Photoneutron field analysis near an Al-based target at the CLEAR accelerator

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CLEAR operators: W. Farabolini, L. Dyks

Introduction

- **Two R2E test campaigns** have been carried out at the CLEAR electron accelerator at CERN, primarily to measure neutrons produced via photonuclear reactions:

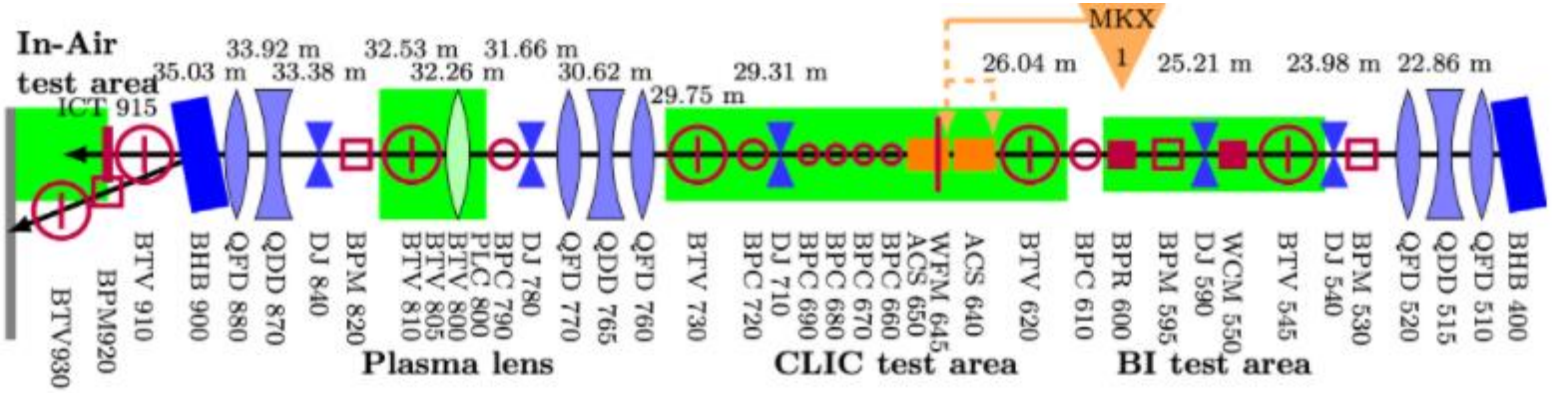
1) **October 2020**: SEU measurements with SRAMs near the beam dump
   - Results presented at the 44th MCWG meeting and at RADECS 2021
   - Paper submitted to IEEE TNS (just accepted!)

2) **June 2021**: Radiation level measurements near an Al-based target (today's focus)
   - Summer internship project of Pierre Pelissou
   - Presented at the 48th MCWG meeting, full test report in EDMS 2708377

