From last presentation…

TO DO LIST:

- Define and write a proposal to use the neutron beam at n_TOF (1-2)
- Establish contact with an AMS laboratory(1-2)
- Building shielding for the neutron detector (3)
- Calibration of the neutron detector (3)
- Are Bonner Spheres avalilable? Which is the hypothetical time scale for the calibration? (4)
- Theoretical study on the contribution of protons and the intermediate spectrum of neutrons
- Developing simulations (5)

Production of ^{10}Be and ^{26}Al by protons

Same ingredients as for the production rate by neutrons

- Proton flux
- Cross section
- Target nuclei

Production of ^{10}Be and ^{26}Al: proton flux

I used the PARMA code to calculate the proton flux: https://github.com/WeiMXi/PARMA/tree/master

RESEARCH ARTICLE

Analytical Model for Estimating Terrestrial Cosmic Ray Fluxes Nearly Anytime and Anywhere in the World: Extension of PARMA/ EXPACS

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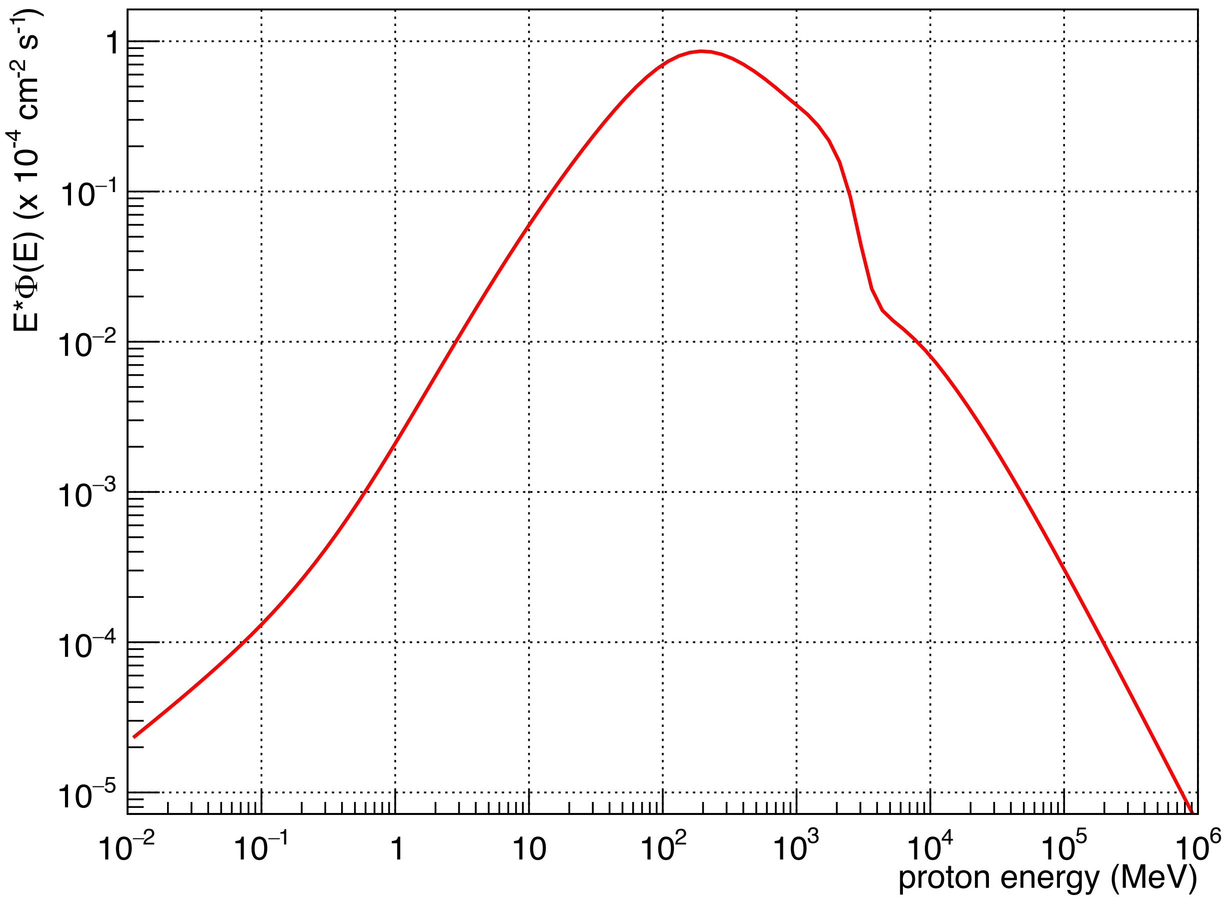
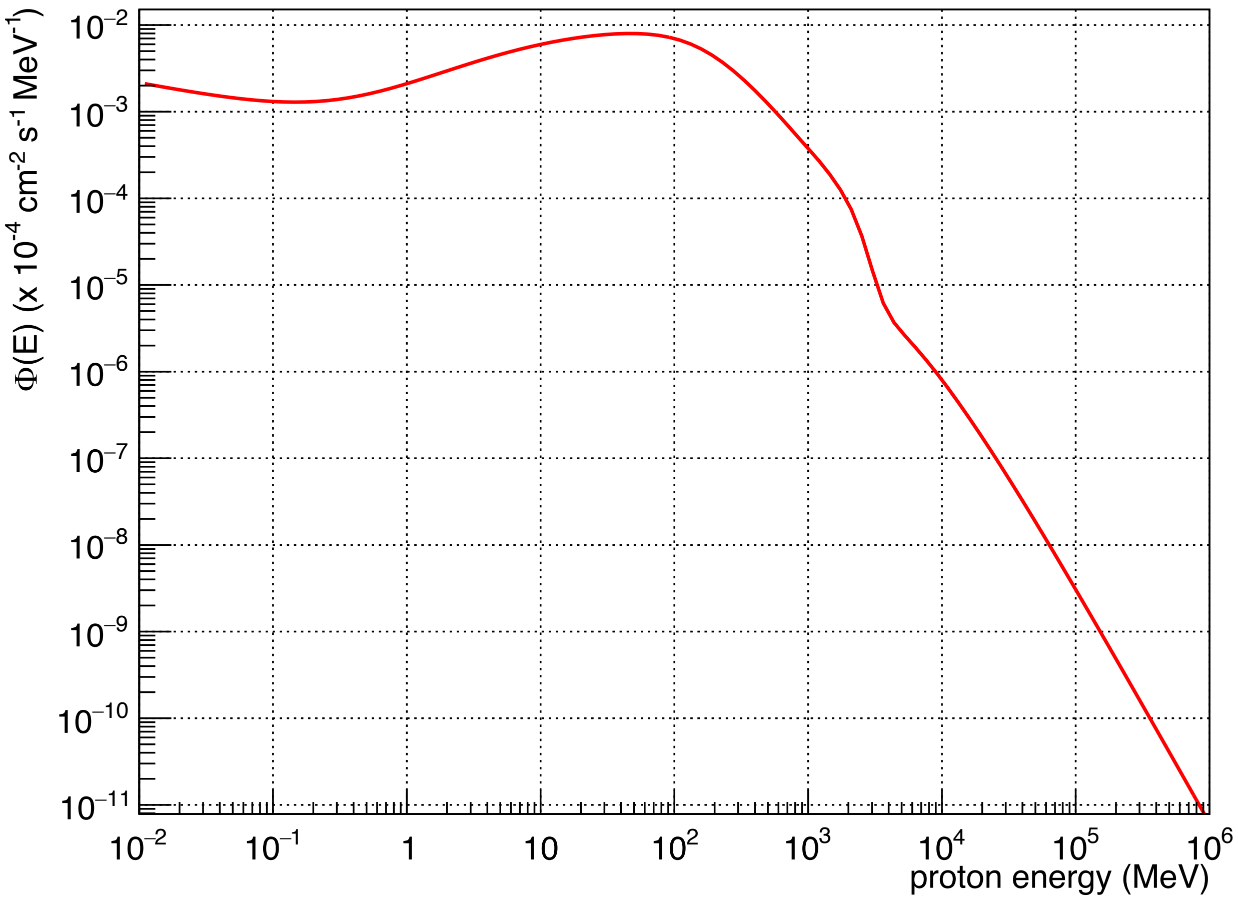
With this tool, I reproduced the calculations done for the neutrons to check my correct understanding of the program…

