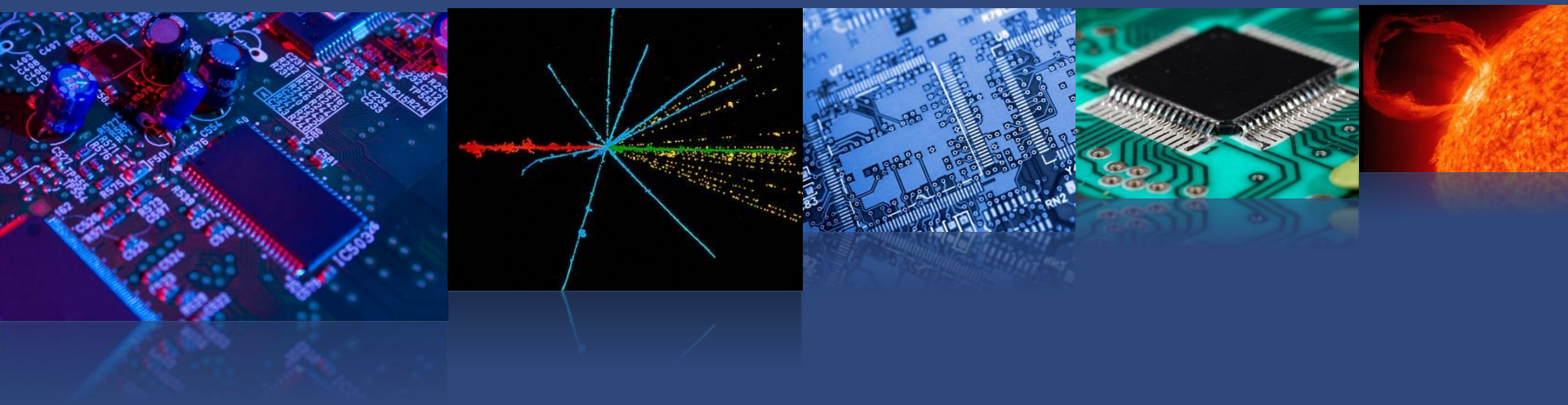
System level testing in ChipIr

An atmospheric-like neutron facility



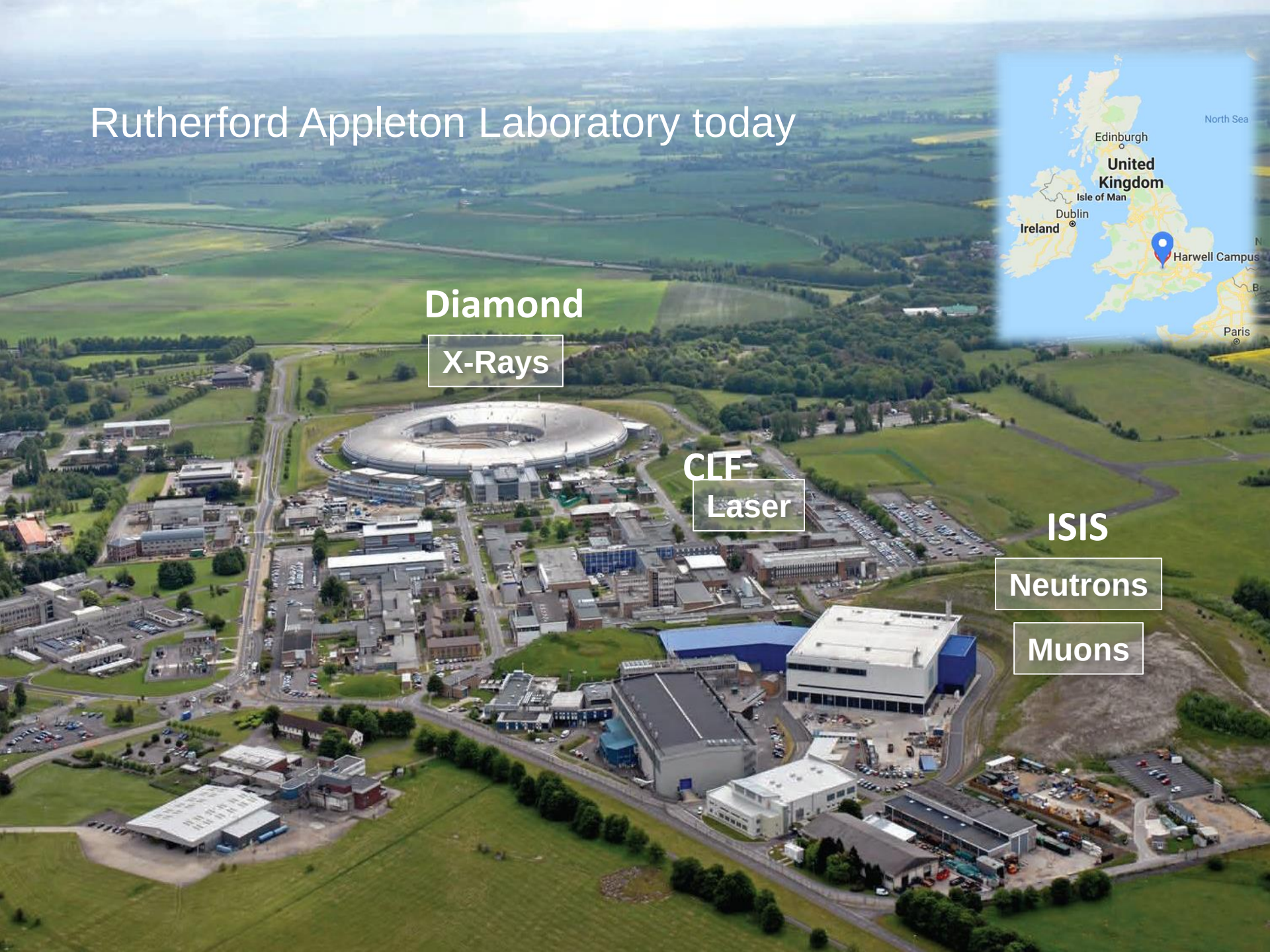
Carlo Cazzaniga

STFC, Rutherford Appleton Laboratory, UK

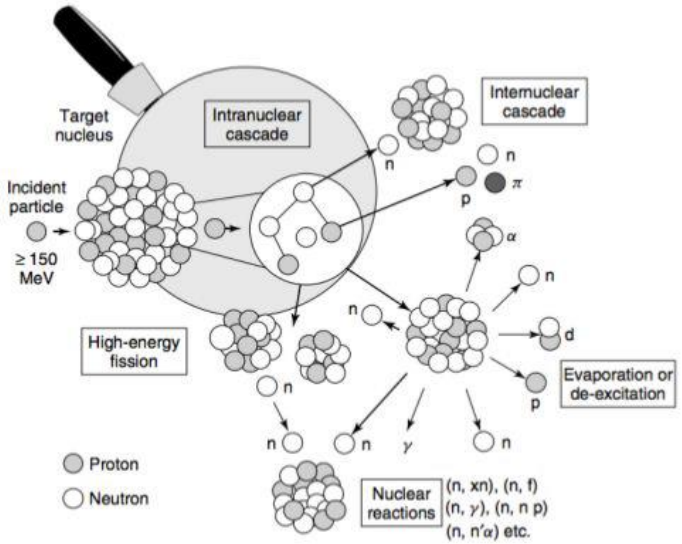
carlo.cazzaniga@stfc.ac.uk

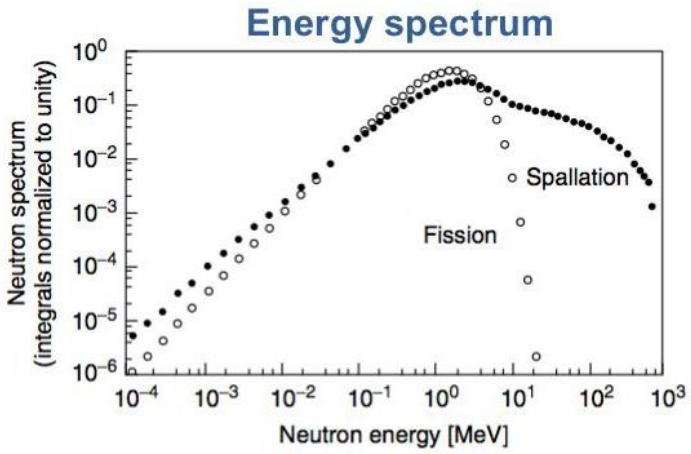
Contribution for the RADSAGA WP3/WP4 review, 12 Nov 2019

