Development of an innovative silicon pixel detector for imaging applications in radioguided surgery

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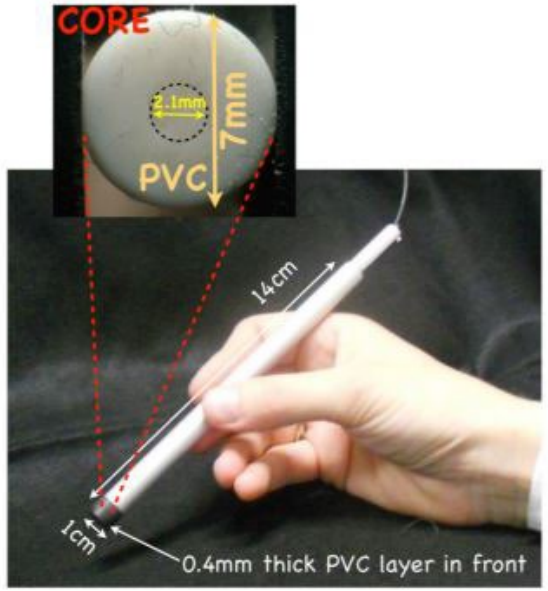
Fabio Colamaria (INFN Bari)
Domenico Colella (INFN Bari)

SCIENTIFIC GOALS OF THE PROJECT

- Radioguided oncological surgery (RGS) is a technique that involves the administration of β^+/ β^- emitting radiotracers, preferably absorbed by tumor tissues, for real-time localization (during the excision of the tumor mass) of the mass and, after its removal, of any residues to be removed.

- Compared to the γ tracers commonly used, the use of β^+/ β^- radiotracers allows to reduce the background emissions of healthy tissues at a great distance from the tumor and to reduce the administered dose:
  - **β^+**: γ background at 511 KeV, wide range of use (typical case, 18F-FDG, also used for PET)
  - **β^-**: no γ background but still few tracers available (90Y-DOTATOC) and limited applications
- Currently available prototypes of probes based on scintillators+SiPM, in study applications with silicon pixels, in both cases only with counting applications.



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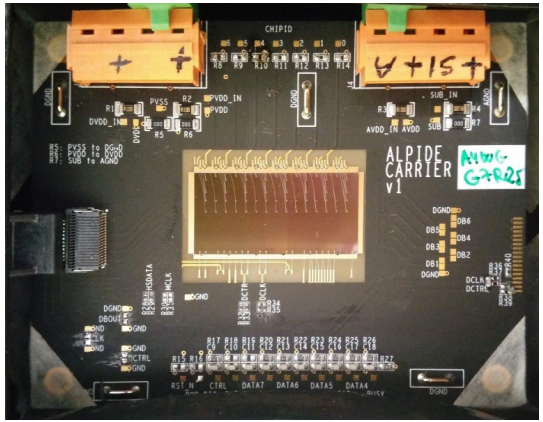


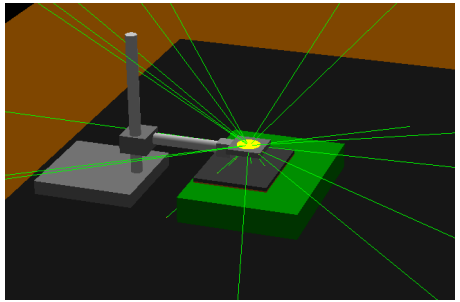
- The ALPIDE chip, based on MAPS, used for the ITS upgrade of the ALICE experiment, also has optimal potential for use as a probe: :
  - High detection efficiency, high γ rejection, low electronic noise, compactness
  - Usable not only for counting, but potentially also for real-time 2D imaging

