# **Abstract**

Recent developments in Monolithic Active Pixel Sensors (MAPS) have made it possible to have sensor designs with high readout speed, fine granularity, minimal material interaction length, and low power consumption, all at relatively low cost. The latest generation of MAPS sensors, developed for the particular application of the ALICE detector at the LHC, could also be well suited for a possible upgrade to future detectors at Relativistic Heavy Ion Collider (RHIC) or a future vertex detector in an Electron Ion Collider (EIC), given the very low material budget, excellent vertex resolution and the possibility of high-speed readout at very high collision rates.

The ALICE-USA group of research institutions, together with the ALICE collaboration, have developed this state-of-the art silicon-based technology to be used for the ALICE Inner Tracking System (ITS) in future runs of the LHC.The key components of this technology are being built at CERN for the ALICE inner tracking system, with the possibility of building additional components for other applications.

Brookhaven National Laboratory (BNL) is very interested in aquiring this silicon technology as part of the effort to develop modern silicon detector capabilities for future use in a potential Electron Ion Collider detector, or possible upgrades to detectors at the Relativistic Heavy Ion Collider, given the excellent tracking capabilities in a high rate/high radiation environemnt.

The purchase of this technology from CERN will provide a cost-effective way to obtain key parts of a state-of-the art inner tracking system without the additional cost and time required for an independent development and construction of such a system. It is also a purchase that is time critical because CERN is currently producing the ALICE ITS components of interest, and it may be significantly more expensive or even impossible to produce these components in the near future due to the redirection of production facilities to other tasks at CERN.

We propose to purchase from CERN the key components developed for the ALICE Inner Tracking System. Because the ALICE-USA group of research institutions have developed the key expertise and technology, it is a natural extension of the ALICE-USA BTU grant to apply for the supplemental funding to buy such components from CERN. The University of Tennessee is a member of the ALICE collaboration, the sPHENIX Collaboration and a potential collaborator on a future EIC experiment.

# **2 Proposal**

# **2.1 Overview**

The state of the art technology developed for tracking in heavy ion collissions at the ALICE experiment is based on the latest Monolithic Active Pixel Sensor (MAPS) technology. The basic unit of detection, the stave, consist of nine MAPS sensors (ALPIDE version) glued and wire bonded to a Flexible Printed Circuit that provides bi-directional signal paths for configuration and control, signal paths-out for data, and the necessary power and ground connections. The Flexible Printed Circuit is mounted onto a carbon fiber cold plate that contains embedded cooling tubes. The structural strength of the stave is provided by the use of a carbon fiber truss structure that supports the cold plate. The sensors are thinned to 50 um and arranged in a linear array covering approximately 15 mm x 270 mm of active area with 1024 rows x 512 columns of pixels per sensor giving approximately 4.5M pixels per stave.

The readout system for the staves will use the radiation hard Readout Units (RUs) also developed for the ALICE ITS upgrade.

This proposal would allow for the purchase 84 staves, similar to the ones in production for the ALICE ITS, for use in a future detector either at RHIC or EIC, and 60 Readout Units.



Figure 1 Assembled ALICE ITS stave showing the top and bottom views with the space frame visible in the upper stave. Flex power extension cables are not shown.

## **2.2 Staves Technical Details**

The complete detector element, stave, that has been developed for the ALICE Inner Tracking System Upgrade contains the following main components:

* **Space Frame**: a carbon fiber structure providing the mechanical support and the necessary stiffness;
* **Cold Plate**: a sheet of high thermal-conductivity carbon fiber with embedded polyimide cooling pipes, which is integrated into the Space Frame. The Cold Plate is in thermal contact with the Pixel Chips to remove the generated heat;
* **Hybrid Integrated Circuit**: an assembly consisting of a polyimide Flexible Printed Circuit (FPC) on which nine Pixel Chips and some passive components are bonded. The flex power extension cables will be modified to extend their length from 15 cm to 40 cm long for better adaptability to potential future detectors.

