Simulation of e-ASTROGAM

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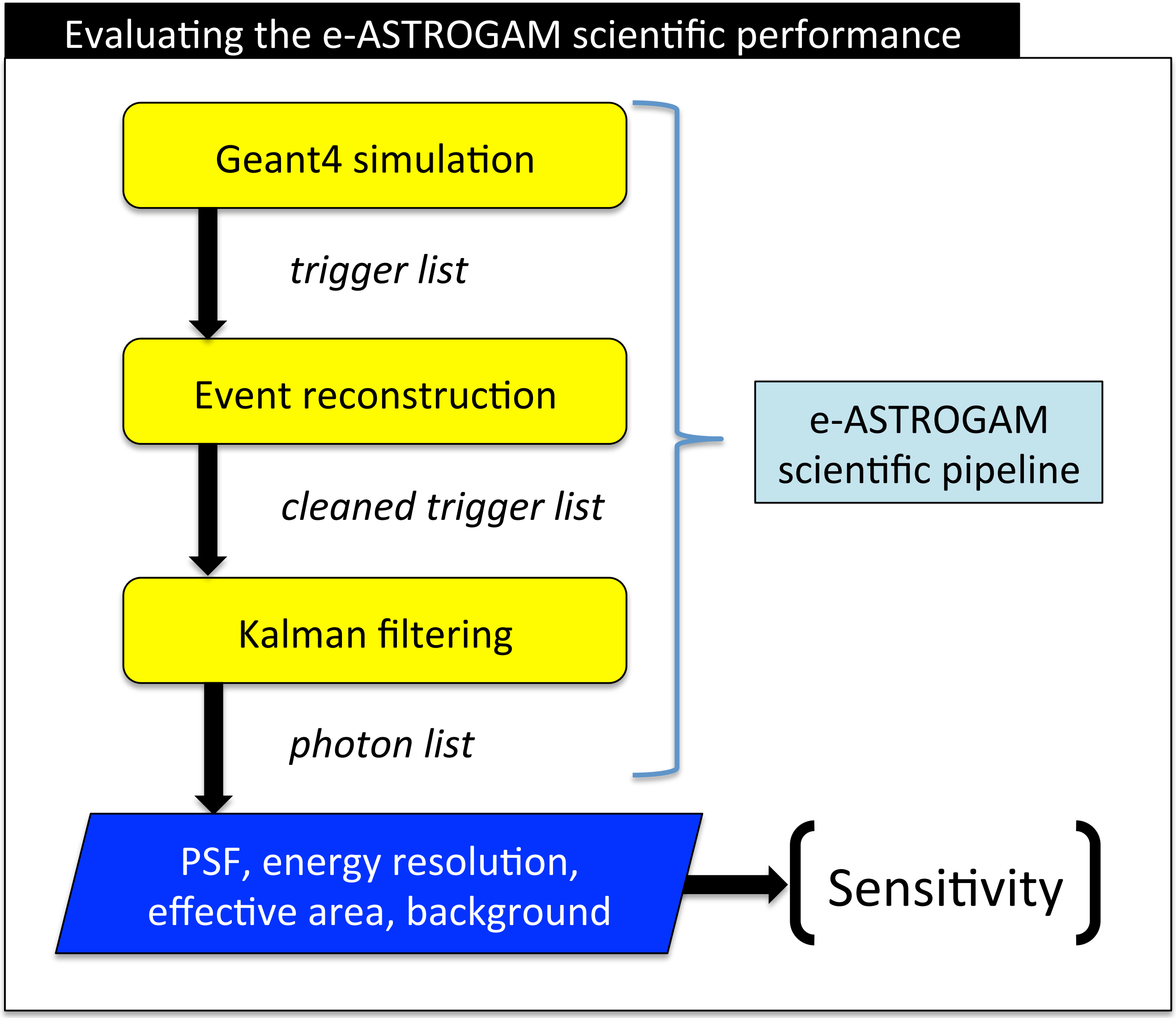

Evaluating the e-ASTROGAM scientific performance
Geant4 simulation
trigger list
Event reconstruction
cleaned trigger list
Kalman filtering
photon list
e-ASTROGAM scientific pipeline
PSF, energy resolution, effective area, background
Sensitivity

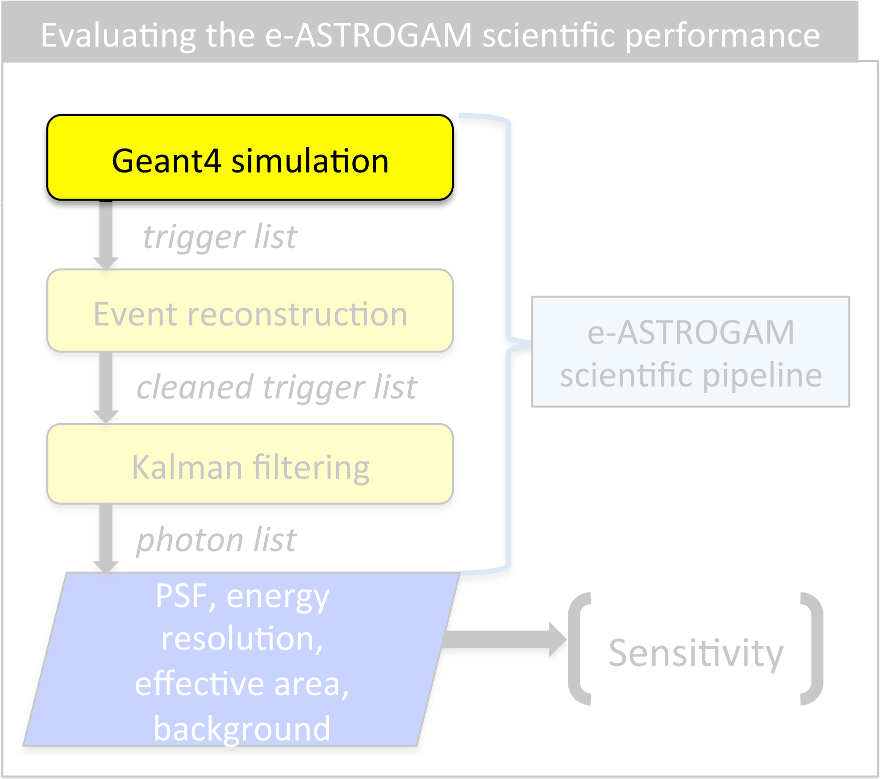
- Development of the e-ASTROGAM simulation, reconstruction, and analysis pipeline in the pair production regime, with focus on the tracker design and optimization
- Sensitivity evaluation in the 10 MeV – 3 GeV energy range

