Displacement damage test

Plan to irradiate samples with protons (or neutrons) and span over 10^9 to few 10^{11} n_{eq}

Characterization of:

- DCR increase vs damage dose
- Afterpulsing before/after irradiation
- Random Telegraph Signals after irradiation
- DCR activation energies before/after irradiation
- Damage recovery with thermal annealing

Two device available for test (1 from NA, 1 from BO) + additional one in Pavia

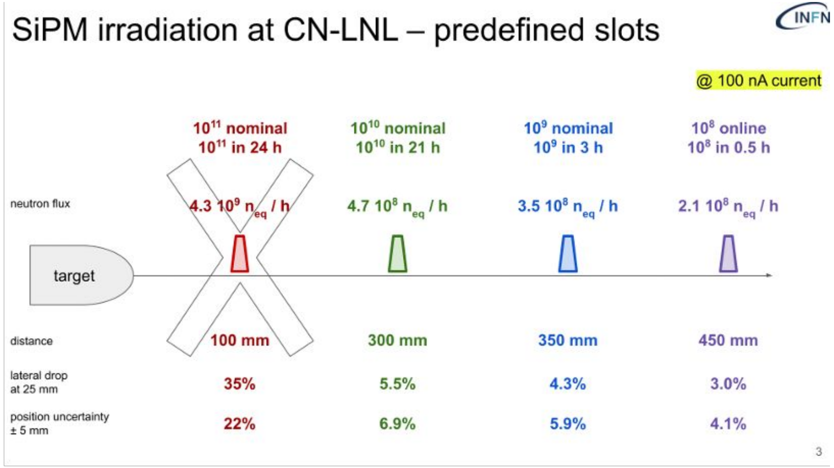
Two chance to perform irradiations (before end of the year)

Irradiation opportunities 2025

From Luigi and Roberto

LNL 2 days in the week 20th – 27th October
Parallel irradiation possible. “On-line” irradiation possible due to low doses Timing is more relaxed and will be a nice preparation test for December.

(Neutrons) 1MeV neq up to 10^{10} in < 24h
higher rates staying closer, but with more critical alignement/positioning and potential losses in lateral uniformity



TIFPA 2 h available, likely on Thursday 12th December evening. Final dates will be verified, test will be crowded. Possible parallel irradiation with other electronics, will discuss with the ePIC team how feasible it is.

(Protons): 2 possible beam setups (large field / pencil)

- At 2 nA 1.25 10^{6} 1 MeV neq/s (6 cm diameter uniform field)
- At 14 nA 10^{9} 1 MeV neq in 120 s (6 cm diameter uniform field)
- Up to 10^{13} 1 MeV neq with 120 nA in < 1h (1 cm pencil beam)

Displacement damage test

Both BO and NA have setup inplace for testing the ASAP chips.

- Firmware and setup tested in a WP2 hands on session before summer break.

What's still missing:

- Need to fully characterize both chips before the test(s):
  - BD, DCR, AP, Xtalk at room temperature (should be quick)
  - activation energies -> DCR vs Vov vs T (require many days and climatic chamber)
- Need to define which structure and how test it at irradiation steps
- Need an additional firmware for DCR real time monitoring

Backup

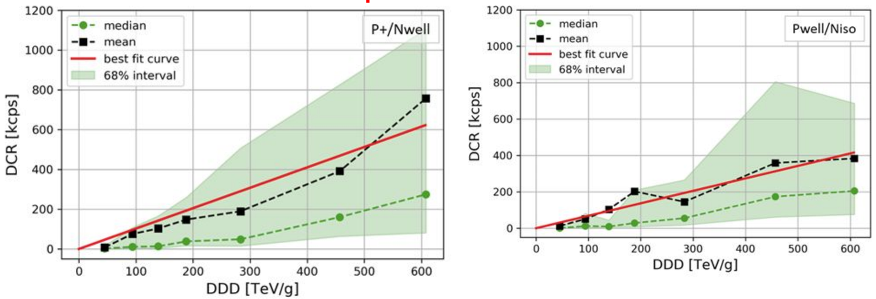
Bibliography

Large degradation observed in previous studies [1]:

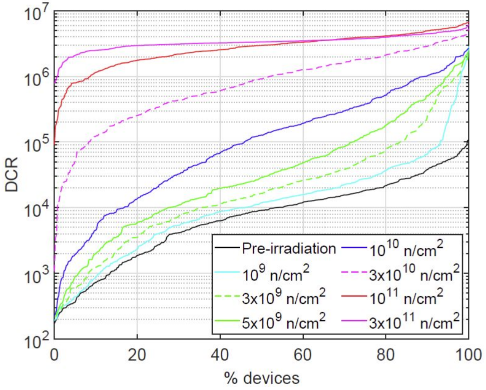
- First 150 nm devices -> few MHz/mm^2
    - □ GHz/mm^2 at 10^{10} p/cm^2

- APIX 180 nm devices: 1 MHz/mm^2 [2,3,4]
    - □ GHz/mm^2 at 10^{11} n_{eq}/cm^2
    - +30% DCR increase with 1 Mrad

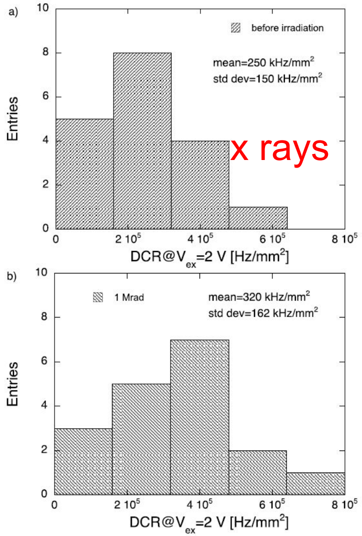
proton irradiation



neutron irradiation



x rays



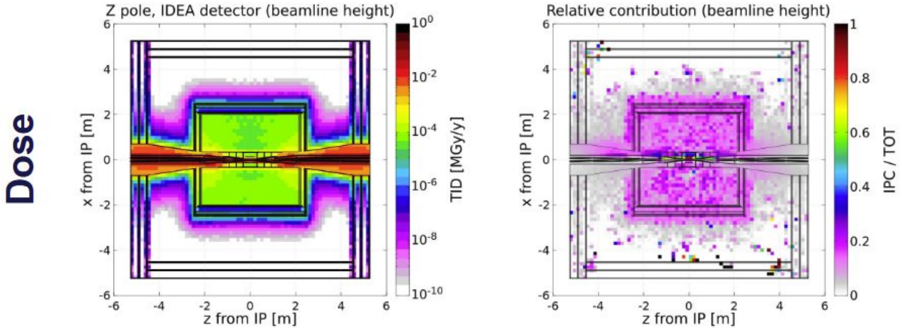
[1] M. Campajola, et al., Proton induced dark count rate degradation in 150-nm CMOS single-photon avalanche diodes, NIMA
[2] M. Musacci, et al. "Radiation tolerance characterization of Geiger-mode CMOS avalanche diodes for a dual-layer particle detector." NIMA
[3] L. Ratti, et al. "Dark Count Rate Degradation in CMOS SPADs Exposed to X-Rays and Neutrons" TNS
[4] A. Ficorella, APPLICATION OF AVALANCHE DETECTORS IN SCIENTIFIC AND INDUSTRIAL MEASUREMENT SYSTEMS, PhD thesis

FCC doses

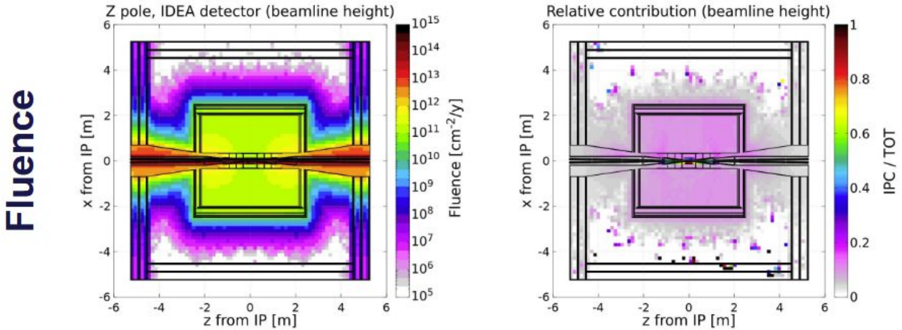
link

IDEA radiation levels (RB + IPC)

incomplete magnetic field map: results will be altered, to be revisited with the a map covering the full detector



