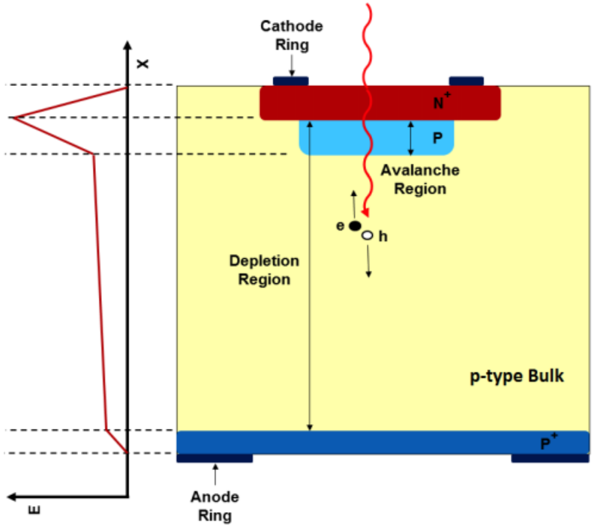
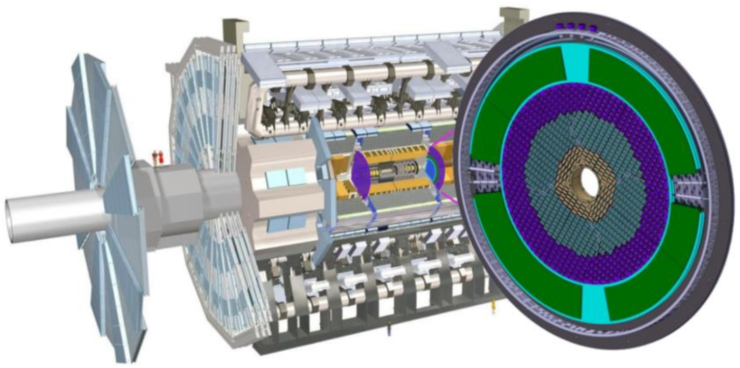
High Granularity Timing Detector Data Acquisition system

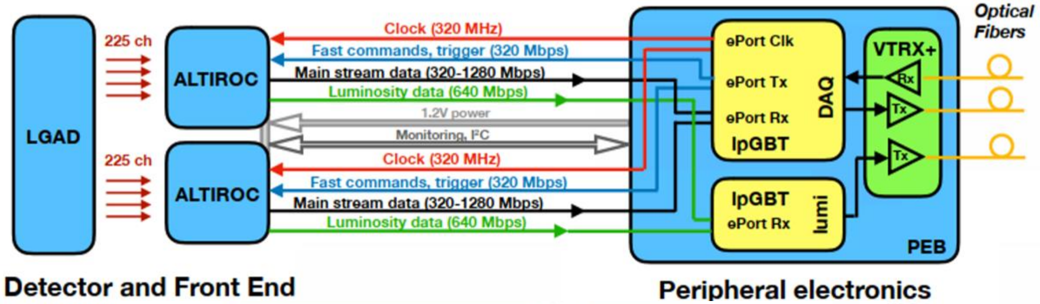
Aonan Wang
on behalf of HGTD DAQ software team and USTC HGTD group

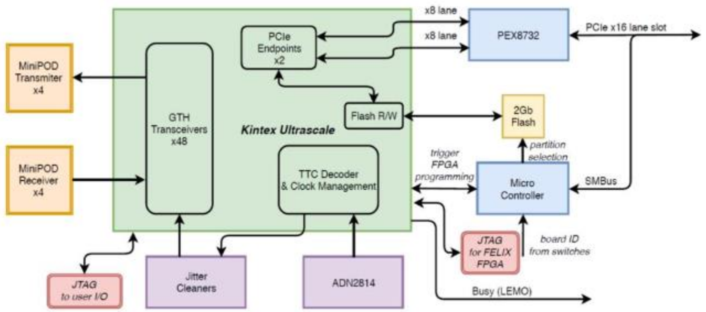
CLHCP, 11/1/2025

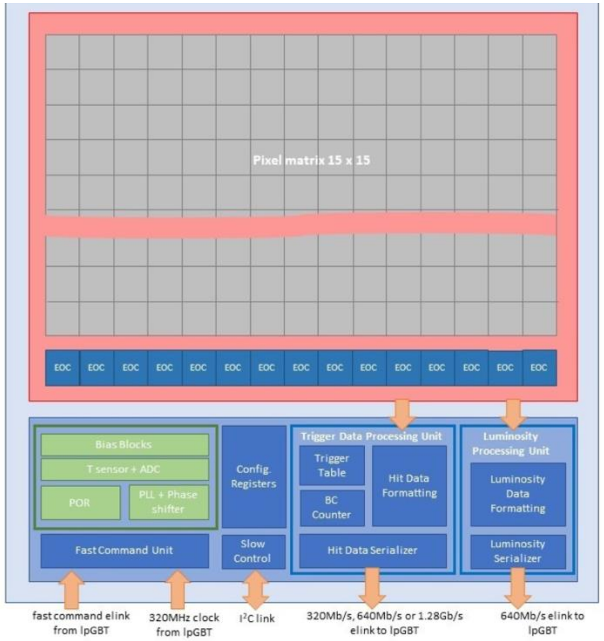
HGTD









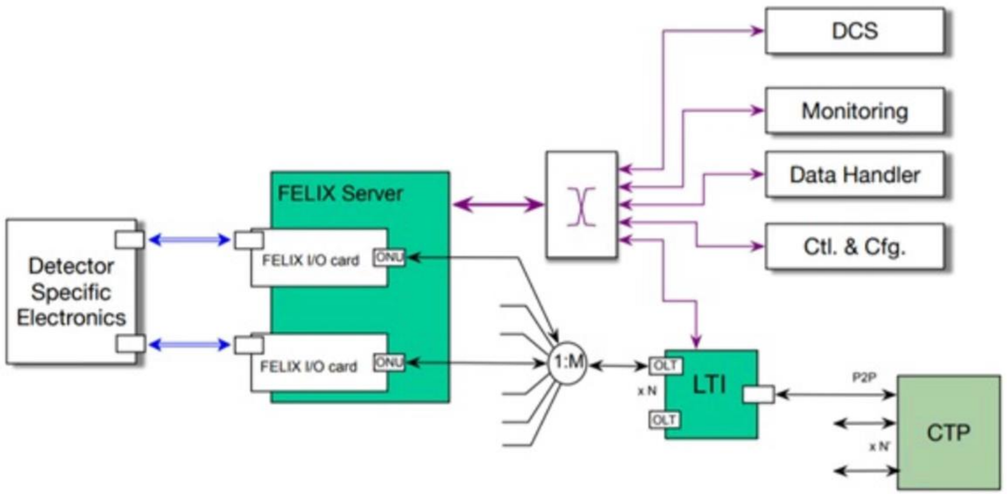


- The High Granularity Timing Detector (HGTD) will provide time information in the forward region.
- By using high-precision timing information, the increase in pile-up interactions from the LHC to the HL-LHC can be effectively mitigated.
- The sensor will be the Low Gain Avalanche Detector (LGAD).
- The front-end electronic ASIC is named ALTIROC.
- A common back-end for the ATLAS Phase-II upgrade, including lpGBT, VTRx+, and Felix, will be used.
- The data will be transmitted to memory via the PCIe bus, where the DAQ software takes over data handling.

