The HADES Experiment

The next ten years

Joachim Stroth

Research Retreat, TU Darmstadt, Germany

July 18 – 19, 2023

Many greetings to you from the HADES Collaboration!

GSI March 2023

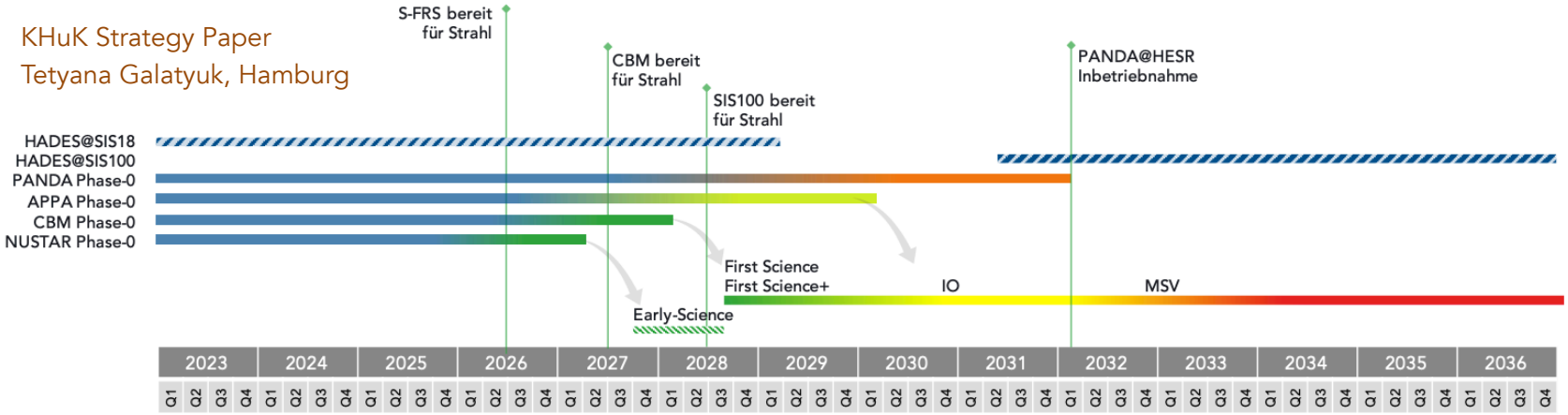
HADES in the next 10 years

I. Original FAIR Phase-0 program

II. Extended running with pion and proton beam?

III. Transfer to CBM cave

KHuK Strategy Paper
Tetyana Galatyuk, Hamburg



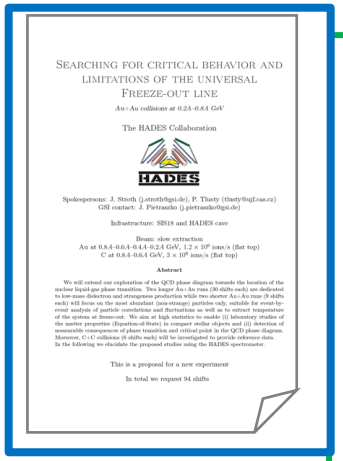
Acc. Operation total / days	134	44	140	140	110	restricted shutdown	90	90	200	240	240	
Physics beam time/ days	107	0	100	100	100		120*	140*	180	180		

GSI/FAIR Retreat Q1/2023
Stefan Reimann, Bensheim

(I) HADES proposals for FAIR Phase-0

- Unexpectedly, it might take until 2028 to finish
- Also in the planning, more pion beam experiments - in particular also π + Ag

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 0.8,4–0.6,4–0.4,4–0.2,4 GeV, 1.2×10^9 ions/s (flat top)
C at 0.8,4–0.6,4 GeV, 3×10^8 ions/s (flat top)

