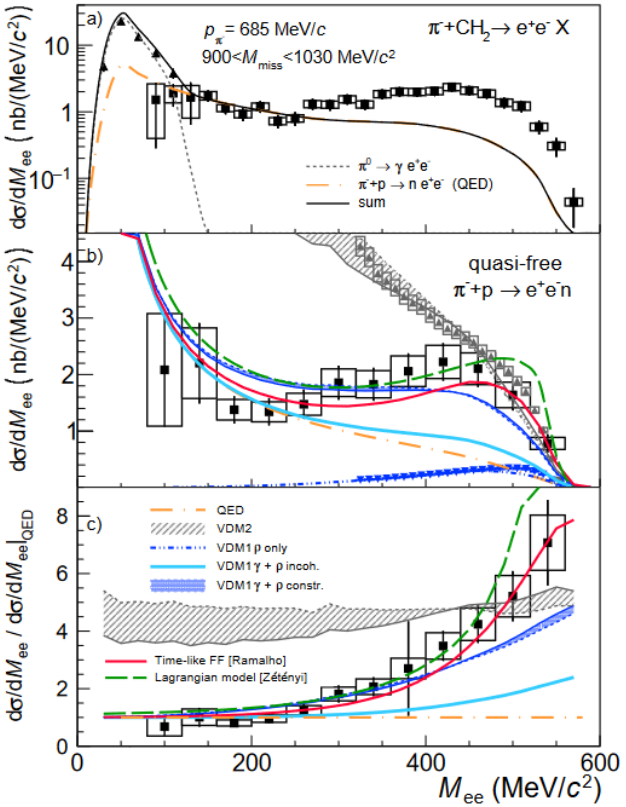
Virtual Photon Emission from N* Baryon Resonances

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

First measurement of timelike electromagnetic structure of baryons in the second resonance region

- A crucial test of Vector Meson Dominance (VMD) inspired models
- Importance of electromagnetic Transition Form Factors confirmed
- VMD2 model is widely used in several transport models !
- Unique combination of HADES di-electron detection capabilities and GSI pion beam facility

HADES, arXiv:2205.15914v2



Multi-differential Flow Measurement for p, d and t

HADES, Phys.Rev.Lett. 125 (2020) 262301
HADES, arXiv:2208.02740 [nucl-ex]

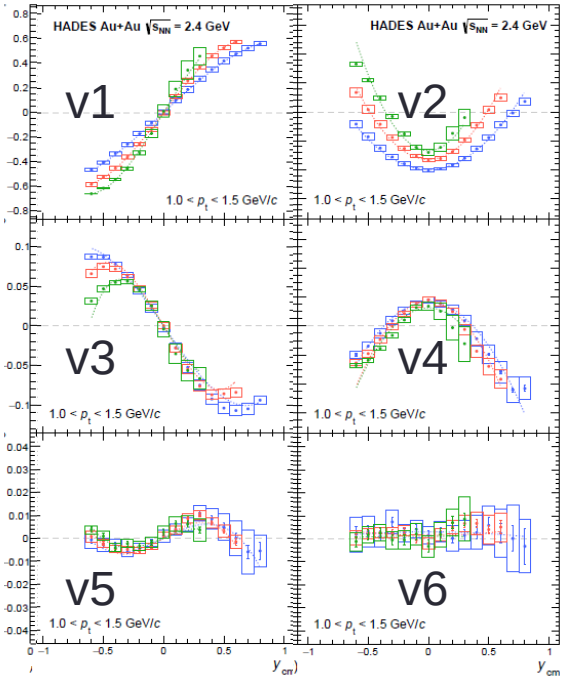
High precision flow coefficients for Au+Au at $\sqrt{s_{NN}}$ = 2.4 GeV

