Reconstruction and Particle Identification with *CYGNO* Experiment

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On Behalf of CYGNO Collaboration

Date: 03/12/2021

Daejeon, South Korea

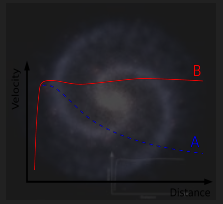
Outline

1) Dark Matter And Background
2) CYGNO/INITIUM detector
3) Monte-Carlo Simulations of track
4) Development of Discriminating variables
5) Nuclear recoil and Electron recoil discrimination using Deep Learning Models

Dark Matter Introduction

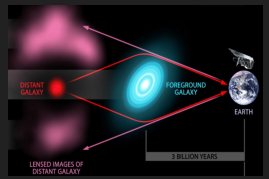
Dark Matter and Background

1. Galaxy's rotation curve

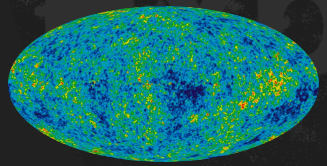


2. Motion of galaxies

These observations shows that there is more mass than measured.



3. Gravitational Lensing

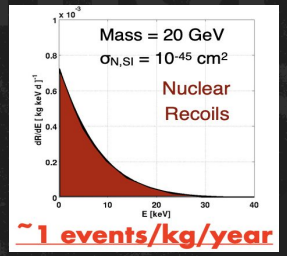


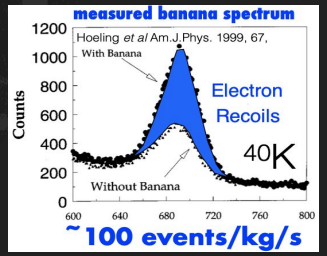
4. CMB measurements

WIMPs Detection Challenge

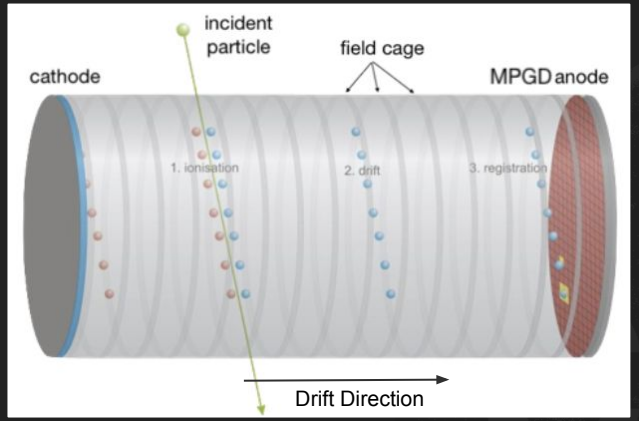
Direct Dark Matter detection measuring the recoiling nuclei in the elastic scattering of Dark Matter Particles

- Low event rate (0.1 event/kg/year)
- Background much higher than event rate
  - Neutrinos from sun and atmosphere
  - Cosmic rays and cosmogenic activation of detector material
  - Natural radioactivity



