Beta-Delayed Neutron Emission Using the Beta Paul Trap

Sabrina Strauss
University of Notre Dame

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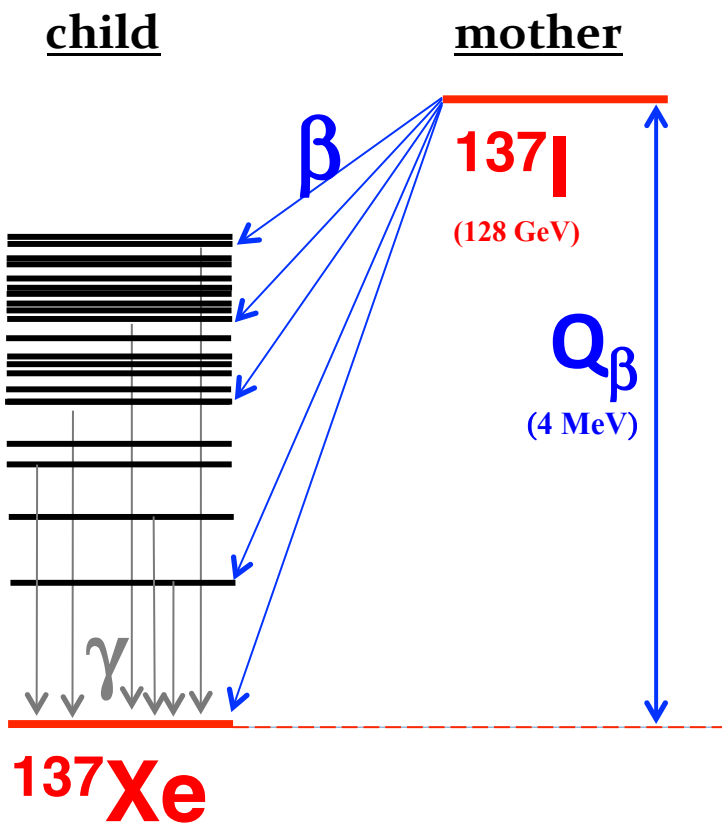
Beta-Decay

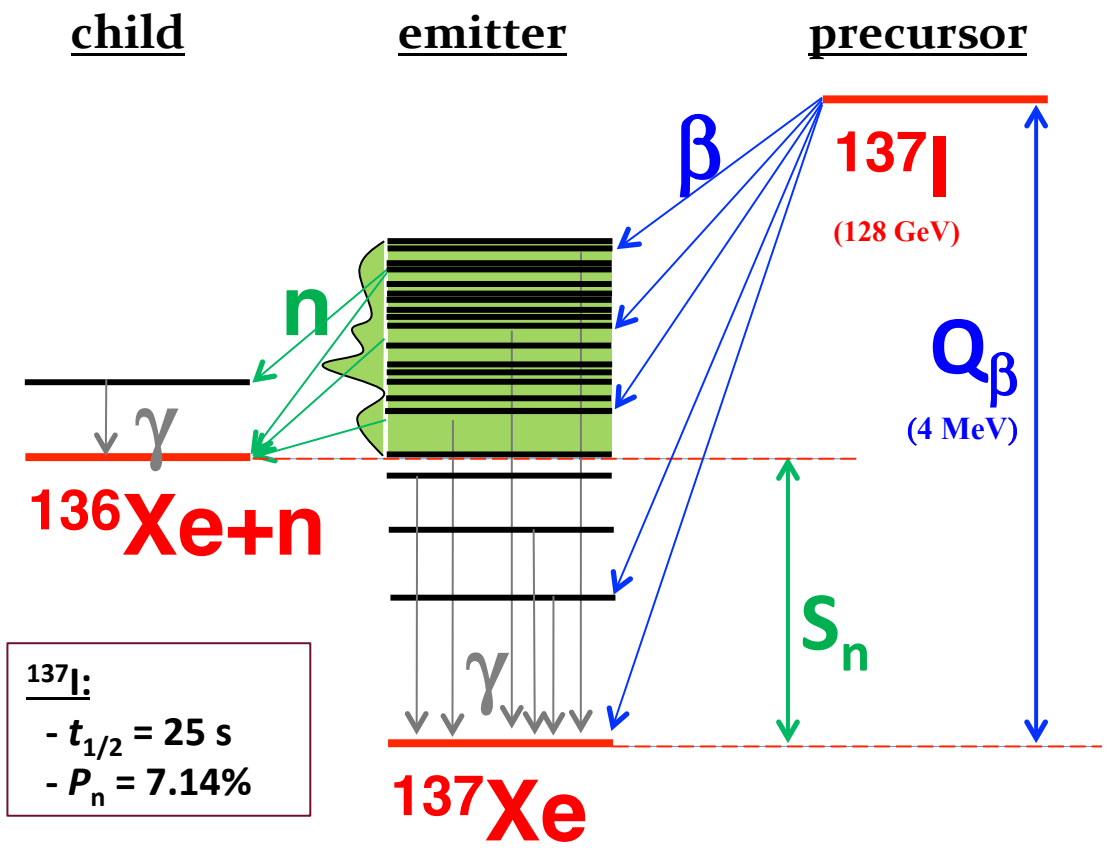


Q_β : Total energy released from beta decay through kinetic energy (β, ν, and daughter) and excitation energy (daughter)

^{137}I:

- $t_{1/2}$ = 25 s

Beta-Delayed Neutron Emission

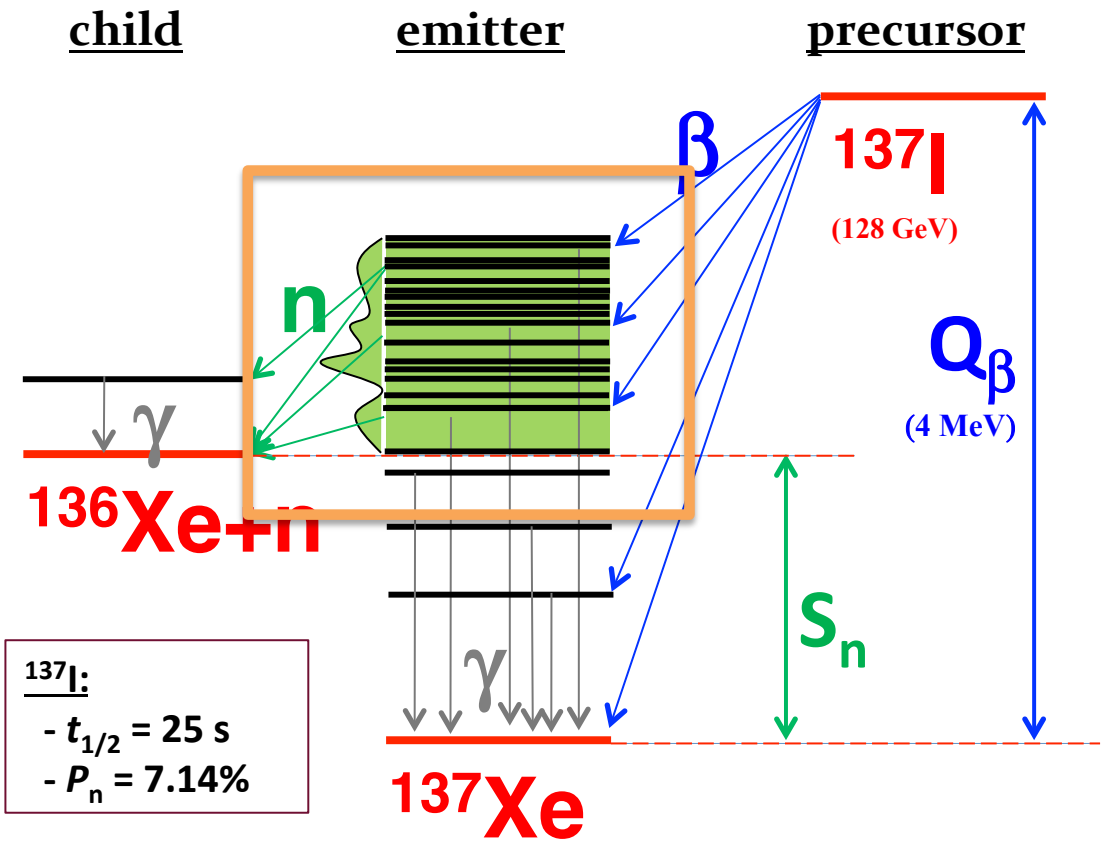


$Q_\beta > S_n$

Q_β : Total energy released from beta decay through kinetic energy (β, ν, and daughter) and excitation energy (daughter)

