An Internet Of Things (IoT) pilot project as a primer for the future development of IoT technology for particle physics detector data acquisition systems.

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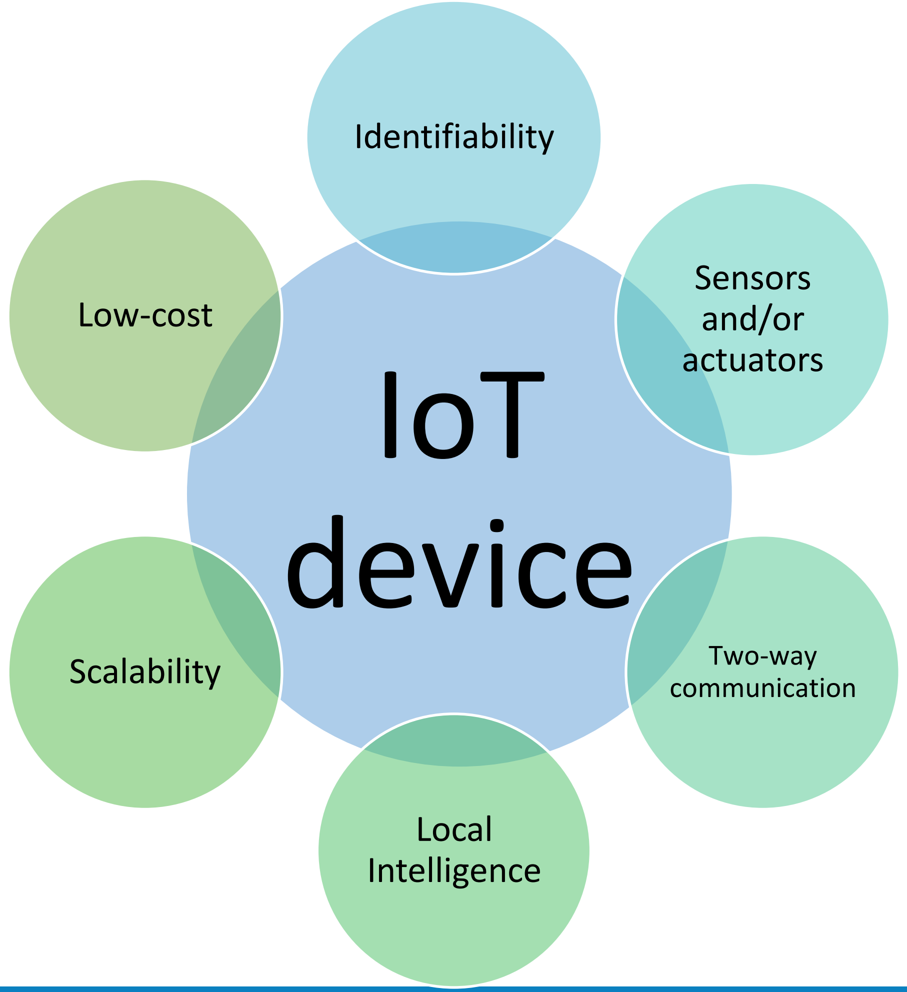
What is the Internet of Things (IoT)?

Definition: “The Internet of Things (IoT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment.” —Gartner research

- Provides the ability to share information and autonomously respond to real/physical
- Combines embedded systems with internet connectivity and has become possible due to the emergence of low-power microprocessors, low-power wireless technologies and low-cost sensors.

Generalized key characteristics of an IoT system:

- Identifiability on the internet (a unique IP address)
- Local intelligence often in the form of a microcontroller
- Sensors and/or actuators
- Ability for two-way communication



Future of DAQ Frameworks and Approaches, and Their Evolution towards the Internet of Things}

IoT and Particle Physics

- IoT is one of the drivers of “Big Data” due to the proliferation of IoT devices, particle physics is another.
- The large number of individual sensors and the huge amount of data are something that IoT has in common with particle physics Data Acquisition (DAQ) systems such as the ATLAS Hadronic Tile-Calorimeter Trigger and Data acquisition (TDAQ) system:

Create allot of data

Require low-power electronics

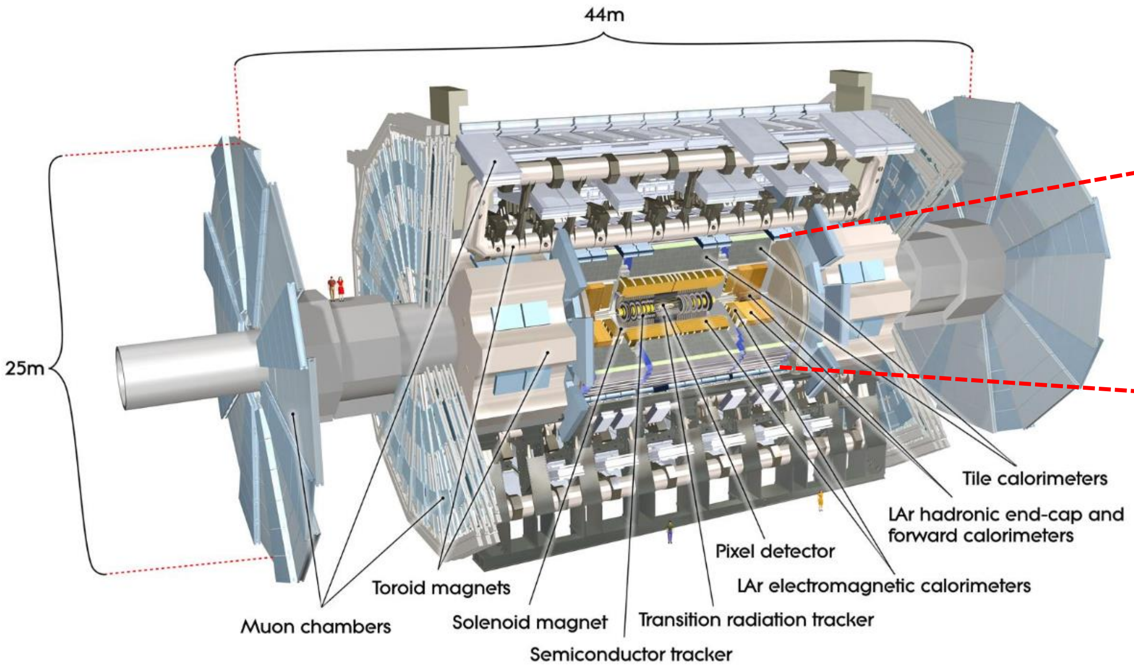
Require local intelligence

Driven by standardization

The ATLAS Tilecal as a working example

- The Tile-Calorimeter (TileCal) is a sampling calorimeter which forms the central region of the Hadronic calorimeter of the ATLAS experiment.
- In the Phase-II upgrade for the High-luminosity LHC, the analogue system will be replaced, and all data from the front-end electronics will be sent to the trigger system at 40 MHz and with a maximum latency of about 1.7 μs.
- The new scheme requires 2048 optical links (plus another 2048 for redundancy/backup) with a bandwidth of 9.6 Gbps per link.

