Radiation Tolerance Tests for SFP+ Transceivers

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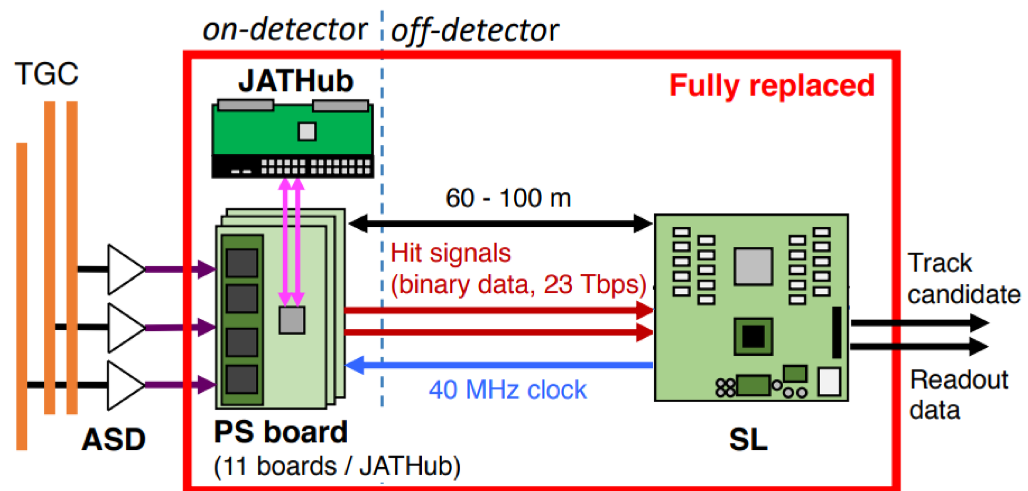
Introduction

The radiation tolerance of the electronics components used in the detector area is a key of the electronics systems at high energy physics experiments.

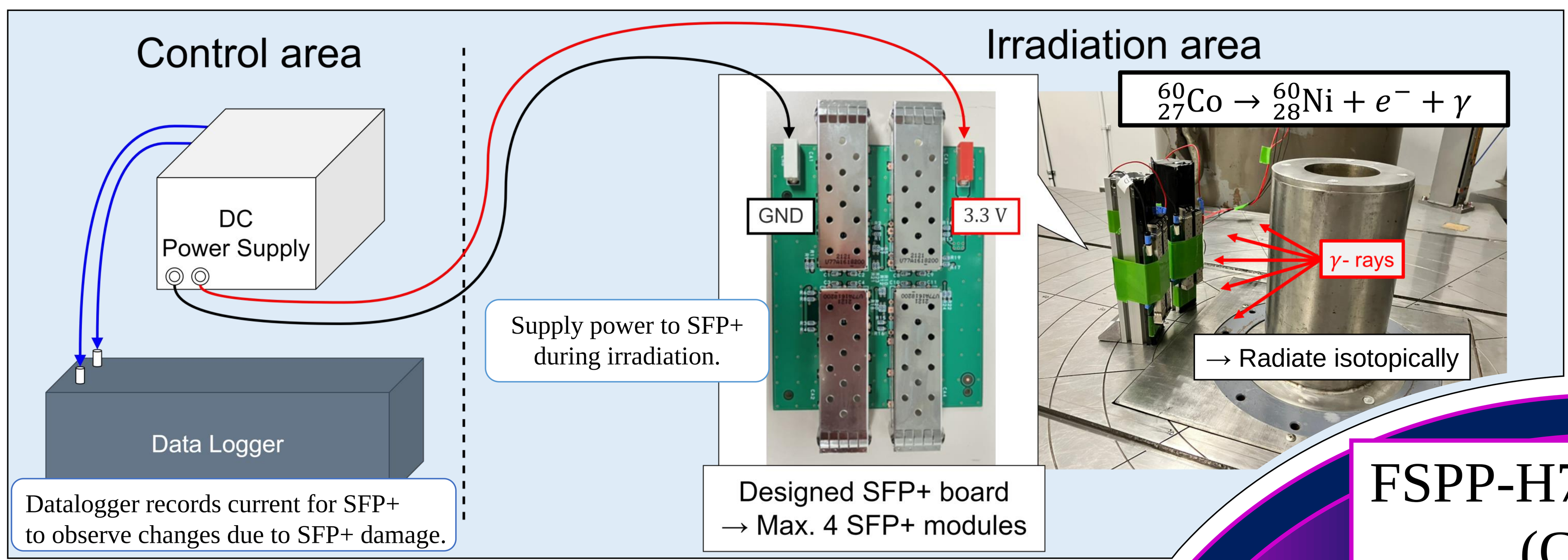
The ATLAS experiment at High Luminosity LHC will begin in 2029. To cope with increased collision rate, Thin Gap Chamber (TGC) electronics need to be replaced. The optical link between the frontend PS boards and the backend Sector Logic boards is crucial for the Level-0 muon trigger at HL LHC. This link enables high-speed serial communication at 8.0 Gbps using an SFP+ transceiver mounted on the PS board. The radiation tolerance of the SFP+ transceivers should be studied carefully before the installation.



