Embedded Neural Networks on FPGAs for Real-Time Computation of the Energy Deposited in the ATLAS Liquid Argon Calorimeter

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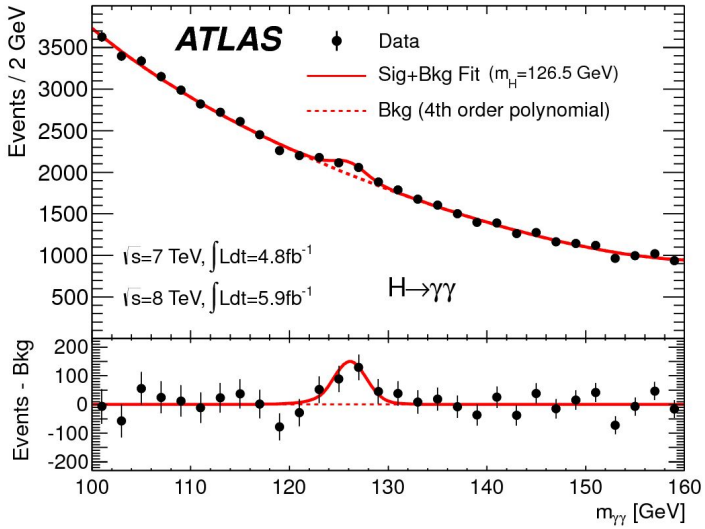
The LHC Upgrade (HL-LHC)

- Higgs boson discovered
  - Standard Model of particle physics complete
- Future of particle physics:
  - Focus on finding new physics phenomena
  - Search for new fundamental particles
- LHC is most powerful particle accelerator we will have for the next 30 years
  - Should fully exploit data at the LHC

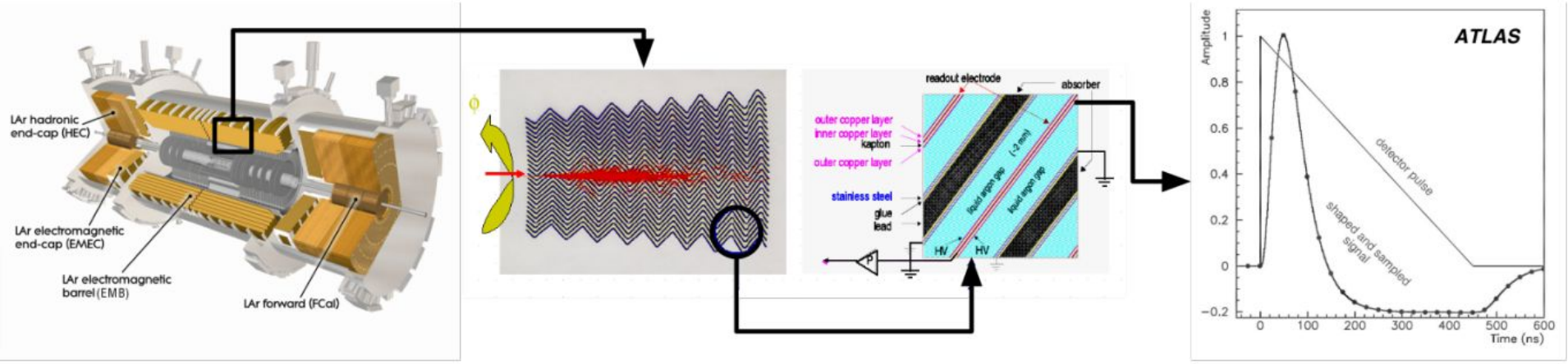
Higgs Boson discovery
June 2012



- Upgrade the LHC to increase its luminosity
  - 90% of the LHC data is still to be collected
  - Unique opportunity to discover new particles
- Searching for very rare events
  - Need very precise detection techniques to separate the tiny signal from the huge background
  - Resolution and precision of the detectors is a critical point
- Increased luminosity -> increased data rate
  - Huge amount of data to process

