First Results from the Online Radiation Dose Monitoring System in ATLAS Experiment

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FLUKA simulations by:

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University of Sheffield, UK

Lot of work with radiation sensors (characterization, selection, calibration, annealing studies etc...) was done by F. Ravotti, M. Glaser, M. Moll et al. from the CERN RADMON team
http://lhc-expt-radmon.web.cern.ch/lhc-expt-radmon/

Introduction

- detectors and electronics in ATLAS experiment will be exposed to large doses of radiation
- continuous monitoring of doses necessary to understand performance of the detector
- online radiation dose monitoring system measures accumulated ionizing dose in SiO_2, displacement damage in silicon and fluences of thermal neutrons.
- doses are monitored at 14 locations in the Inner Detector and at 48 locations at larger radii
- sensors are read out every 60 minutes and readings are stored in the database.

➔ results of dose measurements after 2 years of ATLAS data taking are presented

More information about the monitoring system in:

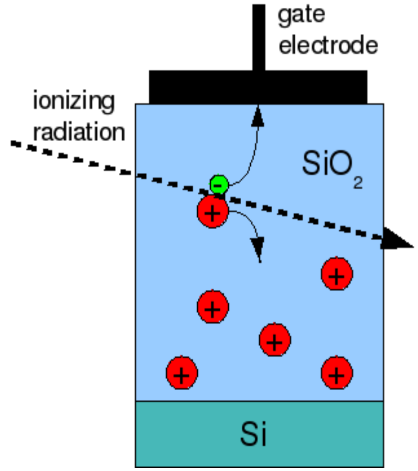
➢ Mandić et al.,"Online integrating radiation monitoring system for the ATLAS detector at the large hadron collider," *IEEE Trans. Nucl. Sci.*, vol. 54, no. 4, pp. 1143–1150, Aug. 2007.

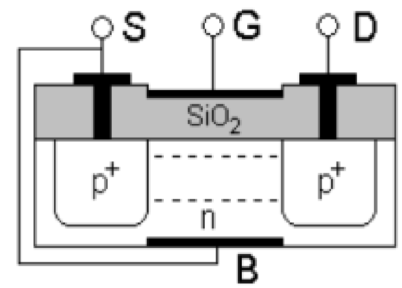
➢ J. Hartert et al., "The ATLAS radiation dose measurement system and its extension to SLHC experiments," in *Proc. Topical Workshop Electronics for Particle Physics*, Naxos, Greece, ,2008, http://indico.cern.ch/getFile.py/access?contribId=121&sessionId=15&resId=0&materialId=paper&confId=21985

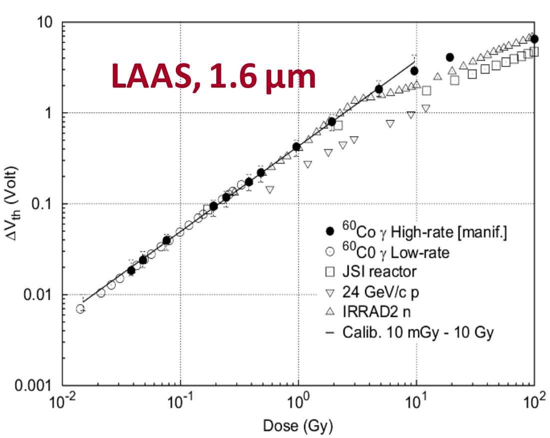
➢ https://twiki.cern.ch/twiki/bin/viewauth/Atlas/AtlasInDetRadMon

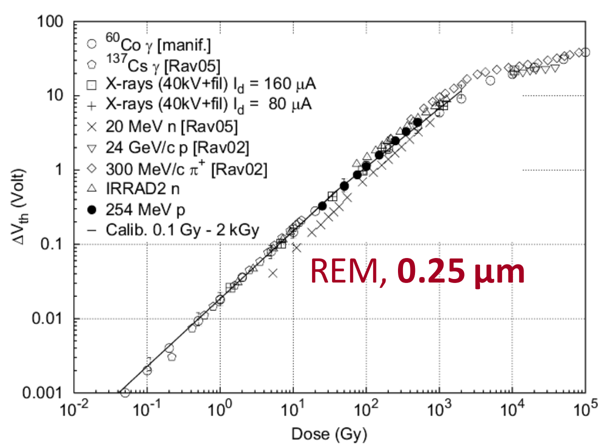
TID measurements with RadFETs

- 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:









<u>Inner detector:</u>

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

<u>Other locations (lower doses)</u>:

- LAAS 1.6 µm

Radfet calibration curves (F. Ravotti ,PhD thesis, CERN-THESIS-2007-013)

