ALICE-France in LHC runs 3+4 and upgrade of the inner tracker, ITS3

ALICE-France

For the ALICE ITS3 part, there is a list of specific signatories, made available in Appendix α.

Summary

The **ALICE experiment** has undergone a complete upgrade of its readout electronic and data acquisition system during the last Long Shutdown of the LHC (LS2). During this period, all detectors Readout and Front-end electronics have been upgraded to be able to cope with the increase of the luminosity and the new data taking paradigm based on continuous readout, opposite to the triggered-event one exploited in Runs 1 and 2. The Muon Spectrometer, composed of the Muon Chambers (MCH) and the Muon Identifier (MID), has been upgraded accordingly. In addition, two novel detectors were installed, namely the Muon Forward Tracker (MFT) and the Inner Tracking system (ITS2), both based on the CMOS silicon pixel technology. These 4 projects profit from a strong involvement from the French teams as IN2P3 projects. In **Part A** of this report it will be shown that, during the last period of 5 years, the ALICE-France community successfully exploited the data collected during Run 1 and 2, publishing important physics results improving our understanding of high density hadronic physics and the characterization of the Quark Gluon Plasma phase, leading at the same time the finalization of the LS2 upgrade program culminating in the installation and the commissioning of the ITS2, MFT, MCH and MID, in preparation of Run 3. These upgrades have been carried out within the planned time and budget constraints, adapting on the fly to worldwide conditions such as the Covid pandemic. The physics potential corresponding to the exploitation of the upgraded detectors in Runs 3 and 4 will be discussed, as well as implications of the French IN2P3 teams within those projects.

One step forward in the upgrade of the ALICE detector is the **ITS3 project**, which will be extensively discussed in **Part B** as a proposal for a new project. The goal of the ITS3 upgrade program is to replace the 3 innermost layers of the current tracker ITS2. The new layers will sit at closer radii (*r* ranging from 1.8 to 3 cm) and will be made of **hypergranular** (O[20x20 µm²]) and **ultra-thin** (≤ 0.05% X_0 per layer) sensors, of which most of the assembly is performed directly on the silicon substrate, *i.e.* at the stage of silicon lithography at the foundry, with sensor suture of sub-units (**stitching**). This results in detection units that cover each a large functional area (O[10x27 cm²] ≈ O[wafer]). Such thin sensors are flexible and can therefore be bent to shape an almost perfectly cylindrical layer geometry. (See key specifications of ITS3 in section I.B.)

Several groups of IPHC Strasbourg have already contributed to the ITS3 effort since 2019 and would like to expand their commitments, be they on simulations, on reconstruction as well as on instrumental grounds (chip design, integration). Teams in IP2I Lyon and LPSC Grenoble also aim at joining the project, progressively, in a proportionate manner with respect to their resources.

Through recent (ITS2 and MFT) and future (ITS3) tracker upgrades, the three ALICE groups of IP2I, IPHC and LPSC wish to form a common research axis within the collaboration, with synergies on the instrumental level and with a community of interests on the front of the data exploitation and of the data analysis. These tighter bonds between teams and look towards a common horizon is of strategic interest for the continuation of the research program over the coming decade, involving three clearly intertwined aspects (defining a multi-differential analysis approach):

- the particle identification (e.g. mesons vs. baryons)
- the correlated productions between central and forward rapidities
- the physics dependences as a function of the parton flavour (*g + u + d,s,c,b*)

Part A - ALICE in LHC runs 3 and 4

I. - Bottom line of ALICE in Run 2 [2015-2018]

The analysis of the LHC Run 2 data has seen the French teams of the ALICE Collaboration involved on several fronts. Their contributions can be grouped into four main areas: i) study of production mechanisms and collective effects in the heavy quark sector; ii) specific hadro- and photo-production mechanisms for the ($c\underline{c}$) and ($b\underline{b}$) bound states, their modification in the deconfined medium, and their dependence on the charged-particle multiplicity; iii) multiplicity-dependent strangeness production; iv) hard or electroweak probe measurements. In an important fraction of the measurements performed, the analyses were carried out as a function of the charged particle multiplicity, with the aim of highlighting the role of the latter as an effective scaling parameter, determining the deviation of the observed effects from the vacuum reference, independently of the collision mode size.

The measurements concerning the production of hadrons containing heavy quarks (*c* and *b*), in the first place the dependence on the transverse momentum and the azimuthal asymmetries, give precious indications for the determination of the transport properties of the QGP, the characterization of the hadronization mechanisms for heavy quarks in a deconfined medium, and the determination of the corresponding parameters. Among the key measurements in this field, carried out with the participation of French teams, we can mention the demonstration of the absence of collective flow for the ϒ meson in Pb-Pb collisions, the first time that such a behavior is observed for a hadron in nuclear collisions at LHC energies, the first measurement of the elliptic flow of jet-associated particles in p-Pb, and the measurement of collective phenomena in pp and p-Pb collisions where no significant volume of QGP is expected to be produced. The study of the evolution of the meson/baryon ratios as a function of the multiplicity of charged particles, and the comparison of the production rates of different species of charm and beauty mesons or baryons, offer an important contribution to the characterization of the hadronization mechanisms of heavy quarks.

- *Search for collectivity with azimuthal J/ψ-hadron correlations in high multiplicity p-Pb collisions at 5.02 and 8.16 TeV* - PLB 780 (2018) 7-20 [arxiv:1709.06807]
- *J/ψ azimuthal anisotropy at forward rapidity in Pb-Pb collisions at 5.02 TeV* - JHEP 1902 (2019) 012 [arxiv:1811.12727]
- *Measurement of ϒ(1S) elliptic flow at forward rapidity in Pb-Pb collisions at 5.02 TeV* - PRL 123 (2019) 19, 192301 [arxiv:1907.03169]
- *Azimuthal anisotropy of jet particles in p-Pb and Pb-Pb collisions at 5.02 TeV* - to be submitted to PRL / proceedings : [arXiv:2110.15852]
- *Measurements of azimuthal anisotropies at forward and backward rapidity with muons in high-multiplicity p-Pb collisions at 8.16 TeV* - to be submitted to PLB
- *J/ψ-hadron correlations at midrapidity in pp collisions at 13 TeV* - to be submitted to JHEP
- *Observation of a multiplicity dependence in the p_T-differential charm baryon-to-meson ratios in proton-proton collisions at 13 TeV* - submitted to PLB [arXiv:2111.11948]
- *Inclusive heavy-flavour production at central and forward rapidity in Xe-Xe collisions at 5.44 TeV* - PLB 819 (2021) 136437 [arXiv:2011.06970]

- *Production of muons from heavy-flavour hadron decays at high transverse momentum in Pb-Pb collisions ar 5.02 TeV* - PLB 820 (2021) 136558, [arXiv:2011.05718]
- *Measurement of prompt D^0, D^+, D^{*+}, and D^+_s production in p-Pb collisions at 5.02 TeV* - JHEP 2019 (2019) 92 [arXiv:1906.03425]
- *Measurement of inclusive charged-particle b-jet production in pp and p-Pb collisions at 5.02 TeV* - JHEP 2022, 178 (2022) [arXiv:2110.06104]

Beyond the measurements concerning the evidence of flow and correlation phenomena involving heavy flavors, quarkonia measurements allow to address fundamental questions concerning the production mechanisms of cc and bb bound states in a hadronic collision environment, the role of photoproduction mechanisms, and the existence of dissociation and regeneration mechanisms in the presence of a deconfined medium. Measurements in this field are mainly focused on the analysis of the evolution of the quarkonia production rate with the multiplicity of charged particles or the transverse momentum, from pp collisions to Pb-Pb collisions.

- *Centrality and transverse momentum dependence of inclusive J/ψ production at midrapidity in Pb-Pb collisions at 5.02 TeV* - PLB 805 (2020) 135434 [arXiv:1910.14404]
- *ϒ production and nuclear modification at forward rapidity in Pb–Pb collisions at 5.02 TeV* - PLB 822 (2021) 136579 [arXiv:2011.05758]
- *Multiplicity dependence of ϒ production at forward rapidity in pp collisions at 13 TeV* - submitted to PLB [arXiv:2209.04241]
- *Inclusive quarkonium production in pp collisions at 5.02 TeV* - submitted to EPJC [arXiv:2109.15240]
- *Measurement of ψ(2S) production as a function of charged-particle pseudorapidity density in pp collisions at 13 TeV and p-Pb collisions at 8.16 TeV with ALICE at the LHC* - submitted to JHEP [arXiv:2204.10253]
- *J/ψ production as a function of charged-particle multiplicity in p-Pb collisions at 8.16 TeV* - JHEP 2020 (2020) 162 [arXiv:2004.12673]
- *Photoproduction of low-p_T J/ψ from peripheral to central Pb-Pb collisions at 5.02 TeV* - accepted by PLB [arXiv:2204.10684]

Measurements of the production of particles containing an s-quark play an essential role in the characterization of the thermalization and hadronization mechanisms of quarks in a dense hadronic medium. Indeed, the mass of the s quark being intermediate between those of the light quarks u and d and the heavy quarks c and b, it is extremely interesting to study how the interaction of this quark with the hadronic environment evolves as a function of the complexity of the created system, quantified by the multiplicity of charged particles. On the one hand, the production rate of the s quark is strongly suppressed in very low multiplicity collisions, whose environment is close to that of vacuum, compared to predictions based on a thermodynamic approach; on the other hand, in the most energetic nuclear collisions the s quark participates in the thermalization phase which characterizes the evolution of the volume of QGP created, its production rate finding the thermodynamic equilibrium with the production rates of the light u and d quarks.

- *Enhanced production of multi-strange hadrons in high-multiplicity proton-proton collisions* - Nature Physics *13*, 535-539 (2017) [arXiv:1606.07424]

- *Multiplicity dependence of (multi-)strange hadron production in proton-proton collisions at 13 TeV* - EPJC 80, 167 (2020) [arXiv:1908.01861]
- *Energy dependence of φ meson production at forward rapidity in pp collisions at the LHC* - EPJC 81 (2021) 772 [arXiv:2105.00713]
- *φ meson production at forward rapidity in Pb-Pb collisions at 2.76 TeV* - EPJC 78 (2018) 559 [arXiv:1804.08906]

Finally, measurements with hard or electroweak probes such as high-p_T particles or jets, isolated photons, and Z and W bosons, which are not very sensitive to the presence of hot or cold hadronic matter, allow us to establish a reference for measurements of effects related to the presence of a deconfined medium, to probe the partonic distribution functions (PDFs) of the nuclei involved in collisions, or to test perturbative QCD computations in a near vacuum environment.

- *W boson production in p-Pb collisions at 8.16 TeV and Pb-Pb collisions at 5.02 TeV* - accepted by JHEP [arXiv:2204.10640]
- *Z boson production in p-Pb collisions at 8.16 TeV and Pb-Pb collisions at 5.02 TeV* - JHEP 09 (2020) 076 [arXiv:2005.11126]
- *Measurement of Z°-boson production at large rapidities in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV* - PLB 780 (2018) 372-383 [arXiv:1711.10753]
- *Measurement of the inclusive isolated photon cross section in pp at 7 TeV* - EPJC (2019) 79: 896 [arXiv:1906.01371]
- *Measurement of charged jet cross section in pp collisions at 5.02 TeV* - PRD 100, 092004 (2019) [arXiv:1905.02536]
- *Multiplicity dependence of charged-particle jet production in pp collisions at 13 TeV* - EPJC (2022) 82: 514 [arXiv:2202.01548]

II. - Upgrades during Long Shutdown2 [2019-2021] for ALICE

The ALICE experiment has been approved for the two upcoming data-taking campaigns at the LHC, Runs 3 [2022-2025] and 4 [2029-2032]. At the beginning of 2022, the collaboration completed the installation of major upgrades that will remain in place for the next ten years. This includes the time projection chamber with novel GEM-equipped readout planes (TPC-2) [TPC-TDR], and, as far as some French teams are concerned, the inner trackers based on silicon pixel sensors, positioned at central rapidity (ITS2) [ITS2-TDR] and at forward rapidity (MFT) [MFT-TDR]. Installed downstream of the MFT, the muon spectrometer consists of muon chambers (MCH) and muon identifier (MID), both essentially led by French teams. The electronic readout [RO-TDR] of the muon spectrometer was completely revisited to accommodate the triggerless/continuous readout now enforced in the experiment, the master piece of such an upgrade strategy hinging on the so-called Common Readout Unit cards integrated in the completely new online-offline software environment [O^2-TDR]. The EMCal detector [EmCal-perf], partially designed and built by IN2P3 groups, was not significantly involved in the LS2 upgrade program and will not be discussed in what follows; it should be mentioned, however, that some of the French groups will continue exploiting its data and assure calibration activities during Runs 3 and 4.

