The proton puzzle.....

Per Grafstrom
University of Bologna
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Start with a recap from Granger 2014:

The cosmogenic nuclides ^{10}Be and ^{26}Al are both produced by multiple mechanisms. Remarkably, the production rate ratio of ^{26}Al to ^{10}Be has been found to be constant regardless of latitude, altitude, or depth, at least to within experimental uncertainties (~5%). This is very important for burial dating, because it means that the ratio $^{26}Al/^{10}Be$ can be predicted with confidence regardless of geographic location or burial depth.

Experimental values for the production rate ratio (P_{26}/P_{10}) range from about 6.7 to 7.0. Most researchers use a value near 6.8 by convention. In practice, the value that is used must be reported, and should be validated by measurement of a zero-age (i.e., unburied) sample.

Production rates by all three methods (neutron spallation, negative muon capture, and fast muon reactions) can be approximated by the following equation, with the variables $A_{i,j}$ and L_j representing production rate factors and penetration length factors shown in Table 2.

$$P_i = \sum_j A_{i,j} e^{-z/L_j} \qquad [2]$$

Experimental values for the production rate ratio (P_{26}/P_{10}) range from about 6.7 to 7.0. Most researchers use a value

The remarkably thing is that these ratios seems to be the same for neutrons and muons!!!

The "puzzle" is that the p26/p10 ratio seems to be much different for protons

What is the evidence that the P26/P10 ratio is the same for muons and neutrons ?

Granger and others often refers to results from depth profiles obtained from long core drills from the surface down to 15-20 m.

However I got basically the same results from calculations.
At the meeting https://agenda.infn.it/event/42981/
I showed the result of calculating P10 and P26 from first principle (cross section and fluxes) for fast muons

Results and comparison with the exponential approach

p10 at depth of 6300 g/cm2 Units =atoms/gr/year

My calculation	Granger 2014	Braucher directly			
0.0052	0.0091	0.0098			

p26 at depth of 6300 g/cm2

My calculation	Granger 2014	Braucher directly			
0.046	0.061	0.017			

fast muons

Taking the ratio here we get p26/p10=0.046/0.0052= 8.8

Now p26/p10 for neutrons

I never calculated the ratio for neutrons from first principles but I calculated P26 for neutrons (results at the meeting https://agenda.infn.it/event/44144/

Now as I have the flux and the cross section I can estimate the p26 -value for spallation neutrons

(p-value= flux(n/sec/cm2) * cross section(cm2)* Si atoms/ gr)

I will use as flux 12 neutrons/hour/cm2 and 20 mb as cross section

neutrons

p26 (spallation) = **21 'atoms /g /year**

On the next slide I show the calculation for p10

I will now calculate P10 for neutrons in order to also get the ratio for neutrons

I have found the cross section in this article

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Cross section measurements at neutron energies 71 and 112 MeV and energy integrated cross section measurements ($0.1 < E_n < 750$ MeV) for the neutron induced reactions O(*n*,*x*)^{10}Be, Si(*n*,*x*)^{10}Be, and Si(*n*,*x*)^{26}Al

M.W. Caffee [a,*], K. Nishiizumi [b], J.M. Sisterson [c], J. Ullmann [d], K.C. Welten [b]

[a] Department of Physics, Purdue University, West Lafayette, IN 47907-1396, USA
[b] Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA

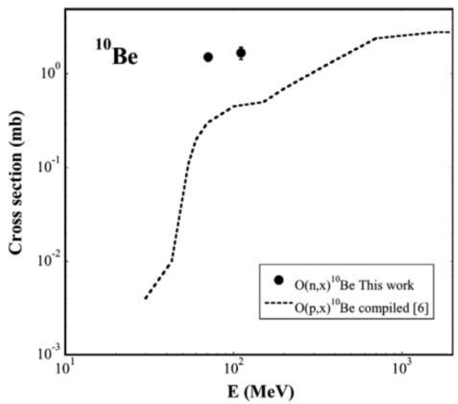


Fig. 2. Cross section for the reactions O(*n*,*x*)^{10}Be (solid symbols) [this work]. The dashed line shows the excitation function of O(*p*,*x*)^{10}Be compiled by [6]. Only an upper limit (<0.1 mb) for the O(*n*,*x*)^{10}Be cross section at 14.6 MeV was published [21].

Table 3
Cross section measurements.

