DEVELOPMENT OF THE 2 MeV PROTON BEAM DIAGNOSTICS SECTION IN PREPARATION FOR NEUTRON PRODUCTION AT FRANZ

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Abstract

The Frankfurt Neutron Source (FRANZ) at the Institute of Applied Physics in Frankfurt (IAP) is advancing toward the commissioning of proton beams up to 2 MeV. To support beam tuning behind the RFQ–IH-DTL acceleration chain, a dedicated diagnostics section is being installed downstream of the IH-DTL cavity. The setup focuses on transverse beam characterization using scintillation screens combined with radiation-tolerant camera systems, enabling multi-angle (two-view) imaging of the proton beam under various beam-current and RF settings. Additional instruments include phase probes for energy and RF-phase monitoring, as well as a Faraday cup for current measurements. The camera-based diagnostics are designed to provide reliable visual feedback during early commissioning, particularly in an environment with limited access and the radiation levels typical for this region of the accelerator. This contribution presents the concept, implementation approach, and intended diagnostic capabilities of the camera-driven setup as FRANZ prepares for subsequent steps toward routine 2 MeV operation and the following delivery of the proton beam onto the lithium target for the first neutron production campaigns.

INTRODUCTION

The Frankfurt Neutron Source (FRANZ) is a compact accelerator-driven facility at the Institute for Applied Physics (IAP) at Goethe University Frankfurt, designed to produce neutrons via the ${}^{7}\mathrm{Li}(p,n){}^{7}\mathrm{Be}$ reaction with a 2 MeV proton beam [1]. The driver linac consists of a CHORDIS ion source, a 60 keV electrostatic post-accelerator, a Low Energy Beam Transport (LEBT) line, and a coupled RFQ–IH-DTL cavity that accelerates the beam from 60 keV to 2 MeV [2]. Following successful commissioning of the 700 keV RFQ beam with 10 mA peak current [3], the coupled RFQ–IH-DTL has been conditioned and first 1.9 MeV beam was delivered to the diagnostics section [4]. The beam is pulsed at a repetition rate of 10 Hz with a macro-pulse length of 2 ms, resulting in a duty cycle of 2 % and a peak current of up to 6 mA. To support beam tuning behind the RFQ–IH-DTL acceleration chain, a dedicated diagnostics section has been installed downstream of the IH-DTL cavity. This contribution presents the design and first results of this diagnostics section, with particular emphasis on the multi-camera system for non-invasive transverse beam profile measurements using Beam Induced Fluorescence (BIF) in residual gas.

DIAGNOSTICS SECTION LAYOUT

The diagnostics section is installed directly downstream of the IH-DTL exit flange (see Fig. 1). An external quadrupole triplet, positioned immediately behind the IH-DTL, complements the internal IH-DTL quadrupole triplet lens. Together, these two triplets allow matching of the beam envelope throughout the drift section. The beamline is constructed from standard CF cross-pieces equipped with vacuum viewports, providing optical access for the camera systems. The section houses the following instruments:

- A movable scintillation screen mounted opposite the first camera, allowing the operator to switch between interceptive screen imaging and non-invasive BIF observation.
- Two capacitive phase probes separated by a known drift distance for beam energy determination via the Time-of-Flight (ToF) method.
- A Faraday cup at the end of the beamline for absolute beam current measurement.
- Multiple vacuum viewports for external camera installations enabling non-invasive BIF profile monitoring from two orthogonal viewing angles.

By varying the quadrupole field strengths, the beam focus can be adjusted on the scintillation screen or, alternatively, the transverse beam envelope along the drift section can be studied through BIF imaging at different magnet settings.

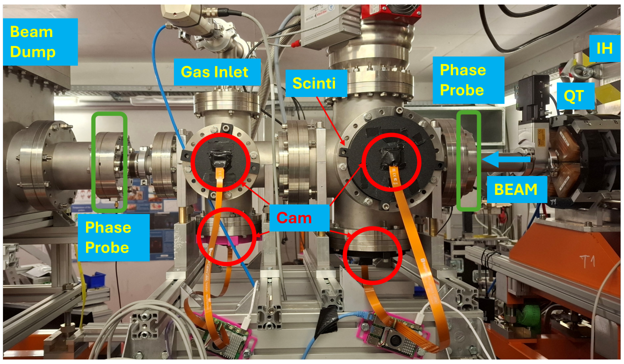

Figure 1: Layout of the diagnostics section downstream of the IH-structure, showing the quadrupole triplet, cross-piece arrangement with vacuum viewports, phase probes, and Faraday cup.

