Online Radiation Dose Monitoring System in ATLAS Detector

I. Mandić[a], V. Cindro[a], I. Dolenc[a], M. Deliyergiyev[a], A. Gorišek[a], G. Kramberger[a], M. Mikuž[a,b], J. Hartert[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*

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

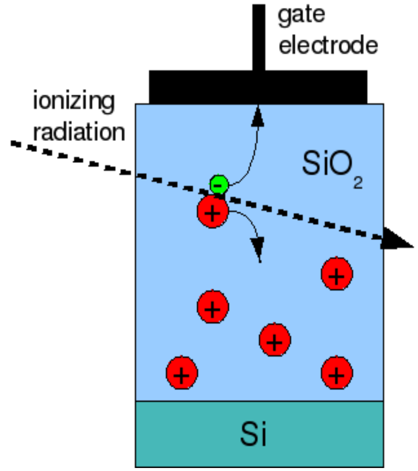
- online radiation dose monitoring system measures accumulated total ionizing dose TID, displacement damage in silicon (NIEL) and fluences of thermal neutrons.
- doses are monitored at **14 locations in the Inner Detector** and at **48 locations at larger radii**
- sensors are read out every 60 minutes and readings are stored in the DCS database.

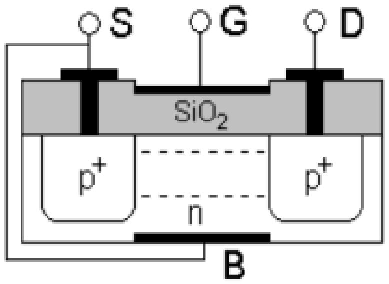
More information about the monitoring system in:

- 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.
- 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.
- 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.*
- 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:
  $\Delta V = a\ x\ (TID)^b$
- sensitivity and dynamic range depend on oxide thickness:





NIEL measurements with diodes

- bulk damage in silicon: increased resistance, reduction of carrier lifetime, increase of reverse current
  ➔ forward bias: voltage at given forward current increases $\Delta V = k \cdot \Phi_{eq}$
  ➔ reverse bias: reverse current increases $\Delta I = \Phi_{eq}/\alpha V$

Forward bias:
•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

Reverse bias:
• **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

Thermal neutrons

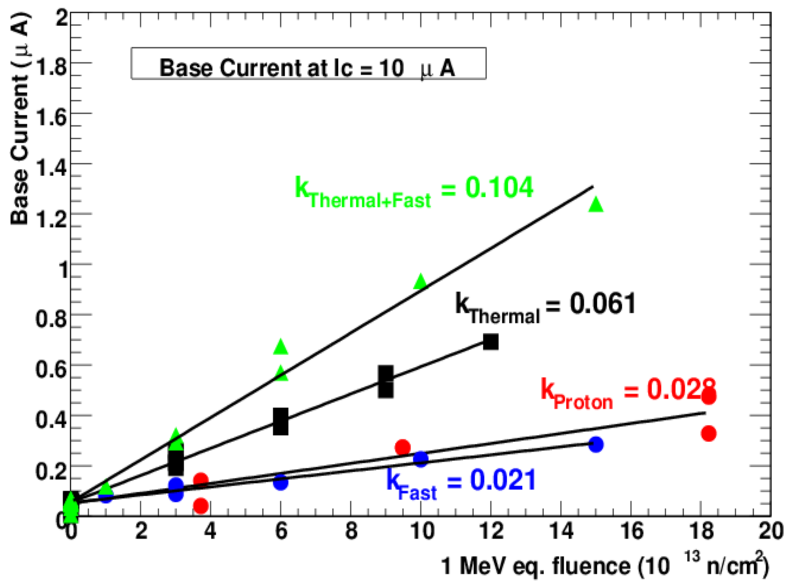
- DMILL bipolar transistors produced by ATMEL
- measure base current at 10 uA collector current in common emitter configuration

  → sensitive to fast and thermal neutrons

  → same transistors as ABCD3T input transistor

  → monitoring the status of chips

$\Delta I_b/I_c = k_{eq} \cdot \Phi_{eq} + k_{th} \cdot \Phi_{th}$; k_{eq}, k_{th} and Φ_{eq} known → Φ_{th} can be determined



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

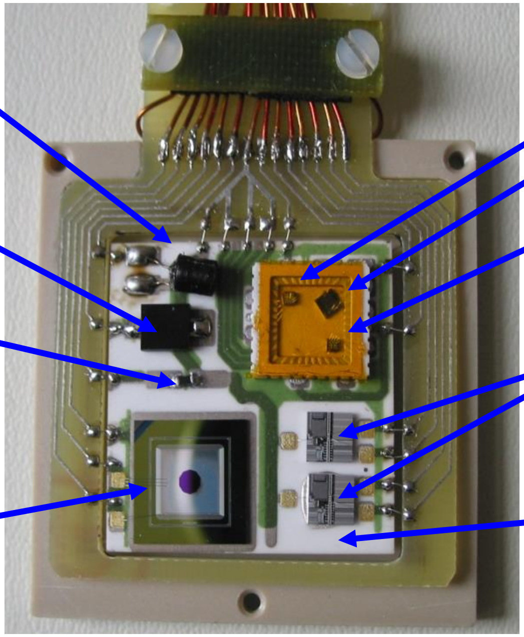
  ➔ stabilize temperature to 20 ± 1°C by heating back side of the ceramic hybrid

CMRP diode

BPW34 diode

Thermistor

epi diode



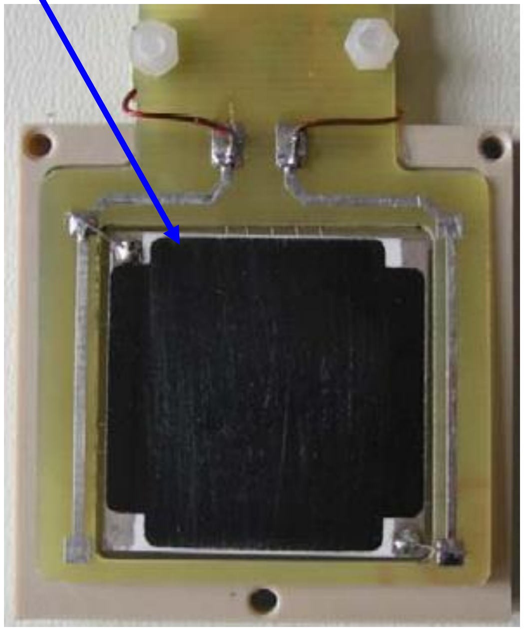
4 cm

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

Bipolar transistors

Ceramic hybrid (Al_2O_3)

