Nuclear Beta Spectroscopy of the Future: Creation of a ^{131m}Xe source

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Questioning the Standard Model

- Motivation: search for new physics beyond the standard model's description of the weak interaction
- SM shows a Hamiltonian with vectors and axial-vector current components
- New physics challenges this, proposes scalar and tensor current components
  - includes "chirality-flipping", right handed neutrinos

$$
\begin{aligned}
H = \overline{\Psi}_f \gamma^{\mu} \gamma_5 \Psi_i \quad & 2C_A \bar{e}^{L} \gamma_{\mu} \gamma_5 \nu_e^{L} + \\
\overline{\Psi}_f \sigma^{\mu\nu} \Psi_i \quad & \left[(C_T - C_T^{'}) \bar{e}^{L} \sigma_{\mu\nu} \nu_e^{R} + (C_T + C_T^{'}) \bar{e}^{R} \sigma_{\mu\nu} \nu_e^{L} \right]
\end{aligned}
$$

What are we looking for?

$$H = \overline{\Psi}_f \gamma^\mu \gamma_5 \Psi_i \quad 2C_A \overline{e}^L \gamma_\mu \gamma_5 \nu_e^L +$$
$$\overline{\Psi}_f \sigma^{\mu\nu} \Psi_i \quad \left[(C_T - C_T') \overline{e}^L \sigma_{\mu\nu} \nu_e^R + (C_T + C_T') \overline{e}^R \sigma_{\mu\nu} \nu_e^L \right]$$

$$dw = dw_0 \left[1 + a \frac{\overrightarrow{p_e}}{E_e} \cdot \frac{\overrightarrow{p_\nu}}{E_\nu} + b \frac{\Gamma m_e}{E_e} \right]$$

dw = decay rate

$$a \approx -\frac{1}{3} \frac{2|C_A|^2 - |C_T|^2 + |C_T'|^2}{2|C_A|^2 + |C_T|^2 + |C_T'|^2}$$

Electron-neutrino correlation

$$b \approx \pm \frac{\mathrm{Re}\left[2C_A \left(C_T + C_T' \right) \right]}{2|C_A|^2 + |C_T|^2 + |C_T'|^2}$$

Fierz interference

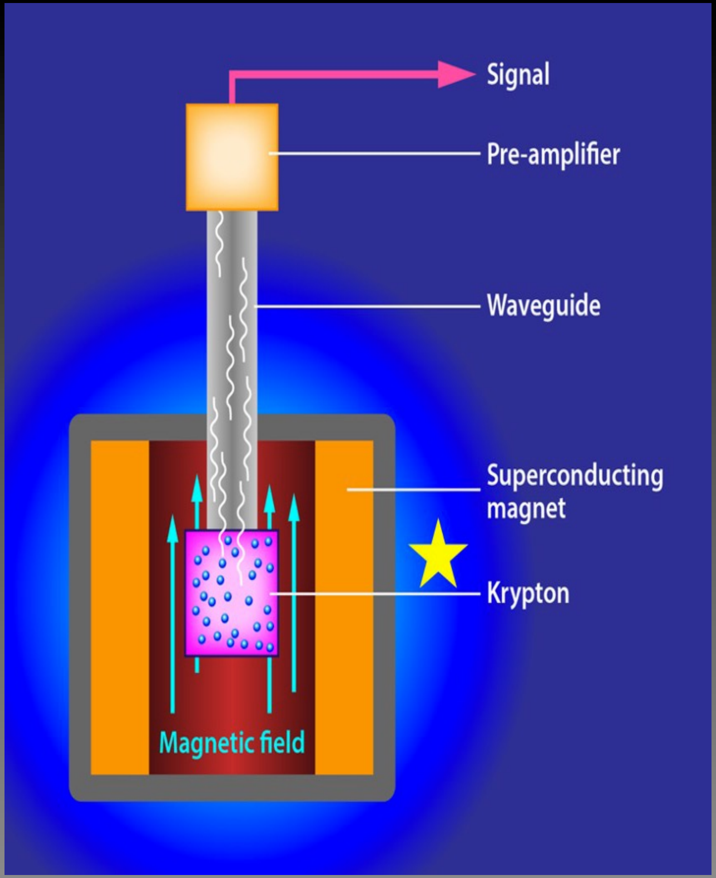
^{6}He Project

- High intensity source of ^{6}He delivers about 10^{10} ^{6}He atoms/s
- ^{6}He decay produces interactions that the standard model predicts to be purely axial
- Finding deviations from this SM prediction would point to the existence of tensor currents