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SCINTILLATION SCREENS & PHASE PROBES

Scintillation Screen Tests

Prior to obtaining commercial scintillator material, several in-house coating attempts were made to produce low-cost interceptive screens. Copper substrates were coated using a custom-built spin coater with three different materials: Barium Fluoride (BaF_2), P46 phosphor, and flame-deposited carbon soot (see Fig. 2). Under 1.9 MeV proton irradiation, BaF_2 and P46 showed rapid degradation within minutes due to the high energy deposition density at this beam energy. The carbon soot layer provided a visible beam spot initially but was destroyed after only a few minutes of exposure. Subsequently, a commercial Chromium-doped Aluminium Oxide screen (Chromox) was installed, which proved significantly more resistant to beam impact and provided reliable beam spot imaging throughout the commissioning period.

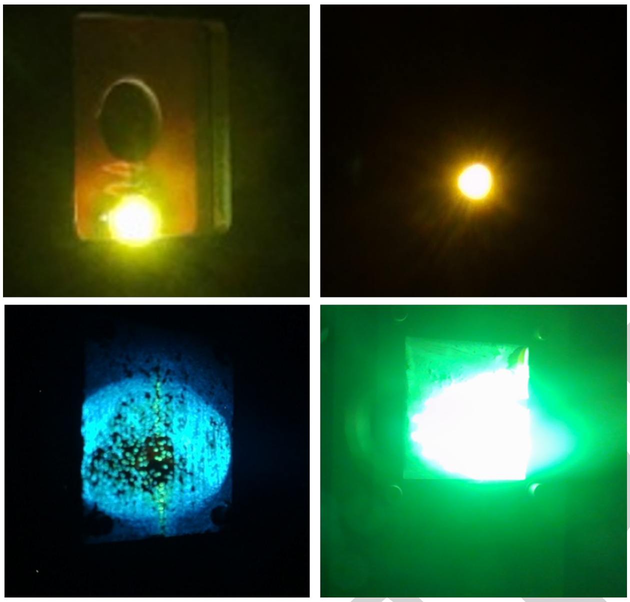
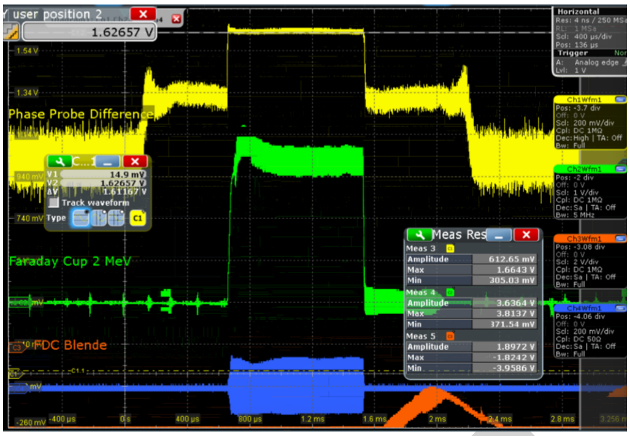


Figure 2: Scintillation materials tested under 1.9 MeV proton beam: (top left) Chromox, (top right) flame-deposited carbon soot, (bottom left) BaF_2, and (bottom right) P46 phosphor showing severe coating degradation.

Phase Probe Energy Measurement

Two capacitive phase probes are installed in the diagnostics section for beam energy determination via the Time-of-Flight method. The phase difference between the two probe signals is measured using an AD8302 gain/phase detector IC, which provides a DC output voltage proportional to the RF phase difference between its two input channels. The measured phase difference $\Delta\phi$, combined with the known probe separation and the RF frequency, yields the beam velocity and thus the kinetic energy. Figure 3 shows an oscilloscope trace correlating the AD8302 output with the Faraday cup signal, confirming proper beam synchronisation.



Meas 3
Amplitude 612.65 mV
Max 1.6643 V
Min 305.03 mV
Meas 4
Amplitude 3.6364 V
Max 3.8137 V
Min 371.54 mV
Meas 5
Amplitude 1.8972 V
Max -1.8242 V
Min -3.9586 V

Figure 3: Oscilloscope traces showing the macro-pulse correlation between the AD8302 phase probe difference signal (yellow) and the 1.9 MeV Faraday cup signal (green).

