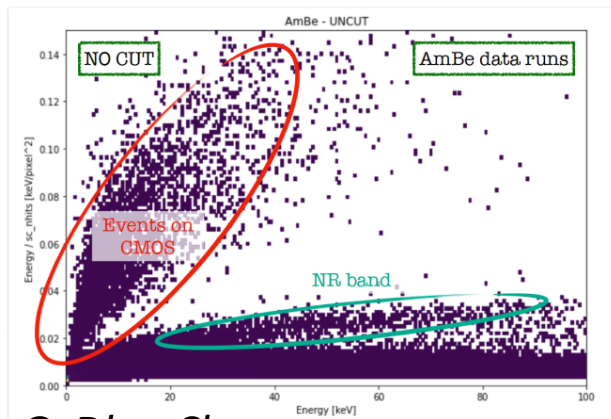
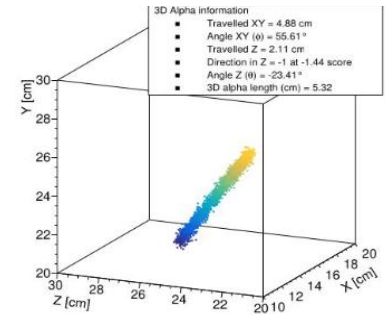


Status of Analysis

Giorgio Dho



Istituto Nazionale di Fisica Nucleare (INFN-LNF), Frascati (RM), Italy



CYGNO Collaboration meeting

G. Dho, Clusone

Dec 18 2025

Who Are We

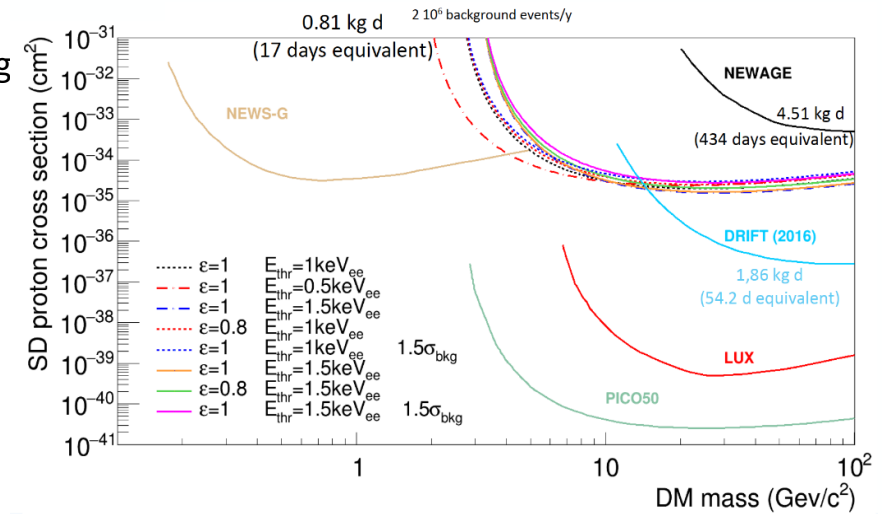
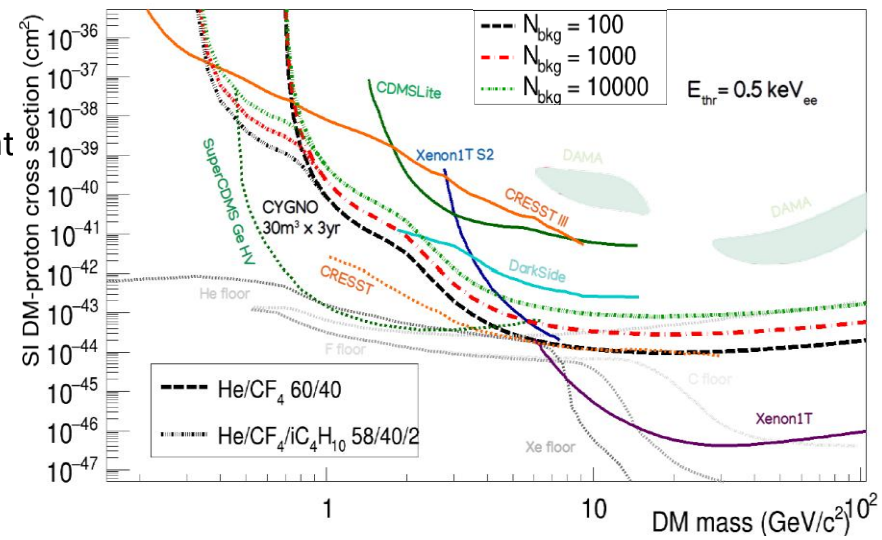
- People from different institutions joined the effort of analysis

G. Dho		E. Baracchini	
R. Antonietti	(5%?)	F. Amaro	
P. Meloni	(Leaving?)	F. Scamporlino	(Leaving?)
D. Pinci		L. Gomes	
S. Piacentini		G. Lopes	(Leaving?)
D. Fiorina		I. Pains	
A. McLean	New	R. Gregorio	New
M. D'Astolfo		L. Bignell	New
R. Nobrega		E. Di Marco	

- We look a lot but almost no-one is full time on analysis
- We should focus on key elements for CYGNO science (spoilers ahead)

