DEVELOPMENT AND CHARACTERIZATION OF A NEUTRON BEAM AT THE BONN ISOCHRONOUS CYCLOTRON

Helmholtz-Institut für Strahlen- und Kernphysik

M. Loepke, R. Beck, S. Neubert, D. Sauerland

HISKP, Bonn, Germany

UNIVERSITÄT BONN

IPAC26 Deauville

The Bonn Isochronous Cyclotron provides proton, deuteron, alpha and other light ion beams with a charge-to-mass ratio Q/A ≥ 1/2 and kinetic energies ranging from 7 to 14 MeV per nucleon. The beam is guided through a high-energy beam line (HEBL) to one of five experimental sites. The installation of the proton irradiation site for high-uniformity radiation hardness tests of Si detectors is now complete. Additionally, a irradiation site for an Ion Beam Analysis Setup will be commisioned soon. Here, it is intended to use low energetic alpha particles between 2 and 5 MeV to perform material analysis of a probe by means of Rutherford-Backscattering (RBS) and Particle Induced X-Ray Emission (PIXE). Further a neutron irradiation site is under commisioning. Here, a collimated neutron beam, generated in a thick carbon converter through the deuteron breakup and proton stripping reactions, can be used for irradiation. Protons are stopped in the converter whereas the neutrons' flux and angular energy distribution is optimized by a subsequent copper/tungsten collimator.

This contribution gives an overview of the state of the neutron irradiation site and first measurements of the beam profile as well as simulations of the energy distributbution.

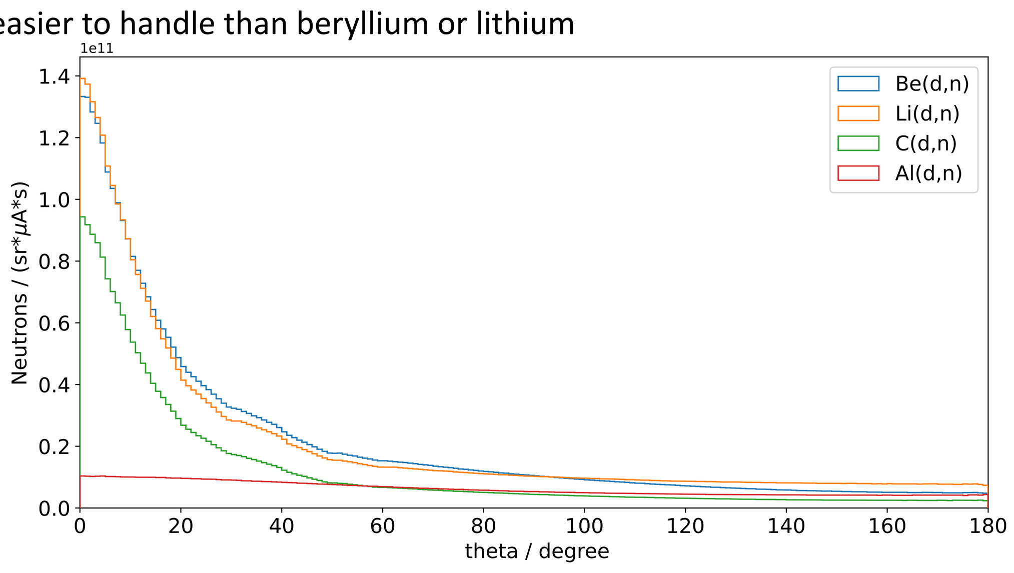
Neutron Production

Neutrons are produced using a deuteron beam and a light element thick target:

Beam and Target: C(d,xn)

Deuterons: 14 - 28 MeV (selectable), up to 1μA beam current
highest neutron yield in this energy region due to deuteron break-up, deuteron stripping: forward peaked neutron ditribution (momentum conservation)

Graphite: high neutron yield, forward peaked distribution, good mechanical properties, easier to handle than beryllium or lithium