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.

from the ESA/M5 proposal

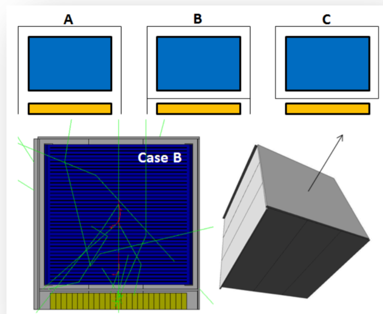
e-ASTROGAM simulation with BoGEMMS

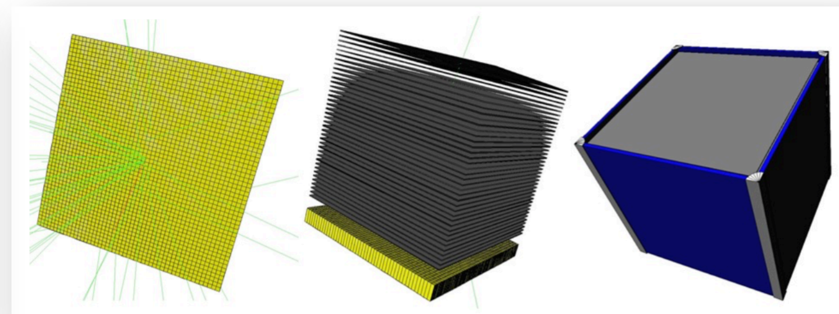


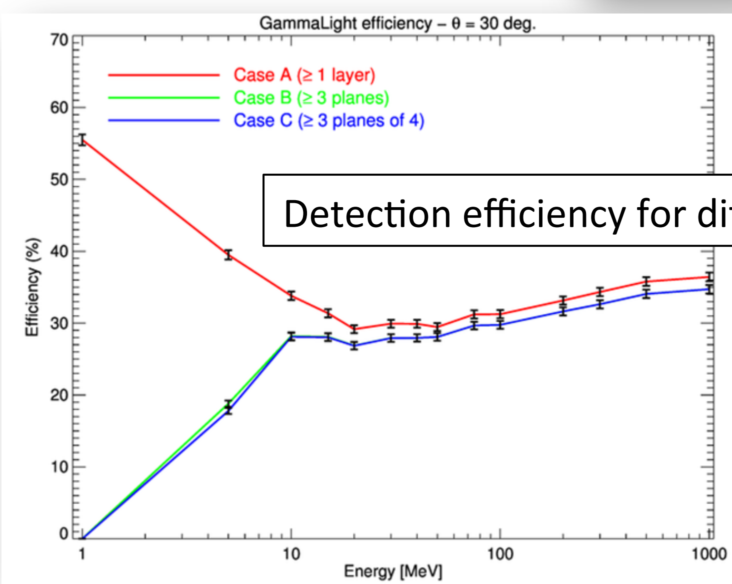
BoGEMMS (Bologna Geant4 Multi-Mission Simulator) is a Geant4 based customizable simulation framework for the design and optimization of high energy instruments. Used for the scientific performance evaluation of X-ray (Simbol-X, NHXM, XMM-Newton, ATHENA) and Gamma-ray (AGILE, GAMMA-400, GAMMALight, ASTROGAM, e-ASTROGAM) space missions, **it provides a fully validated Gamma-ray simulation branch for AGILE-like electron tracking telescopes (*Fioretti+2014*).**

Some examples

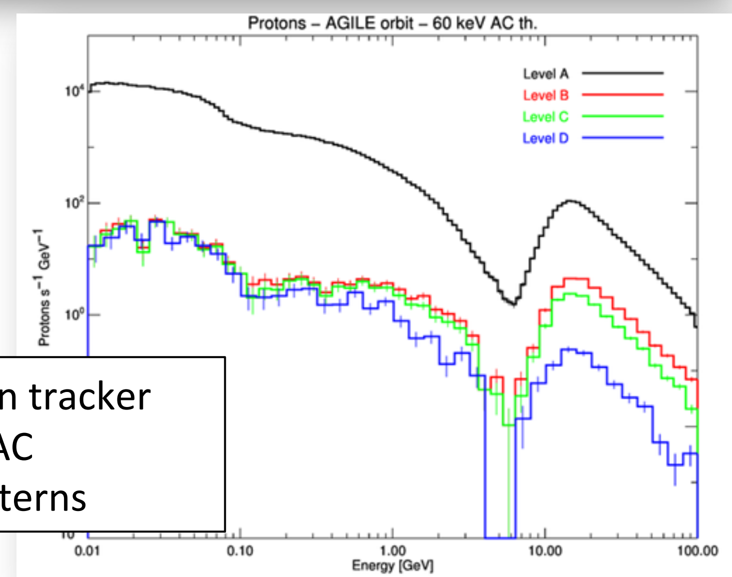
Mass model:
- tracker
- calorimeter
- AC
- electronics



