# BoGEMMS simulation of the AGILE mission and its benefits to future gamma-ray space telescopes

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and the AGILE team

Geant4 Space Users Workshop 2017 – Guildford (UK)

# Outline

- The need for a “Geant4 virtual telescope”
- the BoGEMMS framework
  - the BoGEMMS gamma-ray branch
- AGILESim – Geant4 simulation of the AGILE mission
- BoGEMMS application to future gamma-ray space telescopes

Space telescope simulation group tasks in a nutshell:

Astronomers

- Scientific goals
- Top scientific requirements (e.g. sensitivity, angular and spectral resolution)
- Top technological requirements (e.g. background level, effective area, focal length)
- …

Simulation group

- ✓ Modelling of the space radiation environment
- ✓ Definition of the shielding system and general design
- ✓ Evaluation of the mission Instrument Response Functions
- ✓ Design of the scientific analysis pipeline
- ✓ Inputs to data calibration

Engineers

- Mass budget
- Payload design
- Feasibility study (e.g. materials, tolerances, thermal control)
- …

Payload design study main issues:

1. Unprecedented scientific requirements → New background sources
2. Unprecedented mission design → New technological solutions
3. Evolution of the mission design (budget) along the years → Customizable simulations
4. Detailed performance evaluation → Simulated data as a real observation in space

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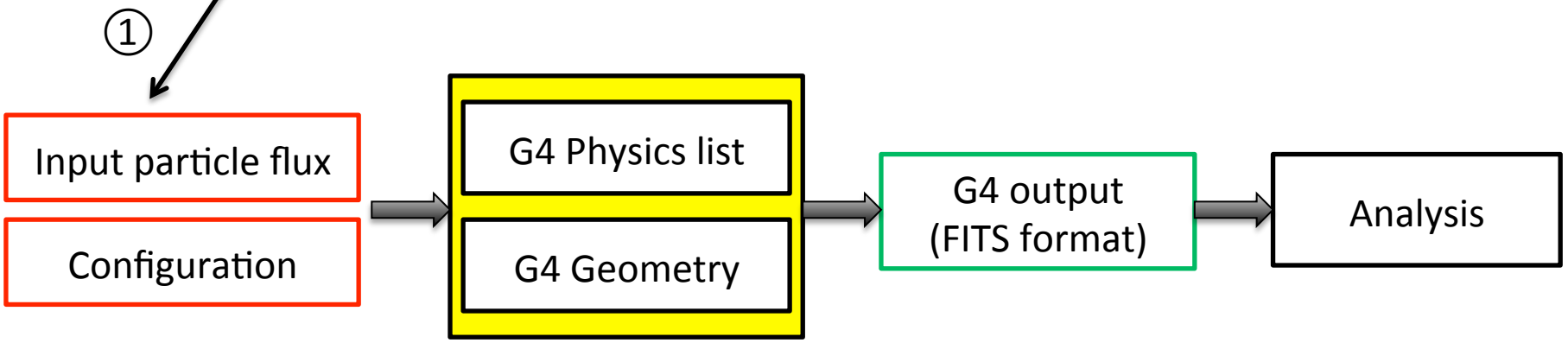
## BoGEMMS (Bologna Geant4 Multi-Mission Simulator)

A Geant4 based customizable simulation framework (Bulgarelli+2012) 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

The user sets the radiation environment, the physics list, the geometry and the output file from a configuration file (it is a flexible tool!)



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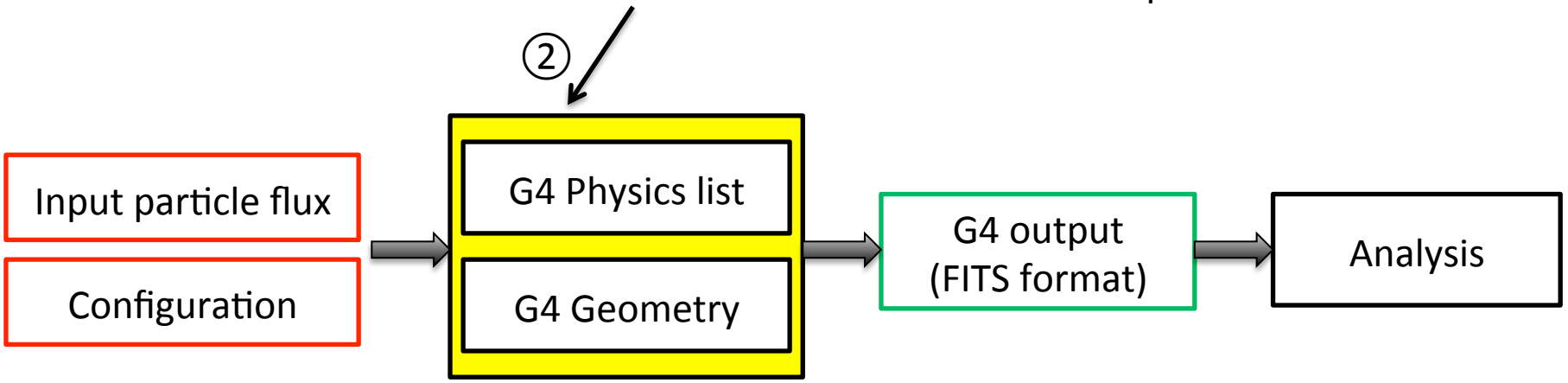
The BoGEMMS core, where the Geant4 libraries are called, produces the simulation output in FITS format. It allows to create a 3d model of the spacecraft.



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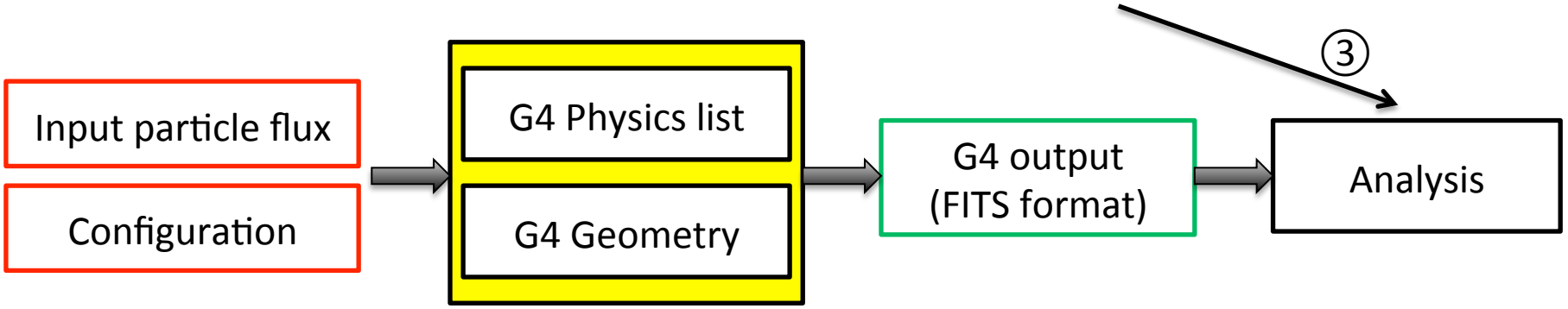
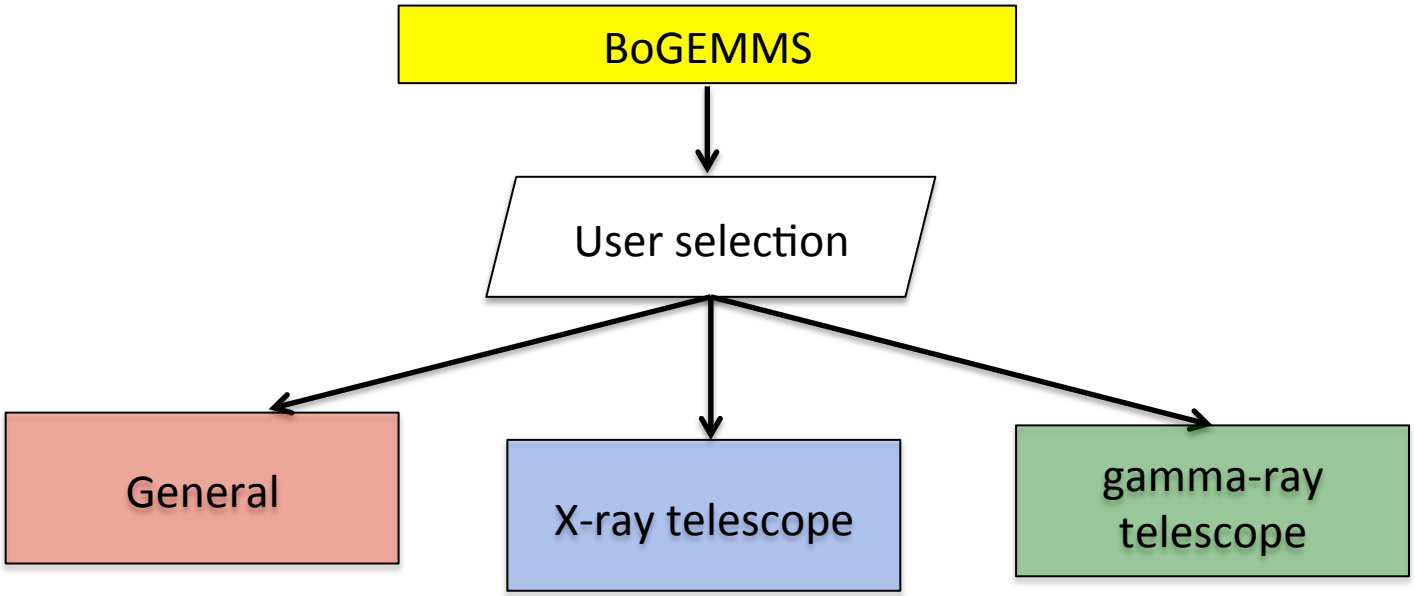
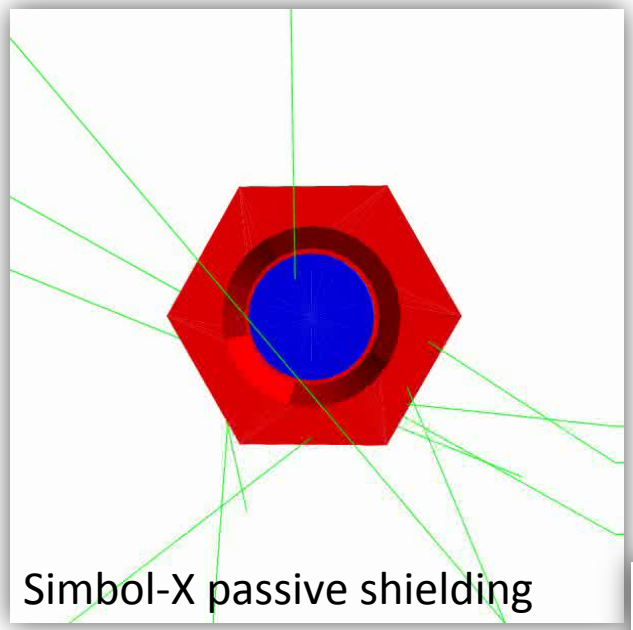
The analysis software filters the output (e.g. energy range, removal of the active shields concidence counts, pattern analysis) as a real observation in space and produces the expected background spectrum, the detection efficiency, etc.

