Phase-I Upgrade of the Trigger Readout Electronics of the ATLAS Liquid-Argon Calorimeters and the Expected System Performance

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On behalf of the ATLAS LAr Calorimeter Group

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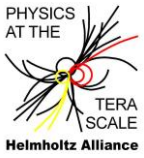

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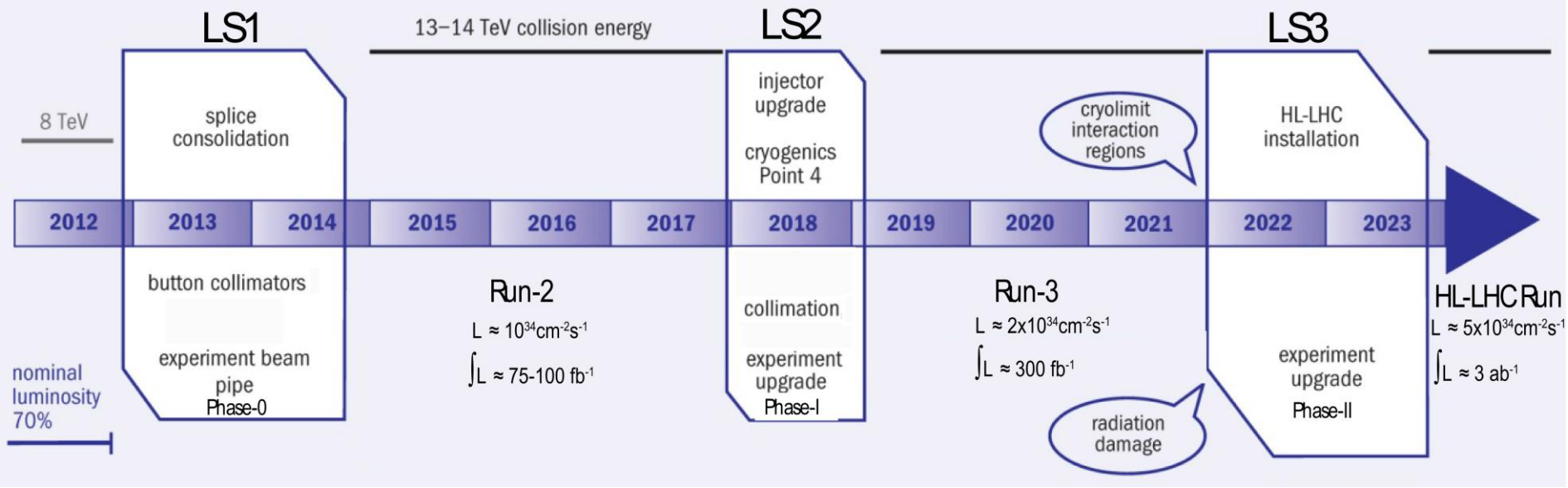
LHC Upgrade Baseline Roadmap

- Current LHC maintenance and upgrade schedule:

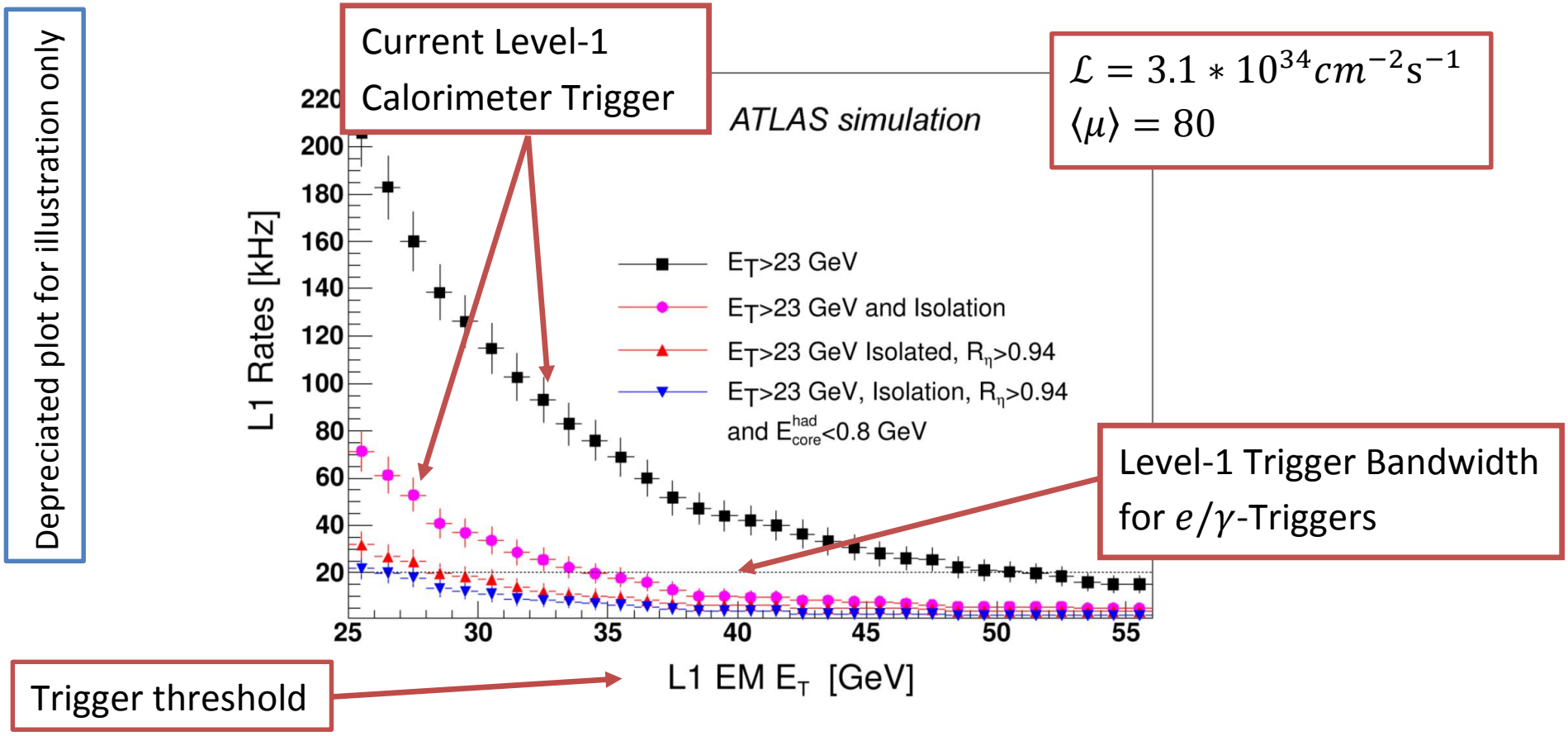


[ATLAS LAr Phase-1 Upgrade TDR]

