The ATLAS Tile Calorimeter, its performance with pp collisions and its upgrades for high luminosity LHC

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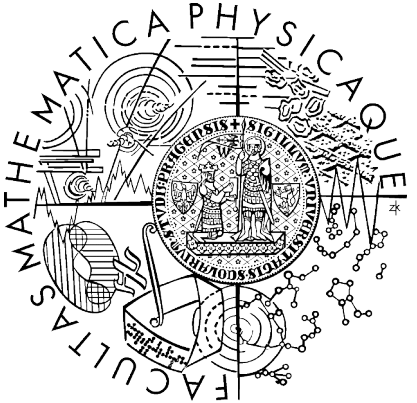
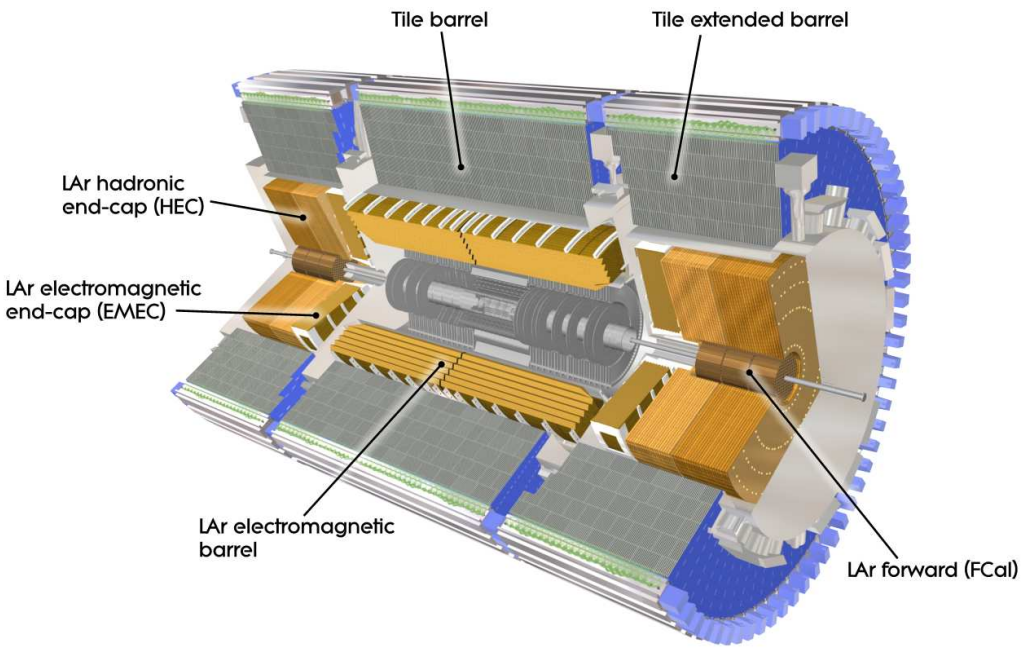
on behalf of the ATLAS Collaboration



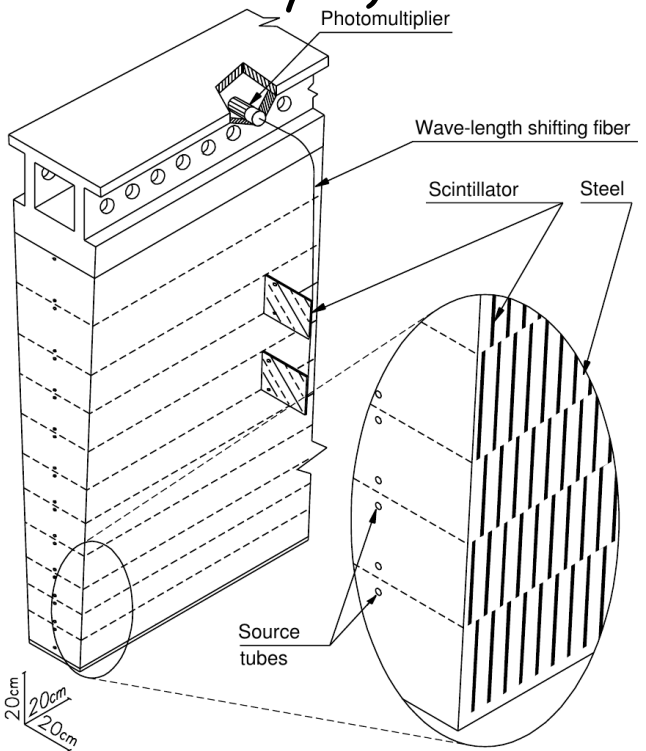
DIS 2016, Hamburg

Tile Calorimeter



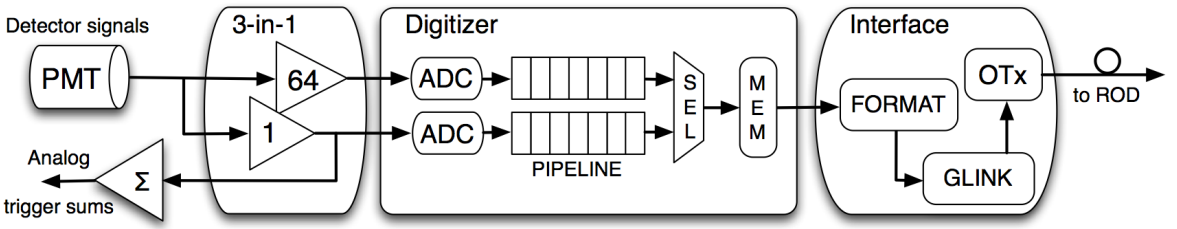
- Sampling iron/scint calorimeter
  - light from tiles collected by WLS fibers and routed to PMTs, pulse shaped and digitized; 2 channels per cell
  - 3 radial layers, 7.4 λ_{int} in total
  - $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ (0.2 x 0.1 in the last radial layer)

- Hadronic calorimeter in ATLAS central region ($|\eta| < 1.7$)
- Central Long Barrel and two Extended Barrel sections surrounding the LAr barrel elmg and hadronic end-cap calorimeters

