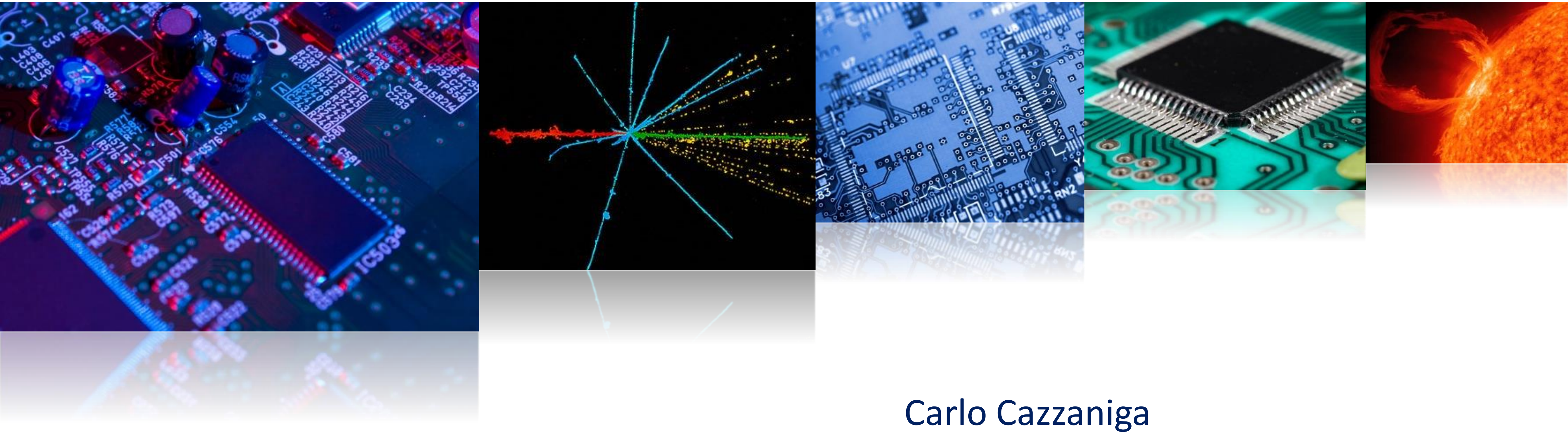
Atmospheric-like neutrons at the ChipIr beamline

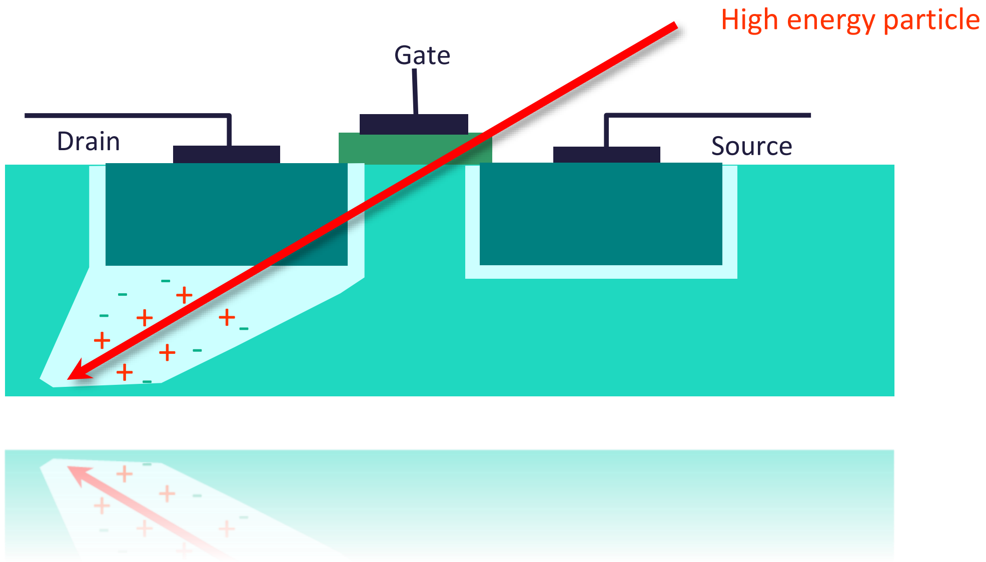


Carlo Cazzaniga

ISIS Facility, Rutherford Appleton Laboratory, UK

UKRI Science and Technology Facilities Council

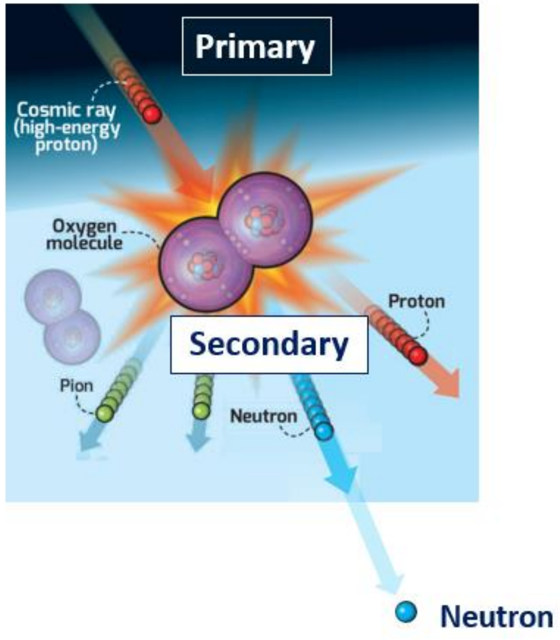
A Single Event Effect (SEE) is when a highly energetic particle present in the environment, strikes sensitive regions of an electronic device disrupting its correct operation

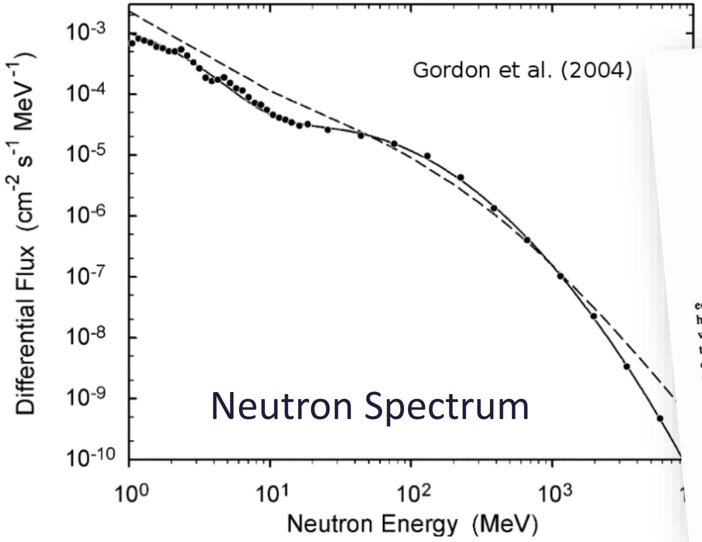


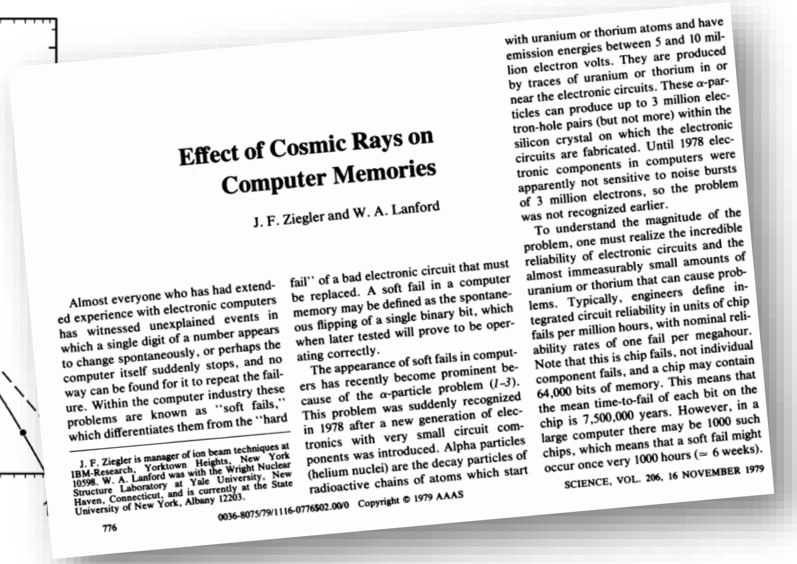
Science and Technology Facilities Council

Sources of Radiation Causing SEE

A nuclear cascade takes place as the primary (galactic) cosmic rays interact with the atmosphere (predominantly nitrogen and oxygen) to create a shower of secondary particles extending down to aircraft altitudes and ground level.







Effect of Cosmic Rays on Computer Memories

J. F. Ziegler and W. A. Lanford

Almost everyone who has had extended experience with electronic computers has witnessed unexplained events in which a single digit of a number appears to change spontaneously, or perhaps the computer itself suddenly stops, and no way can be found for it to repeat the failure. Within the computer industry these problems are known as "soft fails," which differentiates them from the "hard fail" of a bad electronic circuit that must be replaced. A soft fail in a computer memory may be defined as the spontaneous flipping of a single binary bit, which when later tested will prove to be operating correctly.

The appearance of soft fails in computers has recently become prominent because of the α-particle problem (1–3). This problem was suddenly recognized in 1978 after a new generation of electronics with very small circuit components was introduced. Alpha particles (helium nuclei) are the decay particles of radioactive chains of atoms which start with uranium or thorium atoms and have emission energies between 5 and 10 million electron volts. They are produced by traces of uranium or thorium in or near the electronic circuits. These α-particles can produce up to 3 million electron-hole pairs (but not more) within the silicon crystal on which the electronic circuits are fabricated. Until 1978 electronic components in computers were apparently not sensitive to noise bursts of 3 million electrons, so the problem was not recognized earlier.

To understand the magnitude of the problem, one must realize the incredible reliability of electronic circuits and the almost immeasurably small amounts of uranium or thorium that can cause problems. Typically, engineers define integrated circuit reliability in units of chip fails per million hours, with nominal reliability rates of one fail per megahour. Note that this is chip fails, not individual component fails, and a chip may contain 64,000 bits of memory. This means that the mean time-to-fail of each bit on the chip is 7,500,000 years. However, in a large computer there may be 1000 such chips, which means that a soft fail might occur once very 1000 hours (≃ 6 weeks).

