Investigation of cosmic ray effects on silicon carbide power MOSFETs and future requirements

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Agenda

1 Who we are

2 Radiation effects on power devices

3 Neutron research projects

4 Neutron failure mechanisms in power devices

5 Atmospheric neutron spectrum and altitude effect

6 Neutron destructive test results

7 Neutron no-destructive test results

8 Needs of new radiation facilities

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Who we are

We are creators and makers of technology

One of the world's largest semiconductor companies

Over **50,000** employees of which **9,500+** in R&D

$17.3 billion revenues in 2023

Over **80** sales & marketing offices serving over **200,000** customers across the globe

14 main manufacturing sites

Signatory of the United Nations Global Compact (UNGC)
Member of the Responsible Business Alliance (RBA)

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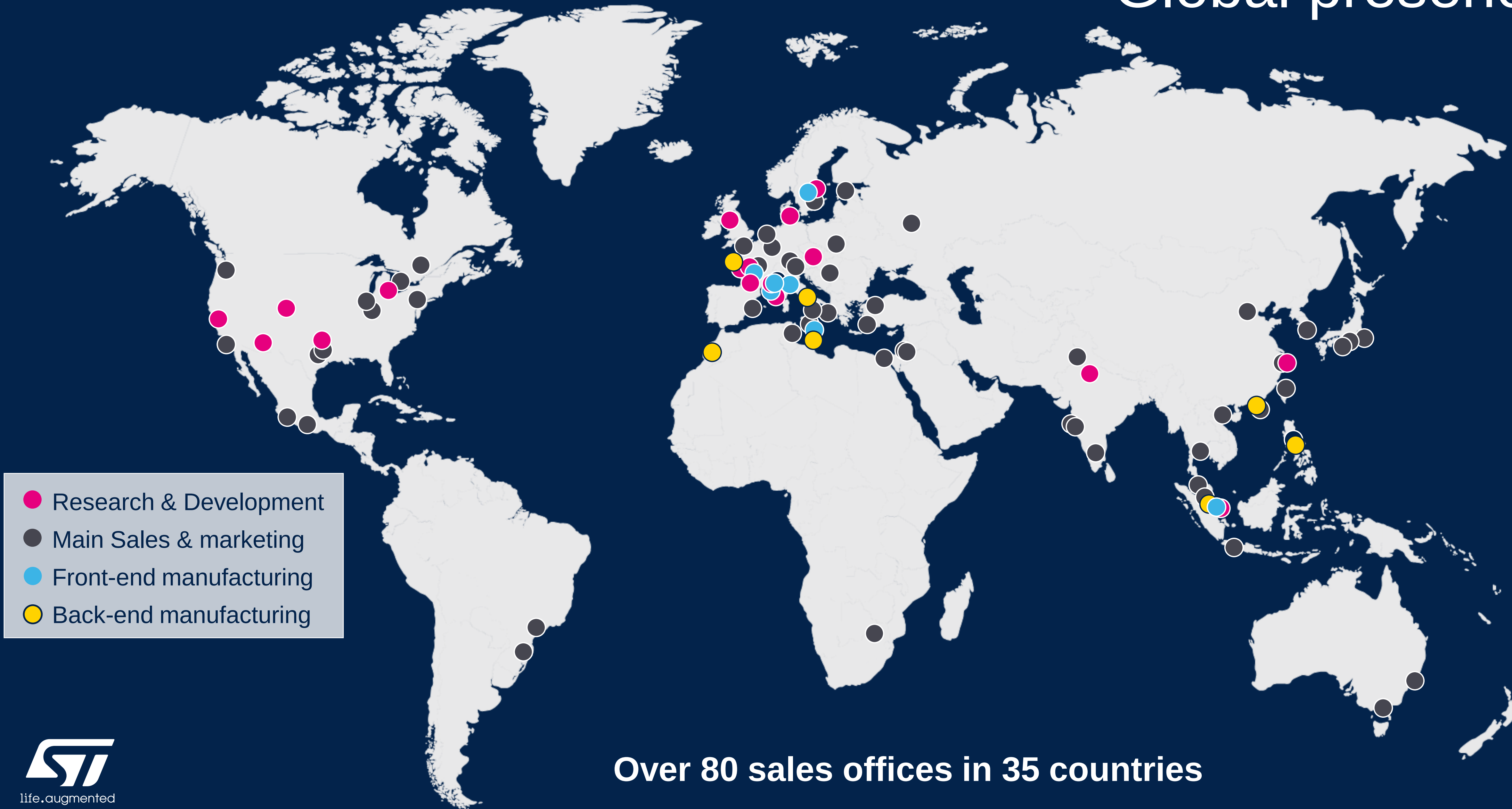
As of December 31, 2023

