PROTON IRRADIATION SITE FOR SI-DETECTORS AT THE BONN ISOCHRONOUS CYCLOTRON

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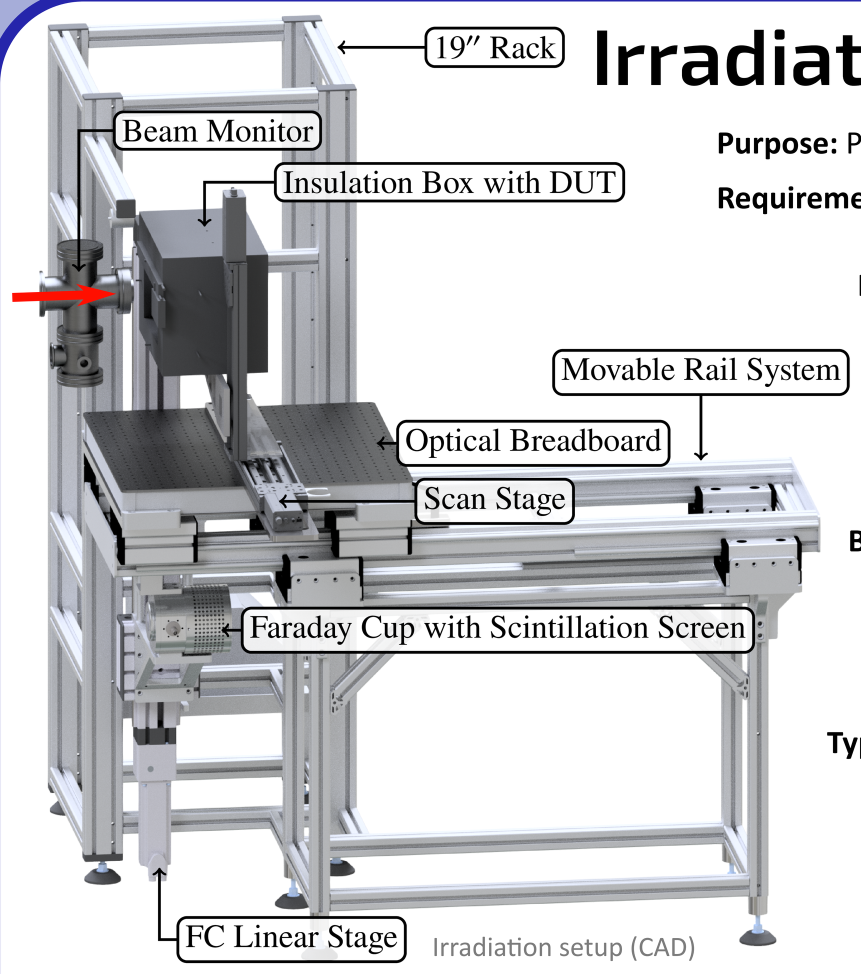
The Bonn Isochronous Cyclotron provides proton, deuteron, alpha particle and other light ion beams with a charge-to-mass ratio Q/A of >= 1/2 and kinetic energies ranging from 7 to 14 MeV per nucleon.

At a novel irradiation site, a 14 MeV proton beam with a diameter of a few mm is utilized to homogeneously irradiate silicon detectors, so-called devices-under-test, to perform radiation hardness studies. Homogeneous irradiation is achieved by moving the device through the beam in a row-wise scan pattern with constant velocity and a row separation smaller than the beam diameter. During the irradiation procedure, the beam parameters are continuously measured non-destructively using a calibrated, secondary electron emission-based beam monitor, installed at the exit window of the beamline. The diagnostics and the irradiation procedure ensure a homogeneous irradiation with a proton fluence error of < 2 %.

In this work, an overview of the accelerator facility is given and the irradiation site with its beam diagnostics is presented in detail.

