Results from SiPM test at the FNG

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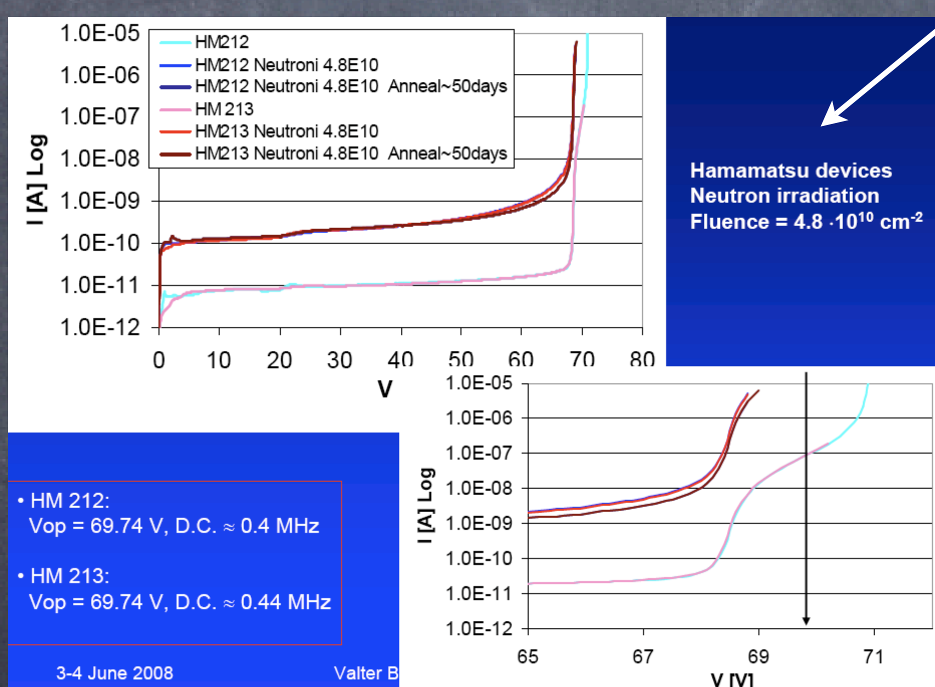
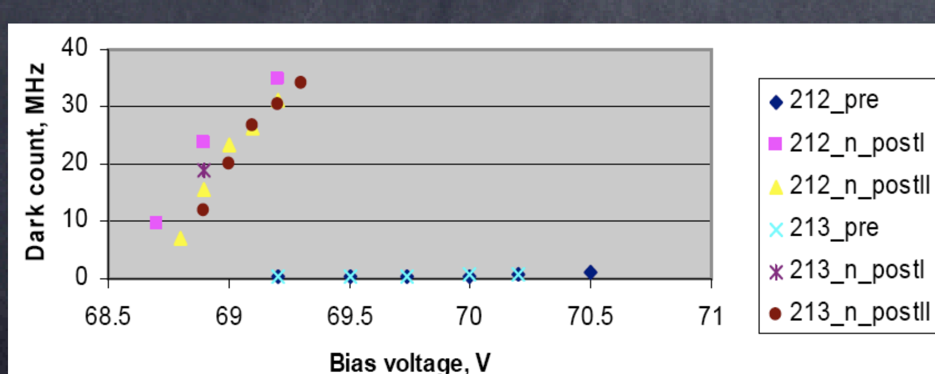
What is known on the SiPM rad hardness

- The effects of neutrons on SiPM were already measured on nuclear reactor of Institute Josef Stefan of Ljubljana by the "Factor" collaboration.
- They studied the effects on the dark currents and on the dark rates of a dose of 4.8 10^{10} cm^{-2} integrated neutrons on both Hamamatsu and IRST devices.

