ALICE

ITS Readout Electronics

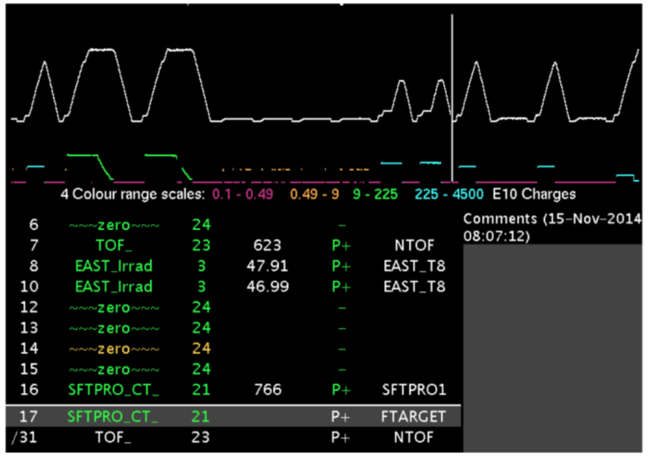
01 Oct 2017

RUv1 testing – Full board testing (CHARM)

We may have overlooked something critical, therefore whole board testing is anyway necessary. Specific DCDC testing will be carried out at LBNL BASE facility (55 MeV protons)

Proton Beam Conditions PS T8

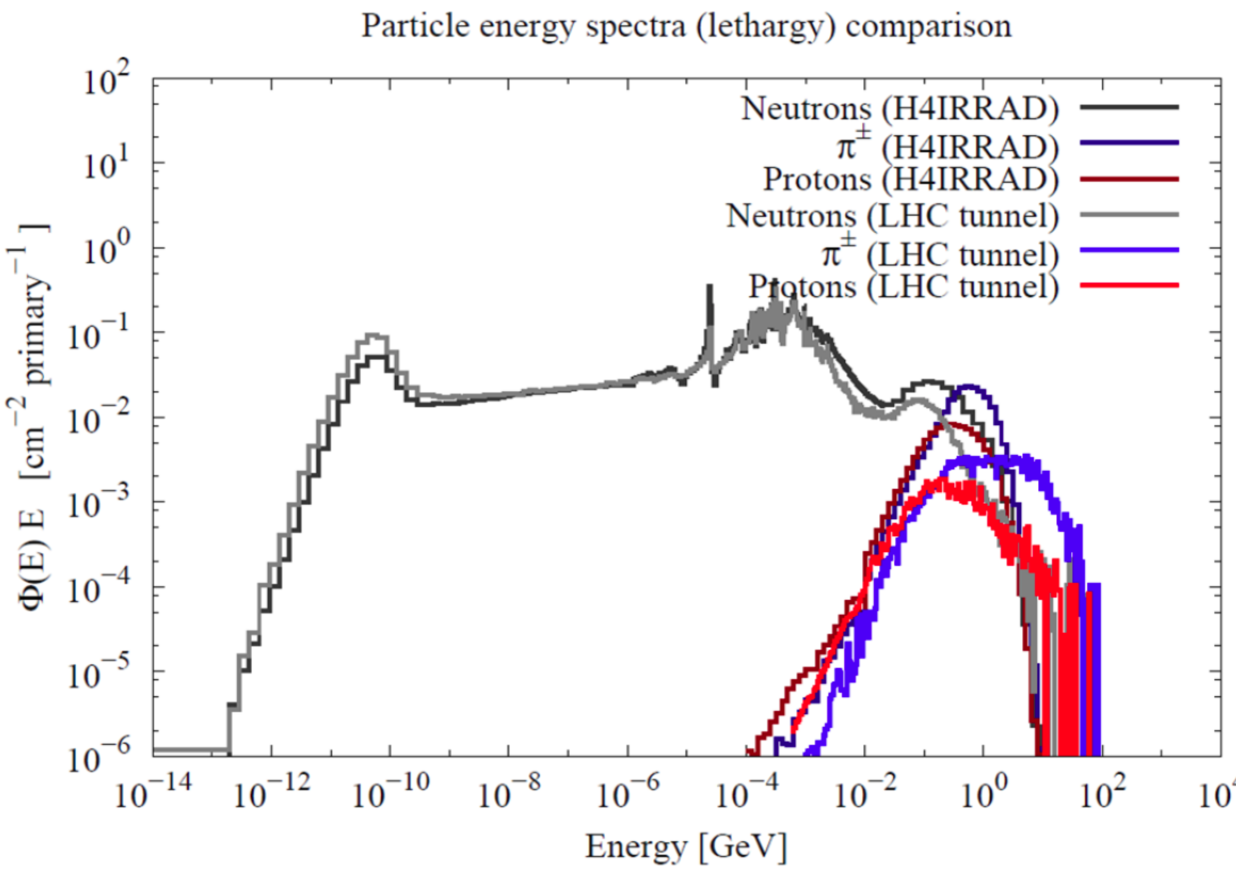
- 1e11 - 5e11 p's per spill
- Up to 6 spills per super cycle for CHARM
- Average:
  - 3 spills per min
  - 3e11 p's per spill
  - 1.8e10 p's per s
  - 1.5e15 p's per day
- FWHM 1 – 2cm
- "blown-up" beam with 8 – 12 cm FWHM



1 spill lasts about 300ms, making any scrubbing useless. Testing from Prague anyway show the expected number of particle per spill per cm^2 is within our "working range", i.e. we will survive each spill with very reasonable amount of error (with or without TMR).

