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Pixel Chamber: a solid-state active-target for 3D imaging of charmand beauty

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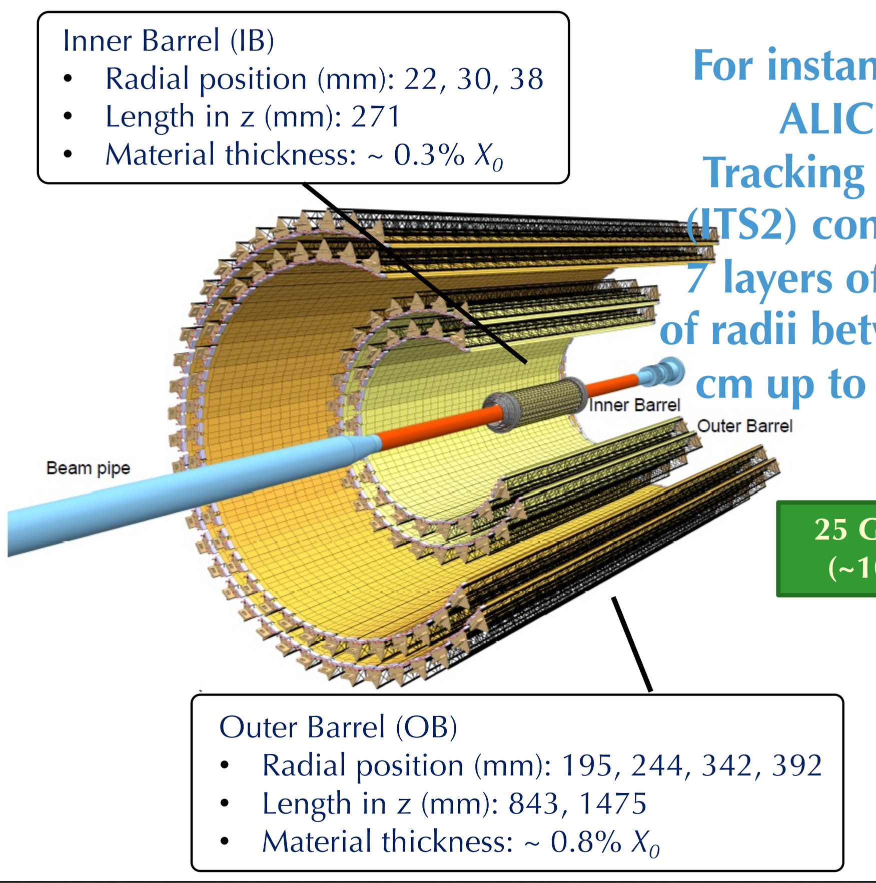
Silicon trackers in particle physics

Trackers at collider experiments are based on cylindrical or planar layers of silicon sensors. This kind of detectors satisfy the stringent requirements in terms of material budget, granularity, power consumption, readout speed and radiation hardness.

Silicon detectors are key for the detection of charm and beauty particles. Located close to the interaction point, they provide precision measurement of particles produced in the interaction points (primary vertices) and in decay vertices (secondary vertices). Their intrinsic limitation is the finite distance between the sensors and the particles production points. The Pixel Chamber project aim is the production of a bubble-like, solid state active target capable to perform continuous tracking to detect primary and secondary vertices inside the detector with a very high precision.



For instance, the ALICE Inner Tracking System (ITS2) consists of 7 layers of MAPS of radii between 2 cm up to 40 cm.