II.A - Inner Tracking System, version 2 (ITS2)

The ITS2 consists of 7 coaxial layers divided into 2 groups: the 3 internal layers installed closest to the beam pipe (r_{pipe} = 1,82 cm) at distances r_{L0} ≈ 2,3 cm, r_{L1} ≈ 3,2 cm et r_{L2} ≈ 3,9 cm, and the 4 outer layers positioned between r_{L3} ≈ 19,5 cm et r_{L6} ≈ 39,3 cm. The 7 layers are instrumented to cover a range of pseudorapidity *at least* equal to $|\eta| < 1.3$ (see Tab. 1.1 in [ITS2-TDR]). The detector is composed of a set of pixelated monolithic active sensors (MAPS) exploiting a **180-nm CMOS** technology, following an ALPIDE architecture specially developed for this purpose. The whole ITS2 accounts for about 10 m² of active silicon surface, segmented into 12.5 billions pixels of about 27x29 µm² each. The main characteristics of the detector are listed in the first column of Tab. B.1 of this document. The ITS2 will already increase for the LHC Run 3 the detection efficiency of charged particles at low transverse momenta (e.g. at p_T = 0,1 GeV/c, $\varepsilon_{\text{tracking ITS-1}}(h^{\pm})$ ≈ 10 % vs. $\varepsilon_{\text{tracking ITS-2}}(h^{\pm})$ ≈ 60 %, see Fig. 7.12 in [ITS2-TDR]).

The IPHC group in Strasbourg participated and participates to the ITS2 project on several fronts:

- The design of the ALPIDE chip [VCI-2016] equipping the ITS2 was partially carried out in Strasbourg (C4pi, PICSEL)
- The *module* assembly, for which the IPHC was one of the 5 sites in charge in the ALICE collaboration (a module consists of 2x7 sensors positioned, glued and wire-bonded on a flexible printed circuit); 585 functional modules, defining about 25% of the grand total of modules, have been produced, between November 2017 and May 2019, requiring 4.5 FTE (C4pi, ALICE-IPHC).
- Technicians and engineers further committed themselves at CERN during the installation, to cable the various parts of the detector and set up its operation (implement detector slow control and cooling); they followed, intervened and/or co-organised aspects related to the electronic connection-reconnection during the various ITS2 relocations, from Meyrin to LHC point-2 ground to the underground ALICE cavern (C4pi, PICSEL, ALICE-IPHC).
- In parallel with the activity on the hardware side, Iouri Belikov from the IPHC ALICE team has been in charge (since the time of the ITS2 TDR, in 2013) of the software working group dedicated to detector simulations, tracking and reconstruction with the ITS2 (international group of about 50 persons in the collaboration).

II.B - Muon Forward Tracker (MFT)

The MFT is designed to add in Run 3 vertexing capabilities to the muon spectrometer (MCH + MID), improving the sensitivity of muon measurements (increasing the signal/background ratio) especially at low p_T, and providing offset information for charm-beauty separation. The MFT consists of two half-cones each containing five detection half-disks installed along the beam axis between −460 mm and −768 mm away from the interaction point, covering the pseudo-rapidity range $-3.6 < \eta < -2.5$. The basic detection element is the aforementioned ALPIDE silicon pixel sensor, developed for both ITS2 and MFT.. The 920 silicon pixel sensors of the MFT are assembled, using the same technology as for the ITS2, on 280 ladders of 2, 3, 4 or 5 sensors each. The read-out electronics, common to both ITS2 and MFT, has been jointly developed by the two projects. [MFT-TDR].

The MFT and associated services have been installed in the ALICE cavern in December 2020. The year 2021 was dedicated to the integration and commissioning of all components into the central ALICE data taking and more specifically the Detector Control System (DCS), Readout, Quality Control and Data Compression with the synchronous reconstruction successfully validated by the Pilot Beam at $\sqrt{s}$ = 900 GeV. In 2022, the MFT entered in production phase running at 500 kHz and 1 MHz interaction rate for proton-proton collisions.

Subatech-Nantes, IP2I-Lyon and LPC-Clermont carried out important roles in the MFT design, conception, production, assembly, installation and integration:

- Mechanical support, Readout System and Firmware, Slow Control (ALF-FRED), installation at IP2I
- Power Supply Unit, cooling system, Slow Control (ALF-FRED), MFT-MCH track matching, Commissioning at Subatech
- Geometry integration into simulation, ladder assembly, installation, commissioning at LPC.

French teams have a leading role in the management of the project with Guillaume Batigne (Subatech) as deputy project leader and System Run Coordinator in 2023, Sarah Porteboeuf-Houssais (LPC) as Data Run Coordinator and System Run Coordinator in 2021, Rafael Pezzi (Subatech + Brasil) as software coordinator and System Run Coordinator in 2022. Antonio Uras (IP2I) is the MFT Physics Coordinator.

II.C - Muon spectrometer

The ALICE forward muon spectrometer studies the complete spectrum of heavy quarkonia (J/ψ, ψ(2S), ϒ(1S), ϒ(2S), ϒ(3S)) and weak bosons via their decay in the $\mu^+\mu^-$ channel, as well as low-mass vector mesons, and single muons from heavy flavor decays. It provided a wealth of results during Runs 1 and 2, corresponding to approximately 50 publications. The spectrometer acceptance covers the pseudorapidity interval $2.5 \leq \eta \leq 4$ and the resonances can be detected down to zero transverse momentum. The invariant mass resolution is of the order of 70 MeV/c^2 at the J/ψ mass, and about 100 MeV/c^2 close to the ϒ(1S). During the Long Shutdown 2, the front-end electronics of both MCH and MID have been upgraded. The software has been fully redesigned in the new Online-Offline (O^2) framework. Both detection systems are now integrated in the global ALICE data taking, with very good performances in terms of readout stability and efficiency.

II.C.1 - Muon chambers (MCH)

The MCH is composed of 5 tracking stations (2x5 Multi-Wire Proportional Chambers) complemented with an absorber system. The total number of detectors is 156 (140 slats and 16 quadrants) with overlaps to avoid dead zones. The tracking system covers a total area of about 100 m² for about 1.1×10^6 readout channels.

IJCLab took in charge the production of the Dual Sampa cards for the whole project, coordinating the production of 19300 FEE cards via a manufacturer. In addition to the Dual Sampa production, a complete test bench was designed (mechanics and software) to be given to the manufacturing company allowing the complete testing and validation of all boards. The new FEE required a complete redesign of station-1 large PCB interfacing the FEE to the readout SOLAR crates, *i.e.* DAQ. Hence the routing, prototyping and production of 11 different boards. In addition, quadrants were reworked, opened, cleaned and validated with X-ray sources, to better cope with the high intensity expected in Pb-Pb collisions. Technicians and engineers have been involved in the installation and cabling of station 1 on-site and also participated in the station-2 installation. Readout cabling and commissioning were carried out by physicists of the group. The upgrade project started in 2013 and ended in 2021 involving up to 6 FTE.

Subatech played a crucial and leading role in the development and delivery of the fully O^2-integrated MCH software. The triggerless data taking implies a major rewriting and testing of existing code. The laboratory took charge of about 85% of the MCH software preparation for Run 3, including the simulation, clusterization, reconstruction and calibration codes. In addition, a Subatech physicist is in charge of the software maintenance and commissioning, since O^2 updates are still released on a weekly basis. On the technical side, Subatech participated in the installation and commissioning of stations 3, 4 and 5 and committed a dedicated engineer with a specific expertise to the repair of slat detectors. These maintenance operations are still ongoing on demand, when slat detectors are repaired and exchanged.

Christophe Suire (IJCLab) is the project leader of MCH and Laurent Aphecetche (Subatech) is the MCH-O^2 coordinator.

II.C.2 - Muon Identifier (MID)

The MID is composed of 72 Resistive Plate Chambers (RPCs) arranged in 2 stations of 2 planes each for a total surface of about 150 m² and about 21×10^3 readout channels. The MID (for Muon Identification) is the upgrade of the MTR (for Muon Trigger) project: the front-end electronics was fully replaced in order to include an amplification phase with the aim of reducing the working voltage of the RPCs and, consequently, the aging process. The readout electronics was fully replaced as well, in order to allow for triggerless continuous acquisition. These improvements result in a completely new system from the point of view of data acquisition. The reconstruction of the detector, which was previously based on the trigger algorithm, was changed as well and now includes clustering and tracking in the 4 RPC planes.

French institutes have a major role in the upgrade. The LPC-Clermont is in charge of the Front-End electronics (FEE) with the design, production and installation of the FEE with amplifications (FEERIC) and of the distribution of the thresholds. A total of 2384 FEERIC cards were installed. The threshold distribution is currently based on the Xbee wireless protocol, which will be further replaced by WiFi at the next winter shutdown. The institute is also responsible for the quality control monitoring of the detector.

Subatech-Nantes is in charge of the design, production, installation and slow control of the readout electronics. A total of 16 crates, each consisting of 16 local cards, 1 regional card and 1 J2 bus for the communications of the local and regional cards have been installed and commissioned. The laboratory also developed the quasi totality of the simulation and reconstruction software. It also took care of the integration of the different components in the data acquisition framework, from DAQ to online track segment reconstruction for online event display.

French teams have a leading role in the project with Pascal Dupieux (LPC-Clermont) who coordinated the MID upgrade up to the end of its installation in ALICE cavern, Diego Stocco (Subatech-Nantes) as current deputy project leader of the MID and Baptiste Joly (LPC-Clermont) who ensured a two-years presence at CERN as a CERN Project Associate for the integration and commissioning of the FE and readout electronics.

II.E - Online-Offline Common Readout Unit (O^2 CRU)

Starting in 2018, the LPSC gradually took over the responsibility for the firmware of the Common Readout Unit (CRU) acquisition card of the ALICE experiment. This electronics is a common service used by 10 sub-detectors of the ALICE experiment. This firmware has been reworked and lightened in order to free up FPGA hardware resources (from 43% to 29% for the logic modules used). In 2019, the ITS2 and TPC detectors, which are the most demanding in terms of CRU usage, have started their commissioning phase. This required continuous support as well as corrections where necessary. In addition, major but missing functionalities have been added, *i.e.* i) flow control for *continuous* reading as ALICE will work mainly in the absence of a specific trigger, ii) the addition of a trigger mode (for testing but also for the transition phase with non-updated detectors during the long LS2), as well as iii) the remote update of the firmware (about 500 cards to maintain in operation).

III. - Commissioning the ALICE-2 experiment

The installation and integration of the ALICE upgrades have been completed in time by the end of 2021. The next step was then the full integration into the ALICE data taking infrastructure including the Central Trigger Processor, Detector Control System, Readout and acquisition, Synchronous processing and Data Compression, Online Quality Control, all supervised by the Online-Offline (O^2) software. The ALICE data taking is not based anymore on the concept of “physics event” but on the one of “Time Frame” which includes all raw data from all detectors during 11.6 ms. The Time Frames are then compressed based on online reconstructions (compression factor of about 20). The readout is continuous for most of the detectors, replacing the trigger mode of Runs 1 and 2. This makes the ALICE experiment in Run 3 (ALICE-2) a complete new experiment from the point of view of the readout and data acquisition, which required dedicated commissioning to ensure a good data sanity and quality.