Global presence



Over 80 sales offices in 35 countries

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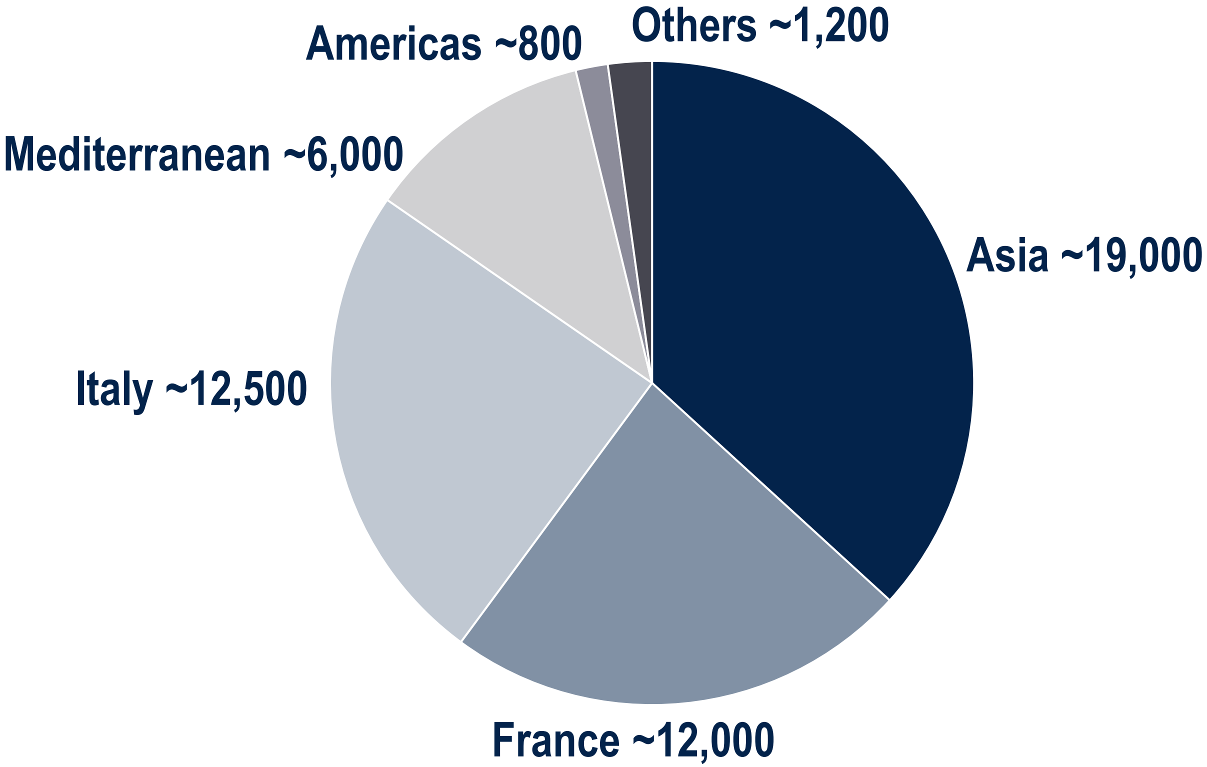
Our technology starts with our people



Manufacturing	~ 64%
Research & Development	~ 18%
Marketing & Sales, Divisional Functions, Administration & General services	~ 18%

As of December 31, 2023

Today's challenge: energy!