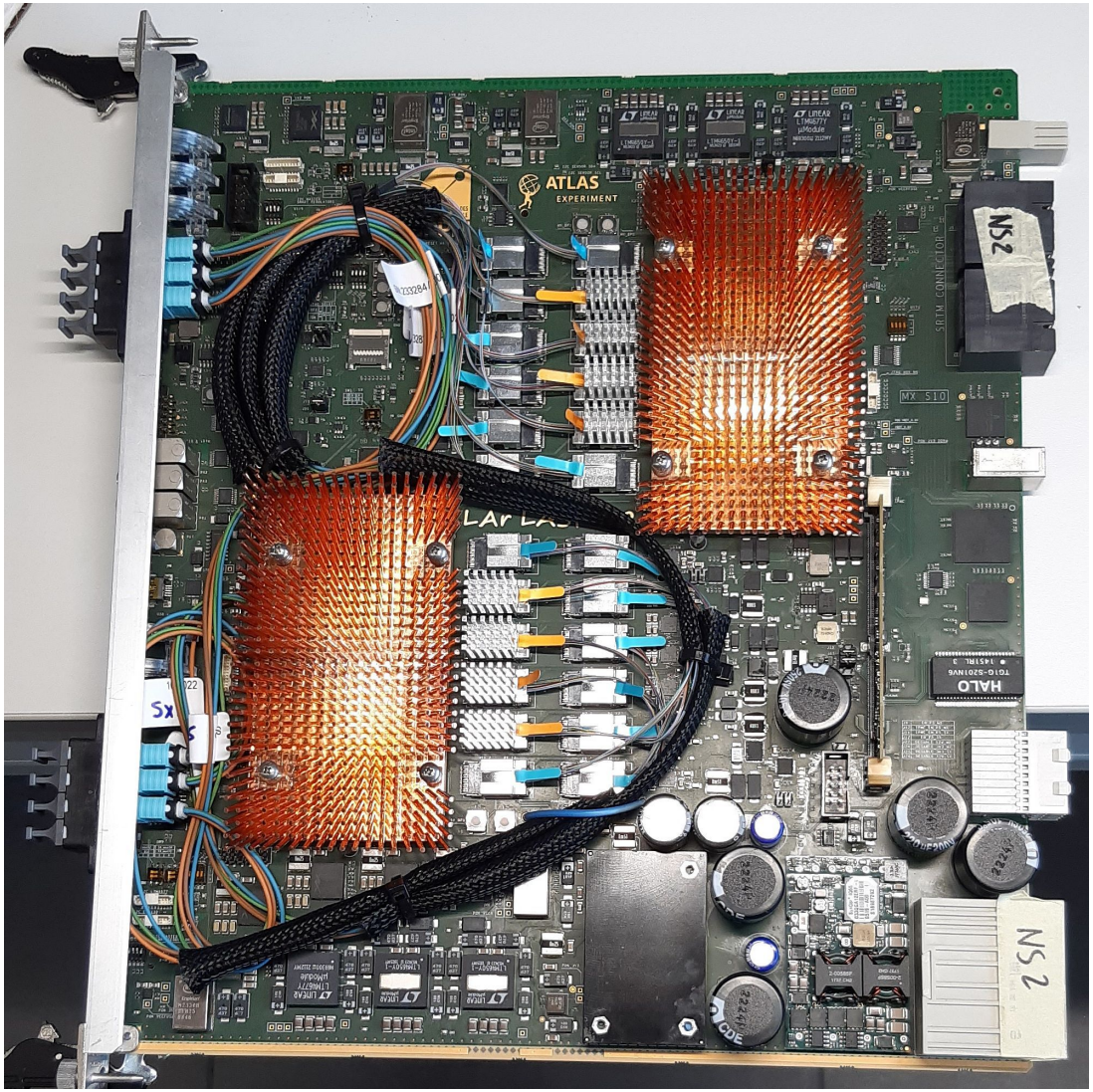
The ATLAS Liquid Argon Calorimeter

- Measures the energy of electromagnetically interacting particles mainly electrons and photons
  - 180000 channels that should be processed in parallel
- Particles deposit energy in the calorimeter which lead to an electric pulse
  - Pulse sampled and digitized at 40 MHz
  - Basically we get one number (called sample) corresponding to the electric pulse amplitude each 25 ns per channel
  - Energy can be computed from a sequence of many samples
- 400 Tb/s to process, energy computed in less than 125 ns
  - Can't use normal computers (CPU/GPU)
  - Need to use specialized hardware (FPGAs)
  - New electronic board developed at CPPM to do this processing (LASP)



