MODELING OF THE EARTH ATMOSPHERE SPECIFIC YIELD FUNCTION

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MAIN WORK AIMS

AN ESTIMATION OF THE EARTH'S ATMOSPHERE IONIZATION INDUCED BY THE PARTICLES OF THE GALACTIC AND SOLAR COSMIC RAYS

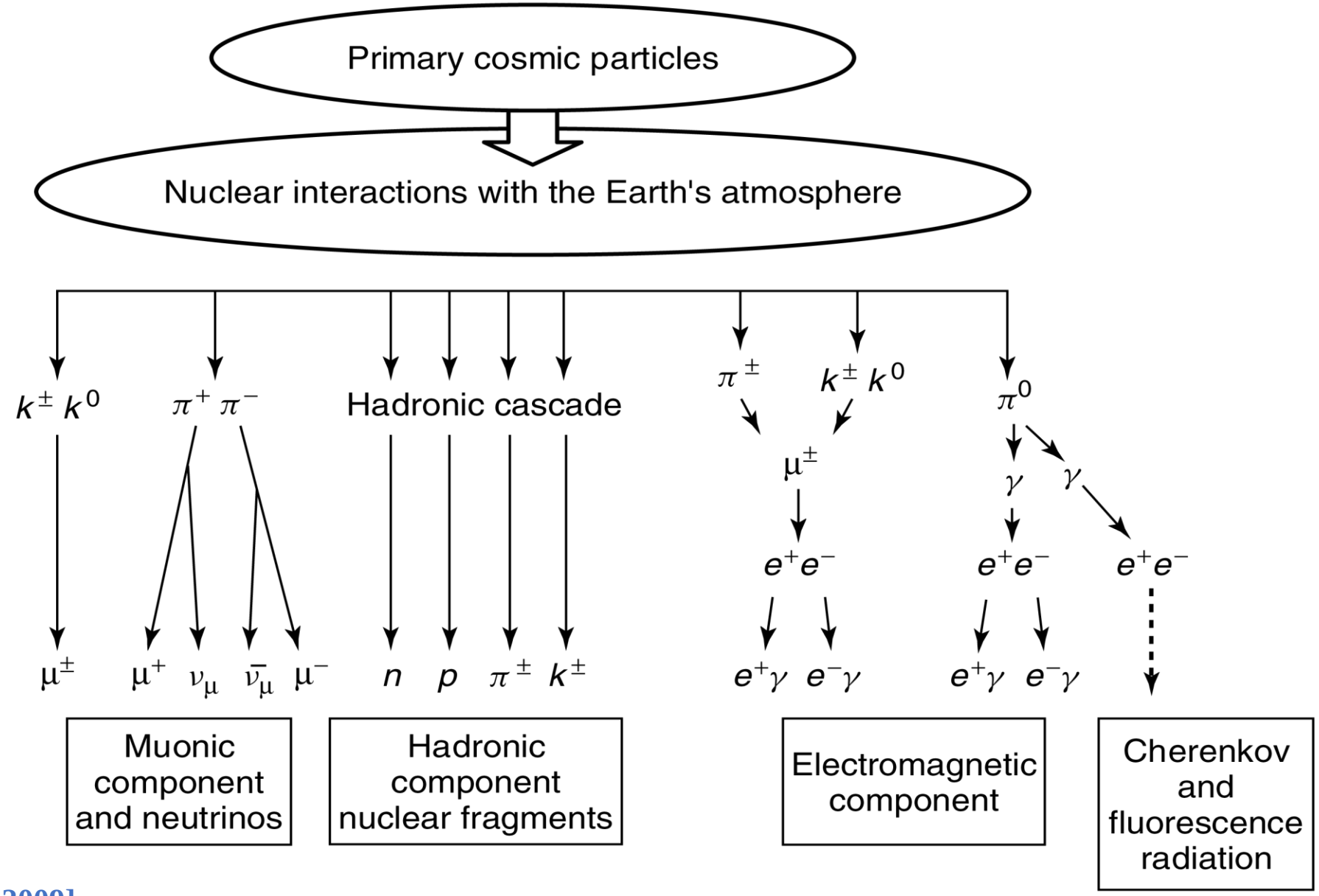
A calculation of the ionization atmospheric response function (**YIELD FUNCTION**) to the cosmic ray particles (also including gathering of information about the angular distributions and the secondary particles spectra)

A development and improvement of the GEANT4 based tool (like the PLANETOCOSMICS) needed for the specific yield function calculation

The application of the specific yield function to calculate the galactic cosmic rays affect on the Earth's atmosphere

The application of the specific yield function to calculate the solar cosmic rays affect on the Earth's atmosphere (for GLE's time)

THE DEVELOPMENT OF THE COMPONENTS OF COSMIC RAYS PROPAGATING IN THE EARTH'S ATMOSPHERE



[Filges D. and Goldenbaum F., 2009]

GEANT4 SOFTWARE DEVELOPMENT TOOLKIT

GEANT4 11.0 (latest), constantly updated

DATA_SETS (SHORT LIST)

- Neutron data files (with thermal CS) [**G4NDL4.6**]
- Low energy electromagnetic processes [**G4EMLOW8.0**]
- Photon evaporation [**G4PhotonEvaporation5.7**]
- Radioactive decay [**G4RadioactiveDecay5.6**]
- Evaluated cross-sections [**G4SAIDDATA2.0**]
- Evaluated particle cross-sections on natural composition of elements [**G4PARTICLEXS4.0**]
- Nuclear shell effects in INCL/ABLA hadronic mode [**G4ABLA3.1**]
- Proton and neutron density profiles in INCL [**G4INCL1.0**]
- Shell ionization cross-sections [**G4PII1.3**]
- Nuclides properties [**G4ENSDFSTATE2.3**]

[https://geant4.web.cern.ch/support/data_files_citations]

INTERACTION MODELS (MAIN LIST)

- The quark-gluon string Parton model (for hadrons E > 10 GeV) [Amelin et al., 2001]
- The Bertini cascades (for hadrons E < 10 GeV) [Heikkinen et al., 2003]
- The low-energy neutron interactions model (E < 20 MeV) [Garny et al., 2009]

OWN_MODULES

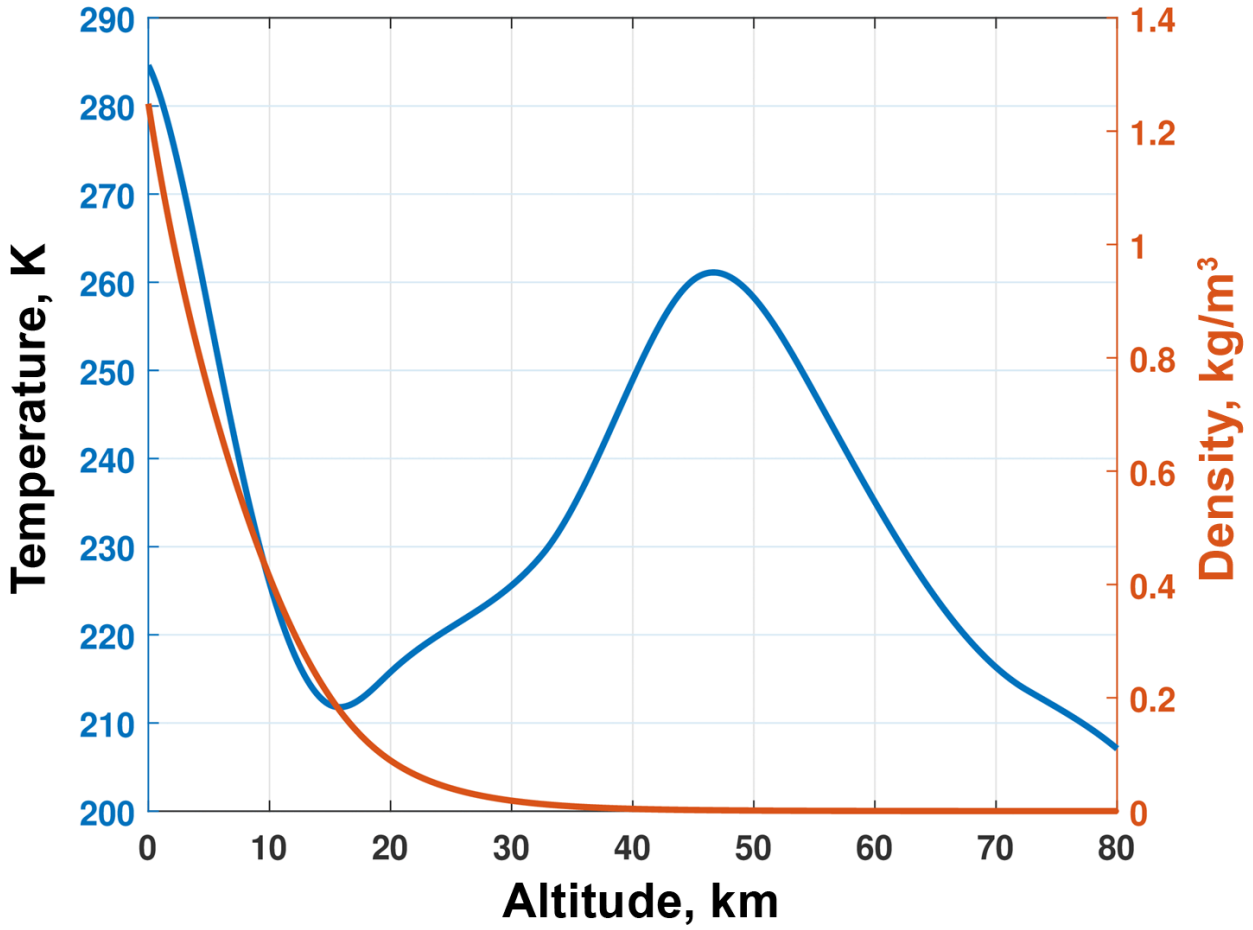
- Primary particle generators
- Geometry
- Angle distribution detector
- Energy-binned scorer
- Ionization yield function scorer
- Particle flux scorer

