

UPGRADED READOUT AND TRIGGER ELECTRONICS FOR THE ATLAS LIQUID- ARGON CALORIMETERS AT THE LHC AT THE HORIZONS 2018-2022

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Argon Calorimeter Collaboration

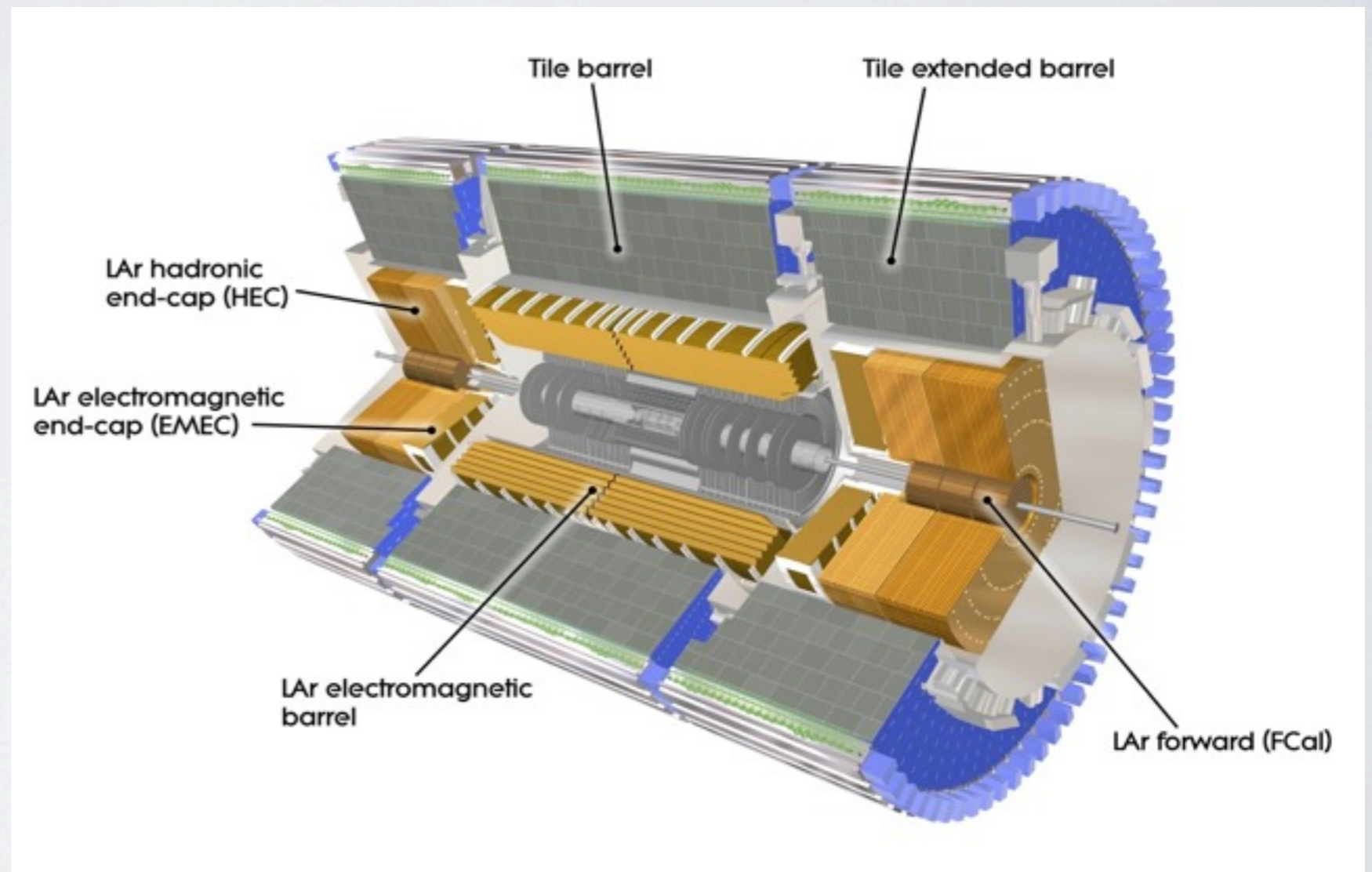


CHEF 2013,
Paris, France



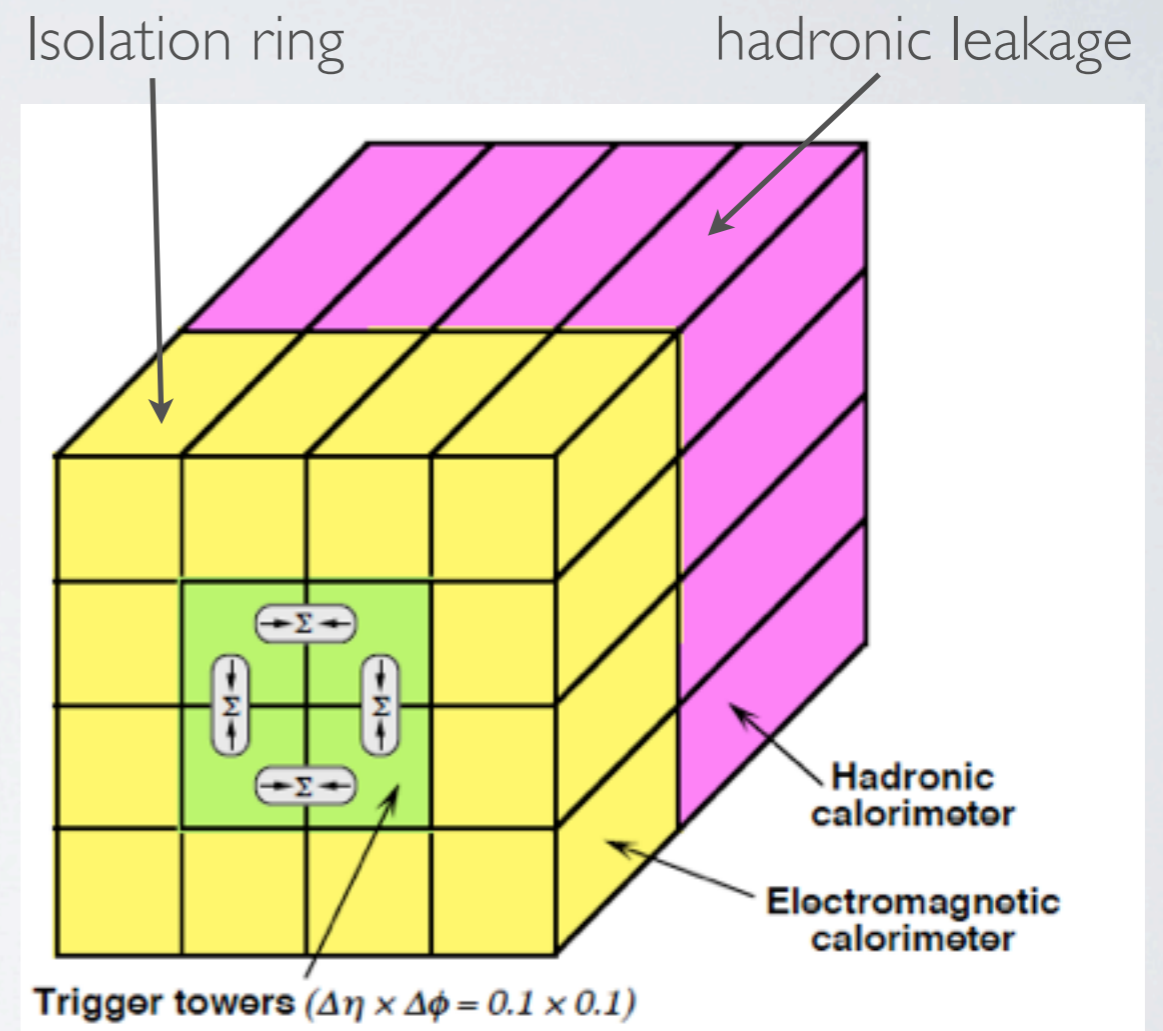
ATLAS CALORIMETER SYSTEM

- ATLAS calorimeter system is built with different technologies and comprises more than 187,000 cells.
- Electromagnetic calorimeter is composed of lead/liquid argon. There are 4 longitudinal layers of cells.
- Hadronic calorimeter is composed of copper/liquid argon and iron/scintillator. Up to 4 longitudinal layers of cells.
- Forward calorimetry with tungsten rods/liquid argon for complete angular coverage.
- Refined granularity allows for precise energy measure and particle identification but produces a large amount of data to be analyzed.



