Overview Chapter 7:

Hadrons and dileptons as probes of strongly interacting matter

Convenors: J. Aichelin, E. Bratkovskaya, ML

Contributors: J. Aichelin, P.P. Bhaduri, M. Bleicher, C. Blume, E. Bratkovskaya, C.-M. Ko, T.Galatyuk, C. Hoehne, ML, B. Ramstein, T. Reichert, S. Roy, P. Salabura, T. Song, J. Stroth, A.Szczurek, L. Tolos, J. Torres-Rincon, G. Wolf

This talk has two aspects:

– A **scientific** part focusing on highlights

– An **editorial** part addressing cross-references to other chapters

Manuel Lorenz

Goethe-University Frankfurt / GSI

7.1 πp, pp and pn reactions

7.1.1 Transition from hadron to parton interaction
7.1.2 Particle multiplicities as a function of $\sqrt{s}$
7.1.3 Resonance studies in π-induced reactions

7.2 pA (πA) reactions

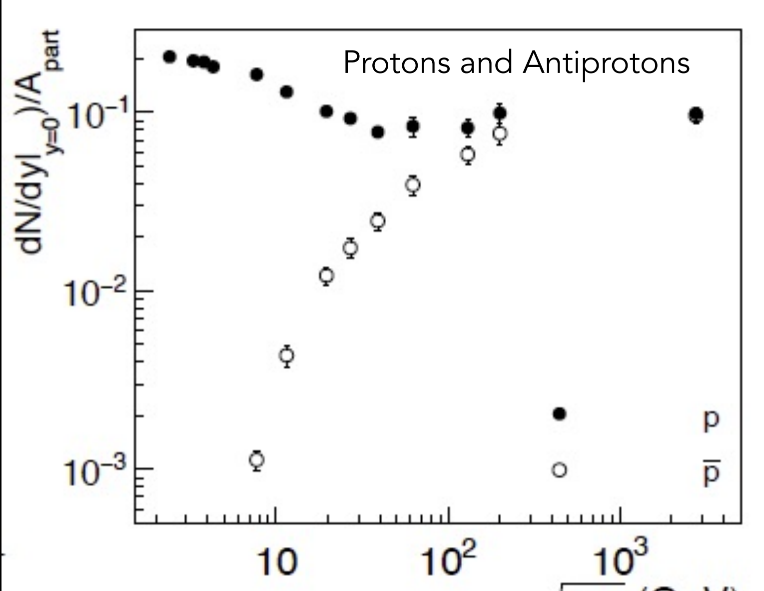
7.2.1 Short range neutron-proton correlation
7.2.2 Study of the in-medium properties of vector mesons by dileptons
7.2.3 Drell-Yan processes in p+A collisions
7.2.4 Study of the in-medium properties of strange hadrons
7.2.5 Study of the in-medium properties of open and hidden charmed hadrons
7.2.6 Production of charmed hadrons from secondary pbar + p annihilations
7.2.7 Production of light nuclei and hypernuclei
7.2.8 Determination of momentum dependence of the optical potential
7.2.9 Influence of the electromagnetic fields on particle dynamics in nuclear matter
7.2.10 Dark Matter search

in-medium hadron properties

22 pages in total

Heavy-ion Collisions: Extreme QCD Matter in the Laboratory

→ Current accelerator facilities cover 3 orders of magnitude from a few GeV to TeV

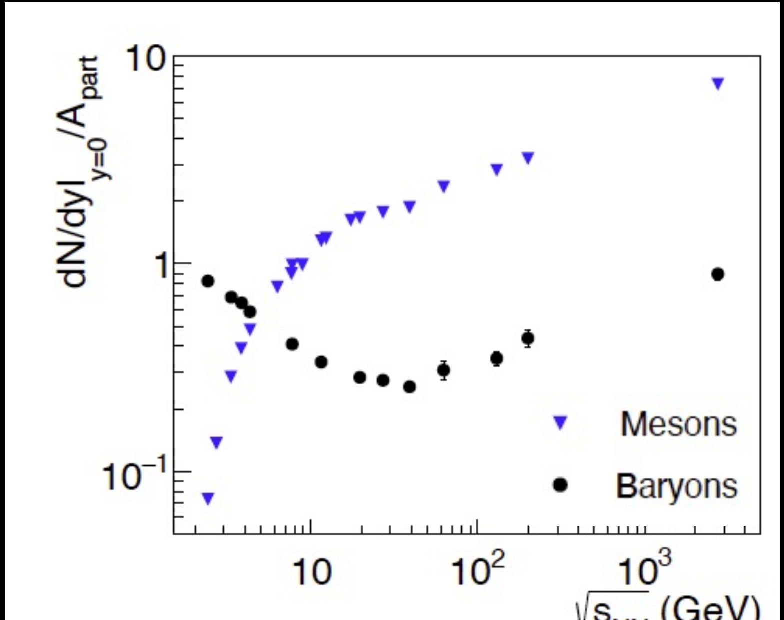


Data compilation ML, Habilitationsschrift, 2022

Similar amount of matter and antimatter at LHC at mid-rapidity

Heavy-ion Collisions: Extreme QCD Matter in the Laboratory

→ Current accelerator facilities cover 3 orders of magnitude from a few GeV to TeV

