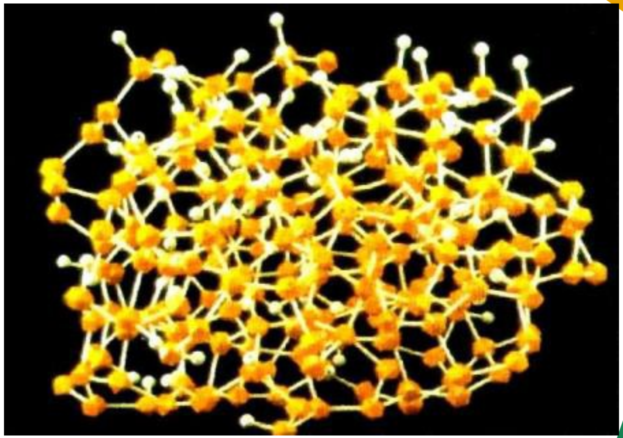
a-Si:H as active material for the detection of different radiations observed during the evolution of Solar Energetic Particle events

L.Servoli
and the HASPIDE Collaboration

Why a-Si:H as material?

- → *it is intrinsically radiation resistant;*
- → *it has a charge collection efficiency half the c-Si;*
- → *it can be deposited in thin layers (~ 1-100 μm);*
- → *it can be deposited with any pattern on the substrate (lithography)*
- → *it can be deposited on different substrates, even flexible ones like mylar and kapton;*
- → *it is possible a low weight device with a wide area.*



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 propagation and transport effects.

- *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: goal medium-intense events (>10^7 protons cm^{-2} > 30 MeV).

See C. Grimani talk 22-june

How a device will look like?

p-i-n structure: signal generated in intrinsic layer

Intrinsic a-Si:H detector layer 10-20 um

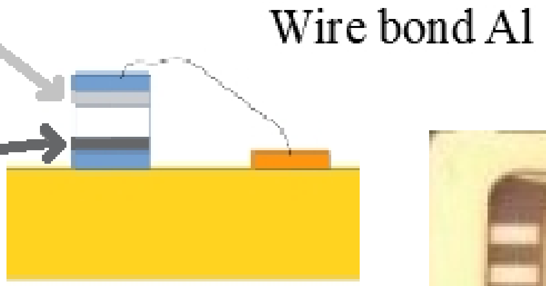
70 um kapton

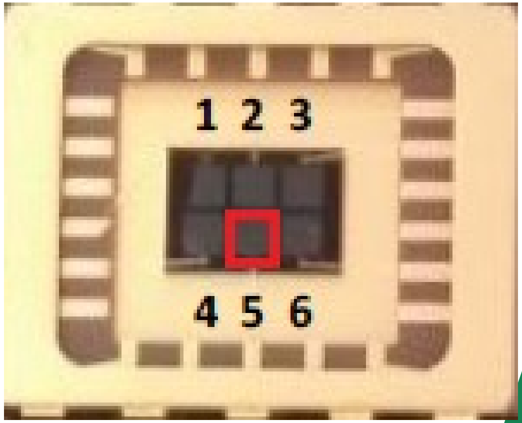
p-doped a-Si:H junction layer

Metal layer (Cr + Al)

n-doped a-Si:H junction

detector pad or bias Pad in Copper

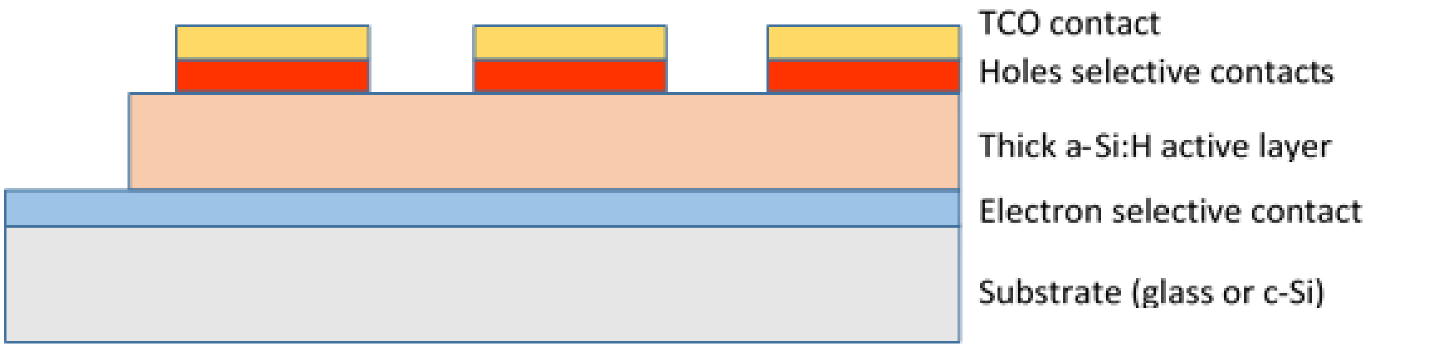




6 diodes: 1x1 mm x 10 μm

a-Si:H contact types

Charge Selective Contacts (CSC): two thin layers of metal oxides sandwiching the sensitive a-Si:H film.