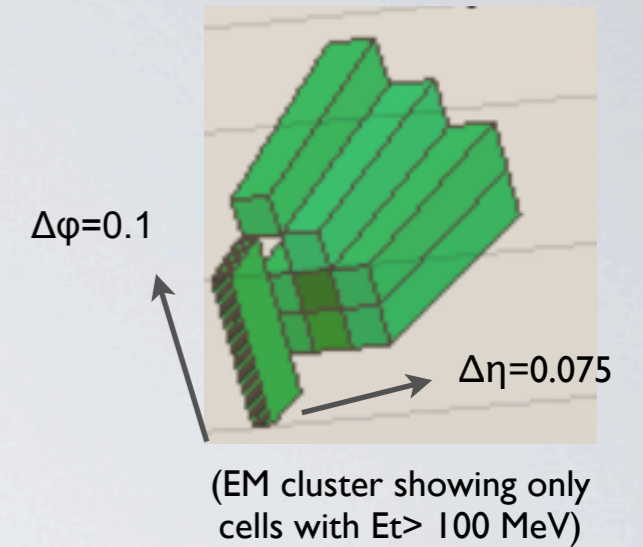
LI CALORIMETER SYSTEM

- The ATLAS trigger system is staged in 3 levels.
- The Level 1 (L1) Calorimeter uses a coarser granularity of the detector, grouping analogically many cells into Trigger Towers (TT - up to 60 cells in the EM barrel). Readout with ~ 1 GeV Least Significant Bit.
- Two longitudinal segmentations (EM and hadronic - a total of 6400 TT in the EM region) available to the L1 : reduction of data volume for real-time and low-latency L1 processing.
- A local maximum of the vertical or horizontal sums (green) of two trigger towers is considered to be a possible electron candidate.
- The L1 (see talk by J. Bracinik in this meeting) behaves quite well up to the luminosity levels reached so far by the LHC.

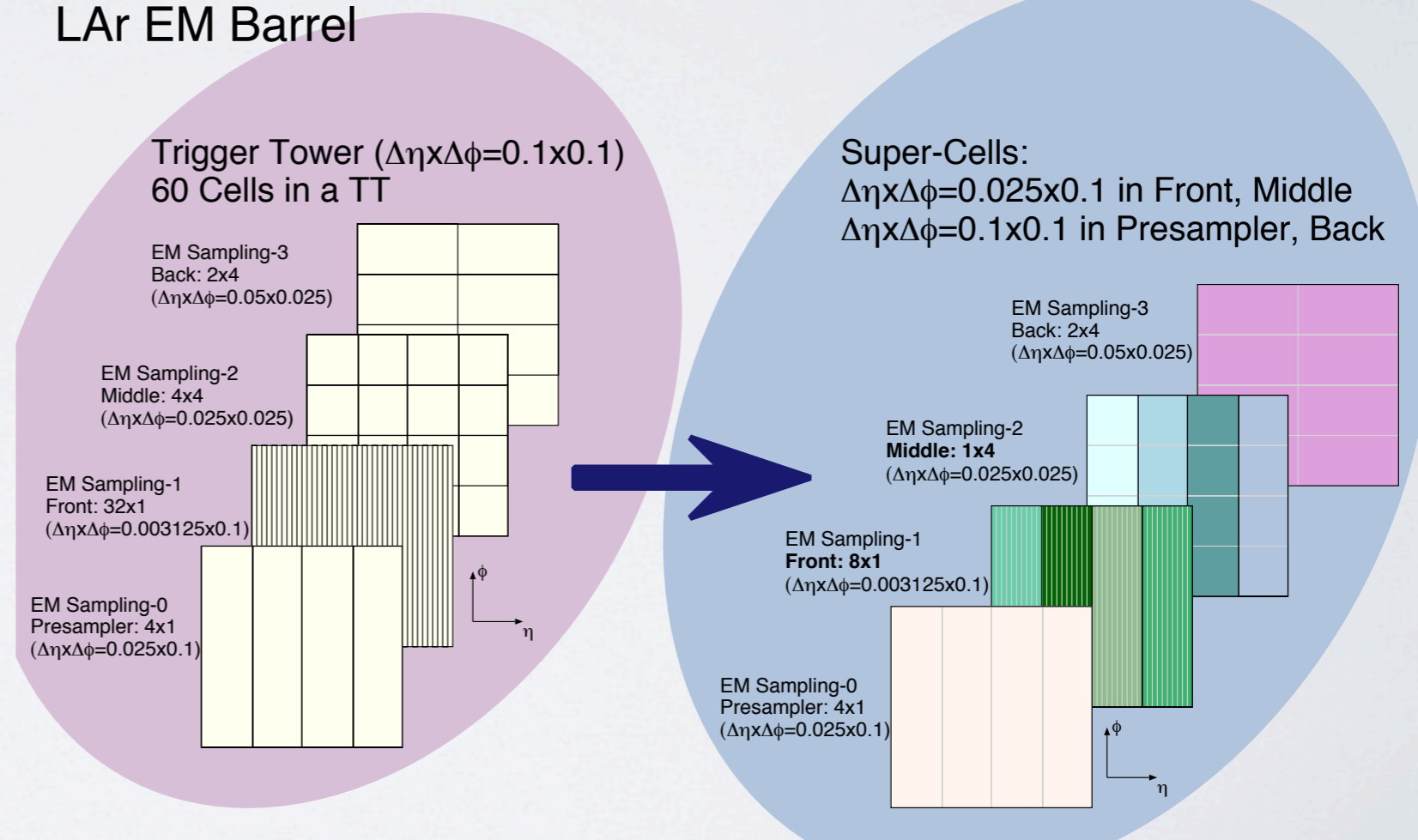


INCREASE OF GRANULARITY

- When beyond the present luminosity levels ($> 10^{34} \text{cm}^{-2}\text{s}^{-1}$), some of the isolation variables used, may lose effectiveness.
- In order to deal with the increasing amount of pile-up events, it is important to increase the granularity accessible at the LI : hence the concept of Super-Cells.
- Also the energy resolution of the object shall increase (initial analysis indicates improvements when using LSB of 65 MeV - first layer - and 250 MeV - second layer).
- There will be 4 layers of Super-Cells in the EM session : could later be explored for energy calibration techniques similar to the ones used offline.



