# Space background simulation for ATHENA mission. Geant4 overview and recommendations

A. Mantero, P. Dondero

21st Geant4 Collaboration Meeting

13/09/2016

# In this talk...

1) ATHENA and AREMBES

2) Proton scattering

3) Electron scattering

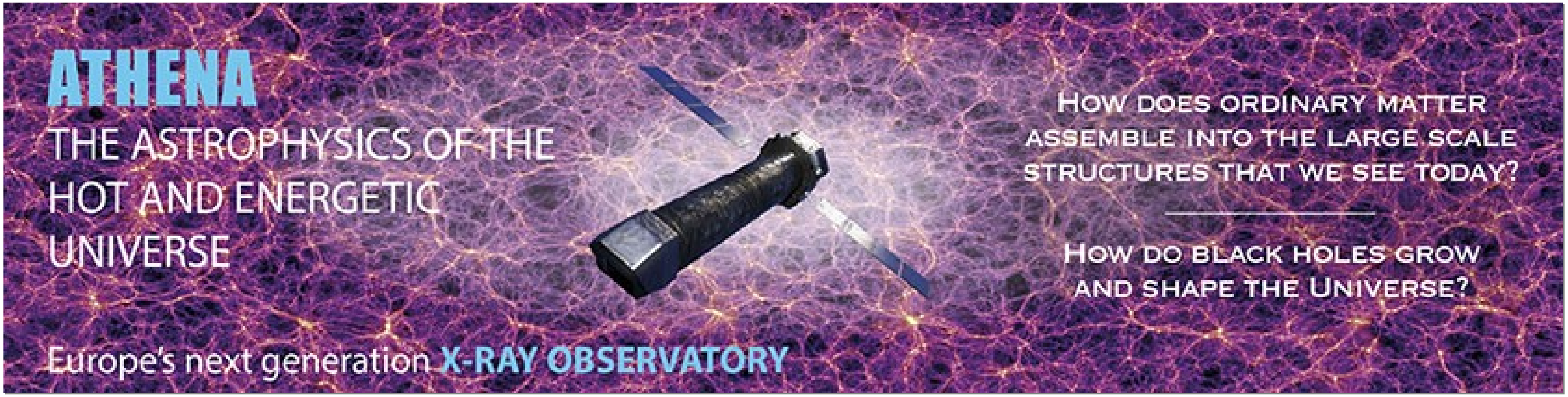
4) Other processes

5) Conclusions

Feedback, updates and all relevant news from you are important!

# ATHENA Mission

## Advanced Telescope for High-ENergy Astrophysics




Spatially-resolved X-ray spectroscopy and deep, wide-field X-ray spectral imaging to:

- Mapping hot gas structures and determining their physical properties
- Chemical evolution of hot baryons
- Searching for supermassive black holes

Halo orbit around L2, the second Lagrange point of the Sun-Earth system

Launch 2028, five years program with possible five-year extension

AREMBES

# ATHENA Radiation Environment Models and X-Ray Background Effects Simulators

Supported by ESA's Science Core Technology Programme.

**Goal: development of a simulator for radiation effects on the ESA L-Class ATHENA mission.**

- Develop new models of the L2 low-energy radiation environment
- Implement the new models in a G4-based simulation framework
- Review (and update if needed) the relevant G4 physics
  - For the propagation of radiation through the ATHENA optics and structures
  - For the creation of background on the detectors

# AREMBES WP3 and SWHARD

AREMBES Working Package 3: V. Fioretti, A. Bulgarelli, T. Mineo, C. Macculi, S. Lotti, A. Mantero, P. Dondero, V. Ivantchenko

Activities:

- Comprehensive review of existing literature about the validation of interest processes in G4
- New models for grazing incidence angle protons: Firsov and Remizovich
- Proton energy deposition tests

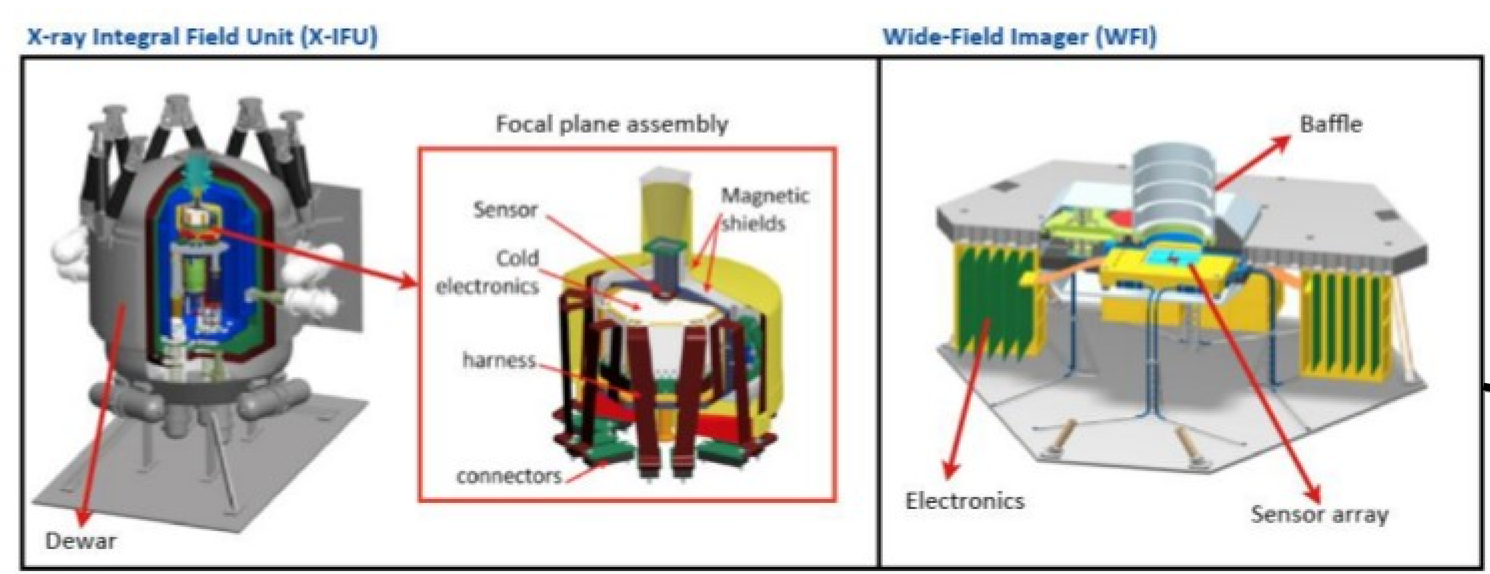
Work In progress, will include Collaboration Workshop reportings!