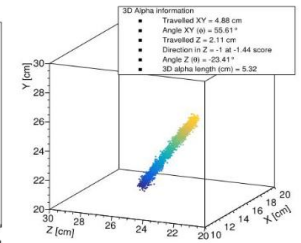
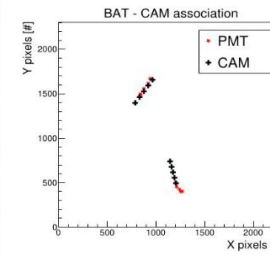
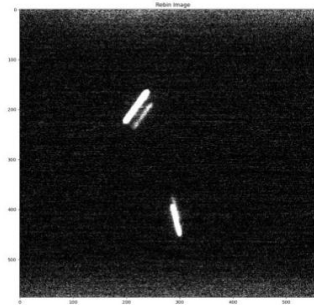
DM Analysis

- To make physics drive our choices and improvement we need something that translates experimental features (especially the **directional**) in physics limits
- What it means? Produce templates of signals and background in the multidimensional parameter space we measure (energy, angle, z)
- Different WP1 physics topics can be tested (DM, neutrinos, axions, polarimetry)
- Stefano, I started this work, Samuele improved it and Rita placed the starting point for the BAT framework
- A person is needed on this topic** but basically nothing happened this year
- O'Hare from Australian group could be helping (still to be determined depending on his agenda)



3D Reconstruction

- We are 3D detector with PMT and camera.
- David's work showed how 3D encloses huge amount of information and can improve all the topics
- David's code now works for straight tracks
- Expansion is required:
 - Use data with different sampling rate to determine minimal energy-size for 3D
 - Generalize 3D to slice matching to reconstruct NR and ER
 - Provide structured code for Event-builder and analysis
- McLean (AU) showed great interest in this topic and should start soon

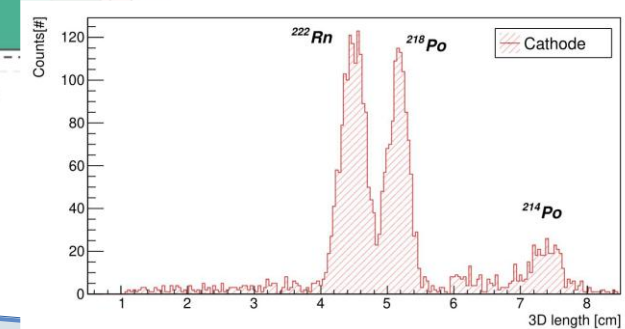
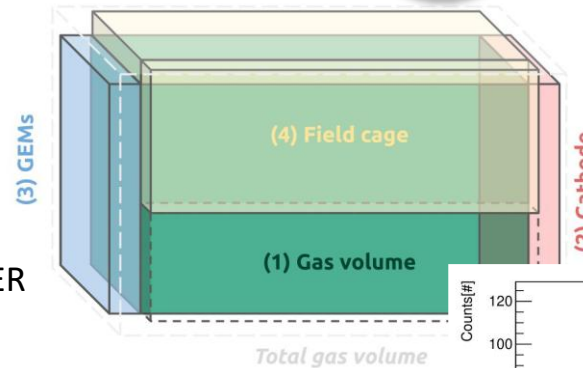


PAPER

1 published

<https://link.springer.com/article/10.1140/epjc/s10052-025-14965-6>

1 to be written



ER vs NR

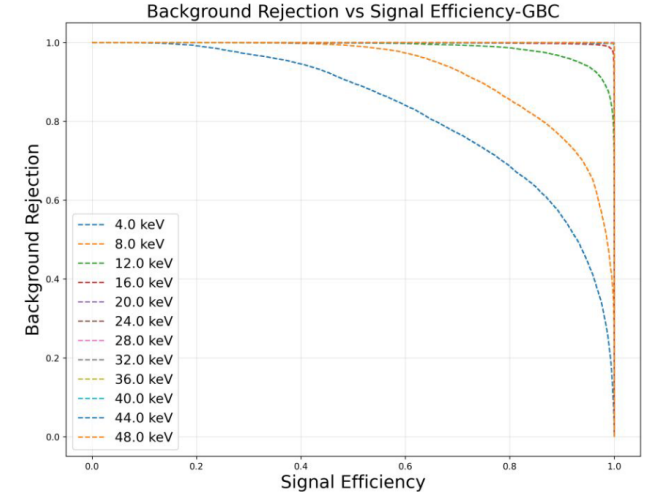
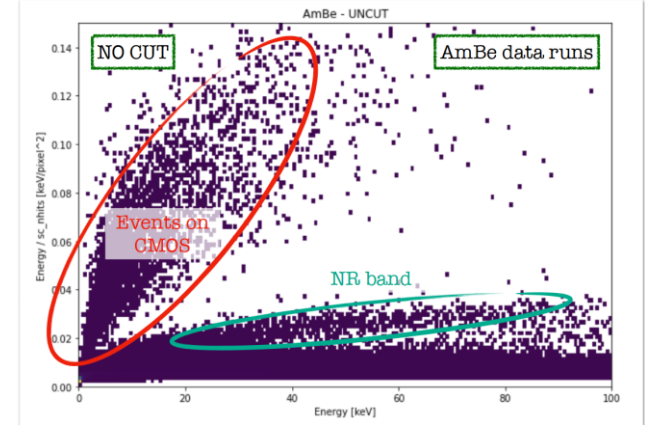
See Gomes' presentation later

- Key tool is to be able to determine signal from background (as impactful as energy threshold)
- We need a spectrum of rejection power as a function of energy
- Only full study done by Atul but should be adapted to the data (Gomes)
- New track-shape variables are being implemented by Gomes
- Simulation procedure and dataset are ready, now application to simulated data and AmBe should be possible



