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The Compact Muon Solenoid Experiment

CMS Performance Note

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ECAL Trigger Performance in Run 3

CMS Collaboration

Abstract

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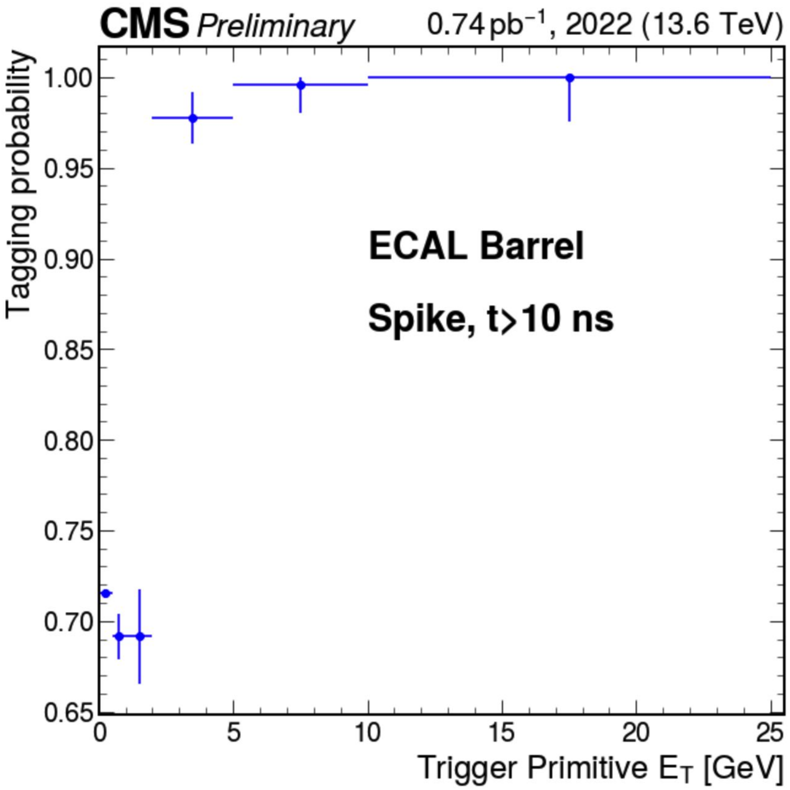
1) Double weights

Double weights tagging probability in Run 3 data: Spikes



Caption: Double weights tagging probability in Run 3 data: Spikes

Probability for the double weights algorithm to flag a subset of “late” spikes as an out-of-time signal, plotted as a function of the Trigger Primitive (TP) E_T in the ECAL Barrel. Data are taken from a 1h long full readout run obtained in 2022.

The data have been recorded with a specific double weights working point, with the ODD weights optimized for out-of-time signals with δ_{min} = 2.5 GeV [1]. The data were taken with the double weights operating in “tagging+killing” mode.

The subset of spikes is selected by requiring that the pulses are out-of-time (t > 10ns), and that the energy spread between crystals is not consistent with that of an EM shower. Spikes are observed to exhibit a long positive tail in their time of arrival, extending for tens of ns [2], and it is these late out-of-time signals that the ODD weights have been optimised for.

The energy in each 1x5 crystal region, or “strip”, within a trigger tower has been computed with two sets of amplitude weights - the ODD weights and the EVEN weights respectively. The former should return a larger amplitude value for out-of-time signals and the latter should return a larger value for in-time signals. The energy of a strip is zeroed if the ODD weight output is greater than the EVEN weight output. If this occurs for one or more strip in the tower, the fine grain bit (FGBit) for the TP in question is set to indicate this.

The plot shows the probability of the FGBit being set in data versus the emulated TP E_T in GeV. Here the emulator is used to represent the transverse energy of the TP since the action of the killing mode suppresses the data TP E_T.

