Geant4 simulation of the LEO radiation environment on the X-ray prompt background:

the NHXM mission as a case study

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in collaboration with

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The shielding design of a space X-ray telescope is the result of detailed simulations of the space radiation physical interaction with the spacecraft, allowing to:

- test the shielding efficiency
- evaluate the background level, that in turns defines the expected sensitivity and the telescope performances

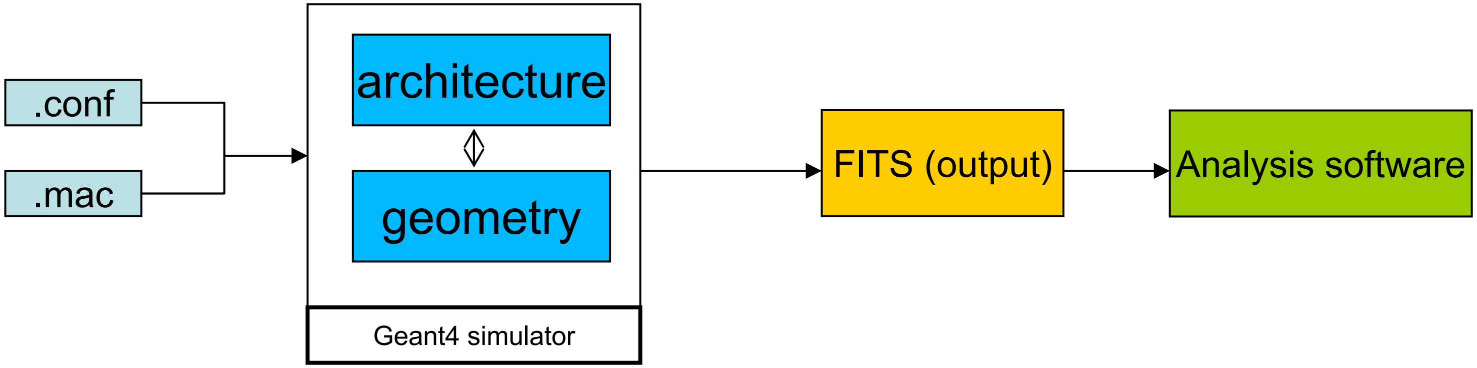
The results presented here refer to:

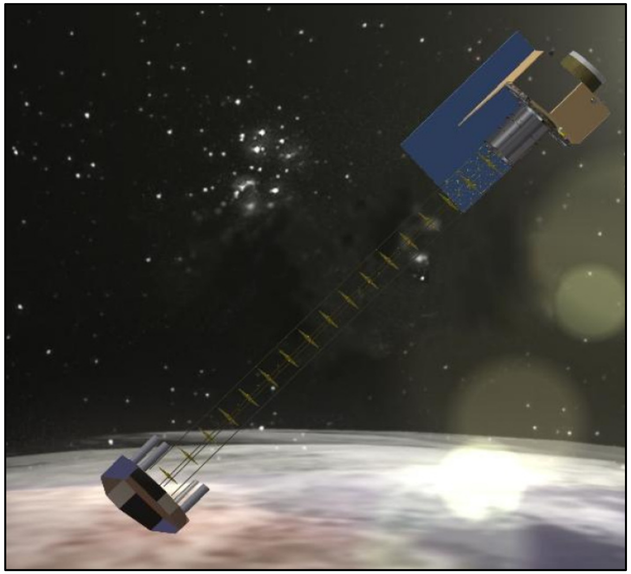
- the “prompt” background, i.e. due to signals in coincidence with the primary interactions and not to delayed events (decays)
- the shielding design of the NHXM X-ray camera as the case study
- the Low Earth Orbit radiation environment as particles source

The Geant4 simulator

On the basis of the Geant4 toolkit, we have built a customizable background simulator with the following properties:

- The simulator architecture connects the input parameters (from the .conf and .mac files) to the Geant4 libraries and the simulation output
- The configuration file (.conf) sets the geometry, the physics list and the output file, so that the same simulator can perform the background evaluation of completely different missions without changing the code
- The .mac uses the GPS to define the input particles
- The output is recorded as FITS files, a format widely used in Astronomy data analysis
- At the end, a dedicated analysis software, IDL based, filters the output as a real observation in space (e.g. pattern analysis, active shield triggering)





- Angular resolution < 20 arcsec HEW
- Focal length = 10 m (extendible bench)
- Four coaligned grazing incidence telescopes:
    - Three spectral-imaging cameras (0.5 – 80 keV)
    - One imaging polarimeter (2 – 35 keV)
- FOV ≥ 12´
- Effective area = 1000 cm^2 @ 5 keV, 350 cm^2 @ 30 keV
- Planned orbit = Low Earth Orbit (mean altitude = 550 km, low inclination)
- Launch date = 2016?

The X-ray spectral-imaging focal plane is hybrid:

- Silicon Low Energy Detector (LED) = 0.5 – 20 keV
- CdTe High Energy Detector (HED) = 5 – 100 keV

Sensitivity < 1 μCrab (10 – 40 keV) → Background flux < 2 × 10^{-4} cts cm^{-2} s^{-1} keV^{-1}

