Neutron measurements in medical LINACs through SRAMs

Matteo Cecchetto (CERN)
R. García Alía, G. Lerner
on behalf of the R2E project

Lukas Gabrisch, Björn Poppe (**Oldenburg Univ**.)
Johannes von Vangerow (**PTW**)

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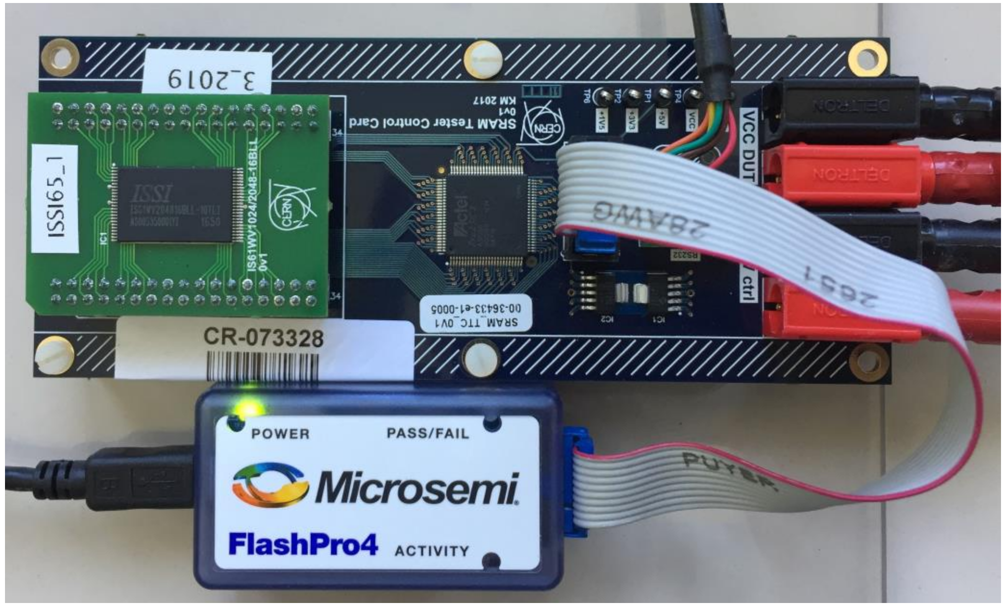
Purpose of the tests

- Verify the capability of SRAM detectors employed at CERN to characterize the **neutron environment of a medical LINAC**: at the patient position and surrounding areas
- Assess the impact of different **field sizes** on the neutron flux that is generated
- Measure the **thermal neutron flux** with respect to highly energetic particles
- Compare measurements with Monte Carlo simulations/Bonner sphere measurements

Detectors – Single Event Upsets (SEUs)

SRAM Tester



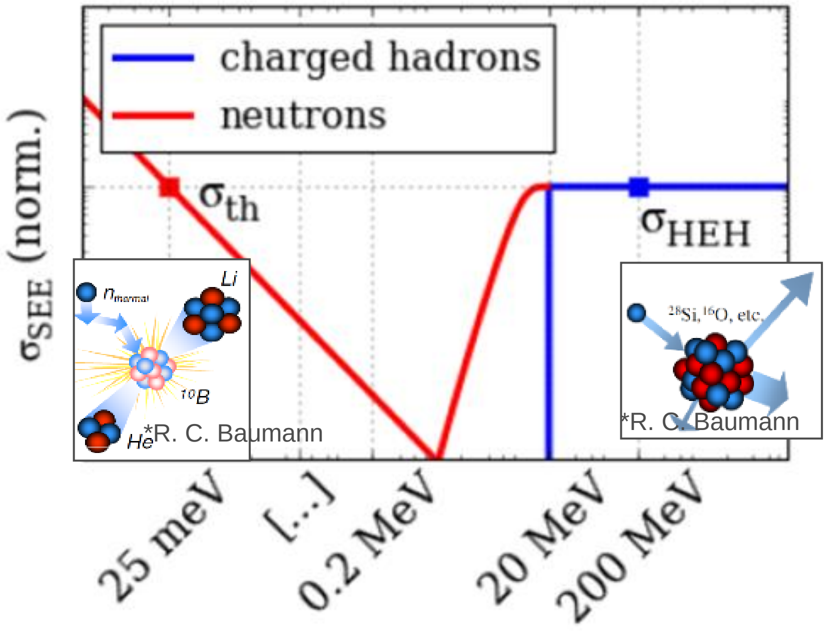
1x ISSI 40 nm SRAM 3.3 V

(IS61WV204816BLL-10TLI1650)

