WP9-TA1: Neutron, muon and mixed-field spallation facilities and irradiation

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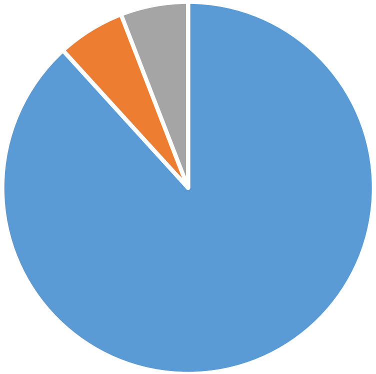
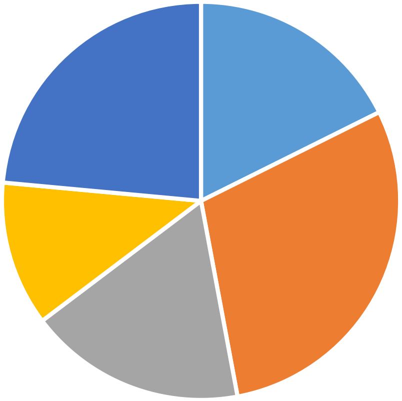
RADNEXT Kick Off Meeting – 19-21 May 2021
https://indico.cern.ch/event/983095/
https://indico.cern.ch/event/1029314/

WP9: big variety of facilities





Neutron Facilities

Neutron Facilities	Energy range	Flux ($s^{-1}cm^{-2}$)	Yield (s^{-1})	Neutron production	Country
ChipIr (UKRI)	Atmospheric	$6 \cdot 10^6$	-	Spallation (up to 800 MeV)	UK
TRIUMF	Atmospheric	$5 \cdot 10^5 - 3 \cdot 10^6$	-	Spallation (up to 500 MeV)	CA
FNG (ENEA)	14 MeV (or 2.5 MeV)	Up to $5 \cdot 10^9$	10^{11}	DT (or DD)	IT
Fraunhofer INT (INT)	14 MeV (or 2.5 MeV)	Up to $3 \cdot 10^8$	10^{10}	DT (or DD)	DE
NESSA (UU)	14 MeV	Up to 10^9	$4 \cdot 10^{10}$	DT	SE
CNRS-LPSC	14 MeV (or 2.5 MeV)	Up to $5 \cdot 10^7$	$8 \cdot 10^9$	DT (or DD)	FR
PTB	monoenergetic up to 20 MeV	$10^3 - 10^8$	-	Nuclear reactions	DE
NPI-CAS	quasi-monoenergetic up to 30 MeV	$10^3 - 5 \cdot 10^8$	-	$^7Li(p,n)$	CZ
GANIL-SPIRAL2 (GANIL)	quasi-monoenergetic up to 30 MeV		-	$^7Li(p,n)$	FR
ILL	Thermal	$3 \cdot 10^9$	-	Nuclear Reactor	FR
EMMA (UKRI)	Thermal	$2 \cdot 10^6$	-	Pulsed, spallation moderated	UK
NPI-CAS	Low and intermediate energy white beam	$10^{11} - 10^{12}$	-	Be converter	CZ
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Atmospheric neutrons – High energy

