A pioneering Compton Camera for hadrontherapy with a 3D silicon Pixel Chamber

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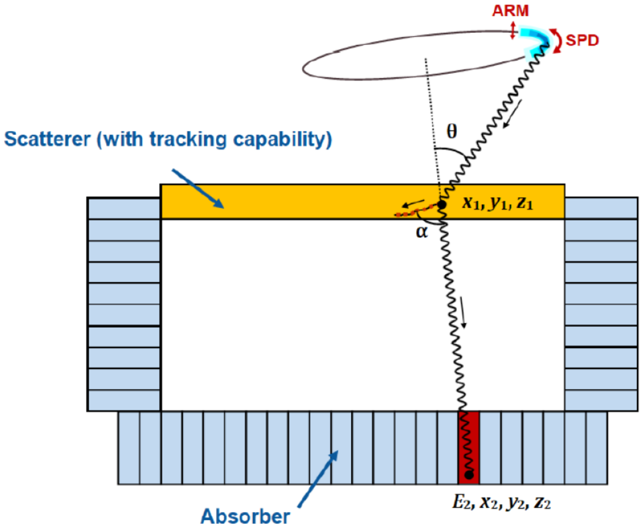
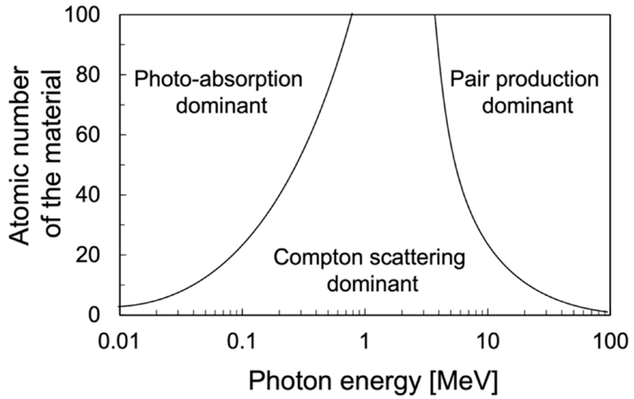
PROJECT SCIENTIFIC GOALS

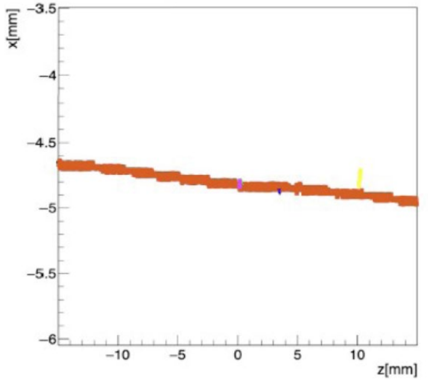
- A Compton camera consists of two position- and energy-sensitive sub-detectors: scatterer and absorber
- A single γ that undergoes a Compton scattering in the first detector and is then absorbed in the second detector does not allow to determine univocally its direction, but only a cone of possible directions. Therefore a large number of γ the same source point is needed to reconstruct the source position
- We propose a new concept of Compton Camera that exploits a Pixel Chamber as the scatterer
- The Pixel Chamber consists of a stack of thin pixel detectors and it provides a continuous tracking, which offer the possibility to also reconstruct the direction of the emitted electron
  - With this additional piece of information, the original direction can be ideally already constrained using a single photon
- A first prototype of Pixel Chamber is proposed considering state-of-the-art monolithic active pixel sensors, the ALPIDE chips developed for the ITS of the ALICE experiment at the CERN LHC



PROJECT SCIENTIFIC GOALS

- One of the main requirement hadrontherapy techniques is the in vivo proton/ion beam monitoring
  - Compton Cameras can perform this task, but present detectors do not yet allow an on-line monitoring, which requires high-resolution imaging of gamma sources to be performed within few seconds.
  - The usage of the Pixel Chamber as scatterer detector in Compton Cameras would drastically reduce the numbers of γ required for performing a precise source imaging, and thus the acquisition time.
- The new detector will also have a relevant impact in astrophysics, for the precise localization of γ-ray sources (in an energy range from few hundred KeV to 1 GeV)
- Moreover, the concept of the Pixel Chamber is naturally suited for realizing an “active target” at particle accelerators