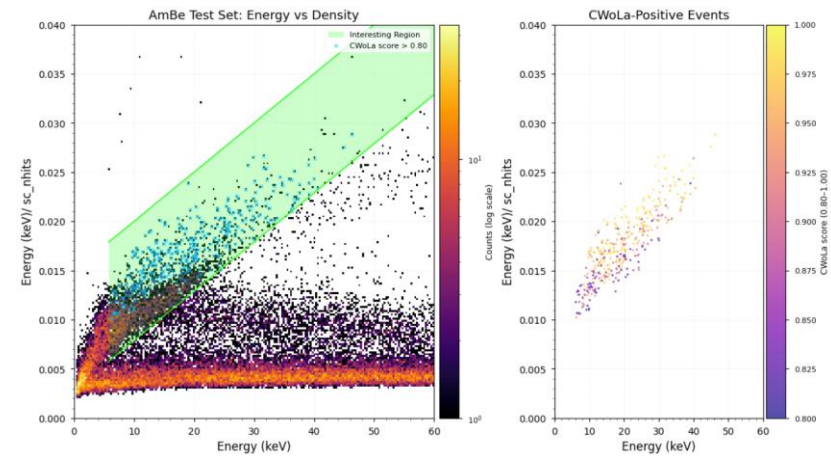
$$\rho \equiv \frac{sc_rms}{sc_nhits}$$

- | | |
|------------------|--------------|
| • energy | • thin track |
| • size | • SDCD |
| • nhits | • ChargeUnif |
| • length | • MaxDen |
| • width | • CylThick |
| • slimness | • eta |
| • Gaussian Width | • dE/dX |
| • LAPA | • dE/dA |



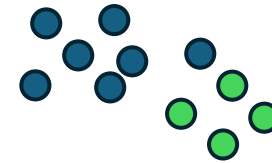
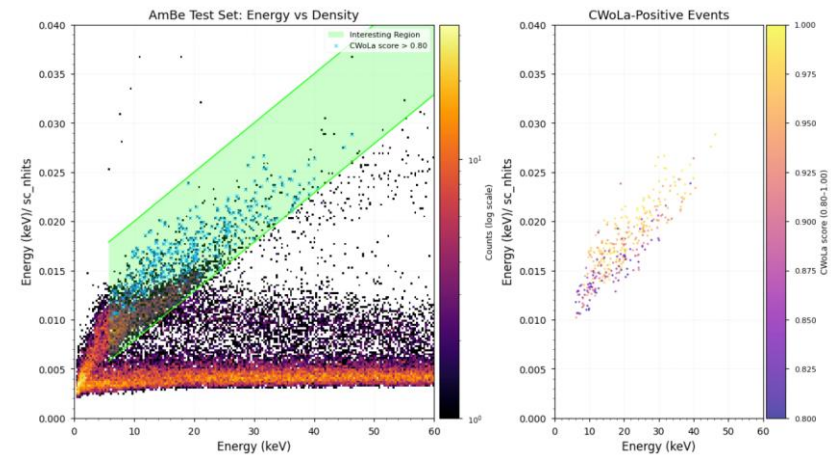
ER vs NR II

- Oppedisano tried a different approach with ML directly applied to images
- **Applied to AmBe** (but no validation on MC and mostly to separate populations, no ER from NR)
- Training on pedestal for on sensor noise and tracks (done)
- Training on ER with data easy on gamma sources (To be done? Now on simulation)
- No dependence on NR potentially unreliable simulation (could it be done?)



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- Anomaly detection with generative AI could be a real step forward
- We need someone on this! (Giuseppe again?!)



AI Classifier

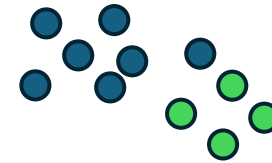
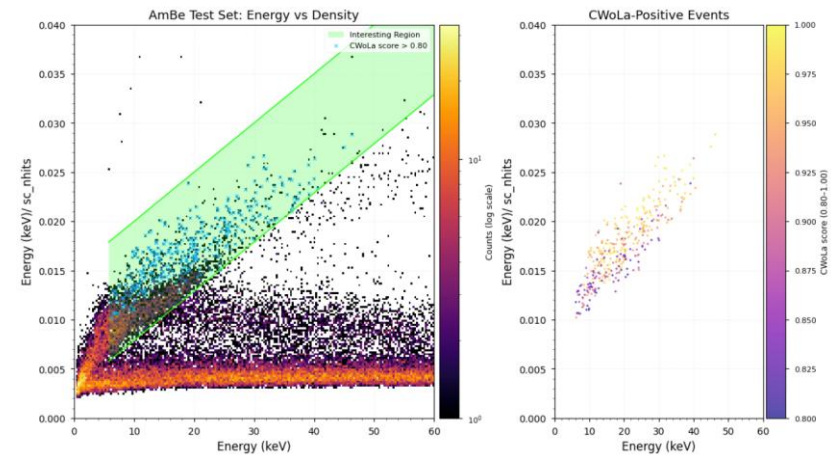
- Finds boundary in latent space between species
- Only species trained on are considered
- Requires NR to classify NR

Blu

Green

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<https://arxiv.org/abs/2410.20047>

AI Classifier

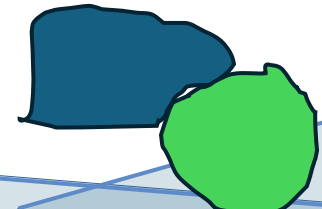
- Finds boundary in latent space between species
- Only species trained on are considered
- Requires NR to classify NR

Generative AI

- Samples distribution in latent space
- Better cuts on space can be made
- Does not require NR simulation

Blu

Green



Background Understanding

See D'Astolfo's presentation later

Vavalà and Meloni's presentations yesterday

- Understanding the behaviour of the background from LIME data is important to:

Validate the MC chain

Learn methods to fit and constrain background components

- Run4-5 data-MC comparison still missing (D'Astolfo on the topic and Di Marco as well)

- Alpha-Rn contamination and effect on low energy under study (Pinci, Vavalà and Gregorio soon)

- Pietro structured and defined the simulation optimization for MC data generation

- How do we analyse data that come from simulation and from the detector?

