Scientific Perspectives of the NUSTAR collaboration for Early and First Science at FAIR

This document describes the current vision of the NUSTAR collaboration for Early Science (ES) with beams from SIS18 and First Science (FS) with beams from SIS100 currently planned in the years 2027/28. We envisage two scenarios (see Fig.1), the first one with operation in the high-energy cave (HEC) and the focal plane in front of it (FHF1&2) and the possibility to operate certain experiments in the middle focal plane of the Super-FRS (FMF2). This scenario fully respects the recommendations of the review committee, but as we will show poses severe constraints on the operation of several NUSTAR experiments. The second scenario also includes the two focal planes of the low-energy branch (FLF2&3) located at the end of the Super-FRS tunnel and at the entrance of the low-energy building, respectively. This scenario respects the spirit of the recommendations of the review committee since it preserves the intended cost savings by neither procuring the low-energy buncher spectrometer nor the full technical infrastructure (TBI) the low-energy building. In the following, the experimental possibilities and challenges of both scenarios are discussed, while details for the individual experiments can be found in the respective annex.

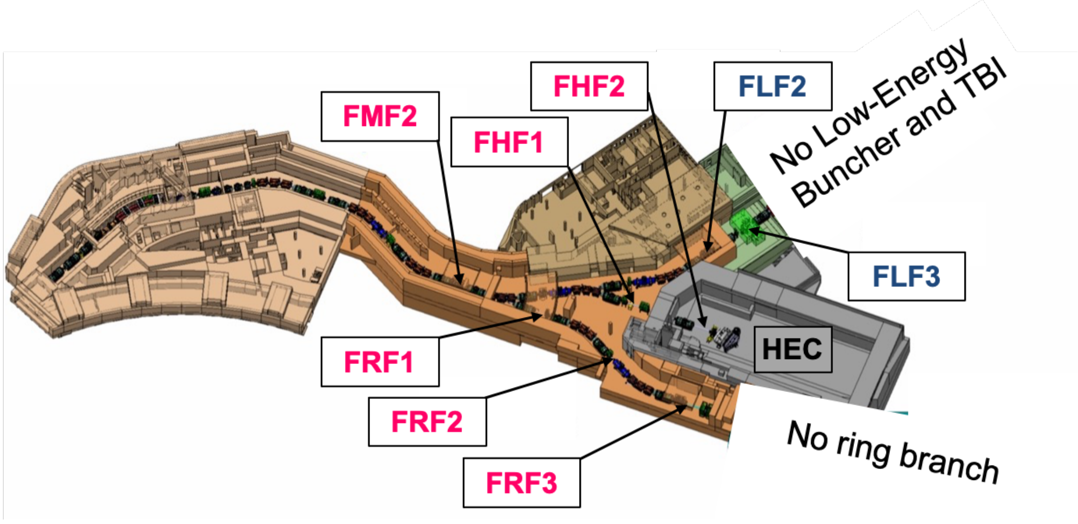

Fig. 1 Possible locations of the NUSTAR experiment for Early and First Science; the focal planes relevant to discussed scenarios are marked.

In any scenario, NUSTAR ES would start with a common NUSTAR set-up at FHF2 in the HEC in front of the GLAD magnet. Details of this set-up still have to be worked out, but it would allow for new isotope searches, including their lifetimes and possibly isomer and beta decay spectroscopy with a simplified DESPEC set-up. After this initial campaign in 2027, in the first scenario the R3B set-up would be completed with the detectors surrounding the secondary target (CALIFA etc.), while DESPEC and the Super-FRS EC would share FHF1 for experiments. Any set-up with radiation sensitive detectors, e.g., the DEGAS Germanium detectors, may need to run at FHF2, unless efficient shielding can be provided. This operation requires flexible set-ups, which can be quickly moved around in a matter of days, similar to the current situation at FRS-S4. At this point R3B will be fully operational, while DESPEC would provide detailed decay spectroscopy and the Super-FRS EC ground-state masses using the Cryogenic Stopping Cell (CSC) and MR-ToF devices. In addition, other Super-FRS EC set-ups can be operated in the middle focal plane of the Super-FRS (FMF2). For details of the planned experiments see annex of the respective NUSTAR sub-collaboration.

