Experimental Evaluation of External Facilities

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https://indico.cern.ch/event/971222/

Introduction

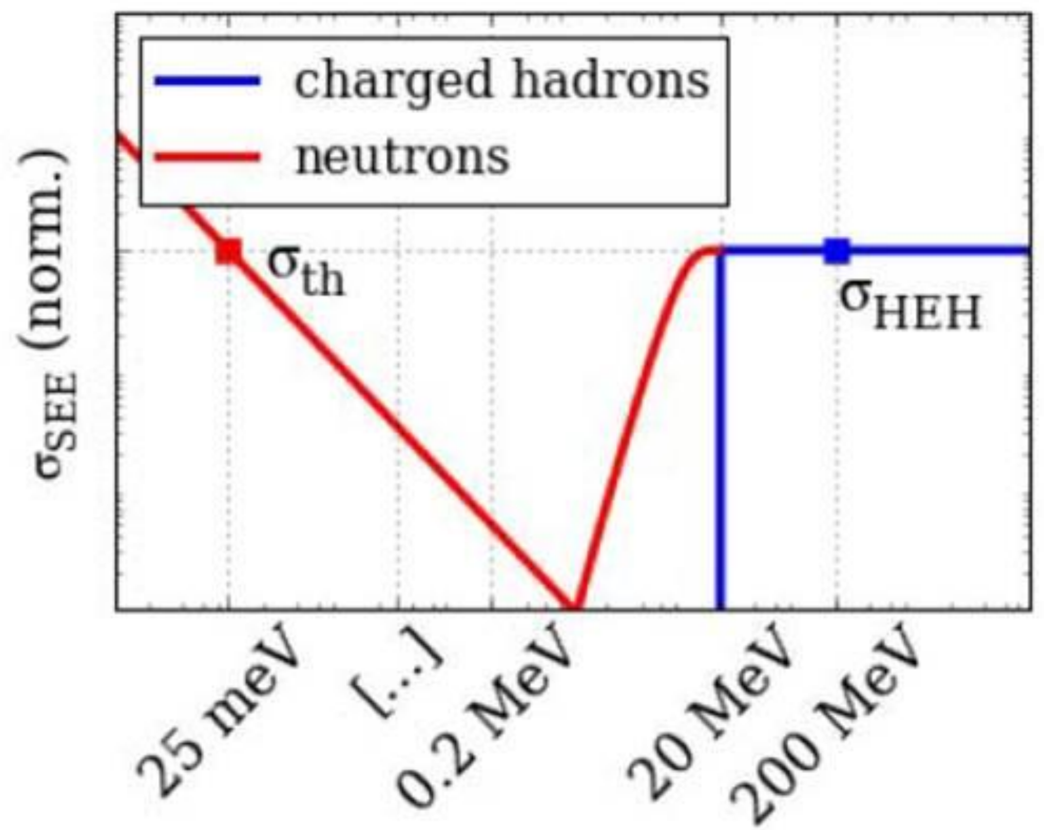
Facilities for radiation testing at CERN (plus PSI) are supposed to cover most of the needs for accelerator radiation testing.

However, availability is a big constraint. So, external alternatives may be a need over certain time periods.

Electronics is constantly evolving towards more and more integrated solutions and radiation effect sensitivity is also changing.

Several radiation effects are better studied if we can isolate the multi-particle, wide-energy spectra that we have at CERN into separate contributions and verify whether the hypotheses that we assumed to be true for accelerator based on less integrated technologies still hold true when considering state-of-the-art technologies and new materials.

Introduction



- All devices are assumed to have a similar SEE response in the accelerator that comprises:
  - The high-energy hadron step function response
  - The fallout at intermediate energy
  - The thermal neutron cross-section
- The high-energy hadron equivalence approximation typically holds, but it is worth assessing whether it still stands for highly-integrated technologies.