Not really worth for verifying firmware!

but very useful to test with broad spectrum of particles/energies to check that everything works as expected (other option installing in the cavern).



RUv1 testing – Firmware testing with protons

Constraints we have in proton testing of the **firmware** (we can shield all others components on RUv1):

$$TID_p \cong LET_p \times Fluence \times 1.6 \times 10^{-5}$$

1.6×10^{-2} (30 MeV)
9.6×10^{-3} (55 MeV)

To reach **1 MRad**$_{(30\ \mathrm{MeV}\ p)}$ → ≈ **4×10^{12}** p cm^{-2} fluence

At ITS Readout System exposure (1 kHz cm^{-2})
This is equivalent to an operation length of

1 RUv1 FPGA exposed for ≈ 45,000 days
200 RUv1 FPGAs exposed for ≈ 225 days

Necessary about **1×10^9** p cm^{-2} fluence to simulate 1 hour operation of the whole ITS

Beware: realistic testing should not use proton flux higher than 10^4 p cm^{-2} s^{-2}

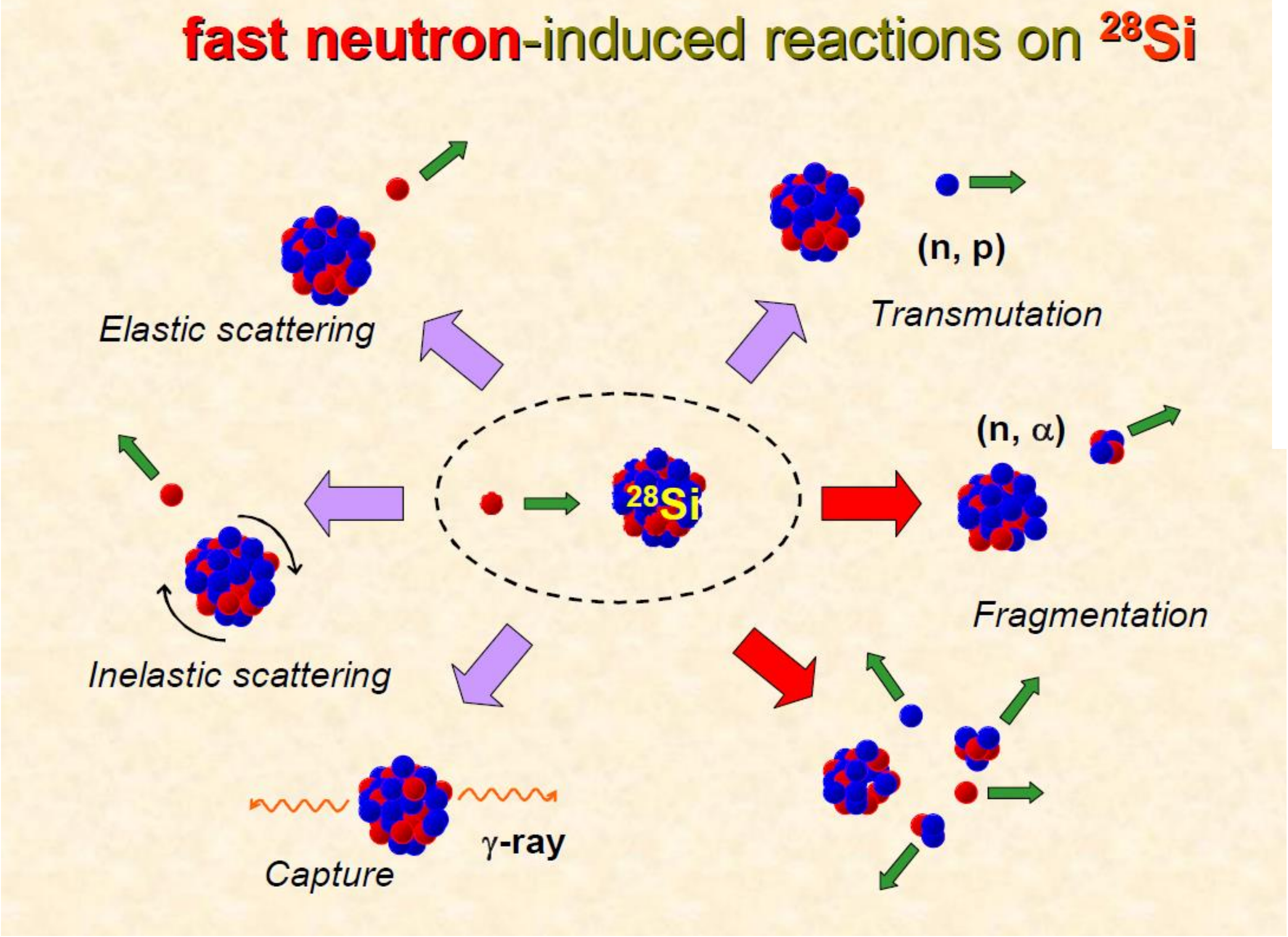
≈ 20 hours on a single FPGA

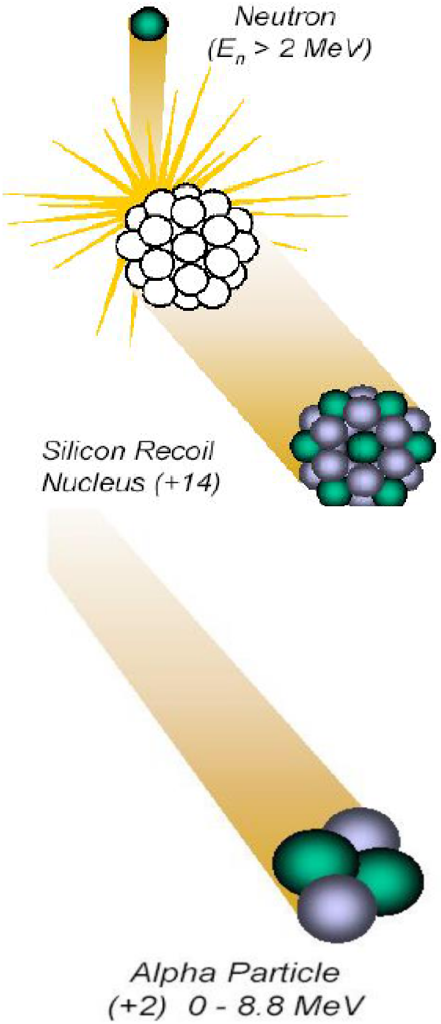
We have simulations and models we used to exploit higher flux beam-test

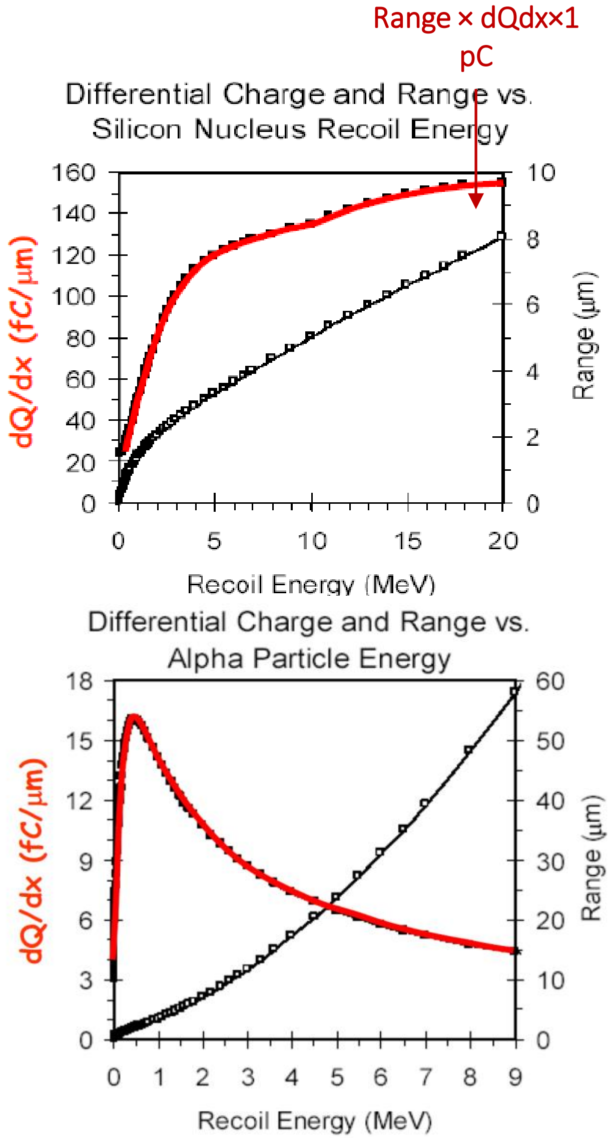
TID effects negligible as long as we have to verify FPGA firmware functionality

Impossible to have energetic heavy ions interacting with our electronic (they cannot reach it), yet neutrons can generate ions ($_{14}$Si nuclei, $_{2}\alpha$ particles, oter fragment) by nuclear interaction within the device. These secondary then act as ionizing particles in the active volume of the device.

