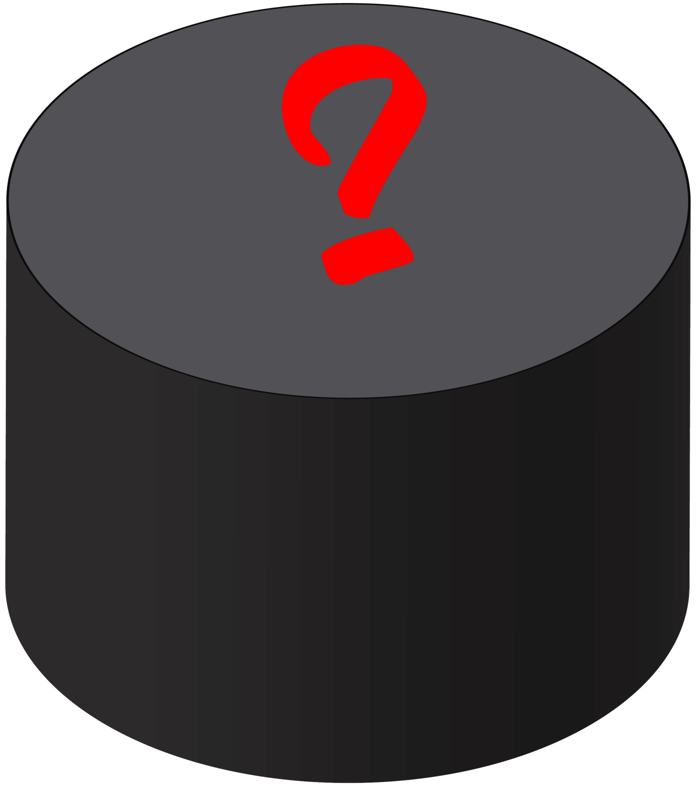
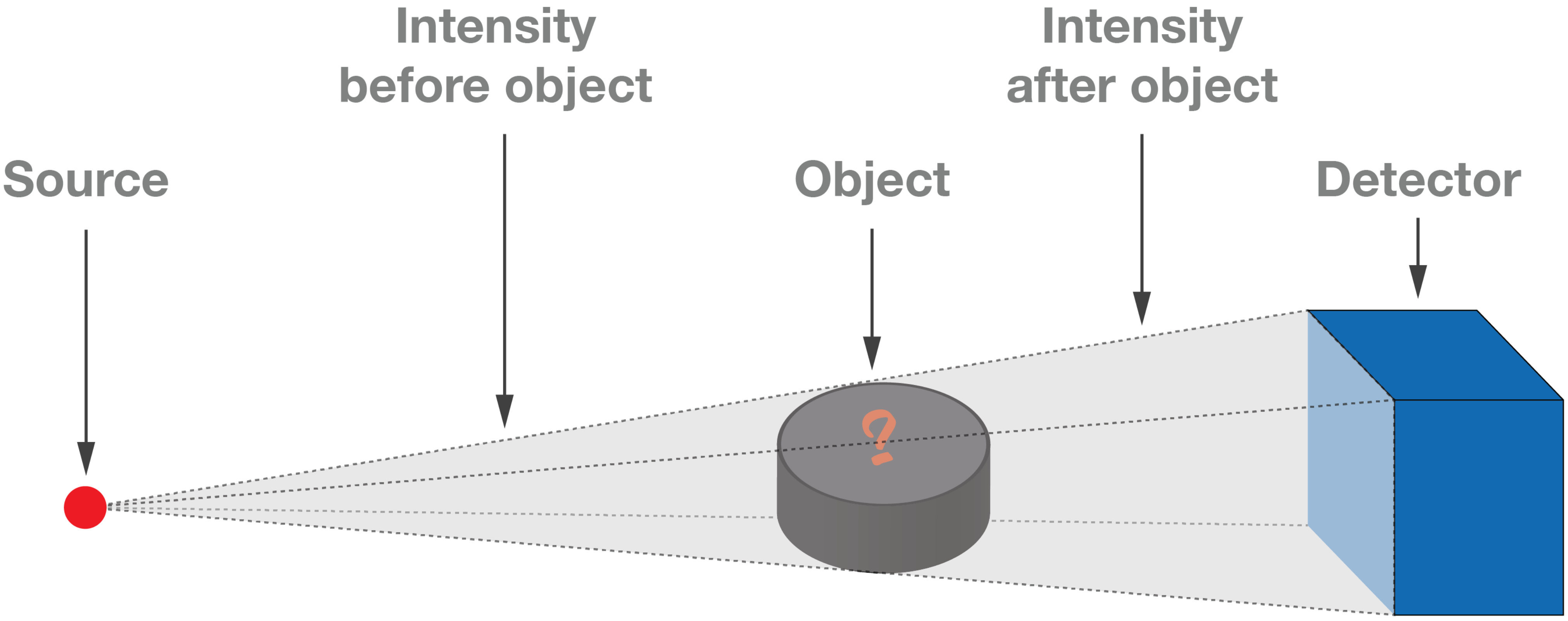
Optimization of a compact D-D fast neutron generator for imaging applications

Heiko Kromer
June 17, 2020

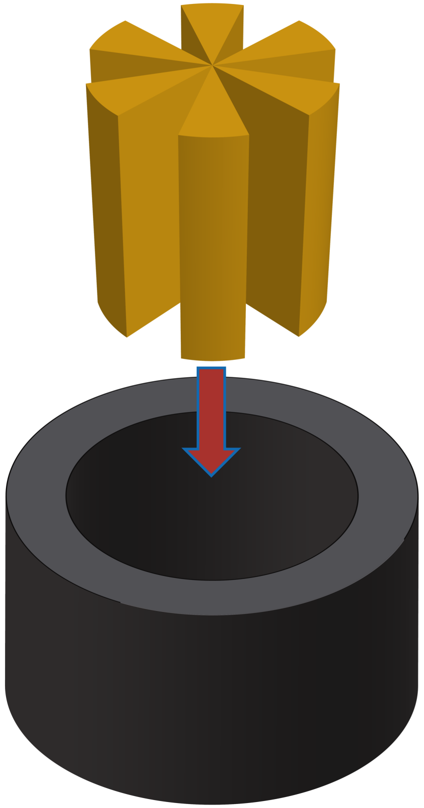
Consider the following scenario…



Transmission-based tomography can be used for non-destructive testing



Fast neutrons are a powerful non-destructive testing tool in certain scenarios

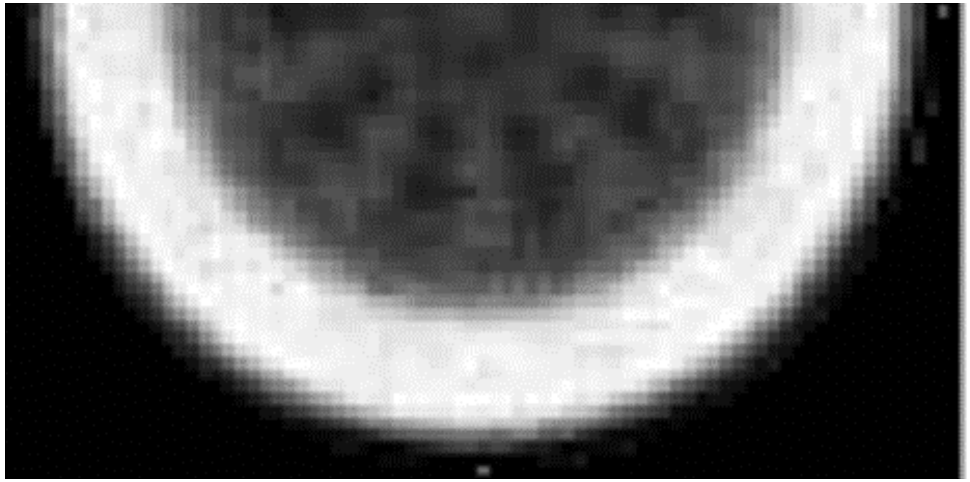


Shielded siemens star test object

Low-Z shielded by high-Z material

Transmission-based tomography

Fast neutrons



Gamma (^{60}Co)

