



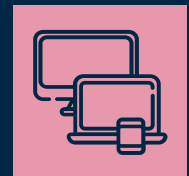
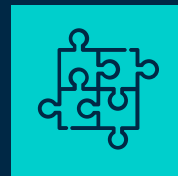
FIRE: THE FIRST-YEAR
INNOVATION & RESEARCH
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SIMULATING PARTICLE DETECTION

HGCAL Electromagnetic Calorimeter Performance

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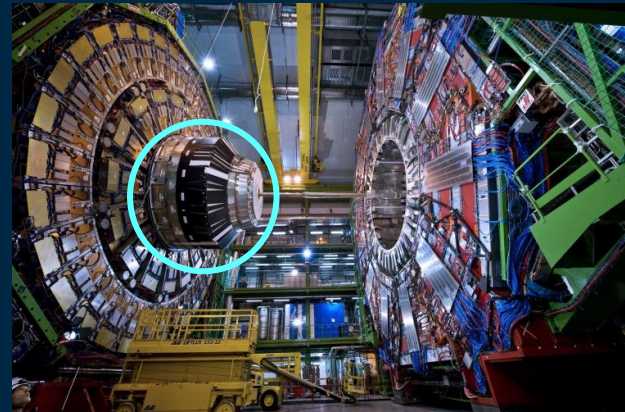
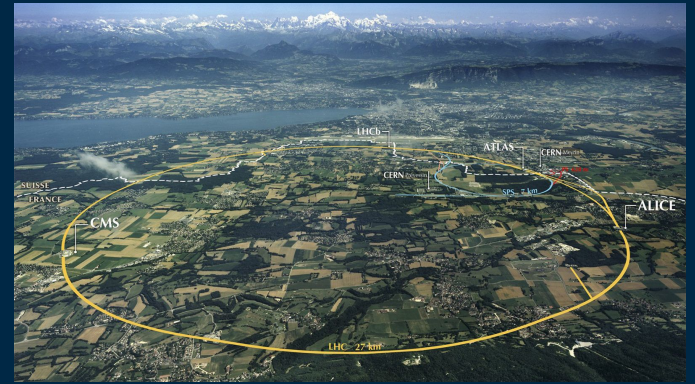
Motivation and Big Picture

- The LHC's high luminosity (**HL-LHC**) upgrade warrants an upgrade in detector components.
- The High-Granularity Calorimeter (**HGCAL**) is an important component of the HL-LHC upgrade for the Compact Muon Solenoid (**CMS**) experiment.
 - This upgrade needs to be planned thoroughly.
- Supplementing this, we conduct studies on detector component performance by using CMS Offline Software (**CMSSW**).
 - Data was obtained from the CMS experiment at the European Organization for Nuclear Research (**CERN**)
- CERN is an indispensable part of the entire scientific community
 - Discovery of fundamental building blocks of matter
 - Birthplace of the World Wide Web
 - Superconductivity and materials science



Introduction

- The **HGCAL** is part of the **HL-LHC upgrade**.
- Has electromagnetic (**CE-E**) and hadronic (**CE-H**) sections
 - Improved calorimetry by withstanding high radiation and pileup environments
 - Desired energy resolution [1]
- Current understanding of particle calorimetry suggests that **the resolution in energy measurement is dependent on the energy of the particle**. [2]
- This research aims to supplement efforts in detecting and correcting **documented shower leakage** in calorimeters. [3, 6]



- We focused on **CE-E** in the **TeV** range.
 - Used generated electron (e^-) and positron (e^+) events simulated and reconstructed using detector parameters released under **CMSSW**
- We mainly studied the longitudinal shower profiles in pseudorapidity (η) regions 1.5 - 1.6 and 2.9 - 3.0 (Figure 1).
 - η describes angular distance from the beam, with $\eta \rightarrow \infty$ along the beam axis.
- The main purpose of this study was to
 - Investigate the η -dependency of reconstructed energy resolution at 1 TeV
 - Compare the energy reconstruction resolution between 1 TeV and 100 GeV