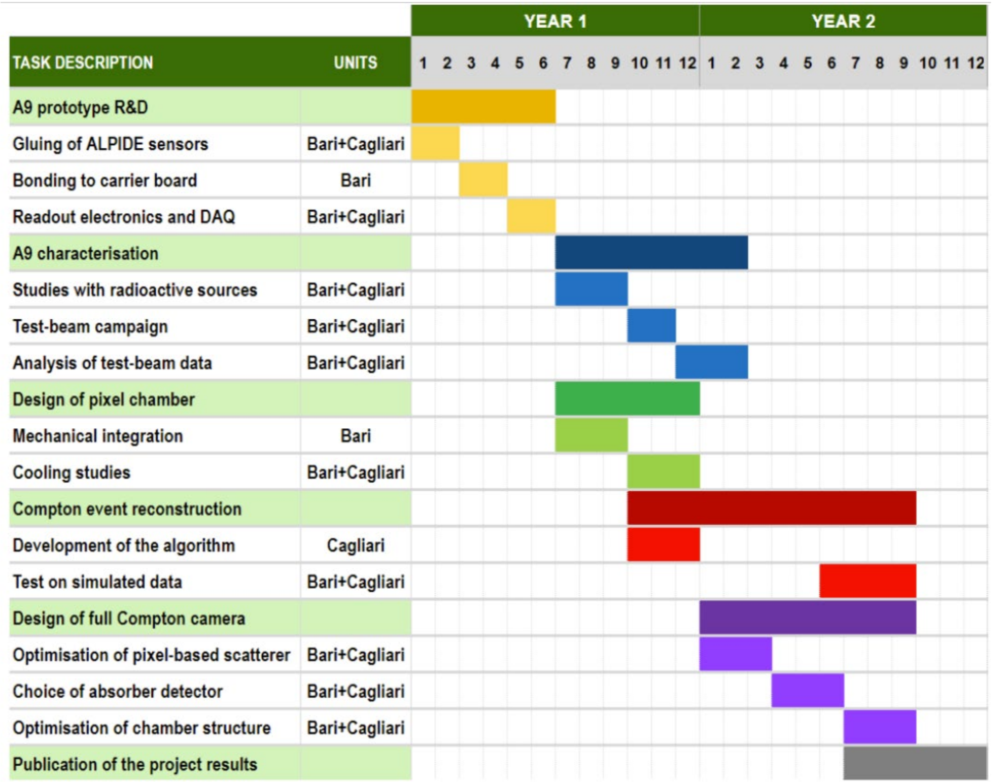




- Reconstruction of an electron track crossing an ALPIDE sensor

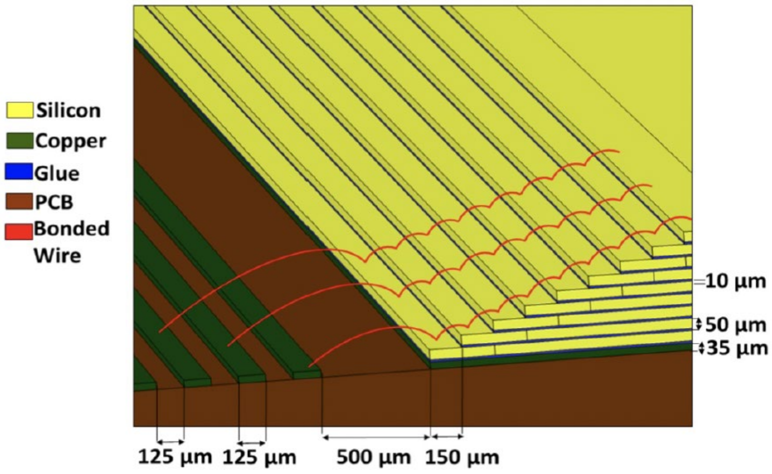
OUTLINE

- Main milestones foreseen for the PRIN:
  - R&D of the A9 stack, the basic element of the Pixel Chamber and realisation of a A9 prorotype (+ electronics & readout)
  - Characterisation of the A9 stack with radioactive sources and test-beam
  - Design of the Pixel Chamber → scatterer element of the chamber, made of multiple A9 stacks
  - Development of an algorithm for the reconstruction of Compton events recorded by the chamber
  - Design of the full Compton Chamber (scatterer + absorber)



