Effects of Very High Radiation on SiPMs

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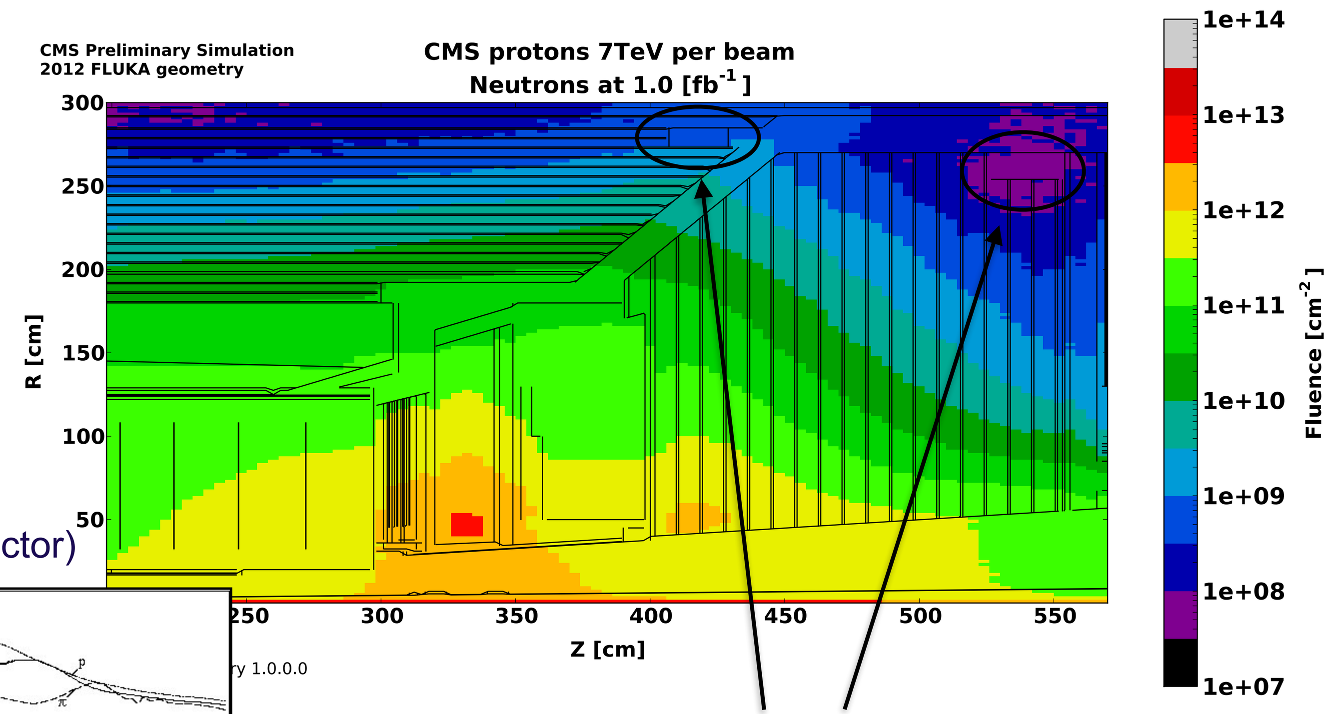
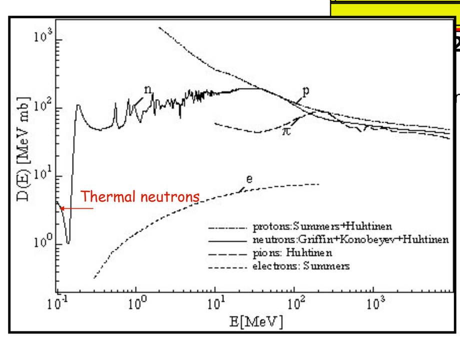
Radiation Damage in CMS



(Si - NIEL factor)