Thick film resistive layer R = 320 Ω

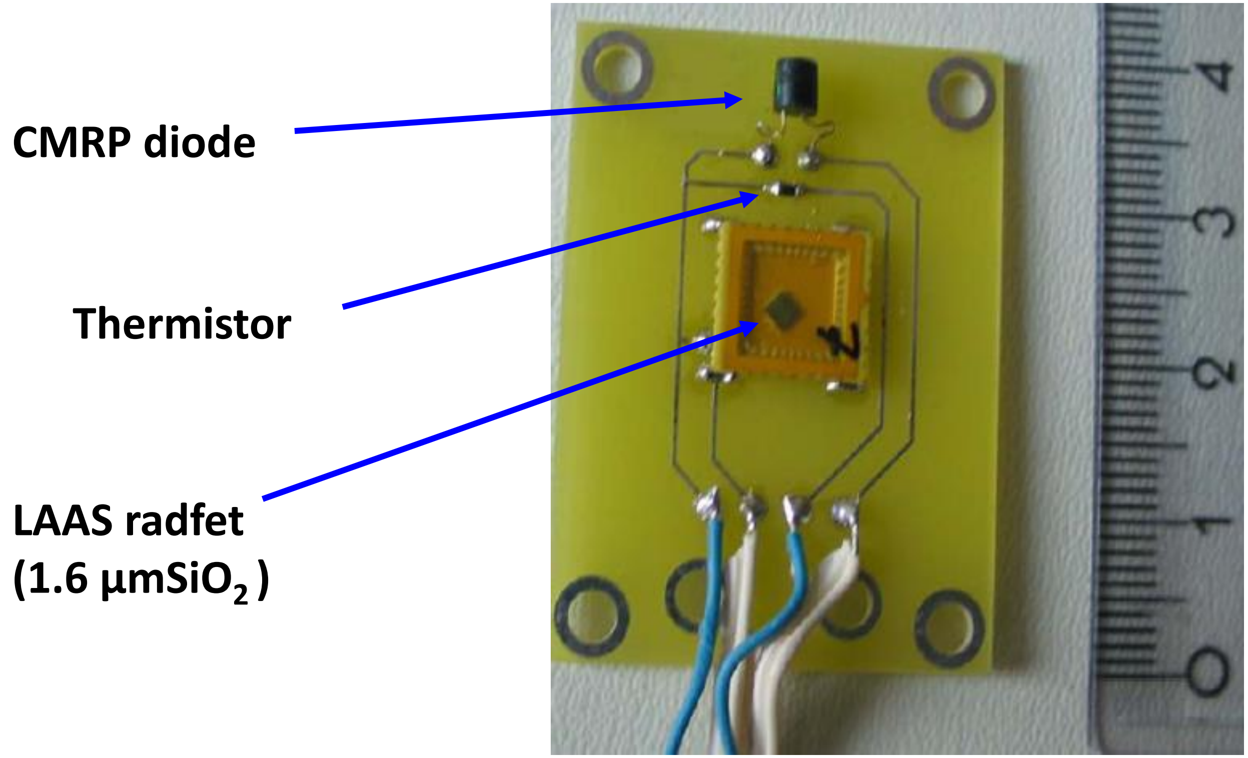


Back side

Radiation Monitor Sensor Board (RMSB)

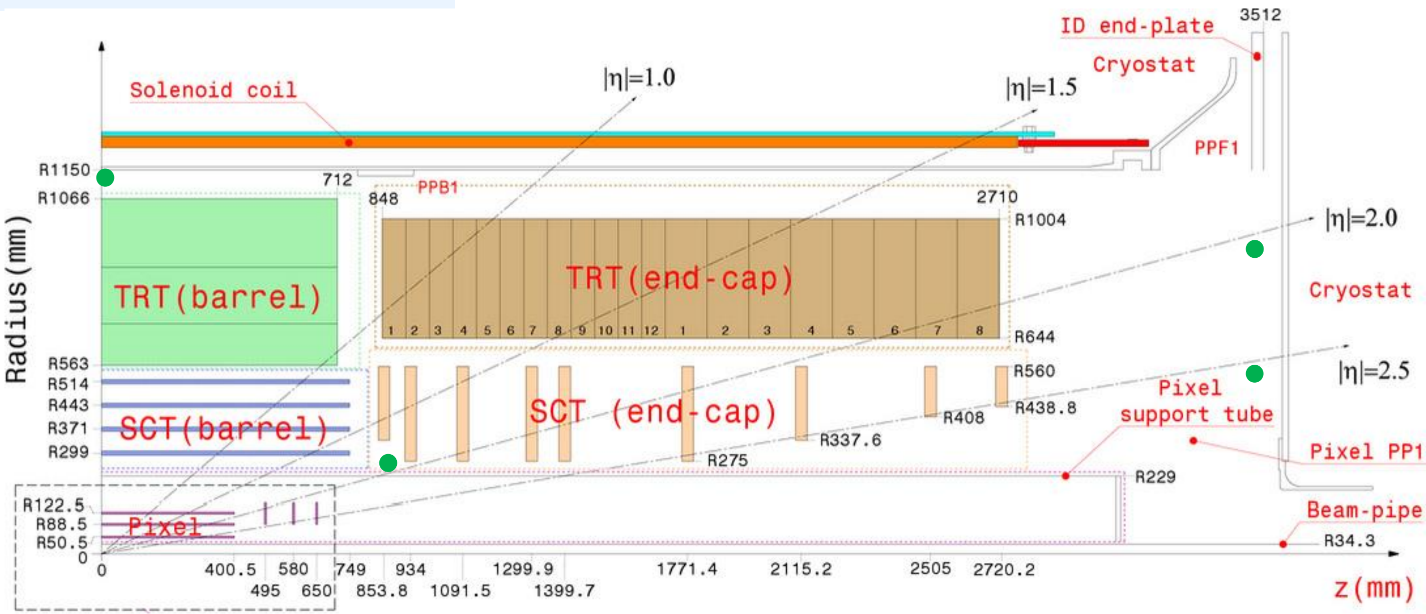
Other locations (Calorimeters, Muons, PP2)

- 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

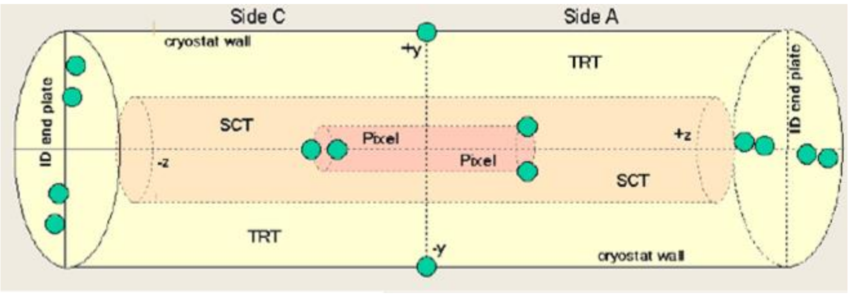


Results: Inner Detector

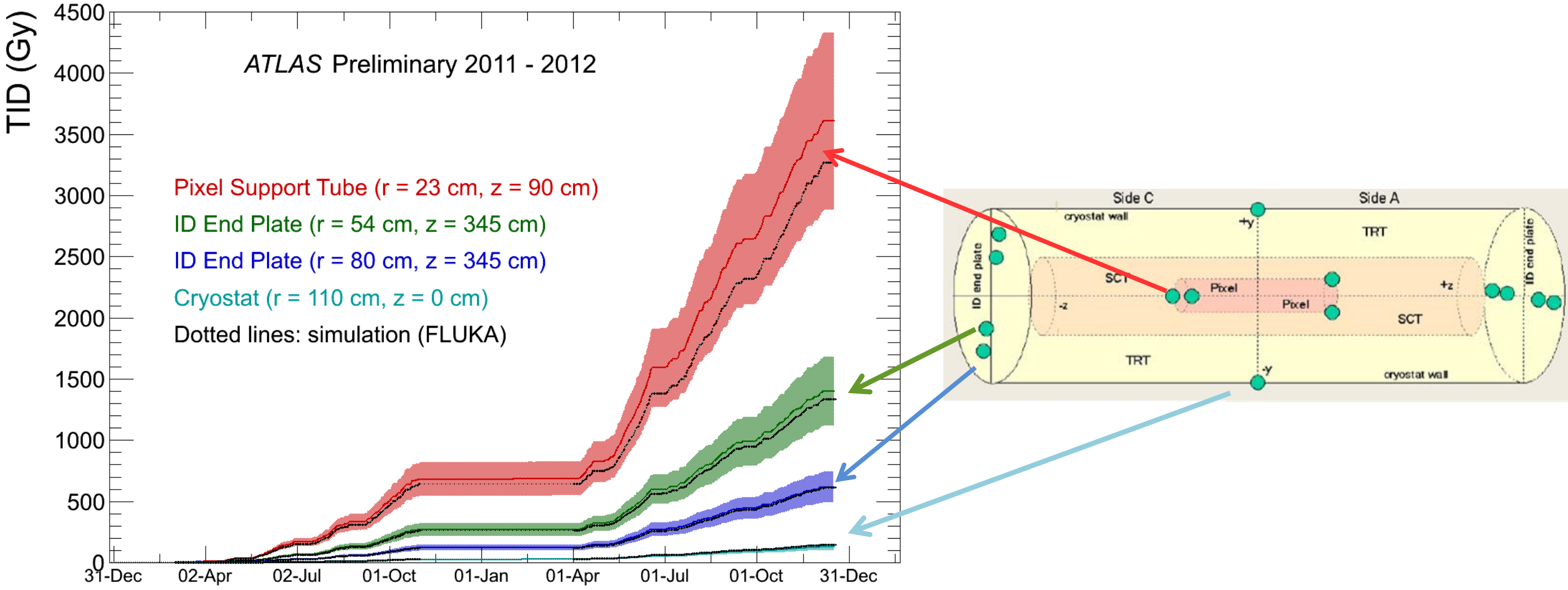
- 14 monitors in the Inner Detector



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



Results TID



- REM 0.13 µm RadFETs
- plot shows averages for each location type, error bars = sqrt(spread^2 + (20%)^2)