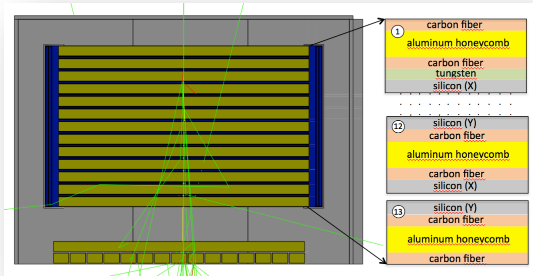


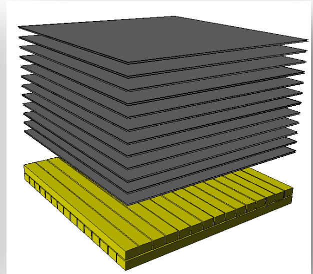


Detection efficiency for different trigger logics



Proton rate on tracker for different AC triggering patterns



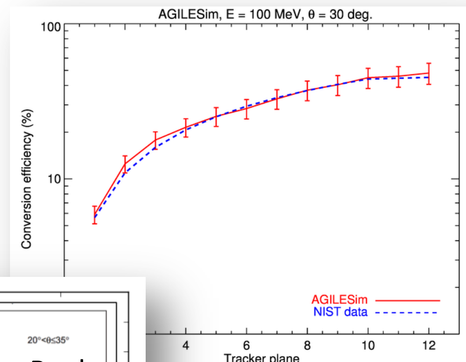


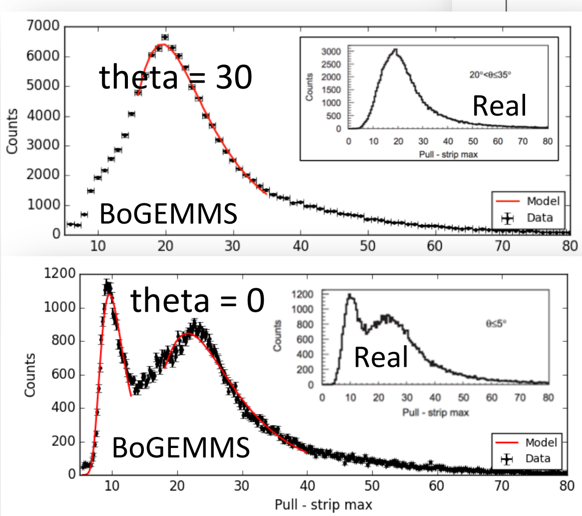
AGILESim – BoGEMMS simulation of the AGILE/GRID instrument.

Laboratory measurements and in-flight data consistent with simulation (*Fioretti+ in prep.*)