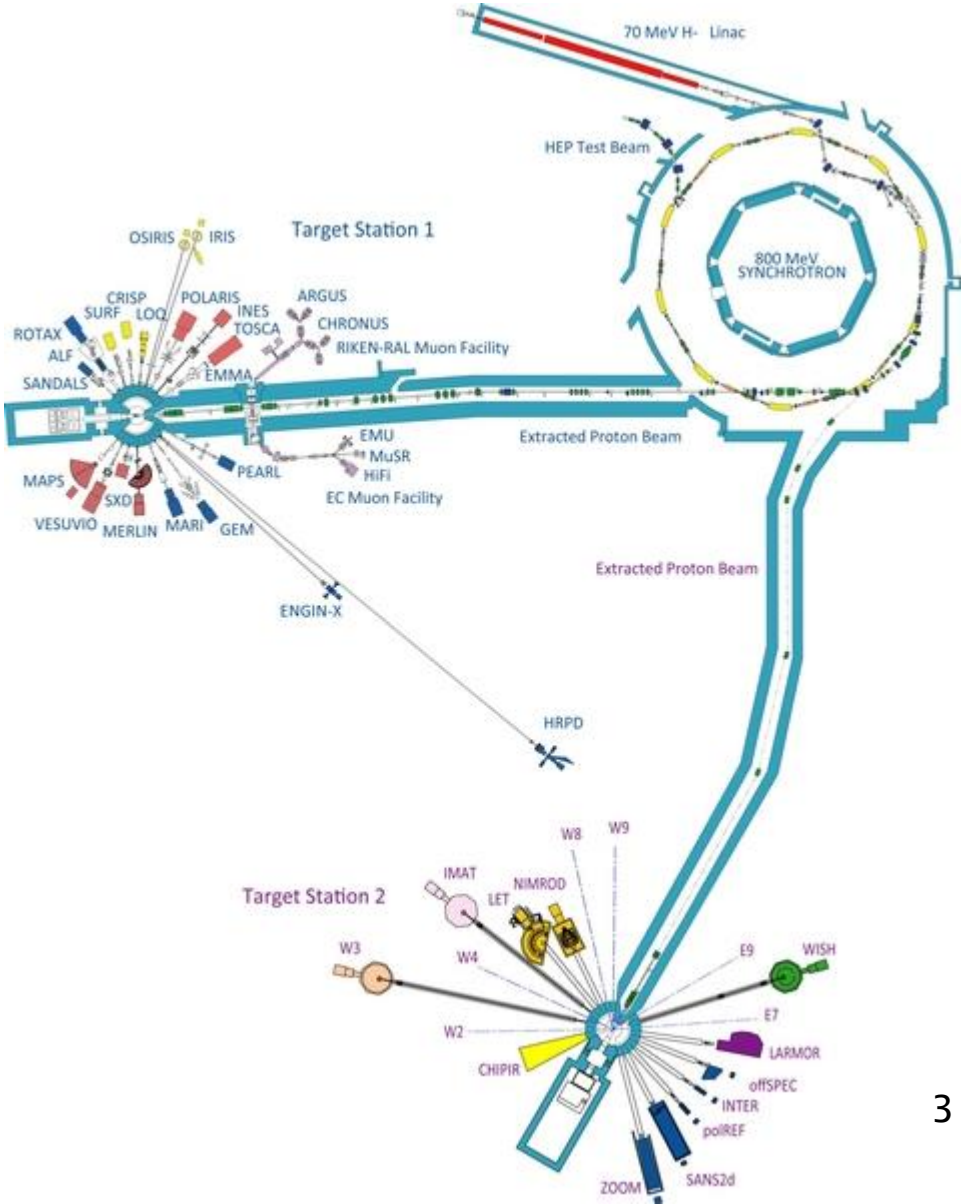
Rutherford Appleton Laboratory today



The spallation neutron source at RAL

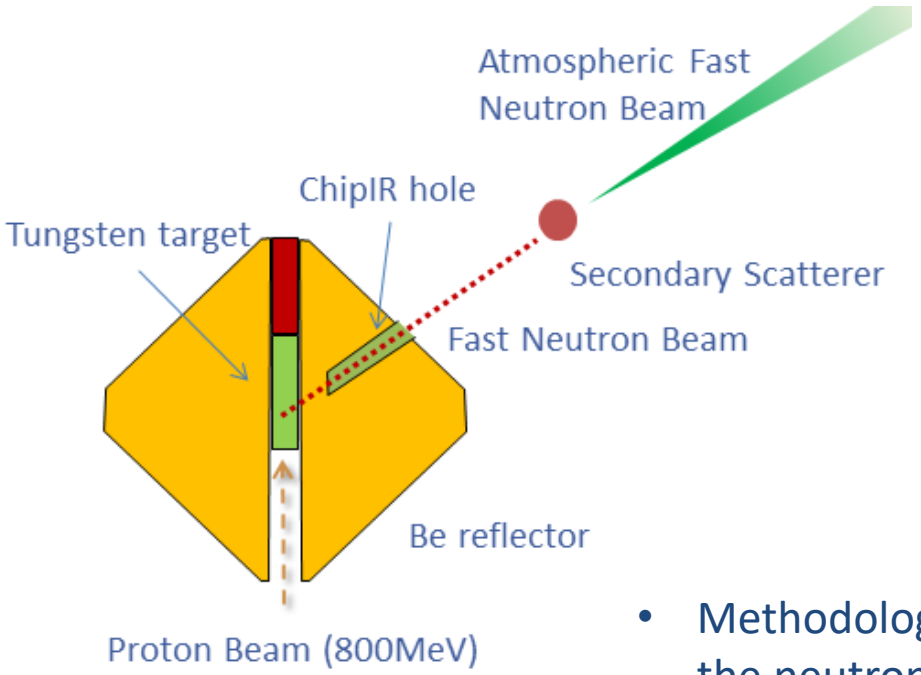


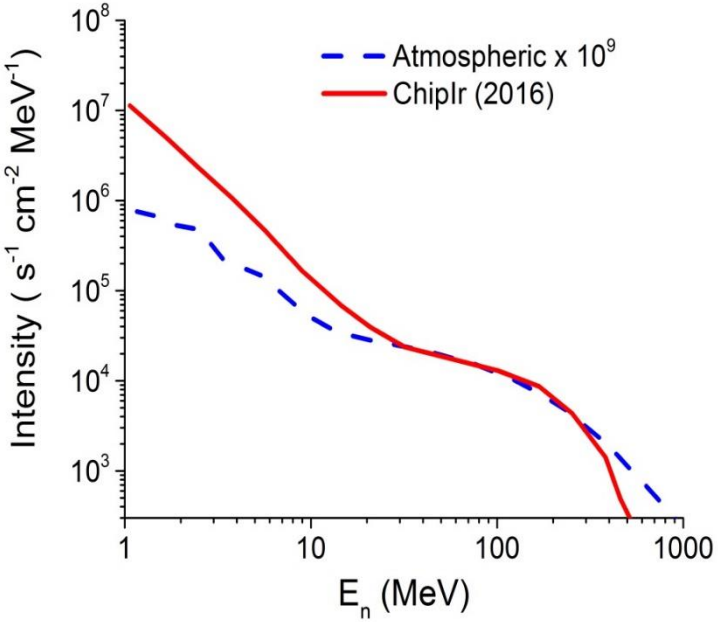




Reproducing the atmospheric neutron spectrum

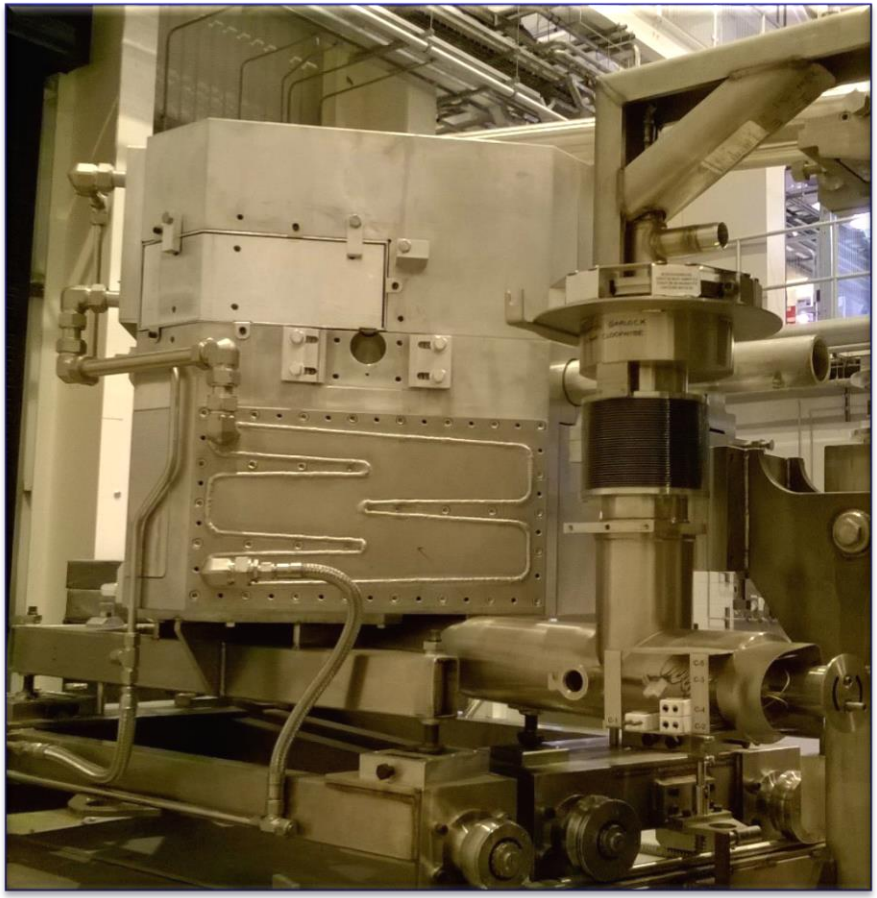
Fast neutron transport Optimized on the basis of Monte Carlo calculations





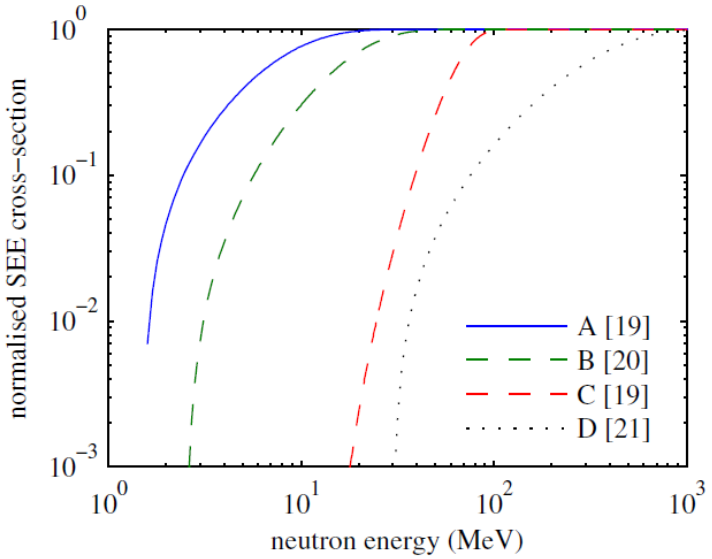
- Methodology of testing: scaling the error rate with the neutron flux above 10 MeV, as specified in the JEDEC standard
- ChipIr flux is $5 \cdot 10^6$ n/cm^{2}s, that is about 10^9 times more intense than the atmospheric one at ground level

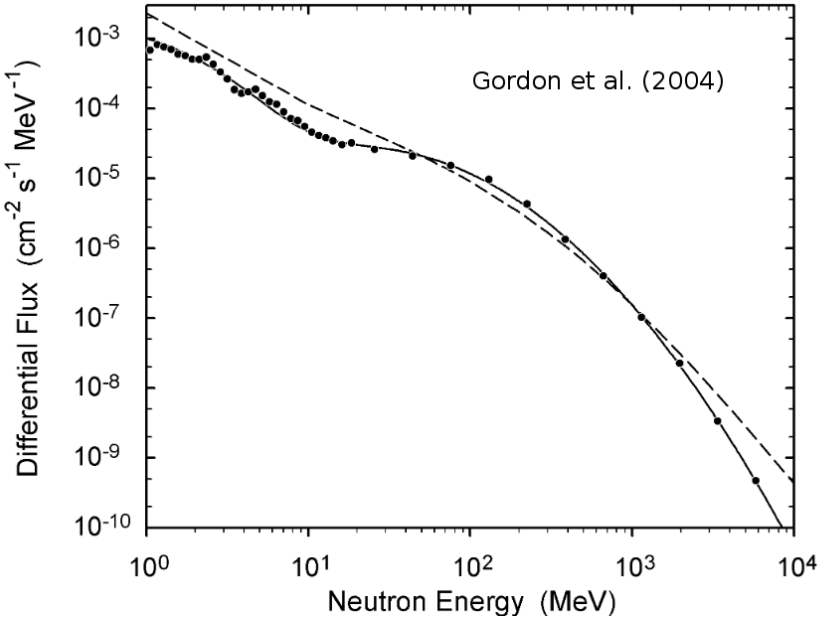
The Target



Spectrum, why is it important?

