Workshop "*Physics opportunities with proton beams at SIS100*", Cracow, June 21, 2023

Executive summary

Purpose & organisation of the workshop

This document provides a short description of the most important conclusions as a result of a one-day workshop on the topic "Physics opportunities with proton beams at SIS100" connected to the MESON2023 conference held in Cracow, June 2023. The objective of the workshop is to brainstorm on the physics possibilities one could pursue using proton beams up to 30 GeV at FAIR with SIS100. It was meant as a kick-off discussion, preparing a follow-up and more extensive workshop which eventually should lead to the formulation of an extended program to strengthen the physics reach at FAIR. The workshop program and slides of the various presentations given at the event can be found at

https://indico.gsi.de/event/17693/

About 25 participants attended the workshop and 12 presentations were given. The talks and discussions covered a broad spectrum, including proton structure and conceptual ideas (Craig Roberts, Antoni Szczurek), open-charm production (Rafal Maciula), light-meson production (Piotr Lebiedowicz), the structure and spectroscopy of hyperons (Volker Crede, Matthias Lutz), interaction studies exploiting femtoscopy (Laura Fabbietti), input to heavy-ion dynamics (Nu Xu, Tetyana Galatyuk), and the perspectives of competing/complementary facilities world-wide (Mikhail Bashkanov for KL facility, Hiroyuki Noumi for J-PARC). In the following we describe those items that potentially show some good perspectives to further followed-up, ordered according to topic. Note that this is an incomplete list biased on the opinions of some of the participants and editors of this report. Therefore, one should consider this as a working document whereby follow-up iterations including discussions within a larger community will be necessary.

Charm content of the proton

The structure of the proton is certainly one of the key topics in the field of hadron physics and in principle can be addressed with proton beams at SIS100. Hidden and open-charm final states potentially can probe the structure of the proton and address fundamental questions associated with the origin of its mass (emergent hadron mass (EHM) and trace anomaly contribution) and its (valence) charm contents. With proton beams available at SIS100, one has the opportunity to produce hidden-charm and open-charm final states (J/ψ, open charm D, Λ_c). Interesting is the capability at SIS100 to access charm quark distributions of the proton with Bjorken-x larger than 0.1, thereby sensitive to the valence-quark region. The recent claim of the discovery of an intrinsic charm component of the proton based on "data fitters" is presently weak. Hence, data based on charm-production with SIS100 protons with its capability to discriminate between sea and valence contributions may have an excellent discovery potential.

A strongly connected topic to intrinsic charm is to exploit charm production on the proton to study the gluonic mass radius and associated information on the trace anomaly contribution to the mass of the proton. Conceptually, the radius/EHM/trace anomaly contribution can be accessed via V+p->V+p processes whereby "V" refers to vector mesons. Based on recent (electro)photon production data (JLAB) and exploiting cross section measurements of near-threshold production of charmonium on the proton, such radius measurements were performed. The interpretation of the data hinges, though, on the vector meson dominance assumption which is heavily critized by the community. Alternative approaches complementary to (electro)photo-production studies may provide a more model-independent including charmonium production in p+p scattering and measuring charmonium-nucleon final state interactions (FSI) and via femtoscopy in p+A. Since vector mesons will play a key role in our endeavour, it would be important to get a better understanding of reaction dynamics that play a role at SIS100 energies in pp->ppV processes: hadronic vs partonic picture. This is also very important for the heavy-ion community interested in nuclear modifications of charmonium. With SIS100, one has the possibility to produce strange/charm mesons and baryons close to their production threshold providing unique kinematics and relatively a clear signal.

One may consider to further explore protons at SIS100 as a potential “valence quark machine”, similar to the strategy used by AMBER (pion valence quark machine) and connecting to Drell-Yan studies in antiproton-proton collisions. In general, the valence-quark domain is EHM territory with a strong overlap with heavy-ion program, e.g. deconfinement and chiral-symmetry aspects.