The Geant4 simulation

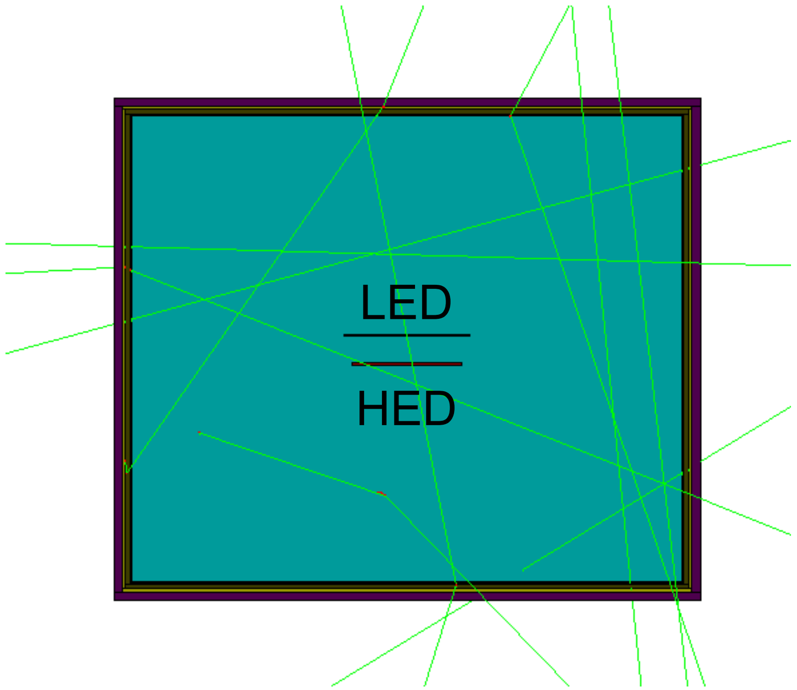
A simplified box-shaped active and passive shielding geometry is developed in order to characterize the impact of each class of particles on the background level:

- Active shielding (external) = Plastic scintillator

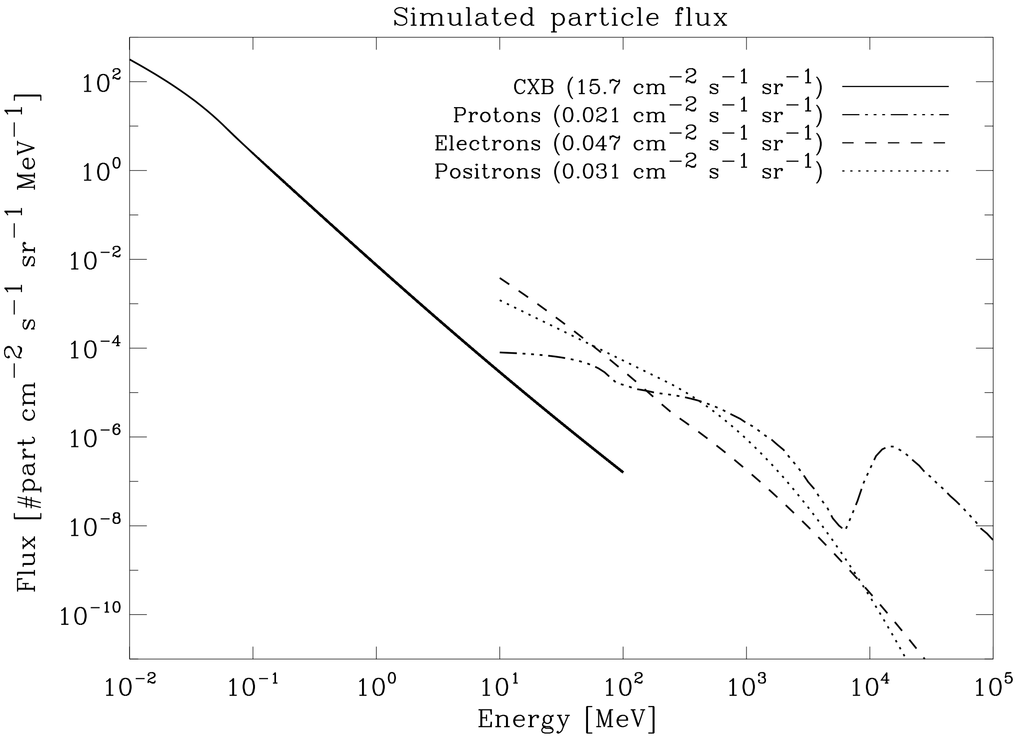
If the active shield signal (an energy deposit above the AC) is followed by an (almost) coincidence event in the detector, then the detected count can be discarded because produced by the same background particle and not by the observed X-ray source.

- Passive shielding (internal) = Tantalum + graded layers (Sn+Cu+Al+C)

an high Z, high photoelectric cross-section material that prevents the CXB photons from reaching the detectors through directions outside the telescope field of view.



The simulated space radiation environment*



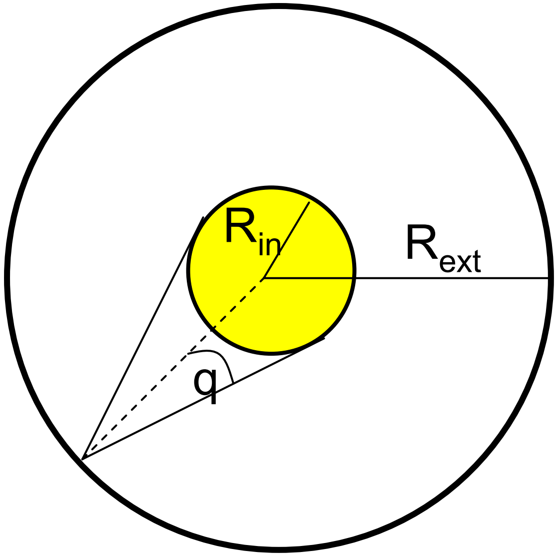
The ingredients are:

- **Cosmic X-ray Background (CXB, Gruber et al. 1999)**
- **Primary (Cosmic rays) and secondary (albedo) protons**
- **Secondary (albedo) electrons and positrons**

