Measurement of radiation field in the ATLAS Inner Detector with Online Radiation Dose Measurement System

I. Mandić[a], representing ATLAS ID Rad. Mon. group

[a]*Jožef Stefan Institute, Ljubljana, Slovenia*

Introduction

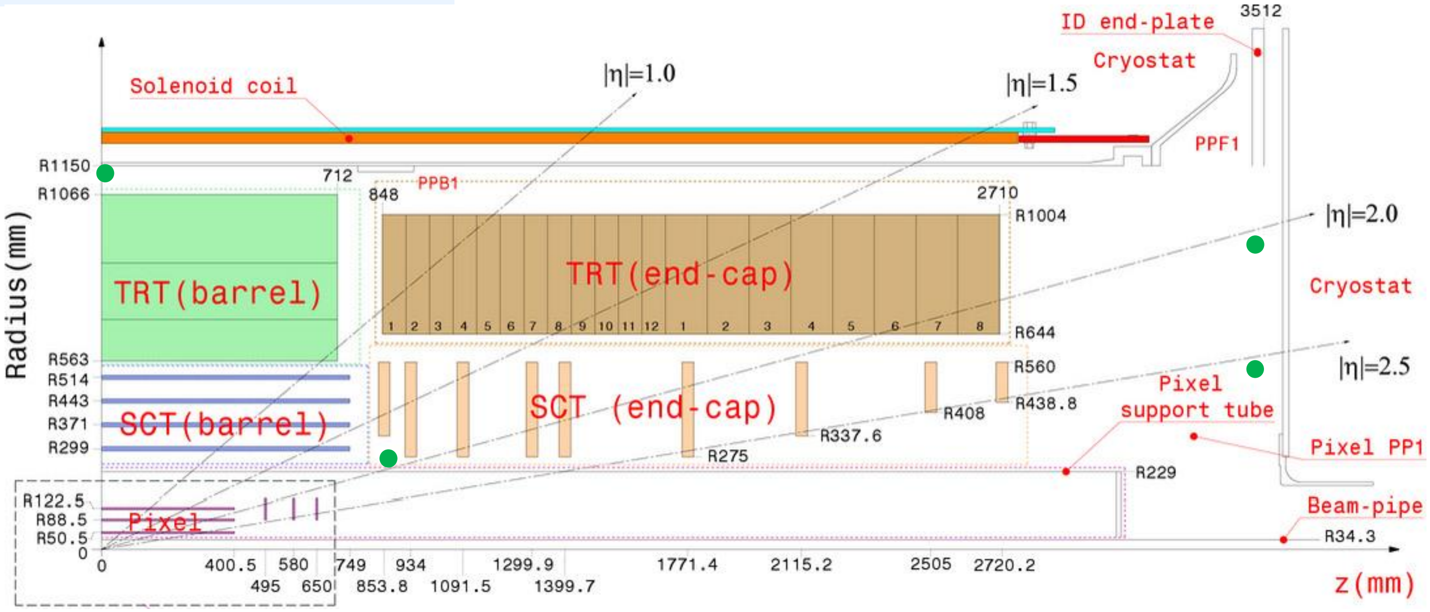
- online Radiation dose monitoring measures accumulated ionizing dose (TID) in SiO_2 and displacement damage in silicon
- doses are monitored at 14 locations in the Inner Detector, sensors read out every 60 minutes
- purpose: monitoring of radiation damage in detectors and electronics

More information about the monitoring system in:

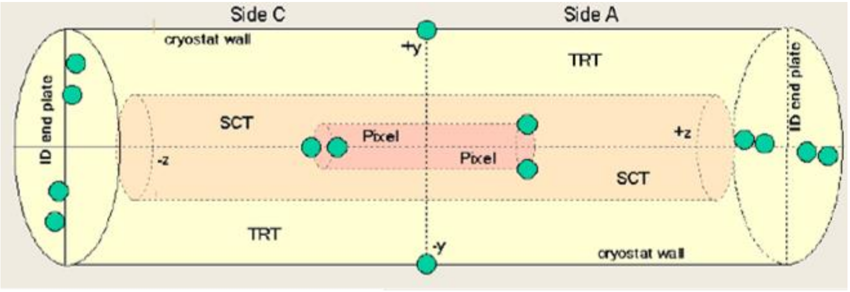
- I. Mandić et al.,"Online integrating radiation monitoring system for the ATLAS detector at the large hadron collider," *IEEE Trans. Nucl. Sci.*, vol. 54, no. 4, pp. 1143–1150, Aug. 2007.
- I. Mandić et al., "First Results from the Online Radiation Dose Monitoring System in ATLAS experiment" 2011 IEEE Nuclear Science Symposium Conference Record, NP3.M-40
- https://twiki.cern.ch/twiki/bin/viewauth/Atlas/AtlasInDetRadMon

Monitoring Locations

- 14 monitors in the Inner Detector

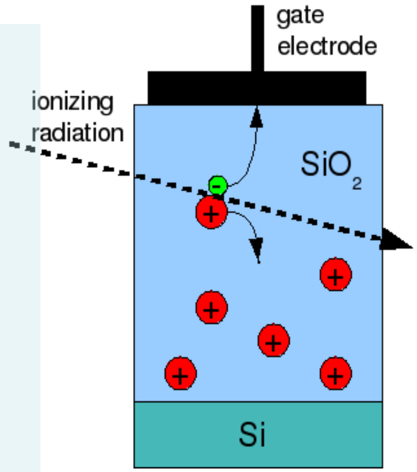


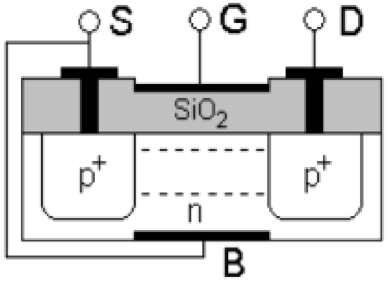
Location	*r* (cm)	|z| (cm)
Pixel Support Tube (PST)	23	90
ID end plate small r	54	345
ID end plate large r	80	345
Cryostat Wall	110	90



