Grazing angle proton scattering with Geant4

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21st Geant4 Collaboration Meeting

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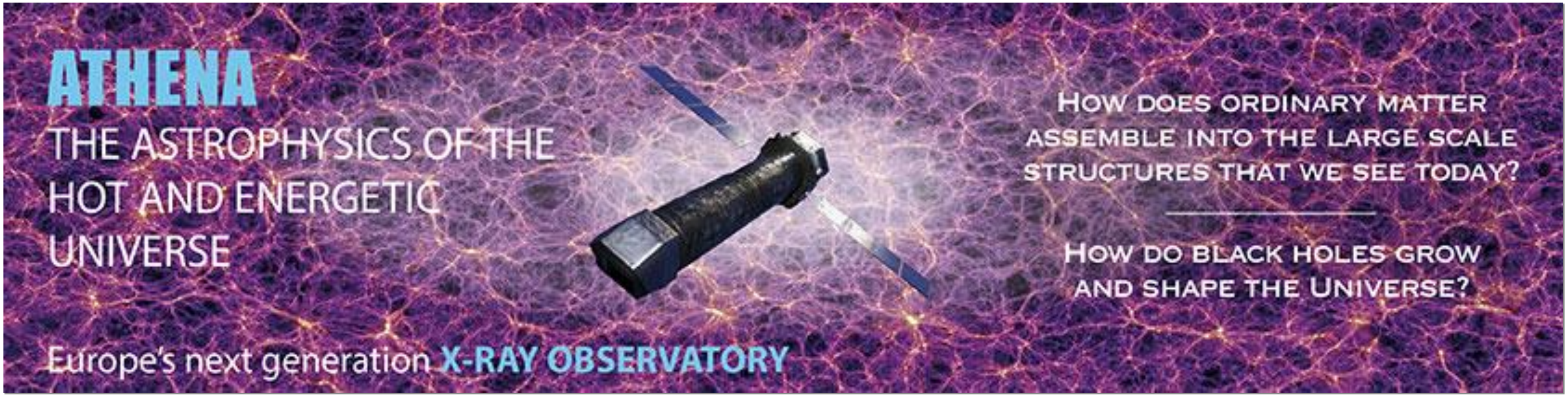
ATHENA

Advanced Telescope for High-ENergy Astrophysics



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

- 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

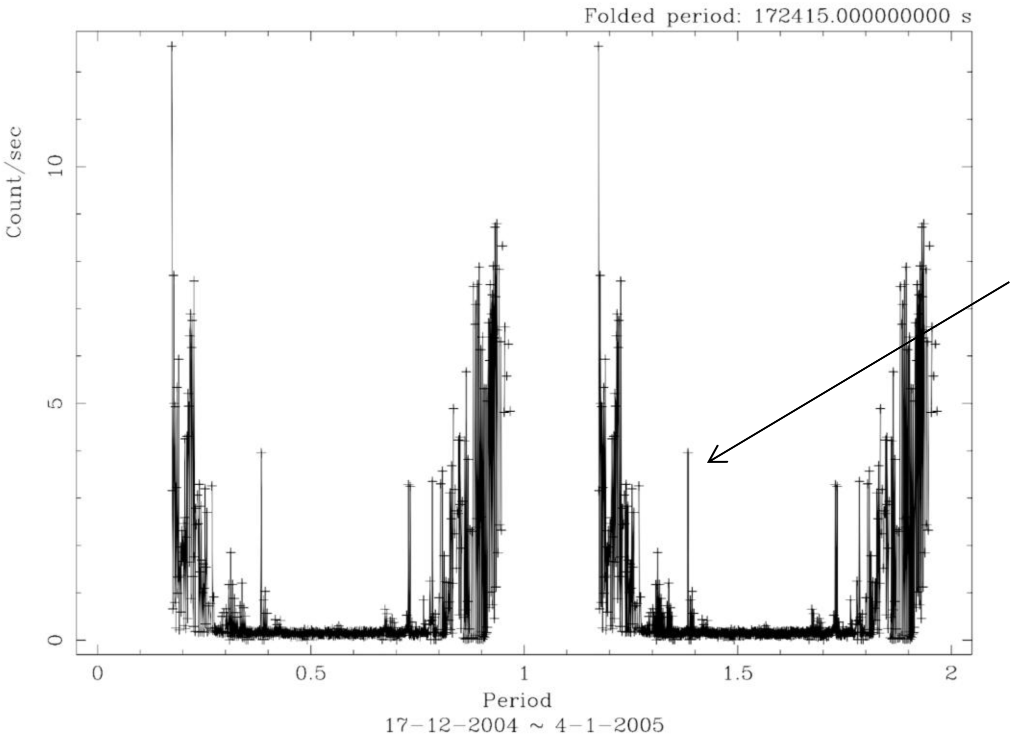
Supported by ESA's Science Core Technology Programme.

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

Grazing angle proton scattering in X-ray space telescopes

- 1999 damaging of Chandra/ACIS instrument
  - outside Van Allen belts < 200 keV **p** funnelled by X-ray optics
  - reach the focal plane,
  - Background/degradation the detector



XMM-Newton soft proton flares detected outside radiation belts (Fioretti+2016)

An accurate simlatioin of protons scattering on the 'mirror' is mandatory for designing effective shielding solutions (magnetic diverter? for future missions, including ATHENA

Grazing angle proton scattering in Geant4 – current status

Past:

- Coulomb-based scattering processes for LowEnergy grazing angle protons
- G4 MSC first used in 2001 for XMM-Newton simulations
- Firsov “scattering” has been implemented (Fan Lei) in G4 in 2004
    - Sub-ensamble of Remizovich model
    - Used fo XMM-Newton simulations
    - Incresed flux on the ocal plane
    - Never included in G4 Release.