Since all these areas are part of the same radiation area, work on any of the set-ups (including the HEC) would prohibit beam time on any of the other experiments and vice versa. In this scenario, also the operation of R3B and HISPEC/AGATA is mutually exclusive unless a costly second beam line and focal plane behind the GLAD magnet is realised. Finally, this scenario will not allow the installation of MATS and LASPEC, strongly limiting the investigation of the further ground-state properties of newly identified isotopes. In conclusion, in this scenario first experiments of the DESPEC, R3B and Super-FRS EC collaborations will be possible, but with a strong limitation of the scientific output, in terms of realised experiments.

In the second scenario, DESPEC and/or the CSC/MR-ToF set-up would move to the focal point FLF2 of the low-energy branch of the Super-FRS still located in the Super-FRS tunnel. Moving the shielding wall planned behind FLF2 in front of it would create a second separate radiation area allowing parallel installation work and beam time in the two branches. The efforts for this reconfiguration are minor as compared to rearranging the HEC for several experiments and are currently being quantified. In this way the DESPEC, R3B and Super-FRS EC set-ups could be operated fully independently increasing the scientific output by a factor 2 to 3 as compared to the first scenario.

Assuming finally the possibility to operate equipment at FLF3, located at the entrance of the low-energy building, would also allow the operation of HISPEC/AGATA as well as MATS and LASPEC. For HISPEC this assumes additional external funding for an analysing magnet behind AGATA, which we are currently negotiating with several countries. For MATS and LASPEC, the fact of the missing energy buncher would reduce the available intensity of secondary beams by about a factor of three, but important advances are still expected in view of the superior production rates of RIBs from the Super-FRS. Both experiments would, however, require close to nominal beam intensities from SIS100 and would therefore operate 1-2 years later.

In addition to the new experimental areas at the Super-FRS, NUSTAR will continue to operate the FRS, in particular for ILIMA at the ESR and until the CR will become operational. Here a rich experimental program on highly charged ions can be pursued, but limited to stable or near-stable nuclei due to the limited transmission from the FRS into the ESR. Further measures to improve the transmission would be highly appreciated. Other experiments, which are either not possible at the Super-FRS under the scenarios described above or would severely impede other experiments, are also envisaged. Examples are the operation of a new Super-WASA detector in the mid-focal plane (S2) of the FRS or certain DESPEC set-ups with larger space requirements could operate at S4.

Request from the NUSTAR collaboration for the engineering runs 2023 and beyond

1. Re-Commissioning of the FRS after the shutdown.
2. Improvement to the Micro and Macro spill structure in routine operation for all experiments and beams.
3. Intensity optimization of the newly developed ^{170}Er beam, possibly through the whole accelerator chain.
4. High intensity for beams on FRS target, especially for ^{208}Pb and ^{238}U, by
    - 4.1. Optimizing transmission from SIS to FRS target at the highest rigidities
    - 4.2. Standard operation of the pulsed Hydrogen stripper for experiments
    - 4.3. Higher spill rate: 1 per second at 100ms slow extraction.
5. Verification of ^{48}Ca, ^{54}Cr intensities for SHE experiments at the UNILAC.
6. Verification of the shielding factor of the new TASCA shielding hut with an intense ^{40}Ar beam.
7. Commissioning of NUSTAR set-ups (whenever beams can be made available during the engineering runs).
8. Repair of the ESR electron cooler in time for experiments in 2024.
9. Transmission improvement FRS-ESR (as soon as the ESR is available again).
10. Installation of the new terminal for the ^{238}U beam to enable 2.7 Hz operation in time for the start of SIS 100.

In addition, runs associated to preparatory work for the Super-FRS are supported by NUSTAR.

   a. Test of HRU (FAIR in-kind) 5 shifts (Z = 36 to 54). This project is done by the Super-FRS EC collaboration, even though it is an in-kind to the accelerator cost book.