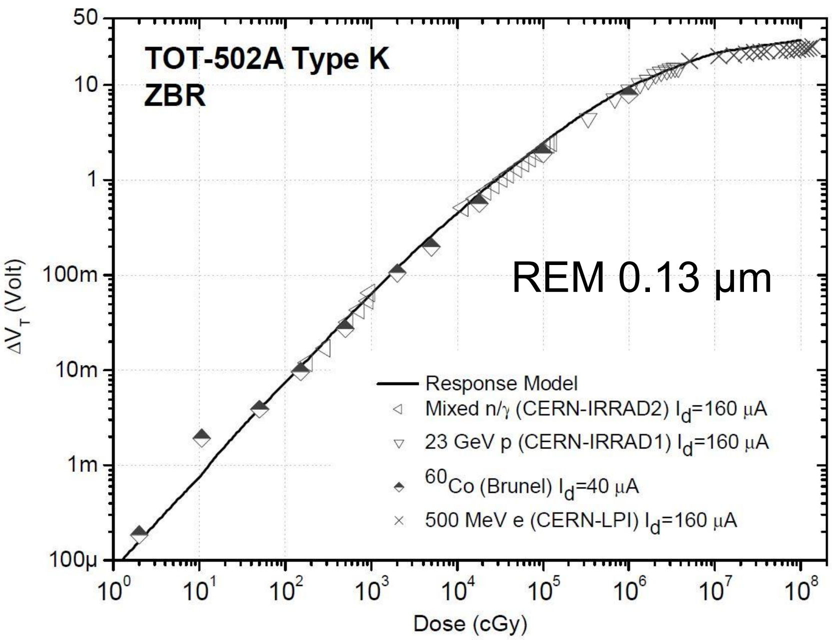
TID measured with RadFETs

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





- 3 RadFETs at each monitoring location:
  LAAS 1.6 µm;
  REM 0.25 µm;
  REM 0.13 µm



A.H. Siedle, F. Ravotti, M. Glaser, *The Dosimetric Performance of RADFETs in Radiation Test Beams*
2007 IEEE Radiation Effects Data Workshop, https://doi.org/10.1109/REDW.2007.4342539

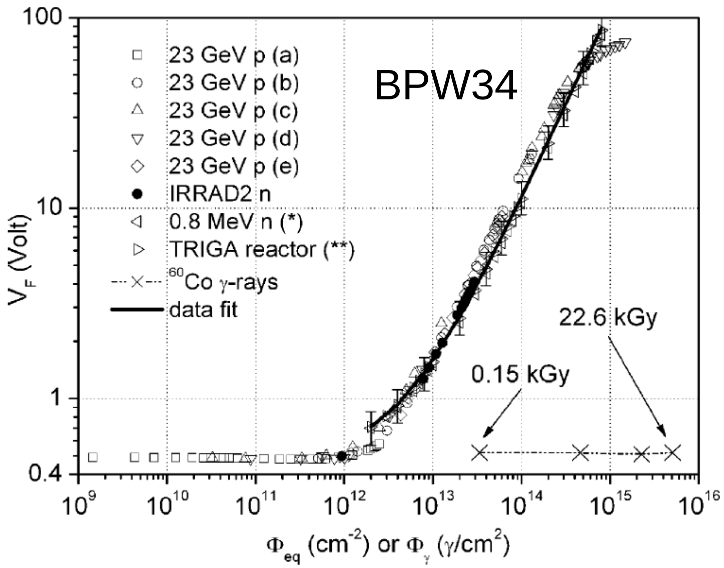
1 MeV n eq. fluence measurements with diodes

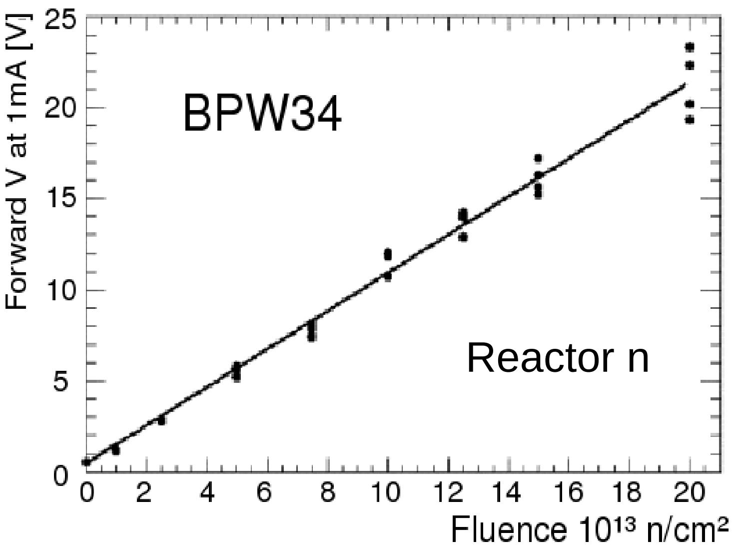
- displacement damage in silicon:
  increased resistance, reduction of carrier lifetime, increase of reverse current

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

Forward bias

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





F. Ravotti et al. , *BPW34 Commercial p-i-n Diodes for High-Level 1-MeV Neutron Equivalent Fluence Monitoring,* IEEE TNS, VOL. 55, (2008), p 2133