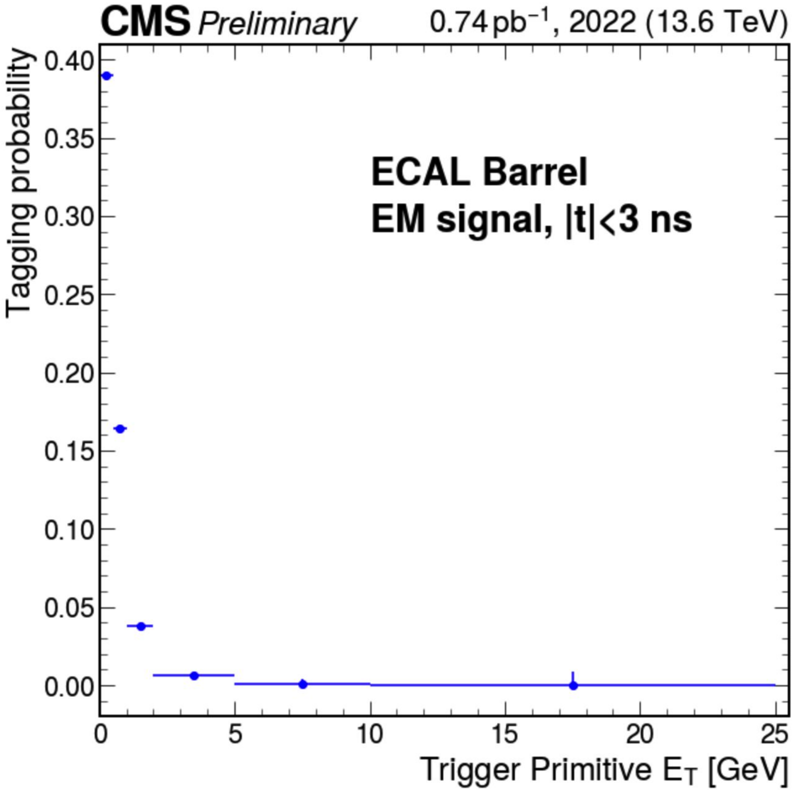
Below 2 GeV, noise and out-of-time pileup may make up a large fraction of the total energy. For the working point being considered, the algorithm flags more than 99% of the out-of-time spikes with $E_T \geq 5$ GeV. The data is recorded with a ZeroBias trigger - in this case most of the events are in the 0-0.5 GeV bin, hence the small statistical error for the first point .

This plot represents an update of the similar plot shown in CMS-DP-2022/007 [1]. That plot was made by re-emulating 2018 data with a software version of the double weights mechanism. This plot is the first demonstration of the on-detector hardware-based double weights flagging of out-of-time spikes in collisions data.

[1] https://cds.cern.ch/record/2808229/files/DP2022_007.pdf

[2] https://cds.cern.ch/record/1457923/files/DP2012_008.pdf

Double weights mis-tagging probability in Run 3 data: EM signals



Caption: Double weights mis-tagging probability in Run 3 data: EM signals

Probability for the double weights algorithm to mis-tag an in-time EM signal as out-of-time, plotted as a function of the Trigger Primitive (TP) E_T in the ECAL Barrel. Data are taken from a full readout run obtained in 2022.

The data have been recorded with a specific double weights working point, with the ODD weights optimized for out-of-time signals with δ_{min} = 2.5 GeV[1]. The data were taken with the double weights operating in “tagging+killing” mode.

EM signals are selected by requiring that the pulses are in-time ($|t| < 3$ns), and that the energy spread between crystals is consistent with that of an EM shower.

The energy in each 1x5 crystal region, or “strip”, within a trigger tower has been computed with two sets of amplitude weights - the ODD weights and the EVEN weights respectively. The former should return a larger amplitude value for out-of-time signals and the latter should return a larger value for in-time signals. The energy of a strip is zeroed if the ODD weight output is greater than the EVEN weight output. If this occurs for one or more strip in the tower, the fine grain bit (FGBit) for the TP in question is set to indicate this.

