

# CYGNO simulation plans

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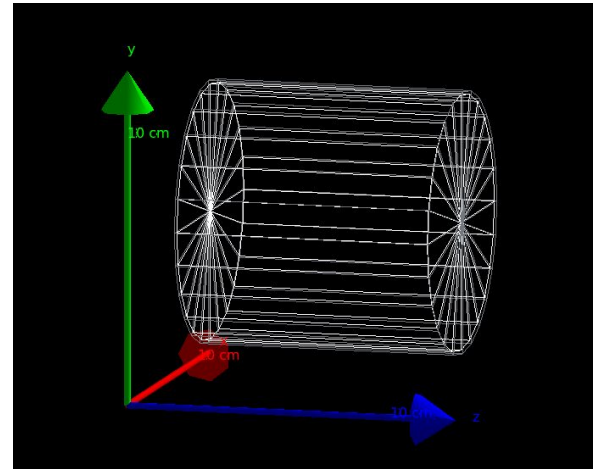
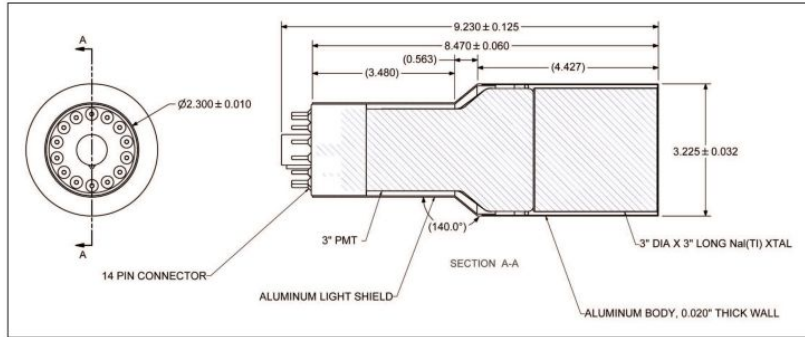
Giulia D'Imperio

16/05/23

CYGNO simulation meeting

# Simulation of NaI crystal

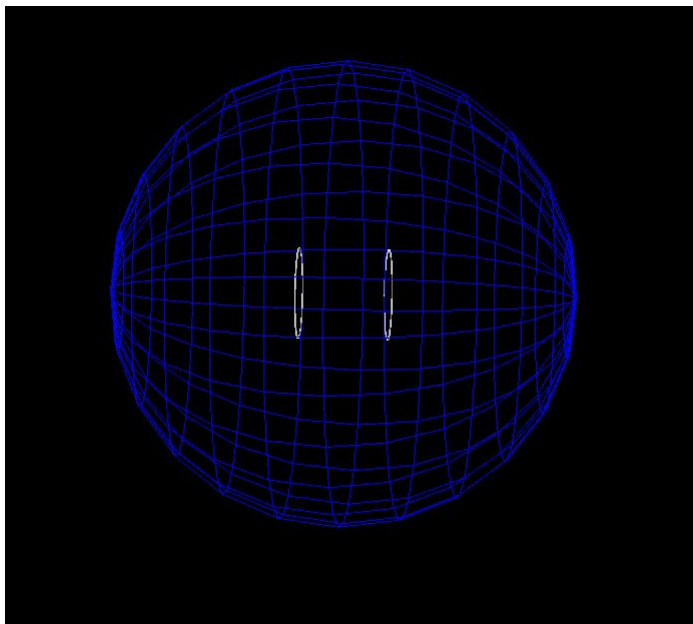
- 3"x3" cylindrical crystal with 0.5 mm Aluminum case



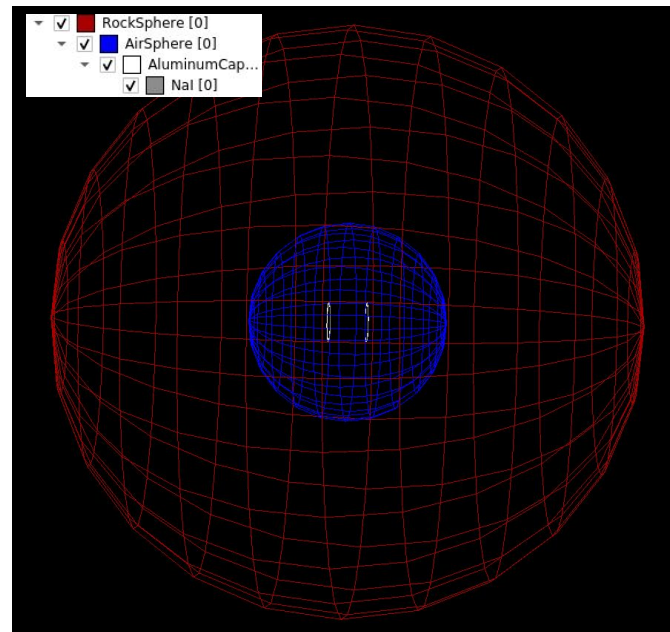
- Simulate decay of  $^{40}\text{K}$ ,  $^{238}\text{U}$  chain and  $^{232}\text{Th}$  chain (gamma emitters)