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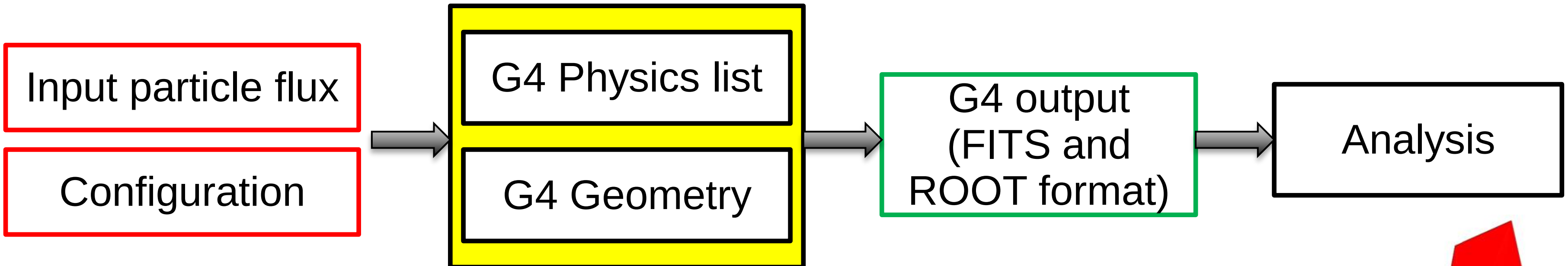
On top of Geant4 10.2

- **Firsov re-Implementation**
- **Remizovich (elastic) new implementation**
- **Comparison wrt MSC (Opt 3 and Opt4) and with SS**
- **Comparison wrt exp data**

The BoGEMMS framework

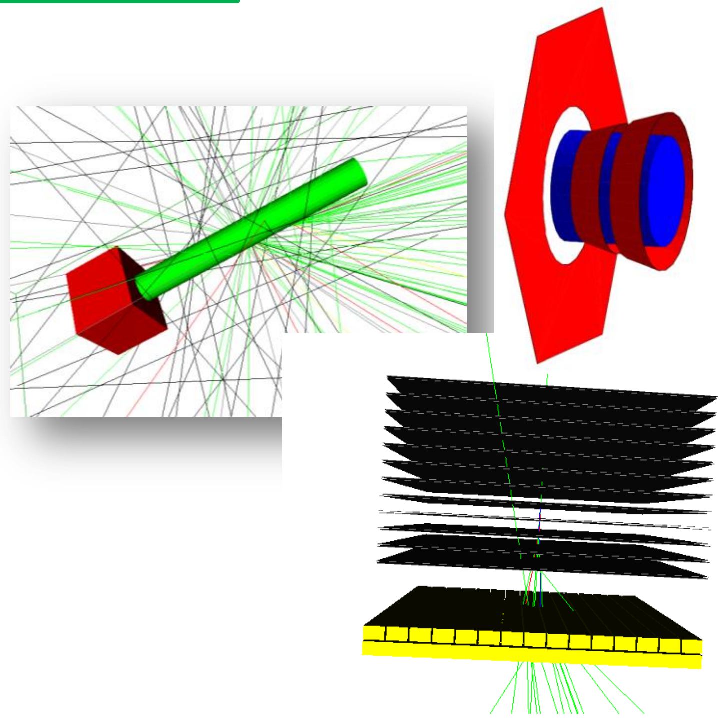
BoGEMMS (Bologna Geant4 Multi-Mission simulator) i

- Developed at the INAF/IASF Bologna (2012)
- For X-ray and Gamma-ray space missions performance (backgrounds, effective area).
- Physics and Geometry interactive settings
- “Normal” data analysis
- Alpha-state web interface: *http://giove.iasfbo.inaf.it/tremila/index.html*



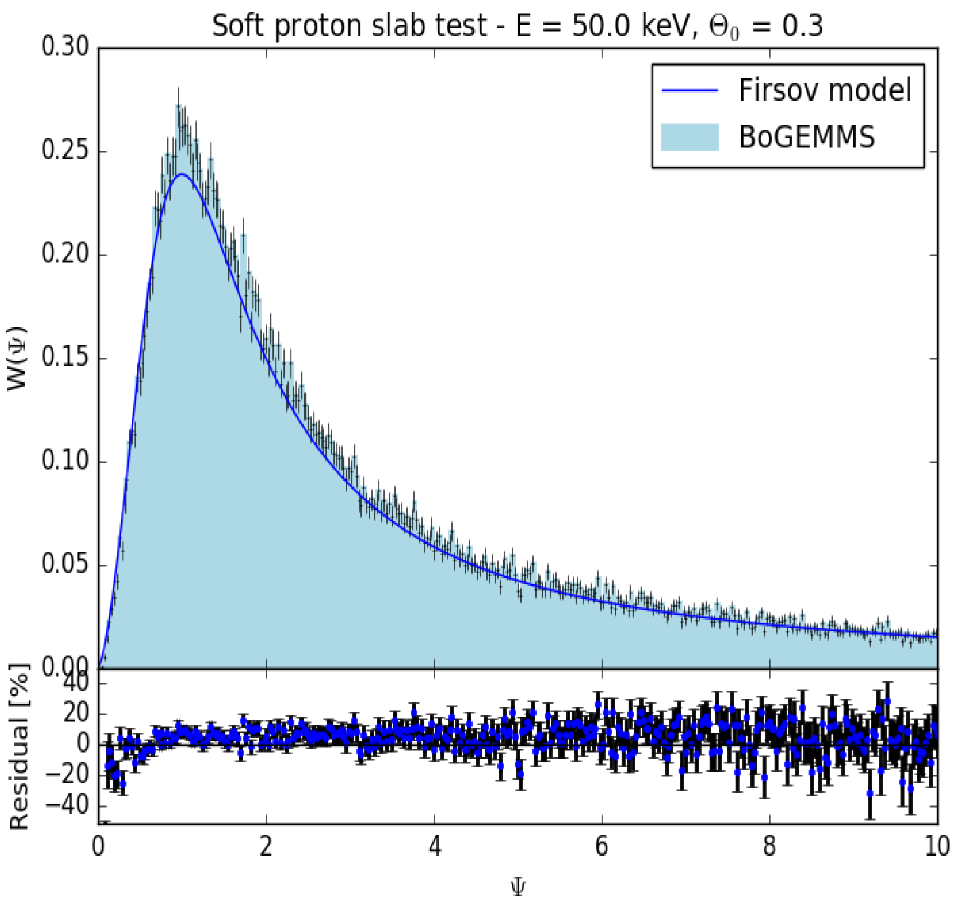
Used For:

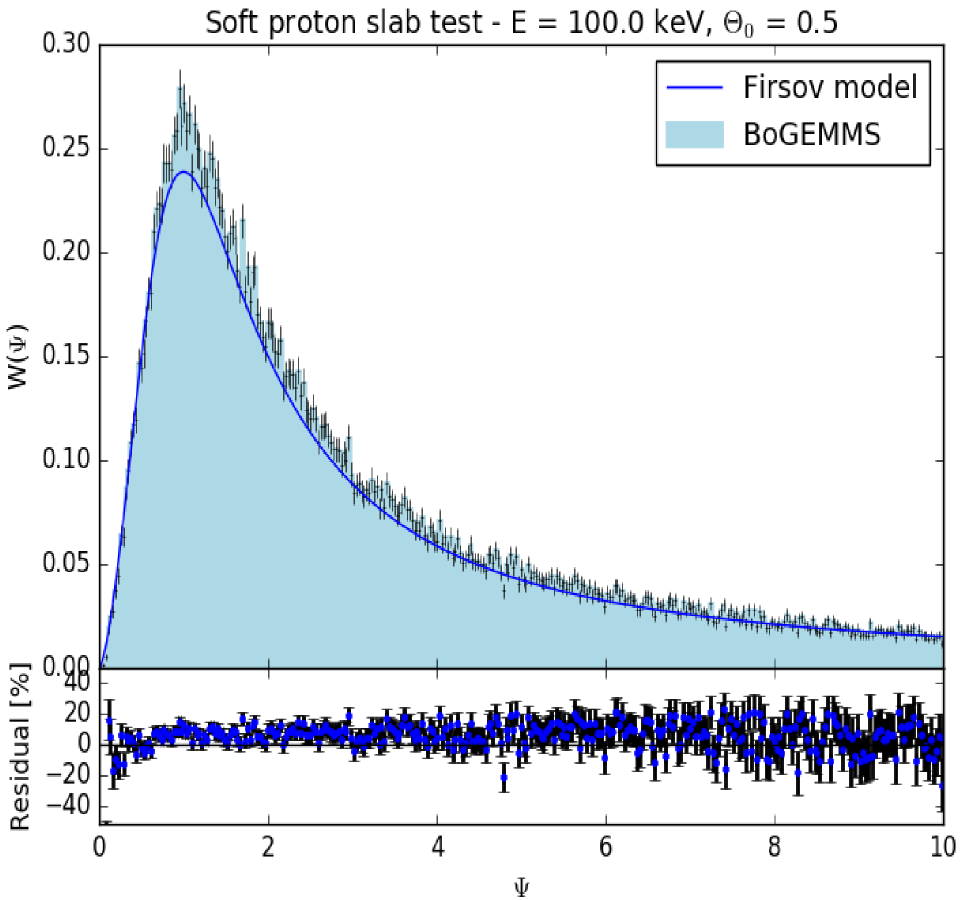
- X-ray telescopes
    - Simbol-X, NHXM, XMM-Newton, ATHENA
    - Gamma-ray
    - AGILE, GAMMA-400, Gamma-Light, ASTROGAM, eASTROGAM)



