The ATLAS Radiation Dose Measurement System and its Extension to SLHC Experiments

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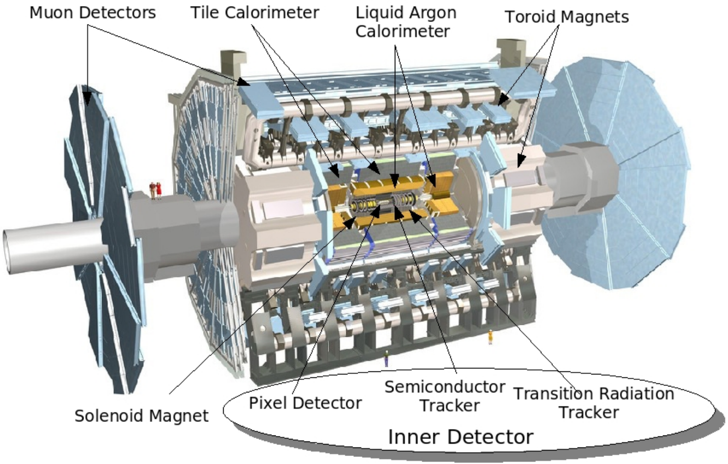
The ATLAS Experiment

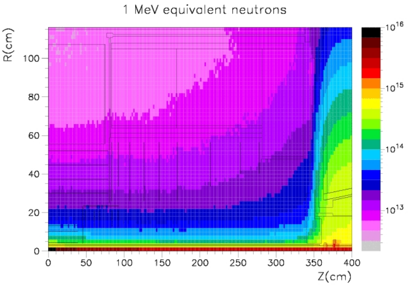
Proton-proton collisisions at $\sqrt{s} = 14\,\text{TeV}$ and $\mathcal{L} = 10^{34}\text{cm}^{-2}\text{s}^{-1}$



Radiation Field in ATLAS

- Exposure of electronics to:
  - radiation from pp-collisions (mainly pions)
  - neutrons from interactions of hadrons with detector material
- After 10 years of LHC operation electronics irradiated up to:
  - Total Ionizing Dose: $\mathrm{TID} > 100\,\mathrm{kGy}$
  - Non Ionizing Energy Loss $\Phi_{eq} > 10^{15}\ 1\,\mathrm{MeVn/cm^{-2}}$
- Monitoring of radiation levels needed in order to:
  - cross check simulations
  - understand change in detector performance
  - and as independent measurement

Non Ionising Energy Loss in the ATLAS Inner Detector



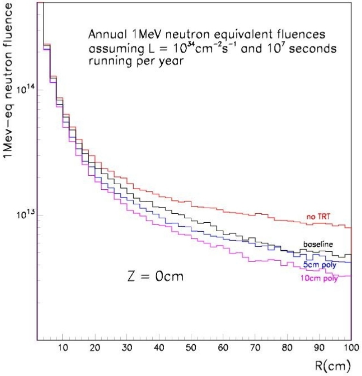
FLUKA simulation by Ian Dawson

Radiation Field at SLHC

- Luminosity: $\mathcal{L}(\text{SLHC}) \approx 10 \times \mathcal{L}(\text{LHC})$
- Ionizing dose scales with luminosity:

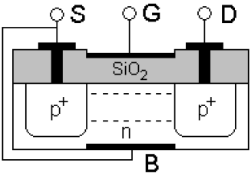
  $\mathrm{TID(SLHC)} \approx 10 \times \mathrm{TID(LHC)}$
- Upgrade of ATLAS tracker to full silicon
  $\rightarrow$ loss of moderating effect of the Transition Radiation Tracker
  $\rightarrow$ NIEL not expected to scale with luminosity
  $\rightarrow$ as compensation introduce a 5 cm thick moderator

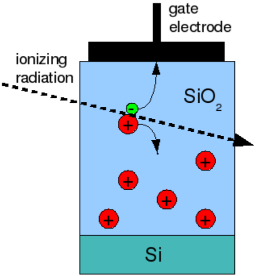
Non Ionising Energy Loss at the SLHC



Ian Dawson

Total Ionizing Dose (TID) Measurement - RadFETs





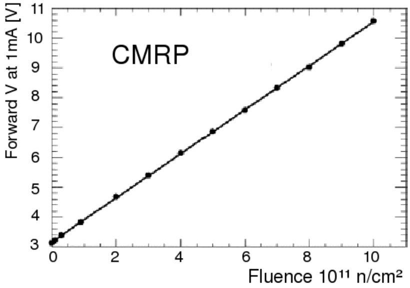
- RadFET: Radiation Field Effect Transistor
- Electrons escape, holes are trapped in SiO_2-Si boundary.
- Higher negative gate voltage needed to open transitor.
- Measure gate voltage increase at given drain current. $\Delta V = a \times (TID)^b$
- Sensitivity depends on oxide thickness
- Three RadFETs used in ATLAS to cover large range of doses:
    - 0.001 Gy to 10 Gy: 1.6 μm from CNRS LAAS, Toulouse, France
    - up to 10^4 Gy: 0.25 μm from REM, Oxford, UK
    - up to 10^5 Gy: 0.13 μm from REM, Oxord, UK