Setups used to characterize beams and effects

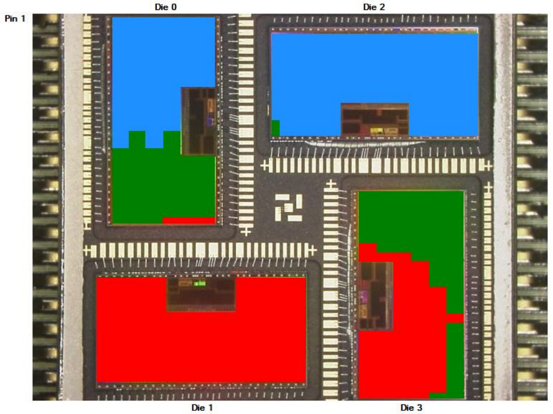
Memories

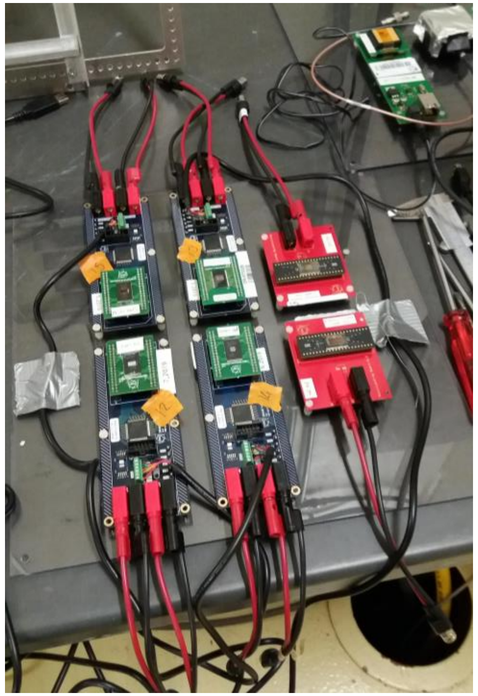
RadMon
- CERN standard (also equipped with RadFET and pin-diode for TID and DD)

ESA Monitor (250 nm)
- Logical-to-physical mapping allows assessing beam homogeneity

SEU assessment for commercial SRAM in lower technology nodes (40-65 nm)
- ISSI 40 nm
- Cypress 65 nm
- RADSAGA 65 nm

SEL assessment for commercial SRAM





Setups used to characterize beams

Destructive events in power devices

- Si
- SiC
- GaN

Silicon diodes

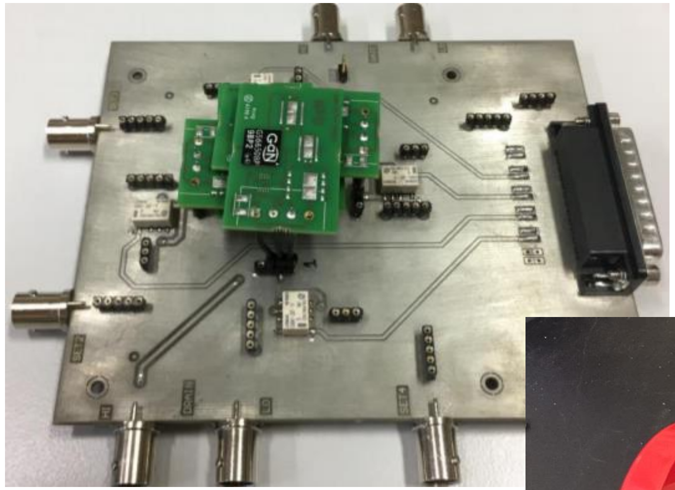
- Experimental energy deposition from the beam (direct and indirect ionization)
- Can be used as a flux monitor as well