S_n: Difference in energy/ mass of a nucleus ^{A}X vs a free neutron + ^{A-1}X

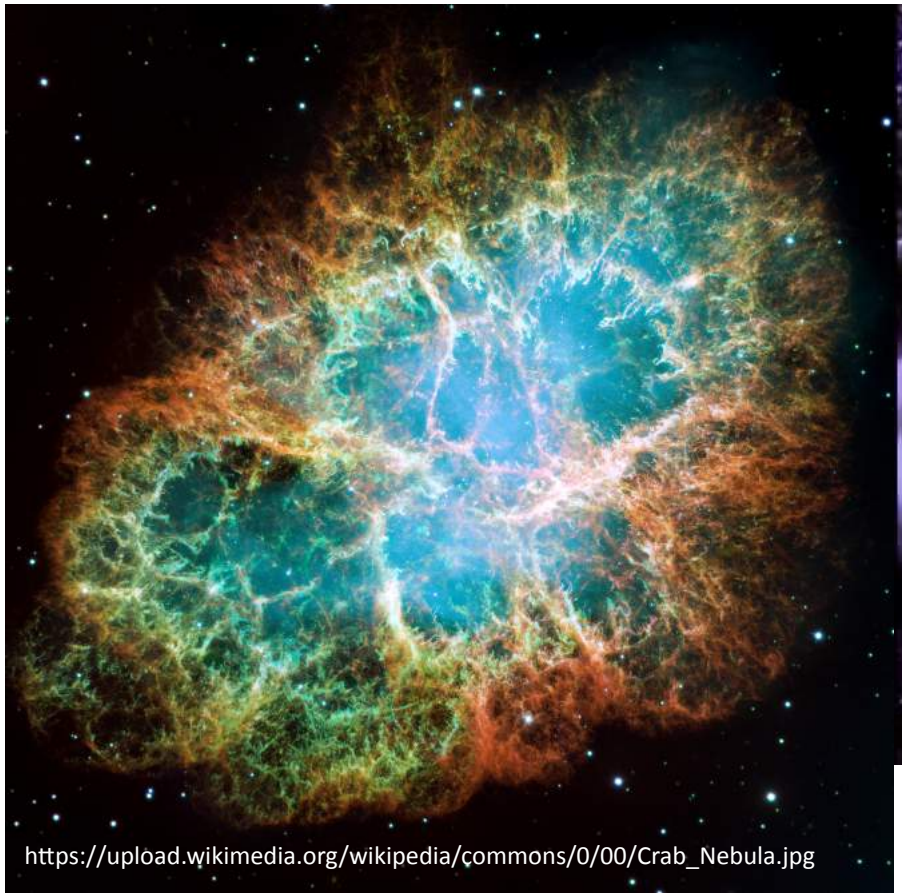
BDN: Two quantities to measure



P_n: The neutron emission probability.

E_n Spectrum: **The energy spectrum of the neutrons emitted. Different energy neutrons have different cross sections in reactions.**

How are the elements made?

