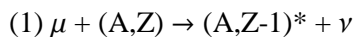


Capture

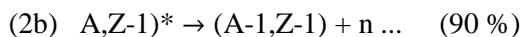
```
In[1]:= << Graphics`Graphics`;  
th = 0.007;  
GStandardOptions := SetOptions[{Plot, ListPlot, LogPlot, LogLogPlot, ParametricPlot},  
  Frame → True, AspectRatio → 1 / GoldenRatio, PlotRange → All,  
  PlotRegion → Automatic, Axes → True, AxesStyle → Automatic,  
  PlotStyle → {{RGBColor[0.5, 0.5, .5], Thickness[th]}, {RGBColor[1, 0, 0], Thickness[th]},  
    {RGBColor[0, 1, 0], Thickness[th]}, {RGBColor[0, 0, 1], Thickness[th]}},  
  TextStyle → {FontSize → 18, FontWeight → "Bold"}];  
GStandardOptions;  
DispOn := SetOptions[Plot, DisplayFunction → $DisplayFunction];  
DispOff := SetOptions[Plot, DisplayFunction → Identity];  
<< Graphics`Colors`  
<< Miscellaneous`PhysicalConstants`  
<< Graphics`Legend`
```

Basic Formalism

The process is described in two steps



then



i.e. roughly 10% of nuclei remain bound and 90% have 1 n (or 2 n or charged particle emission).

Let us consider such a simple two stage model. The cross section is dominated by the isobaric analogs to the photonuclear giant dipole resonance, with a nuclear excitation energy of ~ 22 MeV. Accordingly the neutrino momentum q in reaction (1) is ~ 85 MeV/c (with a width reflecting the giant resonance width).

```
en = 1;
```

```
vecN = {"N", 14 m0,  $\frac{q^2}{2 \cdot 14 m0}$ ,  $\frac{q}{14 m0}$ };
```

```
vecO = {"O", 16 m0,  $\frac{q^2}{2 \cdot 16 m0}$ ,  $\frac{q}{16 m0}$ };
```

```
vecn = {"n", mn, en,  $\sqrt{2 \frac{en}{mn}}$ };
```

```
MatrixForm[{vecN, vecO, vecn}]
```

```
Out[21]/MatrixForm=
```

```
( N 13041. 0.277011 0.00651791 )
( O 14904. 0.242385 0.00570317 )
( n 939.6 1 0.0461364 )
```

According to Peter W. EH~0.085 MeV and EVH~0.35 MeV. So the EVH should cut significantly into this naive energy spectra and apparently it does not, for N.

We denote lab variables with small and nucleus CMS variables with capital letters. The next step is to calculate the spectral shape because of the emission of a neutron of energy t_n . Here we assume the nucleus is at maximum velocity $v_i = v_m = \frac{q}{M}$ and $v_i=0$. As the neutron velocity v_n is large against the velocity of the nucleus v_i , we set $t_n=T_n$ or $v_n=V_n$. If the n is emitted with $u=\cos\theta$ in the nucleus CMS moving with velocity v_i , the nuclear recoil energy will be

```
In[22]:= t0[M_, vi_, Tn_, u_] :=
```

$$\left(v_n = \sqrt{2 \frac{T_n}{mn}}; v_{rec} = v_n \frac{mn}{M - mn}; v_f = \text{Sqrt}[v_i^2 + v_{rec}^2 - 2 v_i v_{rec} u]; \frac{(M - mn) v_f^2}{2} \right)$$

```
In[87]:= M = vecN[[2]]; vi = vecN[[4]]; {M, vi};
```

```
Tn = {0.5, 2., 3.5, 5.};
```

```
MatrixForm[Table[{t0[M, vi, Tn[[i]], 1], vi, vrec}, {i, 1, 4}]]
```

```
Plot[{t0[M, vi, Tn[[1]], u], t0[M, vi, Tn[[2]], u], t0[M, vi, Tn[[3]], u],
      t0[M, vi, Tn[[4]], u]}, {u, -1, 1}, FrameLabel -> {"cosθ", "Trec (MeV)"},
      PlotLegend -> {"0.5", "2.0", "3.5", "5.0"},
      LegendLabel -> "Tn (MeV)",
      LegendPosition -> {.4, .2},
      LegendSize -> {.5, .4},
      PlotLabel -> "Nitrogen"
];
```

