The upgrade of the CMS PbWO₄ crystal electromagnetic calorimeter for the HL-LHC and prospects for precision timing resolution

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**ECAL**

The CMS ECAL is:
- A homogeneous calorimeter made of 75,848 PbWO₄ scintillating crystals
- Compact, hemispheric, fine-grained and with excellent energy resolution

**ECAL Barrel (EB):**
- Divided into 36 super-modules of 1700 crystals
- Scintillation light read out by avalanche photodiodes (APDs)

**ECAL Endcaps (EE):**
- 7,324 crystals for each of the 2 endcaps
- Scintillation light read out by vacuum phototriodes (VPTs)

**ELECTRONIC UPGRADE**

The barrel upgrade is a good opportunity to mitigate several radiation and pleup induced effects:
- Mitigate radiation-induced increase in APD noise
- Improve direct hadronic interaction rejection ("spikes")
- Improve timing resolution

How?
- New VFE boards with fast trans-impedance amplifier (TIA) and 160 MHz ADC sampling, characterized by 2 gains per channel (i.e., two ADCs).
- New streaming Front End (FE) card
- New low voltage regulator
- Lower operating temperature (-9°C)
- Off-detector transmission of all samples and off-detector trigger formation

**TEST BEAM**

Electron beam from CERN SPS test line:
- 20, 50, 100, 150, 200 GeV

Reference time defined by a Multi-Channel-Plate Detector (MCP), used to measure the electron time of arrival.

Timing resolution: 25 ps

**TEMPERATURE TEST**

Upgrade of the cooling system is needed in order to mitigate the increase of APDs dark current. The VFE are tested in a range of 18 to 6 °C varying also the beam energy. A minimal change in pulse shape is observed at lower temperature (slightly longer PbWO₄ decay time).

**TIME PERFORMANCE**

The time of arrival of the electrons is measured using a template fit. The timing resolution is obtained by comparing the time of the APD pulse at the rear face of the crystal with the time of arrival of the electron at the front face, given by a MCP. The timing resolution is compared as a function of pulse amplitude divided by the electronic noise for different sampling frequencies: 80 MS/s for both different phases, 160 MS/s and 5 GS/s. N and C are free parameters of the fit.

The figure shows a dependence of 80 MS/s from the phase; 160 MS/s is required. 160 MS/s timing resolution gives the same performance as 5GS/s. Resolution of 30 ps is achievable at 2 - 250, which corresponds to a 25 GeV photon at the start of the HL-LHC.

**ECAL at HL-LHC**

High-Luminosity:
- Increase instantaneous luminosity of a factor 2 to 5
- Accumulate 3 ab⁻¹ of data until the end of Run 4, in 2030
- 200 PU concurrent interactions per LHC bunch crossing

GOAL: maintain the same performance as in phase 1.

EB will be upgraded to:
- Increase trigger flexibility
- Mitigate the effect from spurious signals ("spikes")
- Mitigate PU from previous and following bunch crossing
- Mitigate signal contamination from concurrent interactions in the same bunch crossing (through timing)
- Mitigate the noise effect from APD-leakage current, increased by long exposure to radiation
- Identify the vertex of origin of the photons (useful for lepton channels)

EE replaced by high-granularity silicon-based detectors