ShowerGeneration from ν Interactions in Water

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ARENA Workshop 28/06/06

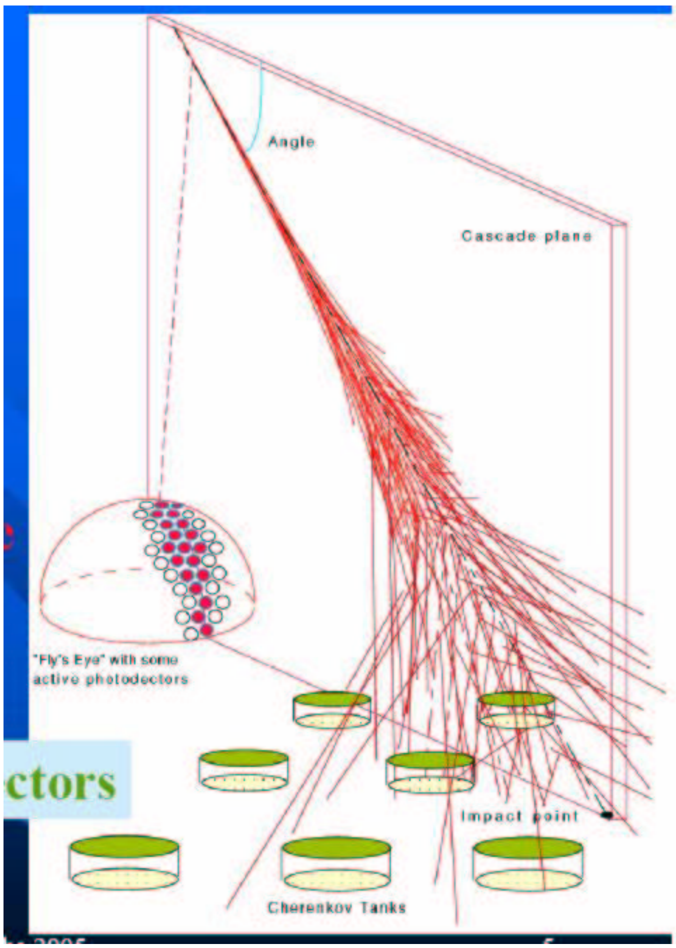


Figure 1: Air showers simulated by the CORSIKA program.

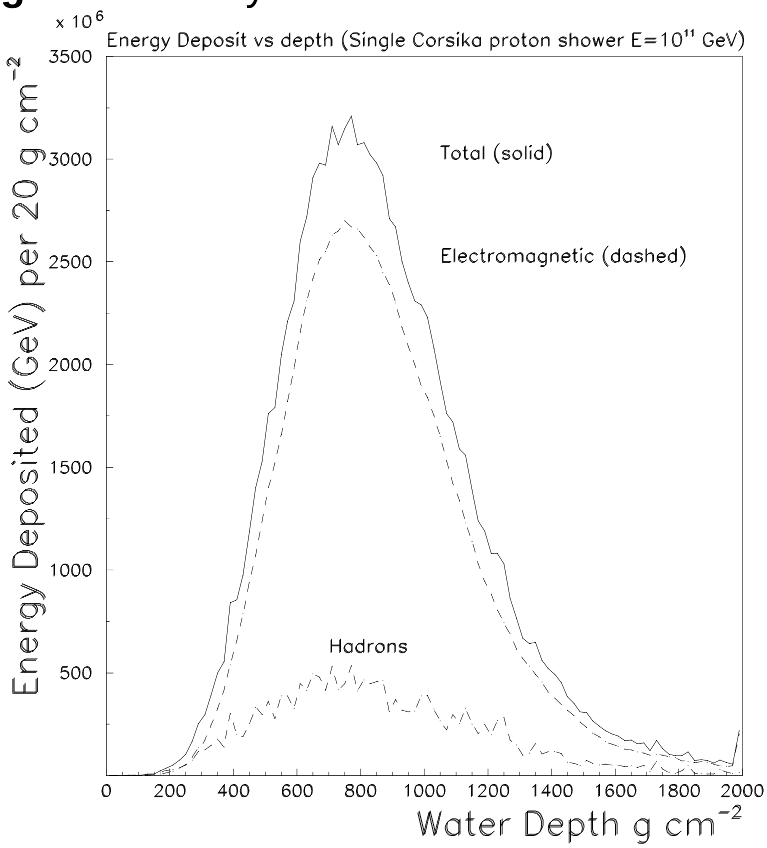
CORSIKA has been modified to simulate interactions in water.

Compare with Geant4 and other published work. (Geant4 fails to work at higher energies than 10^5 GeV).

Simulation of neutrino interactions is ongoing.

10^{11} GeV Protons in water - average of 100 showers

Modelling Cosmic Ray interactions - CORSIKA modified for water.



Shower mainly electromagnetic - similar effect is seen in hadron calorimeters.

Reason - $\sim 1/3$ of energy becomes neutral hadrons (decaying to photons) at each hadron-nucleus interaction. So at n^{th} interaction, energy fraction in charged hadrons $\sim (2/3)^n$ and $\sim 1-(2/3)^n$ is electromagnetic.

Modifications to CORSIKA

Maintain structure of program as closely as possibe. i.e.four layers of atmosphere with three substances.

The non-uniform density air atmosphere in CORSIKA has been replaced by a medium of uniform density 1.025 g/cm^3 of thickness 20 m (i.e. 2000 g/cm^2 - 2 times thickness of air atmosphere).

The sea water medium is made of hydrogen, oxygen and NaCl (66.2% of atoms are hydrogen, 33.1% oxygen and 0.7% atoms with $A = 29.2$ the mean of Na and Cl).

Other changes to the program -

Modified dE/dx to allow for density effect in water

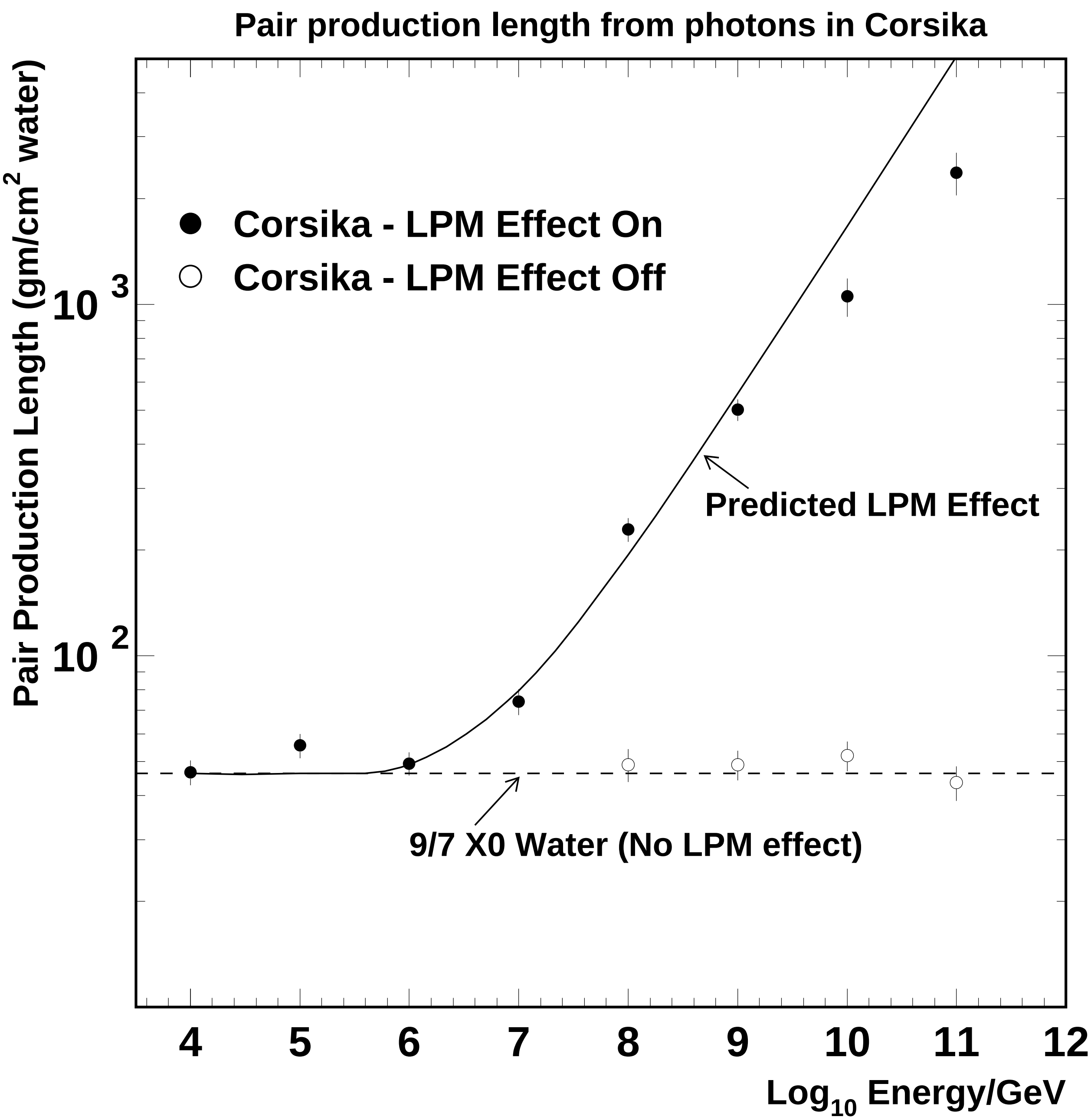
Smaller radial binning.

Change threshold for LPM effect ($E_{LPM} = 7700X_0$ GeV, X_0 = radiation length in cm).

