Istituto Nazionale di Fisica Nucleare

CYGNO Experiment

Simulation update

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CYGNO general meeting 02/07/20

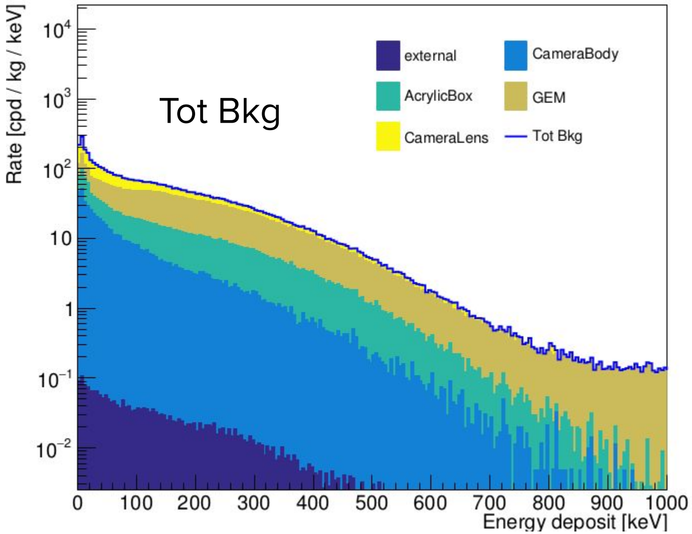
Background simulations

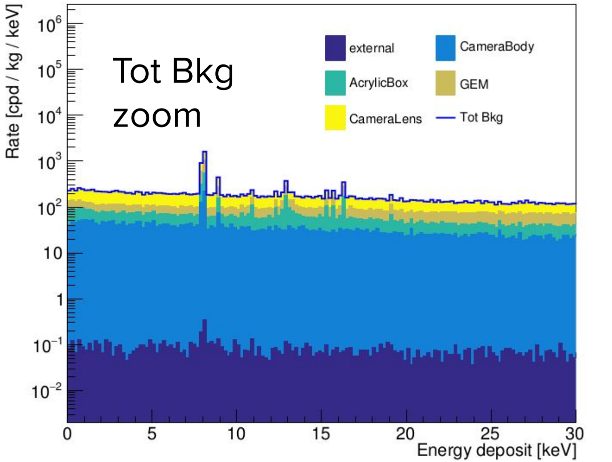
Summary of backgrounds in CYGNO (wip)

	ER/yr 1-20 keV	NR/yr 1-20 keV
GEM	5.14E+05	5.07E+03
AcrylicBox	4.34E+05	-
CameraBody (shield)	4.46E+05	-
CameraLens (shield)	9.83E+05	-
External Gammas (200Water + 5Cu)	9.75E+02	-
Total	**2.38E+06**	**5.07E+03**

CameraBody (no shield)	3.20E+06	0.00E+00
CameraLens (no shield)	1.60E+06	0.00E+00

Summary background spreadsheet:
https://docs.google.com/spreadsheets/d/1SKkd1C-zJoFzb0ZRkG0D9_vNOr5A9S34slWkOKHQqxg/edit?usp=sharing





Camera and lens background in LIME

Isotope	Radioactivity	Counts [0-20] keV
Th-232	0.98 Bq/lkg	139
U-238	18.72 Bq/kg	6312
U-235	0.188 Bq/kg	676
K-40	0.893 Bq/kg	1178
Total	20.781 Bq/kg	8305

Isotope	Radioactivity	Counts [0-20] keV
Th-232	0.726 Bq/kg	148
U-238	6.15 Bq/kg	4076
U-235	0.145 Bq/kg	154
K-40	51.5 Bq/kg	22961
La-138	2.44 Bq/kg	0
Total	60.961 Bq/kg	27339

	Counts [0-20] keV
Total	35644

Close to the goal 10^4 events/year

Roughly scales as expected O(100) less than CYGNO (only 1 camera and ~20 times smaller active mass)

Shielding studies

Table 1: Background rates. Copper costs (25 €/kg) assuming for LIME: 50 × 50 × 100 cm^3 internal shielding size; 0.162 m^3 for 5 cm, 0.406 m^3 for 10 cm, 1.188 m^3 for 20 cm; for 4×LIME: 90 × 90 × 200 cm^3 internal shielding size 1.040 m^3 for 10 cm