Project 8 Collaboration

- Uses Cyclotron Radiation Emission Spectroscopy to determine the energies of beta emissions
- Measure beta spectrum for a gaseous Tritium source

Cyclotron Radiation Emission Spectroscopy (CRES)



- Electrons within a uniform magnetic field exhibit cyclotron motion at a frequency that can be used to determine the energy of the electron

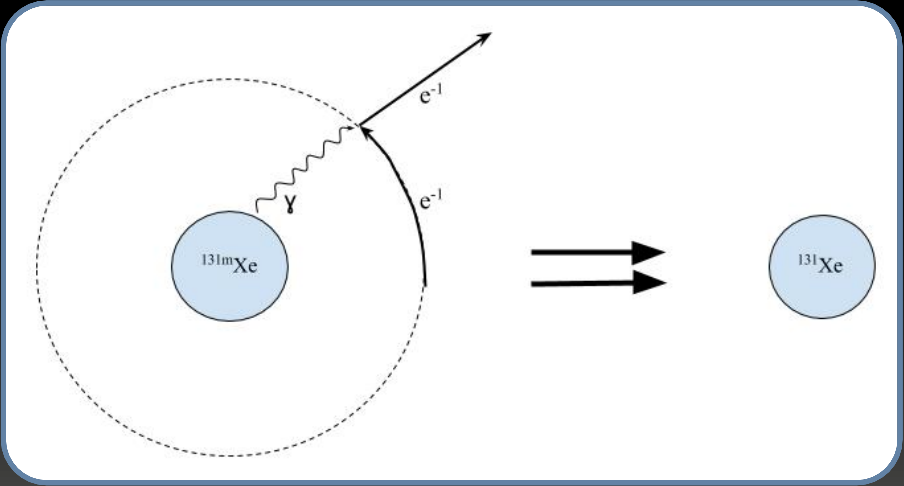
$$\omega = \frac{qB}{E}$$

Goal of my summer: create a calibration source to connect to the Project 8 apparatus

- CRES has the potential to lead to a more precise value of *b*
- Has been successful in measuring energy of particles between 18 and 32 keV, but what about higher energy electrons
- We want a source that:
  - Emitted monoenergetic electrons
  - Had a half-life longer than one day.
  - Emitted electrons with energies in the 30 keV range as well as above 100 keV
  - Fulfilled the above qualifications at a pressure compatible with the Project 8 apparatus.

^{131m}Xe

^{131m}Xe

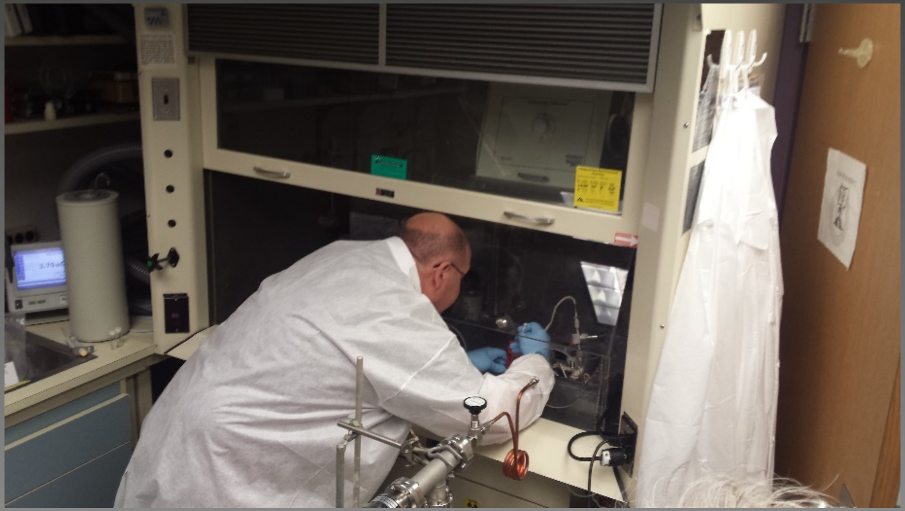


Shell	Binding Energy (keV)	Energy of Electron (keV)	Fraction (%)
K	34.9	129	60.7
L-M	3.9	~ 160	33.44
Auger Electron	–	25	4.4

