ÖAW AUSTRIAN ACADEMY OF SCIENCES

SMI – STEFAN MEYER INSTITUTE

Radiation Hardness Study of the SciTil

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On behalf of the Panda SciTil group

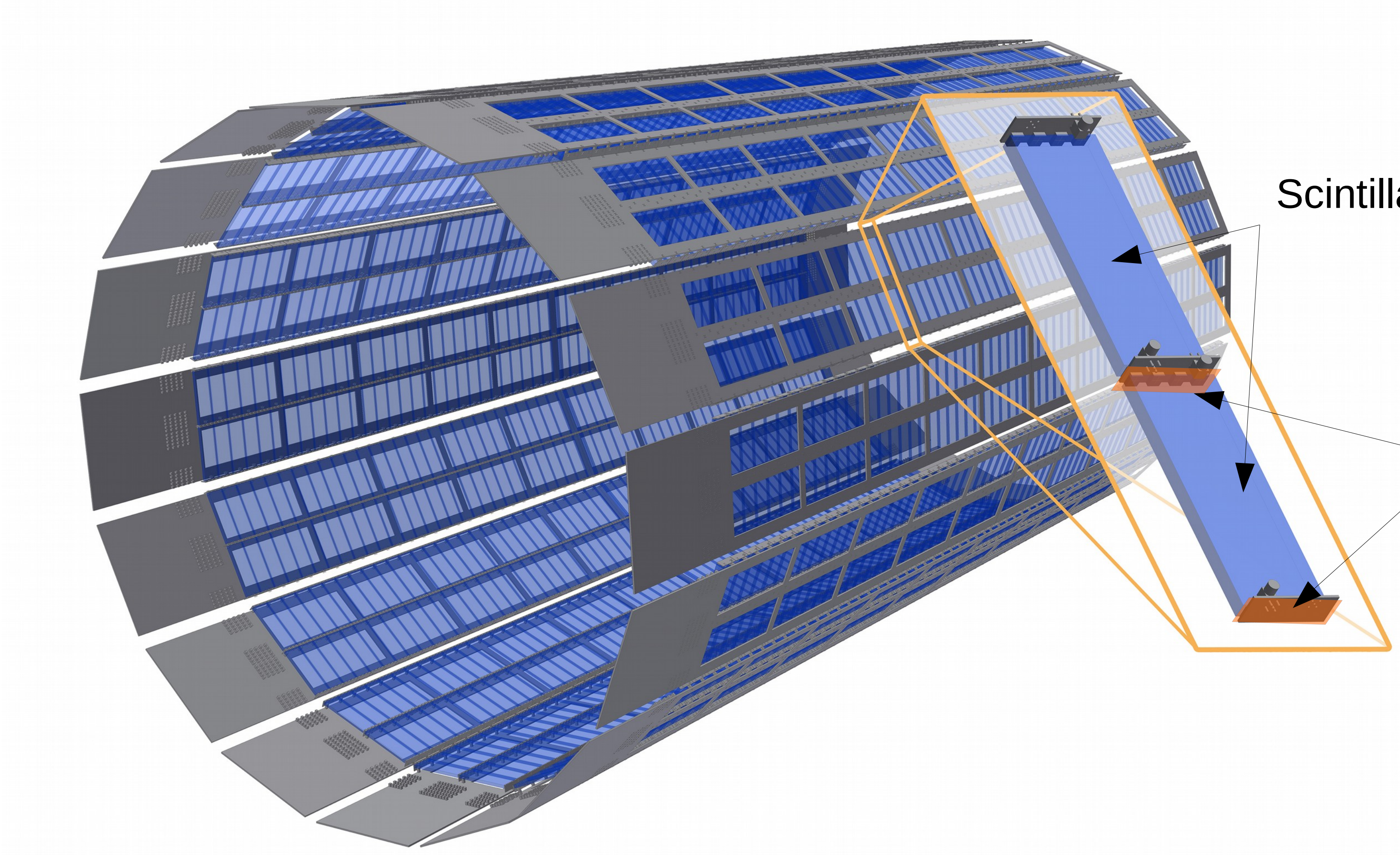
GSI, 07.12.2016

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

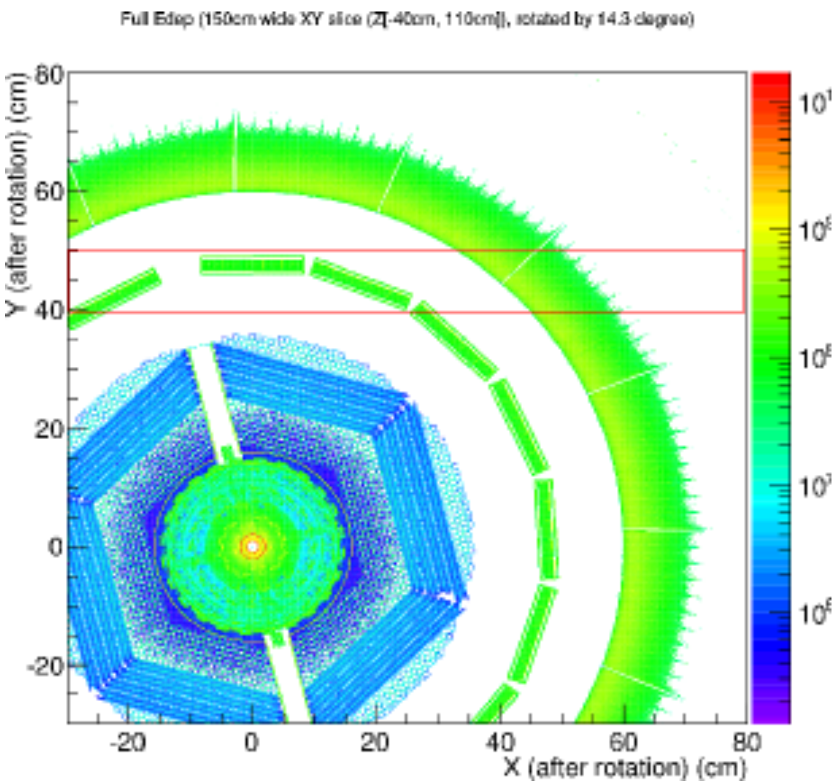
Disclaimer

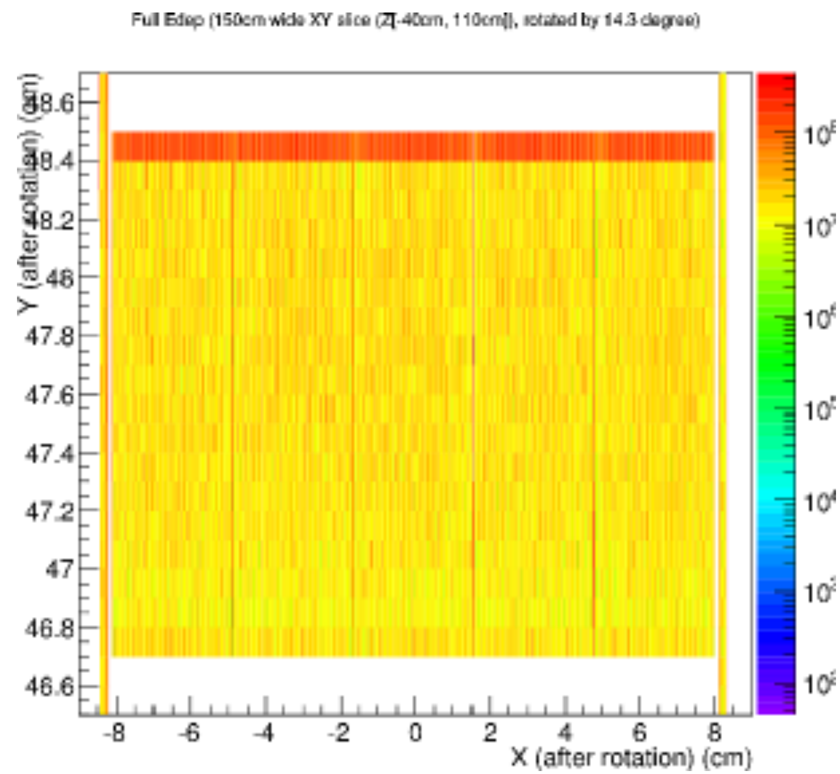
- No radiation tests performed ourselves **YET**
- Literature was studied to estimate the effects on the SiPMs and the scintillators
- We are confident that our components are sufficiently radiation hard
  - The following is the explanation why

The BarrelTOF



Estimated Radiation Dose





- Dose is given in Gy per year for the Barrel DIRC

- Estimated value of 1 to 5 x 10^7 GeV per bin

Estimated Radiation Dose

- Energy per bin: 5x10^7GeV
- Bin dimension:

  0.1 x 1/30 x 150 cm^3
- Area towards the beam:

  1/30 x 150 cm^2 = 5 cm^2

- MIP energy loss for fused silica of the DIRC:

  373.7 keV/mm
- Numper of MIPs:

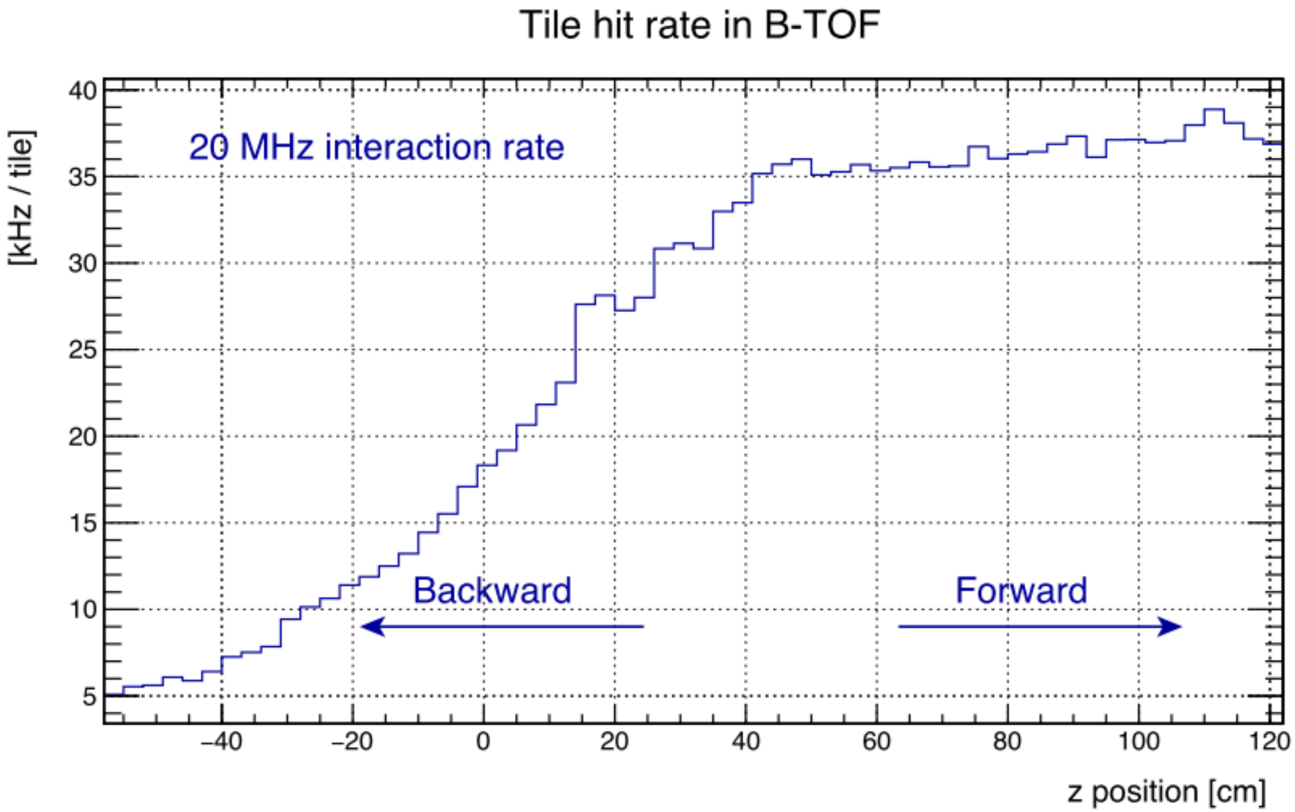
$$n_{MIP} = \frac{10^7\,\mathrm{GeV}/(\mathrm{cm}^2 \cdot 1\,\mathrm{mm})}{373.7\,\mathrm{keV}/\mathrm{mm}} \tag{3.1a}$$

$$= 2.67 \cdot 10^{10}\ \mathrm{MIPs}\ /\mathrm{cm}^2 \text{ for 1 year} \tag{3.1b}$$

$$\Rightarrow \quad 2.67 \cdot 10^{11}\ \mathrm{MIPs}\ /\mathrm{cm}^2 \text{ for 10 years} \tag{3.1c}$$

Hit Distribution

- Rate in the forward part is 28% higher than the average of 26.7 kHz



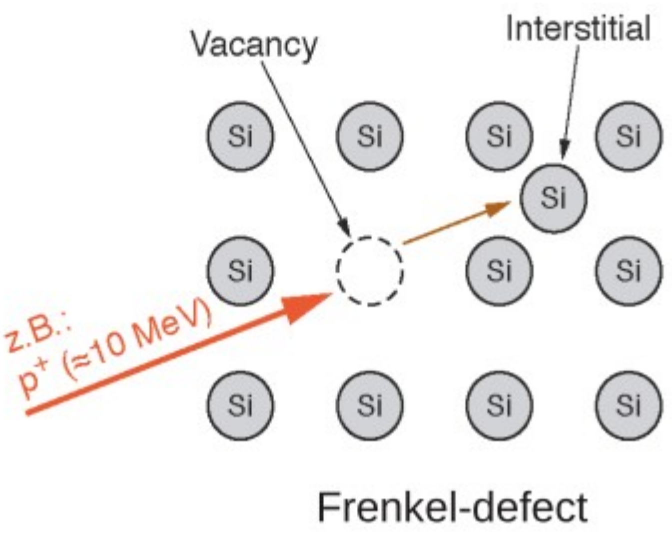
Radiation Damage

- Electrons cause temporary effects
- Hadrons cause permanent damage by dislocating atoms