- This talk: LAr calorimeter upgrade for Phase-1 (LS2) with demonstrator installed during LS1
- Preparation of the detector for $\mathcal{L} = 2 \ldots 5 * 10^{34}$ respectively $\langle \mu \rangle = 80 \ldots 140$

Physics Motivation for Trigger Readout Upgrade

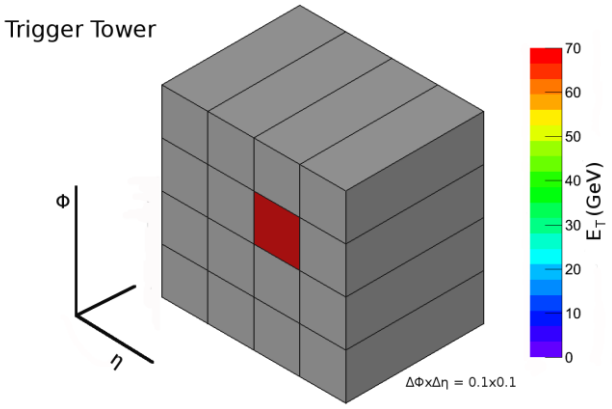
Expected EM object trigger rates for Run 3 with current and possible improved trigger algorithm:



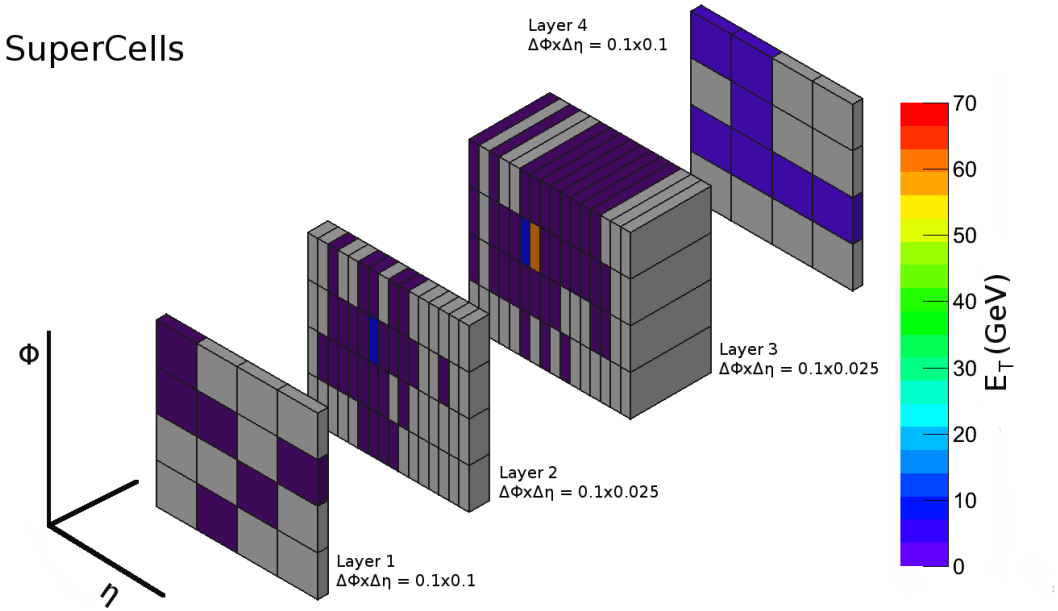
[ATLAS LAr Phase-1 LoI, CERN-LHCC-2011-012]

Main Concept for Trigger Readout Upgrade

Currently Trigger Towers feed to Level-1 Trigger (Sum of 60 calorimeter cells in area of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$)



In future Super Cells (SC) send to Level-1 (10 Super Cells per Trigger Tower, 1-4-4-1 schema)



[ATLAS LAr Phase-1 Upgrade TDR]

Differences in shower shapes of signal and background exploitable by Level-1 Trigger

