AHEAD 2020

Integrated activities for the High Energy Astrophysics Domain

Funded by the Horizon 2020 Framework Programme of the European Union
Grant Agreement No. 871158

WP14.2 – advanced background modeling [M1-M48] tasks

- **Background correlation with external particle monitors:** AHEPAM particle monitor, correlation between the external measured fluxes and the X-IFU unrejected background.
- **X-IFU residual background spatial distribution characterization:** need 100 ks of equivalent time for simulations
- **High energy band background:** establish the correlation between the high energy counts and the in-band counts, as a function of the total time dedicated to closed observations.
- **Effect of the closed position on the residual background:** put upper limits on the effect of the closed position on the residual background.
- **CryoAC hard X-Ray background:** AHEAD WP9.2c extend the instrument sensitivity up to 20 keV

- People/institutes involved in the task
  - Simone Lotti (INAF-IAPS Roma)
  - Claudio Macculi (INAF-IAPS Roma)
  - Matteo D'andrea (INAF-IAPS Roma)
  - Silvano Molendi (INAF-IASF Milano)

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WP14.2 – advanced background modeling [M1-M48] tasks

- Current status:
  - Procurement and setup of the computer cluster for the MC simulations concluded. Roughly 100 ks of equivalent time simulated in a month.
  - The X-IFU detector model has been updated, filters models updated, FPA and cryostat information still pending

  - **Background correlation with external particle monitors:** Ongoing (preliminary results)
  - **X-IFU residual background spatial distribution characterization:** *completed*
  - **High energy band background:** simulation complete, analysis TBD
  - **Effect of the closed position on the residual background:** TBD
  - **CryoAC hard X-Ray background:** Ongoing (preliminary results)

- A high-level document on the background calibration for X-IFU has been delivered to Athena XCAT on November 2021. It relies on several results of this WP activity, listing background calibration sources and how to handle them, such as:
  - Ahepam
  - WFI
  - X-IFU high energy band
  - CryoAC
  - Filter wheel closed time observations
  - Other satellites

The aim is to produce a global model of the background that will allow to put together all the information from the different calibration sources to produce a reliable estimate of the background during a X-IFU observation.

High statistics simulation result

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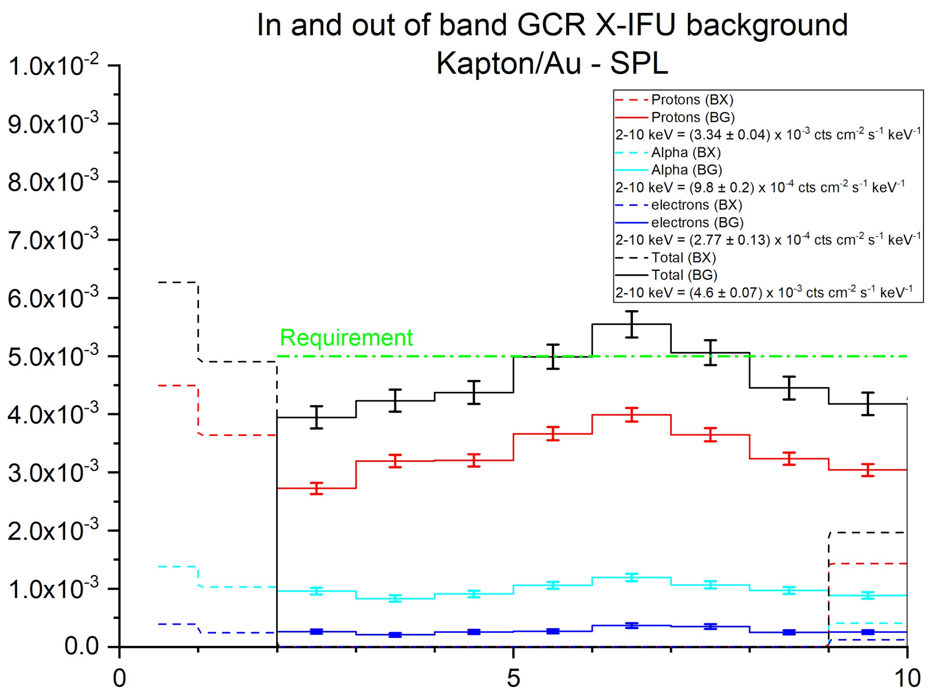
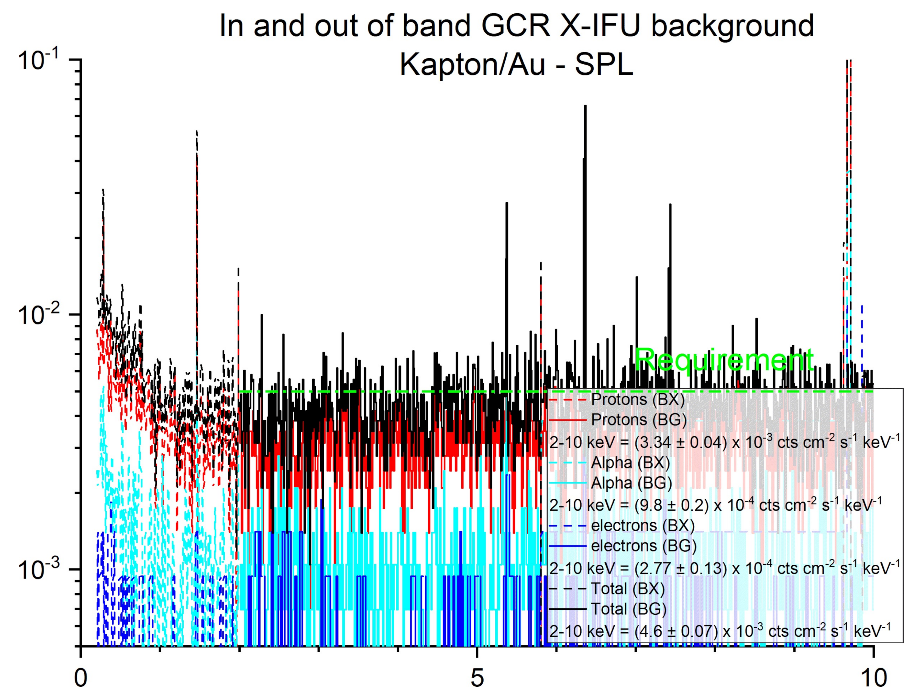
GCR protons, alphas and electrons with a 100 ks equivalent simulation reported a total background level of (4.6 ± 0.07) × 10^{-3} cts cm^{-2} s^{-1} keV^{-1} in the 2–10 keV energy band, compliant with the scientific requirement