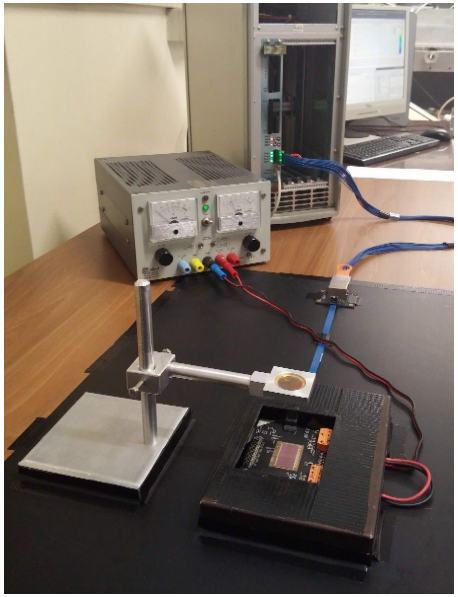
- Main milestones planned for the PRIN:
  - Characterization of the performance of the ALPIDE in RGS through studies with phantoms, using ALPIDE + carrier in a first phase, and a prototype probe when available
  - Design and realization of a demonstrator (i.e., a compact probe prototype with the ALPIDE as the sensitive element)
  - Full-body simulation of possible clinical situations of applicability with GEANT4 software. The presence of β+/β- radiotracers in healthy and tumoral tissues, at their respective concentrations, the propagation in the body and in the detector of their emissions, and the simulation of the demonstrator are expected

PRELIMINARY STUDIES

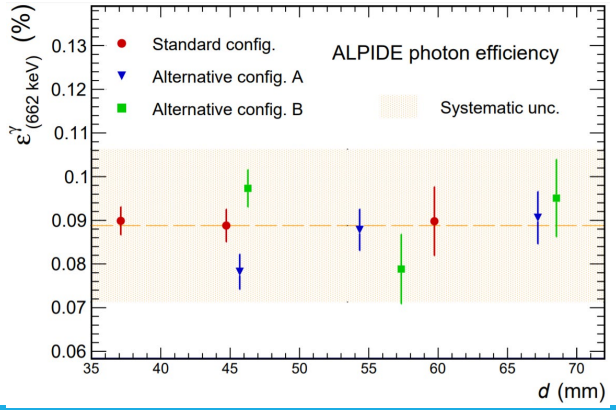
Efficiency studies for low-energy γ (background for RGS)

- Efficiency measurement with Cs-137 source, (Eγ = 662 KeV), with shielding for suppression of electrons and X emitted by the source
- Subtraction of residual X and electron contaminations through Geant4 simulations





- Cross-check with Fe-55 for measurements at lower energies (E = 6 KeV)
  - Master degree of Rocco Serena

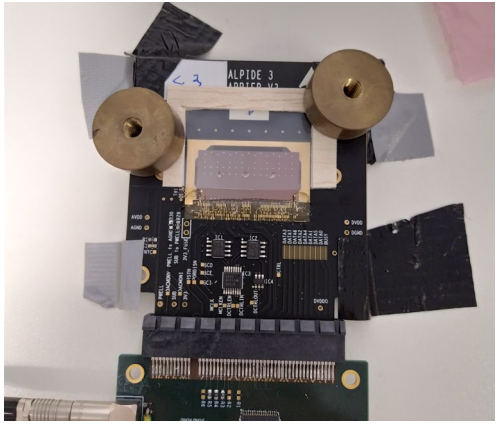


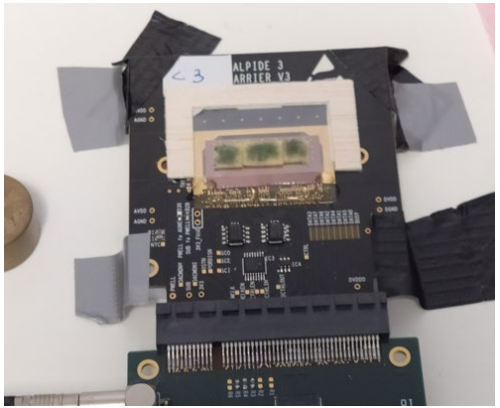
- $\varepsilon_{\gamma} \approx$ **0.09%** for photons at E = 662 KeV
- $\varepsilon_{\gamma}/\varepsilon_{ch} <$ **1‰** (vs ≈2% of Medipix chip)
  - Excellent rejection of the gamma background from annihilation
- Results presented at the Iwasi 2019 workshop
  - «Study of the photon rejection of the ALPIDE pixel detector for medical applications»

