Perspectives for provision of high quality space radiation environment data using the Energetic Particle Telescope (EPT)

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Abstract—**Models of energetic electrons and protons at low altitudes in space display significant discrepancies. In this paper the possible causes of the observed differences between the most frequently used models are discussed, including instrument-induced data inaccuracy. In parallel, on the basis of simulations and in-beam experimental results, solutions to the instrumentation issues are described focusing on the implementation of these into the Energetic Particle Telescope.**

Index Terms—**Energetic Particle Telescope, EPT, Radiation Monitor, Space Radiation.**

I. INTRODUCTION

THE evaluation of radiation level is an important task performed during early space mission specification phases. The NASA radiation environment models of which the last versions are AE-8 and AP-8 have been intensively used since early 80's for electron and proton flux predictions, respectively. However, since the 90's, analysis of data acquired on board the satellites SAMPEX, TIROS and Ørsted lead to the conclusion that the flux of energetic trapped protons at LEO was underestimated by AP-8. This did not lead to discontinuation of use of AP-8 on the one hand because the models derived from these new data have limited spatial and temporal coverage, but mainly because the data acquired later on board PROBA-1 satellite were in good agreement with AP-8. The anisotropy of proton fluxes at low altitude is the most common explanation of the differences between AP-8 and models such as SAMPEX/PSB97 and TPM [1]. But while [2] showed that the anisotropy could not explain differences of an order of magnitude in flux, [3] confirmed by a thorough analysis of data from the Standard Radiation Environment Monitor (SREM) onboard PROBA-1 satellite that PROBA-1/SREM results are in good agreement with AP-8. The fact that the actually developed AP-9 model gives systematically higher fluxes of energetic protons than those of AP-8 does not help to clarify the LEO proton flux issue [4].

In that context, the Energetic Particle Telescope (EPT) was developed with the objective to significantly reduce sources of systematic uncertainties in flux measurements. The instrument is based on a new concept that was described in [5] and which allows measurements of 0.2 – 10 MeV electrons in Channels 1 – 19, 4 – 300 MeV protons in Channels 20 – 38, 0.016 – 1 GeV α-particles in Channels 39 – 57 and heavier ions in Channels 58 – 76.

This paper contains illustrations of the results reached through the efforts to accurately measure fluxes of charged particles in space. The strategies to accurately evaluate response functions, to perform on-ground and in-flight calibration, to definitely prevent inter-species contamination, to reduce pile-up and avoid dead-time are presented, along with methods to discard other sources of variances in data-based radiation models.

II. RESPONSE FUNCTION

The response function of space radiation monitors and science-class instruments needs to be evaluated for use in counts-to-flux conversions. Advanced simulation tools such as GEANT4 have been developed and allow quite comprehensive predictions of counts in instrument channels for a given radiation environment and vice versa. The main decision to be taken when simulation is undertaken is related to the definition of the starting point of particle tracking (primary vertex), i.e. the setting of the effective field of view

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(F.O.V) angle of the instrument. In that respect, tracking particles from satellite walls requires detailed geometry models of payload and is time consuming, whereas assuming that all recorded particles cross the instrument aperture may lead to inaccurate response functions if strict shielding and (anti)coincidence measures are not taken.

Fig. 1 shows an EPT cut with highlighted F.O.V defining sensors S1, S2 and S3.

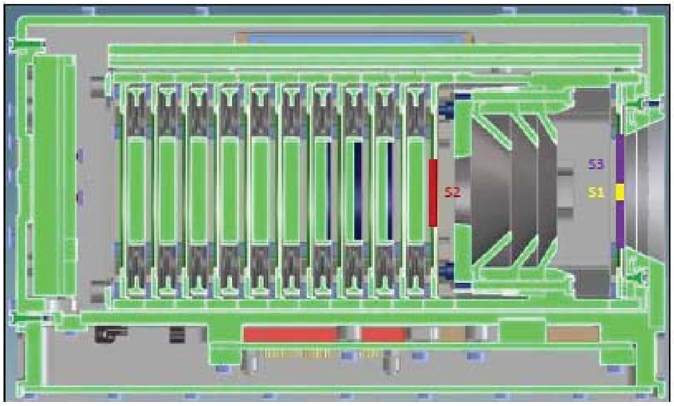

Fig. 1: EPT sensors S1, S2 and S3 that define the 50° F.O.V angle.

In order to be recorded in one of the 2 x 76 EPT channels, a particle must hit either S1 and S2 sensors, or S3 and S2. Moreover, it must not hit any of 10 the anti-coincidence sensors that surround the 10 main detectors arranged along the instrument axis. This mechanical assembly and electronics setting define a 50° F.O.V angle for the EPT and it has been experimentally demonstrated that no particle coming from outside the aperture is counted by the instrument. Fig. 2 and Fig. 3 show the results of the validation of the F.O.V. angle definition using a 62 MeV proton beam.

