ATLAS EXPERIMENT

大阪大学 OSAKA UNIVERSITY

HIGH ENERGY PHYSICS YAMANAKA GROUP

ATLAS ITk

DEVELOPMENT AND QA/QC OF NEW PIXEL DETECTORS FOR UPGRADING THE LHC ATLAS EXPERIMENT

Measurement System Workshop 2021 @
Kyushu University (28th-29th October)

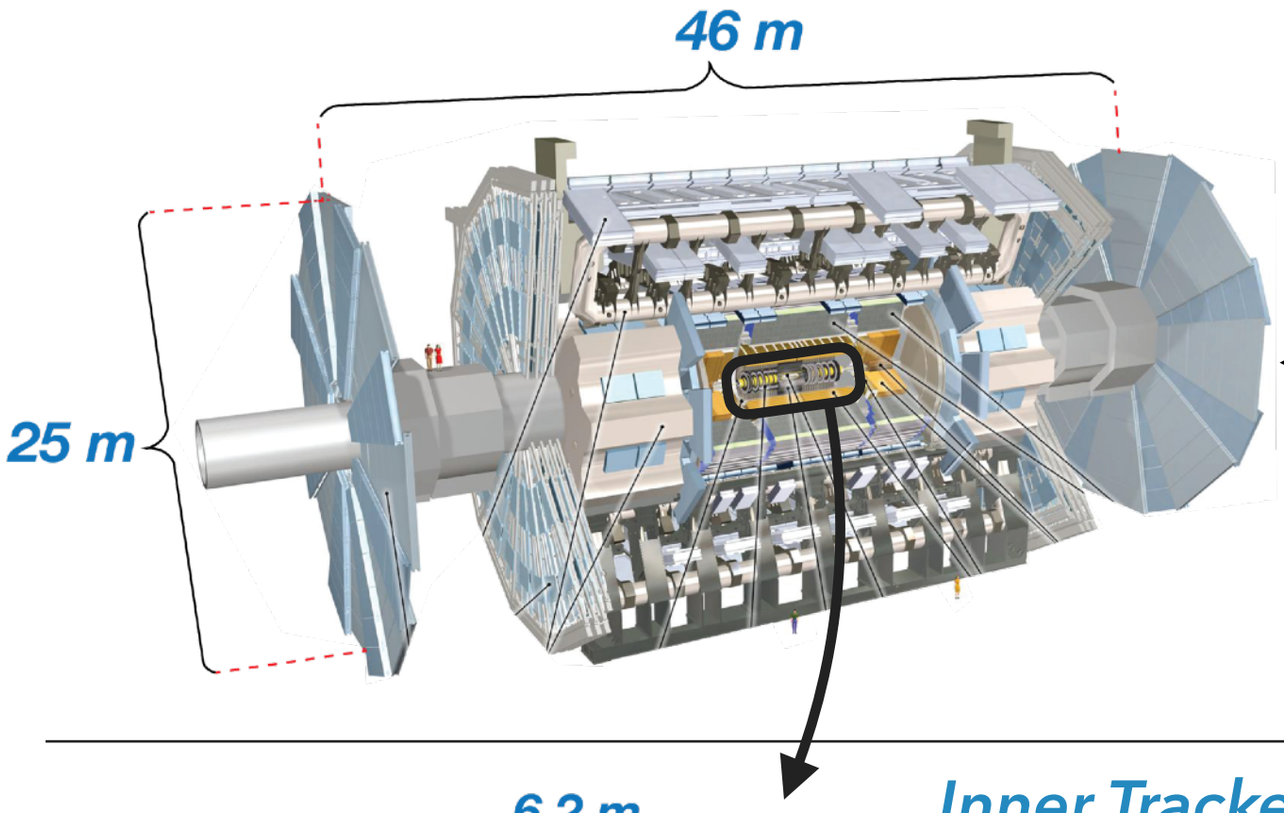
LAKMIN WICKREMASINGHE ON BEHALF OF THE ATLAS ITK PIXEL GROUP

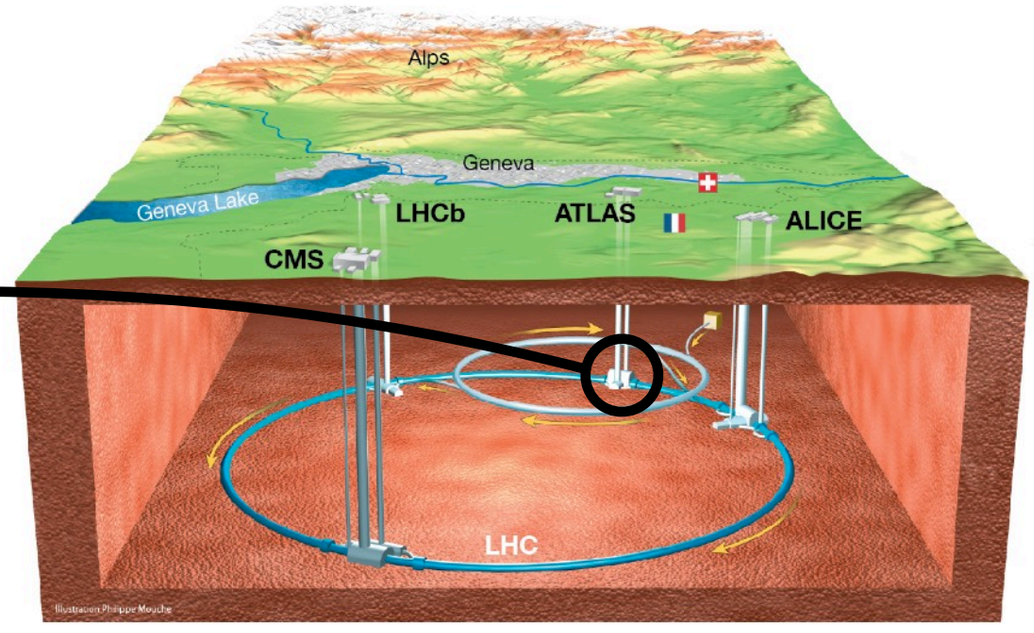
ATLAS Detector – CERN

LHC 2008 - 2024

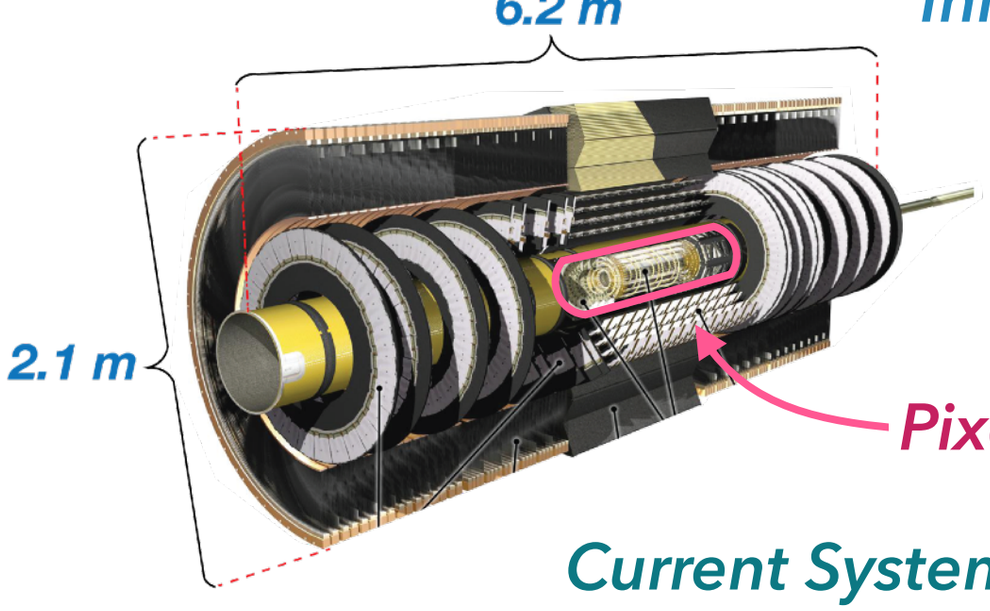
5~8 X Intensity

High Luminosity LHC 2027 ~

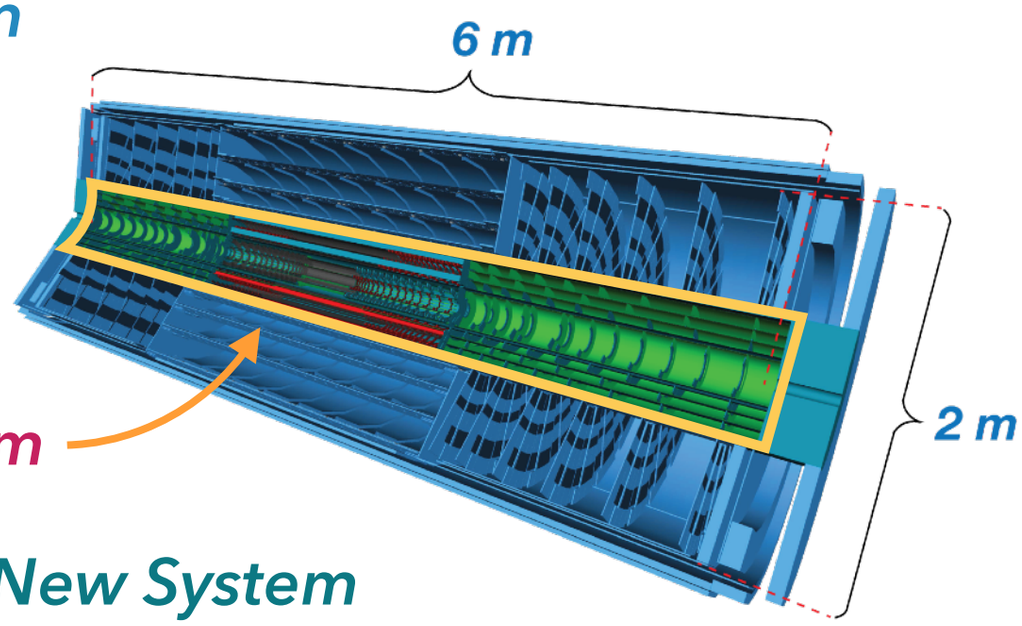




Inner Tracker System



Upgrade



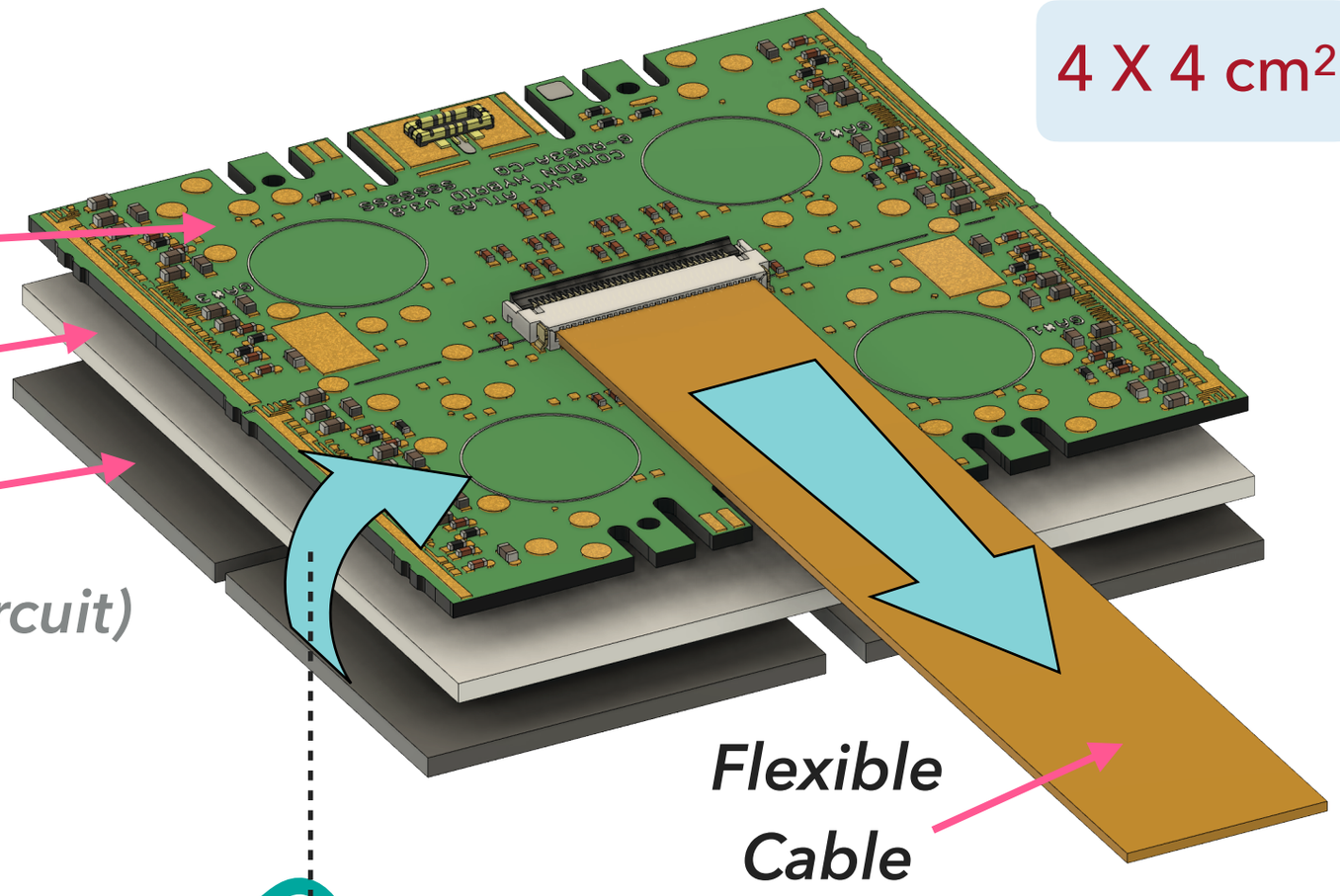
Pixel Detector System

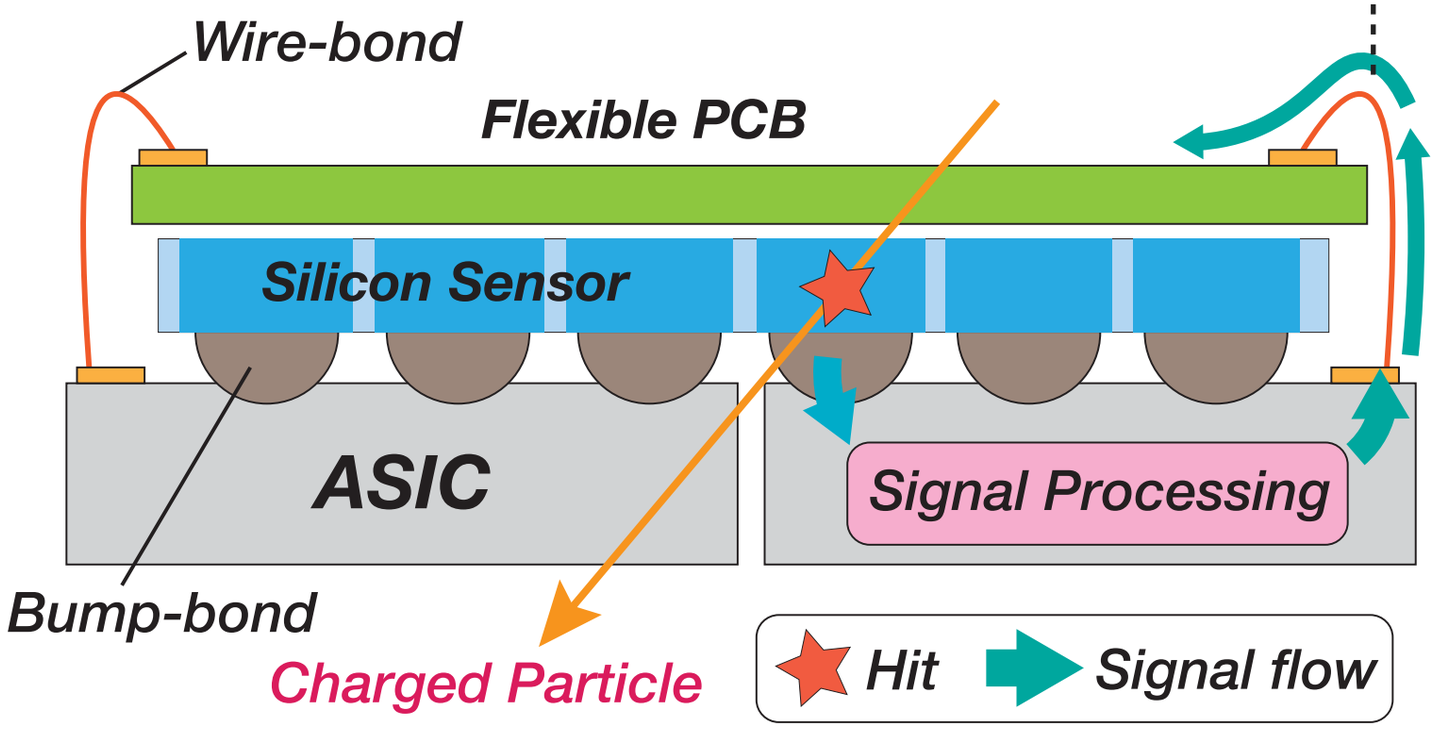
Current System

New System

NEW PIXEL MODULE

4 X 4 cm^2





