Report on Letter of Intent Supernumerary G-PAC meeting 25-27 January 2022

LOI : SPARC Strategy for the years 2022 to 2025/2026
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Summary

SPARC regroups several research projects ranging from fundamental tests in QED, super-critical systems, ion-ion collisions, to nucleus-atom physics interface. Several projects have also a great importance for astrophysics or plasma physics. Most of the experiments have to be performed on ESR, CRYRING or HITRAP. There is also a set-up developed for high-precision measurements in Cave A, which can also allow to compare different nuclei obtained in secondary beams through atomic effects.

For the years to come, the particular focus of the strategy of SPARC is the exploitation of the worldwide unique research capabilities of the ESR and the CRYRING@ESR cooler and storage rings as well as the trapping facility for highly-charged ions HITRAP by utilizing dedicated FAIR instrumentation already developed by the collaboration. In the LoI, SPARC describes its approach to perform the commissioning (CRYRING@ESR) and re-commissioning (HITRAP) in a stepwise approach aiming to reach their complete parameter space (design parameters) required for the exploration of their full physics potential. This will be done by performing very first physics production runs with the focus on key-experiments with SIS beams but also by making use of the stand-alone operation of both the HITRAP and the CRYRING@ESR facilities. For the time period from 2023 until 2025, a clear priority is given to the key experiments. At the same time the SPARC collaboration plans to maintain and upgrade the facilities which are essential for successful mid-term and long-term scientific programs. SPARC underlines the importance of the facilities of relevance to remain open-user facilities, promoting novel physics projects and ideas.

Recent Achievements

In 2020, after a break of many years, ESR equipped with the new FAIR control system was brought back into operation. In 2020 also the commissioning and very first experiments have started at CRYRING@ESR with high-Z ions from the ESR and also with ions from the local injector.
A broad portfolio of SPARC-specific FAIR instrumentation has been developed and is already available for the planed, research program.
ESR
Since the restart of the ESR (2020 and 2021) several highlights have been achieved at the ESR, among which are successfully accomplished experiments:

E121 Bound state beta decay of ^{205}Tl, highly demanded (since more than 40 years) decay rate, which could only be measured in the ESR, has been measured. *publication in preparation*
E125 Δn=0 transitions in He- and Li-like Uranium, a sensitive test of quantum-electrodynamics and electron correlation effects in few-body systems in the extremely strong Coulomb field was done with very high

precision. *publication in preparation*
E127 Astrophysical (p,γ) reactions, for the first time the (p,γ) reaction in the energy range of the astrophysical p-process could be measured for a radioactive beam. *publication in preparation*
E132 1s-1s ionization and charge transfer, investigation of quasi-molecular states in Xe^{54+}-Xe collisions with measuring in coincidence the emitted photons, electrons as well as recoils and charge-exchange products. *publication is in preparation*
E143 2-photon transitions in nuclei, in collaboration with ILIMA, the developed highly sensitive Schottky detectors were employed to study rare nuclear decays. *publication in preparation*

CRYRING@ESR
Ion beams are routinely available from both, the ESR injection channel and the local ion source, even though the beam intensity is presently still insufficient for many experiments. The optimization of transfer efficiencies is ongoing.

E131: The electron collision spectroscopy setup at the electron cooler is working very close to its theoretically expected performance for, e.g., high-resolution spectroscopy of deeply bound states in highly charged ions, such as for 2s-2p transitions in Be-like Pb^{78+}. *publication in preparation*

E140: T**he determination of absolute rates of astrophysical relevance** (E140, to be continued in 2022), and exotic transitions (E153, KLn demonstrated, KK-LLn to be continued in 2022-*using CRYRING off-line*).

