Radiation damage studies of SiPMs for the SciTil detector of PANDA

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PANDA TOF meeting
March 17, 2015

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Motivation

- Silicon Photomultipliers become more and more attractive for experiments in particle physics, astrophysics or medical imaging.
- Many of these experiments operate in harsh radiation environments which produce damage in the used detectors.
- A dedicated example is the PANDA experiment where it is planned to use SiPMs in the barrel TOF system. A time resolution below 100 ps sigma has to be achieved and maintained during PANDA lifetime.
- What is the amount of radiation SiPMs can withstand? How does the performance change? How and to which extend SiPM parameters change during irradiation? Such questions have to be answered to allow the use of SiPMs in dedicated HEP experiments (e.g. PANDA).
- Therefore it is necessary to study the resilience of SiPMs against ionizing radiation. If needed it is planned to do a first test within the following months using a proton beam.
- In the following a basic introduction about radiation damage in silicon detectors is given and expected effects on the detector performance are discussed. Afterwards it is shown how the damage produced in some test beam experiment can be related to the damage expected in a dedicated application (e.g. PANDA) using the NIEL scaling hypothesis. Finally a possible proton irradiation experiment is discussed in detail and previous studies by other groups are described.

Radiation damage in silicon detectors

- Interaction of particles (radiation) in the detector:

  – with electrons: resulting in temporarily effects only
  – with atoms: causing permanent changes (defects) in the detector
    –> dislocation of atoms
    –> atom transformations: nuclear reactions

In general, one distinguishes between damage (defects) in the detector bulk and damage in the detector surface.

The defects can change with time. Therefore, one also distinguishes between primary and secondary defects. Secondary defects are caused by moving primary defects and appear with time.

Radiation damage in silicon detectors

- Bulk (crystal) damage due to Non Ionizing Energy Loss (NIEL)
  - primarily produced by massive particles (neutrons, protons, pions)
  - mainly displacement damage: displaced atoms in the lattice
  - build up of crystal defects –> secondary defects

- Surface damage due to Ionizing Energy Loss (IEL)
  - primarily produced by photons and charged particles
  - mainly generation of charges in the oxide (SiO_2) and interface (Si/SiO_2)
  - due to isolating character of the oxide the charges cannot disappear and lead to build up of local concentrations of charges

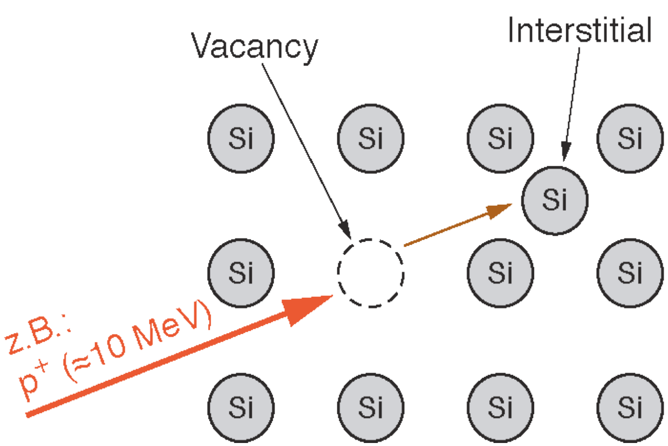
These microscopic effects lead to macroscopic impact on the detector performance.

Bulk (crystal) damage – NIEL

<u>Concerning bulk damage one distinguishes between point and cluster defects:</u>

- Point defects:

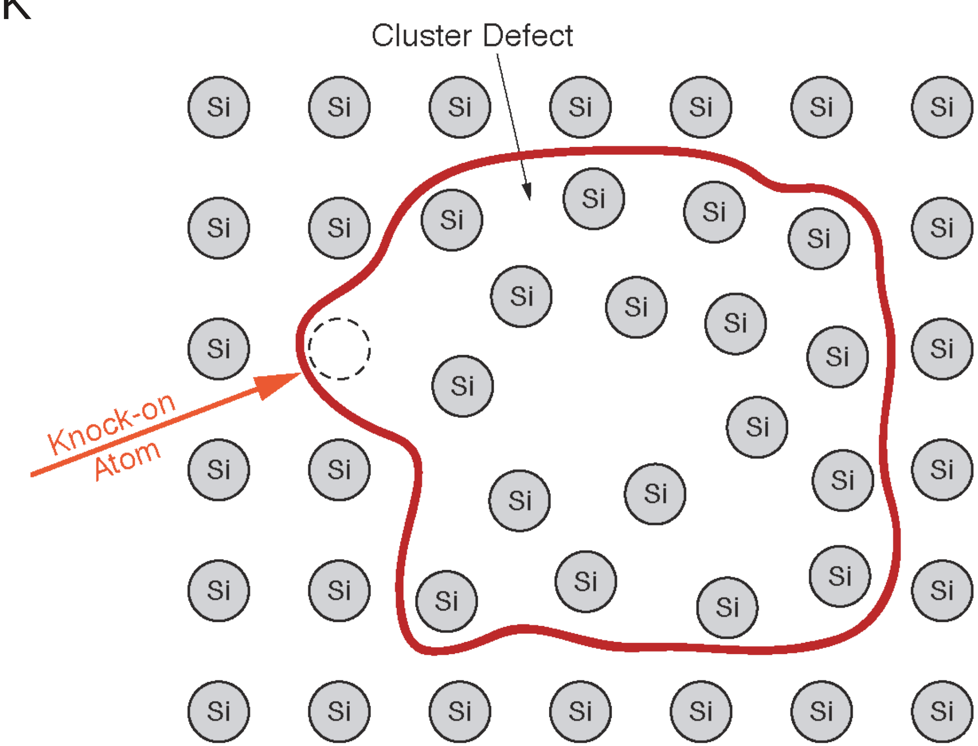
– a silicon atom gets displaced by the incident particle → Primary Knock-on Atom (PKA)
– creation of a vacancy-interstitial pair
– interstitials and vacancies can move inside the lattice and are very mobile above 150 K



Frenkel-defect

- Cluster defects:

– the PKA can displace additional atoms
– possible creation of cluster detects
– the cluster usually appears at the end of the PKA track



Cluster defect

Point and cluster defects

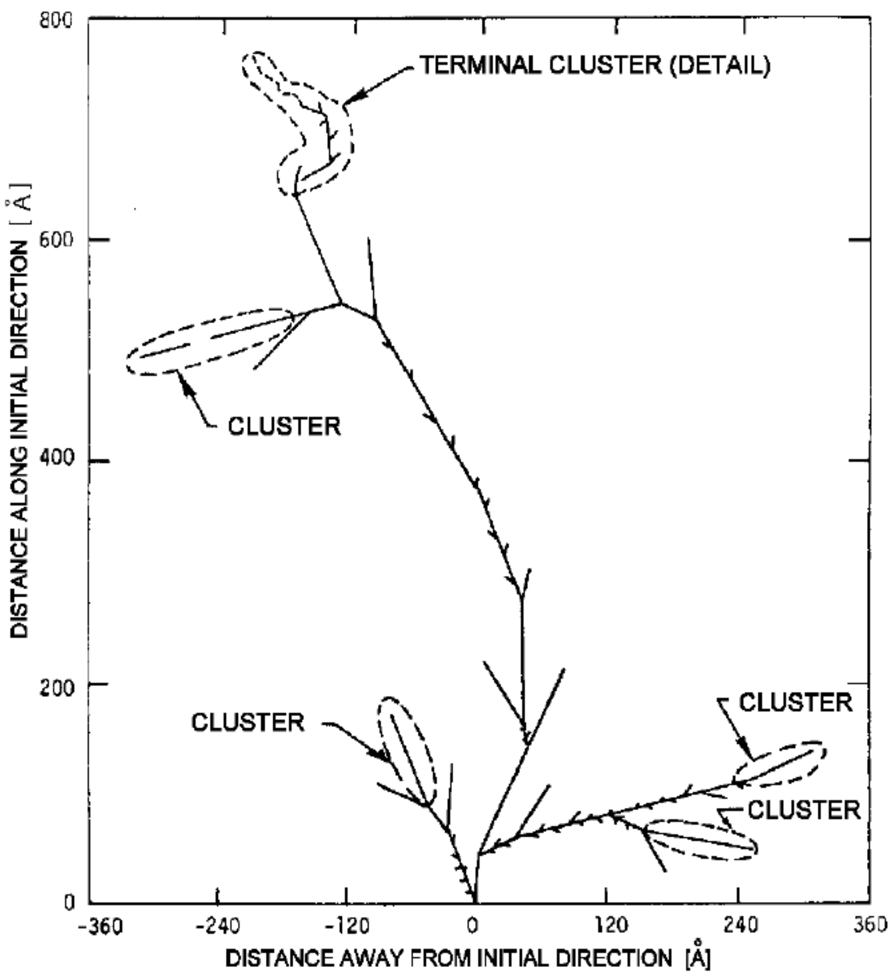


Figure 3.1: Monte Carlo simulation of a recoil-atom track with a primary energy E_R of 50 keV [Lin80].

The primary recoil energy of 50 keV has been chosen because it is approximately the average kinetic energy that a 1 MeV neutron imparts on a PKA. The PKA releases its energy over a distance of about 1000 Å to the silicon lattice. Approximately 37% of the recoil energy will go into ionization effects and the rest can displace further lattice atoms. In average 3 terminal clusters are produced with a typical diameter of about 50 Å [Laz87, Mue82].