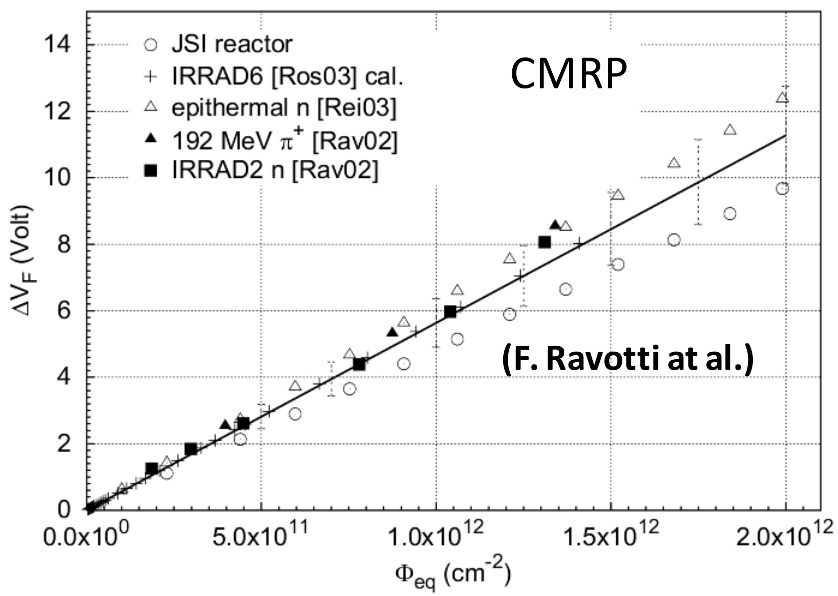
NIEL measurements with diodes

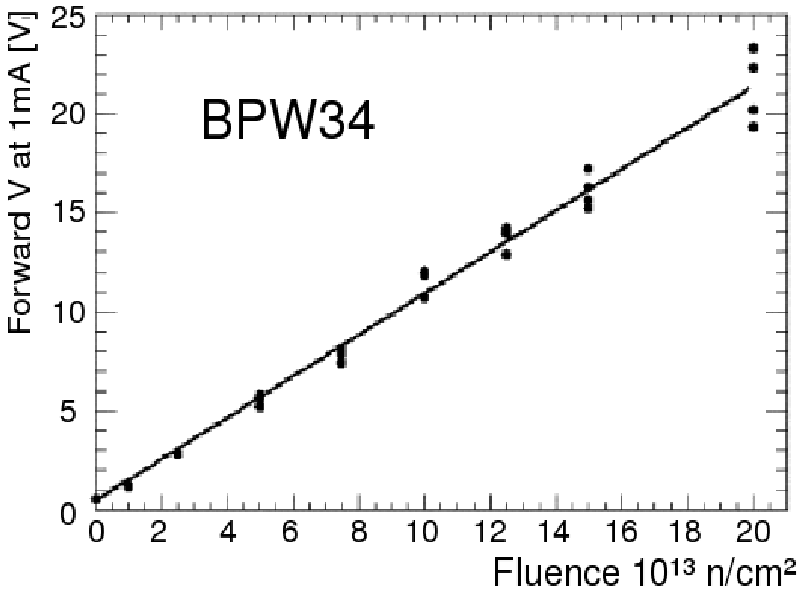
- bulk damage in silicon consequence:
  increased resistance, reduction of carrier lifetime, increase of reverse current

  ➔ 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}





NIEL measurements with diodes

Reverse bias

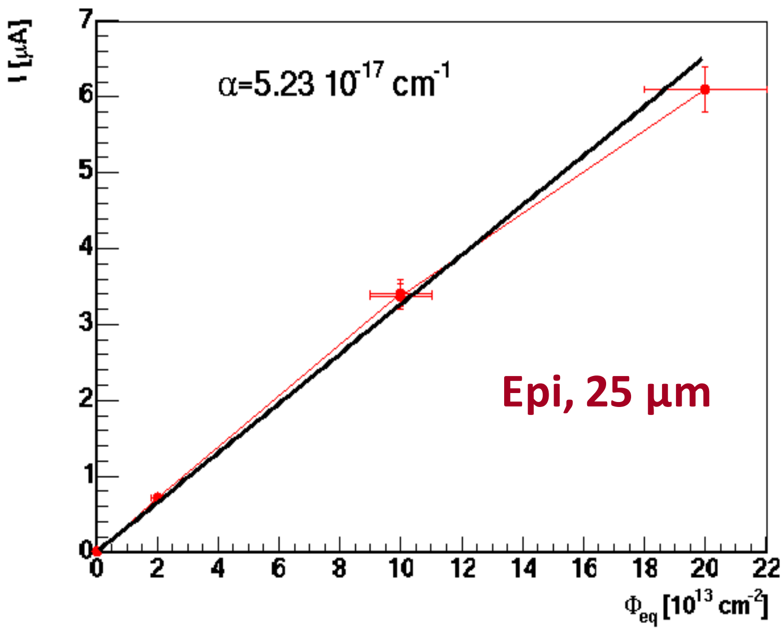
Reverse current proportional to fluence $\Delta I = \Phi_{eq}/\alpha V$

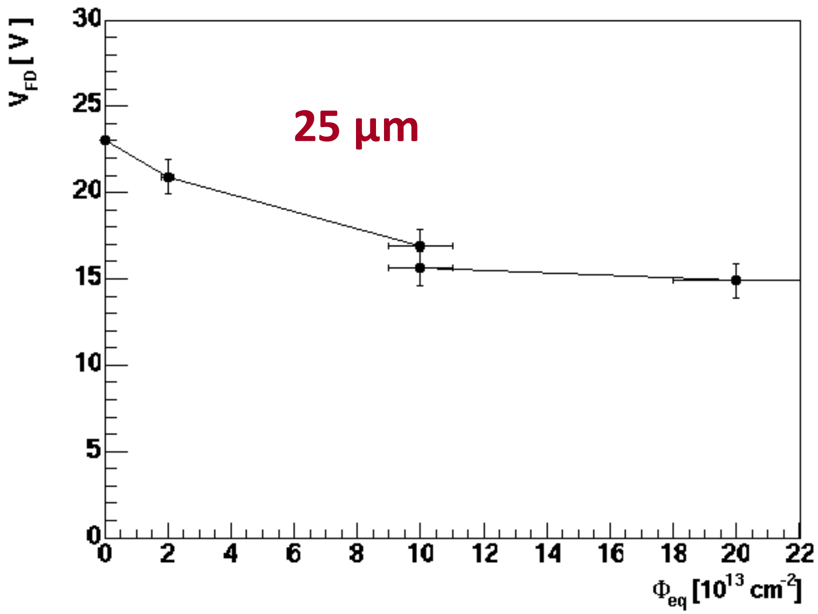
- **25 µm** x 0.5 cm x 0.5 cm pad diode with guard ring structure processed on epitaxial silicon