Firsov model implementation and verification

Counts vs Scattering Angle

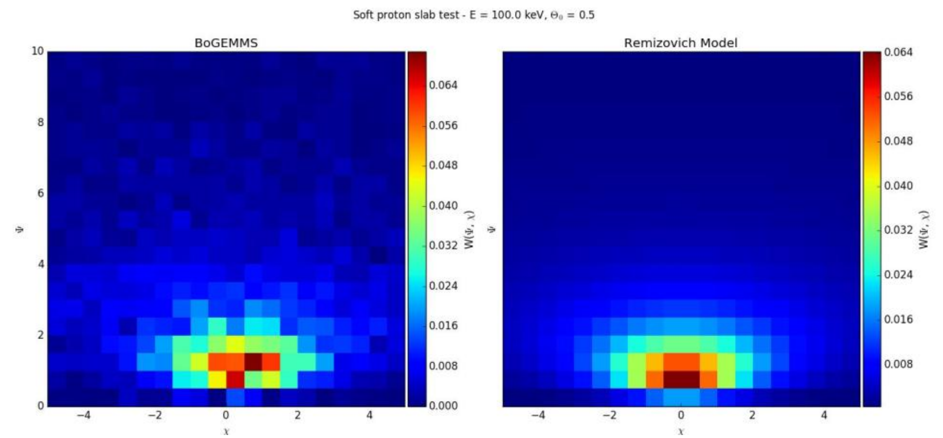




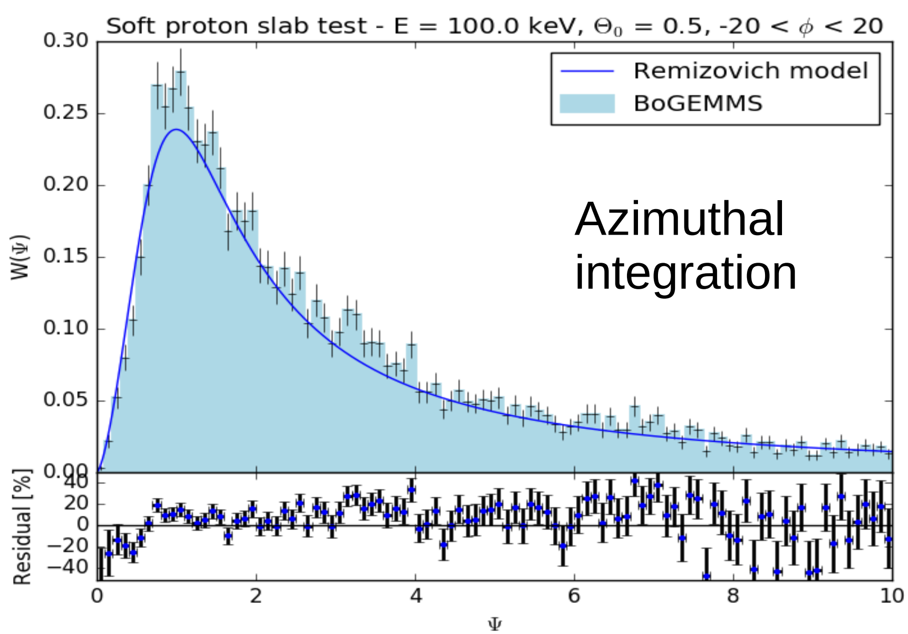
Sistematic deviation of +10% wrt model on the peak

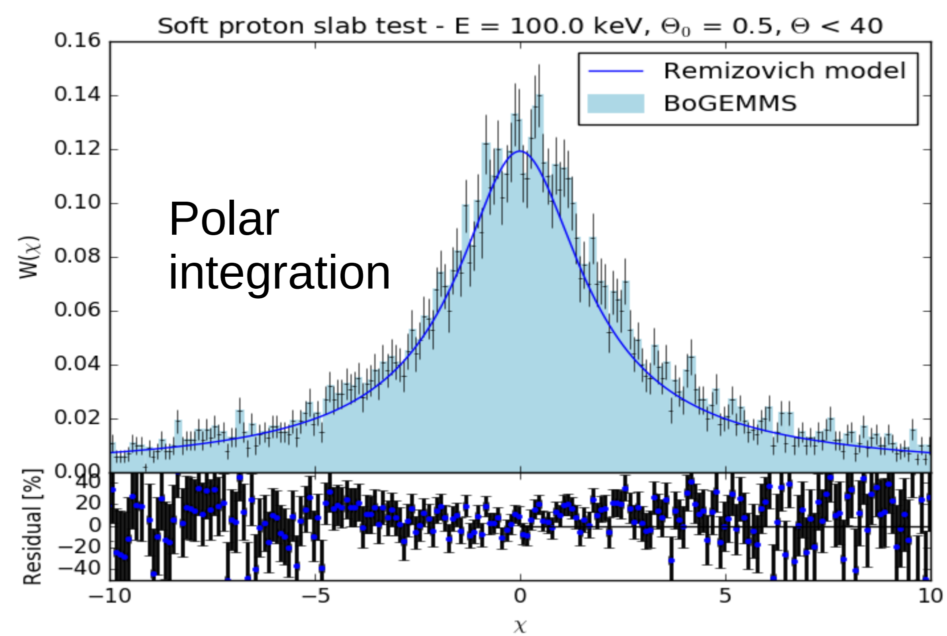
Remizovich model implementation and verification

- Proton reflection on θ φ
- elastic scattering approx
- 3 keV / scattering enelrgy loss