IMAGING & VISION

The core of the diagnostics system is a multi-camera setup for non-invasive beam profile monitoring via BIF in residual gas [5]. Four Raspberry Pi Camera Modules (Version 3), controlled by two Raspberry Pi 5 single-board computers (designated Pi 88 and Pi 92), are mounted behind vacuum viewports on cross-pieces along the diagnostics beamline (see Fig. 4). Each Raspberry Pi drives two cameras simultaneously. The two camera pairs are oriented at 90° to each other, separated by a longitudinal distance of 324 mm, providing independent horizontal and vertical beam profile measurements.

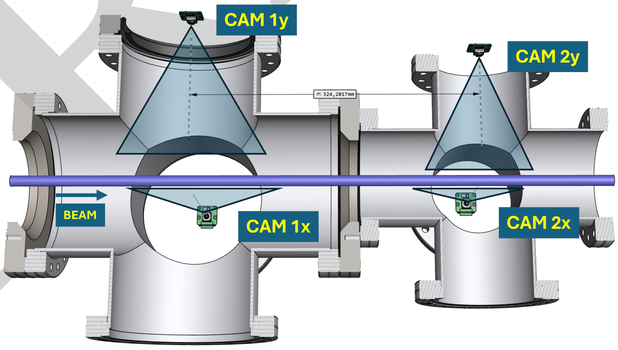
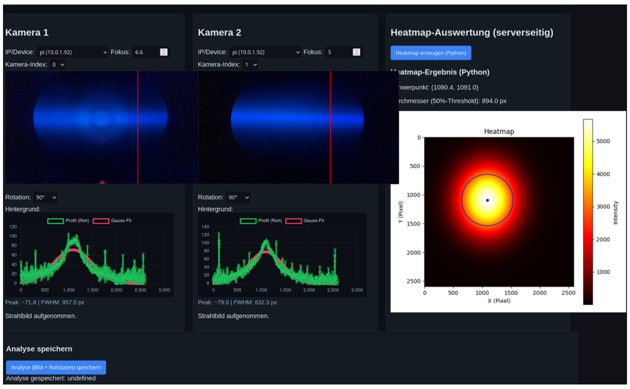


Figure 4: CAD model of the four-camera arrangement around the beampipe. Two Raspberry Pi 5 units, each equipped with two cameras, are mounted at 90° relative to each other.

Image acquisition is managed by a custom Python-based camera server running on each Raspberry Pi, accessible via the laboratory network. A web-based control interface (see Fig. 5) provides real-time camera control, automated background subtraction, 1D beam profile extraction with Gaussian fitting, and 2D intensity heatmap visualization. All images are timestamped and stored centrally for offline analysis and correlation with machine logs.

For BIF imaging, argon is injected into the beamline via a remotely controlled piezo leak valve at pressures on the order of 5×10^{-3} mbar. Due to the relatively low fluorescence



IP/Device: pi (10.0.1.92) Fokus: 6.6
Kamera-Index: 0
Rotation: 90°
Hintergrund:
Peak: ~71.8 | FWHM: 957.5 px
Strahlbild aufgenommen.

IP/Device: pi (10.0.1.92) Fokus: 5
Kamera-Index: 1
Rotation: 90°
Hintergrund:
Peak: ~79.0 | FWHM: 832.3 px
Strahlbild aufgenommen.

atmap-Ergebnis (Python)
werpunkt: (1090.4, 1091.0)
rchmesser (50%-Threshold): 894.0 px

Analyse gespeichert: undefined

Figure 5: Screenshot of the web-based control interface showing real-time camera feeds, 1D beam profile extraction with Gaussian fitting, and 2D heatmap analysis.

cross section at 1.9 MeV proton energy and the limited solid angle captured by the cameras, exposure times of approximately 90 s are required to accumulate sufficient signal for beam profile extraction. The primary argon emission lines at 650 nm to 850 nm fall within the peak sensitivity region of the CMOS sensor, making argon an effective fluorescence gas for this application. Despite the long integration time, the 2 % duty cycle and stable beam conditions during a macro-pulse train allow meaningful time-averaged profile measurements. A key operational advantage of the layout is that high local argon pressures can be injected into the diagnostics section without compromising the vacuum in the IH-DTL cavity. The combination of the small IH beam aperture of 24 mm diameter, a turbomolecular pump installed between the gas inlet and the IH-DTL exit flange, and the long drift tube of 40 mm diameter acts as an effective differential pumping stage. This allowed the local argon pressure in the diagnostics section to be raised to 5×10^{-3} mbar while maintaining the base pressure in the IH-DTL at 10^{-7} mbar with only minimal pressure increase observed upstream.