Irradiation Site



Irradiation setup (CAD)

Purpose: Probing radiation hardness of silicon pixel detectors

Requirements: Application of a homogeneous proton fluence on the device under test (DUT)

Irradiation Setup: DUT in a temperature controlled environment, cooled down to < -20 °C, using a N_2 cooling system

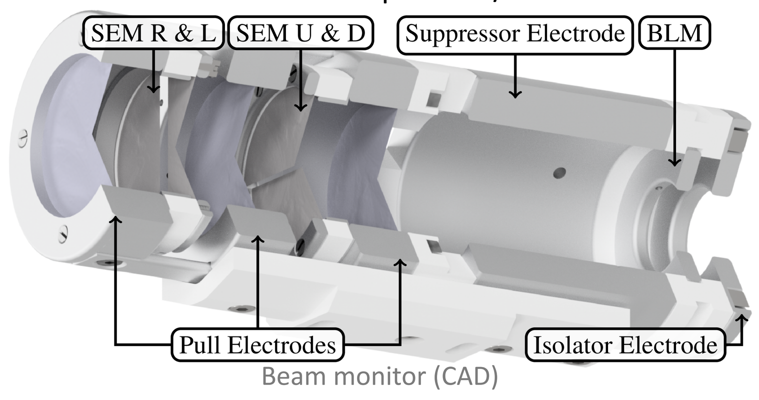
Mounted behind dedicated Al shielding, exposing only the DUT to proton beam

Control DUT position via scan stage

Beam Diagnostics: Beam monitor upstream of extraction for continuous non-destructive measurement of beam parameters

Faraday Cup with Chromox scintillation screen

Typical Parameters: 14 MeV Protons at 1 µA for aim fluence of $1.25 \cdot 10^{15}$ protons /cm^2



Beam monitor (CAD)

Beam Monitor

SEM: Secondary Electron Monitor for beam position and current measurements

Anticipate foil-carbonization in vacuum with time by using carbonized 5 µm-thick Al foils

Pull electrodes draw secondary electrons (SE) away from SEM-foils (Sim: charge-collection eff. >99%)

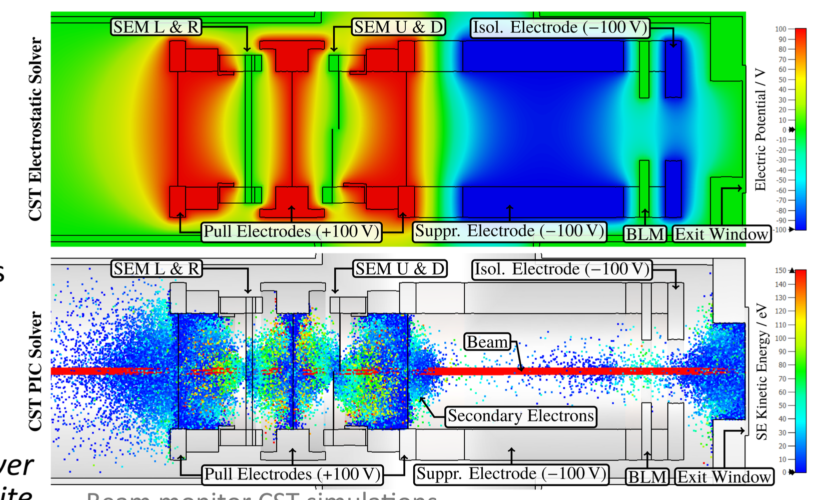
Absolute beam current measurement after calibration, utilizing the Faraday cup

BLM: Beam-Loss Monitor for beam-truncation detection

Charge-loss due to SE emission upon beam impact is minimized by suppressor electrode ($I_{loss}/I = 5 \cdot 10^{-3}$)

