Monitoring Quality of ATLAS ITk Strip Sensors/wafers through Database

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Abstract

High-Luminosity LHC upgrade necessitated a complete replacement of the ATLAS Inner Detector with a larger all-silicon tracker. The strip portion of it covers 165 m^2 area, afforded by the strip sensors. Following several prototype iterations and a successful pre-production, a full-scale production started in 2021, to finish by the beginning of 2025. It will include over 20,000 wafers and a factor of 5 higher throughput than pre-production, with about 500 sensors produced and tested per month. The transition to production stressed the need to evaluate the results from the Quality Control (QC) and Quality Assurance (QA) tests quickly to meet the monthly delivery schedule. The test data come from 15 collaborating institutes, therefore a highly distributed system with standardized interfaces was required. Specialized software layers of QA and QC Python code were developed against the backend of ITk database (DB) for this purpose. The developments included particularities and special needs of the Strip Sensors community, such as the large variety of different test devices and test types, the necessary test formats, and different workflows at the test sites. Special attention was paid to techniques facilitating the development and user operations, for example creation of "parallel" set of dummy DB objects for practice purpose, iterative verification of operability, and the automatic upload of test data. The scalability concerns, and automation of the data handling were included in the system architecture from the very inception. The full suite of functionalities include data integrity checks, data processing to extract and evaluate key parameters, cross-test comparisons, and summary reporting for continuous monitoring. We will also describe the lessons learned and the necessary evolution of the system.

INTRODUCTION

ITk DB is a flexible online DB implemented as a cloud-based application. It has a user interface and API, which is based on REST [1)] API. The DB allows customization of the object types/properties/tests/stages for each ITk component. The complete setup is the responsibility of each activity area. We describe here a development for Strip Sensors.

DB interactions permeate nearly all actions the community performs with the sensors:

- Reception => registration + Vendor data upload
- Shipment => Shipment in DB, shipment reception
- QC tests => test results analysis/reporting, upload
- QA tests => test results analysis/upload, reporting
- Reception approval => QA and QC summaries/reporting, upload
- Trends, correlations => DB reporting
- Production reporting => DB reporting

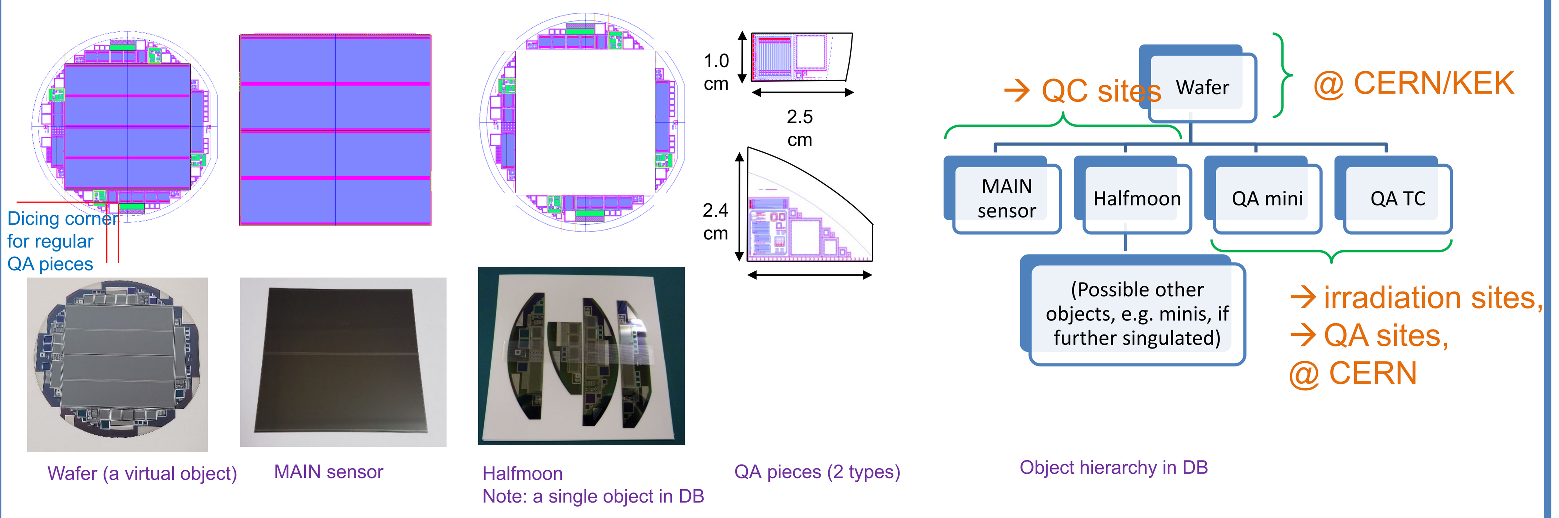
The DB infrastructure should map well to the real-world usage to be workable.

