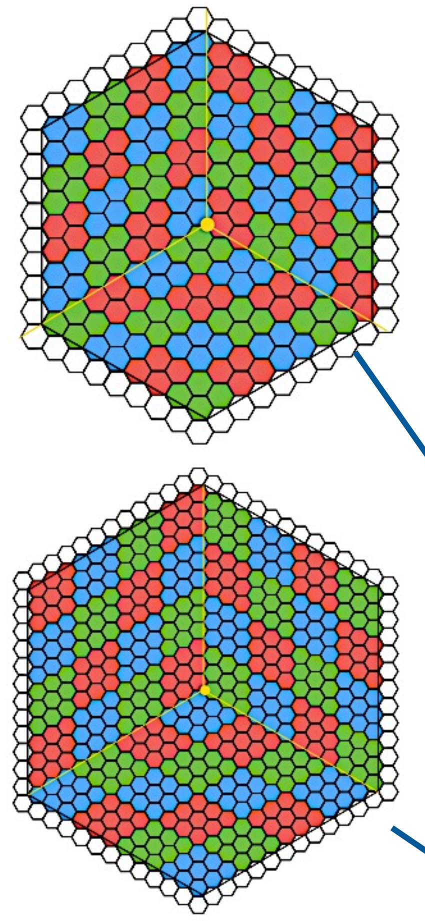
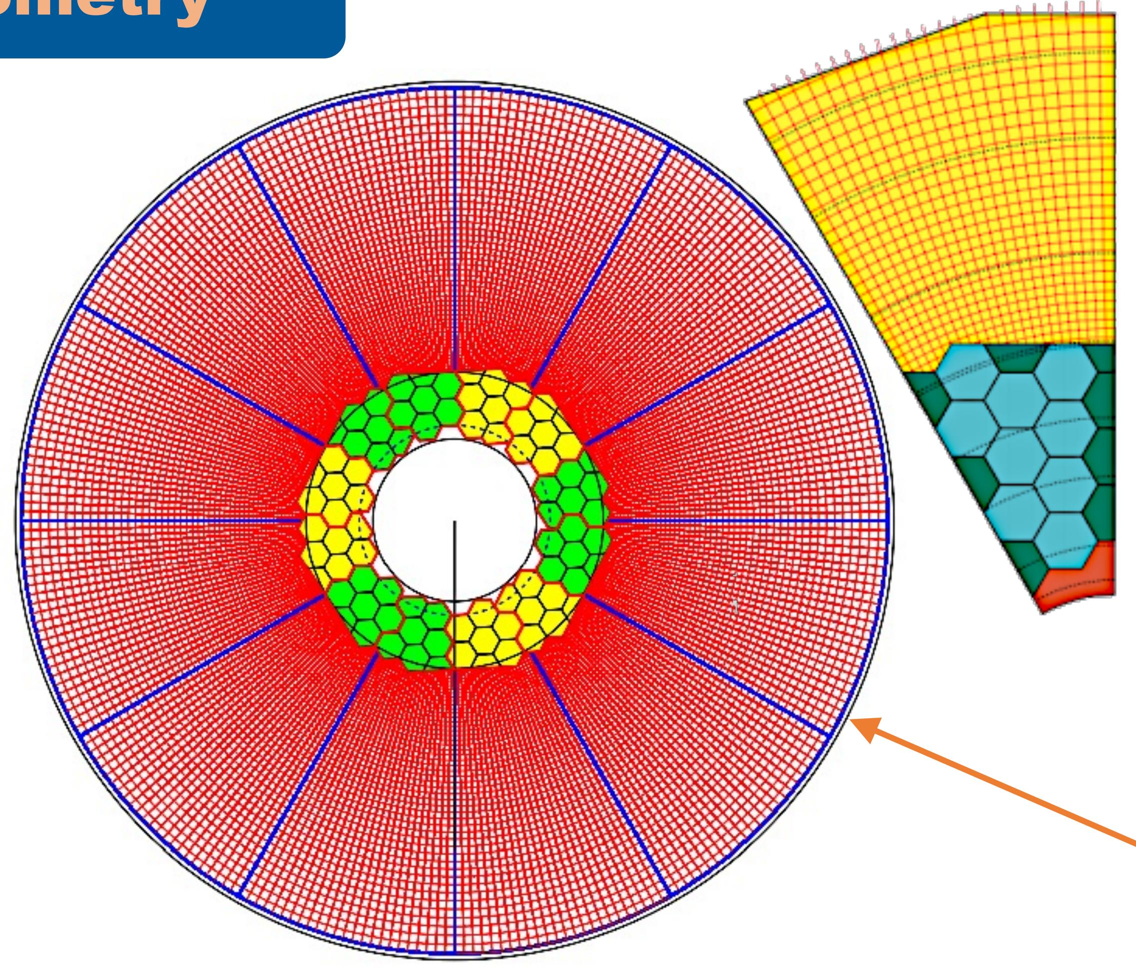
HELMHOLTZ AI | ARTIFICIAL INTELLIGENCE COOPERATION UNIT