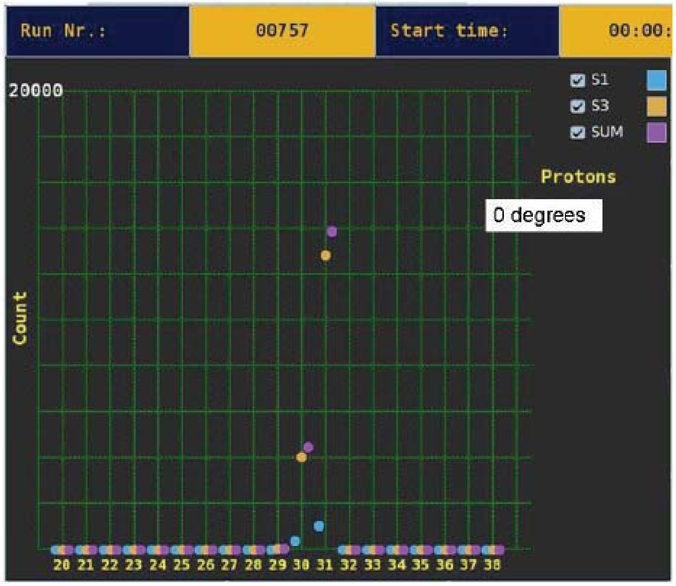

Fig. 2: Counts in the EPT channels for a 62 MeV proton beam at 0° incidence angle, at the UCL Light ions Irradiation Facility (LIF).

62 MeV protons are mainly recorded in Channel 31 (devoted to 61 – 91 MeV protons) with perceived high intensity for 0° incidence angle, intermediate intensity at 16° incidence angle (not shown here) and very low intensity at 26° incidence angle at the limit of the F.O.V.

Fig. 3: Counts in the EPT channels for a 62 MeV proton beam at 26° incidence angle, at the UCL Light ions Irradiation Facility (LIF).

F.O.V validation experiments performed using a ^{90}Sr source and an α-particle beam demonstrate that particles coming from outside the EPT aperture are not recorded. The response function for any channel may be evaluated using particles tracked from the instrument aperture around the F.O.V.

III. CALIBRATION

Incorrect calibration of radiation detectors may induce systematic errors in threshold settings and consequently in counts measurements. On the other hand, in-flight calibration of instruments may be helpful whenever channels are suspected of over- or under-estimating counts.

The EPT calibration process includes the definition of the relationship between the energy deposited in sensors and the corresponding digital information that is transmitted as input to the Data Processing Unit (DPU). The validation of the calibration is subsequently performed through recording of beam particles in adequate channels as shown in Fig. 4.

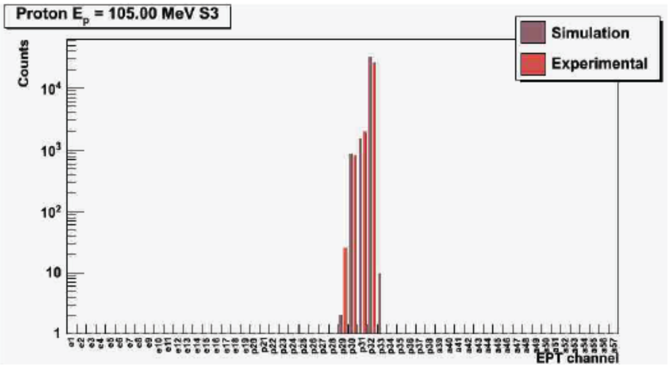

Fig. 4: Comparison between simulation and experimental counts in the EPT channels for a 105 MeV proton beam at 0° incidence angle, at the PSI Proton Irradiation Facility (PIF).

The 105 MeV proton beam was selected for comparison between simulation and experiment because at that energy, no energy degrader is crossed by particles on their path to the EPT aperture. In fact, it was noticed that such degraders produced beam diffusion possibly resulting in loss of beam in the collimator. It can be noted that the 105 MeV protons are mainly recorded in the EPT Channel 32 (devoted to 91 – 125 MeV protons) when the instrument is correctly calibrated. Experimental results are in good agreement with simulation predictions.

In-flight calibration of the EPT is possible through the measurements of protons and α-particle counts in reconfigurable channels.

IV. CONTAMINATION

Inter-species contamination is one of the most deleterious causes of loss of the flux data quality. In particular, contamination of proton spectra by electrons is suspected as being responsible of proton flux overestimations. Thanks to the "EPT concept" protons do not contaminate electrons or α-particle channels as shown in the example of Fig. 4.

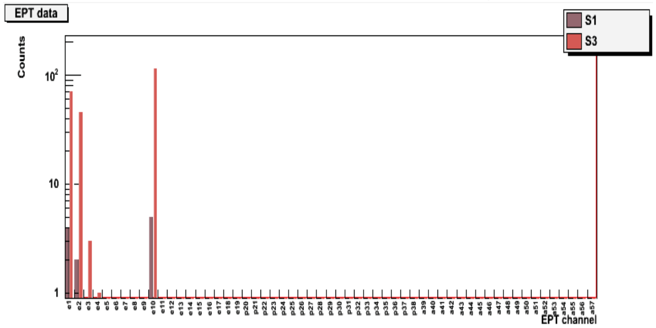

Fig. 5: Counts recorded by the EPT exposed to a weak ^{90}Sr beta source.