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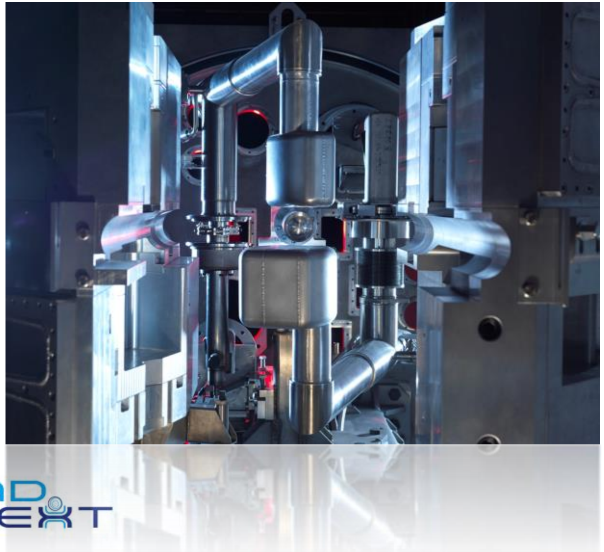
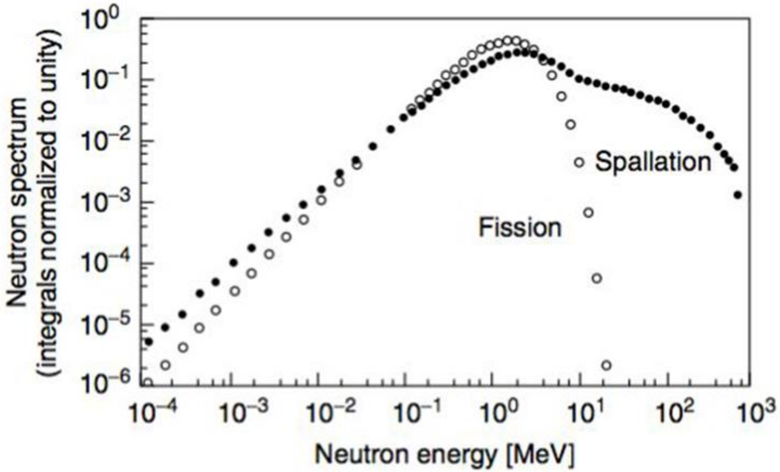
TRIUMF BL1B - TNF (TRIUMF)	Atmospheric	$5 \cdot 10^5$ - $3 \cdot 10^6$	Spallation (up to 500 MeV)	CA

Spallation sources produce spectrums that go up to the proton energy (500MeV/800MeV); a much broader, high energy spectrum than can be obtained from fission reactors sources





Neutron Source Requirements Driven by Standards

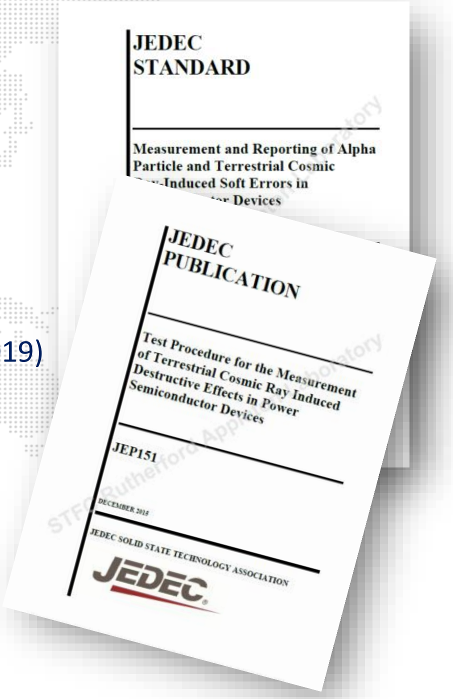
Standards for SEE testing by JEDECS and IEC committees

JEDECS: JESD89A: Measurement and Reporting of Alpha Particle and Terrestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices

JEDECS: JEP151: Test Procedure for the Measurement of Terrestrial Cosmic Ray Induced Destructive Effects in Power Semiconductor Devices

IEC TR 62396 - Process management for avionics Atmospheric radiation effects

IEC: TR 62396-1: Atmospheric radiation (2016)
IEC: TR 62396-5: Thermal Neutrons neutron (2014)
IEC: TR 62396-6: Extreme space weather (2017)
IEC: TR 62396-8: Protons, electron, pion, **muon fluxes** (due 2019)



Major areas of current commercial research:-

- Systems for autonomous **‘driverless’ cars**
- Device and system level for **internet** and communication infrastructures
- **High power devices** for renewable energy applications and automotive
- **Aerospace** applications