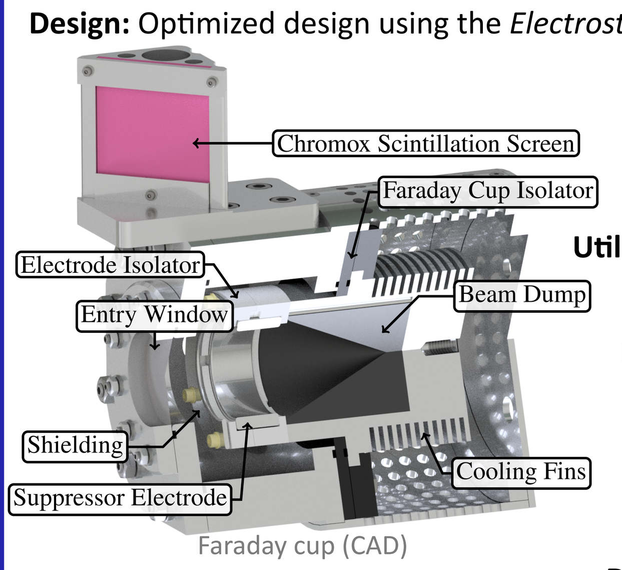
Isolator electrode shields BLM from SE, emitted when beam traverses exit window ($I_{SE,exit}/I = 10^{-3}$)

Design: Optimized design using the *Electrostatic* and *PIC Solver* of *CST Studio Suite*



Beam monitor CST simulations

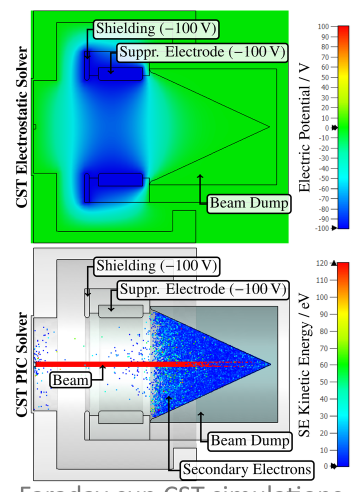
Faraday Cup



Faraday cup (CAD)

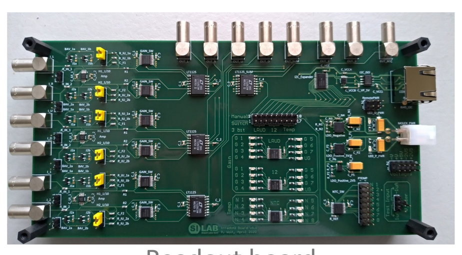
Utilization: Faraday cup or scintillation screen can be moved in front of exit window

Design: Minimized charge-loss due to SE emission, using a suppr. electrode and beam dump with inverted cone shape ($I_{loss}/I = 8 \cdot 10^{-5}$)



Faraday cup CST simulations

DAQ and Control


Readout board

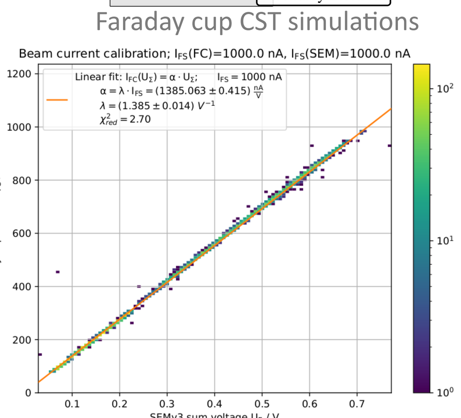
Digitization: Linear IU conversion via custom-made readout board

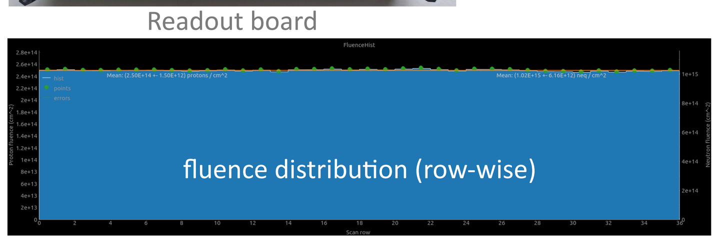
ADC board with *Raspberry Pi* single-board-computer

