European Cosmic Ray Symposium
25-29 July 2022
Nijmegen, the Netherlands

UNIVERSITY OF OULU

Atmospheric cutoff energies for cosmic rays registered by polar neutron monitors

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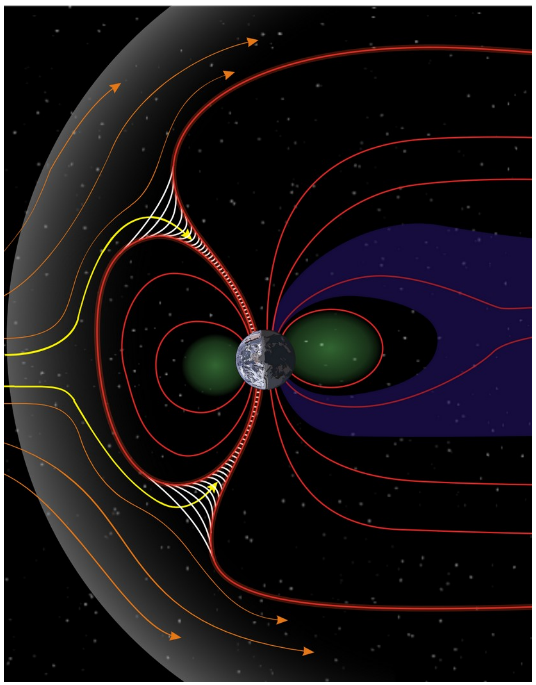
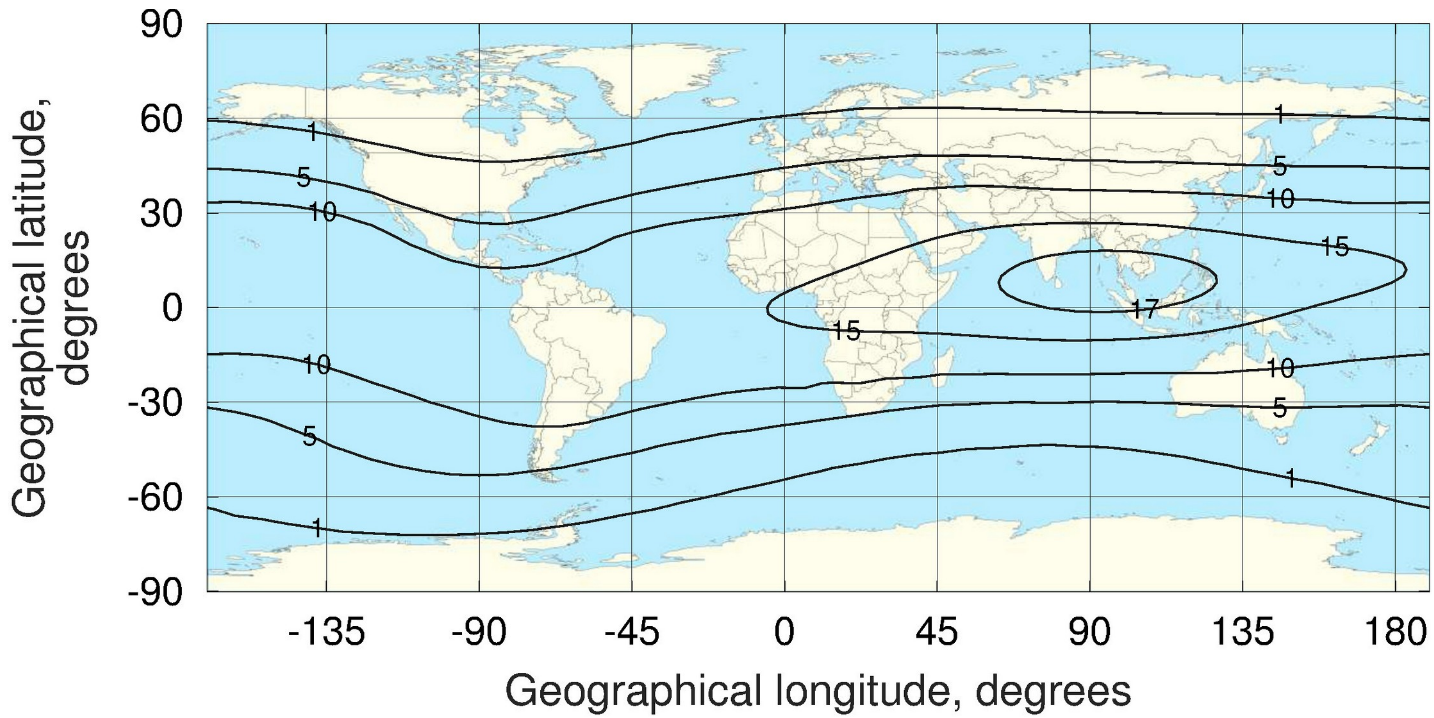
Introduction: geomagnetic cutoff