Most importantly, electrons do not contaminate proton channels as can be seen in Fig. 5, where 0.5 – 2.3 MeV electrons from the ^{90}Sr source are shown to be confined to electron channels (1 to 19). The typical spectrum of ^{90}Sr electrons is recorded in Channels 1, 2, 3, 4 and 10. The information in some of those channels is redundant, but electron spectra are readily extracted by applying the accurately evaluated response functions [6] or a neural network incident spectrum recognition method [7].

V. DEAD-TIME AND PILE-UP

Dead-time and pile-up in instruments may result in flux underestimations if corrective calculations are not performed. Count rate saturation is easily detected in space radiation data set when it occurs and there is no evidence that it did cause order of magnitude discrepancies in energetic proton fluxes. However, steps have been taken to avoid saturation of the EPT even in storm time conditions where electron fluxes can be extremely high:

- The data processing unit (DPU) was designed to continuously store incoming information and process it off-line to identify particles and measure their energy. There is no dead-time in the EPT DPU;
- The front EPT sensor (S1/S3) is made of two concentric "pads" of 3.5 mm and 35 mm diameter, respectively. As a consequence, when the EPT is exposed to space radiation, the impact rate on the S1 sensor is 1% of that on S3, which significantly reduces the pile-up rate in that sensor.

It is assumed that pile-up occurs whenever the time interval between two consecutive particle events is lower than the 0.5 µs peaking time of the EPT analog signals. Thereby, if a poissonian distribution of events and a $2\,10^5\ particles/s$ hit rate on the S1 sensor are assumed, less than 10% of particles will be lost due to misclassification caused by pile-up. That hit rate on the S1, corresponds to a $\geq 8\,10^6\ cm^{-2}\ s^{-1}$ particle flux, with S1 assumed to be directly exposed to an isotropic flux in space. In practice, the most exposed EPT sensors (S1 and S3) are accommodated behind a $200\ \mu m$ Aluminum foil or a $60\ \mu m$ Gold layer on kapton. Simulations of the instrument taking into account the S1 sensor shielding window and its accommodation deep inside of the satellite walls have demonstrated that space particle fluxes as high as $10^7\ cm^{-2}\ s^{-1}$ will be readily measured by the EPT and an order of magnitude higher flux can be reached if a Gold on kapton aperture foil is used and that a 10% particle loss due to pile-up is considered acceptable.

VI. OTHER SOURCES OF UNCERTAINTIES

A. Space Weather

Variations of conditions in space that affect particle fluxes are source of uncertainties in space radiation models. A model like CRRESPRO implemented QUIET and ACTIVE versions to account for proton flux variations induced by the 24 March 1991 storm mainly in the slot region. The plan for the EPT data analysis and exploitation includes the development of a model of steady state fluxes and a model of transients that contributes the most to flux variances [8] [9]. It will be recommended then, that cross-calibration of instruments be based on steady state flux values at given position rather than on short or long-term flux averages.

B. Mission Duration

Data acquisition by a space radiation detector may be interrupted due to satellite or instrument failure. As a consequence, data sets with a limited time and space coverage (implying high uncertainties on averaged values) are maintained but with no contribution to space radiation model advances.

The EPT has been designed according to the most constraining standards. In particular, the large number of sensors (23) required that steps be taken to ensure that failing electronics chains could be disabled to allow continuation of data acquisition though with reduced performances. Sensor ageing effects may be compensated for by the implemented in-flight calibration and configuration capability. It has been estimated that the EPT can operate in nominal conditions during 3 years at the PROBA-V and PROBA-3 orbit, even though the end-of-life maximum operating temperature would be reduced to 25°C due to sensor ageing.

C. Electronic noise

Electronic noise can induce counts in instrument channels devoted to low energy particles, but also in high energy channels if coincidence of low energy deposit is required.

Beside the strict coincidence conditions required to record an energetic particle in the EPT channels, much work has been done to reduce the noise in the EPT sensors to less than 100 keV peak-to-peak. Moreover, in order to monitor the sensor integrity and thus the validity of measured spectra, the temperature and environment-dependent noise signature of the instrument is recorded with every spectrum. It is expected that such a measure will contribute to additional data quality assessment.

VII. CONCLUSION

Within this paper, the results obtained from an effort to design and test an instrument that allows uncertainties reduction in space radiation flux data have been presented. The validation of the same features on the EPT Engineering Qualification Model is underway and will be followed by the same activity on the Flight Model to be accommodated on PROBA-V satellite scheduled for launch end of 2012. It is our wish that using the EPT to acquire uncontaminated flux data will open new perspectives for the development of improved space radiation models.

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