End-to-End reconstruction using machine learning to search for exotic decays of Higgs

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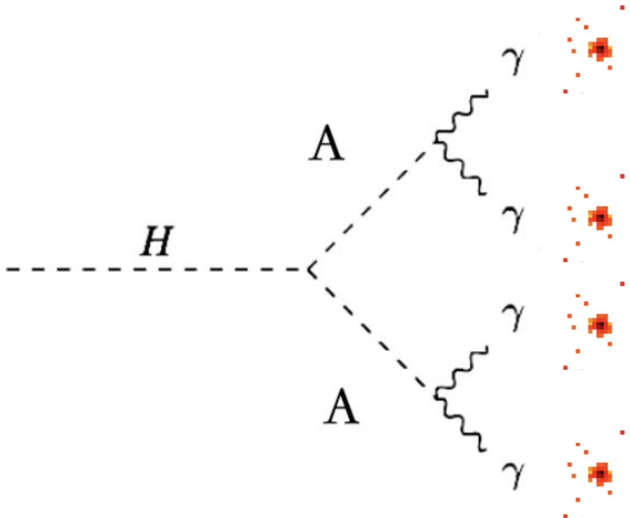
Probing exotic decays of Higgs

- ➔ We probe using the newest discovered particle Higgs
  - ◆ Existing measurements leave room for BSM decays of Higgs

Br(H—>BSM) ~ O(10%) allowed

- ➔ H —> AA, A is a light scalar or pseudoscalar, well motivated in BSM models like 2-Higgs doublet (2HDM+S), Next-to-minimal SUSY (NMSSM), axion-like particle (ALP)

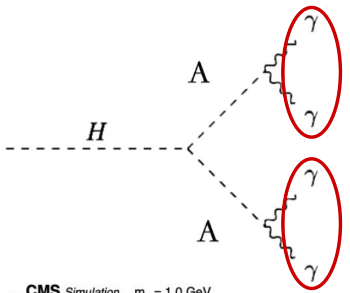
- ➔ For low masses, photons offer a clean gateway



Probing exotic decays of Higgs

➔ However, low mass creates challenges: Makes these invisible to us

0 < mA < 1 GeV



Merged into 1 photon

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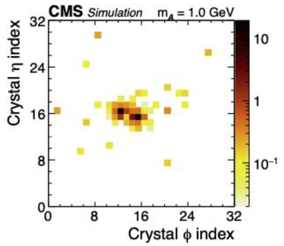
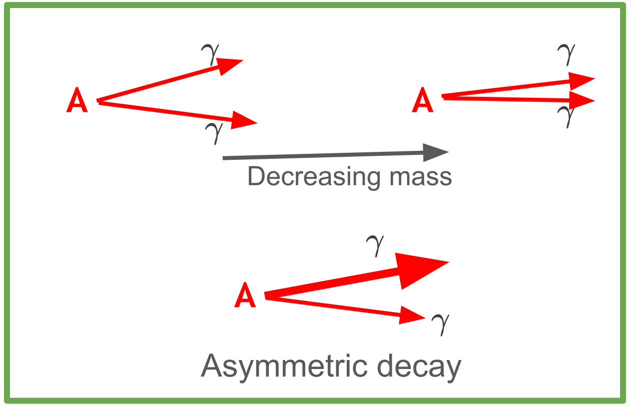
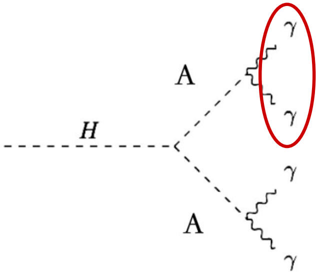
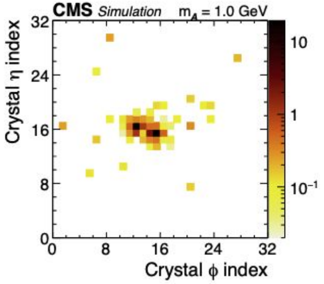