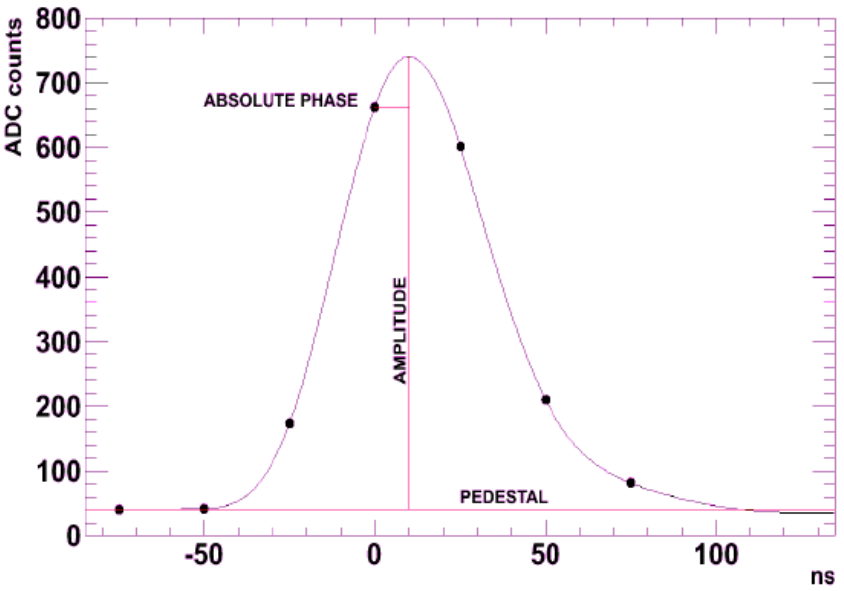


Signal processing

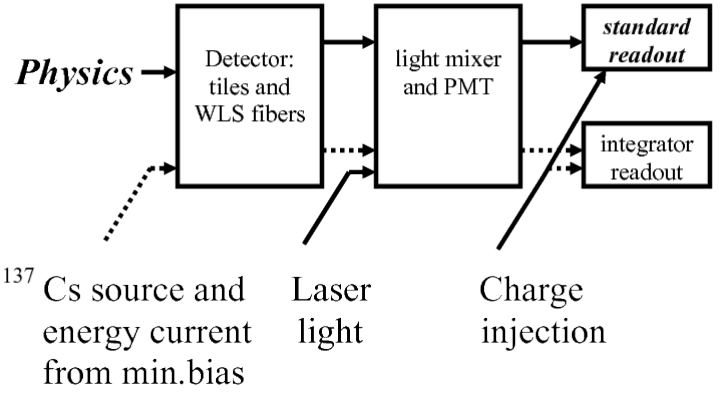
- **Analog path**: signals are summed up and sent directly to Level-1 trigger



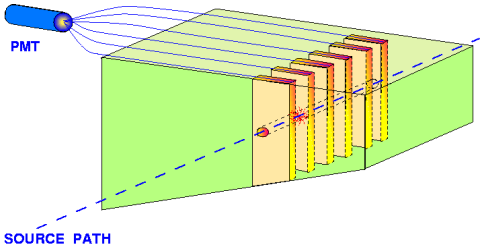
- **Digital path:**
  - signal split into two gains (1:64)
    - good signal-to-noise ratio for small signals (muons)
    - dynamic range up to 1.6 TeV energy per cell
  - shaped signals sampled every 25 ns, stored in pipeline memories and sent off-detector when Level-1 trigger accept is received
  - amplitude, time and quality factor reconstructed in Readout Drivers



Calibration (1)



- Three dedicated systems to calibrate different stages of signal propagation
  - Cesium
    - calibrates optics, PMT gain and „slow" electronics by passing the radioactive source through the whole detector; primary tool to set EM scale
    - readout path shared with minimum bias system that averages signals from collisions over several msec
  - Laser
    - illuminates every PMT, calibrates PMT gain and „fast" readout electronics
    - also used for time monitoring during physics data taking
  - CIS
    - calibrates electronics by injecting pulses of known charge, measures amplitude [ADC] to charge [pC] conversion coef.



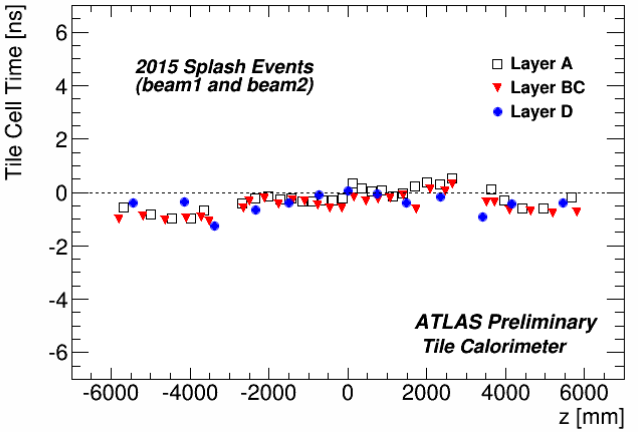
Calibration (2)

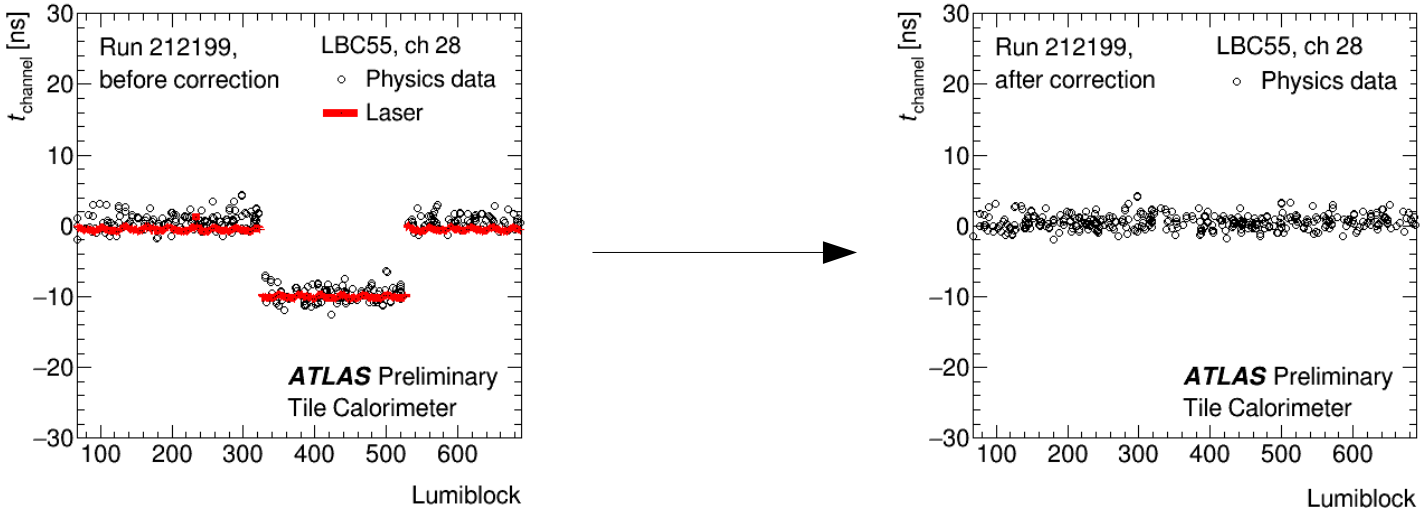
measured with electrons at testbeams

- Channel energy calibration (EM scale):

$$E\,[GeV] = A\,[ADC] \times C_{Cs} \times C_{las} \times C_{CIS}\,[pC/ADC] \times C_{TB}\,[pC/GeV]$$

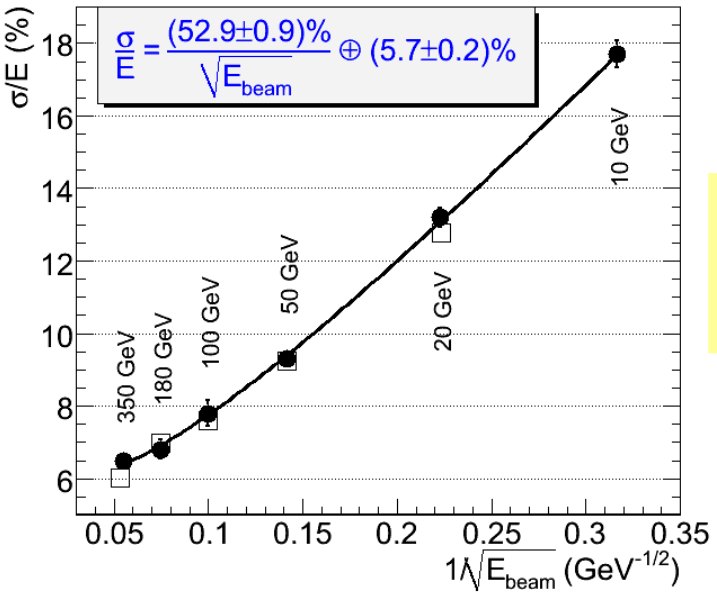
- Time calibration
  - initially set with lots of high-energetic muons passing the calo parallel to beam axis (splashes)
  - later fine-tuned with jets
  - monitored during physics data taking with laser, eventual corrections performed before the data are reconstructed for physics analysis



