Development and characterization of a novel alpha particle SOI pixel sensor for neutron detection

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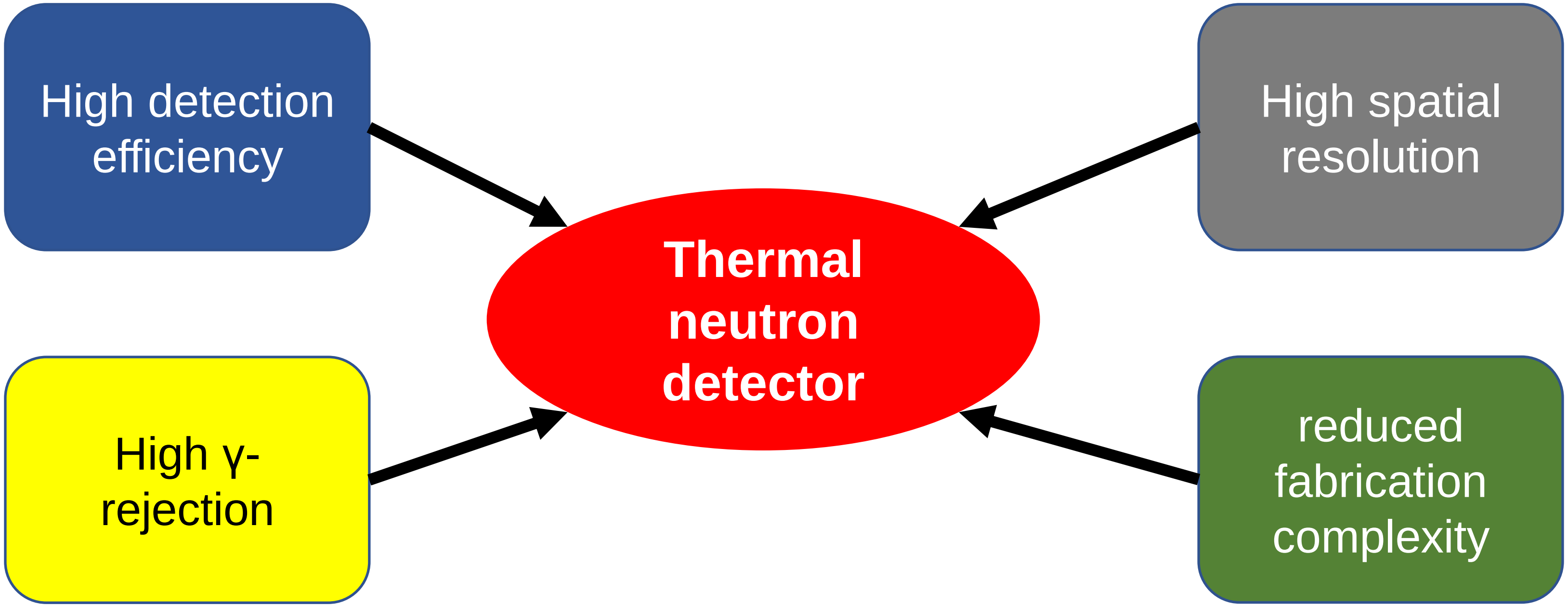
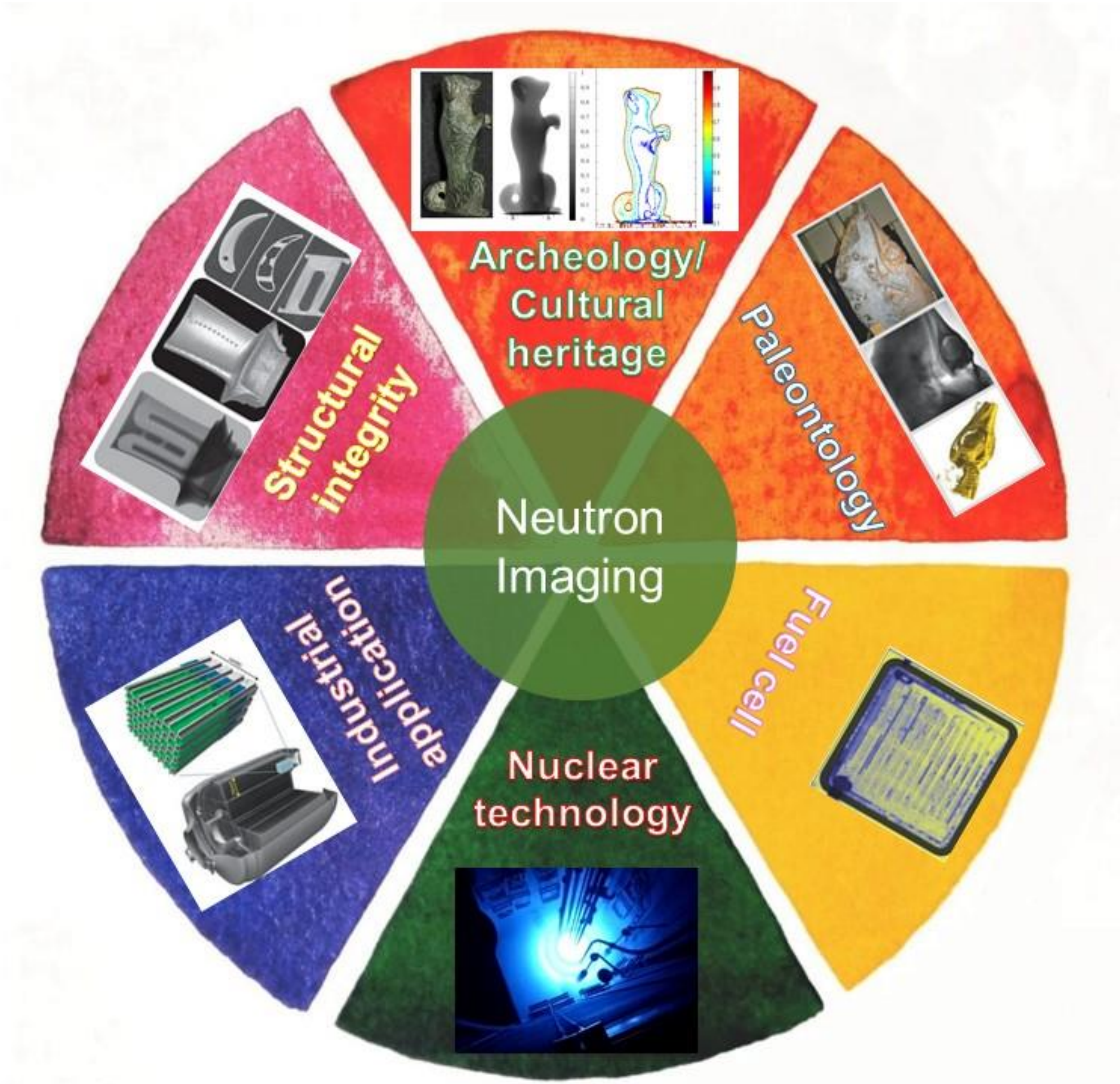
DEEP_3D stand for:
Detectors for neutron imaging with Embedded Electronics Produced in 3D technology