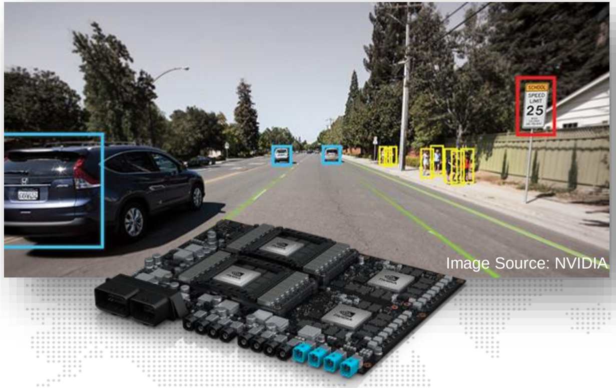


Image Source: NVIDIA

Image Source: Infineon

Image Source: Cobham

Monoenergetic sources

Neutron Facilities	Energy range	Flux ($s^{-1}cm^{-2}$)	Yield (s^{-1})	Neutron production	Country
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GANIL-SPIRAL2 (GANIL)	quasi-monoenergetic up to 30 MeV	10^5	-	$^7Li(p,n)$	FR

Source: PTB

Based on nuclear reactions.
Low scattering facilities

Many other different applications:
- Nuclear Fusion R&D
- Metrology, spectrometry and dosimetry of neutron radiation
- Nuclear data for energy production
- Nuclear data for astrophysics
- etc.

Monoenergetic sources and electronics

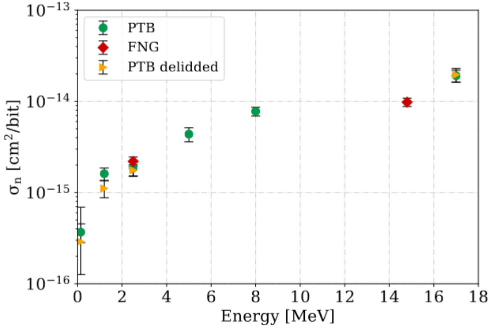
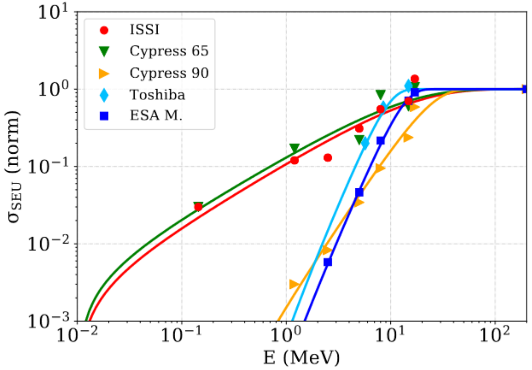


Fig. 1. ISSI 40 nm neutron cross sections, measured at FNG and PTB. Comparison with the delidded memory for some energies. Error bars are reported with 95% of confidence level, including statistical and fluence uncertainties.