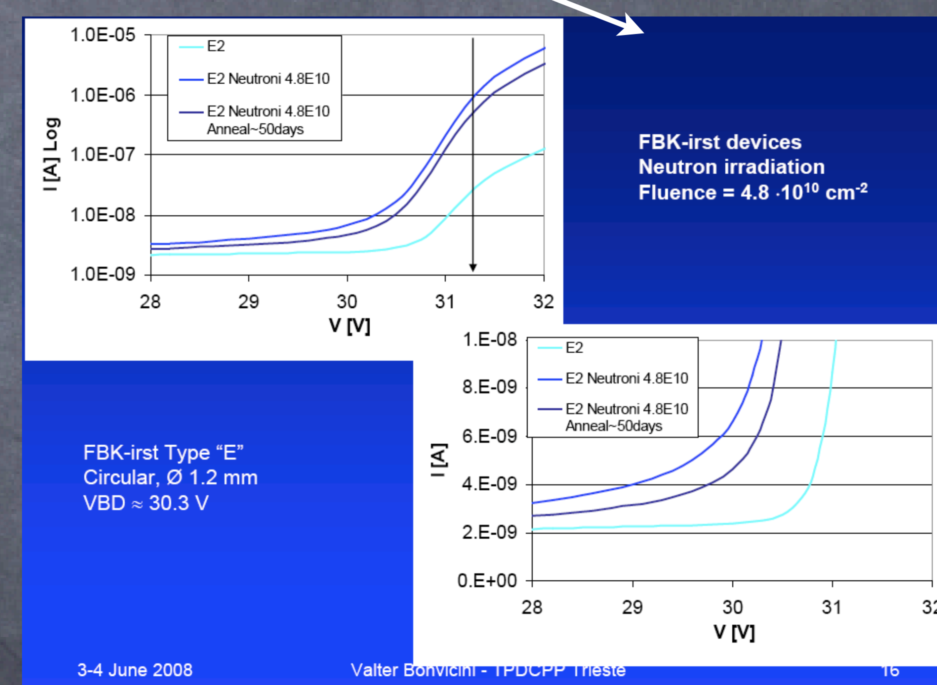
Dark Currents



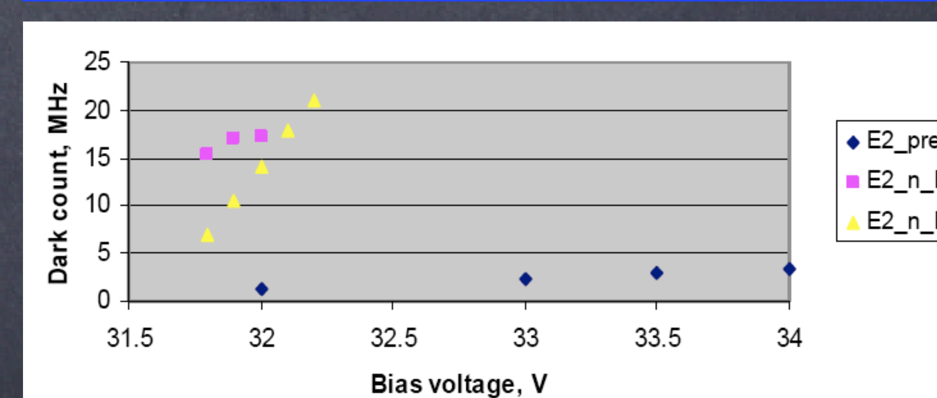
Dark Rates



Dark Currents



Dark Rates



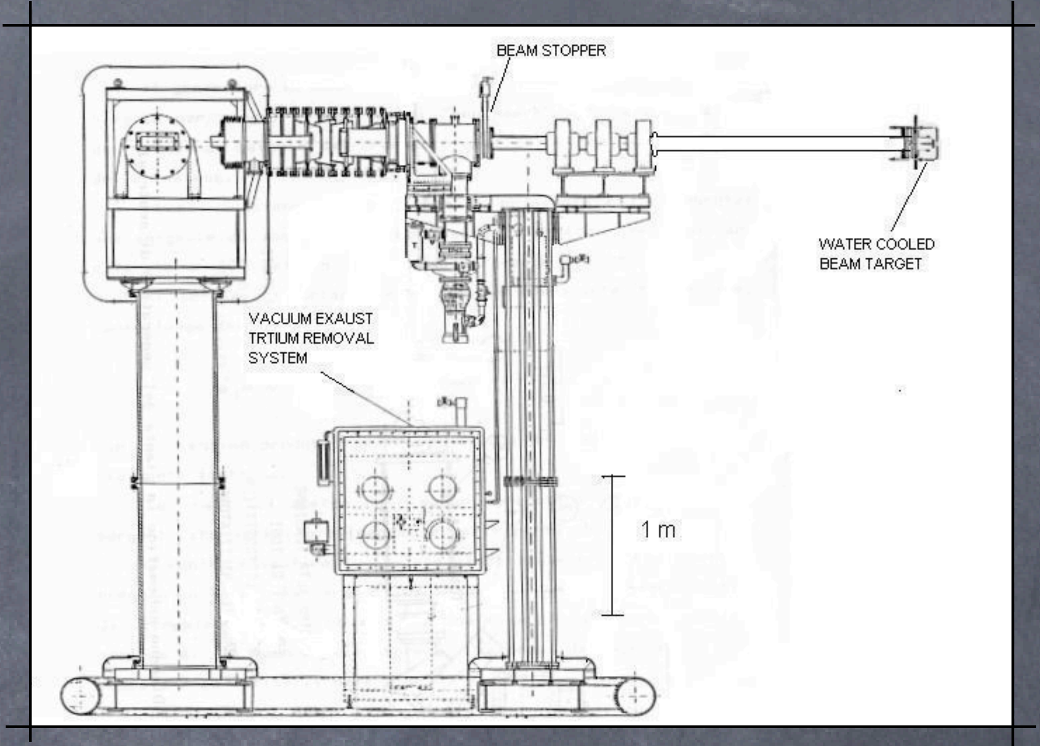
Results from previous tests

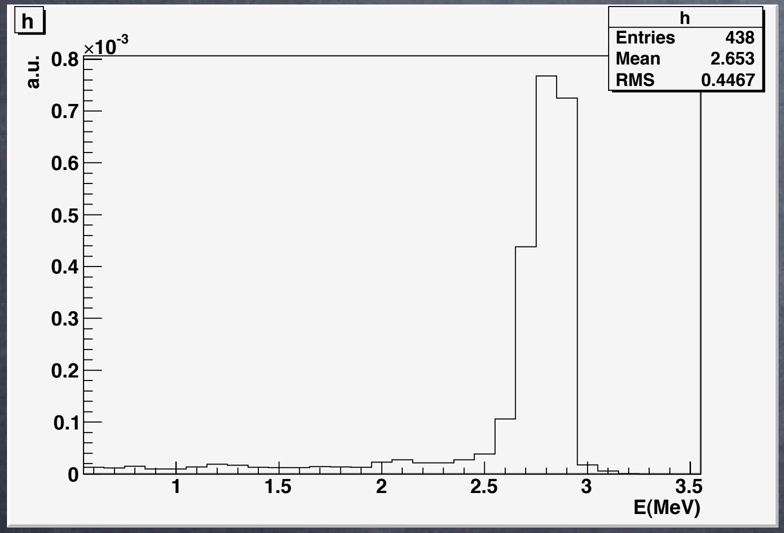
- For the Hamamatsu MPPC:
  - The dark current increases of a factor 10 under the operation voltage and several hundreds at 70 V;
  - The dark rates grows from 0.5 MHz to more than 50 MHz;
- For the IRST SiPM:
  - At the operation voltage the dark current increases of a factor 30;
  - The dark rates increases from 1 MHz to 15-20 MHz;
- In both cases the effects of about 5 10^{10} n/cm^2 were found to be very large;
- Is this a "threshold" effect or do the performance of these devices deteriorate "gradually" as long as the neutrons are integrated?
- A tunable and monitored neutron flux is needed...

The Frascati Neutron Generator

- The 2.5-MeV Frascati neutron generator (FNG) is based on the T(d,n)α or D(d,n)3He fusion reactions designed and built at ENEA Frascati;

- We used the D(d,n)3He "mode" to produce up to 10^8 Hz of 2.5-MeV neutrons in 4π

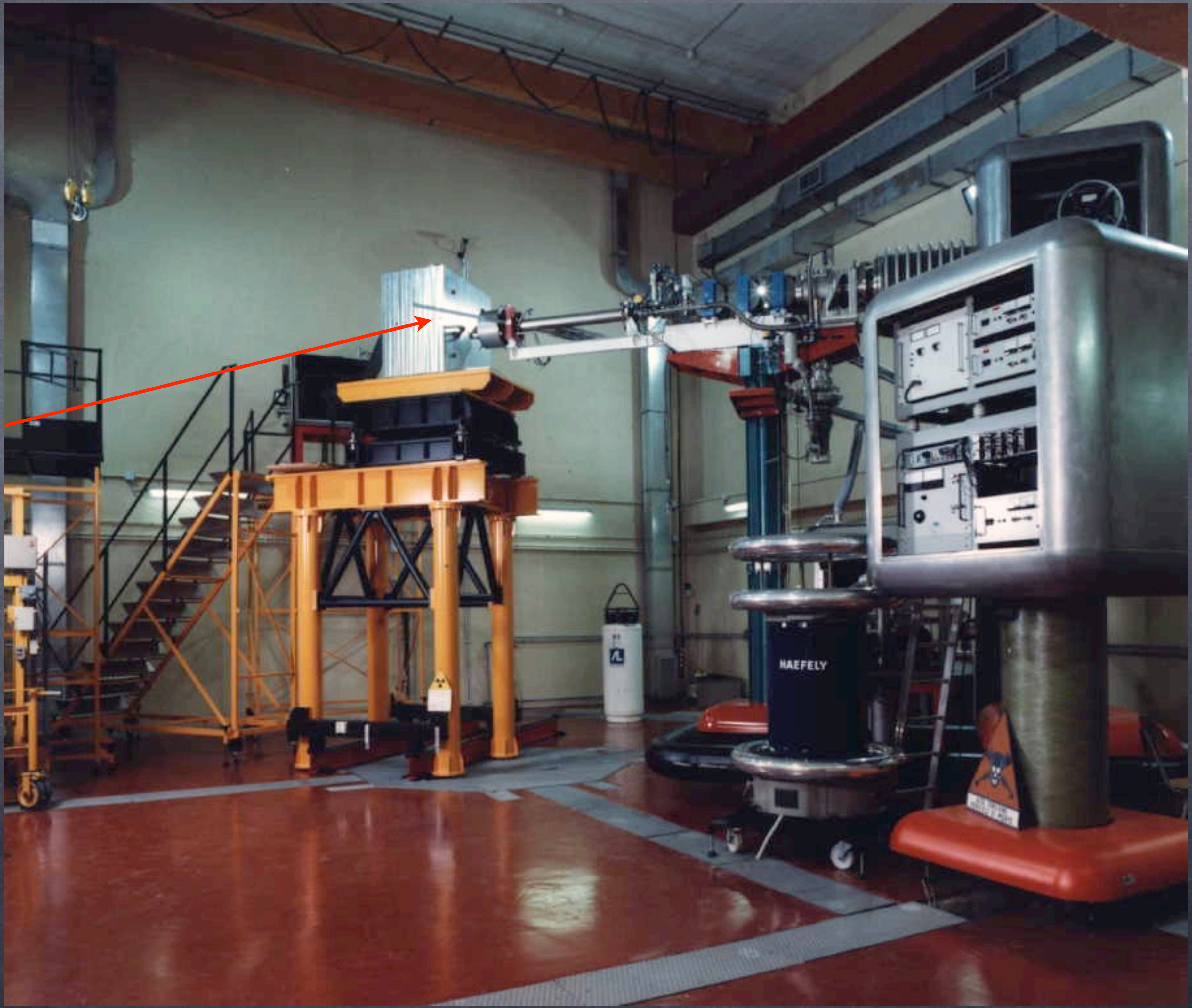




D^+ beam energy	230 KeV
D^+ beam current at the target	1 mA
Beam spot at the target	10 mm
Minimum distance from neutron source to expose samples	4 mm
14 MeV neutron intensity on solid angle of 4π	10^{11} Hz
2.5 MeV neutron intensity on solid angle of 4π	5 10^8 Hz
Neutron output monitor method	associated particle

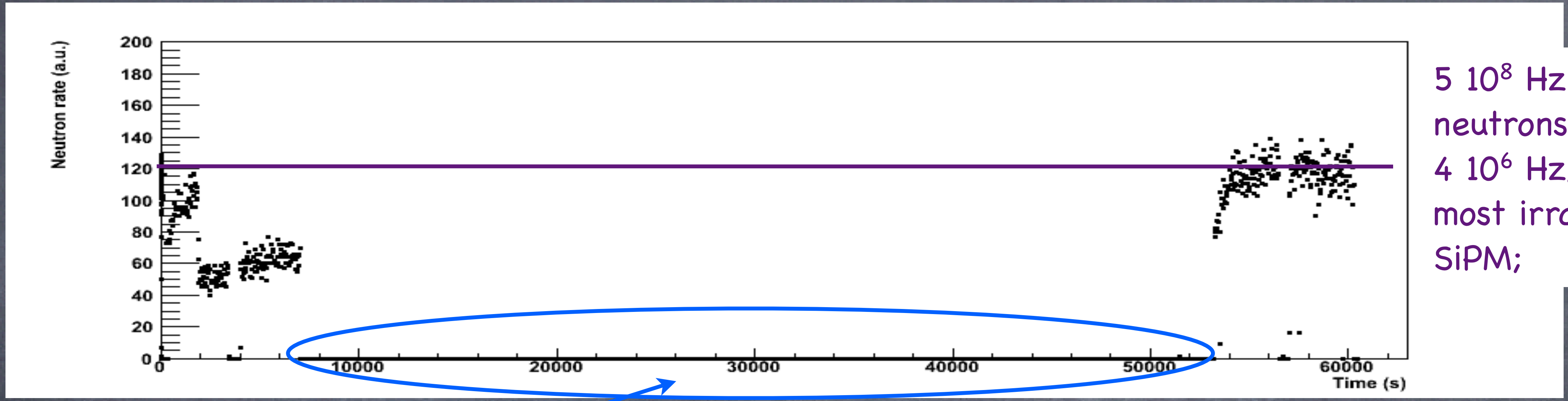
The Frascati Neutron Generator

In order to reduce as much as possible neutron background coming from neutron reflection the position of the devices under irradiation is more the 4 m far from wall, floor and ceiling.