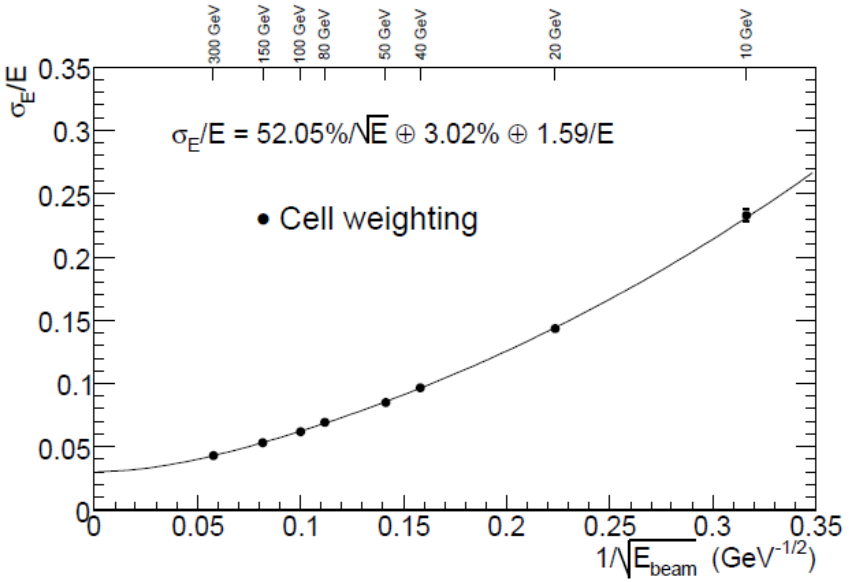


Energy resolution

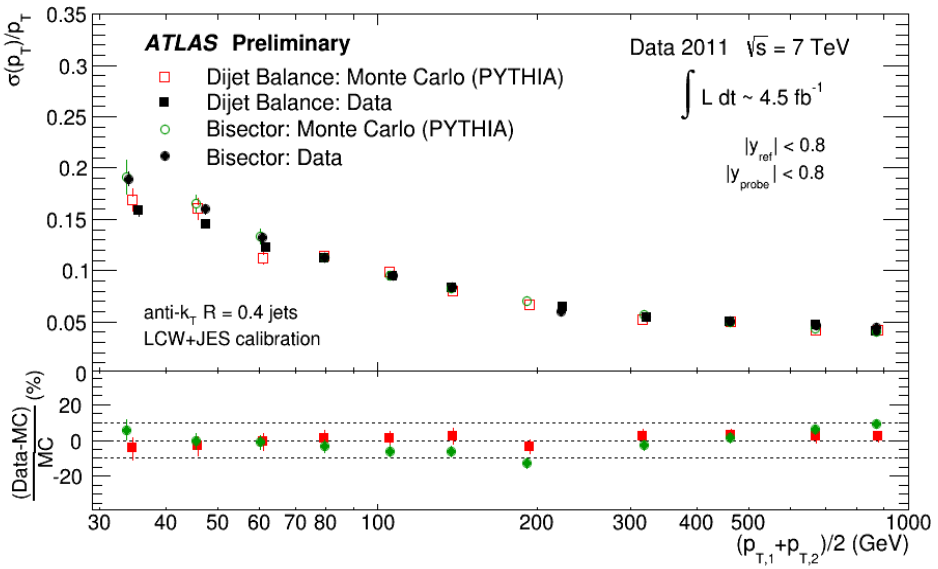
- Standalone testbeam (η=0.35, equivalent depth 7.9λ_{int})
- Combined EM LAr+Tile prototypes testbeam (η=0.25 → 10.5λ_{int})



pions in testbeam, calorimeters at EM scale

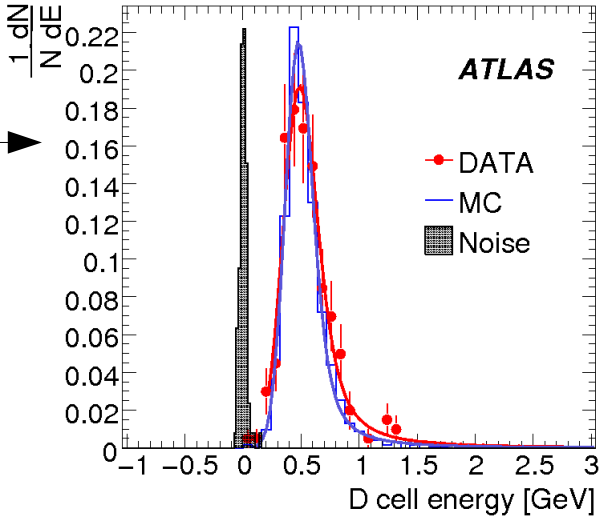


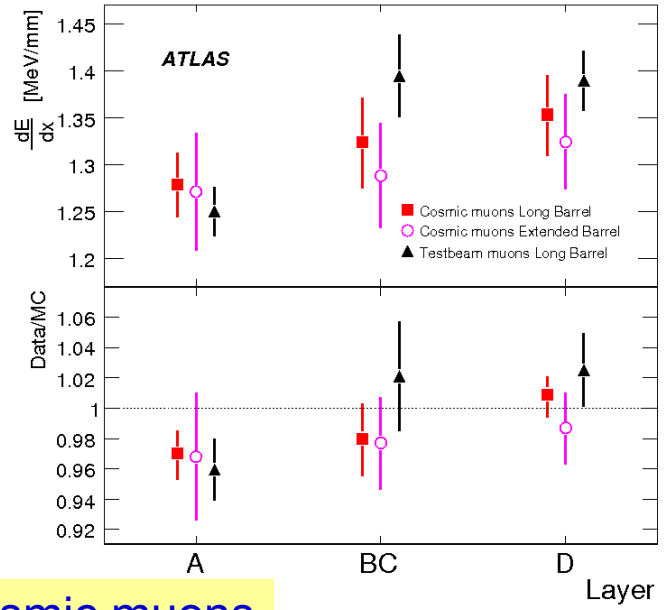
- Performance in ATLAS - jet resolution close to design
  - constant term ~3%
  - resolution for low-p_T improves after pile-up corrections
  - slightly better results obtained with LCTopo



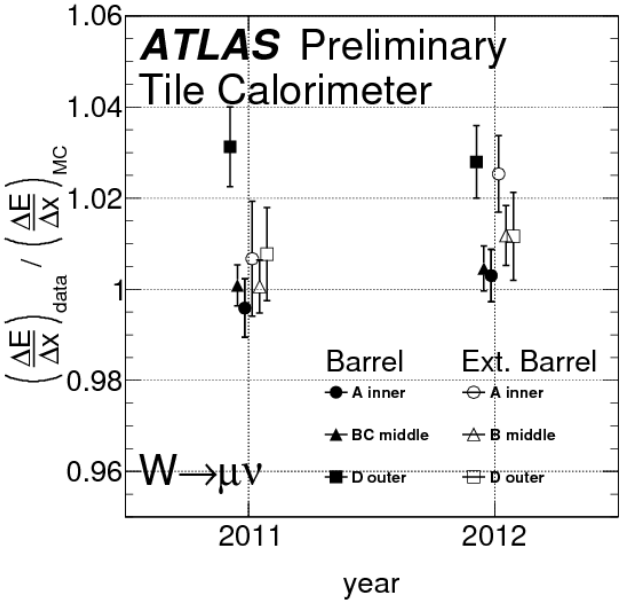
Electromagnetic scale validation (1)

