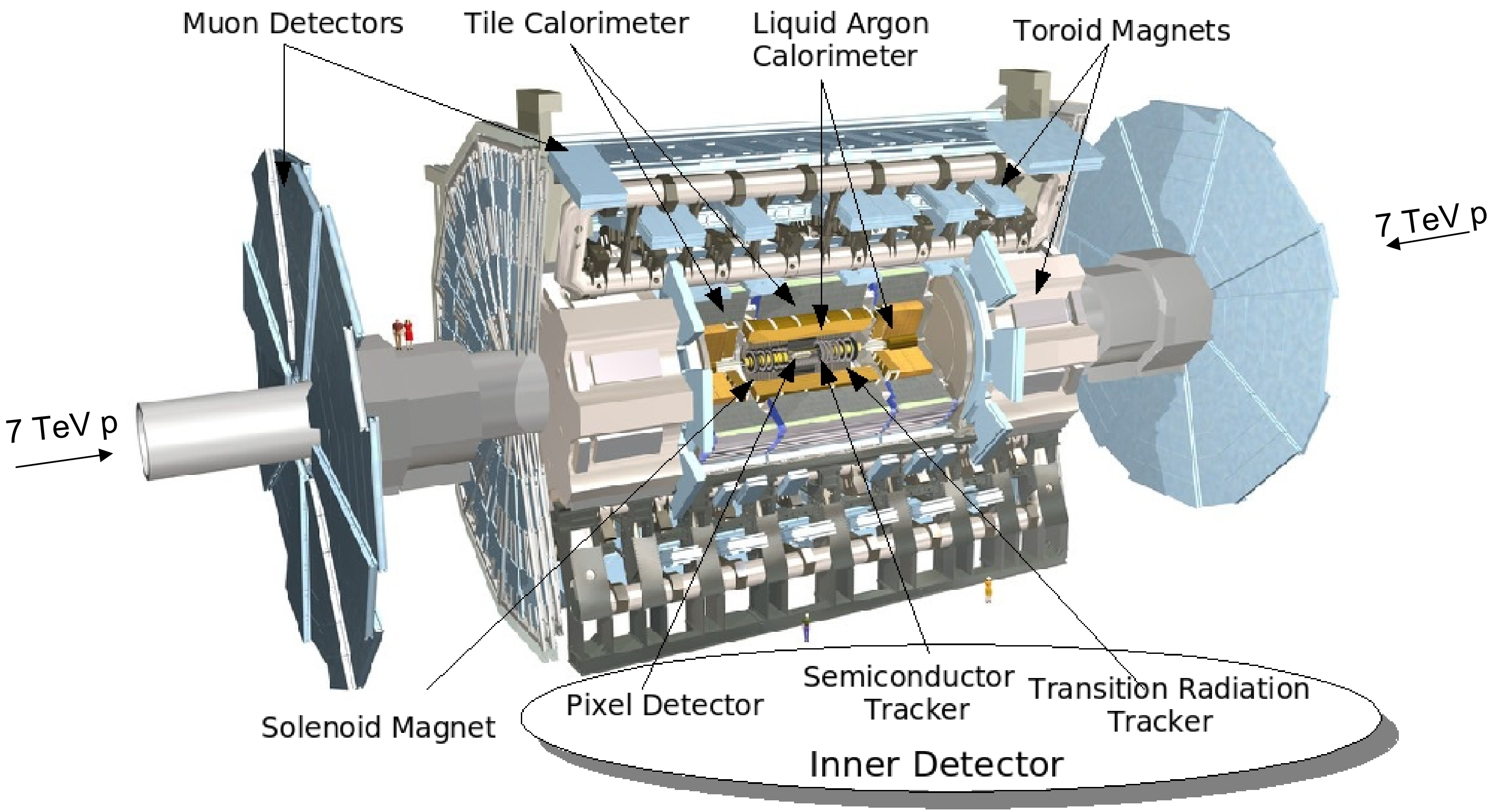
Online Radiation Dose Measurement System for ATLAS experiment

I. Mandić[a], V. Cindro[a], I. Dolenc[a], A. Gorišek[a], G. Kramberger[a], M. Mikuž[a,b],
J. Hartert[c], J. Bronner[c], S. Franz[d]

[a]*Jožef Stefan Institute, Jamova 39, Ljubljana, Slovenia*
[b]*Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, Ljubljana, Slovenia*
[c]*Physikalisches Institut Universität Freiburg, Hermann-Herder-Str. 3, Freiburg, Germany*
[d]*CERN, Geneva, Switzerland*

The ATLAS experiment

- experiment at the Large Hadron Collider at CERN
- proton-proton collisions, E_p = 7 TeV, Luminosity = 10^{34} $cm^{-2}s^{-1}$

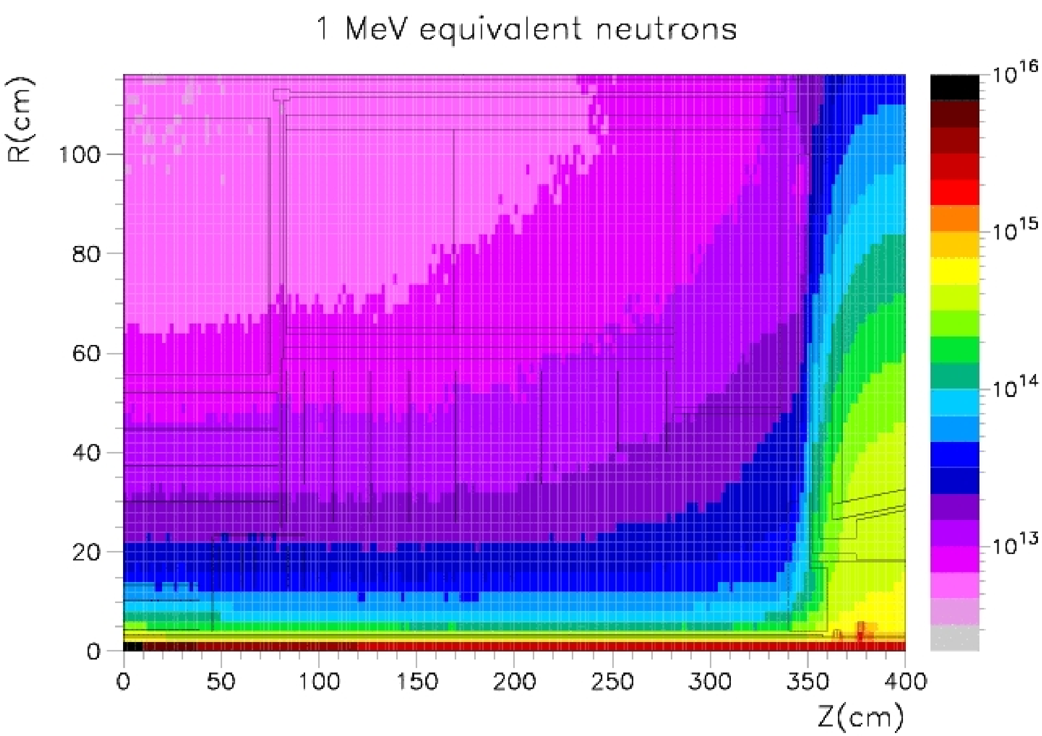


Radiation Field in ATLAS

- secondary particles from p-p interaction point - mostly pions
- radiation from interaction of secondary particles with detector material - neutrons

Radiation levels after 10 years of LHC operation:

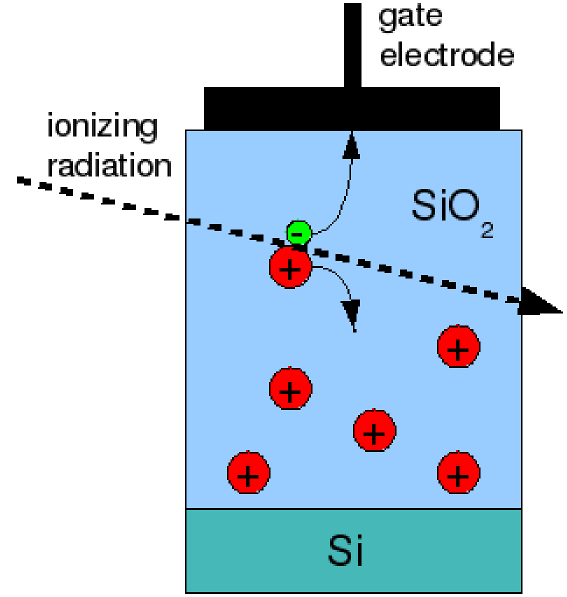
- Total Ionizing Dose (TID): TID > 100 kGy
- Non Ionizing Energy Loss (NIEL): $\Phi_{eq} > 10^{15}$ n/cm^2 (1 MeV equivalent neutrons in Si)
- Thermal neutrons $\Phi \sim 10^{15}$ n/cm^2

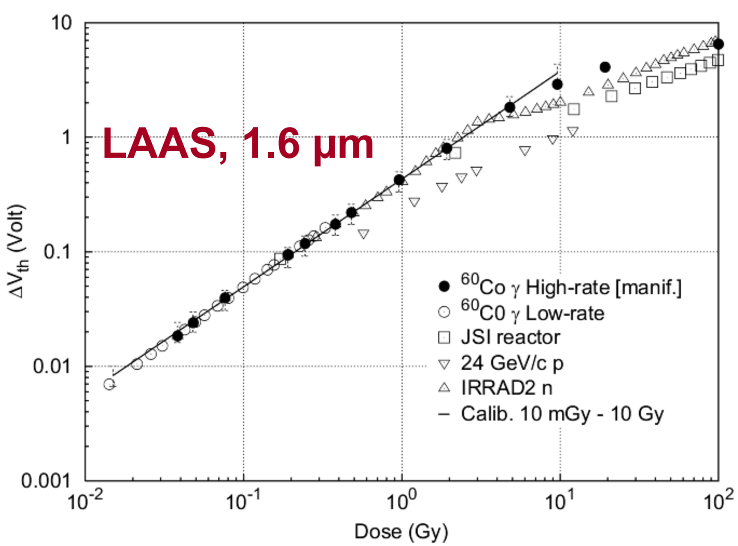


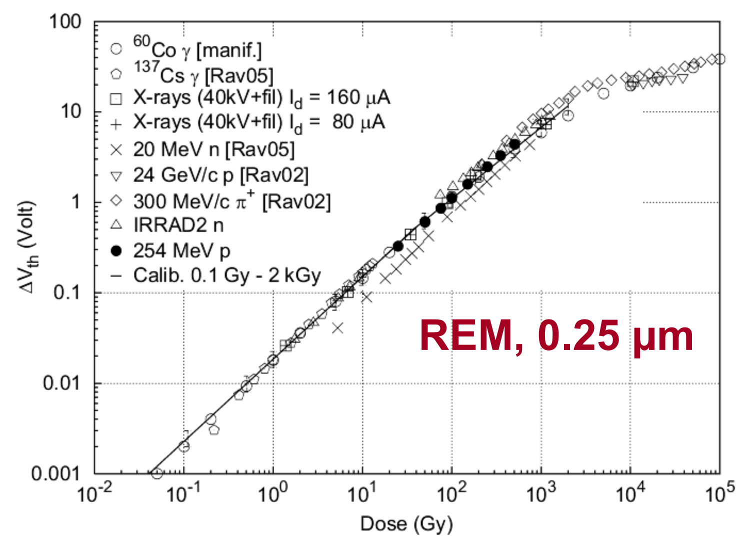
- such radiation levels cause damage to detectors and readout electronics
  - ➔ dose monitoring necessary to understand detector performance
  - ➔ cross check of simulations and make predictions

TID measurements with RadFETs

- RadFETs: p-MOS transistor
- holes created by radiation get traped in the gate oxide:
  ➔ increase of threshold voltage with dose:
  $\Delta V = a \times (TID)^b$
- sensitivity and dynamic range depend on oxide thickness:







- characterizations, selection, calibrations done by CERN RADMON team: F. Ravotti, M. Glaser, M. Moll....

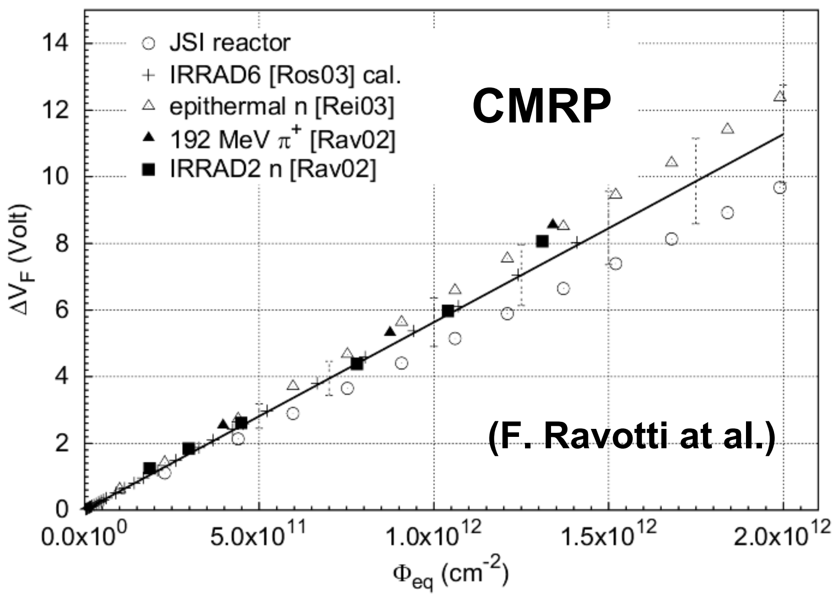
NIEL measurements with diodes

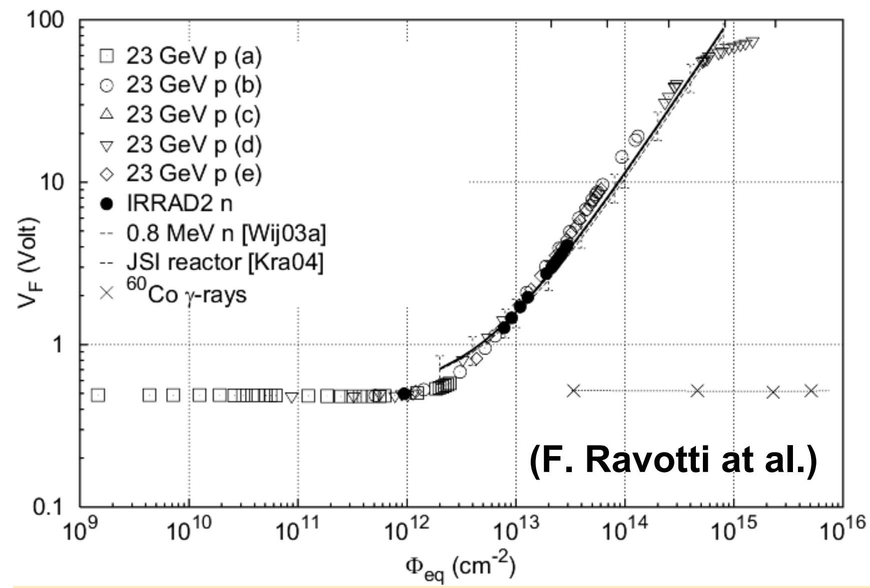
- hadrons cause bulk damage in silicon. Consequences:
  - increased resistance, increase of reverse current.....