SELECTED SEE CROSS-SECTION FUNCTIONS



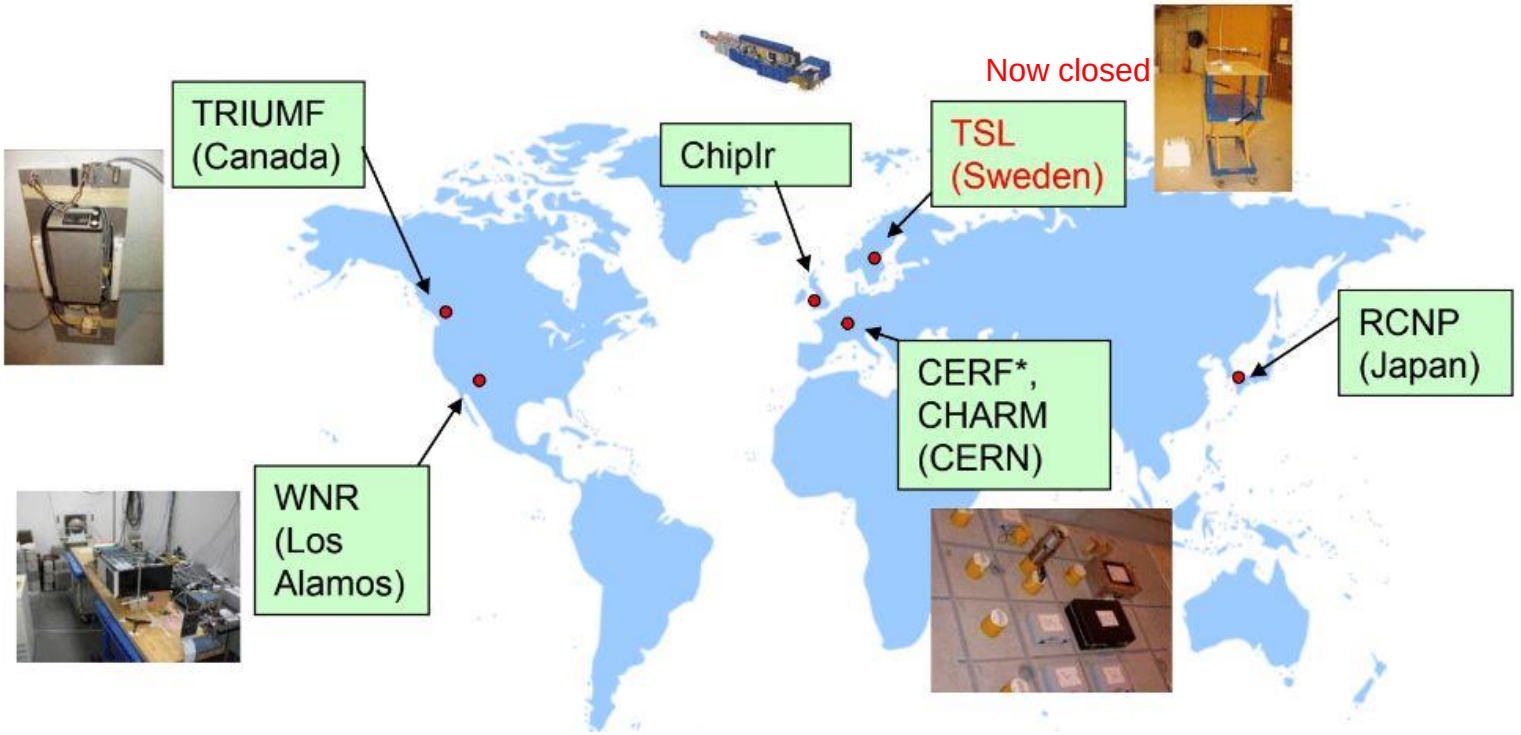


Neutron Spectrum

$$SER = \int \sigma_{SEE}(E) \left(\frac{d\phi(E)}{dE} \right) dE$$

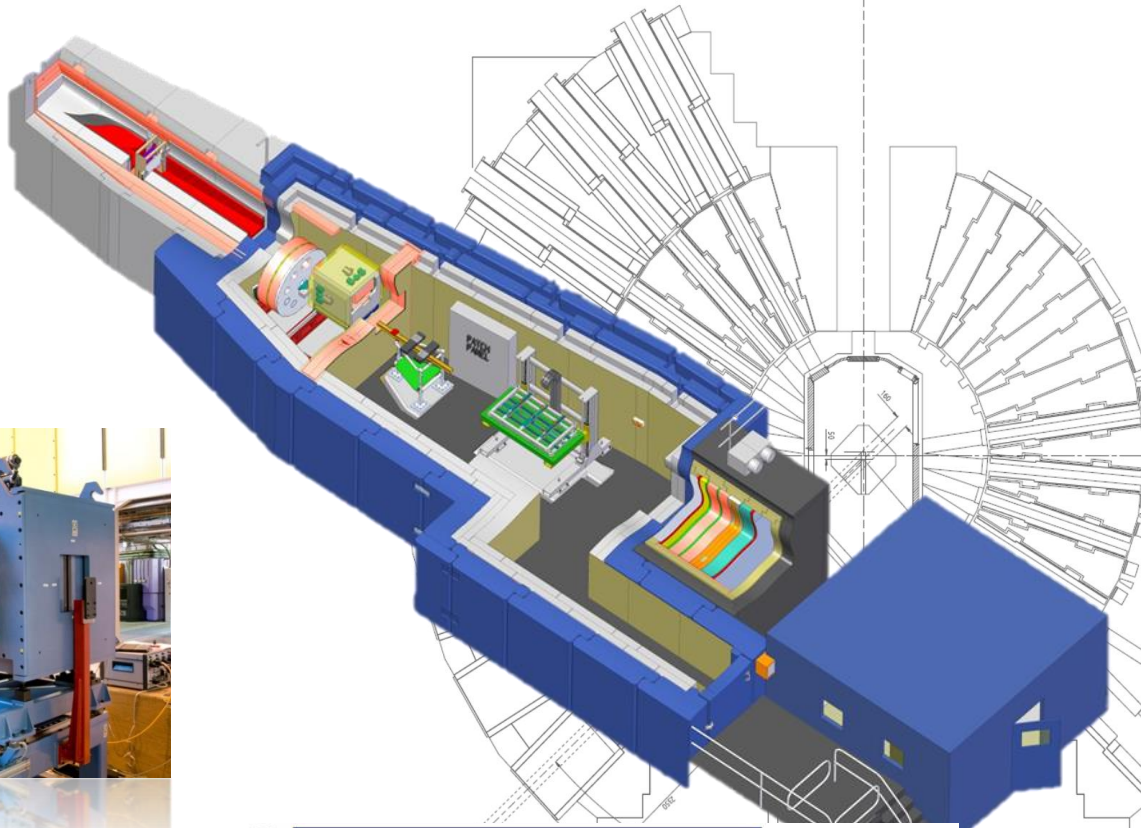
Atmospheric neutrons facilities

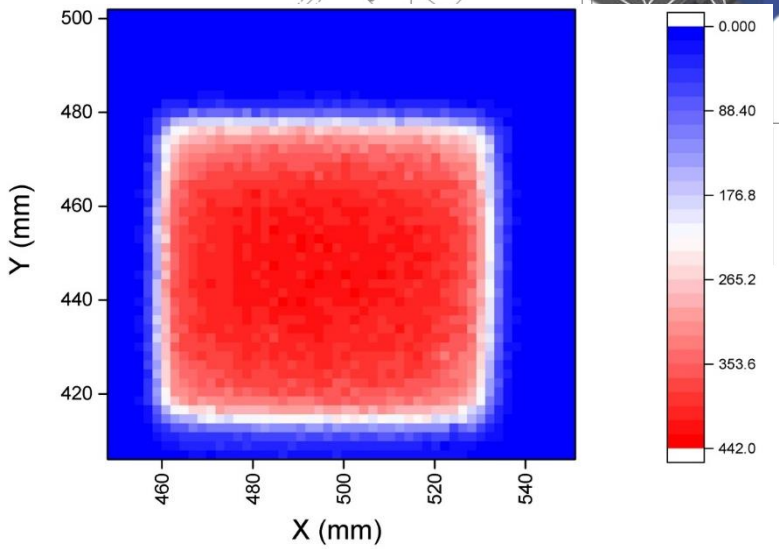
- Few appropriate facilities worldwide:



- Chinese Spallation source: in construction.
- SNS: proposed.