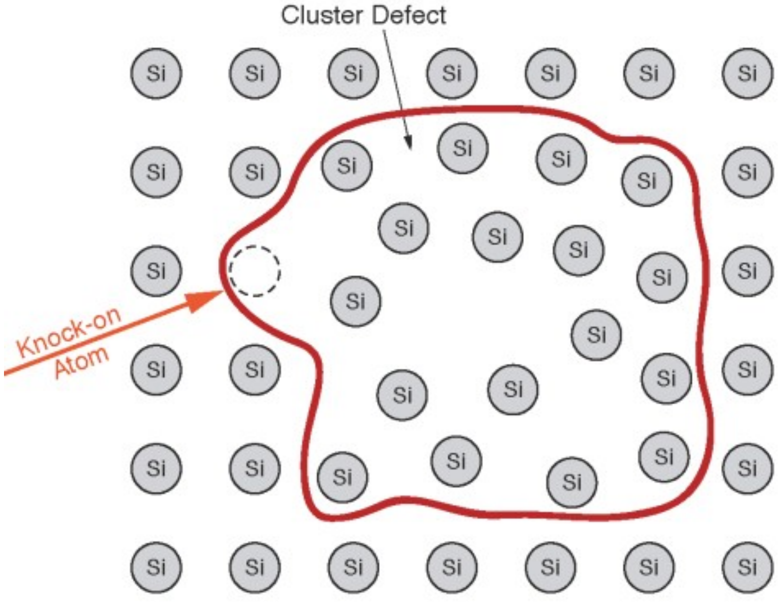
- Surface damage due to Ionizing Energy Loss (IEL):
  - Mainly generation of charges in the oxide ($SiO2$)
- Bulk damage due to Non-Ionizing Energy Loss (NIEL):
  - Mainly displacement damage

Types of Defects

- Silicon Atom displaced by incident particle
  - Primary Knock on Atom (PKA)



- The PKA can displace additional atoms
  - Clusters at end of PKA track



Macroscopic Effects

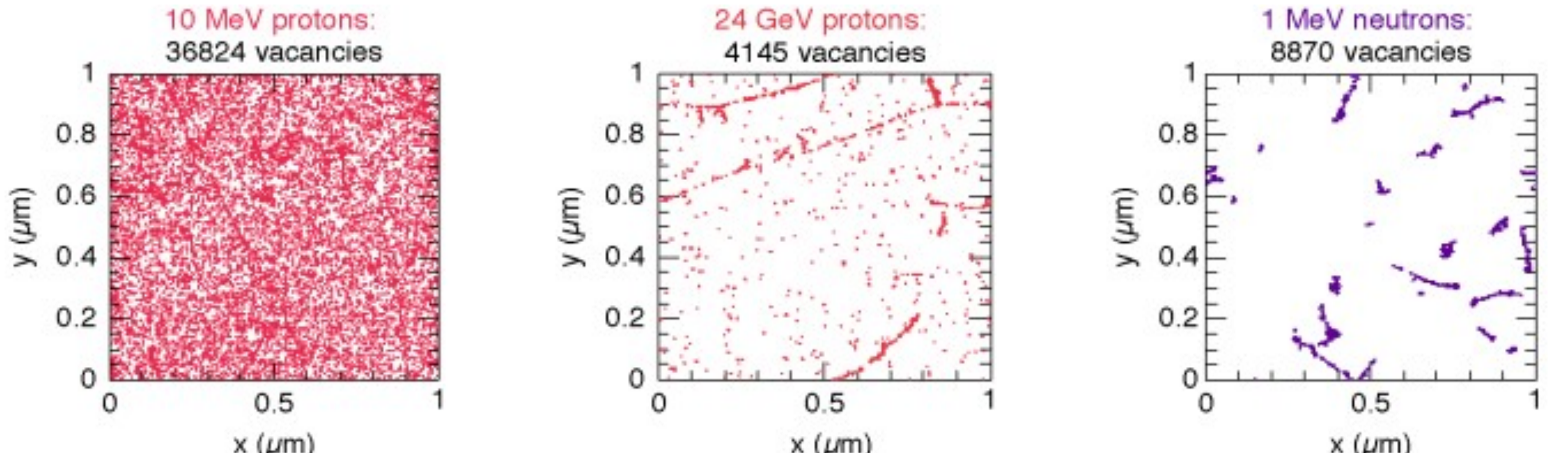
- Defects in the in the Silicon lattice create energy levels between the conduction and valence band

- Change of effective doping concentration
  - Modification of the depletion (break down) voltage
- Increase of charge carrier trapping
  - Loss of charge (signal)
- Easier thermal excitation of electrons and holes
  - Increase of leakage current (dark current)

Damage of Different Particles

Radiation	e^-	p^+	n	Si^+
Interaction	electromagnetic	electromagnetic and strong	strong	electromagnetic
T_{max}	155 eV	133.7 keV	133.9 keV	1 MeV
T_{av}	46 eV	210 eV	50 keV	265 eV
E_{min} point defect	260 keV	190 eV	190 eV	25 eV
E_{min} cluster defect	4.6 MeV	15 keV	15 keV	2 keV

Source: G. Lutz, *Semiconductor Radiation Detectors* Springer-Verlag, 1999



M. Huhtinen, *Simulation of Non-Ionising Energy Loss and Defect Formation in Silicon*, Nucl. Instr. Meth. A 491, 194 (2002)