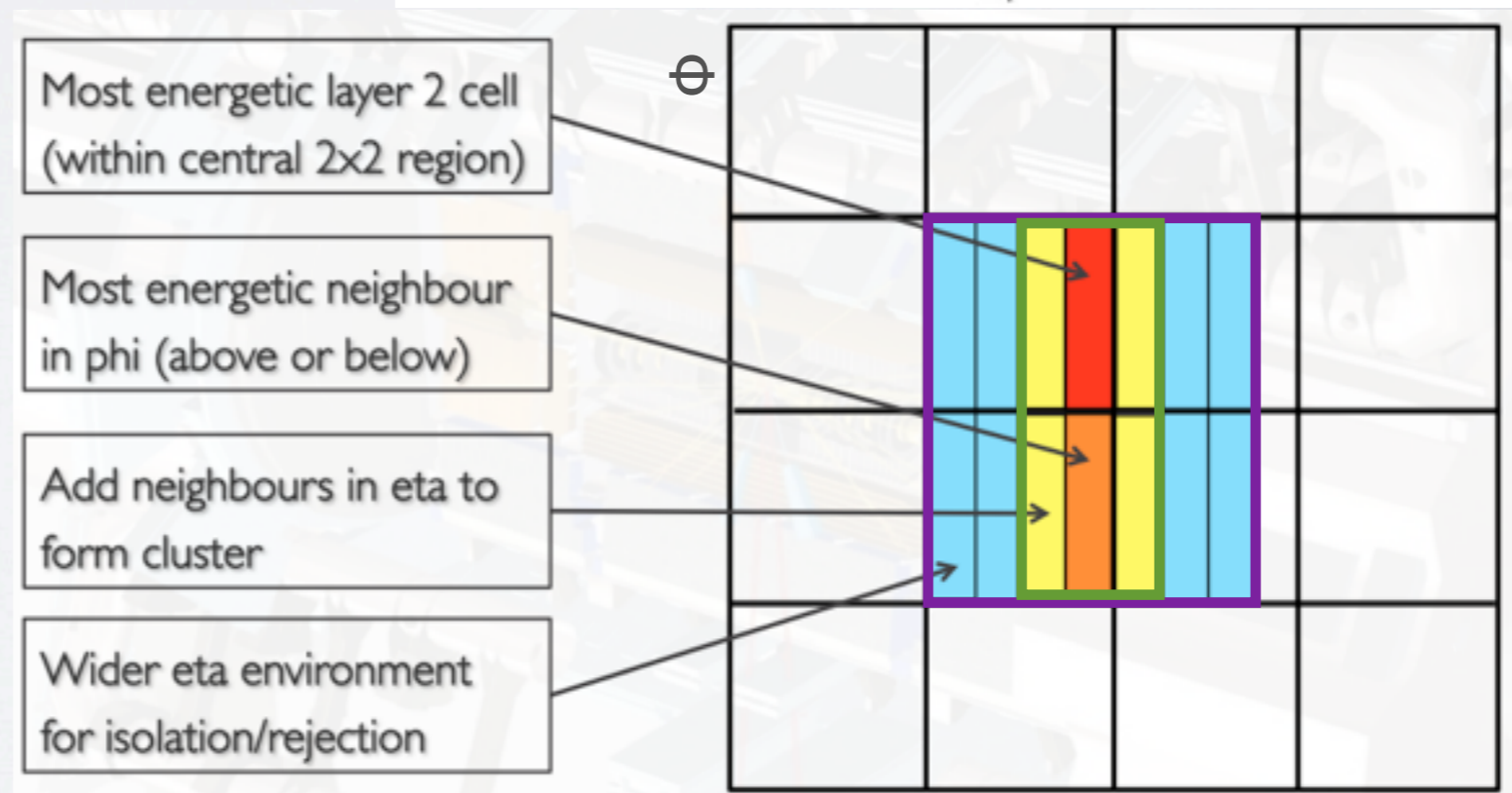
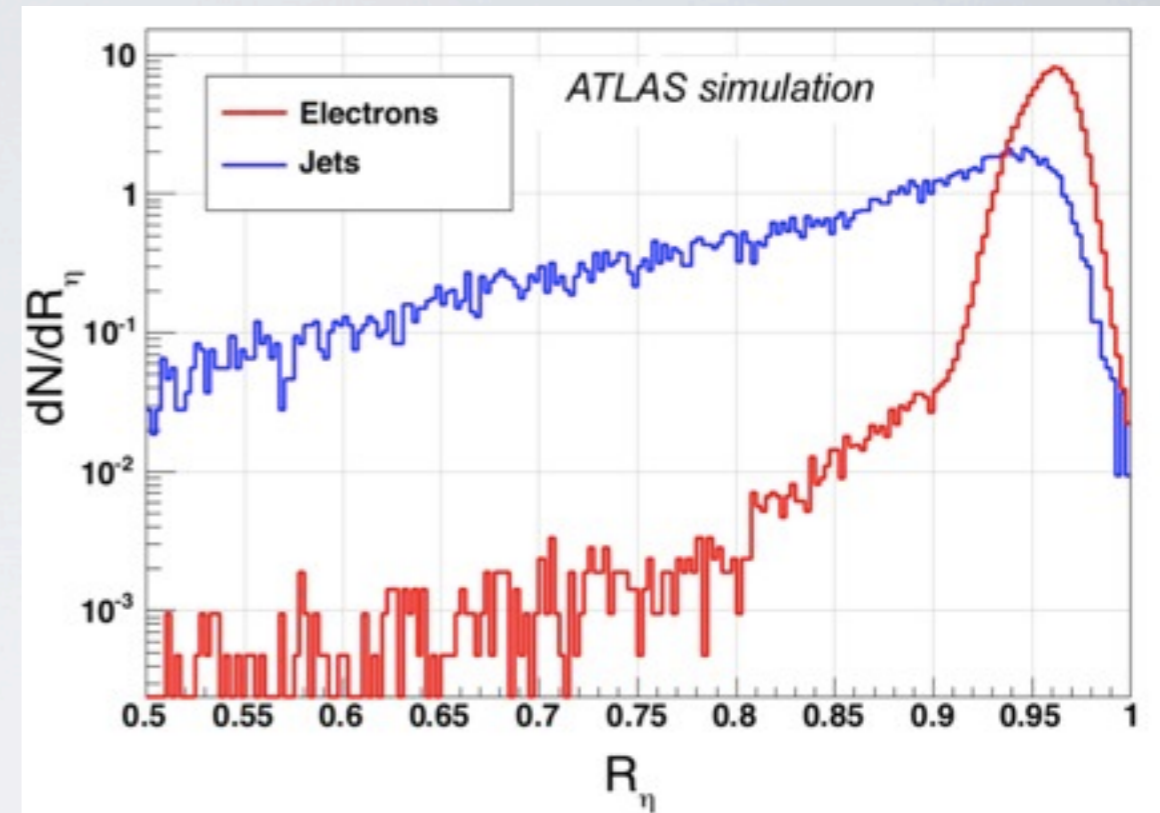
LAr EM Barrel



NEW SHOWER SHAPE VARIABLE

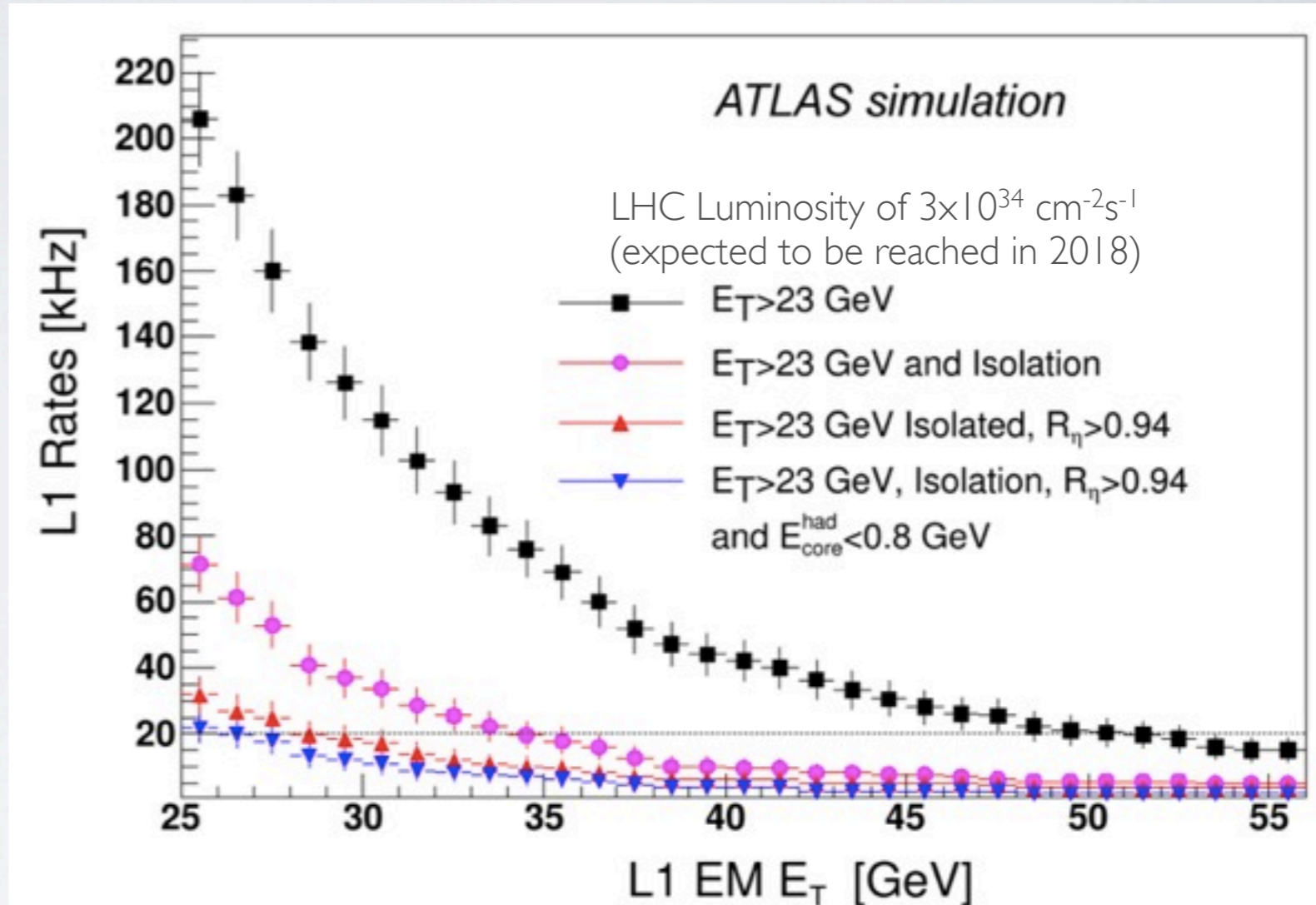
$$R_\eta = E_{3 \times 2} / E_{7 \times 2}$$

- Inspired by the offline software, we define a new variable called R_η of the second layer.
- This shower shape variable is more robust to the change of pile-up level (given its intrinsic energy normalization).