…And I found P_{26} ~ 21 atoms/g/y (Same results of Per's calculations)

Production of ^{10}Be and ^{26}Al: proton flux





Production of ^{10}Be and ^{26}Al: reactions of interest and threshold

^{28}Si + p
(E_{lab} = 100000 keV)

Reaction Products	Q-Value (keV)		Threshold (keV)	
^{10}Be + p + 2^{3}He + 3α	-71237.47	8	73804.16	8
^{10}Be + d + 3^{3}He + 2α	-89590.52	8	92818.47	8

^{28}Si + p
(E_{lab} = 100000 keV)

Reaction Products	Q-Value (keV)		Threshold (keV)	
^{26}Al + ^{3}He	-16924.91	7	17534.71	7
^{26}Al + p + d	-22418.38	7	23226.12	7
^{26}Al + NN + 2p	-24642.95	7	25530.83	7

For ^{26}Al ⟹ Lowest threshold at 18 MeV

For ^{10}Be on Si ⟹ Lowest threshold at 74 MeV

For ^{10}Be on O ⟹ Lowest threshold at 37 MeV

^{16}O + p
(E_{lab} = 100000 keV)

^{8}Be + 2p + t + α	-34342.37	4	36506.97	4
^{10}Be + 3p + α	-34347.35	8	36512.26	9
^{9}B + p + t + α	-34528.2	9	36704.5	10
^{8}Be + t + 2^{3}He	-47201.95	4	50177.09	4
^{10}Be + p + 2^{3}He	-47206.93	8	50182.38	9
^{10}B + NN + 2^{3}He	-47432.398	15	50422.062	16
^{8}Be + p + d + t + ^{3}He	-52695.43	4	56016.82	4
^{10}Be + 2p + d + ^{3}He	-52700.40	8	56022.11	9
^{9}B + d + t + ^{3}He	-52881.3	9	56214.4	10
^{8}Be + 3p + 2t	-54156.24	4	57569.71	4
^{10}Be + 4p + t	-54161.21	8	57574.99	9
^{11}C + 3NN + 3p	-54178.30	6	57593.15	6
^{8}Be + NN + 2p + t + ^{3}He	-54919.99	4	58381.60	4
^{10}Be + NN + 3p + ^{3}He	-54924.97	8	58386.89	9
^{8}Be + 2p + 2d + t	-58188.90	4	61856.55	4
^{10}Be + 3p + 2d	-58193.88	8	61861.84	9
^{9}B + p + 2d + t	-58374.7	9	62054.1	10
^{11}N + 3NN + ^{3}He	-60959	5	64801	5
^{9}Be + NN + 4p + t	-60973.50	8	64816.65	8

Production of ^{10}Be and ^{26}Al: cross section

Look at EXFOR to search reaction and references:
10.1016/S0168-583X(96)00409-0

Table 1
Cross sections for the production of radionuclides from Si targets

Proton energy [a] [MeV]	Si(p, x)^{7}Be [mb]	Si(p, x)^{10}Be [mb]	Si(p, x)^{22}Na [mb]	Si(p, x)^{26}Al [mb]
500	5.7 ± 0.43	0.554 ± 0.033	17.7 ± 1.31	18.7 ± 1.09
400	4.25 ± 0.32	0.397 ± 0.029	17.5 ± 1.29	20.4 ± 1.18
300	3.9 ± 0.3	0.262 ± 0.0159	17.5 ± 1.31	22.1 ± 1.3
200	2.9 ± 0.26	0.114 ± 0.0073	15.1 ± 1.16	24.8 ± 1.44
157.3 ± 1.0	1.41 ± 0.15	0.066 ± 0.0064	16.1 ± 1.45	32.6 ± 2.54
148.2 ± 2.0	1.3 ± 0.15	0.062 ± 0.005	16.1 ± 1.46	29.1 ± 2.22
128.7 ± 2.0				32.3 ± 1.88
128.0 ± 2.0	1.19 ± 0.15	0.045 ± 0.0044	16.5 ± 1.49	34.6 ± 2.64
127.5 ± 2.0			17.9 ± 0.99	
127.0 ± 2.0	1.11 ± 0.34	0.048 ± 0.0038		
97.0 ± 3.0	0.87 ± 0.16	0.023 ± 0.0026	16.8 ± 1.53	36.4 ± 2.76
87.4 ± 3.0	0.84 ± 0.14	0.019 ± 0.0019	18.1 ± 1.63	38.8 ± 3.01
77.2 ± 3.5	0.75 ± 0.13	0.011 ± 0.0013		43.9 ± 3.36
67.4	0.66 ± 0.24			
66.9	0.81 ± 0.16	0.0097 ± 0.0012	19.9 ± 1.82	47.0 ± 3.57
65.6		0.005 ± 0.0005	25.5 ± 2.4	50.5 ± 2.87
65.2	0.88 ± 0.203			
61.7 ± 4.0	0.41 ± 0.16	0.0065 ± 0.0009	20.0 ± 1.84	53.0 ± 4.04
59.0			22.4 ± 2.08	
58.7			22.0 ± 2.09	
56.5 ± 4.0	0.31 ± 0.15	0.0024 ± 0.0009	16.8 ± 1.54	51.3 ± 5.04
52.4	0.5 ± 0.105			
50.2		0.0009 ± 0.0002	11.6 ± 1.09	70.2 ± 4.05
44.5				67.0 ± 3.95
41.0			1.16 ± 0.12	
29.8				5.99 ± 0.38