Fast Neutron Beam

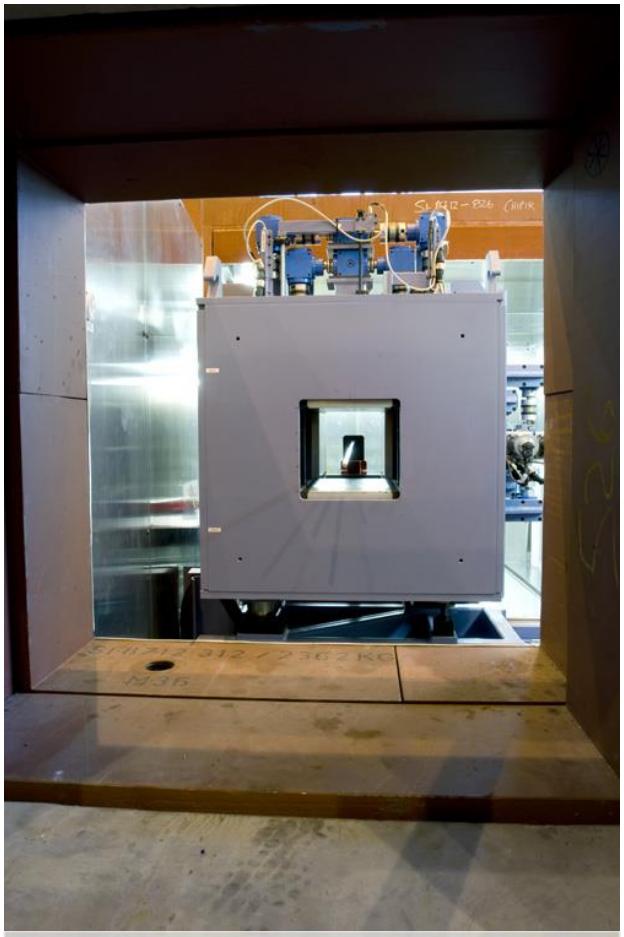




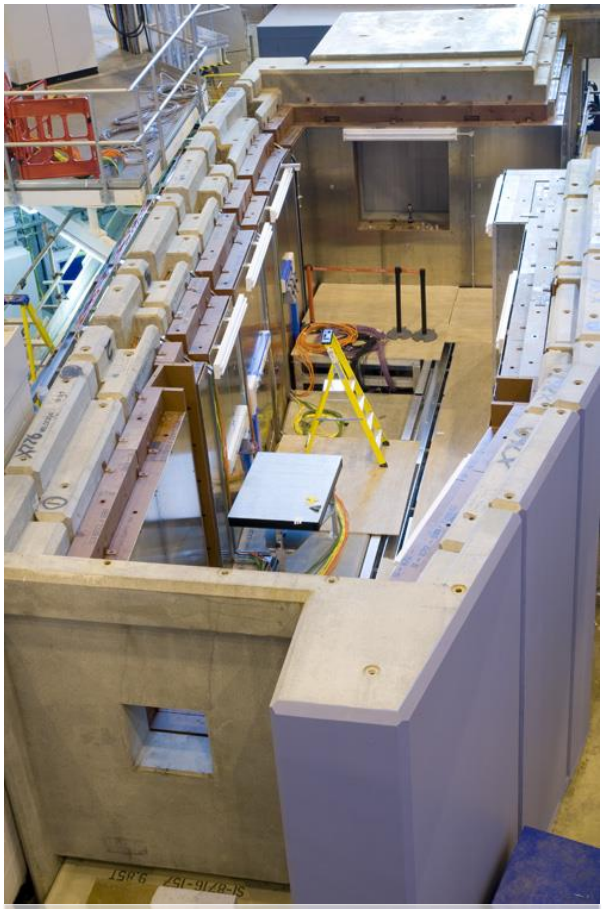
State-of-the-Art Instrument

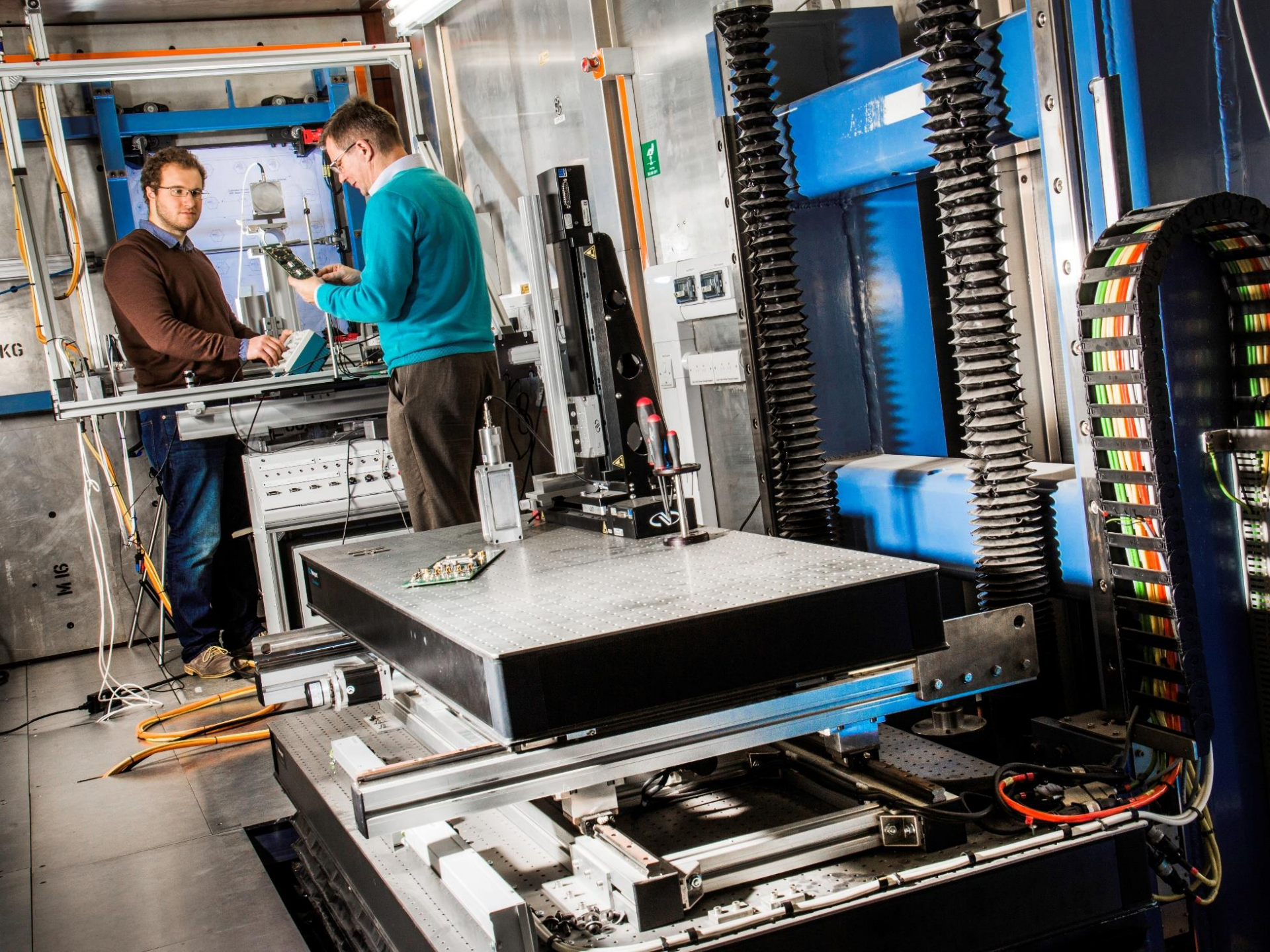
- Optimised flux and spectrum
- Collimators and filters
  - Sizes from few cm^2 to 40x40 cm^2
- Two irradiation position

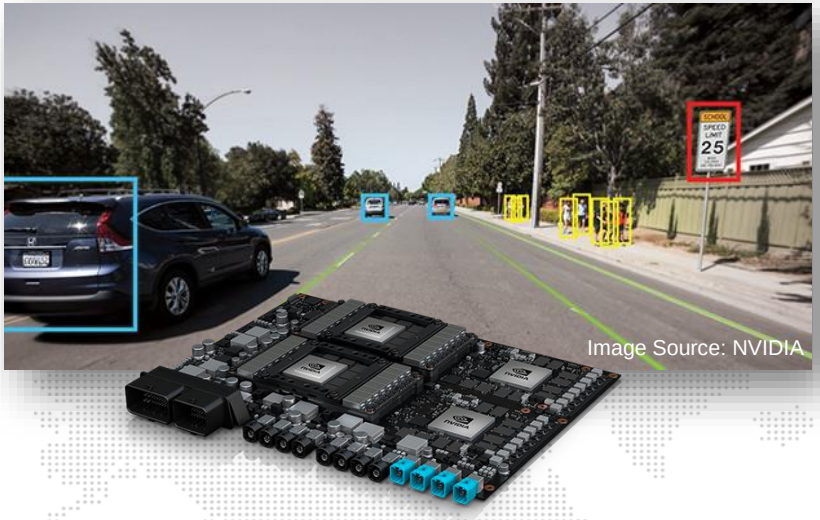
Build



Build



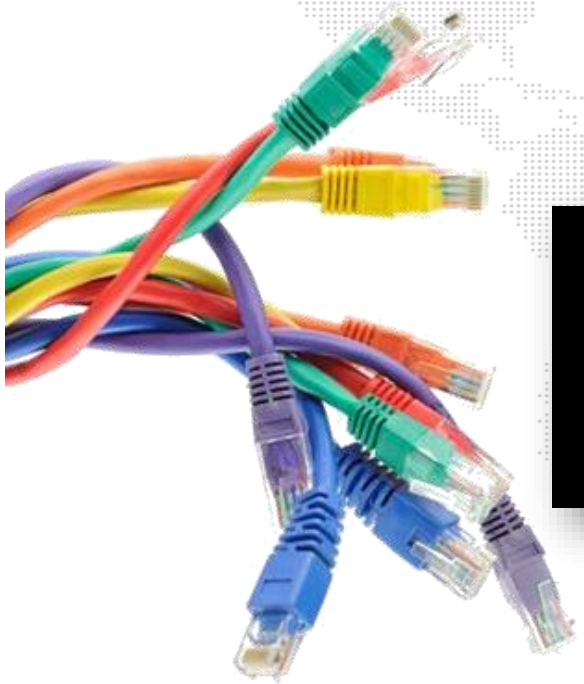




Major areas of current commercial research:-

System Level

- Systems for autonomous **‘driverless’ cars (automation).**
- **Internet** and communication infrastructures
- **Aerospace & space** applications



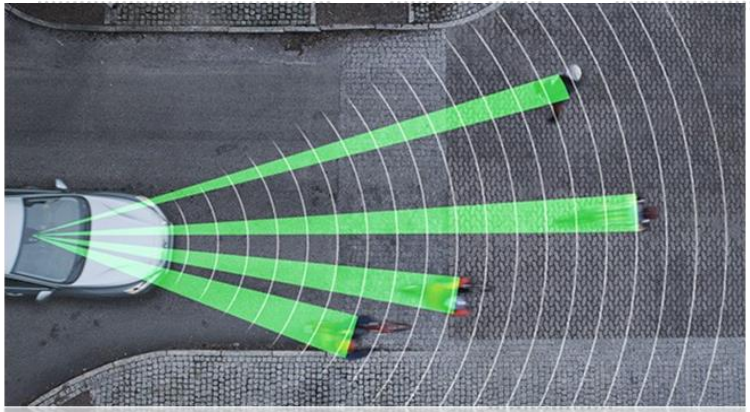
Air flight Experience of SEE

- **Cosmic Radiation Effects & Activation Monitor** flown on Concorde between **1988 & 1992**, and on SAS in **1993**.
- 5 solar particle increases seen.
- PERFORM computer withdrawn for tests in 1991 following accumulation of errors in SRAM memory.
- More than one upset per flight in 280 64K SRAMs on Boeing E-3 AWACS and NASA ER-2.
- Autopilot design altered after faults (every 200 flight hours) shown to correlate with altitude and latitude.
- Saab CUTE experiment in 1996 showed upset every 200 flight hours in 4 Mbit SRAM. 2% are multiple-bit upsets.
- At least 3 major equipments with latch-up problem (including burn out)- probable cause of an emergency landing due to smoke in cockpit.
- Possibly implicated in **QF72 accident in October 2008** when aircraft twice dropped several hundred feet.