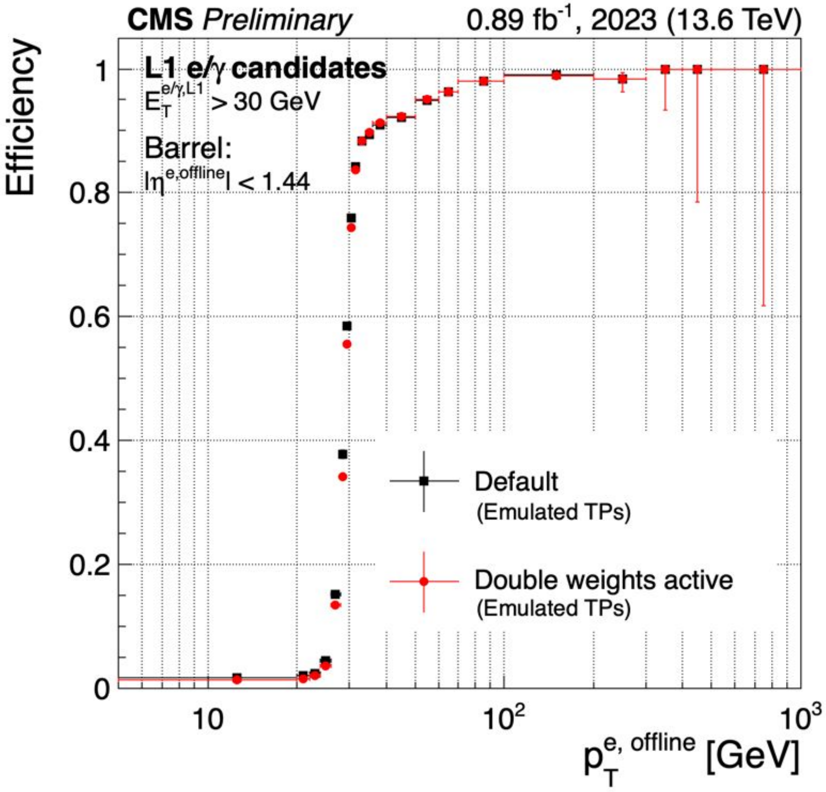
The plot shows the probability of the FGBit being set in data versus the emulated TP E_T in GeV. Here the emulator is used to represent the transverse energy of the TP since the action of the killing mode suppresses the data TP E_T.

Below 2 GeV, noise and out-of-time pileup may make up a large fraction of the total energy and this contributes to the mis-tagging fraction. For the working point being considered, the mis-tagging probability for EM signals with $E_T \geq 2$ GeV is less than 1%.

This plot represents an update of the similar plot shown in CMS-DP-2022/007. That plot was made by re-emulating 2018 data with a software version of the double weights mechanism. This plot is the first measurement of the on-detector hardware-based double weights mis-tagging rate of in-time EM signals in collisions data.

[1] https://cds.cern.ch/record/2808229/files/DP2022_007.pdf

Impact of double weights on L1 EG efficiency



Caption: Impact of double weights on L1 EG efficiency

The plot shows the efficiency of the Level-1 (L1) electron/photon (EG) trigger plotted as a function of the matched offline electron supercluster transverse momentum. The plot uses data recorded in July 2023, with an integrated luminosity of ~0.9 fb-1, with two configurations of the ECAL trigger primitives: the default configuration used so far in CMS, and with the double weights method active, using a working point with the ODD weights optimized for out-of-time signals with δ_{min} = 2.5 GeV [1].

The efficiency is measured from Z→ee events using a tag-and-probe method. Only candidates in the Barrel region of CMS ($|\eta|<1.44$) are used.

