Proposal and conceptual design of a direct beam line from SIS18/FRS/ESR to the HESR – G2H

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Executive Summary

The G2H beam line proposed in this document provides a second connection between the existing GSI facilities SIS18/FRS/ESR and FAIR. This connection is independent of other FAIR facilities and can be completed significantly earlier, allowing for physics experiments in HESR before 2025. Even after the commissioning of the full MSV, the G2H beam line will remain very useful, allowing for parallel operation of HESR independent of other FAIR facilities.

The cost of the G2H beam line is estimated as 12 million Euros. The civil construction for the standard MSV is not affected. The impact on the overall FAIR Accelerator execution is minimized by utilizing standard FAIR components as much as possible.

Only in the case of a significant delay of the CR building, a temporary installation for providing the technical infrastructure for bringing HESR to operation would be necessary. The additional costs for this provisional infrastructure are estimated to an amount of 15 to 20 million Euros.

In summary, the realization of G2H beam line and HESR enables the start of physics at FAIR at the beginning of 2024. In addition, the physics program at the GSI facilities is not affected.

Proposal and conceptual design of a direct beam line
from SIS18/FRS/ESR to the HESR – G2H

Draft January 29, 2019

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1 Introduction

Perspectives for the realization of early experiments at FAIR were discussed in 2014. A task force, established at that time, identified a cost-efficient solution, which could enable the first FAIR physics experiments already in 2019, i.e. a few years before SIS100 could deliver beams to FAIR experiments.

The work done by that group was presented in workshops[1], to the Joint Scientific Council in October 2014, to the FAIR-MAC in April 2015 and summarized in an activity report by B. Franzke. A new beam line was proposed, which allows for the injection of beams from SIS18 or ESR directly to the HESR. Also, sufficiently long-lived nuclear fragment beams from FRS could be available after cooling and accumulation in ESR. The beam line would also be important after SIS100 being commissioned: either for time-sharing with other FAIR experiments or during a shutdown of SIS100 due to maintenance work.

The approach presented here is the updated version of the 2014 proposal. Since the plan for an extension of Cave C has been dropped, the beam transport could be simplified and improved. In addition, we decided to reduce the maximum bending power of the magnetic elements from 13 Tm to 10 Tm to adapt to the ESR maximum bending power. Furthermore, we envisaged a different injection point at HESR, and actualized time schedule and cost estimates. This scenario is now named as **G**SI-to-**H**ESR beam line, a.k.a. G2H.

1 http://indico.gsi.de/conferenceDisplay.py?confId=2941, also discussed at HIC for FAIR workshop, Hamburg, Germany, 2015 (presentation by Y. Litvinov), https://indico.gsi.de/event/3368/

2 Requirements for the direct injection to HESR from SIS18/ESR/FRS

The following design requirements were defined in 2014 and verified and updated during the latest study:

- Ion beams from SIS18, ESR and FRS should be available in the HESR. In particular, the availability of nuclear fragments (RI-beams) generated in the FRS after cooling and possibly accumulation in the ESR would significantly enhance the experimental possibilities at HESR.
- The maximum magnetic rigidity of the ion beams should be 10 Tm. The rigidity of the antiproton beam cooled in the CR to be injected on the east side of the HESR is 13 Tm. Thus, for the injection of ion beams from the target hall, the design of the pbar injection could be adopted without changing the technical specifications of all necessary components.
- For the desired variation of ionic charge states, the existing stripper station (upstream in GTH4) is re-activated.
- The existing experiment sites in ESR Hall and Target Hall should be affected as little as possible by the new beam line. Beam time sharing with other experimental sites in the Target Hall (e.g. HADES and R3B) would also be essential for the preparation of the FAIR experiments until their move to the final position at FAIR.
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The main beam parameters for the direct connection G2H line are given in Table 1.

Table 1: Beam parameters for the direct connection of HESR to SIS18/FRS/ESR.