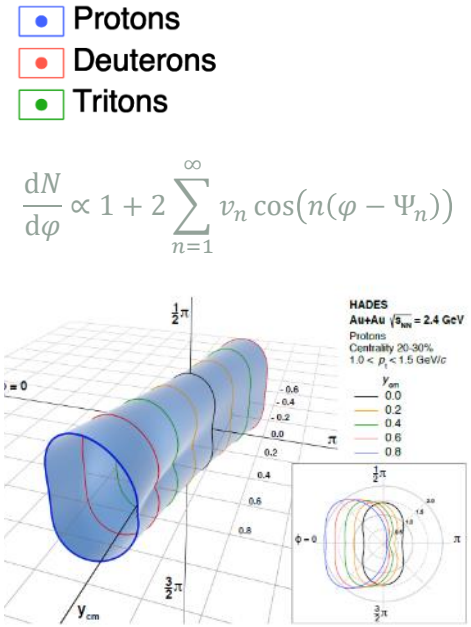
- v1- v6 for Protons/Deuterons/Tritons
- Centrality, p_T, rapidity dependences determined
- Odd coefficients consistent with zero at mid-rapidity

Angular emission pattern constructed

Major step in constructing the EoS of dense baryonic matter

Understanding properties of Neutron-Star matter





"Constraining Neutron-Star Matter with Microscopic and Macroscopic Collisions"
Nature 606 (2022), 276-280

Hypernuclei at HADES

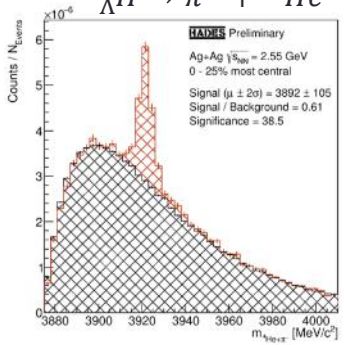
Data from Ag+Ag ($\sqrt{s_{NN}}$ =2.55 GeV)

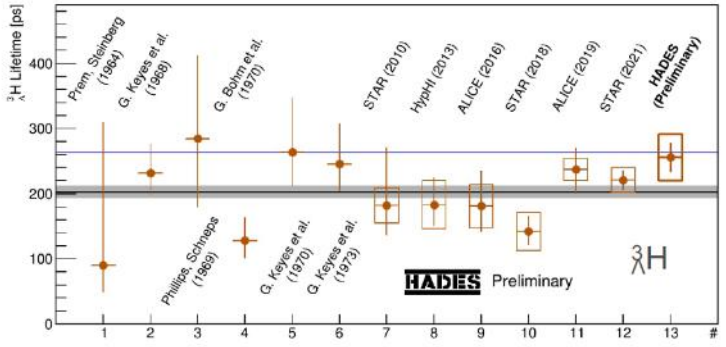
- ~ 4000 Hyper-triton candidates
- ~ 1000 Hyper-helium candidates

Multi-differential studies possible

Obtained lifetimes in-line with other experiments

$^{3}_{\Lambda}H \rightarrow \pi^{-} + {}^{3}He$





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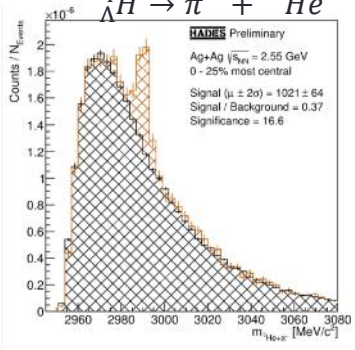
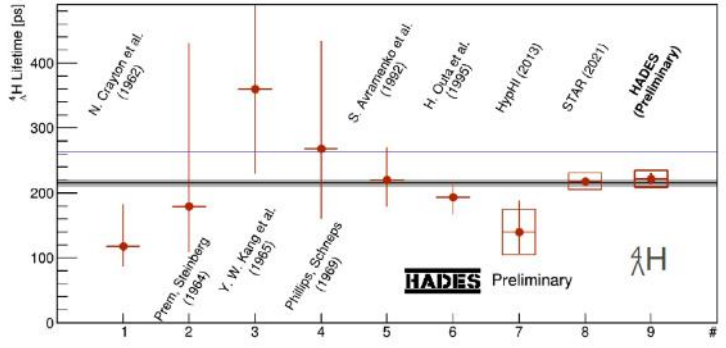




HADES plenary, QM2022

HADES in 2022 – Continued Upgrade Program

Major upgrade projects until 2022:

- Outer Tracking 2006 (France, Germany)
- RPC 2011 (Portugal)
- EMC 2016 (Poland, Czech Republic, Russia)
- RICH Photon detector 2018 (MAPMT)

  (HADES-CBM cooperation, Germany)

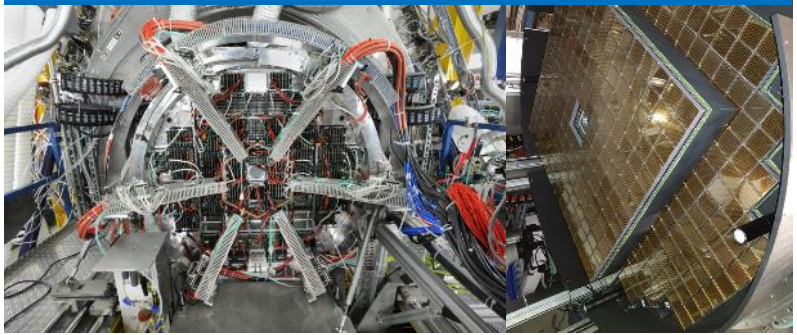
and many more like DAQ, Trigger, T0 …..

RPC 2011

Outer Tracking 2006

EMC 2016

RICH Photon detector 2018



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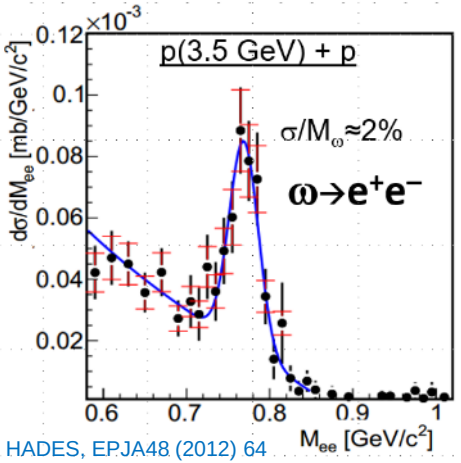
RPC 2011

→ High multiplicity events
→ Precise timing (< 100ps sigma)

Outer Tracking 2006

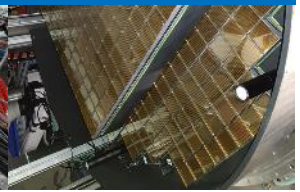
→ High precision momentum reconstruction



HADES, EPJA48 (2012) 64

RICH Photon detector 2018

→ Improved Dielectron efficiency
→ Conversion rejection
→ Background rejection



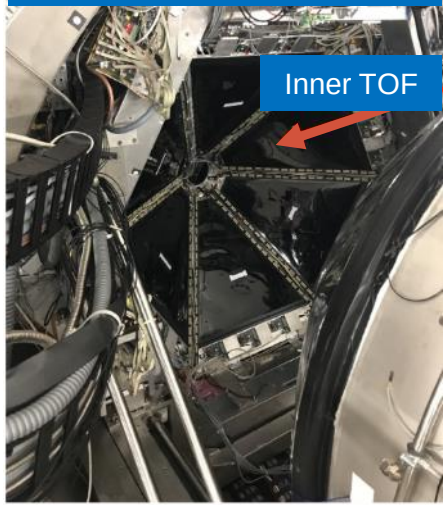
EMC 2016

→ Neutral mesons
→ Dielectron purity

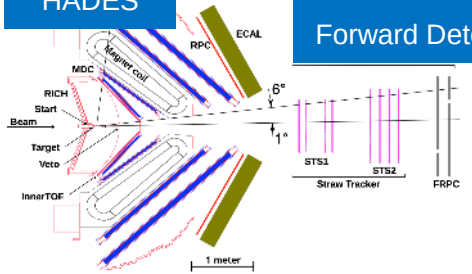
HADES in 2022 – Continued Upgrade Program

HADES – PANDA cooperation. Experiment conducted in 02-03.2022 (proton-proton at 4.5GeV)

Inner TOF
(FAIR-NRW, Germany)

