Mini.PAN: REAL-TIME PENETRATING PARTICLE ANALYZER for ARTEMIS. X. Wu[1], on behalf of the PAN Collaboration. [1]Department of Nuclear and Particle Physics, University of Geneva, 24 Quai Ernest-Ansermet, CH-1211, Geneva 4, Switzerland, xin.wu@unige.ch

Introduction: Mini.PAN is an innovative energetic particle detection technology to precisely measure and monitor the flux and composition of highly penetrating particles (> ~100 MeV/nucleon), which can provide precise information of the energetic particle environment in the lunar orbit and on the lunar surface in the framework of the ARTEMIS program.

Science objectives: In deep space, including the lunar orbit, and on the lunar surface, particle radiation comes from 2 main sources: Galactic Comics Rays (GCRs) and Solar Energetic Particles (SEPs) generated by solar flares. GCR is the dominant particle source above few hundred MeV, consisting mainly of protons and Helium nuclei, but also heavier nuclei produced by nucleosynthesis and through the interaction of GCRs with the interstellar medium. In deep space the GCR flux below a rigidity R ~20 GV is strongly affected by solar activities though solar winds and the modulation of the interplanetary magnetic field, therefore requires in-situ measurements. SEPs are burst of energetic particles produced by solar flares, consisting of mainly electrons below 1 MeV, but also with protons and Helium nuclei, mostly with energy below 30 MeV. Occasionally a large flux of penetrating particles of above 100 MeV/n are produced.

Energetic particles above about 100 MeV/n, in particular proton and nuclei, cannot be stopped easily, thus become "penetrating". Because of this they cannot be measured precisely with the classical energetic particle instruments based on the ΔE-E method that are wildly used in deep space missions, e.g. the CRIS instrument [1] on the ACE mission or the CRaTER instrument [2] on the LRO mission. For this reason, precise measurements of particle flux between ~100 MeV/n to ~10 GeV/n in deep space and on the lunar surface is therefore missing.

At LEO, the geomagnetic field is a natural shield for particles up to 20 GV. In the lunar orbit and on the lunar surface, however, since the geomagnetic field provides almost no shielding effect, penetrating particles represent a serious radiation hazard. It is therefore crucial to fill this observation gap in order to build a detailed understanding of the dynamic penetrating particle environment on the lunar orbit and on the lunar surface, in particular with respect to the solar activities, and possible magnetosphere shielding effect on these particles during SEP events.

The precise and long-term measurements of the flux and composition of these particles, together with concurrent dosimetry measurements, are indispensable for the assessment of the related health risk, and the development of an adequate mitigation strategy.

Detection principle: Magnetic spectrometer (MS) is a proven detection technology for particles between 100 MeV/n and 20 GeV/n (e.g. Pamela [3] and AMS-02 [4]). In this energy range, the classical ΔE – E method is not optimal since particles will interact with the detector material and produce a shower of secondary particles. In a MS, the momentum resolution, thus the energy resolution, has 2 contributions: one, related to the magnetic field (strength and length) and the tracker precision, increases with momentum; the other, due to the multiple Coulomb scattering (MCS), decreases with momentum. With appropriate instrument design, such as PAN [5], it is possible to mitigate these two effects to achieve a good energy resolution over the desired energy range. Figure 1 shows the energy resolution obtained with the Mini.PAN design described below, estimated with the Gluckstern formulas [6]. For protons, the energy resolution is <10% between 500 MeV and 5 GeV, and ~20% at 100 MeV and 10 GeV.

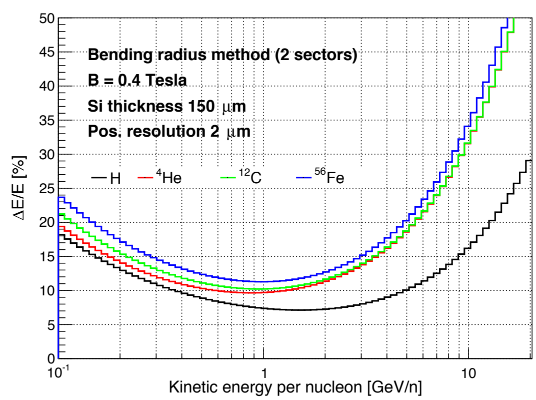

Figure 1. Energy resolution as a function of energy per nucleon for proton, Helium, Carbon and Iron nuclei from 100 MeV/n to 20 GeV/n, with the baseline Mini.PAN design.