The CLEAR accelerator and THz test area

THz test area and dump

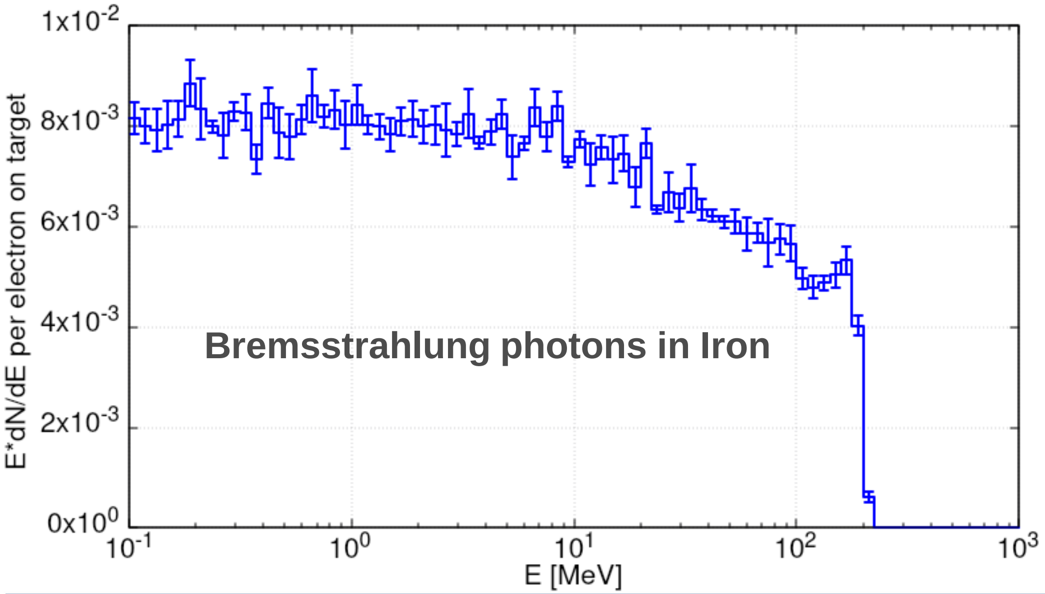
CLEAR electron beam

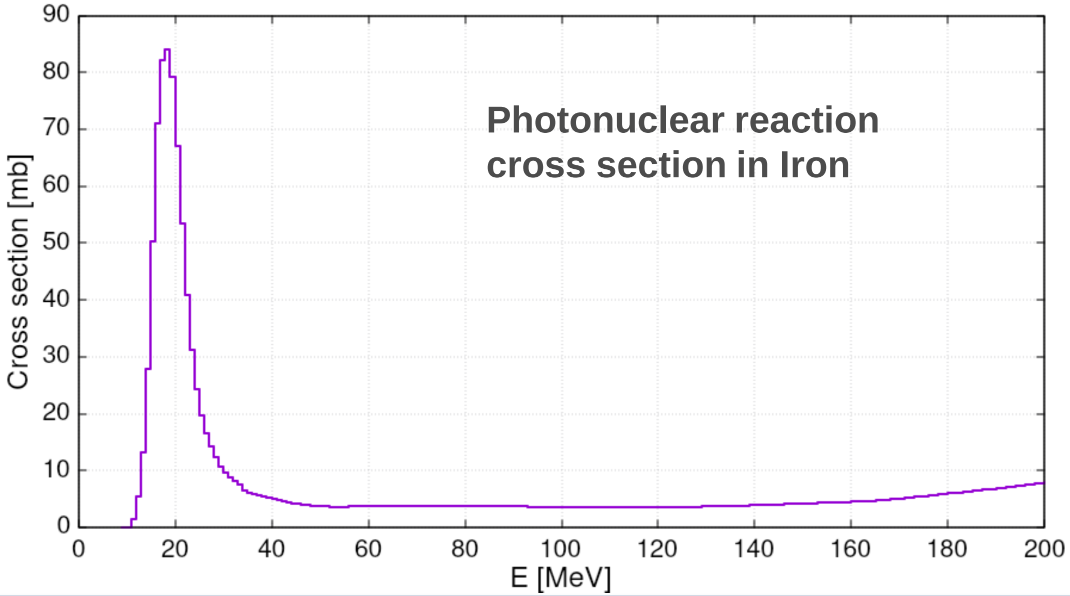


- CLEAR accelerator at CERN (https://clear.cern/):
  - **Electron energy**: 60-220 MeV (~200 MeV during our tests)
  - **Intensity**: max reference ~30 nC/train at 10 Hz repetition rate, yielding ~**$6.75 \cdot 10^{15}$ electrons per hour**

Neutron production with a 200 MeV electron beam

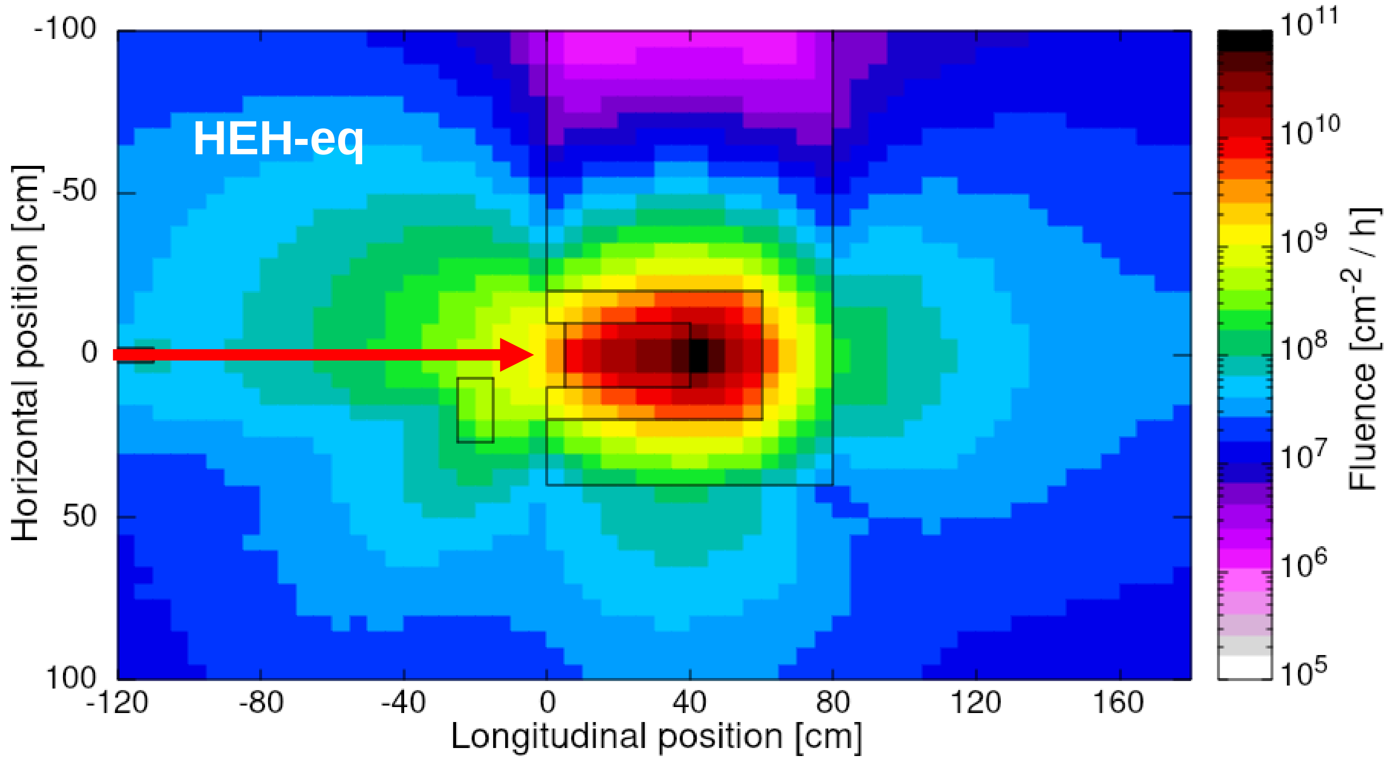
- The beam dump effectively acts as a **target for photoneutron production**
- Two-step process:
  1) **Electrons** from the beam producing **photons** produced via Bremsstrahlung
  2) **Photons** producing **neutrons** via photonuclear reactions
- Electronuclear reaction (direct neutron production) are sub-dominant





October 2020 test (RADECS 2021, accepted by IEEE TNS)

- High intensity CLEAR 200-MeV electron beam impacting directly on the THz beam dump
- Significant **High Energy Hadron equivalent (HEH-eq)** and **thermal neutron equivalent fluxes** around the dump, confirmed with FLUKA and SRAM SEU measurements