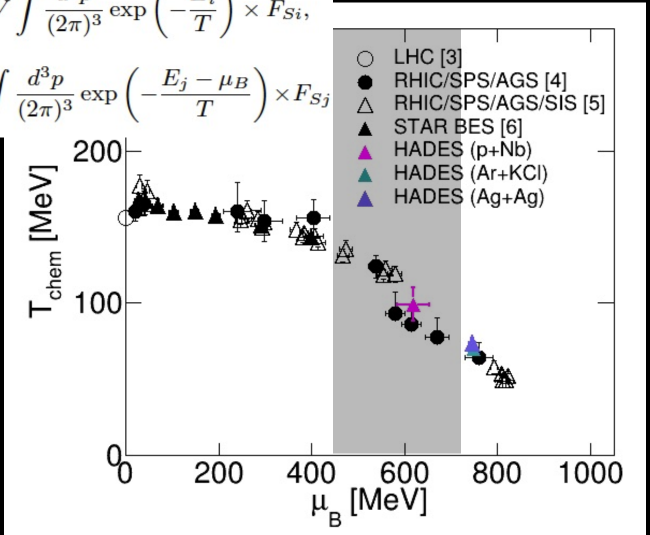


Data compilation ML, Habilitationsschrift, 2022

Switch from a baryon to meson dominated system at 4 GeV

$$\sum_i M_{m_i} = \sum_i g_i V \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E_i}{T}\right) \times F_{Si},$$

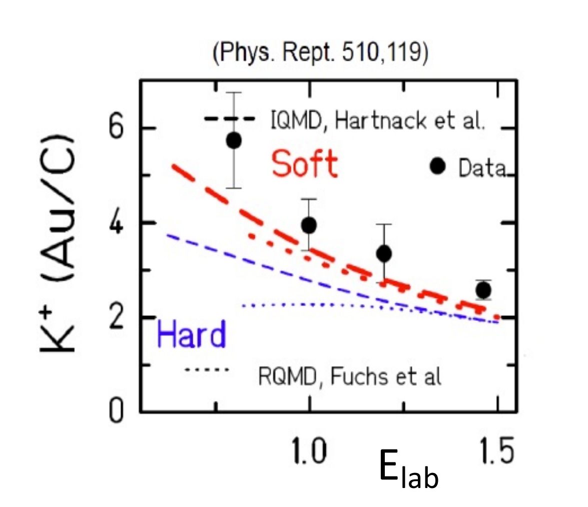
$$\sum_j M_{b_j} = \sum_j g_j V \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E_j - \mu_B}{T}\right) \times F_{Sj}$$



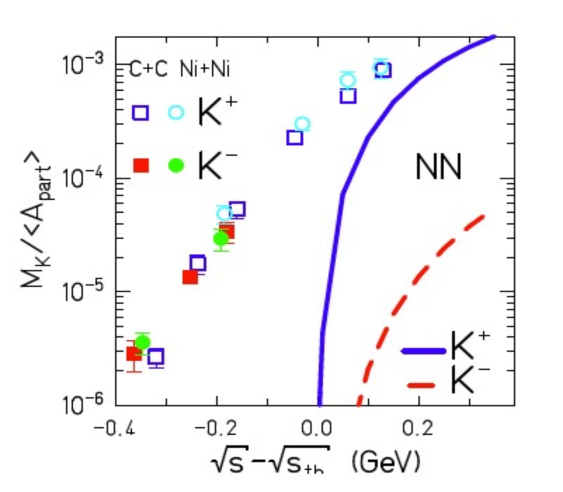
Measurements at different √s line up on a common curve
- HIC allow to probe systematically the phase diagram.
- √s changes from GeV to TeV, T_{chem} changes by factor 3.

→ Hadronic interactions important at all energies.

Heavy-ion Collisions: Access to fundamental matter quantities



Equation of state, deduced from K^+ yield compared to transport model.



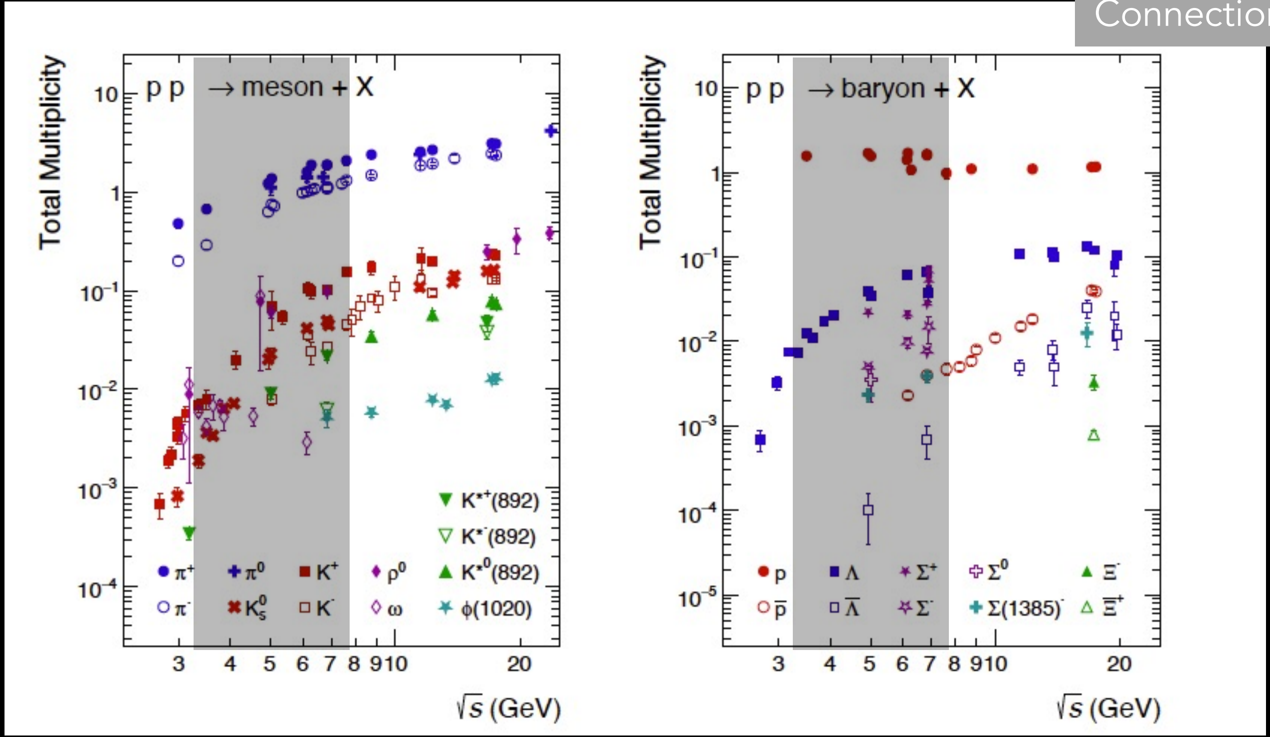
Large excess yield already in small C+C compared to NN.

