STATUS OF THE BONN ISOCHRONOUS CYCLOTRON

Helmholtz-Institut für Strahlen- und Kernphysik

SI LAB Silizium Labor Bonn

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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 irradiation site for high-uniformity radiation hardness tests of Si detectors is now complete. Additionally, a neutron irradiation site will be commissioned soon. Here, a collimated neutron beam, generated by a stripping reaction of the deuteron beam in a carbon target, can be used for irradiation. To provide stable beam with constant optics for these experiments, the power supplies (PS) of all magnets in the HEBL will be replaced. The replacements must meet strict criteria regarding output current's stability, which were derived from measurements of the existing PS. In this spirit, a new corrector magnet PS system, enabling bipolar operation, PS/magnet operation safety/health and power consumption monitoring, is close to commissioning. Additionally, the cyclotron's extraction septum is upgraded to increase operation robustness. Here, an new antiseptum is designed together with a new septum blade holder, which is intended to be additively manufactured with the laser-powder bed fusion technique.

Proton Irradiation Site

Silicon pixel detectors are probed for radiation hardness by applying a homogeneous proton fluence on the device (DUT) in a beam-driven irradiation scheme with a statistical fluence error of << 1 %.

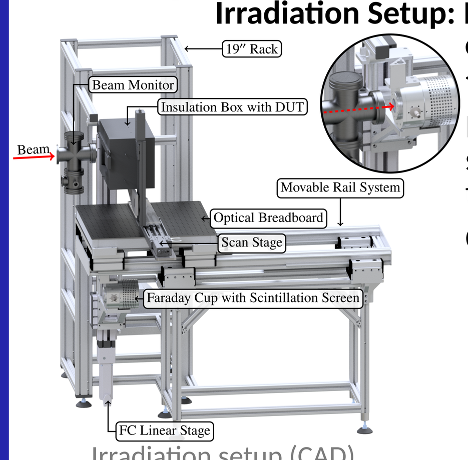
Typical Parameters: 14 MeV Protons at 1 µA for aim fluence of 1.25×10^{15} protons /cm²

Setup

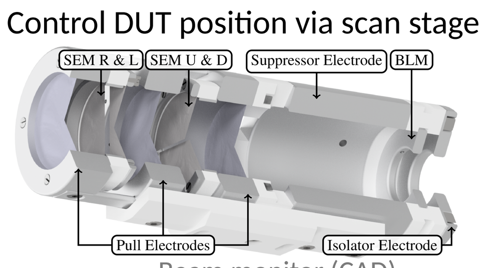
Irradiation Setup: DUT in a temperature controlled environment, cooled down to < -20 °C, using a N cooling system.

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

Control DUT position via scan stage



Irradiation setup (CAD)



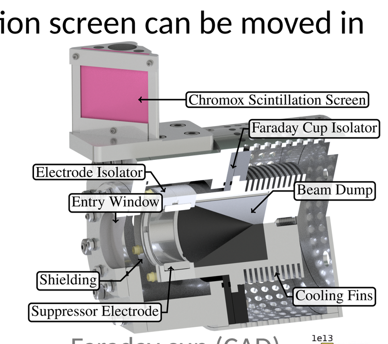
Beam monitor (CAD)

