From AGILE to e-ASTROGAM: Geant4 simulations in the pair regime

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ABSTRACT

BoGEMMS (Bologna Geant4 Multi-Mission Simulator [1]) is a modular and parameterized Monte Carlo simulator based on the Geant4 [2] toolkit developed at INAF/IASF Bologna. The BoGEMMS gamma-ray branch [3], allowing the configuration at run time of the tracker, calorimeter, and anticoincidence system of an electron-tracking gamma-ray telescope, has been validated by the simulation of the AGILE [4] in-flight Point Spread Function (PSF). The framework is now used for the simulation of the scientific performance, in the pair regime, of the e-ASTROGAM next-generation Compton and Pair gamma-ray mission [5], proposed to the ESA M5 2016 call. We present the main results of a prototype processing pipeline composed by Geant4 simulations, Kalman filtering, event reconstruction analysis and Instrument Response Function production in the 10 MeV – 3 GeV energy range. Thanks to the experience gained in the design of AGILE simulations and analysis algorithms, the BoGEMMS simulator is of crucial importance for on-board trigger studies, PSF determination and sensitivity evaluation of the e-ASTROGAM mission.

The enhanced-ASTROGAM mission

- a Compton and pair creation mission concept to be operated in LEO proposed to the ESA Call for the fifth Medium-size mission (M5) of the Cosmic Vision Science Programme;
- planned launch date is 2029.
- sensitive to the 0.3 MeV – 3 GeV energy range thanks to:
  - a Tracker made of 56 planes of double-sided Si strip detectors with a total area of 1 m^2;
  - a Calorimeter composed by an array of 5×5×80 mm^3 CsI(Tl) bars;
  - surrounding plastic scintillation panels acting as Anticoincidence system (AC) and a Time of Flight veto system for background minimization;
- continuum sensitivity < 5×10^{-5} MeV cm^{-2} s^{-1} at 10 MeV (T_{obs} = 10^6 s, high-latitude source)
- gamma-ray imager angular resolution ≤ 1.5° at 100 MeV (68% containment radius)

e-ASTROGAM scientific pipeline

A dedicated scientific pipeline (Fig. 1) has been developed for the simulation of the PSF, energy resolution, effective area, and background flux in the pair regime (10 MeV – 3 GeV). The resulting sensitivity evaluation is being used for scientific simulations and it is part of the e-ASTROGAM ESA/M5 proposal.

The pipeline building blocks are:

- Geant4 simulation (using BoGEMMS);
- Event reconstruction
- Kalman filtering

to get in the end a photon list for the IRF computation.

