# Particle-induced charge generation in advanced power transistors

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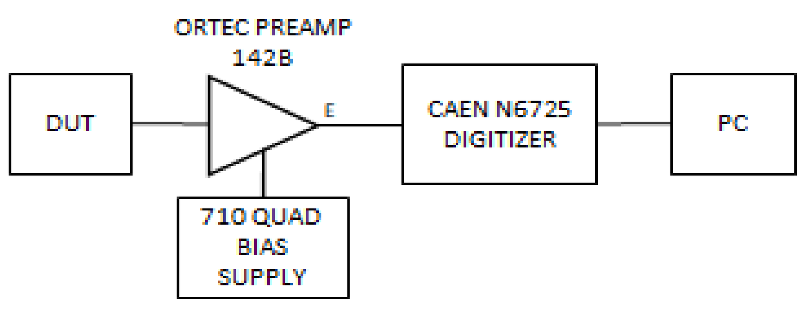
## 1. Introduction

Alpha particles are one of the most abundant species in the space radiation environment, whereas neutrons are the main component of the radiation field on Earth. Relatively few studies have been published for alpha-particle- and neutron-induced Single-Event Effects (SEEs) in advanced technologies such as UMOSFETs, the current main candidate to supplant the traditional DMOSFET technology, and in the state-of-the-art GaN-on-Si HEMTs. In this work, experimental results of SEEs induced by alpha-particles in DMOSFET and UMOSFET technologies, and by quasi-monoenergetic fast neutrons in DMOSFET, UMOSFET, NEXFET, and GaN-on-Si HEMT technologies are presented. Some aspects of the ion-induced charge collection in these devices are discussed. Based on an existing model from the literature for SEE worst-case response prediction in DMOSFETs, a predictive model for SEE worst-case response in UMOSFETs is proposed.

## 2. Methodology

### Experimental setup




Electronic acquisition system diagram for particle-induced charge spectroscopy in transistors.

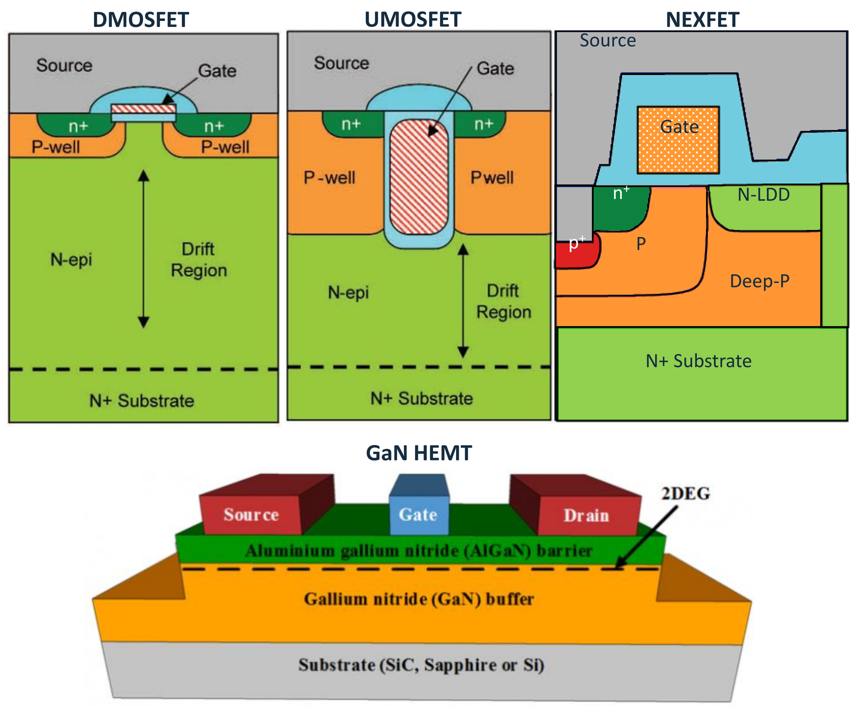
- **Alpha-particles:** $^{241}$Am radiation source. Activity of $3.4(1) \times 10^5\ \alpha$/s and peak centroid 4.84(9) MeV. Tests carried out in high-vacuum.
- **Fast neutrons:** Deuteron-Tritium neutron generator with a typical yield of about $10^8\ n$/s with ~14 MeV.