- ^{131}I undergoes gamma decay to produce ^{131}Xe
- ~ 1% of these decays result in a metastable state of ^{131}Xe (^{131m}Xe) which has a half-life of 11.84 days
- As metastable ^{131}Xe decays, it releases conversion electrons
- Normally, this is done by neutron irradiation of Xe, but this gives sources with pressures of < 1 atm

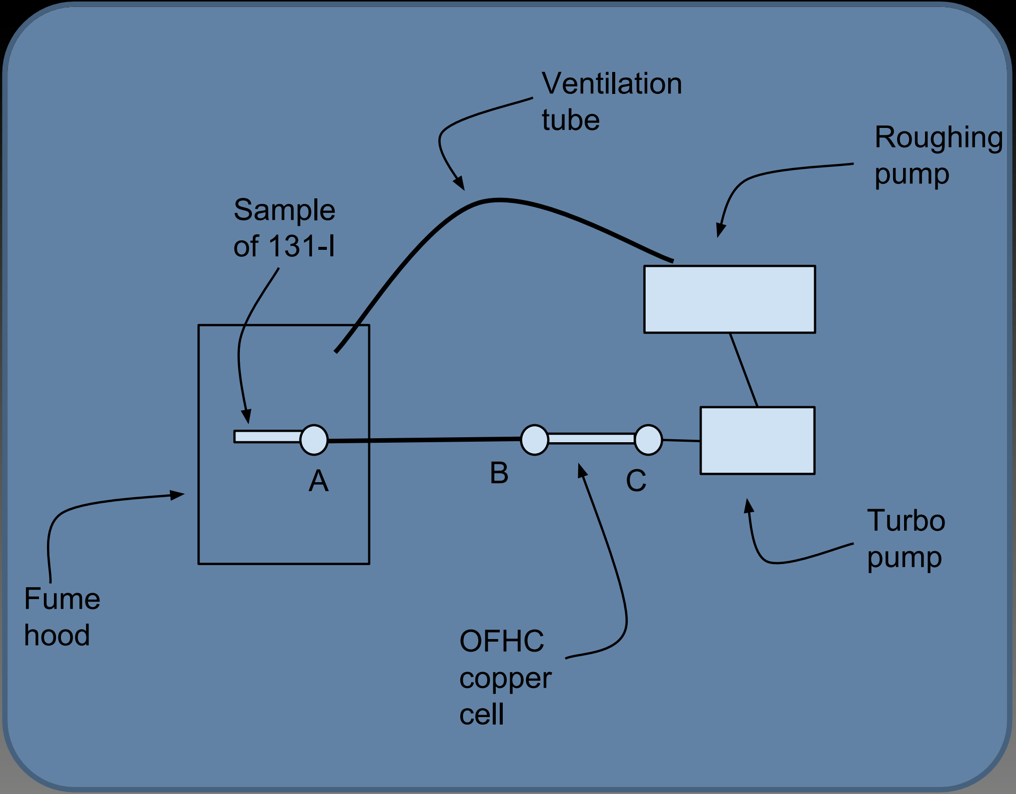
Step 1 – ^{131}Xe extraction

- Collaboration with Don Hamlin at the hospital
- Hospital setup for ^{131}I
- Ag zeolite for absorbing ^{131}I
- Zeolite: porous material used for absorbing radioactive waste



