Recent Upgrades to the Calibration System of the CMS HCAL

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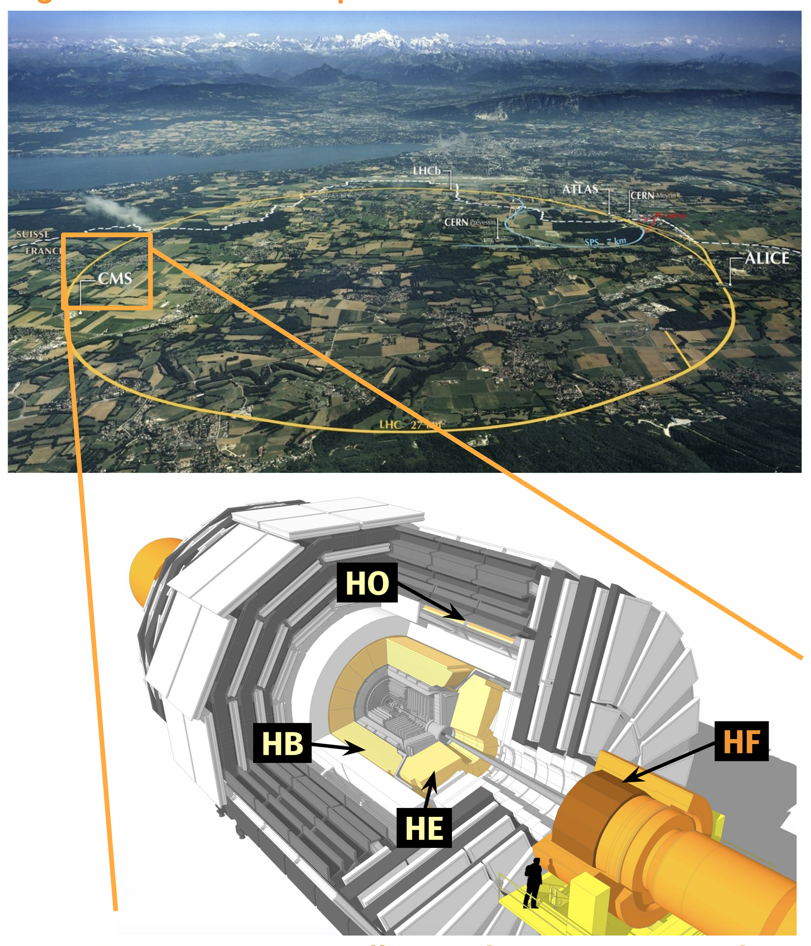
Figure 1. The CMS experiment and HCAL detector



HB: |η|< 1.39, Scintillator + brass, SiPM readout
HO: |η|< 1.26, Scintillator + solenoid, SiPM readout
HE: 1.31<|η|< 3.0, Scintillator + brass, SiPM readout
HF: 3.0<|η|< 5.2, Quartz fibers + iron, PMT readout

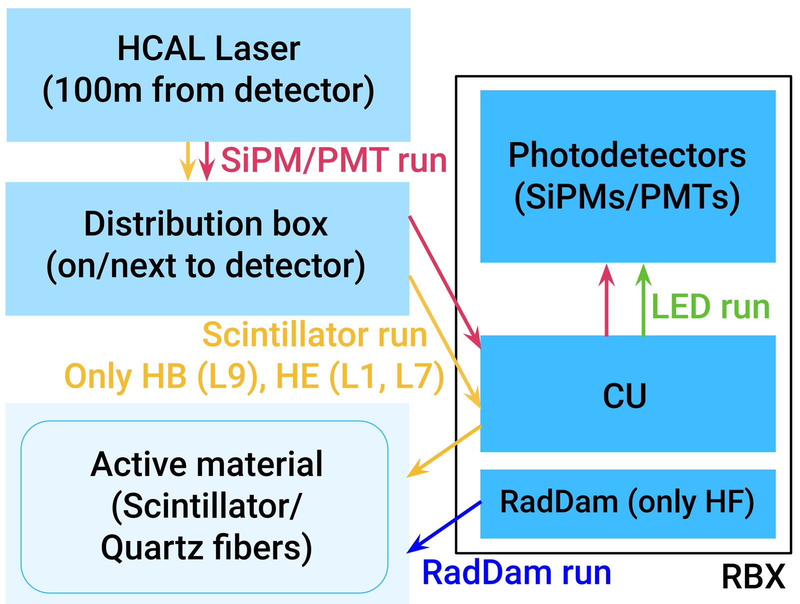


Figure 3. Block diagram of the HCAL calibration infrastructure (sourcing channels not shown)