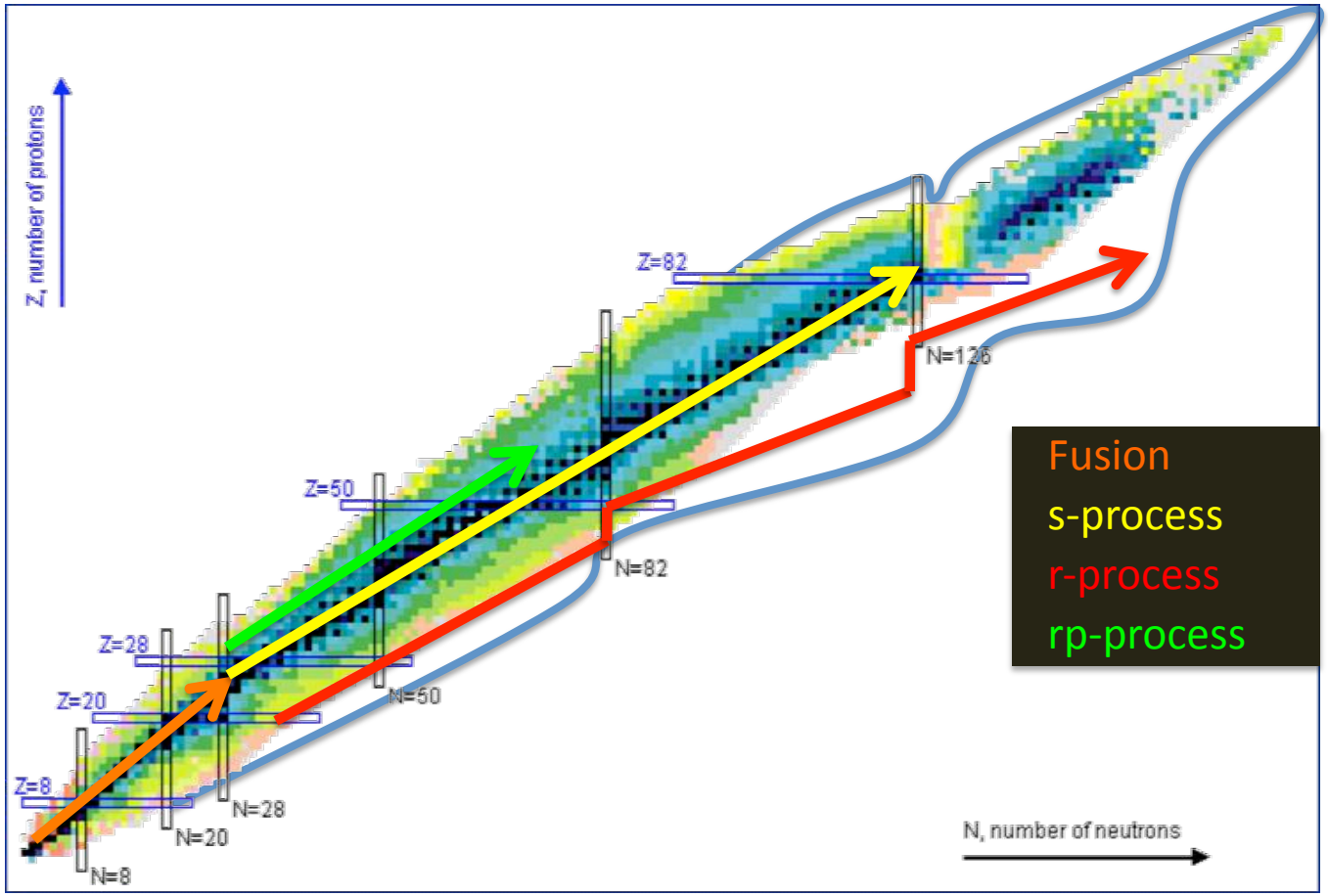


https://upload.wikimedia.org/wikipedia/commons/0/00/Crab_Nebula.jpg

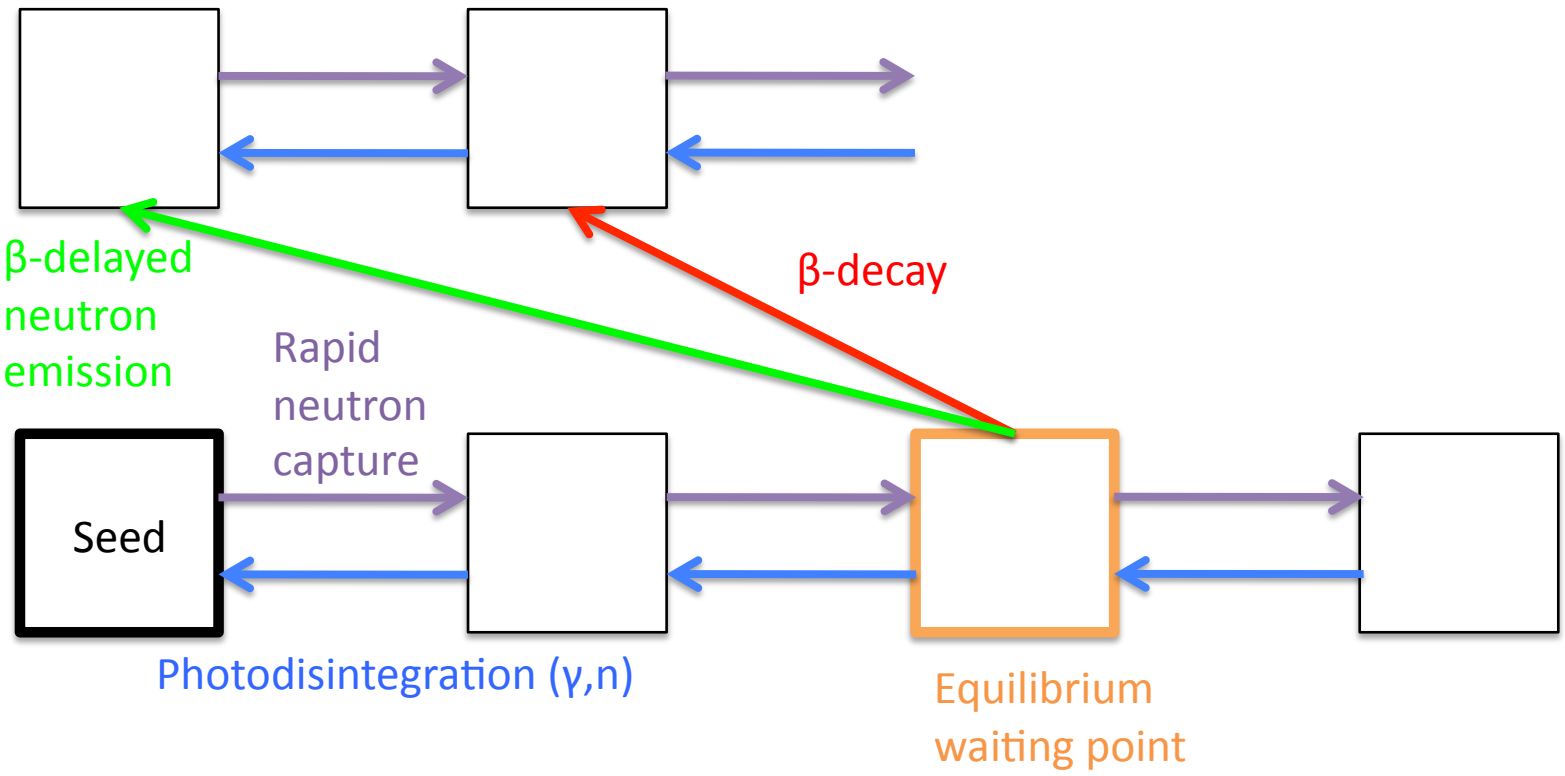
https://i.ytimg.com/vi/IZhNWh_IFuI/hqdefault.jpg

Astrophysical processes create the elements

How are the elements made?