[1)] ***RE****presentational* ***S****tate* ***T****ransfer (REST) is a web architectural style (see https://restfulapi.net/)*

DB OBJECTS

Anticipate ~125,000 objects by the end of the project.

Wafer pieces:



The vendor (HPK) creates their test files before shipping them to ATLAS => The DB serial numbers are assigned before the objects are created in DB => Allocated the address space and encoded the different pieces and sensor types.

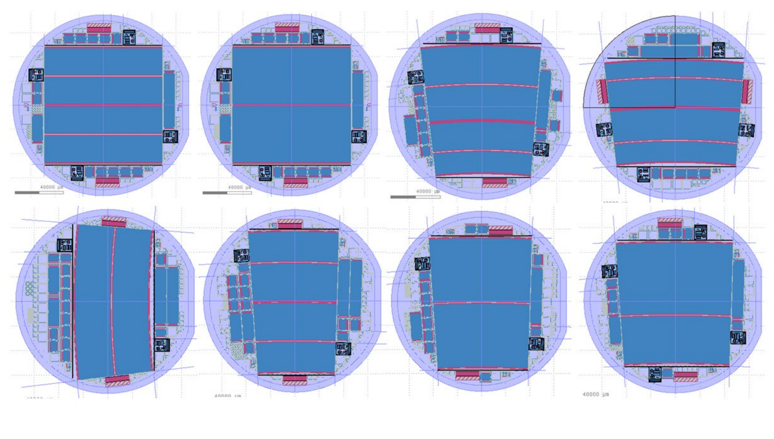
A production LS type wafer number 13567 would have the following objects since it arrives from HPK:

- 20 U SB SL 0 **5** 13567 (Sensor Wafer)
- 20 U SB SL 0 **0** 13567 (Main sensor)
- 20 U SB SL 0 **9** 13567 (Halfmoons)
- 20 U SB SL 0 **1** 13567 (Mini & MD8 QA piece)
- 20 U SB SL 0 **7** 13567 (Test Chip & MD8 QA piece)

If the wafer is further diced there will be new objects like:

- 20 U SB SL 1 **4** 00335 (Mini), *and so on.*

There are 8 sensor types, with different layouts for the final design that went into pre-production and production [1]. In the example above, SL is for "Long Strip" type. For "Short strip" it would be SS, for R2 type it would be S2, etc.



For each object type, we created a "shadow"/dummy analog to enable the development and practice of DB uploading and reporting.

Dummy Types (*_TEST)

Object type	DB handle	Alternative reference
Wafer	SENSOR_WAFER	VPXnnnnn-Wnnnnn-WFR
Sensor W test	SENSOR_W_TEST	VPXnnnnn-Wnnnnn-WRT
Sensor	SENSOR	VPXnnnnn-Wnnnnn
Sensor S test	SENSOR_S_TEST	VPXnnnnn-Wnnnnn
Sensor Halfmoons	SENSOR_HALFMOONS	VPXnnnnn-Wnnnnn-HFM
Sensor H test	SENSOR_H_TEST	VPXnnnnn-Wnnnnn-HMT
Sensor Testchip&MD8	SENSOR_TESTCHIP_MD8	VPXnnnnn-Wnnnnn-TCM
Sensor QAchip test	SENSOR_QCHIP_TEST	VPXnnnnn-Wnnnnn-TCT
Sensor Mini&MD8	SENSOR_MINI_MD8	VPXnnnnn-Wnnnnn-MIM
Sensor QAmini test	SENSOR_QAMINI_TEST	VPXnnnnn-Wnnnnn-MIT