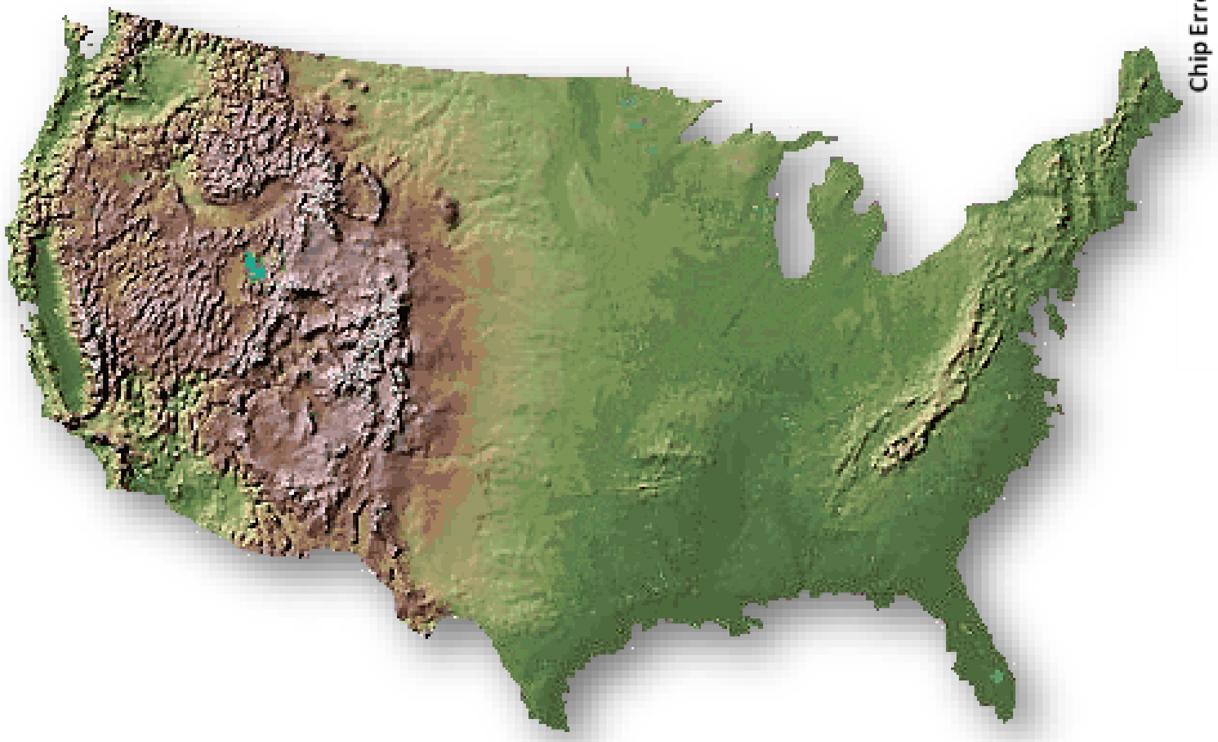
J. F. Ziegler is manager of ion beam techniques at IBM-Research, Yorktown Heights, New York 10598. W. A. Lanford was with the Wright Nuclear Structure Laboratory at Yale University, New Haven, Connecticut, and is currently at the State University of New York, Albany 12203.

0036-8075/79/1116-0776$02.00/0

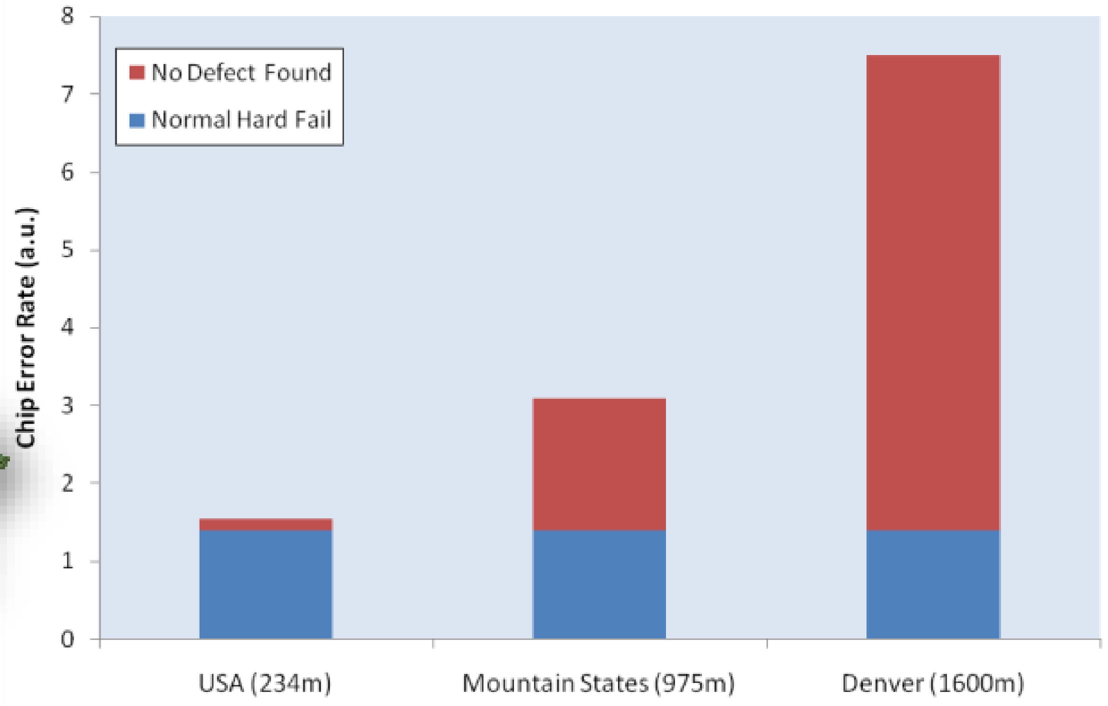
Ziegler and Langford in a landmark 1979 Science paper predicted that cosmic rays neutrons would cause major reliability problems at ground level (and aircraft altitudes).

Science and Technology Facilities Council

Images: STFC/Ben Gilliland



Source: National Elevation Dataset: USGS



Reproduced from J.F.Ziegler et al IBM. J. Res. Develop. 40, 1996, p3

Science and Technology Facilities Council

How alien invaders can change government

Schaerbeek, Belgium

May 18th 2003, 22:30

"worried about the influence of Martians on these elections….
unless the cosmic rays affect our lists in a positive way!"

4096 (2^{12}) votes added to an electronic voting machine

0	0	0	0	0	1	0	0	0	1	1	0	0	1	1	0	1

4096

‘Real-world Incident’

7th October 2008 at 04:40:26
Flight Qantus QF72
Singapore to Perth

Travel News

'Cosmic rays' may have hit Qantas plane off Australia's northwest coast

By Ben Packham | Herald Sun | November 19, 2009 12:01am

- Two terrifying dives by Qantas Airbus
- Flight attendant, passengers injured
- Cosmic rays from space may be to blame

COSMIC rays may have been responsible for a near disaster involving a Qantas jet off Australia's northwest coast.

Safety investigators have isolated the cause of two terrifying dives by the Airbus A330-303 to an onboard computer.

But the computer itself, fitted to about 900 aircraft worldwide, was found to be in perfect working order, the Herald Sun reports.

A flight attendant and 11 passengers were seriously injured and many others experienced minor injuries in a near-miss on October 8 last year.

The aircraft's nose pitched violently downward twice in rapid succession, diving 650ft and 400ft, throwing unsecured passengers and luggage around the cabin / File

An Australian Transport Safety Bureau report into the incident found at least six passengers' seatbelts came unfastened during the event.

Oak Ridge National Laboratory's TITAN Supercomputer

18,000 NVIDIA Teska K20 GPU
working together with AMD 16-core Opteron CPU

Most powerful in November 2012 at 17.79 petaFLOPS

Work at ISIS reported at RADECS 2013 (Oxford)
"we have 1 error every 10 minutes"