Abstract

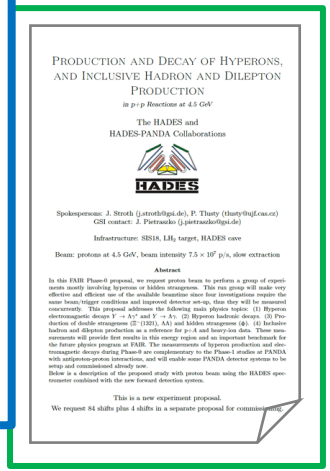
We will extend our exploration of the QCD phase diagram towards the location of the nuclear liquid-gas phase transition. Two longer Au+Au runs (30 shifts each) are dedicated to low-mass dielectron and strangeness production while two shorter Au+Au runs (8 shifts each) will focus on the most abundant (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

Scheduled for March 2023

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 $\Upsilon^* \to \Lambda\gamma^*$ and $\Upsilon^* \to \Lambda\gamma$. (2) Hyperon hadronic decays. (3) Production of double strangeness (Ξ^- (1321), AA) 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.

Successfully conducted in Feb./March 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. Ben, 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

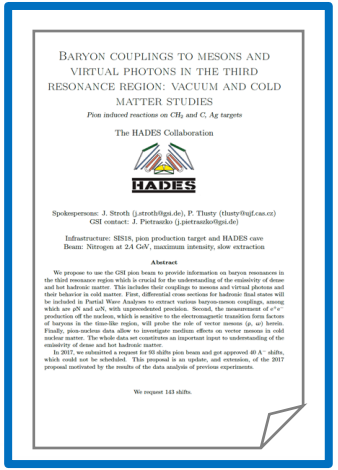
Abstract

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) or 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.

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 2.4 GeV, maximum intensity, slow extraction

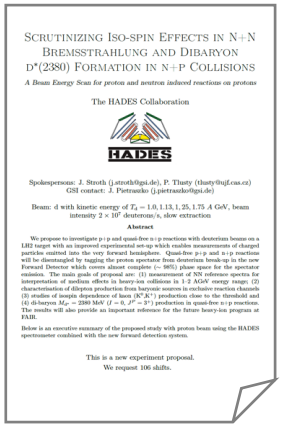
Abstract

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.

On hold otherwise A

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 ($\sim$ 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 $M_{pn} = 2380$ 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.

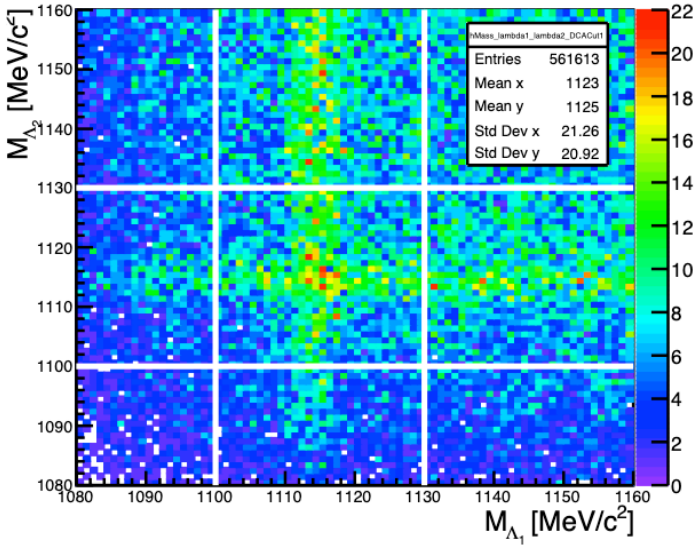
This is a new experiment proposal.
We request 106 shifts.