- Due to very good signal-to-noise ratio, isolated muons (cosmic rays or from collisions) represent a good tool to validate the EM scale





cosmic muons



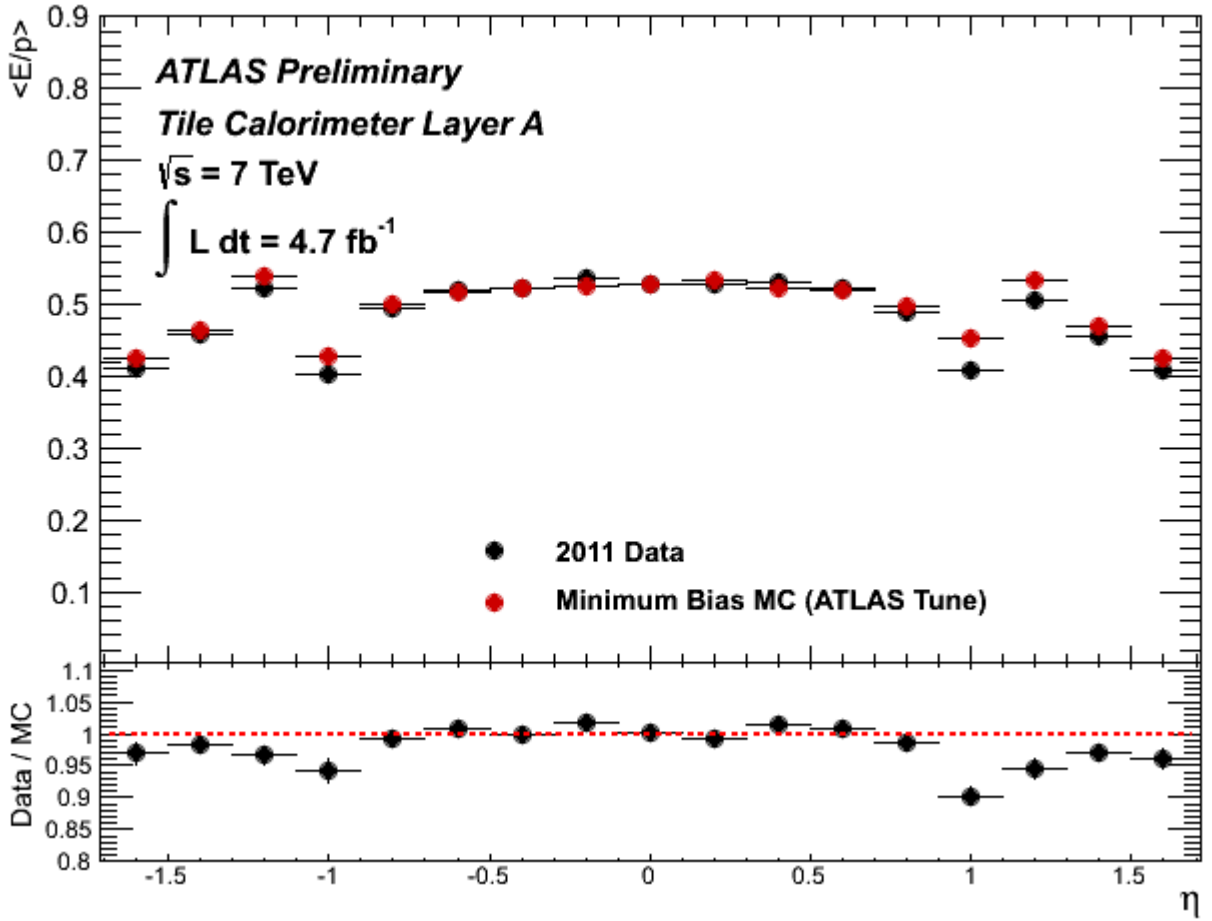
collision muons

	R_{2008}	R_{2009}	R_{2010}
LB-A	0.966 ± 0.012	0.972 ± 0.015	0.971 ± 0.011
LB-BC	0.976 ± 0.015	0.981 ± 0.019	0.981 ± 0.015
LB-D	1.005 ± 0.14	1.013 ± 0.014	1.010 ± 0.013
EB-A	0.964 ± 0.043	0.965 ± 0.032	0.988 ± 0.014
EB-B	0.977 ± 0.018	0.966 ± 0.016	0.988 ± 0.014
EB-D	0.986 ± 0.012	0.975 ± 0.012	0.982 ± 0.014

- Very good stability of the cosmic muon response in 2008 - 2010
- Similar results obtained in several analyses, maximum difference between radial layers 4%

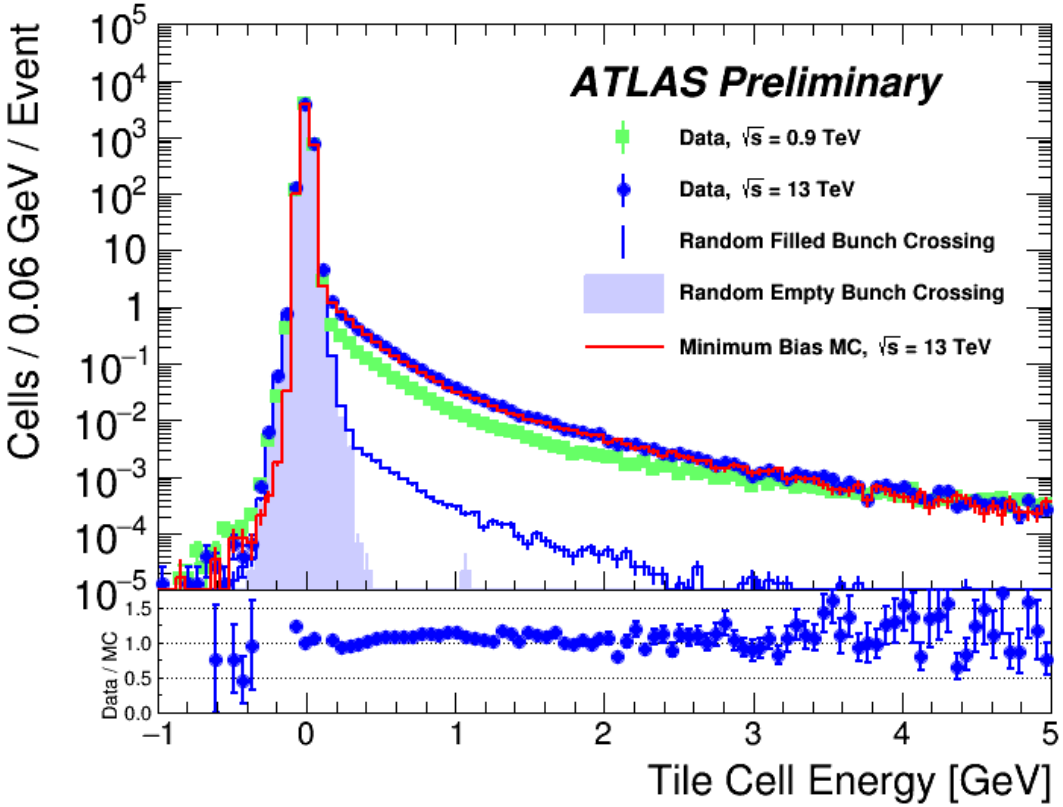
Electromagnetic scale validation (2)