Automotive

Driverless Cars: Highly complex systems being deploy in automotive sector

Underpinning technologies known to have susceptibility to neutrons



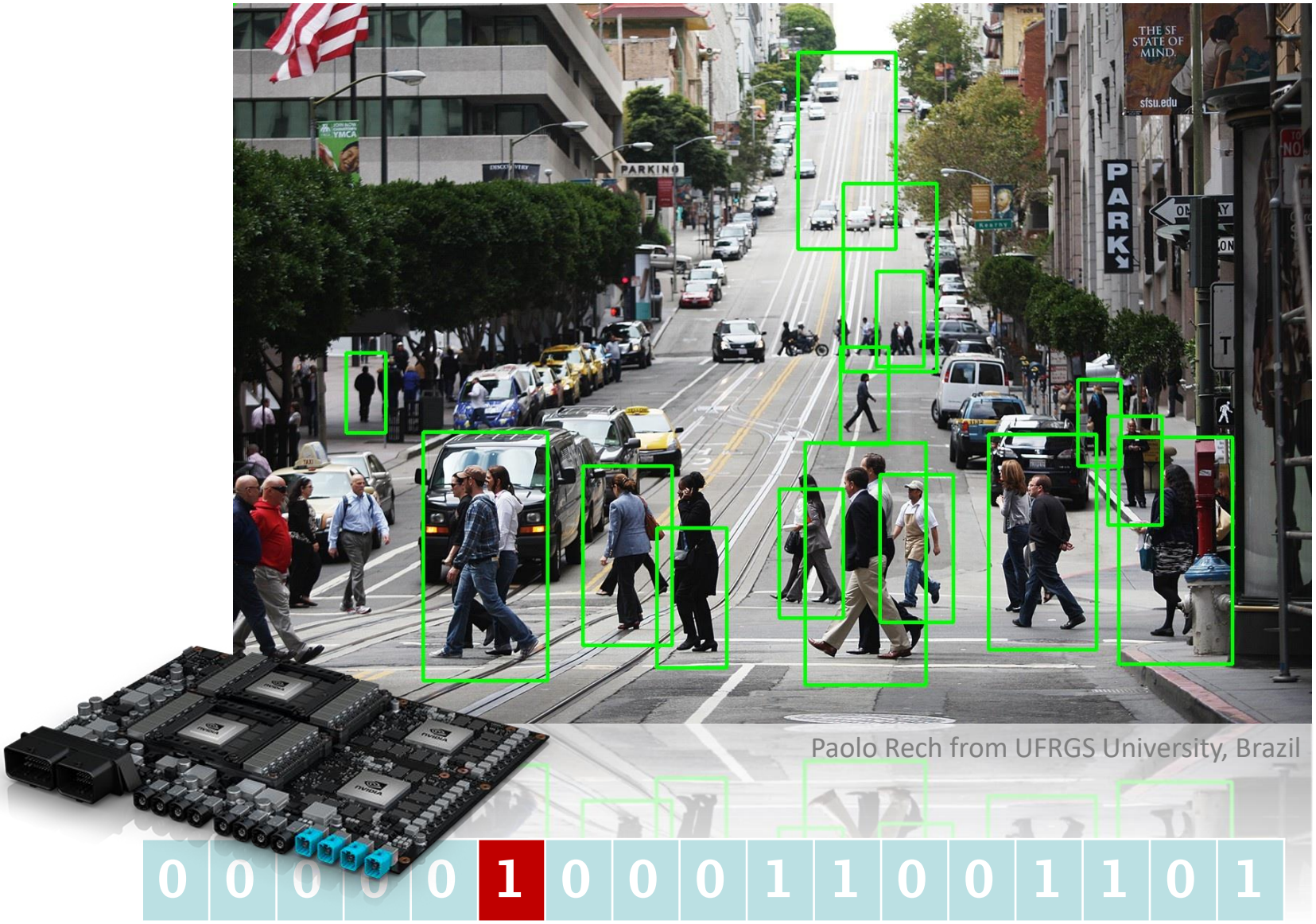
Future of Mobility

ISO26262 - Automotive Safety Integrity (ASIL) level D

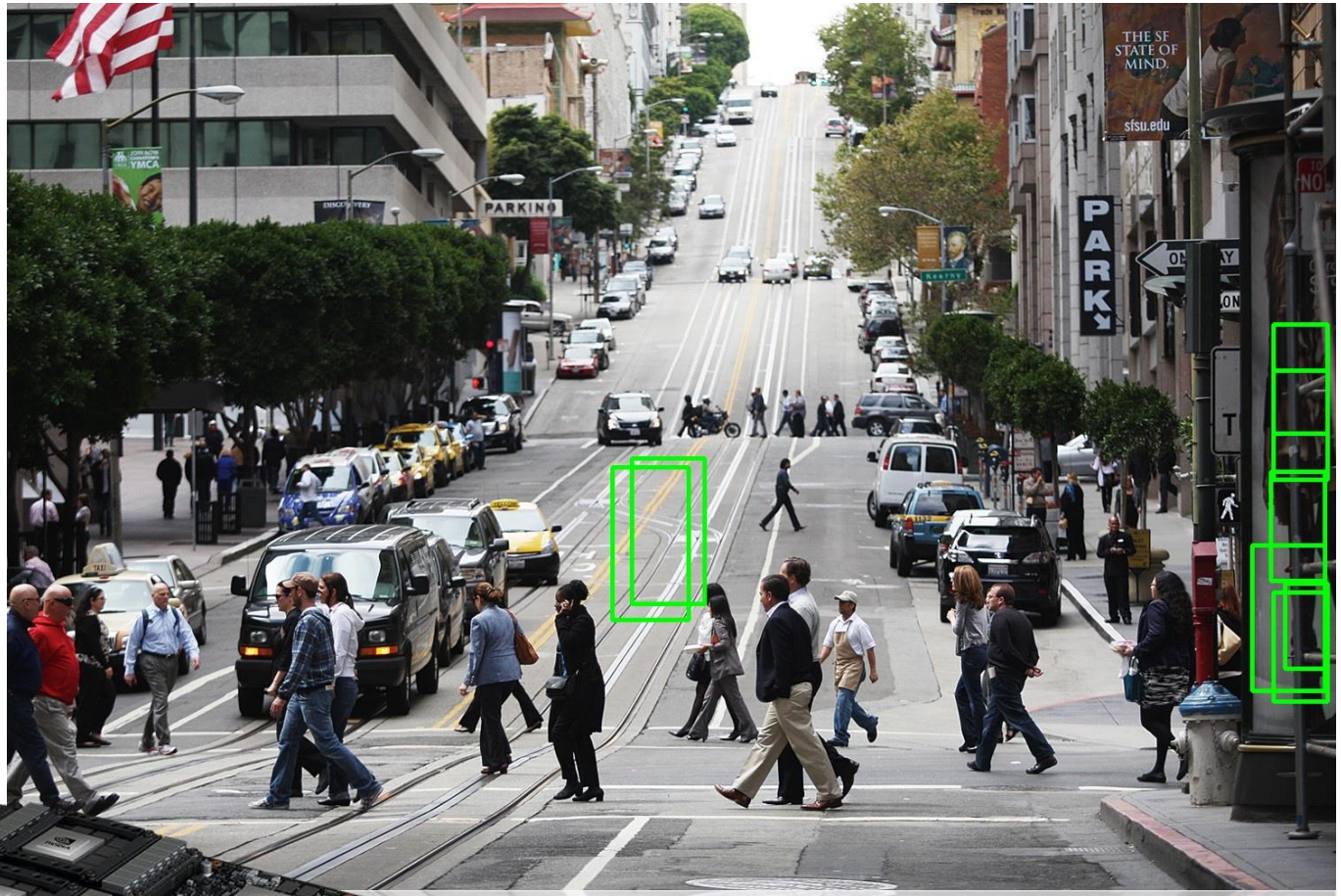
1 – Detect 99% of faults

2 – Error rate < 10 FIT (10 errors in 10^9h of operation)

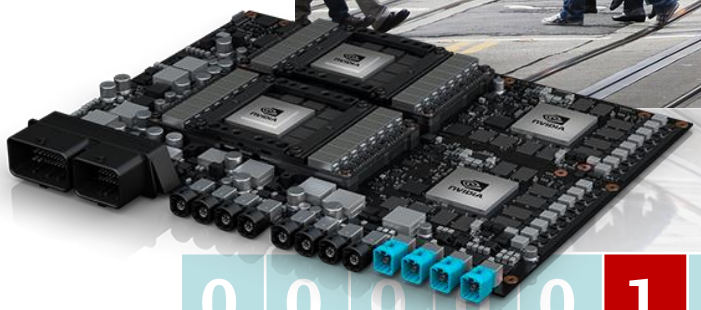
human driver error rate:
28,582 FIT!



