Jorge Berenguer Antequera
University of Cordoba

1st DRDCalo - Spain Meeting
IFIC – Valencia
13th January 2026

What do we do at UCO?

Young University: ~50 years
Research
~200 research groups
Biomedical Sciences   Agri-food Sciences

Collaborating since 2023

Modeling and Simulation of Physical Systems

Knowledge Discovery and Intelligent Systems

Jorge Berenguer Antequera

→ 2020: R&D in highly segmented calorimetry
→ 2023 Joining CALICE

José Luis Ávila Jiménez

→ Graph Neural Networks and particle physics

→ UCO Project: Computational development for experiments of a Higgs factory based on an e+e- collider - 2023 IP.- Jorge Berenguer Antequera (UCO)

→ Ministry Project: Advancing in HEP: Collider Experiments and Technological R&D. PID2024-158190NB-C22 IP.- Mary-Cruz Fouz Iglesias (CIEMAT)

People

Jorge Berenguer Antequera

Participation in CALICE from 2009-2013: PhD thesis in the SDHCAL group at CIEMAT

Postdoct in Turin (2018-2020)
COMPASS: MPGD prototype for future fixed-target experiments at the SPS and EIC
CMS: ECAL VFE for HL-LHC period (pandemic through)

AMBER Experiment (2023)
HARDWARE: Collaboration with Turin for development of MM for tracking system
ANALYSIS "Antimatter production cross-section for indirect search DM" Group

José Luis Ávila Jiménez

IA expert: embedded systems, biomedicine, industry, and military.
Competitive research and technology transfer projects
International colaborations in Germany

GNN for Particle Physics

WP1: Highly granular calorimeters

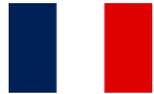## Task 1.3: Hadronic section with gaseous readout

Subtask 1.3.1: T-SDHCAL	Resistive Plate Chambers/ Steel	6.2	e^+e^- collider central detector	Prototype for finalising R&D for LC, Specification for CC and of timing for PFA needed

SDHCAL Technological prototype

Semidigital Hadronic Calorimetry – GRPC based

Timing measurement

→ Separation of nearby hadronic showers
→ Improve PFA application

- **Simulation studies to implement the time information**
- Study and development of a cooling system and new cassettes
- New readout electronics ("faster" ~100 ps)
- Data acquisition (DAQ) system
- Construction of several MGRPC prototypes
- **Beam testing of MGRPC prototypes**
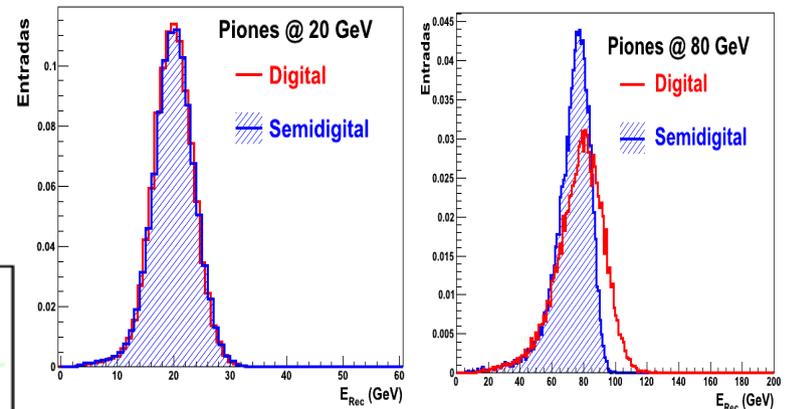
Graph Neural Network

Signal classification

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SDHCAL- Quickly Description
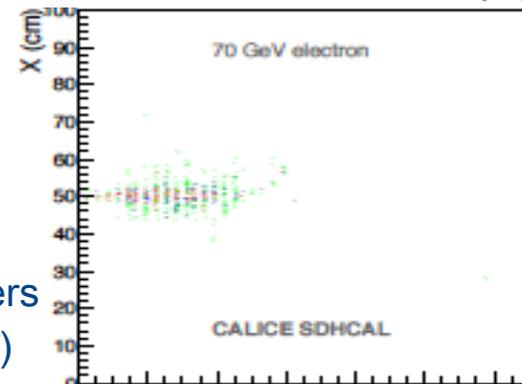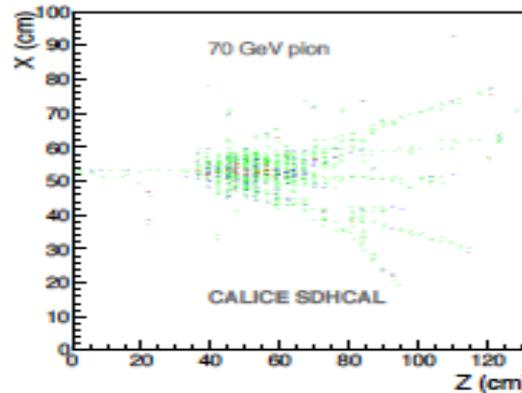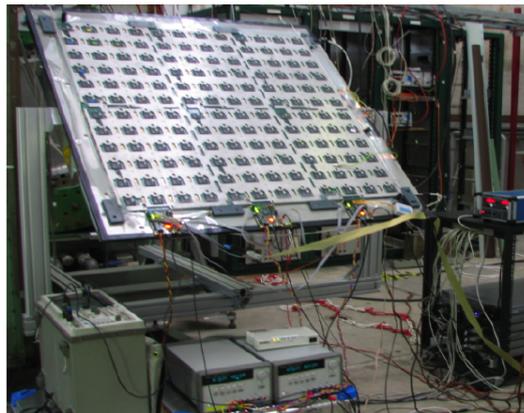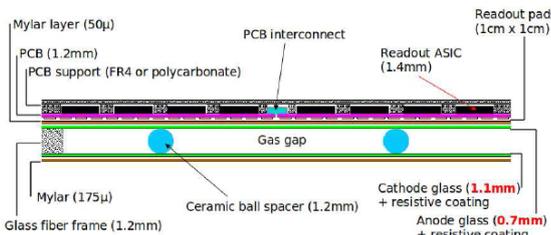