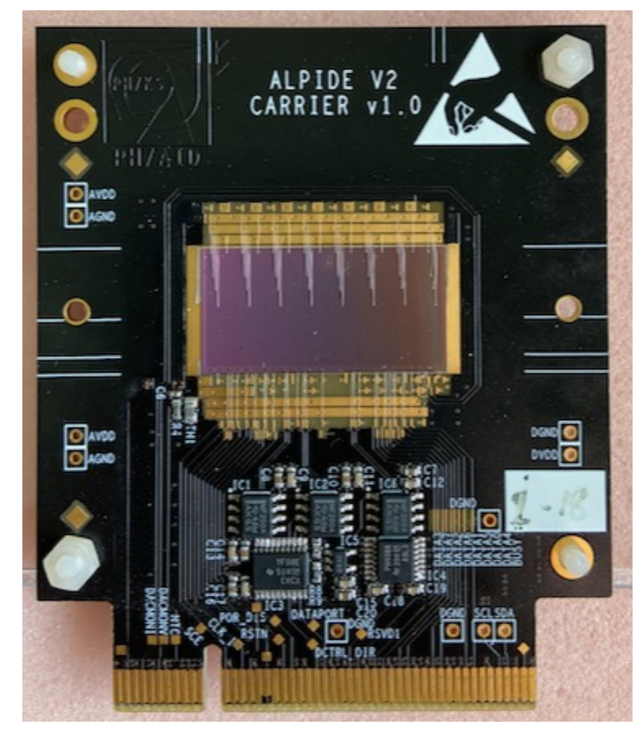
ALice PIxel DEtector (ALPIDE) chip

The ALice PIxel DEtector is a low-power monolithic pixel chip developed in 2013-2016 by a collaboration formed by CCNU(China), CERN, INFN (Italy), and Yonsey (South Korea).

1024 columns of 512 pixels (pixel size 29μm x 27μm) with in-pixel discriminators. Each two columns of pixels (double column) read by the same structure, the address-encoder reset-decoder (AERD), which also performs zero suppression operations.

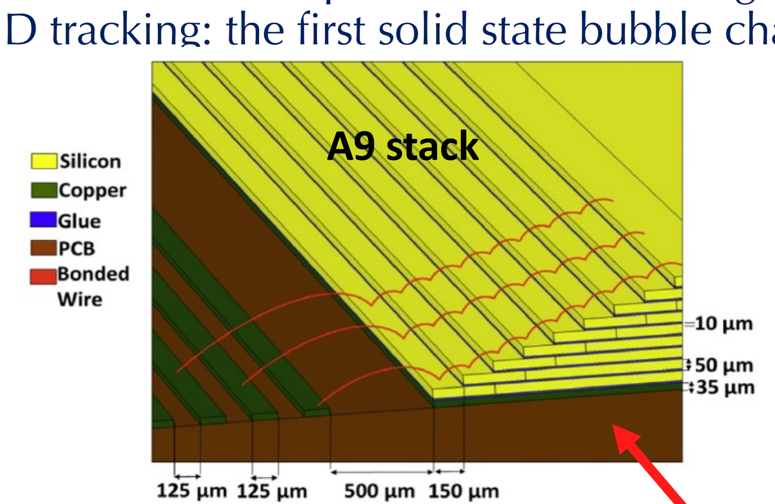
The digital periphery performs data compression, buffering and external data transmission through a 1.2 GB serial link.

The pads, to access the signal and power circuits of the sensor, reside on one side of the surface of the sensor along its length.