Having a simulation roughly equivalent to a real observation allowed us to exploit a realistic number of background counts to perform the in-depth analysis required by several tasks

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Cross correlation with external particle monitors

- The flux of the external particles measured by the GCR monitor AHEPAM is correlated with the background level induced by those populations on the detector

$$C_{bkg} = k_p\, C^{P}_{AHEPAM} + k_{alpha}\, C^{alpha}_{AHEPAM} + k_{ele}\, C^{ele}_{AHEPAM}$$

- We simulated the background induced by the fluxes measured by AHEPAM to estimate the correlation k and used it to predict the background level during an observation and its accuracy, considering error propagation

Cross correlation with external particle monitors

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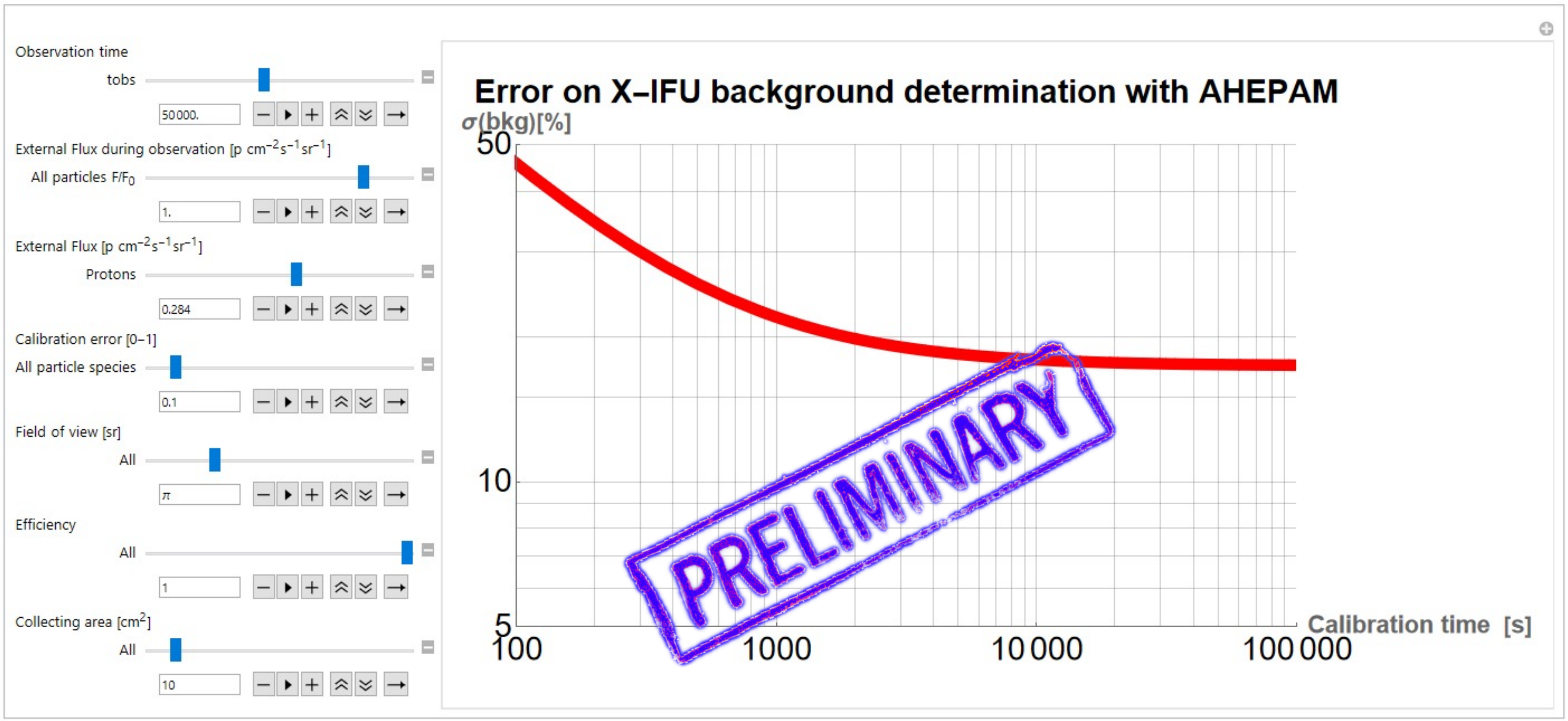
- We produced a software to investigate the effect of the AHEPAM and observation features on the accuracy of the background determination