SEEs: response function SRAMs

Thermal neutron equivalent fluence

$$\varphi_{ThNeq} = \int \sqrt{\frac{0.025[eV]}{E\ [eV]}} \frac{d\varphi_n(E)}{dE} dE$$



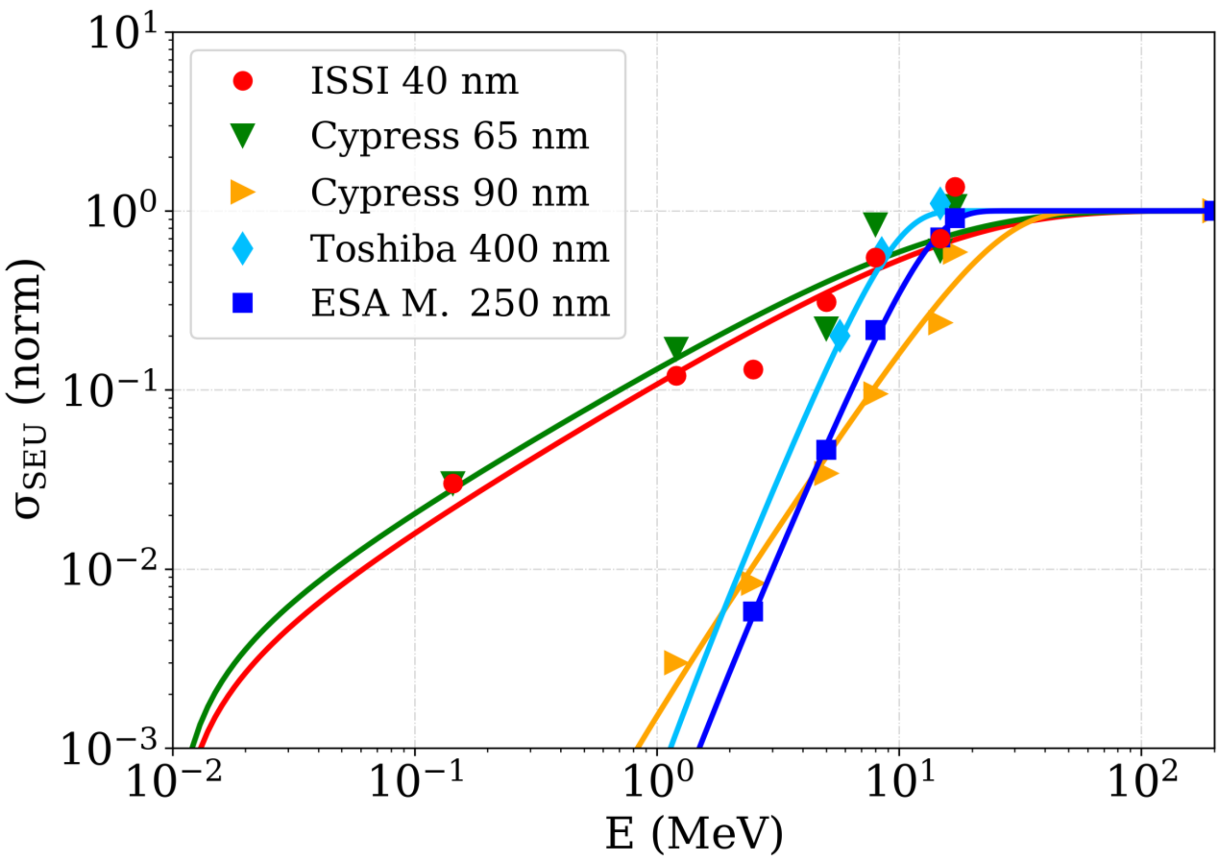
HEHeq = High Energy Hadrons + Intermediate energy neutrons

from 0.01 to 20 MeV, the device (SRAM) cross section is strongly energy-dependent

$$\varphi_{HEHeq} = \int_{0.01MeV}^{20MeV} w(E) \frac{d\varphi_n(E)}{dE} dE + \int_{20MeV}^{+\infty} \frac{d\varphi_{HEH}(E)}{dE} dE$$