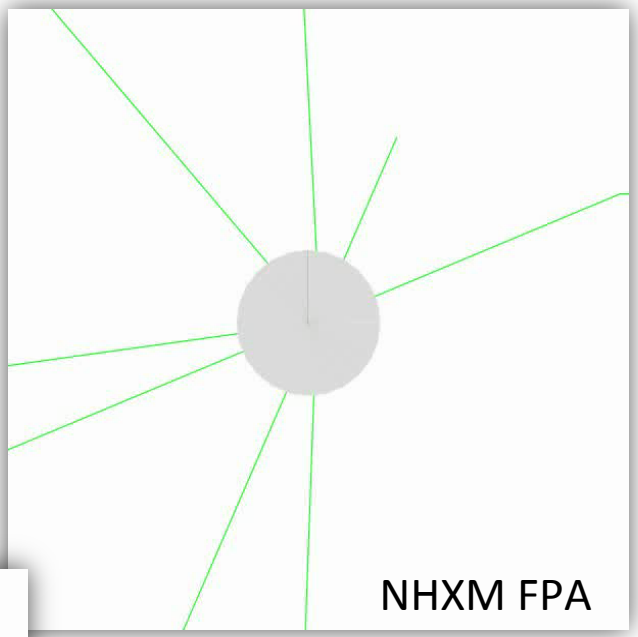


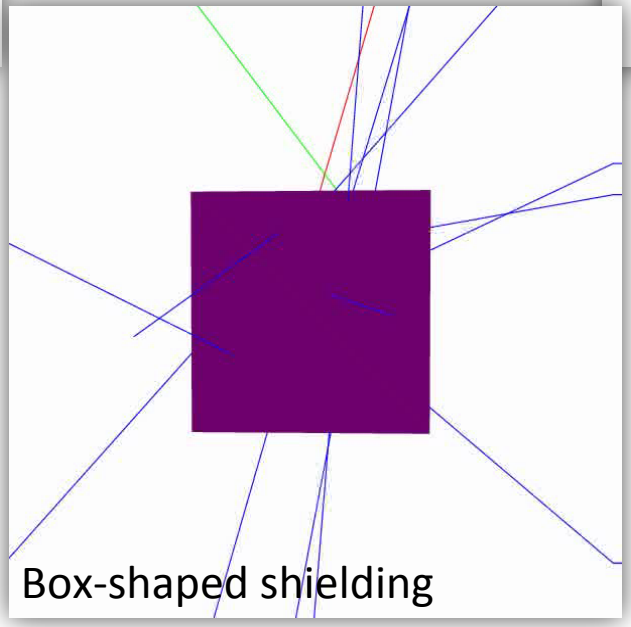
- Although the main requirement of the BoGEMMS simulator is the maximum flexibility of the geometry configuration, some fields of applications require a detailed modelling of specific instruments and/or the analysis of a particular material property.

- An application-dependent mass model can be built in addition to the general, totally customizable, BoGEMMS environment.




Simbol-X passive shielding


NHXM FPA

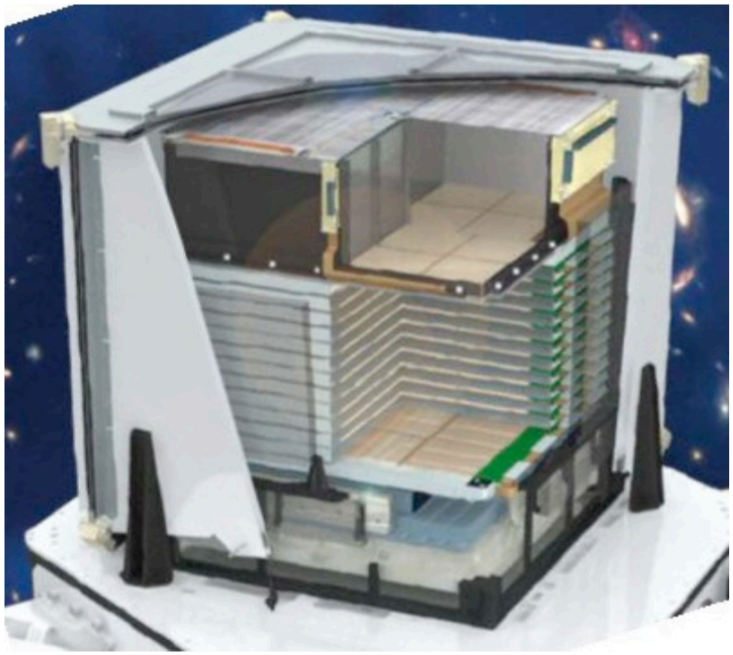

Box-shaped shielding

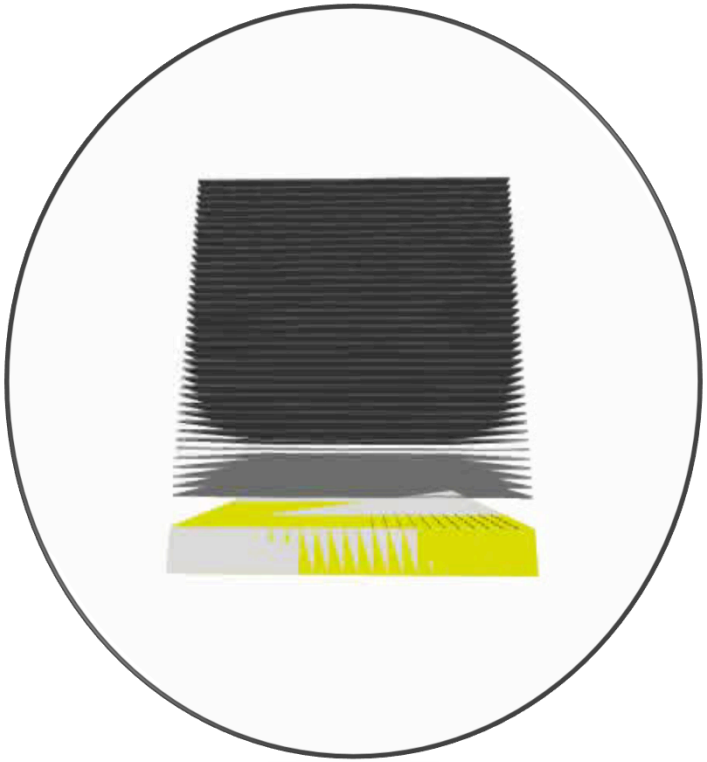
More on this:

- Fioretti+2012
- Fioretti+2016

A new extension is built for the simulation of an electron tracking Gamma-ray space mission for Compton/Pair production telescopes (e.g., AGILE, FERMI, e-ASTROGAM), **conceived to work as a common, multi-purpose framework for present and future gamma-ray space telescopes (*Fioretti+2014*).**

The ASI/AGILE gamma-ray mission (Tavani +2009), launched in 2007, carries the GRID instrument for pair tracking (30 MeV – 50 GeV energy range)





## AGILESim: BoGEMMS AGILE/GRID Geant4 simulation

For the first time an indipendent simulation tool is used to reproduce "a posteriori" an operative mission.