Application fields



Converter materials

Material	Reaction products	σ[b]
^{10}B	α+7Li	3840
^{6}Li	3H+α	940
^{157}Gd	γ (low energy)	24000
^{113}Cd	γ (558.6 & 651.3keV)	20000

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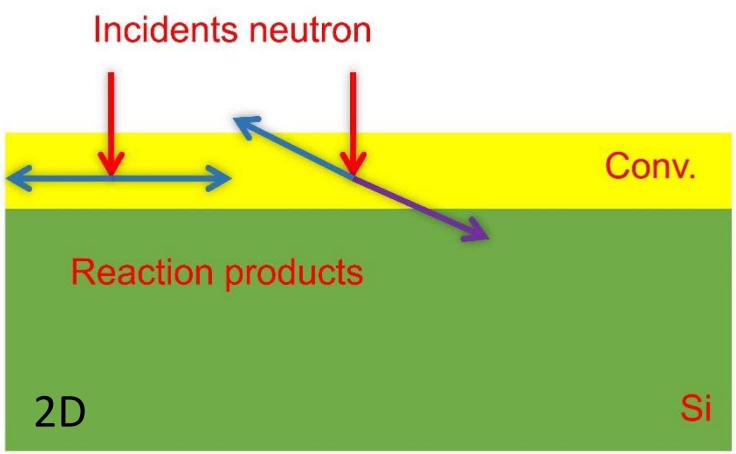
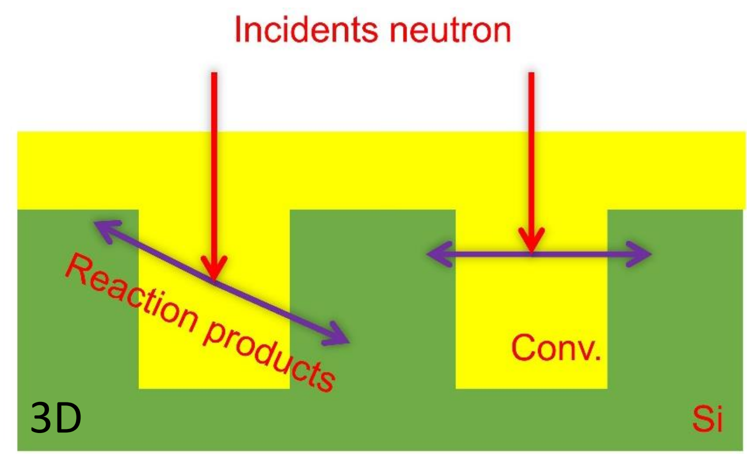
$$^{6}Li + {}^{1}_{0}n \rightarrow \; ^{3}H\ (at\ 2.73\ MeV) + \alpha\ at\ \ 2.05\ MeV)$$

$$^{10}B + {}^{1}_{0}n \rightarrow \begin{cases} ^{7}Li\ (at\ 1.015\ MeV) + \alpha\ at\ 1.77MeV) \\ ^{7}Li\ (at\ 0.840\ MeV) + \alpha\ at\ 1.47MeV) \end{cases}$$

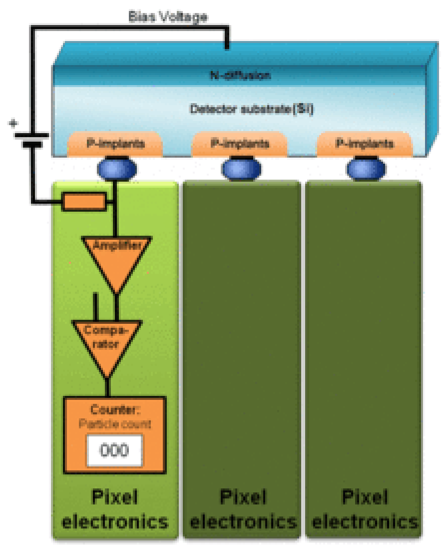




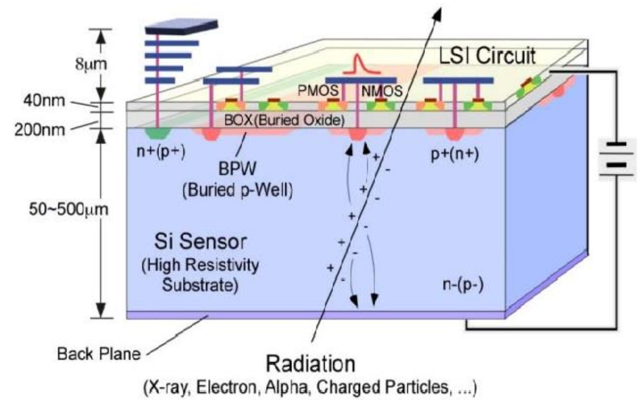
The reaction products have a random angle: this allow an higher detection probability in 3D structure where there is an high aspect ratio

Deep_3D: phases

phase I
Done!



