5/4/2021 Milind Diwan

This was originally written as part of Daya Bay analysis and rate calculation.

In this notebook we will calculate the Neutrino detected event spectrum from a nuclear reactor at various distances with and without oscillations.

We use tabulated spectra (as explained in the other notebooks) and standard neutrino oscillation parameters.

Petoe[] is the probability of survival for an electron neutrino given the various oscillation parameters.

In[22]:=
```
(* Some constants, may not be used here *)
Dground = 1.2;
Rearth = 6371;
Phia = Dground / Rearth;
Dstret = 2 * 6371 * Sin[Phia / 2];
Pow = 1; (* GW *)
Rnorm = 6.02240576 * 10^-12; (* some kind of normalization *)
Distance = 1 ; (* km *)
TargetMass = 10^6; (* gm*)
Avagadro = 6.022141 * 10^23;
TargetNucleons = TargetMass * Avagadro;
HydrogenFraction = 30 / (30 + 12 * 18); (* for C18H30 *)

Petoe[Enu_, Len_, dm21_, dm31_, th23_, th12_, th13_, δ_] :=
 Module[{α, Ahat, JCP, ICP, D31, D32, D21, Gfermi, Den, V, NA, Ne, T1, T2, T3, T4, tot},
  α = dm21 / dm31; Den = 3.0;
  Ahat = 7.6 * 10^{-5} * Den * Enu / dm31;
  JCP = (1 / 8) * Sin[δ] * Cos[th13] * Sin[2 * th12] * Sin[2 * th13] * Sin[2 * th23];
  ICP = (1 / 8) * Cos[δ] * Cos[th13] * Sin[2 * th12] * Sin[2 * th13] * Sin[2 * th23];
  D31 = 1.27 * dm31 * Len / Enu;
  D21 = 1.27 * dm21 * Len / Enu;
  D32 = D31 - D21;
   Gfermi = 1.16637 * 10^-5; NA = 6.022 * 10^23;
  Ne = Den * NA / 2.; V = Sqrt[2] * Gfermi * Ne;
  T1 = 1 - 4 * (Sin[th13] * Cos[th13])^2
      ((Cos[th12])^2 * (Sin[D31])^2 + (Sin[th12])^2 * (Sin[D32])^2) -
    4 * (Cos[th13])^4 * (Sin[th12])^2 * (Cos[th12])^2 * (Sin[D21])^2;
  tot = T1;
  Return[tot ]]
```

Tabulated flux and cross section for inverse beta decay. Check units carefully. Flux is in per m^2

For reactor.dat. Energy is in GeV we convert to MeV. The flux needs to be converted to
per MeV per day per m^2 at 1 km for 1 GWt by appropriate multipliers as below.

For cross section data from XCCreator.dat . Energy is in Log10[GeV] and cross section is in units of 10^-46 cm^2 in the table. We will simply fix this in the code. But we are not using this since it disagrees with Vogel and Beacom. I do not

know where it came from but it has weird behaviour at threshold.

The tabulation of cross section from the IBD-crsssection.nb is at the bottom of this notebook.  The units are cm^2

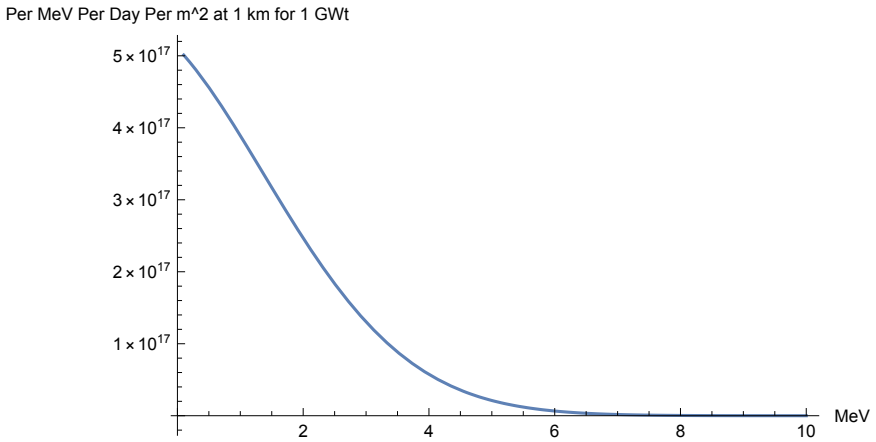
In[34]:=
```
FluxData =
  ReadList["/Users/diwan/Documents/Projects/basic-reactor-calc/Reactor.dat",
   {Number, Number, Number, Number, Number, Number, Number}];
Earray = Table[FluxData[[i]][[1]] * 1000, {i, 1, 501}]; (* convert to MeV *)
Anuearray = Table[FluxData[[i]][[5]] / 1000 / (5 * 10^-6), {i, 1, 501}];
(* convert to per MeV per day per m^2 at 1 km for 1 GWt *)
AnueFunc = Interpolation[Table[{Earray[[i]], Anuearray[[i]]}, {i, 1, 501}]];

(* This tabulation is not in use *)
CrossSection =
  ReadList["/Users/diwan/Documents/Projects/basic-reactor-calc/XCCreactor.dat",
   {Number, Number, Number, Number, Number, Number, Number}];
Elogarray = Table[CrossSection[[i]][[1]], {i, 1, 1001}];
Xccarray = Table[CrossSection[[i]][[5]], {i, 1, 1001}];
XccFunc = Interpolation[Table[{Elogarray[[i]], Xccarray[[i]]}, {i, 1, 1001}]];

FluxData2 = ReadList[
  "/Users/diwan/Documents/lbn_review/Review/LBN_review/plot/reactor_spectrum.txt"
, {Number, Number}];  (* This is detected spectra according to Daya Bay
 model but it is not normalized for any particular distance or power *)
Earray2 = Table[FluxData2[[i]][[1]], {i, 1, 1200}];
Anuearray2 = Table[FluxData2[[i]][[2]], {i, 1, 1200}];
AnueFunc2 = Interpolation[Table[{Earray2[[i]], Anuearray2[[i]]}, {i, 1, 1200}],
  InterpolationOrder → 8];  (* not normalized *)
```

In[49]:=
```
Plot[AnueFunc[x], {x, 0.1, 10.},
 AxesLabel → {"MeV", "Per MeV Per Day Per m^2 at 1 km for 1 GWt"}]
```

Out[49]=




## Calculate the integral for 1 GWt for 1 sec

In[46]:=
```
NIntegrate[AnueFunc[x] * (4 * Pi * 1000^2) / (24 * 3600), {x, 0., 10.}]
```

Out[46]=
$$1.60141 \times 10^{20}$$

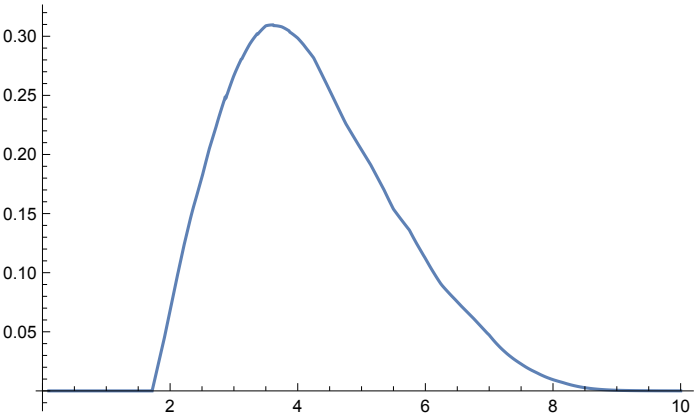
In[47]:=
```
dbint = NIntegrate[AnueFunc2[x], {x, 0, 12}]
```

NIntegrate: NIntegrate failed to converge to prescribed accuracy after 9 recursive bisections in x near {x} = {2.85919}. NIntegrate obtained 3455.512378192166` and 0.006051042792757543` for the integral and error estimates.