This detector integration has been performed over 2021 and 2022 with regular milestones given by the ALICE collaboration (Milestone Weeks) or by the Machine with the 2021 and 2022 Pilot Beam at injection energy ($\sqrt{s}$ = 0.9 TeV). At the first data taking at $\sqrt{s}$ = 13.6 TeV (05 July 2022), ITS2, MFT, MCH and MID were included in all steps of the data taking showing good performances. Examples of Quality Control graphical displays are highlighted in Appendix β. During July and August, ALICE initiated a ramp-up phase (correlated with LHC beam intensity ramp-up) where the ALICE data taking moved from initial 10 kHz up to 1 MHz. The baseline proton-proton data taking is at 500 kHz where about 800 collisions are included in a Time Frame, the total ALICE raw Readout is about 600 GB/s, compressed down to about 30 GB/s of data stored. The muon tracking and matching is part of the asynchronous reconstruction but is running online for quality control and event display purposes. All the detectors, and more specifically the ITS2, MFT, MCH and MID have shown a very good availability in data taking with stable running conditions. The calibration runs are integrated into the flow of operations, either in standalone running (noise and pedestal runs) or during the acquisition for online calibrations (ITS2). The detectors are now converging toward the finalization of alignment studies which will allow the first physics outcome. As a preparation for Pb-Pb data taking, regular high-rate scans are organized up to 4 MHz of visible interaction rate. 3.5 MHz pp interaction rate corresponds to the equivalent track load on the detectors of 50 kHz Pb-Pb and allows the commissioning of the hardware and an appropriate understanding of the ability of the full system chain to sustain Pb-Pb data taking.

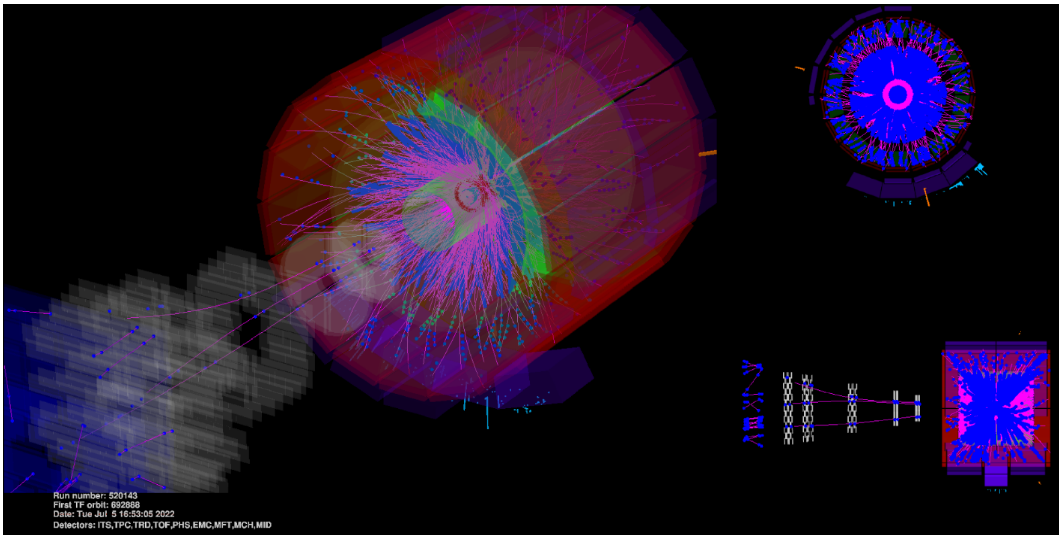


Figure A.1 - Event display of pp collisions at $\sqrt{s}$ = 13.6 TeV collected for one Time Frame during Run 3 (05 July 2022) by ALICE-2. The display shows tracks reconstructed in the central barrel and in the forward arm.

IV. - Timeline in LHC run 3 [2022-2025] and run 4 [2029-2032]

The current planning for LHC campaigns over the next decade is not fully settled. A likely timeline is given in Fig. A.2 below. The next decade will cover two LHC runs of 3-4 years each. Each year typically restarts around March with beam recommissioning, then moving, around middle spring, to proton beams typically accelerated up to maximum energy (6.8 TeV in 2022), delivering collisions at $\sqrt{s}$ = 13.6 TeV, meant for physics in the experiments. Towards the late fall of the year, a dedicated data taking should take place for 3-5 weeks, with typically Pb-Pb collisions with $\sqrt{s_{NN}}$ around 5 TeV [arXiv:1812.06772]. pp campaigns at an energy different from the top energy will be covered during such periods typically, also including further p-Pb data. Special runs of O-O and p-O, for short periods (*O*[day(s)]), are foreseen in 2024. One should not forget that ALICE also takes data in pp collisions at 13.6 TeV, the top LHC energy in Run 3. In a first stage, the pp data taking will focus on the collection of Minimum Bias events (500 kHz); it will later move to a data skimming approach via software trigger, meant to inspect integrated luminosities of about 200 pb^{-1} and focus on i) high-multiplicity events ii) diffractive events and iii) rare signals such as production of light nuclei (d,t,^{3}He,^{4}He…) or of heavy-flavour jets [ALICE-PUBLIC-2020-005]. As of September 2022, the international context of the year (*e.g.* energy cost) makes the 2022-December Pb-Pb run postponed to 2023 with an extended Pb-Pb data taking (5 weeks). In 2022, a test Pb beam of two fills with pp-like optics is expected (*i.e.* low intensity).

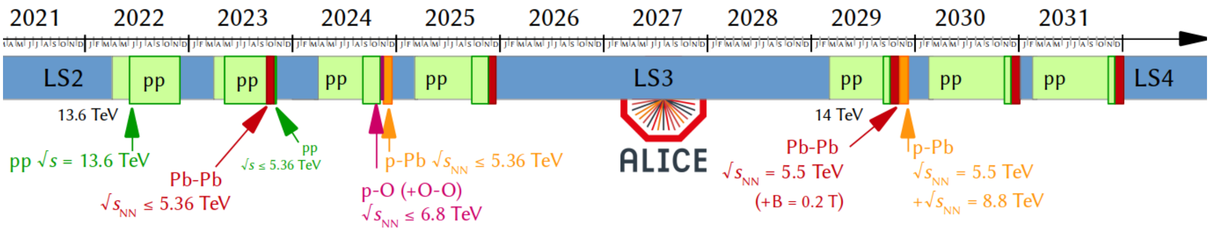


Figure A.2 - Tentative overview of the LHC campaign planning for Run 3 [2022-2025] and Run 4 [2029-2031(2032)], as currently anticipated from the ALICE experiment perspective. See LHC updates at *lhc-commissioning.web.cern.ch*. As far as it is foreseen in September 2022, the colliding energies ($\sqrt{s_{NN}}$) for pA and AA periods are not yet fully settled, it depends on collimation and training quench performances, still to be assessed.

V. - Involvement of IN2P3 teams in Run 3 and Run 4

The priority of the teams involved in ITS2, MFT, MCH, MID and EMCal is i) to ensure the maintenance and operations of the detectors they are in charge of, until the end of Run 4, as well as ii) to exploit the full physics output. Due to natural aging of teams members as well as few scientific transitions to other field, a decrease of approximately 25% of permanent physicist human resources is expected towards the early Run 4 (2029) (cf. Table A.1).

Table A.1 - Inventory of the workforce per ALICE France team, for current year (2022) and *projected* for the coming years (rest of LHC Run 3 [2022-2025], future Run 4 [2029-2032]). It accounts for announced departures (research migration and retirements - some of the retired scientists could however get the status of emeritus) but it does *not* include possible new recruitments. In order to provide a coherent picture, post-docs are *excluded* from the count, and only permanent staff persons are considered; the first number corresponds to researcher positions, the second to university positions. M&OA corresponds to ALICE authors with a PhD; as a function of their number, each team owes a certain amount of service work for the experiment operation itself and/or for ALICE collaboration functioning (2022 : 0.25 FTE/year/ M&0A, including post-doc though).

Team	**"M&OA" (2022)**		**Due service work FTE/year (2022)**	**Main detector activities in Runs 3 *(+ Run 4)***	**"M&OA" *(projected end Run 3, 2026)***		**"M&OA" *(projected early Run 4, 2029)***	
IJClab Orsay	4 + 1	5	1.5	MCH, O²	4 + 1	5	4 + 1	5
IPHC Strasbourg	5 + 1	6	1.5	ITS2 *(+ ITS3)*	4 + 1	5	4 + 1	5
IP2I Lyon	3 + 0	3	0.75	MFT *(+ ITS3)*	2 + 0	2	2 + 0	2
LPC Clermont	2 + 5	7	1.75	MID, MFT	2 + 5	7	1 + 4	5
LPSC Grenoble	2 + 2	4	1	readout, DPG *(+ ITS3)*	2 + 2	4	2 + 1	3
Subatech Nantes	7 + 2	9	2.75	MID, MCH, MFT	4 + 2	6	3 + 2	5
TOTAL	23 + 11	34	9.25		18 + 11	29	16 + 9	25

The French groups will pursue their implication in the analysis of the data collected by the ALICE detector during LHC Runs 3 and 4, exploiting the information coming from the upgraded detectors, a fundamental asset to open new opportunities for the physics programme of the experiment.

More specifically, the data collected at forward rapidity with the muon spectrometer will profit for the first time from the information offered by the MFT on the offset of the tracks at the primary vertex, and the possibility of reconstructing secondary vertices corresponding to the decay of long-lived particles: the two main examples are the separation, in the $\mu^+\mu^-$ channel, between prompt J/ψ and J/ψ coming from the decay of B mesons, and the separation of the open charm and open beauty production in the semi-muonic decay channel. The French groups are expected to keep the leadership in these analyses in Runs 3 and 4, thanks to a major involvement in the dedicated working groups and their role in the operation of the MFT and MUON detectors.

The data collected at mid-rapidity will profit from the better spatial resolution offered by the ITS2, for the reconstruction of the primary and secondary vertices, allowing for a better rejection of the background and a higher efficiency in the reconstruction of the decay chains of charm and beauty hadrons, especially at low p_{T} (0-2 GeV/c). These performances will be further improved in Run 4 thanks to the installation of the ITS3 (replacement of the three innermost layers of the ITS2). The French groups will have an active role in the corresponding physics analyses, the main goal being the study of the hadronization and energy loss mechanisms of heavy flavours in the medium.

Measurements correlating observables at mid and forward rapidity will also be possible, opening the possibilities to new probes with respect to Run 2.

Both at forward- and mid-rapidity, the expected statistics will allow for a significant improvement of the sensitivity for any measurement addressing multiplicity-dependent effects, with the goal of investigating the origin of collective behaviour. In that respect, after Runs 1 and 2, charged-particle multiplicity in events has already been identified as an effective scaling parameter driving the deviation of the observed effects from the vacuum reference. The Run 3 and Run 4 follow-up implies then the scrutiny of the event activity itself and its correlations with each probe or particle species of interest, in any of the collision systems which will be available in Runs 3 and 4.

At the Run 4 horizon, it should be mentioned that the ALICE Collaboration itself foresees possibly two other upgrades: FoCal and ALICE-FT. The installation of the FoCal (Forward Calorimeter) will open the way to new measurements at very forward rapidity, providing the opportunity to study the low-x region with the search for possible gluon saturation effects predicted by the color glass condensate model, and the study of the modifications of gluon (n)PDFs at small-x and Q^2. The fixed-target program in ALICE (CERN-PBC-Notes-2019-004) will provide further insight on the high-x gluon, antiquark, and heavy-quark content of the colliding nucleons and nuclei. Interested people in the French community may be involved during Run 4 in the analyses based on the data collected by the FoCal detector and the ALICE-FT system.

Part B - ITS3

I. - Introduction : context, ITS2 et ITS3 projects

I.A - Which physics for ALICE with ITS3 ?

The letter of intent for the ITS3 project [LoI], in December 2019, presented an insight of the physics analyses significantly improved or made possible with such an instrument. They are listed below to provide an overview of the available opportunities. The aspects that are of particular interest to the French groups will be covered later in this document in a dedicated paragraph.