The requirement

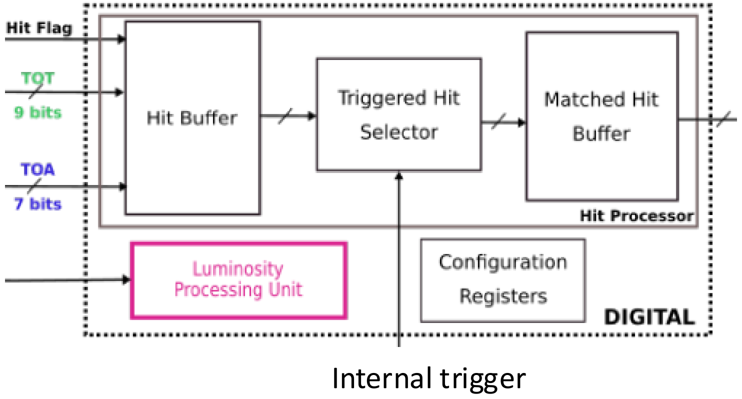
	1.28 Gb/s	640 Mb/s	320 Mb/s	Luminosity	Total
Nb of module	1216	2976	3940	4192	8032 (Timing) + 4192 (Luminosity)
Total bandwidth	1556.48 Gb/s	1904.64 Gb/s	1260.8 Gb/s	2682.88 Gb/s	7404.8 Gb/s

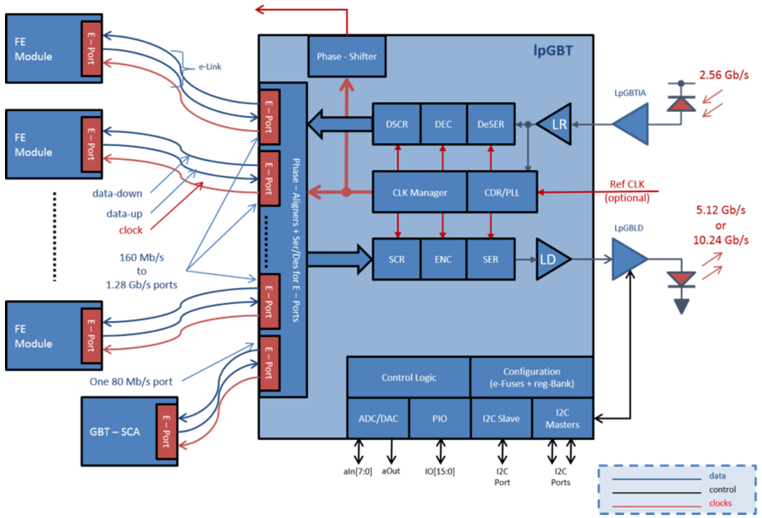
lpGBT	VTRx+
1728	1120



- Each ASIC has 225 channels. The data from different channels need to be organized, and only triggered bunch crossings (BC) are read out to control the bandwidth and number of links in a reasonable range.
- According to the simulation, modules at different radii require different readout bandwidths, but 8032 modules will bring a very high bandwidth requirement.
- After the data are transferred to the Felix, they are distributed across different servers. We must gather all data fragments and assemble them into complete events over a high-speed network.

The solution

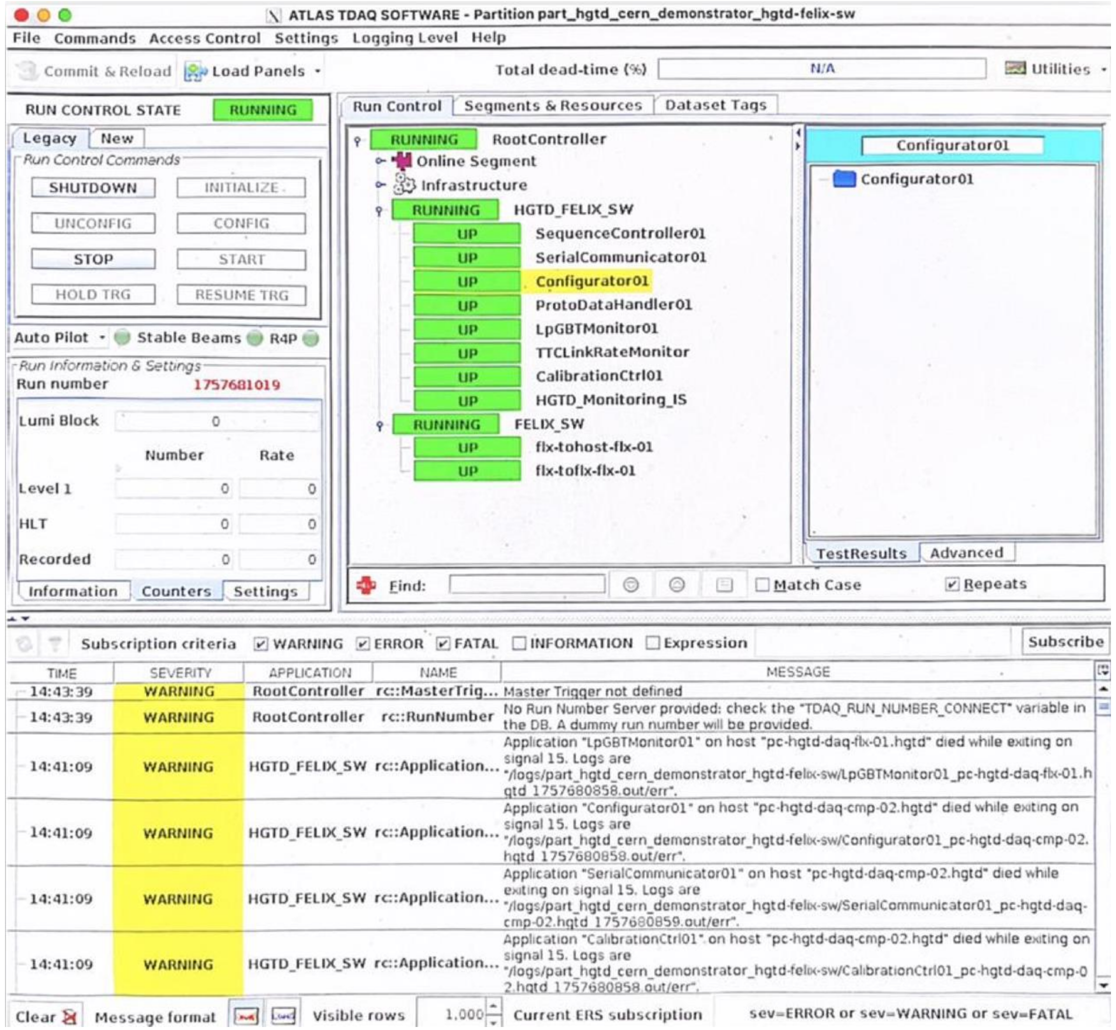




- The general strategy for handling such massive data is distributed and parallel processing.
- In the ASIC, the signal is amplified, discriminated, and converted to a digital signal in all channels in parallel. A buffer stores all data that exceed the threshold.
- The depth of the buffer is decided by latency of the trigger, once received the trigger, the ASIC will organize the hits from all channels into a frame along with the BCID and l0id.
- The lpGBT collects data from multiple ASICs, organizes them into frames, and tags them with e-links.
- The Felix will collect the data from different lpGBTs and tagged with Link.
- Then the software takes over data handling and event building across the distributed servers.

