Lunar Radiation Study

August 4, 2006

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Study Objectives

- Calculate Lunar Environments
  - p, n, e, γ, π, μ, heavy ions, et cetera
  - Energy: MeV or greater, lower for n
  - Calculate scatter using FLUKA
- No Comparisons With Other Codes
- No Validations
  - Radiation shielding program
- Create An Extensive Data Set
  - For use by others to validate, compare, et cetera

Outline

- Applications of These Data
- Various Cases
- Choice of FLUKA
- Data
- Summary

Data Applications

- Human Survival
  - Total dose
- Component Reliability
  - Total dose
  - Displacement damage
  - Single event effects
  - Dose rate
- Material Integrity

Variety of Cases

- Radiation Types
  - Cosmic Rays, p, α, Li through Ni
  - Solar Event Particles, p, α, C through Ni
- Material
  - Lunar Soil
    - Apollo 16 Site Average
    - JSC-1 Simulant
  - Bulk Materials
    - Helium-3
    - Iron
- Direction of Scattering
  - Backscatter
  - Forwardscatter

Why FLUKA?

- GEANT4, MCNPX, HZETRN
- Only FLUKA and GEANT4
  - Monte Carlo
  - 3 Dimensions
- FLUKA Chosen
- Decision Based On The Codes Status At That Period Of Time
- Opinions Are Strong, Like Partisans In A War

FLUKA versus GEANT4

- CERN and the Large Hadron Collider
- GEANT4 - CERN
  - Difficult to set up runs
  - C++, Object Oriented
- FLUKA - INFN
  - Difficult to Run
  - FORTRAN
  - Had Been Verified
- Both Are Converging To The Same Physics

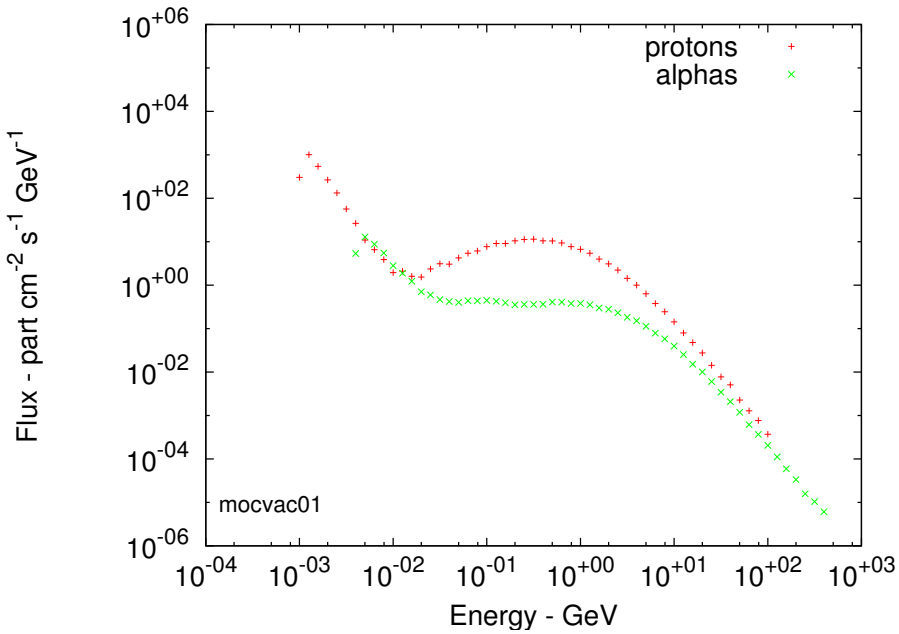
Some FLUKA Models

- EGS4 or EGSnrc: e, γ
- MCNP: n, E , 20.0 MeV
- RQMD: Heavy ions, 1/10 AGeV $<$ E $<$ 5.0 AGeV
- DPMJET III: E $>$ 5.0 AGeV

