Proton LINAC for the Frankfurt Neutron Source FRANZ

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Abstract. The **Fra**nkfurt **N**eutron Source at Stern - Gerlach - **Z**entrum (FRANZ) will use the ^{7}Li(p,n) reaction to produce a intense neutron beam. The planned experiments require an adjustable neutron energy between 10 and 250 keV. Hence the energy of primary proton beam should be adjustable between 1.8 MeV and 2.2 MeV. The FRANZ beam line consists of two branches to allow different methods of neutron capture measurements. The compressor mode offer time of flight measurements in combination with a $4\pi BaF_2$ detector array. The proton beam of about 150 mA will be compressed to a 1ns pulse with a peak current of about 8 A at the repetition rate of 250 kHz. The activation mode uses a continuous neutron flux. The primary cw proton beam with a low current up to 30 mA will be focussed onto the production target.

FRANZ is not only a neutron generator but also a test bench for new accelerator and diagnostic concepts for intense ion beams. The planned proton beam properties on the target leads into a challenge accelerator design to overcome the space charge forces. This presentation emphasises on the ongoing construction of the proton injector.

1. Introduction

Institute of Applied Physics (IAP) has an international expertise for the development of accelerator concepts. The design of the low energy part of the EUROTRANS proton driver LINAC is an example of actual activities [1]. For further developments an accelerator test bench was planned at Stern-Gerlach-Zentrum to proof new accelerator components and beam diagnostic tools. A volume type ion source will deliver a 120keV, 200mA proton beam continuously. A LEBT section consisting of four solenoids is under construction to transport the beam and to match it into the acceptance of the RFQ. A chopper system between solenoid 2 and 3 will provide beam pulses with a length of about 50 to 100 ns with a repetition rate of up to 250 kHz. The RFQ and the following IH drift tube LINAC will be coupled together to achieve an efficient beam acceleration. Furthermore only one power amplifier will be needed to provide the RF power for both accelerator stages. The Mobley type bunch compressor will merge 8 micro bunches formed in the accelerator module to one single 1ns bunch with an estimated peak current of up to 9.6 A. A rebuncher will provide the post acceleration to final beam energy adjustable between 1.8 and 2.2 MeV [2]. The whole system is optimized for high beam intensity causing high space charge forces. FRANZ comprises two operation modes. At compressor mode the proton beam will be compressed to a 1ns pulse with a peak current of about 9.6 A and a repetition rate of 250 kHz. Activation mode uses a continuous (cw) proton beams with a current up to 8 mA on solid targets and up to 30 mA on liquid metal targets as a later option are feasible. Target development in cooperation with FZ Karlsruhe and GSI is planned to overcome the expected power density. Figure 1 shows the conversion of primary proton beam properties into neutron beam properties for the compressor mode. After collimation the pulsed neutron beam with length of 1ns offers time of flight measurements in combination with a 4π BaF2 detector array.

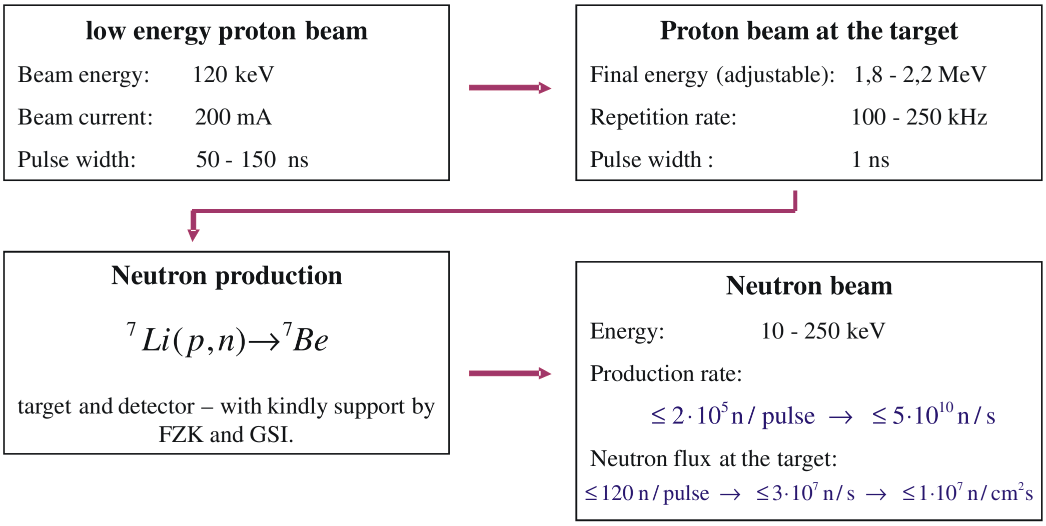

FIG. 1. Scheme of conversion primary proton beam into collimated neutron beam for the compressor mode.