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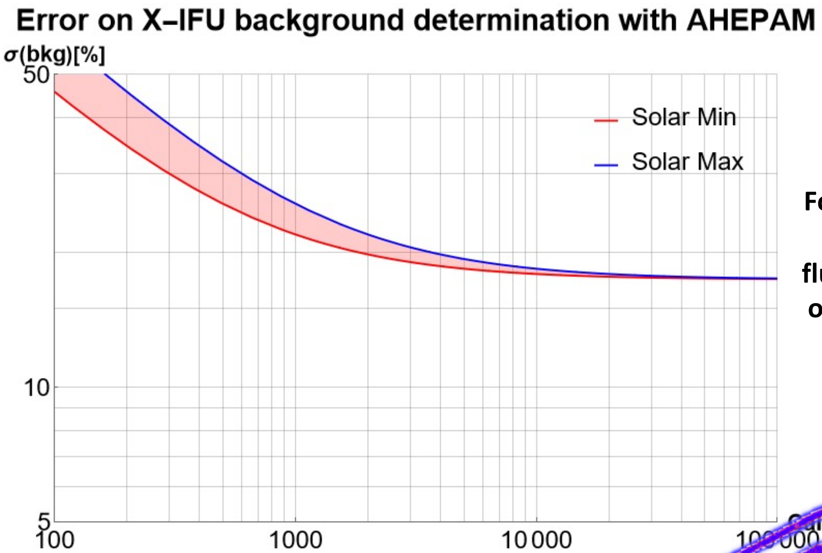
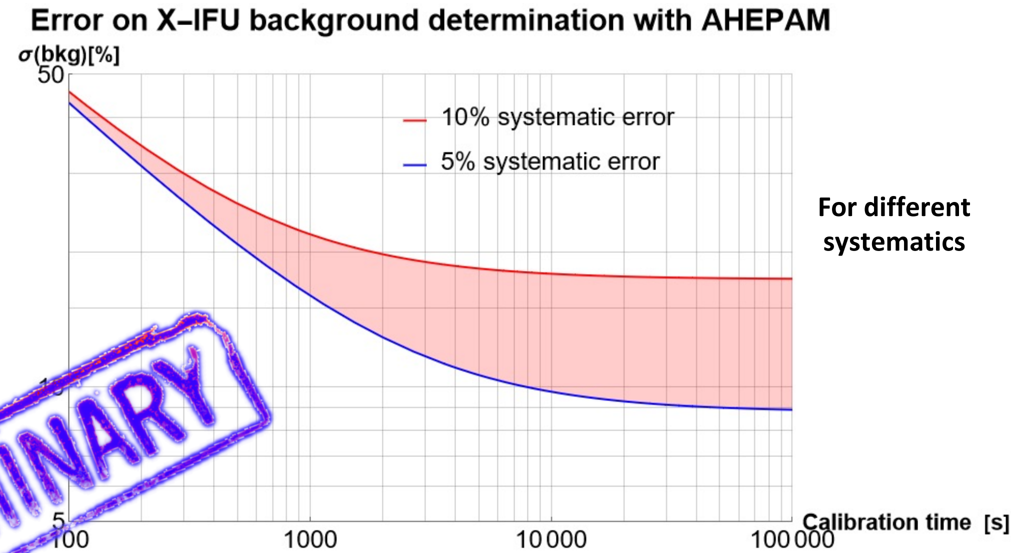
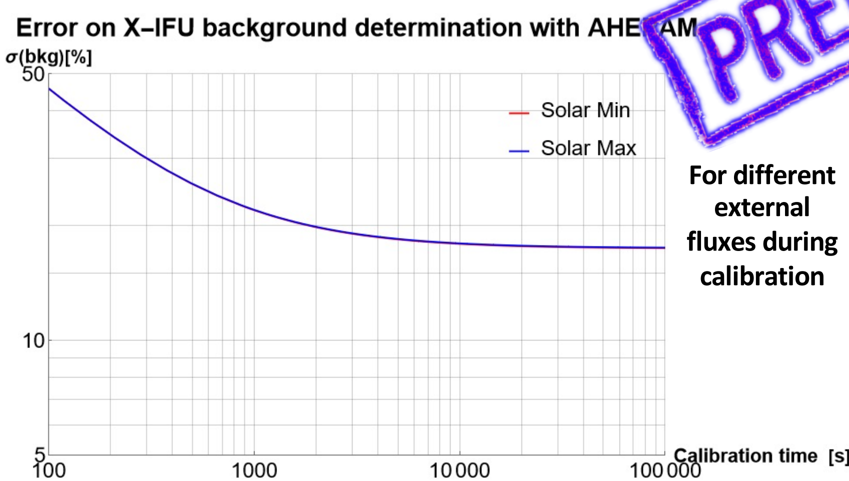
Cross correlation with external particle monitors



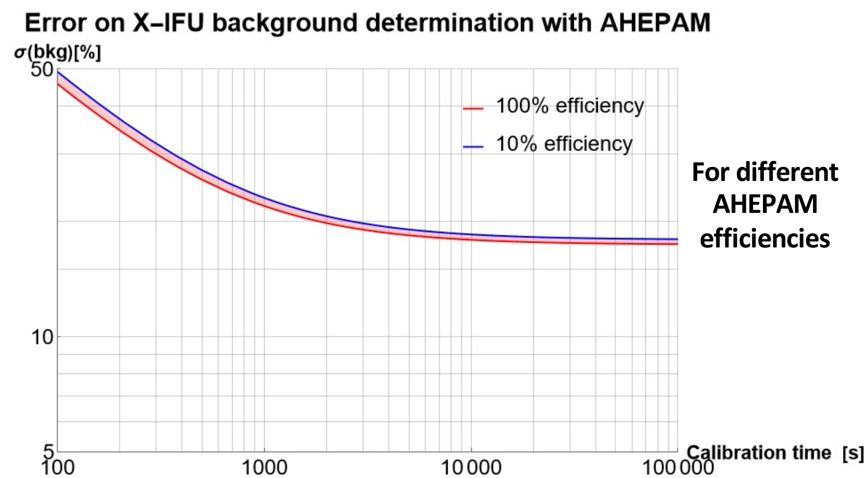
For different external fluxes during observation



For different systematics



For different external fluxes during calibration



For different AHEPAM efficiencies

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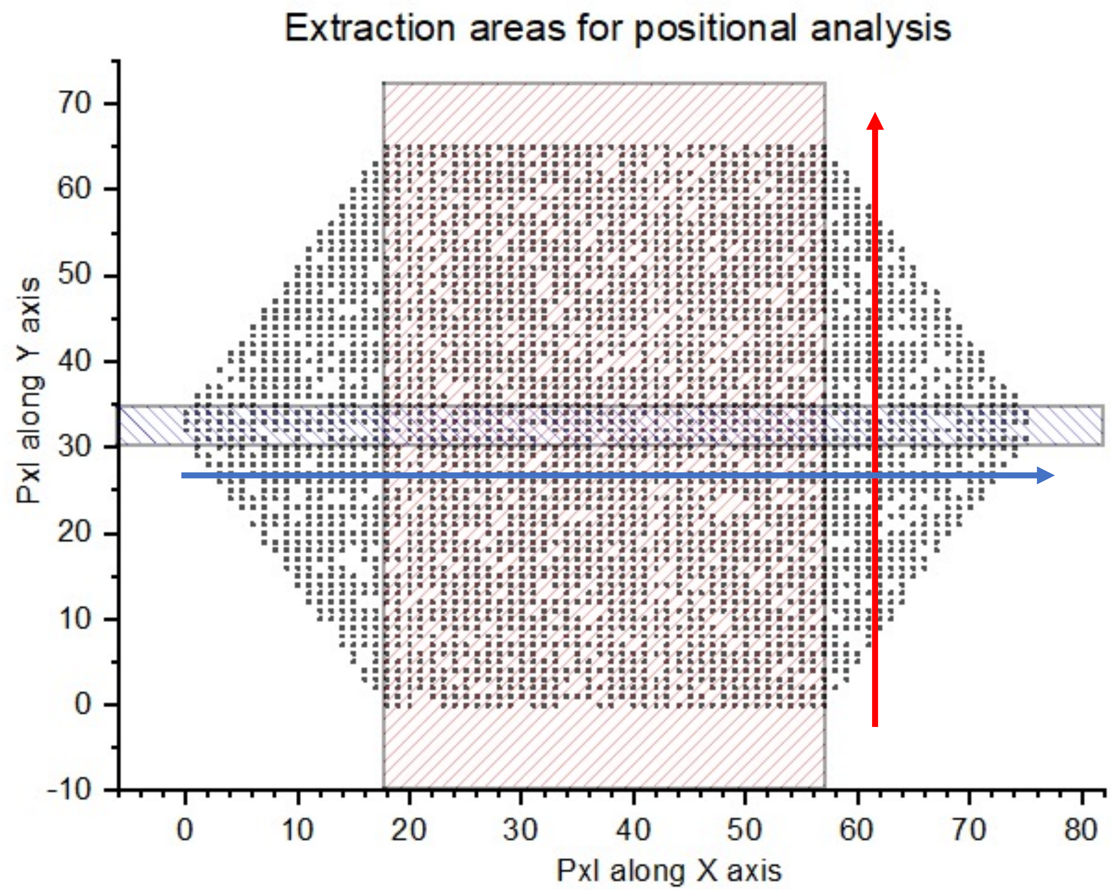
High statistics simulation result: background spatial distribution

