A "Space dedicated" GEANT4 physics list from the AREMBES project

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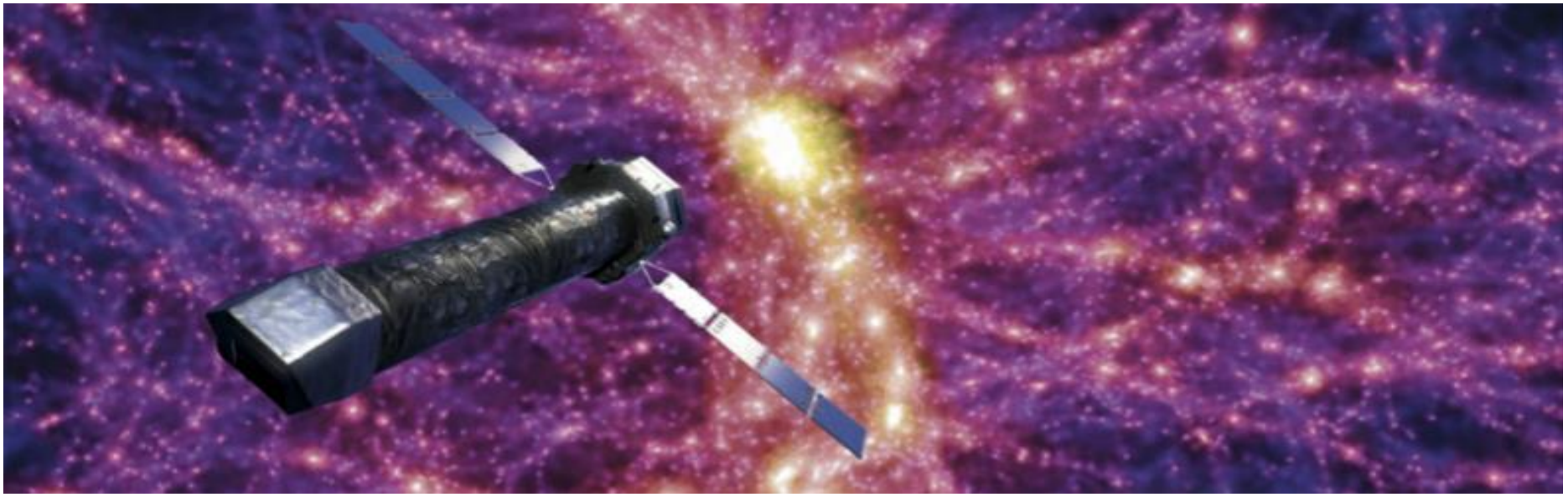

AREMBES* - ATHENA Radiation Environment Models and X-Ray Background Effects Simulators: the new ESA bkg software simulator designed for the ATHENA mission (see general talk by S. Lotti).

- Background estimation → key ingredient
- Simulation framework based on Geant4
- Need to identify the best possible physics models for space applications into Geant4 and prepare a physics list "space dedicated" to be used in the AREMBES simulator.

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Key processes

1) Proton scattering and energy deposition (up to 1 GeV)

- MSC, SS, mixed models in G4
- Energy deposition

2) Electron scattering (secondaries, up to some MeV)

