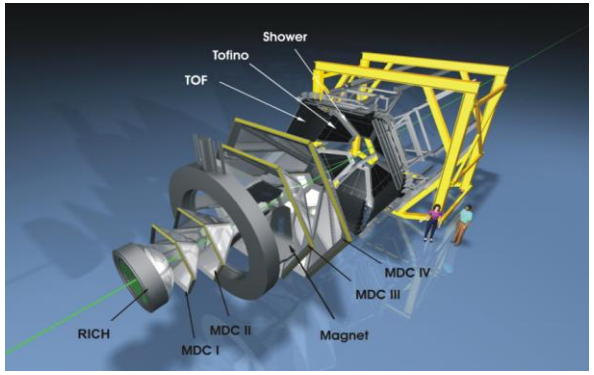
HADES experiments at GSI



B. Ramstein/S. Harabasz (IJClab)
and I. Ciepal (IFJPAN)

Outline

- Motivations of HADES experiments:

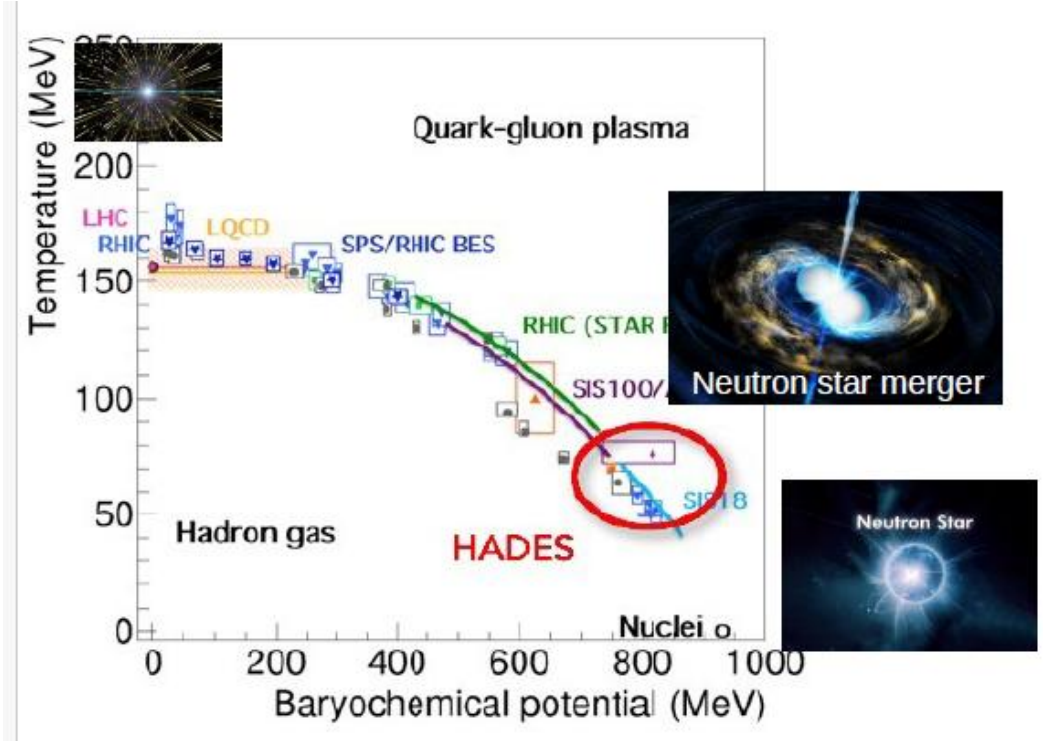
  Complementarity between heavy ion and elementary reaction programs

- IFJ-PAN collaboration:

  Activities since the 2023 pre-project

- Future plans

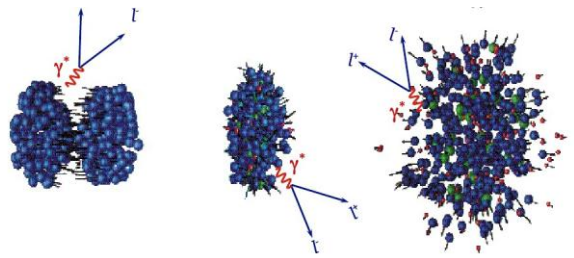
HADES: exploring dense QCD matter



- Hadronic matter properties at large baryochemical potential and moderate temperatures
  (complementary to SPS,RHIC,..)

- Microscopic structure
  Role of baryonic resonances, hyperons

SIS18 beams at GSI:
Au: E_{max}=1.25A GeV, $\sqrt{s_{NN}}$ = 2.4 GeV
p : E_{max}=4.5 GeV, $\sqrt{s_{NN}}$ = 3.46 GeV



Observables:
- ✓ Correlations and fluctuations
- ✓ Collective effects
- ✓ **Dileptons**
- ✓ **Strangeness**

Goals of the HADES elementary reaction program

Leading role of the Polish-French collaboration !

pp , np (dp) ,πp

- References for **in-medium studies**
  e^+e^- excess yields (fire ball production)
  distortion of (strange) hadron momentum distributions (potential effect)……

- Production cross sections + unknown (or badly known) hadron properties (decay branching ratios, electromagnetic form factors) including hyperons at the highest SIS18 energies
  → Inputs for hadronic models: production of e+e- and hadrons in NN and secondary πN interactions
  → Intrinsic interest (hadron structure and hadron interactions)

The HADES Collaboration

HADES Collab Meeting Warsaw, August 2024

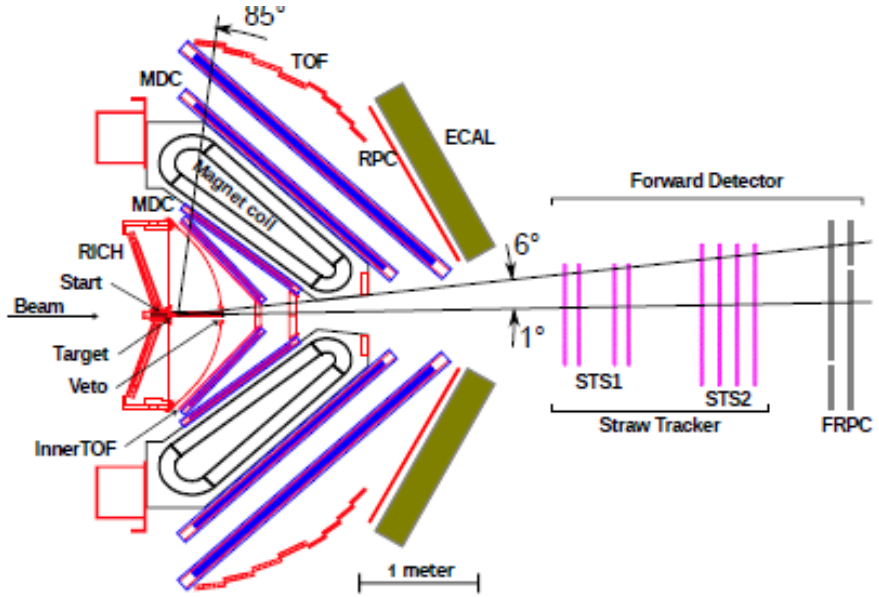
About 120 physicists

- **Jagiellonian Univ., Cracow, Poland (1994)**
- **IFJ PAN Cracow, Poland (2017)**
- Univ. of Warsaw, Poland (2017)
- Warsaw Univ. of Technology, Poland (2019)
- AGH Cracow , Poland (2021)
- **IPNO → IJCLab Orsay , France (1997)**
- **NPI, Rez,Czech Rep.**
- **Stockholm University, Sweden**
- **Upssala University Sweden**
- **Coimbra University, Portugal**
- **Frederick University, Cyprus**

- **GSI, Darmstadt , Germany**
- **Frankfurt Univ., Germany**
- **Giessen Univ., Germany**
- **FZJ Jülich, Germany -> FFN ,GSI**
- **Univ of Wuppertal , Germany**
- **ITEP Moscow , Russia**
- **MEPhI Moscow, Russia**
- **INR Moscow, Russia**
- **JINR Dubna, Russia**

Collaboration with institutes of the Russian Federation is stopped since March 2022

High Acceptance DiElectron Spectrometer at FAIR/GSI

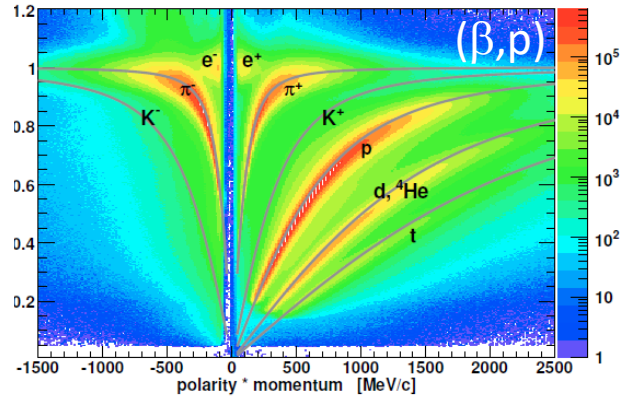


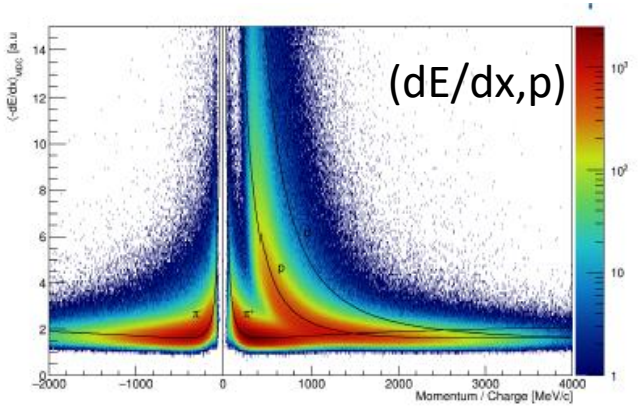
Acceptance:
Full azimuth, polar angles 18° - 85°

Momentum measurement:
$\Delta p/p$ ~ 1-2 %, low material budget optimized for electron detection