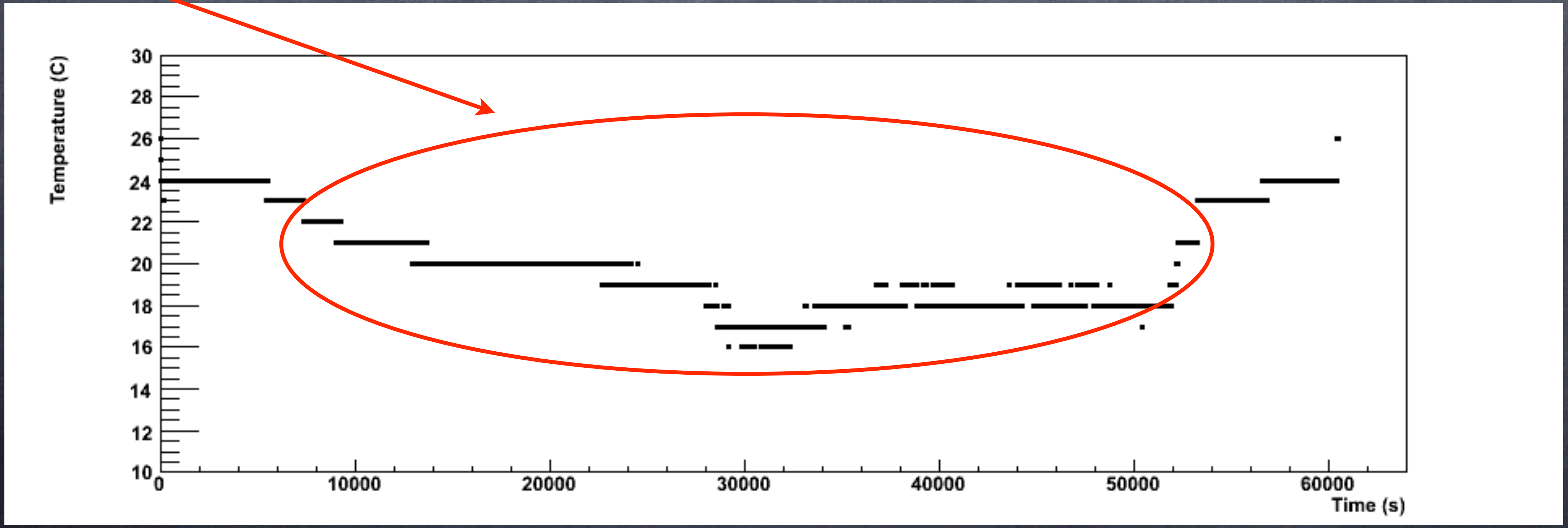
Neutron and temperature monitors

- The neutron flux was monitored on line by acquiring the rate of associated particles measured with a liquid scintillator and provided by the FNG-group;



5 10^8 Hz produced neutrons;
4 10^6 Hz/cm^2 on the most irradiated SiPM;

- The temperature was also monitored and it was found to be stable except for one night run (without neutrons);



Measurement set-up

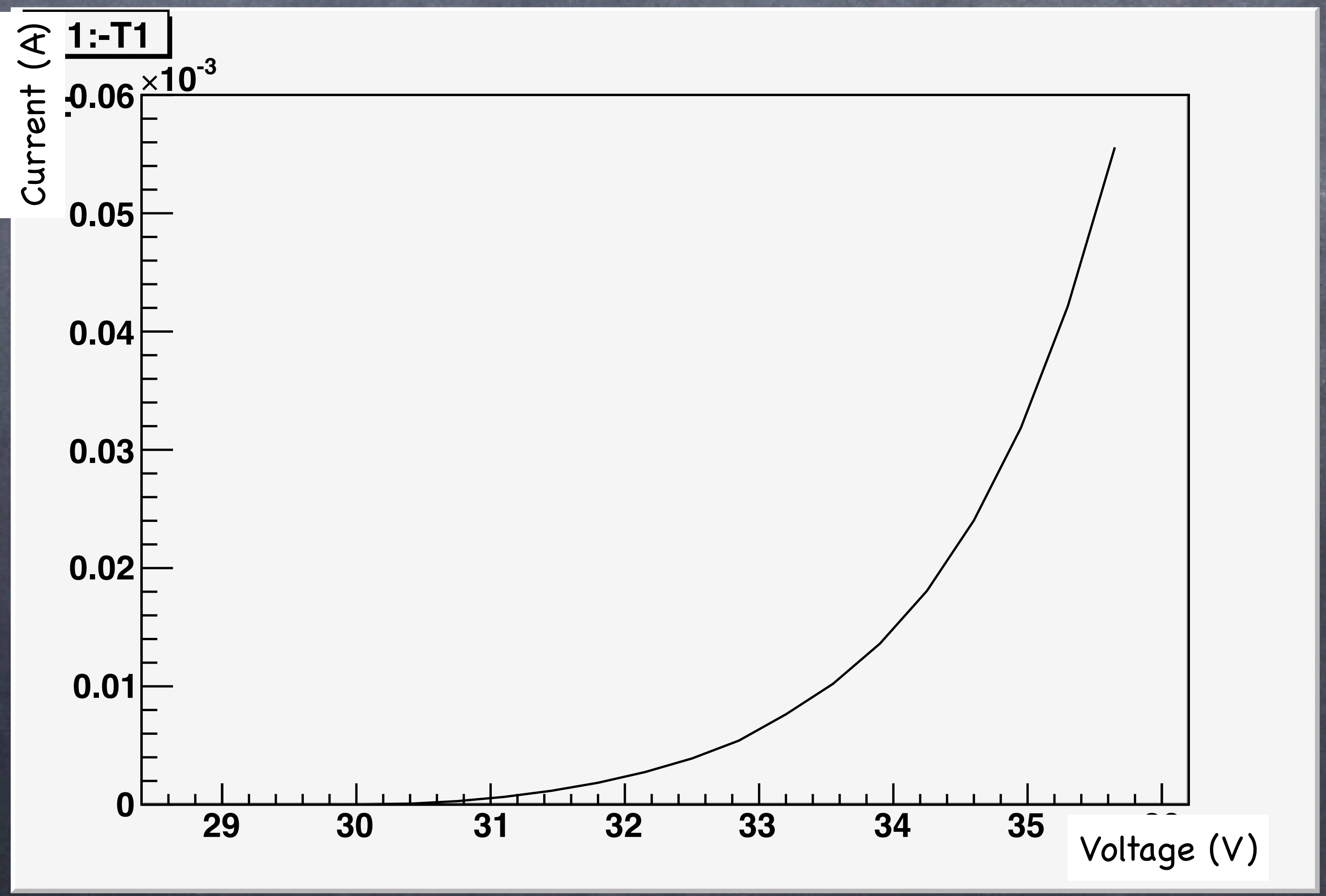
- We used a test bench able to house up to 6 devices a time;
- We tested 5 1x1 mm^2 + 1 2x2 mm^2 SiPMs (IRST) and 4 MPPCs (Hamamatsu) in two "rounds";

Round	Device	x (mm)	y (mm)	z (mm)	Damage equiv @ 1 MeV (10^{10} cm^{-2})
Round #1	SiPM #4	5	0	3	1.25
Round #1	SiPM#6	3	1.3	3	2.71
Round #1	MPPC #2	1	0	3	7.32
Round #1	SiPM #8	-1	0	3	7.32
Round #1	MPPC #1	-3	0	3	3.07
Round #1	SiPM 2x2	-5	0	3	1.25
Round #2	SiPM #4	5	0	3	0.25
Round #2	MPPC #5	-0.5	0	2.5	4.26
Round #2	MPPC#6	0.5	0	2.5	4.26
Round #2	SiPM #5	1.5	0	13	0.18
Round #2	SiPM #7	-0.5	0	13	0.18

- By varying the distance from neutron production point it was possible to irradiate the devices with different rates.
- The damage equiv. for 1 MeV neutrons on silicon was evaluated from "Standard practice for Characterizing Neutron Energy Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation Hardness Testing of Electronics", ASTM E 722 - 93.