Sensor Registration

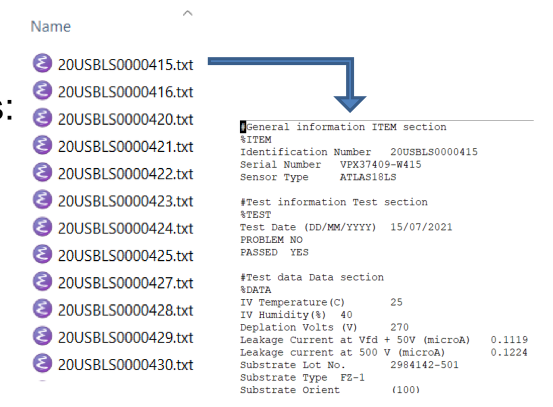
Due to the large number of objects, GUI approach is not viable. Instead, automated scripts take in the vendor data (text files) and perform several tasks:

- Parse the directory with serial numbers.
- Register the full wafer/MAIN/halfmoons/QA pieces hierarchy
- Upload the HPK test data

To avoid interference, this is only performed by the sensor reception sites (CERN and KEK), when they receive new deliveries.

With experience, added extra features:

- Input data integrity verification (also as a stand-alone check).
- Re-uploading the data in case of changes.



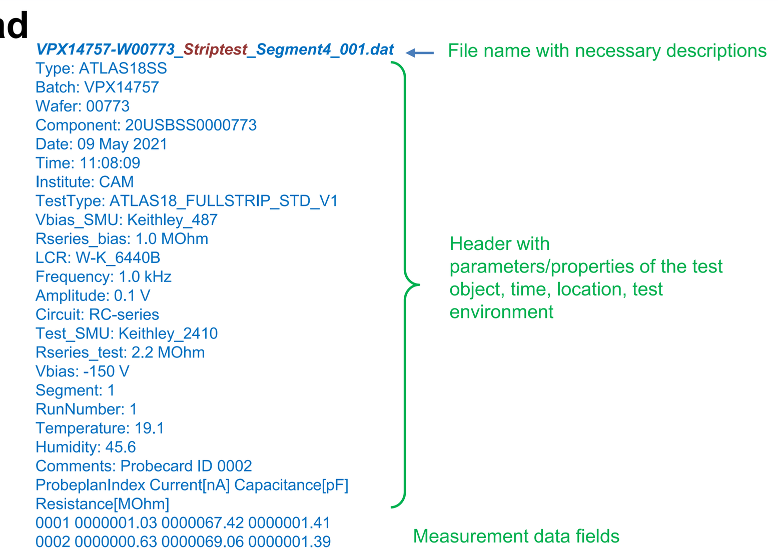
Test Data and Upload

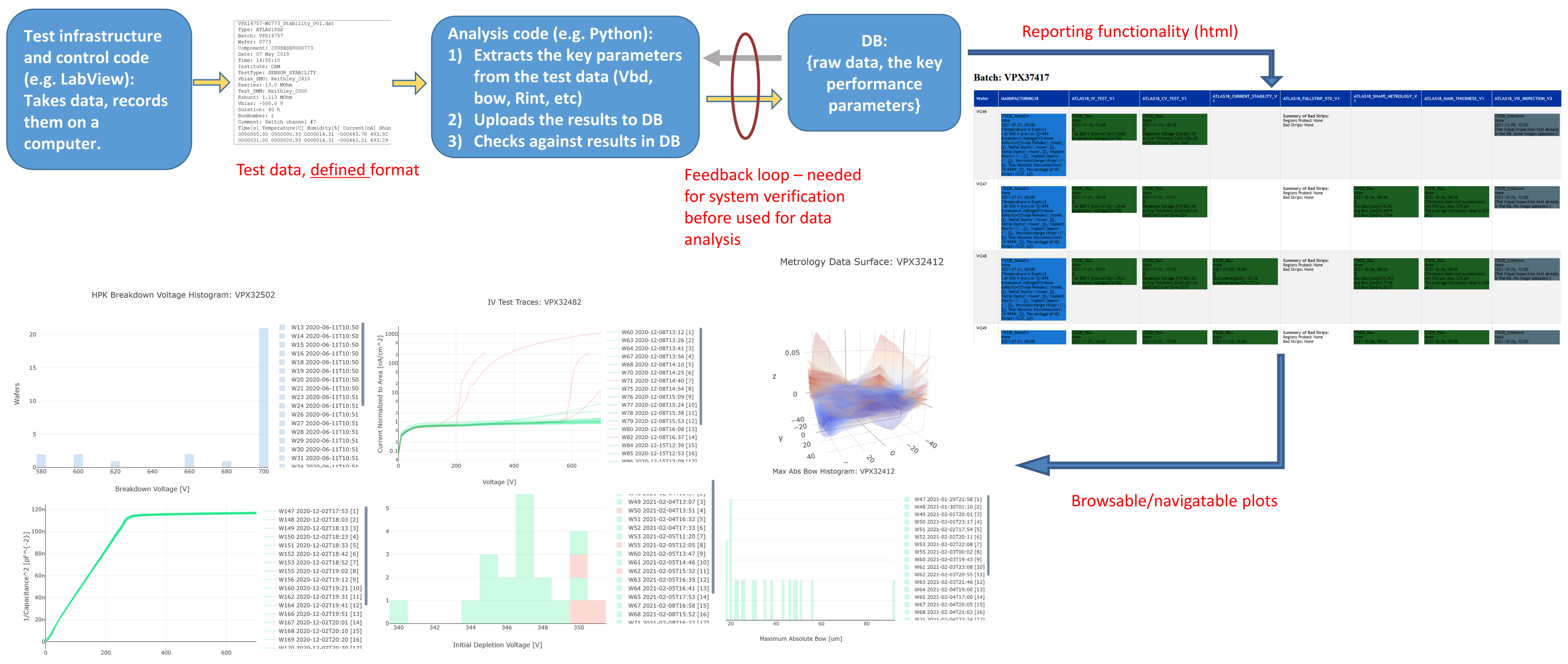
Intentionally fixed the "local data format" for all test types and documented it:

- A big simplification for the DB interface
- Another backup option
- Possibility to exchange/check earlier data at an earlier stage

The uploading scripts have powerful functionality [2]:

- Data analysis
- Data upload
- "Reporting" of the data already in DB
  - VERY important, since this enables the verification loop



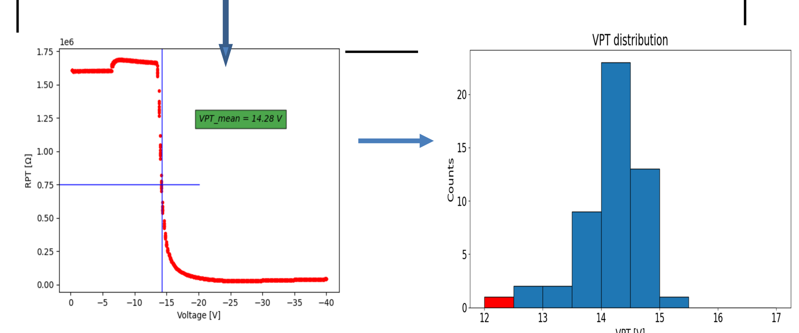


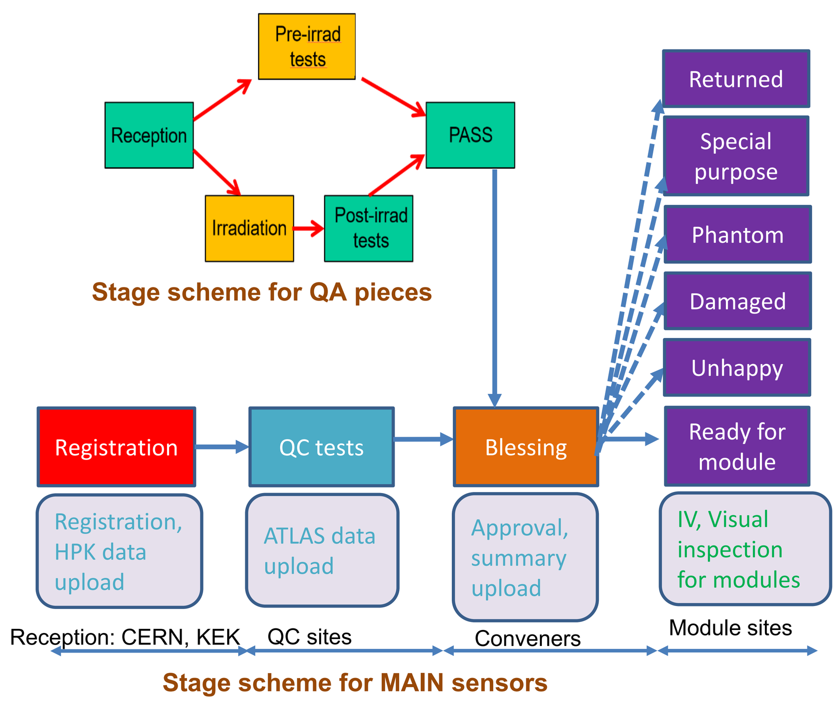
Approvals

The lifecycle of the different parts is reflected in their "stages" sequence:

- Notably, all QC tests for sensors and halfmoons are uploaded at "QC stage", to allow testing flexibility
- There is a "final state" classification for each sensor, depending on its properties and destination
- The QA tests are a critical input to the classification:
  - Judged by progression to the final stage, linked to the test results
    - Based on a lot of QA tests, with a large number of parameters => mostly key parameters are stored

- CBR-I_IV
- CBR-M_IV
- CCPL_C
- CCPL_IV10
- CCPL_IV100
- CFLD_CV
- INT_LOW_C
- INT_LOW_IV
- INT_MID_C
- INT_MID_IV
- INT_UP_C
- INT_UP_IV
- PTP_IV
- RBIAS_IV
- MD8_CV
- MD8_IV
- MINI_CCE
- Irradiation

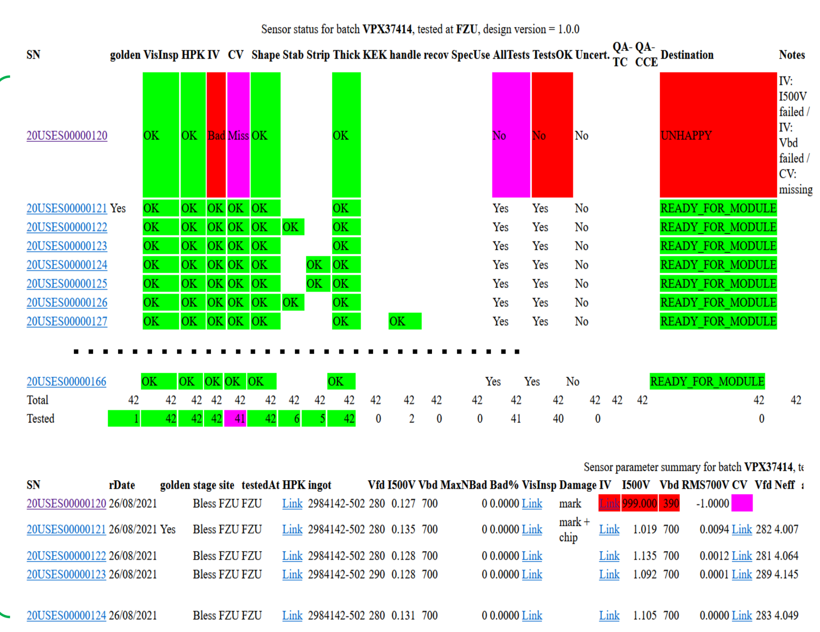




The acceptance approval for each of the monthly delivery happens at the end of the four-month evaluation process. At this time the following is done for every batch.

- The QA data are reviewed.
- The QC data completeness and values are reviewed.

The approval is semi-automated. Software pre-classifies the sensors into the final categories, but there is a provision to manually overwrite the conclusion in special cases.



CONCLUSIONS

The ITk Strip Sensors community has developed a working DB implementation, that is essential for collecting and evaluating data from 15 test sites distributed around the world. The system captures the key features of the different components and the acceptance evaluation cycle. The key feature of the development was going through iterative cycles with the community to ensure that the software suites are usable and adequate. Given the software complexity, continuous work is required on "maintenance" and addressing new requests from the community (e.g. a new test variant or reporting aspect). This DB implementation is scalable and suited to handle large data quantities. It has been used for pre-production and production phases over the last 2 years. To-date, over 4400 sensors have been evaluated through the acceptance tests.

References

1) Unno, et al., "Specifications and Pre-production of n+-in-p Large-format Strip Sensors fabricated in 6-inch Silicon Wafers, ATLAS18, for Inner Tracker of ATLAS Detector for High-Luminosity Large Hadron Collider", Presented at 23rd International Workshop for Radiation Imaging Detectors (iWoRID2022), Submitted for publication in JINST, preprint no. JINST_002T_1022 (2022) url: https://indi.to/yPLxQ
2) D. Rousso et al., "Test and extraction methods for the QC parameters of silicon strip sensors for ATLAS upgrade tracker", accepted to NIM A, https://doi.org/10.1016/j.nima.2022.167608

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