Link: Upgrade of ATLAS Hadronic Tile Calorimeter for the High Luminosity LHC:



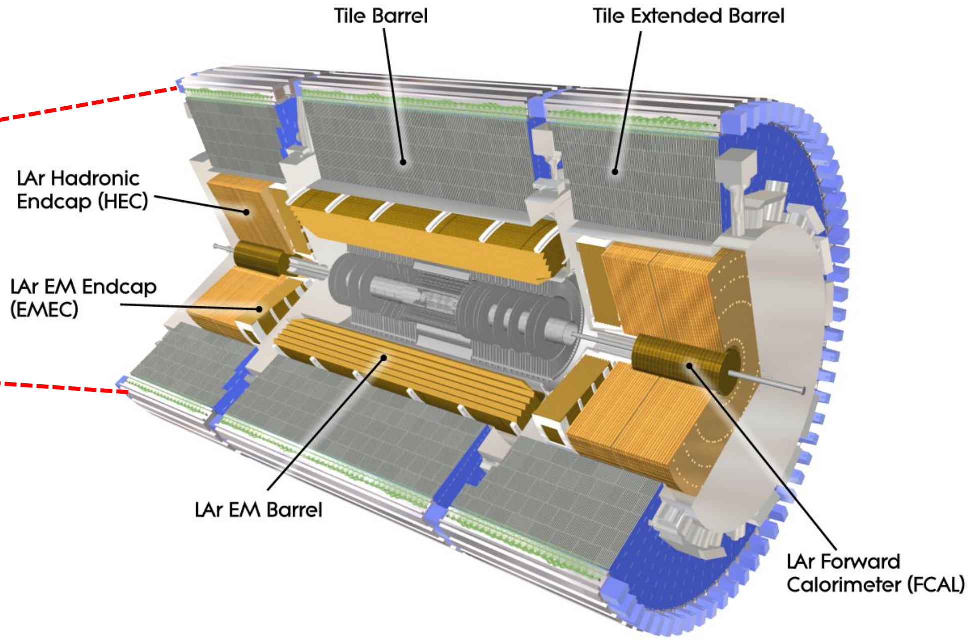


Fig. The ATLAS detector (Left). The ATLAS inner Barrel (Right) -*J. Pequenao, Computer Generated image of the ATLAS calorimeter,(2008), https: // cds. cern. ch/ record/ 1095927*

Particle Physics DAQ systems

- DAQ systems are typically designed in unison with the detector and are very specialized.

A DAQ system in general includes the following functionalities:

- Data transport from the detector
- Event-building in case of multiple data-sources
- a job control for the typically many software processes involved
- Some interface for monitoring of inflight data for the purposes of quality control and debugging.
- A control-system to steer the acquisition. It also should interface to and/or synchronize with important external systems. – Such as the LHC
- An interface to data processing
- An interface to long-term storage

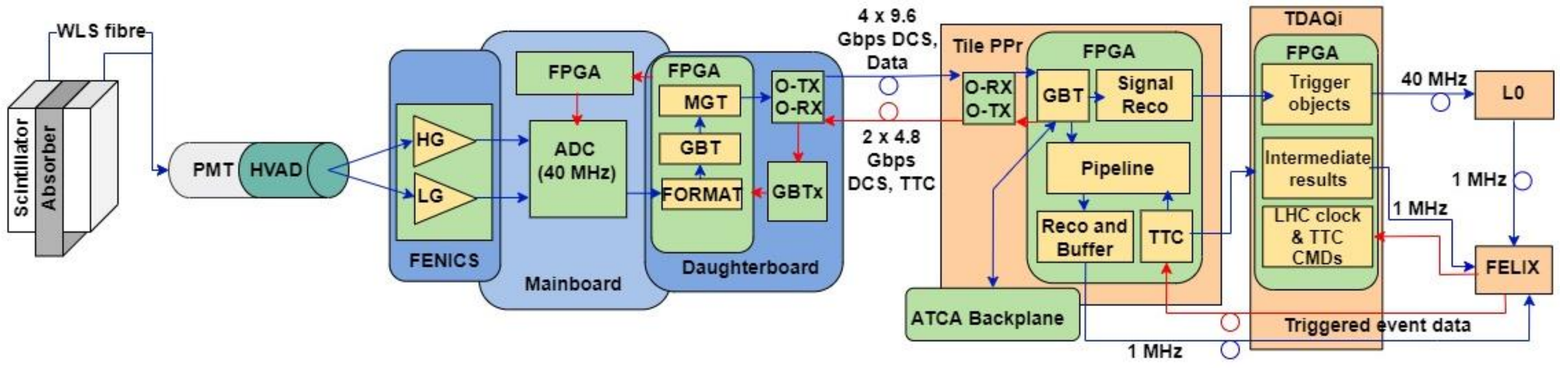


Fig. Schematic signal and data path for the upgraded Tile Calorimeter. (As of 2021)