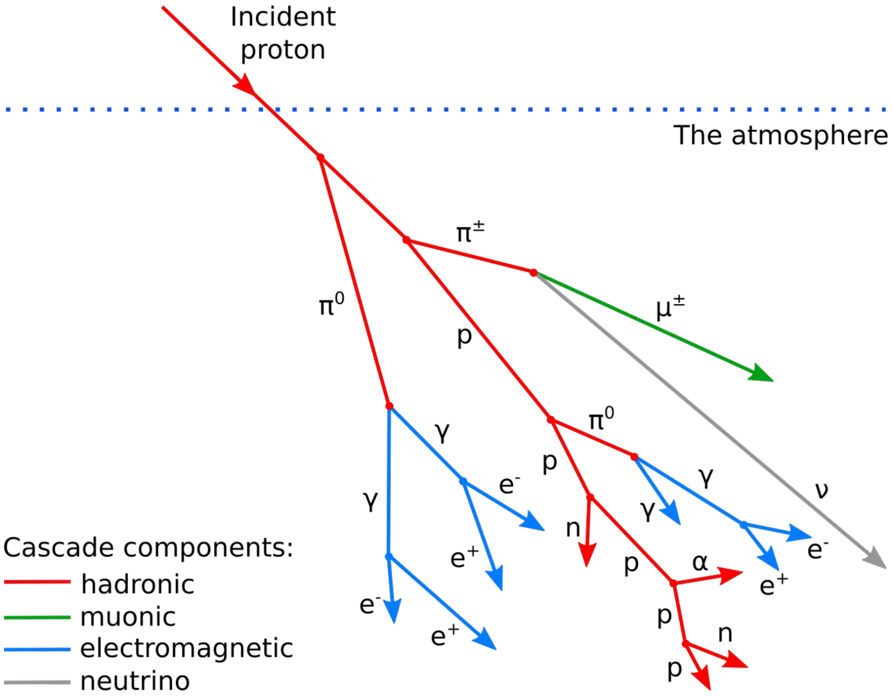


(NASA)

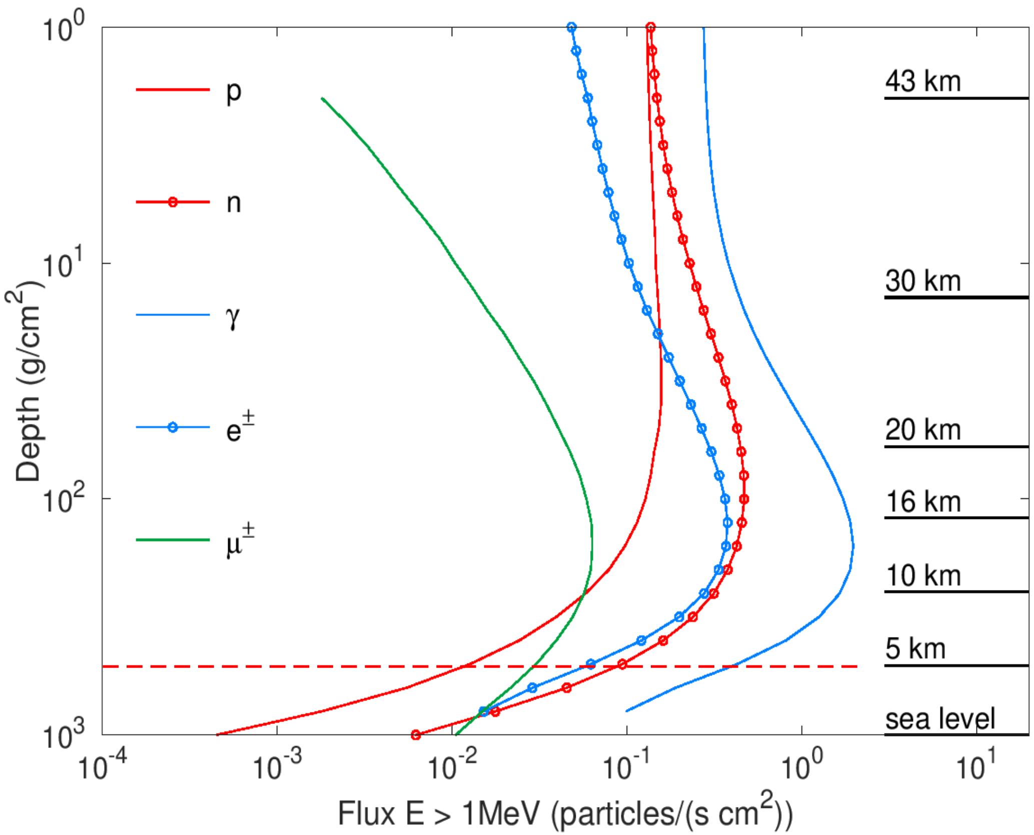
The geomagnetic cut-off rigidity (GV)



Introduction: effective atmospheric cutoff



Averaged cascade from GCR during moderate solar activity



Atmospheric cutoff: physical and instrumental approaches

Solar Physics (2021) 296:129
https://doi.org/10.1007/s11207-021-01875-5

About the Altitude Profile of the Atmospheric Cut-Off of Cosmic Rays: New Revised Assessment

Alexander Mishev[1,2] · Stepan Poluianov[1,2,3]