→ Precision cross sections measurements of resonances at FAIR energies basis for solid interpretation of heavy-ion data (also at high energies)!

7.1 Elementary πp, pp and pn reactions

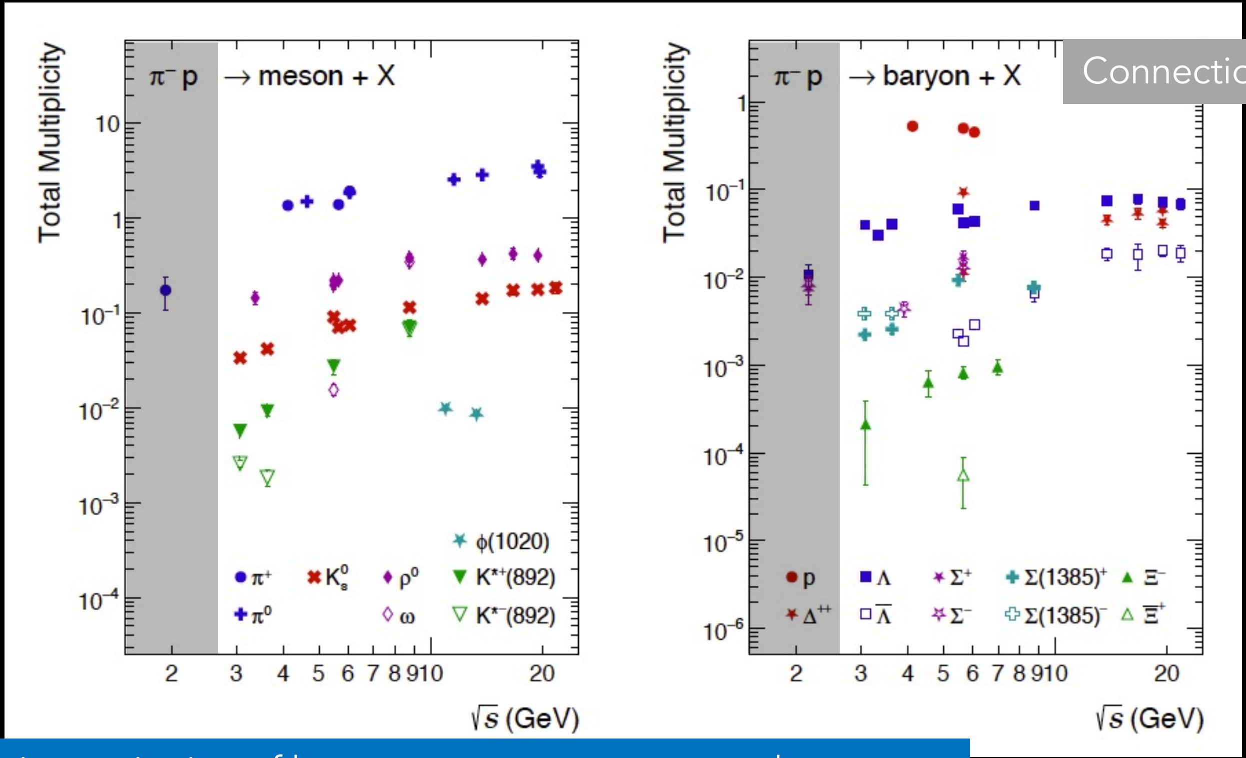
7.1.2 Particle multiplicities as a function of √s

Connections (3), 4



Excitation function not precisely measured in FAIR energy range, in particular for resonances and antibaryons.

7.1.3 Resonance studies in π-induced reactions

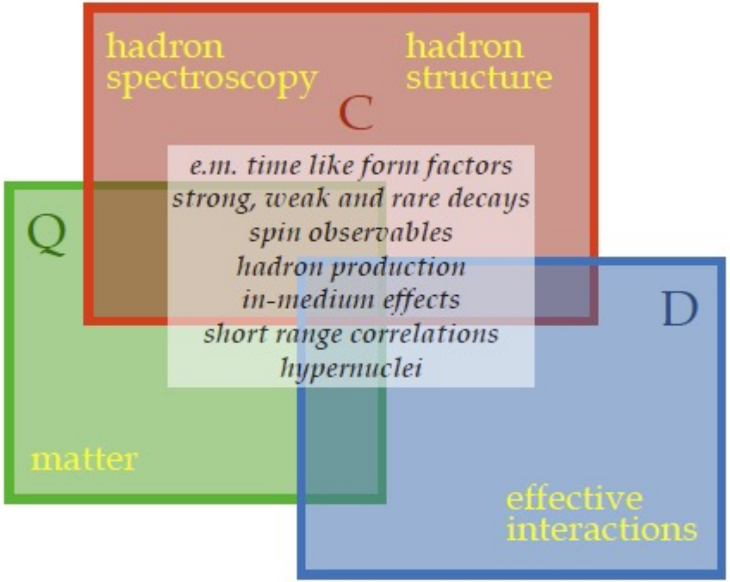


Connections 3, 4

More selective excitation of baryon resonances compared to p+p:
- test partial decay widths to given final states (important for interpretation of ϕ HIC data)
- advantageous for PWA

https://hades.gsi.de/sites/default/files/web/media/documents/proposals/HADES_Proposal_Pion_Update-1.pdf