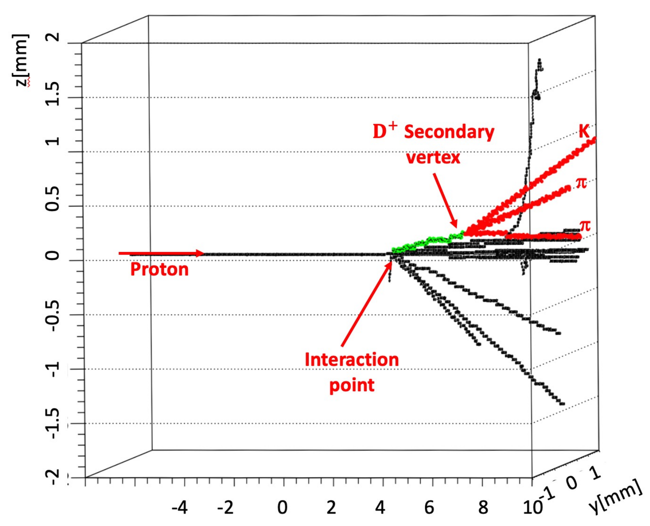


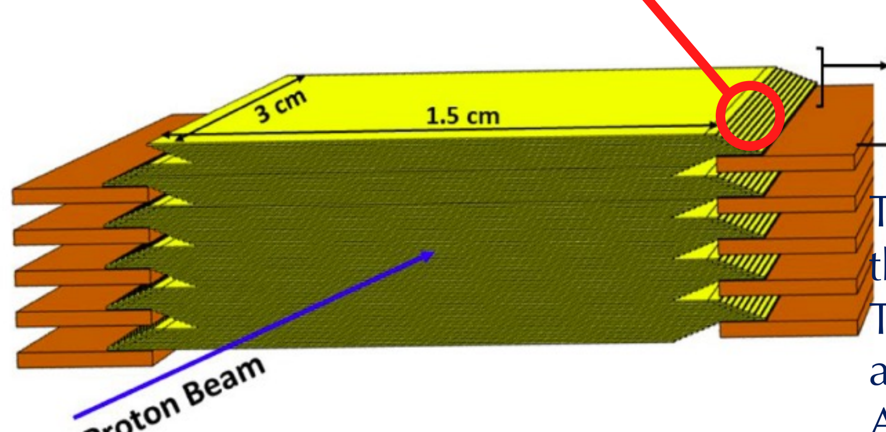
Pixel Chamber

We want to pioneer the first silicon 3D active-target ever built based on silicon pixel sensors. The main idea is to create and validate an ultra-high granular stack of hundreds of very thin monolithic active pixel sensors (MAPS) glued together, providing **continuous**, high-resolution 3D tracking: the first solid state bubble chamber.



3D volume of ~10^8 pixel will allow to reach unprecedented spatial resolution.





Stack of 9 ALPIDE. total thickness: 540um

PCB for support, readout and powering. Thickness: 400μm

The building block of the Pixel Chamber is the 3 x 1.5 cm² ALPIDE CMOS sensor chip. The proposed basic unit of Pixel Chamber is a stack of nine ALPIDE sensors - called the A9 stack. The nine sensors are arranged in a staggered fashion with an offset of 150 μm to provide the space for wire bonding of the sensor pads.

Between two sensors there will be a layer of electrically insulative glue with a thickness of about 10 μm.

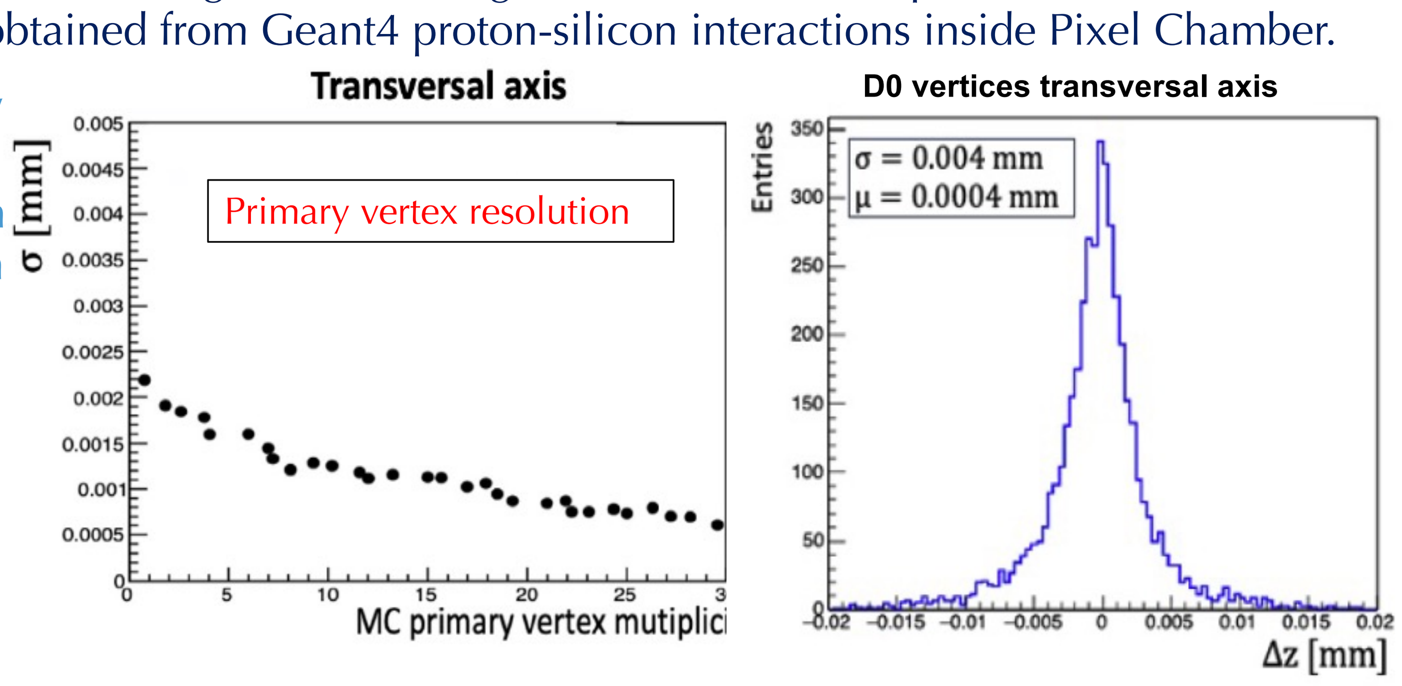
The total thickness of the A9 stack is 540 μm.

