# Muon-induced Soft Errors in FinFET and Planar SRAMs

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# Muon: potential source of soft error

Muon accounts for 70% of secondary particles on earth

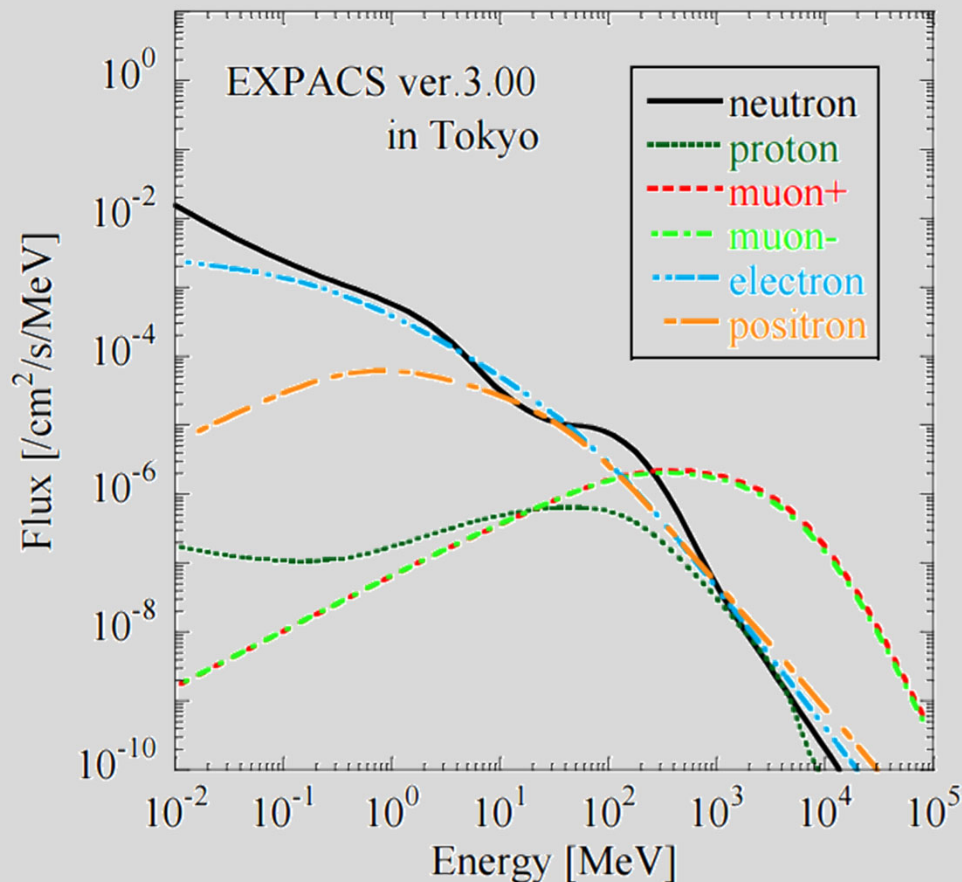
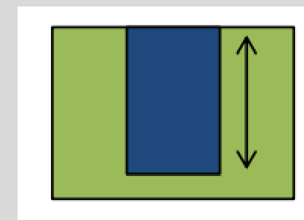



Fig. Flux spectra from EXPACS: T. Sato et al., EXPACS, *Radia. Res.*, 166, 544-555, 2006

Decrease in critical charge

**Deposited charge can exceed critical charge of modern devices!**

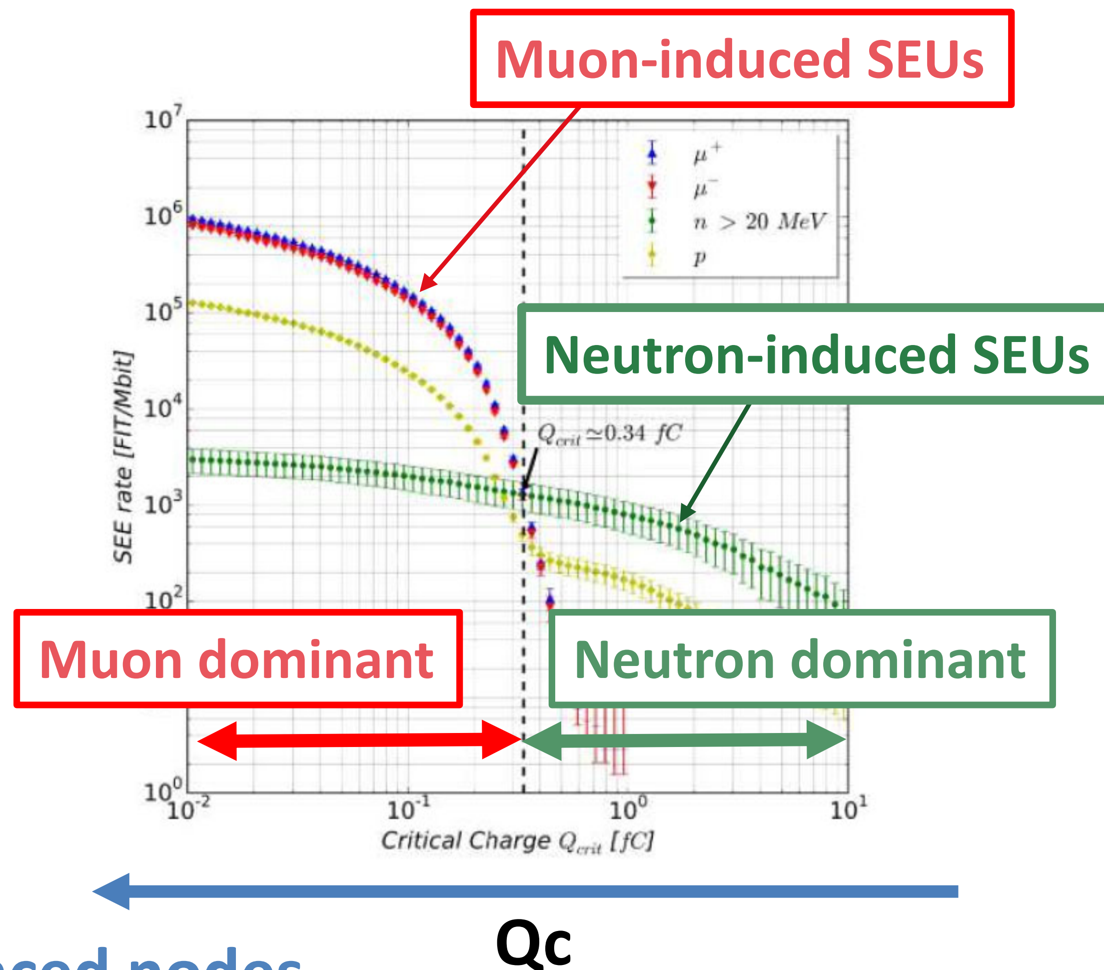


Sensitive volume depth 0.5μm

| Energy | dE/dx | Deposited Charge in 0.5μm |
|---|---|---|
| 1GeV | 0.47keV/μm | 0.02fC |
| 40KeV | 73keV/μm | **1.80fC** |