Beam Diagnostics

SEM: Secondary Electron Monitor for beam position and current measurements

BLM: Beam-Loss Monitor for beam-truncation detection

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

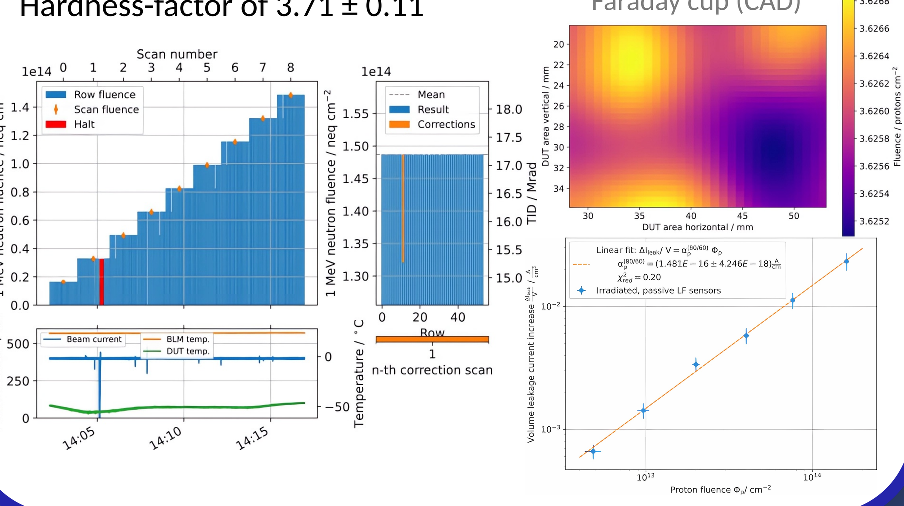


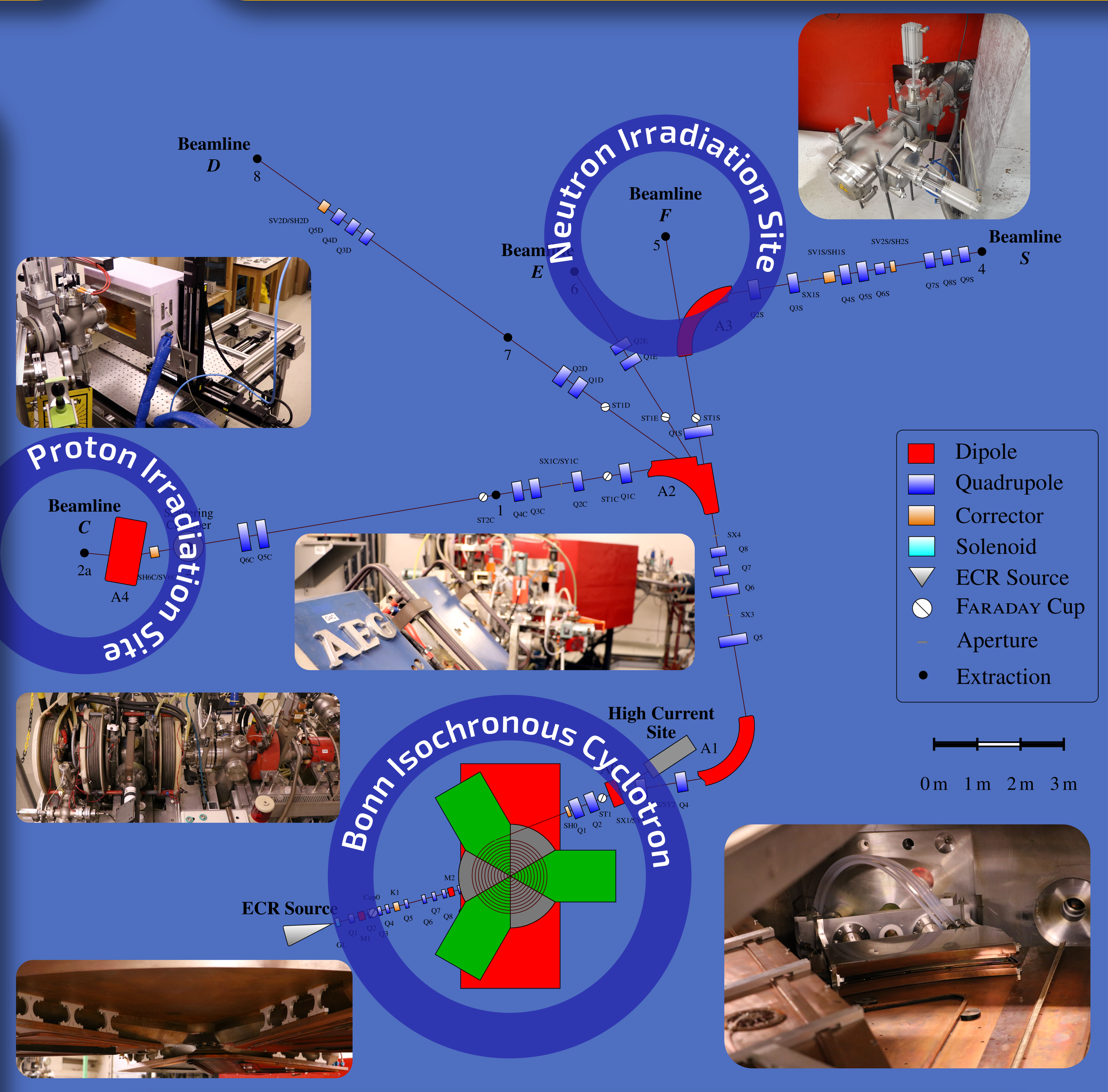
Faraday cup (CAD)