Source: V.A.J. Van Lint et al., *Mechanisms of Radiation Effects in Electronic Materials*, John Wiley & Sons, 1980

Collision properties

Kinematic collision properties of particles in Si, given also for Si as PKA. For a particle energy of 1 MeV, T_{max} is the maximum transferred energy and T_{av} is the average transferred collision energy. E_{min} is the minimal energy needed to create a point or cluster defect.

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

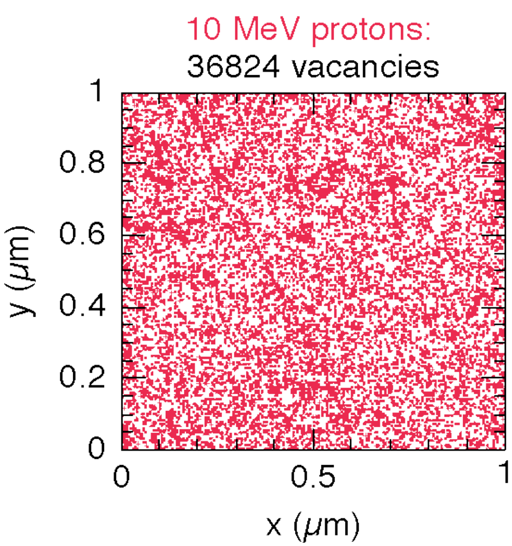
Source: G. Lutz, *Semiconductor Radiation Detectors*, Springer-Verlag, 1999

Defect formation

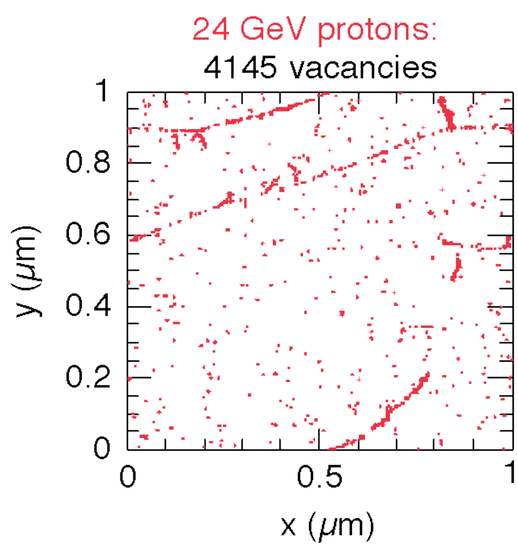
The type and frequency of defects depends on the particle type and the energy.
–> Damage in silicon detectors depends on particle type and energy.

Plots below show a simulation of vacancies in 1 µm thick material after an integrated flux of 10^{14} particles per cm^2:

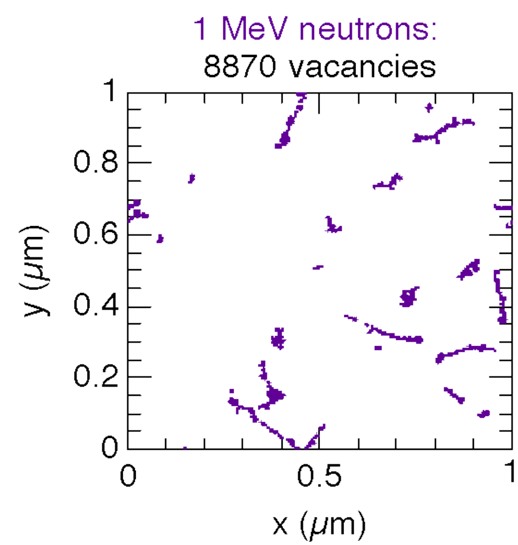
M. Huhtinen, *Simulation of Non-Ionising Energy Loss and Defect Formation in Silicon*, Nucl. Instr. Meth. A 491, 194 (2002)



Many vacancies produced



Less vacancies, a significant part of the energy is consumed to produce cluster deffects



Very few vacancies, energy of the neutrons is used up to produce cluster defects.

Annealing and secondary effects

- Annealing
  - interstitials and vacancies are mobile
  - dislocated atoms may fall back in a regular lattice position and defects disappear
  - this effect is called annealing
  - annealing strongly depending on temperature

- Permanent defects
  - the discussed primary defects may combine with other defects and form immovable and stable secondary defects
  - these can be combinations of interstitials (I), vacancies (V) with C, O, P atoms
    –> formation or removal of donors and acceptors
  - e.g.: VP, VO, Divacancy (V_2), Trivacancy (V_3)

Macroscopic effects

What kind of effects can we expect concerning the performance of our detector?

Defects in the silicon lattice create energy levels in the band gap between valence and conduction band. The defects lead to macroscopic deterioration of the detector performance.

Depending on the position of the energy levels different effects can occur:

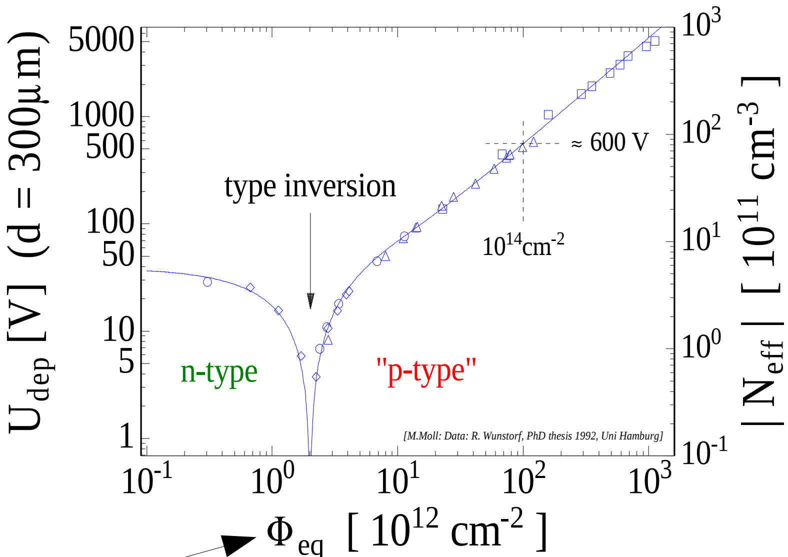
- **Change of effective doping concentration:**
  – mainly acceptor like defects are produced (donors are removed)
  –> **modification of the depletion (breakdown) voltage**
  –> under-depletion
  – caused by shallow energy levels close to the band edges

- **Increase of charge carrier trapping:**
  – reduced life time of charge carriers
  –> **loss of charge (signal)**
  – mainly caused by deep energy levels

- **Easier thermal excitement of electrons and holes**
  –> **increase of the leakage current (dark current)**
  – mainly due to energy levels in the middle of the band gap

Effective doping concentration

Change of depletion voltage (U_{dep}) and effective doping concentration (N_{eff}) with particle fluence:



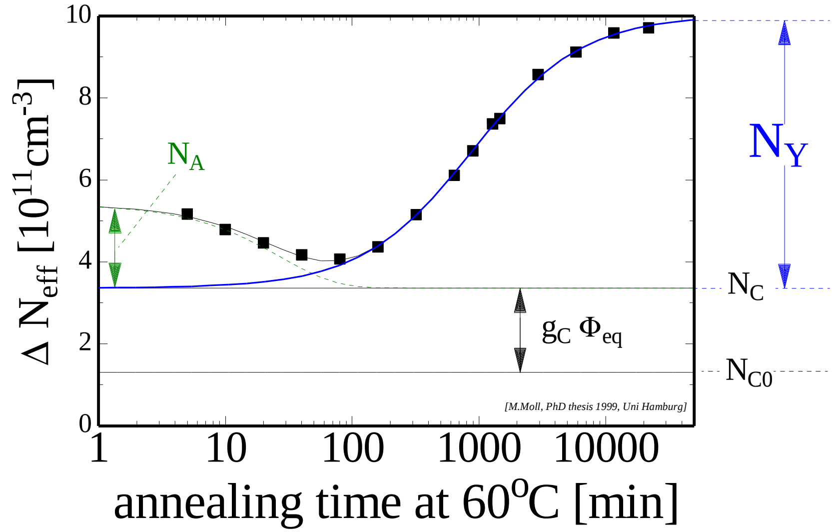
1 MeV neutron quivalent fluence (see also later)

$$V_{FD} \approx \frac{e}{2\varepsilon_0\varepsilon_r}|N_{eff}|\,d^2$$

Full depletion voltage

Type inversion may happen depending on the primary type of material (n-type, p-type).