	Detector Volume (m^3)	Water/Copper Thickness (cm)	Water Cost (k€)	Copper Cost (k€)	[1-20] keV cpy
CYGNO	1	250/5			1×10^2
CYGNO	1	200/5			1×10^3
CYGNO	1	100/5			2×10^5
CYGNO	1	85/5			1×10^6
CYGNO	1	50/5			8×10^6
LIME	0.05	-	-	-	3×10^8
LIME	0.05	50/5	20	40	5×10^5
LIME	0.05	50/10	20	95	5×10^4
LIME	0.05	100/5	25	40	3×10^4
LIME	0.05	110/10	25	95	2×10^3
LIME	0.05	50/20	20	270	1×10^3
	0.40	90/10	50	250	2×10^4

LIME 2x2x2 → "CYGNO in a bottle"

Our rejection capability in [1-20] keV is something between **10^2-10^3**

Background rates were evaluated with simulation

There are 3 solutions that fit in the Hall-F;

- CYGNO ($1m^3$) with a too high bkg rate;

- LIME (50 l) with 110/10 shielding scheme ($2x10^3$);

- A matrix of 2x2 double-LIMEs (0.4 m^3) with 90/10 shielding scheme ($2x10^4$);

Next steps

- To do: simulate radioactivity of other parts close to sensitive volume (cathode, field cage, GEM and cathode frames)

- Study the position of nuclear recoils and optimize fiducialization
  ➔ need dedicated simulations that save the information of hits positions

- Do we need dedicated simulations of "CYGNO-in-a-bottle"?
  Maybe for internal background we can rescale CYGNO simulations, and run full simulation only for external backgrounds to optimize the shielding

MC digitization ad analysis

Improvements to digitization

F.Petrucci

Notes on how to improve in digitization:
- Sensor noise
- Gain & fluctuations
- Diffusion

Sensor noise

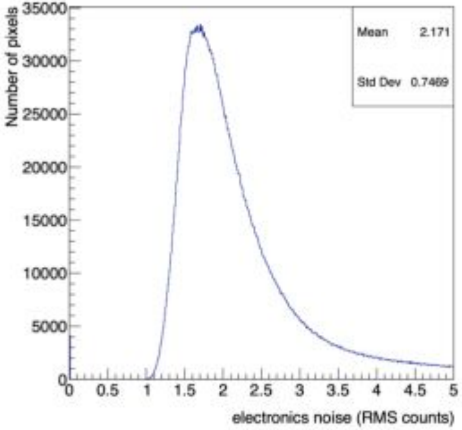
- Current implementation: Add to each image pixel a random value from a Gaussian distribution with mean=99 photons and σ=2 photons.

BUT:

- data shows a pixel noise RMS distribution with non Gaussian tails well above the mean value of 2.

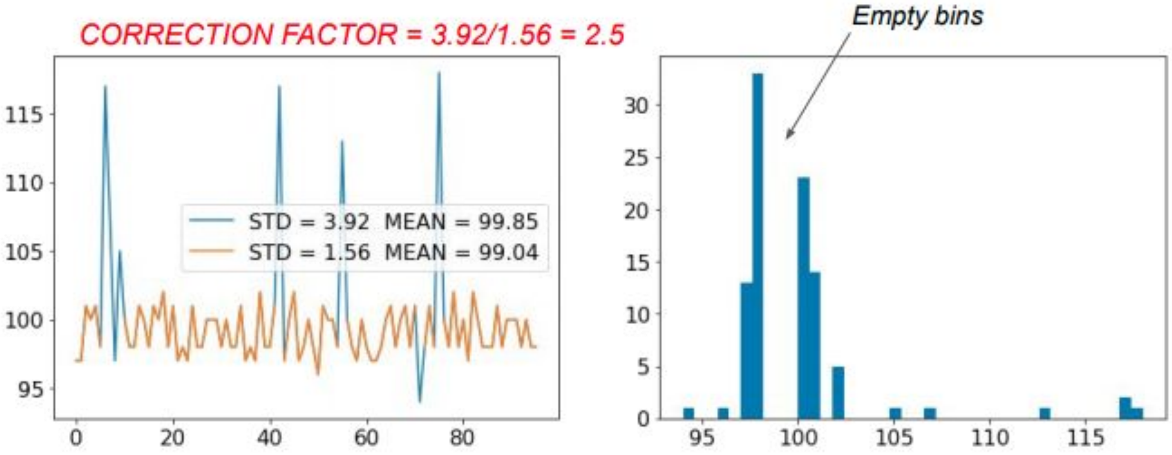
"Easy fix":

- Assign each pixel a different Gaussian noise RMS:



ORCA Flash sensor - Noise characteristics

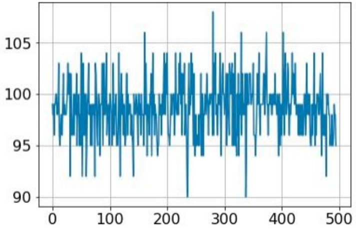
- ORCAD Flash sensor noise process
  - Non Gaussian
  - High occurrence of telegraph noise (“spikes”) **~ 20%**
  - Empty bins

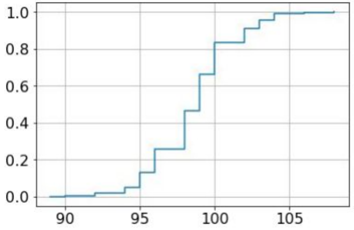


R. Nobrega

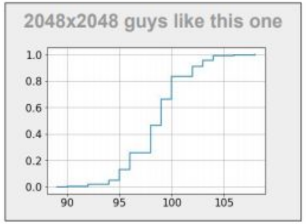
ORCA Flash sensor - Simulation proposal

- Simulate noise from its ECDF measurement
- Each pixel with its own ECDF





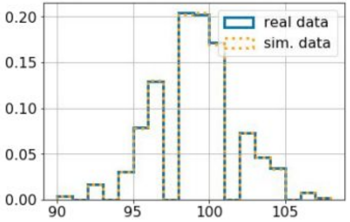
1. Creation a ECDF_map file (~ ped_map) from a noise acquisition run

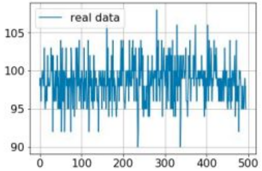


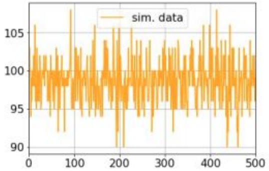
2. Simulation using ECDF_map file

Simulating 100k samples to compare simulated and real data

Example of a pixel







R. Nobrega

Next steps

- Noise simulation current approach: gaussian noise with 2 ph RMS
  - Improve sensor noise simulation ➔ follow Rafael's approach
- Diffusion simulation current approach: fixed to 500 um for LEMON
  - Improve diffusion simulation introducing z dependence:

$$\sigma_T = \sqrt{\sigma_{T_0} + D_T^2 \cdot z} \quad \text{where:}$$

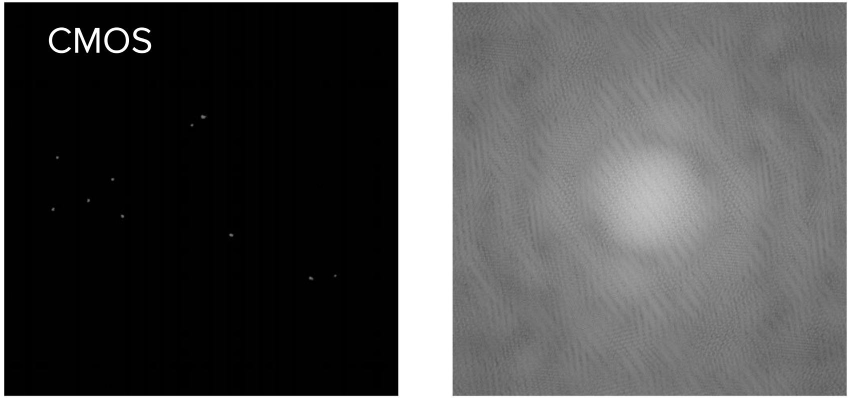
  - $\sigma_{T_0} = 300\mu m$ (measured from data)
  - $D_T = 141\ \mu m/\sqrt{cm}$ (from simulation?)

- Introduce gain fluctuations simulation
  - Convolution of poisson distribution of primary e- production (mean 42 eV/e-), and exponential distribution of each GEM (gain of single GEM ~80)

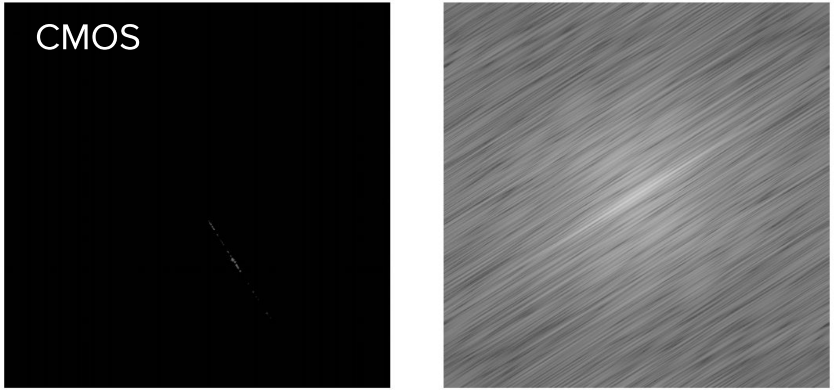
CMOS analysis with ML

Fourier Analysis of CMOS images

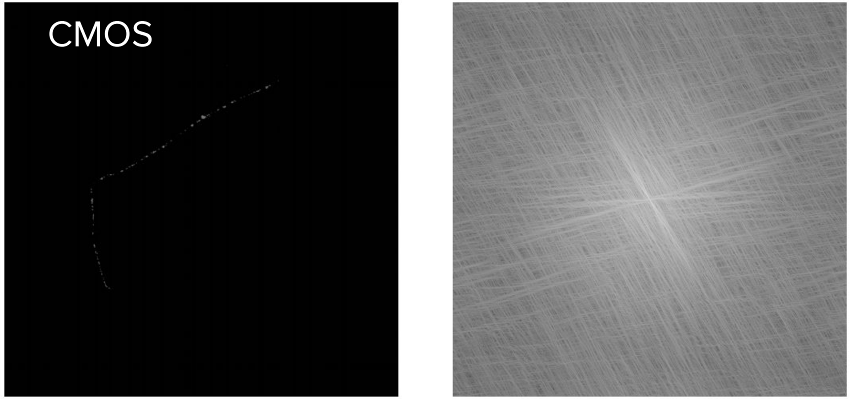
^{55}Fe tracks



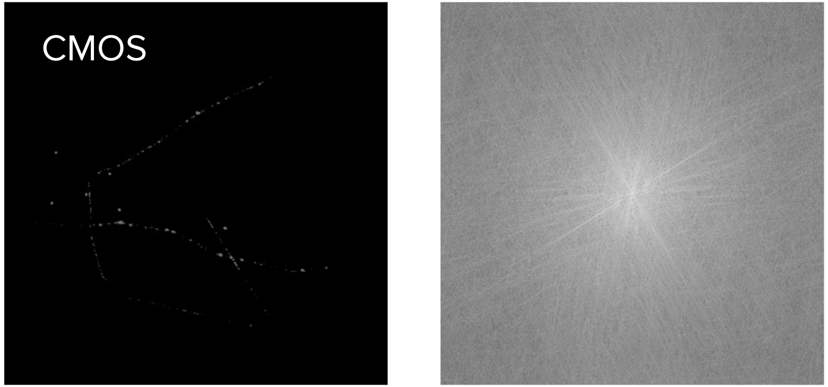
Cosmics track



Low energy electron track



Many tracks of different types



G.V. López, A. Coto

Ideas for next steps

- Fourier transform of different type of tracks look visually very different
- Idea: use Fourier transform of CMOS pictures for machine learning analysis
- Input needed:
  - MC digitized pictures of ER and NR of various energies to train the algorithm
- This approach can be used in parallel to the standard analysis of tracks in order to cross-check the results and compare the performances

Backup

Radioactivity measurements

Camera Body Orca Flash	Limit/Meas	Activity (Bq/kg)
U238 (Th234)	M	3.16E+00
U238 (Ra226)	M	8.13E-01
U235	M	1.81E-01
Th232 (Ra228)	M	9.49E-01
Th232 (Th228)	M	9.49E-01
K40	M	8.59E-01
Cs137	M	4.07E-02
Co60	L	5.42E-03

Camera Lens Orca Flash	Limit/Meas	Activity (Bq/kg)
U238 (Th234)	M	4.22E+00
U238 (Ra226)	M	1.92E+00
U235	M	1.45E-01
Th232 (Ra228)	M	3.61E-01
Th232 (Th228)	M	3.65E-01
K40	M	5.15E+01
Cs137	L	2.67E-02
Co60	L	4.64E-02
La138	M	2.44E+00

Acrylic Box	Limit/Meas	Activity (Bq/kg)
U238 (Th234)	L	3.50E-03
U238 (Ra226)	L	3.50E-03
Th232 (Ra228)	L	5.00E-03
Th232 (Th228)	L	4.50E-03
K40	L	3.50E-02

GEM	Limit/Meas	Activity (Bq/kg)
U238 (Th234)	M	1.63E-01
U238 (Ra226)	M	3.25E-02
U235	L	1.58E-02
Th232 (Ra228)	L	3.09E-02
Th232 (Th228)	L	1.56E-02
K40	L	3.58E-01
Cs137	L	8.13E-03
Co60	L	7.48E-03