Verification

Pair conversion efficiency: BoGEMMS vs NIST



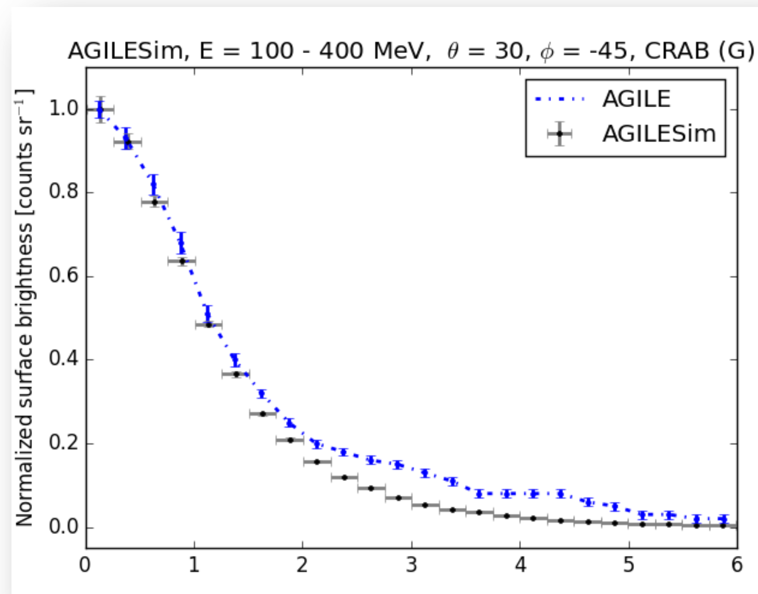


Pull distribution: BoGEMMS vs real data

Laboratory measurements from Bulgarelli+2010

Validation

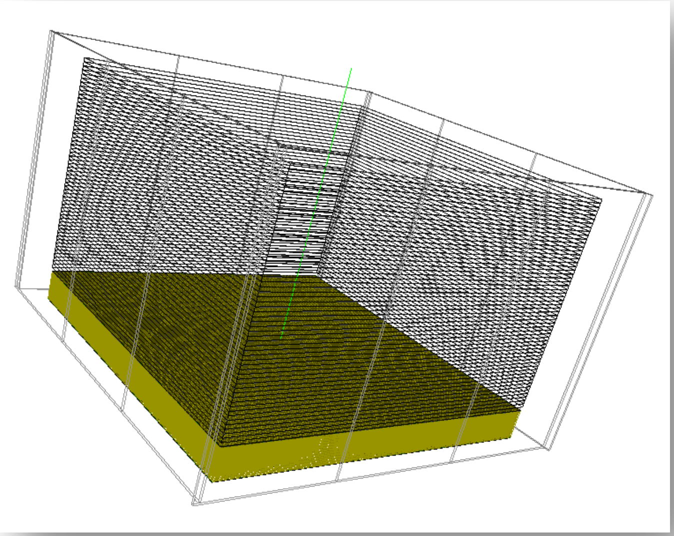
PSF: BoGEMMS vs in-flight data



AGILE in-flight data from Sabatini+2015

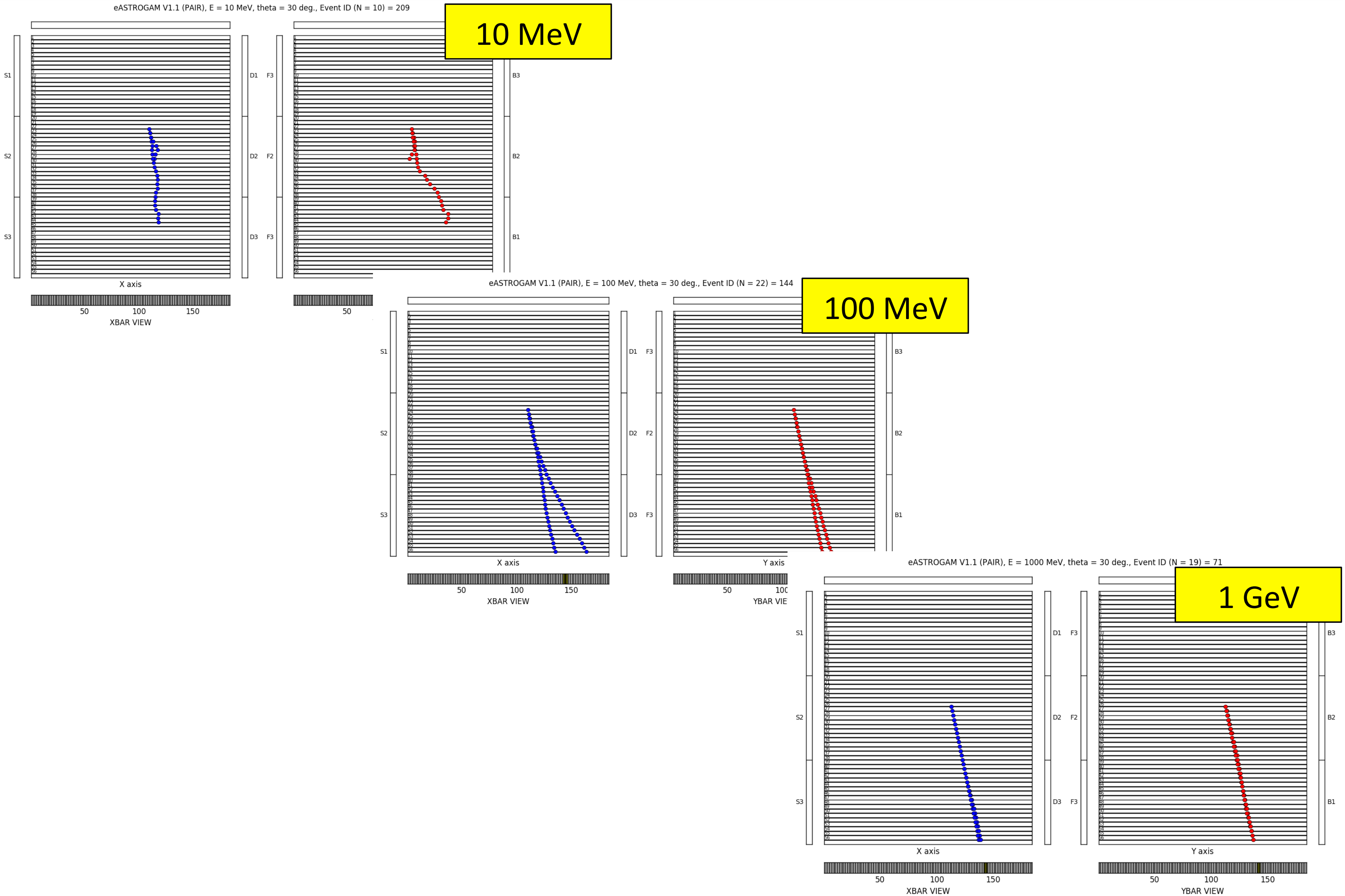
- MEGAlib (*Zoglauer+2006*, Compton simulations) vs BoGEMMS:
  - same Geant4 physics list and cuts
  - simulation tests give consistent results

- e-ASTROGAM mass model for M5:

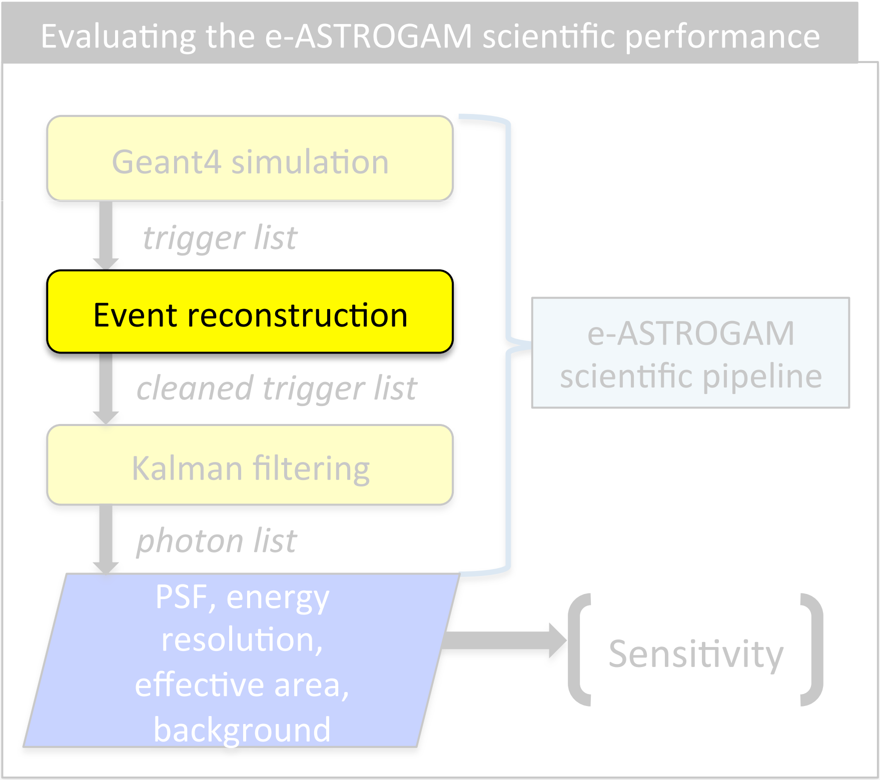


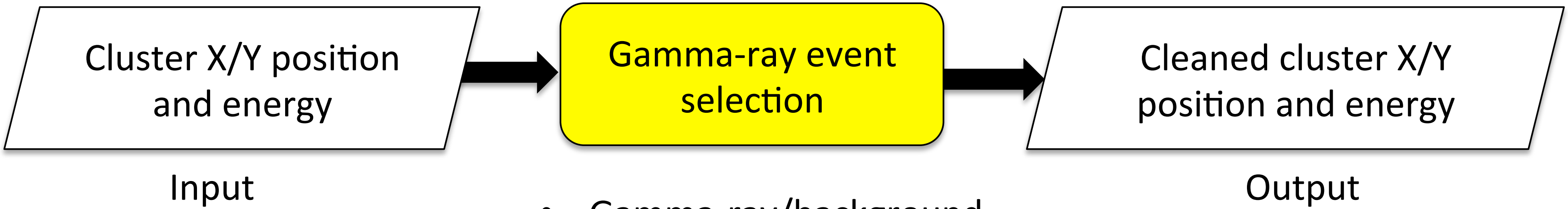
- e-ASTROGAM simulation analysis:
  - Tracker DSSD energy threshold = 15 keV
  - Calorimeter energy threshold = 30 keV
  - Analogic readout applied
  - Cluster reconstruction and baricentered position applied