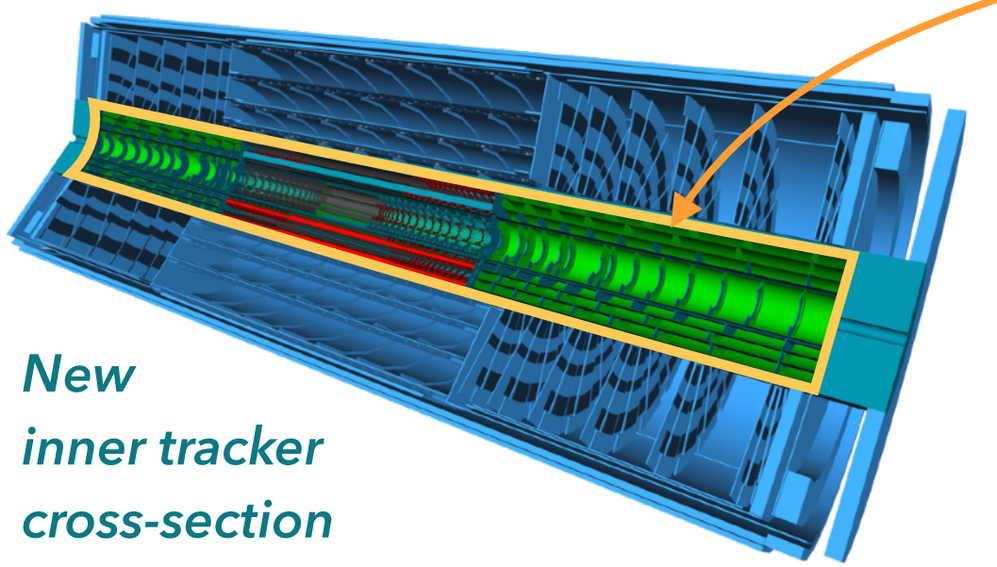
Features

Pixel : 50 μm X 50 μm

Data Rate of 1.28 Gbps per data lane

MASS PRODUCTION AND QA/QC

We need ~10,000 pixel modules (Japan plans to produce ~2,500 pixel modules)

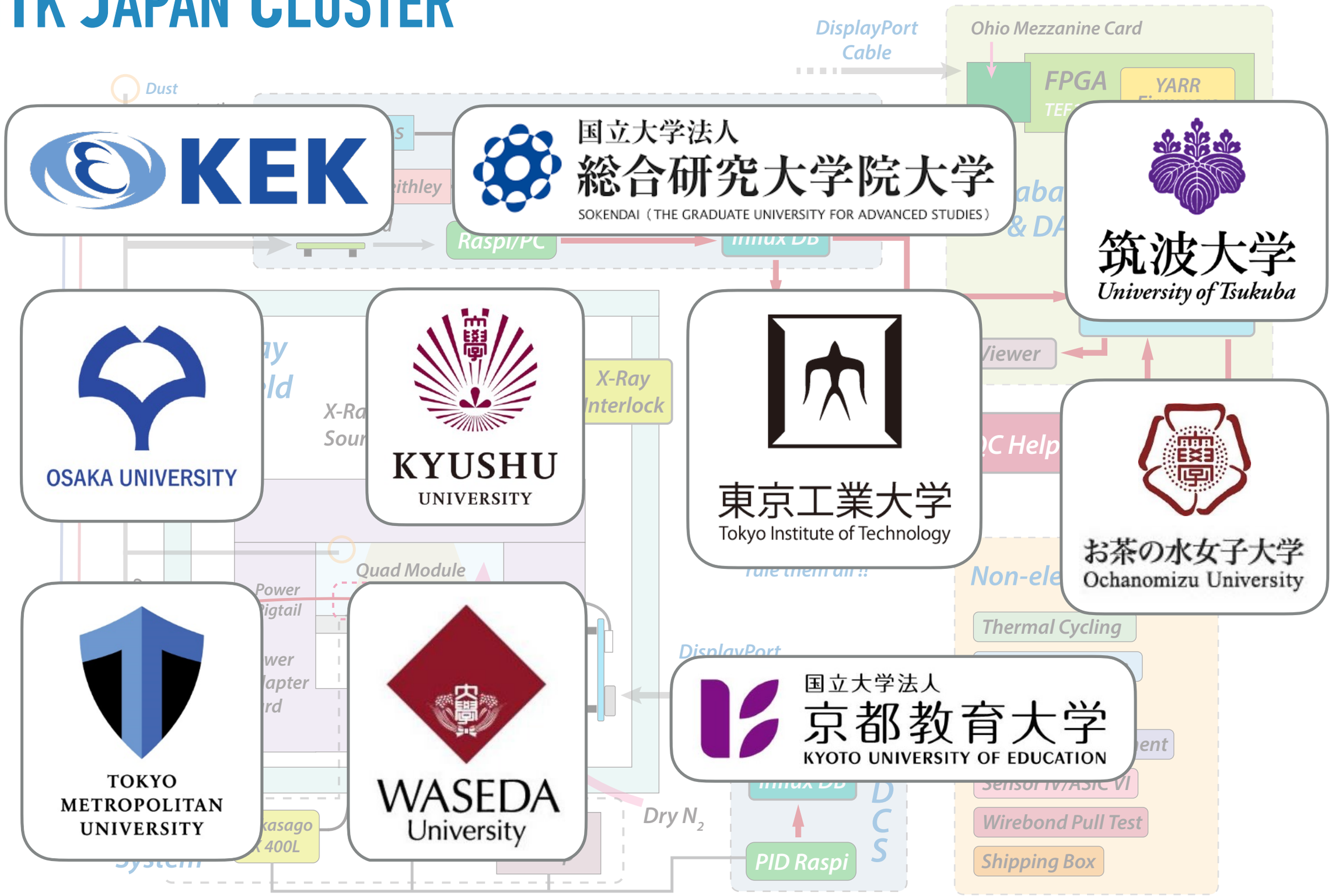


New inner tracker cross-section

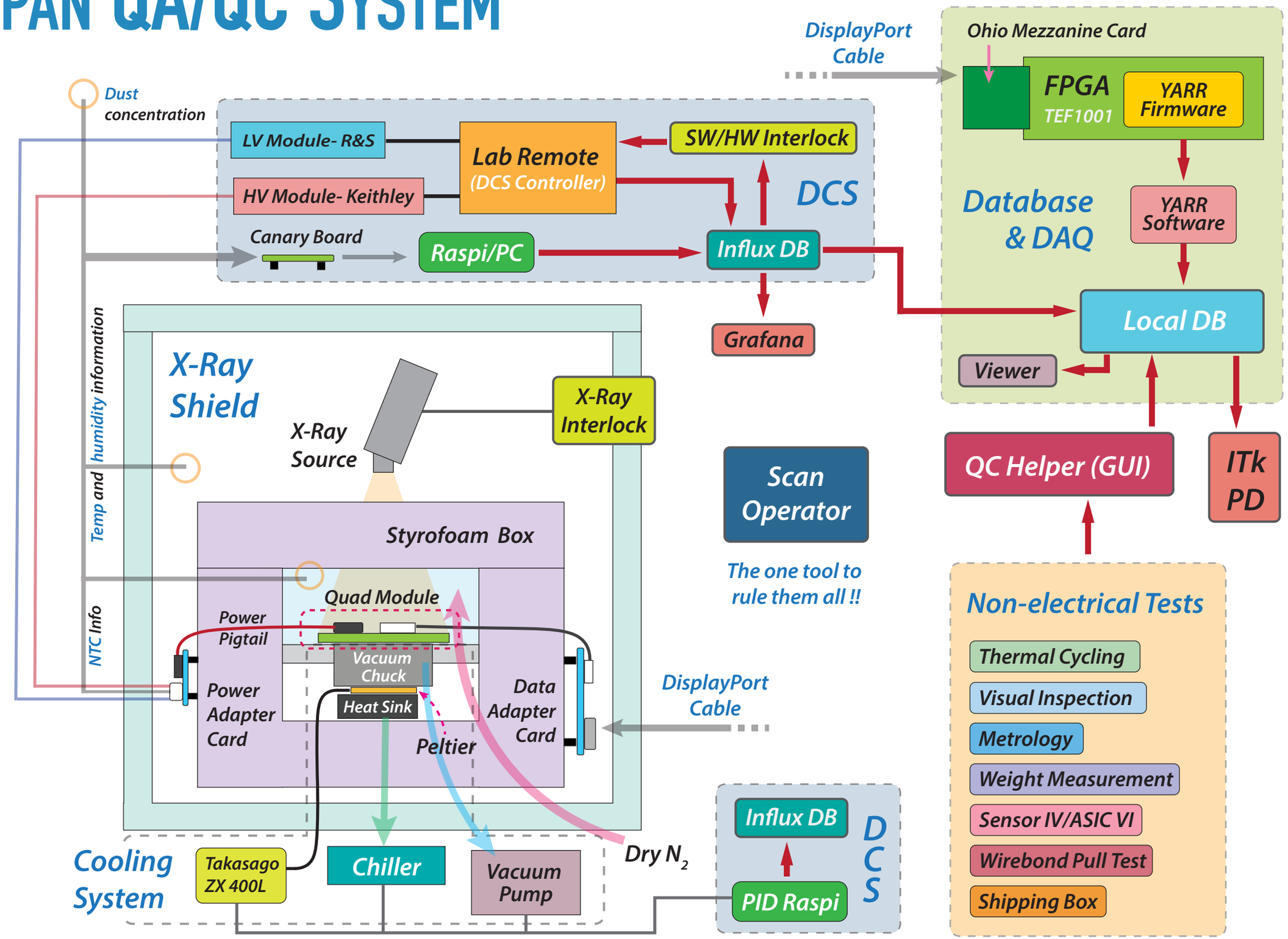
Need to test these new modules, and assess its quality (**QA**) and control its quality (**QC**)

- There are more than 30 institutes around the world.
- Design and build an efficient assembly flow and QA/QC system from the start.

ITk Japan Cluster



JAPAN QA/QC SYSTEM

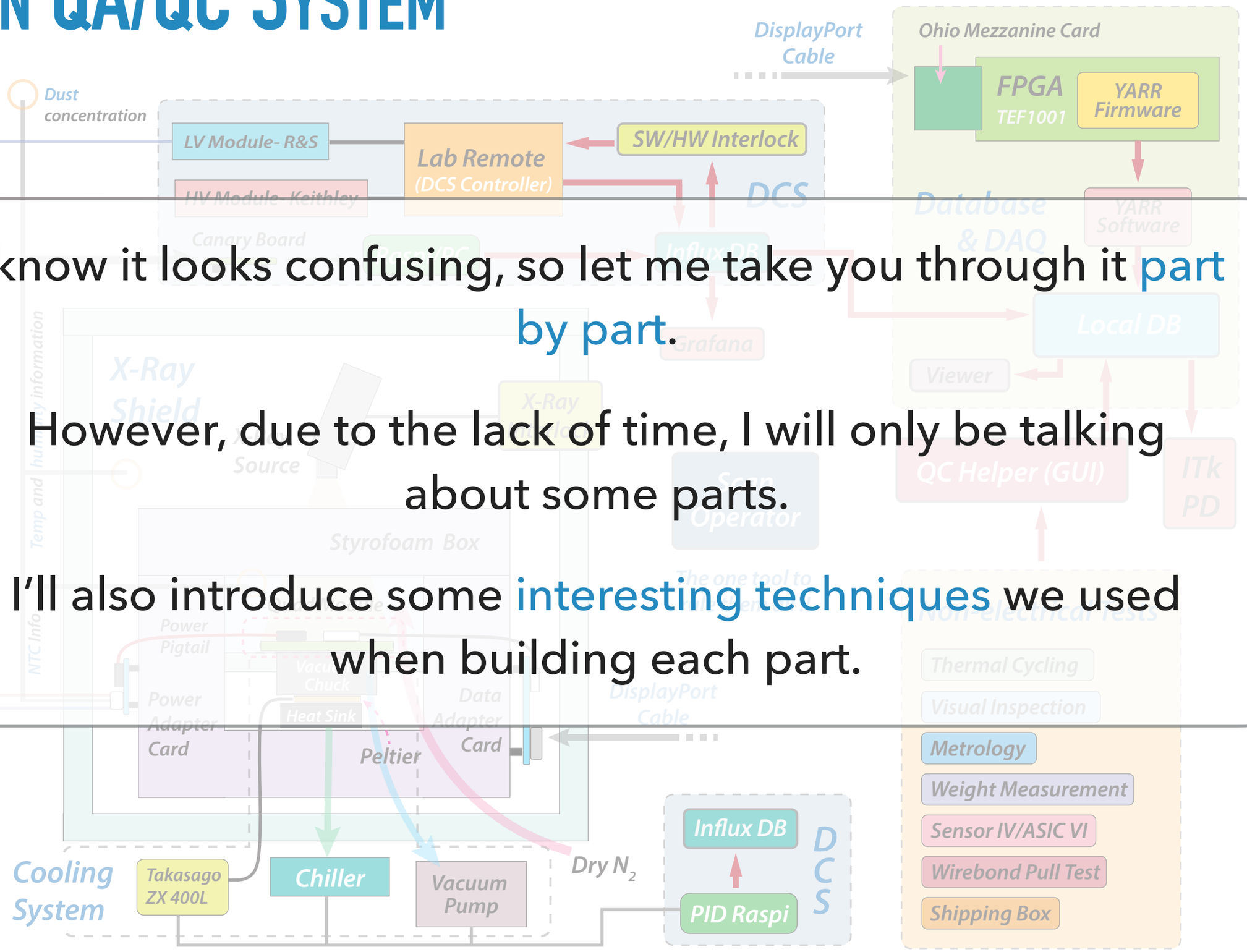


JAPAN QA/QC SYSTEM

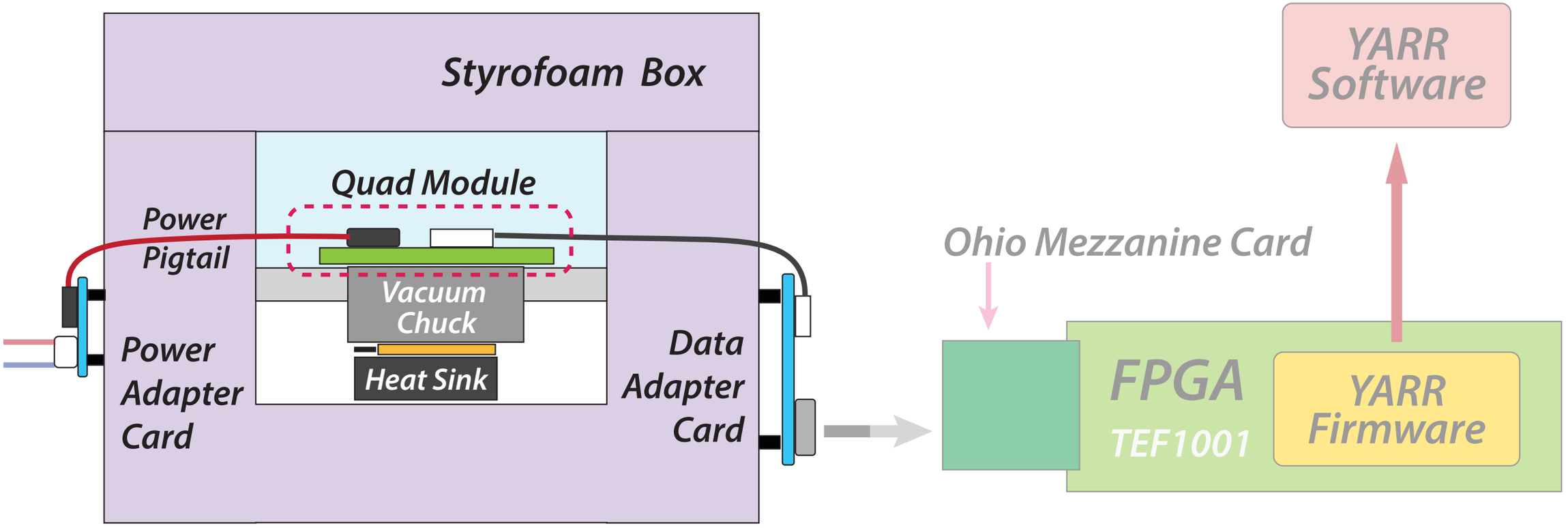
I know it looks confusing, so let me take you through it part by part.