For both of these two operation modes the neutron energy will be adjustable by the primary proton beam energy. The maximum neutron energy of about 250keV is limited by the radiation protection.

2. The Proton LINAC

The proton LINAC consists of a 150kV terminal with volume source, low energy beam transport section, coupled RF accelerator stages followed by a bunch compressor of Mobley type. Two rebuncher cavities, for activation and compressor mode, provide a proton beam energy variation between 1.8 and 2.2MeV. Figure 2 shows an overview of the LINAC with estimated beam properties.

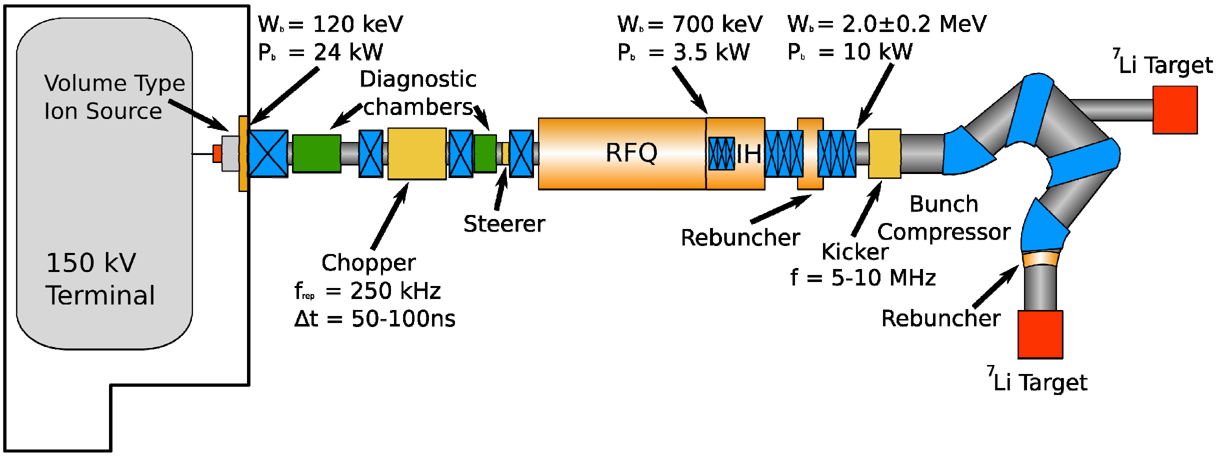

FIG. 2. Scheme of the Frankfurt Neutron Source at Stern-Gerlach-Zentrum (FRANZ).

2.1. Ion Source

A volume type ion source was chosen for FRANZ to extract the proton beam from a hot filament driven gas discharge plasma [3]. Figure 3 shows this source type. The life time of the filament is limited to about two weeks of operation. The plasma temperature of a gas discharge due to moderate arc power is as well as the confining magnetic field very low compared with other source types e.g. ECR sources. Therefore the beam emittance is small and gives the possibility to investigate causes of emittance growth during beam transport and acceleration along the whole LINAC.