# Increasing trend of muon impact

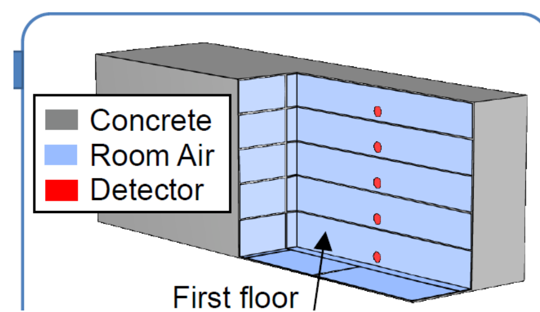
**As Qc decreases, there is a possibility that muons will become dominant [2]**



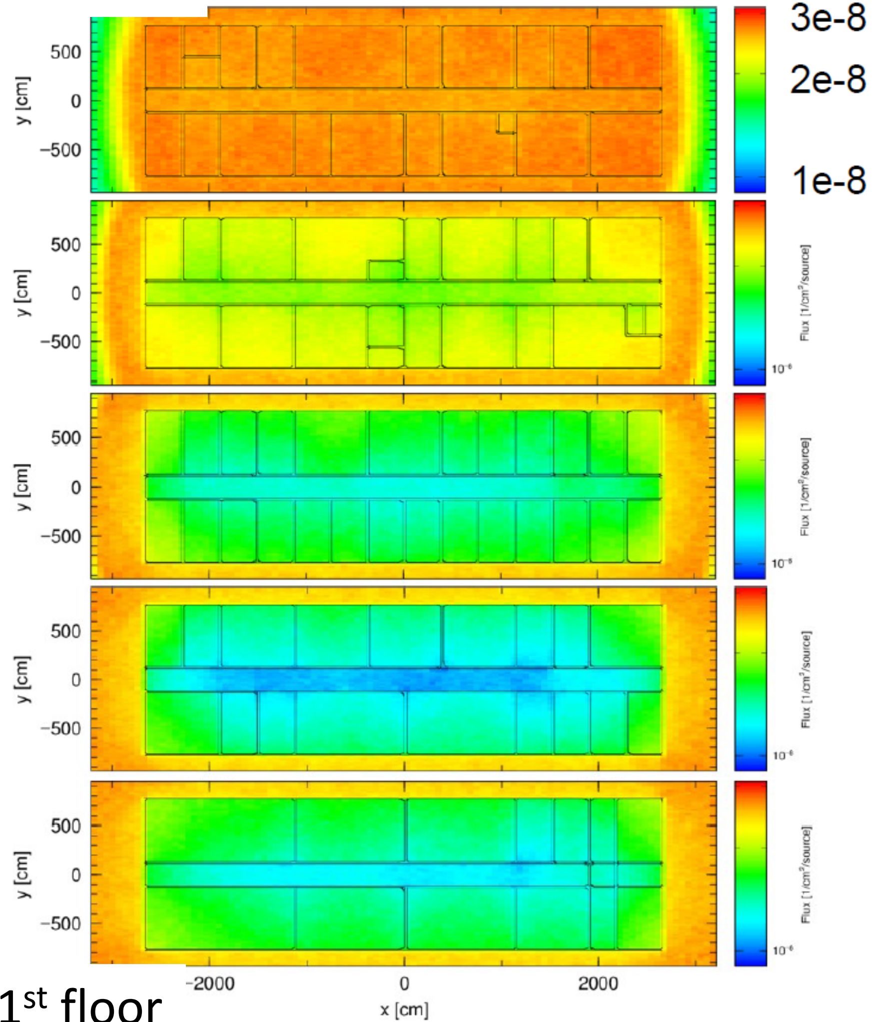

**[2]: A. Infantino: TNS, 2017.**

**More advanced nodes**

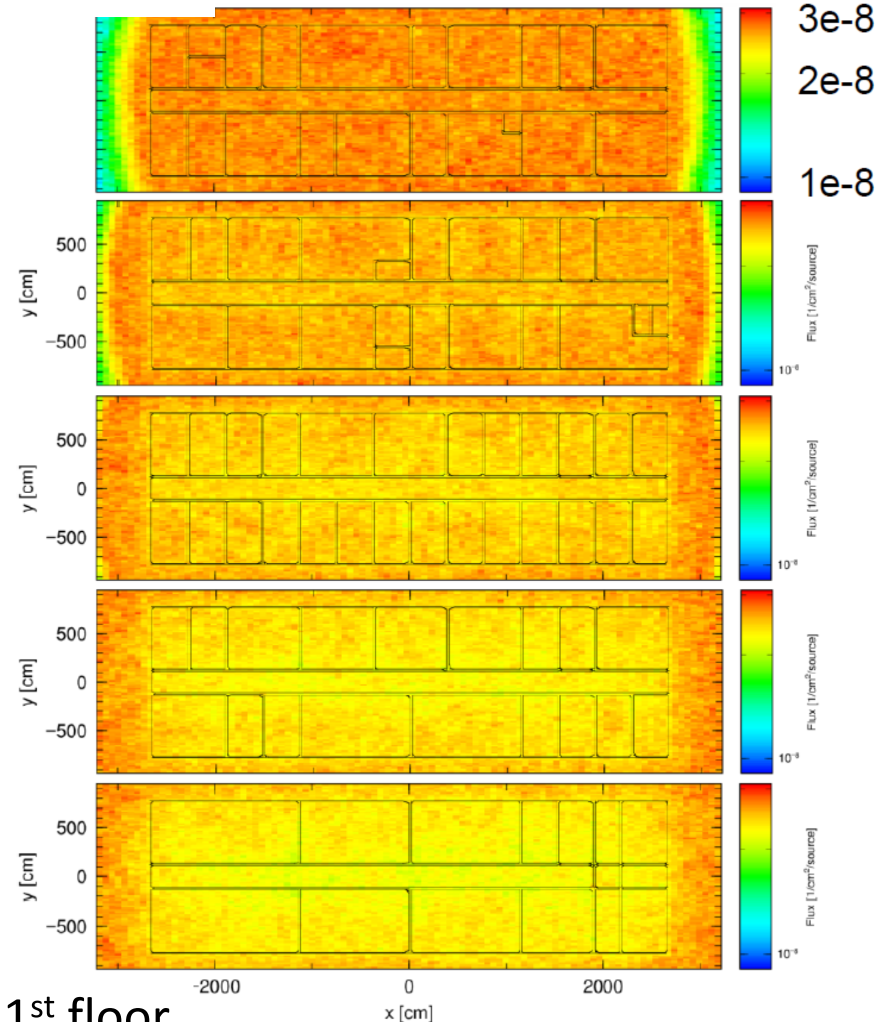
# Neutron and muon in a concrete building




Courtesy to Dr. Abe, JAEA.