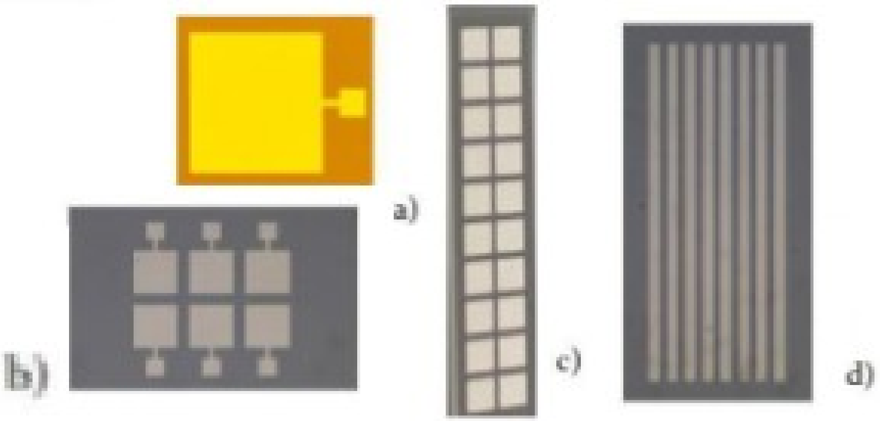
Our first prototypes:

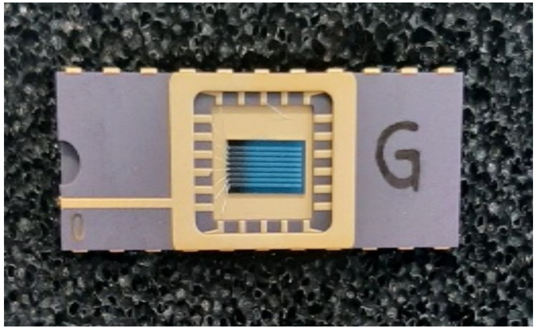
→ electron selective contacts: ZnO:Al or TiO_2

→ hole selective contacts: MoOx

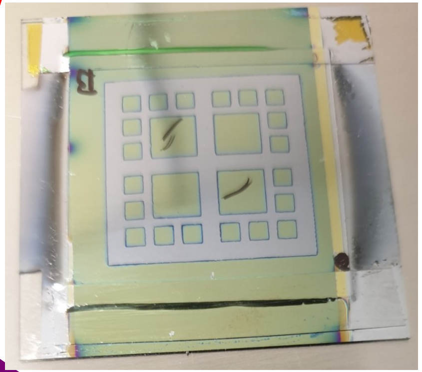
Selective contact layer thickness < 30 nm; intrinsic layer (1-10 μm)

a-Si:H protoypes



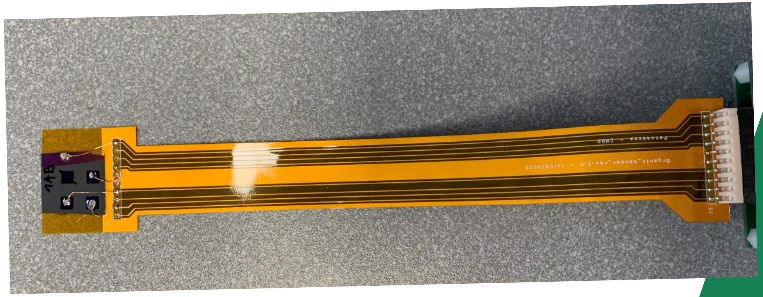


Packaging: socket



p-i-n devices over Kapton (25 μm)
2x2 mm² and 5x5 mm².