Out[47]=
```
3455.51
```

In[50]:=
```
Plot[AnueFunc2[x] / dbint, {x, 0.1, 10}]
```

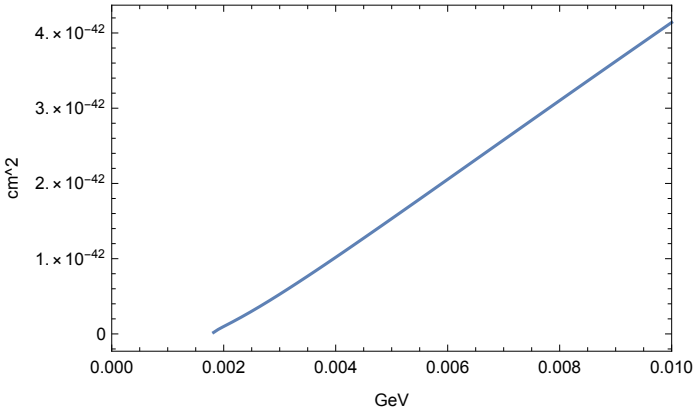
Out[50]=



Plot the cross section to make sure it works. This tabulation Appears to be too high at low energy. I am not sure where it came from. But we will work with it as well as the raw calculation from the other notebook as a test for this notebook.

In[51]:=
```
Plot[10^-46 * XccFunc[Log10[x]], {x, 0.00182, 0.010},
 PlotRange → {{0, 0.01}, Automatic }, Frame → True, FrameLabel → {"GeV", "cm^2"}]
```

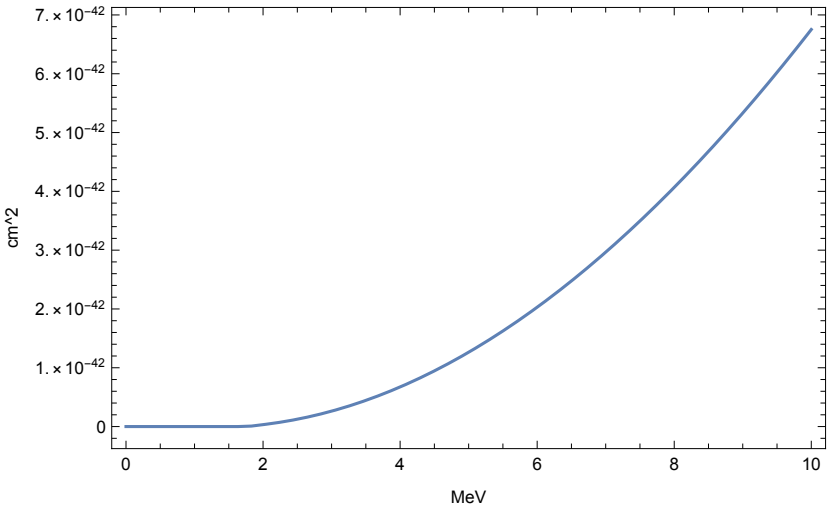
Out[51]=




The Vogel/Beacom standard IBD tabulated cross section is at the bottom of this notebook. This is the correct cross section at low energy and near threshold.

In[58]:=
```
Plot[CrossIBD[x], {x, 0, 10.}, Frame → True, FrameLabel → {"MeV", "cm^2"}]
```

Out[58]=




Calculate event rate per day at 1 km in 1 ton detector for 1 GWt. Tabulate as a function of threshold.

In[59]:=
```
EventRate1 = NIntegrate[AnueFunc[x] * 10^-4 * XccFunc[Log10[x * 10^-3]] *
    10^-46 * TargetNucleons * HydrogenFraction, {x, 1.8, 10.}]
```

Out[59]=
```
1.473
```

This is the correct one.  IT leads to the usual 1 event/ton at 1 km for 1 GW.

In[60]:=
```
EventRate = NIntegrate[
  AnueFunc[x] * 10^-4 * CrossIBD[x] * TargetNucleons * HydrogenFraction, {x, 1.8, 10.}]
```

Out[60]= 0.934679

In[62]:=
```
Ratetable1 =
 Table[{thres, NIntegrate[AnueFunc[x] * 10^-4 * XccFunc[Log10[x * 10^-3]] *
      10^-46 * TargetNucleons * HydrogenFraction,
     {x, thres, 10.}]}, {thres, 1.8, 9.8, 1.}] // TableForm
```

Out[62]//TableForm=

| | |
|---|---|
| 1.8 | 1.473 |
| 2.8 | 1.16562 |
| 3.8 | 0.667443 |
| 4.8 | 0.295952 |
| 5.8 | 0.105098 |
| 6.8 | 0.0304114 |
| 7.8 | 0.00718295 |
| 8.8 | 0.0013063 |
| 9.8 | 0.0000783018 |

In[63]:=
```
Ratetable =
 Table[{thres, NIntegrate[AnueFunc[x] * 10^-4 * CrossIBD[x] * TargetNucleons *
      HydrogenFraction, {x, thres, 10.}]}, {thres, 1.8, 9.8, 1.}] // TableForm
```

Out[63]//TableForm=

| | |
|---|---|
| 1.8 | 0.934679 |
| 2.8 | 0.811535 |
| 3.8 | 0.539709 |
| 4.8 | 0.278345 |
| 5.8 | 0.113649 |
| 6.8 | 0.0372878 |
| 7.8 | 0.00984203 |
| 8.8 | 0.00196622 |
| 9.8 | 0.0001264 |

This is the table of event rate per day  in 1 ton at 1 km for 1 GWt as a function of threshold.

In[64]:=
```
TableForm[Ratetable]
```

Out[64]//TableForm=

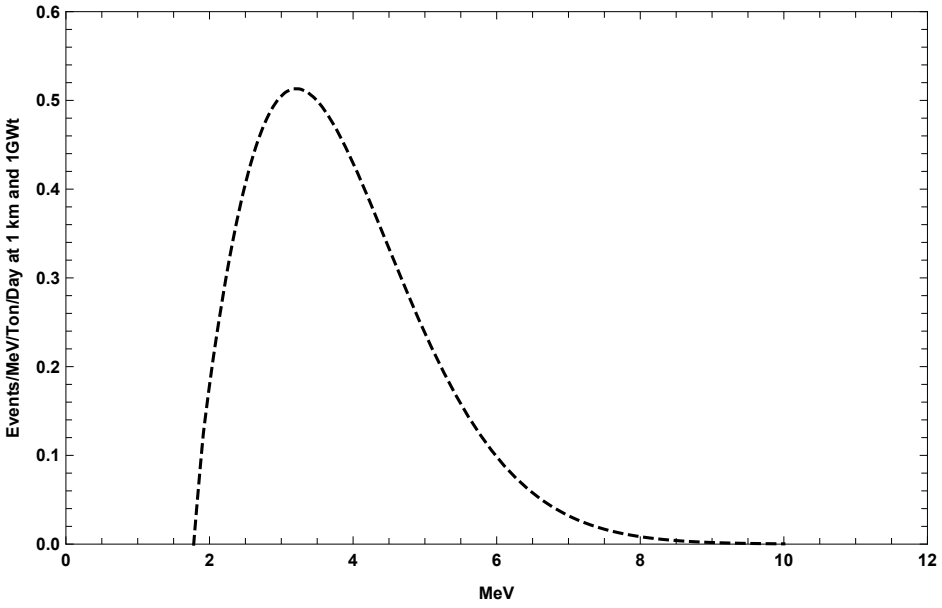
| | |
|---|---|
| 1.8 | 0.934679 |
| 2.8 | 0.811535 |
| 3.8 | 0.539709 |
| 4.8 | 0.278345 |
| 5.8 | 0.113649 |
| 6.8 | 0.0372878 |
| 7.8 | 0.00984203 |
| 8.8 | 0.00196622 |
| 9.8 | 0.0001264 |