The full Pixel Chamber stack: assembly of 24 A9 stacks - for a total of 216 sensors (thickness - 13mm). The width of the usable active area is 10 mm making the chamber volume to be 30 x 10 x 13 mm³. In Pixel Chamber, signal and power lines will be distributed by a combination of rigid and flex pcbs forming the carrier board.

Tracking and vertexing

A Geant4 simulation of a prototype consisting of a stack of 216 ALPIDE was developed: a matrix of 10^8 pixels. Tracking and vertexing Pixel Chamber's capabilities were tested on Monte Carlo data obtained from Geant4 proton-silicon interactions inside Pixel Chamber.

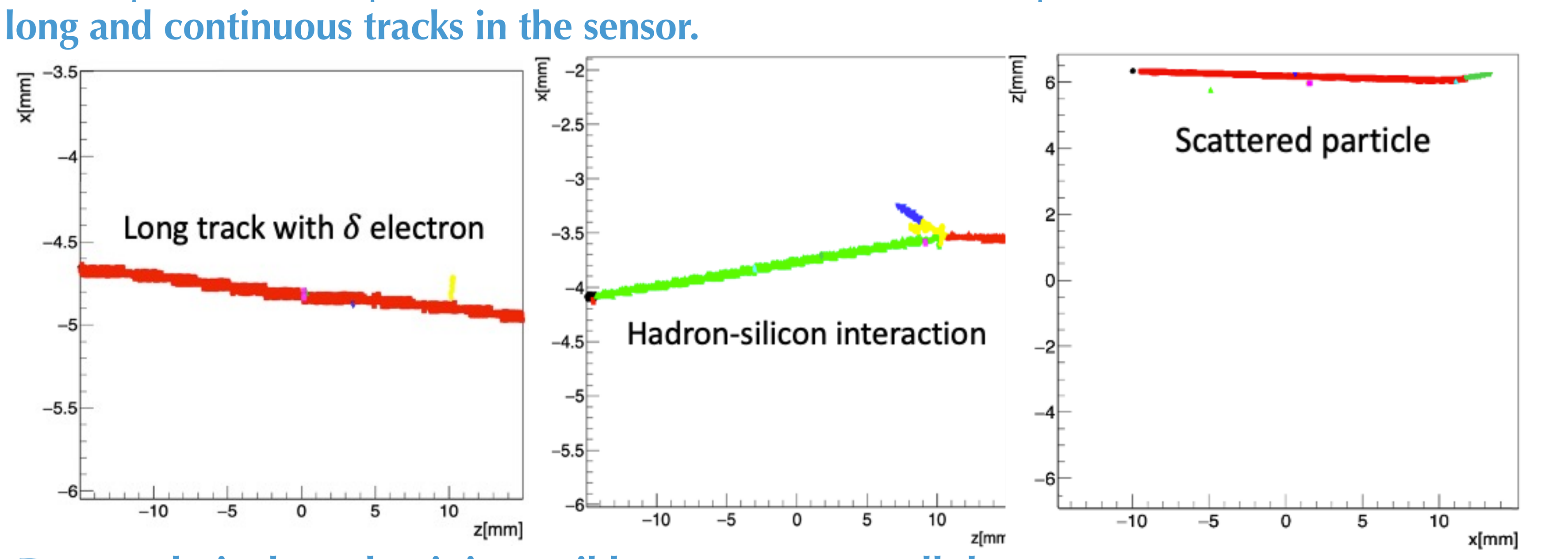
Data analysis show that it is possible to reconstruct with very high precision hadronic tracks produced in p-Si interactions and it possible to reach very high resolutions both for primary and secondary vertices



