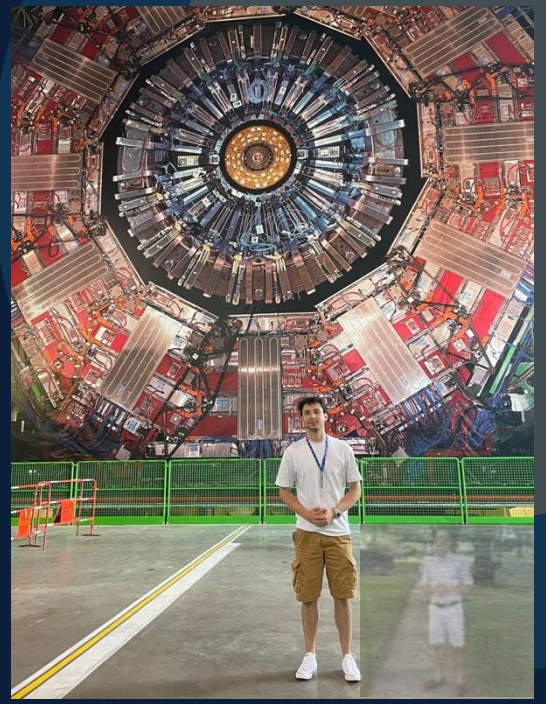
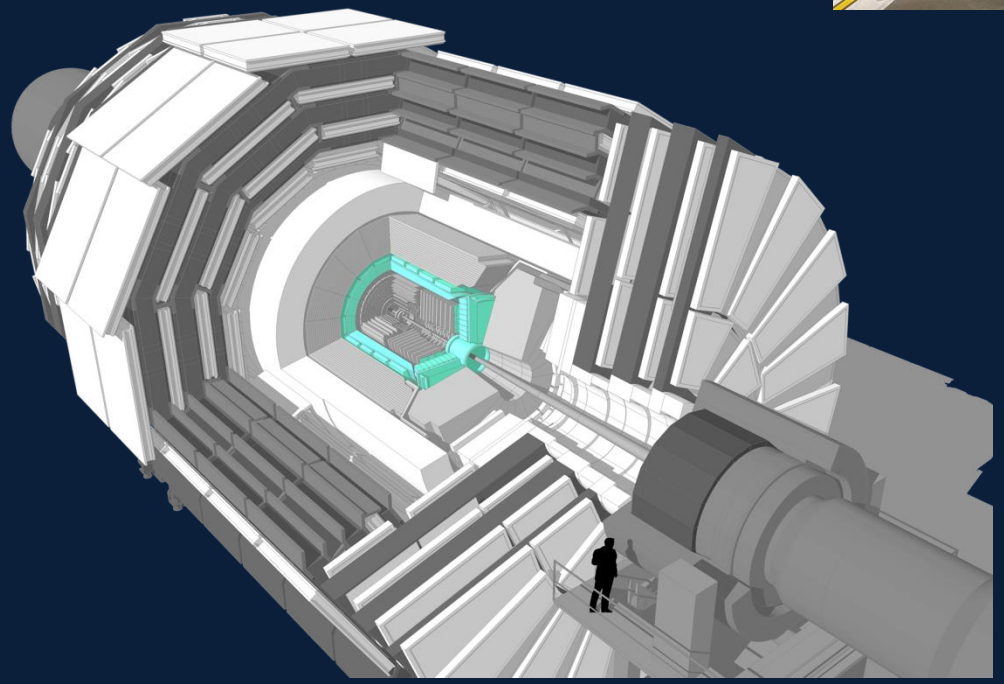
GraSPA 2026 Summer School - LAPP

Estimating CMS ECAL Transparency for HLT-Level Reconstruction

A predictive model for live, real-time correction of crystal transparency loss in the CMS Electromagnetic Calorimeter