- measurement of low-mass e^+e^- pair production
- measurement of single-charmed baryons Λ_C^+(*udc*) [$c\tau$ = 60 µm] and mesons D_S^+(*csbar*) [$c\tau$ = 150 µm]
- measurement of single-charmed and strange baryons of type Ξ_c, Σ_c, Ω_c
- discovery of light nuclei with a charmed baryon content, d_c(bound n+Λ_C^+)
- measurement of beautiful baryons Λ_B^0(*udb*) [$c\tau$ = 441 µm]
- measurement of the anisotropic flow of heavy-flavored hadrons (charm and beauty)

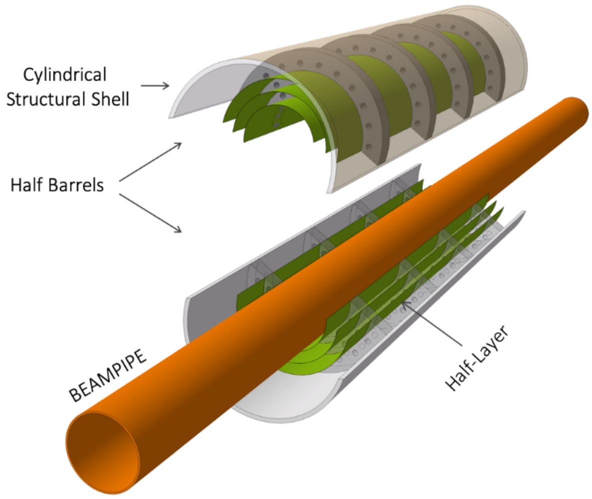
The ITS3 upgrade will notably allow for real advances in the identification of short-lived hadrons as well as their correlations with other signals. One can cite the examples of baryons Λ_C^+(*udc*) [cτ = 60 µm] and of mesons D_S^+(*cs*) [cτ = 150 µm] with an expected significance larger than 25 for $p_T > 2$ GeV/*c* in the most central (0-10 %) Pb-Pb collisions (≈ 4 times the expected significance with ITS2, see Fig.13 in the corresponding [ITS2 TDR]) and a reconstruction capability down to p_T ≈ 0-1 GeV/*c*, implying that the reconstruction of charmed hadrons will be possible where they are mainly produced (typically ≈ 25% of the production sits < 1 GeV/*c*, ≈ 50% < 2 GeV/*c*).

I.B - Key specifications of the ITS3 detector

Keywords: 3 internal layers, hypergranular (*O*[20x20 µm²] pixels) and ultra-thin (0.05% X_0 per layer) sensors of large scale (*O*[silicon wafer]), *bent* sensors, perfectly cylindrical geometry of the layers, absence of flexible printed circuit, *stitching* between sub-sensors, *r* > 1.8 cm.

The ITS3 project [ITS3 LoI] aims at replacing the 3 innermost layers of the ITS2 (see section III.A about ITS2 above). It will be implemented during Long Shutdown 3 [2026-2028], for a commissioning phase accompanying the start-up of the HL-LHC in Run 4 [2029-2032]. The pseudo-rapidity coverage (η) is very slightly extended compared to Run 3 (|η| < 2.7, 2.4 and 2.2 for the new internal layers with respect to |η| < 2.5, 2.3 and 2.0 of the current ITS2) but remains limited by the 4 outer layers (|η| < 1.5 to 1.3) which remain those of ITS2 [TDR]. The layout of the detector is shown in Fig. B.1 below. The main characteristics of the ITS3 are summarized in Tab. 1.

In a nutshell, the guideline of this upgrade is not the collection of larger instantaneous luminosities (on this point, preserving temporal performance is targeted: 2-5 µs of timing resolution, in a continuous readout devoid of any triggering) but a better spatial precision (granularity + radial location of the 1st layer closer to the primary collision point) coupled with a minimum thickness of the detection layers. This last aspect relates to thinning of the silicon substrate but also ultimately to layers that, once they are integrated in terms of mechanics, cooling, readout, … still manage to remain broken free from all limiting factors. We will see below what it means.



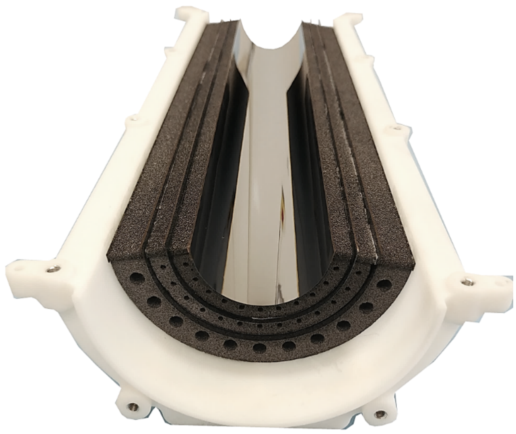


Figure B.1 - Left: Sketch of the ITS3 layout (Fig. 7 in [ITS3-LoI]) with the 6 silicon sensors (green) folded as two hemi-cylinders around the beam pipe (orange). Right: Photograph of Engineering Model 2, done during 2022. Mock-up of one hemi-cylinder using *dummy* silicon sensors, having the proper thickness (40-µm), the proper length (Z=28 cm), bent to proper radii (r_0 = 1.8 cm, r_1 = 2.4 cm, r_2 = 3.0 cm) and mounted on carbon foams (longerons along Z and half-rings at the extremities).

The ITS3 will again rely on MAPS CMOS sensors as the ITS2, but a **65-nm CMOS** technology is targeted in this case.

[Linked to the question of the material budget] The sensors have the ambition to overcome three technological limitations in terms of material budget. The detector will be :

1. freed from any mechanical supports in the form of carbon ladders;
2. freed from any forced-cooling circuitry, allowed only upon drastic specifications on the power consumption and dissipation (< 20 mW/cm² on the pixel matrix);
3. devoid of assemblies on the usual flexible printed circuits, needed for the supply of power, slow control and for the extraction of data. In turn, the absence of flex requires sub-units of sensors sutured together (**stitching**), directly on the substrate, *i.e.* at the stage of silicon lithography by the foundry. This requires a radical revision of power management, voltage distribution, remote control and low-level acquisition. The finished objects will then become active sensors gathered in blocks of **large surface** (O[10x27 cm²]), on which the detector steering and the data extraction will be relegated to the periphery of the large active circuit.

In the end, the combination of the three above specifications makes it possible to reduce the material budget to its bare minimum, namely 30-50 µm of silicon thickness per layer (30 µm of silicon corresponds to **0.03 % x/X$_0$**). The sensors become therefore flexible and consequently

bendable; a few large sensors can thus be wound and joined together in a perfectly cylindrical geometry, resulting in an almost uniform distribution of the material budget per detection layer..

[Linked to spatial resolution] the improvement in spatial precision (localization of the path of a charged particle and distance of closest approach to the primary vertex) is related to two technological points:

1. The aforementioned structural flexibility allows the layers to be rolled with a small radius, allowing sensors to be placed at smaller **radial distances** from the beam axis ($r_{L0} \approx 1{,}8$ cm, $r_{L1} \approx 2{,}4$ cm et $r_{L2} \approx 3{,}0$ cm), around a beam pipe of still smaller size ($r_{tube} = 1{,}60$ cm).
2. The 65-nm technology makes it possible to push the **hypergranularity** a little further down (pixel *O*[20x20 µm²]) compared to ALPIDE chips, well below what can typically be obtained with hybrid pixels (> 50x50 µm²).

I.C - State of the art (Sept. 2022)

The ITS3 project is regularly monitored by the LHCC and benefits from a very positive feedback from the latter (see minutes from LHCC meetings [CDS], going from the 139th session in September 2019 [LHCc-139] to the 149th in March 2022 [LHCc-149].)
R&D by the collaboration has been underway since mid-2019 and is progressing with promising results:

- The bending of flexible sensors while preserving their detection potential is now acquired, on the basis of the tests carried out on the ALPIDE chips (*NB:* 180-nm technology) [BentAlpide]. An "ITS3-like" mini-configuration, based on ALPIDE chips, has been extensively tested; the curvature for radii between 1.8 and 3 cm does not alter the detection efficiency (>99%).

- The 65-nm technology exhibits the same characteristics as the 180-nm technology in terms of detection efficiency. This conclusion proceeds from multiple test campaigns, in the lab and under beam test (CERN-PS $\pi^{\pm}$ 5-10 GeV/*c*, CERN-SPS $\pi^{\pm}$ 120 GeV/*c*, DESY-PETRA $e^{\pm}$ 3.4 GeV/*c*), with or without irradiations (10^{13} to 10^{15} 1-MeV $n_{eq}.cm^{-2}$ NIEL / 1-10 Mrad TID).
- Note that, to date (Sept 2022), the bending of such detectors in 65-nm has not yet taken place (too small-size prototypes).
- Radiation hardness is studied over time in parallel of new versions of chips being submitted to the foundry. So far, the 65-nm technology exceeds the needed specifications (ITS3 requests $>3.10^{12}$ 1-MeV $n_{eq}.cm^{-2}$ for Non-Ionising Energy Loss, 0.3 Mrad for Total Ionising Dose). It is already validated with $>2.10^{14}$ 1-MeV $n_{eq}.cm^{-2}$ and >1 Mrad irradiations, at room temperature.

- The issue of stitching and its performance will be addressed for the first time with the fall-2022 submission.

- Integration studies are in progress (cooling by air flow, mechanics on carbon foam, connections to the outside world, etc.)

Table B.1 - Main characteristics of the ITS-2 and ITS-3 silicon trackers of the ALICE-2 experiment. Data in *italics* relate to the outer layers (*L3 to L6*) of the trackers, when they differ from the inner layers (*L0* to *L2*); these outer layers remain those of ITS-2 for the next decade.

	ITS-2 (TDR)	**ITS-3** (LoI)
LHC period(s)	Run3 [2022-2025] + Run4	Run4 [2029-2032]
Number of layers	3+4	3 (*+4 ITS-2*)
beryllium pipe inner radius R_{pipe} (thickness ΔR)	1.82 cm [CERN-news] (0.08 cm, = 0.22% x/X_0)	1.6 cm (0.05 cm, = 0.14% x/X_0)
r_{L0} / r_{L1} / r_{L2} … r_{Last}	2.3 / 3.2 / 3.9 … *39.3 cm*	1.8 / 2.4 / 3.0 … *39.3 cm*
Magnetic field $B_{solenoïd}$	0.2 and 0.5 T	0.2 and 0.5 T
Material budget per layer	0.3 % to *0.8 %* x/X_0	0.05 % to *0.8 %* x/X_0
CMOS technology	180 nm	65 nm *(180 nm)*
Pixel size	≈ 27 x 29 µm²	≈ 20 x 20 µm² (*+ ≈ 27 x 29*) µm²
Size of *unitary* base sensor	≈ 1.53 x 3 cm²	≈ (5.6-9.5) x 27 cm²
Nb of sensors to assemble 3 inner layers	432	6 (!)
Non-Ionising Energy loss radiation	> 3.10^{12} 1-MeV $n_{eq}.cm^{-2}$	> 3.10^{12} 1-MeV $n_{eq}.cm^{-2}$
Total Ionising dose	> 0.3 Mrad	> 0.3 Mrad
Consumed power (in the active volume, i.e. over the pixel matrix, ≠ in the periphery…)	< 35 mW/cm²	< 20 mW/cm²
Time resolution on hits	2-5 µs	≤ 2-5 µs
Time for charge collection per pixel	< 10 ns	≤ 1 ns
Spatial resolution	5 µm	≤ 5 µm
Coverage in η	|η| < 2,0 to *1,3*	|η| < 2,2 to *1,3*
$\varepsilon_{tracking\ ITS}$ ($p_T(h^{\pm})$ = X GeV/c)	1 GeV/c : 98% 0.1 GeV/c : ~60%	1 GeV/c : 98% 0.1 GeV/c : ~75%
Fake hit rate	<< 10^{-6} $event^{-1}.pixel^{-1}$	< 10^{-7} $event^{-1}.pixel^{-1}$
Particle hit density	5 $MHz.cm^{-2}$	8.5 $MHz.cm^{-2}$
Total costs [R&D + Construction] (+ beam pipe, out of the given project)	≈ 15.2 $x10^6$ CHF (...)	≈ 6.0 $x10^6$ CHF (1.5 $x10^6$ CHF)
Nb of institutes / Nb of countries	30 / 16	(≥19) / (≥ 8)

I.E - Synergia and general interests for the HEP community

The first bullet in the list of top 4 priorities in the conclusion in the 2021 ECFA roadmap for Detector R&D (ECFA-21, ch. 11, p.219) reads: "Develop cost-effective detectors matching the precision physics potential of a next-decade Higgs factory with beyond state-of-the-art performance, optimised granularity, resolution and timing, and with ultimate compactness and minimised material budgets."
The same document underlines in passing where such R&D can take place (ch. 8, p.176) : experiments like "ALICE, EIC, Belle II and µ3e are natural stepping stones for R&D towards a future e^+e^- Higgs-factory collider" because "luminosity levels are moderate [*e.g.* unlike ATLAS, CMS cases] while precision vertexing and PID are key elements".
Such a family of experiments (ALICE, EIC, Belle II, µ3e) addressing quite different topics within HEP do have in fact a significant fraction of technological specifications in common. This is illustrated in the qualitative spider chart in Fig. B.2 below and similarly illustrated in the solid state chapter of the ECFA roadmap (see visual Fig. 3.1 and quantitative Fig. 3.2 p.60 in ECFA-21).

