Reconstruction and Particle Identification with CYGNO Experiment Using Machine Learning

INITIUM: **I**nnovative **N**egative **I**on **TI**me projection chamber for **U**nderground dark **M**atter searches

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F. Amaro, R. Antonietti, E. Baracchini, L. Benussi, D. S. Cardoso, C. M. B. Monteiro, S. Bianco, C. Capoccia, M. Caponero, G. Cavoto, R. J. C. Roque, I. A. Costa, E. Di Marco, G. D'Imperio, G. Dho, F. Di Giambattista, R. R. M. Gregorio, F. Iacoangeli, H. P. L. Júnior, G. S. P. Lopes, G. Maccarrone, R. D. P. Mano, D. J. G. Marques, G. Mazzitelli, A.G. McLean, A. Messina, R. A. Nobrega, I. Pains, E. Paoletti, L. Passamonti, S. Pelosi, F. Petrucci, S. Piacentini, D. Piccolo, D. Pierluigi, D. Pinci, F. Renga, **A. Prajapati***, F. Rosatelli, A. Russo, G. Saviano, N. Spooner, R. Tesauro, S. Tomassini, S. Torelli, J. M. F. dos Santos
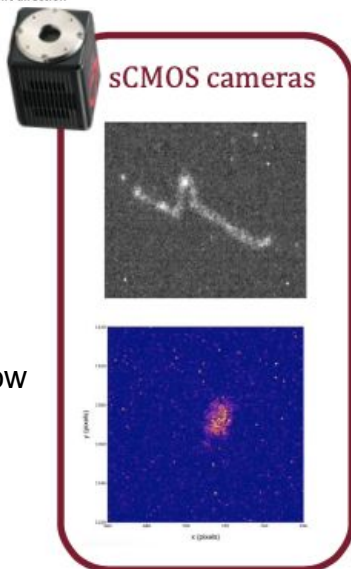
CYGNO Approach
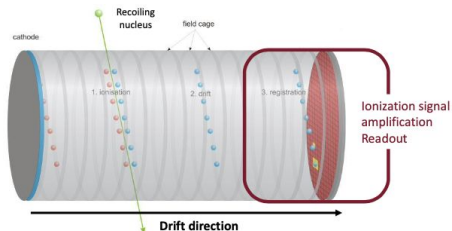
Triple GEM
Charge amplification & light production

Camera & PMT
Light produced by the de-excitation of the gas molecules during electron multiplication is optically read by sCMOS and PMT
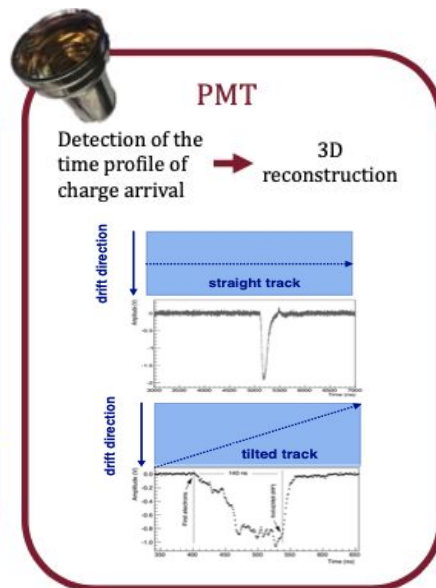
sCMOS cameras

We can measure energy and X-Y coordinate using sCMOS's high granularity and low readout noise.

Gas Electron Multipliers
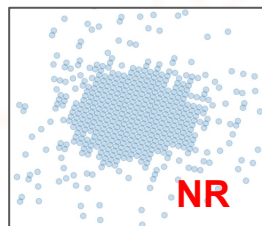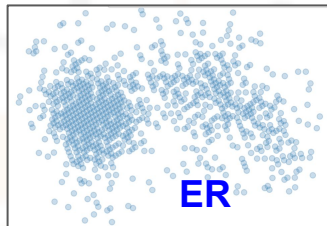
Ionization clusters