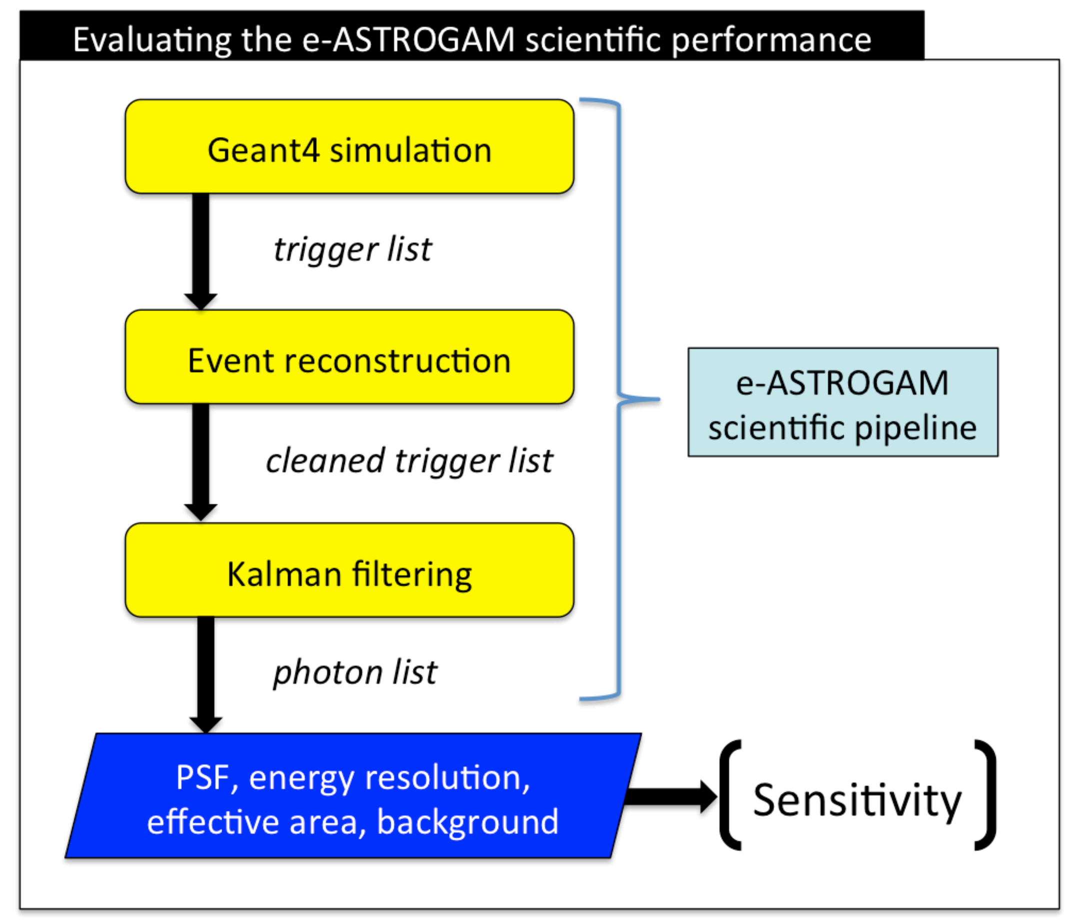


Figure 1. e-ASTROGAM scientific pipeline in the pair regime.

Geant4 simulation

Validation

- The BoGEMMS simulation framework has been validated by the AGILESim (BoGEMMS simulation of the AGILE/GRID instrument) application be means of the successful comparison of the in-flight and simulated PSF for Crab observations (*Fioretti+ in prep.*).
- BoGEMMS is being used for the e-ASTROGAM Geant4 simulation in the pair regime.

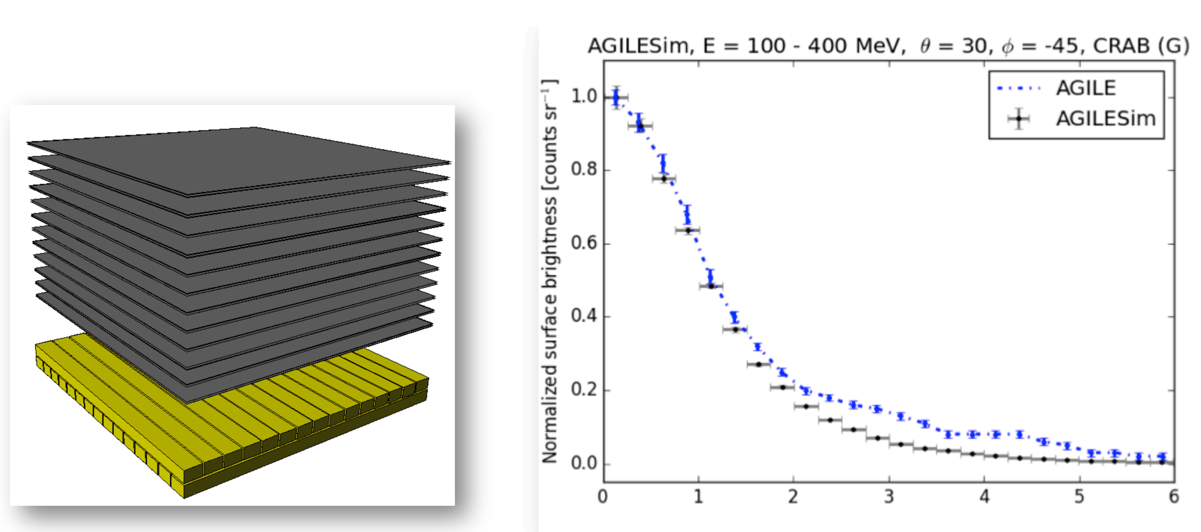


Figure 2. AGILE mass model (left panel) and comparison (right panel) between the simulated and detected PSF [6] in the 100 – 400 MeV energy range.