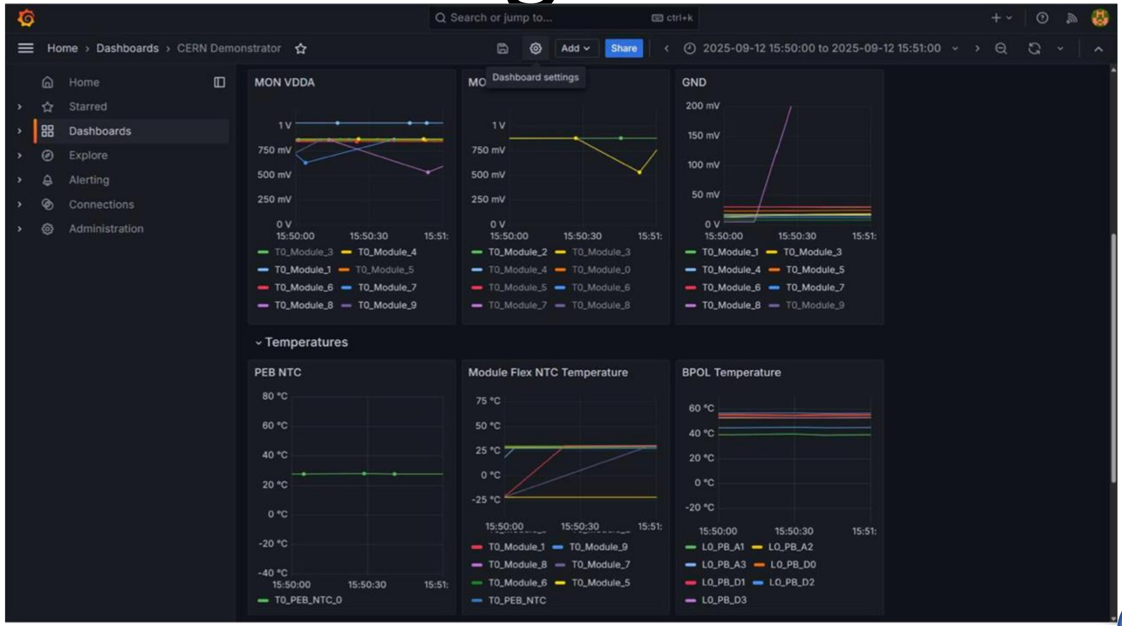
OKS database and Partition

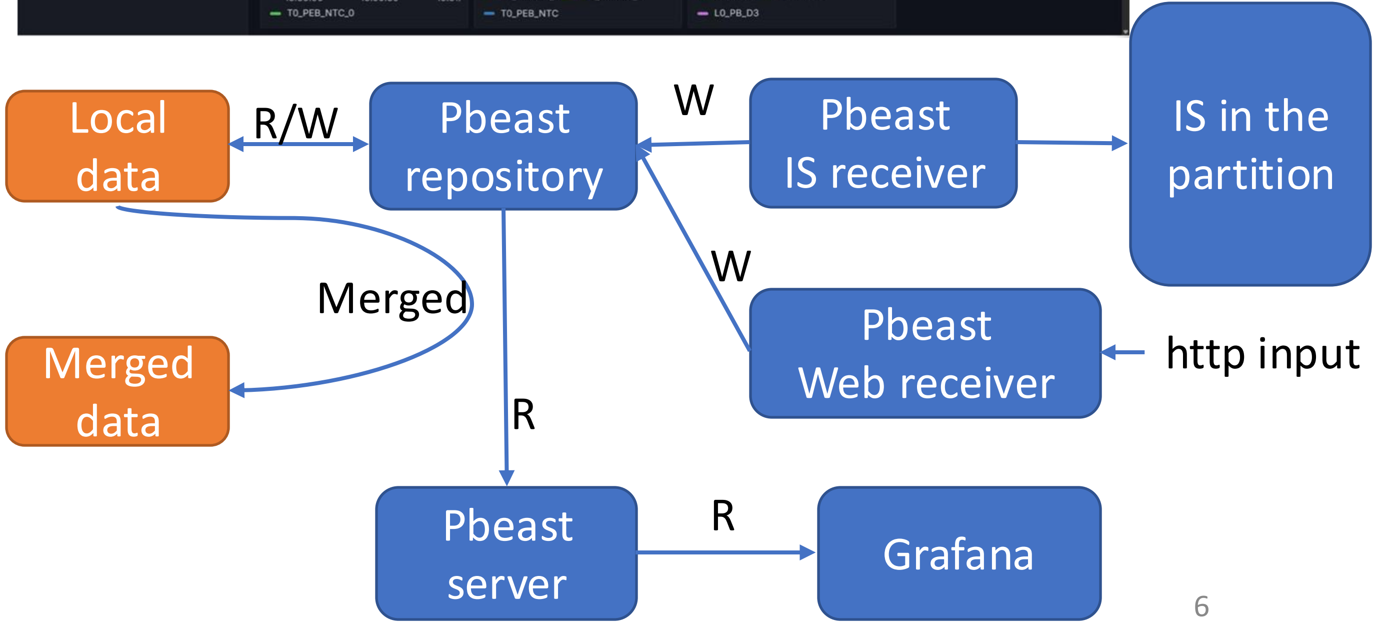
- The DAQ software of ATLAS will be organized into partitions, using the Object Kernel Support (OKS) database.
- All processes in the ATLAS DAQ system need to follow the finite state machine designed by TDAQ group, so that the process can be coordinated.
- Everything required for TDAQ operation is included in the partition.
  - The hardware resources.
  - The processes that need to be started.
  - The environment required by any software.
- The DAQ for the HGTD is organized by the OKS database and successfully running on the demonstrator.