Ionizing track

Electrons

Photons   Photons
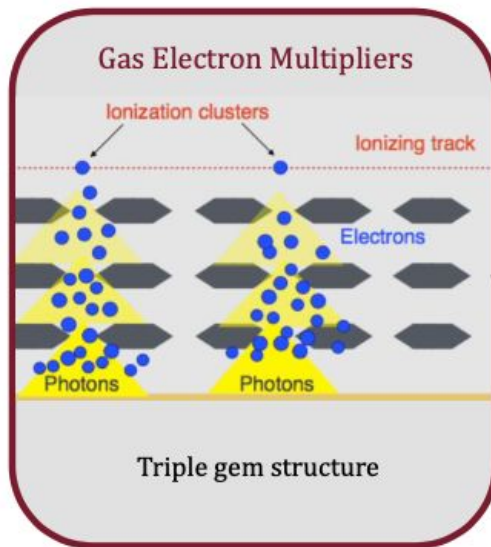
Triple gem structure

PMT

Detection of the time profile of charge arrival → 3D reconstruction

drift direction — straight track

drift direction — tilted track

PMT measures the integrated energy and time of arrival (dZ) of charge carriers with high sampling rates.
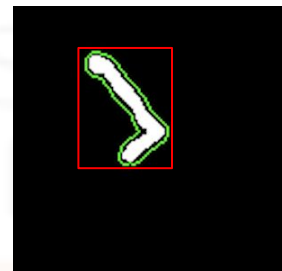
X-Y + Energy

Z + Energy

What do we want from ML?

Starting with the Reconstructed Variables

ER

NR

❖ Models: DNN, RFC,GBC

❖ Classification (Classify into ER and NR)

Starting with the Images

❖ Model: Mask-RCNN
❖ Classification
❖ Semantic Segmentation
❖ Object Detection
❖ Instance segmentation (Finds the cluster around the tracks for each object (track) detected.)

Preparing the dataset for training

ER & NR simulation	Digitization	Reconstruction	Discriminating Variables