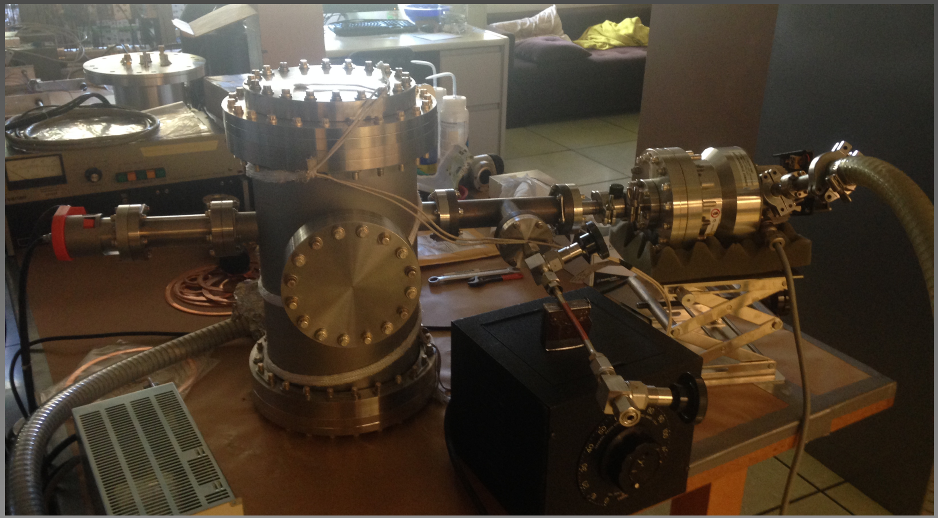
Hospital Setup and Procedure

- Pumped overnight with all valves (A, B, and C), achieved a vacuum of about mid 10^{-6} Torr
- Closed valve A
- After five days, turned off heat, closed valve C , open valve A
- Cell was cooled using liquid N_2 causing Xe to condense on the walls of the copper cell.
- Close valve B was closed
- Disconnect cell



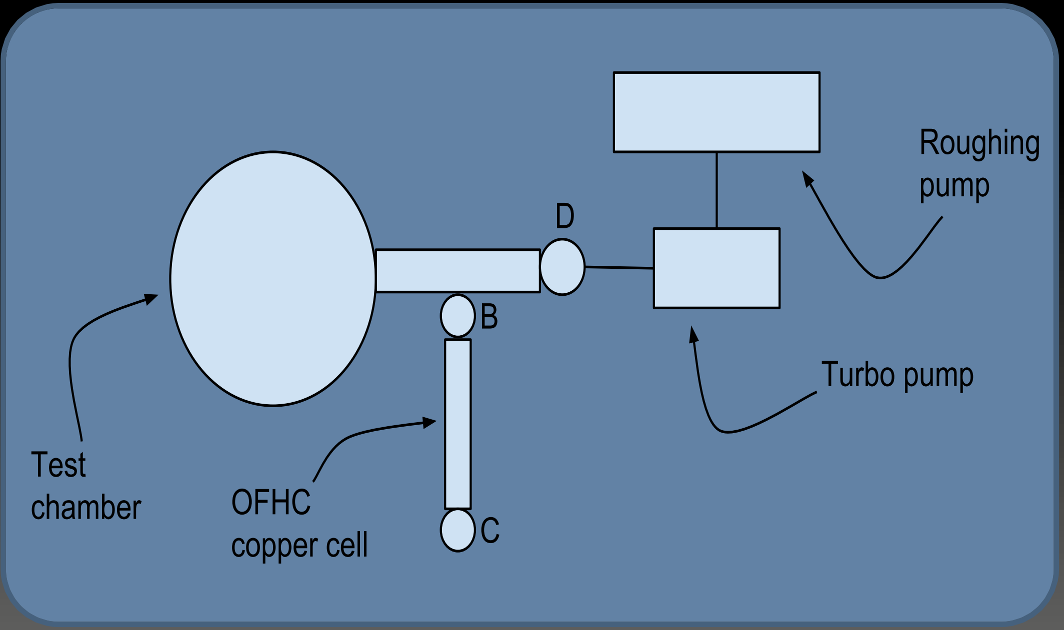
Step 2 – Test pressure inside cell

- Put cell in Ge detector in CENPA room 106
- Connect cell to test chamber to measure pressure within cell
- See if pressure would be compatible with project 8 setup
- Hoping for a pressure of 10^{-6} Torr



Counting Room Setup and Procedure

- Pumped and baked for several days to establish a baseline pressure of 10^{-6} Torr with valve D open
- Connected copper cell, closed valve D
- Opened valve B and released the contents of the copper cell into the test chamber
- The spike in the pressure reading of the test chamber α to the pressure within cell