**Neutron**




**Muon**

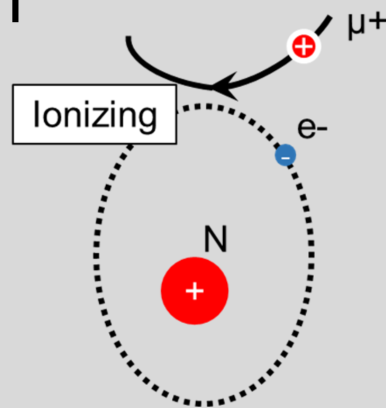
# Previous works: muon-induced SEU

Positive muon:

- Experiments [1-4]
  - 14nm,22nm, etc.
- Simulation [2,4]

Charge Generation

- Ionization



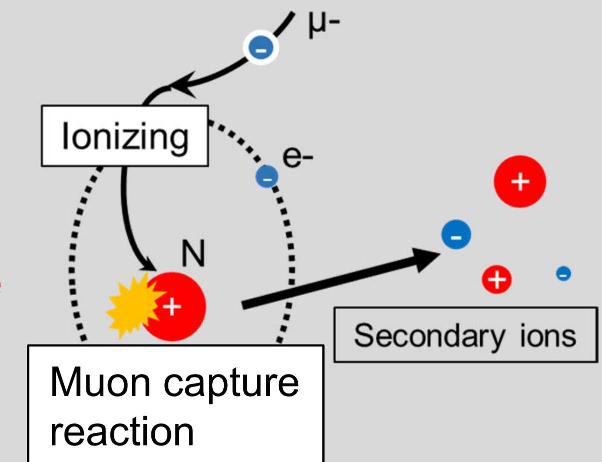

Negative muon:

- Experiments [5]
  - Only in 1980s
- Simulation [2,4]

Charge Generation

- Ionization
- Muon capture

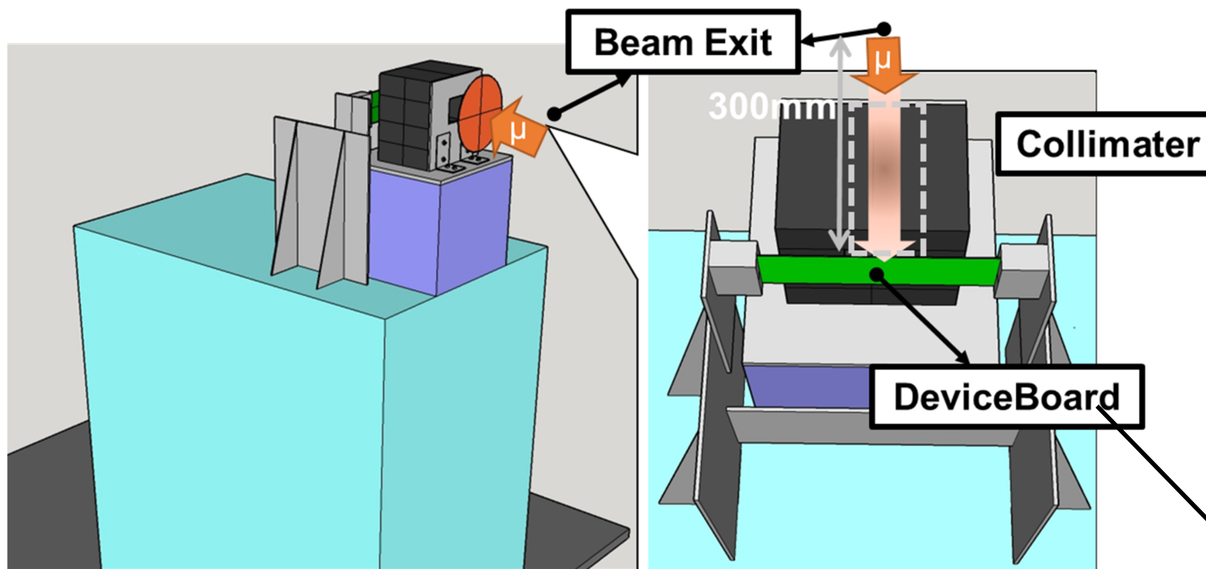
Secondary ions can deposit large charge




**Impact of negative muon capture had not been studied in experiments.**

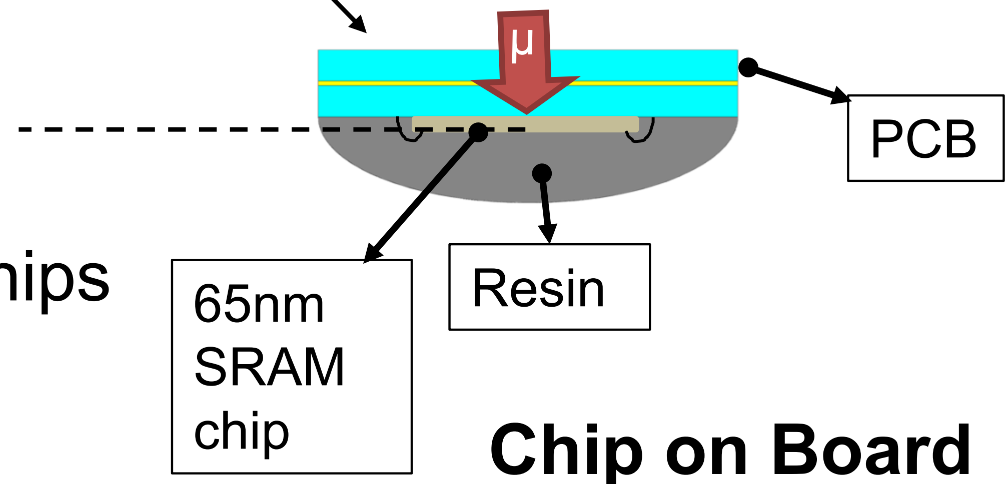

[1],[2]: Sierawski et al., *TNS*, 2010 & *IRPS*, 2014,
[3]:Seifert: *IRPS*, 2015 [4]: S.Serre, *RADECS*, 2012 [5] :J. Dicello, *Nucl. Inst. MPR*,1987