THE A9 STACK

- A9 stack: basic unit of the Pixel Chamber up to nine ALPIDE sensors, in a staggered fashion to provide the space for wire bondings
  - Bondings from the chip periphery pads to a Printed Circuit Board (PCB)
  - Cascade bondings can be performed for all the signals (except the 1.2 GB/s high-speed which requires serial lines, if needed)
- Offset between sensor layers of 150 µm
  - Could be too small for optimal bonding (see later)
- ALPIDE chips stacked either with a electrically insulating glue or with 5 µm thick adhesive tape (Nitto 5600)
  - The total thickness of the A9 stack is 540 µm



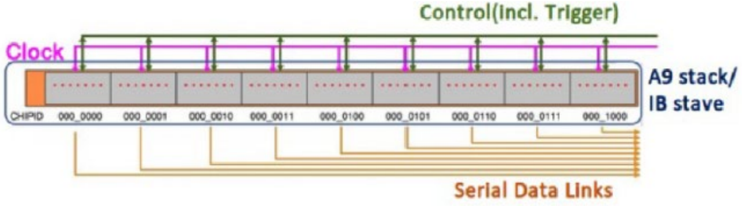
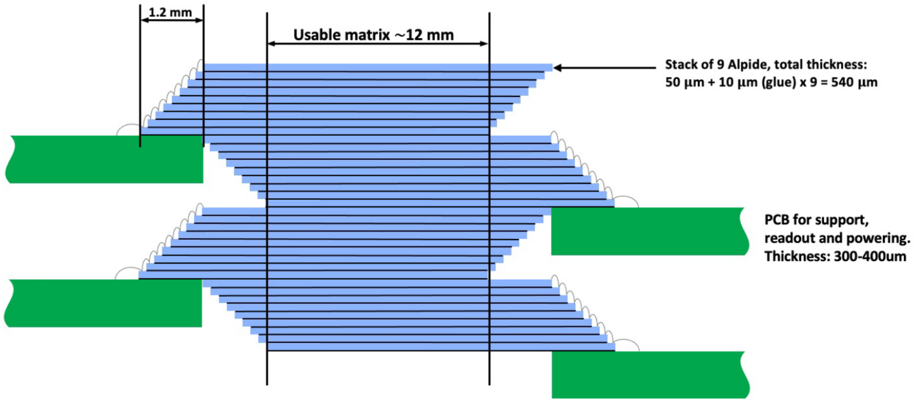


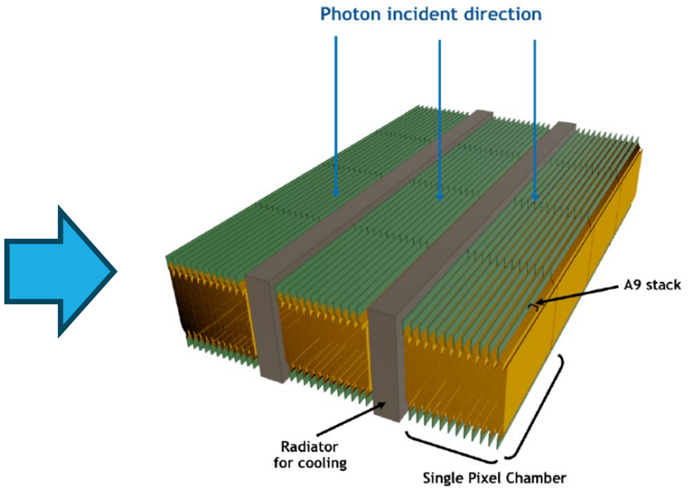
Fig. 7 - Data channels for the A9 stack

THE PIXEL CHAMBER

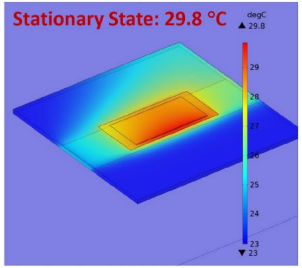
- A Pixel Chamber will be composed of 24 A9 stacks, to compose a high-granularity, sensitive surface
- A total of 216 sensors, for a thickness of about 13 mm, width of active area of 12 mm, total volume of 30x12x13 mm^3
- In turn, multiple Pixel Chambers (4 per row, for a 12 cm-long element, interleaved by dedicated radiator elements for the cooling), will compose the scatterer of the Compton chamber (total area of 100 cm^3)

