CMS
Compact Muon Solenoid

Radiation Monitoring for CMS

F.Ravotti
(EST-LEA-CMS)
M.Glaser
(EP-TA1-SD)

Outline …

- Monitoring System for CMS ?
- CMS Radiation Environment
- Active Monitors for CMS
  - RadFETs
  - OSL
  - p-i-n diodes
- Conclusions
- Future work

Monitoring System for CMS … why ?

- Radiation = danger for all systems.
- To establish relationship between the measurements close to the beampipe (Beam Condition Monitor) and radiation levels throughout CMS.
- To check the integrity of shielding and accuracy of simulations.
- Long term monitoring of radiation exposure and background together with TIS ionization chambers.

↓

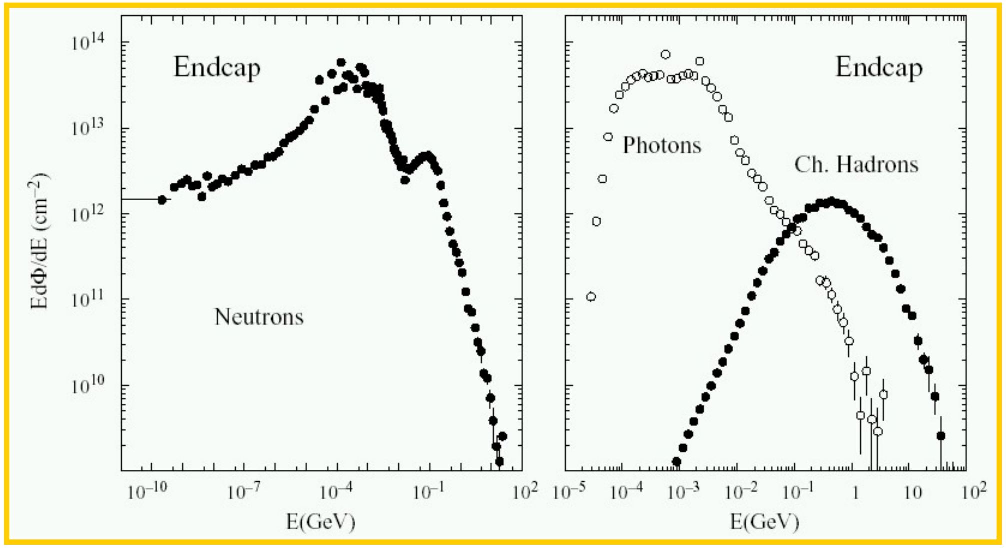
Basically small and cheap Active Monitors able to measure Dose (ionization) and particle Fluence (displacement damage)

CMS Radiation Environment

→ Mixed radiation environment dominated by neutrons.

→ Different for each sub detector *f* (*r*).

→ Different requirements in terms of Sensitivity and Dynamic range:



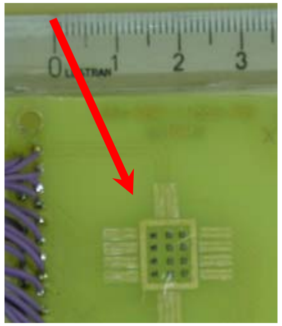
Radiation Spectra in CMS ECAL from FLUKA

After M.Huhtinen (EP/CMM)

ECAL	MUON	
100 Gy –100 kGy	< 100 Gy	← 10 years CMS operation
$1x10^{14}$ part / cm^2	$1x10^{11}$ part / cm^2	
2 – 2000 Gy	< 2 Gy	← 1st year CMS operation
1-1000 mGy/h	< 1 mGy/h	

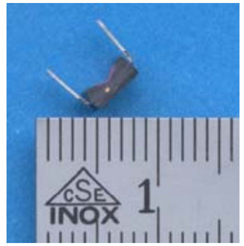
Active Monitors under development for CMS

RadFETs



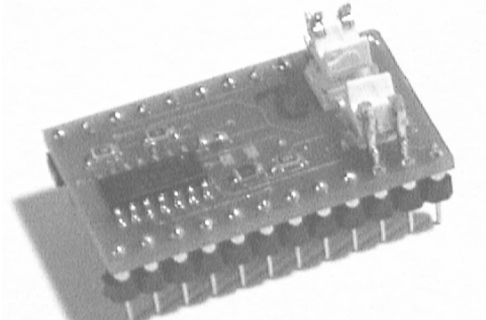
Build-up of charge in MOS SiO_2 (Dose) → Increase of the MOS gate voltage (threshold) when biased with fixed drain current (integrating measurement).

BPW34F p-i-n diodes



Bulk damage in high ρ Si-base (displacement damage) → Increase of base resistance when biased forward with low constant current (integrating measurement).

Optically Stimulated Luminescence (OSL)



3 cm x 1.5 cm

Charge trapped in sensitive material (Dose) → Charge detrapped by IR stimulation with subsequent emission of visible light proportional to the absorbed dose (after each reading the material is completely "reset").

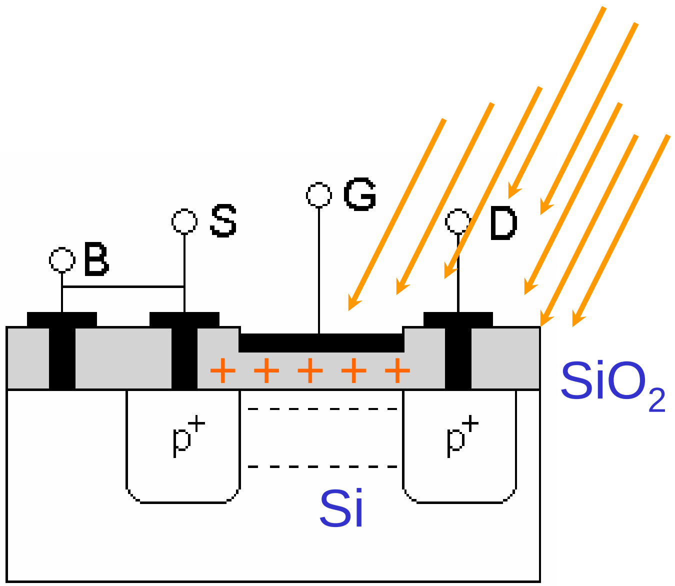
RadFETs – General

Previous work (Camanzi, Ravotti, Glaser) ……

1. Characterized in different radiation environments.
2. Different SiO_2 thickness = different sensitivities.
3. Sensitivity decreases over the integration.
4. They can integrate doses in the 10 Gy – 100 kGy range.

… from this year ……

5. New thick devices (CNRS, Toulouse) tested in proton (see after) and mixed-neutron environment (analysis still ongoing).



6. Annealing of the trapped charge is the “enemy” of the devices over their lifetime: we are worried about device long-term behaviour !

→ Isochronal annealing program

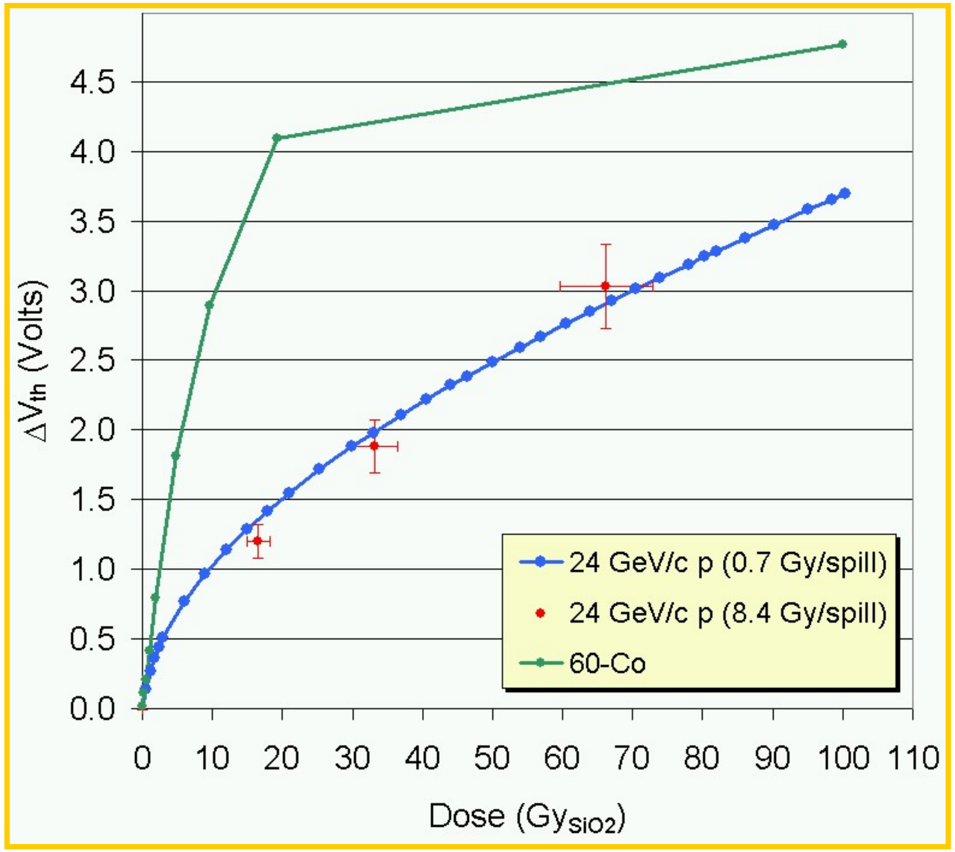
RadFETs – New devices

1. Charge build-up is dose-rate independent.
2. "Radiation dependent" response: the response with photons is 64% higher than the protons one:
   - Higher h/e pair recombination for protons.

→ calibration environment has to be carefully chosen, ex:

CMS like spectrum of the
CERN PS-T8 IRRAD2 facility.

→ Important in a mixed environment to monitor different quantities!



Example of response curves for thick CNRS devices in 24 GeV/c proton beam

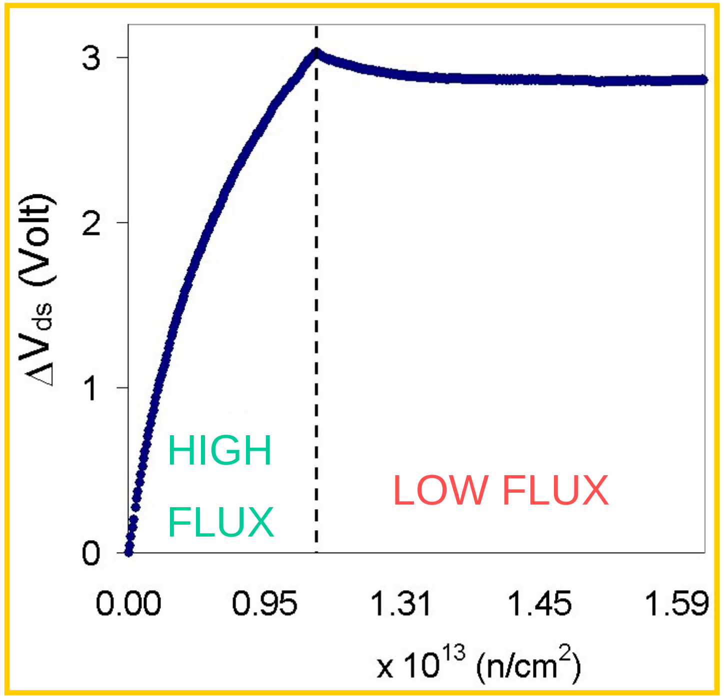
RadFETs – Isochronal Annealing 1/2

During lifetime of the devices:

- Trapped charge annealing (prompt time scale).
- Delayed generation of interface states due to irradiation can occur (years time scale).

↓

MISINTERPRETATION OF REAL RADIATION FIELD CONDITIONS →



Device measured in CERN-TCC2

↓

We have to predict the RadFETs long time behaviour to be sure about the values we will measure over the time! (e.g. the trapped charge spectrum into SiO_2).

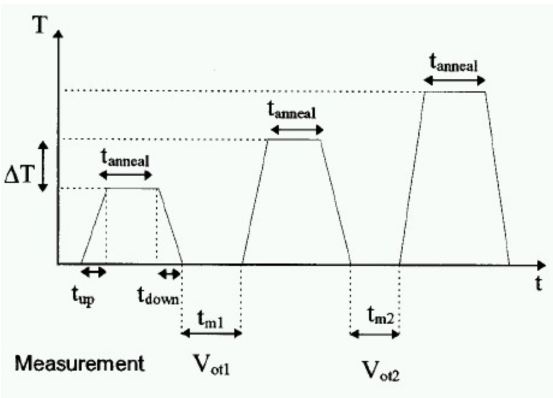
→ Prediction based on the scaling annealing time ⇔ annealing temperature

RadFETs – Isochronal Annealing 2/2

1. Irradiation to $Dose_{max}$ < SiO_2 saturation
2. Define the "mission" of the dosimeter:

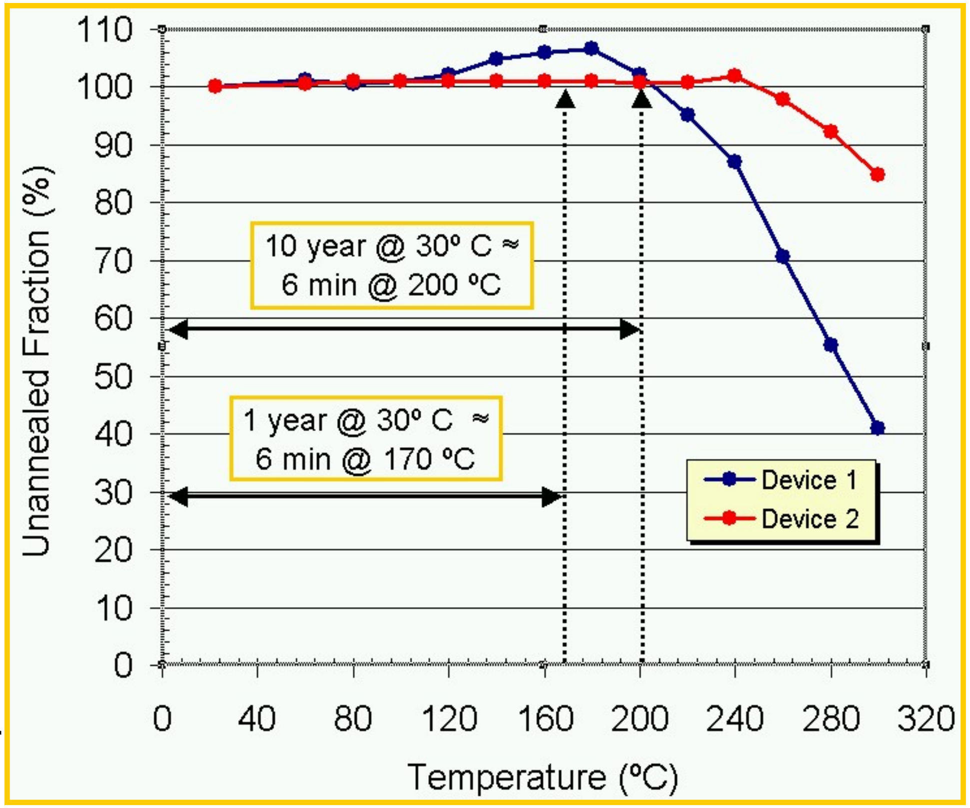
   (1 y. and 10 y. @ 30ºC)

3. Calculate the characteristic T*.
4. Perform the heating program:



6 minutes annealing at different T

After L.Dusseau CEM² - Montpellier



Example of Isochronal annealing

(after 20 Gy of proton irradiation)

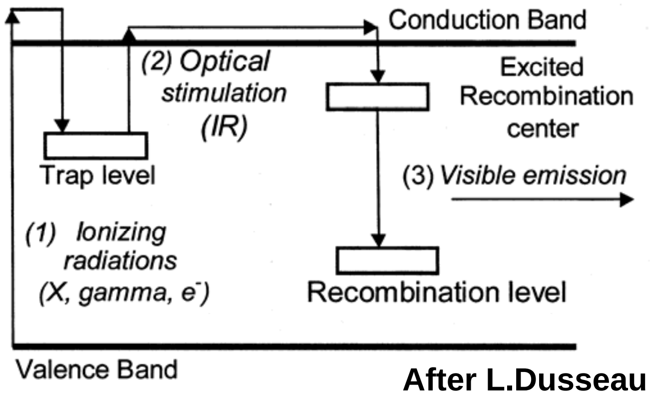
5. Interpretation of the curves:

   Unannealed charge vs. Temperature.

Optically Stimulated Luminescence

(collaboration between CERN and CEM[2] – Montpellier)

The behavior of the SiO_2 in a mixed radiation environment and the loss of sensitivity during time, suggests to have a complementary way to measure the ionization (Dose).



After L.Dusseau

Rare-earths doped materials that emit visible light proportionally to the absorbed dose when they are stimulated by IR lights.

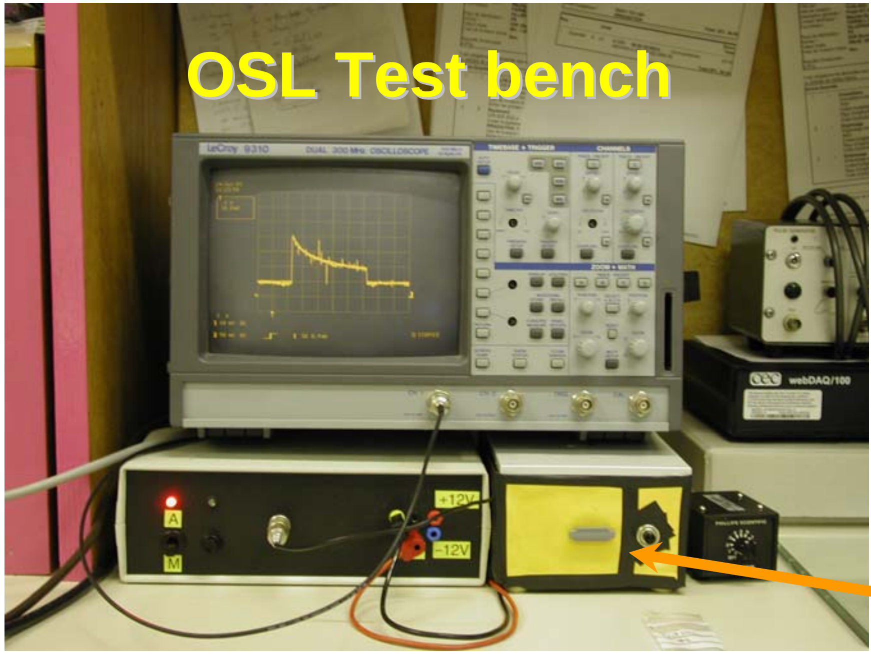
High sensitivity (µGy to 100 Gy range) depending of readout electronics.

A sensor based on these materials (developed for space/medical applications) already exist.

OSL @ CERN

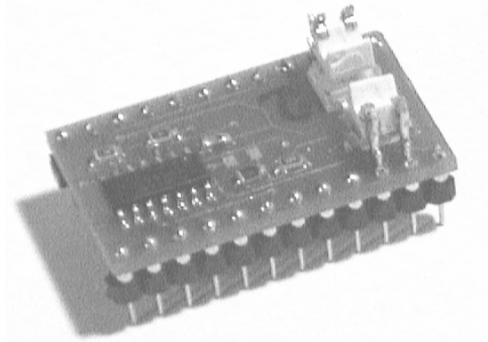
We began the study of this new dosimetric technology following 3 different ways:

Sensitivity of the standard OSL material "strontium-sulfide doped" (SrS) to High Energy Particles



Development of SrS-based compounds with calibrated neutron sensitivity

Test of the integrated sensor in High Energy Particles environment.



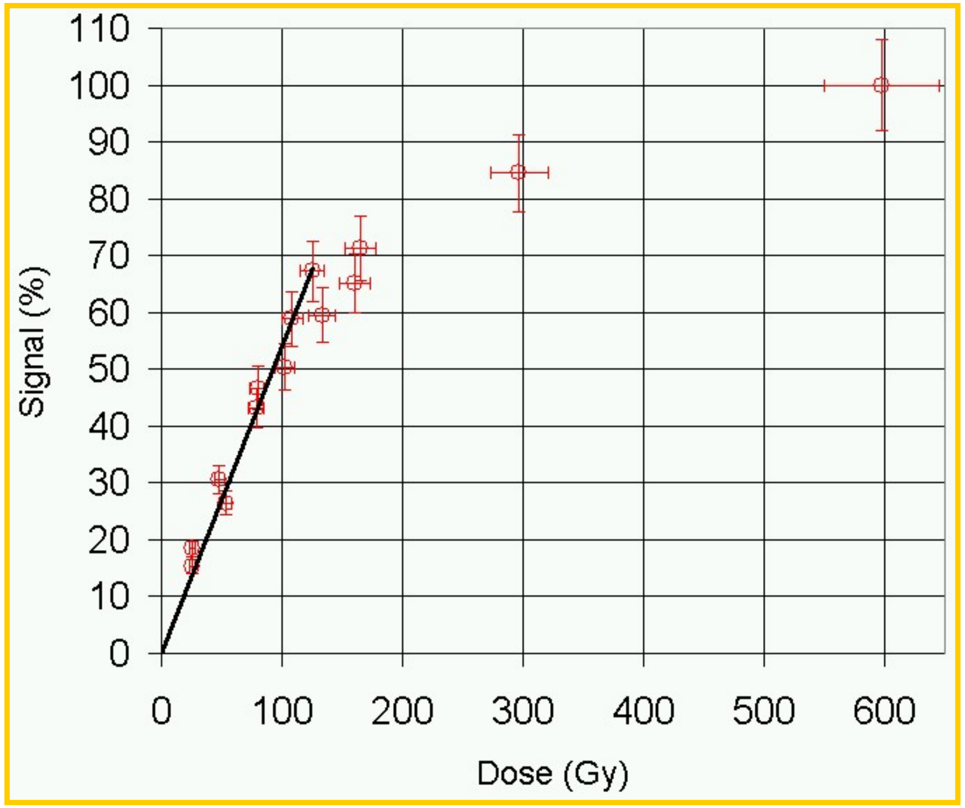
Designed for the range (50 mGy – 100 Gy)

OSL DAQ LabVIEW controlled

OSL @ CERN – Sensitivity to HEP

1. Tested samples 5x5 mm^2 of SrS deposed on Kapton Foils.

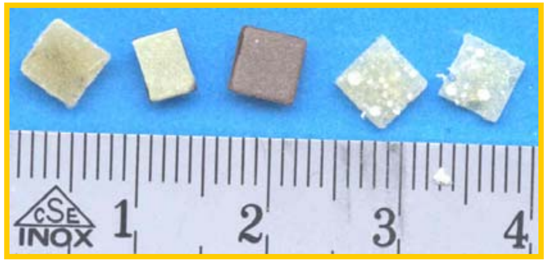
2. Several Irradiations with different beam conditions performed at the CERN PS proton IRRAD1 facility;
3. Dynamic range up to 100 Gy
4. Material handling quite difficult due to products light sensitivity.
5. Charge annealing and temperature influence on trapping process have to be studied in details.



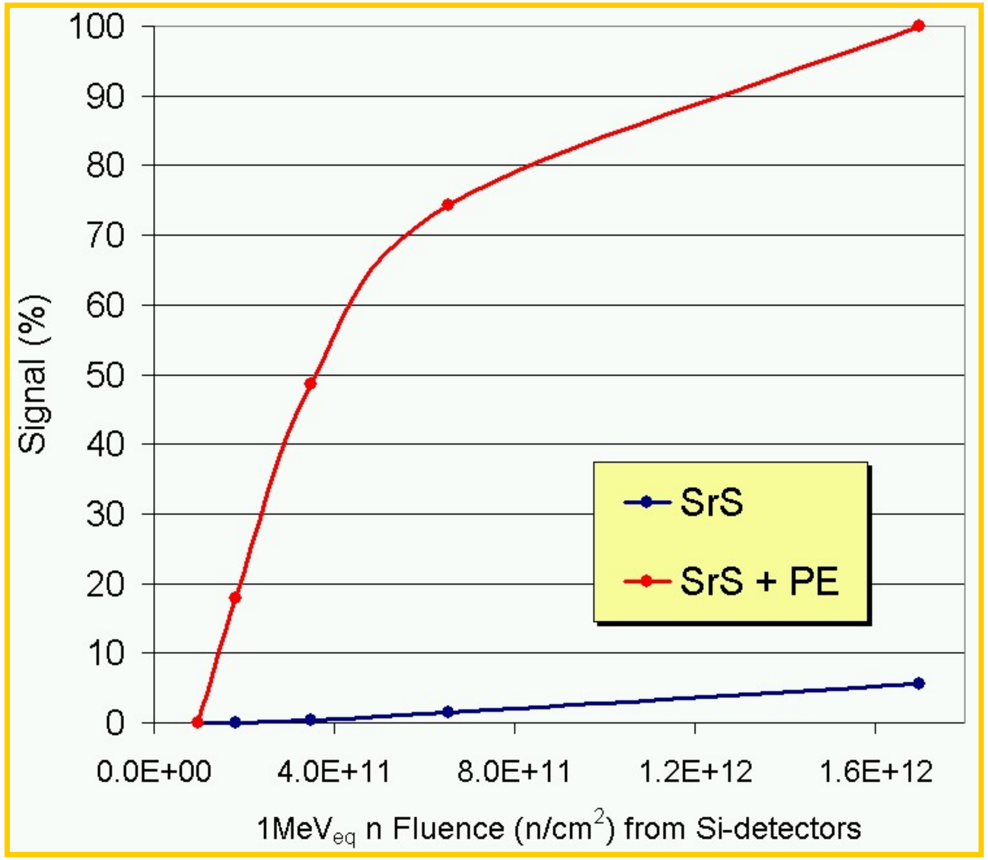
SrS response to 24 GeV/c proton beam (IRRAD1 facility)

OSL @ CERN – neutron sensitive materials

1. Tested samples 5x5 mm^2 of different mixtures of SrS + Polyethylene (PE)/Boron(B).



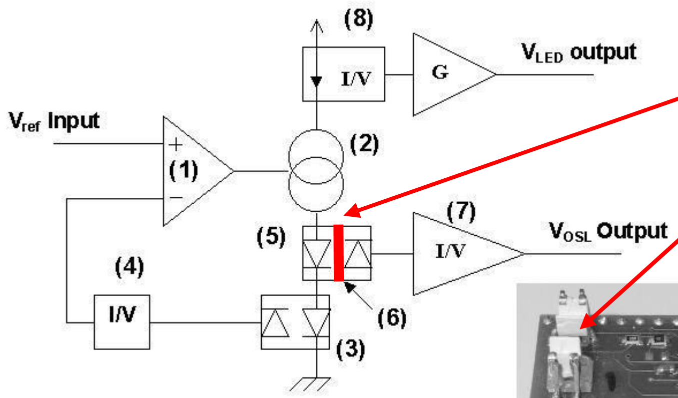
2. Pure SrS almost insensitive to neutrons.
3. Sensitivity SrS+PE ~ 20 Sensitivity SrS.
4. SrS + B homogeneity ?, strong annealing ?
5. SrS + PE + B no signal! (problem during materials preparation).

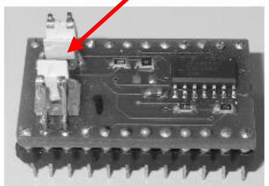


New neutron irradiation is under way at JSI TRIGA reactor in Ljubljana.

responses into IRRAD2 environment

OSL @ CERN – Integrated Sensor





After L.Dusseau

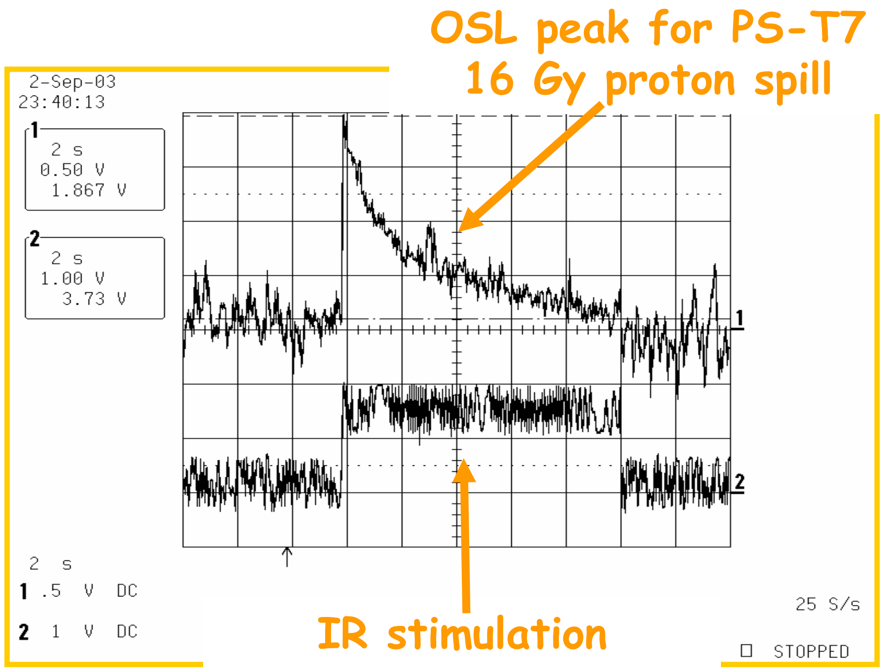
Sensitive material +

(SrS block sandwiched between diode and photodiode)

Radhard electronics =

(degradation of IR LED emission compensated)

RADHARD INTEGRATED SENSOR



BPW34F p-i-n diodes - General

Other p-i-n diodes tested in the past (University of Wollongong, Australia)

base width = 1.2 mm and ρ = 1.7 kΩ·cm

→ very high sensitivity for fluences < 10^{12} part./cm^2

↓

To cover high fluences we try to investigate a new types of diodes → OSRAM BPW34F

base width = 210 μm and ρ = 2.5 kΩ·cm

- Devices not designed for dosimetric purposes.
- Some investigations already done also here at CERN/TIS in the past.

↓

We are studying proton/neutron irradiated diodes comparing "on-line" and "off-line" measurement in collaboration with the CERN EP-TA1-SD group.

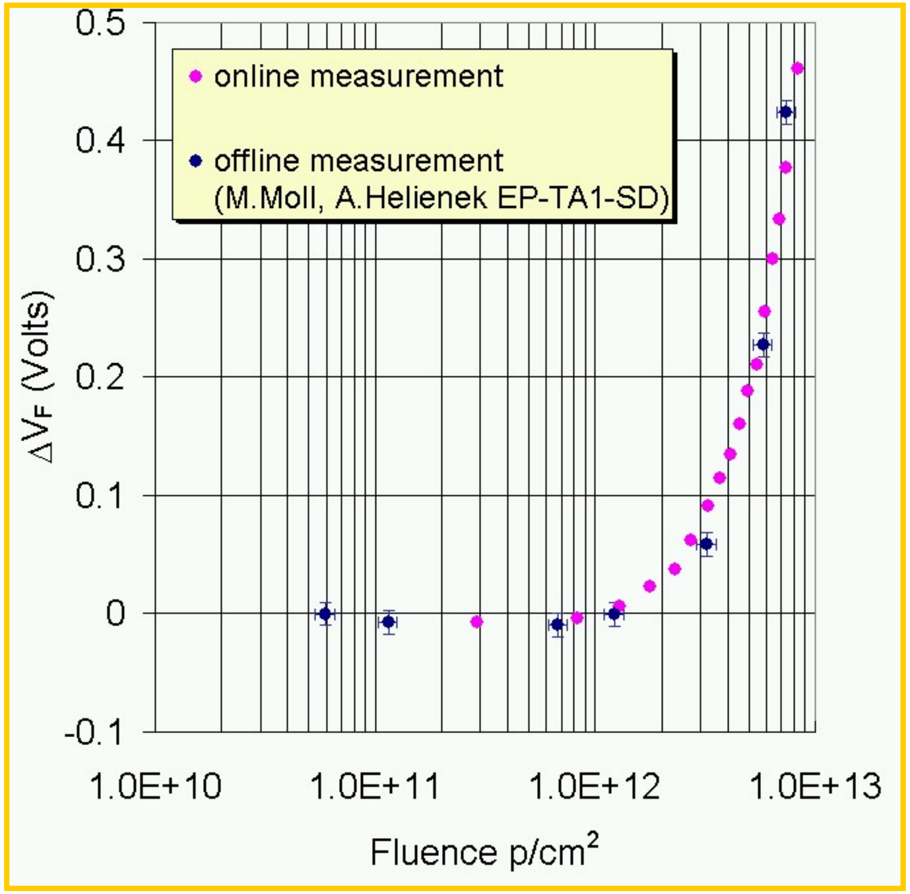
BPW34F p-i-n diodes – 1/2

"on-line measurement" & "off-line measurement"

in 24 GeV/c proton beam

readout of the V_F under forward bias

(current pulse 1 mA x 180 ms).



→ Strong temperature influence:

(~ 35 mV / ºC → ~ $2x10^{12}$ p/cm²/ ºC);

→ Devices useful to measure high fluences:

Threshold > 1.5 x 10^{12} p/cm²

(> 1 x 10^{12} n_{1MeVeq} / cm²)

→ The relatively weak annealing now under investigation.

BPW34F p-i-n diodes – 2/2

Protons data → $\Phi_{n1MeVeq} = \Phi_p \times k$.

Neutrons data → $\Phi_{n1MeVeq}$ from FLUKA simulation normalized with Si-detectors fluence measurement.

→ NIEL scaling is respected.

→ Sensitivity of 1.1 V/ 10^{13} n_{1MeVeq} / cm^2.

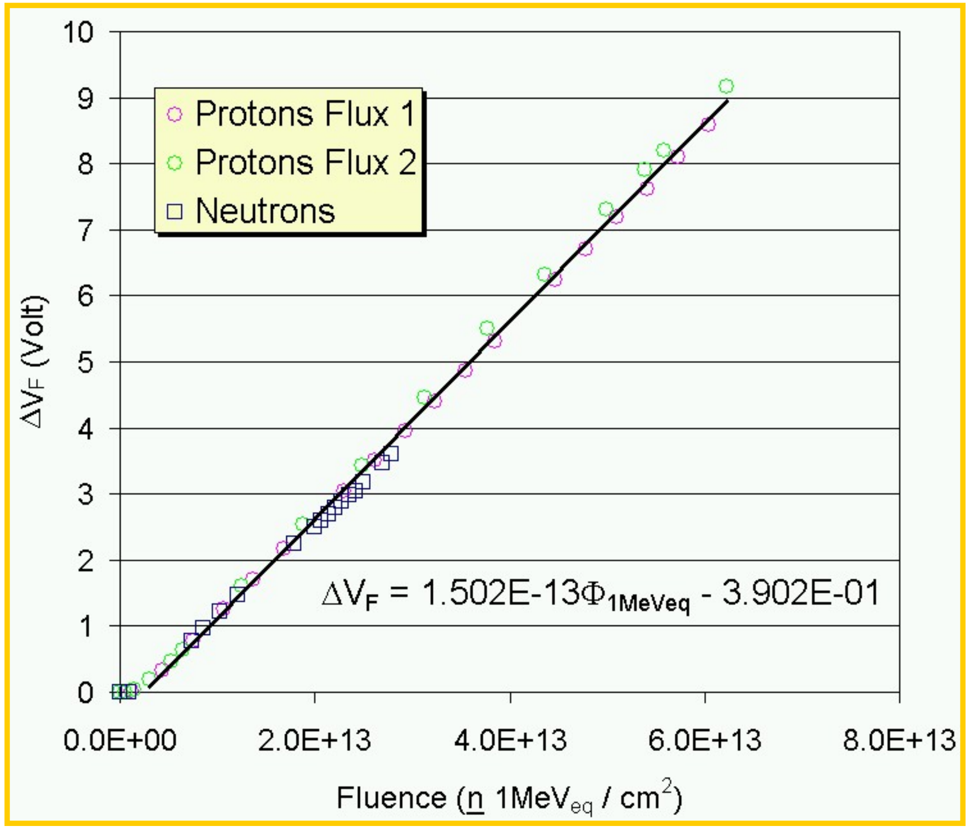
→ Results coherent with previous test.

→ Irradiations with:

lower fluence (< 4×10^{12} part/cm^2).

higher fluence (~ 10^{16} part/cm^2).

already performed: analysis still ongoing!



BPW34F data's (IRRAD1 / IRRAD2 CERN facilities) normalized to 1MeV$_{eq}$ neutrons

Conclusions

RadFETs dosimeters:

- New devices can help to fit better CMS requirements.
- We need to perform isochronal measurements to finish the characterization of this technology.

OSLs dosimeters:

- We proved that SrS materials work in HEP environment;
  → Accurate annealing studies has to be done.
- Encouraging results in the development of neutron sensitive materials;
  → Work on the materials has to be continued.

BPW34F p-i-n diodes:

- We found a device to measure high particle fluences.
- Annealing and temperature effects have to be fully investigated.

Future work .....

RadFETs

(integrated dose measurements with sensitivity that decreases over the time)

OSLs

("instantaneous" and high-sensitivity dose measurements)

PT100

(Temperature control)

p-i-n-diodes

(fluence measurements)

INTEGRATION

Considering that …

1. We need different technologies to monitor a mixed radiation environment with Si-based devices.
2. All devices under test have small dimensions.
3. Basically we inject a current to read voltages as dosimetric parameters.

→ To integrate all these technologies in one PCB !

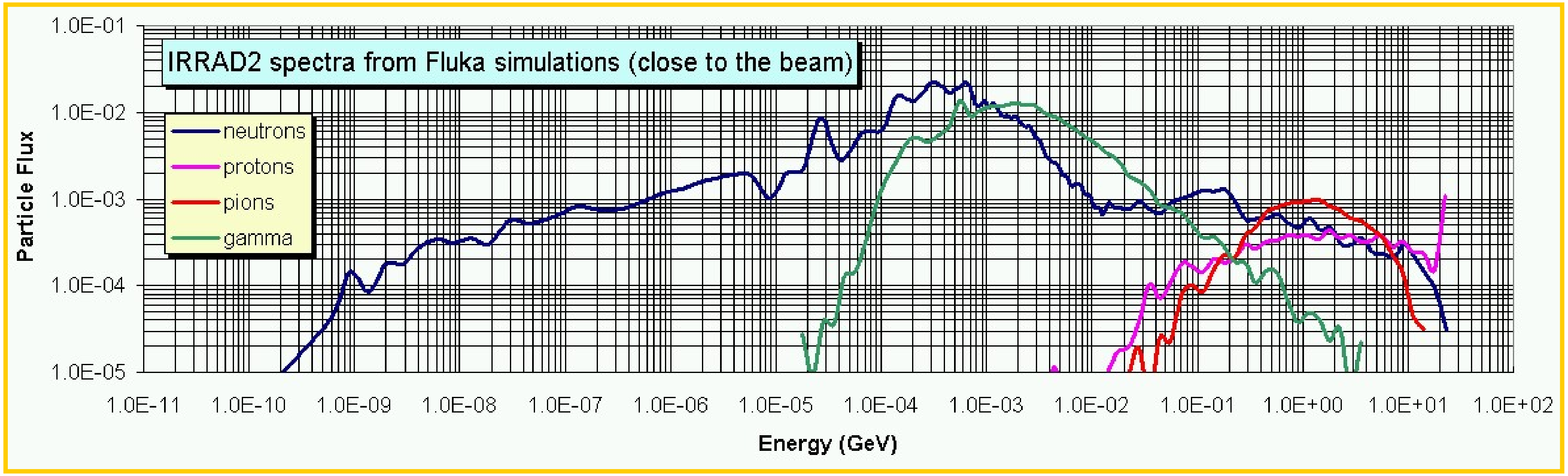
Acknowledgments

- EP Irradiation team for the use of their facilities on PS complex (http://www.cern.ch/irradiation).
- EP-TA1-SD section for their support.
- CEM^2 – Montpellier University for the support on OSL materials.
- CNRS-LAAS of Toulouse for the support on new RadFETs devices.

RadFETs calibration → PS IRRAD2 Facility

Shuttle system to place the samples at different distances (z) from target

- Deposed dose known by FLUKA simulations (M.Huhtinen).
- Optimization of the calibration for the different CMS sub-detectors.



After Maurice Glaser