# Experimental setup

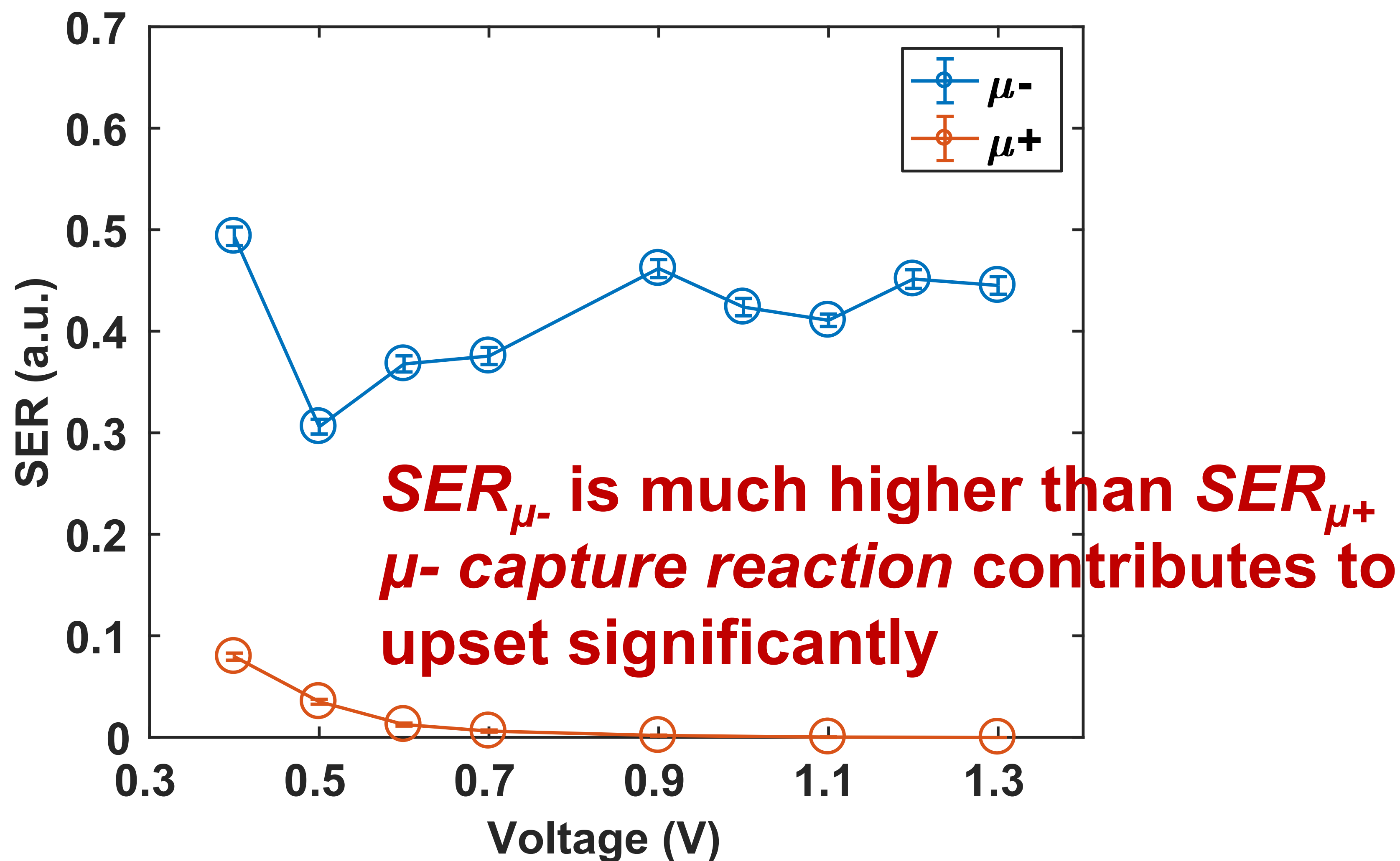



Beam facility:
MUSE
(muon science facility)
of MLF, J-PARC

Control momentum of muon
(@38MeV/c)
for making muons stop inside chips near transistors



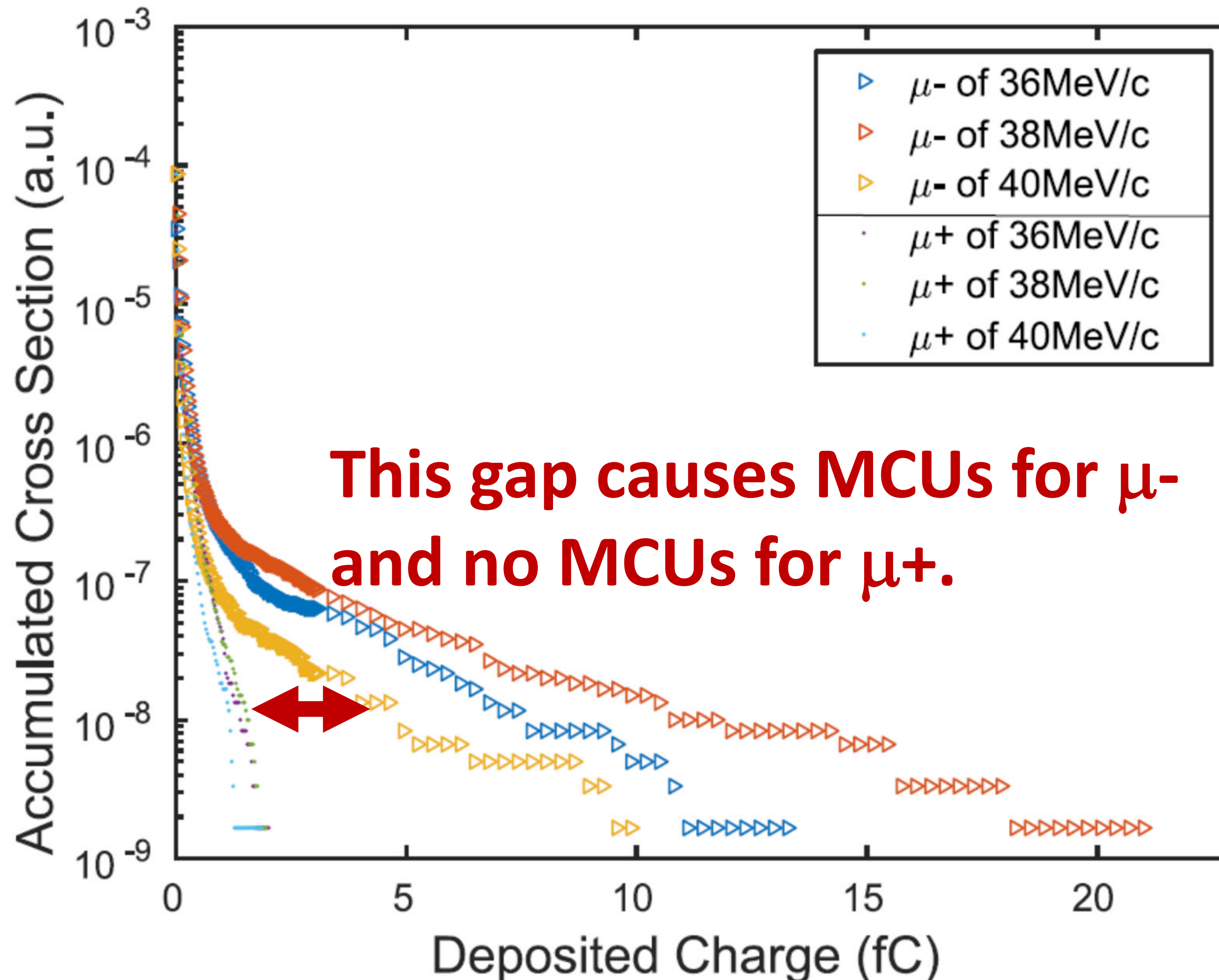
# Positive vs. negative muons in bulk




W. Liao, et al., "Measurement and Mechanism Investigation of Negative and Positive Muon-Induced Upsets in 65nm Bulk SRAMs," *IEEE Trans. Nuclear Science*, August 2018.

