The Radiation Monitoring System for the LHC and LHC Experimental Areas

Ch. Ilgner, May 4 2004

Beam condition monitoring

- protecting LHC experiments
- tests of CVD diamond sensors

Radiation monitors for the LHC experimental caverns

- various active and passive sensors

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The Beam Condition Monitor (BCM)

Purpose of the BCM:

provide real-time radiation monitoring within CMS and ATLAS (others are welcome) to detect and initiate protection procedures for detector subsystems at the onset of beam instabilities and accidents

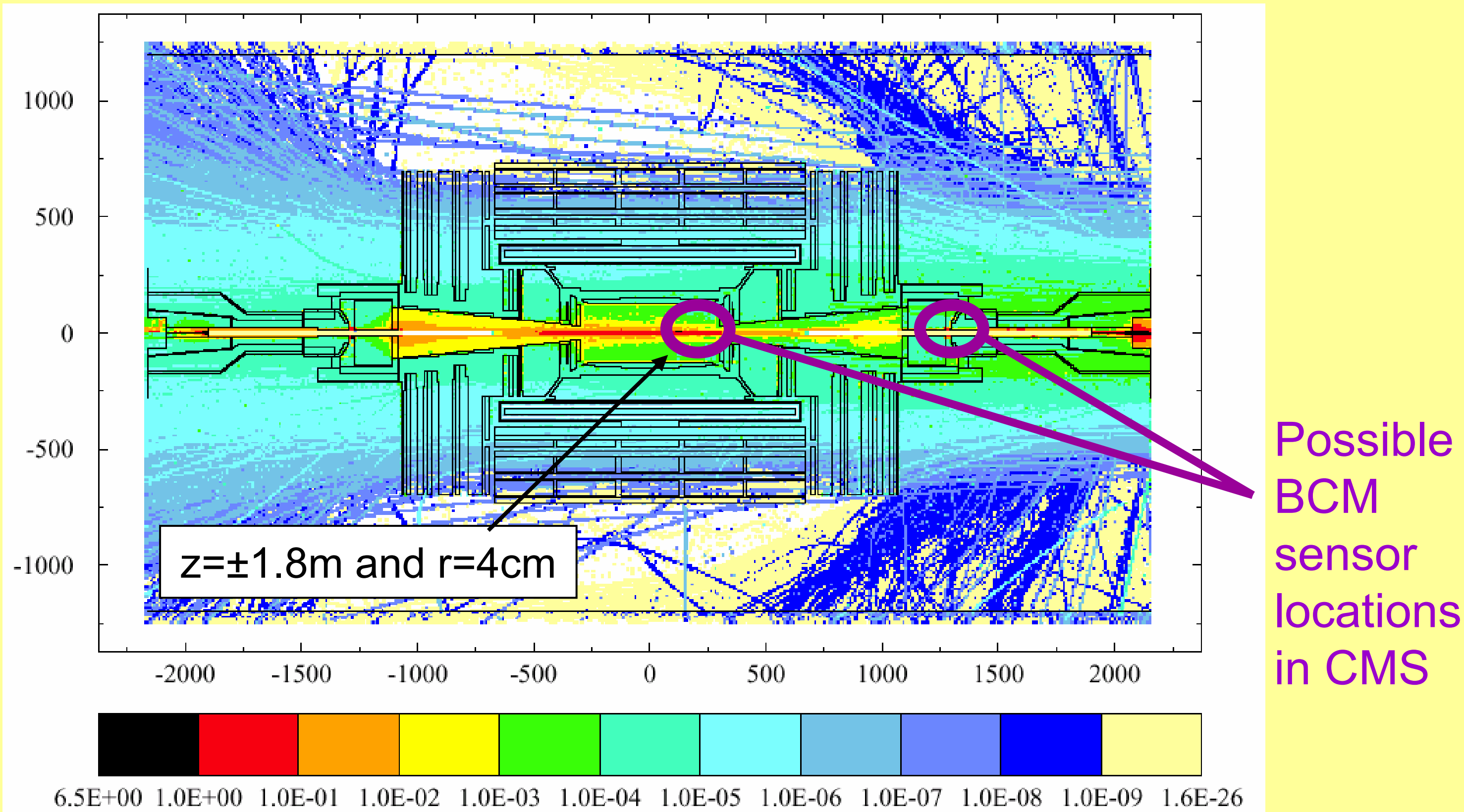
Goal:

provide monitoring information in the time scale of the LHC beam structure of 25ns → beam dump request, detector HV ramp down

