Radiation Damage Studies of Silicon Photomultipliers for SLHC at CERN PS IRRAD facility

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With thanks to the CERN PS IRRAD facility i.d. Maurice Glaser and Micheal Moll

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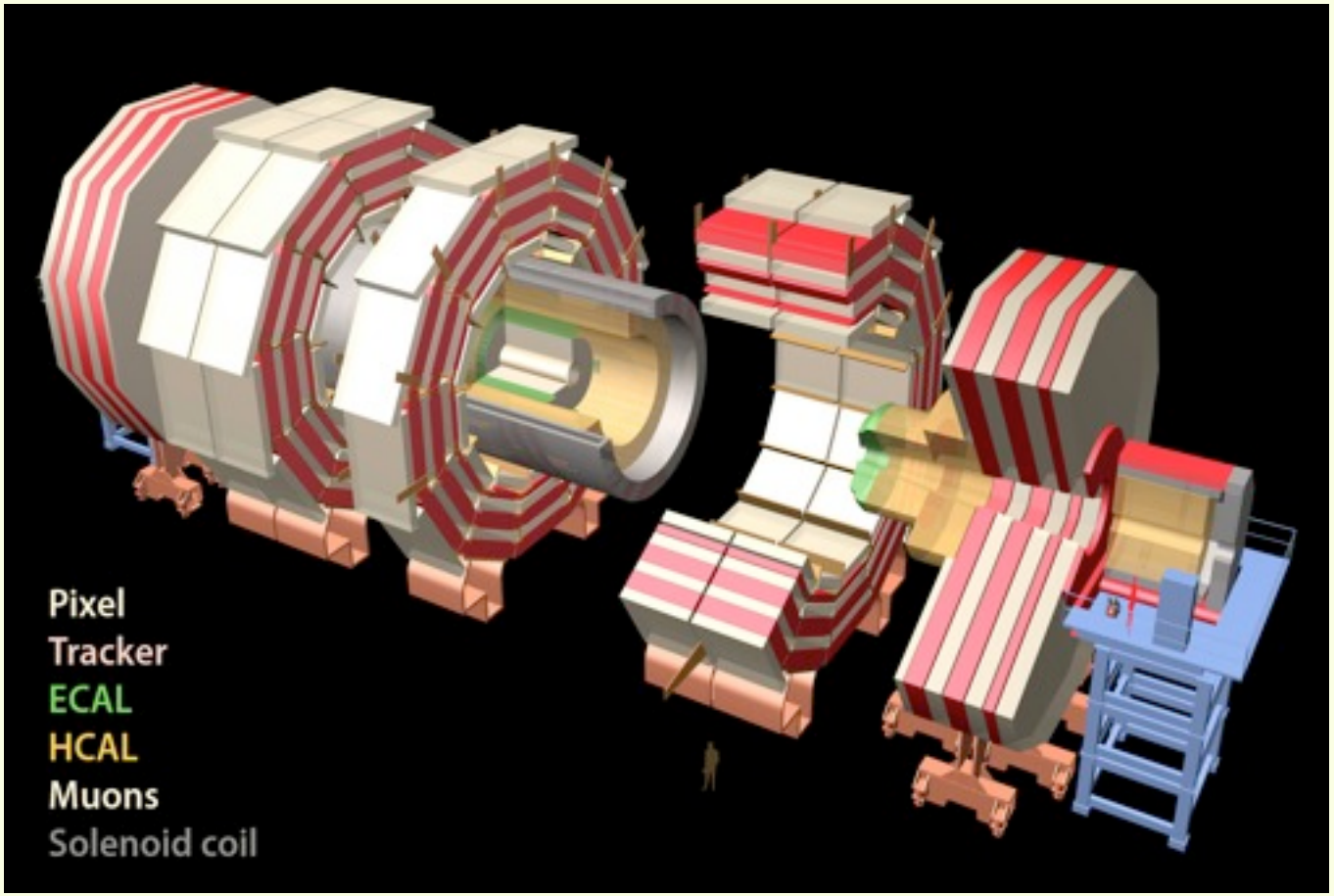
CMS- Hadronic Calorimeter



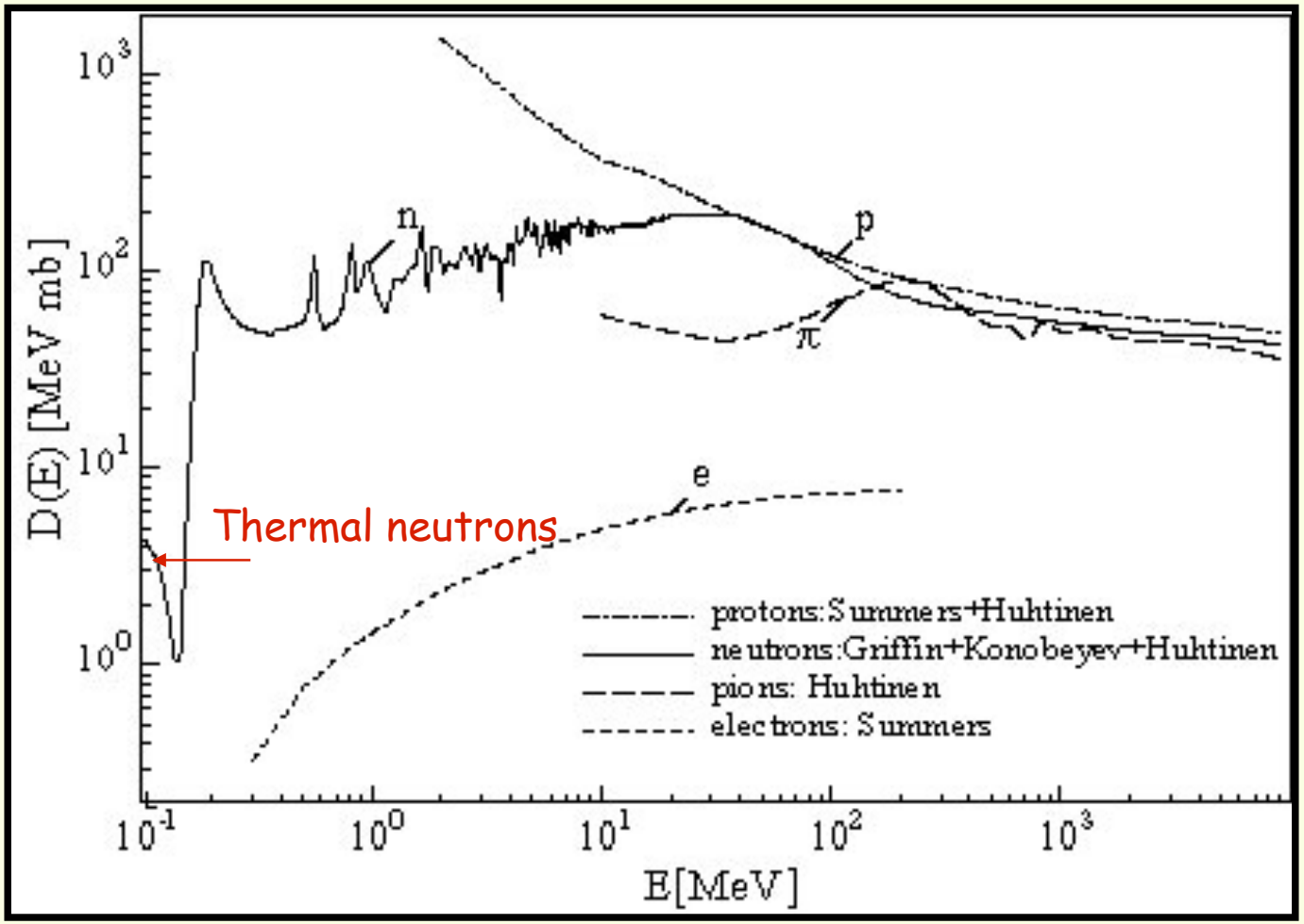
HCAL is a scintillator sampling calorimeter inside the 4 Tesla field