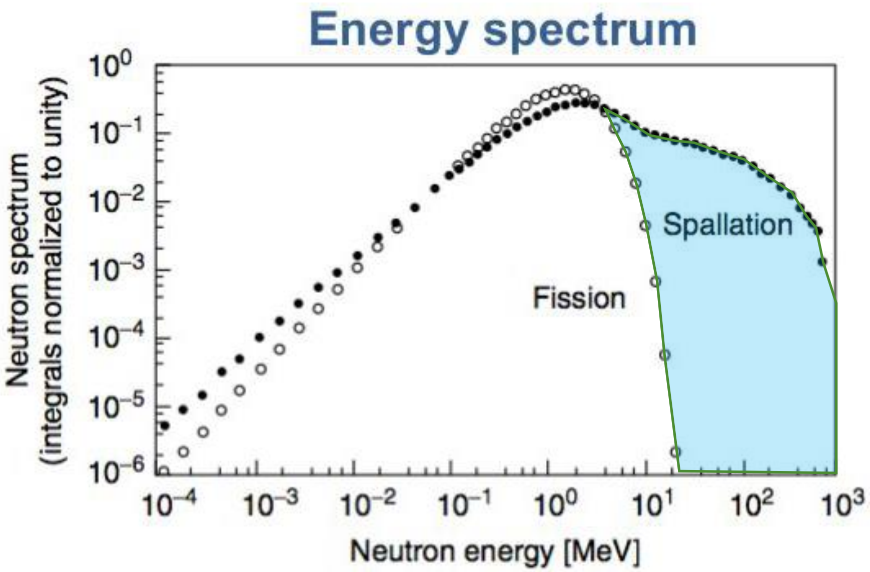
Super Mario impossible jump in 2021

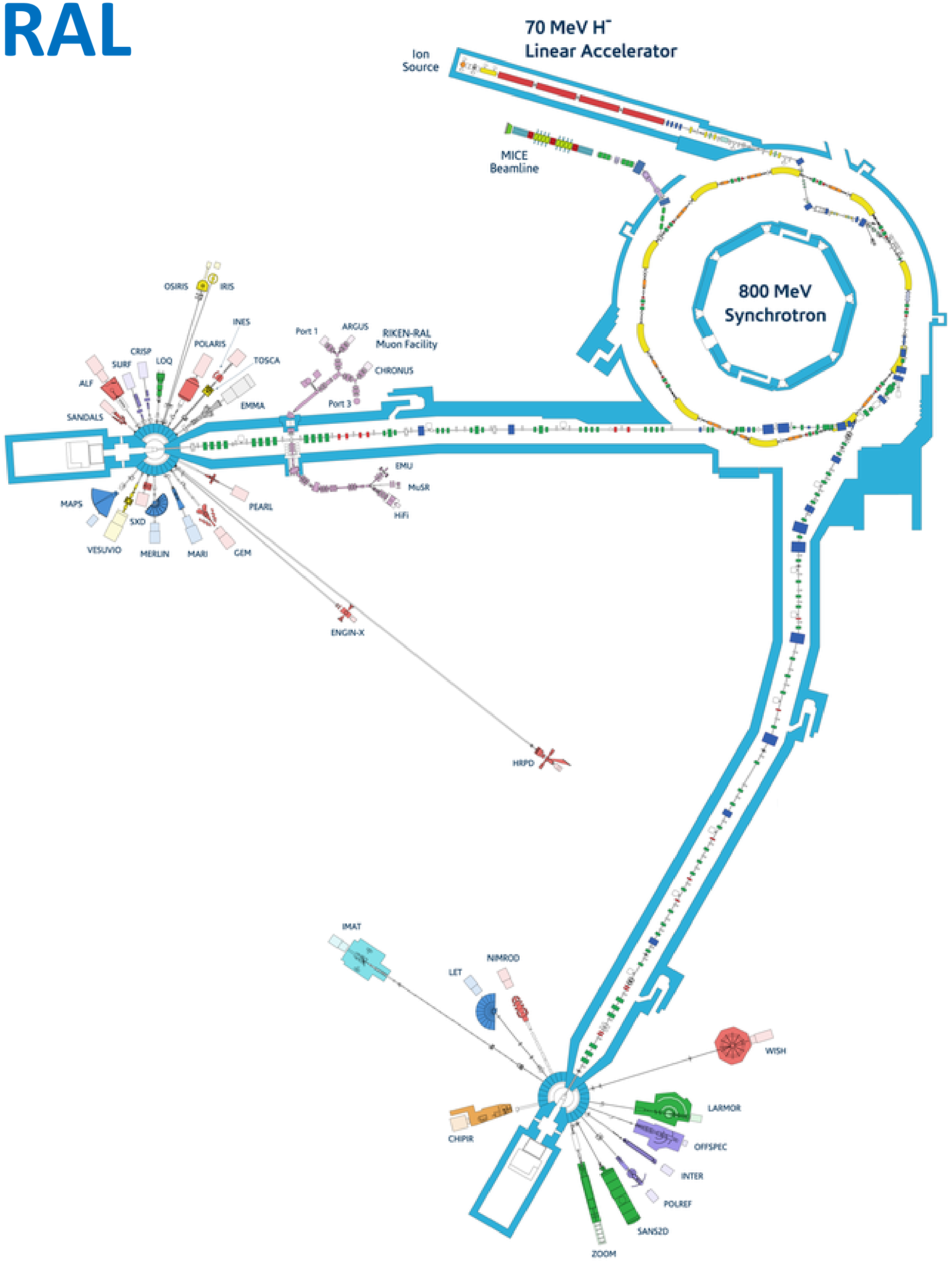
A speedrunner was streaming Super Mario 64, and experienced an unknown glitch which instantly warped him to a higher point in the level. **To this day, no bugs have been discovered that could cause this effect (with an unclaimed $1,000 bounty for whoever finds one)** and the leading hypothesis is that a stray cosmic ray happened to hit the streamer's N64 in the part that was currently storing Mario's Y coordinate, toggling a single bit which resulted in the observed effect.

SEE have been linked to an impossibly fast Super Mario 64 speedrun

The ISIS spallation neutron source at RAL

SEE test facilities require spallation sources as they produce **<u>fast-neutron spectrum</u>** that go up to the proton energy (of 800MeV at ISIS); a much broader, higher energy spectrum than can be obtained from fission reactors sources

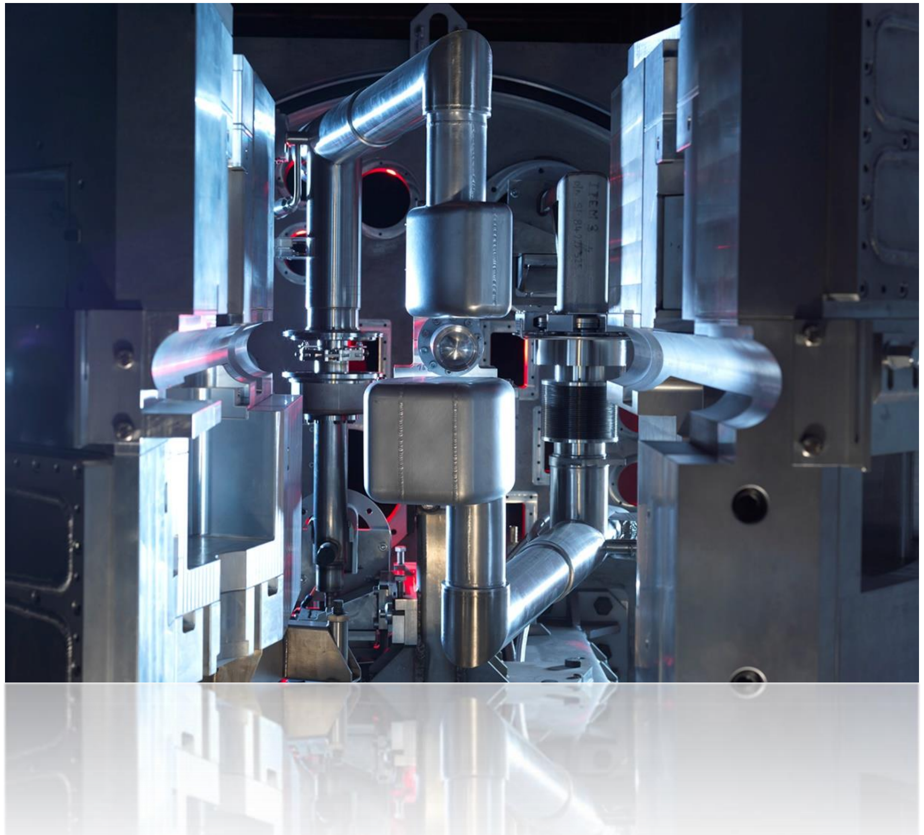




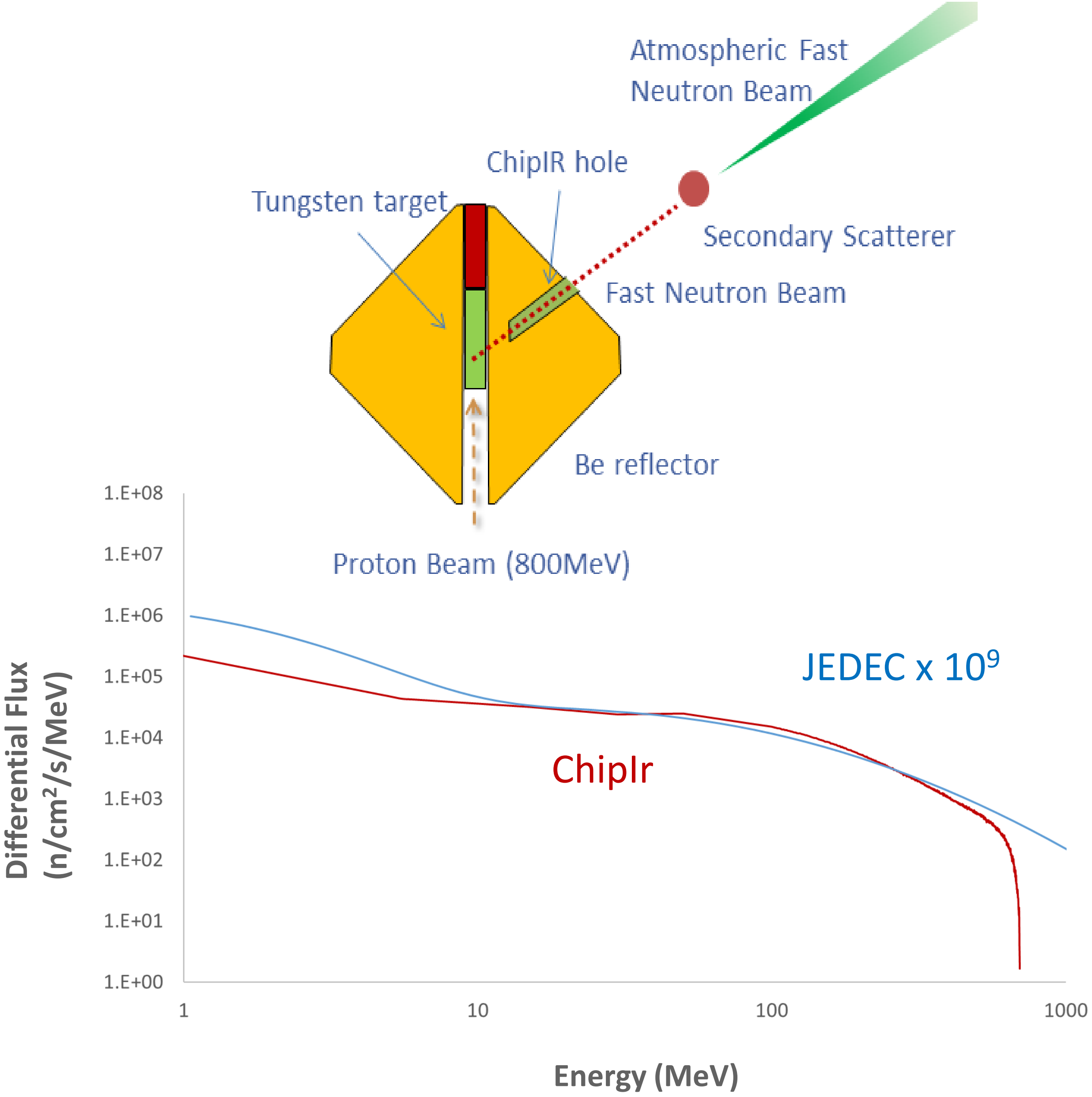
Science and Technology Facilities Council