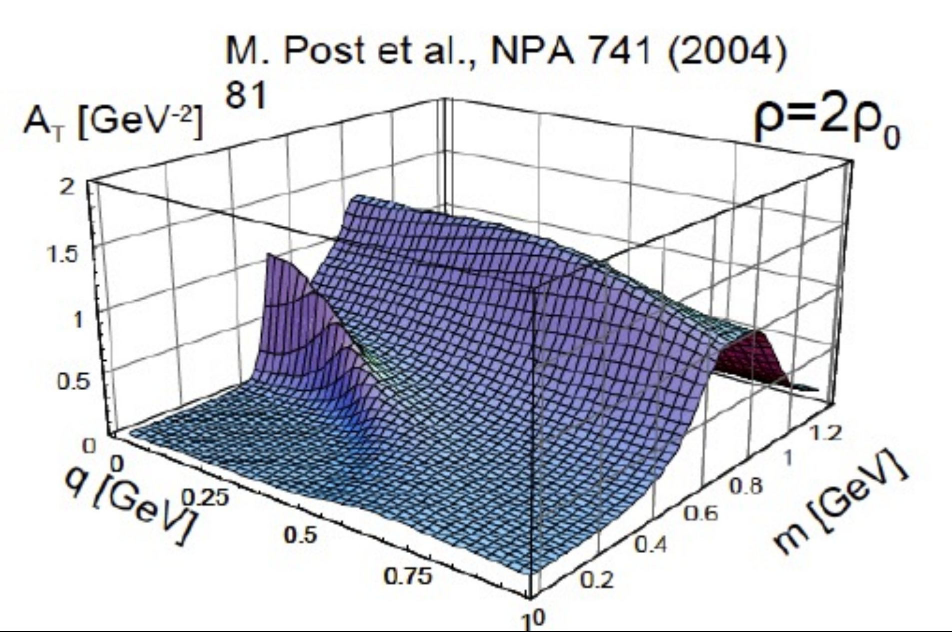
π - QCD



boosting the understanding of
non-perturbative QCD
by combining pion beams with HADES
and involving three pillars

πA reactions

7.2.2 Study of the in-medium properties of vector mesons by dileptons



Medium effects restricted to low momenta!
→ ensure acceptance

Geometrical Acceptance at low momenta

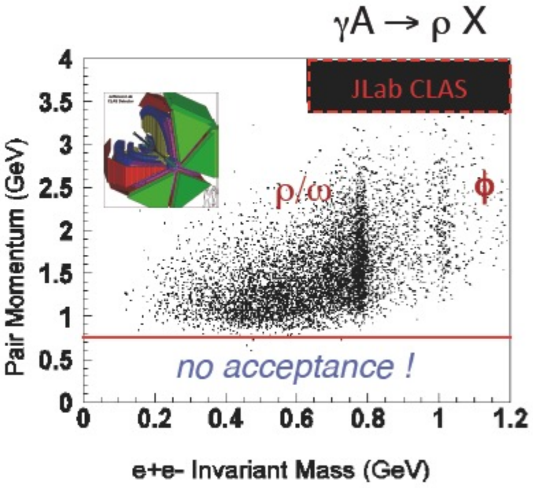
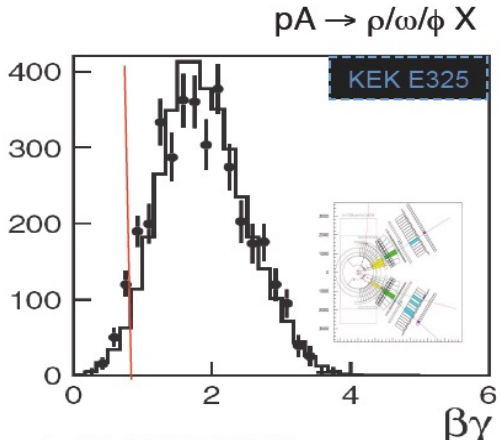
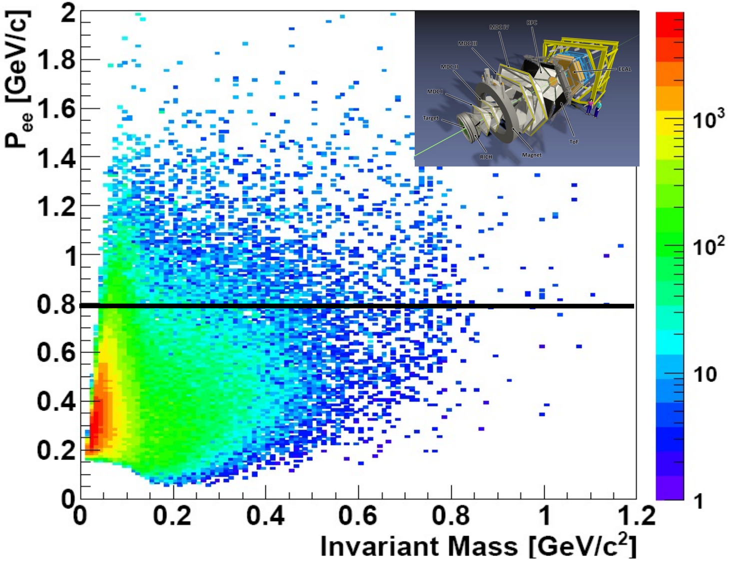


Fig. from S.Leupold et al., nucl-th 0907.2388



Muto et al., PRL 98 (2007) 042501



Low momentum coverage:
feature of HADES
+ dilepton reconstruction capability
+ low recoil momenta due to π beam