E138: New 0/180° x-ray windows and novel 64-pixel magnetic microcalorimeters (MMC) yielded order of magnitude resolution gain in x-ray spectroscopy. Despite the very low beam intensity, for a heavy He-like ion the experiment accomplished the very first observation of the line-splitting of the Kα-line in U^{90+} (to be continued in 2023)
publication in preparation

E148: Laser fluorescence spectroscopy has been established and manipulation of stored ion quantum states into specific magnetic quantum states could be demonstrated (*using CRYRING off-line*)
publication in preparation

E129: **The proof-of-principle experiment on photoionization** yielded valuable data for future setups at different storage rings. (*using CRYRING off-line*)

E141: Major new infrastructures have been prepared for the 2022 beamtime block and needs to be brought into operation: gas-jet target and CARME reaction setup (*scheduled* for 2022)

Strategic Plan

Strategy for the transition period: The particular focus of the strategy of SPARC is the exploitation of the ESR and CRYRING@ESR cooler and storage rings as well as the trapping facility for highly-charged ions HITRAP by utilizing dedicated FAIR instrumentation, which is being continuously developed by the collaboration.

Central priorities are:

- To maximize the physics output with concentration on highly visible experiments which utilize the unique features of the storage and trapping facilities of GSI/FAIR as well as the SPARC instrumentation;
- To push all the facilities under discussion for providing the full (design) parameter space and reliable operation. One immediate goal is to achieve efficient deceleration and transport of ions from the ESR to CRYRING@ESR;
- To operate the facilities of relevance as open-user facilities always promoting new ideas and developments.

Reaching the design parameters is a prerequisite for the optimal use of the facilities for physics production runs. The integration of equipment into the XUV vacuum of the rings ($\approx 10^{-11}$ mbar) is mostly unavoidable, however, it should be minimized and thoroughly coordinated to perform the most efficient use of beam time. In particular, the compatibility to other planned experiments needs to be checked carefully. Setups and experiments which require substantial construction works and which may block the rings for other experiments for a long time period should be avoided, at least at the present situation of very limited beam time availability. ***Therefore, priority and full concentration should be given for reaching reliable facility operation and for pushing towards the design parameters.***

Key-experiments for reaching the design parameters should have the highest priority:

ESR

- Di-electronic-recombination-assisted laser spectroscopy
- (p,γ) studies within the Gamov window
- Resonant coherent excitation of electron cooled high-Z ion at Cave A

CRYING@ESR

- Dielectronic Recombination experiments for high-Z few-electron ions
- 1s Lamb-shift studies, based on the application of micro-calorimeters

CRYRING off-line

- Integration and commissioning of FISIC setup at CRYRING
- Photo-ionization experiments

HITRAP

- E130 'Cooling and precision spectroscopy of $^{209}Bi^{82+}$ ion ensembles with the ARTEMIS and SPECTRAP experiments.

Answers to

The goal of each LoI final report is clearly to distinguish the part of the

Questions

science and the instrumentation

a) which can and should be employed in the FAIR Phase-0 call of 2023-2024 in terms of excellence, uniqueness, feasibility and readiness,

ESR

Internal jet target: an upgrade is being prepared for 2022-2023 to reduce the target size, increase intensity and increase the stability;

Particle detectors: the detectors in roman pots (gas, plastic) as well as in ultra-high vacuum (silicon, solar cells, diamond) need steady maintenance and upgrades based on the fast-developing detector and electronics technologies;

Non-destructive detectors: upgrades in line with technology developments.

CRYRING@ESR

Setup for laser spectroscopy (chamber, detectors, laser), already installed, commissioned ready for first runs in 2022.

XUV- laser setup for laser spectroscopy in storage rings: tested/ commissioned at CRYRING; can be used in ESR and CRYRING for physics runs.

CARME: Spectrometer for Nuclear reactions investigations; installed and prepared for commissioning in 2022.

Internal jet target, basic ring instrumentation to serve a large number of experiments; in the installation phase, to be commissioned in 2022.

Transversal electron target: to be implemented in the ring during the second half of 2022.