[https://geant4.web.cern.ch/]

NRLMSISE-00 - GEOMETRY PARAMETRIZATION BASIS

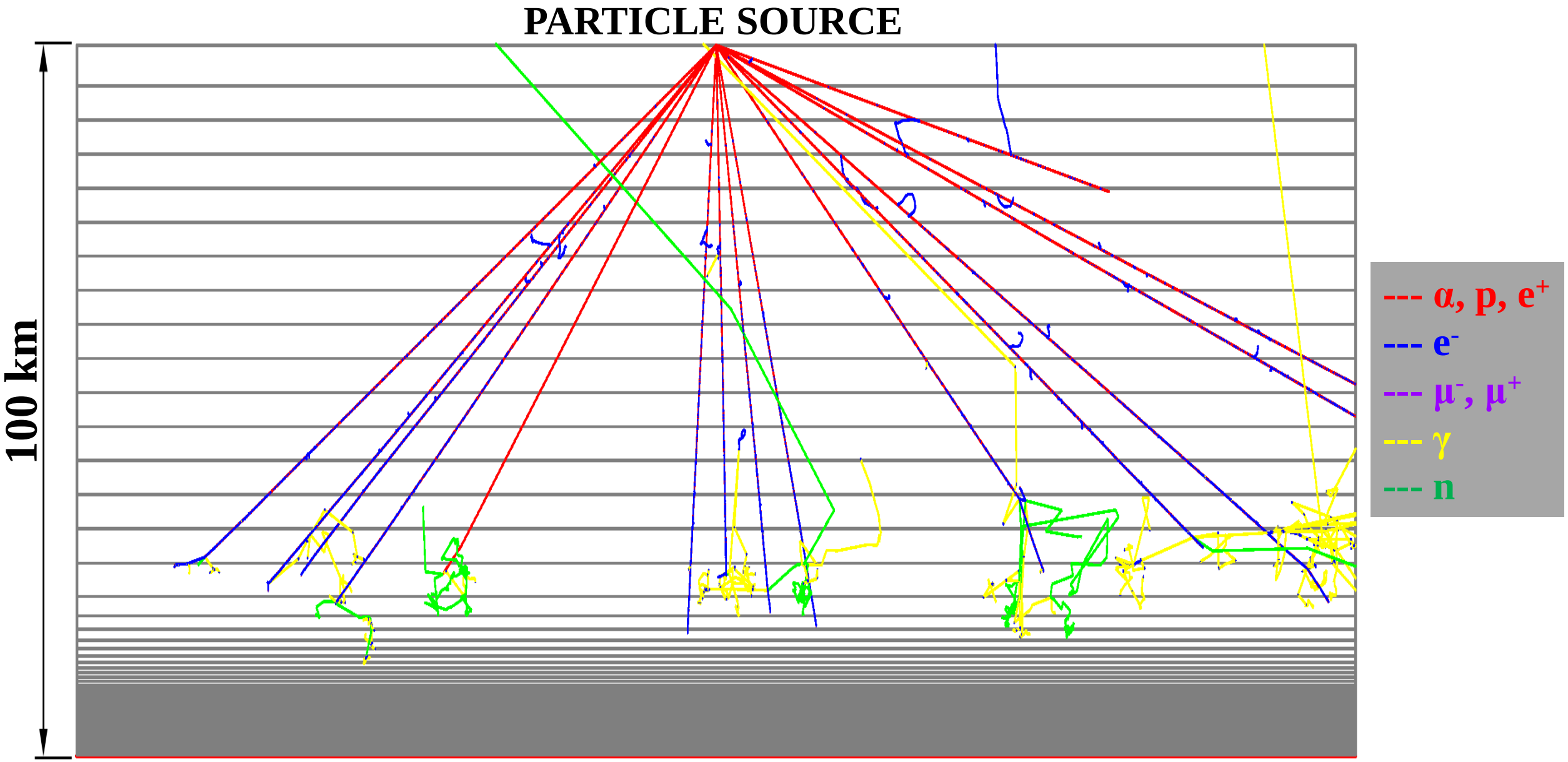
H, km	T, K	ρ, kg/m³	He, %	O, %	N, %	Ar, %
0,00	263,17	1,31	5,24E-04	2,10E+01	7,81E+01	9,34E-01
0,10	262,89	1,30	5,24E-04	2,10E+01	7,81E+01	9,34E-01
0,20	262,59	1,28	5,24E-04	2,10E+01	7,81E+01	9,34E-01
0,30	262,27	1,27	5,24E-04	2,10E+01	7,81E+01	9,34E-01
0,40	261,94	1,25	5,24E-04	2,10E+01	7,81E+01	9,34E-01
0,50	261,59	1,24	5,24E-04	2,10E+01	7,81E+01	9,34E-01
0,60	261,22	1,22	5,24E-04	2,10E+01	7,81E+01	9,34E-01
0,70	260,84	1,21	5,24E-04	2,10E+01	7,81E+01	9,34E-01
0,80	260,45	1,20	5,24E-04	2,10E+01	7,81E+01	9,34E-01
0,90	260,04	1,18	5,24E-04	2,10E+01	7,81E+01	9,34E-01
1,00	259,62	1,17	5,24E-04	2,10E+01	7,81E+01	9,34E-01
1,10	259,18	1,16	5,24E-04	2,10E+01	7,81E+01	9,34E-01
1,20	258,74	1,14	5,24E-04	2,10E+01	7,81E+01	9,34E-01
1,30	258,28	1,13	5,24E-04	2,10E+01	7,81E+01	9,34E-01
1,40	257,81	1,12	5,24E-04	2,10E+01	7,81E+01	9,34E-01
1,50	257,33	1,10	5,24E-04	2,10E+01	7,81E+01	9,34E-01
1,60	256,83	1,09	5,24E-04	2,10E+01	7,81E+01	9,34E-01
...	...	...	...	...	...	...

An example of a NRLMSISE-00 model output file with a density, a temperature, and an elements percentage parameters