➔ **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

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

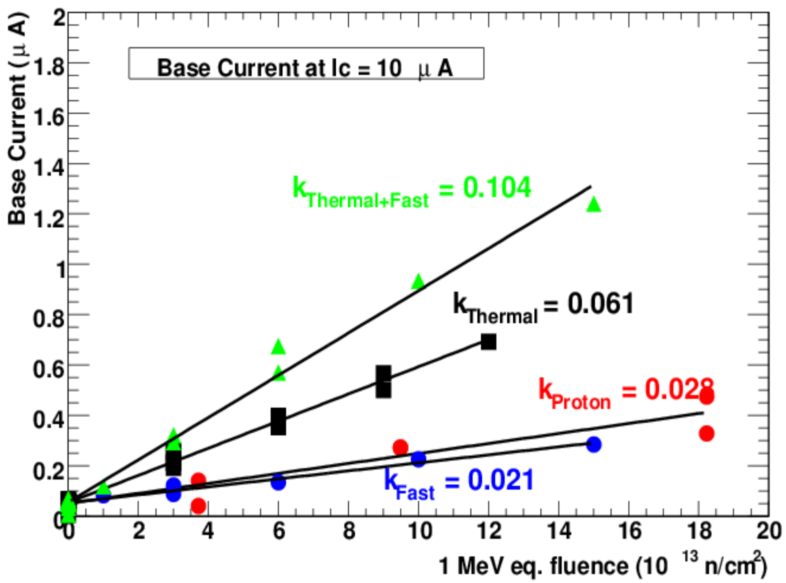


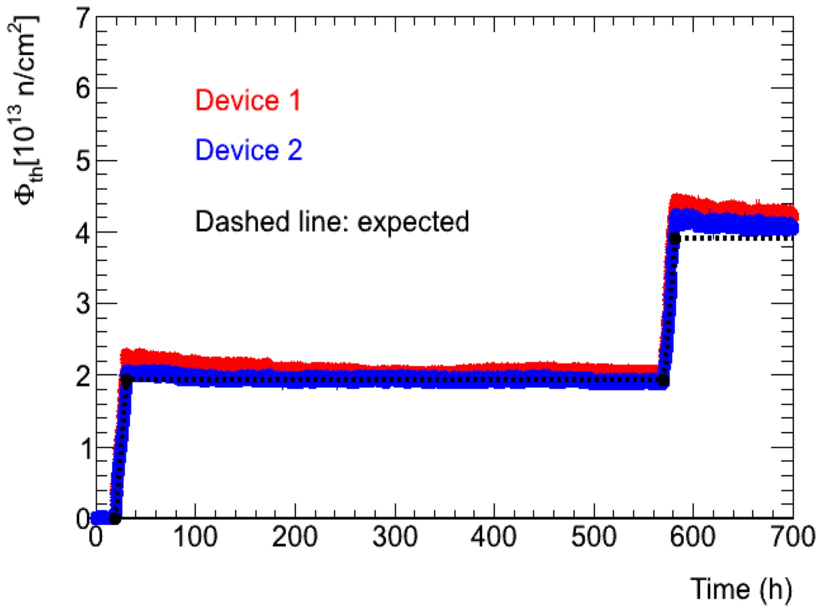


Thermal neutrons

- bipolar transistors (DMILL) used in front end ASICs
- measure base current at given collector current
  - ➔ monitor status of front end electronics
  - ➔ 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





Response to thermal neutrons (reactor)

Radiation Monitor Sensor Board (RMSB)

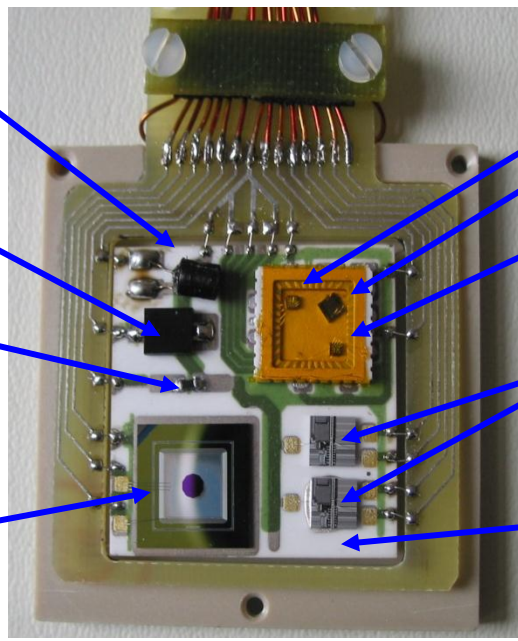
Inner Detector

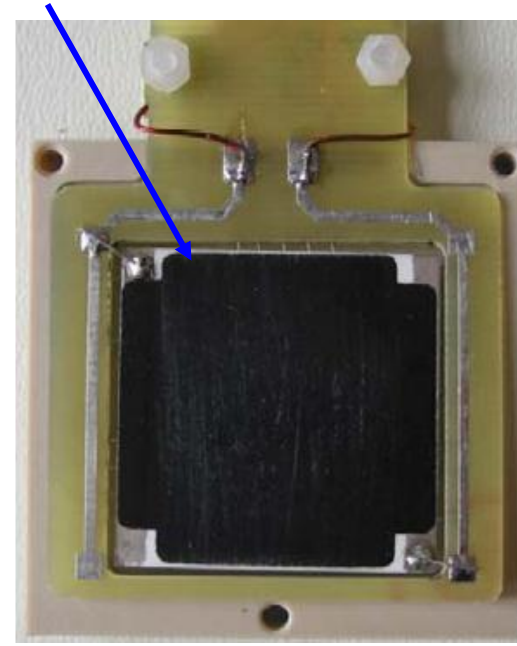
- for dose monitoring in the Inner Detector:
  - large range of doses
  - no access in 10 years