Main issues:

- Lack of budget resources to be spent to something already achieved
- Need of a detailed knowledge of the technical design (technical documents often not accessible or lost)
  - *BoGEMMS authors are part of the AGILE team*
- Need of a detailed knowledge of the data processing in order to compare the results
  - *AGILE filter and data analysis developed at INAF/IASF Bologna*
- Need to interface the simulation output with the official AGILE scientific analysis tools
  - *AGILE data analysis pipeline developed at INAF/IASF Bologna*

Benefits:

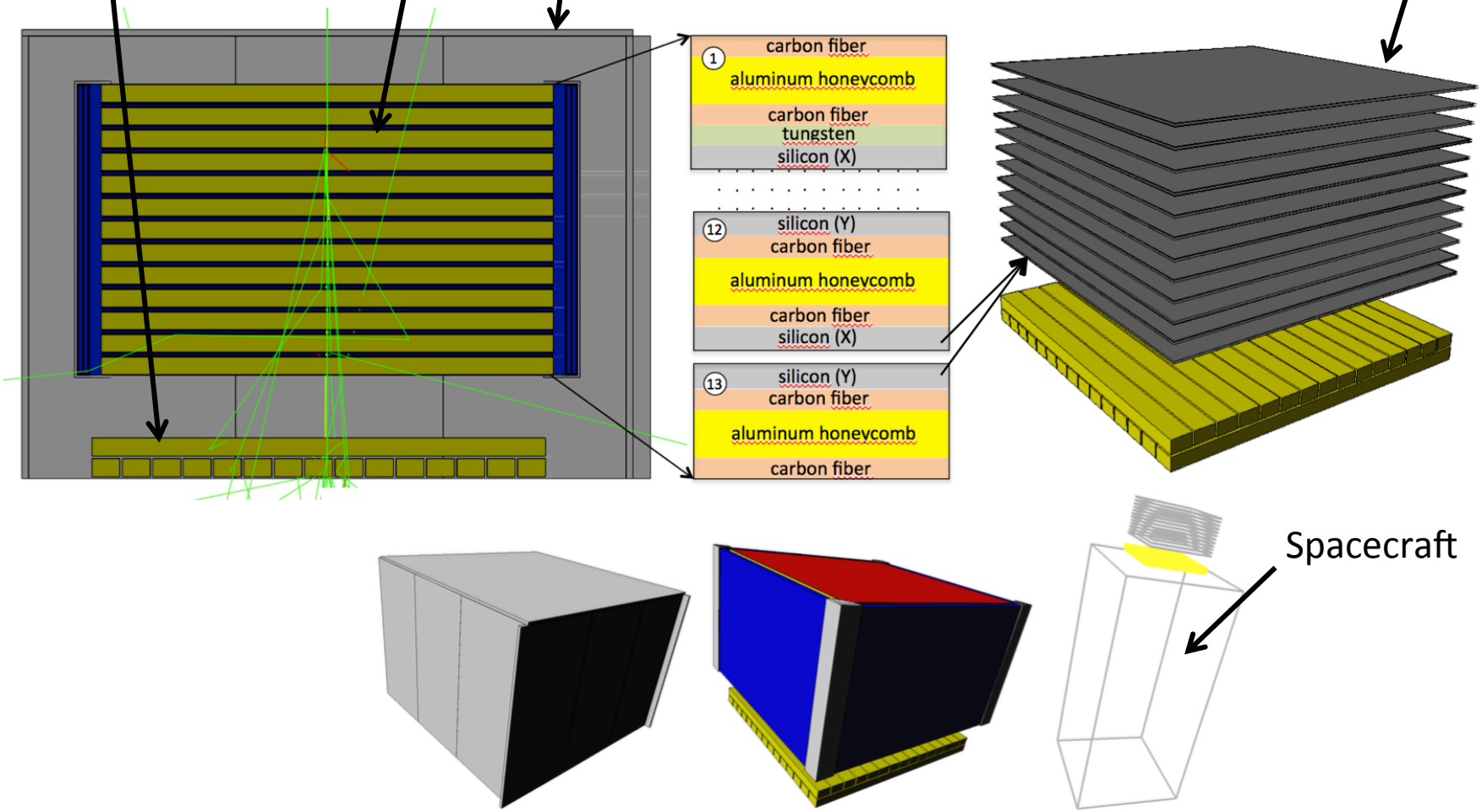
- scientific validation of the BoGEMMS gamma-ray application for its application to future mission proposals
- validation of Geant4 gamma-ray physics library
- refined calibration of AGILE data (original AGILE simulation in GEANT3)
- Education tools (currently used by undergrad students in laboratory tests and theses)

Mass model building blocks (AGILESim):

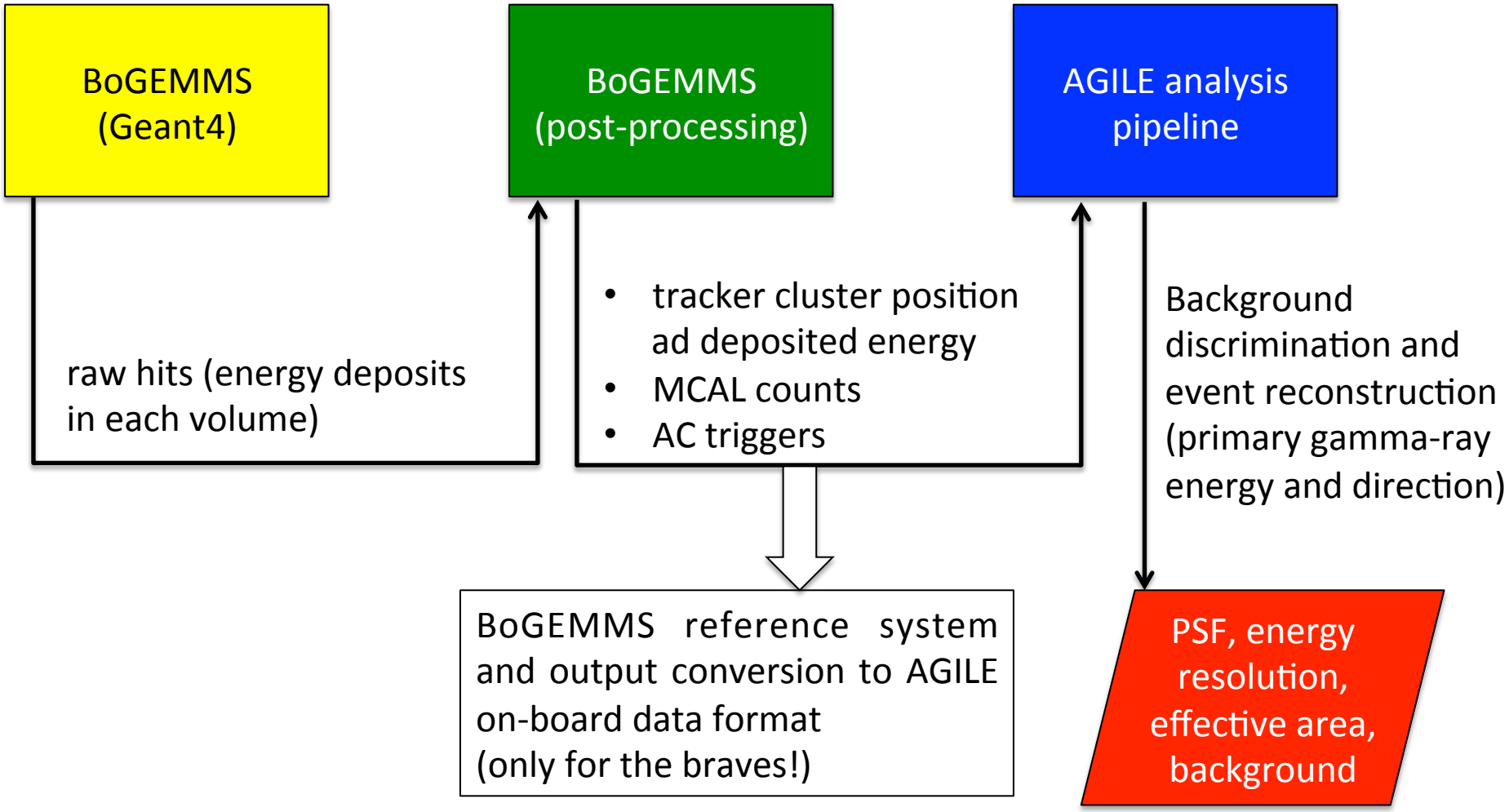
- Anticoincidence (plastic scintillator)
- Tungsten-Silicon tracker
- Calorimeter (AGILE/MCAL)