Radiation levels for CMS Hadronic

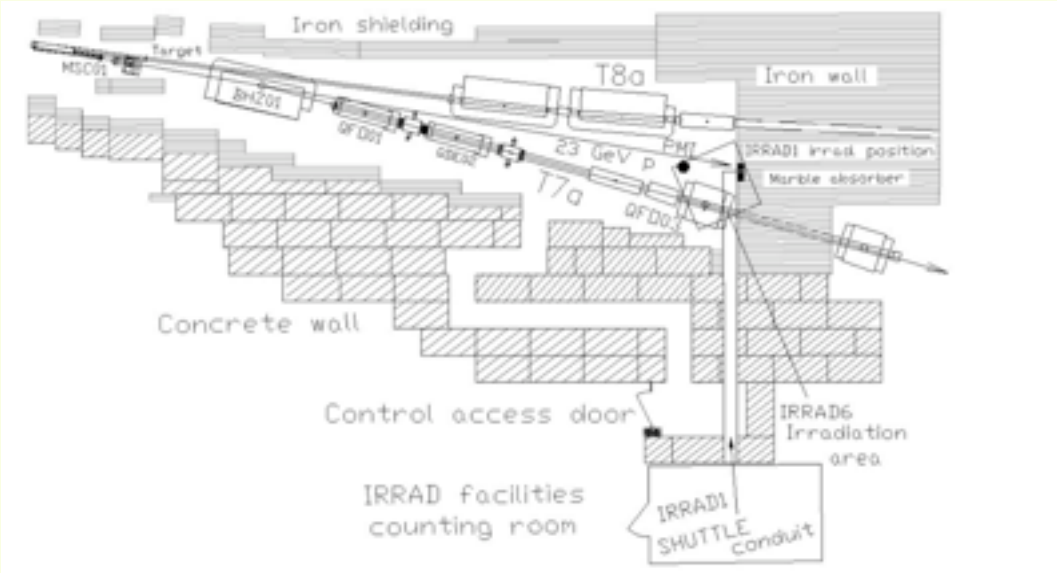
SLHC (3000 fb-1) at FE- electronics readout

HCAL Section	>100 keV n/cm^2	Thermal n/cm^2
Barrel/Endcap (HB/HE)	3E12	3E13
Outer Layers (HO)	3E11	3E12
Forward (HF)	1E14	1E15
Total dose for SLHC with a Safety factor=3		

Silicon damage factor (NIEL)