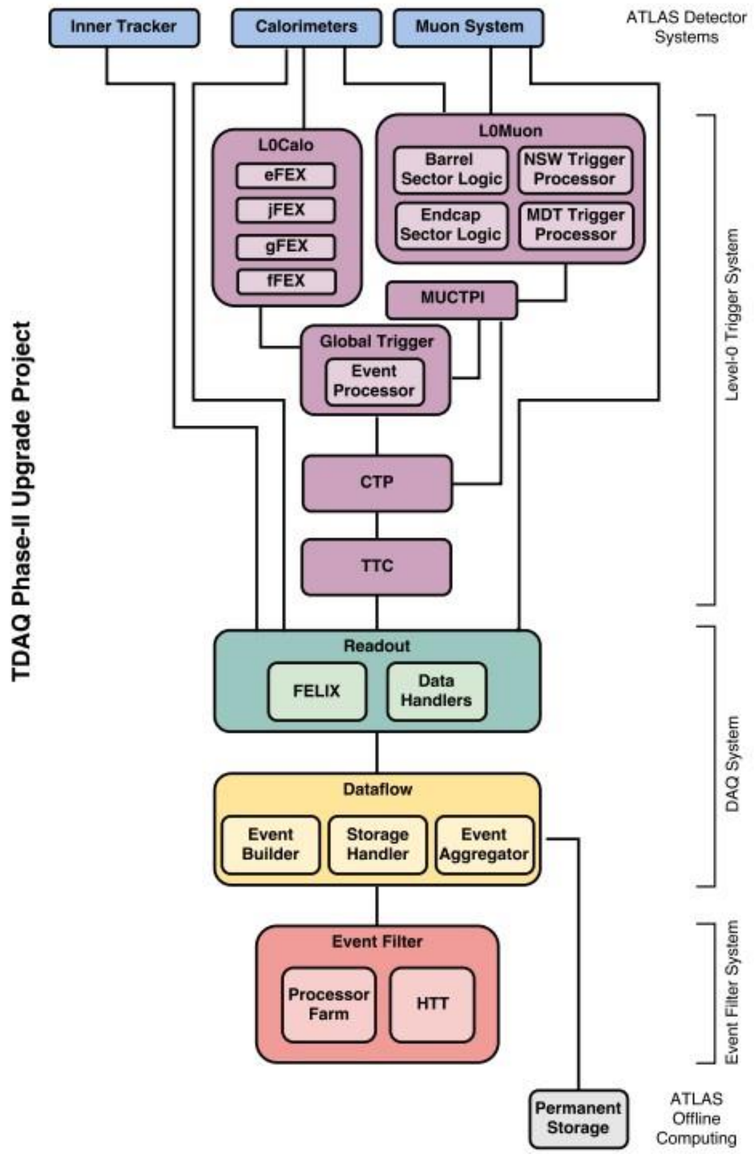


Fig. Design of the TDAQ Phase-II upgrade architecture, *ATLAS-TDR-029-TDAQ*

Particle Physics DAQ systems and ‘dead material’

- Currently lots of data = lots of high-speed infrastructure
- The front-end electronics also require a ‘slow’ detector control system that uses conventional wiring.
- When we then consider services such as cooling, high and low voltage power distribution systems etc there is allot of ‘dead material’ within the detector.
- Dead material can be defined as anything within a detector that does not directly contribute to particle detection.

Let's focus on Wiring which is undesirable due to many reasons:

- Accessibility
- Risk of damage during detector maintenance
- Risk to technicians during maintenance periods in radiation-controlled zones.
- Costly
- Does not directly contribute to particle detection. In fact, it causes heightened complexity due to multiple scattering and nuclear interactions that degrade the precision on the measurement of track momentum and interaction vertices.
- Occupies space that could otherwise be used by active material (the sensors).

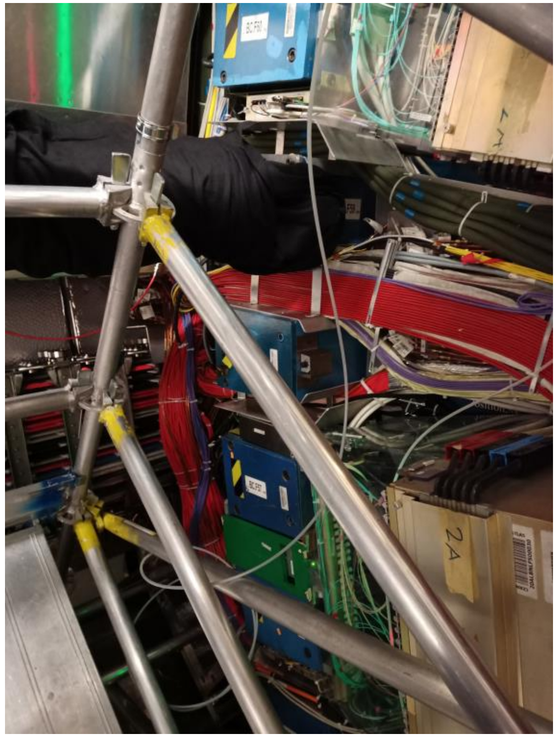


Fig. The ATLAS Tilecal during maintenance

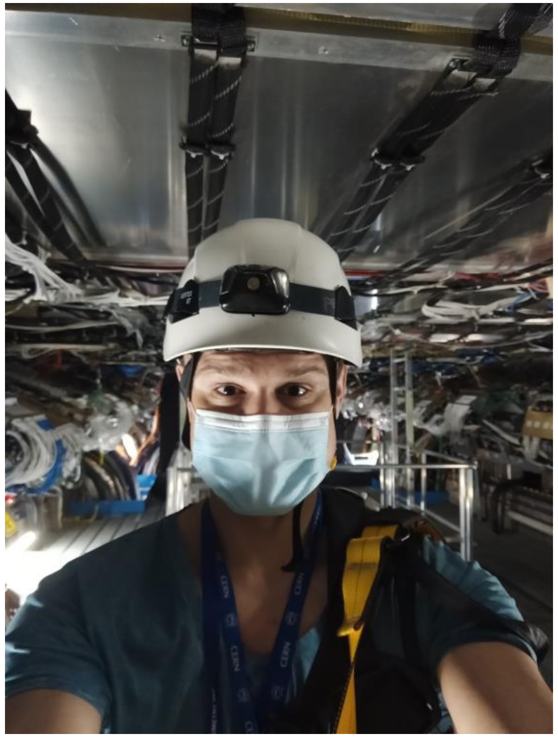


Fig. Inside the ATLAS detector, wires everywhere!

The use of IoT in DAQ systems

- Wireless technologies offer a unique and very elegant opportunity to send broadcasts. This is particularly interesting for steering and control of a complex detector system and might save a lot of cables if one single signal is sent to many receivers.
- The total or even partial removal of cables and connectors will result in cost reductions, simplified installation and repair, and reductions in detector dead material. These two last aspects are especially important in tracking detectors and may become particularly important in case of limited access or/and hostile environment
- Wireless data transfer offers the possibility to realize topologies which are much more difficult to be realized using wires, as data from one single point can be sent to several receivers or several transceivers send to one receiver.

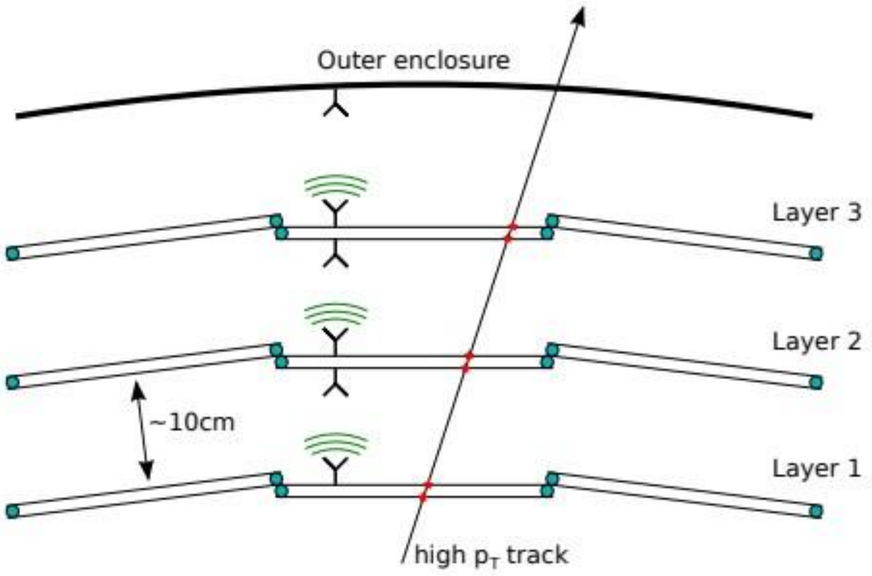


Fig. **Proposal of a radial readout for the tracker detector of the ATLAS experiment. arXiv:1604.06259v1**