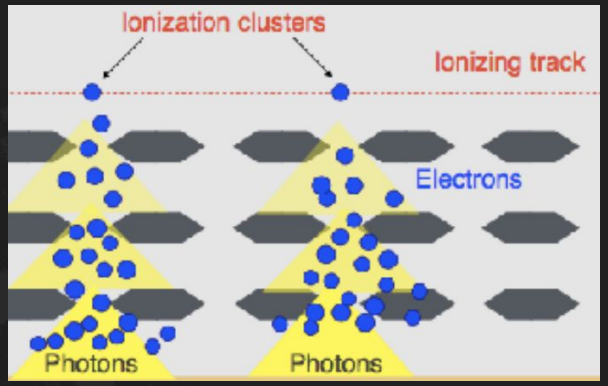


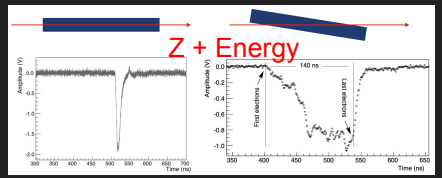
CYGNO/INITIUM Detector



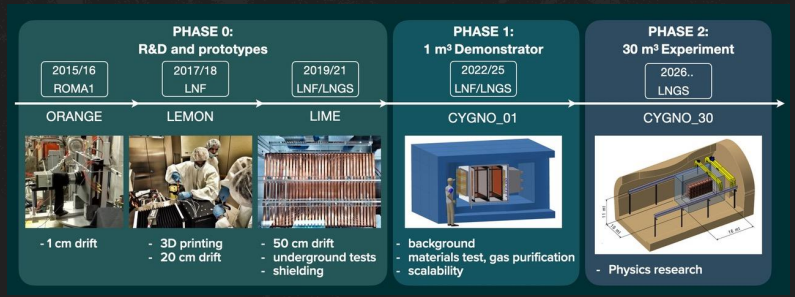
Amplification Region + Readout (sCMOS + PMT)

- Gaseous TPCs are inherently a 3D detector
- Tracking
- Head tail asymmetry
- dE/dX recognition
- Gas Flexibility





- CYGNO uses He:CF_4 gas mixture
- 3 GEM stack is used for charge amplification
- INITIUM is a part of CYGNO project which focuses on the development of TPCs with negative ion drift using SF_6 gas



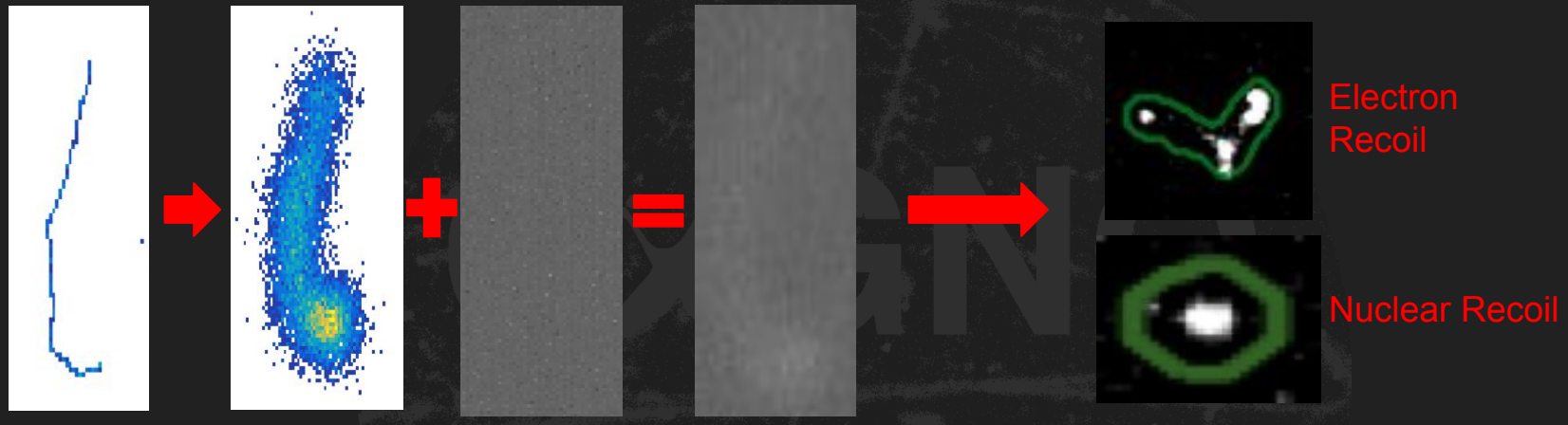
European Research Council
Established by the European Commission

INITIUM

https://iopscience.iop.org/article/10.1088/1742-6596/1468/1/012039
https://iopscience.iop.org/article/10.1088/1748-0221/15/07/C07036

Monte-Carlo Simulations

Monte-Carlo Simulations



(a) Track w/o diffusion

(b) Track after diffusion

(c) Camera Noise

(d) Digitised track

- 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 images are reconstructed with a density based algorithm to find the cluster around the track