# ATHENA physics

The mission includes two focal plane detectors: the X-ray Integral Field Unit (X-IFU) and a Wide Field Imager (WFI). Energy Range 0.3-12 keV.

- X-IFU is an array of 3840 transition-edge sensors (TES), resolution of 2.5 eV at E < 7 keV
- WFI provide X-ray images in the 0.1-15 keV energy range, resolution 150 eV at 6 keV

Silicon optics




detectors

# ATHENA physics

**L2-orbit background:**

- high-energy (E > ~100 MeV) cosmic rays interacting with satellite
- low-energy (E < ~100 keV) protons and ions focussed by optics

Particles in the intermediate energy range
- are not efficiently focused by the X-ray mirrors
- do not possess enough energy to reach the detectors passing the shielding.

# ATHENA physics

**L2-orbit background:**

- high-energy (E > ~100 MeV) cosmic rays interacting with satellite
- low-energy (E < ~100 keV) protons and ions focused by optics

**Low-energy ions and protons are focused toward the focal plane via <u>low-angle surface scattering</u>**

# ATHENA physics

Modern X-ray telescopes: high efficiency optics in focusing grazing low-energy particles.

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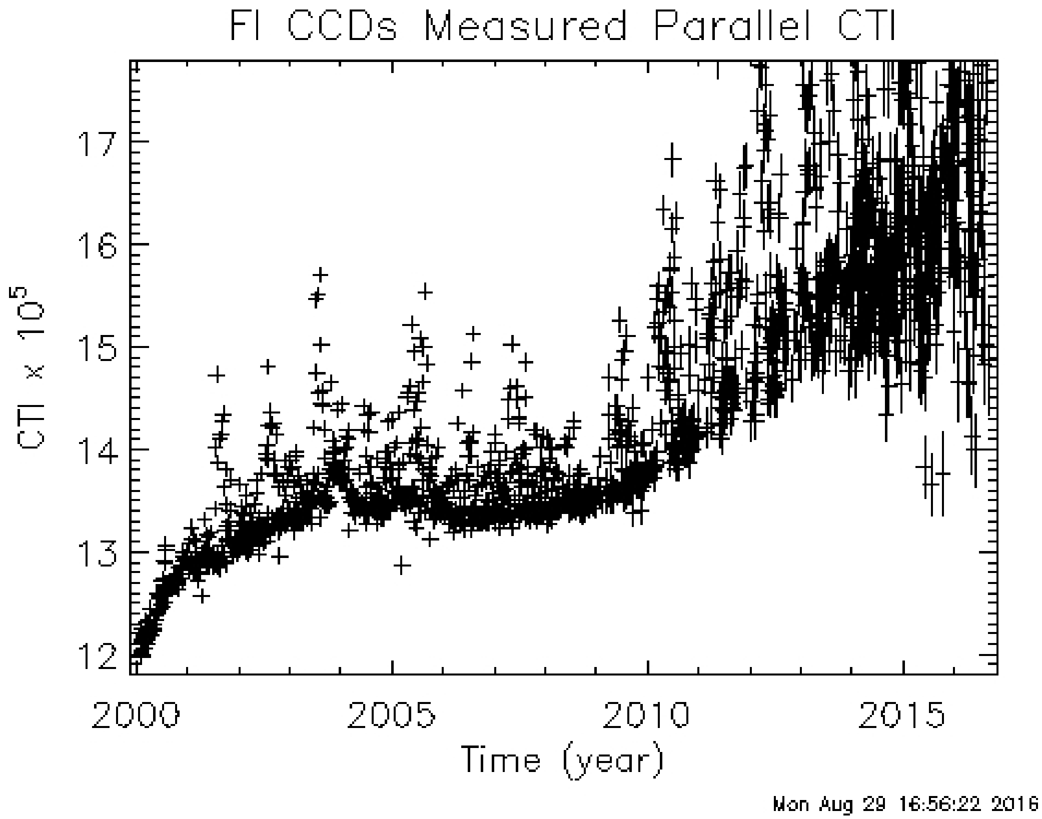


# ATHENA physics

Modern X-ray telescopes: high efficiency optics in focusing grazing low-energy particles.

- Chandra:  unexpected degradation of the front illuminated CCDs

- XMM-Newton:
  - limited performances due to soft proton contamination
  - highly variable, poorly reproducible background
- solar events reduce exposure time up to 50%