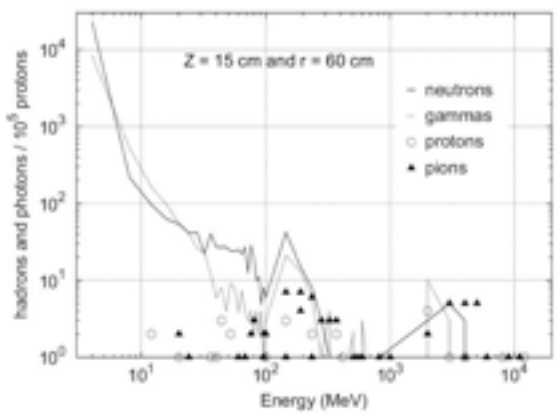


CERN PS - Irrad 6

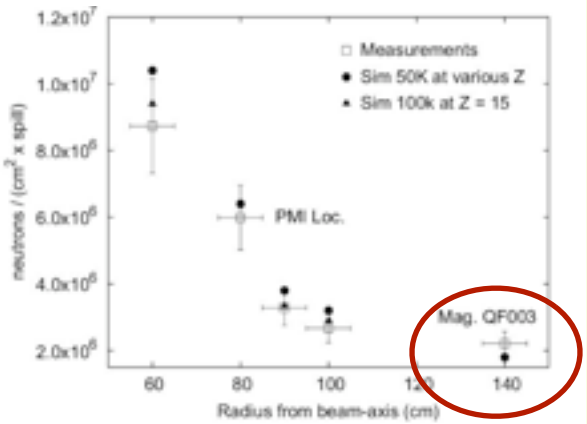


Large uniform beam
with
LHC like conditions

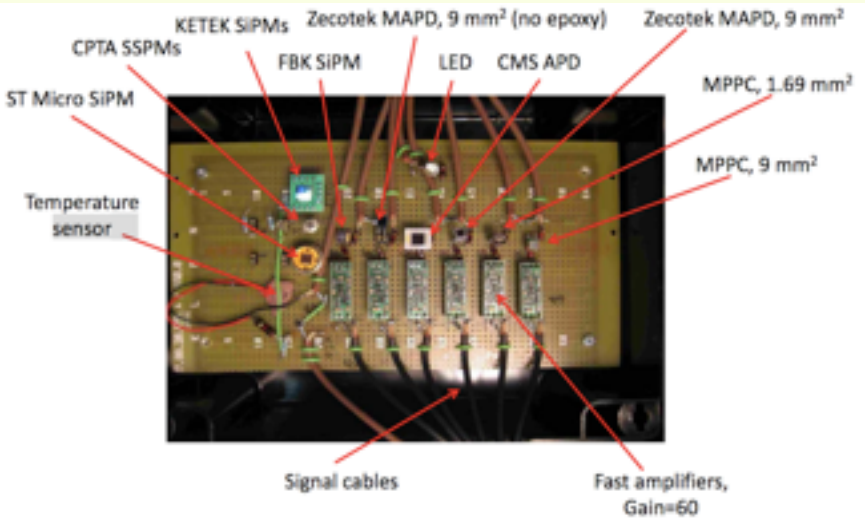
Energy spectrum

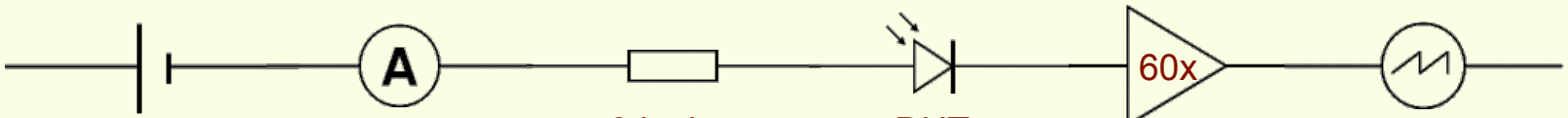


Intensity for 2E11 23 GeV protons /spill



Setup





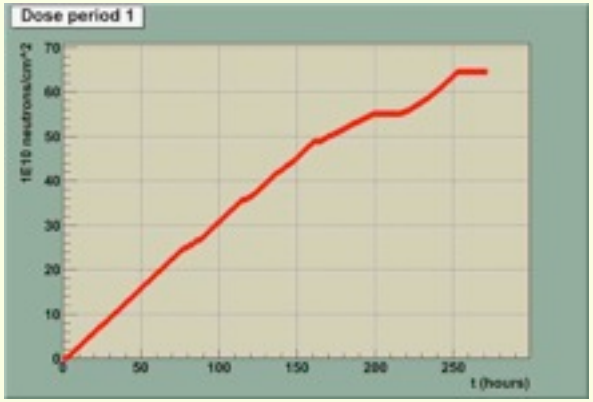
Keithley
voltage source/ampmeter

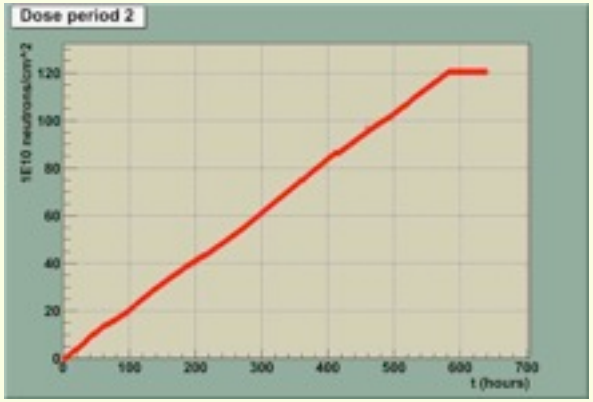
3 k ohm

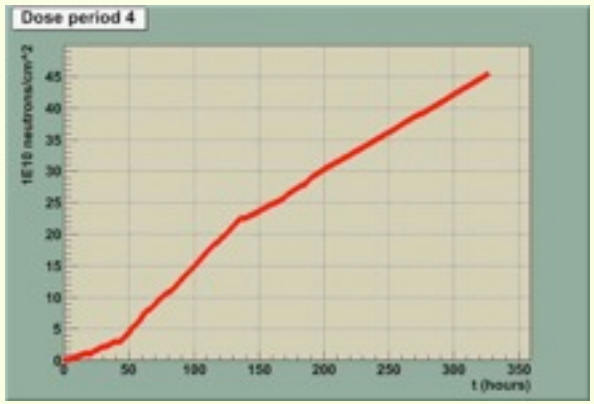
DUT

50 ohm Pico scope

SEC calibration data of 6 periods





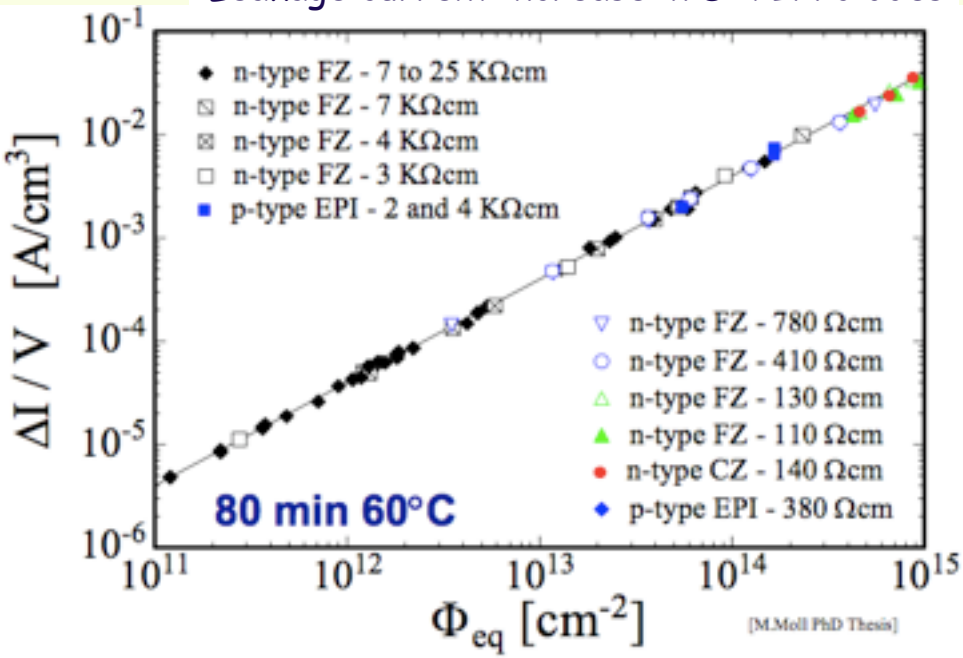


No Data

Number of primary protons measured with Secondary Emission Chamber

GM-APD Radiation Damage

Leakage current increase in Si-PIN diodes eq. 1 Mev neutrons



Similar damage seen in GM-APDs

slope= **3.5E-17 A/cm**

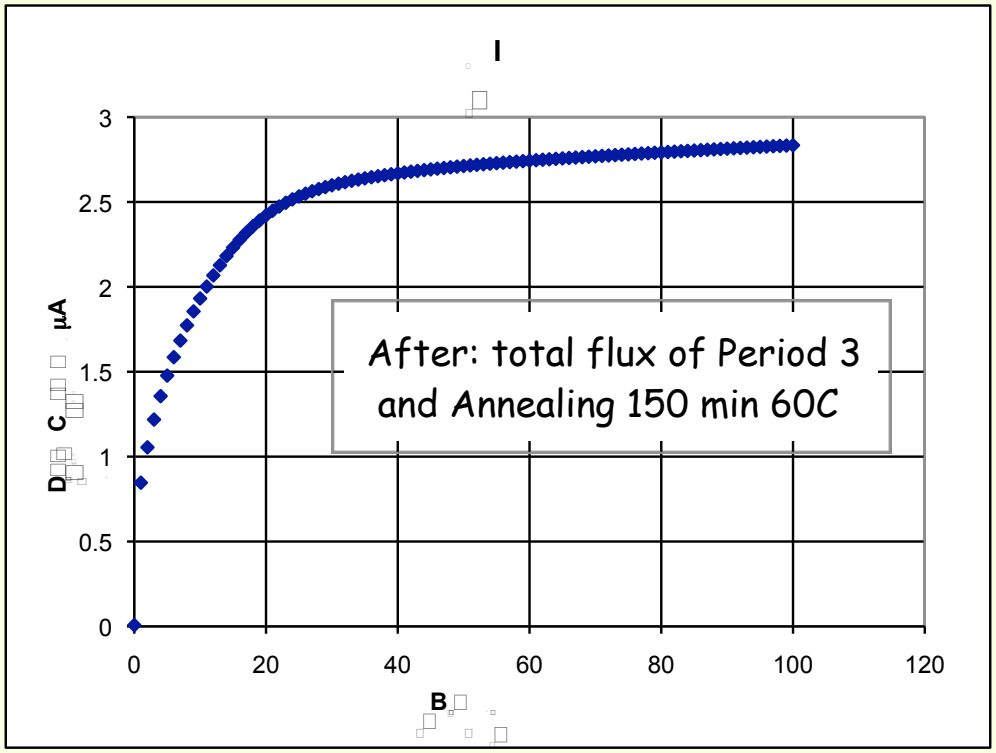
V= cell size * d_{epi} (few microns)

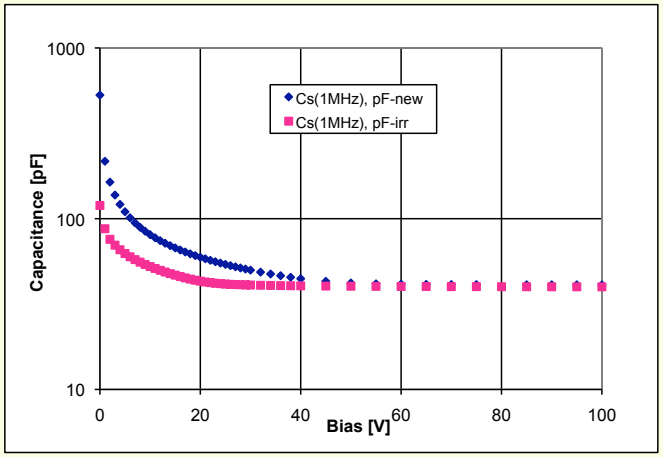
Due to high gain we can see the current increase in Si as single p.e. counts:

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

high dose ==> MHz noise /cell (more cells is more radiation hard)