Status

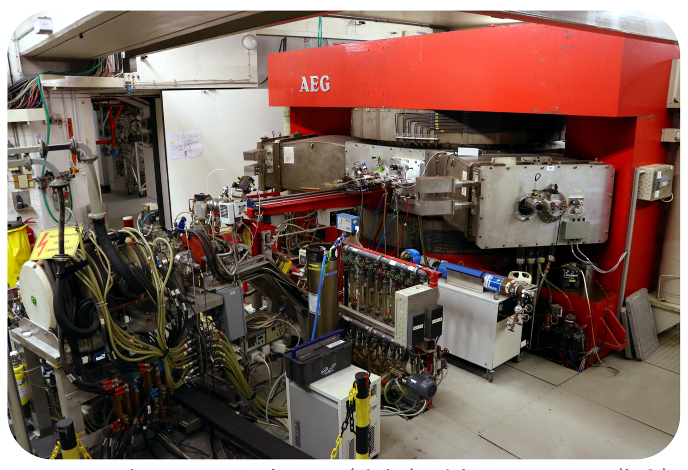
Operational: Since 2021 the site has already irradiated ATLAS ITk Pix V1.1, LF-Monopix2, TJ-Monopix2 (Belle-II), ATLASPix3 (LHCb), ...

High-Damage Irradiation: Proton Hardness-factor of 3.71 ± 0.11





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)

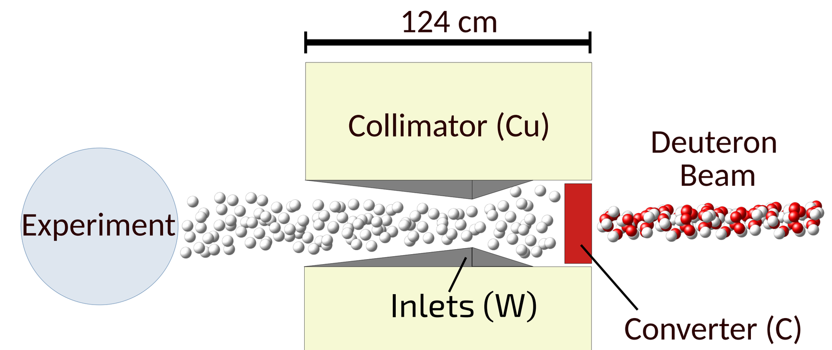
Single-turn extraction into compensated-field channel via electrostatic septum

Position and angle stabilization of extracted beam via slit apertures

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

Neutron Irradiation Site

The facility's irradiation capabilities are extended by a new neutron irradiation site at beam line F, where amongst others, silicon pixel detectors with a thickness > 300 µm can be irradiated with up to 10^6 n/cm²/s at 1 µA beam current.