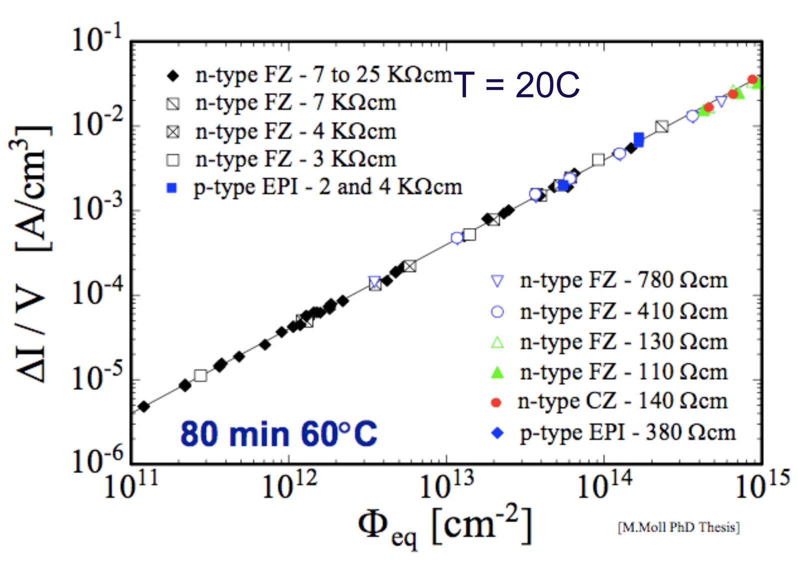


Currently Approved SiPM installation for max 10^{12} n/cm^2
1 Mev eq. for a CMS total integrated luminosity of **3000 fb^{-1}**

MORE R&D needed to achieve development of SiPMs capable of operating closer to the beam pipe

Theory vs measurement

Leakage current increase in Si-PIN diodes for 1 MeV equivalent dose



Similar damage seen in GM-APDs or SiPMs

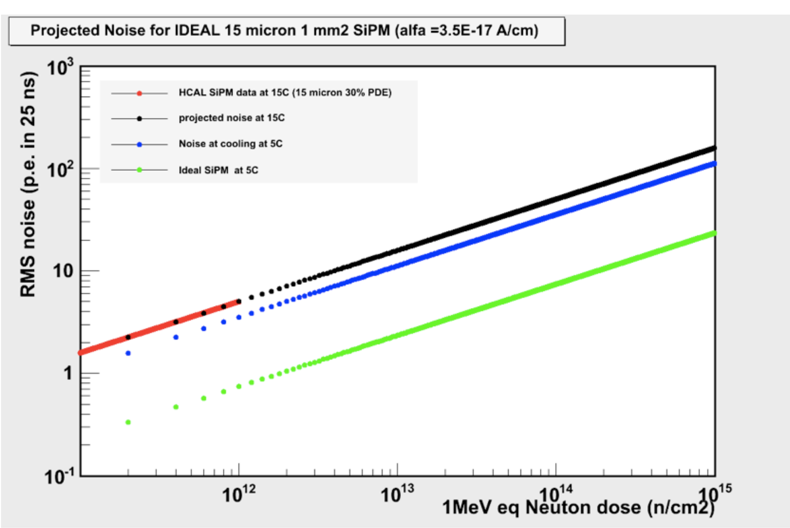
slope= 3.5E-17 A/cm
V= cell size * d_{epi} (few microns)

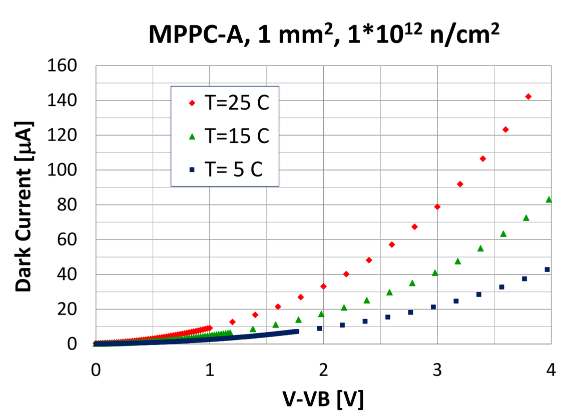
Due thin epitaxial layer SiPMs are intrinsically radiation harder than PIN diodes