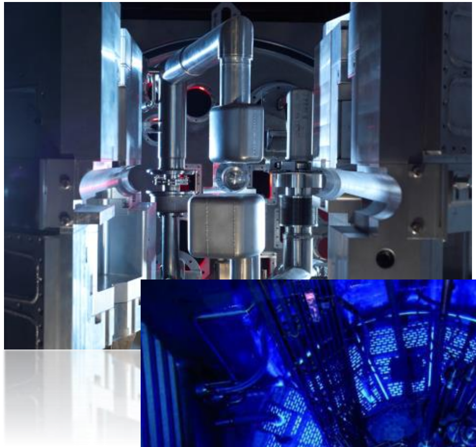


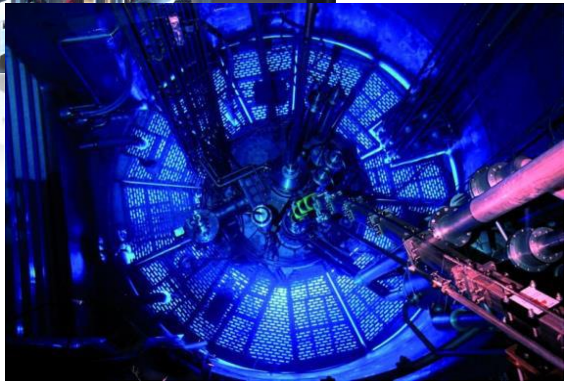
Source: Cecchetto et al. 2021

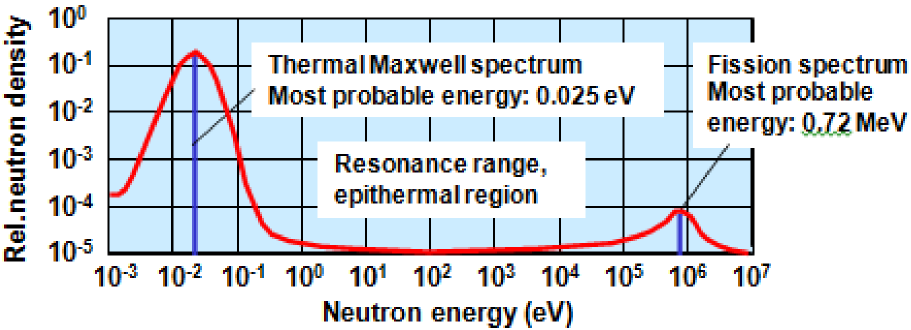
- **<u>Measurement of cross sections as a function of energy</u>**
- **<u>Comparative studies</u>**
- **<u>Application of electronics for nuclear technology</u>** because they are more representative of **<u>fusion (or fission) reactors environment</u>**.
- Preparation and **<u>test of setups and methods</u>** (more availability than spallation sources).
- Characterisation of dosimeters as a function of energy.
- They are NOT fully representative of the atmospheric spectrum, but they can be used in a complementary way.

Thermals

Neutron Facilities	Energy range	Flux ($s^{-1}cm^{-2}$)	Neutron production	Country
ILL	Thermal	$3 \cdot 10^9$	Nuclear Reactor	FR
EMMA (UKRI)	Thermal	$2 \cdot 10^6$	Pulsed, spallation moderated	UK

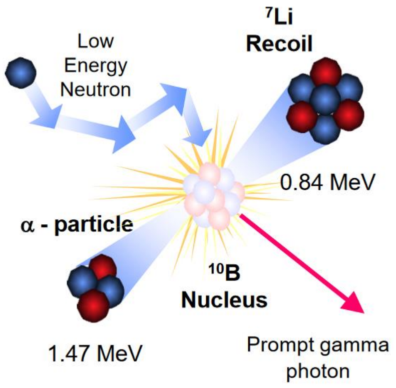


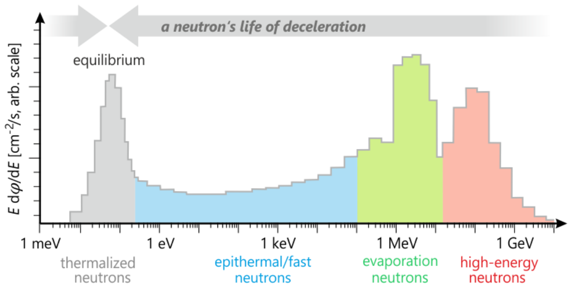




- Fast neutrons slow down in a moderator
- Thermal equilibrium -> Maxwell-Boltzmann distribution, most probable energy KT=25meV
- Use of thermal neutrons for neutron scattering.
- EMMA and ILL, complementary flux. Continuous vs. pulsed.