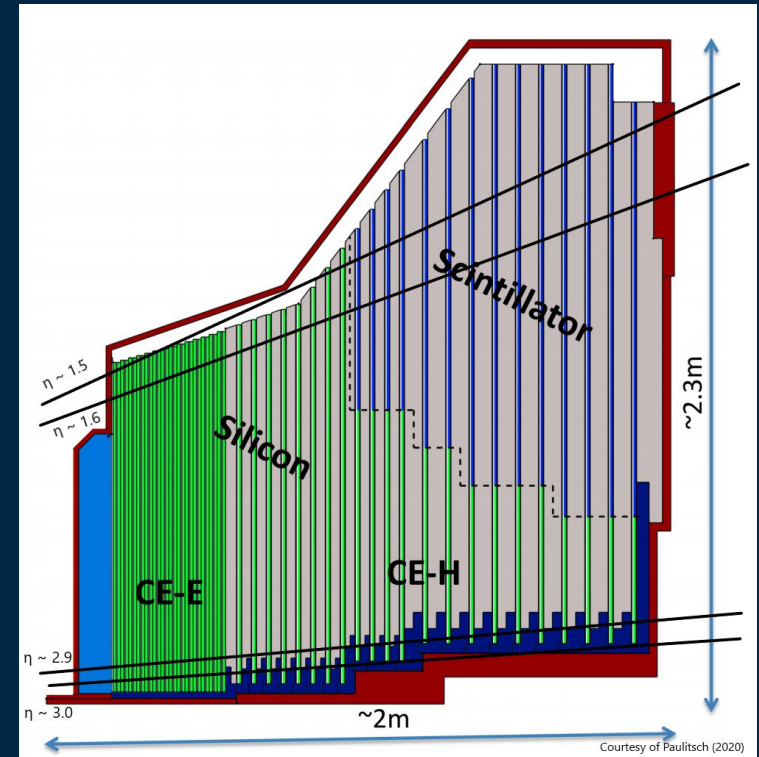
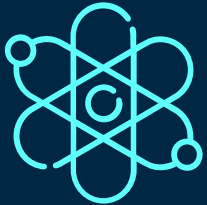
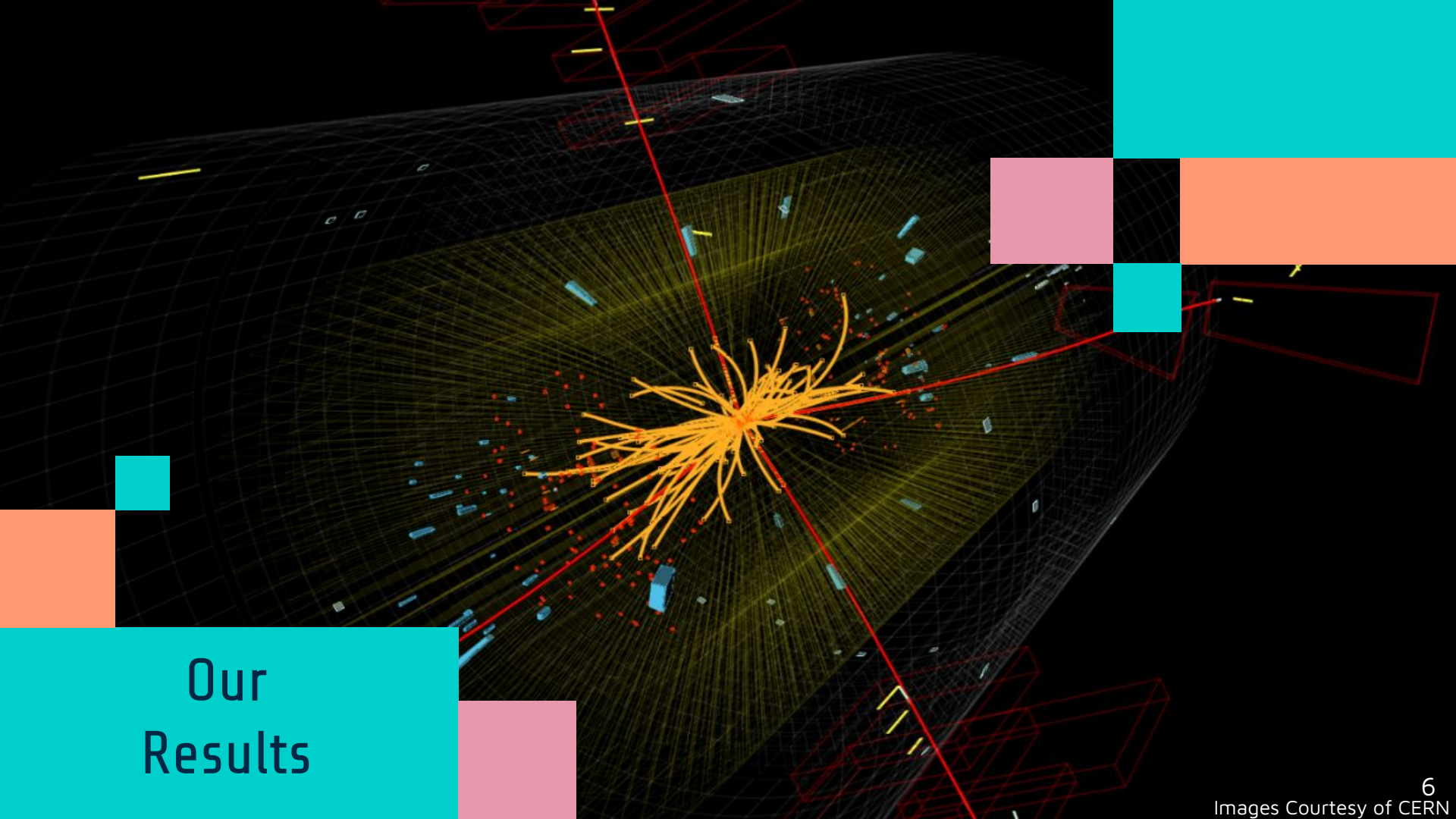


