A fast convolutional neural network for identifying LLP decays in a high-granularity calorimeter

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LLP8

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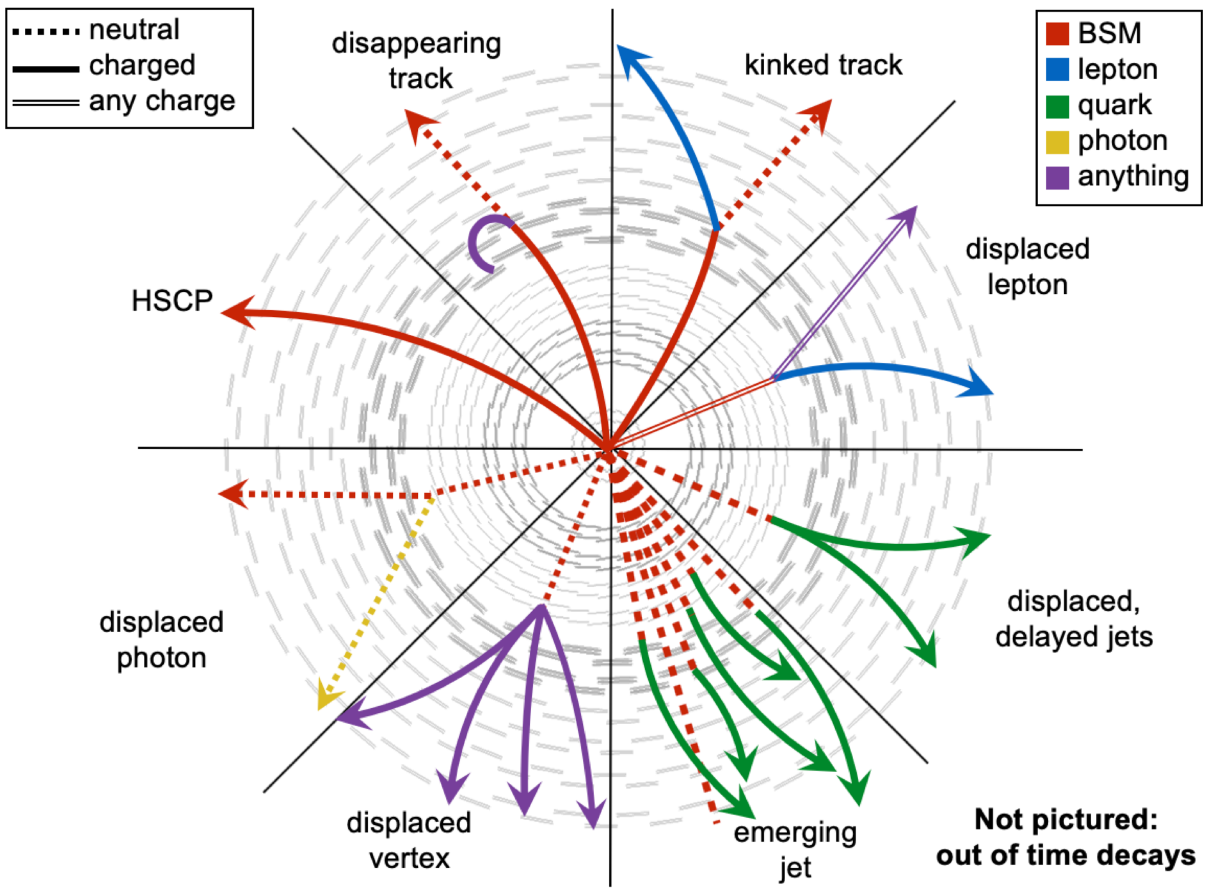
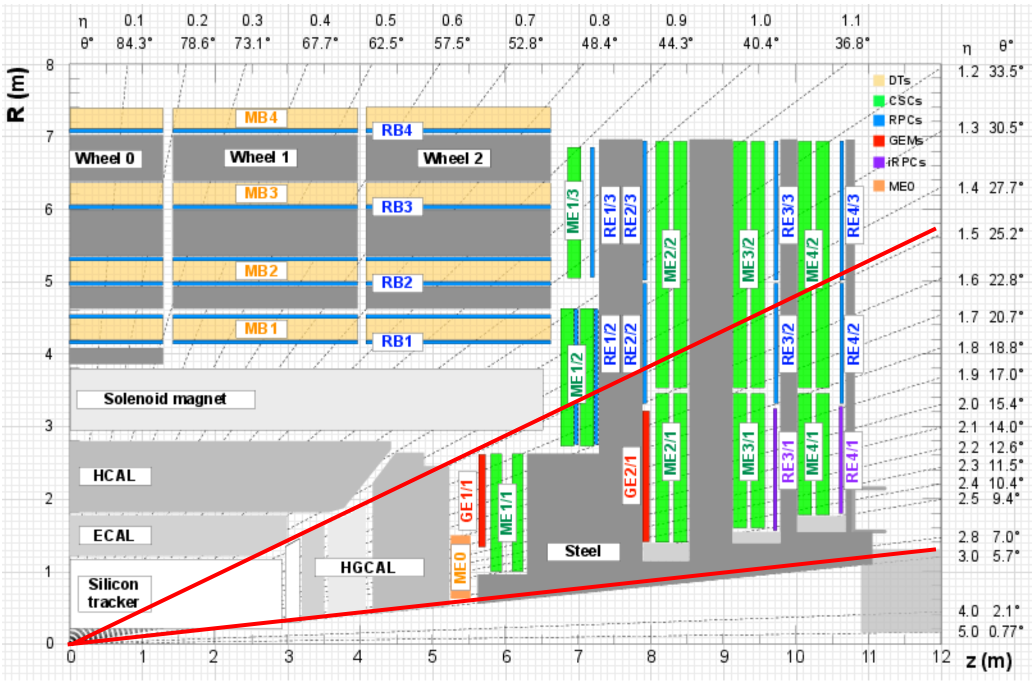
Triggers for Long-Lived Particles

- LLP searches span a wide variety of signatures, models, lifetimes, masses, decay locations, etc.
- The signatures are often **unusual** and **not covered** by “standard” reconstruction or triggers
- If your data is not triggered, it’s lost!
- **Dedicated triggers for LLPs are crucial!**

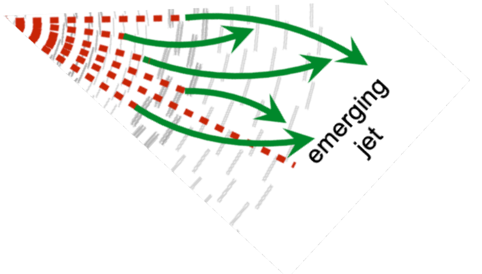


Displaced Particles in CMS Phase 2 at Level 1

- **Can we trigger at level 1 (L1) on displaced/ delayed particles in the CMS at the HL-LHC?**
- <u>Track trigger:</u>
  - Only for charged particles
  - Only for $|\eta|<2.1$
  - Only for $|d_0|< 10$ cm, with the track trigger extension
- <u>MIP Timing Detector (MTD):</u>
  - Will not be used at L1
- <u>ECal and HCal barrel:</u>
  - Timing available at L1
- <u>High-Granularity Calorimeter (HGCal):</u>
  - No timing at L1
  - Current HGCal L1 reconstruction assumes pointing showers

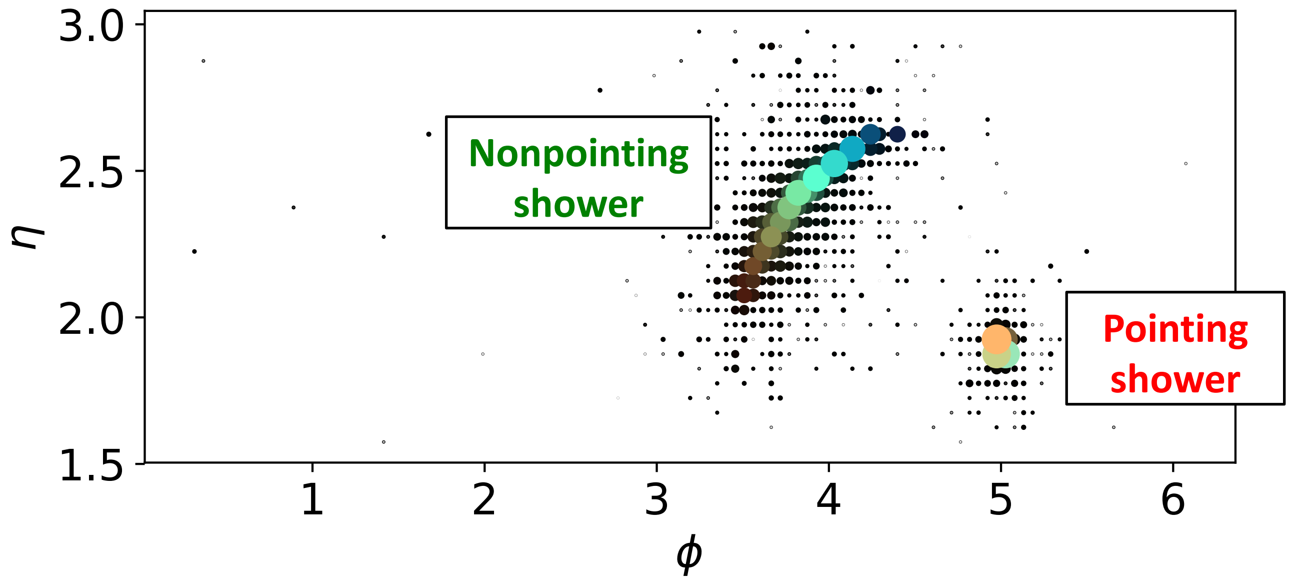


- **Displaced/delayed signatures from LLPs in the forward region could be completely missed with CMS in Phase 2, without a dedicated trigger**
- <u>Example LLP signature</u>: Emerging jets (t-channel production)



CNN Trigger for LLP Decays in HGCal

- Developed a fast convolutional neural network (CNN) to find nonpointing showers in a high-granularity calorimeter (HGCal)
- Computer vision image recognition can easily differentiate between nonpointing and pointing showers
- Proof of concept paper (https://arxiv.org/abs/2004.10744) recently accepted by JINST

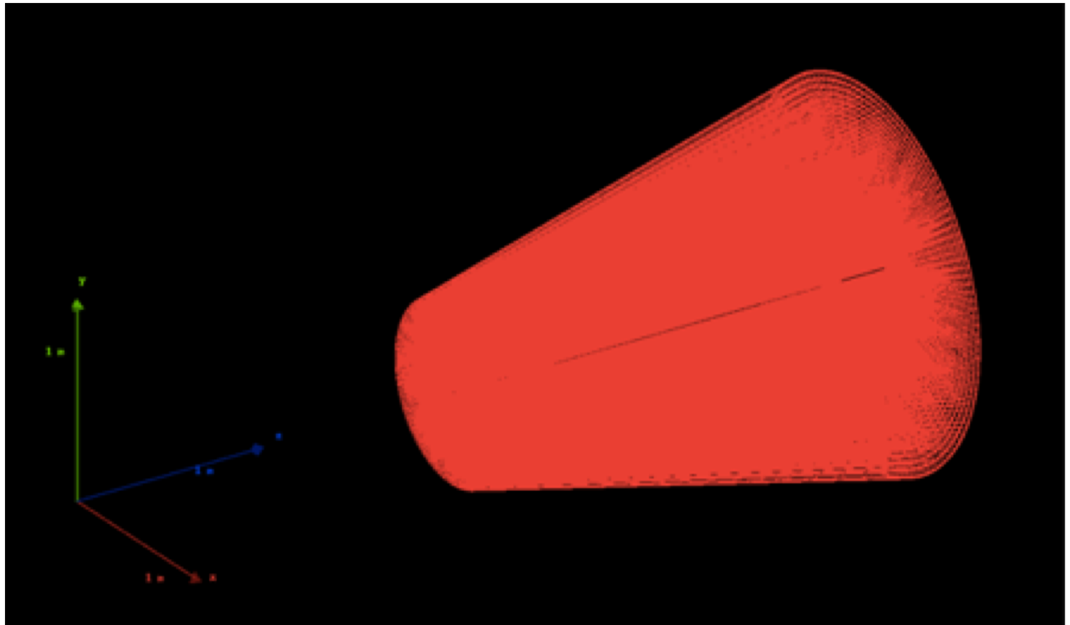


Colors indicate calorimeter layer number

Marker size indicates deposited energy

Detector

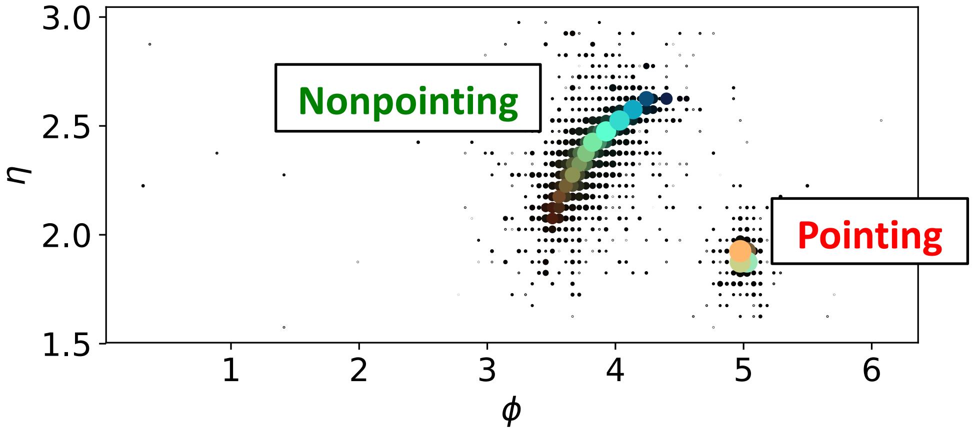
- Toy calorimeter in Geant4
- Granularity, geometry, and material like the EM part of CMS HGCal at L1 trigger
- Use projective geometry, regular η-ϕ grid
  - 30 x 120 x 14 pixels in η/ϕ/layer
  - NB: CMS HGCal will have sets of hexagonal sensors of different sizes: will need to make this structure fit in a grid, in order to use it with CNNs
- 1T magnetic field



(just for illustration, this still includes an hadronic part)

Data Sample

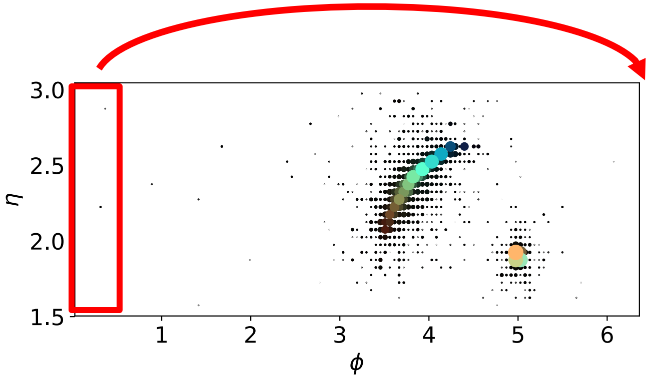
- Signal:
  - Focus on EM showers
  - Generate photons in Geant directly in front of calorimeter, with displacements between 20 and 60 cm
  - Choose angle wrt projection axis (α) uniformly between 0 and $\pi/3$
    - Adjust rotation such that particles traverse the calorimeter
  - Select energy between 10 and 200 GeV
  - 780k events for training, 8.8k for validation, 14.4k for testing
  - **Model-independent**



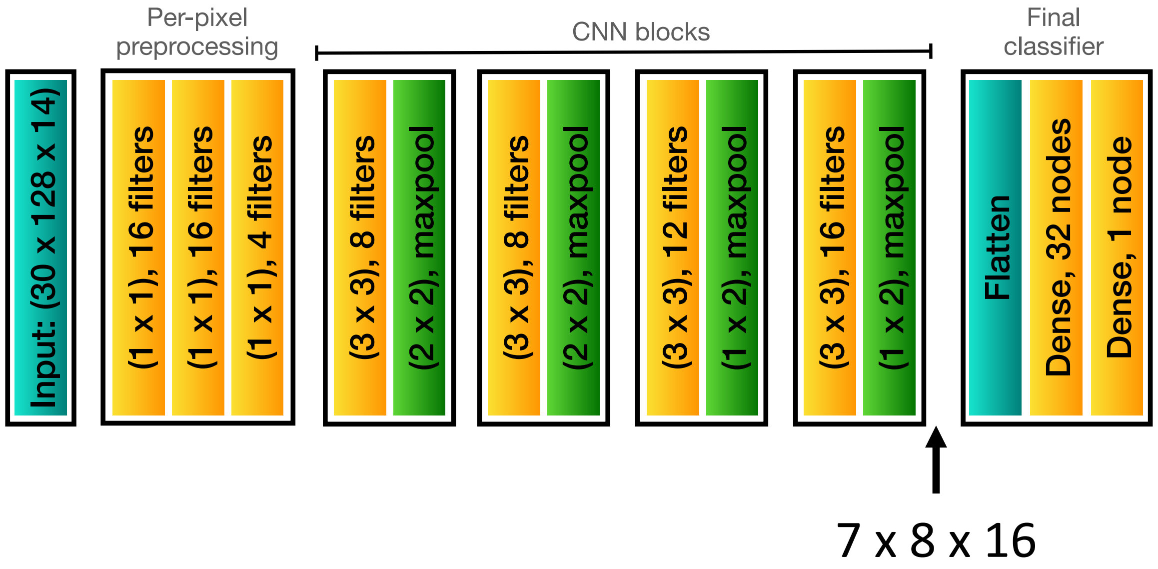
- Minimum-bias background and pileup:
  - CMS minbias configuration
  - Generate individual events (15.3M for training, 4M for testing and validation) with Pythia8
  - Mix 200 randomly selected events to form one minbias event
  - Overlay with signal

Neural Network and Training

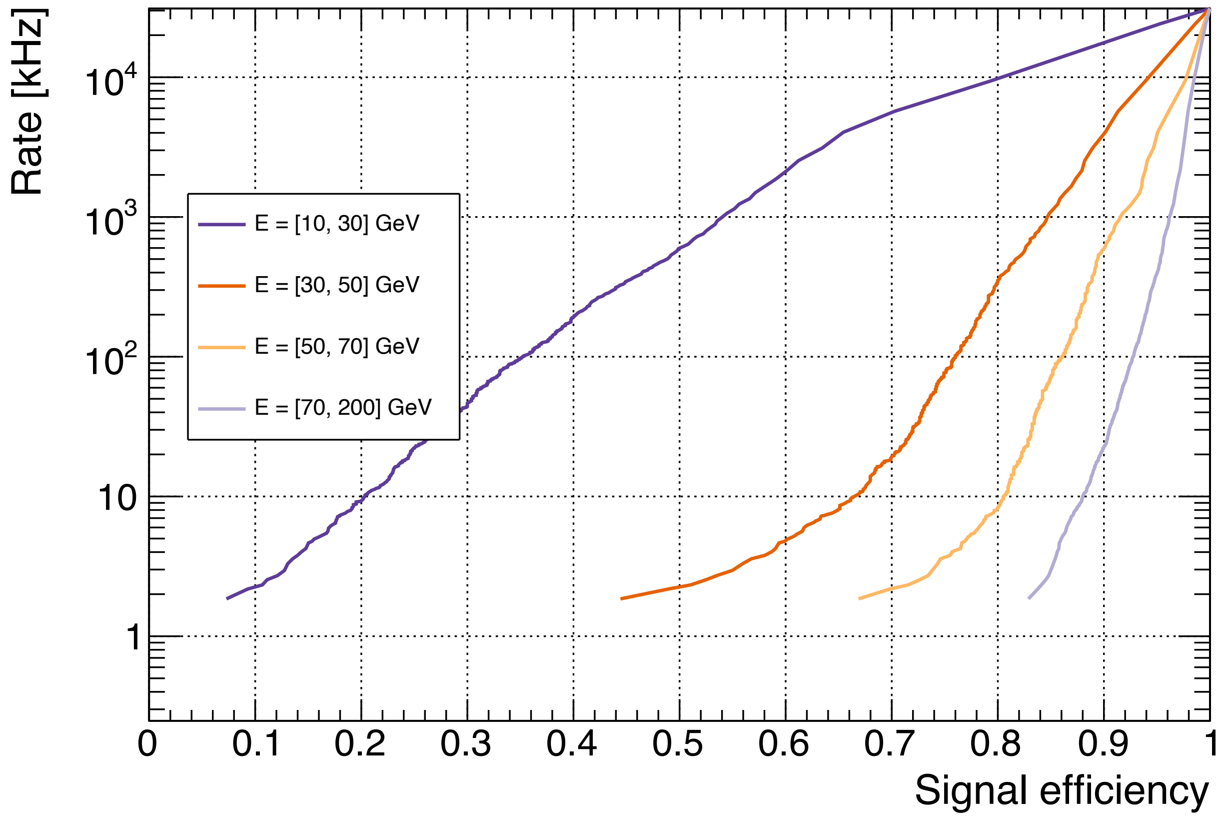
- **Simple CNN designed to provide compromise between performance and resource requirements**
- Pixels from ϕ=0 to ϕ=0.4 are repeated at ϕ=2π to account for particles that enter the calorimeter at ϕ~ 0
  - Therefore 120 pixels in ϕ become 128



- Per-pixel preprocessing: 14 layers → 4 "colors", to make input to CNN blocks small
- Simple CNN + max pool blocks
- Final classifier with low parameter count
- Trained with Adam optimizer
  - 1 epoch with a batch size of 50, learning rate of 1e-4
  - 30 epochs with a batch size of 500, learning rate of 3e-4
  - 1 signal event : 1 minbias event for training
- 1 signal event : 70 minbias events for testing



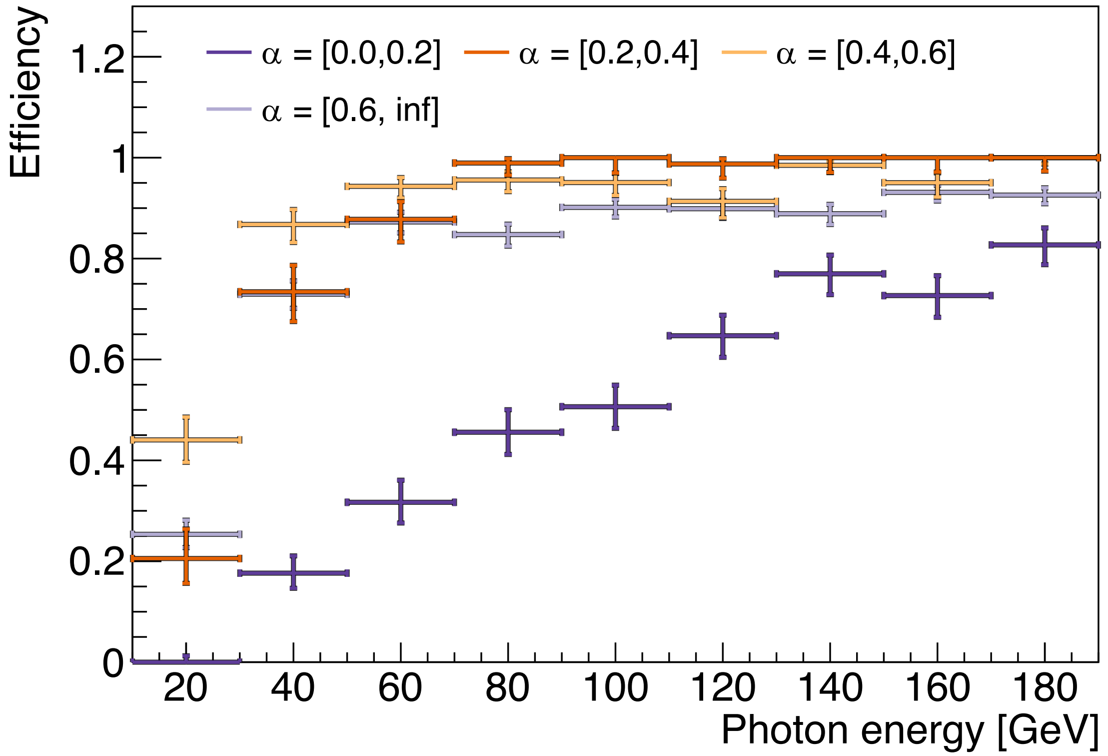
Results

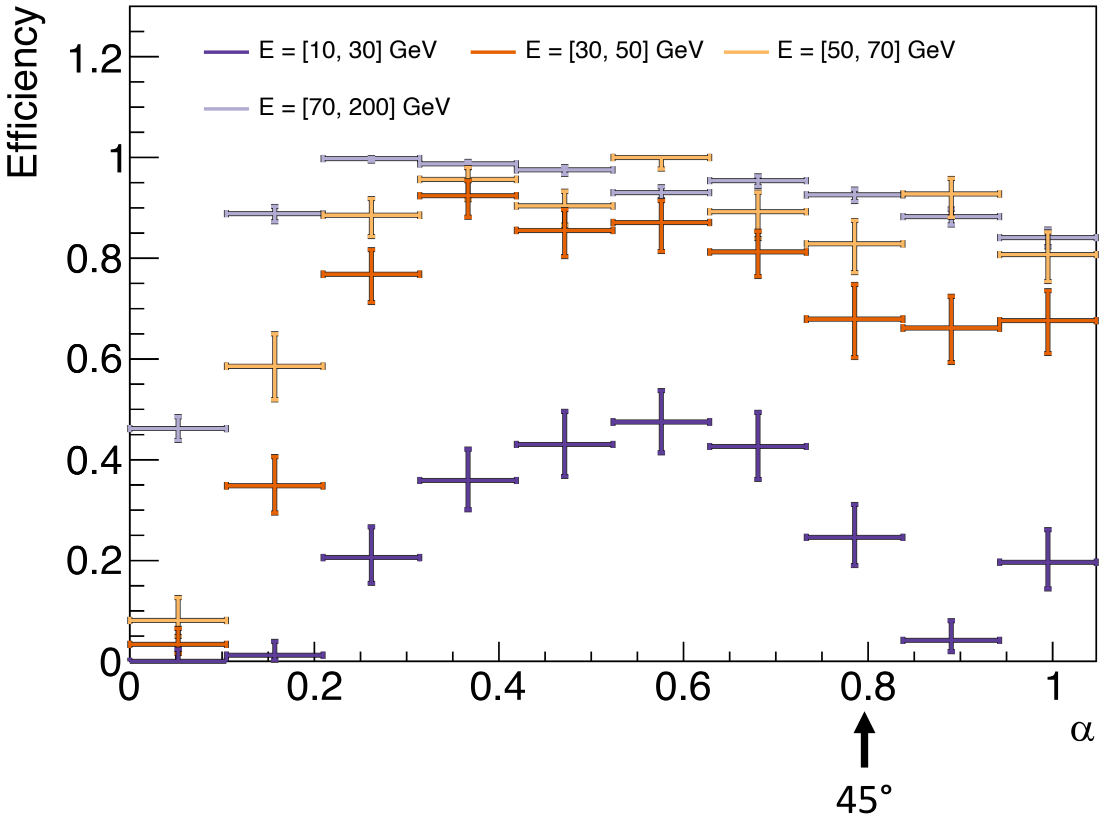


Good performance already at low energy (this is energy, not p_T)

Efficiency vs Energy and Angle

- Select a working point of 15 kHz based on previous slide
- Promising, model-independent results





Summary and Outlook

- Showed that a fast CNN-based pattern recognition trigger is able to identify nonpointing showers in a forward, high-granularity calorimeter with reasonable efficiency and rate
- Dependence on energy and shower angle behaves as expected
- Now working with CERN HLS4ML group to see how feasible this would be for FPGAs in the real Phase 2 CMS HGCal at L1
- Ultimate goal is to have this as a trigger for the CMS HGCal