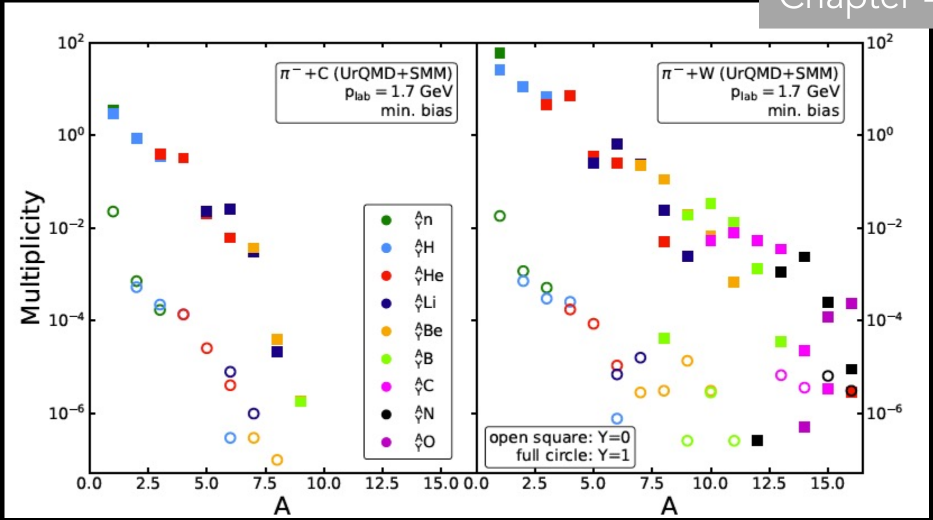
→ World-wide unique feature!

Strangeness and Hypernuclei in πA reactions

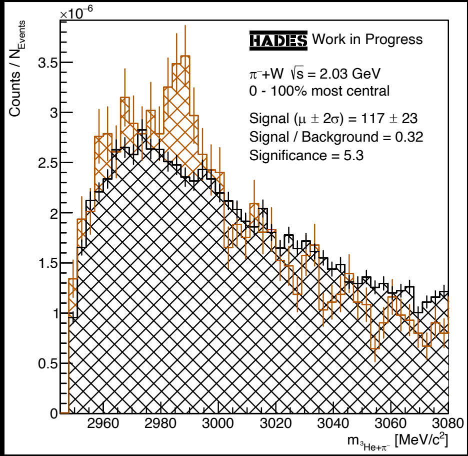
Chapter 4

π N→ Y K^+: $\sqrt{s}$ = 1.61 GeV, E_{inc}= 0.9 GeV
→ ϕ N: $\sqrt{s}$ = 1.96 GeV, E_{inc}= 1.6 GeV
→ KKΞ $\sqrt{s}$ = 2.3 GeV, E_{inc}= 2.3 GeV

- ϕ meson line shape (KK, ee statistics?)
  --> JPARC community
- K^- and ϕ absorption, bound ϕ-N state?
  PLB 848 (2024) 138358
- K-N and Y-N potentials, relevance for EOS



→Large production cross rates of hypernuclei do to kinematic

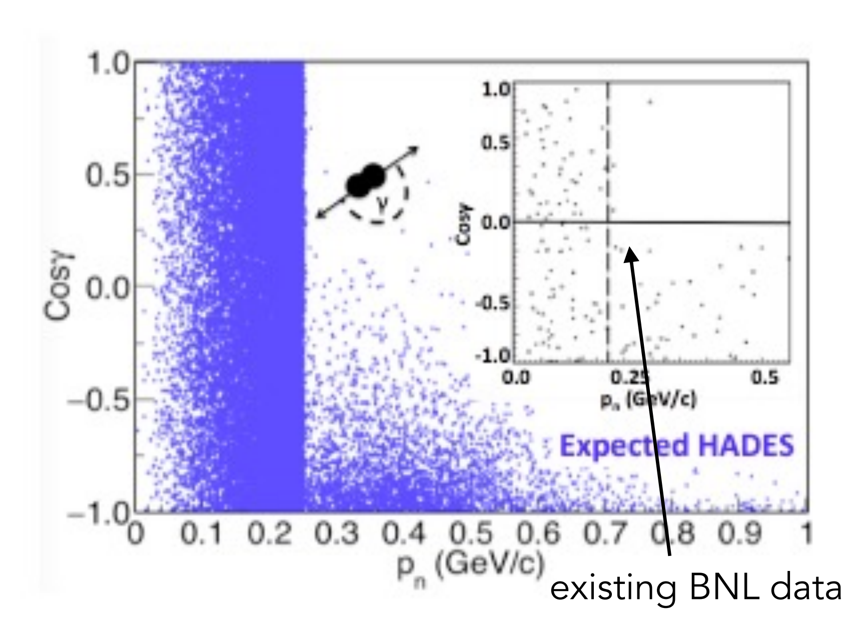


HADES feasibility study based on pioneering 2014 data.
expected gain factor (DAQ, Accelerator): f_{gain} = 50