We observed a pressure spike of 1×10^{-6} Torr within test chamber

Calculations – activity of ^{131}I

- Measured using hospital's Ge detector on June 13, 2016
- Efficiency of detector found using a ^{133}Ba source

$$\eta_{Barium} = \frac{\frac{dN}{dt}_{measured}}{\frac{dN}{dt}(Fraction)}$$

$$\frac{dN}{dt} = \frac{dN_{June\ 13}}{dt} e^{-\lambda T}$$

- Activity calculated to be 6.059 x 10^5 Bq on the day of extraction

$$\frac{dN}{dt}_{measured} = \eta \frac{dN}{dt}(Fraction)$$

Calculations – amount of ^{131}Xe

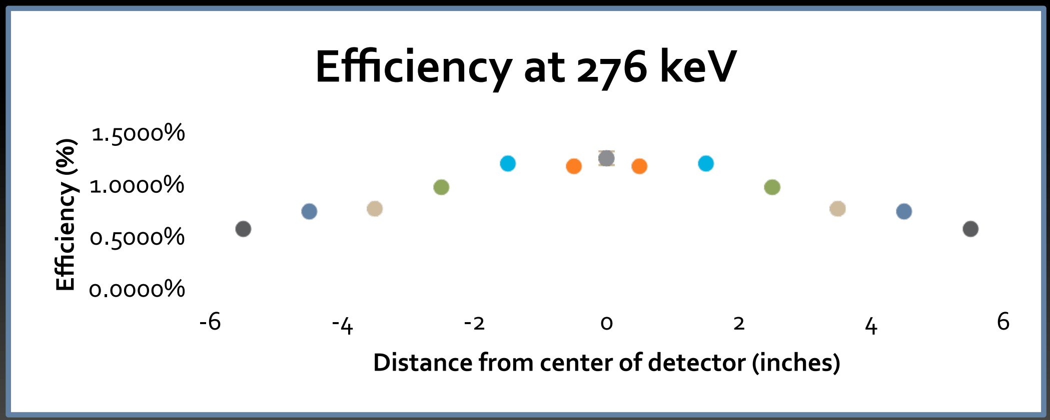
- Over period of 5 days, ^{131}I should generate 2.62×10^{11} molecules of Xe
- Test chamber was roughly 3000 times larger than cell
- Expected pressure inside cell: 1.680×10^{-6} Torr
- Expected pressure change in test chamber: 6.249×10^{-10} Torr

$$PV = NkT$$

Conclusions

- Pressure within chamber of 10^{-6} Torr means pressure within cell of 10^{-4} Torr
- There must have been materials inside the cell other than the ^{131}Xe
- This pressure, although greater than we expected, would still be compatible with the Project 8 set up.
- The getter pumps on the Project 8 apparatus should filter out any harmful material that may be in the cell.