Detailed technical specifications of the staves for the ALICE ITS Upgrade, including construction, assembly and qualification procedures can be found at the following link:<https://indico.cern.ch/event/631636/>.

## **2.3 Readout Units (RU) Technical details**

The main component of the new readout system for the ALICE ITS Upgrade are the Readout Units (RU). It is a radiation tolerant electronic board, which provides detector data readout, control, and triggering. It supports up to 28 input high-speed electrical links (at 400Mbit/s, 600Mbit/s or 1.2 Gbit/s) and 3 output (and 2 input) optical links for a total bandwidth of 10 Gbit/s. The board is based on Commercial Off–the-Shelf (COTS) components as well as radiation hard custom-made components to drive the optical links, the so-called GBT chip set, developed by CERN.

Detailed technical specifications of the Readout Unit for the ALICE ITS Upgrade, including technical drawings, characterization procedures and results can be found at the following link:<https://indico.cern.ch/event/698929/>.

## **2.4 Testing, Shipping, and Acceptance**

The Stave and RU Testing, Shipping, Acceptance/Detector Construction are the responsibility of LBNL and UT-Austin, respectively. The stave and RU production will be carried out at CERN under the supervision of the ALICE ITS technical staff there. Any quality problems identified will be resolved by consulting with the ALICE ITS upgrade project manager, and silicon experts at BNL and LBNL.

The ALICE/CERN Team, which is responsible for the construction of the staves for the ALICE ITS Upgrade, will

* build and test 84 ALICE ITS Staves, which meet the ALICE Gold/Silver QA standards; Only staves that are fully qualified with Gold/Silver will be invoiced.
* build 60 ALICE ITS Readout Units (fully assembled motherboards only);

and supply them to Brookhaven National Laboratory (BNL) as components of a future silicon vertex detector.

Detailed Detector-Specific Quality Assurance Plans (DQAP) have been developed for stave and RU production.

### **2.4.1 Staves testing, shipping and acceptance**

LBNL will be the responsible organization for shipping and implementing the QA requirements for all staves delivered from CERN

At CERN, all relevant stave QA parameters related to the assembly, electrical bonding, metrological analysis, thermal and electrical tests of each fully assembled stave, as well as of each individual component (pixel chip, support structure, electrical substrate, etc.) will be stored in the ALICE construction database, to which BNL will be granted access for its information purposes.

Staves will be hand-carried from CERN to LBNL with special containers being designed by LBNL and CERN engineers. After receiving staves, LBNL personnel will perform the same ALICE ITS upgrade stave QA procedures to check the integrity of all 84 staves, and log all relevant parameters into a database. Additional stave QA procedures will be developed, as necessary, if early production experience indicates they are warranted. Similarly, the QA procedures listed herein may be modified or improved, as experience dictates. All such additions and modifications will be captured in a formal revision to the DQAP for the staves.

### **2.4.2 Readout Units testing, shipping and acceptance**

The Readout Unit module consists of a motherboard, mezzanine interface boards for power and signals, and a cooling plate. ALICE CERN Team will procure fully assembled motherboards, without mezzanine interface board and without cooling plate, and will make them available to BNL untested.

UT-Austin Physics will be the responsible organization for shipping and implementing the QA requirements for all Readout Unit production activities through completion of testing and subsequent shipment to BNL. After receiving RUs at Univ. of Texas at Austin, UTA personnel will perform the same ALICE ITS upgrade RU QA procedures to check the integrity of all 60 RUs, and log all relevant parameters into a database. Additional Readout Unit production QA procedures will be developed, as necessary, if early production experience indicates they are warranted. Similarly, the QA procedures listed herein may be modified or improved, as experience dictates. All such additions and modifications will be captured in a formal revision to the DQAP.