Due to the hexagonal geometry of the detector, we defined 2 extraction areas and analyzed the background distribution.



High statistics simulation result: background spatial distribution

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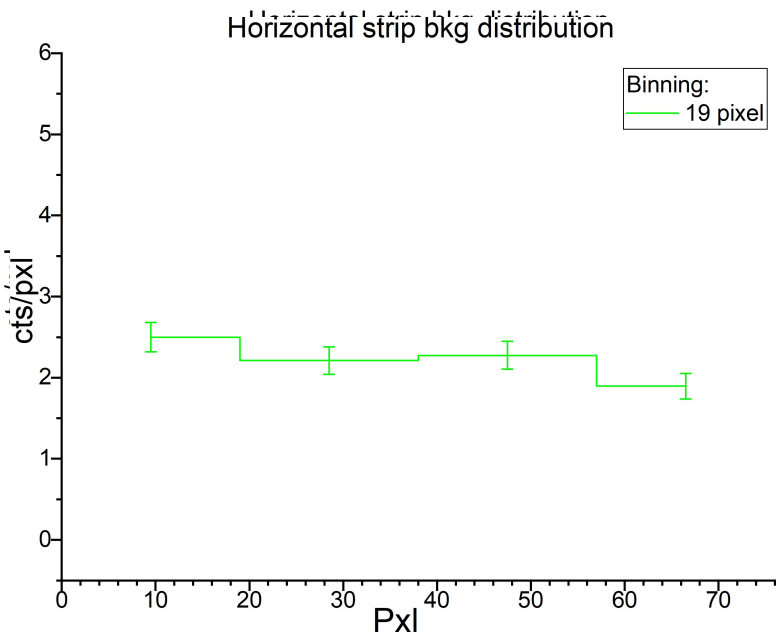
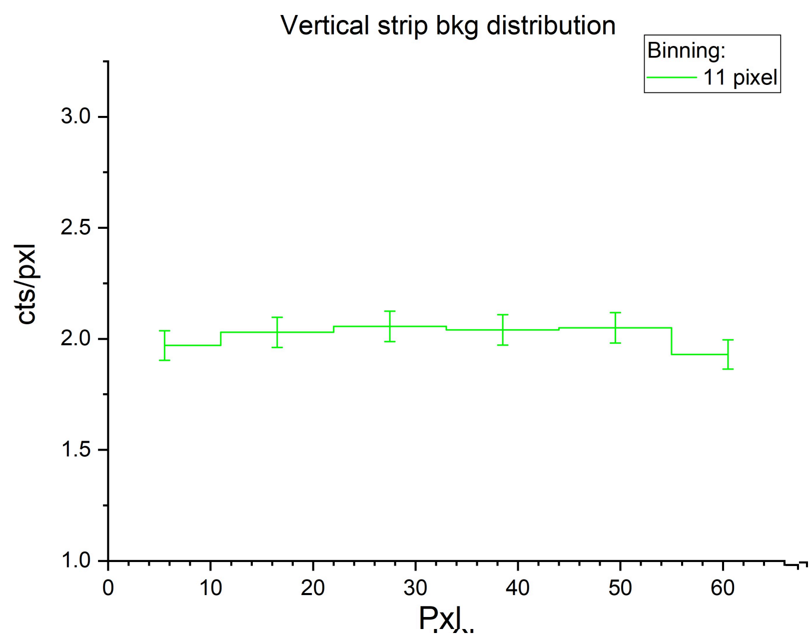
The background showed no spatial dependence in any direction → confirmed the goodness of the current CryoAC