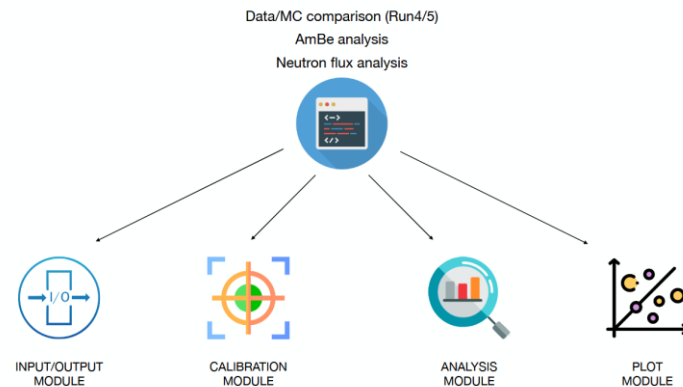
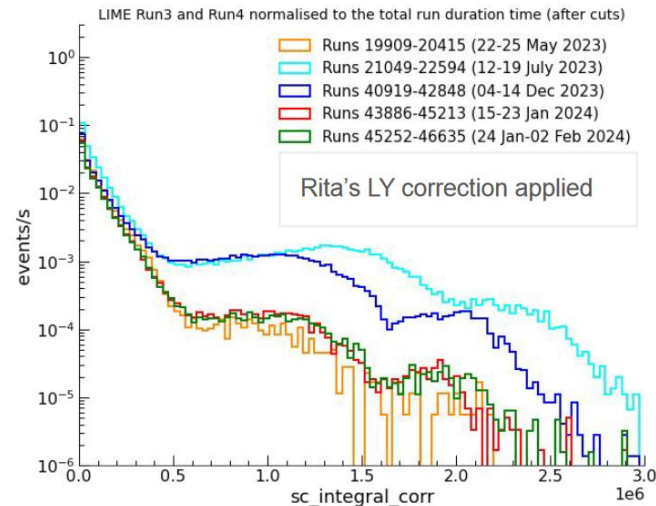
Which cuts?

Association?

Env correction

Treat $E_{\text{threshold}}$

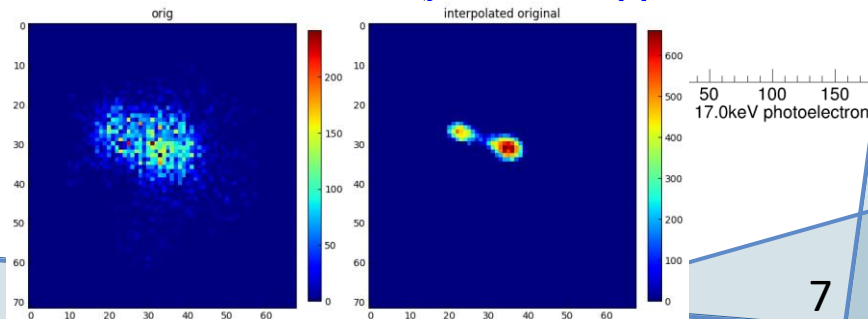
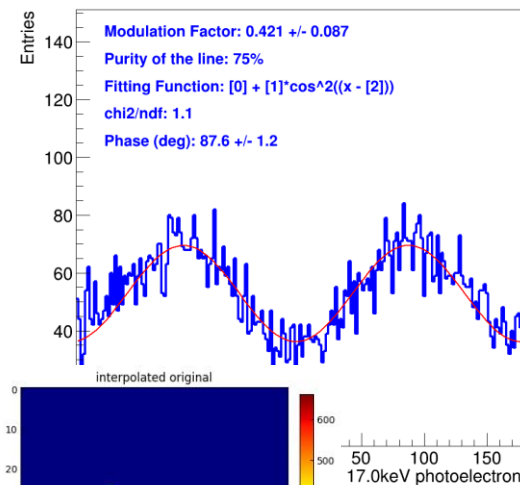
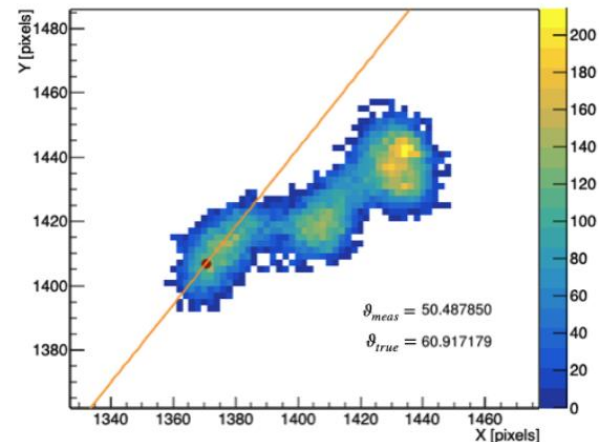
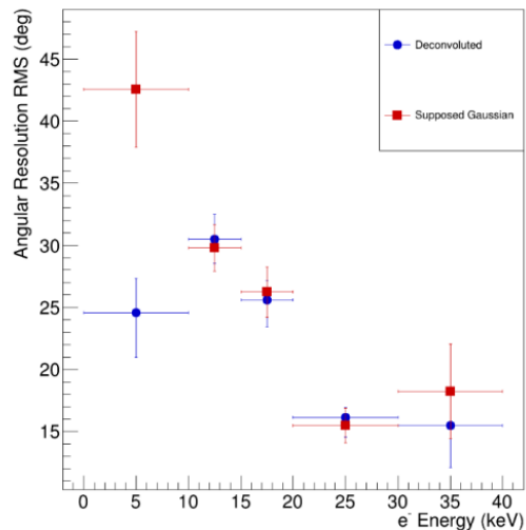
z-LY dependence



In Melba we trust

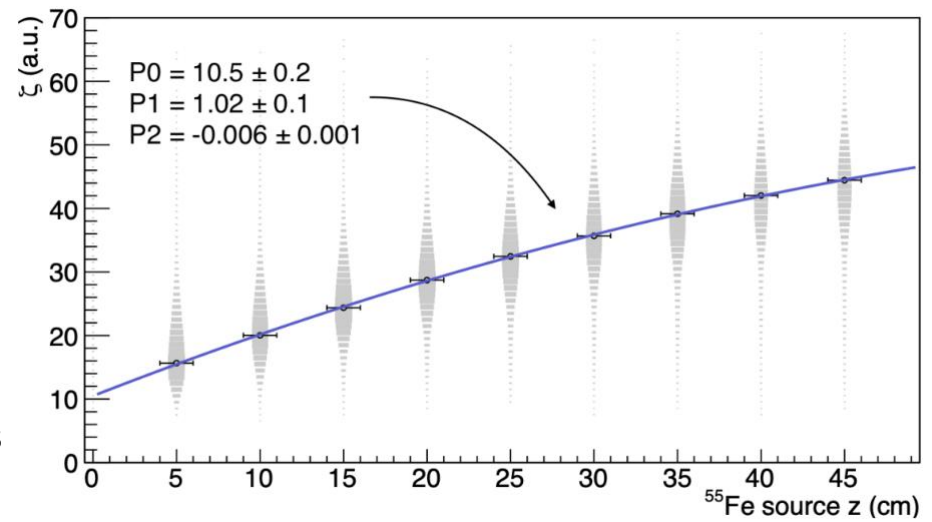
Head-Tail and Angular Resolution

- Head-tail recognition and angular resolution affect the limits calculation and quality of physics reach
- Using 2D Samuele's code, optimized by DavideF
- **We need a similar plot for NR**, possibly on data nothing happened this year
- **We need a plot for HT**
- Polarimetry results show good results for 9 keV as well
- Good results could come from deconvolution studies (Scamporlino later)



Z-fiducialization

See Scamporlino's presentation later

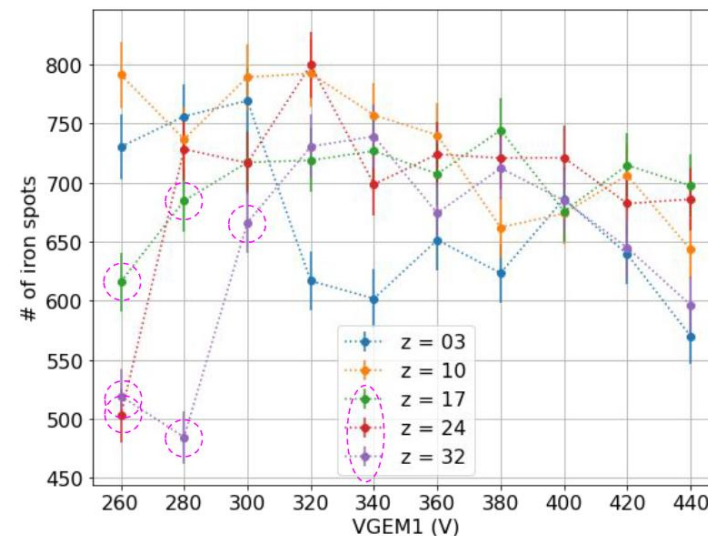
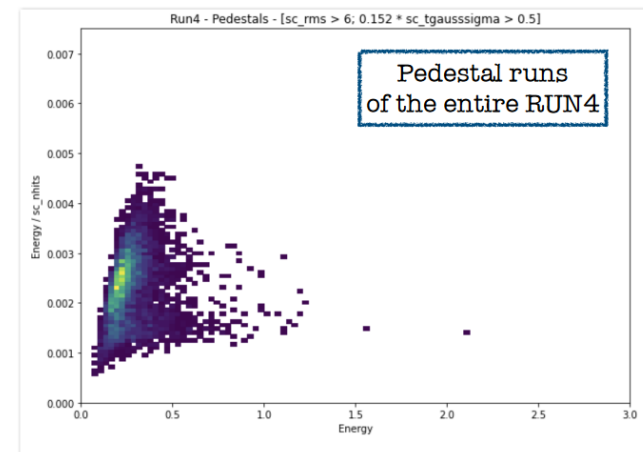


Old plot no spoilers

- Determination of absolute z is the only way to fiducialize the detector for events close to cathode or GEM
- Best results valid only on round spots up to today based on studies by Emanuele and Rita Roque (4 cm resolution close to GEM and 8 cm close to cathode). **Should be improved**
- Master thesis by Scamporlino with ML on this topic. Below 4 cm possible?
- Reduction on amplification stage diffusion could improve results
- Calibration of the z with different detector under study