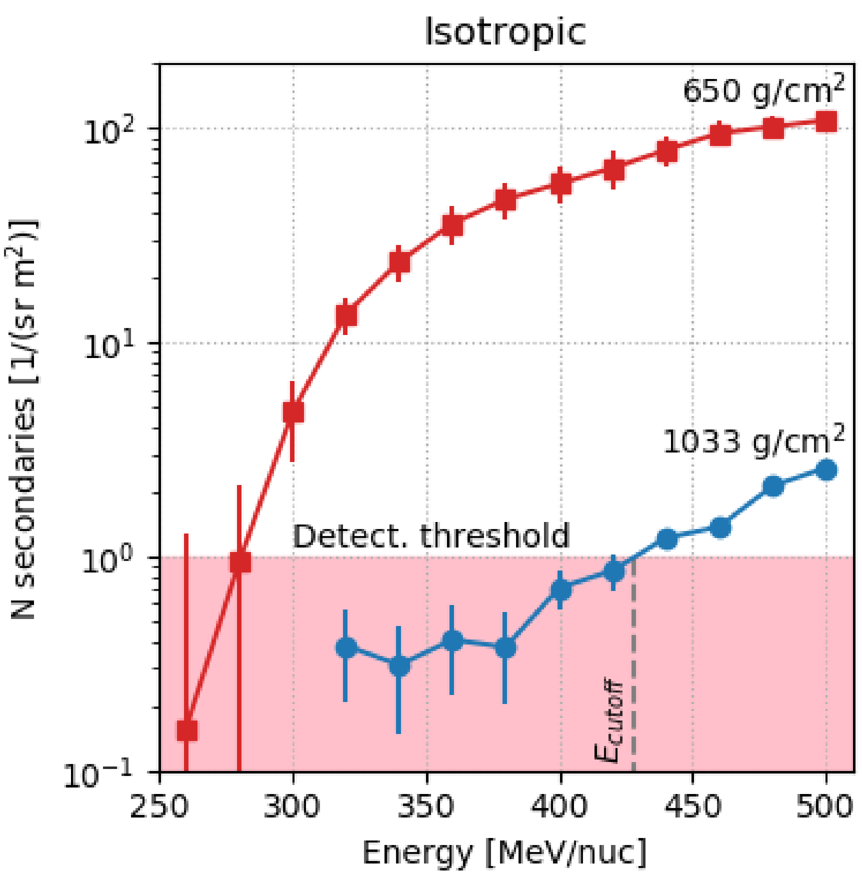
"Physical":

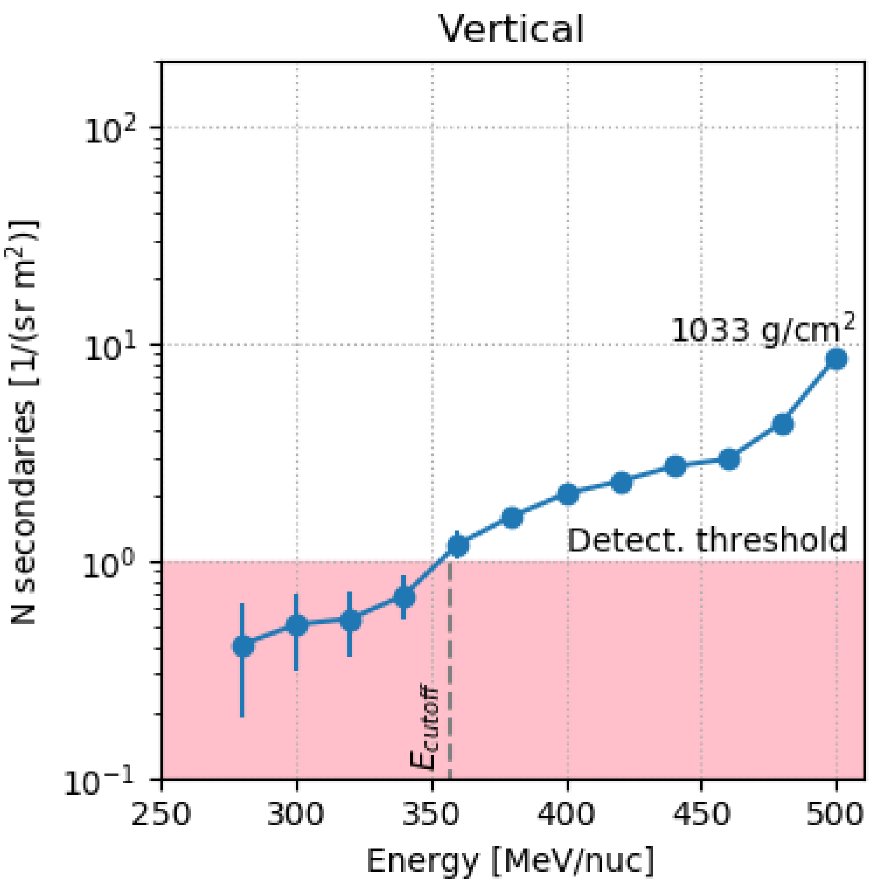
- Simulation of cosmic-ray cascades (Geant4/PLANETOCOSMICS)
- Incident protons: energies 200-500 MeV, vertical and isotropic angular distributions
- Registration of secondary neutrons at depths 600-1033 g/cm^2 (3.7-0 km a.s.l.)
- Criterion for registration of the cascade: at least 1 secondary neutron per cascade in average