Particle identification: γ, e^+/e^-, π^+/π^-, K^+/K^-, p

Trigger: < 50 kHz





French contribution:

- MDCIV –largest MDC chamber
- Liquid Hydrogen Target
- Forward detector (support mechanics and STS2 financial contribution)

Polish contribution:

- Pre-Shower (replaced in 2019 by ECAL)
- ECAL (Jagiellonian University, mechanical frame)
- Forward detector (Jagiellonian University + IFJ PAN)

STS2 (2nd straw tube station) construction

The HADES experimental program (2004-2025)

- **Hadronic matter studies**

C+C 1 and 2A GeV, Ar+ KCl 1.75A GeV, Au+Au 1.25A GeV, Ag+Ag 1.65A GeV
+ recent energy scan Au+Au and C+C (200-800A MeV)

- **Cold matter:**

p+Nb 3.5 GeV, π^-+C 0.7 GeV/c, π^-+C/W 1.7 GeV/c

- **Elementary reactions:**

p+ p 1.25, 2.2 , 3.5 GeV, 4.5 GeV, d+p 1.25 GeV/nucleon
π^-+CH_2 0.7 GeV/c

Main focus of the
B. Ramstein/ I. Ciepal
collaboration

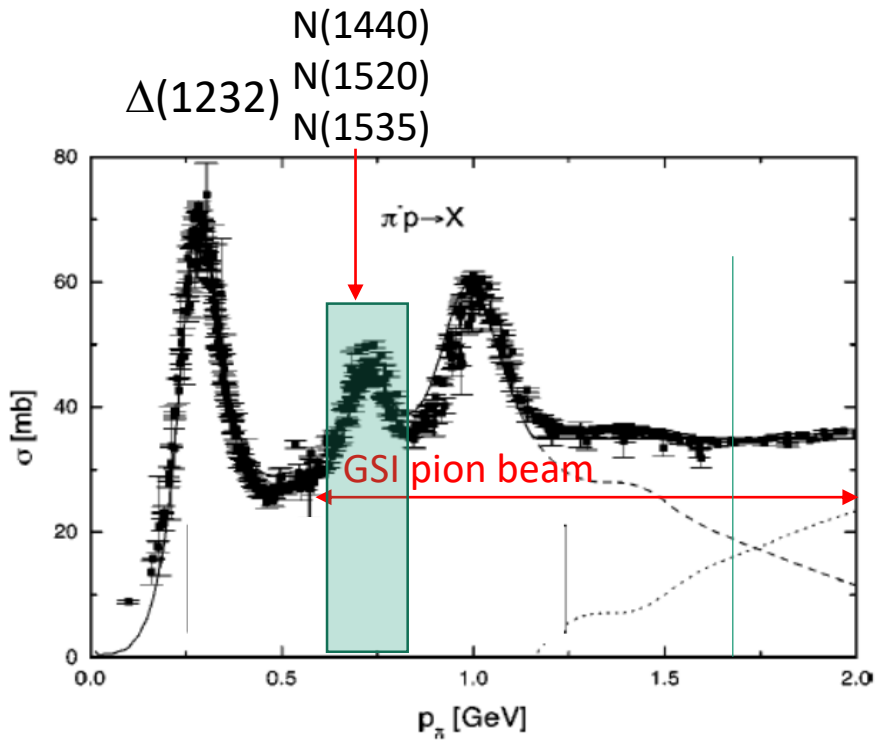
S. Harabasz formerly postdoc at TU-Darmstadt recruited at IJCLab/CNRS Dec.2024
existing collaboration with IFJ PAN , R. Ryblewski (IFJ PAN), W. Florkowski (initialy IFJ PAN, later Jagiellonian University)
on thermal models

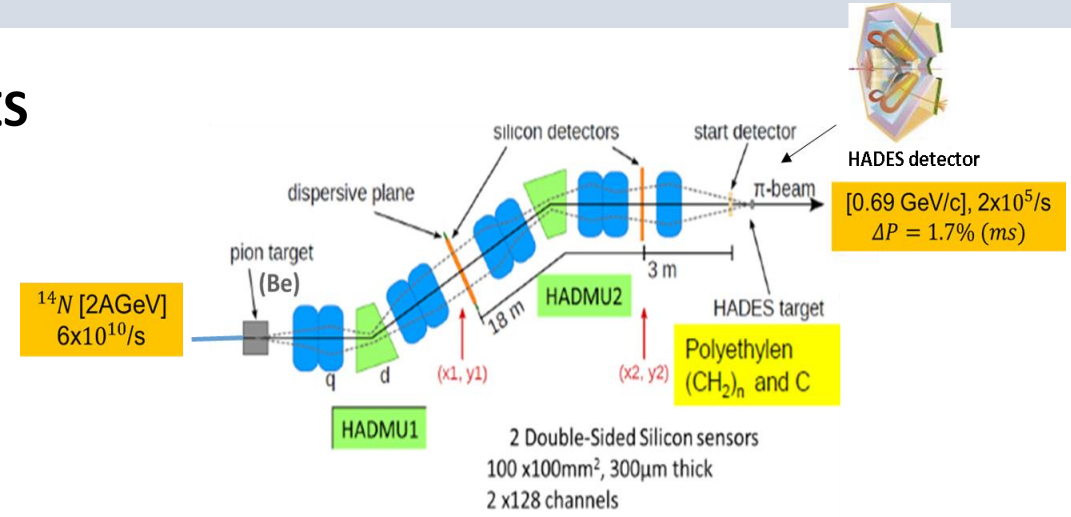
Pion beam experiments

A facility for pion-induced nuclear reaction studies with HADES

HADES coll. Eur. Phys. J. A (2017) 53: 18

- Primary beam:
  4 × 10^{10} Nitrogen ions/s at E = 2*A* GeV
- Secondary π^- beam: 2 × 10^5 /s
- Momentum acceptance = 2 % (rms)
- Momentum range p_{π} = 0.65 – 2 GeV/c





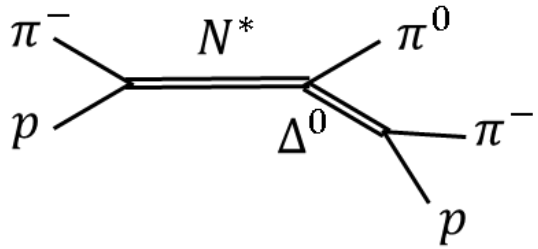
HADES measurements:

- W and C targets p =1.7 GeV/c kaon and ϕ production
  Eur.Phys.J.A 60 (2024) 7, 156
- CH2 and C targets 0.61, 0.66, 0.7, 0.75, 0.8 GeV/c (N1520 region)
  π^-+p : baryon resonance properties
  Phys.Rev.C 102 (2020) 2, 024001 (2π decays: Δπ, ρN, σN , 8 PDG entries)
  Phys.Rev.C 111 (2025) 2, 024908 inclusive e^+e^- production
  arXiv: 2309.13357 [nucl-ex] exclusive $\pi^-p \rightarrow n\, e^+e^-$ production
  π^-+C at 0.7 GeV/c : proton and pion correlations
  Fatima Hojeij's PhD, Paris-Saclay, Nov. 2023 (cosupervised by I.Ciepal)

Main channels in $\pi^- + {}^{12}C$

- Quasi-elastic and charge exchange:
  - $\pi^- + p \rightarrow \pi^- + p$ 17.8 mb (SAID)
  - $\pi^- + n \rightarrow \pi^- + n$ 12 mb (SAID)
  - $\pi^- + p \rightarrow \pi^0 + n$ 10 mb (SAID)
- Inelastic (pion production)
  - $\pi^- + p \rightarrow n + \pi^- + \pi^+$ 6.1 mb
  - $\pi^- + p \rightarrow p + \pi^- + \pi^0$ 3.3 mb
  - $\pi^- + n \rightarrow p + \pi^- + \pi^-$ 0.4 mb

Main contribution from s-channel N* excitations

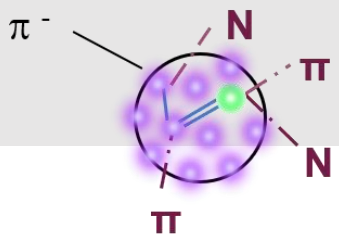


+ rescatterings (multi step) $\pi N \rightarrow \pi N$, $\pi N \rightarrow \pi\pi N$, $NN \rightarrow NN$, but $NN \rightarrow NN\pi$ kinematically suppressed

+ absorption $\pi NN \rightarrow NN$

- Analysis of many exit channels : π^-p, π^+p, pp, π^-pp, $\pi^+\pi^-p$, ...
- Comparison between reconstructed events (in HADES acceptance) from measurements and from Geant simulations
  - JAM2, GiBUU, SMASH (transport models)
  - INCL++ cascade model (GEANT4 hadronic model)

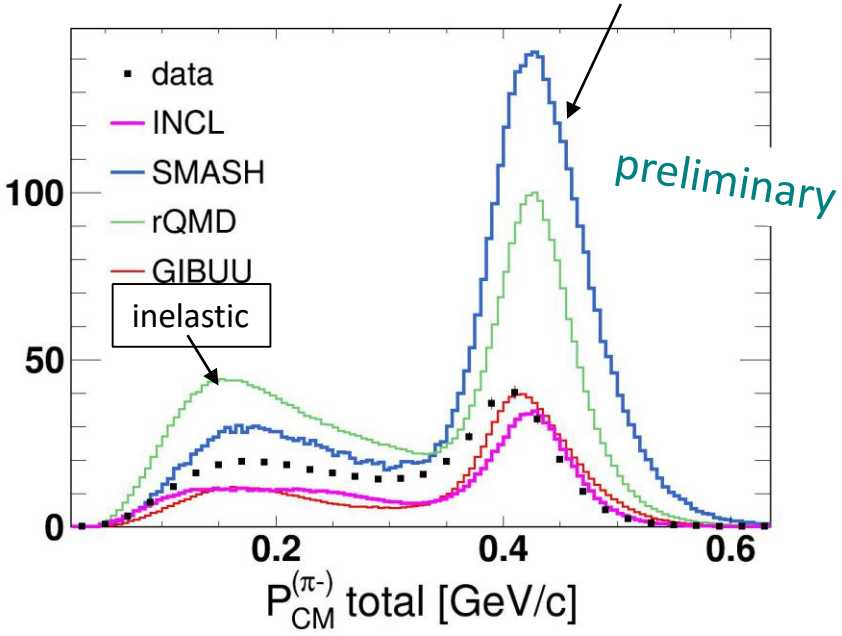
Hadronic channels in π^- + C @ 0.69 GeV/c : ideal test bench for transport model calculations