Testing electronics with thermal neutrons





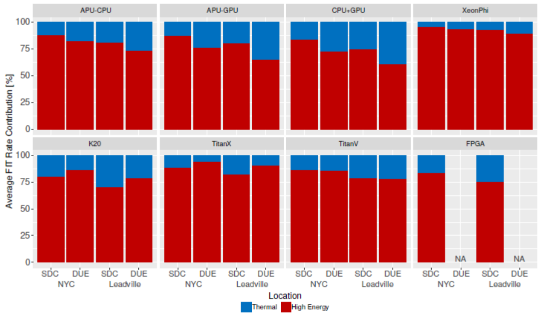


Fig. 5: Percentage of total FIT rate due to high energy and thermal neutrons. All tested parts except Xeon Phi show significant errors due to ^{10}B levels.

- Thermal neutrons are known to induce **SEE in the electronics when Boron is present**.
- Enrichment of ^{11}B is a too expensive solutions, in particular for commercial electronics.
- **Recent studies** have found probabilities of SEE induced by thermal neutrons to be of the same order as fast neutrons, for **commercial devices (COTS)** to be used for safety-critical applications.

White beams (low and intermediate energy)

Neutron Facilities	Energy range	Flux ($s^{-1}cm^{-2}$)	Neutron production	Country
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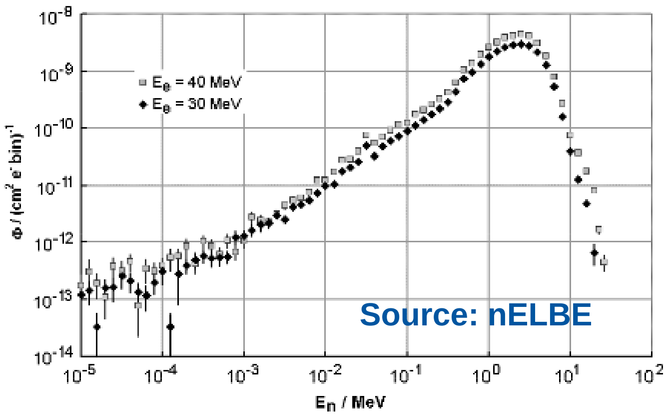
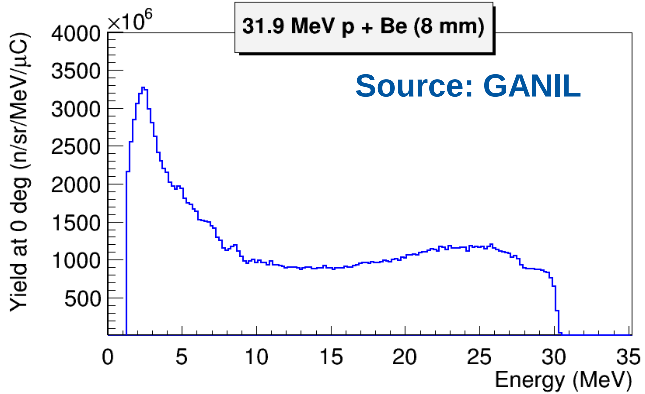
High Fluxes!



Electron beam on Target: ^{nat}Ta 3.52 cm



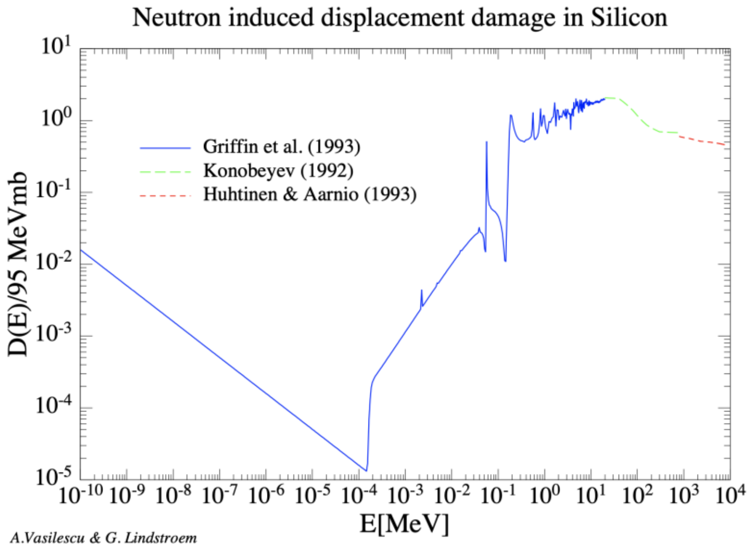
Measured continuous energetic spectra with thick Be converter and proton and deuteron beam