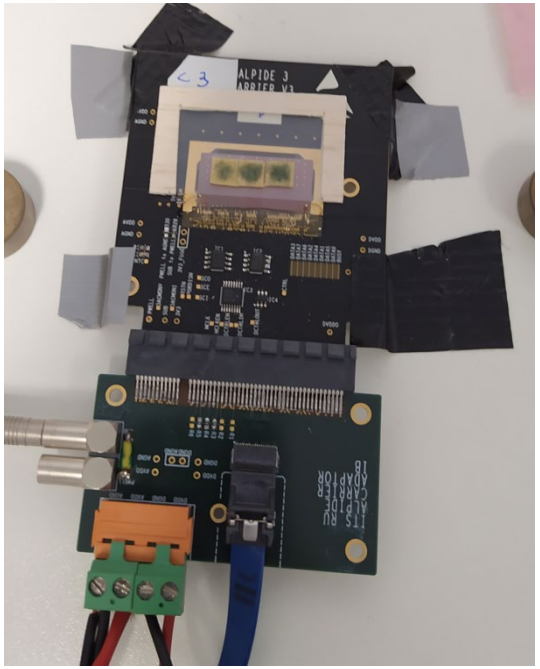
PRELIMINARY STUDIES

First performance studies with radiotracers

- Tests carried out at ITEL (Ruvo di Puglia) with ALPIDE+carrier setup
- Sponges soaked in 18F-FDG (β+ emission) with typical concentrations for healthy and tumoral tissues placed in different geometric configurations and at different vertical distances (0 to 4 mm) from the chip
- Acquisition and production of hitmap and subsequent analysis to study the possibility of signal discrimination from the background, as a function of acquisition time
- GEANT simulations to reproduce the same experimental situation
  - Goal: validation of simulations, to be able to extend them to more complex cases







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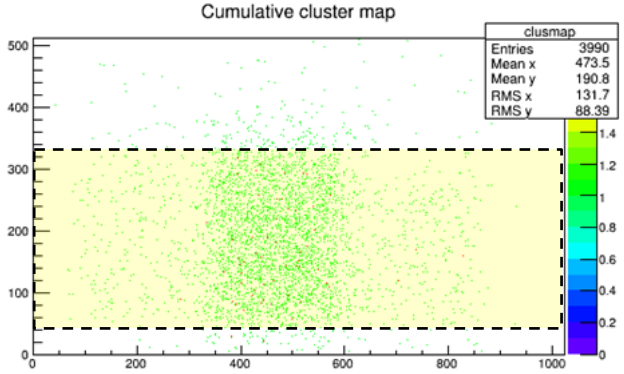
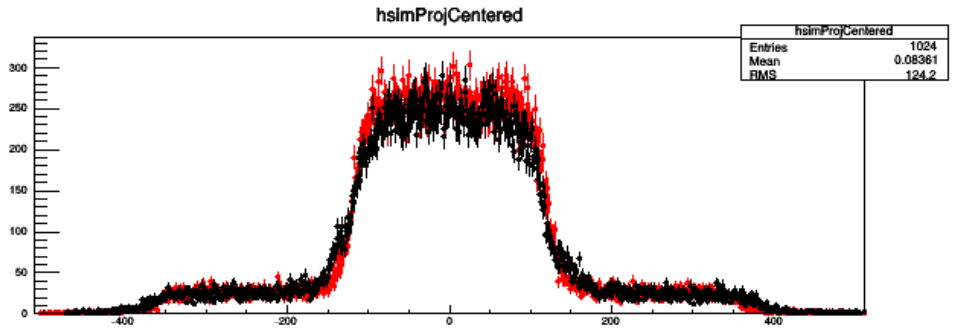
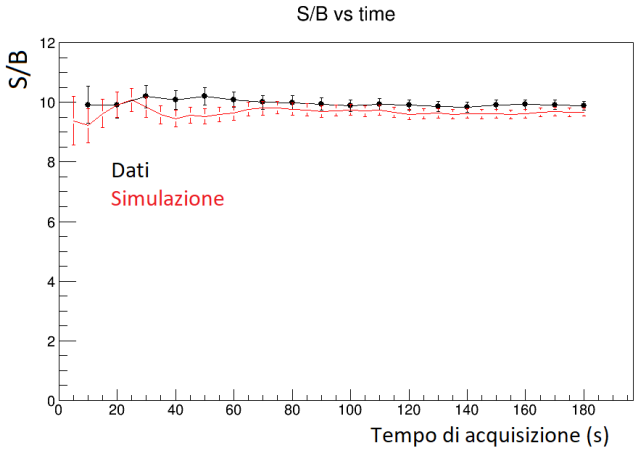






Top left: hitmap related to 10 seconds of acquisition for a type T (tumor) sponge of 7x7x1 mm^3 flanked by two type H (healthy) sponges of 7x7x1 mm^3, placed one on each side. The sponges are in contact with the chip, except for a protective layer of mylar 23 µm thick.