The ISIS facility at RAL

ChipIR

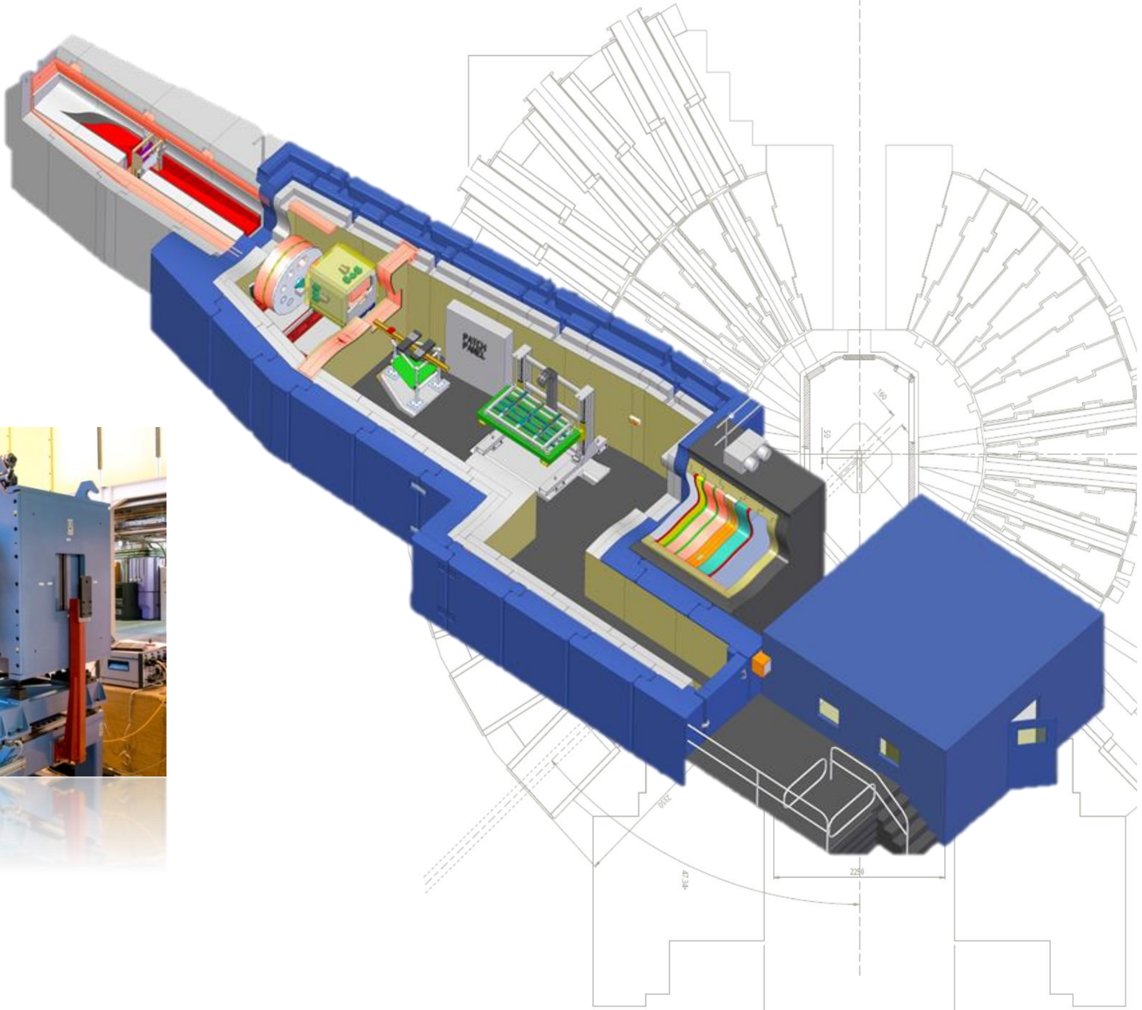


ChipIr Flux = 5.4×10^{6} n $cm^{-2}s^{-1}$



Science and Technology Facilities Council

Fast Neutron Beam



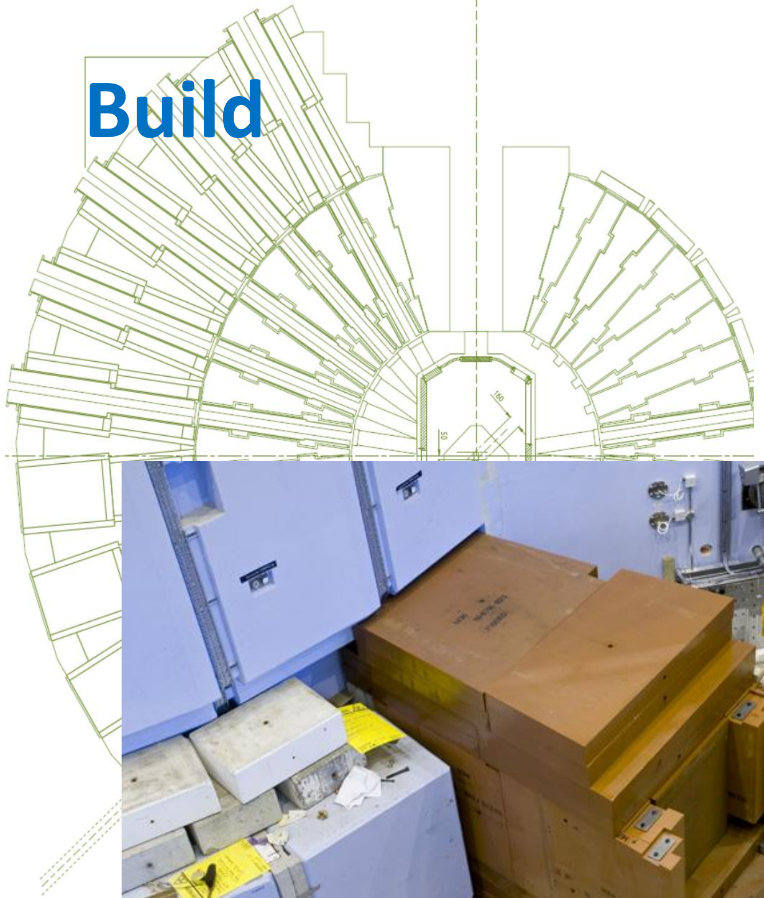
State-of-the-Art Instrument

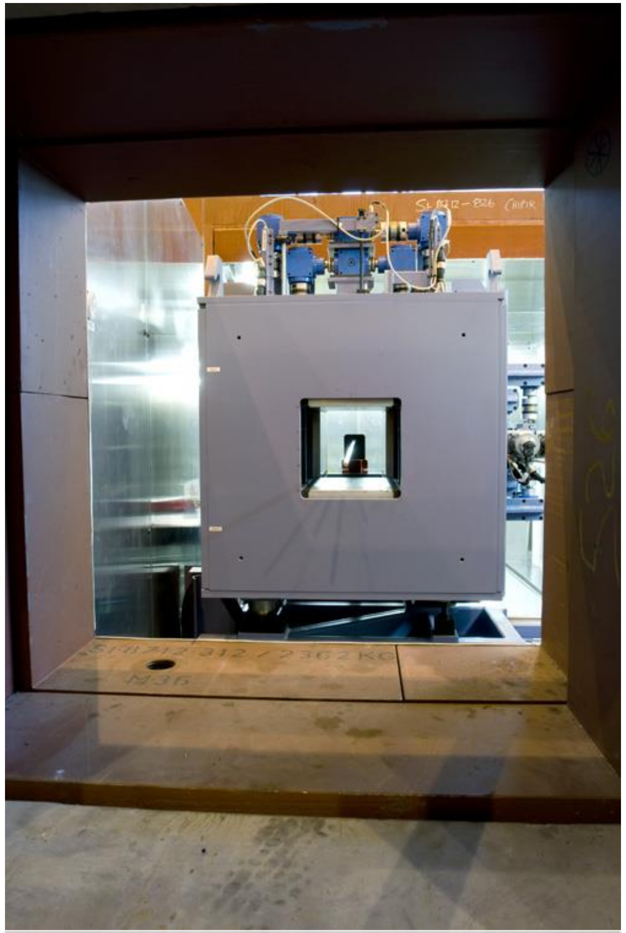
- Optimised flux and spectrum
- Collimators and filters
- Two irradiation position

Neutron measurements

- Flux and spectrum
- Profiles and maps
- Different configuration of the beamline (eg. 800 MeV and 700MeV)

