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HVI-TEST SETUP OF IN-SITU SPACE DEBRIS DETECTOR

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Collisions of spacecraft in orbit with Space Debris (SD) or Micro-Meteoroids (MM) lead to payload degradation, anomalies or failures in spacecraft operation or even to loss of a whole mission. Existing flux models and impact risk assessment tools, like MASTER or ORDEM, PIRAT, ESABASE2 and BUMPER II are used to analyze the mission risk concerning this hazard potential. The validation of the flux models so far is partly based on SD and MM impact data from in-situ impact detectors, e.g. DEBIE, GORID, capture cells and on the analyses of retrieved hardware from space, e.g. LDEF, HST or EURECA. However the knowledge on the small objects populations (millimeter down to micron sized) in space is rather limited and needs to be enhanced for reliable models. As a contribution Deto software validation in terms of data acquisition, a new type of impact detector is currently under development at DLR. The Solar Generator based Space Debris Impact Detector (SOLID) makes use of spacecraft solar panels and therefore offers a large sensor area and high flexibility regarding the orbit. This paper presents the impact detector design as well as the Hyper-Velocity-Impact (HVI) test setup, foreseen for corresponding tests at the Fraunhofer Institute for High-Speed-Dynamics, Ernst-Mach-Institut (EMI) in Freiburg, Germany.

Abbreviation:

ACS	Attitude Control Subsystem
CFRP	Carbon-Fiber-Reinforced Plastic
DEBIE	Debris in-Orbit Evaluator
DH	Data Handling Subsystem
DL	Detection Layer
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.
E-BOX	Electronics Box
EMI	Ernst-Mach-Institut
EPS	Electrical Power Subsystem
EQE	external quantum efficiency
ESA	European Space Agency
EURECA	EUropean Retrievable Carrier
GORID	Geostationary Orbit Impact Detector
H/W	Hardware
HST	Hubble Space Telescope
HVI	Hypervelocity Impact
LEO	Low Earth Orbit
MASTER	Meteoroid and Space Debris Terrestrial Reference Model
MM	Micro-Meteoroids
ORDEM	Orbital Debris Engineering Model
P/L	Payload
PIRAT	Particle Impact Risk and Vulnerability Assessment Tool

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S/C	Spacecraft
S/G	Solar Generator
SA	Solar Array
SD	Space Debris
SGS	Solar Generator Structure
TM&TC	Telemetry & Telecommand

I. INTRODUCTION

Space missions can be endangered by Space Debris (SD) and Micrometeoroids (MM). Impacting objects can damage or even destroy spacecraft (S/C) or payloads (P/L). The MM population consists of a superposition of a sporadic background flux with a number of seasonally recurring meteoroid streams. However, in contrast to the highly dynamic space debris environment, the annual mean meteoroid environment can be assumed to be static [1]. Space activities over the past 55 years led to a progressive increase of the creation of SD. Table 1 gives an overview of the SD situation today.

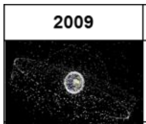
2009	Size	Quantity	Comments
	Ground based surveillance (normal) 16.300 Objects within radar catalog (some of them ca. 5cm) Ca. 800 active Satellites Mission lost in case of collision.		
	>10cm	29.000	Ground based surveillance (limited) Mission lost in case of collision.
	>5cm	60.000	Ground based surveillance (limited) Mission lost in case of collision.
	>1cm	700.000	1 cm object releases energy equivalent to hand grenade Mission lost in case of collision.
	>1mm	200 million	***Retrieved Surfaces / In-Situ Detectors,*** High probability of spacecraft damage in case of collision.
	>100μm	trillions	***Retrieved Surfaces / In-Situ Detectors,*** Damage /degradation of spacecraft in case of collision possible.