Interaction of the particles with gas is simulated using either GEANT4 (for ER) or SRIM (for NR).

These tracks are then projected to a 2D plane and detector effects are added like diffusion, camera noise, effective ionisation, gain fluctuation and geometrical acceptance etc.

Digitized tracks are reconstructed for the tracks using a iterative density based scanning algorithm called iDBSCAN.

Reconstructed tracks are used to build several discriminating variables like skeleton, Length along principal axis, Charge uniformity, Maximum density, Slimness, Integral etc.

E Baracchini et. al., "Identification of low energy nuclear recoils in a gas TPC with optical readout", arXiv:2007.12508v1
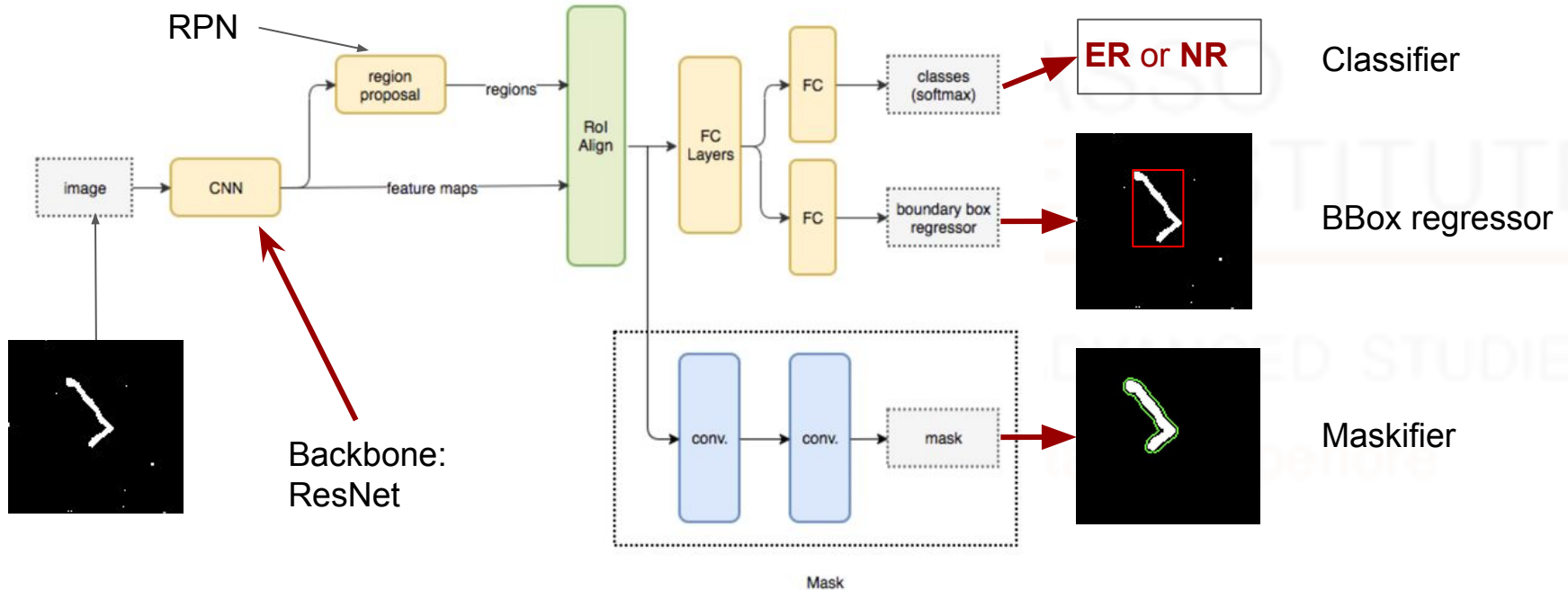
Background Rejection
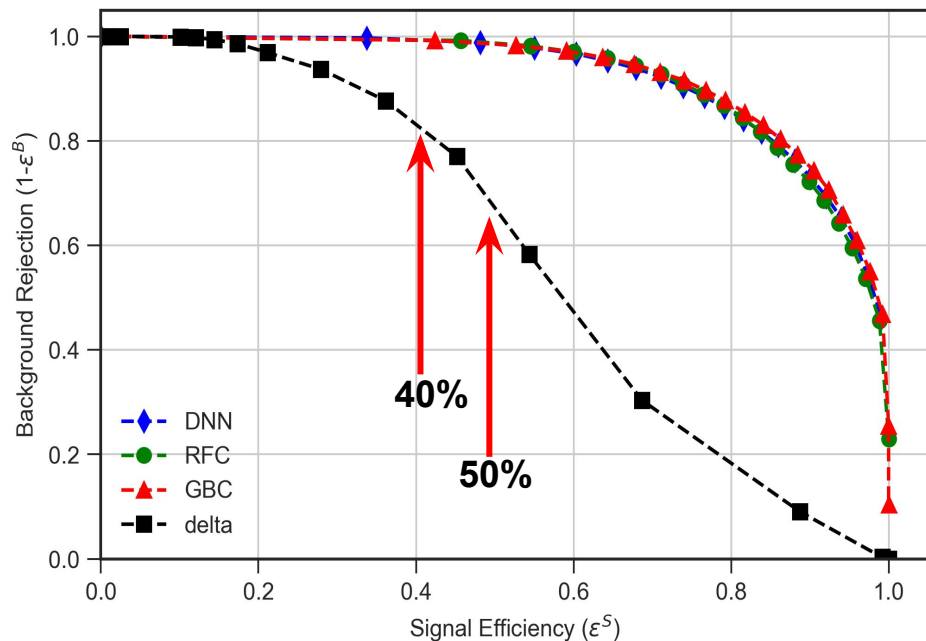
Models	Signal Eff. $[\epsilon^S]\%$	Bkg. Rej. $[1-\epsilon^B]\%$
RFC	40	99.54
	50	98.78
GBC	40	99.38
	50	98.55
DNN	40	99.43
	50	98.50
Cut-based	40	83.13
	50	67.20