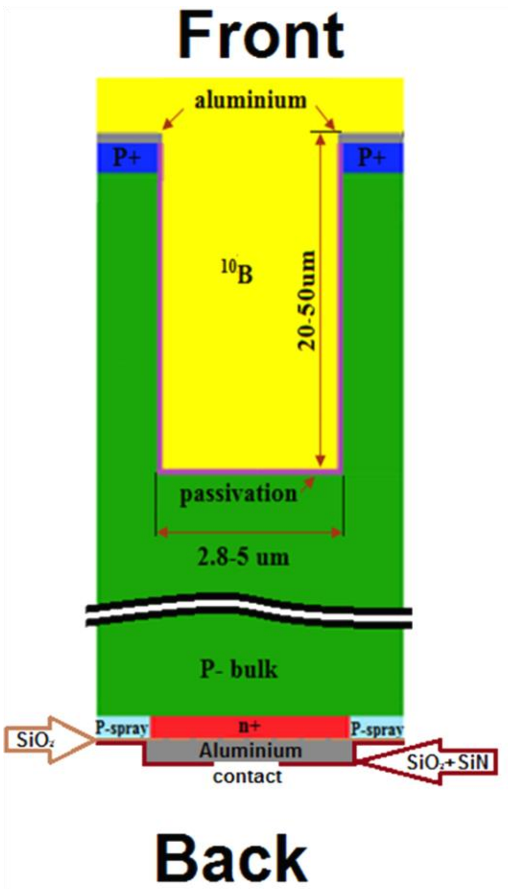
phase II

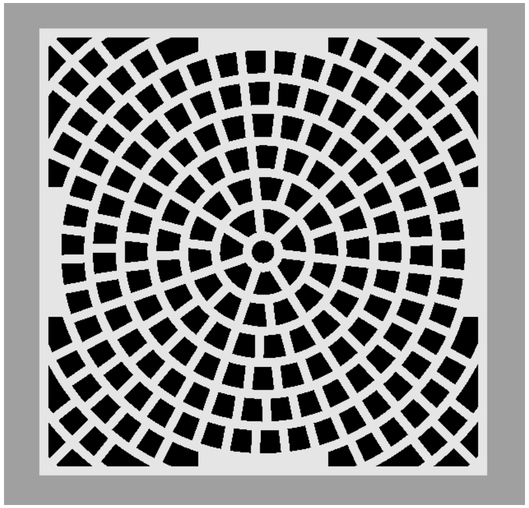


- 55 × 55 μm^2 pixel pitch
- noiseless image construction owing to neutron counting
- high gamma ray rejection > 10^5
- real image resolution of ~ 100 μm
- neutron reactive converter used LiF

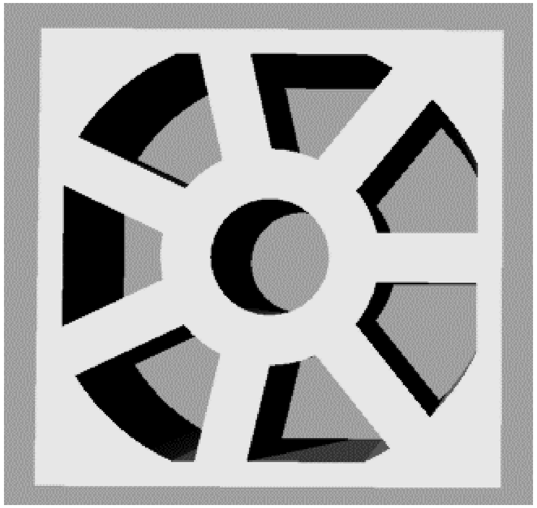
The monolithic design is expected to increase the spatial resolution performance by a reduction of the pixel pitch and by changing the converter material from lithium fluoride to enriched Boron