## We will now make some plots of spectra and compare them.

In[65]:=
```
plt1 = Plot[AnueFunc[x] * 10^-4 * XccFunc[Log10[x * 10^-3]] * 10^-46 * TargetNucleons *
    HydrogenFraction, {x, 1.7, 10.}, PlotRange → {{0, 12.}, {0, 0.6}},
  LabelStyle → {GrayLevel[0], Bold}, PlotStyle → {Black, Dashed}, Frame → True,
  FrameLabel → {"MeV", "Events/MeV/Ton/Day at 1 km and 1GWt"}]
```

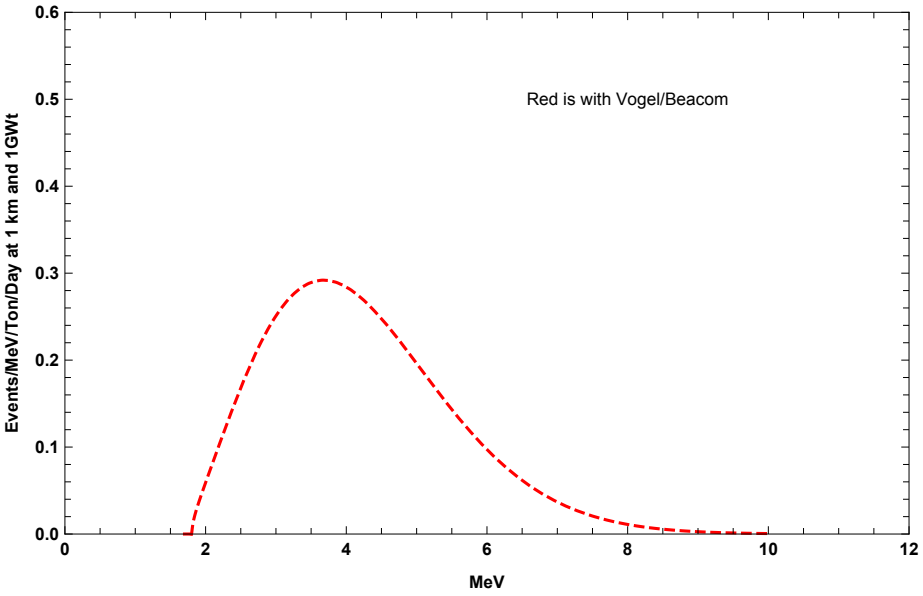
InterpolatingFunction: Input value {−2.76951} lies outside the range of data in the interpolating function. Extrapolation will be used.

Out[65]=



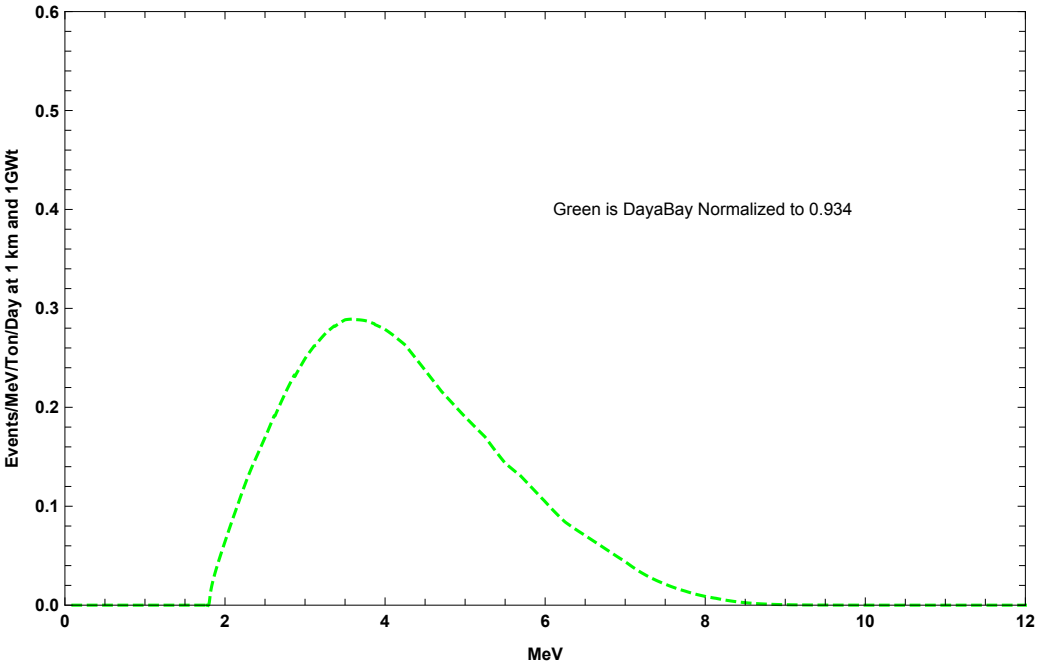
In[66]:=
```
plt = Plot[AnueFunc[x] * 10^-4 * CrossIBD[x] * TargetNucleons * HydrogenFraction,
  {x, 1.7, 10.}, PlotRange → {{0, 12.}, {0, 0.6}},
  LabelStyle → {GrayLevel[0], Bold}, PlotStyle → {Red, Dashed}, Frame → True,
  FrameLabel → {"MeV", "Events/MeV/Ton/Day at 1 km and 1GWt"},
  Epilog → Inset["Red is with Vogel/Beacom", {8, 0.5}]]
```

Out[66]=




In[67]:=
```
pltdb =
 Plot[0.934 * AnueFunc2[x] / dbint, {x, 0.1, 12}, PlotRange → {{0, 12.}, {0, 0.6}},
  LabelStyle → {GrayLevel[0], Bold}, PlotStyle → {Green, Dashed},
  Frame → True, FrameLabel → {"MeV", "Events/MeV/Ton/Day at 1 km and 1GWt"},
  Epilog → Inset["Green is DayaBay Normalized to 0.934 ", {8, 0.4}]]
```