Sensor candidate:

CVD diamond close to beam pipe, at a distance of about 1.5m from the interaction points. Fast electronics outside the main volume

BCM: accident scenarios – unsynchronized beam abort



after M. Huhtinen

Doses in Gy over 260ns throughout the CMS spectrometer

BCM: accident scenarios – resulting doses

Loss type	Dose per event (on inner Si strip layer of CMS tracker)	Flux factor	ratio
Unsynchronized beam abort	10 mGy	1	1
One 7 TeV proton lost on TAS	15 pGy	10^{12}	1500*
One 450 GeV proton lost on TAS	1 pGy	10^{12}	100*

after A. Macpherson

Unsynchronized beam abort : 10^{12} protons lost in IP5 over 260 ns

Dose rates up to 1000 times higher if consecutive full bunches lost

BCM: accident scenarios – time scales

Outline:

Beam condition monitor (BCM)

Accident scenarios

CVD diamond

Test results

Layout (CMS)

Radiation monitors

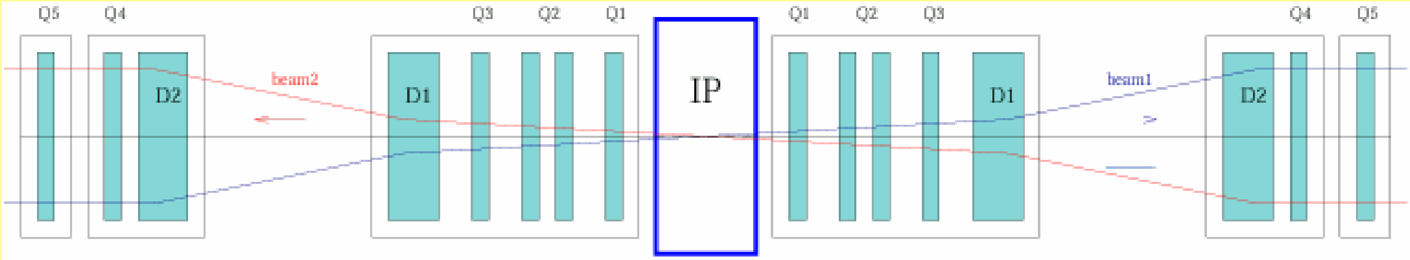
Active sensors

Passive sensors

Name	Operation mode	Loss type	Loss location	ΔT/turns
D1 warm	collision	local	triplet/collimator	5
damper	injection	local	arc/triplet	6
warm quadrupoles	any	distributed	collimator	18
dump septum	any	local	diluter kicker/septum	35
warm orbit corrector	aollision	local	triplet/collimator	55
RF (?)	any	local	arc/triplet/septum	55
D1 warm	injection	local	arg/triplet/collimators	120
D1 Cold	collision	local	triplet/collimator	220
warm orbit corrector	injection	local	arc/triplet/collimator	250
MB quench	collision	local	triplet/collimator	280

after A. Macpherson

BCM: accident scenarios – D1 magnet failure



after V. Kain, R. Schmidt, R. Assmann, EPAC 2002

D1 magnet failure:

fastest generic beam-loss scenario, timescale: 5 turns ~ 500 ns

→ defines the response time scale

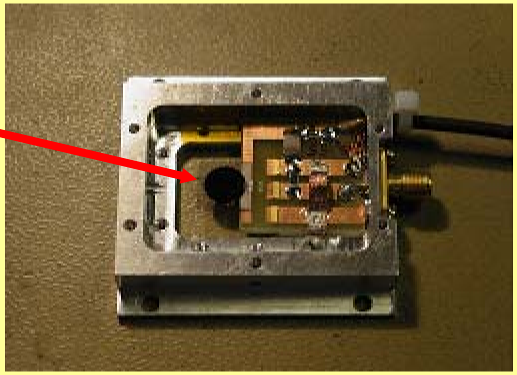
information from BCM need to be provided on a bunch-by-bunch basis, a few 100 ns for decision on beam dump