Micro-calorimeters have already been used in the 2021 run E138.

High Voltage Divider with high precision for experiments at the cooler: installed at the CRYRING cooler.

COLTRIMS spectrometer: expected for installation in 2024.

FISIC setup for ion-ion collisions: expected for installation in 2024.

HITRAP

ARTEMIS g-factor precision trap

SPECTRAP for laser spectroscopy on cooled and trapped ions

Pulse gaseous target station for ion-matter interaction of astrophysical relevance in the keV/u regime**.**

A workshop to revive the HITRAP physics program after a decade of idling is planned for July 22, from which a number of new science proposals can be expected for the period 2023-25.

b) and the science parts which would benefit greatly from the connection of

SIS18 to the new caves and the subsequent increase in intensity, transmission, and new instrumentation or other conditions beyond 2025. but also, to a different mode of operation at FAIR in which physics runs will not be compacted in a three-months period but spread throughout the year, thus making experiments with long installation or commissioning times easier, HESR would open FAIR to a new class of experiments, using cooled relativistic of heavy ions, like photo-ionization, atomic collisions near Schwinger limit, laser cooling, X-UV laser spectroscopy… One should not forget about the unique physics potential that would be brought to FAIR by ensuring that the antiproton transfer line from HESR to ESR will be build, so that antiprotons are available at ESR and CRYRING to get slow, cooled antiprotons, allowing for slow extraction, which is not possible at CERN. *c) conclusions on more general recommendations / resolutions as guidelines for detailing the call for submissions and assessment of proposals in the next regular G-PAC.* Reaching the design parameters is a prerequisite for the optimal use of the facilities for physics production runs. In terms of efficient use of beam time, the integration of equipment into the XUV vacuum of the rings ($\approx 10^{-11}$ mbar) if mostly unavoidable, should be minimized and carefully planned. In particular, the compatibility with other planned experiments needs to be checked carefully. Setups and experiments which require substantial construction work and which may block the rings for other experiments for a long time period should be thoroughly examined and their installation requires coordination with all the affected users, at least in the present situation of very limited beam time availability. Also, one needs to take into account that experiments scheduled for CRYRING@ESR and HITRAP set strict boundary conditions for the experiments at the ESR. Setups which may affect the vacuum of the ESR (e.g., integration of silicon detectors, which cannot be baked to the required temperatures) should be avoided as far as possible since they are likely to seriously affect the deceleration efficiency of the ESR. *a), b), c) should help the FAIR Phase-0 program to ensure the best possible science output during this transition period towards FAIR Day One experiments and clarify our future discussions on the next round of proposals which will be submitted at the next regular G-PAC in September 2022.*

Recommendation to the collaboration	• Flexibility of planning is essential in the present phase. SPARC is by atomic physics standards a large collaboration with 430 participants from 25 countries and several subprojects carried by very active groups at a large variety of facilities proposing top experiments. Regular meeting of the board and spokespersons of the different proposals should continuously be organized as it is being done, to evaluate readiness of the setups, and coordinate eventual problems... If needed, reprogramming of

other SPARC experiments, compatible with the various constraints (required beam…) in a given beam time period should be proposed to the beam coordinator.

- Besides their impact on the facility and interaction with other setups, the feasibility of experiments which require large modifications and everything working at the limit should be carefully examined by both the collaboration and the FAIR management before being programmed. For example, the proposal E146 requests 10^8 Pb^{82+} ions while during 2021 operations the maximum intensity reached ~$2x10^6$ ions of U^{91+}. In the same way FISIC (E155) will require maximum intensity.
- In the very tight situation in terms of beam time, and with the various strict boundary conditions during the considered period, the collaboration should be sure to promote even stronger than in the past the standalone operations of HITRAP and CRYRING@ESR to compensate (at least partially) the scarcity of beamtime. Such stand-alone operation is as well essential for commissioning (if possible) of new instrumentations.