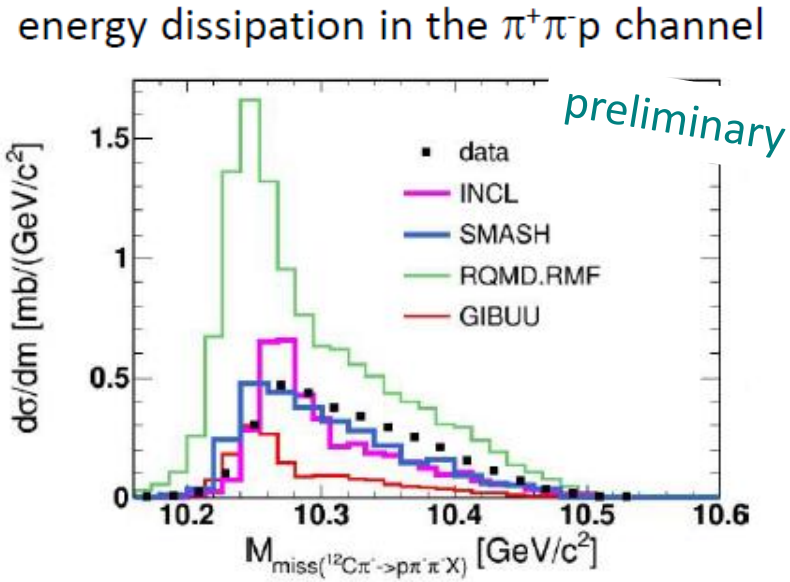


Quasi-elastic
$\pi^- + \text{'p'} \rightarrow \pi^- + p$

examples

Multiparticle final states
$\pi^- + C \rightarrow \pi^- + \pi^+ + p$





Fatima Hojeij's PhD defended 14 Nov. 2023 at IJCLab (cosupervised by I. Ciepal) presented at NSTAR 2022, MESON 2023, EMMI workshop 2024

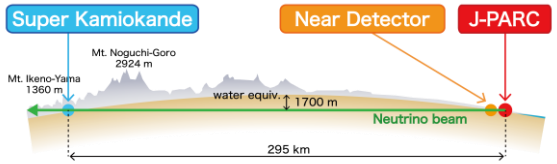
- Detailed tests of various models (GiBUU and INCL++ cascade also used for simulations of neutrino-nucleus interactions)
- HADES objectives: test models for heavy-ion reactions (FAIR) → can be also useful for neutrino physics

  → Motivation for an IJCLab/ IFJPAN collaboration **HADES-neutrino**

Long Base Line neutrino oscillation experiments

T2K /Hyper-K

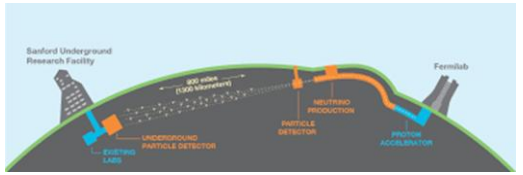
IFJ PAN



H_20 and CH detectors

DUNE

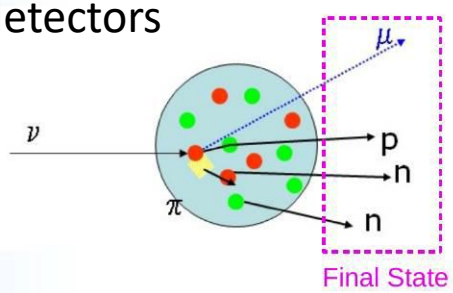
Laboratoire de Physique des 2 infinis Irène Joliot-Curie

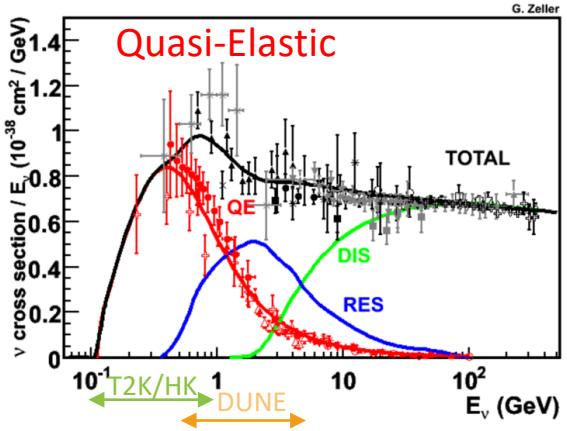


DUNE Ar detectors

ν/ $\bar{\nu}$ yields need to be precisely measured
as a function of energy in Near and Far detectors

Evolution of LBL experiments :
lepton detection → « calorimetry »





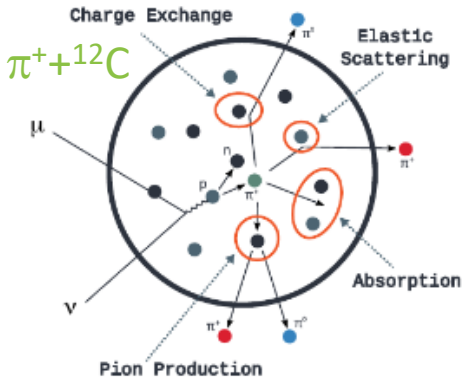
- E_ν < 0.8 GeV : cross sections mostly sensitive to Quasi-Elastic process
  Models are well constrained.
- E_ν > 0.8 GeV (DUNE) importance of pion production ($\Delta(1232)$ and higher resonances)
  Large model uncertainties

Resonance excitation
(1 pion emission)

Deep Inelastic
(multi-particle emission)

a large fraction (~50%) of the uncertainties on oscillation parameters is due to hadronic model dependency !

Pion induced experiments can help !



Hadronic Models for neutrino detection need to be tuned to pion beam data !

- Modeling the nuclear response :

different primary interactions with π and ν, but similar energy dissipation processes (elastic/inelastic reactions, baryon resonance propagation, pion regeneration)

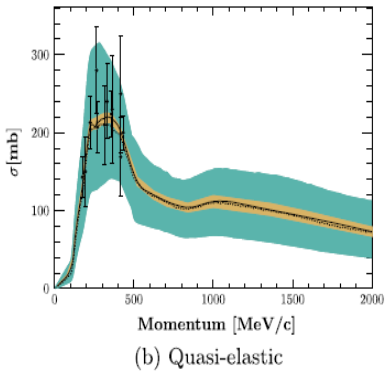
- pion detection: direct impact (pion interactions in the detector)

Very scarce existing pion beam data base

- $P_\pi < 250$ MeV/c : $\Delta(1232)$ resonance region rather well-known.
- $300 < P_\pi < 500$ MeV/c : few measurements (π, πx) or (π, $\pi\pi$x)

(LAMPF, TRIUMF, KEK) + DUET recent data

- $P_\pi > 500$ MeV/c : only σ_{tot} (Saturne-1, NIMROD, BNL) and diff. elast. cross sections (KEK).



(b) Quasi-elastic

Available HADES data (p = 610-800 MeV/c) using pion beam at GSI can be useful !

Pre-project HADES-neutrino

IJCLab/IFJ PAN pre-project : Dec 2023

HADES (hadronic physics)
IJCLab : Béatrice Ramstein
IFJ PAN : Izabela Ciepal

accelerator neutrino physics
IJCLab/DUNE: Fabien Cavalier, Yoann Kermaidic, Thibaut Houdy
IFJ PAN/T2K and HK: Tomasz Wąchała, Grzegorz Żarnecki, Marcela Batkiewicz-Kwasniak

Collaboration objectives: specific reanalysis of HADES data at 0.690 GeV/c

- Identify most important observables for neutrino reconstruction for T2K and DUNE (topology, missing energy,..)

channel topology : Quasi-Elastic, absorption (no pions), charge exchange (π^+/ π^0 in the final state)
missing energy/masses (semi-exclusive)

- quantify INCL++ and GiBUU (and possibly other event generators) deviation w.r.t. data

Cotutelle PhD subject: analyze other existing HADES data : π^-+C 0.612, 0.656, 0.750, 0.800 GeV/c
test hadronic physics models used for heavy-ion and neutrino physics (INCL++ and others) and possibly improve them

Impact: - reduce uncertainties on neutrino osc. parameter measurement
- share expertise on T2K analysis physics and develop new methods for T2K and DUNE
- improve the visibility of our teams in our collaborations (HADES, DUNE,T2K,HK)

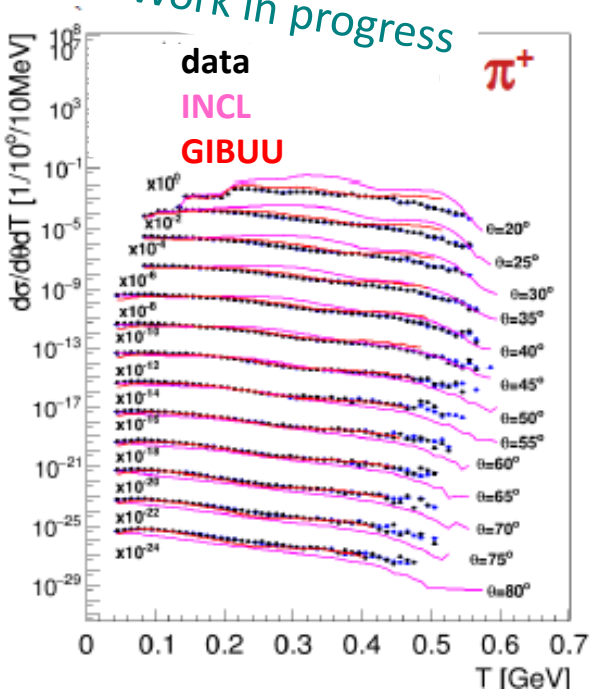
A candidate, but no funding !