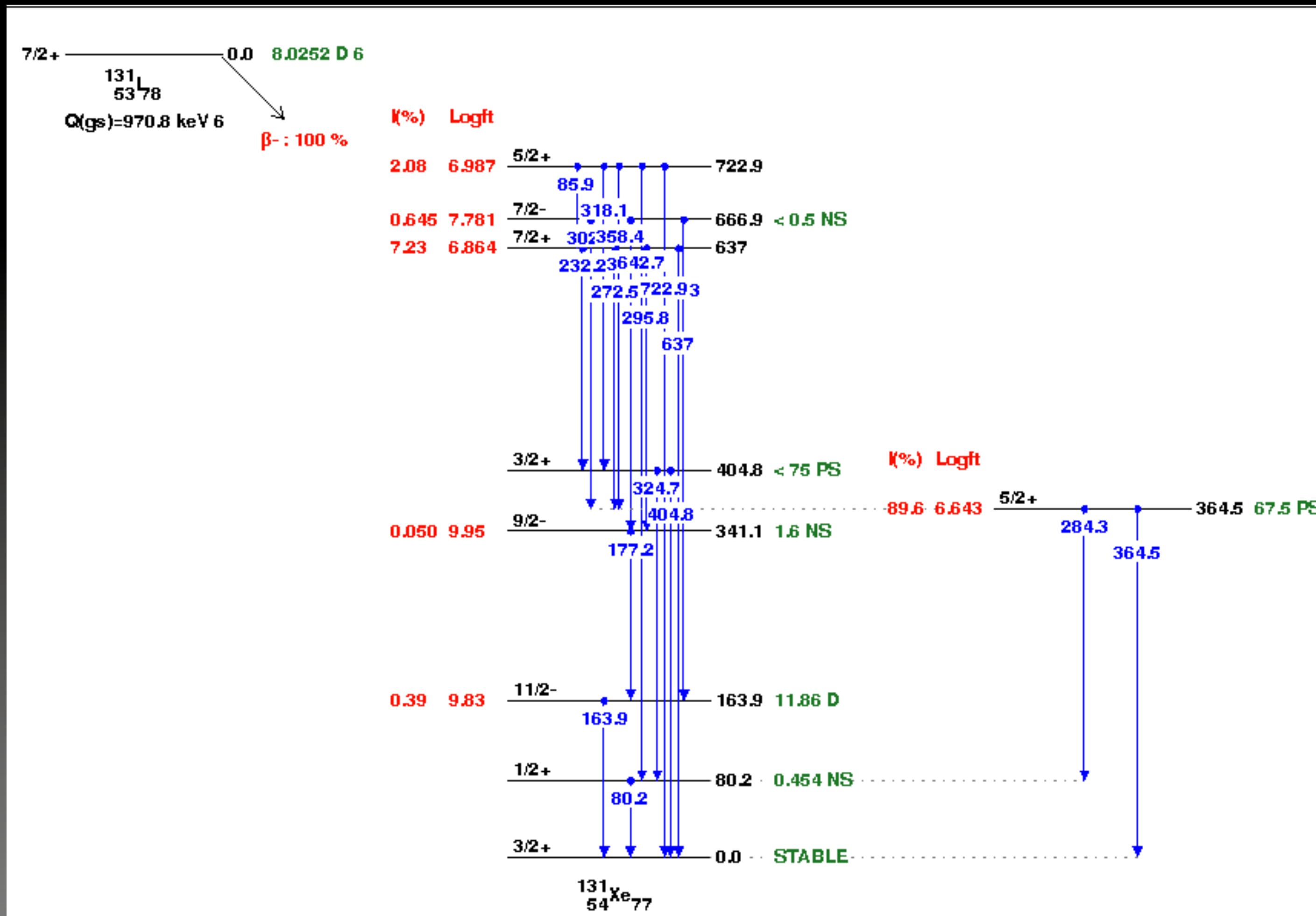
What's next?



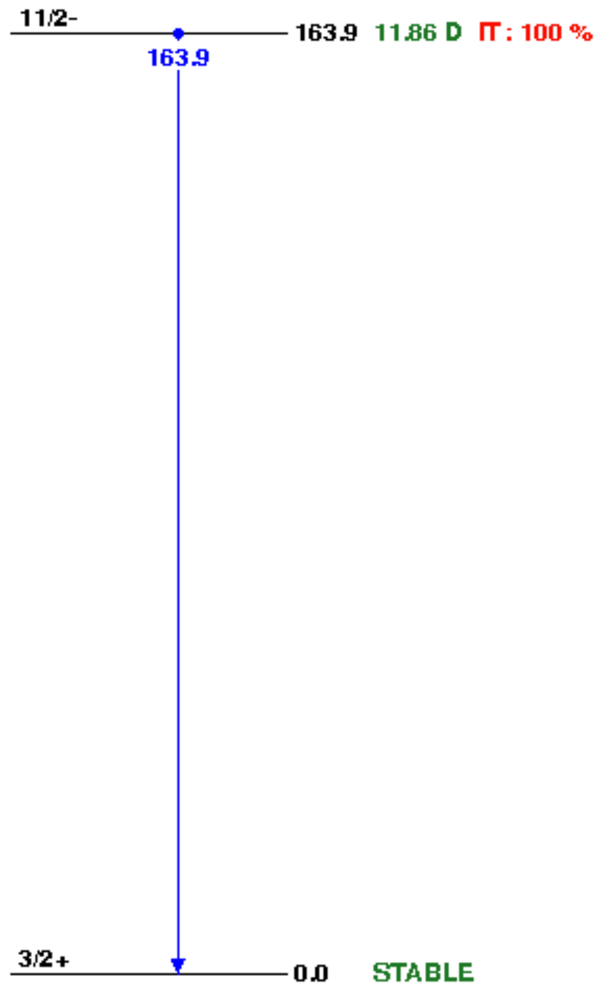
- Measurement of ^{131m}Xe source using Ge detector in room 106
- Connect source with Project 8 setup and test!