Possibility to create devices < 100 μm thickness on flexible support

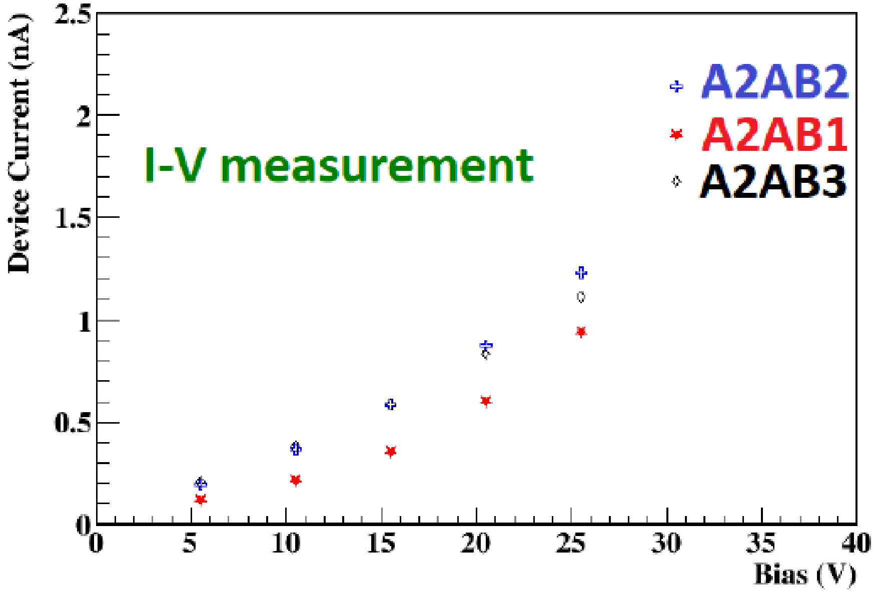


Packaging: using kapton long tails

Characterization of a-Si:H device

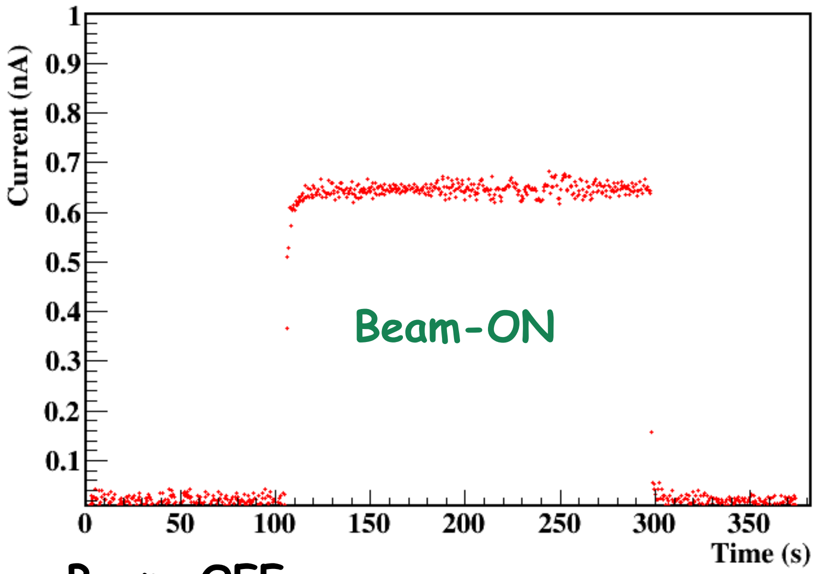
I-V curve for devices belonging to same batch is similar,on average within 5%