➔ forward bias: forward voltage at given forward current increases
➔ reverse bias: increase reverse current

<u>Forward bias</u>

- linear response $\Delta V = k \cdot \Phi_{eq}$ (V measured at I = 1 mA)
- high sensitivity diode (CMRP, University of Wollongong, AU) 10^9 to ~10^{12} n/cm^2,
- commercial silicon PIN photodiode BPW34F 10^{12} to ~10^{15} n/cm^2





➔ sensitivity can be shifted to lower Φ if diode is pre-irradiated with ~ 3 $\cdot 10^{12}$ n/cm^2

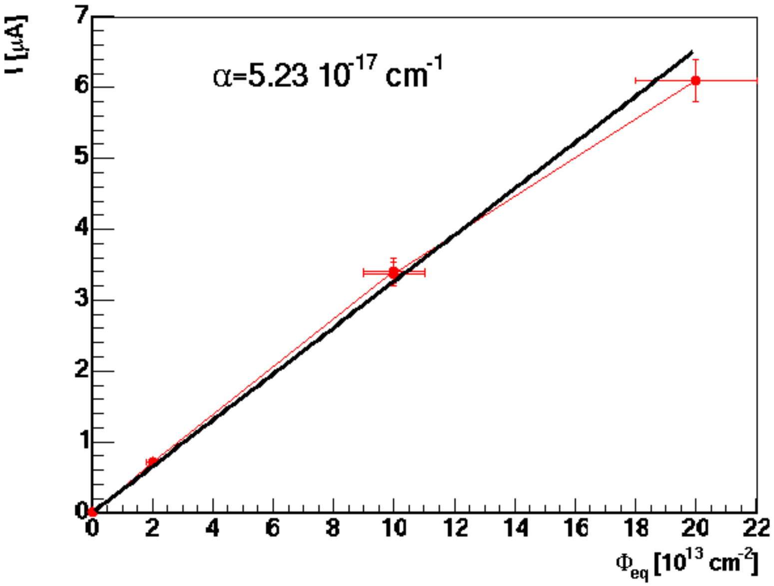
NIEL measurements with diodes

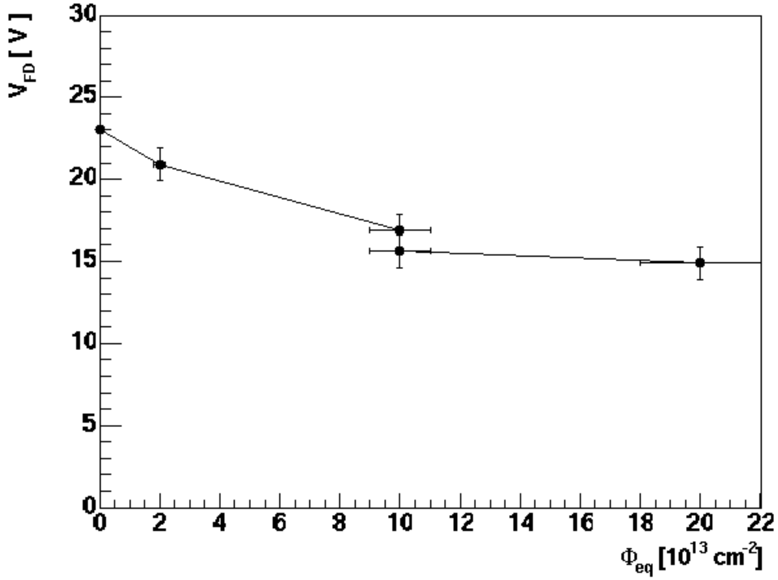
Reverse bias

Reverse current proportional to fluence $I = \Phi_{eq}/\alpha V$

- **25 μm** x 0.5 cm x 0.5 cm pad diode with guard ring structure processed on epitaxial silicon
  - ➔ **thin epitaxial** diode can be depleted with V_{bias} < 30 V also after irradiation with 10^{15} n/cm^2
  - ➔ in this fluence and time range V_{bias} does not increase with annealing

- suitable for fluences from 10^{11} n/cm^2 to 10^{15} n/cm^2





Thermal neutrons

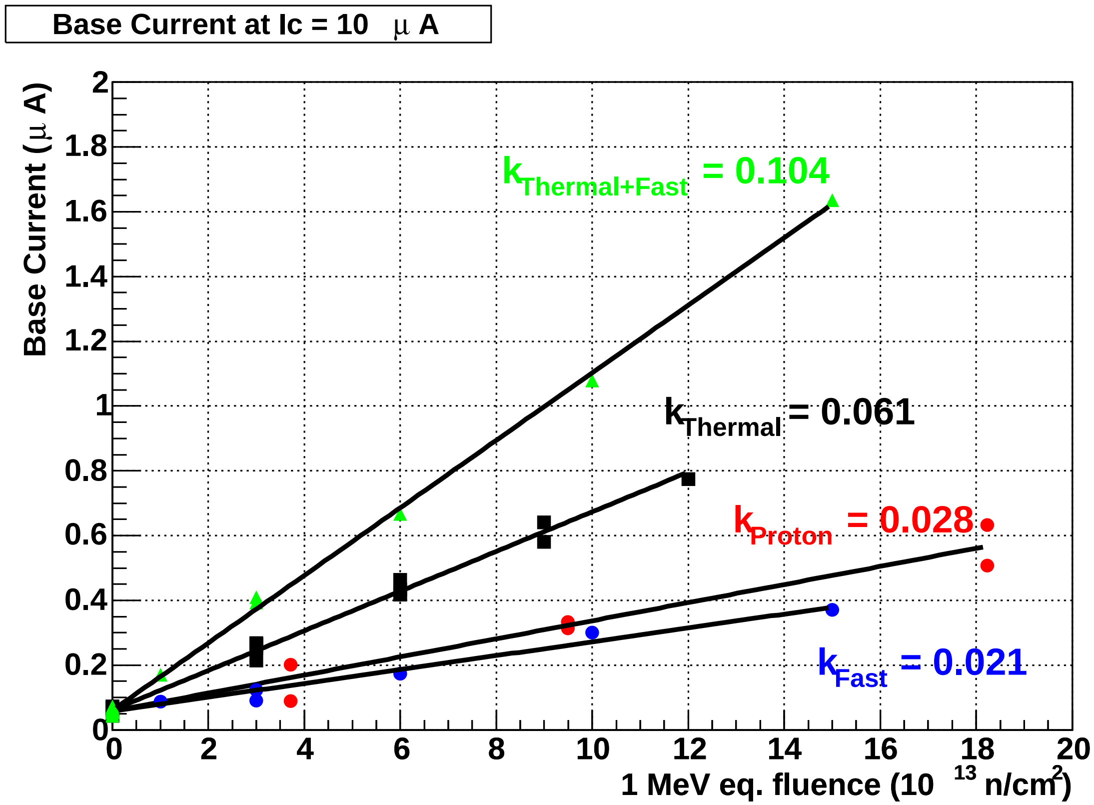
- bipolar transistors (DMILL) used in front end ASICs
- measure base current at given collector current

➔ sensitive to fast and thermal neutrons

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

k_{eq}, k_{th} and Φ_{eq} known

→ Φ_{th} can be determined
(range: ~10^{12} to ~10^{15} n/cm^2)



Radiation Monitor Sensor Board (RMSB)