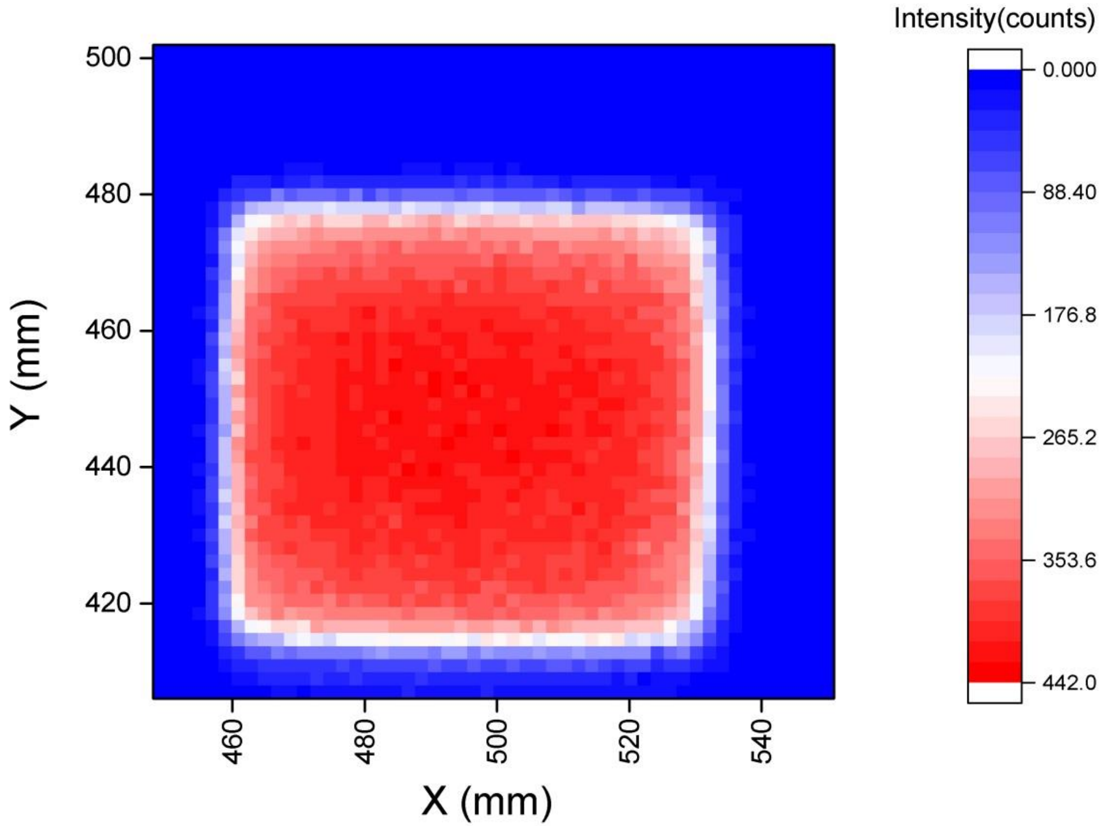
Build

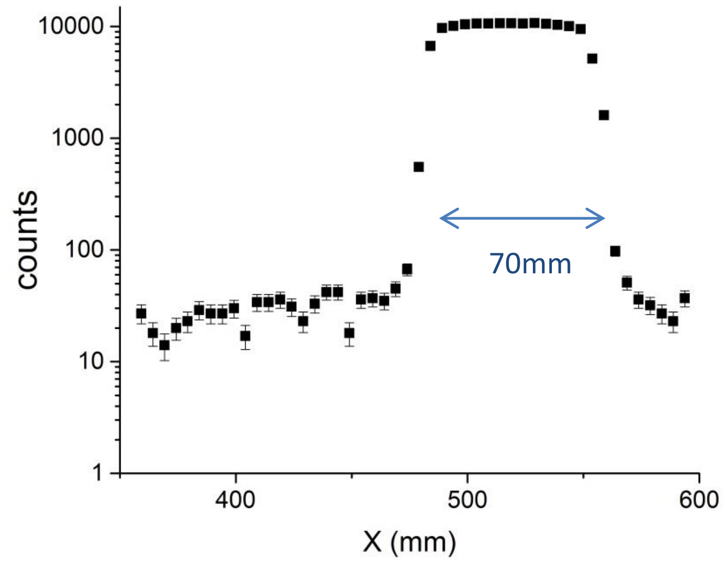


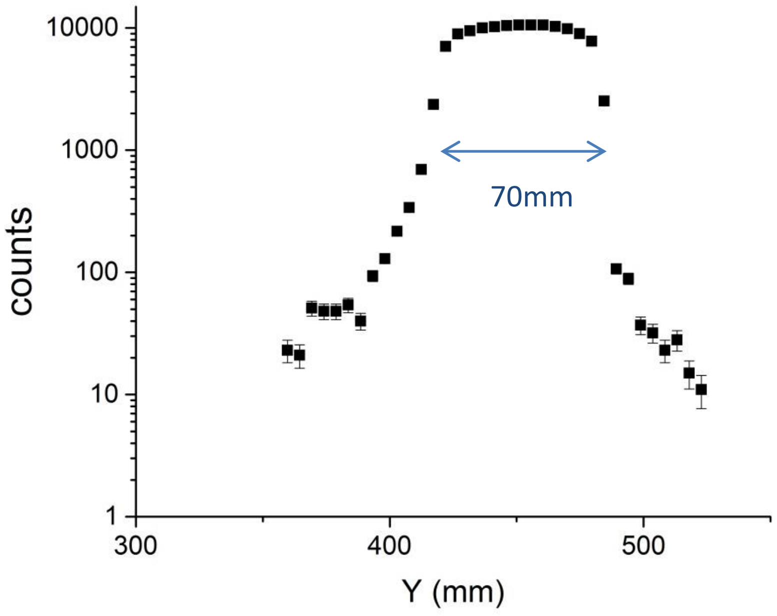


Build

Maps and Profiles of a 70 x 70 mm^2 beam

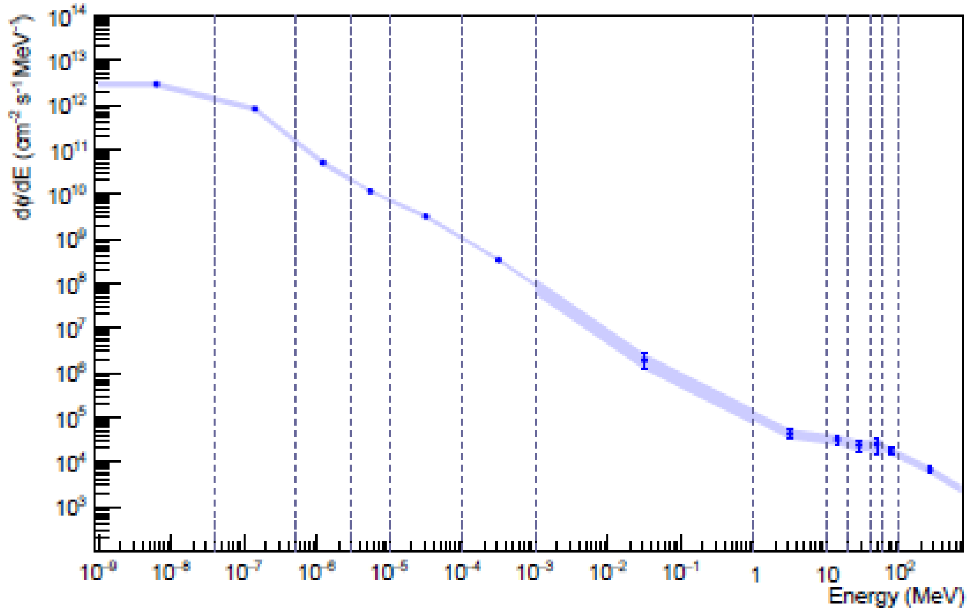


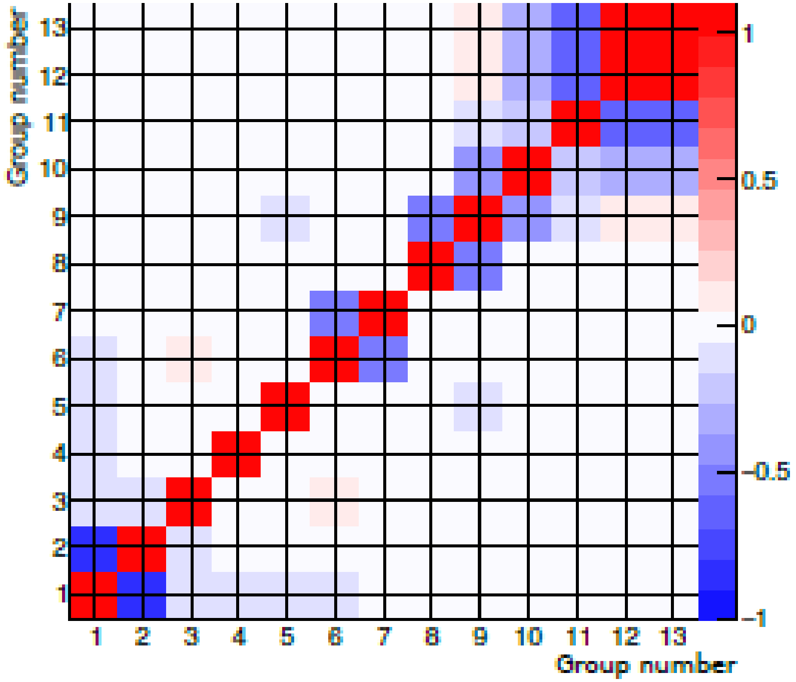


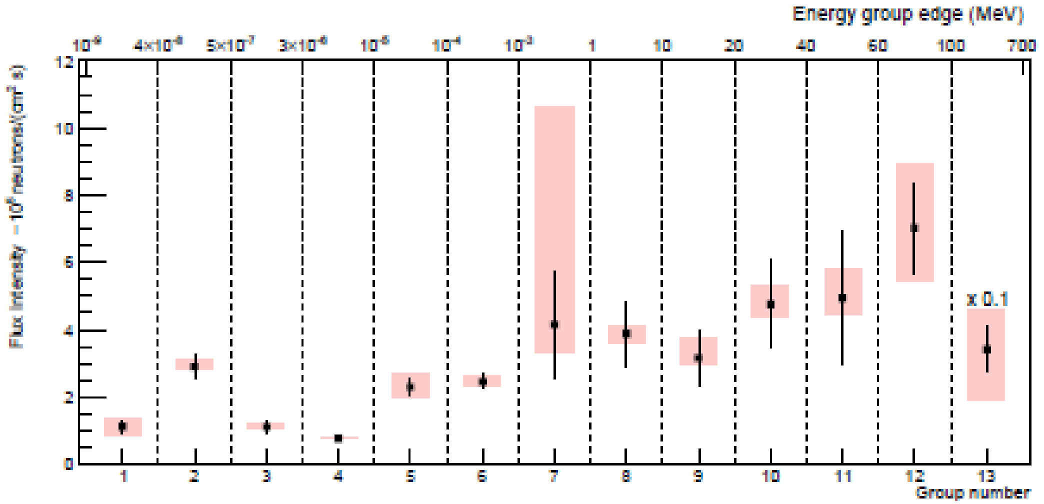


Map is measured with a diamond detector with 2 mm accuracy

Characterization of the spectrum with activation foils







Chiesa, Davide, et al. "Measurement of the neutron flux at spallation sources using multi-foil activation." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 902 (2018): 14-24.

