Ionization in the Atmosphere

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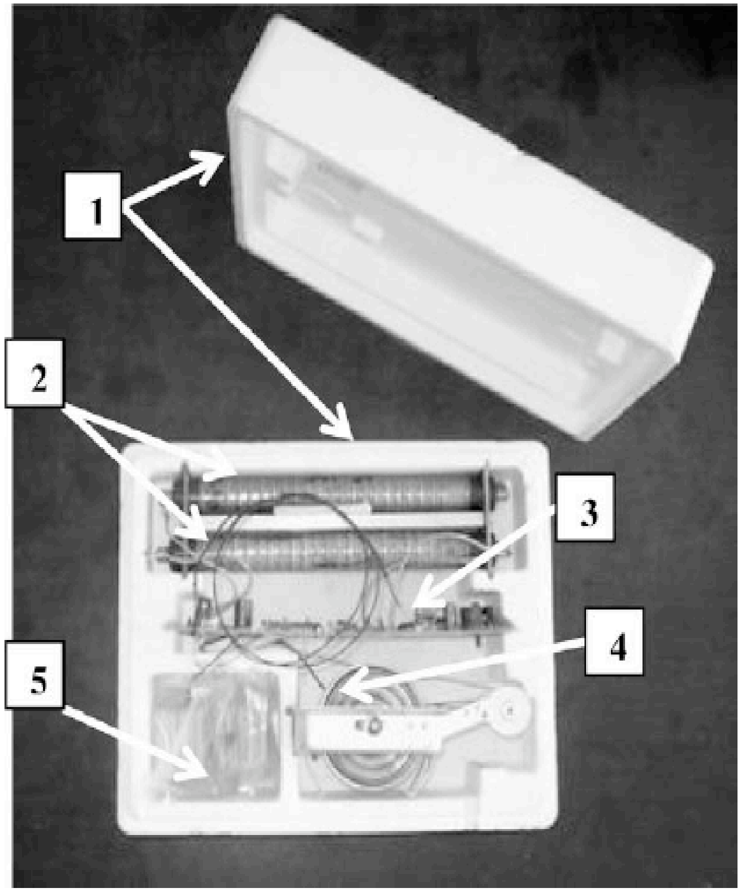
A survey of the World data on measured particle fluxes and the rate of ionization by Cosmic Rays (CR) is presented.

Measurements as a function of altitude, time and rigidity cut-off (R_C) are compared with simulations.

The LPI Data

Lebedev Physical Institute (LPI) has carried out a long term survey of particle fluxes at various altitudes in a series of daily balloon flights from 1957-present.



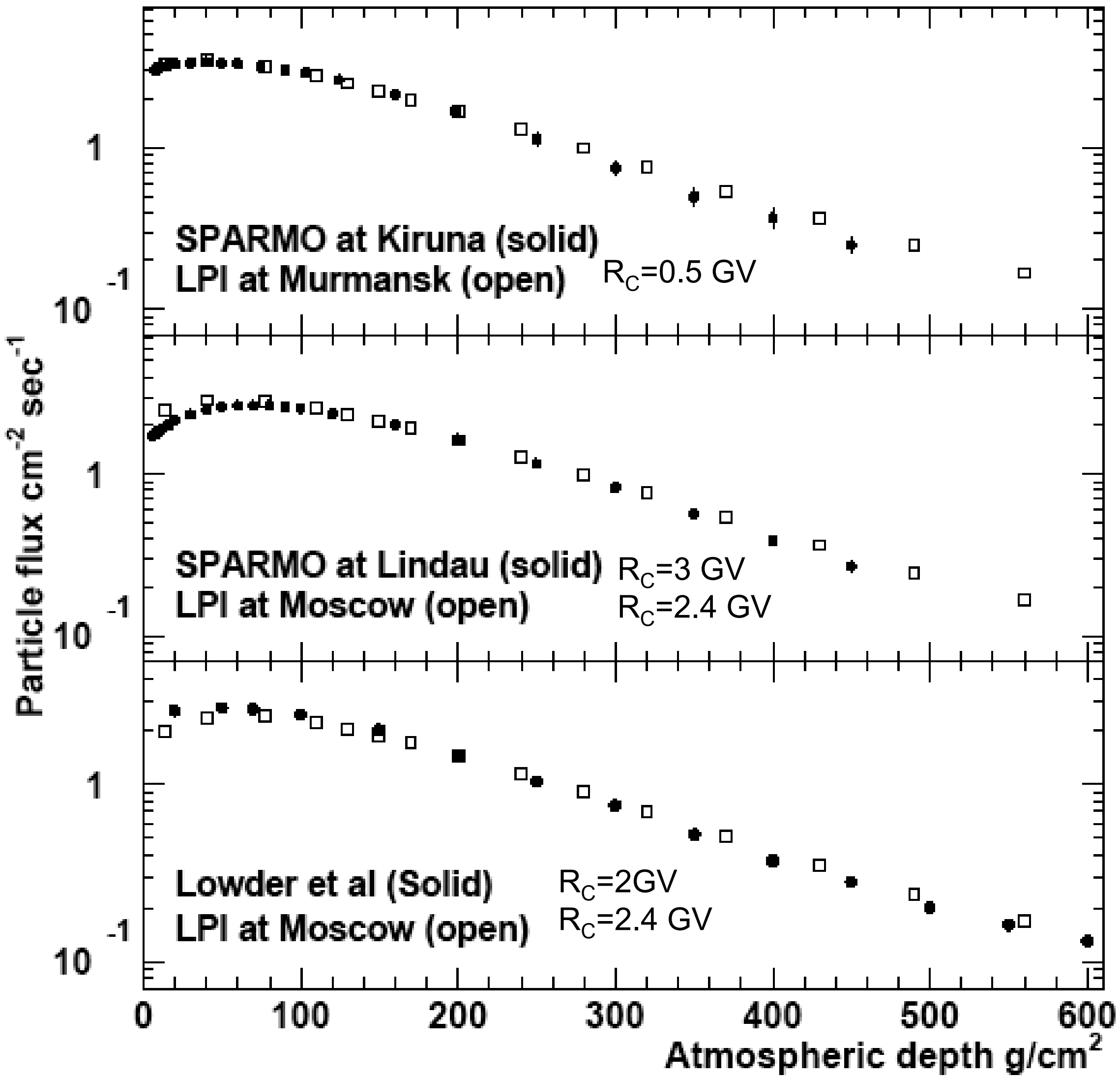
LPI apparatus: Geiger Counters (label 2) in foam plastic box (label 1) with pressure sensor (label 4) and telemetry (labels 3 and 5).

Foam plastic box keeps temperature > 0C.

Upper Geiger measures omnidirectional particle fluxes which will be discussed here.

Other Data Used

- SPARMO data – balloon measurements of CR particle flux in 1964
- Lowder et al. - both CR flux and and ionization measurements in 1970.
- Neher et al ionization measurements in 1965.
- Hess and Kolhorster measurements in 1912 and 1913.



Compare SPARMO and Lowder with LPI fluxes.

Difference at low depth due to R_C differences

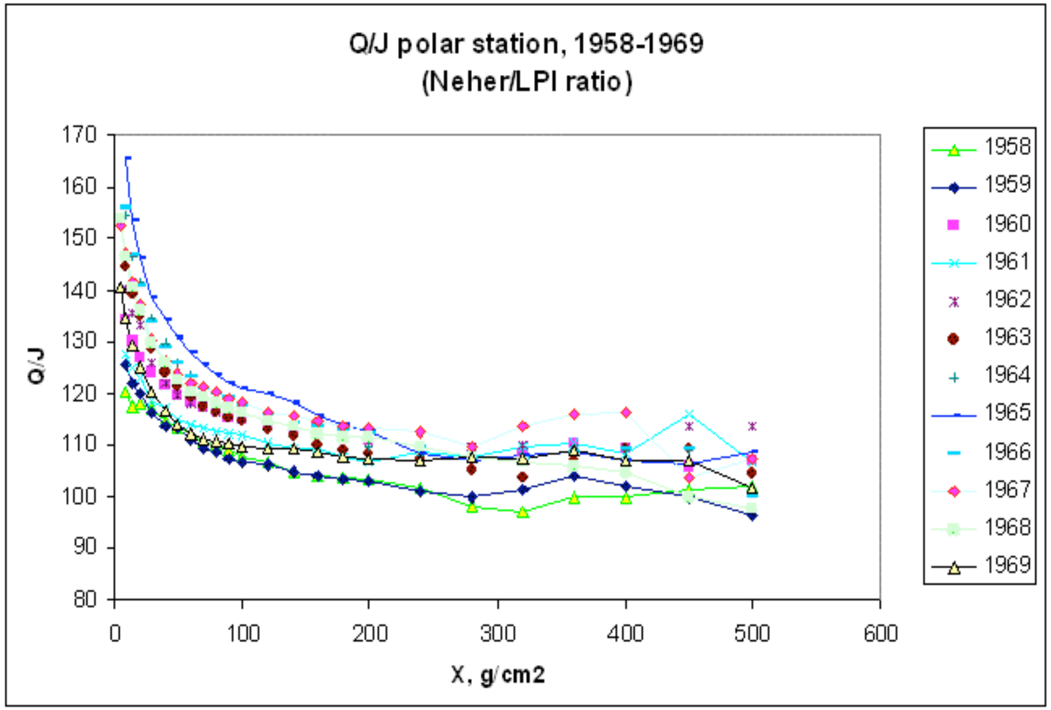
Agreement between data sets is mostly within 10%.
- 20% in one region.

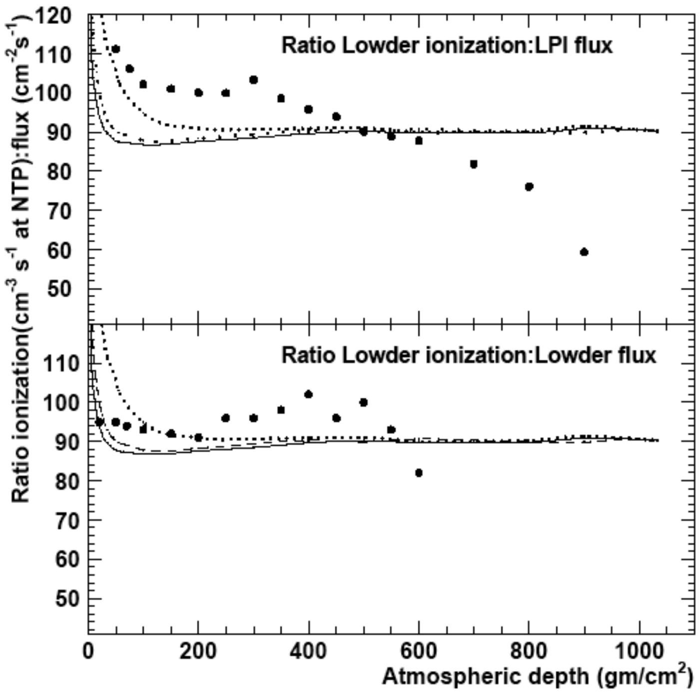
Simulations

- Usoskin-Kovaltsov – CORSIKA based (ionization only as function of time).
- Berne simulation Desorger et al.,- based on Geant 4 (flux in 1976 available only).
- O'Brien simulation (both flux and ionization available as function of time).

Difference between flux and ionization

- Particle flux J cm^{-2} per sec creates ionization at rate of Q ion pairs per gm per sec.
- The two are related by $Q=J \langle dE/dx \rangle/\alpha$ where $\langle dE/dx \rangle$=mean dE/dx of the particles produced. α is the energy to produce each ion pair (35 eV).
- For dE/dx=2 MeV/gm cm^{-2} (i.e. minimum ionizing) expect Q/J=5.7 10^4 per gm air or 74 per cm^3 of air at STP.





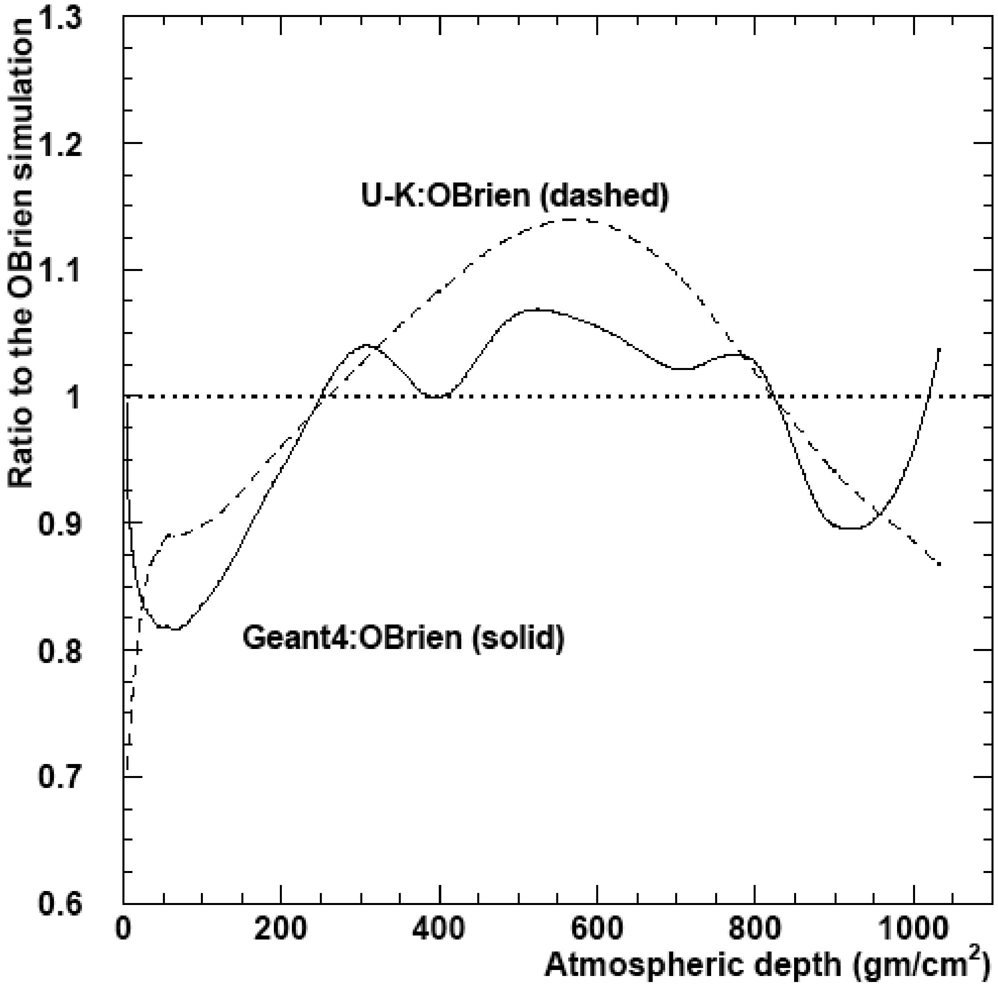
Ratio Q/J Polar (RC=0)

Moscow RC=2.4 GV

Curves for RC=0 (dotted)

0.5 (dashed), 2.4 (solid)

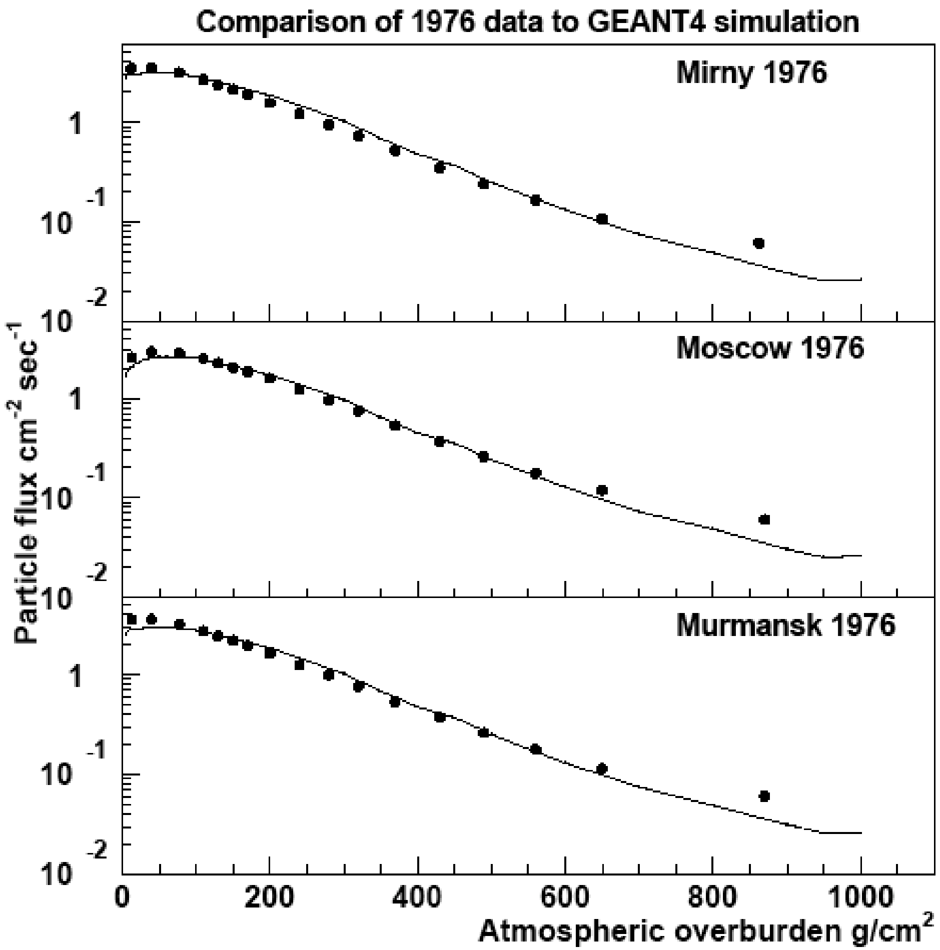
NB Data ~35% above MIP level.



Comparison of simulations

- dashed U-K to O'Brien ionization. Solid Geant 4 to O'Brien flux
- consistent to better than 20% almost everywhere except very high altitude where U-K and Berne are lower than O'Brien.

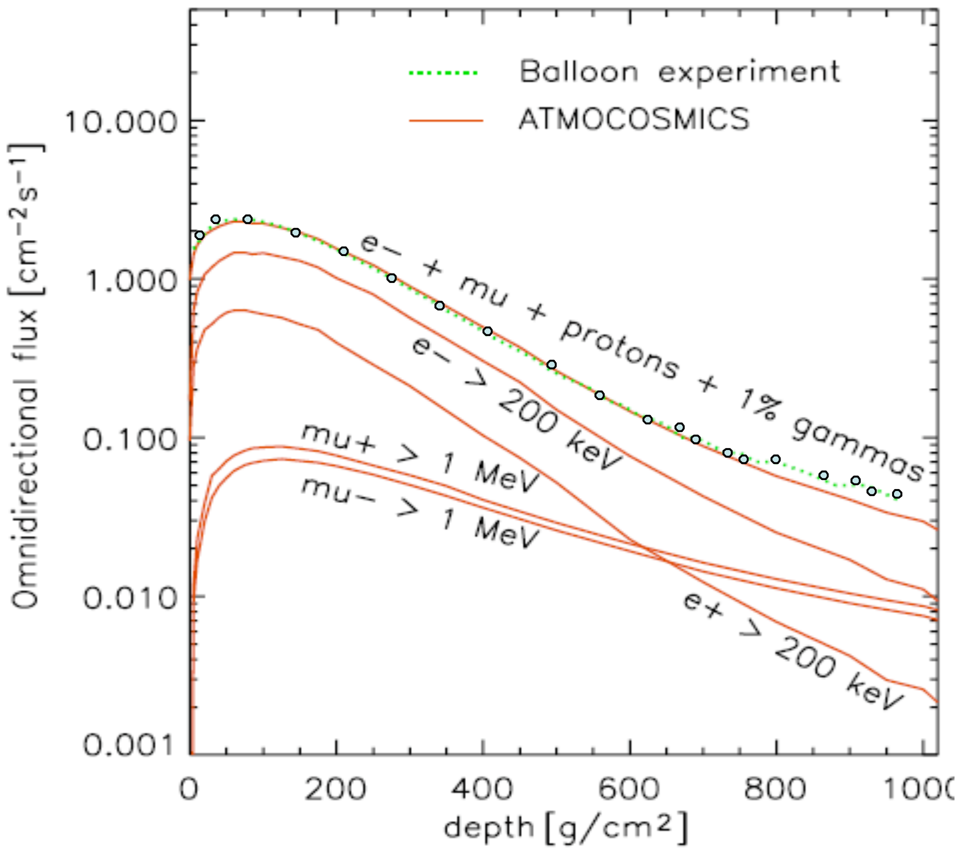
Altitude dependence – compare LPI data and Geant 4 simulation



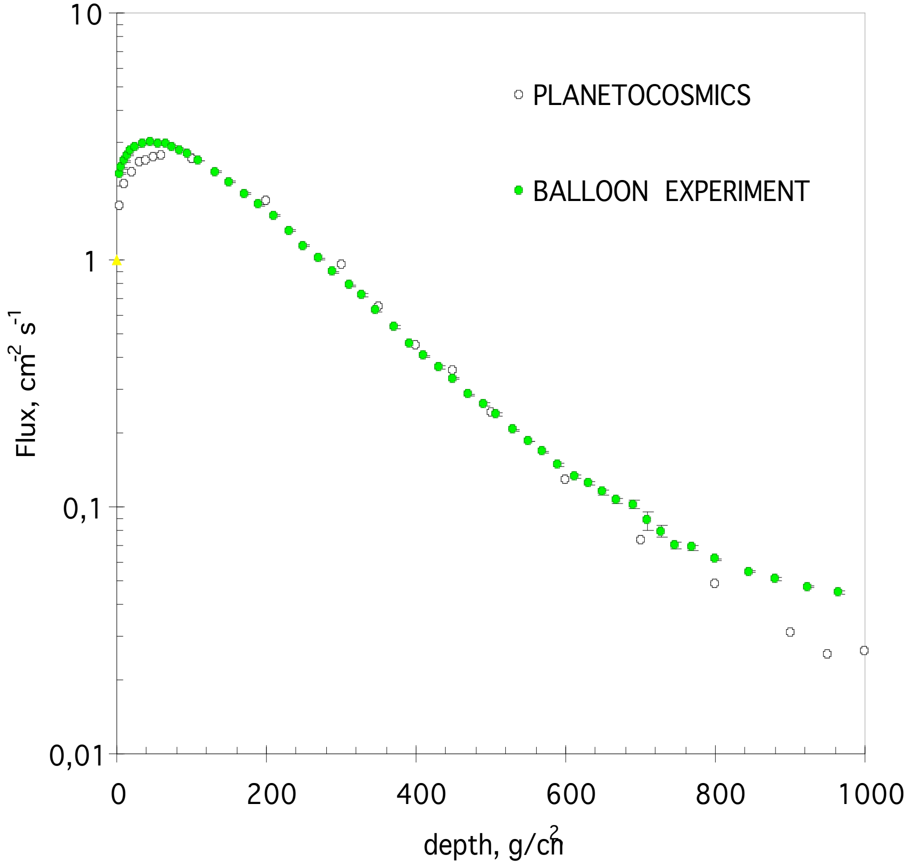
Data high at highest altitude and lowest altitude relative to the simulation.

MOSCOW, 2000

MOSCOW, 1976

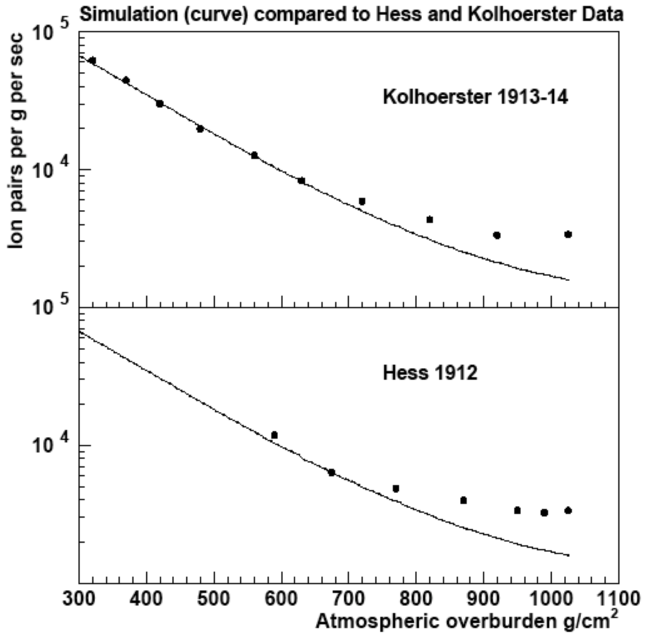


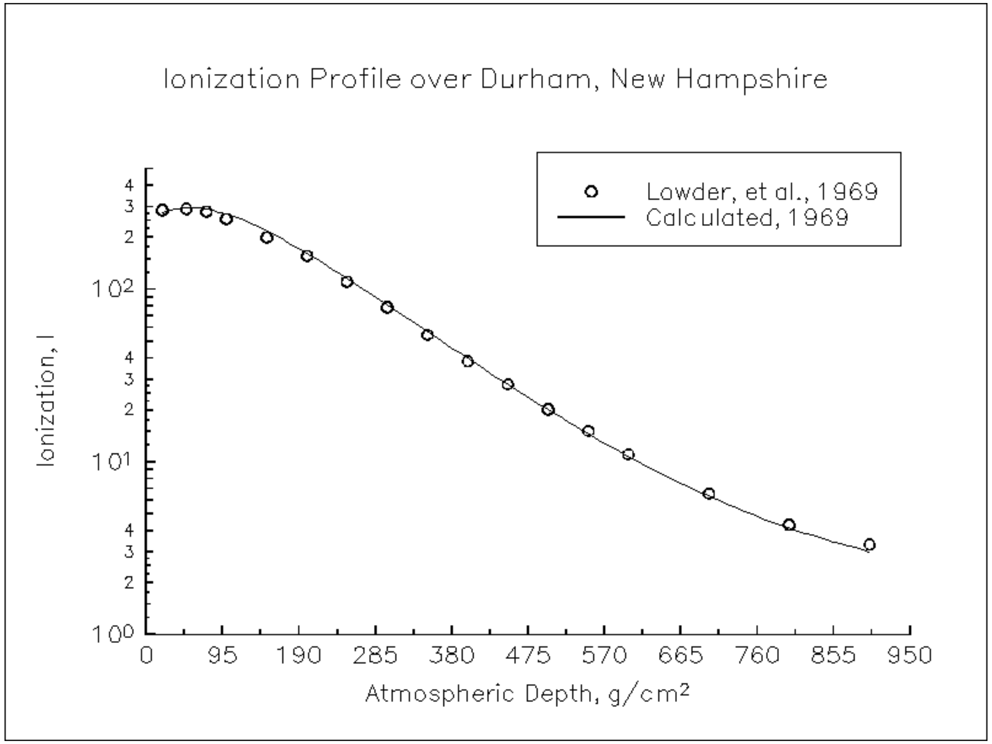
Desorgher L, Flueckiger E., et al. 2005



Makhmutov et al., 2009

GEANT4 simulation of the CR balloon measurements





Historic data compared to U-K ionization simulation

Lowder et al data compared to O'Brien simulation

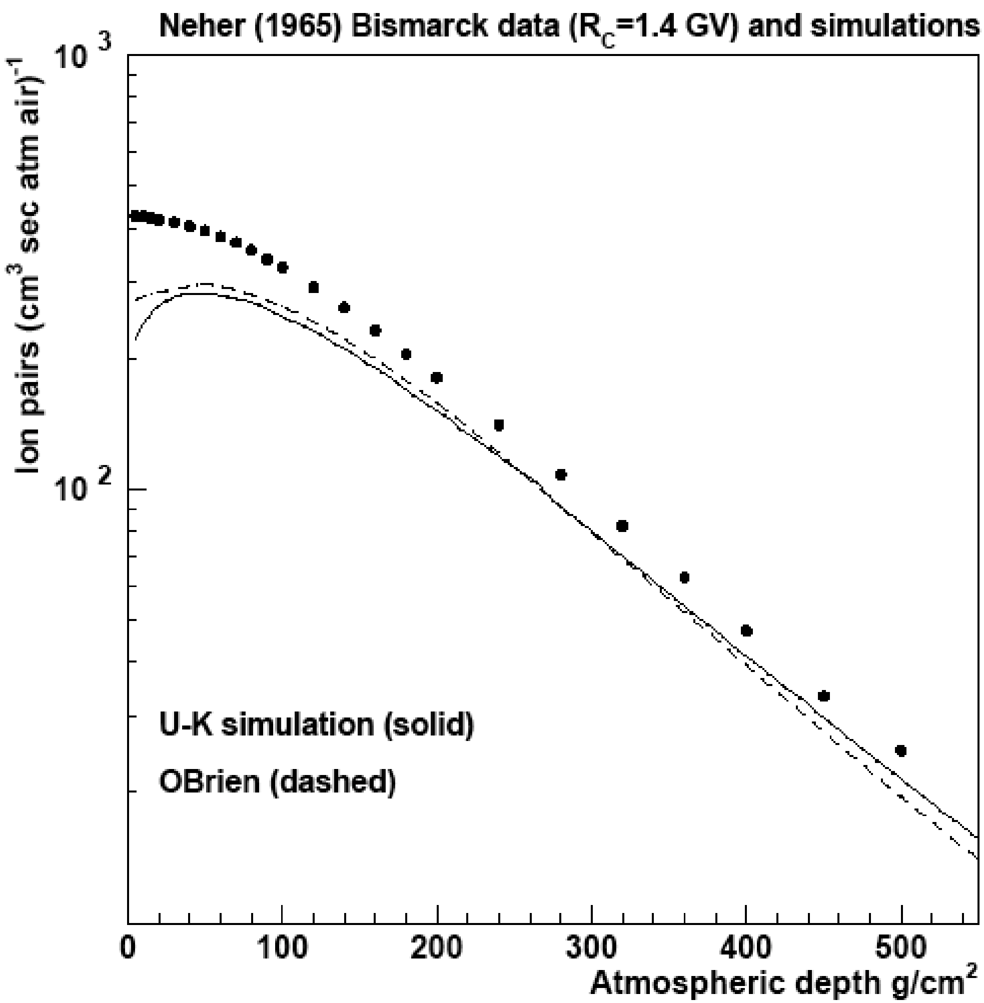
Historic data also show excess at low altitude. Lowder data do not.

Lowder data use high pressure ion chamber with thick walls – insensitive to low energy particles. All other measurements use thin wall detectors.

So excess must be at low energy – radioactivity ? At 2-3 km altitude ? Probably not since occurs also at Mirny (near South pole)

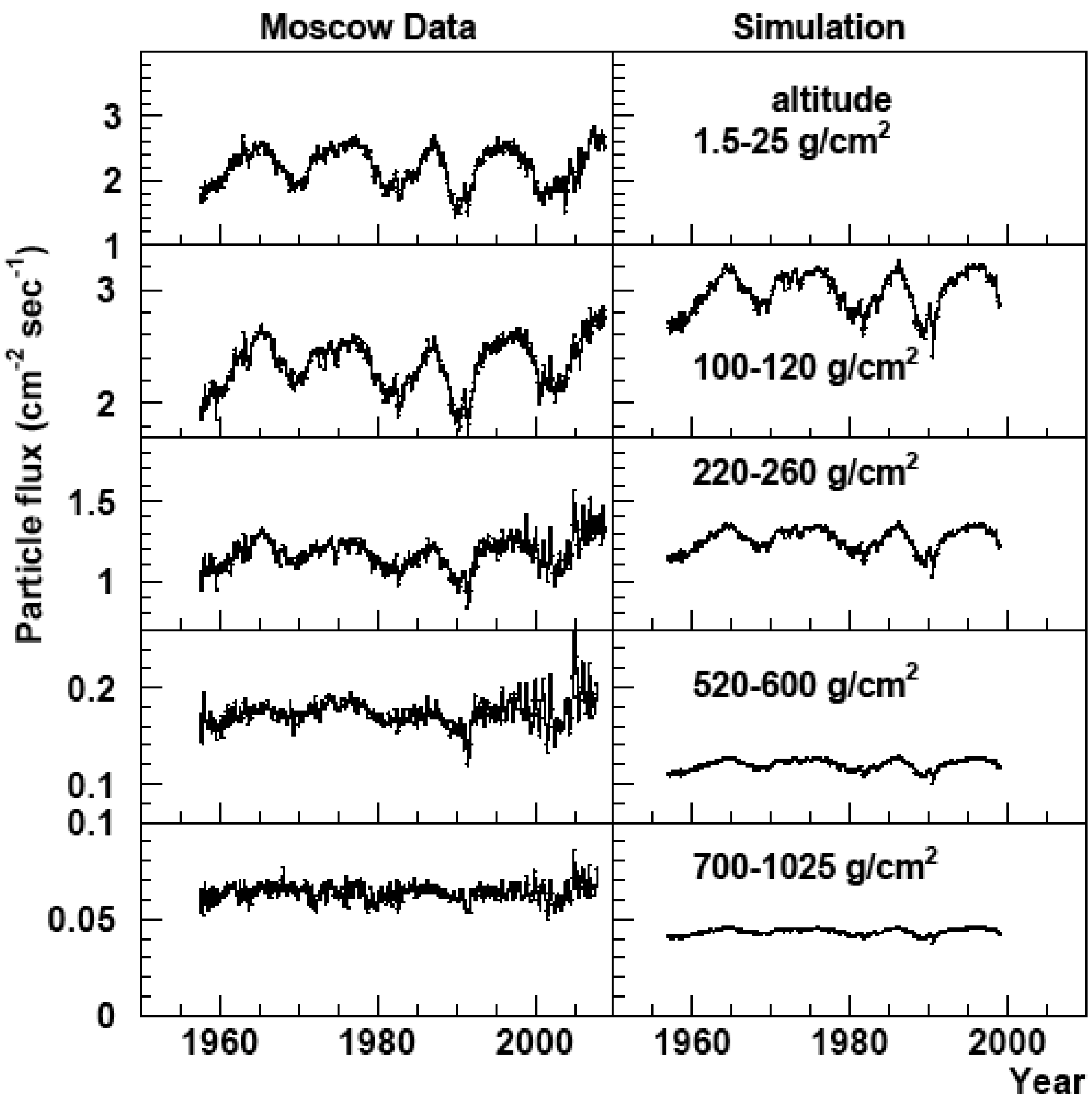
High altitude ionization measurements from Neher

Normalisation difference of 20% from simulations. Shape agrees better with O’Brien than with U-K simulation.

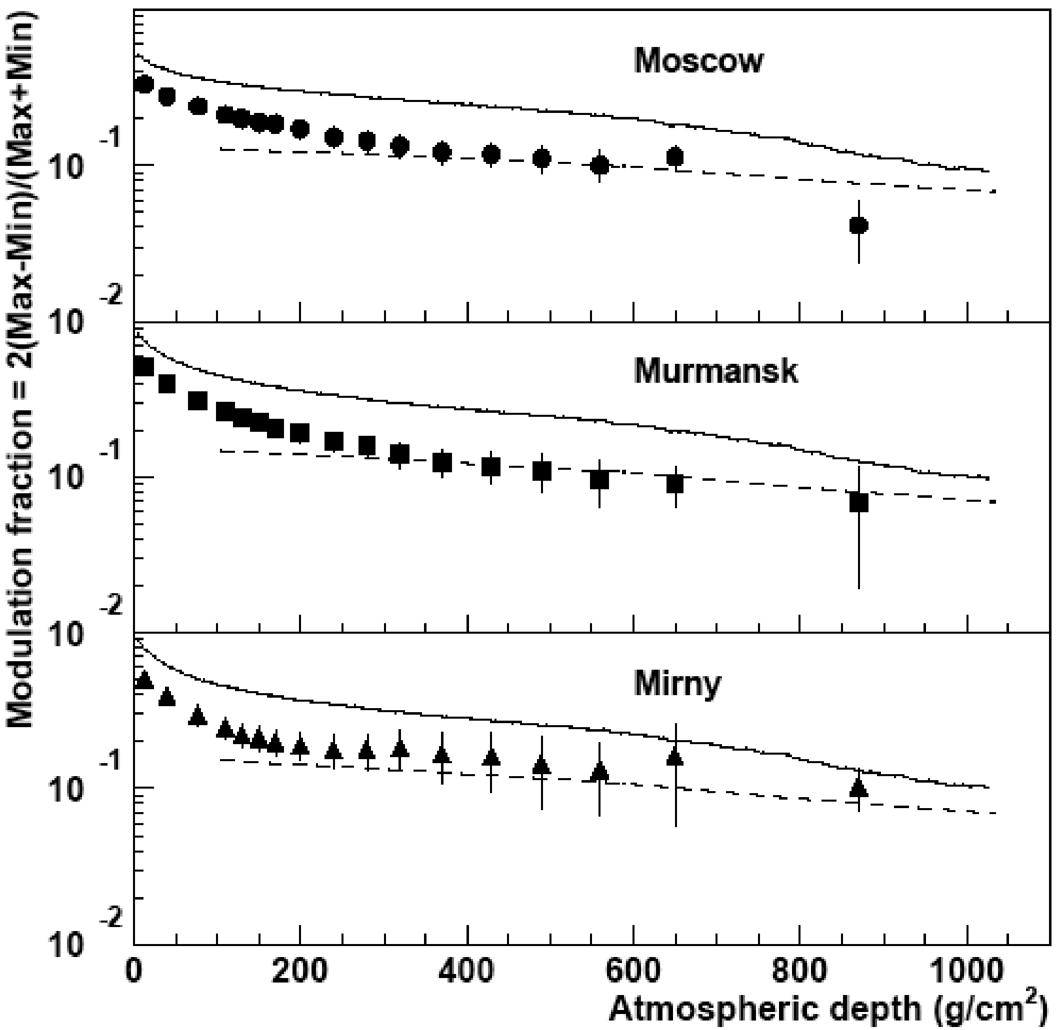


Time dependence of LPI flux compared with O'Brien simulation.

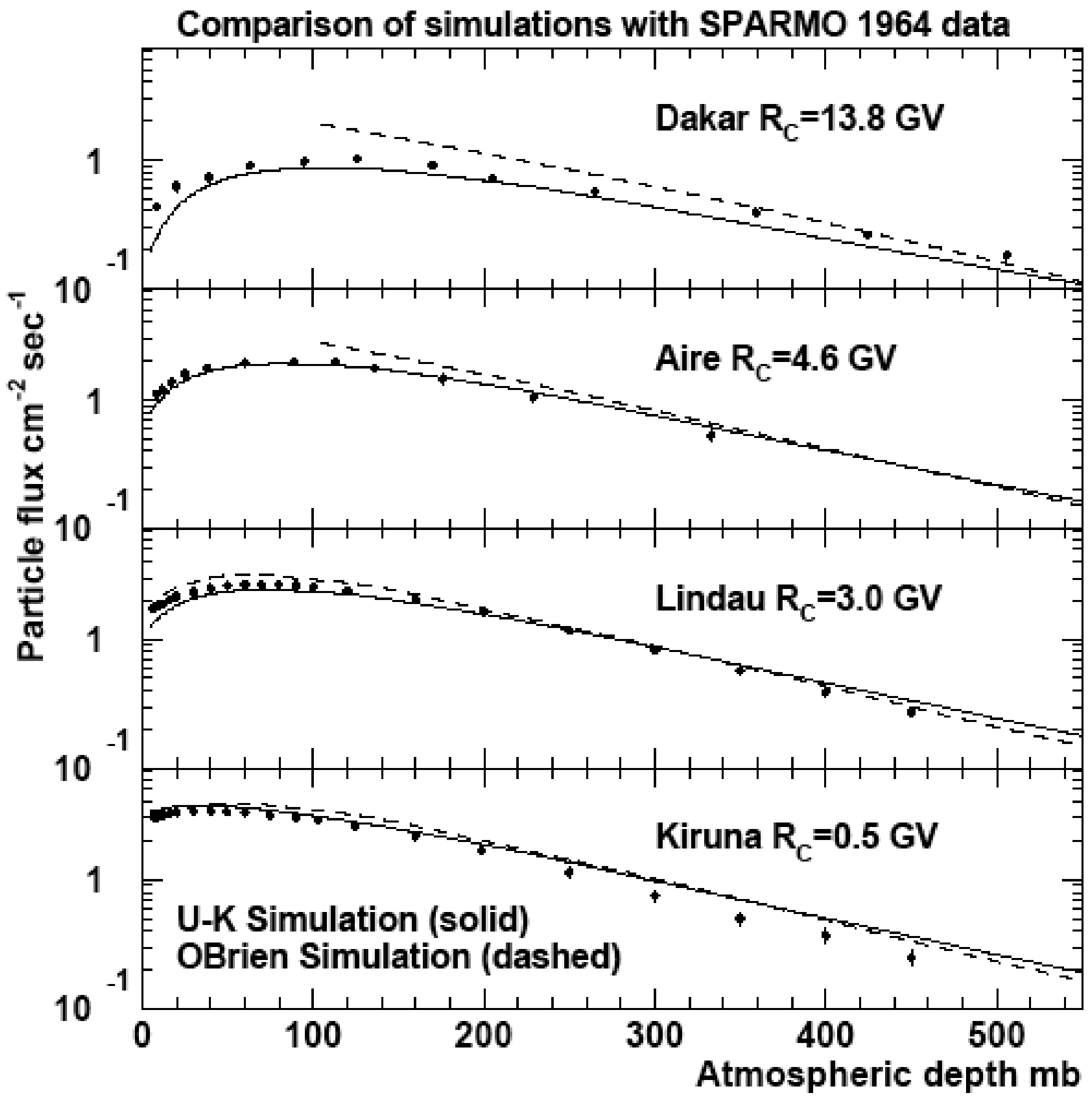
- measure solar modulation from max to min change



Fractional change due to solar modulation against altitude compared to simulations (solid = U-K, dashed = O'Brien)



R_C dependence compared to simulations.



CONCLUSIONS

- Simulations generally agree with data.
- Possible problem at high altitude in U-K simulation.
- Problems occur at low altitude from low energy particles– probably not radioactivity.
- U-K predicts twice as much solar modulation as observed.
- O'Brien simulation is overestimates data at high R_C and high altitude.