  ➔ **need many sensors**

- large temperature variations (5 to 20°C) at different locations

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



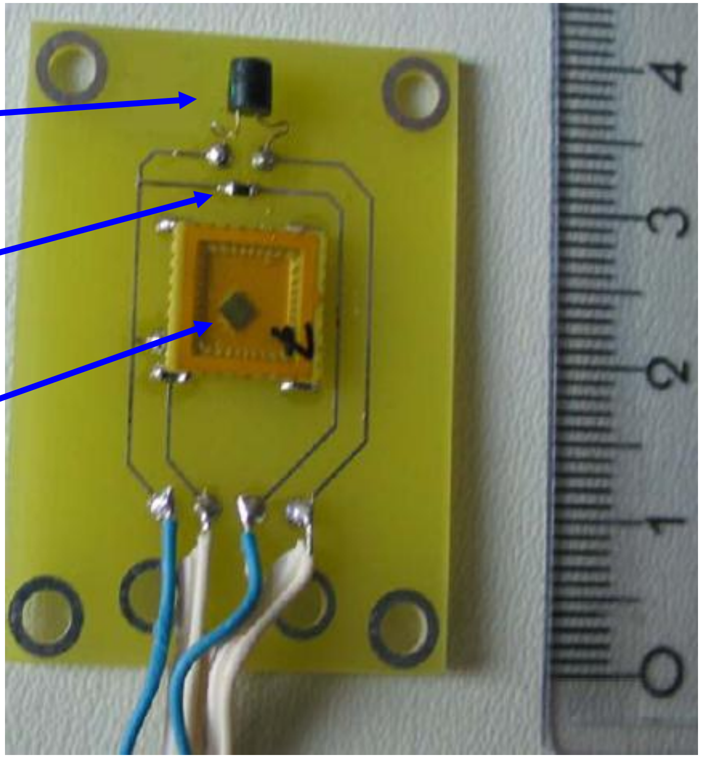


Back side

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



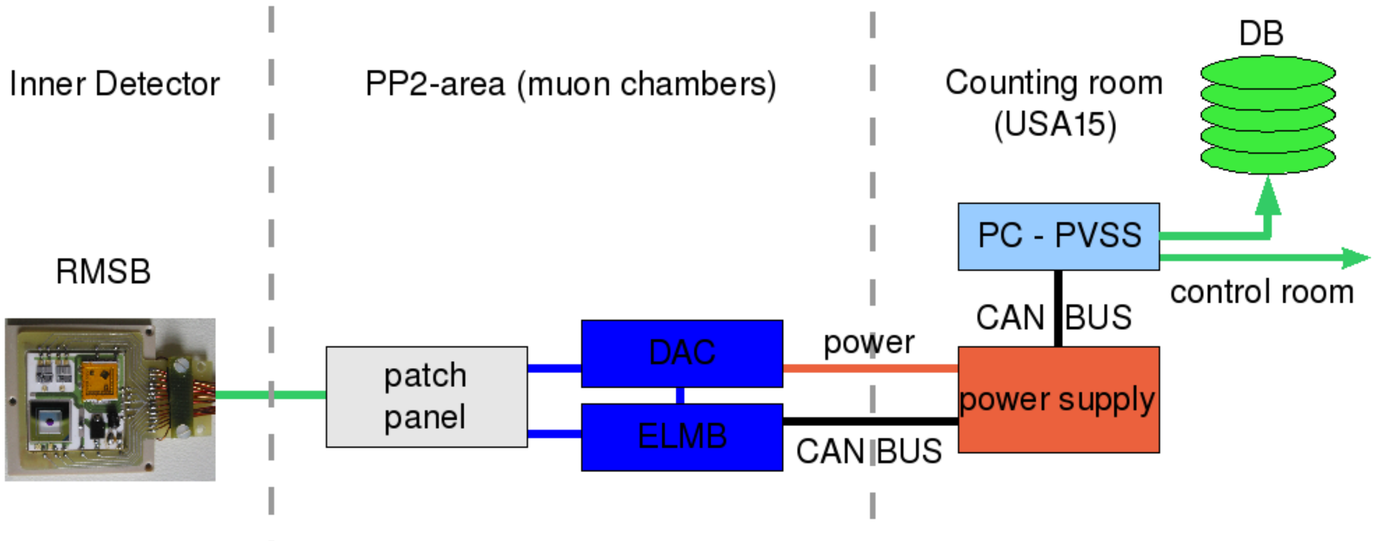
CMRP diode

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

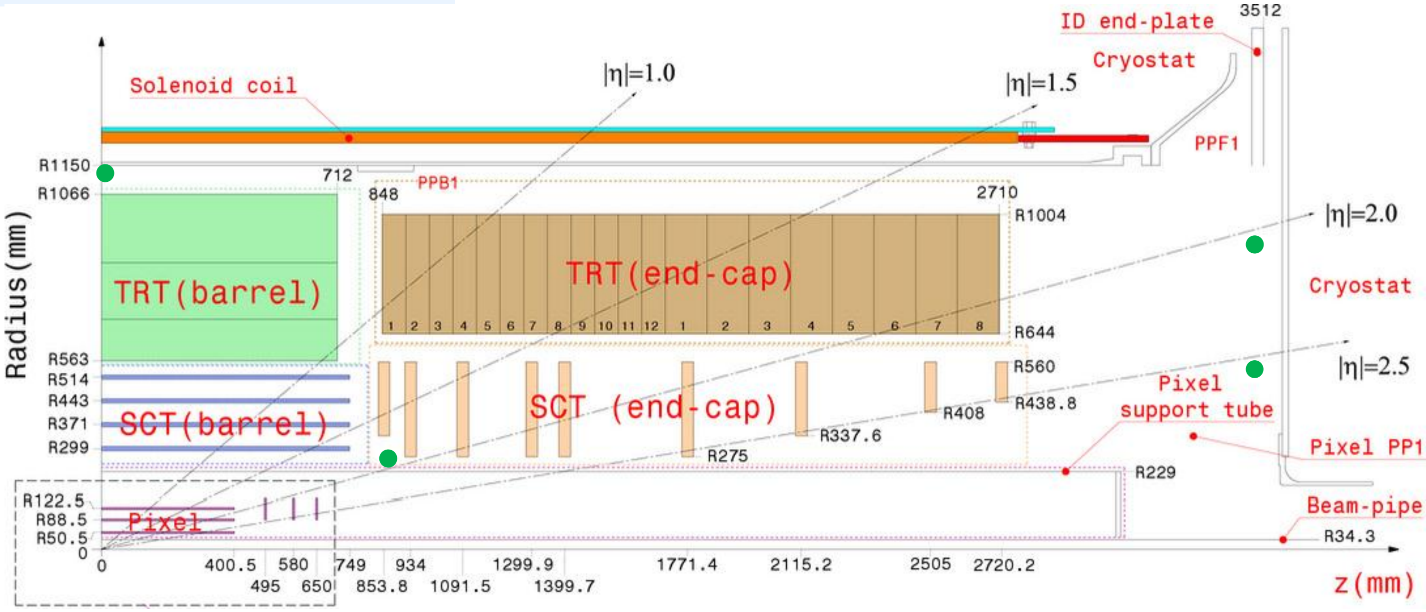


Cable length
~ 18 m

