Status of the Super-FRS project at FAIR

H. Simon, M. Winkler,
GSI Darmstadt
FAIR construction

Connection SIS18 to SIS100

SIS18 shielding

Power station north
Connection SIS18 to SIS100

(photo: G. Otto, GSI)
Synchrotrons: 1.1 km
HESR: 0.6 km
With beamlines: 3.2 km

Total area > 200 000 m²
Area buildings ~ 98 000 m²
Usable area ~ 135 000 m²
**Volume of buildings** ~ 1 049 000 m³
Substructure: ~ 1500 pillars, up to 65 m deep
Procurement of FAIR accelerator components is progressing well...

- Accelerator and detector contributions from many different partner institutions
What are the limits for existence of nuclei?
   Where are the proton and neutron drip lines situated?
   Where does the nuclear chart end?

How does the nuclear force depend on varying proton-to-neutron ratios?
   What is the isospin dependence of the spin-orbit force?
   How does shell structure change far away from stability?

How to explain collective phenomena from individual motion?
   What are the phases, relevant degrees of freedom, and symmetries of the nuclear many-body system?

How are complex nuclei built from their basic constituents?
   What is the effective nucleon-nucleon interaction?
   How does QCD constrain its parameters?

Which are the nuclei relevant for astrophysical processes and what are their properties?
   What is the origin of the heavy elements?
Main Objectives

Increase in primary beam intensity

Matched with acceptance and selectivity of a versatile Separator: Ion optics and instrumentation ...

⇒ Experiments
GSI FRS $\rightarrow$ FAIR Super-FRS

H. Simon • EMIS2018
Location of experiments

Super-FRS collab. parts from HISPEC / R³B

to storage rings ILIMA, EXL,...

3rd waiting point

r-process path

MATS / LaSpec

Cryogenic stopping cell

HISPEC/DESPEC

100m
## NUSTAR – The project 1.2

<table>
<thead>
<tr>
<th>PSP</th>
<th>Experiment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2.2</td>
<td><strong>HISPEC/DESPEC</strong></td>
<td>In-beam $\gamma$-spectroscopy at low and intermediate energy, $n$-decay, high-resolution $\gamma$, $\beta$, $\alpha$, $p$, $p^*$, <strong>spectroscopy</strong></td>
</tr>
<tr>
<td>1.2.3</td>
<td><strong>MATS</strong></td>
<td>In-trap <strong>mass measurements</strong> and decay studies</td>
</tr>
<tr>
<td>1.2.4</td>
<td><strong>LaSpec</strong></td>
<td><strong>Laser spectroscopy</strong></td>
</tr>
<tr>
<td>1.2.5</td>
<td><strong>R$^3$B</strong></td>
<td>Kinematically complete <strong>reactions</strong> with relativistic radioactive beams</td>
</tr>
<tr>
<td>1.2.6</td>
<td><strong>ILIMA</strong></td>
<td>Large-scale <strong>scans of mass and lifetimes</strong> of nuclei in ground and isomeric states</td>
</tr>
</tbody>
</table>

| 1.2.10 | **Super-FRS Exp** | **High-resolution spectrometer** experiments                                |
| 1.2.11 | **SHE**           | Synthesis and **study of super-heavy elements**                             |
| 1.2.8  | **ELiSe(\*)**    | Elastic, inelastic, and quasi-free $e^--A$ **scattering**                    |
| 1.2.9  | **EXL(\*)**      | **Light-ion scattering** reactions in inverse kinematics                     |

\(\text{(*) NESR required – alternative/intermediate “operation” within MSV under discussion. SHE physics case to be evaluated.}\)
Definition of NUSTAR experiment phases

- **Phase 0 (2019 … )**
  - R&D and experiments to be carried out with present facilities and FAIR/NUSTAR equipment

- **Phase 1 (2025 … )**
  - Core detectors and subsystems completed
  - First measurements with FAIR/Super-FRS beams
    - Carry out experiments with highest visibility as part of the core program and within the FAIR Modularized Start Version (MSV)

- **Phase 2**
  - FAIR evolving towards full power
  - Completion of experiments within MSV
    - Essentially the full program of MSV can be performed

- **Phase 3**
  - Moderate projects, which have been initiated on the way (outside MSV) can be included (e.g. experiments related to return line for rings)

- **Phase 4**
  - Major new investments and upgrades for all experiments
Schematic Layout

- **Energy (MeV/u)**
  - FAIR-Super-FRS
  - RIBF / FRIB

- **Z**

- **Q-Z 95%**

- **Diagram Labels:**
  - Energy Buncher
  - Magnetic Spectrometer
  - Low-Energy Branch
  - High-Energy Branch
  - Ring Branch