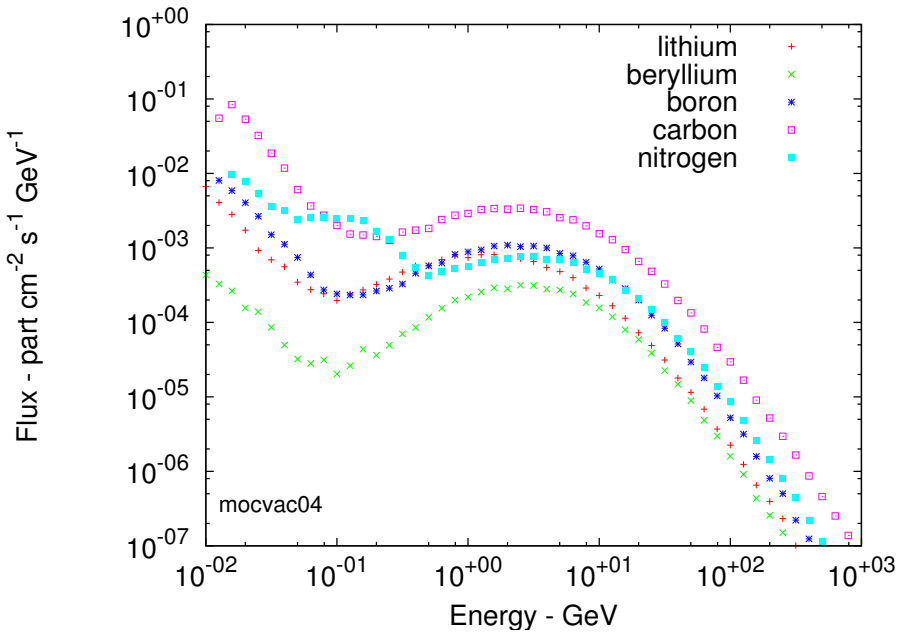
GEANT4/FLUKA

- Assume Both Codes Have The Same Physics
- First Time Cosmic Ray Transport Can Be Adequately Estimated
- With Enough Experimental Verification This Is A Major Step Forward
  - Applied physics
  - Engineering issues
- Approximations Often Do Not Represent Reality
  - Don't expect people to discover breakthroughs
  - Test ban negotiations
  - Tortoises
- Tremendous Cost Savings

