Design studies for the Phase II upgrade of the CMS Barrel Electromagnetic Calorimeter

Target for CMS ECAL Phase II upgrade at HL-LHC:
Maintain physics performance for $H \rightarrow \gamma\gamma$ at 5x higher luminosity and pile-up (PU), increased radiation levels and adjusting to the increased first level trigger rate of 750 kHz at 12.5 $\mu$s latency.

Upgrade strategy & implementation:
- PbWO$_4$ Crystals, APDs, mother boards, & overall mechanical structure will remain
- Reduce temperature from 18º C to 8º C
- VFE similar, but change shaping + digitization
- FE card becomes pipeline, most processing off-detector
- Same data stream for trigger & data
- Full detector readout with upgraded links
- Off-detector electronics upgraded to higher transfer rates & generation of trigger primitives
- FE : Move L1A pipeline off-detector with arbitrary trigger latency
- Trigger primitive generation off detector - single crystal granularity. See poster by Nabarun Dev.
- Data links from detector to readout cards updated to versatile link w/ GigaBit Transceiver (GBT) ⇒ full granularity readout for the trigger
- Potentially more advanced topological filtering of anomalous events
- VFE : Re-designed ASICs to optimize shaping time & sampling ⇒ reduce impact of noise, out-of-time PU, spikes, precision timing.
- Pulse shaper/preamplifier ASIC options : Trans Impedance Amplifiers (TIA) or iteration of current architecture (MGPA, CR-RC), optimized for 130 nm process, faster shaping & additional spike rejection logic. See poster by Sema Zahid.
- ADC: Multi-channel ADC with ~12 bit resolution, sampling rate up to 160 MHz
- Prototype boards undergoing lab & test beam measurements, Simulation studies ongoing to optimize shaping time & sampling rate

Performance of the upgraded detector:
- Noise reduction:
  - APD dark current increases with integrated lumi due to irradiation ⇒ noise increase x10 (~400 MeV/channel) after 3000 fb$^{-1}$
  - Mitigate by operating EB colder: 18º C → 8º C, reduce noise by 35%
  - Shortening the signal shaping time in VFE will also reduce noise
- Spike rejection:
  - Anomalous signals (spikes) are energy deposits directly into APD bulk. Create fake EM-like pattern.
  - Spike rejection currently rejected at L1 using coarse topological algorithm
  - Efficiency will degrade to unacceptable levels at HL-LHC due to noise & PU
  - Upgrade for better spike rejection using pulse shape & finer granularity L1
- Precision timing @ 30 ps:
  - Intrinsic timing resolution of PbWO$_4$+APD is < 30 ps, as measured at test beam. See poster by Vincenzo Ciriolo.
  - Use cases for precision timing : Vertex resolution for $H \rightarrow \gamma\gamma$, subtraction of neutral energy from PU that enters EM clusters, identification of PU jets
  - New system designed to approach 30 ps timing precision for high energy EM signals