# Event generation

- Radioactive decays from a spherical surface in air of  $R=20$  cm

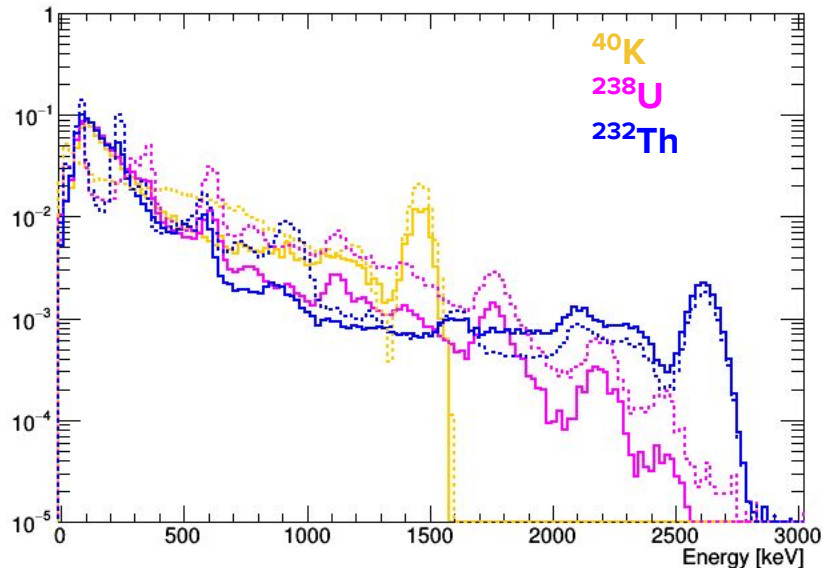


- Radioactive decays from a spherical shell of  $R_{int} = 20$  cm and 40 cm thickness



# Simulation on NaI crystal

- Energy deposits in the NaI detector
- Apply experimental resolution to the simulated spectra
- Dashed lines → templates from simulation from air sphere
- Solid lines → templates from simulations from rock sphere

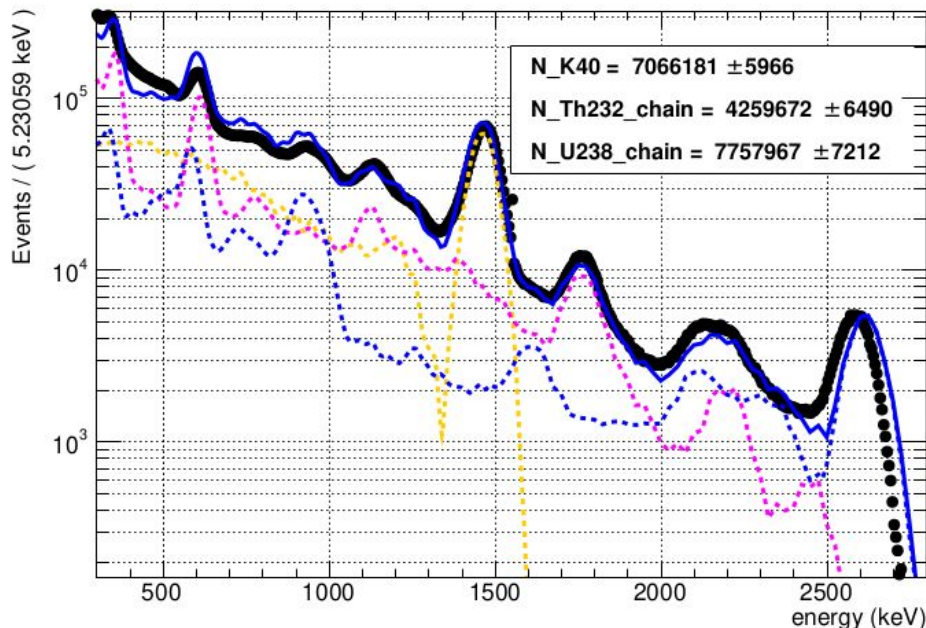


There is a significant difference between templates from the 2 simulations

→ simulations from rock shell are more realistic

# Fit data with simulated spectra (air sphere)

- Use dataset outside shielding (in LIME control room), ~6 days livetime
- Fit range from 300 keV to 2800 keV