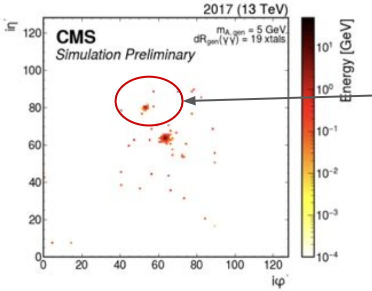
1 < mA < 15 GeV



Merged/ One photon lost by standard reconstruction



+



CMS photon reconstruction ignores this photon due to low energy pattern

Standard CMS reconstruction reconstructs 1 photon per A
2 photon final state instead of 4 photons

Standard CMS reconstruction reconstructs 3 photon final state

Probing exotic decays of Higgs

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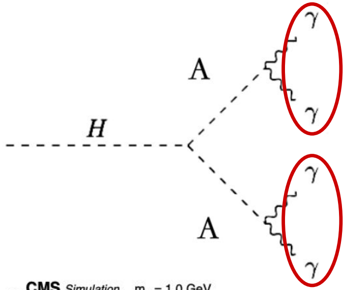
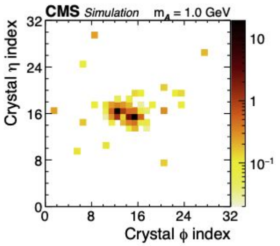
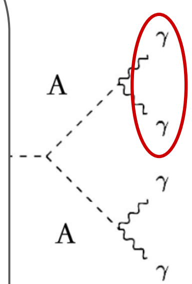


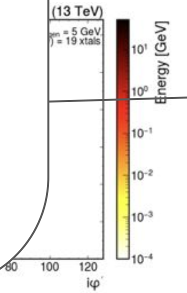


Impossible to probe such interesting new physics using standard techniques

< mA < 15 GeV



Merged/ One photon lost by standard reconstruction



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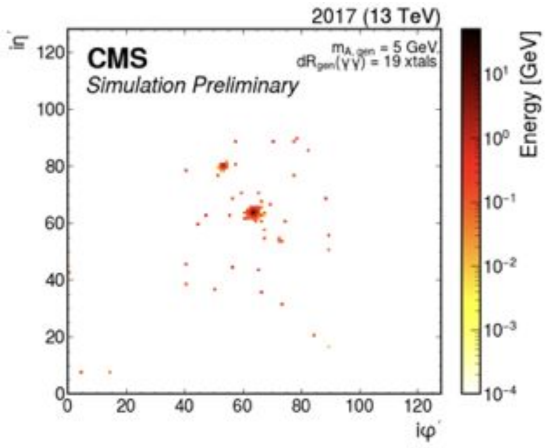
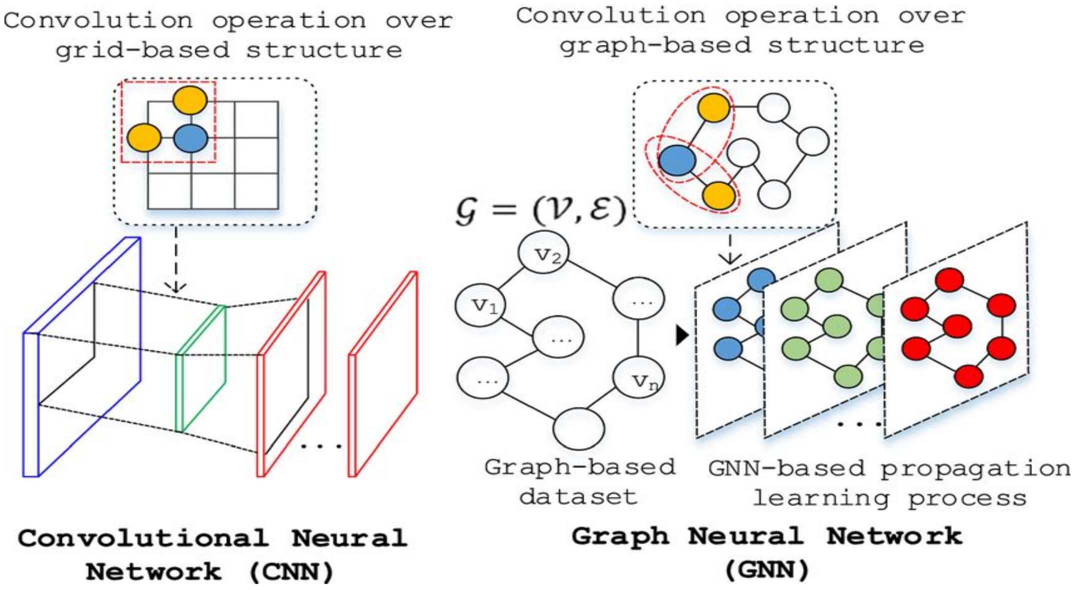
Moving to Graphs