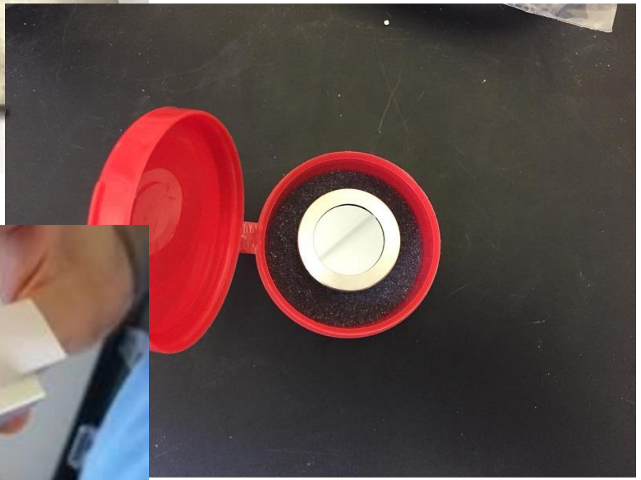
TimePix3

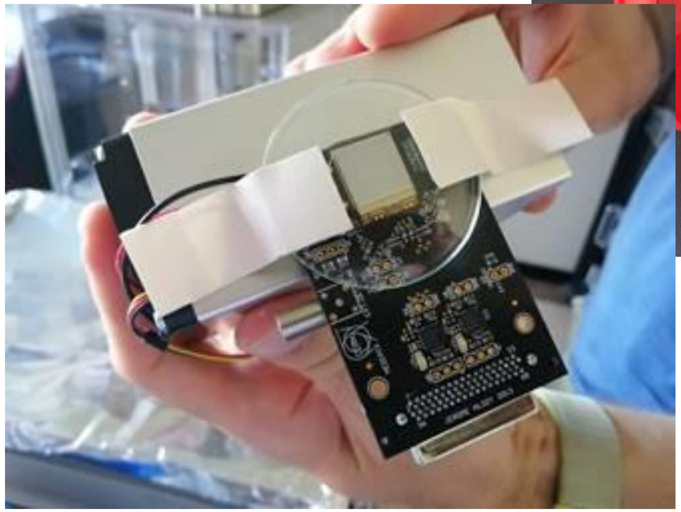
- Under development

Ionization chamber

- From RP







Thermal neutron facilities for R2E

D50 @ ILL

- Pure thermal neutrons (flux 10^9 n/cm^2/s)
- No longer available as of 2021

TENIS @ ILL

- Fission spectrum (flux $3x10^9$ n/cm^2/s)
- Epithermal and fast neutrons

EMMA @ RAL

- Spallation spectrum (flux $2x10^6$ n/cm^2/s)
- Neutron thermalization (thermal and epithermal)

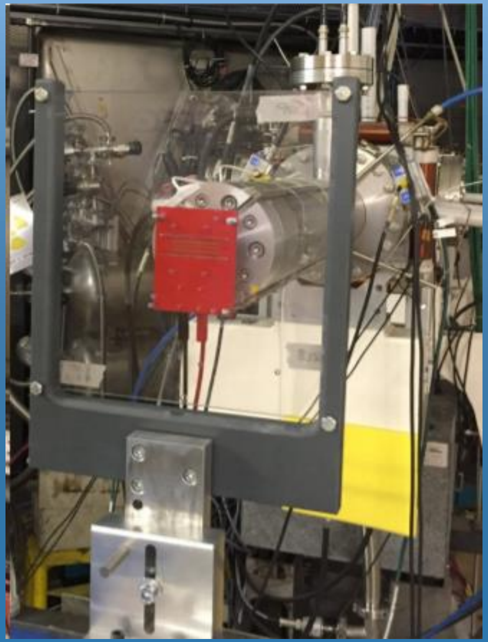
Thermal neutron facilities for R2E

SRAM	D50	TENIS	TENIS B_4C	EMMA
RadMon Toshiba 3 V	1.31×10^{-13}	1.19×10^{-13}	1.26×10^{-16}	-
RadMon Cypress 90 nm	4.70×10^{-16}	5.13×10^{-16}	4.26×10^{-18}	-
ESA Monitor	3.36×10^{-15}	3.01×10^{-15}	2.48×10^{-18}	-
ISSI 40 nm	3.16×10^{-15}	3.53×10^{-15}	7.45×10^{-18}	2.69×10^{-15}
Cypress 65 nm	4.91×10^{-16}	6.24×10^{-16}	6.39×10^{-18}	4.98×10^{-16}
RADSAGA 65 nm	4.74×10^{-14}	4.56×10^{-14}	Low statistics	-
Cypress 90 nm	3.88×10^{-16}	-	-	3.33×10^{-16}

- Cross-sections from TENIS very similar to D50
- Still events when using B_4C, but cross-section is 100-1000 times lower
  ➡ thermal neutron component dominant
- Cross-sections from EMMA also quite compatible and no events with B_4C