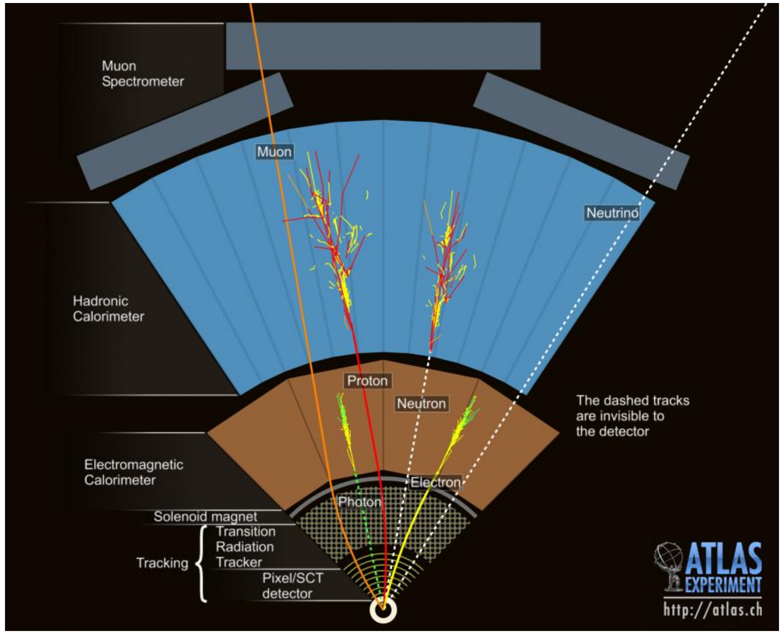


Fig. An illustration of an event cross-section as detected within the ATLAS detector

Possible Future –ee accelerators

Future Circular Collider (FCC-ee)

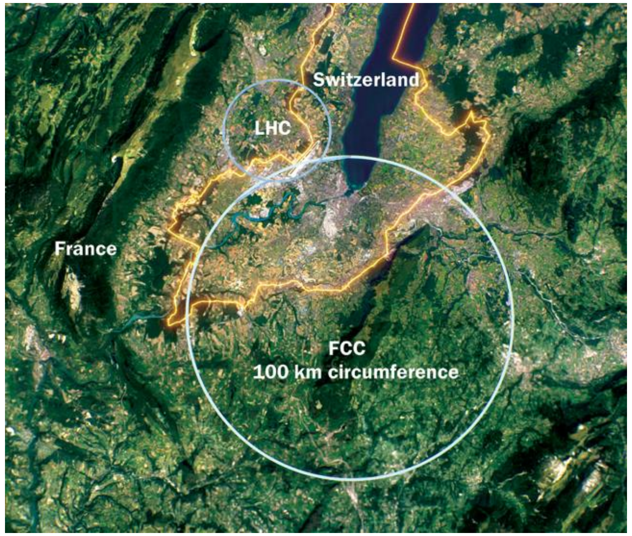


Fig. **The proposed layout of the Future Circular Collider. Credit: CERN**

International Linear Collider (ILC)

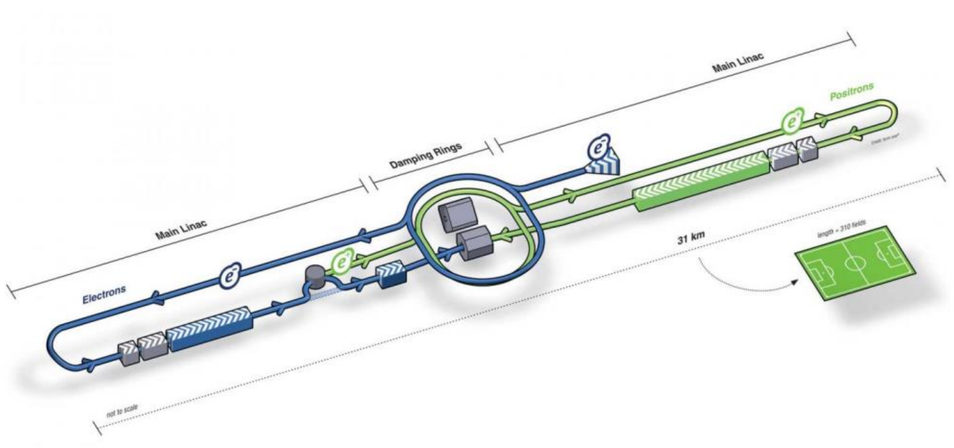


Fig. **The proposed layout of ILC . Credit: ILC**

Compact Linear Collider (CLIC)

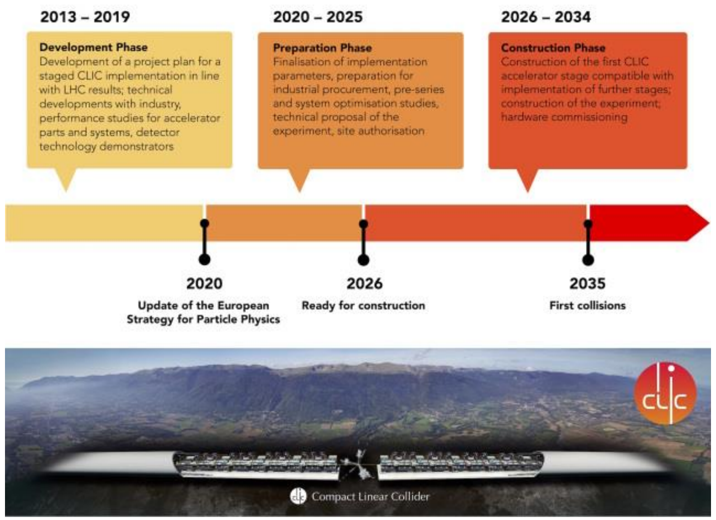


Fig. The CLIC project timeline **. Credit: CERN**

CLICK status 2021

ILC Status 2021

CEPC status 2021

FCC -ee status 2021

Circular Electron Positron Collider (CEPC)