Inner Detector

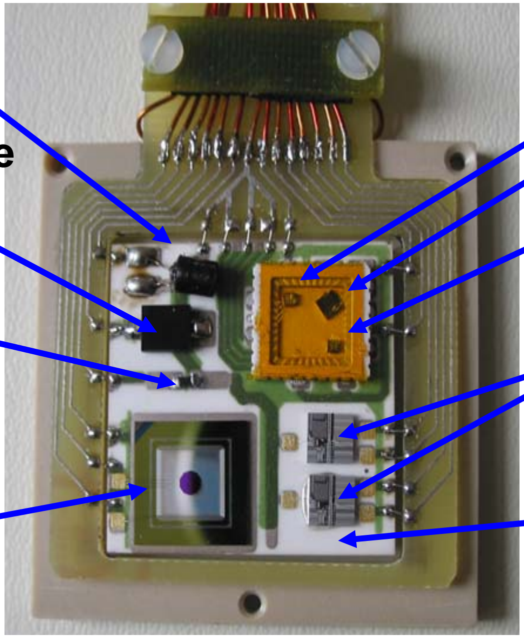
- for dose monitoring in the Inner Detector:

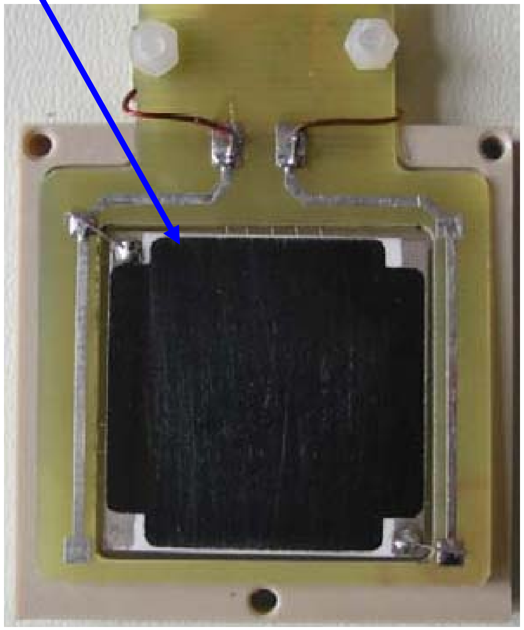
  - large range of doses
  - no access in 10 years

  ➔ **need many sensors**

- large temperature variations (-10 to 20°C) at some locations

  ➔ stabilize temperature to 20 ± 1 °C by heating back side of the ceramic hybrid





Back side

Radiation Monitor Sensor Board (RMSB)

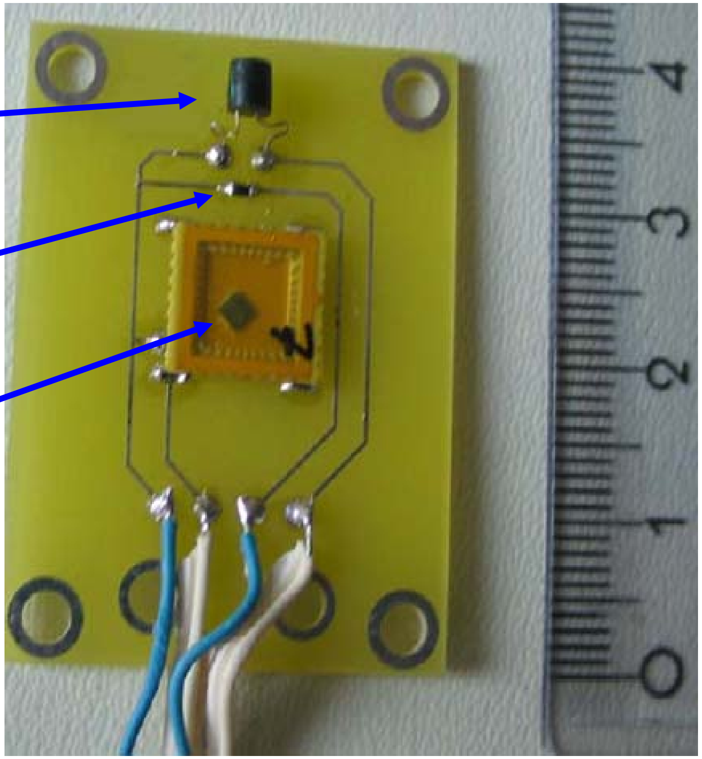
Other locations

- lower dose ranges
  ➔ mGy to 10 Gy, 10^9 to ~10^{12} n/cm^2
- no temperature stabilization
  ➔ correct read out values with known temperature dependences

CMRP diode

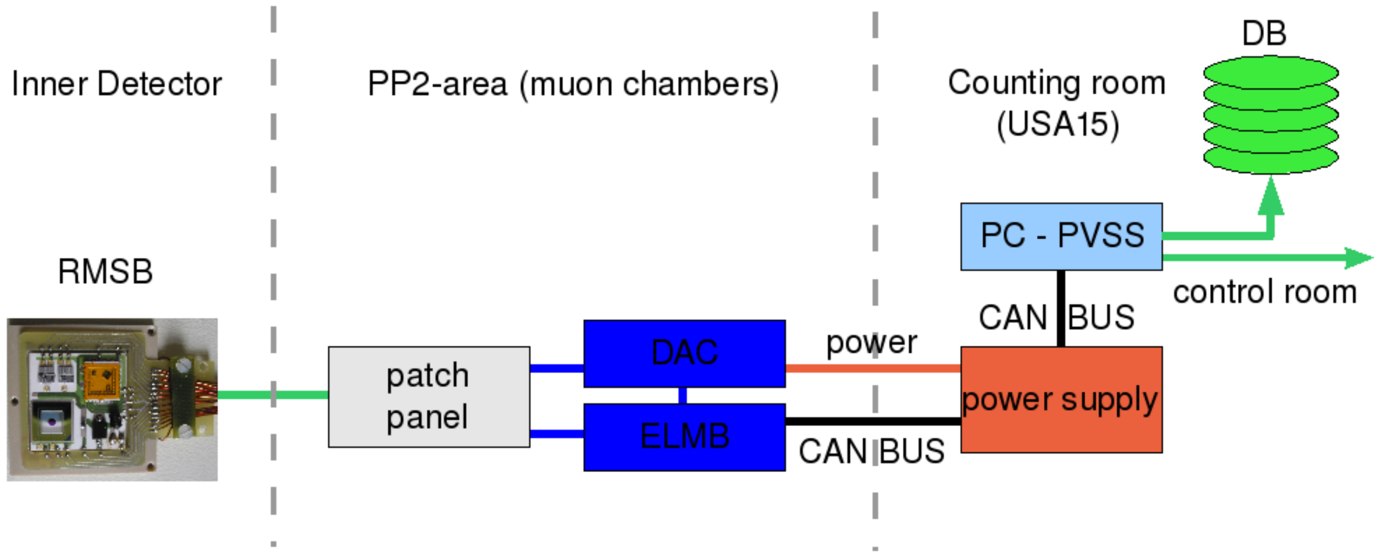
Thermistor

LAAS radfet (1.6 µmSiO_2)



Readout

- use standard ATLAS Detector Control System components
  - **ELMB:**
    - 64 ADC channels
    - can bus communication
  - **ELMB-DAC:**
    - current source, 16 channels (I_{max} = 20 mA, U_{max} = 30 V)
- sensors are biased only during readout (~ few minutes every hour)
- software written in PVSS
- readout values available in the ATLAS control room and archived for offline analysis