Topic: Results for gamma and neutron irradiation tests for COTS (Commercial Off The Shelf) FSPP-H7-M85 SFP+ transceivers

TID (Total Ionizing Dose)

Cobalt-60 facility @Nagoya University

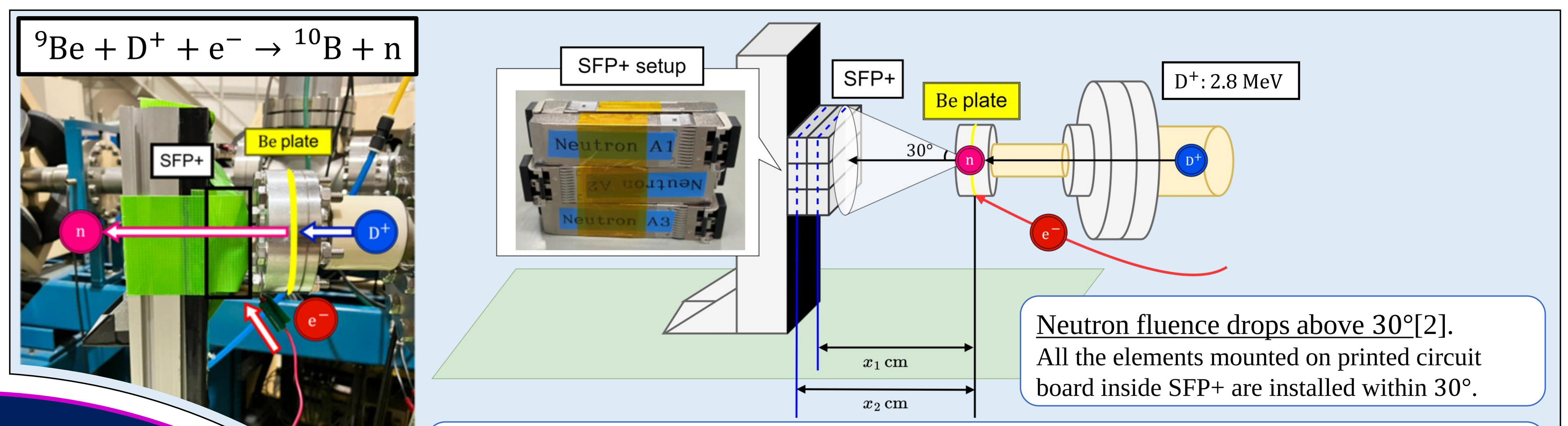


Gamma irradiation test for TID @Nagoya University

- Requirement (4000 fb^{-1}): 33 Gy [1]
- Number of irradiated modules: X3DM (5), X3DMi (5)

NIEL (Non-Ionizing Energy Loss)

Tandem electrostatic accelerator @Kobe University



Neutron estimated [3]

$$N(x,t,I) = (4.9 \pm 1.5) \times 10^6\ \mathrm{neutrons/cm^2/\mu A/s} \times \left(\frac{10}{x}\right)^2 \times \int_0^t I(t')dt'$$

- I [μA]: Target current per unit time
- x [cm]: Target distance
- t [s]: Irradiation time

Neutron irradiation test for NIEL @Kobe University

- Requirement (4000 fb^{-1}) : 1.3×10^{12} neutrons/cm^2 [1]
- Number of irradiated modules: X3D (1), X3Di (1), X3DM (3), X3DMi (3)