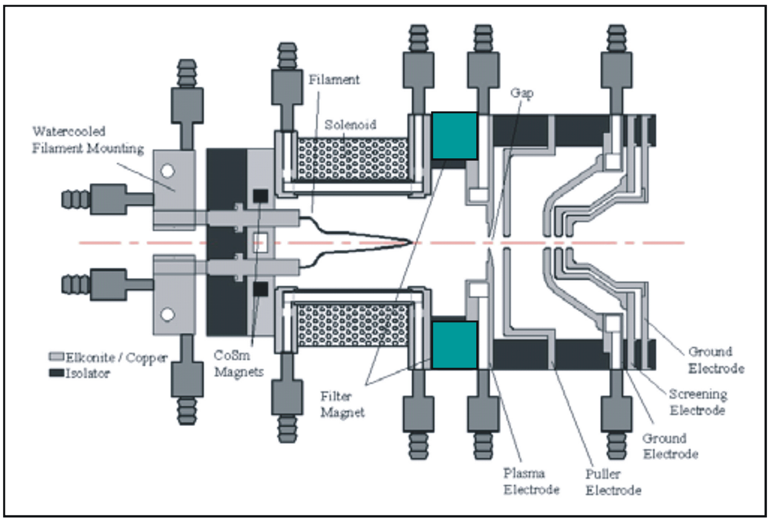

FIG. 3. Cross sectional view of the hot filament driven gas discharge ion source.

For the planned beam intensities a pentode extraction system keeps quite well the beam emittance during the extraction and pre acceleration phase when compared with other extraction schemes [4]. Numerical simulation of the beam extraction by the use of the IGUN code [5] were made under respect of a multi species beam with approximately H^+ = 80%, H_2^+ = H_3^+ 10%. The chosen aspect ratio of $S = 0.2$, an emission area of 0.78 cm^2 and an extraction field strength of 6.2 kV/mm results in a beam radius of $r_{beam} = 5$ mm, in an emittance of $\varepsilon_{rms} = 0.06\ \pi$ mm mrad and a divergence angle of r' = 74.5 mrad.

2.2. Low Energy Beam Transport

The LEBT section consists of 4 solenoids for beam focussing and includes partial of space charge compensation due to residual gas ionisation. Figure 4 shows a scheme of the planned LEBT. The first and second solenoid will be used for separation of ion species and to match the proton beam into the chopper system. Downstream of the chopper two solenoids will focus the beam into the acceptance of the RFQ. Two pumping and diagnostic tanks will be used for several non interceptive diagnostics e.g. optical beam profile measurement and beam potential measurements using a residual gas ion energy analyzer. The chopper system consisting of a kicker and a septum magnet combined with a slit provide the 100 ns proton beam pulses. A fast magnetic or electric kicker deflects the beam with a repetition rate of 250 kHz whereas the static septum magnet provides the post separation and a pulse with a flat top of at least 50 ns. Comparison of electric and magnetic kicker systems by the use of numerical simulation shows an influence of secondary electrons. The high production rate of electrons in the chopper system gives the possibility for partial space charge compensation of short beam pulses. Preliminary studies result in approximately 30% of space charge compensation by the use of a magnetic kicker system. For an electric kicker the secondary electrons bear the risk of sparking and sputtering from the electrodes [6]. Beam transport and chopping leads to an emittance growth at a factor of 4. It seems possible to reduce this value by further optimization of beam transport with respect to the filling degree of the solenoids and more detailed analysis of space charge compensation. Pulsed beam with proton densities of n_p =

$8.2\cdot10^{14}$ m^{-3}, generalized perveance of $K = 3.1\cdot10^{3}$ and pulse length of about 100ns will be injected in the coupled RFQ-IH DTL.