However, due to the lack of time, I will only be talking about some parts.

I'll also introduce some interesting techniques we used when building each part.



DATA ACQUISITION (DAQ) SETUP



Developed by: OSAKA UNIVERSITY and BERKELEY LAB Lawrence Berkeley National Laboratory

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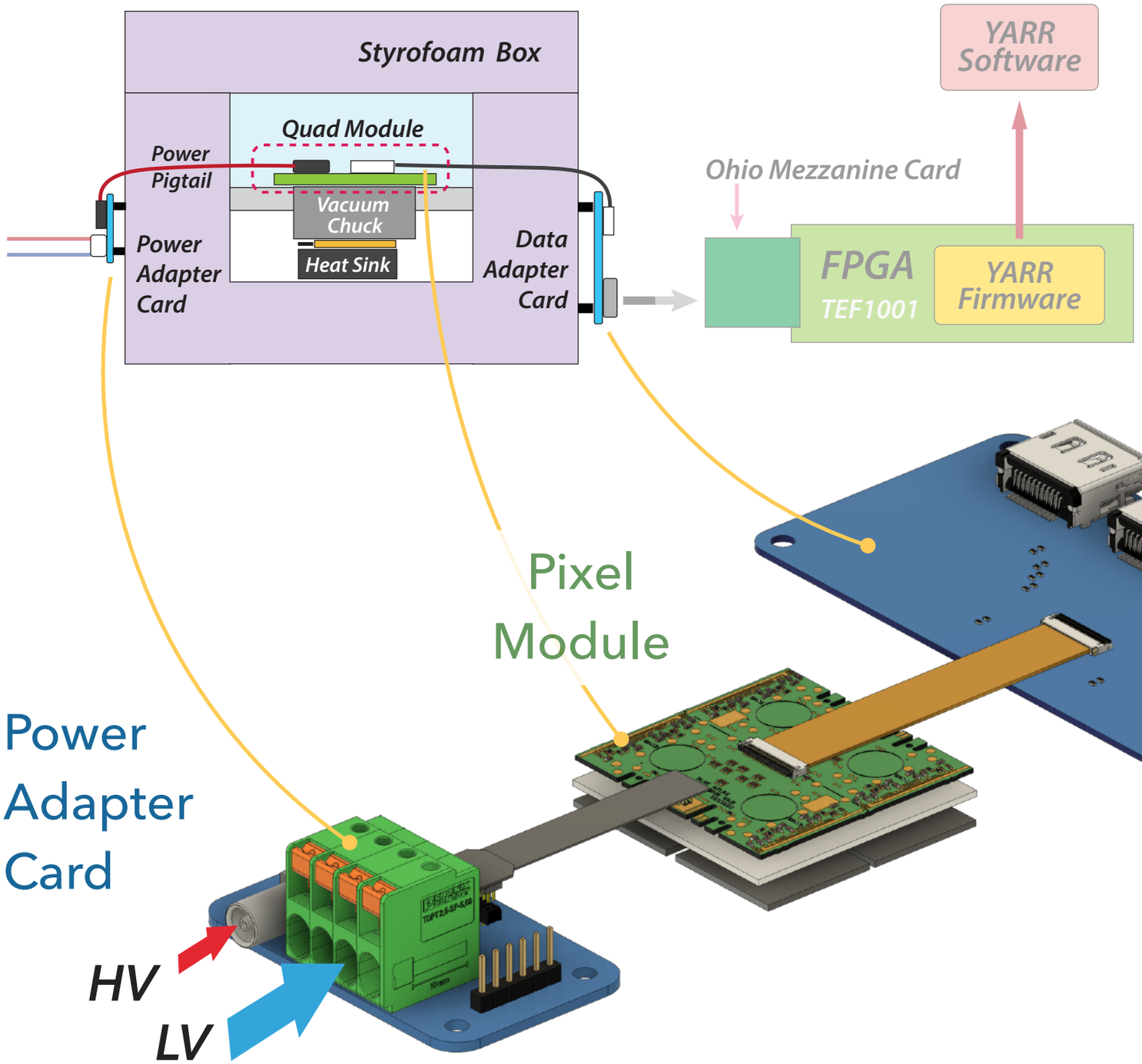
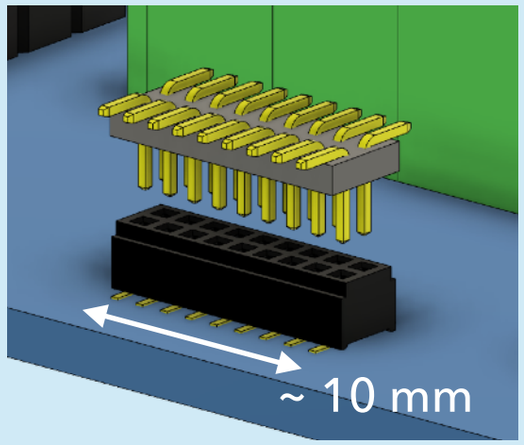


- First developed for the prototype detectors.
- Expanded to the final system.
- Common for the world.

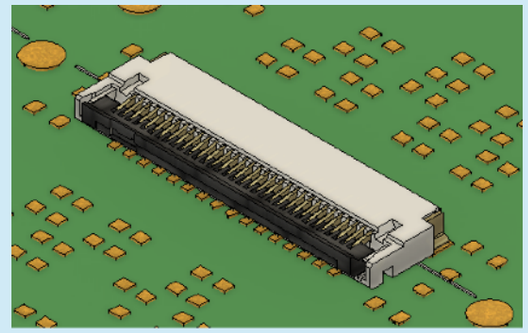
USEFUL CONNECTORS



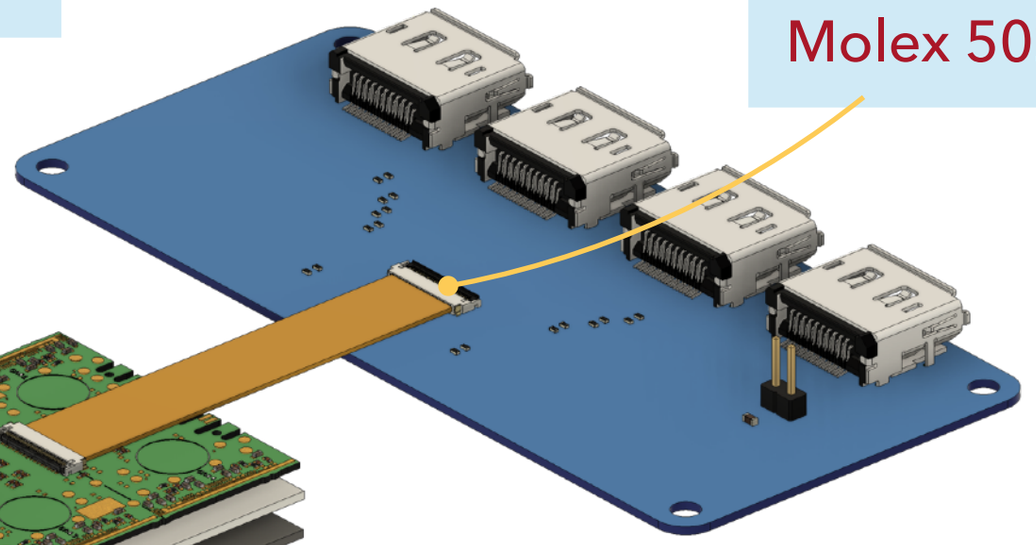
Current Rating (mated)- 2.8 A per pin
Contact Resistance- 15 mΩ per pin

Power Connector:
Samtec FTM/CLM

Speed- Tested for > 6.25 Gbps
Mating Cycles- More than 1000 times



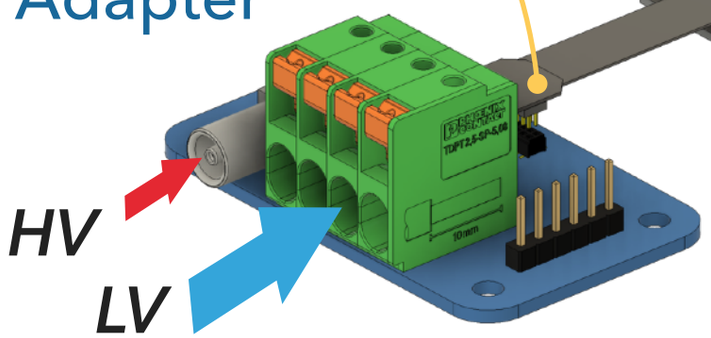
ZIF Connector:
Molex 502598-3393



Pixel Module

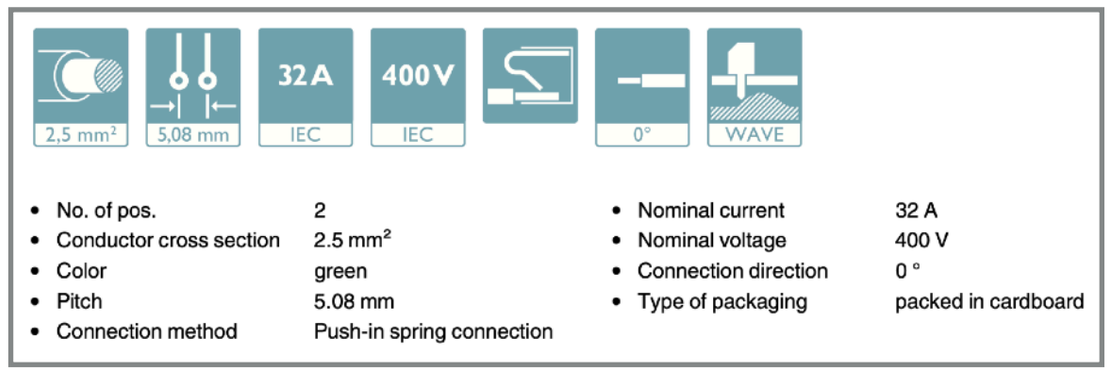
Data Adapter Card

Power Adapter Card



HV Connector - LEMO (tested till ~1000 V)

LV Connector - Phoenix Contact

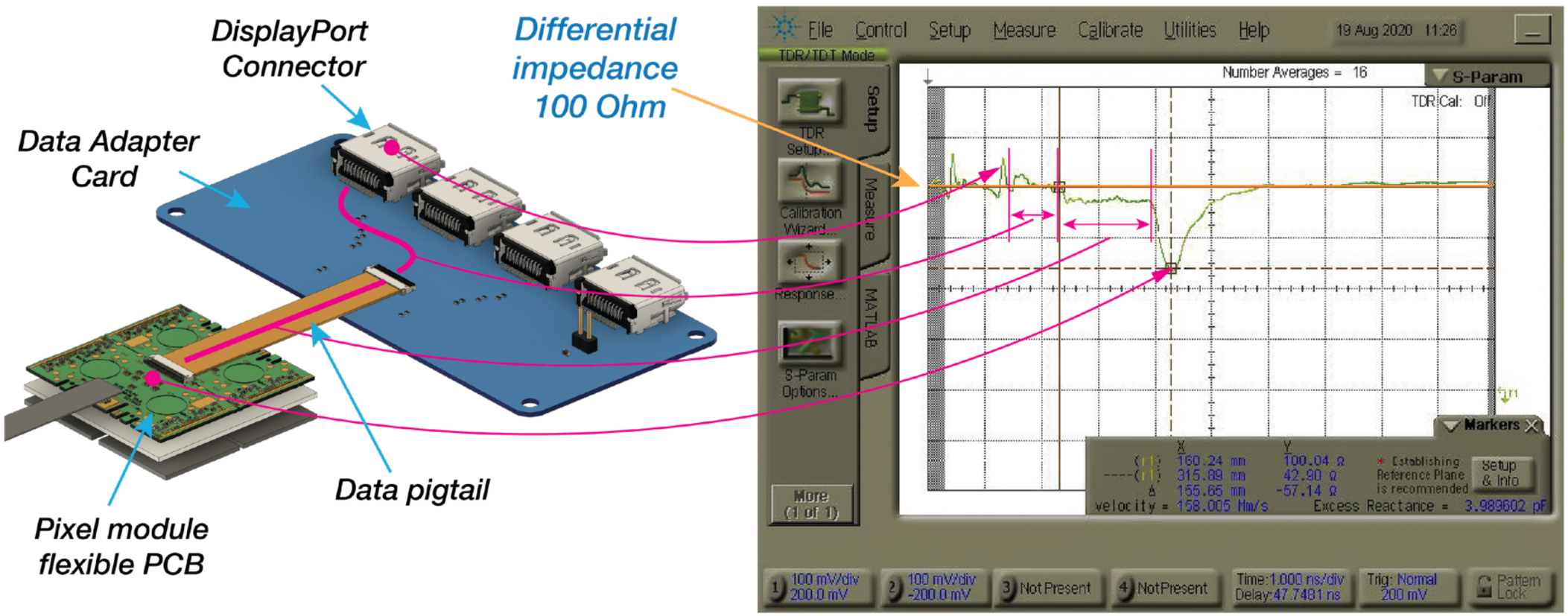


No. of pos.	2	Nominal current	32 A
Conductor cross section	2.5 mm²	Nominal voltage	400 V
Color	green	Connection direction	0 °
Pitch	5.08 mm	Type of packaging	packed in cardboard
Connection method	Push-in spring connection		

DATA ACQUISITION (DAQ) SETUP

(TDR - Time Domain Reflectometry)

TDR Result from ITk SLAC Team



- The Adapter Card is well controlled to ~100 Ω (Diff. Impedance) just by calculation !
- We used KiCAD for the design, and Saturn PCB impedance calculator.
- Produced through PCBWay (JLCPCB) for a low price ➡ Recommend for quick prototyping.
- Tips (for RF Signal Designs)
  - Use more than 2 layers, to get ~100 Ω diff.impedance.
  - Avoid signal lines going through via's if possible.

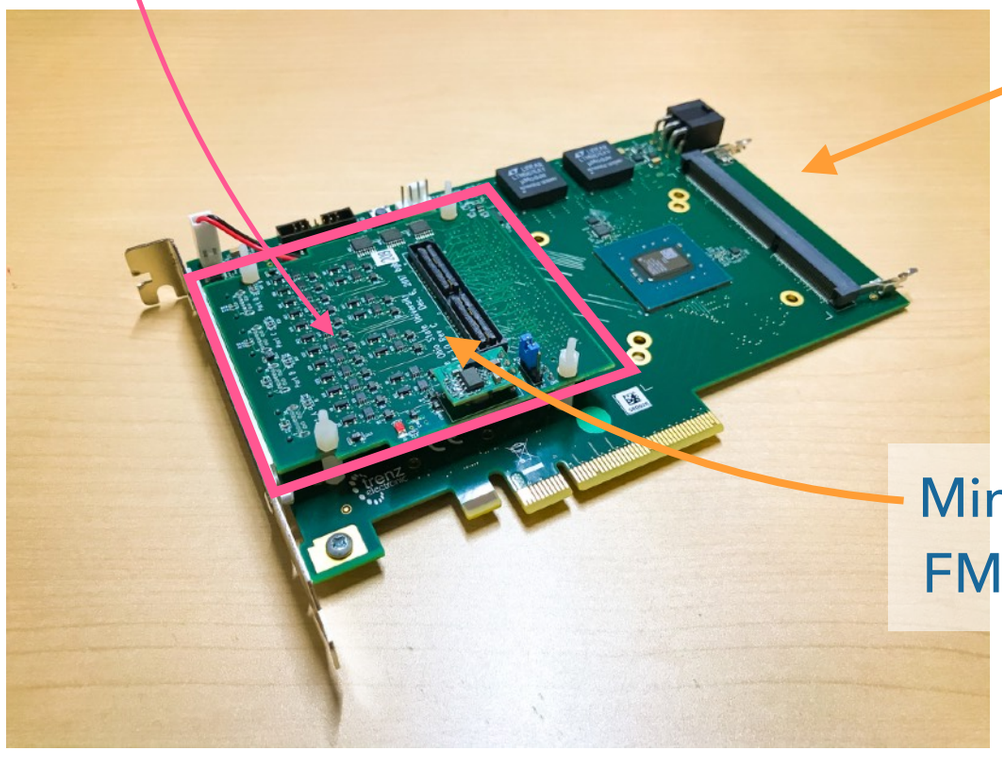
Prototype testing succeeded!