Maximum difference < 20 %



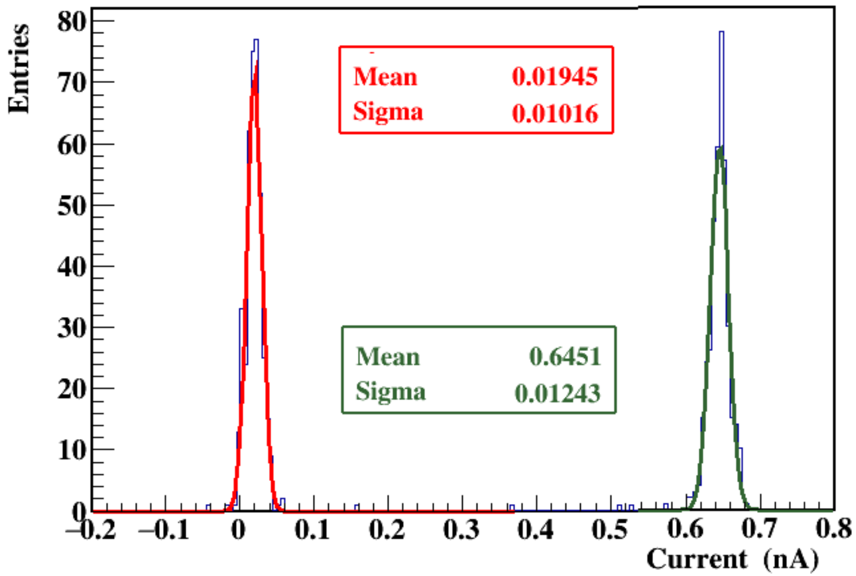
Noise of a-Si:H device

Response to X-ray beam: 30 kV, 100 μA, 4x4 mm^2, 8.2 μm thick, 0 V bias



Beam-OFF

Beam-OFF



Dark Current

Sensor Response

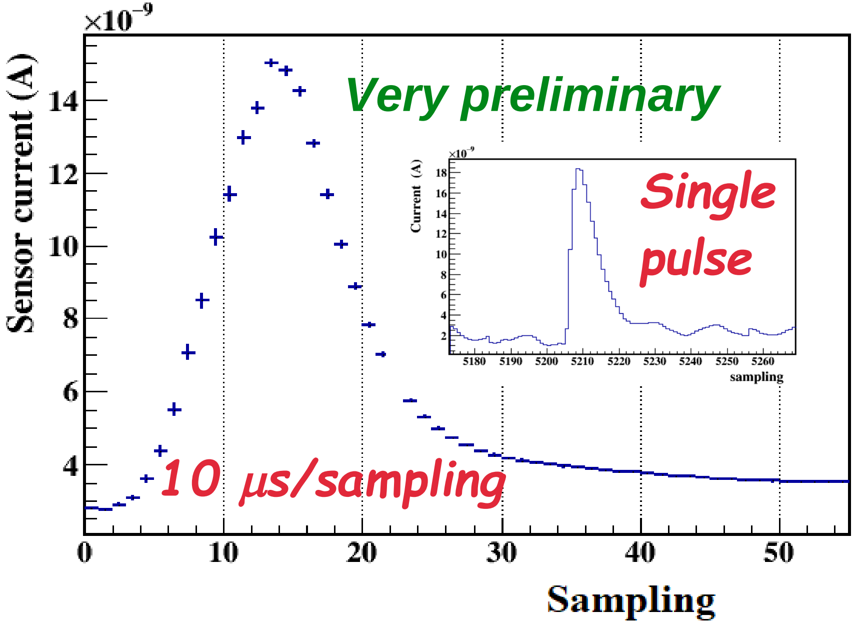
Noise Beam-OFF ~ 10 pA

Signal = $S_{Beam-ON} - S_{Beam-OFF}$

Noise Beam-ON ~ 12 pA

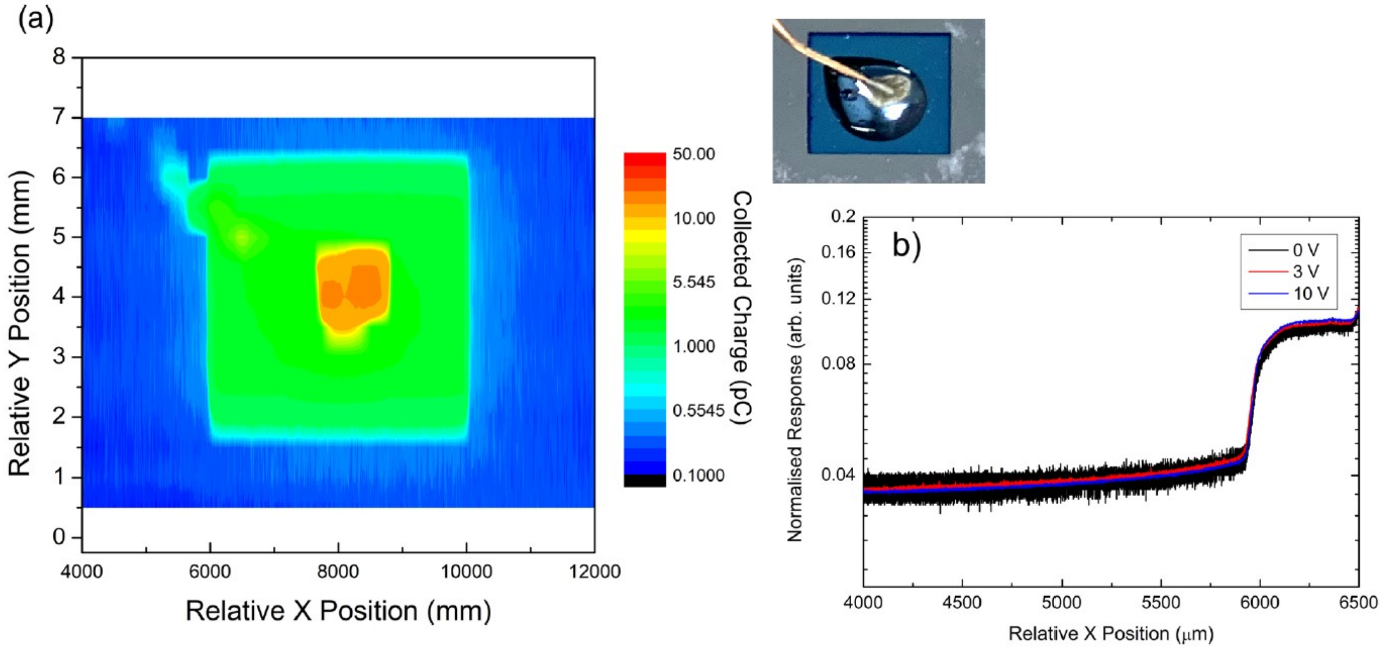
Time response of a-Si:H device

X-ray from clinic beams: many "pulses", 3 μs long made of many subpulses and spaced by 3 ms. With our front-end we could