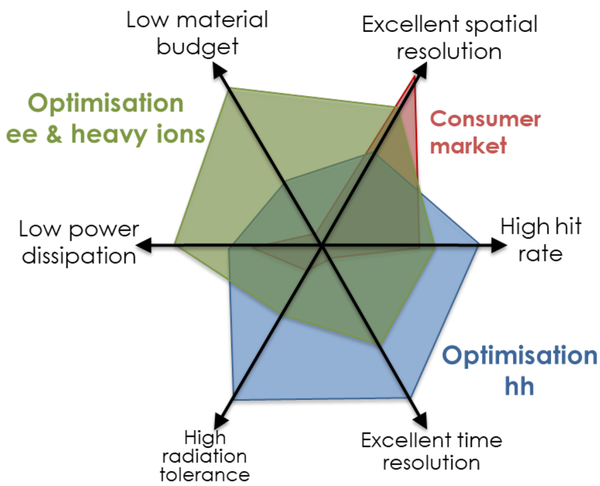


Figure B.2 - Spider chart showing *qualitatively* the various characteristics to be optimised on silicon sensors in view of HEP applications for trackers. The chart covers 3 use cases, for experiments focusing on high-luminosity proton-proton collisions (*e.g.* ATLAS and CMS), for experiments related to e^+e^- or heavy-ion collisions (*e.g.* like Belle2, ALICE), for the consumer-driven market. (*Courtesy Jérôme Baudot.*)

II. - Overall roadmap of the ITS3 project

II.A - Milestones of the project

The ITS3 upgrade project concerns a relatively modest surface to be equipped (0.12 m² of active surface, compared to 9.9 m² of the whole ITS2 or 0.41 m² of the MFT).

Keys :

- Foundry : Tower Semiconductor (bought by Intel, 15 Feb. 2022), facilitated access via an existing market at CERN for ALICE ITS development (without competitive tendering) and running at least until 2025, within a predefined money volume covering the Engineering Runs.

- New technology[1] : from 180-nm process (ex: ALPIDE ITS2) to 65-nm one.
- The production yield by the foundry for chips of large scale remains an open question to date, specific to the R&D phase of the project, which will be addressed with the upcoming 2022 submission.

- In this project, detector R&D and technology development is the central aspect, taking a large fraction of the time and resources. The final production only takes a relatively short time and comparatively modest resources.
- The reduction of two orders of magnitude in the number of unit sensors to be produced makes it possible to significantly accelerate the construction phase. The actual assembly of the 6 final "wafer-scale" sensors will be an extremely delicate phase (large and fragile objects) but rather fast in its implementation.
- The construction of the final detector will take place at CERN directly (given the small size of the final product and the low number of building objects).

The major milestones of the project hinge on the 4 *Engineering Runs* of the project. These main steps must take place at a typical rate of 1 run/year. The typical cycle time between the submission and the chips returned to ALICE on bench for test is approximately 7 months (submission validation 1 month, production 5 months, thinning and dicing 1 month).

2020-12 : MLR1 submission

. Objective (validated): detection efficiency in 65-nm technology (>99%) vs. 180-nm ALPIDE
. Flag : "generic R&D" (i.e. WP1.2 MAPS CERN, within the CERN EP R&D)
. Technology node : 65 nm

→ 54 different prototypes of sensors, all of (very) small surfaces (from 6x6 to not more than 64x32 matrix, e.g. to be compared with ALPIDE having 512x1024 pixels)

Exp. 2022-11 : ER1 submission

. Objective : stitching 1D (+ assess yields by the foundry)
. Flag : "generic R&D"
. Technology node : 65 nm, pitch: 18 and 22,5 µm
24 wafers with 2 sensor variants : MOSt and MOSs

→ MOSs (see Fig. B.3) is 1.4 x 25.9 cm² and consists of 10 chips of 1.4 x 2.55 cm² each, *stitched* "natively" on the wafer, in the close spirit of what ITS3 should look like. MOSs comes with safety margins regarding line spacing and circuit density to avoid shorts; MOSt is more aggressive on such aspects but this is to allow a very fine-grained way of turning off possible malfunctioning parts, it thus comes with alternative distribution of power and data distribution.

Exp. 2024-02 : ER2 submission

. Objective : power and readout, one single sensor ITS3-like (+ foundry yield)
that is, aim for a full-scale demonstrator with complete set of functionalities
. Flag : "ALICE ITS3-specific R&D"

[1] Note that such size (technology node) refers to the smallest element being possibly lithographed for a given process, this is not to be mixed with the pixel pitch (*e.g.* *O*[20 µm]), which rather gives an idea of the pixel size.

Exp. 2025-06 : ER3 submission

. Objective: a priori, last fixes and final run for the production, *i.e.* final large-scale sensors
. Flag : “ALICE ITS3-specific R&D”

+ 2026 : final construction within a few months

Notes:

- The available contingency is currently of 1-2 years, allowing for a potential ER4 during LS3 [2026-2028], if need be.
- A Technical Design Report (TDR) is expected for October 2023, following the fir characterisations (in the lab only) of the ER1 sensors that should be back for tests around late spring 2023.

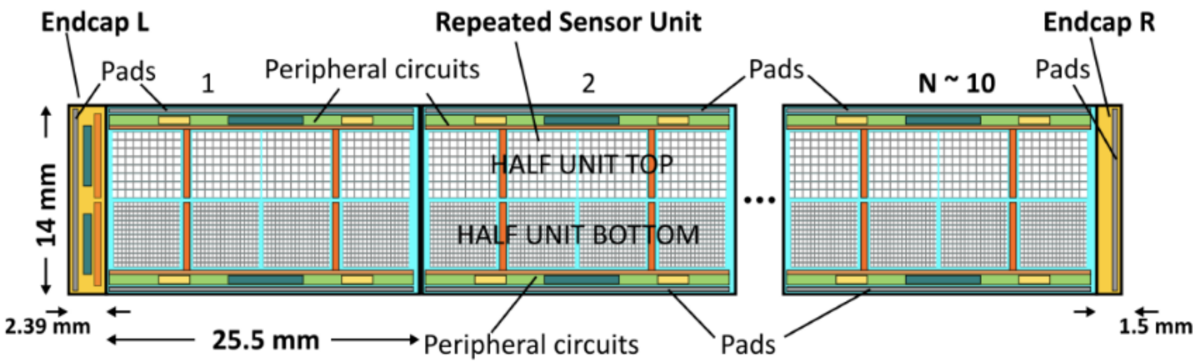


Figure B.3 - Sketch of the MOSS chip submitted to ER1 of ITS3 (late 2022), where one can identify the 10 sub-units of ($r\varphi$ x z) = (1.4 x 2.55) cm² repeated 10 times along the z axis. From [Mager-ICHEP22].

II.B - Global budget for the project (2019)

The following table B.2 is a 2022 update of the cost table that can be found in the [ITS3-LoI] from 2019 (Section 7, p.29, Tab.8). The typical figures to be updated concerns :

- the costs of a foundry run which now amount to 650-700x10³ $ per run, including post-processing like thinning and dicing (and not anymore 300-400x10³ $ like for the 180-nm technology node)
- 200-300 x10³ CHF/year for DAQ cards and tests
- *NB* : the beam pipe, initially part and parcel of the ITS3 budget (up to 1.5 million Swiss francs), will now be borne by the entire ALICE collaboration and therefore extracted from the ITS3 budget as such.

Table B.2 - Project cost estimate breakdown for the whole ITS3 project (kCHF). The *R&D* column concerns activities around MLR1, ER1 and ER2, while *Construction* relates to ER3. Partial update of the estimate are given here with respect to the Tab. 8 of the [ITS3-LoI] issued in 2019. Updates concern i) the rising costs around 65-nm Engineering Runs (foundry + tests) and ii) beam pipe R&D (600 kCHF) and construction (900 kCHF) costs, which are now taken out of the ITS3 project itself and will be covered by the ALICE collaboration as a whole. For explanation of what each line covers, please refer to Tab. 8 of the [ITS3-LoI]. Figures are based on the ALICE ITS2 experience.

Item	***R&D***	***Construction***	***Total Cost***
TOTAL	≈ 3450 *(LoI: ~~1900~~)*	≈ 2500 *(LoI: ~~3400~~)*	≈ 5950 *(LoI: ~~5300~~)*
Beampipe	*(LoI: ~~600~~)*	*(LoI: ~~900~~)*	*(LoI: ~~1500~~)*
Pixel CMOS sensors	3x700 = 2100 *(LoI : ~~600~~)*	700 *(LoI : ~~800~~)*	2800 *(LoI : ~~1400~~)*
Sensor test	3x250 = 750 *(LoI: ~~100~~)*	250 *(LoI: ~~150~~)*	1000 *(LoI: ~~250~~)*
Thinning & bending	200	300	500
Hybrid printed circuit	100	100	200
Mechanics	150	350	500
Assembly & test	50	200	250
Installation & alignment	-	200	200
Air cooling	100	150	250
Services	0	100	100
Patch panels	0	150	150

II.C - Institutional partners, committed or expected

To date, there is no Memorandum of Understanding available. The main partners expected would be, in order of expected commitments :

- CERN
- Italy (INFN+)
- France (IN2P3+)
- the Netherlands (NIKHEF, Utrecht)

- Korea (Inha, Yonsei, Pusan)
- Sweden (Lund)
- Norway (Bergen, USN Vestfold)
- Tchech Republic (Prague Univ, Prague National Academy of Sci)

- USA (Berkeley, BNL ? LNL ? Stanford ? if happening, it will be in good part linked with instrumental synergies found with EIC collider and/or Cool Copper Collider)

II.D - Project organisation (2022)

Project Leaders: Magnus MAGER (CERN) and Alex KLUGE (CERN)

Work Packages (https://indico.cern.ch/category/11668/)

- WP1 - Physics, Simulation and Reconstruction
  - Fabrizio GROSA (CERN), Andrea ROSSI (INFN Padova)
- WP2 - Pixel Sensor Design
  - Gianluca AGLIERI RINELLA (CERN), Walter SNOEYS (CERN)
- WP3 - Sensor Characterisation and Qualification
  - *Serhiy SENYUKOV (CNRS IPHC),* Miljenko SULJIC (CERN)
- WP4 - Thinning, Bending, Interconnection
  - Domenico COLELLA (INFN Bari), Giacomo CONTIN (INFN Trieste)
- WP5 - Mechanics and Cooling
  - Massimo ANGELETTI (CERN), Corrado GARGIULO (CERN)

III. - Workload and hardware/software contributions from IN2P3 teams

Note:

There is no existing ALICE memorandum of understanding associated with the ITS3 project, MoU on which the present proposal could hinge on. Moreover, the IN2P3 scientific council appears ahead of any official decision made locally (*e.g.* local scientific council) in the ITS3-concerned IN2P3 laboratories (IP2I, IPHC, LPSC). The content of the following sections is thus the result of ongoing discussions *i*) with the ALICE ITS3 management, *ii*) among teams attached to different IN2P3 labs, *iii*) teams within given labs and *iv*) with their respective lab directorates.