Applications

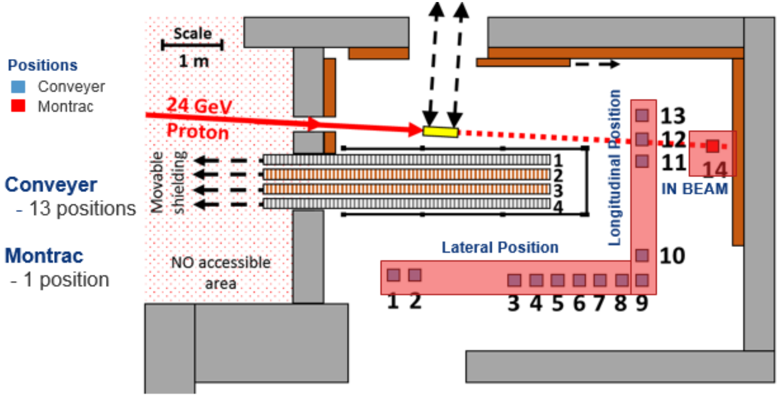
Other applications:

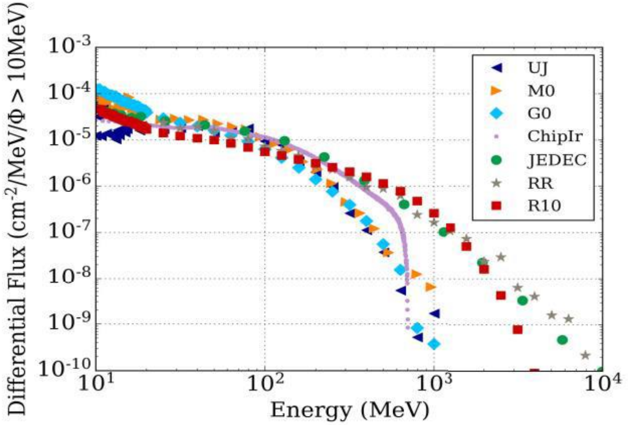
- Nuclear data (fast neutrons)
- Nuclear technology (eg. transmutation of actinides)
- Etc.

- Electronics testing:
  - High fluxes useful for displacement damage studies
  - Comparative testing, method development
  - Nuclear environments
  - Time of Flight can be interesting for detector testing



Mixed Field (CHARM)





CHARM comparison with the atmospheric neutron spectrum

- CHARM's spallation mixed field (mainly **neutrons, protons and pions**)
- Main interest from radiation effects community: representative radiation environment at **system level**, thanks to very large radiation field available (homogeneous, highly penetrating)
- **Strong interest from space community:** lifetime effects – TID, displacement damage – and SEEs
- Testing electronics for **accelerator environment**.

Muons

- Muons are the **largest component** of the atmospheric flux on the ground
- Muons **cross sections are much smaller** than neutrons. At the moment they are not a problem for industry, but more an academic interest.
- Facilities need to be ready if the problem increases with **scaling down of microelectronics**.