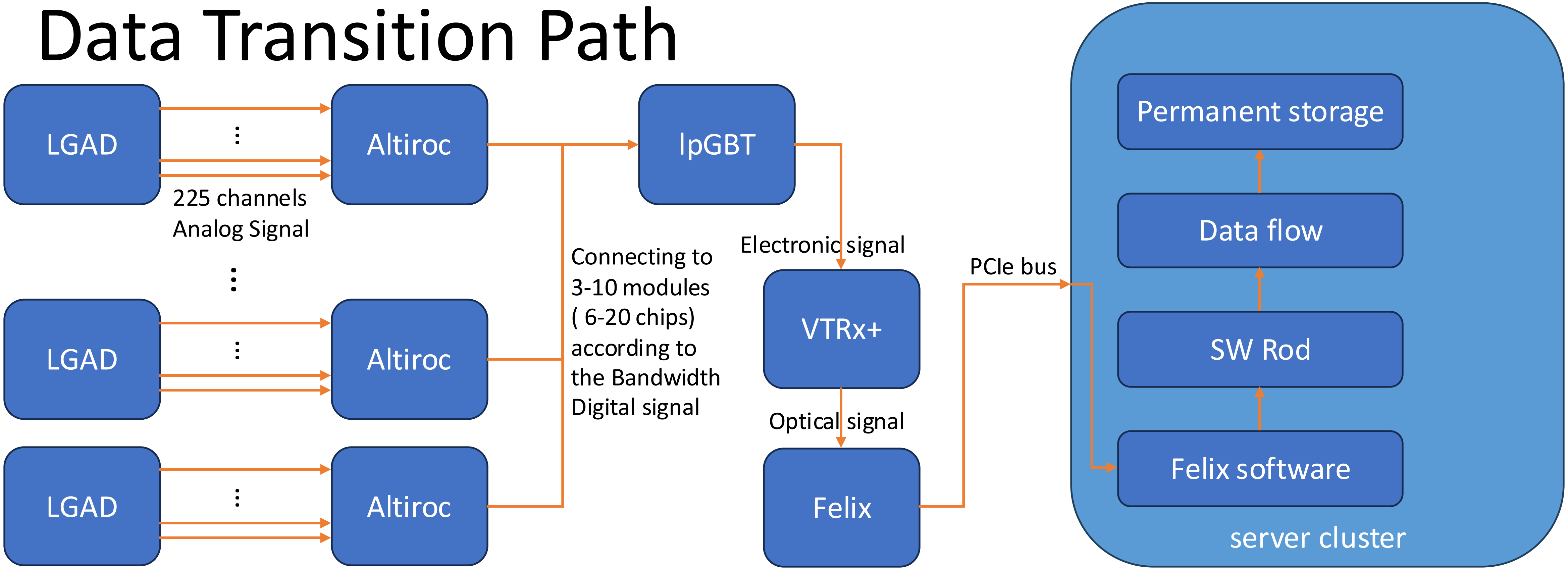
Front-End Electronic Monitoring

- The front-end electronics monitoring is based on the Persistent Back-End for the Atlas Information System (P-BEAST), developed by the TDAQ group.
- The monitored voltage is converted to a digital signal at the lpGBT, read by the HGTD custom software, and published to the information service.
- Later, the P-BEAST receiver will retrieve these monitoring data from the IS.
- The data are permanently stored in the P-BEAST database.
- Grafana is used to visualize the recorded data, making detector status monitoring much easier.





Data Transition Path

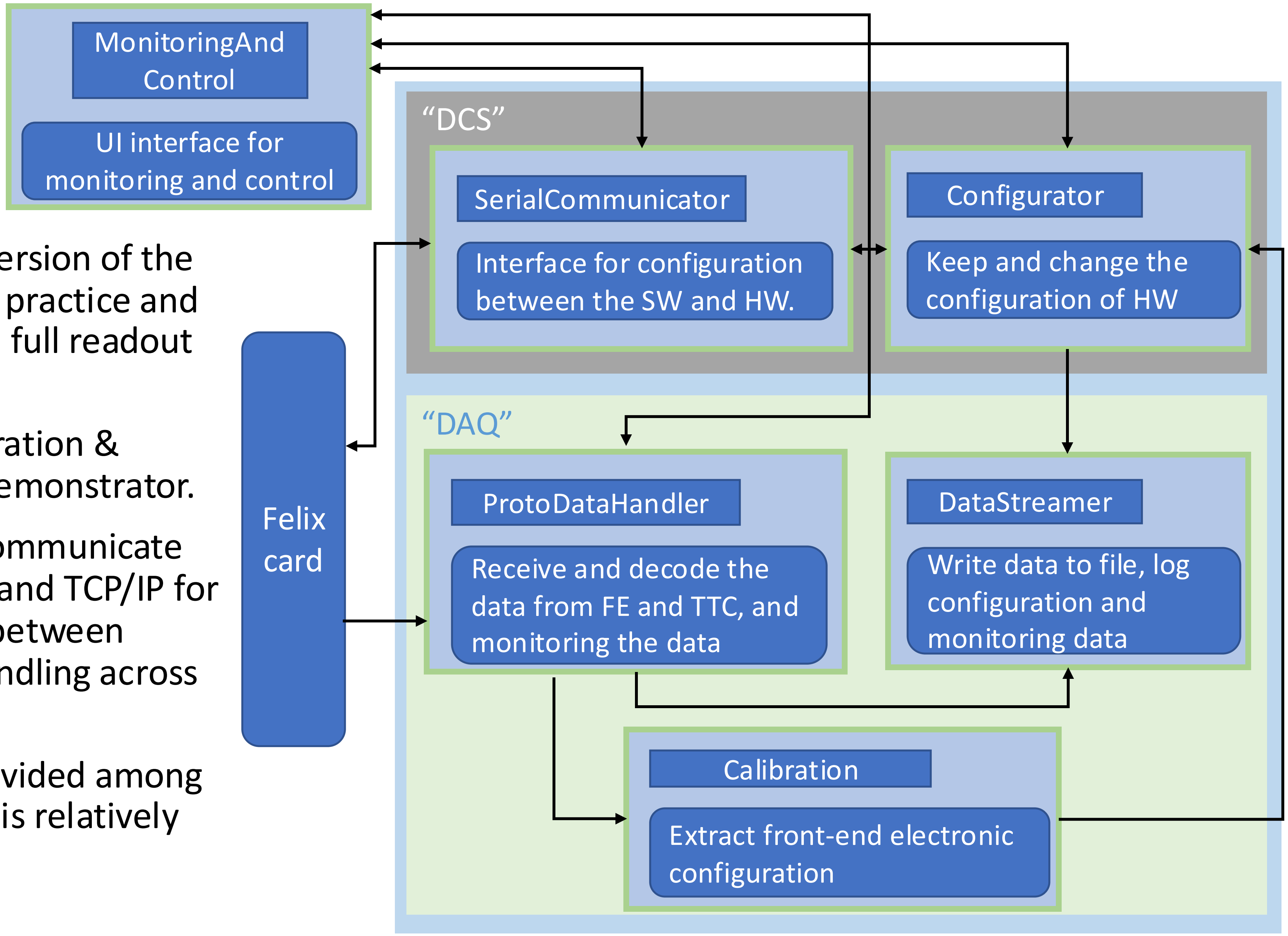


- When a charged particle passes through the sensor, the induced signal is transferred to the ALTIROC, where it is amplified, discriminated, and digitized.
- The data are passed to the lpGBT and VTRx+ on the PEB, where they are converted into optical signals.
- The data are received by the server through the Felix card.