Mass model and simulation filtering

- The mass model is composed by the Tracker, the Calorimeter, and the AC system;
- the e-ASTROGAM simulation analysis main features:
  - Tracker DSSD energy threshold = 15 keV
  - Calorimeter energy threshold = 30 keV
  - Analogic readout applied
  - Cluster reconstruction and baricentered position applied

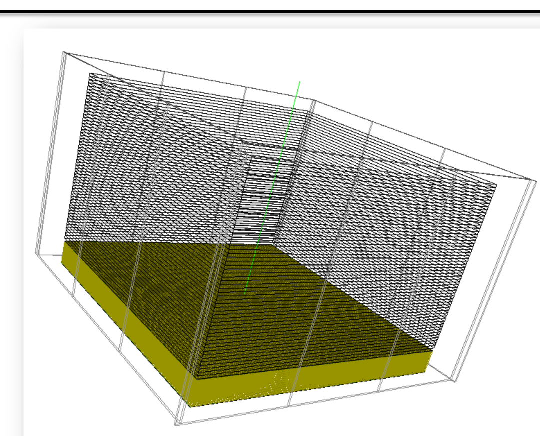
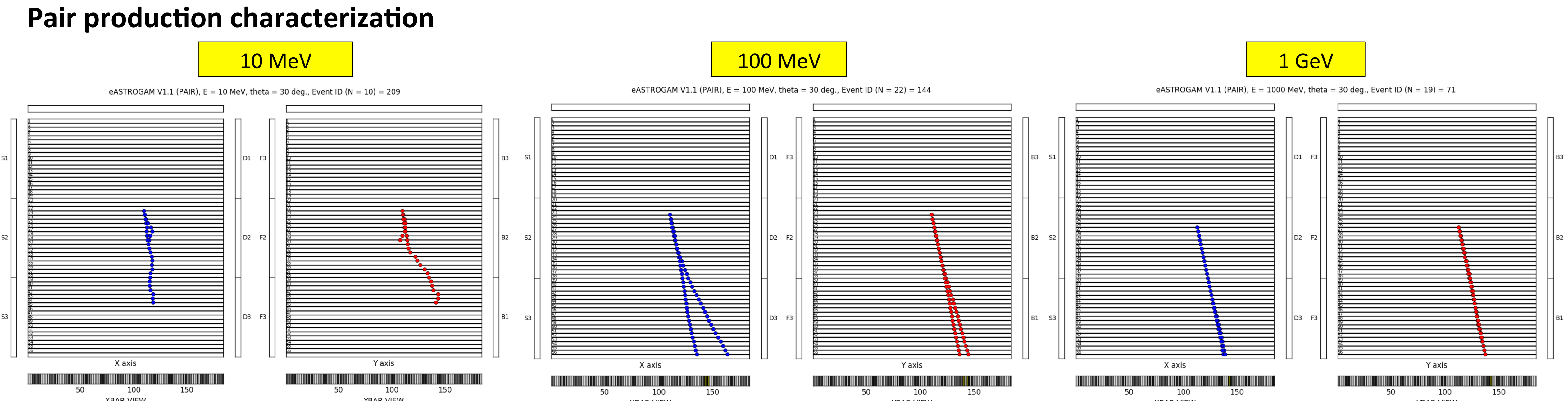