Change of effective doping concentration with time:



- Short term: **"Beneficial annealing"**
- Long term: **"Reverse annealing"**
  - **time constant depends on temperature:**
    - **~ 500 years (-10°C)**
    - **~ 500 days (20°C)**
    - **~ 21 hours (60°C)**
  - Consequence: **Temperature must be stabilized even when the experiment is not running!**

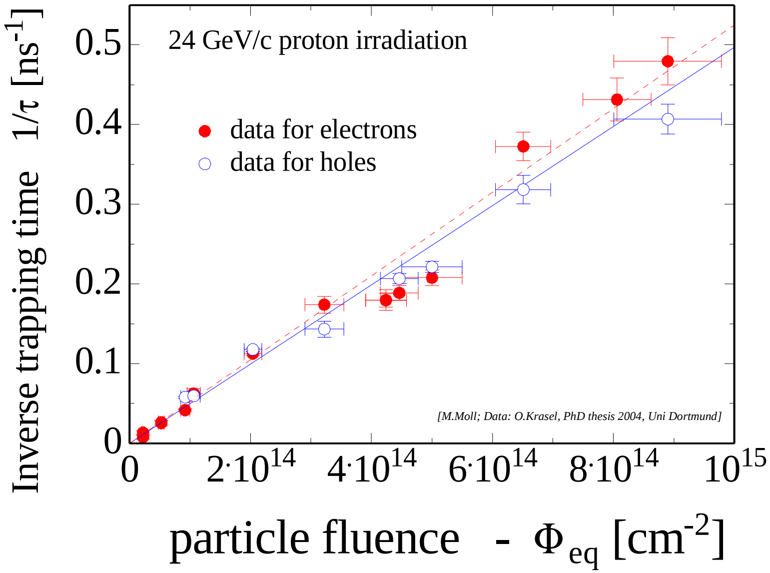
G. Lindström, *Radiation Damage in Silicon Detectors*, Nucl. Instr. Meth. A **512**, 30 (2003)

Charge collection efficiency

Two basic mechanisms reduce the collectable charge:

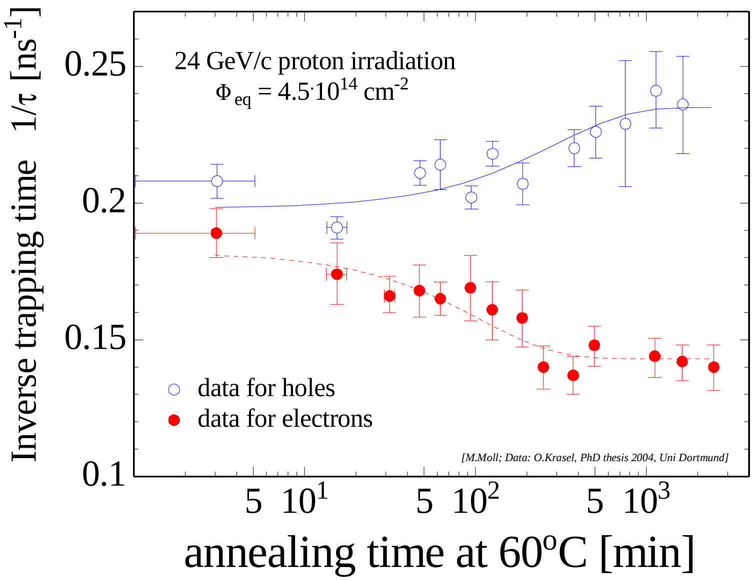
- **Trapping of electrons and holes (see below)**
- **Under-depletion (next slide)**

Increase of inverse trapping time with particle fluence:



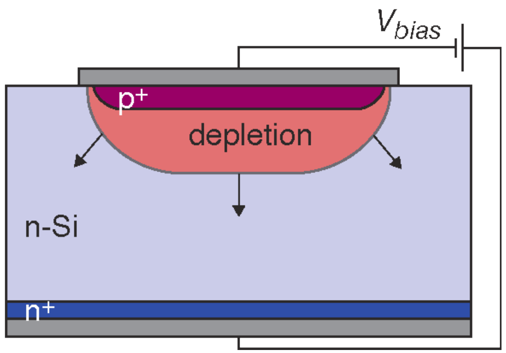
Change of inverse trapping time with time:

….. and change with time (annealing):

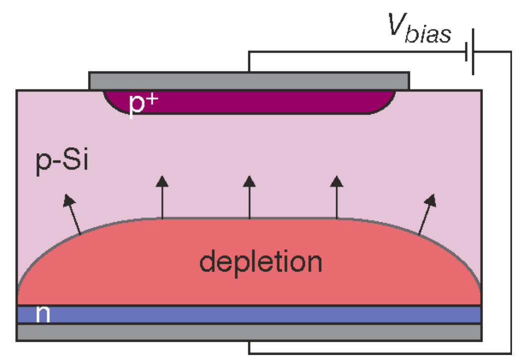


Charge collection efficiency

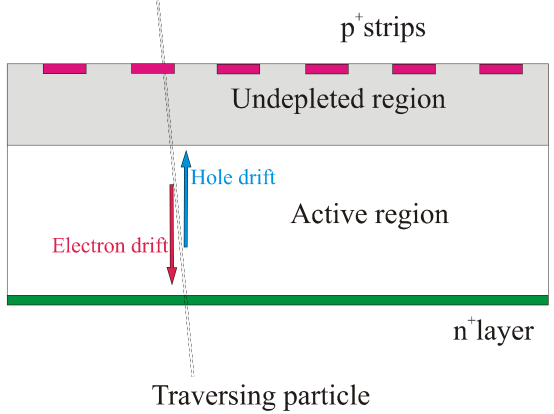
p+n (n-type) before irradiation:



p+n after high fluences:
→ type inversion:
→ under-depletion

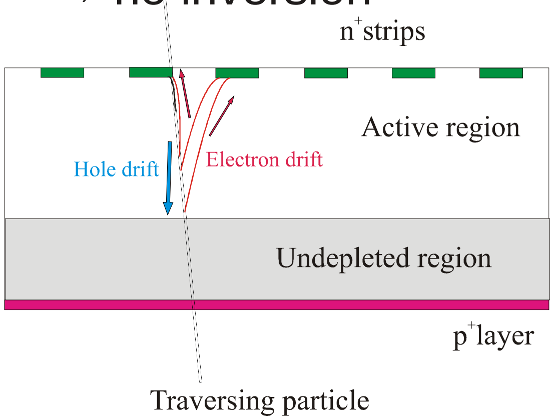


→ Charge spread
→ Worse resolution
→ Charge loss



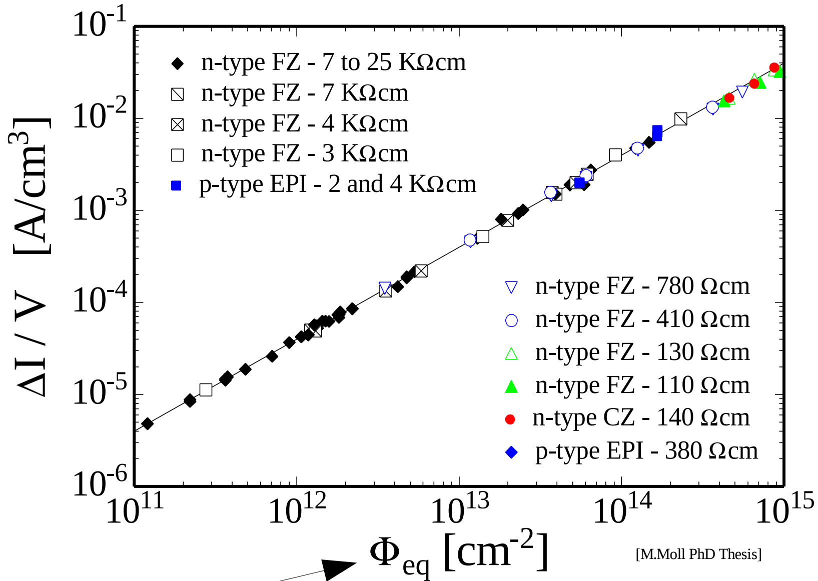
n+p after high fluences:
→ no inversion

p-type remains p-type after high fluences:



Leakage current

Change of leakage current with particle fluence:



1 MeV neutron quivalent fluence (see also later)

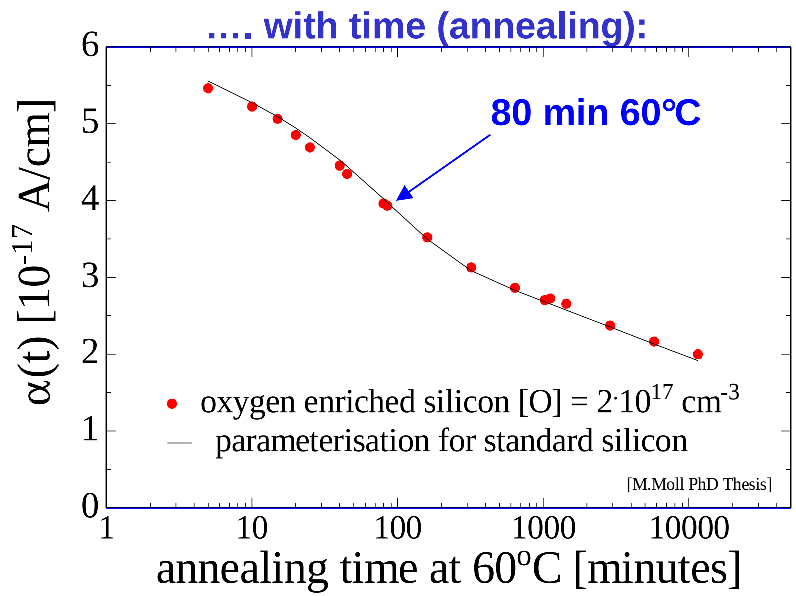
- Damage parameter α (slope in figure)

$$\alpha = \frac{\Delta I}{V \cdot \Phi_{eq}}$$

Leakage current per unit volume and particle fluence

- α is constant over several orders of fluence and independent of impurity concentration in Si. Can be used for fluence measurement

Change of leakage current with time:



- Leakage current decreasing in time (depending on temperature)
- Strong temperature dependence

Consequence:

Cool detectors during operation!
Example: I(-10°C) ~1/16 I(20°C)

But: No extensive cooling foreseen for SciTil

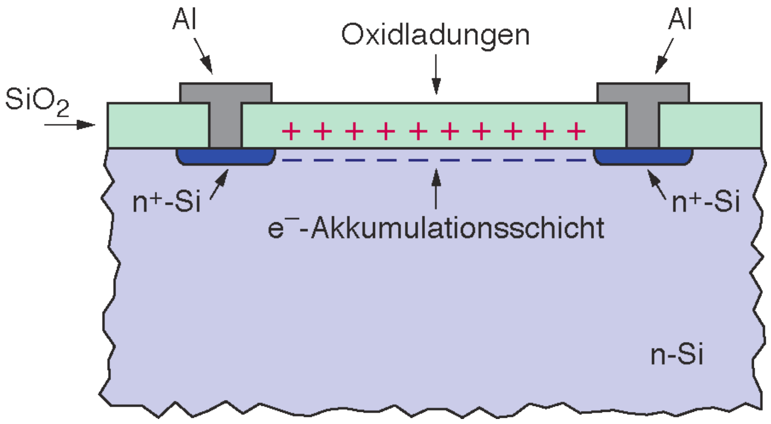
Surface (oxide) defects – IEL

In the amorphous oxide dislocation of atoms is not relevant. However, ionizing radiation creates charges in the oxide.