Floating Parameter	FinalValue +/-	Error
N_K40	7.0662e+06 +/-	5.97e+03
N_Th232_chain	4.2597e+06 +/-	6.49e+03
N_U238_chain	7.7580e+06 +/-	7.21e+03

## Corresponding activities

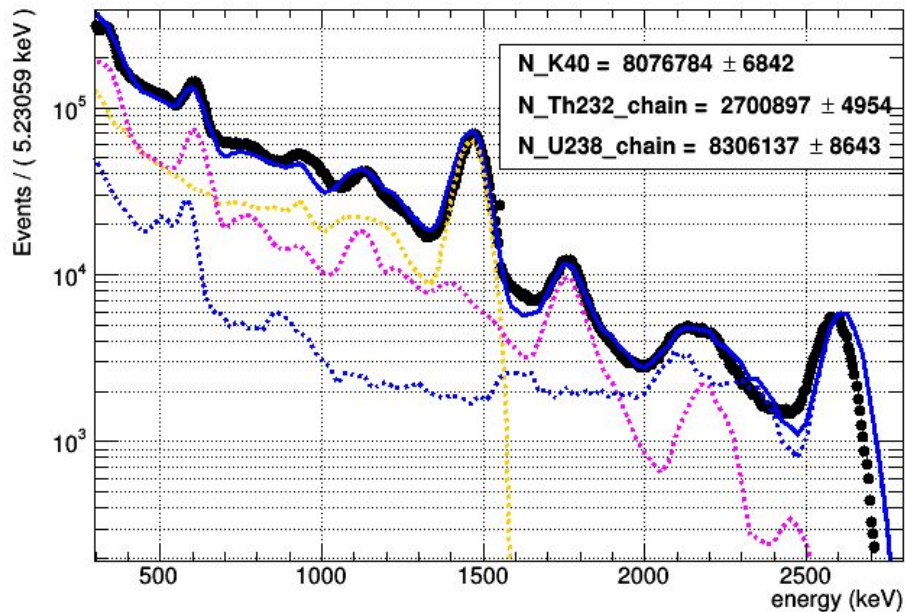
- $^{40}\text{K} \rightarrow 1.71$  decays/cm<sup>2</sup>/sec (BR = 0.11)
- $^{238}\text{U} \rightarrow 0.64$  decays/cm<sup>2</sup>/sec
- $^{232}\text{Th} \rightarrow 0.33$  decays/cm<sup>2</sup>/sec

## Correcting for branching ratios:

- $^{40}\text{K} \rightarrow 0.18$  gammas/cm<sup>2</sup>/s
- $^{238}\text{U} \rightarrow 0.64$  gammas/cm<sup>2</sup>/s
- $^{232}\text{Th} \rightarrow 0.33$  gammas/cm<sup>2</sup>/s
- **Total 1.15 gammas/cm<sup>2</sup>/s**

# Fit data with simulated spectra (rock sphere)

- Use dataset outside shielding (in LIME control room), ~6 days livetime
- Fit range from 300 keV to 2800 keV



Floating Parameter	FinalValue +/-	Error
$N_{K40}$	$8.0768e+06$ +/-	$6.84e+03$
$N_{Th232\_chain}$	$2.7009e+06$ +/-	$4.95e+03$
$N_{U238\_chain}$	$8.3061e+06$ +/-	$8.64e+03$