# AREMBES physics

**Key processes:**

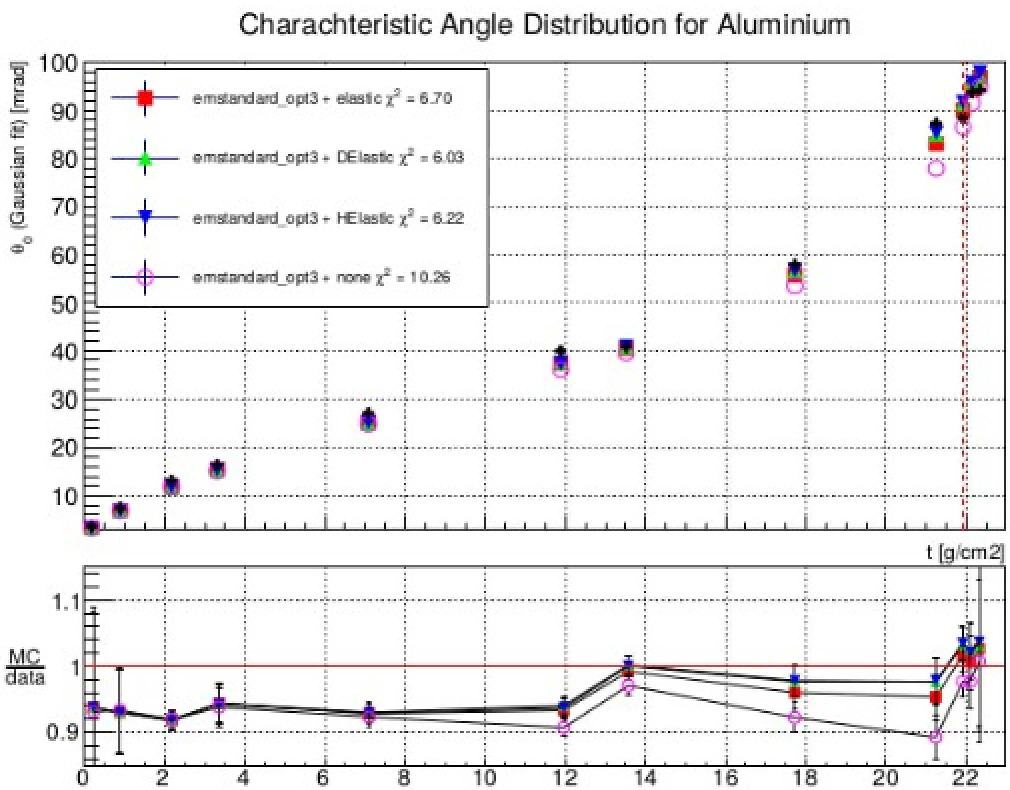
1) Proton scattering and energy deposition (up to ~1 GeV)
- MSC, SS, mixed models
- Energy deposition
- Low angle scattering: new models?  → see talk in session 3A

2) Electron scattering (secondaries, up to some MeV)
- MSC, SS, mixed models
- Electron backscattering  → see talk in session 2A

**...but do not forget other relevant processes !**
- Photon processes  → see Susanna's talk
- Radioactive decays
- Ionization
- Bremsstrahlung
- Atomic Relaxation, PIXE

# EM Processes: Protons Scattering

- Several validation tests performed regularly
- Several experimental data to compare
- In general good agreement, best SS and opt3




**Example**: benchmark performed on 160 MeV protons by Gottschalk & al. (see Sacha Schwarz presentation at 18 G4 Coll. Meeting)

# EM Processes: Protons Energy deposition

NEW

- Based Reduced Calibration Curve (RCC), see [1]
- Projected range VS particle energy, normalized to initial energy and full projected range.
- RCC Advantages:
  - nearly material independent
  - weakly dependent on the initial energy

**Geant4.9.6 and Geant4 10.2**

Simulation based on TestEm6

Energies from 1 MeV to 1 GeV

G4EmStandardPhysics_option0
G4EmStandardPhysics_option3
For the Tungsten also G4EmStandardPhysics_option4 and G4EmStandardPhysics_SS in Geant4.10.2

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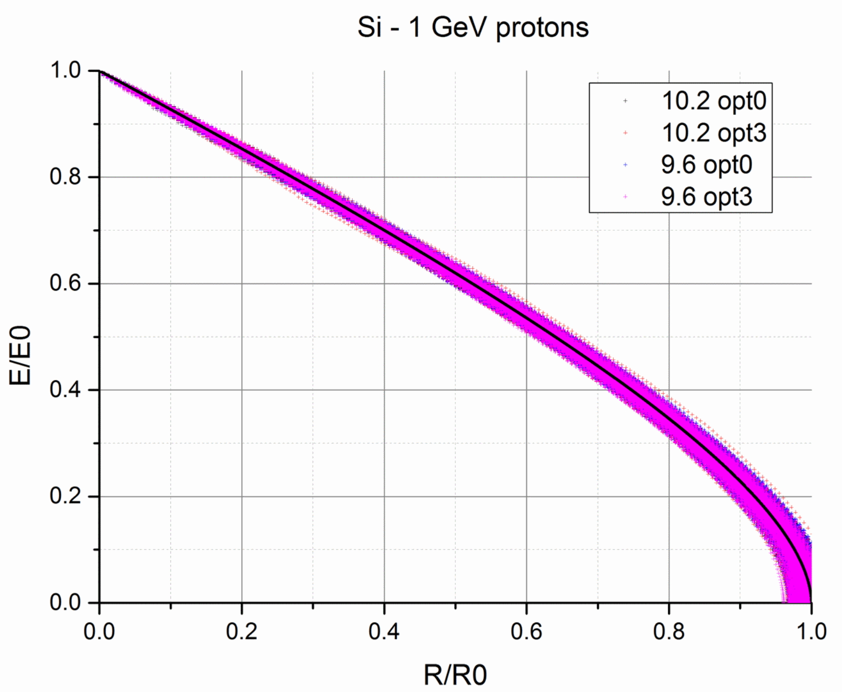
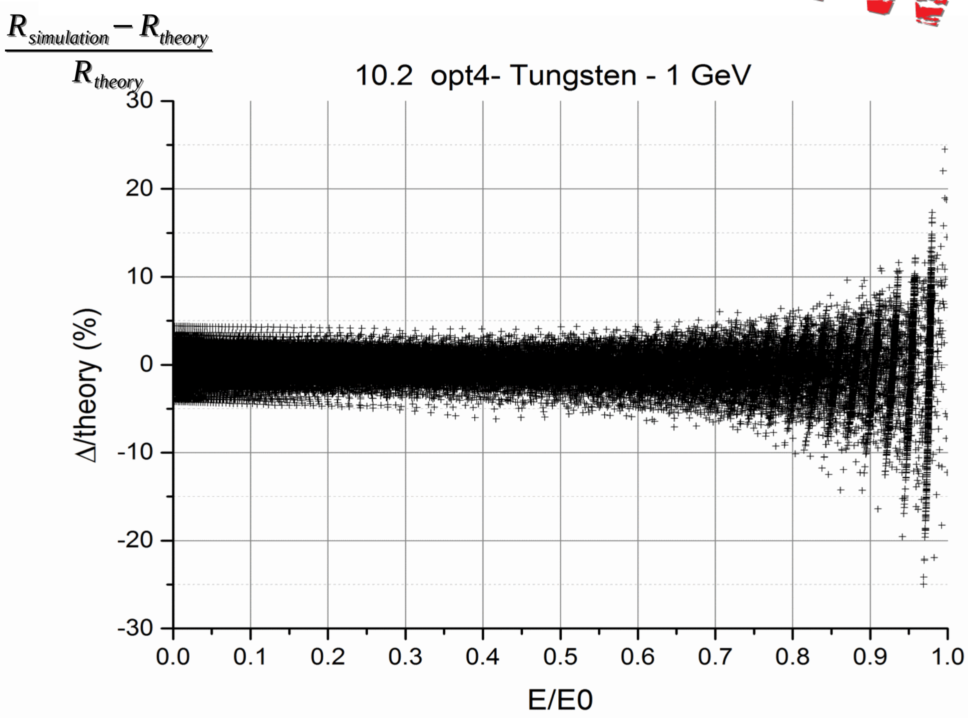
# EM Processes: Protons Energy deposition