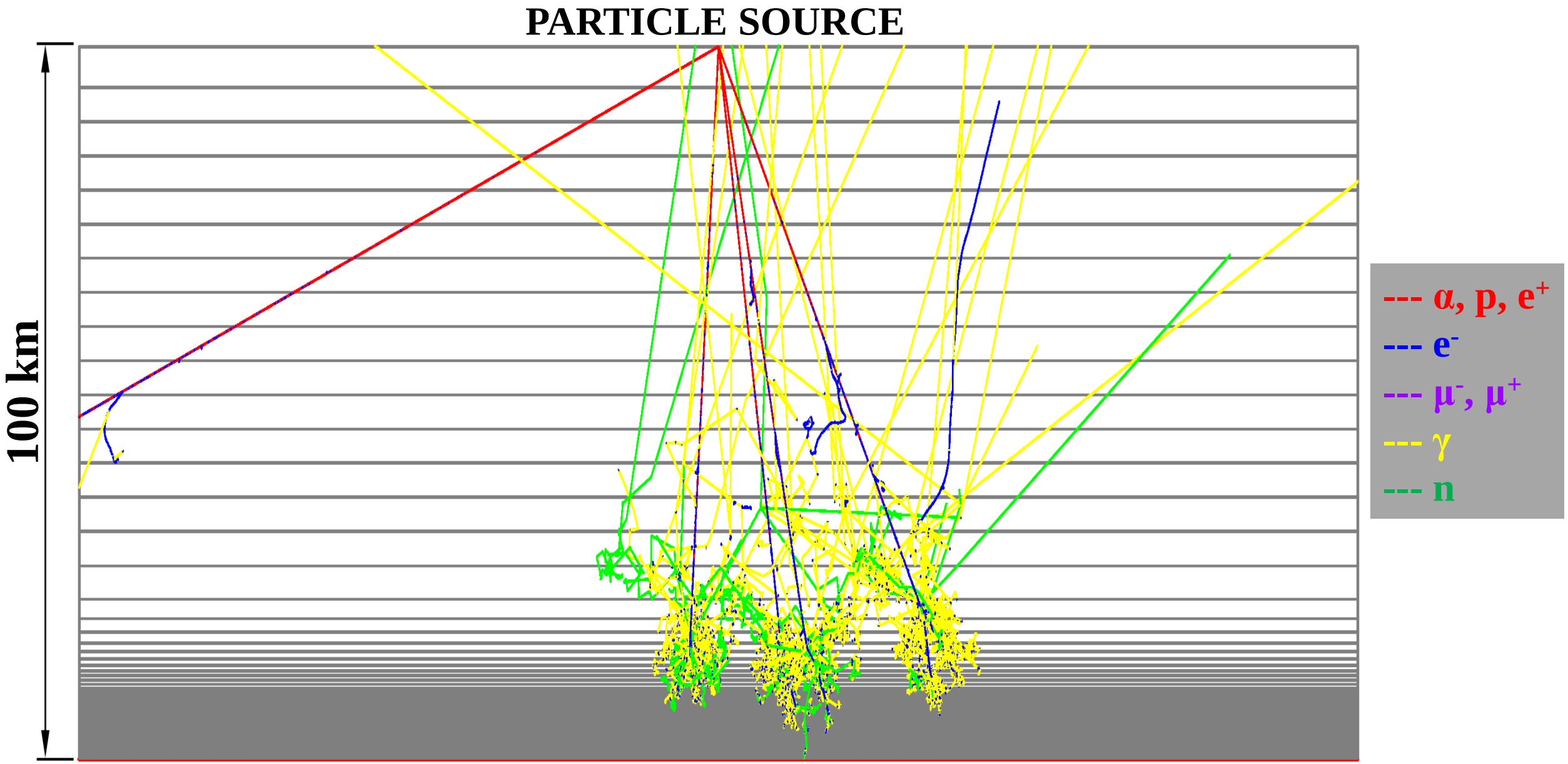


The graphical representation of a temperature and a density distribution

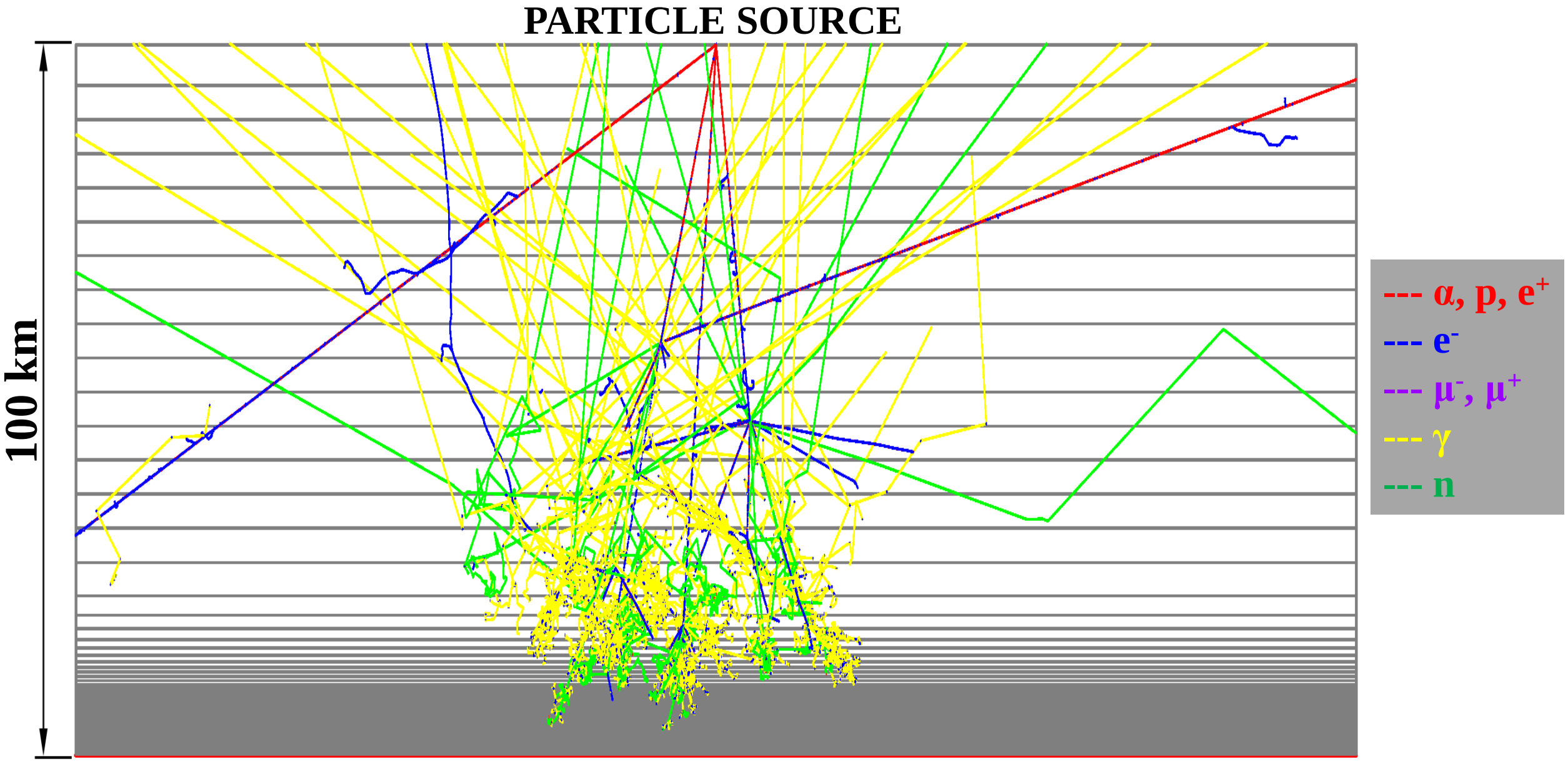
400 MEV PROTON TRACKING TROUGH THE ATMOSPHERE