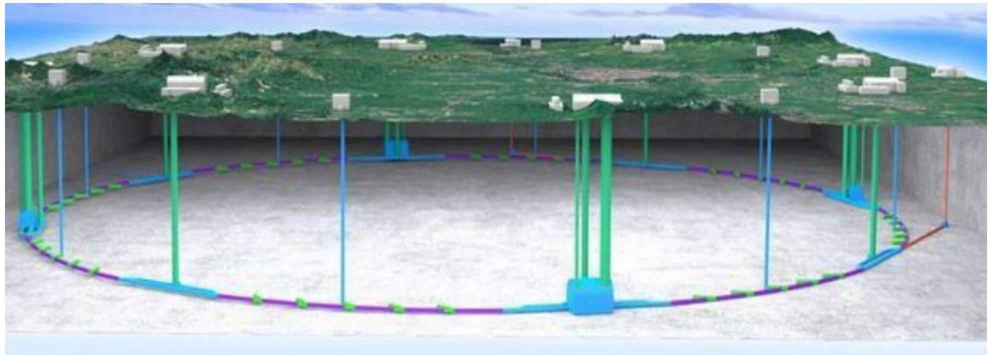
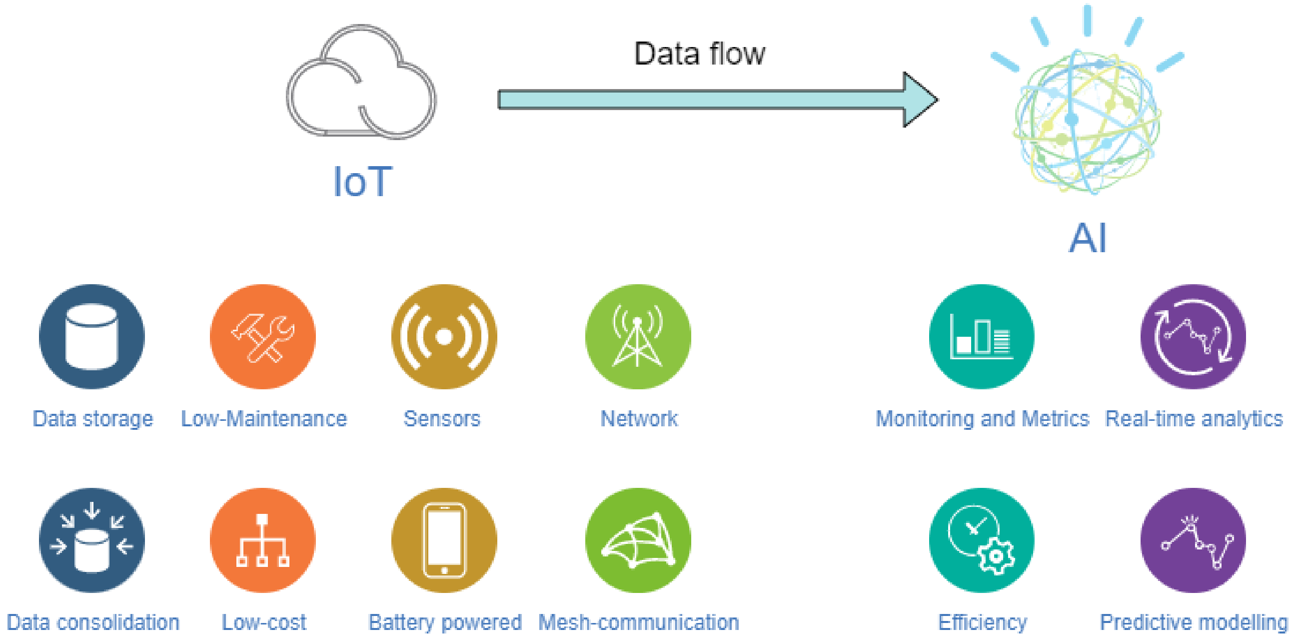


Fig. **The proposed layout of CEPC . Credit: CEPC**

Pilot project Overview

- Purpose – The development of the key skills required for design and deployment of novel IoT systems within particle physics DAQs.

- WITS in collaboration with the University of Valencia has undertaken the development of a “smart” surveillance system that combines the fields of low-power IoT and artificial intelligence.
- The system utilizes battery-powered sensor nodes that communicate over a wireless mesh network.
- The nodes, once activated, take a series of images which are then transmitted to a cloud for analysis.
- Once on the cloud, the images make use of a machine-learning algorithm to determine if they contain any indicators of human activity.
- Based on the outcome a notification is sent to the user.



Pilot project –IoT node

We want to emulate as many key aspects as possible of a possible IoT application for on-detector electronics:

Triggering
- Via local PIR

Sensors
- Temperature, humidity and optical

Local Intelligence
- Nordicn nRF52840 SoC

Wireless communication
Nordic nRF52840 Dongle

- The figure on the right displays a computer aided design of a IoT device that has been optimized for low-cost production and low-energy consumption.
- The device is centered around the Nordic nRF52840 Dongle.

Fig. **Nordic nRF52840 Dongle** *, Credit: Nordic Semiconductor*

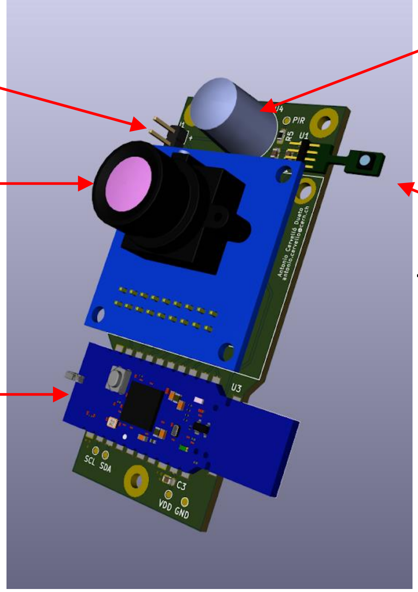
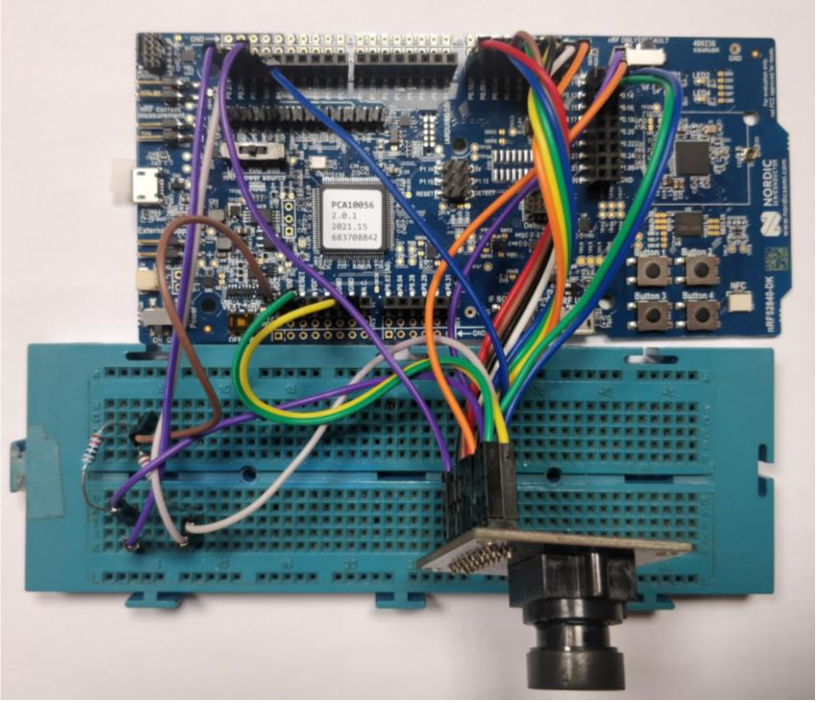