The mobility of electrons in SiO_2 is much larger than the mobility of holes
–> electrons diffuse out of the oxide, holes remain semi permanent fixed
–> the oxide becomes positively charged due to these fixed oxide charges.

Consequences for the detector:

- Reduced electrical separation between implants
- Increase of interstrip capacitance
- Increase of detector noise
- Worsening of position resolution
- Increase of surface leakage current



Positive oxide charges cause electron accumulation layer.

NIEL hypothesis

We saw already that the radiation damage depends on the type and energy of the particles.

Is there a way to scale and compare damage effects produced by different particles with different energies?

- Bulk damage is due to Non Ionizing Energy Loss (NIEL)
- According to the NIEL hypothesis the radiation damage is linear proportional to the non-ionizing energy loss of the penetrating particles (radiation) and this energy loss is again linear proportional to the energy used to dislocate lattice atoms (displacement energy).
- The NIEL hypothesis does not consider atom transformations nor annealing effects and is therefore not exact.
- Nevertheless, it is common to scale the damage effects of different particles using the NIEL hypothesis. As normalization one uses 1 MeV neutrons and instead of using the integrated flux of a particular particle the equivalent fluence Φ_{eq} (integrated equivalent flux) of 1 MeV neutrons is used.

Damage function

The cross section for a dislocation (damage function D(E)) can be calculated using the recoil energy E_R of the PKA and the so-called Lindhard probability function $P(E_R)$:

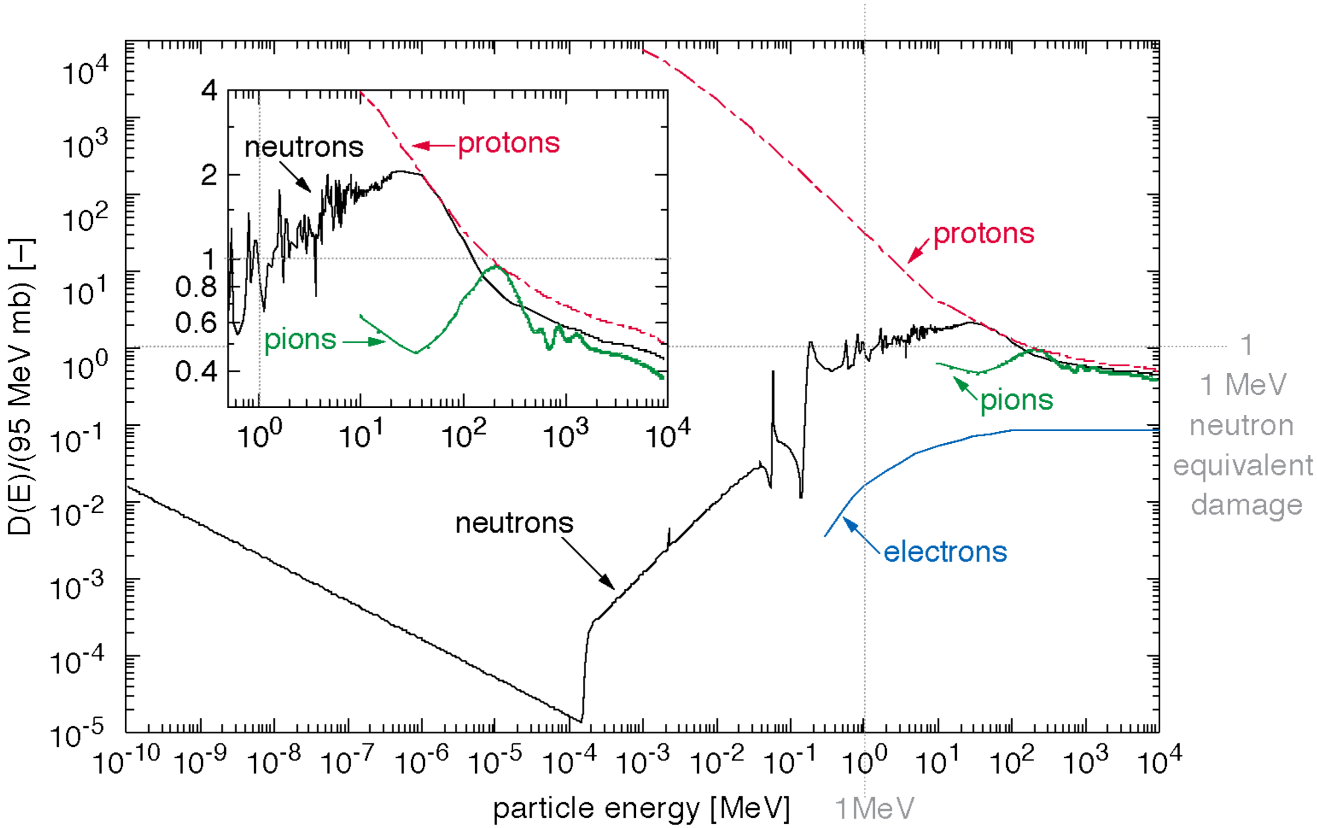
$$D(E) = \sum_{\nu} \sigma_{\nu}(E) \cdot \int_0^{E_R^{max}} f_{\nu}(E, E_R)\, P(E_R)\, dE_R$$

Index ν runs over all possible interactions between the incoming particle with energy E and the silicon atoms leading to a dislocation of a lattice atom. σ_ν is the cross section corresponding to the reaction with index ν and $f_\nu(E,E_R)$ the probability of a particle with energy E to produce a PKA with energy E_R. Integration is over all recoil energies. Below the displacement threshold the partition function is set to zero: $P(E_R < E_{d,min}) = 0$.

E.g.: for silicon the relation between D and NIEL is 100 MeV mb = 2.144 keV cm² / g

Damage function

Damage function according to the NIEL hypothesis for various particles as function of the energy. D(E) in the plot below is divided by 95 mb to be normalized to the damage caused by 1 MeV neutrons:



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

Hardness factor

- With the help of the displacement damage cross section D(E) (damage function) it is possible to define a hardness factor κ for each particle (radiation), allowing to compare the damage efficiency of different radiation sources with different particles and individual energy spectra $\Phi(E)$.

- κ is defined as the irradiation damage of the particular particle compared to the irradiation damage of mono energetic neutrons with 1 MeV and the same fluence:

$$\kappa = \frac{\int D(E)\,\Phi(E)\,dE}{D(E_{\text{neutron}} = 1\,\text{MeV}) \int \Phi(E)\,dE}$$

- D(E_n = 1 MeV) is fixed to be 95 MeV mb.

- The integrated equivalent flux Φ_{eq} (1 MeV neutrons) can therefore be calculated as:

$$\Phi_{eq} = \kappa \cdot \Phi = \kappa \int \Phi(E)\; dE$$

For a reliable comparison of different irradiation experiments it is therefore essential to have a good knowledge about the different energy distributions!

Example ATLAS (LHC)

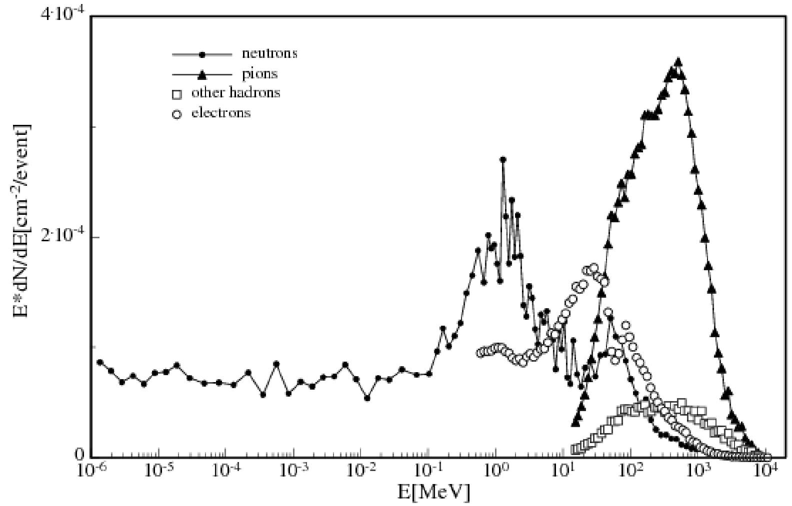


Figure 7: Expected particle spectra in the ATLAS silicon detector at the LHC

A. Vasilescu, *Notes on the fluence normalisation based on the NIEL scaling hypothesis*, ROSE/TN/2000-02, June 2000

"From Fig. 8 we conclude that reactor neutrons, ranging mainly from 1 to 10 MeV, are adequate for reliable damage tests and that indeed irradiations with 250 MeV pions, available at PSI-Villigen, should result in similar damage as expected in LHC."