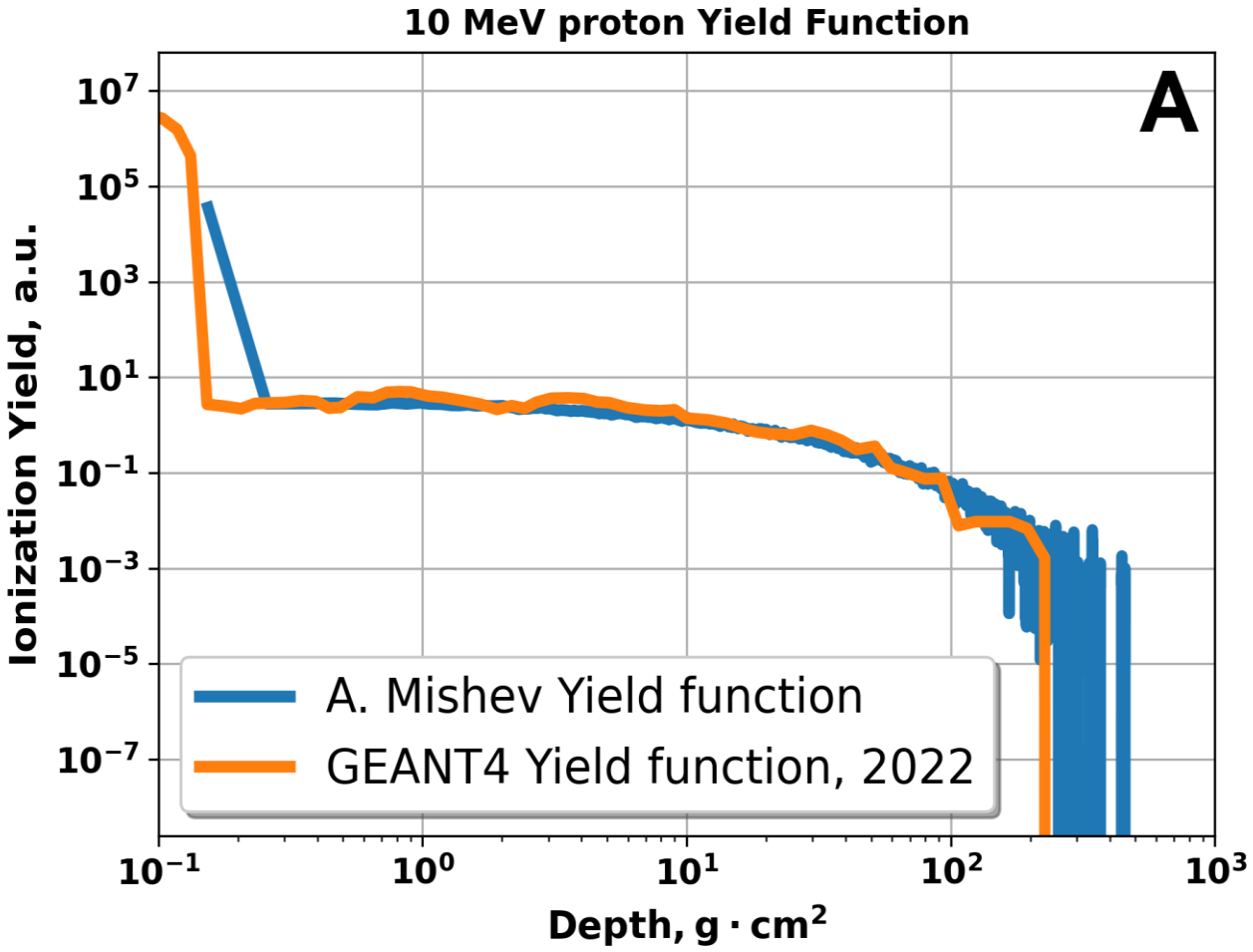
10 GEV PROTON TRACKING TROUGH THE ATMOSPHERE

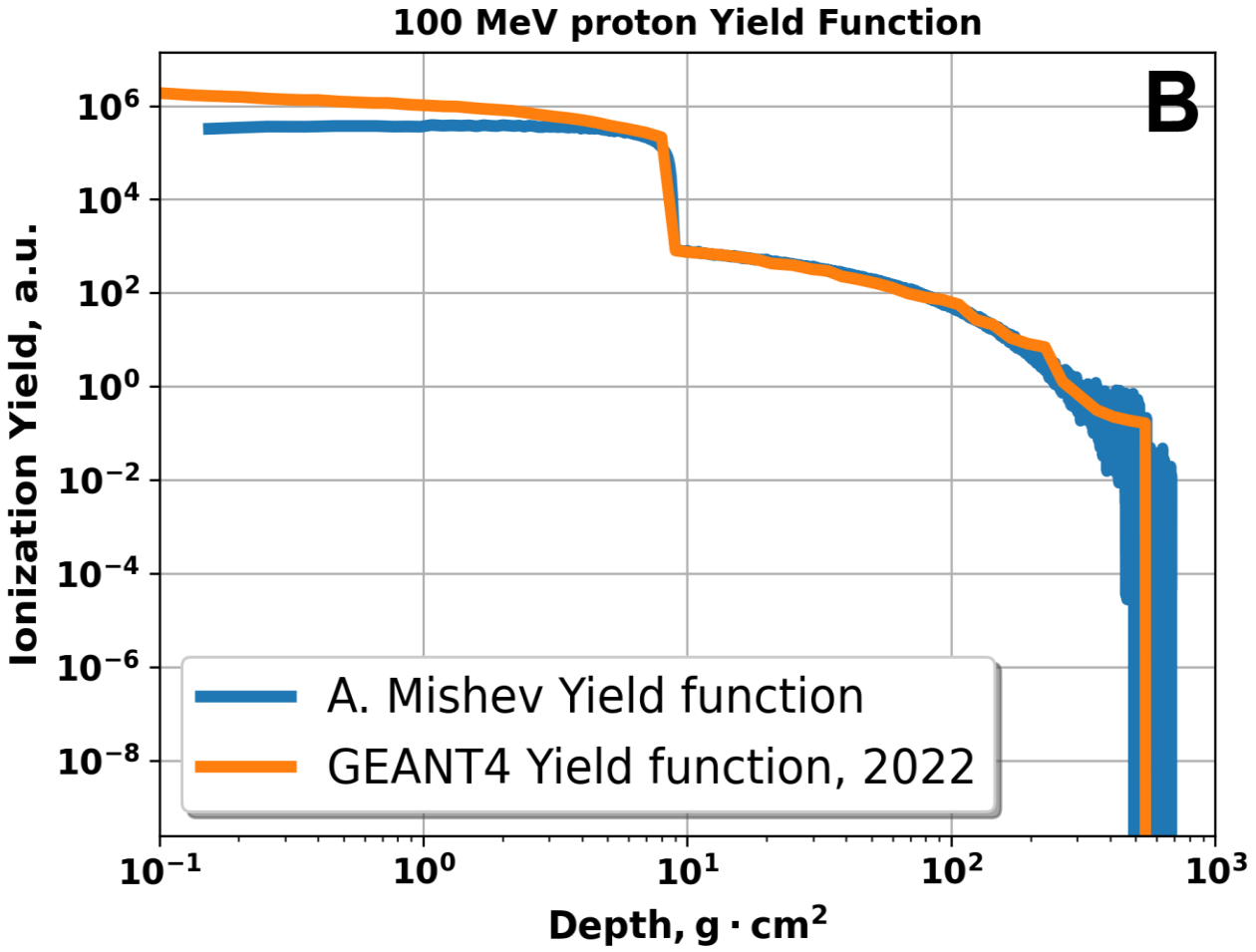


10 GEV ALPHA TRACKING TROUGH THE ATMOSPHERE



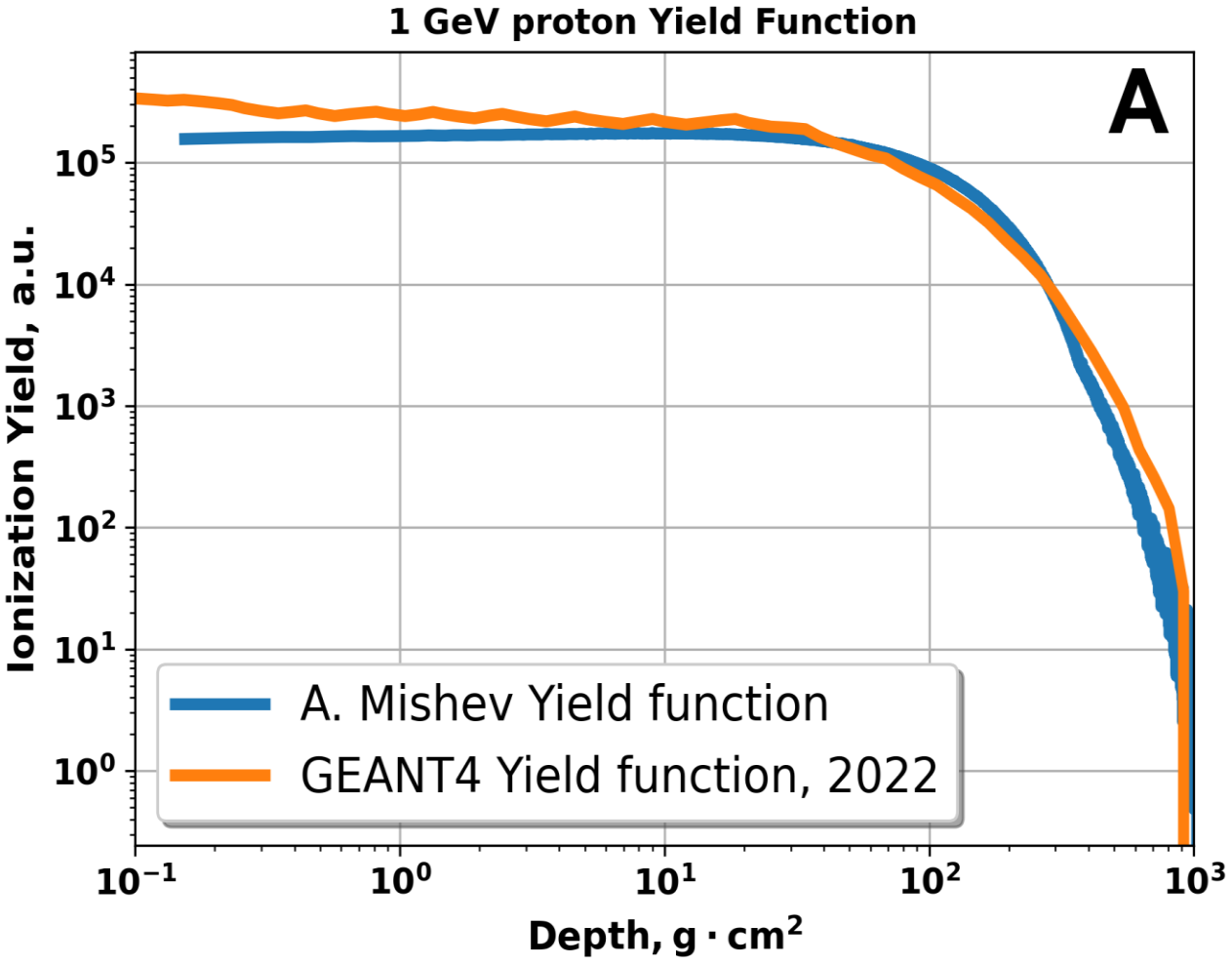
THE FIRST ITERATION YIELD FUNCTION (1)