Concept

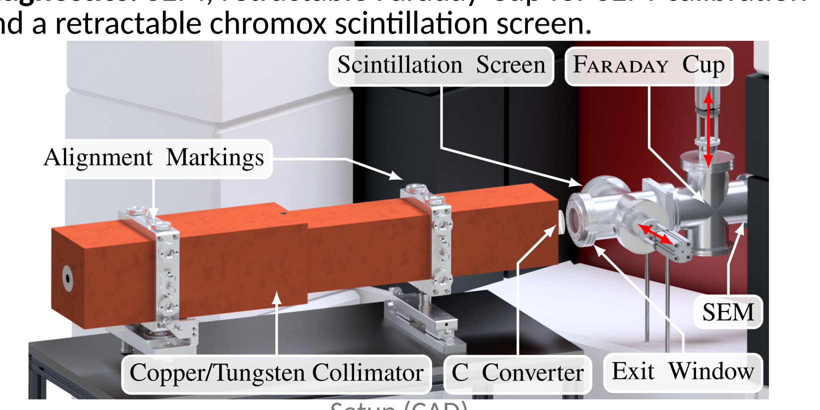
Generation: Neutrons from (d,N)-reactions of the deuteron beam (26 MeV) in a thick carbon converter.

Shaping: Manipulate neutron beam flux and energy distribution using a copper collimator with tungsten inlets, which form a double-conical geometry.

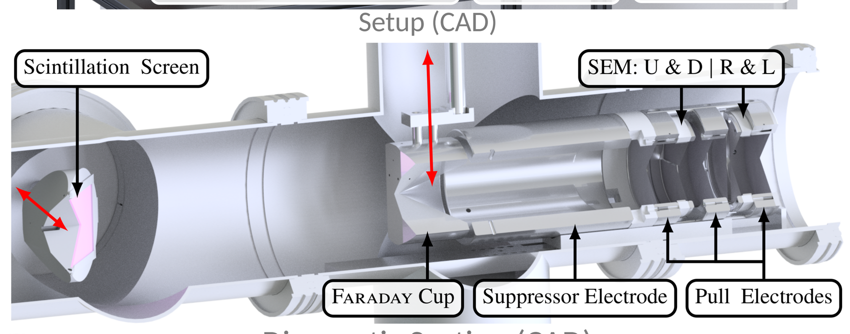
Setup

General: Diagnostic section followed by converter and collimator

Diagnostics: SEM, retractable Faraday-Cup for SEM-calibration and a retractable chromox scintillation screen.



Setup (CAD)



Diagnostic Section (CAD)

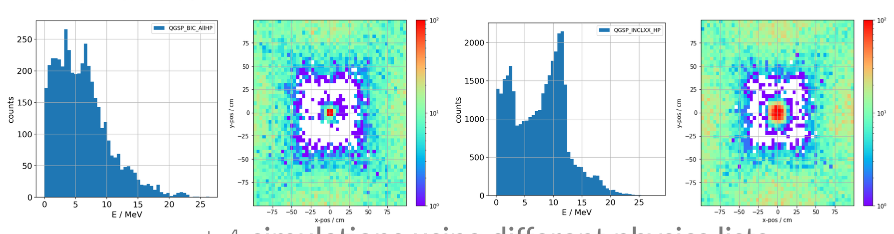
Status

Installation: Diagnostic section commissioned and fully tested.

Simulations: Neutron beam shaping with collimator, inlets and shielding geometry are simulated and further optimized using `geant4`.

Collimator: Manufacture W-Inlets and equip collimator. Then it will be aligned on the beam axis using a laser tracker.

Characterization: The neutron beam's spatial distribution will be characterized using N-γ discrimination in a liquid EJ-309/NE213-scintillator and its energy spectrum will be determined using the metal foil activation method.



`geant4` simulations using different physics lists

Modernization of Magnet Power Supplies

To provide operation with constant machine optics for the experiments, the existing power supplies (PS) of all magnets will be replaced by modern PS in stages in future. The PS will be integrated into modern Programmable Logic Controller (PLC) Systems and will be controlled by the future cyclotron control system.