Up to +20% wrt analytical data





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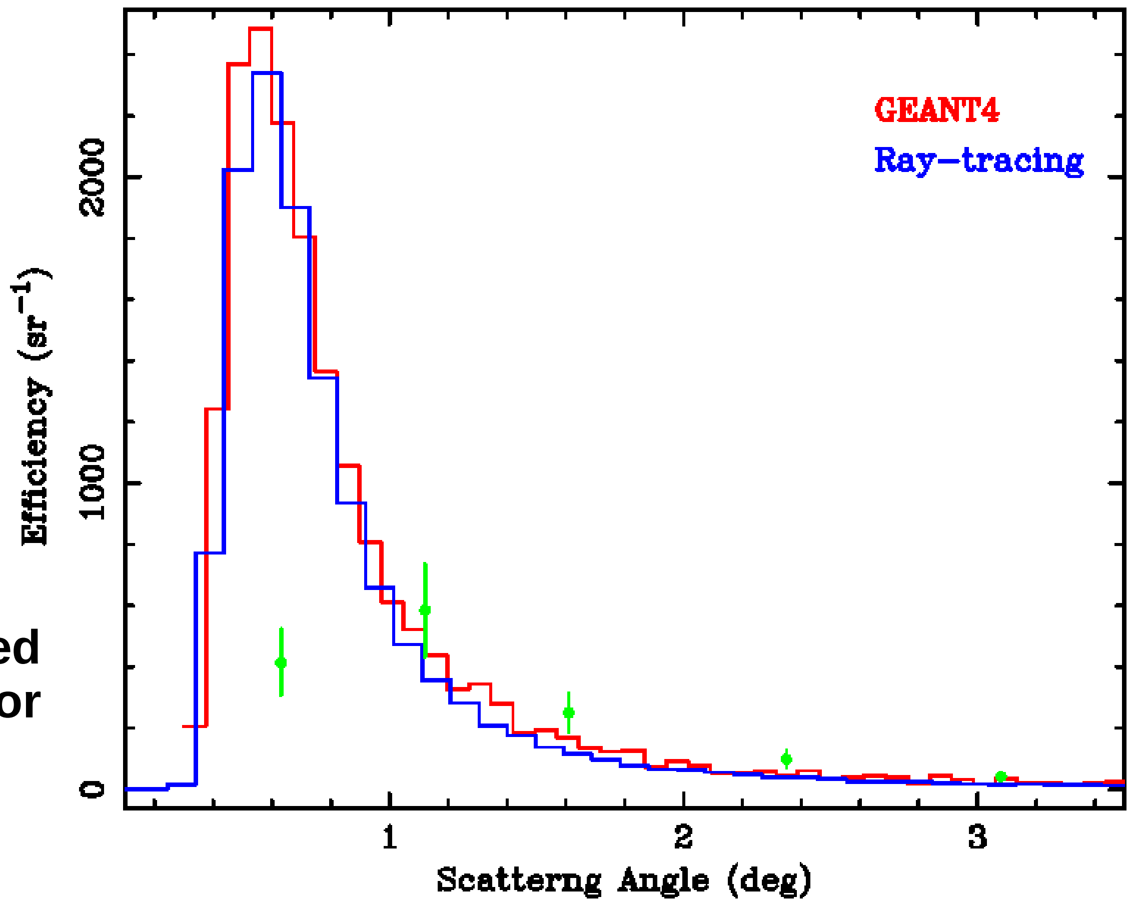


Remizovich implementation compared wrt independent ray-tracing simulator (courtesy of T. Mineo)

Benchmarks

- probability distribution computed **at each interaction**
  - CPU time strongly affected
  - feasible for the Firsov model, NOT for the Remizovich

TEST: 10^4 protons at 250 keV for an incident angle of 0.36 degrees.

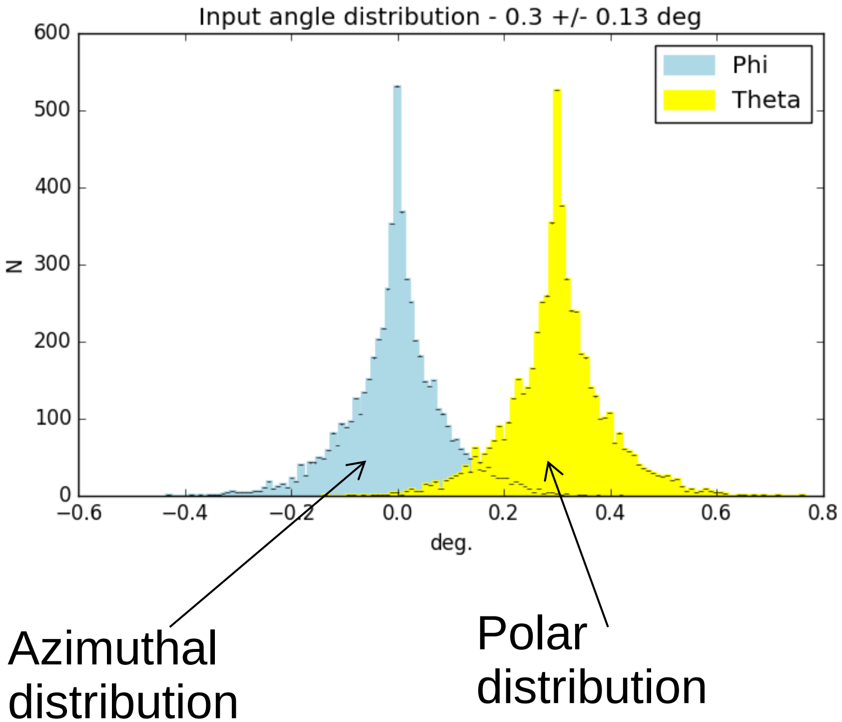
	MSC-opt3	**MSC-opt4**	**SS**	**Remizovich**	**Firsov**
CPU time	1	1.05	21.25	**366.7**	3.1

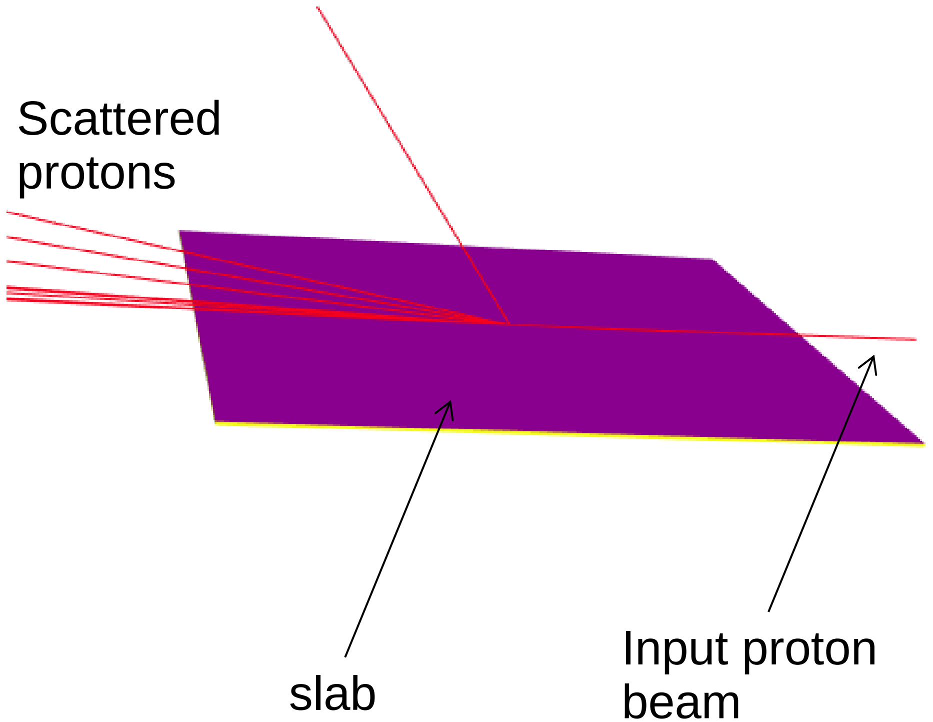
Solutions:

- **algorithm optimization: DONE (50% CPU time)**
- **probability distribution binning fine tuning: DONE**
- parallelization of the for loop
- Geant4 multithreading: to do
- Tabulate angle distribution: to be tested

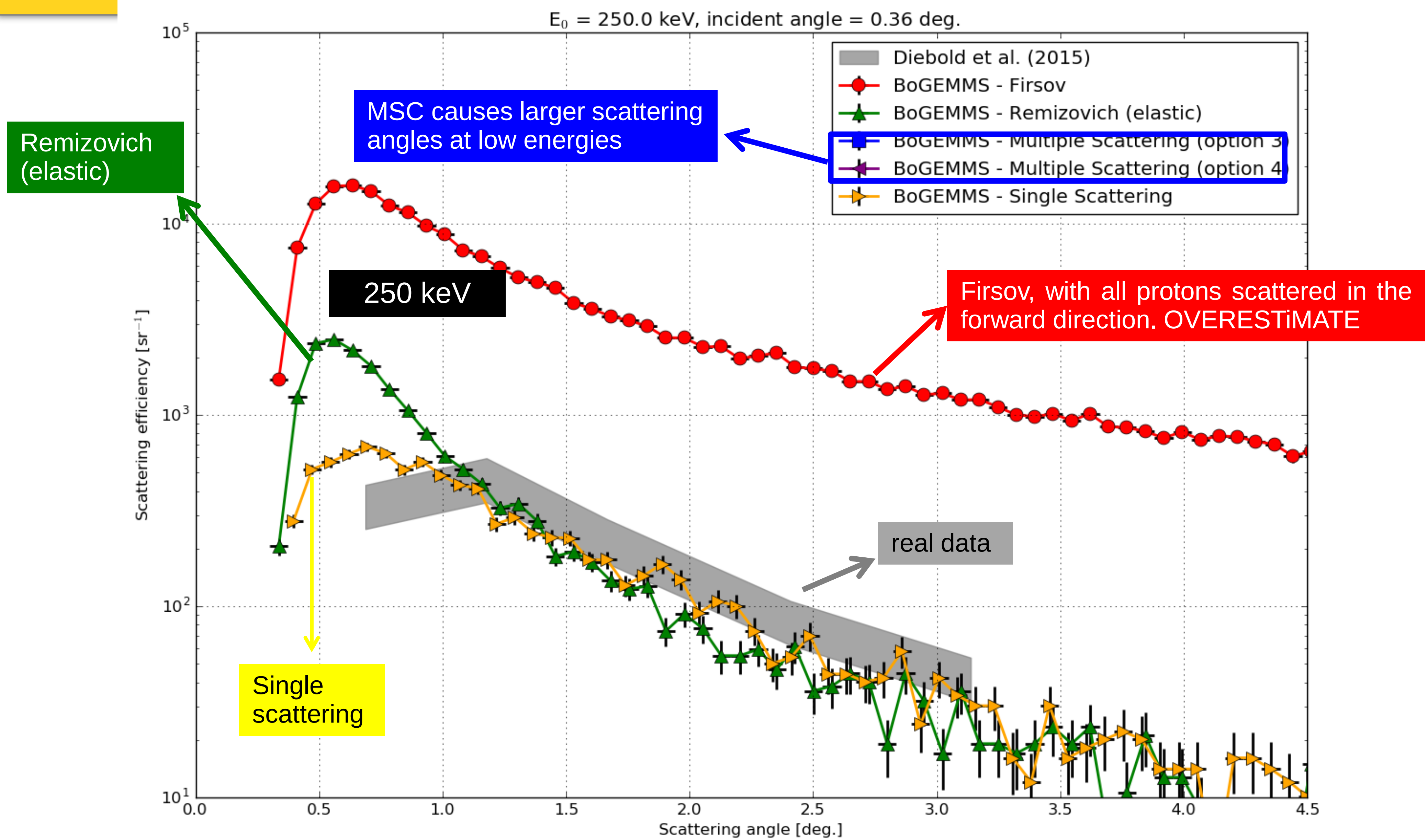
Laboratory measurements of soft proton scattering

- Exp Data: Diebold 2015
  - scattering efficiency, in sr^{-1}
  - energy loss
  - P @ 250, 500, and 1000 keV
  - 0.3 – 1.2 deg scattering on eRosita shell sample