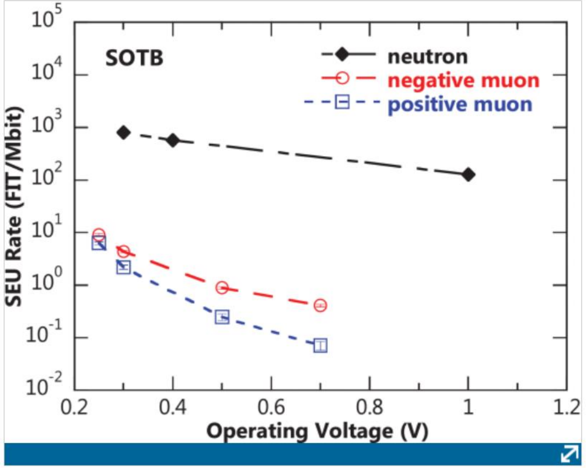
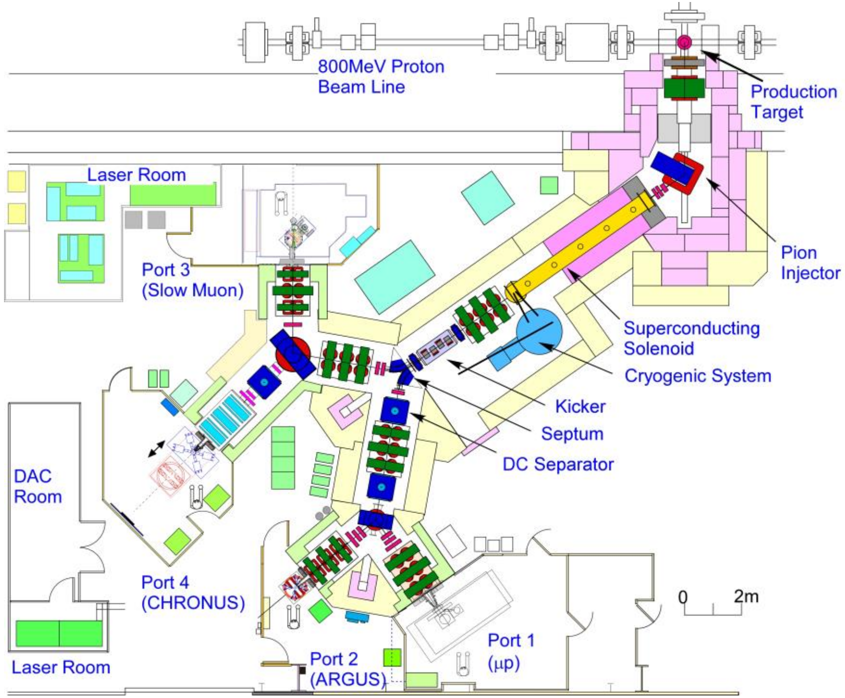


Fig. 5.
Ground-level SEU rate induced by cosmic-ray neutron, negative muon, and positive muon on the 65-nm SOTB SRAM.

Source: Manabe et al. 2019



RAL-RIKEN Muons up to 60 MeV/c

WP9: Relationships with Joint Research Activities (non-TA) WPs

WP5

- **Radiation monitors, dosimeters and beam characterization**
  - Neutron fields are very different (meV to GeV), need a variety of techniques and methods.
  - Importance of cross-calibration between facilities (at least of the same kind).
  - Need of innovative monitors that can be reference for users.

WP6

- **Standardization of system level radiation qualification methodology**
  - Neutrons are very attractive for system level testing (high penetration, large volumes)
  - Need standardization for use (eg. Using neutron for space as proxy for protons).

WP7

- **Cumulative radiation effects on electronics**
  - Facilities with high fluxes for TID and displacement damage.
  - Decoupling SEE and cumulative effects

WP8

- **Complementary modelling tools**
  - Need Measurements to benchmark simulation tools
  - Simulations can be used to compare results obtained with different radiation fields.

Transnational Access

<u>Please see NA2 presentation later in the morning</u>

Description of work

- Users will be given **<u>access to RADNEXT through TA</u>**. The access to the facilities and information of various facilities are made more readily available to all.
- Help will be provided for the **<u>selection of suitable facility</u>** and proper beams for user's research needs.
- An ad-hoc **<u>User Selection Panel</u>** (USP) will be established at the beginning of the project. The USP will thoroughly evaluate the proposals according to its scientific excellence, impact on the radiation effects community, and implementation description and feasibility.

Thanks for your attention!

Image Source: STFC