7.2 pA reactions

7.2.1 Short range neutron-proton correlation

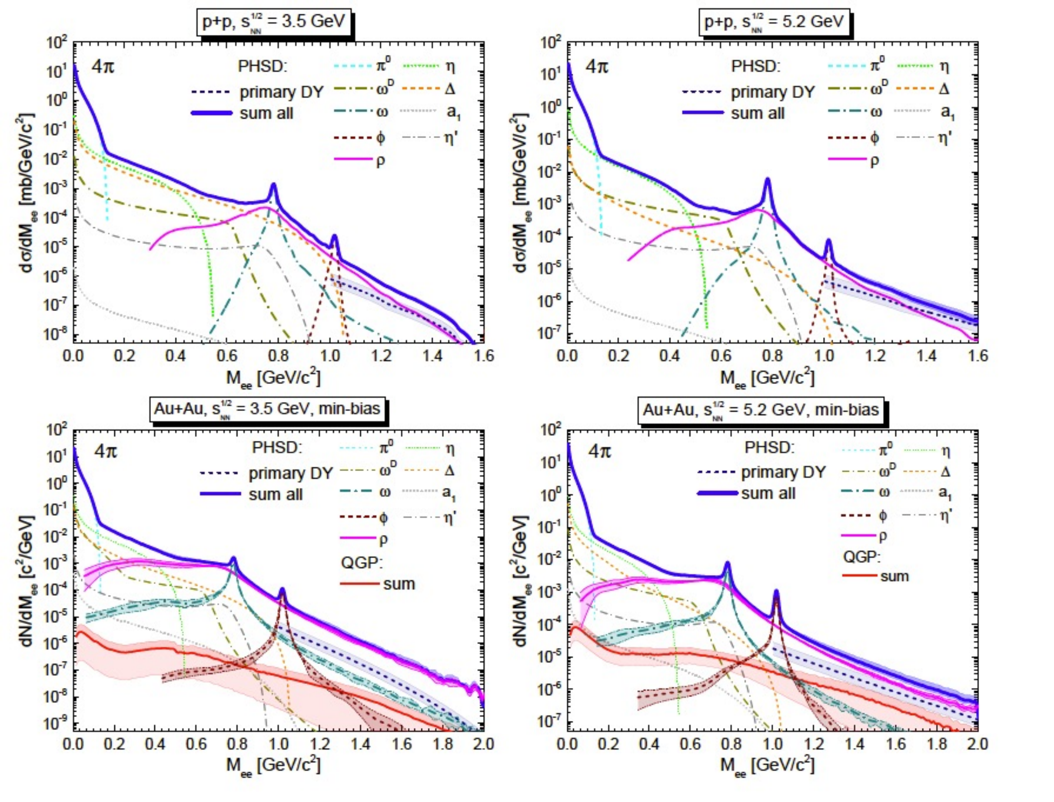
Quasi p+p elastic scattering have a strong preference for interacting with forward going high momentum nuclear protons, “Selective Attention“.
→ 4.5 GeV kinetic energy optimal,
e.g. possible with HADES+NeuLand



The Migdal jump mapped with the anticipated HADES+NeuLAND technology events (factor 50 compared to BNL data).

https://www.hen-lab.com/srchades

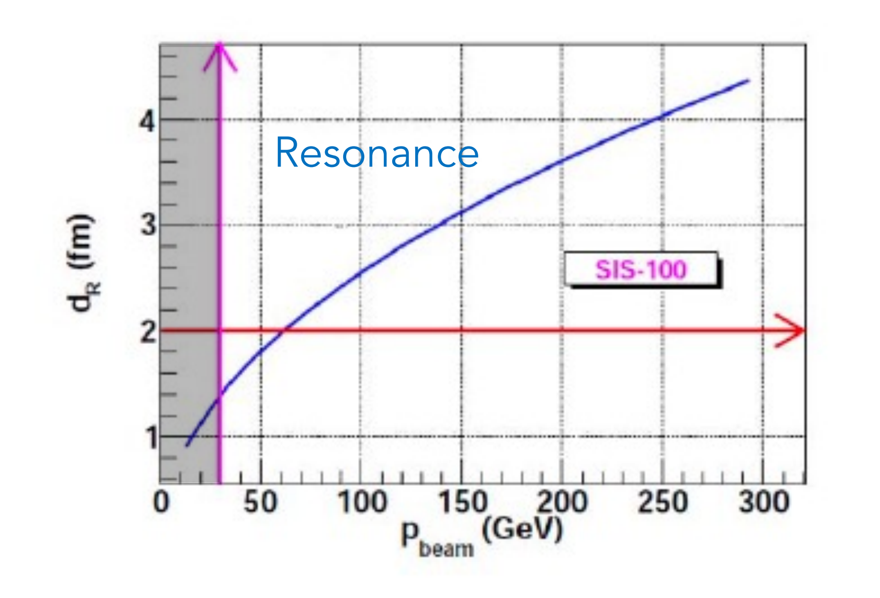
Dileptons and Drell-Yan processes in pA



Drell-Yan contribution is expected to be a dominant source for M_{ee} > 1 GeV→ pA reference

Open- and Hidden-Charm

Hadron	Rate per 90 days p+Au			
	$E_{lab} = 30A$ GeV		$E_{lab} = 20A$ GeV	
	M/B exch.	Quark model	M/B exch.	Quark model
$\Lambda_c^+ \overline{\Lambda_c^-}$	$3.1 \cdot 10^4$	$9.0 \cdot 10^3$	$4.9 \cdot 10^3$	$1.4 \cdot 10^3$
$\Sigma_c^+ \overline{\Lambda_c^-}$	$2.2 \cdot 10^3$	$8.0 \cdot 10^1$	$2.7 \cdot 10^2$	$1.0 \cdot 10^1$



P. P. Bhaduri et. al. J. Phys. G 45 (2018)

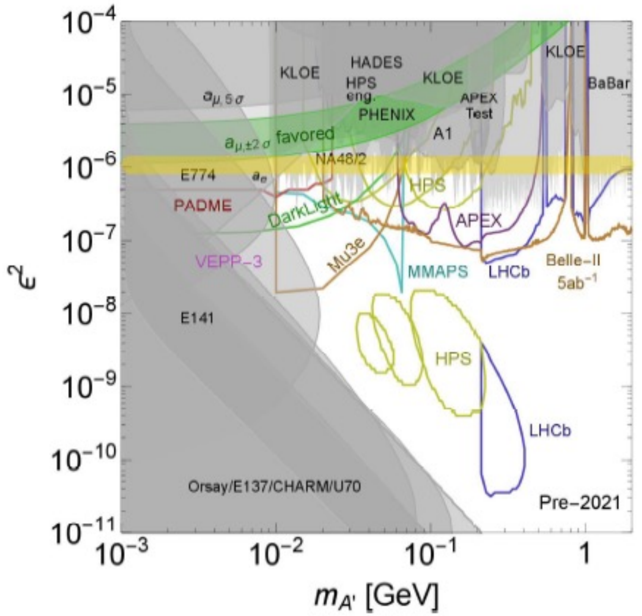
- Cross section and production mechanism unknown at SIS100 energies $\sqrt{s_{NN}} < 8$ GeV.
- Large production rates of charmed hadrons from secondary pbar + p annihilations