In our case, φ_{HEHeq} is given by the first term, as no neutrons (or other hadrons) above 20 MeV are present in the medical LINAC environment

Response function of SRAM detectors



ISSI 40 nm SRAM presents high sensitivity at low energies

3.16e-15 [cm^{-2}/bit]

1.4e-14 [cm^{-2}/bit]

$$N_{SEU} = \sigma_{ThN} \cdot \Phi_{ThN} + \sigma_{HEH} \cdot \Phi_{HEHeq}$$

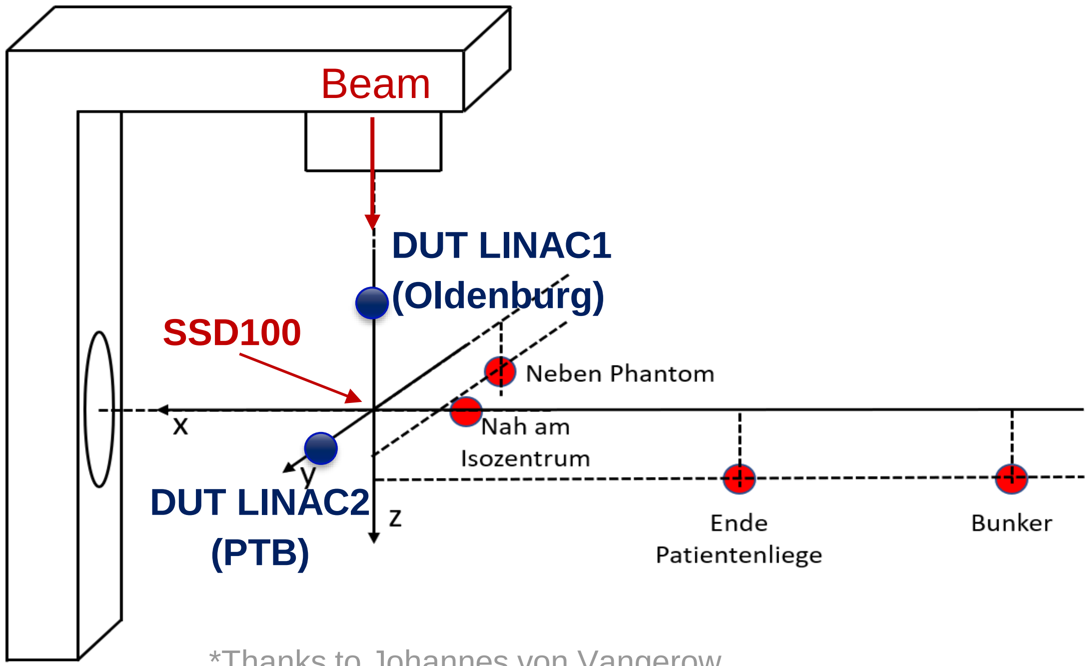
SEUs due to thermal neutrons

SEUs due to HEHeq

*M. Cecchetto *et al.*, "0.1–10 MeV Neutron Soft Error Rate in Accelerator and Atmospheric Environments," in *IEEE TNS*

Medical LINACs - setups

Neutron fluence measurements were performed in two different medical LINACs and the Device Under Test (DUT) was installed in different positions.