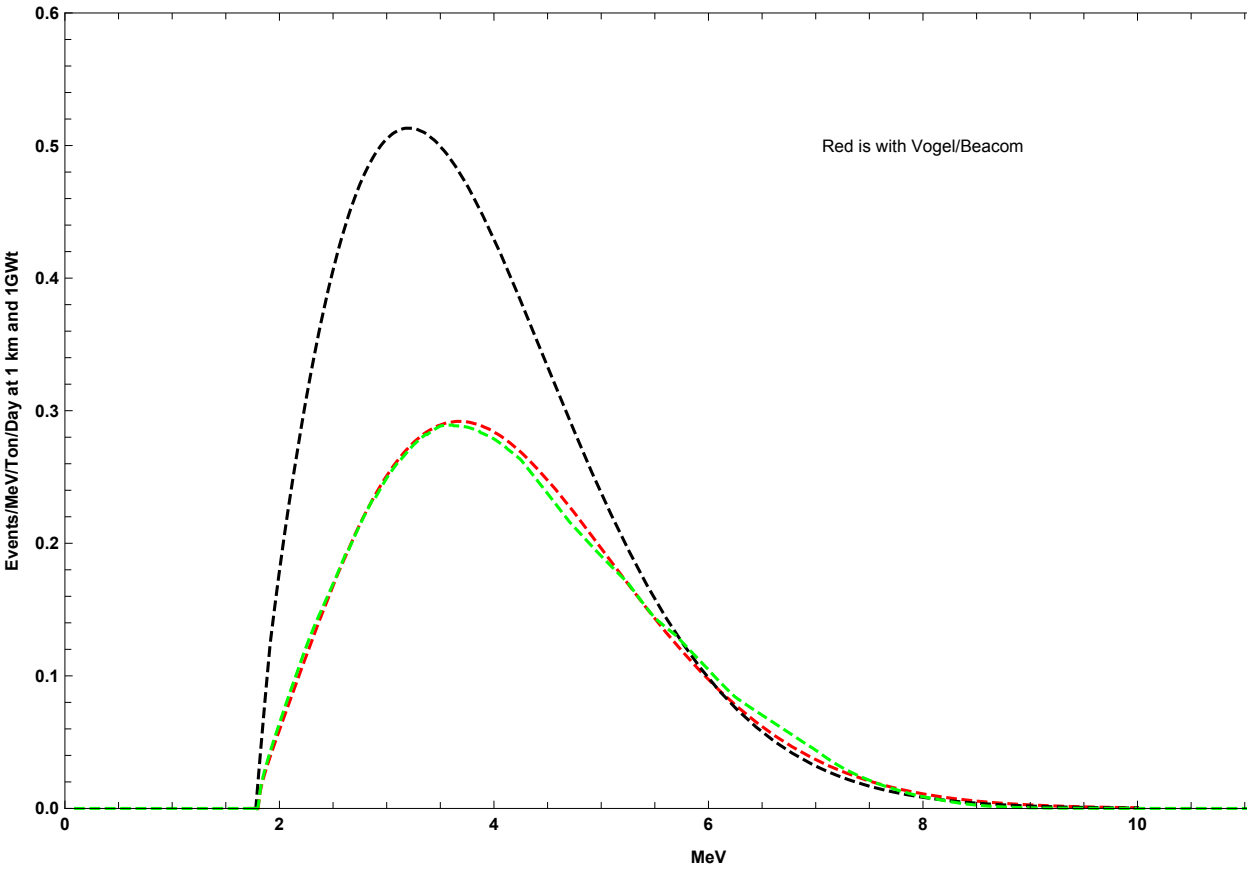
Out[67]=



We compare the models. The Dayabay data based spectrum is clearly much closer to the Vogel/Beacom model.

In[68]:=
```
Show[plt, plt1, pltdb]
```

Out[68]=

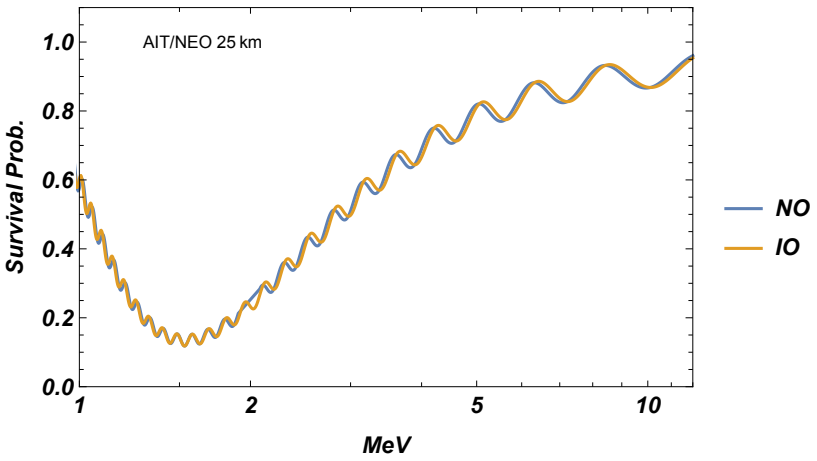


## We will now calculate spectra for various distances including Oscillations.

### First we plot the oscillations at 25 km for Watchman, 53 km for JUNO distance, and 200 km for detector at Pottipuram. For each the pair of curves are for NO, and IO.

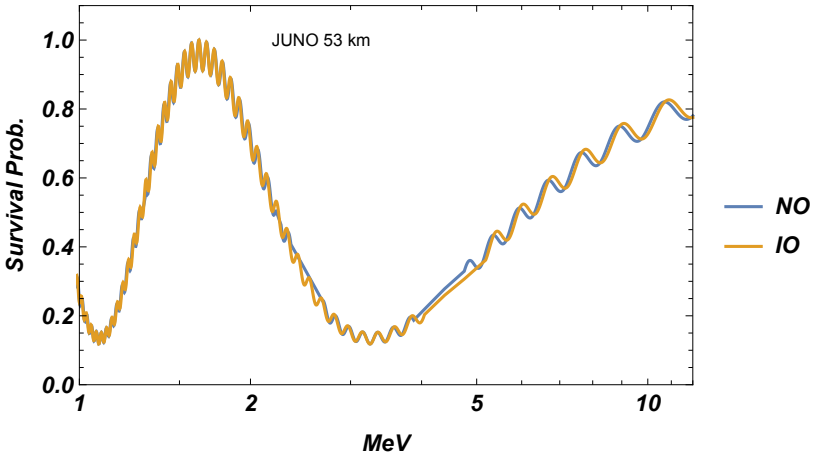
In[69]:=
```
LogLinearPlot[{Petoe[x, 25000, 7.6 * 10^-5, 0.0025, Pi/4, Pi * 34.01/180, 0.15, 0],
  Petoe[x, 25000, -7.6 * 10^-5, 0.0025, Pi/4, Pi * 34.01/180, 0.15, 0]},
 {x, 0.2, 12}, PlotRange → {{1., 12}, {0, 1.1}}, Frame → True,
 FrameLabel → {"MeV", "Survival Prob."} , FrameStyle → Bold,
 LabelStyle → {Bold, Medium, Italic} , PlotLegends → {"NO", "IO"},
 Epilog → Inset["AIT/NEO 25km", {0.5, 1}]]
```

Out[69]=



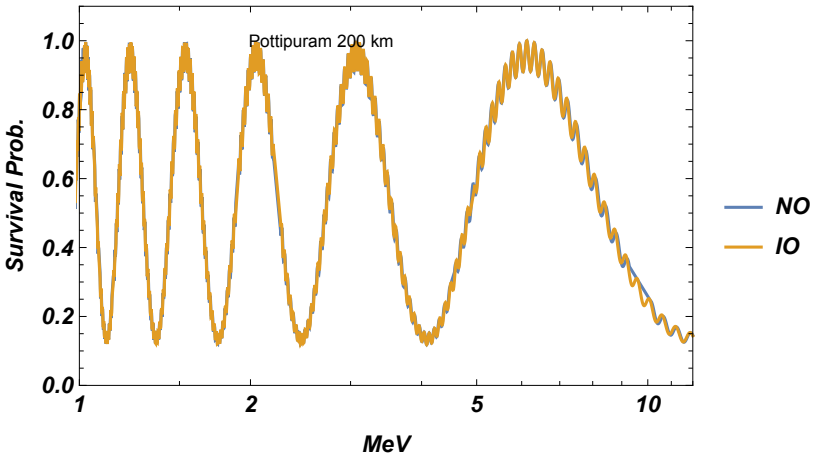
In[70]:=
```
LogLinearPlot[{Petoe[x, 53 000, 7.6 * 10^-5, 0.0025, Pi / 4, Pi * 34.01 / 180, 0.15, 0],
  Petoe[x, 53 000, -7.6 * 10^-5, 0.0025, Pi / 4, Pi * 34.01 / 180, 0.15, 0]},
 {x, 0.2, 12}, PlotRange → {{1, 12}, {0, 1.1}}, Frame → True,
 FrameLabel → {"MeV", "Survival Prob."} , FrameStyle → Bold,
 LabelStyle → {Bold, Medium, Italic} , PlotLegends → {"NO", "IO"},
 Epilog → Inset["JUNO 53 km", {0.98, 1}]]
```

Out[70]=




In[71]:=
```
LogLinearPlot[{Petoe[x, 200 000, 7.6 * 10^-5, 0.0025, Pi / 4, Pi * 34.01 / 180, 0.15, 0],
  Petoe[x, 200 000, -7.6 * 10^-5, 0.0025, Pi / 4, Pi * 34.01 / 180, 0.15, 0]},
 {x, 0.2, 12}, PlotRange → {{1., 12}, {0, 1.1}}, Frame → True,
 FrameLabel → {"MeV", "Survival Prob."} , FrameStyle → Bold,
 LabelStyle → {Bold, Medium, Italic} , PlotLegends → {"NO", "IO"},
 Epilog → Inset["Pottipuram 200 km", {0.98, 1}]]
```

Out[71]=




Now we calculate the event rate at these various locations. But for each case the detector size the the reactor power are different. And so, we will make a table.

For each, we plot the spectrum with and without oscillations per year. And

calculate the event rate per year with and without oscillations.