- E/p measurements with isolated charged hadrons
  - hadrons showering predominantly in Tilecal 1st radial layer (A)
  - good agreement with MC description



Cell response in collision data

- Distribution of the energy deposited in TileCal cells from pp collision data ($\sqrt{s}$ = 13 TeV and 0.9 TeV)



- events with just one reconstructed primary vertex are shown
- Pythia minimum bias MC is overlayed
- good description data/MC

Further TileCal performance plots available on

- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TileCaloPublicResults
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsTile

Upgrade

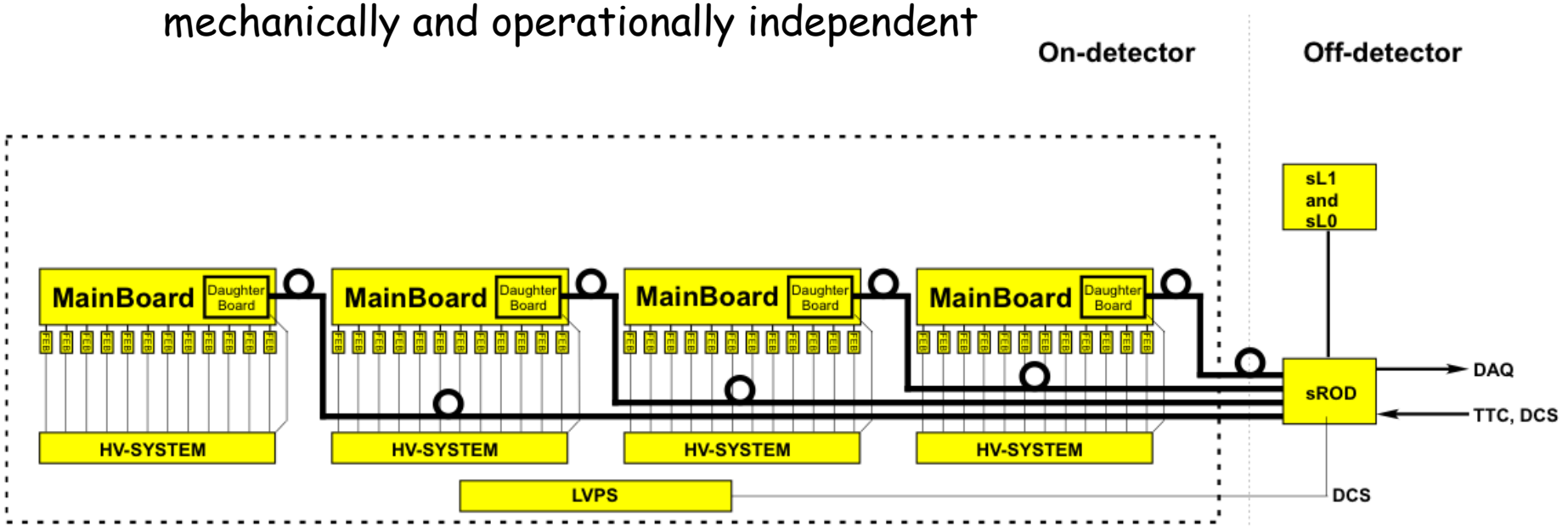
Upgrade plans (1)

- **Phase 0**: all power supplies were replaced. Reliability improved, number of trips dramatically reduced, also electronic noise slightly reduced → better performance in Run-2
- **Phase 1**: replacement of the gap/crack scintillators due to material ageing
- **Phase 2**: major upgrade of the whole readout electronics system

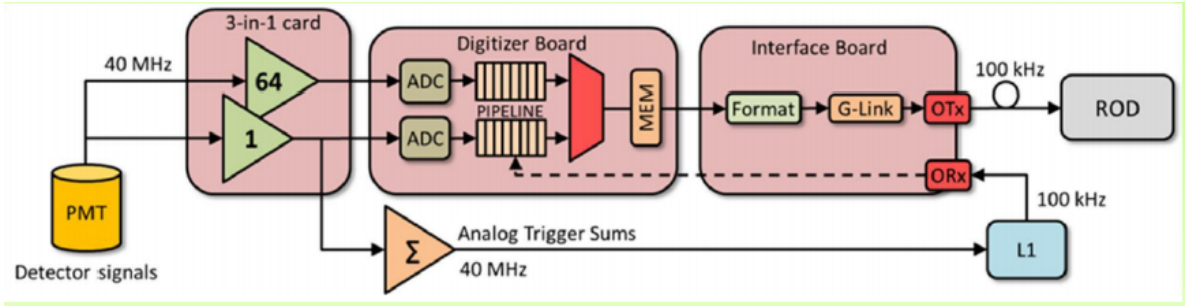
Upgrade plans (2)

- Major TileCal electronics upgrade for the HL-LHC (Phase II)
  - higher radiation tolerance, faster and more modern electronics
  - allow better precision and finer granularity of the ATLAS trigger → all Tile signals digitized and sent off-detector @ bunch-crossing rate (40 MHz), requiring high bandwith

    readout philosophy changed !!
  - increase redundancy and reliability
    - current electronics superdrawers split into 4 „mini-drawers", mechanically and operationally independent