# Charge amount induced by positive and negative muons

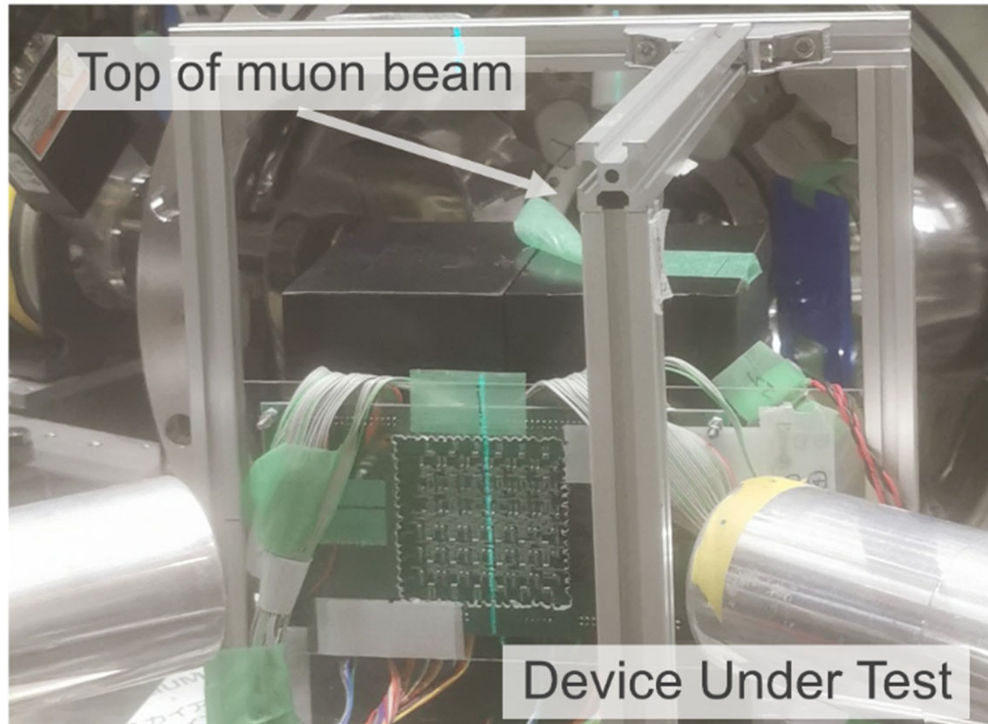
PHITS simulation



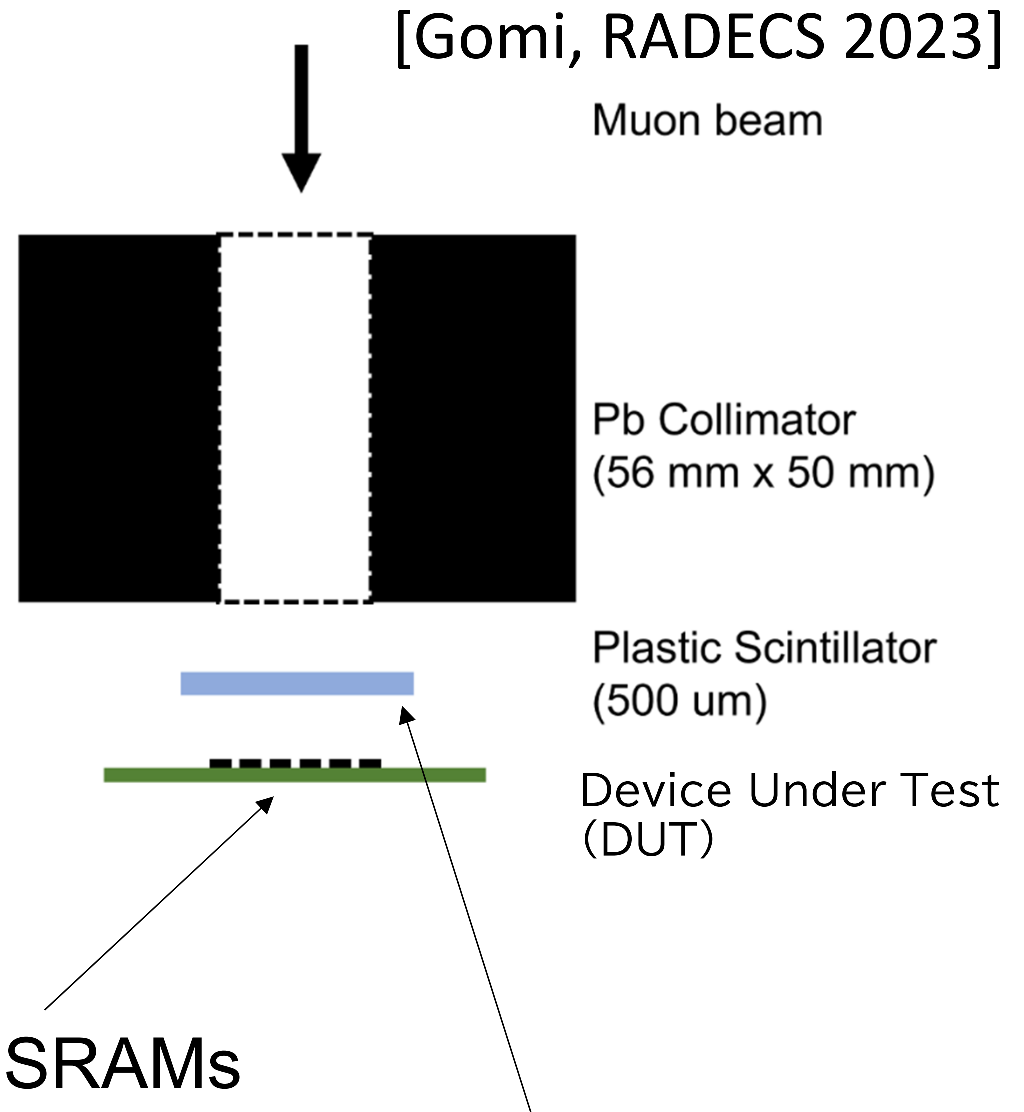

W. Liao, et al., "Measurement and Mechanism Investigation of Negative and Positive Muon-Induced Upsets in 65nm Bulk SRAMs," *IEEE Trans. Nuclear Science*, August 2018.