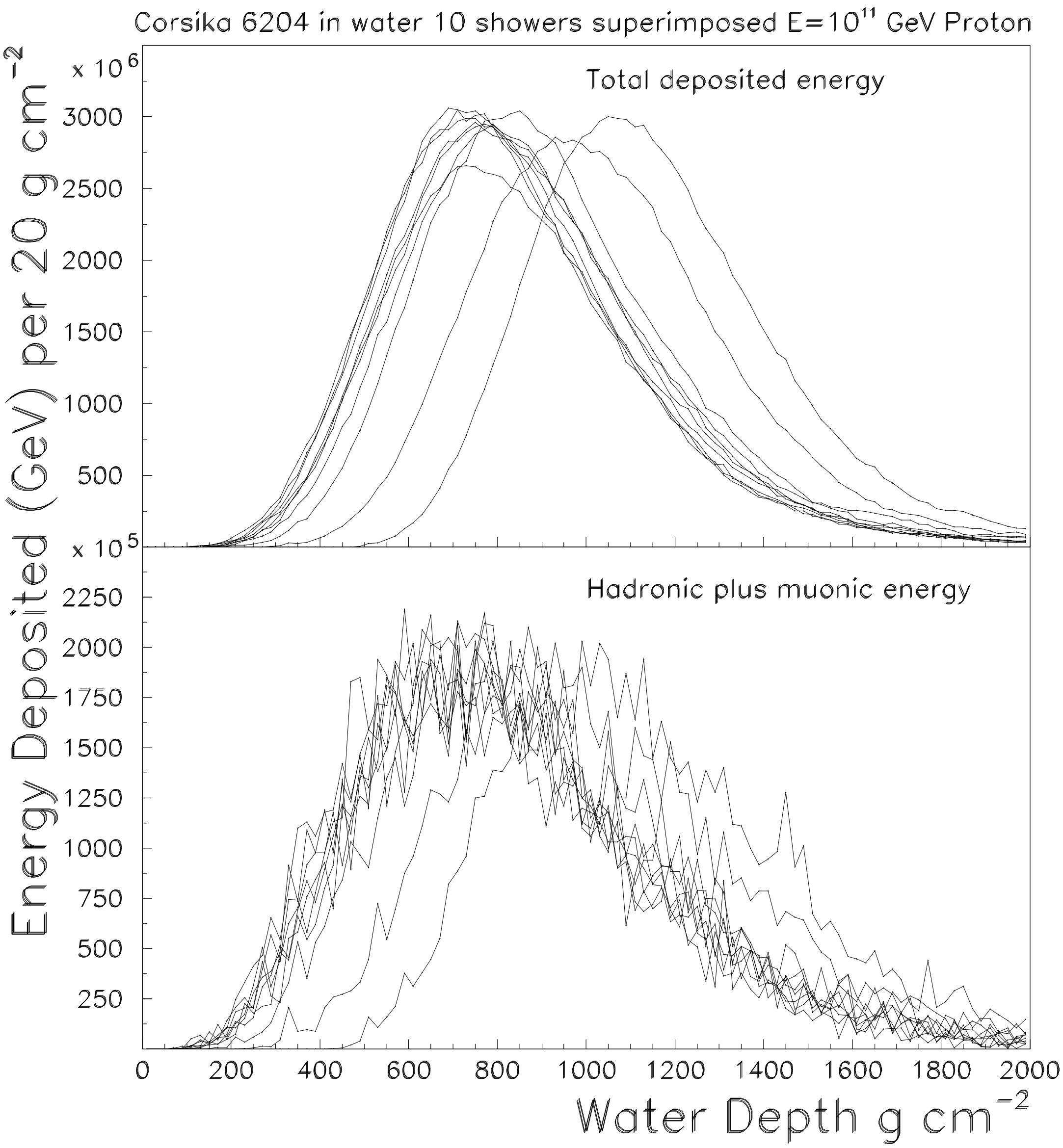
π^0 tracked for interactions for $E > 10^5$ GeV ($\beta\gamma c\tau > 3$ cm).

LPM Effect

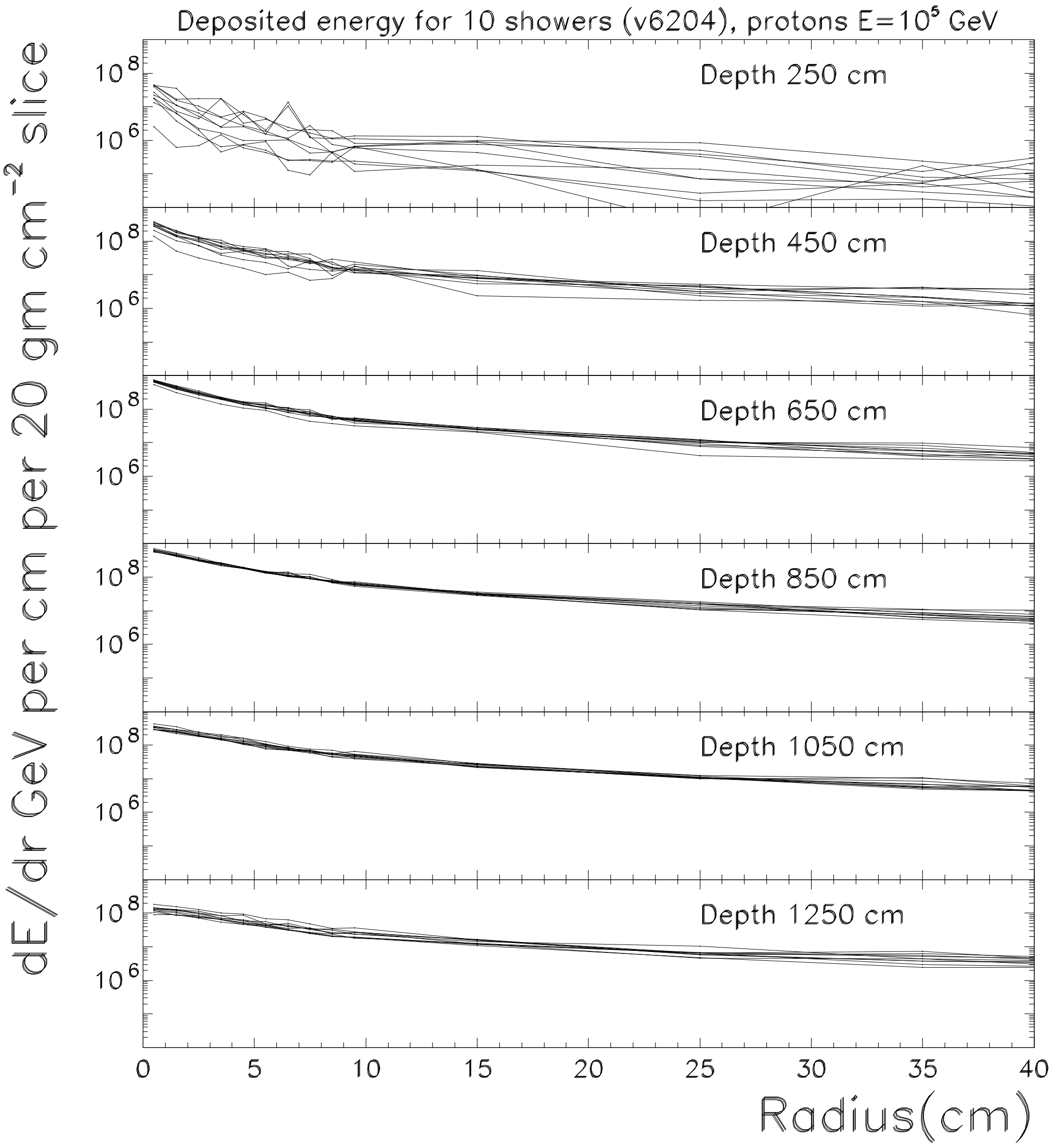
Tested by measuring conversion length of photons in water.



