Single Event Rates by thermal neutrons in the Mu2e setup

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Outlook. Boron issue in microelectronics

- Natural boron is often used in integrated circuits in

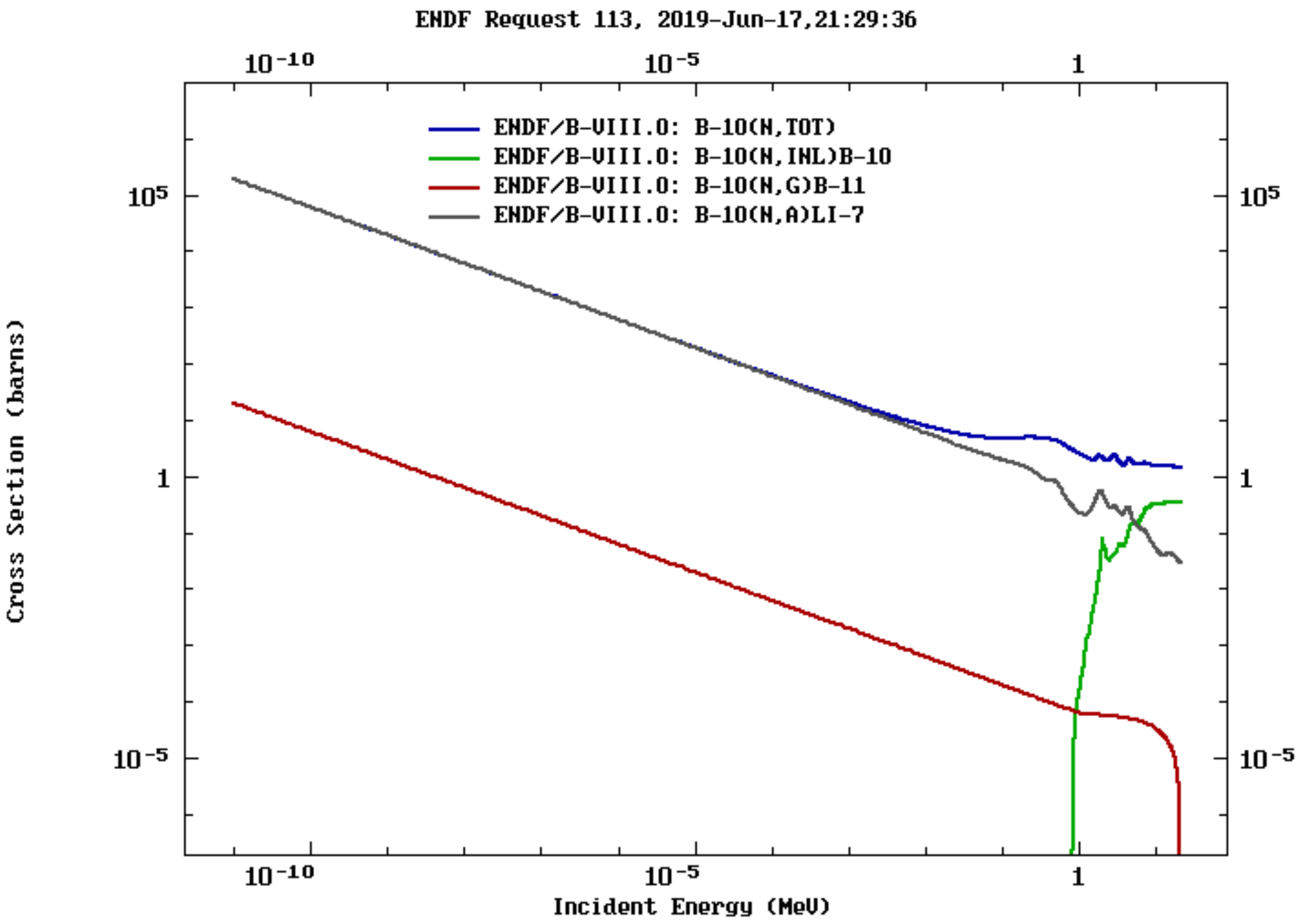
1) substrate doping
2) borophosphosilicate glasses (BPSG) in the back end of line