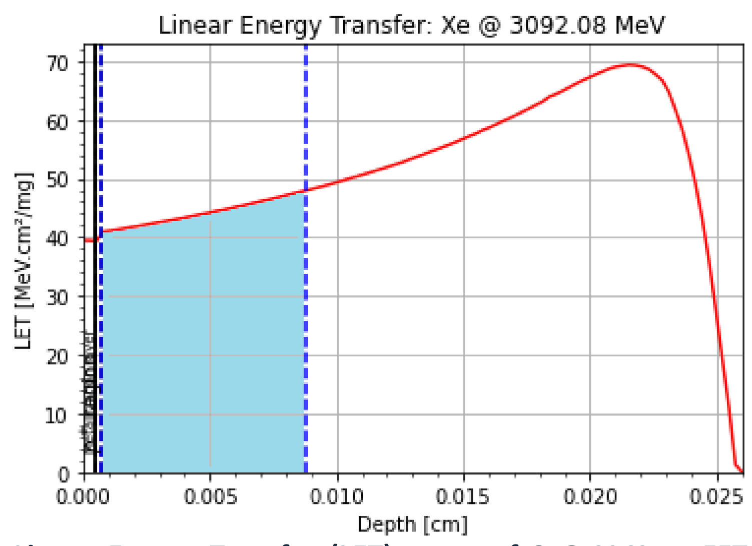
### Computational methods: SEE worst-case response

Titus *et al.* (IEEE TNS, 2003) developed and experimentally demonstrated the relevance of their model for the SEGR worst-case response prediction. The model of Titus *et al.* solely considers charge collection contribution via drift mechanism.

$$E_{crit} = \left[\frac{Z^{1.333} \cdot BV_{DS}}{176} + \frac{382 \cdot Z}{112 - Z}\right] \sqrt{\frac{V_{DS}}{BV_{DS}}}$$

### Transistor technologies



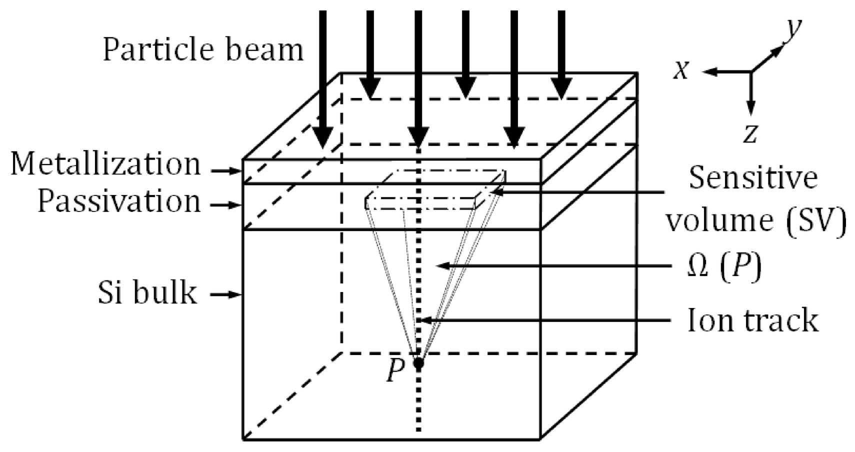




Linear Energy Transfer (LET) curve of 3 GeV Xe a FET structure. Calculated using SRIM code.