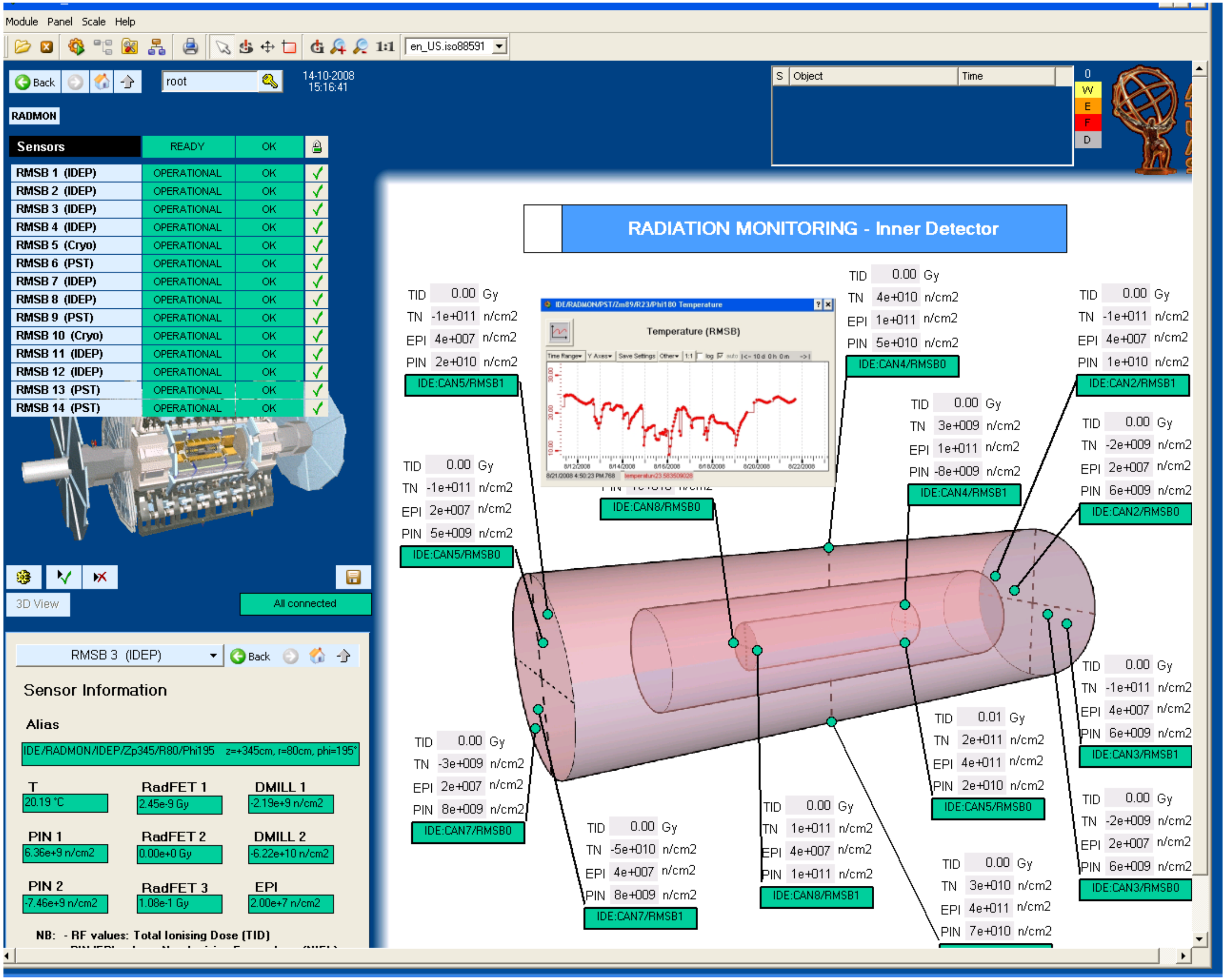


Cable length ~ 18 m

Cable length ~ 100 m

Monitoring locations

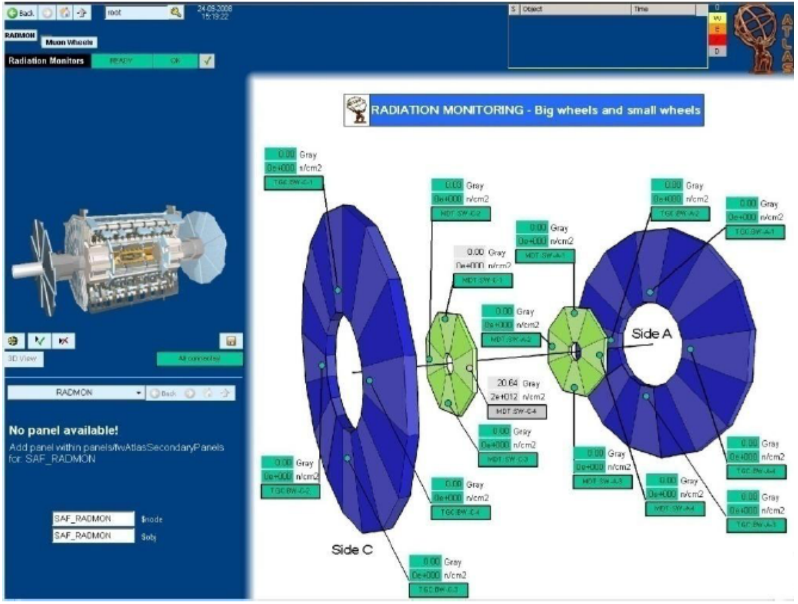
- 14 monitors in the Inner Detector



Monitoring locations

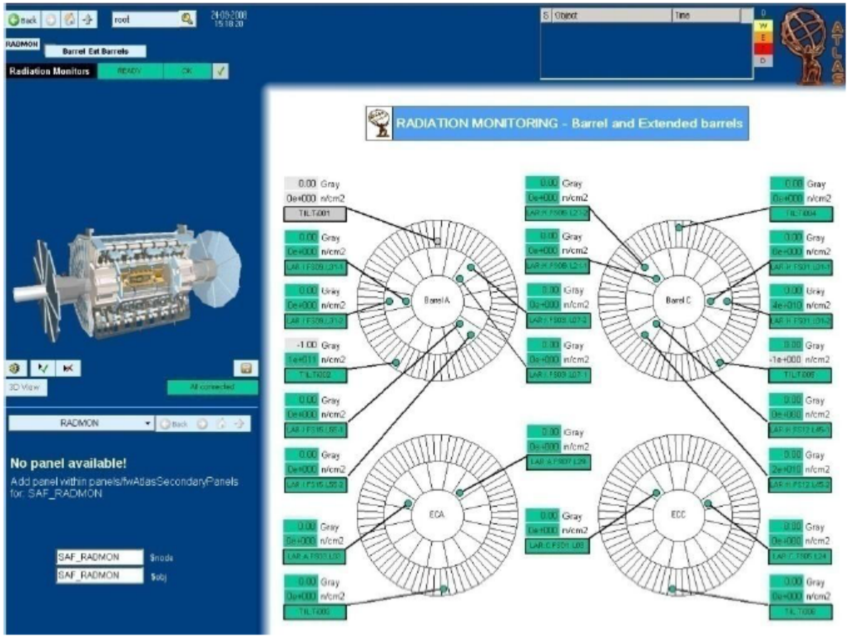
• 48 locations outside if the Inner Detector

