**Effects of Very High Radiation on SiPMs**

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### Radiation Damage in CMS

![Image](image1.png)

**Dark Count** = \(1/q \times V \times \Phi\)

Due to high gain we can see the current increase in SiPMs.

Radiation Damage in CMS

- Modification of electric field profile of the SiPM's p-n junction and cell periphery may (mainly by tunneling via radiation-induced defects in Si) as well as by cell edge effects.
- During R&D for the CMS HCAL Phase I Upgrade, we found that theory vs measurement

**Theory vs measurement**

- Leakage current increase in Si-PIN diodes for 1 MeV equivalent dose
- Similar damage seen in GM-APDs or SiPMs
- slope = 3.5E-17 A/cm
- Due thin epitaxial layer SiPMs are intrinsically radiation harder than PIN diodes

![Image](image2.png)

Due to high gain we can see the current increase in SiPMs as single p.e. counts:

- Dark Count = \(1/q \times V \times \Phi \times \text{slope} \times 
\text{G.F.} \times P_\text{inc}\)

**Measurements show 4X more noise**

![Image](image3.png)

During R&D for the CMS HCAL Phase I Upgrade, we found that the dark noise generation rate in APDs/SiPMs is dominated by high electric field effects (mainly by tunneling via radiation-induced defects in Si) as well as by cell edge effects.

Modification of electric field profile of the SiPM's p-n junction and cell periphery may help to reduce these effects.

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### Current R&D with FBK

**Ultra high density cells with trench technology**

First results of SiPMs with 7.5 micron show good PDE due to IRST - FBKs advanced trench technology

- Dark current 1 mA/mm²
- Low PDE change
- Gain reduction due to self heating of the device

![Image](image4.png)

Combined effort between FBK and CMS looks very promising.

We hope to further reduce gain and field effect tunneling in future R&D wafer runs to increase radiation hardness.