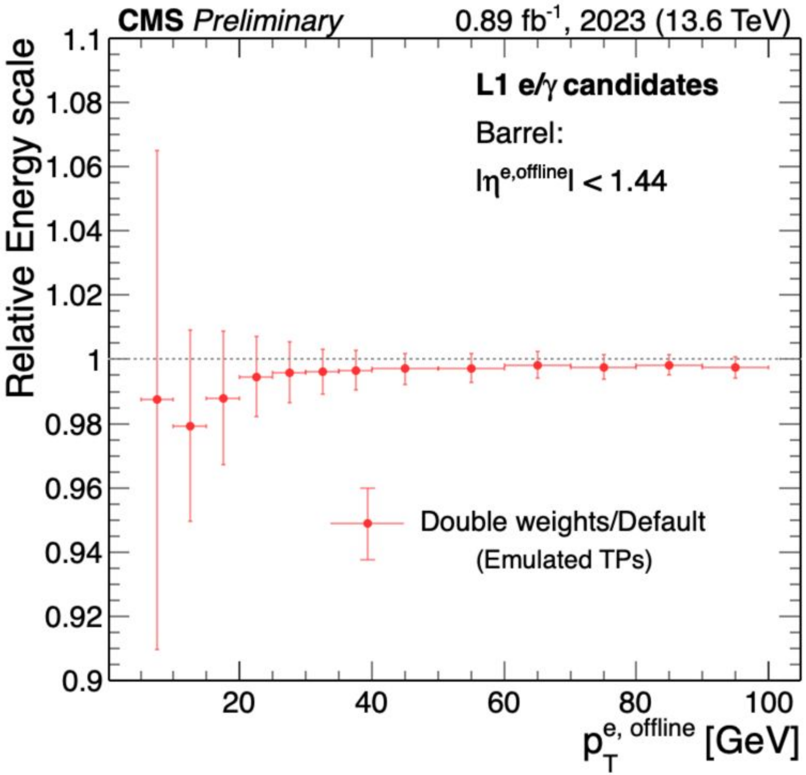
Events are selected using a single electron High Level Trigger. The offline electron, satisfying the medium electron ID, with a transverse energy greater than 30 GeV, which is geometrically matched to the HLT electron triggering the event, is called the tag.

The other electrons in the event are unbiased by the trigger selection, and are called probe(s). They satisfy the loose electron ID and are used to evaluate the L1 e/γ efficiency. The invariant mass of the dielectron system must satisfy $60<m_{ee}<120$ GeV.

The efficiency is plotted for L1 EG candidates with $E_T>30$ GeV, and is computed for EG trigger candidates re-emulated using the default weights configuration, and from those re-emulated with double weights active. There is no significant difference between the two, indicating that the double weights working point being considered for improved spike rejection does not have a significant effect on the efficiency for triggering on electrons and photons.

[1] https://cds.cern.ch/record/2808229/files/DP2022_007.pdf

Impact of double weights on L1 EG energy scale



Caption: Impact of double weights on L1 EG energy scale

The plot shows the relative energy scale of Level-1 (L1) electron/photon (EG) candidates computed with two configurations of the ECAL trigger primitives, plotted as a function of the offline electron supercluster transverse momentum. The plot uses data recorded in July 2023, with an integrated luminosity of around 0.9 fb^{-1}. The two trigger primitive configurations used are:

- Numerator: trigger primitives emulated with the double weights method active, using a working point with the ODD weights optimized for out-of-time signals with δ_{min} = 2.5 GeV [1].
- Denominator: trigger primitives emulated with the default weights configuration used so far in CMS.

The energy scale is measured from Z→ee events. Only candidates in the Barrel region of CMS ($|\eta|<1.44$) are used. The invariant mass of the dielectron system must satisfy $60<m_{ee}<120$ GeV.

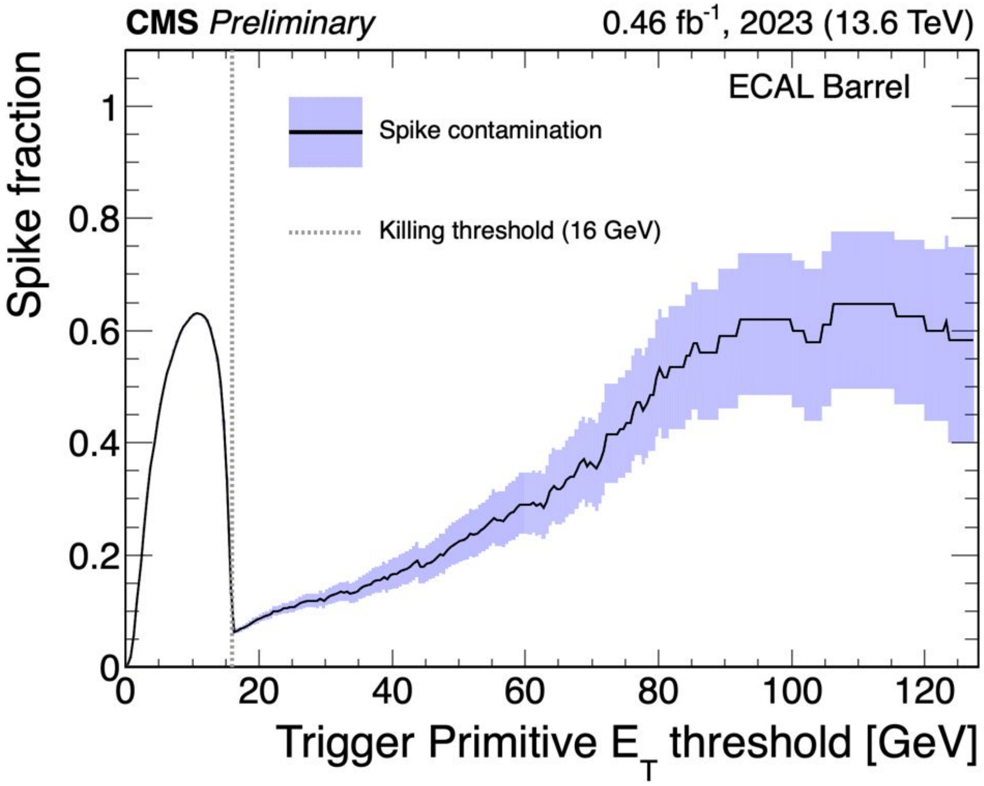
Events are selected using a single electron High Level Trigger. The L1 EG candidate is matched to an offline electron, satisfying the medium electron ID.