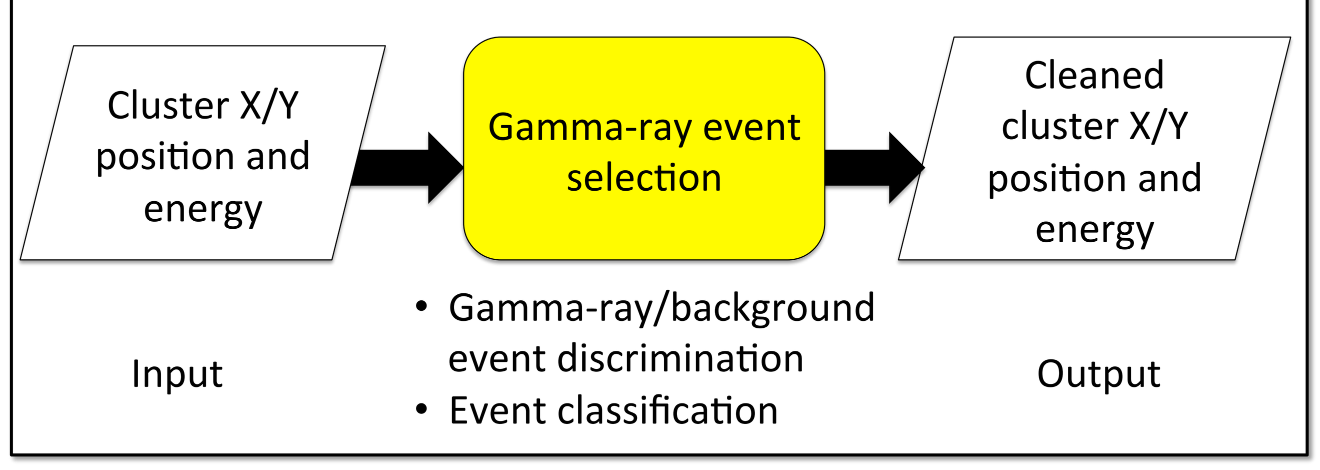
Figure 3. e-ASTROGAM mass model.

Pair production characterization



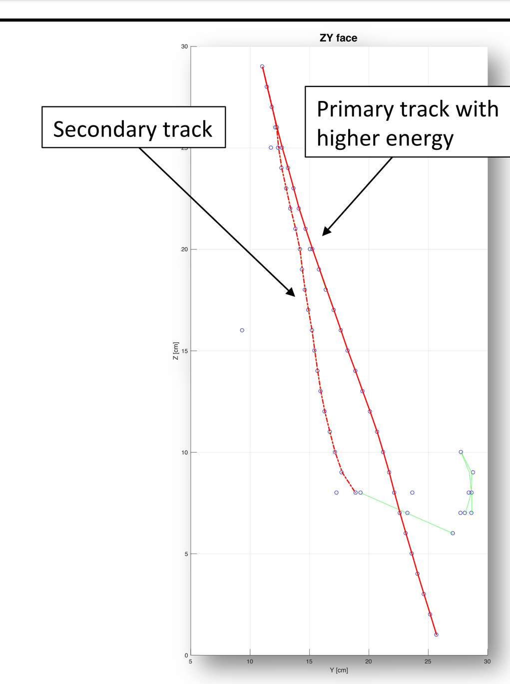
Event reconstruction

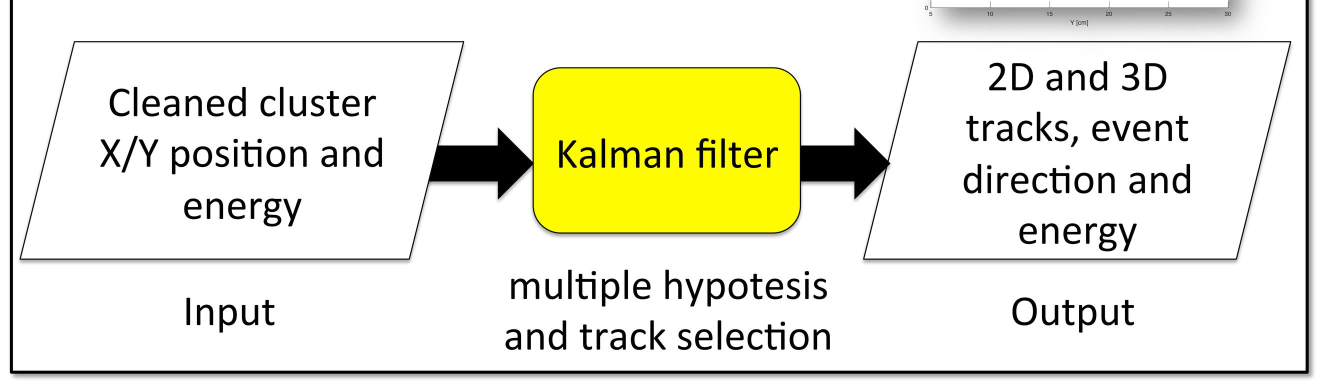
The event reconstruction takes as input the filtered simulation output, applies the gamma-ray event selection algorithm, and produces a cleaned list of event clusters. The event selection also provides multi criteria selection parameters for Neural Network training.