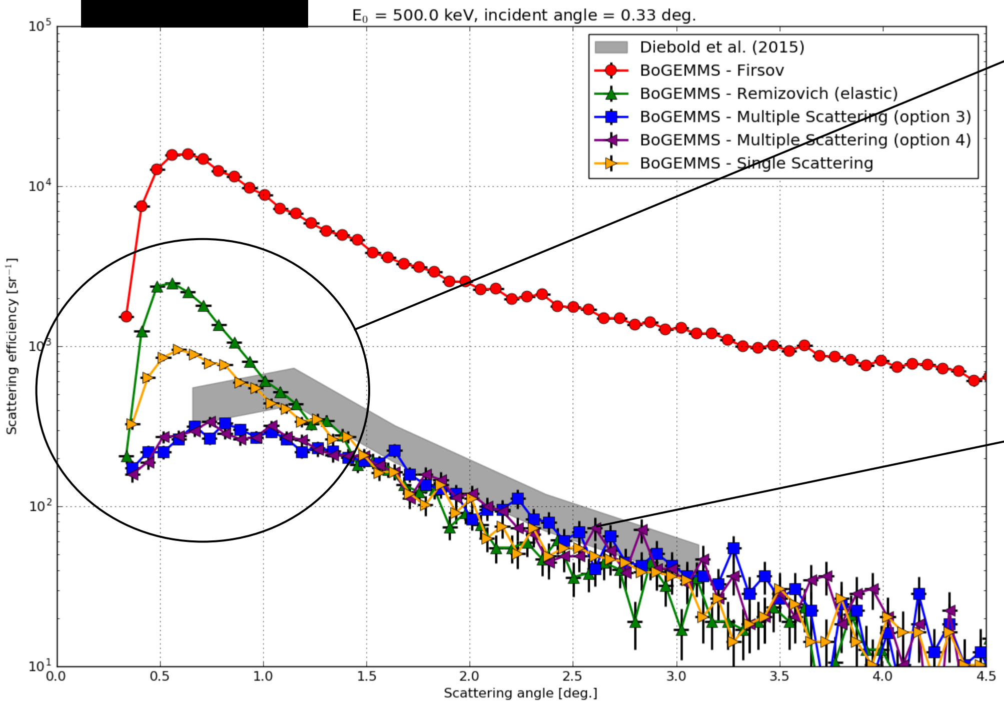


Comparison with real data – Scattering efficiency



Comparison with exp data – Scattering efficiency

500 keV

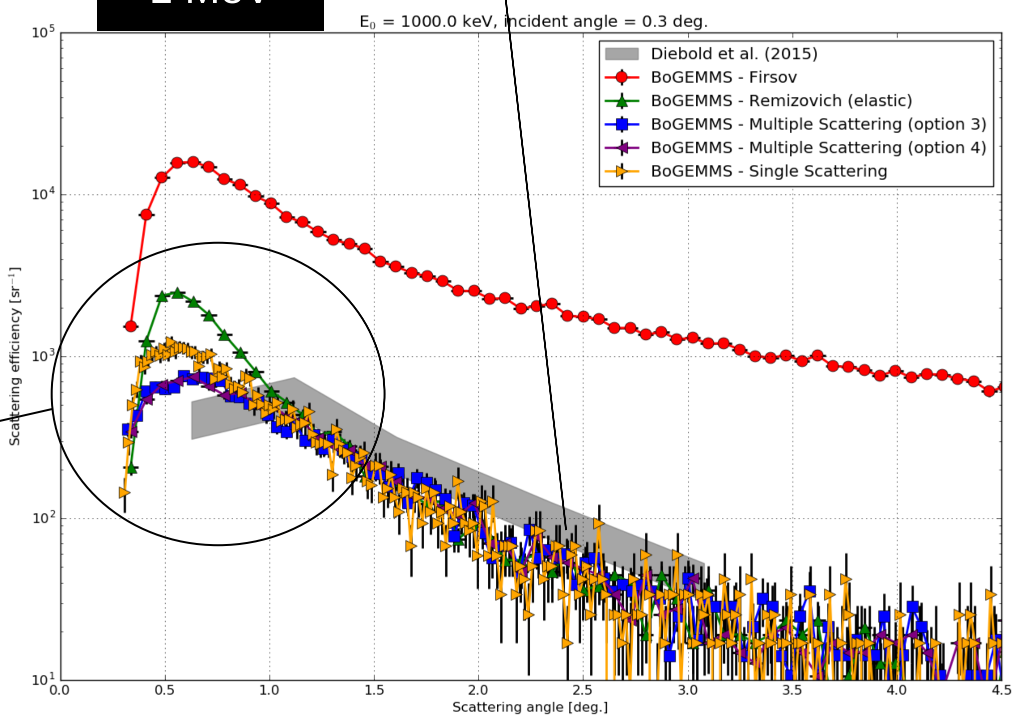


- Remizovich and SS:
  - higher scattering @ low angles
- Option3 and Option4: good agreement

@ scattering angles > 1.5 deg
Good agreement for all

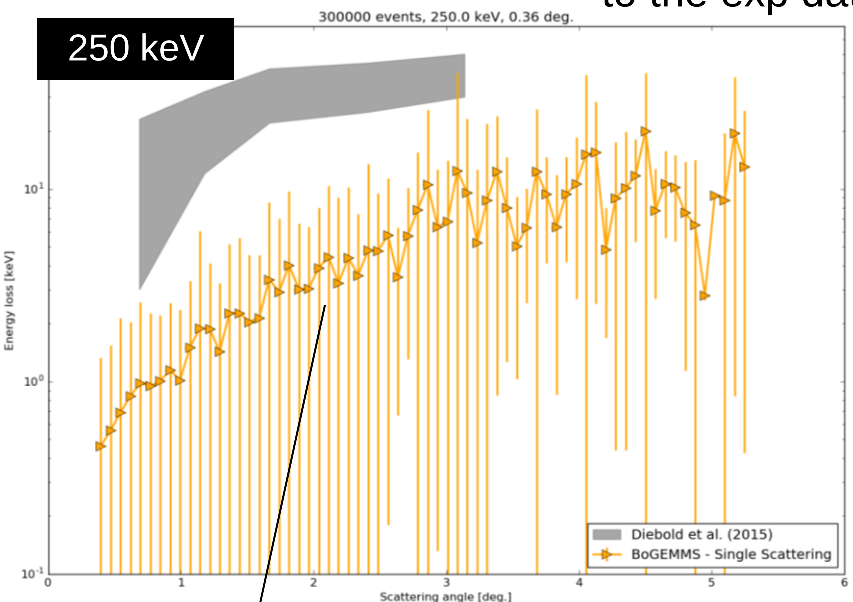
- SS and MSC give better agreement!
- Remizovich still higher
- All models overestimate