Table 1: Space Debris size and quantity distribution source [3]

As can be seen, the quantity of the objects increases strongly if the object diameter becomes smaller. The radar catalogue comprises today ca. 16.300 objects, which are mostly tracked by Space Surveillance Network (SSN). Some of the tracked objects are 5cm in diameter. By examination of Table 1, it becomes clear that even objects larger than 10cm in diameter cannot be fully covered by ground based surveillance systems. Consequently the data concerning smaller objects can be gained only by examination of retrieved H/W from space or by *on-orbit (in-situ) detectors*. To better understand the space environment, ESA has performed post flight impact analysis on retrieved hardware (H/W) from space. Extensive investigation of damage on solar generators had been performed e.g. on EUropean Retrievable Carrier (EURECA) and Hubble Space Telescope (HST) [7,8]. The gained understanding on SD is used to validate the environmental models, like MASTER [7]. Investigation of retrieved H/W can contribute to better understanding of the space environment but they cannot provide the information of impact time and corresponding position on orbit. For these purpose *in-situ detectors* offer convenient solutions [2,3]. The gained measurement data are useful for:

- verification of meteoroid and debris environment models,
- verification of meteoroid and debris environment evolution models,
- real-time detection of unexpected events, such as explosions in orbit.

From a systems engineering point of view the prime focus of data acquisition with *in-situ detectors* for environmental models validation should lie on objects larger 100μm in diameter, because:

- considerable damage to the Spacecraft (S/C) or Payload (P/L) can be expected already from 100μm particle,
- the quantity of the objects in this size range is very high and the knowledge of the small objects population in space is rather limited and need to be enhanced for reliable models.

II. SOLID DESIGN

This paper focuses on HVI-testing of SOLID and gives just a short concept description. More detailed information on the general idea as well as details on the manufacturing of SOLID can be found in [4,5,6].

Unlike most conventional detectors, the proposed ***new*** concept makes use of ***already existing subsystems (SS)*** of the spacecraft bus and adapts those for impact detection as depicted in Figure 1. The Electrical Power Subsystem (EPS) and the Attitude Control Subsystem (ACS) are used for data acquisition. The Data Handling subsystem (DH) and Telemetry and Telecommand subsystem (TM&TC) serves for the data processing and data transfer to Earth. The Solar Generator based Space Debris Impact-Detector (SOLID) [5,6] is a large area impact detector which can be flown in any orbit.

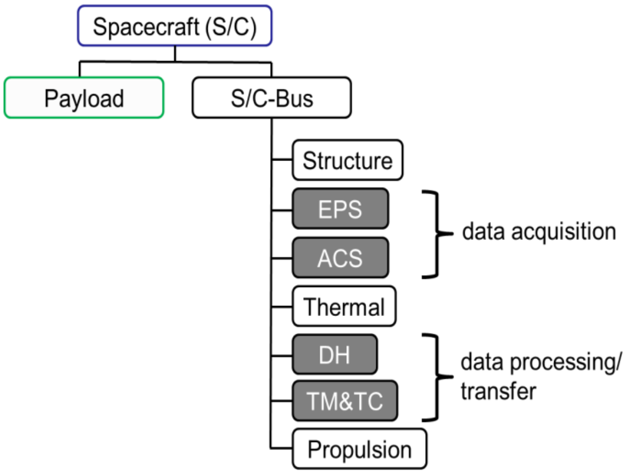


Figure 1: S/C Subsystems Adaptation

Figure 2 illustrates the functional principle of SOLID. The core element of the concept is a solar generator (S/G) with photovoltaic cells (PV). Furthermore SOLID has an autonomous electronic box (E-BOX) which is implemented into the interior of the S/C.