Chapter 4

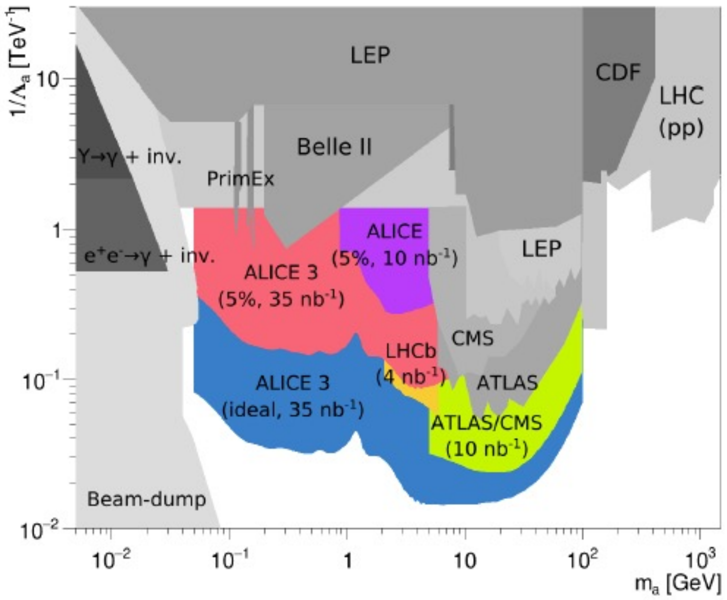
- $^{J}/_{\psi}$ multiplicities key observable for QGP *A. Andronic et. Al. Eur.Phys.J.C* 76 (2016) 3, 107
- Important reference measurement of $^{J}/_{\psi}$ absorption in cold nuclear matter possible at CBM

Dark Matter Search

Chapter 8



Dark photon



Axions

Summary

pp

- Precision cross sections measurements at FAIR basis for solid interpretation of heavy-ion data (also at high energies)

πp

- More selective excitation of baryon resonances compared to p+p:
  - test partial decay widths to given final states (important for interpretation of ϕ HIC data)
  - advantageous for PWA

πA

- Low momentum coverage: feature of HADES
  + dilepton reconstruction capability
  + low recoil momenta due to π beam

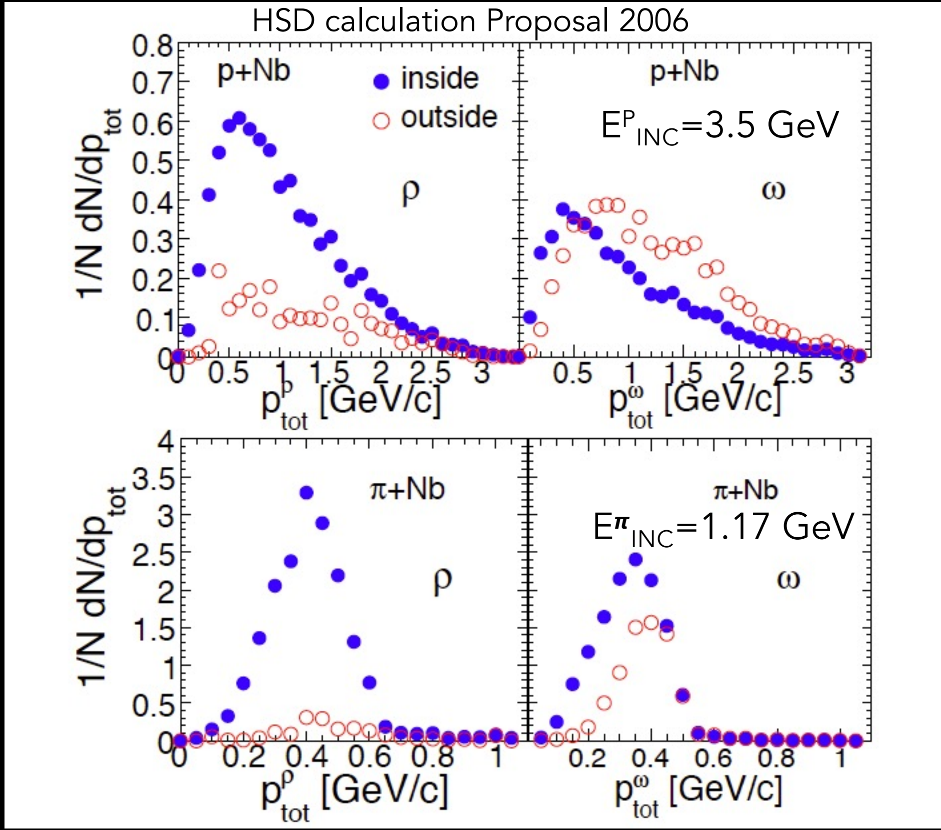
- Large production cross rates of hypernuclei do tofavorable kinematic

pA

- Large production rates of charmed hadrons from secondary pbar + p annihilations