Recent analysis work in π^-+C at 0.69 GeV/c

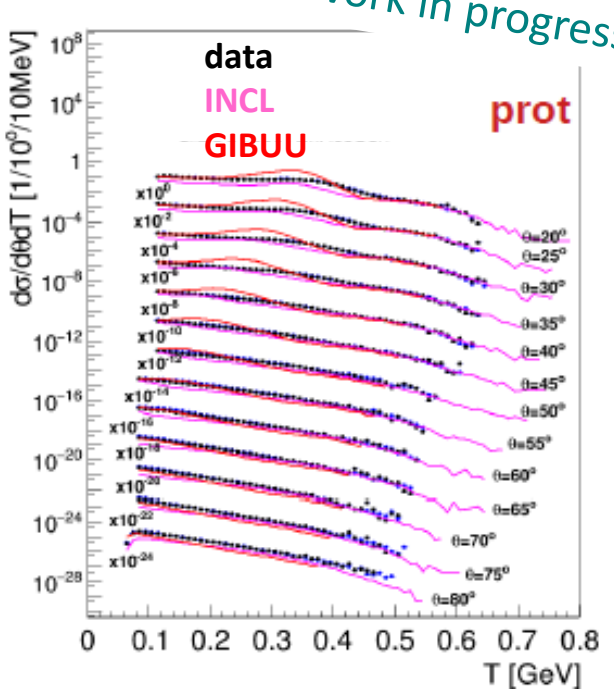
Inclusive π^-

Progress in systematics estimate, acceptance and trigger corrections

Work in progress

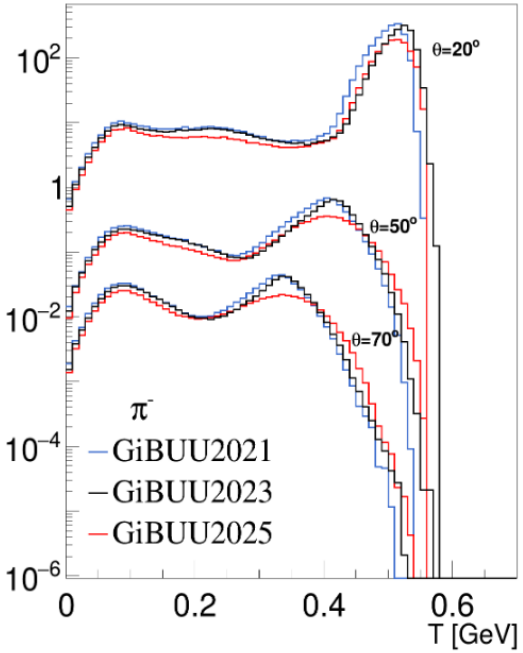


Work in progress



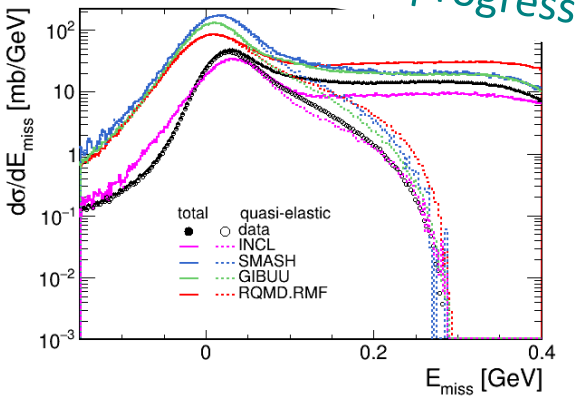
+ inclusive π^+ , d and t

Comparison to new model versions



Missing energy for quasi-elastic channels (relevant for ν energy reconstruction)

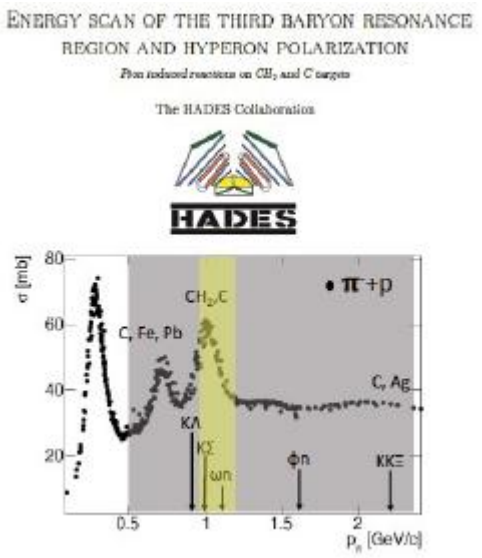
Work in progress



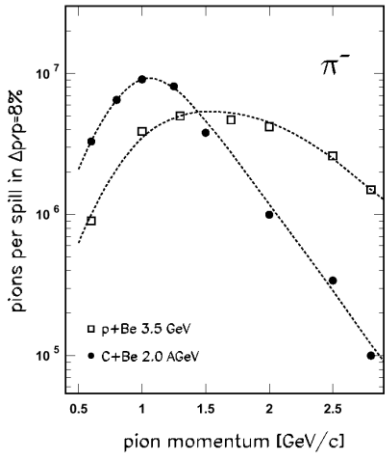
Data compared to INCL++ , GiBUU (used by the neutrino physics community !) and other transport models

Future HADES pion beam experiments

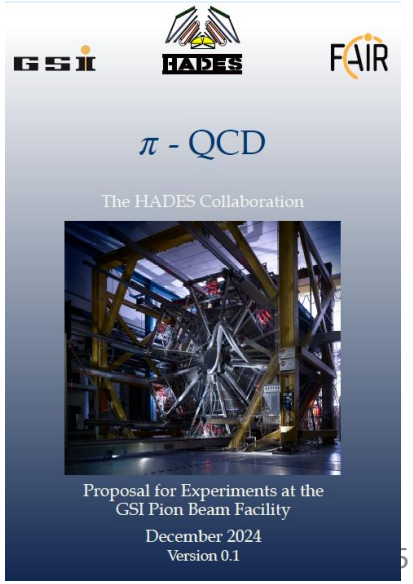
- New pion beam proposal (I.Ciepal, M. Lorenz, J. Messchendorp)
  scheduled in 2027: 55 shifts at p_π = 1.01, 1.06, 1.11, 1.23 GeV/c on C and CH_2 targets



- ✓ Mostly driven by hadronic structure motivations
  π^- + p reaction
- ✓ Large statistics π^- + C data → further test of hadronic models



- Longer term : HADES pion beam program 2026-2030 (π - QCD)
  Broader program explicitly including specific measurements for ν physics
  - measurements at p= 500, 600, 700 MeV/c with 12C, 56Fe, 208Pb (T2K)
  - measurements at p= 1.17 GeV/c with 12C, Ag, KCl (?) (DUNE)
  - Inclusive + semi-inclusive measurements
    → Input for neutrino-nucleus reaction modeling.



Synergies between ν and HADES (FAIR) communities

- Already clear in 2023 : (cf IJCLab/ IFJ PAN) pre-project with DUNE and T2K colleagues

- Recently confirmed : NuInt conference (Mainz, Oct. 2025)
https://indico.fnal.gov/event/64969/

✓ HADES results presented by Manuel Lorenz

✓ *Sara Bolognesi (IrFu) overview talk on FSI models in MC generators*

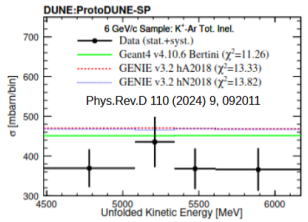
Pion-nucleus

Phys.Rev.D 99 (2019) 5, 052007

- Summary and fit of all available data (+ **DUET in 2017**):
pi+, pi-, C, O and heavier nuclei
Sparse data, especially for separate channels (abs, chEx, ...)

- Then **LarIAT, now protoDUNE** (measurement with K!) →

- In general, doable in test beams:
looking forward to **WCTE results**



Also doable as pion scattering measurements in **ND280, MicroBoone,** …

~All~ available data only measure the xsec as a function of the incoming pion momentum
→ we also need differential measurement as a function of the kinematics of the outgoing particles

→ **HADES data!**

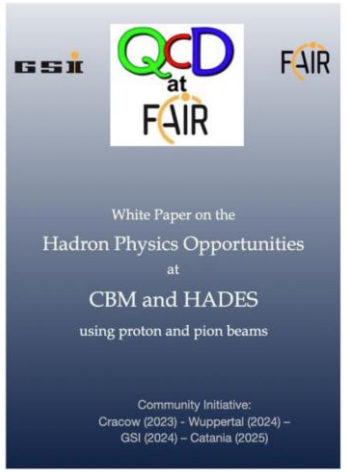
✓ Also highlighted in the summary talk by Kendall Mahn (MSU) !