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

Dark Count = 1/q * V * Φ * slope * G.F. * $P_{(V)}$

Measurements show 4X more noise



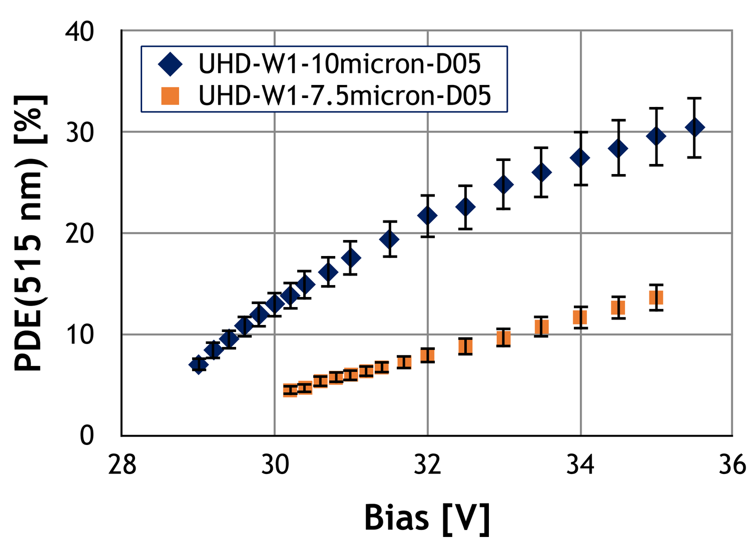


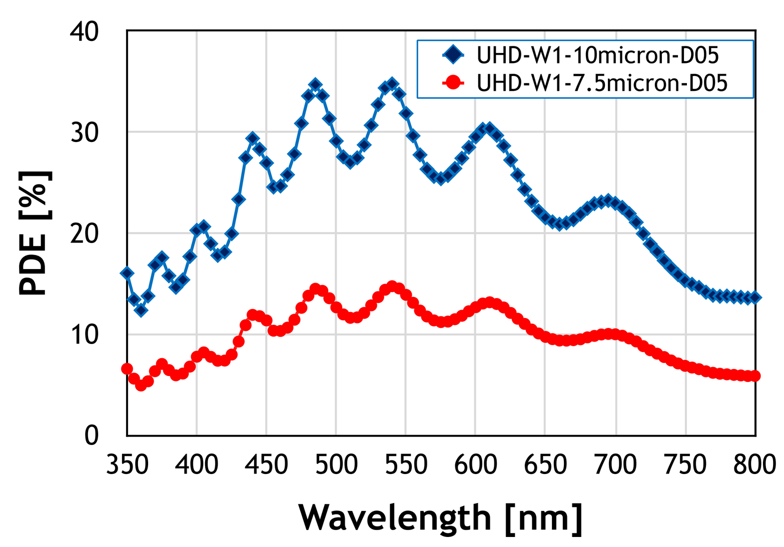
During R&D for the CMS HCAL Phase I Upgrade, we found that the dark noise generation rate in APDs/SiPMs is dominated by high electric field effects (mainly by tunneling via radiation-induced defects in Si) as well as by cell edge effects. Modification of electric field profile of the SiPM's p-n junction and cell periphery may help to reduce these effects.