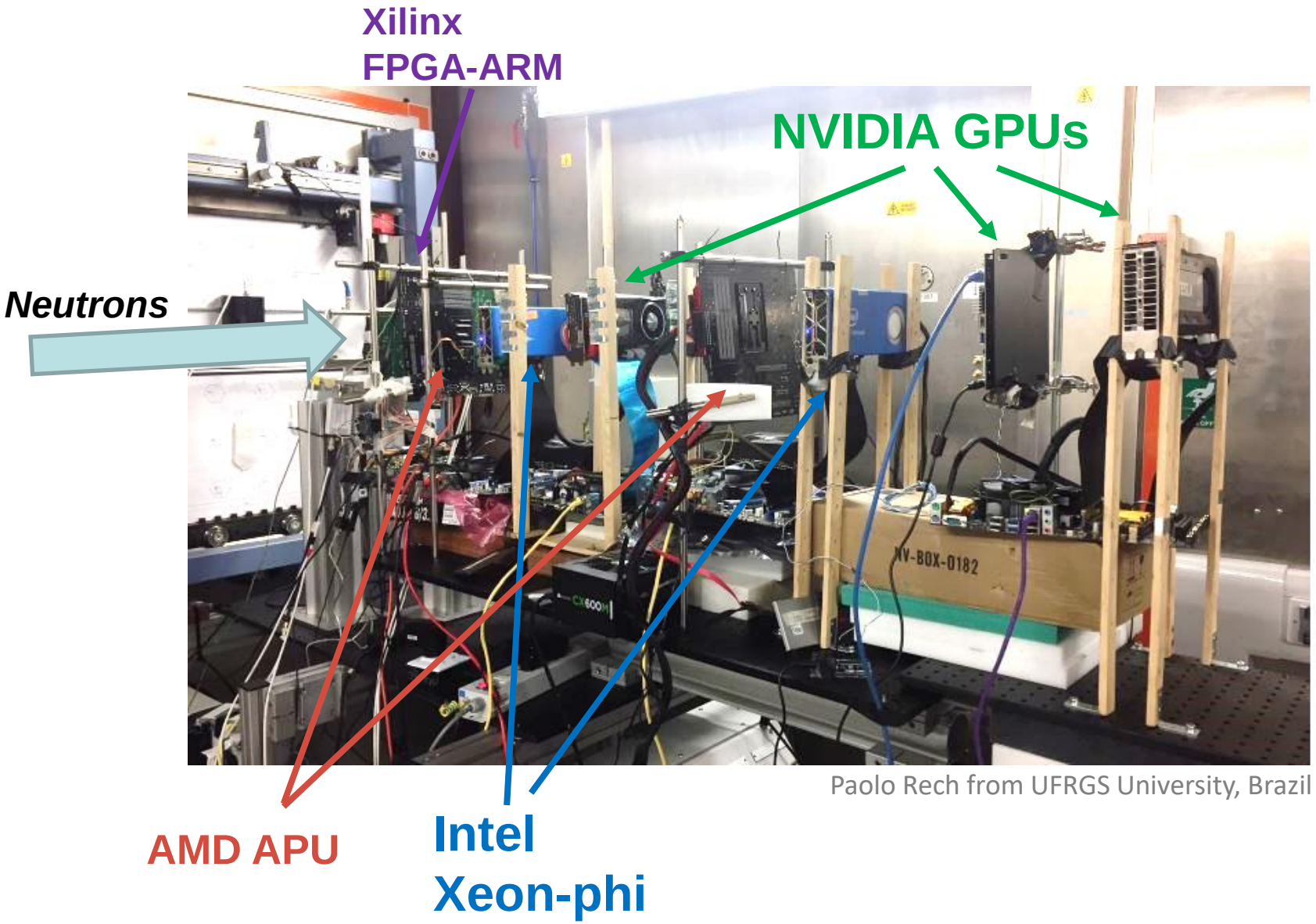
Paolo Rech from UFRGS University, Brazil



Paolo Rech from UFRGS University, Brazil



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



Paolo Rech from UFRGS University, Brazil

Fast neutron penetration

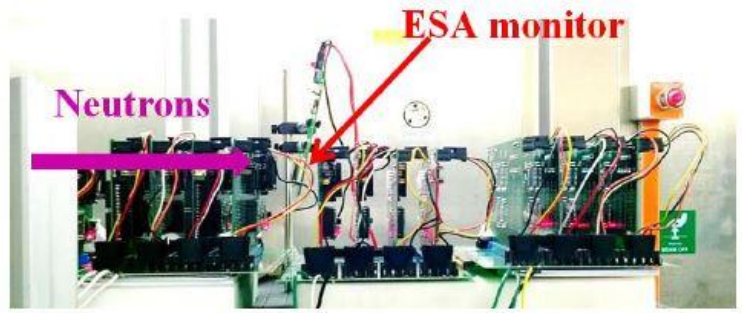
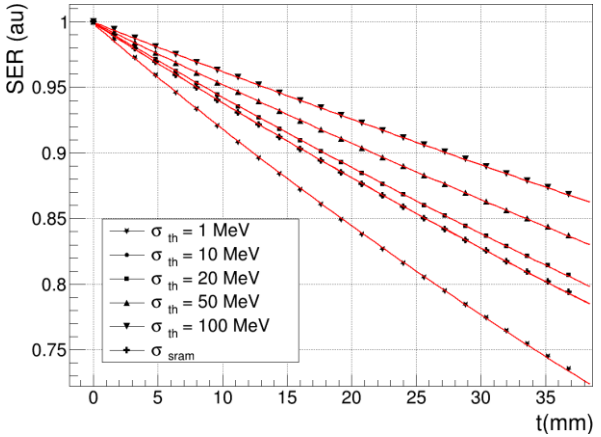
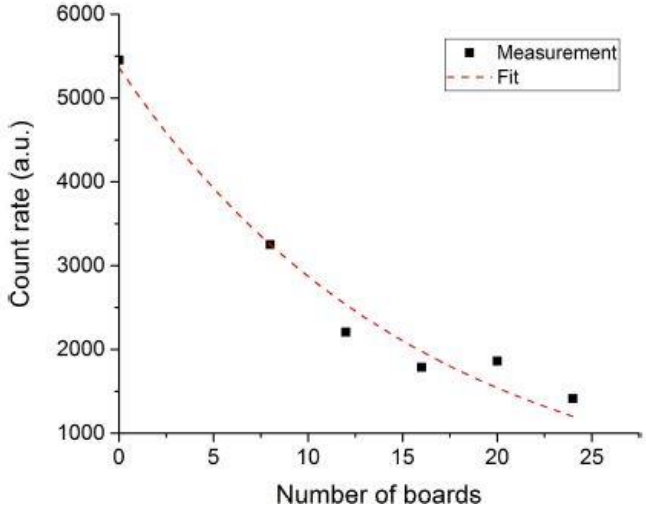
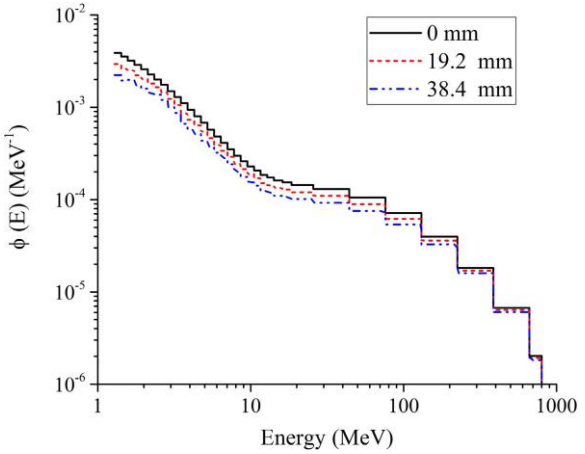


Fig. 5. Photograph of the experimental setup on ChipIr.





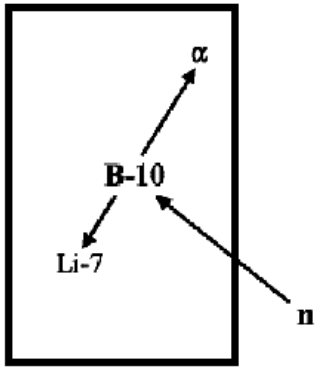
Materials have different cross sections at different energy. Spectral changes might need to be considered.

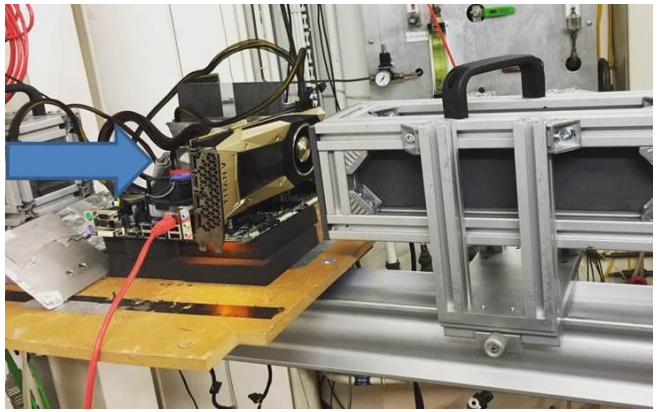


Fast neutrons are very penetrating, but for multiple boards attenuation need to be considered

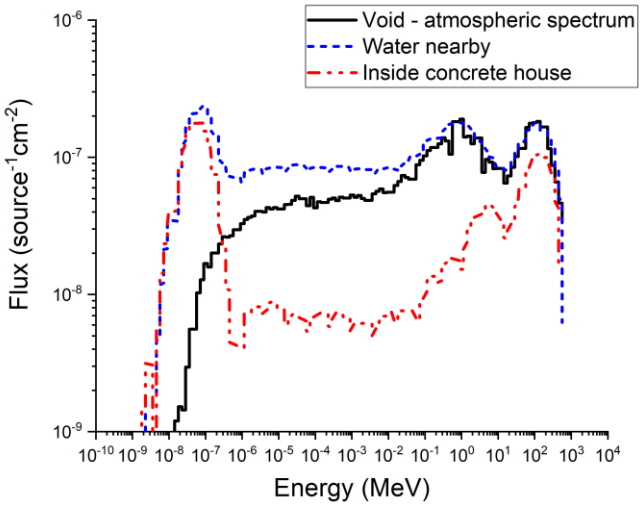
Cazzaniga, Carlo, et al. "Atmospheric-Like Neutron Attenuation During Accelerated Neutron Testing With Multiple Printed Circuit Boards." IEEE Transactions on Nuclear Science 65.8 (2018): 1830-1834.