HISPEC/DESPEC collaboration

Introduction:

Given the outcome of the FAIR Review Report, the HISPEC-DESPEC collaboration sees a strong reduction of its planned scientific program, and some topics will need to be put on hold until the LEB is available. The collaboration is discussing the extent of such delays and the actual impact of a much-delayed operation of some equipment. The experimentation related to, for example, the G-SPEC program for g-factor measurements, the HISPEC-10 slowed-down beams programs, and the measurement of beta-delayed neutron emission using the MONSTER equipment will need to be reconsidered, and the programs might not be competitive anymore on such a long timescale.

Most importantly, the experimental program using the latest-generation HPGe array AGATA is strongly impaired by the constraints outlined in the report. AGATA is a priority for the collaboration, given the investments in this core instrument and the agreements within the international collaboration.

AGATA installation and operation requires adequate running time and considerable resources (manpower and capital) and therefore cannot be squeezed into short runtime periods. The installation must start at least one year prior to the campaign and an extended dedicated campaign is envisaged to best exploit AGATA.

Missing out on the opportunity of hosting AGATA at FAIR before 2030 will strongly impact the scientific output of the NUSTAR collaboration.

The NUSTAR collaboration is actively helping the bottom-up process of finding the best solutions to fulfil an outstanding and competitive experimental program.

Here below we briefly describe the basic set-ups that we envisage under the new scenarios:

Beta- and isomeric-decays of most exotic systems: The experimental program would focus on high-resolution spectroscopy, timing measurements, and beta-decay properties. The basic set-up includes DEGAS+FATIMA+AIDA, with possible use of DTAS and BELEN as alternatives. This configuration is referred to as DESPEC in the following sections.

In-beam spectroscopy: Based on Coulomb excitation, knock-out and secondary fragmentation reactions, the program will aim at measuring low-lying levels, collective states, and electromagnetic transitions in exotic systems, either directly or via the determination of lifetimes. The set-up is based on AGATA+LYCCA. LYCCA, together with a magnetic separator, is needed to identify the outgoing particles and to reconstruct trajectories. Identification and reconstruction are based on TOF and energy loss, so a minimum flight path is to be considered. AGATA is to be run in dedicated campaigns to best exploit its installation and commissioning, which requires at least one year. This is referred to as HISPEC in the following sections.

As agreed within NUSTAR, early science will start with a common NUSTAR experiment dealing with exotic isotopes identified with a simple set-up at FHF2 commonly built and operated by the NUSTAR collaboration during the Super-FRS early commissioning. HISPEC-DESPEC supports this experiment and suggests a sub-set of DEGAS detectors for straightforward, fast and reliable ID validation through detection of gamma rays depopulating isomeric states. These detectors, as well as FATIMA detectors, may also be used for the discovery of new isomeric and beta decays. The AIDA implantation detector can be used as active implantation detector and for ion-beta correlations.

1. Experimental set-ups at FMF2, FHF1 and FHF2

As soon as the Super-FRS will have the capability to provide exotic isotopes, DESPEC experimental set-ups, as they are currently used at the S4 focal plane of the FRS, can be employed at FHF1. However, the available space at FHF1 will be limited, and the potentially larger radiation levels in the Super-FRS tunnel pose some risk to damage - or even destroy - sensitive detectors. Moreover, assumed sharing of the space with the cryogenic stopping cell and other set-ups of the Super-FRS EC limits the potential operation of DESPEC detectors further. Extended set-ups, e.g. including MONSTER, will not be feasible. The frequent blocking by Super-FRS commissioning together with preparation and operation of all other experiments is assumed to limit the experimental outcome strongly.

Assuming that the operation of HISPEC set-ups is technically not possible at FHF1:

Operation of DESPEC set-ups similar to FHF1 would be possible as well at FHF2. This focal plane in the HEC has the advantage of better shielding of the radiation load from the tunnel. However, space and time sharing with R3B would lead to a similar limitation of scientific throughput as pointed out in the case of FHF1.