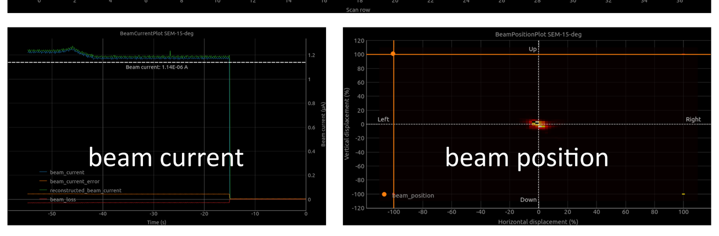
Control: Software *irrad_control* (python)

Online monitoring of beam parameters

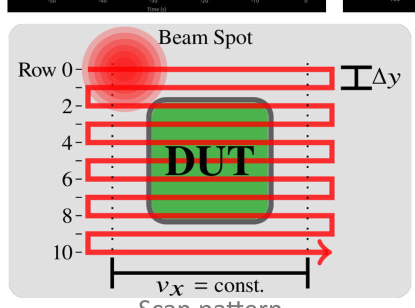
Remote control of scan and FC linare stages


SEM calibration





Beam-Driven Irradiation Procedure



Scan pattern

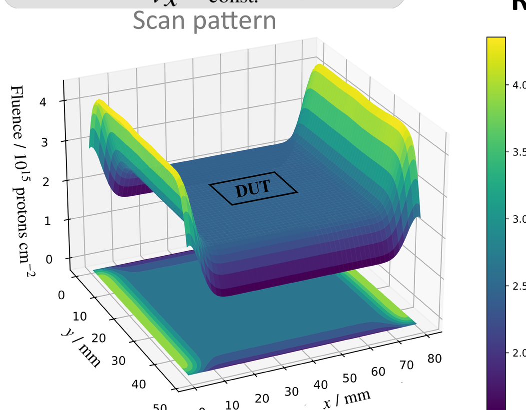
Pattern: Row-wise scan pattern with constant hor. velocity and a row separation smaller than beam diameter

Scan pattern is repeated until desired aim fluence is applied onto the DUT

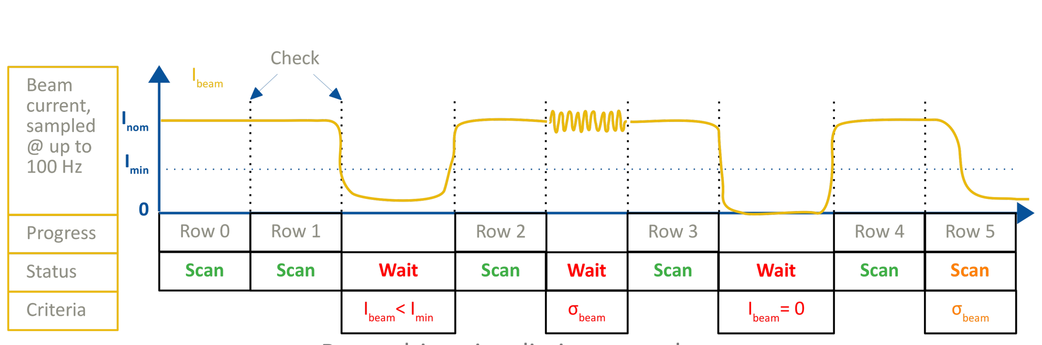
Procedure: Autonomously and beam-driven, adapting to changing beam conditions

Beam condition check (current, stability, position) at turning points, pauses until requirements are met