detect each pulse as a convolution of pulse shape and front-end time resolution.



Sensitive Volume of a-Si:H device

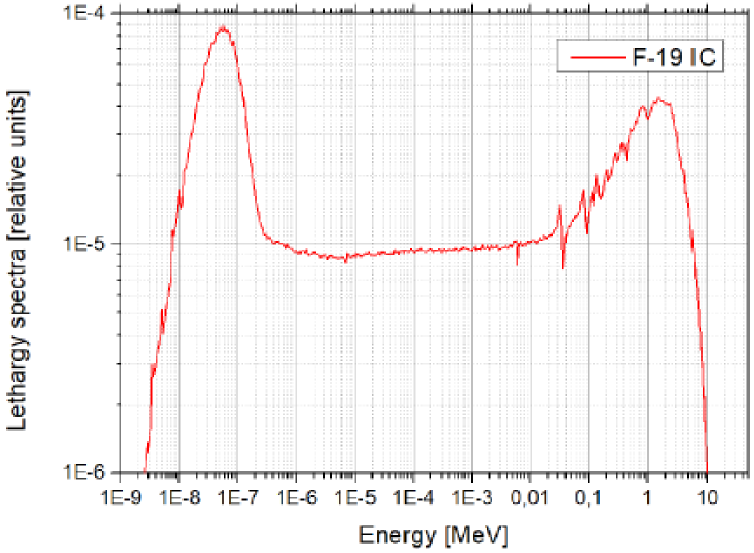
X-Ray Beam Induced Voltage (XBIC) technique:



M. Large et al: "Hydrogenated amorphous silicon high flux x-ray detectors for synchrotron microbeam radiation therapy" , Phys. Med. and Biol. doi: 10.1088/1361-6560/acdb43

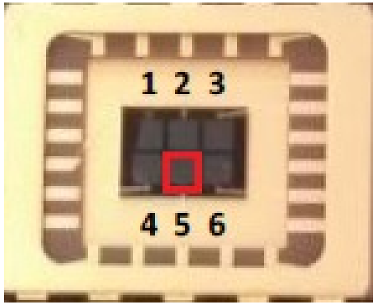
Radiation Resistance of a-Si:H device

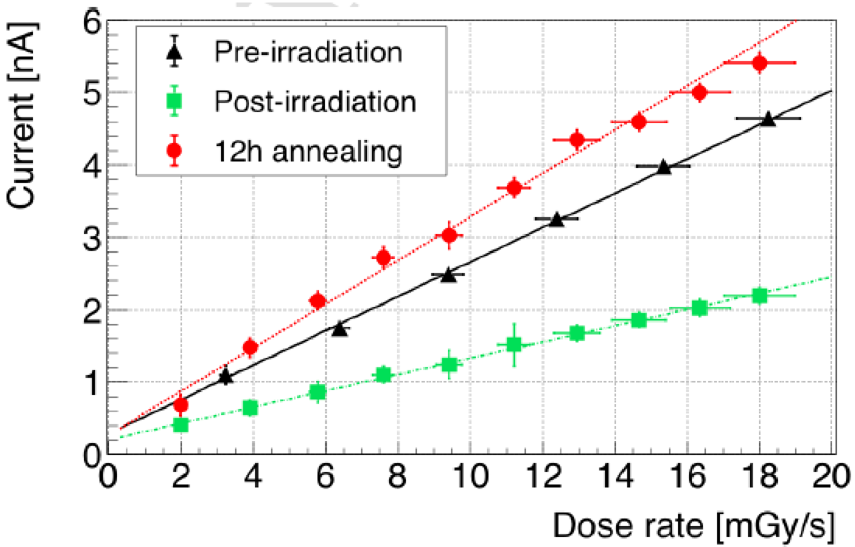
Damage using neutrons (JSI – Ljubljana)