### A proposed model for SEE worst-case response in UMOSFETs

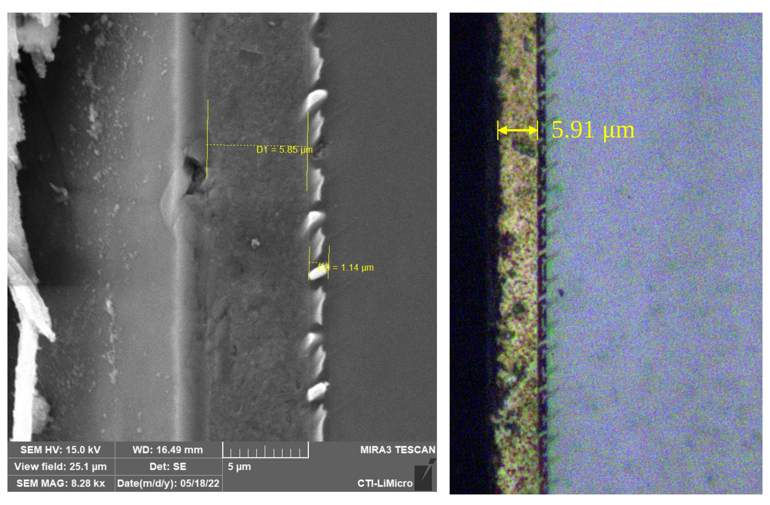
Including a pseudo-diffusion model introduced by Wrobel *et al.* (IEEE TNS, 2006):

$$Q_{col} = Q_{dep}(P) \cdot \frac{\Omega(P)}{4\pi}.$$



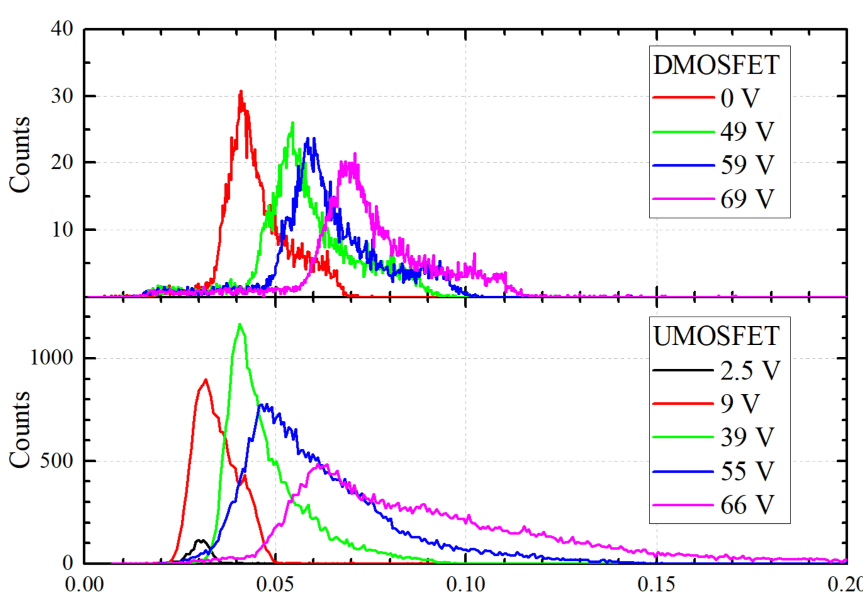

Principle of the diffusion model of Wrobel et al. [6].

- **Case study: a 60 V UMOSFET**

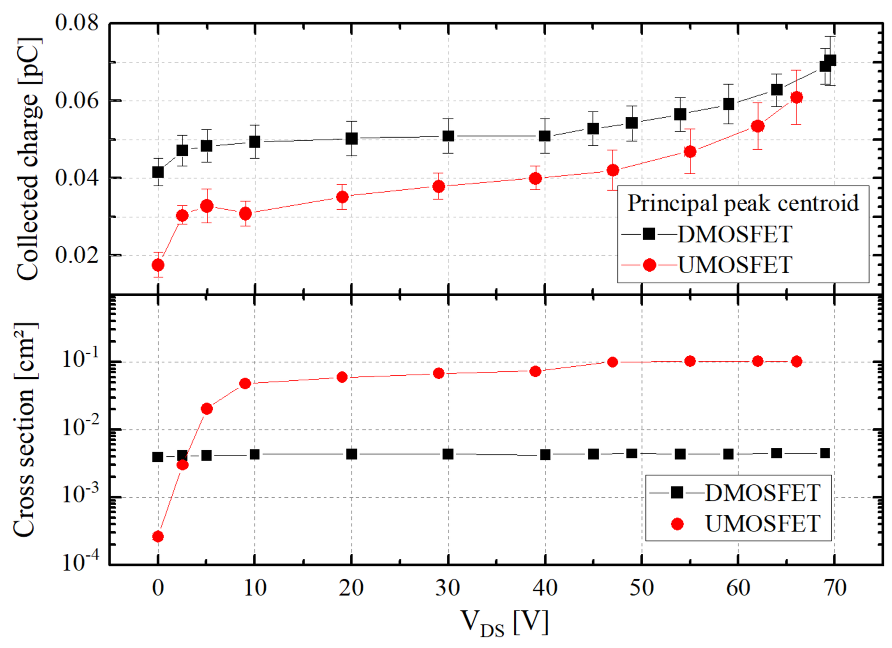



UMOSFET parameters were extracted from Scanning Electron Microscopy (SEM) and Optical Microscopy (OM).