Figure 1. A schematic of one quadrant of HGCal [5] modified to show the η values [4]; this detector piece is located ~ 3 m away from the collision point in the beam axis. We mainly studied the edges.

Data Samples

- This study was conducted using e^- and e^+ particle gun simulations, generated under the CMSSW software release, with version 11 geometry 2026D46.
 - Samples containing 2000 events each (one e^- and one e^+)
 - Generated η cuts of 1.5 - 1.6 and 2.9 - 3.0 for the 1 TeV e^-
 - The 100 GeV e^- sample contained 2000 events originally
 - Covered the full HGICAL region, but constrained to the same ranges
 - TeV samples for each η range were generated and then combined
 - Energy was reconstructed by summing up the energies in CE-E cells oriented toward direction of the generated e^-
- Analyzed using CERN's ROOT framework





Our Results

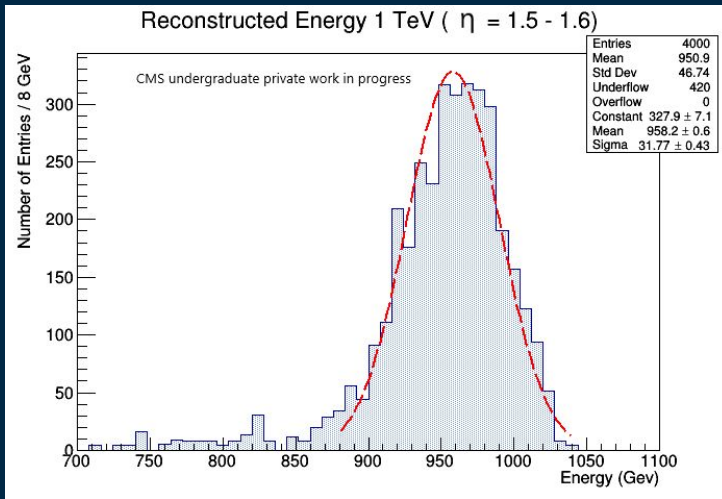
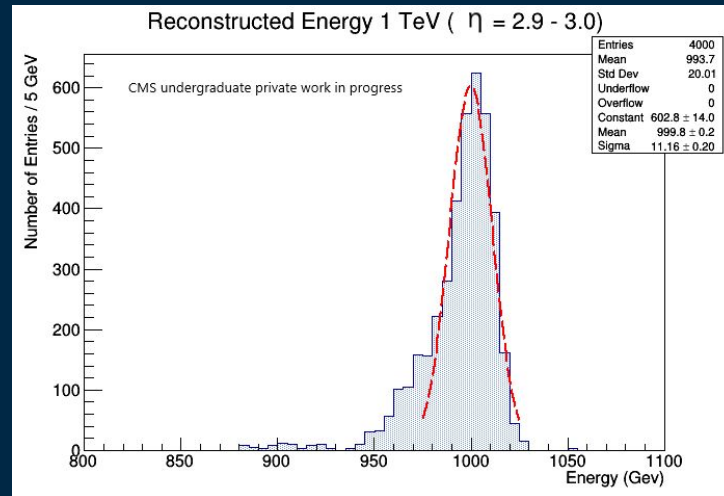