The AGILE/GRID core:

- Silicon planes divided in 3072 strips (121 μm side)
- Calorimeter (15x15 CsI bars)

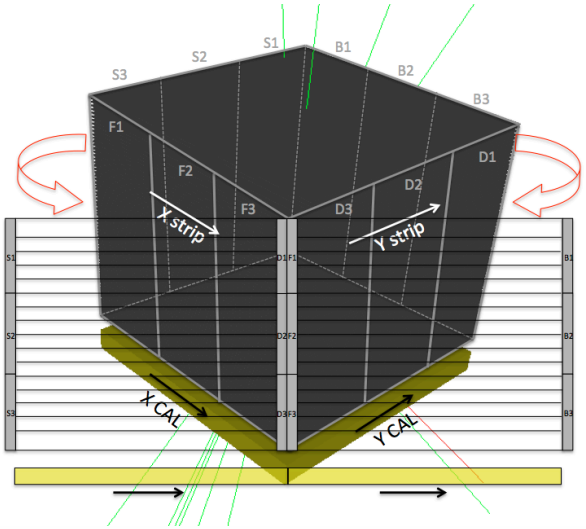


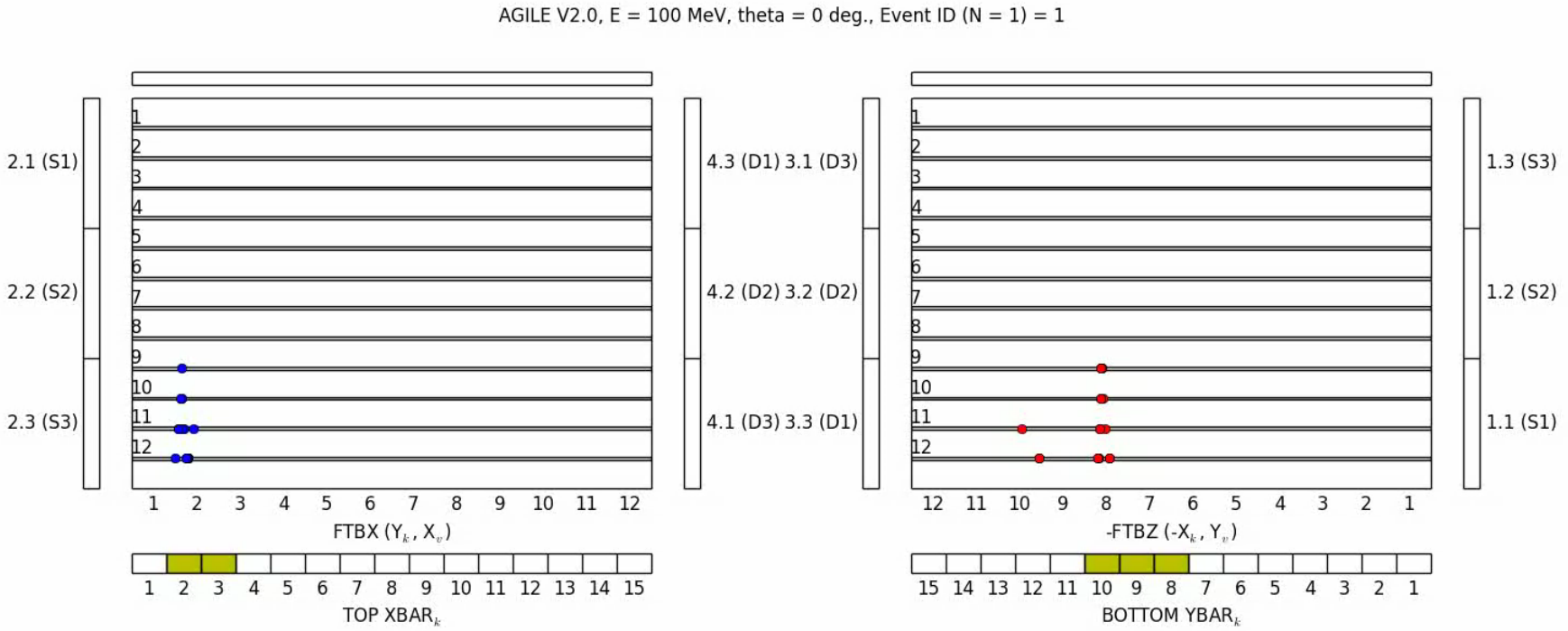
# AGILESim: analysis pipeline



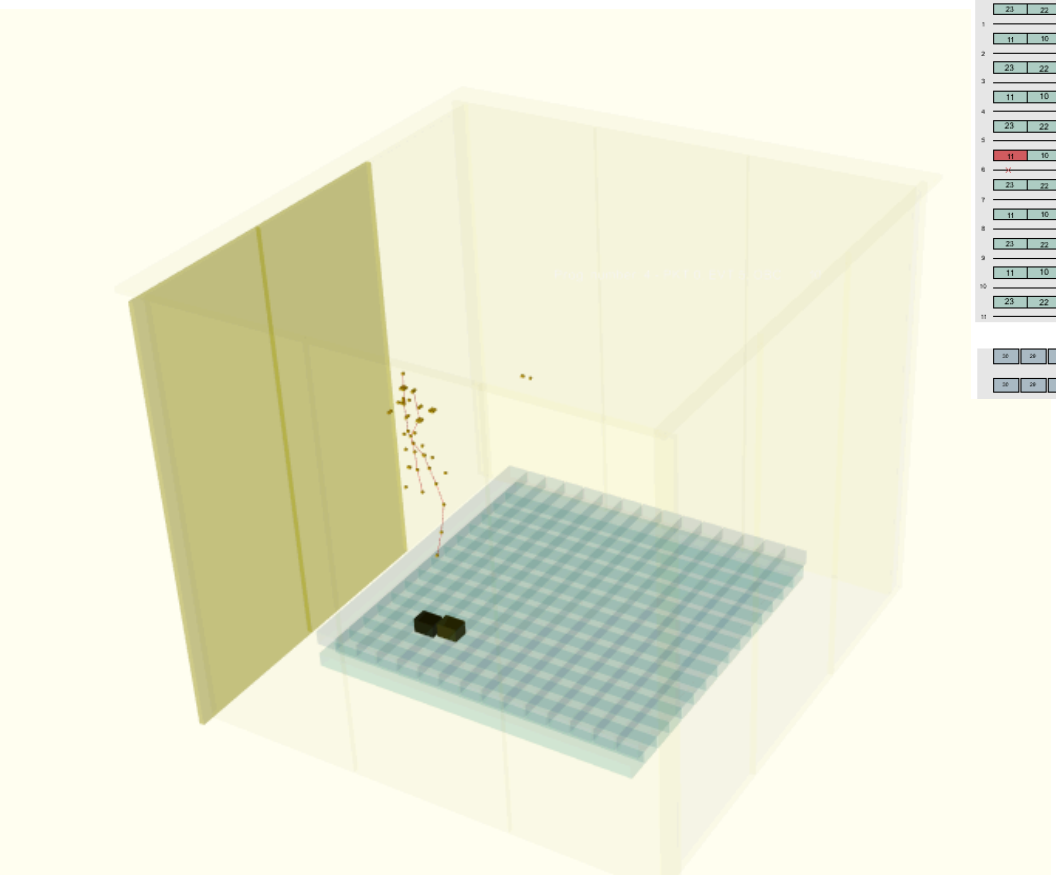
# AGILESim
# Verification and Validation