Assuming that the operation of HISPEC set-ups is technically not possible at FHF2:

Operation of DESPEC set-ups similar to FHF1 would be possible at FMF2. However, the beam quality at the mid-section of the Super-FRS is considerably worse compared to the end foci. Ongoing investigations indicate that HISPEC with AGATA could be employed at FMF2 if a completely new high-precision rotating holding structure for AGATA would replace the already existing frame for half of the array. The identification of outgoing beam-like particles would be achieved in a favourable way using the second half of the Super-FRS. *The drawback of this location is that it blocks any other NUSTAR experiments for roughly one year to set it up plus 1-2 years of operation time.*

2. Experimental set-ups at FLF2/FLF3

The full DESPEC suite of experiments can run at FLF3 for comparable cost and effort as would be needed for installation at the locations discussed above. Running behind FLF2, but with the movable wall put upstream, would also work in a limited version. HISPEC could also be employed at FLF3 as it is at its originally planned position. However, this requires funding of the first dipole of the buncher/spectrometer and/or the installation of two available multiplets from the ring branch of Super-FRS. This solution would enable the full HISPEC program and does not interfere with other NUSTAR activities.

3. Conclusions

For HISPEC the only realistic location is FLF3, assuming that the cost of the needed dipole magnet and some infrastructure can be covered.

A considered alternative would be placing AGATA at FMF2 or HEB. The additional infrastructure costs would be somewhat lower than the costs for the FLF3 solution, because of existing analysing magnets. However, this would pose severe constraints on other NUSTAR experiments, which would be blocked for 2-3 years (condition that might not be considered acceptable from the NUSTAR collaboration). Detailed feasibility studies including the GLAD or ALADIN magnet are indispensable for this scenario.

For DESPEC the favourable location is, again, FLF3 as this allows for the full scientific programme without hampering other NUSTAR experiments and without significant extra cost or effort. A reduced programme for the same cost, high risk of detector damage and with strongly reduced operation time for all NUSTAR would be still possible at FHF1 or FHF2 and FLF2.

ILIMA collaboration

The ILIMA (Isomeric beams, Lifetimes and Masses) collaboration aims at precision measurements of atomic masses and lifetimes of exotic nuclei as well as the exploration of rare decay phenomena of highly-charged (radioactive) ions. The ultimate feasible goal is to obtain a precision mass value (on the ppm level or better) from a single produced (yields of one ion per day/week or even lower) short-lived ($T_{1/2}$>~10 ms) radionuclide, providing thus nuclear data on nuclei inaccessible by other means. The ring branch, where ILIMA will address the most exotic nuclei produced at the Super-FRS and stored in the large-acceptance Collector Ring (CR), will unfortunately not be realized in the first FAIR construction phase planned until 2028. Although ILIMA will remain competitive also in the next decade, the reach of nuclei to be measured will be reduced, often in a much more tedious and costly manner than would be possible with ILIMA.

The existing storage rings ESR and CRYRING@ESR are available. This situation restricts the applicability of our methods and is different from the primary goals of the collaboration. Nonetheless, currently proposed experimental proposals are all still unique worldwide and feasible with the existing facilities until 2028. They are categorized as follows:

1) Mass measurements
   a. Search for long-lived isomeric states: Neutron-rich Hf isotopes
      Conventional gamma-ray spectroscopy has difficulties to search for long-lived species, since the time correlation between production and decay is lost. Storage-ring mass spectrometry is a powerful alternative technique, as shown for example by the discovery of new isomers in Hf-Os region. Nuclear shell evolution and prolate-oblate shape transition have been addressed in the same experiment. It is worth noting that the very discovery of the isomers in the ESR facilitated dedicated spectroscopy experiments.
   b. Emission probabilities of one or several beta-delayed neutrons are crucial to understand the r-process after the freeze-out. Despite many neutron detection techniques, which often give controversial results, the storage-ring with the in-ring detector setups provides a unique way to determine branching ratios without detecting the emitted neutrons accompanied by about unity detection efficiency of the daughter nuclei. New technical developments are required, such as new and larger pocket detectors with fast pneumatic control.
   c. All remaining regions where nuclei with unknown masses/lifetimes are still accessible at FRS-ESR (heavy species around ^{216}Pb, around ^{100}Sn and around ^{19}C), at same time beta-delayed neutron branches where applicable.
2) Rare decays of highly charged ions (HCI)
   a. Bound-state beta decay of ^{205}Tl
      This is a unique experiment possible only at ESR in the world. ^{205}Tl ions are stable if neutral, however become radioactive if fully stripped. This exotic decay mode is very sensitive to the ionization degree in stellar environments and is in turn essential for s-process cosmo-chronometry and/or cosmo-thermometry, and further to the integrated solar neutrino flux project (LOREX).
   b. Two photon decay and bound pair creation