Thank you Alejandro and Arnaud!!

Any questions?



7/2+
0.0
8.0252 D 6
131 53 I 78
Q(gs)=970.8 keV 6
β- : 100 %
I(%) Logft
5/2+ 722.9
2.08 6.987
85.9
318.1
7/2- 666.9 < 0.5 NS
0.645 7.781
7/2+ 637
7.23 6.864
358.4
342.7
272.5
722.9
295.8
637
3/2+ 404.8 < 75 PS
324.7
404.8
9/2- 341.1 1.6 NS
0.050 9.95
177.2
I(%) Logft
5/2+ 364.5 67.5 PS
89.6 6.643
284.3
364.5
11/2- 163.9 11.86 D
0.39 9.83
163.9
1/2+ 80.2 0.454 NS
80.2
3/2+ 0.0 STABLE
131 54 Xe 77

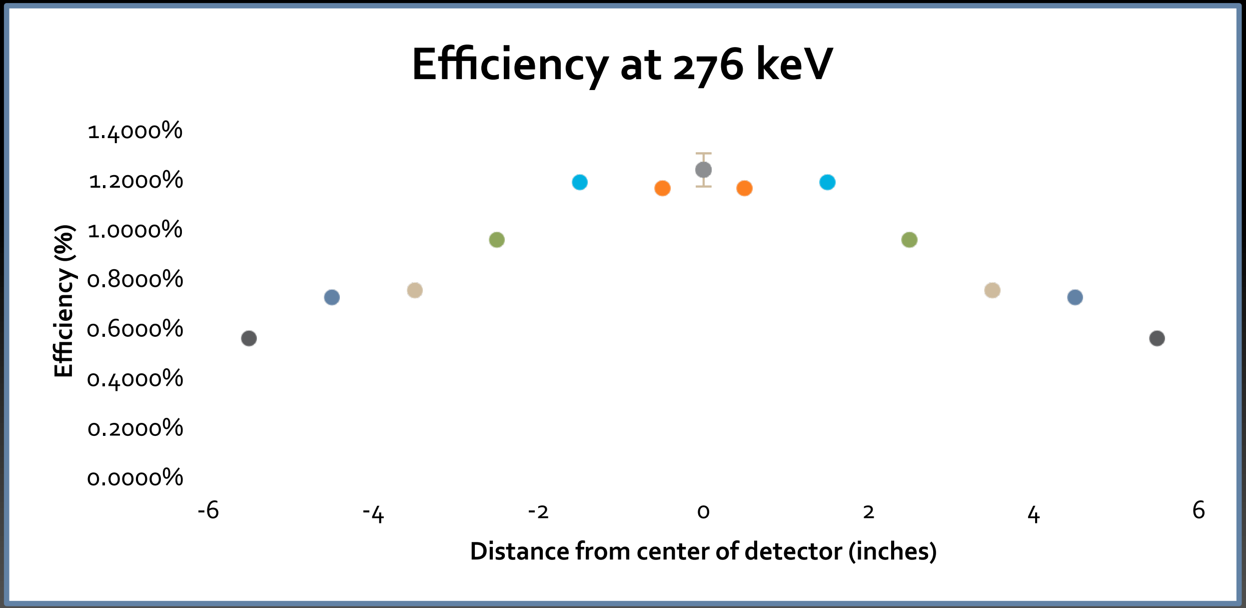

11/2-
163.9
11.86 D
IT : 100 %
163.9
3/2+
0.0
STABLE

Calculation of Ge detector Efficiency

$$N_1 = \sum_{C_1 - C_2} A_i$$

$$N_2 = \sum_{C_2 - C_3} A_i$$

$$N_3 = \sum_{C_3 - C_4} A_i$$



$$Background = \frac{\left[\frac{N_1}{C_2 - C_1}\right] + \left[\frac{N_3}{C_4 - C_3}\right]}{2} [C_3 - C_4]$$

$$Net\ area = N_2 - Background$$