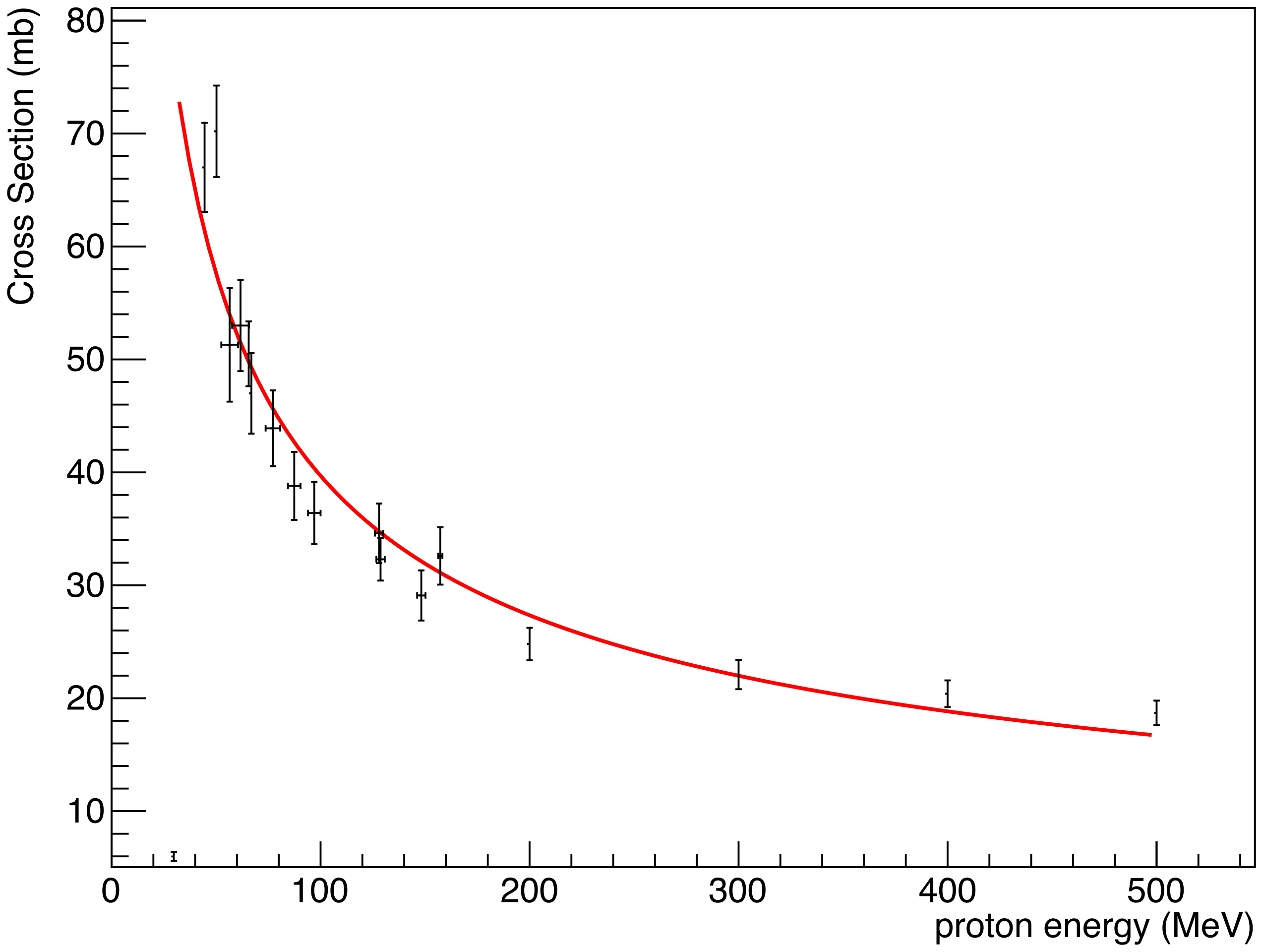
[a] 200–500 MeV TRIUMF; lower energies; with energy spread indicated, HCL; no energy spread indicated, Davis.