This is a currently running unique experiment at ESR where the method is further employed to different species to clarify the specific decay mechanisms. Two photon decay occurs as the only possible decay mode for fully-stripped nuclei where both ground and first excited ($<2m_ec^2$) states have a spin 0. Bound electron-positron pair creation occurs when an excitation energy is less than the pair creation threshold but the missing energy is compensated by atomic binding energy. An electron appears in an atomic orbital of daughter, while a positron escapes to free space. These rare decay modes need to be experimentally established.

c. Hyperfine interaction effect on nuclear beta decay of HCI
Nuclear beta decay of radioactive isotopes with a few electrons dramatically depends on the total angular momentum of the system. Evidence was found in ^{140}Pr and ^{142}Pm, and further confirmation experiments are planned. If confirmed, this additional degree of forbiddance in weak decay will be exploited to study electron screening, week decay branches etc.

d. Search for nuclear excitation by electron capture (NEEC)
Experimental confirmation of NEEC is still controversial. With the unique features of a storage ring, this new phenomenon can be studied clearly. In this regard, free and bound electron targets available at the ESR/CRYRING combined with capabilities to produce pure isomeric beams at various charge states and collision energies are the key to solve the exiting 9-orders discrepancy between experiment and theory as well as to systematically study this decay.

The physics cases mentioned above are all unique, however, due to the limited transmission between FRS and ESR, we must mainly focus on physics of HCI. Studies on the most exotic nuclei will only be feasible at the future CR. It is also noted that new technical developments ongoing at the ESR are very important to the future ring branch of CR and HESR, which are

- Developments of Schottky diagnostics: Single-ion sensitive transversal Schottky detector, which is sensitive to the storage orbit in the ring, phase measurements with high-sensitive longitudinal Schottky, and correlation measurements with multiple Schottky detectors.
- New mass spectrometry mode: Schottky mass spectrometry under a high precision isochronous ion-optical condition of the ring. Studies of the ion-optical conditions and dedicated time-of-flight detectors with position readout.

The major development needed for the ILIMA research program in the next years is the improved transmission between the FRS and ESR. Machine beam time has been requested several times, but was not allocated due to scheduling issues.

We note that the ILIMA experiments at the ESR decisively profit from the collaboration with SPARC, where we share and commonly develop the corresponding equipment. Although several improvements and larger upgrades of the ESR might improve the overall performance, the common view is to avoid any unnecessary shut-down periods and explore the still unique capabilities of the FRS-ESR-CRYRING facilities for the foreseeable future.

LASPEC and MATS collaborations

The mass and laser spectroscopy experiments (MATS and LASPEC) aim at high-accuracy mass measurements with an advanced Penning trap system and laser spectroscopy of short-lived isotopes to determine nuclear spins, electromagnetic moments, and charge radii. Both collaborations have working installations that can be installed at the Super-FRS' Low Energy Branch, once the cryogenic stopping cell has been implemented and the technical building infrastructure is completed. During FAIR Phase-0, the LASPEC beamline is operated at Argonne National Lab in the Area 1 taking beams from CARIBU and nuCARIBU after decommissioning of CARIBU. MATS has an ongoing program in the TRIGA reactor hall at Mainz University.

One of the first regions to be investigated by laser spectroscopy at FAIR will be the region of the refractory metals around zirconium, where a sudden onset of deformation has been observed at N=60. Later on, the region southeast of lead around the N=126 shell closure will be targeted, which is also of interest for mass measurements. As the LEB has presently lower priority and the funding for the energy buncher is currently missing, the collaborations have no opportunity to install their developed and working setups at FAIR. A temporary installation in the High Energy Cave (HEC), as it has been suggested, is not considered a useful option. On the one hand, it severely constrains the operation and the set-up of other experiments in the cave. On the other hand, the characterization of systematical uncertainties, which requires long time offline measurement periods, is a prerequisite for high-precision experiments, particularly the elaborated Penning trap system. Among other, this requires regular access to the cave, also in parallel to HEC experiments. Furthermore, the superconducting magnets of MATS cannot be easily transferred from cave to cave but should rather be permanently installed in one location.