working point	Signal efficiency			Background efficiency			Bkg. Rej
	ε_S^{presel}	ε_S^{δ}	ε_S^{total}	ε_B^{presel}	ε_B^{δ}	ε_B^{total}	
WP_{50}	0.98	0.51	0.50	0.70	0.050	0.035	96.5 %
WP_{40}	0.98	0.41	0.40	0.70	0.012	0.008	99.2 %

Results are for simulated data in range 2-36 keV for NR and ER. While results published in paper mentioned below is for NR energy range of 1-100 keV discriminated against 6 keV ER.
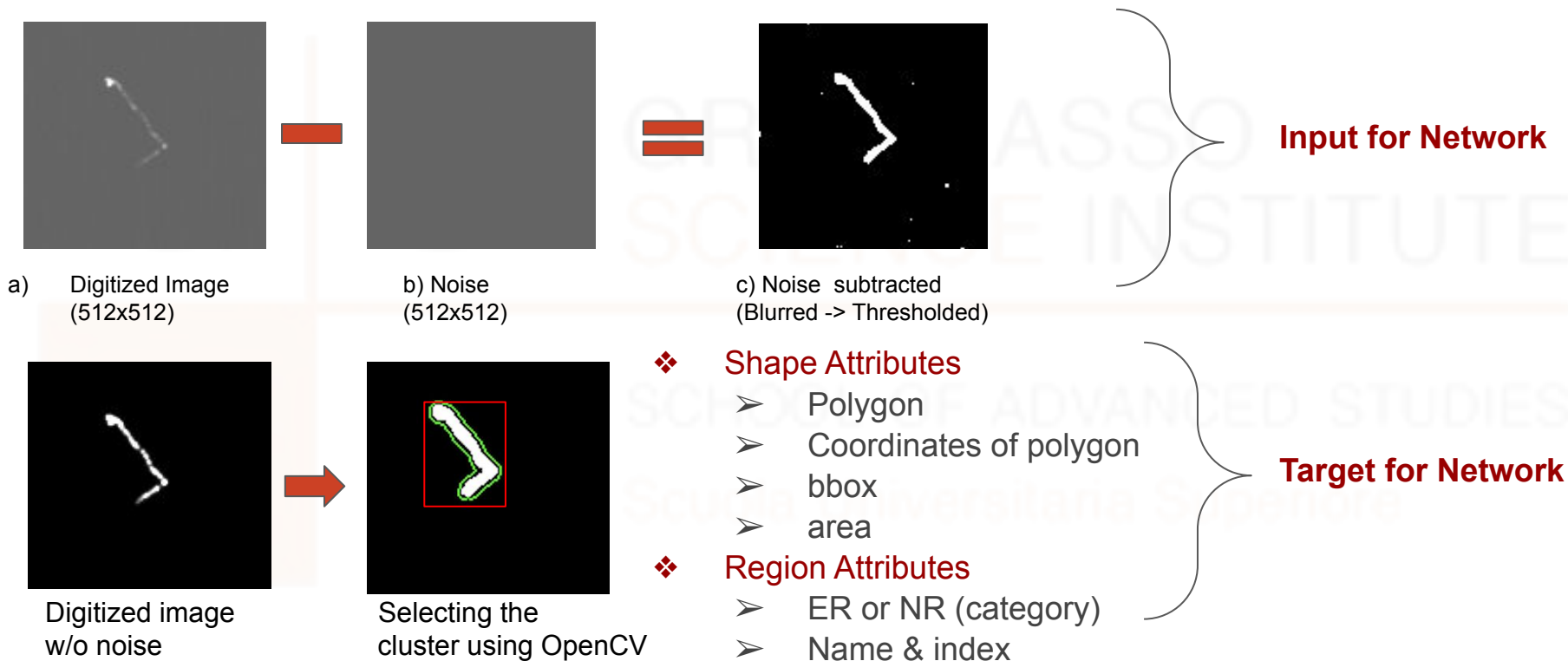
E Baracchini et. al., "Identification of low energy nuclear recoils in a gas TPC with optical readout", arXiv:2007.12508v1
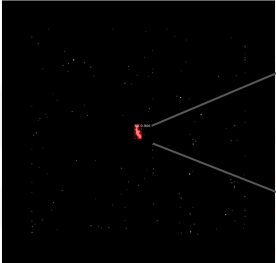
Architecture of Mask-RCNN

RPN

region proposal → regions

CNN

image

Backbone: ResNet

feature maps

RoI Align

FC Layers

FC → classes (softmax) → **ER** or **NR**   Classifier

FC → boundary box regressor → BBox regressor

conv. → conv. → mask → Maskifier

Mask

Mask-RCNN Paper: https://doi.org/10.48550/arXiv.1703.06870

Data for Mask-RCNN

a) Digitized Image (512x512)

b) Noise (512x512)

c) Noise subtracted (Blurred -> Thresholded)

Input for Network

Digitized image w/o noise

Selecting the cluster using OpenCV

❖ **Shape Attributes**
  ➢ Polygon
  ➢ Coordinates of polygon
  ➢ bbox
  ➢ area
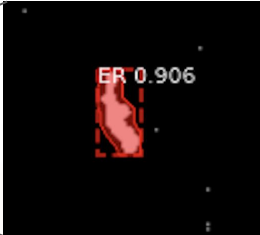❖ **Region Attributes**
  ➢ ER or NR (category)
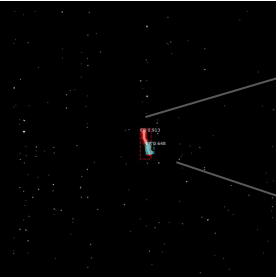 ➢ Name & index

Target for Network

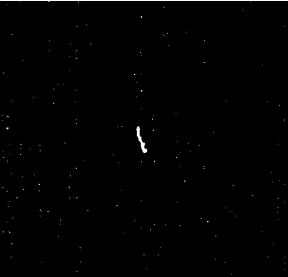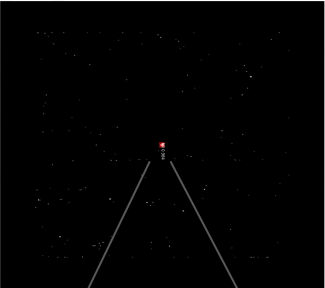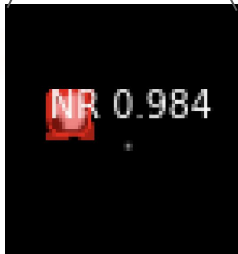# First results from Mask-RCNN

Input

Prediction

Zoomed Track
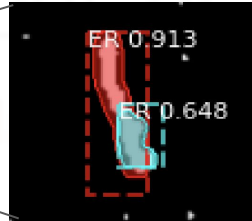
Input

Prediction

Model was trained just with 4 input images and for 20 epochs.