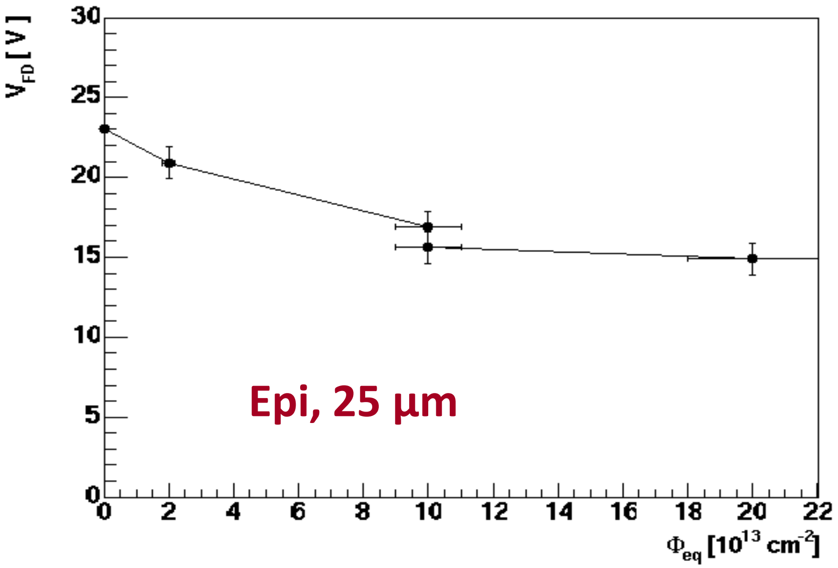
1 MeV n eq. fluence measurements with diodes

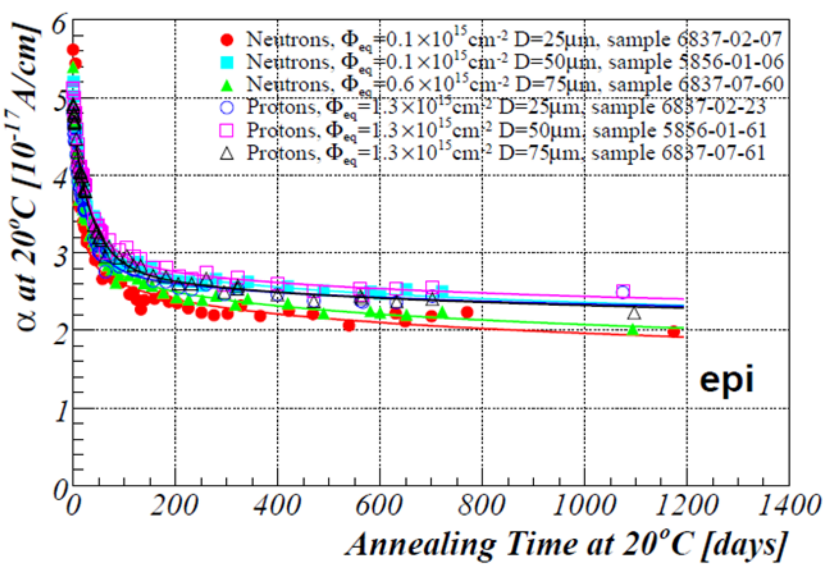
Reverse bias

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

- **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

- sensitive from 10^{11} n/cm^2 to 10^{15} n/cm^2
- relatively large annealing corrections needed



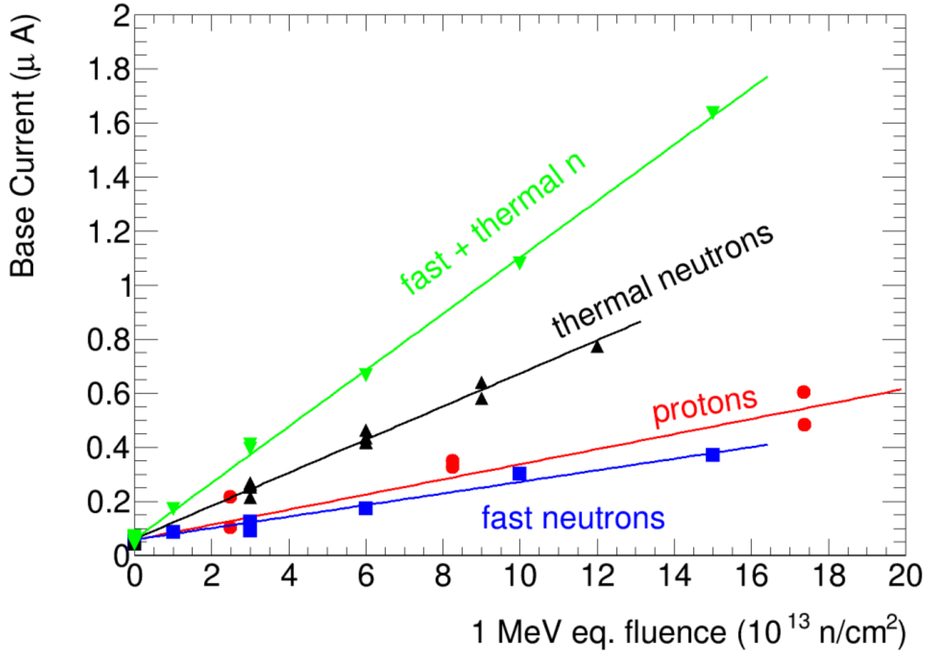


Thermal neutrons

- DMILL bipolar transistors produced by ATMEL
- measure base current at 10 uA collector current in common emitter configuration
  → sensitive to fast and thermal neutrons
  → same type of transistors as input transistor in ABCD3TA chip → info about chip performance

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

k_{eq}, k_{th} *from* calibration, Φ_{eq} measured with diodes → Φ_{th} can be determined