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



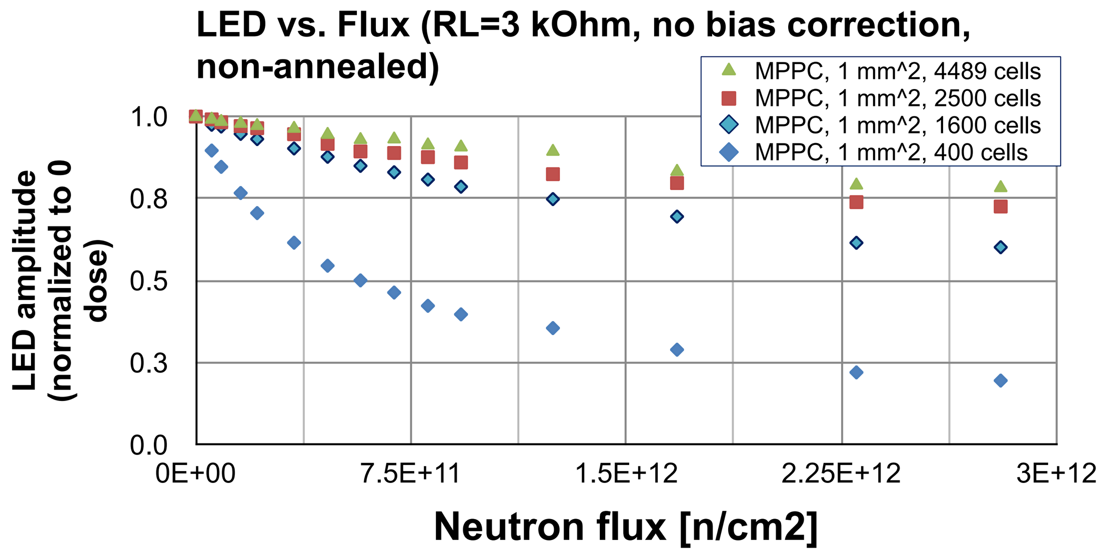


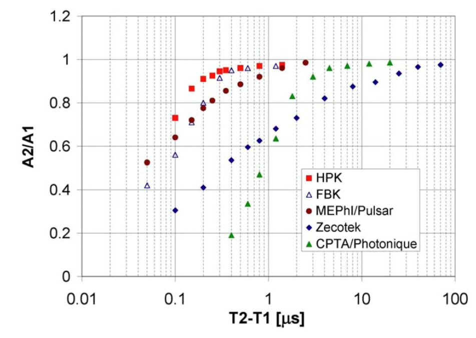
Combined effort between FBK and CMS looks very promising.
We hope to further reduce gain and field effect tunneling in future R&D wafer runs to increase radiation hardness

Three Data Sets

Radiation Damage test up to 3*10^{12} n/cm^2

Cern irrad 6 Neutrons from backscattered protons (2010)

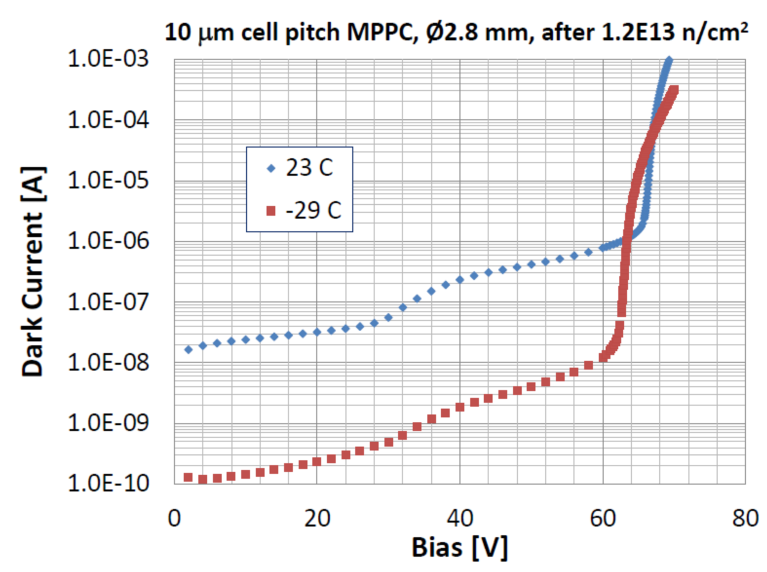


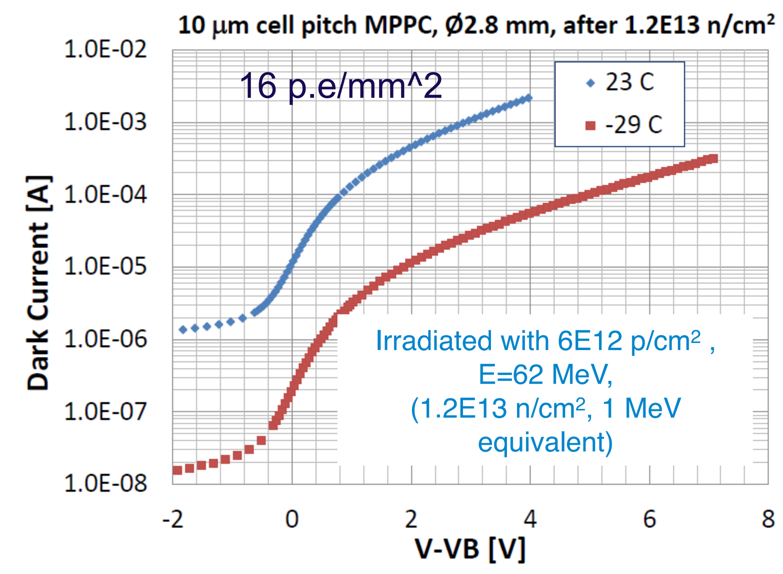


Cell size and Recovery time are important factors

Radiation Damage test to 1*10^{13} 1MeV eq n/cm^2

LIF at UCL Belgium (2014)