NEW



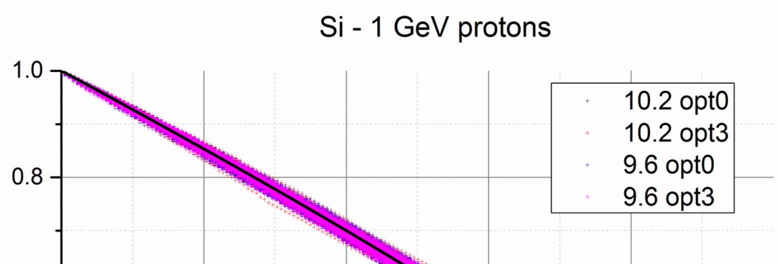



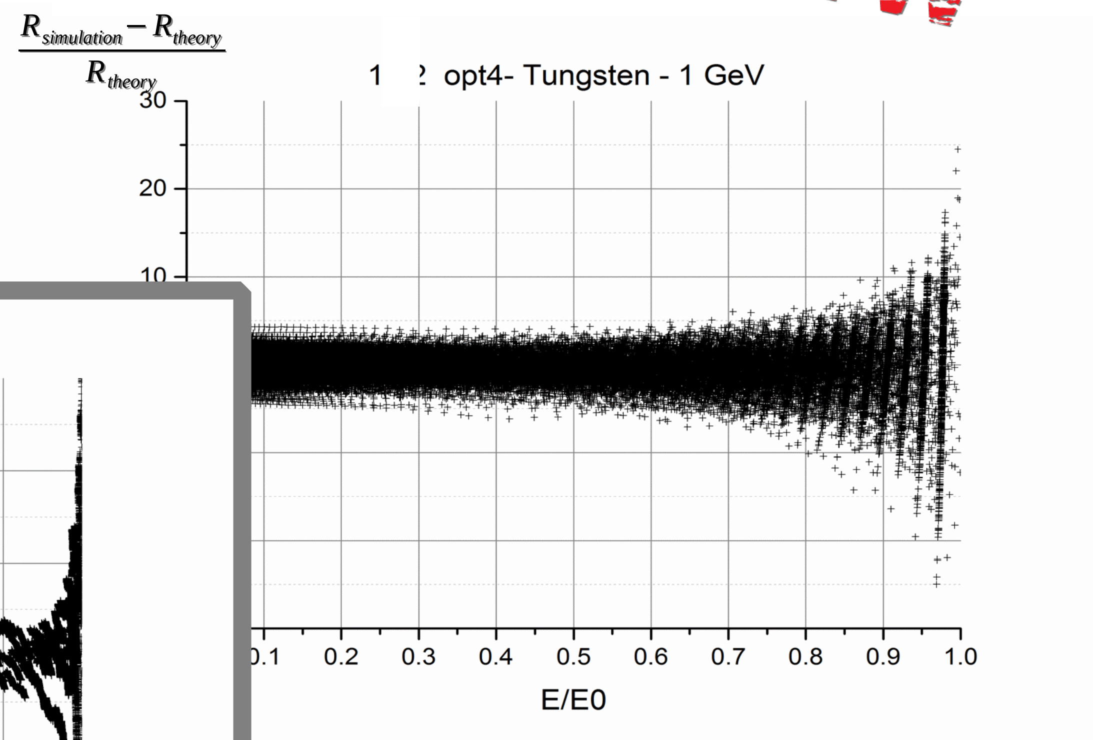

Proton beams of different energies $E_0$ impacting to a volume with size $l \geq R_0$, where $R_0$ is the full projected range expected for a particle of energy $E_0$, taken from the NIST database.

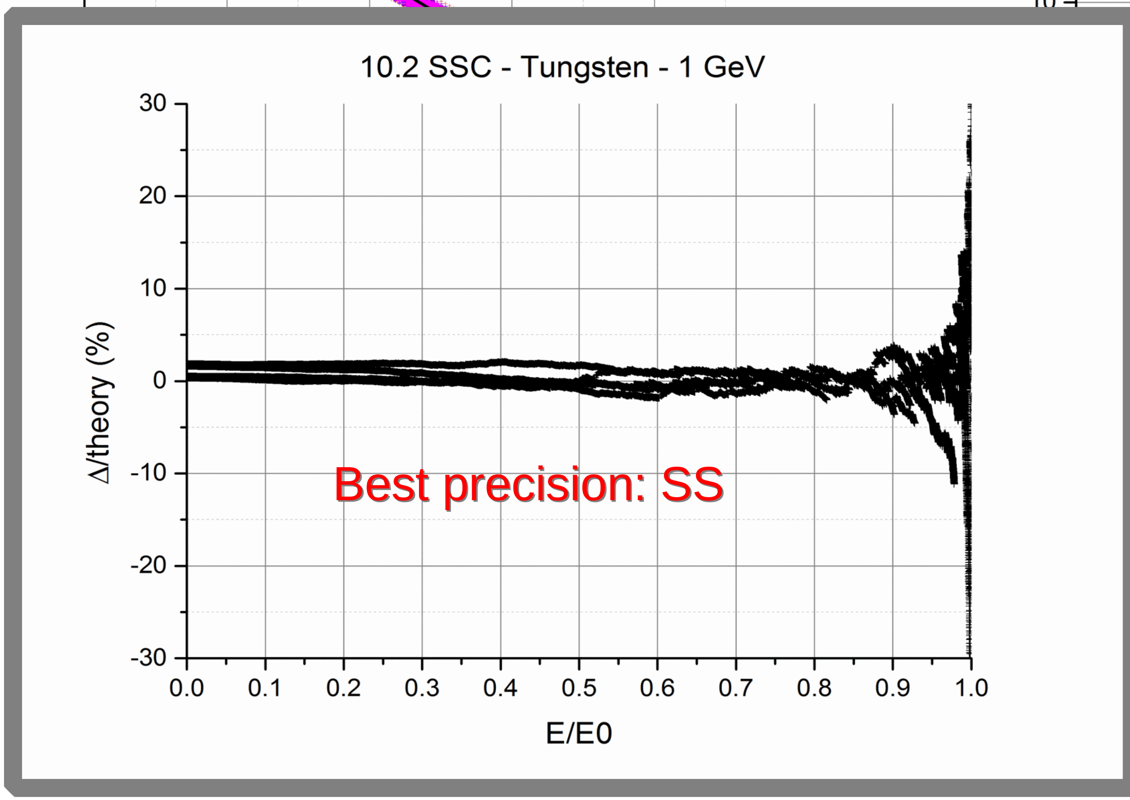
- Energy deposition reproduced to ~ percent accuracy by any physics lists
- Increasing precision as the particle travels through the medium
- Single Scattering provides higher accuracy but more computational times