- **Notation:**
  - Pre-Separator
  - Degrader 1
  - Degrader 2
  - Beam Catchers
  - Focusing System
  - Driver Accelerator

- **Scale:**
  - 20 m
Schedule is governed by magnet production.
• Collaboration between CERN and GSI
  ➢ CERN Build. 180: Infrastructures, renovation
• Cold (4K) testing of the SC dipoles and multiplets
  ➢ 3 test benches,
  ➢ incl. magnetic field measurements
• Addendum to collaboration agreement
  • Covering operation phase 5.5 years
  ✓ Signed January 2018
• Facility commissioning ongoing
  ➢ FoS multiplet expected for 10/18
Sc Magnet testing facility (Bât. 180)
Scope:
• 8 short multiplets (PS)
  ➢ QS configuration
• 25 long multiplets (mainly MS)
  ➢ Quadrupol triplet
• include corrector elements & steerer

Main characteristics:
• iron dominated, cold iron (up to 37 tons)
• common helium bath
• warm beam pipe (38 cm inner diameter)
• individual powering, max. current <300A

Schedule FoS SC multiplets
✓ Contract closed 07/2015 (ASG, Genova)
✓ Design phase for SM and LM done
  ✓ FDR 12/16
  ✓ PRR SM 07/17
  ✓ PRR LM 12/17

• Construction phase for FoS running
  ➢ FAT FoS SM 09/18
  ➢ shipment CERN 10/18,
  SAT FoS SM 03/19
FOS short Multiplett production

- All coils produced (quadrupol, sextupol)
  - vacuum impregnated
  - electrical integrity tests
- Laminations punched (sub-provider)
- Yoke assembly tool manufactured
- Yoke assembled (short quad, sextupole)
- CL prototype qualified (20 bar, M&W)
  - CL for FoS SM manufactured
  - Thermal shield manufactured
  - LHe vessel manufactured
  - Vacuum vessel manufactured
  - Assembly bench manufactured (subprovider)
  - Final assembly ongoing
Sc Dipole Magnets

Scope
- 3 units 11°, 18 units 9.75° + support
- Warm iron, SC coil
- Aperture ±190mm x ±70mm
- Weight: 50 to 60 ton

Collaboration with CEA, Saclay:
✓ TCC signed, includes:
  ➢ Detailed design, CDR, Spec, 3D Model
  ➢ Technical follow-up

Tender Status:
✓ Announcement published April 2017
✓ Qualifying submission closed mid May 2017
✓ Offers received by mid July 2017
✓ 1st round negotiation closed mid November 2017
✓ 2nd round negotiation closed Jan. 22, 2018
✓ Contract award Feb. 8, 2018
✓ Kick-off: March, 1, 2018
• FDR expected Q3/2018
• FAT of FoS expected Q2/2019

H. Müller, E.J. Cho et al.

H. Simon ● EMIS2018

manufacturing plant ELYTT, Bilbao Spain
Branching Dipole Magnets

Schedule (R&D work):

- Collaboration agreement with CEA/Saclay
- Detailed design, CDR, Spec, 3D Model
- Kick-off meeting 06/2017
- PDR 12/2017
- FDR 09/2018
- Final Report, Detailed Specs 10/2018
- FAIR tender directly after

PDR/FDR status

- Geometry (yoke, coil, cryostat)
  - Bdl achieved, I adopted
  - magnetic field quality, chamfers included
- Assembly Scenario
- Thermal behavior after cool-down
  - 2 active thermosiphon loops foreseen
  - use heaters to force flow direction
  - design modification done
  - thermal budget simulated
  - thermosiphon experimental mock-up
- Magnetic interference
  - Fringe field evaluated
  - Interference study started

H. Müller, E.J. Cho et al.
Many systems in progress

Super-FRS

- Production of First-of-Series sc multiplets running
- CERN magnet testing facility ready for operation
- sc standard dipole contract signed (Elytt Bilbao, Spain), CDR done
- sc branched dipole design phase running with (CEA Saclay, France), CDR done
- Quench detection prototype board developed
- Detectors (MUSIC) contract is signed
- FAT of First-of-Series y-slits successfully passed
- CDR beam catchers successfully passed
- Handling of target area components (shielding plug concept) verified
- Agreement with BINP to build radiation resistant dipole magnets
Beam Instrumentation (e.g. ΔE and ToF)