For more info see:
I. Mandić et al., "Bulk Damage in DMILL npn Bipolar Transistors Caused by Thermal Neutrons Versus Protons and Fast Neutrons", IEEE TNS, VOL. 51, (2004) p. 1752

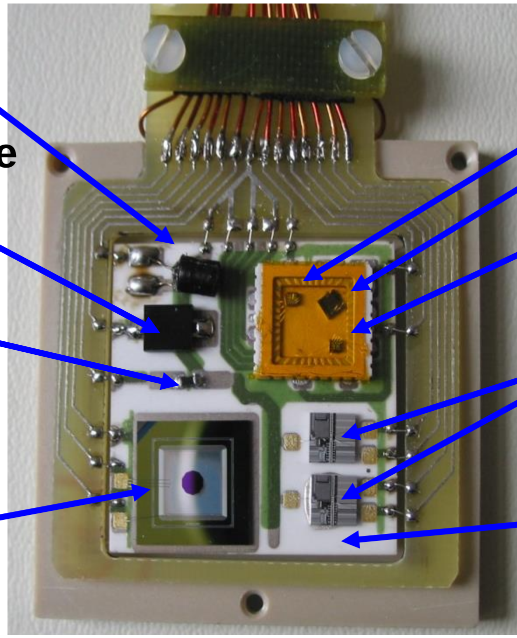
Radiation Monitor Sensor Board (RMSB)

CMRP diode

BPW34 diode

Thermistor

epi diode



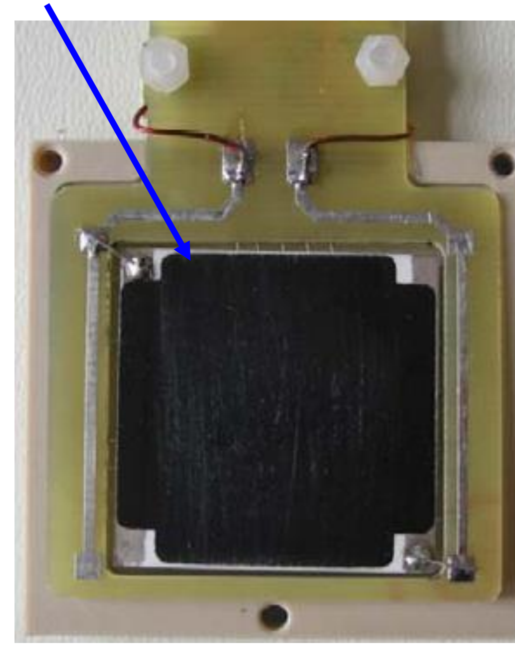
Radfet package:
- **0.25 μm SiO_2**
- **1.6 μmSiO_2**
- **0.13 μmSiO_2**

Bipolar transistors

Ceramic hybrid (Al_2O_3)

4 cm

Thick film resistive layer R = 320 Ω

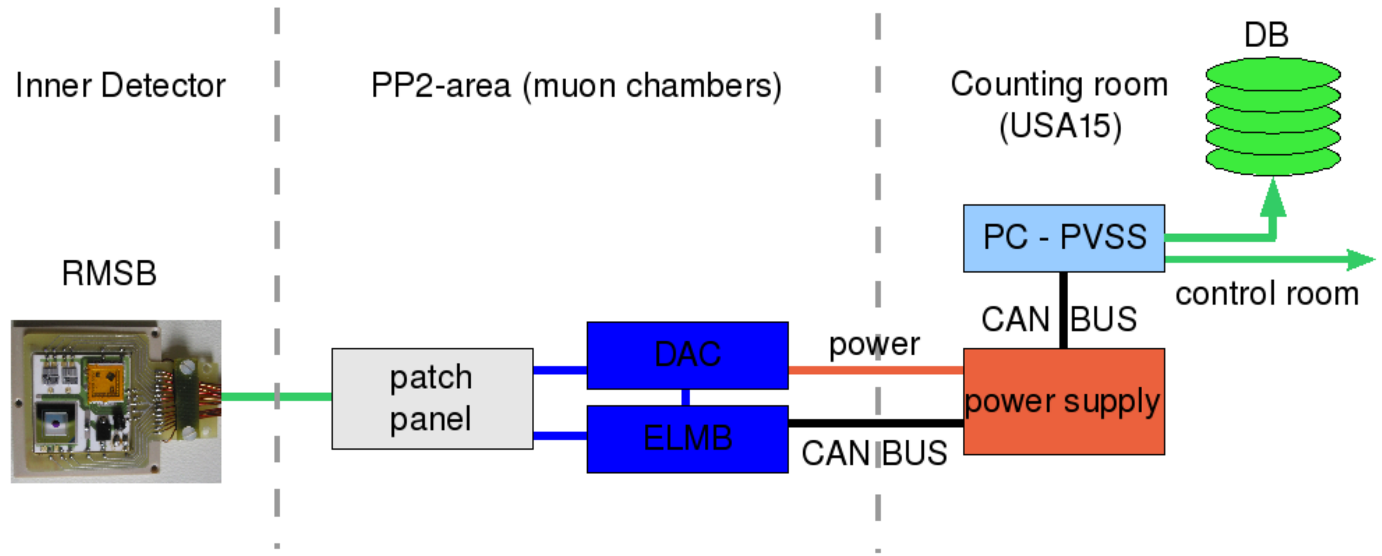


Back side

stabilize temperature to 20 ± 1°C by heating back side of the ceramic hybrid
→ useful on PST

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
- sensors read out once per hour, data stored in DCS database
- integrated in the ATLAS DCS