Smart Mobility

Electric vehicles sales* from ~10 million in 2021 to **~30 million** in 2025

Over **30**% global electricity demand increase from 2020 to 2030

Power & Energy

45% CO_2 emission reduction from 2010 to 2030 to limit warming to 1.5°C

Electrical energy from renewal sources from **~10%** in 2020 to **~20%** in 2030

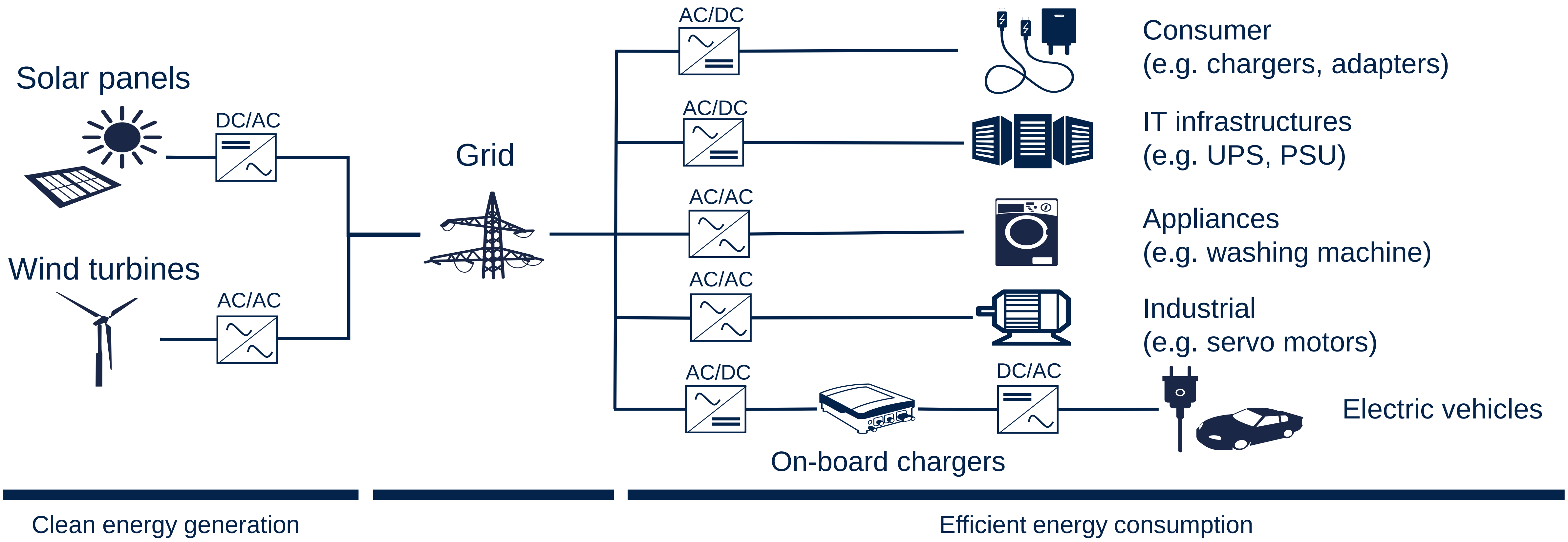
Internet of Things & Connectivity

Four billion cellular IoT connections by 2025

More than **20 Billion** IoT connected devices per year by 2025

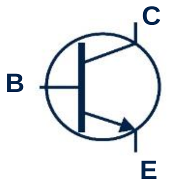
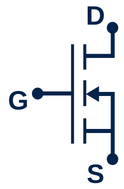
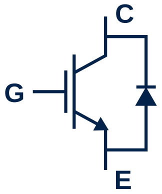
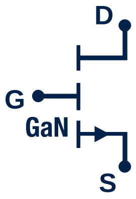
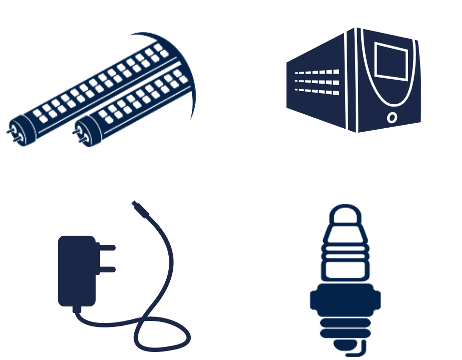
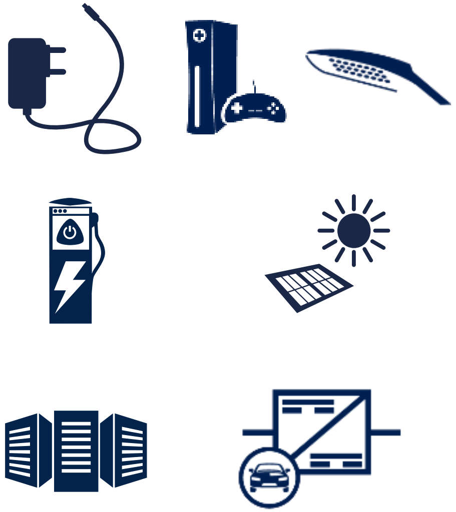
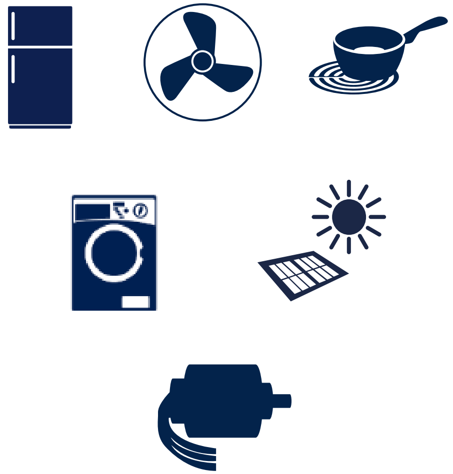
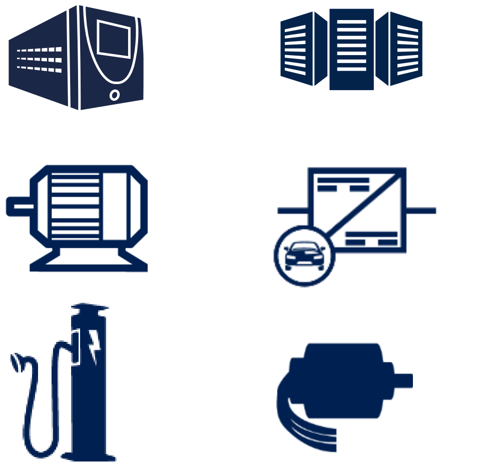
Electricity becomes the most important energy carrier

Power semiconductor is key for the conversion, control and processing of electricity



Power transistor Sub-Group

Portfolio overview by technologies and applications

Silicon-based transistors			WBG-based transistors	
 Power Bipolar	 MOSFET	 IGBT	 SiC MOSFET	 Power GaN Transistor
V_{CES} from 15V to 1,700V	V_{DS} from 250V to 1,700V	V_{CES} from 300V to 1,700V	V_{DS} from 650V to 2,200V	V_{DS} 100V, 650V to 900V
				

Main applications needing high voltage power transistors

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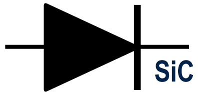
Discretes technologies range

Enabling innovation technologies for industrial and automotive

STPOWER · ST PROTECT



Wide-bandgap-based

650 V and 1200V

SiC / GaN RECTIFIER (STPOWER)

- Power supply
- Solar inverter
- UPS
- LED Light
- OBC , V2L
- Charging Station

Silicon-based

600 V to 1600V

THYRISTOR & RECTIFIER (STPOWER)