Stability of Existing PS

Measurement: Integrate a DCCT into magnet-PS circuit and measure its output voltage with a 7 ½-digit digital multi meter

Magnet PS	$I_{RMS} / \langle I \rangle / 10^{-5}$	Dur. / h	Sampl. rate / Hz
Cycl. Magnet	1.12	24	0.1
A1	0.09	4	1
A2/A3	7.69	4	1
Q1	2.41	4	1
Q2	12.82	4	1
Q3	2.84	3.5	1
Q4C	2.15	4	1
Q5	3.05	2	1
Q6	6.30	3	1
Q7	0.42	2	1

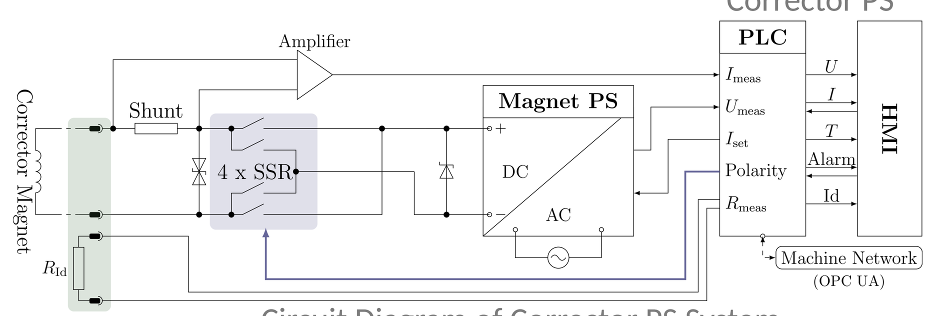
Stability Measurements

New Corrector PS System

New Corrector PS: 8 new PS (up to 24 A at 35 V) with a 8h-current stability of 9×10^{-5} were integrated into a PLC-controlled system.

System Features: 8 PS controlled by 1 PLC; Bipolar operation of the PS by switching output polarity during zero-crossing using 4 solid-state relays; Magnet identification and corresponding system configuration by individual R_{Id}; Readback of output current by a shunt;

Corrector PS



Circuit Diagram of Corrector PS System

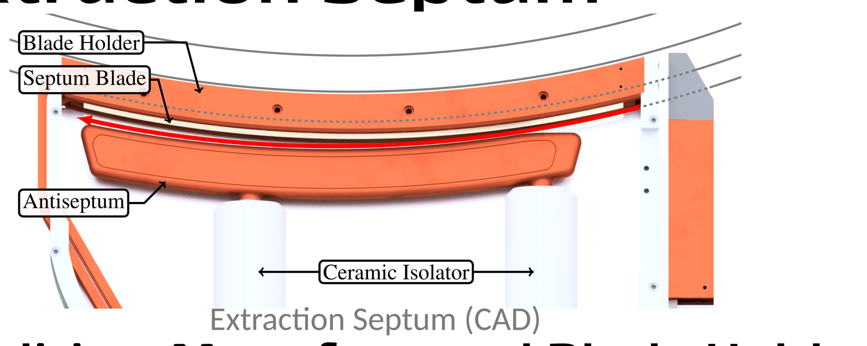
Status

PS Purchase: New Septum HV-PS; Ongoing survey on parameters of existing magnet PS of low- and high energy beam line.

Corrector PS System: Hardware installation and wiring complete.

Upgrade of the Extraction Septum

In the past, the extraction septum, an electrostatic deflector, was a main contributor to cyclotron downtimes due to leaks of its water cooling system into the cyclotron's vacuum. To increase its operation robustness, the design of the water-cooled antiseptum and the two septum blade holders is altered significantly.



Extraction Septum (CAD)

Extraction Septum

Specifications: The deflection voltage between septum blade (GND) and antiseptum (HV) is up to -40 kV, deflecting the beam by approx. 30 mrad towards the extraction channel.