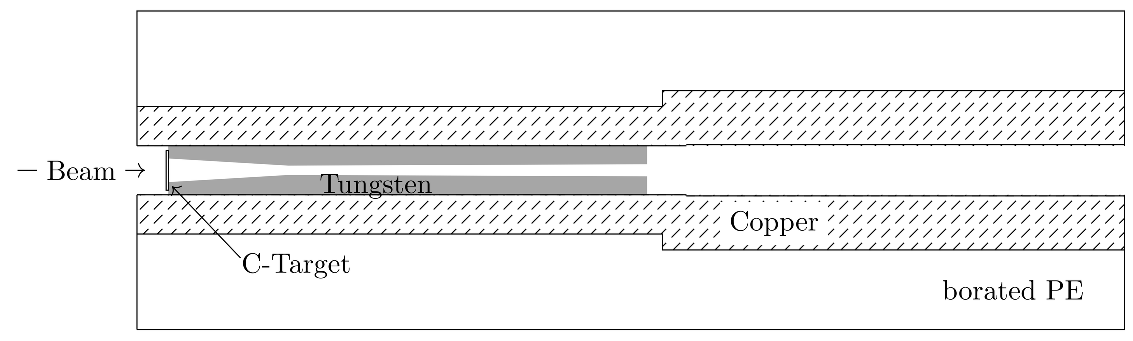
With Geant4 simulated differential neutron yield for thick berryllium, lithium, carbon and aluminum targets bombarded with 26 MeV deuterons.

Collimator: 3 layers, 1.24 m length

Tungsten: high atomic number -> small neutron energy change due to elastic scattering, conical geometry for sharper neutron beam edge

Copper: fast neutron moderator - large cross-sections for (n,n') above 1 MeV, (n,2n) above 10 MeV and (n,3n) above 20 MeV

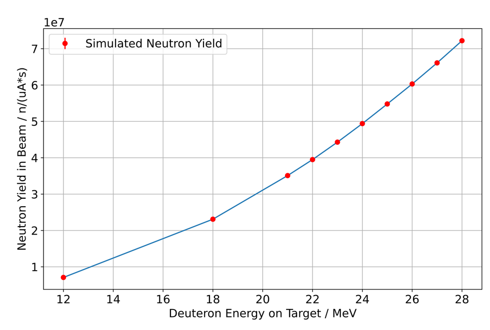
borated PE: hydrogen rich -> kinematically best moderator for neutrons, boron -> large (n,a) cross-section (neutron removal) below 1 MeV



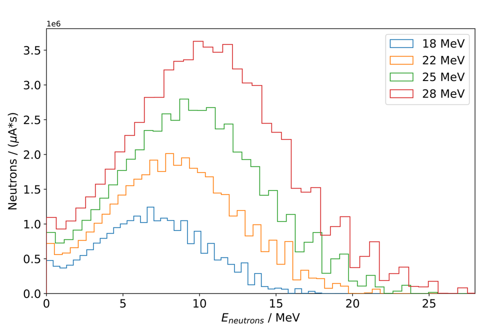
Sketch of the copper/tungsten collimator.

Neutron Energy Distribution

The neutron energy distribution was simulated with Geant4 v11.0.3 using the QGSP_BIC_AllHP physics list which utilizes evaluated data and cross-section from the TENDL-Database for reactions of deuterons below 200 MeV. It is planned to verify the simulations by a measurement of the energy distributions with multi-foil activation method using an unfolding algorithm like GRAVEL or MLEM.

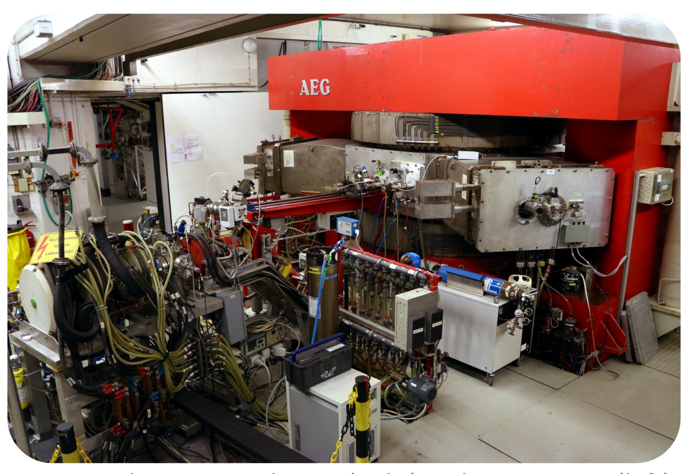


Simulated neutron yield for different beam energies. Points are connected to guide the eye.