e-ASTROGAM BoGEMMS simulation – pair production analysis



e-ASTROGAM event reconstruction



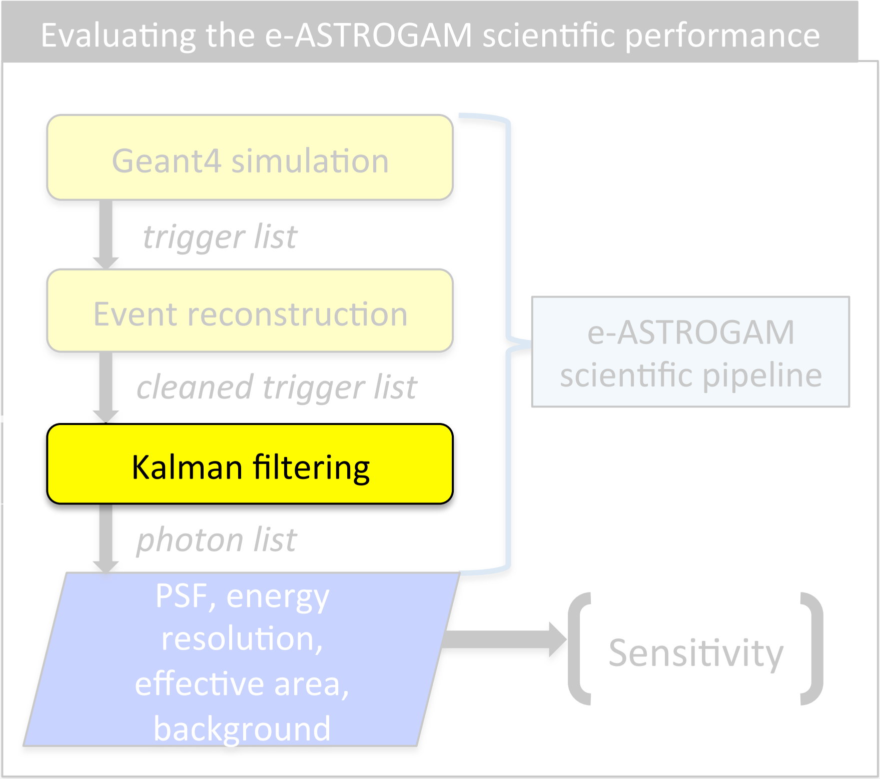


- Gamma-ray/background event discrimination
- Event classification

- We are working on finding the best “trigger criteria” for the selection of Gamma-rays interacting with e-ASTROGAM
- These “trigger criteria” are providing also multi criteria section parameters for Neural Network training

Credits: A. Bulgarelli

e-ASTROGAM Kalman filtering



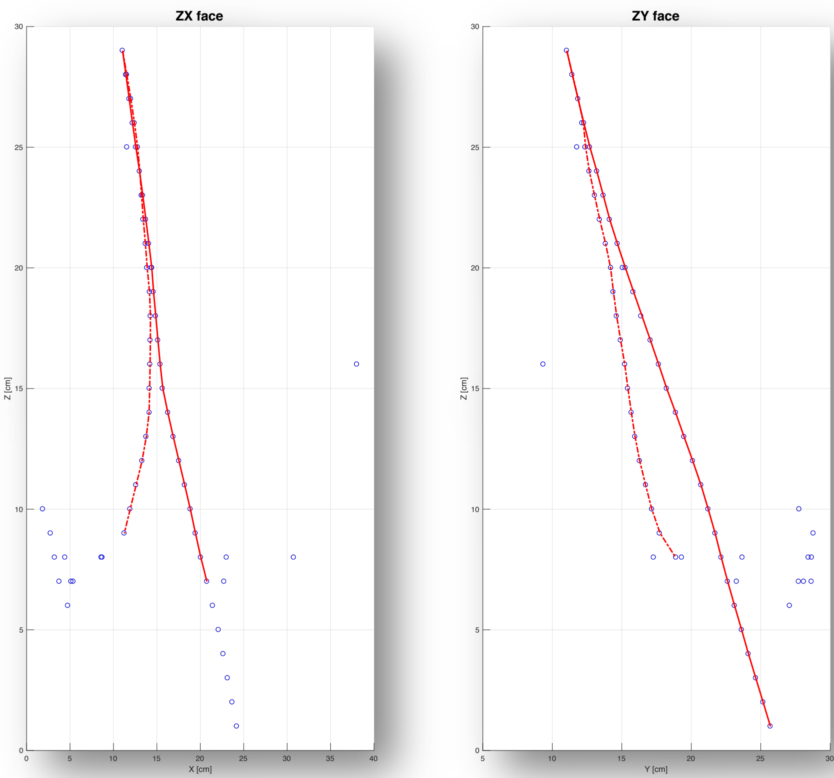
e-ASTROGAM Kalman filtering for position reconstruction

Cleaned cluster X/Y position and energy → **Kalman filter** → 2D and 3D tracks, event direction and energy