My PhD work addresses the low neutron yield of compact fast neutron generators

Compact fast neutron generators
favour

- mono-energetic flux,
- are small-sized to be
- mobile and
- are low-priced

but exhibit a low neutron output
resulting in long exposure times

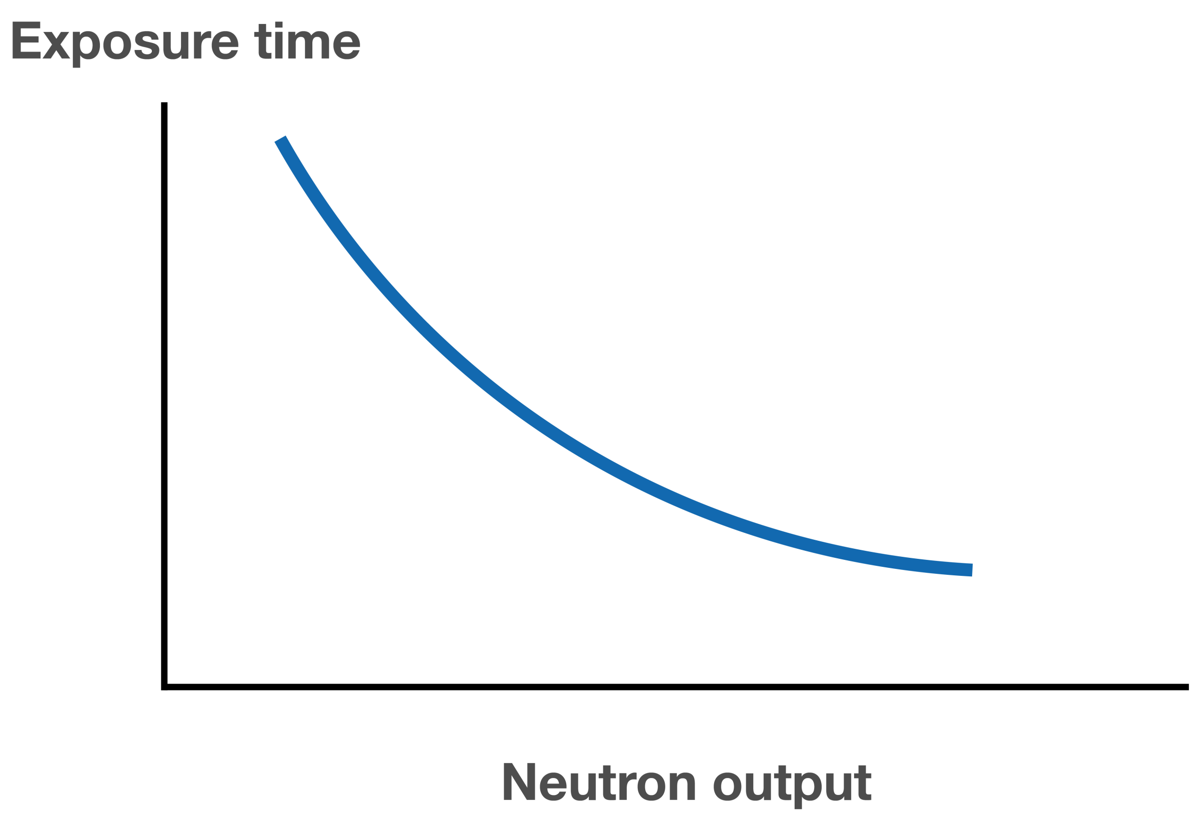


Table of contents/Agenda

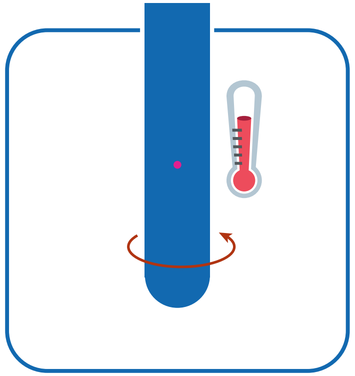
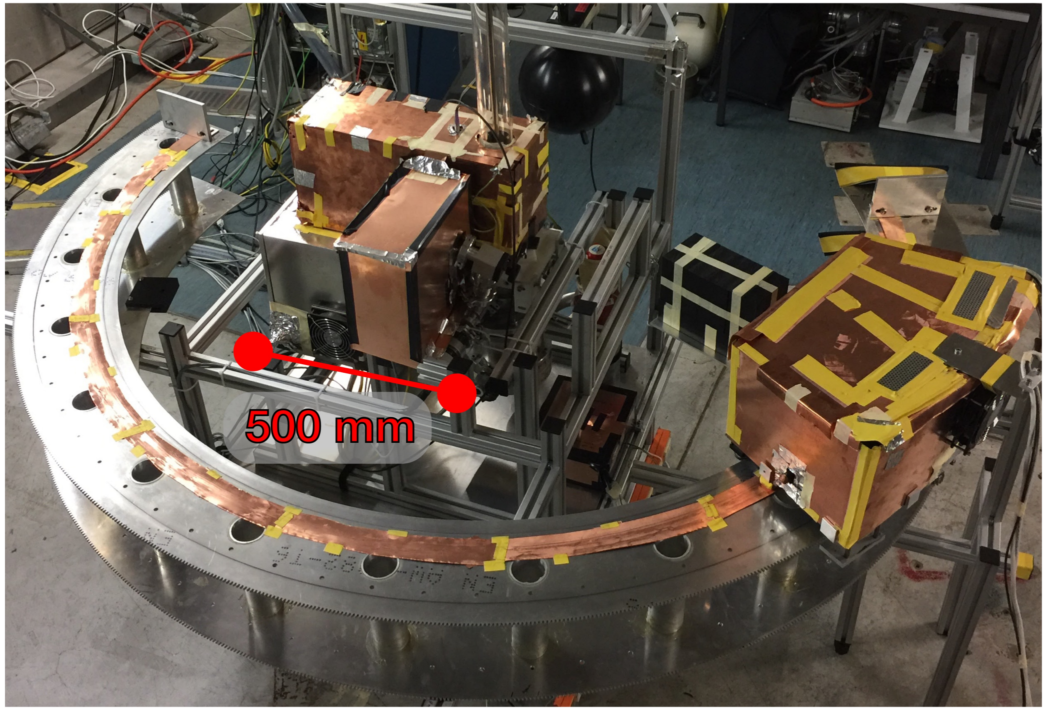
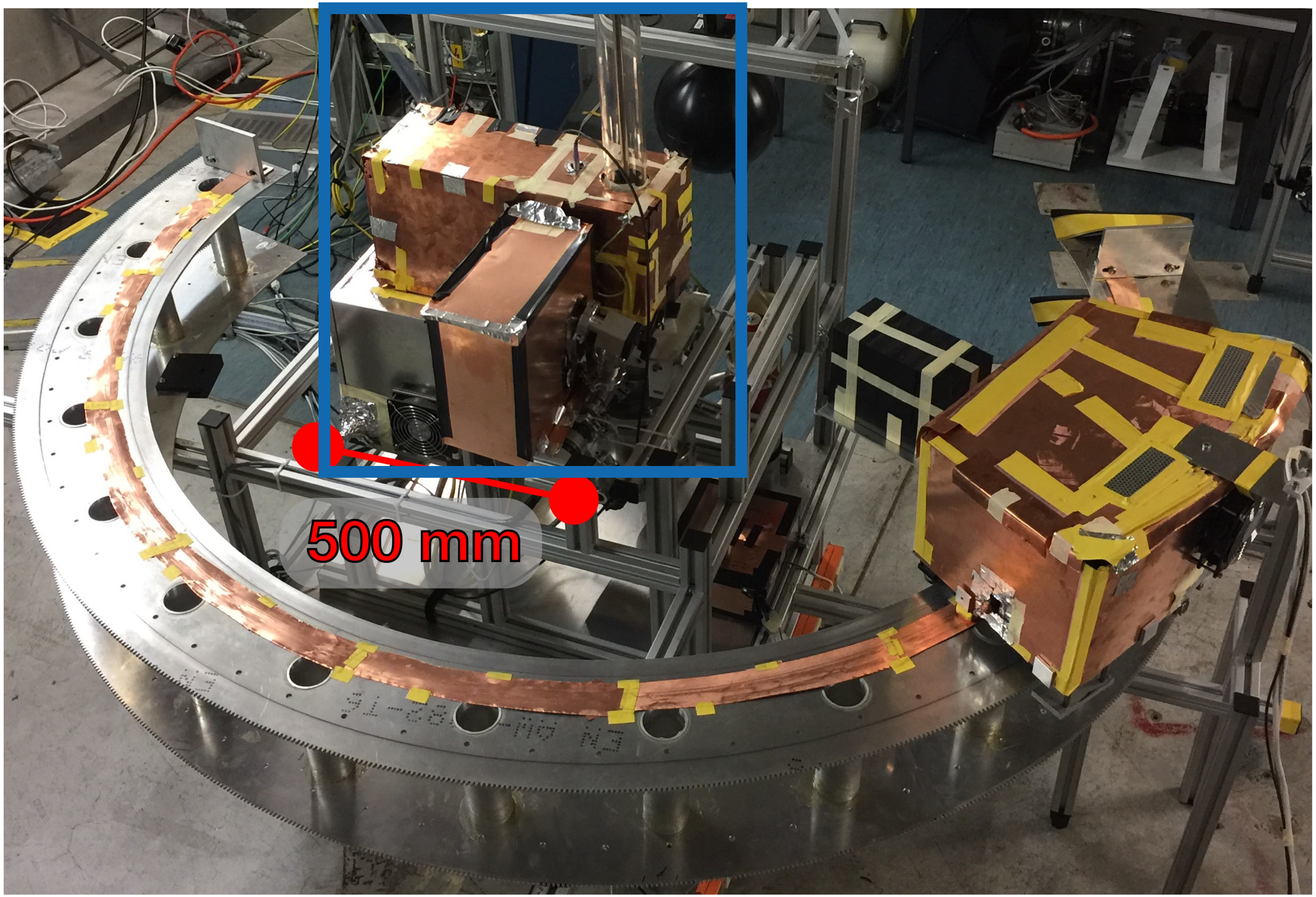


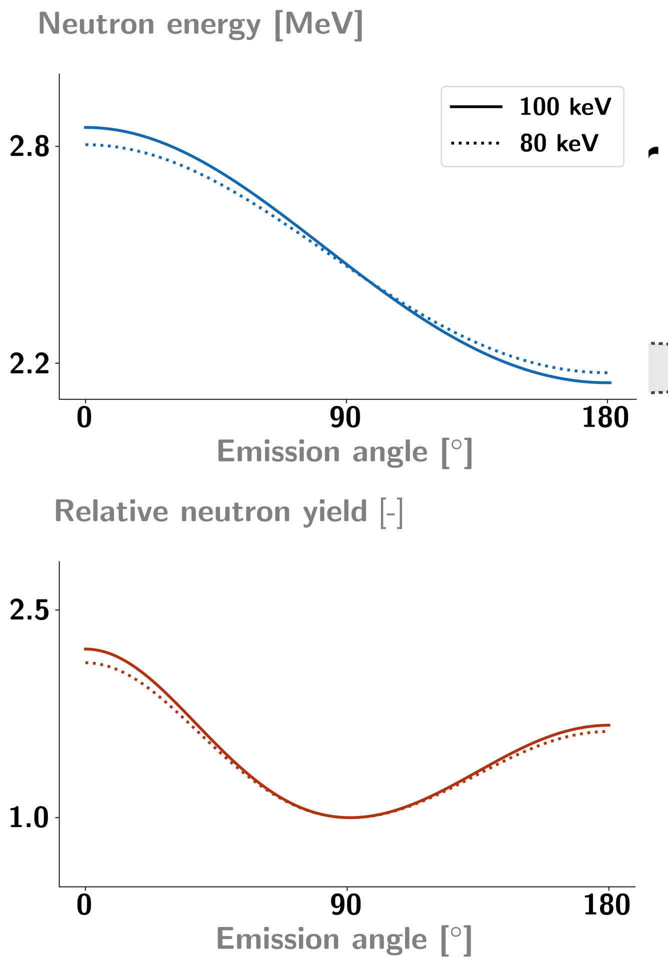
Table of contents/Agenda

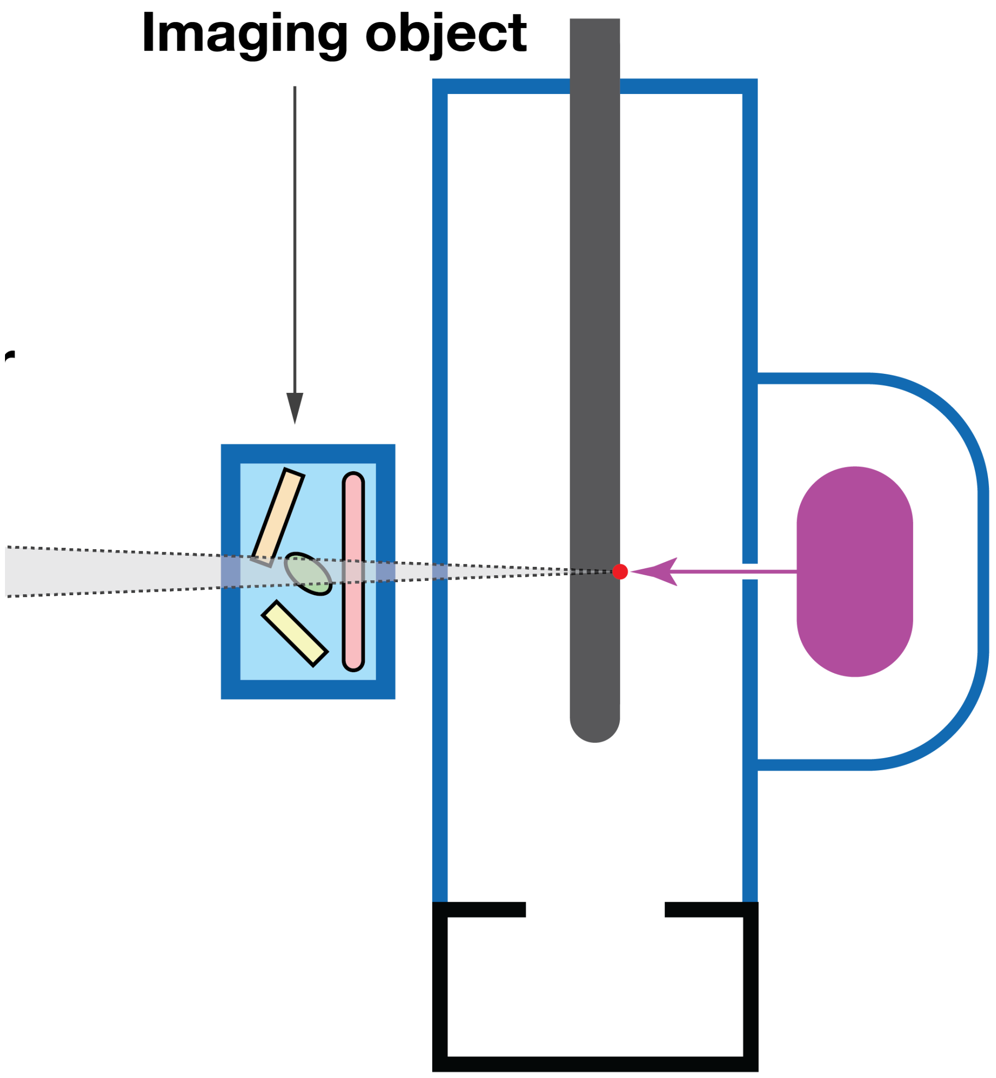


The compact D-D fast neutron generator at PSI

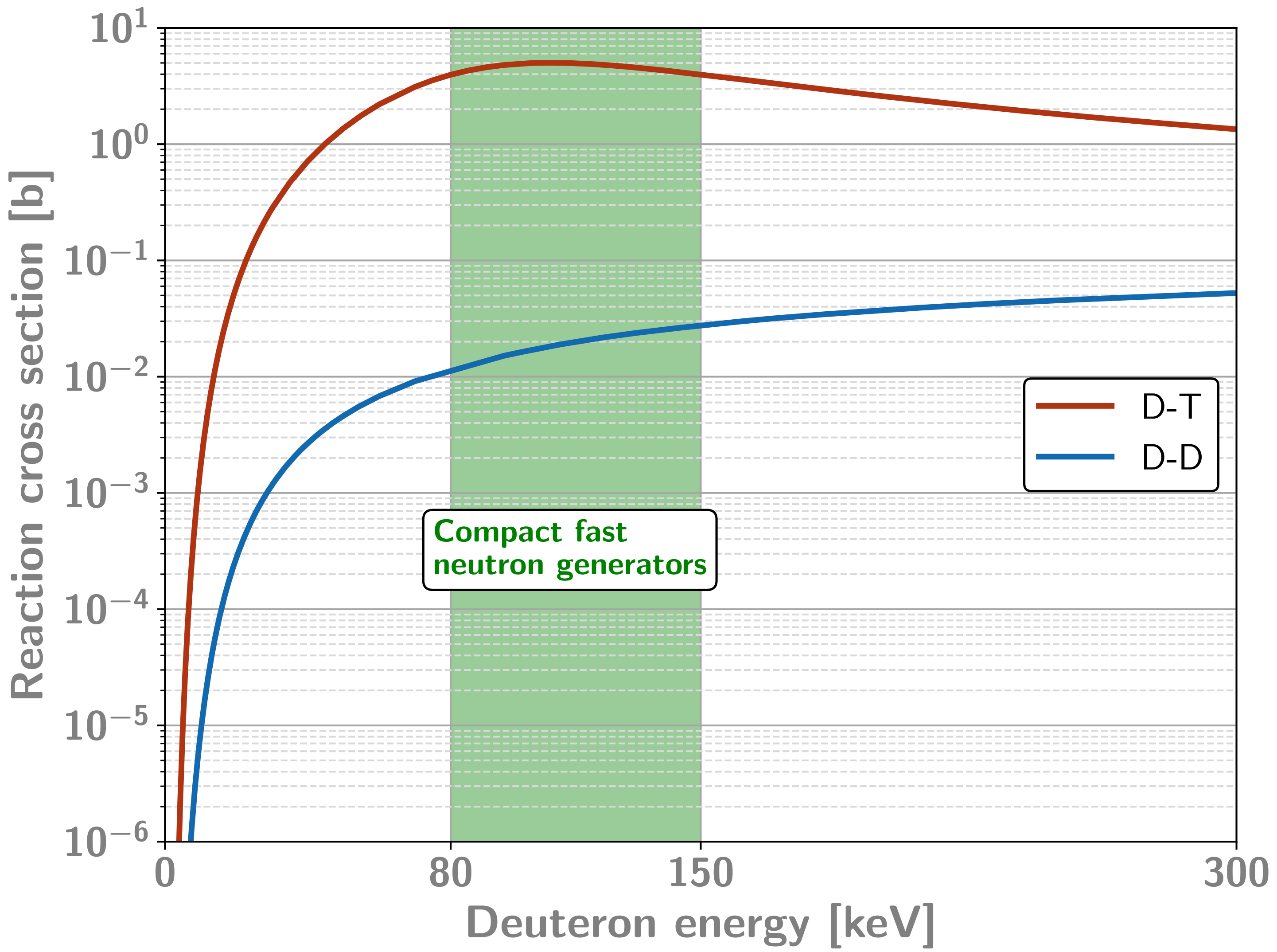


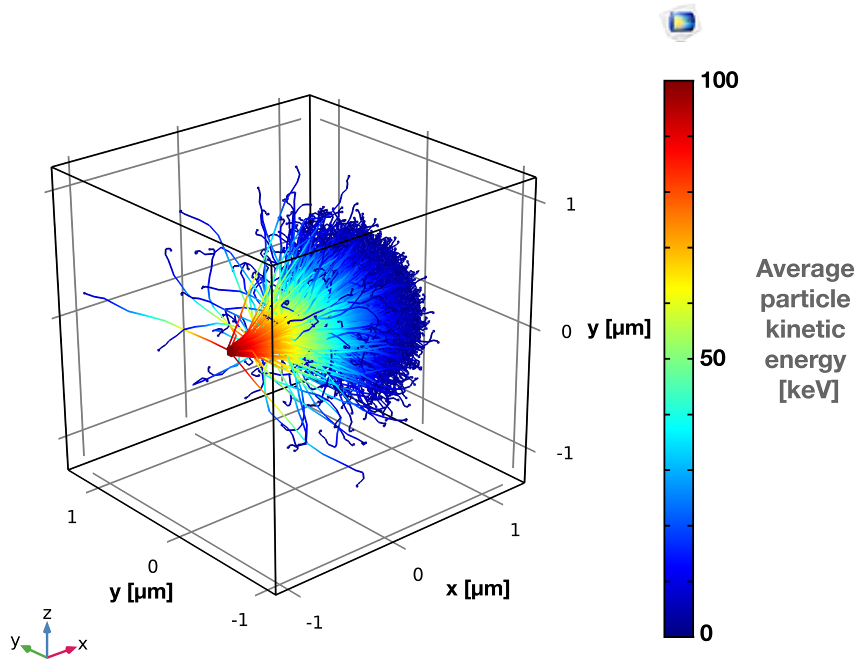
The fast neutron generator at PSI uses the deuterium-deuterium fusion reaction