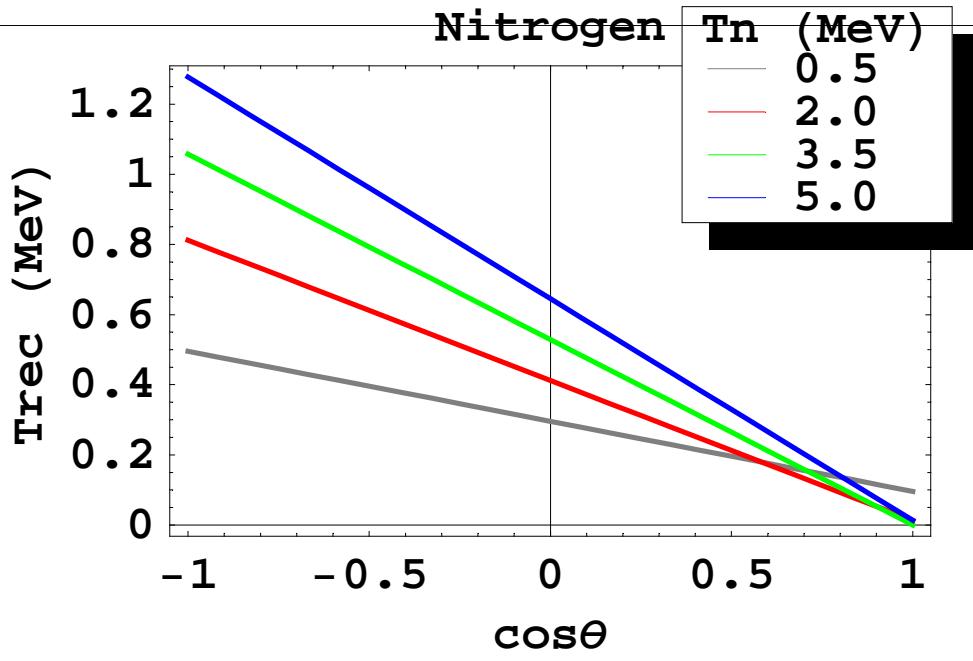
```
M = vecO[[2]]; vi = vecO[[4]]; {M, vi};
```

```
MatrixForm[Table[{t0[M, vi, Tn[[i]], 1], vi, vrec}, {i, 1, 4}]]
```

```
Plot[{t0[M, vi, Tn[[1]], u], t0[M, vi, Tn[[2]], u], t0[M, vi, Tn[[3]], u],
      t0[M, vi, Tn[[4]], u]}, {u, -1, 1}, FrameLabel -> {"cosθ", "Trec (MeV)"},
      PlotLegend -> {"0.5", "2.0", "3.5", "5.0"},
      LegendLabel -> "Tn (MeV)",
      LegendPosition -> {.4, .2},
      LegendSize -> {.5, .4},
      PlotLabel -> "Oxygen"
];
```