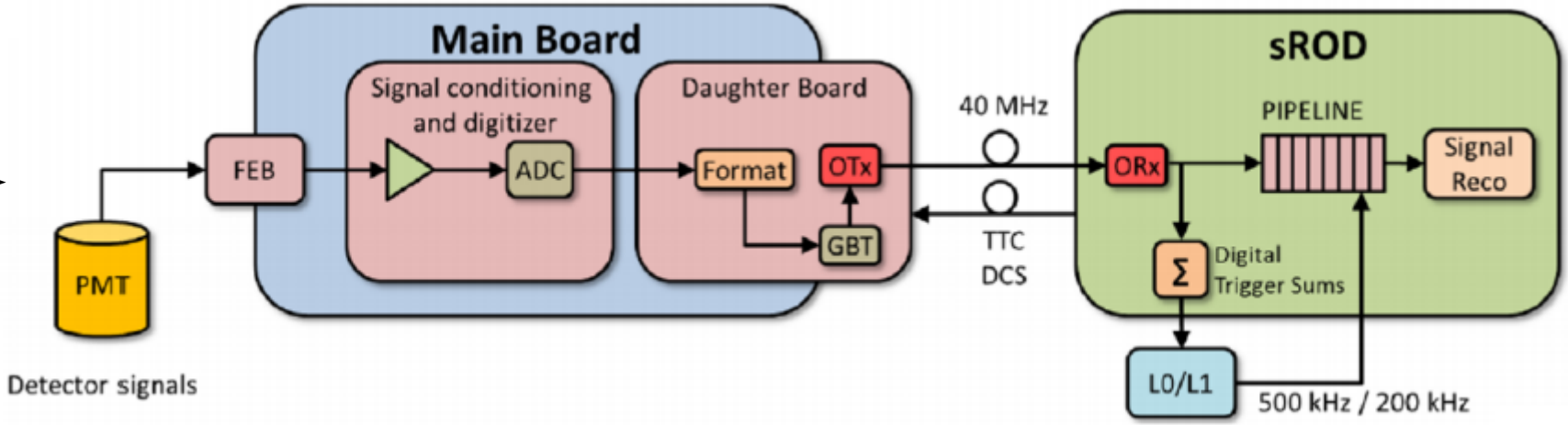


Current vs new signal flow



current

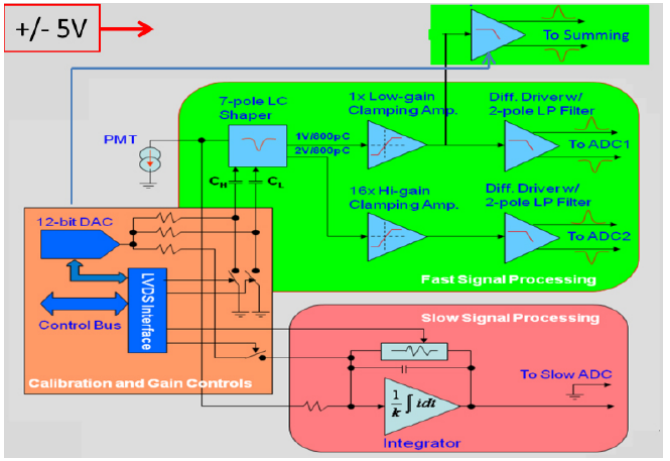
new



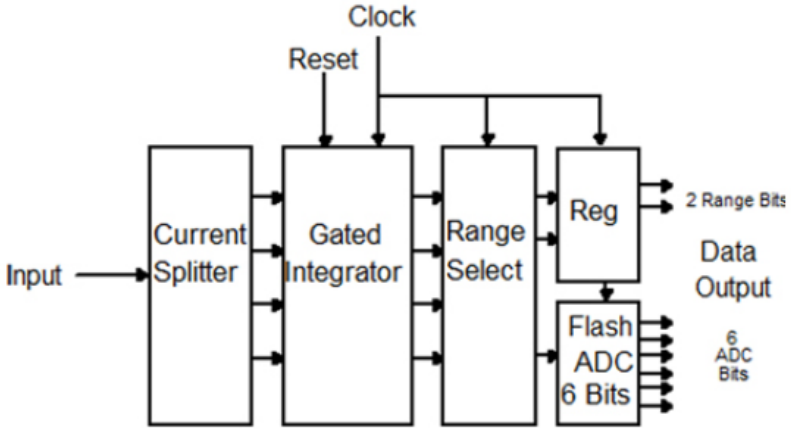
- Each Mainboard serves 12 channels (PMTs)
- Daughter boards communicate with off-detector electronics (sROD)
  - controlled by two Kintex-7 FPGAs
  - sent out digitized signals (at 40 MHz rate compared to current O(100) kHz) & receive slow control commands and route them to Mainboards

Front-end board options

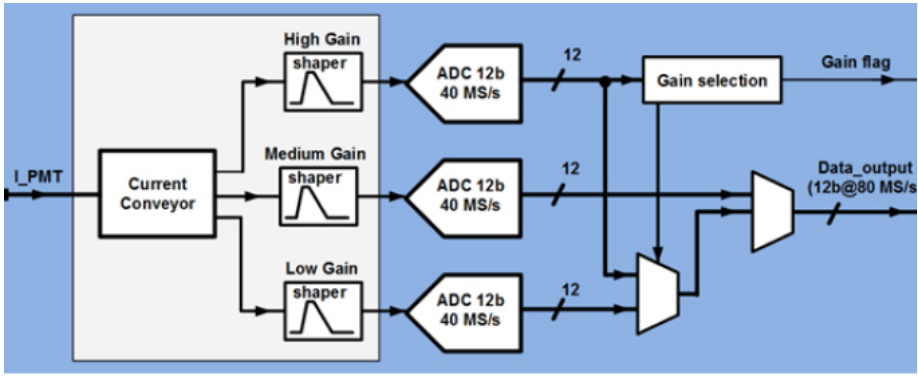
- Modified 3-in-1
  - pulse shaped and digitized with 12-bit ADC and 2 gains (1:32)
  - also provides CIS and slow integration (Cs and minimum bias)



- Charge Integrator and Encoder (QIE)
  - based on ASICs
  - no pulse shaping, digitization with 6-bit ADCs and 4 gains

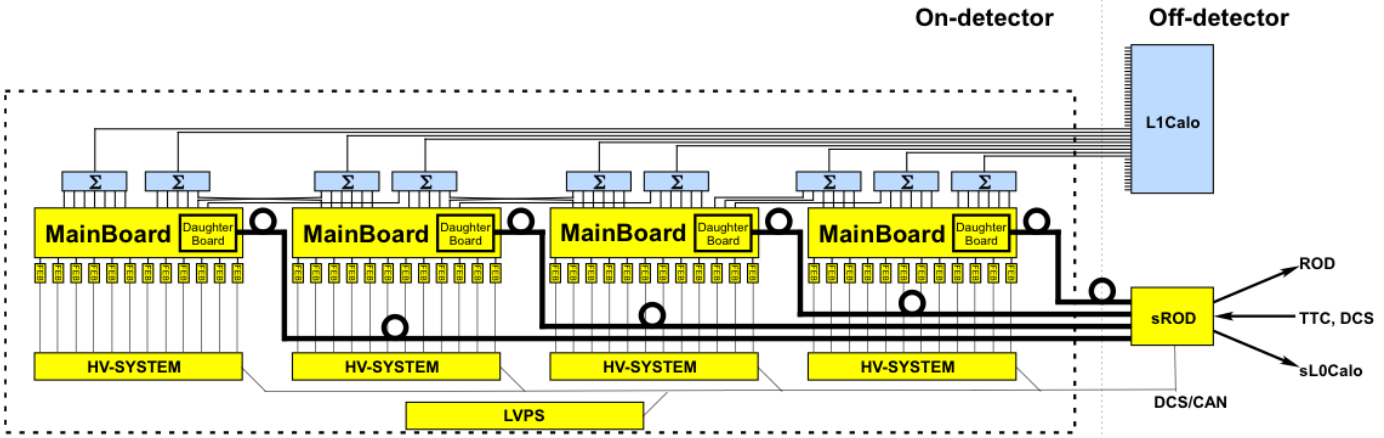


- FATALIC
  - combination of two ASIC chips
  - pulse shaped and digitized with 12-bit ADCs and 3 gains (1:8:64)