YARR DAQ FRAMEWORK

Yet Another Rapid Readout - YARR Docs

Last Year's Slides - 計測システム研究会2020

- A PCIe based high speed DAQ system, with configurable I/O.
- FPGA aggregates data from the ASIC chips.
- Everything sophisticated is done by the YARR software.

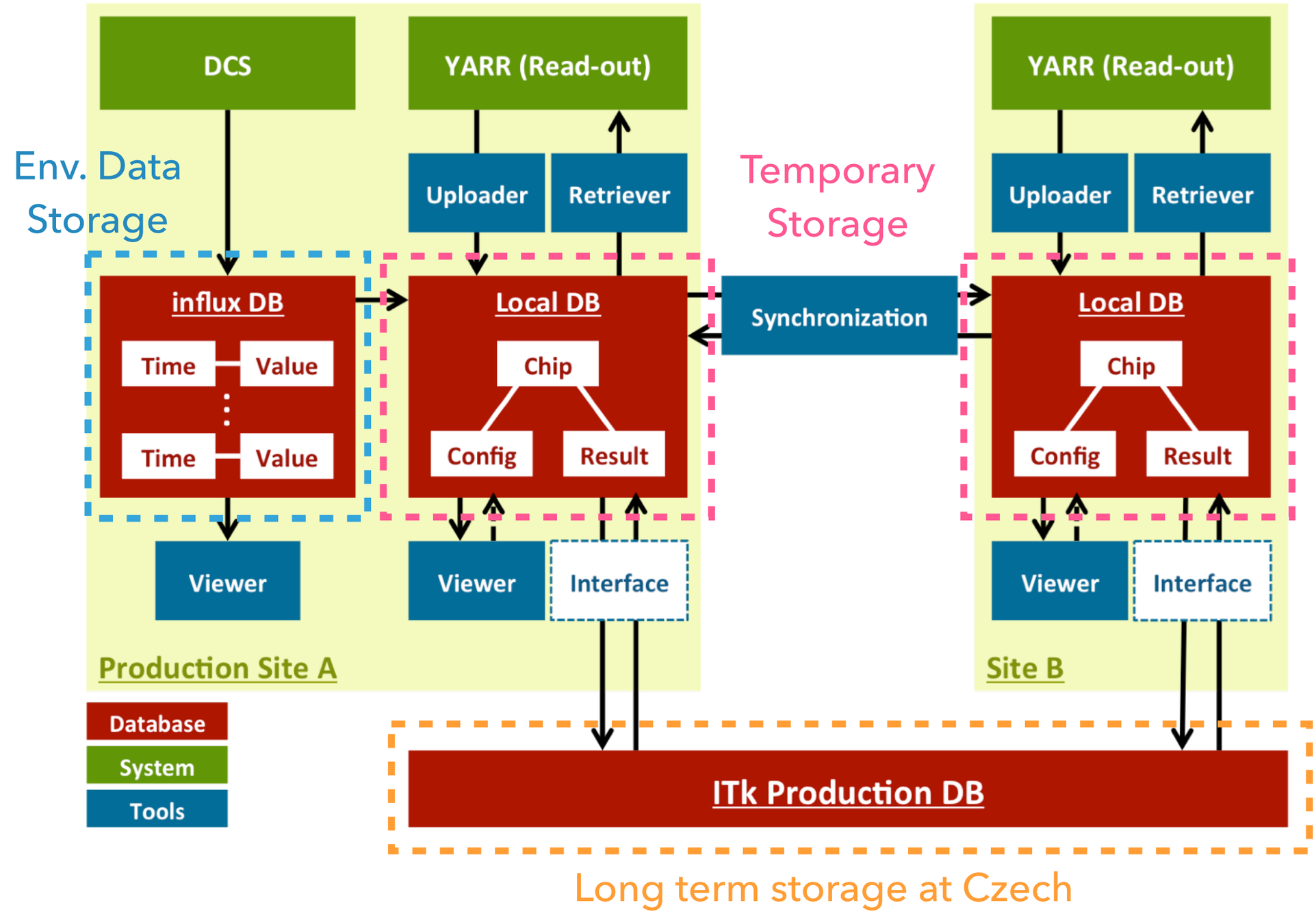


DATABASE

Details can be found on Last Year's Slides - 計測システム研究会2020

Mainly developed and maintained by:

東京工業大学
Tokyo Institute of Technology



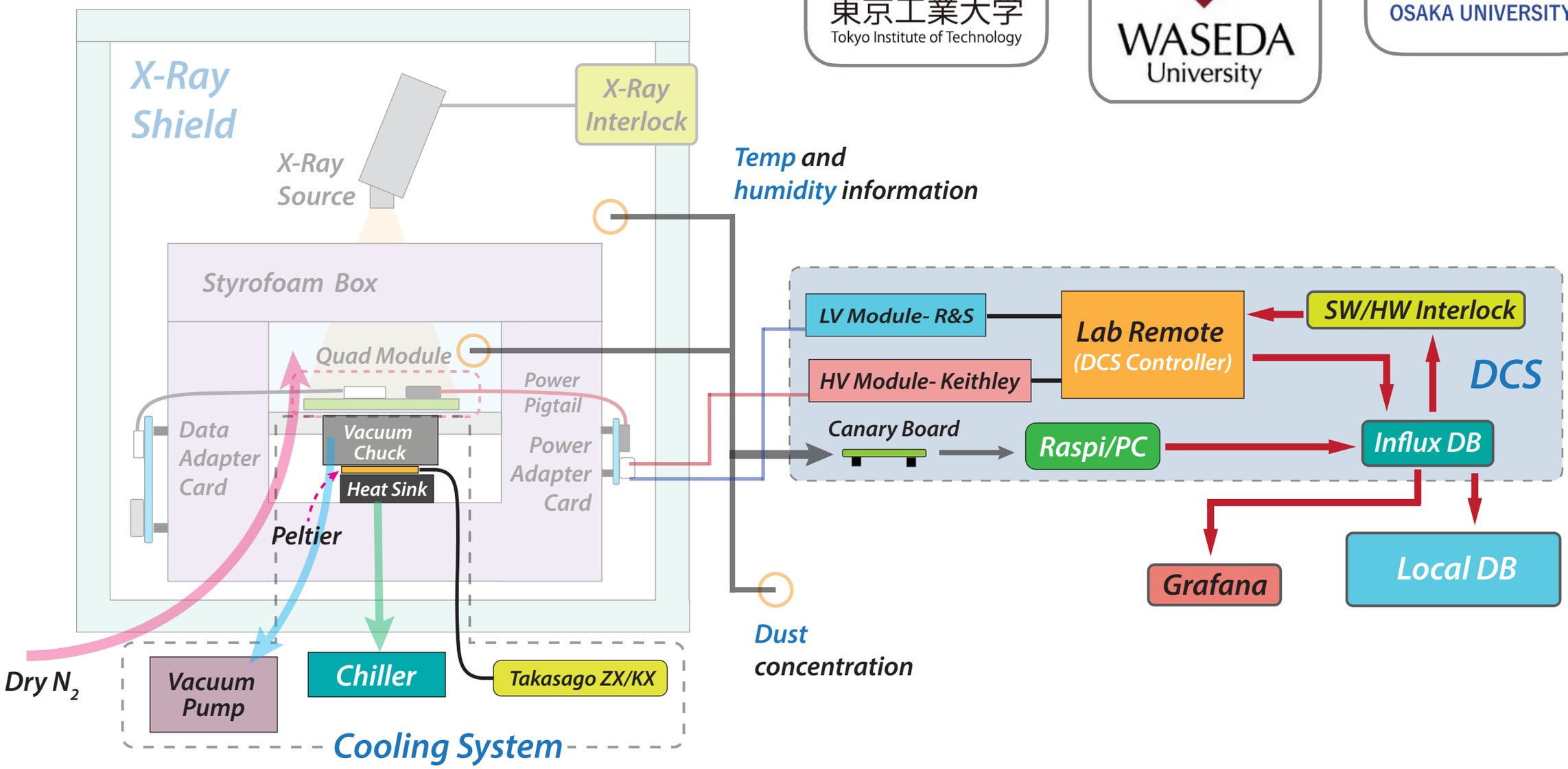
COOLING AND DETECTOR CONTROL SYSTEM (DCS)

Mainly developed and maintained by:

東京工業大学 Tokyo Institute of Technology

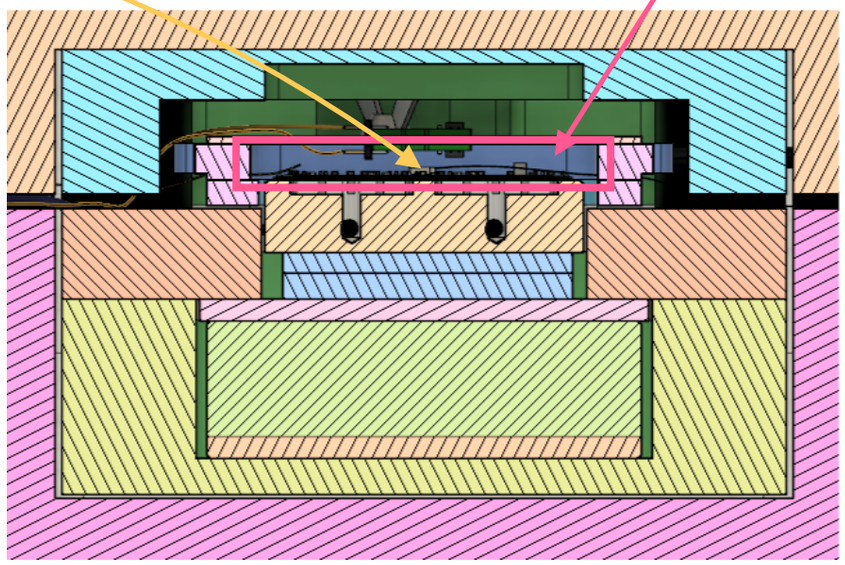
WASEDA University

OSAKA UNIVERSITY

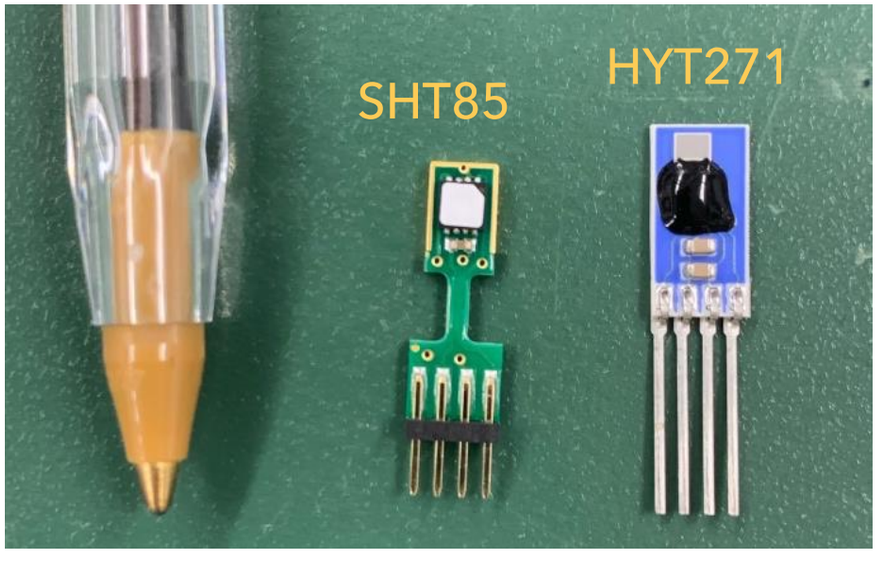


COOLING AND DETECTOR CONTROL SYSTEM (DCS)

- Some challenges we had:
  - We need to cool to -45 ℃ ➡ Simply said, use a Peltier (CUI Devices **CP854705-2**) + Chiller.
  - The air should be extremely dry to avoid condensation ➡ Use dry Nitrogen in a small cavity and make the air circulation fast
  - Maintaining temperature at a particular value ➡ PID Control
  - Accurate measurement of dew point ➡ We used the SHT85 sensor at first, but found that **HYT271 sensor performs better**.



Cooling box cross-sectional View



	SHT85	HYT271
Price@DigiKey	¥4,020	¥3,664
Communication	I2C	I2C
Bits	16	14
Temp. Range	-40~105 (± 0.1)	-40~125 (± 0.2)
RH. Range	0~100 (± 1.5)	0~100 (± 1.8)

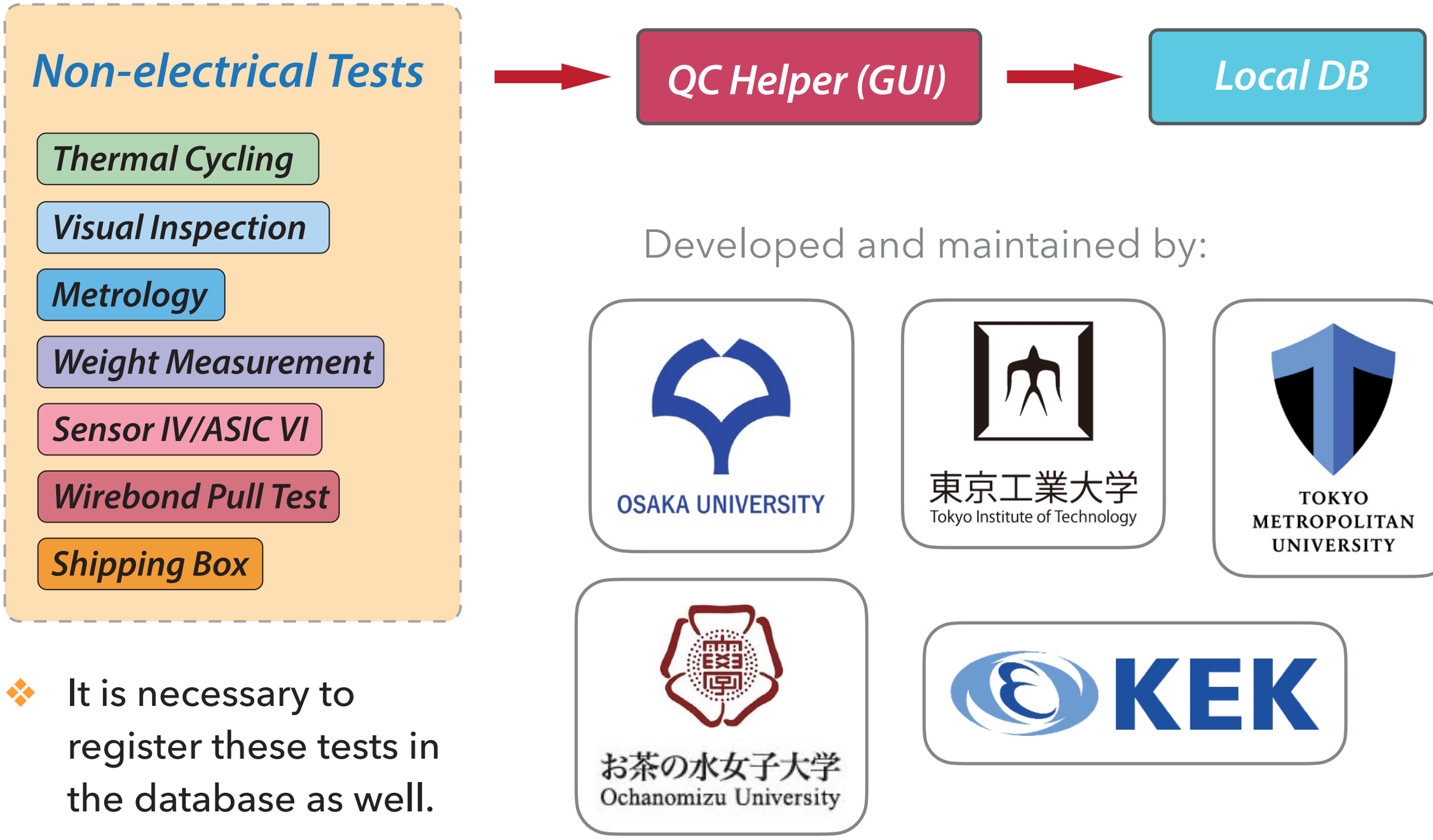
POWER SUPPLY CONTROL

- A pixel module is operated at ~8 A Constant Current (an ASIC chip consumes ~2 A current at ~1.5 V) and tested up to 1000 V (the sensor).
- We have built a common SW (called **labRemote**) in order to automate the controlling of lab equipment (power supplies, chillers, etc.) through SCPI.
  - Comes with Python bindings.
  - Already supports a lot of common lab equipment.
  - However, it can also be easily expanded to other power supplies and lab equipment which uses **SPCI**.