Noise in 25 ns is 16 p.e. and 2.6 p.e. /mm2 at Vb =3V at resp. 23C and -29 C

Radiation Damage test up to 1.3*10^{14} p/cm^2

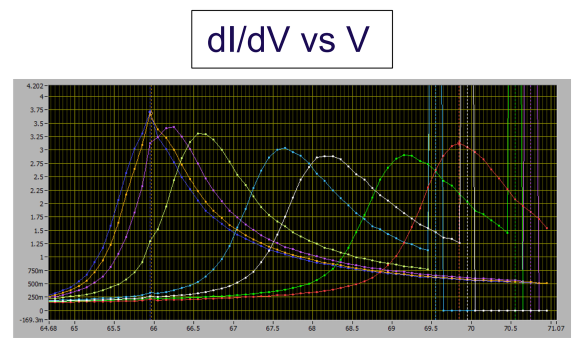
CERN 23 GeV proton Beam (2015)

- HPK 6 mm^2 10 micron cell with different dose

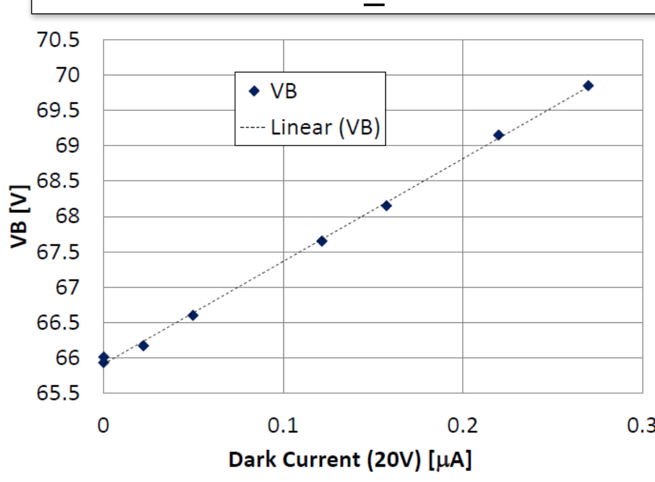
(8 channel array ; Ch 2 in full beam ; Ch 8 farthest away from beam)

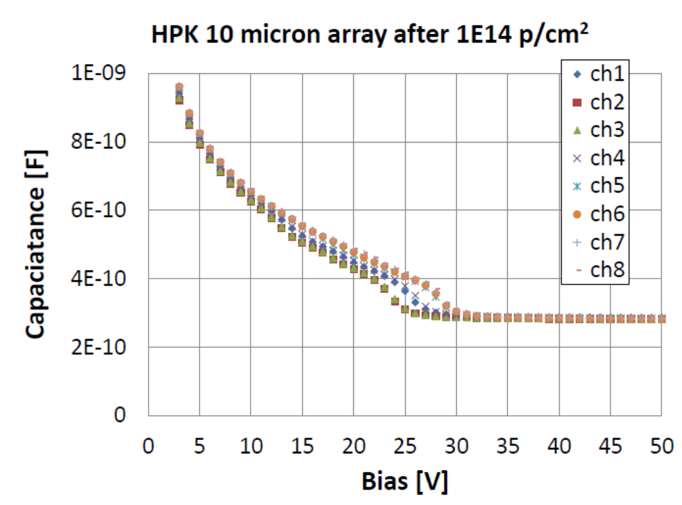
Leakage currents after radiation show large shift in Break down voltage

dI/dV vs V



Linear Behavior of V_breakdown vs dose





- FBK 1 mm^2 12 micron cell with thin epitaxial layer

Measured at T= 23 Celsius

- Small bias shift of 0.5V
- Low PDE change
- Dark current 1 mA/mm^2
- Gain reduction due to self heating of the device