Thermal neutrons

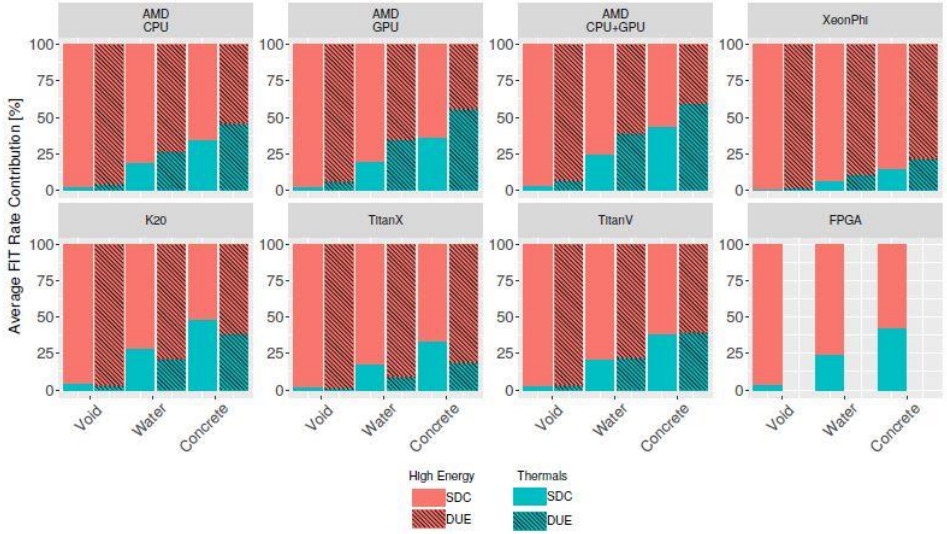




The rotax beamline at ISIS



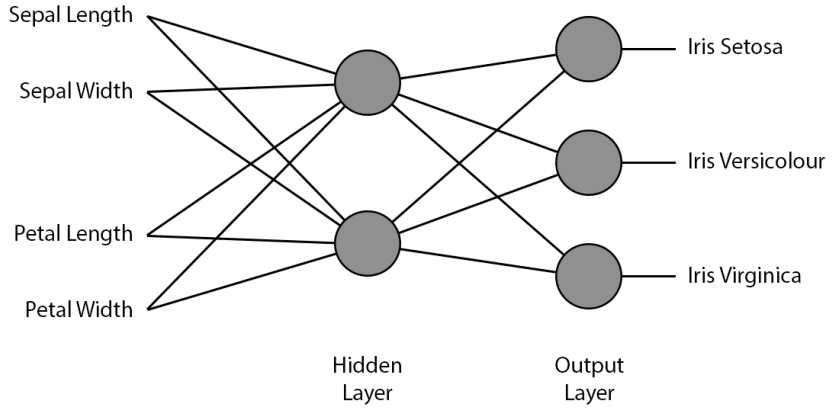
Neutron spectra from MCNP simulations evaluating three scenarios.



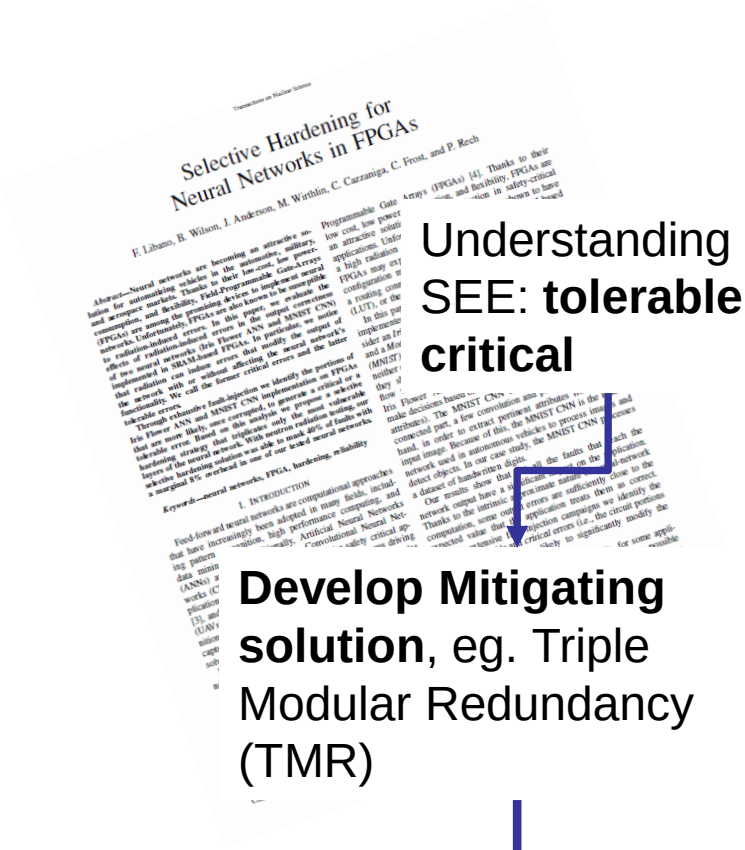
Average high-energy vs. thermal neutron FIT rate contribution for all devices evaluating different surrounding materials

D. Oliveira et al., High-Energy vs. Thermal Neutron Contribution to Processor and Memory Error Rates, submitted to IEEE-TNS

Neural networks are becoming an attractive solution for automatizing vehicles.



An Artificial Neural Network computes a solution by propagating data through layers of neurons connected and interacting via synapses

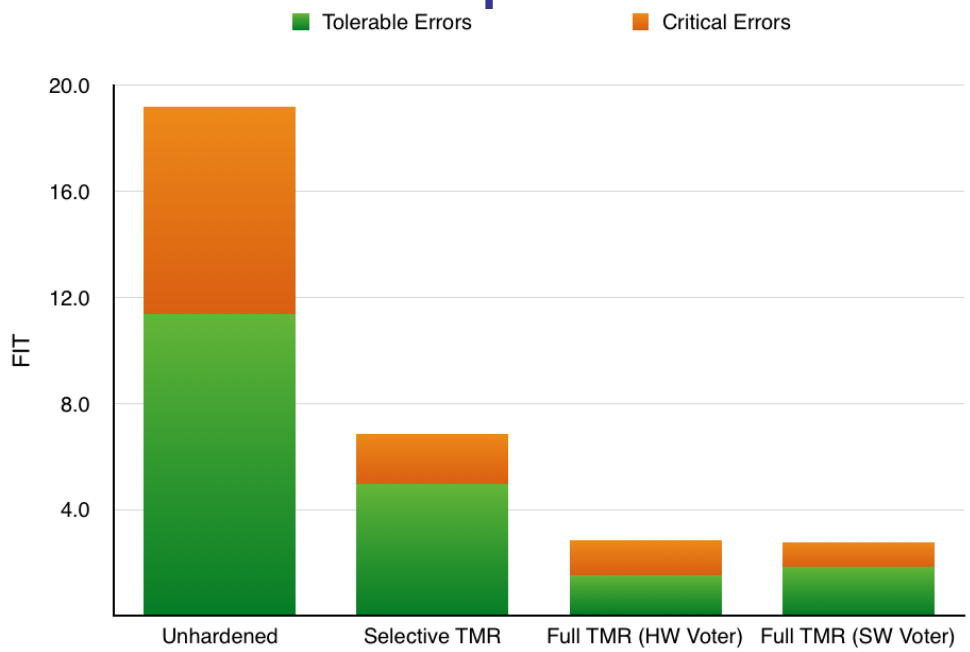

Selective Hardening for Neural Networks in FPGAs

F. Libano, B. Wilson, J. Anderson, M. Wirthlin, C. Cazzaniga, C. Frost, and P. Rech

Understanding SEE: **tolerable, critical**

Develop Mitigating solution, eg. Triple Modular Redundancy (TMR)

Neutron testing at ChipIR

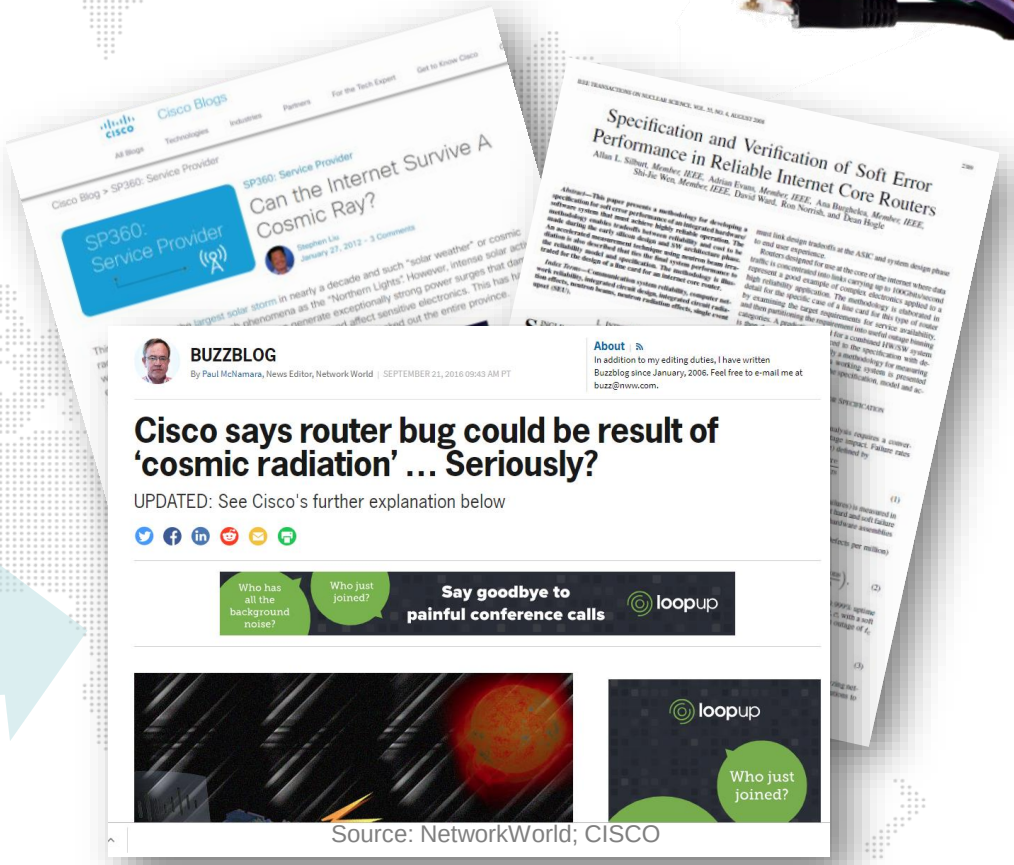


Digital Infrastructure

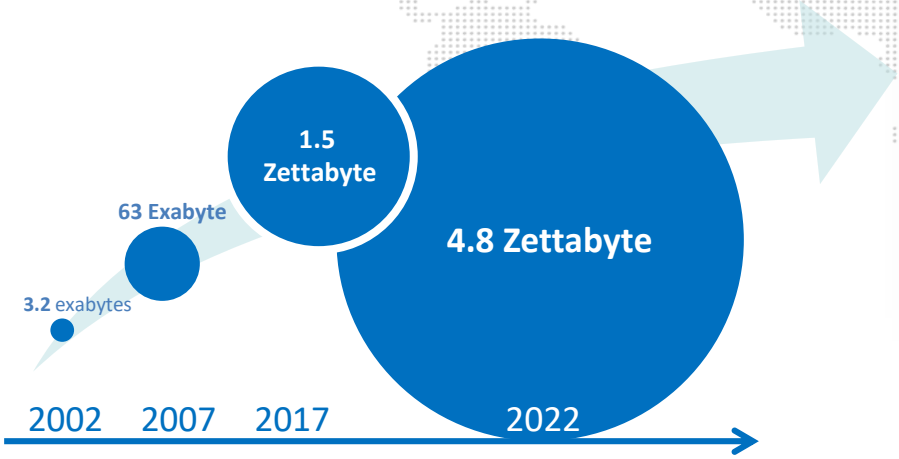
Internet Infrastructure: Huge growth in internet in last three decades