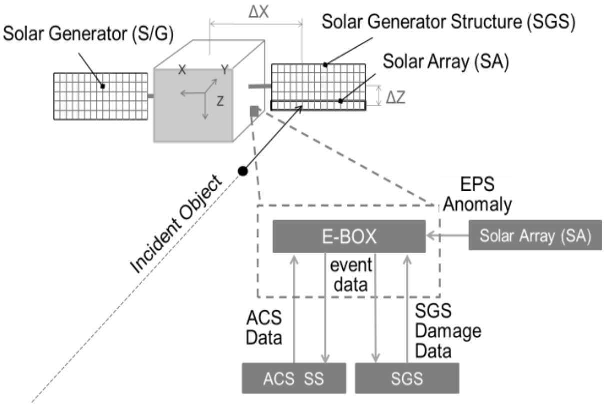


Figure 2: Functional principle of SOLID concept

The incident particle (see Figure 2) which hits the solar cell could lead to an anomaly in power supply. The E-BOX monitors the power SS for these types of events and compares them to the predefined impact disturbance behaviour. Once the anomaly has been identified as an impact, the solar generator structure (SGS) is analysed concerning presence of damage on the SGS. From this analysis the impact location and damage to the SGS, caused by impact, is determined. The latter allows an estimation concerning incident particle diameter. The ACS data is also analysed to ascertain the momentum transfer to the S/C related to SD or MM impacts. Also this data acquisition takes place within a predefined time after the impact. The combination of the known impact position and the particle diameter from SGS analysis with the momentum transfer from ACS SS enables an implication of the particle velocity.

Figure 3 shows the principal adaptation method of the standard SGS for the purpose of impact detection. In comparison to commonly used SG for Space applications, the SOLID concept modifies the insulation layer (e.g. Kapton), which is placed in between solar cell adhesive and the sandwich face sheet. Kapton has excellent thermal insulation and electrical insulation properties and is therefore a common material for S/Gs. The SOLID concept integrates two layers of copper lines between the Kapton layers and forms a detection grid. In the case of an impact event the incident particle causes damage which can range from cover glass down to the detection layer and consequently sever the copper lines. In this case number and position of the severed strips can be identified by the detection electronics/software (see Figure 2 E-BOX). A diameter estimation of the incoming particle which caused the damage could be made by using known damage equations as seen in [12].

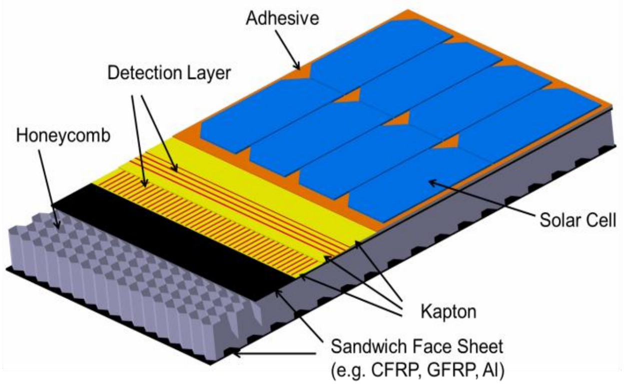


Figure 3: SG adaptation for SOLID concept

Figure 4 shows the SOLID prototype for concept verification through HVI-tests. The SOLID detection layer is made of polyimide with dimensions of 380mm x 255mm. Diodes are implemented to the top side of the detection layer. The detection area will be covered by six solar cells which covers an area of 160.5mm x 121mm. The application of the solar cells to the detection layer is foreseen for autumn 2012. The dimensions of the detection grid foreseen for impact detection are 168mm x 120mm. Marginal smaller dimension of the detection grid was caused by the dimensions limitations of the polyimide used for detection layer manufacturing. The detection layer is applied to the

CFRP/Al primary structure (sandwich). The used aluminum honeycomb is perforated to allow venting of the encapsulate air since the tests are performed in vacuum environment.