- Ind. Motor EV traction
- Circuit breaker
- Power supply
- Charging Station
- BMS, OBC
- Solar inverter

5 V to 500 V

TVS & ESD PROTECTION (ST PROTECT)

- Automation
- Gaming-Adapter
- Medical
- Body & convenience
- Traction inverter
- ADAS

Radiation effects on power devices

Space environmental

Ionizing radiation

X and gamma rays

TID test

Degradation of electrical performance is mainly due to charge trapping in the oxide

Radiation particle

Light and heavy ions

SEE test

The strike of ions can damage or destroy the power device in some operating conditions

Earth's atmosphere

Cosmic ray

Cosmic rays produce protons and neutrons down to sea level:
At altitude 0 – 12km, the main particles are neutrons with energy 0 – 1GeV

- 13 n/cm2 h (flux at sea level)
- 6000 n/cm2 h (flux at 12km)

Neutron test

The neutron strikes can destroy the power device in some operating conditions

EFFECTS on power devices

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Neutron research projects

Research projects

- Cosmic ray effects on power high voltage MOSFETs (BVDss>250V)
- Temperature effects on the neutron interaction performance in the silicon and SiC power high voltage MOSFETs
- Combine application stressing mechanism and neutron interaction

Test campaigns inside SWIMMR

(ISIS experiment numbers)
RB2000005 - 2019
RB – 2020
RB No: 2200028 – 2022
RB **2320007** – 2023
RB 2410040 (test planned in Oct)

Acknowledgment

It was performed inside the SWIMMR (funded by UK) project and in cooperation by:

- CHIPIR facility
- Physics and Chemistry Department of Palermo University
- STMicroelectronics

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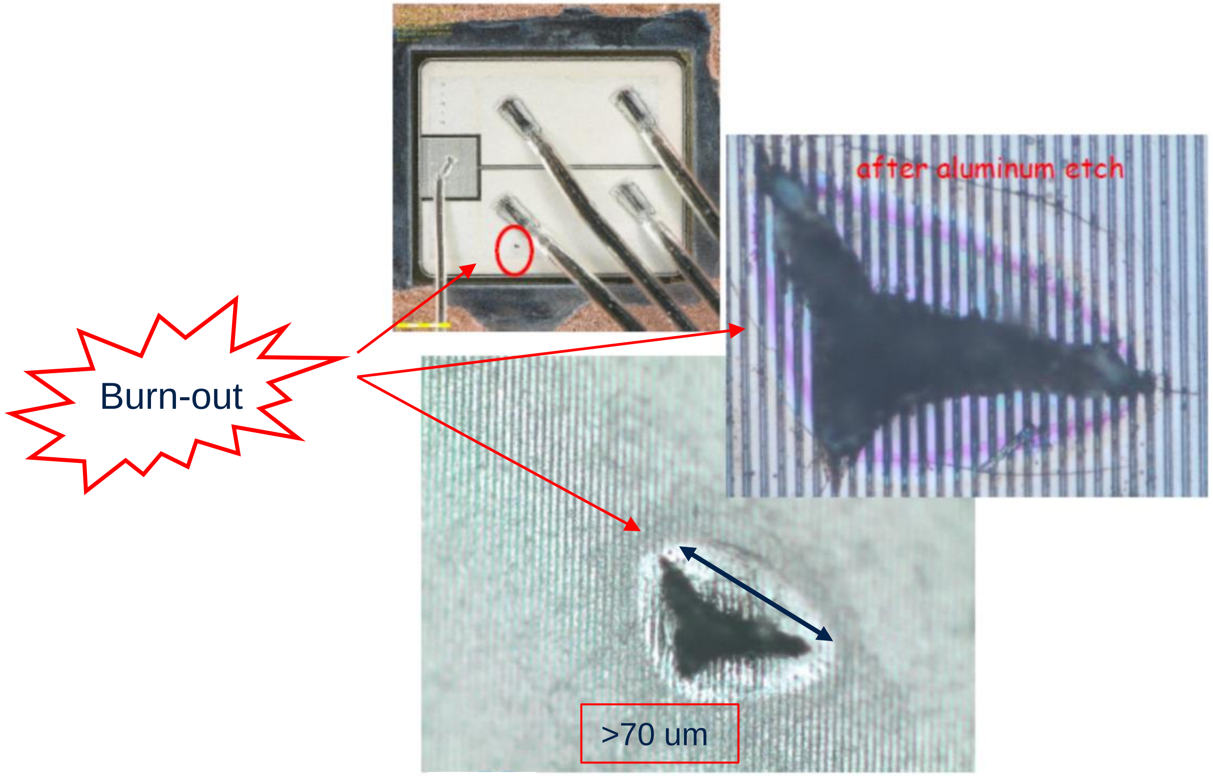
Neutron failure mechanisms in power devices