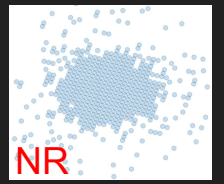
Discriminating Variable

Discriminating Variables

Observables for recoil identification in gas TPCs
arXiv:2012.13649v1

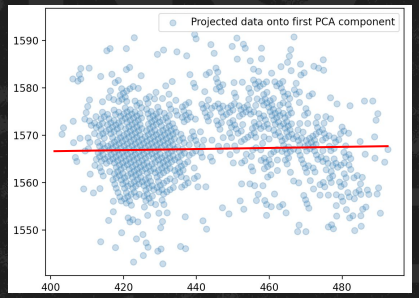
- Standard Deviation of Charge Distribution 2D(SDCD_2D):

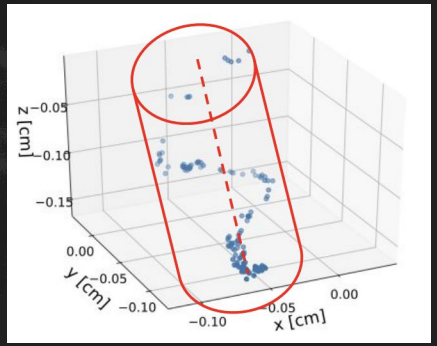
$$SDCD = \sqrt{\frac{\sum_{i=1}^{N}(\mathbf{r_i} - \bar{\mathbf{r}})^2}{N}}.$$



- Charge Uniformity 2D (ChargeUnif_2D)
- Maximum Density 2D (MaxDen_2D)
- Light Density (Delta)
- Skeleton Length
- Length Along Principal Axis (LAPA)

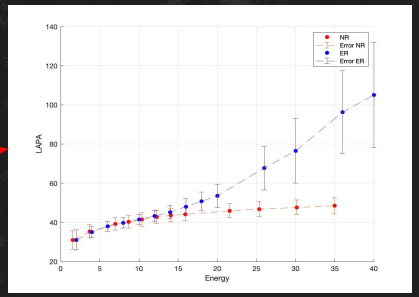
LAPA





Cylindrical Thickness

Discrimination is very difficult at enrgies below 20 keV using traditional approach.