RATE REDUCTION

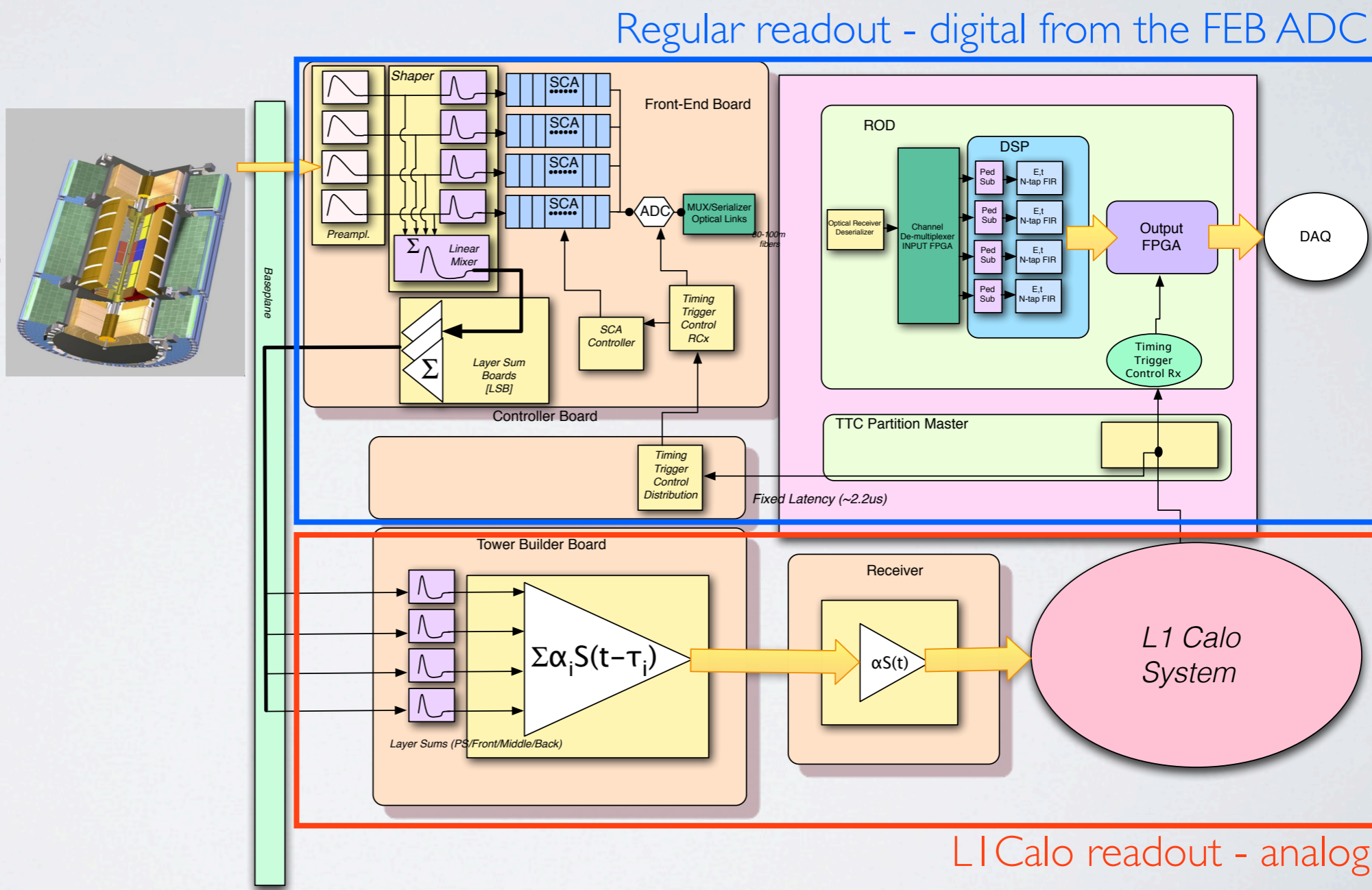
- Offline electron detection efficiency of 98%.
- The present L1 trigger would fire at 20 kHz with a 34 GeV threshold.
- Using R_η , we manage to reduce the threshold even further to 28 GeV.



Selection criteria	Rate reduction	
	Fraction of (1)	Fraction of (2)
(1): Level-1 EM $E_T > 23 \text{ GeV}$	100%	-
(2): (1) and Level-1 isolation	34.9%	100%
(3): (2) and R_η	14.25%	40.8%
(4): (3) and $E_{\text{core}}^{\text{had}}$	11.45%	32.8%