NIEL Scaling Hypothesis

- Experimental Observation leads to the assumption that the damage effects are proportional to the displacement damage cross section (D)
- Does not consider atom transformations and annealing effects
- Common way to scale the damage by different particles of different energies
- Normalized to the damage of 1 MeV neutrons
  - Measured in 1 MeV neutron equivalent fluence Φ_{eq}

Damage Function

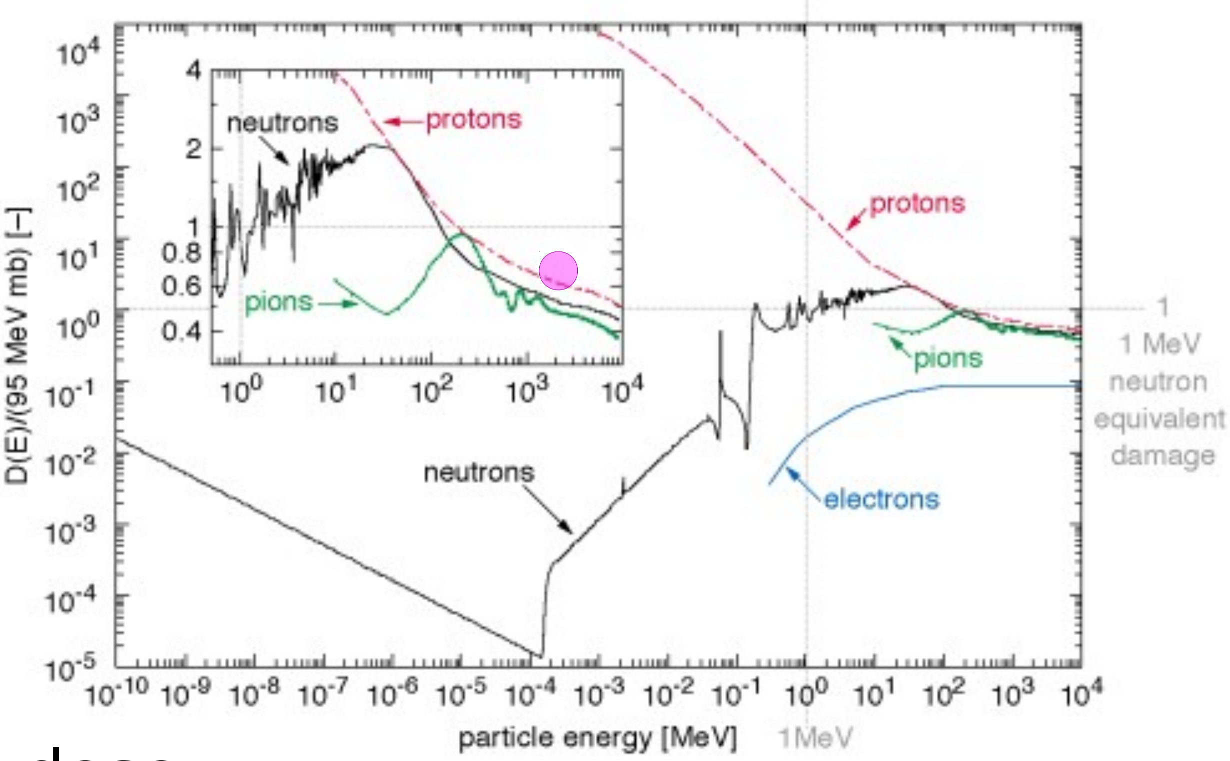
- Calculate with the recoil energy E_R of the PKA and the Lindhard probability function $P(E_R)$

$$D(E) = \sum_{\nu} \sigma_{\nu}(E) \cdot \int_{0}^{E_R^{max}} f_{\nu}(E, E_R)\, P(E_R)\, dE_R$$

- ν runs over all possible interactions, $f_\nu(E,E_R)$ is the probability of a particle with energy E to produce a PKA with energy E_R
- $P(E_R < E_{d,min}) = 0$

Damage Function
for Multiple Different Particles

Assuming MIP protons at 2 GeV



G. Lindström, *Radiation Damage in Silicon Detectors*, Nucl. Instr. Meth. A **512**, 30 (2003)

- Expected 1 MeV neutron equivalent dose:

  $2.7\ p/cm^2 \times 0.62 = 1.7\times10^{11}\ n_{eq}/cm^2$

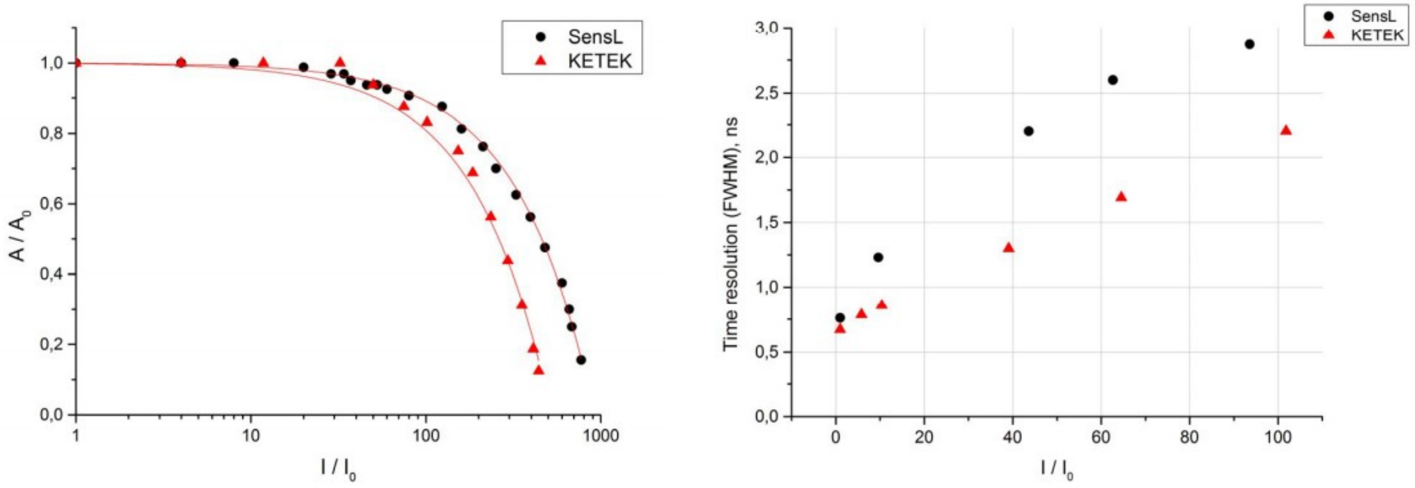
Literature

- Multiple Studies of the dark current and the signal strength after irradiation
- No direct studies on the timing performance

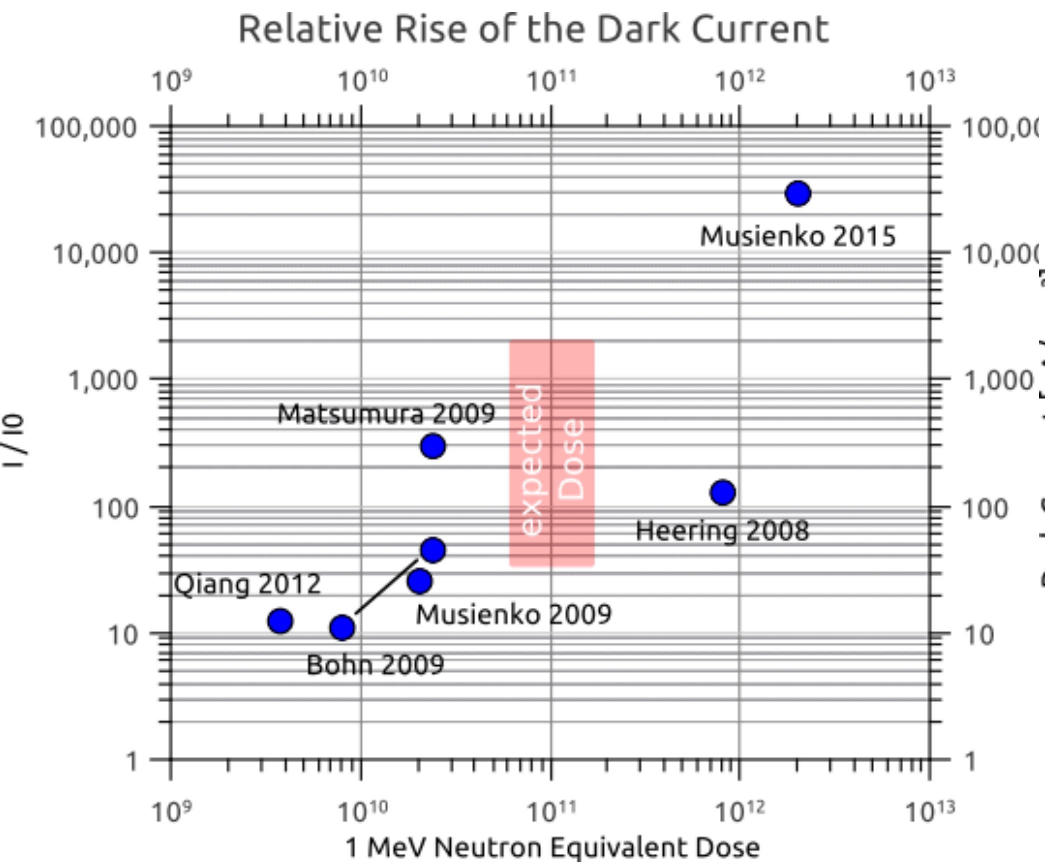
- SiPMs operational up to Φ_{eq} = 2.2E14 cm^{-2}
- Significant signal reduction and dark current increase (linear with dose) due to increased dark count rate