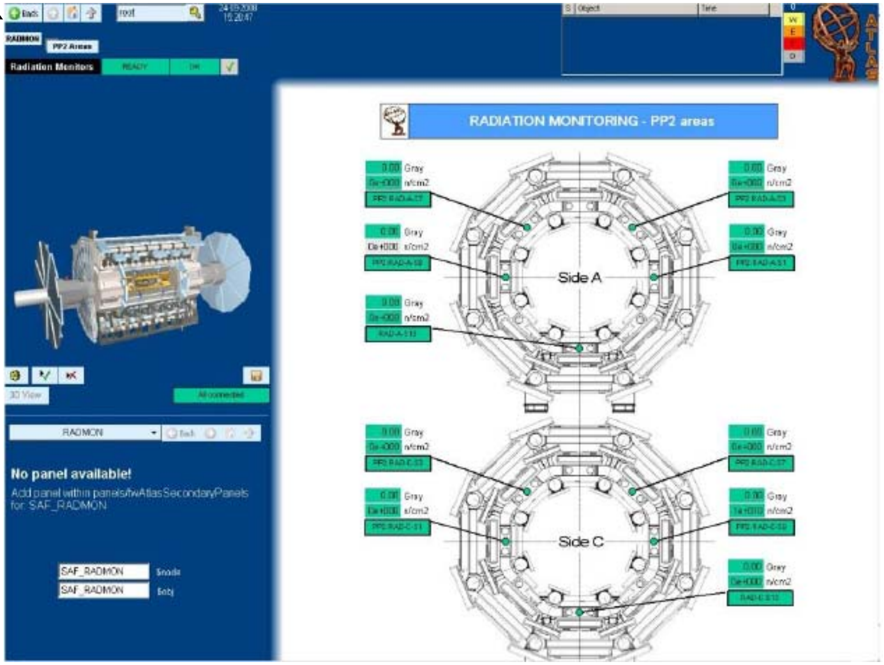
Muon detectors



Calorimeters

TRT electronics

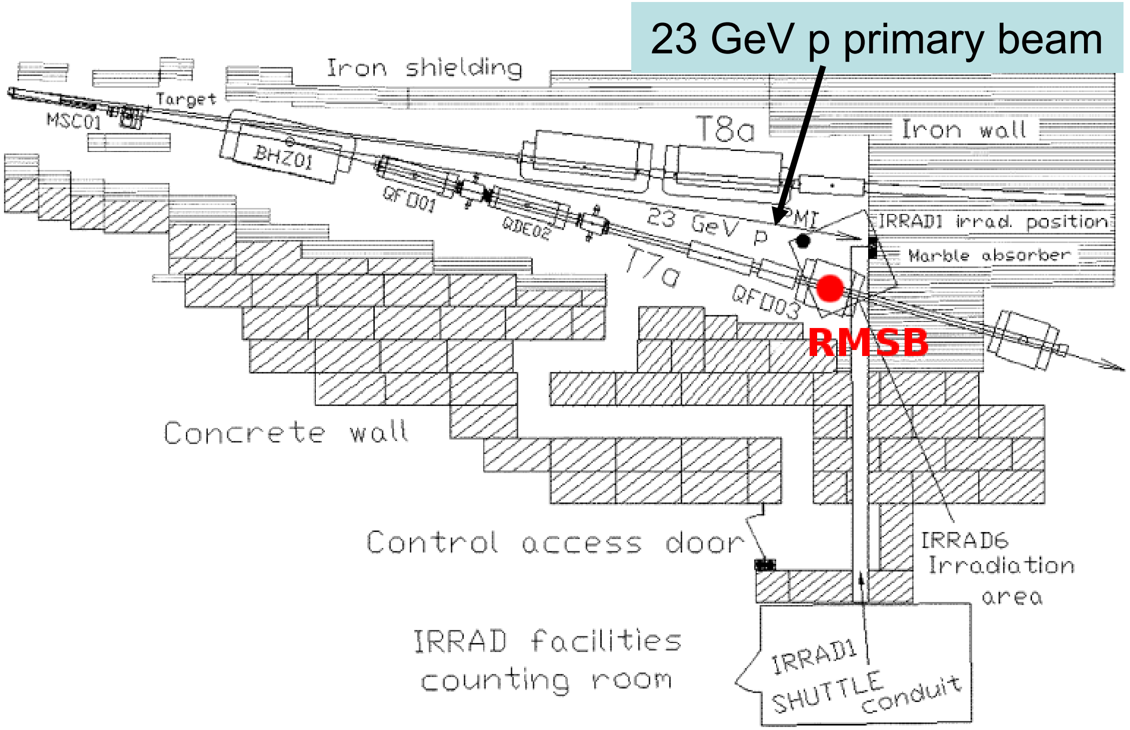




Tests in Mixed Radiation Environment

- system with 2 ID-type RMSBs installed in the IRRAD6 irradiation facility at CERN in 2008
- mixture of pions, protons, neutrons, photons
- low dose rates, beam on-off
  ➔ similar conditions as in ATLAS

- SEC counter Secondary Emission Counter (SEC): counts number of protons in primary beam
  ➔this number is proportional to the dose at RMSB location



F. Ravotti, M. Glaser et al., *IEEE TNS Vol. 54 (4), pp. 1170-1177, 2007.*

Tests in Mixed Radiation Environment

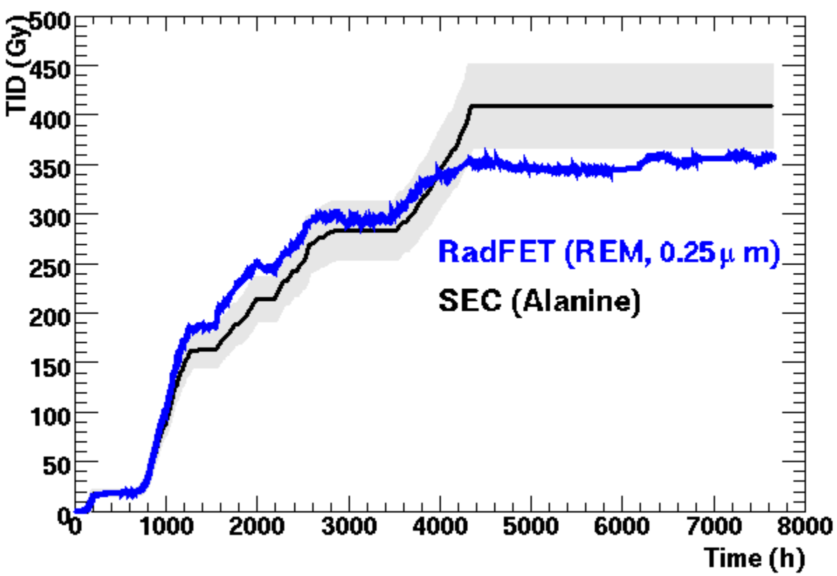
TID

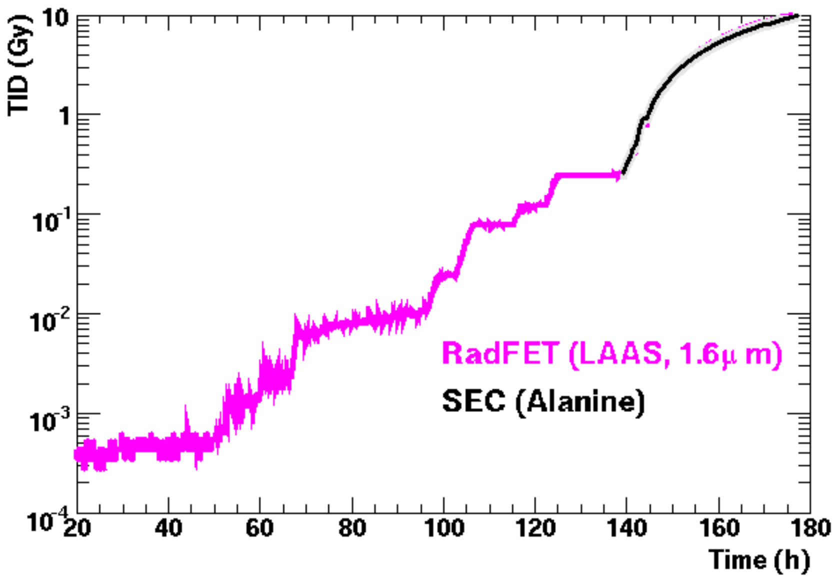
- SEC counts converted to dose (Gy) with alanine dosimeter