The LASP Electronique Board

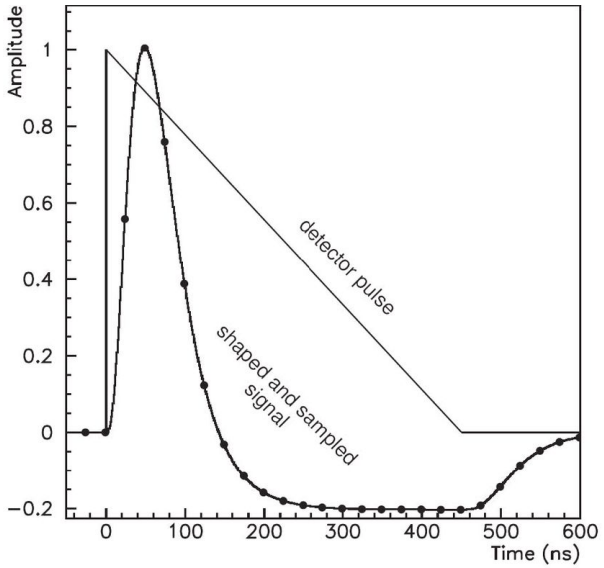
Board designed at CPPM with two high-end FPGAs



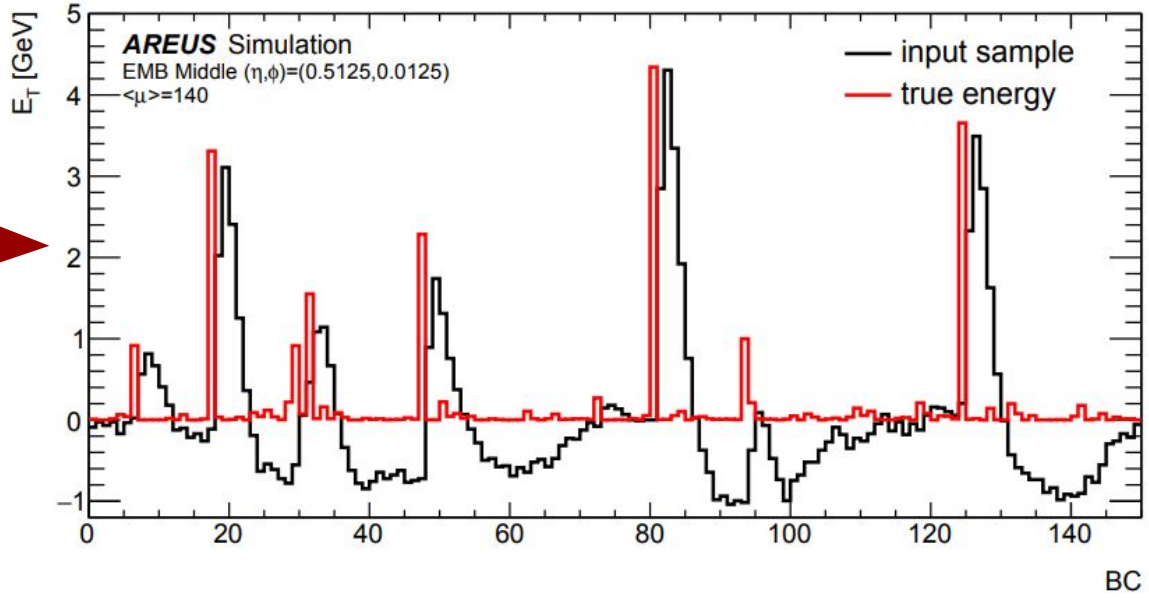
The Energy Reconstruction Challenge

- More luminosity leads to higher event rate
  - Closer energy deposits in time that overlap
- Current energy reconstruction algorithms cannot handle overlap
  - Need new algorithms that detect past energy deposits and learn how to correct for them
  - Use neural networks to handle this issue
- Neural networks need significant amount of processing power
  - Hard to implement on FPGAs
  - New development needed to make them run on FPGAs