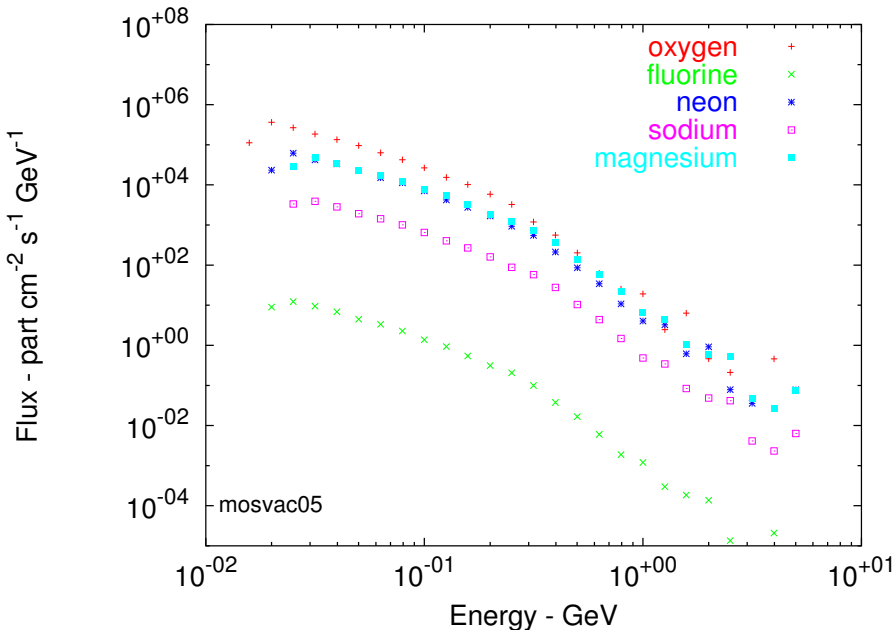
Cosmic Proton and Alpha Flux



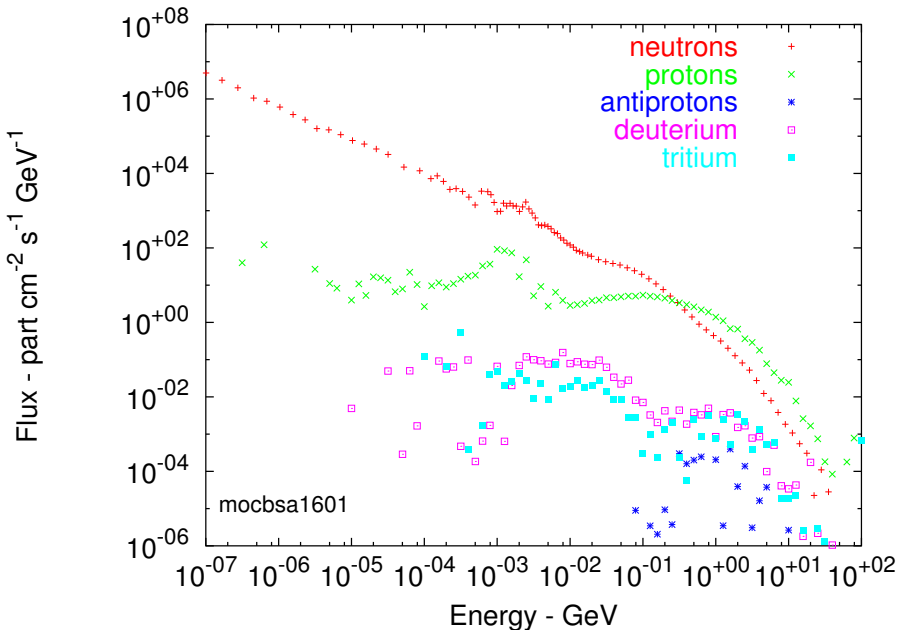
Cosmic Light Ion Flux



Solar Oxygen Thru Magnesium



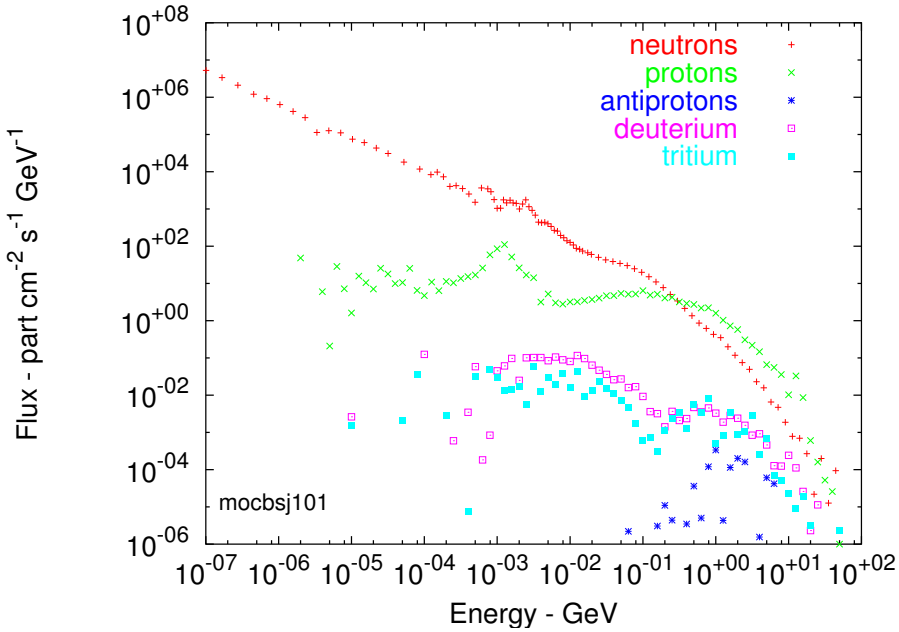