See E. Gülmez's talk on Tuesday for more on the new HF RadDam system

1. The CMS Hadron Calorimeter (HCAL)

The CMS HCAL comprises two different technologies. The barrel (HB) and endcap (HE) regions have layers of brass absorber plates interleaved with plastic scintillator tiles as the active material. The barrel is augmented by a layer of 'outer' scintillators (HO) beyond the CMS magnet. These subdetectors are read out by silicon photomultipliers (SiPMs). The HCAL also comprises a Cherenkov detector in the forward region (HF) made of steel absorber with quartz fibres and read out by photomultiplier tubes (PMTs).

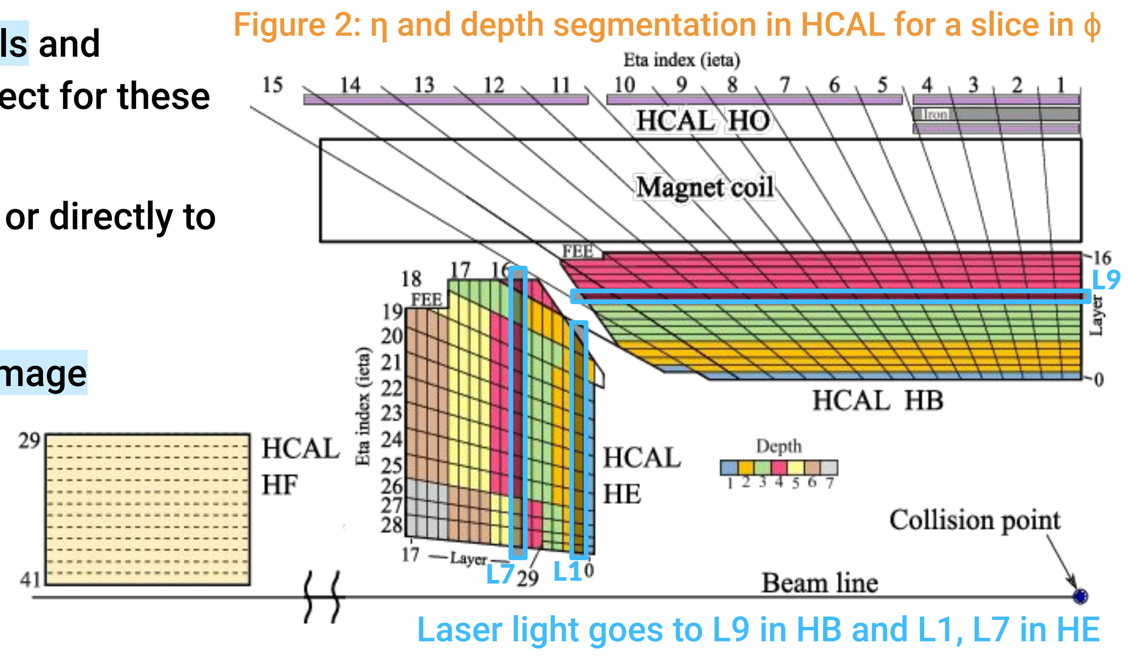
Each subdetector is read out by on-detector readout boxes (RBXes) segmented in ϕ. The readout is additionally segmented in η (and, for HB and HE, depth).