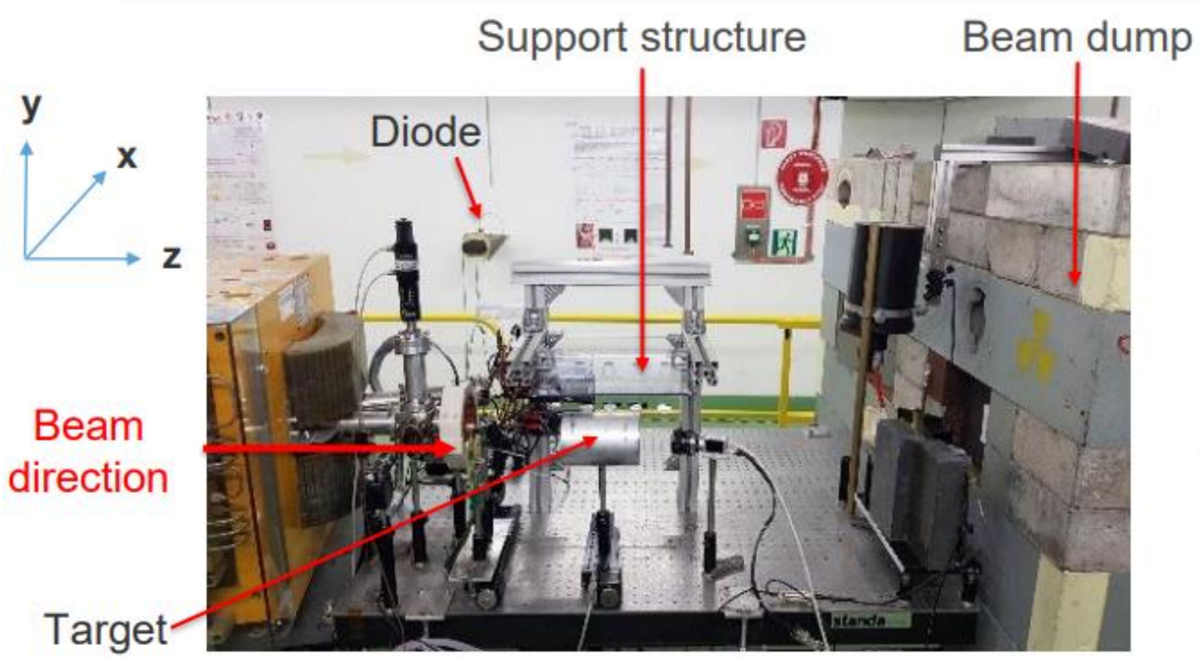


Position	B_4C lid	ISSI HEH-eq flux	thermal n-eq flux
POS1	No	$7 \cdot 10^8$ cm^{-2}/h	$3 \cdot 10^8$ cm^{-2}/h
	Yes		not considered
POS2	No	$9 \cdot 10^7$ cm^{-2}/h	$1.5 \cdot 10^9$ cm^{-2}/h
	Yes		not considered
POS3	No	$1.5 \cdot 10^8$ cm^{-2}/h	$1.5 \cdot 10^9$ cm^{-2}/h
	Yes		not considered
POS4	No	$2 \cdot 10^7$ cm^{-2}/h	$1 \cdot 10^9$ cm^{-2}/h
	Yes		not considered
POS5	No	$4.5 \cdot 10^7$ cm^{-2}/h	$7 \cdot 10^8$ cm^{-2}/h
	Yes		not considered
POS6	No	$4.5 \cdot 10^7$ cm^{-2}/h	$6 \cdot 10^8$ cm^{-2}/h
	Yes		not considered

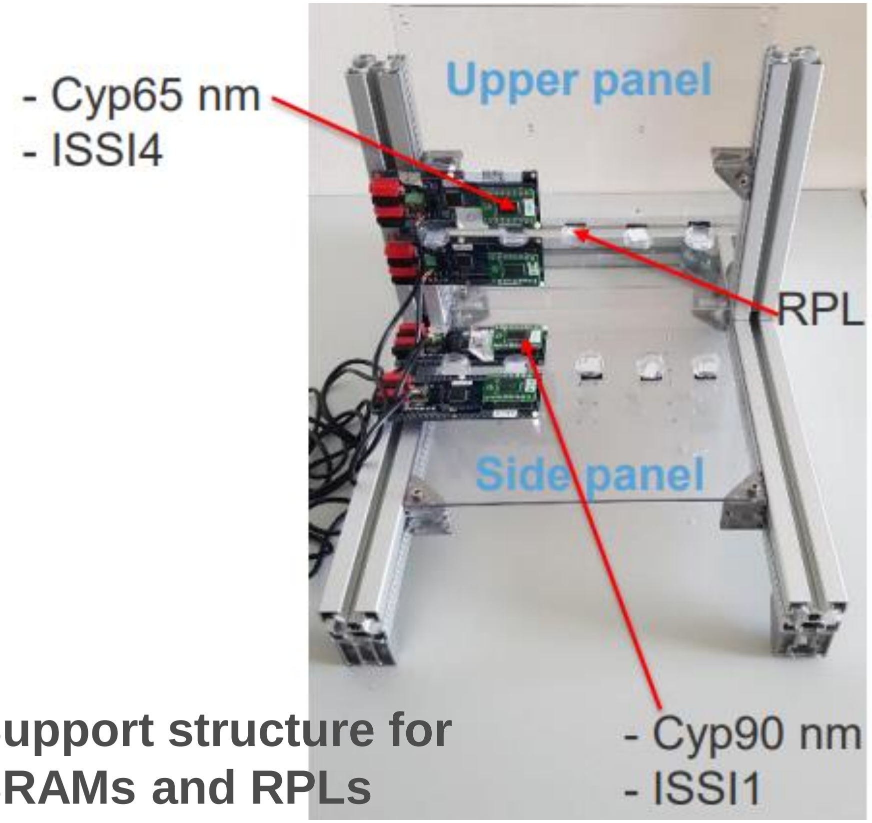
June 2021 test setup

Memory	σ_{sat} [cm^2/bit]	E_{th} [MeV]	W [MeV]	s
ISSI 40 nm	$1.40 \cdot 10^{-14}$	0.01	14.05	0.82
Cypress 65 nm	$7.73 \cdot 10^{-14}$	0.01	11.57	0.80
Cypress 90 nm	$2.16 \cdot 10^{-13}$	0.1	24.22	1.98