- Recently confirmed : π^- beam activities embedded in a broader program to promote proton and pion beams at GSI/FAIR.

p+A :important for ν flux

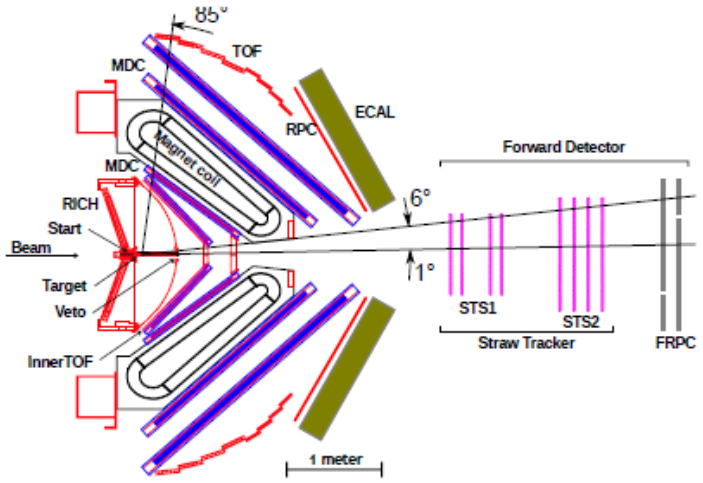
Hadron Physics Opportunities at FAIR

J. G. Messchendorp[a], F. Nerling[a,b,c], P. Achenbach[d], J. Aichelin[e,f], M. Albaladejo[g], L. An[h], K. Aoki[i], G. Appagere[j], V. Baru[k], M. Bashkanov[l], A. Bauswein[a], A. Belias[a], J. Bernhard[m], P. P. Bhaduri[n], Ł. Bibrzycki[o], D. Blaschke[p,q,r], M. Bleicher[s,c], C. Blume[b,a,c], S. Bolognesi[t], N. Brambilla[u,v,w], E. Bratkovskaya[a,s,c], I. Ciepał[ba], S. Collins[x], V. Crede[y], R. Das[z], S. Diehl[aa,ab], S. Dobbs[y], S. Dolan[m], B. Dönigus[b], M. Döring[ac,ad], A. Dubla[a], G. Eichmann[ae], E. Epelbaum[k], C. Fernández Ramírez[af], L. Fields[ag], C. S. Fischer[aa,c], A. M. Foda[a], T. Galatyuk[a,ah,c], P. Gasik[a,ai], F. Giacosa[aj], K. Götzen[a], B. Grube[d], F.-K. Guo[ak,al], A. Guskov[am], J. Haidenbauer[ao], H. W. Hammer[an,c], C. Hanhart[ao], C. Höhne[aa,c,a], P. Hurck[ap], N. Huesken[aq], K. Itahashi[as,ar], R. Kamiński[ba], K. Kampert[au], R. Kliemt[a,k], C. M. Ko[av], B. Kubis[aw], A. Kupsc[ax,ay], S. Leupold[ax], M. Lorenz[a,b], F. Maas[az], R. Maciula[ba], K. B. M. Mahn[bb], V. Mathieu[bc,ca], M. Mai[bd,ac,aw], D. Mihaylov[be,bf], M. Mikhasenko[k], C. Morningstar[bg], D. Mohler[ah,a,c], Y. Morino[i], E. Nandy[a], H. Noumi[bh,i], J. R. Pelaez[bi], M. T. Peña[bj], A. Pilloni[bk,bl], C. Rappold[bm], B. Ramstein[bn], T. Reichert[s,c,f], D. Rönchen[ao], C. D. Roberts[bo,bp], J. Ritman[a,k], S. Roy[a], P. Salabura[bq], F. Sakuma[ar], T. Saito[br,a], F. Sánchez[bs], L. Schmitt[a,ai], C. Scheidenberger[a,aa,c], T. Song[a], J. Steinheimer[a], J. Stroth[b,a,c], C. Sturm[a], A. Szczepaniak[bt,bu,bv,bw], A. Szczurek[ba], H. Takahashi[i], L. Tolos[by,bz], J. M. Torres-Rincon[bc,ca], I. Vidaña[bl], J. Taylor[a], R. Tyson[d], T. Wąchała[ba], D. Wielanek[cb], D. Winney[aw], G. Wolf[cc], H. Zbroszczyk[cb], G. Żarnecki[ba]



White paper endorsed by the GSI/FAIR joint scientific Council Oct. 2025.

pp reaction at 4.5 GeV

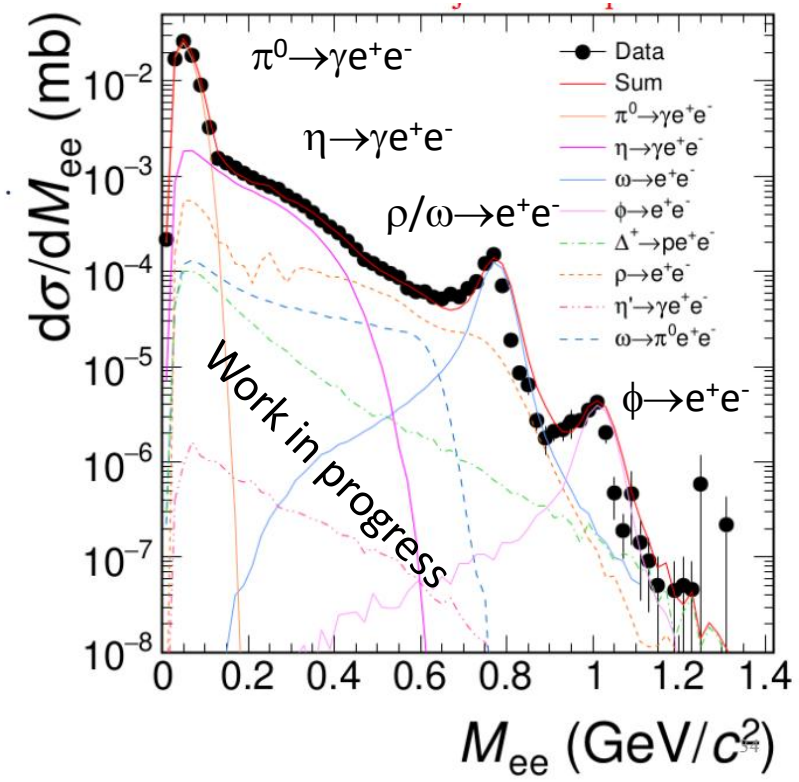


- February 2022: one month of beam time at SIS18
  FAIR-Phase0 experiment
- Highest proton beam energy at SIS18 /GSI
  (Au: Emax = 1.25 AGeV)
  benchmark for future p+p experiments at FAIR
- Forward Detector (Polish and French inputs) used for the first time
  HADES collab, Eur. Phys. J. A57, 138 (2021)

Strong involvment of IJCLab and IFJPAN teams :

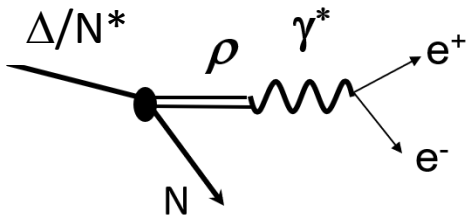
- data analysis (I.C. and B. R. with students and post-docs)
- simulations (I.C.)
- trigger corrections (I.C.)
- coordination of the Exclusive Channel Physics Working Group (B.R.)

pp reaction at 4.5 GeV: inclusive e^+e^- production



Comparison of HADES data with SMASH simulations with adjusted cross sections

- ✓ Meson production cross sections
- ✓ ρ and ω line shapes (coupling to baryons)



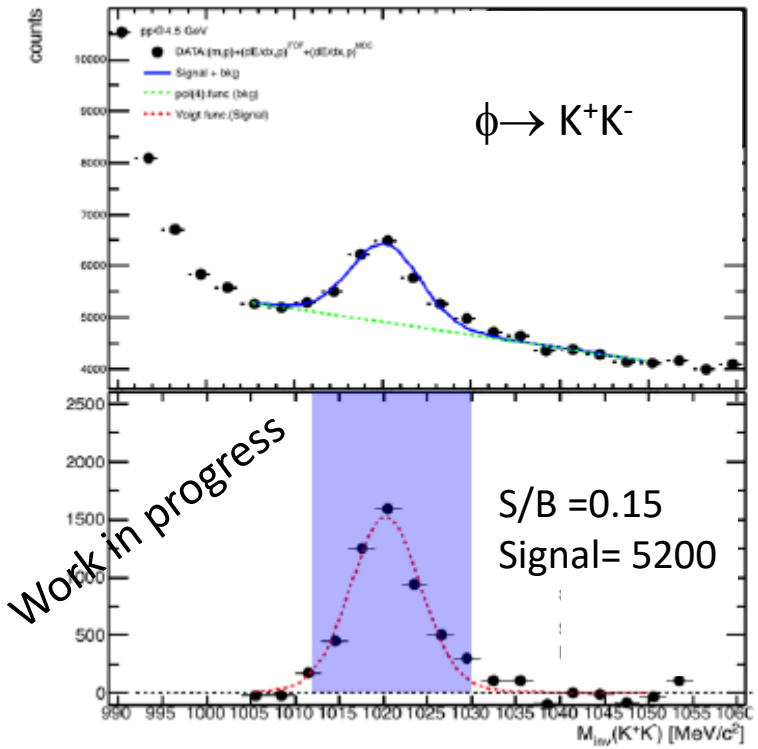
R. Abou-Yassine, PhD IJClab/TU-Darmstadt, Dec. 2024

Joint IJCLab/IFJ PAN work on simulations

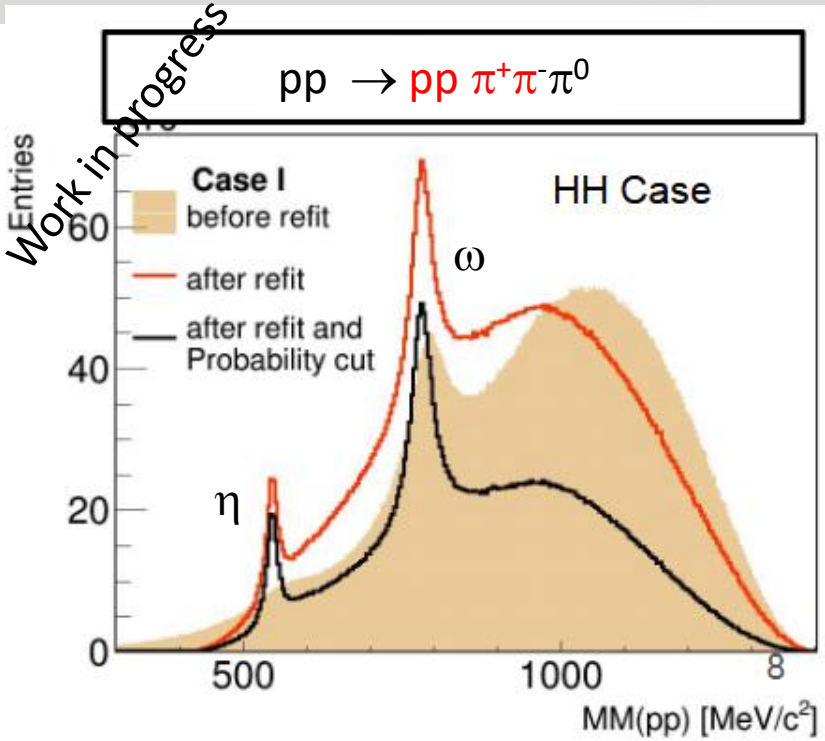
To be updated (new data generation, PID based on Neural Network) and completed by exclusive channel $pp \to ppe^+e^-$ analysis