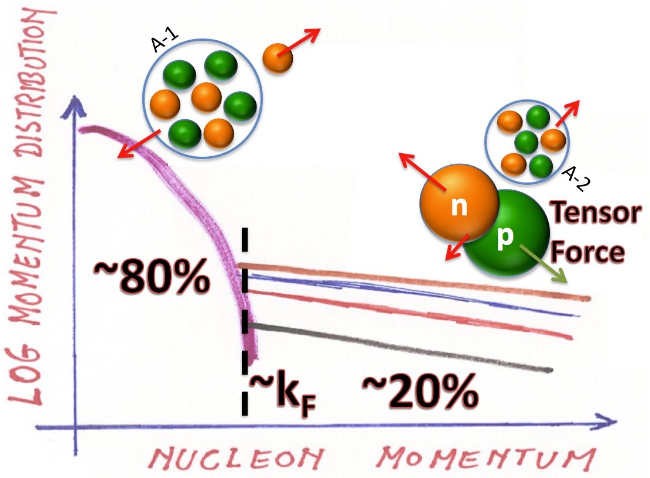
- Important reference measurement of $^{J}/_{\psi}$ absorption in cold nuclear matter possible at CBM

π induced reactions: small recoil momenta of secondaries

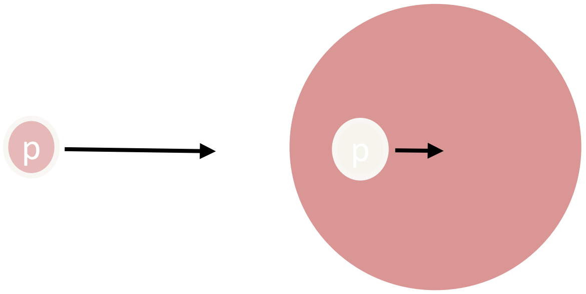


Optimal population of low momentum VM!

Short Range Correlations (SRC)



Quasi p+p elastic scattering have a strong preference for interacting with forward going high momentum nuclear protons, "**Selective Attention**".



4.5 GeV is ideal!

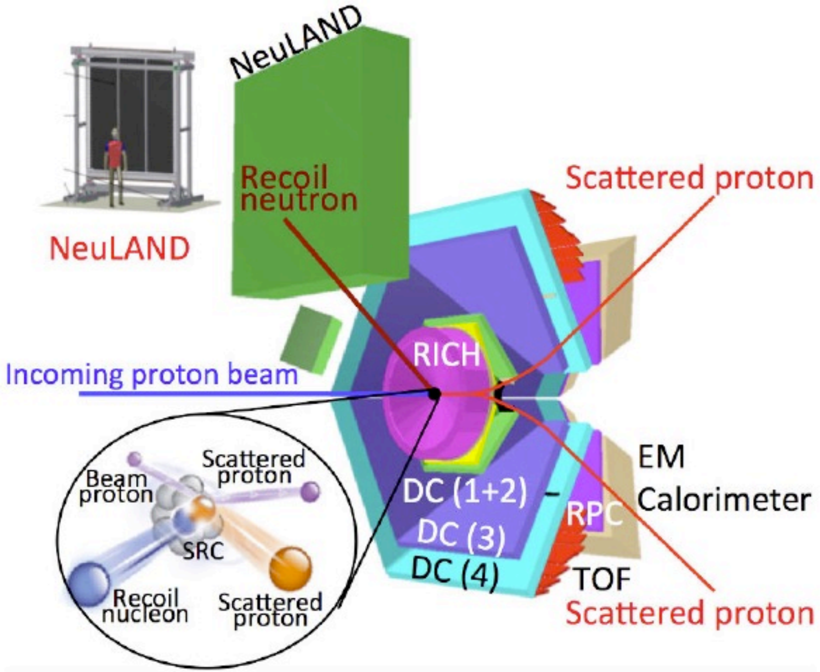
Map out the the transition (Migdal jump) in the nucleonic momentum distribution from a mean-field part to the high-momentum tail dominated by SRC.

Study the factorization of the reaction mechanisms at low energies (important test for studies of SRC in inverse kinematics at FAIR).

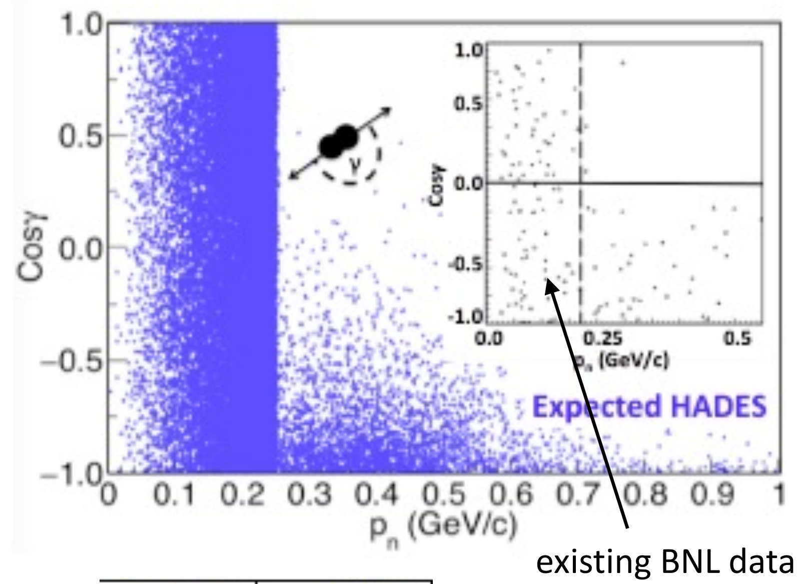
Short Range Correlations (SRC)

Experimental Setup:

- HADES as detector for the 2 forward p
- NeuLAND technology for the recoil neutron



The **Migdal jump** mapped with the anticipated HADES+NeuLAND technology events (factor 50 compared to BNL data).



np-SRC	pp-SRC
4×10^3	2.5×10^3