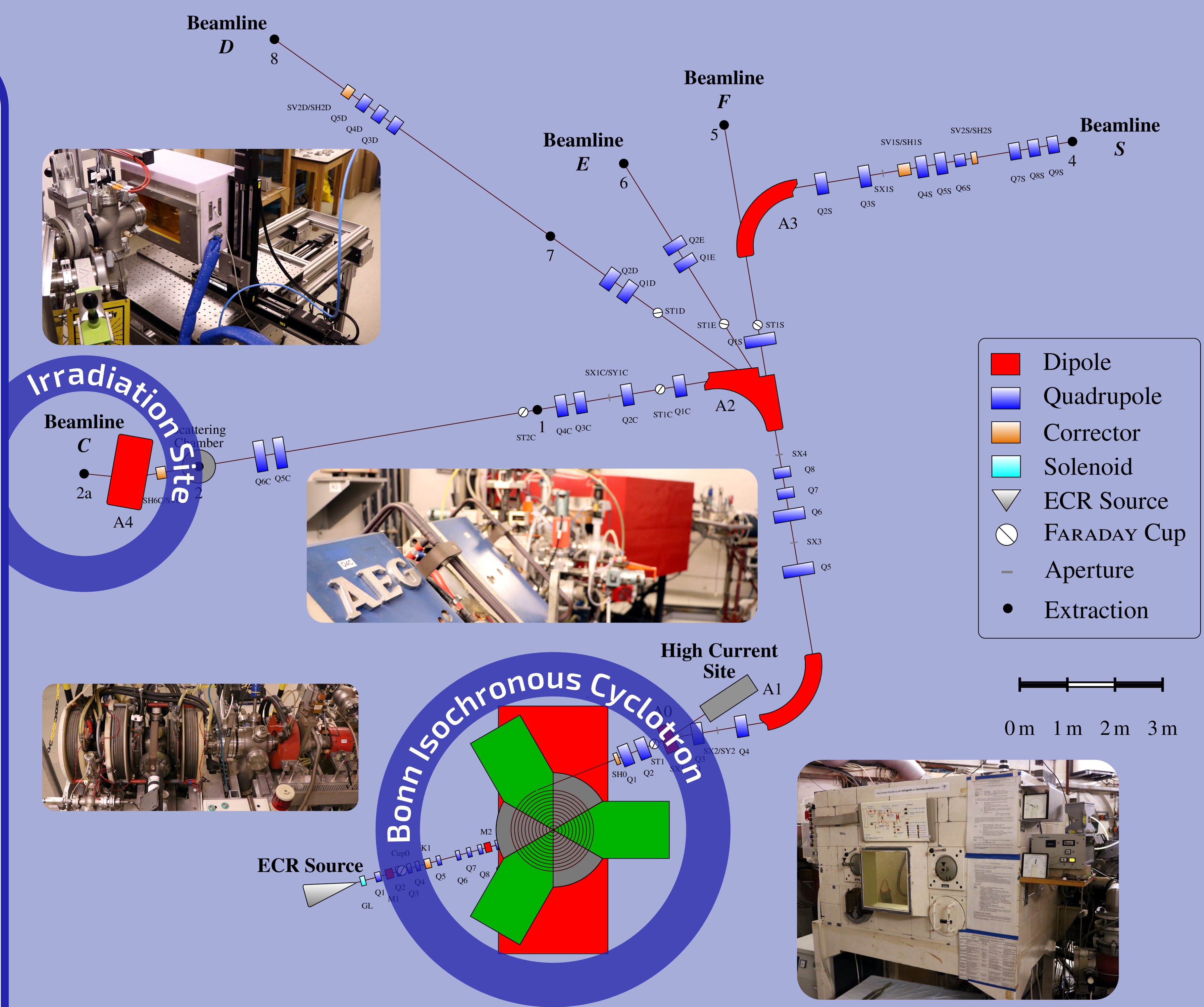
Results: Variance of proton fluence within the DUT region is insignificant with respect to the rel. uncertainty of the beam current measurement (<1.7%)