# Recent experiment for FinFET SRAMs

[Gomi, RADECS 2023]




@J-PARC

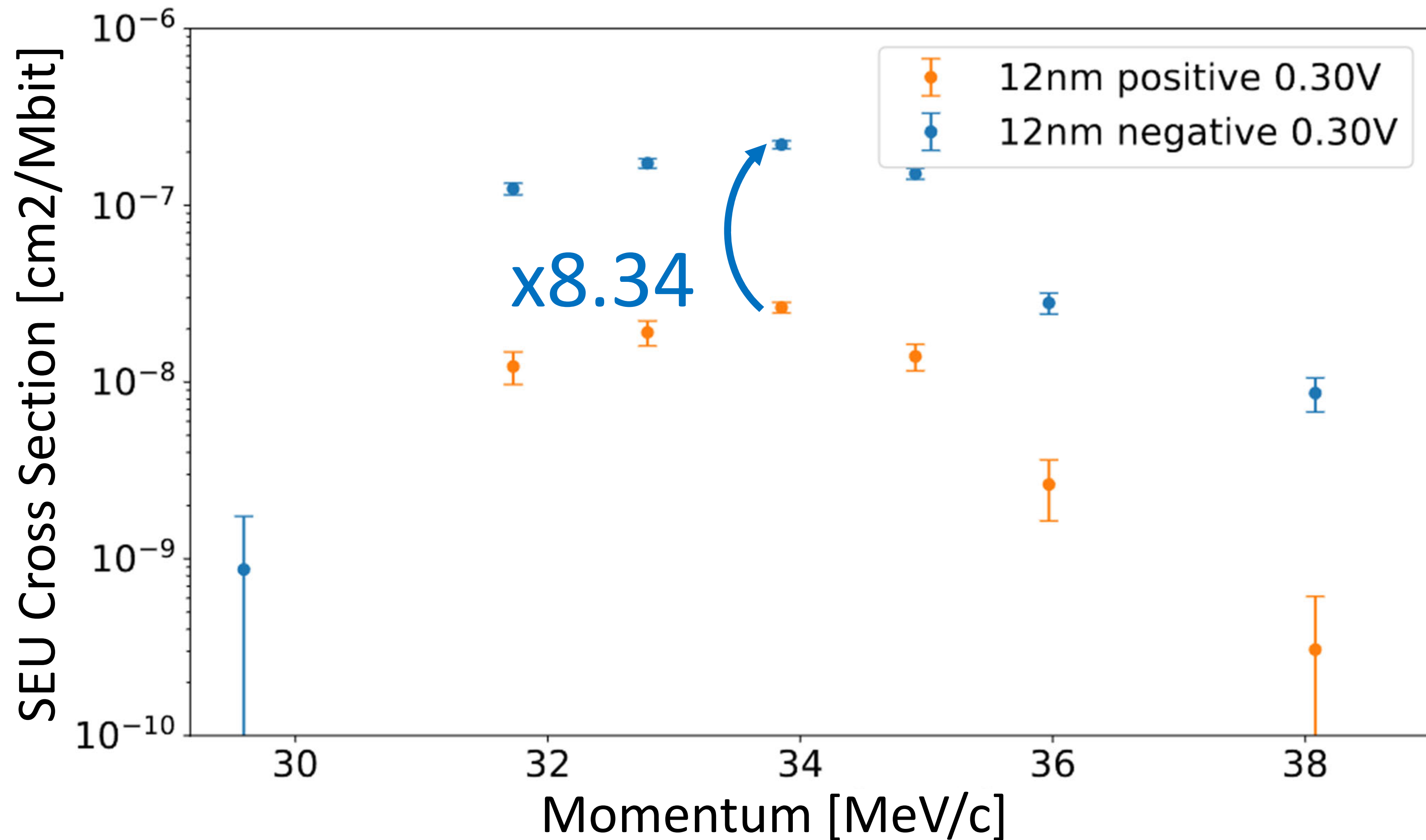



12-nm FinFETs or 28-nm SRAMs

Plastic scintillator counts # of muons

# Dependence of SEU cross section on muon momentum

[Gomi, RADECS 2023]