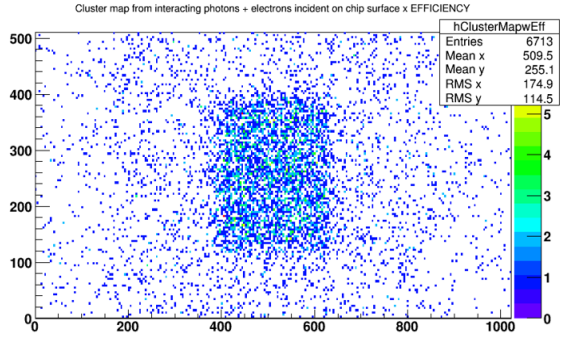
Above: comparison of the projections on the x-axis of the hitmap of data (black) and GEANT4 simulations (red), for a prolonged acquisition (180 s)

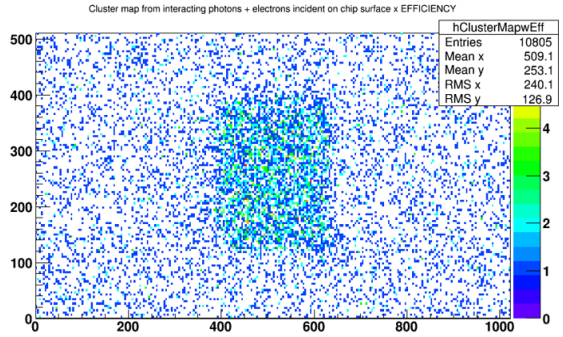
Bottom left: Comparison of S/B for data (black) and simulation (red), as a function of acquisition time. Results related to a type T sponge of 7x7x1 mm^3 flanked by two type H sponges of 7x7x1 mm^3.

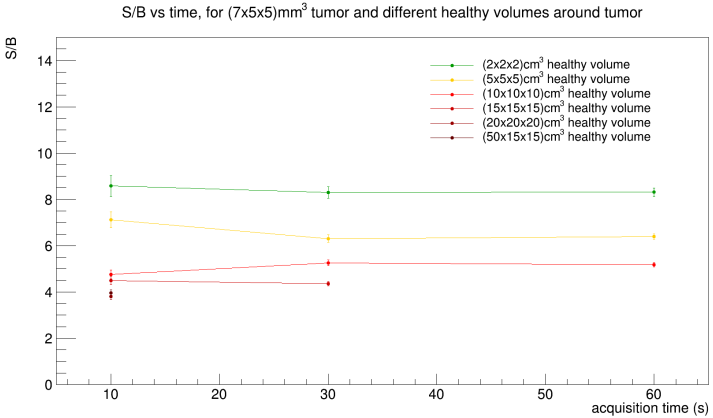
PRELIMINARY STUDIES

Further studies with GEANT4 simulations

- Simulations of tumoral tissues extended in three dimensions (parallelepipeds) immersed in a volume of healthy tissue, of different sizes
- Reproduction of the hitmap and related profiles, and evaluation of the signal-to-background ratio for different acquisition times







Top: hitmap simulations for 10 s of acquisition, for a tumor of 7x7x5 mm^3 surrounded by a volume of healthy tissues of 20x20x20 mm^3 (left) or 100x100x100 mm^3 (right).

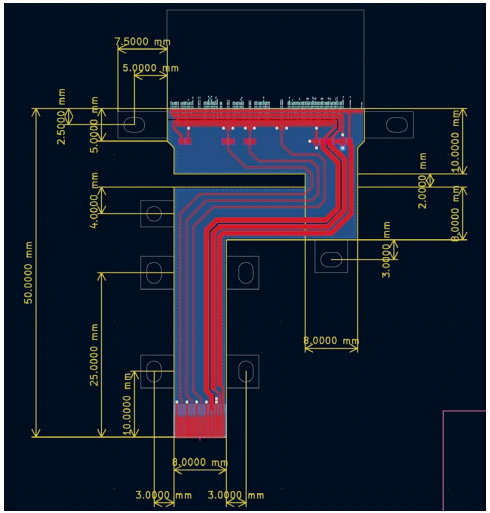
Left: trend of S/B as a function of the simulated healthy tissue volume, for 10, 30 and 60 seconds of acquisition (simulations).