## 3.1. Results: alpha-particle irradiation



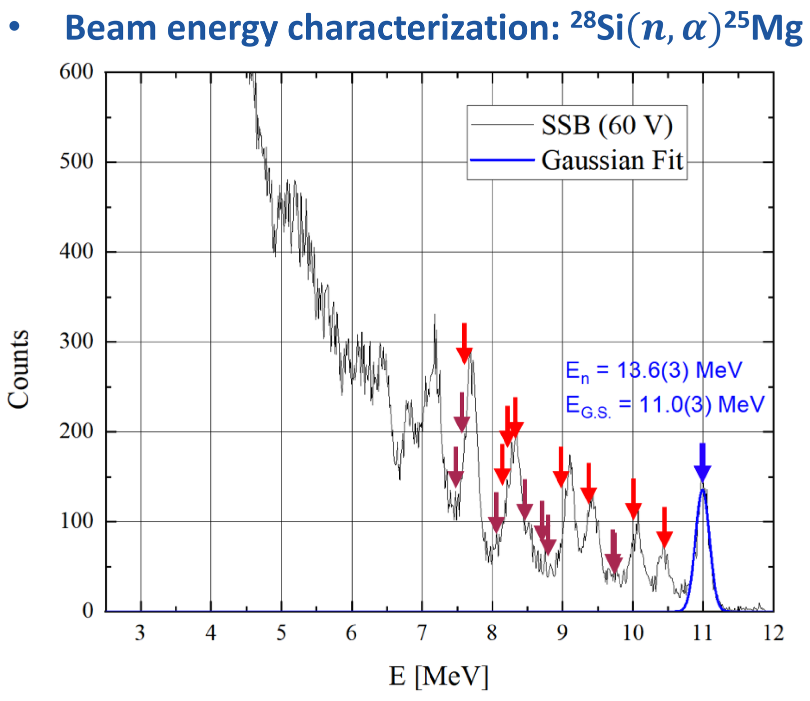

Collected charge spectra of alpha-induced SEEs in the DMOSFET (top) and the UMOSFET (bottom) for several $V_{DD}$. The charge spectra were normalized to the same fluence.




Collected charge principal peak centroid (top) and SEE cross section (bottom) induced by alpha-particles as a function of $V_{DS}$ for the DMOSFET and UMOSFET.