Things are more complicated in the higher masses

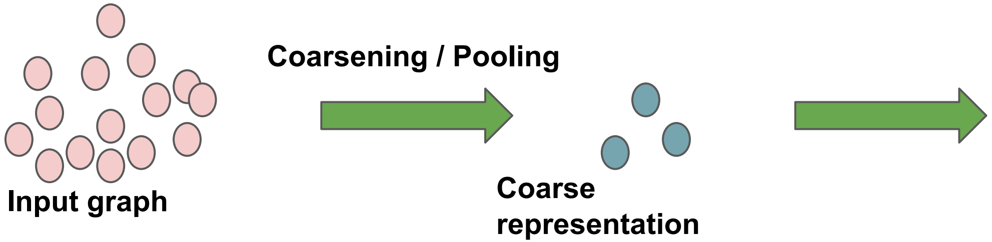
- Both merged and semi merged
- Patterns over large detector area -> lot of sparsity
- Move from CNN to Graph Neural Networks

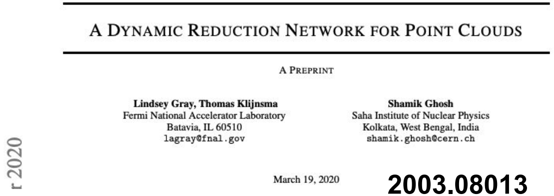




Novel Graph Neural Networks

Particle property estimations using graph pooling (Dynamic Reduction Network)




A DYNAMIC REDUCTION NETWORK FOR POINT CLOUDS

A PREPRINT

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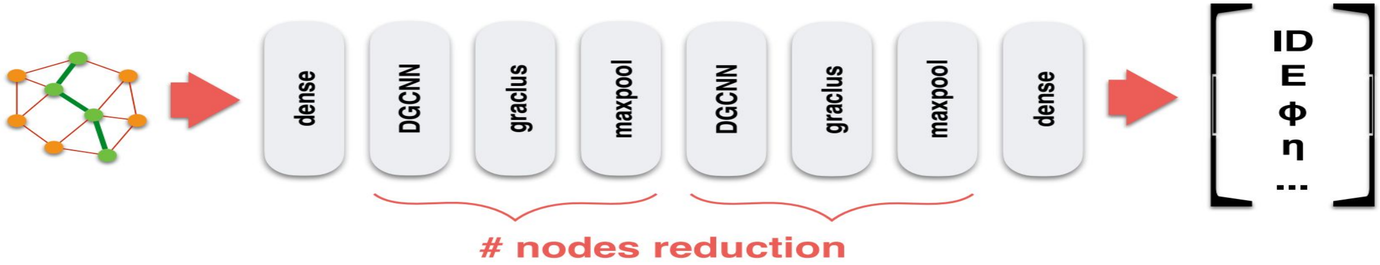
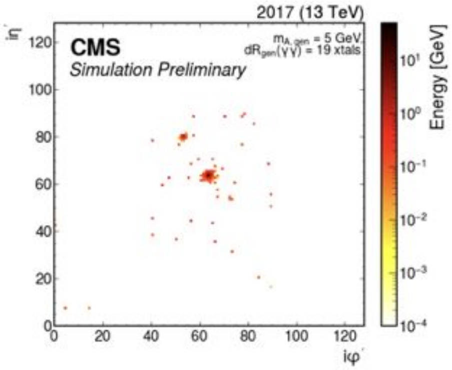
Graph Properties