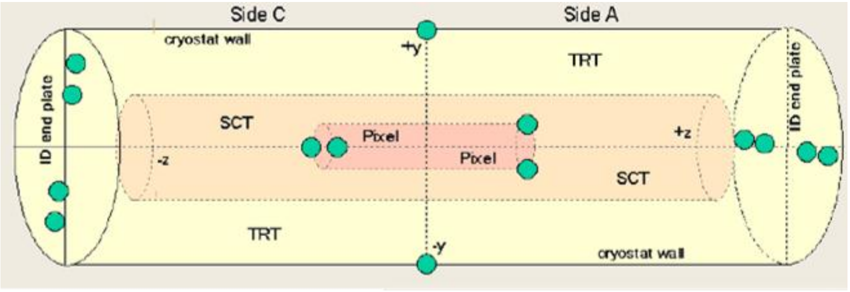
Cable length
~ 100 m

Monitoring Locations

- 14 monitors in the Inner Detector



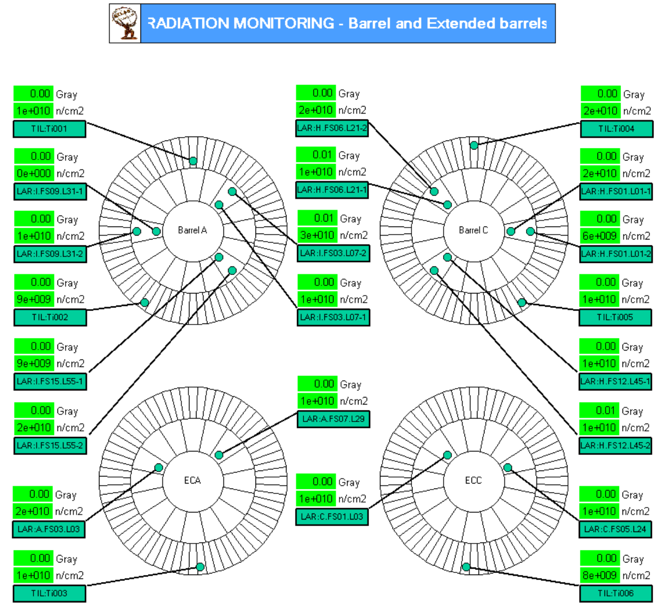
Location	*r* (cm)	|*z*| (cm)
Pixel Support Tube (PST)	23	90
ID end plate small r	54	345
ID end plate large r	80	345
Cryostat Wall	110	90



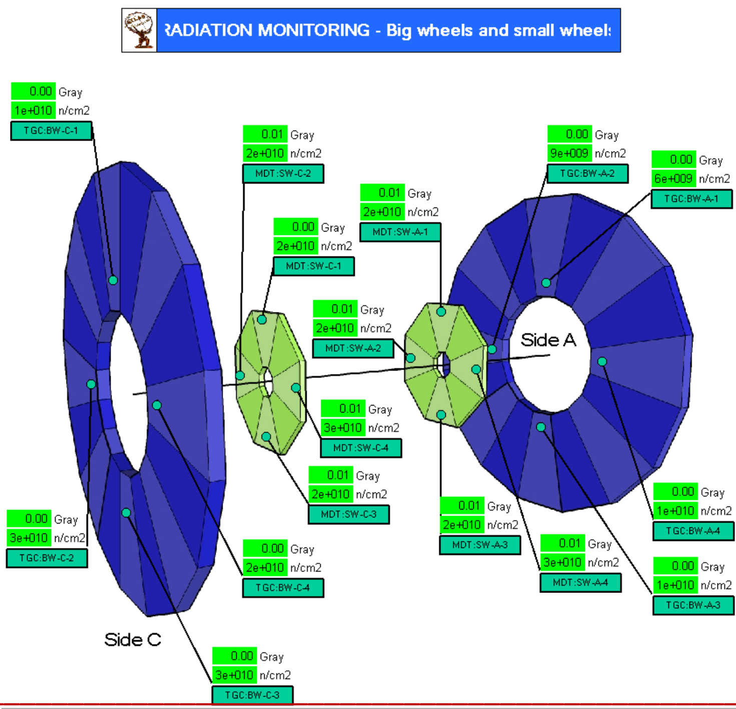
Monitoring Locations

- 48 locations at larger radii
- 2 monitors near ALFA (z = 240 m, r = 0.2 m)