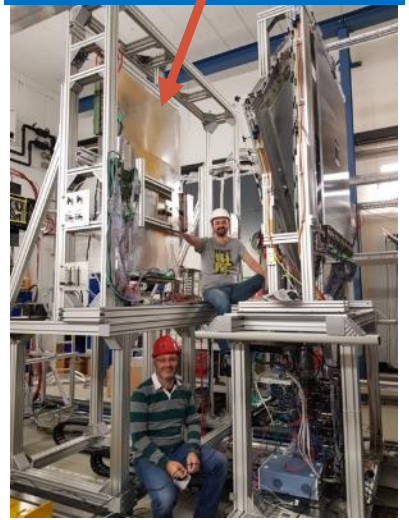


HADES

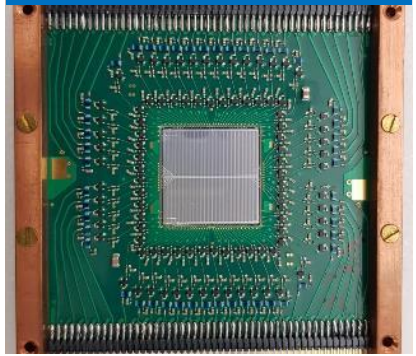


Forward Detectors

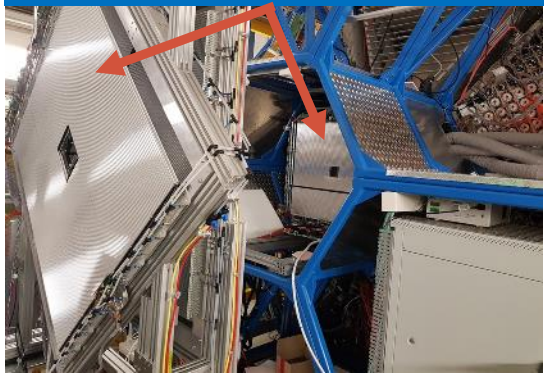
Forward RPC
(LIP, Portugal)



LGAD T0
(GSI/ TU DA, Germany)