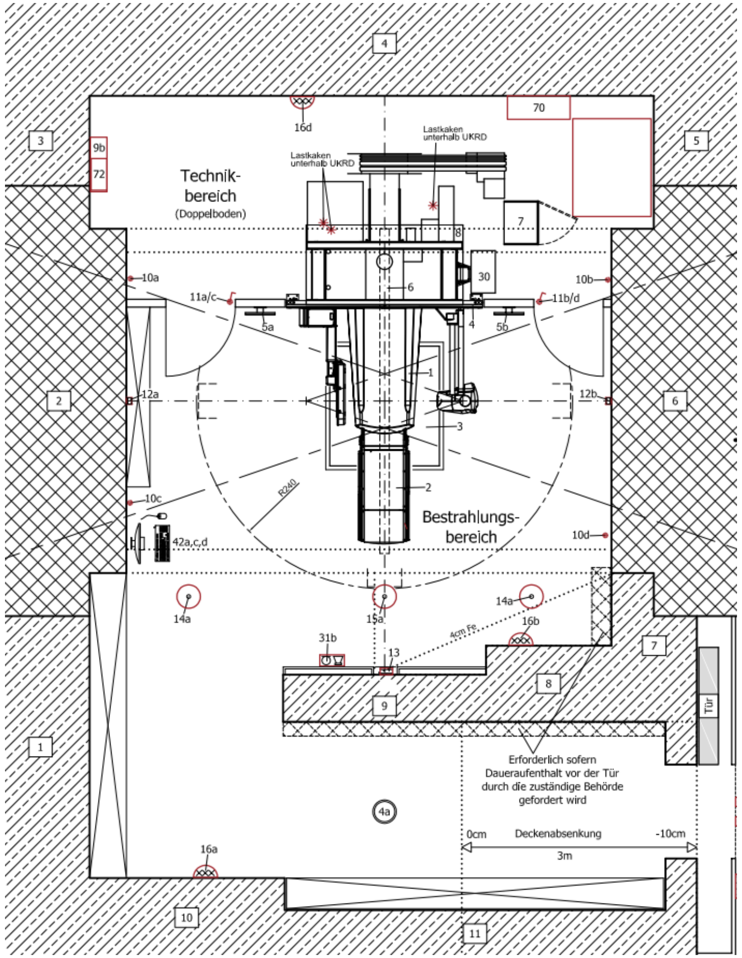


*Thanks to Johannes von Vangerow

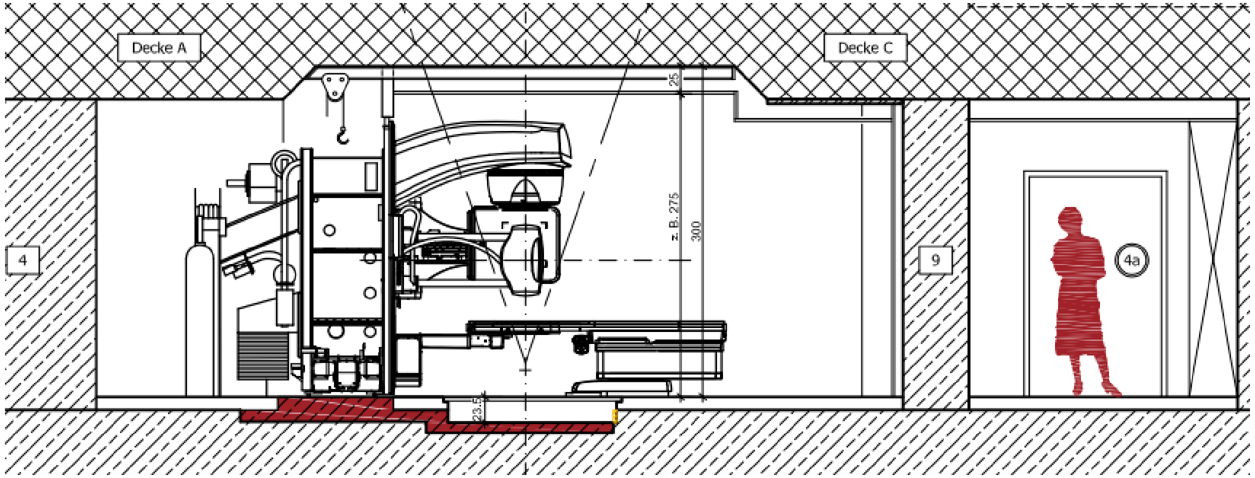
LINAC	Photon energy (max) [MeV]	SSD100 Target	DUT position with respect to SSD100 Z [cm]	Y [cm]
1 (Oldenburg)	15	-	-45	0
2 (PTB)	25	5x PMMA plates	0	40