In conclusion, for MATS and LASPEC the only realistic location for an early start is an installation at the entrance of the Low-Energy Cave (LEC) assuming that the cost of the required infrastructure can be covered. We suggest to explore whether such an installation might be possible. Costs connected with the infrastructure in this cave will inevitably have to be covered at some point and will not cause additional spending.

R^3B collaboration

R^3B is an international sub-collaboration of the FAIR-Pillar NUSTAR, formed by more than 200 scientists from 23 different countries. The sub-collaboration was created as a strategic alliance for the design, construction, and exploitation of a versatile experimental setup with unprecedented efficiency, acceptance, and resolution for kinematical complete measurements of reactions with high-energy radioactive beams.

The R^3B setup enables an extended scientific program comprising nuclear structure and dynamics as well as astrophysics. New possibilities of measurements of ground-state properties and nuclear excitations, for the understanding of the reaction mechanisms, for constraining the symmetry energy of the equation of state in asymmetric nuclear matter, for determining the role of nucleon-nucleon correlations including short-range correlations (SRC), for the investigation of hyper-nuclear matter, and for determining astrophysical reaction rates.

The R^3B experimental setup is optimized for the kinematically-complete measurement of reactions at high beam energies up to around 1 GeV/u. Compared to competing projects worldwide, which are the SAMURAI spectrometer at RIBF at RIKEN, and a similar setup at the future FRIB facility, R^3B will be unique in the foreseeable future due to the combination of high-energy beams, large acceptance, high resolution, and large efficiency including multi-neutron detection. Already in its present state of upgrading, R^3B has reached a performance level beyond any other comparable setup being planned. The major part of the R^3B physics program builds on the availability of 1 GeV/u beams. The concept of magnetic beam separation and magnetic analysis after the secondary target requires fully stripped ions. This implies that the competing projects at RIBF (SAMURAI, typical secondary beam energies around 250 MeV/u) and FRIB (similar to RIBF) will, in contrast to R^3B, not be able to provide kinematically-complete measurement of reactions with heavy beams ($Z>50$). Moreover, due to the higher beam energies employed by R^3B, thicker targets can be used and the acceptance is generally larger as compared to the competing projects at RIBF and FRIB. The detection efficiency of R^3B for multi-neutron decays is unprecedented in comparison to any other running facility or planned project. It is worthwhile to mention the availability of a precursor Si-tracker setup based on FOOT detectors that will allow to perform (p,2p) experiments in full kinematics. This configuration is currently being developed and already in use during the R^3B Phase-0 experiments, and provides an intermediate step towards the realization of the full-fledged system with 4π solid-angle coverage.

Specific examples of the R^3B physics program relying on the highest beam energies are the measurements planned for an extensive EoS program at R^3B, which will provide different observables with high sensitivity to the symmetry energy and its density dependence. Most of them are based on high-energy reactions of different kind, like quasi-free scattering, fragmentation, and Coulomb dissociation. These are the precise measurements of neutron skins by neutron-removal reactions, the dipole response and dipole polarizability, which both provide independent constraints on the density dependence of the symmetry energy close to saturation. These measurements will be complemented by studying short-range correlated nucleon pairs for asymmetric nuclei, properties of the hyperon interactions, as well as heavy-ion collisions, all providing information at higher densities. The different programs are being started already by first pilot experiment during FAIR Phase-0. A systematic study of neutron-proton flow in heavy-ion collisions at different energies is foreseen to run in the year when R^3B starts to move to the FAIR site. Another application of quasi-free scattering we want to highlight here, the determination of fission barriers for heavy neutron-rich isotopes, providing invaluable information for the understanding of the development of fission barriers towards neutron-rich nuclei, which provide the basis to test theories used to compute crucial input for the r-process nucleosynthesis modelling.

The development of the R^3B research program will be in line with the recommendations provided by the Committee for First-Science and Staging Review of the FAIR Project. These recommendations include as first priority the completion of the Super-FRS to provide radioactive beams for the HEB cave, the next high-priority stage is the completion of SIS100 providing beams for the S-FRS and the HEB cave. This scenario includes all technical conditions necessary to perform the R^3B research program for early and first science cases. Based on the present project time line it is planned to start dismounting our experimental set up (Cave C) in Q3-Q4 2025, in order to be ready to host early-science experiments end of 2027. An efficient use of the available beamtime will be ensured with the realization of the experiment ASY-EOS II during the moving period in 2025/26.