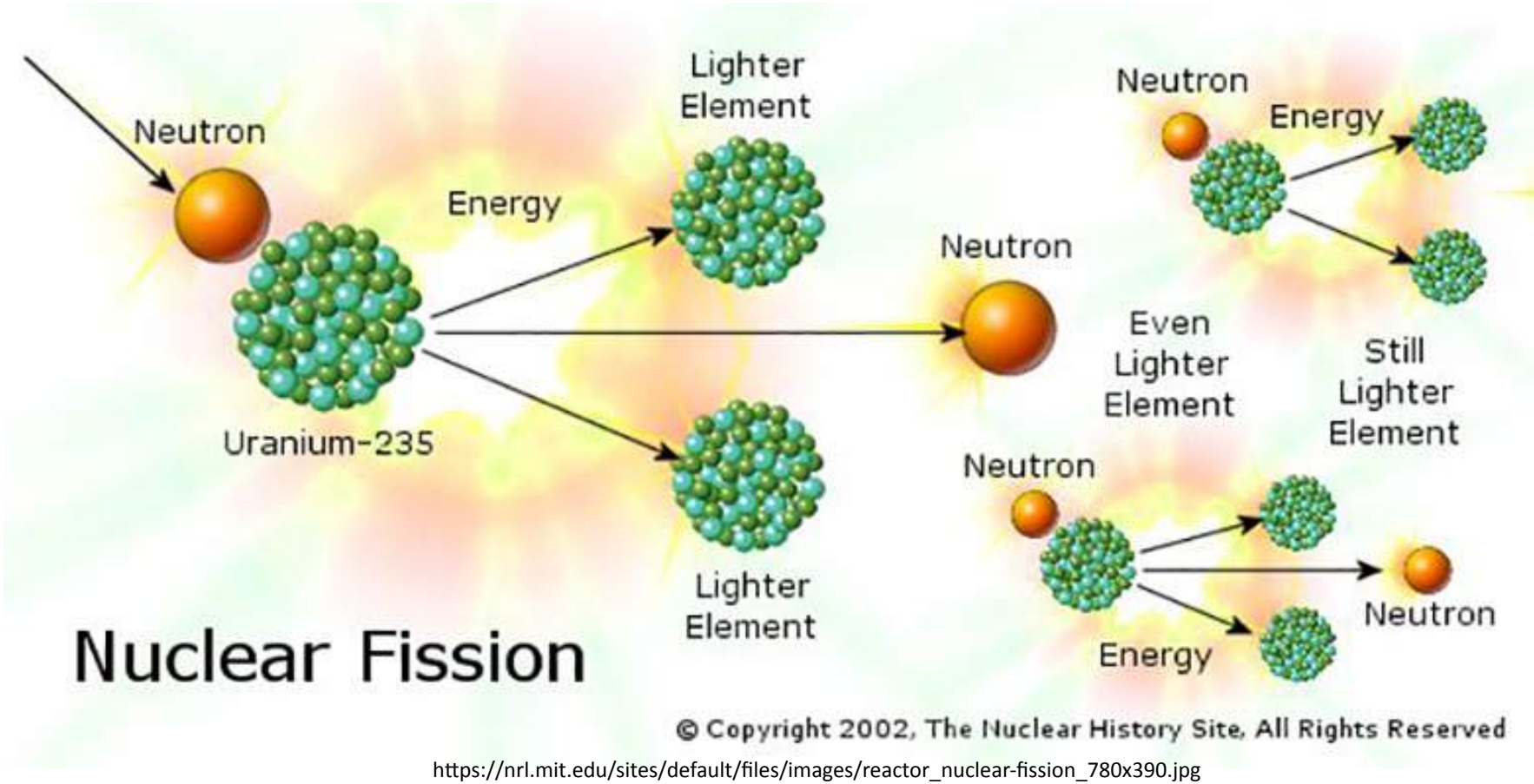
The r-process: Rapid Neutron Capture



Nuclear Physics in the r-process

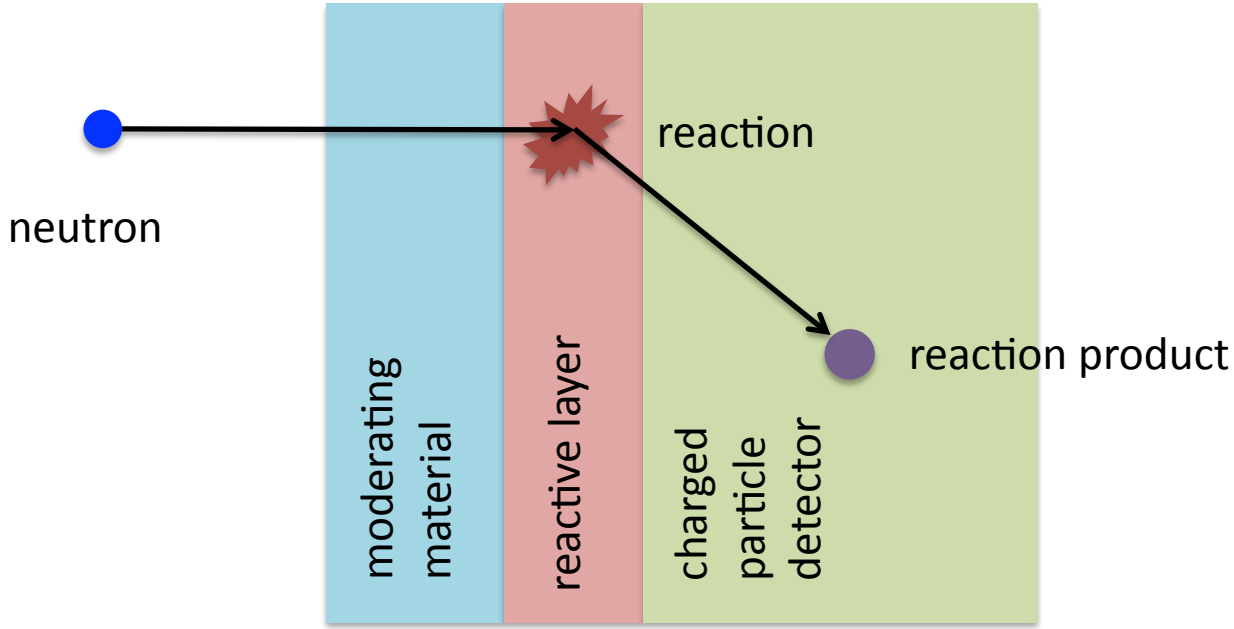
Quantity		Effect
S_n	Neutron separation energy	Path
$T_{1/2}$	β-decay half-lives	Abundance pattern Timescale
P_n	β-delayed neutron-emission branching ratios	Final abundance pattern
Fission (branching and products)		Endpoint Abundance pattern Degree of fission cycling
$N_A\langle\sigma v\rangle$	Neutron capture rates	Final abundance pattern

Nuclear Reactors: The second motivation



https://nrl.mit.edu/sites/default/files/images/reactor_nuclear-fission_780x390.jpg

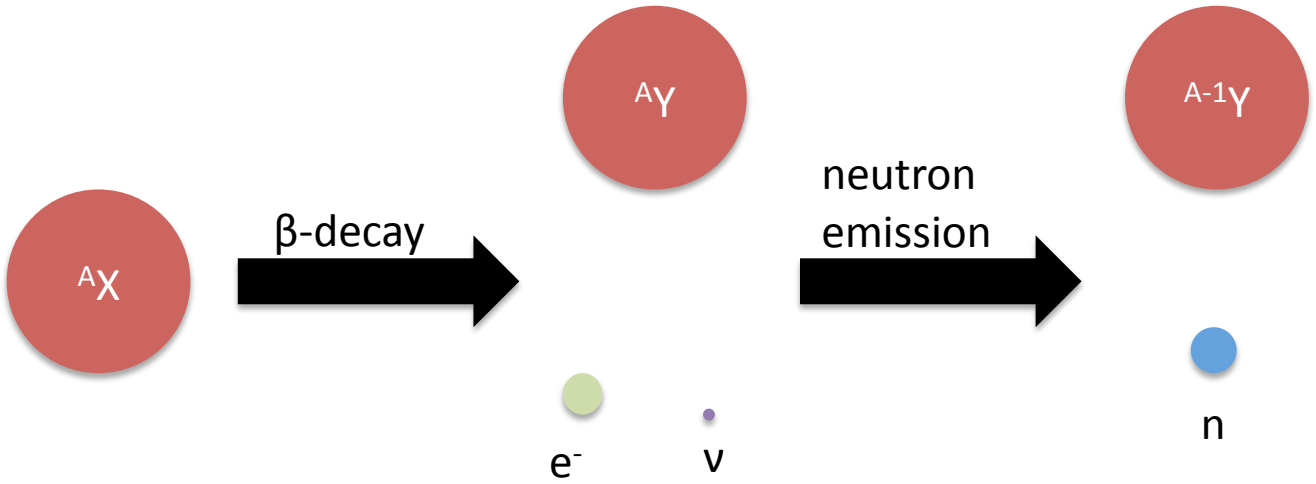
How to measure beta-delayed neutron emission



By measuring the neutrons, of course!

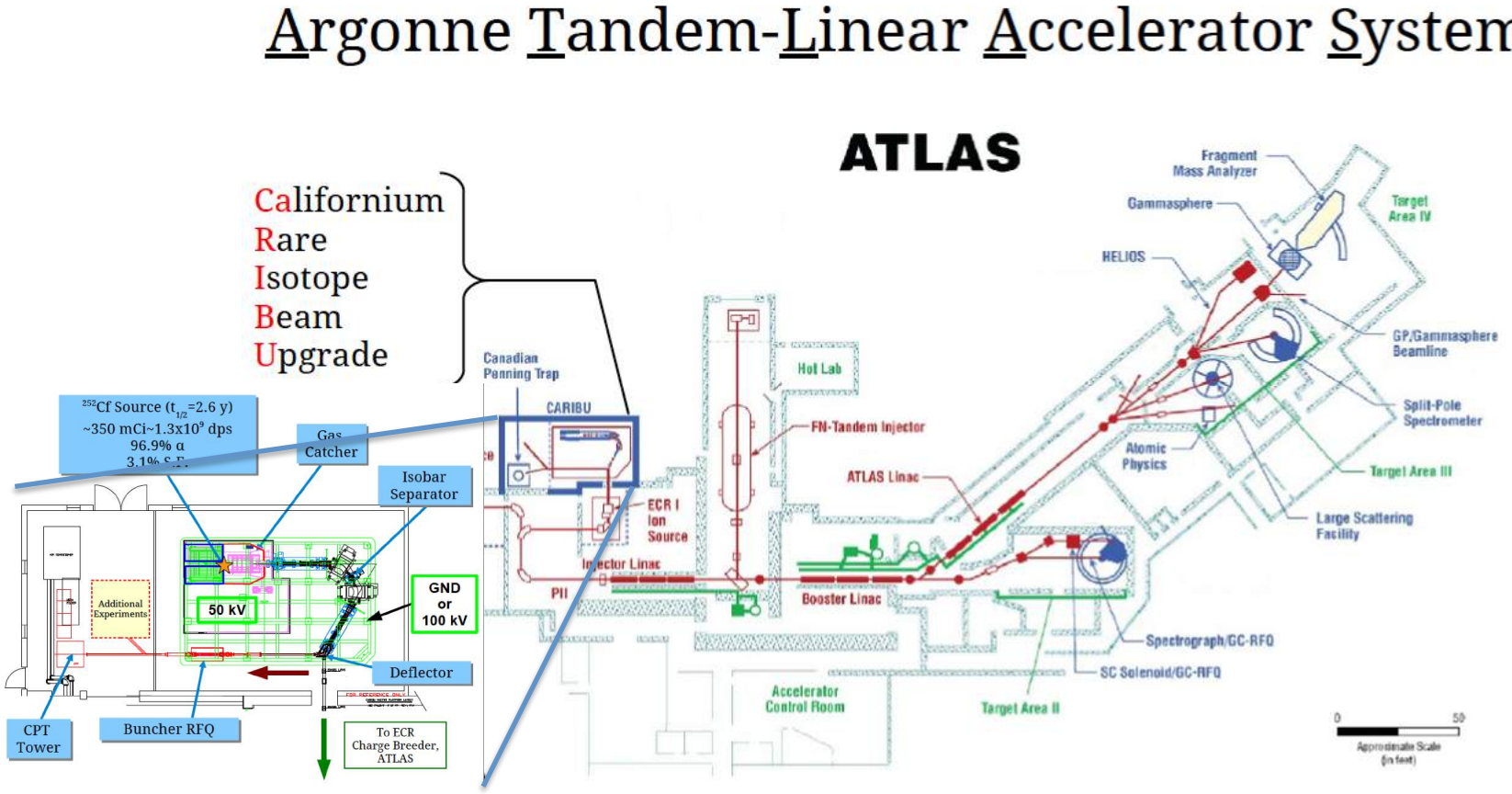
How to measure beta-delayed neutron emission

What if we could cut out the reactive layer?