- Main beam composed of photons but also parasitic neutrons that are produced by several elements
- SSD100 (source skin distance, 100 cm from source) is the reference position
- SRAMs fluence compared to that from FLUKA simulations (Oldenburg) and Bonner sphere measurements (PTB)

1) Elekta medical LINAC (Oldenburg)



Top view



Side view

The accelerator provides:

- Photon beams: 6 and 15 MeV
- Field size (at 100 cm): from 0.5 cm^2 to 40 cm^2
- Dose uncertainty: < 0.5%

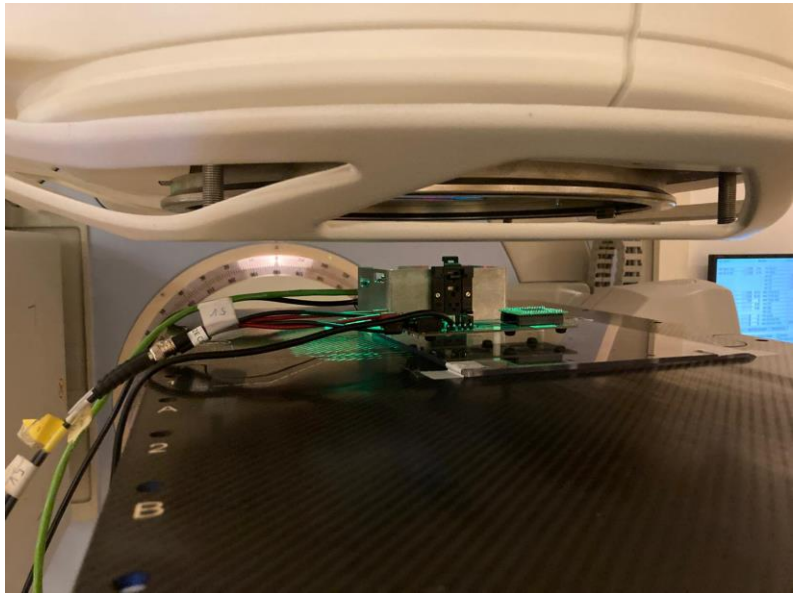
Courtesy of L. Gabrisch, B. Poppe

SEU measurements – 15 MeV

The ISSI memory was irradiated at the closest test position (55 cm) with about 100 Gy per run to obtain a good SEU statistics

Run	Field size [cm^2]	Monitor Units	Dose [Gy]	SEU ISSI
1	20x20	10k	100	108
2	4x4	10k	100	106
B4C	4x4	10k	100	105
B4C	20x20	10k	100	104

*100 Monitor units correspond to 1 Gy at SSD 90 in 10 cm of water with 10x10 cm2 photos beam size



SRAM under the beam

- **Field size does not impact the neutron fluence**
- A layer of boron carbide (B4C) was interposed between beam and detector:

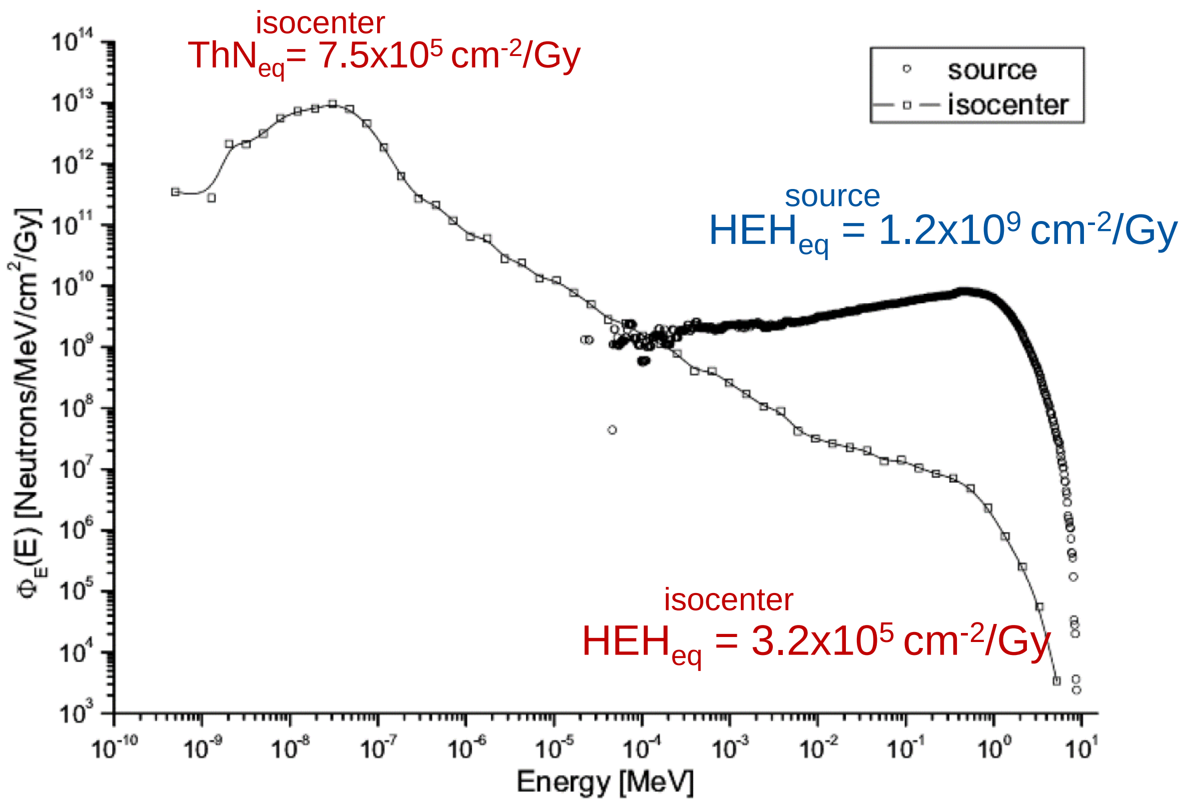
  → no significant difference on the SEU counts → **no thermal neutrons in the main beam**
  → Measured SEUs are due to neutrons above 1 eV, according to the HEHeq response

1) Neutron fluence and comparison to simulations

		Simulations		Measurement
Distance	E (max)	ThNeq	HEHeq (ISSI)	HEHeq (ISSI)
[cm]	[MeV]	[cm^{-2}/Gy]	[cm^{-2}/Gy]	[cm^{-2}/Gy]
100	15	7.5x10^{5}	3.2x10^{5}	7.0x10^{5} ±20%

- Considering the measurement at SSD 55 cm we can estimate the HEHeq fluence at the isocentre (100 cm), with the **strong assumption of 1/R^2 law**.
- Preliminary simulations are compatible to the measurements within **a factor ~2**.
- For comparison a typical value in the LHC:

$$^{B}\varphi_{HEHeq}\text{ (LHC)} = 10^{9}\ [\text{cm}^{-2}/\text{Gy}]$$



FLUKA simulations[A] - neutron spectrum

[A]J. Becker, "Simulation of neutron production at a medical linear accelerator", M. thesis, 2007

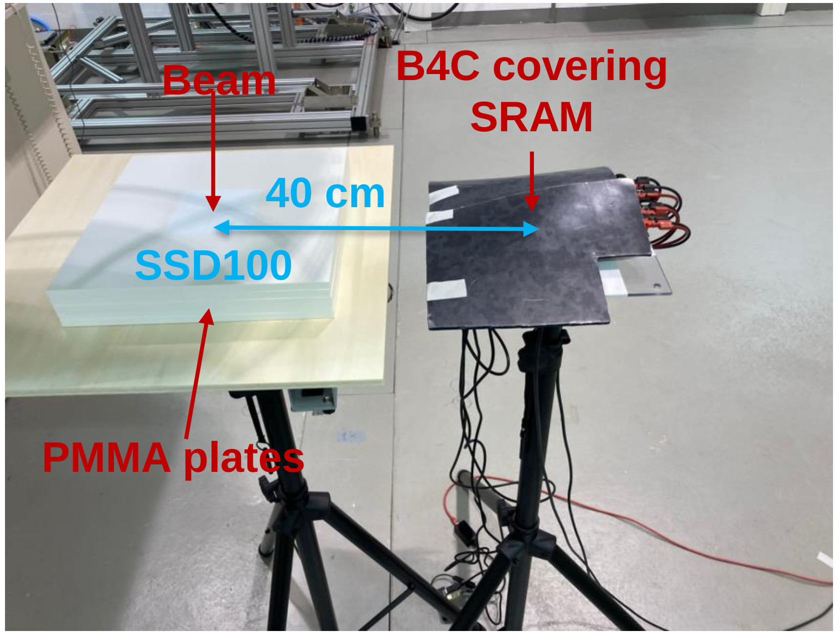
[B]D. Prelipcean "Conversion coefficients between different quantities measuring radiation levels at the LHC"

