Hydrogenated amorphous silicon (a:Si-H) detectors for Space Weather Applications

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Possible applications in space of a-Si:H detectors: the scientific case

- *Solar energetic particle (SEP) continuous, multi-spacecraft observations* allow us to study the role of interplanetary scattering and transport effects (for instance PSP, SolO, BepiColombo, STEREO, ACE)

- *Critical energy differential flux measurements* from tens of MeV up to not less than 400 MeV for protons are proposed for reliable measurement parameterization above these energies and for flux normalization with Space Station observations: goal medium-intense events (>10^{7} protons cm^{-2} > 30 MeV).

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Possible applications in space of a-Si:H detectors: the scientific case

- *SEP and inner S/C dose monitoring* allowed by a:Si-H detectors. These detectors with different arrangements can be also considered for soft (1.55-12.42 keV) X-ray and solar electron detection
- *Neutron production in the atmosphere* (SEP contribution vs Forbush decreases and proton precipitation in the atmosphere - mandatory SEP flux correct estimates above 500 MeV)
- *a:Si-H detectors are characterized by high dynamic range, radiation resistance, adjustable geometrical shape, low weight and power consumption*

SEP event November 29, 2020

Kollhoff et al., A&A 656, A20 (2021)

Mason G. M. et al., A&A 656, L12 (2021)

F. Sabbatini (SolO EPD/HET data)

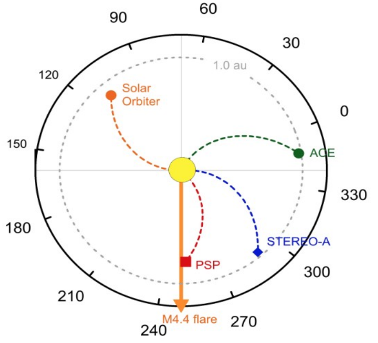


Fig. 1. Spacecraft locations in Carrington longitude and heliocentric radius at the time of 29 Nov. 2020 flare. Magnetic spirals assume 400 km s^{-1} solar wind speed.

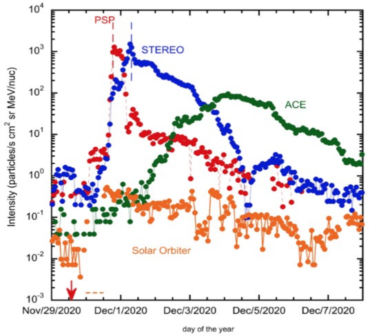
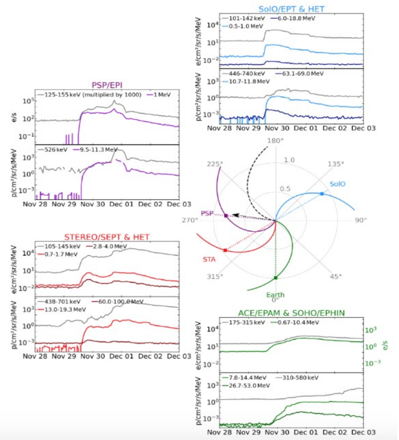
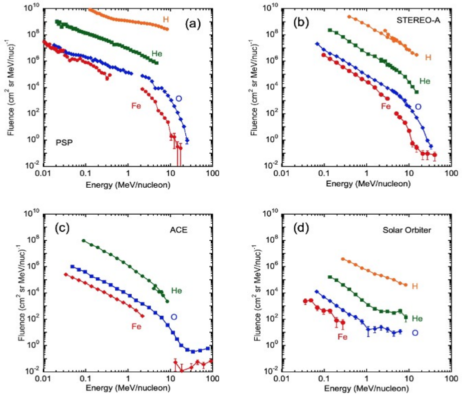
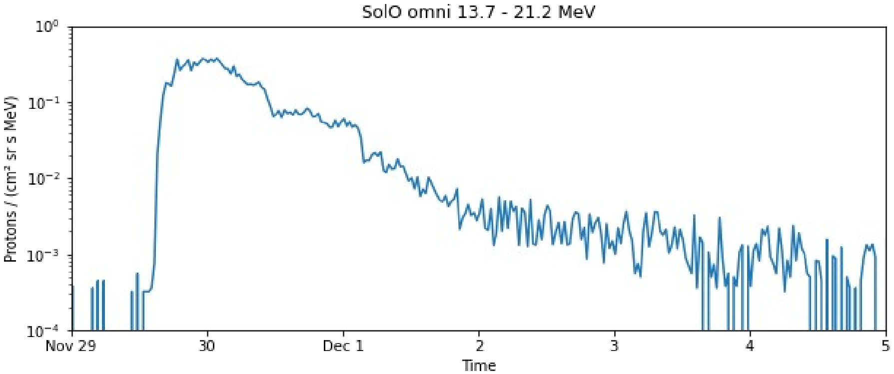
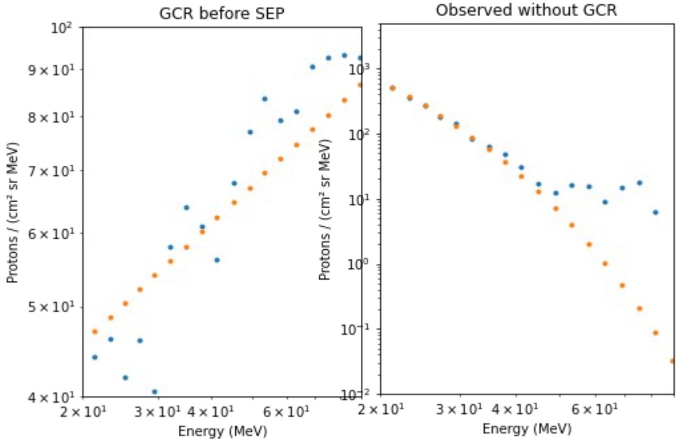