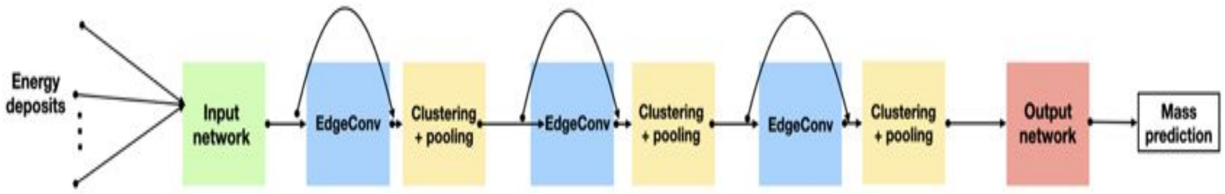


- Take in an unordered set and reduce to a vector of physically relevant quantities
- EdgeConv fused with clustering, learns best organization of input data to regress to desired properties

Training the reconstruction model

Perform Mass reconstruction from raw detector hits using DRN

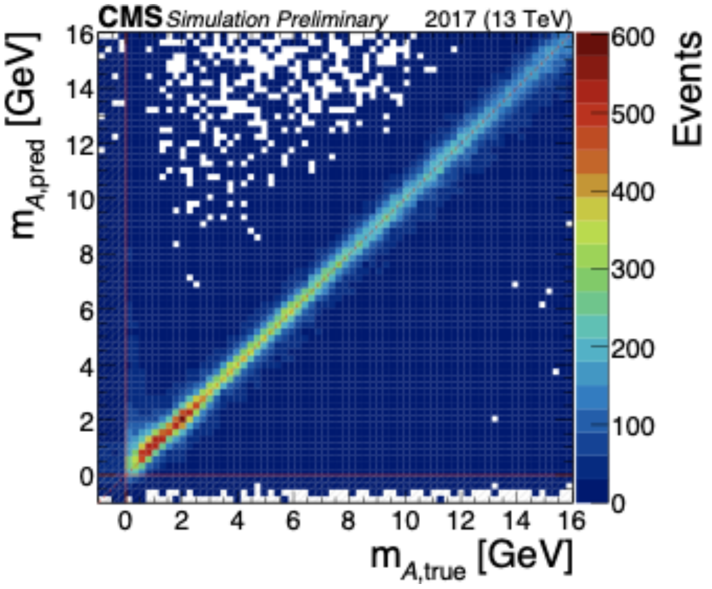




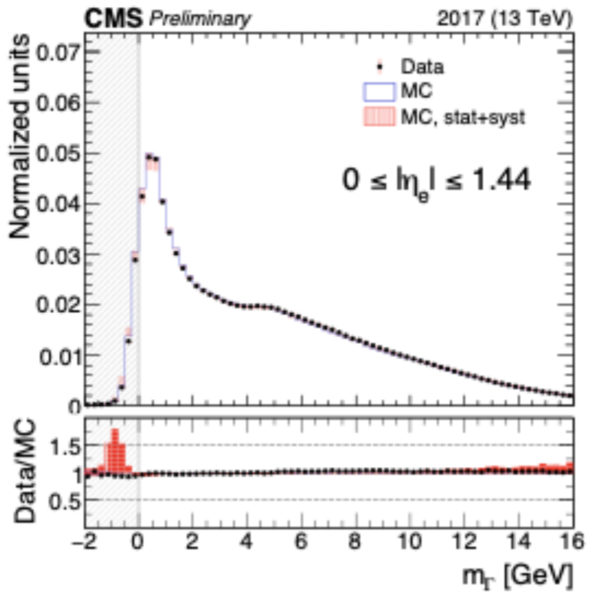
GNN is trained to predict mass of the system from raw hits (**large dataset sizes!**)
Performs at the same time (**End-to-End**)