Kalman filtering

- Based on a Rauch-Tung-Striebel smoother and endowing a Kalman filter as the forward step, the algorithm builds 3D tracks matching 2D profiles
- the algorithm keeps multiple hypothesis about the particle trajectories





Summary and future actions

- the e-ASTROGAM mission concept sensitivity in the pair regime has been evaluated by means of a dedicated scientific pipeline based on the experience gained in the simulation of the AGILE mission.
- The resulting IRFs have been included in the ESA/M5 proposal (Fig. 4).
- A refined mass model version is being developed, along with the update of the simulation pipeline, the introduction of new criteria for the event reconstruction and kalman filtering for a better e-ASTROGAM sensitivity

E (MeV)	ΔE spectrum[(a)] (MeV)	PSF[(b)]	Effective area[(c)] (cm^2)	Inner Galaxy Backgr. rate (count s^{-1})	Inner Galaxy Sensitivity (ph cm^{-2} s^{-1})	Galactic Center[(d)] Sensitivity (ph cm^{-2} s^{-1})	Extragal. Backgr. rate (count s^{-1})	Extragal. Sensitivity 3σ (ph cm^{-2} s^{-1})
10	7.5 - 15	9.5°	215	3.4×10^{-2}	7.7×10^{-6}	1.3×10^{-5}	3.8×10^{-3}	2.6×10^{-6}
30	15 - 40	5.4°	846	1.6×10^{-2}	1.4×10^{-6}	2.4×10^{-6}	1.6×10^{-3}	4.3×10^{-7}
50	40 - 60	2.7°	1220	4.0×10^{-3}	4.6×10^{-7}	8.0×10^{-7}	3.4×10^{-4}	1.4×10^{-7}
70	60 - 80	1.8°	1245	1.3×10^{-3}	2.6×10^{-7}	4.5×10^{-7}	1.0×10^{-4}	7.2×10^{-8}
100	80 - 150	1.3°	1310	5.1×10^{-4}	1.6×10^{-7}	2.7×10^{-7}	3.2×10^{-5}	3.9×10^{-8}
300	150 – 400	0.51°	1379	4.8×10^{-5}	4.5×10^{-8}	7.8×10^{-8}	1.1×10^{-6}	6.9×10^{-9}
500	400 – 600	0.30°	1493	1.4×10^{-5}	2.2×10^{-8}	3.8×10^{-8}	1.8×10^{-7}	3.3×10^{-9}
700	600 – 800	0.23°	1552	6.3×10^{-6}	1.5×10^{-8}	2.5×10^{-8}	7.6×10^{-8}	3.2×10^{-9}
1000	800 – 2000	0.15°	1590	2.1×10^{-6}	8.3×10^{-9}	1.4×10^{-8}	2.1×10^{-8}	3.1×10^{-9}
3000	2000 - 4000	0.10°	1810	3.3×10^{-7}	2.9×10^{-9}	5.0×10^{-9}	2.9×10^{-9}	2.8×10^{-9}

(a) Source spectrum is an E^{-2} power-law in the range ΔE.
(b) Point Spread Function (68% containment radius) derived from a single King function fit of the angular distribution.
(c) Effective area after event selection.
(d) The background for the Galactic Center is assumed to be 3 times larger than that of the Inner Galaxy.

Figure 4. e-ASTROGAM IRFs in the pair regime from the ESA/M5 proposal

References

[1] Bulgarelli et al., Proc. of SPIE, 8453 (2012)
[2] Allison et al., NIM A, 835, 186 (2016)
[3] Fioretti et al., Proc. of SPIE, 9144 (2014)
[4] Tavani et al., A&A, 502, 995 (2009)
[5] De Angelis et al., Exp. Astr., accepted (2017)
[6] Sabatini et al. ApJ, 809, 60 (2015)