Objectives of the Phase-I LAr Trigger Readout Upgrade

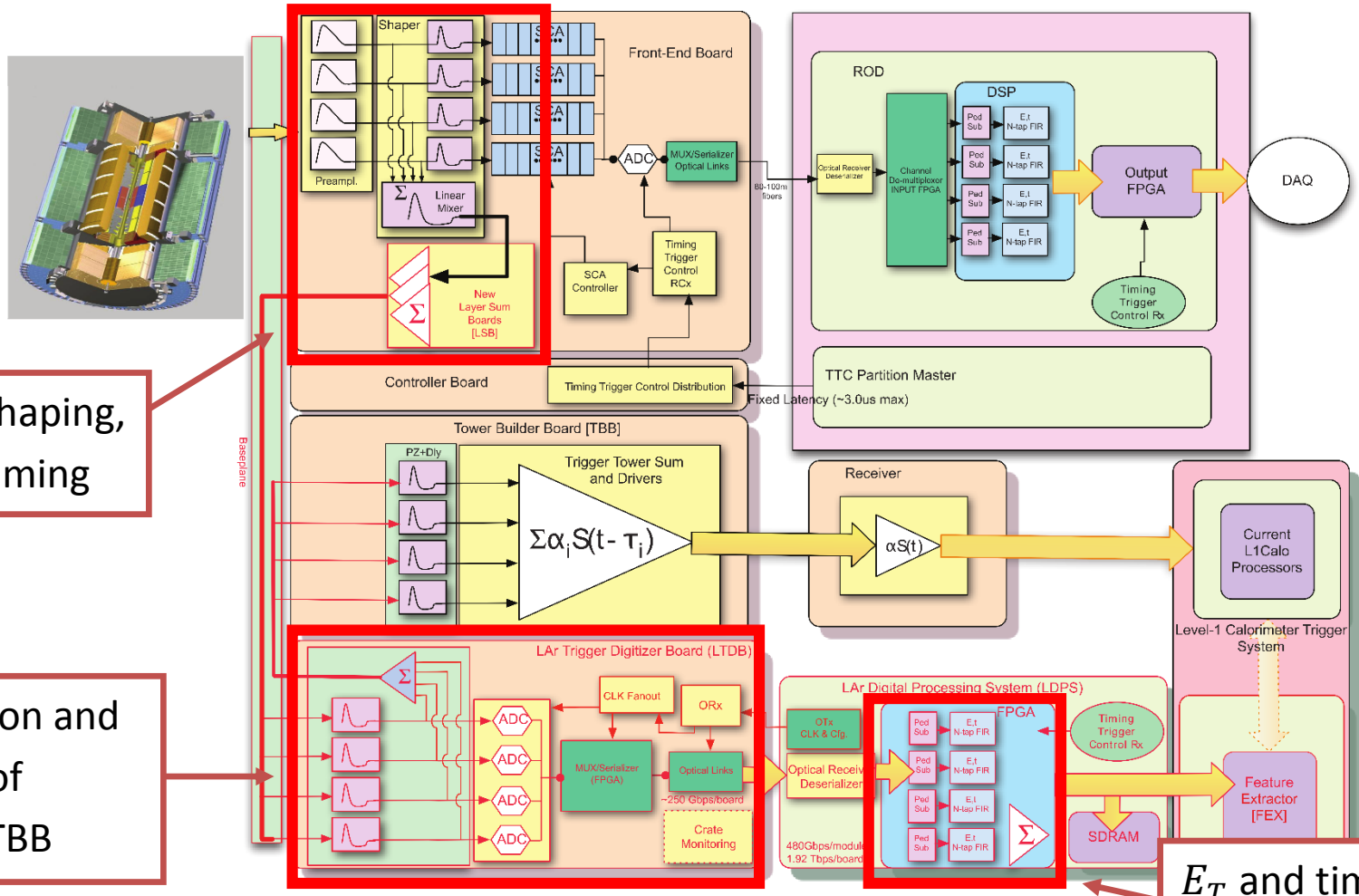
Technical Targets:

- Provide finer lateral and spatial granularity to Level-1 Trigger (Super Cells)
- Maintaining of current Trigger Tower readout path to Level-1 Trigger
- Digitization of Super Cells on-detector with high precision
- Reconstruction of E_T and time for each SC at every bunch crossing (BC)
- Meeting of tight latency budget (budget $\leq$ 51 BCs, used 44.2 BC, 1 BC $=$ $25ns$)
- Full compatibility with Phase-II upgrade

Physics Targets:

- Lower Level-1 EM/τ trigger thresholds due to improved algorithms based on SCs
- Lower Level-1 trigger rates for Jets and E_T^{miss} due to improved resolution

Schema of new Trigger Readout Electronics



Pulse shaping, SC summing

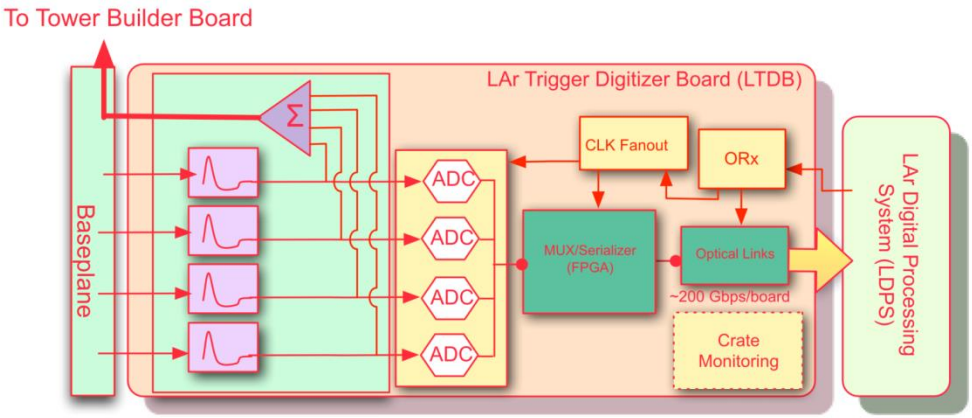
Digitization and feeding of current TBB

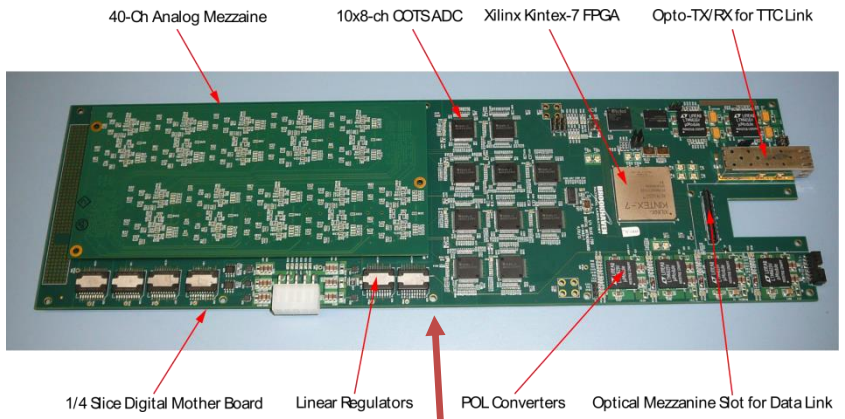
E_T and time reconstruction

[ATLAS LAr Phase-1 Upgrade TDR]

LAr Trigger Digitizer Board (LTDB)

- New baseplane delivers analog SC pulses from FE board to new LTDB (320 SCs per LTDB)
- Sends layer sums to TBB to keep current trigger chain unaffected (difference $< 0.1\%$)
- Digitizes SC pulses with 40 MHz and send them with optical links to back end electronics



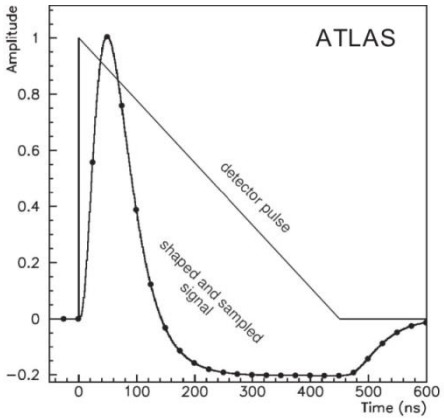


[ATLAS LAr Phase-1 Upgrade TDR]