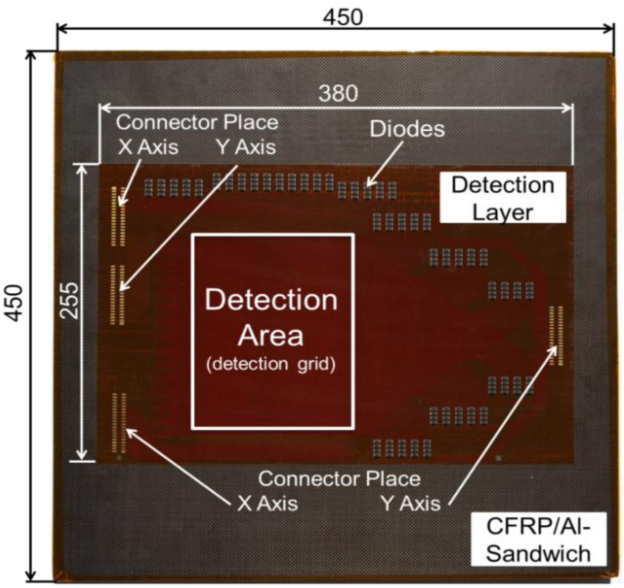


Figure 4: SOLID prototype for HVI testing

I. HVI TEST SETUP

The understanding of the physical processes during hypervelocity impact (HVI) is supported by ground based hypervelocity accelerators [7,9]. The corresponding HVI test facilities are used to perform basic and applied research, e.g. [7,8,10]:

- development and verification of shielding methods,
- research on material behavior and impact features,
- development and verification of impact detectors.

The most frequently used accelerators are based on the two-stage light gas gun principle [11] The verification of the in-situ detector SOLID will be performed at Fraunhofer EMI's Space Gun in Freiburg, Germany. This gun can accelerate millimetre-sized particles up to about 9 km/s.

DLR is currently performing the HVI test planning and preparation for SOLID verification. Figure 5 shows the principle HVI test setup. SOLID is placed free-hanging on a traverse. The solar cells covered area represents the detection zone. This area is adjustable to allow the projectile to reach every point on it. The operational condition of the solar generator is simulated by using a sun equivalent light source.