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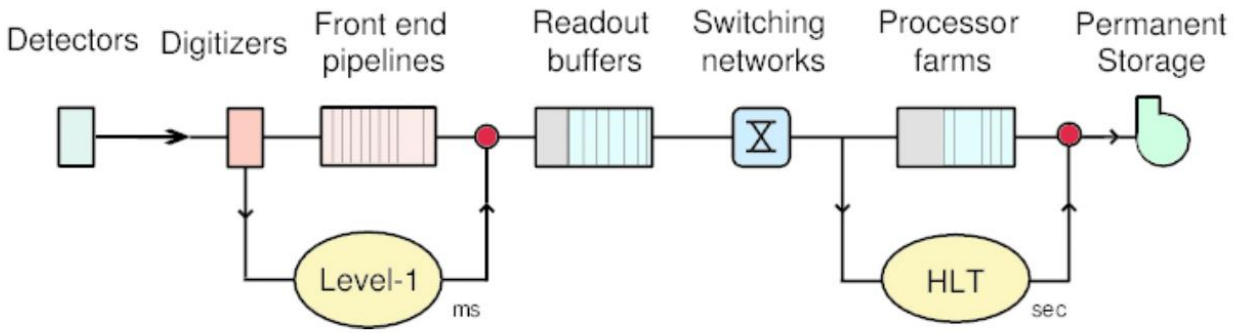
Trigger System at CMS

40 million collisions per second with $\sim$ 1 MB/event $\Rightarrow$ need to reduce recorded data. The trigger system selects potentially interesting events.

- **L1** consists of hardware processors; uses information from the calorimeters and muon systems
- **HLT** (High Level Trigger) runs on CPU farm; software-based $\Rightarrow$ highly flexible



Events rate reduction

L1: 40 MHz $\rightarrow$ 100 kHz

HLT: 100 kHz $\rightarrow$ 1 kHz

Crystal Transparency

CMS ECAL, radiation damage, and the real-time reconstruction challenge

Correction needed

$$S_0 = S(t) \times LC, \qquad \text{with} \quad LC = \left[\frac{1}{\text{transparency}}\right]^{\alpha} = \left[\frac{R_0}{R(t)}\right]^{\alpha}$$

1 The ECAL

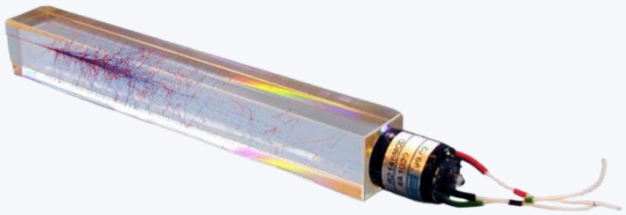
~76,000 PbWO4 scintillating crystals measure the energy of electrons and photons produced in LHC collisions.

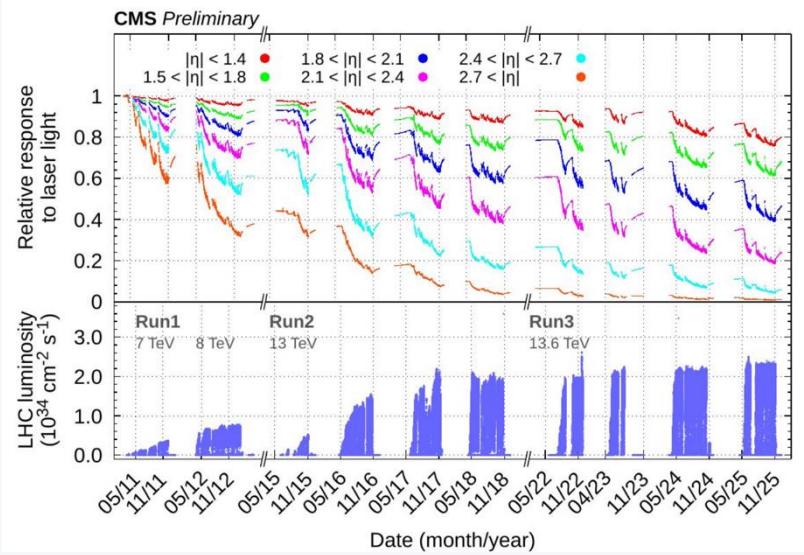
2 Radiation damage

Intense irradiation forms color centers in the crystals, absorbing scintillation light → loss of **transparency** and signal.

3 Monitoring

A Laser Monitoring System continuously measures **transparency = R(t)/R0** across the full calorimeter.