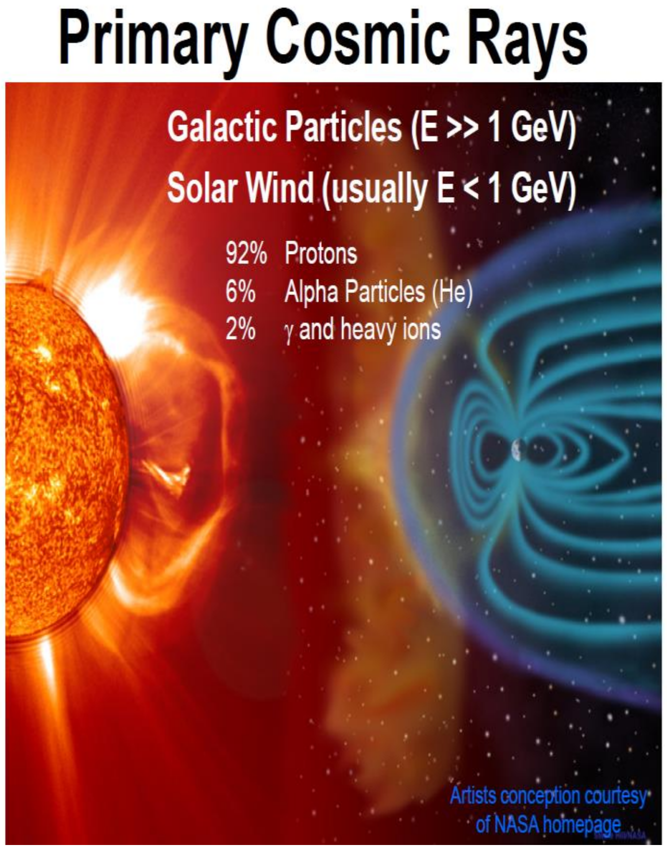
SEB (single event burn-out) could occur in power devices, operating at high voltage, when a neutron passes through it.

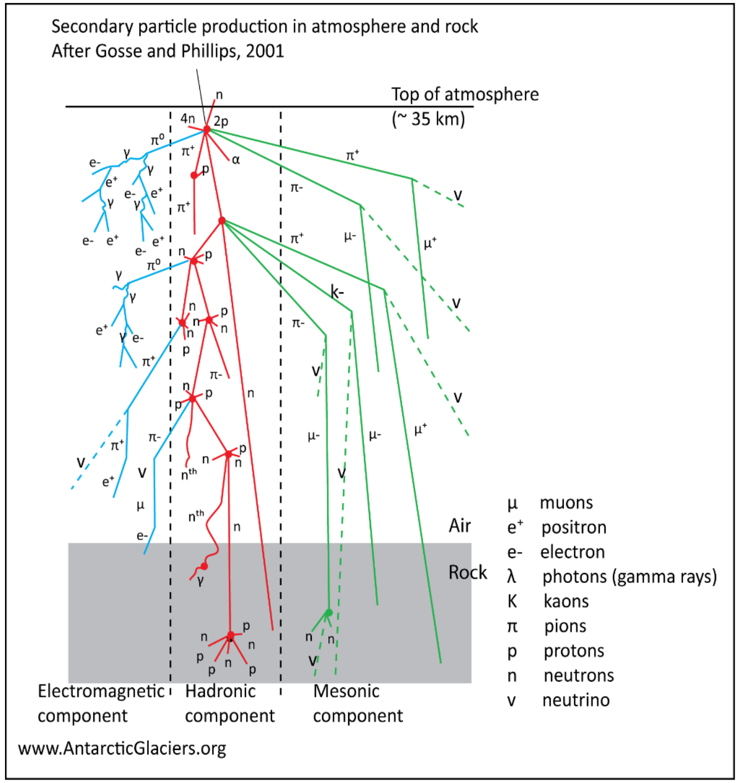


The device is **OVER**

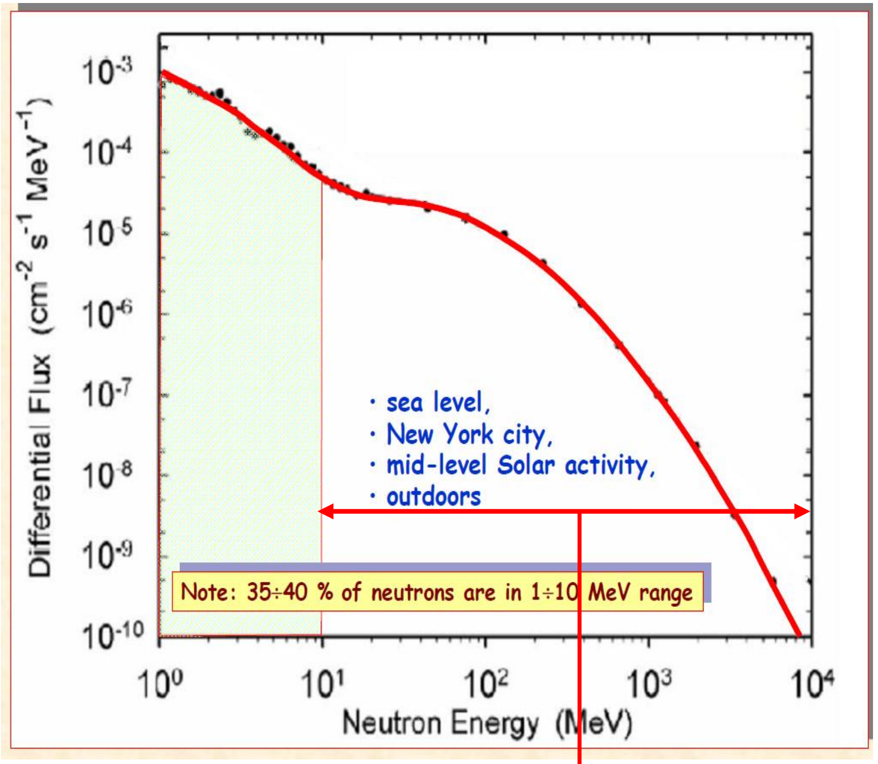
IMPROVING KNOWLEDGE: Neutron effects on power devices