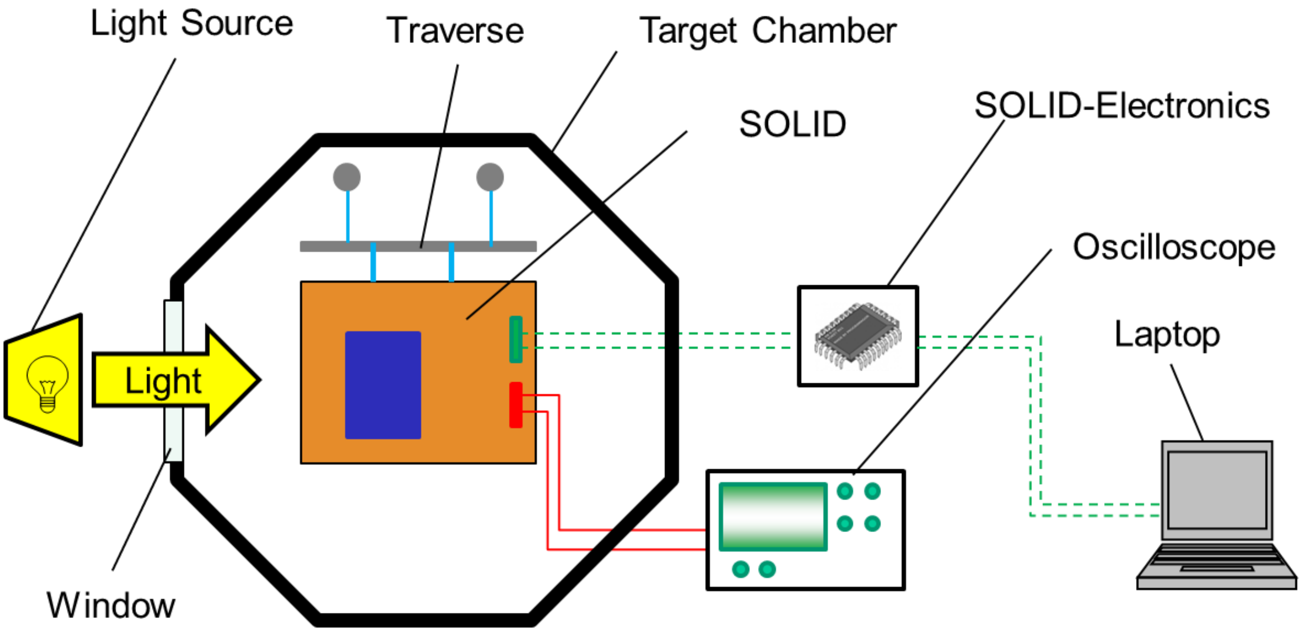


Figure 5: HVI-test setup for SOLID verification

During the HVI tests the SOLID electronics performs an analysis of current and voltage of the solar cell strings. Once an anomaly is identified, the detection layer, which is placed behind the solar cells, is analysed concerning presence of damage. The data is then read out and analysed by the software on a computer. Oscilloscopes are used in parallel to SOLID electronics to generate high resolution data sets for comparison reasons. As mentioned above the solar cells are illuminated by an external light source only (AM0, AM1,5 spectrum) to simulate operational conditions. The light source provides the solar cells with sufficient electromagnetic spectrum and intensity for power generation.

Additionally to the SOLID electronics and oscilloscope analyses at the HVI testing, the generated ejecta cloud and the dynamics of the projectile penetrating the target are monitored by using high speed camera. The preliminary requirements for HVI test setup and HVI test execution are:

- electronics and light placed outside the target chamber
- cables are protected by hose,
- target adjustment: X +/- 10cm; Y +/-15 cm,
- target adjustment accuracy in X and Y: +/- 0,5mm,
- shot quantity: n>6 per test object
- SOLID shielding: aluminum 2mm
- Image acquisition: high speed camera

SOLID uses GaInP/GaAs/Ge triple junction solar cell from AZUR SPACE for concept verification purposes. As shown in Figure 6 these solar cells are operating in the range of ca. 300nm - 1800nm of the electromagnetic spectrum. The used solar cell generates the main part of the electrical energy from the received solar radiation within the first two cells (see Figure 6 top and middle cell) which operates in high energetic short-wave region.

For the HVI testing of SOLID the solar cells have to provide the electronics with sufficient energy to allow the impact detection. Since the generated power by solar cells is used only for anomaly triggering in the electrical power subsystem it is not required to produce max power for the envisaged SOLID testing. Thus, it is just necessary to generate the threshold value of the current, to allow the impact detection. For this reason the falsifications which are caused by the target chamber window and the atmosphere outside and inside the chamber can be neglected. The lower current threshold value is not defined so far since the electronics has to be tested. For the SOLID testing it is foreseen to measure the power before and during the HVI test and to use relative values for analysis purposes. Since the main objective of the HVI testing of SOLID is to perform analysis which allows the identification of broken lines, the made assumptions are believed to be sufficient for the planed HVI testing