The ITS3, together with existing ITS2 and MFT projects of the ALICE experiment, respond to common interests of the IN2P3 teams from Strasbourg, Grenoble and Lyon altogether, around the physics of dense hadronic matter. The “joint” exploitation of these detectors will allow in Run 4 [2029-2032] to establish a coherent scenario of the physics of collectivity, combining the main research topics addressed by the groups, ranging from the study the response of the medium according to the quark flavours, the question of the meson vs. baryon productions, or the interaction between the created medium and the parton showers.

III.A - Motivations for an IN2P3 participation

IPHC

The IPHC groups (ALICE + C4Pi platform + PICSEL) wish to commit on the fronts of software, integration preparation and microelectronic design of 65-nm CMOS chips, depending on the team, for or in connection with the ITS3 project.

It should be noted in particular that, in close collaboration with the C4PI platform, the PICSEL team is leading a generic R&D program on MAPS, with a particularly strong commitment on the *new* "65-nm" technology node, in a joint effort with ITS3. ALICE-IPHC and PICSEL interests are converging, following the very similar specifications between the ITS3 detector and the vertex detectors for BEH boson factories (ILC, FCCee). As far as and as and as long as there are common interests and skills to be gained for the Higgs factory projects, the PICSEL team wishes to work in concert with the ALICE ITS3 project.

[On the software front]

- In a natural extension of the tracking and simulation expertise acquired along with the operation of ITS1 (more generally, ALICE-1) and also along the implementation of ITS2, working on similar issues for ITS3 proceeds with a natural logic for the ALICE team.
- Such developments will be coupled with the study of the physical performances of the ITS3, in particular concerning the reconstruction of mono-charmed and strange baryons with the concept of *Strangeness Tracking* (*e.g.* $\Omega_c^\circ \rightarrow \pi\ \Omega^-$), allowing the tracking of charged strange baryons $\Sigma^\pm$, $\Xi^\pm$ and $\Omega^\pm$ themselves (for explanation and illustration, [ALICE3-LoI], Section 3.2.1.3, p.65).

[On the front of electronic integration and micro-connectics]

The bending of sensors over small radii, the crampedness of the available space require advanced thinking on all the integration issues (mechanical structure, cooling by air flow, assembly, wiring, installation). For the IPHC, it is a question of approaching the aspects of electronic micro-connectivity, the interconnection between these large-scale sensors and the outside world; this is done in coordination with the CERN and Bari teams (as was done for ITS2).

[On the aspects linked to pixel chip design]

The very design of the sensors is the cornerstone of the ITS3 project, on the analog side, for the optimisation of the charge collection especially, and on the digital side, to set up all the necessary logic functions and processing within the sensor. The IPHC C4Pi platform is already involved (via some upstream generic R&D) but is particularly awaited by the ALICE collaboration in view of the coming engineering runs, ER2 in 2023 and ER3 in 2024 (see section [II.A - Project milestones] for the deadlines). The stakes are to undertake about half of the design efforts (approx. 8 FTE in total for the whole project), essentially along with the CERN design team (EP R&D WP1.2), as of late 2022-early 2023. As such, the participation of the IPHC is crucial and even considered vital by all the participants to the project.

This request comes as the load at the IPHC on the design of the MIMOSIS sensors (used by the CBM experiment at FAIR) will be on the downward path; it also comes in parallel with the design of the OBELIX chips for Belle2. For IPHC members, completing version 2 of MIMOSIS, carrying the design of both ITS3 and Belle2 chips appears as a workload proportionate to the workforces of the platform.

LPSC

[Mechanics for ITS3]

The mechanical department (SERM) of LPSC Grenoble contributed to the manufacture of large-scale molds for the production of composite parts for the ITS2 detector. It also participated in the design and production of an assembly tool for the units of the intermediate layer of the ITS2 detector.

The SERM would like now to join and work also in the ITS3 project. A precise definition of the SERM contribution to ITS3 project is currently being studied with the technical coordination of the ALICE Collaboration as well as with the ITS3 convenor for mechanical integration. It should initially focus on the production of composite mandrels for ITS3 prototype assembly. To this end, and more broadly, the SERM would rely on its mechanics workshop for the machining of dedicated parts. A second contribution could consist in the development of a monolithic bi-material air intake manifold for the ITS3 cooling. Such complex development would imply the manufacture of several prototypes with full-scale mockups. And finally, on the longer term, a contribution to the final detector integration and assembly tooling (with the help of the mockups already produced for the manifold development) is also envisaged.

[Readout electronic cards]

During the pixel chip design stage, the integrability of the chip in the system must be studied. The baseline plan of the ALICE collaboration is to reuse the existing Readout Unit designed for the ITS2. However, it is already known that the ASIC data rate will be increased by a factor of 5 for ITS3; some additional slow control functionalities will be added (particular sensor configuration, power supply management, …) which could potentially be managed with firmware improvements, but also with the redesign of transition boards between the sensor and the readout. Consequently, the aimed strategy is to get involved as soon as possible in the project and to provide a readout and system expertise for the ASIC digital design team. So in the early stage, and in agreement with the collaboration, we will contribute and also assess what are the requirements for the readout solution of the final ITS3.

From the current knowledge of the O^2 system (see the LPSC electronic department contribution described in Part A, section II.E - Online-Offline Common Readout Unit), the sensor readout integration in the global DAQ and the global triggering and timing scheme might be complex. As a consequence, the design of a new ITS3-dedicated *readout system* might be required. This new ITS3 readout would be fully in line with the sensor requirements yet to be precisely defined, but also with adequate intermediate processing capabilities. The milestone to have a clear answer for that is the ER2 stage of the project.

If we were to go for a combined new hardware/firmware design, we size the manpower contribution to about 3 FTE. In that case, in the prototype phase, we target the construction of about 3 to 4 readout boards. They are needed to equip the various laboratories involved in the sensor testing and characterization. Then, in a second phase, and depending on the unit price of electronics, we consider a contribution to the construction of the upgraded electronics. Depending on the sensor stitching efficiency, the readout unit count would typically be either 24 (only one side readout, over full sensor length that is *O*[27 cm] to handle 10 stitched chips) or 48 (two-side readout, half-length only, *O*[13 cm] to handle 5 stitched chips).

IP2I

The priority of the IP2I ALICE group for Run 3 and Run 4 is to ensure the operation of the MFT and the coordination of the associated physics program. This activity does not foresee the involvement of technical services, but requires the availability of the group members to ensure on-call duties in the ALICE control room at CERN.

In this context, the group's involvement in the ITS3 project remains a desired scenario, the precise framework of which must be defined before the end of 2022 with the ITS3 management and within the laboratory. This involvement could for instance materialize with the participation in the test of prototypes of the ITS3 sensors; this would enable the development within the IP2I's microelectronics department of the skills needed for an IP2I's active participation in future large instrumental projects using the technology of wafer-scale and ultra-thin CMOS sensors, the ALICE3 project being the one with the closest time horizon.

III.B - Budget requests to IN2P3

IPHC (among which C4Pi)

As a preliminary remark, the peculiar spending profile of the project should be borne in mind, especially in regard of the CERN contribution with time. CERN is limited in the fraction that it can invest in a collaborative project (<50% of the total), the bulk of the funds have already been invested for MLR1 (2021) and ER1 (2022). In the years to come (2023 with ER2 and 2024 with ER3), it will therefore be up to the ALICE partner institutes of the ITS3 project to share the financial burden of sensor submissions to Tower.
In the current thinking, a major fraction of the IN2P3 financial participation would be allotted to the submission of runs, this will amount to about 500-600k€ for the entire IN2P3 project (*i.e.* for the ALICE, PICSEL and C4Pi teams, summing ALICE R&D and upstream generic R&D).

Table B.3 - Overview on the budget requests for IPHC relating to the ITS3 project.

Object	year	budget request	Comment
Engineering Run 2	2023, 1 year	100 k€	(via the ALICE CERN tender with Tower)
Engineering Run 3	2024, 1 year	200 k€	(via the ALICE CERN tender with Tower)
Missions at CERN for design activities	[2023-2025] 3 years	15 k€	30+30 [2023+2024] +15 [2025] days at CERN

Budget for the characterisation and qualification (under beams) of sensor prototypes (including associated missions)	[2023-2026] 4 years	20 k€ (≈ 5 k€/year)	Contact person: Serhiy Senyukov (ITS WP3)
Integration (for CERN missions)	[2023-2026] 4 years	48 k€ ≈ 1 k€/week x 10-12 weeks/year	Contact person : Marc Imhoff
Final assembly	2025 or 2026, 1 year	8 k€ = a 2-month stay at CERN	
Equipments for R&D micro-connectics on bent sensors, of type SuperAlpide	[2023-2026] 4 years	40 k€ ≈ 10 k€/year	Contact person : Franck Agnèse

Note:

There exist and will exist in parallel accounting lines dedicated to generic upstream R&D with the "Circuit Exploratoire" CE65nm for the PICSEL/C4pi teams, such parallel budget comes aside the one presented in the table but would enter the gross total mentioned in the sub-section header for the budget invested by IN2P3 and will be recognised by the ALICE Collaboration.

LPSC

- On the mechanical aspects, the definition of a dedicated budget is being prepared. For 2023, a first estimate would amount to 15.8 k€ for manifold prototype manufacturing and the purchase of corresponding materials (Peek-ULTEM…). The purchase of a 3D printer dual-head for the manifold manufacturing may also be necessary on the long term but for initiating the project, the rental of a dual-head printer is the preferred option. 1.5 k€ were also requested in 2023 for travel expenses.
- For the electronic readout solution, the budget can't be defined yet, we expect to have a clearer view by mid-2023 (whether we need to produce new prototype readout boards, whether we aim to participate in the production).
    - Prototype part procurement would start either by end of 2023 or very early 2024, the most expensive component would be the FPGA (about 3k€ a piece => 12k€ for the production of 4 boards)
    - 4 board manufacturing and cabling would occur by early 2024 => 20 k€
    - Travel expenses : 5k€ per year
    - Production : to be defined after mid-2023.

IP2I

Decisive discussions are taking place in fall 2022.

III.C - Human-resource consequences for IN2P3

IPHC

- Chip design with C4pi : 3,5-4 FTE/year (estimates with an uncertainty of about ±0.5 FTE). Details of the distribution over the years as well as the share among analog and digital parts is listed in the table below.

Numbers of FTE/year	***Analog*** designers	***Digital*** designers
2^{nd} half 2022 (for ER1)	2	2
2023 (for ER2)	1.5	2
2024 (for ER3)	1	3

- Chip characterisation :
  - 0.5-1 FTE in 2023, then ≈ 1 FTE/year over 2 years [2024-2025] (C4Pi)
  - ≈ 0.5 FTE/year over 4 years [2023-2026] (PICSEL)
  - ≈ 0.2 FTE/year over 3 years [2023-2025] (2 months/year for lab tests at CERN on ER*x* sensors) (ALICE-IPHC)
- Integration and micro-connectics for bent sensors :
  - 1 FTE/year over 4 years [2023-2026] (C4pi)
  - 0.6-0.8 FTE/year over 6 years [2023-2028] (ALICE-IPHC)
- Simulation, reconstruction and physics performances :
  - 0.5-0.7 FTE/year over 7 years [2023-2029] (ALICE-IPHC)
- Project management
  - 0.1-0.5 FTE/year over 7 years [2023-2029] (ALICE-IPHC)

LPSC

- Electronics
  - Electronics system engineering : 1 FTE for 2 years, then decreasing to 0.5 FTE/year
  - Firmware design : 1 FTE for 4 years
  - CAD layout : 0.5 FTE for 3 years (or 1 year, if work limited to upgrade of transition board)
- Mechanics
  - 0.4 FTE (+ workshop manpower)
  - a 6-month draughtsman (AI-level) short-term contract would also be required

IP2I

To be defined according to the outcome of the aforementioned discussions.