UPSclaySTAR-PHY (post-doc) application on-going

pp reaction at 4.5 GeV: meson production



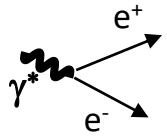
S. Deb, Post-doc IJClab (2023-2024)



π^0 reconstructed by kinematical fit

ϕ, η, ω analysis

- ✓ Differential and total cross sections
- ✓ Production mechanism
  baryon resonance contribution ?
- ✓ polarization (ϕ and ω)

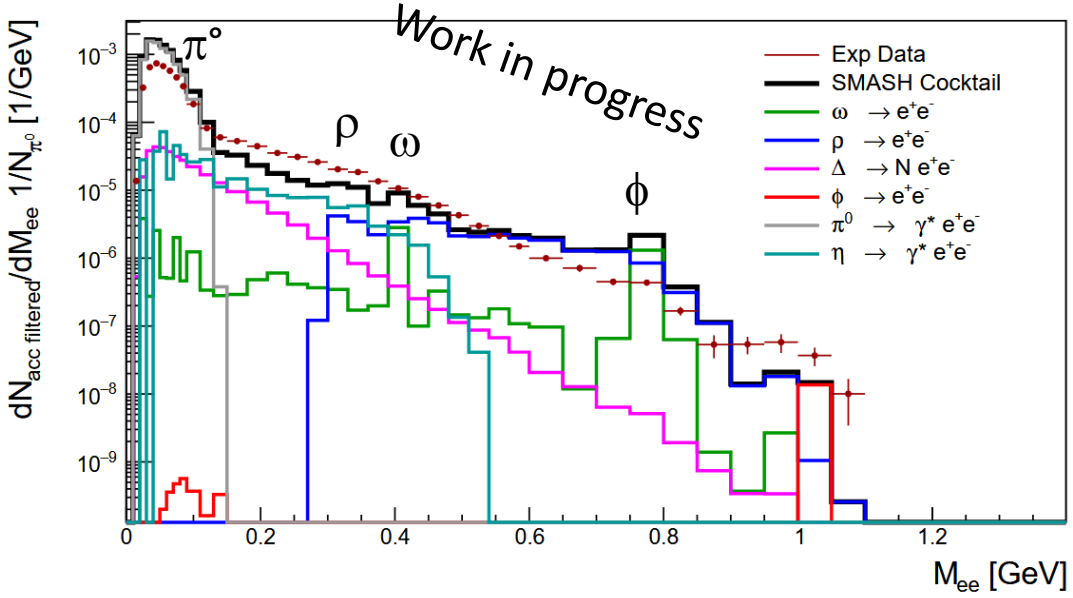


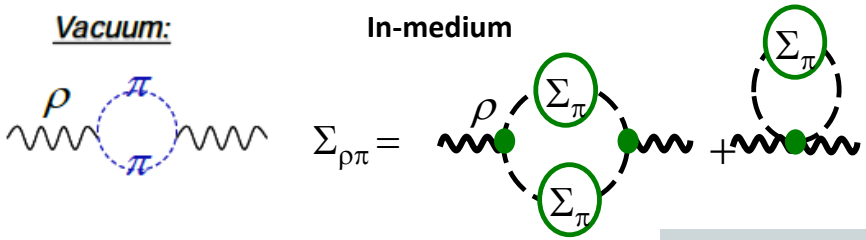
S. Trelinski , PhD cotutelle AFJ PAN/ Bochum university
Application *France-Excellence SSHN* for a stay at IJClab in 2026 being prepared

$f_1(1285)$ studies: $f_1(1285) \rightarrow \eta[\eta \rightarrow \pi^+ \pi^- \pi^0]\pi^+ \pi^-$ *post-doc position at IFJ PAN in 2027*
light axial-vector $I^G J^{PC}$ $0^+ 1^{++}$ qq state / molecular KK* state ?
Predictions for production cross sections: 150 nb *IFJ-PAN theoreticians*
P. Lebiedowicz, O. Nachtmann, P. Salabura, A. Szczurek, PRD 104, 034031 (2021)

Heavy-ion analysis

Sacha Mehat, cotutelle PhD IJCLab/TU-Darmstadt, Oct 2025

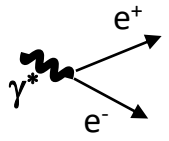




Ag+Ag at $\sqrt{s_{NN}} = 2.55$ GeV

- study cross-sections and in-medium modifications of the vector meson (ρ, ω, ϕ) spectral shape
- Invariant mass, transverse momentum, rapidity, lepton angular distributions

γ^* polarization



$$\frac{dN}{d^4x d^4q d\Omega} = \mathcal{N}(1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos\varphi + \lambda_\varphi^\perp \sin^2\theta \sin 2\varphi + \lambda_{\theta\varphi}^\perp \sin 2\theta \sin\varphi)$$

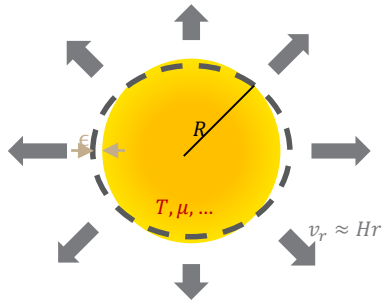
- Sensitive to γ^* production mechanisms and spin-dependent medium effects
- Connection to the pp reference

Coordination of the Dilepton Physics Working Group: Szymon Harabasz

Phenomenological description of heavy-ion collisions at few GeV

Objective: develop a Monte Carlo generator of *thermal particle production* adapted to physics at HADES

Extract fireball parameters (T,μ,R,..) by fitting the particle distributions

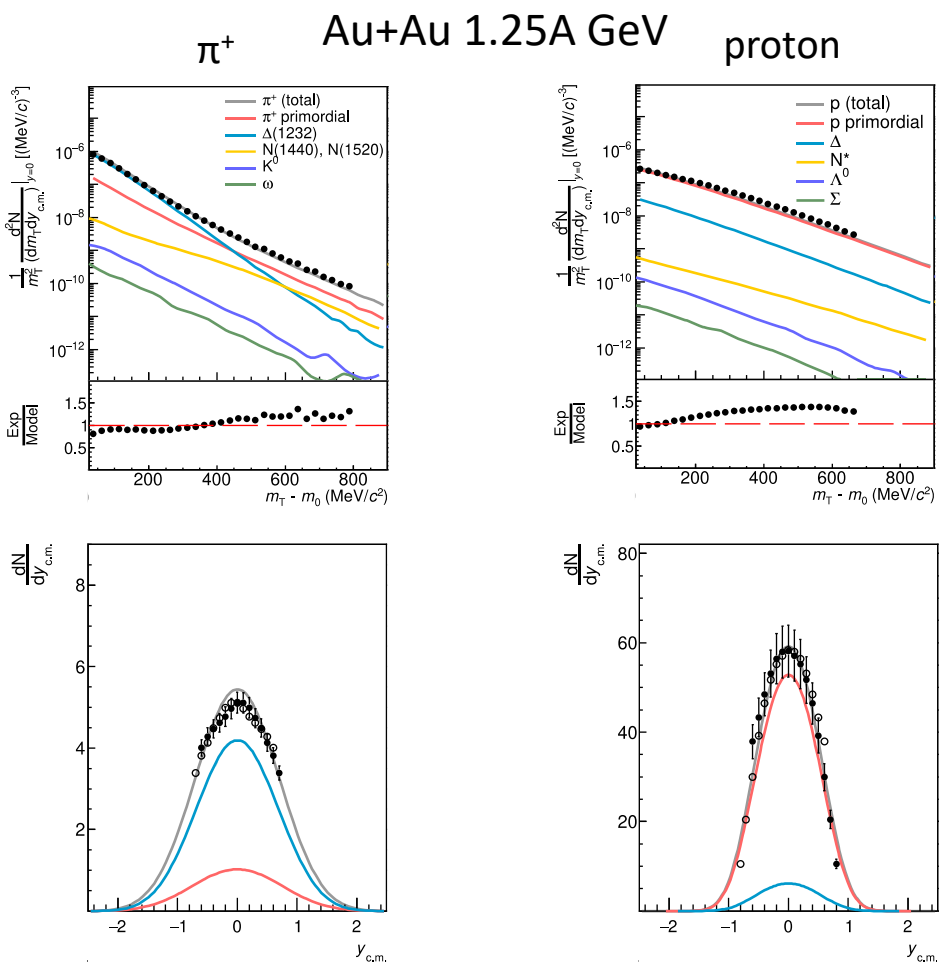


Recent developments:

- improve algorithm workflow
- parameter extraction without strangeness
- extension to new HADES data sets
  (Au+Au at lower energies, Ag+Ag)

On-going collaboration with IJF-PAN (Radoslaw Ryblewski)

S. Harabasz et al, Phys.Rev.C 102 (2020) 5, 054903,
S. Harabasz et al. Phys.Rev.C 107 (2023) 3, 034917



IJCLab/IFJ-PAN collaboration on HADES summary and plans for near future

✓ Collaboration on data analysis:
dilepton and mesonic channels in pp@4.5 GeV
hadronic channels in π^-+C 0.7 GeV/c

Frequent video conferences
HADES collaboration and analysis meetings
Visit of B. R. and S. Harabasz to Cracow in Nov. 2025

✓ Collaboration on phenomenology:
thermal model to determine fireball properties

✓ HADES – neutrino :
strong progress towards a synergy between GSI/FAIR and neutrino communities
direct impact of HADES data to reduce uncertainties of LBL experiments still to be evaluated