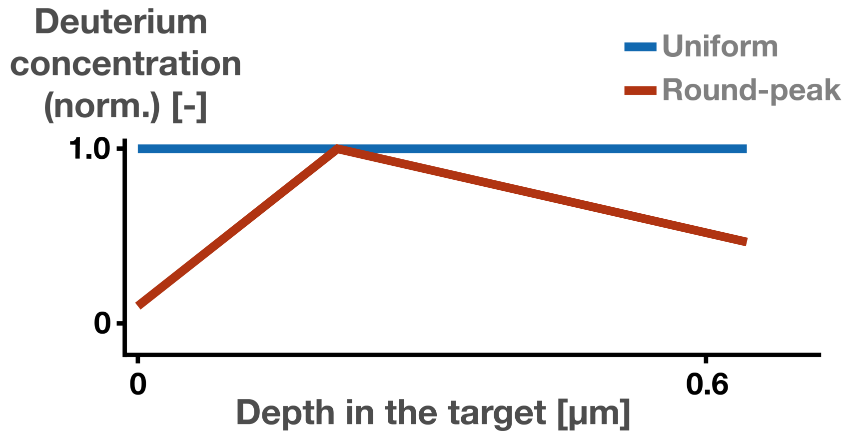




Several parameters affect the neutron yield







Overheating and outgassing of implanted deuterium limits neutron yield

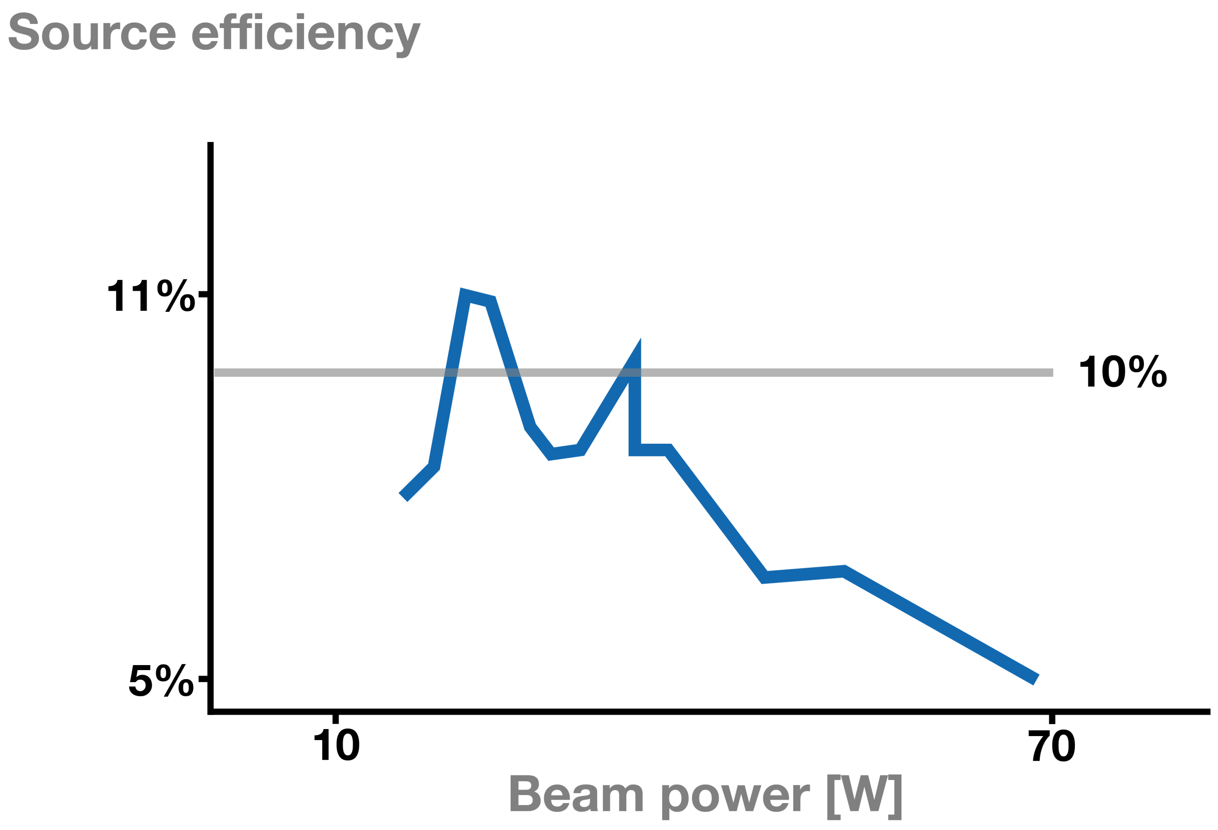
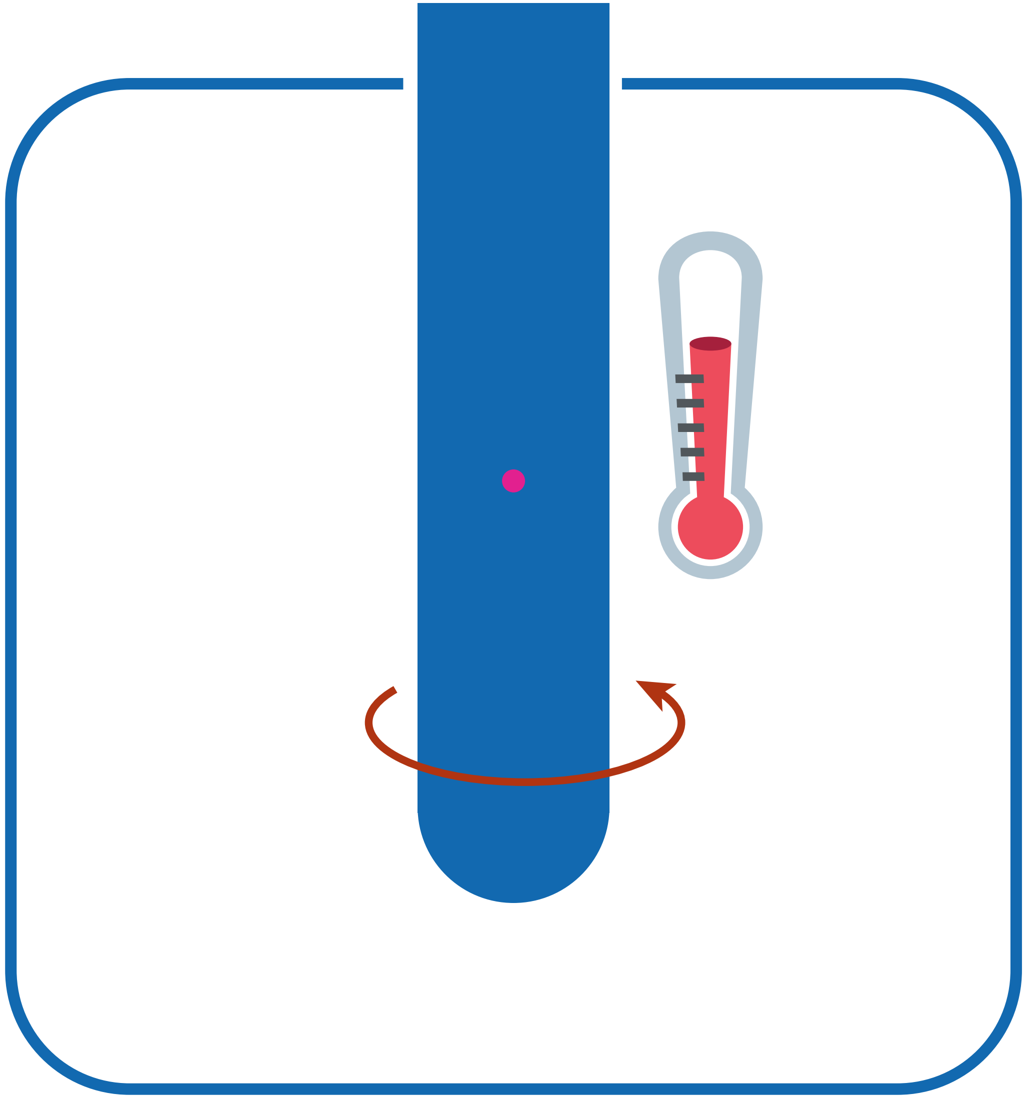
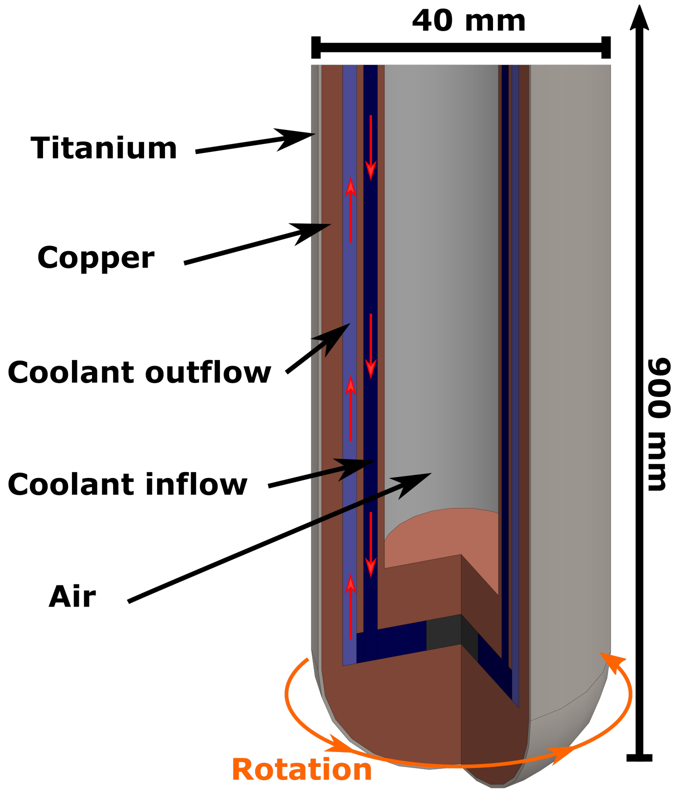
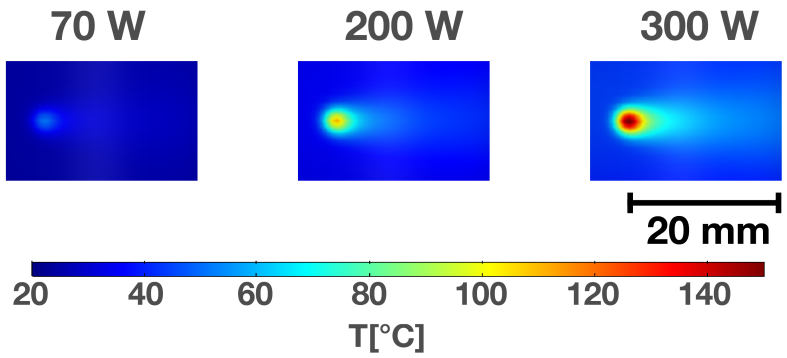


Table of contents/Agenda

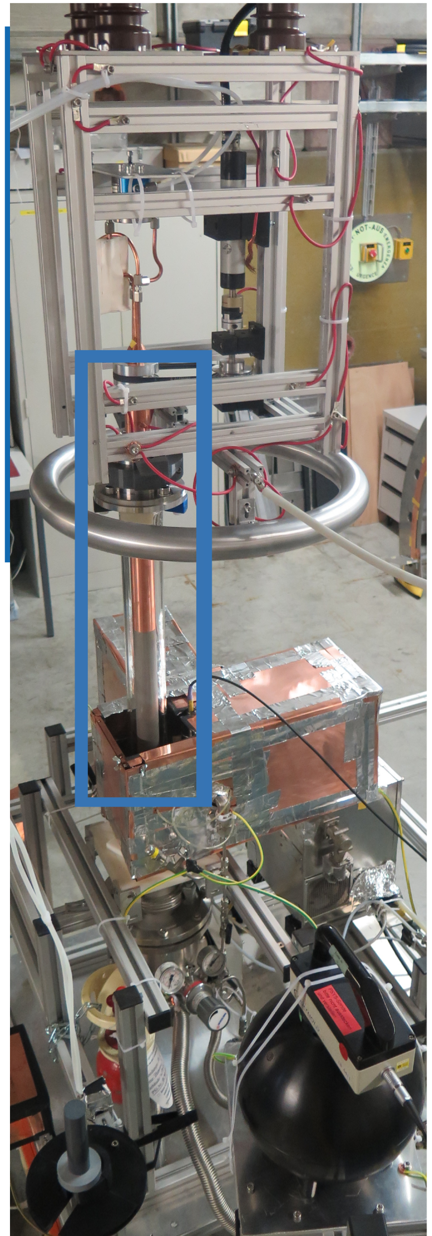


A new rotating target was designed and installed to prevent loss of deuterium by overheating

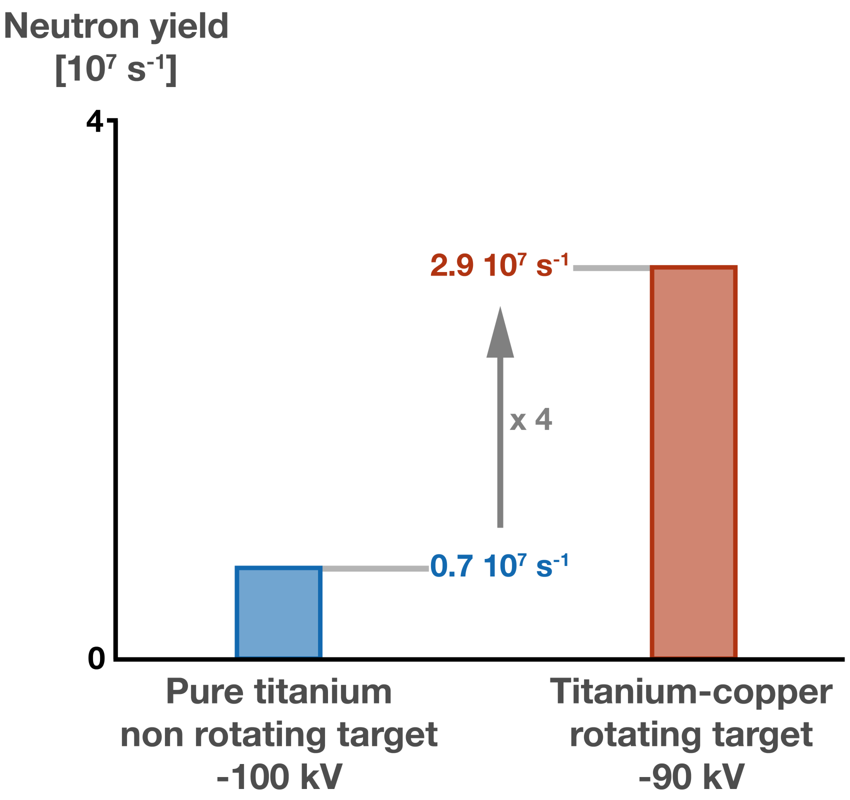




A new rotating target was designed and installed to prevent loss of deuterium by overheating