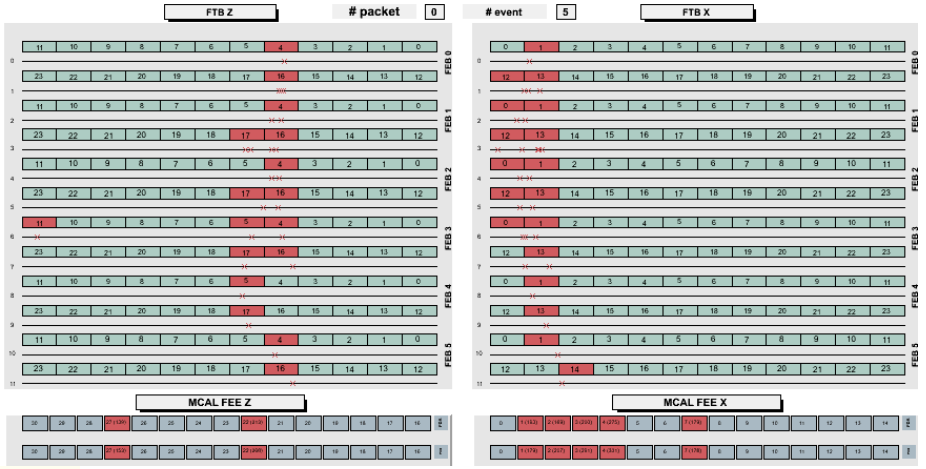
A Python-based visualization tool has been developed to compare the track topology from the BoGEMMS output alone and the AGILE Quick Look analysis tool

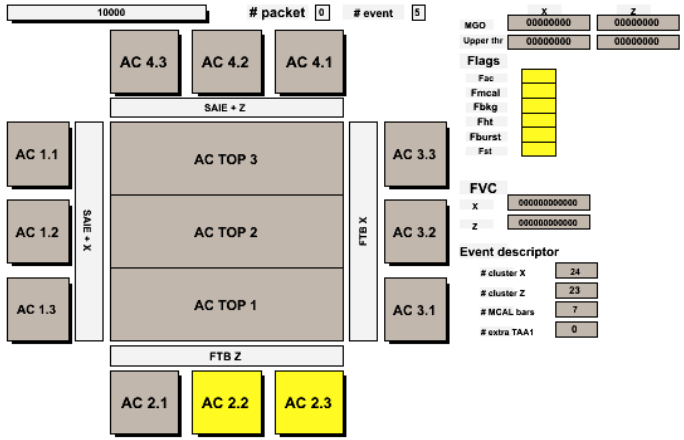


# AGILESim verification: track visualization from AGILE Quick-Look

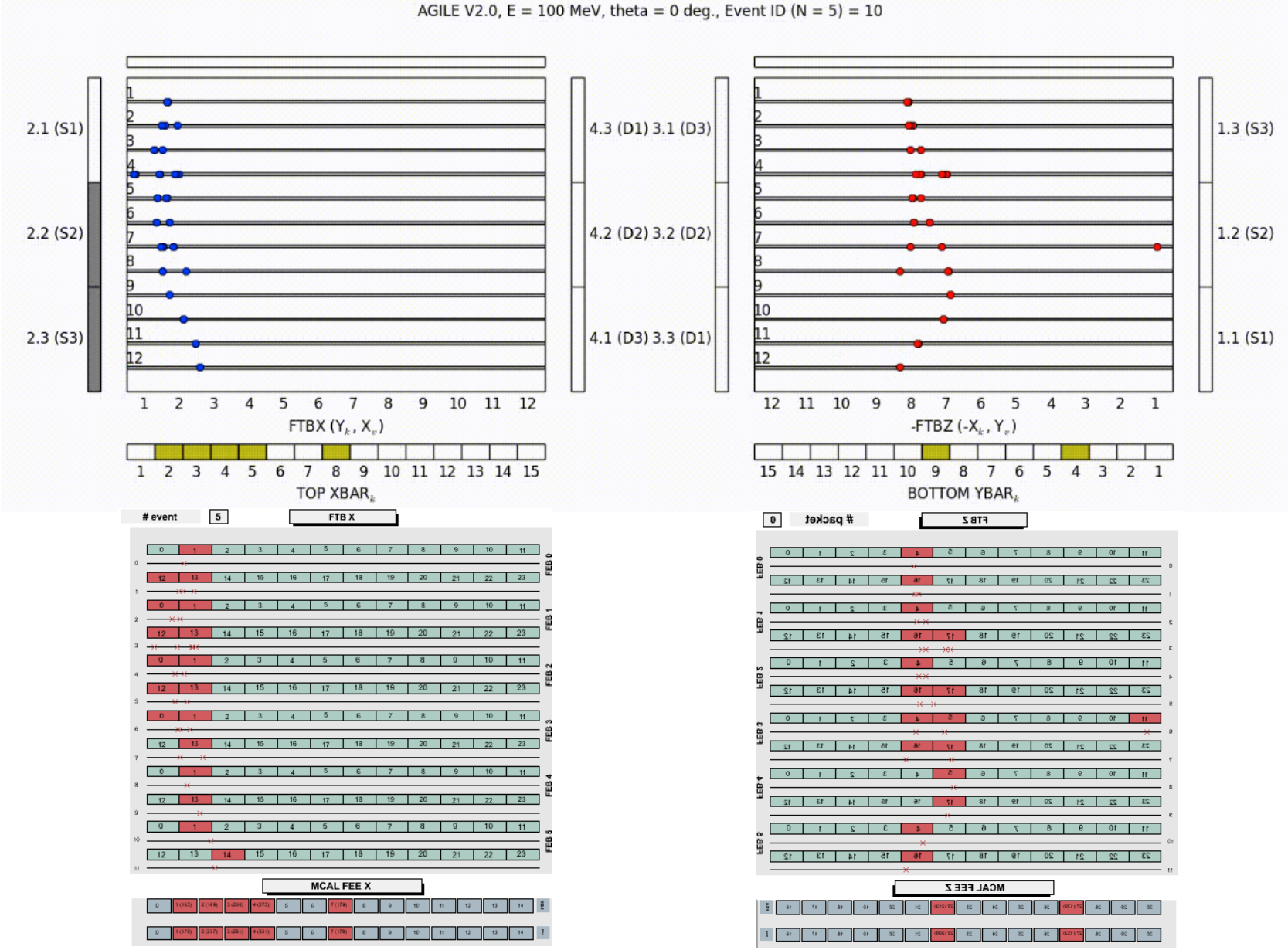




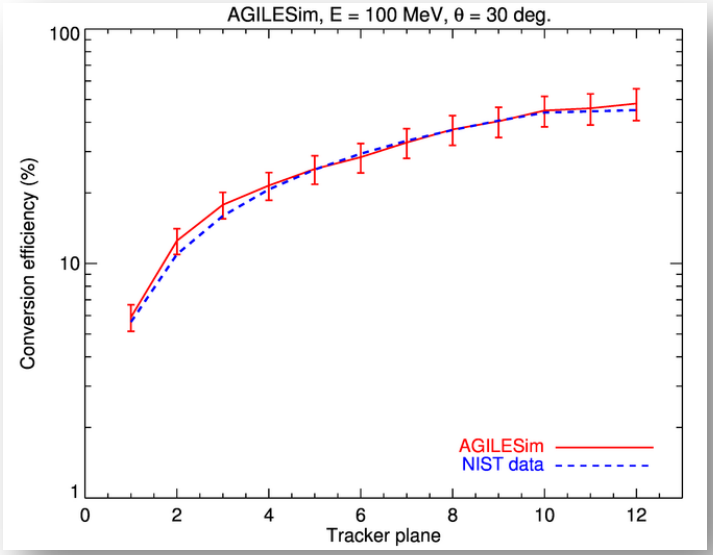

Input: BoGEMMS simulation

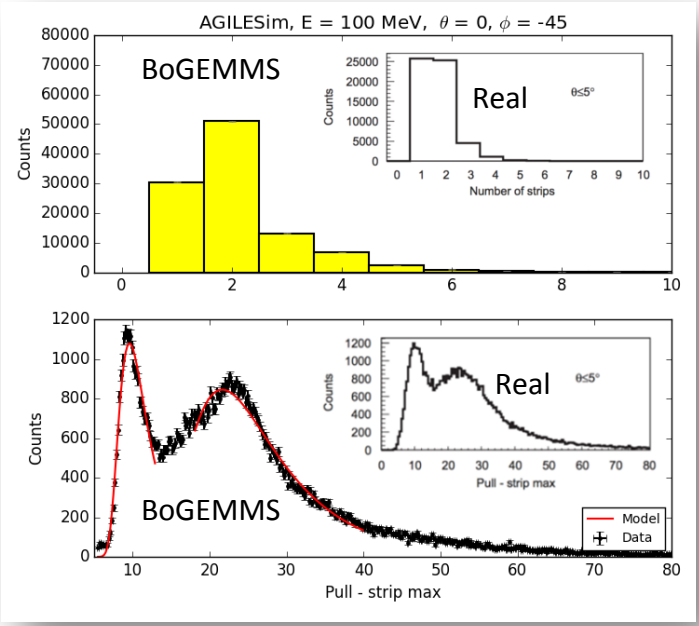
# AGILESim verification: BoGEMMS – AGILE pipeline interface OK