Input

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

Output



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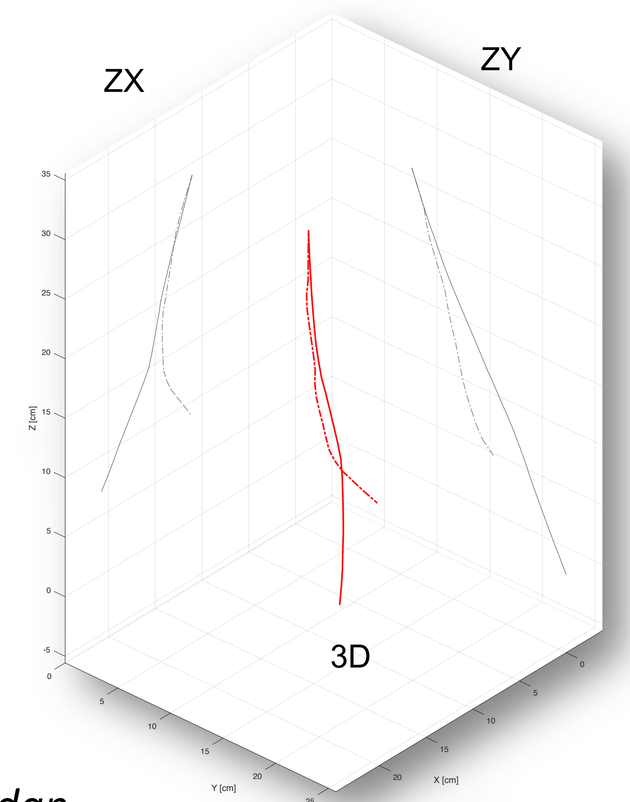
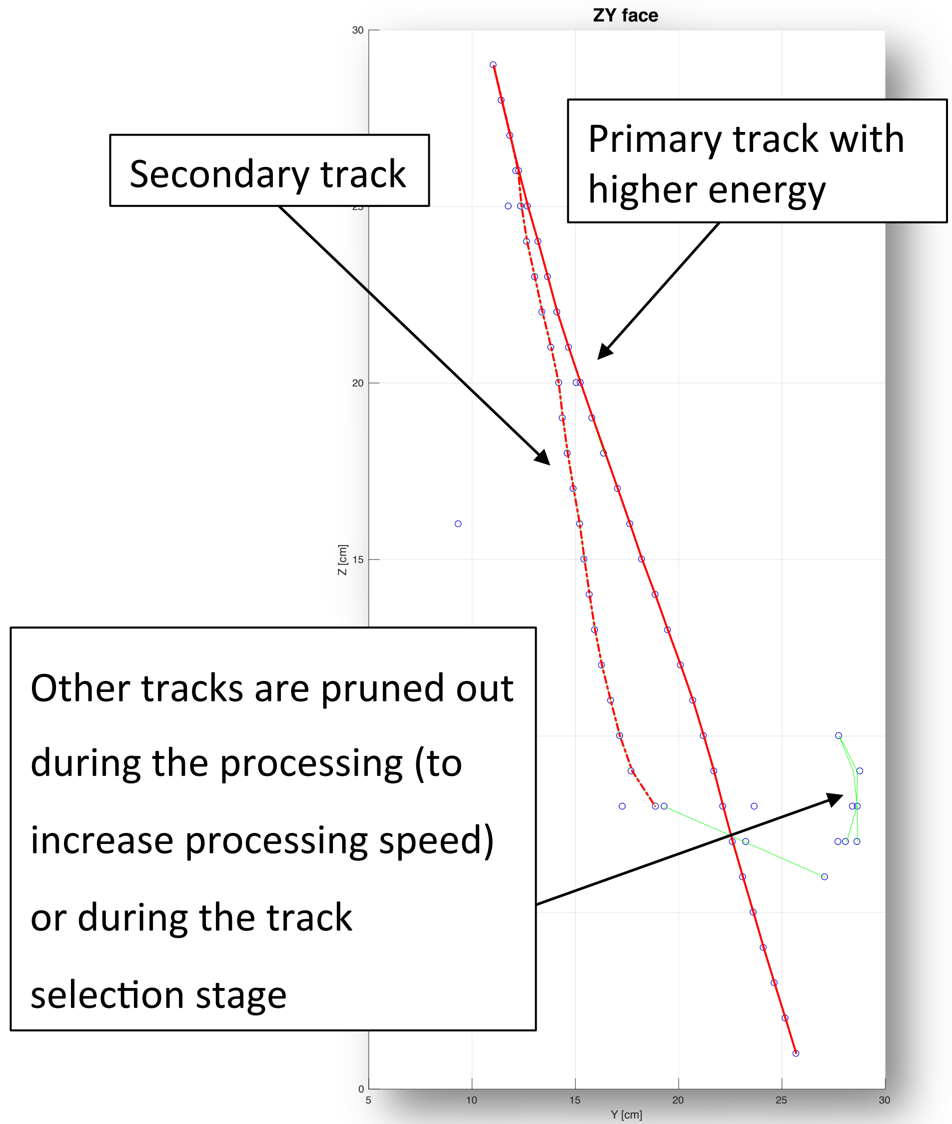


Credits: A. Aboudan

Each track has its own state:

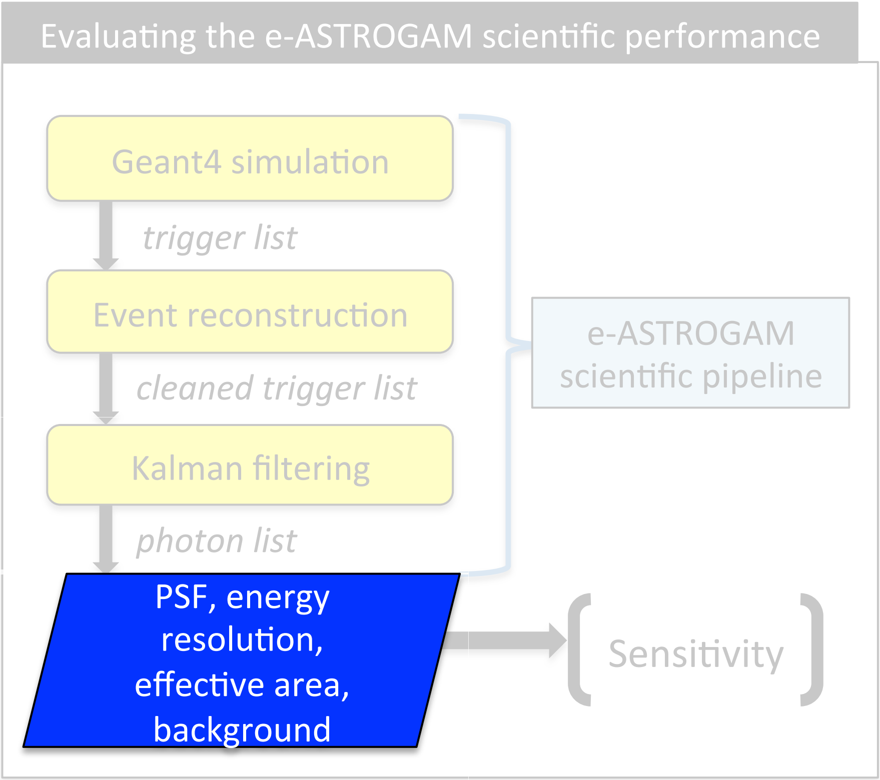
- It is confirmed only if associated with a suitable number of hits
- Only confirmed tracks are considered to reconstruct the event

Measurements that are not associated with tracks are used to create new tracks or to split tracks: the algorithm keeps **multiple hypothesis** about the particle trajectories