Deep_3D: Layout





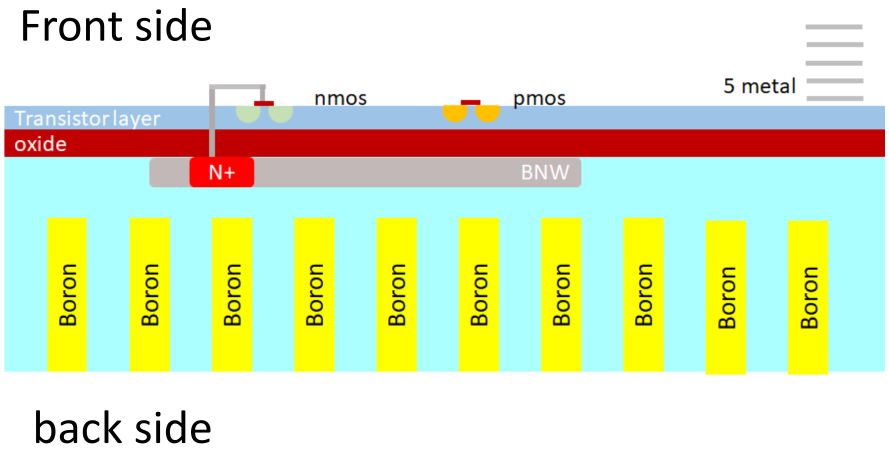
Boron converter layout



Lithium converter layout

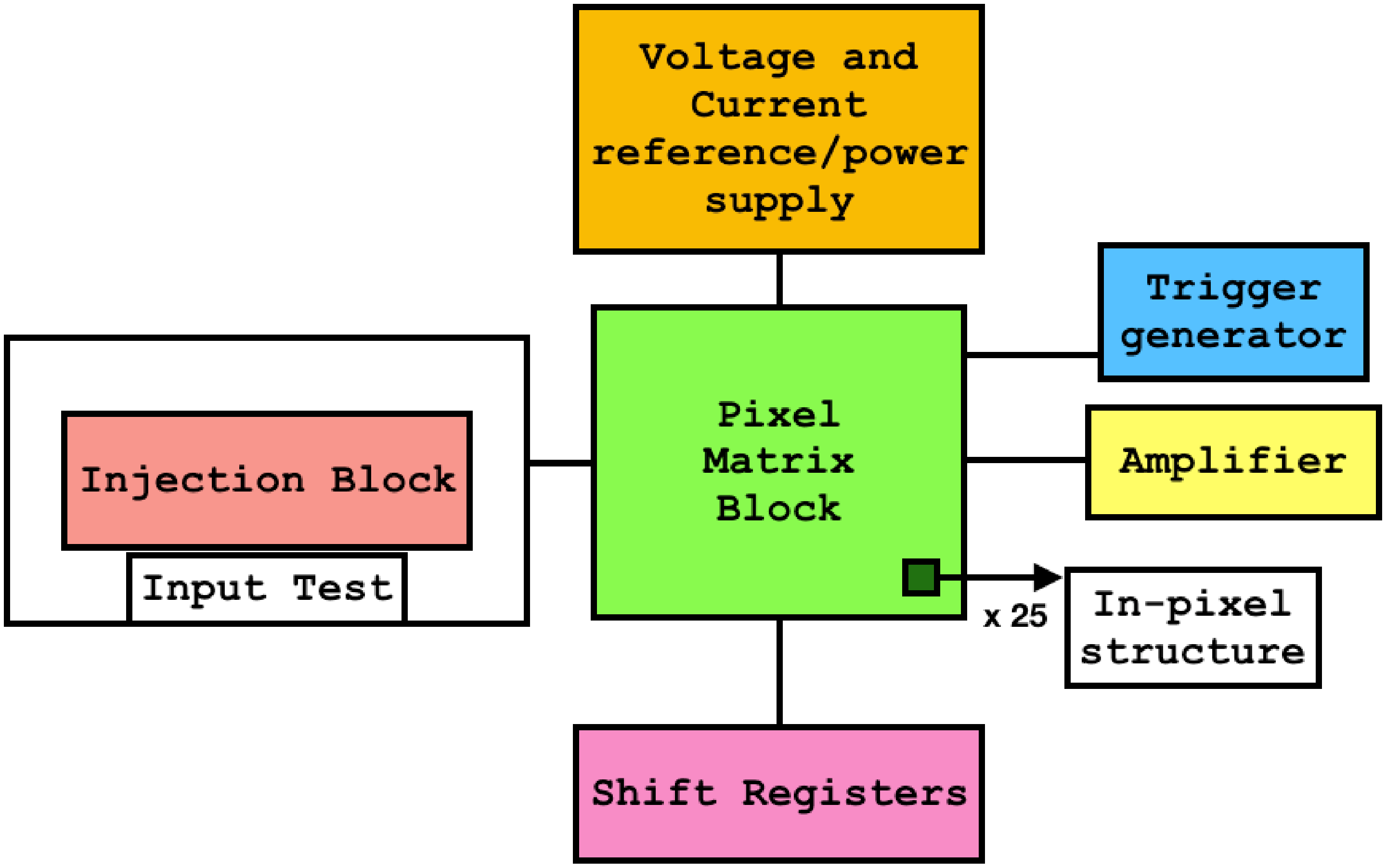
- The layout also in this case consists in a web structure
- Mean free path of reaction products in Lithium is higher, so the trenches can be larger and deeper
- The increased geometries allows to be filled with enriched LiF, using cheaper and simpler techniques