Boron has two isotopes:

1) ^{11}B (80%) neutron cross section is extremely small, not a problem
2) ^{10}B (20%) capturing neutrons can emits photon (0.48 MeV), ^{7}Li (0.84 MeV) and (1.47 MeV) ^{4}He, all can cause SEU

- contemporary electronics almost eliminated BPSG
- boron is still present at the silicon level because the drain implantation technology is not sensitive to isotopes
- ^{10}B can be present at back end of line (coating of tungsten plug)
- (Wen 2010) showed that SRAM circuits in the technology range 0.25 μm–45 nm are sensitive to thermal neutrons

10B neutron cross sections

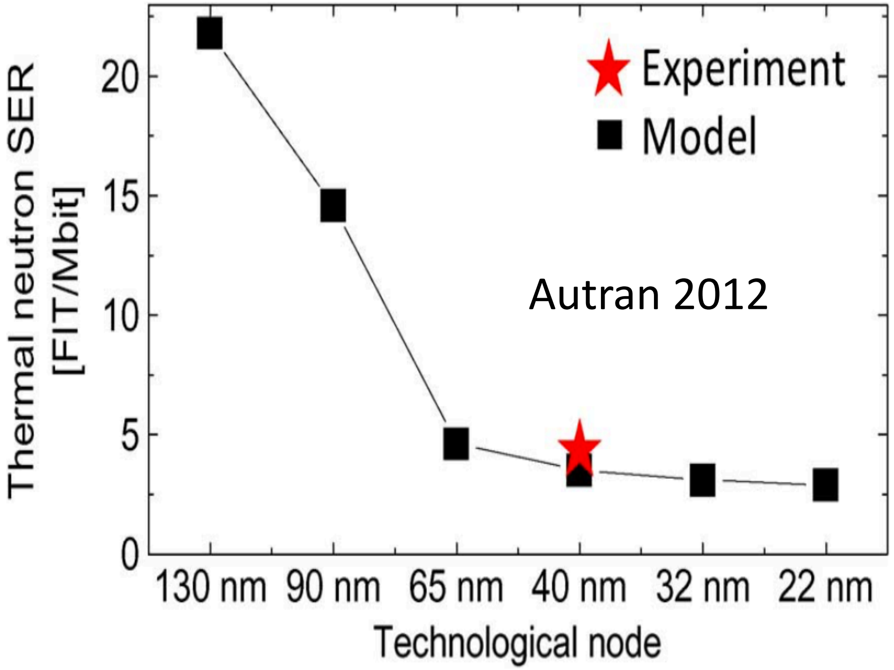


10B(n, alpha)7Li is the dominant reaction channel for low-energy neutrons

SEU by thermal neutrons

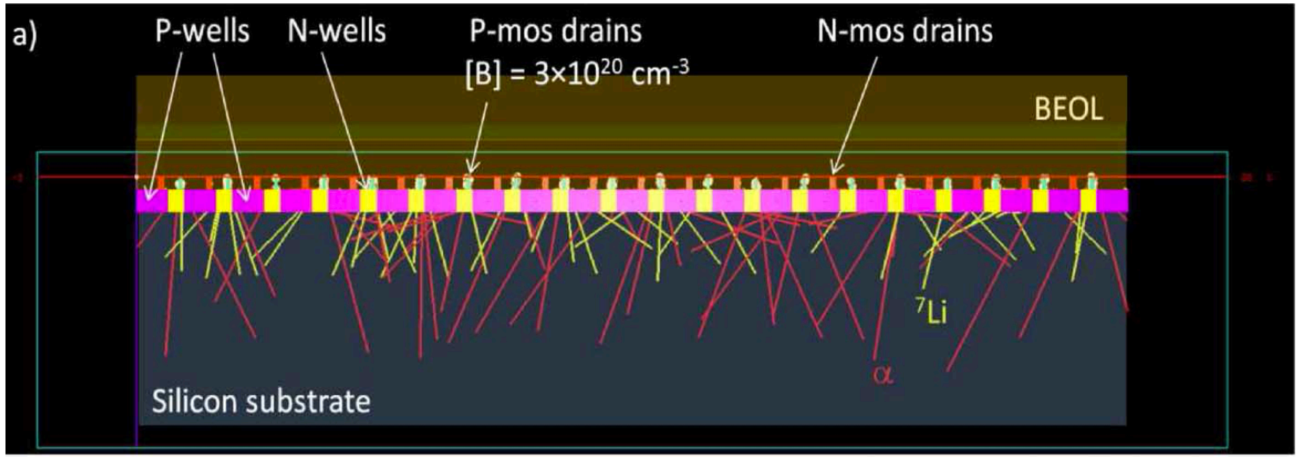
- Interactions of thermal neutrons with ^{10}B is a major source of soft errors in electronic circuits (SRAM)

FIT = failures per billion hours



Autran (2012) used atmospheric neutron spectrum of NYC (US DHS) < 1eV and PROMO40v5 test chip by STMicroelectronics

$$^{10}B + {}^{1}n \rightarrow [^{11}B] \rightarrow {}^{4}He + {}^{7}Li + 2.79\ MeV$$