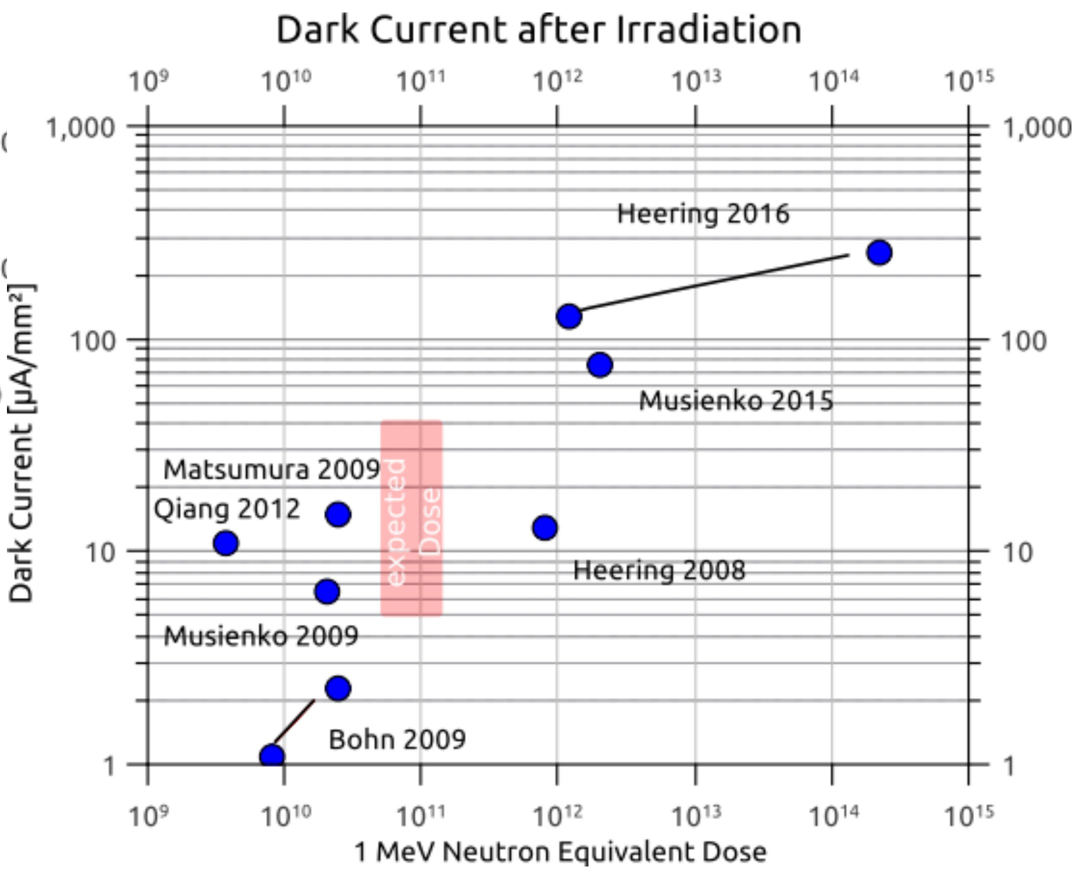
Simulation of dark current increase

- Study done by V.A. Kaplin et al., *”Time and Amplitude characteristics of large scintillation detectors with SiPM”* -2015
- Dark current increase simulated by continuous low intensity illumination by an LED



Summary of the Literature Study





Time resolution expectation

- Expected current between 8 and 40 µA/cm^2
- For 3x3 mm^2 sensors: up to 360 µA
- Taking the measurements of KETEK and SensL sensors as a reference we expect deterioration of the time resolution by ~30% to ~70% over 10 years
- Reduced pixel dead time should reduce the effect of the radiation
  - Hamamatsu: 50 ns, KETEK & SensL: >200 ns
- True impact however is not known