The ratio of the two energy scales differs by 1-2% below 20 GeV and <0.5% above 30 GeV, indicating that the double weights working point being considered for improved spike rejection has no significant effect on the energy scale of L1 electron and photon candidates.

[1] https://cds.cern.ch/record/2808229/files/DP2022_007.pdf

2) Spike killer

Spike contamination in 2023 data



Caption: Spike contamination in 2023 data

This plot shows the fraction of trigger primitives (TPs) in the ECAL Barrel, above a given transverse energy (E_T) threshold, that are contaminated by spikes. The data was collected in May 2023, with an average pileup of 61.2.

A TP is considered to contain a spike if one of the reconstructed hits associated with the trigger primitive is flagged as a spike by either its topology or timing.

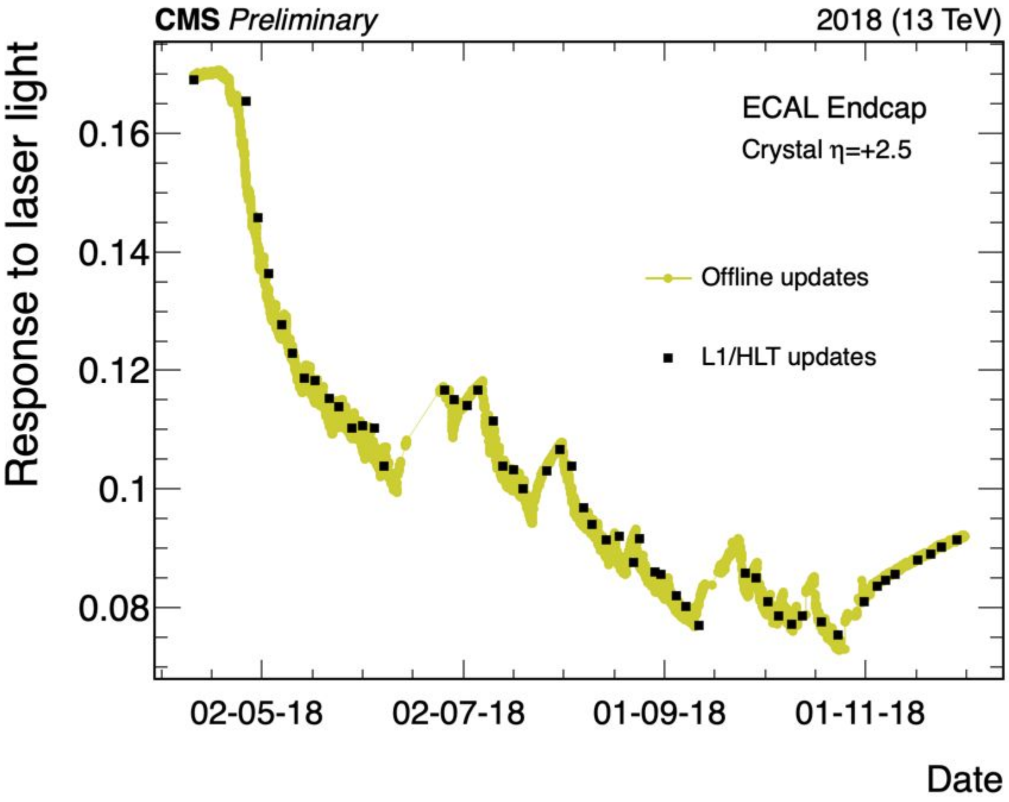
The blue shaded region represents the statistical uncertainty on the spike contamination at each E_T threshold value.