IV. - Physics analyses considered among IN2P3 teams

- **Heavy quarks (*c,b*) facing collectivity (IPHC, IP2I)** :

  - measuring total cross-section of charm production for p_T>0 and $y \approx 0$ [mesons and baryons : D^0(*cu*), D^+(*cd*), D_S^+(*cs*), Λ_C^+(*udc*) and quarkonia *cc* [η_C, J/ψ, ψ(2S), χ_{Cj} ...]
  - exploring of baryons that are single-charmed (and strange in addition) [Λ_C^+(*udc*), Ξ_C^+(*usc*), Ξ_C^0(*dsc*), Ω_C^0(*ssc*)] and beautiful baryons [Λ_B^0(*udb*), …]. The objective is especially to inspect the hadronization of charmed quarks (recombination mechanisms) and their sensitivity to the medium (hydrodynamisation, chemical equilibration, thermalisation / transport coefficients) in the quark-gluon plasma. Such an objective requires a drastic increase in the significance of the reconstructed signal and in the spatial precision (on the impact parameter of track, in particular) to reconstruct increasingly complex decay topologies, typically ranging from 2 to 6 bodies.

- **Interactions between hard partons and with medium constituents (LPSC, IPHC)** :

  - assessing intra-jet modifications (jet shapes, jet structures, reconstructed using charged particles) with reduced systematic uncertainties (say <10%), thanks to high granularity and access to the tracks that make up the jets down to low p_T^{track}.
  - studying the interplay between jets and the surrounding underlying event in the collision, in pp and in AA systems.
  - in the longer term, accurate flavour-tagging di-jets (*i.e.* complete topological reconstruction of heavy mesons and baryons within the jets) for measurements on the energy losses of charm and beauty as a function of multiplicity/centrality.

- **Correlations between rapidity domains (IP2I, IPHC, LPSC) :**

  - Exploiting the correlation between the information from the ITS3 (mid-rapidity) and the MFT (forward rapidity), in order to characterize and map the event activity over a large *y* range, and over the whole gamut of collisions delivered by the LHC, from proton-proton collisions to Pb-Pb collisions.
  - Using the data from the ITS3 and the MFT will also make it possible to establish a separation in phase space between the measurement of the heavy-flavour signals and that of the underlying event, casting a specific light on possible collective effects involving charmed and beautiful quarks.

V. - SWOT analysis

Strengths:

- The expertise of the French community (MAPS chip design, readout electronics, integration, tracking, data analysis) is known, identified and recognised within the ALICE Collaboration. It is based on more than a decade of skills and knowledge that have been developed and nurtured along ALICE operation and evolutions.
- A fraction of the interested people has approached the ITS3 project since its early stage in 2019. The persistent close contact with main players gives to the French community a valuable reading of the situation.

Weaknesses:

- Undertaking the next upgrade while the ALICE-2 experiment after Long Shutdown 2 is not yet fully mastered (brand new experiment, especially with the completely renewed strategy for a triggerless readout) is a difficult task. The multiplication of the open fronts (exploiting the past detector outcome in terms of physics, run and comprehend the current experiment, prepare the next version of it) is rather expected for any mature experiment as now ALICE is; it remains nonetheless a challenge for the collaboration and for the individual groups and members.
- The ITS3 project is intrinsically a challenge on its own, since it cannot rely on solidified and well-established detector solutions. It has to opt for a challenging solution to move ahead decisively, and the success of the enterprise was not granted when it was first proposed. In 2022, even if the R&D progress has already shed very positive lights on the problems to be met, the project will remain a continuous defy till its finalization, vulnerable to "known unknowns" revealing as bottlenecks (*e.g.* stitching Vs foundry yields).

Threats:

- The roadmap of the ALICE Collaboration as a whole is rather clear, for LHC Run 3 [2022-2025], Run 4 [2029-2032] and even beyond (ALICE3 proposal). The role that ALICE France could play in the ITS3 adventure has to be defined at various levels : by the individual teams themselves, by the corresponding laboratories, and by the IN2P3 direction. A delay in our common decision making for a participation could lead us to miss decisive milestones of the project (*e.g.* ER1); this would be detrimental to the visibility that we would like to gain in the project and the know-how that we would like to nurture along the various steps. We are on time but we may not afford any adjournment.
- Human resources could be under tension with years passing by:
    - LPSC : in the electronic department, there have been several retirements over the last years and will continue in the years to come.
    - IPHC C4pi : 1 retirement in 2022-08 (BIATSS Unistra) and 2 retirements to come in early 2025 (head of the platform)
    - IP2I : the ALICE team is reduced to 2 permanent CNRS after fall 2022.
    - The ageing effect concerns also for the ALICE teams in the two other laboratories, for IN2P3 ALICE teams in general.

- The ongoing tension on the silicon market casts some uncertainty on the supply timeline and costs. It does not concern so much the outcome of the foundry, but rather possibly the "peripheric" silicon, like FPGA and electronic components needed for readout cards.

Opportunities :

- Quite some key opportunities relate to technical aspects and skills to be fostered via ITS3 for the IN2P3 :
    - ITS3 will be a unique opportunity in the decade to come to tackle and master the 65-nm technology node for a "large"-scale project in HEP, paving the road towards silicon tracker of next generations, not only for ALICE but also other experiments (ALICE 3 at the LHC or the experiments foreseen at future facilities like FCC-ee and ILC)
    - Along a similar line, ITS3 will be an effective test bench for mastering specific techniques of general interest, that are active-silicon bending and stitching at the wafer level.
- The effectiveness of ITS3 detector will open unprecedented physics roads for the ALICE collaboration. The detector will be more accurate spatially, closer to beam interaction point and lighter than the already improved ITS2 inner layers. This will enable better efficiency, while keeping fake hit rate under control, better determination of distance of closest approach. Those aspects are for instance vital for a better characterisation of the event activity and for studies related to the heavy-flavour sector in QCD. Event multiplicity, jet activity, strangeness, charm and beauty will be at the core of the programme for the French community, in particular, but more generally for the whole ALICE collaboration in Runs 3 and 4. This will maintain IN2P3 on high grounds, with acute visibility, at the forefront of the LHC experiment.

Selected references

Related to Long Shutdown 2 [2019-2021] and Run 3 [2022-2025]:

[**ITS2-TDR**] ALICE Collaboration, *Upgrade of the Inner Tracking System - Technical Design Report*
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CERN-LHCC-2013-024 ; ALICE-TDR-017
url : https://cds.cern.ch/record/1625842
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[**VCI-2016**] Gianluca Aglieri Rinella (for the ALICE Collaboration), *The ALPIDE pixel sensor chip for the upgrade of the ALICE Inner Tracking System*
Nucl. Inst. Methods A, VCI 2016, **2017**, *845*, 583-587.
doi : https://www.doi.org/10.1016/j.nima.2016.05.016

[**MFT-TDR**] ALICE Collaboration, *Muon Forward Tracker - Technical Design Report*
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url : http://cds.cern.ch/record/1603472

[**O²-TDR**] ALICE Collaboration, *Upgrade of the Online-Offline Computing System - Technical Design Report*
CERN-LHCC-2015-006 ; ALICE-TDR-019
url : http://cds.cern.ch/record/2011297

Related to ITS3 :

[**ITS3-LoI**] ALICE Collaboration, *Letter of Intent for an ALICE ITS Upgrade in LS3*, Dec. 2019.
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[**BentAlpide**] ALICE ITS project, *First demonstration of in-beam performance of bent Monolithic Active Pixel Sensors*
Nucl. Instrum. Methods A, **2022**, 1028, 166280.
eprint : https://arxiv.org/abs/2105.13000
doi : https://www.doi.org/10.1016/j.nima.2021.166280

[**ALICE3-LoI**] ALICE Collaboration, *Letter of intent for ALICE 3: A next generation heavy-ion experiment at the LHC*
CERN-LHCC-2022-009 ; LHCC-I-038
url : https://cds.cern.ch/record/2803563

Appendix α - Persons (to be) involved in the ITS3 project

For the ALICE ITS3 part, to give a glimpse of the human workforce potentially involved, you will find below specific signatories. It lists the three ALICE-IN2P3 teams concerned but also persons from technical departments (electronics, mechanics, platform, …) within IN2P3 laboratories.

How to read this list ? A few guidance comments are given below :

1. *For physicists of the ALICE teams, provisional dates of retirement before the end of Run 4 [2029] are mentioned where applicable. A similar exercise is also ongoing among the technical teams but is not yet carried to its end for any team, any laboratory.*
2. *Any percentage number indicated in parentheses corresponds to an early estimate of the fractional time already invested and/or to be invested into the ITS3 project, when already known. When a percentage range is quoted, it corresponds to estimates adapted to the project period as a function of its stage.*
3. *Conversely, the mention of people with no percentage next to their names is the mark of a current interest by such persons, but without being in position to quantify their degree of commitment (various hypotheses are on the table, influencing in different extent their respective involvement).*
4. *Among the signatories, contributors in grey are persons who have already identified technical aspects to contribute to.*

IPHC :

- team ALICE : Iouri BELIKOV (50-75%), Boris HIPPOLYTE (15-25%), Christian KUHN (20%), Antonin MAIRE (40-80%), Fouad RAMI (retired 2023-12), Christelle ROY, Yves SCHUTZ (retired 2019, emeritus)
  - + Marc IMHOFF (80%)
  - + (doctorants: Alexandre BIGOT, Romain SCHOTTER, Yongzhen HOU, Yitao Wu)
- team PICSEL : Auguste BESSON (5%), Ziad El Bitar (5%), Serhiy SENYUKOV (30-50%)
- platform C4π : Jérôme BAUDOT, Claude COLLEDANI, Christine HU (15%), Frédéric MOREL (50-70%),
  . design CMOS : Andrei DOROKHOV (70%), Xiaochao FANG (100%), Thanh Hung PHAM (15%), Isabelle VALIN (15%), Grégory BERTOLONE (20%), Abdelkader HIMMI (15-50%)
  . microconnectics : Franck AGNESE (40%), Olivier CLAUSSE (30%), Christophe WABNITZ (30%)
  . tests : Kimmo JAASKELAINEN (50-100%),
  - + (doctorants: Jean SOUDIER (50%), Corentin LEMOINE (>50%))

IP2I :

- team ALICE : Cvetan CHESHKOV (15-25%), Brigitte CHEYNIS (retired 2022-11), Antonio URAS (15-25%)
  - + (doctorante: Sarah Herrmann)

LPSC :

- team ALICE : Gustavo CONESA BALBASTRE, Julien FAIVRE, Christophe FURGET (retired ≥2027), Rachid GUERNANE (40-80%)
  - + (doctorants: Carolina ARATA, Takuya KUMAOKA)
- electronic department :

. firmware and electronic system : Olivier BOURRION
. Computer-Aided-Design layout : Jean-Luc BOULY
. card conception and integration tests : Damien TOURRES

- mechanical department SERM :
  . mechanics design : Denis GRONDIN (10%)
  . drafting : Francis VEZZU (20%)
  . mechanics workshop : Sébastien ROUDIER (10%)

Appendix β - Selected performance plots from the upgraded detector commissioning

This Appendix includes a selection of performance plots from the detector commissioning during 2022. All plots are part of the Online Quality Control monitoring tool.

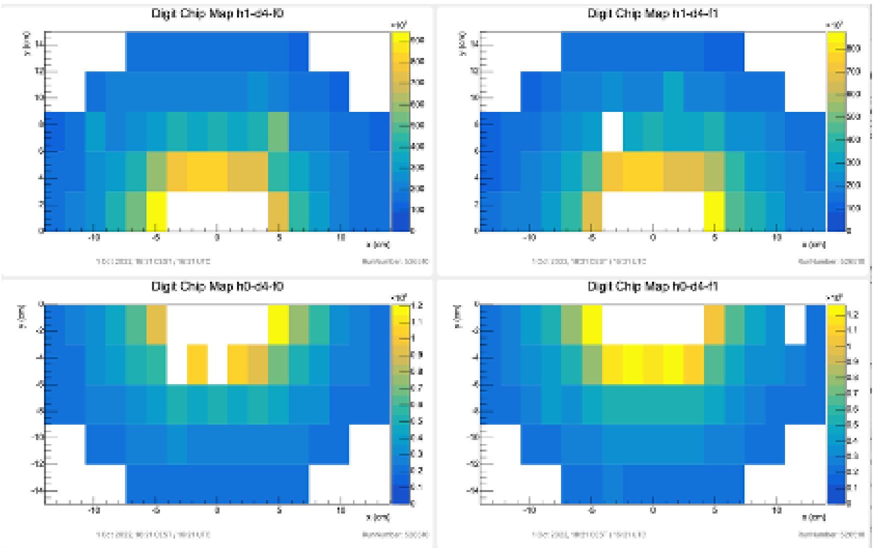

Figure β.1 - **MFT** DIgit Occupancy of the disk 4 (the furthest disk from interaction point), top and bottom half-disk, both faces. The Digits are reconstructed online. The occupancy is radially increasing with respect to the beam position, as expected. The 4 white squares indicate problematic ALPIDE chips. These plots are part of the Online Quality Control Monitoring. The example displayed here was collected during a 1-MHz data taking.