## Corresponding activities

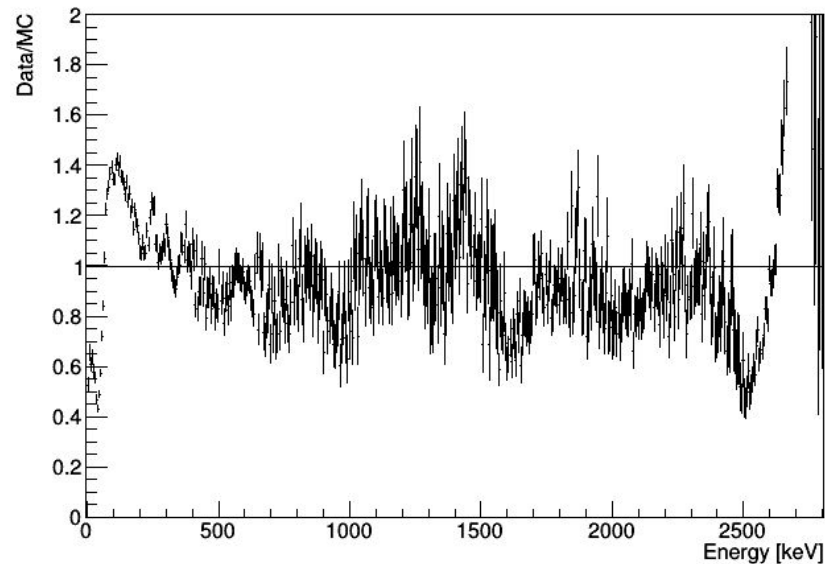
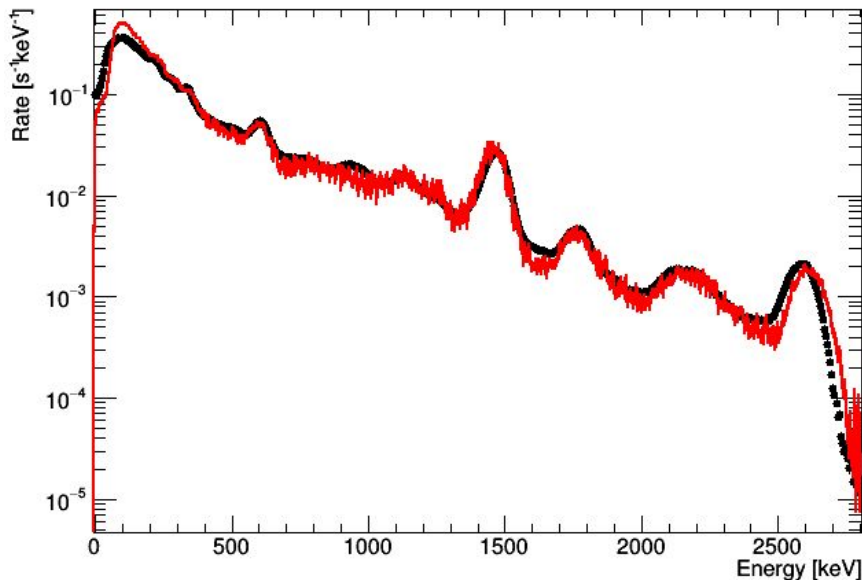
- $^{40}\text{K} \rightarrow 93.5 \text{ Bq/kg}$
- $^{238}\text{U} \rightarrow 7.9 \text{ Bq/kg}$
- $^{232}\text{Th} \rightarrow 4.1 \text{ Bq/kg}$

## Counting gammas entering the air sphere

- $^{40}\text{K} \rightarrow 0.21 \text{ gammas/cm}^2/\text{s}$
- $^{238}\text{U} \rightarrow 0.25 \text{ gammas/cm}^2/\text{s}$
- $^{232}\text{Th} \rightarrow 0.12 \text{ gammas/cm}^2/\text{s}$
- **Total 0.58 gammas/cm<sup>2</sup>/s**