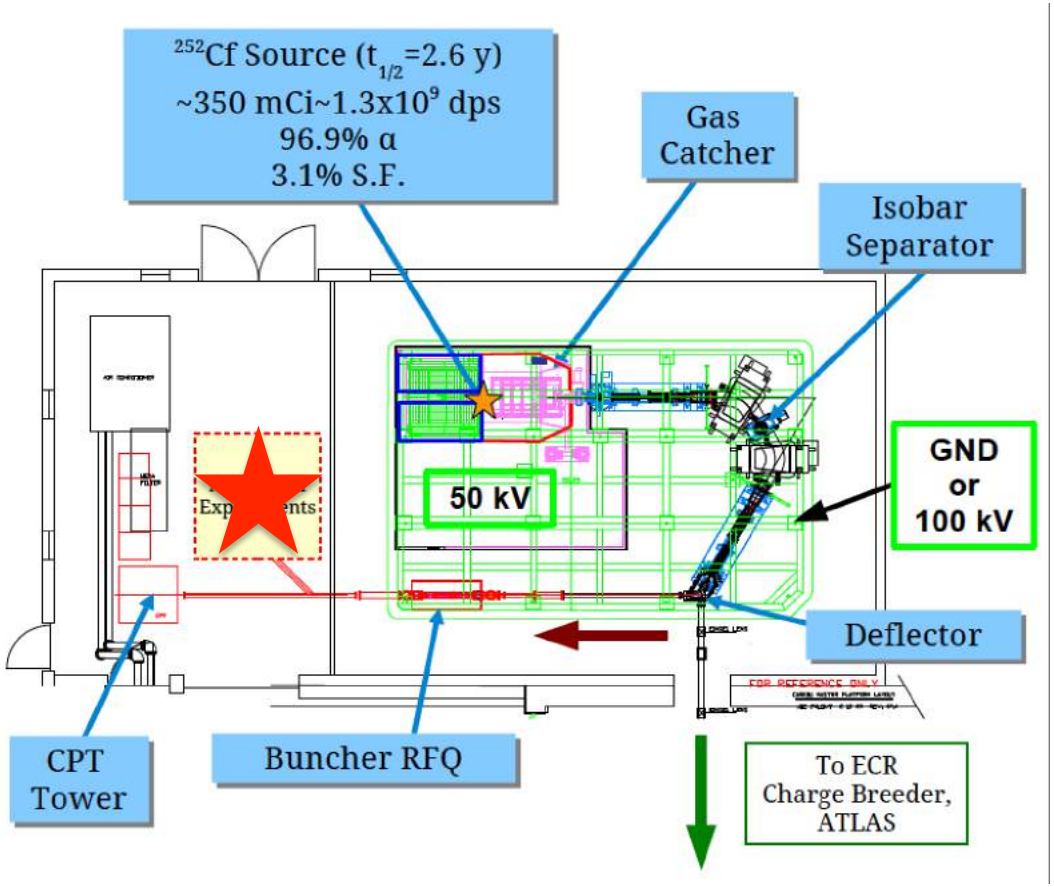


The initial decay already has a charged particle!