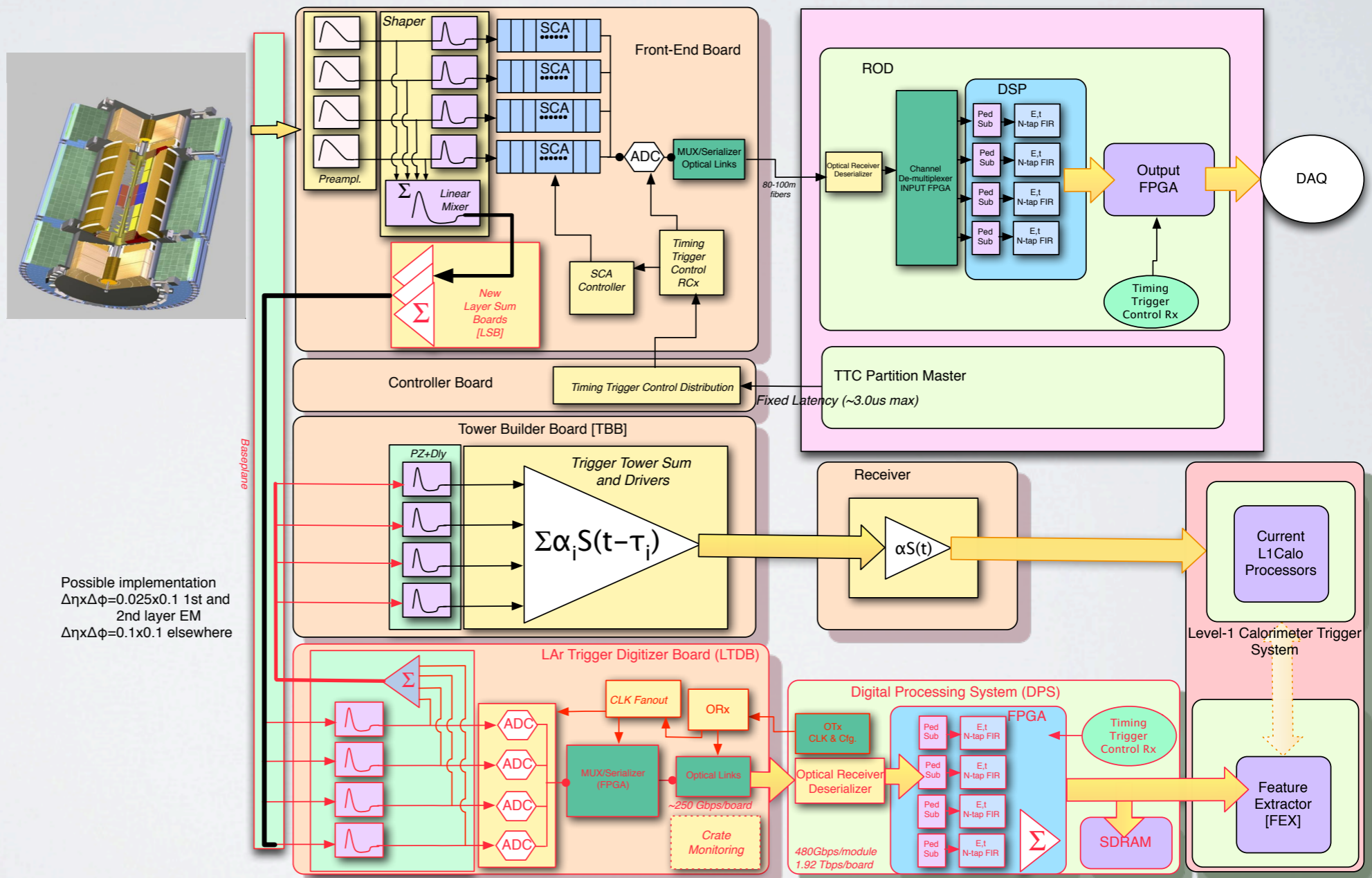
PRESENT LAR-L1 INTERFACE

- The cells energy values wait in a Switch Capacitor Array (SCA) of the Front-End Boards (FEBs) and digitization ONLY performed for accepted events.
- A partial sum of the analogue pulses is performed within each FEB by the Layer Sum Board.
- These partial sums are fed to the Tower Builder Board which makes the final Trigger Tower sum, sending the results to the L1 Trigger.
- All sums and operations up to the L1 Calo System are analogue.



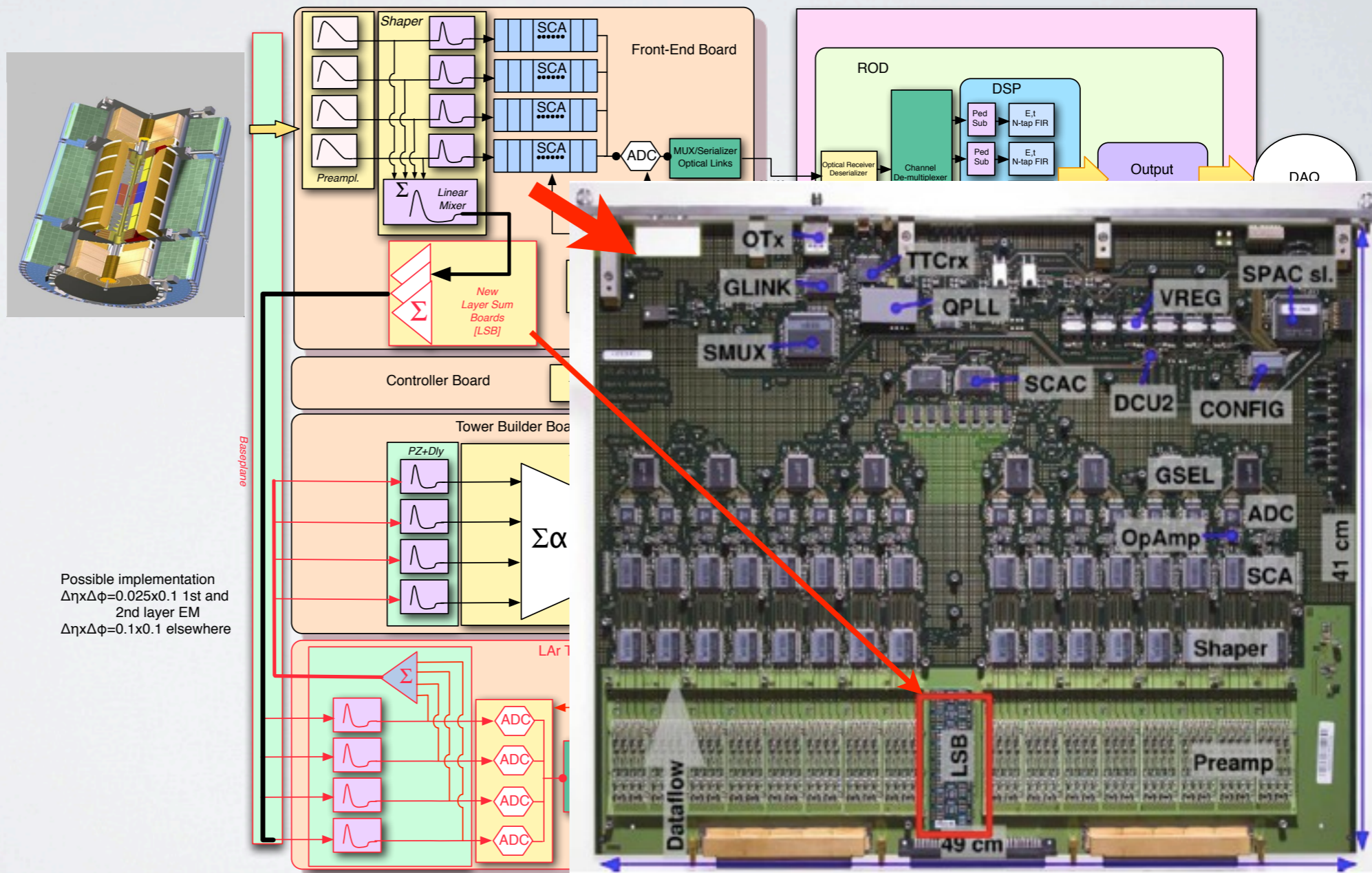
PHASE-I SYSTEM

- The Layer Sum Boards (LSB) are planned to be changed to produce partial sums restricted to the Super-Cell within each FEB for each layer.
- New LAr Trigger Digitizer Boards - LTDB are planned to be added to each crate. They digitize the signals and send data using optical links for further processing.
- Analogue signals are foreseen to be sent to the present LI infrastructure to provide back compatibility.
- The analogue signals would be digitized at the LHC clock rate and the energy calculated per bunch crossing in the Digital Processing System (DPS).



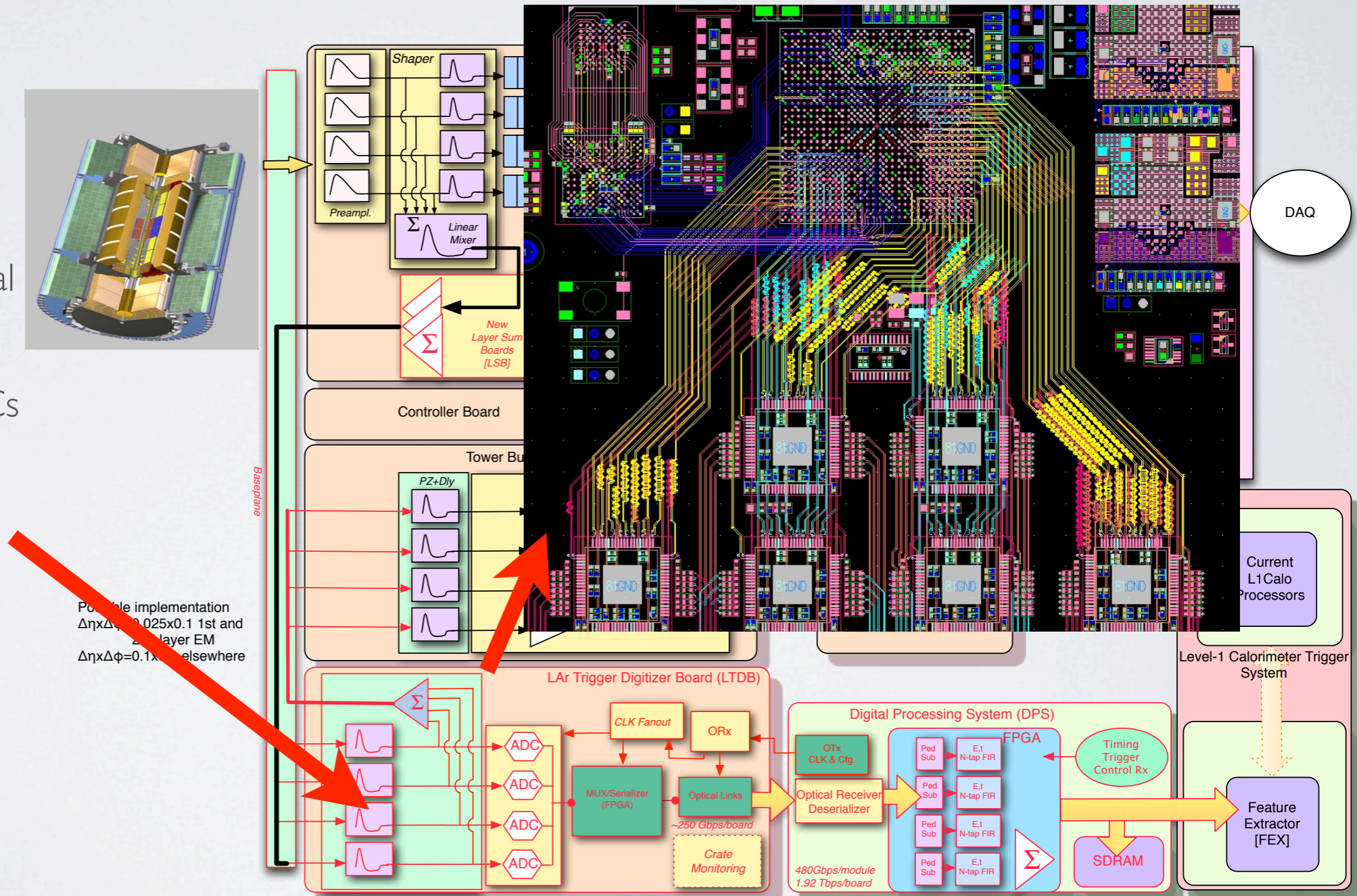
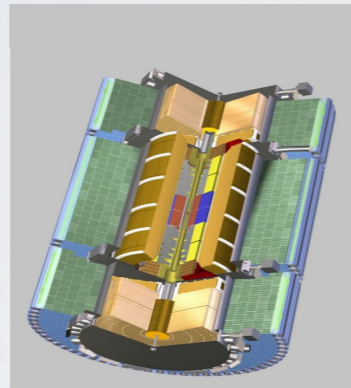
HARDWARE MODIFICATIONS