Cosmic Backscatter Ap16 Soil



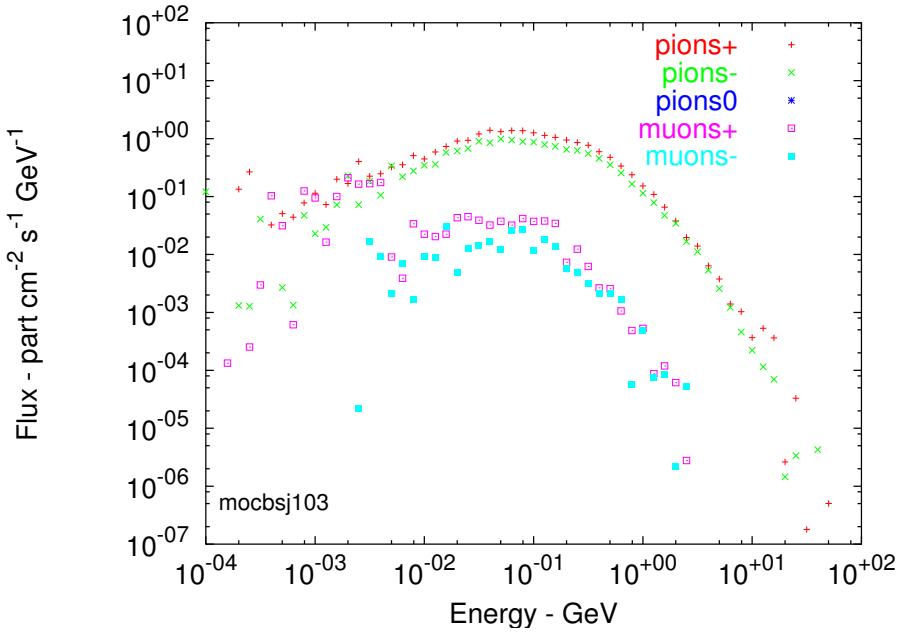
Cosmic Backscatter Ap16 Soil

- Heavy Ion Backscatter Chart Has Been Removed
- Problem Discovered With Heavy Ion Detector
  - It can only be used as a two-way detector