- Drift chamber: 100 Gy/year
- Calorimeter: <10 Gy/year
- RB dominates
- IPC contributes up to 20% in the drift chamber



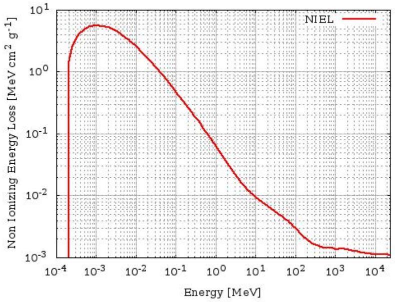
- Drift chamber: 10^{11} cm^{-2}/year
- Calorimeter: <10^{10} cm^{-2}/year
- RB dominates
- IPC contributes up to 10% in the drift chamber

SR (screened relativistic) NIEL (non ionizing energy loss) Calculator
Ions&Protons: SR-NIEL – 7 ver. 10.20 - 14.February.2025

protoni

https://www.sr-niel.org/Simulation/258586niel_p.html

Input Parameters
^{1}H in Si
Displacement Threshold Energies [eV]: 21.00;
Minimum Energy [MeV]: 8.0e+01
Maximum Energy [MeV]: 1.0e+02
IonModel Selected : Hadron+Coulomb
IonModel Available : Hadronic Contribution Available
Hadronic Contribution : No Scaling
Particle Fluence [cm^{-2}]: 1.00e+00



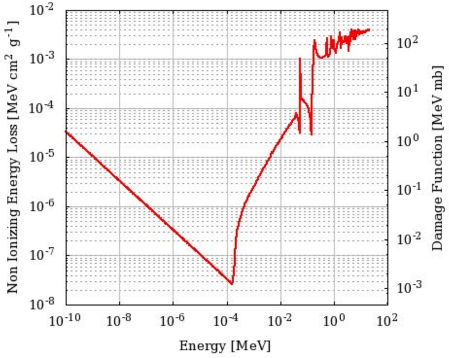
Energy (MeV)	NIEL (MeV cm^2 g^{-1})	NIEL Dose* (MeV g^{-1})	NIEL Dose* (Gy)
8.0000e+01	3.4243e-03	3.4243e-03	5.4877e-13
8.5000e+01	3.2999e-03	[illegible]	[illegible]2884e-13
9.0000e+01	3.1841e-03	[illegible]	[illegible]1027e-13
9.5000e+01	3.0762e-03	3.0762e-03	4.9298e-13
1.0000e+02	2.9757e-03	2.9757e-03	4.7687e-13

NIEL

SR (screened relativistic) NIEL (non ionizing energy loss) Calculator
Neutrons: SR-NIEL – 7 ver. 10.20 - 14.February.2025

https://www.sr-niel.org/index.php/sr-niel-web-calculators/niel-calculator-for-neutrons-using-astm-standards/neutrons-niel-calculator

Input Parameters
Neutrons in Si
ASTM Standard E722-19
Displacement Threshold Energies [eV]:
Minimum Energy [MeV]: 9.0e-01
Maximum Energy [MeV]: 1.1e+00
Particle Fluence [cm^{-2}]: 1.00e+00



Energy (MeV)	NIEL (MeV cm^2 g^{-1})	NIEL Dose* (MeV g^{-1})	NIEL Dose* (Gy)
1.0500e+00	1.6573e-03	[illegible]	[illegible]e-13
9.8000e-01	2.4078e-03	[illegible]	[illegible]e-13
9.4000e-01	2.3967e-03	2.3967e-03	3.8408e-13
9.0000e-01	1.9476e-03	1.9476e-03	3.1212e-13

be thick enough to fully absorb the kinetic energy of recoil nuclei or other reaction products.