Intermediate-energy neutron facilities for R2E

GENEPI2 @ LPSC

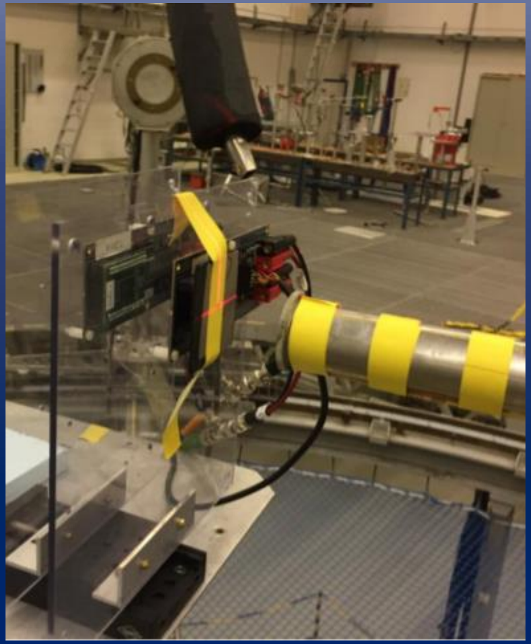


- 14 MeV neutrons (flux $5x10^7$ n/cm^2/s)
- 2.5 MeV neutrons (lower flux)

FNG @ ENEA

- 14 MeV neutrons (flux $3x10^8$ n/cm^2/s)
- 2.5 MeV neutrons (flux $4x10^6$ n/cm^2/s)

PIAF @ PTB



- 0.144-19 MeV neutrons (flux $4x10^5$ – 10^8 n/cm^2/s)
- More targets/projectiles

Intermediate-energy neutron facilities for R2E

SRAM	LPSC 14 MeV	FNG 14 MeV	PTB 17 MeV	AmBe (Toshiba)	AmBe (actual response)	ChipIr
ESA Monitor	2.49×10^{-14}	1.84×10^{-14}	-	1.25×10^{-14}	2.46×10^{-14}	2.10×10^{-14}
ISSI 40 nm	-	9.81×10^{-15}	1.91×10^{-14}	2.88×10^{-14}	1.33×10^{-14}	1.19×10^{-14}
Cypress 65 nm	-	4.60×10^{-14}	8.19×10^{-14}	1.25×10^{-13}	5.04×10^{-14}	1.16×10^{-13}
Cypress 90 nm	6.81×10^{-14}	5.06×10^{-14}	1.25×10^{-13}	4.63×10^{-14}	1.64×10^{-13}	5.73×10^{-14}

- Intermediate-energy neutrons can be used as a proxy to high-energy SEU cross-section (SEU only). Data also compatible with Am-Be.
- Intermediate-energy neutrons (0.1-10 MeV) can contribute for about 60% of total SEU rate in accelerator
- Toshiba HEH approximation can provide innacurate results for assessment of AmBe data

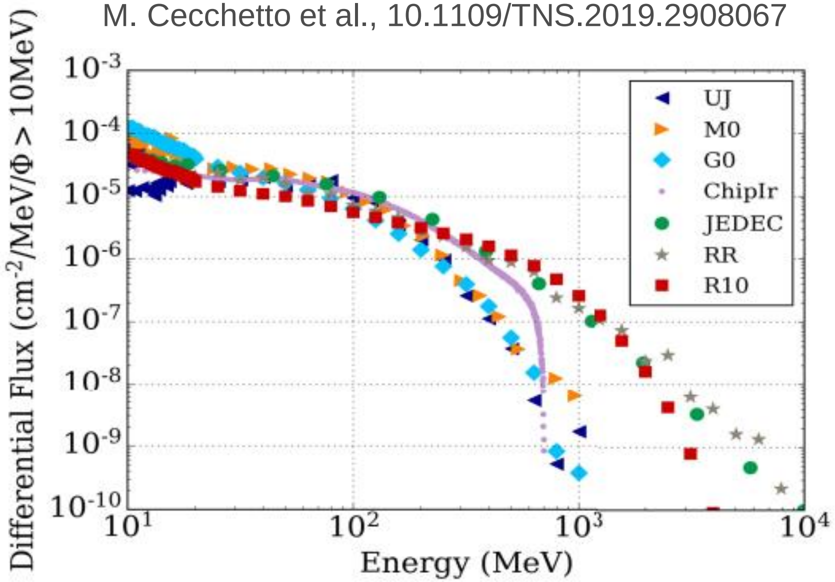
Spallation neutrons for R2E

ChipIr @ RAL

- Spallation neutrons
- Deeply penetrating beam
- Flux calibration

φ_{HEHeq} [cm^{-2}/s/o]			$\varphi_{>10MeV}$ [cm^{-2}/s/o]	$\varphi_{>20MeV}$ [cm^{-2}/s/o]
ESA M.	Toshiba	Cypress		
3.54×10^6	3.63×10^6	3.46×10^6	3.57×10^6	3.25×10^6