NIEL folded energy spectra

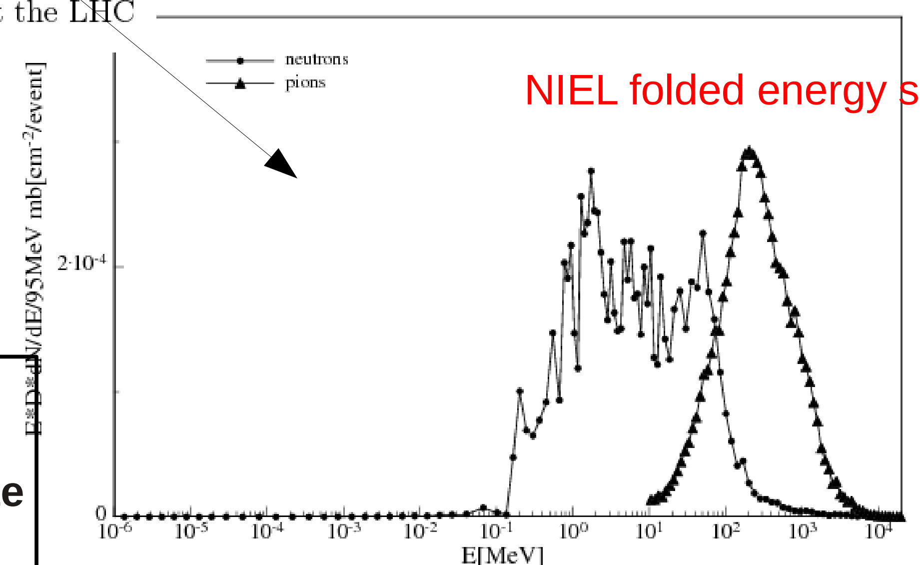


Figure 8: Impact of displacement damage to silicon detectors in ATLAS

Proton induced displacement damage in silicon is tabulated between 1 keV and 9 GeV:

G.P. Summers et al., IEEE NS 40 (1993) 1372

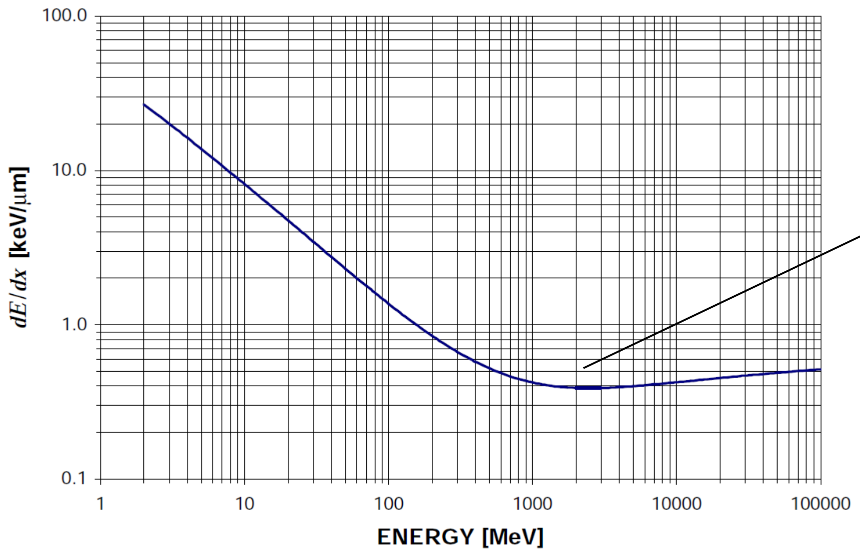
M. Huhtinen and P.A. Aarnio; NIM A 335 (1993) 580

We try at the moment to simulate the particle spectra expected in PANDA using PandaRoot in order to produce the same spectra and estimate the displacement damage for the SiPMs in SciTil. See talk by D. Steinschaden.

Estimation PANDA

PANDA SciTil 10 years: assumption 1 x 10^{12} MIPs (protons) / cm²

dE/dx vs. E of protons in silicon



Minimum ionization: ~ 2 GeV

SciTil: hardness factor 2 GeV protons: 0.62 (tabulated value)

→ 1 x 10^{12} p (2 GeV) / cm² equivalent to 6.2 x 10^{11} n (1 MeV) / cm²

SiPM radiation studies – literature

Y. Musienko et al. 2009 [12]

82 MeV protons at PSI
Up to 1 x 10^{10} protons/cm^2 –> ~ equivalent to 2 x 10^{10} 1 MeV neutrons/cm^2
SiPMs (1x1 mm^2) from CPTA/Photonique, MePhI/Pulsar, FBK-IRST, Zecotek, Hamamatsu
SiPM parameters were measured before and 90 days after irradiation

<u>Results:</u>
- – significant increase in leakage current and dark count rate for all devices
- – no change of breakdown voltage and quenching resistor
- – relative change of PDE < 10%
- – significant reduction (> 10%) of signal amplitude for some devices

P. Bohn et al. 2009 [13]

212 MeV protons at Massachusetts General Hospital
Up to 3 x 10^{10} protons/cm^2 –> ~ equivalent to 2.4 x 10^{10} 1 MeV neutrons/cm^2
SiPMs (1 mm^2 to 6.2 mm^2) from CPTA, FBK, Hamamatsu
SiPM current was measured continuously during irradiation
Other parameters were measured during pauses in between irradiation steps

<u>Results:</u>
- – significant increase in leakage current and dark count rate for all devices
- – reduced gain under large bias currents after irradiation
- – significant reduction (4% – 49%) of signal amplitude
- – loss of photon counting capability at max fluence
- – SiPMs remained functional as photon counters
- – annealing at room temp –> reduction of leakage current by factor 2 in 100 days

SiPM radiation studies – literature

T. Matsumura et al. 2009 [14]

53.3 MeV protons at Research Center for Nuclear Physics, Osaka
Up to 2.8 x 10^{10} protons/cm² –> ~ equivalent to 4.8 x 10^{10} 1 MeV neutrons/cm²
SiPMs (1x1 mm²) from Hamamatsu (MPPC S10362-11-050C)
SiPM current was measured continuously during irradiation
Other parameters were measured during pauses in between irradiation steps
Results: – significant increase in leakage current
– loss of photon counting capability at highest fluences
– no significant change in the gain up to 9.1 x 10^9 1 MeV neutrons/cm²

Y. Musienko et al. 2007 [15]

28 MeV positrons at PSI
Up to 8 x 10^{10} positrons/cm^2 –> ~ equivalent to 2.7 x 10^9 1 MeV neutrons/cm^2
SiPMs (1 mm² to 4.41 mm²) from CPTA, Dubna, Hamamatsu
SiPM parameters measured before and 2 days after irradiation
Results: – significant increase in leakage current and dark count rate for all devices
– change of gain and PDE < 15%

SiPM radiation studies – literature

S. Sanchez Majos et al. 2009 [16]

14 MeV electrons at MAMI
Up to 3.8 x 10^{12} electrons/cm²
SiPMs Photonique
Results: – significant increase in leakage current
– loss of photon counting capability
– partial recovery after annealing at 80°C

M. Danilov 2007 [17]

200 MeV protons at ITEP synchrotron
Up to 2 x 10^{12} protons/cm² –> ~ equivalent to 1.6 x 10^{10} 1 MeV neutrons/cm²
SiPMs 1.1 x 1.1 mm² from MEPhI/Pulsar
Results: – significant increase in leakage current
– loss of photon counting capability after 10^{10} protons/cm²
– SiPMs still operable after highest fluence but much more noise

Y. Musienko NDIP 2011 [18]
A. H. Heering NDIP 2011 [19]

1 MeV neutrons at CERN IRRAD facility
Up to 3 x 10^{12} neutrons/cm²
New SiPMs from Hamamatsu with different pixel sizes (15U – 50U)
Results: – SiPMs with high cell density and fast recovery time can operate up to 3 x 10^{12} n/cm²
– gain change < 25%

Heering et al.

Heering et al., IEEE Nucl. Sci. Symp. Conf. Rec., *Radiation Damage Studies on SiPMs for Calorimetry at the Super LHC*, 2008

212 Mev protons up to 10^{13} per cm²

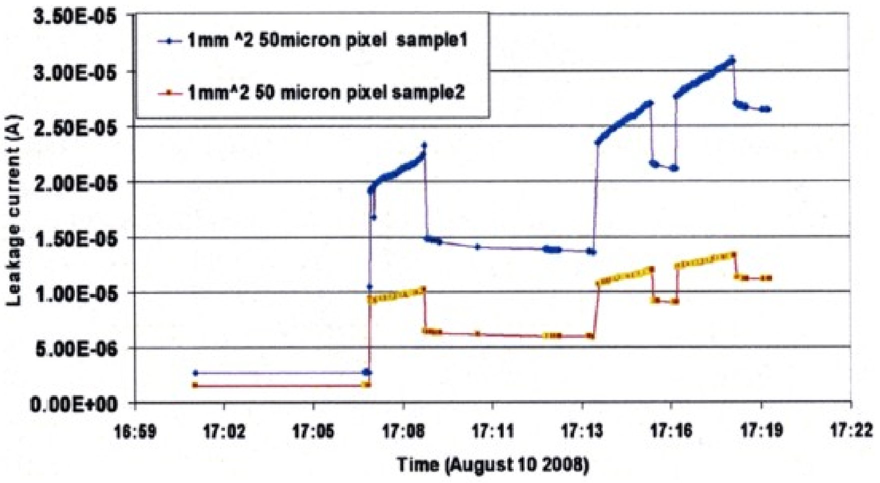


Fig.5. Hamamatsu leakage current vs. time up to a total fluence of 10^{12} protons per cm^2.