Table 2
Cross sections for the production of radionuclides from O using SiO_2 targets

Proton energy [a] [MeV]	O(p, x)^{7}Be [mb]	O(p, x)^{10}Be [mb]
500	10.2 ± 0.77	
400	10.3 ± 0.77	1.18 ± 0.068
300	11.1 ± 0.85	0.952 ± 0.058
200	10.3 ± 0.77	0.712 ± 0.046
158.9 ± 1.0	6.82 ± 0.63	0.56 ± 0.048
149.9 ± 2.0	7.11 ± 0.66	0.51 ± 0.057
129.9 ± 2.0	7.3 ± 0.69	0.42 ± 0.044
129.9 ± 2.0	6.27 ± 0.56	
99.9 ± 3.0	7.57 ± 0.74	0.44 ± 0.047
89.9 ± 3.0	7.25 ± 0.68	0.33 ± 0.038
79.9 ± 3.5	7.66 ± 0.73	0.27 ± 0.032
69.9 ± 3.5	7.69 ± 0.75	
67.4		0.33 ± 0.02
64.8 ± 4	7.68 ± 0.75	0.21 ± 0.037
59.8 ± 4	8.44 ± 0.83	0.18 ± 0.022
49.9		0.038 ± 0.0029
41.8		0.0079 ± 0.0008
30.9		0.0052 ± 0.0004

[a] 200–500 MeV TRIUMF; lower energies; with energy spread indicated, HCL; no energy spread indicated, Davis.

Production of ^{10}Be and ^{26}Al: $Si(p,x)^{26}Al$ cross section



- Plot of cross section in Table 1 (previous slide)
- Fit (from 30 to 500 MeV) to find a relation between cross section and energy:

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

A = 472.0 ± 54.3
B = 0.54 ± 0.02

Production of ^{10}Be and ^{26}Al: ^{26}Al production rate

Now I have all ingredients:

- Proton flux
- Cross section
- $N_a/(28+16*2)$ = Si target nuclei

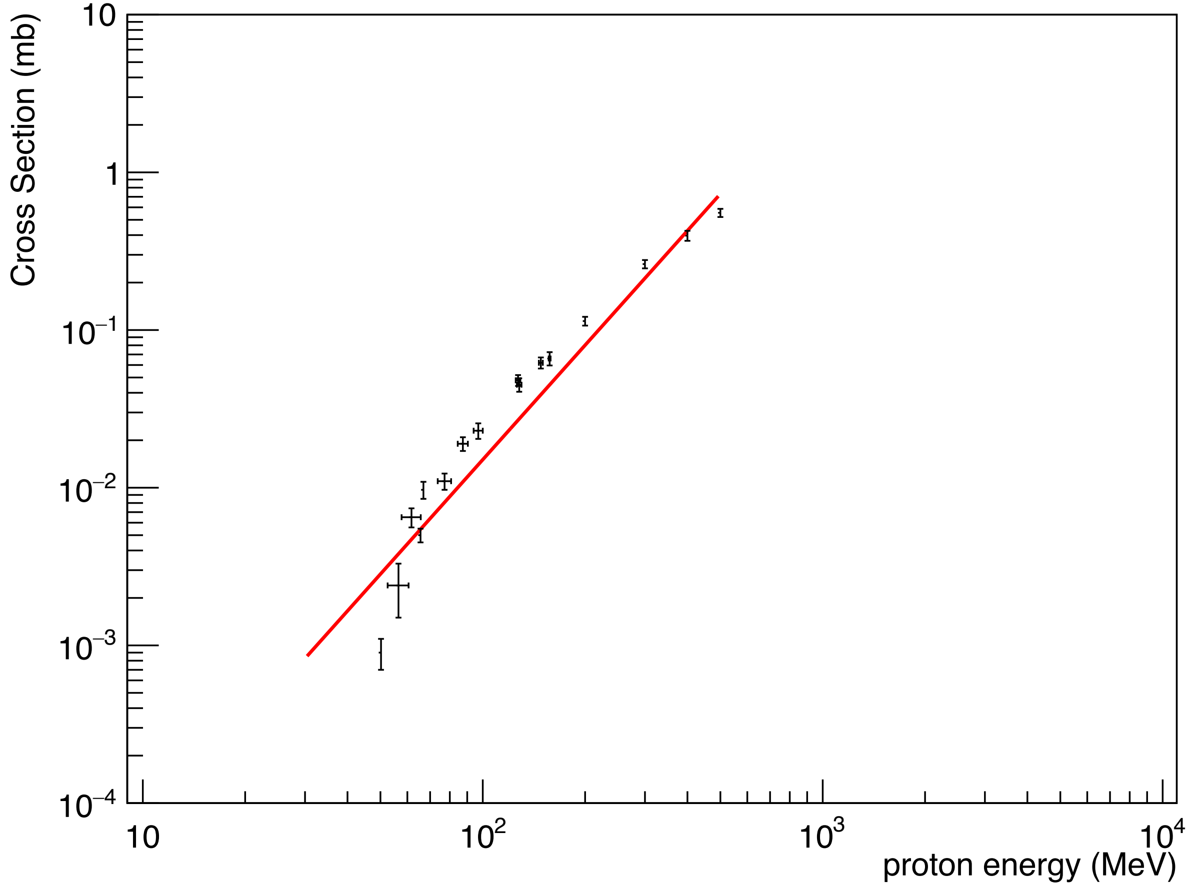
$$\Longrightarrow P_{26} = 1.96\ atoms/g \cdot y$$

(calculated from 30 to 500 MeV)

Value calculated by Per for spallation due to neutron:

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

Production of ^{10}Be and ^{26}Al: Si(p,x)^{10}Be cross section



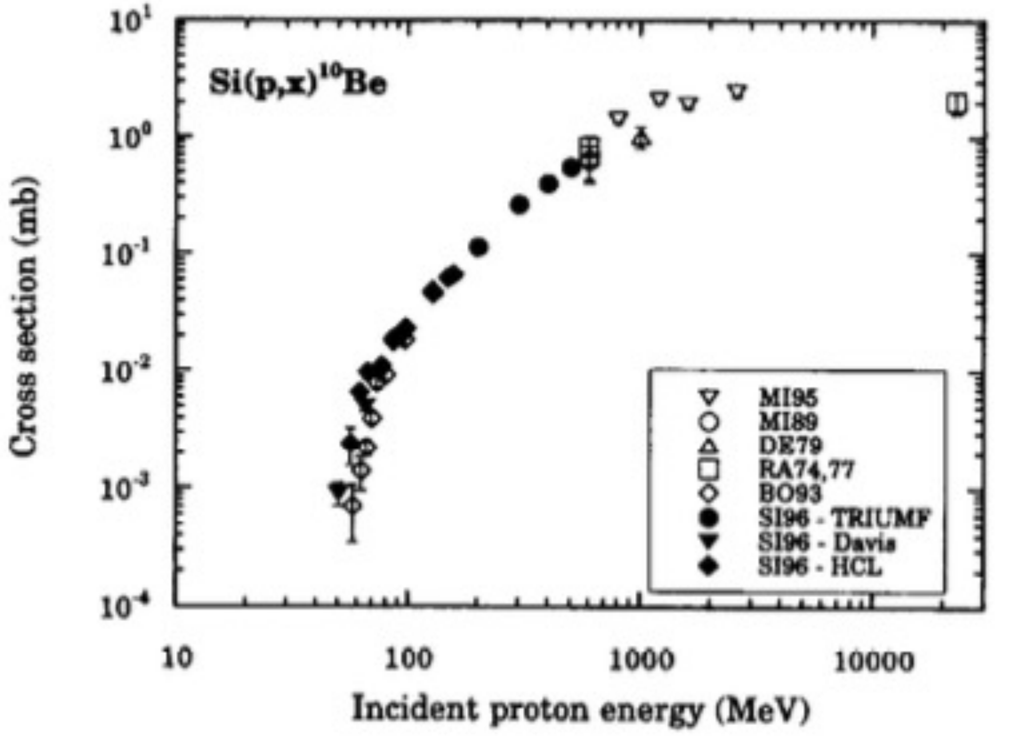


Fig. 1. Si(p, x)^{10}Be; errors are as shown or are smaller than the plotted symbol.

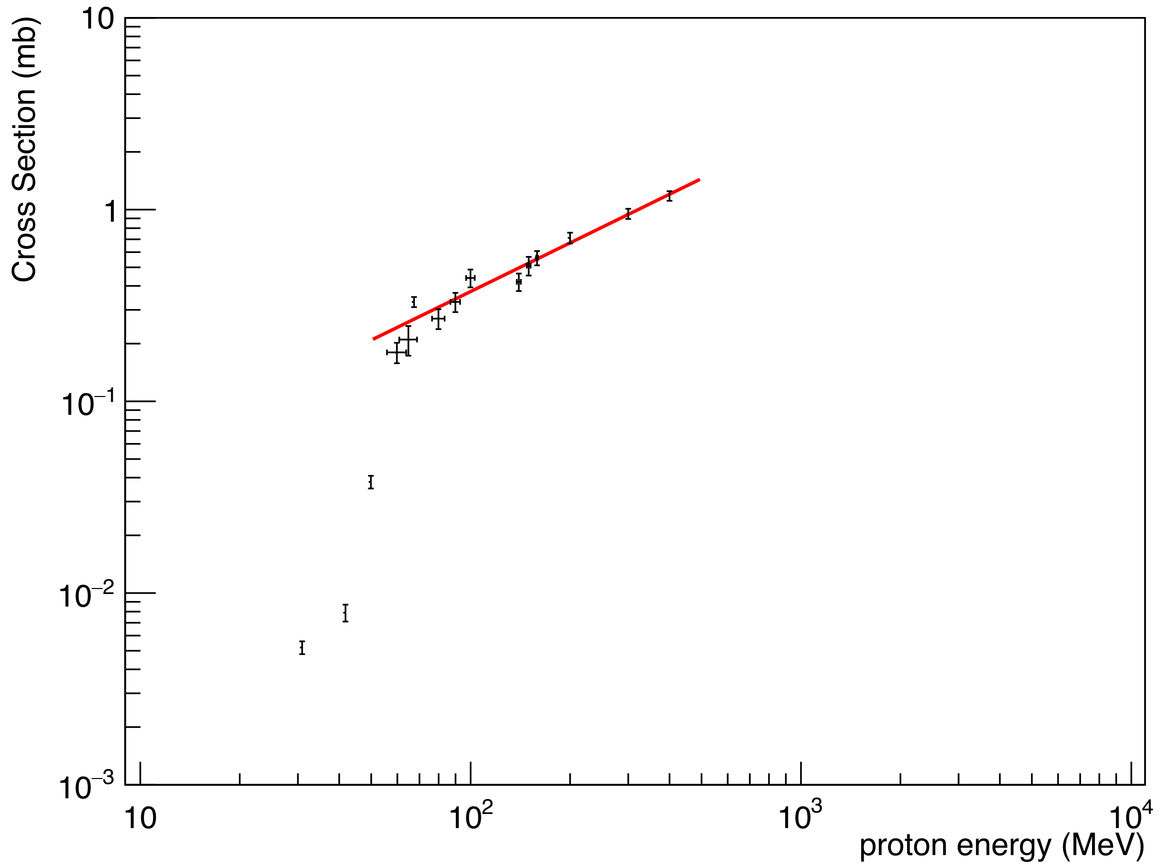
Fit (from 30 to 500 MeV) to find a relation between cross section and energy:

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

A = $(2.27 \pm 0.31) \cdot 10^{-7}$

B = -2.4 ± 0.03

Production of ^{10}Be and ^{26}Al: $O(p,x)^{10}Be$ cross section



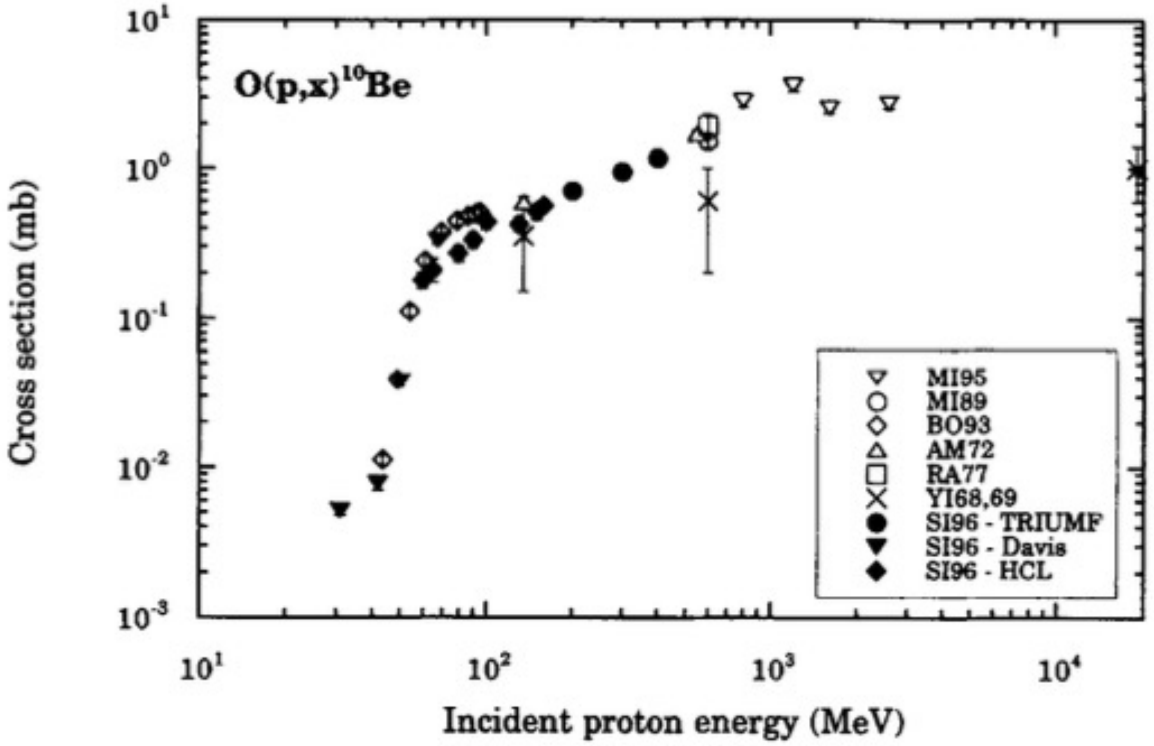


Fig. 5. O(p, x)^{10}Be; errors are as shown or are smaller than the plotted symbol.

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

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

A = $(7.7 \pm 1.5) \cdot 10^{-3}$

B = -0.84 ± 0.04

Production of ^{10}Be and ^{26}Al: ^{10}Be production rate

Now I have all ingredients:

- Proton flux
- Cross section
- $N_a/(28+16*2)$ = Si target nuclei
- $2*N_a/(28+16*2)$ = O target nuclei

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

(calculated from 50 to 500 MeV)

Cf Granger table 2 from exponential fits:
P_{10} = 4.5 at the surface

Production of ^{10}Be and ^{26}Al: Concusions

- Contribution of protons at the ^{10}Be production rate is the 1.75%
- Contribution of protons at the ^{26}Al production rate is the 8.54%

The contribution of protons to the production rate, especially for aluminum, can be taken into account during rock dating calculations because it contributes a non-negligible percentage. Unlike neutrons, for protons, there are more experimental values available for both flux and cross-section, so it is not a priority to perform measurements to improve these values.