2. How do we use our calibration system?

The irradiation of the HCAL subdetectors results in decreased signal output from the active materials and increased noise in the SiPMs and PMTs. A dedicated calibration system is used to monitor and correct for these effects and to help synchronise the timing of the subdetectors. It consists of:

- HCAL laser system: Sends light to either the photodetectors (SiPMs in HB, HE, HO + PMTs in HF) or directly to some of the scintillators in HB and HE, specifically in layer 9 for HB and in layers 1 and 7 for HE
  - → Take both types of laser data runs ~every day during breaks in beamtime
  - → Compare these to laser data taken at the start of the year to measure effects of radiation damage
  - → Can use different run types to disentangle scintillator damage from photodetector damage
  - → Can also use laser runs to check for missing channels, broken fibers, bad timing and more
- Calibration Units (CUs): Each front-end readout box (RBX) in the HCAL subdetectors has a CU
  - → Receives and distributes light from the laser system, but also:
  - → Has two in situ LEDs that send light to all the photodetectors in that RBX
- HF RadDam: Starting in Run 3, a separate system is used to measure radiation damage in the quartz fibers of HF
- ^{60}Co sourcing: During long shutdowns, a ^{60}Co source is used with dedicated 'sourcing channels' to measure radiation damage in all the HB and HE scintillators

Figure 2: η and depth segmentation in HCAL for a slice in ϕ



Laser light goes to L9 in HB and L1, L7 in HE

3. Why upgrade the HCAL calibration system for LHC Run 3?

- For the HCAL laser system, the old excimer gas laser had a few limitations:
  - → The laser power would fall by ~15%/day and the beamspot was relatively large, requiring a complex optical setup with two filter wheels and a collimator. This resulted in substantial inefficiencies in the transmission of light to the detector.
  - → The laser would very occasionally fire without a trigger– enough to make it unsuitable for use in the abort gap because of the risk that it would fire in physics.
  - → The system required very frequent calibration during interfills as well as gas replacements every week.
- The main motivations for the development of a separate HF RadDam system were:
  - → The quartz fibers require blue light instead of the UV light used in the rest of HCAL. This was initially accomplished by using wavelength shifters on the UV signal from the laser, but they degraded quickly in the high radiation environment of the HF.
  - → The HF readout expects most of the signal to be contained within 25ns, requiring precise timing and a narrow laser pulse if used with a wavelength shifter.

  A dedicated radiation damage monitoring system was developed for HF, using a 450 nm laser diode mounted on a HF readout card (similar to the HF CU)
- The HB RBXes were upgraded and replaced in LS2 following the earlier HO, HF and HE upgrades. New CUs were prepared to interface with the new electronics.

4. The upgraded HCAL laser system

In the long shutdown before Run 3, we upgraded the HCAL laser to a Photonics DP20 solid state laser, which we operate in UV at a wavelength of 351 nm.

- The laser has an energy rating of 4mJ/pulse and a beamspot of ~1mm, allowing us to greatly simplify the optical setup: the beam is focussed by a lens on one of two fibers selected by a linear motor stage
- Fiber 1 is used to send light to all the photodetectors. It goes to a 1-to-8 splitter with 7x 250µm fibers going to the SiPMs and PMTs: HB+, HB-, HE[+,-], HF[+,-] and one for HO, which is coupled to a 1-to-6 splitter for HO[0,1,2][+,-]. The last of the 8 fibers is a 125µm monitoring fiber, which goes to a box with a wavelength shifting crystal and a PIN diode whose output is connected to an oscilloscope in the laser room.
- Fiber 2 goes to a 1-to-4 splitter and is used to send light to the HB and HE scintillator layers
- An all new laser server was developed to handle communication with the laser and fiber selector, respond to commands sent by DCS and DAQ and implement automatic system recovery
- A new laser DCS panel was also created to reflect changes to the system