AIT/NEO: 1000 ton, 25 km, 3 GW thermal. 360 days
JUNO: 35000 to, 53 km, 17 GW thermal, 360 days
Pottupuram: 1000 ton, 2000 km, 17 GW thermal .360 days

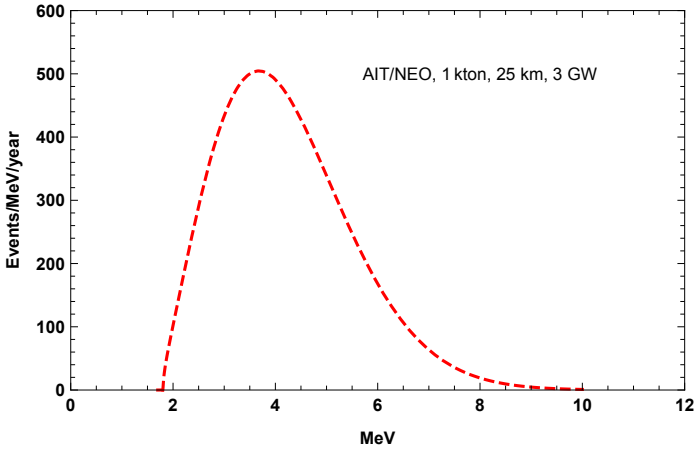
In[100]:=
```
dist = 25;  tons = 1000; pow = 3; days = 360;
TableForm[Table[
  {th, NIntegrate[(1/dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 * CrossIBD[x] *
     TargetNucleons * HydrogenFraction, {x, th, 12}],
   NIntegrate[
    (1/dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 *
     CrossIBD[x] * TargetNucleons * HydrogenFraction * Petoe[x, dist * 1000,
      7.6 * 10^-5, 0.0025, Pi/4, Pi * 34.01/180, 0.15, 0], {x, th, 12}],
   NIntegrate[(1/dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 *
     CrossIBD[x] * TargetNucleons * HydrogenFraction * Petoe[x, dist * 1000,
      -7.6 * 10^-5, 0.0025, Pi/4, Pi * 34.01/180, 0.15, 0], {x, th, 12}]
  }, {th, 1.8, 9.8, 1}], TableHeadings → {None,
   {"AIT/NEO thres (MeV)", "Events/year", "With Osc/NO", "With Osc/IO"} }]
```

Out[101]//TableForm=

| AIT/NEO thres (MeV) | Events/year | With Osc/NO | With Osc/IO |
|---|---|---|---|
| 1.8 | 1615.63 | 1075.26 | 1075.27 |
| 2.8 | 1402.83 | 994.075 | 994.585 |
| 3.8 | 933.116 | 716.9 | 716.158 |
| 4.8 | 481.479 | 395.199 | 395.053 |
| 5.8 | 196.884 | 168.849 | 168.236 |
| 6.8 | 64.9324 | 55.7542 | 55.7739 |
| 7.8 | 17.5061 | 15.9785 | 15.9213 |
| 8.8 | 3.89668 | 3.48082 | 3.51763 |
| 9.8 | 0.717482 | 0.630997 | 0.629483 |

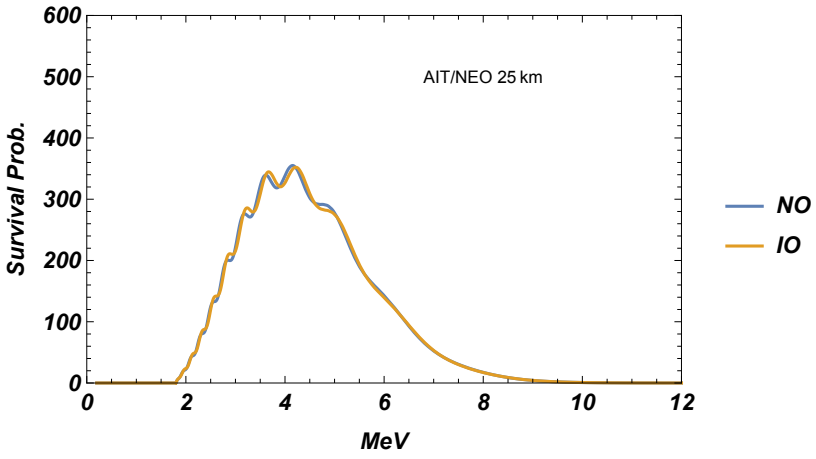
In[102]:=
```
pltait = Plot[(1/dist^2) * tons * pow * days * AnueFunc[x] *
   10^-4 * CrossIBD[x] * TargetNucleons * HydrogenFraction, {x, 1.7, 10.},
  PlotRange → {{0, 12.}, {0, 600}}, LabelStyle → {GrayLevel[0], Bold},
  PlotStyle → {Red, Dashed}, Frame → True, FrameLabel → {"MeV", "Events/MeV/year"},
  Epilog → Inset["AIT/NEO, 1kton, 25 km, 3 GW", {8, 500}]]
```

Out[102]=



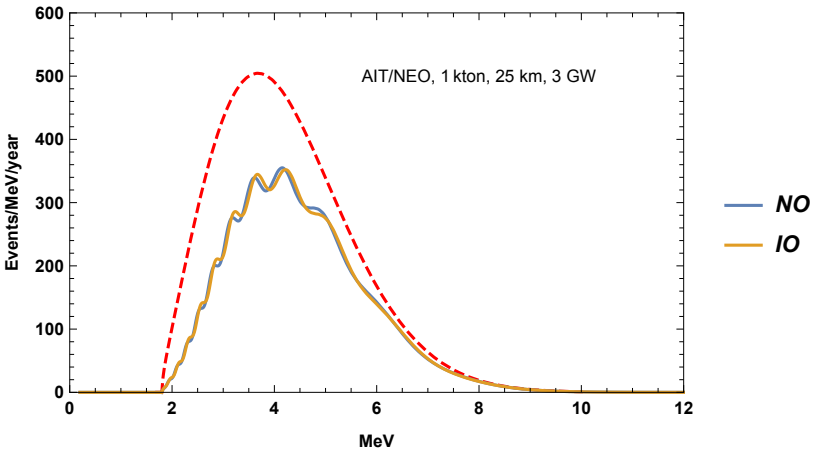

In[103]:=
```
plaitos = Plot[{
   (1/dist^2) * tons * pow * days *
    AnueFunc[x] * 10^-4 * CrossIBD[x] * TargetNucleons * HydrogenFraction *
    Petoe[x, dist * 1000, 7.6 * 10^-5, 0.0025, Pi/4, Pi * 34.01/180, 0.15, 0],
   (1/dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 *
    CrossIBD[x] * TargetNucleons * HydrogenFraction *
    Petoe[x, dist * 1000, -7.6 * 10^-5, 0.0025, Pi/4, Pi * 34.01/180, 0.15, 0]},
  {x, 0.2, 12}, PlotRange → {{0., 12}, {0, 600}}, Frame → True,
  FrameLabel → {"MeV", "Survival Prob."}, FrameStyle → Bold,
  LabelStyle → {Bold, Medium, Italic}, PlotLegends → {"NO", "IO"},
  Epilog → Inset["AIT/NEO 25km", {8, 500}]]
```

Out[103]=



In[104]:=
```
Show[pltait, plaitos]
```

Out[104]=



In[105]:=
```
dist = 53;  tons = 35 000; pow = 17; days = 360;
TableForm[Table[
  {th, NIntegrate[(1 / dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 * CrossIBD[x] *
     TargetNucleons * HydrogenFraction, {x, th, 12}],
   NIntegrate[
    (1 / dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 *
     CrossIBD[x] * TargetNucleons * HydrogenFraction * Petoe[x, dist * 1000,
      7.6 * 10^-5, 0.0025, Pi / 4, Pi * 34.01 / 180, 0.15, 0], {x, th, 12}],
   NIntegrate[(1 / dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 *
     CrossIBD[x] * TargetNucleons * HydrogenFraction * Petoe[x, dist * 1000,
      -7.6 * 10^-5, 0.0025, Pi / 4, Pi * 34.01 / 180, 0.15, 0], {x, th, 12}]
  }, {th, 1.8, 9.8, 1}], TableHeadings → {None,
   {"JUNO thres (MeV)", "Events/year", "With Osc/NO", "With Osc/IO"} }]
```

NIntegrate: NIntegrate failed to converge to prescribed accuracy after 9 recursive bisections in x near {x} = {1.812336445696264}. NIntegrate obtained 21169.82091850765` and 0.02708345027855914` for the integral and error estimates.