DeGeSim and the High Granularity Calorimeter for the CMS experiment at the Large Hadron Collider

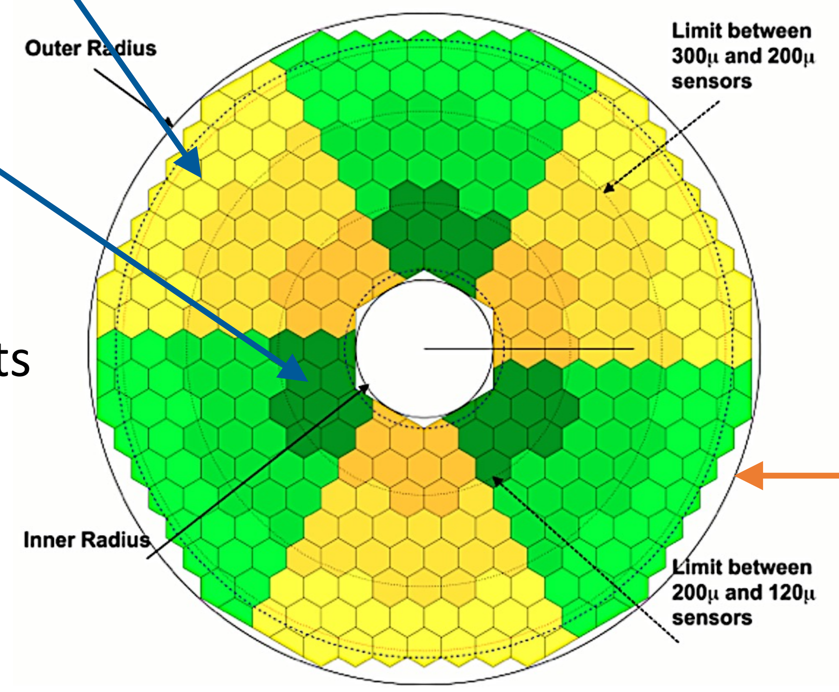
M. Scham[1,2,*], S. Bhattacharya[1], K. Borras[1,4], W. Fedorko[3], J. Jitsev[2], J. Katzy[1], and D. Krücker[1]