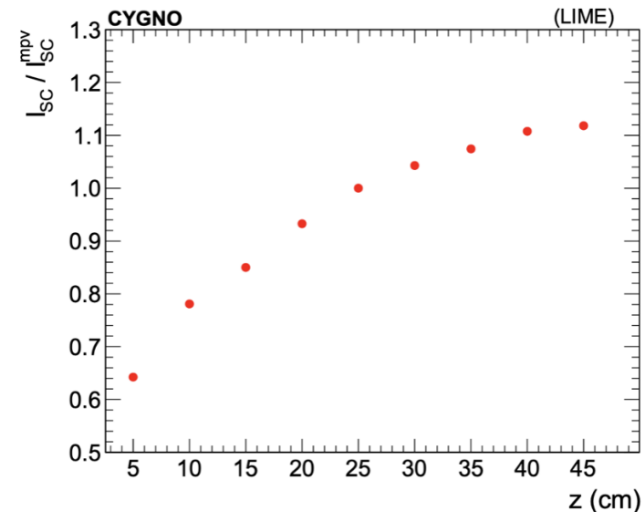
Energy Threshold and Efficiency

- Energy threshold and detection efficiency are required to determine where to look for signal
- Data used for saturation studies could help (Rafael last year)
- Those data suggest that with 440 VGEM, 0.4 keV_{ee} could be detectable with 60% efficiency at far z. (0.6 keV_{ee} with 400V GEM but unknown efficiency)
- But clusters from camera may change the energy threshold. And PMT?
- Probably Rafael is taking on this topic, but this year nothing changed



Saturation

- We are saturating, the charge density is too large in GEM holes and space-charge effects limit the amplification
- Reminder of why this is terrible:
 - Energy threshold and response strongly depends on z
 - Detector non-linear at low energies
 - Z determination becomes fundamental with cm resolution
 - HT and angular resolution worsen at low energy
 - ER and NR are more similar



Modelisation completed (Pinci)

Simulation improved (Meloni)



1 basically published

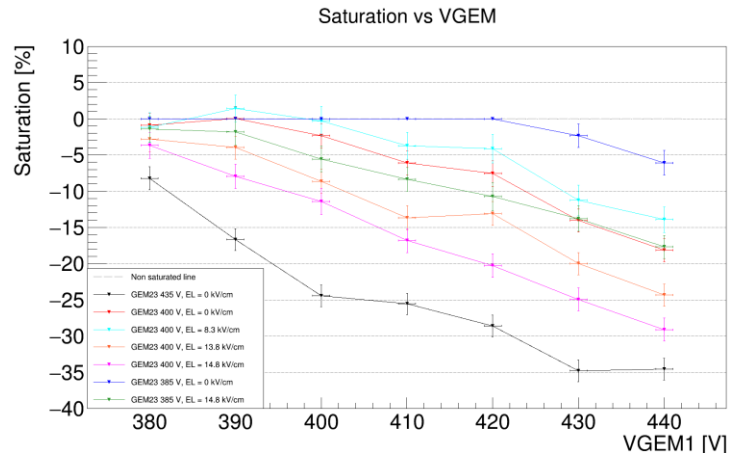
<https://arxiv.org/abs/2505.06362>

1 ready

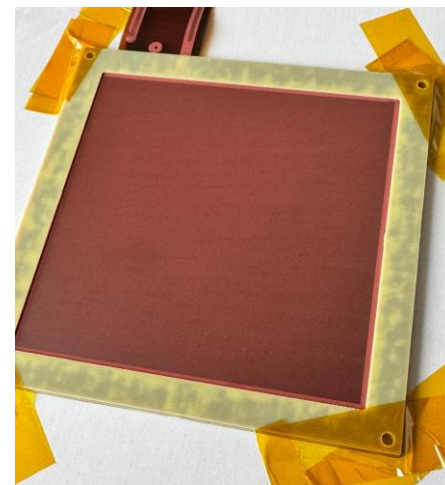
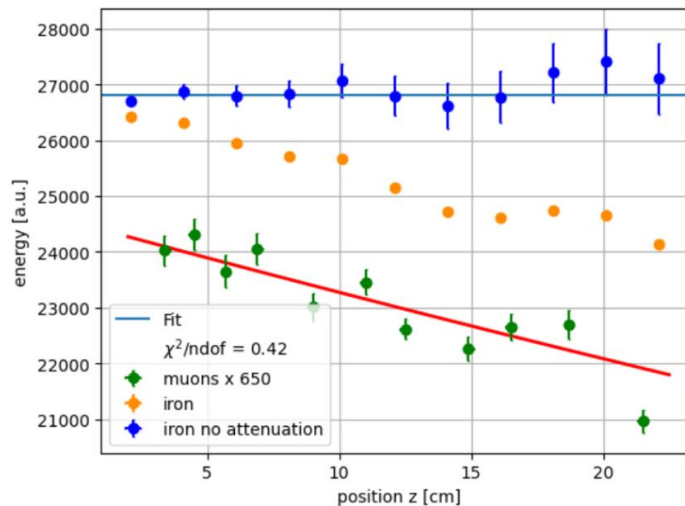
1 or 2 to be written