THE PROBLEM

The High-Level Trigger (HLT) reconstructs events in real time, but:

- **HLT** uses one fixed transparency value per fill
- **Offline correction** more accurate, but only available ~12 hours after data taking

⇒ ***Trigger efficiency is affected by outdated transparency values***

A Predictive Model for Live Correction

Exploiting fill-to-fill reproducibility to predict transparency loss ahead of time

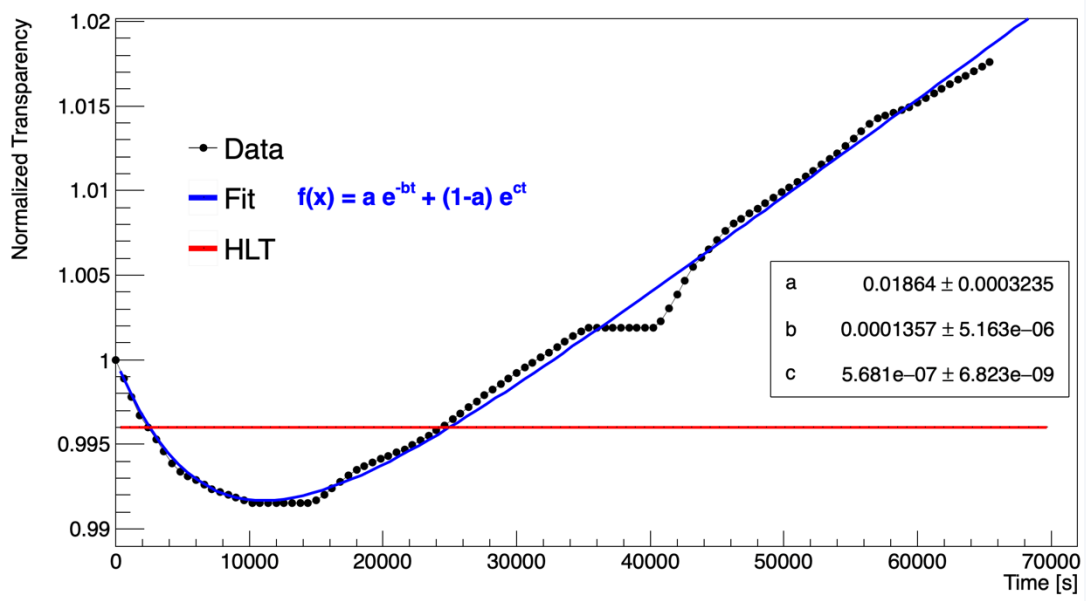
KEY INSIGHT

Luminosity profile and radiation dose are remarkably consistent from fill to fill → the transparency-loss pattern repeats predictably.

From data-driven fit to HLT integration

1. Fit historical transparency curves per crystal region
2. Extract analytic parameters describing the loss/recovery shape
3. Implement the prediction directly inside the CMSSW reconstruction chain
4. Replace the static “mean of previous fill” value used today by HLT

Goal: improve trigger efficiency by correcting energy in real time, without waiting for offline reconstruction.



FIT MODEL (ECAL Barrel)

$$f(t) = a \cdot e^{-bt} + (1-a) \cdot e^{ct}$$

Fitted parameters (barrel, $|i\eta| = 55$):