Tracking algorithm test with test beam data

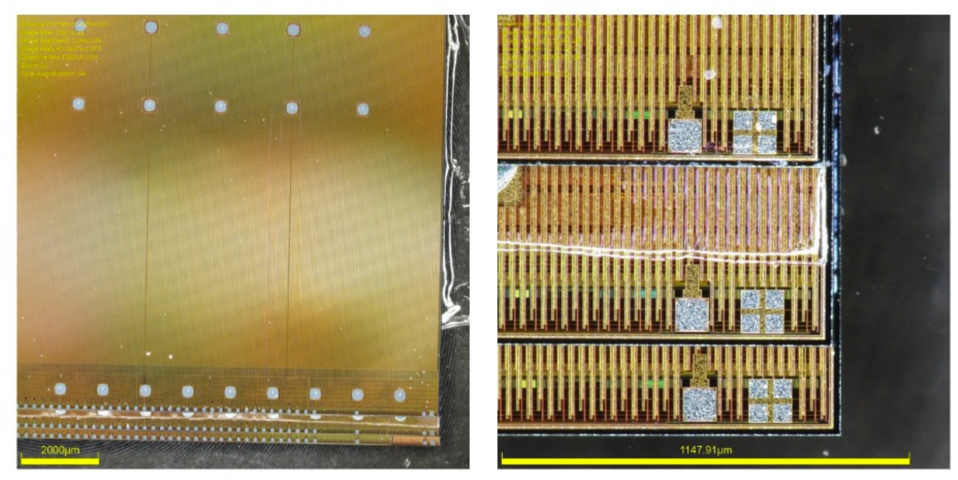
As a prototype of the A9 stack is not yet available, the track reconstruction algorithm performances have been tested on a single ALPIDE sensor using data acquired in three test beams in the context of the ALICE ITS3 development R&D.

The chip has been exposed to electrons and hadrons beams parallel to its surface to obtain **long and continuous tracks in the sensor.**



Data analysis show that it is possible to reconstruct all the long tracks produced in the single ALPIDE in a continuous tracking configuration with very high precision.

R&D towards first prototypes



R&D to build the first A9 stack is ongoing in collaboration with CERN and Geneva University.

We built the first stack of 3 ALPIDE with a flip chip bonding machine at the physics department of Geneva University.

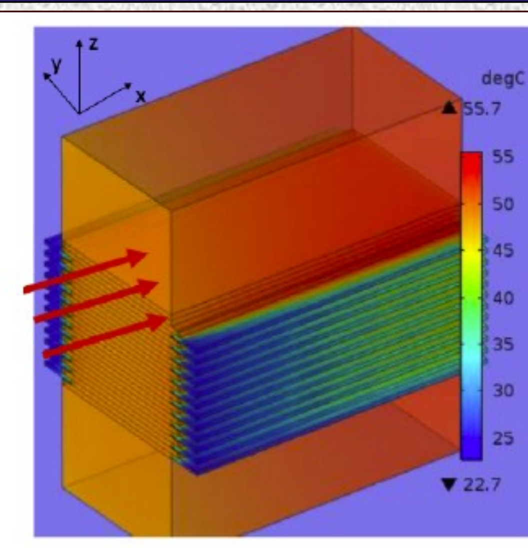
Cooling studies

The increase of temperature of a stack made of 216 ALPIDE can be critical and merits detailed studies to estimate probable effects and practical solution.