Prototype for Demonstrator

Signal Digitization

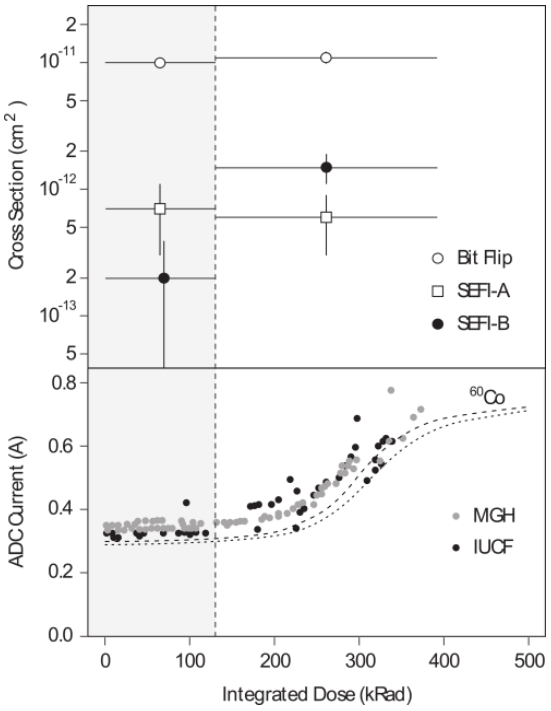
- Signal shape sampled with 40 MHz



- No additional phase shift as reconstruction algorithms compensate sampling offside peak
- Proposed ADC range and precision:

Layer	Bit width	LSB $[MeV]$	E_T^{max} $[GeV]$
Front	12	32	102
Middle	12	125	400

- Several options for ADC choice:
  - Commercial: TI ADS5272 (survived 88 kGy CO^{60} gamma irradiation)
  - Two custom ADC types under development towards Phase-II upgrade



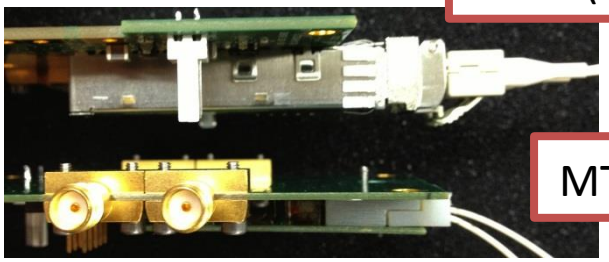
[ATLAS LAr Phase-1 Upgrade TDR]

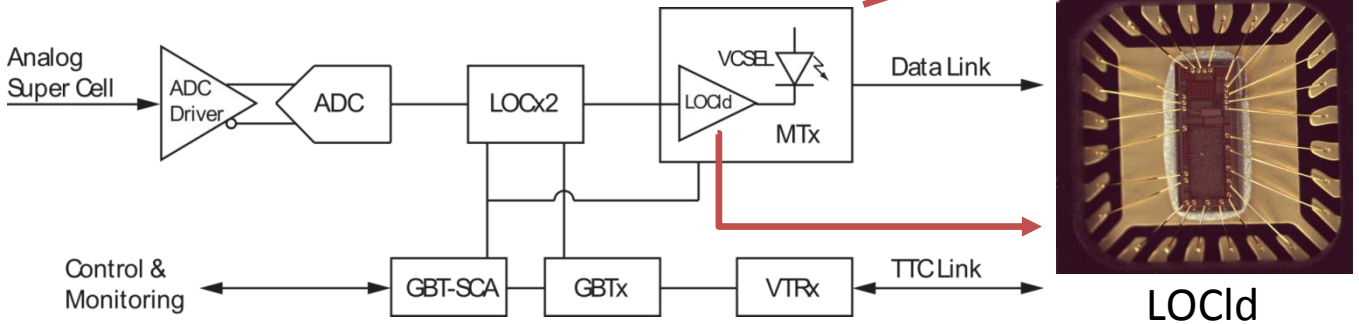
Signal Digitization

- Two series of custom 12-bit ADC developed based on IBM CMOS8RF $130nm$ technology
- Main objective: low power consumption and radiation hardness (TID $3.0kGy$)
  - 4-stage SAR-based pipeline ADC (nevis)
    - Three test ASICSs fabricated and tested under radiation conditions
    - nevis13 chip: two channel 12-bit ADC with power consumption less than $50mW$ per channel and latency of $87.5ns$
  - Full SAR-based architecture ADC (PEALL, Power Efficient and Low Latency)
    - Internal clock generator for low power consumption
    - First prototype (20 MSPS) with $< 10mW$ power consumption tested
    - 4-channel ADC available in November 2013 for testing

Optical Data Transmission from Front End to Back End

- Physical size of transceiver crucial, no commercial modules with height $< 6mm$ available
- Serialization of multiple ADC channel required for optical transmission to BE
- 8 ADC channels multiplexed to 5.12 Gbps bit stream
- 20 2-channel transmitter modules per LTDB