Commissioning and operations

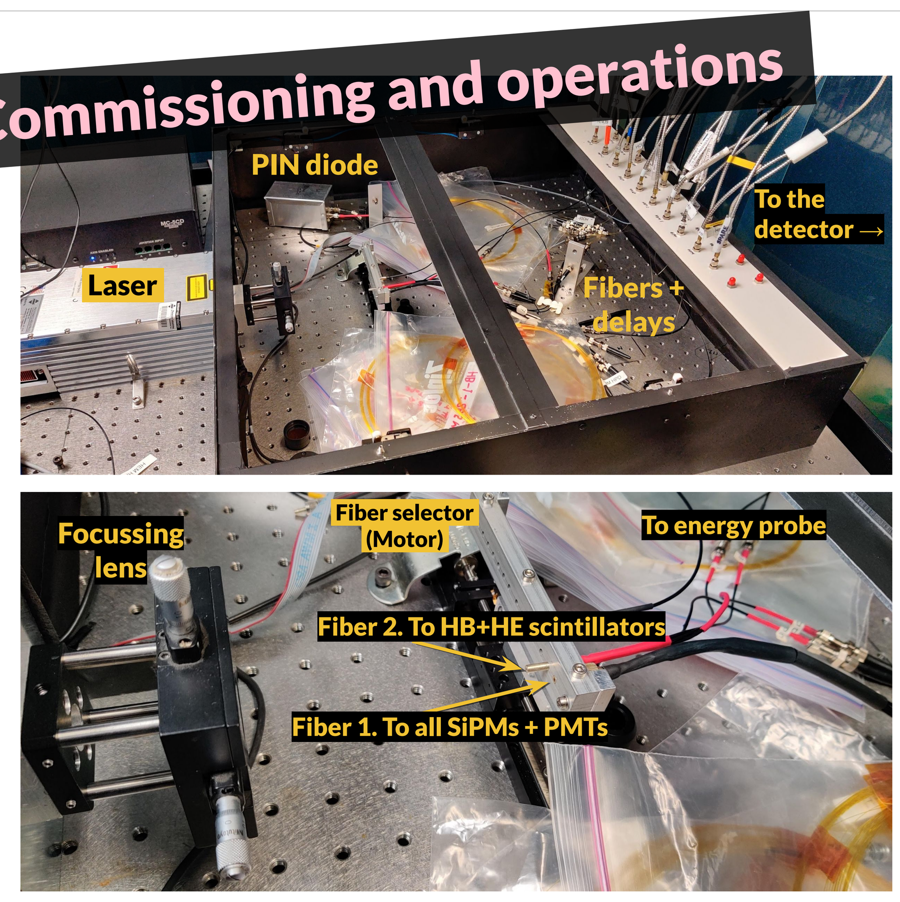


Figure 4. The laser room optical setup (top), zoomed in on the lens assembly and fiber selector (bottom)