- MSC, SS, mixed models
- Electron backscattering

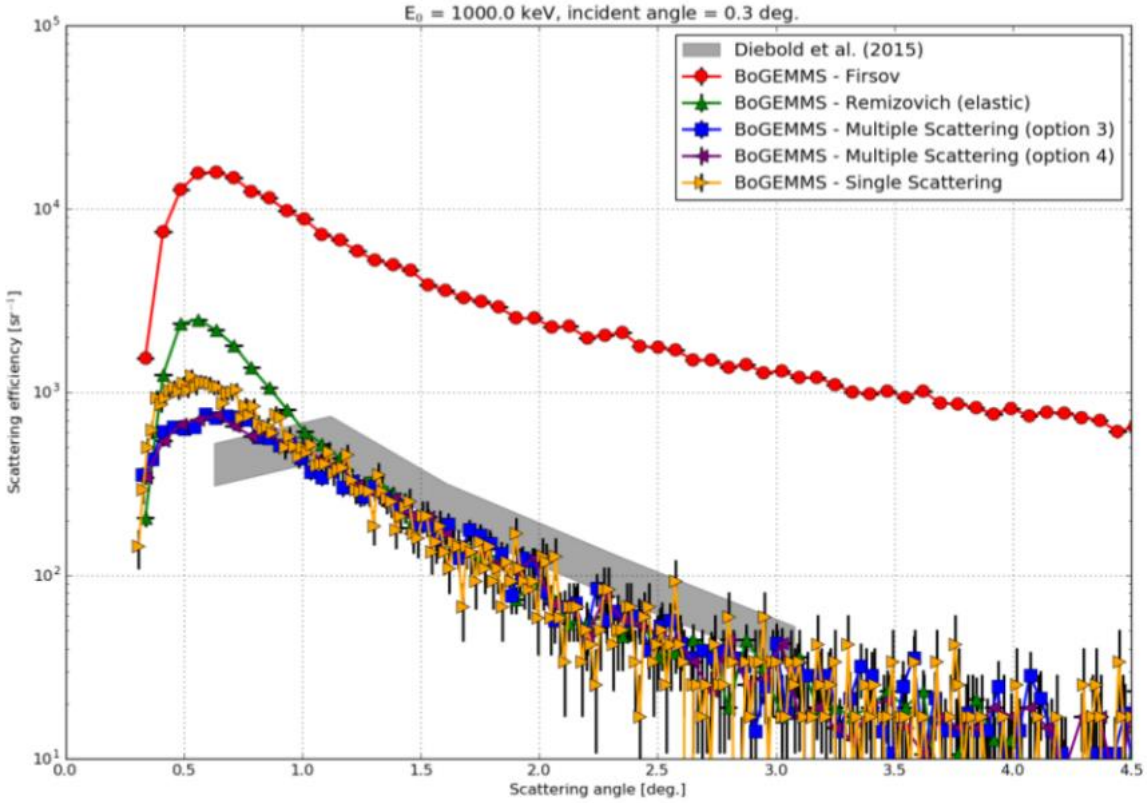
...but do not forget other relevant processes:

- Photon processes
- Radioactive decays
- Ionization
- Bremsstrahlung
- Atomic Relaxation, PIXE

Proton processes

- Periodic and comprehensive validation tests within Geant4 collaboration
- Good agreement in general, great results from SS, opt3 and opt4 standard physics lists
- New results from the AREMBES WP3 and WP4
  - Energy deposition (Reduced Calibration Curve and Ionization), by Simone Lotti
  - Grazing angle scattering (Firsov and Remizovich models), by Valentina Fioretti