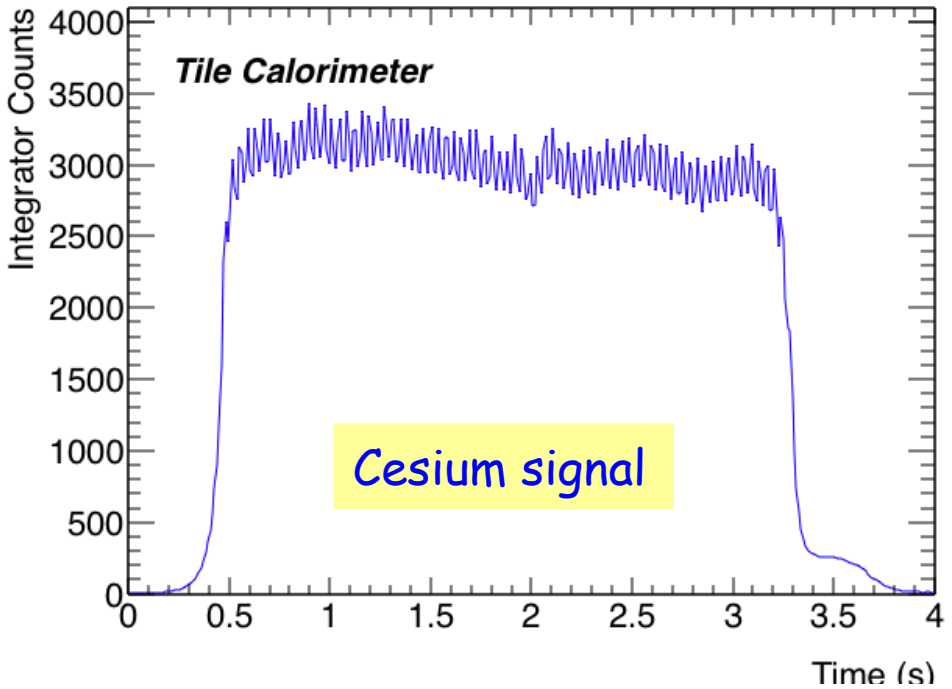


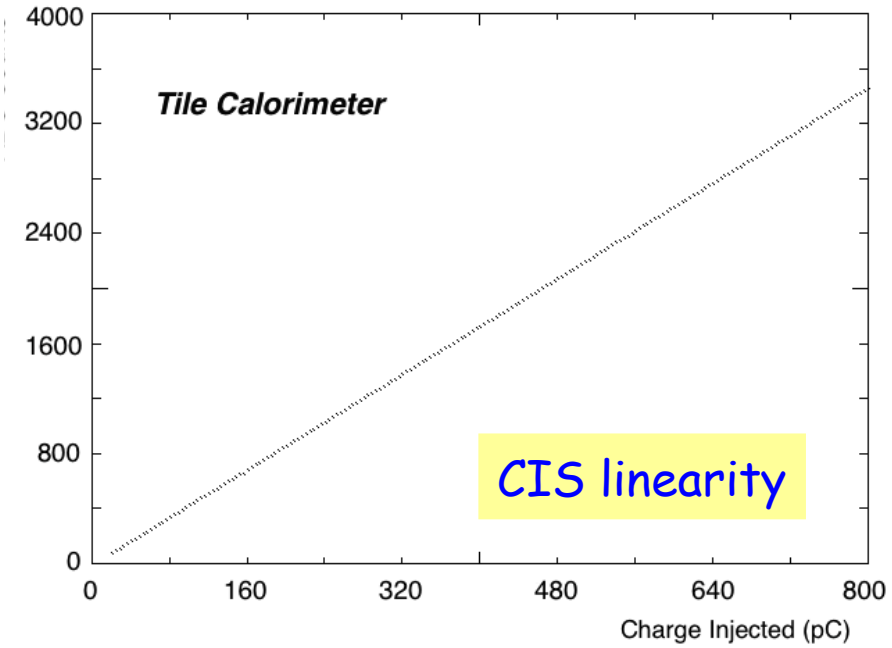
Demonstrator (1)

- A hybrid prototype, compatible with both current and new electronics



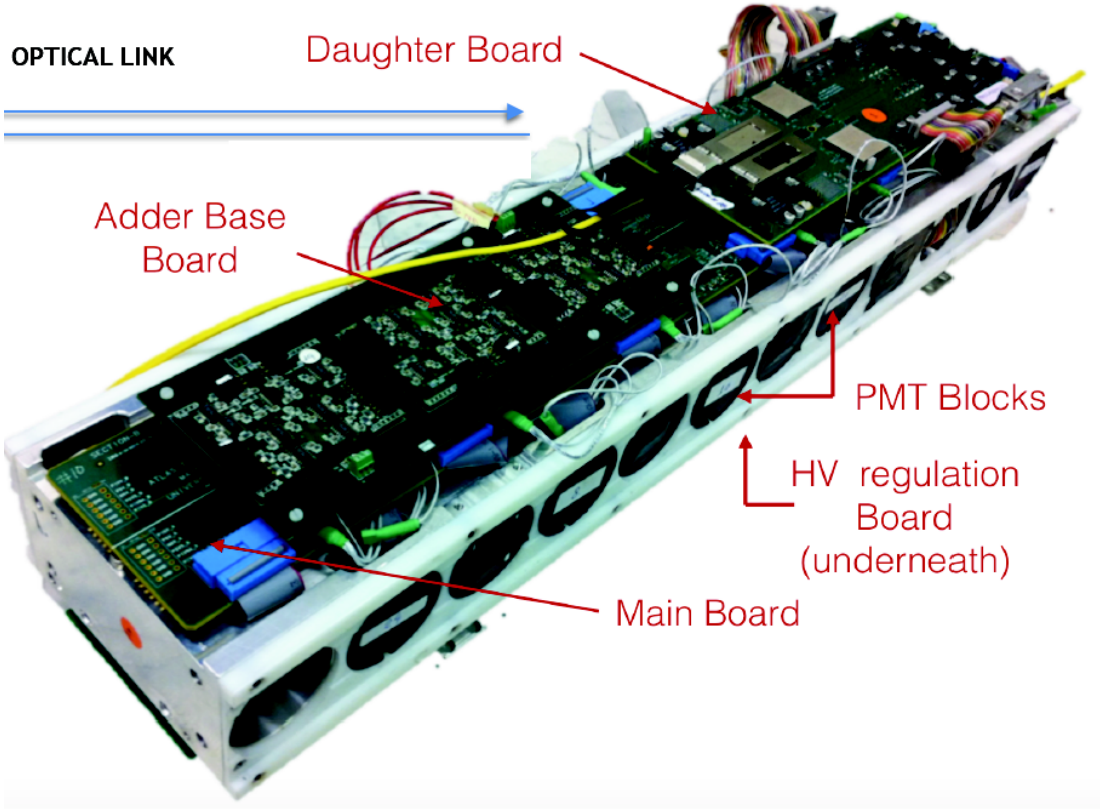
- Already built and tested in labs …





Demonstrator (2)

- … as well as in testbeam (autumn 2015)
- Further intensive tests and two testbeam campaigns are planned this years, especially with other FEB options
- After successfull tests the demonstrator should be inserted in a Tile calorimeter module in ATLAS, maybe already at the end of this year