$1 \times 10^{16}\ n_{eq(1MeV)}/cm^2$

0.5x0.5 mm^2
10 μm thick
60 V bias

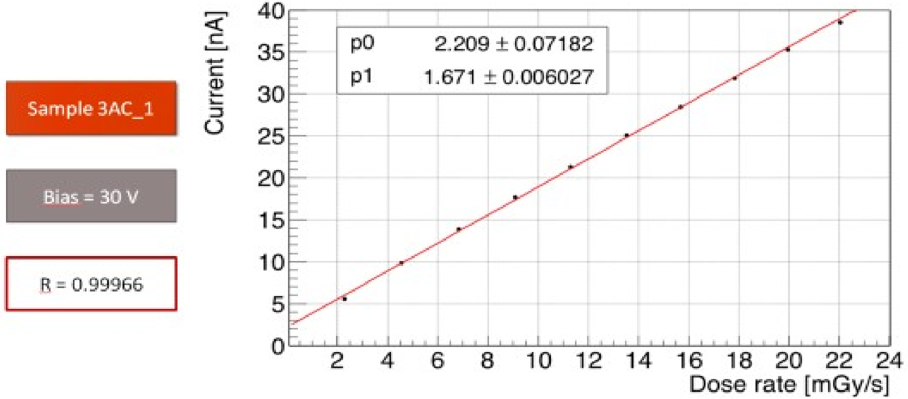




M. Menichelli et al: "Neutron irradiation of Hydrogenated Amorphous Silicon p-i-n diodes and charge selective contacts detectors" , Nucl. Inst. Meth. A (2023) doi: 10.1016/j.nima.2023.168308

Sensitivity of a-Si:H device

X-ray tests in laboratory (< 30 kV, peak energy ~ 10 keV)



Detector type and bias	Sensitivity (nC/cGy)
CSC at 30V bias	11.1 ± 0.3
CSC at 0V bias	0.86 ± 0.03
P-i-n diode at 60V	2.39 ± 0.09

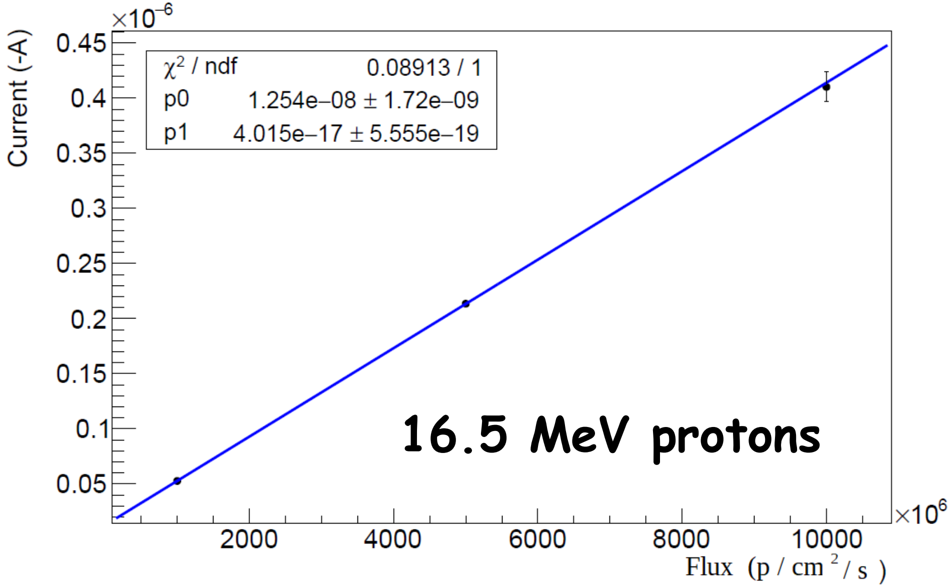
Excellent linearity, deviation < 5%

Sensitivity 1-10 nC/cGy

M. Menichelli et al: "Neutron irradiation of Hydrogenated Amorphous Silicon p-i-n diodes and charge selective contacts detectors" , Nucl. Inst. Meth. A (2023) doi: 10.1016/j.nima.2023.168308

Sensitivity of a-Si:H device

Protons from several sources: 3 MeV (CEDAD), 16.5 MeV (Berne Cyclotron), 228 MeV, 70 MeV (Trento Hadrontherapy)



In all measurements, done with different sensors, a linear response has been found with sensitivity at the same order of magnitude level predicted by SRIM simulations.