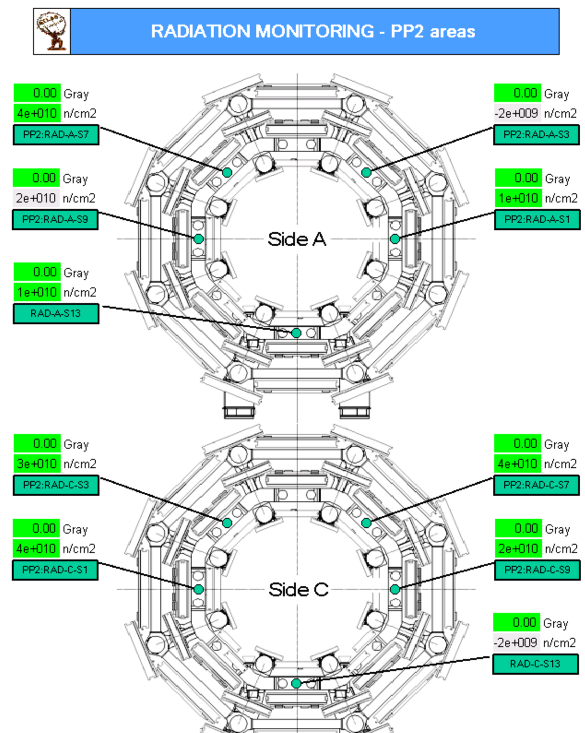
Calorimeters: 22



Muon detectors: 16



PP2: 10



FLUKA Simulations

More in:

- I. Dawson and C. Buttar, "The radiation environment in the ATLAS inner detector", *Nucl. Inst. Meth. A453*, pp. 461-467, 2000.
- M. Bosman, I. Dawson, V. Hedberg, M. Shupe, "ATLAS Radiation Background Taskforce Final Summary Document", ATL-GEN-2005-001.
- I. Dawson et al., "*Fluence and dose measurements in the ATLAS inner detector and comparison with simulation.*" ATL-INDET-INT-2011-004 http://cdsweb.cern.ch/record/1322208
- https://twiki.cern.ch/twiki/bin/viewauth/Atlas/BenchmarkingAtTheLHC

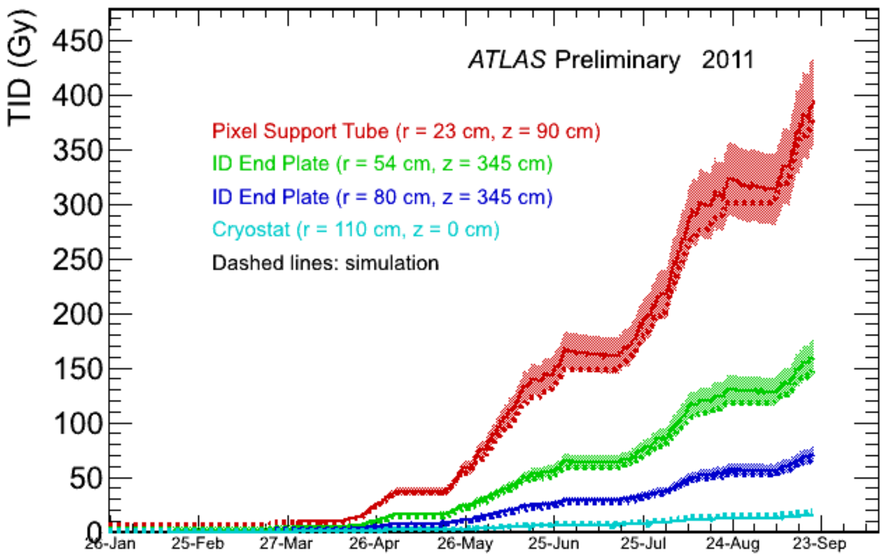
- FLUKA particle transport code
- PHOJET event generator
- simulations done for $\sqrt{s}$ = 7 TeV assuming a proton-proton inelastic cross section 77.5 mb as predicted by PHOJET

Doses and fluences per fb^{-1} of integrated luminosity

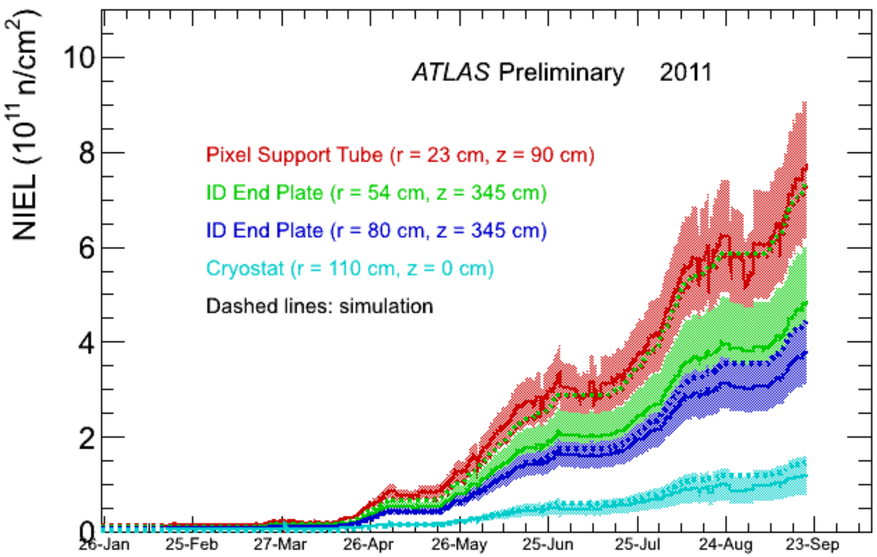
Location	Coordinates	Dose (Gy)	1 MeV equivalent neutron fluence (10^{11} n/cm^{-2})
Pixel support tube	r= 23 cm |z| = 90 cm	110	2.22
Inner Detector End Plate – small radius	r = 54 cm |z| = 345 cm	55.4	2.24
Inner Detector End Plate - large radius	r = 80 cm |z| = 345 cm	27.0	1.35
Cryostat Wall	r = 110 cm |z| = 0 cm	4.9	0.45