Figure 2

Reconstructed energy for e^- generated at an energy of 1 TeV in the **upper bound** of the HGCal. The graph depicts how the HGCal detects these 2000 e^- and e^+ being shot through the detector. The HGCal measured a mean reconstructed energy of $\sim (.95 \pm .05)$ TeV depicted in the histogram. A gaussian was constructed to fit the distribution and quantify the spread. Note the **tail** on the left side, might be the result of missing/underestimation of energy.

Figure 3

Reconstructed energy for e^- generated at an energy of 1 TeV in the **lower bound** of the HGCal. The graph depicts how the HGCal detects these 2000 e^- and e^+ being shot through the detector. The HGCal measured a mean reconstructed energy of $\sim (.99 \pm .02)$ TeV depicted in the histogram. A gaussian was constructed to fit the distribution and quantify the spread.



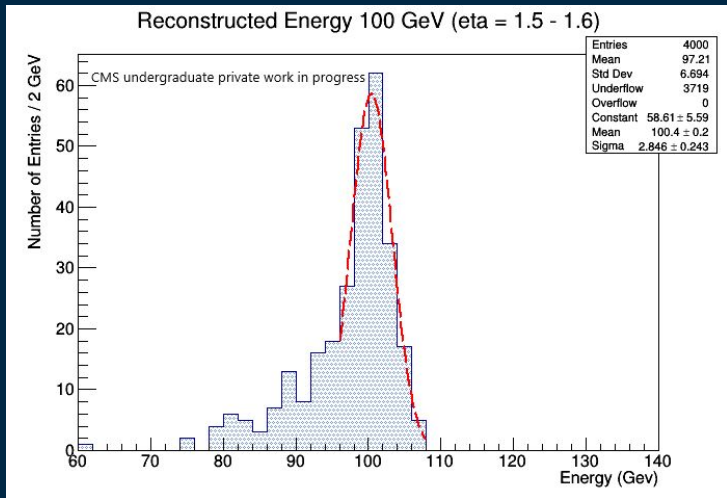
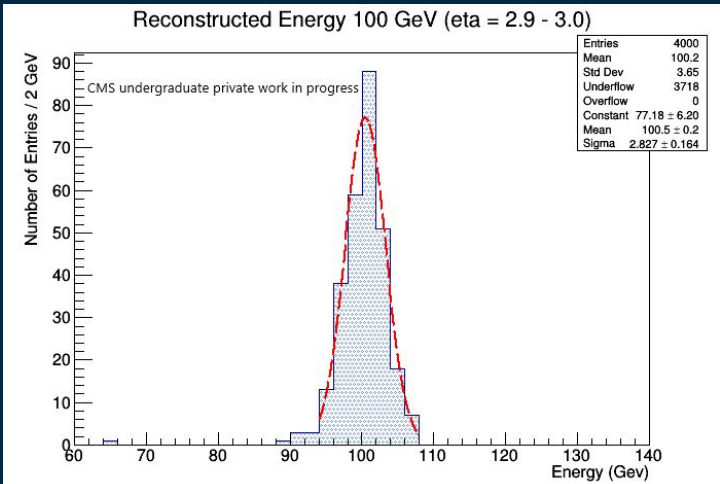


Figure 4

Reconstructed energy for e^- generated at an energy of 100 GeV in the **upper bound** of the HGCal. The graph depicts how the HGCal detects these 2000 e^- and e^+ being shot through the detector. The HGCal measured a mean reconstructed energy of $\sim(97 \pm 7)$ GeV depicted in the histogram. A gaussian was constructed to fit the distribution and quantify the spread. Note the **tail** on the left side, might be the result of missing/underestimation of energy.