- The present LSBs are mezzanine boards.
- More than 1500 FEBs will be removed from the detector, modified and re-installed in the period of less than one year (2017).
- The baseplanes inside each front-end crate are planned to be replaced.



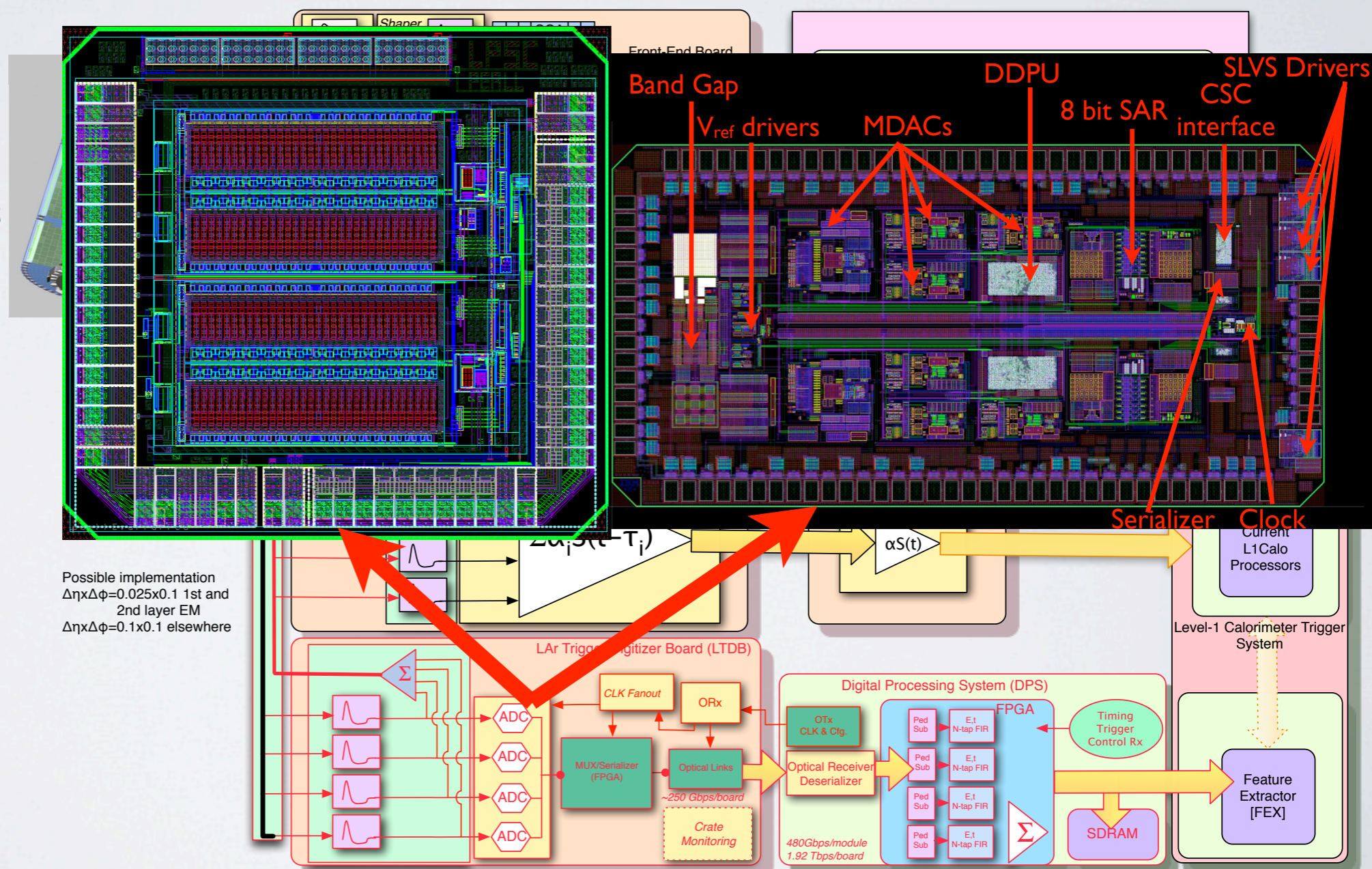
HARDWARE MODIFICATIONS

- LTDB initial design considered.
- Phase-II upgrade compatibility requires radiation tolerance to a total luminosity of 3000 fb⁻¹.
- Pre-Amplifier : custom ASICs currently being tuned and tested with radiation.
- Total Ionization Dose up to 1.74 kGy;
Non-Ionizing energy loss of 5.0×10^{13} neq/cm²;
Single-Event Effect of 9.6×10^{12} h/cm².



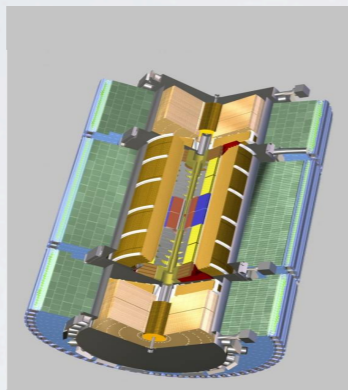
NEW ADC

- Three different solutions being investigated for the LAr calorimeters.
- 12 bits ADCs (present L1 is effectively 8 bits), low latency ($<70\text{ns}$), low power ($<100\text{mW/channel}$).
- 40 MSamples/s with Least Significant Bit yet to be defined (65 - first layer; 250 MeV - second layer).
- Power and radiation studies on-going also for serializer ASICs of the optical links to the DPS.