Cable length
~ 18 m

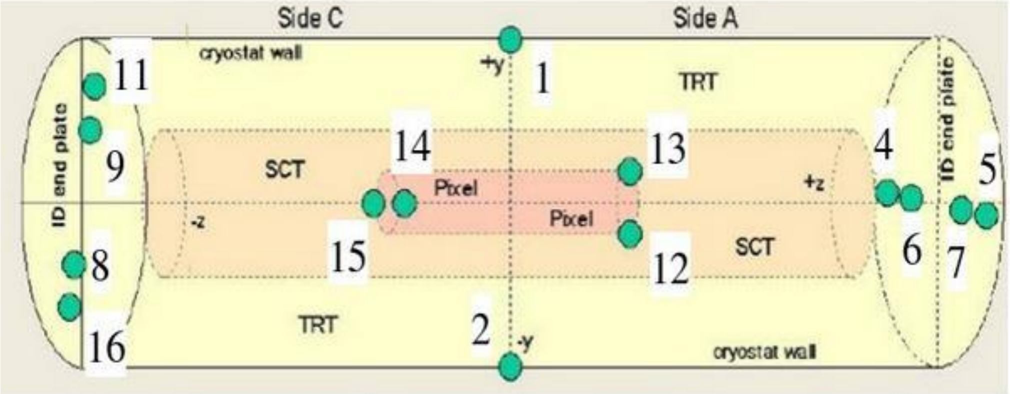
Cable length
~ 100 m

Simulation

- fluence and dose predictions at radmon locations based on Pythia8 + FLUKA simulation:

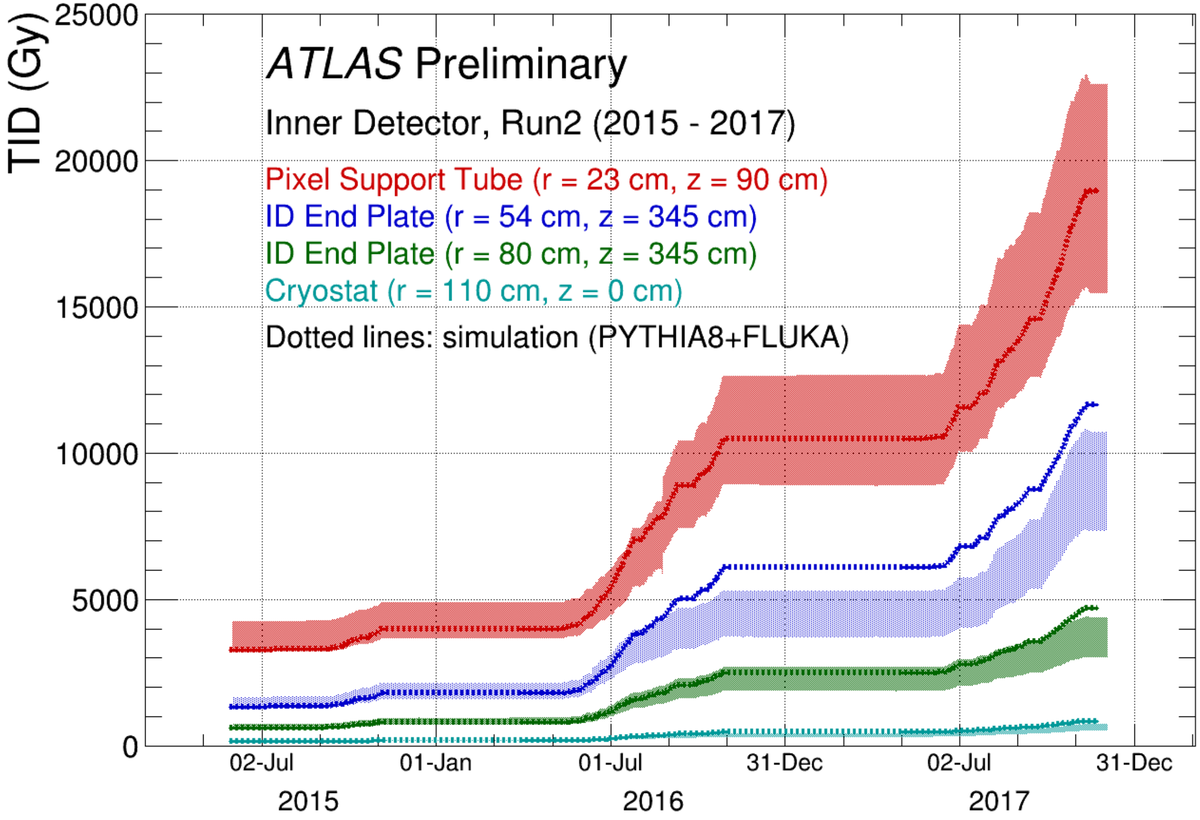
https://twiki.cern.ch/twiki/bin/view/Atlas/RadiationBackgroundSimulationsRun2#Fluence_and_dose_values_at_RadMo

- Dose and fluence factors per 1 fb^{-1} integrated luminosity
- the upper energy limit for scoring of thermal neutrons is 1 eV.
- the fluence and dose values are based on 49900 events for 13 TeV.