Beam parameters at the SIS18 exit			
Magnetic rigidity		≤ 10	Tm
Max. specific ion energy for HESR	$^{238}U^{92+}$	555	MeV/u
	$^{20}Ne^{10+}$	833	MeV/u
	proton	2200	MeV
Transverse beam emittances $\varepsilon_x, \varepsilon_y$	uncooled	$\approx 5\times10^{-6}$	rad m
	cooled at inj.	$\approx 1\times10^{-6}$	
Relative momentum width $\delta p/p$	uncooled	$\pm1\times10^{-3}$	FWHM
	cooled at inj.	$\pm1\times10^{-3}$	
Maximum number of U-ions per bunch & shot		1×10^{9}	
Time between successive shots		≥ 60	s
Beam parameters at the ESR exit			
Magnetic rigidity		≤ 10	Tm
Max. specific ion energy for HESR	$^{238}U^{92+}$	555	MeV/u
	$^{20}Ne^{10+}$	833	MeV/u
Transverse beam emittances $\varepsilon_x, \varepsilon_y$		$\leq 1\times10^{-6}$	rad m
Relative momentum width $\delta p/p$		$\leq 5\times10^{-4}$	FWHM
Accepted beam parameters at HESR injection (acceptance)			
Magnetic rigidity		≤ 10	Tm
Transverse beam acceptances A_x, A_y		$\leq 2\times10^{-5}$	rad m
Relative momentum acceptance $\Delta p/p$		$\leq 5\times10^{-3}$	

3 Layout

After detailed investigations of different source points for the G2H beam line, the branch in the control area NE8, immediately before the CRYRING Cave, was chosen. Other locations have serious disadvantages with respect to costs or interference with the existing experimental sites. The beam line layout proposed in 2014 was taken as a starting point and optimized taking into consideration that Cave C will not be expanded.

The conceptual layout of the G2H beam line is presented in Figure 1. The approximate length between NE8 and the injection point at HESR is 65 m. The G2H tunnel will be a separate control area NE15 with a dedicated access maze. R3B and CRYRING experiments will not be affected by the new beam line.