HV :
Keithley
2410

LV :
Rhode &
Schwarz
HMP4040

NON-ELECTRICAL TESTS AND QC HELPER

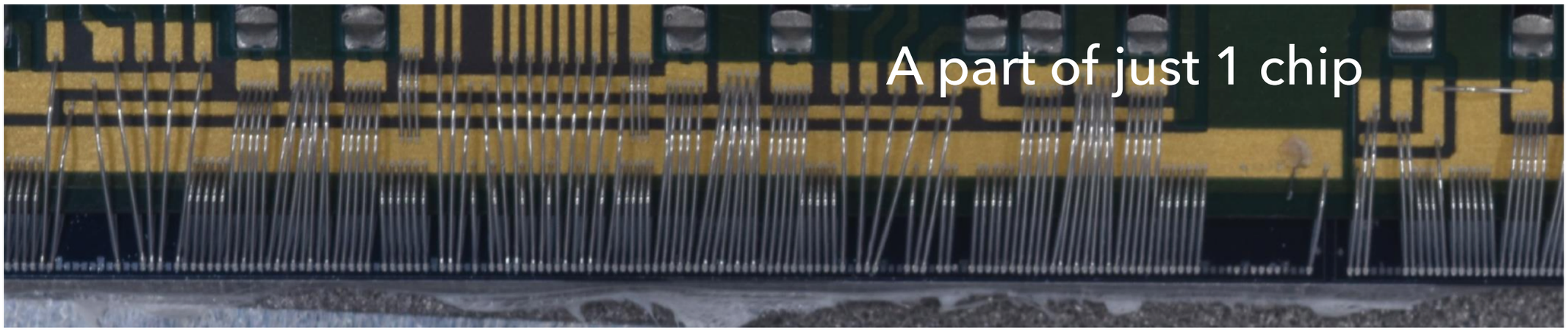


- It is necessary to register these tests in the database as well.

NON-ELECTRICAL TEST EXAMPLE – VISUAL INSPECTION

東京工業大学
Tokyo Institute of Technology

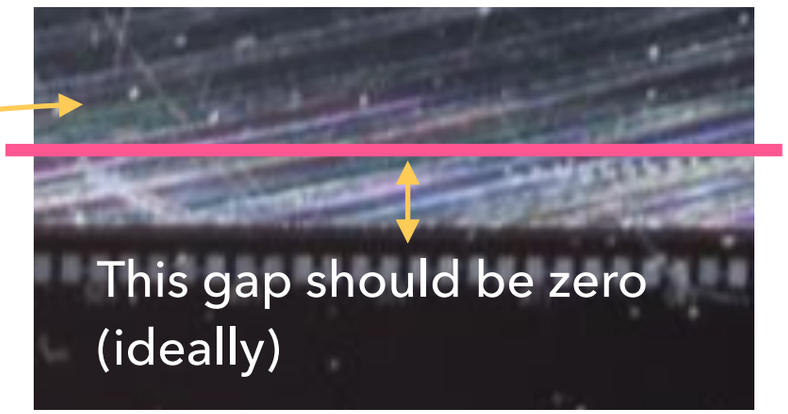
- It is necessary to assess the quality of the wire bonding and detect anomalies such as broken wires or improper welding.
  - Some degree of automation is needed due to the large number of wires.



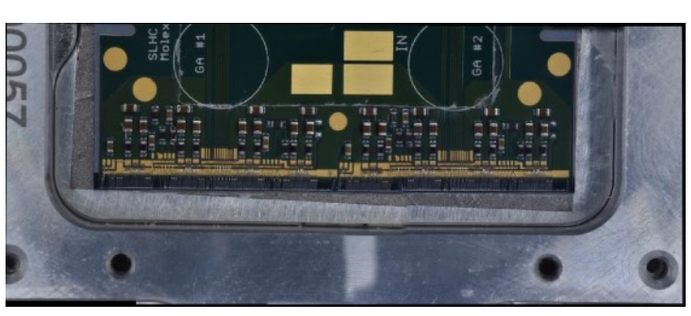
- We need to proceed this in several steps (simply summarized below).
  - Data acquisition (obtaining images - 9 images per pixel module)
  - Correct the camera distortion.
  - Standardization (stitching the images ➡ correction of perspective)
  - Feature extraction (Line tracing, defect detection, etc)

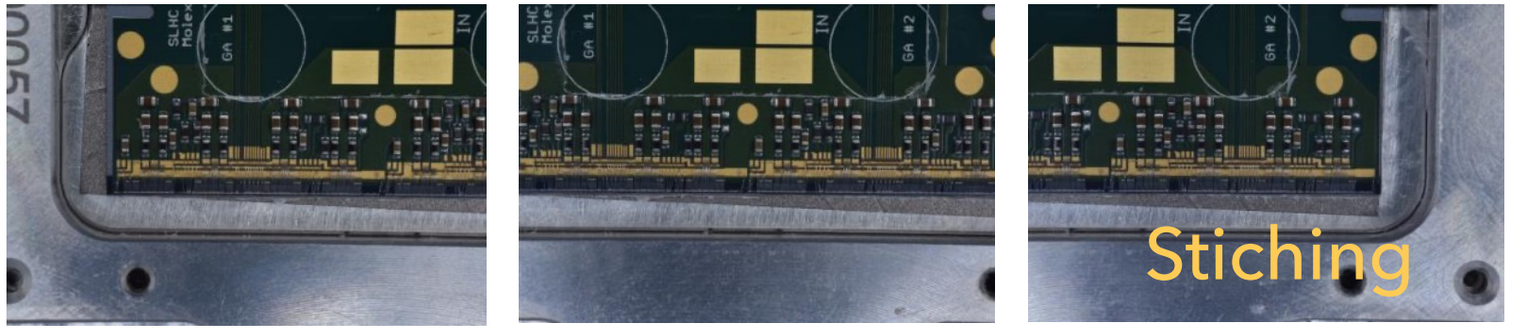
VISUAL INSPECTION

Image is slightly Distorted



Correct distortion

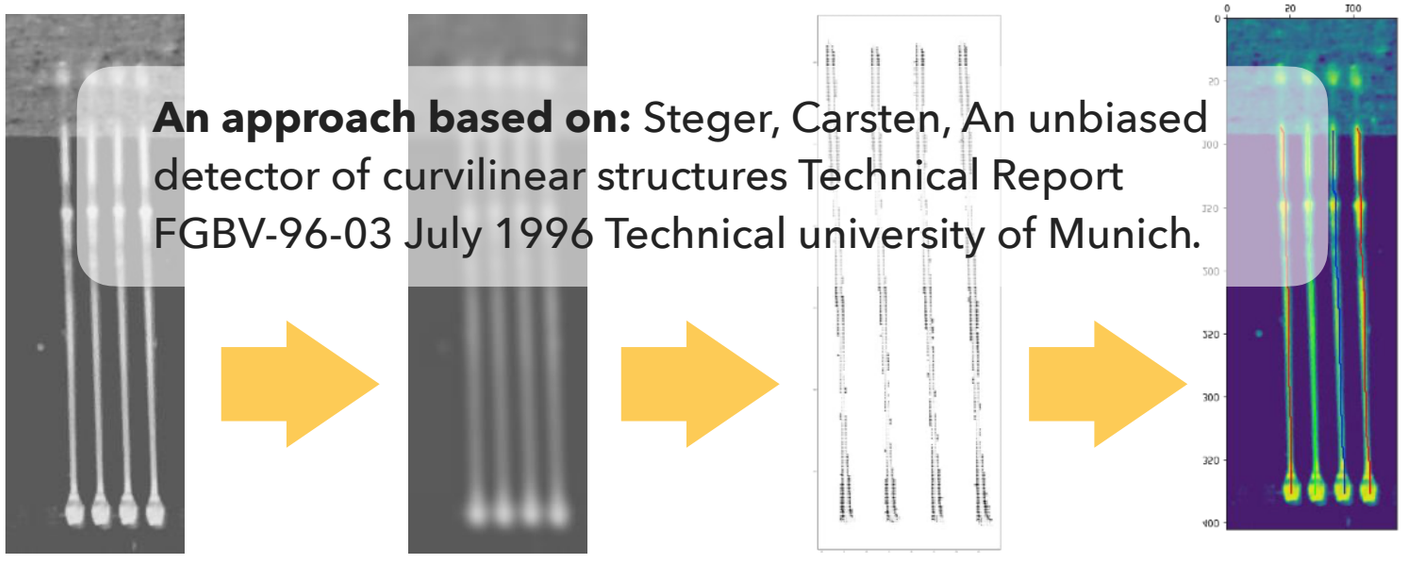




Upload to

Local DB

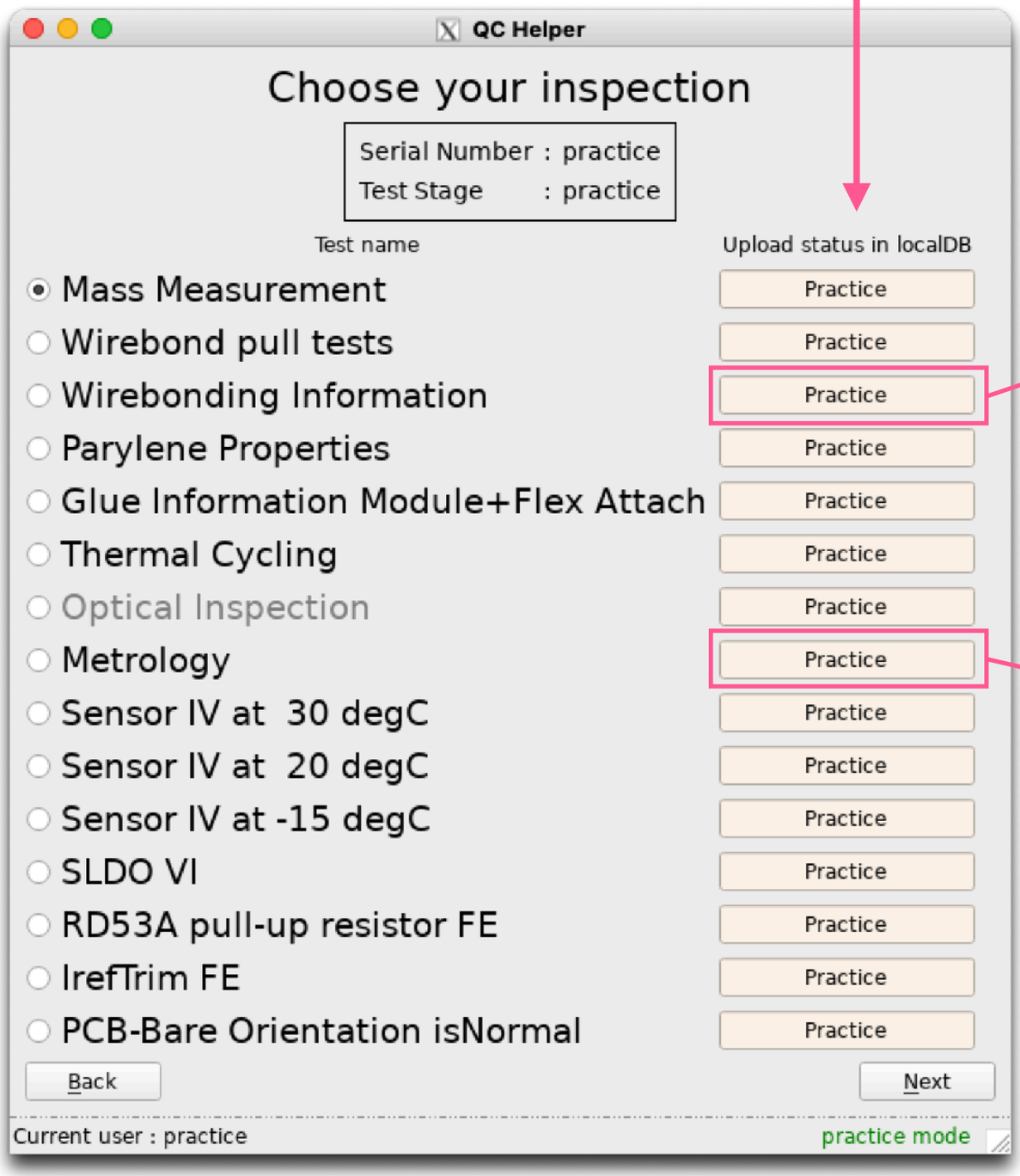
Also, currently we're trying to automate wire bond inspection