10^{11} **GeV Proton showers** superimposed - longitudinal distributions

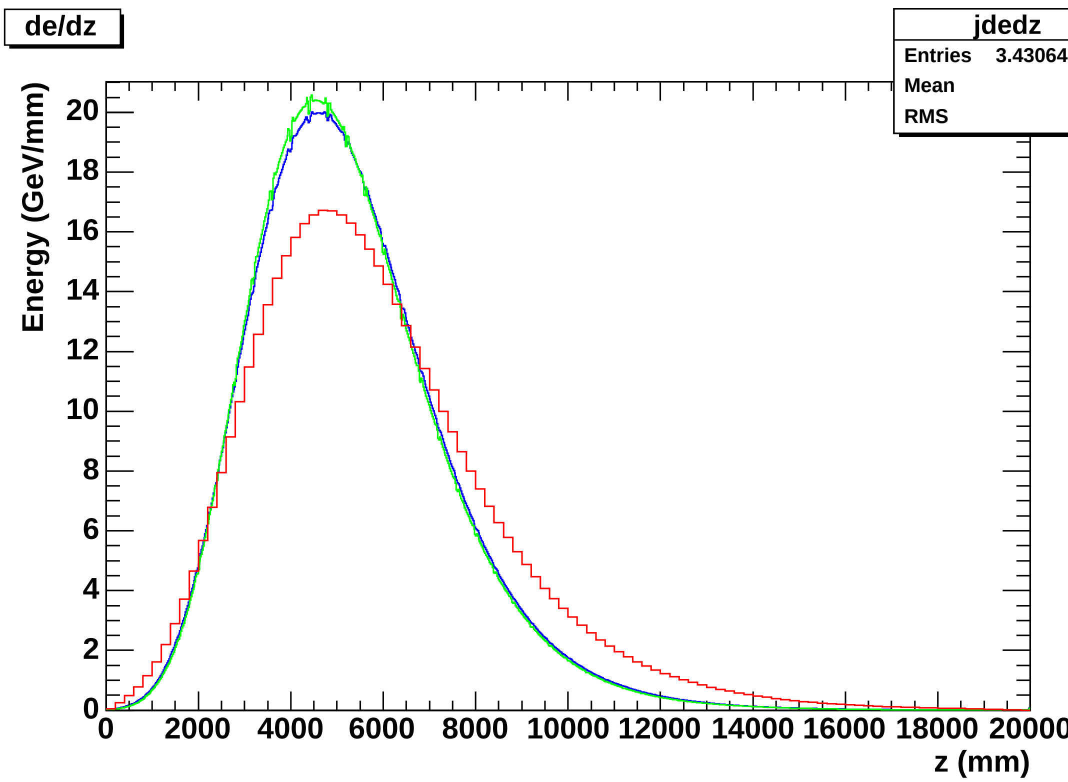


10^{11} **GeV Proton showers** superimposed - transverse distributions

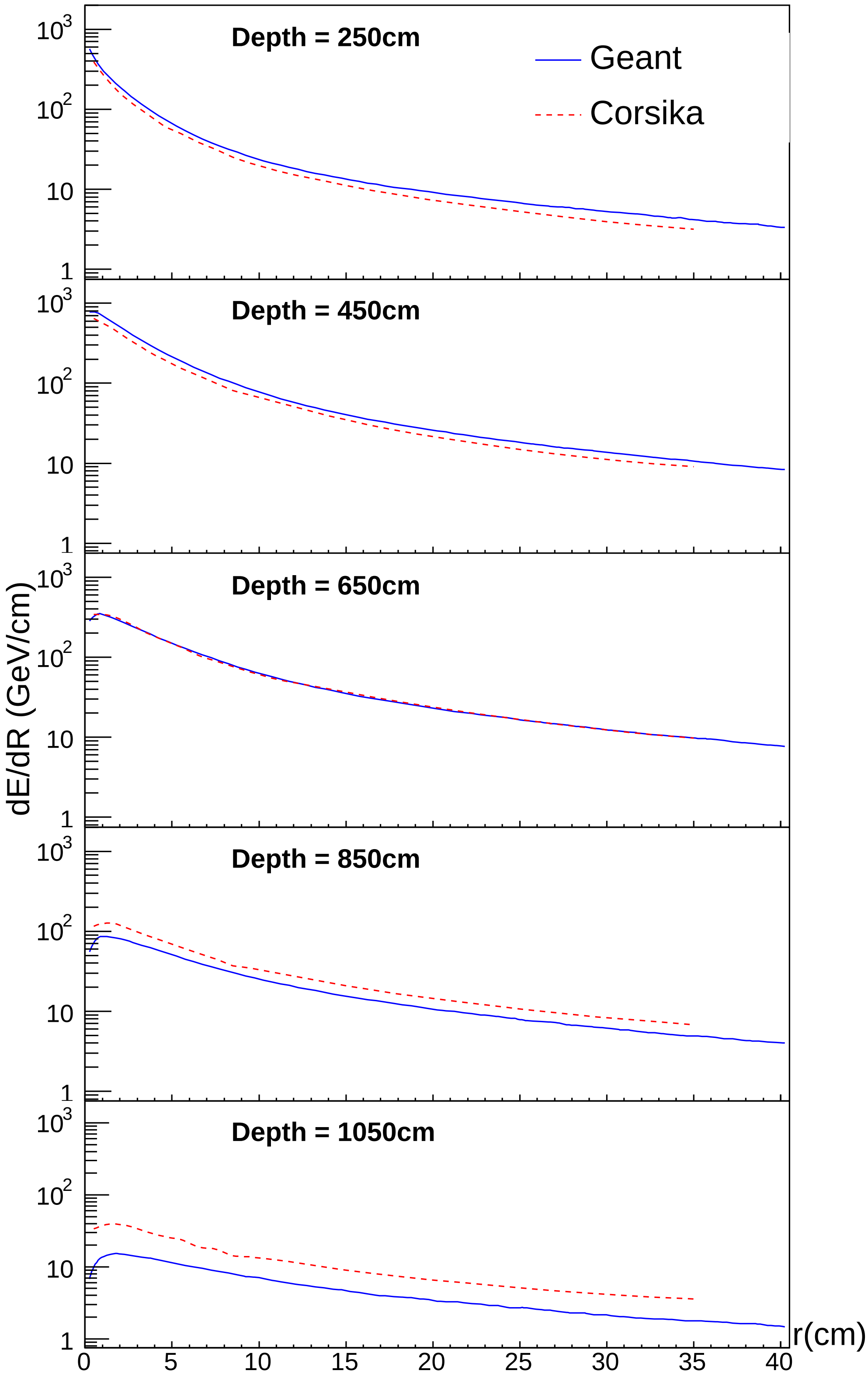


To smooth out statistical fluctuations take averages of 100 showers.

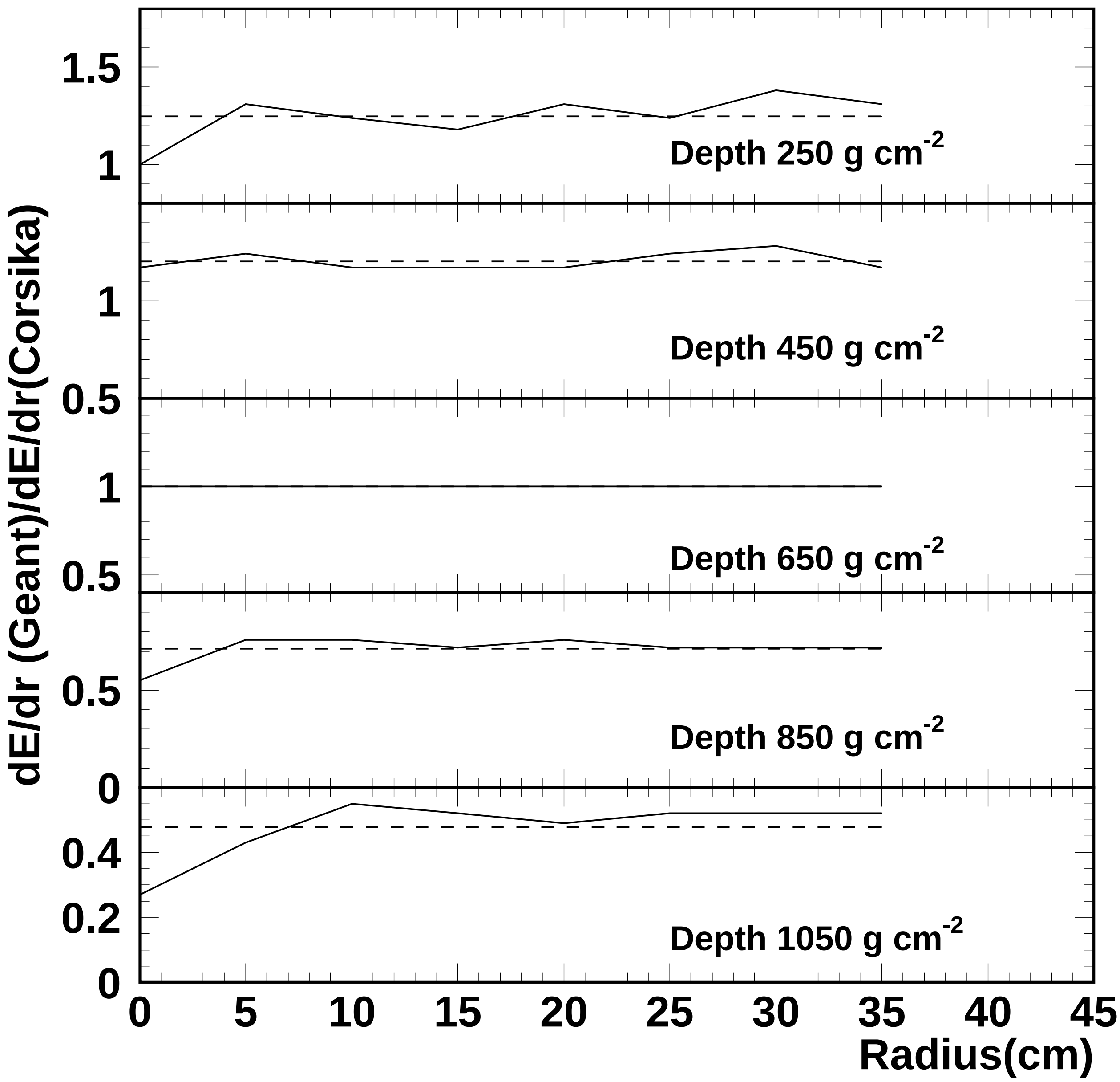
Comparison of protons (E=10^5 GeV) - Geant4 (green=salt water, blue=fresh water) and CORSIKA (red) in water.



CORSIKA seems to give slightly broader showers than Geant4.



Tranverse distributions agree well between CORSIKA and Geant4. Normalisation shift reflects differences in the longitudinal distribution.