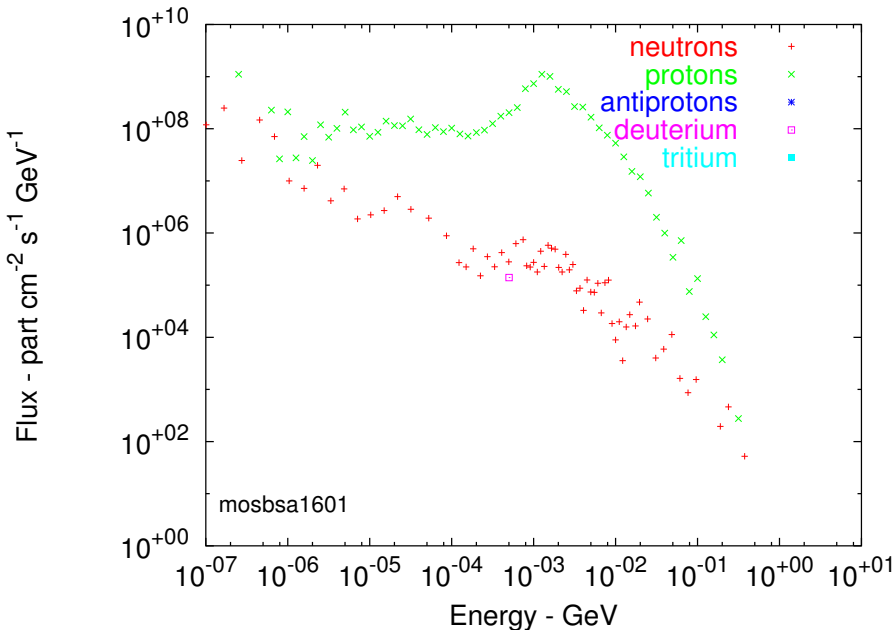
Cosmic Backscatter JSC-1 Soil



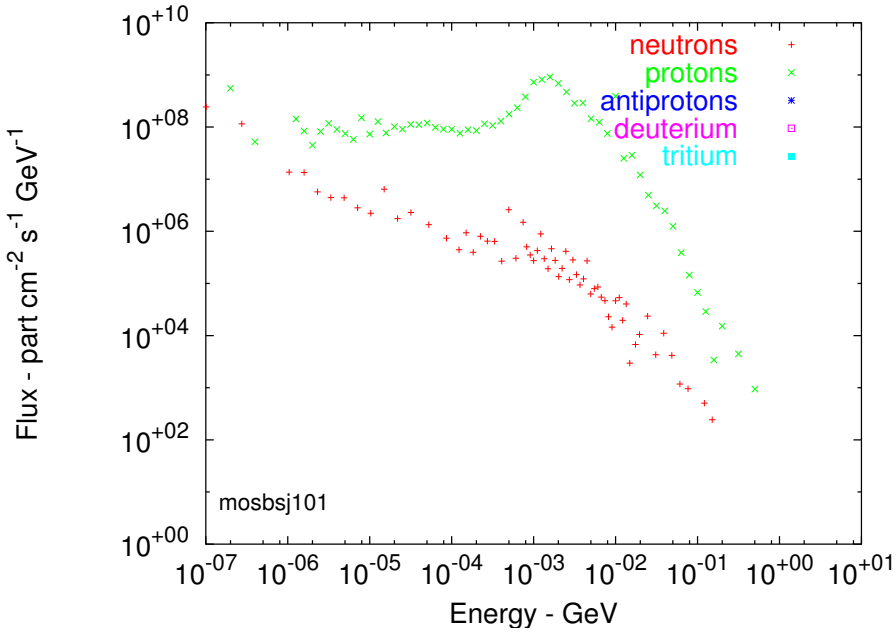
Cosmic Backscatter JSC-1 Soil



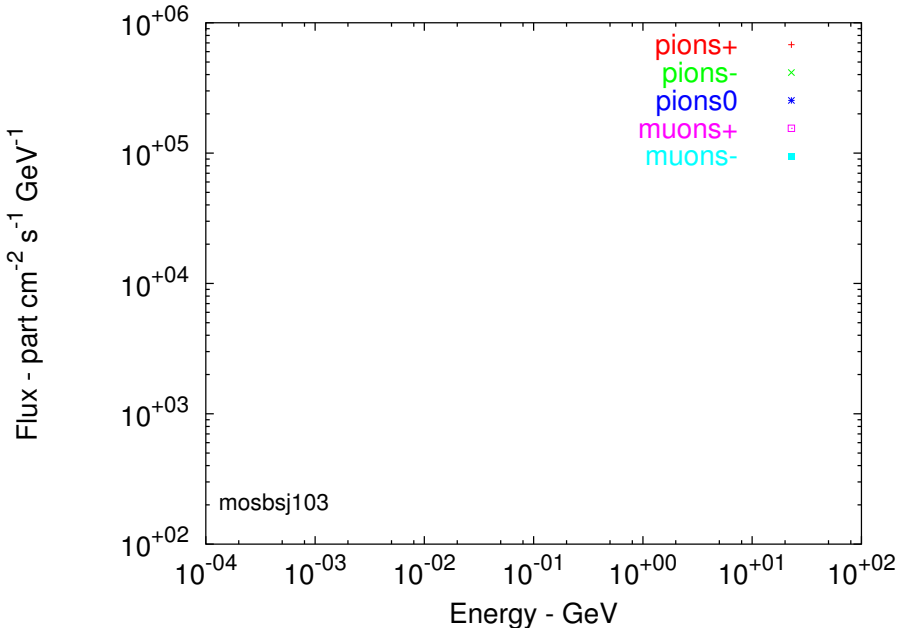
Solar Backscatter Ap16 Soil



Solar Backscatter JSC-1 Soil



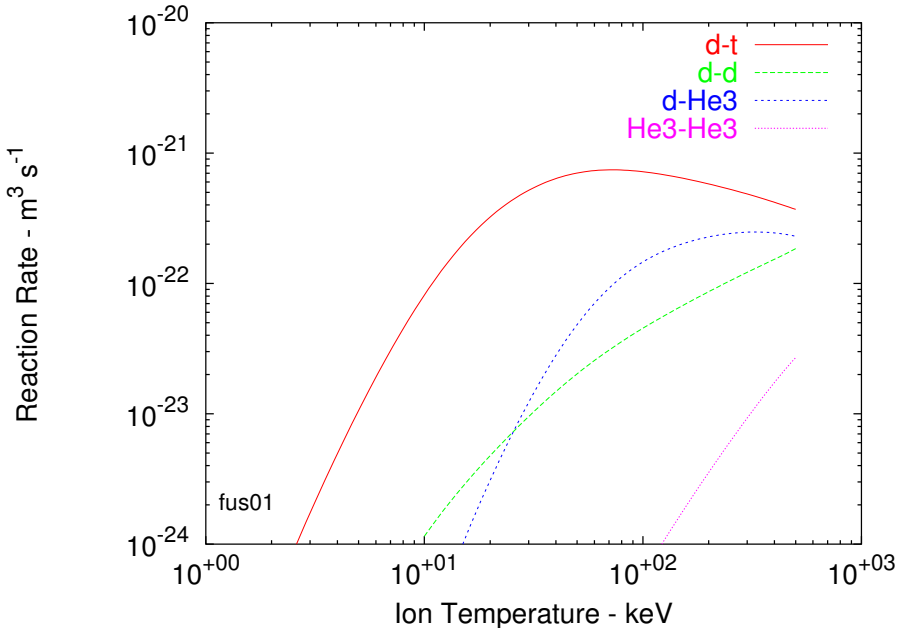
Solar Backscatter JSC-1 Soil



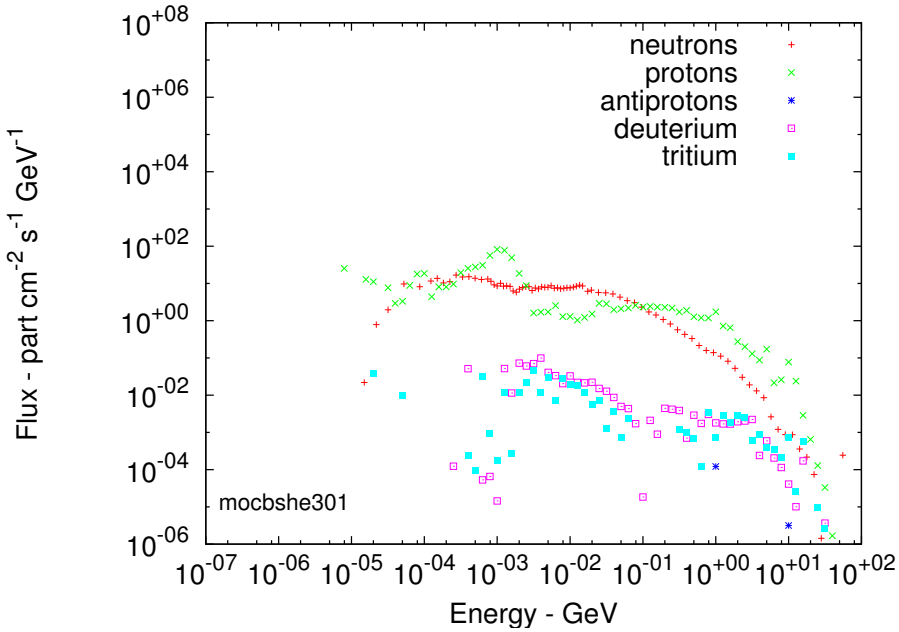
Fusion Reactions

- $\mathrm{D} + \mathrm{T} \quad \longrightarrow \quad \mathrm{He}^4(3.52\mathrm{MeV}) + \mathrm{n}(14.07\mathrm{MeV})$
- $\mathrm{D} + \mathrm{D} \quad \underset{1/2}{\longrightarrow} \quad \mathrm{T} \quad (1.01\mathrm{MeV}) + \mathrm{p}(3.02\mathrm{MeV})$
  $\underset{1/2}{\longrightarrow} \quad \mathrm{He}^3(0.82\mathrm{MeV}) + \mathrm{n}(2.45\mathrm{MeV})$
- $\mathrm{D} + \mathrm{He}^3 \quad \longrightarrow \quad \mathrm{He}^4(3.67\mathrm{MeV}) + \mathrm{p}(14.68\mathrm{MeV})$
- $\mathrm{He}^3 + \mathrm{He}^3 \quad \longrightarrow \quad \mathrm{He}^4 + 2\mathrm{p} \qquad (12.86\mathrm{MeV})$