Fig. 2. Hourly average 273 keV nucleon^{-1} He intensities at each spacecraft. Red downward arrow shows flare time; dashed lines through STEREO and PSP intensities show approximate times of shock passages. Horizontal dashed orange line indicates the data gap in the Solar Orbiter data.









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SEP critical observations energy interval

SEPs > 70 MeV and < 0.4 GeV

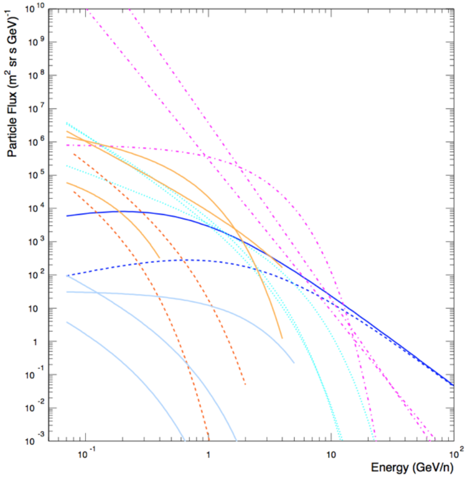

Fig. 12 Solar energetic particle fluxes observed during SEP events of different fluence. Dot-dashed lines correspond to the evolution of the February 23, 1956 event (magenta). Top continuous lines represent the dynamics of the December 13, 2006 event (orange), dotted lines show the evolution of the May 7, 1978 event (cyan), bottom continuous lines indicate the helium flux evolution during the SEP event dated December 13, 2006 downscaled by four orders of magnitude (light blue). The dashed lines represent the peak and decay phases of the December 14, 2006 SEP event (red). The continuous and dashed lines in the middle of the figure (blue) represent the GCR proton spectrum at solar minimum and maximum, respectively, for comparison.