# AGILESim verification: comparison to tabulated and laboratory data OK

Pair conversion efficiency:
BoGEMMS vs NIST tabulated data



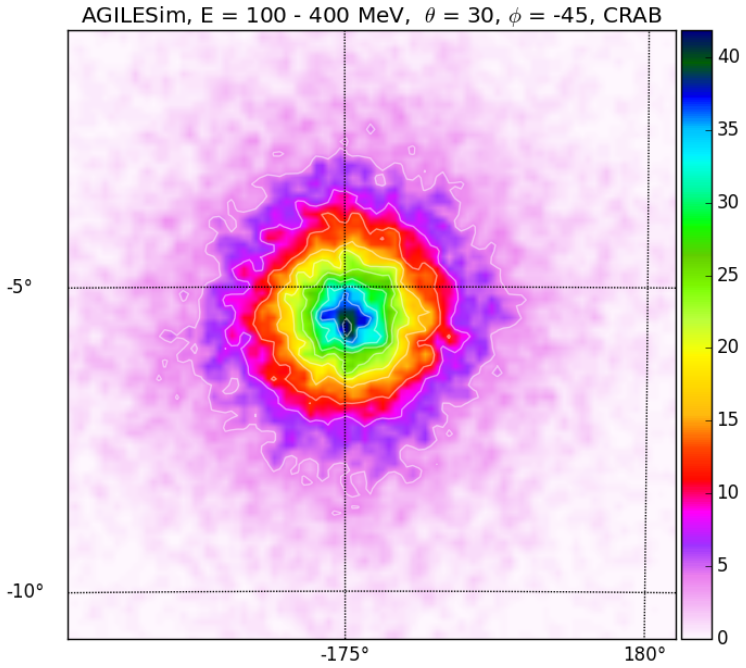

Strip distribution:
BoGEMMS vs on-ground real data

Pull distribution:
BoGEMMS vs on-ground real data

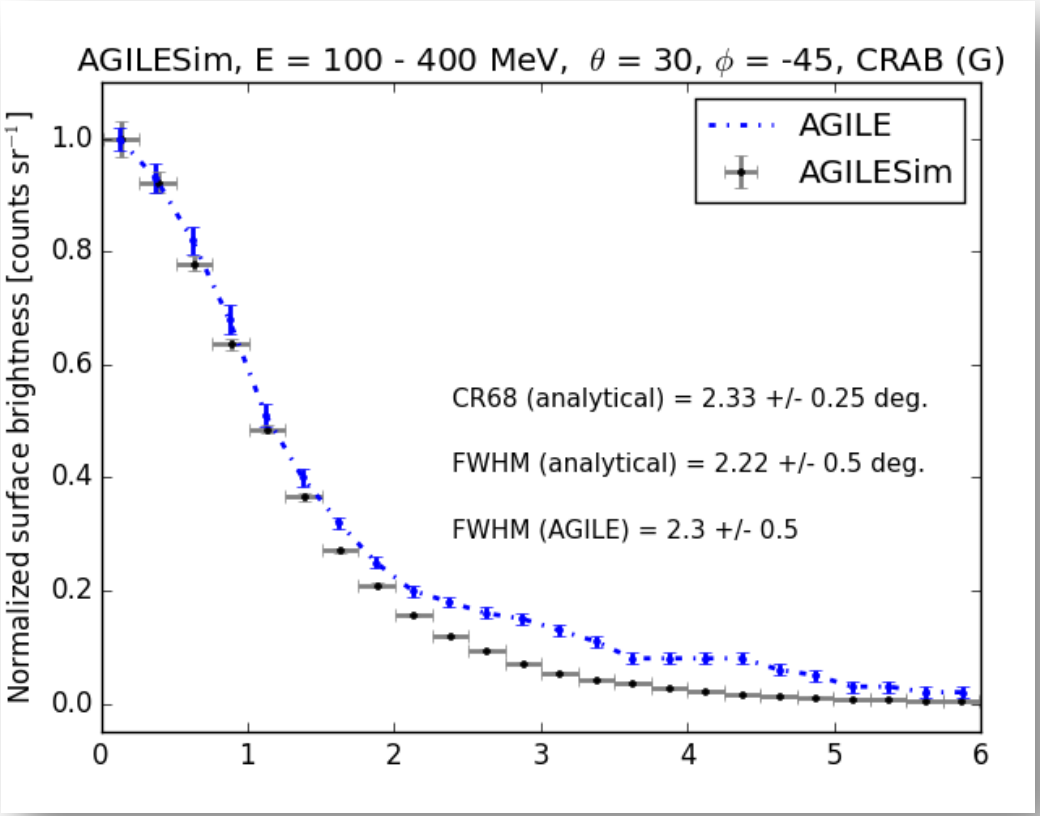
*Laboratory measurements from Bulgarelli+2010*

**We are able to reproduce the AGILE angular resolution during operations (Fioretti+ in prep.)**

AGILESim Crab simulation (100 – 400 MeV)




AGILE PSF for Crab observations (100 – 400 MeV): AGILESim vs AGILE in-flight data

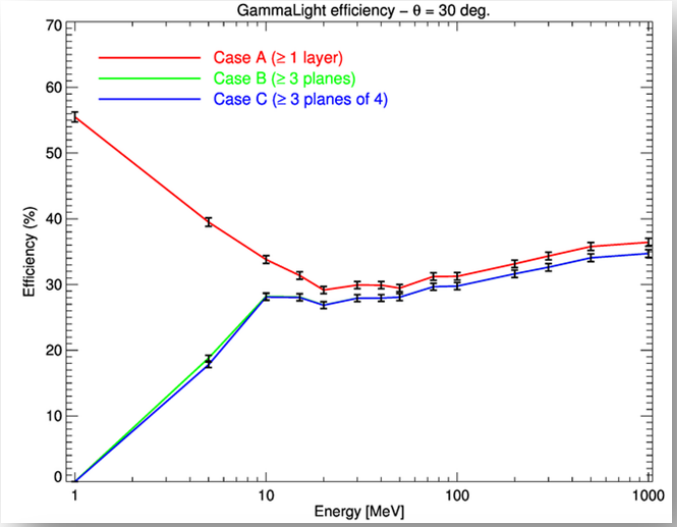



*AGILE in-flight data from Sabatini+2015*

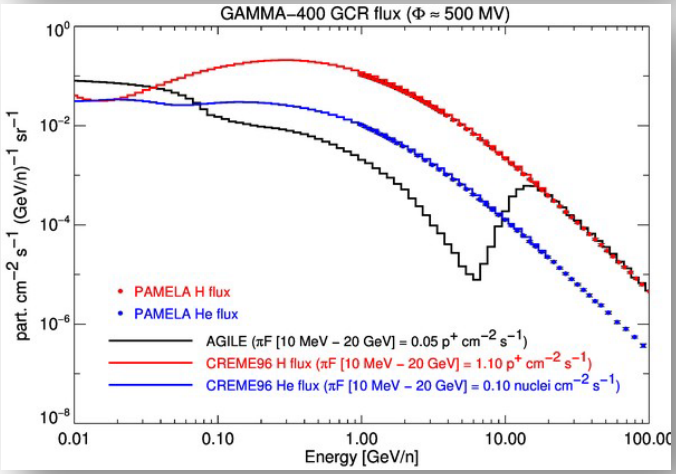
# BoGEMMS application to future gamma-ray missions

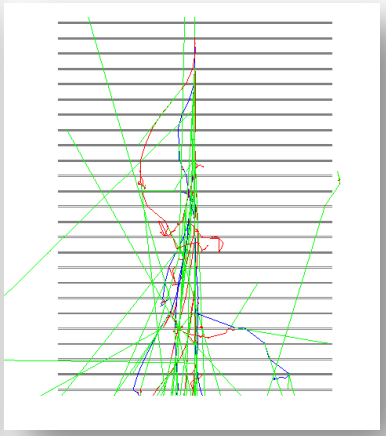
**Past activities:**

- GAMMA-400 simulations
- Gamma-Light simulations for the ESA "Small Mission Programme", 2012
- ASTROGAM simulations for the ESA M4 Mission Programme", January 2015




Gamma-Light detection efficiency for different trigger logics (Fioretti+, Tech. report, 2012)