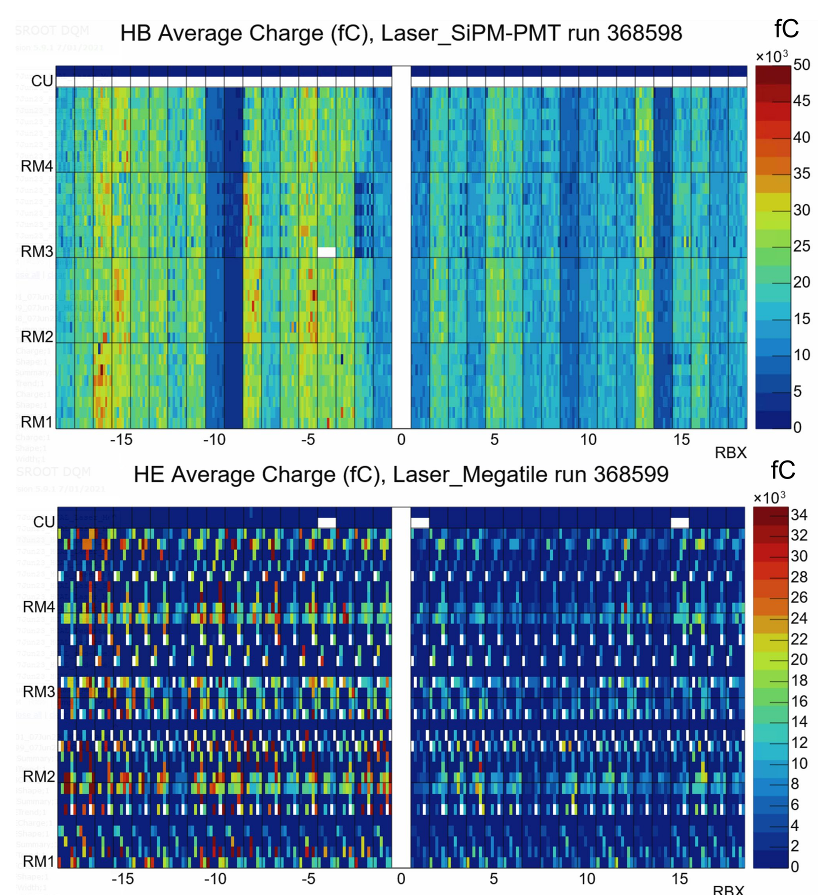


Figure 5. Sample data quality plots showing the laser signal in all expected channels in HB during a SiPM/ PMT run (top) and HE during a scintillator run (bottom)

Results

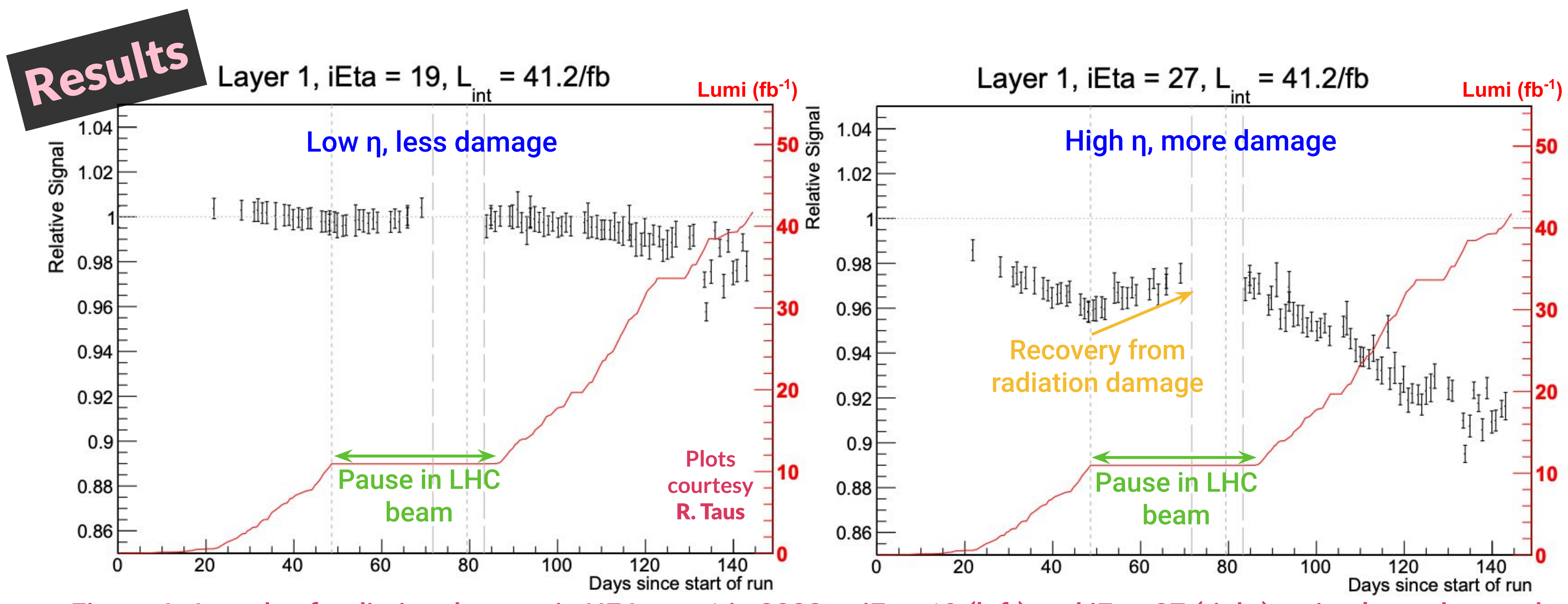


Figure 6. A study of radiation damage in HE Layer 1 in 2022 at iEta=19 (left) and iEta=27 (right), using laser data and corresponding to the 41.2 fb^{-1} of data collected by CMS in 2022. This data was used to derive corrections to the HE gains. The laser signal is normalised to the signal value in Layer 7 and iEta=±17 in the first run of the year. Higher radiation damage (corresponding to a lower relative signal) is expected in Layer 1 than in Layer 7 because of its proximity to the collision point. Higher radiation damage is also expected at higher values of η (or equivalently, iEta). The plot on the right also shows the recovery in the signal response during the pause in beamtime from day 49-84.