Simulated neutron energy distribution for different beam energies.

Bonn Isochronous Cyclotron



Bonn Isochronous Cyclotron (right) with ECR source (left)

providable ions	p, d, α, …, $^{16}O^{6+}$
energy ($h = 3$, $Q/A \geq \frac{1}{2}$)	7 to 14 MeV/A
beam current (ext.)	$\lesssim$ 1 μA
injection / extraction radius	38 mm / 910 mm
number of revolutions	approx. 120
hill sectors	$3 \times 40°$, 0° spiral angle
hill / valley field strength	1.9 / 0.7 T (max.)
flutter	0.62
dees	$3 \times 40°$, 40 kV (max.)
cyclotron harmonic h	3, 9
rf frequency ν_{rf}	20.1 to 28.5 MHz
hor. / vert. emittance	16 / 22 mm mrad
relative energy width	4×10^{-3}

Cyclotron parameters

Beam Preparation: A two-stage 5 GHz or a single-stage 2.5 GHz polarized ECR source (2 to 8 keV)

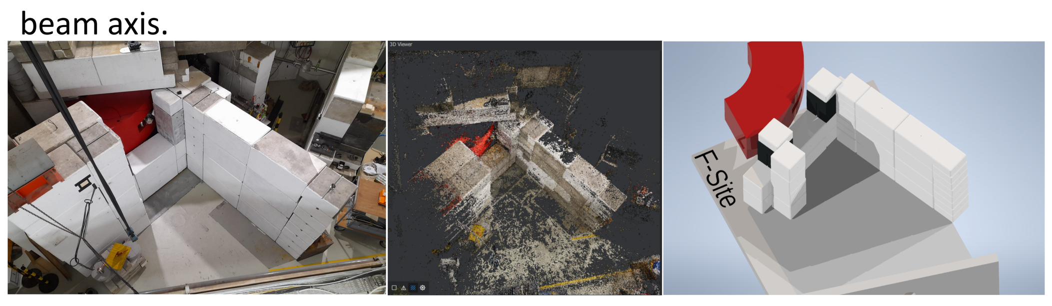
Injection: Vertical injection into the magnetic center of the cyclotron via a low-energy beam line, using an electrostatic hyperboloid inflector

Cyclotron: Isochronous AVF cyclotron with three Hill-and-Valley sectors
Three broadband dees with maximal acceleration voltage of 40 kV (min. gap 23 mm)
Single-turn extraction into compensated-field channel via electrostatic septum
Position and angle stabilization of extracted beam via slit apertures

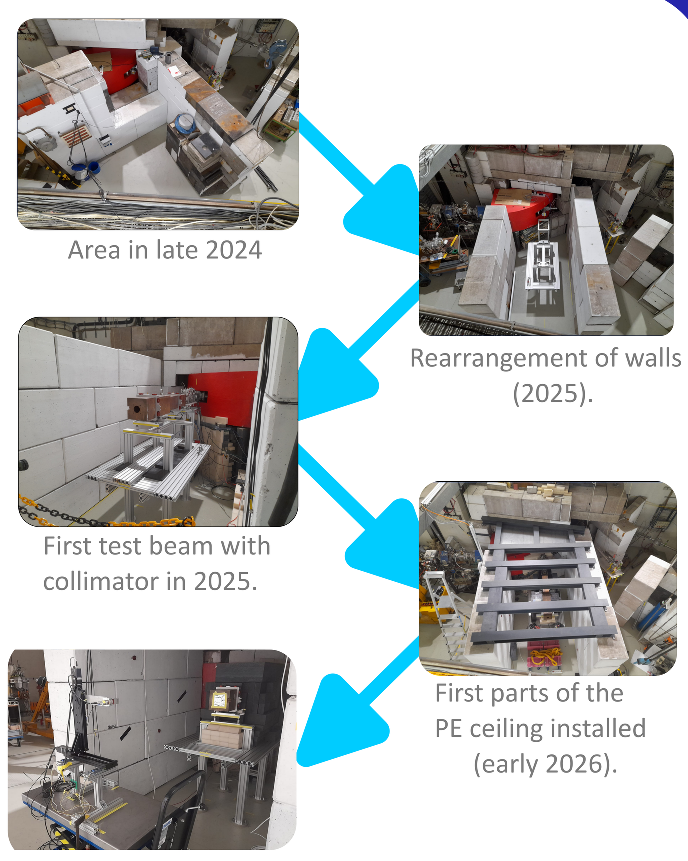
Beam Handling System: Symmetric/asymmetric double-bend monochromator or achromator