15 Billion events Ag+Ag taken already in 2019, 35 Billion p+p in 2022.

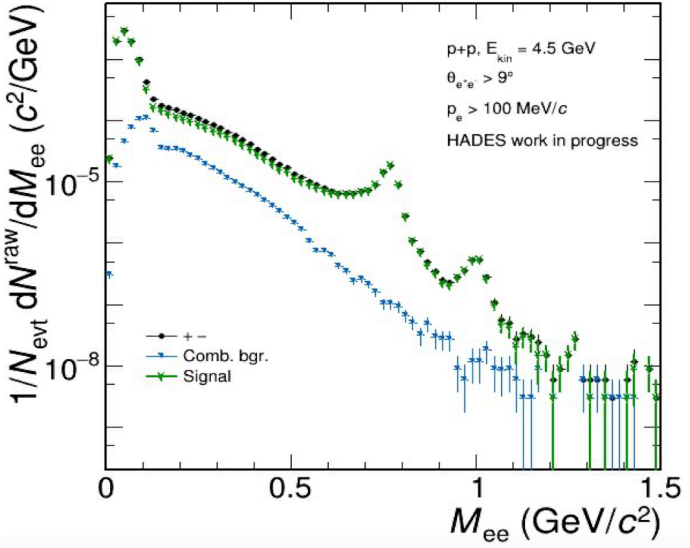
(I) Status analysis p+p 4.5 GeV

- Second generation DST production available (updated alignment and calibrations)
- Integrated luminosity $\mathscr{L} = 6.4\ \mathrm{pb}^{-1}$
- $18.000\ \omega$ reconstructed in e^-e^+ channel – advanced analysis including ECAL ongoing

double strangeness



inclusive dileptons



(I) G-22-00022 (approved)

SEARCHING FOR CRITICAL BEHAVIOR AND LIMITATIONS OF THE UNIVERSAL FREEZE-OUT LINE

Au+Au collisions at 0.2A–0.8A GeV

The HADES Collaboration

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.

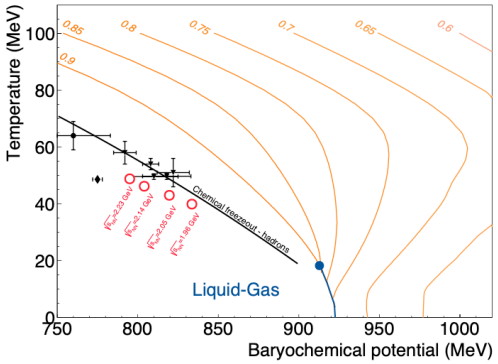
This is a proposal for a new experiment

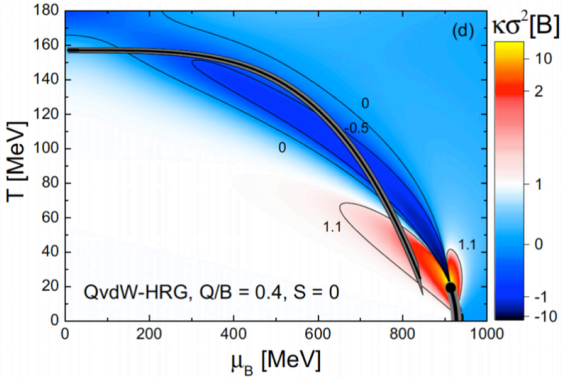
In total we request 100 shifts

Au+Au beam energy scan, C+C for reference

100 shifts Au beam at moderate rigidity

Good micro spill-structure





Active proposals

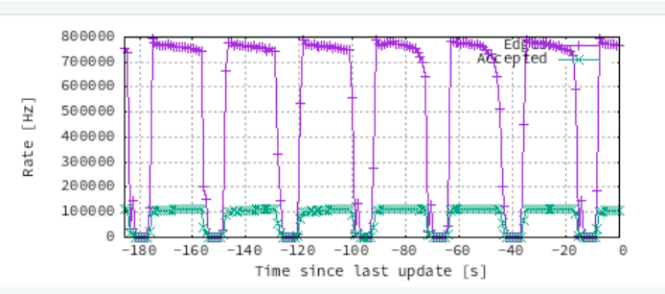
Proposal	Action	Title	Proposer	Facility	ET alloc.	Schedule
G-22-00022		Searching for critical behavior and limitations of the universal Freeze-out line	Joachim Stroth, JWGU Frankfurt/M., DE	1.1-S: HAD	75 Shifts	