The neutron yield with the rotating target increased significantly



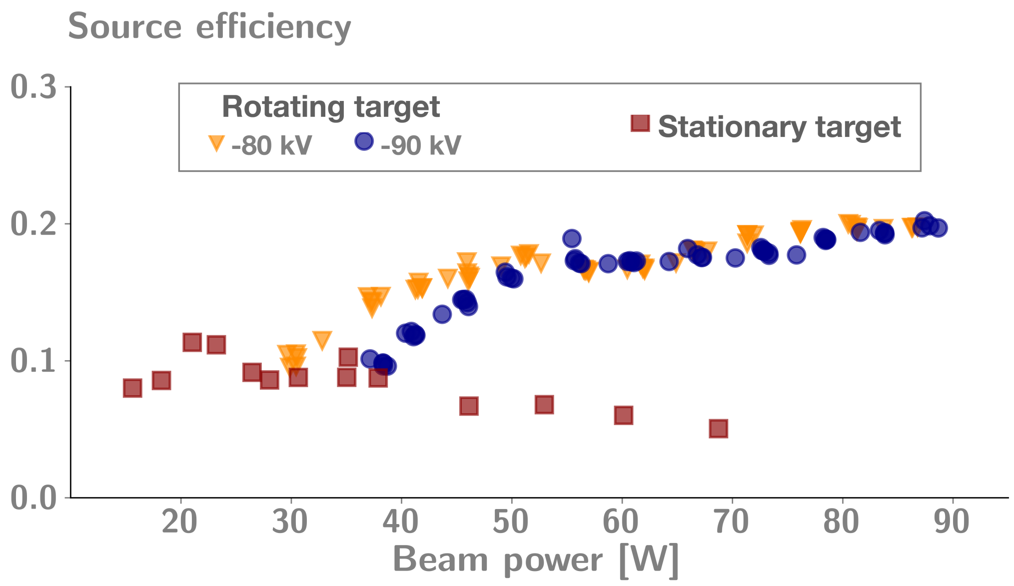
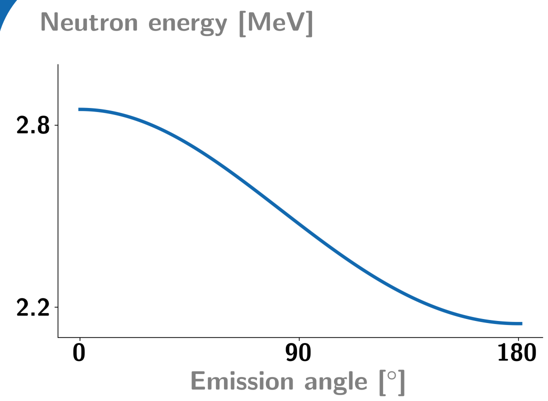


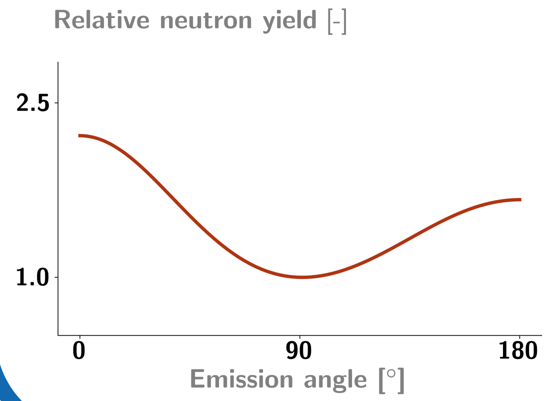
Table of contents/Agenda

Determination of total neutron output

Measurement of the neutron yield is not trivial

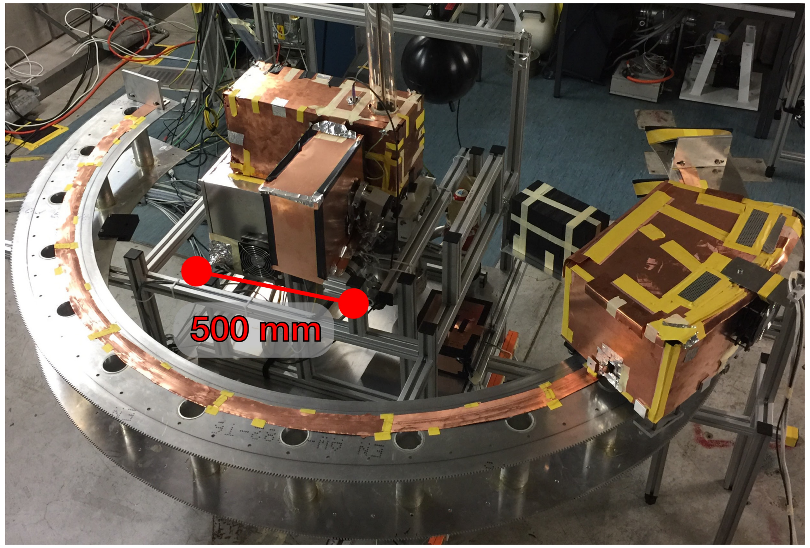
Neutron source





Neutron transport

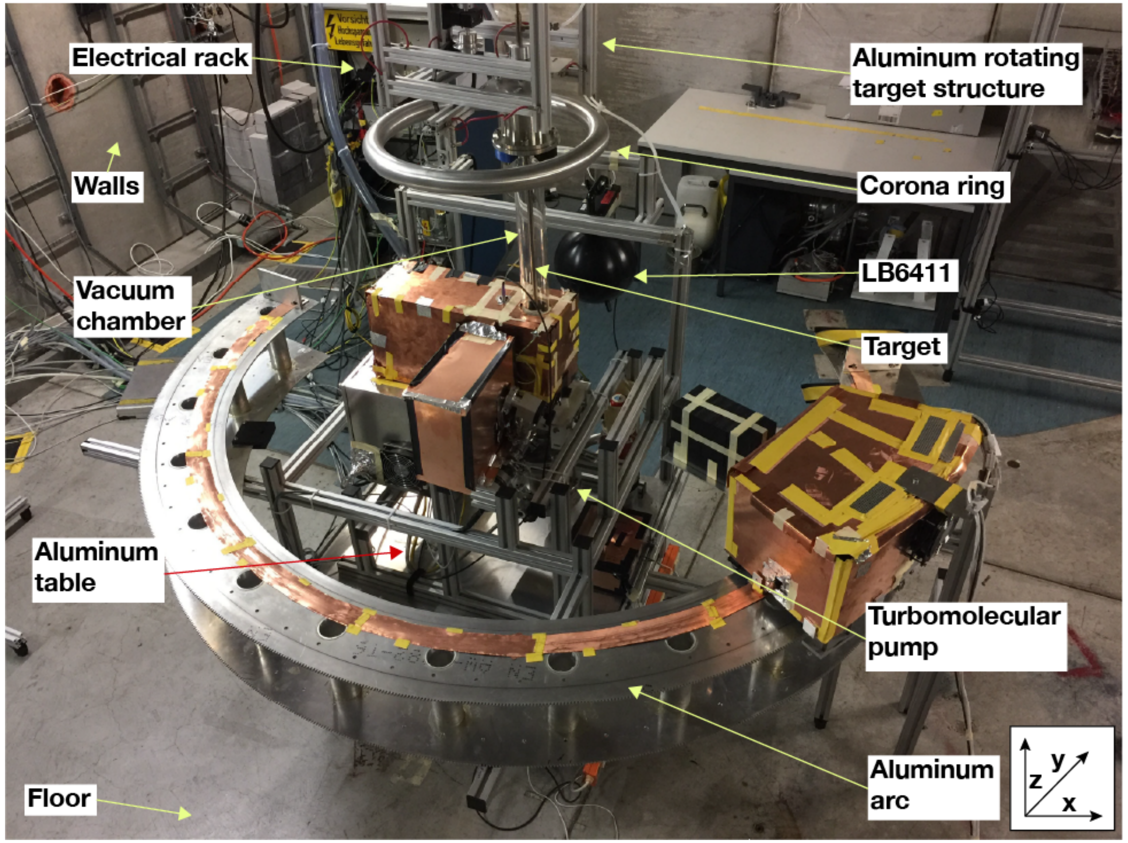
Simulation

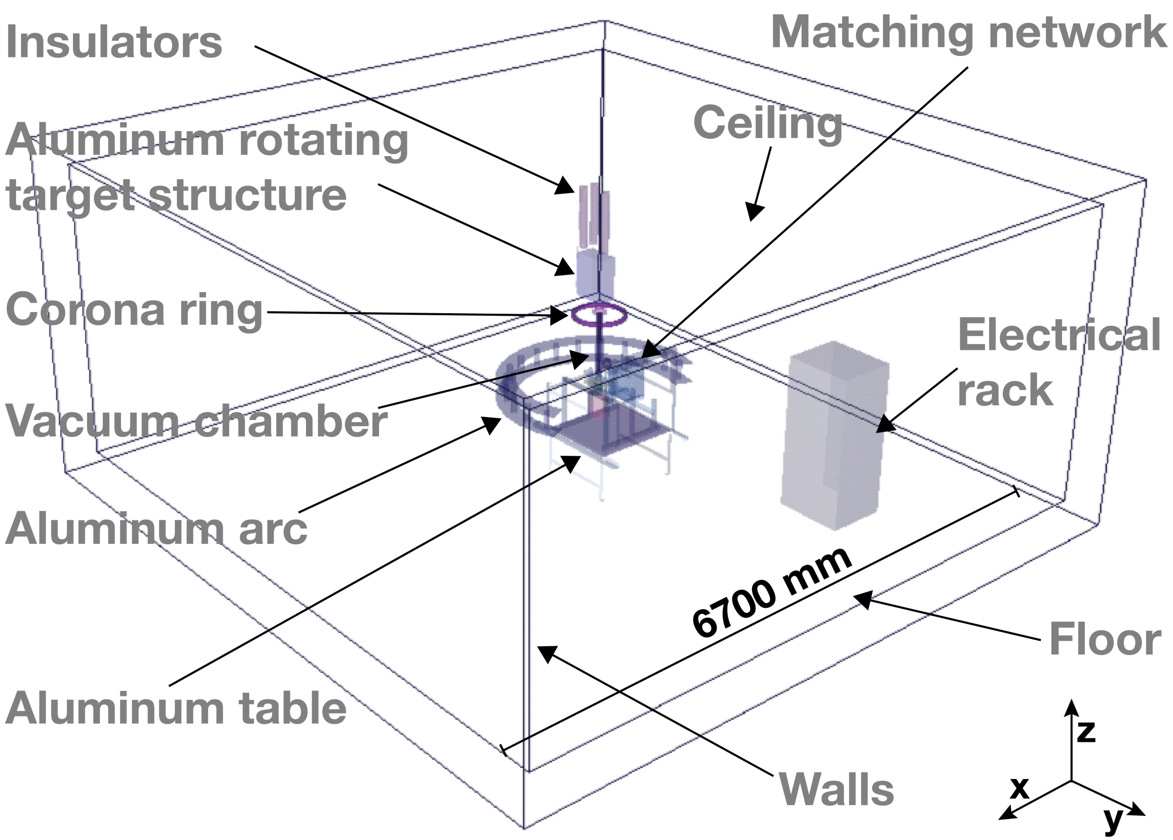


Neutron detector

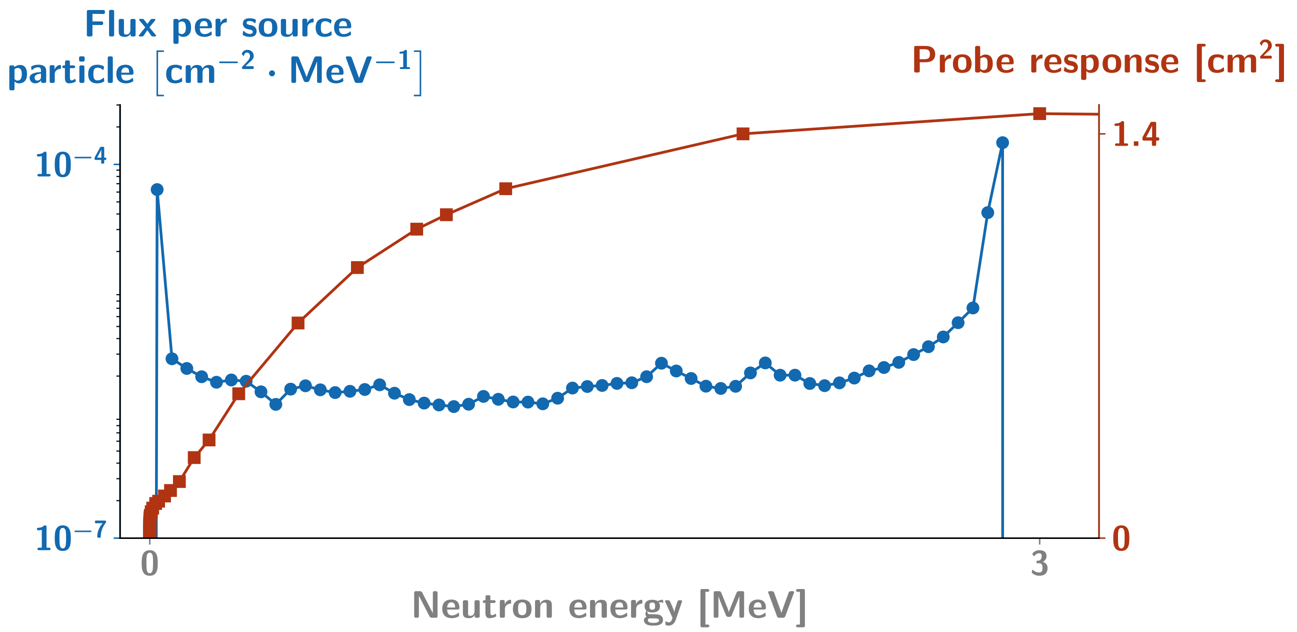
Experiment

A detailed MCNP6 model of the neutron generator and its surrounding was set up





The neutron output was determined combining neutron probe reading and MCNP6 model