- MUSIC (energy-loss, Finnish in-kind)
  - Specification approved Q1/2017
  - 1st IKC for Super-FRS signed!
    - Field cage subcontracted to GSI
  - Kick-off meeting done
    - Schematic design presented
    - Schedule for design phase and FoS development agreed (ready Q3/19 → beam test if possible)
  - PreAmps by CEA Bruyeres
    - Successfully tested at beam time in 2016
    - Contract waiting for signature (CEA)

- Time-of-Flight (Russian in-kind, IOFFE StP)
  - Specification approved Q3/2016
  - IKC drafted Q3/2017
  - Responses from IOFFE 02/17 & 08/18, many proposed changes, still under negotiation

- R&D on diamond and silicon ongoing
Civil Construction
(Overview)

Build. 018
(Target building)

100 m

Build. 006
(HE cave)

Build. 006a
(Service building)

Build. 006b
(LEB cave)

Tunnel 103

July 4, 2017

CC planning Phase 1-4 done
✓ equivalent to LP5 (execution planning)
✓ LEB cave integrated to full extend
✓ interfaces to ‘machine’ defined
Logistic planning & Installation planning running
Construction area south (NUSTAR and other):
• Preparation of tender documents running
  ➢ review of contract specifications ongoing
✓ partly tender already running (e.g. conveyor tech.)
Civil Construction
(Building services)

- Complex technical building infrastructure!
  - Cable data base updated 09/17
  - Power & ventilation demands finalized
  - Collision checks done
Cable cost becomes sizeable (hundreds of km)!
Inconvenient cable path length.

Avoid cabling to single Central DAQ System ➔
Distribution System
Super-FRS and experiments @ FAIR

NUSTAR DAQ TDR accepted 2018 by ECE
https://edms.cern.ch/document/2024803/1

Experiments on large scale

- Couple local DAQ systems to one system
- Run common dead time and time stamped systems together
- Avoid specific (signal) cabling in between caves

Experiment Areas („Caves“) separated by several 100m.

Collector Ring
White Rabbit time distribution timestamps and reference clocks for ToF meas.

Precision clock Distribution

and

event stamping (Example MBS, N.Kurz)
White Rabbit time distribution timestamps and reference clocks.

R³B @ Cave-C (phase-0)

White Rabbit core team:
D. Beck, M. Kreider, C. Prados, S. Rauch, (W. Terpstra,) M. Zweig

EE: Jan Hoffmann: Design of White Rabbit Timing Receivers
Joern Adamczewski-Musch: Linux device drivers
Jochen Fruehauf: VFTX, MBS TOF setups
Nik Kurz: System Integration (MBS)

Open Hardware open firmware
System Check:
WR timestamps/clock & FPGA TDC (VFTX)

time difference between 2 channels fed in identical VFTX:
7.8 ps (RMS)

time difference between 2 channels fed in different VFTX:
22 ps (RMS)

trending of average time differences between 2 channels fed in identical VFTX
(each entry is average of 1000000 TOF measurements)

trending of average time differences between 2 channels fed in different VFTX
(each entry is average of 1000000 TOF measurements)
Firmware for measurements

FPGA TDCs with many applications

The 10-ps Wave Union TDC:
Improving FPGA TDC Resolution beyond Its Cell Delay
Jinyuan Wu and Zonghan Shi
IEEE Nuclear Science Symposium Conference Record, 2008. NSS '08.

In particular useful for our community
• COTS (limited ASIC developments – PADI preamp./disc.)
• Firmware can be ported to newly appearing hardware
• excellent resolution allows for ToT measurement with good
  A/QDC performance – Multihit capability !!!
Application: Sci. Based ToF/ΔE system for RIBs

Performance:

- Time resolution $\sigma_t / t = 2E-4$ ($\Leftrightarrow \sigma_t = 20$ ps for 20 m flight path at 1 AGeV)
- Energy resolution $\sigma_E / E = 1\%$
- High-counting rate capabilities (~1 MHz)
- Large dynamic range (up to Pb-U).
- FPGA based TDC readout ($\Delta E$ via ToT Techniques)

Excellent time and energy resolution at highest rates (multihit time meas.)