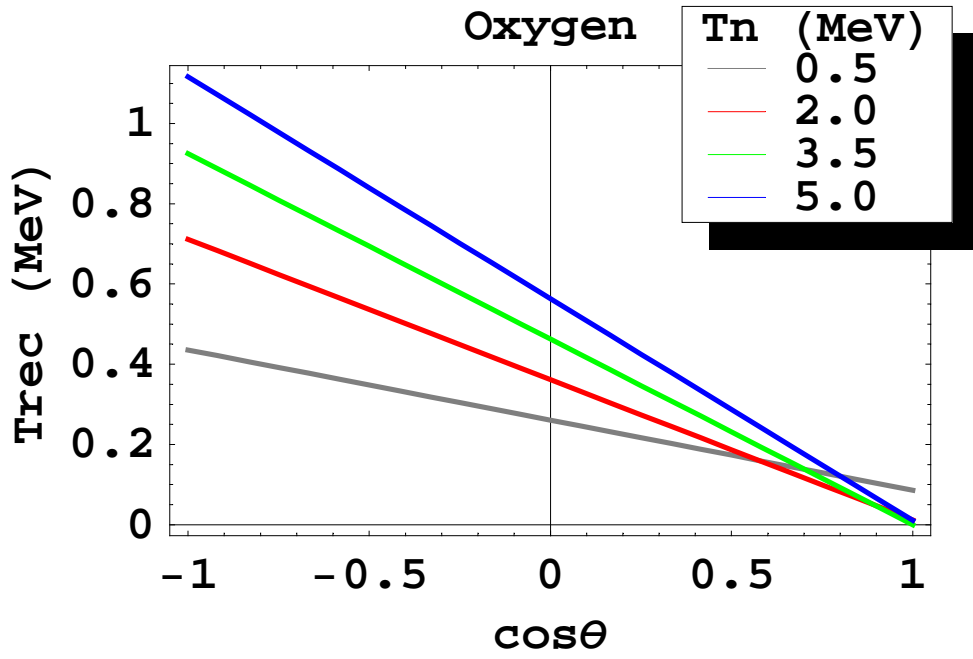
```
Out[89]/MatrixForm=
```

```
( 0.0960817 0.00651791 0.002533 )
( 0.0127549 0.00651791 0.00506601 )
( 0.000204394 0.00651791 0.0067017 )
( 0.0134721 0.00651791 0.00801006 )
```

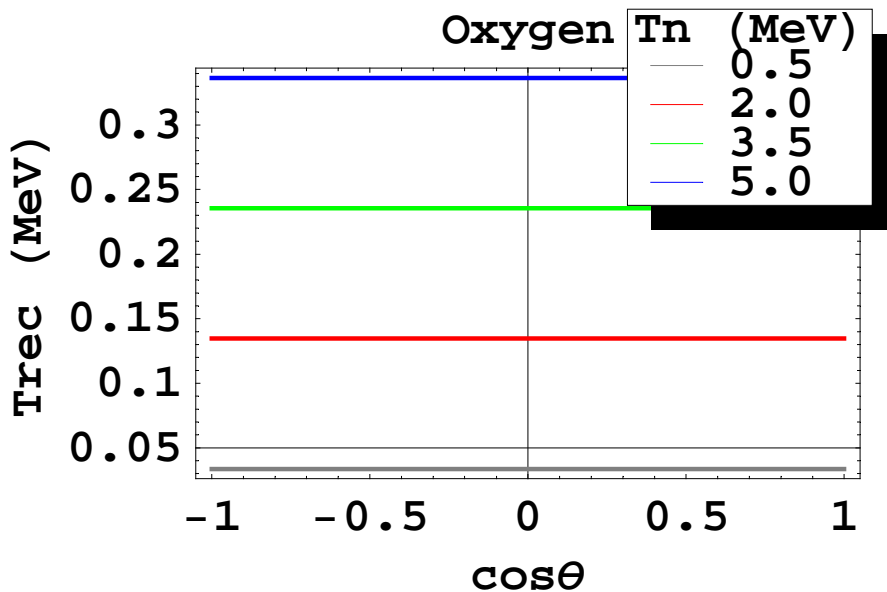
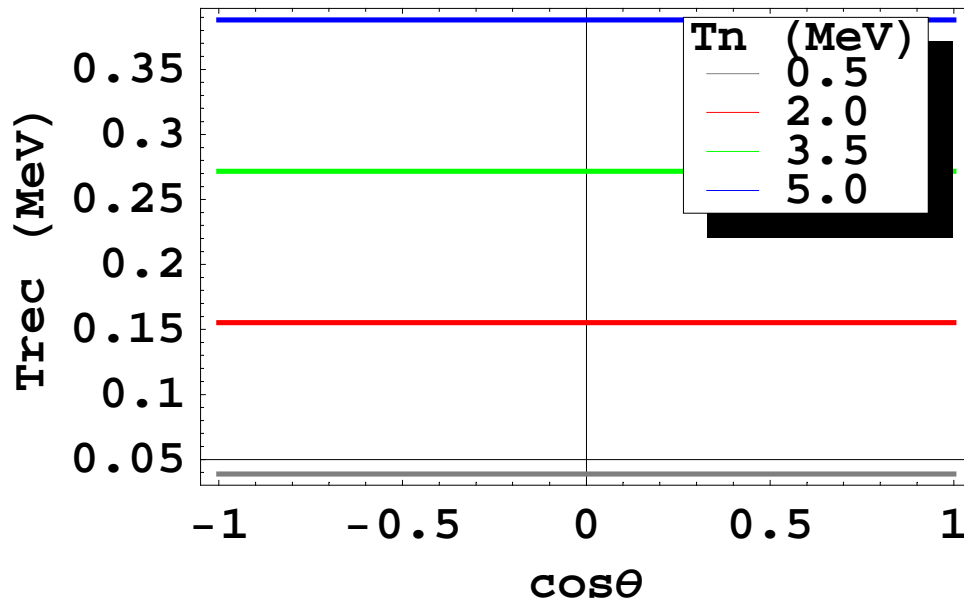