M. Cecchetto et al., 10.1109/TNS.2019.2908067



Despite being cut at lower energy (700 MeV), the ChipIr spectrum provides very representative error rates for several CERN environments

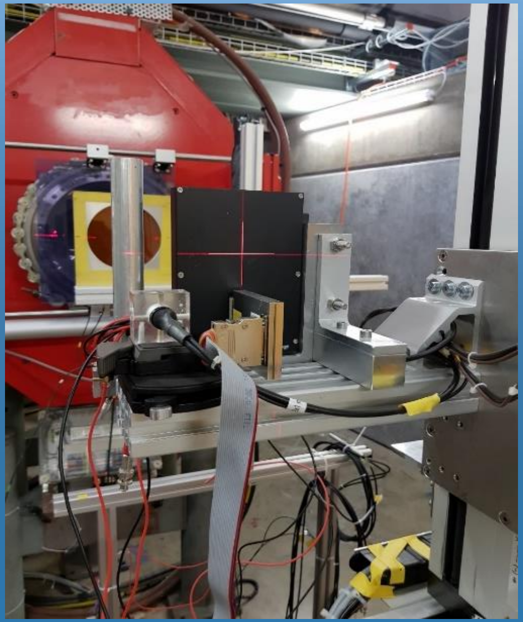
SEU (%) IN THE 1–100 MeV ENERGY INTERVAL IN DIFFERENT ENVIRONMENTS, FROM THE SOFTER TO THE HARDER. CONSIDERED SPECTRUM > 1 MeV

1-100 MeV	Spect %	ESA M.	Toshiba	Cypress	FPGA
UJ	79.1	69.8	68.9	67.9	71.9
G0	95.3	82.1	79.6	77.6	86.6
ChipIr	61.4	56.1	57.1	55.0	58.6
JEDEC	59.8	60.4	59.0	57.5	63.5
RR	75.7	54.5	52.1	50.1	59.3
R10	75.0	48.8	46.3	44.1	54.7