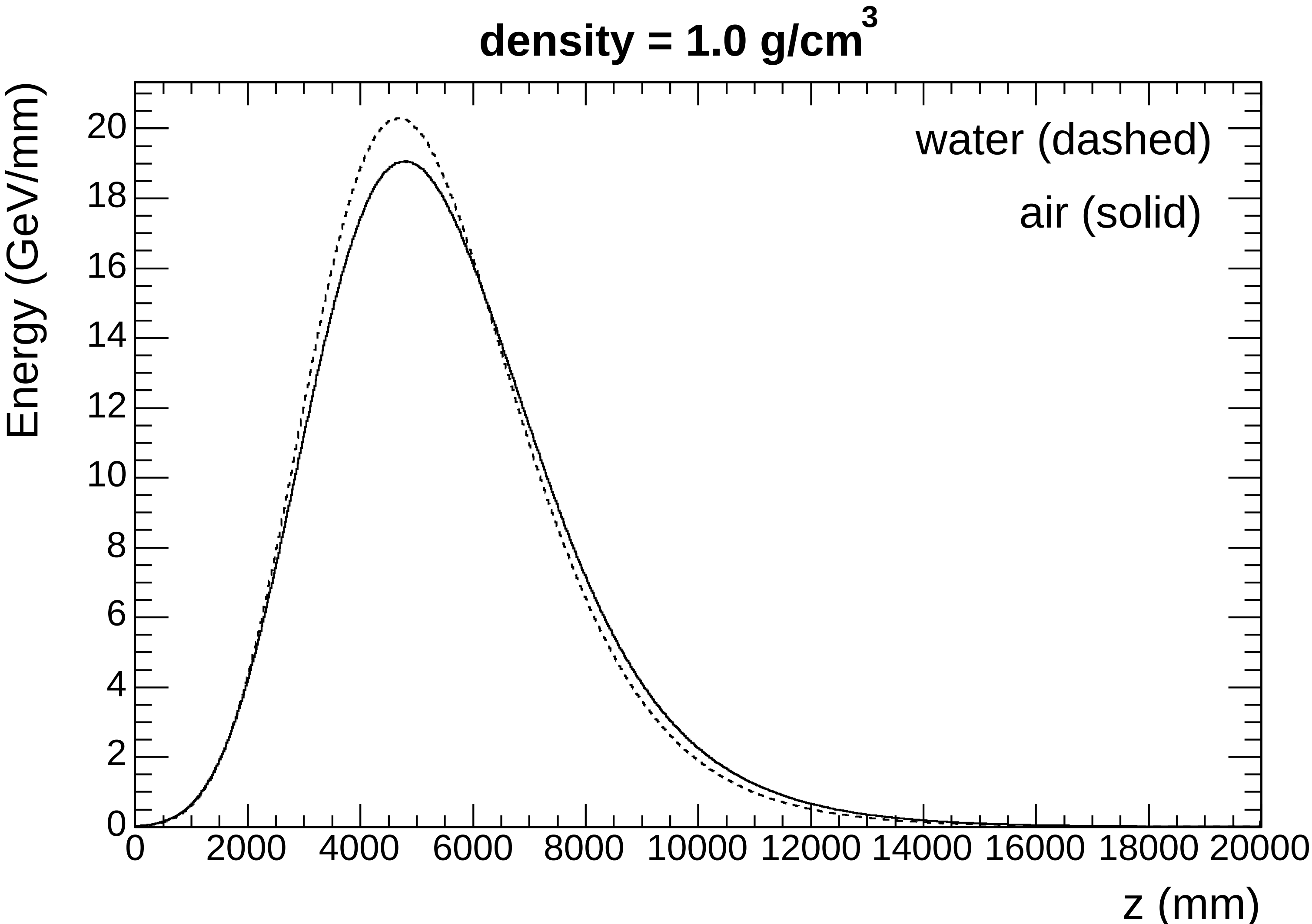


Tranverse distributions agree well at peak energy deposition

Table 1: dE/dz (GeV/mm) against water depth

Depth (g/cm^2)	250	450	650	850	1050
Geant4	10	20	12	4	1
CORSIKA	9	16	12	7	3

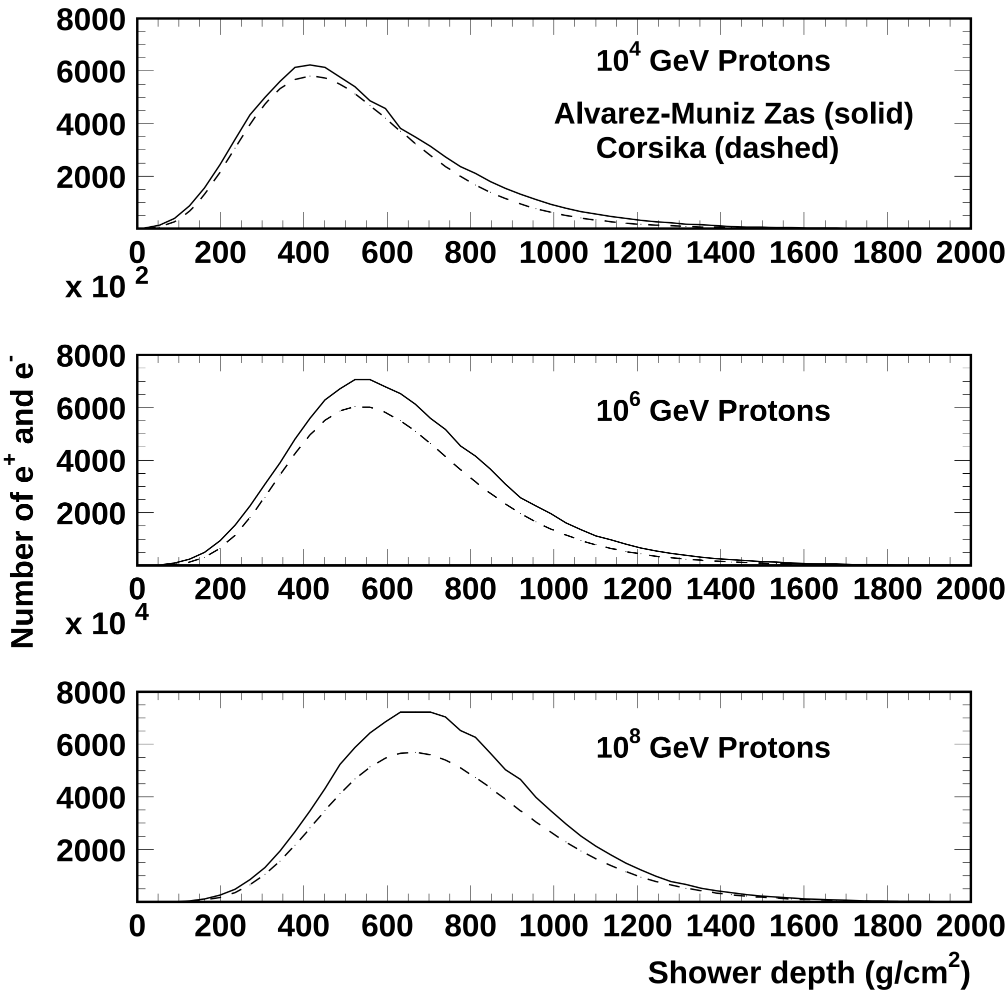
Nuclear Physics Effects



Change from O,N,Ar to H,O,NaCl is height increases by 6.3% and depth of shower maximum decreases from 480 gm/cm^2 to ~ 470 gm/cm^2 - simulation in Geant4.

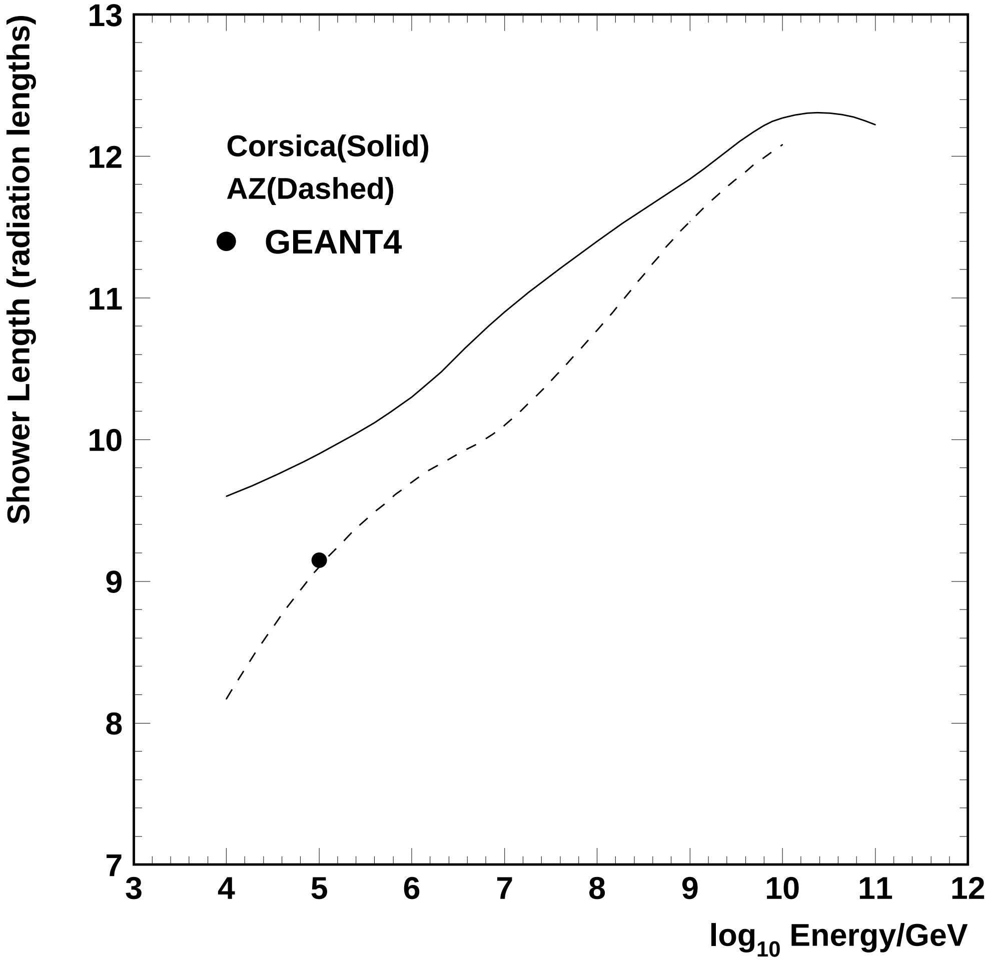
Radiation lengths in water and air are the same but nuclear interaction length in water is 84 g/cm^2 compared to 90 g/cm^2 in air. Hence shower develops more quickly in water than in air.