# EM Processes: Protons Energy deposition

NEW




F… lume with size l ≥ $R_0$, where $R_0$ is
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(…

- … accuracy by any physics lists
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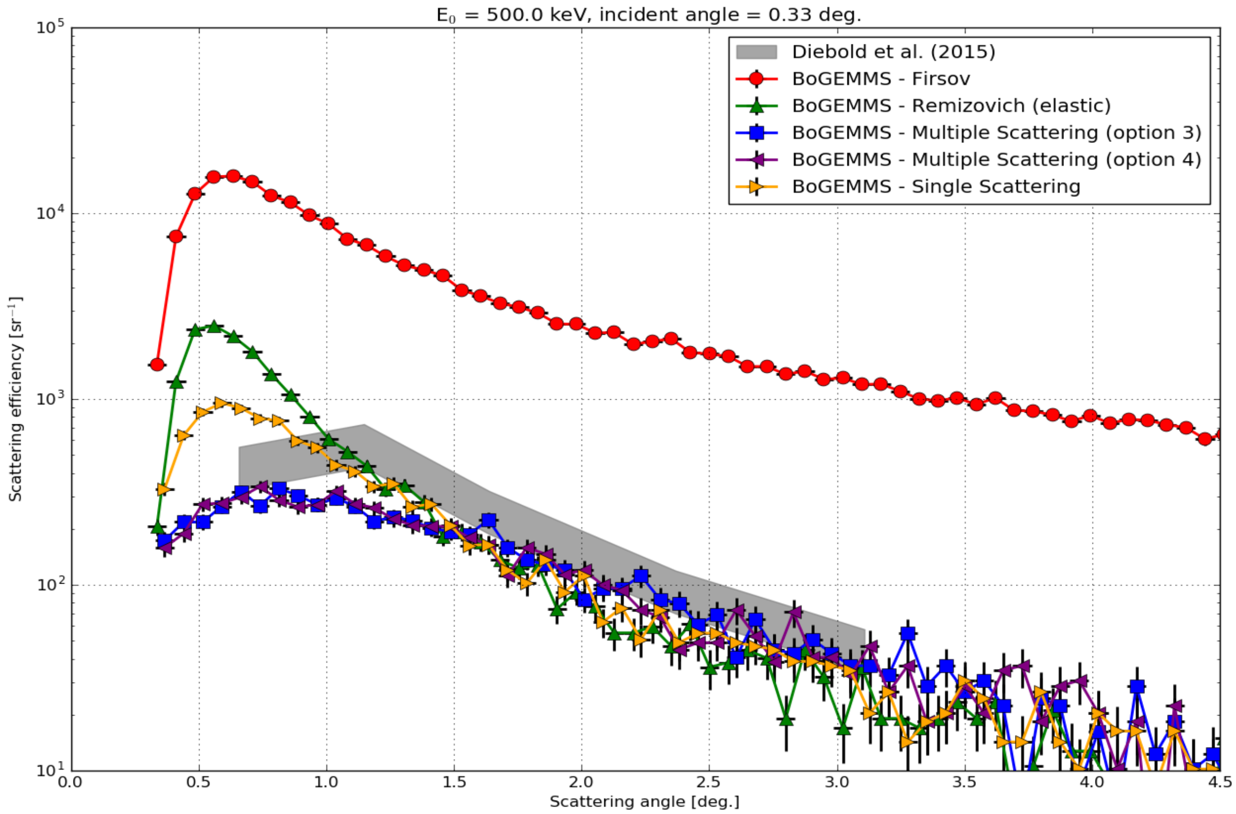
# EM Processes: Protons Low Angle Scattering

NEW

Firsov and Remizovich scattering models implemented on top of Geant4 10.2 (see parallel talk in 3A).




Firsov: problematic.

"Raw" Remizovich comparable to SS (!)

MSC and SS near to exp data (!)

No exp data @ E< 250 KeV

Existing Exp data "uncertain"