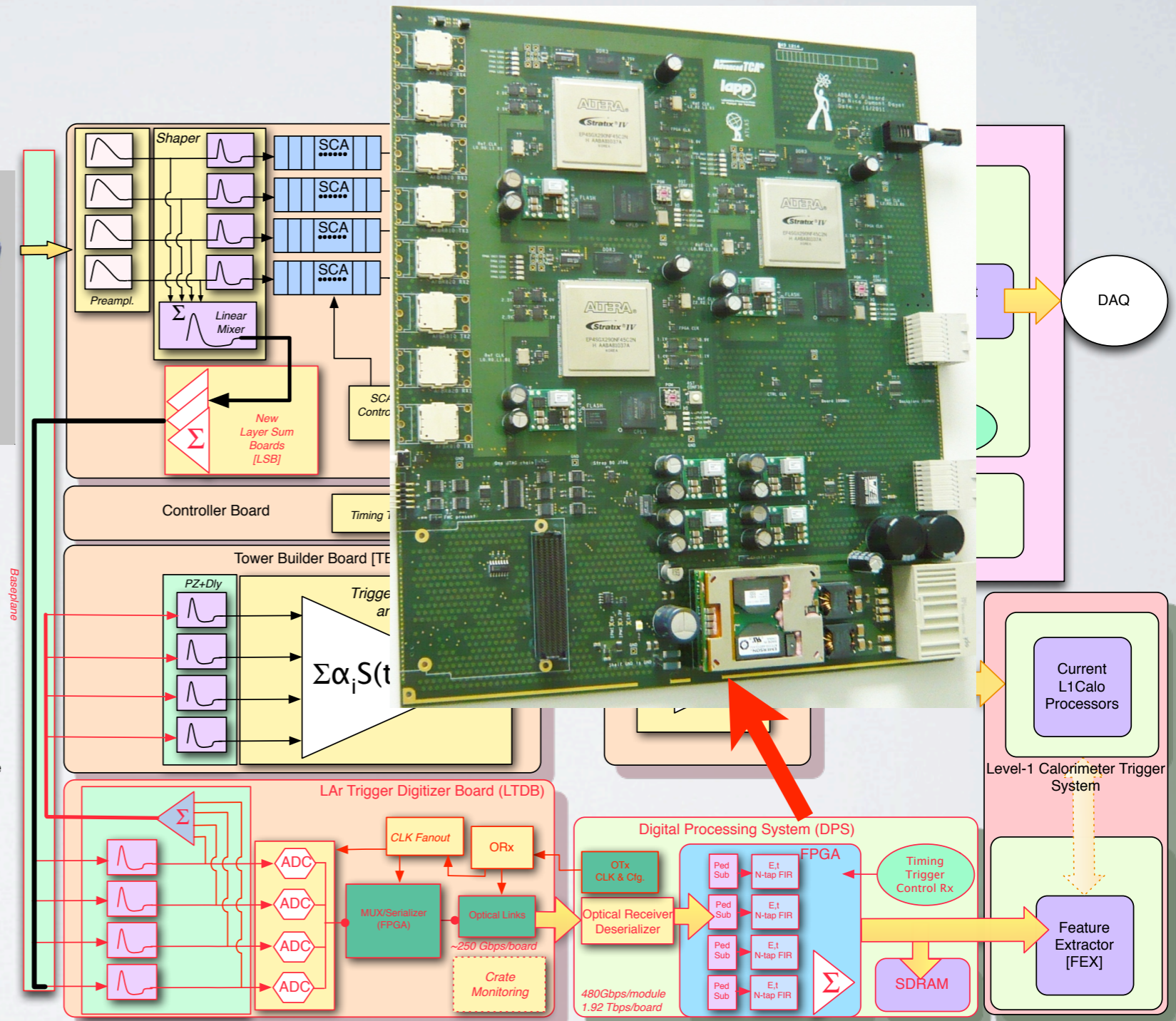


HARDWARE MODIFICATIONS

- The Digital Processing System performs the energy reconstruction for each of the 320 Super-Cells per LTDB.
- Based on the ATCA standard, a prototype with 3 FPGAs was prepared.
- This board is controlled via IPMI network-based system.
- Initial prototypes and test systems being prepared now at CERN : a demonstrator system is planned to be installed during the current LHC shutdown.

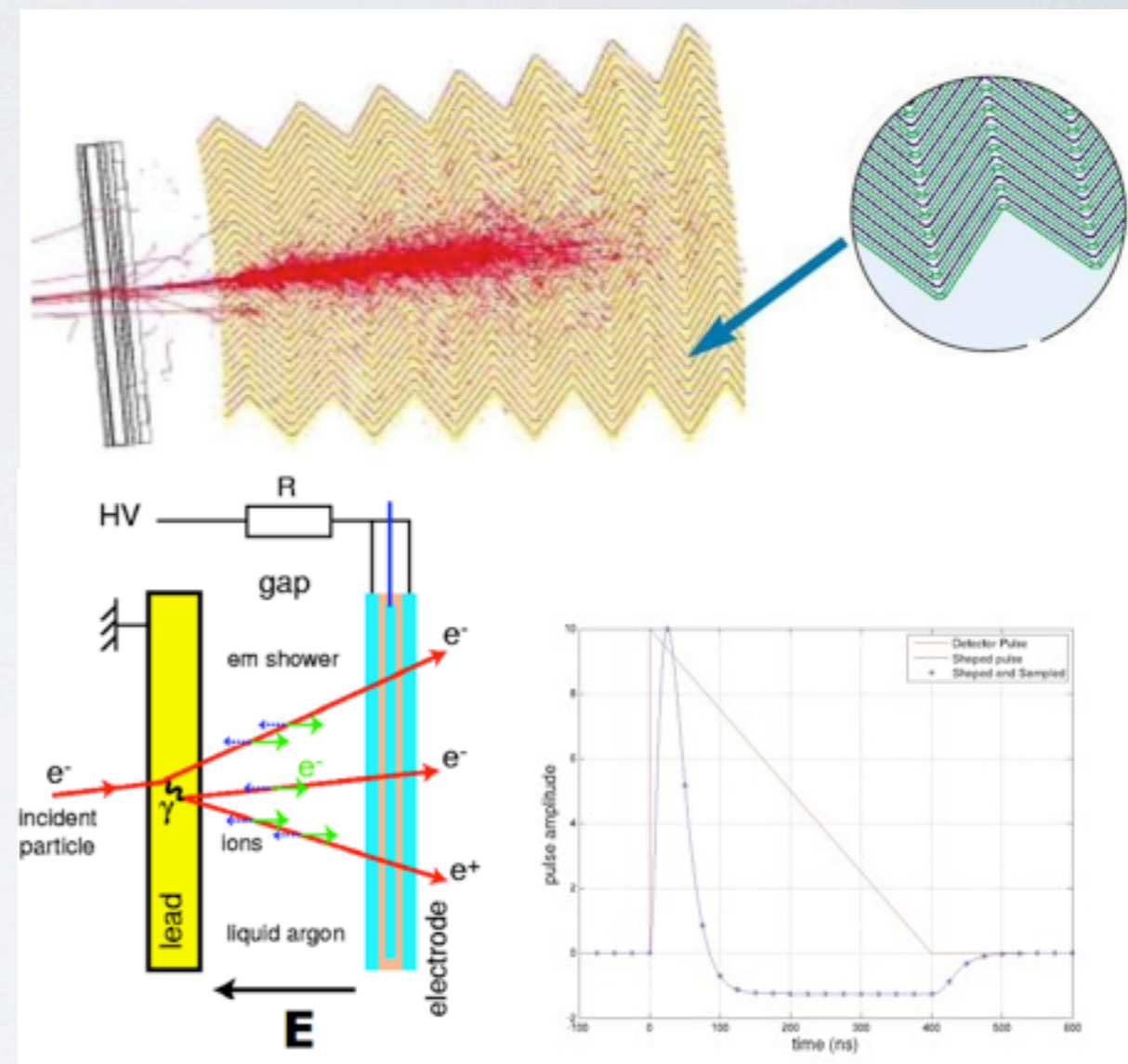


Possible implementation
 $\Delta\eta \times \Delta\phi = 0.025 \times 0.1$ 1st and 2nd layer EM
 $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ elsewhere