Low angle proton scattering



Grey band: experimental data

Firsov model out of scale

Remizovich model good, but time consuming

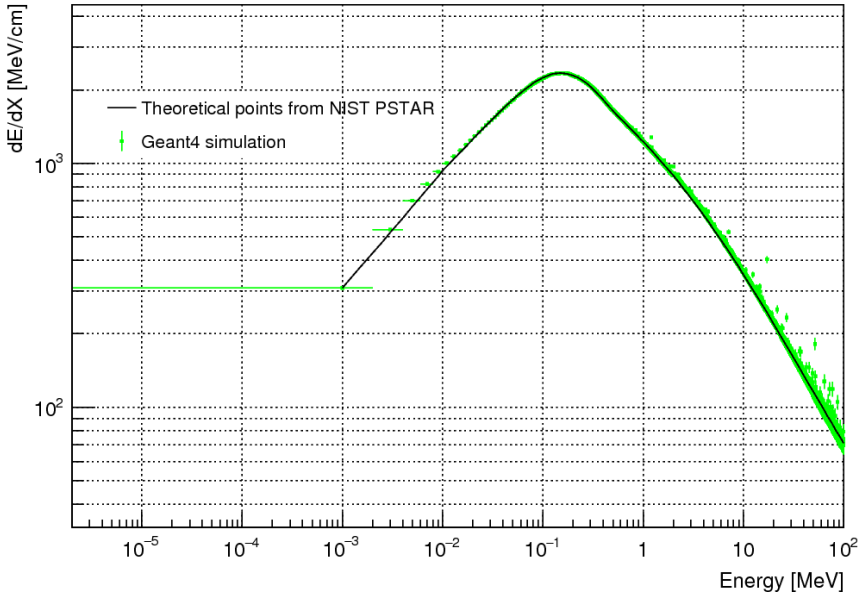
SS good for all tested energies

opt3 and **opt4** good only above 750 keV

Dedicated talk by Valentina yesterday

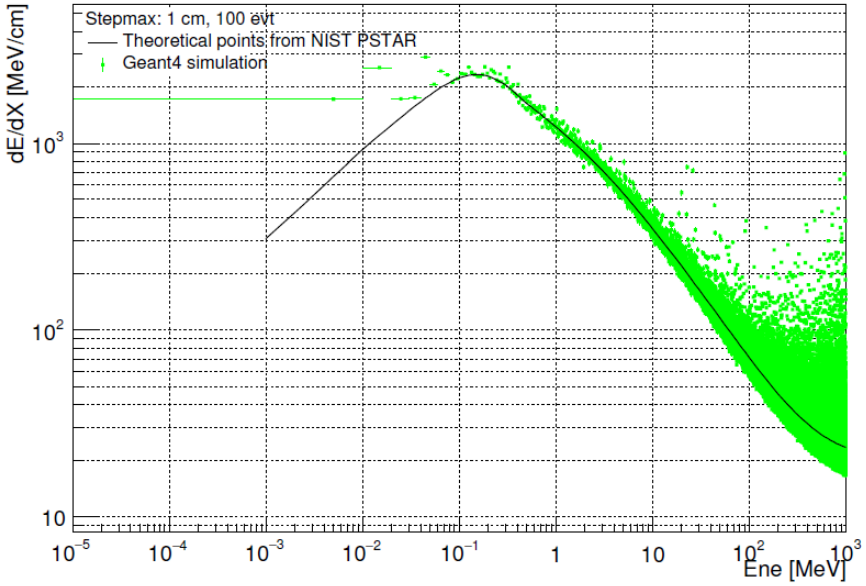
Proton ionization

- Method unbiased if the stopping power not change significantly at each step
- Proton ionization: good agreement of both SS and opt4 with respect to theoretical results from NIST PSTAR
- SS: many tiny steps. Agreement best for average values but larger fluctuations



Em standard opt4 physics list, SetStepFunction(0.02, 0.01µm)

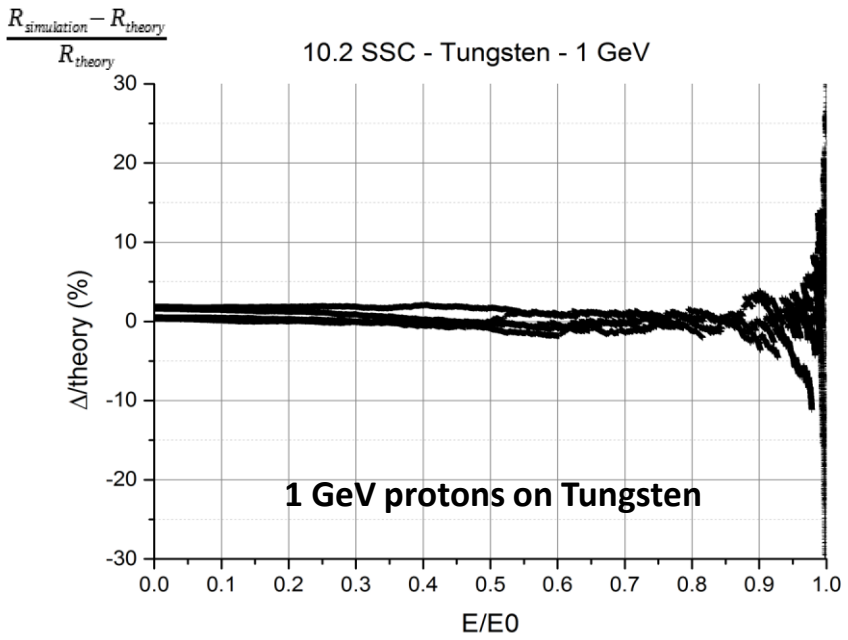
SS: dE/dX distribution



Single Scattering standard physics list (lower stat because time consuming)

Energy deposition tests

- Proton energy deposition tests based on Reduced Calibration Curve
- Comparison of the proton range in matter with respect to the NIST database. Different materials tested and different energies.



Proton impacting on a volume with size $L \geq R_0$

(R_0 is the full projected range expected for a particle of energy E_0 from the NIST database)

Largest fluctuations in the first steps into matter.