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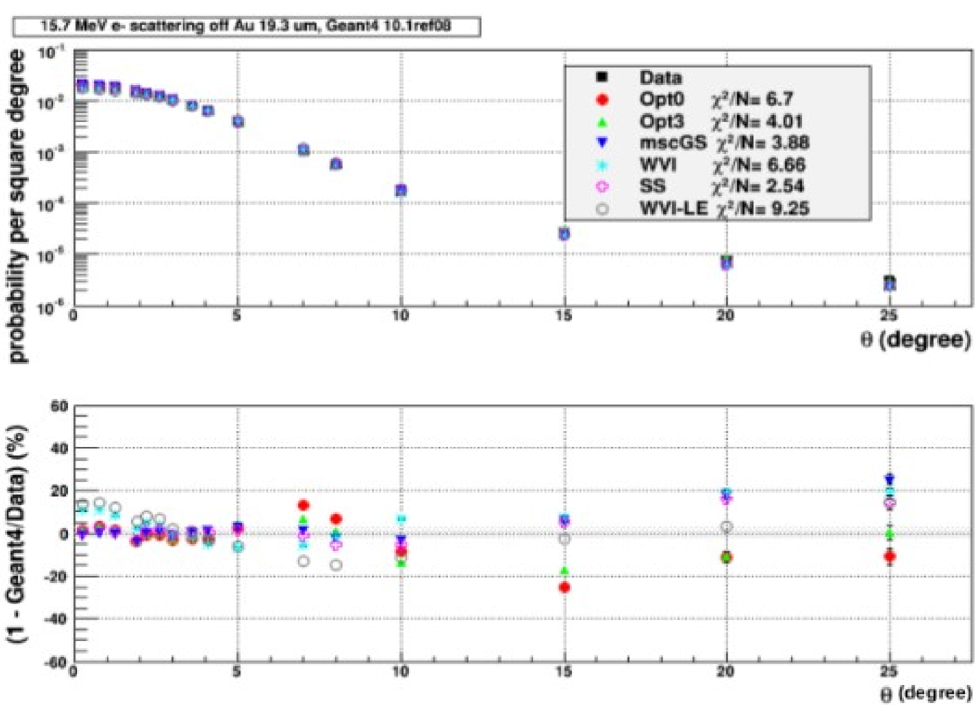
# EM Processes: Electrons Scattering

Several benchmarks at different energies:

- 13/20 MeV electrons by Ross & al.
- 15.7 MeV electrons by Hanson et al.
- 0.5/1 MeV electrons by Sandia Lab.
- 31 keV electrons by Hunger et al.

SS, GS (followed by opt3) the bests in average.



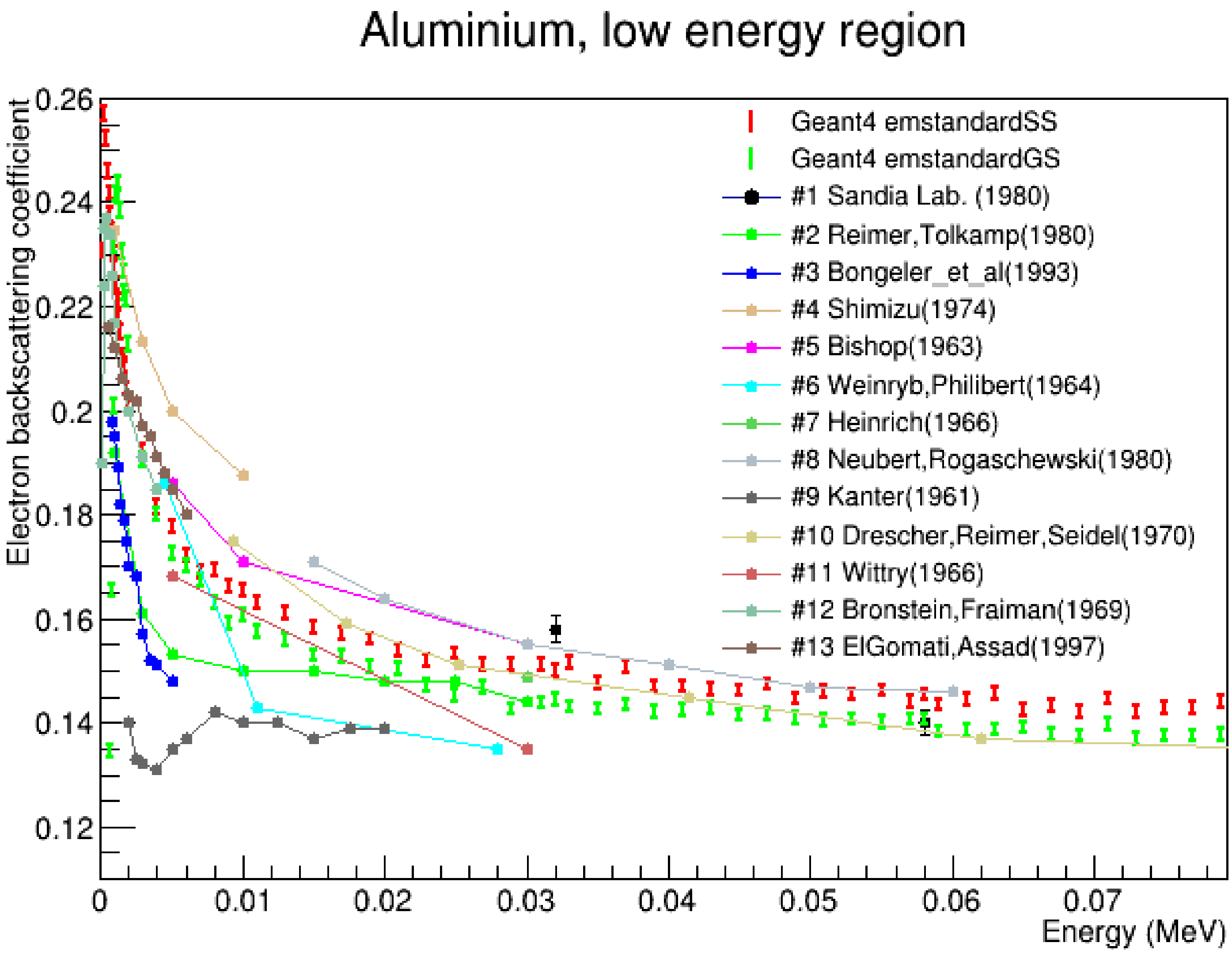

**Example**: scattering angle distribution for 15.7 MeV electrons on Au nuclei.

(see Daren Sawkey talk at 20th Geant4 Collaboration Meeting)

# EM Processes: Electrons Scattering

NEW

## Electron backscattering (see parallel talk in 2A)




**Best agreement:**

- **SS**
  (but time consuming)
- **Goudsmit-Saunderson**
  (faster, E < 100 MeV)

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# EM Processes: Photons


- Systematic comparison wrt NIST data (see Susanna's talk)
- Geant 10.2 added
- Good general agreement (5% from NIST data)
- Best: emstandard_opt4 (and Livermore)