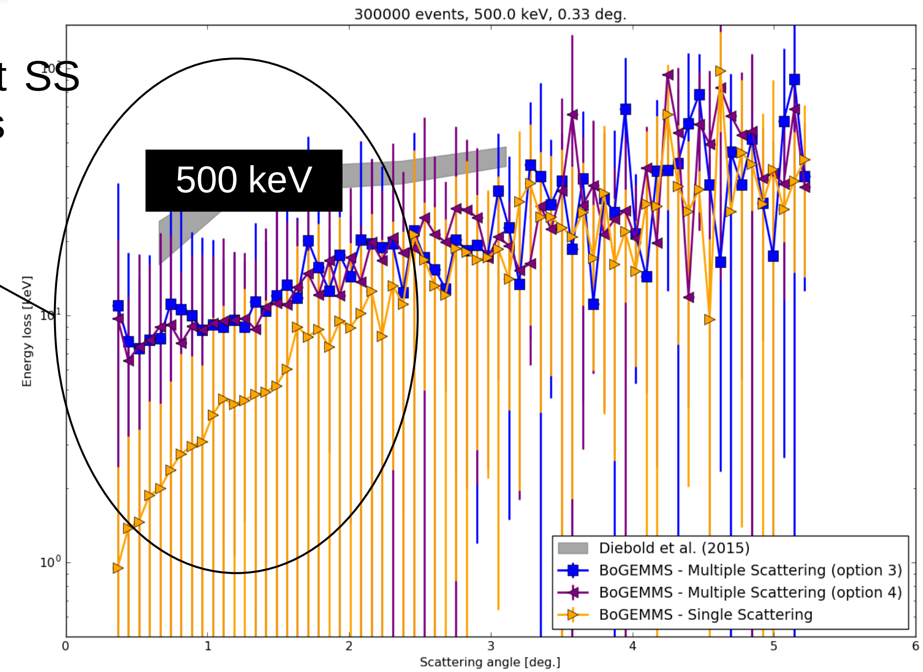
1 MeV



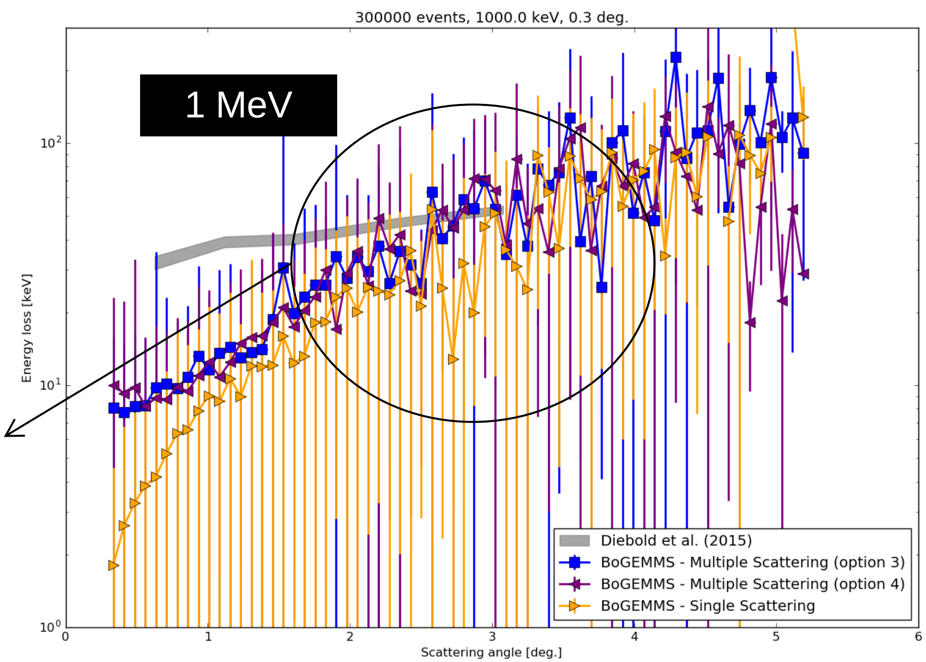
Comparison with exp data – Energy loss

MSC energy loss closer that SS to the exp data @ low angles





SS energy loss ~10 times lower than exp data



MSC and SS consistent @ large scattering angles

A model for grazing angles soft proton scattering - Conclusions

- @ 250 keV, Remizovich and SS consistent with exp data except below < 1 deg.
- SS is the closest to the observation for LowEn, BUT
    - Energy loss is 10 tiimes lower
- MSC good for high energy, both for scattering and energy loss
- @ “large” incident angles all the models are consistent
    - the angular distribution does not depend on p energy
- Firsov (φ = 0 Remizovich integration) overestimates 10 times exp data
- no differences are found between the EM opt3 and opt4 list multiple scattering settings.

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WARNING: experimental data **not** completely representative!

- Lack of efficiency measurements at low energies (<200 keV)
- Lack small reflection angles
- Some discussions on reliability

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More to do:

- Full Remizovich implementation
- Computing efficiency
- Geant4 integration

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More work needed:

- Ad-Hoc measurements
  - Structures
  - Funding