SS gives the higher accuracy

Conclusions for protons

- SS seems the best physics list, but time consuming

- Very good too: opt4
  - Ionization
  - Cpu time
  - Scattering at high and intermediate energies
  - Low angle scattering
  - Low energy scattering

Sensitive items for ATHENA

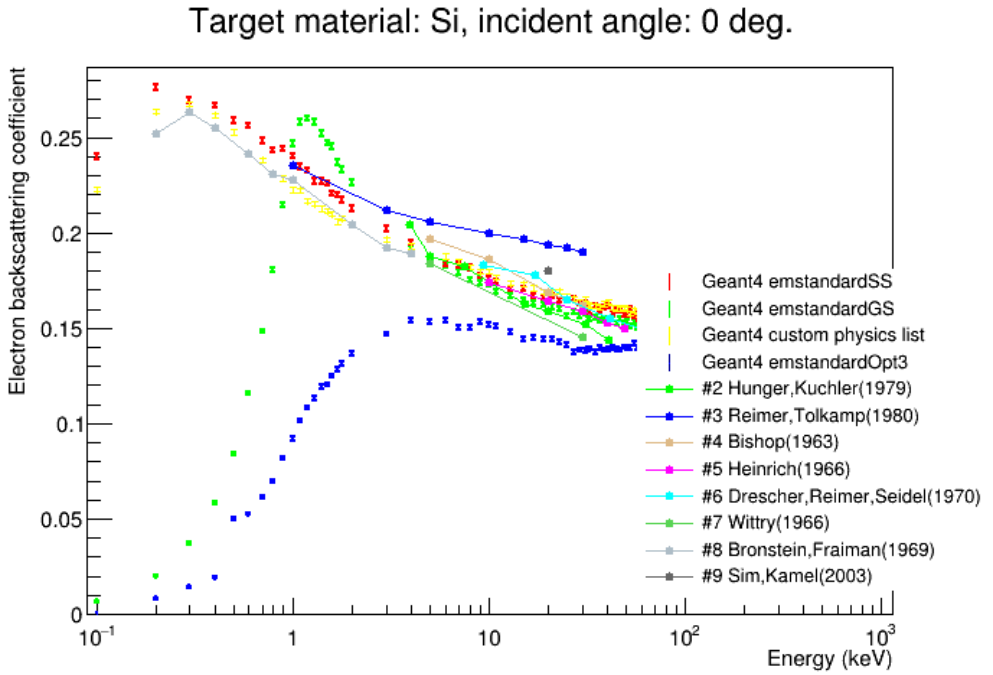
About electrons (in brief)

- Dedicated studies on electron backscattering on several materials, incidence angle and energies
- Several experimental datasets available but different conditions and reliability
- See dedicated talk on physics validation

Conclusions: **SS is the best from 50 eV to GeV**

Other physics lists good above 250 keV.