BCM: CVD diamond

CVD (chemically vapor deposition) diamond:

- promising BCM sensor candidate
- 1 x 1 cm polycrystalline material, typically 300 µm thick
- operation similar to Si, but charge traps need to be filled up
- radiation hard

metallization, 8mm in diameter



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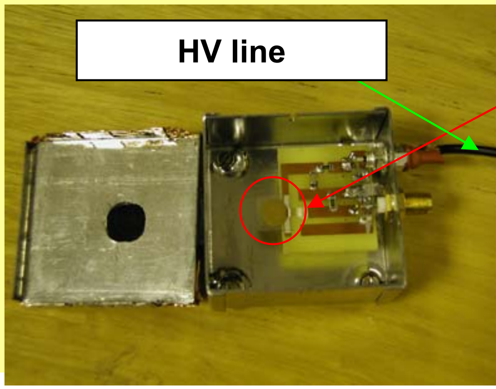
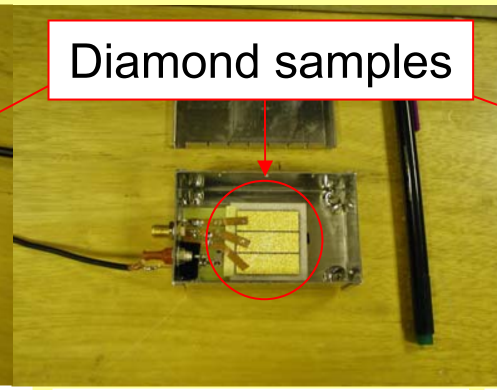
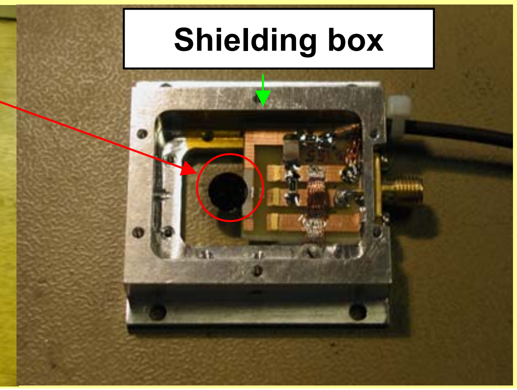


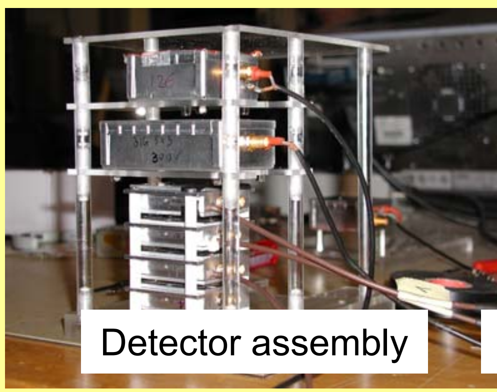




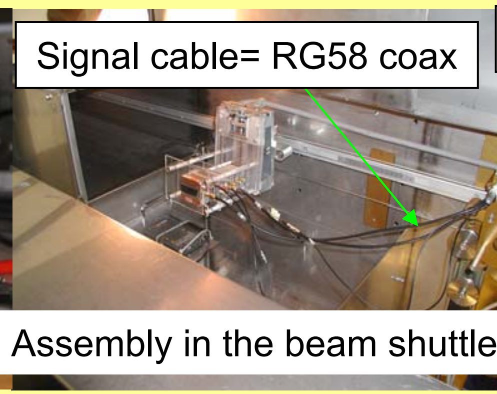
CDS126: 1x1cmx300 um thick
Collection dist ~ 110 um

3x1cmx500 um thick
Collection dist ~ 40 um

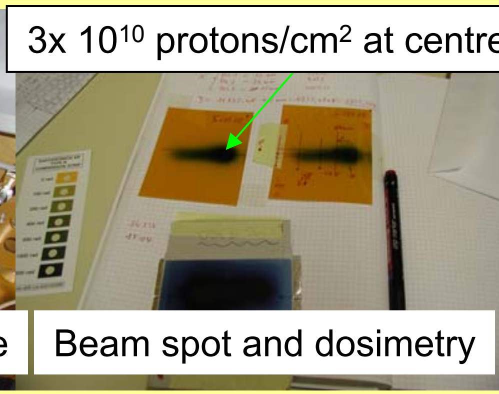
CDS116: 1x1cmx500 um thick
Collection dist ~ 125 um