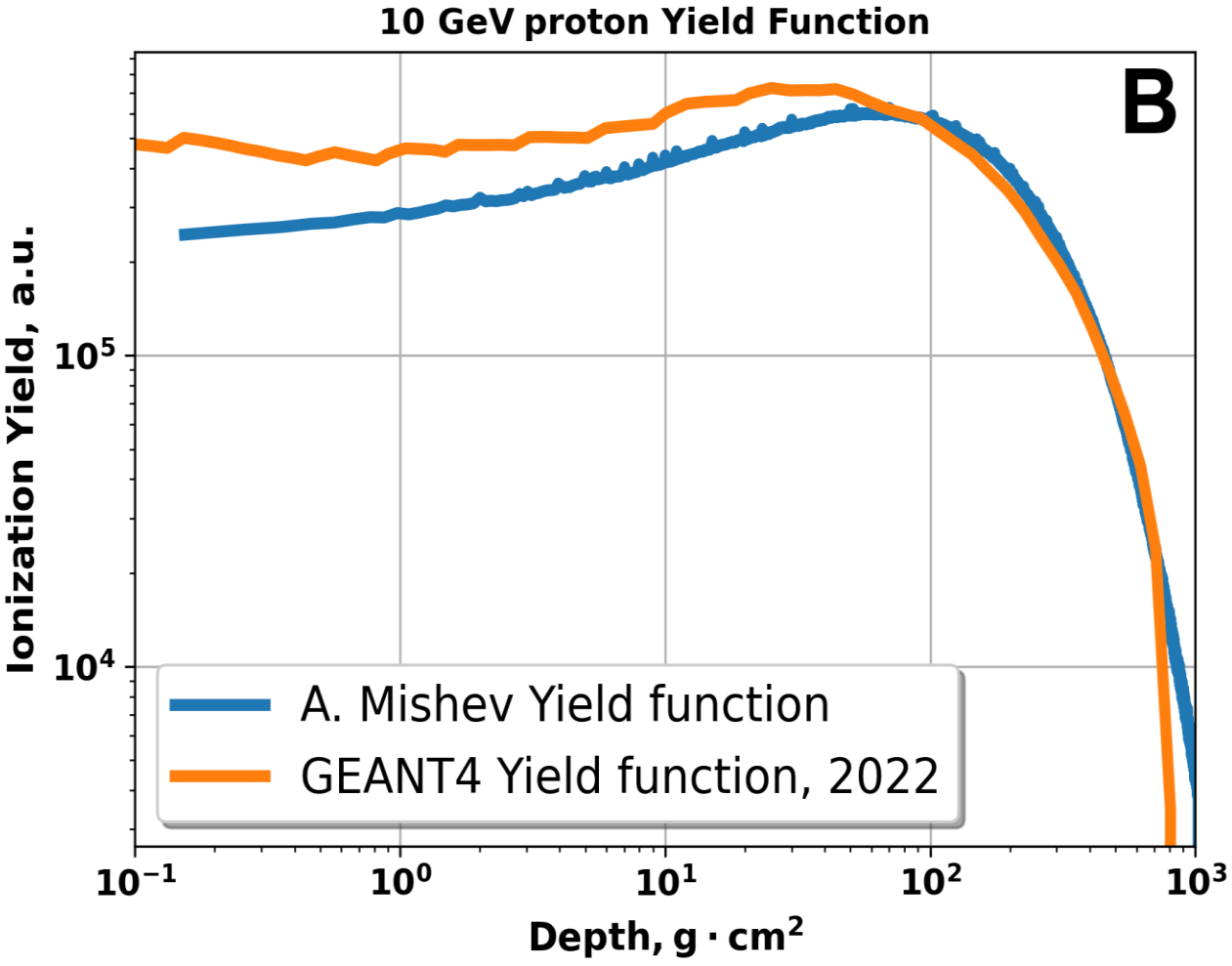




The typical plots of the yield functions for protons with a primary energy of 10 MeV (picture **A**) and 100 MeV (picture **B**). Strong scatter is due to an insufficient number of the primary particles in the simulation.

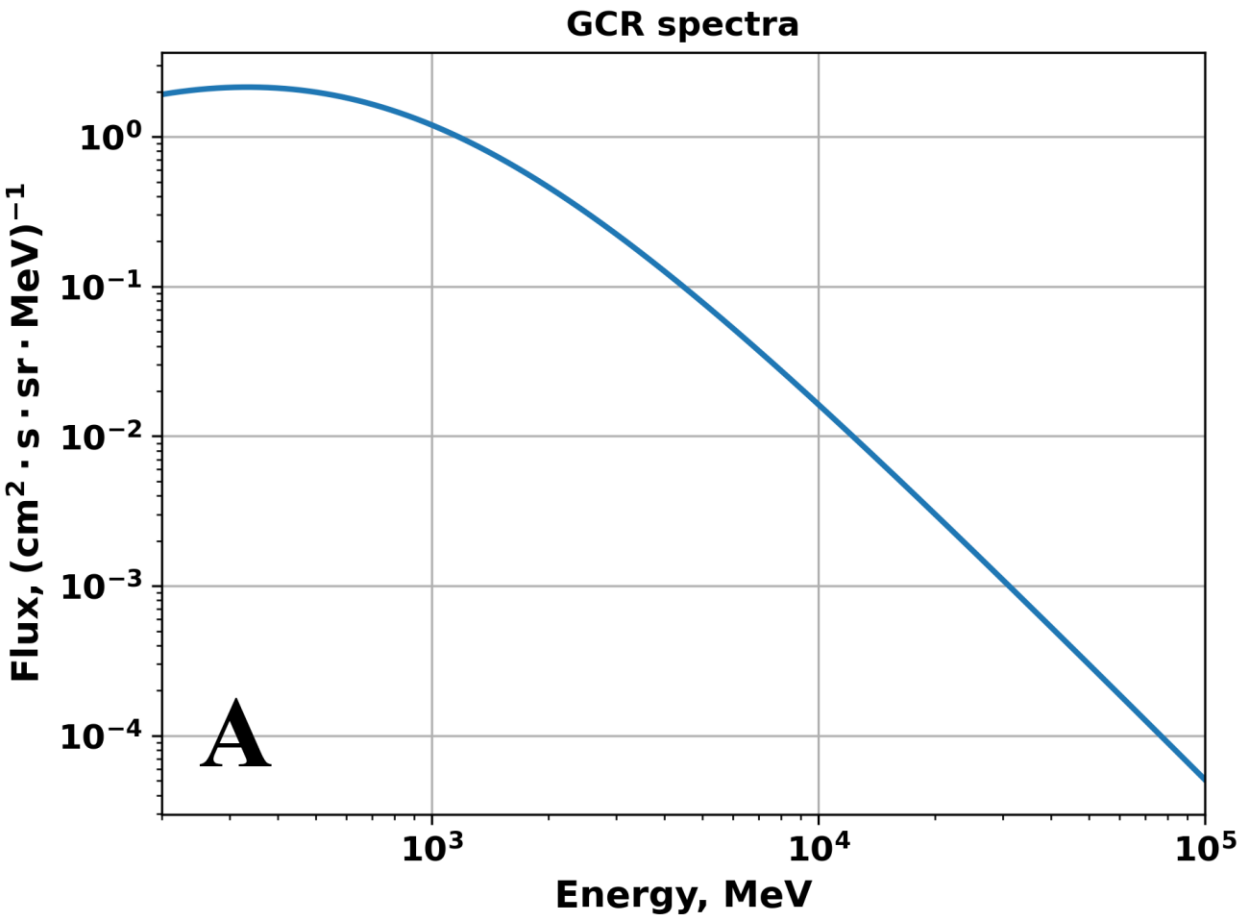
THE FIRST ITERATION YIELD FUNCTION (2)