"Instrumental":

- NM yield functions for different altitudes (Mishev et al., 2020)
- Realistic spectrum of incident particles with isotropic angular distribution
- Detection threshold defined with the known sea-level cut-off energy (433 MeV)
- Criterion for registration of the cascade: response above the detection threshold

"Physical" approach: cascade particles





"Instrumental" approach

NM count rate by particles of type *i*:

$$N_i(h) = \int_0^\infty Y_i(E,h) J_i(E) dE$$

yield function → $Y_i(E,h)$

CR intensity → $J_i(E)$

$$N_i(h) = \underbrace{\int_{E_c}^\infty Y_i(E,h) J_i(E) dE}_{I_{1,i}(h,E_c)} + \underbrace{\int_0^{E_c} Y_i(E,h) J_i(E) dE}_{I_{2,i}(h,E_c)}$$

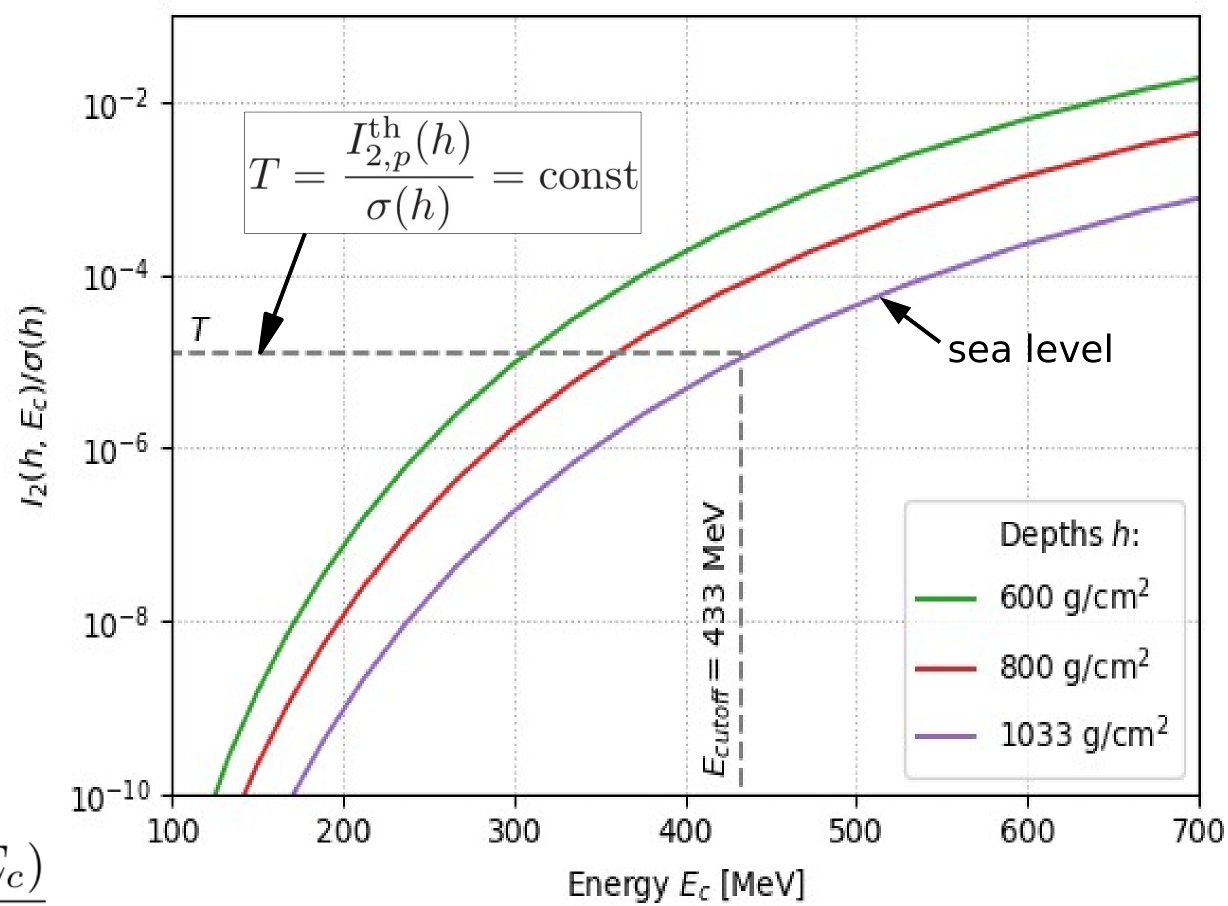
main I_1

remainer I_2

some variable threshold E_c

NM count rate has the Poisson distrib.:
<*N*> and σ=sqrt(<*N*>)