Saturation: Solve

See Dho's presentation later



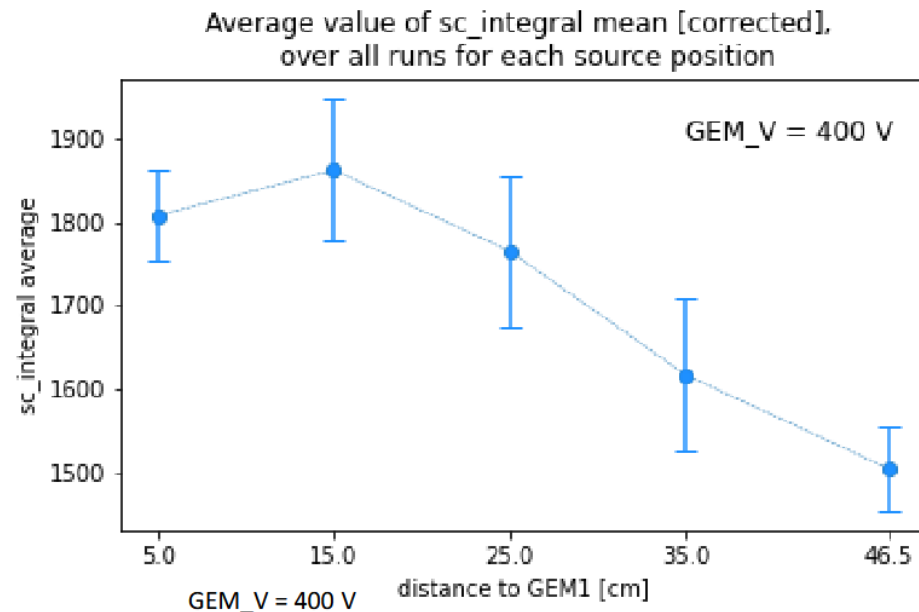
- Analysis and hardware (WP6?) solutions can be employed
- Use of ITO seems the most promising. But it is not ready for CYGNO-04: tests on larger distances, stability tests (Dho)
- V-Bonded GEM looks to be an effective solution to suppress diffusion
- To be tested with large GEMs on CYGNO-04
- More tests with Fiorina/Piacentini setup at LNGS



Saturation: Choose

See Amaro's presentation later

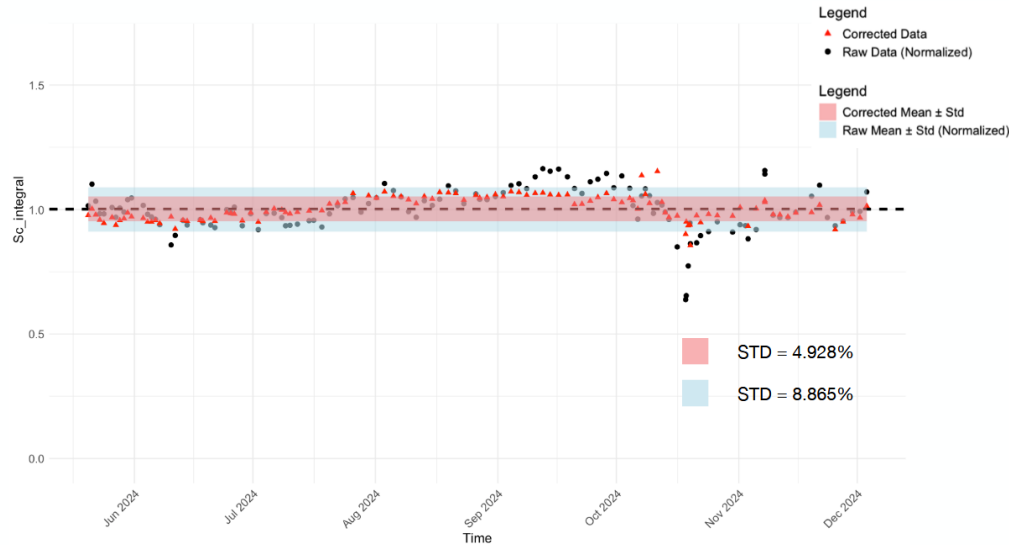
- Data in low gain configuration (0.5 kV/cm drift and 420 VGEM) was collected during Run4 and all Run5
- Also data at 900 V/cm and 400 VGEM
- Analysis and performance studies on this data is crucial (Amaro on it)
- The intensity of the saturation affects reconstruction, HT, direction, z-dependence. Which is the best?



Gas Quality Monitor

See D'Astolfo's presentation later

- Pressure, temperature, oxygen and humidity (PTOH) affect light yield and the detector performances
- Melba studied how to correct data with Run5 large dataset using BAT fit method

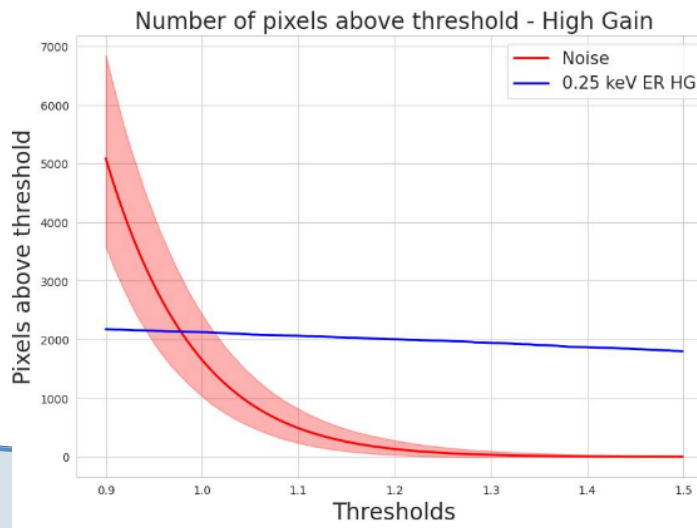
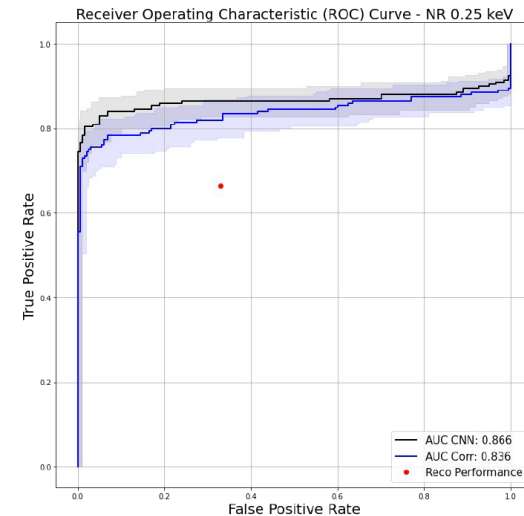