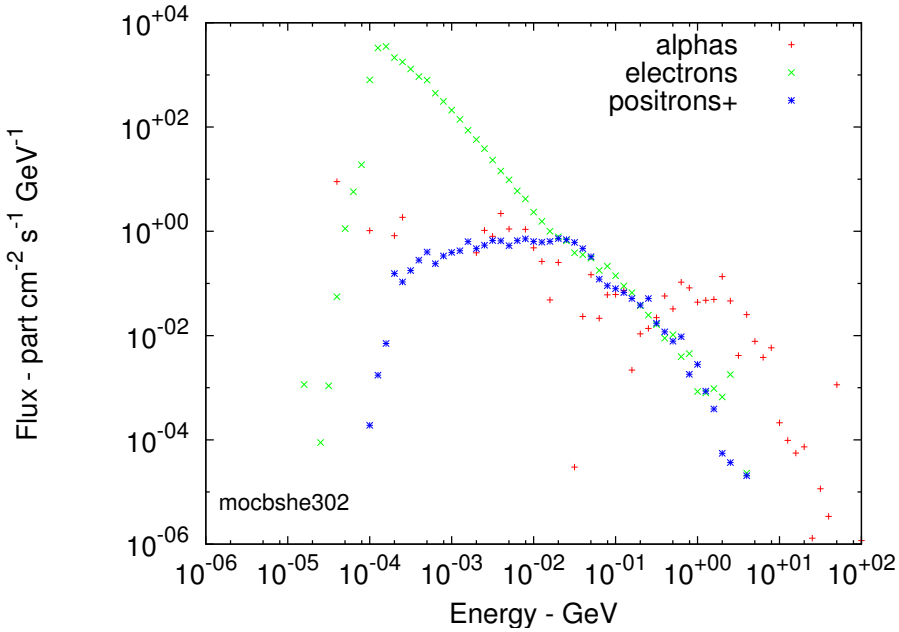
Fusion With Helium-3



Cosmic Backscatter Helium-3



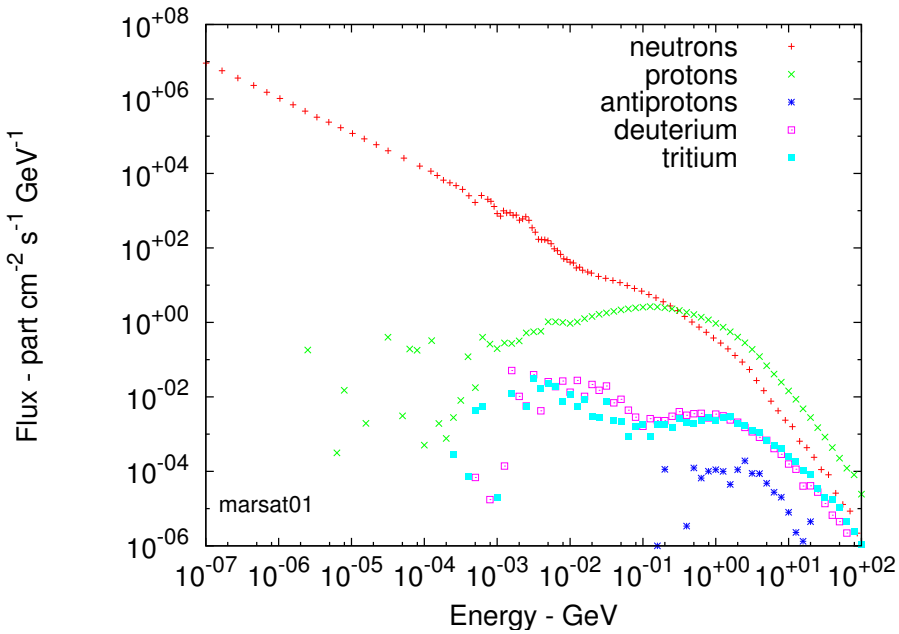
Cosmic Backscatter Helium-3



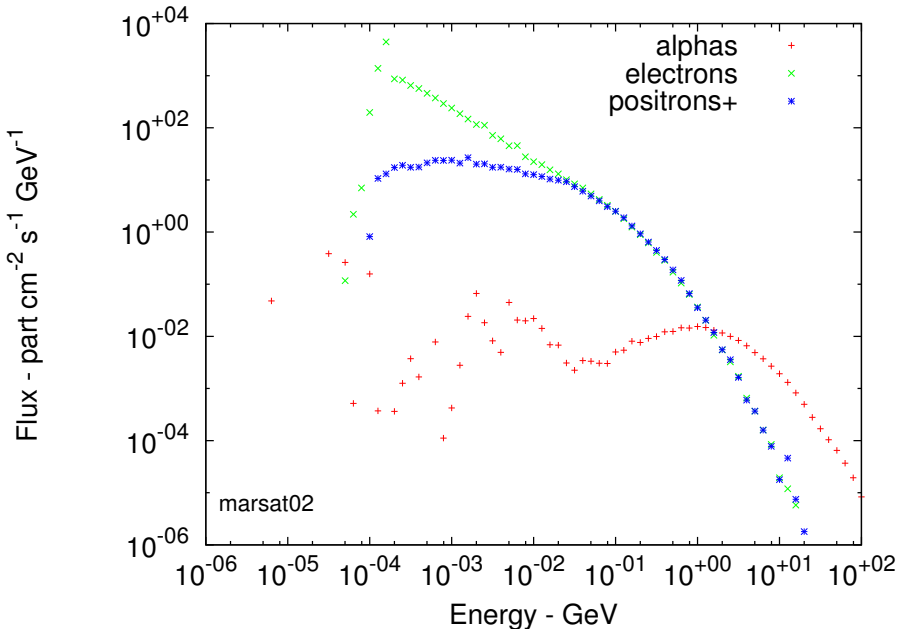
Summary

- Voluminous Data
- Theorectical Discoveries Will Probably Preceed Experiment
- Validity of FLUKA/GEANT4