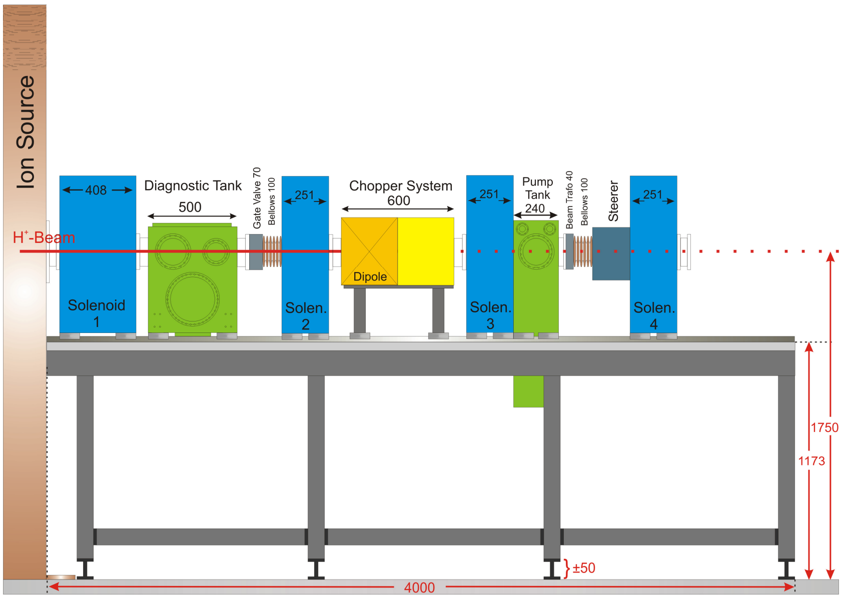

FIG. 4. Scheme of the Low energy Beam Transport section with chopper system in between four solenoids.

2.3. Coupled RFQ-IH DTL

In order to minimize installation costs and to use one compact common RF amplifier a coupling of the RFQ and IH-DTL is foreseen [7]. Figure 5 shows a crossectional view of the coupled accelerator stages. Both of the cavities can also be used separately.

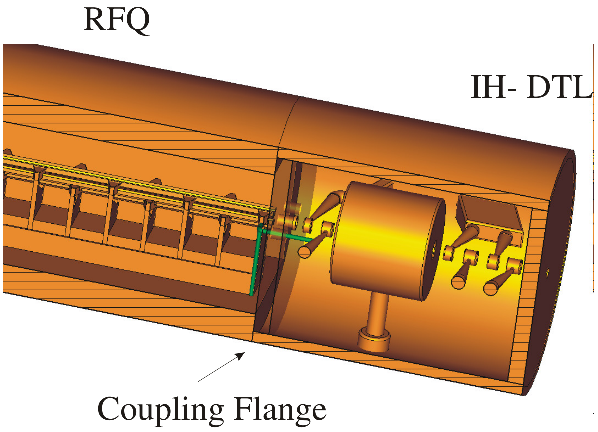

FIG. 5. Cross sectional view of RFQ exit and IH-DTL entrance coupled via galvanic connector.

The RFQ is 1.75 m long and needs an input power of 150 kW [8]. Numerical simulations using the PARMTEQM [9] code show a beam transmission efficiency of 95 % with acceptable emittance growth at the design current I = 200 mA for an electrode voltage of about 75 kV. Output energy of the RFQ will be 0.7 MeV. The IH-DTL will boost the proton beam to its final beam energy of 2 MeV. The power consumption of the IH cavity is in a range of about 45 kW to establish a gap voltage of 300 kV. Due to the fact that a RFQ acts like a buncher the incoming proton beam will be compressed longitudinally. In result of the beam transport simulation the micro bunch phase width is in a range of 60 degree. The average bunch current increases up to 1.2 A and the resulting compression ratio is $\eta = 6$. At beam energy of 2 MeV downstream of the accelerator stages the proton density is $n_p = 8.2 \cdot 10^{14}\ m^{-3}$ and the space charge forces expressed by the generalized perveance decreases of about $K = 2.7 \cdot 10^4$. A following CH-cavity is planned to provide the beam energy variation from just below the threshold of neutron production reaction up to 2.2 MeV. For compressor mode these cavity will be used for longitudinal focussing to prevent an increase of the bunch duration of 1 ns.

2.4. Bunch Compressor

By applying the bunch compressor concept of the Mobley type [10] for high current beams a split magnetic dipole array include edge focusing was chosen [11]. The periodic deflection by the RF kicker at one focus of the bending system guides up to 9 bunches on different paths to the final focus, where the neutron production target is located. As shown in figure 6 in front of the target an additionally rebuncher cavity will be used for energy variation of about ±0.2 MeV of the primary proton beam and longitudinal focussing.