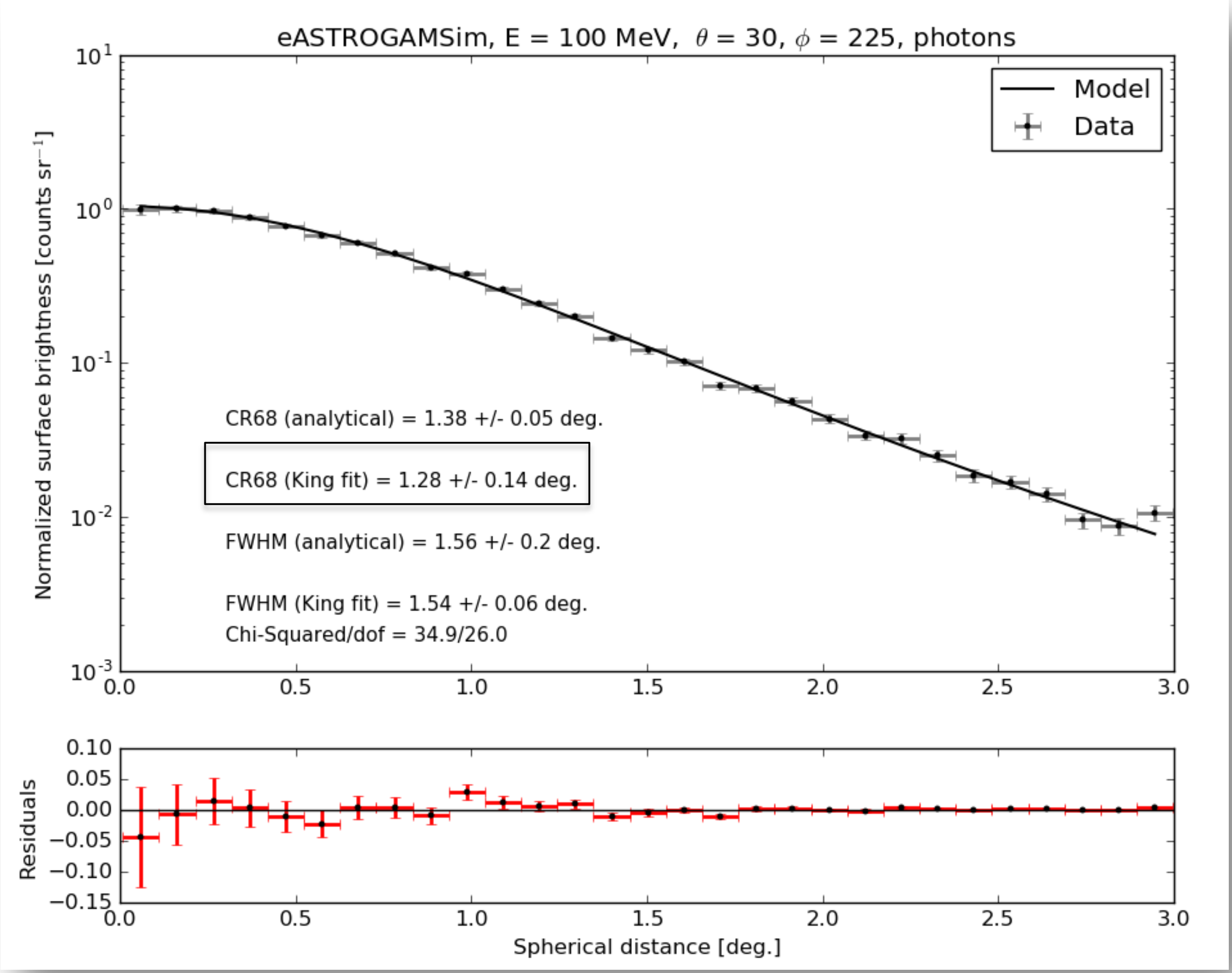


Credits: A. Aboudan

The eASTROGAM Point Spread Function



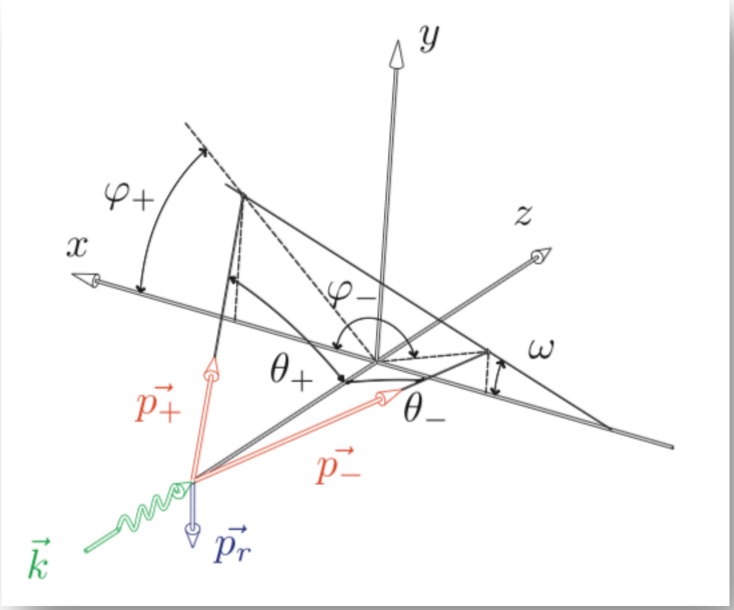
The angular resolution of e-ASTROGAM in the pair production regime is computed using the 68% containment radius of a single King profile fit.



e-ASTROGAM linear polarisation in the pair regime: first tests

General procedure:

- selection of only pair production events from BoGEMMs
- Kalman filter is used to reconstruct the photon direction and the e-/e+ track direction
- Only photons within 68% containment radius are taken
- the azimuthal angle in computed in the photon frame



Credits: D. Bernard

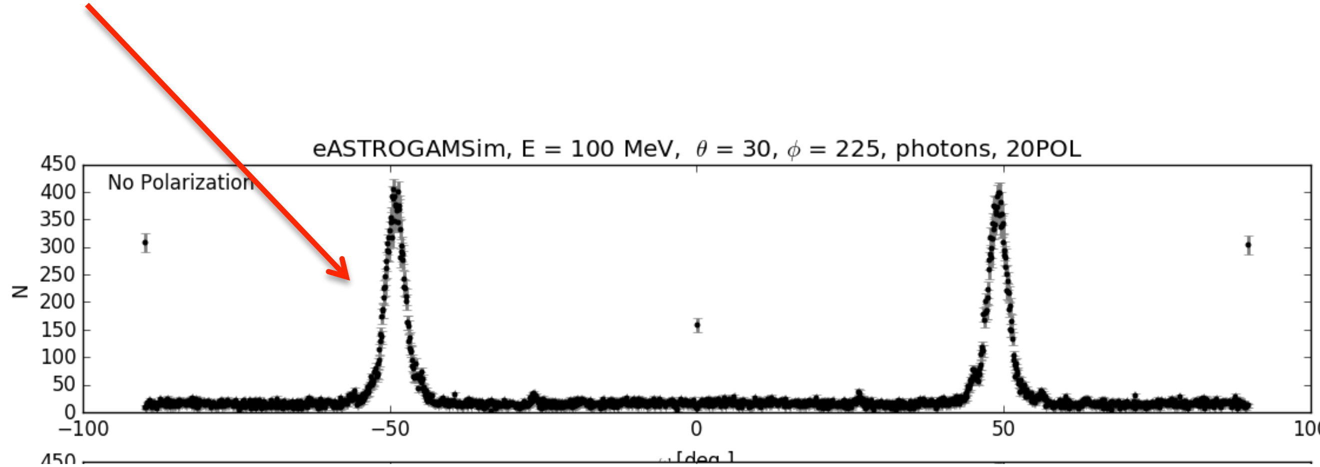
Simulation set-up:

- Energy = 100 MeV
- θ = 30 deg.
- ϕ = 225 deg.
- Polarization angle = 20 deg.

Results: still no significant results, but the activity is in progress (need for more statistics)

In collaboration with D. Bernard and F. Longo

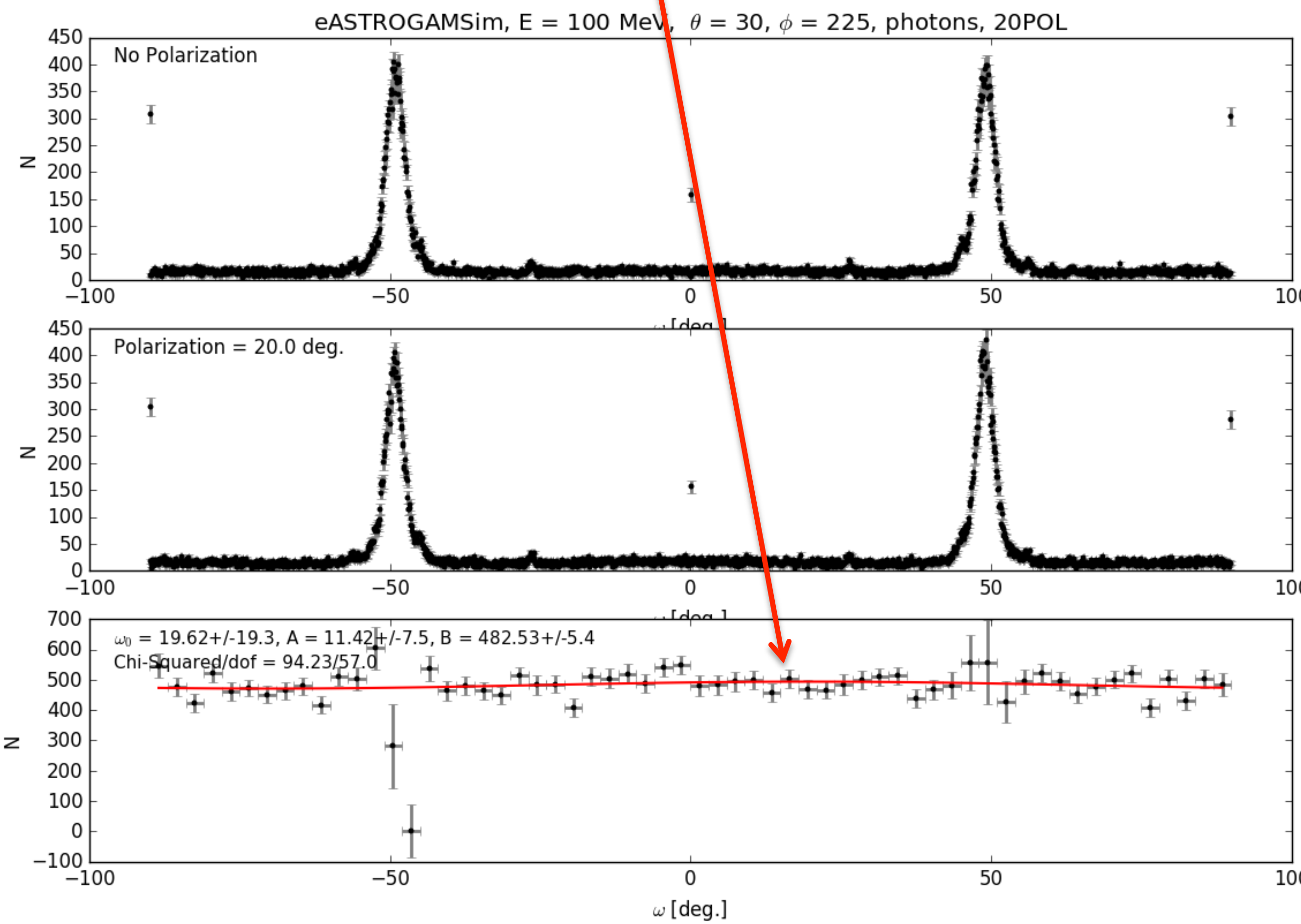
Without polarisation, two peaks appear at about +/- 50 deg. This is a bias of the primary photon azimuthal direction in the tracker system of reference. If θ=30, ϕ=0 is used as primary direction, the peaks in the omega distribution appear at 0 and +/- 90 deg.



The no-polarisation curve is subtracted to the polarized simulation and the resulting histogram is fitted by the model B + A*cos(2(x - omega_0))

The best fit parameters and the reduced Chi2 are:

- w_0 = 20±19 deg.
- A = 11±7.5
- B = 482±5
- Chi2/dof = 94/57



the e-ASTROGAM scientific pipeline 2.0

The optimization of the full simulation and data reduction chain is in progress to improve the e-ASTROGAM sensitivity.

- BoGEMMS simulation:
  - ability to discriminate between Compton and Pair production events to train the event reconstruction
  - statistics improvements
  - physics debugging (it never ends!)
  - linear polarisation evaluation
- Event reconstruction:
  - classification of events in different energy channels and Compton/pair discrimination using multi-variate analysis
  - event reconstruction algorithm optimization (e.g. neural networks/BDT/pattern recognition) for each event class
  - optimized Gamma-ray/background discrimination
- Kalman filter:
  - code parameterisation in terms of detector geometry/tracking algorithm
  - release of a C++ code (currently in Matlab)
  - algorithm optimisation and validation