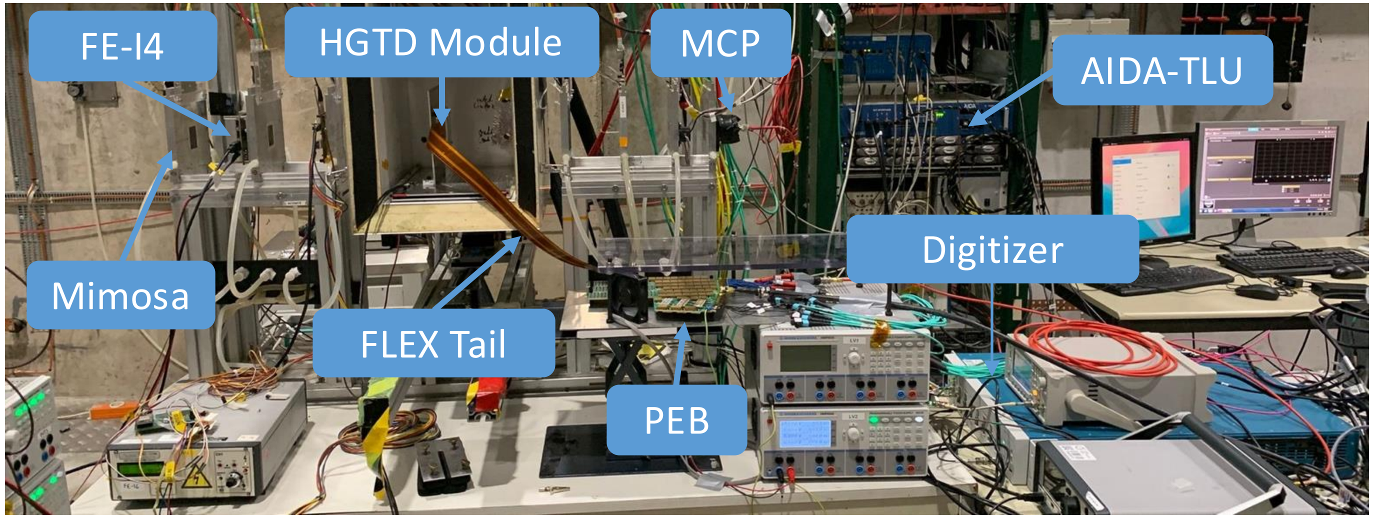
HGTD-FELIX-SW

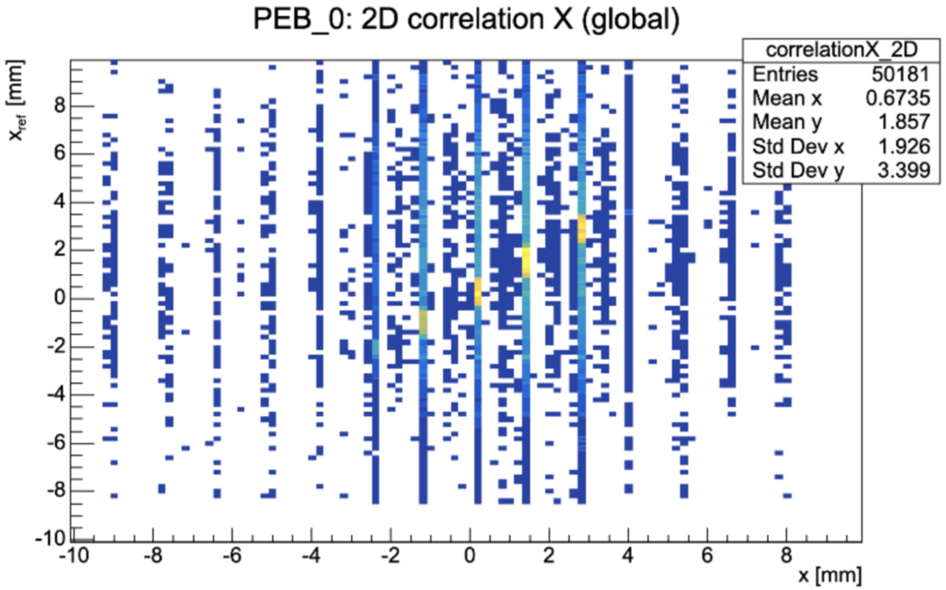
We have implemented the first version of the HGTD TDAQ software, mainly for practice and familiarization. Nevertheless, the full readout chain is fully operational.

- Targeting to develop a configuration & readout software for the full demonstrator.
- The system uses felix-star to communicate with the front-end electronics and TCP/IP for inter-process communication between components, enabling data handling across multiple servers.
- Since different functions are divided among separate processes, scaling up is relatively straightforward.