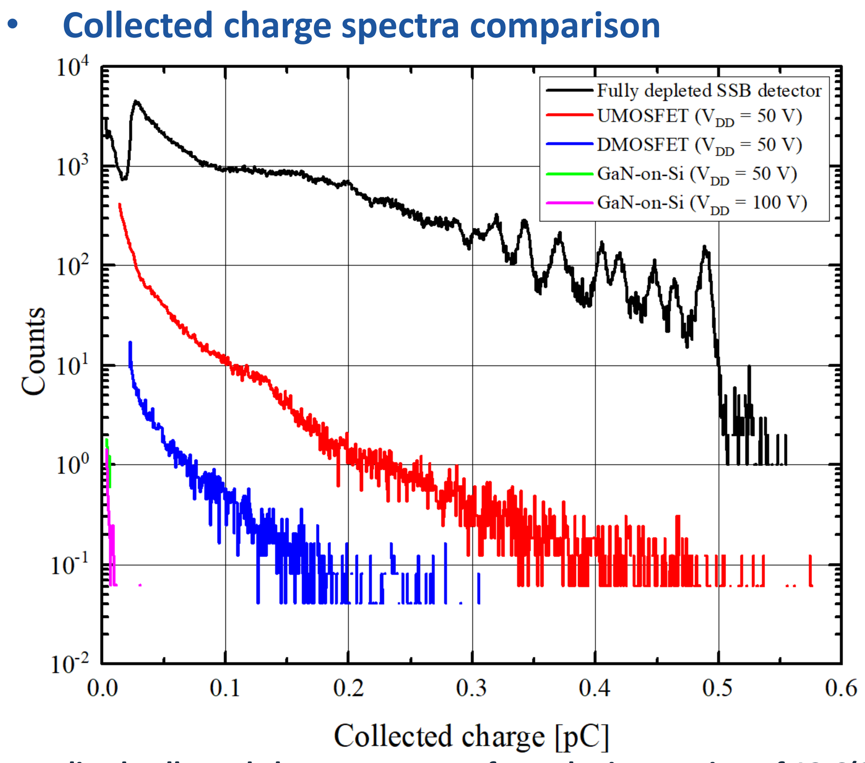
## 3.2 Results: neutron irradiation

- **Beam energy characterization:** $^{28}$Si$(n,\alpha)^{25}$Mg




Energy spectrum produced by the interaction of fast neutrons with a fully-depleted SSB detector. The excited levels of $^{25}$Mg (red) and $^{28}$Al (wine) are shown.

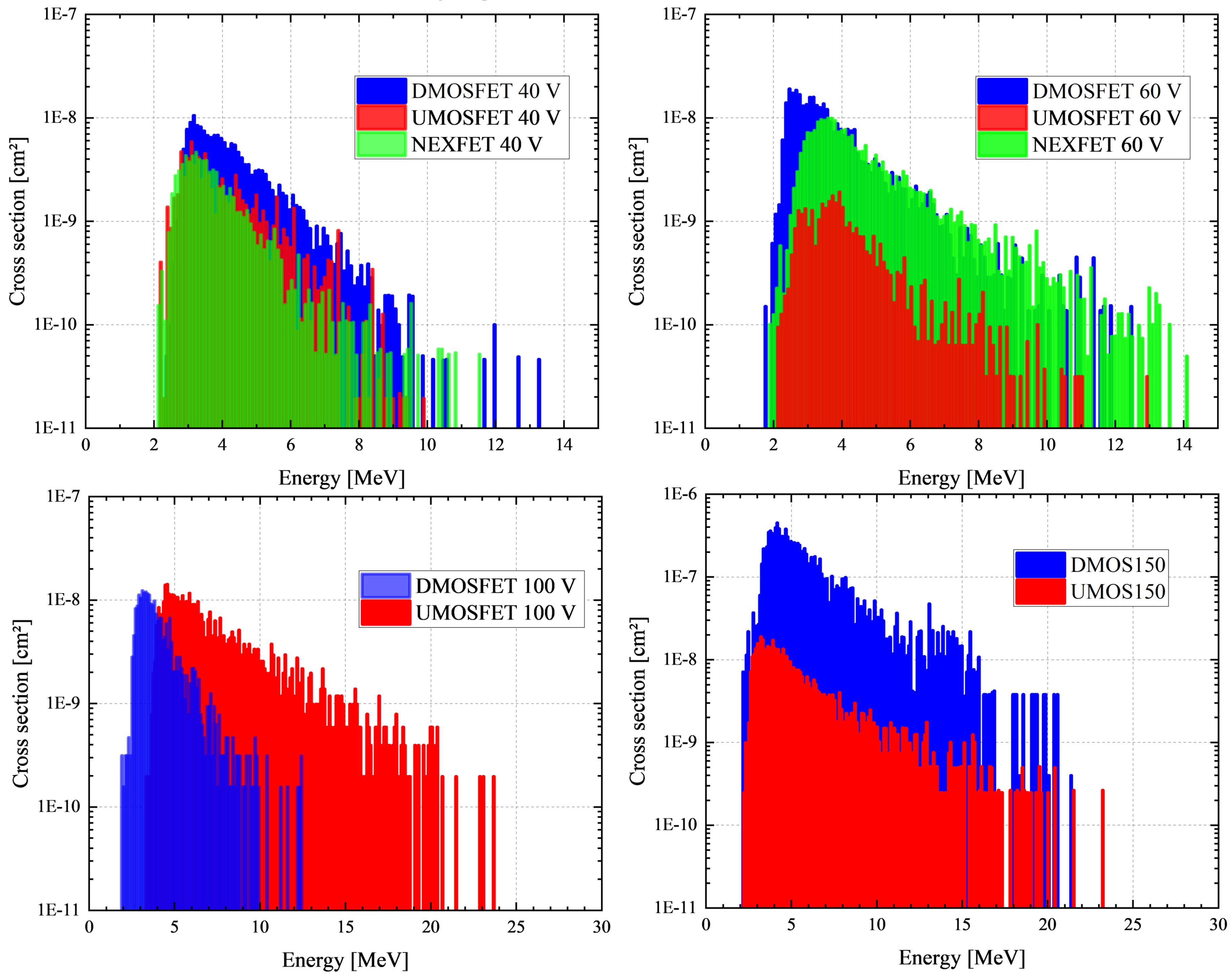
- **Collected charge spectra comparison**