Results ID

- data up to 20th September
  → integrated luminosity ~ 3.4 fb^{-1}



TID measured with 0.13 um RadFET
(low sensitivity)



Fluence measured with CMRP diode
(high sensitivity, forward bias)

- averages of measurements with sensors at similar locations shown

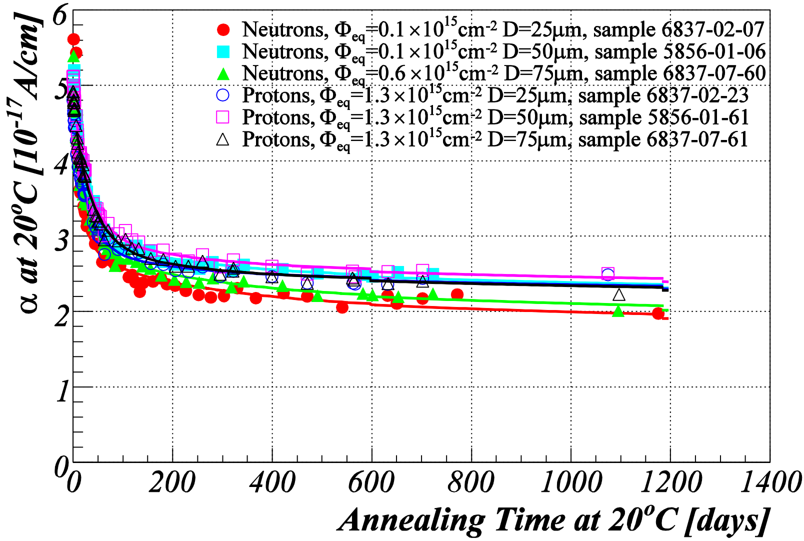
  ➔ excellent agreement with predictions!

