On line radiation monitoring in the LHC machine with COTS ICs and RADFETs

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Outline

- Introduction
  - Radiation Effects
  - Radiation Monitoring
  - Limitations
  - Summary
- LHC Radiation levels
- RADMON
- Radiation monitoring board

Introduction

The most radiation sensitive elements in the LHC tunnel are superconducting coils and electronic equipment :

- ➔ Common points:
  - Large scale installations
  - Reliable operation required
  - Risk of radiation induced damage significant
  - Repairs may be costly ($ and downtime)
- ➔ Protection from radiation
  - Lowest level (at damage level)
    - QPS for magnets - Radtol design for electronics/experiments
  - Higher level (monitoring)
    - BLM for magnets – RADMON for electronics/experiments

Radiation - What are we interested in ?

- ➔ Effects of radiation on superconducting coils and electronic equipment
- ➔ At this moment we concentrate on :
  - Radiation effects in Si :
    - Ionisation
    - Atomic displacement
  - Radiation effects in sc coil :
    - Ionisation
    - Heating

Standard approach

- ➔ Choose appropriate parameterization of the radiation spectrum
  - Ionisation : dose, hadron fluence
  - Atomic displacement : 1 MeV neutron fluence
- ➔ Measure these parameters with a radiation monitor
  - For radiation effects in Si, it is best to measure radiation in a silicon detector
  - For radiation effects in a sc coil, it is best to measure radiation effects in a sc coil

  For example : For a specific radiation spectrum, the dose rate in air, silicon, plastic, diamond will not be the same because of the Z/A dependence of dE/dx in the Bethe-Bloch formula.
- ➔ Associate an appropriate action
  - Correct the orbit, tune
  - Dump the beam (machine, experiments)
  - Increase EDAC frequency
  - Replace components before permanent failure

Ex : Radiation monitoring in a sc coil

- Measure excess of quasi particles.
  - Equip the detectors for the 600A corrector circuits with a dedicated current sensor which is sensitive enough - convert the current into a proportional voltage which is evaluated numerically by the DSP based detector board.
  - Technique not (yet) available for LHC magnets (but could be envisaged for a single magnet during the sector test with beam in 2006)
- Measure change in resistance
  - Measure the I-V characteristics of a superconducting device operated at the transition temperature
  - Technique presently used by QPS (only reliable method, accounts for all effects)
- Measure ionization in air at a given distance
  - Radiation induced current in ionization chamber ~proportional to nbr of protons lost
  - Technique presently used by BLM system

Acknowledgements : R. Denz AT-MEL

Limitations

The radiation induced heat load in a superconducting coil will be most probably the main cause for magnet quenches in LHC but :

- ➔ Measurement of heat load
  - – does not give you any information when a quench will exactly occur, it will only give an indication that there might be a quench in the near future.
  - – probability to quench may also depend on, for example, the heat load distribution, the beam loss scenario, type of magnet, cryogenic assembly, …
- ➔ Measurement of resistance
  - – variance may be caused by other effects (not related to radiation and maybe not even measured)
- ➔ Measurement of ionization in air at a given distance from the coil
  - – not straightforward to deduce the heat induced in the coil [†]
  - – sensitivity, spatial resolution ?

[†] J.B Jeanneret *et al* CERN-LHC-Project-Report-44 May 1996

Ex : Radiation Monitoring for electronics

- Measure e-h pairs created
  - Measure the voltage spike induced in Si by a Minimum Ionizing Particle
  - Technique used in all LHC experiments, DESY, FNAL …
- Measure cumulative trapped charge
  - Measure the variation of the resistance in a transistor
  - Technique used for space applications (satellites)
- Measure cumulative amount of recombination (Shockley-Hall)
  - Measure the I-V characteristics of a PIN (neutron) diode
  - Technique used in nuclear industry

Limitations

- Measure the voltage spike induced in Si
  - Macroscopic effects on a complex ICs difficult to predict
  - Cannot separate between various types of particles
  - Biasing of detector determines sensitivity
- Measurement of dose
  - TID Effects also depends on particle type, energy
  - Dose rate dependence (ELDRs)
- Measurement of 1 MeV eq. neutron fluence
  - NIEL scaling not always correct