NIntegrate: NIntegrate failed to converge to prescribed accuracy after 9 recursive bisections in x near {x} = {1.812336445696264}. NIntegrate obtained 21169.90743204888` and 0.02618264272838522` for the integral and error estimates.

NIntegrate: NIntegrate failed to converge to prescribed accuracy after 9 recursive bisections in x near {x} = {4.124960061523923582349482330755563452839851379394531250000000000000}. NIntegrate obtained 14619.91409626838` and 0.025426758749132333` for the integral and error estimates.

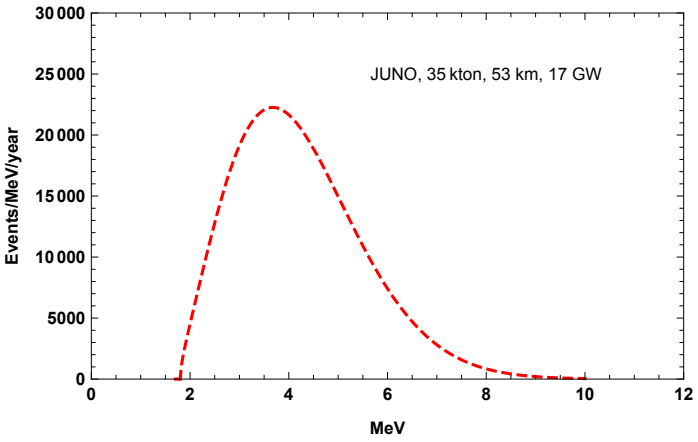
General: Further output of NIntegrate::ncvb will be suppressed during this calculation.

Out[106]//TableForm=

| JUNO thres (MeV) | Events/year | With Osc/NO | With Osc/IO |
|---|---|---|---|
| 1.8 | 71 296.2 | 21 169.8 | 21 169.9 |
| 2.8 | 61 905.6 | 17 712.7 | 17 709.2 |
| 3.8 | 41 177.5 | 14 610.1 | 14 619.9 |
| 4.8 | 21 247.2 | 9731.35 | 9745.95 |
| 5.8 | 8688.29 | 4817.48 | 4818.78 |
| 6.8 | 2865.4 | 1785.6 | 1795.88 |
| 7.8 | 772.526 | 525.173 | 529.339 |
| 8.8 | 171.957 | 127.294 | 128.323 |
| 9.8 | 31.6617 | 24.421 | 24.0748 |

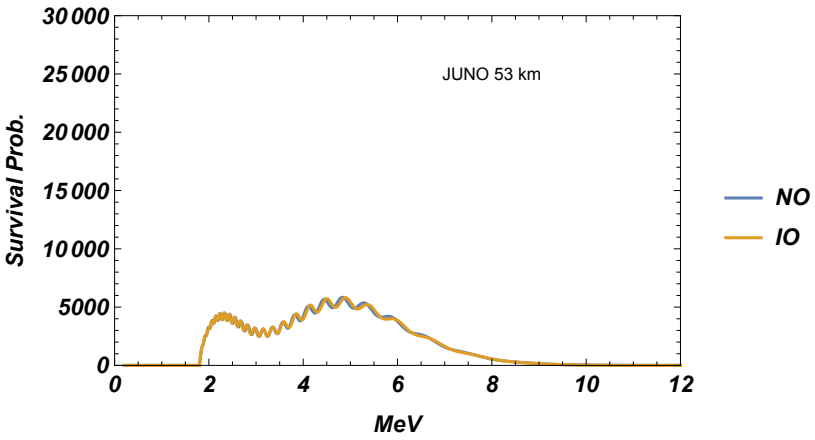
In[111]:=
```
pltjuno = Plot[(1 / dist^2) * tons * pow * days * AnueFunc[x] *
   10^-4 * CrossIBD[x] * TargetNucleons * HydrogenFraction, {x, 1.7, 10.},
  PlotRange → {{0, 12.}, {0, 30000}}, LabelStyle → {GrayLevel[0], Bold},
  PlotStyle → {Red, Dashed}, Frame → True, FrameLabel → {"MeV", "Events/MeV/year"},
  Epilog → Inset["JUNO, 35kton, 53 km, 17 GW", {8, 25000}]]
```

Out[111]=



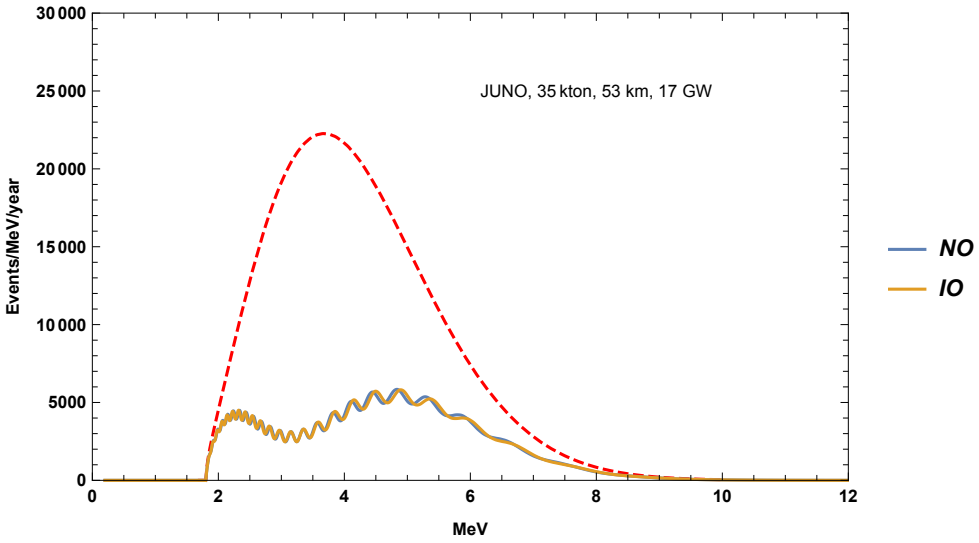

In[113]:=
```
pljunoos = Plot[{
   (1 / dist^2) * tons * pow * days *
    AnueFunc[x] * 10^-4 * CrossIBD[x] * TargetNucleons * HydrogenFraction *
    Petoe[x, dist * 1000, 7.6 * 10^-5, 0.0025, Pi / 4, Pi * 34.01 / 180, 0.15, 0],
   (1 / dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 *
    CrossIBD[x] * TargetNucleons * HydrogenFraction *
    Petoe[x, dist * 1000, -7.6 * 10^-5, 0.0025, Pi / 4, Pi * 34.01 / 180, 0.15, 0]},
  {x, 0.2, 12}, PlotRange → {{0., 12}, {0, 30000}}, Frame → True,
  FrameLabel → {"MeV", "Survival Prob."}, FrameStyle → Bold,
  LabelStyle → {Bold, Medium, Italic}, PlotLegends → {"NO", "IO"},
  Epilog → Inset["JUNO 53 km", {8, 25000}]]
```