Event	Protons Particles (m^2 sr s GeV)$^{-1}$	Helium Particles (m^2 sr s GeV)$^{-1}$
February 23rd 1956		
0400 UT	$850880\ e^{-\frac{E}{1.13}}$	
0430 UT	$3688100\ E^{-5.30}$	
0500 UT	$1026400\ E^{-5.24}$	
0600 UT	$295420\ E^{-4.56}$	
December 13th 2006		
0318-0349 UT	$446900\ e^{-\frac{E}{0.33}}\ E^{-0.51}$	$51079\ e^{-\frac{E}{0.155}}$
0349-0433 UT	$535000\ e^{-\frac{E}{0.20}}\ E^{-1.02}$	$1122\ e^{-\frac{E}{0.28}}\ E^{-1.77}$
0433-0459 UT	$12038\ e^{-\frac{E}{2.53}}\ E^{-1.95}$	$3117\ e^{-\frac{E}{0.19}}\ E^{-1.58}$
0818-0917 UT	$1057\ E^{-3.60}$	$675\ e^{-\frac{E}{0.13}}\ E^{-1.72}$
1650-2235 UT	$58718\ e^{-\frac{E}{0.072}}\ E^{-0.37}$	
December 14th-15th 2006		
2305-0235 UT	$1155\ e^{-\frac{E}{0.24}}\ E^{-2.48}$	
0305-0455 UT	$463\ e^{-\frac{E}{0.27}}\ E^{-2.68}$	
0525-0630 UT	$23005\ e^{-\frac{E}{0.089}}\ E^{-1.13}$	
0750-0800 UT	$400900\ e^{-\frac{E}{0.054}}\ E^{-0.095}$	
1540-1930 UT	$15909\ e^{-\frac{E}{0.056}}\ E^{-0.96}$	
1930-2335 UT	$435\ e^{-\frac{E}{0.079}}\ E^{-2.10}$	

CG+, J. Ph. Conf. Ser. ,31, 045018, 2014

$$F(E) = A\ e^{-\frac{E}{E_o}}\ Particles\ (m^2\ sr\ s\ GeV)^{-1}$$

$$F(E) = A\ E^{-\gamma}\ Particles\ (m^2\ sr\ s\ GeV)^{-1}$$

$$F(E) = A\ e^{-\frac{E}{E_o}}\ E^{-\gamma}\ Particles\ (m^2\ sr\ s\ GeV)^{-1}.$$

Proton percentage below 400 MeV

	Solar minimum	Solar maximum	Onset	Peak/ Decay
GCR	19%	6%		
SEP 13/12/2006			90%	98% (peak)
SEP 14/12/2006			99%	100% (decay)
SEP 23/2/1956			25%	99.5% (peak)

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Detector design

- *a:Si-H active material* and *tungsten passive material*
- *CSDA proton range in tungsten (Z=74)*
- *Tungsten density: 19.25 g/cm^3*
- *Geometrical Factor max for 400 MeV protons and about 1 kg detector: 3 cm^2 sr*

Energy	CSDA range	Range	Mass
300 MeV	99.33 g/cm^2	5.16 cm	2.5x2.5 → 620 g 2.0x2.0 → 397 g 1.5x1.5 → 223 g
350 MeV	127.1 g/cm^2	6.60 cm	2.5x2.5 → 795 g 2.0x2.0 → 508 g 1.5x1.5 → 286 g
400 MeV	156.8 g/cm^2	8.15 cm	2.5x2.5 → 979 g 2.0x2.0 → 627 g 1.5x1.5 → 353 g

INFN HASPIDE Project

→ 3 year project

Competence and resources:

→ R&D on device design and prototype fabrication: EPFL, Lecce, PG, UOW

→ Test facilities and characterization (accelerators, X-ray facilities, synchrotron beamlines access): all research units

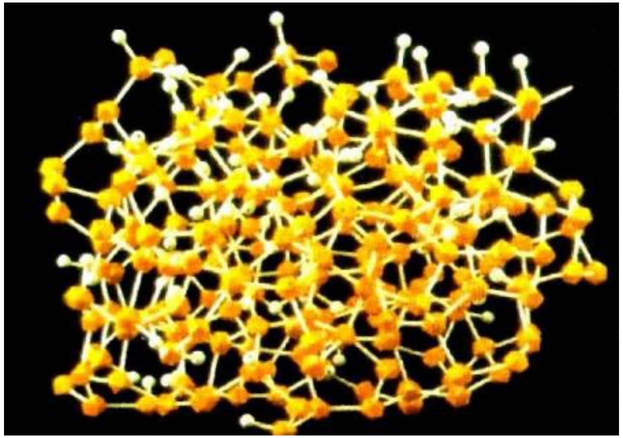
→ Instrument Modelization (Montecarlo methods, TCAD tools): Perugia, Firenze, Urbino, Un. of Wollongong, Lab. Naz.Sud INFN;

→ Data analysis: all research units

→ device production in national industries: several photovoltaic panels production sites are available.