Comparison with simulation of Alvarez-Muniz and Zas



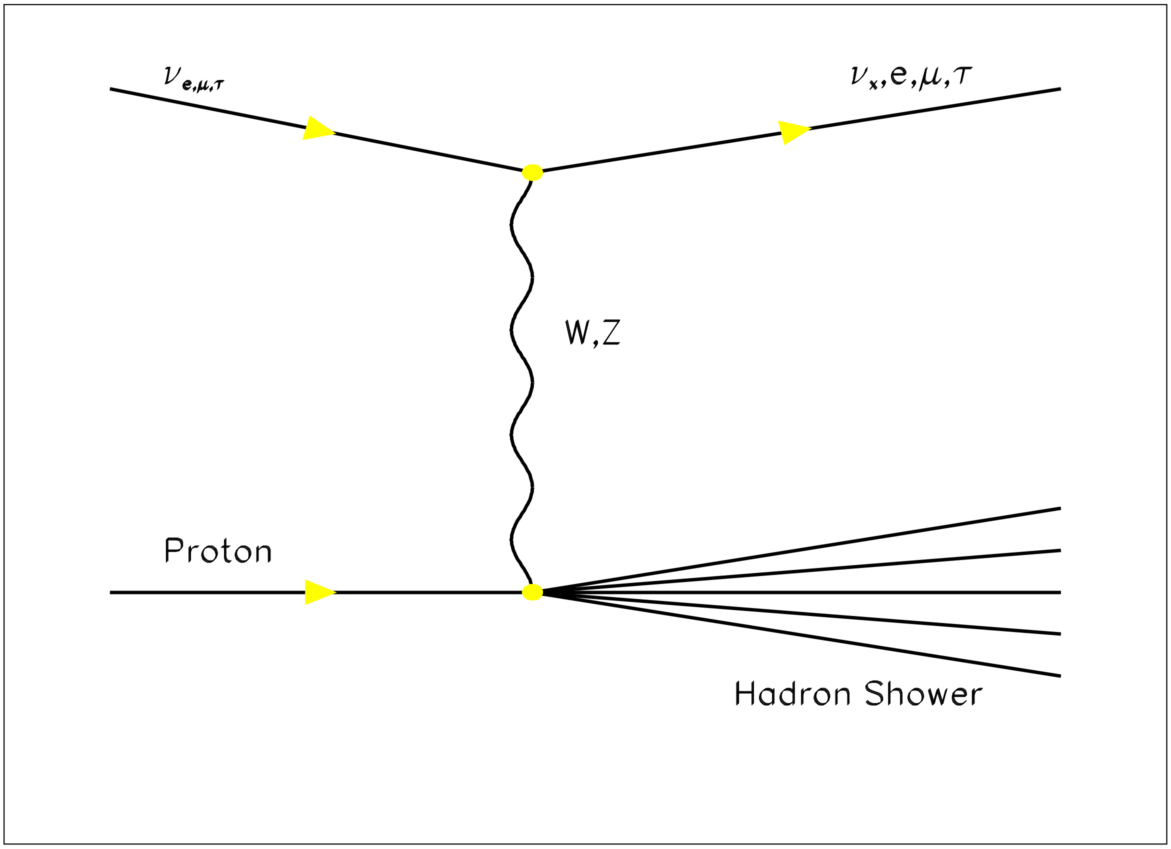
AZ simulation produces more particles than CORSIKA.

Shower length = distance during which number of particles in the shower is more than 70% of peak value.



Conclude that both AZ and Geant4 produce showers which peak at $\sim 20\%$ larger number of particles and are about $\sim 5\%$ narrower.

The accuracy of the simulation $\sim 15 - 20\%$?



$y = E_{had}/E_\nu$, x=fraction of momentum of proton carried by struck quark and $Q^2 = sxy$.

Cross section for CC Interactions $\propto$ parton distribution functions measured in deep inelastic scattering.

$$\frac{d^2\sigma}{dQ^2dy} = \frac{G_F^2}{2\pi y}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2 (F_2(x,Q^2)(1-y+\frac{y^2}{2}) \pm y(1-\frac{y}{2})xF_3(x,Q^2))$$

$$F_2(x,Q^2) = xu(x,Q^2)+xd(x,Q^2)+xs(x,Q^2)+xc(x,Q^2)$$

$$xF_3(x,Q^2) = xu_v(x,Q^2)+xd_v(x,Q^2) \pm (xs(x,Q^2)-xc(x,Q^2))$$

Neutrino cross section by integration

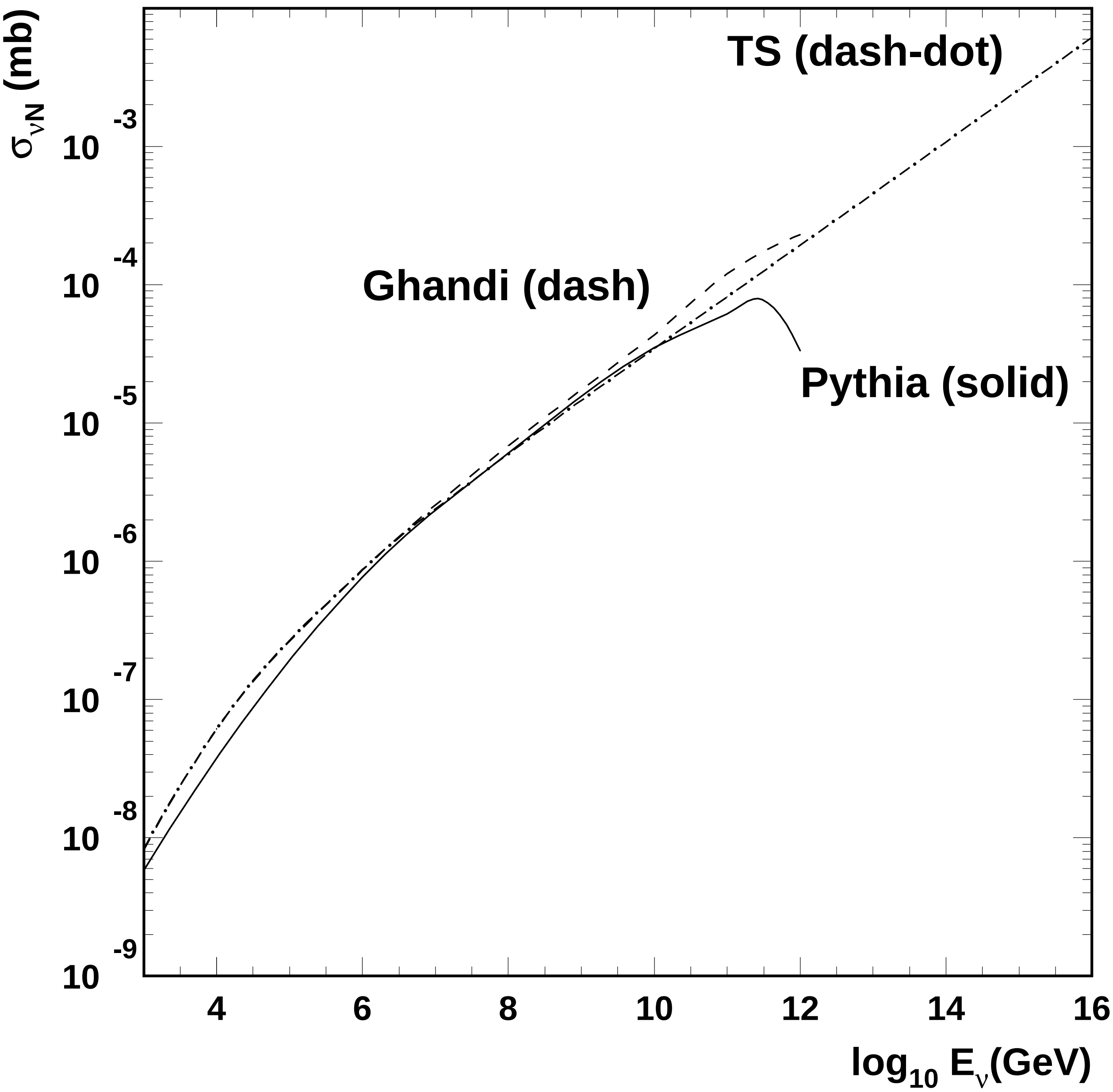


Figure 2: Cross section versus neutrino energy.

Energy into hadrons - interesting for both radio and acoustic detection.