DEEP_3D: phase II

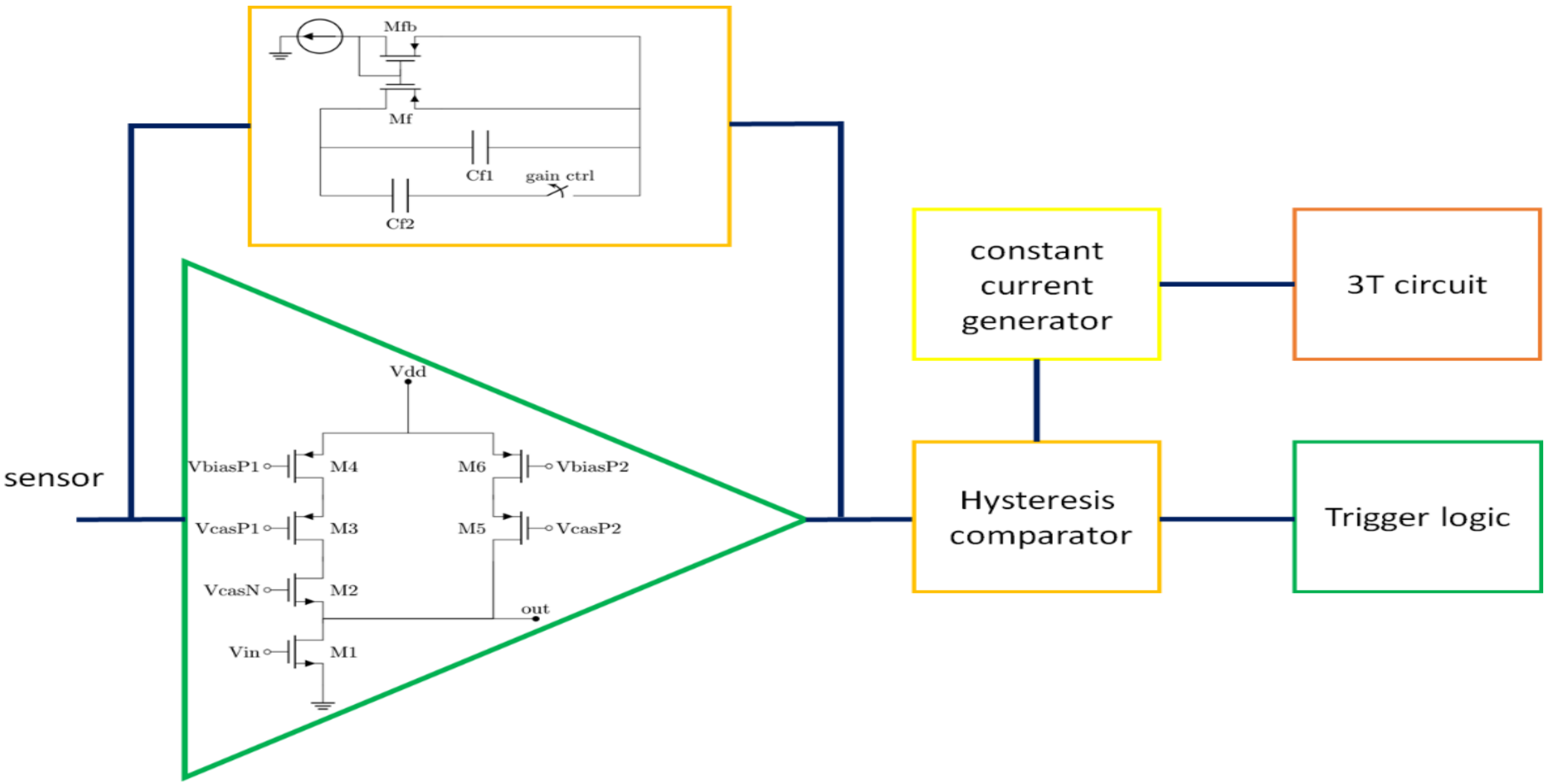


- Silicon On Insulator Pixel
- Technology has been developed by LAPIS Semiconductor
- CMOS technology 200 nm
- “Classic” CMOS MAPS has been considered for this application
- Total area 2.9x2.9 mm^2
- Pixel array 25x25 (625 pixel) and additional 2 test structure

BLOCK scheme of the matrix circuitry

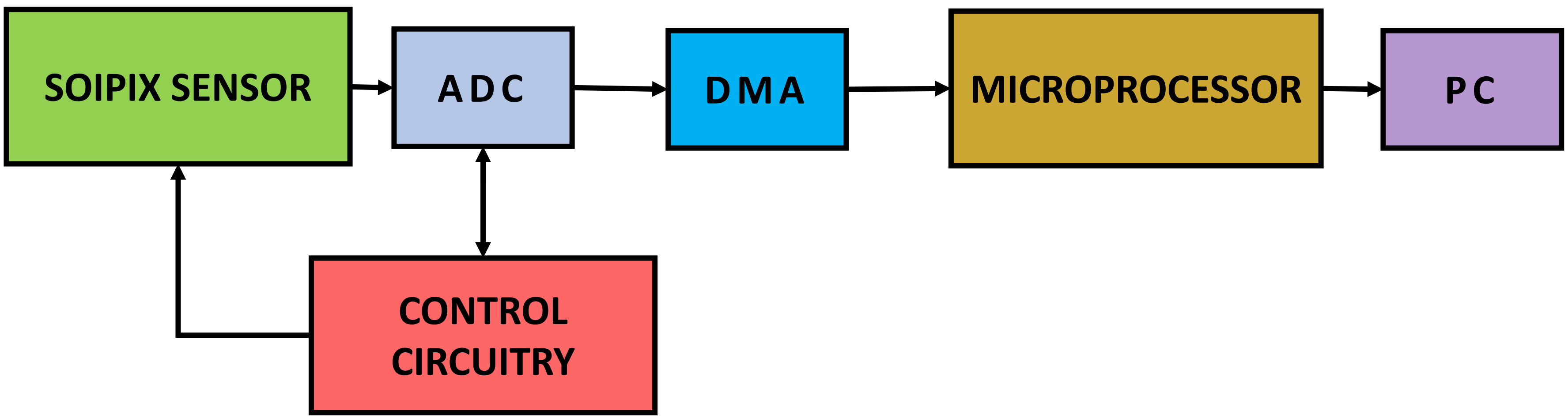


In-pixel READ-OUT electronics



- ✓ Charge Pre-Amplier;
- ✓ Feedback capacitors;
- ✓ Mirror current generator;
- ✓ A hysteresis comparator;
- ✓ Trigger generation;
- ✓ 3T circuit