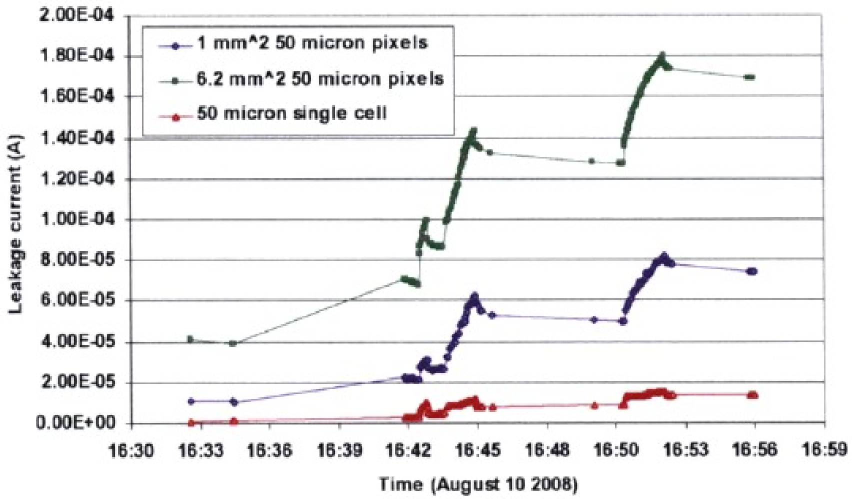


Fig. 6. FBK leakage current vs. time up to a total dose of 7x10^{11} protons per cm^2

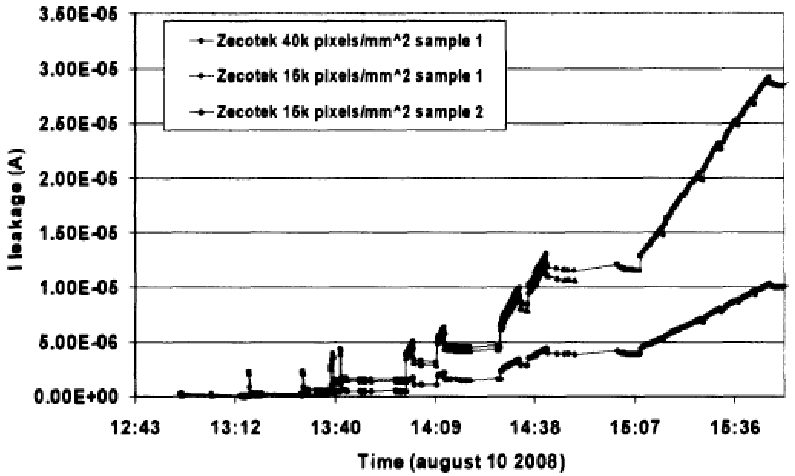


Fig. 8. Zecotek 9mm^2 MAPD leakage current vs. time up to a total fluence of 10^{13} protons pr cm^2.

Looking at the single cell response before and after irradiation:

"At 7x10^{11} per cm² the cell is almost continuously firing which allows no chance of converting incoming photons. Hence the PDE should drop to almost zero. Because the MAPDs have much more cells/mm² we expect the silicon defects per cell resulting in dark count increase to be much smaller for the same dose per cm²"

Heering et al.

Heering et al., IEEE Nucl. Sci. Symp. Conf. Rec., *Radiation Damage Studies on SiPMs for Calorimetry at the Super LHC*, 2008
212 Mev protons up to 10^{13} per cm²

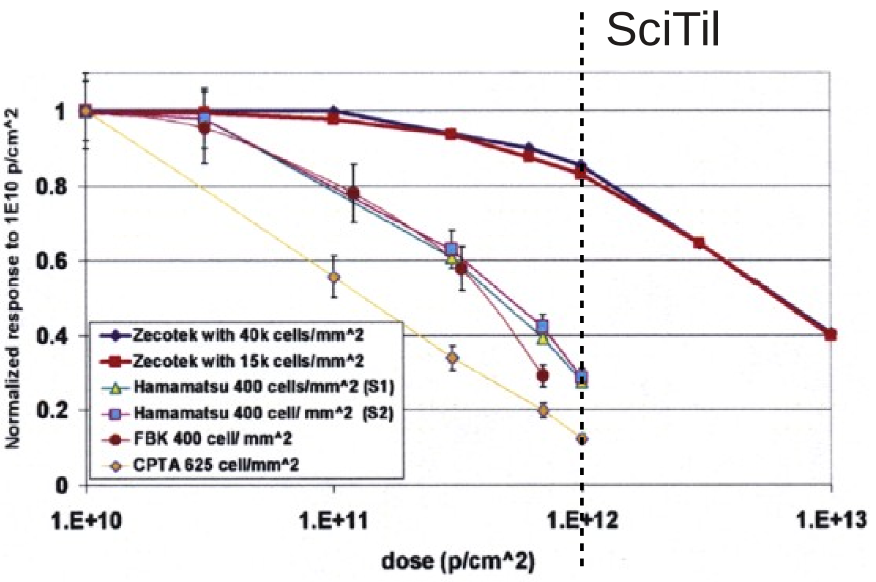


Fig.11. Response vs. radiation fluence for different samples and manufacturers (gain was corrected for voltage drop over the series resistor).

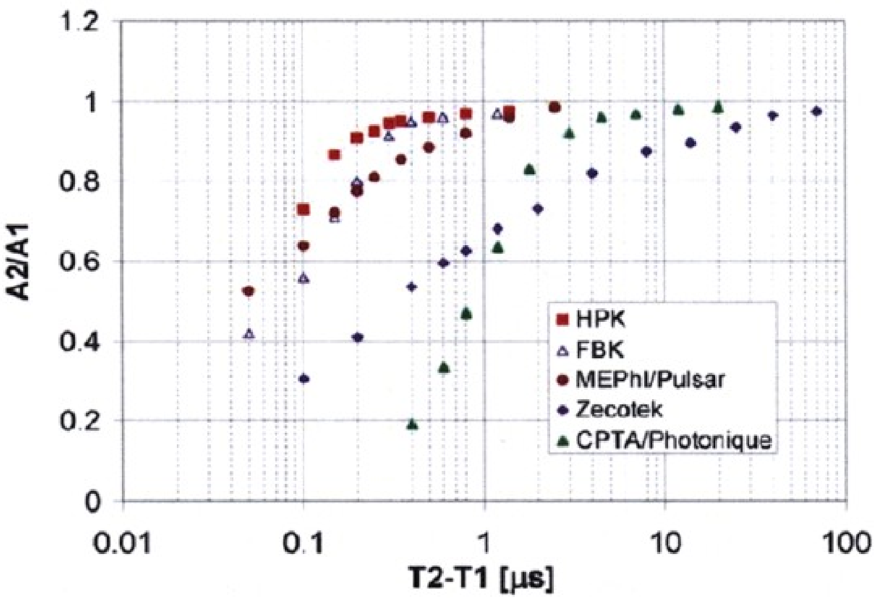
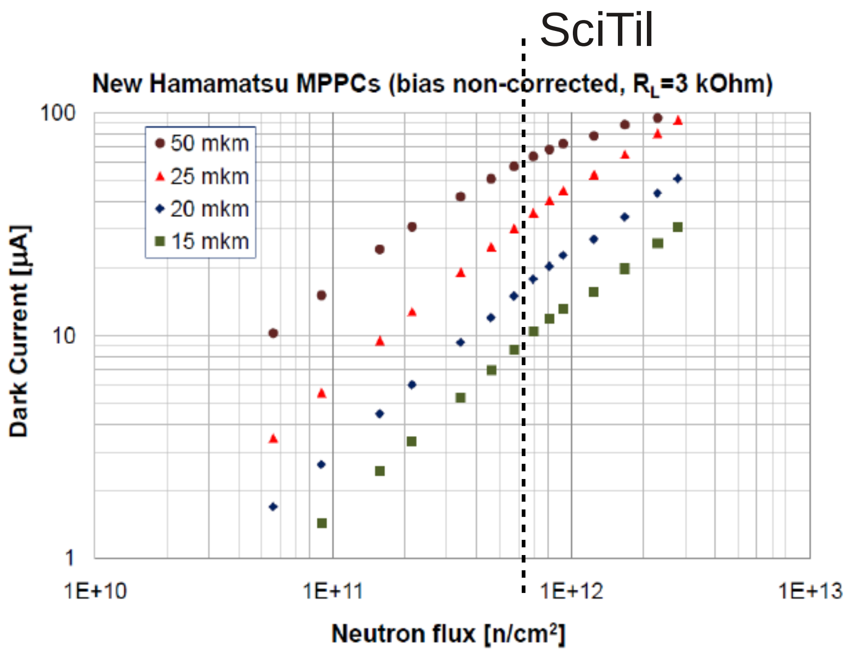


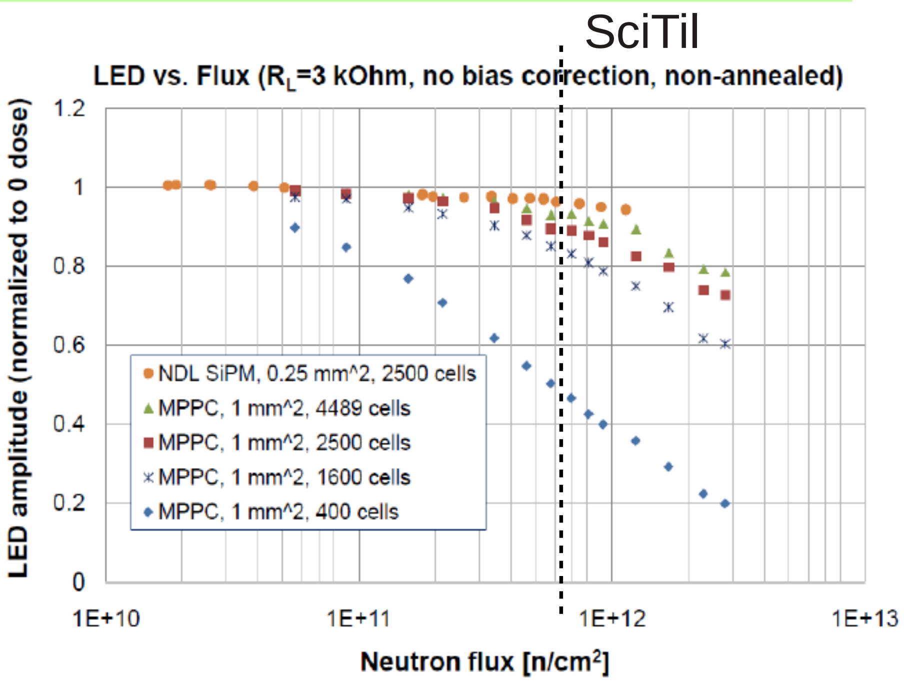
Fig.12. Cell recovery time vs. manufacturer.