Where to get the ions: CARIBU @ ATLAS



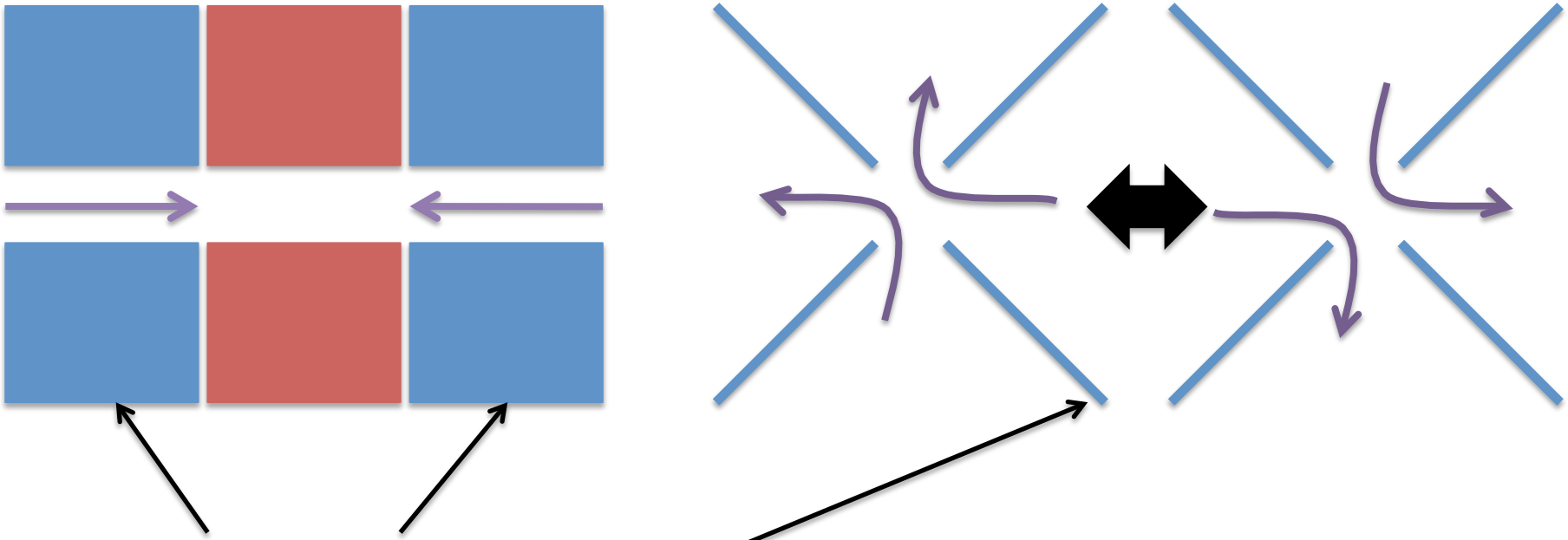
Where to get the ions: CARIBU @ ATLAS



How to trap an ion

Side view

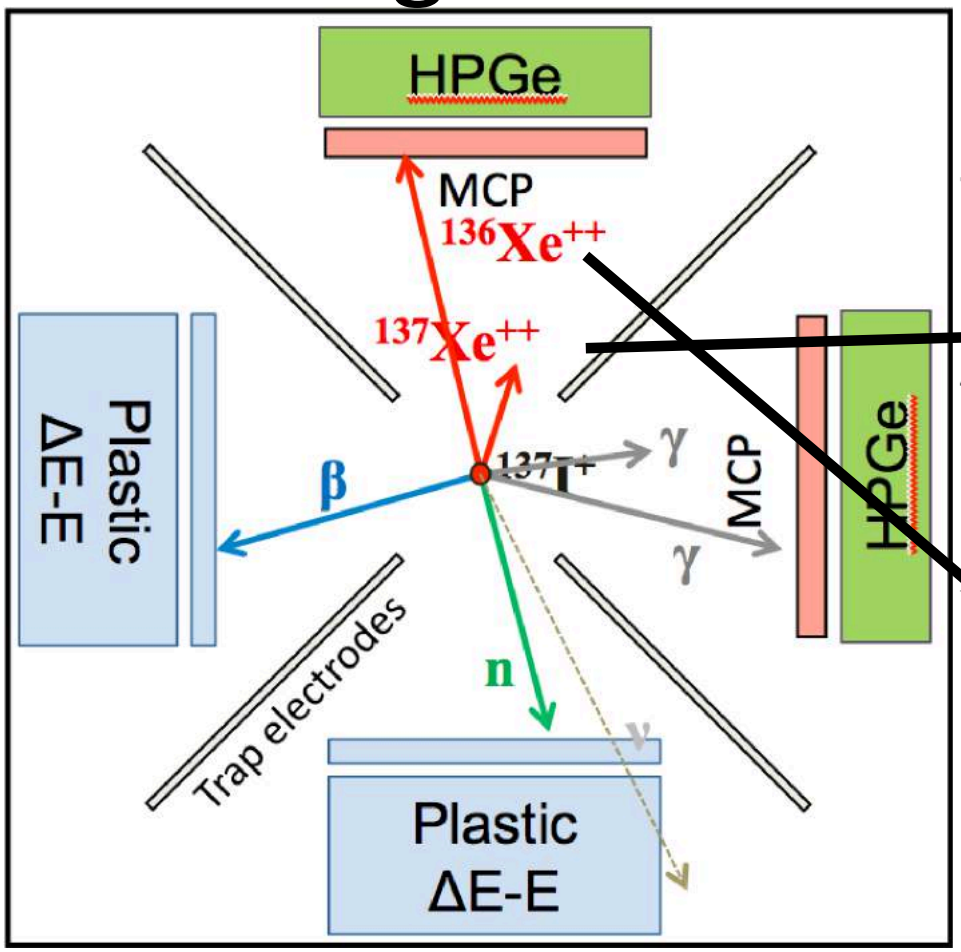
Beam direction

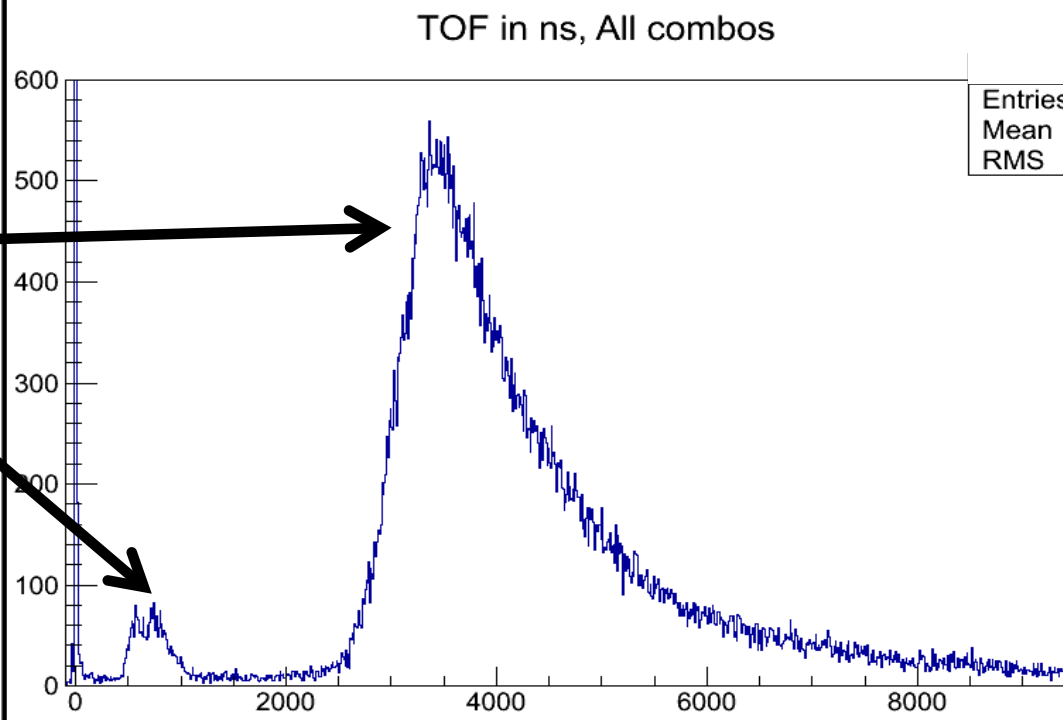


DC Voltage

RF Electric Field

Using the Beta Paul Trap for BDN





Measuring P_n: 3 ways with the BPT

$$P_n = \frac{N_{\beta R}}{N_\beta}\frac{\varepsilon_\beta}{\varepsilon_{\beta_R}}\frac{1}{\langle \Omega_R \varepsilon_R f \rangle}$$

Method 1: beta singles

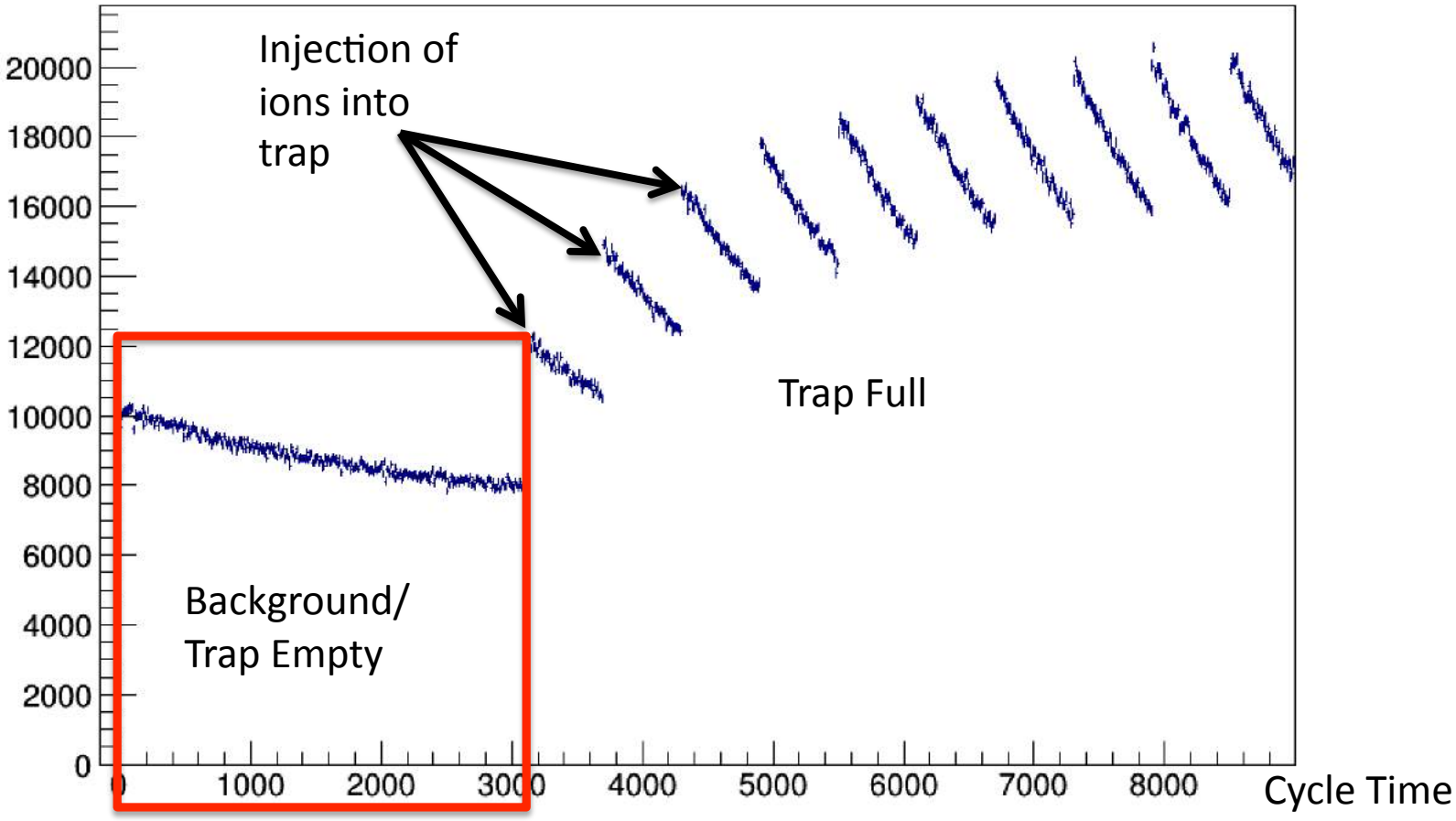
$$P_n = \frac{N_{\beta R}}{N_{\beta\gamma}}\frac{\varepsilon_{\beta_\gamma}}{\varepsilon_{\beta_R}}\frac{BR_\gamma \varepsilon_\gamma}{\langle \Omega_R \varepsilon_R f \rangle}$$