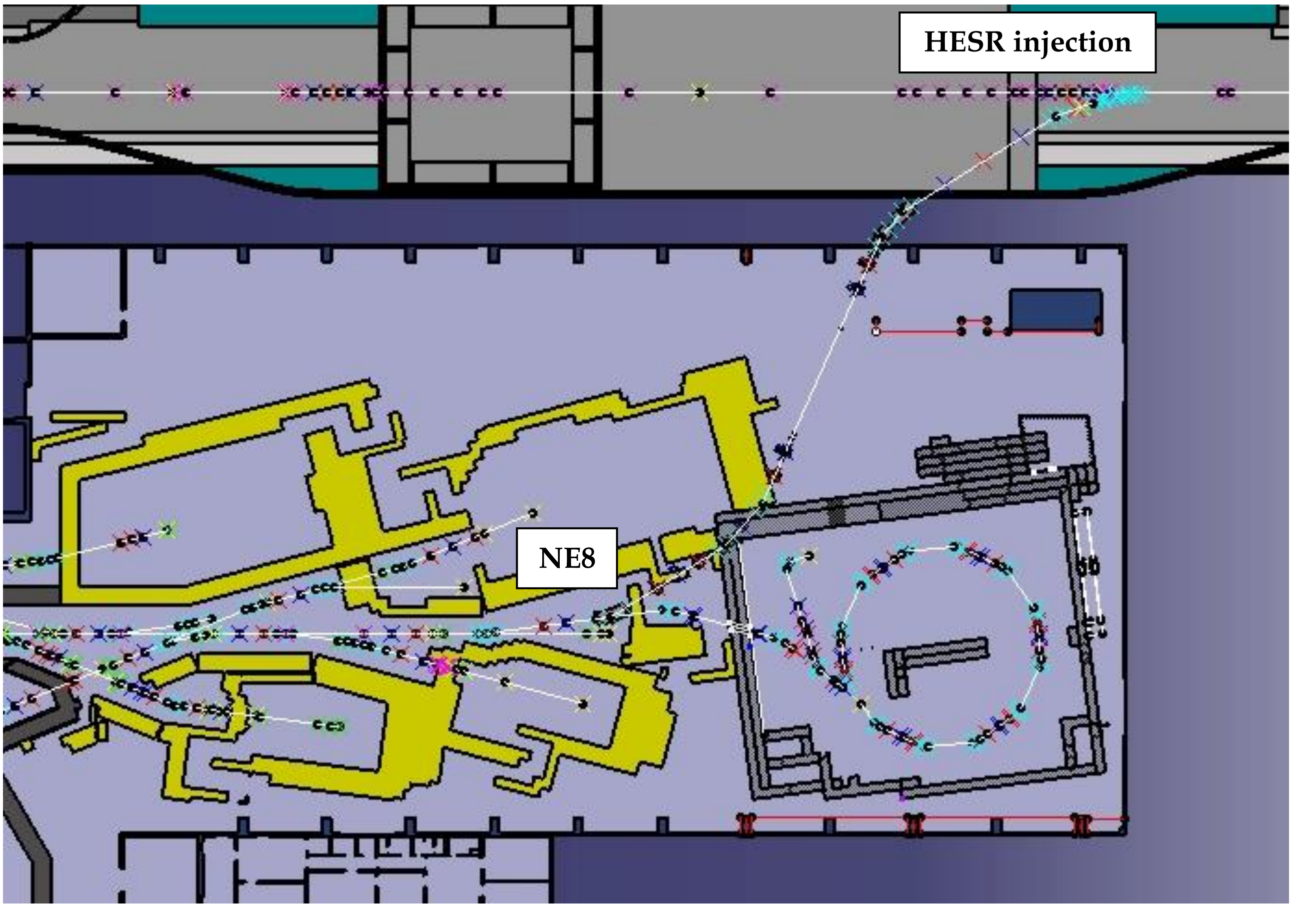


Figure 1: Conceptual layout of the new G2H beam line between the branching point in NE8 control area of the Target Hall and the injection point at the HESR.

The necessary concrete shielding of the beam line was calculated using FLUKA. A wall thickness of 1.5 m is required in places, where 1% of the beam (one bunch per minute with a maximum of 1×10^9 uranium ions at 600 MeV/u) is lost. However, it is proposed to equip the full length of the tunnel with 1.5 m thick concrete walls and ceilings. The shielding will be realized using concrete blocks to enable partial removal in case items from the east part of the hall have to be transported across the beam line tunnel. In that case the respective beam pipe sections would be removed as well.

The construction measures outside the target hall, consisting of a 6 m long traverse to the outer wall of the HESR building and a channel through the HESR building shell, will require corresponding changes in the HESR building plan.

The ion-optical layout of the complete beam line between NE8 and the injection point at the HESR is illustrated in Fig. 2.

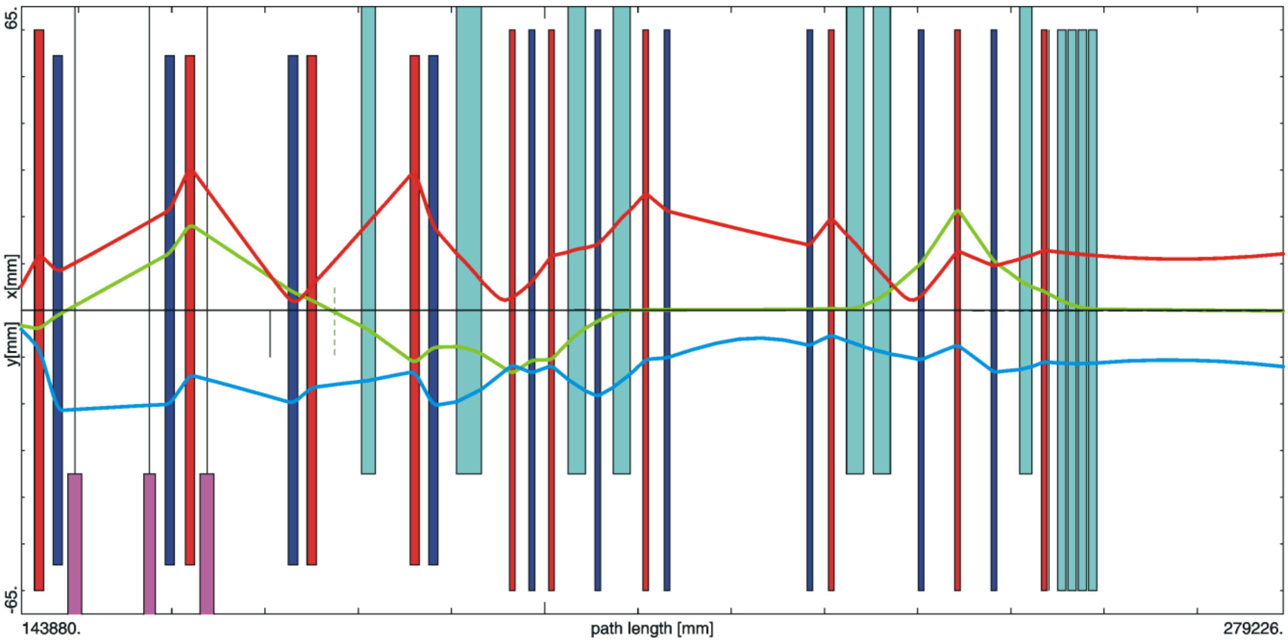


Figure 2: Ion-optical calculation of ion beam envelopes from NE8 to the injection point at the HESR for the beam path shown in Fig. 1.