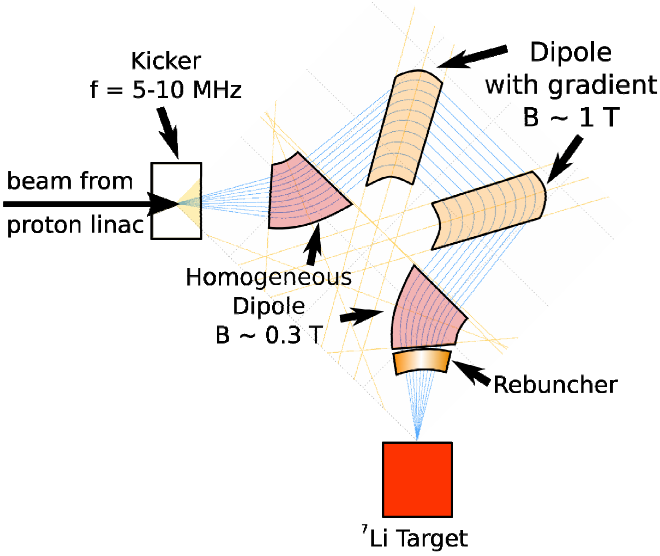

FIG. 6. Scheme of the bunch compressor, beam from LINAC will be guided to 9 traces (blue) through the compressor array.

By choosing adequate parameters all 9 bunches will overlap at the target and produce a 1.1 ns proton pulse with a proton density of $n_p = 8.2 \cdot 1014\ m^{-3}$. Space charge forces become dominant, the generalized perveance is $K = 2.2 \cdot 10^{-3}$. The peak current is 9.6 A and the resulting compression ratio downstream of the whole proton injector is of $\eta = 48$.

3. Target Design

The possibility to build a neutron production target for high beam powers of up to 4 kW shown in figure 7 has been investigated [12]. It was shown that a robust solution can be obtained consisting of a copper backing 1.2 mm in thickness. Cooling is provided by water flowing through capillaries 0.6 mm in diameter and with a spacing of 1.0 mm at a pressure of 50 bar. This concept was subject to computer simulations, which demonstrated that the moderation effect of the cooling water is acceptable and that the surface temperature at 4kW beam power does not exceed 300 °C, sufficiently low if a high temperature Li compound is used as target material.

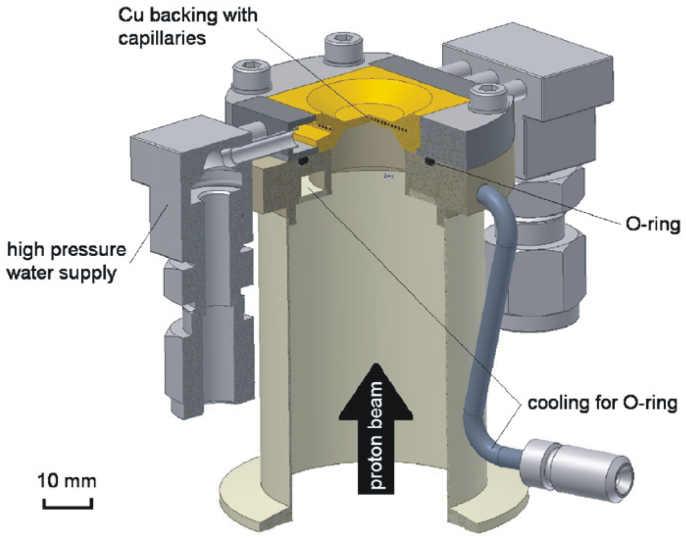

FIG. 7. Scheme of neutron production target with cooling water connections.

Two prototype versions have been built with equivalent cooling properties, but different degrees of complexity. One of these targets has been successfully tested at the Karlsruhe 3.7 MV Van de Graaf accelerator, where a power density of 5 kW/cm^2 has been reached by focusing the beam into a spot 3 mm in diameter. This implies that the target is well suited for the FRANZ facility, where the power density in compressor mode operation is restricted to values below 4 kW/cm^2 due to space charge limitations.

4. Detector Array

The 4π BaF_2 detector array consists of 42 modules arranged to a sphere. The array was used in FZ Karlsruhe and transferred to Frankfurt University in 2008. After reassembling of the detector sphere shown in figure 8 a test program was started to evaluate the behaviour of each single module [13].