Remainer normalized to std. dev.: $\frac{I_2(h,E_c)}{\sigma(h)}$



Atmospheric cutoff from both approaches

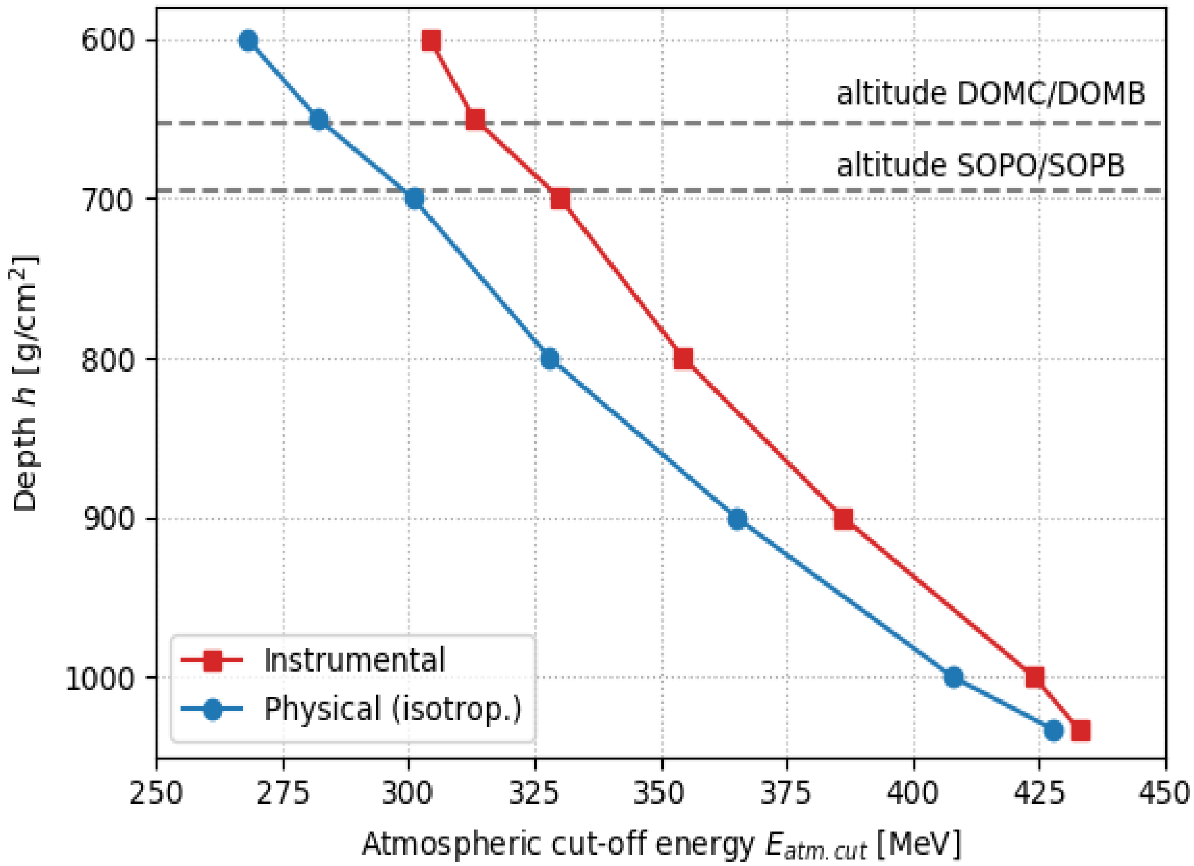
Neutron monitors:

- **DOMC/DOMB atmospheric cut-off:**

  312 MeV at 3233 m asl

- **SOPO/SOPB atmospheric cut-off:**

  322 MeV at 2820 m asl



Effective atm. cutoff of polar neutron monitors

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Advances in Space Research xx (2022) xxx-xxx