<table>
<thead>
<tr>
<th>Rate / kHz</th>
<th>$\sigma_t / \text{ps}$</th>
<th>$\sigma_{\text{det}} / \text{ps}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>41</td>
<td>14</td>
</tr>
<tr>
<td>59</td>
<td>41</td>
<td>14</td>
</tr>
<tr>
<td>375</td>
<td>45</td>
<td>16</td>
</tr>
<tr>
<td>1000</td>
<td>64</td>
<td>23</td>
</tr>
</tbody>
</table>

M. Heil et al.

- Size: 120 x 100 cm$^2$
- No light guide, PMT R8619 coupled directly to scintillator

Detector layout

Prototype studies

R$^3$B @ Cave-C

2014/2016
Summary

• Civil Construction of FAIR facility has started
• Project in full swing, major components in procurement phase
• SC Magnets & Testing (most time critical items):
  ➢ Standard dipoles: contract awarded Feb 2018, design about to be finalized
  ➢ Multiplets: design phase done; manufacturing of FoS SM: last steps
  ➢ Testing@CERN: contract addendum signed, commissioning of cryo-facility running, FoS SM expected in 10/2018
• Development and procurement of various other components under way
• Civil Construction execution planning finalized; tender documentation in preparation, building services planning running
• Distributed Instrumentation for PID and related DAQ concept
  ➢ FPGA TDC application for TOF and energy loss measurements

Thank you for your attention!
Lightweight implementation: time distribution, triggers, scalers, timestamps and reference clocks.

TRLOII/TRIMI
Incl. serial timestamps, no length compensation

```
Set the TRLO II to generate triggers and respect the TRIMI deadtime:
trloctrl --addr=2 --clear-setup \n
"period(1)=10us" "TRIG_PENDING[1]=PULSER(1)" \n
"DEADTIME_IN(1)=TRIMI_TDT"
```

Håkan T. Johansson, Chalmers, Göteborg
Liverpool, November 2013

With thanks to: J. Hoffmann, J. Frühauf, W. Ott, N. Kurz, H. Simon, A. Henriques, M. Heil, B. Löher, A. Charpy, C. Forssén...
Trigger & Timestamp
Distribution via „any“ cable
Open Firmware !
(http://fy.chalmers.se/~f96hajo/trloii)
→ FPGA friendly
→ Works e.g. in LUPO @ RIBF
(see RIKEN docu)
(implementation and testing in less than a week,
NeuLAND @ RIBF campaign)
Magnets
(Radiation Resistant Magnets)

- 3 dipole, 3 quadrupole, and 2 sextupole
- Normal conducting magnets using MIC cable
- Remote connectors and alignment

✓ Prototype dipole built and tested by BINP
✓ Dedicated support structure constructed
✓ Dipole: specification released
  ➢ FAIR procurement
  • tender not yet started, discussion with RU
• Two further specification in preparation
  ➢ DS for QQ
  ➢ DS for QS, includes pump port

Installation of NC magnets within the target-area shielding

QQ after target chamber
QS plus pump port
Target Area (Beam Catcher Plugs)

- 3 BC station equipped with two absorber each
- Indian in-kind, Collaborator: **CMERI Durgapur**
- Design running, based on definition report
  - absorber geometry optimized
  - use C/Cu (fast/slow extraction) → avoid Be
- CDR released 12/17
  - build a absorber mock-up verify RH capability
  - DS in preparation (Q2/2018)
  - in-contract preparation (Q4/2018)
- India started company qualifying phase (Q4/2018)

**BC plugs weight: 7.5 ton**

Absorber and assembly sequence (RH)
Target Area
(Shielding Flask)

✓ Specification ready for approval
  • all dimensions finalized → interface HC finalized
  • internal crane with automatic gripper; load 9 ton
  • shielding: design goal is 10mSv/h on surface
  • includes traverse platform with shielding plate
    ➢ allows for 90° rotation for position adjust
  • MoU between Finland, KVI, PS, GSI in preparation
    ➢ to be signed Q2/2018
✓ in-kind contract with Finland to be established

Traverse platform:
dim: 8.700mm x 3.000mm x 300mm
weight: 19.5 ton
**Target Area**
(Plug System)

- **Target Plug**
- **Detector Plug**
- **Collimator**

**Target wheel plug (details)**
- 4.2 ton (heaviest plug)
- includes target ladder (6 position)
- 2 linear drives + TW motor
- active cooling

**Plug test setup**
Scope
• in sum ~250 PC required
  ➢ 9 PC with high-power (up to 500 kW)
  ➢ other PC medium-power for SC magnets
• Voltage range: from 30V to 745V
• Current range: from 15A to 1.480A

Features
• common topology proposed
• energy recovery system
• all PC are bipolar
• PC include Active Power Correction Factor
• Two different DC voltages for ramp and flat-top
• **QD electronics integrated within the PC rack**
• Output filter, switching frequency up to 90kHz
  ➢ very small current ripple

Status
✓ in-kind (Council) of India
✓ Specifications released (2017)
• Prototype PC under construction
  ➢ FAT expected Q3/2017
  ➢ SAT Q4-18/Q1-19, with CERN FoS SM
• In-kind contract thereafter

A. Wiest, W. Freisleben et al.

H. Simon • EMIS2018