RadMon number	Z (cm)	R (cm)	1 MeV neq (x 10^{11} cm^{-2})	total ionising dose (Gy)	thermal neutrons (x 10^{11} cm^{-2})
1, 2	1	110	0.75	7.51	0.67
12, 13, 14, 15	90	23	4.21	167.4	1.14
6, 7, 8, 9	344	54	4.67	110.2	1.69
4, 5, 11, 16	344	80	2.85	43.6	1.48

TID

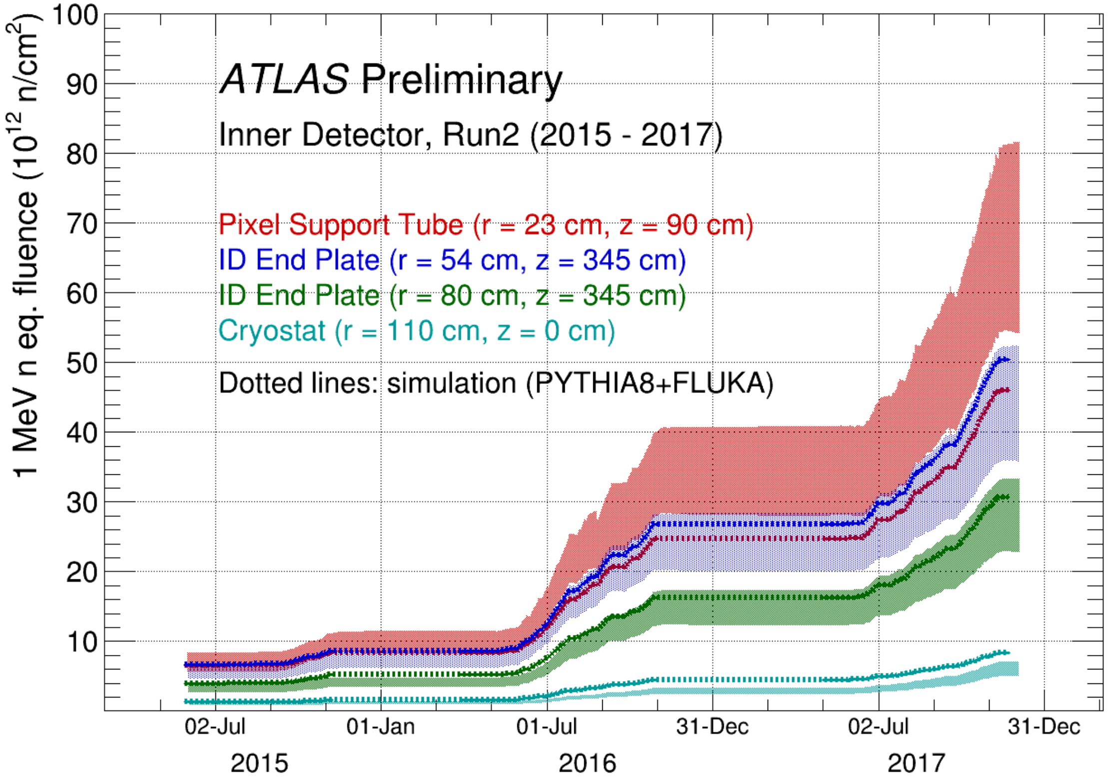


- REM 0.13 µm RadFETs
- bands show measured values, width $w = \sqrt{(\sigma^2 + (\sigma_{cal})^2)}$ where:
  σ is the standard deviation and σ_{cal} = 20% is the accuracy of calibration and corrections

- simulated curves: TID = integrated_luminosity · dose_factor
  → Dose factors (Gy/pb^{-1}) from:

https://twiki.cern.ch/twiki/bin/view/Atlas/RadiationBackgroundSimulationsRun2#Fluence_and_dose_values_at_RadMo

1 MeV n eq. fluence

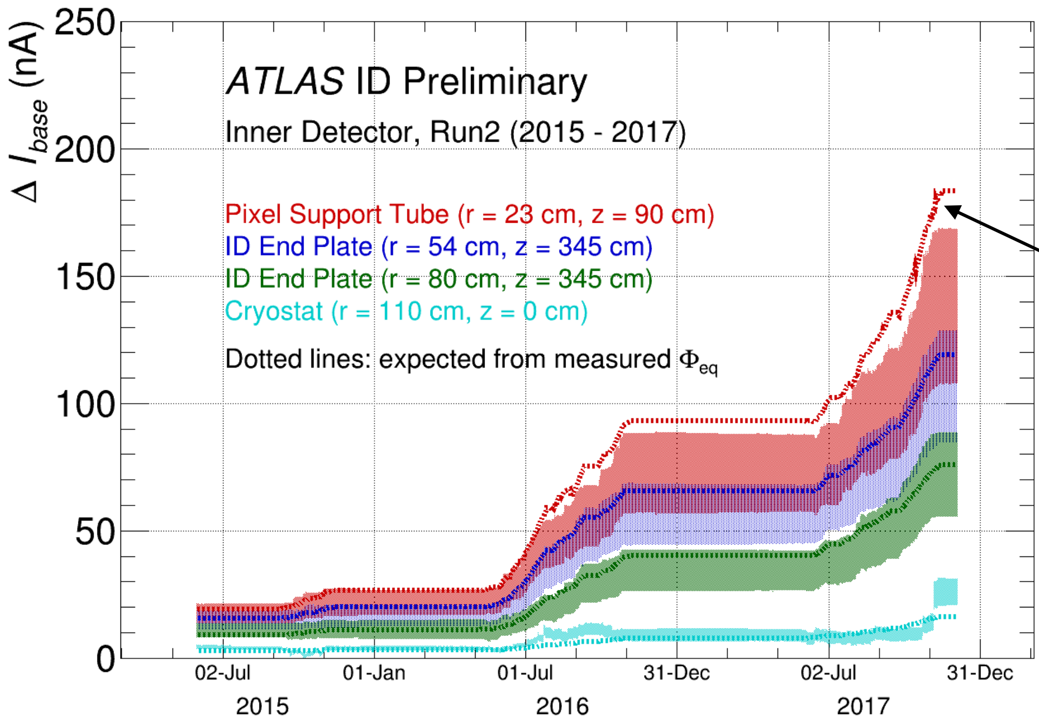


- BPW34 diodes, forward bias at 1 mA forward current
- bands show measured values, width $w = \sqrt{(\sigma^2 + (\sigma_{cal})^2)}$ where:
  σ is the standard deviation and σ_{cal} = 20% is the accuracy of calibration and corrections