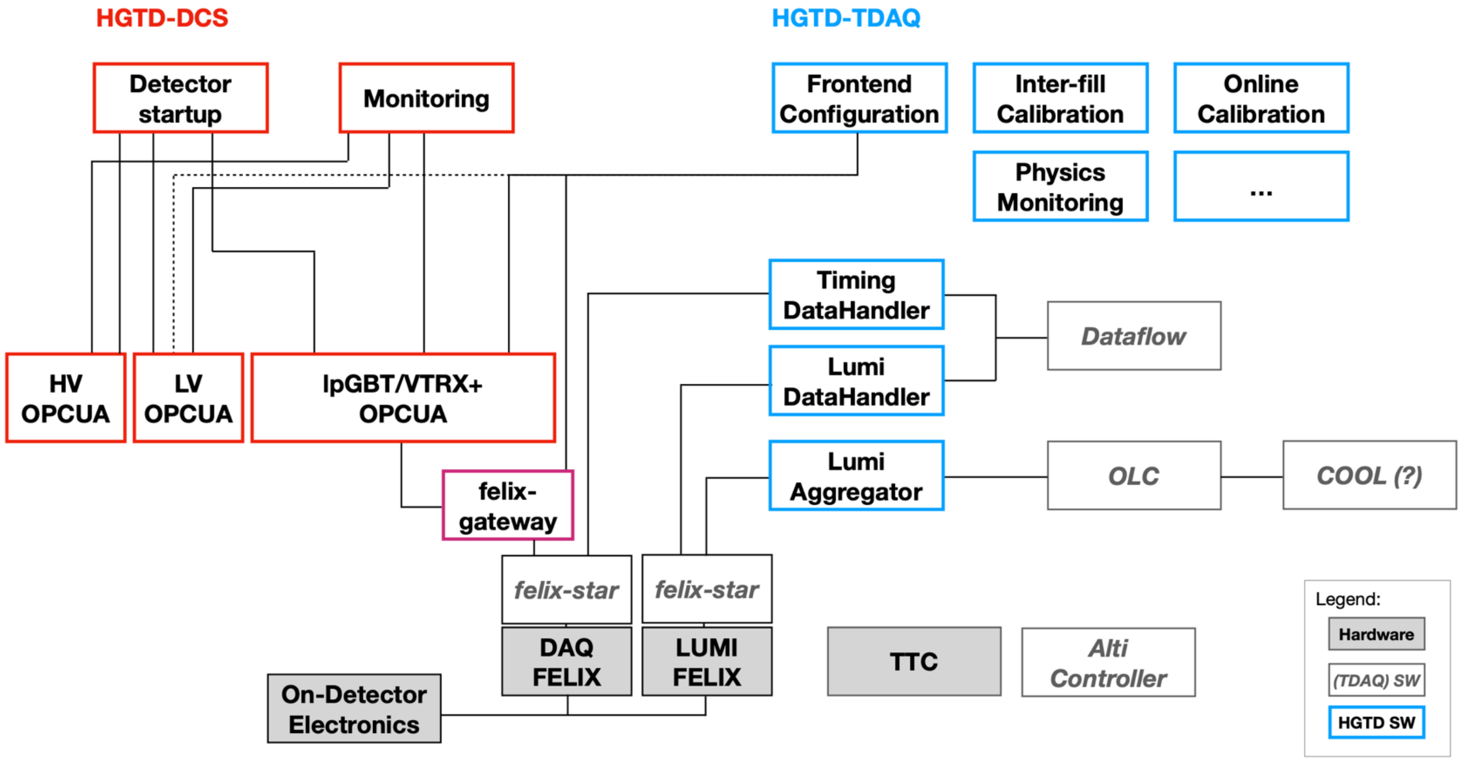
Test beam results





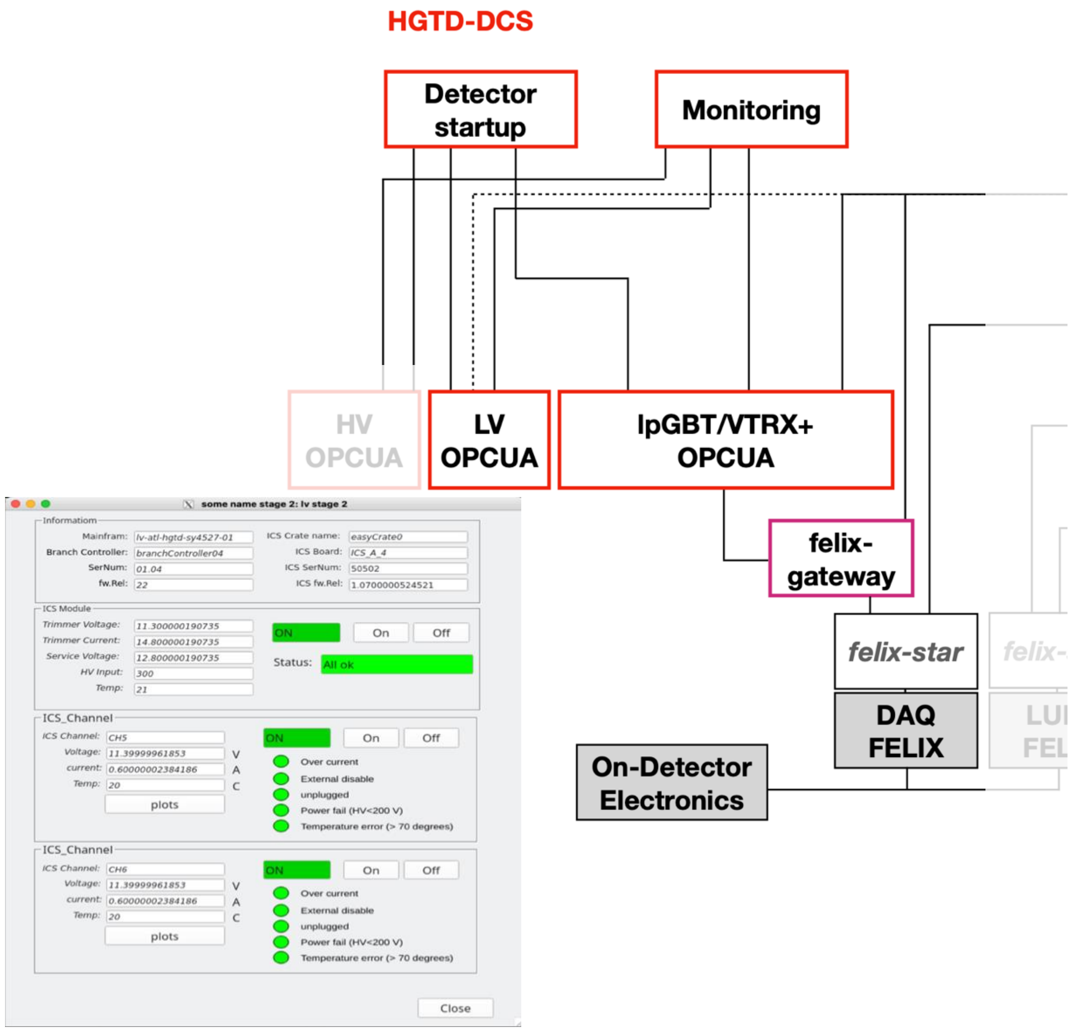
- The setup includes the full readout and control chains.
  - The trigger and clock are distributed from the ATLAS Local Trigger Interface.
  - The data is read out through the PEB and FELIX card instead of the FPGA.
  - The control and DAQ are done with the system mentioned above.
- The setup has been tested with beam at CERN recently.
  - From the position correlation between the telescope and HGTD module, HGTD module gives the position of hits in agreement with the hit from the telescope.
  - We confirm that the full readout chain works well, we get the first time.
  - Further analysis of timing resolution performance is ongoing.

Move to the ATLAS TDAQ infrastructure



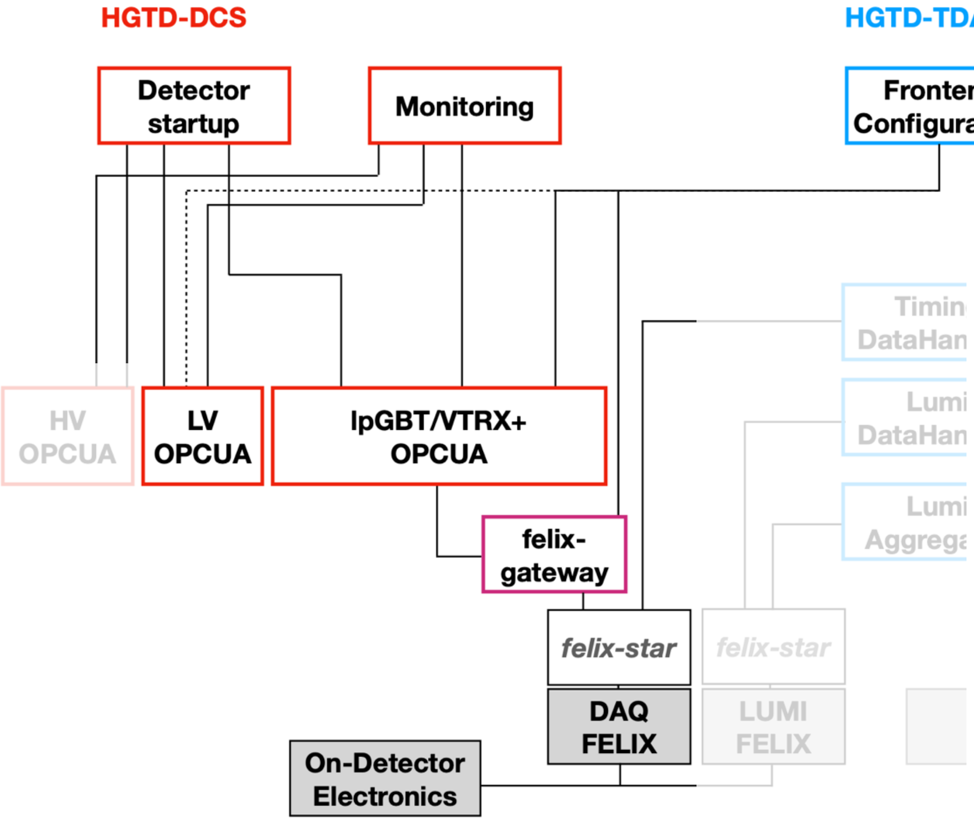
- We have done extensive practice with the previous version, which used a privately implemented inter-process communication layer and a point-to-point structure.
- We are now moving forward to the ATLAS TDAQ infrastructure to ensure full integration for Phase-II operations.
- Following the operation procedure, the functionality of each pack will be discussed following.