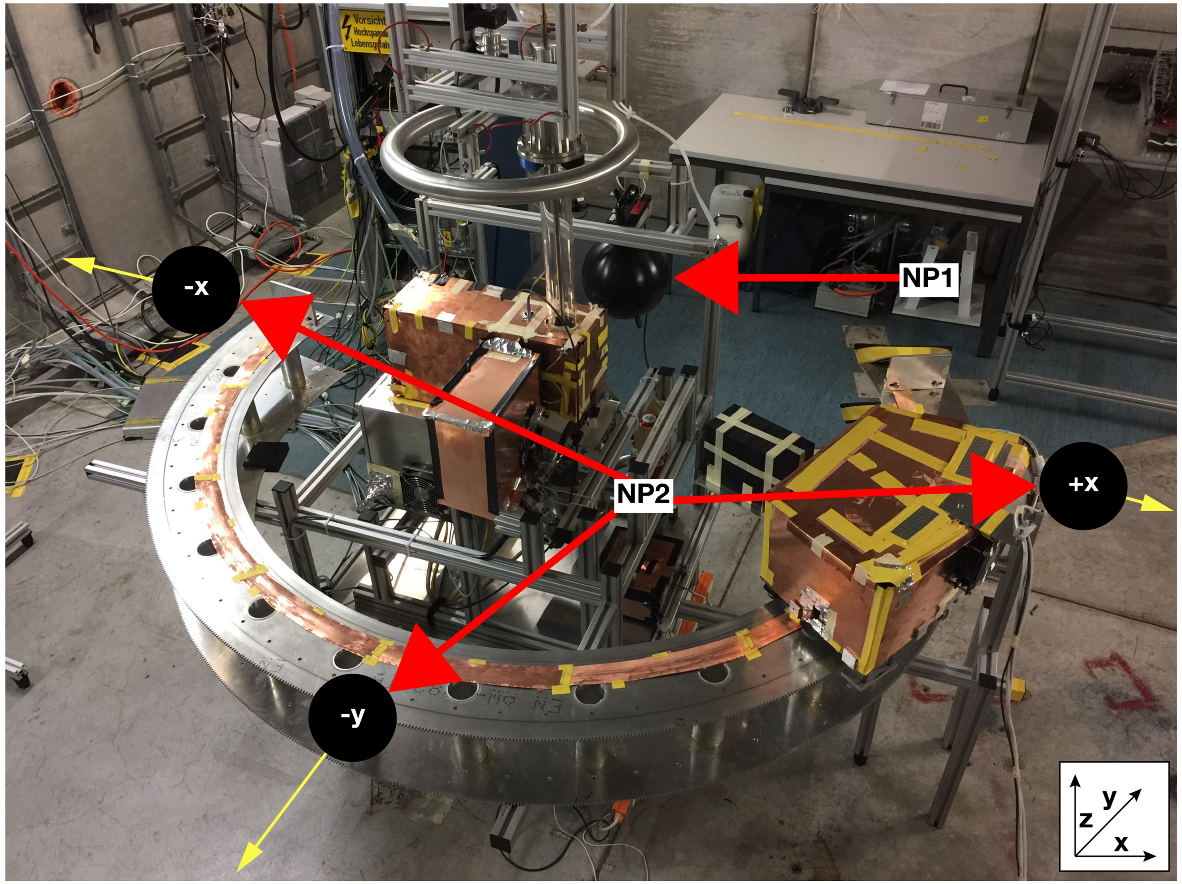
MCNP6 model → Counts per source particle

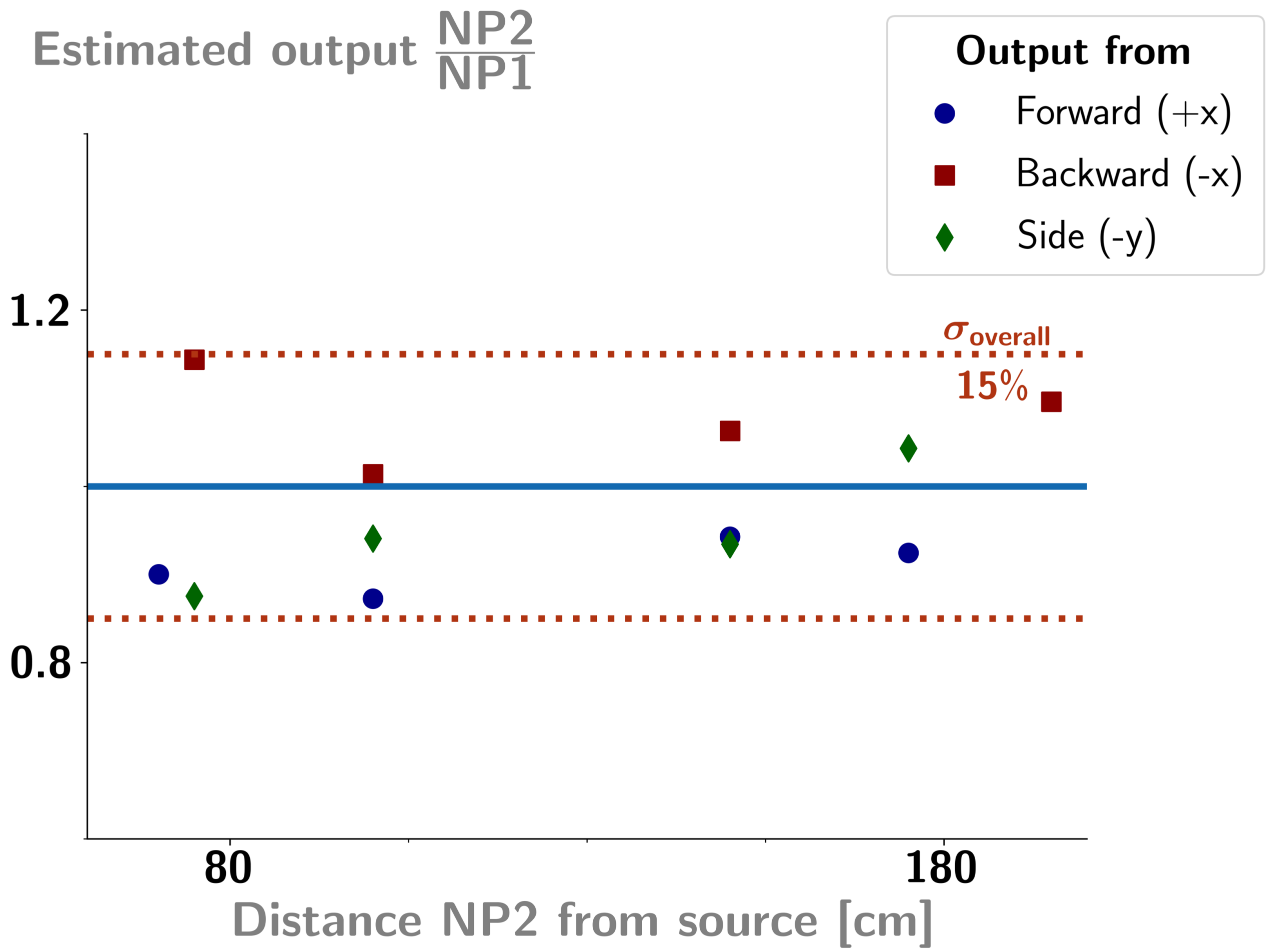
Ambient dose from neutron probe → Countrate

↓

Total neutron output

The approach was benchmarked comparing the neutron yield estimations at various neutron probe positions



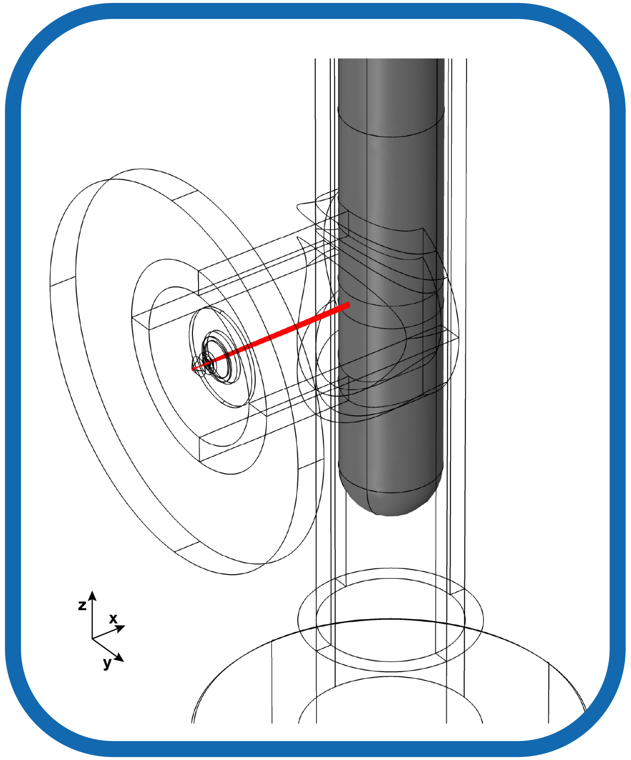


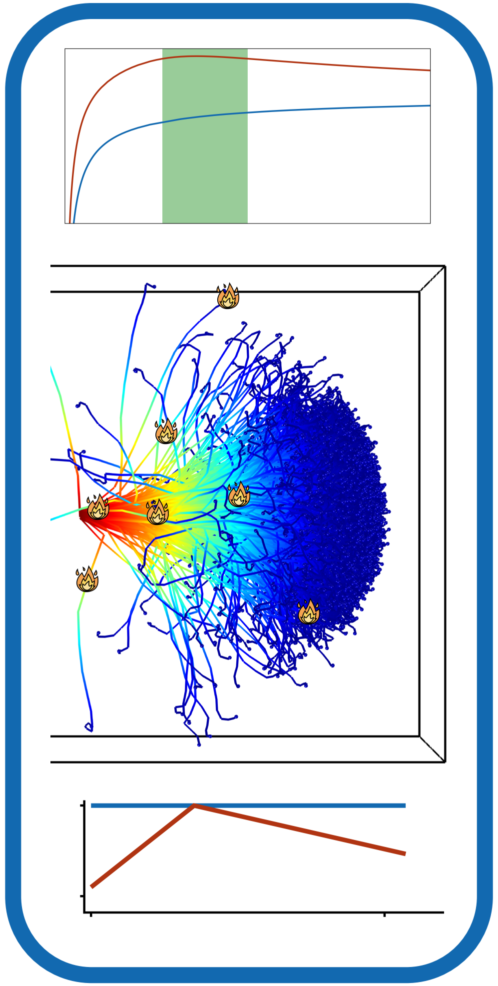
Determination of neutron emitting spot size

The neutron emitting spot size depends on the ion beam spot size and the properties of the beam target