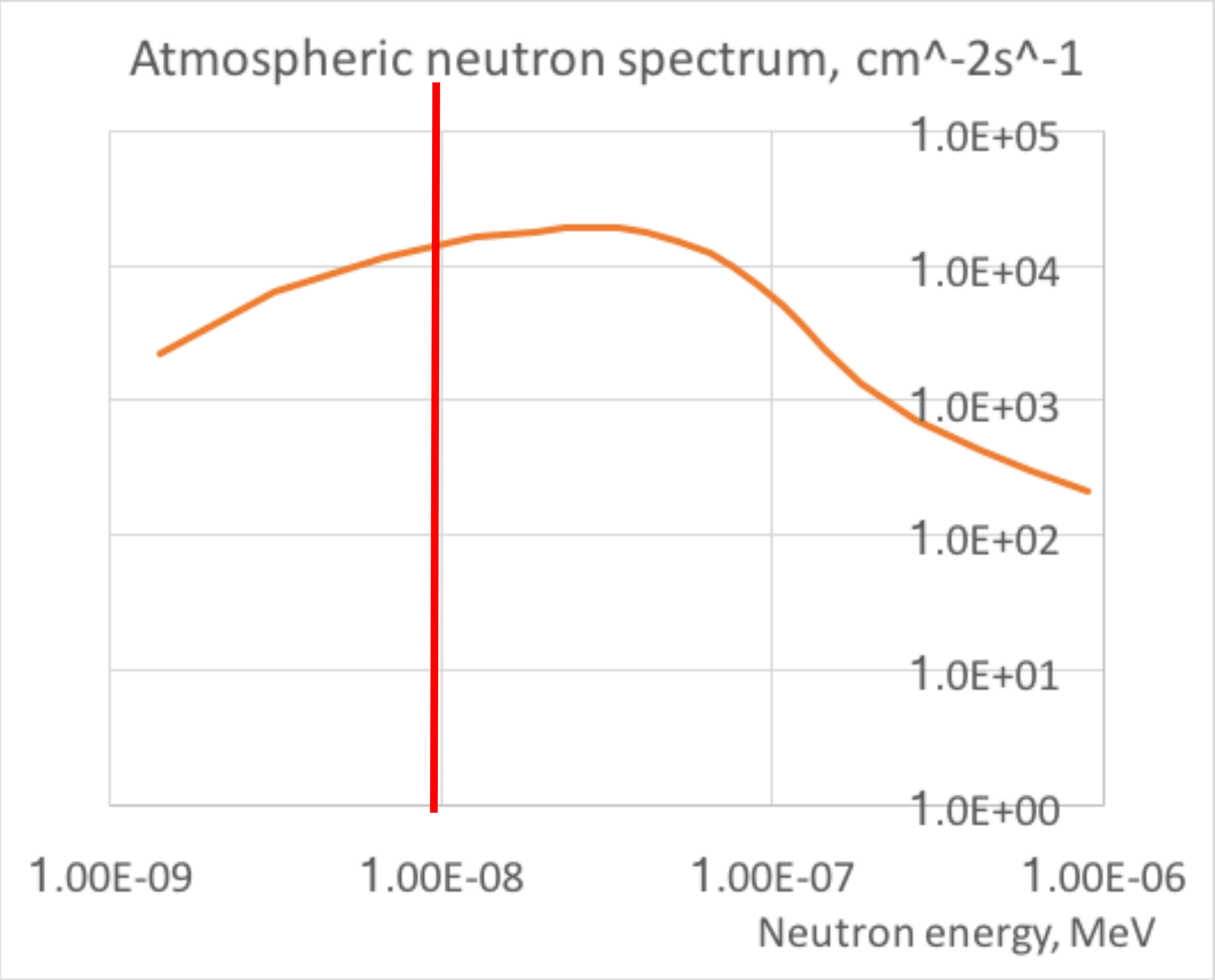


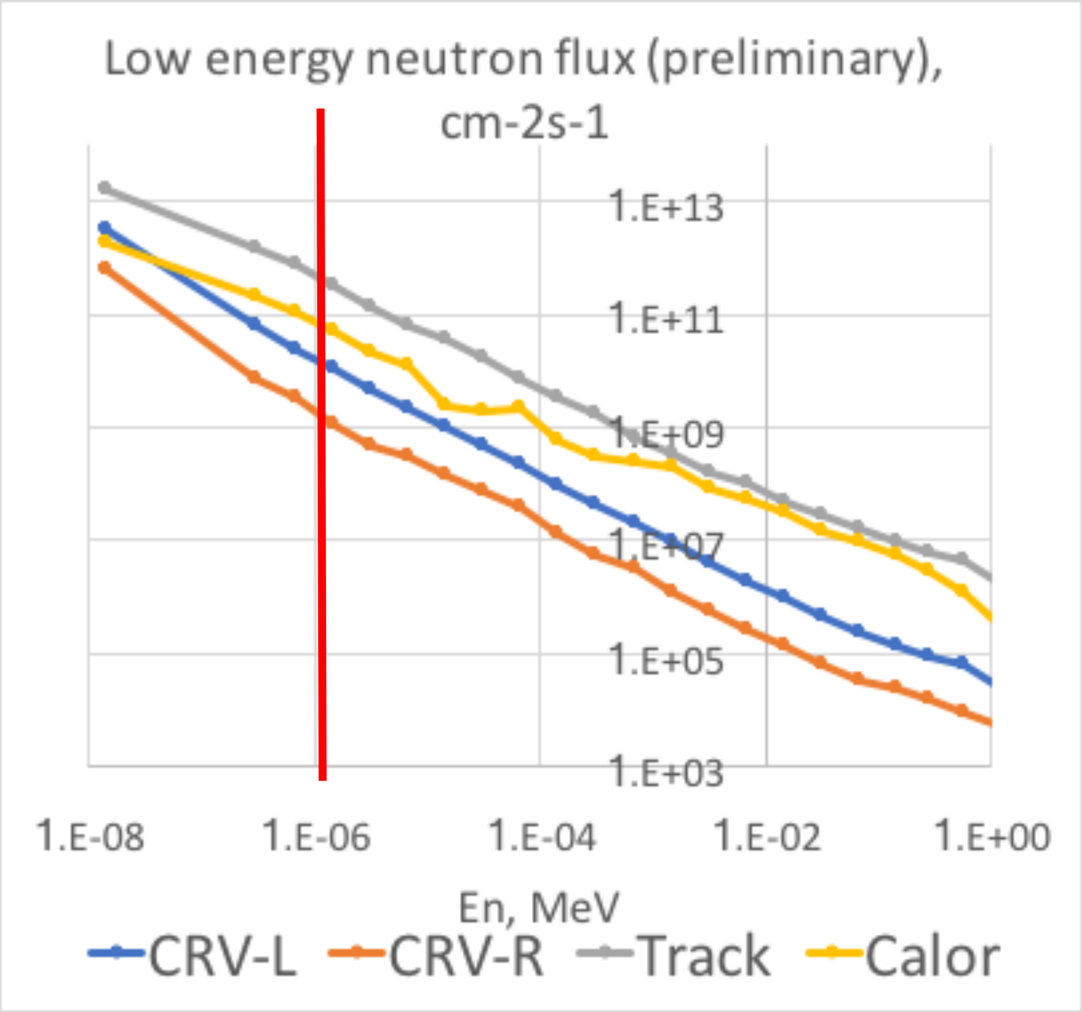
from J.L. Autran et al, 2012

- High concentration of 10B in the