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Simulations of the High-Energy Beam-Transport (HEBT) section at FRANZ

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Summary. — The neutron source FRANZ (Frankfurter Neutronenquelle am Stern-Gerlach-Zentrum), which is currently under construction, will be the neutron source with the highest intensity in the nuclear-astrophysically relevant energy region. The TraceWin code was used to design the High-Energy Beam-Transport section with regard to the experimental requirements at different target positions.

PACS `26` – Nuclear astrophysics.
PACS `29.27.Eg` – Beam handling; beam transport.
PACS `41.85.Lc` – Particle beam focusing and bending magnets and quadrupoles.

1. – FRANZ

The accelerator driven neutron source FRANZ is currently under construction at the Goethe University Frankfurt, Germany [1]. The first stage of construction will consist of the sections illustrated in fig. 1.

The high-intensity proton beam is extracted from the volume-type ion-source, which is arc-discharge-driven [2]. Then, the beam is transported in the so called Low-Energy Beam-Transport section (LEBT). The LEBT consists of four solenoid magnets and a chopper. It fits the extracted beam into the acceptance of the following radio-frequency quadrupole (RFQ) accelerator. In addition, undesired H_2^+ and H_3^+ hydrogen fractions are removed [3]. The chopper is able to divide the continuous beam into macro-bunches. It has a Wien filter-type E×B configuration to combine advantages of magnetic and electric deflection [4].

In the following LINAC section, the proton beam is accelerated up to an energy of 700 keV by the four-rod RFQ of 1.7 m length. Then, the Interdigital H-type drift tube linac (IH-DTL), which is equipped with an internal quadrupole triplet, increases the beam energy up to 2 MeV. The frequency of the coupled accelerators is 175 MHz [5].

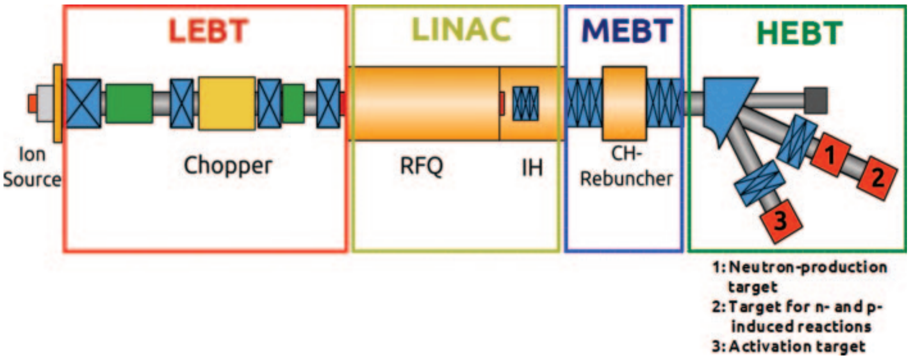

Fig. 1. – Schematic overview of the FRANZ facility in its first stage of construction.

In the Medium-Energy Beam-Transport section (MEBT), a crossbar H-mode (CH) rebuncher cavity is surrounded by two quadrupole triplets. It will be used to vary the final energy between 1.8 MeV to 2.2 MeV allowing to adapt the neutron energy spectrum [6].

The final section is the High-Energy Beam-Transport section (HEBT). Here, a dipole magnet serves different beamlines. The so called In-beam beamline includes two target stations. The neutron production target is at position 1. Inside a 4π-$\mathrm{BaF_2}$ calorimeter, the target for neutron- or proton-induced reactions is installed (position 2). The activation target at position 3 has a separate beamline. This paper shows the results of simulations of the In-beam beamline including the dipole magnet, the quadrupole doublet and the target positions 1 and 2.

Two different operation modes are foreseen for FRANZ: A bunched mode to perform time-of-flight experiments with neutrons and a CW mode for proton-induced and activation experiments. For the time-of-flight experiments a fast calorimeter will be used. It consists of 41 $\mathrm{BaF_2}$ crystals with a total efficiency of 90% and 50% full-energy peak efficiency. The data acquisition system is supported via six CAEN V1751 digitizer modules with eight channels, 10 bit and 1 gigasample-per-second [7].

At its final stage, FRANZ will have the highest proton beam current at an energy of 2 MeV worldwide. Hence, the production of p-nuclei via proton-induced reactions can be studied. Furthermore, neutron capture reactions for the s- and r-processes can be investigated.