- Use an **Al-based target** to enhance the radiation yield
- Upper and side panels with different **SRAMs** (measuring **SEU rate** from **HEH-eq fluence**) and **RPLs** (for **TID**)

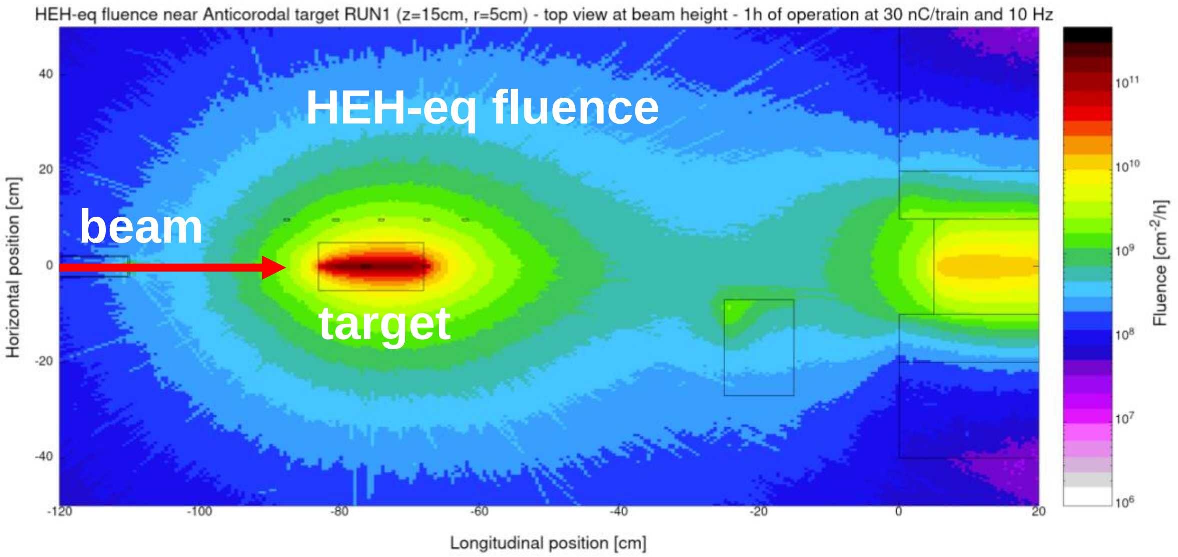


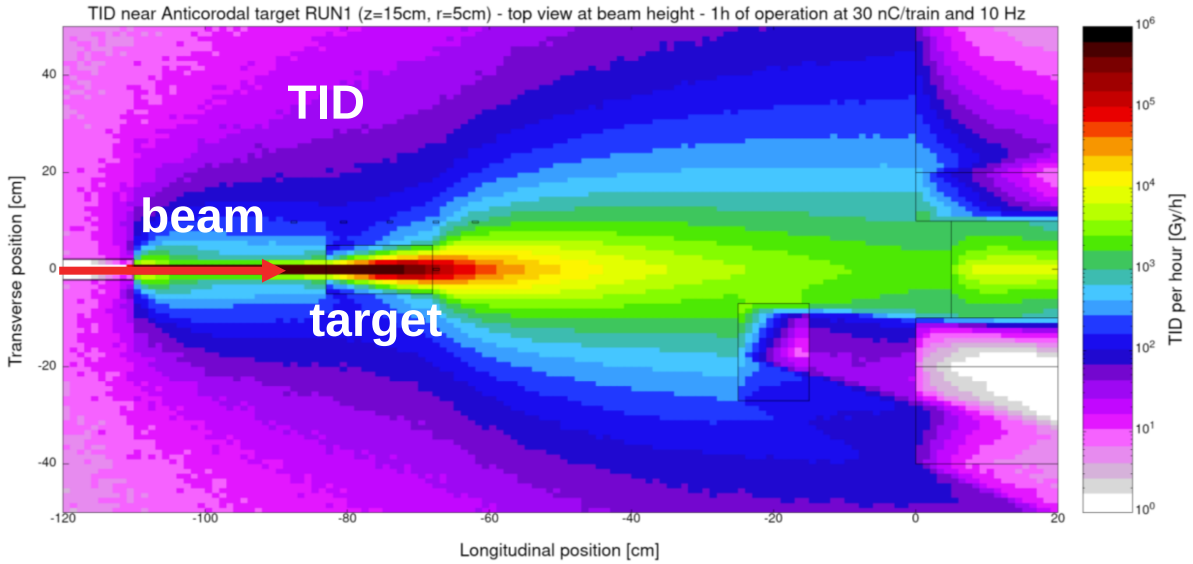
Y-Z plane view



Support structure for SRAMs and RPLs

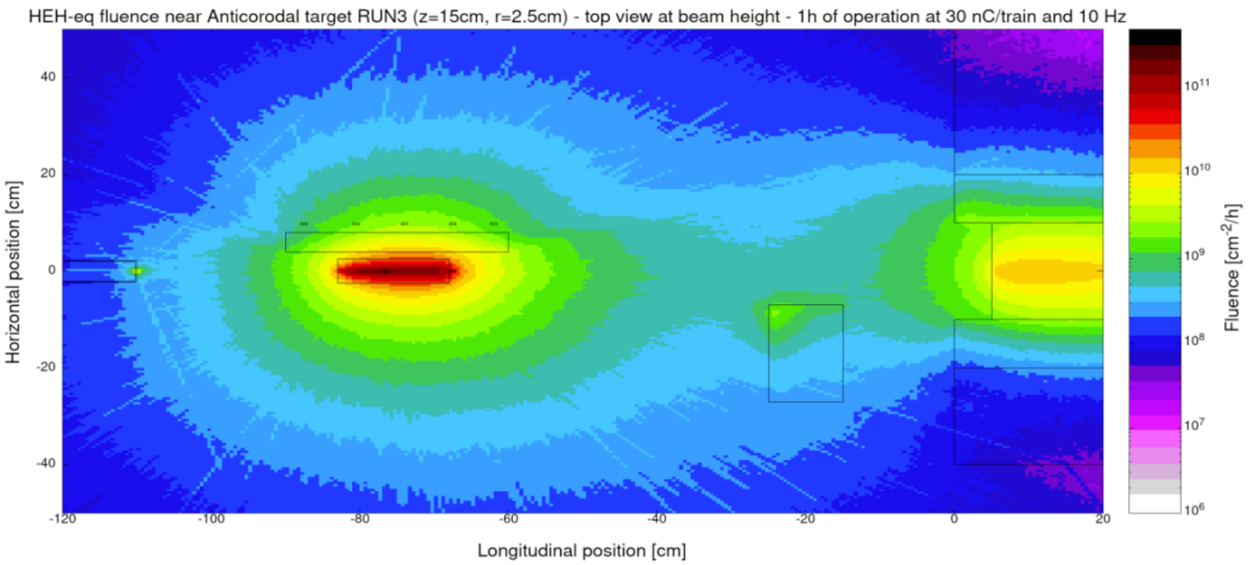
FLUKA HEH-eq fluence and TID near Al-based target