  - Theorectical models, i.e. DPMJET III
  - Comparison of related physics, i.e. muons
  - Experimental tests as were planned in radiation shielding program

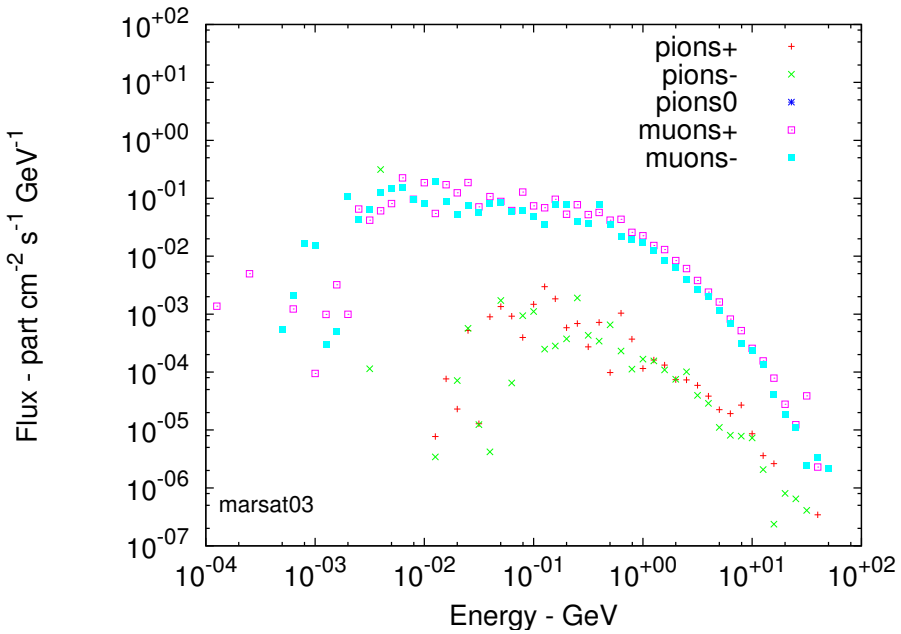
Martian Surface: n, p, $\bar{p}$, d, and t



Martian Surface: α, e^-, and e^+



Martian Surface: π and μ



Solution To Intense Thermal Radiation