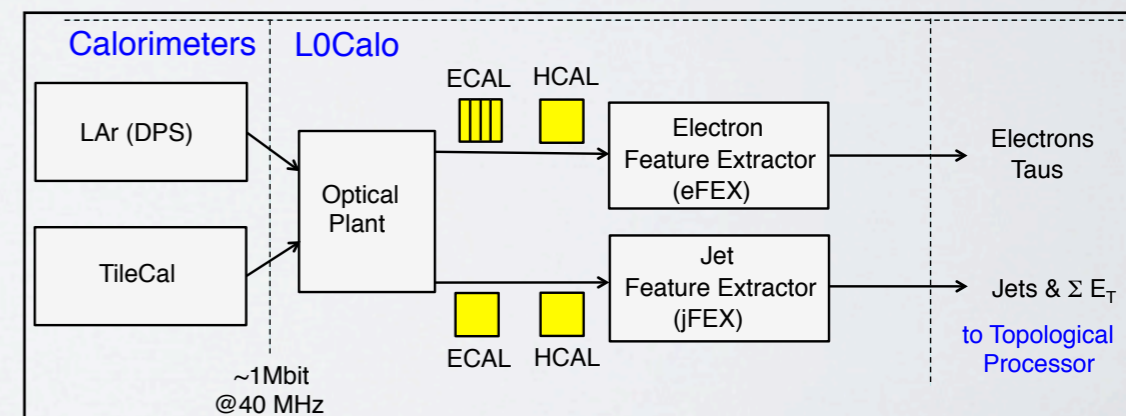
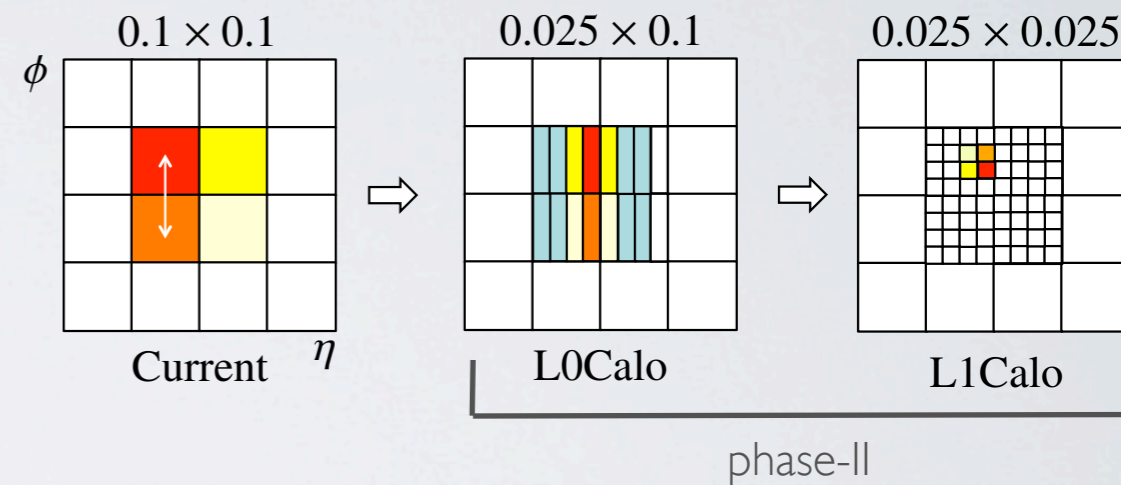
SIGNAL PROCESSING CHAIN

- The Super-Cells signal pulses will have similar shape as pulses from regular cells : Digital filter techniques are developed for Super-Cell signal treatment. These are optimized for high-luminosity phase and can be applied for Phase-II digital readout.
- The usage of solutions to decorrelate the multiple samples of the signal in a given bunch-crossing from pulses in neighbor bunch crossings is a fundamental step to provide a better energy reconstruction. This approach is called the Optimum Filter technique.
- Other signal processing techniques, such as Wiener filters, deconvolution and matched filter techniques are being considered for implementation in the DPS and later in the phase-II Read-Out Drivers (RODs). These techniques are now being implemented for MC simulations.



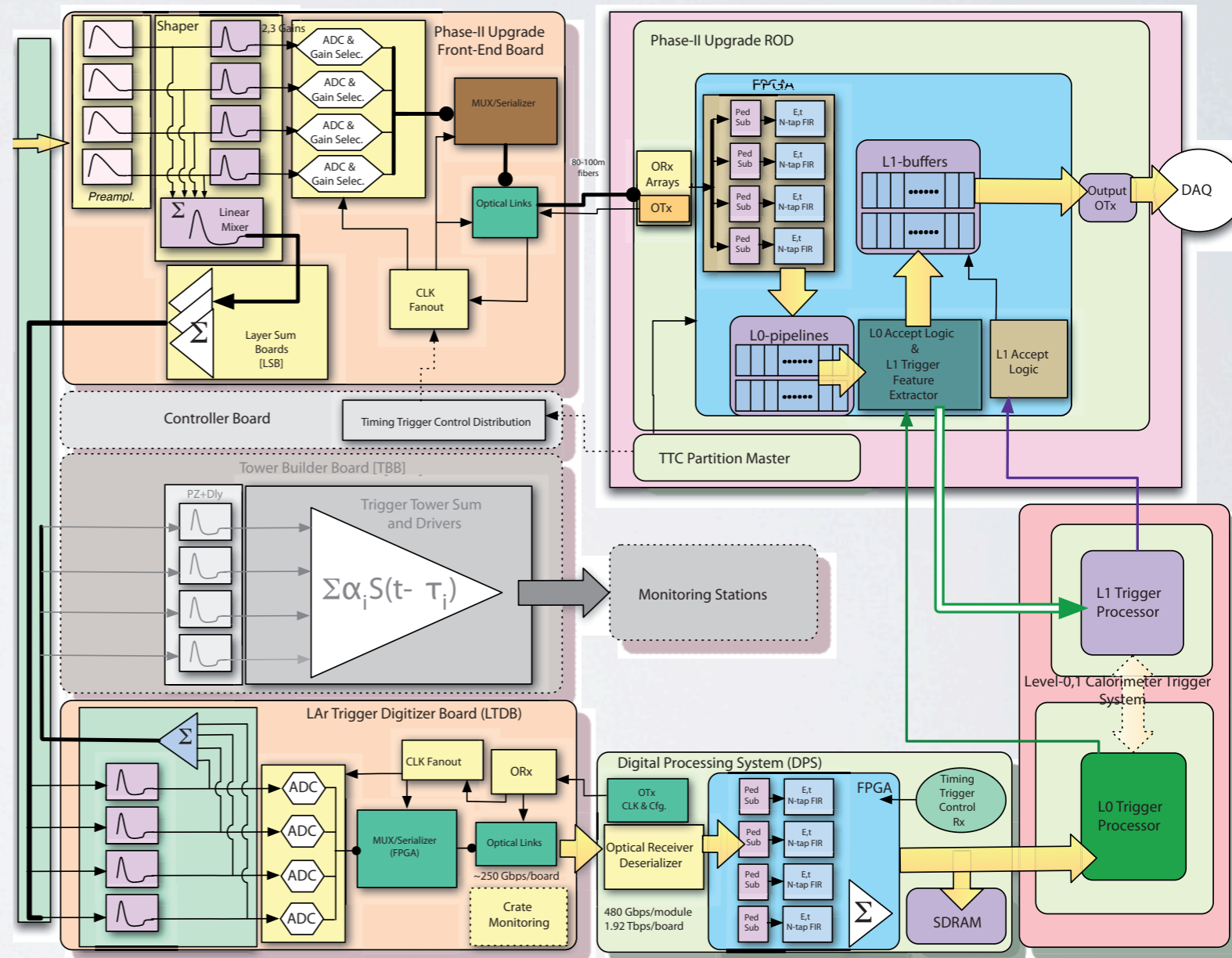
PHASE-II

- In the phase II upgrade of the LHC (after 2022), instantaneous luminosities of up to $5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$.
- A short-latency trigger signal is possibly still required in phase-II: the L1 trigger developed for phase-I can become a L0 trigger in phase-II.
- Higher granularity information is planned to be used at the future L1 (larger-latency) \Rightarrow Readout of all detector cells \Rightarrow much more complex algorithms can be used.
- Optical links will bring the information from the detector to the L1. Possible combination with a L1 tracking system being investigated.



PHASE II SCHEMATICS

- All FEBs will be replaced.
- Signals are planned to be digitized and serialized in free-running mode.
- required bandwidth for the optical connection to the ROD will be much higher.
- The phase-II ROD will implement data buffering and transfer on L0 and L1 trigger accept signals.
- The ADC solutions used in phase-I for the LTDB may be adapted to the phase-II FEBs.
- The phase-I DPS solution (ATCA-based) may evolve to a future phase-II ROD.



CONCLUSIONS

- The improved granularity of the Liquid Argon Calorimeter based trigger readout for the phase-I LHC upgrade is discussed. We also discuss the plans to improve the future detector readout in phase-II. Most of the design being considered now to the Super-Cells readout is directed towards the phase-II regular cells readout (ADC, Digital Signal processing hardware and energy reconstruction algorithms).
- Initial analysis demonstrates clear advantage of using the higher segmentation for electron detection. A reduction of the minimal threshold guarantees keeping the electro-weak sector of the physics to be explored in the High-Luminosity LHC scenario.
- Initial design of the new hardware and modification of the existing hardware is already being planned in details.
- Other triggers are also being explored for jets, taus and missing transverse energy to evaluate performance improvement thanks to the increased granularity (and new trigger algorithms) as well as new energy reconstruction techniques for higher pile-up.

REFERENCES

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