drains of p-channels of pMOS transistors
- one fission reaction – one Single Event Upset
- Multiple Cell Upsets (MCU) due to fission products are not currently taken into account

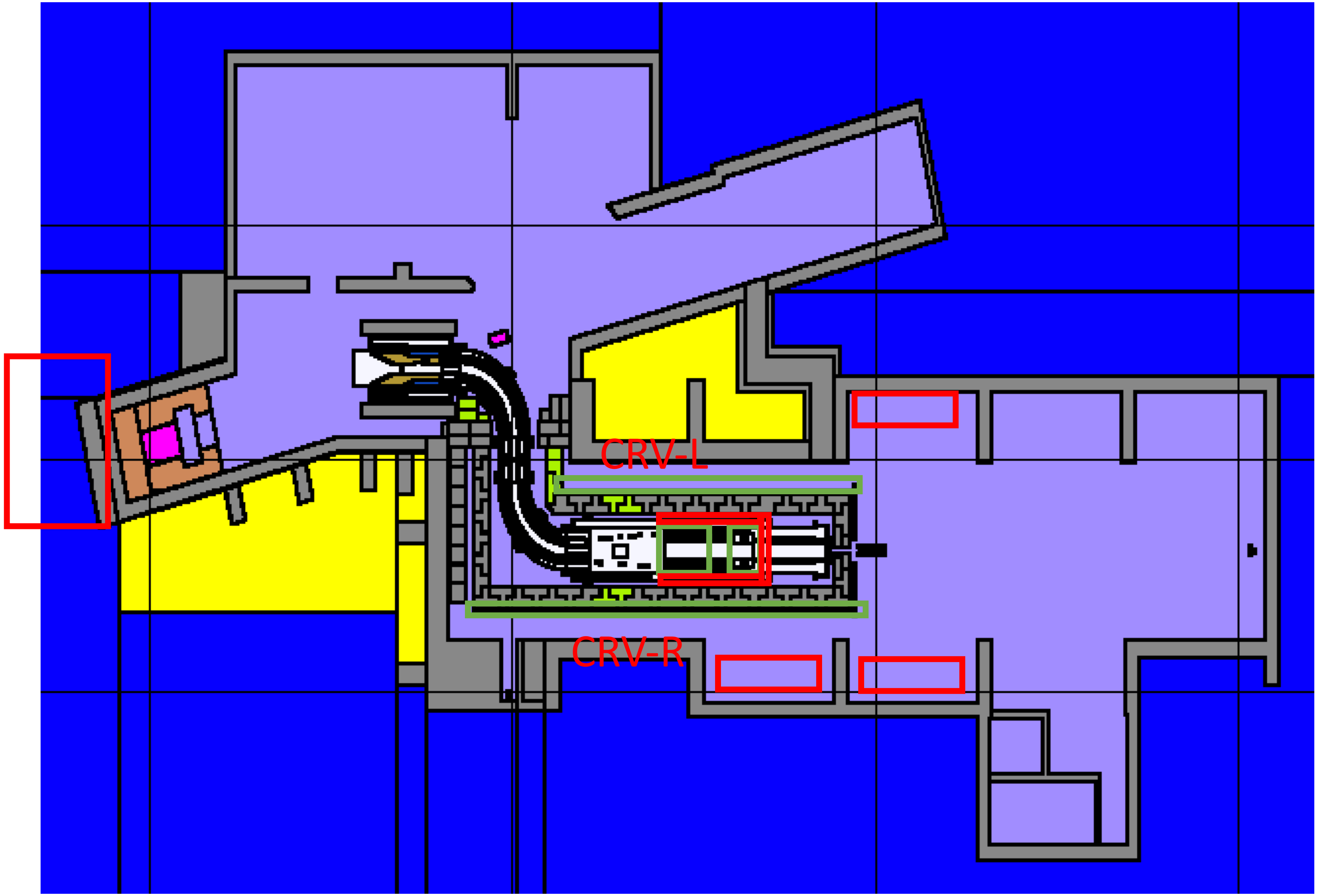
p-mos: P-type metal-oxide-semiconductor
n-mos: N-type metal-oxide-semiconductor