Out[92]/MatrixForm=

0.0859279	0.00570317	0.00219507
0.0120374	0.00570317	0.00439015
0.0000761799	0.00570317	0.00580762
0.0107059	0.00570317	0.00694143



```
Plot[{t0[M, vi, Tn[[1]], u], t0[M, vi, Tn[[2]], u], t0[M, vi, Tn[[3]], u],
      t0[M, vi, Tn[[4]], u]}, {u, -1, 1}, FrameLabel -> {"cosθ", "Trec (MeV)"},
PlotLegend -> {"0.5", "2.0", "3.5", "5.0"}, LegendLabel -> "Tn (MeV)",
LegendPosition -> {.4, .2}, LegendSize -> {.5, .4}, Label -> "Nitrogen";
M = vecO[[2]]; vi = 0; {M, vi};
Plot[{t0[M, vi, Tn[[1]], u], t0[M, vi, Tn[[2]], u], t0[M, vi, Tn[[3]], u],
      t0[M, vi, Tn[[4]], u]}, {u, -1, 1}, FrameLabel -> {"cosθ", "Trec (MeV)"},
PlotLegend -> {"0.5", "2.0", "3.5", "5.0"}, LegendLabel -> "Tn (MeV)",
LegendPosition -> {.4, .2}, LegendSize -> {.5, .4}, PlotLabel -> "Oxygen";
```



In conclusion this study just emphasizes the old issue of nuclear physics uncertainties in making predictions on the relative N and O recoil spectra.

i) From the simple 2-body kinematics both N and O should be cut by the significantly cut by the EVH threshold. However, even this spectrum is uncertain, as it depends on the detailed energy dependence of the capture rate in the giant resonance region.

ii) The additional recoil generated by neutron evaporation of the excited nucleus might significantly modify the recoil energy

Thus, before we have analyzed empirical recoil spectra, we cannot make assumptions on the relative N vs O recoil spectra. In particular, the assumption $\epsilon_H(\text{oxygen}) \approx \epsilon_N(\text{nitrogen})$ cannot be justified.

References

<http://www.npl.uiuc.edu/twiki/bin/view/Main/CaptureFADC> has a literature reference to neutron emission spectra after capture in C and O.