Underestimation only for SEL of devices with high-Z materials

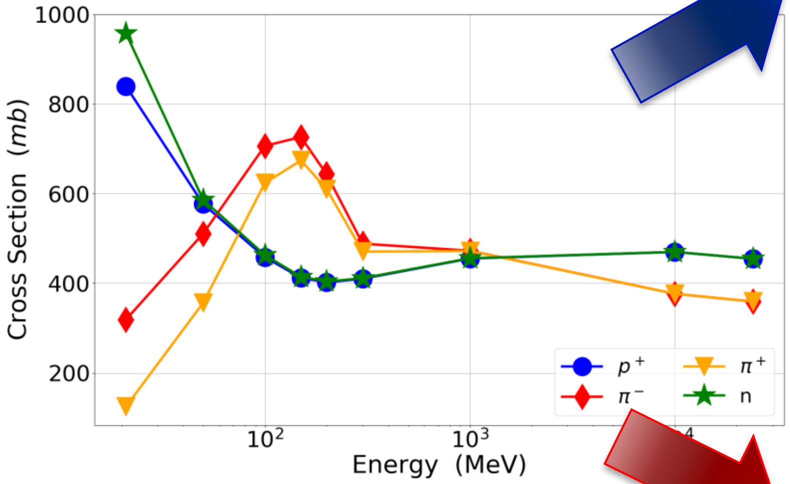
Pion facility for R2E

πM1 @ PSI

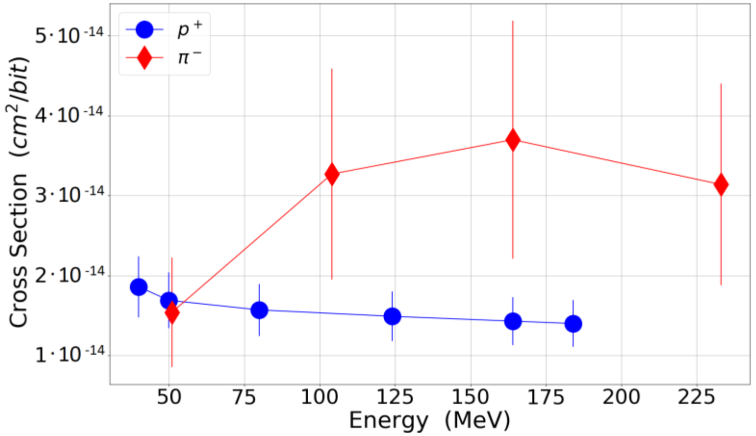


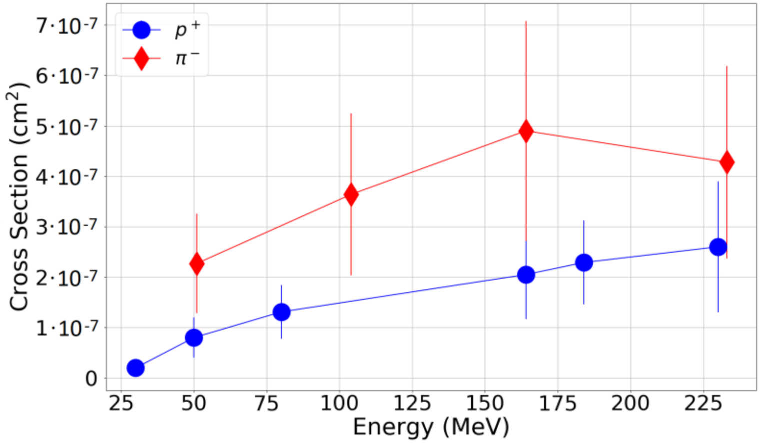
- 50-230 MeV pions (+-)
- Flux $5 \times 10^4 - 3 \times 10^6$ π/cm²/s
- Electron contamination at low-energy

Inelastic cross-section shape is reflected in pion SEU measurements



A. Coronetti et al., DOI 10.1109/TNS.2020.2983599





However, it does not explain alone the SEL measurements at low-energy (pion absorption)

No drastic consequences for HEH approximation, though!

Proton facilities for R2E (other than PSI)