Detector assembly



Assembly in the beam shuttle



Beam spot and dosimetry

BCM: beam-test results

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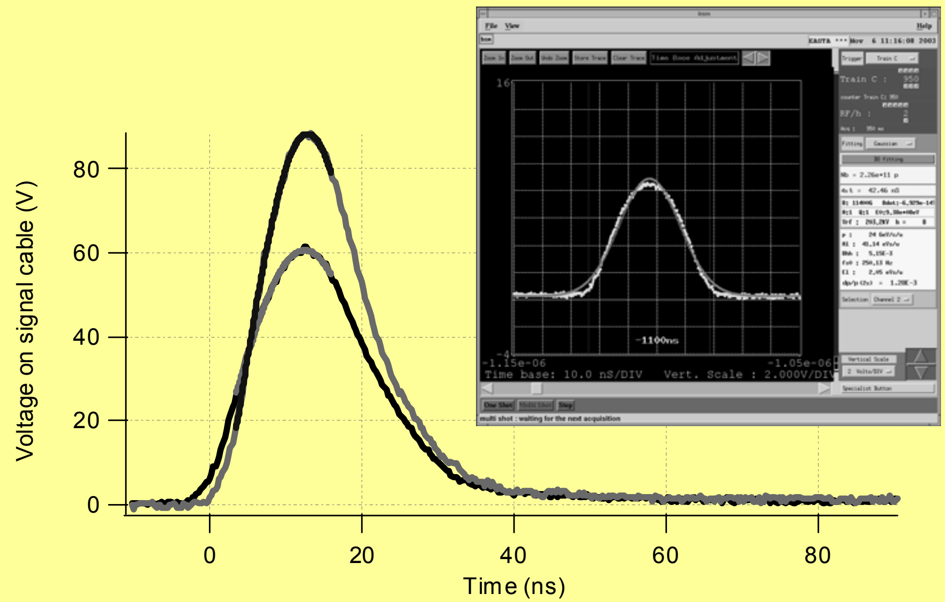

Diamond response to a single shot: sufficiently fast, but the Gaussian tail is not yet understood

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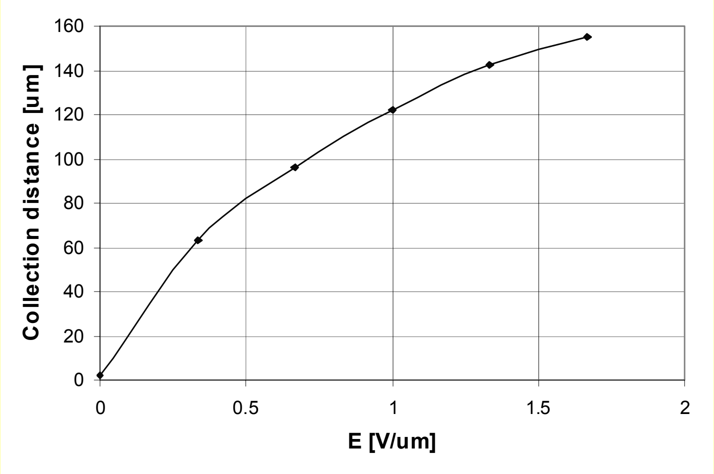
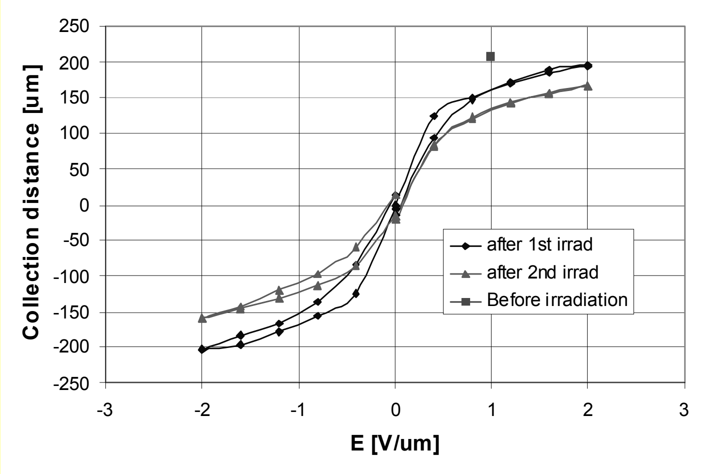
(charge) collection distance: $\delta = \frac{Q_C}{Q_G} \cdot d$, a quality parameter