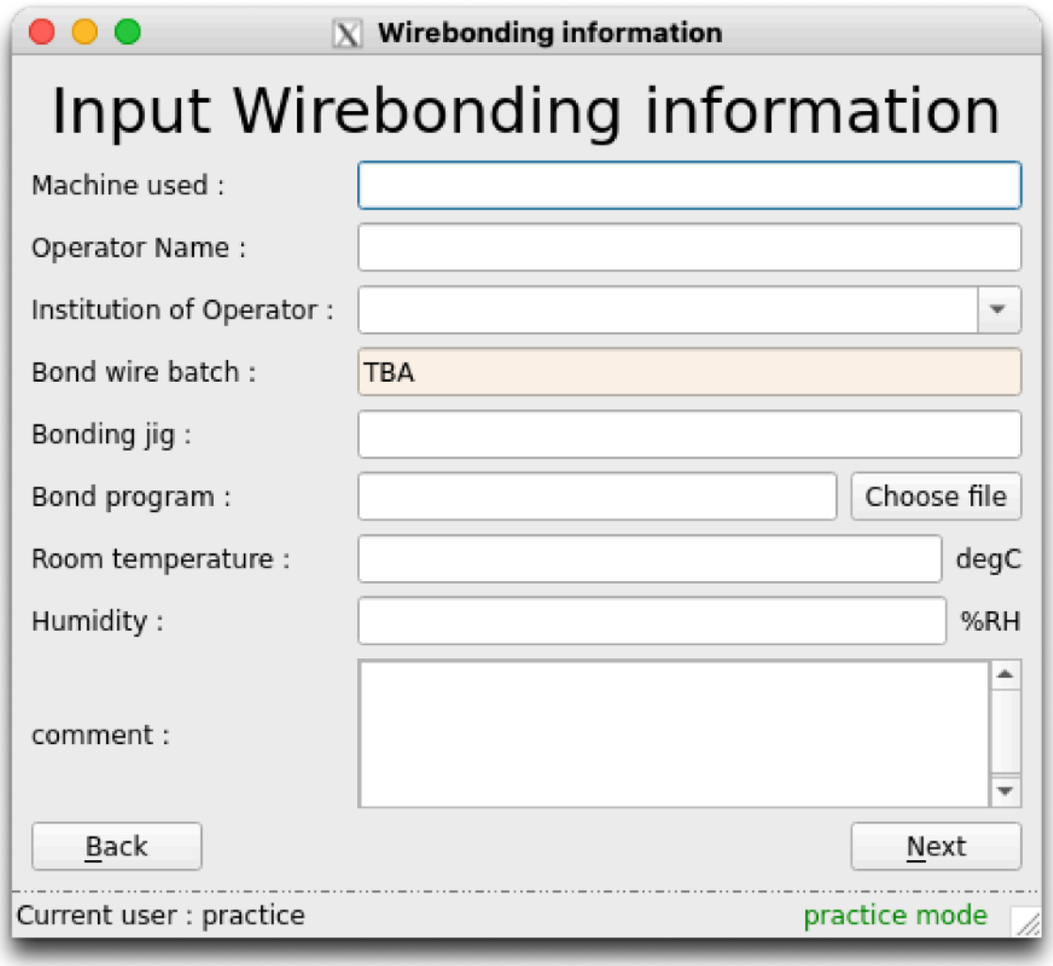


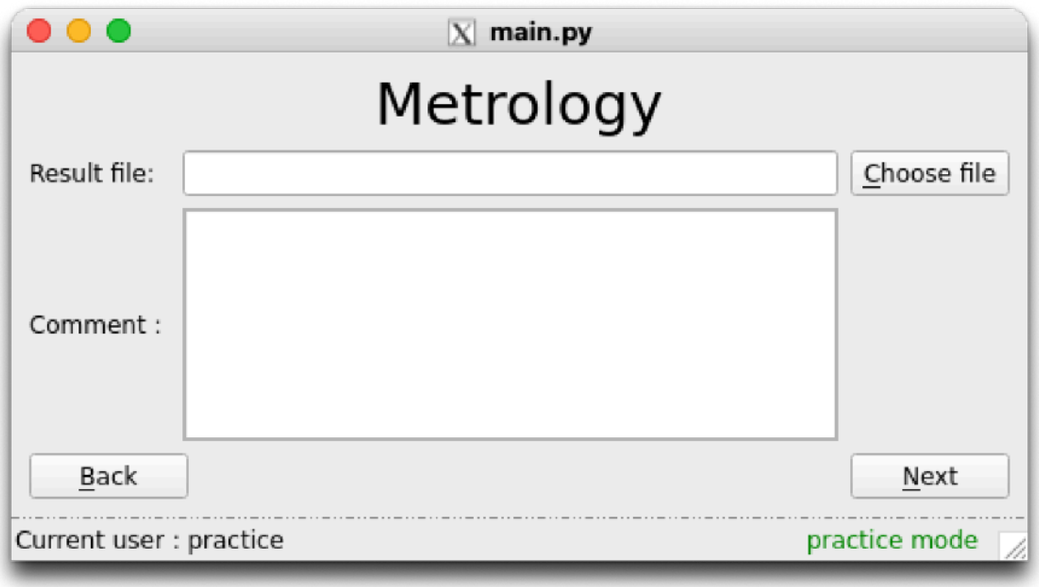
An approach based on: Steger, Carsten, An unbiased detector of curvilinear structures Technical Report FGBV-96-03 July 1996 Technical university of Munich.

QC HELPER

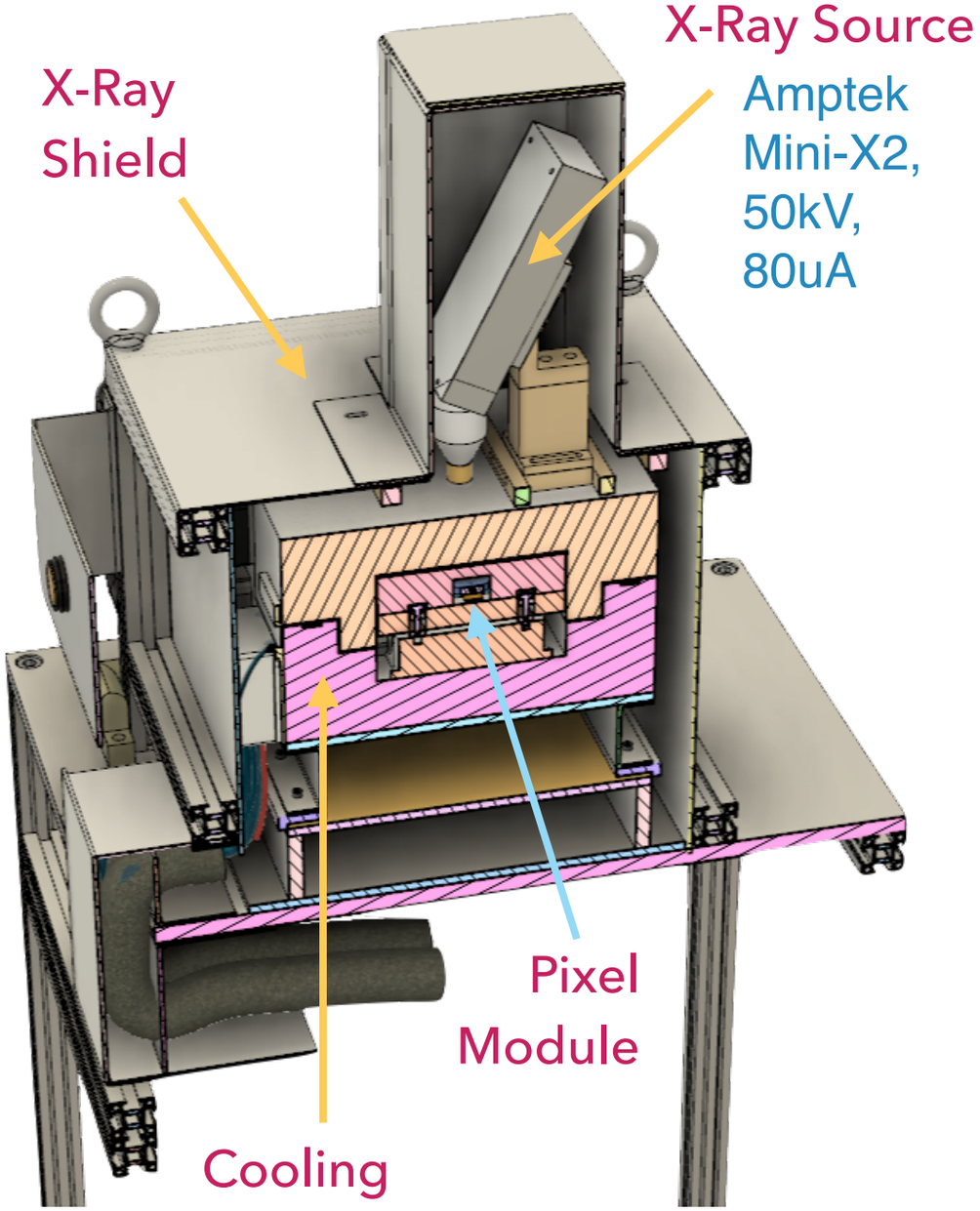
The practice mode for tests

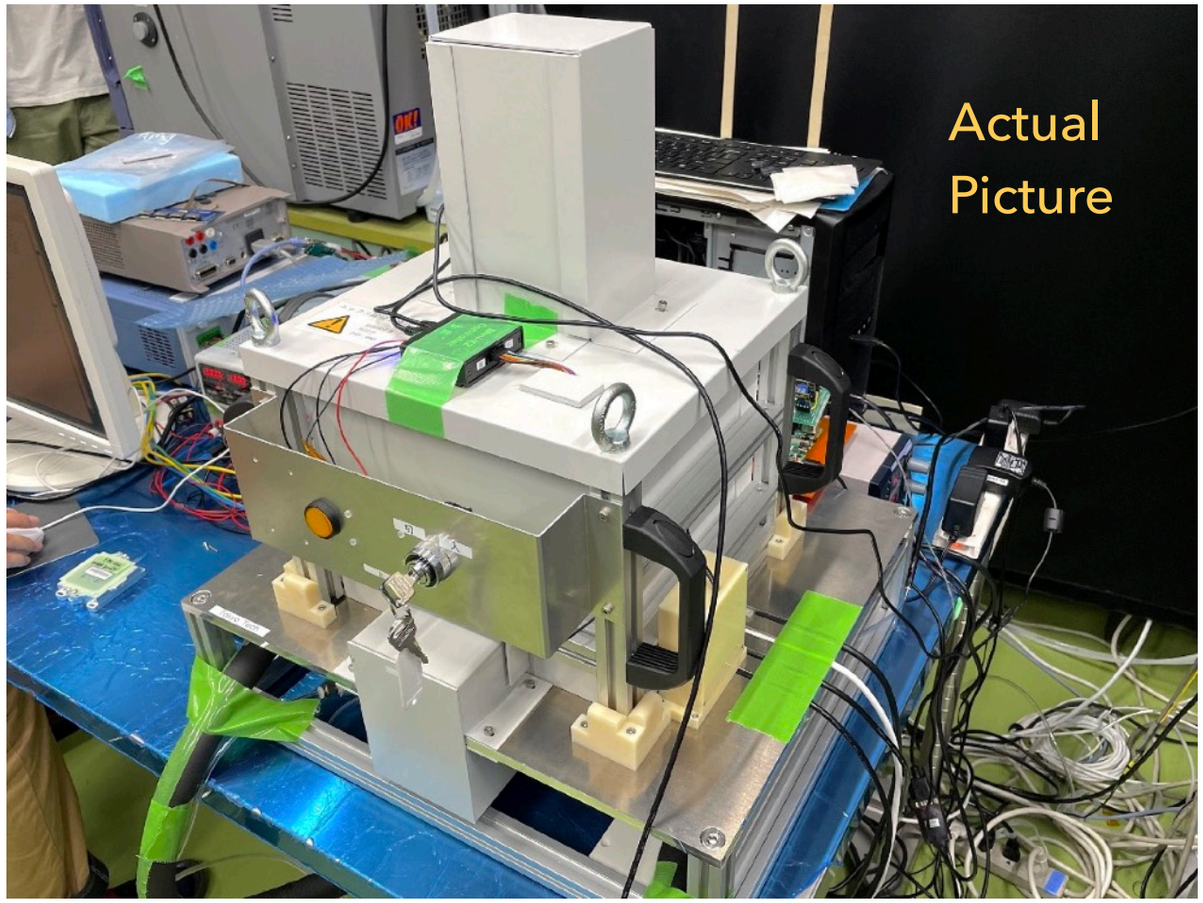






X-RAY SCAN SETUP





Developed and studied by:

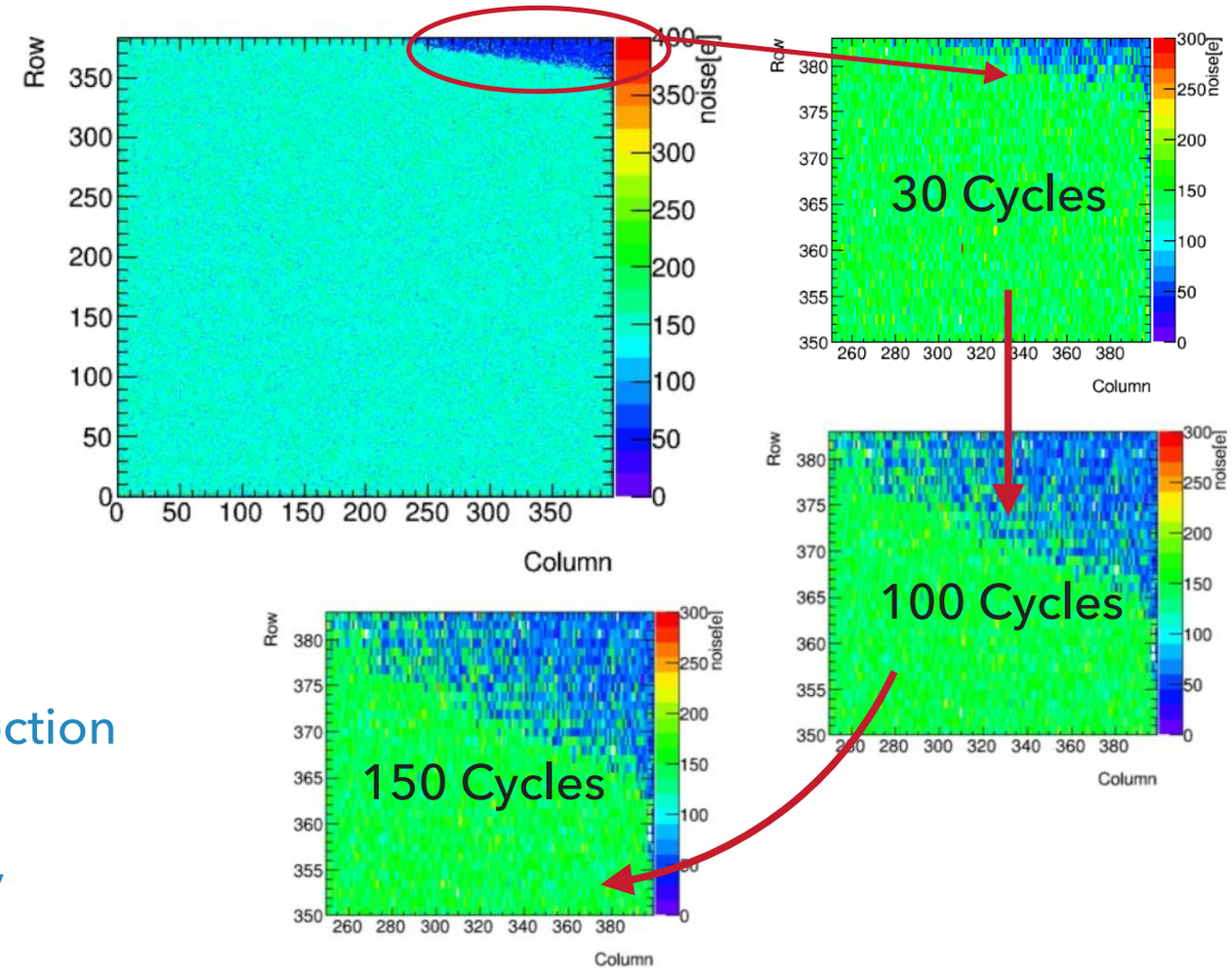
東京工業大学 Tokyo Institute of Technology

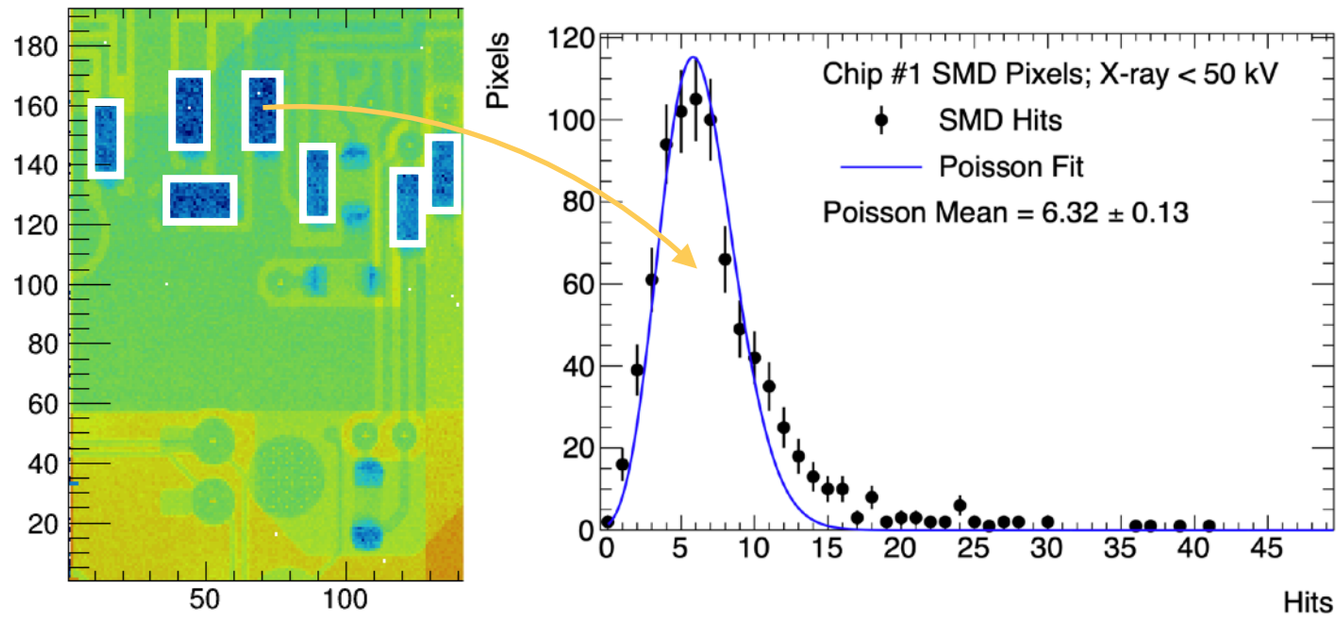
OSAKA UNIVERSITY

筑波大学 University of Tsukuba

X-RAY SOURCE SCAN

- This is effective in evaluating the bump-disconnection quickly.
  - De-lamination happens after thermal cycling.
- Challenge:
  - It is hard to evaluate the bump-disconnection under thick components.
  - Increasing the DAQ time is risky ➡ X-Ray exposure time < 5 mins.
- Solution - currently studying different options.
  - Increasing the DAQ rate to get more hits under components in the same time.
  - Masking parts other than the thick components.