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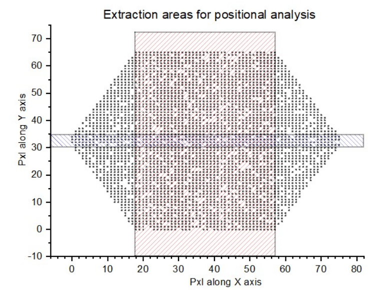
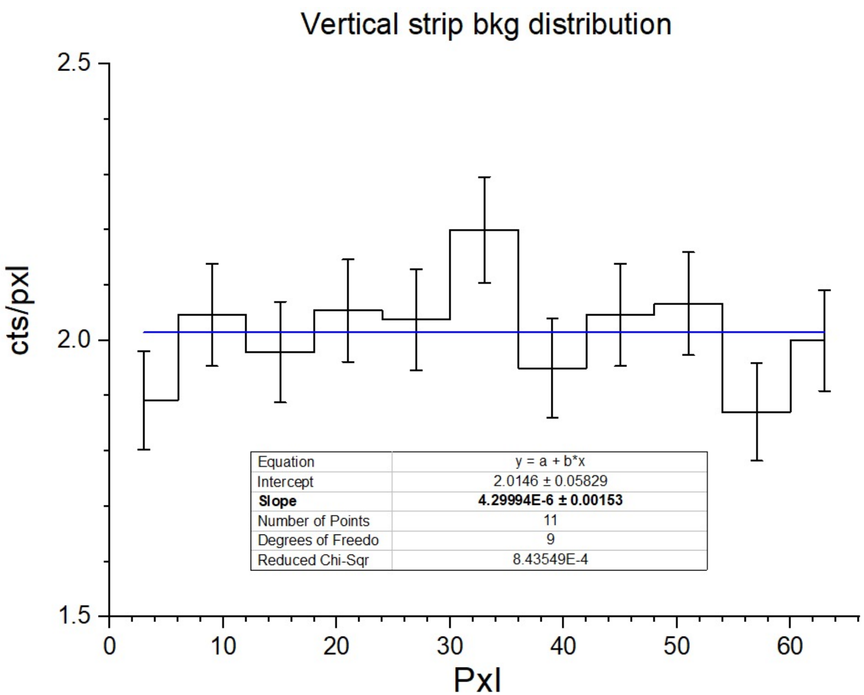
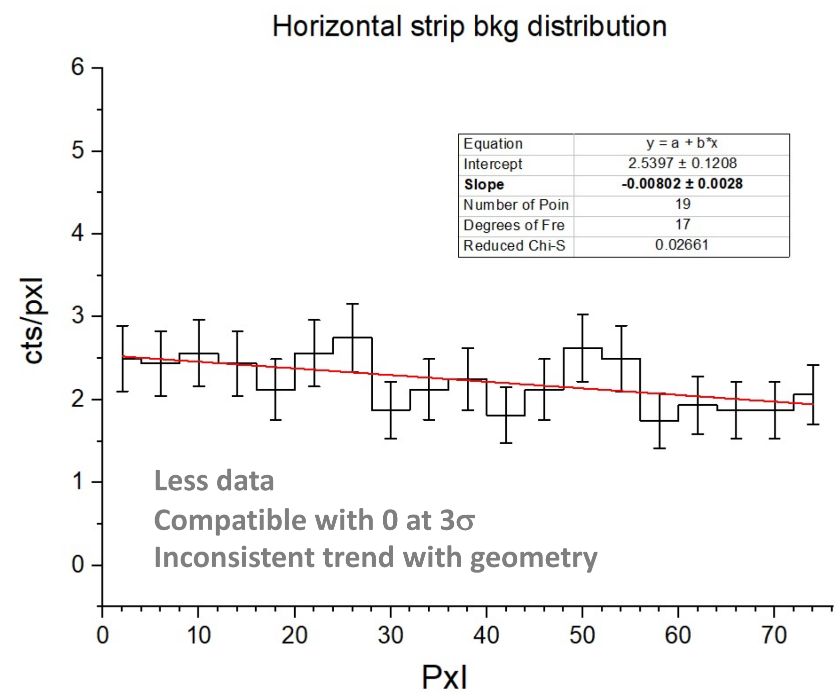
High statistics simulation result: background spatial distribution

The background showed no spatial dependence in any direction. Good for extended sources observations







High statistics simulation result: high energy background

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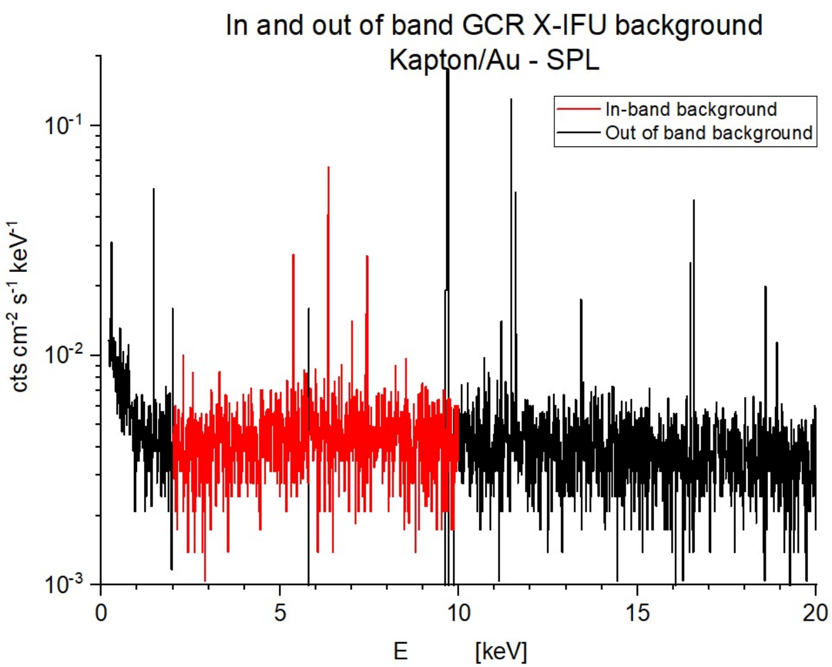
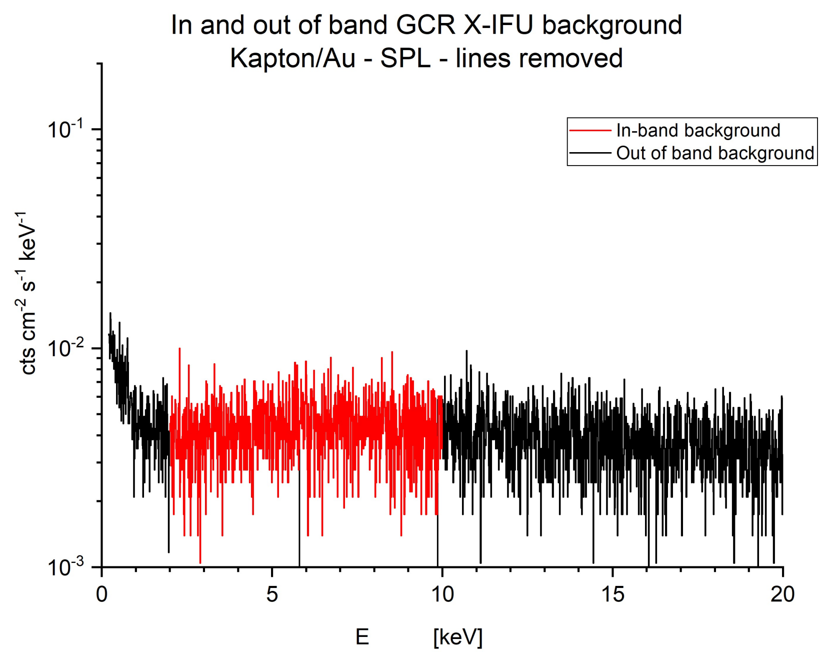
- The mirrors area drops to 0 above 12 keV, everything measured above is background induced by the same particles inducing the in-band counts. We can use these counts to monitor the X-IFU in-band background:

1. Lines removal





High statistics simulation result: high energy background

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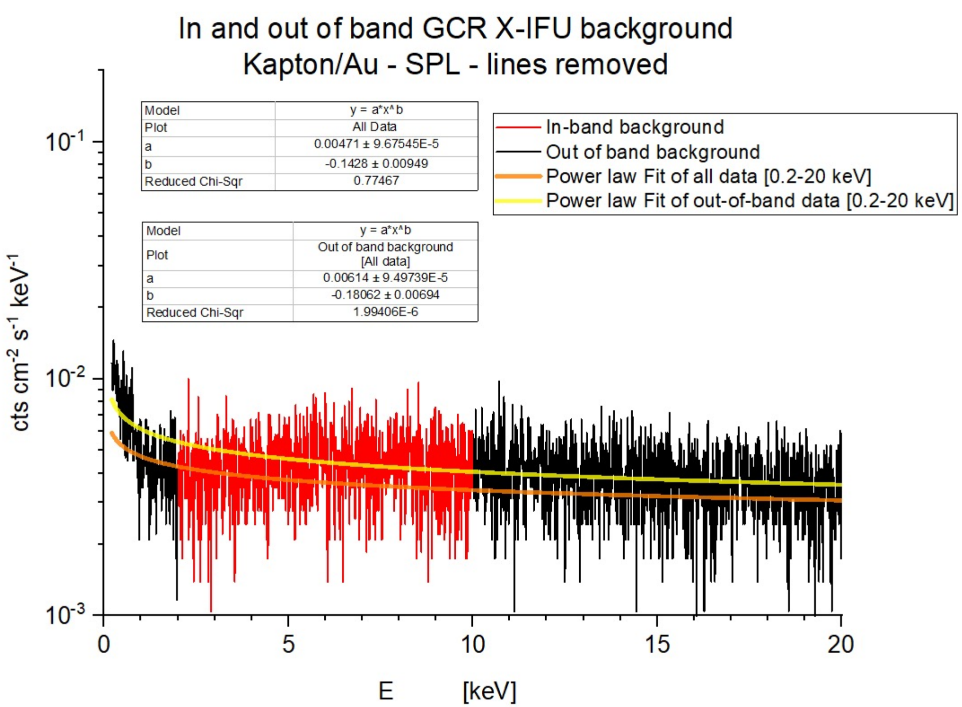
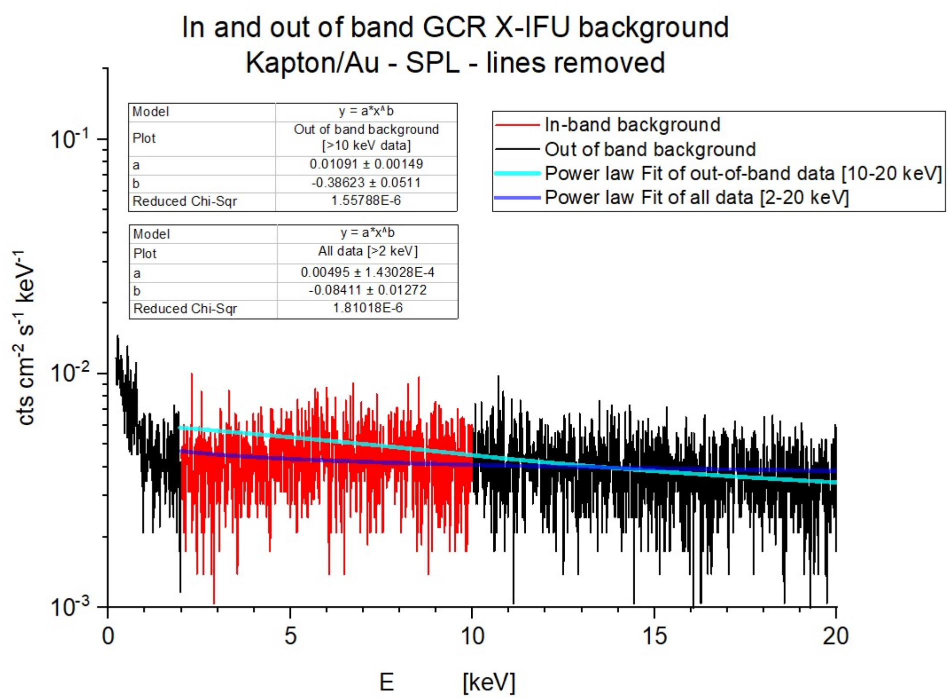
- The mirrors area drops to 0 above 12 keV, everything measured above is background induced by the same particles inducing the in-band counts. We can use these counts to monitor the X-IFU in-band background:

2. Data fit





High statistics simulation result: high energy background

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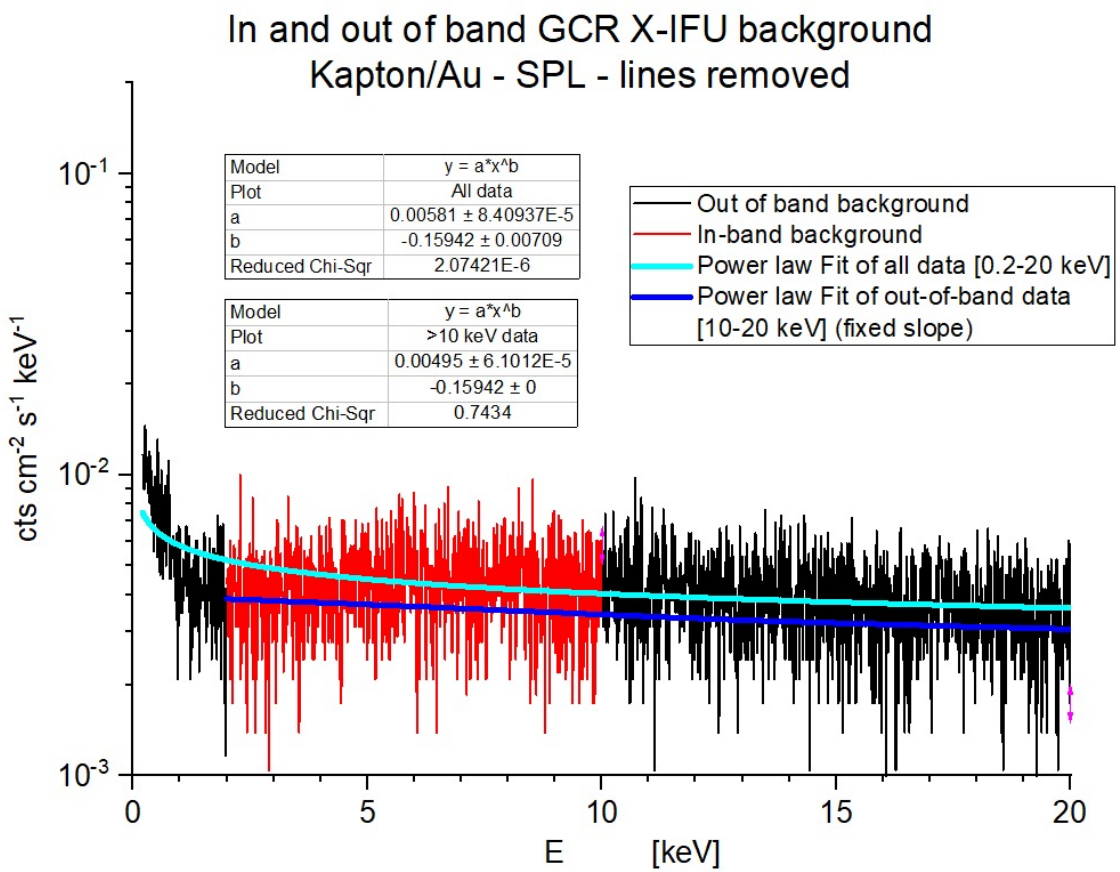
- The mirrors area drops to 0 above 12 keV, everything measured above is background induced by the same particles inducing the in-band counts. We can use these counts to monitor the X-IFU in-band background:

3. Improving fit strategy (ongoing)

4. Error and time dependence inclusion in the analysis (TBD)

5. More realistic fit modeling (TBD)



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High statistics simulation result: scientific assessment of the CryoAC capabilities in the hard X-ray band (10-20 keV)

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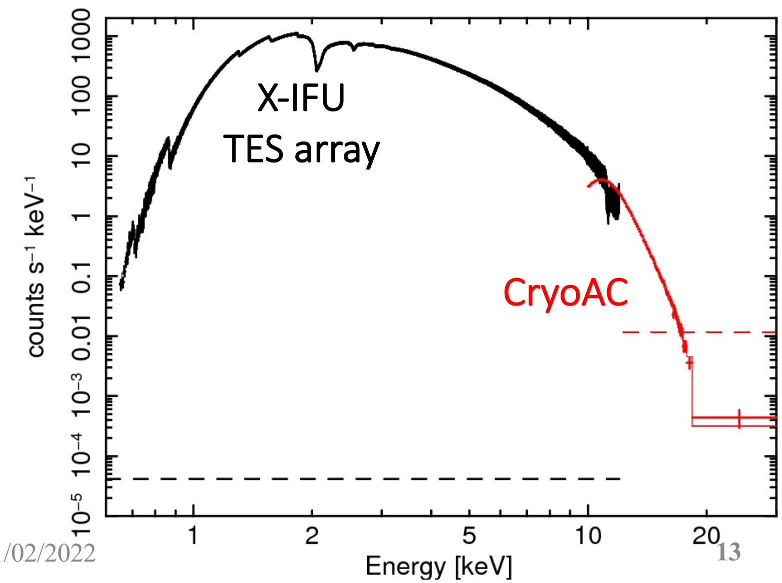
First study performed in 2017
(DOI 10.1007/s10686-017-9543-4)

- In the baseline configuration the CryoAC can operate as hard X-ray detector in the **band 10–20 keV**.
  Limit flux (5σ, 100 ks, 1 pixel): **$1.6 \cdot 10^{-12}$ erg/cm²/s** (~ 0.2 mCrab).
- The energy band is limited by the drop of the optics effective area at high energies, and not by the detector features.
- An optimization of the CryoAC energy resolution up to **ΔE_{FWHM} = 2 keV** could have a scientific return in the observation of bright sources with a spectral cutoff in this band.

Table 1 Limit fluxes for the CryoAC compared with the reference ones for NUSTAR and ATHENA X-IFU (t = 100 ks, n_σ = 5)

Instrument	Energy range [keV]	F_{min} [erg/cm²/s]	F_{min} [mCrab]	Notes and refs.
CryoAC	10–20	$1.6 \cdot 10^{-12}$	0.2	1 pixel
CryoAC	10–30	$6.3 \cdot 10^{-12}$	0.5	1 pixel
NUSTAR	10–30	$5.0 \cdot 10^{-14}$	$0.4 \cdot 10^{-2}$	[11]
ATHENA X-IFU	2-10	$3.2 \cdot 10^{-16}$	$1.6 \cdot 10^{-5}$	Point source [12]

HMXB spectrum with a cut-off at E_C = 12 keV, 50ks observation, Flux 0.2-20 keV = 100 mCrab