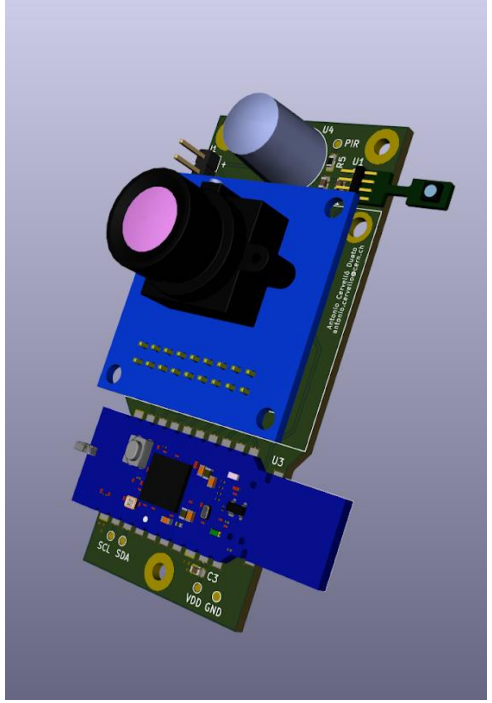
Fig. A computer aided design of a sensor node, Antonio Duato

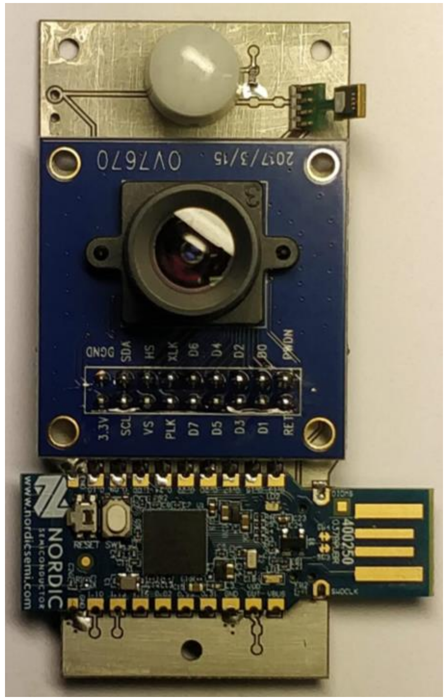
IoT node – prototyping

The development of an IoT node follows a standardized process:

- The use of a development board and peripherals allows for the rapid commencement of work.
- Computer aided design is then utilized for the design of the node.
- An inhouse prototype PCB is produced allowing for the design to be validated.
- The PCBs are then produced by a manufacturer and are populated.







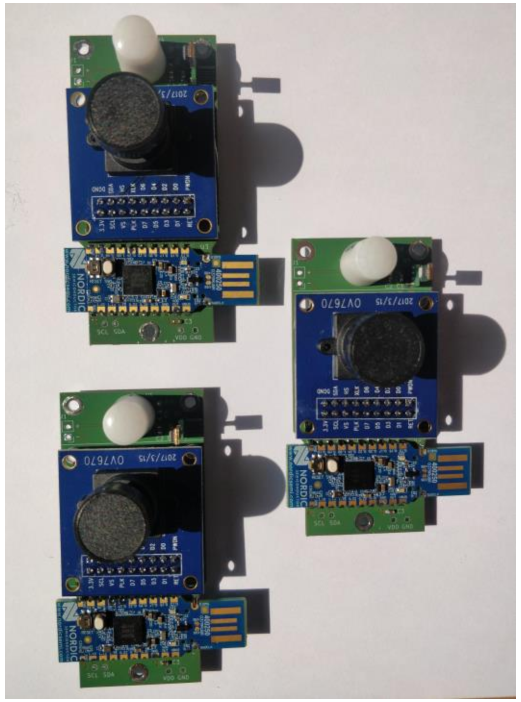


Fig. The evolution of an IoT node prototype, Antonio Duato

IoT node Power Analysis

- The power consumption of the IoT node is a key operational parameter that needs to be understood and then optimized.
- The Nordic power profiler kit is specifically designed to conduct power analysis.
- The power consumption of the Nordic SoC was measured while running the OV7670 camera firmware.
- The results can be seen below with the period power consumption spikes being attributed to the execution of specific lines of firmware code.

200nA to 1A current measurement range with a resolution that varies between 100nA and 1mA
Source mode and ampere meter mode
Source mode includes built-in programmable regulator with a 0.8V to 5V output range and up to 1A current supply
100 ksps sampling rate (10 x greater than previous generation)
8 digital inputs for low-end logic analyzer support
Measure instantaneous and average current on all Nordic DKs, in addition to custom boards
Export measurement data for postprocessing