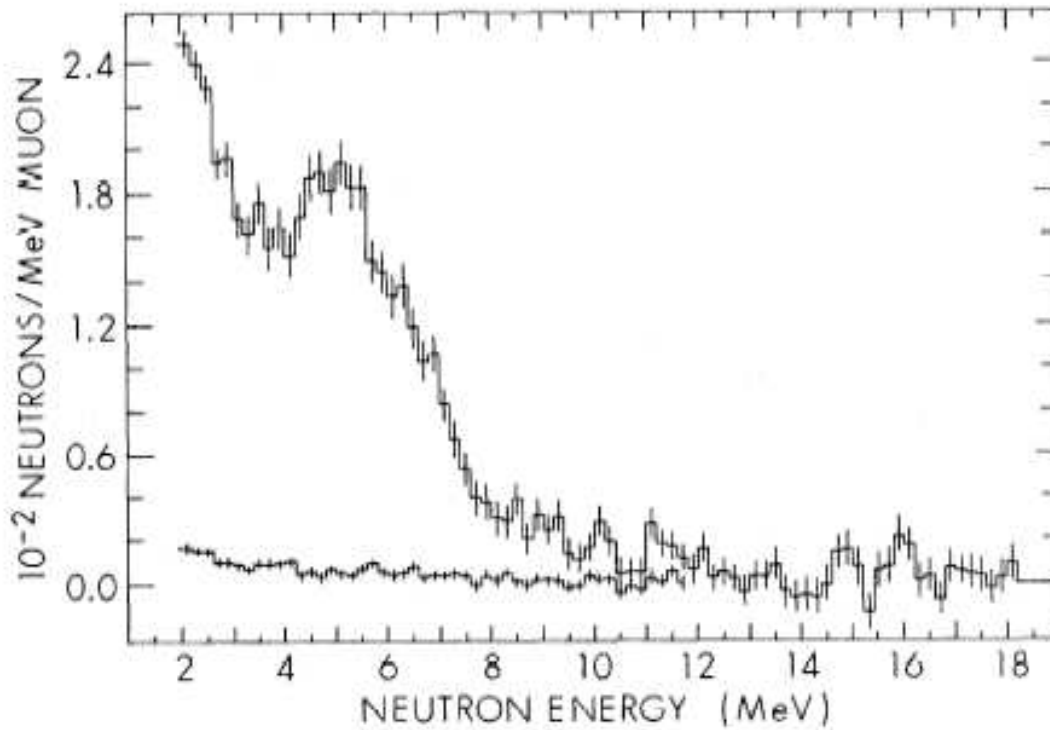


FIG. 2. Unfolded neutron spectrum and background for ^{16}O .

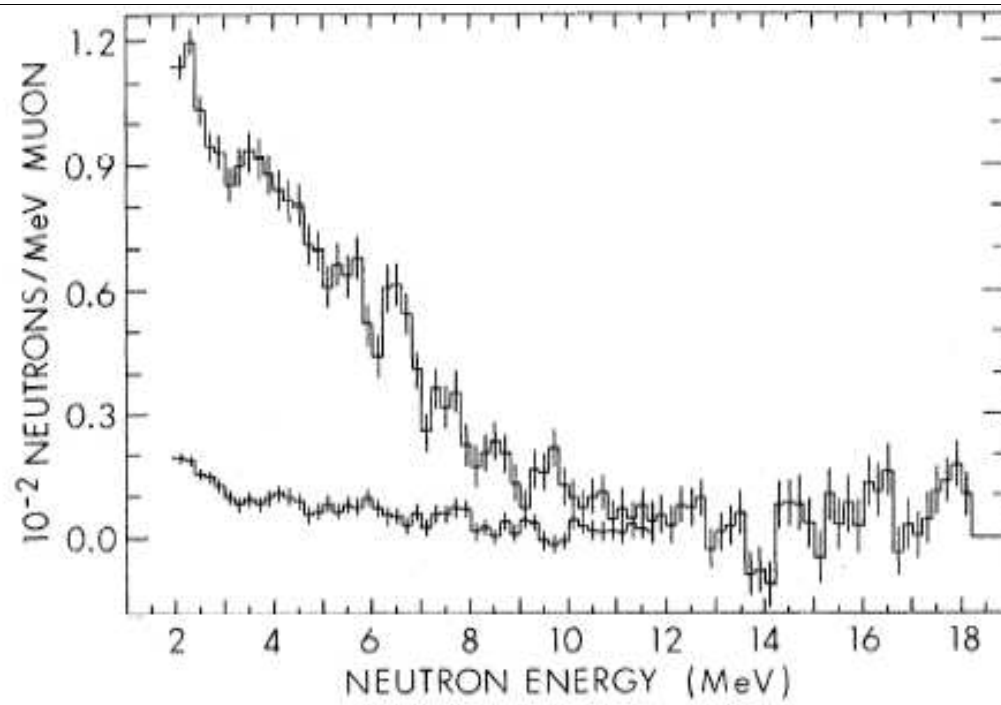


FIG. 6. Unfolded neutron spectrum and background for ^{12}C .