Initialization



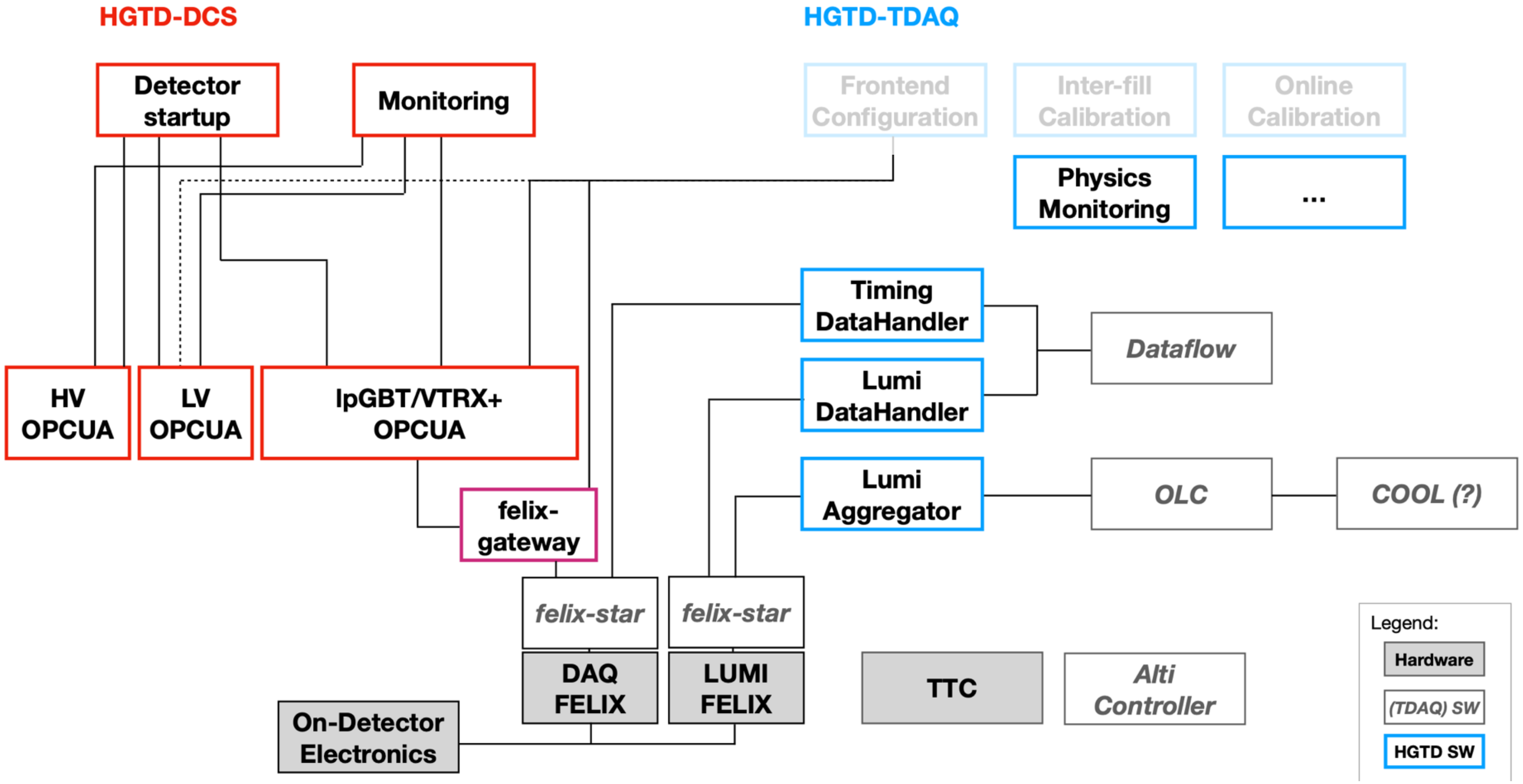
- During the initialization stage.
  - The detector control system will turn on the low voltage power supply.
  - The DCS will monitor the voltage and current provided by low voltage system.
  - The basic configuration for the VTRx+ and the lpGBT will also be handled by the DCS.
- In the latest design, the DCS and DAQ software will not communicate with the felix card. Instead, using the interface layer, felix-gateway, to avoid the card being claimed by one process and starvation of another process.