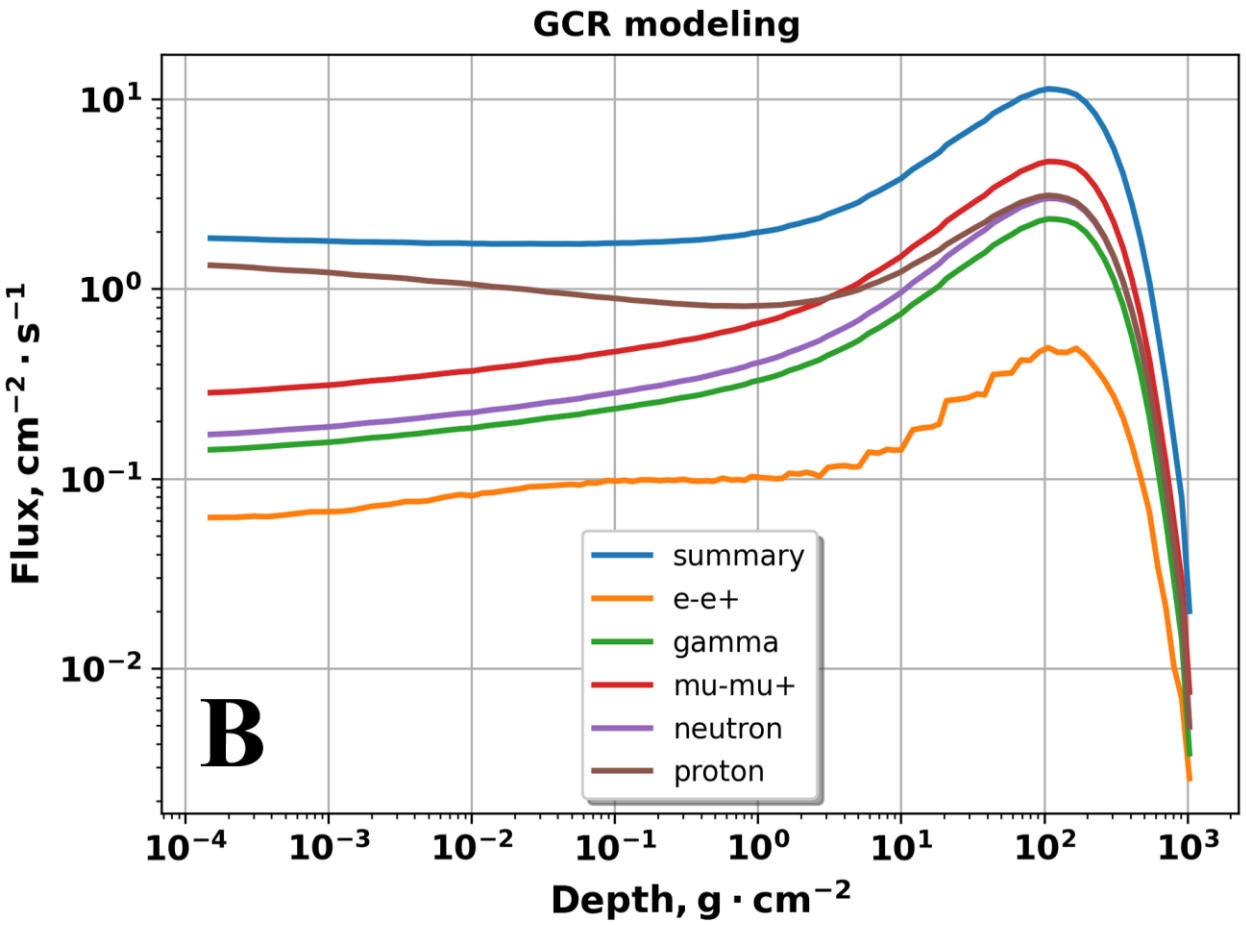




The typical plots of the yield functions for protons with a primary energy of 1 GeV (picture **A**) and 10 GeV (picture **B**). Strong scatter is due to an insufficient number of the primary particles in the simulation.

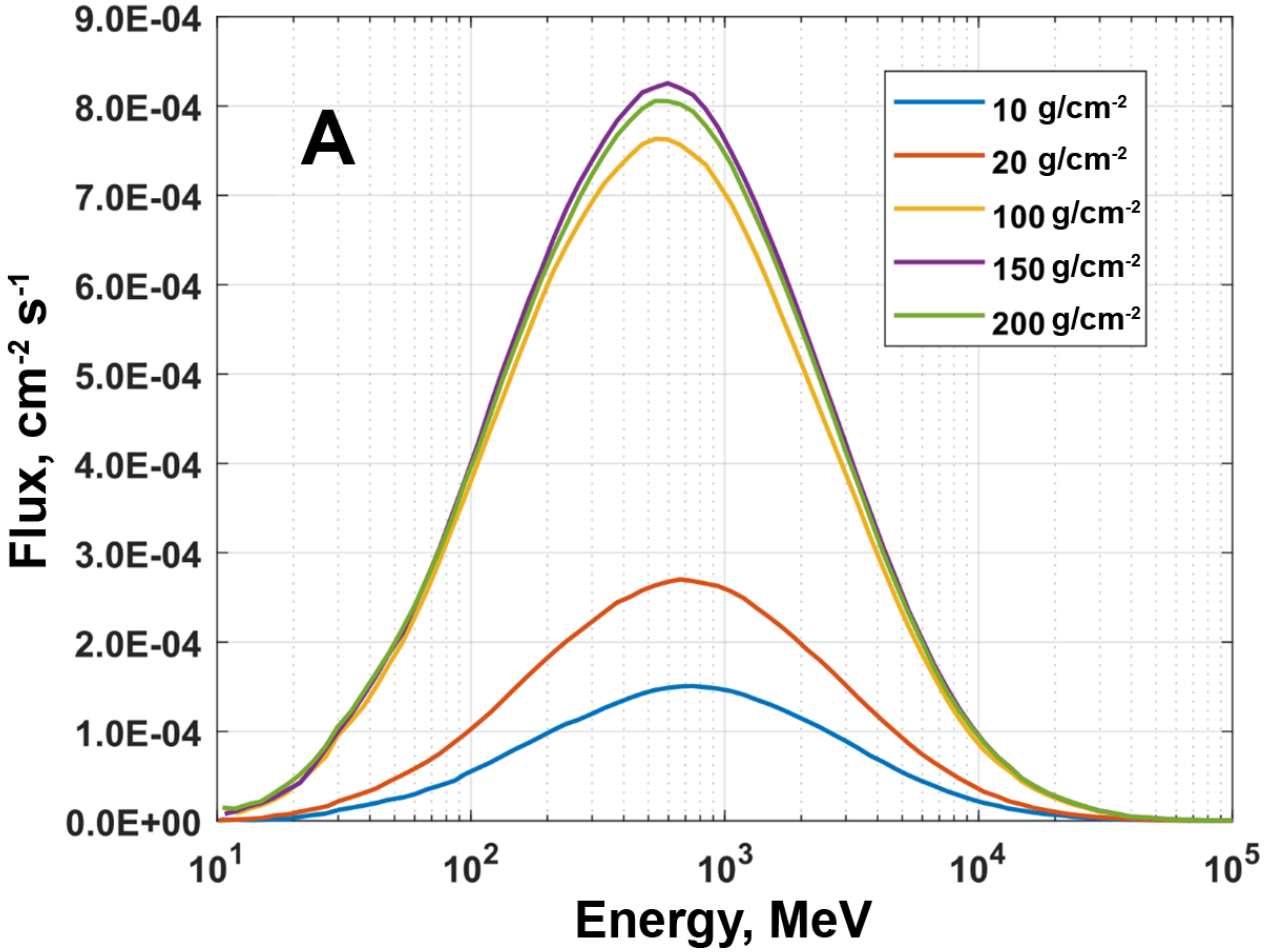
SOME TEST OF THE TRANSPORT OF PROTONS WITH GCR SPECTRA (1)