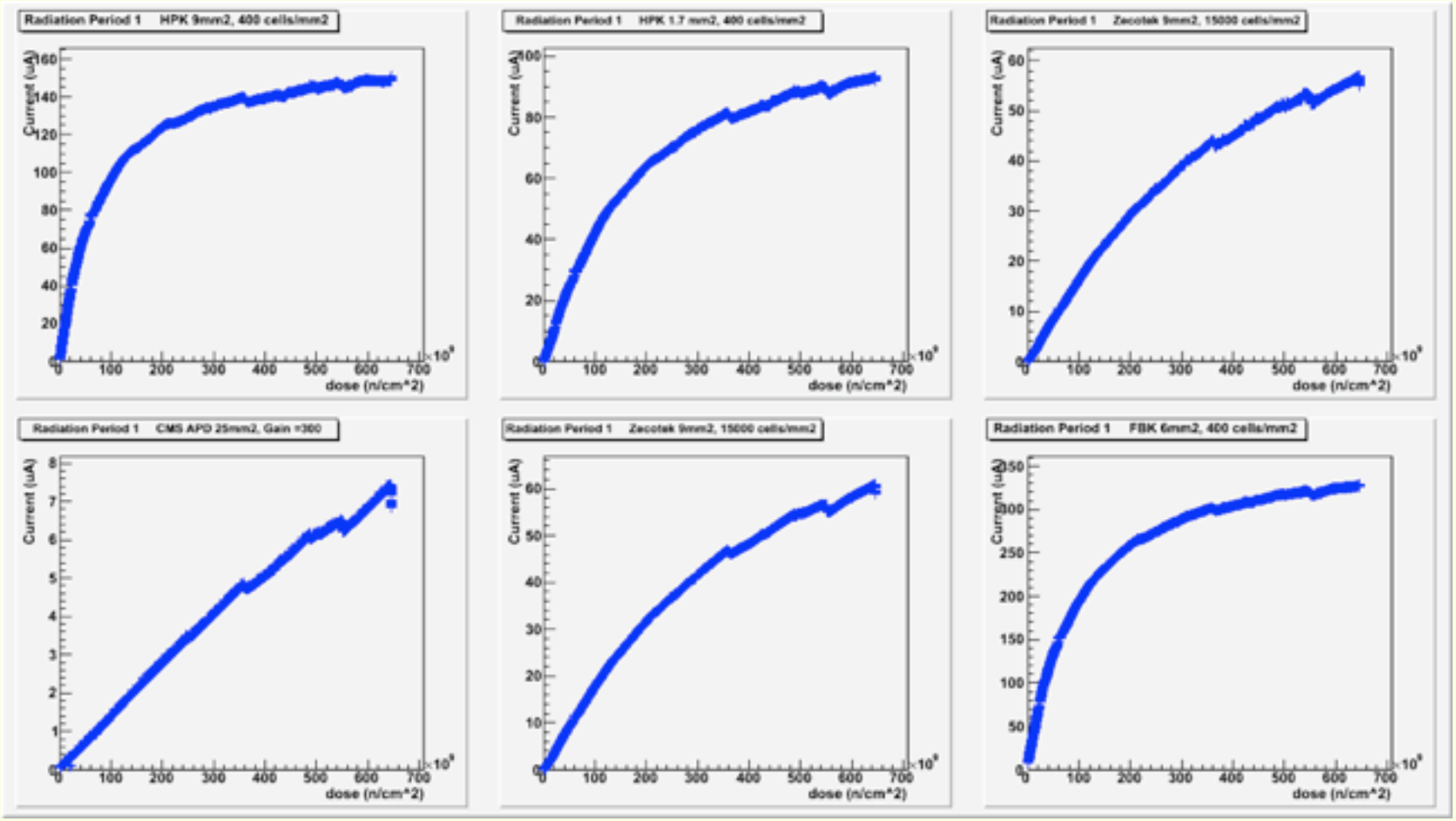
300 micron PIN diode Calibration





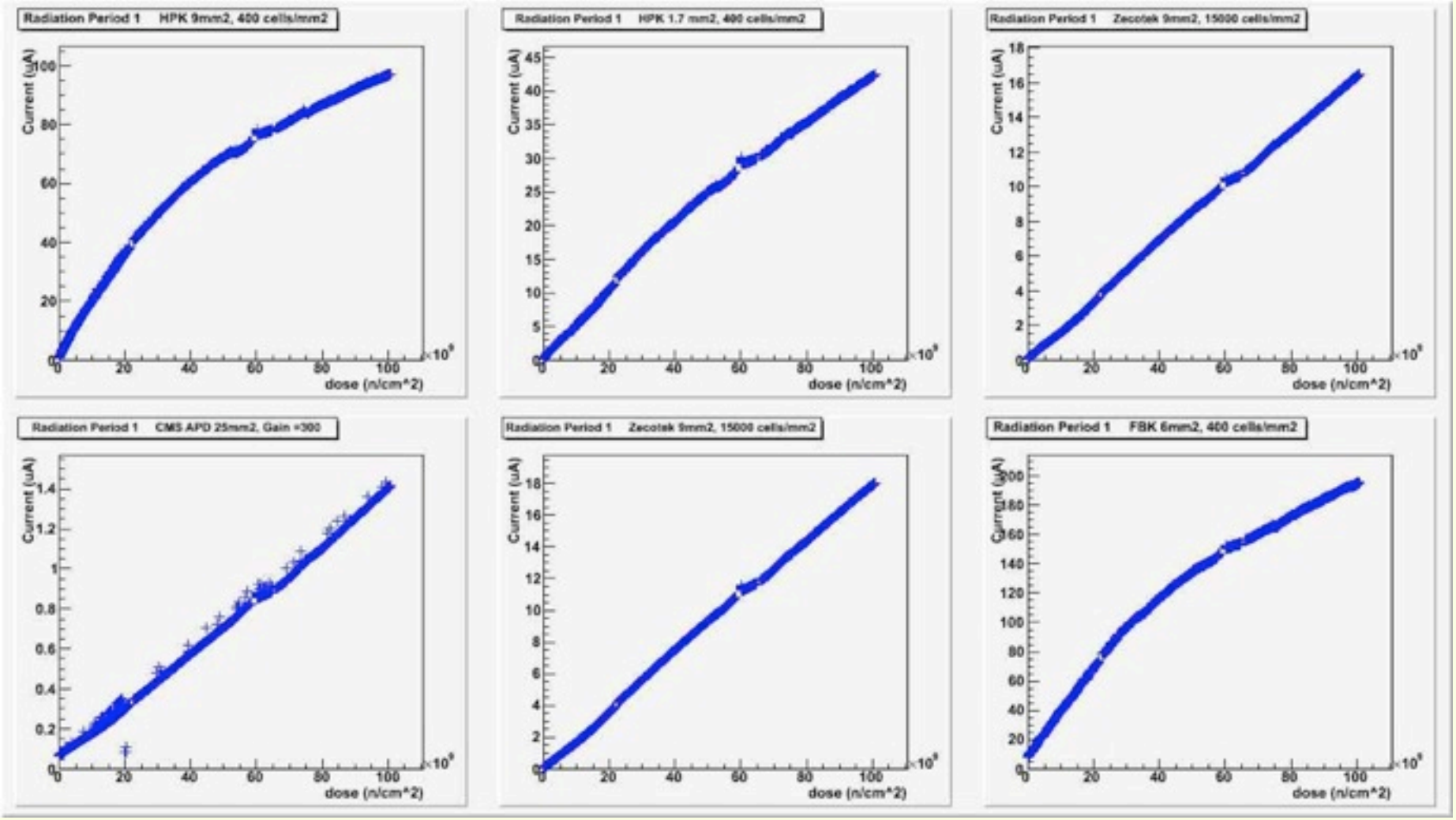
Id, T=22.1 C (uA)	Id, T=20 C, (uA)	V (cm3)	alpha	F, n/cm2
2.63	2.19	0.03	3.50E-17	**2.09E+12**