Neutron energy (MeV)	Polyethylene (cm)	Target	O(*n*,*x*)^{10}Be (mb)	Si(*n*,*x*)^{10}Be (mb)
70.7	–	SiO_2	1.52 ± 0.15	–
110.8	–	SiO_2	1.68 ± 0.25	–
112.0	–	Si	–	0.08 ± 0.03
0.1–750	2.5	Si	–	0.21 ± 0.03

Observe: Be from Si negligible

I will use as flux 12 neutrons/hour/cm2 and 1.6 mb as cross section.

p10 (spallation) = **3.3 atoms /g /year**

For the ration P26/p10 we then get 21/3.3=6.4

Sara calculated the same thing for protons.
see meeting
https://agenda.infn.it/event/46484/

$$\boxed{\Longrightarrow P_{26} = 1.96\ atoms/g \cdot y}$$

$$\boxed{\Longrightarrow P_{10} = 0.08\ atoms/g \cdot y}$$

protons

Ratio =p26/p10 =24.5

Thus in Summary

We have P26/p10 from first principles

for fast muons= 8.8

for neutrons = 6.4

for protons = 24.5

p26/p10 =6.8-7
for all processes
is used in burial dating.

this comes from core drills of profiles

Two things are striking:

- fast muons very similar to neutron ….but very different processes
- protons very different from neutrons …the same process..
  (strong interaction no big difference proton/neutron expected)

Why such a difference between protons and neutrons ?

Tentative answer from Benedetto: the different threshold

What are the different thresholds for creating Al^{26} from Si^{28} and creating Be^{10} from O^{16} both from protons and neutrons ?
(Observe Be^{10} from Si^{28} is negligible)

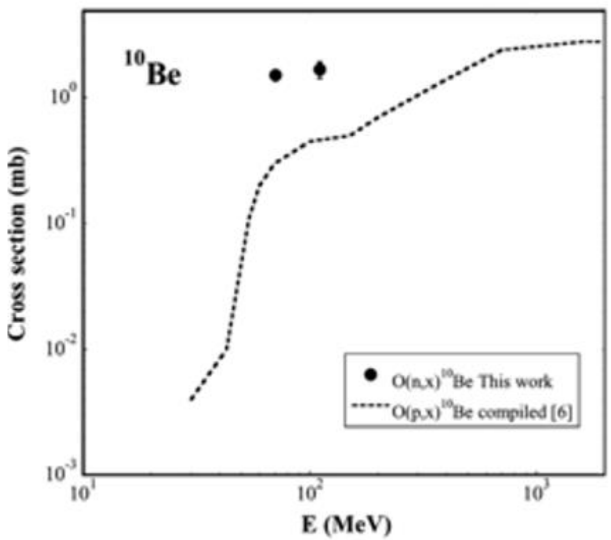
Initial state	Final state	Threshold
$n+Si^{28}$	$Al^{26}+H^3$	16.7 MeV
$p+Si^{28}$	$Al^{26}+He^3$	17 MeV
$n+O^{16}$	$Be^{10}+He^4+He^3$	28.3 MeV
$p+O^{16}$	$Be^{10}+He^4+3p$	36.5 MeV

Threshold similar and cross section also similar

8 Mev difference
Can this explain the lower cross section for protons ?

the neutron cross section from Caffee et all

the proton cross section from Sara's parametrisation

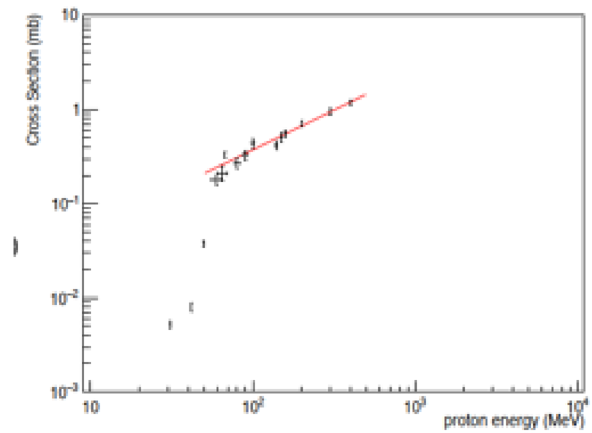


Fit (from 30 to 500 MeV) to find a relation between cross section and energy:

$f(x) = A \cdot x^{-B}$

A = (7.7 ± 1.5) · 10^{-3}

B = -0.84 ± 0.04



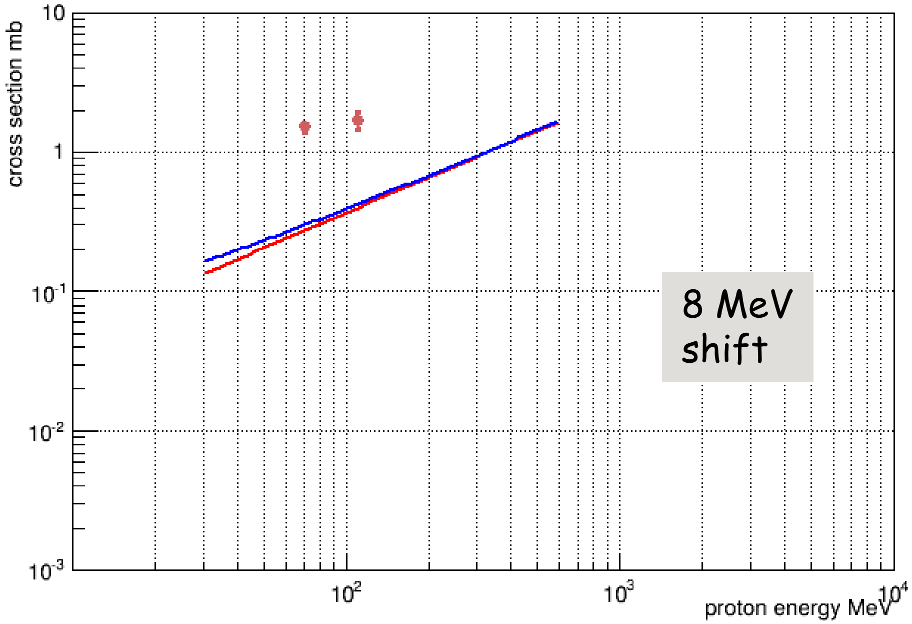
Neutron energy (MeV)	Polyethylene (cm)	Target	O(n,x)^{10}Be (mb)
70.7	–	SiO_2	1.52 ± 0.15
110.8	–	SiO_2	1.68 ± 0.25

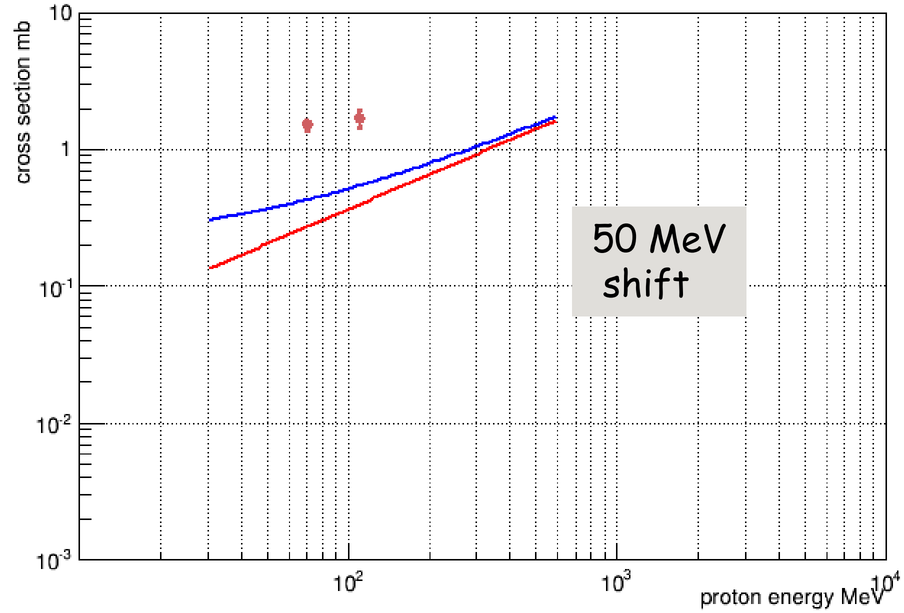
at 100 MeV we get σ =0.37 mb

Thus we have σ =1.6 mb for neutrons and σ =0.37 mb for protons at 100 MeV

Can this be explained by the 8 MeV different threshold ?

To simulate the threshold effect I took Sara's parametrization
and changed the x-scale with 8 MeV and then 50 MeV
(I don't know if this really is a good way to simulate the threshold effect)





(red curve=Sara ;blue curve threshold "simulation" ;data points…the neutron points)

I had hoped for a bigger effect!!

From this it looks like the threshold effect can only be part of the story?
(but caveat….may be the way of simulating is wrong!)

What can it then be……?
May be "real" nuclear physics where the shell structure of protons and neutrons play a role….unfortunately I don't know much about this but I will do some(wild?) guesses

In the case of production of Al^{26} the cross section are more or less equal for protons and neutrons- simple structures here $Si^{28}=Al^{26}+n+p=Al^{26}+d$

Initial state	Final state
$n+Si^{28}$	$Al^{26}+H^3$
$p+Si^{28}$	$Al^{26}+He^3$

a neutron pick up a deuteron and we get H3 (tritium)

a proton pick up a deuteron and we get He3

Rather "natural" that the cross sections are similar

Now the case of Be^{10} from O^{16}

More complicated because many more possibilities to go from A=16 to A=10.

May be thinking of O16 as four He^4 particle makes the neutron induced reaction more "natural" and gives higher cross section than the proton induced reaction?

Initial state	Final state
$n+O^{16}$	$Be^{10}+He^4+He^3$
$p+O^{16}$	$Be^{10}+He^4+3p$

$n+He^4+He^4+He^4+He^4$

$p+He^4+He^4+He^4+He^4$

To understand more I think we need a nuclear physicist and not a particle physicist like me.
It is always nice to understand more but may be not really needed for what we want to do ??

Back up