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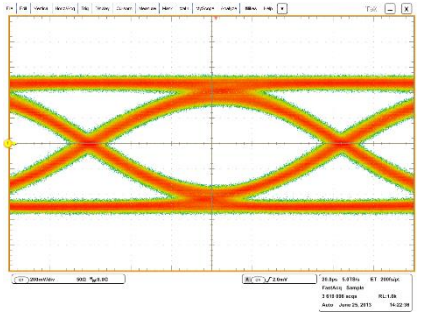
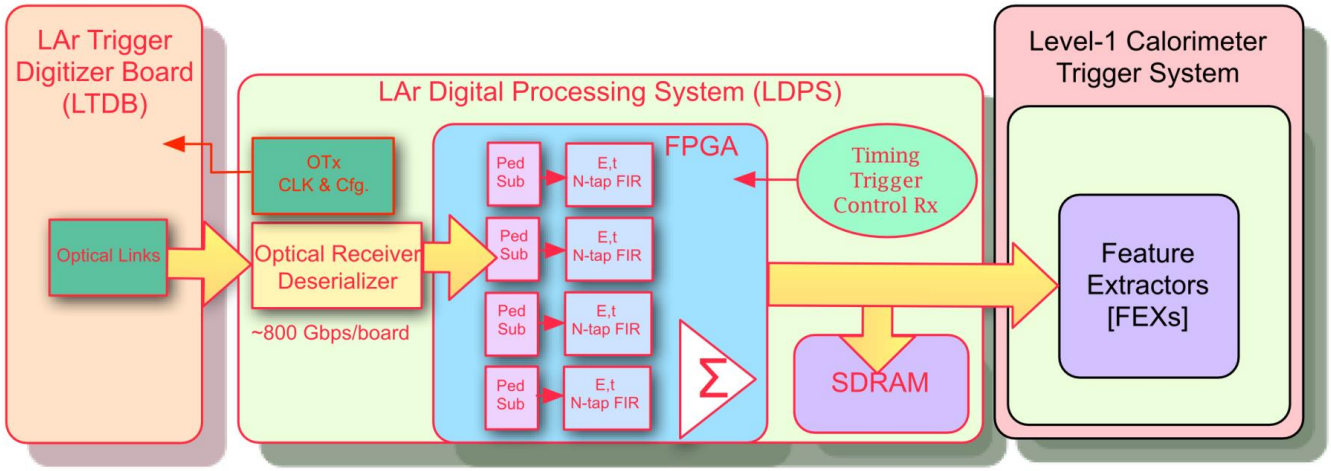


Eye Diagram at 8 Gbps

[ATLAS LAr Phase-1 Upgrade TDR]

LAr Digital Processing System (LDPS)

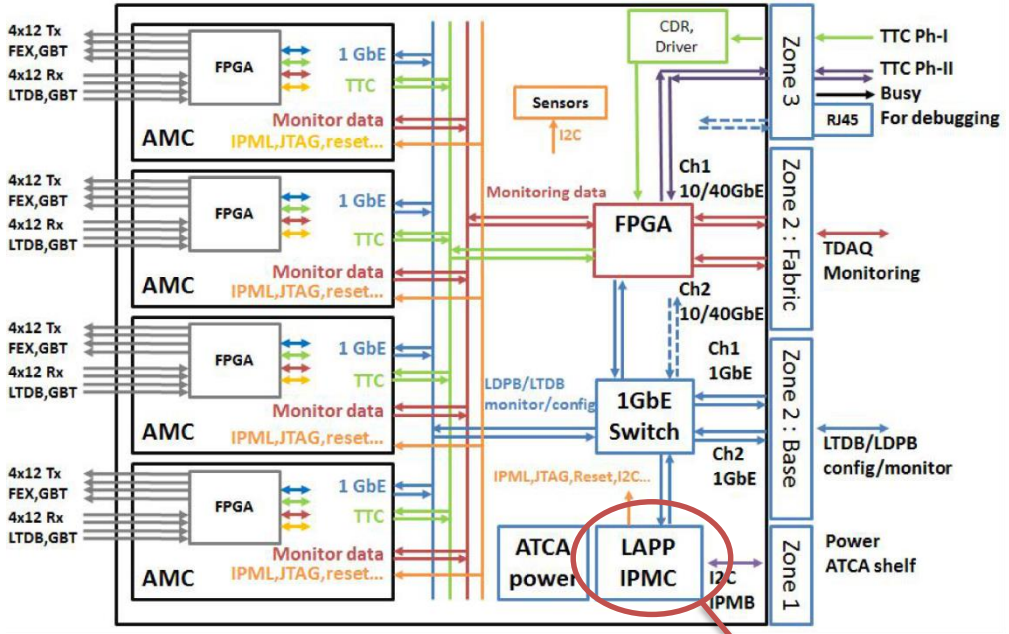
- Receives ADC data from LTDB ($\sim 25\ Tbps$)
- Reconstructs E_T and time and transmits results to Level-1 Calorimeter Trigger ($\sim 41\ Tbps$)
- Also: Monitoring, TTC distribution, configuration
- Localized in counting room with low radiation background



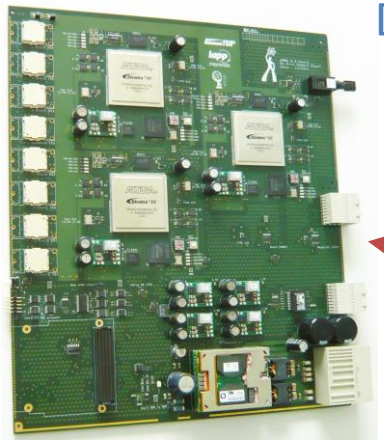
[ATLAS LAr Phase-1 Upgrade TDR]

LAr Digital Processing Blade (LDPB)

- ATCA carrier board
- Equipped with four Advanced Mezzanine Cards (AMC) for actual data processing
- Two possible FPGAs:
  - Altera Stratix IV
  - Xilinx Virtex-7
- 31 LDPBs required with 124 AMCs in total
- 320 SC processed per AMC



[ATLAS LAr Phase-1 Upgrade TDR]