Atmospheric neutron spectrum





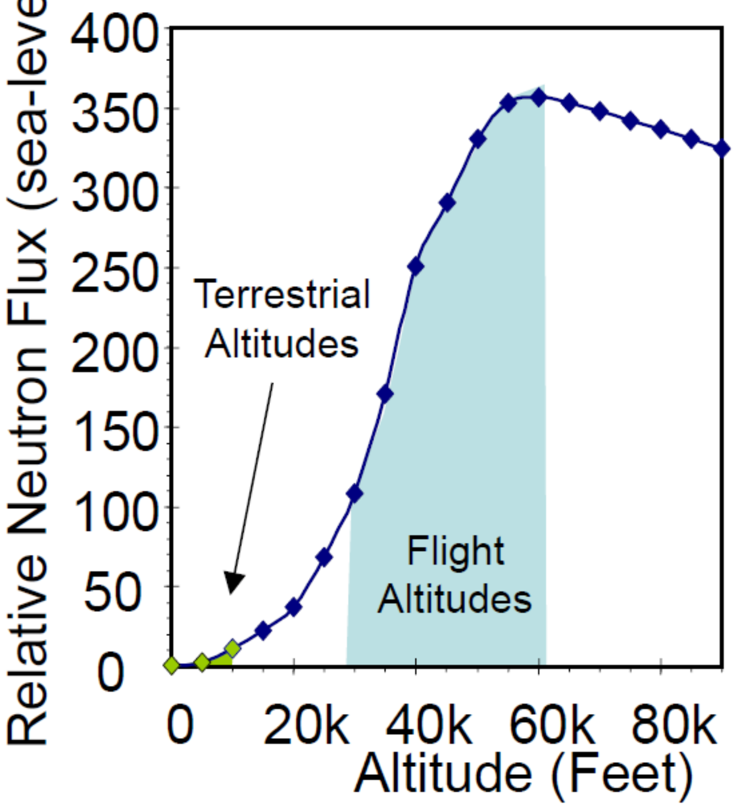
Typical atmospheric neutron spectrum



Neutrons in this energy range can start the SEB failure in the voltage operation bias. Flux = **13n/cm^2 h** (Based on JESD89B spec)

Altitude effect in neutron

After Eugene Normand, “Single Event Effects in Avionics”, IEEE Trans. Nucl. Sci., 43(2), April 1996, pp. 463.



Pop. data from public World Bank and CIA Databases

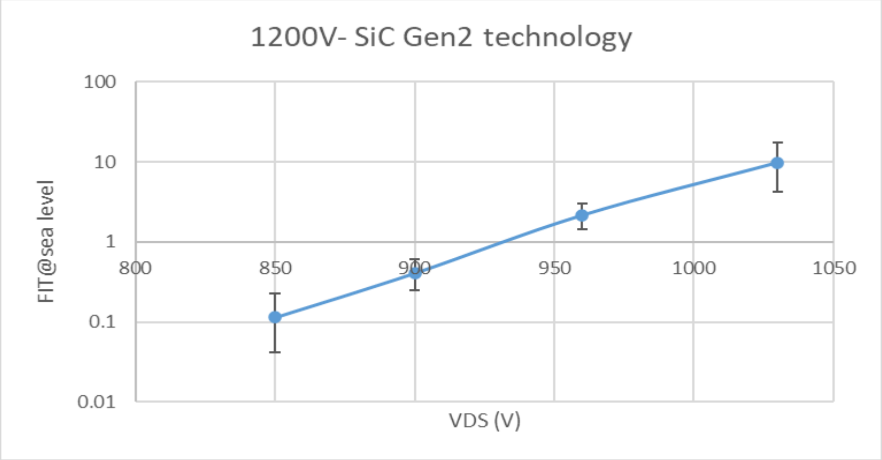
Altitude		relative	% Urban
feet	meters	flux	Pop
0	0	1.0	35%
1200	366	1.5	80%
1700	518	1.7	90%
3600	1097	2.4	95%
5000	1524	2.9	99%
10000	3048	11.4	>99.99%

Going from 0 to 10,000 feet corresponds to a relative neutron flux range of **1.0 to 11.4x**

IMPROVING KNOWLEDGE
Neutron spectrum at high altitude

Accelerated neutron test

The accelerated neutron (destructive) test is mandatory for all high voltage power devices for automotive and industrial applications at sea level



FIT: failure-in-time,1 FIT corresponding to 1 failure in 10^9 device-hours

This FiT (Failure in Time) curve at room temperature **is not enough** to estimate the impact of neutron on the mission application profile.