2) Medical LINAC (PTB)

SEU measurements - 25 MeV

Run	MU	Dose* [Gy]	Field size [cm²]	SEUs 2xISSI
1	25k	~370	0.5x0.5	99
2	25k	~370	10x10	105
B4C	25k	~370	0.5x0.5	72

*68 Monitor units correspond to 1 Gy at SSD 100 in water, FS = 10 cm x 10 cm, z = 10 cm



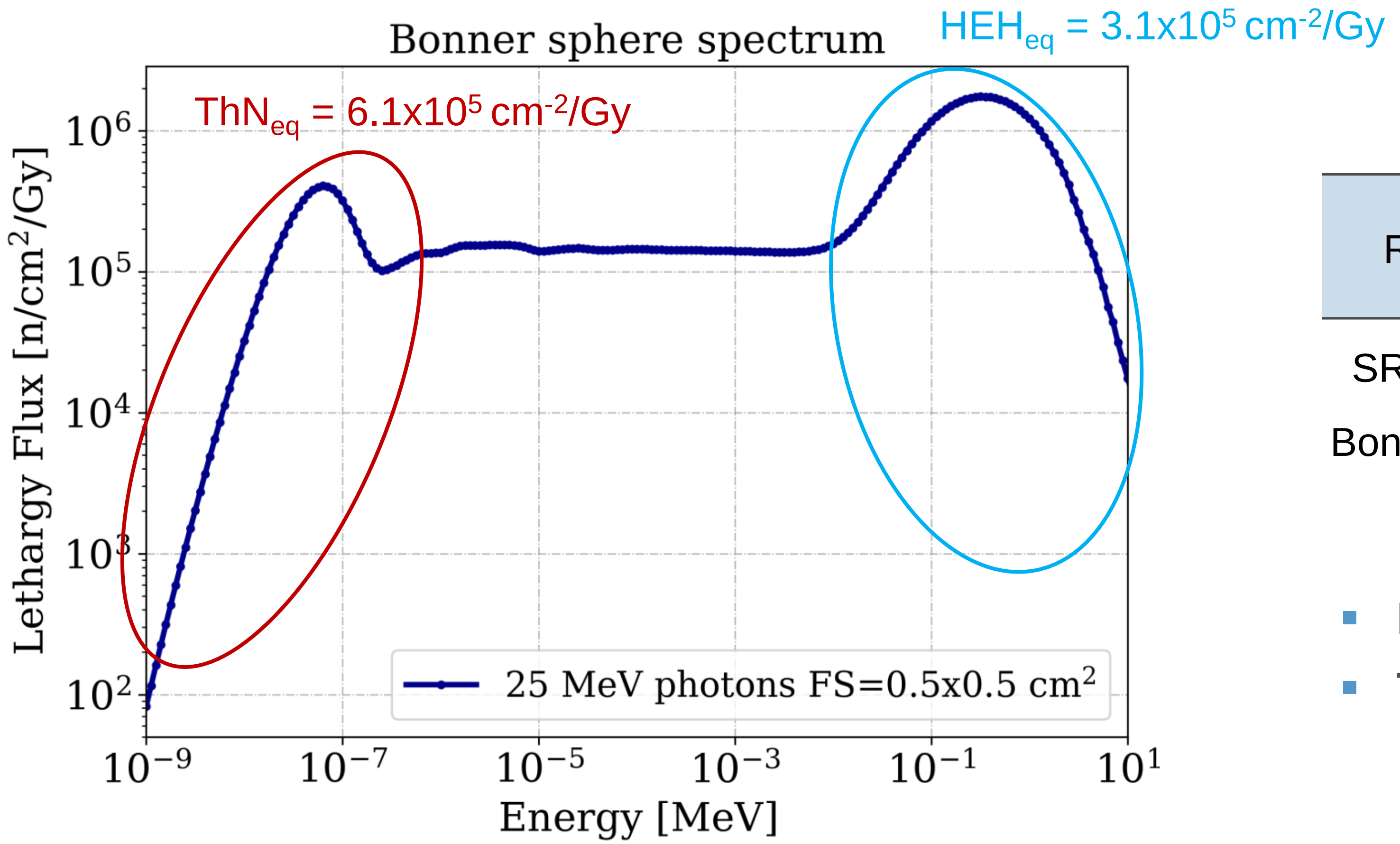
- The **field size does not significantly impact the SEU rate** (as proven also in the Elekta accelerator in Oldenburg)
- By covering the SRAMs with B4C the SEU rate decreased by **30%**