A Complex Geometry

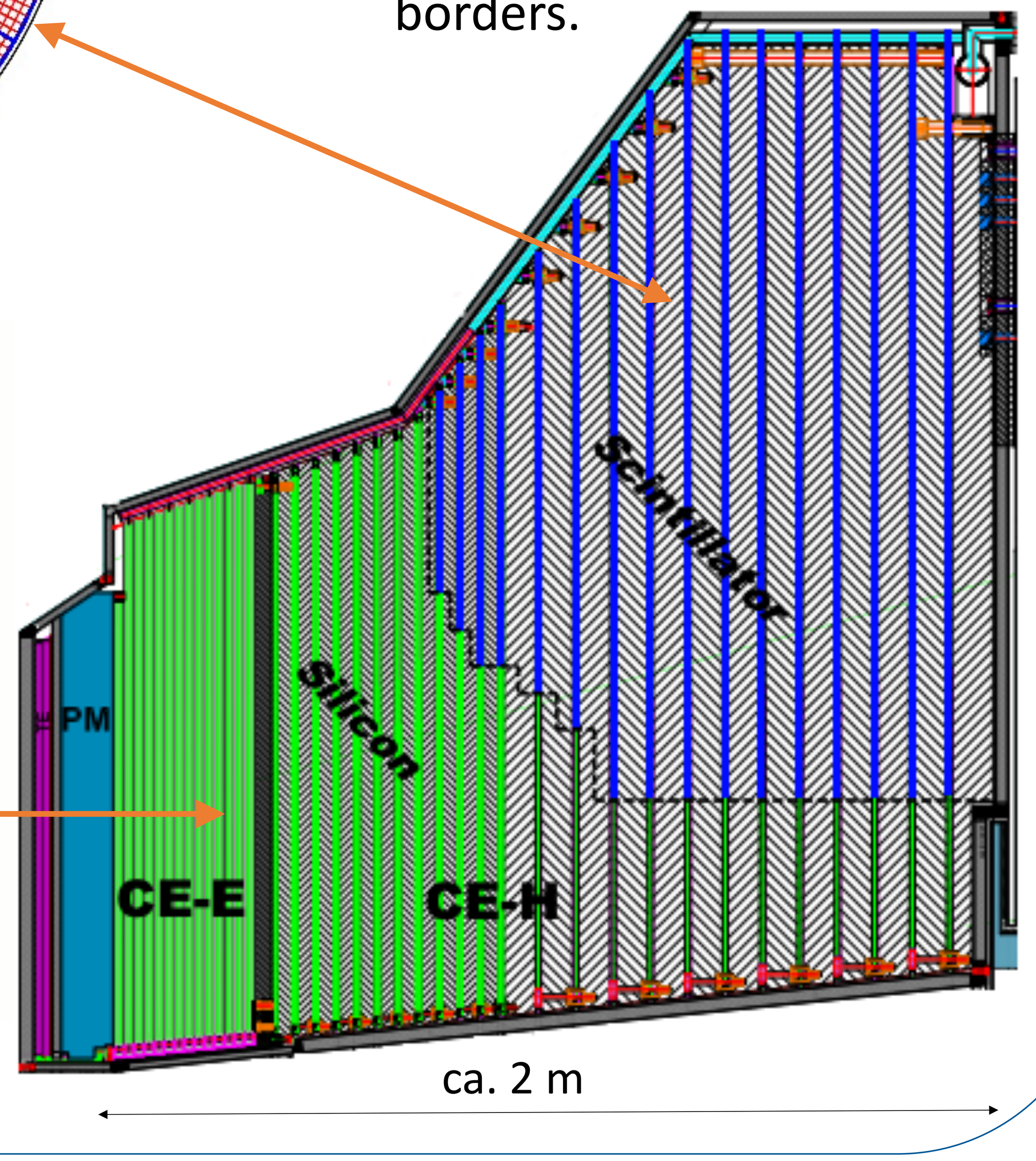


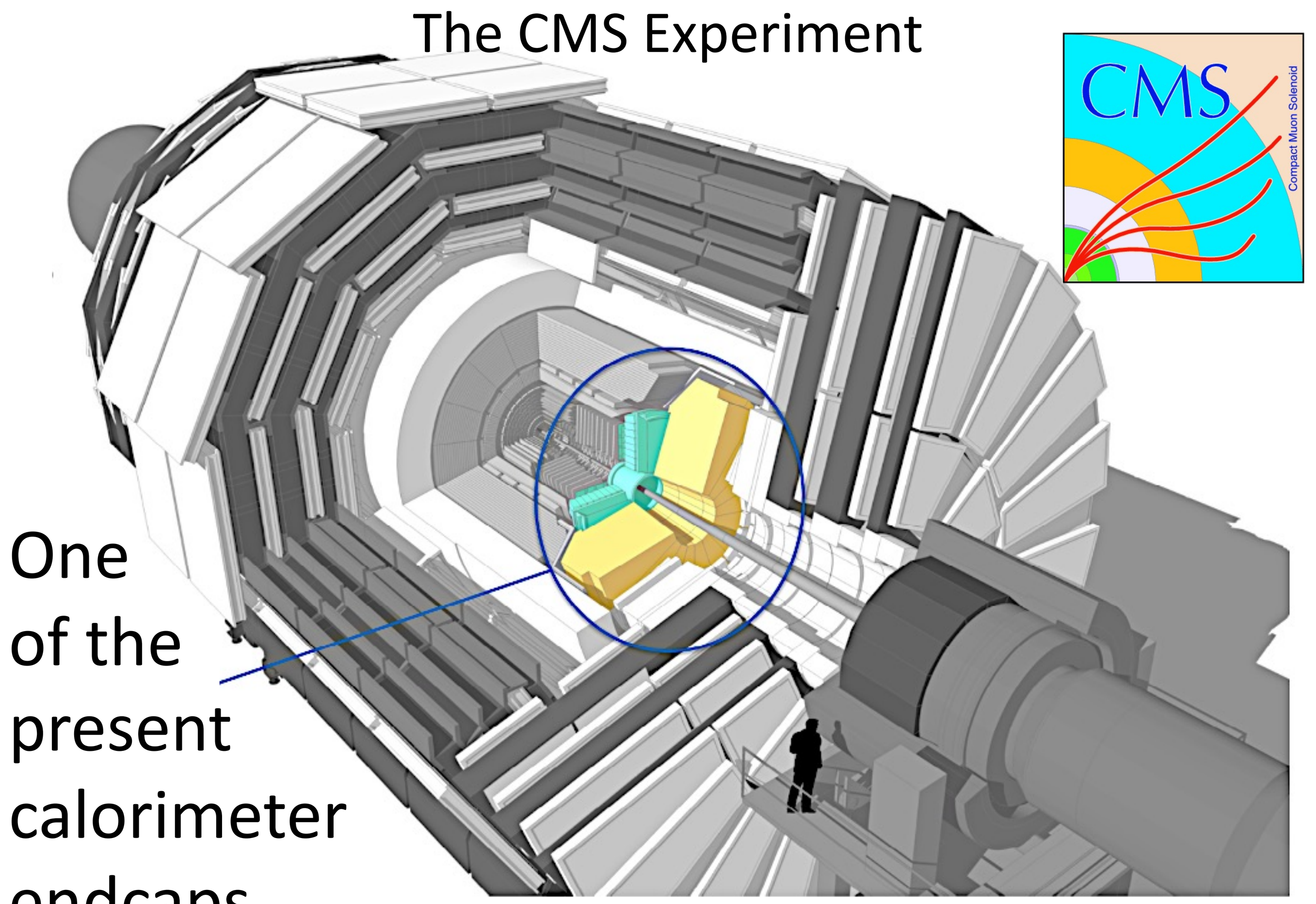


- One mixed layer of scintillator and silicon detectors in CE-H.
- The outer scintillator tiles form a square grid with different edge sizes.
- Note the cut hexagons that define the outer/inner borders.



One silicon layer in CE-E.
- Each hexagon represents a wafer with multiple detector cells (pictures above).
- Higher number of cells in the inner sections.





One of the present calorimeter endcaps

The new **HGCal**

The Challenge

- In particle physics, it is common to work with complete simulations of detector and physical processes (digital twins).
- CMS currently processes several **tens of billions** of simulated events.
  - A large fraction of computational resources are used for this.
- During the high luminosity phase, the data size will increase by an order of magnitude and the **particle tracks density** will increase significantly.
- Deep learning techniques combining fast inference with generative models, e.g., physics-informed GANs-VAEs hybrids, could solve the challenge and provide fast simulations learned from data.
- It is essential to be able to include physical constraints in these models. This can be realized by including constrains in the loss, e.g. for proper modelling of the total energy, or by structuring the latent space to enforce a realistic variability of the produced simulations.

Some Numbers

The HGCal is a sampling calorimeter i.e. active detectors alternating with passive absorbers. Two parts: electromagnetic CE-E and hadronic CE-H.

Each endcap	Sillicon	Scintillator
Area	310 m^2	200 m^2
# Channels	**3 M**†	120 k
# Layers	28	8+14

† The present system has only about 7k channels/endcap.

Absorbers:
Pb CuW, Cu and stainless steel

Weight 215 t

A possible Approach

- State of the art in GAN simulations of calorimeters are cubic grids of **30x30x30** dimension.
- Our system consists of about **3 million** irregular cells (but not all cells are always active).
- Graph Neural Networks are a natural approach to describe the irregular geometry of the HGCal.