The online spike killer is activated above a transverse energy threshold of 16 GeV, termed the “killing threshold”, as shown by the dashed vertical line. The bump in the spike contamination below 16 GeV is therefore due to spikes that are below the killing threshold. The bump has a rounded shape due to two competing effects - the sharply falling spectrum of spikes and minimum bias events as a function of E_T, and a lower efficiency of the offline spike tagging at low E_T.

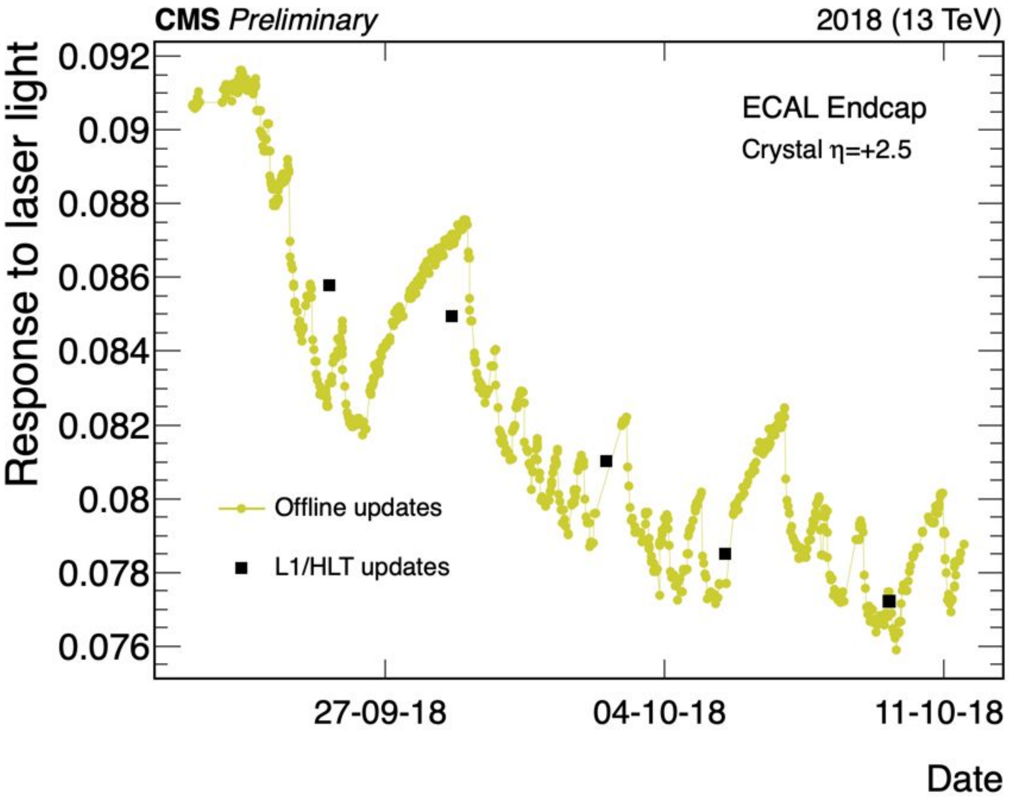
The online spike killer was retuned during Long Shutdown 2 (2019-22) to improve its performance during LHC Run 3. The spike contamination achieved for a threshold of 30 GeV of 12% is significantly lower than the value of 19% achieved at a similar PU value in 2018 (see CMS-DP-2018/015).