Fig. A Nordic Power Profiler kit II. Credit: Nordic Semiconductor

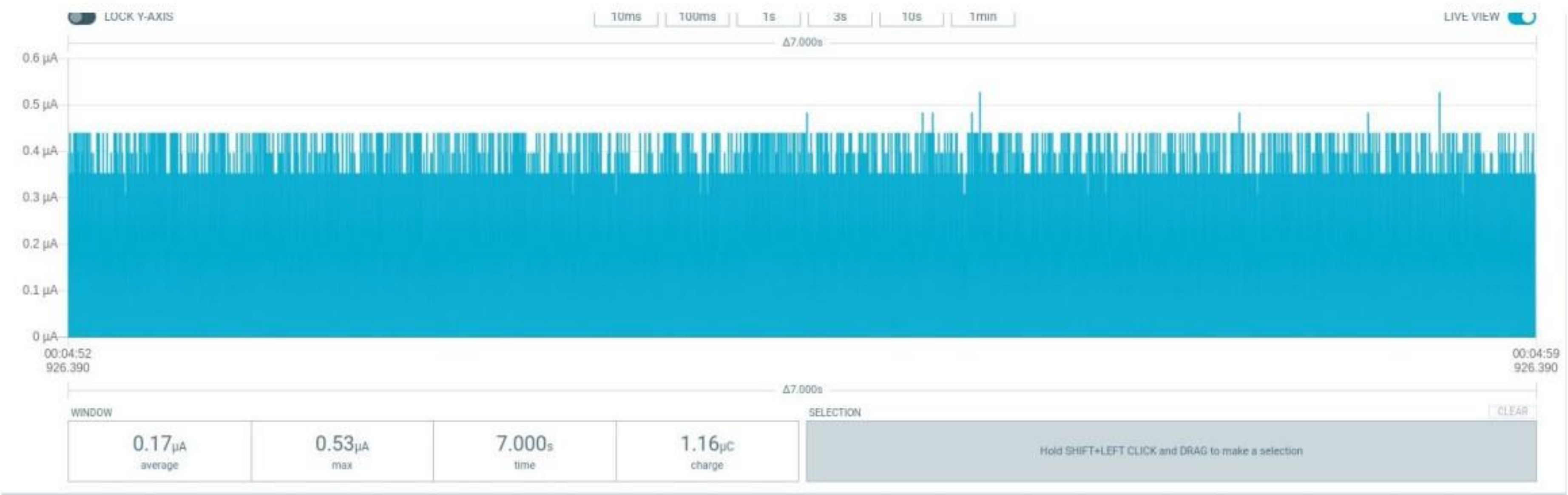


Fig. OV7670 power consumption measurement by Nathan Boyles

Pilot Project – Where to now

POWER OPTIMIZATION RESEARCH OF THE IOT NODE.

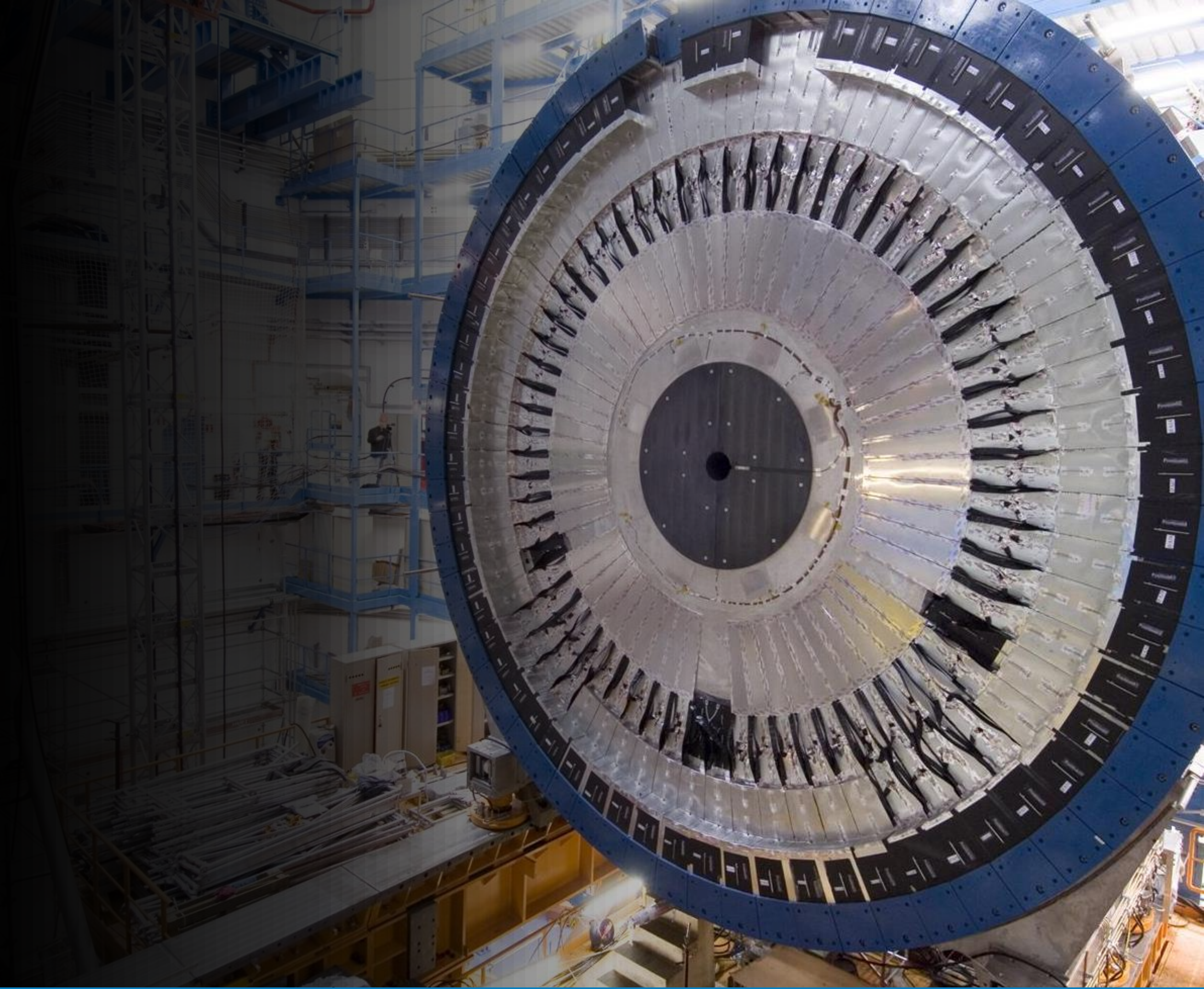
MESH COMMUNICATION BETWEEN MULTIPLE NODES.

TRANSMISSION OF DATA TO CLOUD FOR ANALYSIS.

REMOTE TRIGGERING OF SENSOR NODE.

[CERN Green Village | SCE]

Reference slides



The ATLAS Tile-Calorimeter

- The Tile-Calorimeter (TileCal) is a sampling calorimeter which forms the central region of the Hadronic calorimeter of the ATLAS experiment.
- It performs several critical functions within ATLAS such as the measurement and reconstruction of hadrons, jets, hadronic decays of τ -leptons, and missing transverse energy. It also participates in muon identification and provides inputs to the Level 1 calorimeter trigger system.
- TileCal is composed of 256 wedge-shaped modules which are arranged azimuthally around the beam axis. A module consists of alternating steel (absorber) tiles and plastic scintillating tiles (active medium) with a Super Drawer (SD) housing the Front-End (FE) electronics and the Photomultiplier tubes located on its outer radius.
- A Low-Voltage Power Supply (LVPS), of which there is one per TileCal module, steps down 200 V DC, received from off-detector high-voltage supplies, to the 10 V DC required by the front-end electronics.
- The LVPS's location can be seen in Fig.1 where they are housed within shielding (blue boxes) attached to the outer radii of the Tilecal modules.