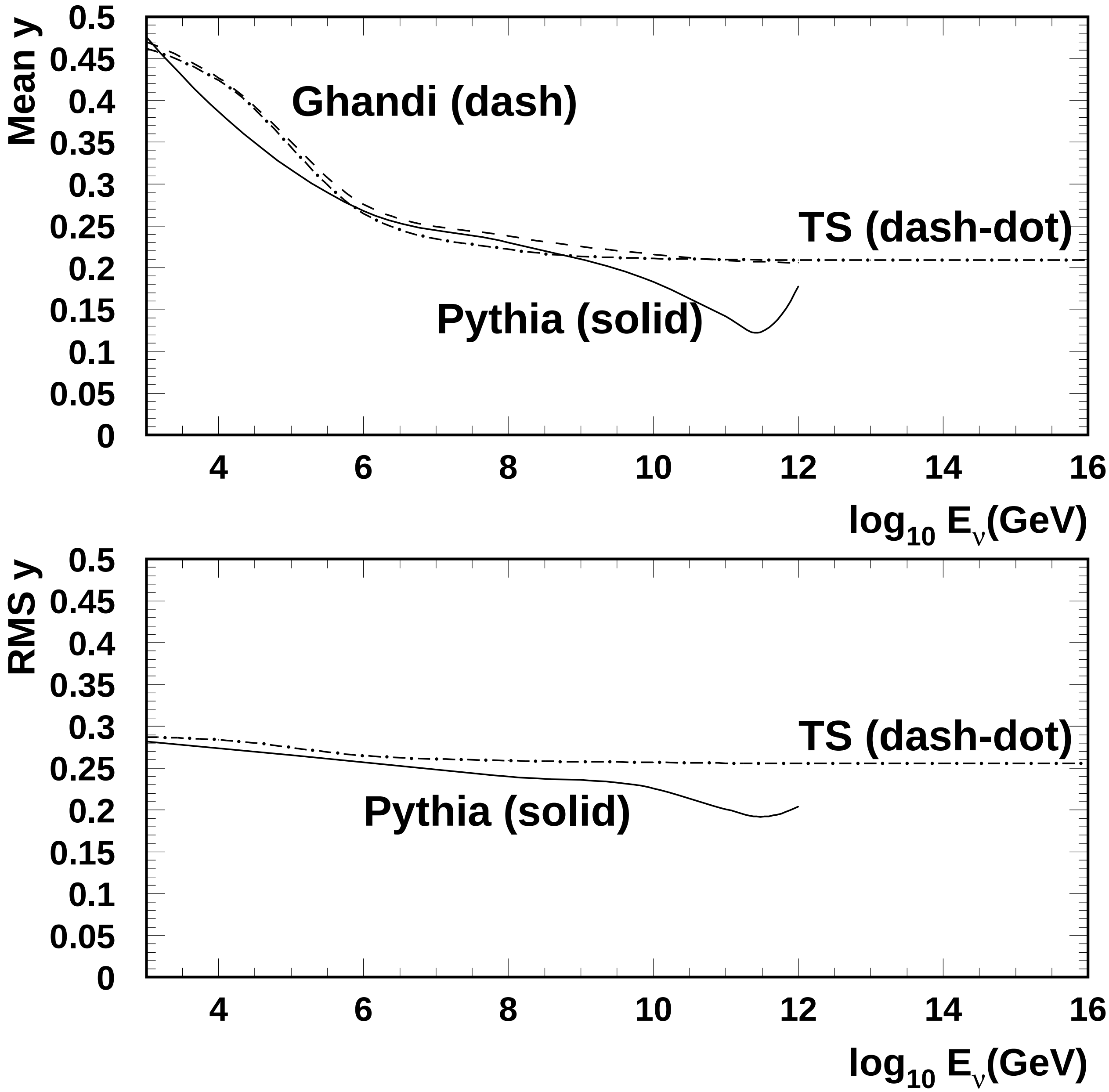
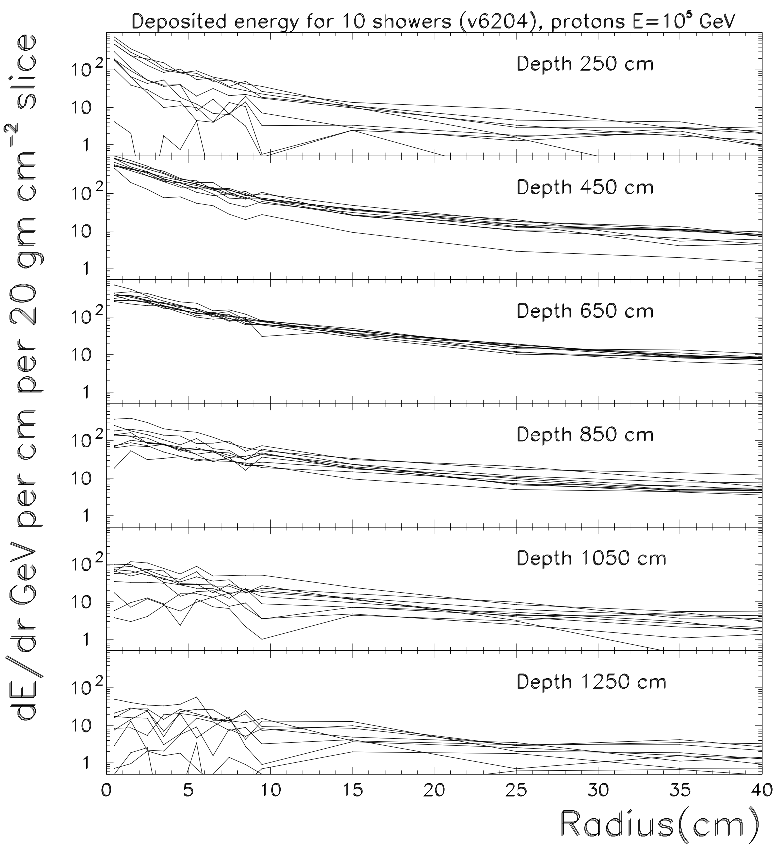
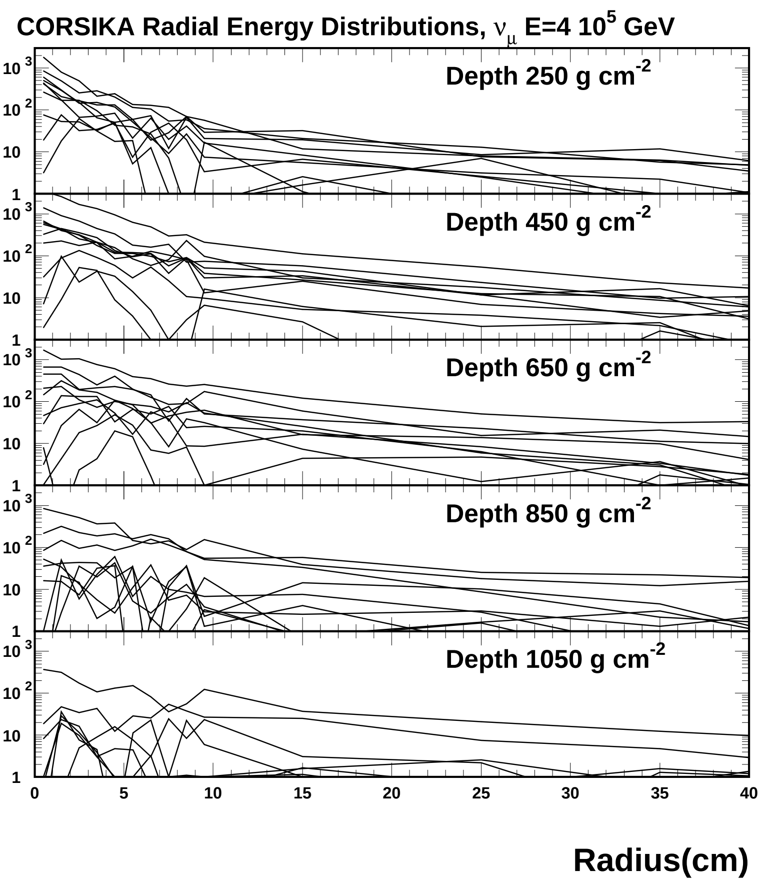


Figure 3: Mean and RMS y = fraction of energy of the ν going into hadron shower

10 proton (E=10^5) GeV and 10 neutrino showers (E=$4\ 10^5$ GeV) superimposed





Observe large ν shower fluctuations, due to y fluctuations.

Computed using HERWIG interfaced to CORSIKA - problems occur with this simulation for energies above $4\ 10^7$ GeV - we are working on them.

10 proton (E=10^5) GeV and 10 neutrino showers (E=$4\ 10^5$ GeV) superimposed - longitudinal distributions.