A preliminary study on cooling has been carried out with COMSOL Multiphysics to keep the temperature of the entire stack to less than 40° C.

The best solution to cool down the detector is to use two copper heat sinks (40 mm thickness) and an air flow at 2 m/s: the stable temperature is then **~36° C**.

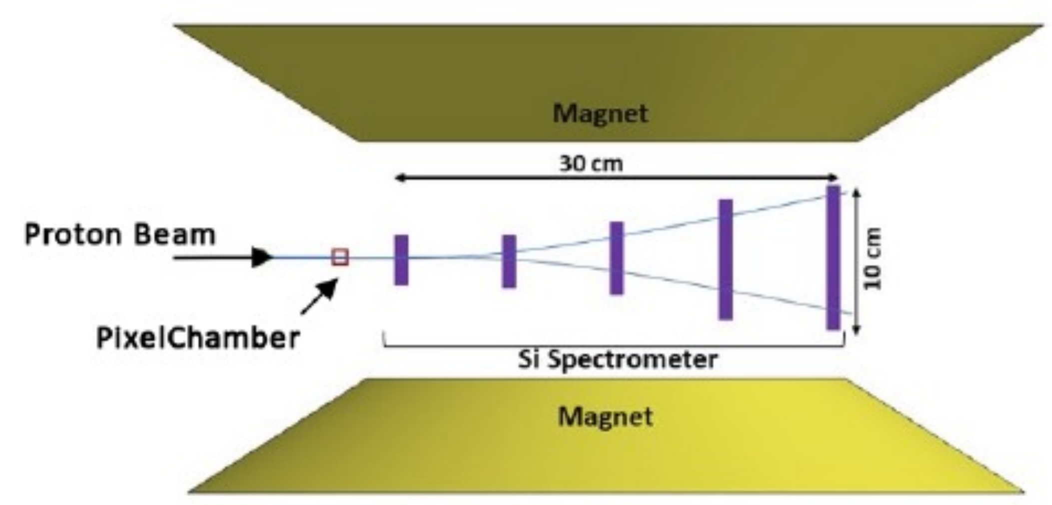
A laboratory setup was developed to validate the simulations.



Future perspectives

Applications for Pixel Chamber are countless.