FPGA BLOCK diagram



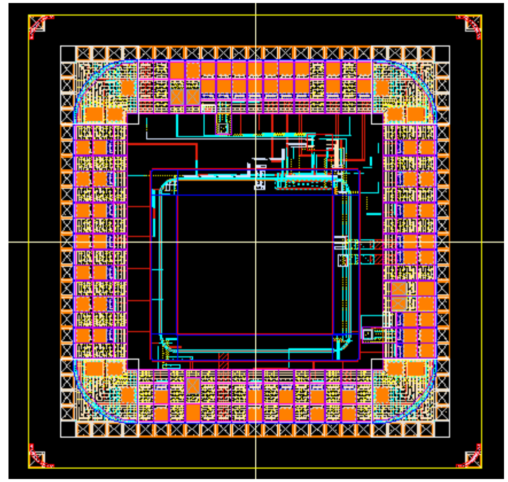
1. The FPGA is configured in order to do not have delay between events

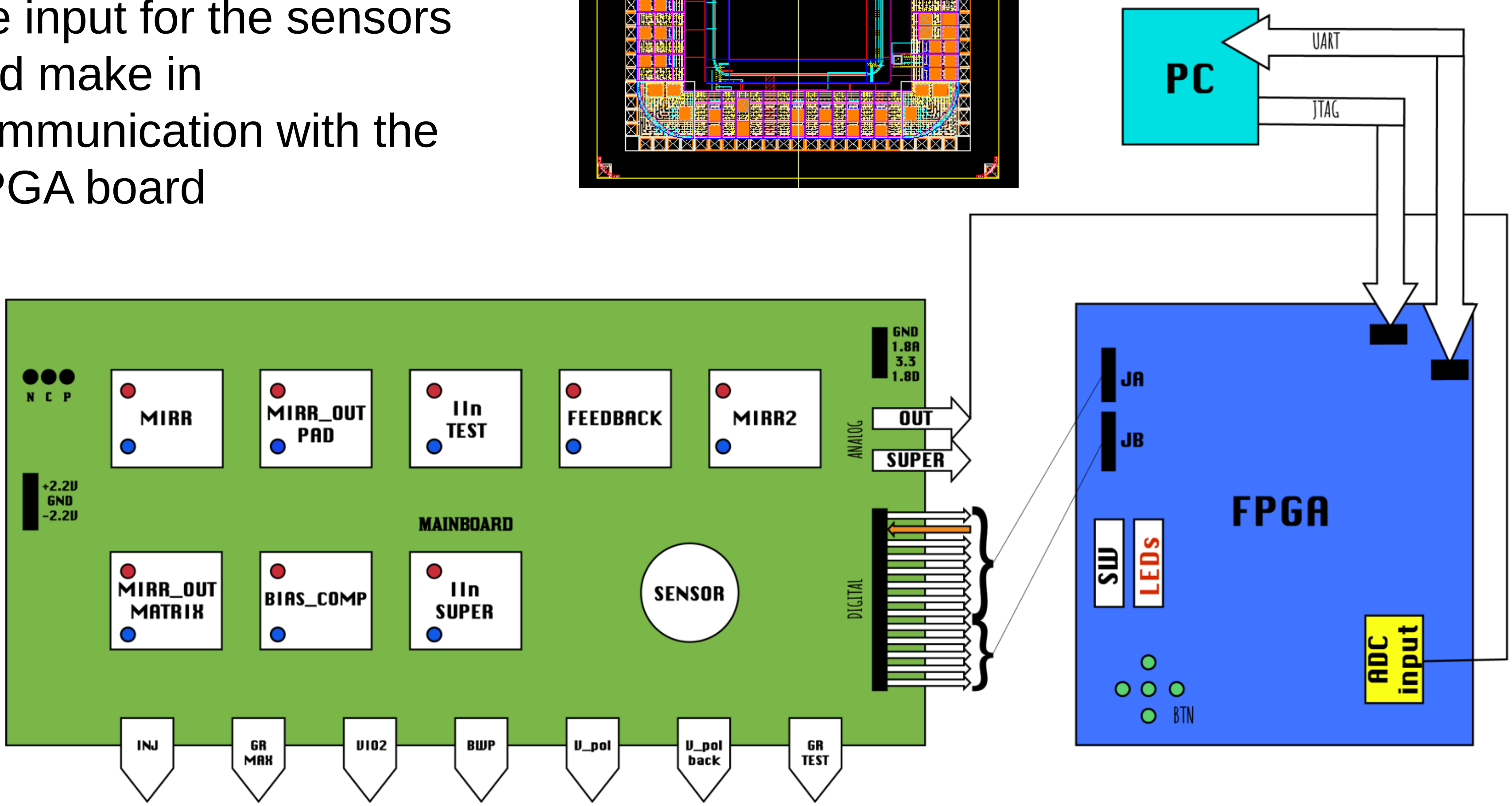
2. The bottleneck is the frequency of chips (2kHz)

3. The DMA ensure a fast communication through the ram memory

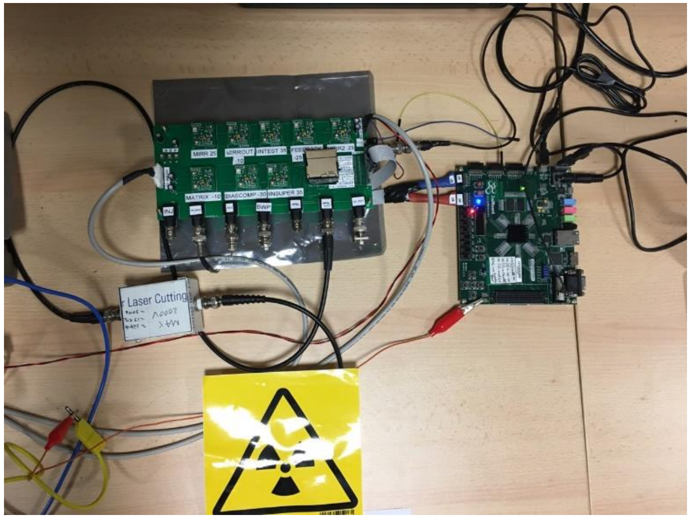
DEEP_3D mainboard

A motherboard has been designed. It provides all the input for the sensors and make in communication with the FPGA board