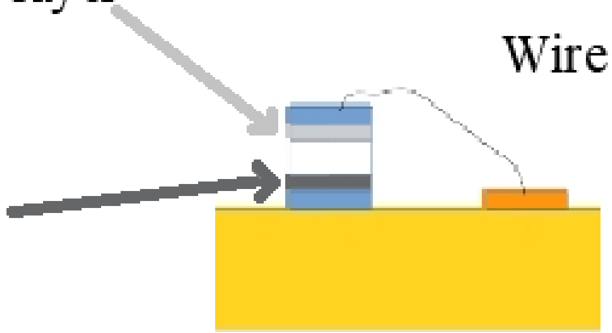
Why a-Si:H as material?

- → *it is intrinsically radiation resistant;*
- → *it can be deposited in thin layers (~ 1-100 μm);*
- → *it can be deposited on different substrates, even flexible ones like mylar and kapton;*
- → *it has a charge collection efficiency half the c-Si;*

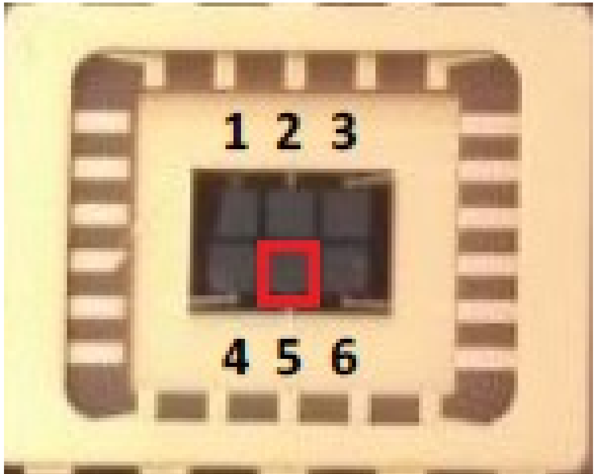


How a device will look like?

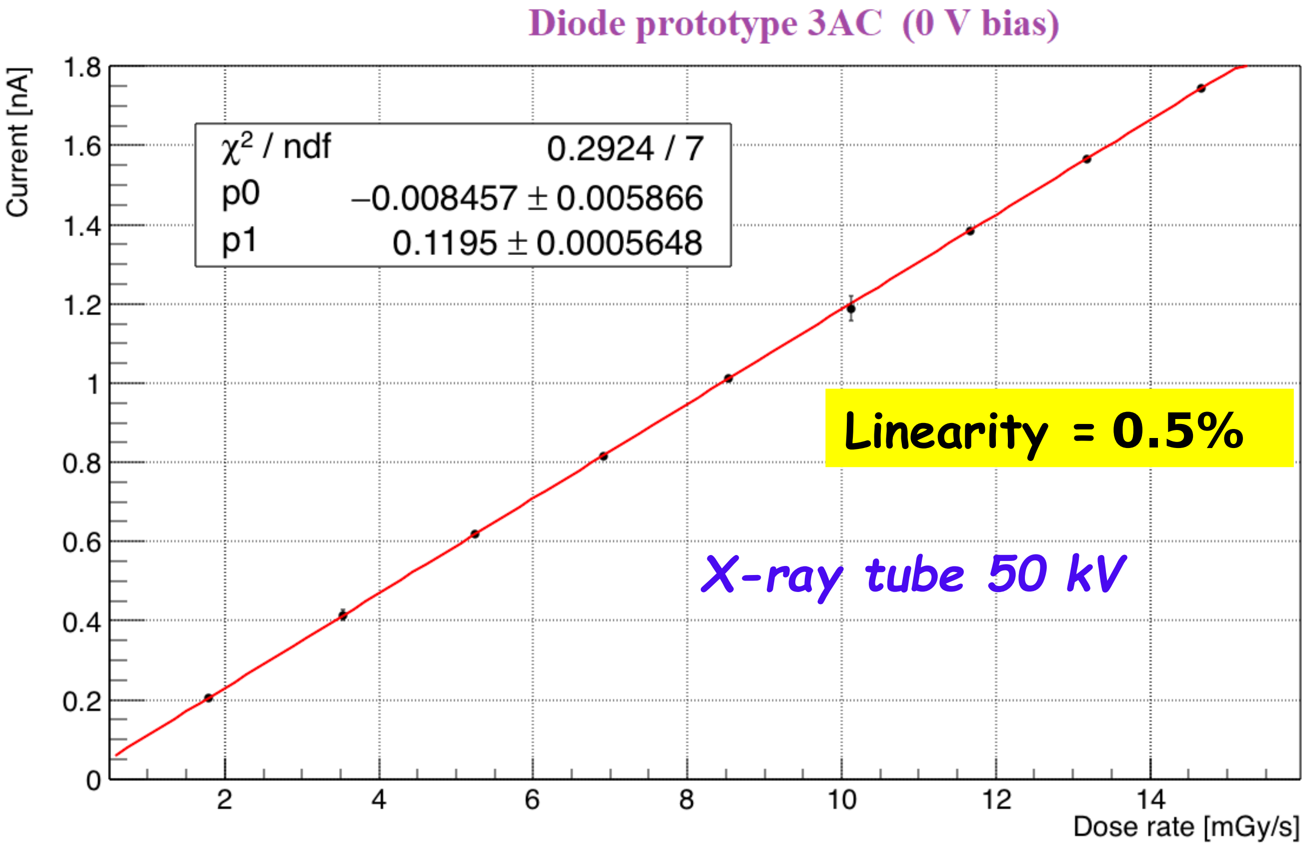
- Intrinsic a-Si:H detector layer 10-20 um
- 70 um kapton
- p-doped a-Si:H junction layer
- Metal layer (Cr + Al)
- n-doped a-Si:H junction
- detector pad or bias Pad in Copper



