**Tracking and Ions Identifications with Minimal Material budget 2 (TIIMM2)**

**1. Research objectives:**

We propose to focus on technological innovation in the field of tracking detectors with particle identification abilities (PID) for hadron physics experiments at high energy (e.g.: LHC particle physics experiments) or low-energy ions applications needed for patient treatment plans in particle therapy, PT, and for radioprotection in space, RPS, (e.g.: FOOT project [18]). These applications require the combination of finely pixelated sensors for tracking and energy loss measurement for particle identification, as well as very low level of crossed material to minimise multiple scattering. Direct charge or time-over-threshold (ToT) measurements should span over few orders of magnitude to cope with the energy loss ranges going from MIP to heavy ions (e.g.: Fe). Furthermore, a time resolution of the order of a nanosecond is of great interest both for background rejection in hadron physics experiments and for proton or carbon computed tomography imaging to decrease the acquisition time for patient. The capabilities of energy loss and time-of-flight measurements can be extremely helpful in identifying ion tracks in experiments aimed at measuring fragmentation cross sections for PT and RPS applications [18].

The MAPS (Monolithic Active Pixel Sensor) detector technology has been widely adopted in high-energy physics experiments, both for ongoing experiments (e.g. the ALPIDE sensor [1] for ITS2-ALICE at LHC-CERN, the MuPix sensor [2] for Mu3e at PSI, the MALTA, Monopix, ATLASPix sensors [3, 4] as candidates for ITK-ATLAS at LHC-CERN, MIMOSIS [5] for MVD-CBM at FAIR-GSI) and for planned upgrades and future projects (e.g. OBELIX [6] for VTX-BelleII at KEK, MOSS [7] for ITS3-ALICE at LHC, MightyPix [8] for MT-LHCb at LHC-CERN, various sensors [9–12] for future 𝑒𝑒 colliders). The interest for the MAPS technology extends beyond high-energy physics, encompassing applications where the measurement of the deposited charge by particles with various ionising power is beneficial, like space radiation detectors [13–15], medical physics applications [16] or related experiments [17, 18]. Its high granularity, high sensitivity and light material budget make such sensors suitable for tracking and vertexing close to the interaction point.

Most MAPS sensors operate in binary mode (i.e.: no signal amplitude is available per pixel) or with limited signal dynamics, in which case some particle identification capabilities have been demonstrated by some partners of the project exploiting the cluster size information. Sensors providing as output the signal amplitude of fired pixels, would allow measurement per particle and significantly enhance identification capabilities. However, the charge collection by diffusion, due to the non-depleted sensing region, and the dynamics limited to the signal equivalent of a few minimal ionizing particles are serious limiting factors. To overcome those hindrances, we had proposed ground-breaking technological improvements that have allowed both fully depleting the sensing region and enlarging its thickness in the previous project STRONG2020 (JRA9/WP27). Four prototypes have been developed and fabricated in the Tower Jazz 180 𝑛𝑚 CMOS image sensor process to investigate the feasibility of ToT method for large dynamic energy-loss measurement. The TIIMM sensor features a matrix of 32 rows and 24 columns with a pixel pitch of 40 𝜇𝑚. Each pixel features a large-dynamic charge sensitive amplifier (CSA) and 6-bit charge encoding with a ToT mechanism. The main purposes of this prototype were, on one hand, to characterise the performances of the CSA, and on the other, to verify the feasibility of the ToT architecture within the sensor. Measurements with 55Fe source and laser pulses clearly shown the capability of the sensor to cope with a range of 0.5 to 700 ke with a charge resolution better than 10%. The results pointed out also the limitation of the 6-bit encoding.

The TIIMM2 project proposes to develop a new sensor in the same technology, Tower Jazz 180 nm, for demonstrating combined tracking and PID performances beyond the achievements of TIIMM1. Re-using the successful CSA previously developed the demonstrator will improve the PID resolution by doubling the signal encoding depth (to 12 bits) with a moderate increase of the pixel size (≲ 50 𝜇𝑚). To broaden the range of demonstrating situations, including ion tracking and identification over several detection planes, the new sensor will feature an enlarge sensitive area, close to 1 cm2. The read-out pixel matrix will hence benefit from an architecture which is scalable, possibly up to reticule size (about 6 cm2) in order to meet the requirements of potential future applications.   
In addition, and suggested by time resolution achieved by other sensors in the same technology, new prototype aim also to assess a timing arrival measurement at the nano second precision level. Such time-stamping ability will greatly benefit applications where background particles un-correlated in time with the signal are presents.

The implementation of the read-out scalable architecture, inspired by existing pixel sensors, allowing nanosecond time-stamping will be the main design task for the new sensor. In parallel, the project will develop the corresponding data acquisition and control system, based on FPGA boards, to operate several – between 3 to 6 – TIIMM2 sensors in parallel, which is compulsory for particle tracking. The technical outcome of the TIIMM2 project will hence be a device ready for demonstrating particle or ion tracking and identification in a variety of situations.

1. **Connection to Transnational Access infrastructures (TAs) and / or Virtual Access projects (VAs)**

To assess the performances of the new prototype to large ionizing particles (e.g.: proton, carbon oxygen, iron, etc at energies < 1 GeV/u), beam tests are foreseen at the GSI/FAIR facility where those ions could be accelerated to the desired energies. Meanwhile, other infrastructures, as CNAO/Pavia where proton, carbon and alpha particles of clinical energies, could also be used to characterise the sensor with other ions up to energies of 400 MeV/u.

**3. Estimated budget request**

Within the requested budget, we expect to deliver setups to the various partner infrastructures and dedicate a number of sensors for evaluation in the hadron physics community.

* Multi-project run at Tower Jazz for prototype 100 k€
* Development of data acquisition system 100 k€
* Development of mechanical system 20 k€
* 1 PhDs contracts (3 years) 120 k€
* Travel money for tests 30 k€
* Travel money for meetings 10 k€

**Total request 380 k€**

**4. Participating and partner institutions**

GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany (Dr. Christoph Schuy)

INFN, Roma 1 Section, Rome, Italy  (Dr. Marco Toppi)

IPHC (Institute Pluridisciplinaire Hubert Curien), In2p3, Strasbourg, France (Dr. Christian Finck)

LNF (Frascati National Laboratory), INFN, Frascati, Italy (Dr. Eleuterio Spiriti)

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