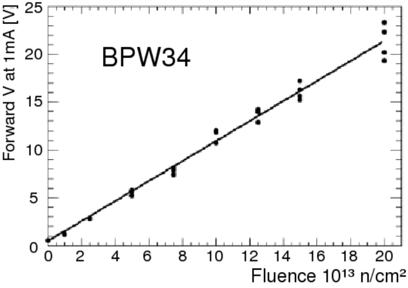
Non Ionising Energy Loss (NIEL) Measurement (1)

First Method: Bulk damage in silicon
→ Increase of voltage at given current in forward biased pin diodes is proportional to the 1 MeV neutron equivalent fluence:

$$\Phi_{eq} = k \times (V - V_0)$$

1. 10^8 to 10^{12} n/cm^2: CMRP from University of Wollongong, Australia
2. 10^{12} to 10^{15} n/cm^2: OSRAM BPW34 Silicon PIN photodiode





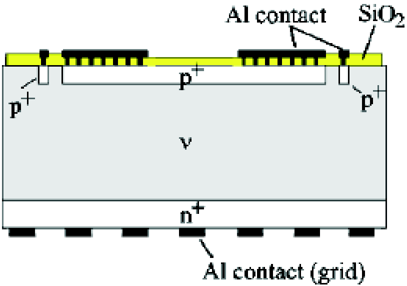
Non Ionising Energy Loss (NIEL) Measurement (2)

Second Method: Bulk damage in silicon

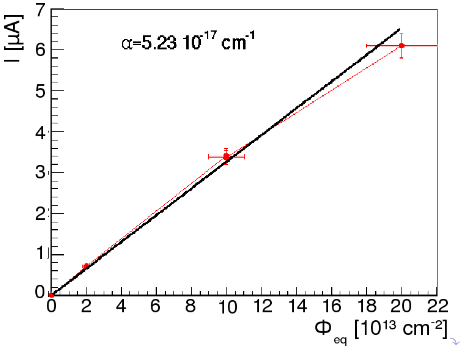
$\rightarrow$ Increase of leakage current (I_{leakage}) in reverse biased diode:

$$\Phi_{eq} = I_{\text{leakage}}/(\alpha V) \qquad \text{(V: Volume)}$$

- 10^{11} to 10^{15} n/cm^2 higher fluences with higher voltage
  - Pad diode with guard ring structure on epitaxial silicon
  - 25 μm thin $\rightarrow$ fully depleted at voltages < 30 V also after irradiation



Federico Ravotti

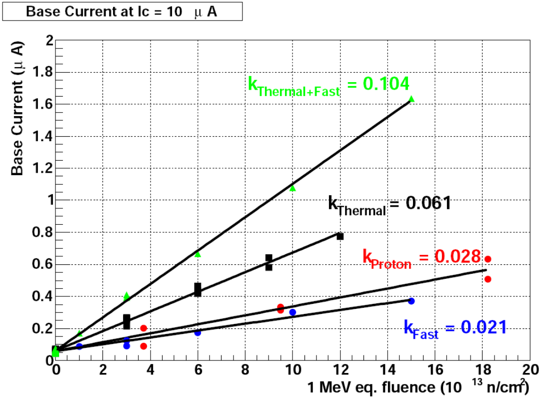


Thermal Neutron Fluence Measurements

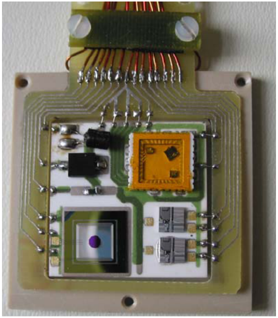
- DMILL transistors are used in readout electronics in parts of the Inner Detector (SCT).
- Base current at fixed collector current sensitive to fast and thermal neutrons:

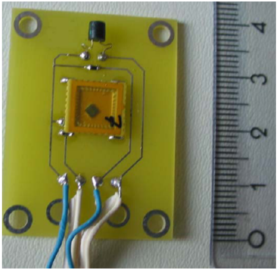
$$\frac{\Delta I_b}{I_c} = k_{eq}\Phi_{eq} + k_{th}\Phi_{th}$$

- k_{eq} and k_{th} known
  Φ_{eq} measured with diodes
  $\rightarrow$ determine Φ_{th}



Radiation Monitoring Sensor Boards

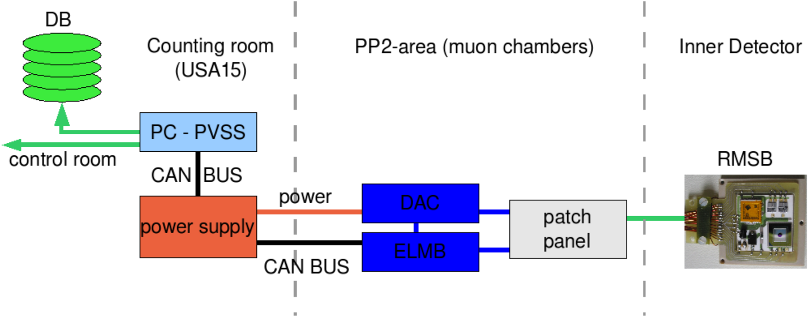




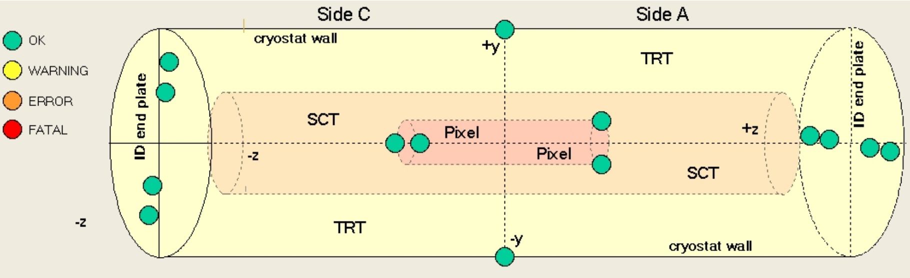
- Inner Detector: 14 Modules that contain:
  - 3 RadFETs for different dose ranges
  - 2 PIN diodes for low and high fluences
  - 1 Epitaxial (large fluence range)
  - 2 DMILL bipolar transistors
  - NTC temperature sensor
  - resistive pad for heating on the back side
- Outside the Inner Detector region: 48 modules
  - 1 high sensitivity PIN diode (CMRP)
  - 1 RadFET
  - NTC temperature sensor

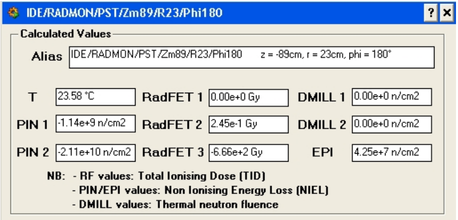
Readout

- Usage of standard ATLAS components for straight forward integration:
  - ELMB: 64 adc channels, CAN bus communication
  - ELMB-DAC: current source, 16 channels
- Sensors are only biased during readout
- PVSS based detector control system (DCS)
- Integration in ATLAS DCS and data base archiving



PVSS Online Monitoring



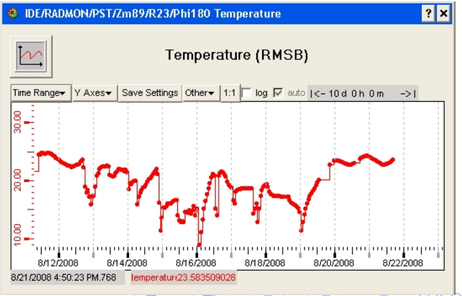

IDE/RADMON/PST/Zm89/R23/Phi180

Calculated Values

Alias: IDE/RADMON/PST/Zm89/R23/Phi180 z = -89cm, r = 23cm, phi = 180°

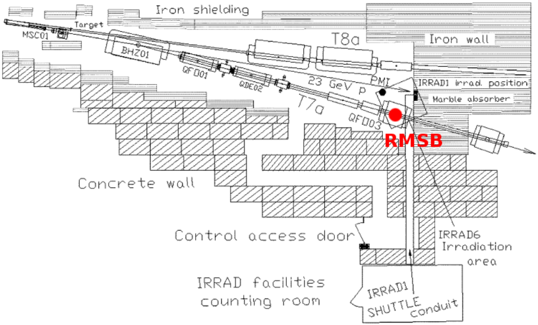
T	23.58 °C	RadFET 1	0.00e+0 Gy	DMILL 1	0.00e+0 n/cm2
PIN 1	-1.14e+9 n/cm2	RadFET 2	2.45e-1 Gy	DMILL 2	0.00e+0 n/cm2
PIN 2	-2.11e+10 n/cm2	RadFET 3	-6.66e+2 Gy	EPI	4.25e+7 n/cm2

NB: - RF values: Total Ionising Dose (TID)
- PIN/EPI values: Non Ionising Energy Loss (NIEL)
- DMILL values: Thermal neutron fluence



Tests in Mixed Radiation Environment at CERN PS

- Mixed high energy particles in IRRAD6 environment at CERN PS.
- Two modules (Inner Detector style) are irradiated since mid May.
- Test of readout setup/procedure and calibration constants.