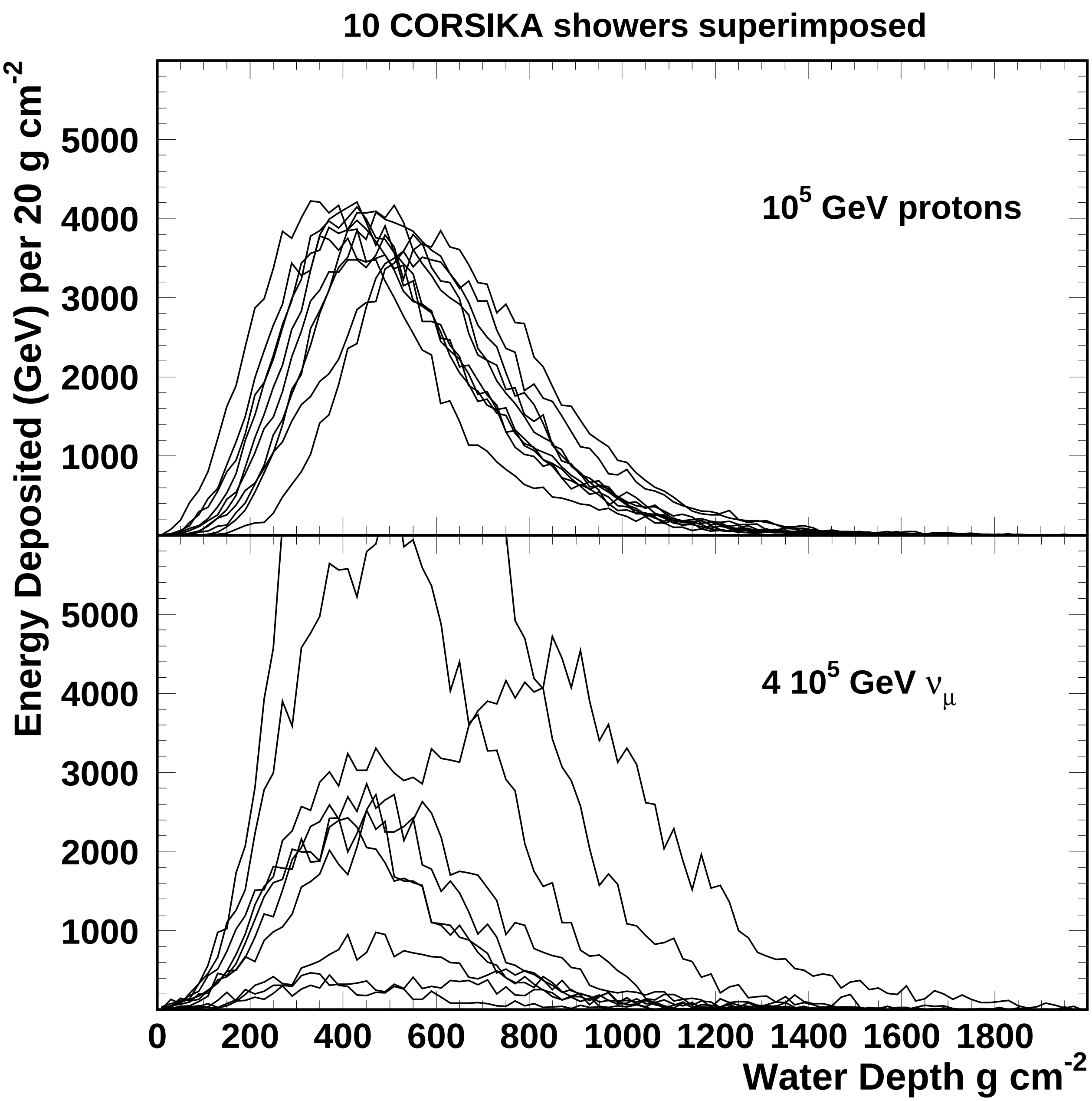
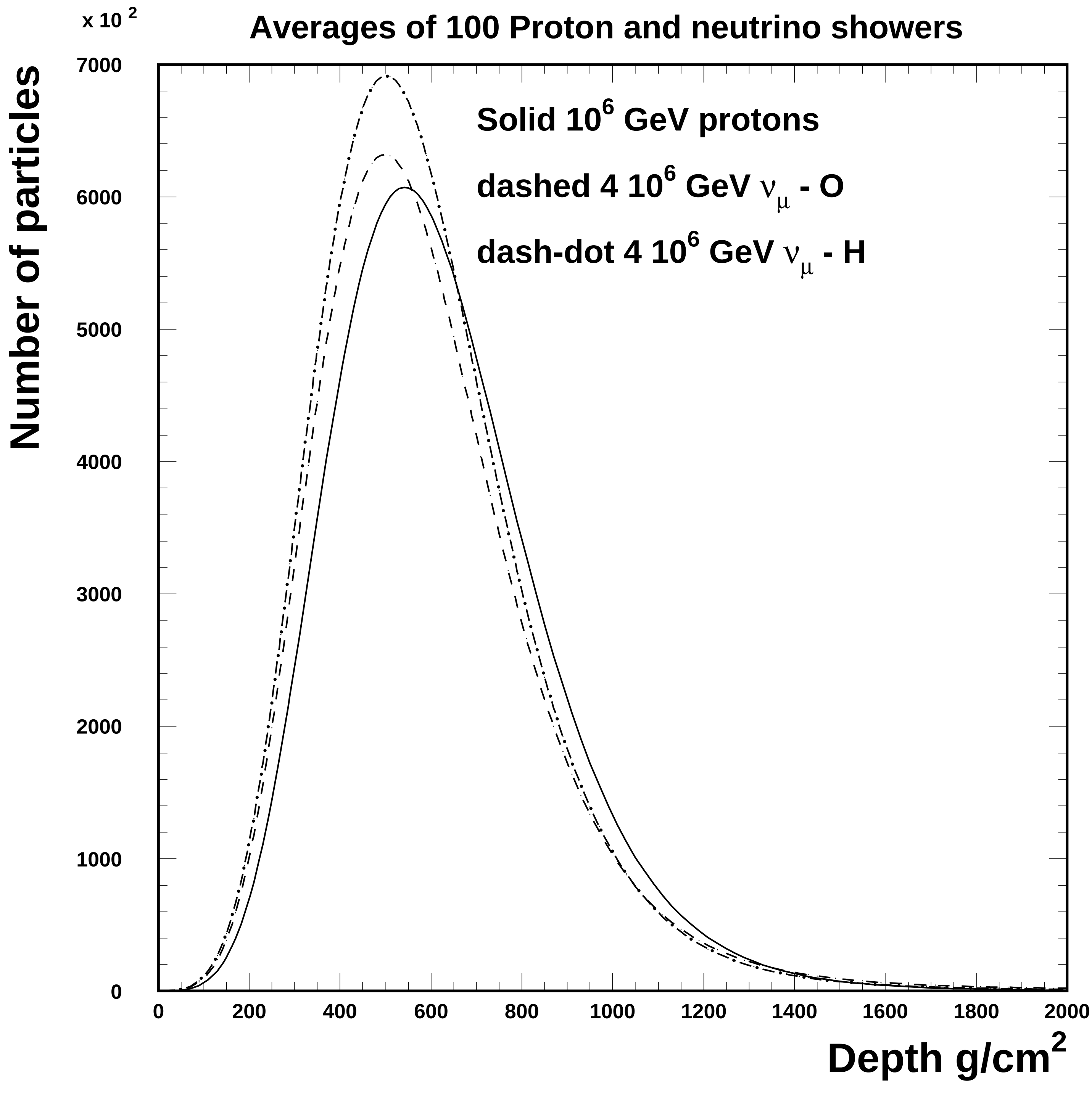


Figure 4: Comparison of 10^5 GeV proton showers with $4\ 10^5$ GeV ν_μ showers

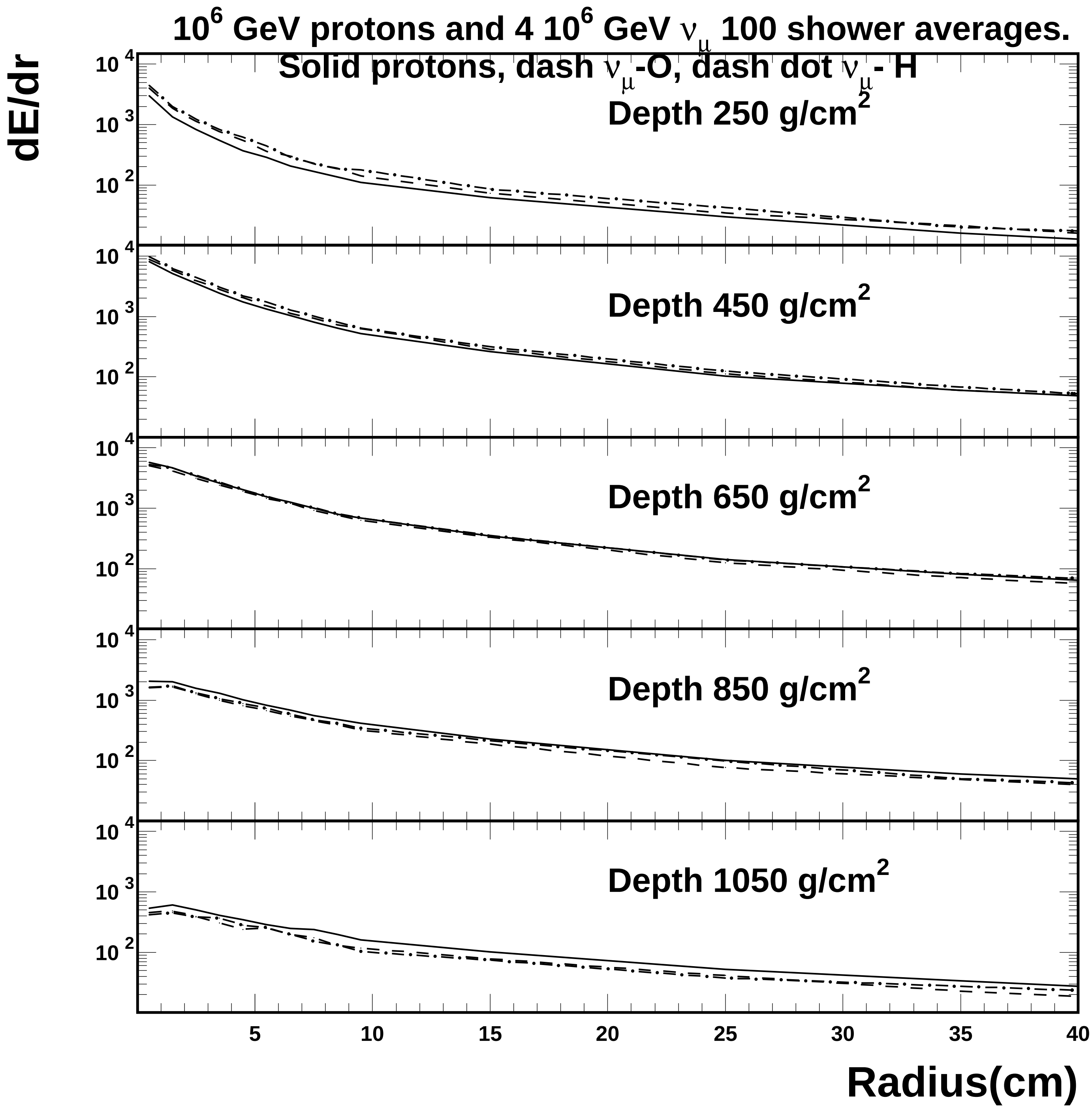
Longitudinal distributions E=10^6 GeV protons, $4\ 10^6$ GeV ν_μ



Difference in height is within statistics.