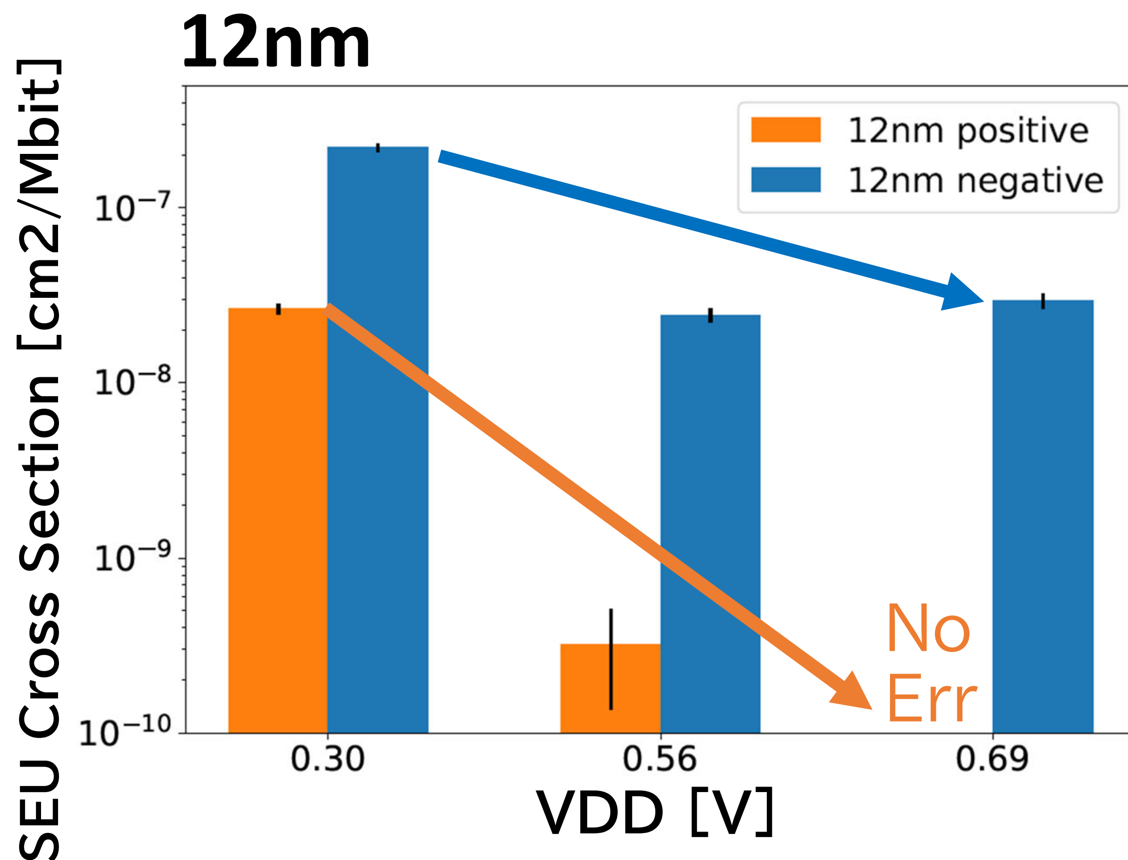


# Dependence of SEU cross section on supply voltage [Gomi, RADECS 2023]

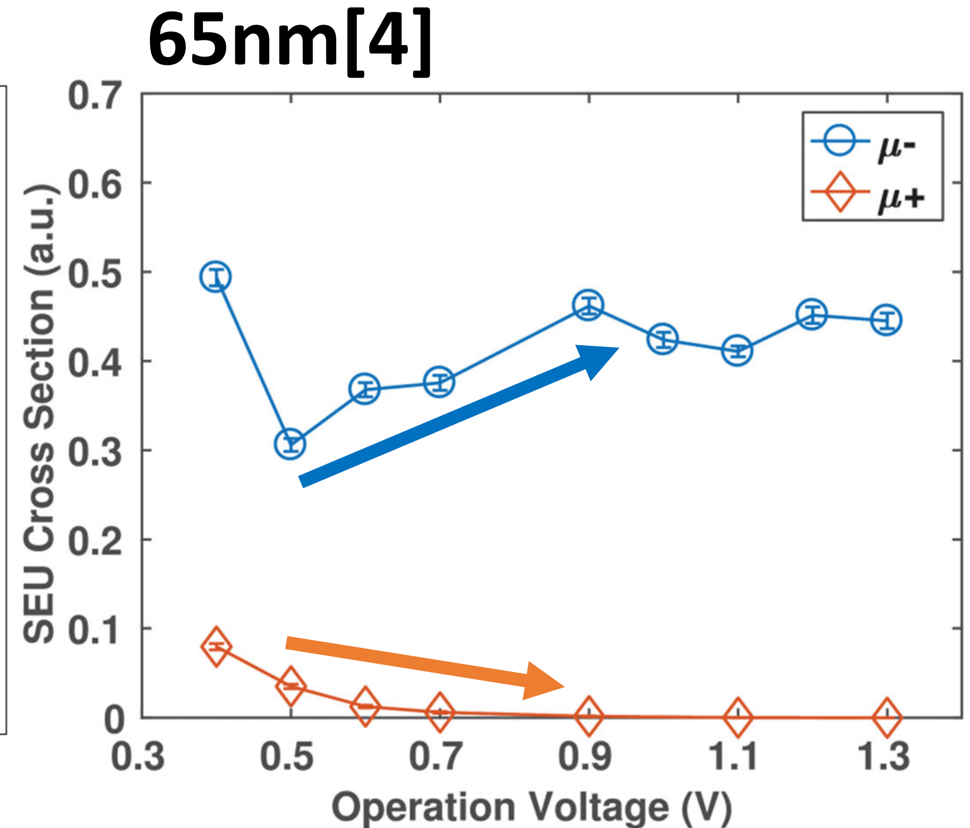
$\mu^-$-induced SEU cross section on 12nm decreases as VDD elevates, different from 65nm.

▶ Weaker contribution of parasitic bipolar effect

**12nm**



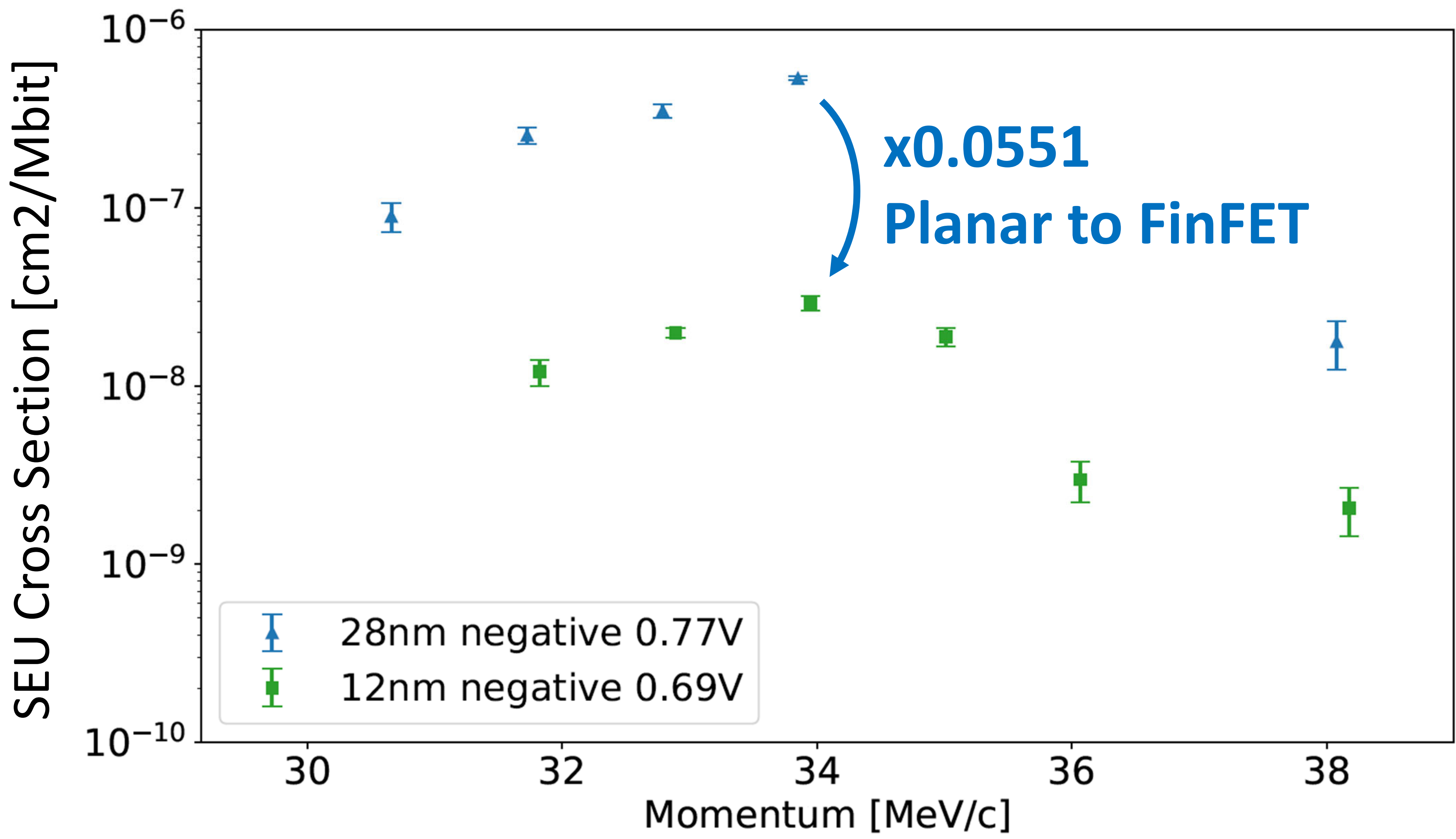

**65nm[4]**




[4] W. Liao et al, TNS, 2018.