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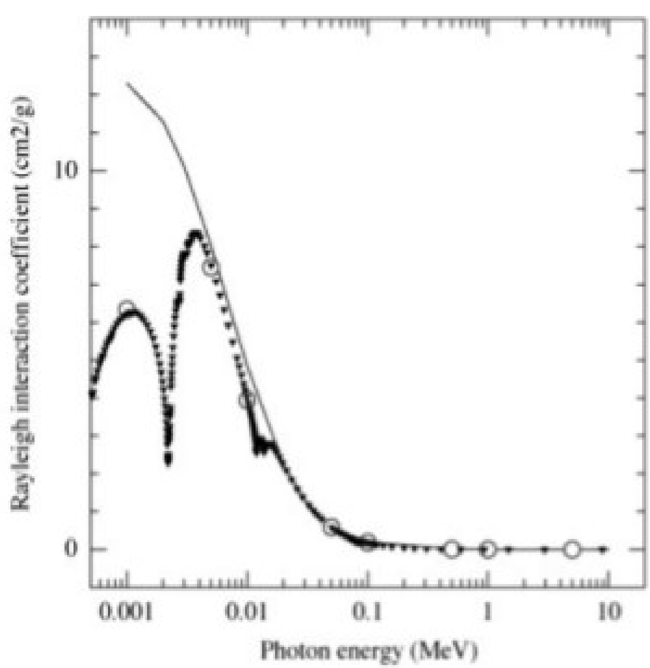



One problem: Rayleigh scattering

- Known issue
- Under study
- not very relevant for ATHENA

# Radioactive decays

Data driven technique using the ENSDF. Systematic validation ongoing, comparing Geant4 wrt NUDAT2 and DDEP databases for:

- Gamma rays
- X-rays
- Electron internal conversion
- Auger electrons
- Alpha emission

Thanks to Laurent Desorgher for the material and the discussion!

Gamma rays are simulated very well

X-ray sand Auger emissions depend on the particular nuclei case.

# EM Processes: Others

## Overview Results:

- Ionization
  PAI best ionization peak, but time consuming:
  - use PAI in target regions

- Bremsstrahlung
  Penelope gives the best results, followed by emstandard option3 and Livermore

- PIXE
  Use standard model + FormFactor for M shells

- Auger
  use full cascade simulation only in target regions

# Space dedicated physics list


Strategy: start from a physics list and add changes for target processes.

Our plan (in progress):

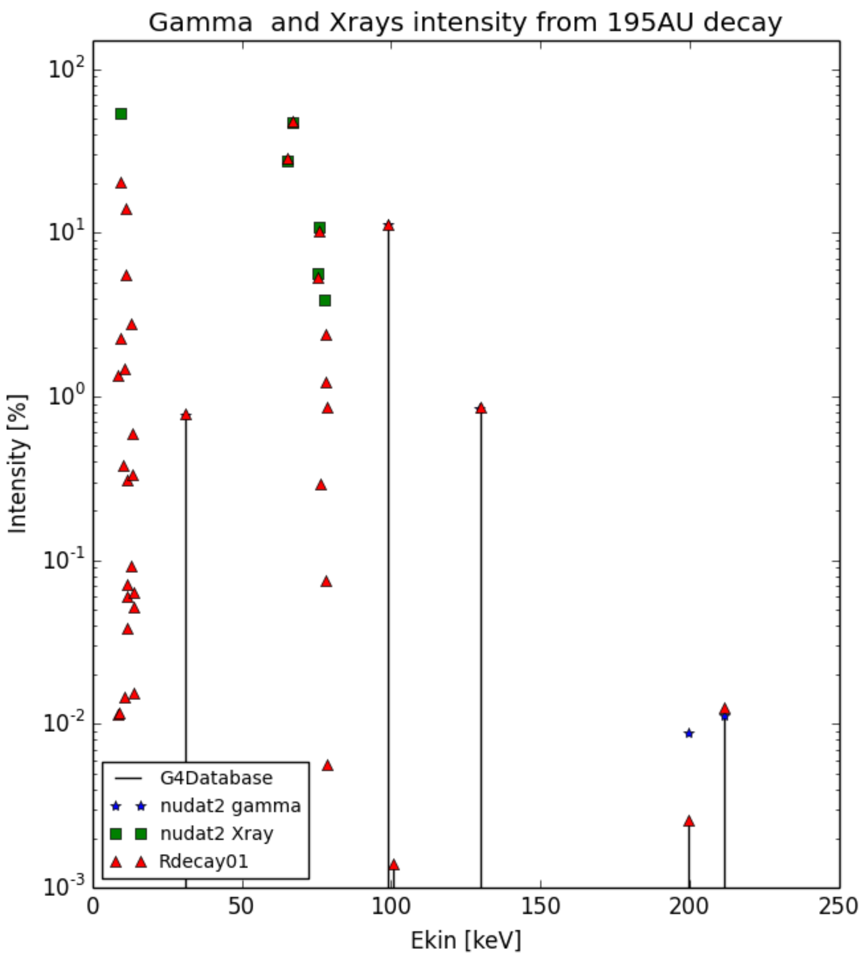
- Start from emstandard_opt3 or emstandard_opt4
- emstandardGS for electrons below 100 MeV
- For photons use opt4 or Livermore
- For bremsstrahlung use Penelope or opt3/Livermore
- Minor tunings: in target regions use PAI (ionization), full cascade simulation (Auger) and form factor cross sections (PIXE).