CONCLUSION

- The Inner Tracker system of the LHC ATLAS experiment will be completely upgraded to a new system (called ITk) for the HL-LHC.
- For this upgrade, Japan plans to produce more than 2000 pixel modules.
  - Proper QA and QC of the pixel modules is necessary before installing in the detector.
  - Japan cluster developed it's own QA/QC system, and validated the performance of each part independently.
- We have completed most parts of our system, and verified it can be used to control and assure the quality of pixel modules.
- Although a few challenges still exist, we are working towards solving them through various studies.


BACK UP

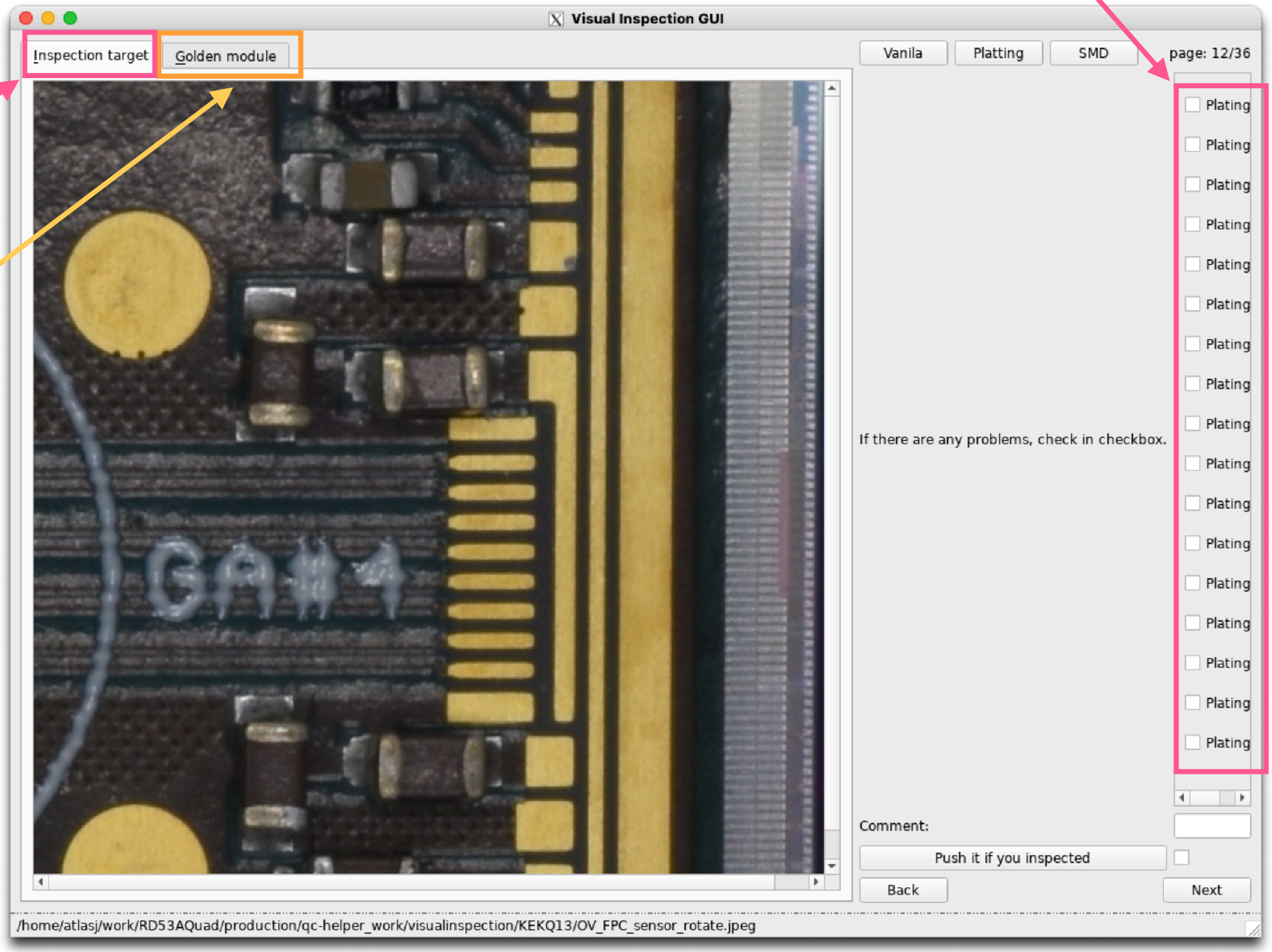
QC Helper – Visual Inspection

A tick box to mark if there is a problem

The module which is being inspected

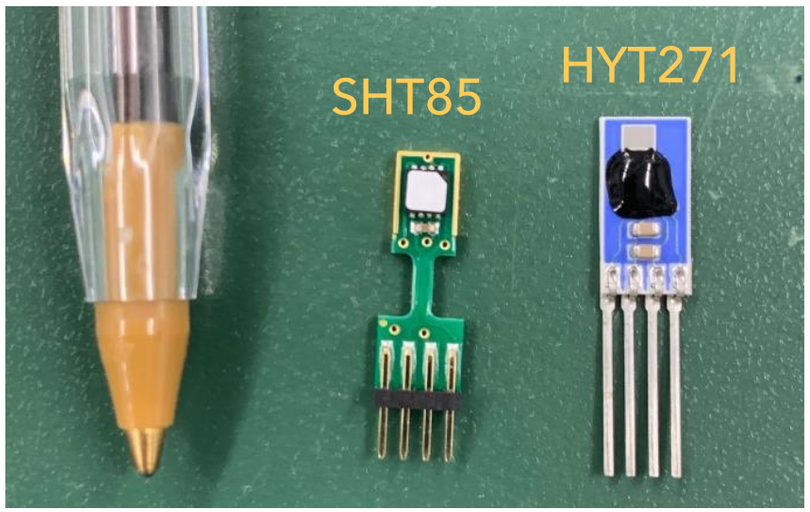
A reference of how it should look like if it was perfect

Results will get uploaded to the database by this tool.



HUMIDITY AND DEW POINT

- Another challenge: Accurate measurement of Humidity & Dew Point.
  - We used the SHT85 sensor at first, but found that **HYT271 sensor performs better**.



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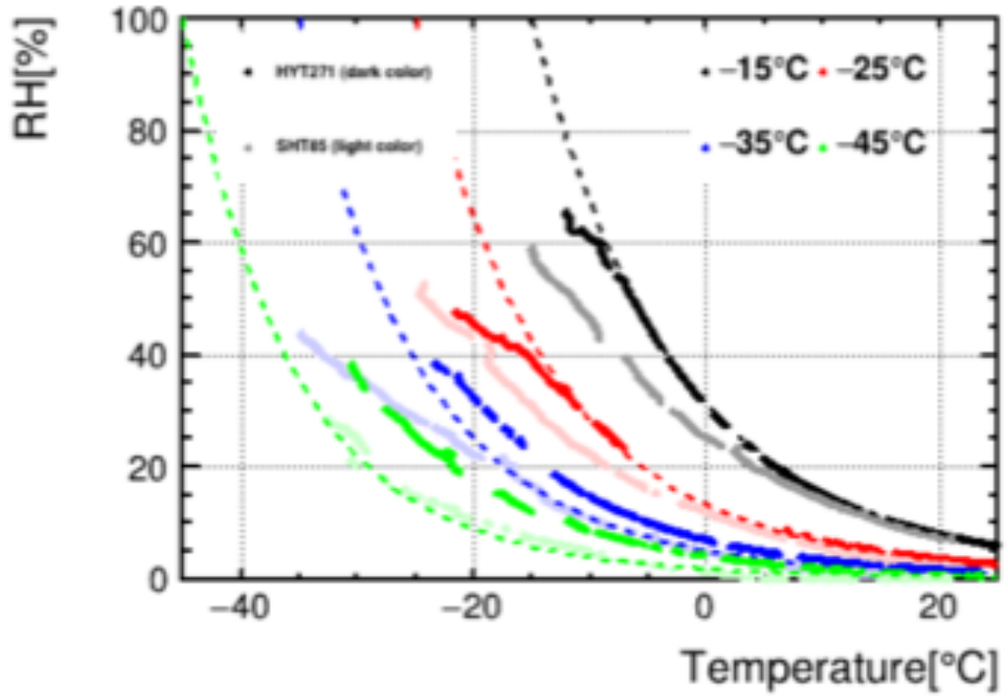
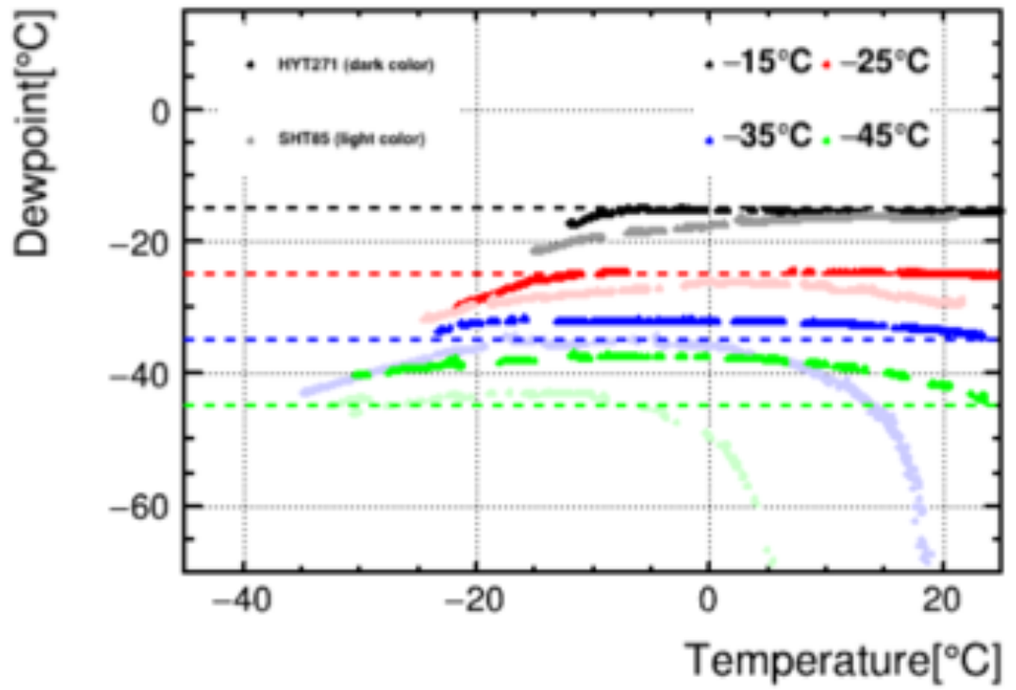




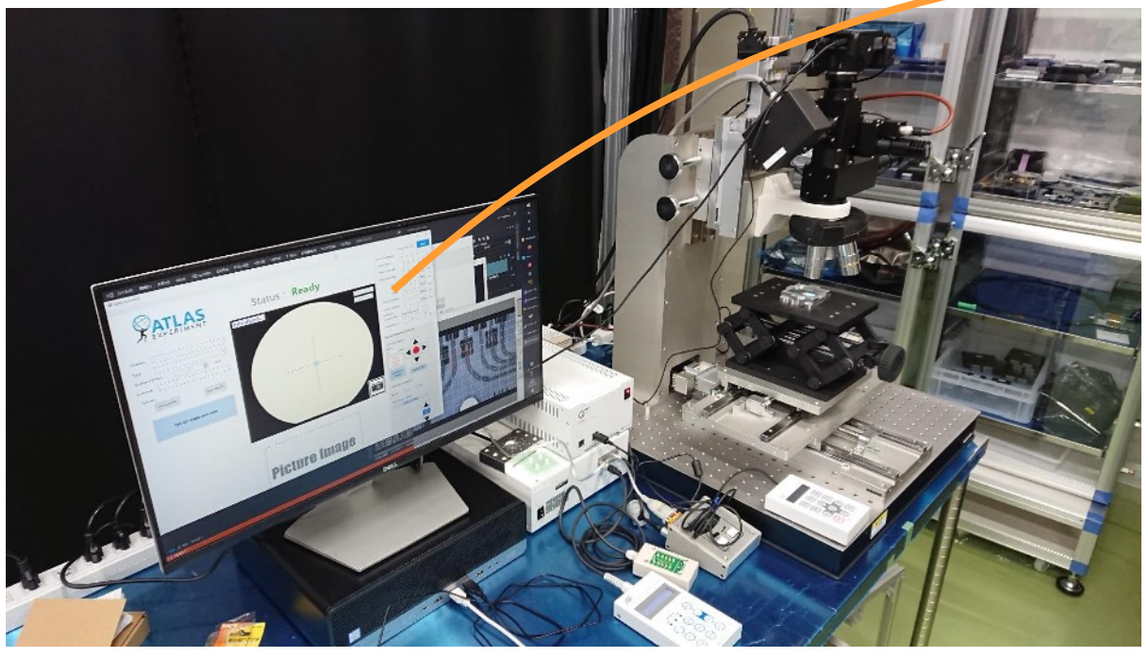
ENVIRONMENTAL MONITORING WITH Grafana

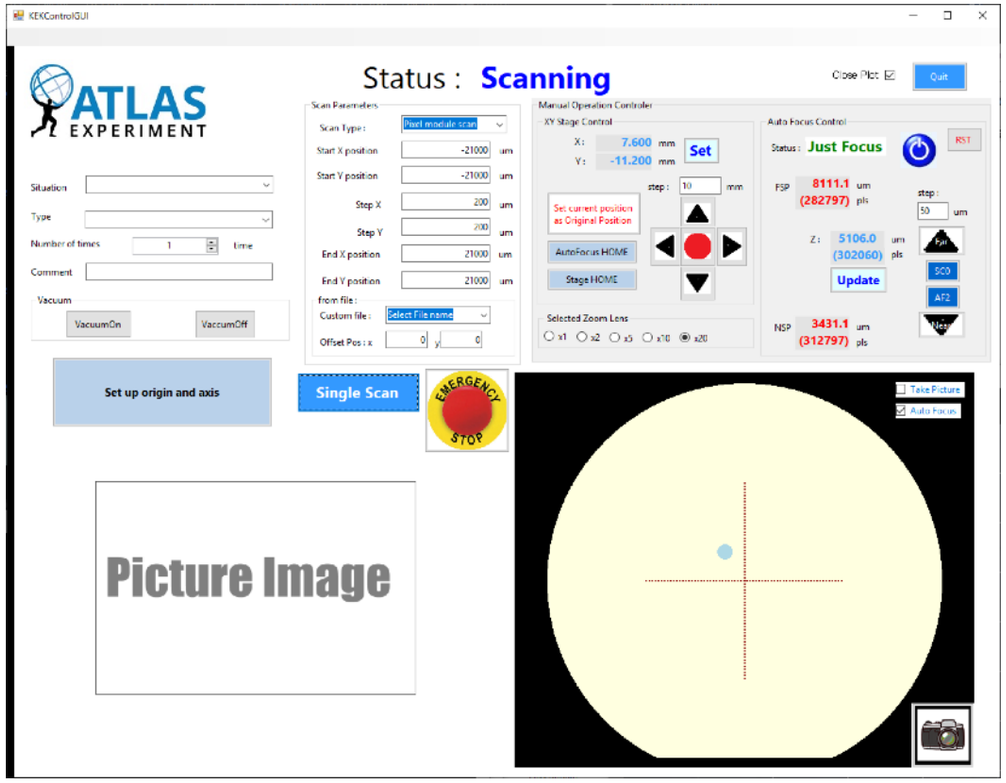
Temperature measurement at different points