6 diodes: 1x1 mm x 10 μm



Preliminary results:



Similar results for exposition to clinical beams and electron beams

Detection sensitivity

Ionizing radiation type	50 kV X-ray Photons	6 MV Photons (Clinical)	6 MeV Electrons (Clinical)	Protons (3 MeV) preliminary
Sensitivity (nC/cGy)	1-20 (CSC)	0.1-1.0 (p-i-n)	~ 0.1 (p-i-n)	0.1-0.2 (p-i-n)

→ Photon and electron data published or presented at conferences;

→ Proton data are being collected in several campaigns at different energies (data analysis in progress).

→ Sensitivity will be improved by HASPIDE project

→ Noise could be reduced to few pA

Simulated detection limit @ 5 x noise

→ Sensor dimension: 4x4x0.008 mm = 0.13 mm^3 volume;

→ Sensor noise: 20 pA; Sensitivity 20 nC/cGy

Photon <energy> (keV)	5	10	20	40
100 pA Signal (γ/s/cm^2/sr)	~5x10^4	~1.5x10^5	~5x10^5	~2x10^6

Simulated detection limit @ 5 x noise

→ Sensor dimension: 4x4x0.008 mm = 0.13 mm^3 volume;

→ Sensor noise: 20 pA; Sensitivity 20 nC/cGy

Proton energy (MeV)	400	200	100	70	50	20	10	5
100 pA Signal ($p/s/cm^2/sr$)	$\sim 2 \times 10^4$	$\sim 1 \times 10^4$	7×10^3	6×10^3	3×10^3	2×10^3	$\sim 10^3$	8×10^2

TRL Status and Future Work

→ *Current TRL is 3-4 for X,γ photons and electron flux;*

→ *TRL for proton flux detection is 2-3;*

→ *check signal wrt proton flux and dynamic range*

→ *develop multichannel readout with higher sensitivity and low power consumption*

→ *optimize sensor area and thickness for space applications*

→ *develop simulations of the demonstrator*

→ *build demonstrator to measure monoenergetic p, e, γ fluxes*

M. Menichelli et al., 2022 JINST 17 C03033;
M. Menichelli et al., 2021 Instruments, 5(4), 32;