- simulated curves: Φ_{eq} = integrated_luminosity · fluence_factor
  → Dose factors (Φ_{eq}/pb^{-1}) from:

https://twiki.cern.ch/twiki/bin/view/Atlas/RadiationBackgroundSimulationsRun2#Fluence_and_dose_values_at_RadMo

Current increase in transistors



Dotted lines: $k_{eq} \cdot \Phi_{eq}$

Current increase expected from fast hadrons only, Φ_{eq} measured with diodes

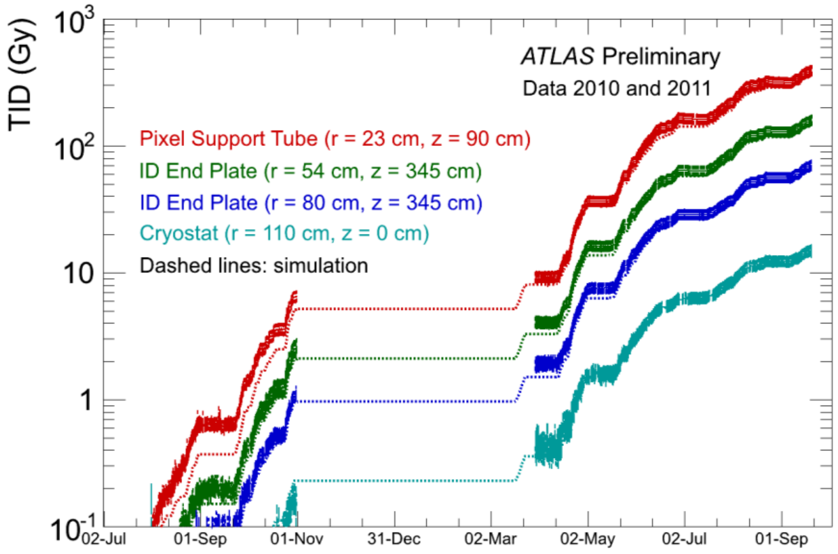
- increase of base current $\Delta I_b = k_{eq} \cdot \Phi_{eq} + k_{th} \cdot \Phi_{th}$
- Φ_{eq} measured with diodes, k_{eq} and k_{th} calibration constants measured in reactor and PS

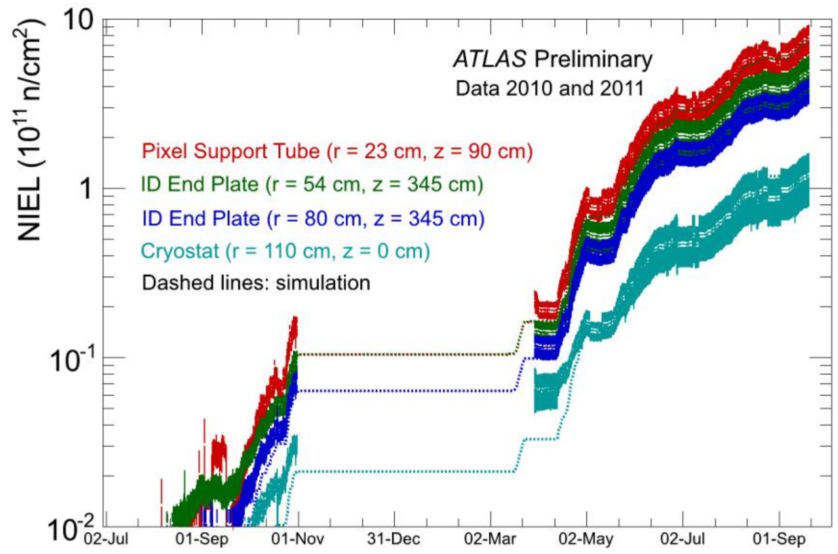
  ➔ expect to see the effect of Φ_{th} if $\Phi_{th} > \sim 0.2 \cdot \Phi_{eq}$ (expected at all monitoring locations)

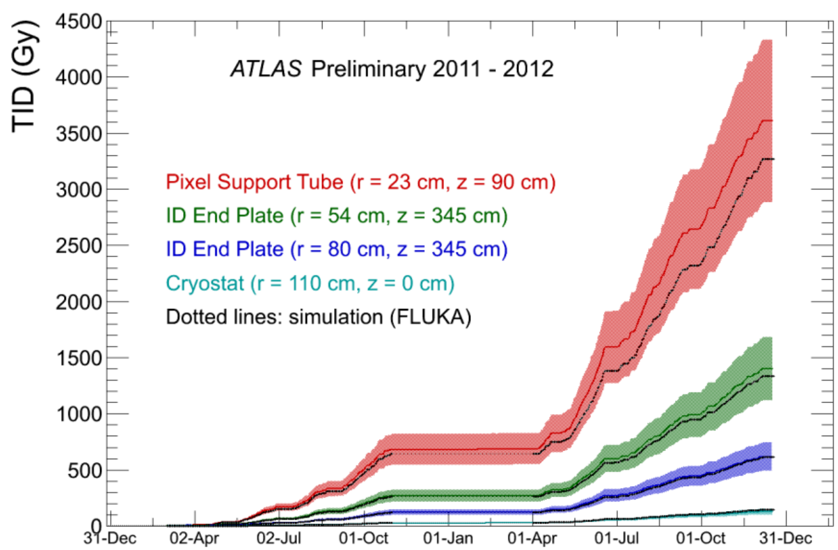
- measured current increase consistent with fast hadrons only