- Clustering of low energy photon
- Estimation of energy-momentum
- Energy corrections

Reconstruction Validation



The model nicely reconstructs masses over a wide range

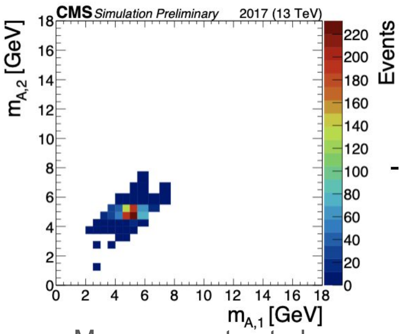


Model response in simulation compared to Z to electron decays in data

Model is also trained with single photons with mass mapped to [-3,0]

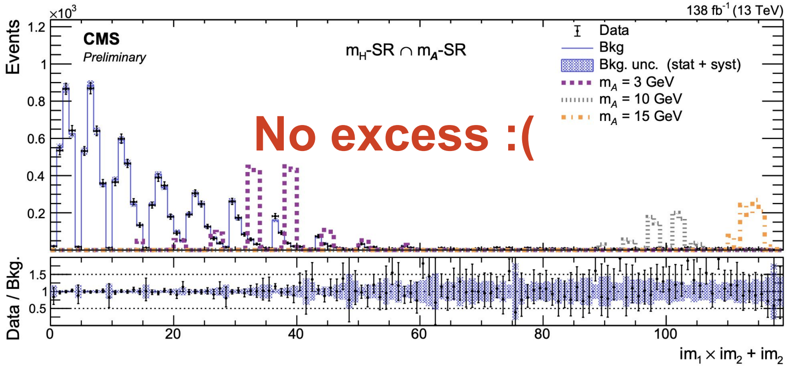
Final Result!

Mass reconstructed from standard photons

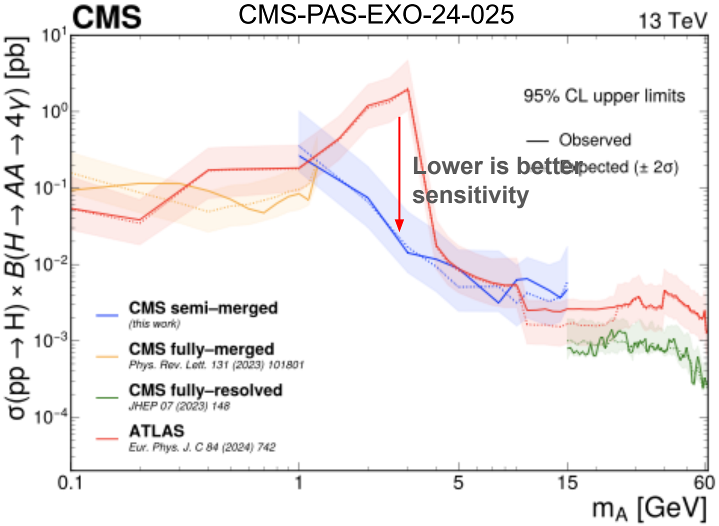


Mass reconstructed from model

unrolled



No excess above SM expectation

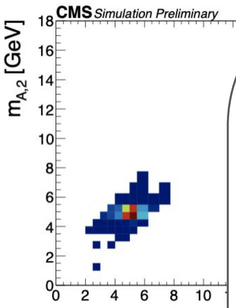


This analysis sets strongest constraints in this mass range: upto 100x better than ATLAS!

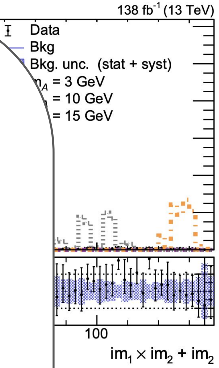
First analysis using GNN end-to-end reconstruction

Final Result!