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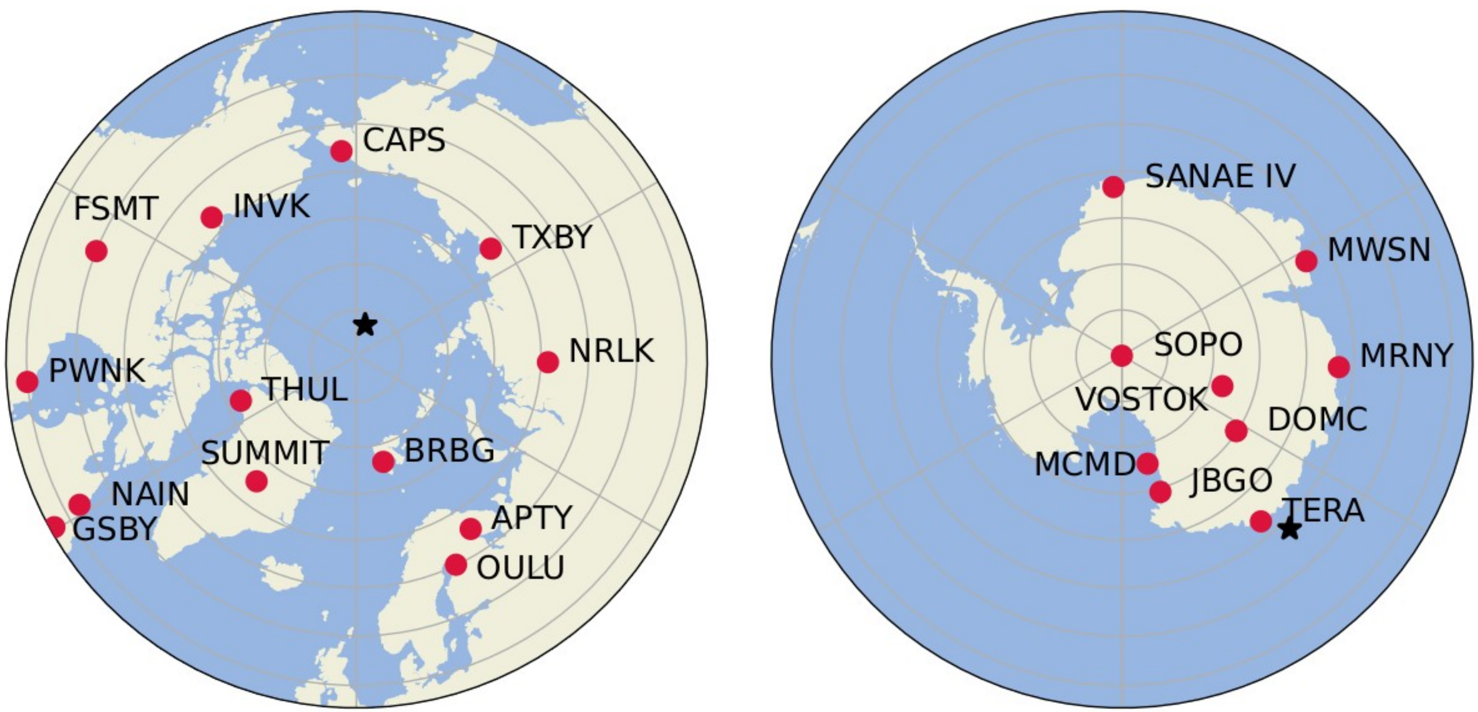
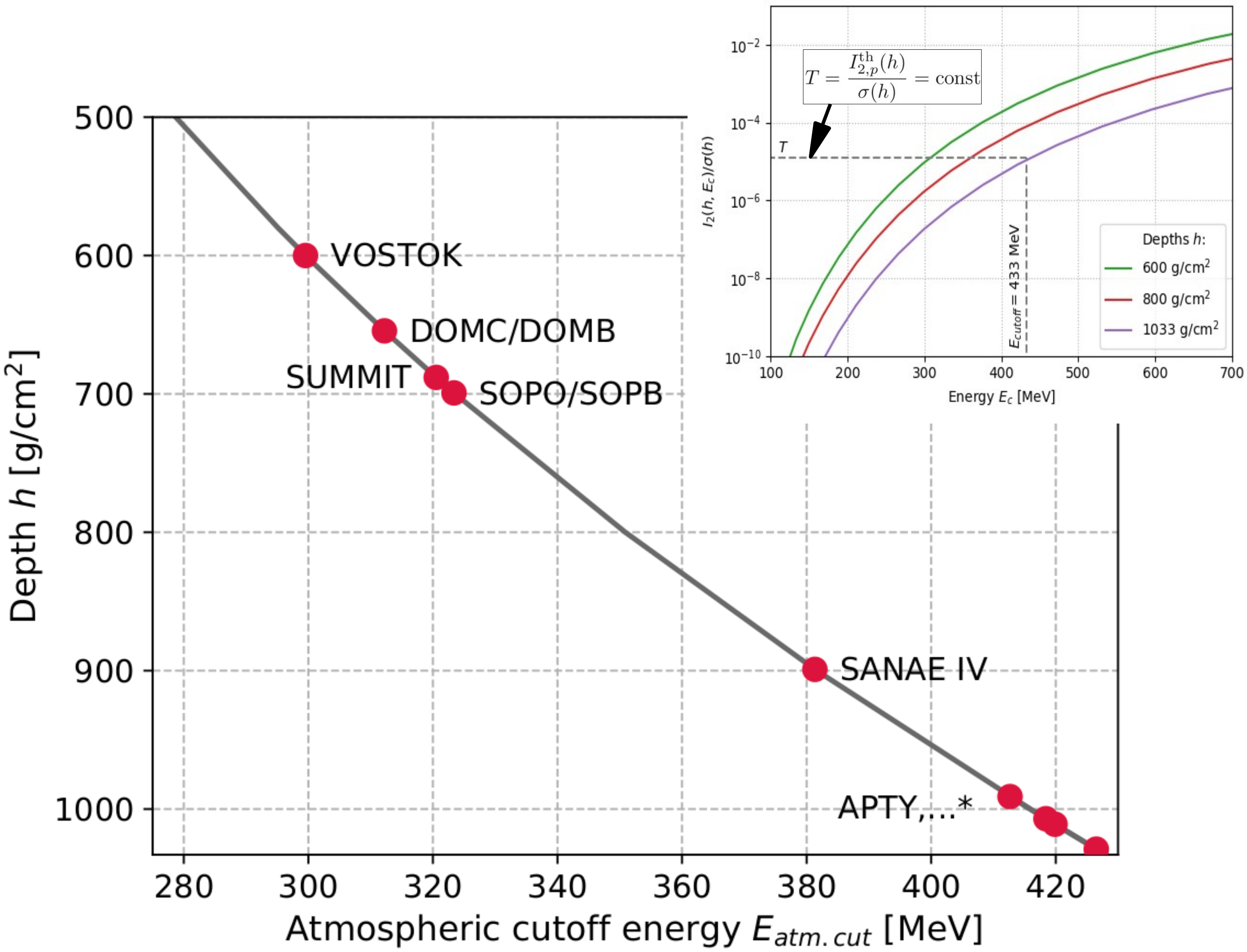
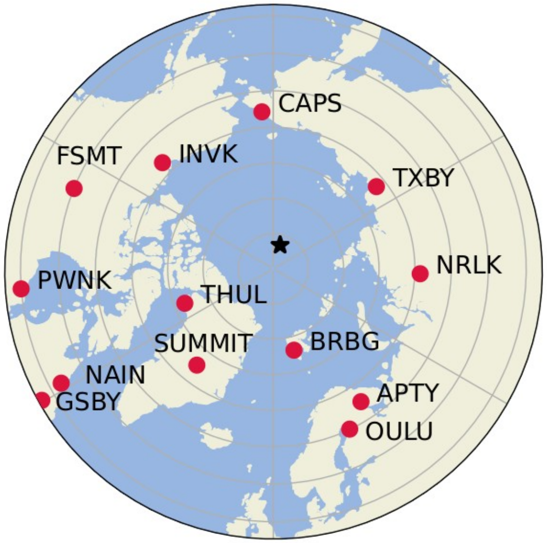
Cosmic-Ray Atmospheric Cutoff Energies of Polar Neutron Monitors

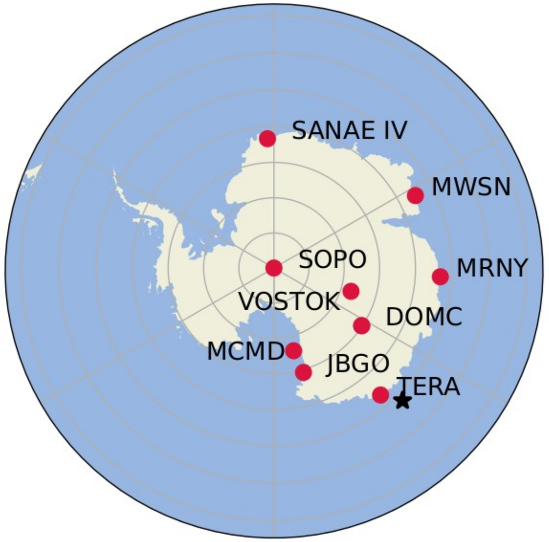
Stepan Poluianov[a,b,*], Oscar Batalla[c]



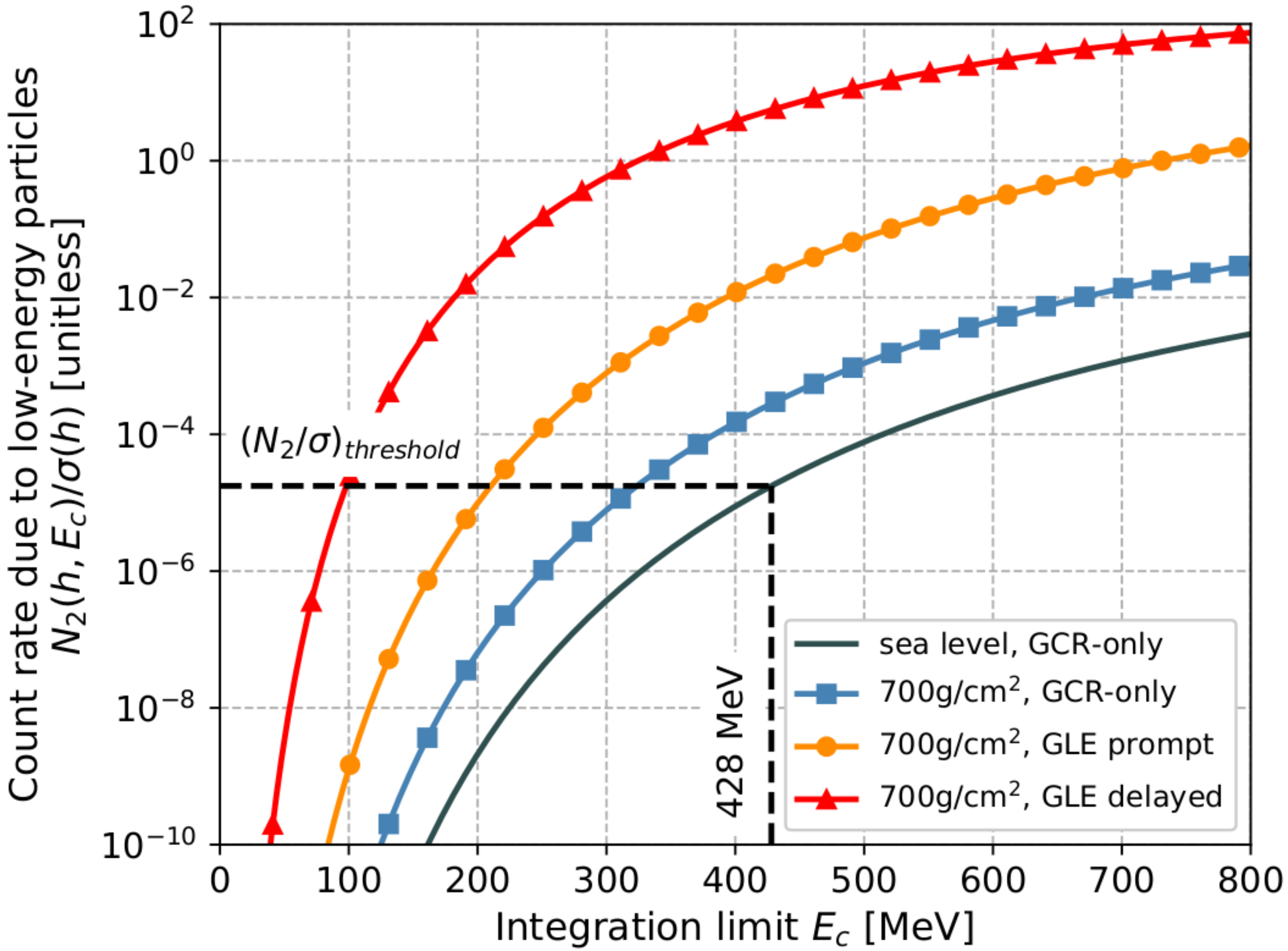
Atmospheric cutoff vs depth







Calculation of the atm. cutoff



Atmospheric cutoff of polar NM

Station	Altitude [m a.s.l.]	Pressure [mbar]	Depth h [g/cm^2]	Geomagnetic cutoff $P_{gm.cut}$ [GV]	$E_{gm.cut}$ [MeV]	Atmospheric cutoff $E_{atm.cut}$ [MeV] GCR only	GLE#05 prompt	GLE#05 delayed
Existing and existed stations:								
APTY	181	991	1011	0.51	129.6	419.9	270.7	131.3
BRBG	70	996	1016	0.06	1.9	421.7	271.9	132.0
DOMC/DOMB	3233	642	654	0.0	0.0	312.1	203.3	94.7
FSMT	180	987	1007	0.30	46.8	418.4	269.8	130.7
GSBY	46	1013	1033	0.96	404.1	428.0	275.9	134.4
INVK	21	1012	1032	0.13	8.9	427.6	275.6	134.4
JBGO	30	981	1001	0.0	0.0	416.2	268.4	129.9
MCMD	48	971	991	0.0	0.0	412.6	266.1	128.6
MRNY	40	981	1001	0.02	0.2	416.2	268.4	129.9
MWSN	15	982	1002	0.14	10.4	416.6	268.6	130.0
NAIN	46	1008	1029	0.60	175.4	426.5	274.9	133.8
NRLK	0	1006	1026	0.43	93.8	425.4	274.2	133.4
OULU	15	1009	1030	0.67	214.6	426.9	275.1	133.9
PWNK	53	1006	1026	0.38	74.0	425.4	274.2	133.4
SANAE IV	856	882	899	0.62	186.3	381.3	246.3	117.1
SOPO/SOPB	2820	679	695	0.08	3.4	322.3	209.5	97.7
TERA	32	983	1003	0.0	0.0	416.9	268.9	130.2
THUL	26	1005	1025	0.0	0.0	425.0	273.9	133.2
TXBY	0	1009	1030	0.42	89.7	426.9	275.1	134.0
Proposed stations:								
VOSTOK	3488	569	580	0.0	0.0	295.1	193.1	90.1
SUMMIT	3216	675	688	0.06	1.9	320.5	208.4	97.1

Motivation:
Sub-GLE definitions

Raukunen O., Vainio R., Tylka A.J. et al., J. Space Weather Space Clim. 2018, 8:A04:

"...so-called sub-GLEs, i.e., large SEP events with increases of protons above 300 MeV, but not with sufficient intensities to be detected with ground level neutron monitors."

Briefly: sub-GLE, if E > 300 MeV.

Poluianov S.V., Usoskin I.G., Mishev A.L. et al., Solar Phys. 2017, 292:176:

"A sub-GLE event is registered when there are near-time coincident and statistically significant enhancements of the count rates of at least two differently located high-elevation neutron monitors and a corresponding enhancement in the proton flux measured by a space-borne instrument(s), but no statistically significant enhancement in the count rates of neutron monitors near sea level."

Briefly: sub-GLE, if registered by 2 high-altitude polar NMs and not seen by any other NMs.

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Conclusion from this work:

They agree well, no contradiction!

Summary

- We calculated effective atmospheric cutoff energies for cosmic ray protons at altitudes 0 - 3.7 km (0 - 600 g/cm2).
- Effective atmospheric cutoff for a list of polar neutron monitors
- Strong GLE#05 reduces of the effective atm. cutoff from 420 MeV (pre-GLE) to 270 MeV (prompt comp.) and to 130 MeV (delayed comp.)
- Atmospheric cutoff of current high-altitude polar NMs:

  SOPO/SOPB - 322 MeV

  DOMC/DOMB - 312 MeV
- Sub-GLE definitions by Raukunen (2018) and Poluianov (2017) are in good agreement. Indeed, sub-GLEs have particles with energies E > 300 MeV.

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THANK YOU!