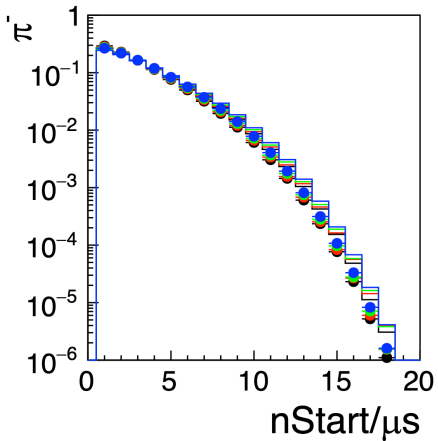
"In view of the scarce beam time available G-PAC recommends to skip the time-consuming di-lepton measurements at 0.6 AGeV, reducing the shifts needed at that energy from 30 to 9 shifts and to skip the reference measurements with C at that energy. The total beam time will this **reduce by 25 shifts to 75** shifts ranked A."

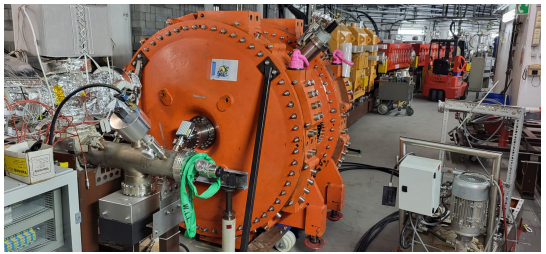
Now: Au+Au (800, 600, 400, 200 *A* MeV) and C+C (800)

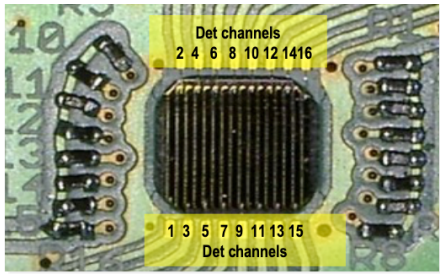
Most important:

- Micro spill-structure
- Duty factor







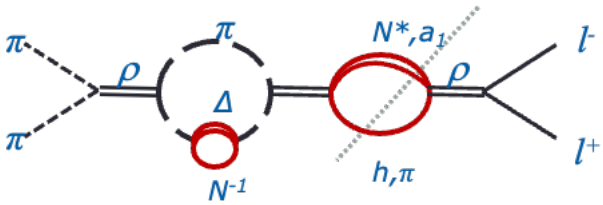


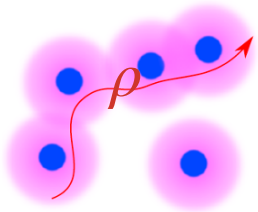
(I) Time-like transition form factors of baryons

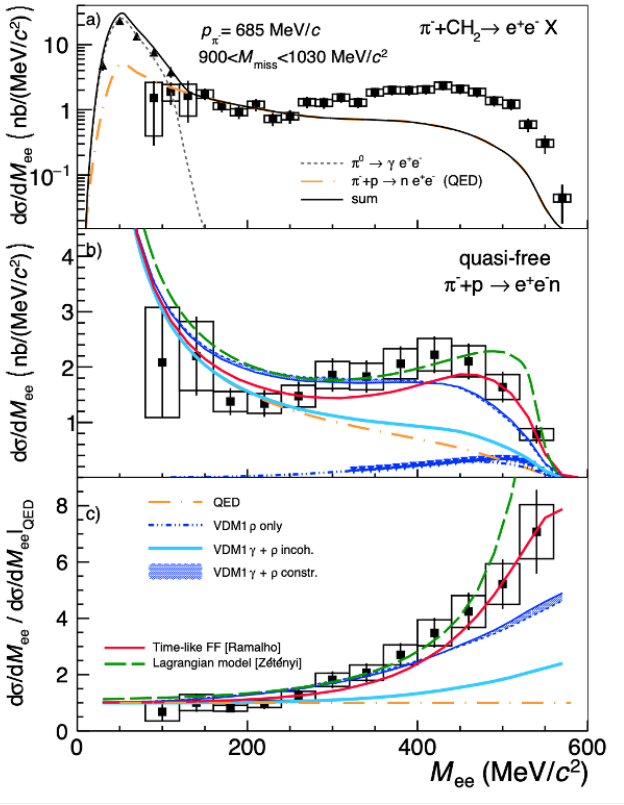
Exclusive channel:

$$\pi^- + p \rightarrow n e^+ e^- @ \sqrt{s} = 1.49\ \text{GeV}$$

- Energy tuned to second resonance region
- Partial wave decomposition by combining with hadron data (Bonn-Gatchina)
- Good description by VMD
- Core-cloud models work even better







(I) G-22-00141 (approved but not scheduled)

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

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 2*A* 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. The present proposal, which is an extension of the 2017 proposal motivated by the results of the data analysis of previous experiments, was submitted to the G-PAC in 2020. Although the scientific interest of the proposed measurements had been recognized by the G-PAC, the experiment was not ranked due to needed improvements of the accelerator to provide the desired beam quality.

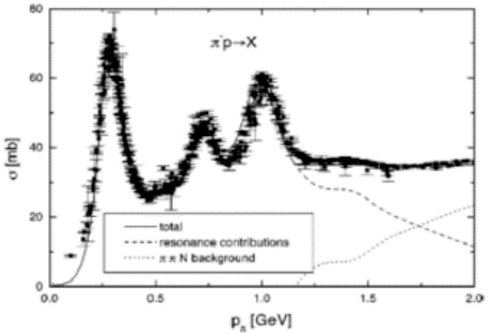
This is a new proposal

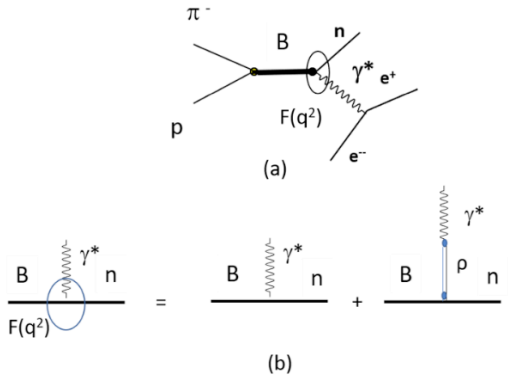
We request 143 shifts.

Baryon resonances in the second resonance region

143 shift with secondary pion beam (π^-)

Highest primary beam intensities at maximum rigidity

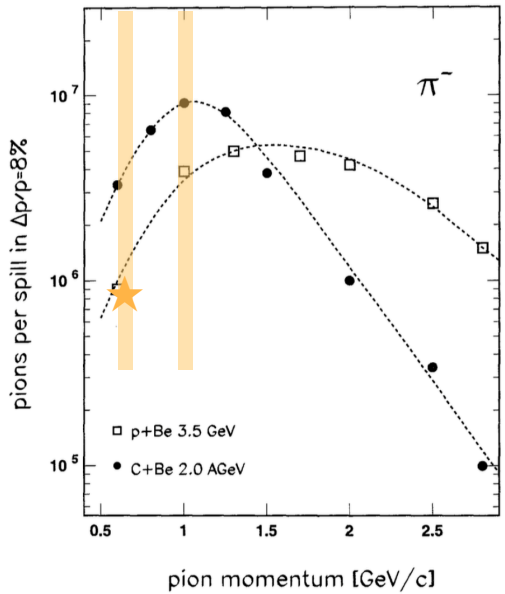




Finished proposals 🤔

Proposal	Action	Title	Proposer	Facility	ET alloc.	Schedule
G-22-00141		Baryon couplings to mesons and virtual photons in the third resonance region: vacuum and cold matter studies	Joachim Stroth, JWGU Frankfurt/M., DE	1.1-S: HAD		

"… strong scientific impact and cannot be performed at FAIR (Phase 1). However, d**ue to recent technical issues** with **the pion beam extraction**, the proposal **cannot be ranked A** …"