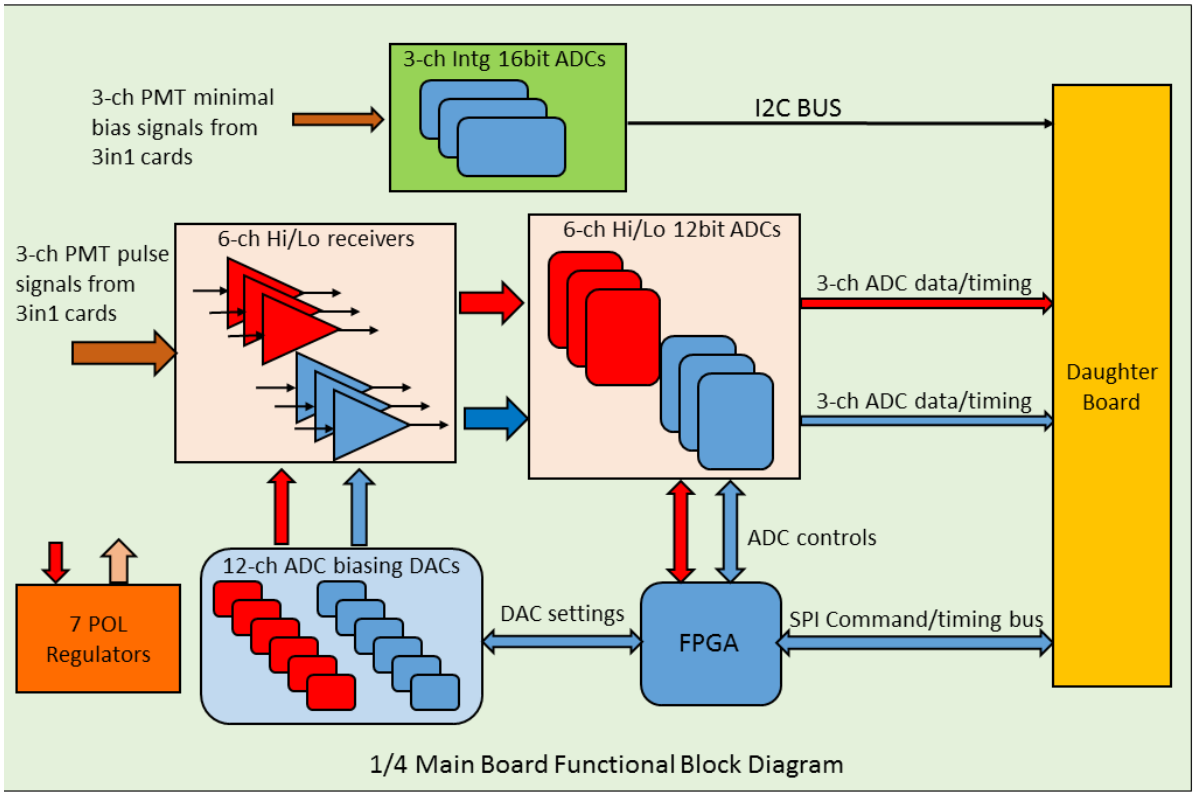
Conclusions

- ATLAS Tile Calorimeter performs very well during LHC Run-1 and Run-2 so far, its contribution to many physics analyses is essential
- Calibration systems achieved precision better than 1%
- After detector consolidation during winter shutdown, we are even in better shape, looking forward for new Run-2 data !!
- For high luminosity LHC, Tilecal is on schedule to replace the readout electronics
  - intensive tests ongoing, demonstrator to be inserted in ATLAS at the next detector opening
  - optics system is expected to suffer from moderate radiation damage → negligible impact on jet performance

BACKUP

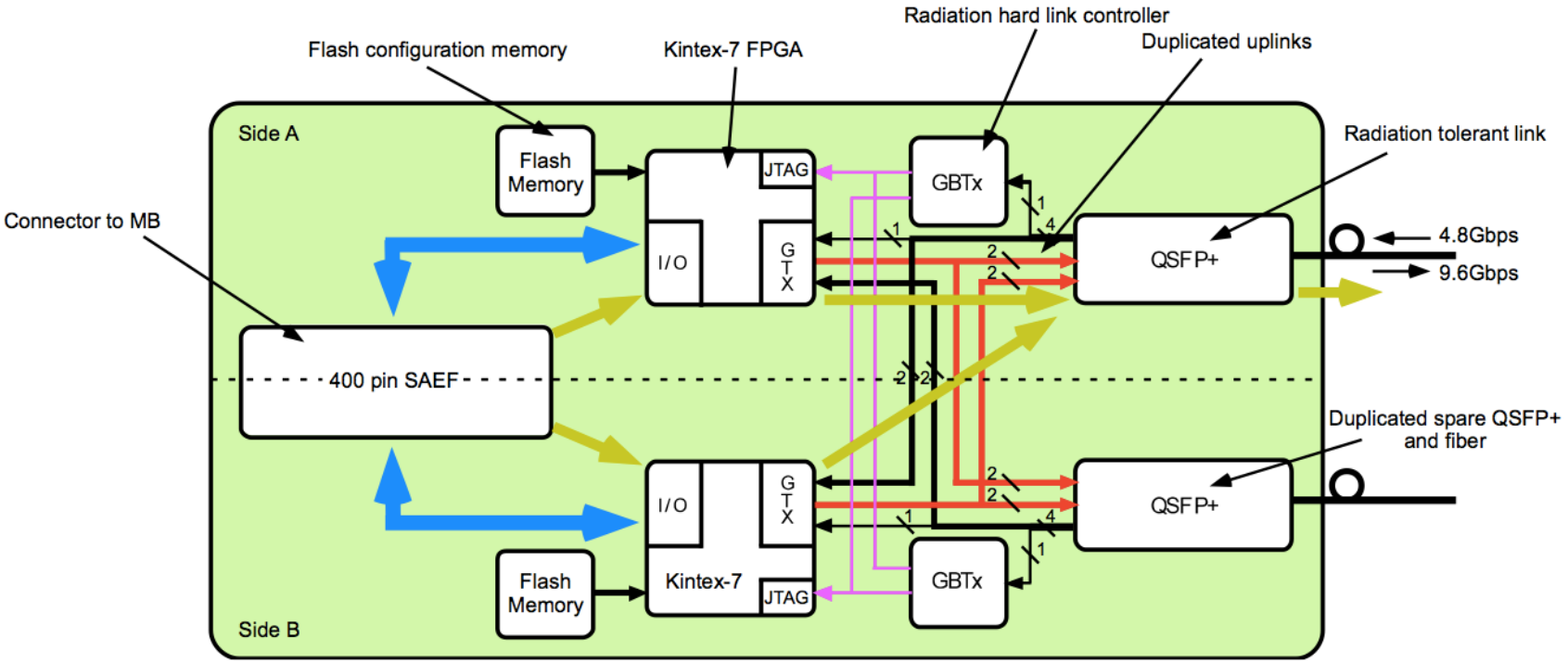
3-in-1 & Mainboard

- Diagram of $\frac{1}{4}$ of a Mainboard for the 3-in-1 front-end option for the TileCal Demonstrator. Each quarter of the Mainboard serves 3 front-end channels for a total of 12 channels per Mainboard.
  - for each channel it provides 16-bit ADCs for the slow integrator readout, receivers and 12-bit ADCs for high and low gains
  - the interface with the back-end to transfer the data and received configuration and control signals is done through the Daughter board.



Daughter board

- The board is divided in two parts which can be operated independently. Each half can readout up to 6 front-end channels.
- The communication with the Mainboard is done through a 400 pin FMC connector. The interface with the PreProcessor in the back-end is done through two redundant QSFP connectors.
- The system is managed by two Kintex-7 FPGAs while two GBTx chips are used to recover the system clock and provide remote reconfiguration of the FPGAs.



Pre-Processor system

- Tentative block diagram of a Pre-Processor (PPr) system
  - one PPr system is able to process the data from 8 TileCal superdrawers. The PPr module is composed of a carrier with four mezzanine boards. The TDAQI provides interface with the FELIX (Front End LInk eXchange) for DAQ and Trigger, Timing and Control.
  - depending on the final trigger level structure, the TDAQI will send preprocessed information to the Level 0 only (L0 option) or also to the Level 1 trigger Calorimeter systems (L0/L1 option).