Wyss 2011



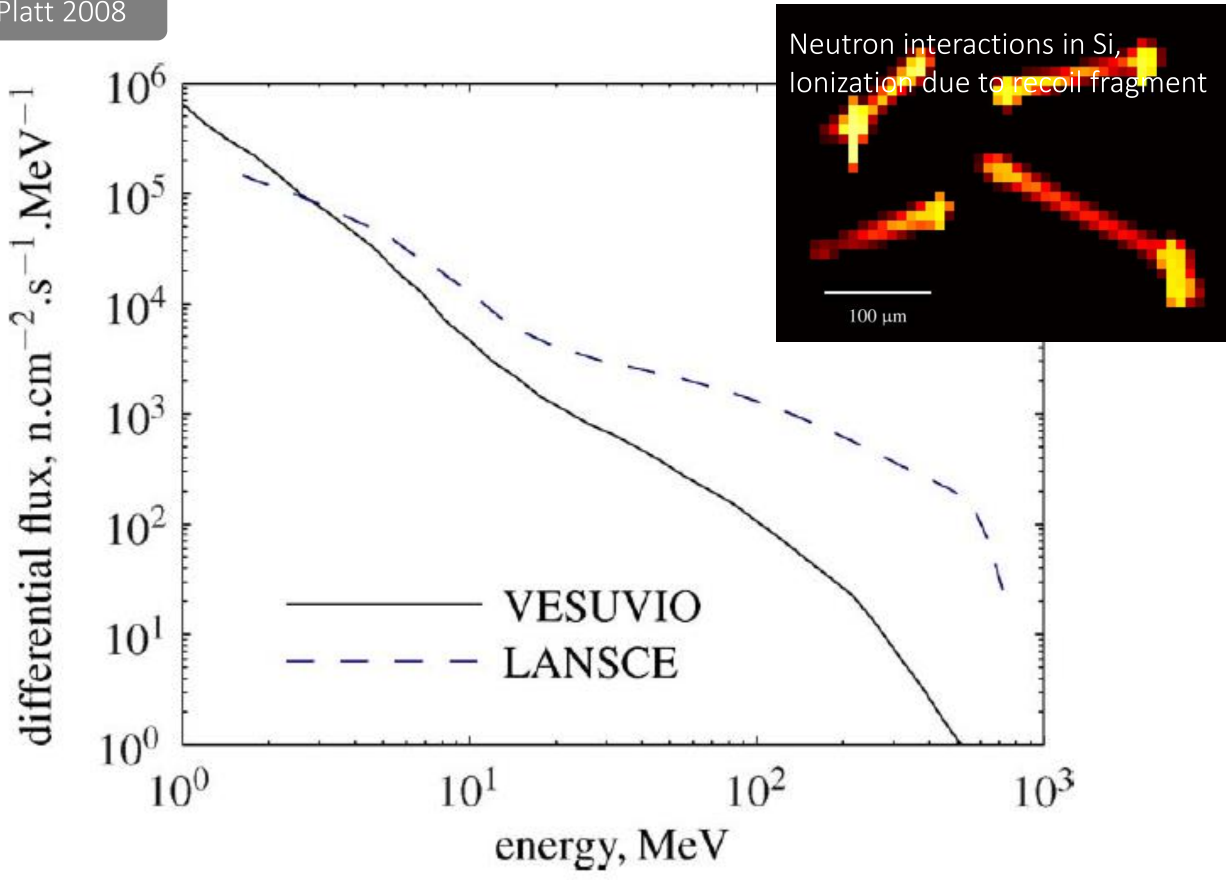




RUv1 testing – Neutron testing basics 2

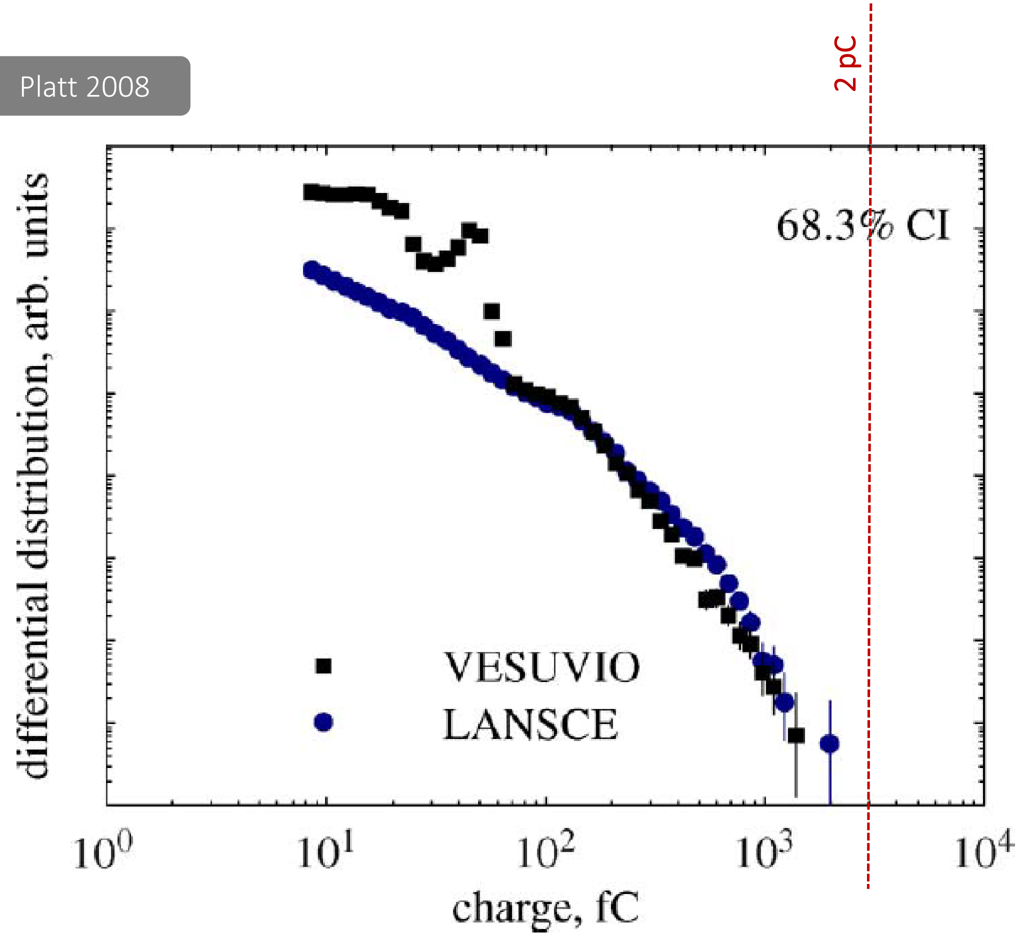
Given a neutron spectrum, there is an upper limit to the energy transfer to the Si nuclei (or any other recoil fragment, see previous slide) and consequently an upper limit to the induced ionization in the Si lattice. For a complete math description see the excellent: C. Leroy and P. G. Rancoita Rep. Prog. Phys. **70** (2007) 493–625