## **3 Budget and Budget Explanation**

List and Cost of CERN Deliverables for future silicon vertex development at BNL, plus additional Expenses

* 84 Pixel Staves = 11850 CHF/units, 84 units = **995400 CHF**
* 84 Pixel Stave flexible power cables, with a length extension from 15 cm (ALICE) to 40 cm (BNL), has an extra total cost = **14000 CHF**
* 84 stave carrier/storage plates = 238 CHF / unit \* 84 units = **20000 CHF**.This carrier plate will be a modified version of the one used for ALICE. The modification is needed in order to accommodate the length extension of the flexible power cable. The cost quoted above includes the design change, the development and qualification of a prototype and the production of 84 units.
* 60 Readout Units = 2500 CHF/unit ∗ 60 units = **150000 CHF**

All costs are net, with no taxes and custom duties included. CERN will not cover any taxes and custom duties. All costs are FOB CERN. CERN is not responsible for the transport of the CERN contributed items from CERN to BNL. CERN will not cover any associated transportation costs, including the development of suitable transport boxes and packaging.

**UTK management Cost**

Dr. Tom Cormier will work on this project 10% of his time for a 12-month period. As a Joint Faculty Member with home institution at ORNL, he is required to charge the appropriate part of his work effort to this project in accordance with the “Guide for ORNL Joint Faculty (JF) Participating in University Proposals”. The salary is based on the ORNL JFO Wage Pool.

**F&A**

For the salary for Tom Cormier we will use the on-campus rate of 51% in accordance with the “Guide for ORNL Joint Faculty (JF) Participating in University Proposals”.

The ITS system is complete integrated piece of research equipment that will be purchased from CERN. We are therefore requesting that it will be treated as capital equipment for F&A calculations.

|  |  |  |
| --- | --- | --- |
| **Proposal Budget \*** | **CHF** | **USD** |
| **Readout Units** | **150,000** | **$151,254** |
| **Staves** | **995,400** | **$1,003,722** |
| **Power extension cables** | **14,000** | **$14,117** |
| **Modified fixtures for assembly** | **20,000** | **$20,167** |
| **Total Capital Equipment Cost for ITS system** | **1,179,400** | **$1,189,260** |
| **UTK management cost** |  | **$30,290** |
| **USD/CHF exchange rate fluctuation 10% of Capital Equipment Cost (Contingency)** |  | **$118,926** |
| **Total (before F&A)**  |  | **$1,338,476** |
| **F&A (51% of Management Cost)** |  | **$15,448** |
| **Total Requested Amount** |  | **$1,353,924** |

 **\*** Calculated using 1 CHF = 1.00836 USD

# **4 Biographical Information**

**Tom Cormier (PI):** Tom has participated in search for and study of Quark Matter from the earliest experiments in the ultra-relativistic energy regime at the Brookhaven AGS: Experiments E814, E877 and E866. In the latter experiment he was the project leader of the large Hadronic Calorimeter that enabled a very sensitive search for neutral strangelets and provided other rare, high mass, triggers. He was one of the founding member of the STAR experiment at the Relativistic Heavy Ion Collider (RHIC) where he was the project leader of the Barrel Electromagnetic Calorimeter and lead the group that developed the methods for heavy ion jet physics and single, non-photonic, electrons for heavy flavor physics. Currently, as a member of the ALICE experiment he is project leader of the ALICE Electromagnetic Calorimeters and the Barrel Tracking Upgrade Project. The former was constructed and available for LHC Run-1 and provides the high PT trigger and jet, electron and photon analysis for the experiment, while the latter is under preparation for high luminosity running in LHC Run-3.

**Soren Sorensen (Co-PI):** Soren has done most of his research within the WA80/93/98 collaboration (transverse energy production, nuclear stopping power, etc.), the PHENIX collaboration (Muon Arm system, responsible for offline computing, heavy flavor physics), and the ALICE collaboration. During the period 2013-2015 he was Coordinator of ALICE-USA and is now chair of the ALICE-USA Council. His research within ALICE has been focused on a) heavy flavor suppression at high pt as measured through single electrons from open heavy flavor decay, b) transverse energy production, and c) the construction of Inner Read-Out Chambers (IROCs) for the upgrade of the TPC.