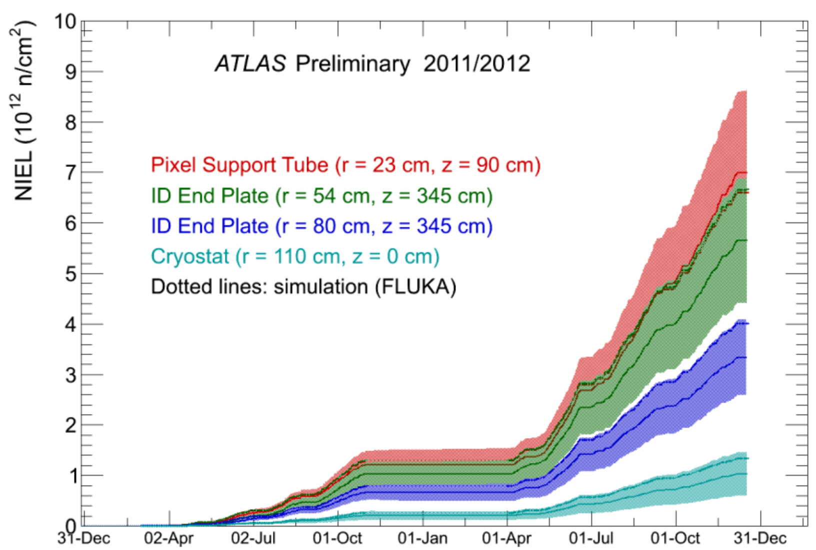
  ➔ not understood: response different than in calibration and/or Φ_{th} much smaller than expected

Results Run 1







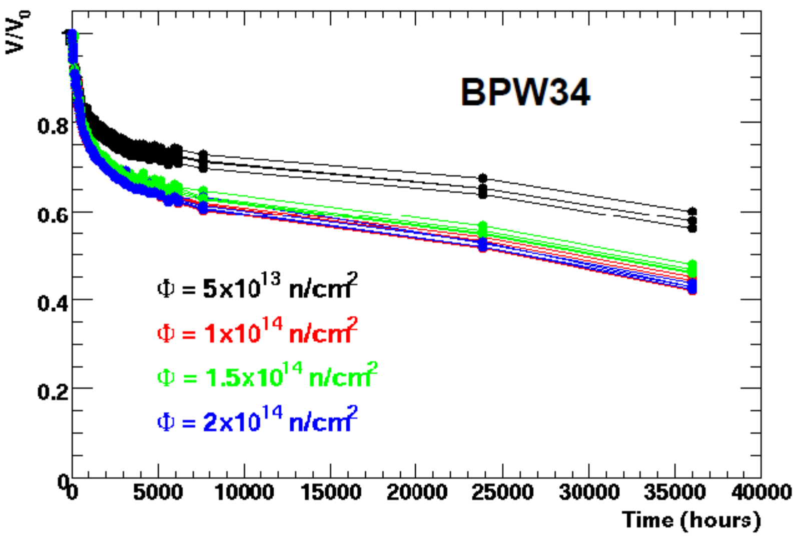


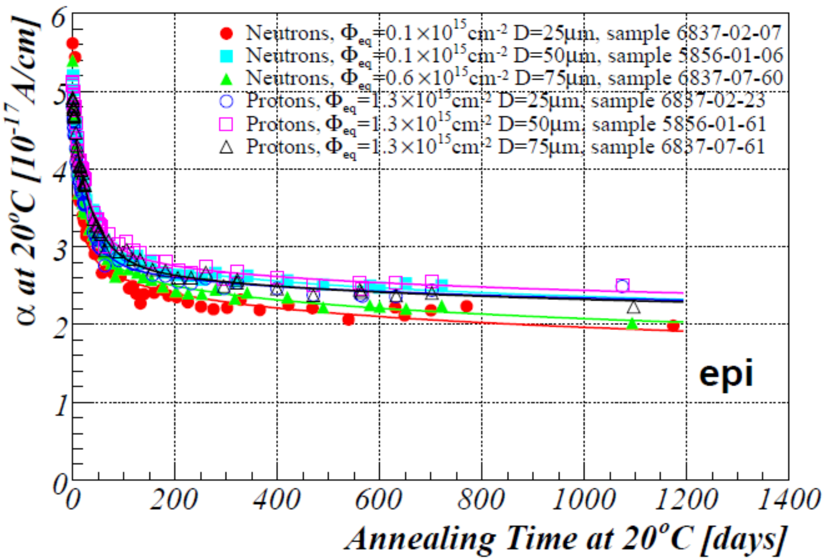
Summary

- measurements of TID and 1 MeV n eq. fluences with online integrated dose monitoring system in the ATLAS ID
  ➔ good agreement with doses and fluences expected from Pythia8 and FLUKA simulation

- increase of base current in bipolar transistors consistent with damage from fast hadrons alone
  → response of sensors different than in calibration or thermal neutron fluences small

Annealing


V/V$_0$
BPW34
Φ = 5x10^{13} n/cm^2
Φ = 1x10^{14} n/cm^2
Φ = 1.5x10^{14} n/cm^2
Φ = 2x10^{14} n/cm^2
Time (hours)


α at 20°C [10^{-17} A/cm]
Neutrons, Φ_{eq}=0.1×10^{15}cm^{-2} D=25µm, sample 6837-02-07
Neutrons, Φ_{eq}=0.1×10^{15}cm^{-2} D=50µm, sample 5856-01-06
Neutrons, Φ_{eq}=0.6×10^{15}cm^{-2} D=75µm, sample 6837-07-60
Protons, Φ_{eq}=1.3×10^{15}cm^{-2} D=25µm, sample 6837-02-23
Protons, Φ_{eq}=1.3×10^{15}cm^{-2} D=50µm, sample 5856-01-61
Protons, Φ_{eq}=1.3×10^{15}cm^{-2} D=75µm, sample 6837-07-61
epi
Annealing Time at 20°C [days]