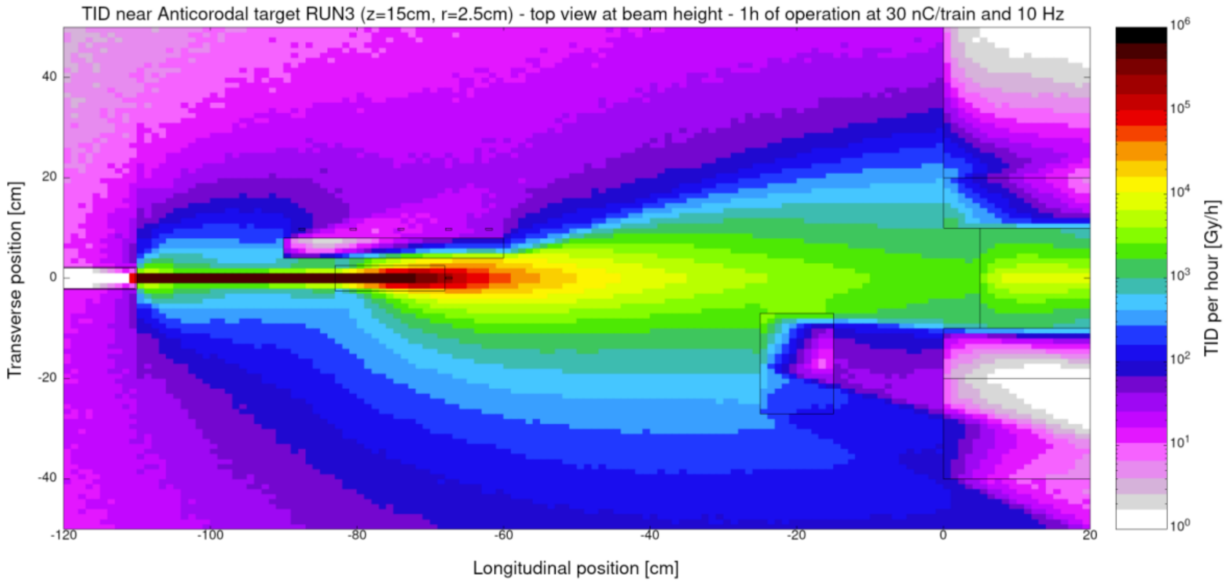




- FLUKA simulations: 2D top view of the showers for 200 MeV electrons on Al-based target:
  - **HEH-eq fluence**: expected levels up to 10^{10} cm^{-2}/h, with highest levels behind the target but also (importantly) on its side
  - **TID**: levels up to >100 kGy/h behind the target, but substantially lower on the target side
  - thermal neutron fluence not shown due to low R-factor (<1) near the target