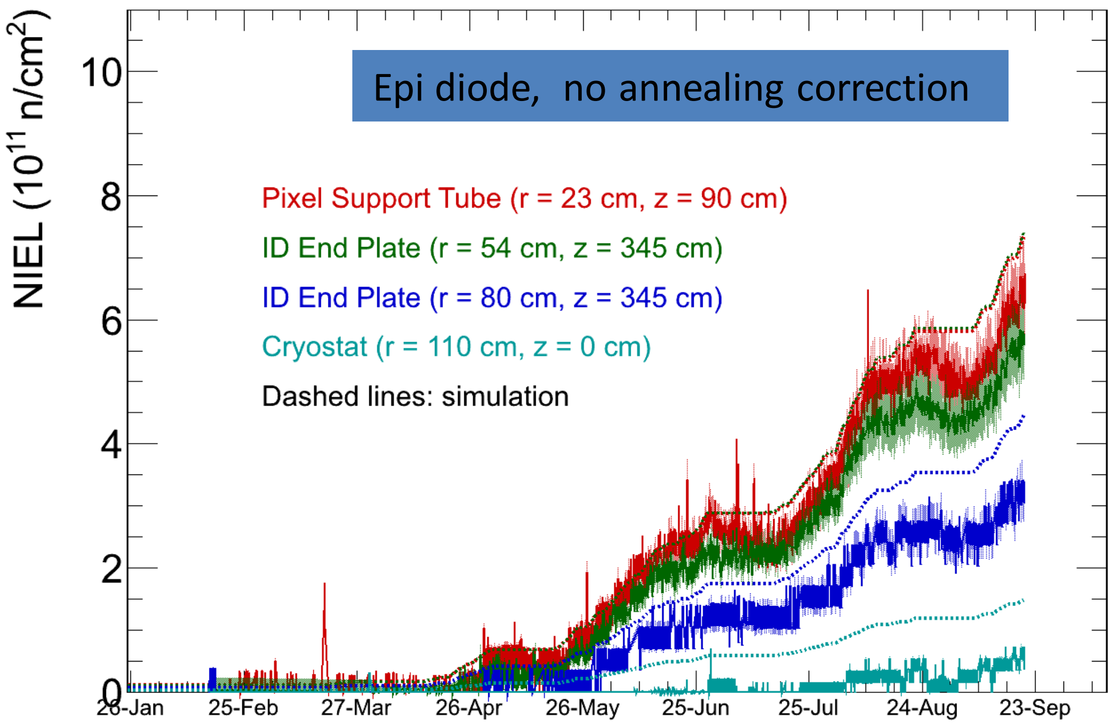
Results with EPI diode

NIEL measurements with EPI diode: ***$\Phi_{eq} = \alpha V I$***

→ use α = 3.5e-17 A/cm, no annealing corrections

➔ good agreement with simulations
→ annealing corrections to be implemented

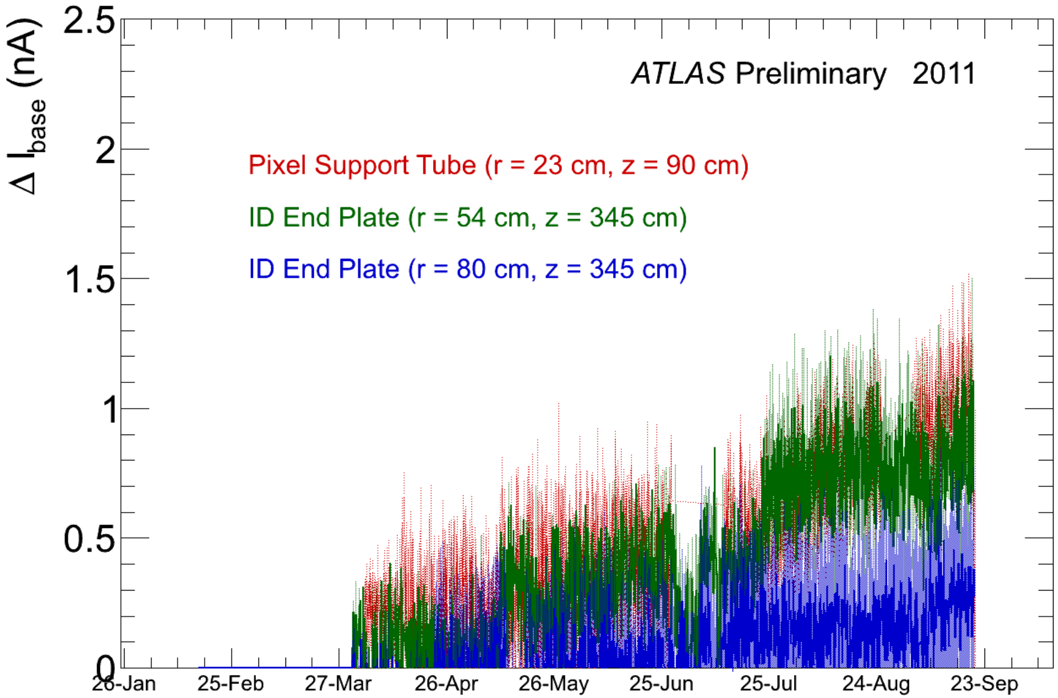




Results ID

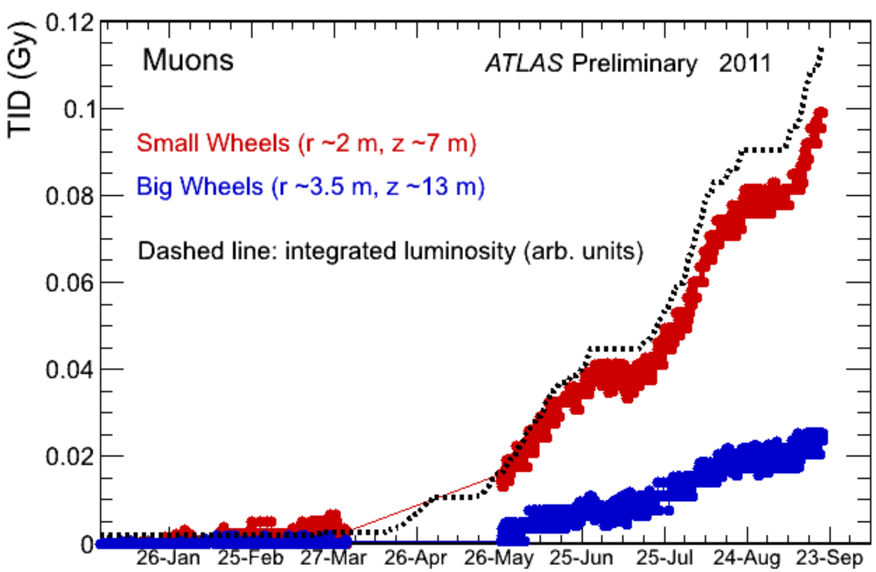
- first signs of base current increase in DMILL bipolar transistors
- current increase consistent with thermal neutron fluence of the order of 1e11 n/cm2

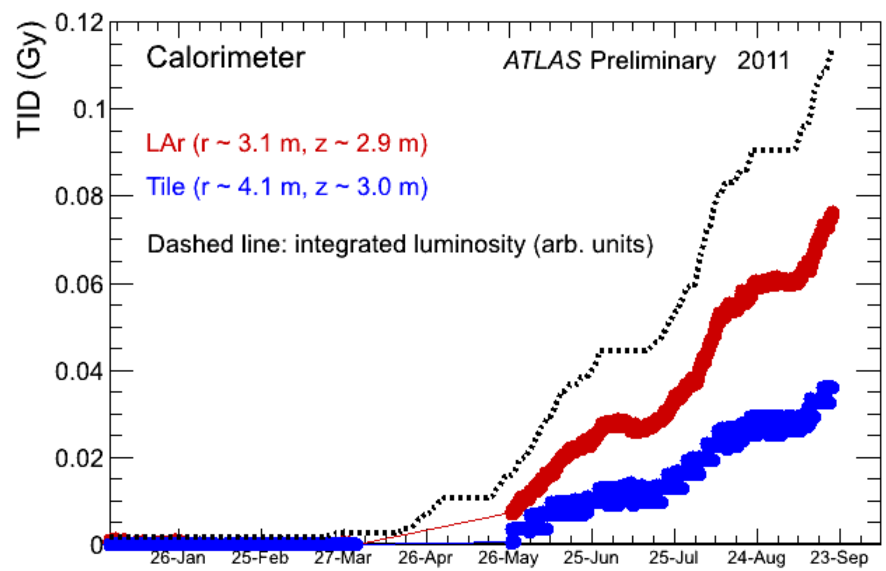
  → in agreement with FLUKA



Results out of ID

- outside of ID doses still very low, on the limit of sensitivity
- accumulated dose proportional to integrated luminosity
- neutron fluences too low for reliable measurements





Conclusions

- doses and fluences proportional to integrated luminosity

- in the Inner Detector excellent agreement with predictions from FLUKA simulations

  → important for prediction of future detector performance

  → and predictions for HL-LHC

Add.1

- TID and NIEL for 2010 and 2011 in log scale