The R^3B Early-science research program will be performed at the HEB with SIS18 beams and Super-FRS operational. R^3B will operate at large acceptance with some restrictions (i.e. CALIFA, Si-Tracker and NeuLAND will not be 100% complete). Already in this stage a tremendous increase in secondary-beam intensity from the separator is expected, thanks to the larger acceptance, and an optimized transmission to the HEC). All programs outlined above will be developed during this phase. For instance, already in this initial stage, R^3B will be able to provide the most precise and accurate determination of the neutron-skin thickness of a heavy neutron-rich nucleus, providing a constraint on the EoS with an accuracy significantly better than the result from the PREX experiment at JLAB.

In the following years the R^3B large-acceptance setup is expected to be completed (assuming funding availability). R^3B first science with the availability of SIS100 beams at nominal intensity will represent an increase in luminosity that in combination with a fully operational Super-FRS will allow to access the most exotic isotopes, e.g., $\underline{^{136}\mathrm{Sn}}$ or ^{218}Pb, for SRC studies and other high-energy reaction studies including the completion of the EoS programs mentioned above.

Super-FRS experiment collaboration

The scientific cases of the Super-FRS EC are based on experiments that use the unique characteristics of (Super-)FRS, as it is described below. The experimental program includes new physics opportunities such as studies of exotic atoms, exotic hypernuclei, delta resonances in exotic nuclei, new exotic radioactivity modes, the importance of the tensor component of the nn-interaction, determination of nuclear radii, the atomic interaction of highly-charged ions of heavy elements, high-momentum nucleons in nuclei, and equation-of-state of cold asymmetric nuclear matter. It also includes stretching the frontiers of physics by search for new isotopes and isomers.

The key of all proposed activities is that they exploit the separator-spectrometer capabilities of the (Super-)FRS. Thereby, various combinations of the magnetic sections of the pre- and main-separator of the Super-FRS can be operated in dispersive, achromatic or dispersion-matched spectrometer ion-optical modes, which allow measurements of momentum distributions of secondary-reaction products with high resolution and precision. This feature is a key ingredient of the various proposed experiments and can be ideally fulfilled using the symmetric branch ending at FHF1, even though a similar ion-optical performance can be achieved also at other achromatic focal planes, e.g., FHF2, FLF2/3 and FRF3 assuming the needed set of detectors towards and at these focal planes are available and space is enough for equipment specific for the experiment.

Several of the experiments of the collaboration use new and dedicated targets and detector setups in addition to standard equipment needed for PID and isotope separation. This equipment needs to be placed typically at FMF2 and/or at the final achromatic focal plane. At the mid-focal plane FMF2 secondary targets (i.e., ^{12}C, Ice, Liquid-Hydrogen, deuteron-target) are foreseen. These targets are surrounded and followed by experiment-specific detectors, e.g., for tracking, decay or Z determination in addition to the standard detectors of the Super-FRS. At the final focal planes, the standard equipment (PID detectors, degraders and slits), Ion Catcher, and for some experiments some dedicated smaller detectors (MWDC, Cherenkov, additional ToF) will be used. Therefore, the complete science program of the Super-FRS EC can in principle be achieved with the early science + configuration with the detectors installed at FMF2 (secondary target, Super-WASA (designed to fit at FMF2), EXPERT), at FRF1 (EXPERT, just space for a neutron detector needed) and FHF1 (standard detectors, Ion Catcher, special detectors for Super-WASA). One main constraint from the early science + configuration comes from the changeover between different mechanical configurations. During this time, the Super-FRS is blocked and no experiment can run. Thus, one should consider the possibility to keep the WASA program at the FRS for the time being to have more flexibility for the science program at the Super-FRS.

Phase-0 in 2025 to 2027

We will continue the scientific program at GSI, to keep the collaboration together and the know-how sustained. For our collaboration, it is rather easy to come up with unique science cases for this period at the FRS.