Industry Standards

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

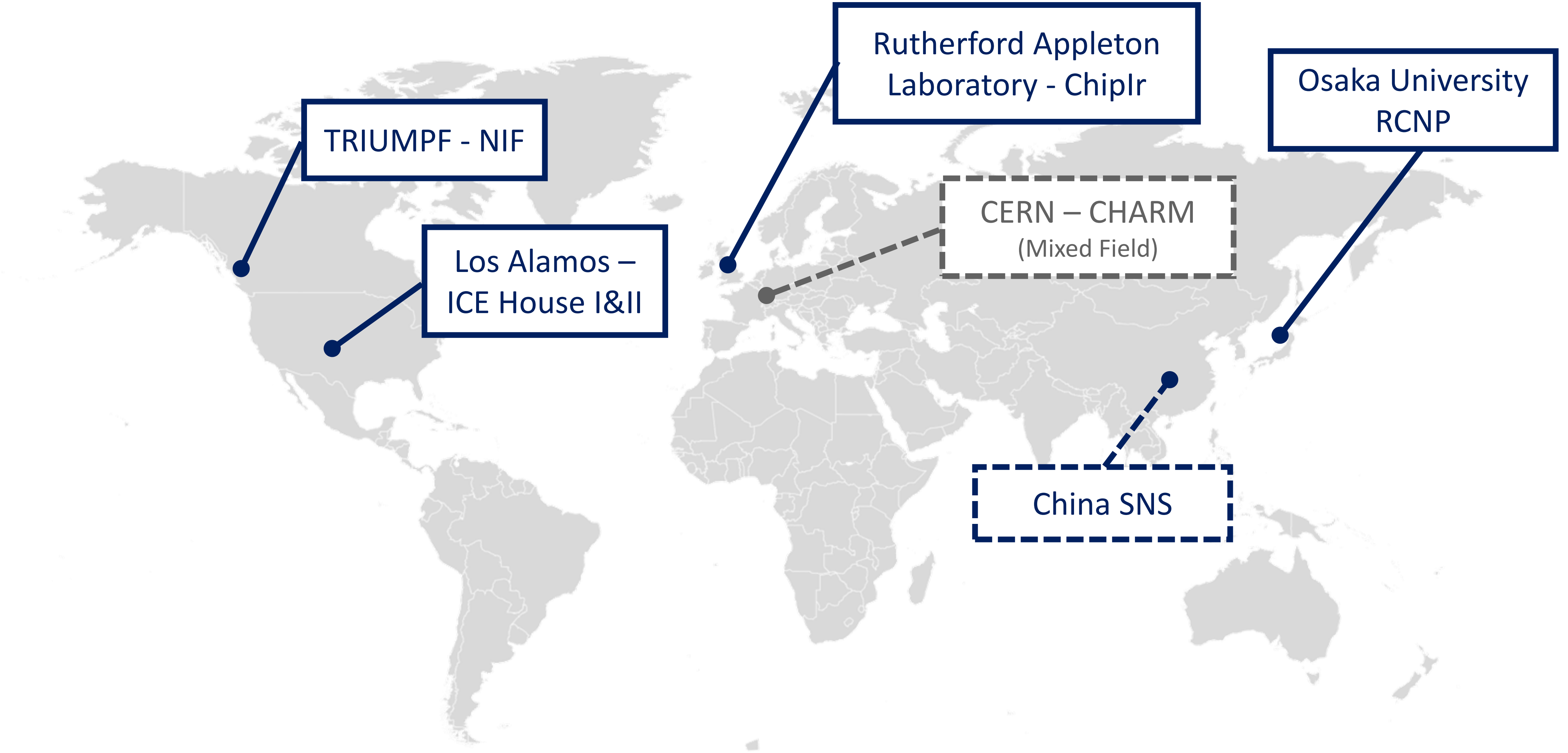
ChipIr now named in JESD89A and IEC TR 62396 latest standards

IEC TR 62396 - Process management for avionics Atmospheric radiation effects

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

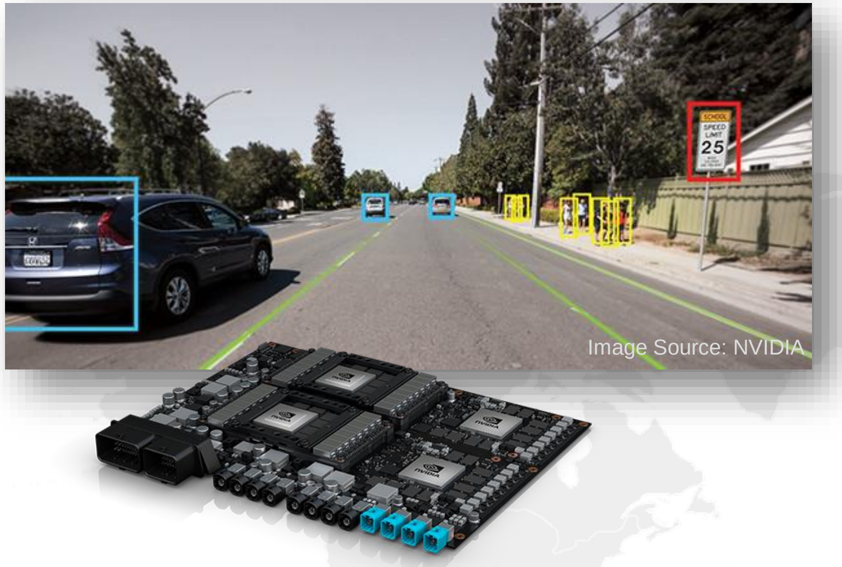
Science and Technology Facilities Council

SEE Testing Facilities – Across the World



Neutron Facilities: High Energy (>400MeV) & High Flux

Science and Technology Facilities Council



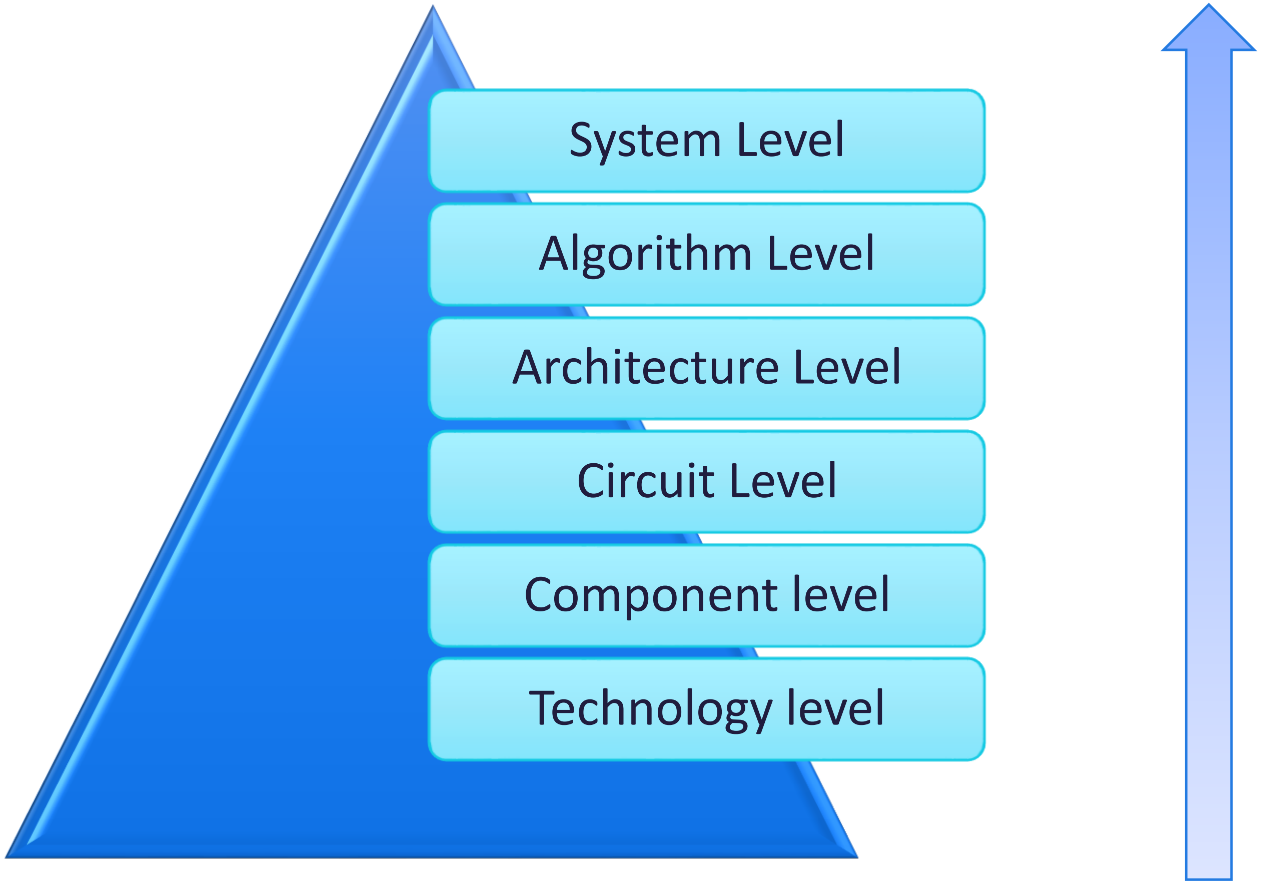
Major areas of current commercial research

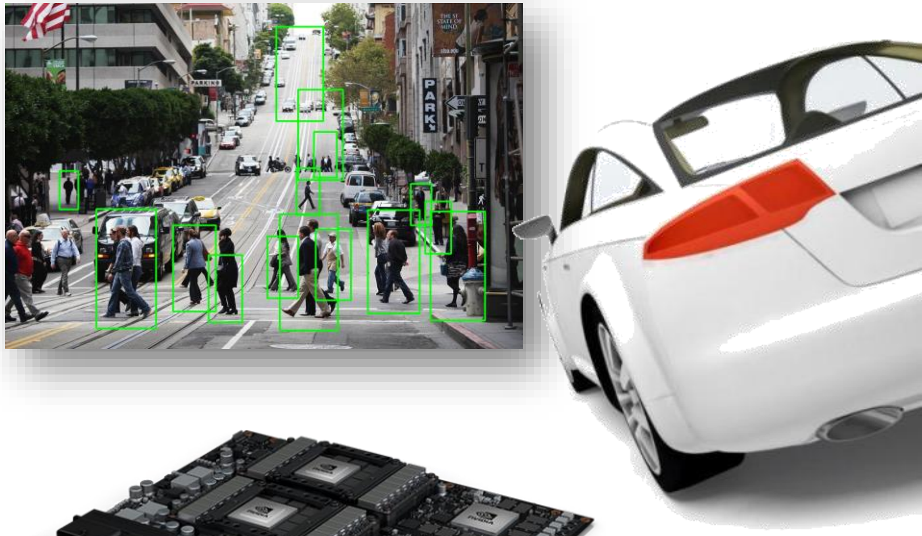
1. **Driverless cars** Autonomous systems
2. **Internet**: Device and system level for communication infrastructures
3. **High power devices** for renewable energy applications and automotive
4. **Aerospace** applications