# Comparison b/w 12nm FinFET and 28nm planar

[Gomi, RADECS 2023]

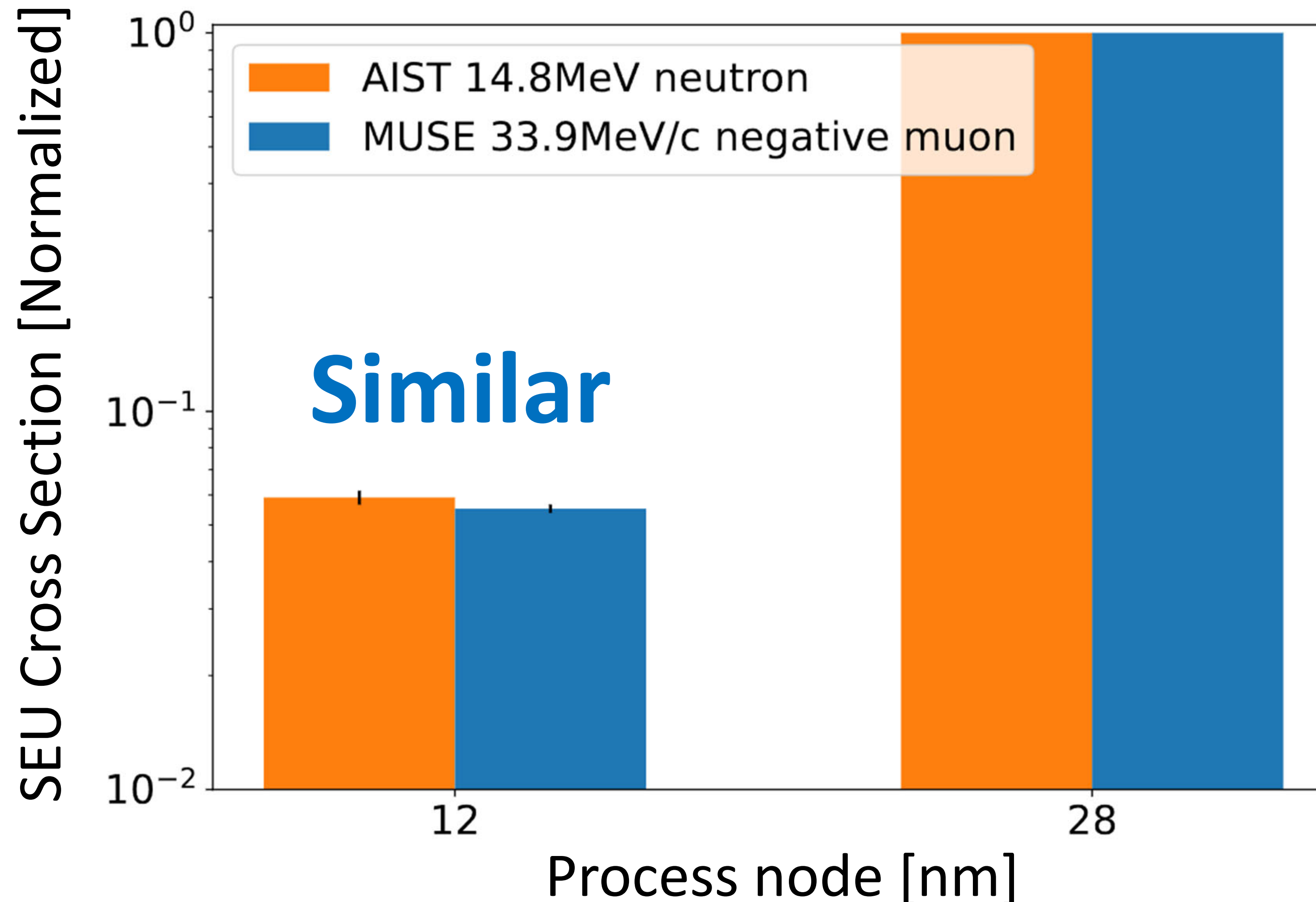


# Comparison b/w μ⁻ and neutron

[Gomi, RADECS 2023]

Similar reduction ratio from 28nm to 12nm

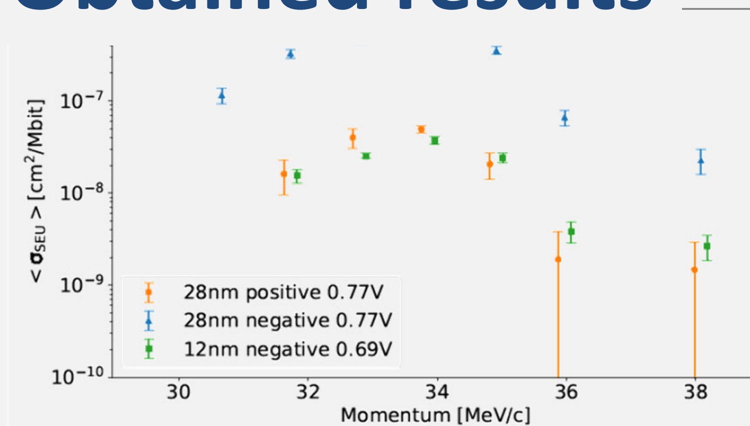
- **Similar secondary ions are causing SEUs**

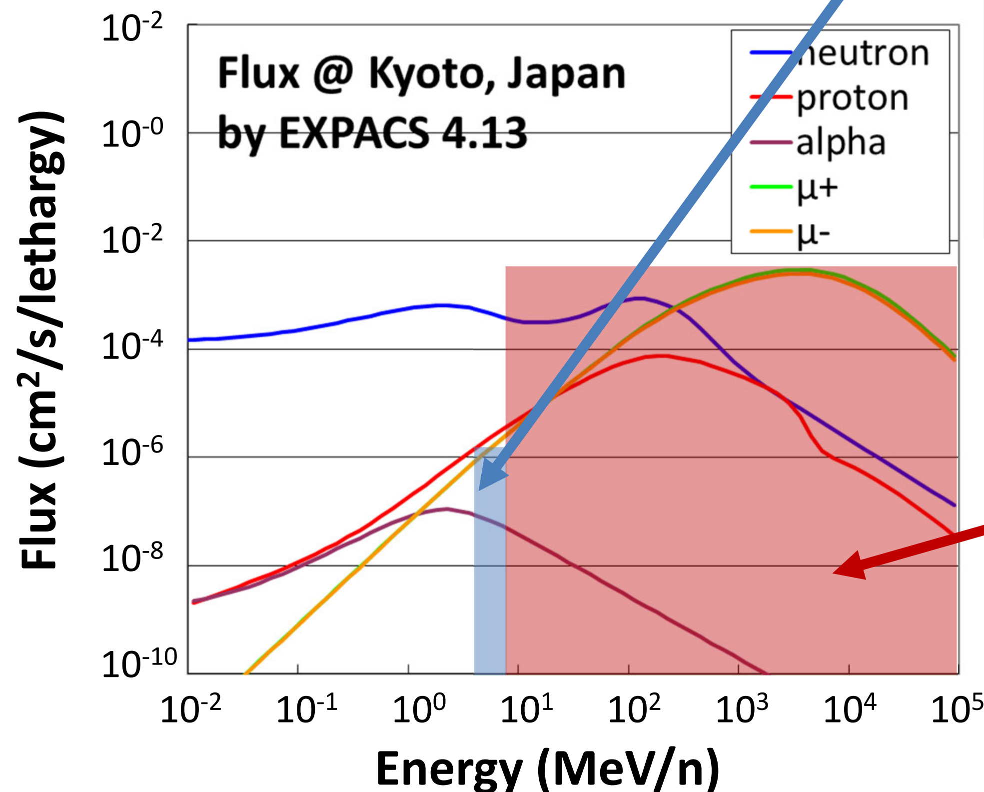


# Conclusion and future direction

- Muons stopping near transistors cause SEUs.
- No increase to 12nm FinFET similar to neutrons

**Need to know muon-induced SEU cross section across all energy range**




**No evaluation despite abundant muons (even e⁻ can induce SEUs)**