Custom physics list based on SS at low energy for electrons



Processes involving photons

Validation performed systematically by the G4 Collaboration

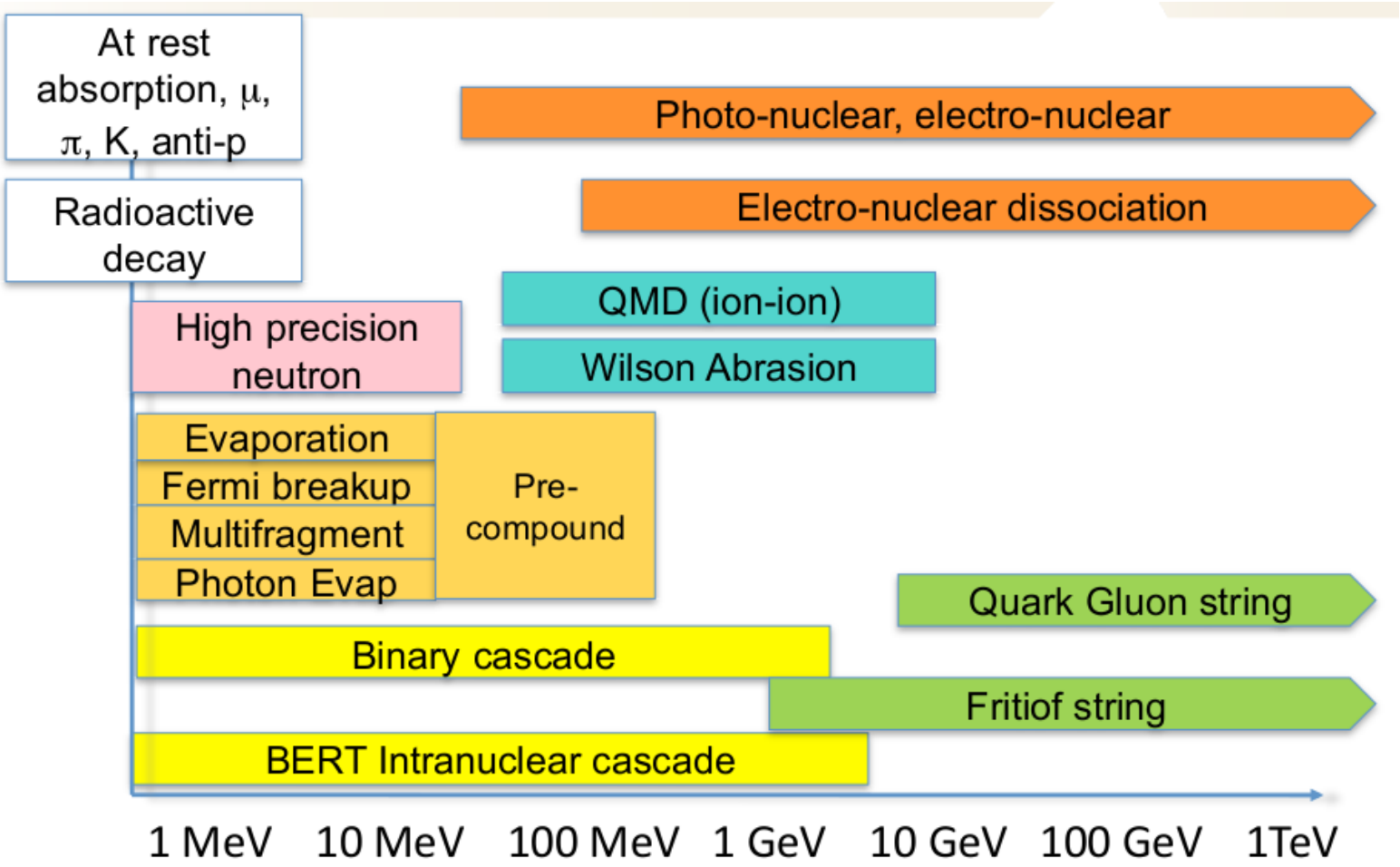
- Attenuation coefficient and stopping power
- Rayleigh and Compton scattering, photoelectric effect, gamma conversion

Photon beam →

Bulk
(Be, C, Al, Fe, Cu, W, Au, Bi, and more tested)

Best results: opt4 and Livermore (for all tested materials and processes)

Hadronic physics sector



Hadronic physics sector

String models

- Quark-Gluon String Precompound (QGSP) model has discrepancies in thin target test and can be applied above ~20 GeV
- FRITIOF Precompound (FTFP) model can work even above ~ 2 GeV

Fritiof most recommendable for space physics applications that require the simulation of hadronic interactions at low energies.

Cascades models

- For protons and neutrons Bertini works better above 1.5 GeV and Binary below. For other particles Bertini can be used in all energy range.

Standard physics list that actually implements best combination of models is QBBC. Created appositely for space physics applications.

The Space physics list recipe

EM sector: opt4 with changes

- SS at low energy
  - For electrons (backscattering)
  - For protons (grazing angles scattering)
- Possibility to disable SS for protons if high precision on ionization peak needed (and less execution time)
- No changes for photons

Hadronic sector: QBBC physics list

- Bertini +FTFP string model
- Binary (for primary proton and neutron interactions with nuclei below 1.5 GeV)
- Designed for space applications, no modification required

Baseline Physics List	Modifications
Electromagnetic Sector	
emstandard_opt4 • *G4KleinNishinaModel* above 20 MeV and *G4LowEPComptonModel* below for Compton scattering • *G4PenelopeGammaConversion model* for gamma conversion below 1 GeV • parameter *RangeFactor* for multiple scattering of e+, e- set to 0.01 • *G4UrbanMscModel* for proton and electron scattering • for e+ and e- algorithm of sampling of lateral displacement enabled	• use SS for proton scattering below 1 MeV • use SS for electron scattering below 250 keV with lowest electron energy cut 50 eV • set lower ionization parameters for protons using the SetStepFunction(0.05, 0.01 m) method
Hadronic Sector	
QBBC • FTFP string model • cascade: combination of Bertini and Binary	• none

Conclusions

- A ''Space dedicated'' Geant4 physics list has been developed within the ESA AREMBES project
- Optimized for ATHENA physics
    - Low incident angle protons
    - Low energy electrons
    - Energy deposition

Further and periodical tests are required, but ATHENA needs are well probed by Geant4.

Active collaboration between AREMBES members and G4 Collaboration, that gives continuous and precious support.

…feedbacks are welcomed (and desired) from all the space community!