Prototypes for Demonstrator

Reconstruction of E_T and time

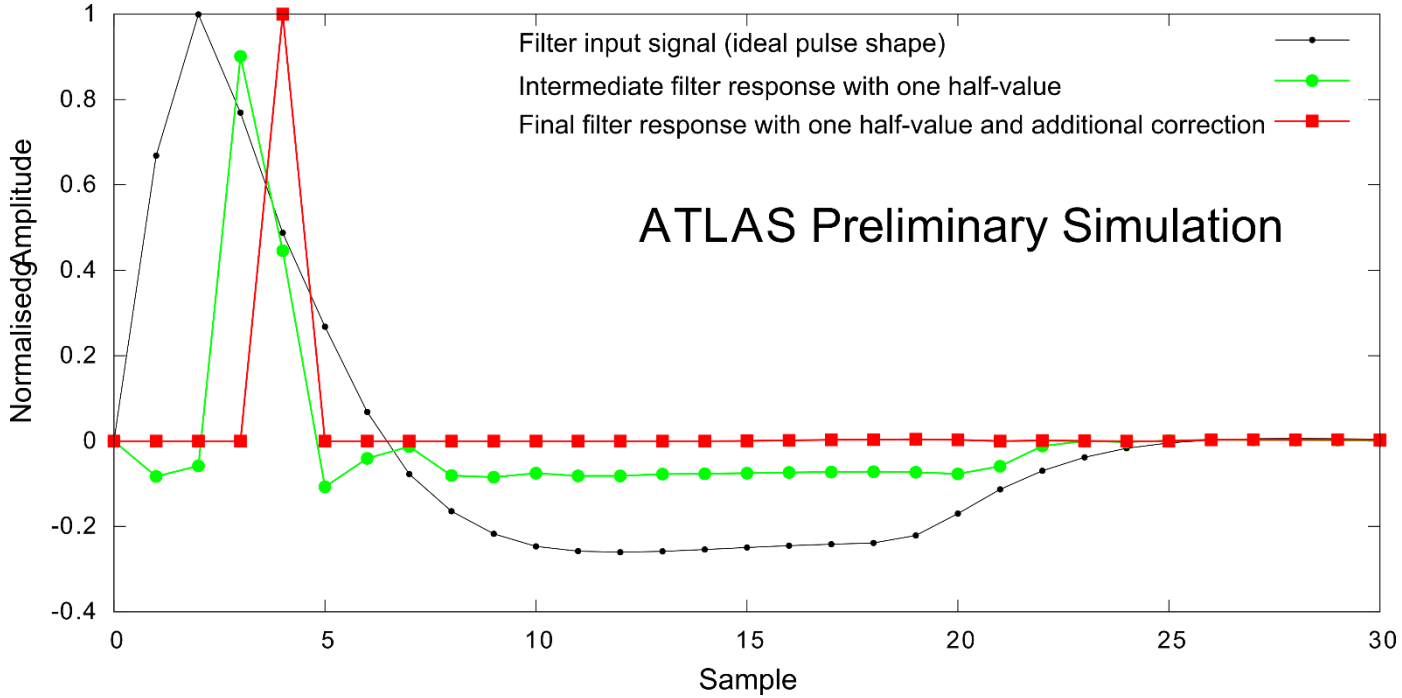
- Most crucial limit for reconstruction algorithm: latency (5 to 6 bunch crossings)
- Several options investigated:
  - Optimal Filtering (OF): $E = \sum_{i=1}^{5} a_i s_i$ with a_i=OF coefficients (FIR filter)
  - "Hit-Trigger" required for OF:
    - OF_{max}: Output only if E_j is maximum of three consecutive BCs (Current L1 Calo)
    - OF_{χ}: Matching of OF output with expected pulse shape

      $|\chi_i| = |s_i - E g_i'| \leq 2^N |s_i|, i = 1, \ldots 5$
  - Wiener filter with forward correction (IIR filter)

    Integrated halve-value trigger allows forward correction of expected pulse shape

Reconstruction of E_T and time

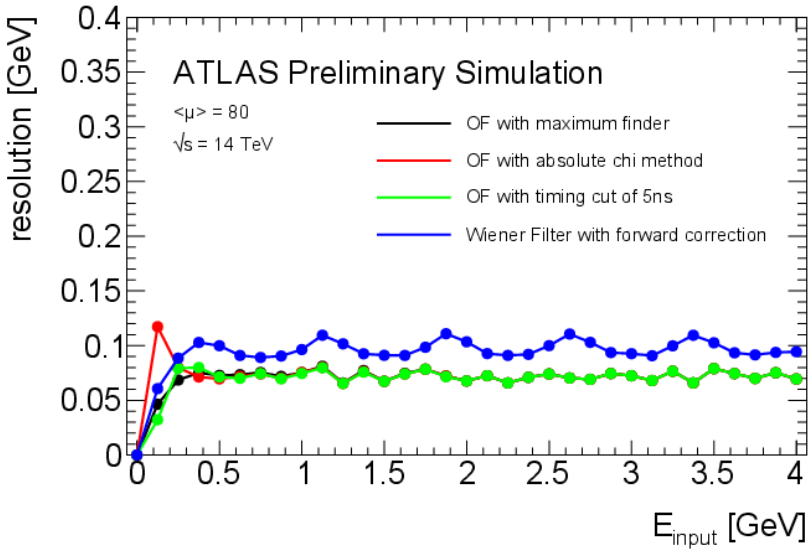
- Working principal of the Wiener filter with forward correction



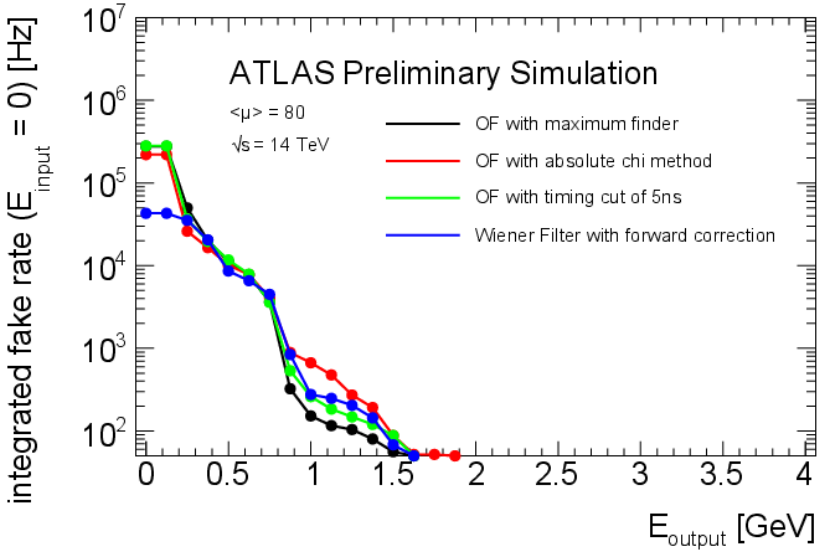
[ATLAS LAr Phase-1 Upgrade TDR]