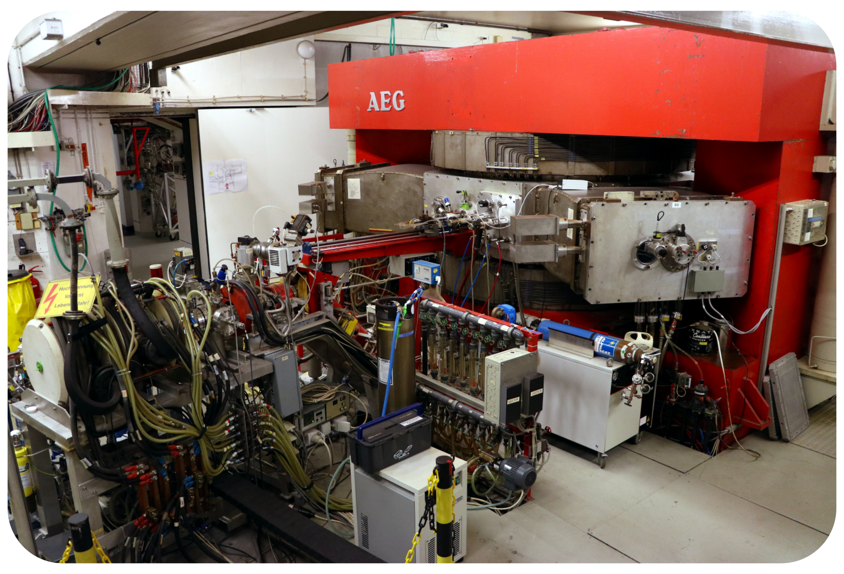
Resulting proton fluence distribution



Beam-driven irradiation procedure



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 beamline, using an electrostatic hyperboloid inflector

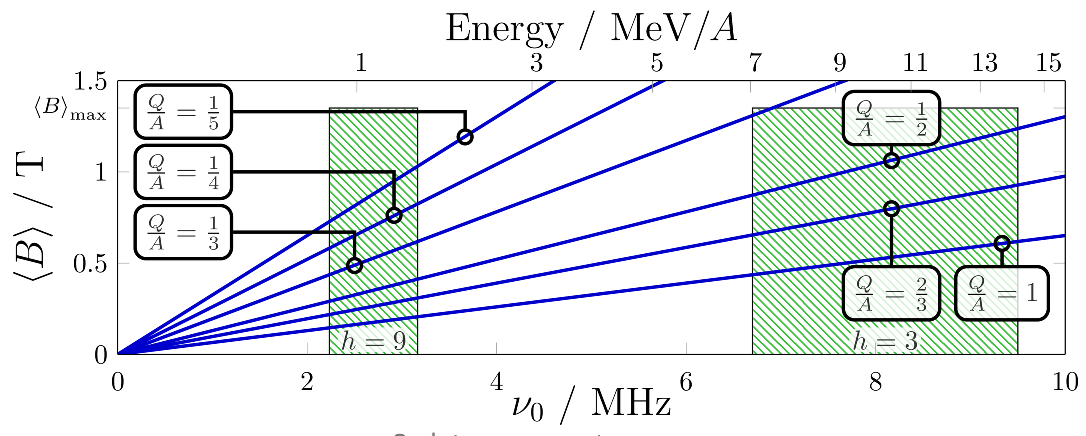
Cyclotron: Isochronous AVF cyclotron with three Hill-and-Valley sectors

Three broadband dees with maximal acceleration voltage of 40 kV (min. gap 23 mm)

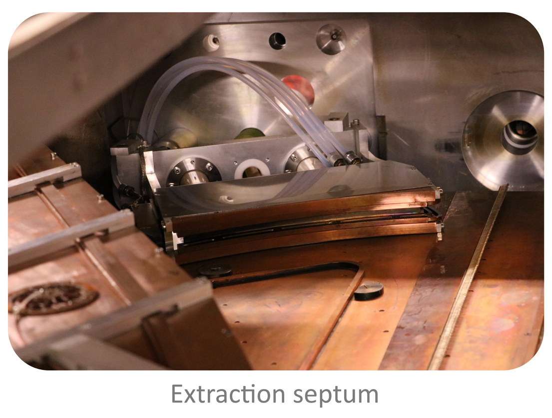
Single-turn extraction into compensated-field channel via electrostatic septum

Position and angle stabilization of extracted beam via slit appertures

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



Cyclotron parameter space


Extraction septum


Magnetic yoke of the cyclotron


South-West Dee

Contact