5. A new HCAL laser trigger

The laser system was operated very successfully in 2022 and offered significant improvements over previous versions. However, it still had some limitations and potential for further development:

- The board used to trigger the new laser behaved quite erratically when powered on– it generated spurious triggers before being configured, and had a 50% chance of switching the polarity of the differential trigger signal supplied to the laser. Such a switch would result in the laser triggering on the wrong timing; one such incident resulted in a substantial loss of laser data in 2023.
- Upon receiving a trigger signal, the laser would start to charge for ~580µs, after which it would start firing on its internal 100MHz clock. This caused a 10ns jitter with the LHC clock.
  - → The laser manufacturer recently developed a modification to the laser which allows it to accept two triggers: one to start charging and a second trigger 580µs later to start firing the laser. Implementing this upgrade would allow us to greatly reduce the jitter, but would require the creation of a system to provide the two trigger signals.
- The laser signal currently cannot be monitored remotely in real-time

A novel solution: repurpose the two LED driver circuits from a spare CU to provide the two trigger signals. Solves both problems and can use the CU to read out the laser signal as well!

The solution has been developed and proof-of principle tests performed, using a single LED channel to successfully fire the unmodified laser.

The laser is presently with the manufacturer for the installation of the hardware modification. The new system will be commissioned upon its return.

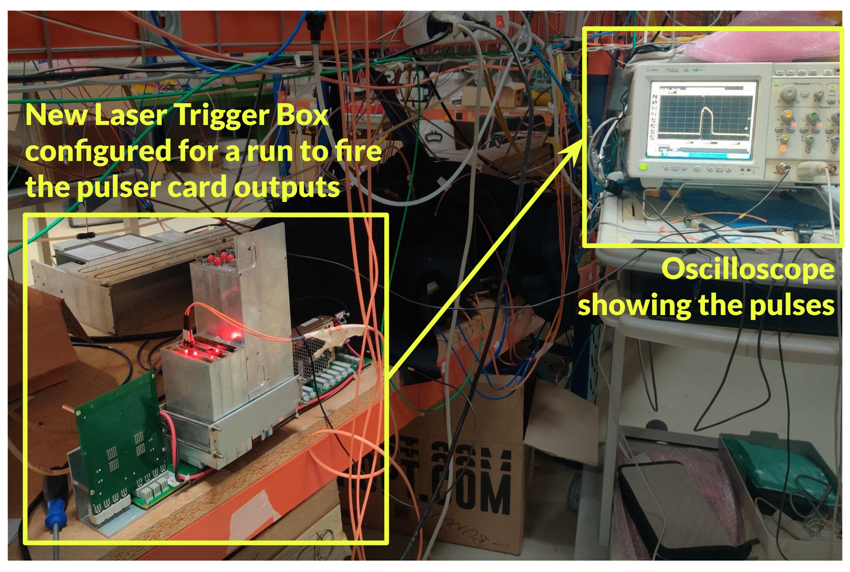


Figure 7. Tests of the new Laser Trigger Box and back-end trigger software with an oscilloscope

6. Conclusions and next steps

- The HCAL calibration system has seen numerous impactful improvements since the end of LHC Run 2
- The upgraded laser system has been shown to work very well for radiation damage studies
- The new laser trigger will be commissioned in Summer 2024, to be followed by the development and commissioning of a real-time remote monitoring system for the laser signal
- New analysis tools will be developed to take advantage of the upgrades to the calibration system to optimise the performance of the HCAL detector

The speaker would like to express gratitude to the entire HCAL Operations crew and give special thanks to her advisor, Prof. John Paul Chou

CALOR 2024 Tsukuba

References:

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