Figure 5

Reconstructed energy for e^- generated at an energy of 100 GeV in the **lower bound** of the HGCal. The graph depicts how the HGCal detects these 2000 e^- and e^+ being shot through the detector. The HGCal measured a mean reconstructed energy of $\sim(100 \pm 4)$ GeV depicted in the histogram. A gaussian was constructed to fit the distribution and quantify the spread.



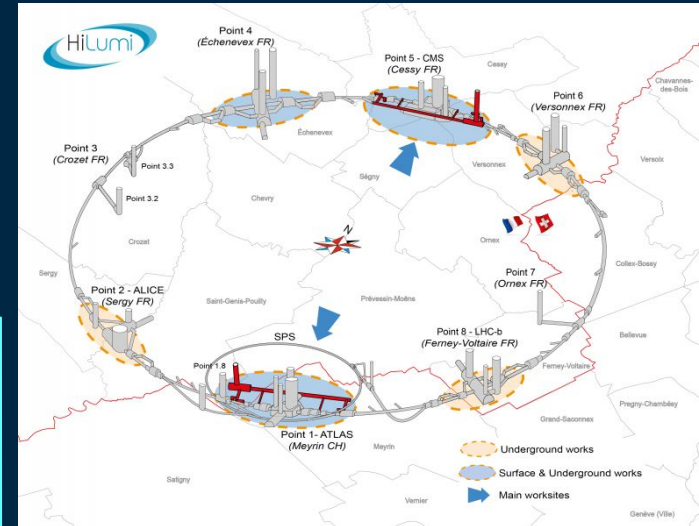
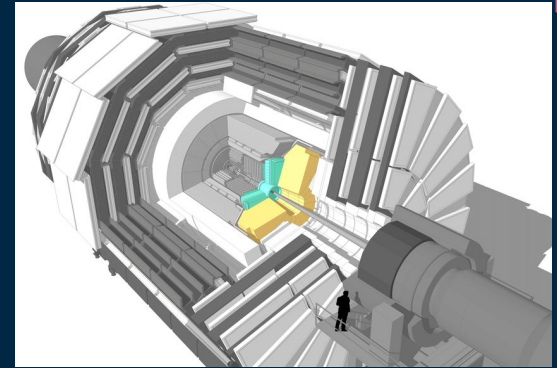
Conclusions

- Is there η -dependency of reconstructed energy resolution at 1 TeV?
 - The detector reconstructs particles that hit the lower edge ($\eta = 2.9 - 3.0$) better than those who hit the upper edge ($\eta = 1.5 - 1.6$).
 - This may be explained by the detector geometry shown in Figure 1. Note that the upper eta ranges lack coverage in certain areas-- these e^- may be escaping and not captured well by the detector, causing worse resolution at those ranges.
 - This also holds in the 100 GeV range.
- Does the high-energy and high-resolution relationship hold at the detector boundaries?
 - For the upper boundaries, the HGCAL obtained a reconstructed energy of $(.96 \pm .03)$ TeV and (100 ± 3) GeV for 1 TeV and 100 GeV generated e^- , respectively.
 - For the lower boundaries, the HGCAL obtained a reconstructed energy of $(1.0 \pm .01)$ TeV and (100 ± 3) GeV for 1 TeV and 100 GeV generated e^- , respectively.
 - Looking at the graphs qualitatively and the statistics, there appears to be no apparent improvement in energy resolution between the 100 GeV and 1 TeV.
 - But, since the higher energies have smaller sigma-reconstructed-energy-ratio, they have better resolution. They have smaller errors for a given energy, suggesting better resolution.



Future Plans

- Our results are limited by the number of samples that we had and the quality of each.
 - We showed evidence suggesting that due to the geometry of HGCAL, particle reconstruction may be affected by the shower leakages at the edges of the HGCAL detector and this is more prone to happen at $\eta = 1.5 - 1.6$.
- We were also informed after our analysis that there was a geometry issue in the detector parameter versions that we used.
- Investigation of this region of CE-E may be done more accurately by using advanced overall reconstruction methods.
- We plan on verifying the η -dependency of energy resolutions by using the correct and updated geometry.



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Questions ?

Please feel free to ask us during the symposium.

Additional Questions about the research?

Feel free to send them to
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