3) Transparency updates

L1/HLT transparency updates in 2018



L1/HLT transparency updates in 2018 - three-week period



L1 transparency updates in 2018 - caption

Transparency updates have been applied at L1/HLT since 2012 to correct for changes in detector response, to stabilise the L1/HLT rates and the online energy scale. In 2018 we updated the L1/HLT transparency corrections twice per week, using laser corrections derived from previous measurements and applied to subsequent LHC fills.

These plots show, for a single reference crystal in the ECAL endcap, how well the laser measurements used for the twice/week updates (shown by the black points) followed the relative laser response measurements applied offline (yellow points, updated once every 45 minutes) in 2018. The effect of crystal response losses during LHC fills and recovery during interfill periods can be observed in the yellow points.

The history plots are made for a) the full data-taking year for 2018, and b) a representative three-week period in Sept-Oct 2018.

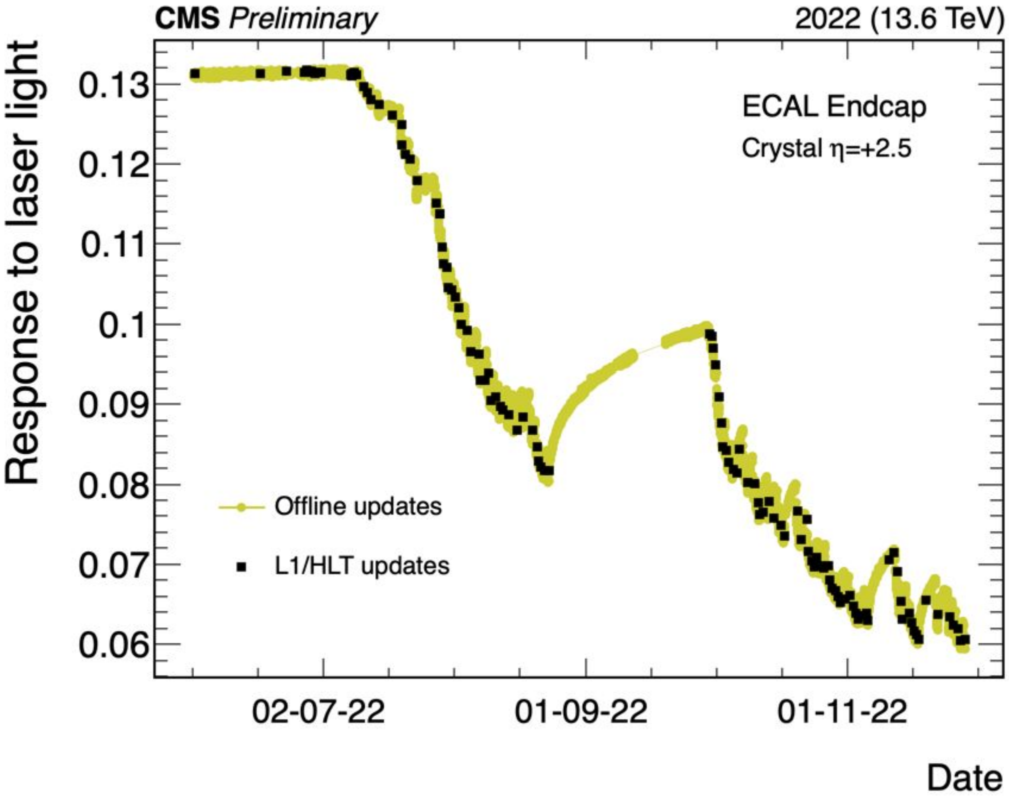
The yellow points show the offline laser response measurements at the time they were recorded, and the black points show the L1/HLT laser response measurements at the time they were deployed online.

The crystal considered is at η=+2.5 in the positive ECAL endcap. Its response has been normalised to a point in March 2011, before significant radiation damage had occurred.