Data of period 1

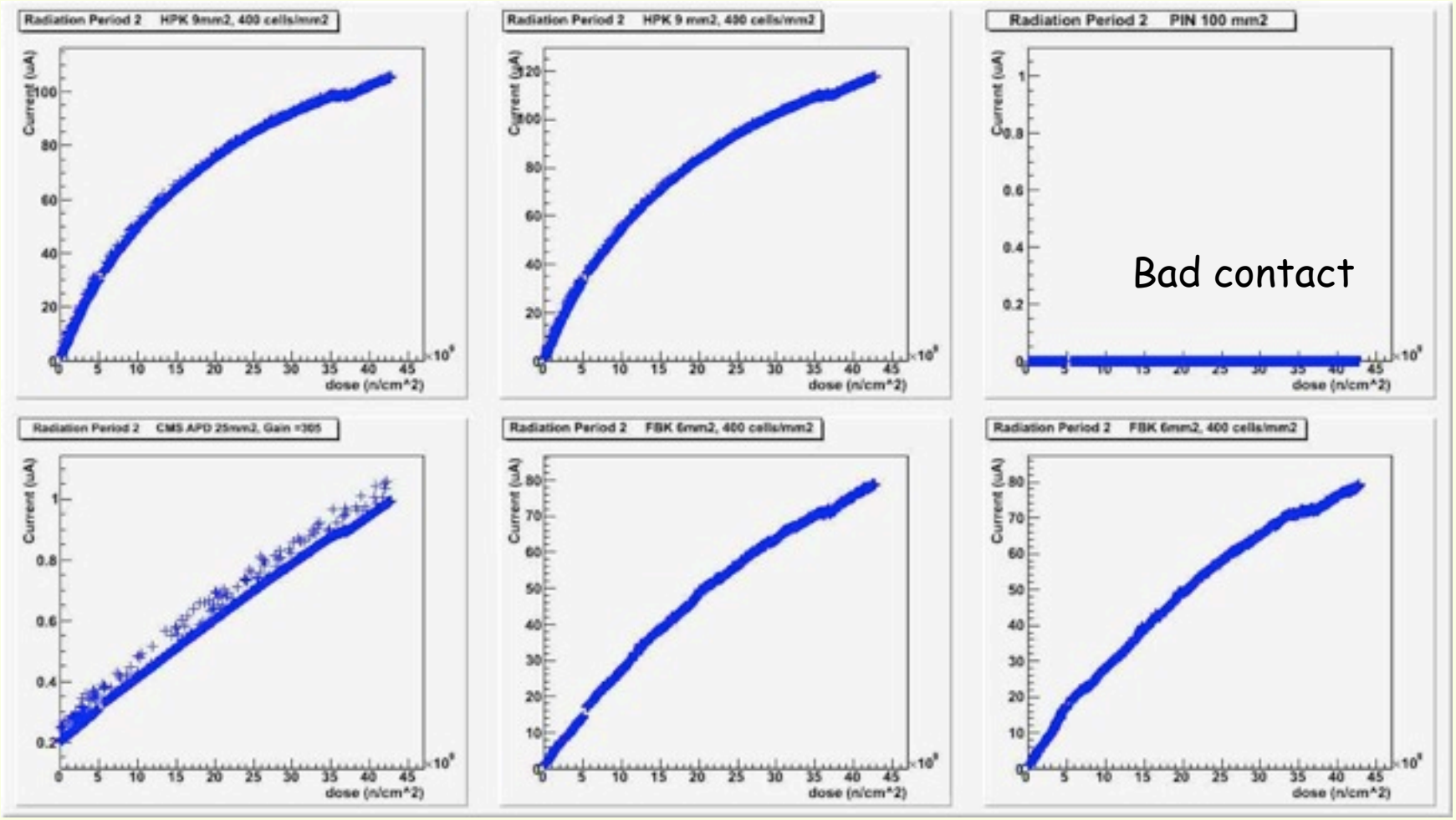


leakage current vs dose for different manufactures ZEC,FBK and HPK

Data of period 1 up to 1E11 n/cm^2

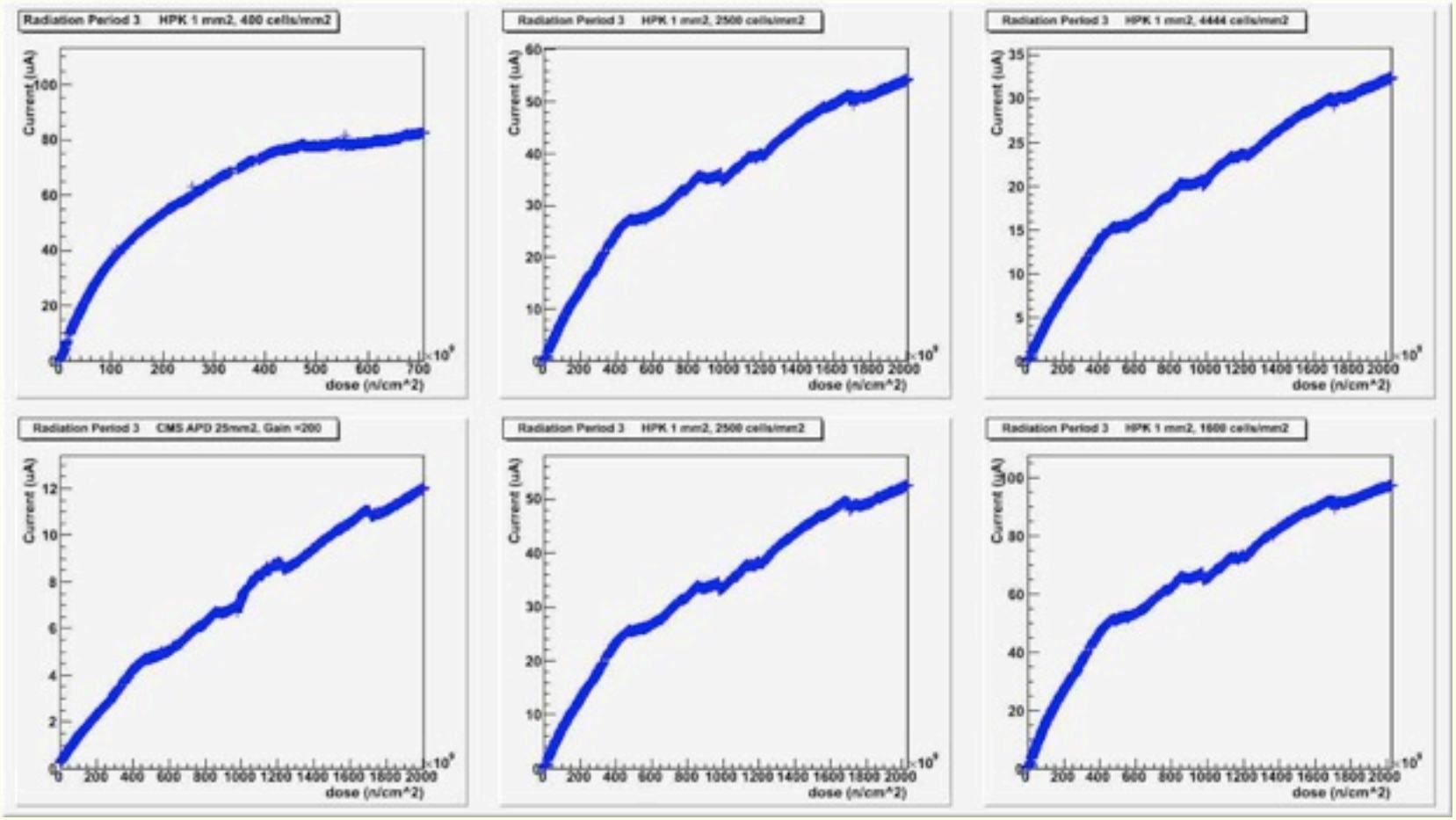


Data of period 2



Data from FBK with different epi layers + CMS APD and HO production MPPC

Data of period 3



Data from different HPK cell sizes, 50,25,20,15 um (special wafer run Thanks to HPK!!)

Amplitude during irradiation

Dependence on # cells and Recovery time !!

230 MeV proton radiation at Massachusetts General Hospital in 2008

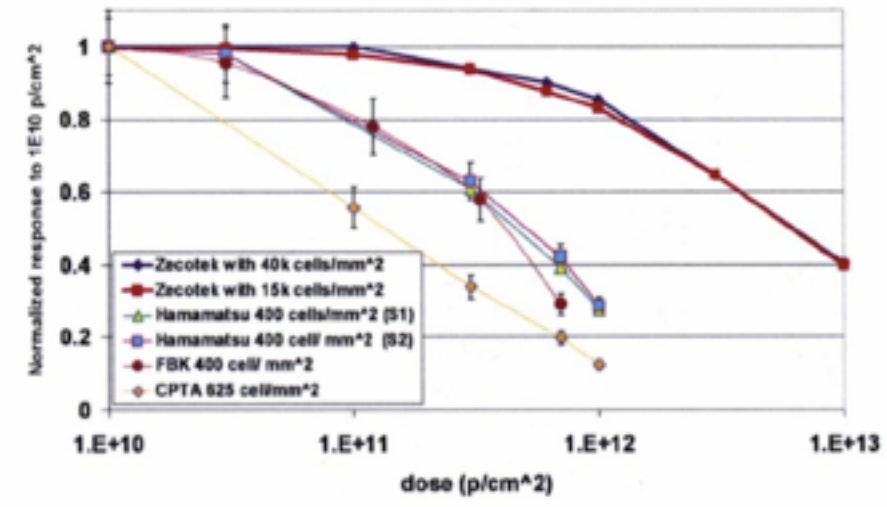
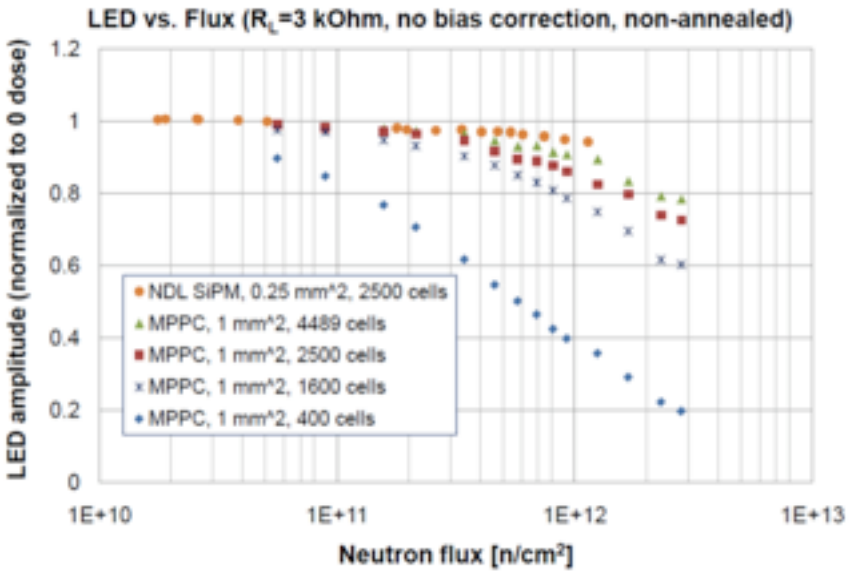
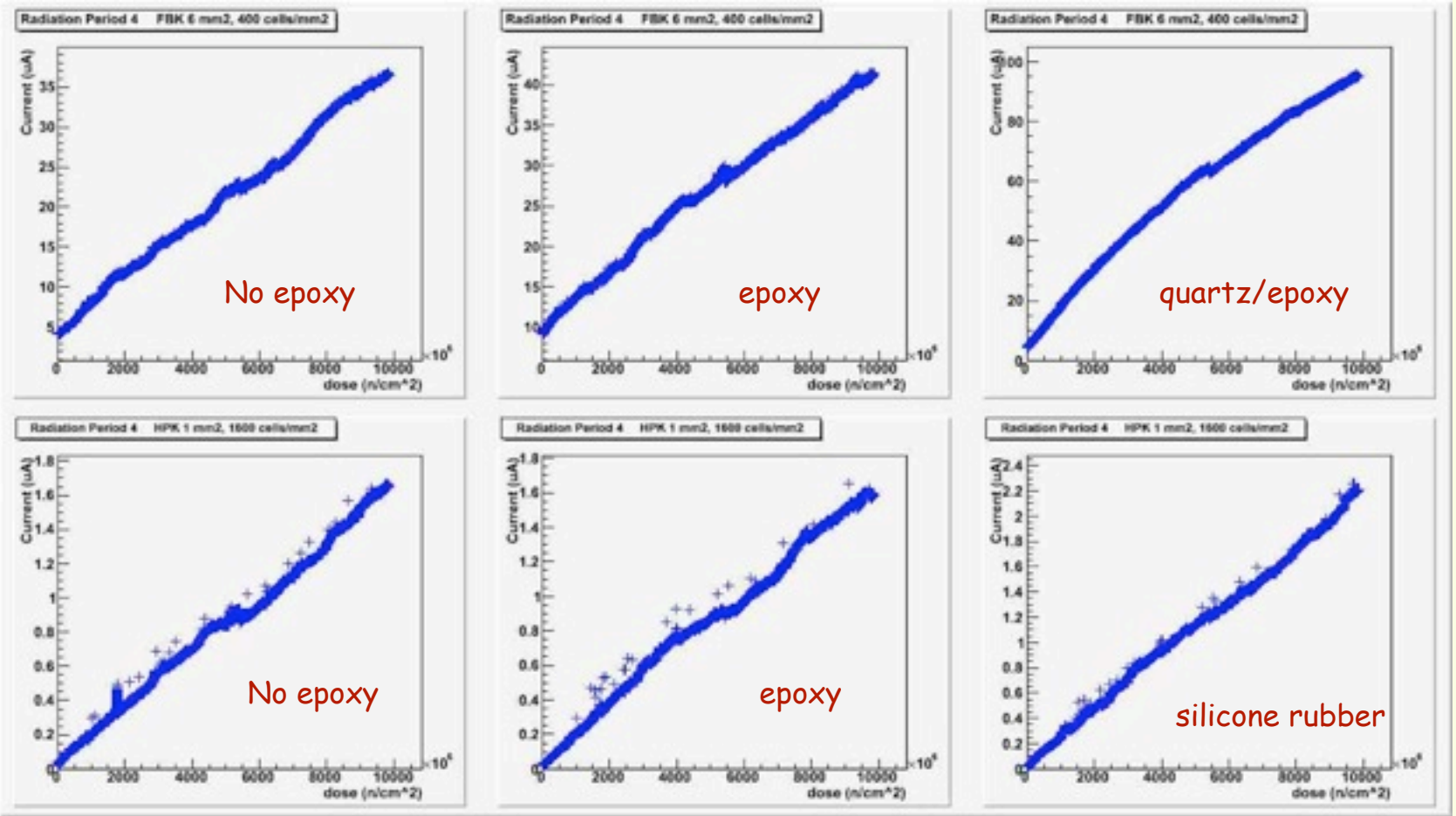


Fig.11. Response vs. radiation fluence for different samples and manufacturers (gain was corrected for voltage drop over the series resistor).