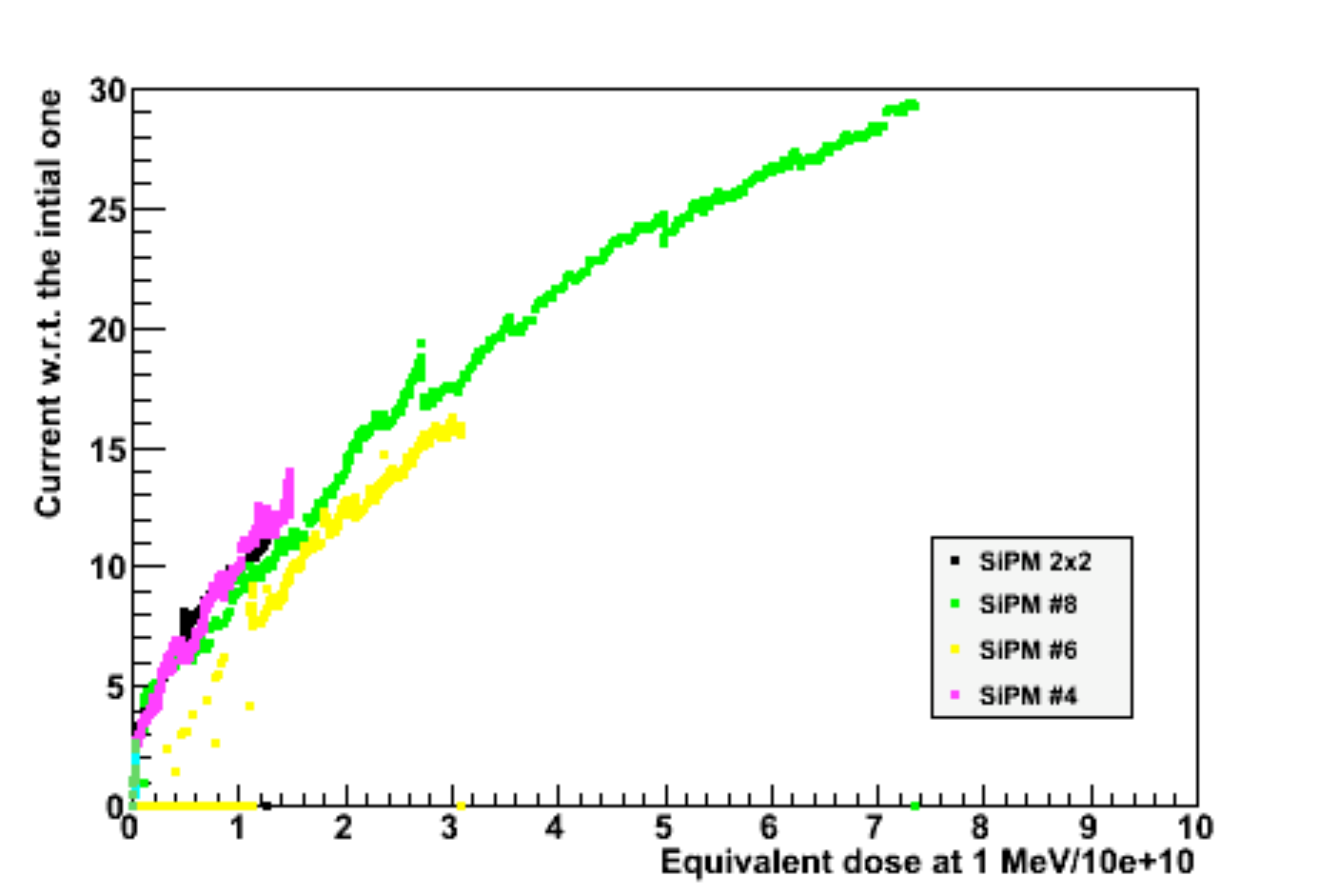
Performed measurements

- For all devices we recorded the drawn current by a Keithley picoammeter and the dark rates during the neutron irradiation;
- We decided to take data with a voltage supply of 60 V for the MPPC (below the working region) and of 33 V for the SiPM (within the working region);
- During the runs with neutrons we "paused" the neutron flux and checked the "health" of our devices by means of a voltage scan;



Results: SiPM currents

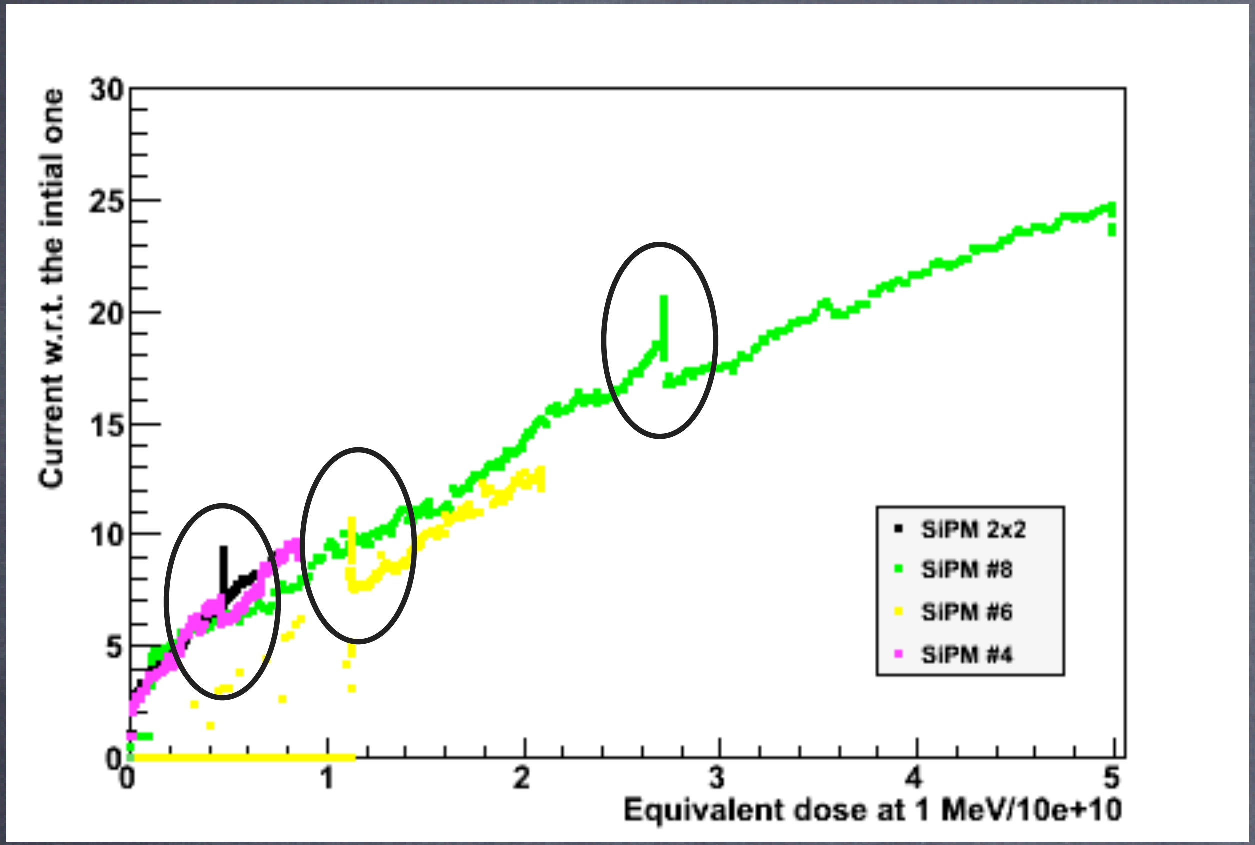
- Ratio between the current drawn by the SiPMs and the initial one as a function of the integrated dose:



- The current drawn grows up to a factor 30 for a dose equivalent of 7.3 10^{10} n/cm^2
- The increasing rate seems to be independent from the neutron fluence.

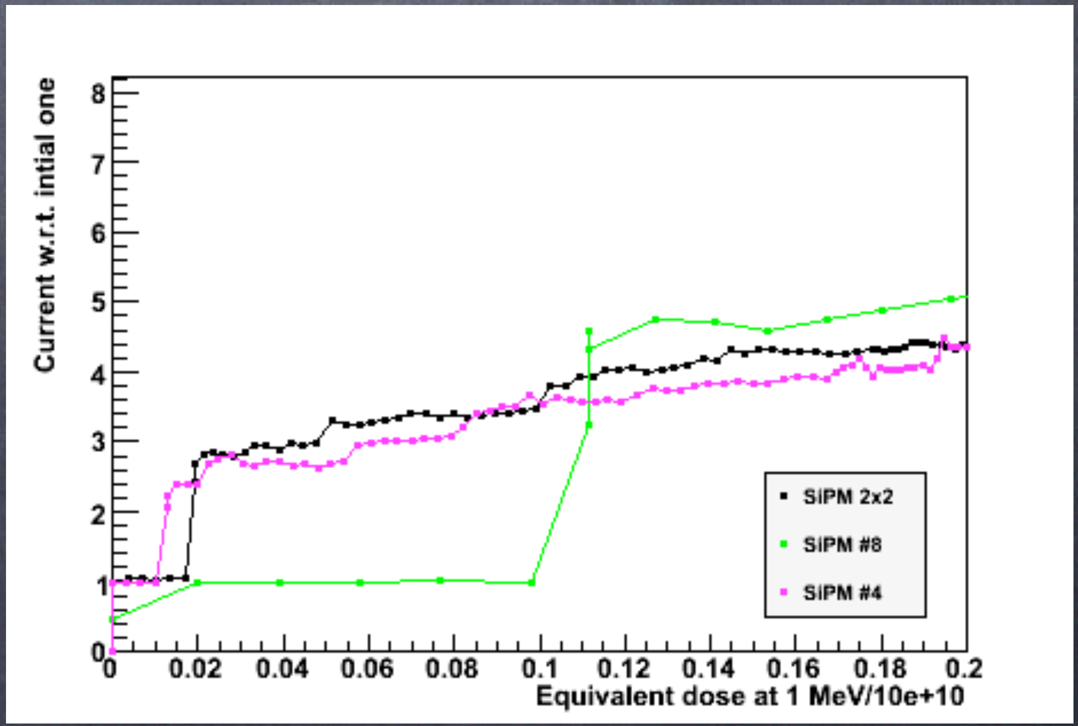
Results: SiPM currents (II)