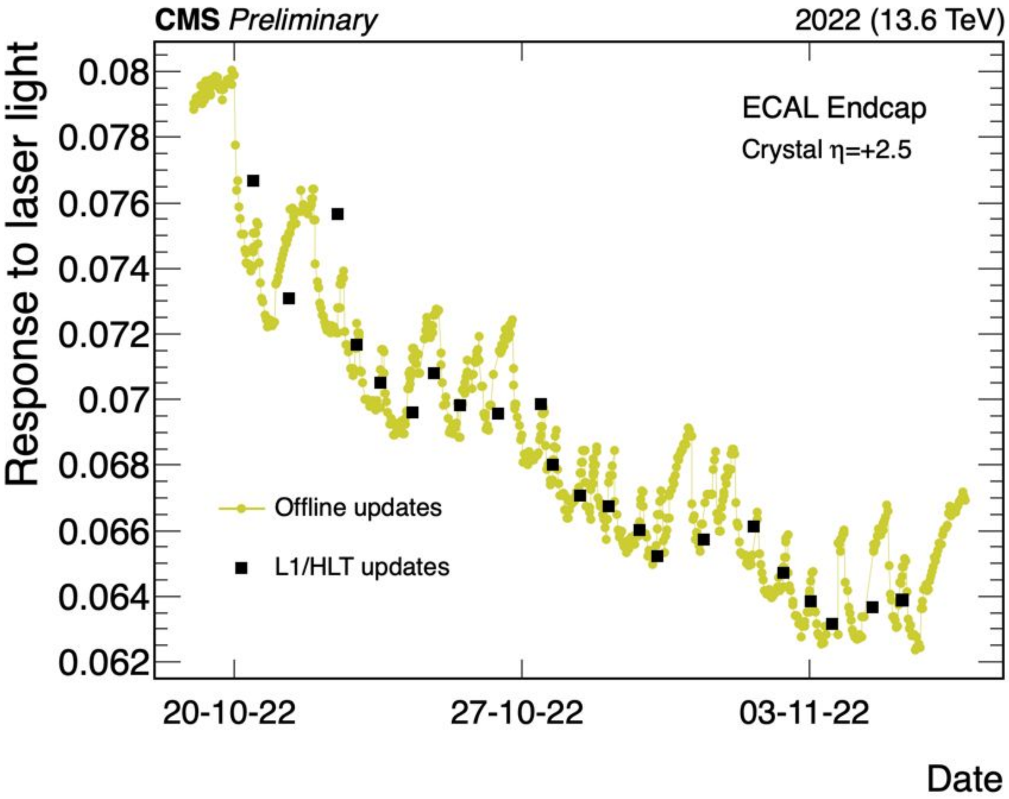
Note that no interpolation between points is possible at L1/HLT and the corrections once deployed persist until a new set is uploaded.

During the 3-week period shown in the zoomed plot, there were 21 LHC fills with >2h of stable beams, and 5 L1/HLT updates

L1/HLT transparency updates in 2022



L1/HLT transparency updates in 2022 - three-week period



L1 transparency updates in 2022 - caption

Transparency updates have been applied at L1/HLT since 2012 to correct for changes in detector response, to stabilise the L1/HLT rates and the online energy scale. In 2022 we updated the L1/HLT transparency corrections once-per-LHC fill, using laser corrections derived from a representative point in a previous fill and applied to the subsequent fills.

These plots show, for a single reference crystal in the ECAL endcap, how well the laser measurements used for the once/fill updates (shown by the black points) followed the relative laser response measurements applied offline (yellow points, updated once every 45 minutes) in 2022. The effect of crystal response losses during LHC fills and recovery during interfill periods can be observed in the yellow points.

Note that the prominent period of crystal recovery observed in Aug/Sept is due to a long LHC stop.

The history plots are made for a) the full data-taking year for 2022, and b) a representative three-week period in Oct-Nov 2022.

The yellow points show the offline laser response measurements at the time they were recorded, and the black points show the L1/HLT laser response measurements at the time they were deployed online.

The crystal considered is at $\eta=+2.5$ in the positive ECAL endcap. Its response has been normalised to a point in March 2011, before significant radiation damage had occurred.

Note that no interpolation between points is possible at L1/HLT and the corrections once deployed persist until a new set is uploaded.

The tracking of the changes in laser response with the once/fill updates in 2022 is significantly better than it was in 2018 with twice/week updates, as expected from CMS DP-2022/042.

During the 3-week period shown in the zoomed plot, there were 27 LHC fills with >2h of stable beams, and 21 L1/HLT updates. The few fills that did not trigger an update were too short for the validation procedure to complete in time.