The main challenge, making or breaking the success of the studies described above, is how well one can achieve a model-independent approach to extract the observables to extract the physics of interest. At present there is no theoretical framework at hand that could be exploited to demonstrate its feasibility. The overall hope is that a study of observables such as scattering lengths and amplitudes of the charm production in the p+p process in a part of phase space with sufficient sensitivity provides access. For example, measurement of nucleon-charm hadron FSI from Dalitz plot (i.e. ppJ/Y or pL_c $\overline{D}$) near the production threshold could offer such opportunity. Challenges lie in understanding and controlling production mechanisms, e.g., partonic versus hadronic degrees of freedom and to develop tools that allow to discriminate between valence and sea quark distributions. Systematic studies both theoretical and experimental, which are not available for these energies and processes should be conducted and placed in a broader program with as ultimate goal to pin-down valuable structure information of the proton. In this context, it would be opportune to connect to the meson-baryon scattering studies on the Lattice and effective-field theoretical approaches.

Hyperon spectroscopy and structure

The most promising spectroscopy aspect one should pursue relates to baryons or baryon-like systems in the strangeness S=-2 and S=-3 sector. To use proton beams to systematically study the mass spectrum is likely not opportune considering the competition from other facilities, particularly using those utilizing kaon beams (KL facility). An exception could be the S=-3 baryonic systems, which requires detailed feasibility studies in comparison with perspectives at other facilities such as JPARC. An aspect that could well be studied using proton beams relates to measurements of mass line-shapes of baryons with strangeness contents via their near-threshold production and by studying their features for different final states. From theoretical considerations, the line-shape in general contains valuable information on their nature allowing to discriminate between conventional three-quark states from molecules, di-quark correlations, or any other exotic features. From the experimental point of view, the widths of excited hyperon states are well accessible given the typical detector resolutions of available setups at FAIR. This is in contrast to hadrons in the heavy-quark sector which are very narrow and, therefore, hard to measure. Also the line-shapes of hadrons in the light-quark sector are hard to extract as a consequence of their large widths with overlapping features and interference effects that have to be accounted for.

The structure studies of hyperons in the S=-2 and -3 sector would be accessible at SIS100 with the appropriate detector setup. In particular, electromagnetic probes (dilepton) have proven to be ideal tools to explore QCD matter: from electromagnetic transition form factors to study “sizes” of baryons and the role of pion/kaon clouds towards the study of electromagnetic spectral functions in dense media. Radiative weak decays from S=-2 to S=-1 may also be interesting as a tool to measure weak form factors, keeping in mind that it requires the capability to detect photons. In general, there is a very clear link and motivation between hadron physics and heavy-ion physics. Particularly, dileptons couple to vector mesons and are, therefore, a key tool to study the transition from hadronic to quark degrees of freedom, e.g. from low-mass region (LMR) to intermediate mass region (IMR). From an interpretation point of view, the connection with Dyson-Schwinger approaches may be extremely powerful. Moreover, effective field theoretical approaches in chiral SU(3) are in principle available and could be further explored and developed to strengthen the strangeness hadronic part of the program.

Other promising topics

- Production measurements of hadrons in proton-proton scattering as a reference for nuclear modification factors (R_{AA}). This would be of high interest for heavy-ion experiments such as CBM.
- The production mechanism of light, axial mesons in proton-proton scattering. Particularly, an energy scan would be helpful to observe the onset of vector-vector fusion and Pomeron exchange mechanisms.
- The discovery of LHCb of pentaquark candidates with hidden-charm in the vicinity of the $\Sigma_c \overline{D}$ threshold has created lots of interest in the community. These states were so-far not observed at JLAB via photo-production studies. This may well be a consequence of a small coupling of the states with photons. A study of such states with proton beams would be unique and naively expected to be stronger with respect to the usage of photon beams. Here it would be interesting to study line-shapes in the $\Sigma_c \overline{D}$ and $J/\psi p$ final states of the observed pentaquarks to reveal their nature.

Johan Messchendorp, October 2023