- In order to check a possible recovery we acquired the data during one whole night without neutrons (zero dose)



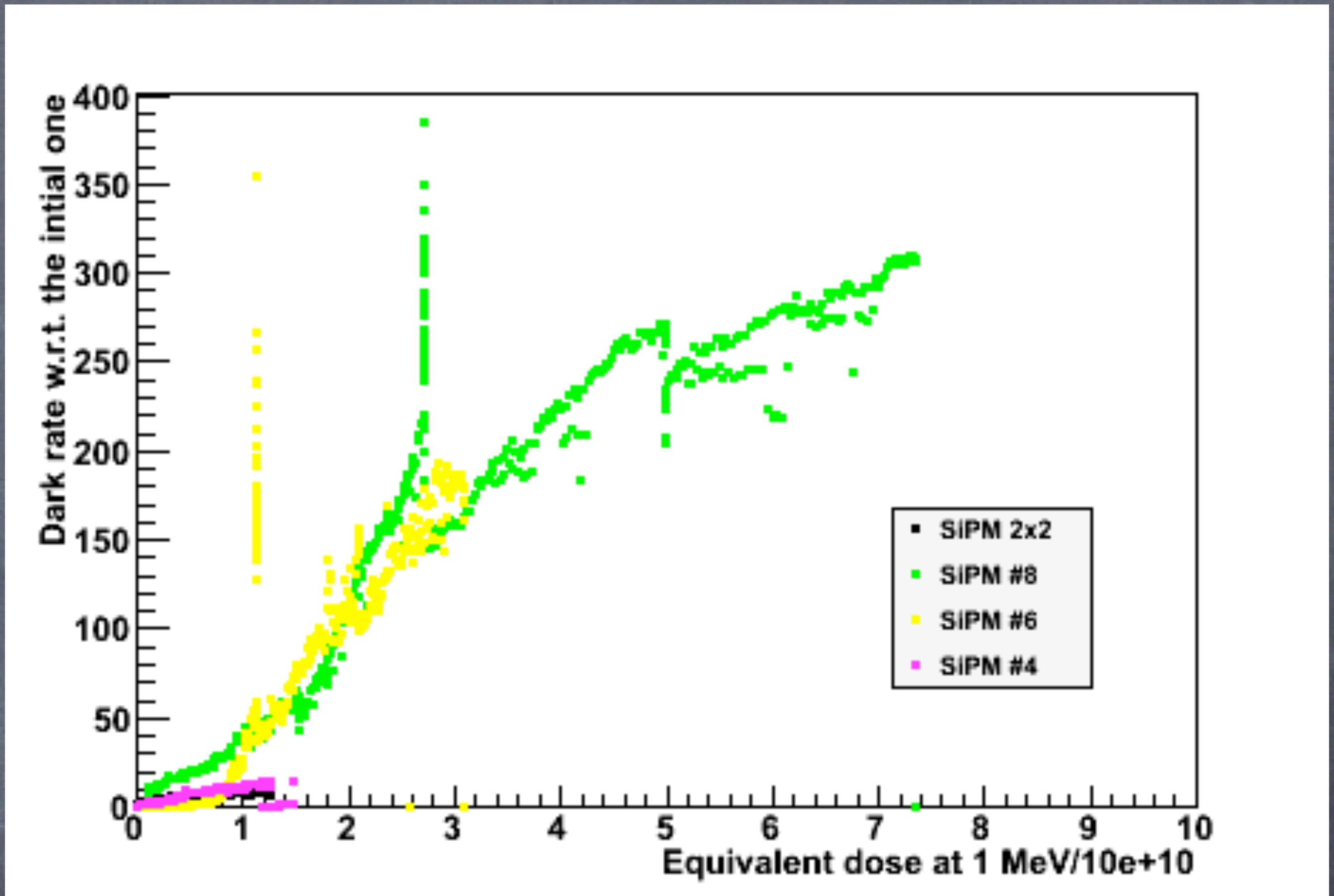
- Except for fluctuations due to temperature variations, no significant recovery effect appeared;
- The absolute value of the ratio and the increasing rate didn't change;

- A zoom for low doses shows that the currents are quite stable for doses of the order of 10^8 neutrons/cm^2 and then, after a jump of a factor 2 or 4 they start to increase.

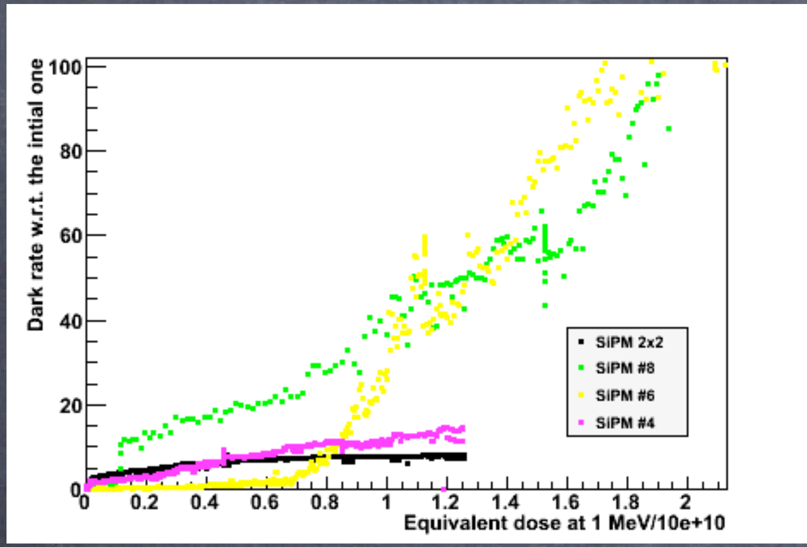


Results: SiPM dark rates

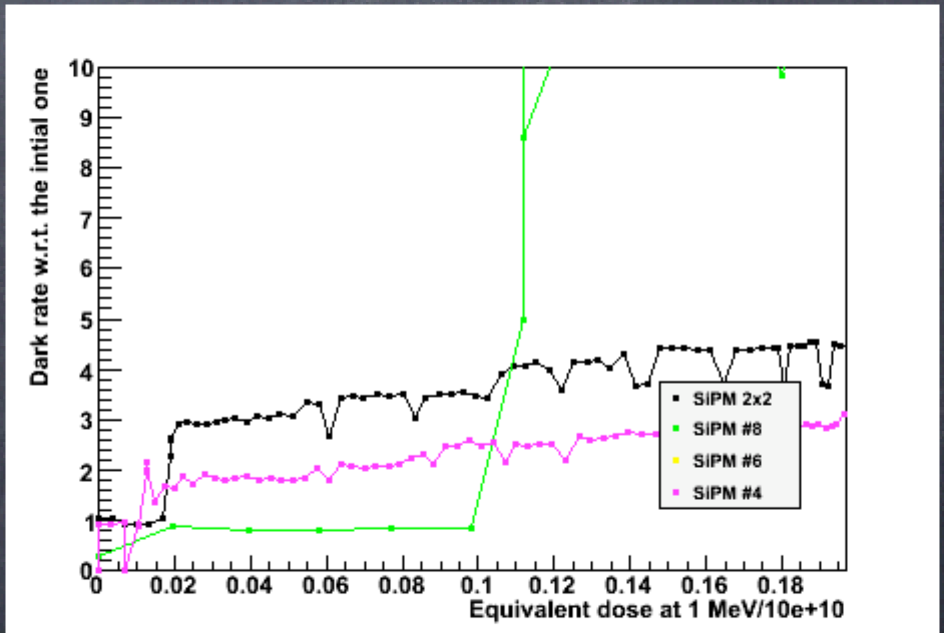
- We also studied the dark count rate of the devices:



- A zoom shows that in this case the behavior of the low irradiated ones is different:

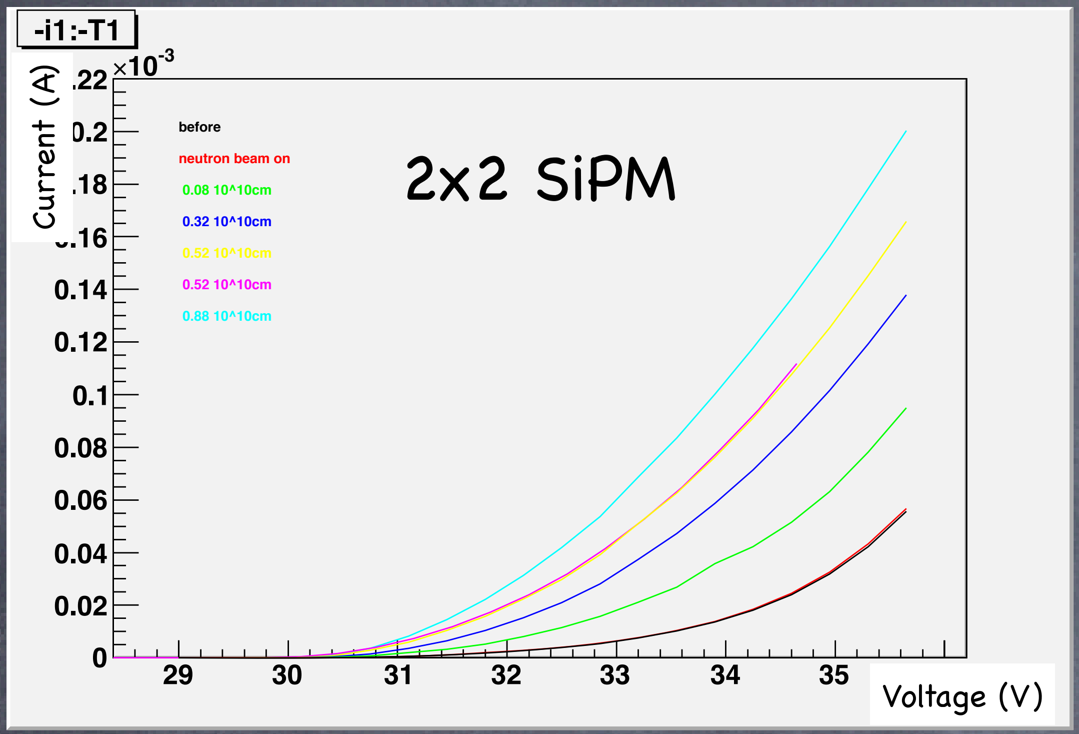


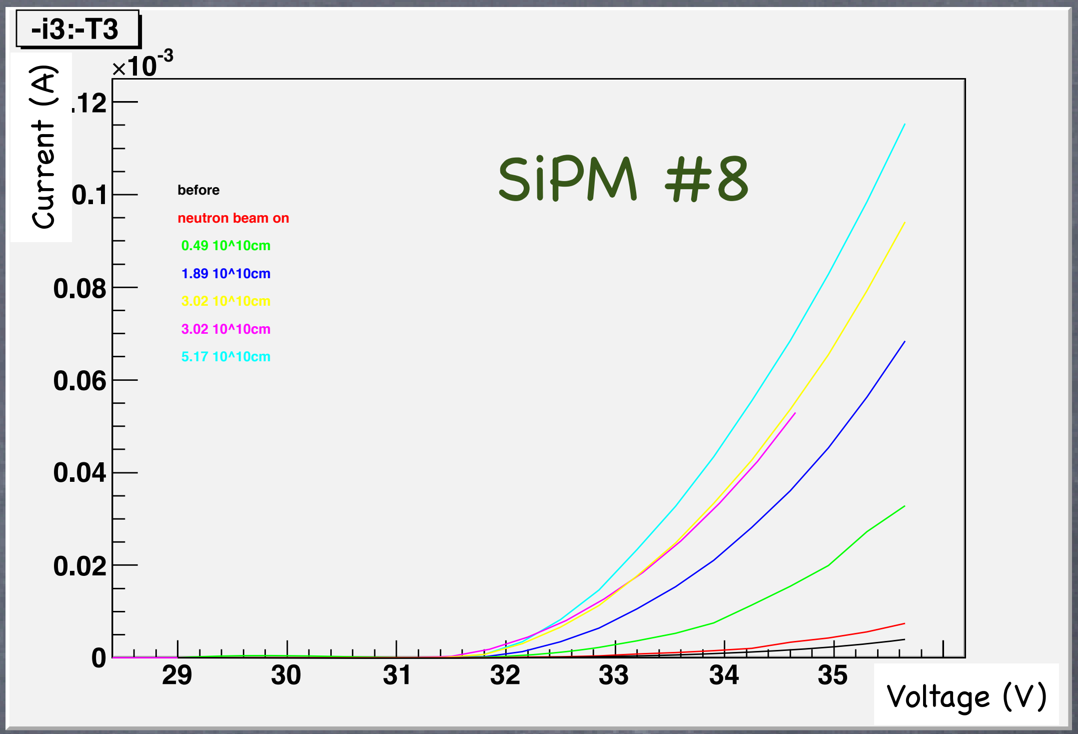
- Also the dark count rates start to increase with a "jump" after an equivalent dose of 10^8-10^9 n/cm^2



Results: SiPM LV-Scan

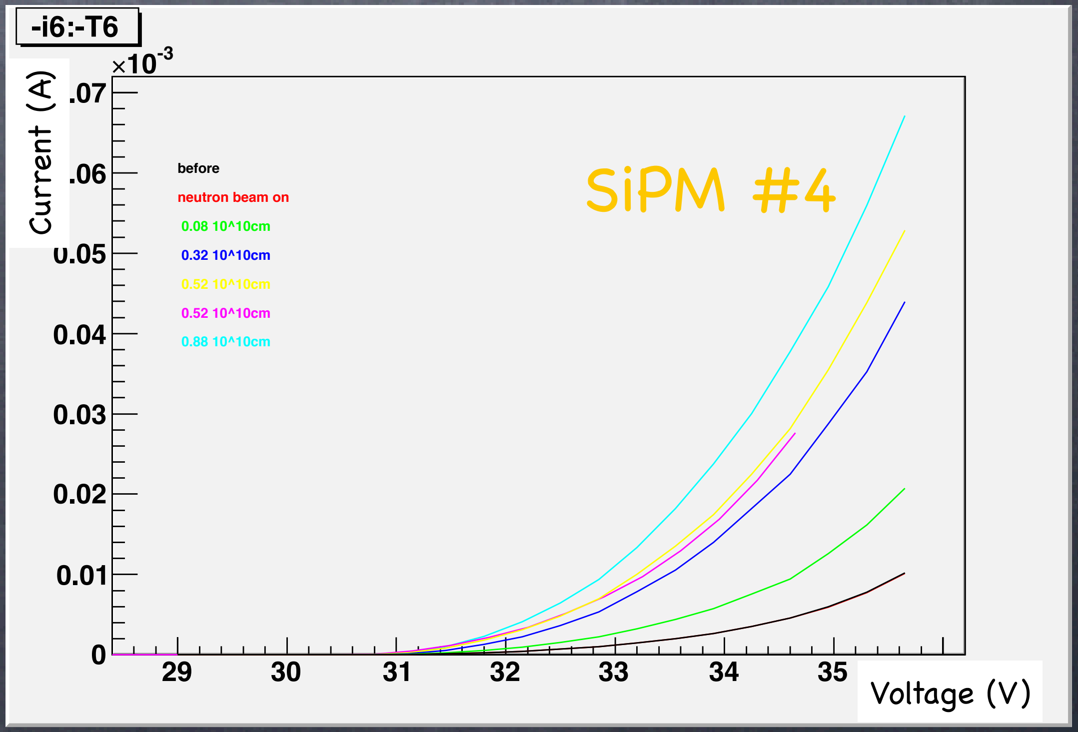
- Several low voltage scans were performed to study the behavior of the SiPM





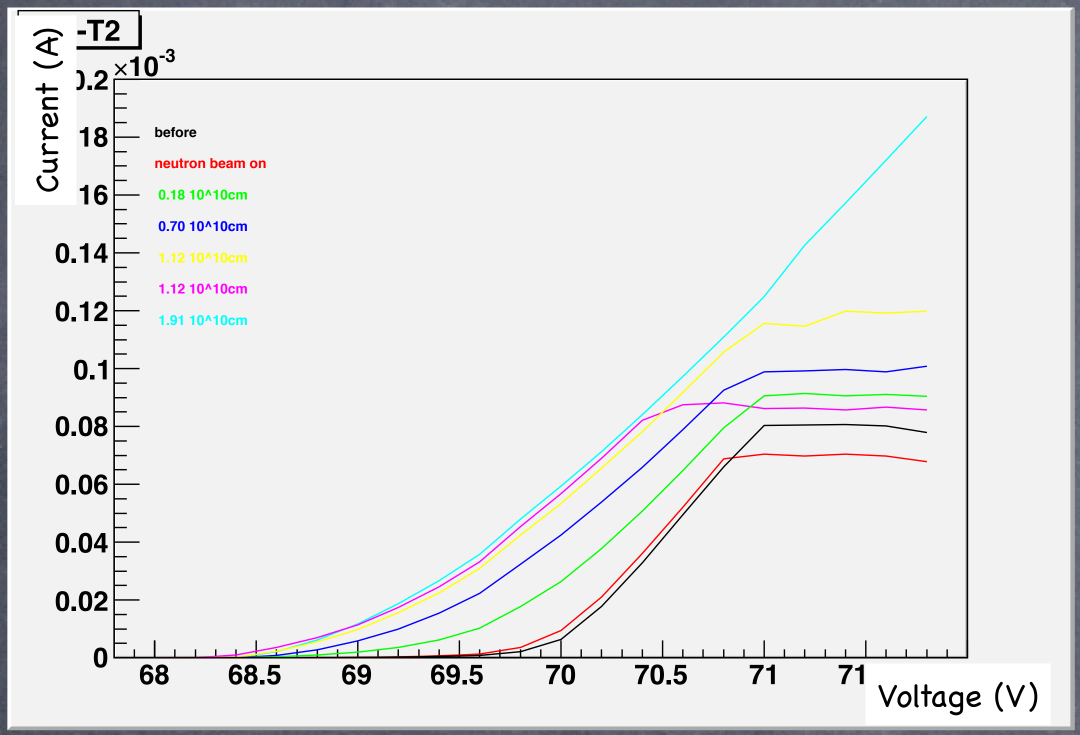
- The effects of neutron damage is clearly evident;