δ as a function of the electric field for two CVD diamond samples:



300 μm thick CVD, unirradiated



500 μm thick CVD, unirradiated and after 10^{15} and additional 2.8×10^{15} protons/cm^2

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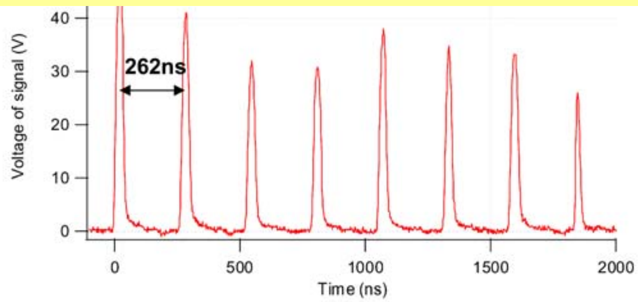
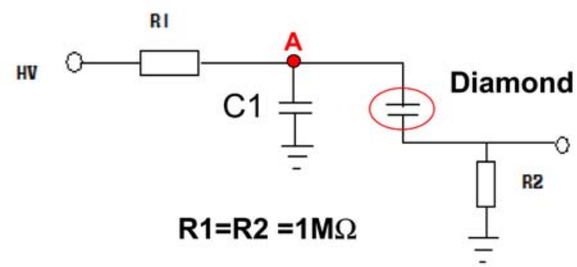
multiple bunches





C1 acts as a reservoir capacitor

=>The larger the value the longer the bias field on the can be maintained.