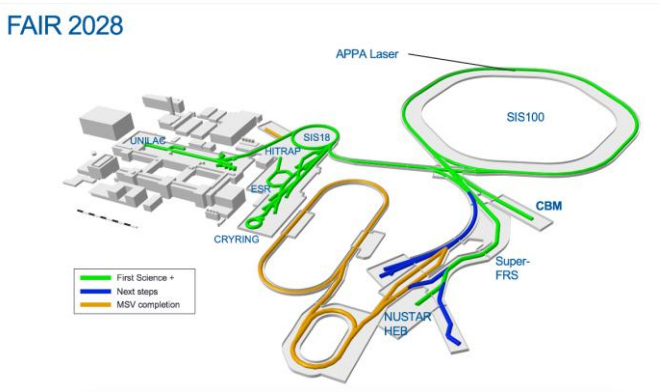
Plans for near future:
✓ Continue these activities with priority on hadronic channels in π^-+C and thermal model developments
✓ Prepare the next π beam experiment (january 2027) I. Ciepal large engagement (trigger simulations/optimization, hyperon polarization simulations)

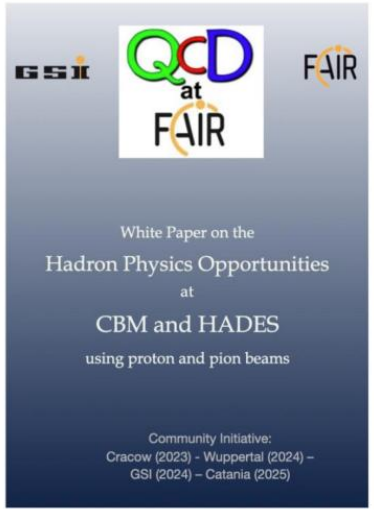
Outlook (GSI → FAIR)

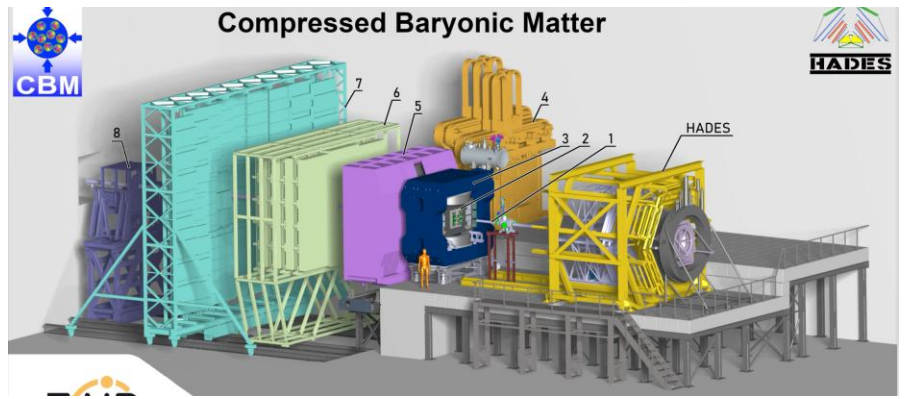
✓ Still a rich program for HADES at SIS18 using p, d and pion beams (depending on beam availability…)
+ possible extension of the π beam program (real synergy with neutrino community)

✓ 2028: first beams at SIS100
✓ CBM experiments (Heavy-ion collisions) will start
✓ Physics program using the proton beam at FAIR (E<29 GeV) and the CBM detector (QCD@FAIR) is proposed

Poland strongly involved in hadronic physics at FAIR !







Thank you – Merci - Dziękuję

Back-up

Neutrino energy reconstruction

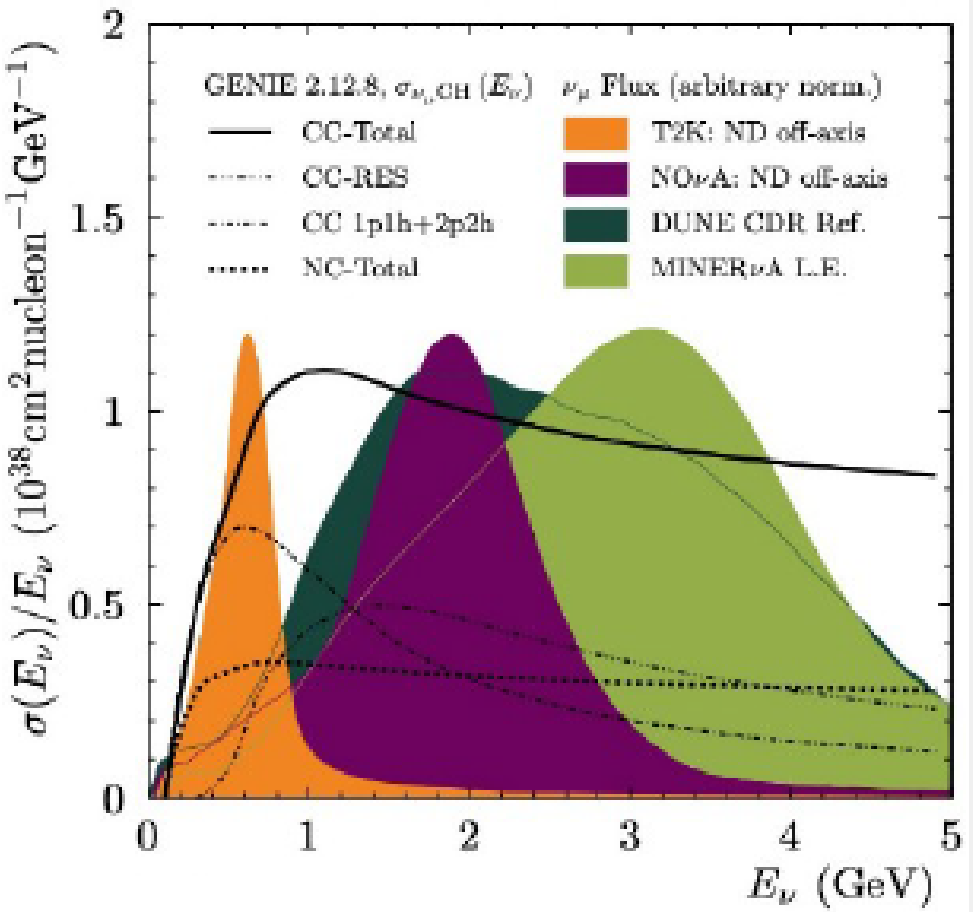
Precision:

- **systematic errors** from neutrino energy reconstruction **5-10%**
- the syst. errors should be reduced to **1-2%**

➢ FSI models are tuned to external **π/p-A** data

Neutrinos vs. pions:

- different primary interactions
- similar energy dissipation processes (elastic/inelastic reactions, baryon resonance propagation, pion regeneration)



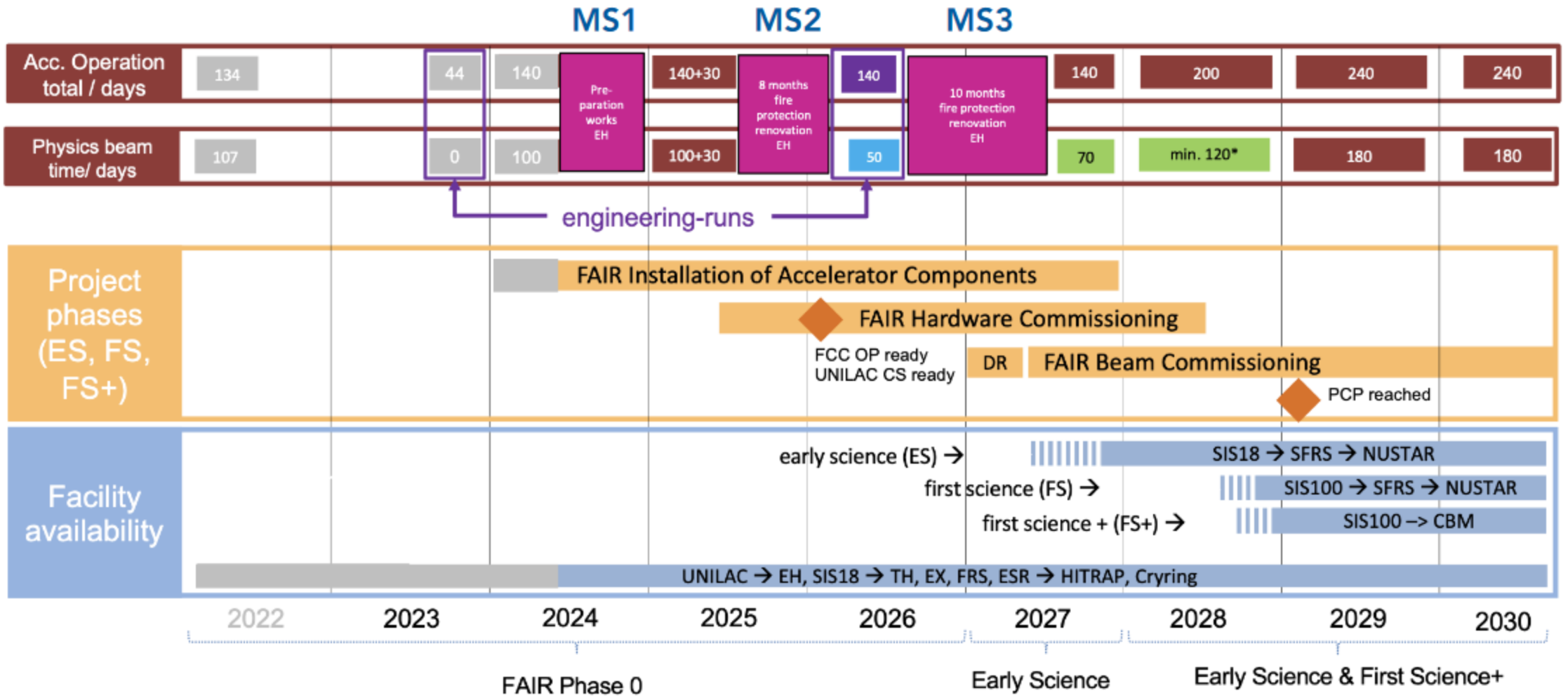
Pion energies:
T2K: 500 - 700 MeV
DUNE: above 1 GeV