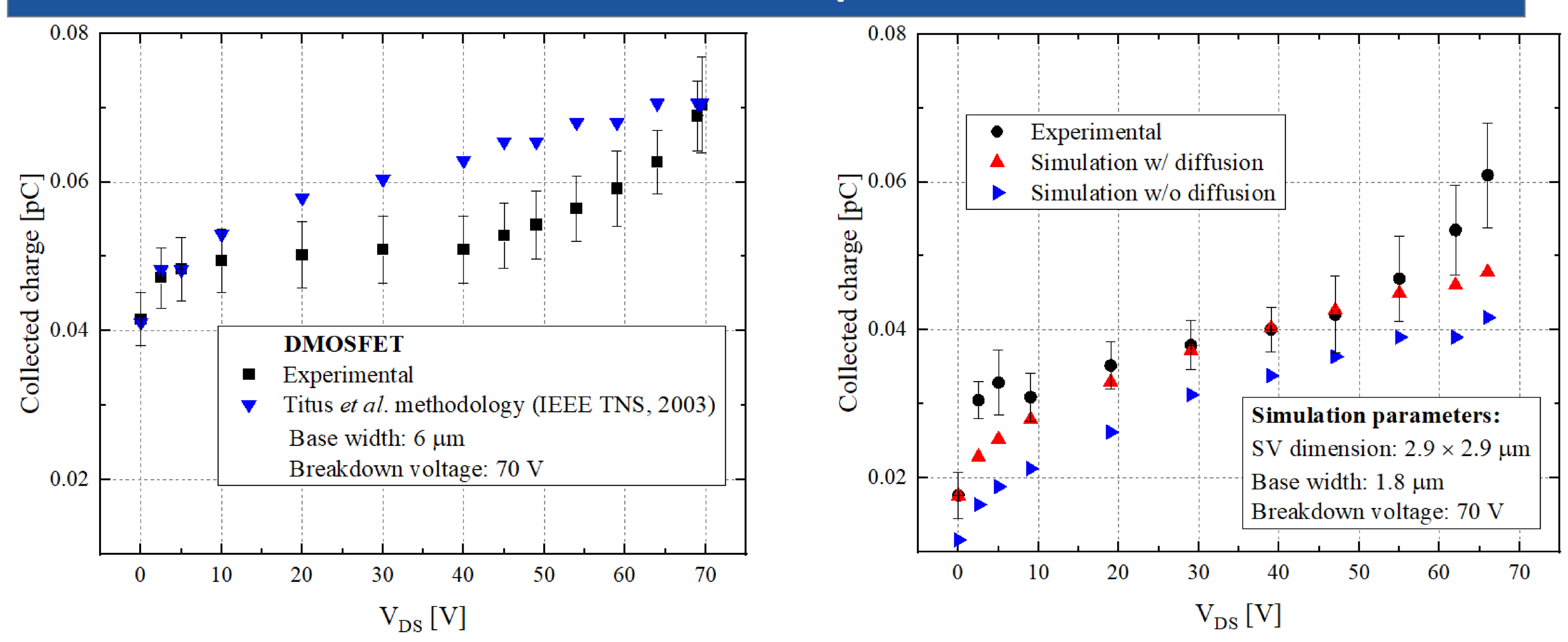

Normalized collected charge spectrum from the interaction of 13.6(3) MeV neutrons with a fully depleted SSB and the power transistors.