All the particles are emitted from a 4π sphere

**Proton, Electron and Positron spectra are courtesy of the AGILE (Tavani et al. 2006) team*

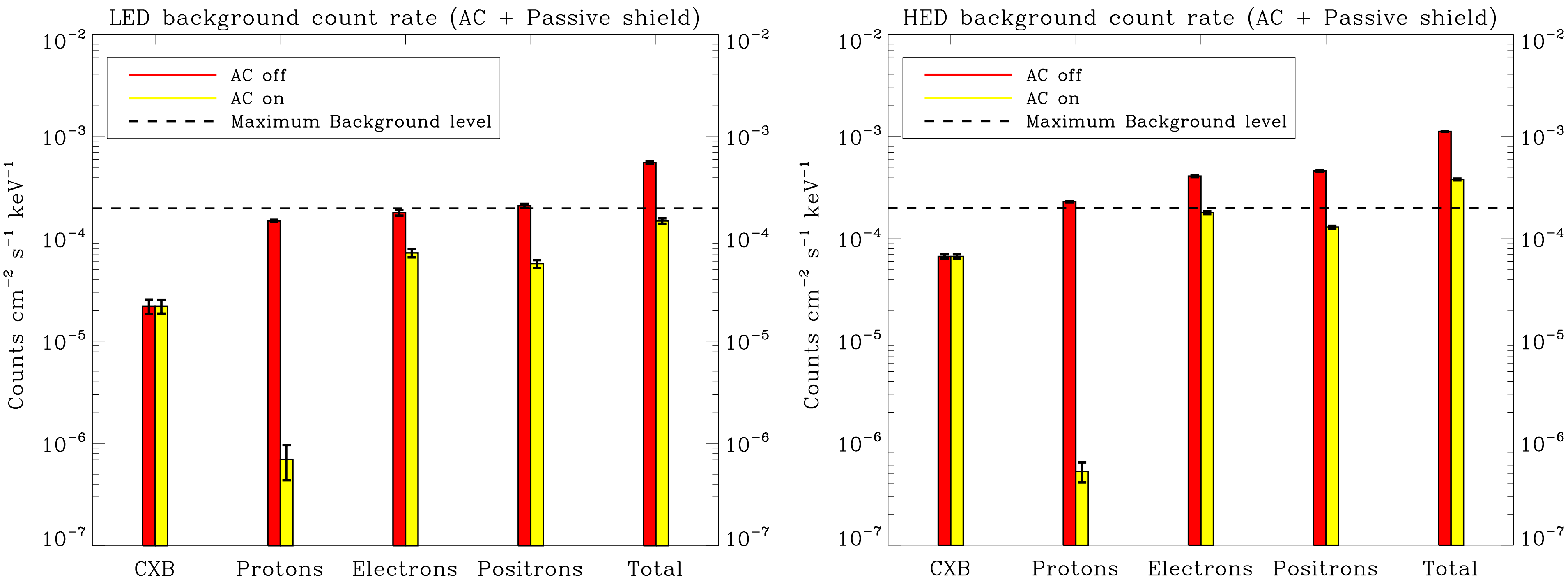
Simulation set-up



Particle	AC threshold	R_{ext}	q	$N_{emitted}$	Exposure time
Photons	1 MeV	50 m	0.003 rad	2×10^9	14.3 ks
Protons	1 MeV	50 m	0.003 rad	3×10^6	15.7 ks
Electrons	1 MeV	50 m	0.003 rad	1×10^6	2.4 ks
Positrons	1 MeV	50 m	0.003 rad	1×10^6	3.6 ks