T2K/Hyper-K: H_2O, Polystyrene (C_8H_8)

T2K: BabyMIND, INGRID detectors contain Fe, Pb

DUNE: Liquid Ar-TPC (^{39}K ^{35}Cl *is close* to ^{40}Ar)

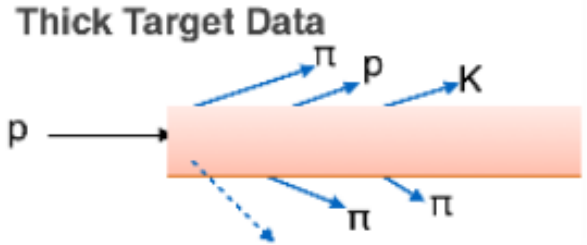
➢ **Future HADES (π beam)/ CBM (p beam) data**


MS1
MS2
MS3
Acc. Operation total / days
134
44
140
Pre-paration works EH
140+30
8 months fire protection renovation EH
140
10 months fire protection renovation EH
140
200
240
240
Physics beam time/ days
107
0
100
100+30
50
70
min. 120*
180
180
engineering-runs
Project phases (ES, FS, FS+)
FAIR Installation of Accelerator Components
FAIR Hardware Commissioning
FCC OP ready
UNILAC CS ready
DR
FAIR Beam Commissioning
PCP reached
Facility availability
early science (ES) →
SIS18 → SFRS → NUSTAR
first science (FS) →
SIS100 → SFRS → NUSTAR
first science + (FS+) →
SIS100 –> CBM
UNILAC → EH, SIS18 → TH, EX, FRS, ESR → HITRAP, Cryring
2022
2023
2024
2025
2026
2027
2028
2029
2030
FAIR Phase 0
Early Science
Early Science & First Science+

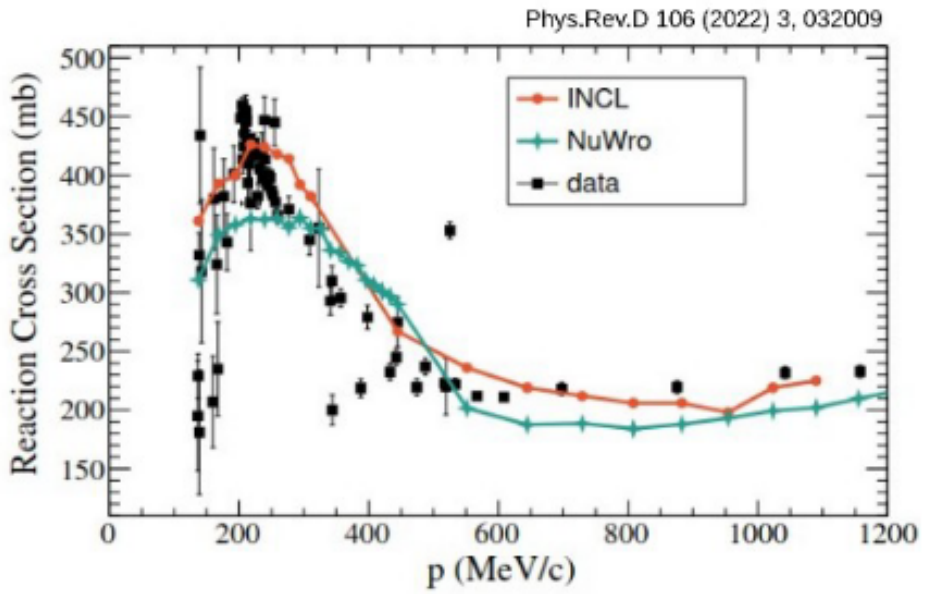
External data to tune the models

p+A

- p+A data important for the beam-flux calibration
- p+A database is quite scarce ... need also for **exclusive** channel (absorption, charge exchange…) - proton-CBM

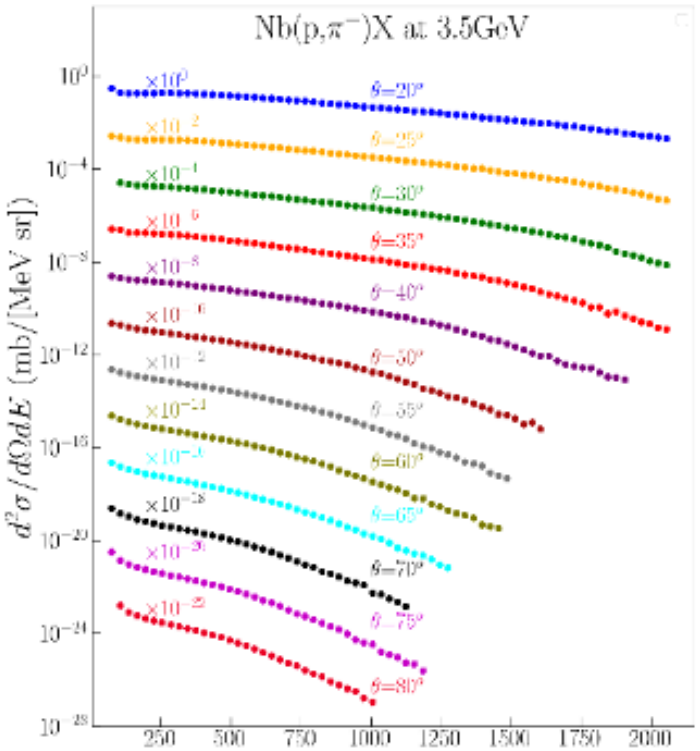


World data: total cross sections

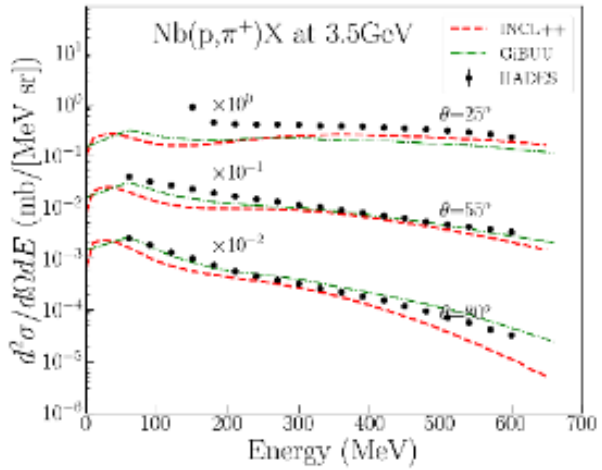


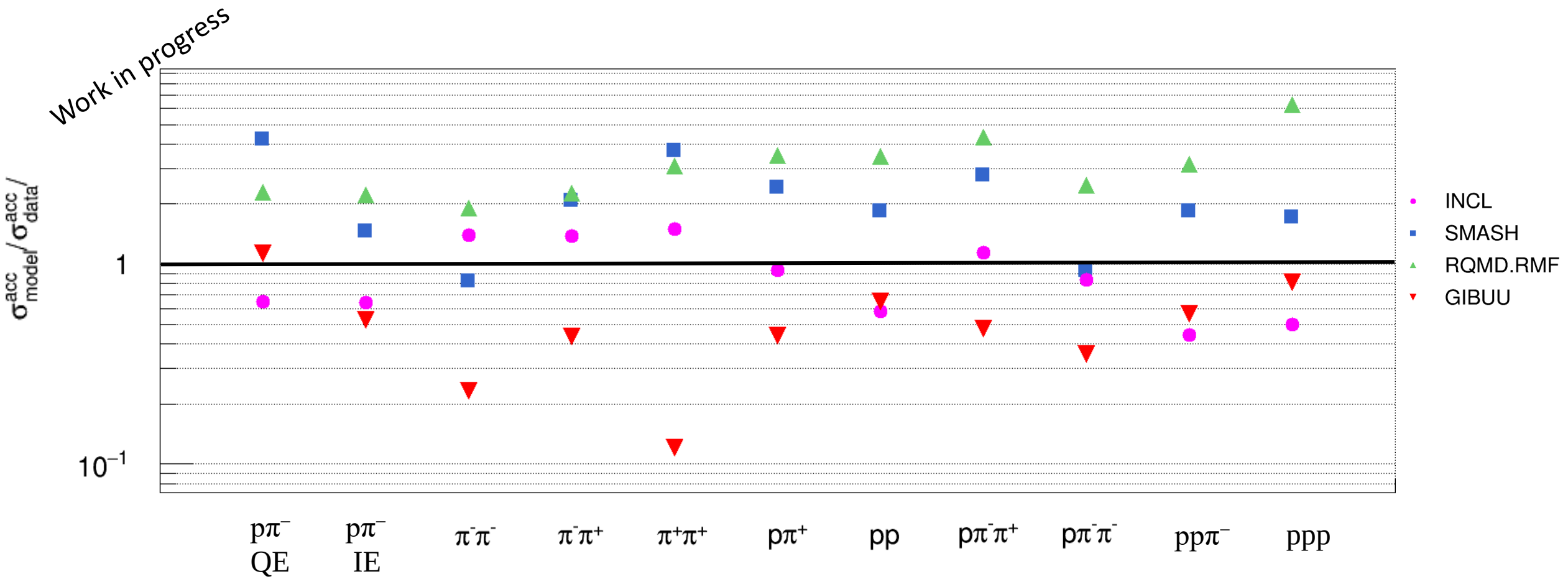
HADES data: inclusive differential cross sections

HADES, PRC 108, 064902 (2023)



p + ^{93}Nb @ 3.5 GeV




Work in progress
$\sigma^{acc}_{model}/\sigma^{acc}_{data}$
1
10^{-1}
INCL
SMASH
RQMD.RMF
GIBUU
pπ⁻ QE
pπ⁻ IE
π⁻π⁻
π⁻π⁺
π⁺π⁺
pπ⁺
pp
pπ⁻π⁺
pπ⁻π⁻
ppπ⁻
ppp