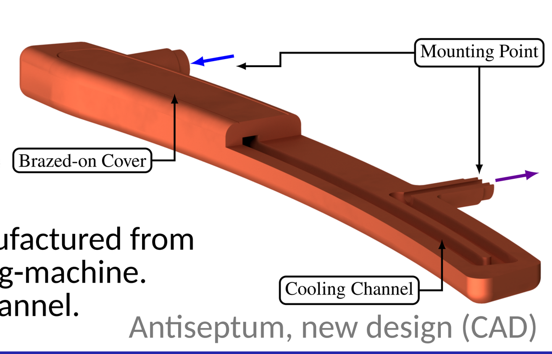
Septum Blade: 0.2 mm-thick tungsten blade with mirror finish, cooling via thermal contact with water-cooled blade holder

Antiseptum: hard chrome-plated copper electrode with rounded corners, water cooling through internal cooling channels

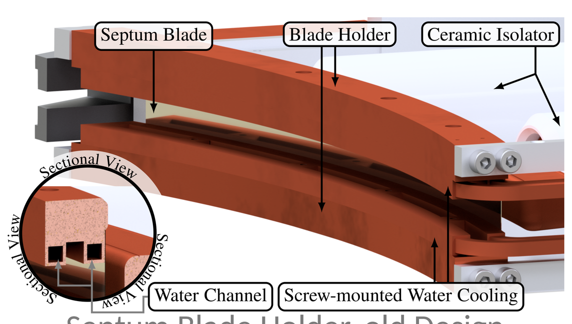
New Antiseptum Design

Flaws of Old Design: Antiseptum mounts and cover had to be brazed separately. During adjustment, often leaks emerged there due to mechanical stress.

New Design: Antiseptum with mounts is manufactured from a single copper block using a 5-axis CNC milling-machine. Only the cover is brazed to seal the cooling channel.



Antiseptum, new design (CAD)

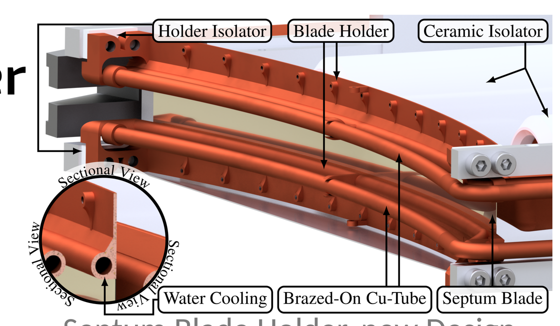


Septum Blade Holder, old Design

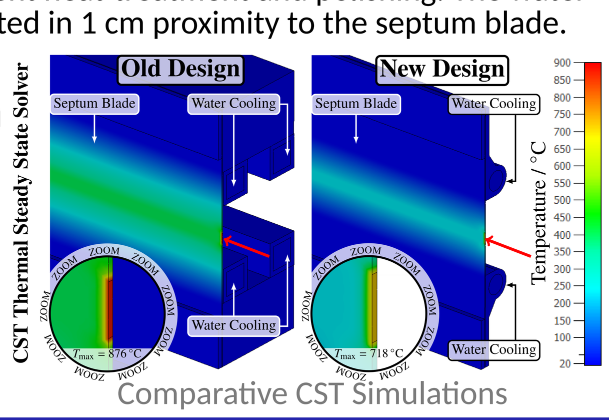
Additive-Manufactured Blade Holder

Goal: Minimize amount of soldered connection of the water cooling while also increase the cooling efficiency of the septum blade.

Additive Manufacturing: Blade holder were redesigned (128 g, 14.3 cm³) for pure-copper laser-powder bed fusion (L-PBF) manufacturing with subsequent heat-treatment and polishing. The water cooling channel is situated in 1 cm proximity to the septum blade.



Septum Blade Holder, new Design



Comparative CST Simulations

CST Simulations: 56 MeV-α beam with 15 µA current (840 W) impinges on the edge and side of the blade show a 20% better cooling efficiency with new design

Status

Antiseptum: Upgrade completed

Blade Holder: Design-Phase finished, L-PBF manufacturing will start soon.

Contact