## 3.2 Results: neutron irradiation

### Neutron irradiation: 2[nd] campaign



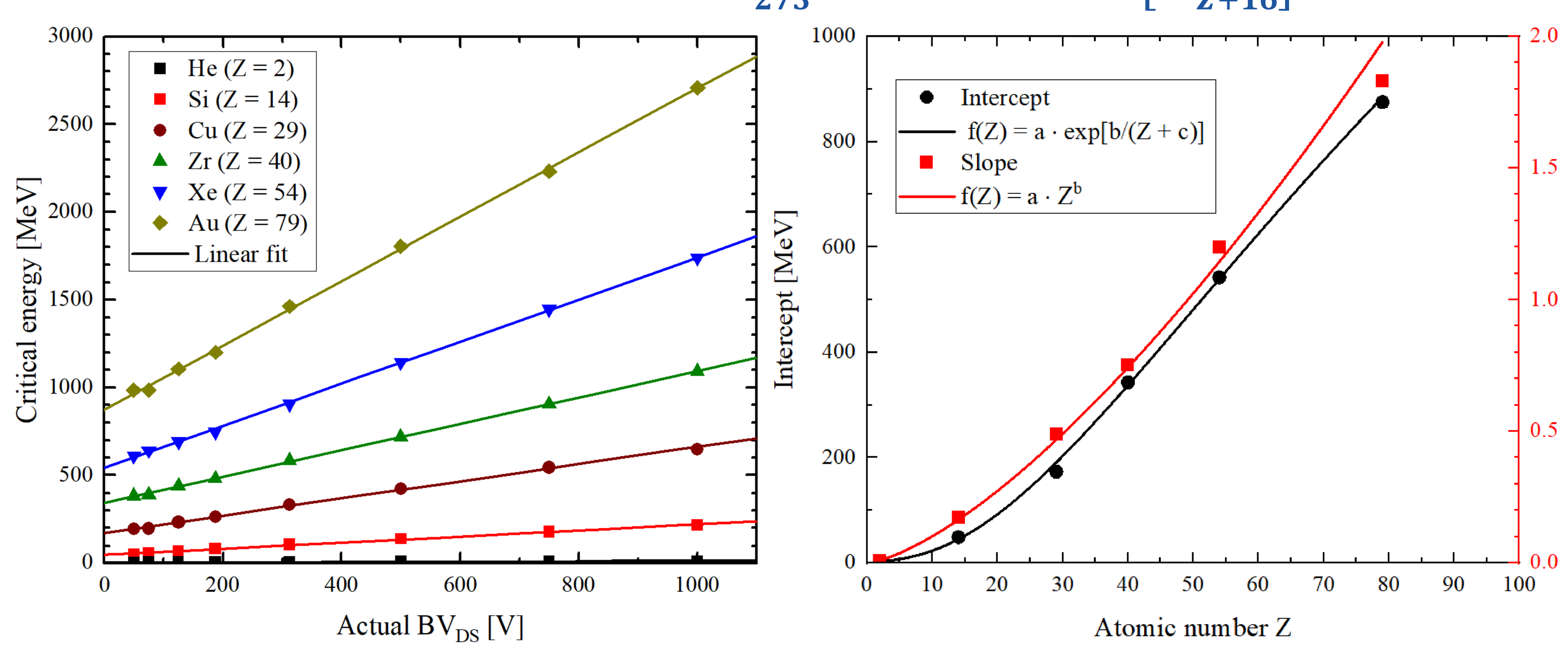

## 3.3. Results: computational



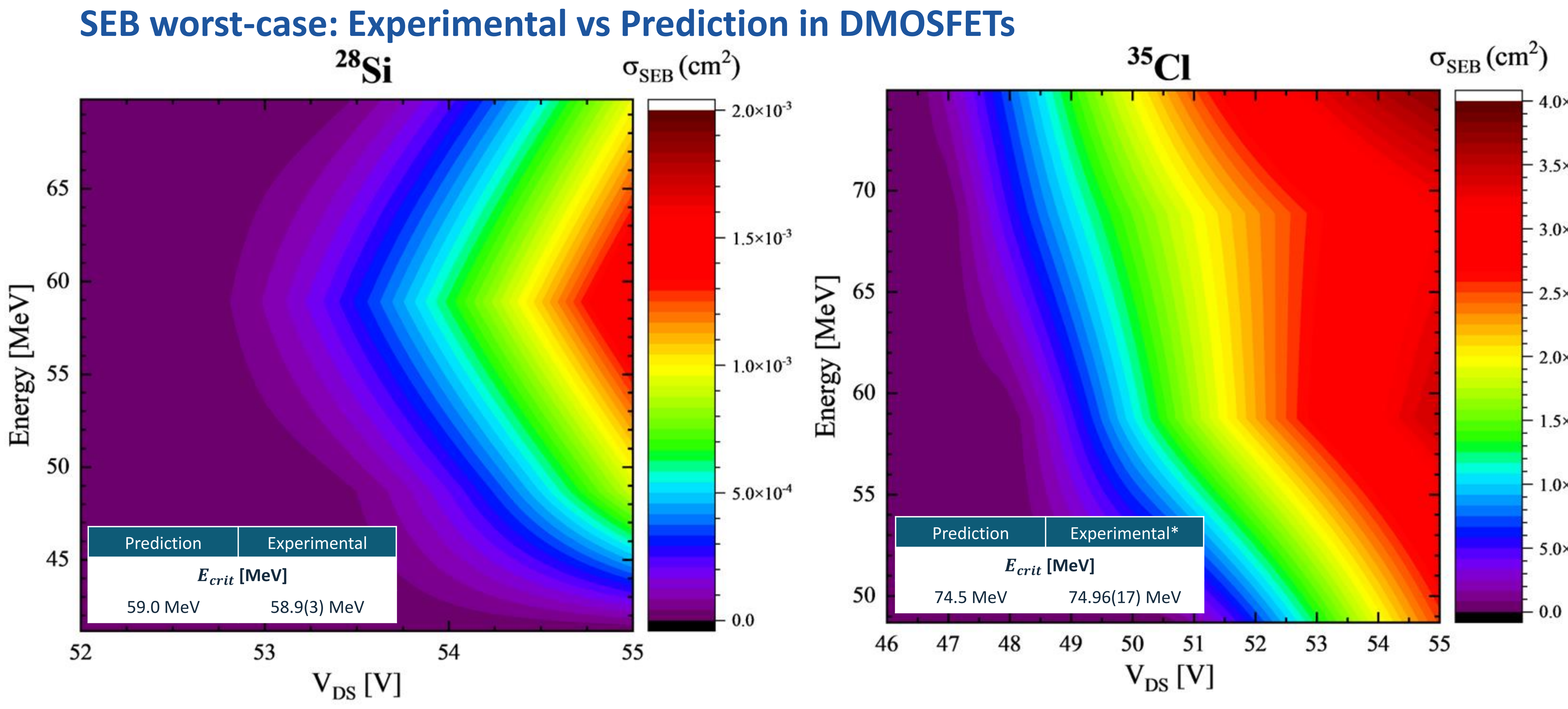

Experimental and calculated collected charge in the DMOSFET induced by 4.8 MeV alpha-particles. Calculations based on model presented by Titus et al. (IEEE TNS, 2003).

Experimental and calculated collected charge in the UMOSFET induced by 4.8 MeV alpha-particles by using the proposed model presented in this work.

### Computational systematics: $E_{crit} = \frac{Z^{1.44} \cdot BV_{DS}}{273} + 3565 \cdot \exp\left[-\frac{133}{Z+16}\right]$




### SEB worst-case: Experimental vs Prediction in DMOSFETs




## 4. CONCLUSIONS

It was experimentally verified that, in general, ion-induced carrier multiplication is a prominent phenomenon in UMOSFET technology. This observation is attributed due to its high cell density and the intense electric field near the trench gate corner. Among the tested devices, the GaN-on-Si HEMT presented very high robustness to SEEs induced by fast neutrons. We provided experimental evidence that the methodology of Titus et al. is relevant for SEB worst-case prediction in DMOSFETs. Nevertheless, their model is unable to accurately reproduce the charge collection/deposition in UMOSFETs. Based on a diffusion model from the literature, a predictive model for SEB worst-case response in UMOSFETs is presented.