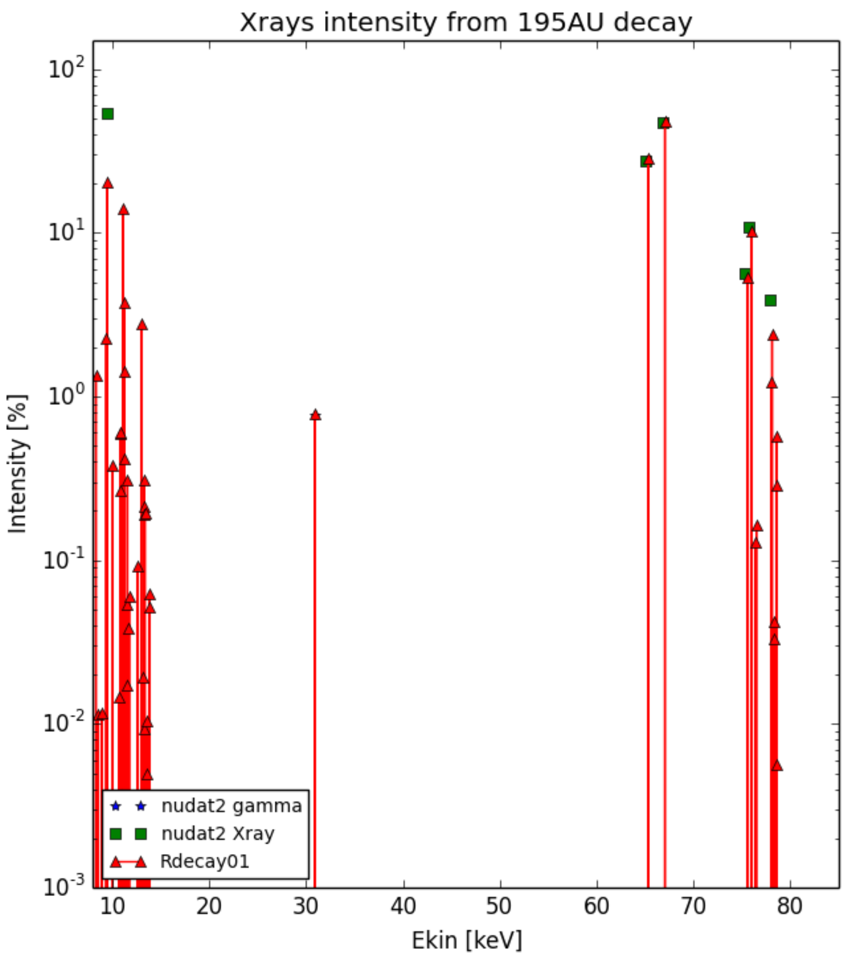
# Backup

# References

[1] Comparison of the GEANT4 releases 8.2 and 9.2 in terms of a pCT reduced calibration curve. DOI:10.1109/NSSMIC.2010.5874220

# Radioactive decays



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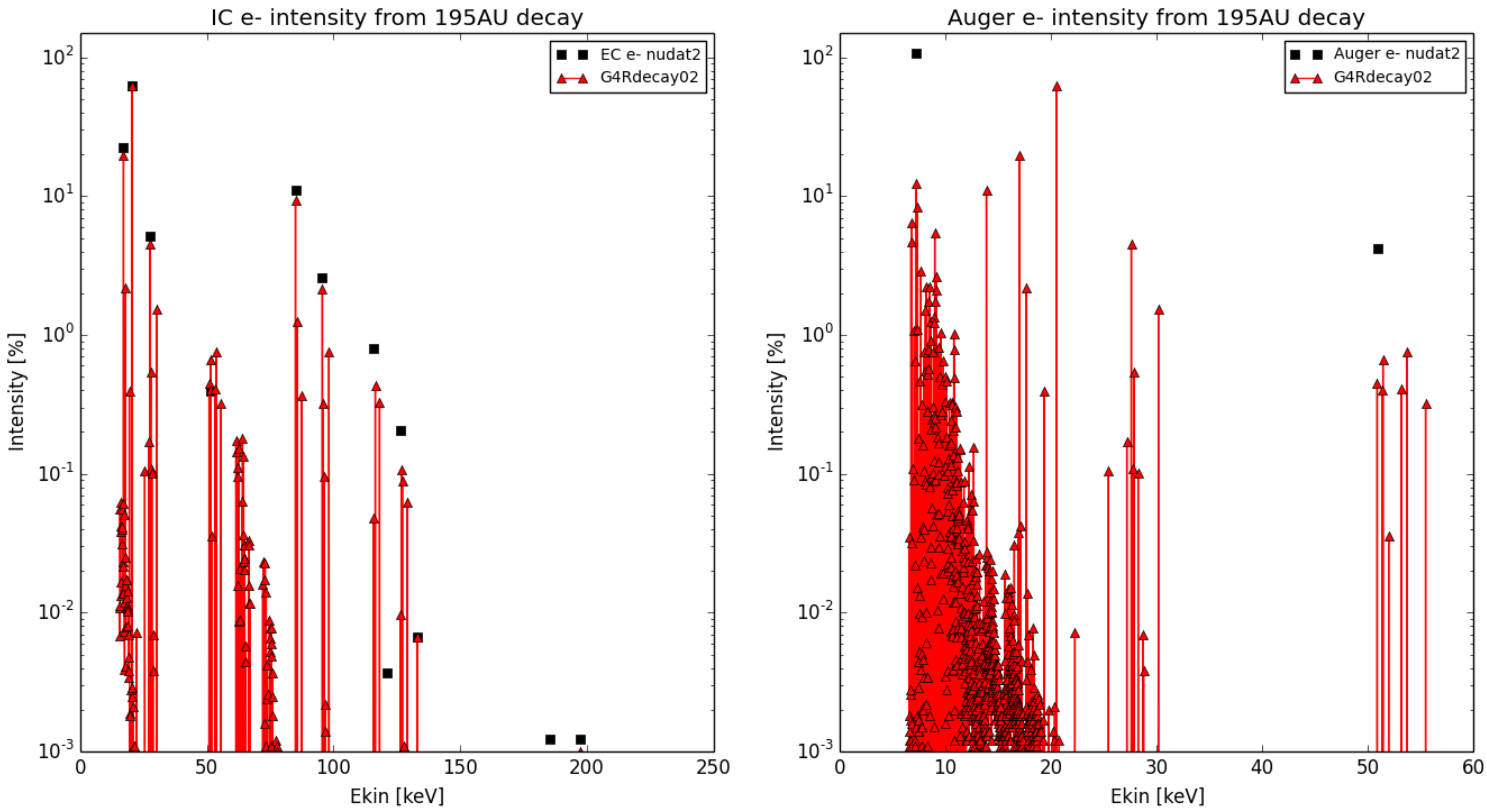

# Proton energy deposition