FSPP-H7-M85 SFP+ (COTS)

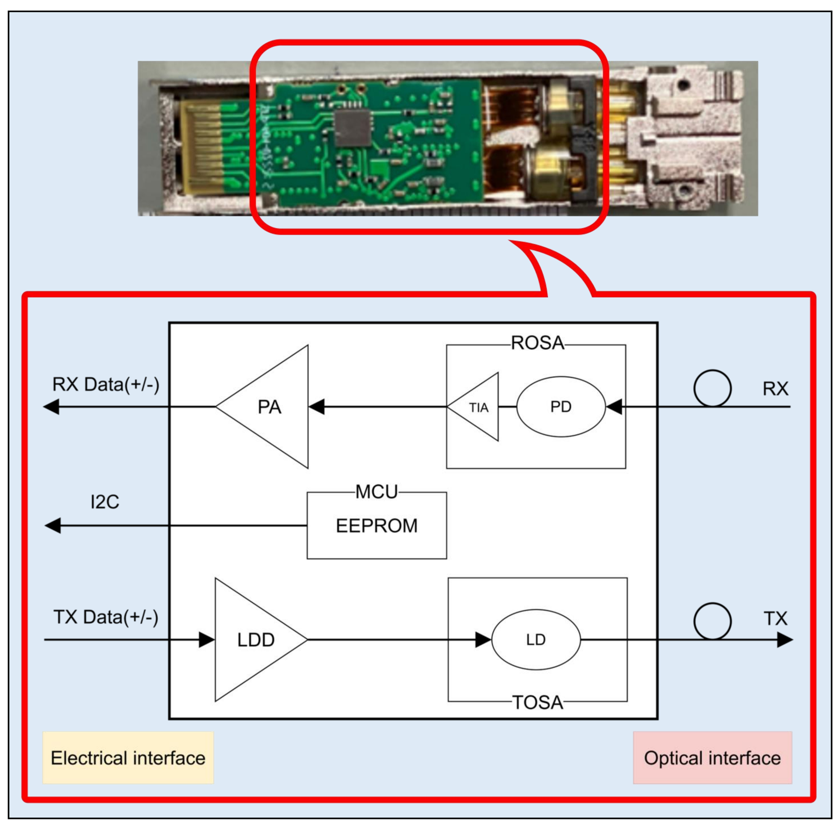
Tested four models SFP+

- FSPP-H7-M85-X3D
- FSPP-H7-M85-X3Di
- FSPP-H7-M85-X3DM
- FSPP-H7-M85-X3DMi

without M: 8.5 Gbps to 11.32 Gbps
with M: 1.0625 Gbps to 11.32 Gbps
without i: 0°C to 70°C
with i: −40°C to 85°C

Overview of SFP+

SFP+ transceiver is a composite device.



EEPROM:
Store data as non-volatile memory

TOSA (Transmit Optical Sub Assembly):
Convert electrical signals into optical signals

LDD (Laser Diode Driver):
Provides driving current for the laser

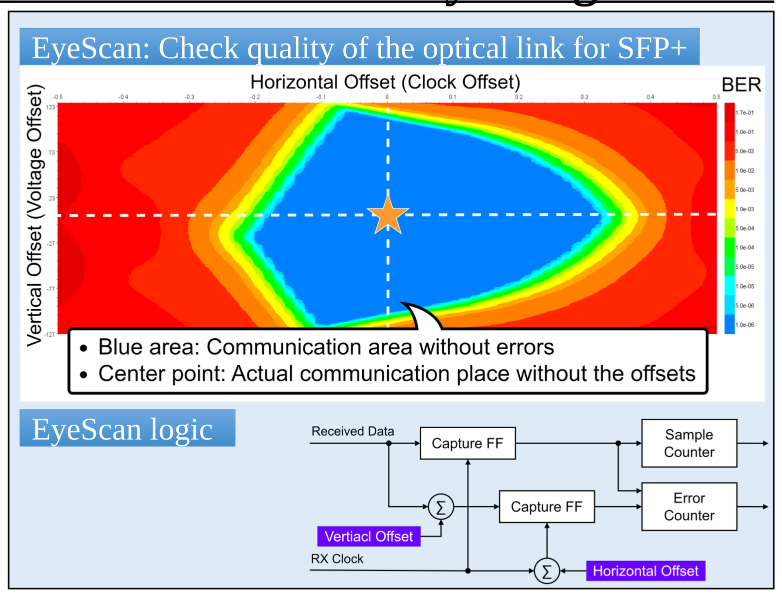
ROSA (Receive Optical Sub Assembly):
Convert the optical signals into an electrical signals through a photodetector (PD)