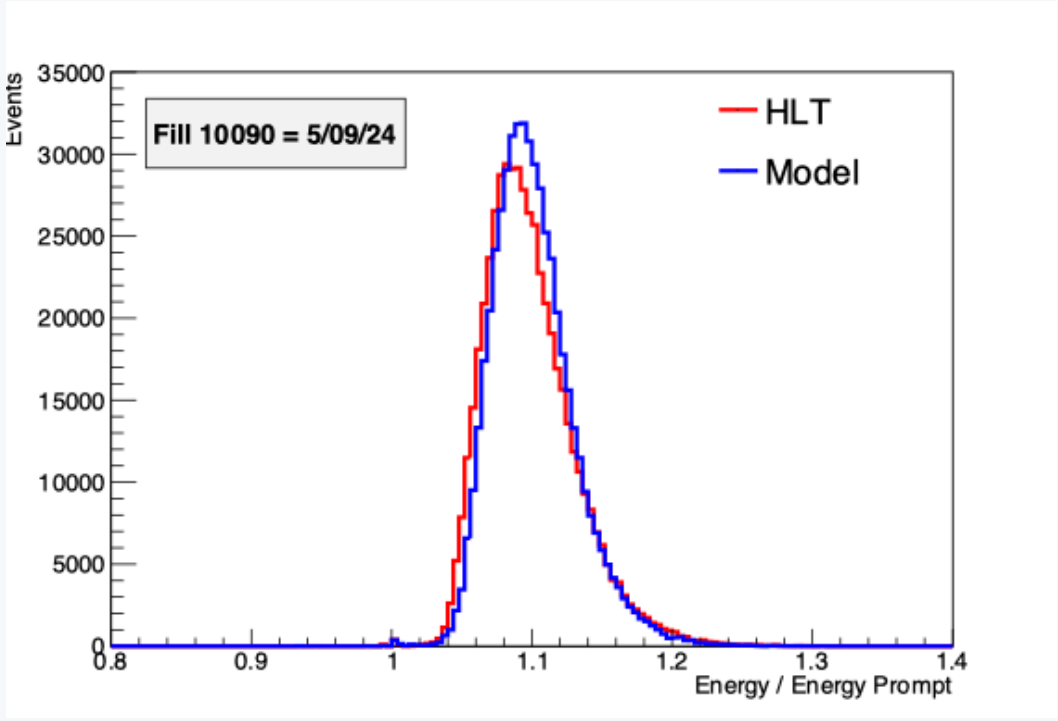
$a = (1.86 \pm 0.03) \times 10^{-2}$

$b = (1.36 \pm 0.05) \times 10^{-4}$

$c = (5.68 \pm 0.07) \times 10^{-7}$

Validation: Resolution & Trigger Efficiency

*Had **access to CERN computational resources**: model implemented in CMSSW and compared against current HLT and offline Prompt RECO (best estimate)*



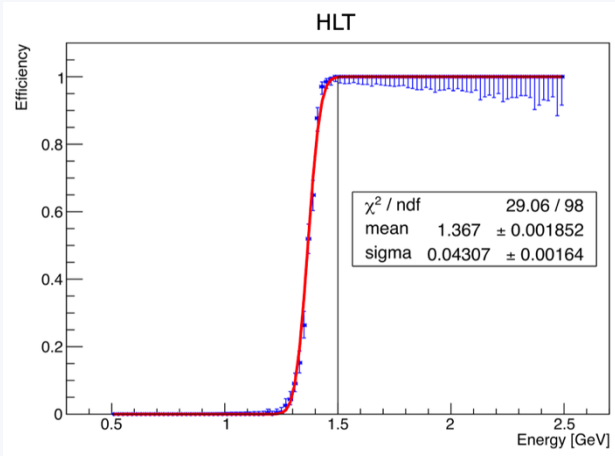
10% improvement in energy resolution with the predictive model

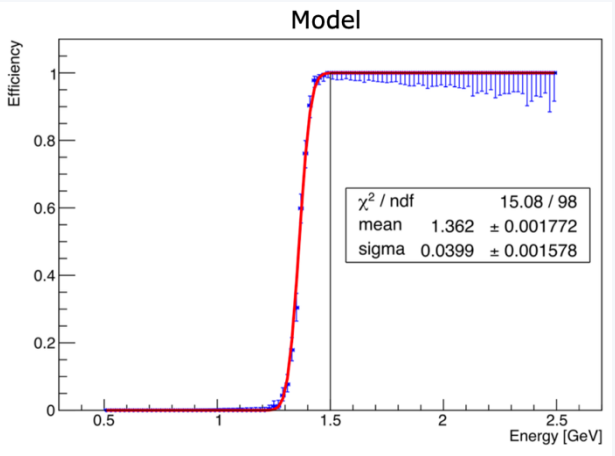
TRIGGER TURN-ON CURVE

Fit with an Error Function to measure how sharply the trigger turns on above threshold:

$$\sigma\,(\text{model}) \,/\, \sigma\,(\text{HLT}) \;=\; 0.93$$

A smaller ratio means a sharper, more precise turn-on — the model reproduces the true (Prompt RECO) efficiency threshold better than the current HLT.





Conclusions & Outlook

WHAT WAS DONE

- **Developed** a live-correction model for ECAL transparency loss, built on fill-to-fill reproducibility
- **Implemented** it inside CMS official software (CMSSW)
- **Validated** it: better energy resolution and a sharper, more accurate trigger turn-on curve than the current HLT correction

FUTURE DEVELOPMENTS

- Fit the model separately for different ECAL regions, to obtain region-specific parameters
- Extend the study to the Endcap crystals, where radiation levels — and thus transparency loss — are higher
- Assess the impact on physics analyses that rely on precise ECAL energy scale and trigger efficiency

Thank you for the attention!! — questions are welcome