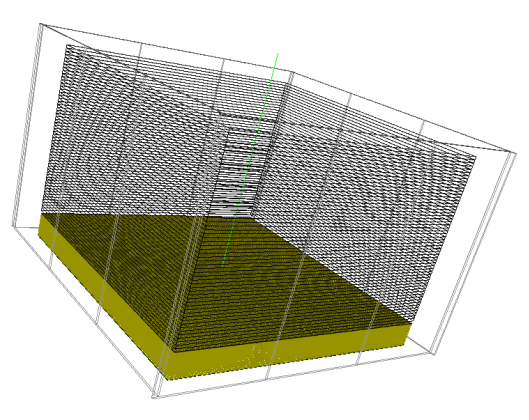



GAMMA-400 space radiation evironment modelling and track analysis

**Current activity:**

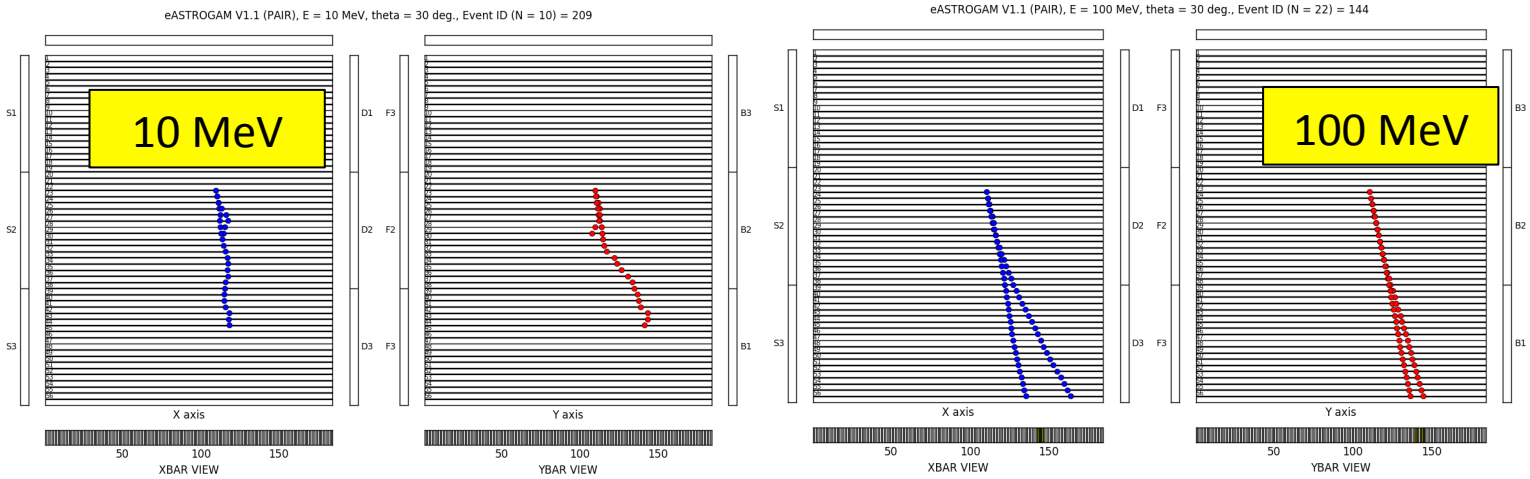
e-ASTROGAM IRF production in the pair regime for the last ESA M5 Mission Programme, October 2016 (*De Angelis+2016, submitted*)

- e-ASTROGAM BoGEMMS mass model for M5:



- Compton/pair telescope (0.3 MeV to 3 GeV)
- 56 Silicon planes
- analogic read-out

- BoGEMMS track analysis



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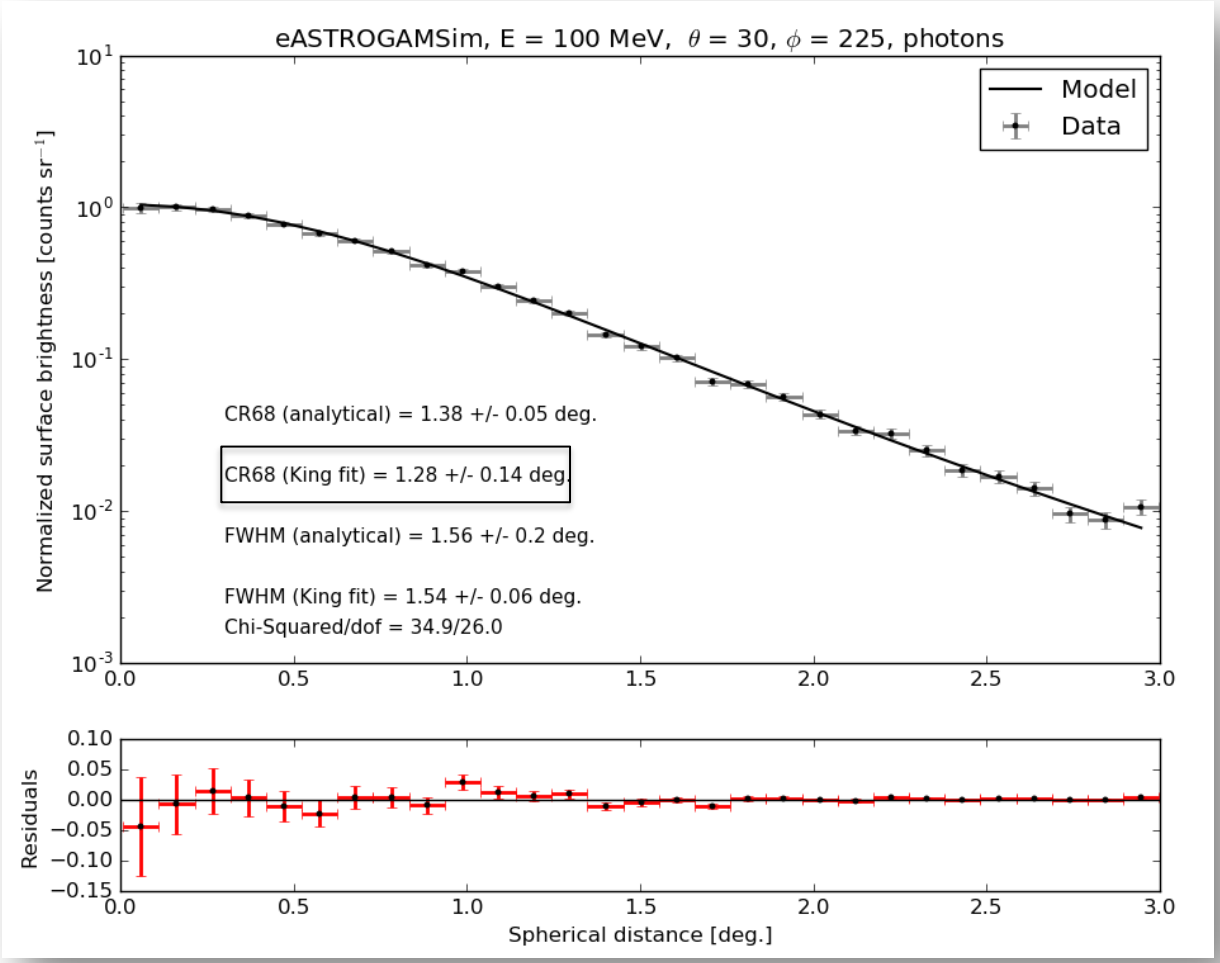
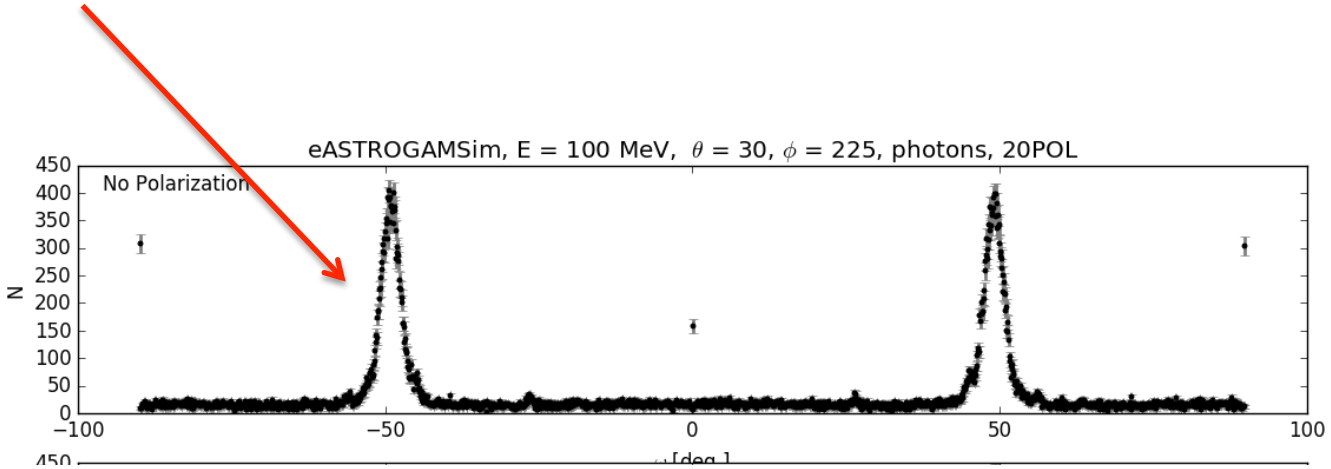
- e-ASTROGAM BoGEMMS PSF evaluation:



Gamma-ray polarisation fro e-/e+ azimuthal distribution after conversion.
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.