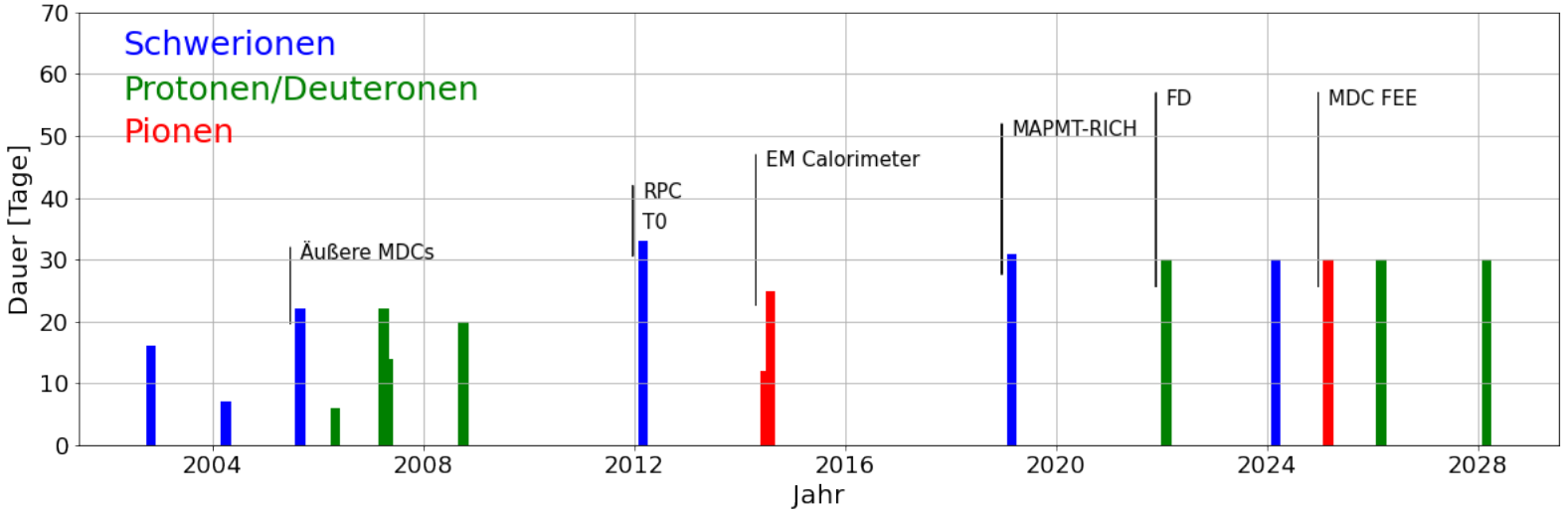
Problem: Ion beam with maximum rigidity and intensity close to space-charge limit cannot be slow-extracted with sufficient efficiency radiation too high.

Observation from past beam times:

- ^{12}C and ^{14}N beams with 1×10^{11} have been accelerated in the past as documented in logbook entries
- Number of nucleons/s on pion production target essential; no heavy-ions because of energy loss $\propto Z^2$
- From 2014 beam time: $4 \times 10^5 \pi^-$ with $p = 687$ MeV/c at 0.8×10^{11} per spill shortly before shutdown due to radiation issues

(II) Ambitious run schedule to finish Phase-0 (2024-2028)

- So far: ten runs in 20 years (0.5/y)
- Finishing Phase-0 proposals from 2020 would require four more runs in five years (0.8/y)
  - Seems very unlikely given the start-up of SIS100 commissioning
  - HADES would offer stand-bye operation during commissioning



(III) HADES at Nuclear Collisions cave

- $Au + Au$ / $Ag + Ag$ measurements at lowest beam energies
  - Dilepton excitation function
  - Fluctuations
- $p + A$ measurements
  - Cold matter studies $\omega, \phi, (J/\psi)$
  - Short-range correlations
- $p + p$ program (exclusive channels)
  - Participation in development of physics program together with PANDA and CBM
  - Decision on detector configurations once physics case is defined