Cosmic ray neutrons a significant problem in routers since 2000s

Ongoing neutron testing at system level required



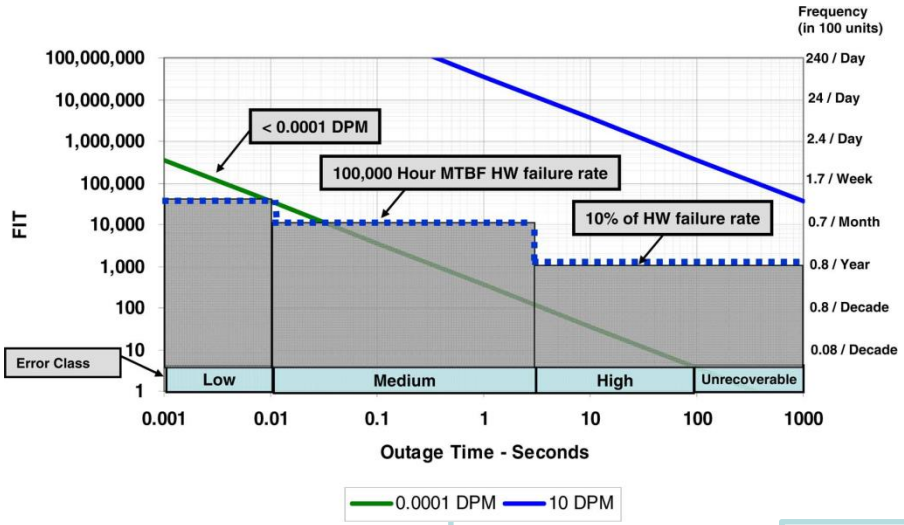
Source: NetworkWorld; CISCO

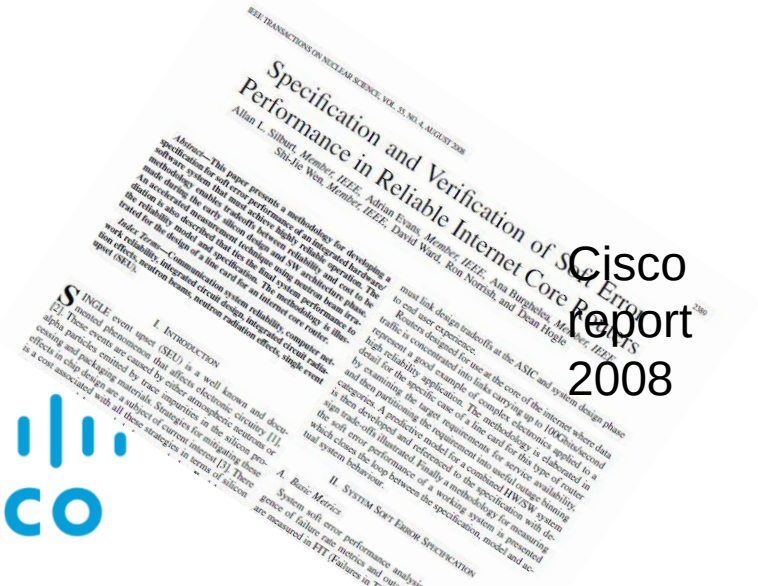


1 Zettabyte =
1,000,000,000,000,000,000,000 bytes

CISCO VNI Forecast

Internet Core Network Requirements
Building the specifications





Cisco report 2008

VERIFYING SOFT ERROR PERFORMANCE – Beam time!

DESIGNING A SYSTEM TO MEET THE SPECIFICATION

- Memories
- *Flip Flops*
- *Flip Flop Error Masking*
- *Model Results*

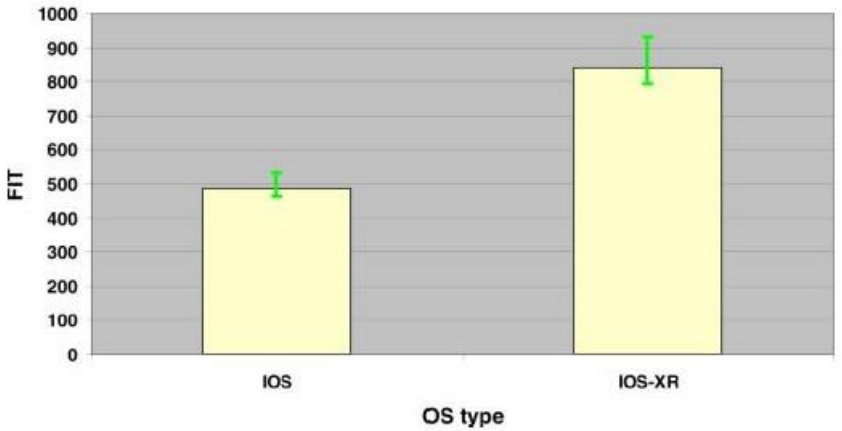
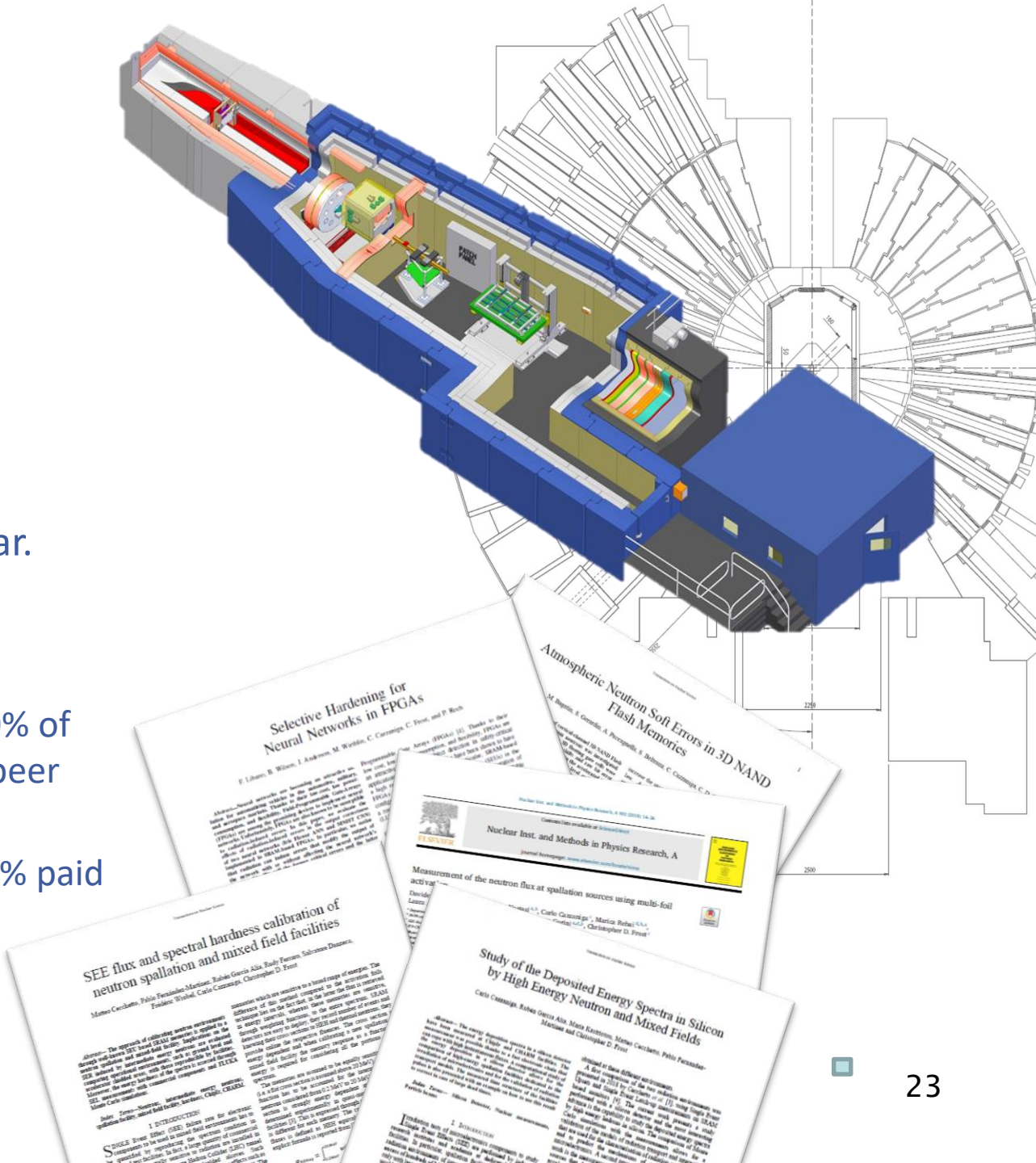


Fig. 4. Measured CISCO 12000 SIP600/601 series line card accelerated soft error rates normalized to New York City sea level reference for the "high severity" category running the IOS and IOS-XR operating systems. Error bars show 90% confidence levels.

Running 150-180 days/year.

Access mode

- **Academic Access**. 30% of beam time through peer review.
- **Industrial Access**: 70% paid beam time



Thank you!