24 GeV backscattered protons (neutrons) radiation at CERN PS 2010



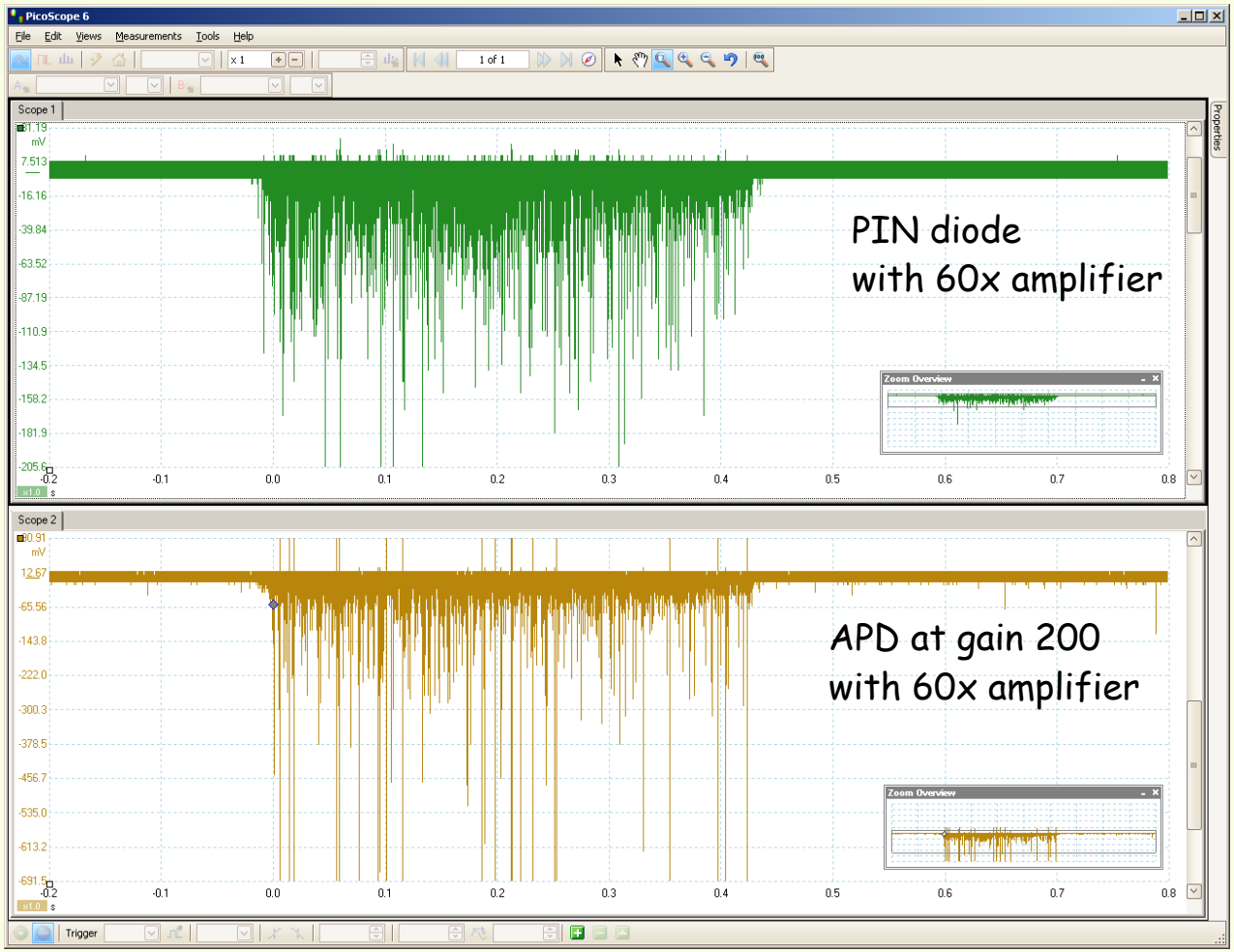
Data of period 4



Data from "neutron spikes" with/without different protective layers

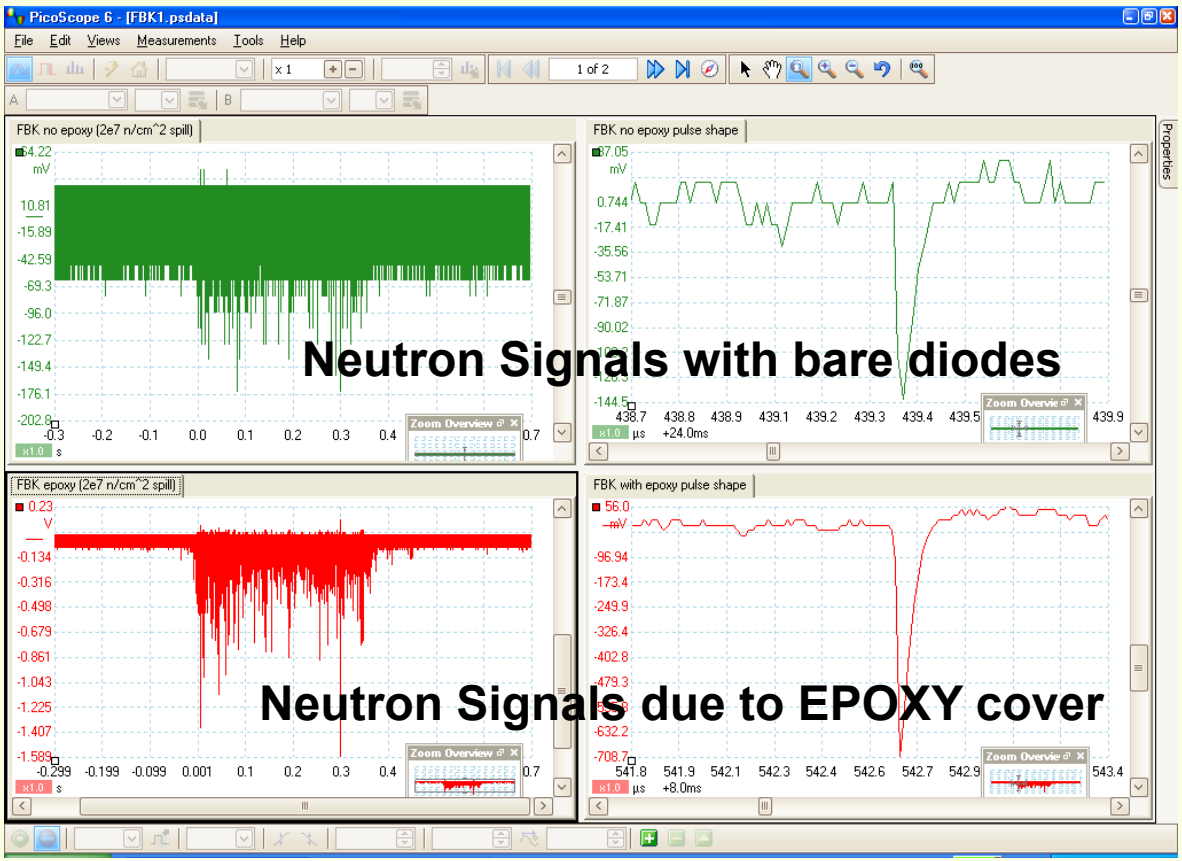
Neutron signals in PIN and APD

One spill with duration of 300ms (total =~1E7 neutrons/cm2)