φ_{HEHeq} = 4.1x10^5 ±20% [cm^{-2}/Gy]

φ_{ThNeq} = 6.7x10^5 ±24% [cm^{-2}/Gy]

NOTE: the dose is referred to as delivered to the isocentre and not on the position of the SRAMs

Fluences from Bonner sphere – SRAM comparison

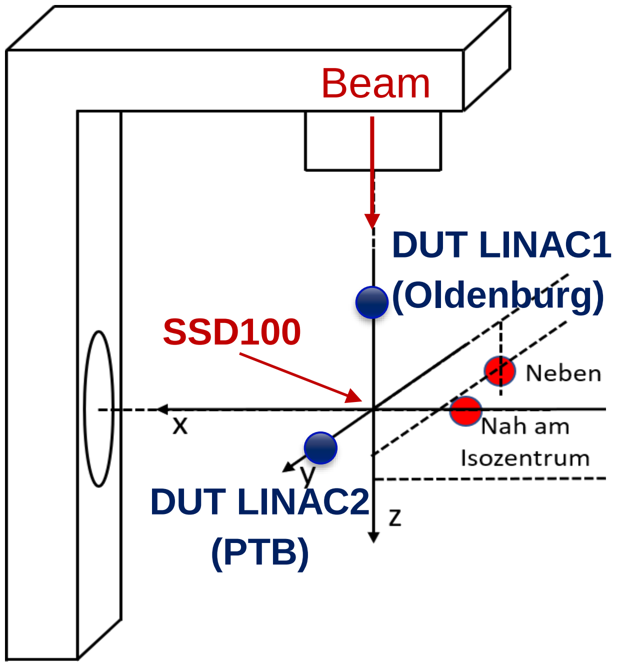


Run	E [MeV]	Field size [cm^{2}]	HEHeq [cm^{-2}/Gy]	ThNeq [cm^{-2}/Gy]
SRAMs	25	0.5x0.5	4.1x10^{5} ±20%	6.7x10^{5} ±24%
Bonner S.	25	0.5x0.5	3.1x10^{5}	6.1x10^{5}

- **HEHeq** fluence agreement ~ **30%**
- **ThNeq** fluence agreement ~ **10%!**

*Bonner sphere spectrum by Johannes von Vangerow

Neutron fluences different accelerators



- In Oldenburg the SRAM was directly on the beam while in PTB the SRAMs were outside the beam field.
- The measured neutron fluence in Oldenburg was coming from the main target (source), while in PTB neutrons (especially **thermals**!) were also produced by the PMMA plates.

Conclusions

- SRAMs were used to measure **neutron fluence** in **medical LINAC** environment.
  - Large Monitor Units (dose) required to accumulate enough statistics
- Field size does not impact the neutron fluence.
- LINAC in Oldenburg:
  - Fluence measurement **under the main photon beam**
  - No thermal neutrons
  - Preliminary simulations agreement HEHeq ~factor 2
- LINAC in PTB:
  - Fluence measurement **outside the main photon beam** + **PMMA** plates
  - Same order of magnitude for ThNeq and HEHeq fluence
  - Good ThNeq and HEHeq agreement with bonner sphere measurements

Thank you for your attention!