Conclusion:
"High energy neutrons/protons produce silicon defects which cause an increase in dark count and leakage current in SiPMs. The single cell measurement shows that the radiation limit for a particular diode is reached when all cells are continuously occupied due to dark count, which results in no sensitivity for incident photons. We therefore conclude that the two limiting parameters for radiation tolerance are the cell density and the cell recovery time of the device."

Musienko and Heering et al.

We performed SiPMs' radiation hardness tests using neutrons (E~1 MeV) at CERN IRRAD-6 facility (see NDIP-2011 talk A. Heering et all. " Radiation damage studies of silicon photomultipliers at SLHC at CERN PS")





G-APDs with high cell density and fast recovery time can operate up to $3*10^{12}$ neutrons/cm^2 (gain change is< 25%).

NDIP-2011, Lyon, 8.07.2011 *Y. Musienko (Iouri.Musienko@cern.ch)* 30

Literature summary

Common results at highest tested flux:

– experiments basically show what is expected from theory
– significant increase in leakage current: factor 10 – 100
– significant increase in dark count rate (pile up → pedestal noise)
– loss of photon counting capability
– reduction of signal amplitude (PDE, gain): 10% – 50%

– SiPMs remained functional as photon detectors
– almost no change of breakdown voltage
– beneficial annealing after irradiation
– SiPMs with small cells and fast recovery time are more radiation tolerant
– no documentation about effects on time resolution

Conclusion:

– the current generation of SiPMs seems to be able to withstand the SciTil dose
– SiPMs seem to be fully functional up to 10^{13} protons (neutrons)
– future innovations will lead to increased radiation hardness
– however the above macroscopic effects will deteriorate the performance
– the above effects are not directly crucial for SciTil
– but the time resolution will be affected
    less photons → worse timing
    more dark counts → pile up → more noise → higher threshold → worse timing
    lower voltage → less dark current → worse timing

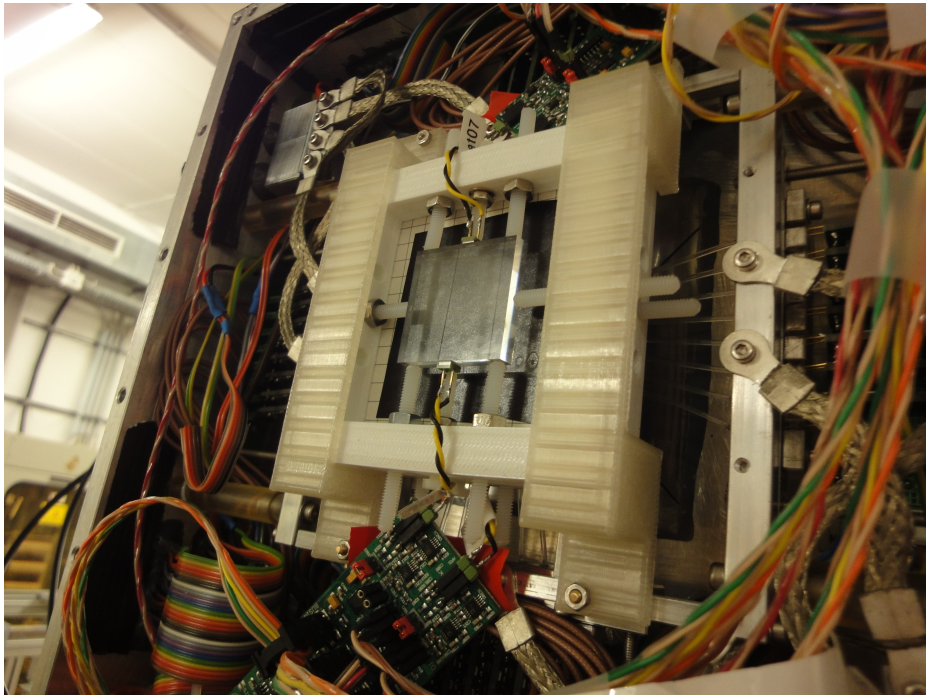
Conclusion

- There is a satisfying amount of literature dealing with radiation hardness of SiPMs, which shows that SiPMs remain in principle fully functional after high doses.
- No paper is dealing with the time resolution of SiPMs after irradiation. However, It can be expected that the time resolution (avalanche generation) is not directly affected.
- For SciTil the most important parameter is a tile time resolution below 100 ps sigma.
- At the last test beam, a time resolution of about 85 ps sigma has been achieved with optimized parameter settings (threshold, voltage).
- It can be expected that these settings have to be adapted after irradiation and therefore the time resolution will be affected.
- In order to definitely say if a time resolution below 100 ps is still feasible after a high dose, a radiation test has to be performed.
- However, it is not necessary to perform a detailed test of all SiPM parameters (leakage current, dark counts, breakdown voltage, gain,...). This has been already done extensively.
- The parameter of interest is the tile time resolution as a function of the applied bias voltage, before and after irradiation.

SciTil time resolution

For the SciTil detector it is important to check if a tile time resolution (i.e. 2 SiPMs attached to a scintillator tile) below 100 ps sigma can still be achieved after a certain dose.

The tile time resolution can be estimated by using an existing setup (Jülich beam time, see picture) and a ^{90}Sr source and determining the time difference between the two SiPM signals. This measurement should be done before and after irradiation of the SiPMs and/or scintillators as a function of over-voltage.



The measurement of the tile time resolution can be repeated several times for different doses and also after irradiation to see a trend of time resolution and study annealing effects.

List of SiPMs

One could irradiate and compare SiPMs from different vendors. However, it is rather clear that the current generation of SiPMs will not be used for the final SciTil detector.

The test may be done only for a small number of SiPMs which are most promising for SciTil and showed the best performance in the SciTil test beam in 2014 at Jülich (*Ref.: L. Gruber, PhD Thesis, Vienna UT*).
Besides it will be also interesting to compare different generations of SiPM.

E.g.:

- Hamamatsu S12572-025P (low afterpulse, new generation)
- Hamamatsu S12931-025P (old generation)
- Ketek PM3360TS (optical trench)
- Philips DPC-3200
- AdvanSiD ASD-NUV4S-P (FBK)

Radiation test at PSI

A radiation hardness test of SiPMs could take place at PSI in Villigen, Switzerland.

The Proton Irradiation Facility (PIF) there is well suited for such tests.

– Proton energy up to 230 MeV
– Max. intensity at 230 MeV: 2 nA
– Intensity between 100 and 200 MeV: 5 nA
– Intensity below 100 MeV: 10 nA
– Max. flux at 230 MeV: ~ 2 x 10^9 p/s/cm²

http://pif.web.psi.ch/pif.htm

We know the facility from previous test beam experiments. We are in contact with the responsible person.

The idea is to test several SiPMs from different vendors and compare the performance before and after irradiation. **Special emphasis will be placed on the time resolution of the irradiated devices.** Time resolution has not been studied in any of the other radiation tests listed on previous slides.