SDHCAL Prototype ($6\lambda_I$)

Dimensions: ~1m³
48 GRPCs (~1m² each)
96x96 pads of 1cm² each
~500 kchannels
3 thresholds
Semidigital readout
Know how many and which hits overcome each threshold

Tests on CERN's PS and SPS
2012, 2015, 2017, 2018, 2020 2022
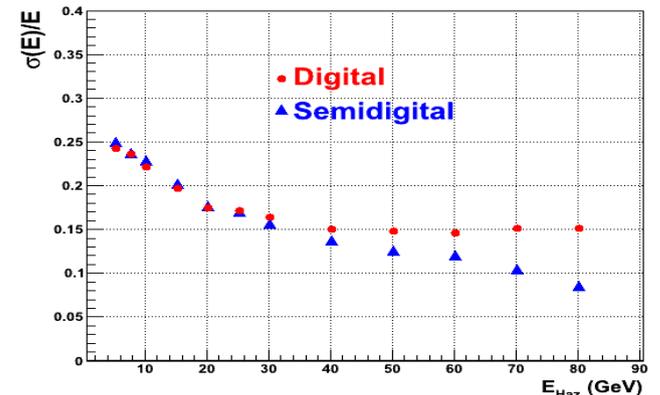
Resolution improvement ~7%

High granularity: great detail of the showers
Easing PID (digital and semi-digital mode)
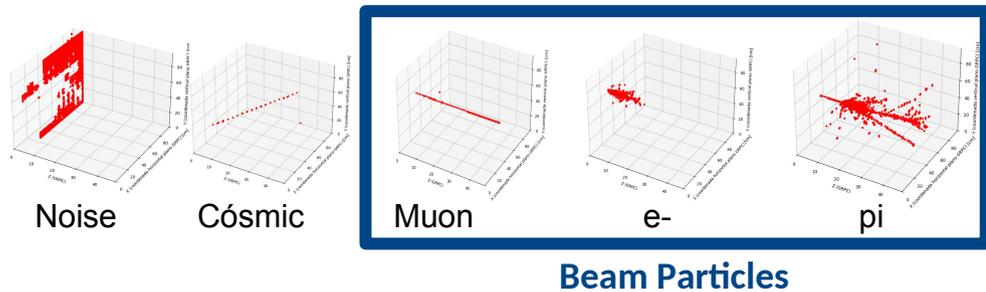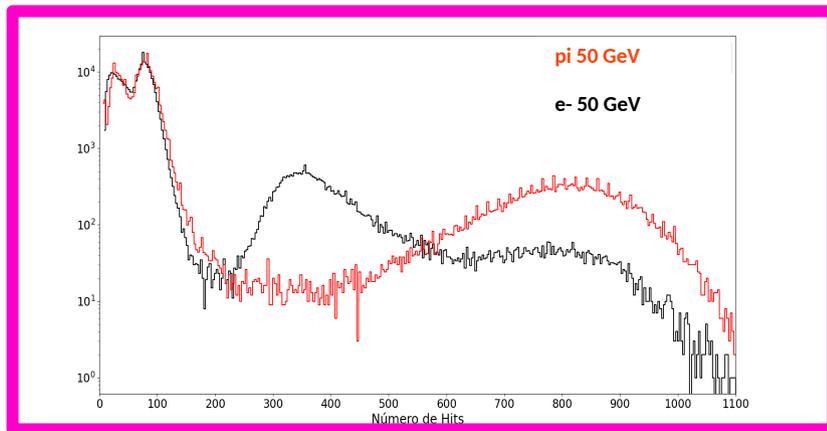
Exploring the SDHCAL data

Highly granular design of the SDHCAL prototype:

→ Transforming real calorimeter events into graphs
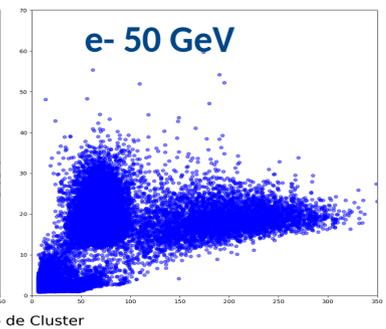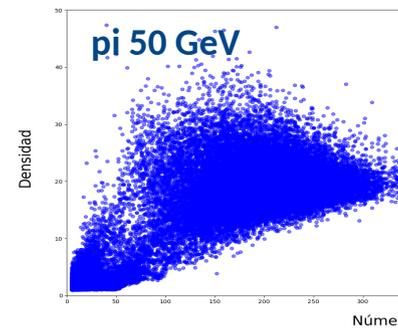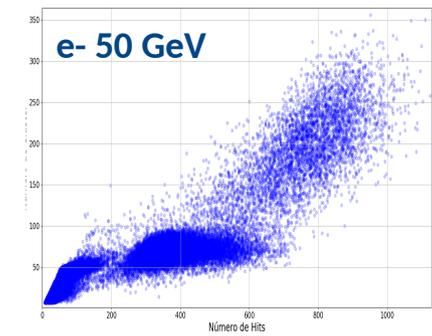→ Using GNNs to identify signals

2012 test campaigns:

Pion and electron beams at 50 GeV

Beam Particles

Bachelor Thesis: Signal clustering in resistive glass plane chambers (GRPC) of a prototype hadronic calorimeter for future e+e- collider experiments
Francisco José Ruiz López
Supervisor: Jorge Berenguer Antequera
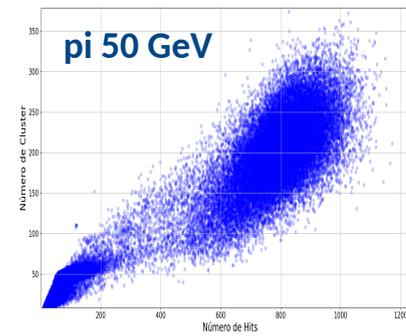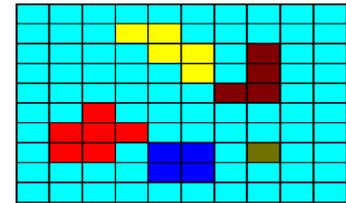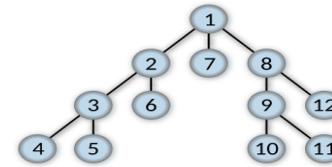
Clustering

Reduction: grouping hits into clusters to decrease computational complexity.

→ Spatial proximity (Nearest neighbors)
→ Depth-First Search (DFS)

Density = Nhit/Nplanes

Graph Neural Network in HEP

Particle detectors generate relational and non-Euclidean data:
- Non-planar geometry (generally)
- Point clouds, graphs, and surfaces
- Topological correlation between signals

→ **GNN:** Deep Learning models designed for graph-structured data

→ **Representation:** nodes: hits or clusters edges: physical relationships.
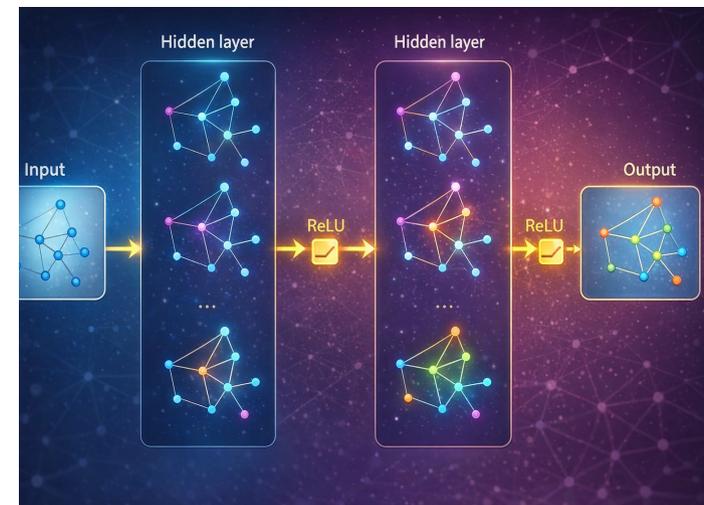
→ **Applications:** tracking, event classification, PID

→ **Performance:**
Accuracy: ratio of events correctly classified over the total number of events
Recall: ratio of true elements identified by the model
F-Score combining accuracy and recall

$$F_1 = 2 \cdot \frac{accuracy \cdot recall}{accuracy + recall}$$

Exploring GNN performance with SDHCAL data

– First approach to computational challenges:

→ Complexity in graph generation
→ Model execution
→ Computationally expensive but manageable

**- Real data used pi (5 GeV) and e⁻ (10 GeV) taking with the SDHCAL**

→ Preprocessing: Python pipeline with batching and multiprocessing
Up to 75% improvement in computational time

→ **Representation: each event is modeled as a multilayer graph of hits connected by its geometry**

→ **Model: DGCNN(Deep Graph Convolutional Neural Network)
   implemented with StellarGraph + TensorFlow/Keras for graph classification**

→ **Results: AUC ≈ 0.875, with precision and recall > 0.75 for electron/pion signal identification**
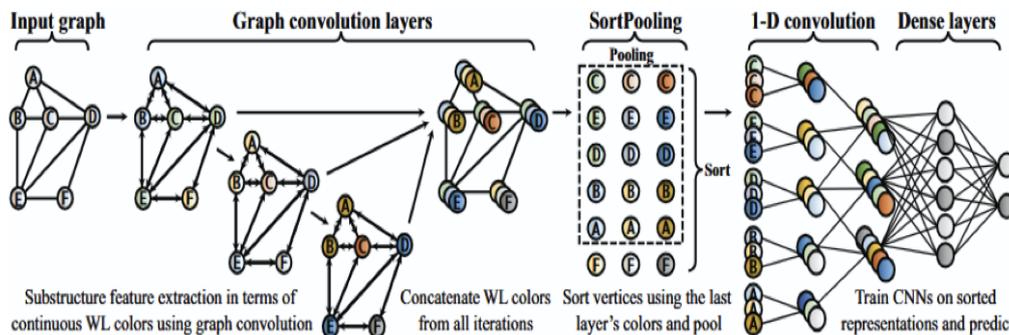
Bachelor Thesis Modeling particle physics detections using graph neural networks.
Esteban Morales Casasola
Director: José Luis Ávila Jiménez
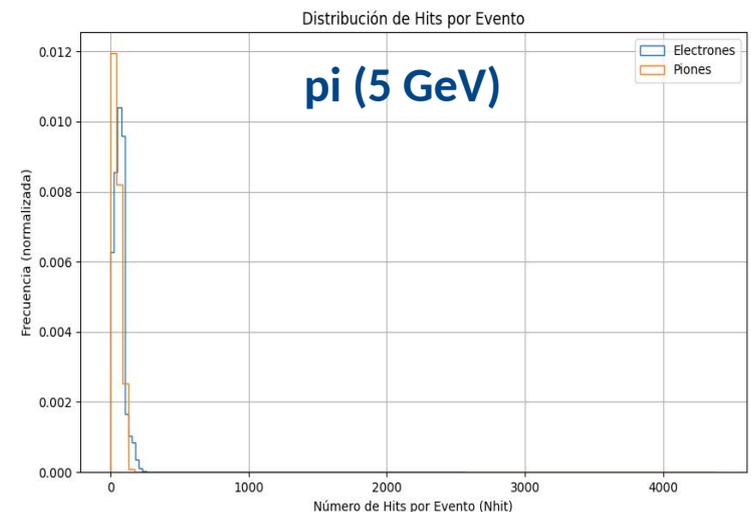
Exploring GNN performance with SDHCAL data

- **Goal:** Separation of muons from "no-muon" signals (pions, electrons, cosmics, noise)

- **2012 test campaigns**
→ Pion beams with electron contamination
→ Electron beams with pion contamination
→ Energies: 10 GeV, 30 GeV y 60 GeV

- **Clustering**

- **Representation:** modeling each event as a graph between consecutive GRPCs of the SDHCAL

- **Nodes:** Cluster size and distance from the centroid to the beam direction
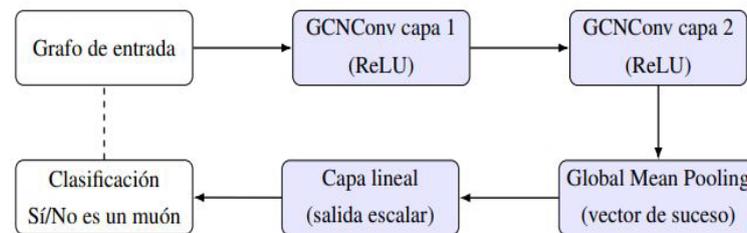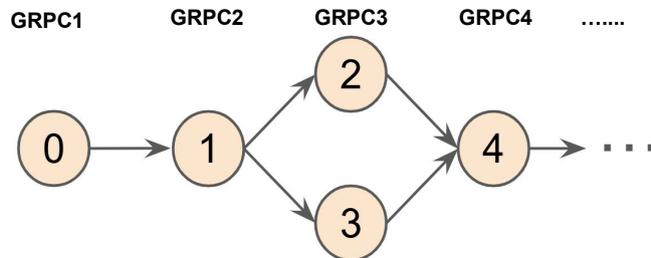
Master Thesis: Exploring ML methods for signal identification in the SDHCAL
Francisco José Muñoz Peñas
Director: Jorge Berenguer Antequera
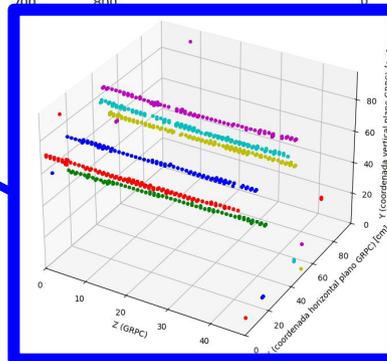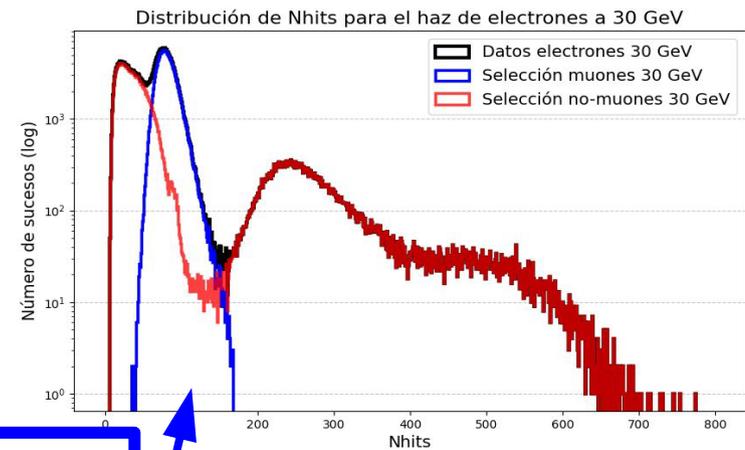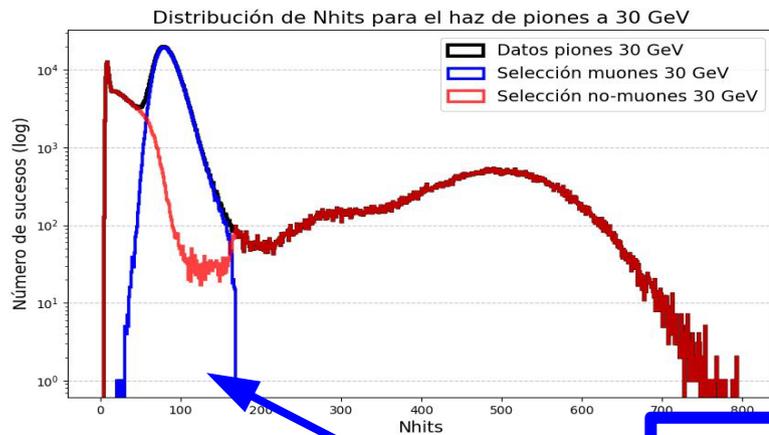
Exploring GNN performance with SDHCAL data

– Training sample: pion beam at 30 GeV
→ Total events: 9.6×10^5

- Topological Criteria
→ 60% muons (5.7×10^5 events)
→ 40% "no-muons" (3.9×10^5 eventss)
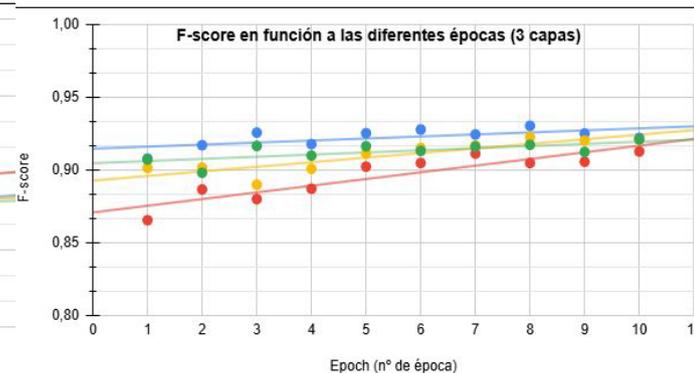→ ratio ~ 1.5
→ 70% of the total events
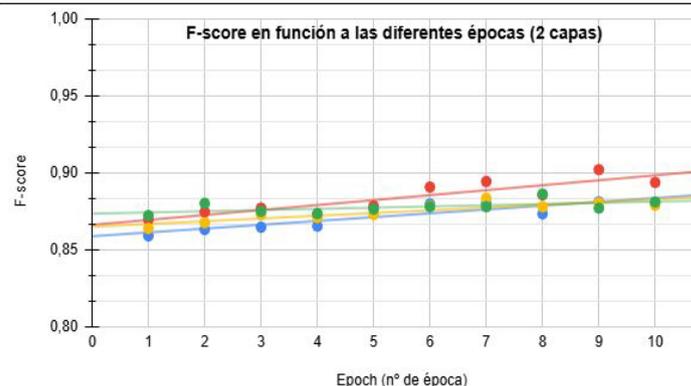→ Remaining 30% as self-assessment
→ Keeping ratio ~ 1.5

Topological Criteria

Criterio	Descripción
Densidad	Densidad menor que 3.5.
Suceso del haz	Señal en las primeras GRPC.
Señal en planos finales	Alguna GRPC de las cinco últimas activa.
Suceso completo	< 3 GRPC consecutivas sin *hits*.
Suceso único	Una sola traza significativa en la entrada.

Distribución de Nhits para el haz de piones a 30 GeV

Distribución de Nhits para el haz de electrones a 30 GeV
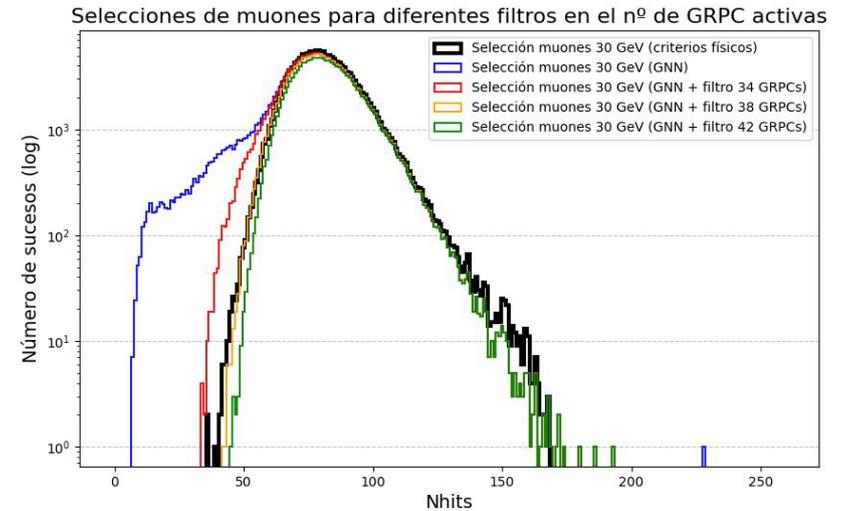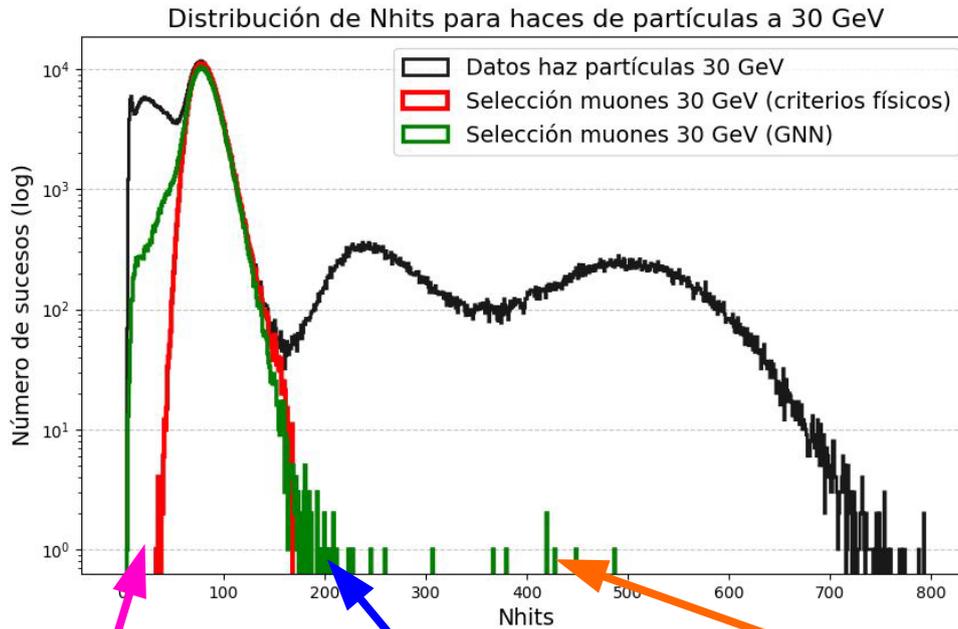
Exploring GNN performance with SDHCAL data

**− Different configurations to optimize the performance − 10 epoch**

- Number of neurons per layer 16, 32, 64, and 128: learning capacity and computational complexity
- Network depth 2 and 3 layers: improves its classification task performance or introduces overfitting issues
- Number of neurons and depth of the network are key factors

Exploring GNN performance with SDHCAL data

Distribución de Nhits para haces de partículas a 30 GeV

Legend:
- Datos haz partículas 30 GeV
- Selección muones 30 GeV (criterios físicos)
- Selección muones 30 GeV (GNN)

Número de sucesos (log) vs Nhits

Selecciones de muones para diferentes filtros en el nº de GRPC activas

Legend:
- Selección muones 30 GeV (criterios físicos)
- Selección muones 30 GeV (GNN)
- Selección muones 30 GeV (GNN + filtro 34 GRPCs)
- Selección muones 30 GeV (GNN + filtro 38 GRPCs)
- Selección muones 30 GeV (GNN + filtro 42 GRPCs)

Simple filters to exclude extreme cases.
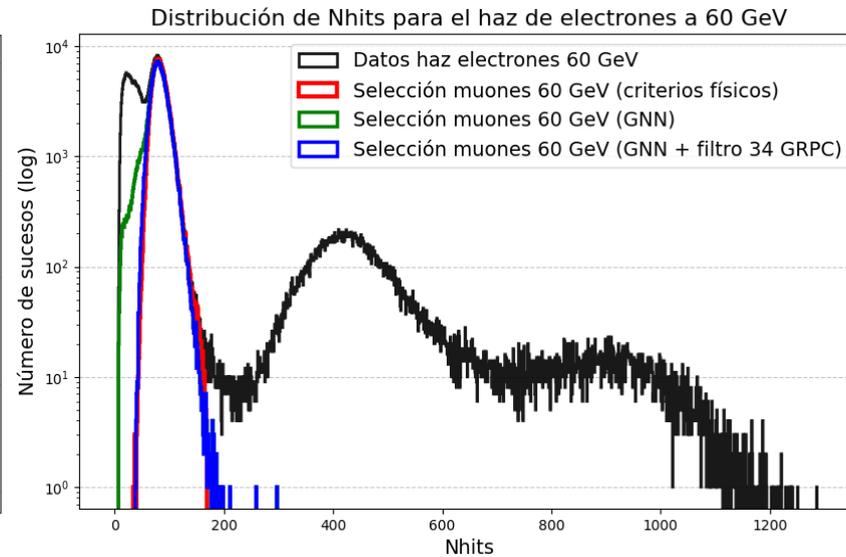Requiring a minimum number of GRPCs with signal to help classify muon events
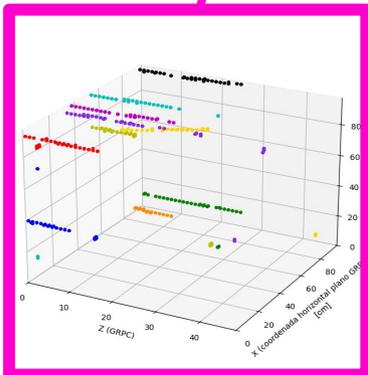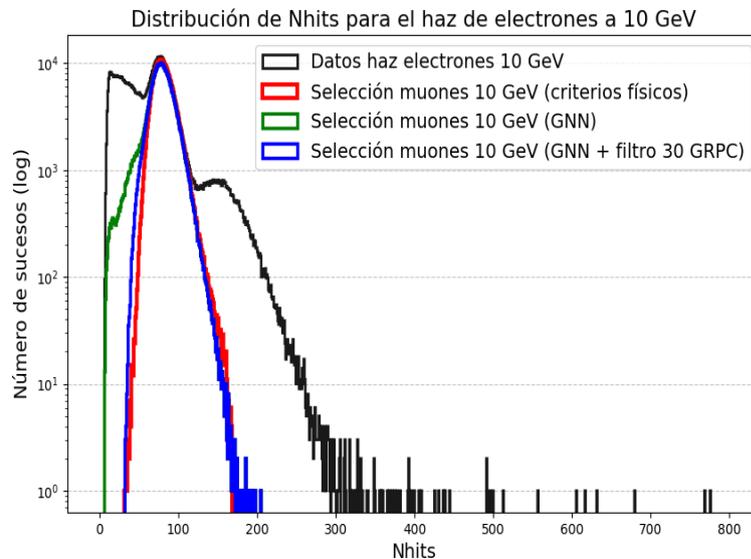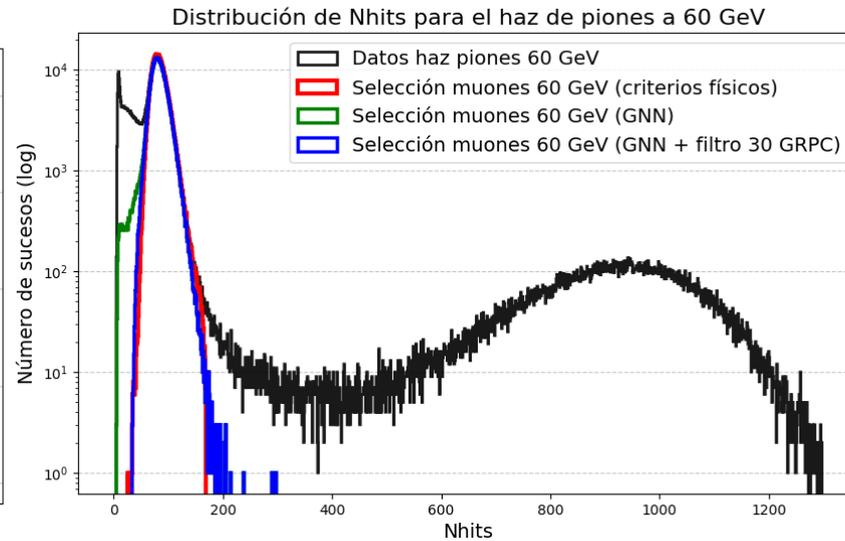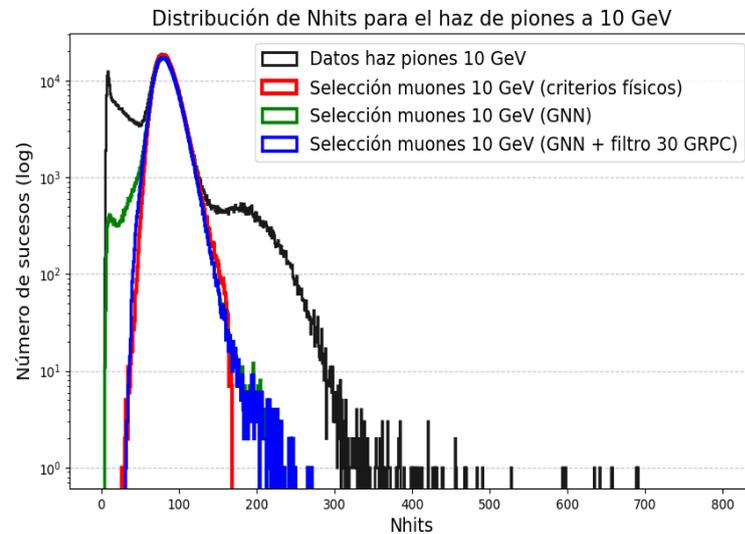
Incomplete events
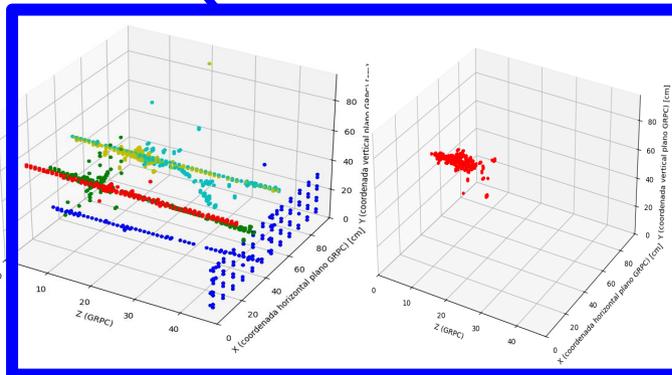
Noise, muons stronger or pions weaker than usual e- events
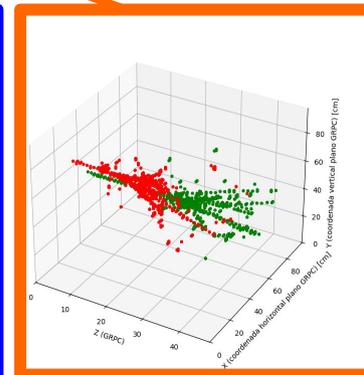
Hybrid approach: combine model decisions with simple filters to suppress extreme events while preserving generalization.

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Other energy values

Summary

→ **UCO joined DRD6:**
 - Modeling and Simulation of Physical Systems Group (Physics)
 - KDISLab Group (Computing)

→ **WP1.- Highly granular calorimeter.**
 Task 1.3.- Hadronic section with gaseous readout
 Task 1.3.1.- TSDHCAL Simulation studies incorporating time-domain informatin and paricipation in future test beams

→ **Application of ML techniques to highly segmented calorimetry data**

→ **Initial study of GNNs computational requirements**
 expensive but manageable

→ **Use of GNNs for signal separation**
 e^- vs π at 5 GeV → separating cascades at low energies is a significant challenge
 muons vs "non-muons" → promising results over a wide energy rangenergía

→ **2 BSc theses and 1 MSc thesis**

Summary

→ **Projects**
- **UCO Project:** Computational development for experiments of a Higgs factory based on an e+e- collider - 2023
  IP- Jorge Berenguer Antequera (UCO)
- **Ministry Project:** Advancing in HEP: Collider Experiments and Technological R&D. PID2024-158190NB-C22
  IP.- Mary-Cruz Fouz Iglesias (CIEMAT)

→ **Next Steps**
- Use GNNs for cascade separation (π / e^-)
- Start simulation studies to implement the time information
- Expected results:
  1 BSc Theses and 1 MSc Thesis 2025/2026
  PhD Theses on going: Olmo Arquero Peinazo (FPU Grant)
  Supervisor: Mary-Cruz Fouz Iglesias (CIEMAT)
  Co-Supervisor: Jorge Berenguer Antequera (UCO)

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Thank you for your atention