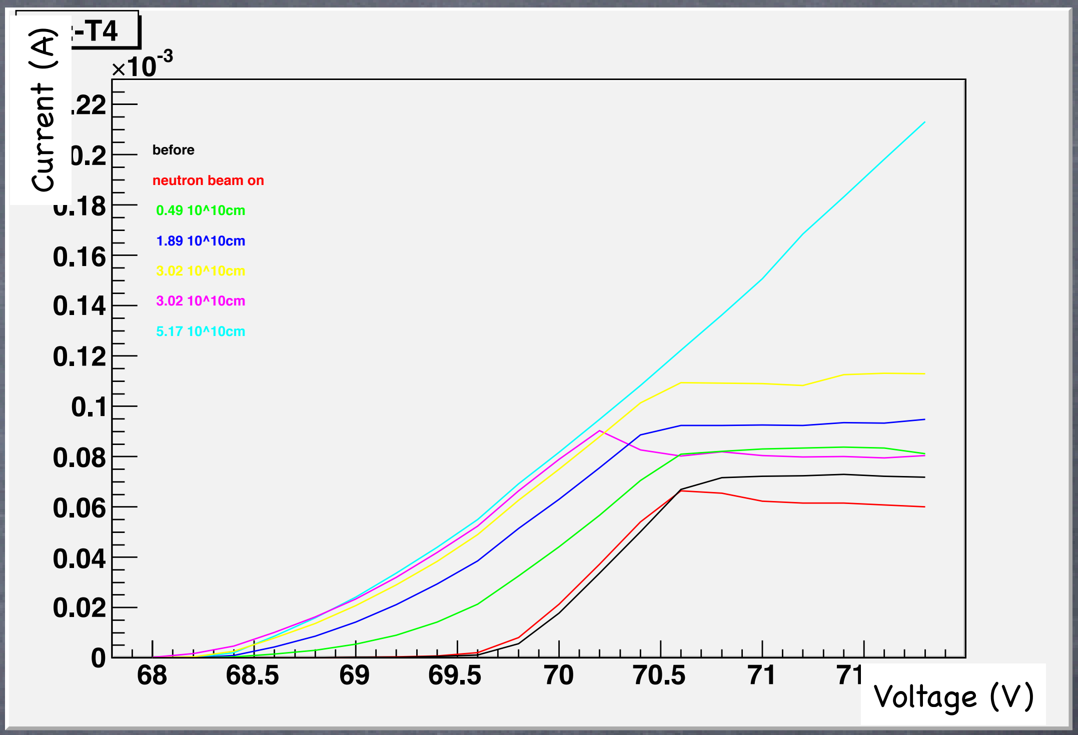
- The LV-scans confirm that a big effect happens already after a low equivalent dose (10^8 n/cm^2);

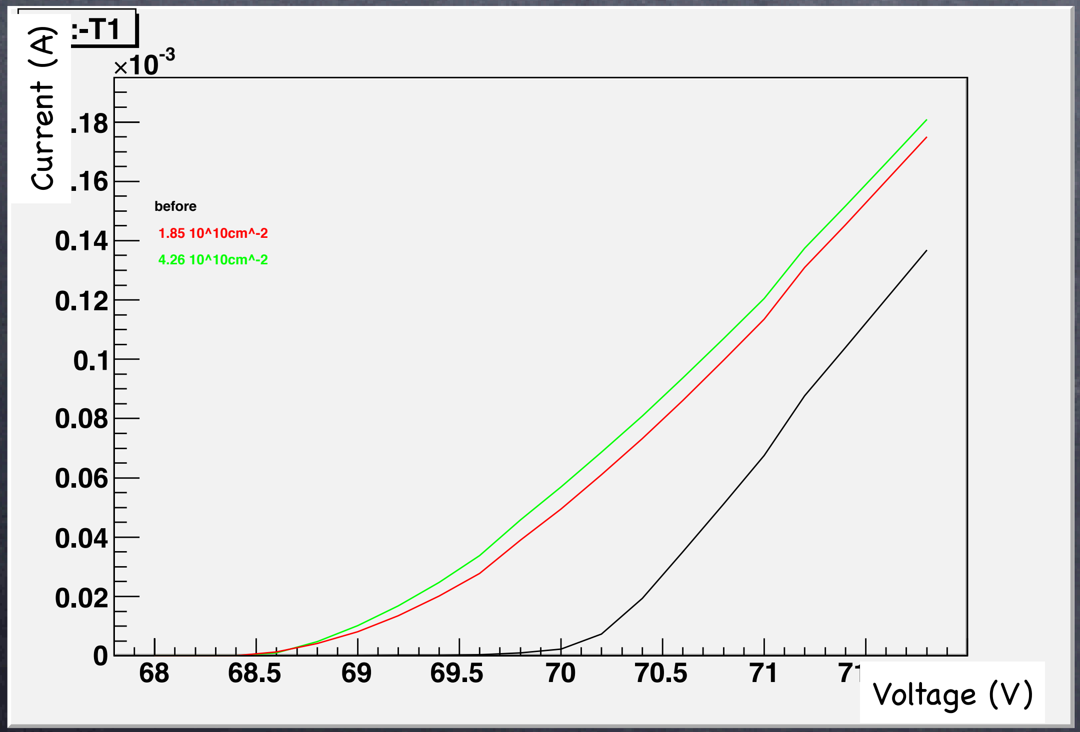


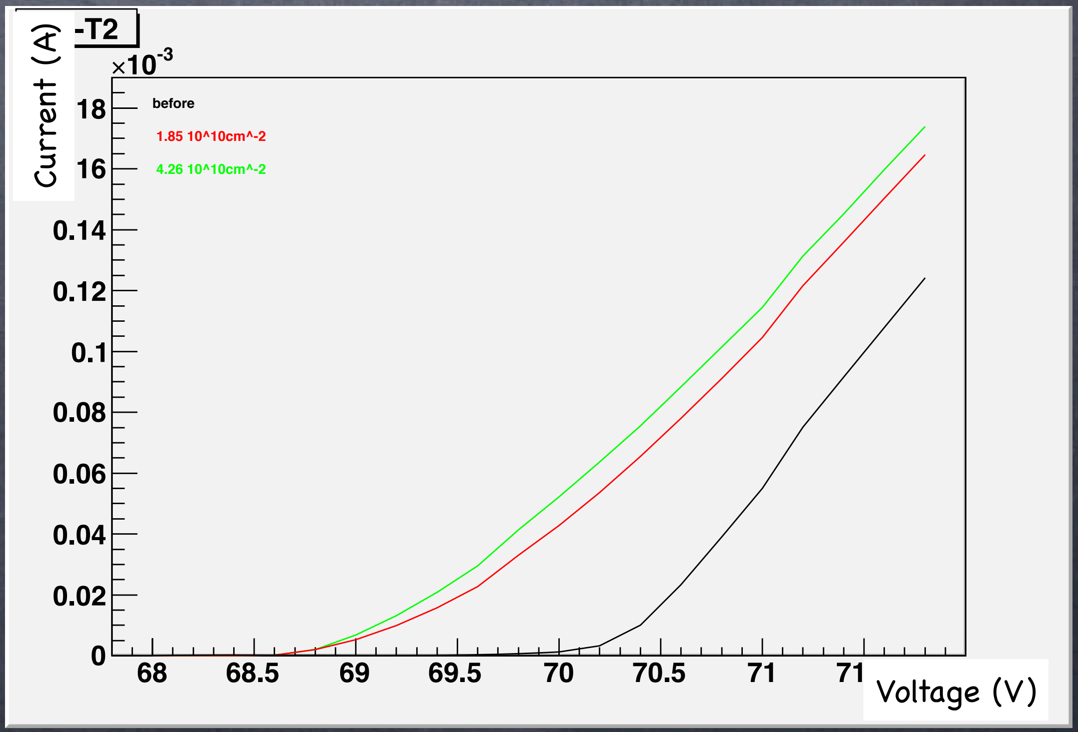
Results: MPPC LV-Scan

- Unfortunately the currents drawn by the MPPCs were smaller than the sensitivity of our picoammeter and we couldn't record them;



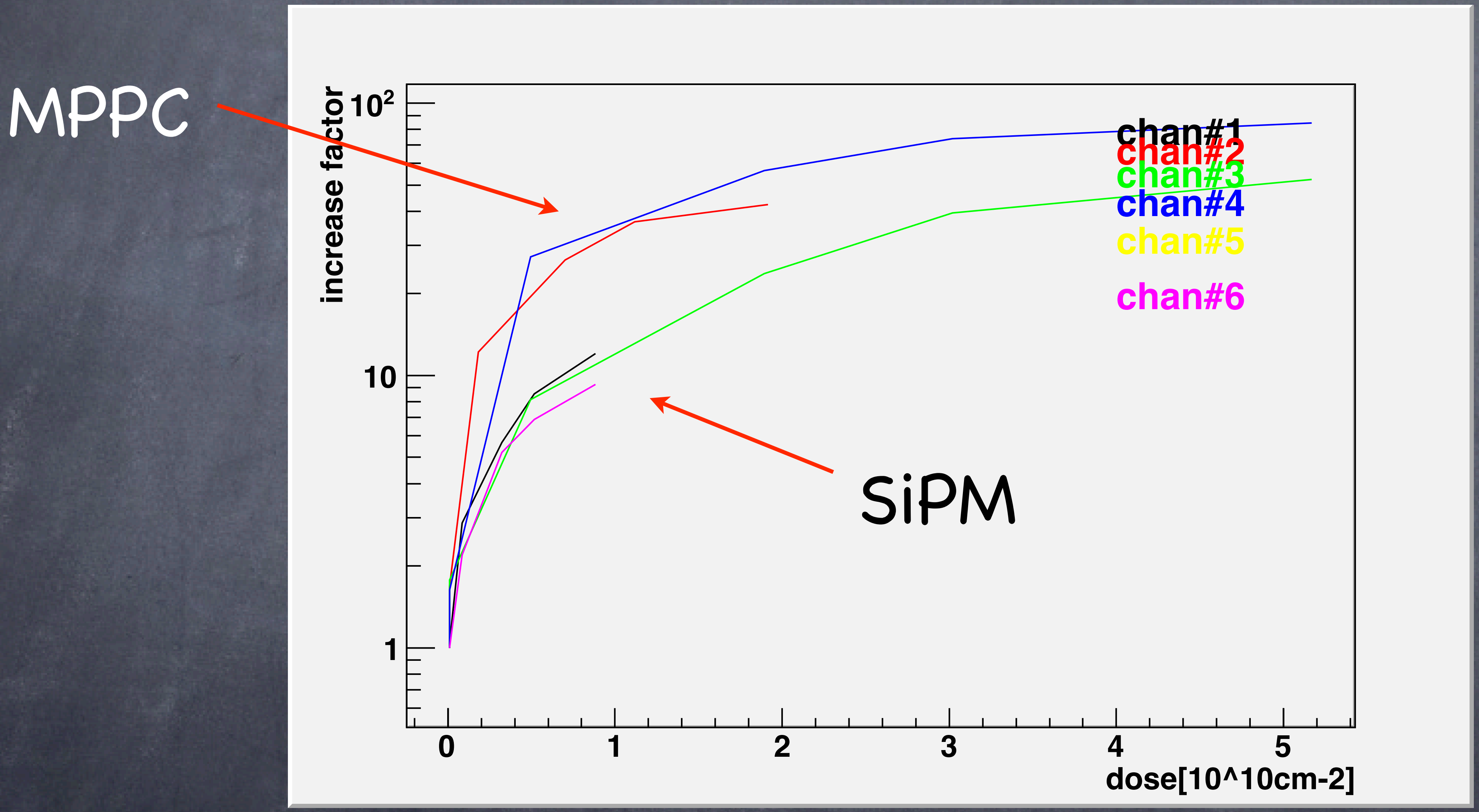






LV Scans: current drawn

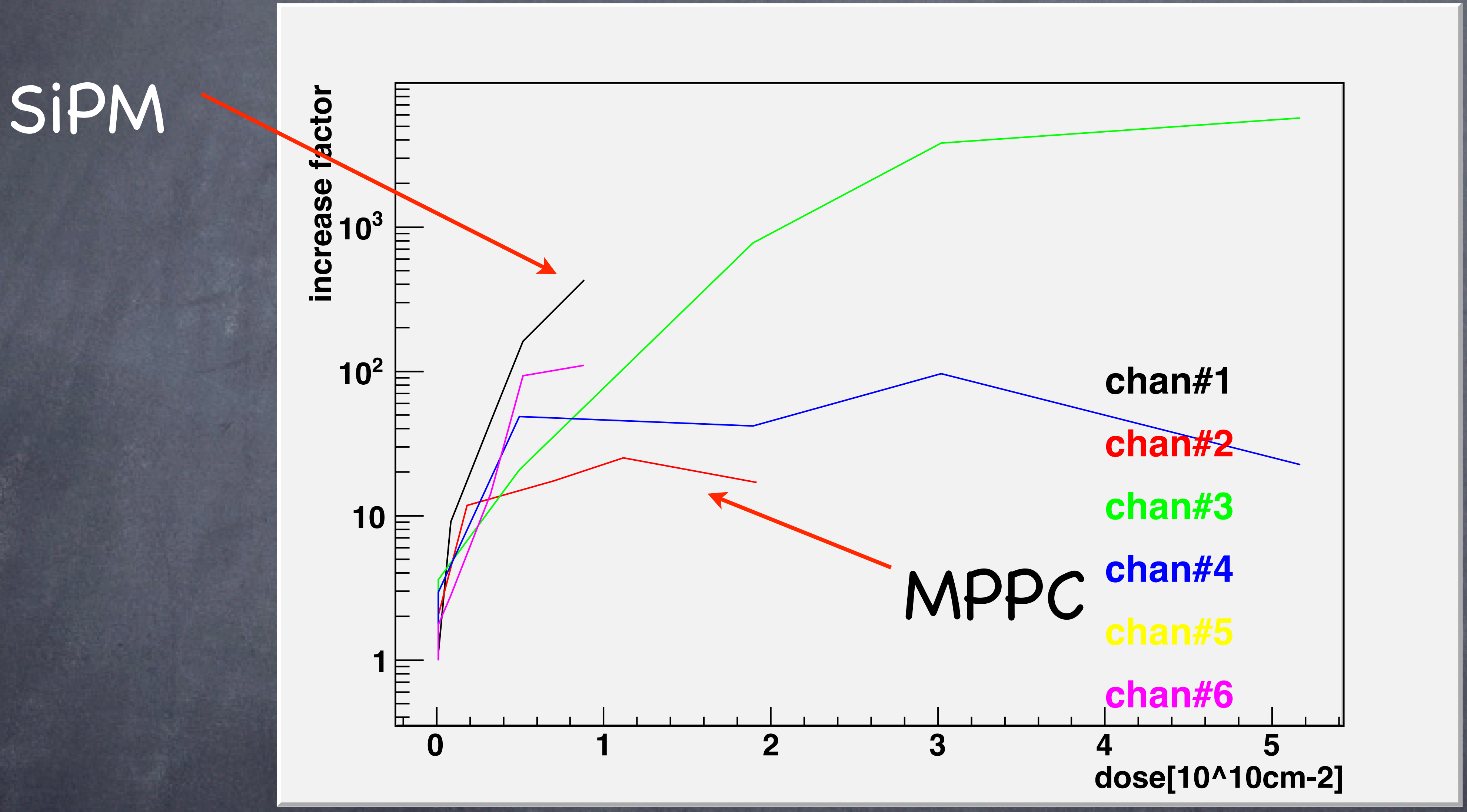
- We studied the behavior of the current in the low voltage scans for the following LV values: 31.8 V, 33.2 V and 32.5 V for the SiPM and 69.4 V and 69.6 V for MPPC



- The current drawn by the MPPC in the working region increase more than the one of SiPM. In both cases more than a facto 50 was found;

LV Scans: dark counting rates

- We studied also the dark current rates found during the low voltage scans:



- The increase of the dark rate of the SiPM reaches 10^4 while for the MPPC it seems to saturate.

Conclusion and future development

- In Babar the neutron rate at the RPC level was 6.5 10^3 Hz/cm^2;
- The current drawn and the dark counting rates of both the SiPM and the MPPC show a continuos increase while the devices are irradiated with neutrons;
- For the SiPM we were also able to see a “jump” effect after an equivalent dose of few 10^8 n/cm^2 (10^5 s in Babar);
- No evidence of recovery after a whole night without neutrons;
- No evidence of difference in the damage as a function of the irradiation rate (only a factor 5 tested);
- We are planning to repeat the measurements with neutrons:
    - With a very lower rate (100/1000 times smaller);
    - By using some shielding (Fe/Pb and/or polyurethane foil...)

SPARES

Neutron rates in Babar

3) Incident neutron flux into various detectors at ~$7x10^{33} cm^{-2} sec^{-1}$:

BaBar Detector	Dist. to the source [cm]	**Inc. rate** [Hz/cm^2]
RPC - forward small radius	~140	~$6.5x10^3$
EMC - forward small radius	~90	~$1.6x10^4$
DCH - electronics backward end	~250	~$2.0x10^3$
DIRC - front end entry into SOB	~450	~$6.2x10^2$
VTX – middle section	~130	~$7.5x10^3$

Temperature effects
MPPC