Method 2: beta-gamma

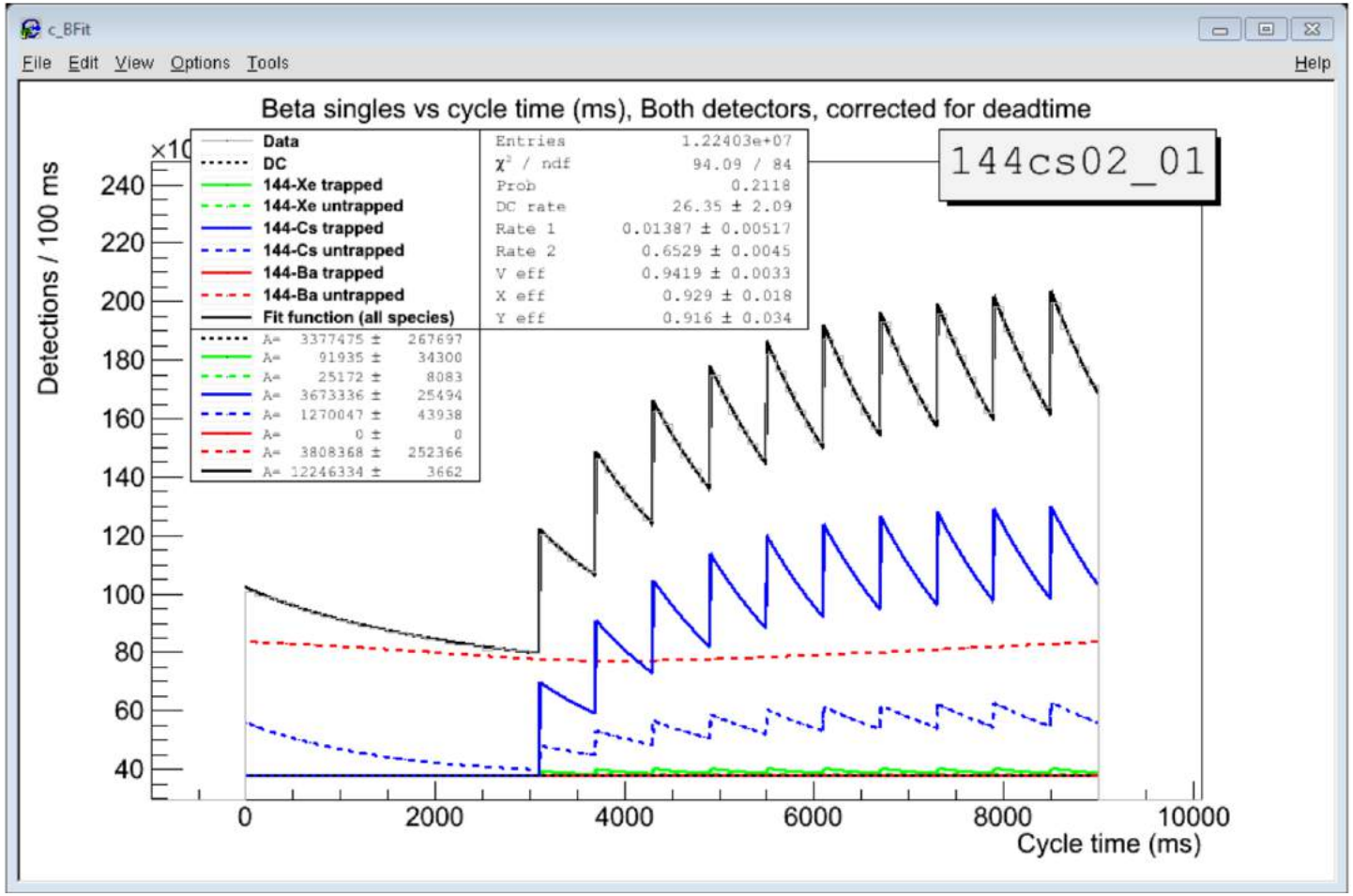
$$P_n = \frac{N_{\beta R}}{N_{\beta r}}\frac{\varepsilon_{\beta_r}}{\varepsilon_{\beta_R}}\frac{\langle \Omega_r \varepsilon_r \rangle}{\langle \Omega_R \varepsilon_R f \rangle}(1 - P_n)$$