Adding a Pb shielding layer on one side…





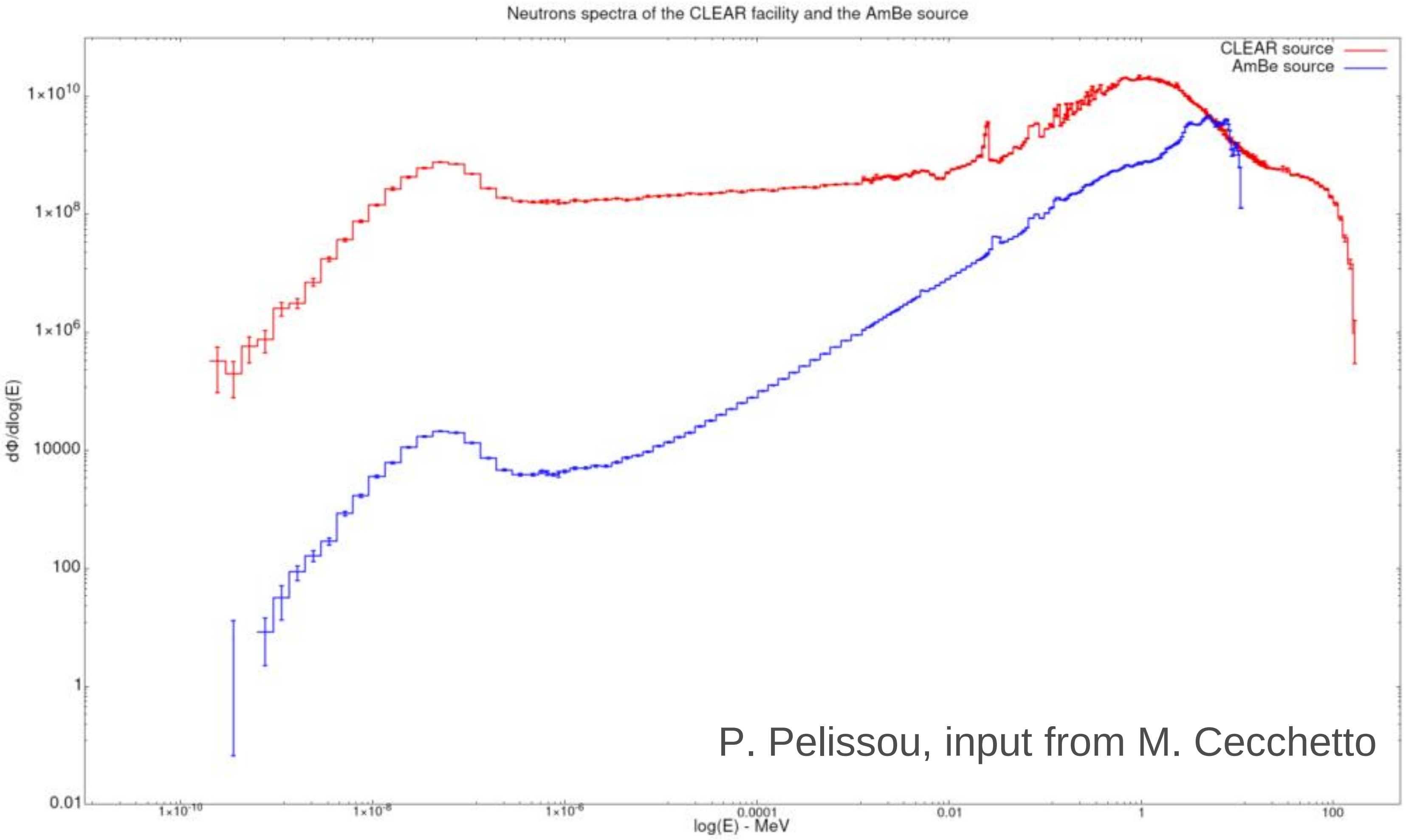
- Impact of lateral Pb shielding
  - **HEH-eq fluence**: there is a reduction behind the shielding (as expected) but not too large
  - **TID**: substantial decrease observed

→ **we can use lateral shielding to maximize the ratio between HEH-eq fluence and TID**

P. Pelissou, G. Lerner

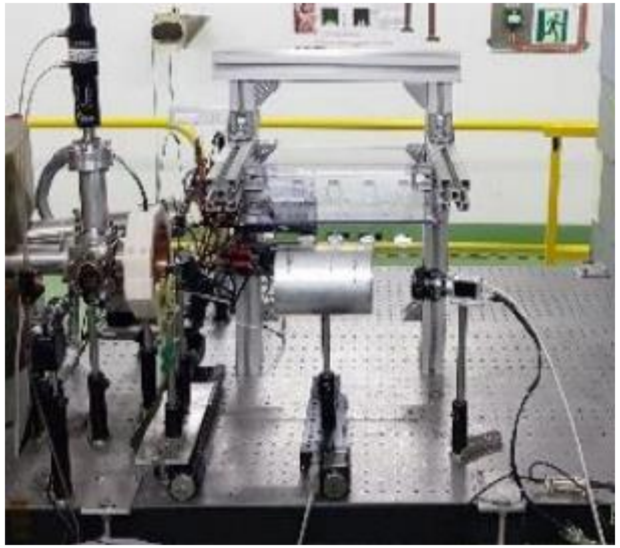
Neutron energy spectrum on the target side

- Neutrons reach up to >100 MeV (unlike AmBe) but they peak at the MeV scale
  → The SRAM SEU rates are driven by the response to intermediate-energy neutrons
- Low R-factor (thermal/HEH-eq fluence) near the target (<1)