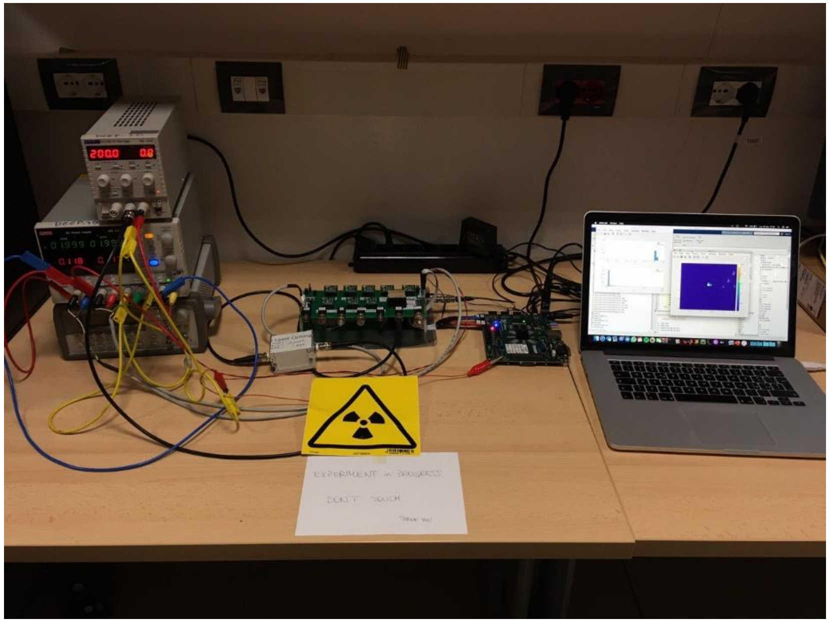


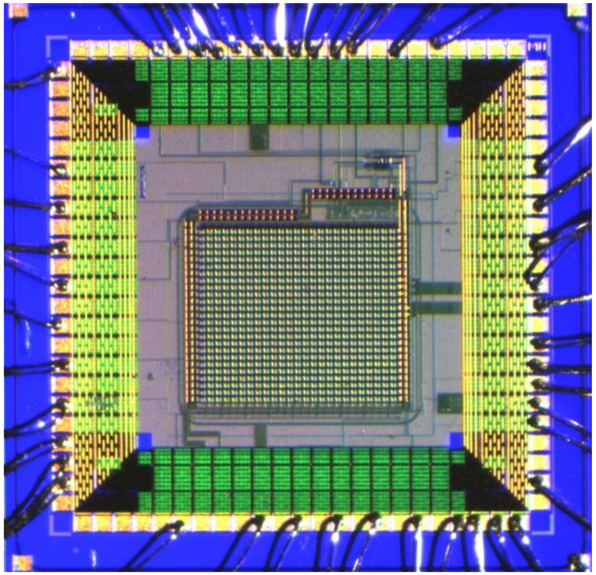


DEEP_3D assembly

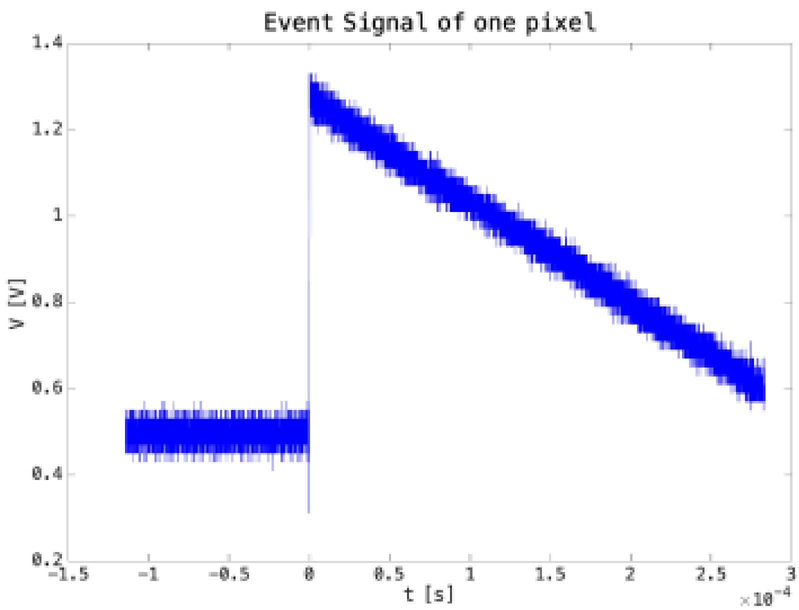


- A FPGA board with an ADC manage the readout of the chip.
- A custom board has been designed for the monolithic electronics and for the sensor
- A Photo of the chip with its connection is also reported



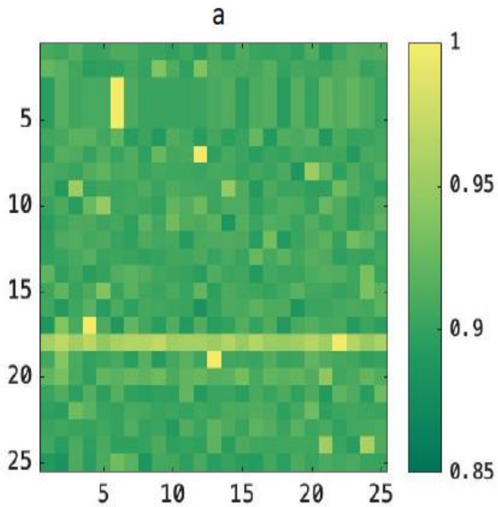


DEEP_3D alpha source: test strucures



- The distance between the sensor surface and the radiation source was of ~ 2 cm.
- The first tests have been performed on the test structure where the output of the pre-amplifier and its feedback circuits is present.
- Considering the pixel size of only 35x40 um^2 and the activity of the source the probability of an event is very low with a rate of 1 event each 12 minutes.