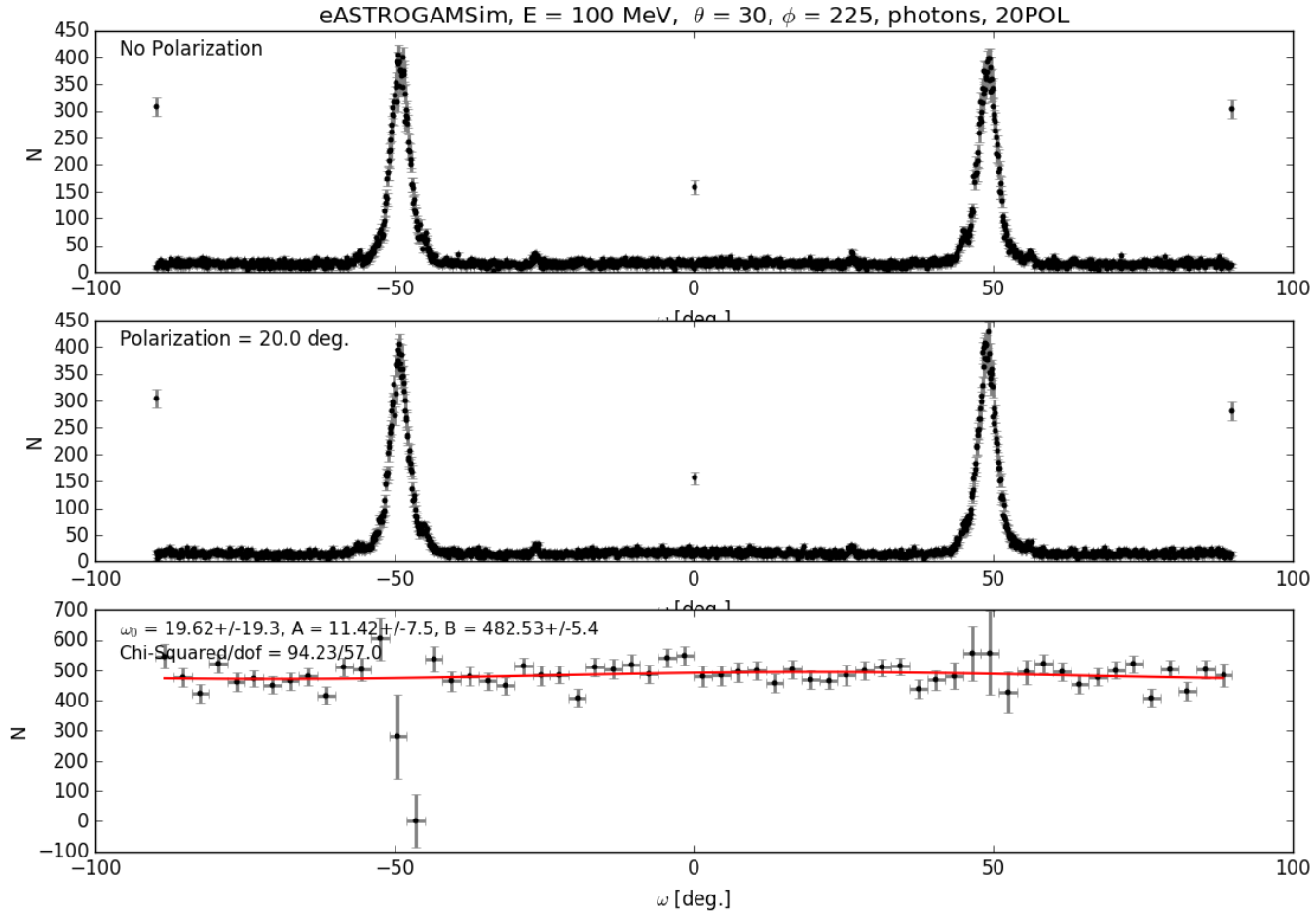

*In collaboration with D. Bernard and F. Longo*

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

**No significant results found – low statistics?**

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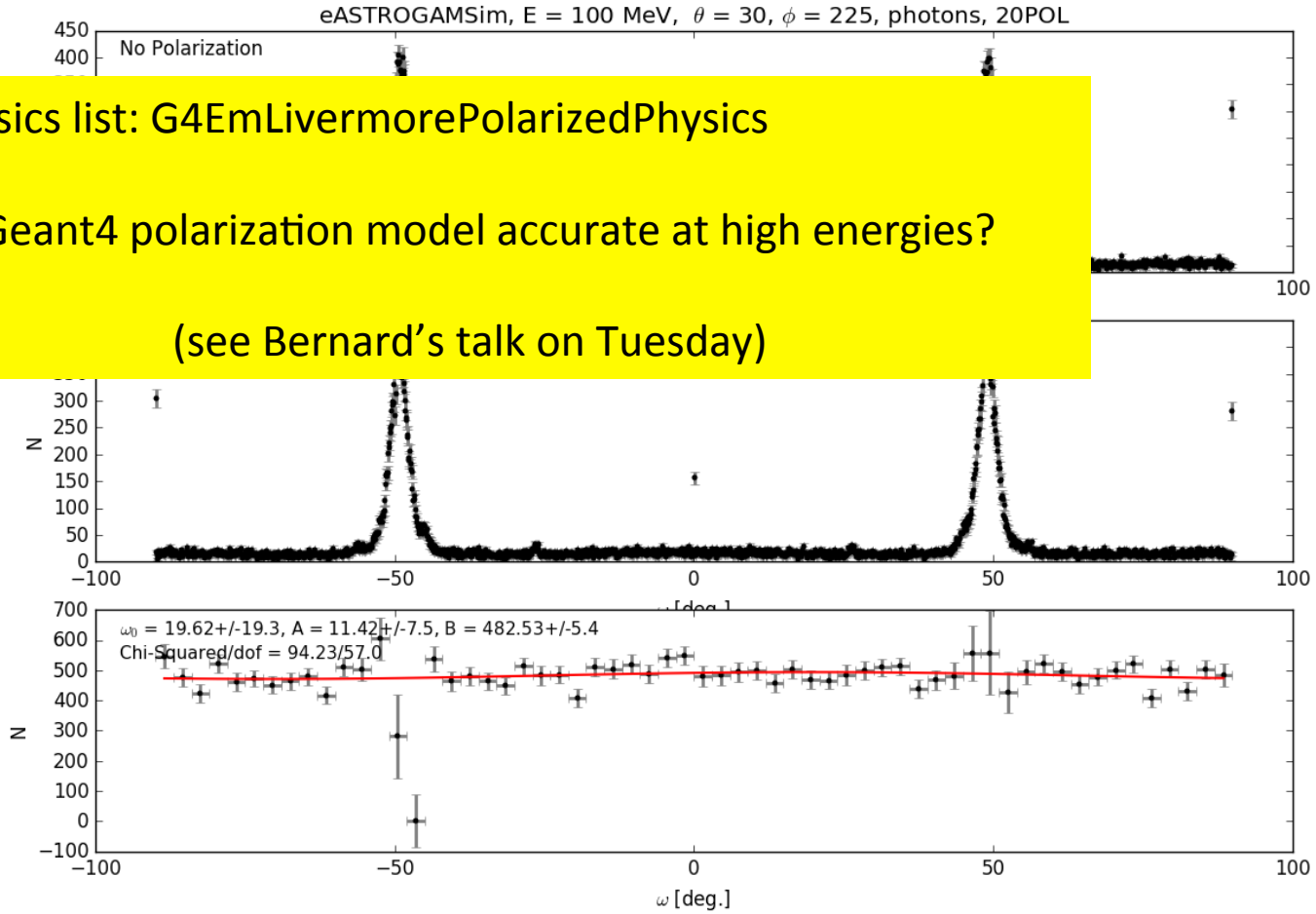
- A = 11±7.5
- B = 482±5
- Chi2/dof = 9

- Physics list: G4EmLivermorePolarizedPhysics

is the Geant4 polarization model accurate at high energies?

(see Bernard's talk on Tuesday)

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# Summary

- BoGEMMS is a Geant4-based customizable framework for the simulation of X-ray and gamma-ray space telescopes
- BoGEMMS is validated for the simulation of pair production electron-tracking telescopes (reproduction of AGILE in-flight data)
- BoGEMMS currently used for the simulation of the e-ASTROGAM IRFs (effective area, background flux, PSF) for the sensitivity evaluation in the pair regime
- what is the current validation status of Geant4 gamma-ray polarisation models above the pair production threshold?