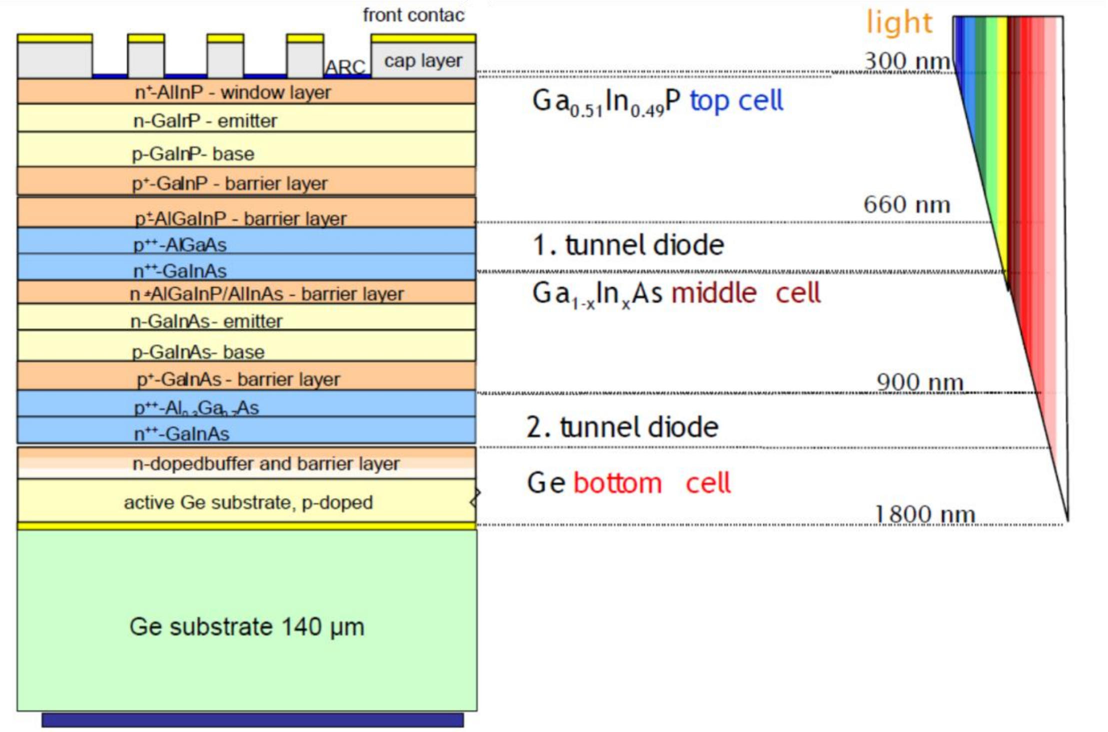


Figure 6: Triple junction solar cell [14]

Figure 7 shows the SOLID arrangement within the SpaceGun target chamber and the horizontal and vertical adjustment possibilities for HVI testing purposes. The horizontal adjustment occurs by sliding of the traverse road. The vertical move is done by manipulating of the threaded rods. The alignment of the detection area to the shot axis (shown in Figure 7) occurs by using a laser pointer. This increases the accuracy in terms of determination of the impact area on the target. Furthermore, it increases the exploitation of the SOLID detection area. The detection electronics and solar array cables are routed outside the target chamber. All wires in-between the SOLID and the target chamber wall are protected by safety hose to avoid possible separation by ejecta.

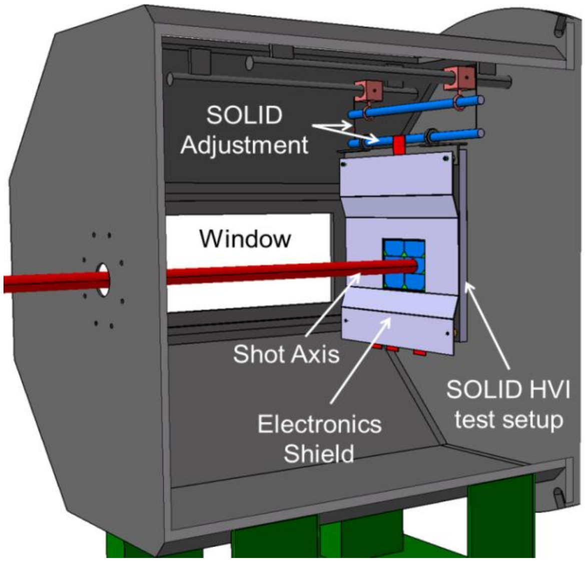


Figure 7: SOLID within the SpaceGun chamber

The projectile will impact the detection area normal to the surface. The HVI causes release of ejecta. According to [12,13] the ejecta for brittle material can be subdivided in categories jetting, cone, spall as shown in Figure 8. The most released ejecta will be accelerated away from the target. Typical values for ejecta elevation angle and velocities taken from [12] are given below (the elevation angle is measured from the surface plane):