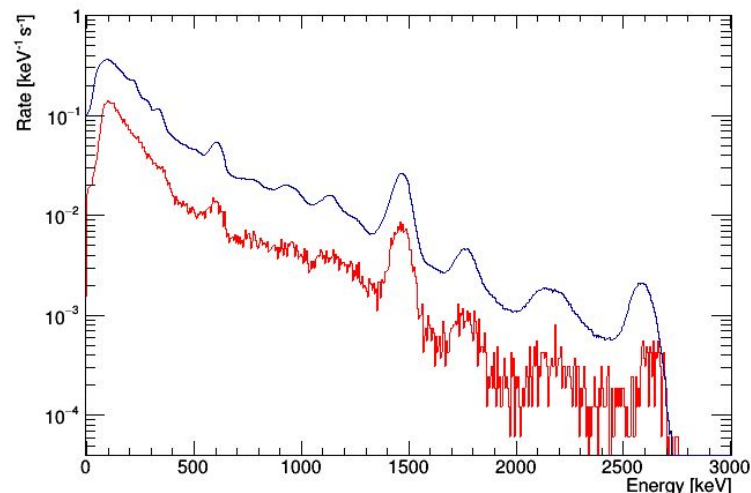
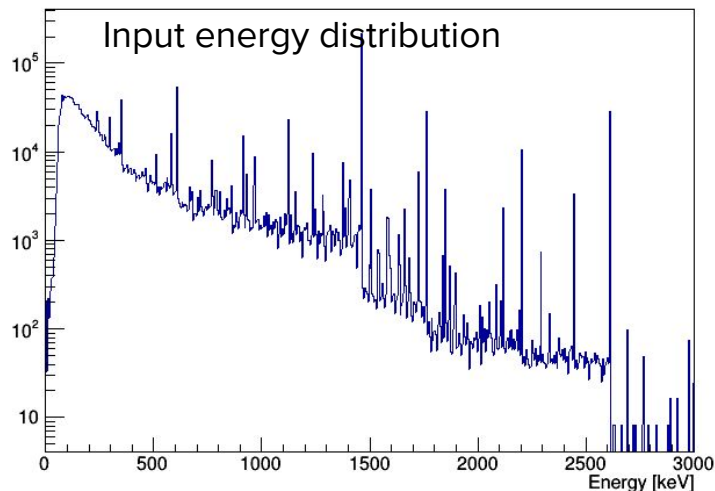
# Data/MC comparison

- Comparison on the full range (fit range [300-2800] keV )
- Agreement is quite good, considering statistics uncertainty of MC



# Closure test

- Generate gammas according to the correct energy distribution
- Isotropic generation from a spherical surface of  $R=21$  cm ( $10^7$  events)
- Normalized to  $0.58$  gammas/cm<sup>2</sup>/s
  - $t_{eq} = N_{gen}/(\text{Flux Area}) = 312$  sec
  - MC rate is  $\sim 3.5$  factor lower than data...



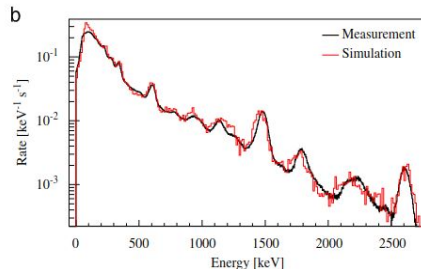
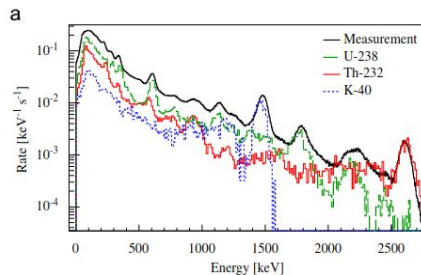
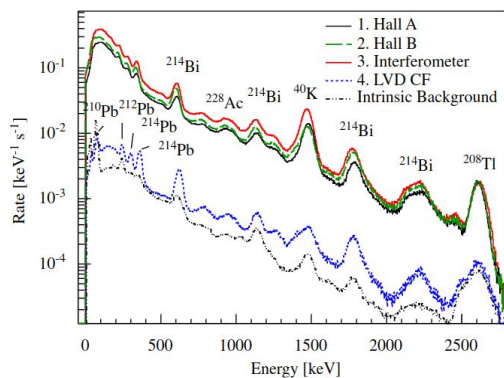


# Comparison with literature

M. Haffke et al. / Nuclear Instruments and Methods in Physics Research A 643 (2011) 36–4138

<https://doi.org/10.1016/j.nima.2011.04.027>

Nal(Tl) cylindrical detector 3", very similar to our detector



**Fig. 3.** Gamma spectrum of LNGS hall A (location 1). Top: measured data and the individual contributions of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  from of a Monte Carlo simulation of the setup. Bottom: measured data and Monte Carlo sum spectrum agree very well over a very large energy range.

**Table 1**

Gamma flux below 3000 keV, measured at several LNGS underground locations with a 3 in. Nal(Tl) detector.

Location	Time	Flux ( $\text{s}^{-1} \text{cm}^{-2}$ )
1. Hall A	3 d	$(0.28 \pm 0.02)$
2. Hall B	3 d	$(0.33 \pm 0.33)$
3. Interferometer tunnel (XENON building)	2 d	$(0.42 \pm 0.06)$
4. LVD Core Facility	10 d	$(0.005 \pm 0.001)$

**Table 2**

Gamma activities of the primordial isotopes (in Bq/kg) as determined from measurements with a 3 in. Nal(Tl) detector.