Detection limits of a-Si:H device

In order to evaluate the detection capability of a a-Si:H device to past SEP events, we define the following device:

4x4 mm^2 area, 8.2 μm thickness, sensitivity 2 nC/cGy.

We define a 5x5 matrix of such devices (20x20 mm^2 total area) connected in parallel.

The total noise of such a device is estimated at 25 pA.

The detection limit is a S/N > 5 , i.e. signal > 125 pA.

Detection limits of a-Si:H device

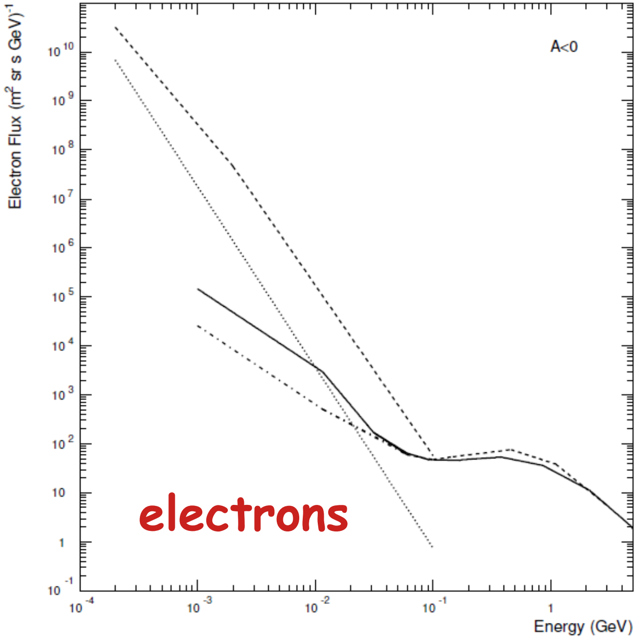
Minimum detectable flux for several photon energies up to 40 keV

Table 5 Detection limits at 5σ for monochromatic photon fluxes.

Photon Energy [keV]	Minimum detectable flux [$\gamma/(cm^2\ s)$]
3.0	$2.4 \cdot 10^3$
5.0	$3.8 \cdot 10^3$
10.0	$10.2 \cdot 10^3$
15.0	$20.2 \cdot 10^3$
20.0	$33.0 \cdot 10^3$
25.0	$47.8 \cdot 10^3$
30.0	$79.8 \cdot 10^3$
35.0	$150.0 \cdot 10^3$
40.0	$237.0 \cdot 10^3$

Detection limits of a-Si:H device

To evaluate the limits for electron flux detection we took the spectra of November 7, 1973 SEP.



Integrating the flux from 50 keV up to 1 GeV, taking into account the deposition of energy with FLUKA simulation, we obtain a signal of 45 pA, i.e. S/N ~ 2 .

Barely over the noise level.
Work in progress

Detection limits of a-Si:H device

For protons we found the minimum flux that will produce a S/N > 5 for monochromatic flux.

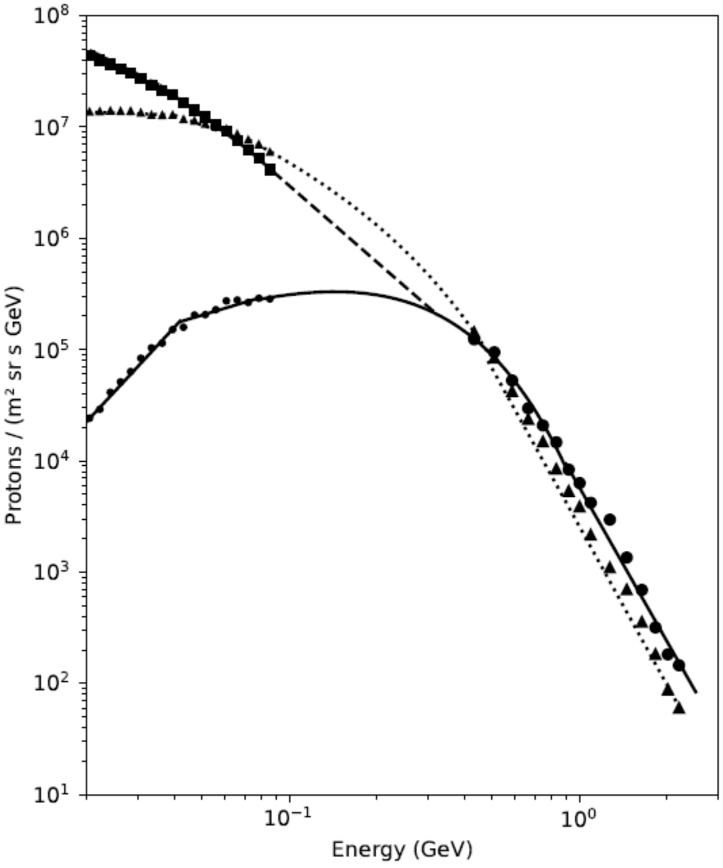
Detection limits at 5σ for monochromatic proton fluxes.