Measurement

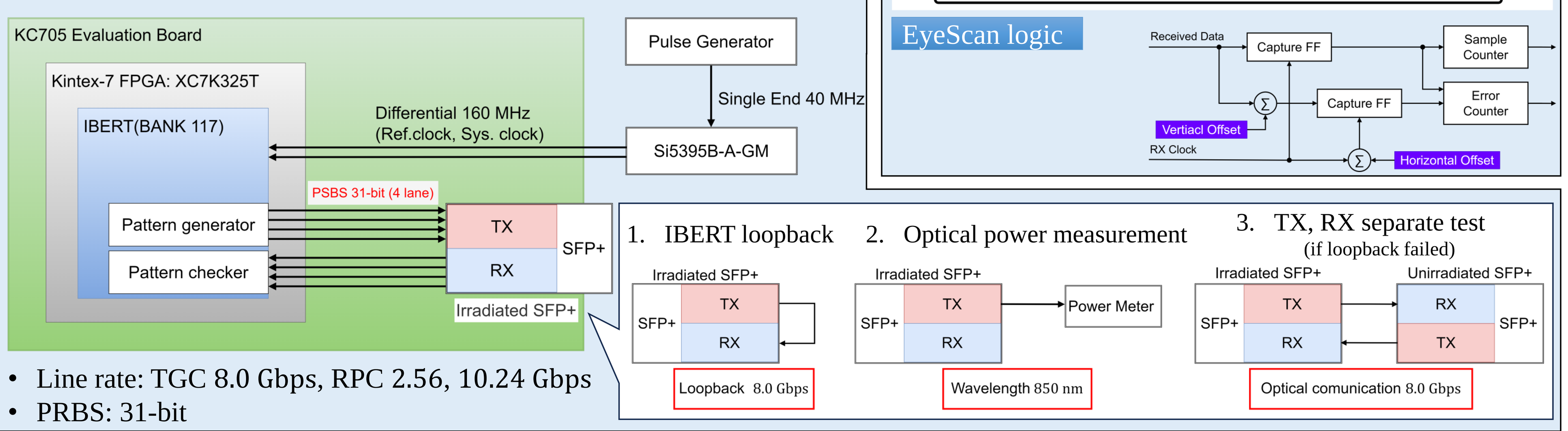
We evaluated SFP+ transceivers by using IBERT.

Check items

- EyeScan, BER, Link status
- Optical Power



Test diagram & items



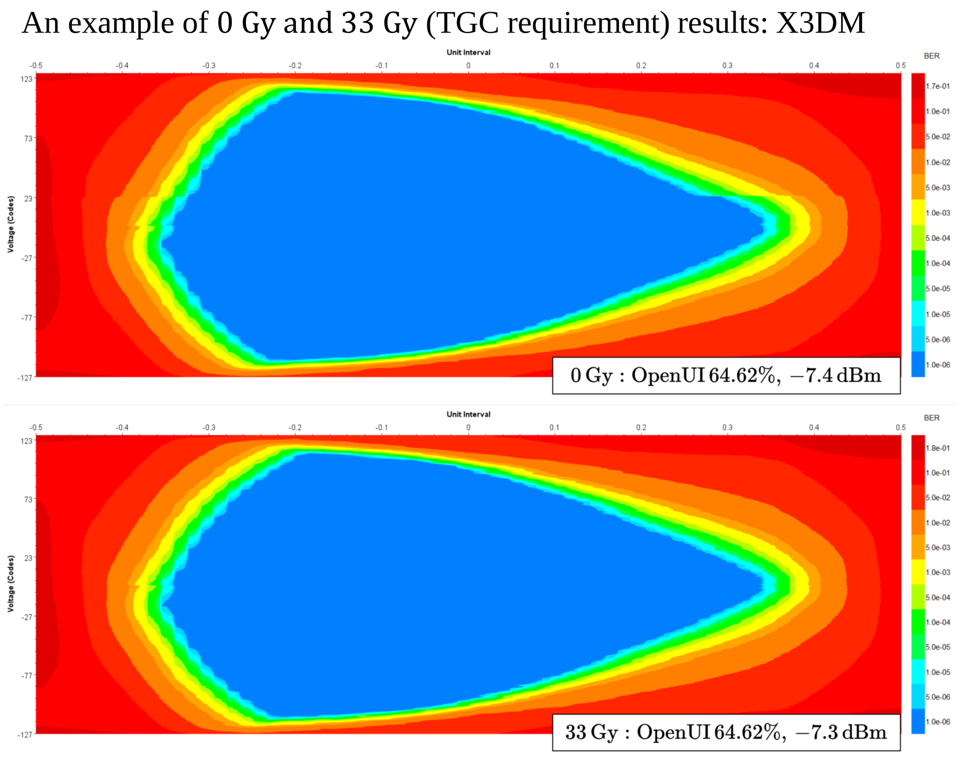
- Line rate: TGC 8.0 Gbps, RPC 2.56, 10.24 Gbps
- PRBS: 31-bit