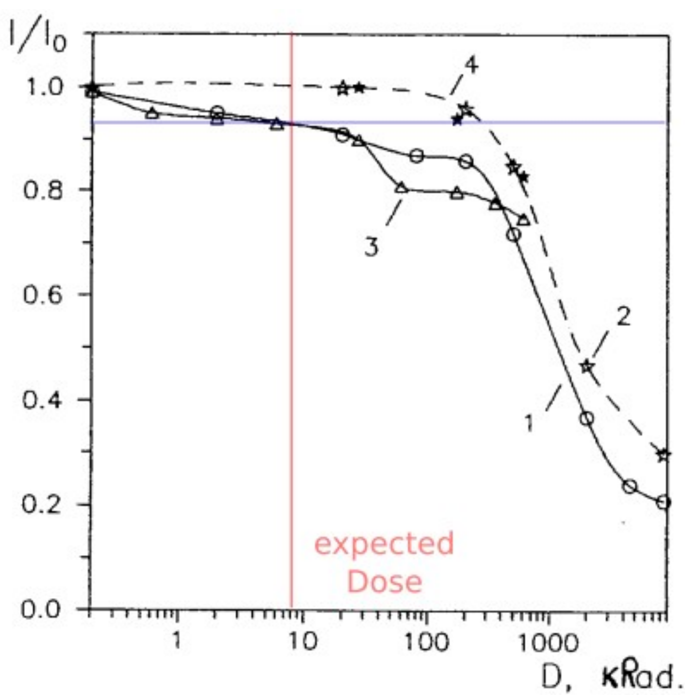
Scintillator Radiation Hardness

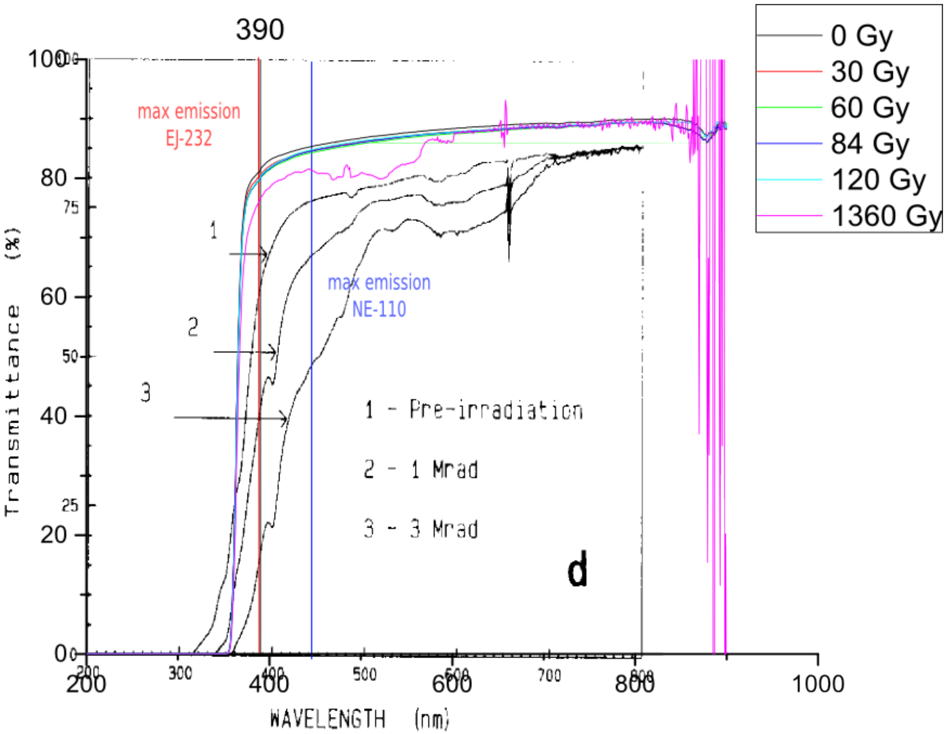
- EJ-232 polymer base: Polyvinyltoluene
- MIPs deposit 2.02 MeV/cm

$$\begin{aligned} D &= 2.7 \cdot 10^{11}\,\frac{\text{MIPs}}{\text{cm}^2} \times 2.02\,\frac{\text{MeV}}{\text{cm}} \div 1.032\,\frac{\text{g}}{\text{cm}^3} \\ &= 5.4 \cdot 10^{11}\,\frac{\text{MeV}}{\text{g}} \quad = 5.4 \cdot 10^{20}\,\frac{\text{eV}}{\text{kg}} \\ &= 83.7\,\frac{\text{J}}{\text{kg}} \quad = 83.7\,\text{Gy} \\ &= 8.4\,\text{krad} \end{aligned} \tag{3.5}$$

Scintillator Radiation Damage

Irradiation with Co^{60}





Possible Irradiation Studies

- Measurement in multiple steps during irradiation
- To measure: Leakage current, Dark count rate, Breakdown voltage, Photon counting capability, Gain, Time resolution

Facility	Location	Energy [MeV]	Max. Flux $[p/(s \cdot cm^2)]$	Time to expected dose
Proton Irradiation Facility (PIF)	PSI in Villigen, Switzerland	6 – 230	$2 \cdot 10^9$	$\sim$ 1 min
Light Ion Irradiation Facility (LIF)	Centre de Recherches du Cyclotron, Louvain-la-Neuve, Belgium	14.4 – 65	$2 \cdot 10^8$	$\sim$ 5 min
Radiation Effects Facility (RADEF)	Jyväskylä, Finland	6 – 60	10^{10}	few seconds
Proton Irradiation Facility (PAULA)	Uppsala, Sweden	20 – 180	up to 10^{12}	few seconds

Summary

- Radiation damage is scaled with the 1 MeV neutron equivalent fluence
- Expected fluence of $1.7 \times 10^{11}\ n_{eq}/cm^2$
  - ➢ SiPMs still functional
  - ➢ Time resolution deterioration roughly in the order of 50%
- Expected dose in the scintillator 8.4 krad
  - Minor losses in signal strength
  - Negligible considering annealing effects
- Own irradiation measurements will need to be performed

Thank you for your attention