Neutron signals in FBK, ZEC, Ketek

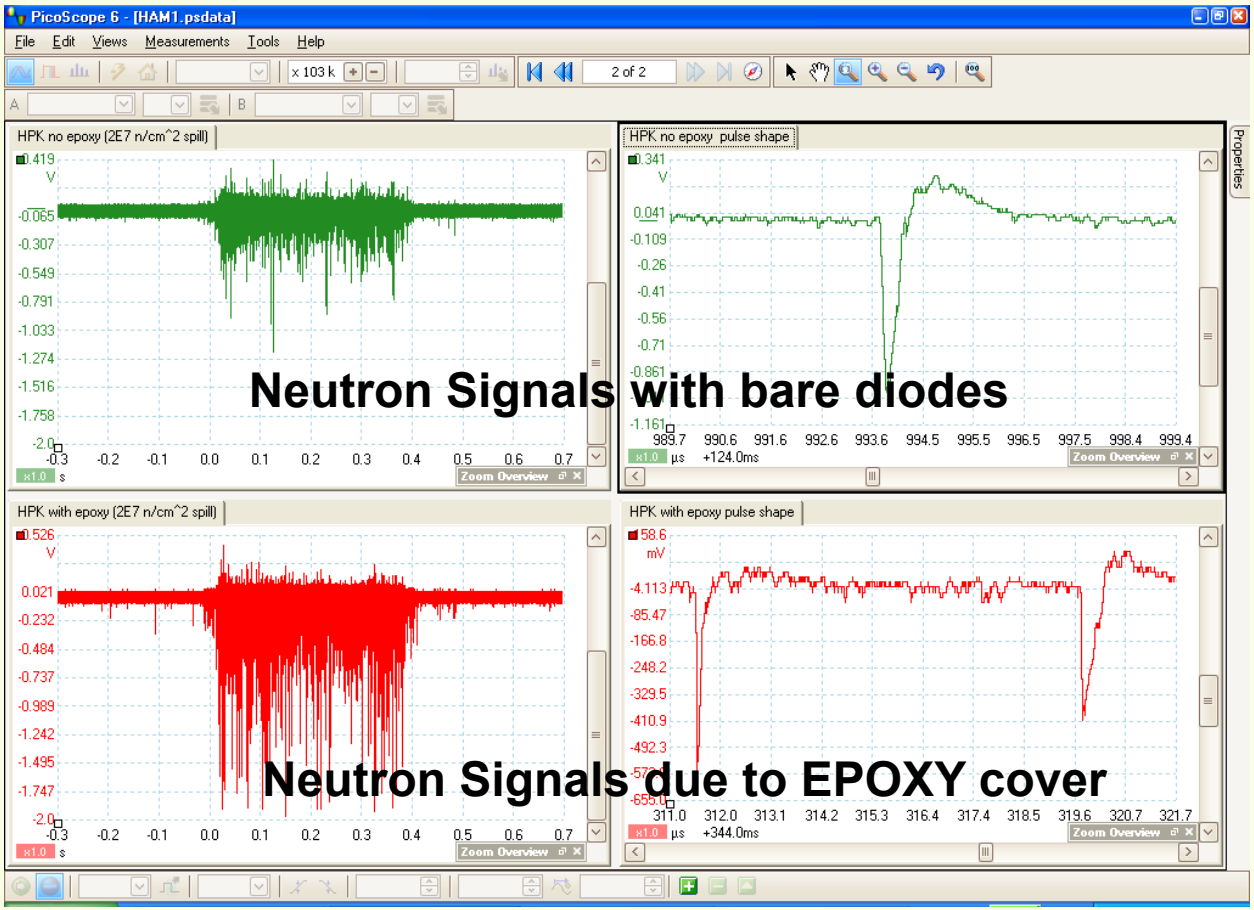
We expect other than PIN and ECAL APD only few cells fired