Platt 2008



Fast neutron spectra at VESUVIO and LANSCE.

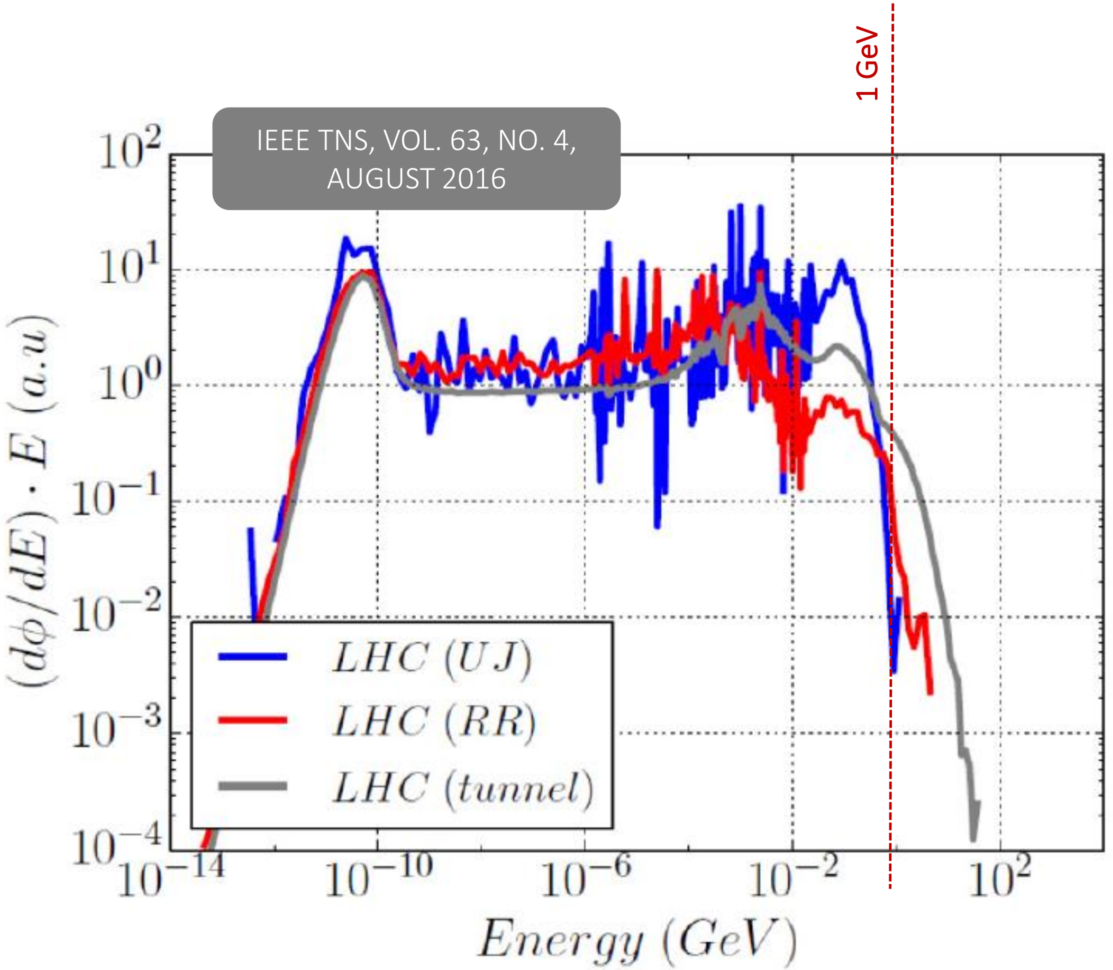
Platt 2008



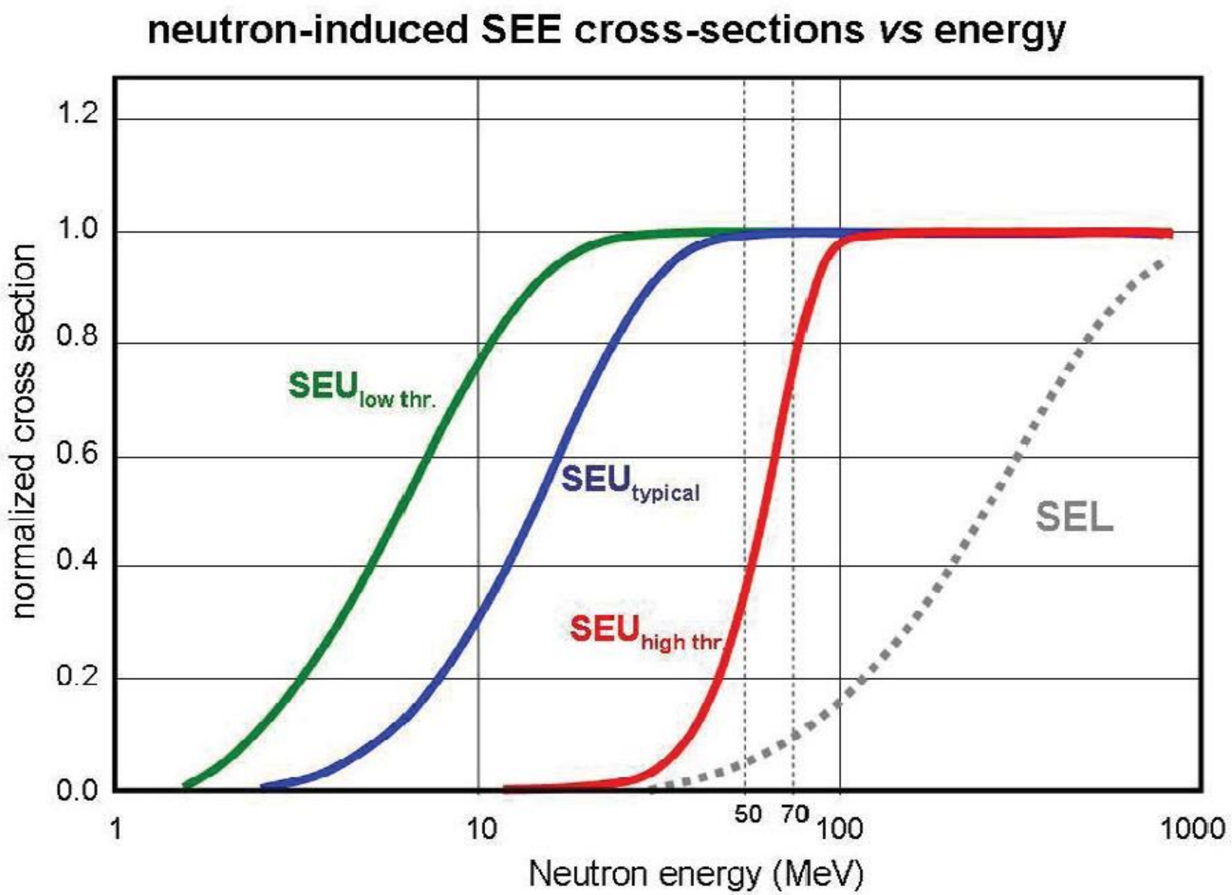
ig. 4. Charge collection spectra in ISEEM at VESUVIO and LANSCE.

RUv1 testing – Neutron testing basics 3

Therefore (also considering the neutron spectrum at the experiment is anyway within 1 GeV) there is an upper limit to the kind of ionizing damage neutrons can induce in devices. This upper limits its reached for neutrons around 100 MeV, and it is roughly equivalent to the damage produced by 100 MeV protons.