Mass reconstructed from
standard photons



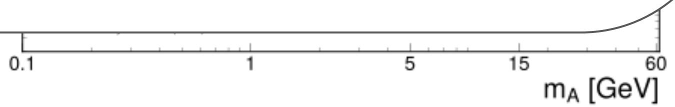
Mass recons
from model



Fully ML driven strategies sheds light on blind spots

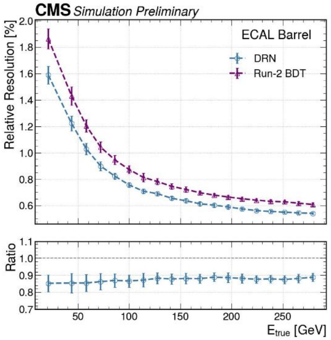
This analy
constrain
upto 100x

First analysi
end-to-end reconstruction

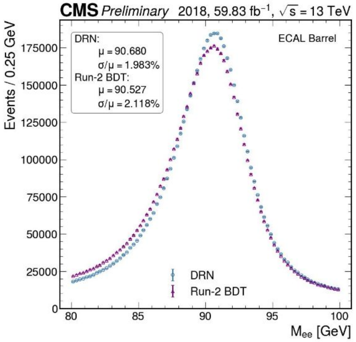


Further Applications

CMS ECAL Calibration

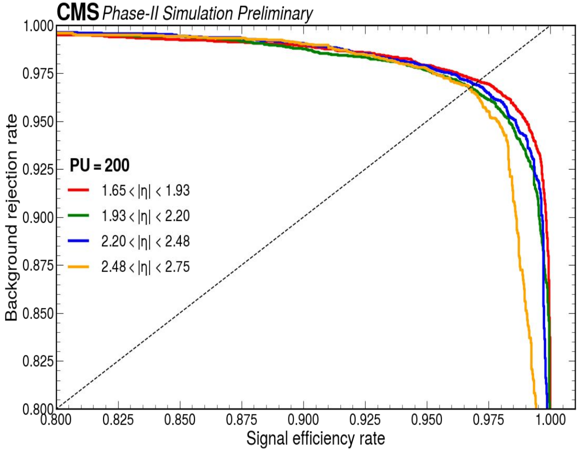


GNN based regression improves energy resolution



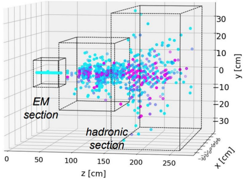
GNN based regression improves mass resolution

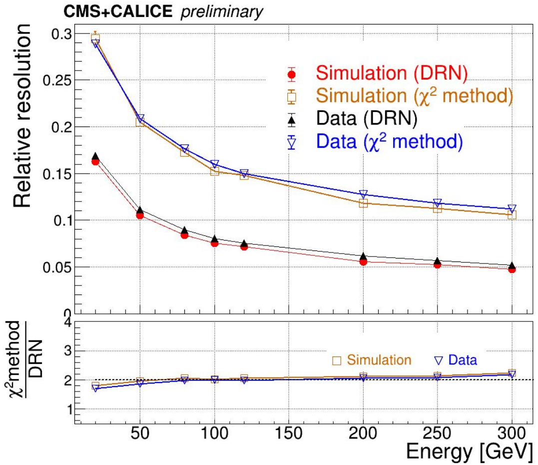
HGCAL PID



GNN based photon tagger performs well in 200 PU

HGCAL Hadron Reconstruction





GNN based pion reconstruction improves energy resolution

Summary

- ➔ Detectors preserve signatures of hard to find signs of new physics
  - ◆ Optimised ML strategies essential to reconstruct them

- ➔ Novel GNN developed to recognise patterns in granular detectors

- ➔ Developed method leads to significant improvements in BSM physics reach
  Read more:
  https://cms.cern/news/one-photon-short-recovering-lost-photons-using-ai-hunt-exotic-higgs-boson-decays

Thanks for listening!

BACKUP