Results

Gamma irradiation test for TID

Test 1, 2 results

An example of 0 Gy and 33 Gy (TGC requirement) results: X3DM

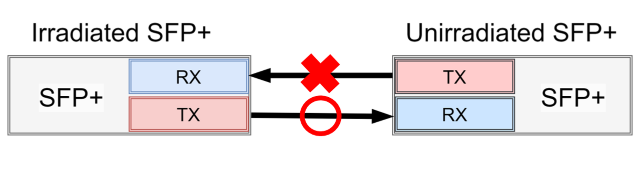


Models	Number of modules	Requirement [Gy]	TID tolerance [Gy]
X3DM	5	33	200
X3DMi	5		200

Both BER and optical power are fine up to 200 Gy in all tested SFP+ modules.

Test 3 results

- X3DM, X3DMi: 200 Gy to1250 Gy



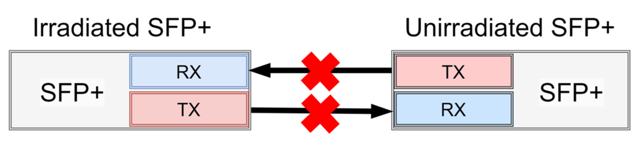
TX: BER ≤ $O(10^{-13})$

- TX output is fine.

RX: No link

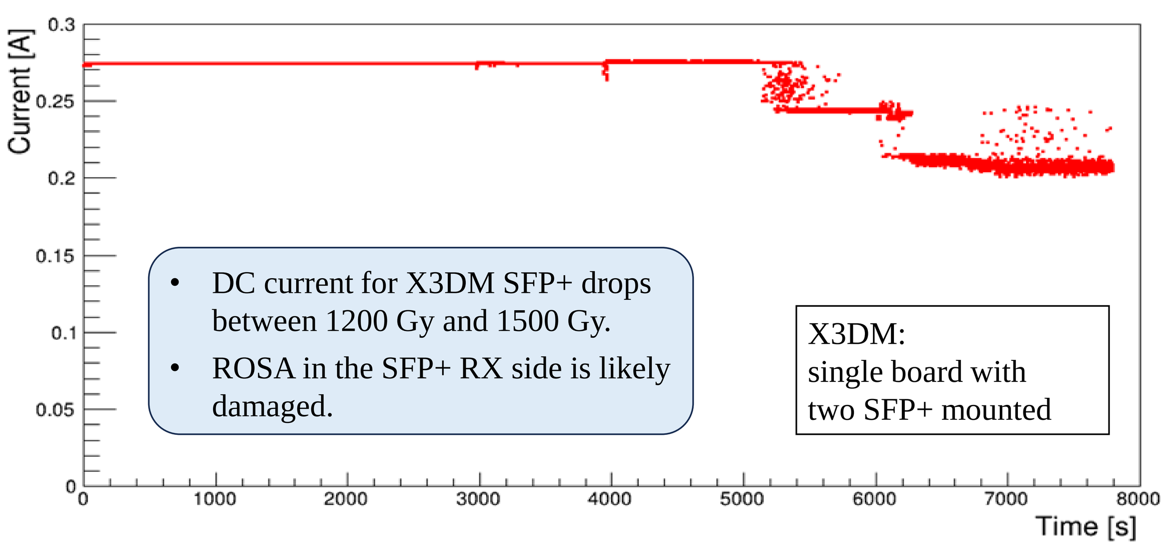
- RX can't receive optical signals.
- X3DM modules at 350 Gy recovered by 3 to 5 days (room temperature).