RESULTS

During commissioning, a complementary two-step diagnostic workflow was established. The movable scintillation screen was first used for rapid beam spot observation and initial focus optimisation using the quadrupole triplet. Once a satisfactory beam focus was confirmed, the screen was retracted and argon gas was injected via the leak valve to switch to non-invasive BIF imaging. Although the 90 s exposure time makes BIF a slower method than the scintillator screen, it provides the crucial advantage of observing the beam without intercepting it, and allows qualitative determination of the beam position relative to the focal waist. Figure 6 shows the first simultaneous BIF beam images recorded by all four cameras during 1.9 MeV proton beam operation. The images were acquired at an argon pressure of 5×10^{-3} mbar with an exposure time of 90 s. The beam cross-section is clearly visible in all four images. The two orthogonal views provide independent projections of the transverse beam distribution, demonstrating the capability of the system for two-plane profile monitoring.

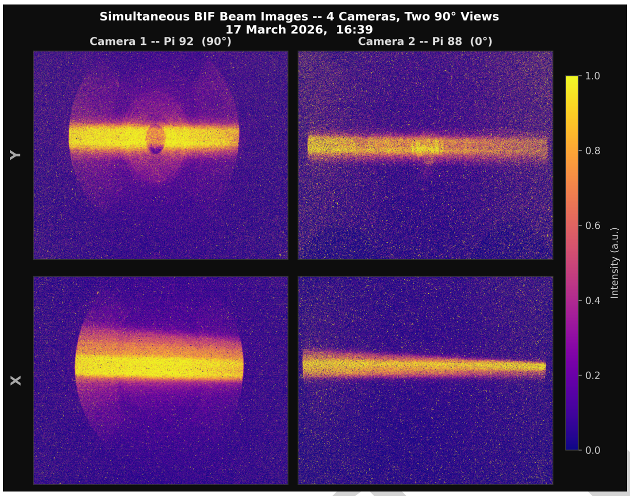


Figure 6: Simultaneous BIF beam images at 1.9 MeV acquired by all four cameras at 5×10^{-3} mbar argon, 90 s exposure. Left column: Camera 2; right column: Camera 1. Top row shows the Y-projection, bottom row shows the X-projection. Compare with the 3D arrangement in Fig. 4.

The results confirm that the Raspberry Pi 5 camera system is capable of imaging the 1.9 MeV proton beam through BIF in residual argon gas. Background subtraction using dedicated dark frames, implemented in the camera server software, significantly improves the signal-to-noise ratio and allows reliable Gaussian fitting to the 1D beam profiles.

OUTLOOK & CONCLUSION

A dedicated diagnostics for the 1.9 MeV proton beam at FRANZ has been successfully commissioned. The section comprises a movable scintillation screen (Chromox), two phase probes read out via AD8302 for Time-of-Flight energy measurements, and a four-camera BIF system for non-invasive transverse profile monitoring. First beam images at 1.9 MeV have been obtained with all four cameras simultaneously. Future work includes the comparison of measured beam profiles with beam envelope simulations using the LORASR code, as well as the installation of a slit-grid emittance measurement device and a fast Faraday cup for longitudinal beam characterisation. Systematic studies of the BIF signal dependence on residual gas pressure and beam current are planned, along with an improvement of the image acquisition efficiency to reduce the required exposure time.

REFERENCES

[1] U. Ratzinger *et al.*, “The FRANZ facility and its neutron source”, in *Proc. PAC’09*, Vancouver, BC, Canada, May 2009, pp. 4592–4594.

[2] R. Tiede *et al.*, “A coupled RFQ-IH-DTL cavity for FRANZ: A challenge for RF technology and beam dynamics”, in *Proc. HB’16*, Malmö, Sweden, Jul. 2016, pp. 404–408. doi:10.18429/JACoW-HB2016-WEAM1Y01

[3] H. Hähnel *et al.*, “Current status of beam commissioning at the Frankfurt Neutron Source”, in *Proc. IPAC’25*, Taipei, Taiwan, Jun. 2025, paper TUPS039. doi:10.18429/JACoW-IPAC2025-TUPS039

[4] H. Hähnel *et al.*, “High power conditioning and first 2 MeV beam results of the coupled RFQ-IH-DTL for FRANZ”, presented at IPAC’26, Deauville, France, May 2026, paper THP4112, this conference.

[5] A. Ateş *et al.*, “Raspberry Pi cameras for beam diagnostics at the Frankfurt Neutron Source”, in *Proc. IPAC’25*, Taipei, Taiwan, Jun. 2025, paper THPS087. doi:10.18429/JACoW-IPAC2025-THPS087