Out[113]=



In[114]:=
```
Show[pltjuno, pljunoos]
```

Out[114]=



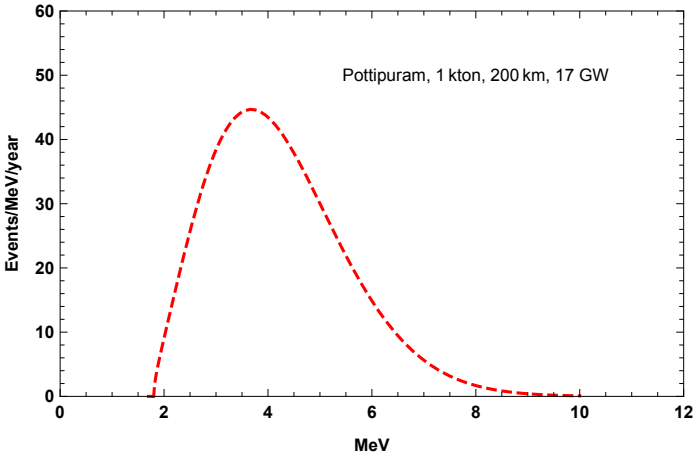

In[115]:=
```
dist = 200;  tons = 1000; pow = 17; days = 360;
TableForm[Table[
  {th, NIntegrate[(1/dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 * CrossIBD[x] *
     TargetNucleons * HydrogenFraction, {x, th, 12}],
   NIntegrate[
    (1/dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 *
     CrossIBD[x] * TargetNucleons * HydrogenFraction * Petoe[x, dist * 1000,
      7.6 * 10^-5, 0.0025, Pi/4, Pi * 34.01/180, 0.15, 0], {x, th, 12}],
   NIntegrate[(1/dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 *
     CrossIBD[x] * TargetNucleons * HydrogenFraction * Petoe[x, dist * 1000,
      -7.6 * 10^-5, 0.0025, Pi/4, Pi * 34.01/180, 0.15, 0], {x, th, 12}]
  }, {th, 1.8, 9.8, 1}], TableHeadings → {None,
   {"Pottipuram thres (MeV)", "Events/year", "With Osc/NO", "With Osc/IO"} }]
```

Out[116]//TableForm=

| Pottipuram thres (MeV) | Events/year | With Osc/NO | With Osc/IO |
|---|---|---|---|
| 1.8 | 143.051 | 78.88 | 78.88 |
| 2.8 | 124.209 | 70.7026 | 70.7046 |
| 3.8 | 82.6197 | 42.2753 | 42.2722 |
| 4.8 | 42.631 | 33.1785 | 33.1911 |
| 5.8 | 17.4324 | 15.0523 | 15.0553 |
| 6.8 | 5.74922 | 4.07976 | 4.08045 |
| 7.8 | 1.55002 | 0.772369 | 0.769931 |
| 8.8 | 0.345019 | 0.112289 | 0.111426 |
| 9.8 | 0.063527 | 0.0133325 | 0.0134335 |

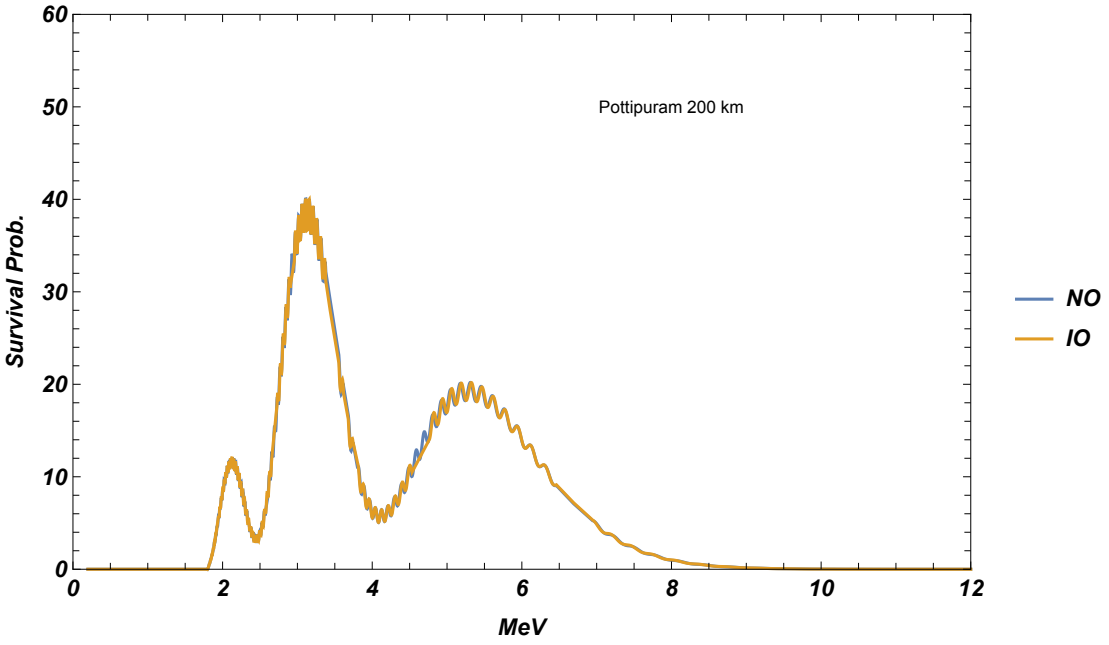
In[122]:=
```
pltpotti = Plot[(1/dist^2) * tons * pow * days * AnueFunc[x] *
    10^-4 * CrossIBD[x] * TargetNucleons * HydrogenFraction, {x, 1.7, 10.},
  PlotRange → {{0, 12.}, {0, 60}}, LabelStyle → {GrayLevel[0], Bold},
  PlotStyle → {Red, Dashed}, Frame → True, FrameLabel → {"MeV", "Events/MeV/year"},
  Epilog → Inset["Pottipuram, 1kton, 200km, 17 GW", {8, 50}]]
```

Out[122]=



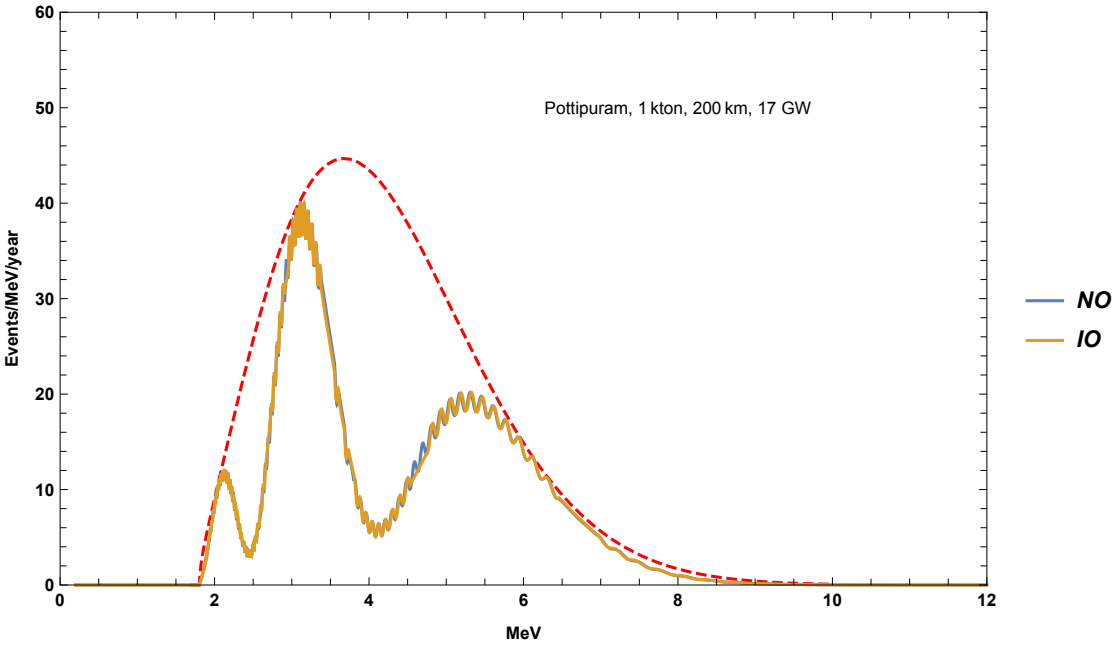
In[124]:=
```
plpottios = Plot[{
    (1 / dist^2) * tons * pow * days *
     AnueFunc[x] * 10^-4 * CrossIBD[x] * TargetNucleons * HydrogenFraction *
     Petoe[x, dist * 1000, 7.6 * 10^-5, 0.0025, Pi / 4, Pi * 34.01 / 180, 0.15, 0],
    (1 / dist^2) * tons * pow * days * AnueFunc[x] * 10^-4 *
     CrossIBD[x] * TargetNucleons * HydrogenFraction *
     Petoe[x, dist * 1000, -7.6 * 10^-5, 0.0025, Pi / 4, Pi * 34.01 / 180, 0.15, 0]},
  {x, 0.2, 12}, PlotRange → {{0., 12}, {0, 60}}, Frame → True,
  FrameLabel → {"MeV", "Survival Prob."} , FrameStyle → Bold,
  LabelStyle → {Bold, Medium, Italic} , PlotLegends → {"NO", "IO"},
  Epilog → Inset["Pottipuram 200 km", {8, 50}]]
```