Ideal case

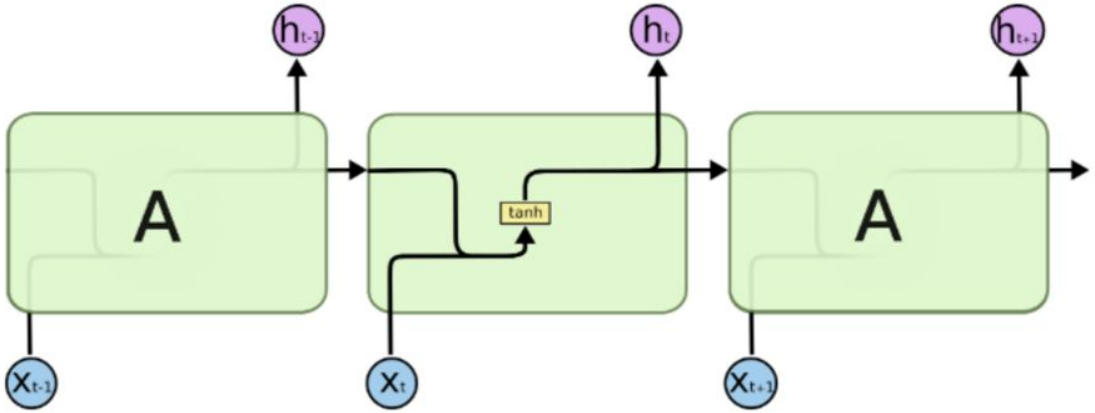


Real life

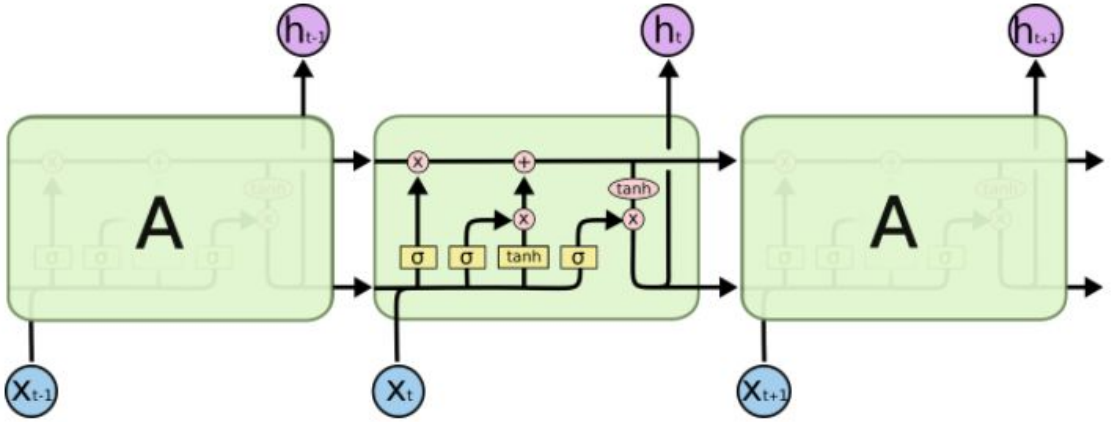


The Neural Networks

- Recurrent neural networks (RNN) adapted to processing time series
  - Take as input the detector electric signal amplitude at time (t)
  - Combine it with previous information from the past and compute the energy
  - RNN cells have internal memory to handle past events



Vanilla RNN
Simple RNN cells with one internal neural network



LSTM
Complex RNN cells with several internal neural networks that handle memorizing or forgetting past events

The Results

- Managed to develop neural networks that perform better than the current algorithms
- Adapted them to run on FPGAs
  - First proof of concept that this is possible
- Extend this work in the future for more applications
  - Measure other properties of particles
  - Detect the presence of new particles

Energy resolution
Smaller and closer to 0 is better