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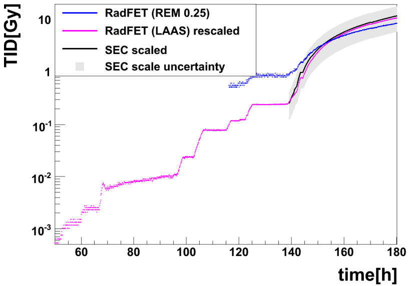
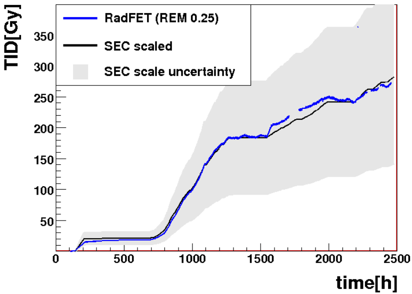
RadFETs in Mixed Radiation Environment

High sensitivity RadFET (LAAS 1.6 μm)

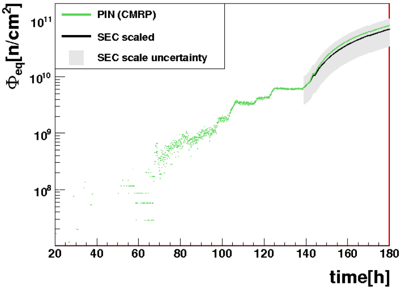


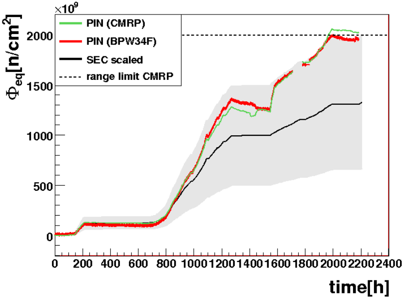
Medium sensitivity RadFET (REM 0.25 μm)



- Secondary Emission Counter (SEC) counts number of protons
  - conversion factors to TID and NIEL from previous measurements
  - not useful for very small doses (unstable beam conditions)
- reduced response of LAAS in proton rich environment $\rightarrow$ recalibration

PIN diodes in Mixed Radiation Environment

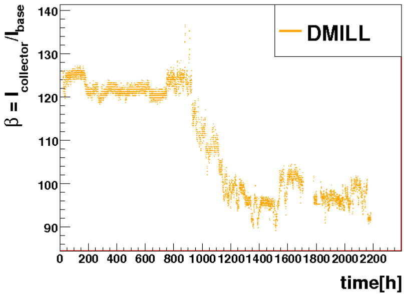




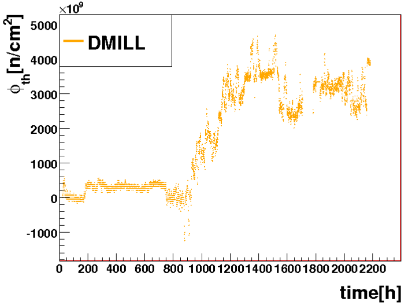
- CMRP PIN diode also sensitive to low fluences (10^9 1 MeV neq/cm^2).
- Good agreement between PIN diodes (20 % uncertainty).
- CMRP "saturated" at 2×10^{12} 1 MeV neq/cm^2

DMILL Transistors in Mixed Radiation Environment

$$\beta = \frac{\text{collector current}}{\text{base current}}$$



thermal neutron fluence



- Directly measure degradation of DMILL transistor performance.
- Determine neutron fluence (using Φ_{eq} from PIN diode as input).

Summary

- Radiation monitoring important - especially at the start of operation
  - to cross check simulations
  - determine the correlation between dose levels and luminosity (SLHC)
  - monitor electronics performance changes - particularly in the inner detector
- The system in ATLAS allows online monitoring of radiation levels:
  - TID in SiO_2 from cGy up to 100 kGy
  - NIEL in Si from $10^8\,\mathrm{neq/cm^{-2}}$ up to $10^{15}\,\mathrm{neq/cm^{-2}}$
  - thermal neutron fluence and degradation of DMILL bipolar transistors
- Integration in ATLAS Detector Control System
- Test and optimization in mixed radiation field at low dose rates