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

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Proton-proton collisions at $\sqrt{s} = 14$ TeV and $\mathcal{L} = 10^{34}$ cm$^{-2}$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: TID > 100 kGy
  - Non Ionizing Energy Loss: $\Phi_{eq} > 10^{15}$ 1 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

1 MeV equivalent neutrons

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: $\text{TID}({\text{SLHC}}) \approx 10 \times \text{TID}({\text{LHC}})$
- Upgrade of ATLAS tracker to full silicon
  - → loss of moderating effect of the Transition Radiation Tracker
  - → NIEL not expected to scale with luminosity
  - → 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 transistor.
- 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 $\mu$m from CNRS LAAS, Toulouse, France
  - up to $10^4$ Gy: 0.25 $\mu$m from REM, Oxford, UK
  - up to $10^5$ Gy: 0.13 $\mu$m from REM, Oxford, 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
Second Method: Bulk damage in silicon

→ Increase of leakage current \( (I_{\text{leakage}}) \) in reverse biased diode:

\[
\Phi_{eq} = \frac{I_{\text{leakage}}}{(\alpha V)} \quad \text{(V: Volume)}
\]

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

Federico Ravotti

\[ \alpha = 5.23 \times 10^{17} \text{ cm}^{-1} \]
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
- \( \Phi_{eq} \) measured with diodes
  → determine \( \Phi_{th} \)
Online Measurement Techniques in Use
Thermal Neutron Fluence

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
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

The ATLAS Radiation Dose Measurement System

Jochen Hartert
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.

F. Ravotti, M. Glaser et. al
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 → recalibration
- 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 $2 \times 10^{12}$ 1 MeV neq/cm$^2$
DMILL Transistors in Mixed Radiation Environment

\[ \beta = \frac{\text{collector current}}{\text{base current}} \]

- Directly measure degradation of DMILL transistor performance.
- Determine neutron fluence (using \( \Phi_{eq} \) 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\textsubscript{2} from cGy up to 100 kGy
  - NIEL in Si from $10^8$ neq/cm\textsuperscript{-2} up to $10^{15}$ neq/cm\textsuperscript{-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