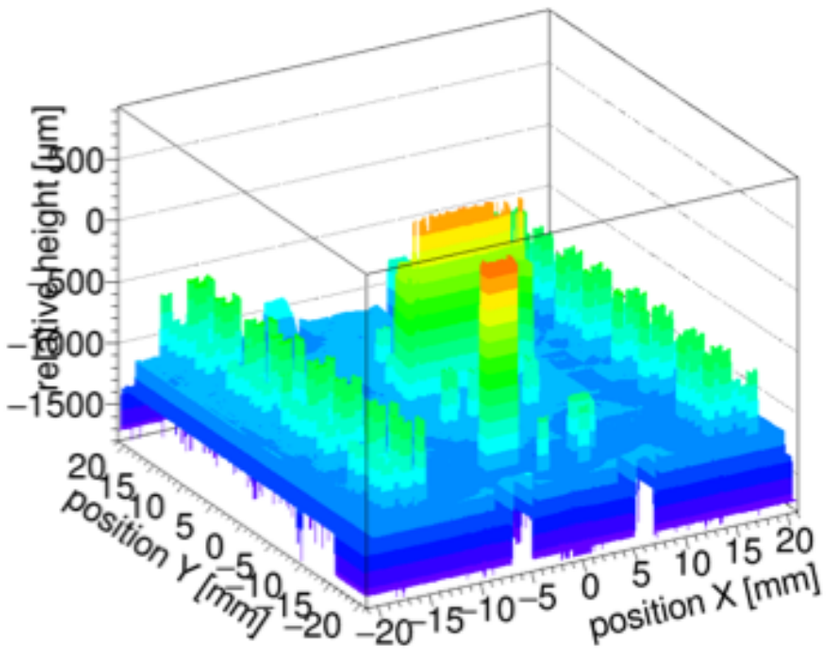
Temperature variation with time

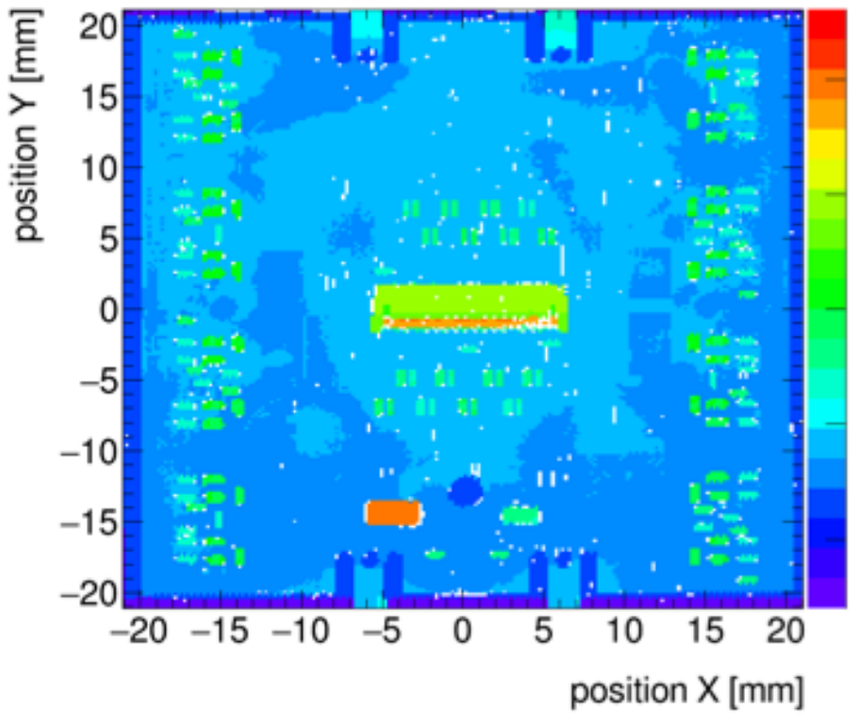
METROLOGY

A GUI designed by us

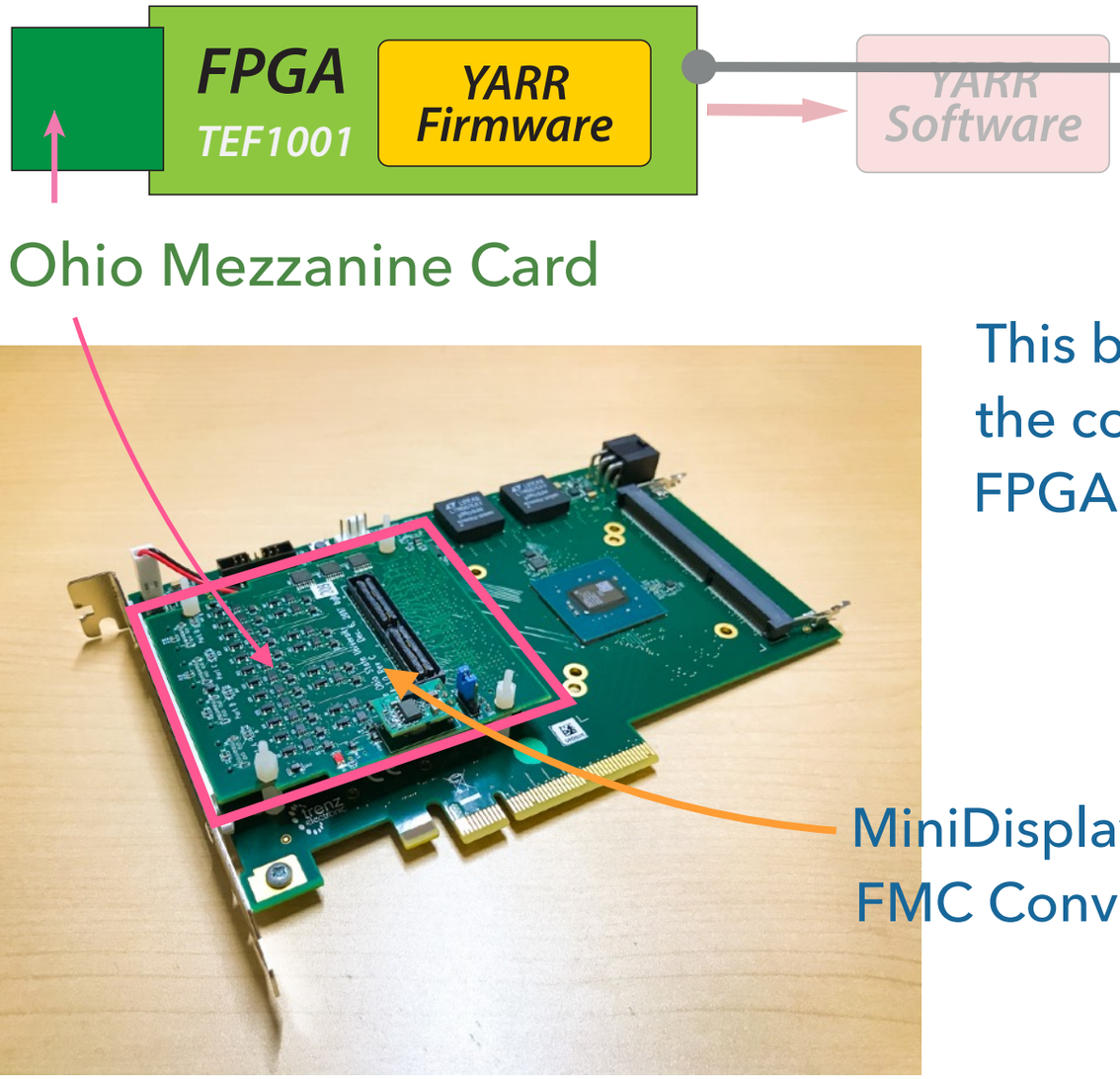








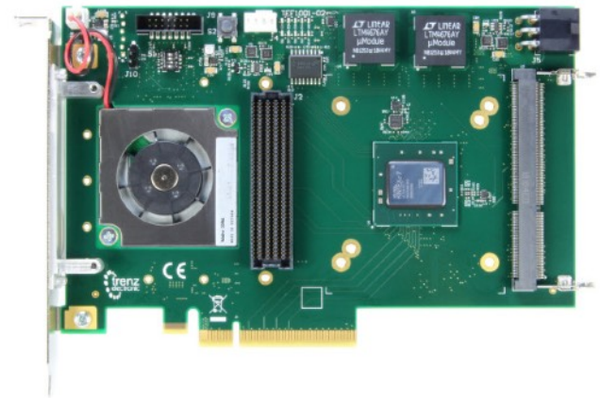
DAQ System – Hardware



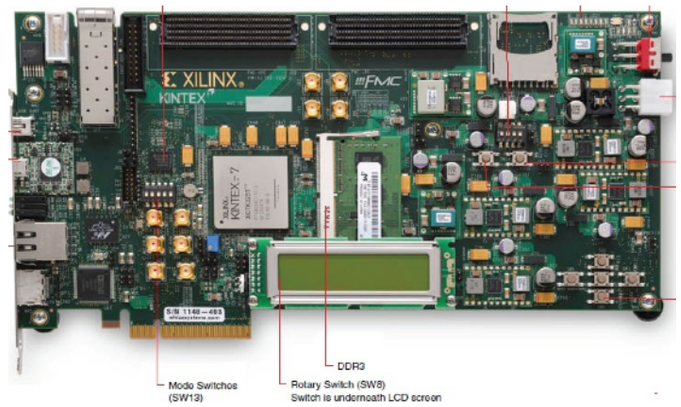
This became the common FPGA board.

Kintex7 FPGA Boards

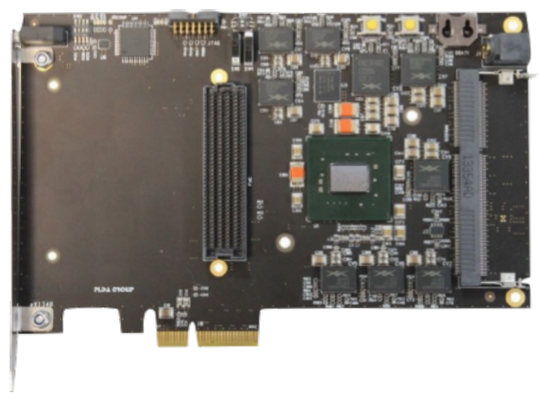
TEF1001 R2



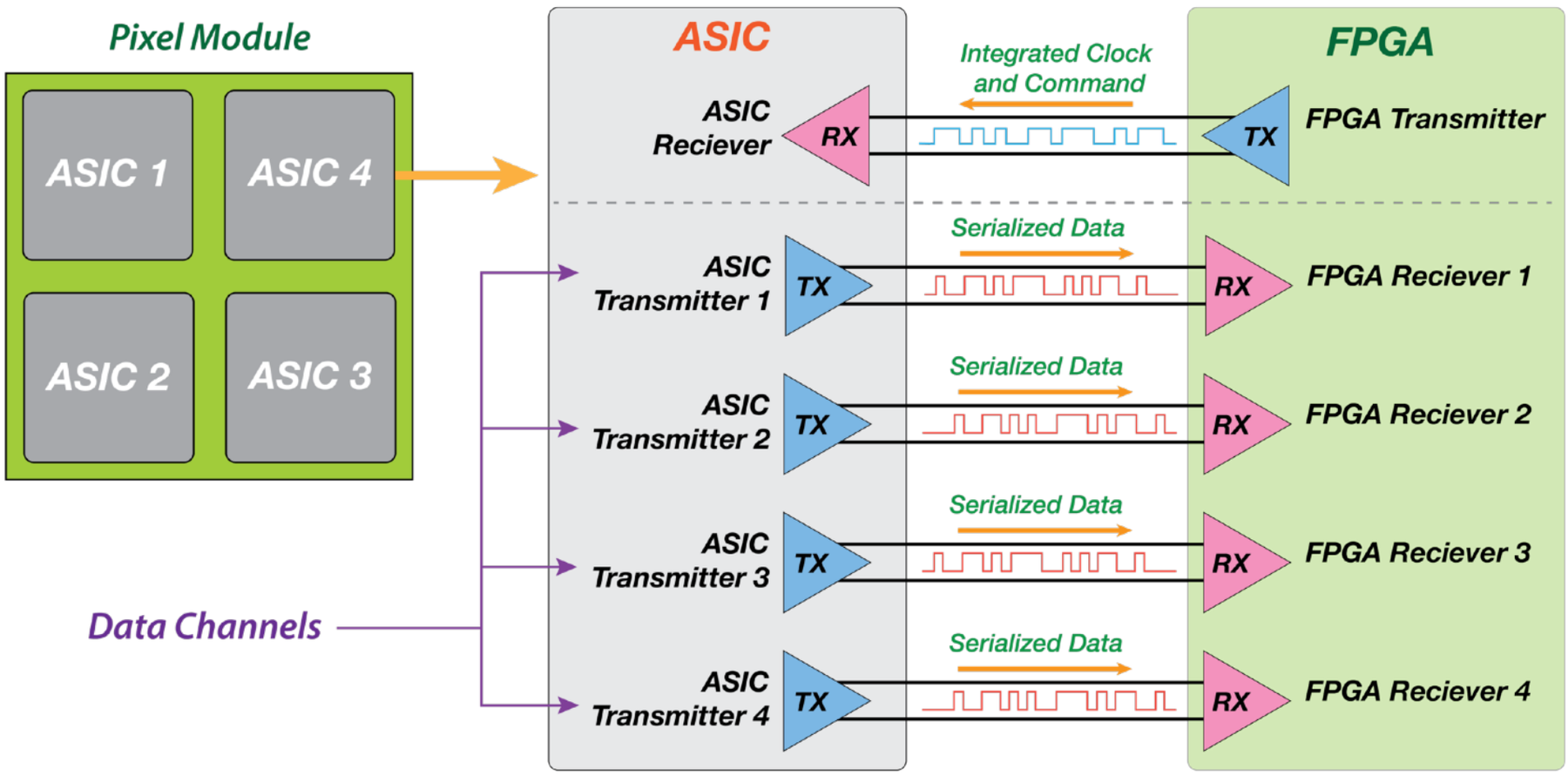
KC705

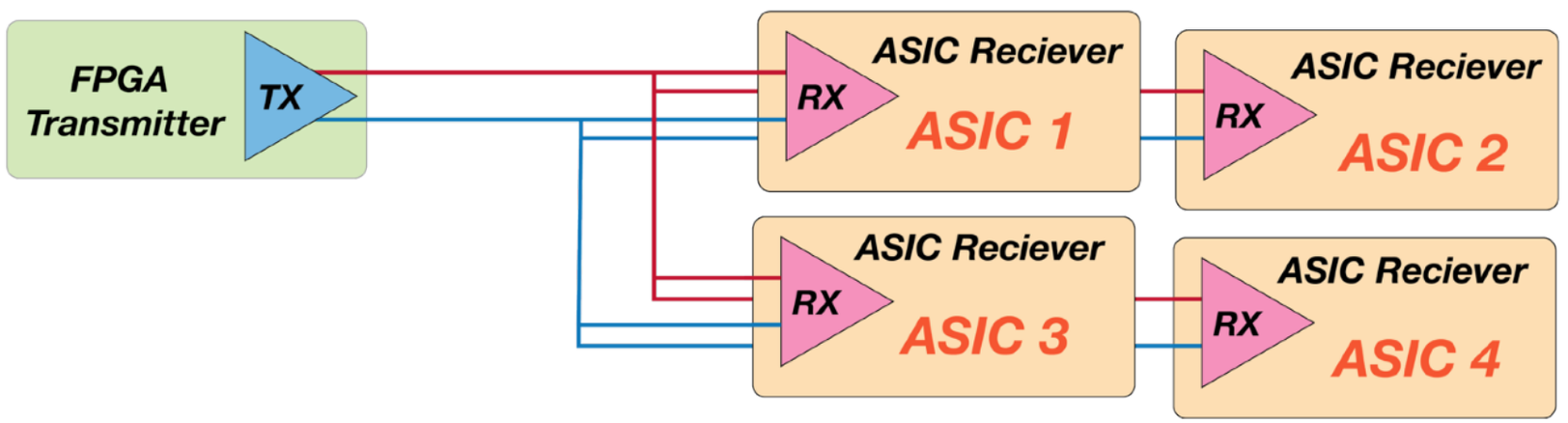


XPressK7



PIXEL DATA TRANSMISSION





UPSTREAM DATA TRANSMISSION IN ITK – I