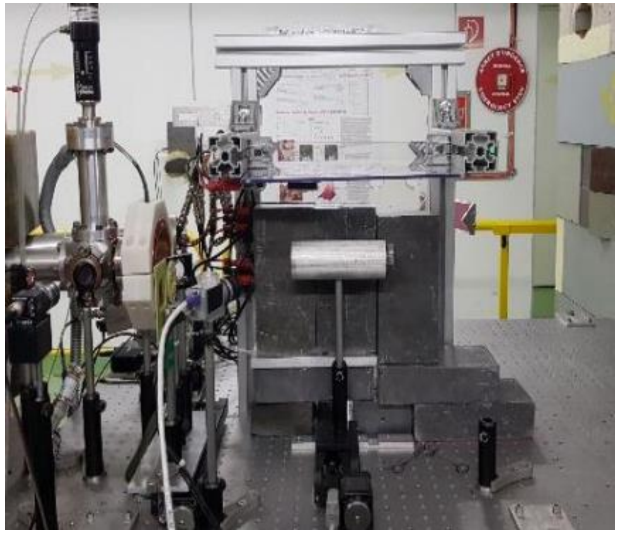
P. Pelissou, input from M. Cecchetto

June 2021 test: run configurations



RUN 1
Target with R=5cm

RUN 2
Target with R=2.5cm
Goal: check impact of target thickness



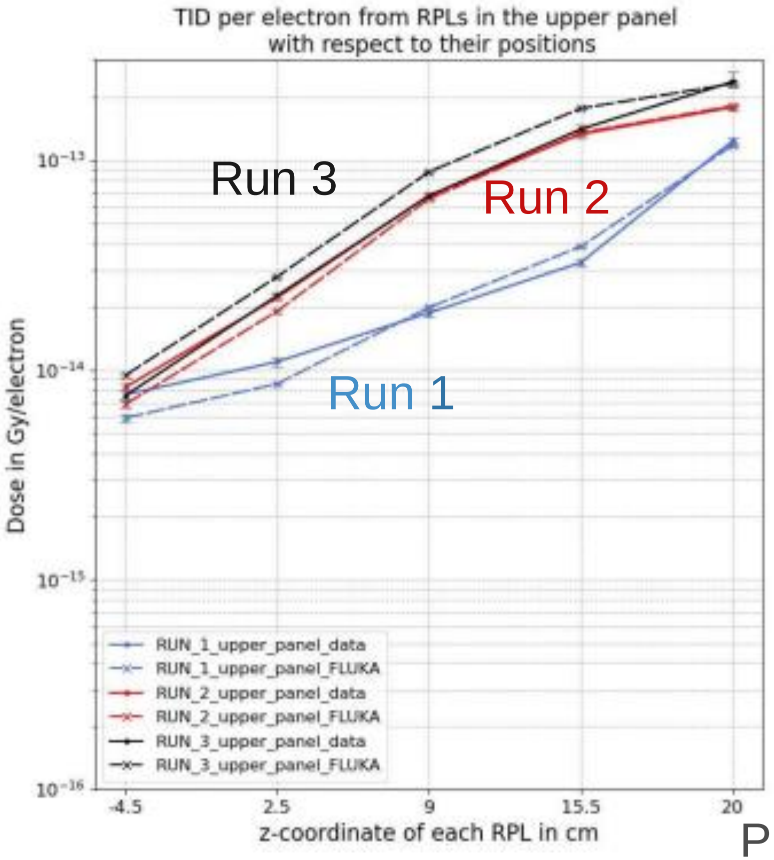
RUN 3
Target with R=2.5cm, Pb shielding in front of side panel
Goal: check impact of the shielding on TID and SEU rate

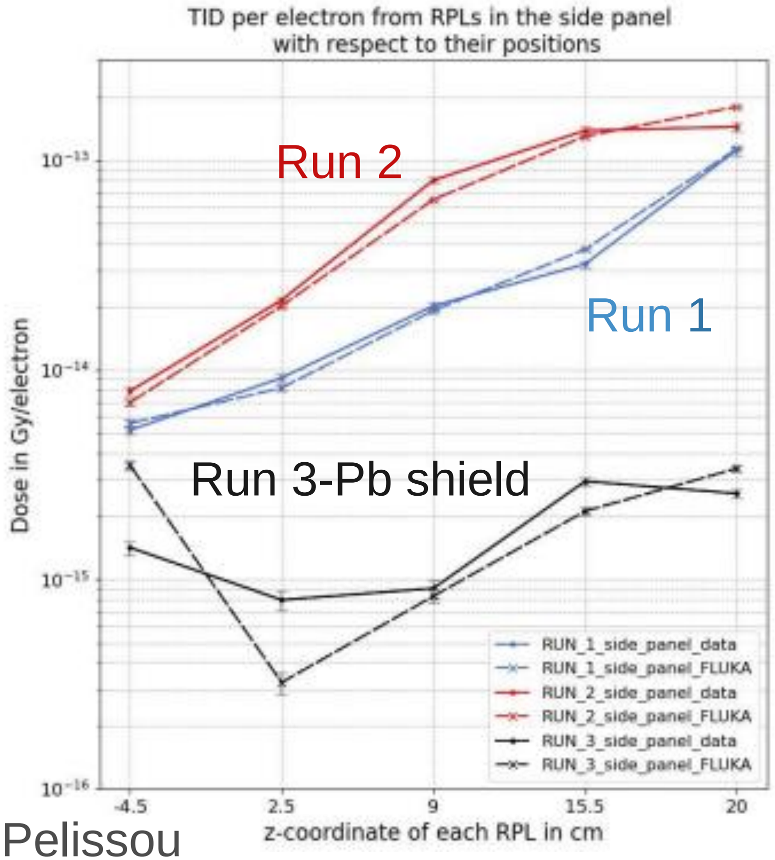
Extra: Run 4 with misaligned panels and extra measurements with diode (not discussed today)

June 2021 test: TID results (RPLs and FLUKA)

- 1D projection of TID vs z on upper and side panels per electron on target (to be multiplied by $6.75 \cdot 10^{15}$ for max TID rate per hour)

- Very good agreement between FLUKA and measured data
- Run 1-2 results are the same in the two panels (as expected)
- Higher TID in Run 2 than in Run 1 on both panels due to smaller target radius
- Very large TID reduction in Run 3 due to Pb shielding