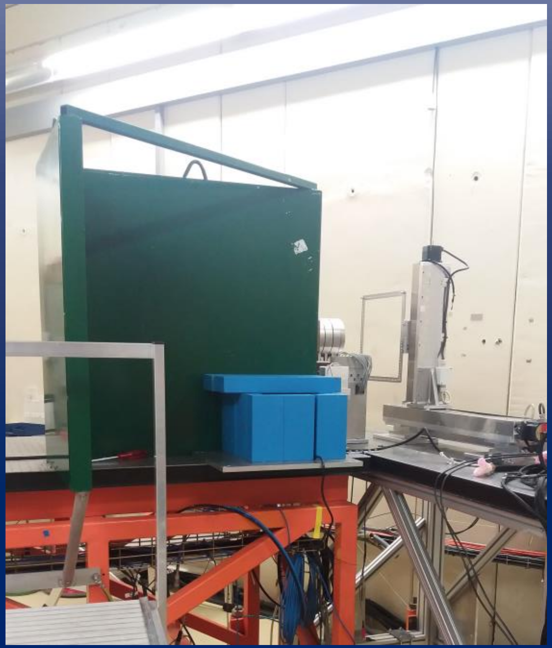
CNA

- Low-energy protons (0.5-5 MeV)
- Flux 10^2-10^{12} p/cm^2/s
- Vacuum

RADEF

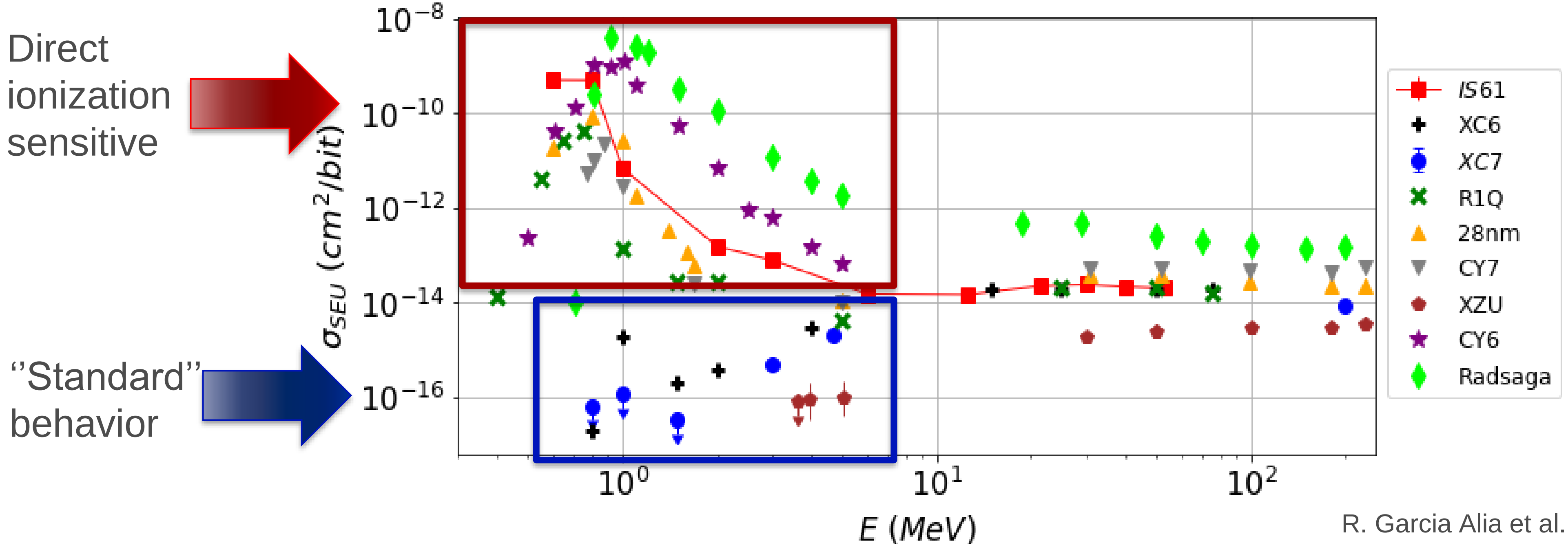
- Several energy ranges (0.5-52 MeV)
- Flux 10^4-10^8 p/cm^2/s
- Vacuum or air

KVI-CART



- 10-186 MeV protons (PSI equivalent)
- Flux 10^3-10^9 p/cm^2/s
- Beam wider than PSI

Proton facilities for R2E (other than PSI)



R. Garcia Alia et al., 10.1109/TNS.2019.2951307

- Low-energy proton SEU cross-sections comparable to heavy ion SEU cross-sections
- LEP introduces another uncertainty that can vary by orders of magnitude from one device to another and may lead to underestimate the expected rate.

Heavy ion facilities for R2E

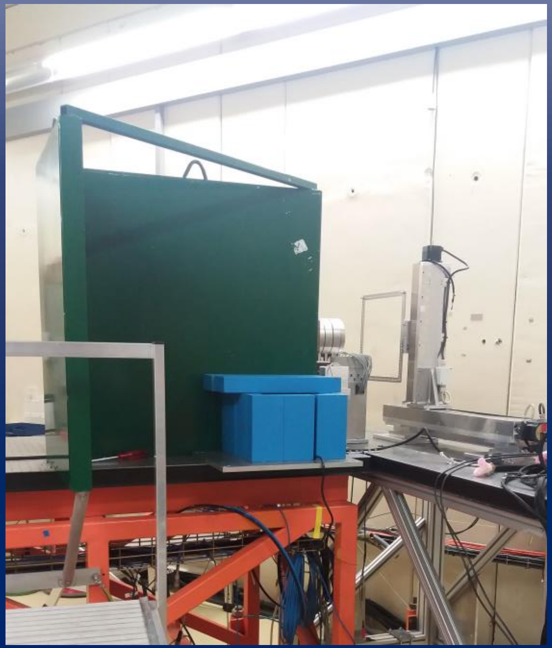
GANIL

- 20-50 MeV/n
- LET 20-100 MeV/(mg/cm^2)
- Flux 10^1-10^4 i/cm^2/s
- Air only

RADEF

- 16.3 MeV/n
- LET 1.5-48 MeV/(mg/cm^2)
- Flux 10^1-10^4 i/cm^2/s
- Vacuum or air