Spectra of atmospheric neutrons (left) and Mu2e MARS15 (right)





The Mu2e setup cross section



Line colors:

Red – studies are needed

Green – SER calculated

SEU model. Determining Vd

- Thermal neutron Single Event Rate:

$SER = 1024^2 * Vd * N_{fis}$

where: 1024^2 – 1 Mbit

N_{fis} – ^{10}B fissions per $mm^2 * \mu m$ per time unit

Vd – volume of pMOS drain, $mm^2 * \mu m$

Vd is usually determined from vendor data

nm	V	Vd
130	1.3E-07	1.6E-08
90	9E-08	1.1E-08
65	6.5E-08	3.5E-09
40	4E-08	2.6E-09
32	3.2E-08	2.3E-09
22	2.2E-08	2.2E-09

For STMelectronics devices

SER by Mu2e thermal neutrons (per year)

Tech node, um	Product	FIT/Mb thermal neutrons in LANSCE spectrum
45	Spartan-6	21
40	Virtex-6	0.7
28	Artix-7 or Zynq-7000	29
28	Kintex-7 and Virtex-7	1.1

from S.Hansen doc-db 15501-v2

The information on sensitive drain volumes is not available from vendor data

Tech node	CRV-L	Track	Calor	CRV-R
nm	Mu2e Failures/Mbit/yr			
130	69.4	364.3	43.3	13.3
90	45.9	241.2	28.7	8.8
65	14.6	76.8	9.1	2.8
40	11.2	58.7	7.0	2.1
32	9.7	50.9	6.0	1.9
22	9.3	48.6	5.8	1.8

Limitations for neutron spectrum:
pre-TDR geometry
virtual detectors for Tracker and Calorimeter span the entire volumes

based on STMelectronics sensitive drain volumes

Conclusion

- SER estimates for the Mu2e CRV thermal neutron spectra are higher than those SRAM from S.Hansen (doc-db 15501) (different neutron spectra) and comparable to those due to >20 MeV neutrons. May be an issue for Mu2e.
- Further work
  - Drain volumes for actual SRAM (not available)
  - Thermal neutrons for current Mu2e geometry model (started)
  - Determine actual Mu2e electronics locations and neutron spectra in them)
- Aim: to define safety factors for the Mu2e electronics based on MARS15 simulations