2. – Neutron production

At FRANZ, the neutrons will be produced via the reaction $^7\mathrm{Li(p,n)}^7\mathrm{Be}$. If the proton energy is about 1.91 MeV, the resulting energy distribution of the neutrons is similar to a thermal distribution at $kT = 25\,\mathrm{keV}$, which is a typical temperature in s-process nucleosynthesis [8]. Because the proton energy is close to the neutron production threshold the neutrons are kinematically collimated in the forward direction.

The neutron production target has a copper backing and two cooling cycles to dissipate the high power deposition of 4 kW of a 2 MeV proton beam with 2 mA of intensity [7].

3. – HEBT simulations

To obtain the general conditions of the magnetic parameters, beam-dynamics simulations with hard edge models were performed. In cooperation with the company

Danfysik, three-dimensional CAD models based on these parameters were developed. Magnetic field simulations with these models were performed via CST EM Studio [9]. The extracted magnetic fields were used as an input for more precise beam-dynamics simulations, which were performed using the software TraceWin [10]. Multi-particle simulations in a space charge regime were performed due the high beam current at FRANZ. 100000 particles were tracked with a beam current of 2 mA, which will be the current for the first stage of FRANZ. The energy was set to 2 MeV and the bunch frequency to 175 MHz.

The simulations of the HEBT section used calculations of the MEBT section as an input. Thus, the sections were treated independently. A dipole gap of 40 mm and a quadrupole aperture radius of 52.5 mm fulfill the requirements on the magnetic parameters and fit into the setup of the beamline. The influence of the magnets can clearly be seen in the envelopes (see fig. 2). The final quadrupole doublet can focus

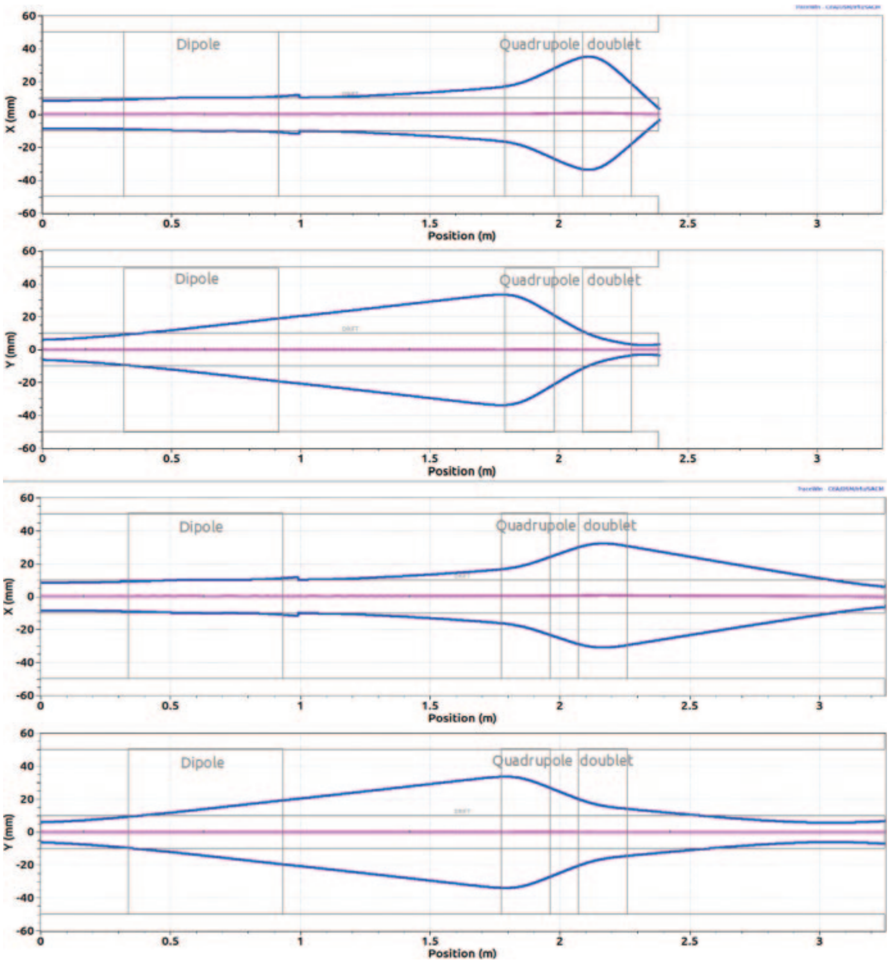

Fig. 2. – Transverse beam envelopes (99%) towards the neutron production target (upper plots, compare fig. 1 position 1) and the target for proton-induced reactions (lower plots, compare fig. 1 position 2).