Summary on introduction part

- ➔ SC magnets and electronic are the most radiation sensitive elements in the LHC tunnel and radiation monitoring is therefore justified
- ➔ Radiation Monitoring (circulating beam) via QPS, BLMs and Si Detectors seems to be a reasonable solution
- ➔ We may not be able to explain all observed radiation induced damage effects from the monitor data
- ➔ To get a better understanding we need to combine/compare data from all other systems that can measure radiation effects

Reminder : *After 6 years radiation testing in the TCC2 target hall we can now monitor dose and particle fluxes on line but we have :*

- Many types of dosimeters : PMIs (3 different types), RPL, Alanine, TLD and many Si dosimeters (RADFETs, PIN diodes, SRAM memories etc etc)
- Two complete FLUKA MC simulations (one including the primary target)
- Stable physics operations conditions (i.e. NA48 in physics mode)

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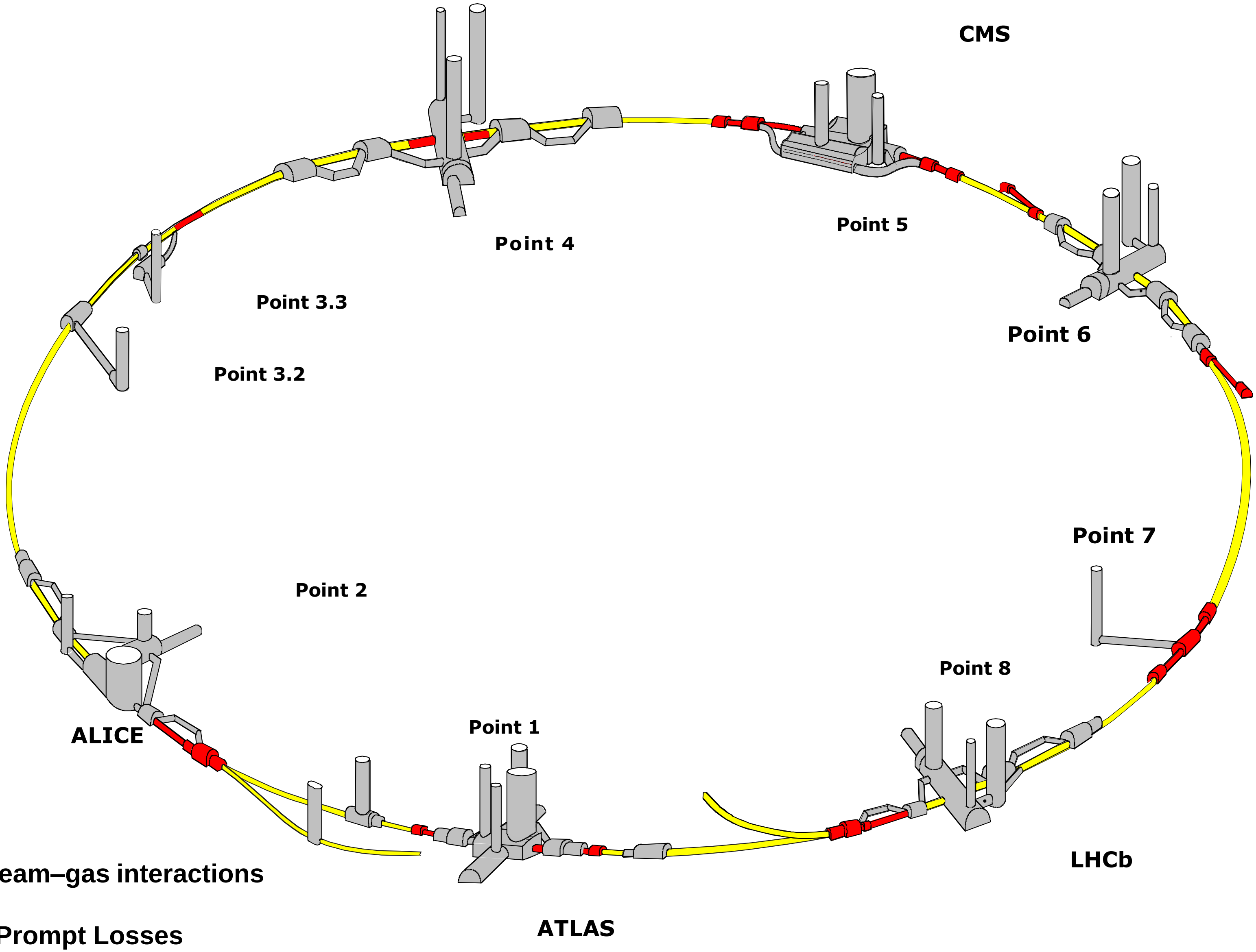
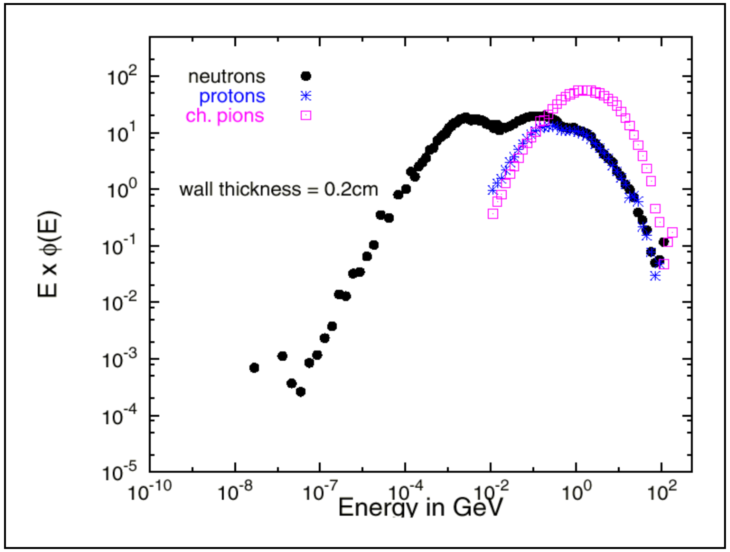
LHC radiation map

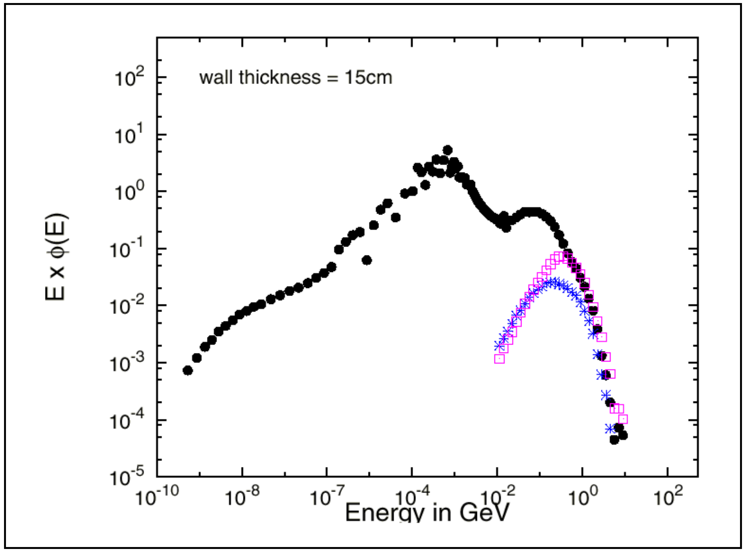


🟨 **Beam–gas interactions**

🟥 **Prompt Losses**

Complex radiation spectra





- Hadronic shower – various types of particles at different energies
- Shielding by cryostat, shielding blocks have an influence on spectra
- Rule of the thumb :
  - “hard” spectra close to the IPs, “soft” spectra in the ARCs
  - radiation levels in Inner triplet ~10 times higher compared to ARC
- Neutrons are our biggest concern

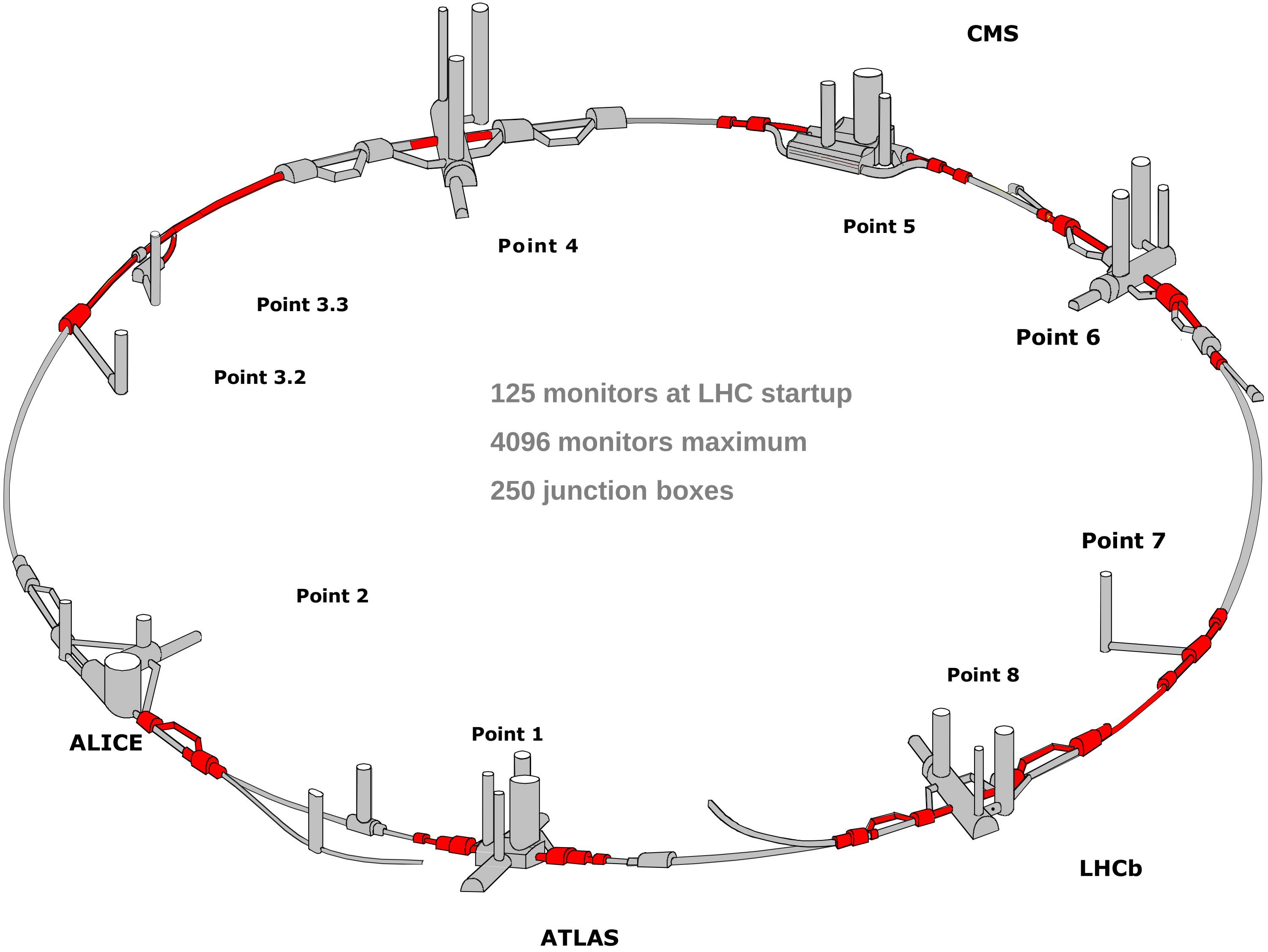
Simulated Annual Radiation Levels

Location	Total Dose [Gy]	Hadron fluence E>20 MeV	1 MeV eq. neutron fluence	Source	Shielding
ARC	10	4×10^{10}	5×10^{11}	Beam gas interactions	no
DS 1,5	100	1×10^{11}	1×10^{12}	Point Losses	no
RR 77, 73	?	?	?	Collimators Pt 7	maybe
RR 13, 17	0.2	1×10^{8}	4×10^{8}	Collisions ATLAS	yes
RR 53, 57	0.2	7×10^{7}	3×10^{8}	Collisions CMS	yes
DS 3	10	8×10^{9}	8×10^{10}	Collimators Pt 3	maybe
UJ 14,16	2	?	?	Collisions ATLAS	foreseen

Radiation Monitors – why ?

- Monitor degradation of electronics due to radiation when beam “on”
- Confirm any instantaneous failures that are caused by radiation (SEEs) instead of by normal MTBF
- Be able to propose the correct radiation tolerant components in case of radiation induced failures
- Be able to test upgraded electronics designs at the correct radiation levels before installation in the machine
- Anticipate replacement of electronics that degraded due to cumulative radiation damage effects
- Cross check FLUKA/MARS/GEANT4 simulation results
  - Dynamic pressure in ARCs in coast, after quench, …
  - Radiation flash, collimation, radiation from collisions in RRs, …
- Measure shielding efficiency – confirm staged implementation

Radiation Monitors – where ?

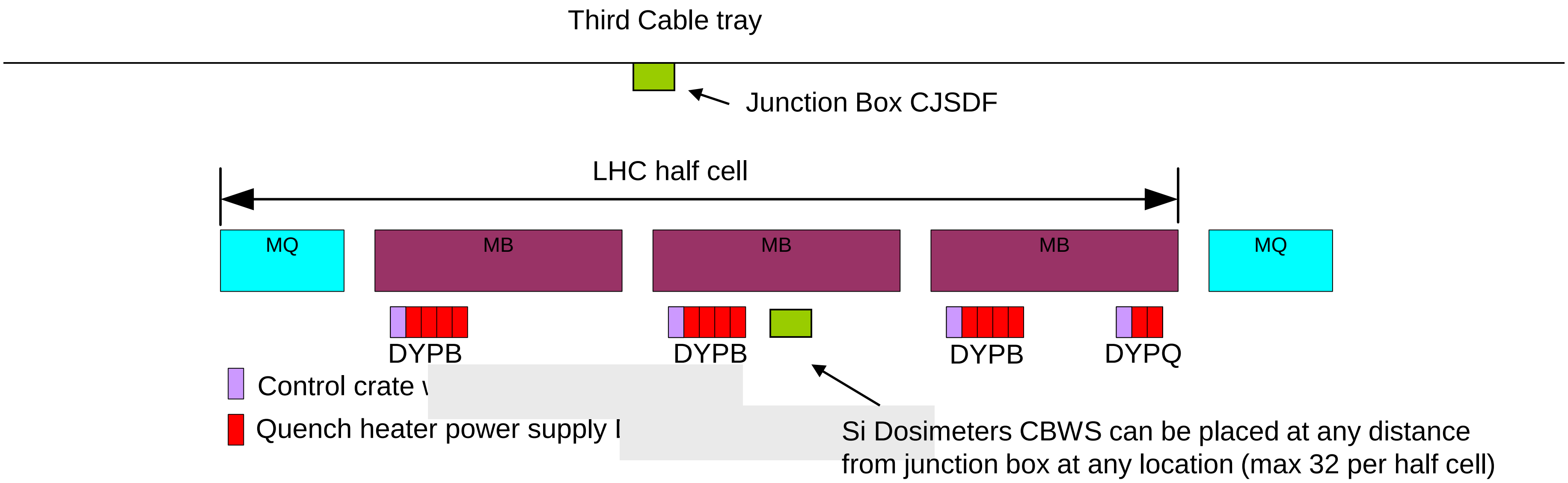


125 monitors at LHC startup

4096 monitors maximum

250 junction boxes

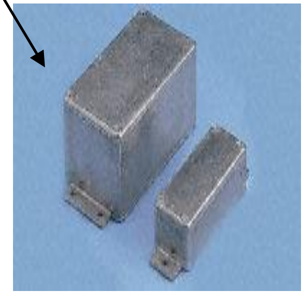
Location of Junction box and dosimeters



🟪 Control crate v

🟥 Quench heater power supply I

Si Dosimeters CBWS can be placed at any distance from junction box at any location (max 32 per half cell)



CBWS Version 3.0

Aluminum casing with cover and sides partially removed

Size : 11 x 9 x 5 cm

(i.e medium sized cigar box)

Radiation data provided

- ➔ Total Ionising Dose in Si [Gy]
- ➔ 1 MeV equivalent neutron flux [$cm^{-2}\ s^{-1}$]
- ➔ Hadron flux (E>20 MeV) [$cm^{-2}\ s^{-1}$]
- ➔ Estimated Inaccuracies
  - TID : 15 % , 1 MeV eq. neutron flux : 15 % , hadron flux : 10 %
- ➔ Estimated Dynamics
  - TID : 0.1 Gy/s, 1 MeV eq. neutron flux : 1E6 $cm^{-2}\ s^{-1}$, hadron flux : 1E8 cm-2 s-1

Radiation Monitoring – How ?

- RADFET
  - Direct measurement : trapped charge in gate oxide
  - I-V change proportional to TID
- SIEMENS BPW34
  - Direct measurement : conductivity variation at high forward injection
  - I-V change proportional to 1 MeV eq.
- Toshiba TC554001AF
  - Direct measurement : radiation induced voltage spike over a reversed biased p-n junction
  - Number of “bit flips” in SRAM direct proportional to the hadron fluence (E> 20 MeV)

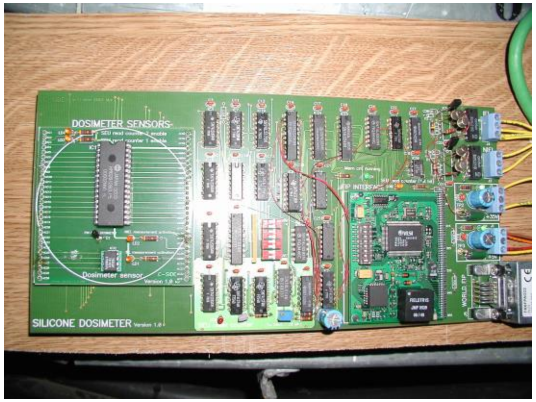
T&N RADFET 0.25 um

SIEMENS BPW34

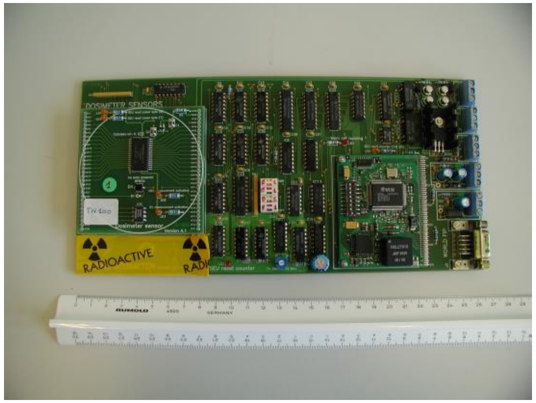
TOSHIBA TC554001AF-70L

Radiation Monitoring – readout boards

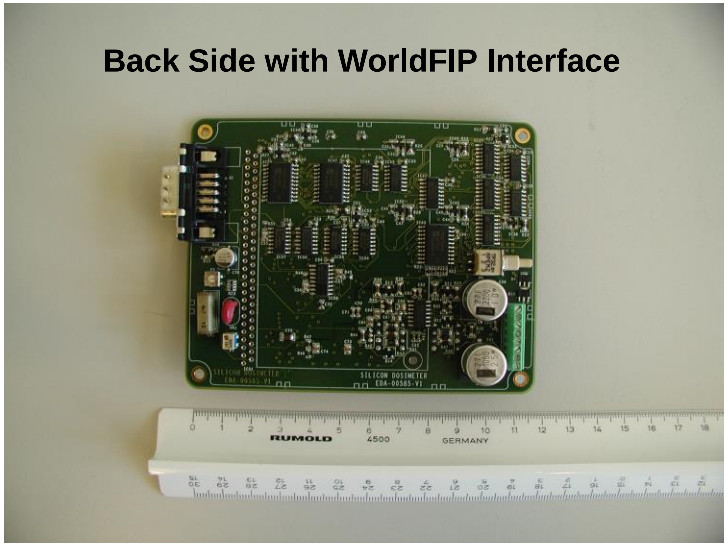
Si Dosimeter V1 – July 2002



Si Dosimeter V2.1 – August 2003

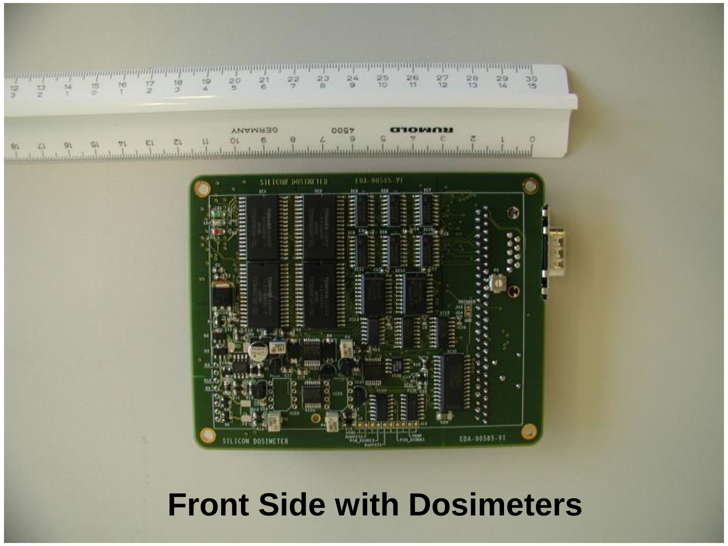


Si Dosimeter V2.2 – September 2003



Back Side with WorldFIP Interface

Si Dosimeter V3.0 – April 2004



Front Side with Dosimeters

Si Dosimeter V3.0 – April 2004

Radiation board

- Mandatory when you use the RADFET and PIN diodes in the LHC machine
- Design heavily based on experience/advice from RADWG members and RADECS community (Precision Voltmeter QPS - R. Denz, ELMB – B. Hallgren, RADFIP – M. A. Rodriguez, Low Beta Jacks – A. Marin, Radiation Effects Unit ESTEC - ESA)
- Key design issues: radiation tolerance, current source, temperature compensation
- Prototype readout board V2 was meant as a “proof of principle”
  - Readout design validated during 2003 SPS proton run
  - Used for calibration test dosimeter I.e.

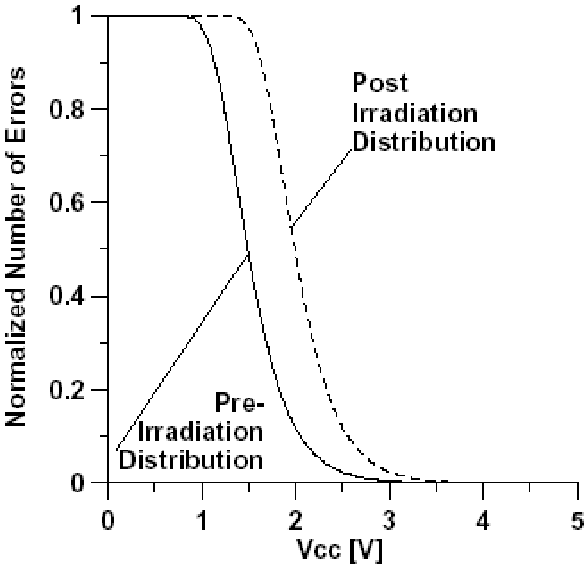
    60 MeV protons, 60 Cobalt, 0.8 MeV neutrons for resp. SEE, TID and NIEL
- Readout board V3 is meant for final test and pre-series production
  - Readout design validated again during 2004 SPS proton run
  - Will be used for final calibration test of dosimeters

Summary and conclusions

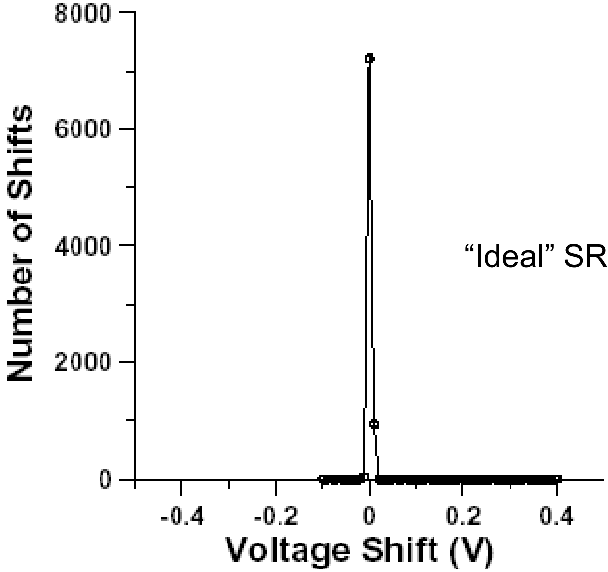
- ➔ Radiation induced effects will have an influence on LHC operation
- ➔ On line signals from QPS – BLMs – RADMONs will probably need to be combined in order to understand “cause and effect” of a lost beam
- ➔ Radiation data from any other equipment will be very useful (nbr of resets, SEU counts in memory, results from passive dosimeters, darkening of fibers …)
- ➔ Design RADMON readout board well advanced
- ➔ Real validation will be in July 2006 …

SRAM – Common features

- SEU X-section varies according to bias applied
- Total dose effects
  - Interface trapping is dominant effect (not in gate oxides)
  - Causes difference between X-section for “0” to “1” and “1” to “0”
  - TID effects on 2 N-channel access transistors modifies SEU x-section



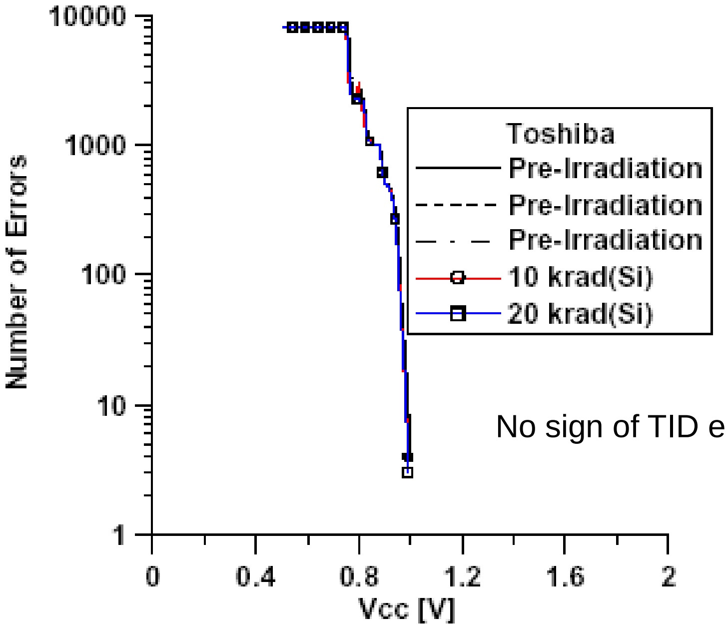
L. Scheick, G. Swift, NSREC 2002



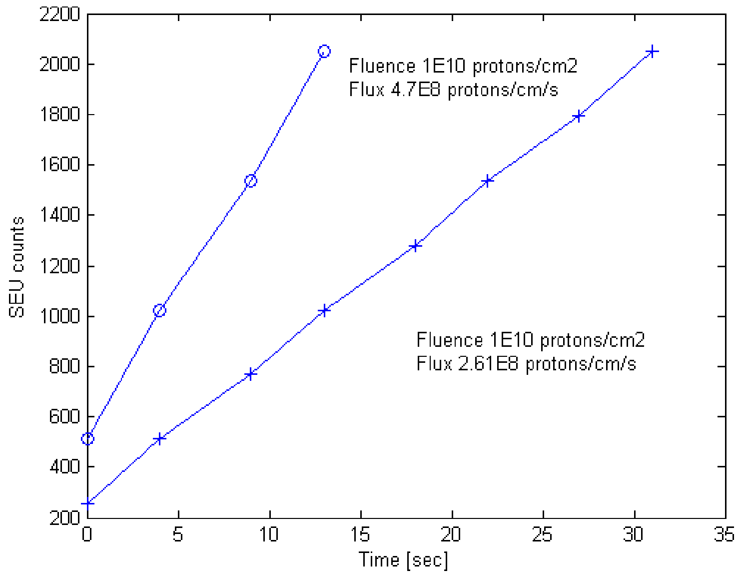
“Ideal” SRAM Dosimeter

Toshiba TC554001AF

- 524.288 words x 8 bits static RAM
- CMOS, 32 pin, 2.7 up to 5.5 Volts
- 99 % of cells report an error within 0.01 volt



No sign of TID effects



SEU cross section 60 MeV protons

L. Scheick, G. Swift, NSREC 2002