PIF at PSI

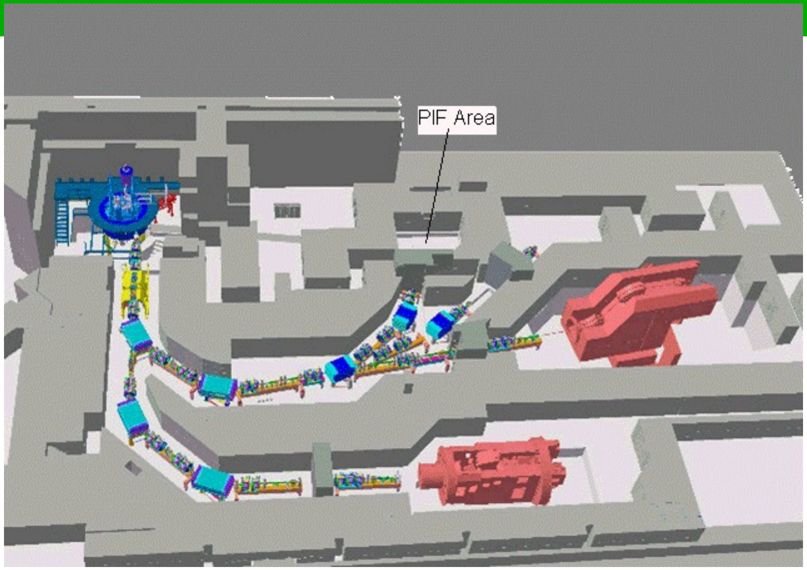


Figure 1. PIF-PROSCAN Hall with the PIF Experimental Area

- Initial proton energies: 230, 200, 150, 100 and 74 MeV (can be modified)
- Energies available using the PIF degrader: continuously from 6 MeV up to 230 MeV
- Energy straggling for the initial beam energy of 74.3 MeV:
  e.g. FWHM = 2.4 MeV at 42.0 MeV, FWHM = 5.6 MeV at 13.3 MeV.
- Maximum beam intensity at 230 MeV: 2 nA (at 74.5 MeV ca. 5 nA effectively)
- Maximum flux at 230 MeV for the focused beam: ~ $2*10^9$ protons/sec/cm²
- Beam profiles are of Gaussian form with standard (typical): FWHM=10 cm
- The maximum diameter of the irradiated area: f 9 cm
- The accuracy of the flux/dose determination: 5%
- Neutron background: less than 10^{-4} neutrons/proton/cm²
- Irradiations, devices and sample positioning are supervised by the computer
- Sample mounting frame 25 x 25 cm² is attached to the XY table
- Data acquisition system allows automatic runs with user predefined irradiation criteria

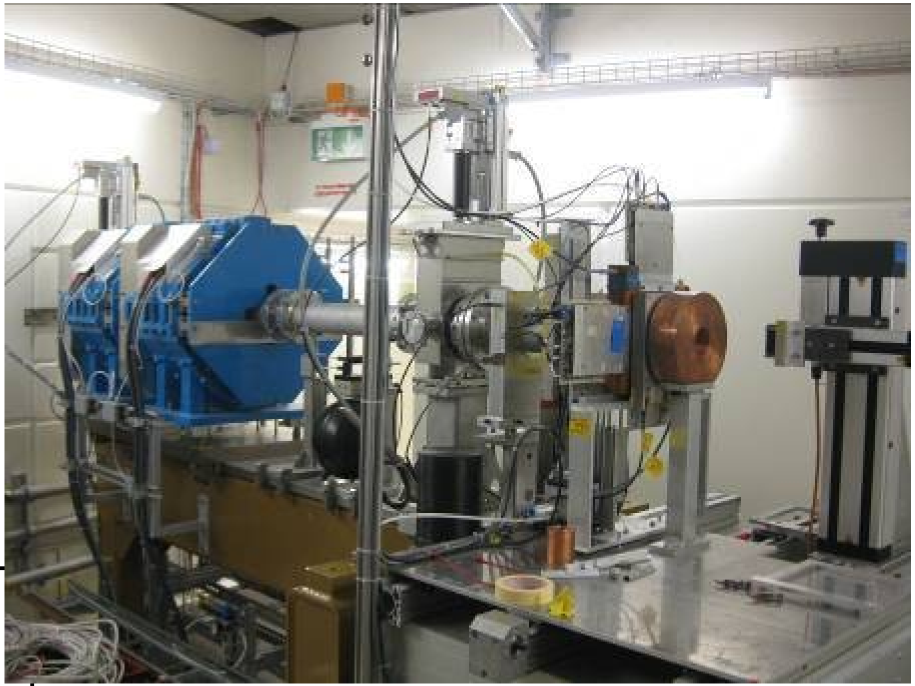
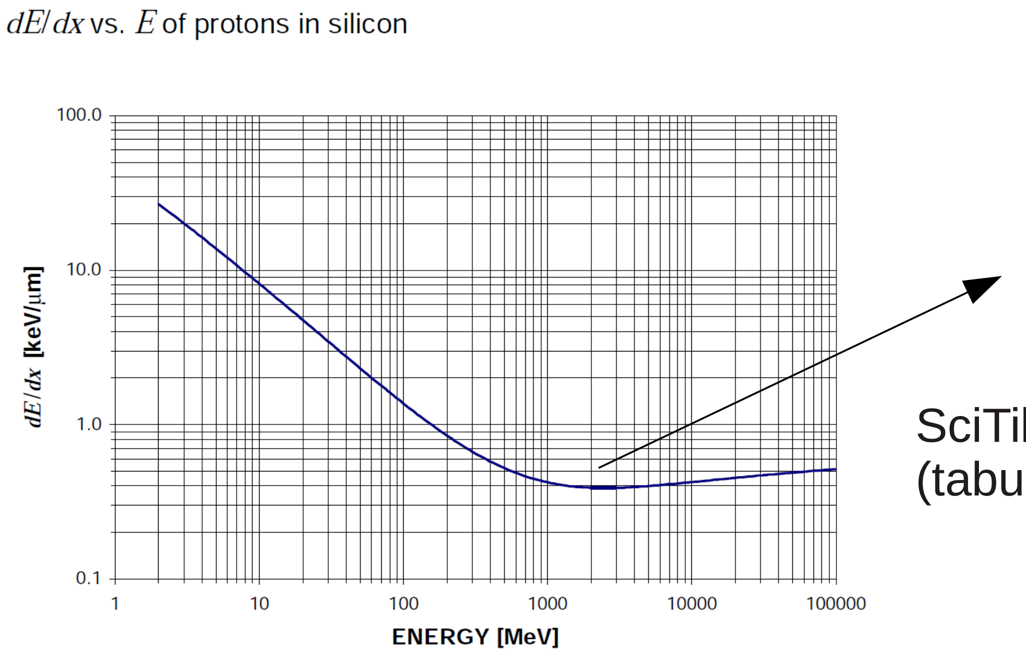


Photo 1. PIF area downstream view with the last quadrupole magnets, beam monitors and PIF station. One can see the XY-table with beam collimator.

http://pif.web.psi.ch/pif.htm

Irradiation time

Estimation: 10 years of SciTil in PANDA: ~ 1 x 10^{12} MIPs/cm^2



Minimum ionization: ~ 2 GeV

SciTil: hardness factor 2 GeV protons: 0.62 (tabulated value)

PIF: hardness factor 230 MeV protons: 0.95 (tabulated value)
PIF: max intensity: 2 x 10^9 p/cm^2/s
Time needed to achieve roughly same damage as expected in PANDA: 325 s ~ 5.5 min

Other possible facilities

PIF facility at PSI seems a promising option. There are also other irradiation facilities available:

- Centre de Recherches du Cyclotron, Louvain-la-Neuve, Belgium

Proton Beam Facility (LIF):
Proton energy up to 65 MeV
Max. flux at 65 MeV: ~ 2×10^8 p/s/cm²
Time needed to achieve expected PANDA dose: ~ 30 min

- Jyväskylä University, Finland

Radiation Effects Facility (RADEF):
Proton energy up to 55 MeV
Max. intensity at 55 MeV: 62 µA
Time needed to achieve expected PANDA dose: ~ 30 min (assuming comparable flux)

- Uppsala, Sweden

PAULA Proton Irradiation Facility:
Energy: Selectable in the range 20 – 180 MeV
Beam spot diameter: 0.4 – 20 cm
Maximum proton flux: Direct beam: 10^{11} - 10^{12} $cm^{-2}s^{-1}$
Scattered beam: $5 \cdot 10^7$ - $5 \cdot 10^9$ $cm^{-2}s^{-1}$
Time needed to achieve expected PANDA dose: few seconds at max. flux

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Thank you !

Spare slides

Measurement plan

- In order to fully describe the SiPM performance the device characterization has to be done before, during and after irradiation. At first the SiPM parameters will be determined before irradiation at the laboratory. At the irradiation facility there are two sets of tests that we would like to perform (see below). After irradiation the SiPMs will be measured again (several times) at the laboratory to see annealing effects.

- **Test A:**

  Irradiation of single devices in several steps (e.g. 6 – 8 steps) up to the full dose. Characterization of the devices after each step. This can be done remotely in beam by using an automated setup (already in preparation) or by taking the SiPMs out of the beam after each step and measuring in a test setup outside the cave. Each step will take roughly 1.5 hours.

  Test A will be interesting to see the change in detector performance in dependence of the dose.

- **Test B:**

  Irradiation of several devices simultaneously with the full dose and characterization afterwards. As time estimations on previous slides show this can be rather quick (few minutes).

  Test B will show if the detectors are still operable after the full PANDA dose.

SiPM parameters

The following parameters should be determined to characterize the SiPMs before, after and during irradiation.

- Leakage current
- Dark count rate
- Breakdown voltage
- Photon counting capability
- Gain
- Time resolution

All parameters will be determined in dependency of the bias voltage.
The time resolution is one of the most important parameters for SciTil.
Time resolution has not yet been considered in other radiation studies.

List of SiPMs

It is planned to irradiate and compare SiPMs from different vendors.

Since Test A is more time consuming this test will be done only for a small number of SiPMs which are most promising for SciTil and showed the best performance in the SciTil test beam in 2014 at Jülich (*Ref.: L. Gruber, PhD Thesis, Vienna UT*). Besides it will be also interesting to compare different generations of SiPM.

E.g.:

- Hamamatsu S12572-025P (low afterpulse, new generation)
- Hamamatsu S12931-025P (old generation)
- Ketek PM3360TS (optical trench)
- Philips DPC-3200
- AdvanSiD ASD-NUV4S-P

In case of Test B we can irradiate a larger amount of SiPMs since several SiPMs can be irradiated in parallel in a single irradiation step (few minutes). Also more than one SiPM of the same type can be put in the beam.

SiPM characterization

Automated setup for SiPM characterization tests based on LabView: