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The Medipix2-based network for measurement of spectral characteristics and composition of radiation in ATLAS detector

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ABSTRACT

The ATLAS detector is now installed at the CERN LHC and a precise evaluation of the radiation environment within and around the detector is required to understand the performance of the various detector systems, and to predict their useful lifetime. Furthermore, validation of earlier Monte Carlo predictions about the radiation field in ATLAS is necessary. In particular, it is important to perform these measurements in the early phases of the LHC operation. Many other radiation measuring devices lack sensitivity to low doses, and usually do not provide information on the composition of the radiation during this low intensity period. A network of 15 ATLAS-MPX devices has been installed at various positions in the ATLAS detector. These devices are capable of providing quantitative real-time information on the fluxes and flux distributions of the main radiation types in the experiment, including slow and fast neutrons. The technical description of the ATLAS-MPX detector network as well as the principles of the data analysis is presented.

1. Introduction

The precise evaluation of the radiation environment within and around the ATLAS detector is necessary for understanding the performance of the various detector systems and prediction of their useful lifetime. Furthermore, there is a need to validate earlier Monte Carlo simulations carried out to predict the radiation field within ATLAS and surrounding cavern. A network of 15 ATLAS-MPX devices has been installed in the ATLAS cavern within the framework of the ATLAS-MPX project [1] to achieve these purposes. These detectors are capable of providing quantitative real-time information on fluxes and flux distributions of the main radiation types in the experiment including slow and fast neutrons, especially during the initial low luminosity LHC operation.

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2. The ATLAS-MPX device

The ATLAS-MPX devices are based on the Medipix2 single photon counting chip [2]. Each detector is assembled with a 300-μm-thick silicon pixel sensor (matrix of 256×256 square pixels with 55 μm pitch) which is covered by a mask of neutron converting materials—^{6}LiF and polyethylene (PE).

^{6}Li enables the detection of slow neutrons by converting them into energetic alpha particles and tritons. Fast neutron detection is based on the detection of protons recoiled from the PE layer. Fast neutrons can also be directly detected via their nuclear reactions in silicon itself and in surrounding materials. These converting materials and their overlaps with the aluminum support foil divide the sensitive area of each device into six different regions (see Fig. 1b).

The ATLAS-MPX devices can be operated in two modes. The first, so-called “tracking mode” is based on “electronic visualization” of tracks and traces of individual quanta of radiation in the sensitive silicon pixel detector volume [3]. The characteristic

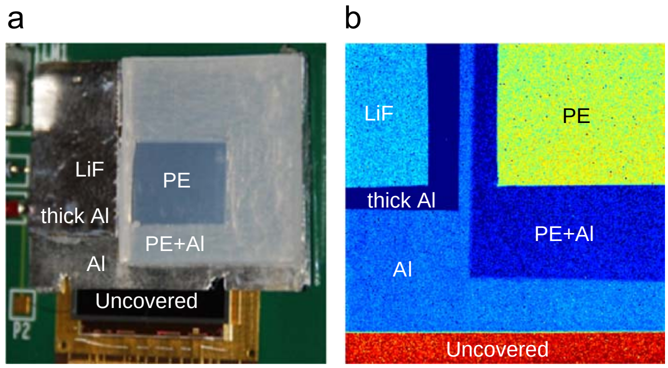

Fig. 1. (a) Photography of a Medipix2 detector with mask of neutron converting materials on the top. (b) X-ray image of the six different detection regions.

shape of a track depends on the type of the interacting particle as well as on the energy threshold settings [4]. In the case of higher count rates (above 5×10^3 Hz) the devices are operated in the so-called "counting mode" when events of energy deposition in pixels are counted at different threshold settings [1]. Calibration of the devices enables one to convert an observation of individual tracks and/or counts measured into fluxes of corresponding radiation quanta and dose rates.

The ATLAS-MPX device can detect all charged particles, including MIPs and heavy ions [5], depositing more than ~5 keV in the pixel sensitive volume with an efficiency of 100%. The detection efficiency for X-rays, gamma rays and neutrons is reduced by the efficiency of converting them into detectable charged particles and by geometrical factors. Thus, the following values are typical:

- X-rays (~10 keV): ~80%
- Gamma rays (~1 MeV): ~0.1%
- Thermal neutrons (^{6}LiF region, <1 eV): ~1%
- Fast neutrons (PE region, MeV range): ~0.5%

3. ATLAS-MPX network

The USB readout interface [6] was used to read the data and control the measurements. For those devices close to the interaction point, radiation-hard LVDS[1] extenders are used to improve their operational lifetime. Detectors on the cavern wall are connected by commercial USB extenders.

The data from each device are recorded to the data-storage computer in the ATLAS computer hall from where they can be visualized on-line. Two web interfaces are available. The first one is public and dedicated to on-line visualization of the data and browsing through the history of measurements, the second one serves for internal purposes only and is used for the whole network management. The position coordinates of the 15 devices in the ATLAS detector and its cavern are also available on the web presentation [7].

4. Principle of data evaluation

For the favored "tracking mode" of operation the acquisition time of each device has to be set short enough to avoid the overlap of tracks generated by interacting particles. These separated tracks are identified and sorted into several categories according to their characteristic shapes [4]. A track "pattern recognition" can be reliably guaranteed for about 100 registered events per frame. In the ATLAS environment, the devices will operate at two basic threshold levels (called "low" and "high"), allowing one to bring into focus different components of the complex radiation field.

[1] LVDS stands for Low Voltage Differential Signaling logic.

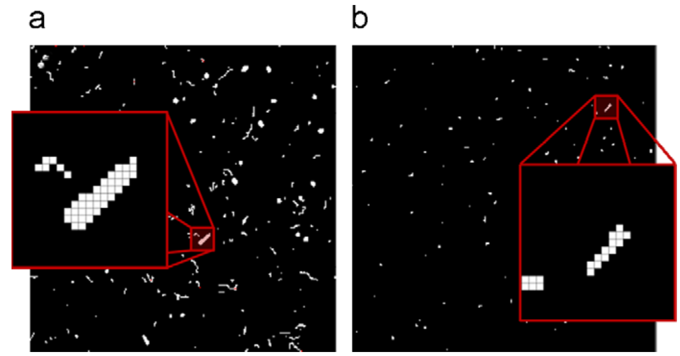

Fig. 2. Two frames obtained from an ATLAS-MPX device irradiated by fast neutrons hitting the device perpendicularly (14 MeV neutrons from Van der Graaff accelerator) and accompanying radiation: (a) low threshold (~10 keV), 1 s acquisition time and (b) high threshold (~250 keV), 5 s acquisition time. Detailed views mark the difference in recoiled proton track shape after threshold increase.

4.1. Low-threshold operation (~10 keV)

At low threshold, the device operates at the highest sensitivity and achieves maximum information from the surrounding radiation field. Each recorded particle trace/track is sorted into one of the following categories (see Fig. 2a):

- *Dot*: one pixel size trace/track of low energy X-ray photon or electron.
- *Small blob*: track of 2–3 pixels in size from X-ray photon or electron.
- *Curly track*: one pixel thick long curved line from electrons from hundreds keV to MeV range.
- *Heavy blob*: circular cluster of 20 pixels or more induced by energetic particles with low range (alpha particles, ions, etc).
- *Heavy track*: more than one pixel thick straight track from energetic heavy charged particles (protons of MeV range, energetic ions, etc).
- *Straight track*: one pixel thick straight line from interaction of energetic light charged particles (MIP, muon, etc).

Interactions of neutrons will show via tracks of "Heavy blob" and "Heavy track" categories.

4.2. High threshold operation (~250 keV)

The high threshold mode of operation was used to exclude all tracks induced by light particles and to significantly decrease the count rate. The insensitivity of the devices to light particles was tested with a ^{90}Sr source. Unlike with the low threshold mode, all tracks observed at high threshold are generated by heavy charged particles with energy losses following the Bragg law. The tracks become thin (see Fig. 2b) and their shape and length depend on energy and angle of particle entering the detector.

All the ATLAS-MPX devices were calibrated using reference neutron sources (^{252}Cf, ^{241}AmBe, thermal neutrons and 14 MeV neutrons from T(d, n)α reaction at the Van der Graaff accelerator (VDG) of Charles University in Prague) in order to determine the detection efficiencies across all detector regions. Fig. 3 clearly

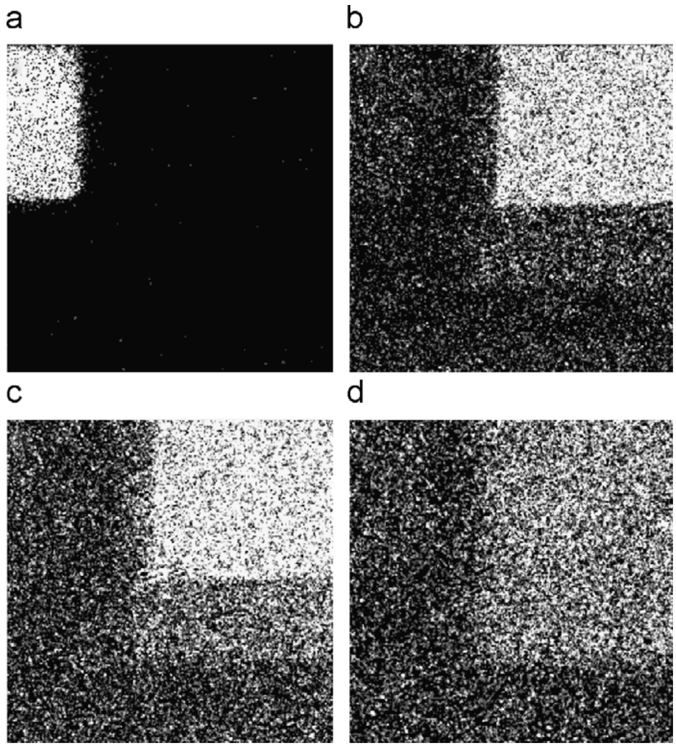

Fig. 3. Integrated frames from neutron calibration measurements (with non-overlapping tracks) at high threshold (~250 keV): (a) thermal neutrons, energy below 1 eV, exposure time of 500 s; (b) ^{252}Cf, mean energy 2.2 MeV, 2000 s; (c) ^{241}AmBe, mean energy about 4.2 MeV, 2000 s; (d) Van der Graaff accelerator, 14 MeV monoenergetic neutrons, 1000 s.

shows the different response of the various detector regions to different neutron spectra.

The detection efficiencies of all ATLAS-MPX devices available have been determined using cluster analysis of the calibration data. Given below are efficiencies determined for a particular device. Relative differences between all produced ATLAS-MPX devices are within 20%.

- Thermal (^{6}LiF region): $(1.41 \pm 0.07) \times 10^{-2}$
- ^{252}Cf (PE region): $(3.69 \pm 0.07) \times 10^{-4}$
- ^{241}AmBe (PE region): $(8.36 \pm 0.20) \times 10^{-4}$
- VDG (PE region): $(1.88 \pm 0.21) \times 10^{-3}$

By comparing the responses of different detector areas (see Figs. 1 and 3) one can estimate the spectral composition of unknown neutron field. First, one can evaluate the thermal part of the neutron spectra from the ^{6}LiF region response. The high energy component of measured neutron spectrum can be estimated using ratios of responses of different regions and their comparison to spectra of calibrated neutron fields. For the device considered above the PE/PE+Al area cluster count ratios are as follows:

- ^{252}Cf: 4.69 ± 0.19
- ^{241}AmBe: 2.28 ± 0.07
- VDG: 1.10 ± 0.03

A detailed description of the neutron efficiency calibration falls outside the scope of this paper and shall be reported in detail elsewhere in the proceedings [8].

5. Conclusion

A network of 15 calibrated ATLAS-MPX devices has been installed in the ATLAS cavern and the principle of their data analysis was described. This network will permit the real-time measurement in the ATLAS environment of fluxes and flux distributions of the main radiation types resulting from the LHC collisions, including slow and fast neutrons. This detection system will be already effective during the initial low luminosity LHC operation.

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References

[1] M. Campbell, C. Leroy, S. Pospisil, M. Suk, Measurement of spectral characteristics and composition of radiation in ATLAS by MEDIPIX2-USB devices, Project proposal at ⟨https://edms.cern.ch/document/815615⟩.
[2] X. Llopart, M. Campbell, R. Dinapoli, D. San Segundo, E. Pernigotti, IEEE Trans. Nucl. Sci. NS-49 (2002) 2279.
[3] Z. Vykydal, J. Jakubek, T. Holy, S. Pospisil, A portable pixel detector operating as an active nuclear emulsion and its application for X-ray and neutron tomography, in: Proceedings of the 9th ICATPP Conference, Como 2005, World Scientific Publishing, Singapore, 2006, p. 779.
[4] T. Holy, E. Heijne, J. Jakubek, S. Pospisil, J. Uher, Z. Vykydal, Nucl. Instr. and Meth. A 591 (2008) 287.
[5] J. Bouchami, A. Gutierrez, A. Houdayer, J. Idarraga, J. Jakubek, C. Lebel, C. Leroy, J.-P. Martin, M. Platkevic, S. Pospisil, Nucl. Instr. and Meth. A, these proceedings, 2009, doi:10.1016/j.nima.2009.03.147.
[6] Z. Vykydal, J. Jakubek, S. Pospisil, Nucl. Instr. and Meth. A 563 (2006) 112.
[7] Operation page of the ATLAS-MPX network measurements at ⟨http://www.cern.ch/Atlas⟩.
[8] D. Greiffenberg, M. Fiederle, Z. Vykydal, V. Kral, J. Jakubek, T. Holy, S. Pospisil, D. Maneuski, V. O'Shea, M. Suk, M. Kralik, C. Lebel, C. Leroy, Nucl. Instr. and Meth. A, these proceedings, 2009, doi:10.1016/j.nima.2009.03.103.