4 Magnets

The G2H layout shown in Fig. 1 requires 12 quadrupoles, 3 vertical steerers and 6 (or 7) dipoles. The quadrupoles are based on short HEBT quadrupole design. The steerers are based on the standard HEBT design. The dipoles are:

- 24.5°- switching dipole with opening for the straight beam to CRYRING and with zero-field coil. Potentially this magnet could be split into two.
- Four dipoles with bending angle of 17°, which could be powered in pairs.
- One dipole with bending angle of 12.02°.

The costs for the magnets were calculated by C. Muehle and Chr. Will in January 2019. It includes design, stands and alignment feet, tools, material, production, documentation and magnetic measurements. It also includes the series effect, manufacturer's risks and benefits. The cost breakdown is shown in Table 2.

Table 2: Costs of magnets required for the G2H beam line.

24.5° switching magnet	419.250 €
17° bending magnets (x4)	972.600 €
12.02° bending magnets	210.600 €
12 quadrupole magnets	736.800 €
3 magnetic orbit correctors (steerers)	117.000 €
Total costs	2.456.250 €

The injection system for HESR requires 4 magnetic septum magnets and 6 ferrite kicker magnets. The cost estimate for the whole system is given in Table 3.

5 Cost Estimate

In numerous interviews with heads of accelerator departments and experts in construction and technical infrastructure, the necessary information required for a reliable cost estimate of the project was compiled. The willingness of the colleagues, despite this unconventional way of getting very quick and careful reliable technical specifications and cost estimates, is acknowledged gratefully. The results are summarized in Table 3. The cost figures in Table 3 are based, among other things, on the following assumptions agreed with plant managers and other experts:

- The magnetic power supplies with control electronics can be installed on the roof of the CRYRING-Cave.
- The electronics for beam diagnostics and vacuum can also be accommodated in the containers on the roof of the CRYRING-Cave.
- All cable lengths and the costs for cable material and installation could be taken into account almost exactly by designating installation spaces.
- The electrical power required for the transport channel was already ensured in the year 2014 by purchasing an additional transformer (2.5 MVA) for the CRYRING.

Detailed documents for determining the amounts listed in Table 3 will be made available in the case of entry into technical planning.

Table 3: Cost estimate for the beam transport channel from the source point in the control area NE8 (see Fig. 1) to the HESR. The table is updated with respect to the presentation at the HESR workshop in 2014.

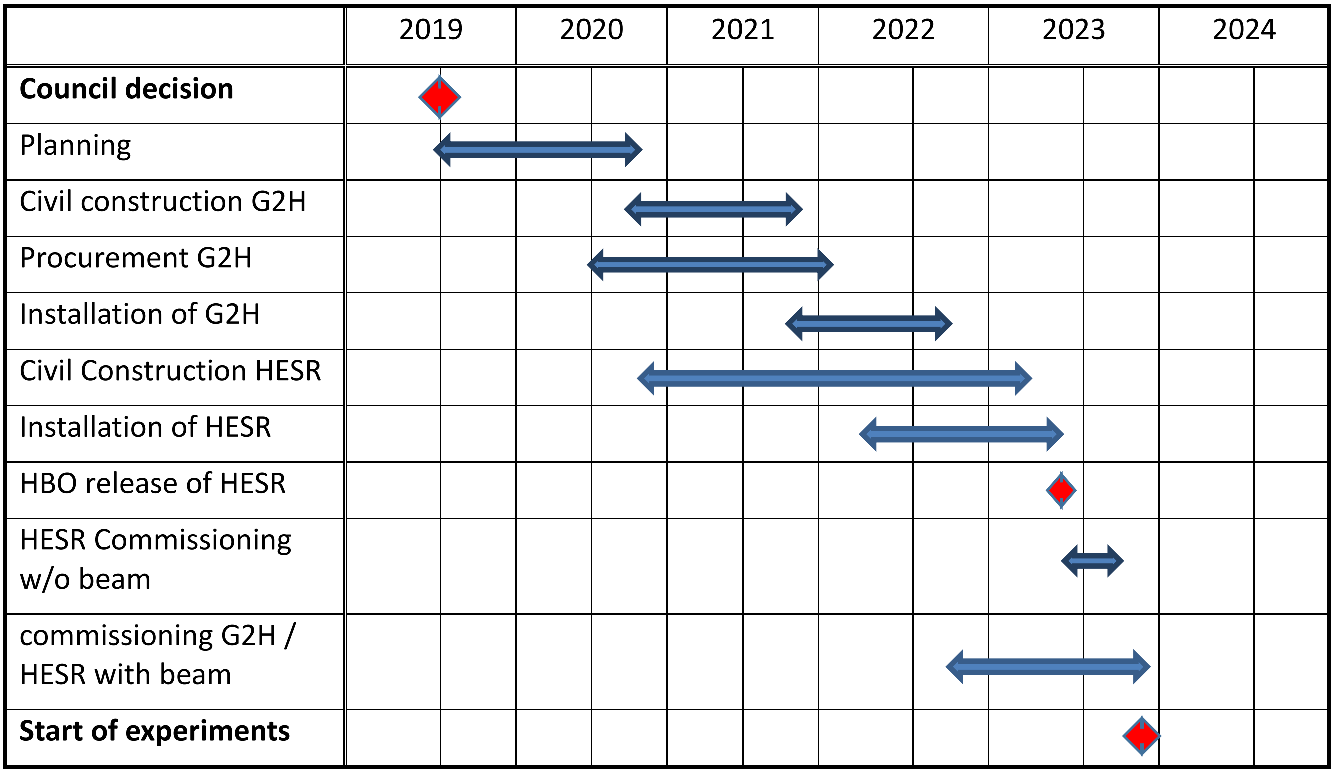
Construction measures outside the TH and at the HESR building	2,000.000 €
Beam guidance tunnel from NE8 to the eastern wall of the TH	150.000 €
Injection to HESR incl. power supplies	4.800.000 €
Magnets (dipoles, quadrupoles, steering)	2.456.250 €
Magnet power supplies incl. cables to magnets	1.287.000 €
Additional cost needed for 400V line	40.000 €
Beam diagnostics incl. cabling and hardware for computer control	600.000 €
Vacuum equipment	500.000 €
Alignment	36.000 €
Assembly material	50.000 €
Hardware for computer control (excl. beam diagnostics)	50.000 €
Technical infrastructure (cable routes, compressed air)	50.000 €
Cooling water	500,000 €
Radiation protection, access control, interlock systems, etc.	150.000 €
Total costs	12.169.250 €