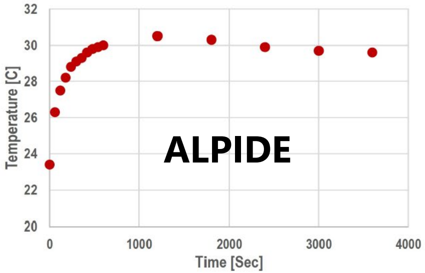


Cross section of part of a Pixel Chamber
(only four A9 stacks are shown)

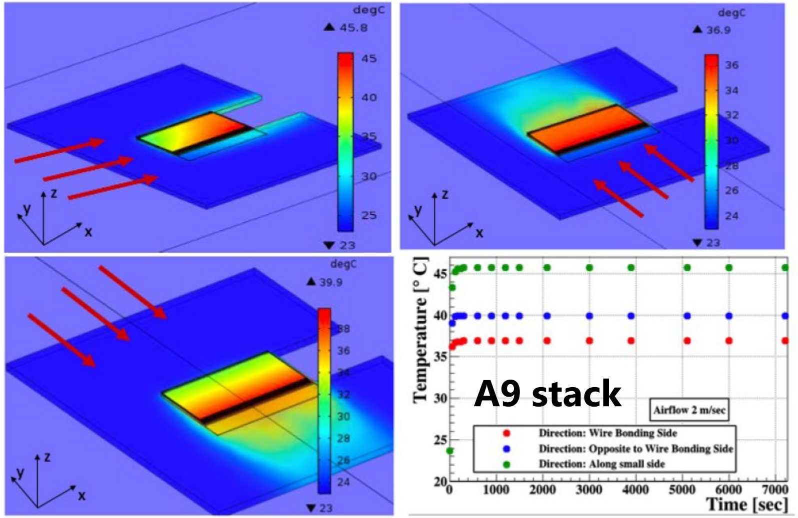


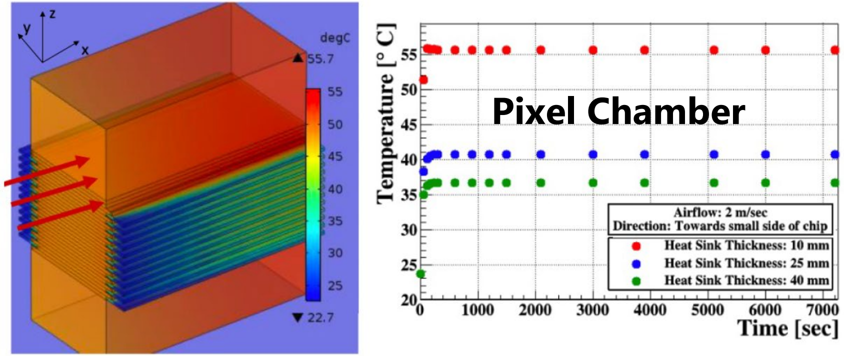
PRELIMINARY COOLING STUDIES





- For the single ALPIDE chip, no dedicated cooling is needed
- For the single A9 stack, from preliminary studies a venting of 2 m/s is required to have a stationary temperature of 37-45 °C (depending on the direction of the air flow)
- For the full Pixel Chamber, dedicated heat sinks are needed
  - Material and thickness to be optimized, see studies below for a copper sink