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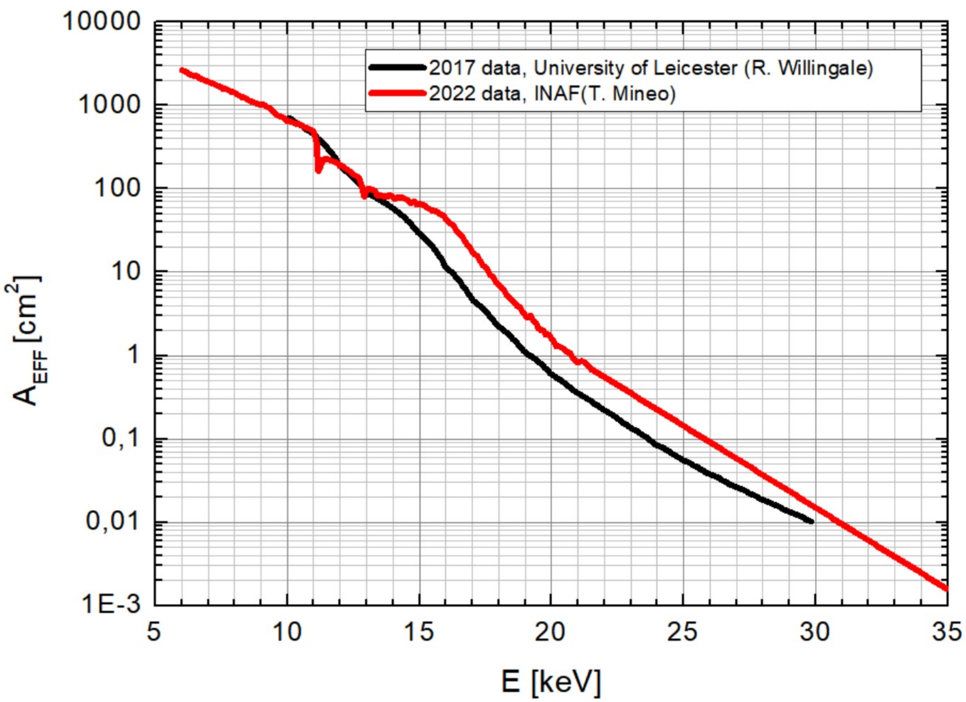
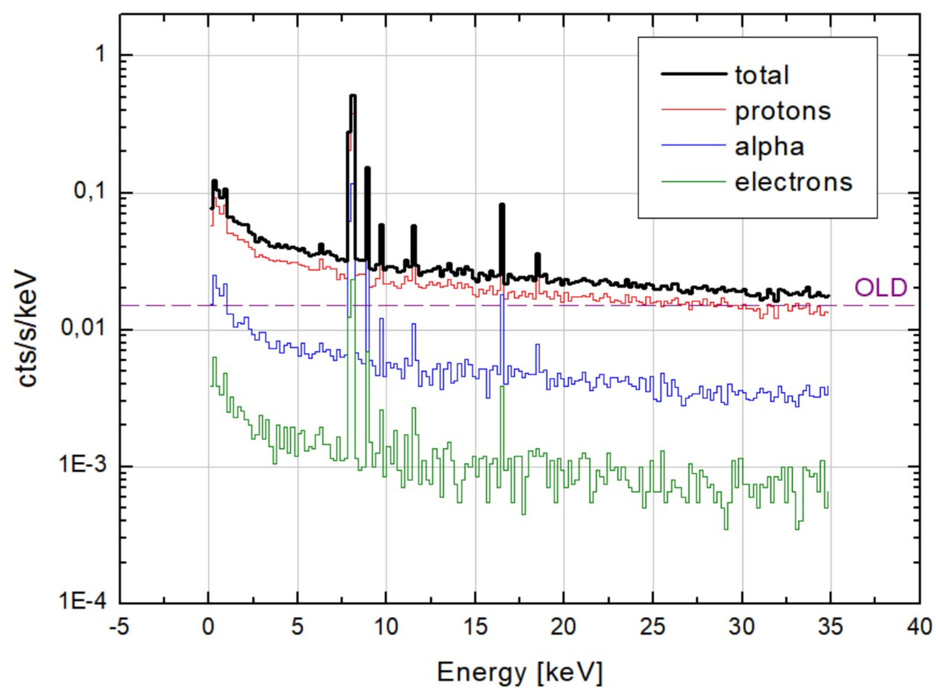
High statistics simulation result: scientific assessment of the CryoAC capabilities in the hard X-ray band (10-20 keV)

Optics effective area at high energy evaluated by ray-tracing simulations



Background level updated to the last 100 ks FPA simulation



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High statistics simulation result: scientific assessment of the CryoAC capabilities in the hard X-ray band (10-20 keV)

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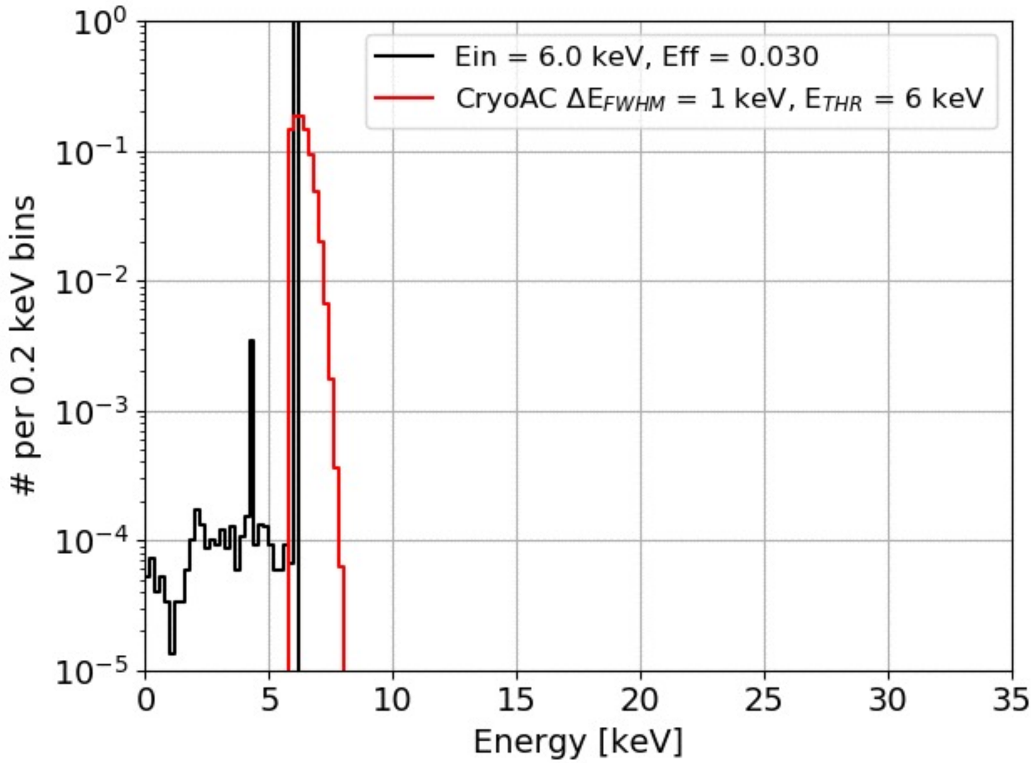
Assumed gaussian responde in 2017 work
Definition of a proper CryoAC redistribution MATRIX via GEANT4 simulation, accounting for Compton and CryoAC quantum efficiency



We created .arf (ray-tracing) and .rmf (Geant4) files for the CryoAC

Need to assess the observational capabilities towards different sources:

- 10 ks Crab
- AGNs
- HMXB

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Conclusions and future work

- Concluded a high statistics 100 ks simulation that enabled most of the work
- Background correlation with AHEPAM results look promising
  - Systematics dominate after calibration for a few ks (or few 10s of ks, depending on their absolute value)
  - Improve and possibly fix the model
  - Explore model results dependence on parameters
- Spatial background distribution proved to be rather flat on the detector → good for extended sources analysis
- High energy background can be used for background calibration:
  - Study ongoing
  - Neeed to improve fit strategy
  - Include errors in the fit
- Prepared a redistribution matrix for hard x-ray observations with CryoAC
  - Includes optics effective area (Ray-tracing)
  - Includes detector response (Geant4)
- Simulate sources observations with the CryoAC in the 10-20 keV band
- Prepare, run and analyze a set of simulations with the filter wheel closed position