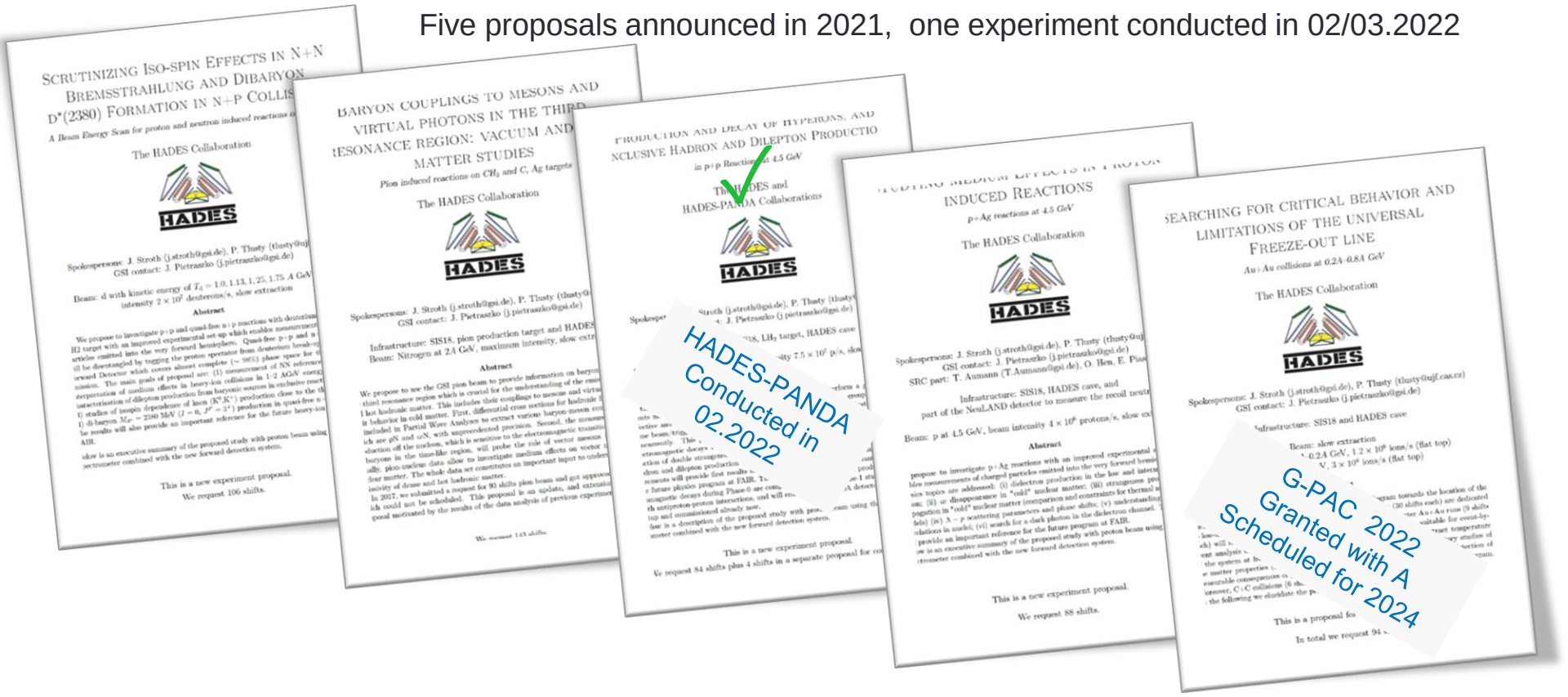


Forward Tracker
(FAIR-NRW, JU, AGH, Germany/Poland)



HADES FAIR Phase-0 Proposals

Five proposals announced in 2021, one experiment conducted in 02/03.2022



HADES FAIR Phase-0 Proposals and Beyond

The HADES **Phase-0** activities - new members

- Polish initiative to increase participation in HADES (coordinated by Prof. Salabura)
  - Institute of Nuclear Physics, Polish Academy of Sciences, Cracow
  - AGH University of Science and Technology, Cracow
  - University of Warsaw - Institute of Experimental Physics
  - Warsaw Technical University
- FZJülich (Prof. J. Ritman's group) – now FAIR-NRW
- Swedish PANDA colleagues (through PANDA-HADES MoU, coord. Prof K.Schönning)
  - Department of Physics and Astronomy, Uppsala University
  - University of Stockholm

Jagiellonian University in Kraków

Institute of Nuclear Physics Polish Academy of Sciences

University of Warsaw

Warsaw University of Technology

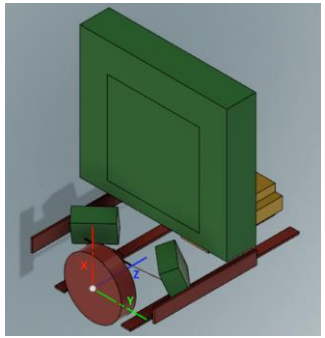
Uppsala Universitet

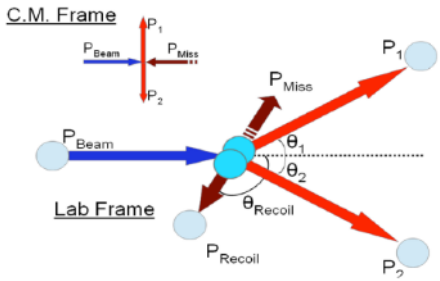
Stockholm University

To come soon: Short Range Correlation (SRC) facility at HADES (coordinated by Prof. Or Hen - MIT)

- Activities started in 2017
  - US (MIT) – Prof. Or Hen
  - Israel (Tel Aviv) – Prof. E. Piasetzky
  - Nustar-R3B – Prof. T. Aumann / Prof. A. Obertelli
- Significant upgrading is expected - international effort
  - Backward neutron detection
  - Precise T0
  - Selective trigger

(Julian Kahlbow - ERC grant submitted)





Anticipated HADES Upgrades for HADES@SIS100

Two subsystems with increased risk of failure:

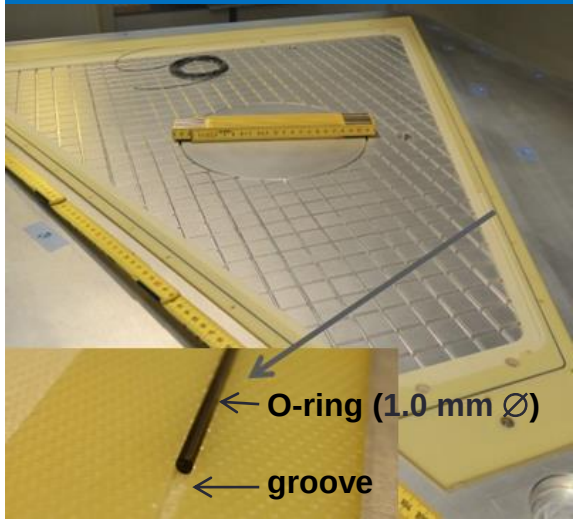
- A part of the inner tracking system (MDC II chambers)
  Prof. Joachim Stroth, GU Frankfurt
  - Built before 1999
  - Aging (Ar/Isobutane)
  - Wire tension loss (Al wires)
- FWALL detector
  - Contains parts from the Kaos experiment
  - PMTs, Scintillator material
  - Limited space at SIS100

DAQ upgrade for HADES at SIS100

- Increased data throughput
- Online data processing
- Trigger selectivity

HADES FWALL Detector

HADES MDC II Chamber

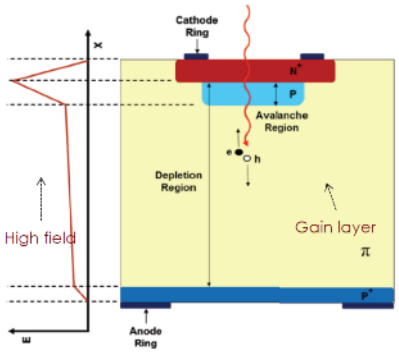


LGAD Technology in HADES

Low Gain Avalanche Detectors (LGAD) technology

(proposed and manufactured by National Center for Micro-electronics, Barcelona)

- Thin gain layer exhibits electric fields (>300 kV/cm)
  - Leads to intrinsic signal amplification
  - Signals with short rise times (<1ns)
- Simultaneous position (<30µm) and time measurement (<50ps), thickness < 200µm



Nicolo Cartiglia, INFN, Torino - Berlin 12/06/18
G. Pellegrini, et al. NIM A765 (2014) 12–16

J. Pietraszko[1,a], T. Galatyuk[1,2], V. Kedych[2], M. Kis[1], W. Koenig[1], M. Koziel[3], W. Krüger[2], R. Lalik[4], S. Linev[1], J. Michel[3], S. Moneta[5], A. Rost[2], A. Schemm[6], C. J. Schmidt[1], K. Sumara[4], M. Träger[1], M. Traxler[1], Ch. Wendisch[1]

[1] GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany
[2] Technische Universität Darmstadt, 64289 Darmstadt, Germany
[3] Institut für Kernphysik, Goethe-Universität, 60438 Frankfurt, Germany
[4] Smoluchowski Institute of Physics, Jagiellonian University of Cracow, 30-059 Kraków, Poland
[5] Università di Pisa, 56126 Pisa, Italy
[6] IMT Atlantique, Campus de Nantes, 44307 Nantes, France

Helmholtz Innovation Pool (MU / MT)

The *Tangerine* Project
Towards Next Generation Silicon Detectors

Assosiated partner (w/o funds) of

HIGH-D

HADES
GSI FAIR

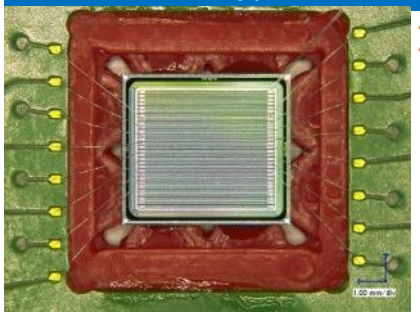
ÖAW HEPHY

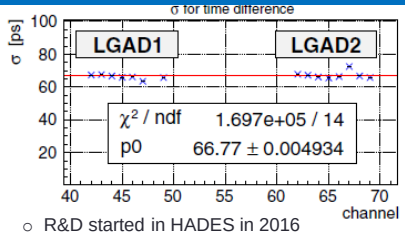
TU WIEN ATOMINSTITUT

CMM CENTER FOR MATERIALS AND MICROSYSTEMS
FONDAZIONE BRUNO KESSLER

INFN TORINO

HADES Prototype LGAD T0 sensor and performance





- R&D started in HADES in 2016
- Excellent performance demonstrated in 2020
  - Time precision below 50ps
  - Rate capability MHz/channel
  - Operation at room temperature