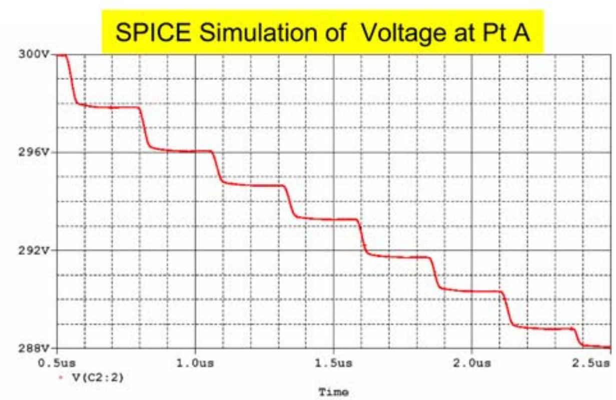
=>Bunch amplitude variation is real

C1(CDS126)=15 nF

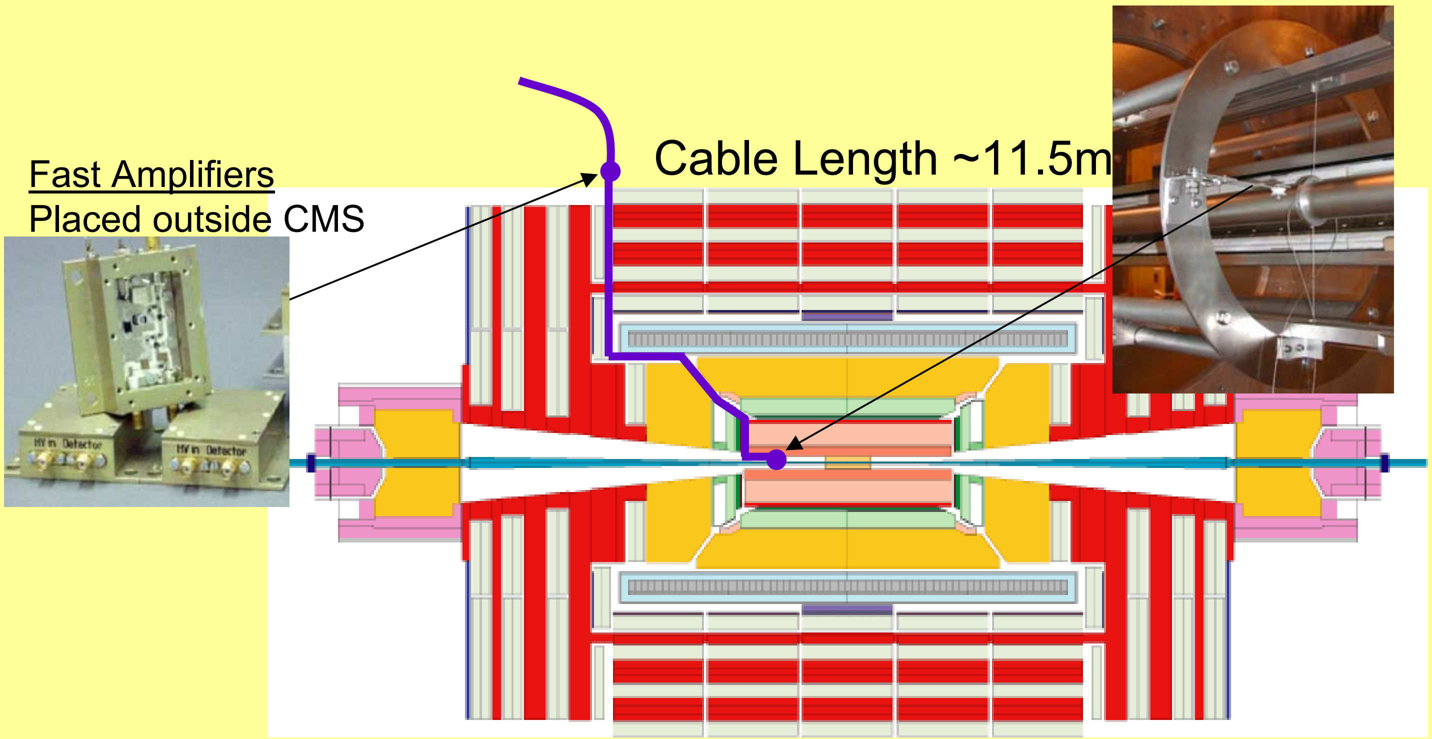
C1 is sufficiently large to maintain bias across the diamond for the 8 bunches.

C1R1 time constant ~15 ms

⇒ recharging of C1 is slow compared to bunch structure



BCM: sensors inside the CMS spectrometer



Radiation monitors: active sensors

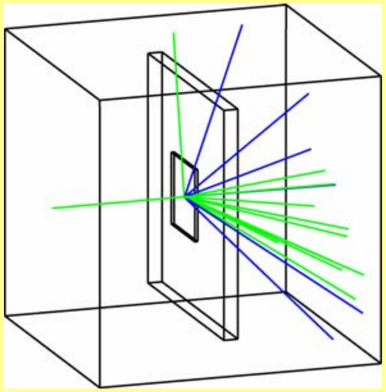
RadFET dosimeters

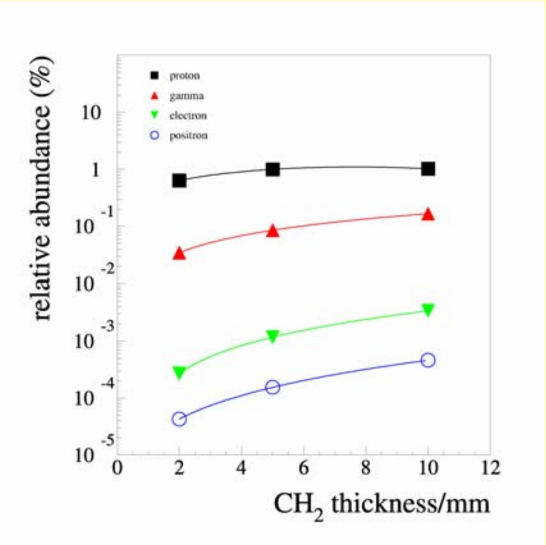
- p-channel MOS transistors used to measure the ionizing dose via a charge build-up in the SiO_2 layer of the device.
- growth of the transistor threshold voltage V_{th} is proportional to the deposited dose when a constant current passes through the device
- integrating dosimeters for long-term measurements

GEANT4 simulation:

polyethylene sensor housing influences the detector response

agrees with simulation results

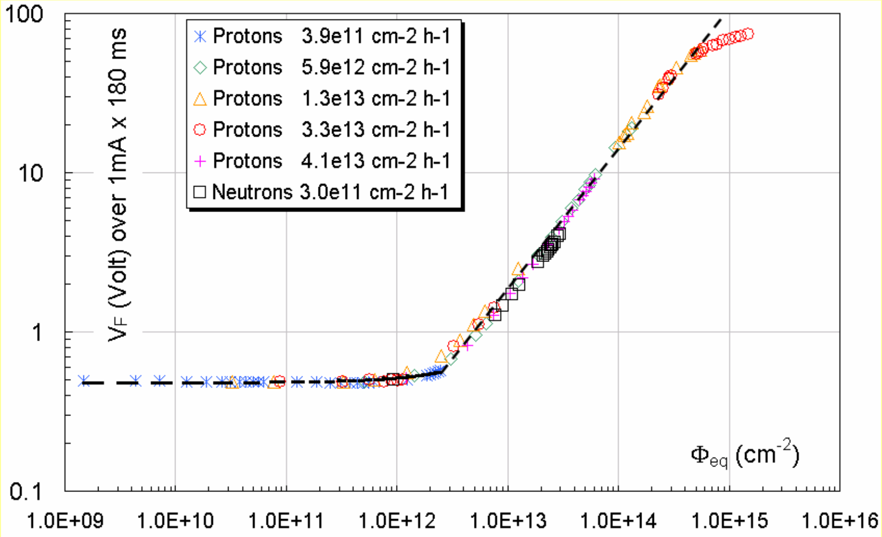




Radiation monitors: active sensors

p-i-n diodes

Radiation causes displacement damage in the bulk silicon material, as well as macroscopic effects, like an increase in Si resistivity and leakage current, both proportional to the received particle fluence



Irradiation response of the OSRAM BPW34F diodes that were tested in forward bias operation applying a current pulse of 1mA over 180ms for the readout.

Radiation monitors: passive sensors

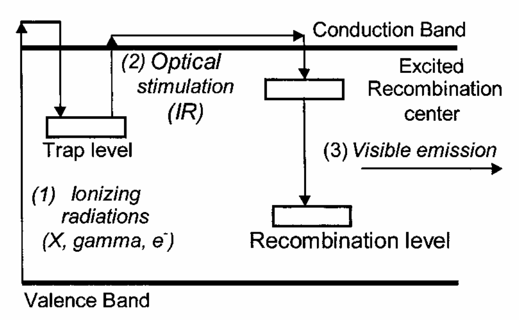
Long-term radiation monitoring, several techniques are available:

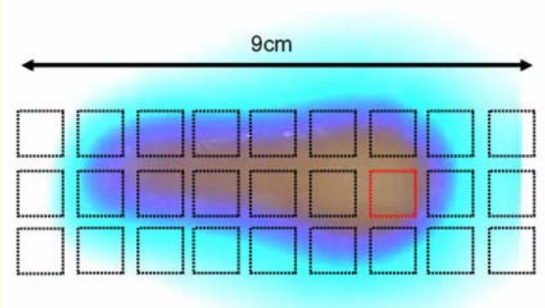
- polymer-alanine (PAD)
- TLD (thermoluminescence dosimeter)
- radio-photo luminescent (RPL) dosimeters

→ formation of stable free radicals (PAD) or color centers (RPL) after irradiation. For readout, they have to be removed. The necessary readout instrumentation and know-how is already in use at CERN (SC/RP department).

- OSL: optically stimulated luminescence: used in BCM test beam

development of an automatic readout system in progress





BCM test beam data (M. Glaser, F. Ravotti)

Conclusion

CVD diamond

is a promising candidate for an LHC beam-condition monitor, capable of withstanding the radiation doses and particle fluence rates such a system will have to deal with.

Its response is sufficiently fast to react on a bunch-by-bunch basis.

A variety of active and passive radiation sensors

is being investigated in collaboration with PH/TA1, in view of the complicated radiation environment in the LHC experimental caverns.