Proton Energy [MeV]	S/N = 5 Flux [p $(cm^2\,s)^{-1}$]
5.0	$0.4 \cdot 10^3$
10.0	$0.5 \cdot 10^3$
20.0	$1.0 \cdot 10^3$
50.0	$1.5 \cdot 10^3$
70.0	$3.0 \cdot 10^3$
100.0	$3.5 \cdot 10^3$
200.0	$5.0 \cdot 10^3$
400.0	$10.0 \cdot 10^3$

At low energy the number of protons / sec / cm^2 is of the order of few hundreds.

Detection limits of a-Si:H device

Using the measured proton spectra of October 28, 2021 SEP we obtain a signal of 85 pA, i.e. S/N = 3.8



Detection limits of a-Si:H device

Improvements:

→ noise reduction below 1 pA. The readout is the current limit and we will improve it. We have just submitted a new ASIC chip in 28 nm node (Cleopatra).

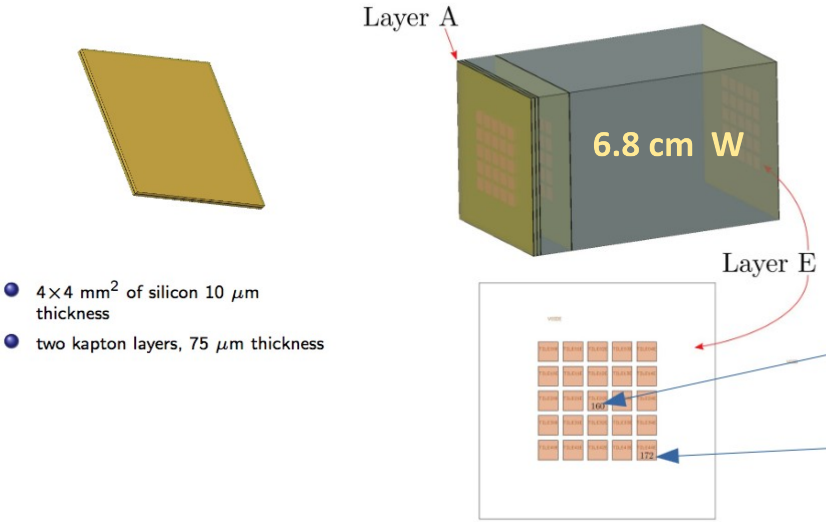
→ improved sensitivity. Better contact type and/or deposition procedures; ~ 5 improvement factor

→ increase sensor thickness; up to 30 μm is feasable. ~ 3.5 improvement factor

Work in Progress:

→ Simulations with Fluka of full device

a-Si:H not present as MC material → we have to parametrize it and validate wrt experimental measurements:



75% of protons fully contained @ 400 MeV

Region	400 MeV		600 MeV	
	Mean (keV)	RMS (keV)	Mean (keV)	RMS (keV)
160	11.7	26.4	4.2	26.1
172	16.1	36.1	2.1	5.0

Final goal: definition of optimized full device

References:

→ M. Menichelli et al: "Fabrication of a hydrogenated amorphous silicon detector in 3-d geometry and preliminary test on planar prototypes" , Instruments (2021) doi: 10.3390/instruments5040032

→ M. Menichelli et al: "Testing of planar hydrogenated amorphous silicon sensors with charge selective contacts for the construction of 3D-detectors" Journ. of Instr. (2022) 17 C03033 doi: 10.1088/1748-0221/17/03/C03033

→ M. Menichelli, L. Servoli, N. Wyrsch: "Status and perspectives of hydrogenated amorphous silicon detectors for MIP detection and beam flux measurements" Frontiers in Physics (2022) 10, 943306 doi: 10.3389/fphy.2022.943306

→ F. Peverini et al: "High-Resolution Photoemission Study of Neutron-Induced Defects in Amorphous Hydrogenated Silicon Devices" Nanomaterials (2022) 12, 3466 doi: 10.3390/nano12193466

→ M. Large et al: "Hydrogenated amorphous silicon high flux x-ray detectors for synchrotron microbeam radiation therapy" , Phys. Med. and Biol. doi: 10.1088/1361-6560/acdb43


Thanks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