J. Pietraszko, *et al.*, Eur. Phys. J. A 56, 183 (2020)

LGAD Technology in HADES and Other Applications

HADES T0 detector

- Placed in primary beam, 10^8 p/s
- Defines the start reaction time (T0) and monitors the beam quality
- Beam HALO rejection, essential part of the PID

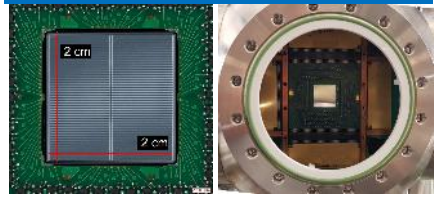
LGAD at S-DALINAC in Darmstadt

- Beam monitoring (time structure) in the energy recovery mode
- 3/6 GHz bunch time structure in the normal/ER modes

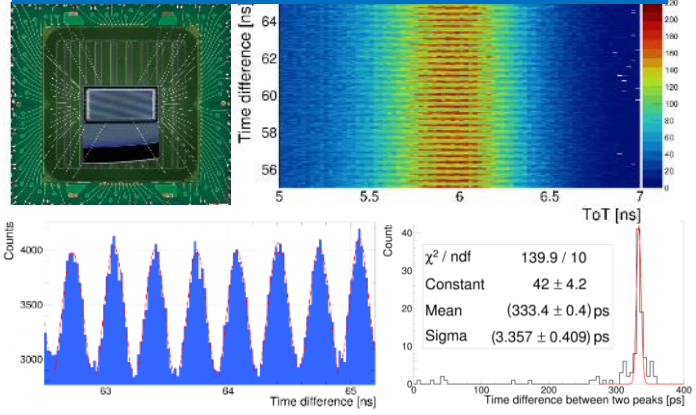
Medical Applications – Ion Imaging

- Relative stopping power distribution inside a patient
- LGAD – Energy measurement by Time-of-Flight
- First proof-of-principle measurement at MedAustron (1)(2)