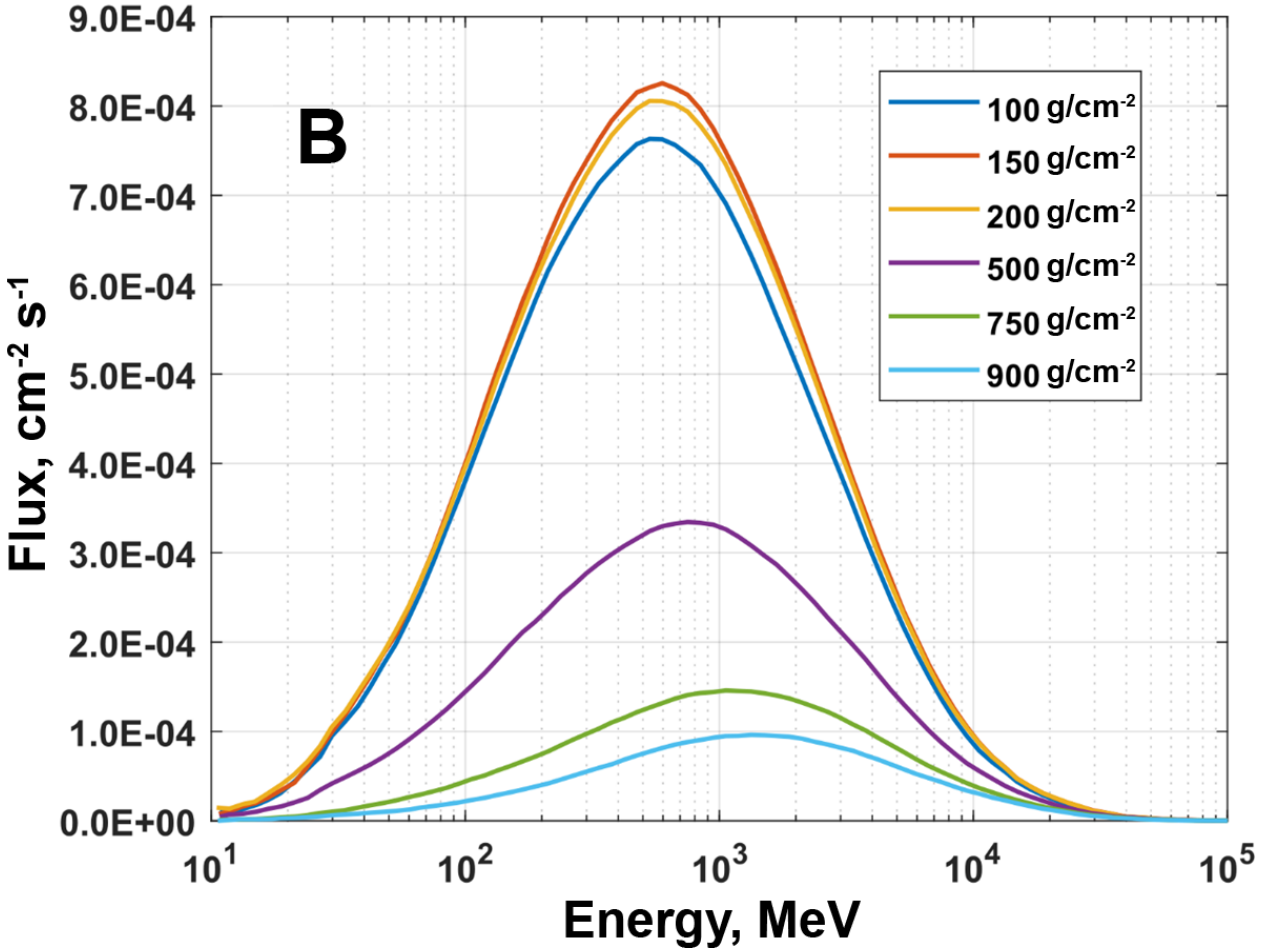




Energy spectrum of the primary galactic cosmic rays protons (A) used as the input parameter for primary source in a modeling (A) and integral secondary particle fluxes obtained as a result of calculation. Depth – is more convenient unit then altitude, a higher value corresponds to the altitude at sea level, a lower value corresponds to the upper part of the atmosphere (100 km in this modeling).

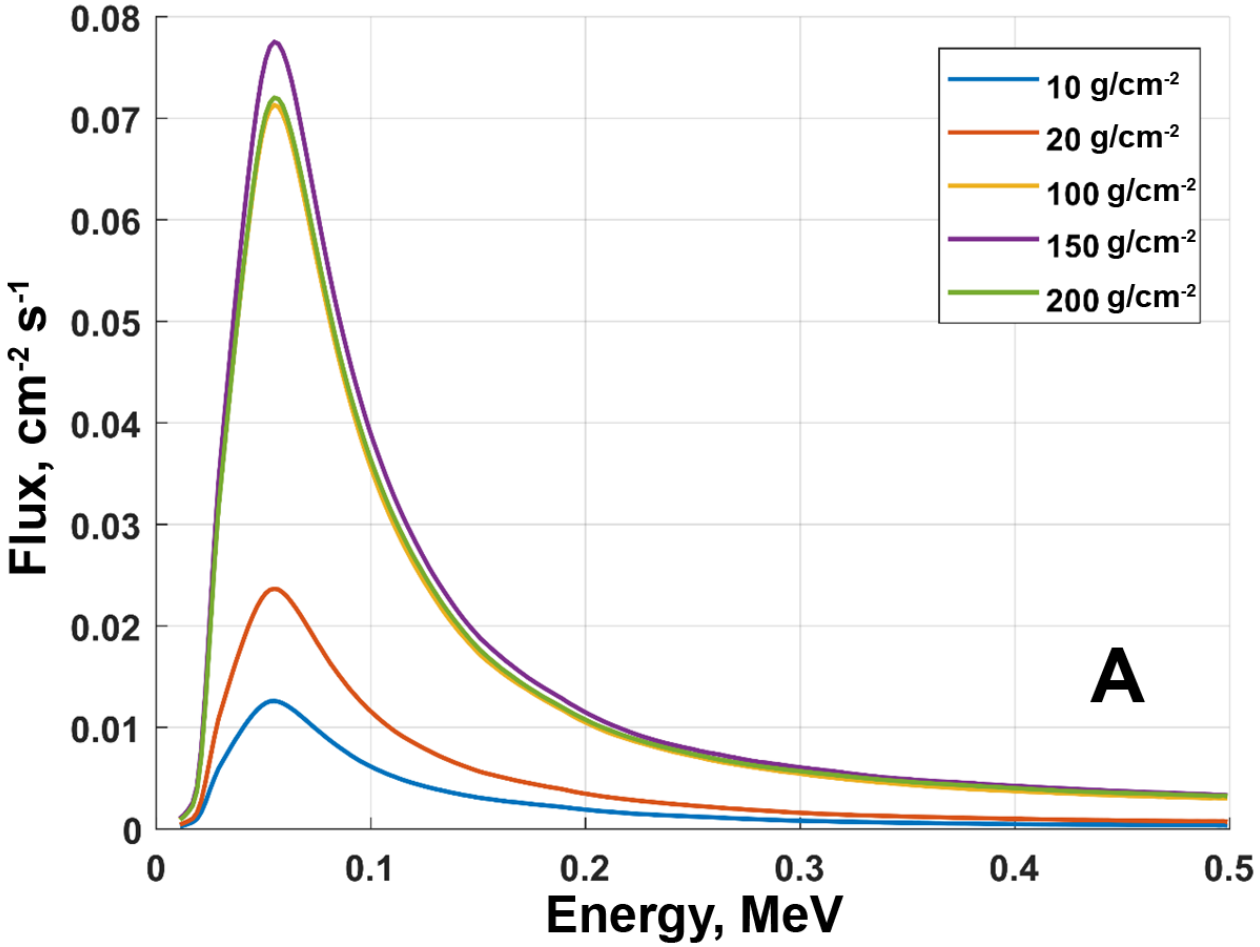
SOME TEST OF THE TRANSPORT OF PROTONS WITH GCR SPECTRA (2)