➔ dose 410 ± 20 Gy measured with alanine at the end of beam period (at 4000 h)

Medium Sensitivity
➔ good agreement with SEC
➔ no significant annealing

High Sensitivity RadFET
➔ mGy sensitivity





Tests in Mixed Radiation Environment

NIEL

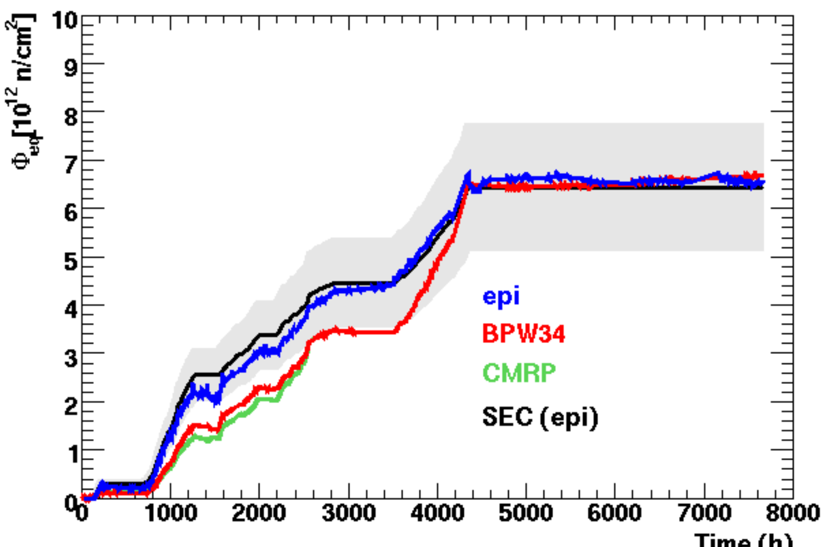
- SEC counts converted to 1 MeV equivalent neutron fluence with epitaxial diode on RMSB
  ➔ fluence **Φ_{eq}= 6.5·10^{12} n/cm^2** at the end of beam period (at t = 4000 h)

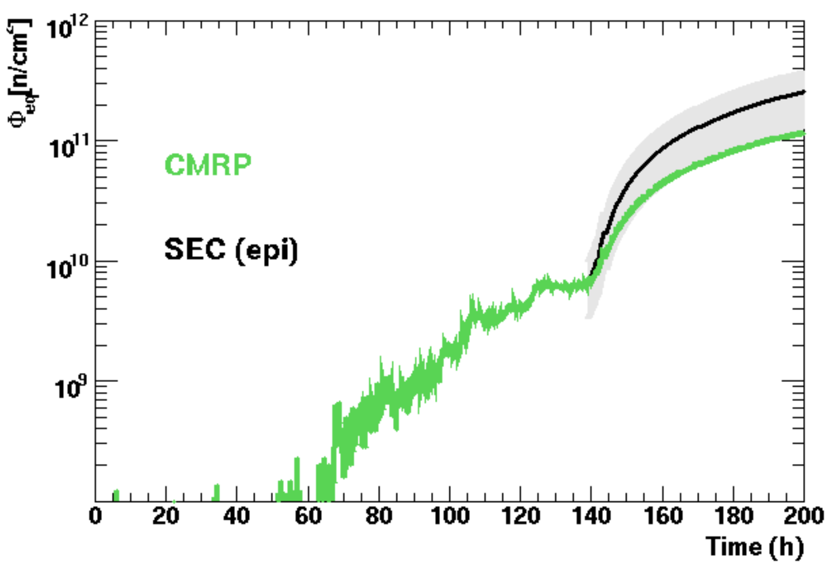
All diodes:
- epi -> reverse bias
- BPW34 -> forward bias
- CMRP -> forward bias

➔ epi and BPW34 corrected for annealing

High Sensitivity PiN diode (CMRP)
- measure forward bias @ I = 1 mA

➔ sensitivity ~ 10^9 n/cm^2





Tests in Mixed Radiation Environment

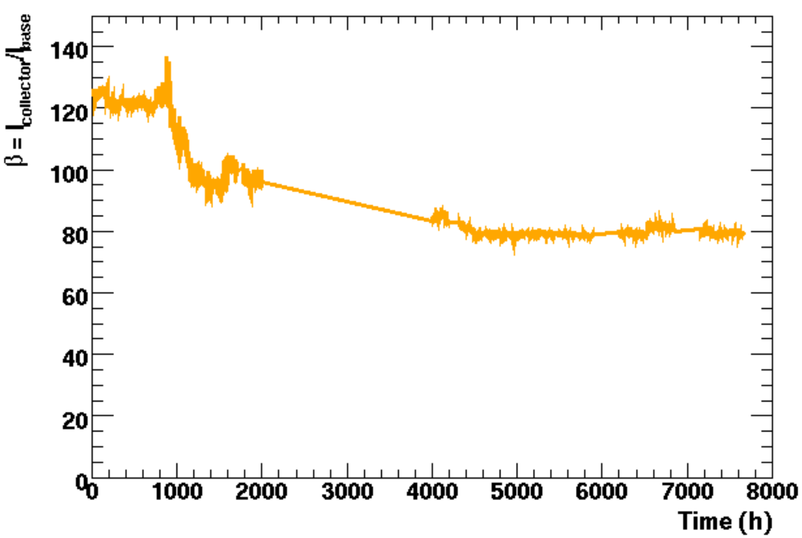
Thermal neutrons

- base current I_b measured at collector current I_c = 10 μA

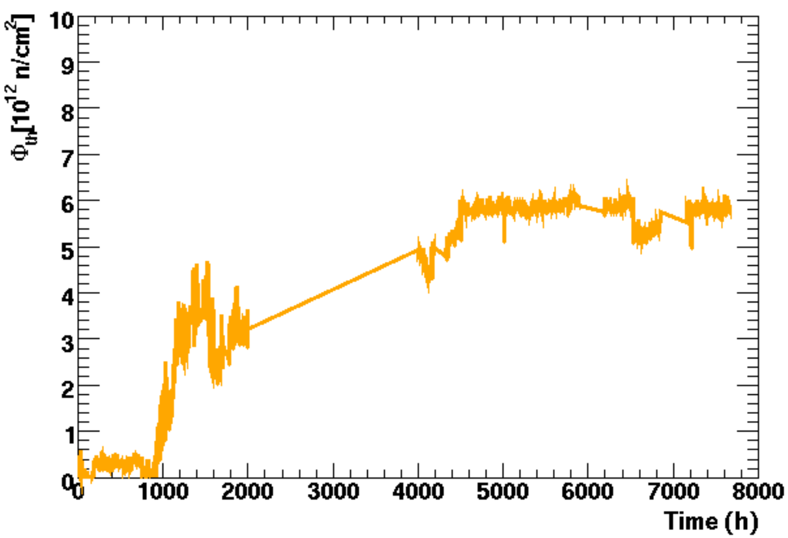
1. monitor current gain $\beta = I_c/I_b$
2. measure fluence of thermal neutrons:

➔ $\Phi_{th} = 1/k_{th}\,(\Delta I_b/I_c - k_{eq}\cdot\Phi_{eq})$, Φ_{eq}: measured with BPW34

β degradation



Thermal neutron fluence



Summary

- system for online radiation monitoring in ATLAS detector:

  ➔ total ionizing dose in SiO_2
  ➔ bulk damage in silicon: 1 MeV equivalent neutron fluence
  ➔ fluence of thermal neutrons (Inner Detector only)
  ➔ readout compatible with ATLAS Detector Control System

- tests in mixed radiation environment

  ➔ sufficient sensitivity: TID ~ mGy, Φ_{eq} ~ 10^9 n/cm^2
  ➔ sufficient accuracy: ~ 20%
  ➔ annealing effect can be controlled

- complete system was installed and integrated in ATLAS DCS in 2008

  ➔ few months of data taking in 2008
  ➔ good stability

Ready to measure doses!