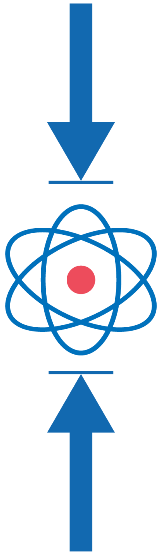
Target

Deuterium ion beam





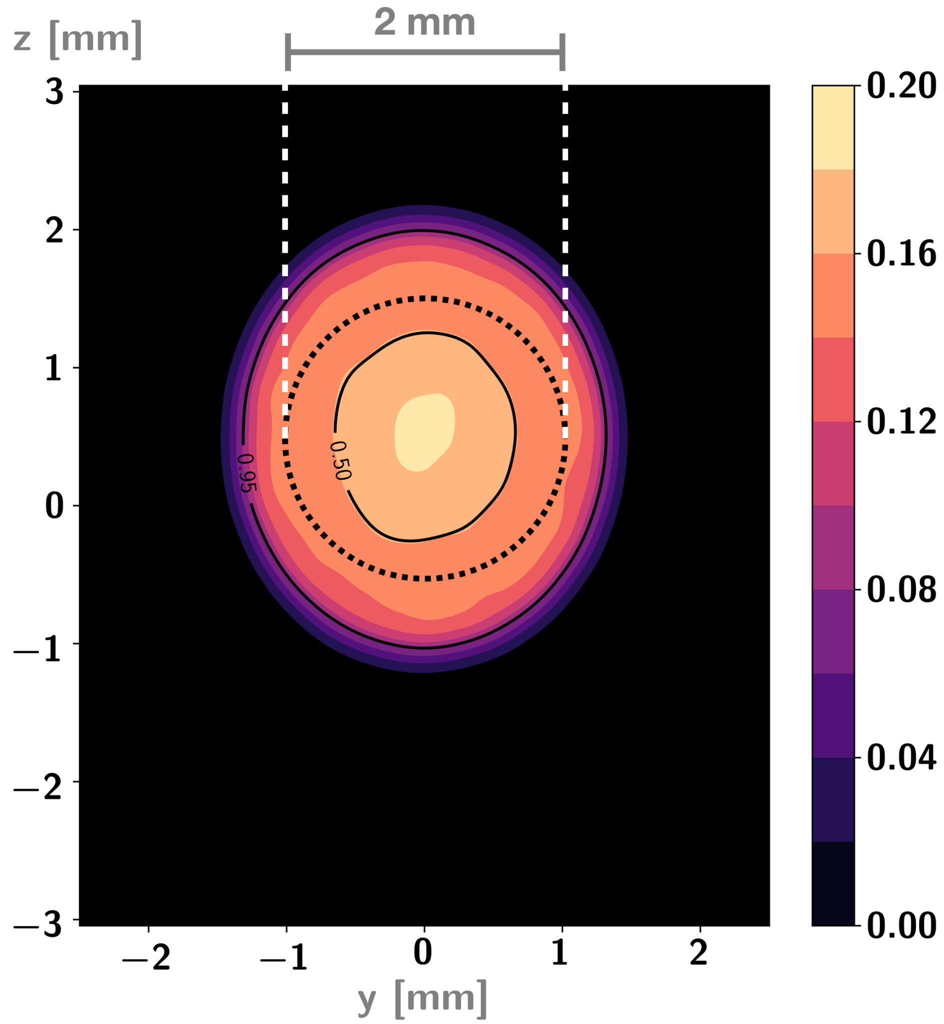
Neutron emitting spot size

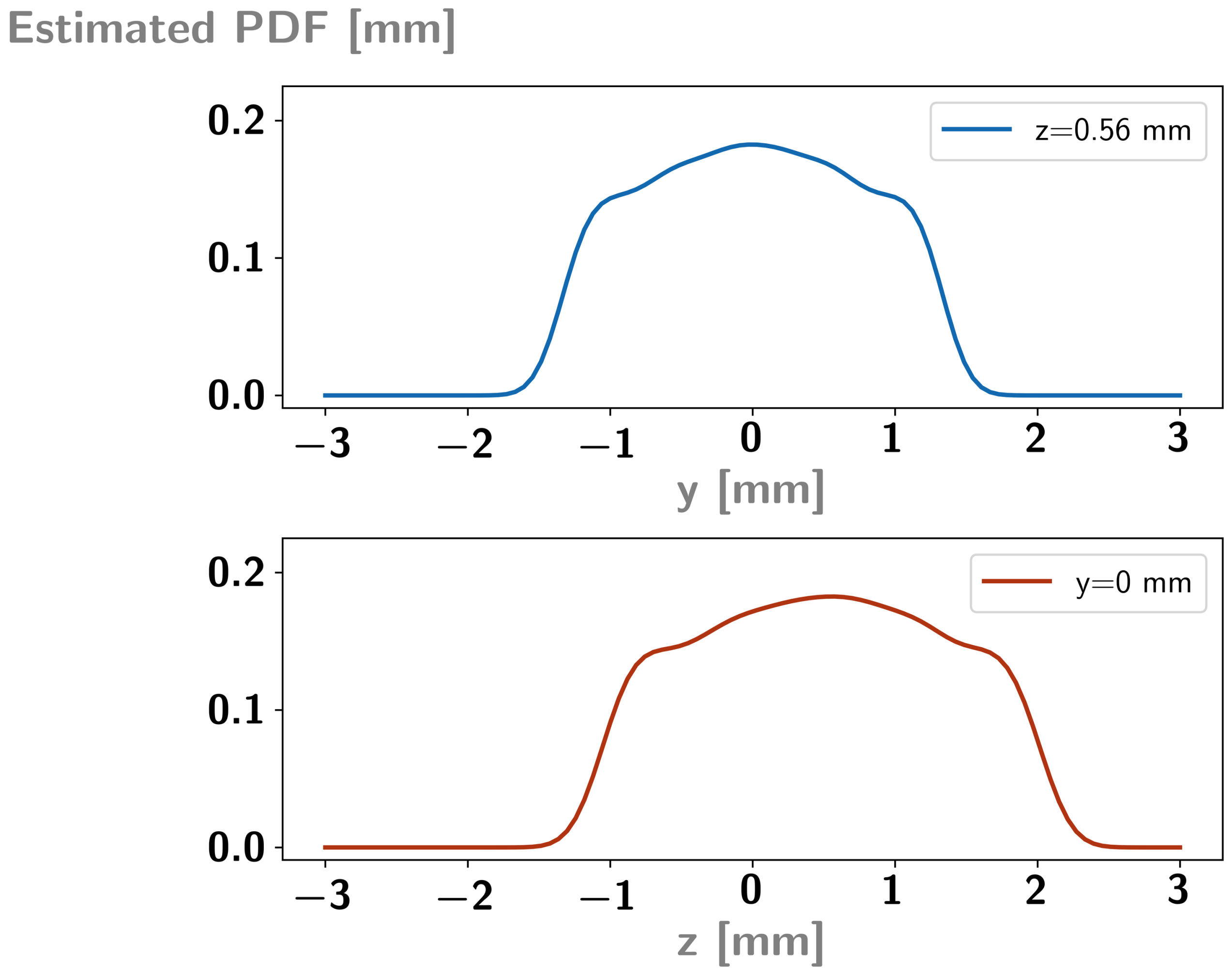


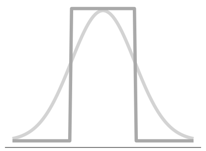
Simulation

Experiment

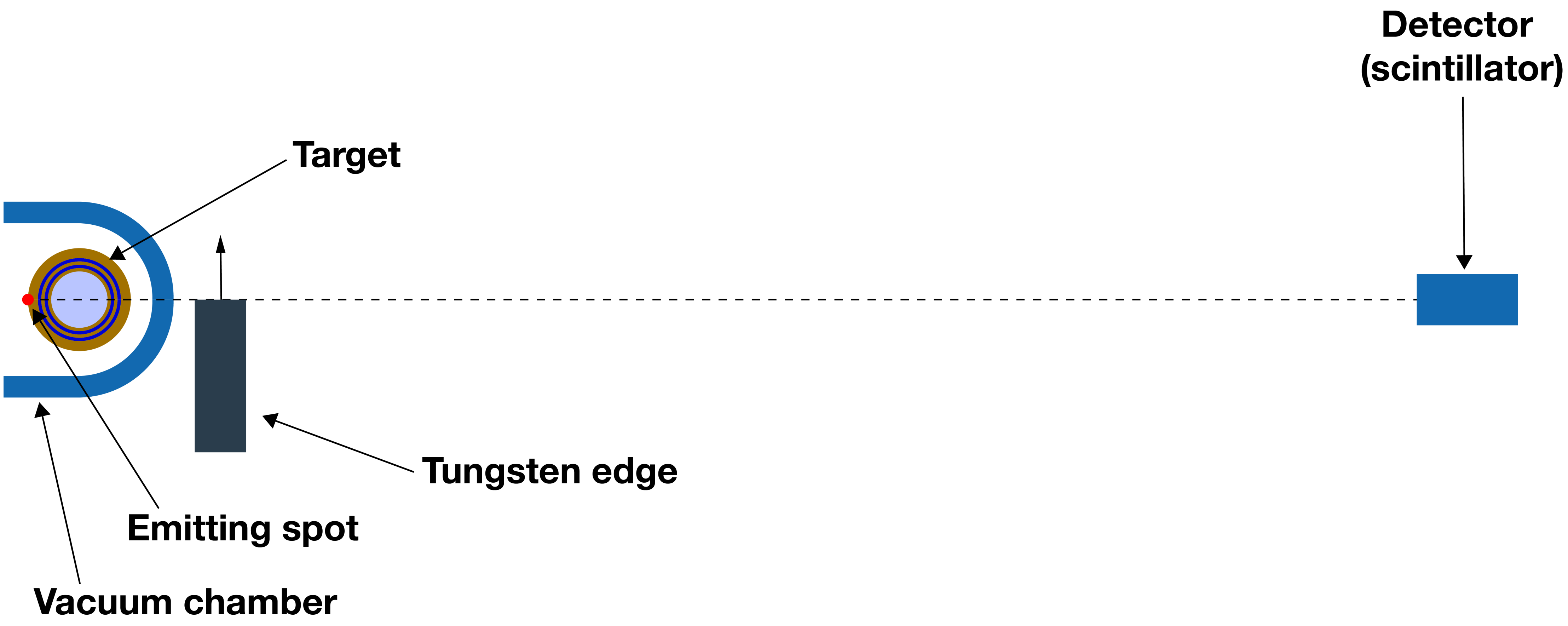
The FWHM of the ion beam spot size on the target surface was estimated between 2 and 2.5 mm



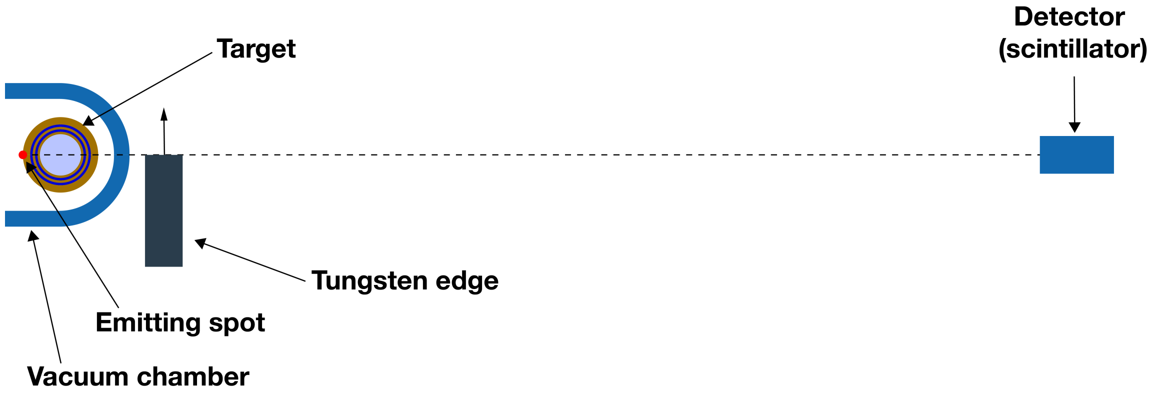


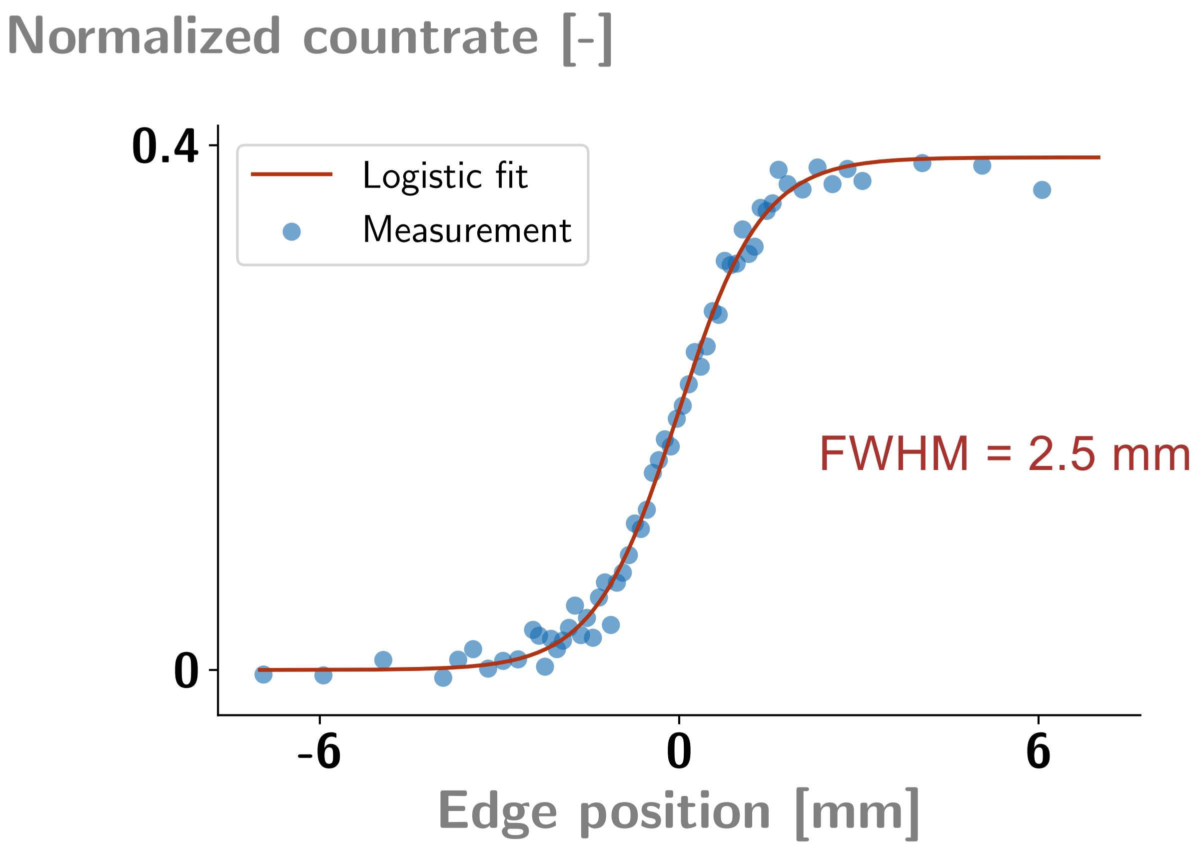


The neutron emitting spot size was estimated using an attenuating edge technique



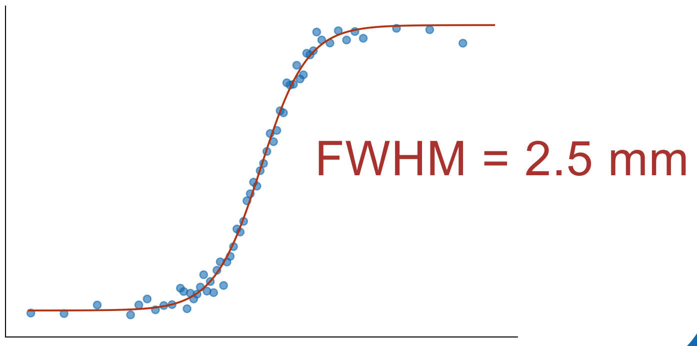
The edge spread function is the response of the countrate in the detector to the movement of an attenuating edge



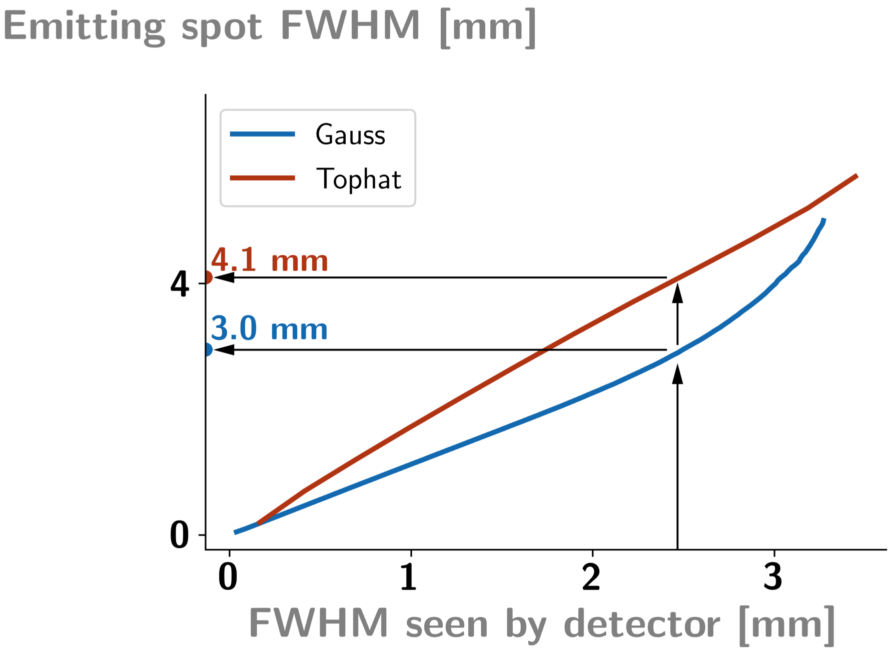


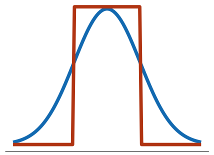
The spot size that the detector sees is modulated by an unknown transfer function that must be corrected