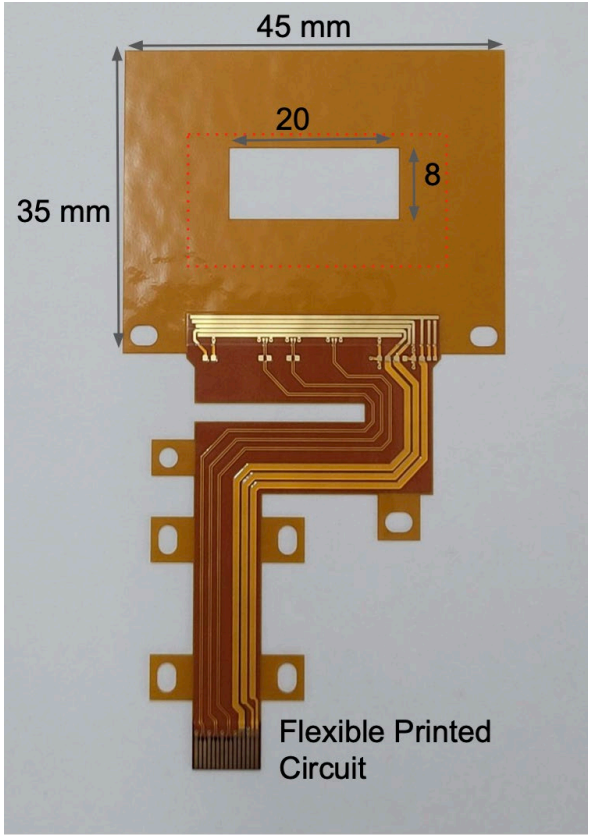
CURRENT ACTIVITIES (HARDWARE)

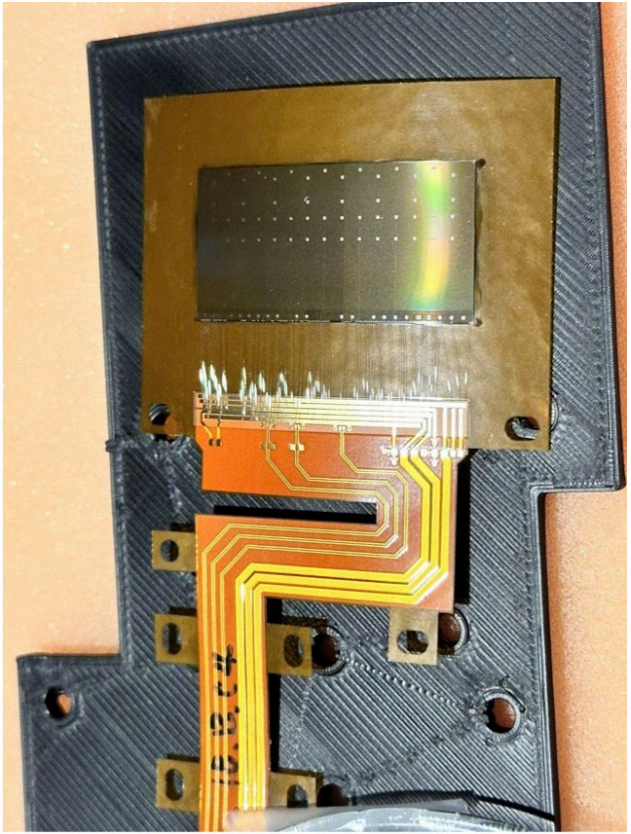
- Discussing with dedicated local INFN services for the realisation of the probe demonstrator and the related electronics
- Main conceptual requirements:
  - Maintain compact horizontal (→short side) dimensions of the probe, to maintain its versatility and allow its use in a wider range of potential clinical situations
    - Ideal case: The ideal would be to have a probe also usable in laparoscopy, but this clashes with the dimensions of the ALPIDE itself
  - Leave as free as possible from material the sensitive side of the ALPIDE
    - Signal electrons are soft (endpoint energy of 635 KeV), immediately absorbed after a few tens of um of material
  - Limit the amount of material on the ALPIDE back side, to reduce the conversion of background photons (from e+e- annihilations) and the relative production of electrons that can enter from the back of the chip and be detected
  - At the same time, ensure sufficient rigidity to the probe so that it can be used precisely and safely by the surgeon
  - Have a compact and autonomous acquisition system (not a stringent requirement for the initial phases)