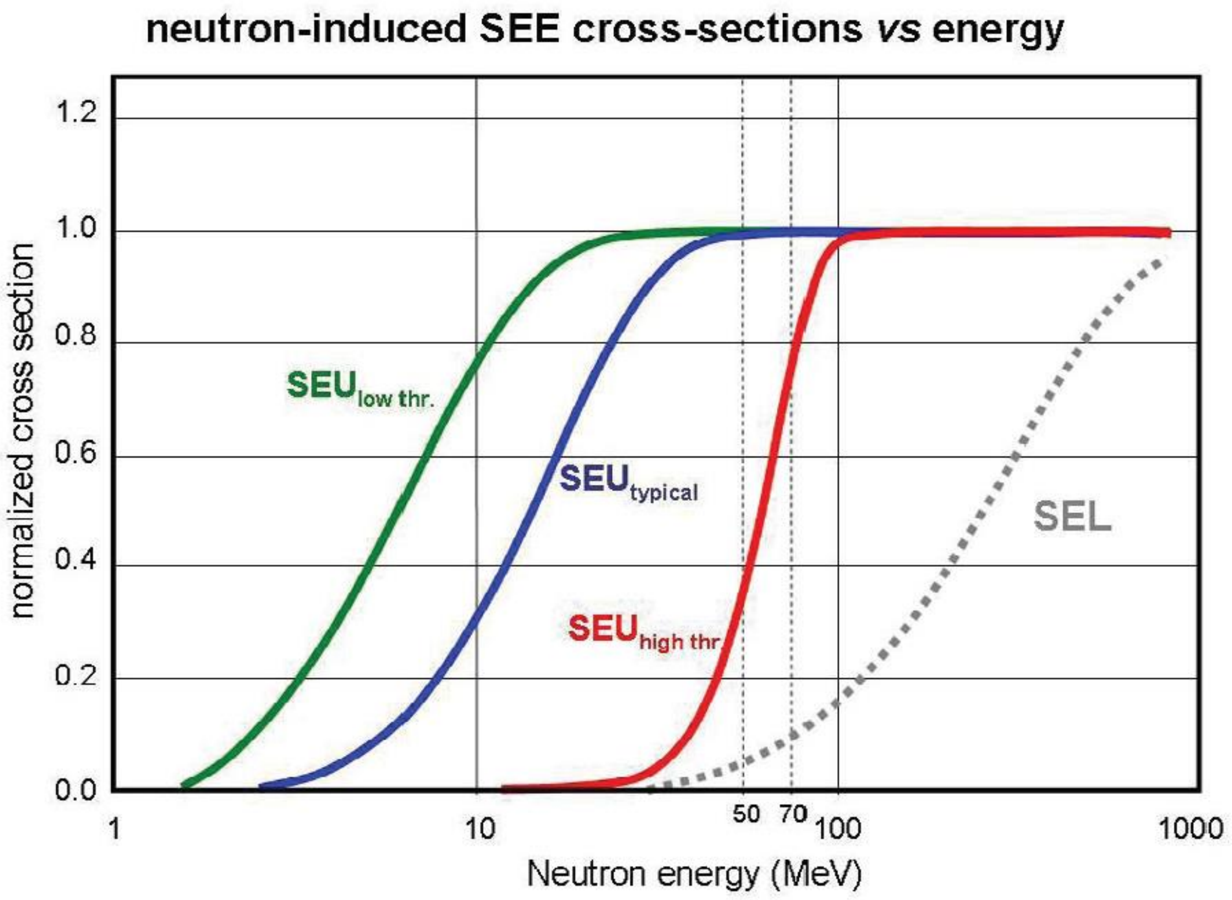


Nutron spectrum at the LHC



RUv1 testing – Neutron testing practical details

Neutron would allow long-exposure testing without being limited by TID. Cross section is not constant below about 14 MeV, but it is easy to set upper limits with neutron measurements.



Facility	Energy	Flux ($cm^{-2}\ s^{-1}$)
CERN	0.1 ÷ 1 and 10 ÷ 100 MeV	To be verified (SPS spill dependent)
LBNL	8-30 MeV	Up to 10^8
Frascati	14 MeV	Up to 10^{11}
PSI	Investigating	
Aachen	Investigating	

Xilinx test data (SRAM FPGA):

- Proton Cross Section **3.40e-14** cm^2 (10 to 100 MeV)
- Neutron Cross Sections (LANSCE Hess Spectrum)
- **>1.5** MeV **1.80e-14** cm^2
- **>10.0** MeV **3.43e-14** cm^2

RUv1 testing – radiation schedule before PRR

Not necessary in this order:

- CHARM: board testing (diagnostic on current and voltages, plus power board).
- Prague 1: firmware with full readout channels (w/ optical RUv1 control if early).
- Prague 2: firmware with final-like firmware shape (w/ optical RUv1 control if early).
- Neutron (facility to be booked): full RUv1 board testing to avoid TID limit on ancillary components.
- Backup (likely in Prague)

RUv1 testing – Statistical limits when testing with protons

Proton testing is limited due to accumulated TID

$$TID_p \cong LET_p \times Fluence \times 1.6 \times 10^{-5}$$

1.6×10^{-2} (30 MeV, Prague)
9.6×10^{-3} (55 MeV, Berkeley)

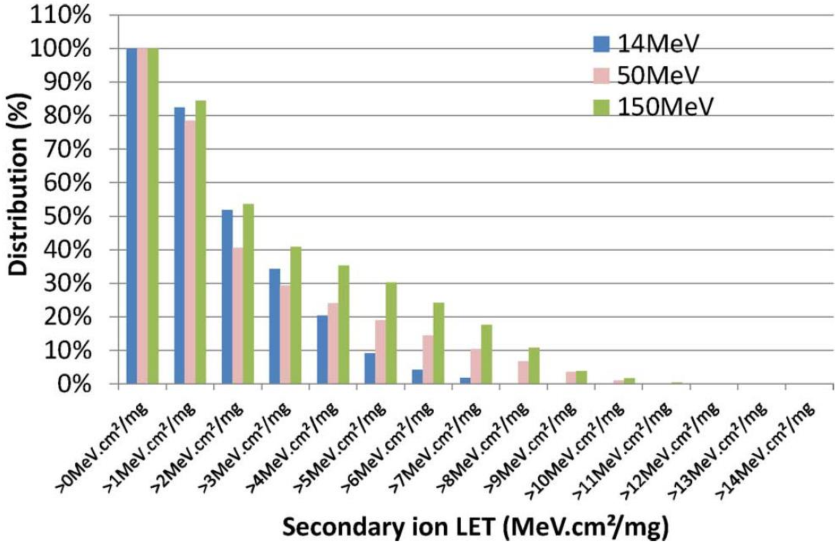
We are TID-limited with proton testing to a statistic equivalent to about 60 days of ITS operation for the FPGA (250 kRad) firmware and about 1 day of ITS operation for the DCDC converter (TID-induced failure supposed to happen around 10 kRad). Testing *n* devices in parallels increases the operation equivalent period by *n*.