The Neutron Irradiation Site

During commisioning, the radiation shielding walls of the experimental area of the neutron irradiation site had to be re-arranged to lower the neutron background and ambient-dose-rate in other areas of the facility. A 3D-model of the area was made with the help of the photogrammetry software Meshroom in order to help with the planning and construction. Two parallel walls of concrete (50 cm) and a ceiling of borated polyethylene (PE) (13 cm) and concrete (20 cm) form a cave which houses the neutron collimator and the diagnostic section for the primary beam. Additional, the collimator is encased in 20 cm of borated PE to reduce the neutron background even further. A laser tracker was used to align the collimator preciesly with the beam axis.



Real world area (left), reconstructed model using photogrammetry (middle) and resulting CAD model (right).



Area in late 2024

Rearrangement of walls (2025).

First test beam with collimator in 2025.

First parts of the PE ceiling installed (early 2026).

In PE enclosed collimator with setup for beam profile measurement (2026).

Neutron Beam Profile

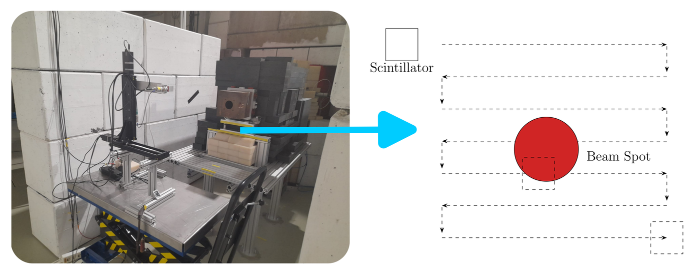
The beam profile is measured via image reconstruction:

Neutron Detection: Pulse-Shape Discrimination (PSD) via EJ309 liquid scintillator (NE213), 1 in³ cube on a x-y-motorstage

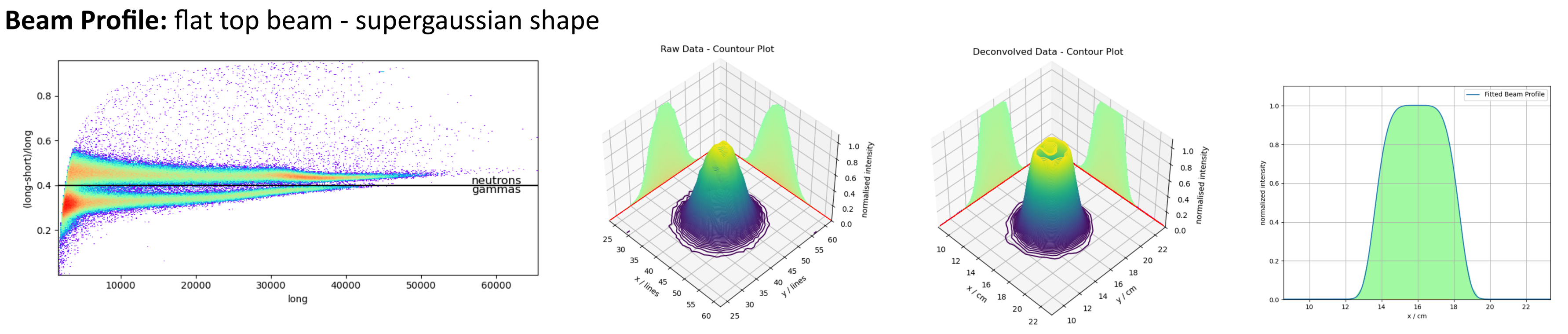
PSD Analysis: dedicated VME electronics (Mesytec MDPP-16)

Profile Measurement: use scintillator cube as 'pixel', 2D-scan through beam, filter for neutrons via PSD, intesity profile = 'blurred' image, reconstruct 'true' profile with Richardson-Lucy-Algorithm