The customer demands an empirical formula describing neutron **FIT vs (Vds, temperature, altitude)**

Investigation of the temperature dependence of Neutron failure mechanisms in silicon carbide power MOSFETs

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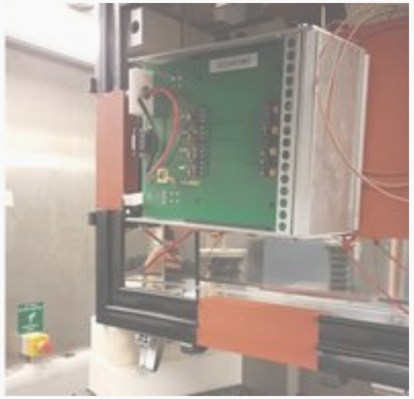
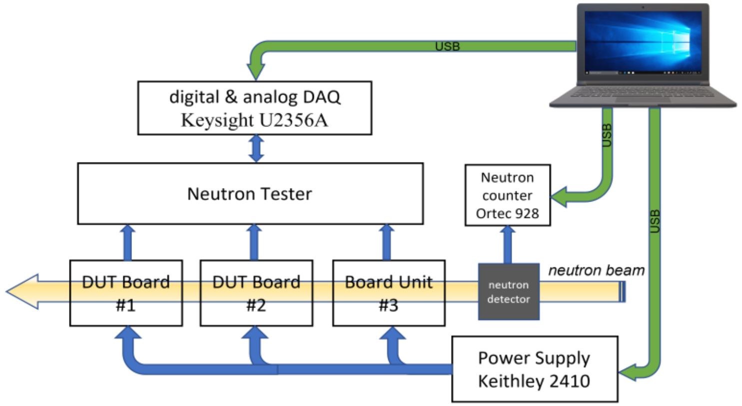
Neutron and temperature test systems

The **thermal Air TA-5000A/B**, with the clamshell chamber for the range[-50, +80] °C



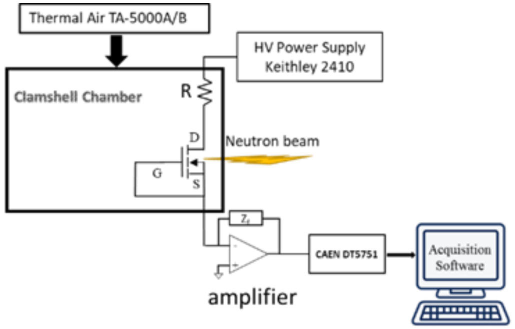
The DUT boards with self-regulating heaters and platinum sensing resistors(PT100), **operating at 80°C, 150°C and 180°C**

Destructive test system



The system measures the drain currents during irradiation, detects the SEB events and counts the neutron fluence on each of the 24 DUTs

Non-destructive test system



The system measures the current in the MOSFET during neutron irradiation using a wideband amplifier and a digitizer with a sampling rate of 1 Gs/s. It can then calculate the charge deposited as a result of neutron interactions

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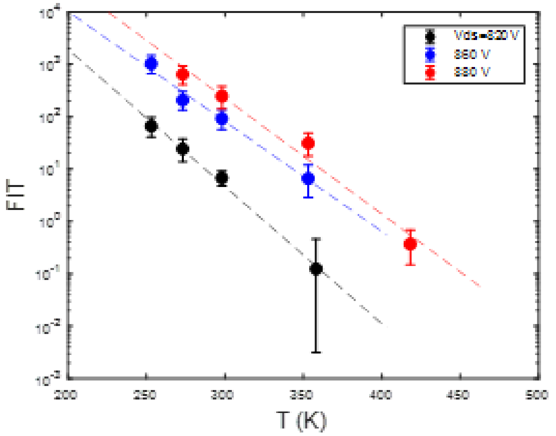
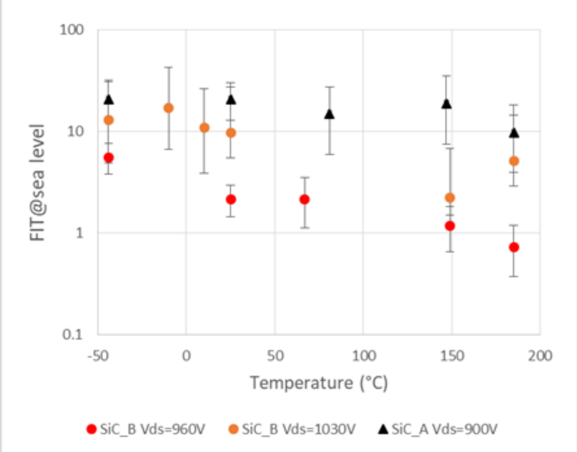
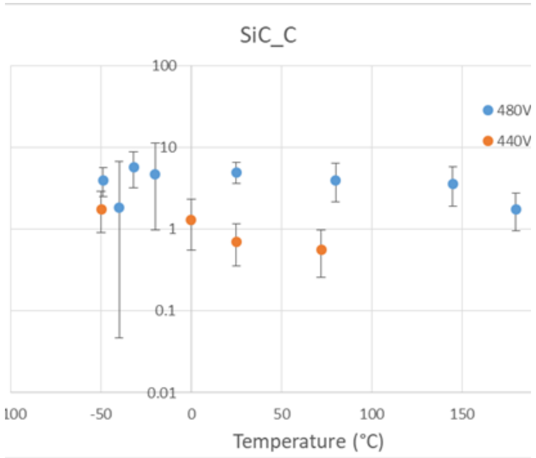
Neutron destructive test results