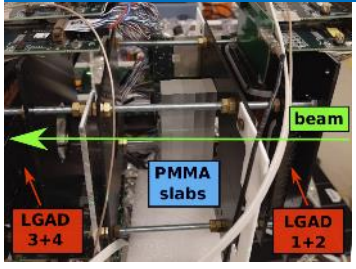
HADES LGAD T0 detector

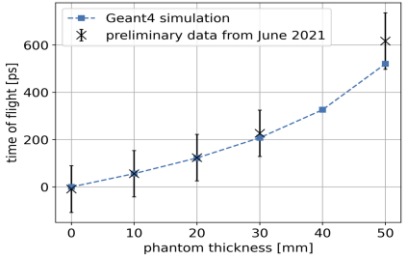


LGAD at S-Dalinac



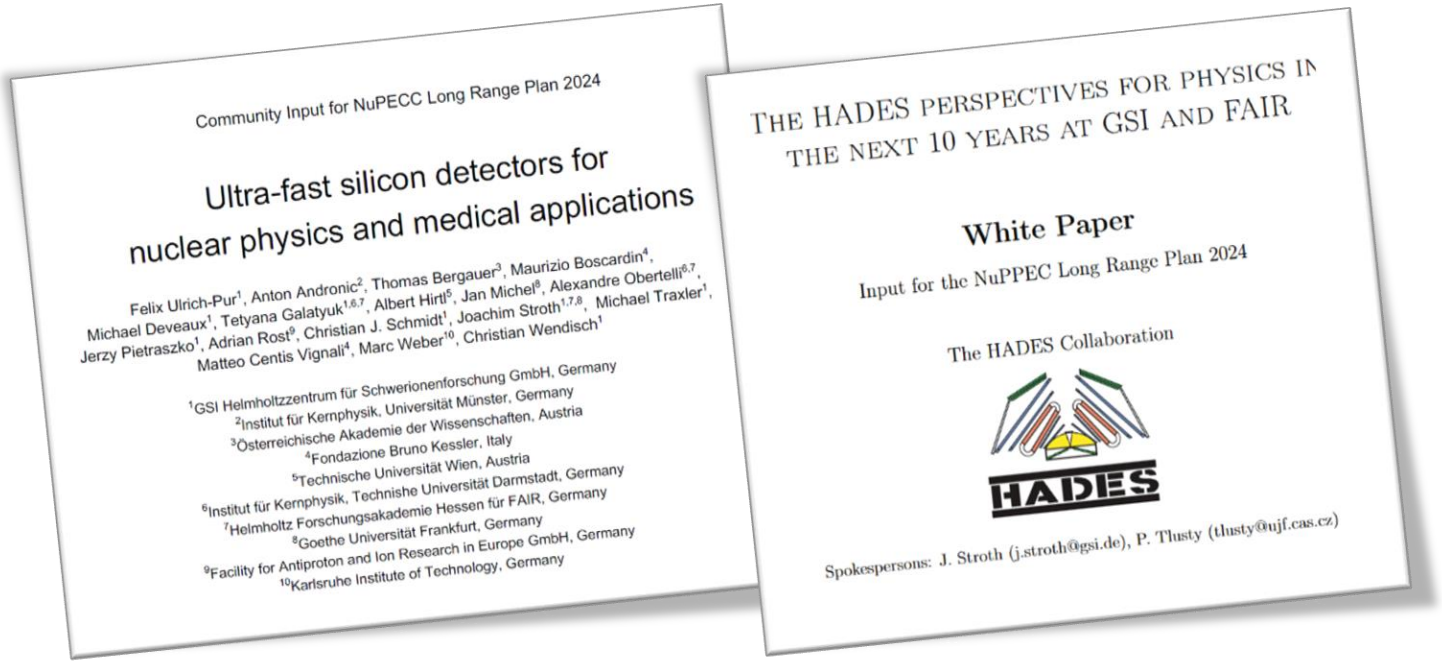
LGAD ionCT at MedAustron





(1) Ulrich-Pur, Felix et al. (Mar. 2022) Physics in Medicine & Biology. ISSN: 0031-9155, 1361-6560
(2) Krüger, W. et al. NIM A 1039 (2022) 167046, LGAD technology for HADES, accelerator and medical applications .

Community Input for NuPECC Long Range Plan 2024



Community Input for NuPECC Long Range Plan 2024

Ultra-fast silicon detectors for nuclear physics and medical applications

Felix Ulrich-Pur[1], Anton Andronic[2], Thomas Bergauer[3], Maurizio Boscardin[4], Michael Deveaux[1], Tetyana Galatyuk[1,6,7], Albert Hirtl[5], Jan Michel[8], Alexandre Obertelli[6,7], Jerzy Pietraszko[1], Adrian Rost[9], Christian J. Schmidt[1], Joachim Stroth[1,7,8], Michael Traxler[1], Matteo Centis Vignali[4], Marc Weber[10], Christian Wendisch[1]

[1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany
[2]Institut für Kernphysik, Universität Münster, Germany
[3]Österreichische Akademie der Wissenschaften, Austria
[4]Fondazione Bruno Kessler, Italy
[5]Technische Universität Wien, Austria
[6]Institut für Kernphysik, Technishe Universität Darmstadt, Germany
[7]Helmholtz Forschungsakademie Hessen für FAIR, Germany
[8]Goethe Universität Frankfurt, Germany
[9]Facility for Antiproton and Ion Research in Europe GmbH, Germany
[10]Karlsruhe Institute of Technology, Germany

THE HADES PERSPECTIVES FOR PHYSICS IN THE NEXT 10 YEARS AT GSI AND FAIR

White Paper

Input for the NuPPEC Long Range Plan 2024

The HADES Collaboration

HADES

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

- Two white papers issued and submitted to the NuPECC
- LGAD: Focus on further 4D Tracking development strongly supported by real applications
- HADES: Several proposals ready, new partners have joined and others expressed interest to join the collaboration

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