Beam Profile: flat top beam - supergaussian shape



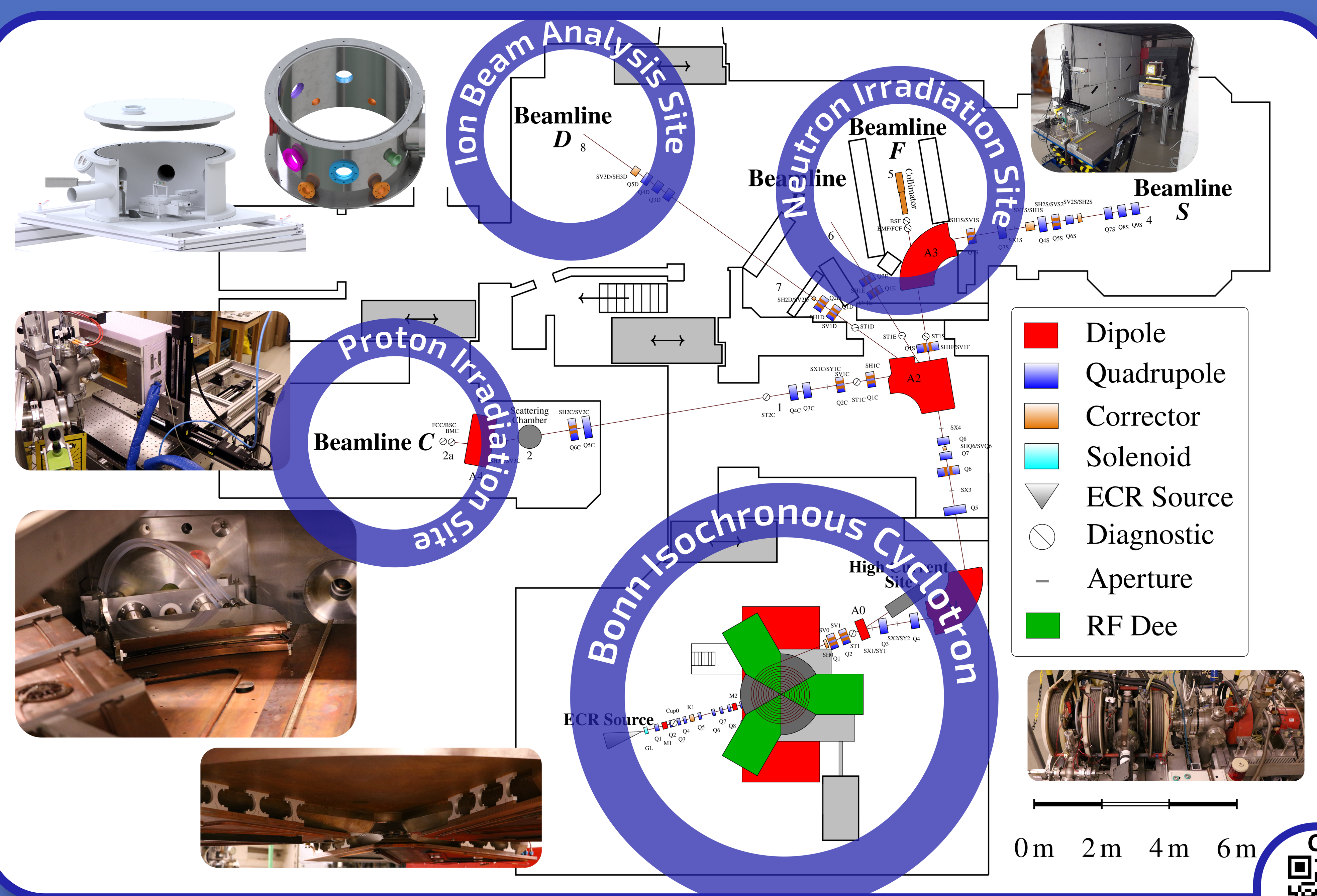
Setup for a beam scan with a EJ309 scintillator mounted on a x-y-stage and scan pattern.



Pulse-Shape Discrimination achieved with the liquid scintillator cube on the motorstage.

Intensity profile of the 'blurred' beam profile (left) and the reconstructed 'true' beam profile (right).

Projection of the beam profile with supergaussian fit.



Contact