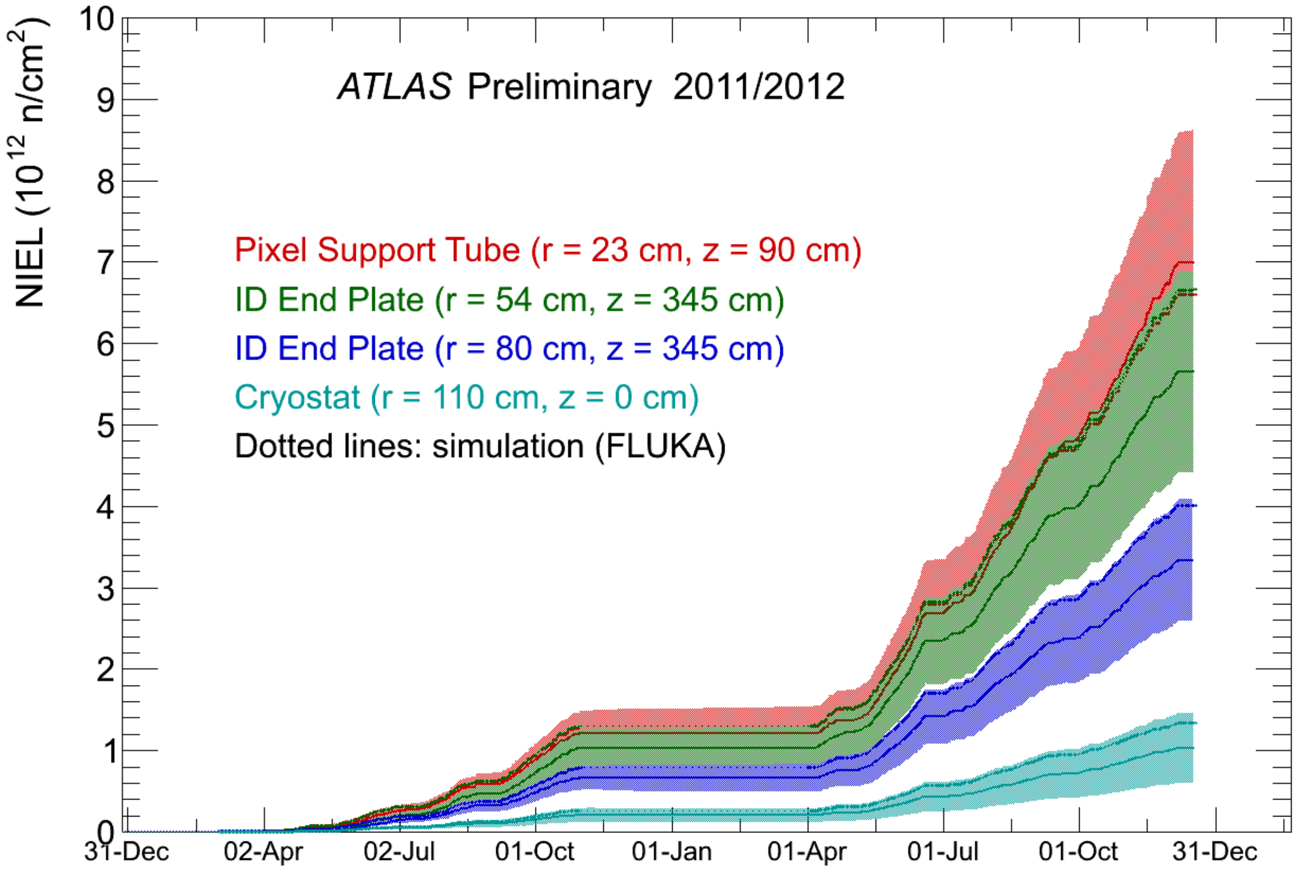
- simulated curves: Dose = Integrated_luminosity * dose_factor

  → Dose factors (Gy/pb^{-1}) from:

  https://twiki.cern.ch/twiki/bin/viewauth/Atlas/BenchmarkingAtTheLHC

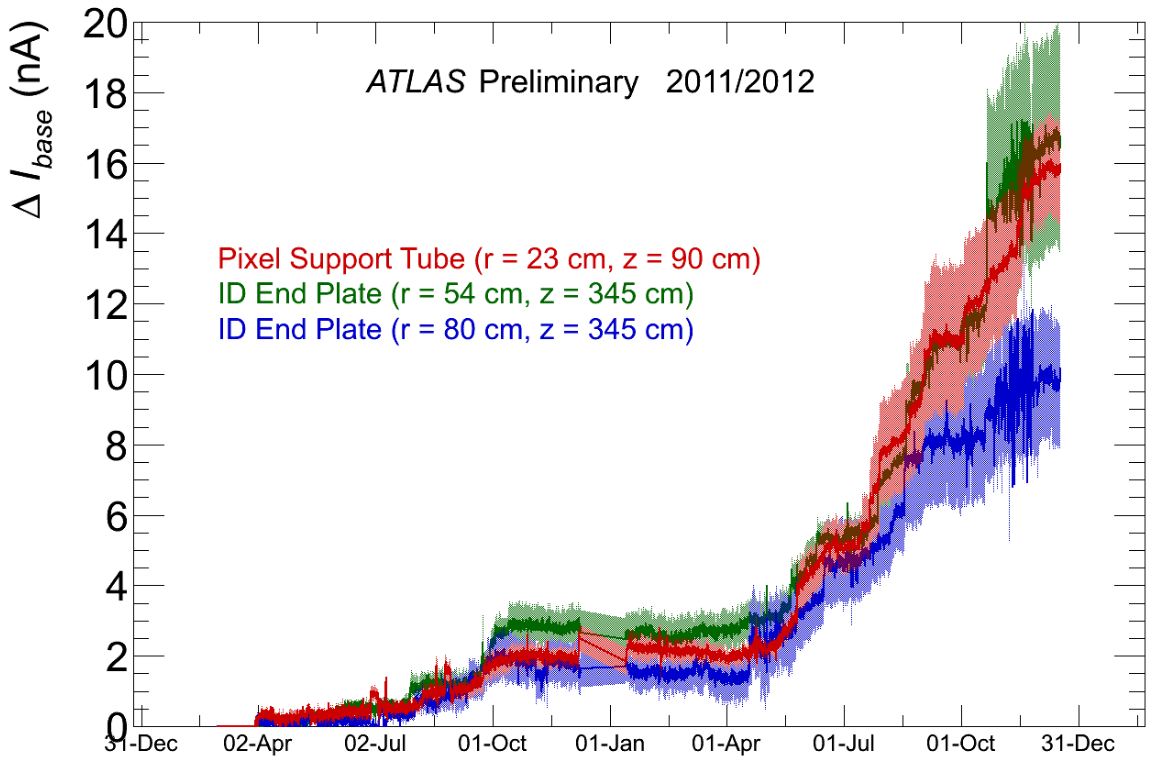
  (Fluka simulations, I. Dawson, L. Nicolas et al.).

Results NIEL (equivalent fluence of 1 MeV neutrons)



- PST and IDE endplates: measured with Epi-diodes
- Cryostat: measured with CMRP diode (high sensitivity)
  → annealing correction made

DMILL transistors



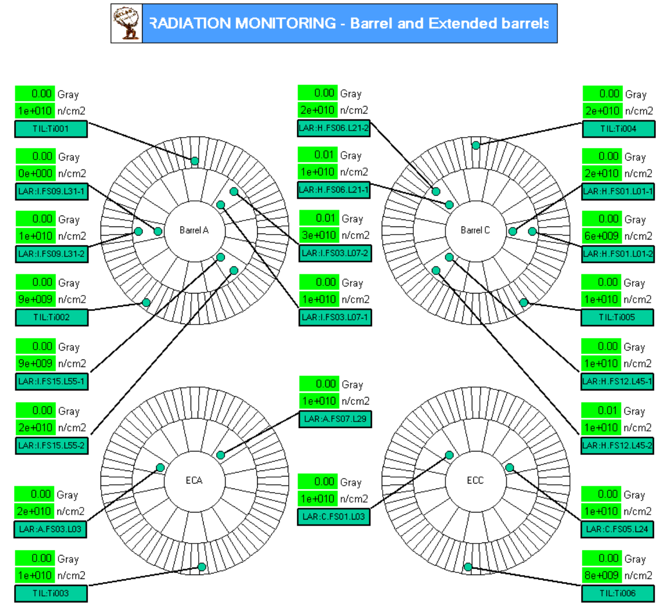
- increase of base current correlated with integrated luminosity observed
- several sharp jumps not yet understood
- consistent with thermal neutron fluences ~ 10^{12} n/cm²

  ➔ consistent with FLUKA

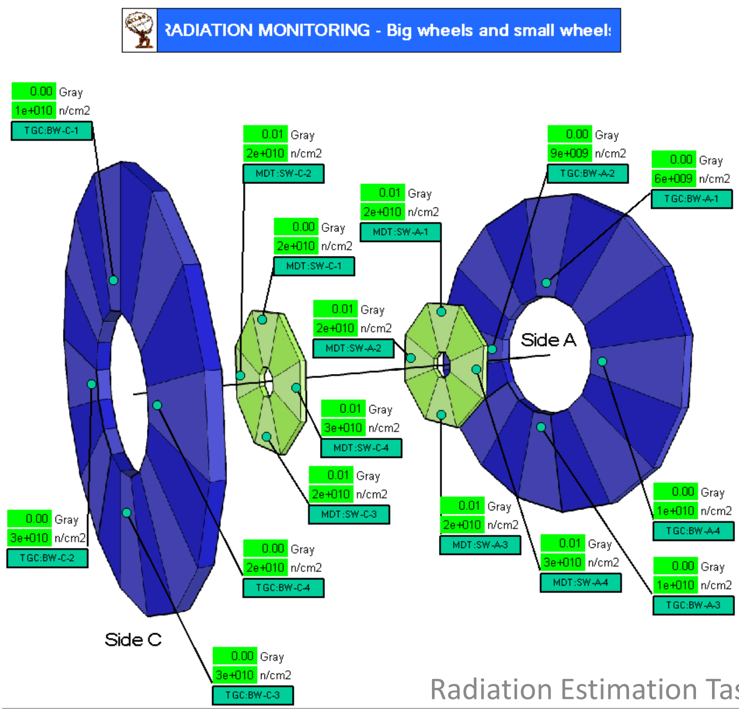
Monitoring locations at larger radius

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

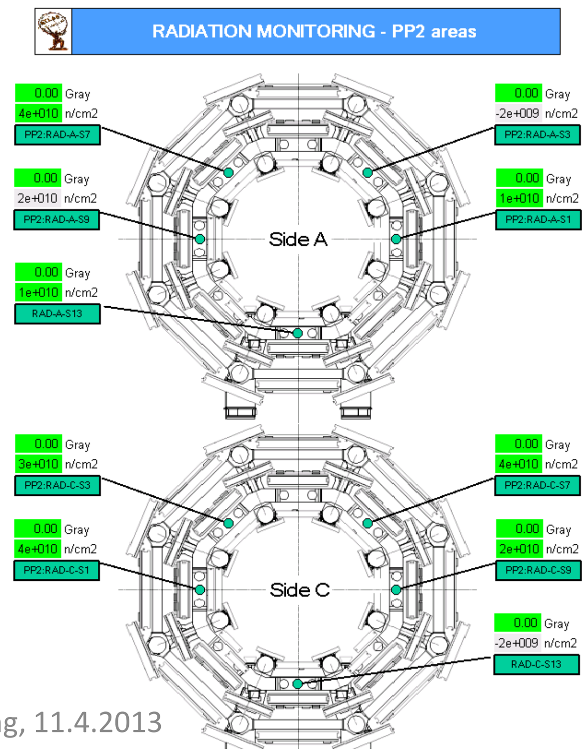
Calorimeters: 22



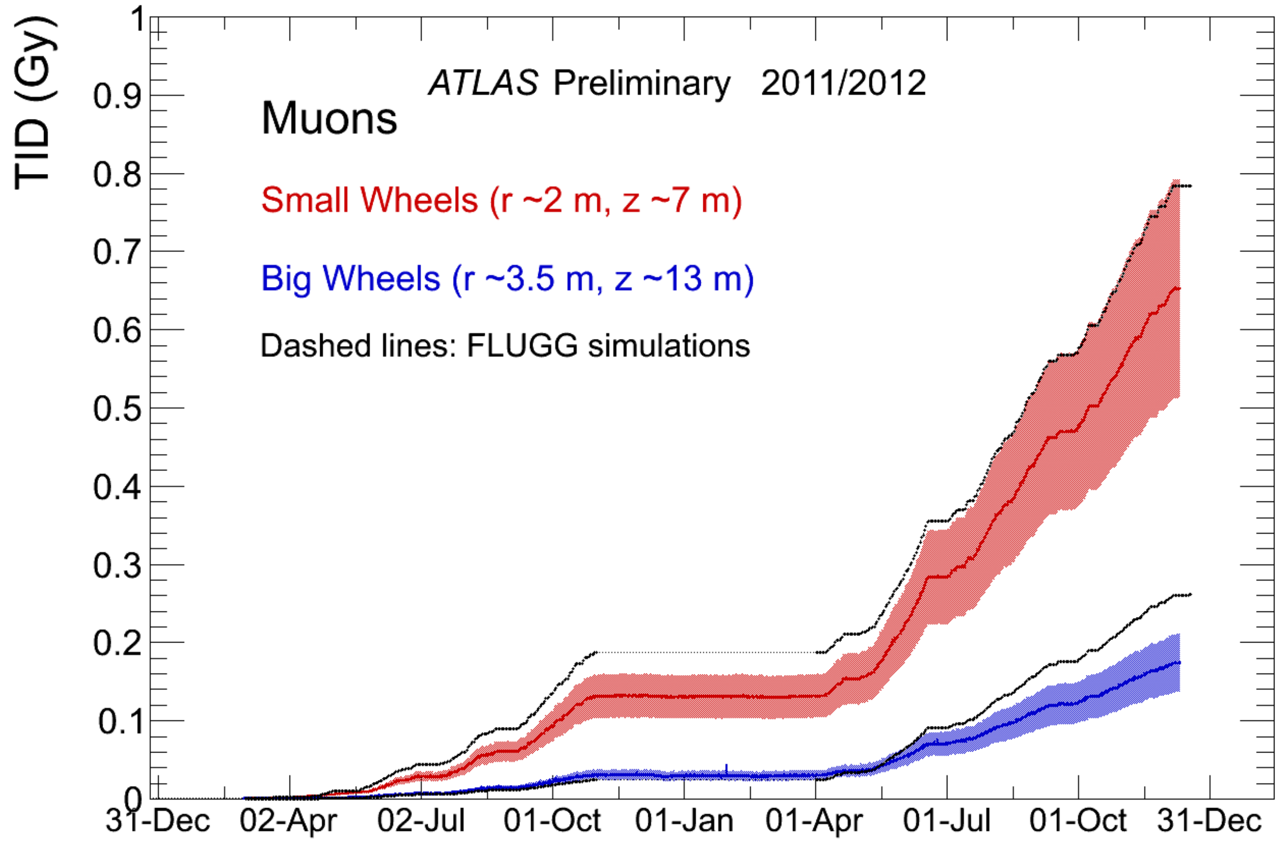
Muon detectors: 16



PP2: 10



Muons TID

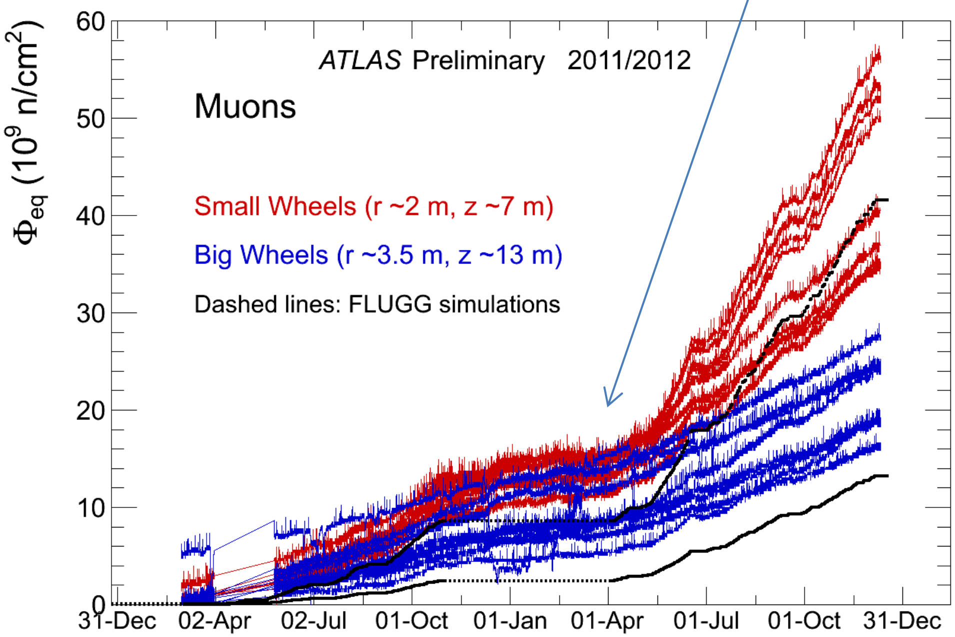


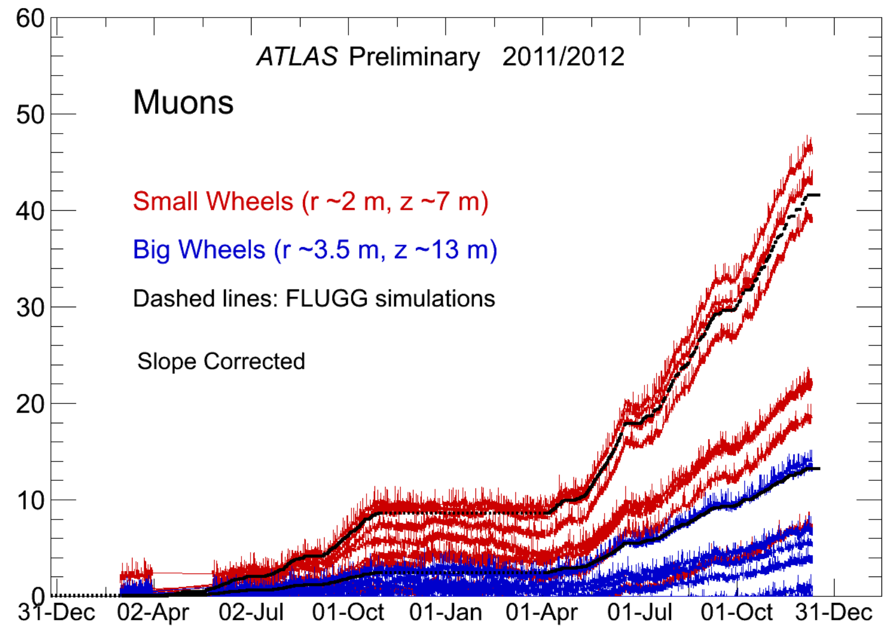
Line: average, shaded area: sqrt(spread^2 + 20%^{2})

TID: good agreement with FLUGG simulation
(simulation numbers from C. Young et al.)

Muons NIEL

➔ problem: for some sensors readout voltage increases with time also when no beam

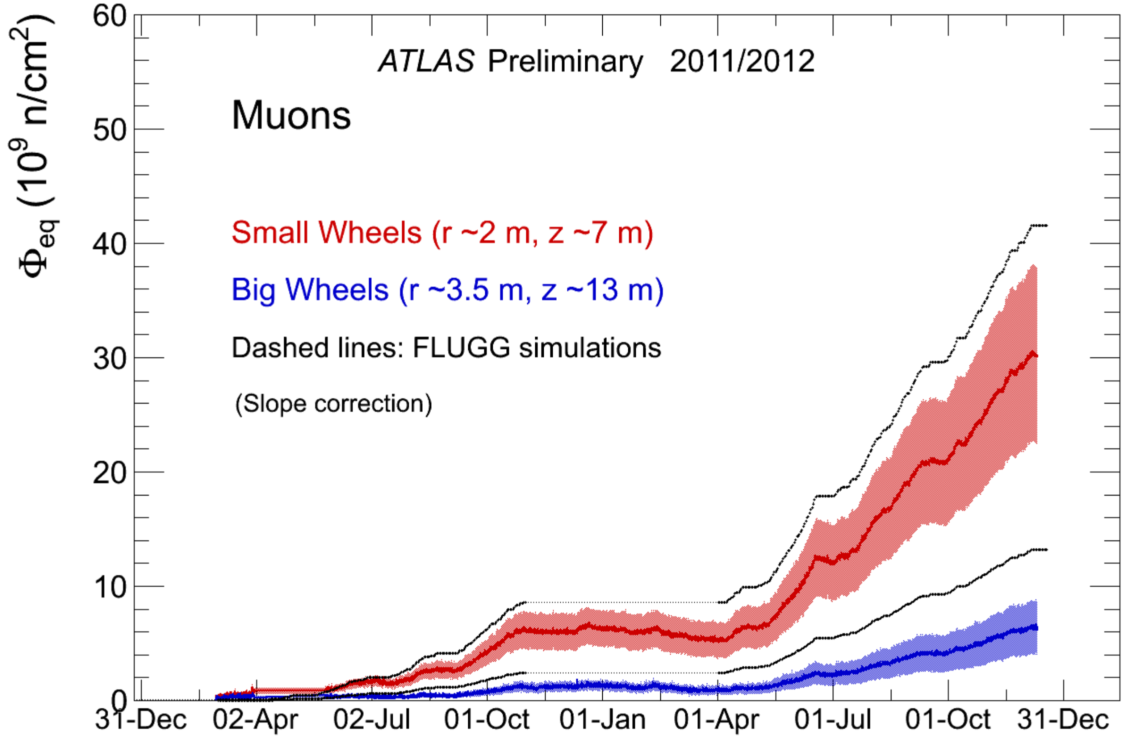




subtract the drift

- try to correct this drift:
  ➔ linear fit during no beam period ➔ subtract the drift contribution

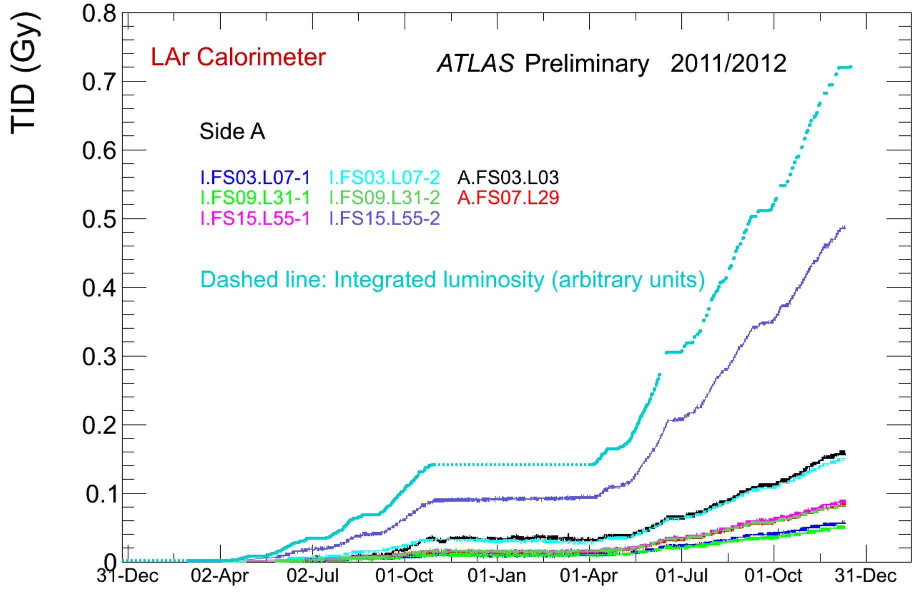
Muons NIEL

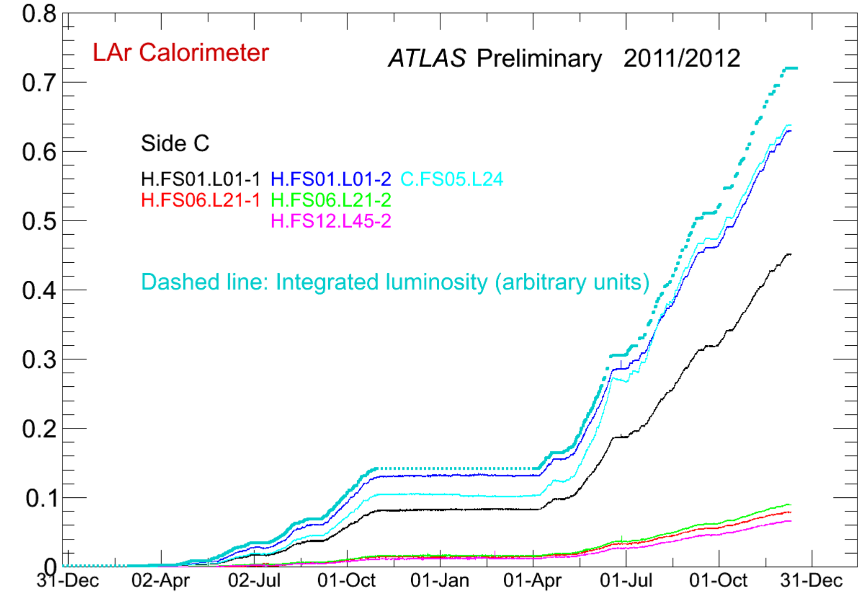


Line: average, shaded area: sqrt(spread^2 + 20%^{2})

- good agreement with simulation → annealing correction to be done

LAr Calorimeter dose





Side A:

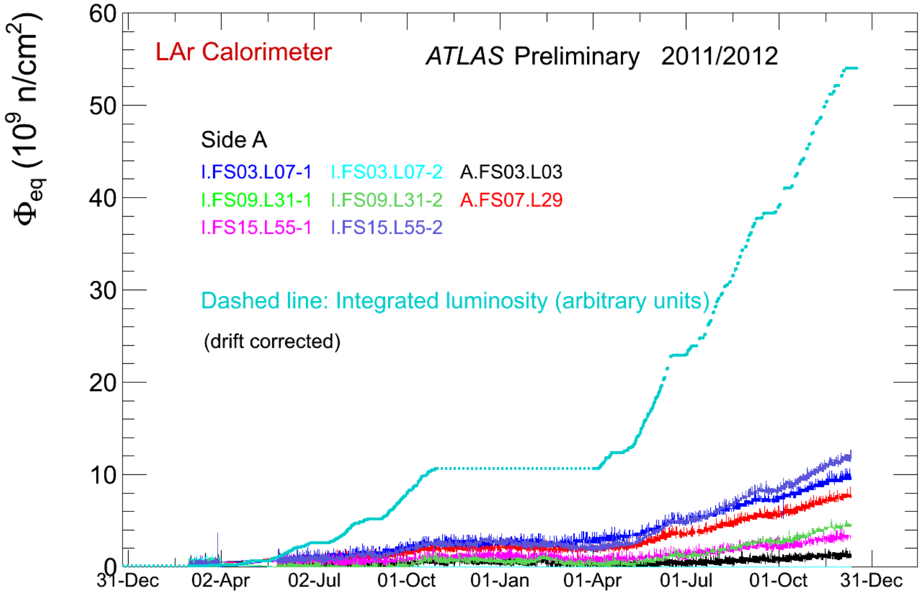
Location	R (m)	Z (m)	Phi (°)	Last Point (Gy)
A.FS03.L03	3075	6430	150	0.16
A.FS07.L29	3075	6430	45	0.08
I.FS03.L07-1	3075	2859	45	0.06
I.FS09.L31-1	3075	2859	180	0.05
I.FS15.L55-1	3075	2859	-45	0.09
I.FS03.L07-2	4130	3169	45	0.15
I.FS09.L31-2	4130	3169	180	0.08
I.FS15.L55-2	4130	3169	-45	0.48

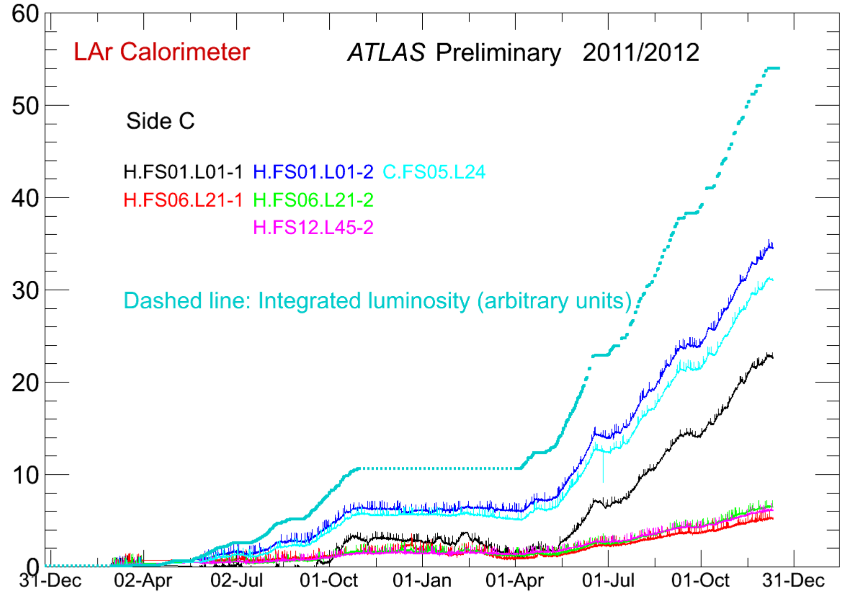
Side C:

Location	R (m)	Z (m)	Phi (°)	Last Point (Gy)
H.FS01.L01-1	3075	-2859	0	0.45
H.FS06.L21-1	3075	-2859	135	0.08
H.FS01.L01-2	3075	-2859	225	0.63
H.FS06.L21-2	4130	-3169	0	0.09
H.FS12.L45-2	4130	-3169	135	0.07
C.FS05.L24	4130	-3169	225	0.64
C.FS01.L03	3075	-6430	135	#
C.FS12.L45-2	3075	-6430	30	#

→ no obvious correlation between location and dose

LAr Calorimeter fluence





Side A:

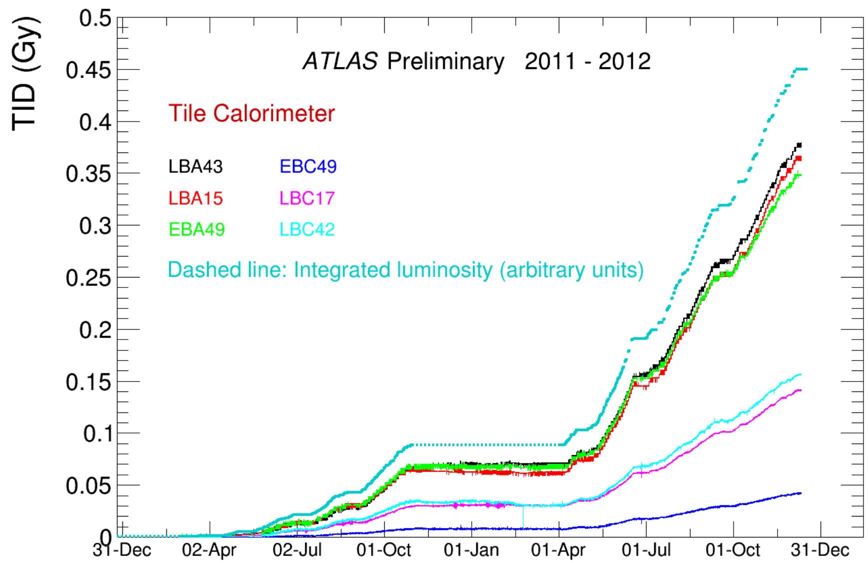
Location	R (m)	Z (m)	Phi (°)	Last Point
A.FS03.L03	**3075**	**6430**	**150**	**1**
A.FS07.L29	**3075**	**6430**	**45**	**8**
I.FS03.L07-1	**3075**	**2859**	**45**	**9**
I.FS09.L31-1	**3075**	**2859**	**180**	**0**
I.FS15.L55-1	**3075**	**2859**	**-45**	**3**
I.FS03.L07-2	**4130**	**3169**	**45**	**0**
I.FS09.L31-2	**4130**	**3169**	**180**	**4**
I.FS15.L55-2	**4130**	**3169**	**-45**	**12**

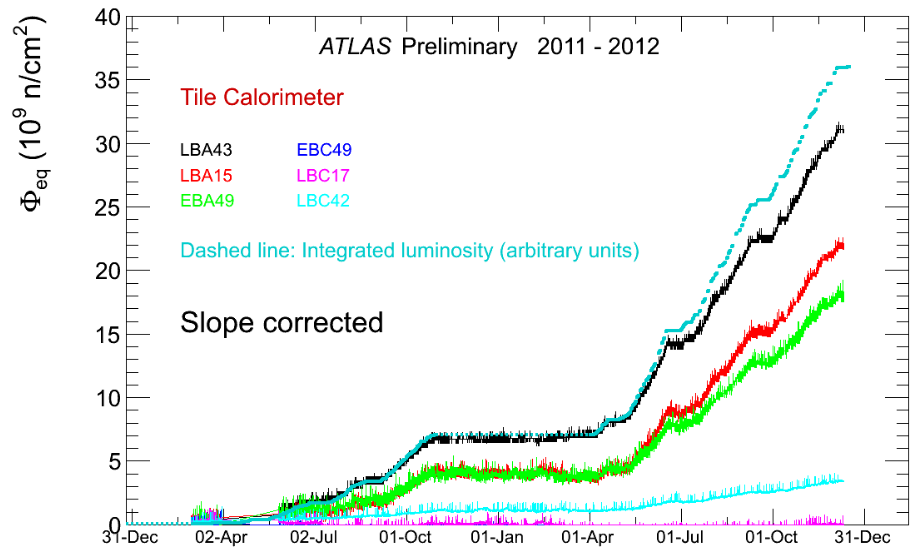
Side C:

Location	R (m)	Z (m)	Phi (°)	Last Point
H.FS01.L01-1	**3075**	**-2859**	**0**	**23**
H.FS06.L21-1	**3075**	**-2859**	**135**	**5**
H.FS01.L01-2	**3075**	**-2859**	**225**	**34**
H.FS06.L21-2	**4130**	**-3169**	**0**	**7**
H.FS12.L45-2	**4130**	**-3169**	**135**	**6**
C.FS05.L24	**4130**	**-3169**	**225**	**31**
C.FS01.L03	3075	-6430	135	#
C.FS12.L45-2	3075	-6430	30	#

→ no obvious correlation between location and dose

Tile Calorimeter:



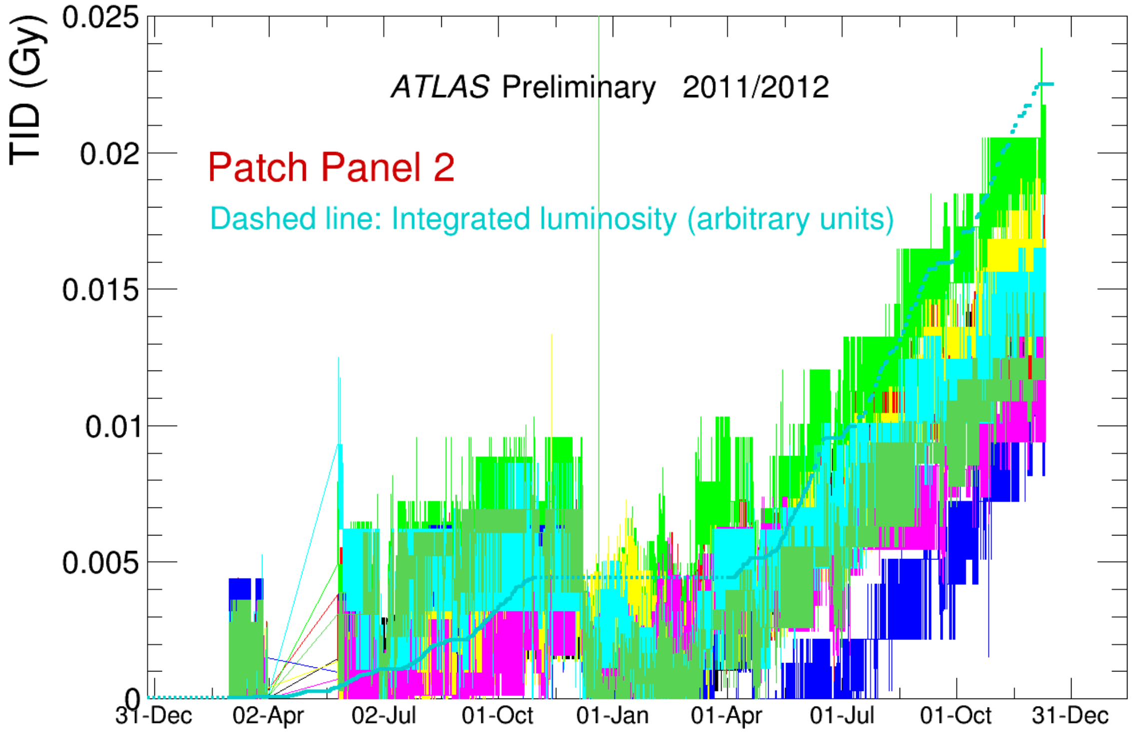


Location	R (m)	Z (m)	Phi (°)
LBA43	**4050**	**2970**	**90**
LBA15	**4050**	**2970**	**-45**
EBA49	**4050**	**6260**	**-135**
EBC49	**4050**	**-6260**	**-135**
LBC17	**4050**	**-2970**	**-45**
LBC42	**4050**	**-2970**	**90**

→ larger doses and fluences on side A than on side C ?

Patch Panel 2

- increase of doses proportional to integrated luminostiy
- fluences too low to be measured



Conclusions

- Inner Detector: measurements in good agreement with simulations
  Largest doses measured at the end of 2012:
  TID = 3500 Gy, NIEL = 7e12 n/cm^2, Thermal neutrons: ~10^{12} n/cm^2

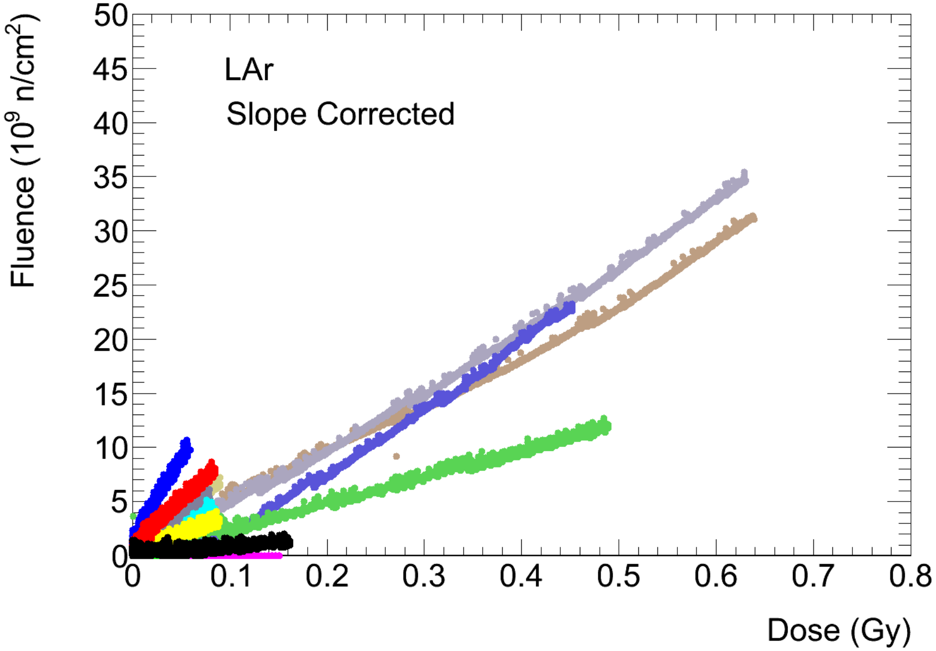
- Muons: Small Wheels: TID ~ 0.7 Gy, NIEL = 3e10 n/cm^2
  Big Wheels: TID ~ 0.2 Gy, NIEL = 6e9 n/cm^2
  → good TID measurements, agreement with simulations
  → NIEL: increase of readout voltage with time in some sensors

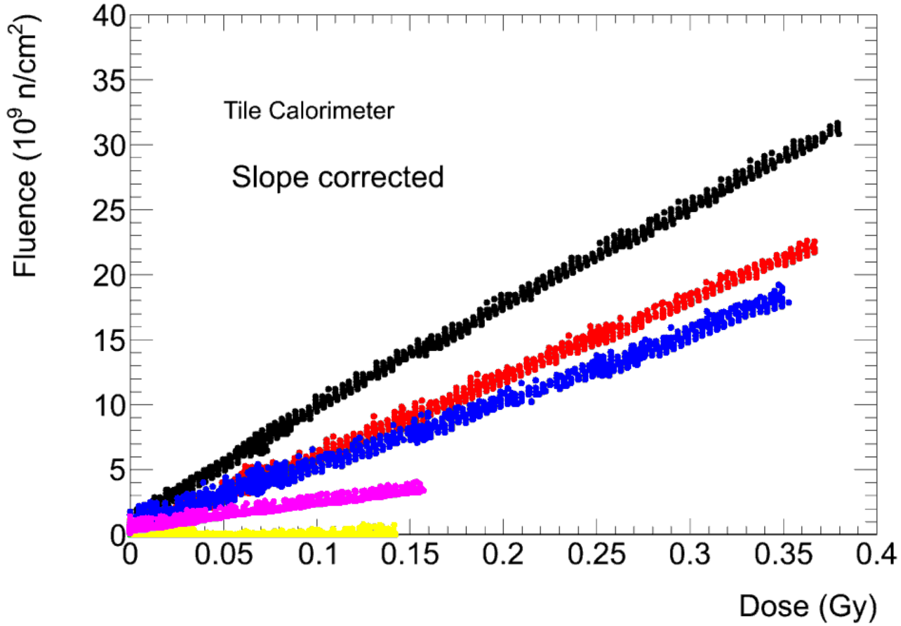
- Calorimeters: largest measured values: TID ~ 0.6 Gy, NIEL ~ 3e10 n/cm^2
  → large spread between locations, drift of NIEL sensors as for muons

- Patch panel 2: increase of dose proportional to integrated luminosity
  Dose at the end of 2012: TID ~ 0.02 Gy, NIEL too small to be measured

Would be nice to have for calorimeters:
- comparison with some other dosimetry results
- check the differences between monitoring locations (e.g. shielding by cables ….)

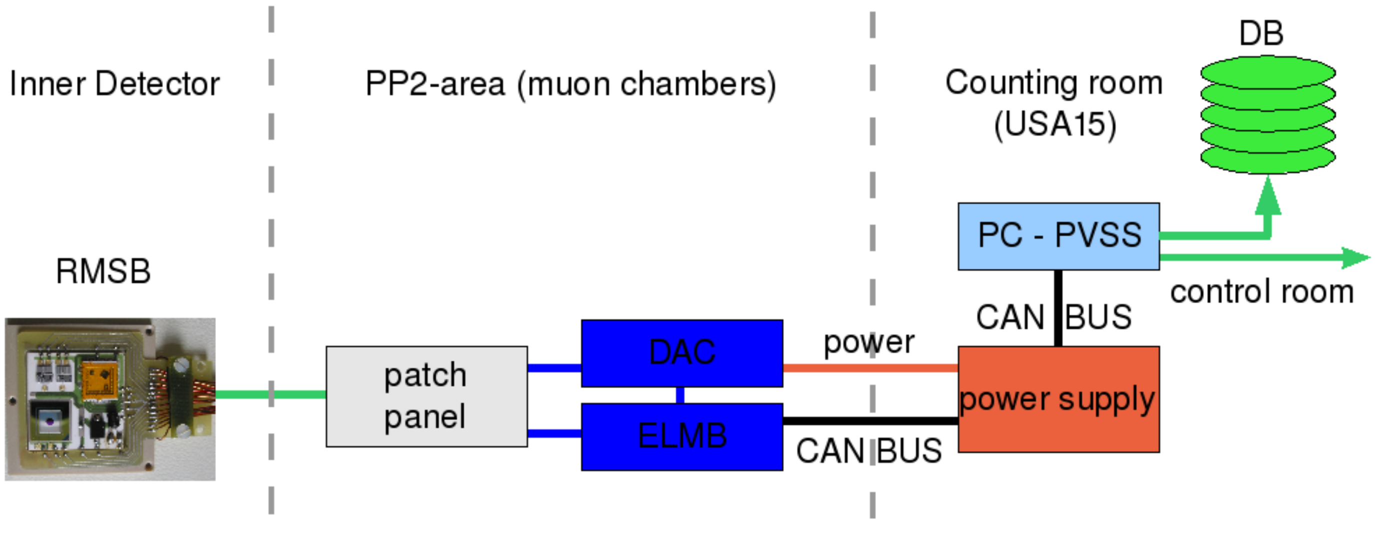
- Correlations between TID and 1 MeV eqivalent neutron fluences for LAr and Tile calorimeters





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