Results

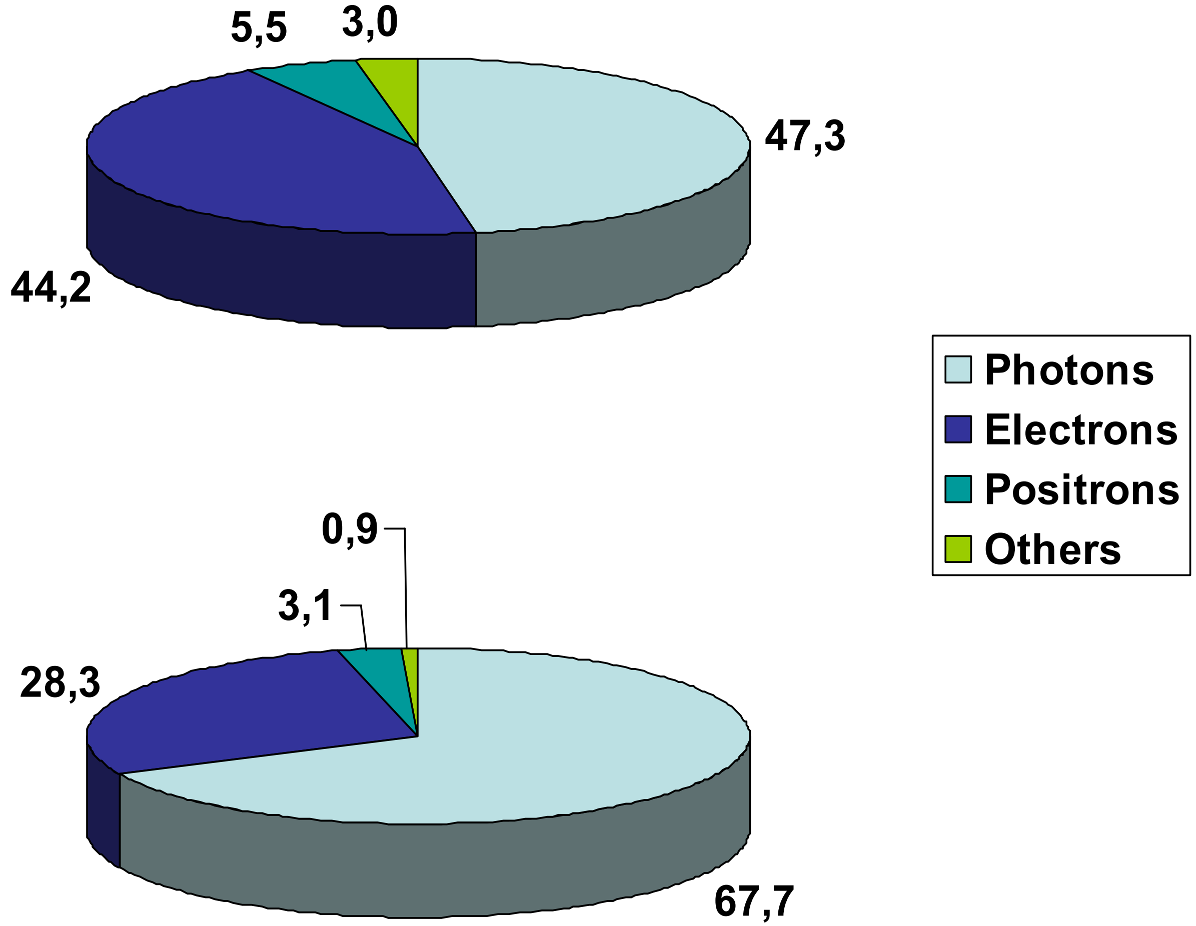
Energy averaged background count rate



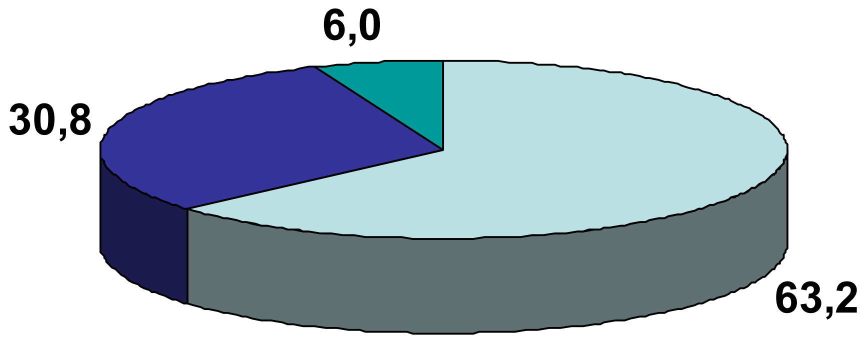
- The HED background is about a factor 2 higher than LED
- The 1 MeV AC threshold shields efficiently the protons (99% of triggered events) but not the electrons (43%) and positrons (28%)