- Intrinsically pile-up robust and bunch train independent

Reconstruction of E_T and time



Energy resolution



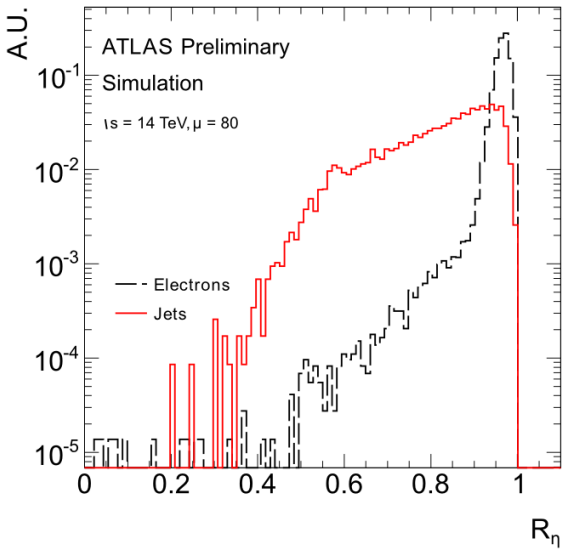
Fake rate

[ATLAS LAr Phase-1 Upgrade TDR]

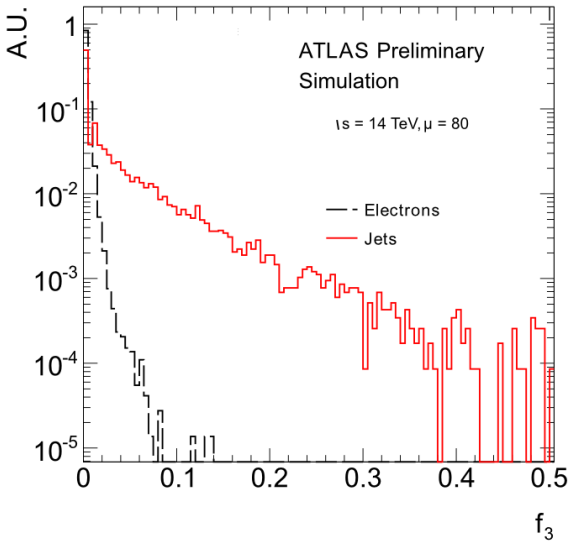
Wiener Filter has worse energy resolution but is more pile-up robust.

Expected Performance of Level-1 Trigger with new Readout

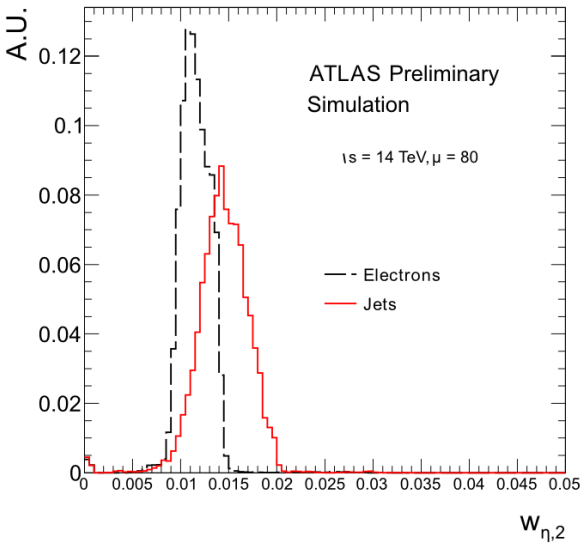
Energy ratio of shower core to total shower on middle layer:



Energy ratio of back layer to total cluster energy:



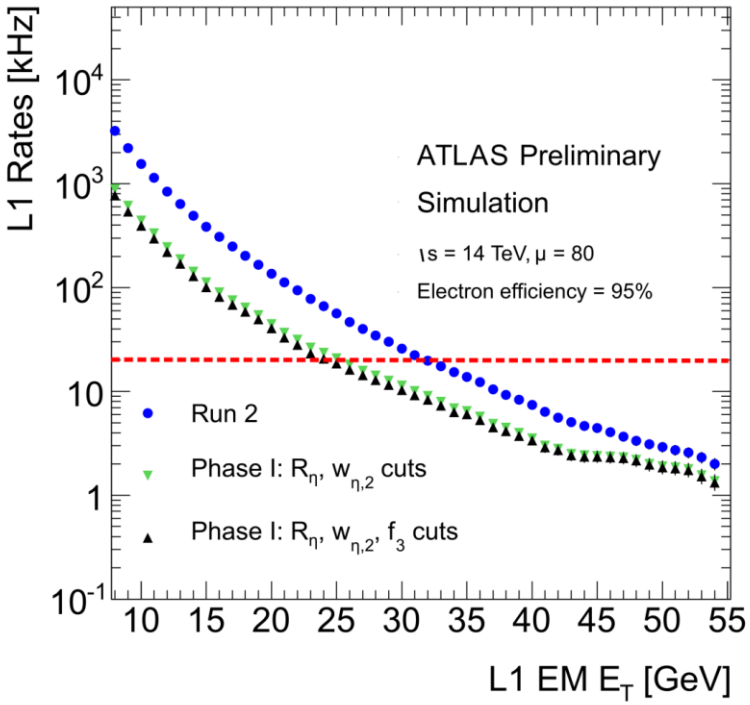
Shower spread in middle layer:



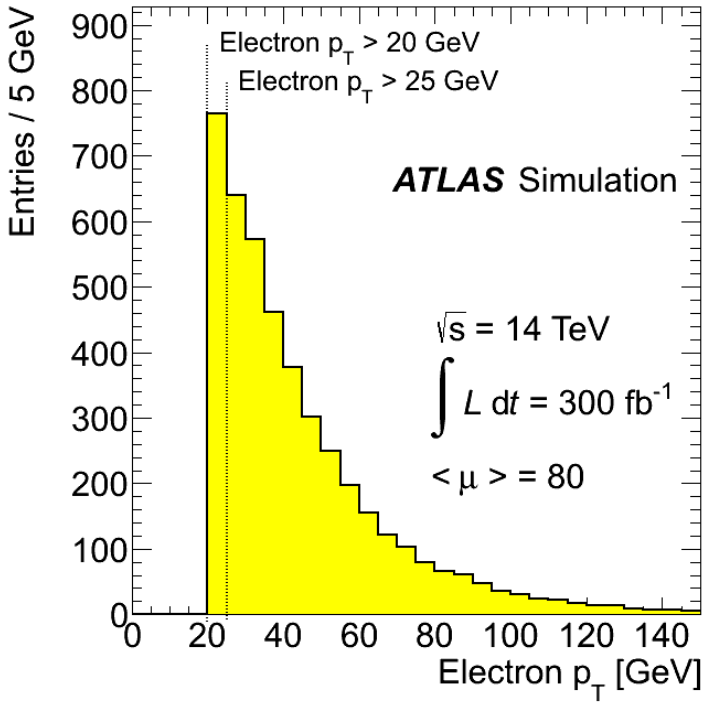
[ATLAS LAr Phase-1 Upgrade TDR]