barrier SiO2 layer and quarts window on package

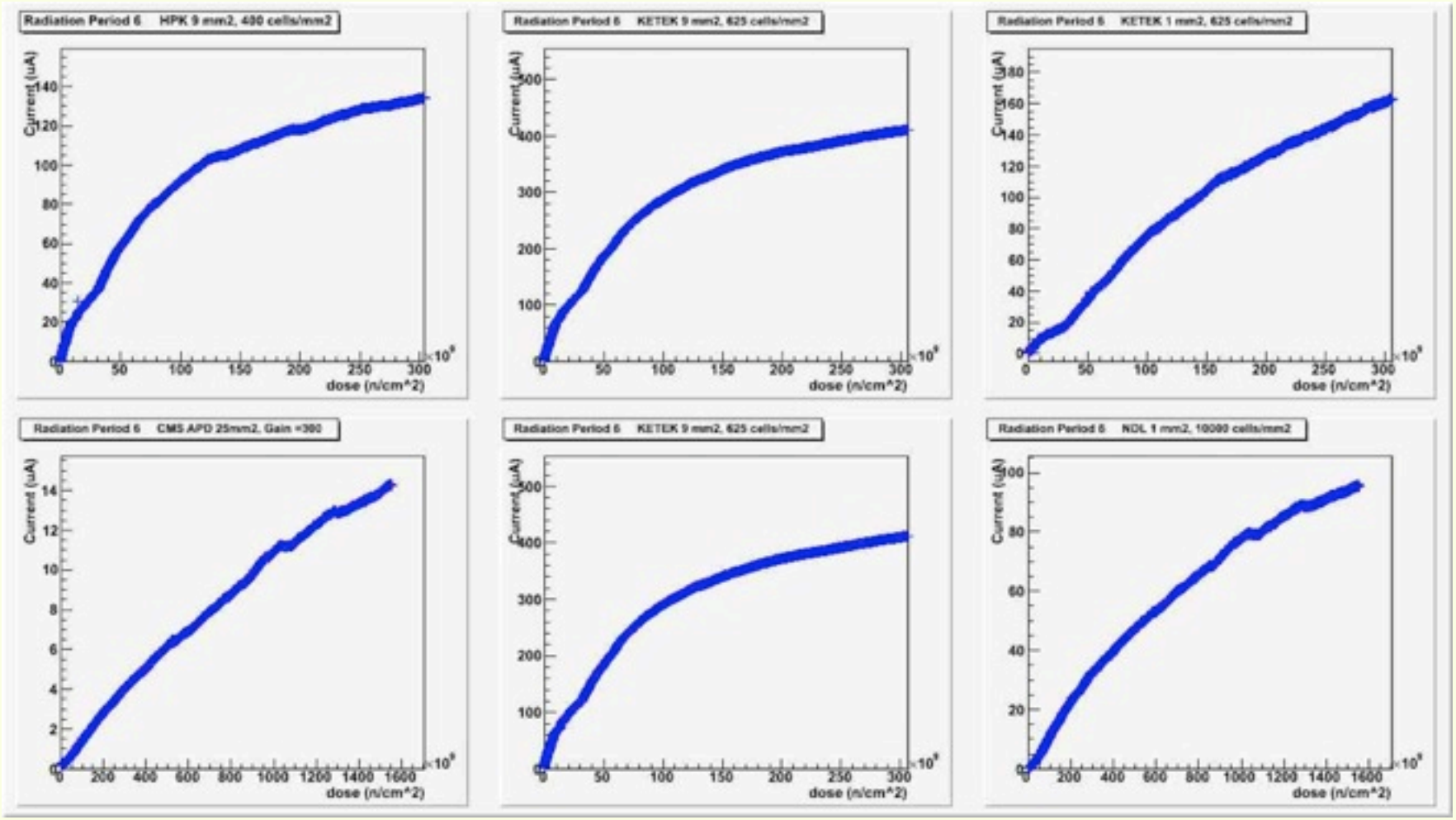
HPK Neutron signals

- We still don't know mechanism of Neutron signals in HPK MPPC



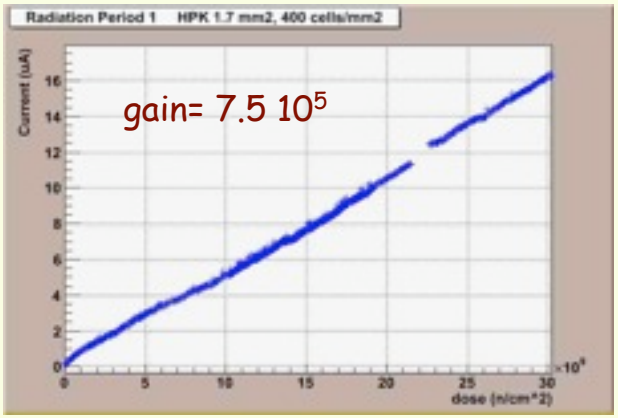
Signals from Bulk? Thinner diode

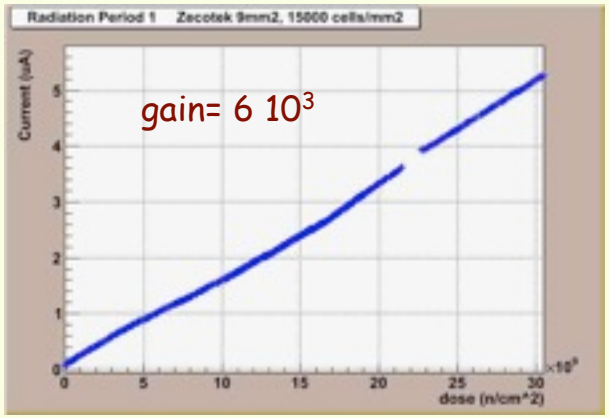
Data of period 6

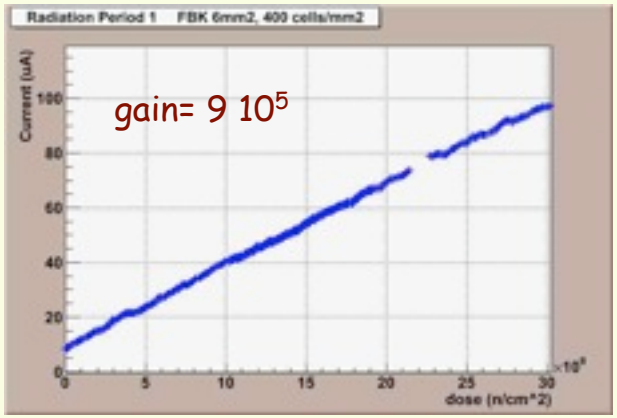


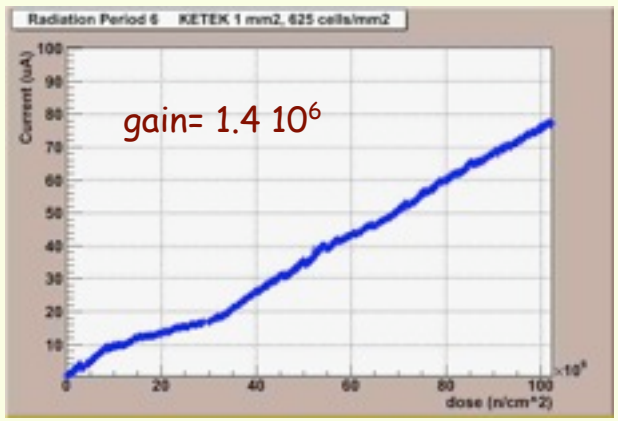
Included KETEK and NDL devices

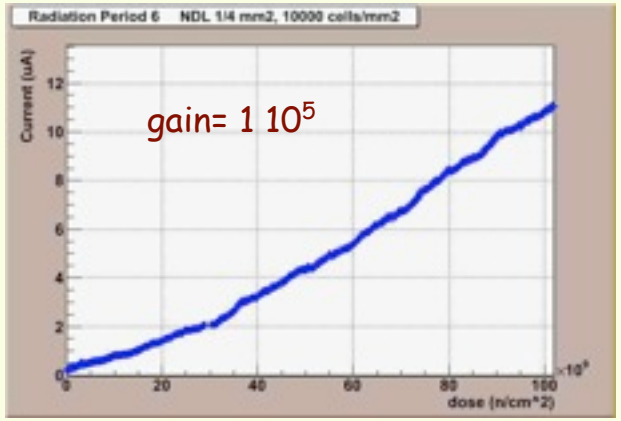
Linear dependence with dose

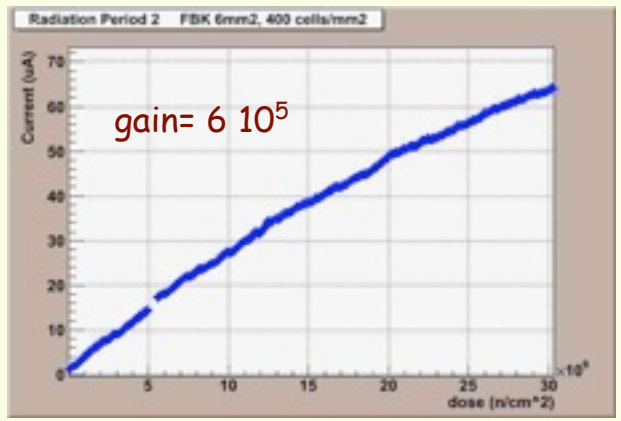








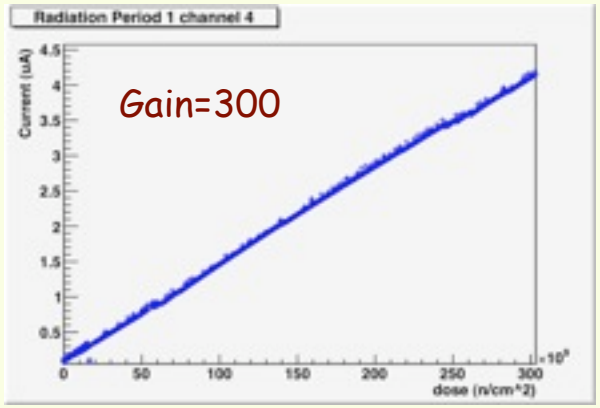


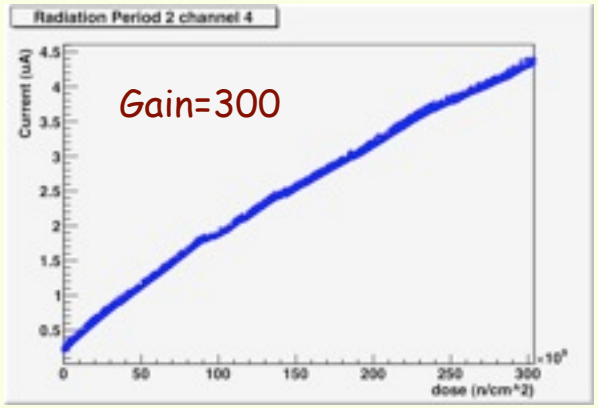


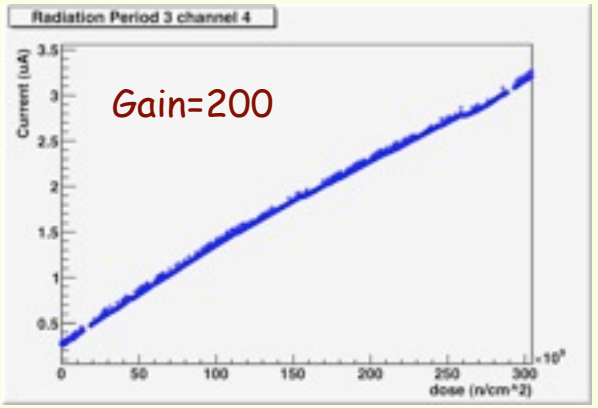
current increase with the dose for different manufactures

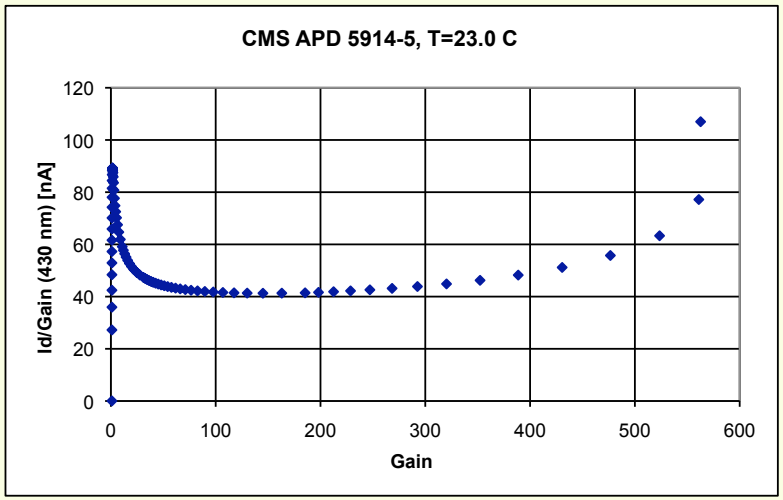
CMS ECAL APD with Annealing

Before annealing Id/gain =5 nA/ 1E11









After Total Dose = 2E12 n/cm^2
and annealing at 150 min at 60 C

2 nA/1E11 >>> Annealling 2.5x

Dark rate increase per 1E10 n/cm^2

						24C	20C	annealing (2.5)	
	ΔI / 1E10 (uA/cm2)	A(mm2)	ΔV (V)	PDE 520 nm	Gain at dV (*1E6)	Δ rate (Mhz/mm2)1E10			thickness (um)
Zecotek	1.6	9	2.0	0.25	0.06	**18.5**	13.2	5.3	**2.4**
HPK 50 um	5.3	1.7	1.0	0.25	0.75	**26.0**	18.6	7.4	**3.4**
HPK 15 um	0.4	1	2.3	0.09	0.13	**20.0**	14.3	5.7	**2.6**
FBK (HG)	30	6	2	0.12	0.90	**34.7**	24.8	9.9	**4.5**
FBK (LG)	25	6	2	0.07	0.60	**43.4**	31.0	12	**5.7**
NDL	1.0	0.25	2.5	0.07	0.10	**250.0**	179	71	**33**
KETEK	7.8	1	1.9	0.14	1.40	**34.8**	24.9	9.9	**4.5**
HPK APD	0.15	25		0.85	0.0003	**125.0**	89.3	36	**16**

Conclusion

More and more company's are making small cell large dynamic range devices with good PDE.

Thanks to this we now have Radiation hard device for the CMS HCAL calorimeter.

More samples arrive this summer from KETEK,HPK,ZEC and CPTA

Measurements at CERN-PS will continue in the next years!