Location	$^{238}\text{U}$	$^{232}\text{Th}$	$^{40}\text{K}$
1. Hall A	$11.7 \pm 3.9$	$14.8 \pm 2.8$	$62 \pm 14$
2. Hall B	$19.6 \pm 4.9$	$13.2 \pm 2.7$	$52 \pm 10$
3. Interferometer	$37.8 \pm 7.3$	$10.9 \pm 2.8$	$206 \pm 37$
4. LVD CF	$1.2 \pm 0.4$	$0.34 \pm 0.07$	$1.04 \pm 0.32$
Concrete (floor) <sup>a</sup>	$26 \pm 5$	$8 \pm 2$	$170 \pm 27$
Concrete (wall) <sup>a</sup>	$15 \pm 2$	$3.8 \pm 0.8$	$42 \pm 6$

<sup>a</sup> These concrete samples taken from the interferometer tunnel were screened in a HPGe detector in order to directly measure the radioactive contamination. They are to be compared to the Nal(Tl) results for location 3. *interferometer*.

# Backup

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# External background in LIME

For LIME simulations we have **assumed a flux of 0.56 gammas/cm<sup>2</sup>/s** from environmental background.

Spectrum is taken from a NaI measurement by SABRE collaboration.

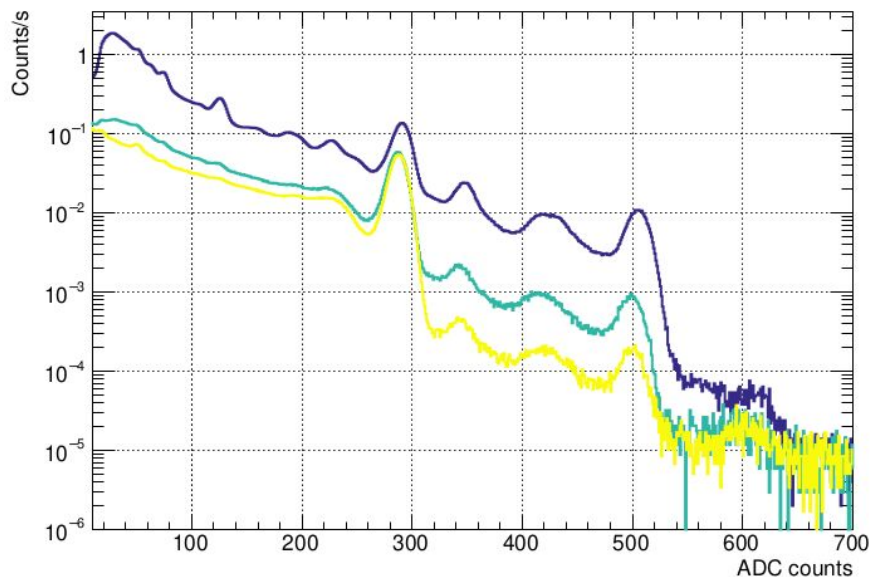
## Summary of LIME MC rates (ER)

	External	Internal	Shield	Tot
	Rate Hz	Rate Hz	Rate Hz	Rate Hz
<b>No shield</b>	35.83	0.23	0.00	<b>36.15</b>
<b>4 cm Cu</b>	0.84	0.23	0.02	<b>1.09</b>
<b>6 cm Cu</b>	0.30	0.23	0.02	<b>0.55</b>
<b>10 cm Cu</b>	0.06	0.23	0.02	<b>0.31</b>
<b>Full (water+Cu)</b>	0.02	0.23	0.02	<b>0.26</b>

- Ratio between rates with different shielding options depends also on the internal background
- To compare LIME rates w/wo shielding with data we need to know the external (and internal) background more precisely
- Previous measurements with NaI suggest difference of factor 2 in gamma background between LNGS Halls

# NaI data (3" crystal)

- We have direct measurements with NaI in LIME experimental area
- Raw data without shield (blue), 4 cm Cu shield (green), and 10 cm Cu shield (yellow)



- Previous measurements by SABRE made with a NaI larger detector (4" x 4" x 16")
  - Difficult to compare directly these spectra (and rates) with previous NaI or LIME MC because:
    - different detectors
    - non-negligible internal background component, especially when we compare shielded spectra
- need a MC simulation of the NaI