KVI-CART



- 30-90 MeV/n
- LET 0.02-45 MeV/(mg/cm^2)
- Flux 10^2-10^7 i/cm^2/s
- Air only

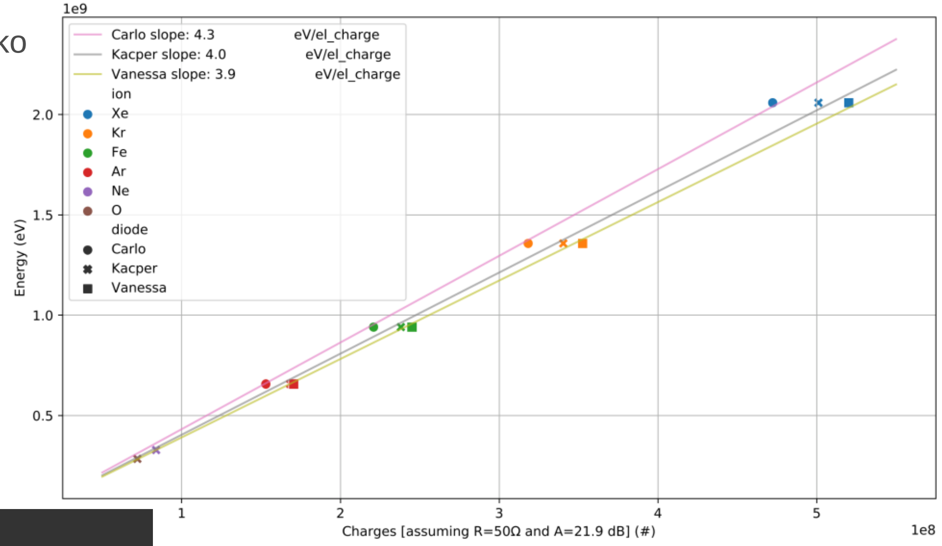
Heavy ion facilities for R2E

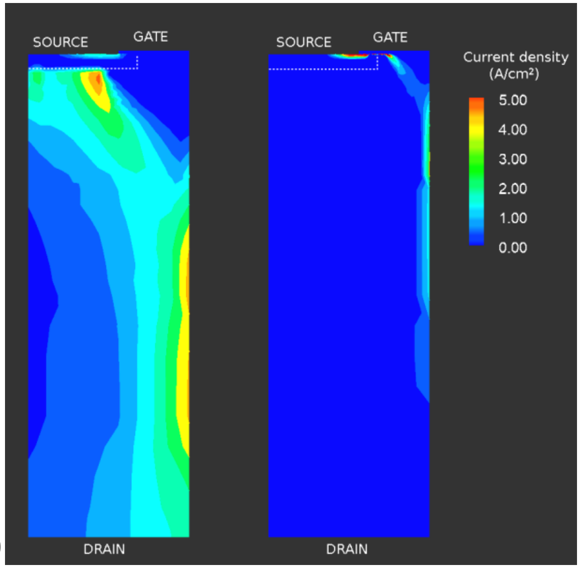
Ions provide fundamental information for device response in hadron fields -> indirect ionization is produced by secondary ions

Used for modelling of device response (sensitive volume simulations to FLUKA, TCAD, etc.)

Used for calibrating beam instrumentation (e.g., diodes)

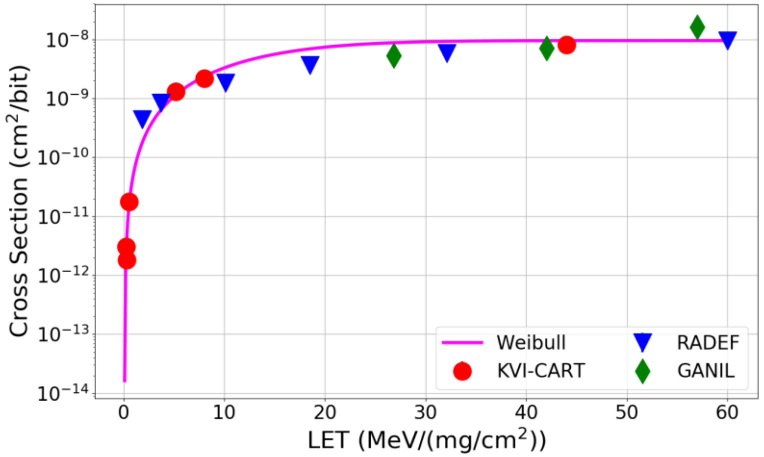
K. Bilko





K. Niskanen et al., DOI 10.1109/TNS.2020.2983599

A. Coronetti et al., DOI: 10.1109/REDW51883.2020.9325822



Practical information

From within the CERN network you can access our Wiki page on facilities:

It contains plenty of information that we collected from our previous tests:

- Beam characteristics
- Dosimetry
- Electrical infrastructure (cables, patch panels)
- Mechanical infrastructure

That may help preparing future test campaigns

RADNEXT (https://radnext-network.web.cern.ch/)

Thank you for your attention!