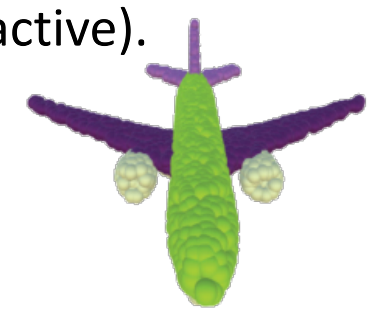
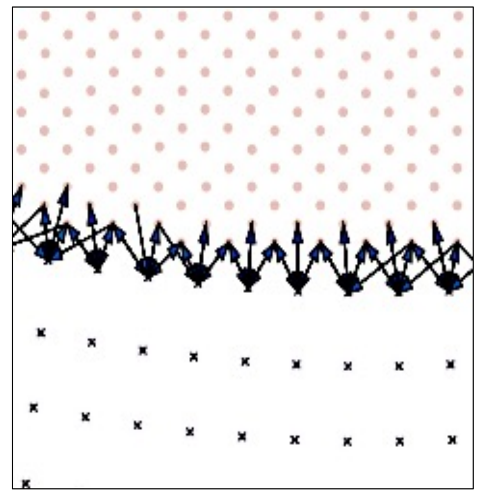


Image from Y. Wang et al., ACM Transactions on Graphics October 2019 Article No.: 146

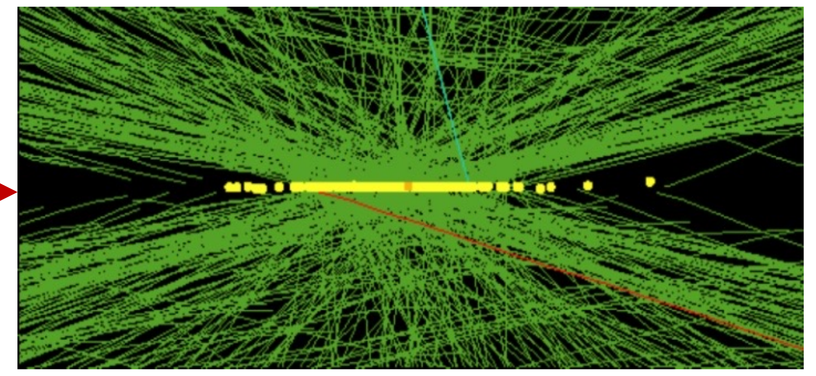


- This image shows the neighborhood construction at the border between silicon and scintillator cells which is needed for the graph construction.
- Currently, we have started to prepare the detailed simulations that will be used as training data for the generative deep learning models that we are going to develop in this project.

More to come!

The High Luminosity Upgrade

- The Large Hadron collider at CERN is a proton-proton (pp) collider.
- Presently the collision data consists of about 40 simultaneously pp collisions.
- The LHC will be upgraded to high intensity beams with **140-200** simultaneous pp collisions.



High Luminosity Phase

Run 2	LS 2	Run 3	LS 3	Run 4 - 5 …
int. luminosity: 190/fb	Long Shutdown	300/fb		3000-4000/fb
2015 - 2018	2019 - 2021	2022 - 2024	2025 - Mid 2027	2027 - 2040
You are here!			Installation and commissioning	

- Not only the accelerator will be upgraded but also the detectors.
- The CMS experiment will get completely new calorimeters in the forward direction (“end caps”) ⟶ The High Granularity Calorimeter **HGCal**.
- To cope with the high particle density we need high spatial resolution ⟶ granularity.
- A calorimeter must stop the energetic particle to measure their energy ⟶ dense material (radiation/interaction length).
- The impacting particles interact by electromagnetic or nuclear reactions and produce secondary showers ⟶ longitudinal resolution.
- We also need high temporal resolution to separate the individual bunch crossings every 25 ns.

DESY.

JÜLICH

JSC - Jülich Supercomputing Centre

TRIUMF

(1) DESY, Hamburg
(2) FZJ and Jülich Supercomputer Center (3) TRIUMF/Vancouver (4) RWTH University of Aachen

*Fund through Helmholtz AI - grant number: ZT-I-PF-5-3

All HGCal images from technical design report:
https://cds.cern.ch/record/2293646/files/CMS-TDR-019.pdf