- jetting:
    - elevation angle φ_{jet}~10° - 20°,
    - velocity v_{jet} up to 2-3 vp,
    - jetting mass is < 1% of total ejected mass
- debris cone:
    - elevation angle φ_{cone} ca.70°´+/- 10°,
    - velocity v_{cone} 100m/s up to vp,
- spall:
    - elevation angle φ_{spall} around 90°,
    - velocity v_{spall} ca. 10-100m/s.

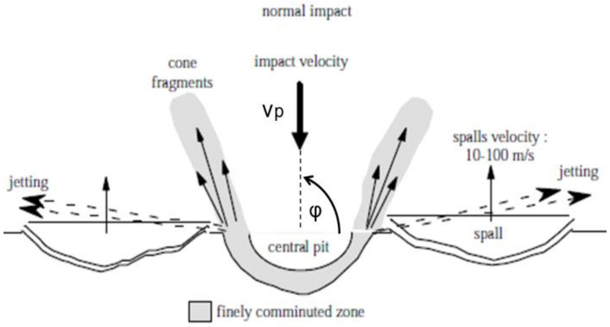


Figure 8:Ejecta processes: jetting, cone, spallation [12]

Since the SOLID setup comprises electronics components e.g. diodes and plugs, they need to be protected against the released ejecta. Figure 9 shows the shielding concept for SOLID detector. All sensitive components e.g. diodes and connectors are hidden behind the 2mm aluminium shield. The released ejecta at small angles (jetting, cone) ricochets on the shielding wall and cannot affect the test setup.

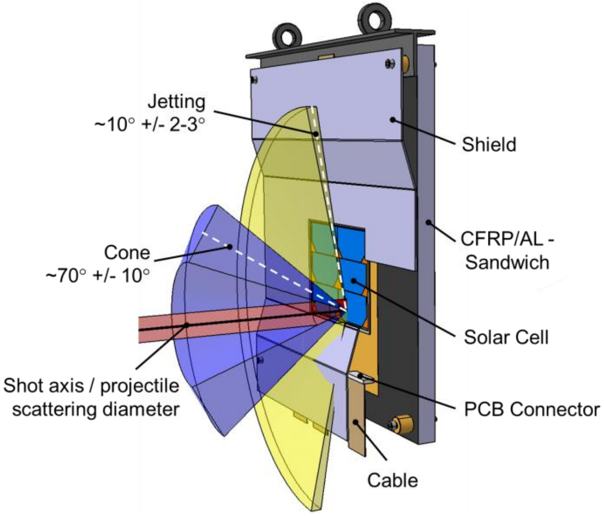


Figure 9: SOLID setup shielding

II. SUMMARY

Impacting Space Debris (SD) or Micrometeoroids (MM) can lead to degradation or damage on Spacecraft (S/C) or Payload (P/L). This hazard can be expected from objects larger than 100µm in diameter. The risk analysis and assessment can be performed by using the environmental models and appropriate software tools e.g. MASTER and PIRAT or ESABASE. Corresponding analyses shall be performed in early design phases of a S/C. Based on the analyses, system solutions regarding S/C and P/L components and possible S/C and P/L shielding can be developed. For validation of the environmental models measured SD and MM data are essential. Those data are limited especially for smaller objects e.g. in sub cm region. The proposed SOLID concept can contribute to data acquisition concerning SD and MM. Collected data sets increase the accuracy of the environmental models with high impact on the spacecraft design. This paper presents the SOLID detector design as well as already manufactured components. Furthermore, it gives an overview of the planed HVI test setup for SOLID verification purposes. The results of HVI test itself will be published in a follow up paper.

III. ACKNOWLEDGEMENTS

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