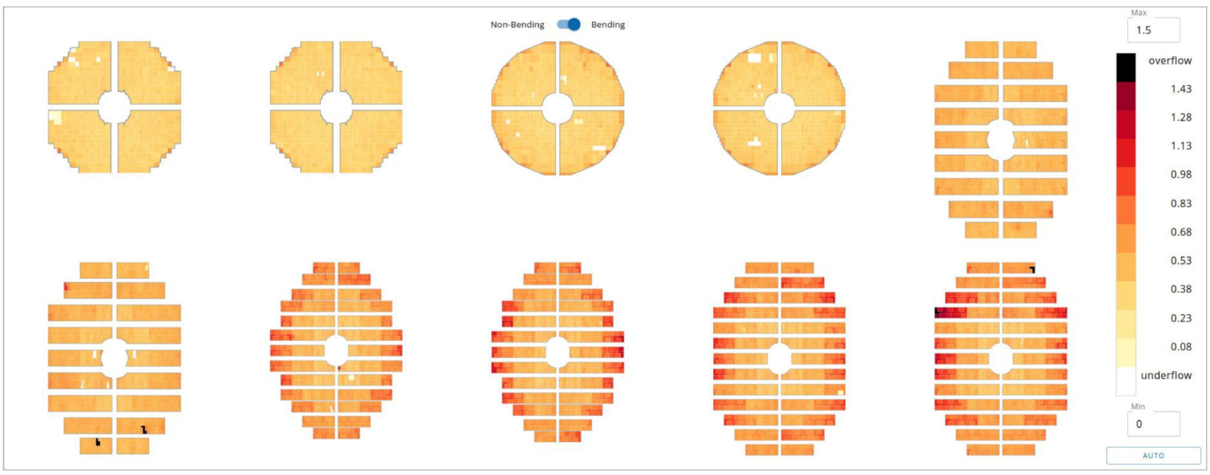

Figure β.2 - **MCH** noise measurement. All channels noise is below 1.5 ADC which is excellent. This graphical tool, MCH Viewer, was developed by Subatech.

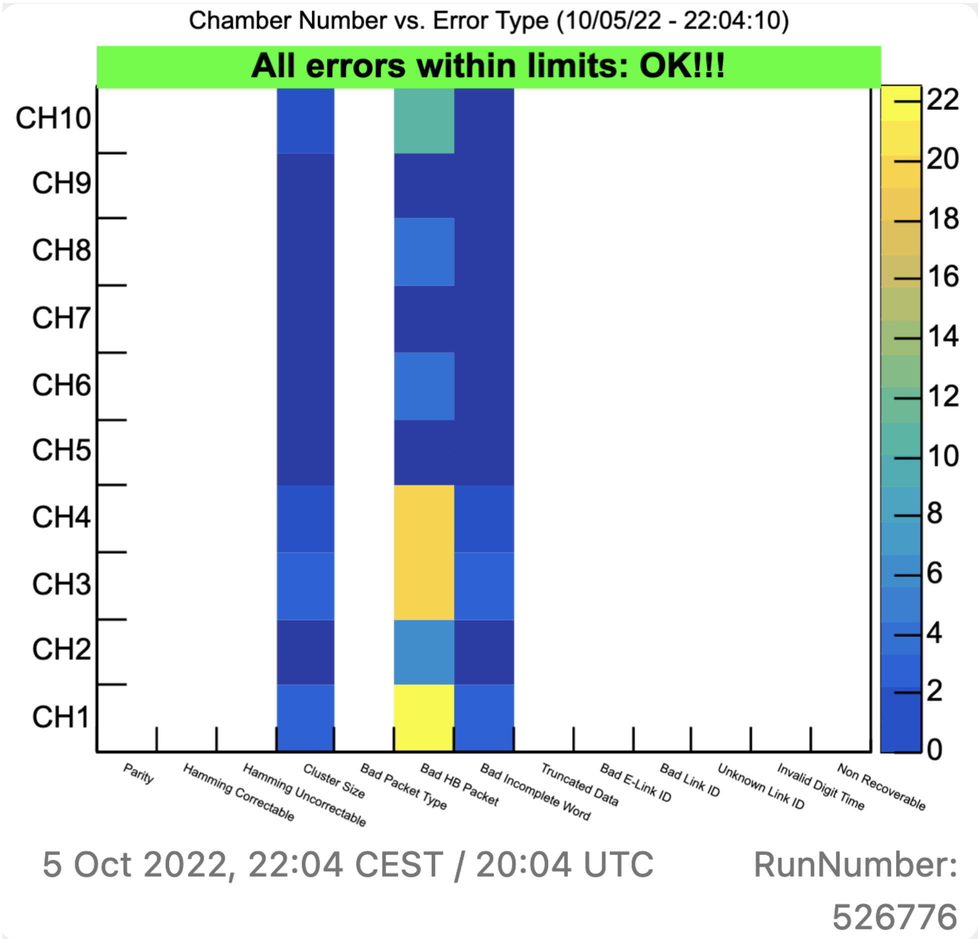

Figure β.3 - **MCH** online quality monitoring of number errors for each chamber per run type.

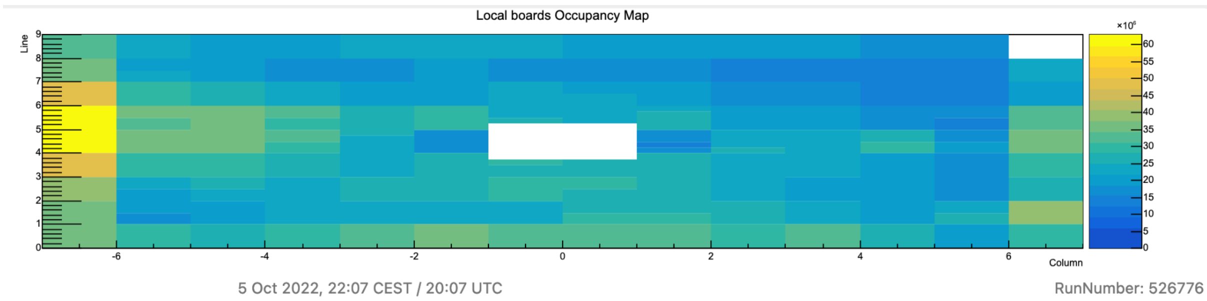

Figure β.4 - **MID** online quality monitoring of local-board occupancy map.

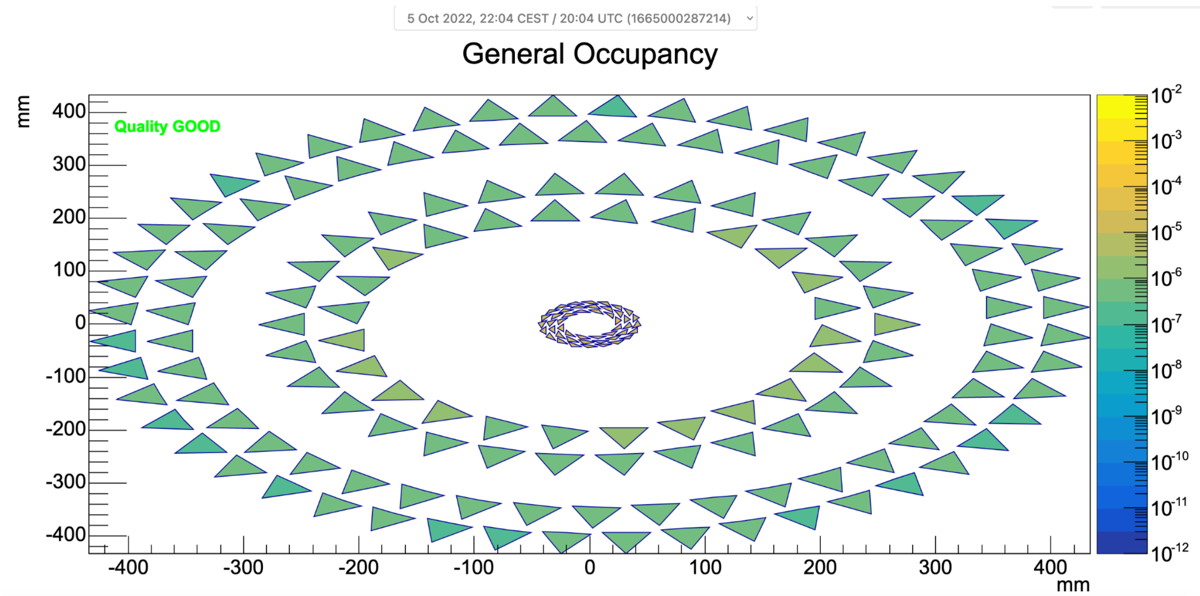

FIgure β.5 - **ITS2** online quality monitoring of ALPIDE chip occupancy.

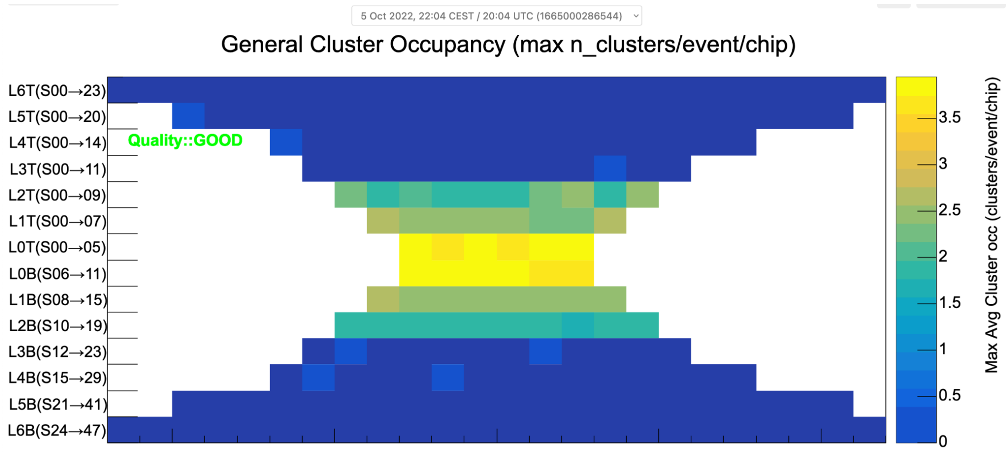

Figure β.6 - **ITS2** online quality monitoring of reconstructed cluster occupancy per layer.

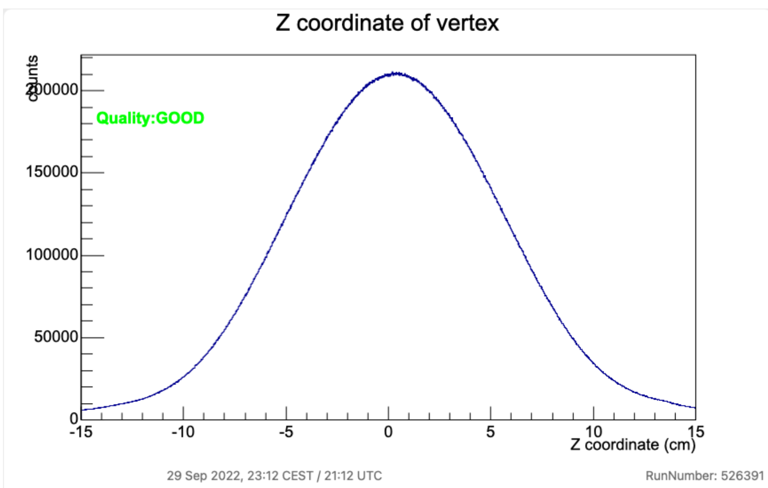

Figure β.7 - **ITS2** online quality monitoring of the position of the collision vertex along *z* axis.