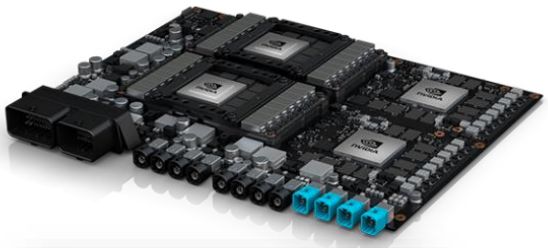
Science and Technology Facilities Council

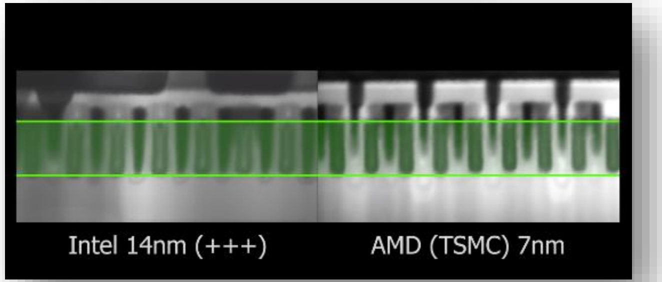
Error criticality across the stack

Goal: quantify and qualify









1. Understand "critical" errors
2. Identify "critical" errors causes
3. Design efficient hardening solutions

Science and Technology Facilities Council

Use of ChipIr for accelerator applications

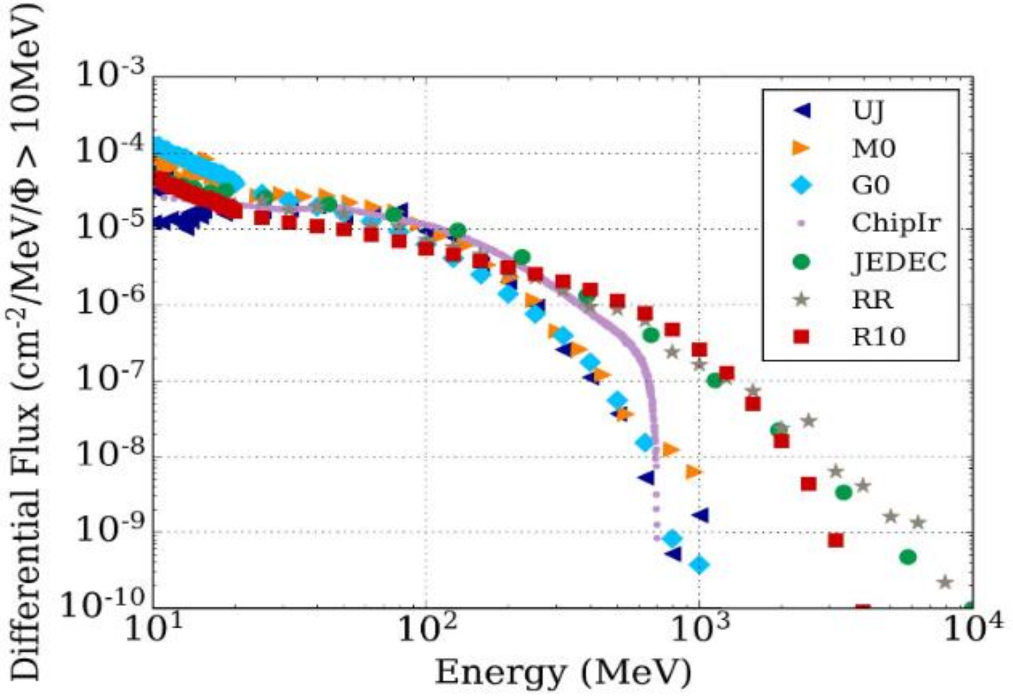


Fig. 5. Differential hadron flux of different spectra from ground level, accelerator, mixed field, and spallation environments. R10, RR, and G0 include neutrons, protons, and pions. Fluxes are normalized above 10 MeV to the JEDEC reference.

The approach of calibrating neutron environments through well-known Single Event Upset (SEU)-based SRAM memories is applied to a neutron spallation and mixed-field facility.

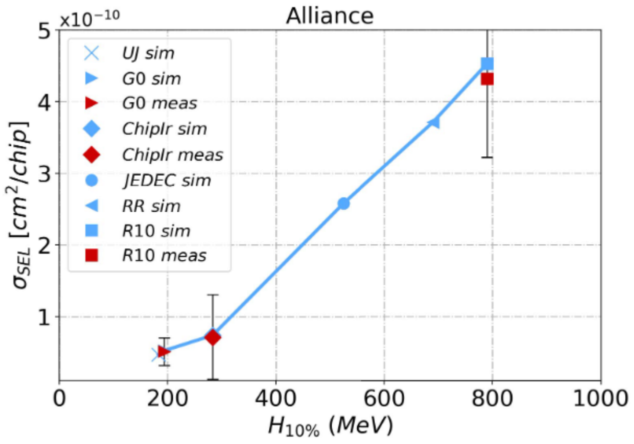


Fig. 9. Alliance SEL cross sections as a function of the hardness factor $H_{10\%}$ retrieved through the FLUKA model and measurements. UJ and G0 values are almost overlaid.

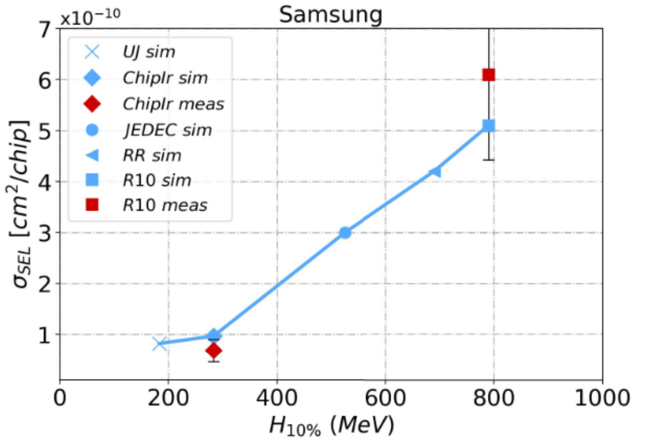


Fig. 10. Samsung SEL cross sections as a function of the hardness factor $H_{10\%}$ retrieved through the FLUKA model and measurements.

Thanks R2E group at CERN

Cecchetto, Matteo, et al. "SEE flux and spectral hardness calibration of neutron spallation and mixed-field facilities." *IEEE Transactions on Nuclear Science* 66.7 (2019): 1532-1540.

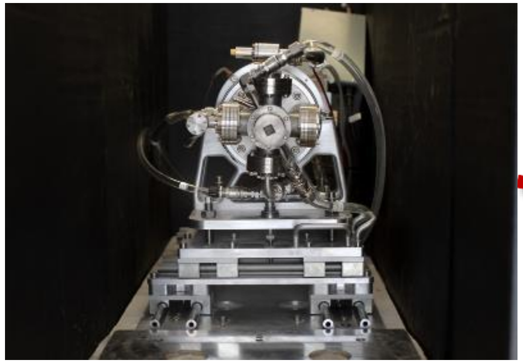
UKRI Science and Technology Facilities Council

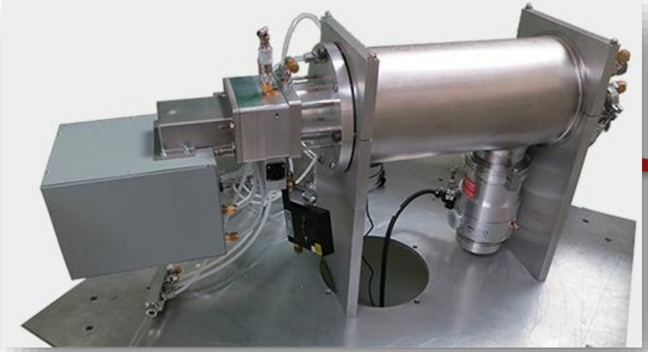
Neutron Test Facilities – Compact Sources

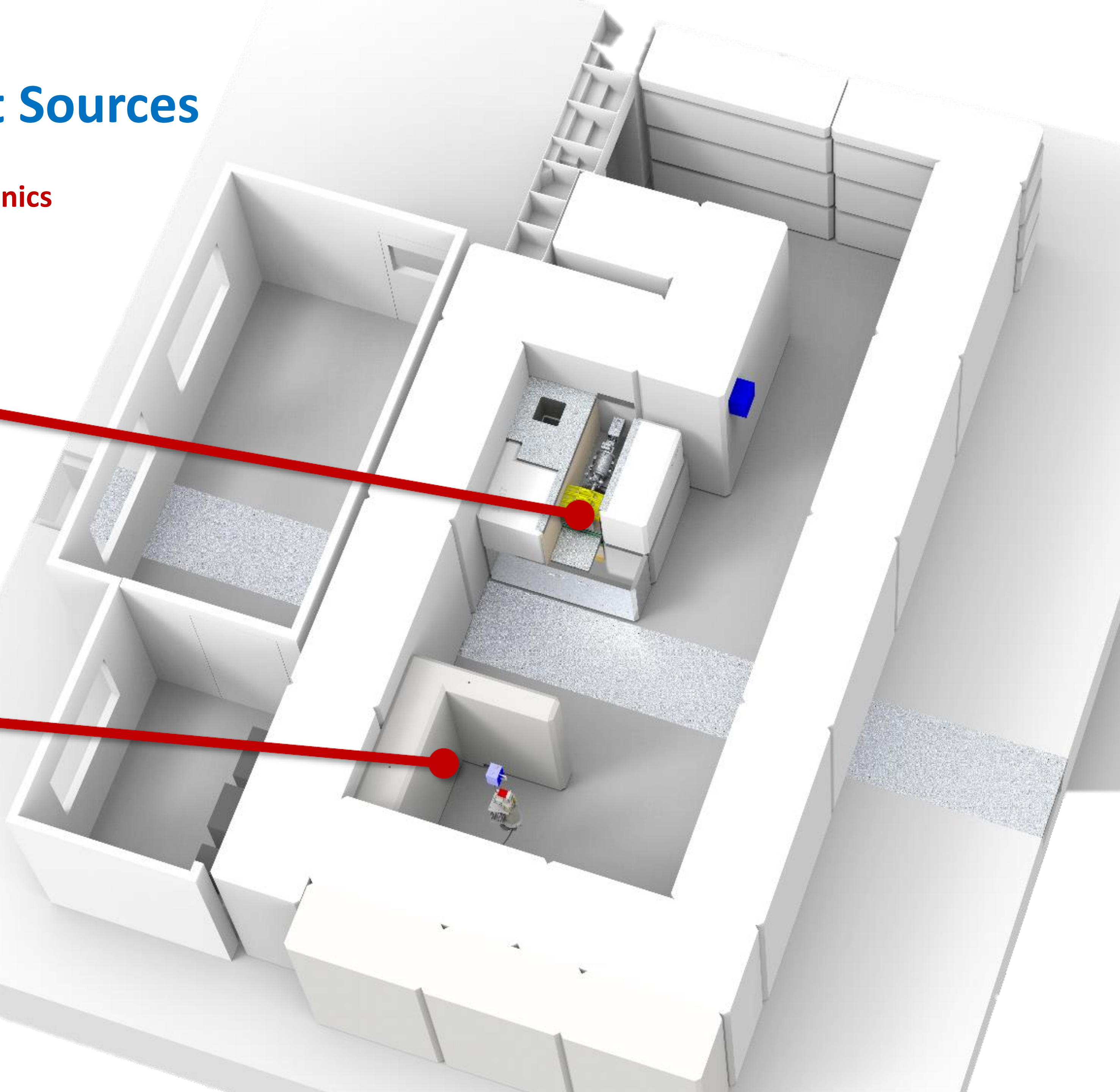
NEW Facility in 2021: NILE – Neutron Irradiation of Electronics