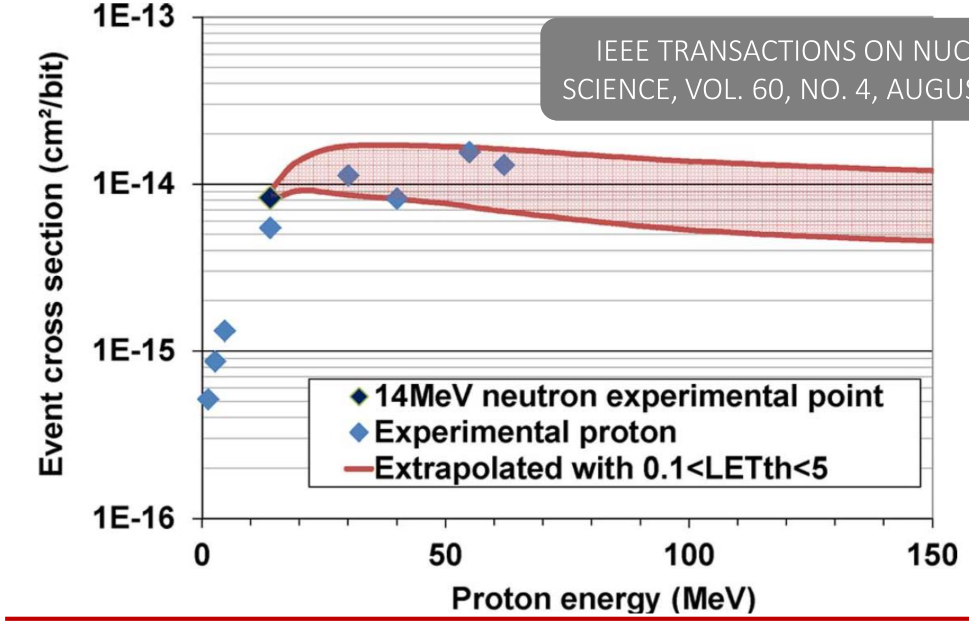
Fluence [p cm^{-2}]	ITS operation eqv. for FPGA [days] [1]	ITS operation eqv. for DCDC [days][2]	TID @ 30 MeV [Rad]	TID @ 55 MeV [Rad]
1×10^{10}	0.6	0.08	2.5k	1.5k
1×10^{11}	5.8	0.83	25k	15k
1×10^{12}	57.9	8.3	250k	150k
1×10^{13}	579	83	2.5M	1.5M
1×10^{14}	5787	827	25M	15M

[1] FPGA equivalent operational period for 200 RUs, each with 1 FPGA
[2] DCDC equivalent operational period for 200 RUs, each with 7 DCDC

RUv1 testing – Neutron possibilities

Neutron testing provides cross sections for SEU/SEL comparable to 100 MeV proton for neutron energies > 10 MeV, no issue with TID effects. In table statistical coverage with reasonable irradiation times (< 2 days, single device).





IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 60, NO. 4, AUGUST 2013

Irradiation at 10^7 n cm^{-2} s^{-1} **will not give more statistics than proton testing!**

Total fluence [n cm^{-2}]	Hours at 10^7 [n cm^{-2}]	ITS operation eqv. for FPGA [days] [1]	ITS operation eqv. for DCDC [days] [2]
1×10^{10}	0.28	0.6	0.08
1×10^{11}	2.8	5.8	0.83
1×10^{12}	28	57.9	8.3

[1] FPGA equivalent operational period for 200 RUs, each with 1 FPGA
[2] DCDC equivalent operational period for 200 RUs, each with 7 DCDC

Irradiation at 10^8 n cm^{-2} s^{-1} necessary, **or 10 device in parallel!**

Total fluence [n cm^{-2}]	Hours at 10^8 [n cm^{-2}]	ITS operation eqv. for FPGA [days] [1]	ITS operation eqv. for DCDC [days] [2]
1×10^{11}	0.28	5.8	0.83
1×10^{12}	2.8	57.9	8.3
1×10^{13}	28	579	83

[1] FPGA equivalent operational period for 200 RUs, each with 1 FPGA
[2] DCDC equivalent operational period for 200 RUs, each with 7 DCDC

RUv1 testing – Roadmap

Particle type	Target eqv. HEH fluence [cm^{-2}]	Target flux [$cm^{-2}\ s^{-1}$]	Duration [hours]	Number of DUT	Facility	Date	Notes
RUv1 Board (broad showstopper verification)							
mixed field	$\approx 10^{12}$	Pulsed	96 Death of DUT	1	Charm	24 Oct	CHARM gives $\approx 2\times10^7$ HEH (30% to 80% being neutron) for each delivered kRad of TID. Destructive test due to TID.
neutron	$\approx 2\times10^{12}$	2×10^7	12	1	Louvain Frascati LBL?	Low priority	Extended reliability test sor SEL/SEU only (no TID effects at first order). NON destructive.
Firmware protection verification							
Proton	10^{12}	10^7	24	1	Prague LBL	High priority	Beam limited to the FPGA only. Most effective way to check firmware design.
Neutron	10^9	10^4	24 ÷ 48	1	CERN Aachen	Low priority	Realistic scrubber speed testing (non mandatory). Neutron could underestimate MBU.
DCDC validation							
Proton	10^{11}	10^8	1	5	LBL	Mid priority	Further testing of TID response to increase statistics (and specifically targeted at 10A model). Destructive test.
Neutron	10^{13}	2×10^7	12	5	Louvain Frascati LBL?	High priority	Realistic scrubber speed testing (non mandatory). Neutron could underestimate MBU.