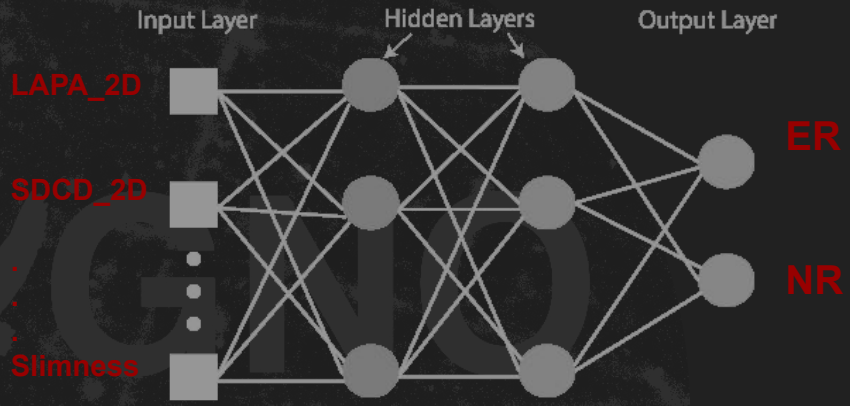


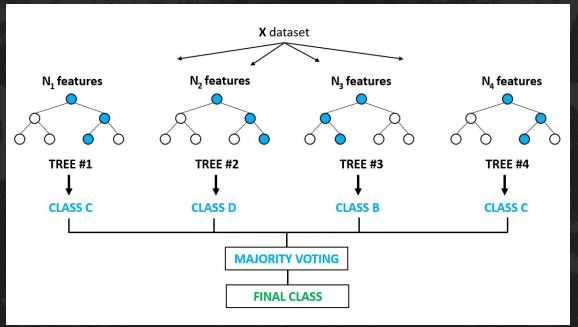
Skeleton Length

Discrimination of ER and NR using Deep Learning Models

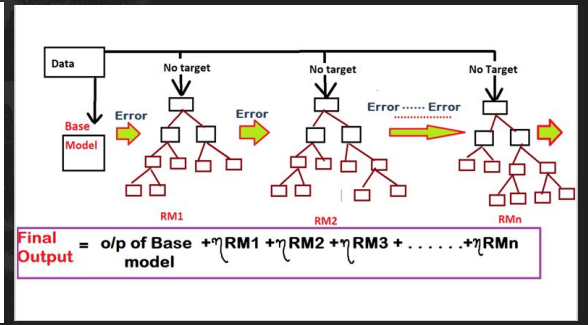
Deep Learning Models for Classification

- Three Models:
  - Pattern net with 3 hidden layers of size [10,10,10] neurons were used.
  - Random Forest Classifier
  - Gradient Boosted Classifier
- Data division [80:10:10]
- Inputs: LAPA_2D, skel_track, SDCD_2D, CylThick_2D, MaxDen_2D, eta, sc_size, sc_nhits, sc_integral, sc_length, sc_width,delta, slimness
- Output: Nuclear recoil and Electron Recoil class





RFC



GBC

- Energy Range : 1-40 keV for both ER and NR

Results of all the models

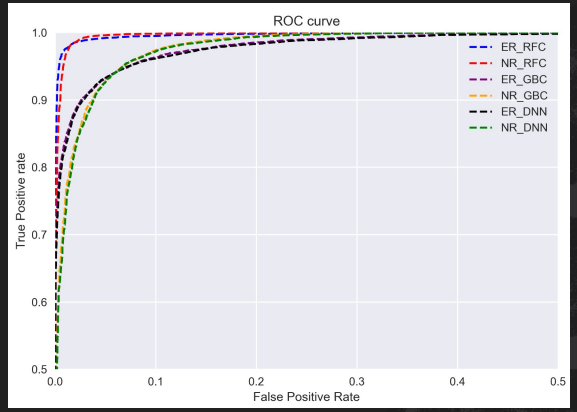


Fig. a

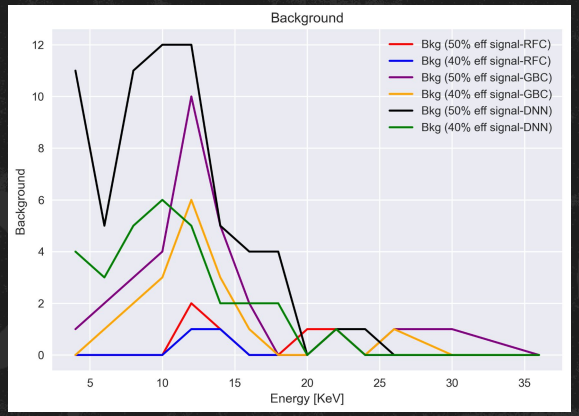


Fig. b

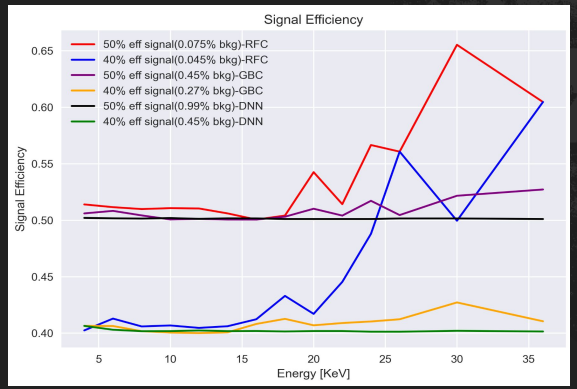


Fig. c

Fig. a: ROC for all Models
Fig. b: Background (ER) classified as Signal (NR) in each energy bin
Fig. c: Signal Efficiency for all models keeping 40 and 50% of efficiency in each bin
Table 1: Minimum signal efficiency in each energy bin is the signal efficiency and Background efficiency is the overall background classified as signal in all energy bins. Here, traditional approach is discrimination by applying a simple cut on the variable.

Models	Signal Eff. [%]	Background Eff. [%]
RFC	50	0.075
	40	0.045
GBC	50	0.45
	40	0.27
DNN	50	0.99
	40	0.45
Traditional Approach	50	3.5
	40	0.8

E Baracchini et. al., “Identification of low energy nuclear recoils in a gas TPC with optical readout”, arXiv:2007.12508v1

Preliminary