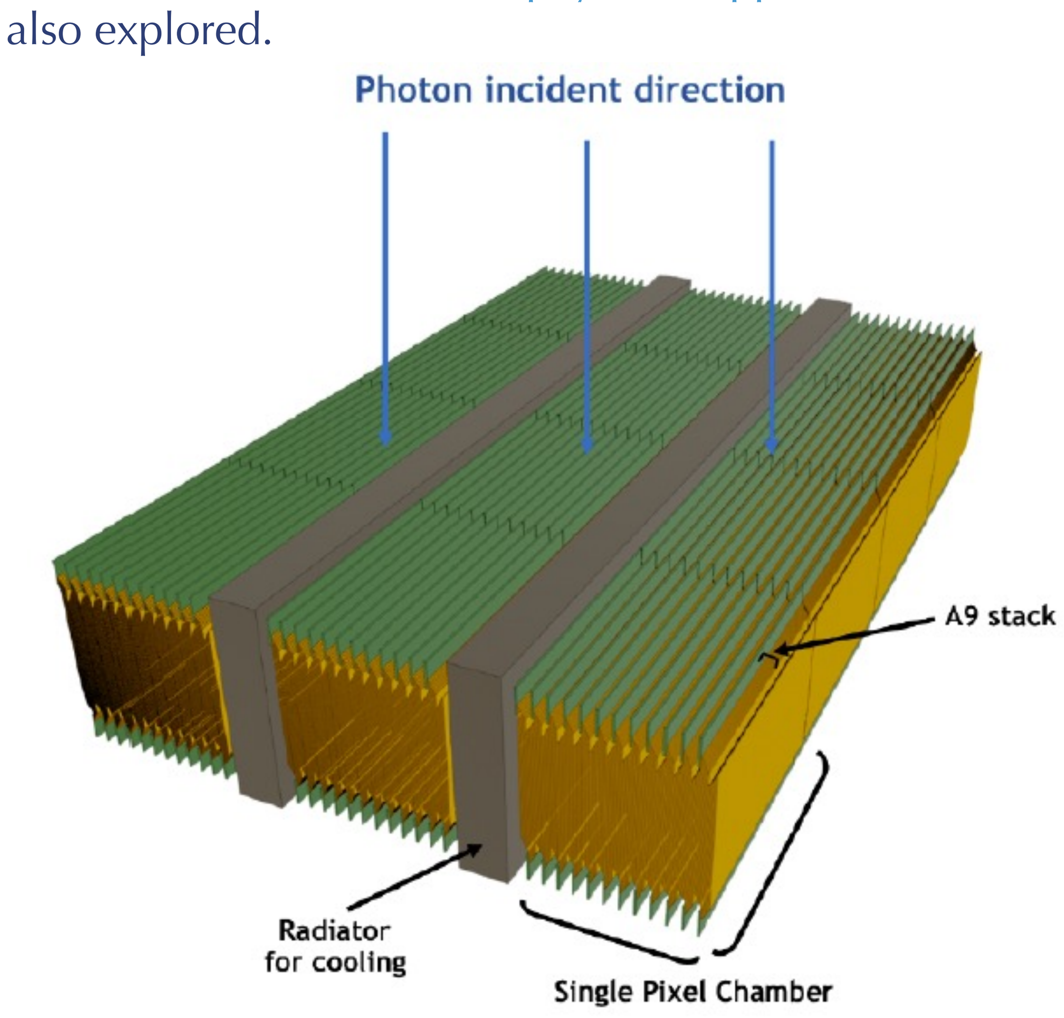
In particle physics experiments, its coupling to a silicon telescope has the potential to allow a **measurement of the charm cross-section in proton-silicon interactions** at CERN SPS energies.



The possibility of using Pixel Chamber for medical and astrophysical applications as scatterer of a **Compton camera** will be also explored.

A Compton camera consists of two position- and energy-sensitive sub-detectors: scatterer and absorber. Several gammas from the same source point are needed to determine the source position. The larger the number of gammas, the better the pointing resolution.

Pixel Chamber has the potential to reconstruct tracks and directions of recoiled electrons with very high precision and can therefore give the possibility to reduce by orders of magnitude the number of gammas needed to perform online and fast imaging in hadron therapy and astrophysics (PRIN submitted in 2022).



R&D to produce large area (~1.5x25 cm²) stitched sensors is under way for the construction of a new ALICE ITS3 at CERN. A pioneering development would be the **first three-dimensional stack with large area monolithic pixel sensors ever built** to overcome the current limitations related to the small size of the sensors. It would be very important in **medical imaging, particle physics and astrophysics.**

Pixel Chamber project was supported by the project funded by Regione Autonoma della Sardegna, Fondo di Sviluppo e Coesione 2014 - 2020 - Interventi di sostegno alla ricerca: Pixel Chamber: a universal silicon heavy-avour imager with monolithic active pixel sensors for measurements of charm and beauty with unprecedentedprecision.

[1] A. Mulliri et al. Pixel Chamber: A solid-state bubble chamber for imaging of charm and beauty. Nuovo Cimento della Società Italiana di Fisica C, 44, 1 2021. ISSN 18269885.

[2] A. Mulliri et al. Pixel chamber: a solid-state active-target for 3D imaging of charm and beauty. Journal of Instrumentation, 16:C12029, 12 2021. ISSN 1748- 0221