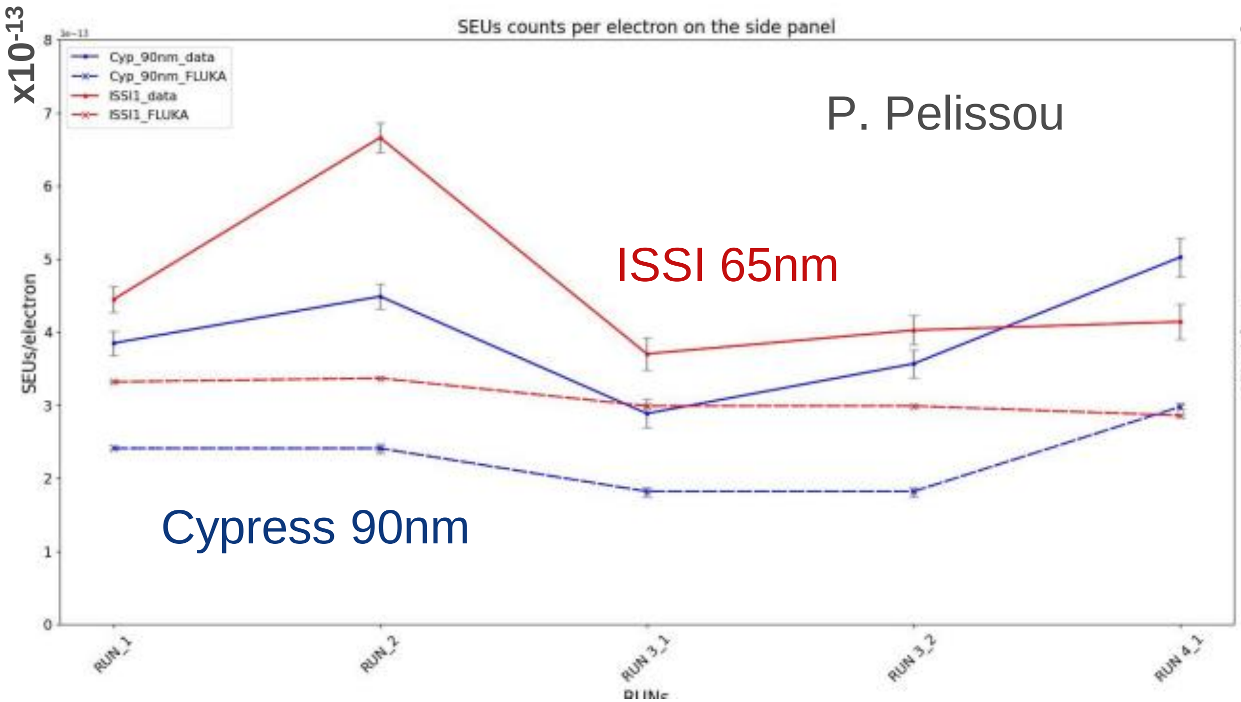


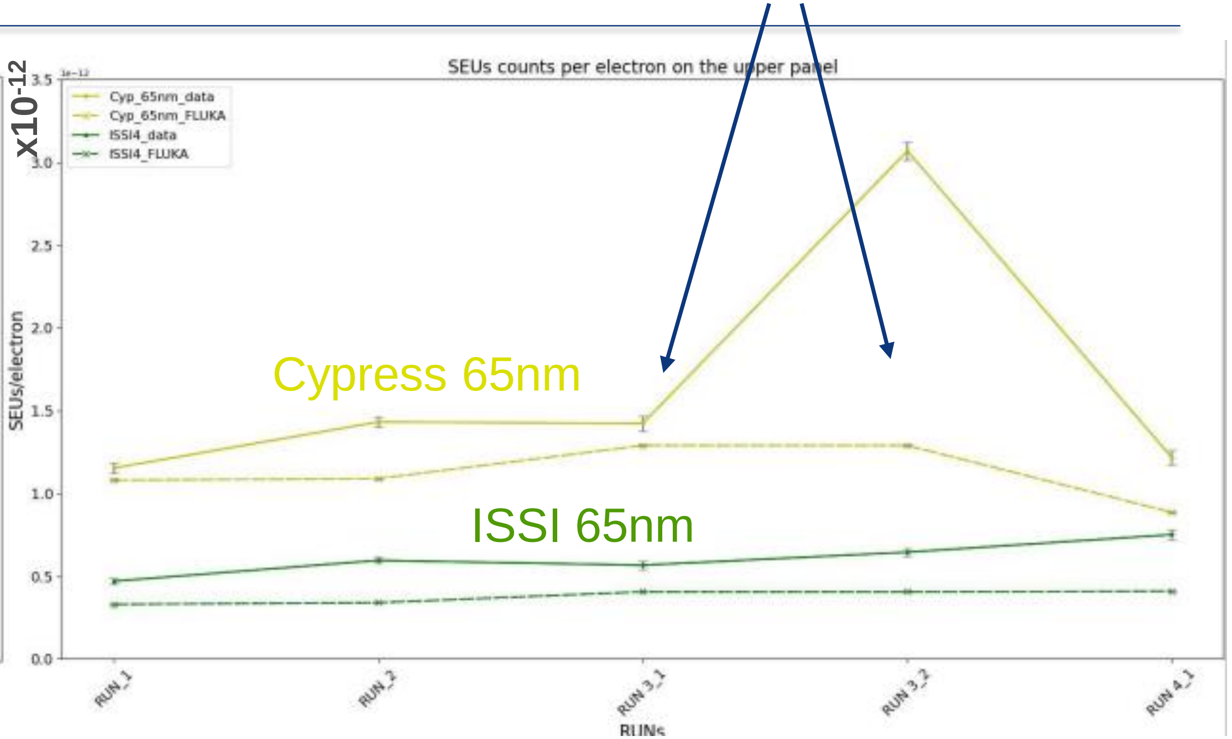


P. Pelissou

June 2021 test: SEU results

Run 3 split into two due to anomalous Cy65 SRAM rate in its second part





- Measured SEUs per electron on target for each SRAM in the different Runs, with FLUKA predictions based on simulated HEH-eq fluence and SRAM SEU cross sections
- Results generally consistent with the expectations, with systematic excess of SEUs compared to the FLUKA-based predictions (by ~50% on average)
  → considered ok given the many potential sources of uncertainty

Summary

- Two R2E test campaigns at CLEAR demonstrated that it is possible to measure **SEUs with SRAMs** in off-beam positions
- Using a target increases substantially the radiation level rates:
  - HEH-eq fluence up to >**10^{10} cm^{-2}/h** in transverse positions, combined with low TID levels (few Gy/h) especially when lateral shielding is used
  - Behind the target, a TID rate of **>100 kGy/h** can be achieved (confirmed by RPL measurements)
- Simulations show that the neutron energy distribution peaks around 1 MeV
  → SRAM SEU rates strongly depend on the response to intermediate-energy neutrons
- Extra: interesting to use Silicon diode detector to measure single-neutron energy deposition spectrum (not discussed today)