Appendix: Tests in Mixed Radiation Environment

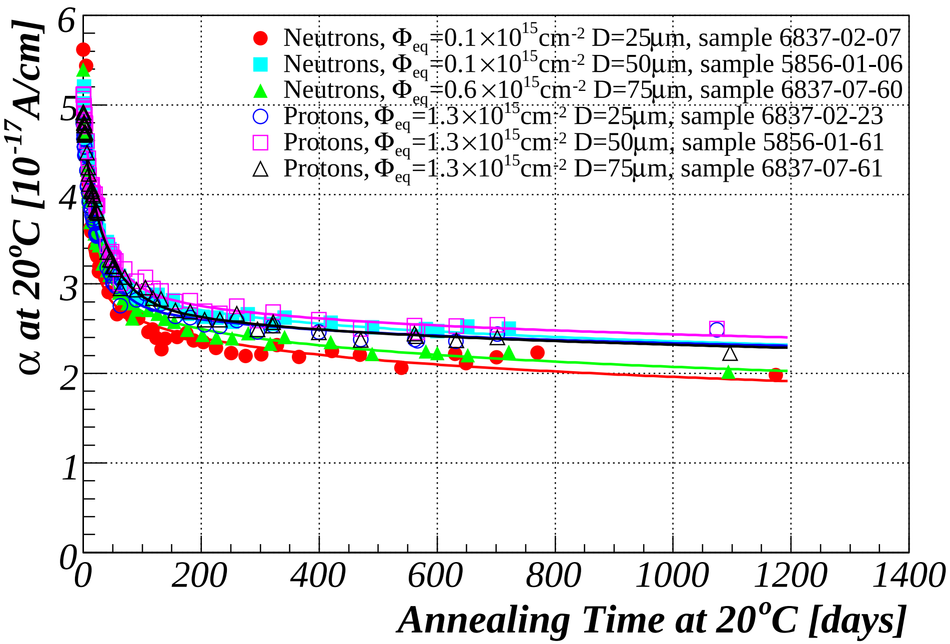
Annealing:

- approximation:

$$I(t) = I_1(t) + I_0$$

$$I_1(t) = V\Phi\alpha_1 \cdot e^{-\frac{t}{\tau}}; \quad I_0 = V\Phi\alpha_0$$

$$dI(t) = -\frac{I_1(t)}{\tau}dt$$



- increase of current ΔI measured at time t in IRRAD6 after time interval Δt:

$$\Delta I = \alpha V \Delta\Phi - \frac{dI(t)}{dt} \cdot \Delta t$$

$$\Delta I = \alpha V \Delta\Phi - \frac{I_1(t)}{\tau} \cdot \Delta t$$

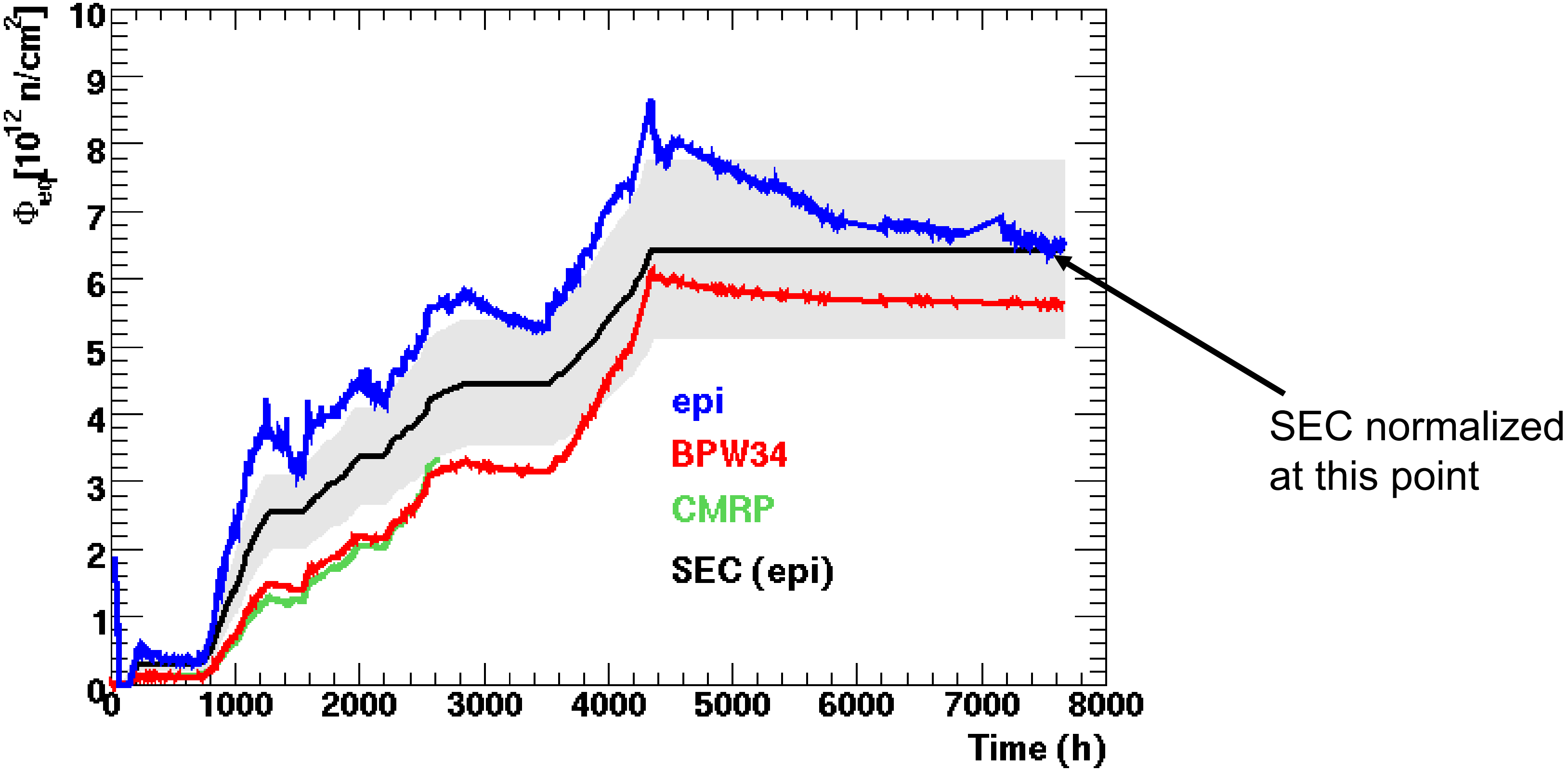
$$I_1(t) = I(t) - V\alpha_0\Phi(t)$$

$$\alpha = \alpha_1 + \alpha_0$$

$$\Rightarrow \quad \Delta\Phi = \frac{1}{\alpha V}\left(\Delta I + \frac{I_1(t)}{\tau} \cdot \Delta t\right).$$

Appendix: Tests in Mixed Radiation Environment

Annealing:



• raw measurements (no corrections for annealing)