The final design of the G2H beam line will use as many components as possible that are already designed or even ordered for the High Energy Beam Transport (HEBT) of FAIR The dipole magnets in Table 2 will be designed with the same cross section as HEBT dipoles, so that the same lamellas can be used, only the coil design and construction has to be adopted to the changed geometry.

This could significantly avoid the cost of planning and manufacturing new components and make the procurement more efficient.

6 Time Schedule

The proposed schedule is visualised in Table. 3. It assumes that the decision is taken in June 2019. It also assumes a current schedule for execution of MSV (including CR building). In the course of this study it was found that it is not possible to accelerate this schedule. It is recommended to follow it. In the proposed scenario the first experiment on HESR could be conducted in the beginning of 2024.



7 Operation of the HESR without the CR building

The technical infrastructure (cooling water, heating, phone lines etc.) and 15 MW of electrical power needed to operate HESR are planned to come from the CR building to the HESR building. Currently, the CR building is optional. In an unfortunate scenario, its construction might be delayed. In this case, the costs for an alternative supply concept were studied by the FAIR Site and Buildings (FSB) group. The initial estimate is about 25 to 30 million Euros, however a significant part of it (about 10 million Euros) could be deduced from the MSV cost (some constructions/hardware items can be re-used). Therefore, effectively the total additional cost of delayed construction of CR building would be about 15 to 20 million Euros.

8 Summary

The G2H beam line proposed in this document provides a second connection between the existing GSI facilities SIS18/FRS/ESR and FAIR. This connection is independent of other FAIR facilities and can be completed significantly earlier, allowing for physics experiments in HESR well before 2025. Even after the commissioning of the full MSV, the G2H beam line will remain very useful, allowing for parallel operation of HESR independent of other FAIR facilities.

The cost of the G2H beam line is estimated as 12 million Euros. The civil construction for the standard MSV is not affected. The impact on the overall FAIR Accelerator execution is minimized by utilizing standard FAIR components as much as possible.

The installation of the G2H beam line will not affect the rest of the FAIR MSV, since civil construction and installation of HESR are following the Master schedule, and the G2H installation can be performed during GSI shutdown periods.

Only in the case of a significant delay of the CR building, the costs of required temporary technical infrastructures for bringing HESR to operation would be increased by an estimated amount of 15 to 20 million Euros.

In summary, the realization of G2H beam line and HESR enables the start of physics at FAIR at the beginning of 2024. In addition, the physics program at the GSI facilities is not affected.

9 Acknowledgement

Authors would like to thank multiple persons especially the FSB group and leaders of various departments for their input to the cost estimation.