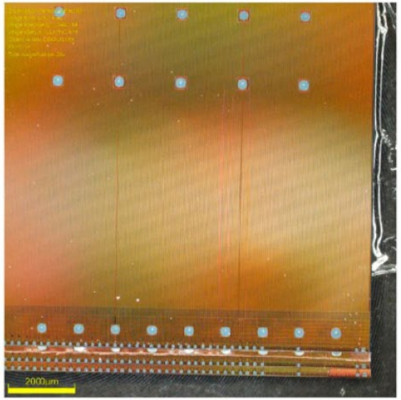


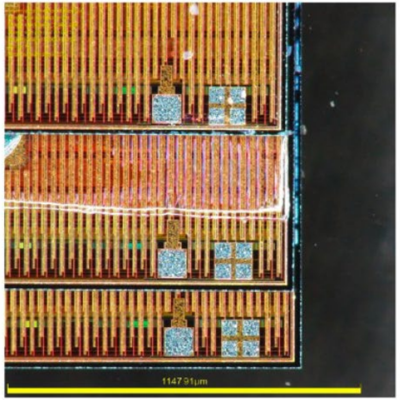
ONGOING ACTIVITIES – A9 ASSEMBLY

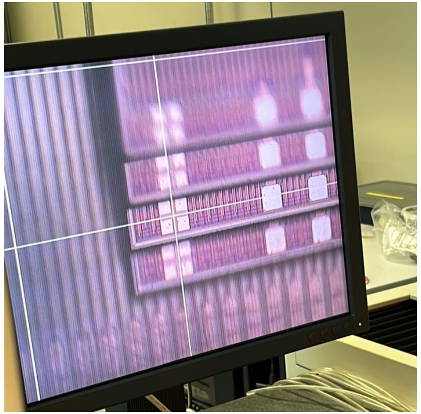
Current alignment and gluing studies:

- From Cagliari (top) using Nitto 5600 film, performed with an ACCuRATM100 flip-chip bonding machine available at University of Geneva
  - Cagliari has just bought a flip-chip bonding machine, but will be available in approx. 1 year

- From Bari (bottom), using araldite glue, with the alignment performed with Mitutoyo machine
  - 5 µm precision achievable, optimal for the A9
  - The horizontal shift of 150 µm is too small for bonding, 200-250 µm seem to be needed

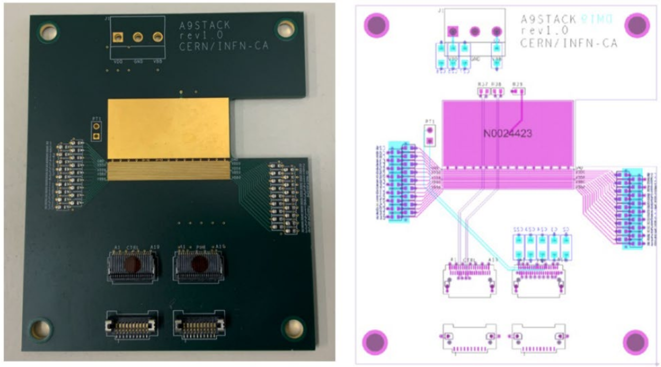






ONGOING ACTIVITIES – A9 BOARD & READOUT SYSTEM

- Two readout possibilities:
  - ➢ Exploiting the Readout Unit developed for the ITS IB:
    - Pro: carrier board for the A9 and RU already available in Cagliari
    - Con: most probably the firmware needs to be updated, and a software for performing the readout needs to be developed
  - ➢ Exploiting the MOSAIC board:
    - Pro: board and readout software already available - we can reuse the codes for the APIDE telescope, which can read up to 10 chips)
    - Con: the current design of the carrier board is inadequate, lacking the high-speed serial lines → need to modify the project



the first prototype of the A9 stack carrier board.

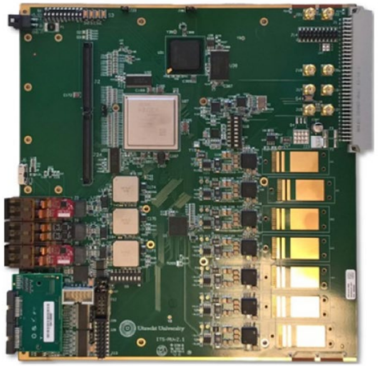


Fig. 8 - Readout Unit to be employed for the A9 stack