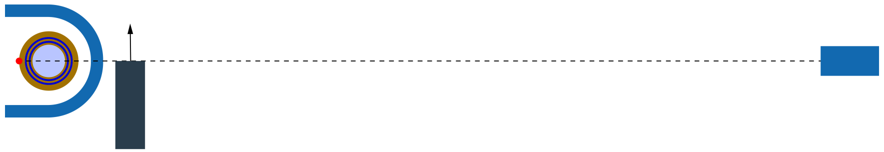
Countrate measurement



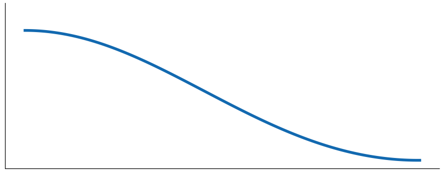
Calibration using MCNP6







Neutron energy



Relative neutron yield

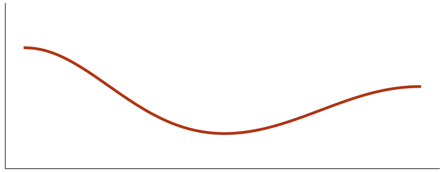
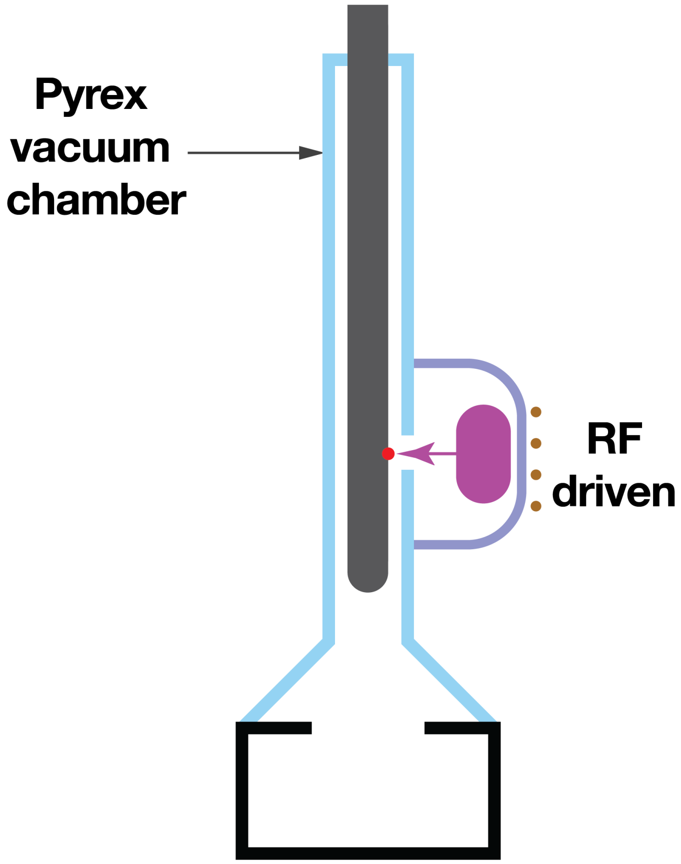


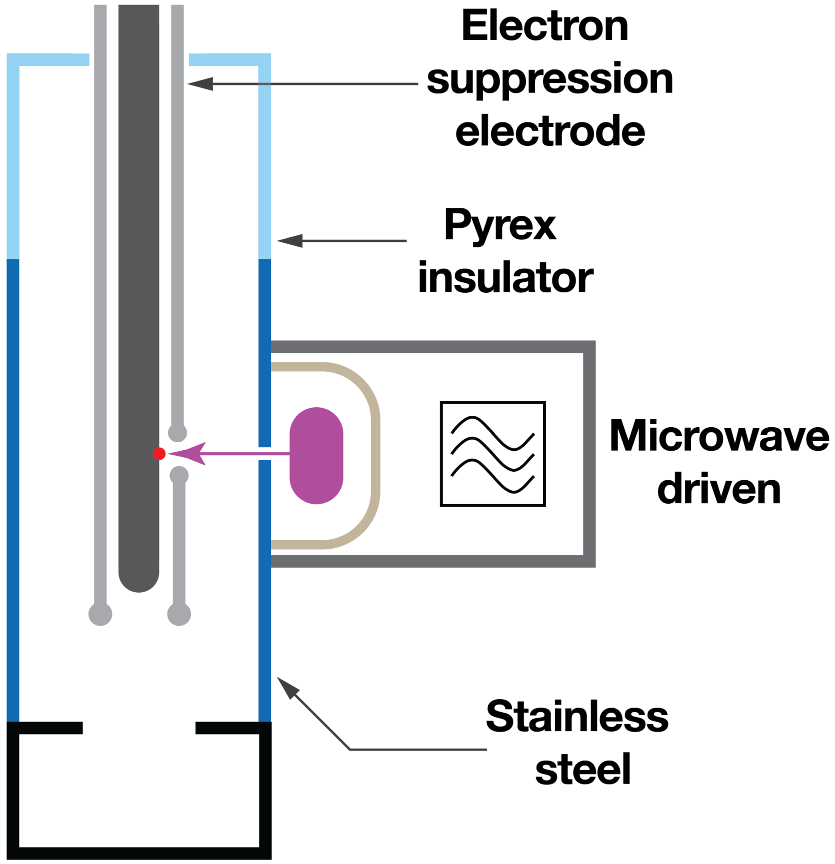
Table of contents/Agenda

The Generation II fast neutron generator at PSI is equipped with microwave driven ion source and electron suppression electrode

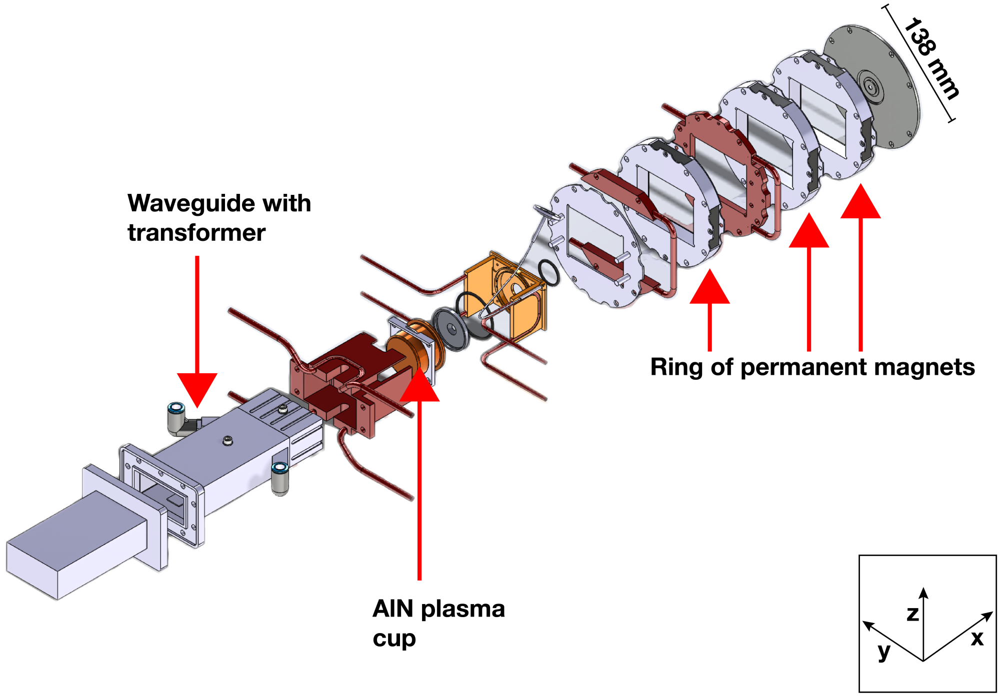
Generation I

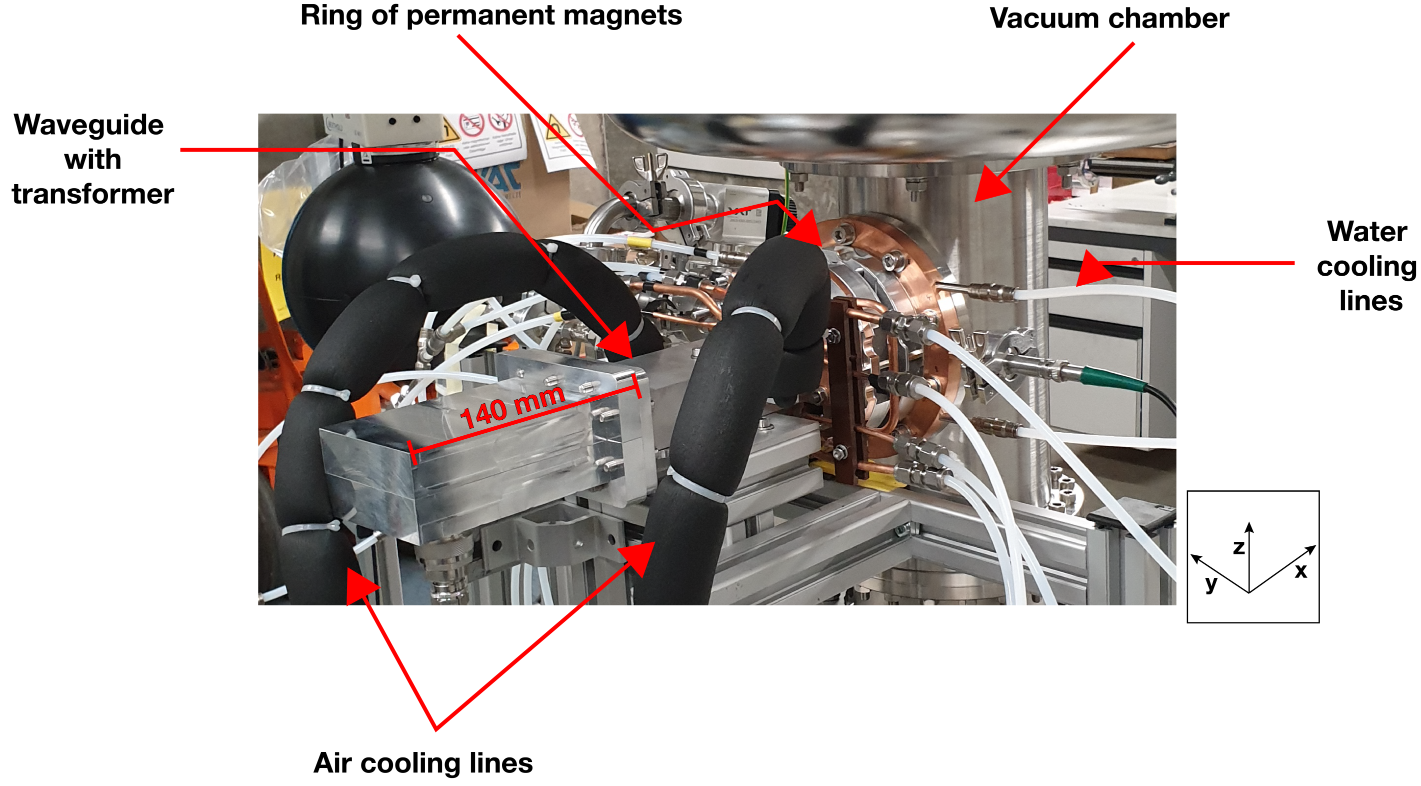


Generation II

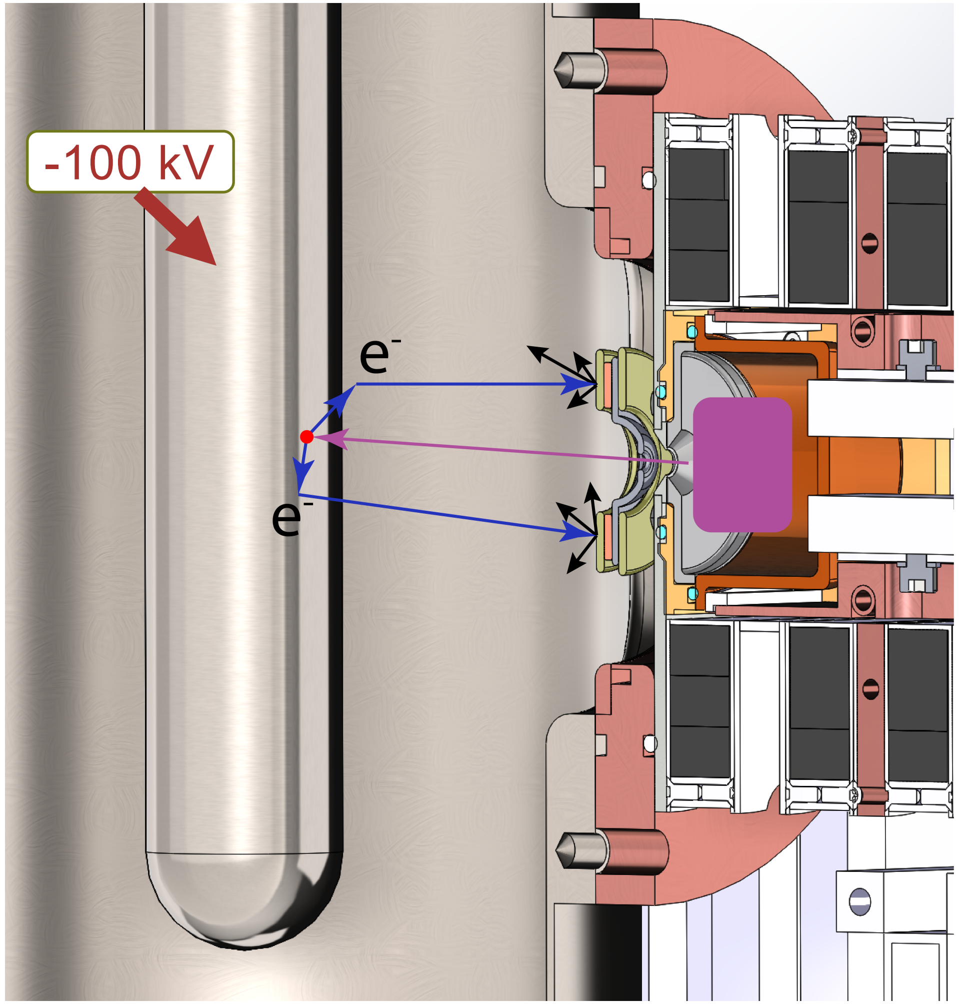


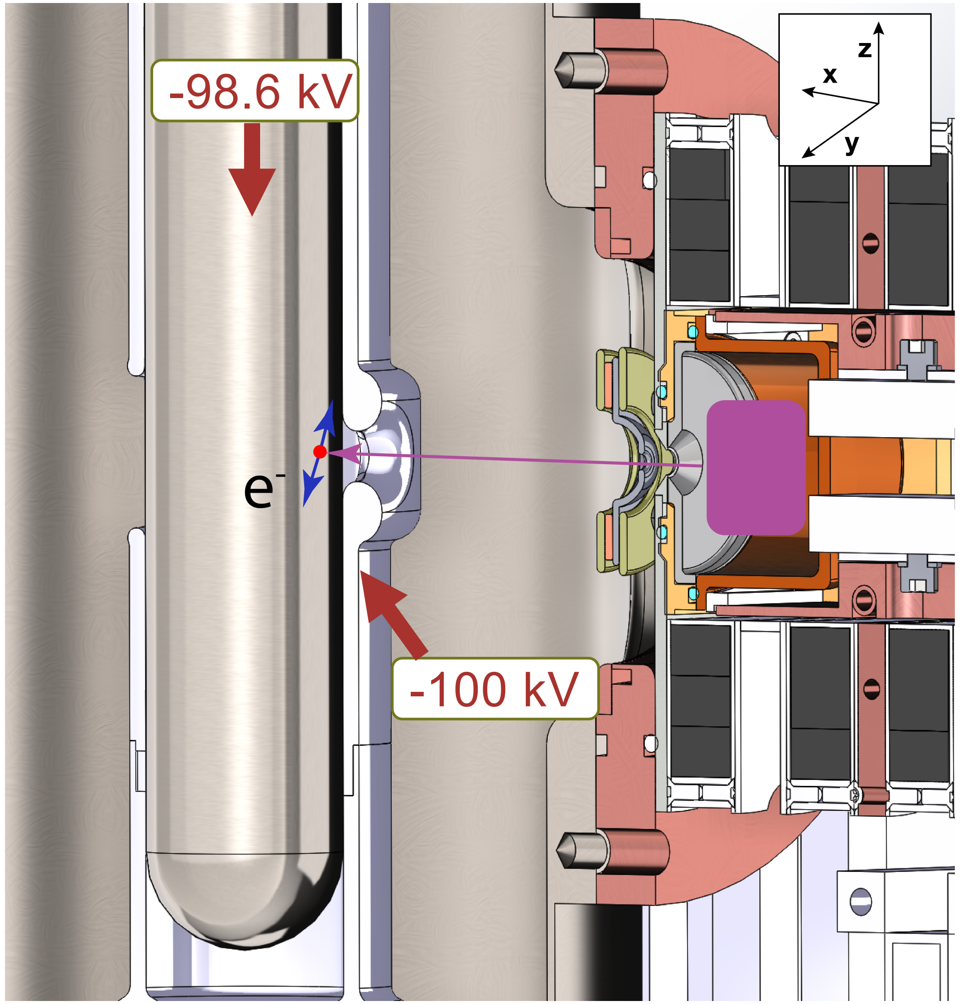
The microwave ion source allows plasma ignition at lower pressure and power levels