This should be implemented as
hardware correction for VGEM in
CYGN0-04



Data Reduction and pixel selection See Pains presentation yesterday

- Data reduction topic is intertwined with DAQ (WP5) and was discussed in detail yesterday.
- The code could improve the signal detection efficiency of current reconstruction code
- Using now actual simulated events below 1 keV and moving to test on QUEST pedestals
- Optimization of threshold

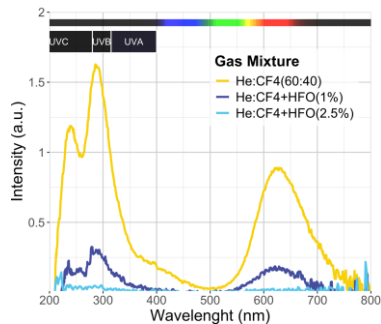


PAPER

All the rest

Gas studies

- HFO measurements for hydrogen mixtures (D'Astolfo, Fiorina, Dho)



1 ready

1 almost ready

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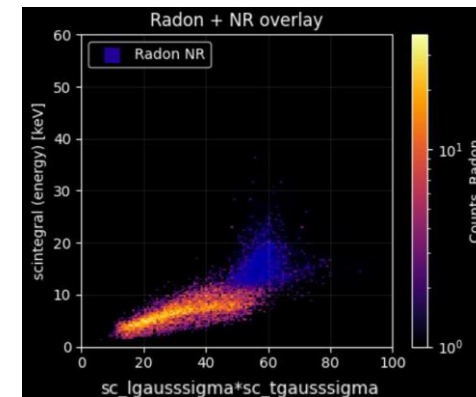
- Rn progeny NR recoils
- Boh peak and copper

Maybe 1?

PAPER

From Run4

https://agenda.infn.it/event/46680/contributions/262852/attachments/134281/200874/AnalysisMeeting_250410.pdf



Algorithm improvements

For clustering algorithm

- Image filtering (Lopes)
- PMT signal extraction (Scamporlino)
- Barreling (Dho)

Replace clustering

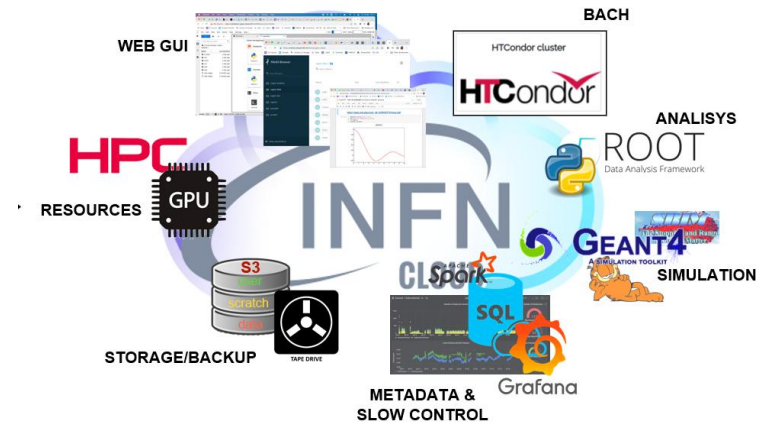
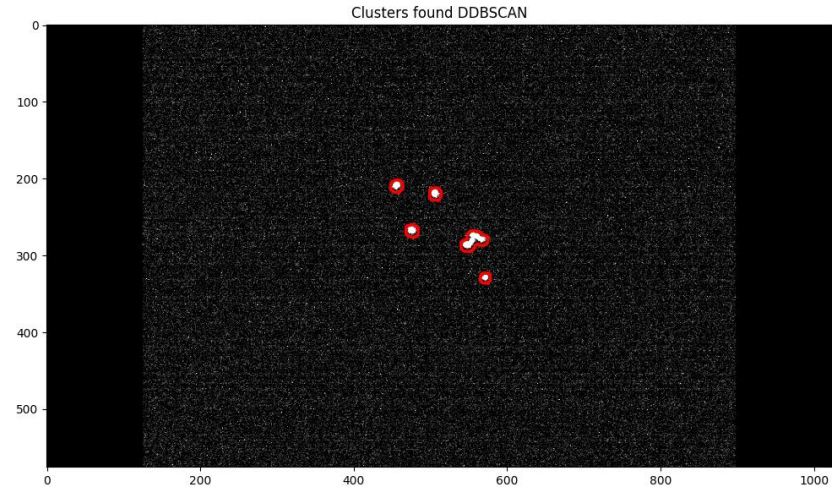
- Autoencoder (Oppedisano) **To be continued**

PAPER

1 almost ready

Reconstruction and Cloud

- The reconstruction code needs constant maintenance and improvements to avoid crashes and provide users with more information
- A lot of work was done, but still a lot ahead to cope with CYGNO-04 (Dho)
- Similarly, the cloud storage and resources are now the skeleton of data analysis
- Improvements on stability and performance are ongoing



Conclusion

- WP2 goal is to provide the framework to analyse data and transform it from images to physics and experimental results
- The number of FTE is quite limited for the amount of tasks to cover (this has not changed)
- A lot of relevant and excellent work has been carried out
- Some important detector performances are still to be addressed or finalised and we should focus on these
ER/NR, 3D reconstruction, directional parameters, z-fiducialization (maybe done?)
- Crucial for CYGNO-04 is the understanding of the saturation conditions we want to work on