DEEP_3D alpha source: matrix @front side

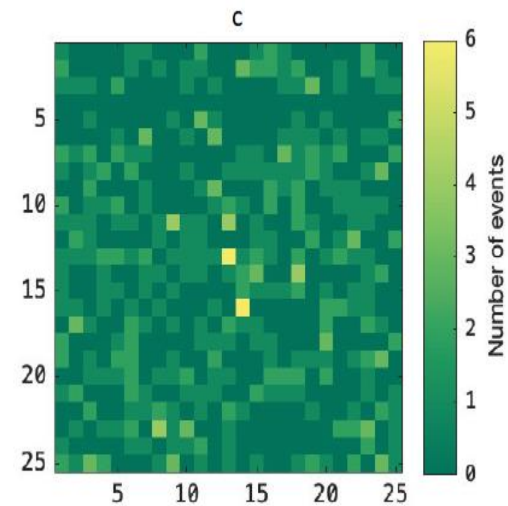


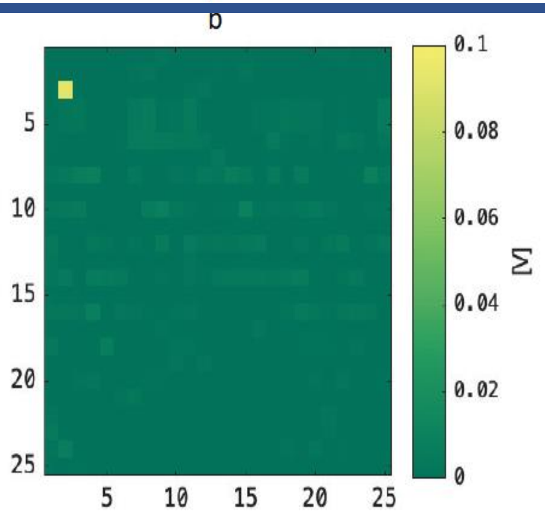
The acquisition of the dark sensor of the single pixel

The inverse polarization has been fixed to -75V.

In order to test the full matrix, the acquisition has been done for long time (~36 h).

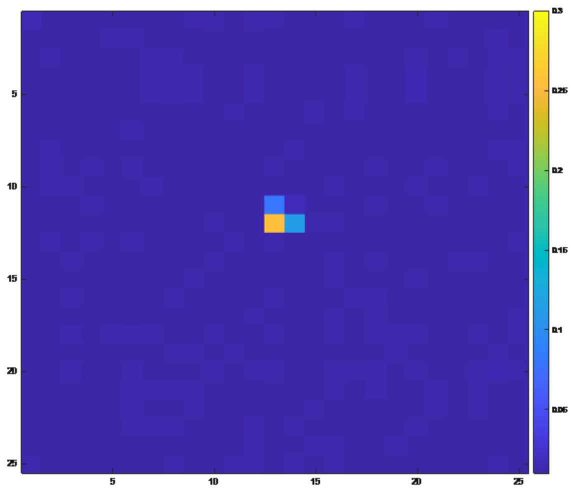
Most of the pixel that was not masked have recording at least one event.

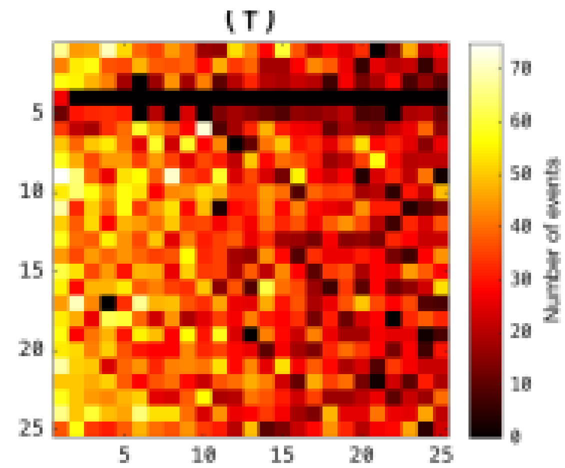




The acquisition of a single alpha particle obtained by removing the acquired data from the dark acquisition. The charge collection from the frontside is not affected (only rare cases) by the charge sharing between neighbor

DEEP_3D alpha source: matrix @back side





- In this case, because the sensor starts to deplete from the top, in order to collect all the charge, it is required a full depletion of the sensor. The voltage has been increased to −200V
- The device has a substrate thickness on the order of 300µm. In order to hit the back side with the particles, a hole was drilled on the motherboard (2,5mm diameter), and the sensor has been stocked upon it, while the source of radiation was placed underneath it at ~ 2mm from the board

Conclusions

- Neutron imaging is a very unique and promising technique of investigation, with possible applications in different fields.
- A combination of planar and 3D detector technologies allow to combine the advantage of both: high efficiency and high fabrication yield and relative low process complexity
- A new monolithic front-end has been developed and tested with alpha particles. The chip can work either with Boron and Lithium converter
- In additional the monolithic approach will give further advance:
  - Higher spatial resolution
  - High efficiency
- A new method for trenches boron filling is currently under development