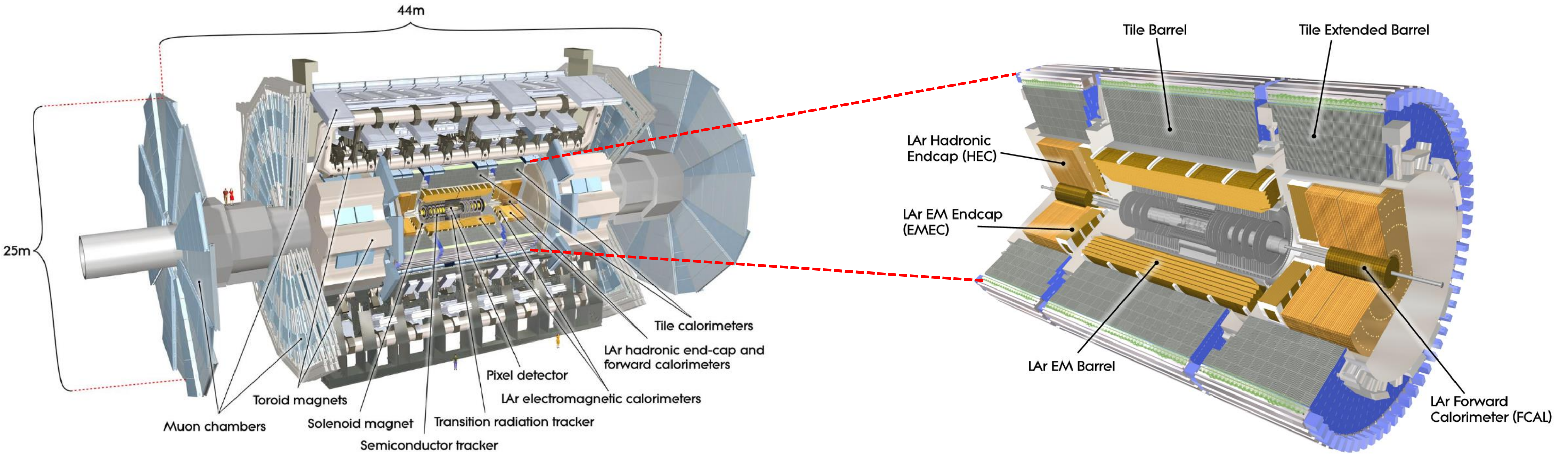


Fig.1 The ATLAS detector (Left). The ATLAS inner Barrel (Right) *-J. Pequenao, Computer Generated image of the ATLAS calorimeter,(2008), https: // cds. cern. ch/ record/ 1095927*

Application of IoT in future particle physics experiments

The application of IoT in the DAQ systems of future electron-positron collider experiments is highly feasible due to:

- Reduced radiation hardness requirements for electronics allowing for further adoption of COTs.
- Experiments will primarily focus on high precision measurements of known particles as opposed to probing the energy frontier necessitating high granularity detectors with reduced dead-material.
- Reduced data transmission requirements. For example, the data to be sent to the FCC –ee IDEA detector acquisition system for each trigger is ~100 GB/s, more than one order of magnitude lower than the amount of data that will be readout by ATLAS during the HL-LHC.

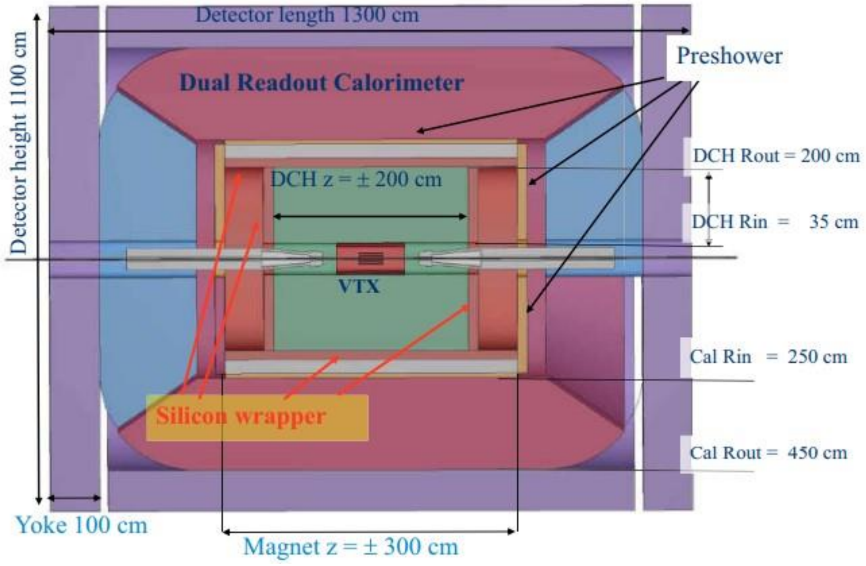


Fig. **Schematic layout of the IDEA detector**.

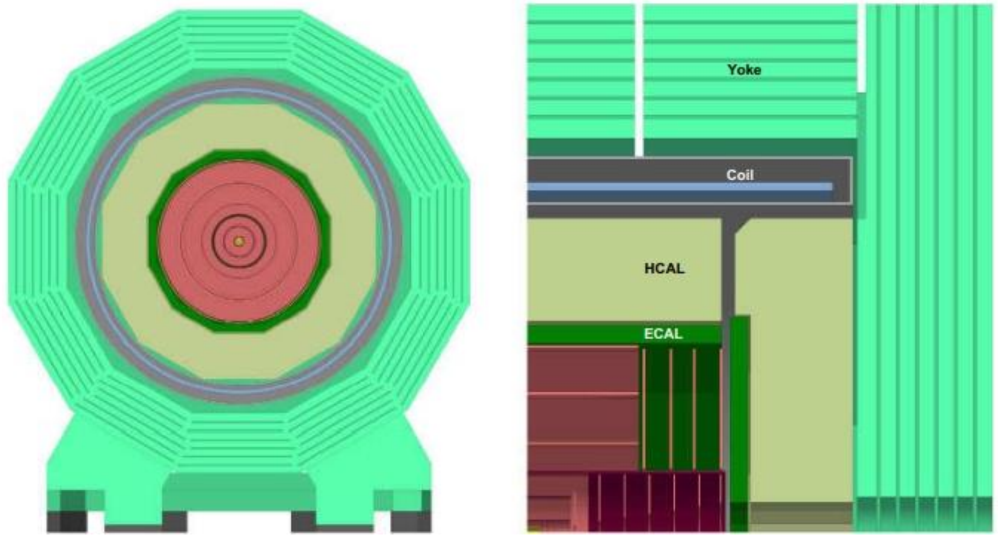


Fig. **The CLD concept detector: end view cut through (left), longitudinal cross section of the top right quadrant (right).**

FCC-ee:The Experimental Challenge FCC-ee: The Lepton Collider - Future Circular Collider Conceptual Design Report Volume 2 - see Pg 515 and 516