Expected Performance of Level-1 Trigger with new Readout

EM trigger rates:



Benchmark channel $H \rightarrow \tau_{lep}\tau_{had}$:



[ATLAS LAr Phase-1 Upgrade TDR]

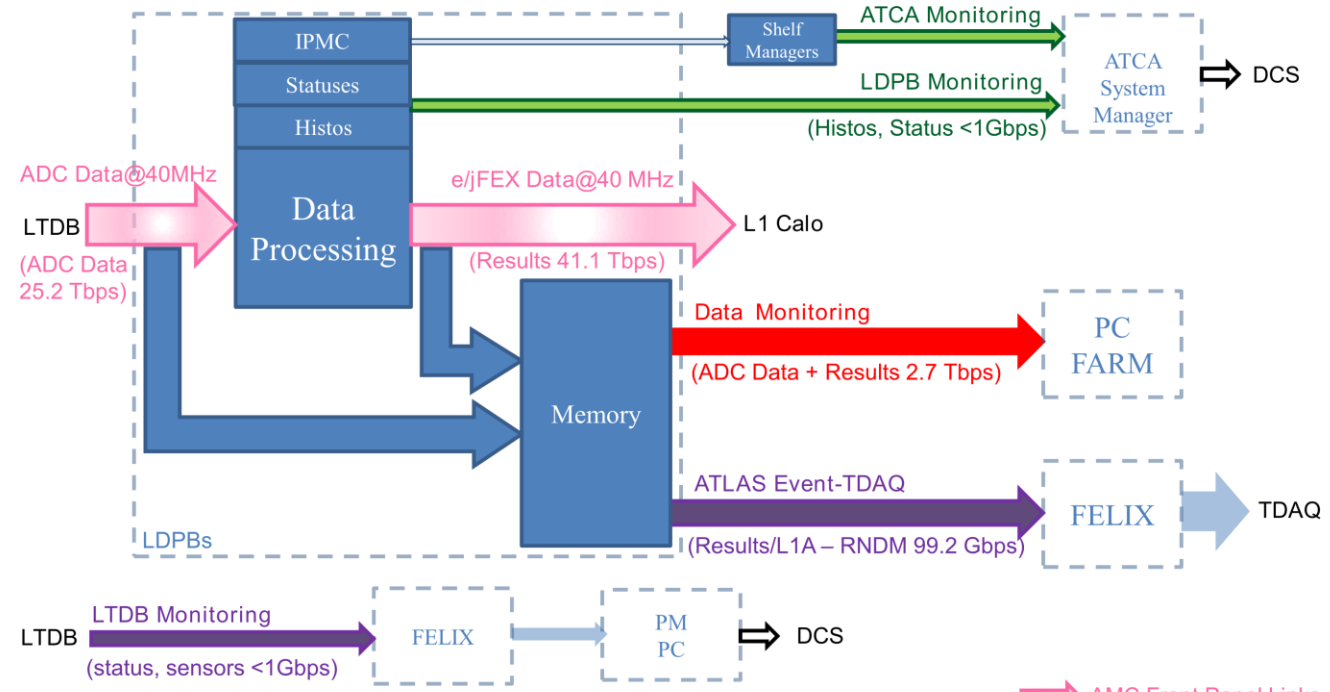
Signal acceptance for $H \rightarrow \tau_{lep}\tau_{had}$ with current L1 trigger decreased by 37% compared to upgraded

Summary

- Increased LHC luminosity takes up improved trigger readout of ATLAS LAr calorimeter
- ATLAS LAr Phase-1 TDR for new trigger readout electronics published including:
  - Finer granularity due to Super Cells
  - Increased energy resolution due to new high precision on-detector ADCs
  - Improved pile-up robustness due to new reconstruction algorithms
- Significant improvements for the ATLAS physics program expected

Backup

Data Flow through the LAr Trigger Readout Electronics



LTDB: 124 Modules LDPB: 31 Blades

Data Flow Rates	ADC Data @40MHz	e/jFEX Data @40MHz	LDPB Monitoring	Data Monitoring	ATLAS Event-TDAQ	LTDB Monitoring	DCS
LTDB	204 Gbps	-	-	-	-	<<1 Gbps	<<1 Gbps
LDPB	814 Gbps	1.3 Tbps	<<1 Gbps	82 Gbps	3.2 Gbps	-	<<1 Gbps
GLOBAL	25.2 Tbps	41.1 Tbps	<1 Gbps	2.7 Tbps	99.2 Gbps	<1Gbps	<<1 Gbps

[ATLAS LAr Phase-1 Upgrade TDR]

Expected Performance of Level-1 Trigger with new Readout

New shower variables based on Super Cells:

- Ratio of energy of shower core to total shower energy on middle layer

$$R_\eta = \frac{E^{(2)}_{T,\Delta\eta\times\Delta\phi=0.075\times0.2}}{E^{(2)}_{T,\Delta\eta\times\Delta\phi=0.175\times0.2}}$$

- Energy ratio of back layer to total cluster energy

$$f_3 = \frac{E^{(3)}_{T,\Delta\eta\times\Delta\phi=0.2\times0.2}}{E^{(1)}_{T,\Delta\eta\times\Delta\phi=0.075\times0.2} + E^{(2)}_{T,\Delta\eta\times\Delta\phi=0.075\times0.2} + E^{(3)}_{T,\Delta\eta\times\Delta\phi=0.2\times0.2}}$$

- Shower spread in middle layer

$$w_{\eta,2} = \sqrt{\frac{\sum\left(E_T^{(2)}\times\eta^2\right)_{\Delta\eta\times\Delta\phi=0.075\times0.2}}{E^{(2)}_{T,\Delta\eta\times\Delta\phi=0.075\times0.2}} - \left(\frac{\sum\left(E_T^{(2)}\times\eta\right)_{\Delta\eta\times\Delta\phi=0.075\times0.2}}{E^{(2)}_{T,\Delta\eta\times\Delta\phi=0.075\times0.2}}\right)^2}$$