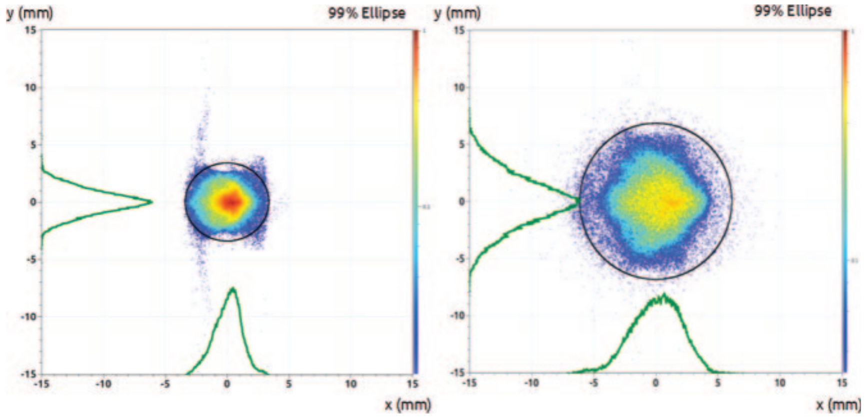

Fig. 3. – Output distribution at the neutron production target (left, compare fig. 1 position 1) and at the target for proton-induced reactions (right, compare fig. 1 position 2).

the beam onto both target positions. The highest particle density is found along the beam axis.

The aim is to have as many protons on the targets as possible, but some losses along the beamline, mainly from off-momentum particles in the dipole, are unavoidable. The total losses in the HEBT section are below 1%, which keeps activation and damage of the beam pipe at a minimum. Behind the dipole, a collimating slit is planned to absorb the off-momentum particles safely.

Figure 3 shows the beam distribution at the first two target positions. The beam spot is circular, matching the geometry of the targets, and the one-dimensional distribution in green has a Gaussian shape. The minimum beam radii are 3.5 mm at target position 1 (left plot) and 6.4 mm at target position 2 (right plot), respectively.

As beam diagnostics elements, Beam Induced Fluorescence (BIF) Monitors are foreseen.

4. – Conclusions

The neutron source FRANZ and its HEBT design has been described. The experimental requirements at the different target positions can be reached with the specified system of a dipole switching magnet and a doublet of focussing quadrupole magnets.

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REFERENCES

[1] Reifarth R. *et al.*, *Publ. Astron. Soc. Aust.*, **26** (2009) 255.
[2] Schweizer W. *et al.*, *Rev. Sci. Instrum.*, **85** (2014) 02A743.
[3] Schneider P. *et al.*, *LEBT Dynamics and RFQ Injection* , in *IPAC'15, Richmond, USA, THPF024* (2015).
[4] Wiesner C. *et al.*, *Chopping High-Intensity Ion Beams at FRANZ*, in *LINAC'14, Geneva, Switzerland, WEIOB01* (2014).

[5] Heilmann M. *et al.*, *Preparation of the Coupled RFQ-IH-Cavity for FRANZ*, in *IPAC'14, Dresden, Germany, THPME059* (2014).

[6] Schwarz M. *et al.*, *A Rebunching CH Cavity for Intense Proton Beams*, in *LINAC'14, Geneva, Switzerland, TUPP062* (2014).

[7] Schmidt S., *Neutrons at FRANZ: Production and Data Acquisition Systems*, PhD thesis, Goethe University Frankfurt, Germany (2015).

[8] Reifarth R., Lederer C. and Käppeler F., *J. Phys. G: Nucl. Particle Phys.*, **41** (2014) 053101.

[9] CST GmbH, *CST EM-Studio*, Darmstadt, Germany (2015), `www.cst.de`.

[10] Duperrier R., Pichoff N. and Uriot D., *CEA Saclay Codes Review for High Intensities Linacs Computations*, in *ICCS, Amsterdam, The Netherlands* (2002).