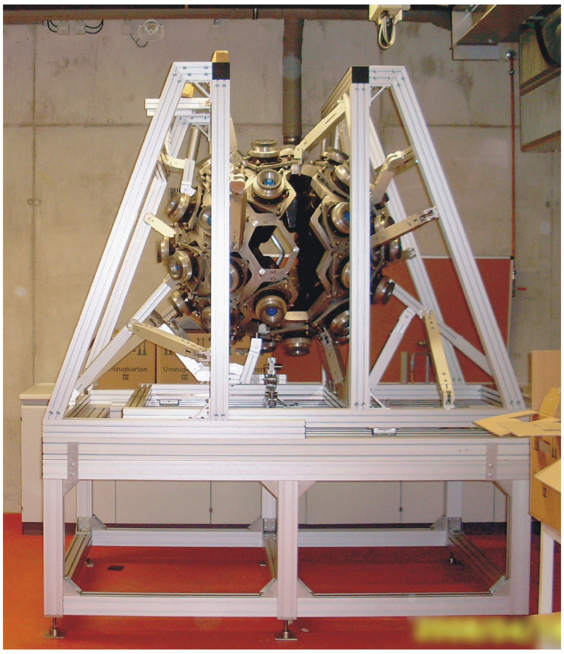

FIG. 8. Reassembled detector sphere on the support table.

The transfer of the 4π BaF_2 detector array from Karlsruhe to Frankfurt was a success. The majority of the modules have been proven to function correctly. In result figure 9 shows the energy resolution of a single module (left) and the time resolution of all modules (left).

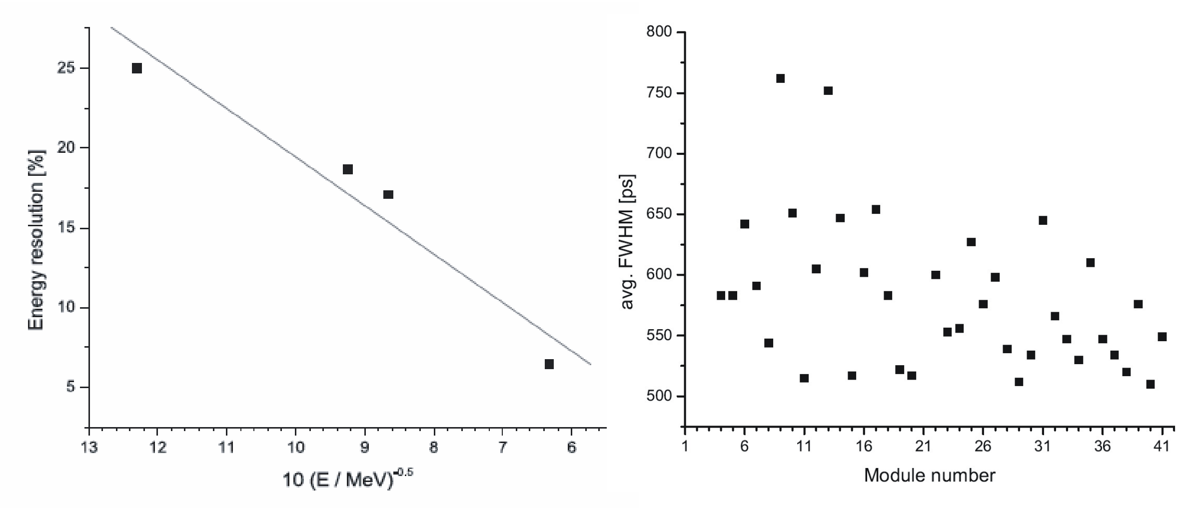

FIG. 9. Exemplary energy resolution of module 23 (left) and time resolution of the detector modules measured using a ^{60}Co probe after reassembling of the detector sphere in Frankfurt.

5. Summary

FRANZ will be a multi purpose experiment that offers the possibility of accelerator and target as well as nuclear astrophysics experiments. The approximated collimated neutron flux of about 10^7 n/cm^{2}s ensures good statistical results by the use of small probes of rare isotopes. Measurement of stellar neutron capture cross sections will continue the research activities of FZ Karlsruhe at higher neutron fluxes. Interaction of intense neutron beams with different kinds of materials is important for reactor design as well as measurement of cross sections for neutron induced fission reactions. Both, development of new accelerator concepts and estimation of nuclear data especially neutron reaction cross sections, are needed for future **a**ccelerator **d**riven **s**ystems (ADS).

6. Acknowledgment

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