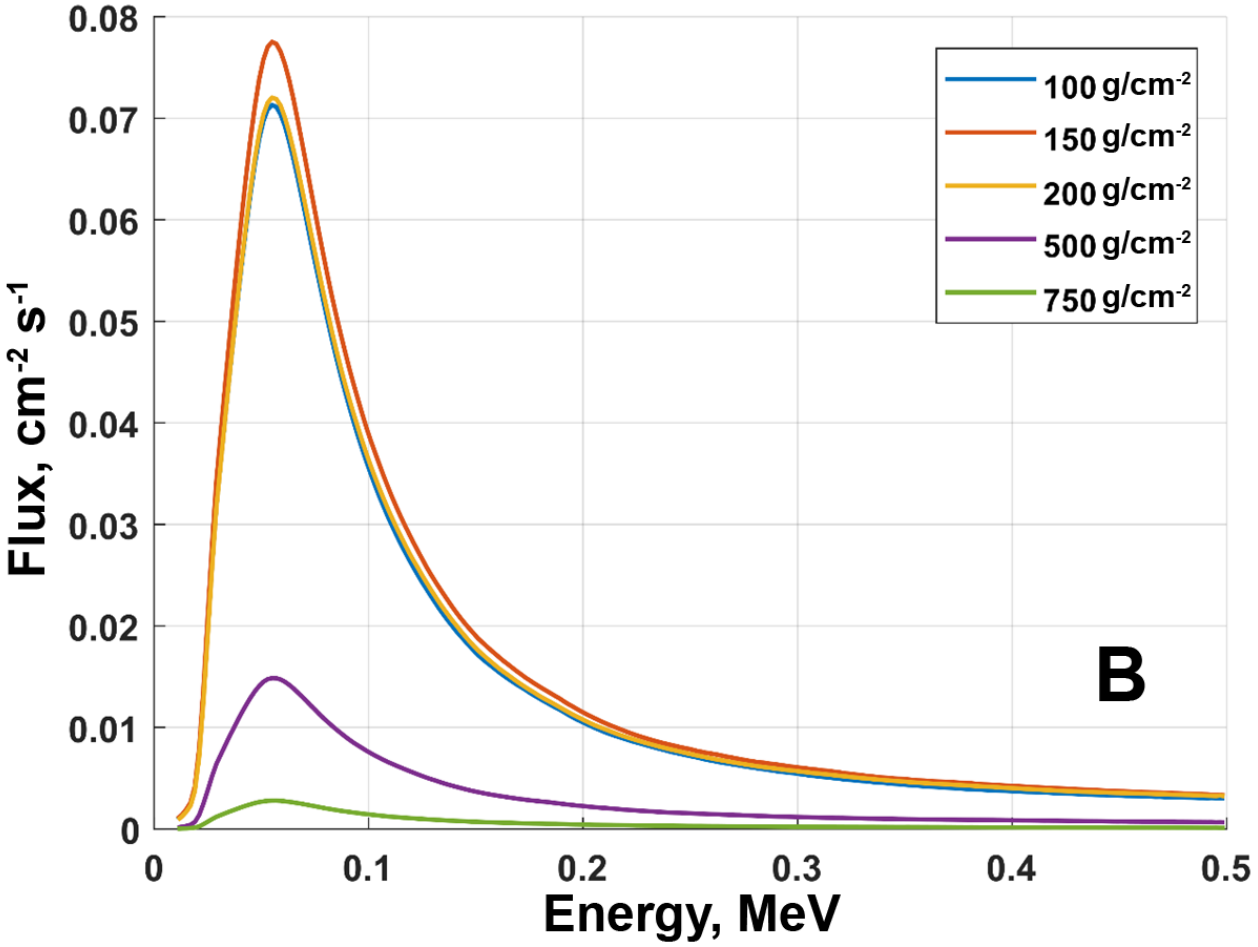




Energy spectra of the negatively charged muons in the depth range of 10 – 900 g/cm2 obtained as a result of modeling the protons propagation through the Earth atmosphere with an energy spectrum corresponding to galactic cosmic rays

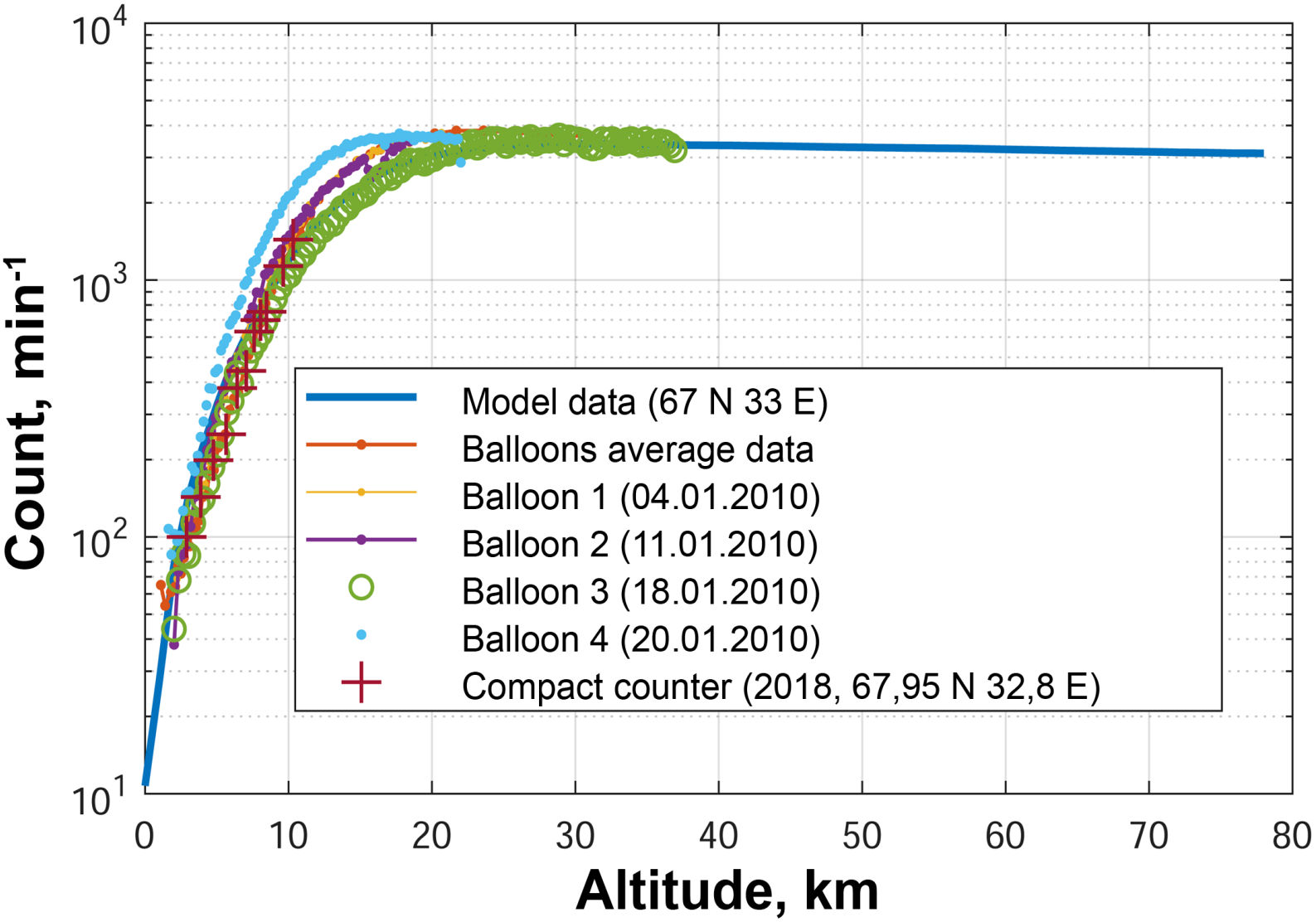
SOME TEST OF THE TRANSPORT OF PROTONS WITH GCR SPECTRA (3)





Energy spectra of the photons in the depth range of 10 – 750 g/cm2 obtained as a result of modeling the protons propagation through the Earth atmosphere with an energy spectrum corresponding to galactic cosmic rays

VERIFICATION WITH EXPERIMENTAL DATA



WHY A NEW MODEL?

1. Possibility to work with own code, absolutely transparent and ready to update
2. Possibility to update it in agreement with new GEANT4 versions
3. Possibility to compile it with multithreading both for GEANT4 library and own way
4. Absolutely flexible (for our team, in future for all) to adjust it to any tasks of cosmic rays transport trough the atmosphere

- Balloon data - *P.N. Lebedev Physical Institute of the Russian Academy of Sciences*
- Compact counter data - *Maurchev E.A. et al., Bulletin of RAS: Physics. 2021. T. 85. № 11. C. 1294-1296.*

FUTURE INVESTIGATIONS

- (in process now) Calculation of the ionization yield function for the protons with an increased number of primary particles
- (in process now) Addition in to the ionization yield function the alpha particles, some nucleus with Z > 2 (e.g. oxygen and nitrogen) and electrons (the function for all particles will be done for the first time)
- (in future) Structuring the received data for a general use
- (in future) Development of the tool based on the particles spectra and pre-computed yield functions as a function of the atmospheric depth
- (in future) Calculation the ionization count rate for the galactic cosmic rays and the solar cosmic rays (with the new YF, for time GLE occurred)

THANK YOU FOR YOUR ATTENTION!