Out[124]=



In[125]:=
```
Show[pltpotti, plpottios]
```

Out[125]=




This is the calculation of the cross section from another notebook. This was calculated from first principles. Check the notebook IBD-crosssection for the calculation.

In[53]:=
```
CTabulate = {{0.`, 0}, {0.01`, 0}, {0.02`, 0}, {0.03`, 0}, {0.04`, 0}, {0.05`, 0},
    {0.06`, 0}, {0.07`, 0}, {0.08`, 0}, {0.09`, 0}, {0.1`, 0}, {0.11`, 0}, {0.12`, 0},
    {0.13`, 0}, {0.14`, 0}, {0.15`, 0}, {0.16`, 0}, {0.17`, 0}, {0.18`, 0},
    {0.19`, 0}, {0.2`, 0}, {0.21`, 0}, {0.22`, 0}, {0.23`, 0}, {0.24`, 0}, {0.25`, 0},
    {0.26`, 0}, {0.27`, 0}, {0.28`, 0}, {0.29`, 0}, {0.3`, 0}, {0.31`, 0}, {0.32`, 0},
    {0.33`, 0}, {0.34`, 0}, {0.35000000000000003`, 0}, {0.36`, 0}, {0.37`, 0},
    {0.38`, 0}, {0.39`, 0}, {0.4`, 0}, {0.41000000000000003`, 0}, {0.42`, 0},
    {0.43`, 0}, {0.44`, 0}, {0.45`, 0}, {0.46`, 0}, {0.47000000000000003`, 0},
    {0.48`, 0}, {0.49`, 0}, {0.5`, 0}, {0.51`, 0}, {0.52`, 0}, {0.53`, 0},
    {0.54`, 0}, {0.55`, 0}, {0.56`, 0}, {0.5700000000000001`, 0}, {0.58`, 0},
    {0.59`, 0}, {0.6`, 0}, {0.61`, 0}, {0.62`, 0}, {0.63`, 0}, {0.64`, 0},
    {0.65`, 0}, {0.66`, 0}, {0.67`, 0}, {0.68`, 0}, {0.6900000000000001`, 0},
    {0.7000000000000001`, 0}, {0.71`, 0}, {0.72`, 0}, {0.73`, 0}, {0.74`, 0},
    {0.75`, 0}, {0.76`, 0}, {0.77`, 0}, {0.78`, 0}, {0.79`, 0}, {0.8`, 0}, {0.81`, 0},
    {0.8200000000000001`, 0}, {0.8300000000000001`, 0}, {0.84`, 0}, {0.85`, 0},
    {0.86`, 0}, {0.87`, 0}, {0.88`, 0}, {0.89`, 0}, {0.9`, 0}, {0.91`, 0}, {0.92`, 0},
    {0.93`, 0}, {0.9400000000000001`, 0}, {0.9500000000000001`, 0}, {0.96`, 0},
    {0.97`, 0}, {0.98`, 0}, {0.99`, 0}, {1.`, 0}, {1.01`, 0}, {1.02`, 0}, {1.03`, 0},
    {1.04`, 0}, {1.05`, 0}, {1.06`, 0}, {1.07`, 0}, {1.08`, 0}, {1.09`, 0}, {1.1`, 0},
    {1.11`, 0}, {1.12`, 0}, {1.1300000000000001`, 0}, {1.1400000000000001`, 0},
```

```
{1.1500000000000001`, 0}, {1.16`, 0}, {1.17`, 0}, {1.18`, 0}, {1.19`, 0},
{1.2`, 0}, {1.21`, 0}, {1.22`, 0}, {1.23`, 0}, {1.24`, 0}, {1.25`, 0}, {1.26`, 0},
{1.27`, 0}, {1.28`, 0}, {1.29`, 0}, {1.3`, 0}, {1.31`, 0}, {1.32`, 0}, {1.33`, 0},
{1.34`, 0}, {1.35`, 0}, {1.36`, 0}, {1.37`, 0}, {1.3800000000000001`, 0},
{1.3900000000000001`, 0}, {1.4000000000000001`, 0}, {1.41`, 0}, {1.42`, 0},
{1.43`, 0}, {1.44`, 0}, {1.45`, 0}, {1.46`, 0}, {1.47`, 0}, {1.48`, 0},
{1.49`, 0}, {1.5`, 0}, {1.51`, 0}, {1.52`, 0}, {1.53`, 0}, {1.54`, 0}, {1.55`, 0},
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{1.6600000000000001`, 0}, {1.67`, 0}, {1.68`, 0}, {1.69`, 0}, {1.7`, 0},
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{3.16`, 3.1565116220169773`*^-43}, {3.17`, 3.1915644635622053`*^-43},
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{3.18`, 3.2267998526634153`*^-43}, {3.19`, 3.2622177553503557`*^-43},
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{3.22`, 3.36956620099254`*^-43}, {3.23`, 3.405713812745606`*^-43},
{3.24`, 3.4420437641337165`*^-43}, {3.25`, 3.478556019609859`*^-43},
{3.2600000000000002`, 3.515250543394112`*^-43}, {3.27`,
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{3.29`, 3.626427363461431`*^-43}, {3.3000000000000003`,
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{3.38`, 3.969788446270828`*^-43}, {3.39`, 4.008849108867822`*^-43},
{3.4`, 4.048091518204652`*^-43}, {3.41`, 4.087515635783201`*^-43},
{3.42`, 4.1271214229658756`*^-43}, {3.43`, 4.1669088409798486`*^-43},
{3.44`, 4.206877850921058`*^-43}, {3.45`, 4.247028413758189`*^-43},
{3.46`, 4.287360490336364`*^-43}, {3.47`, 4.327874041380843`*^-43},
{3.48`, 4.368569027500525`*^-43}, {3.49`, 4.409445409191336`*^-43},
{3.5`, 4.450503146839528`*^-43}, {3.5100000000000002`, 4.491742200724821`*^-43},
{3.52`, 4.533162531023503`*^-43}, {3.5300000000000002`,
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{3.5500000000000003`, 4.658510780672358`*^-43},
{3.56`, 4.700655816419892`*^-43}, {3.5700000000000003`, 4.74298192801065`*^-43},
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{3.66`, 5.132058654752302`*^-43}, {3.67`, 5.176193290334422`*^-43},
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{3.7`, 5.309680796060892`*^-43}, {3.71`, 5.354537693423109`*^-43},
{3.72`, 5.399575052923663`*^-43}, {3.73`, 5.444792833121812`*^-43},
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{3.7600000000000002`, 5.581528282658033`*^-43},
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{3.8000000000000003`, 5.766365581545114`*^-43}, {3.81`,
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{3.83`, 5.906884618023158`*^-43}, {3.84`, 5.95408427567848`*^-43},
{3.85`, 6.0014638527345135`*^-43}, {3.86`, 6.049023307120092`*^-43},
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In[56]:=
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In[57]:=
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Out[57]=