The charge (Z) of the particle can be determined by measuring the energy deposited in the tracking layers and in the Time-of-Flight (TOF) detector, using the dE/dx method. A large dynamic range is needed to measure the dE/dx for Z up to ~26. In addition, the instrument can maintain the detection capabilities for even the strongest solar events by using low power pixel detectors. The identification of electrons is straightforward since they bend in the MS to a direction opposite to that of the nuclei.

Baseline instrument design concept: The baseline design concept of Mini.PAN is shown in Figure 2. It consists of a cylindrical magnetic spectrometer (MS) which is segmented into 2 sectors and instrumented with 3 tracker modules, each consisting of 3 layers of silicon tracking detectors: two to measure the bending plane coordinate (StripX), one for the non-bending plane coordinate (StripY). Two StripX layers are needed per module in order to measure the bending angle of a particle traversing only one magnet sector. Each end of the MS is instrumented with a fast TOF detector and a pixel detector. The TOF and StripY detectors provide the trigger signal.

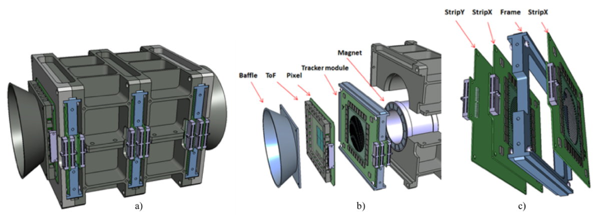

Figure 2. a) Engineering drawing of Mini.PAN. b) Exploded view showing the baffle, the TOF module coupled to the Pixel module, the tracker module and part of a magnet sector. c) Exploded view of a tracker module.

The magnets are made from blocks of NdFeB permanent magnets arranged according to the Halbach scheme. The baseline layout uses a magnet assembly weighing below 2.5 kg to provide a dipole magnetic field of ~0.4 Tesla, in a cylindrical cavity of 5 cm in diameter and 10 cm long. The total geometrical acceptance is about 2x6 cm^2sr. The unique features of the PAN concept are:

- Both the bending radius and bending angle are measured, which, together with a segmented magnet system, allows to increase the geometrical acceptance and improve the energy resolution.
- Very fine pitch (25 μm readout pitch) silicon detectors are used to achieve the best possible position resolution (2 μm) in the bending direction, improving energy resolution at high energy, allowing to achieve the energy resolution shown in Figure 1.
- The thickness of the silicon detector is minimized (150 μm) to reduce the effect of multiple Coulomb scattering, thus improving energy resolution at low energy.
- Low power active silicon pixel detectors are used to enhance high rate capability of the instrument, maintaining the measurement precision for even the strongest solar events.
- The instrument is symmetric, effectively doubling the geometrical acceptance and field of view. The plastic scintillator based TOF with SiPM readout can achieve a time resolution of 100 ps, sufficient for determining the particle entering direction in the energy range of interest.

The PAN instrument concept is robust, scalable and modular, with high redundancy for position, charge and time measurements. Measuring modules can be made mechanically independent from the magnet, allowing them to be exchanged in view of a possible extension of the instrument lifetime with human intervention.

A preliminary estimate of resource requirements is given in Table 1. It can easily be scaled up or down depending on available resources. By design the instrument is highly modular, with replaceable modules, to provide an extra safety margin for very long operation period.

Resources	Requirement
Mass	~8 kg
Power	~20 W
Cost	~10 M$
Volume	~20 cm×20 cm×30 cm
Crew intervention	Setup

Table 1. Preliminary estimated resource requirements.

PAN should be mounted at an external site of the lunar orbiting spacecraft for maximal sky coverage, or on a suitable lunar surface, with a possibility of remotely changing the pointing direction of the instrument.

Status of instrument development: Currently the PAN project is funded by an EU H2020 FET-OPEN 3-year grant (2020-2013) to develop a Mini.PAN demonstrator. The consortium members are the University of Geneva in Switzerland, INFN Perugia in and the Czech Technical University in Prague in the Czech Republic.

References:

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