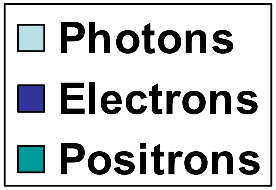
LED

HED

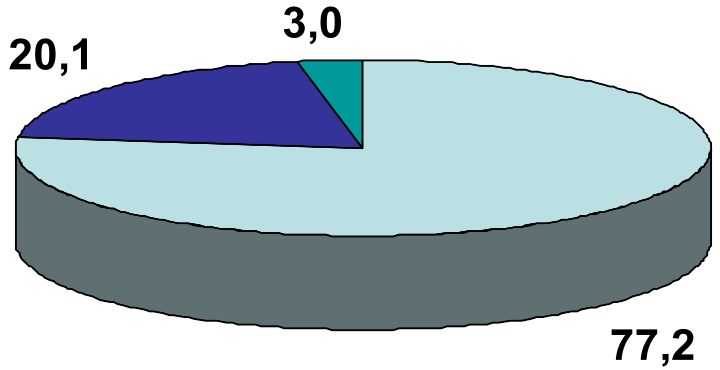

5,5
3,0
47,3
44,2
0,9
3,1
28,3
67,7
Photons
Electrons
Positrons
Others

LED

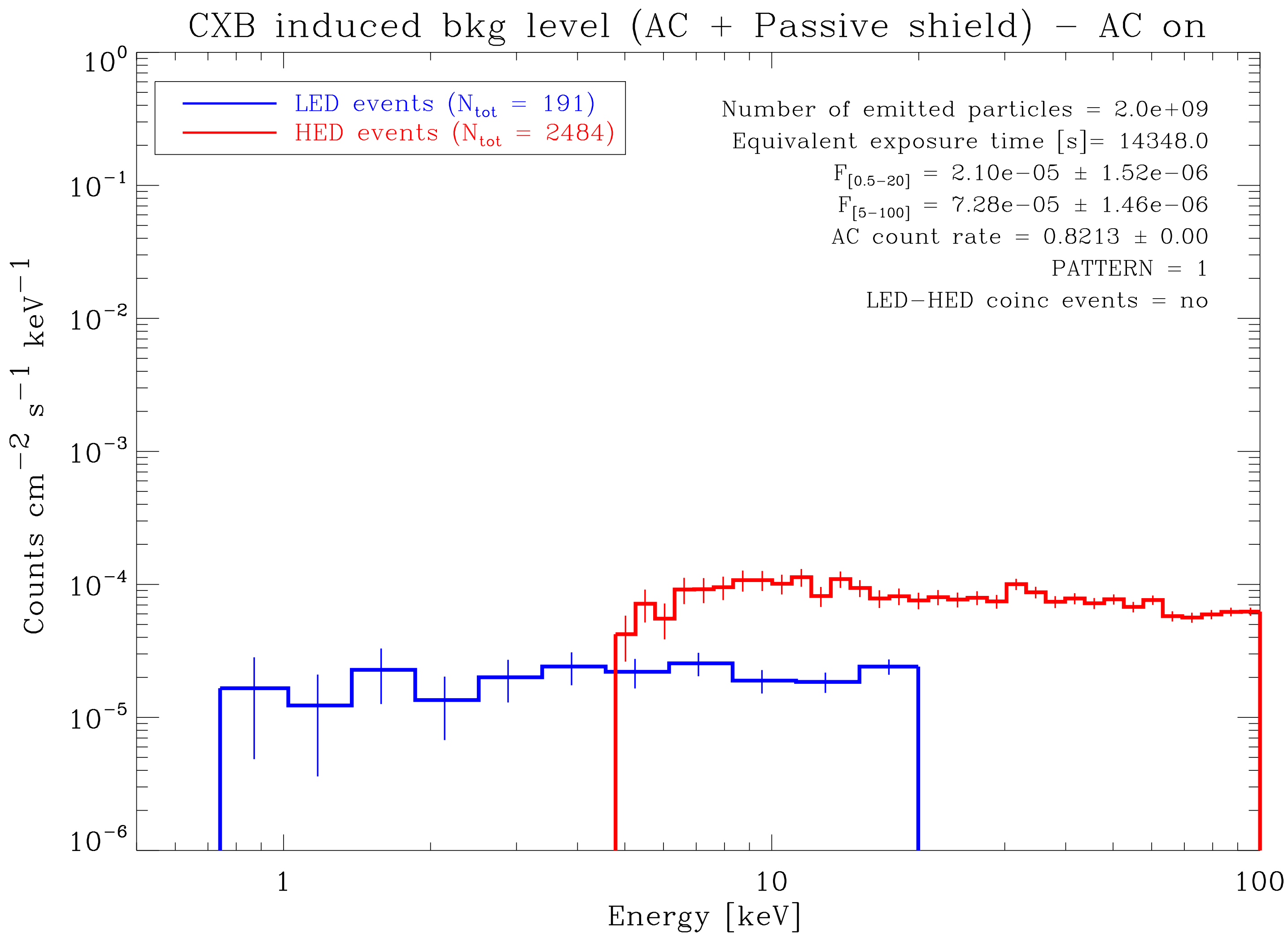