14 MeV D-T Source

Yield 10^{10} n/sec





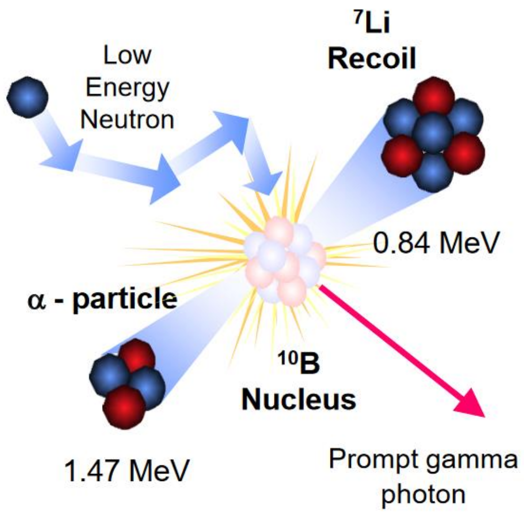


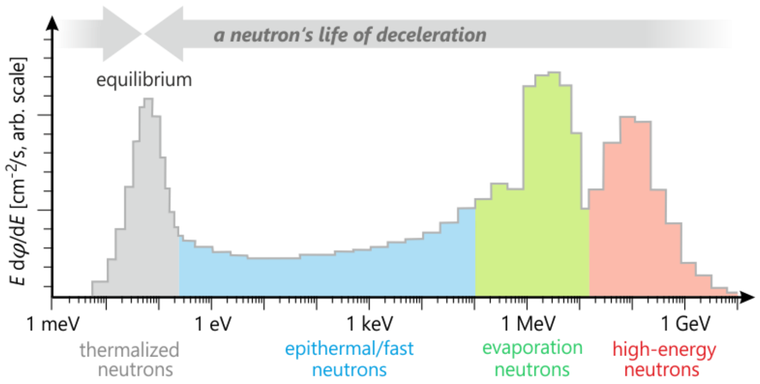
2.5 MeV D-D Source

Yield 10^{9} n/sec

Science and Technology Facilities Council

Testing electronics with thermal neutrons





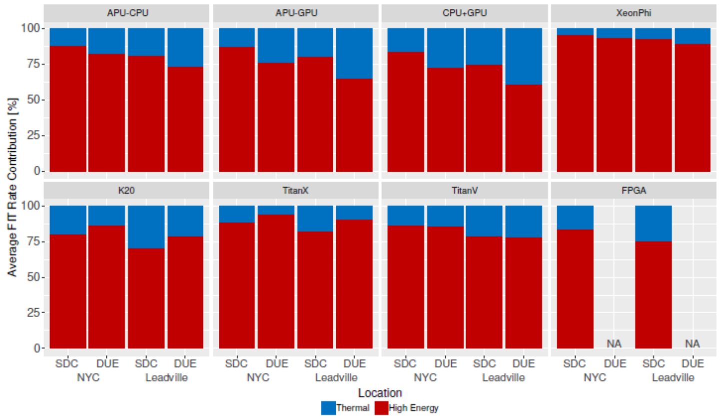


Fig. 5: Percentage of total FIT rate due to high energy and thermal neutrons. All tested parts except Xeon Phi show significant errors due to ^{10}B levels.

- 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.

Science and Technology Facilities Council

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**.

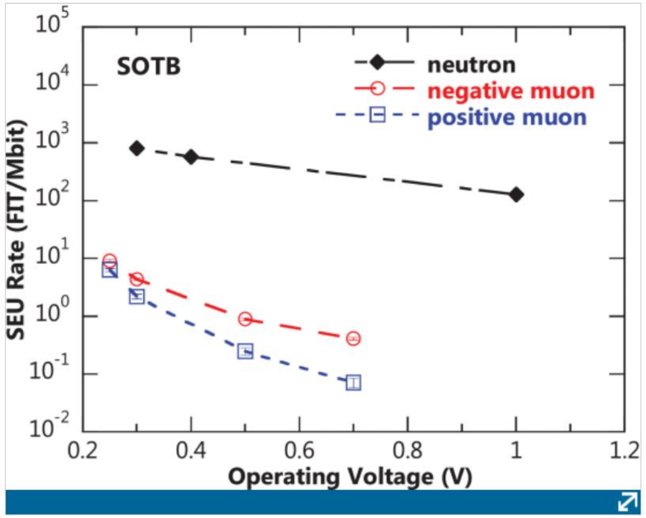
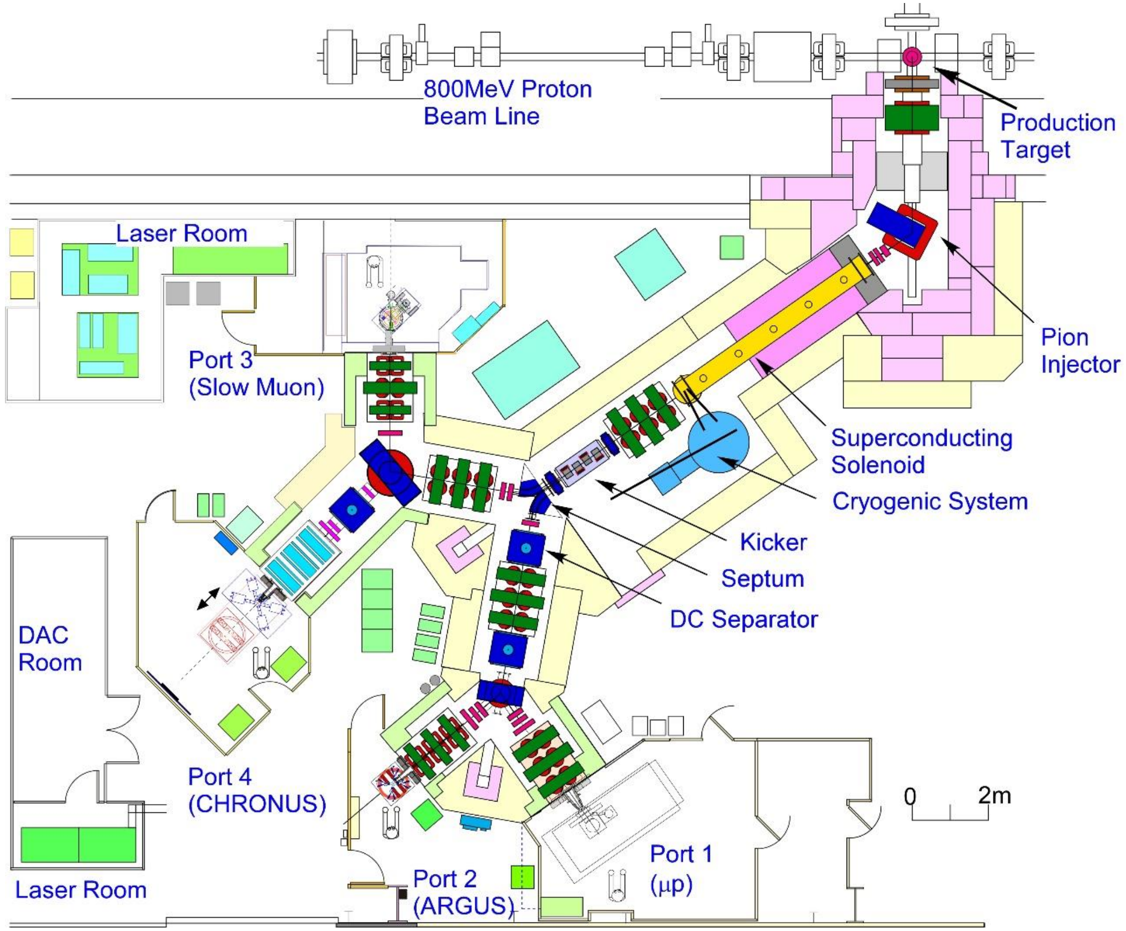


Fig. 5.
Ground-level SEU rate induced by cosmic-ray neutron, negative muon, and positive muon on the 65-nm SOTB SRAM.

Source: Manabe et al. 2019



RAL-RIKEN Muons up to 60 MeV/c

Science and Technology Facilities Council

Access to the facilities at RAL

Industrial Access

- Beam time is paid by industry
- Results are proprietary

Academic Access

- Two “direct access” calls per year + “rapid access”
- A proposal is evaluated through peer-review
- Beam time is awarded
- Results need to be published

Check the RADNEXT project for additional calls and transnational access funding
https://radnext.web.cern.ch/

Science and Technology Facilities Council

Thank You for your attention

Science and
Technology
Facilities Council