- X3DM: 1500 Gy



TX: No link
RX: No link

- TX output ~ − 50 dBm
- TX, RX are both damaged.

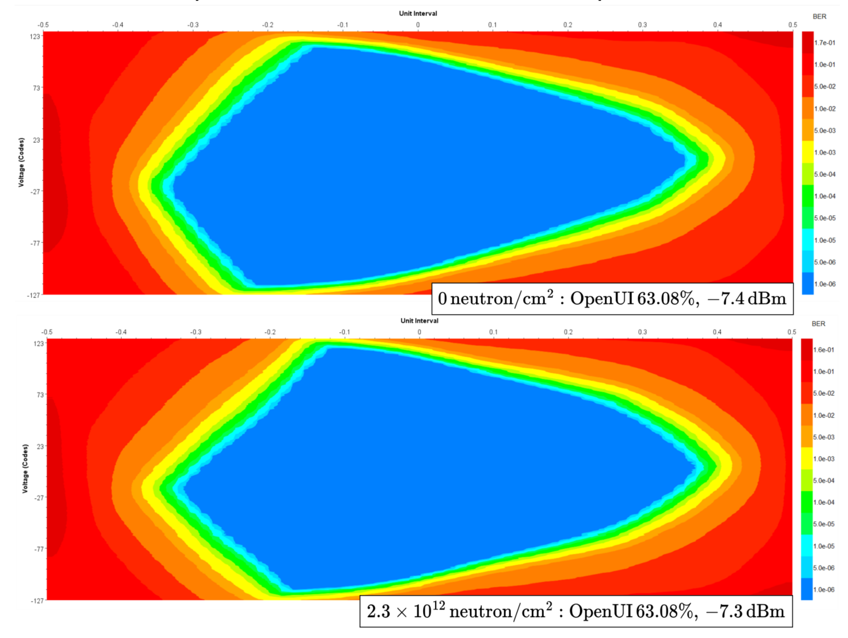


- DC current for X3DM SFP+ drops between 1200 Gy and 1500 Gy.
- ROSA in the SFP+ RX side is likely damaged.

Neutron irradiation test for NIEL

Test 1, 2 results

An example of 0 neutrons/cm^2 and 2.3×10^{12} neutrons/cm^2 results: X3DM



Models	Number of modules	Requirement [neutrons/cm^2]	NIEL tolerance [neutrons/cm^2]
X3D	1	1.3×10^{12}	$> 4.1 \times 10^{12}$
X3Di	1		
X3DM	3		$> 2.3 \times 10^{12}$
X3DMi	3		$> 1.6 \times 10^{12}$

Both BER and optical power are fine up to 1.6×10^{12} neutrons/cm^2 in all tested SFP+ modules.

Conclusion

In this study, we conducted radiation tolerance experiments on the FSPP-H7-M85 series SFP+ modules from Ficer. For the neutron irradiation test, we performed tests on eight modules and confirmed that they survived up to 1.6×10^{12} neutrons/cm^2, exceeding the TGC requirement of 1.3×10^{12} neutrons/cm^2. Also, we performed the gamma irradiation test on ten modules and confirmed that they survived up to 200 Gy, exceeding the TGC requirement of 33 Gy. From this result, FSPP-H7-M85 SFP+ modules have sufficient TID and NIEL tolerance for TGC on-detector electronics of the ATLAS experiment at HL-LHC. A study of the single event effect is required before the actual use at the experiment.

[1] ATLAS Collaboration, Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer, CERN-LHCC-2017-017, ATLAS-TDR-026, 2017.
[2] T. Inada, K. Kawachi and T. Hiramoto, Neutrons from Thick Target Beryllium (d,n) Reactions at 1.0 MeV to 3.0 MeV, Journal of Nuclear Science and Technology, 5:1, 22-29, 1968.
[3] Y. Nakazawa, *et al*, Radiation study of FPGAs with neutron beam for COMET Phase-I, Nuclear Inst. and Methods in Physics Research, A 936 (2019) 351-352, 2019.