Front-end Electronic Configuration



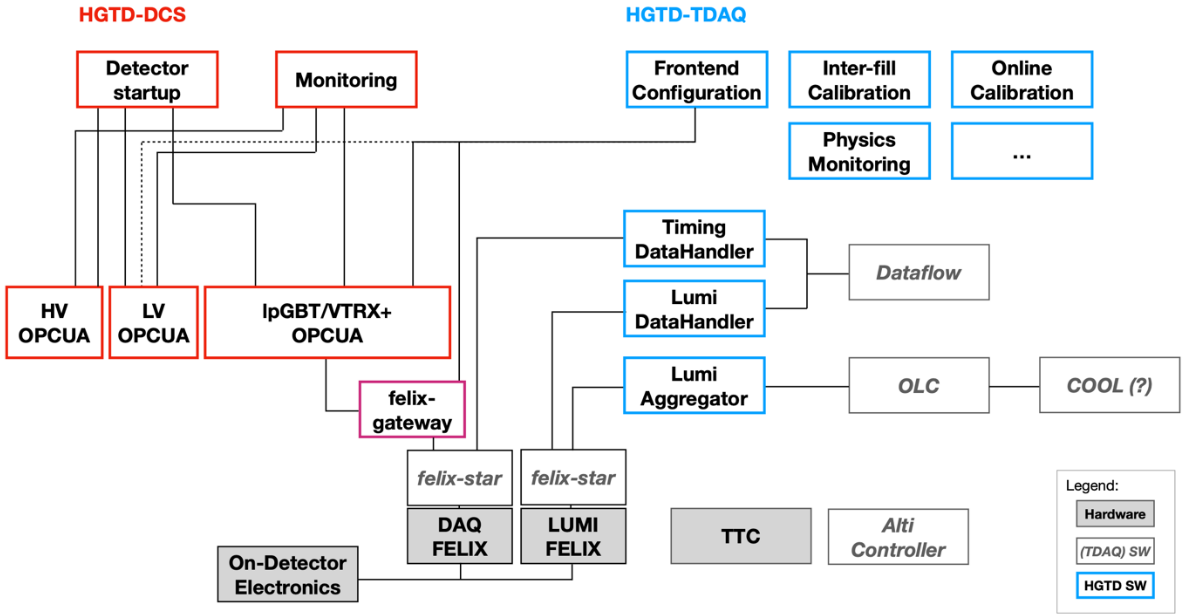
- Followed by the configuration of the front-end electronics.
  - The frontend configuration will be read from the database, including the threshold voltage, latency or TDC adjustment and so on.
  - The configuration will also through the felix-gateway to avoid directly access the felix card resources.
- Due to the configuration of ASIC needs to be tuned during the online calibration, this components is handled by the TDAQ software, instead of the DCS.

Data taking



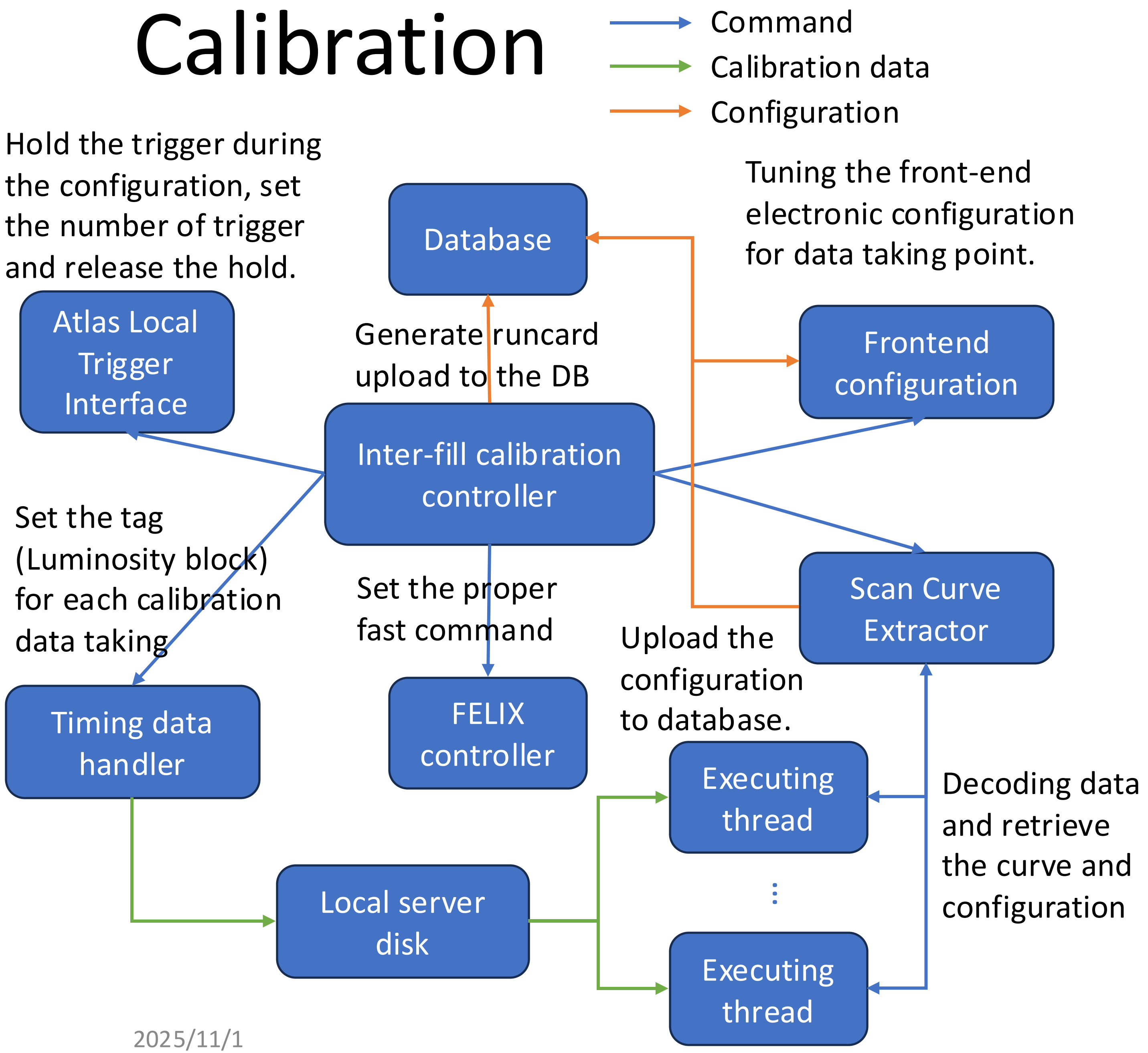
- During the data taking, the HV power supply will be activated and monitored by the DCS.
- And HGTD specific software readout driver, DataHandler will readout the timing information along with the luminosity information (occupancy) related to the triggered event and decode raw data.
- The Lumi Aggregator will provide per-BCID occupancy to the online luminosity calibration.

Calibration



- For the detector operation, we need to take calibration data for:
  - Front-end electronic tuning.
  - Offline data calibration.
  - Detector status monitoring
- During the calibration data taking, we need to adjust configuration for the front-end electronic frequently and coordinate the calibration data taking and these adjustment. That is the reason why we keep the Frontend Configuration in the TDAQ instead migrate it to the DCS.
- Meanwhile, we need to ensure the configuration database is updated. So that, we can trace back to the detector status.

Calibration



- During the inter-fill calibration, we will inject pulses into the front-end electronics and tune the setup step by step. And find out the suitable configuration.
- Besides the taking calibration data, we need to do the analysis and parameter extraction online.
- Due to the data will be sent to different server and are uncorrelated, we prefer to analyze the data locally.
- The extracted configuration will be uploaded to the database.
- The configurator and offline calibration will read the configuration from the database.

Summary and plan

- We have set up the first version of the TDAQ software, which implemented the full readout chain.
- The coordination of the readout software has been migrated to use the OKS database.
- The whole readout chain has been validated with the test beam.
- We have setup the online monitoring system for the front-end electronics.
- There has also been significant progress on the DCS and interlock systems.

- We learned a lot from the first version of the software , now we keep the lesson learnt and working with the ATLAS TDAQ infrastructure from the very beginning for our final version.
- The architecture for the software is already in good shape; some components are already in active developments.
- We aim to implement most core components in the coming year.

Thanks for your attention!

Backup