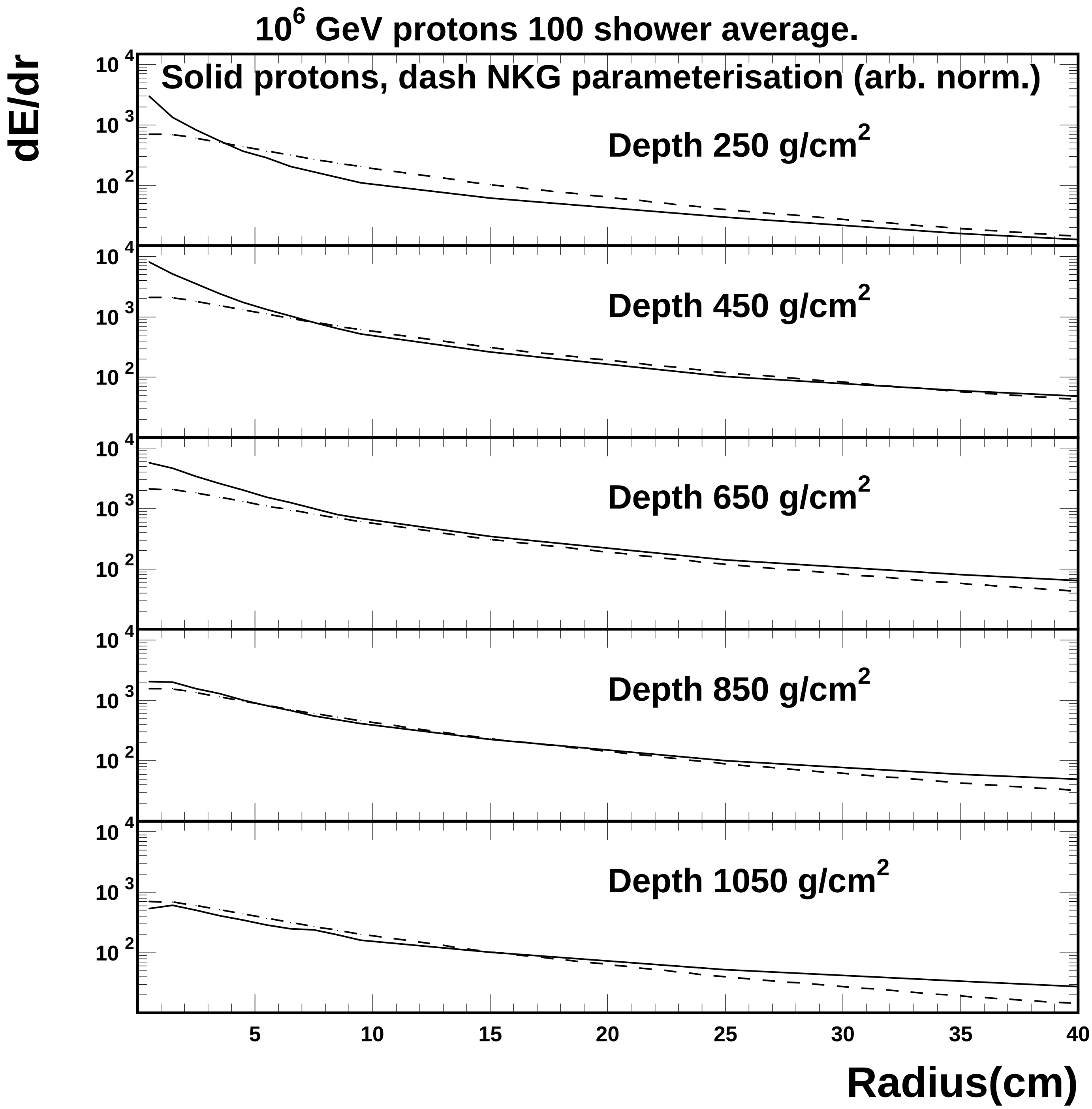
ν showers peak earlier than proton showers - due to large number of lower energy tracks for ν interactions.

Transverse distributions E=10^6 GeV protons, $4\ 10^6$ GeV ν_μ



Tranverse distributions are very similar in shape for neutrinos and protons.

Transverse distributions compared with NKG parameter^n.

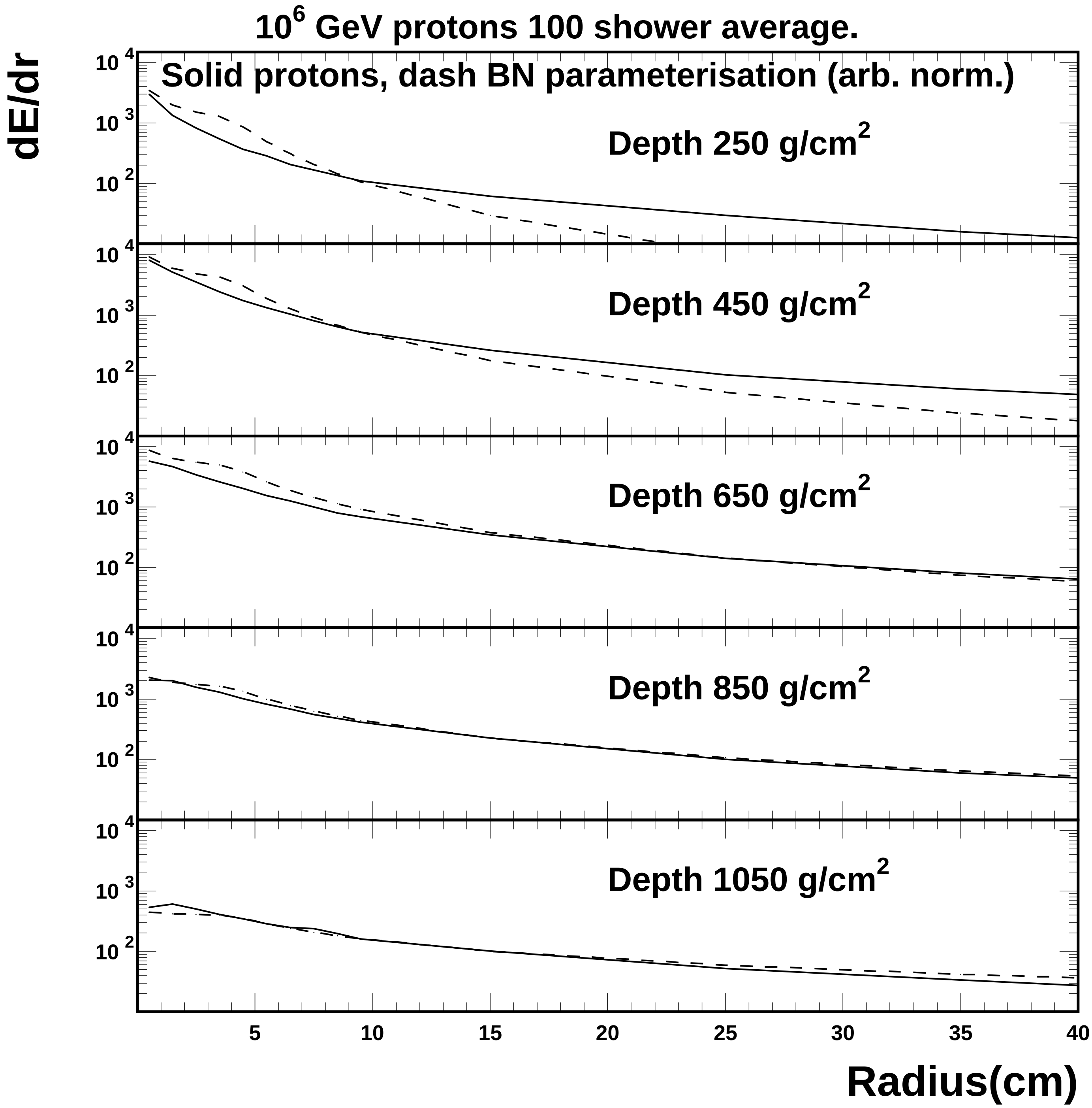


The NKG parameterisation gives less energy at small radius

i.e. CORSIKA gives higher frequency sound signals for

acoustic and radio ν detectors ?

Transverse distributions with Bertin-Niess parameter^n
(astro-ph/0511617).



Better agreement except at low depth with Bertin-Niess parameterisation.

Conclusions

CORSIKA working in water - distributions $\sim 15\%$ lower at peak and a few $\%$ broader than GEANT4. AZ $\sim 10\%$ somewhat above Geant4 at peak.

Work started on generation of real neutrino interactions but not complete (indications of problems at high energy with the HERWIG interface to CORSIKA - may be our problem -being investigated).

The much used NKG parameterisation seems to give broader radial distributions than the Bertin-Niess parameterisation and than CORSIKA.

Implies that there are higher frequency components than expected from the NKG parameterisation in both acoustic and radio detectors.

Reasonable consistency between the Bertin-Niess parameterisation and CORSIKA.