Part number	*Label*	*BV_{DSS} (V) & Technology*
Prototype Technology	SiC_A	1200-planar
SCT100N120G2D2AG	SiC_B	1200 - GEN2 planar
SCT35N65G2VA	SiC_C	650 – GEN2 planar
STW12N120K5	Si	1200-Superjunction

Silicon MOSFET







Several hundred devices were destroyed in this study

OUTCOME

- **The FIT temperature trend of SiC MOSFETs is not marked as for Si devices**
- **The FIT vs temperature depends on the device technology and for the same device change with the bias voltage**

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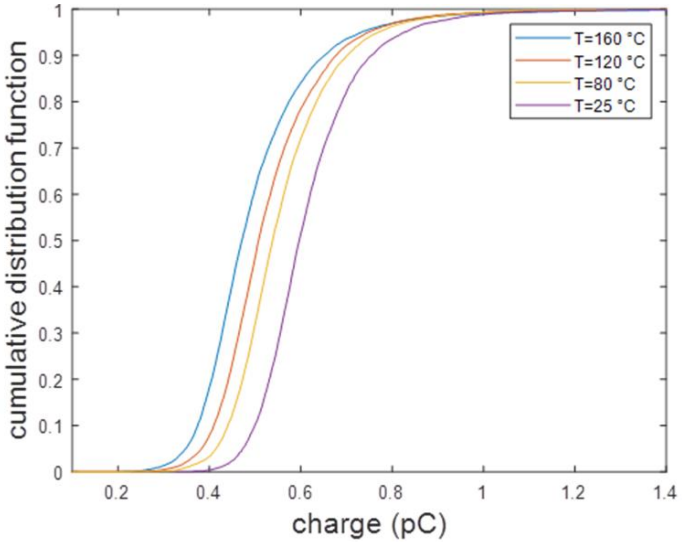
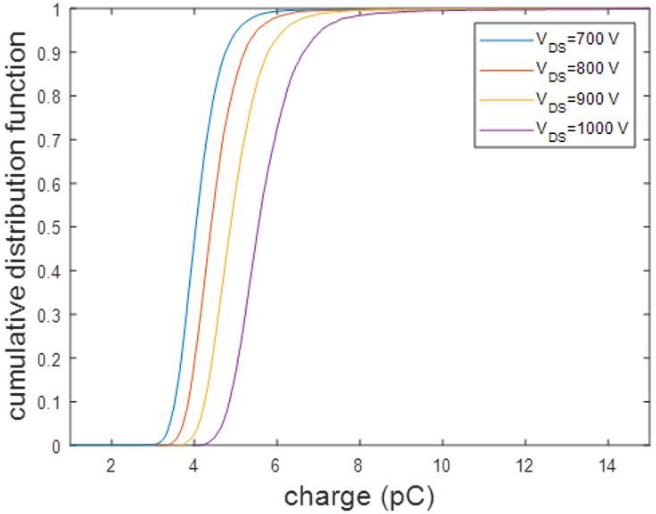
Neutron non-destructive test results

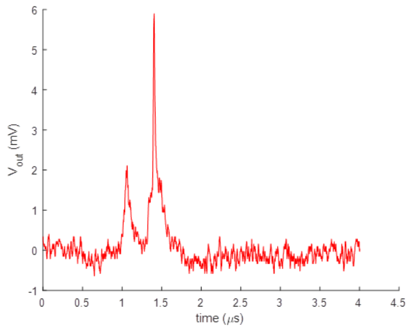




The cumulative distribution functions of deposited charge Q in the SiC_B MOSFET at four different Vds

The cumulative distribution functions of deposited charge Q in the SiC_B MOSFET at four different temperatures

Waveform of the amplified current of the SiC_B power MOSFET during the two neutron bunches interaction



Preliminary outcome

- The cumulative distribution functions of the deposited charge show a clear temperature dependence of the SiC_B MOSFET at VDS=870 V
- The temperature trend of deposited charge confirms that of the FIT data
- This non-destructive method is better than the destructive tests in terms of beam-time and device consumption

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Needs of new radiation facilities

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Space, avionics, automotive & industrial scenarios

AVIONICS

The leading avionics companies are shifting towards the development of new electric aircraft, and new air mobility services, such as air taxis, will be introduced in the next year.

AUTOMOTIVE & INDUSTRIAL

Electric vehicles are transforming terrestrial mobility, and WBG semiconductors are revolutionizing the energy grid distribution with new, more efficient, very high-voltage components with breakdown voltages (BVdss) greater than 3 kV.

More and more radiation test

SPACE

The introduction of WBG material into the new satellite architecture is under evaluation. There is a significant presence of private space companies in satellite constellation projects. New deep space missions are being planned for the Moon and Mars.

The new space era program requires the use of automotive devices (COTS) for space applications in Low Earth Orbit (LEO) orbiters.

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The new radiation facility needs in Europe

- The new heavy ions facility (today two facilities only)
- The new atmospheric neutron facility with the following (suggested) behaviors:
  - Higher flux than the actual CHIPIR (for avionics application)
  - Higher energy neutron than the actual 800MeV (for avionics altitude)
  - N-ToF (Time-of-Flight) for research study to better understand the neutron interaction vs energy

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