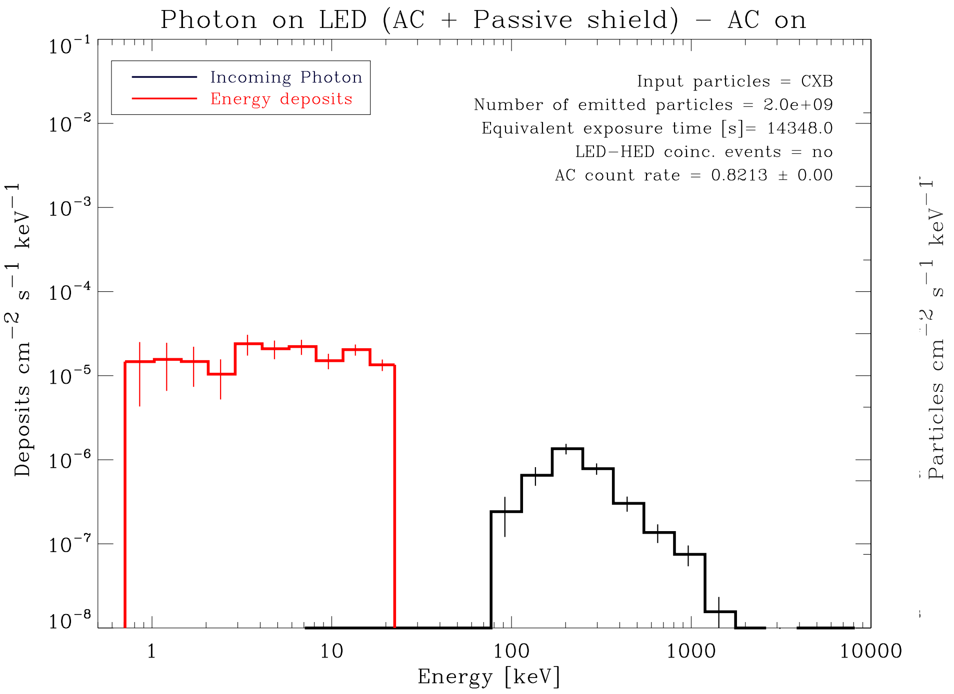
HED



Background spectrum - Photons



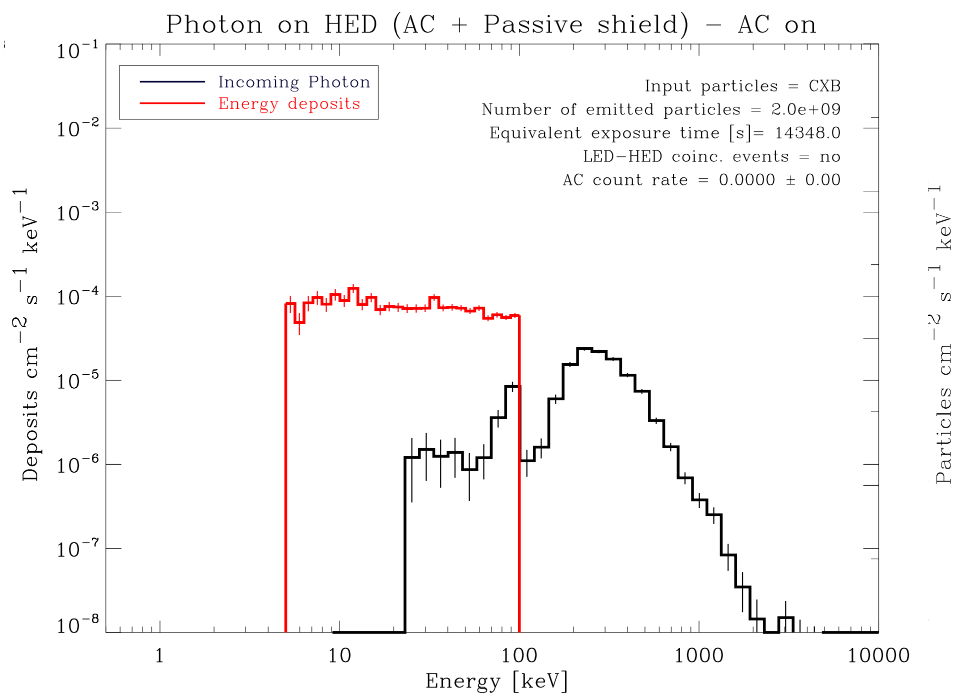
Background spectrum - Photons



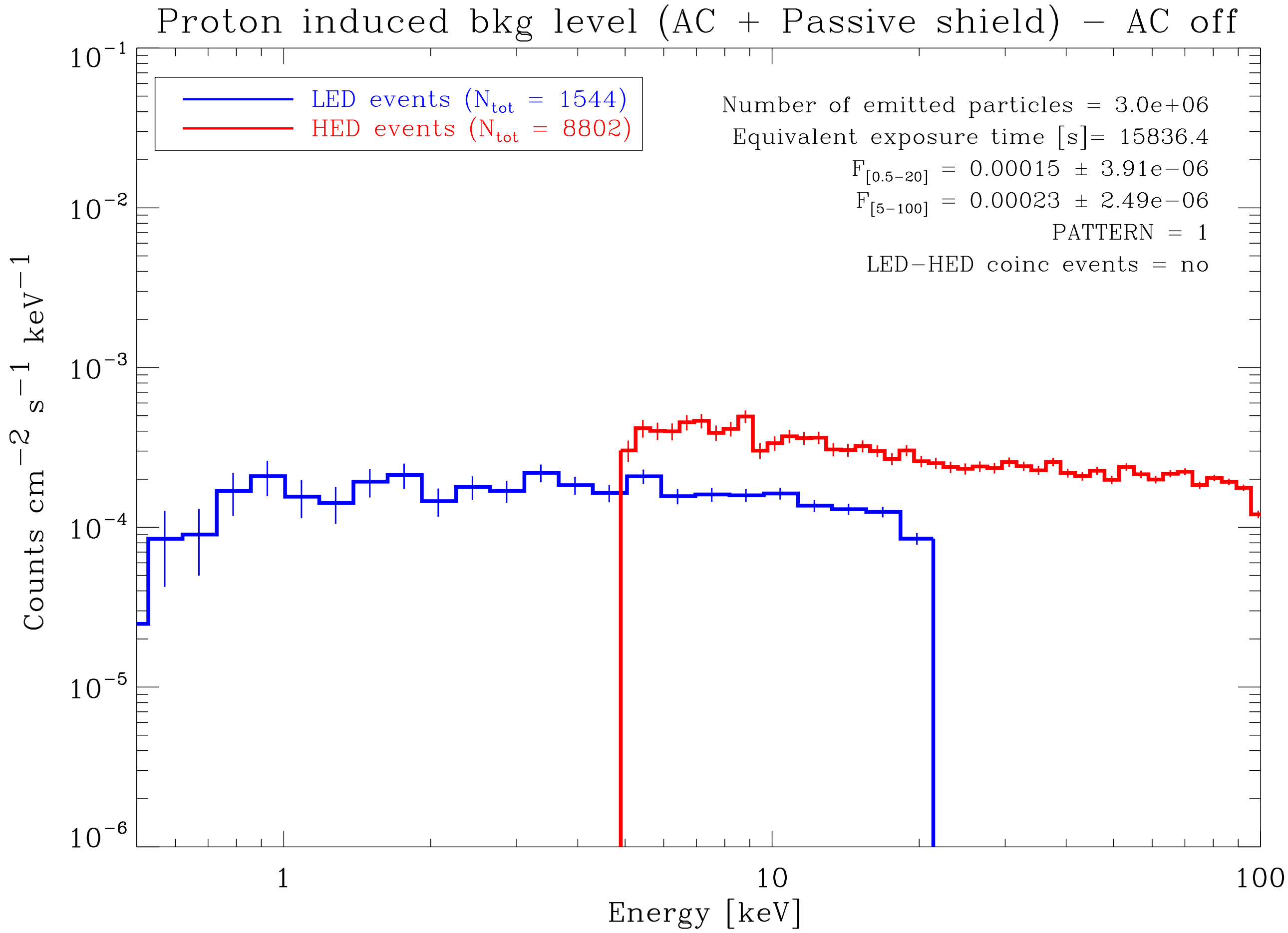
Photons generating the background signals:

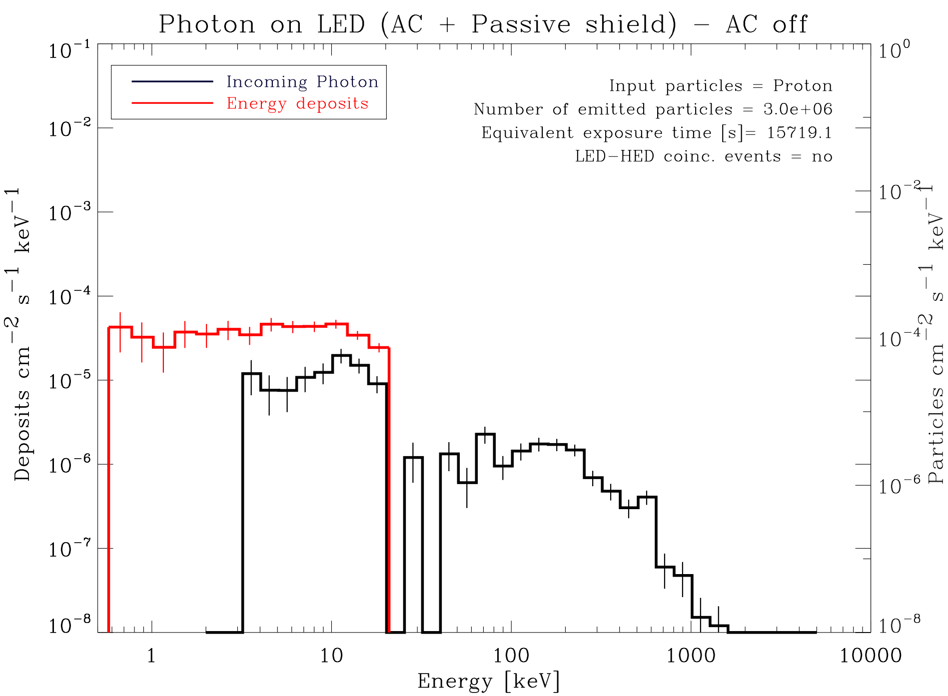
- **Red line** = energy deposits

- **Black line** = photon energy



Background spectrum – Protons (AC off)





Photons generating the background signals:

- **Red line** = energy deposits
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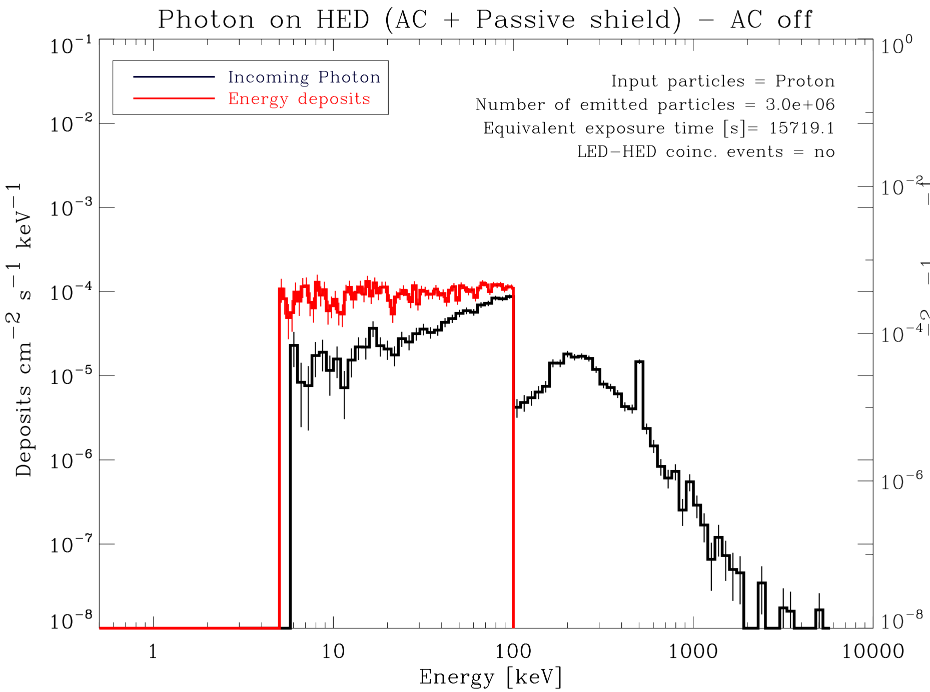
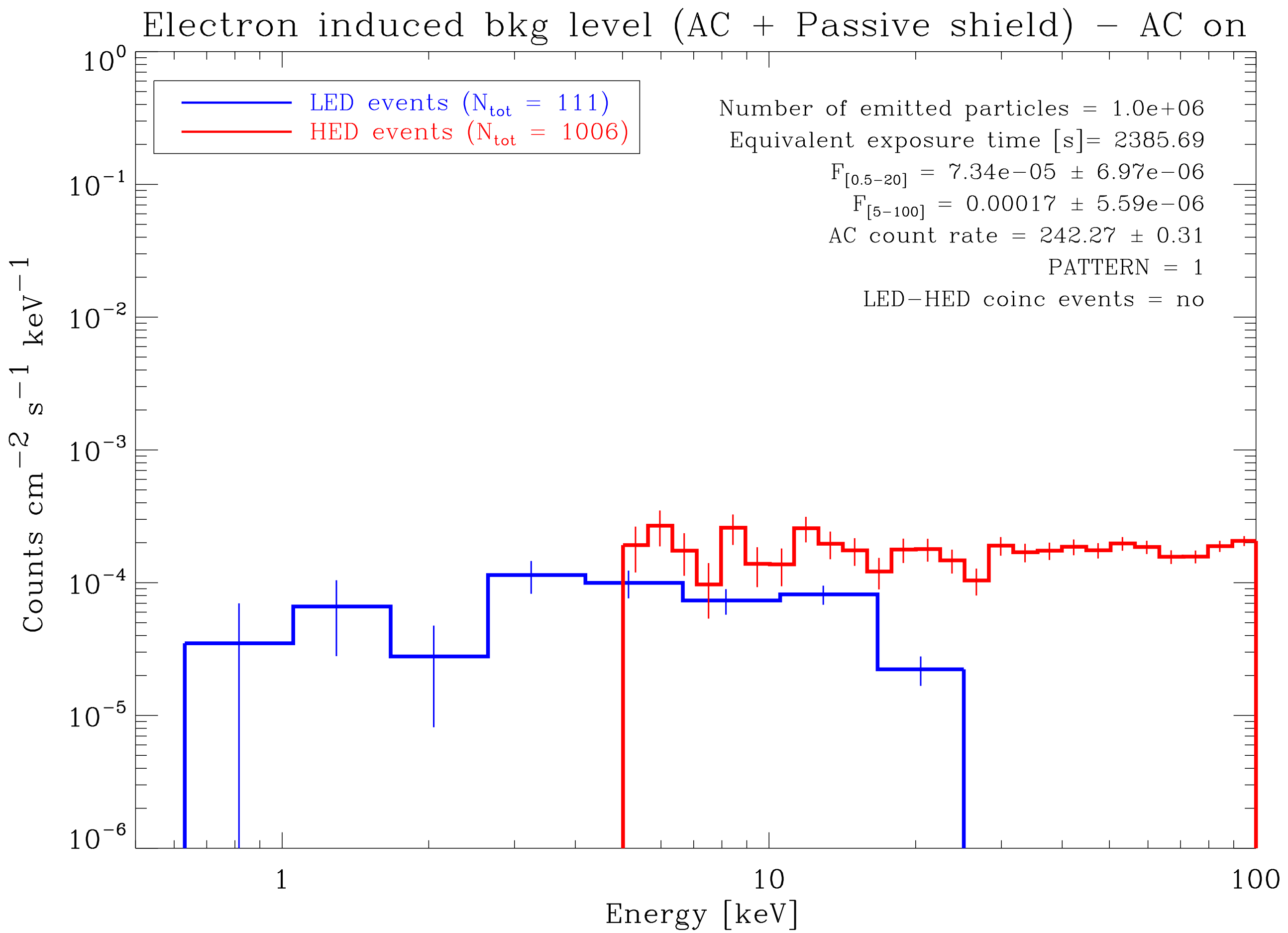
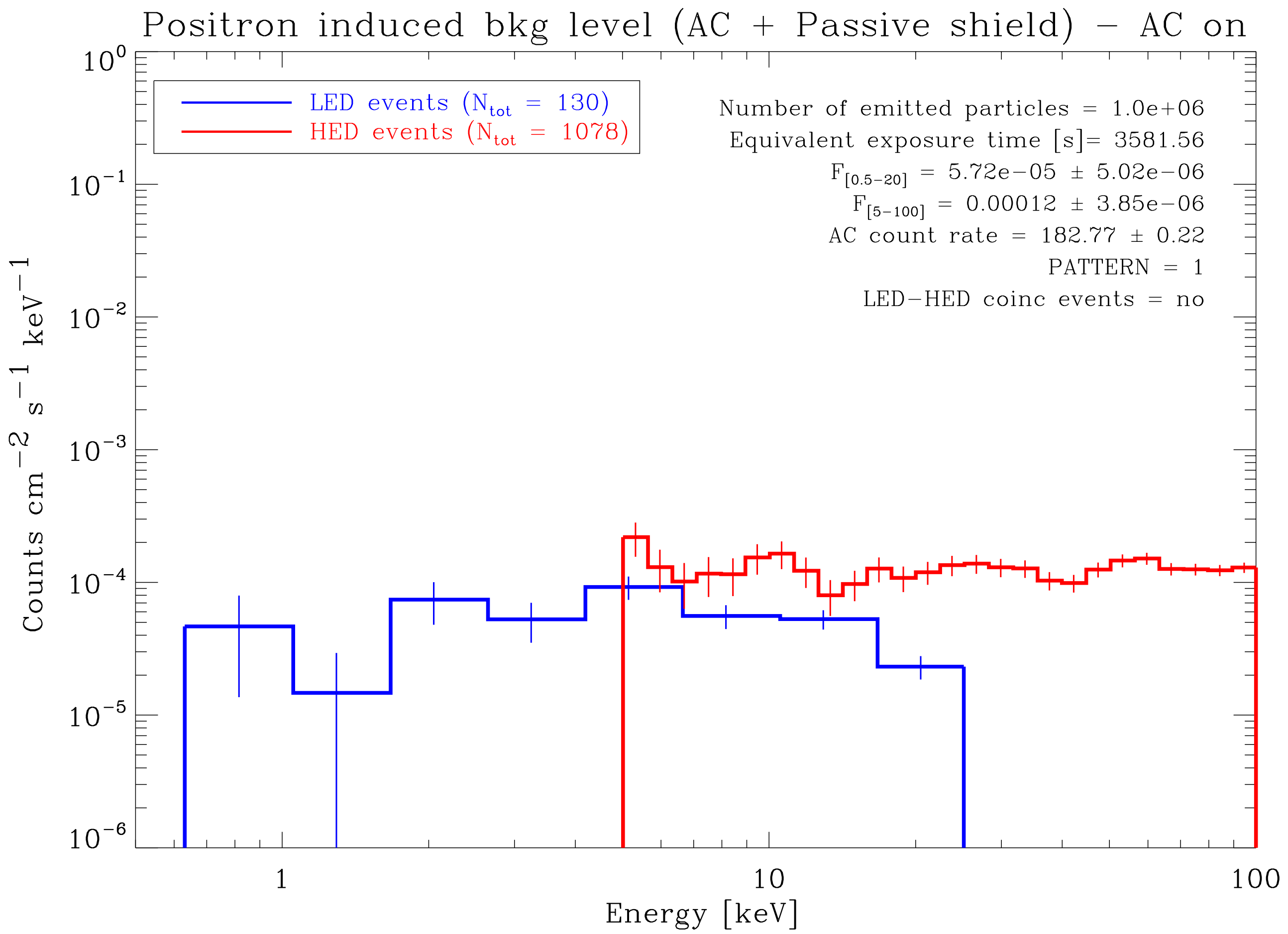


Background spectrum - Electrons



Background spectrum - Positrons



Conclusions

Geant4 programming:

• Development of a customizable Geant4 simulator for background evaluation

• Development of a dedicated analysis software for background spectra production and evaluation of the active shield count rate

General considerations from the background results:

• The CXB induced background is caused by Compton scattering of high energy (hundreds of keV) photons

• The active shield, with a 1 MeV threshold, is less efficient on shielding electrons and positrons respect to protons

• The resulting background is mainly induced by photons (63.2% on the LED, 77.2% on theHED) and electrons (30.8% on the LED, 20.1% on the HED)

• The continuum prompt background is roughly constant