CURRENT ACTIVITIES (HARDWARE)

- Example of currently existing FPC
- Better solution than the carrier, but would lead to a probe width of at least 4 cm

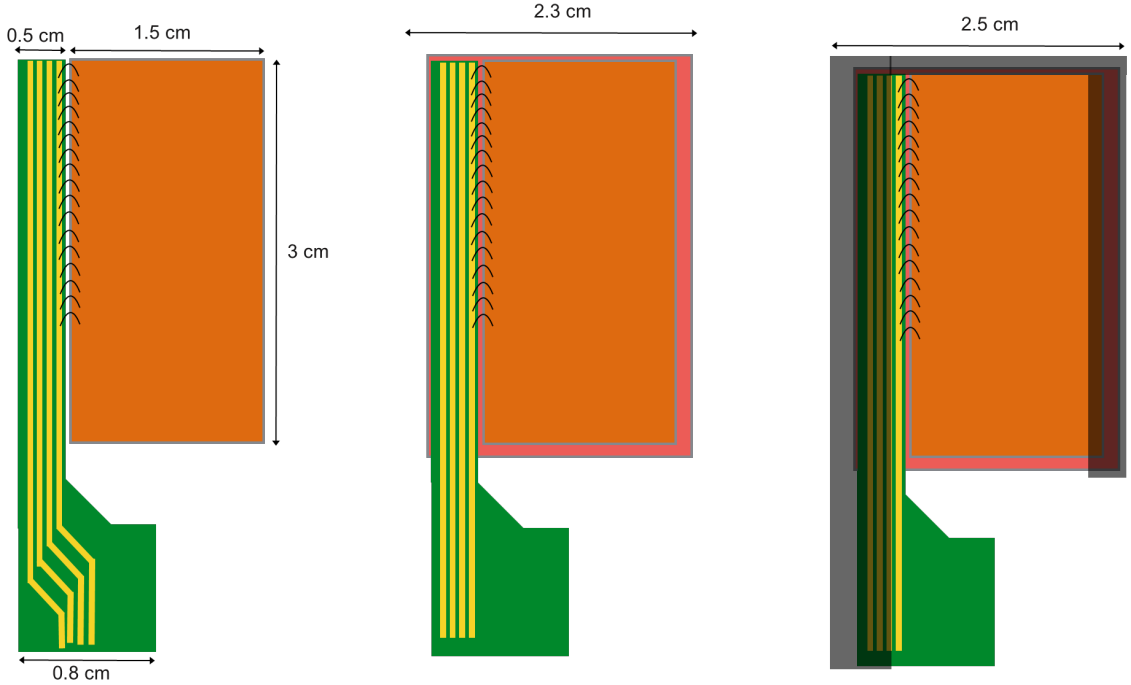






CURRENT ACTIVITIES (HARDWARE)

- Possible new proposal to reduce the horizontal size to <2.5 cm
  - Rigid board that develops along the short direction of the chip, with about 5mm thickness for bonding and tracks
  - The bonding method (using the pads on the periphery?) and the signal connector (USB-C?) are under discussion



FPC to be designed starting from existing one.
Find room for decoupling capacitors and termination resistance.

Kapton adhesive tape with opening below the sensing area.
Actual dimensions to be defined.

Frame 3d printed keeping the assembly in position.
Wire-bonds protected with sylgard; take this into account.
Try to keep the thickness < 0.5 cm.

ULTERIORI NOTE

- Call for an INFN research grant currently open (deadline on 30/3)
  - Dedicated to simulation studies with GEANT4, plus support for hardware activities
- In the near future, a new campaign of acquisitions with radiotracers (for now with ALPIDE+carrier) needs to be organized, more complete and systematic than the studies carried out previously
- In the process of defining with CERN KT a supply of ALTAI chips for this study + the parallel study on the Compton camera
  - The agreement includes a license for use and publication within the scope of the two projects
  - ALTAI: derivation of the ALPIDE chip, with less resistance to radiation damage (irrelevant for us), but without a dual user license (simplified procedures)
  - The purchase procedure is very convoluted, the best way to proceed is under discussion