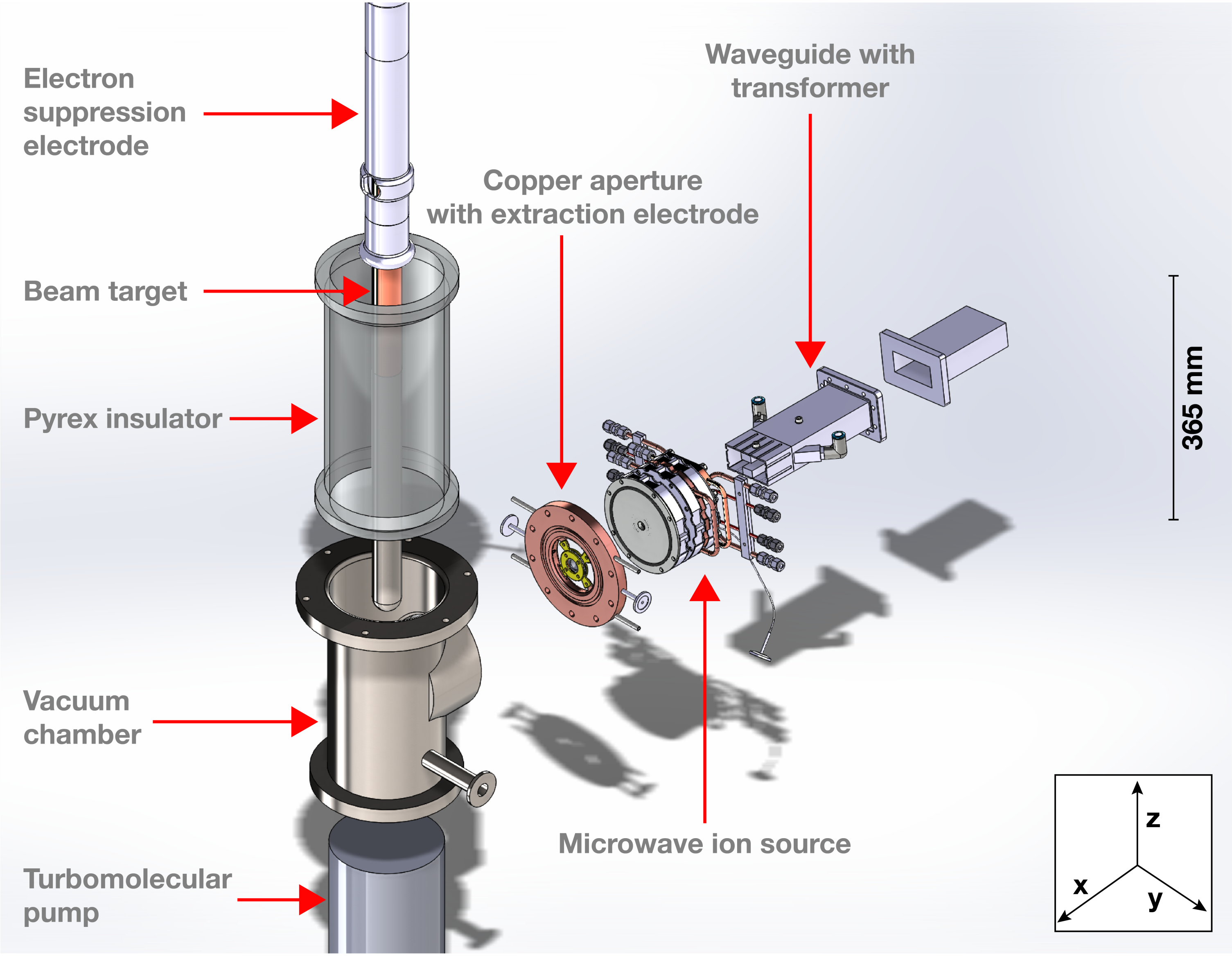


The electron suppression electrode blocks secondary backstreaming electrons



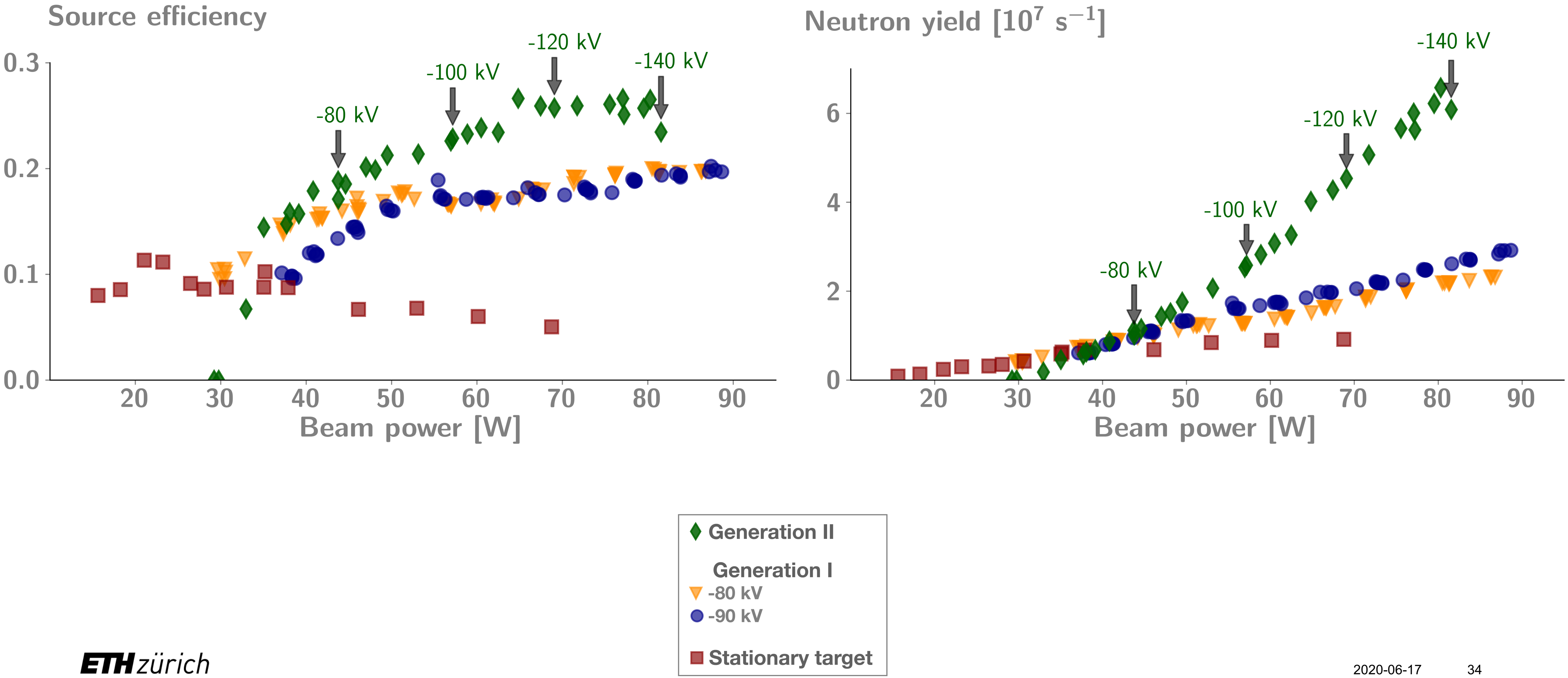


The main components of the Generation II fast neutron generator at PSI



Photograph of the Generation II neutron generator at PSI after assembling

The neutron yield of the Generation II neutron generator is significantly increased



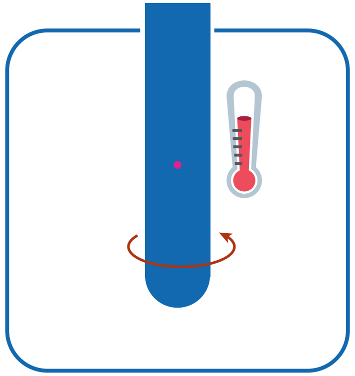
The fast neutron generator at PSI was optimized during the course of this work

Compact D-D fast neutron generator at PSI	Stable operation neutron yield $[10^7\ ^1/_s]$	Emitting spot size [mm]
Generation I	0.7	2
Generation I (rotating target)	2.9	3 to 4
Generation II (microwave, suppression electrode)	5.0	2 to 3

Table of contents/Agenda

Summary

- Compact fast neutron generators are a viable option for fast neutron transmission-based imaging

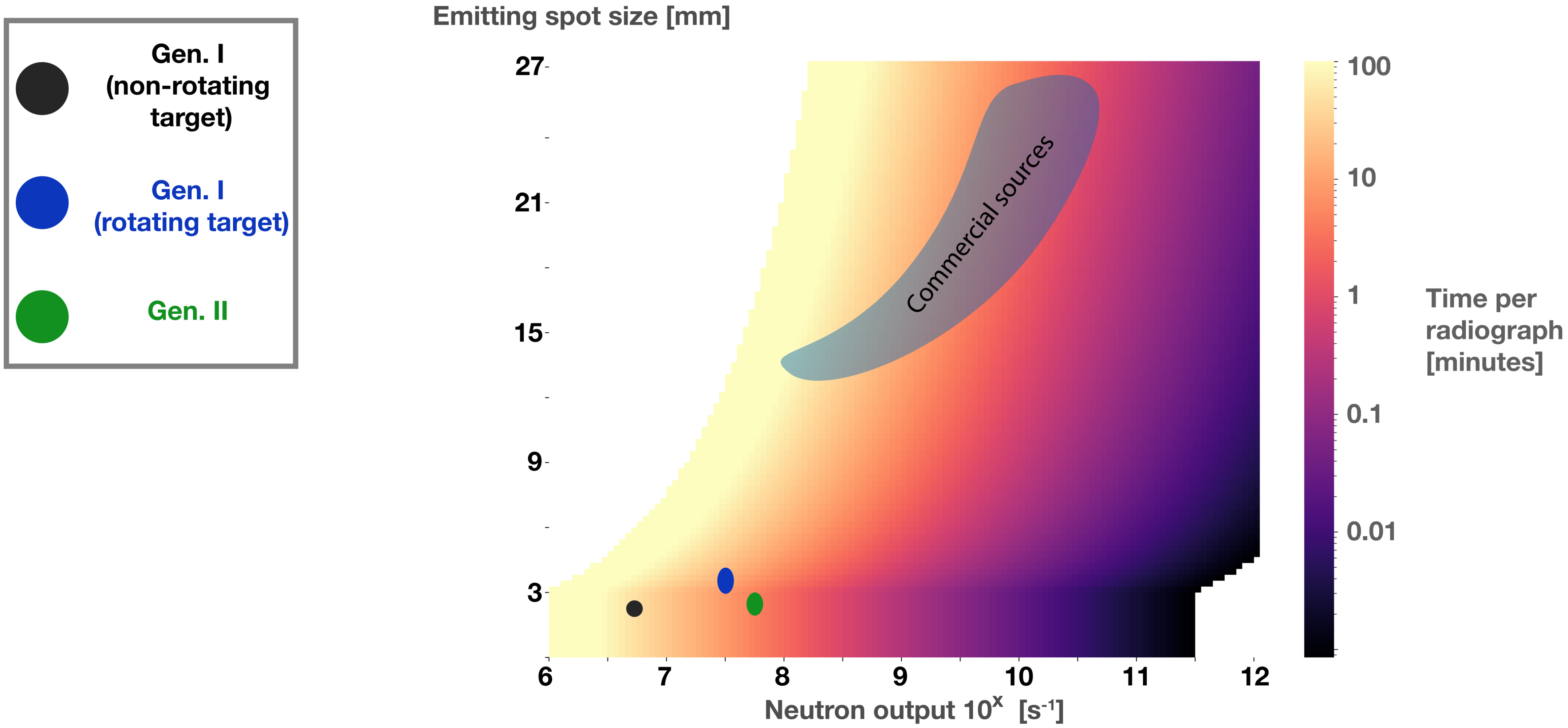


- Rotating beam target prevented loss of deuterium by outgassing and incrased neutron output by a factor of four

- Outlined detailed neutron generator characterization technique

- Upgraded neutron generator system with microwave ion source and electron suppression electrode
  - Stable operation neutron output of $5 \cdot 10^7\ {}^1/_s$
  - Emitting spot size estimated between 2 and 3 mm

The estimated exposure time for a typical imaging scenario is significantly reduced



ETH zürich

Doctoral examination

PAUL SCHERRER INSTITUT PSI

Optimization of a compact D-D fast neutron generator for imaging applications

Heiko Kromer

June 17, 2020