Method 3: recoil ions

Method 1: Beta-Singles

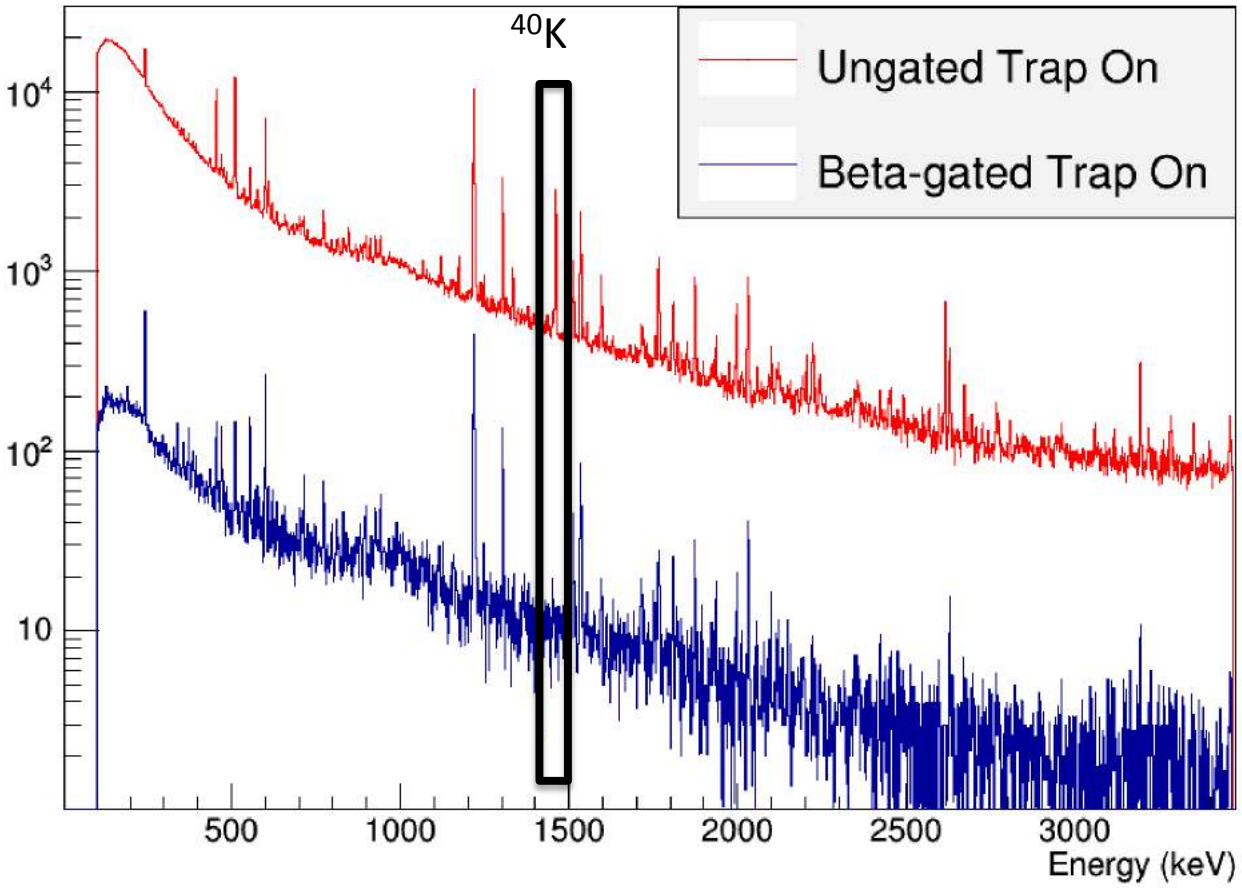


Method 1: Model Dependence



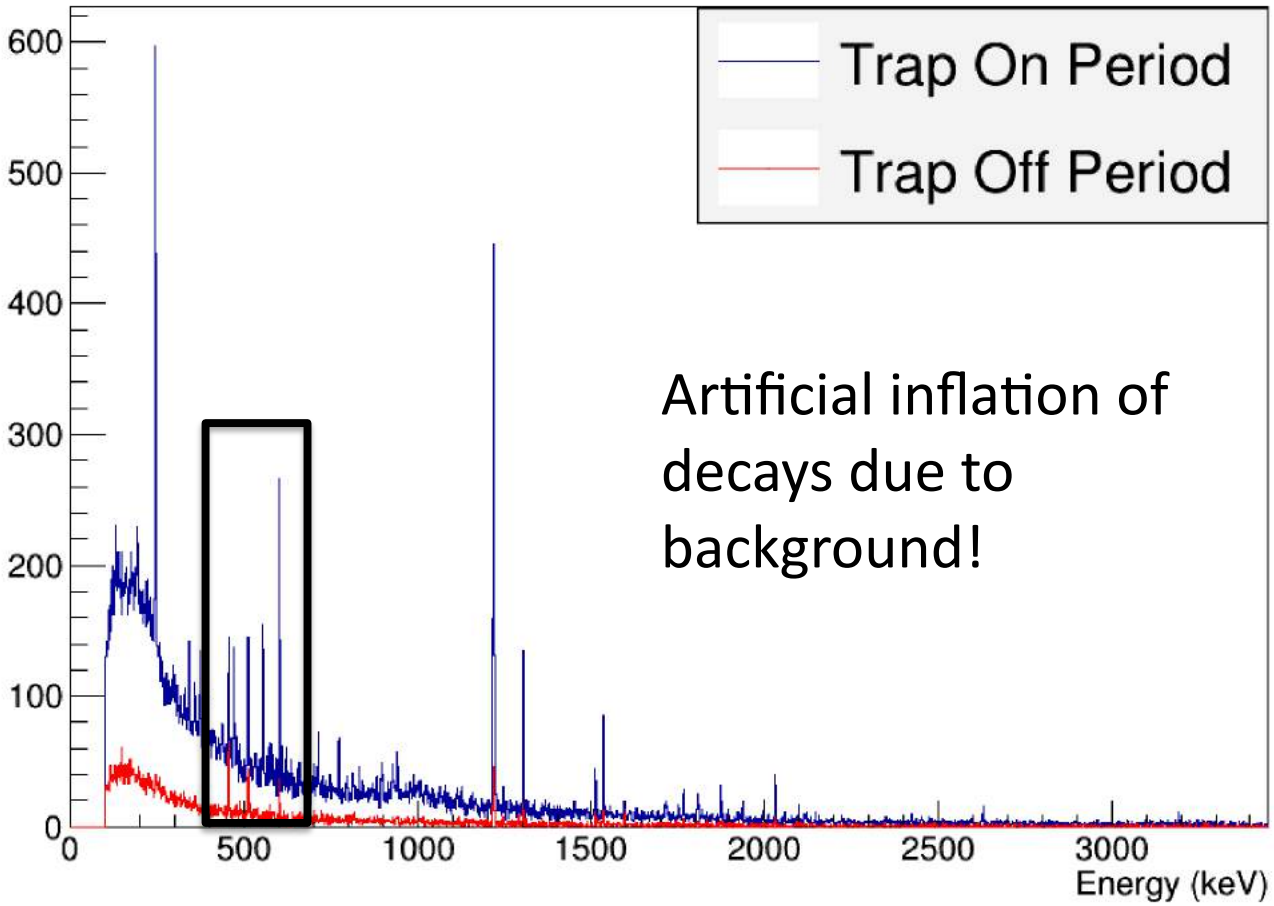
Method 2: Beta-Gamma

^{137}I



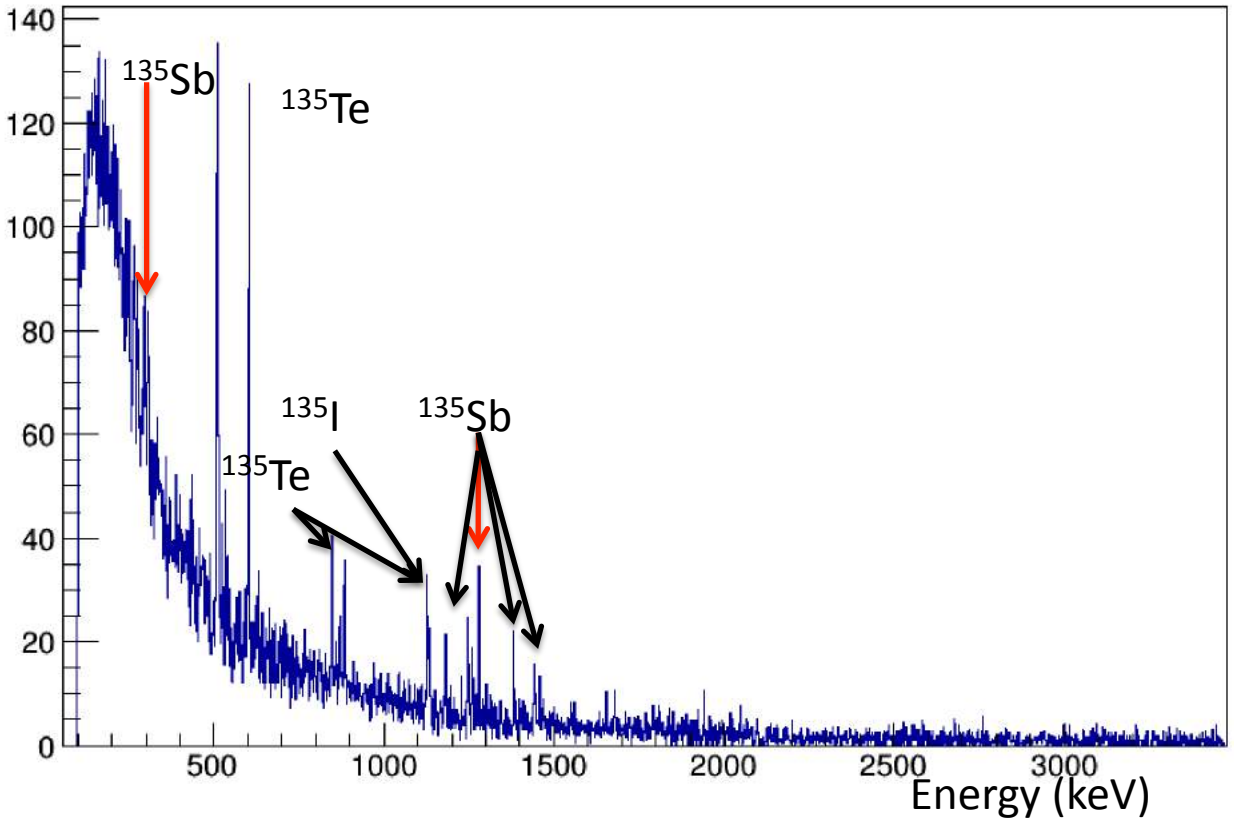
Method 2: Eliminating Trap Background

^{137}I



Method 2: Another way to calculate fast recoils?

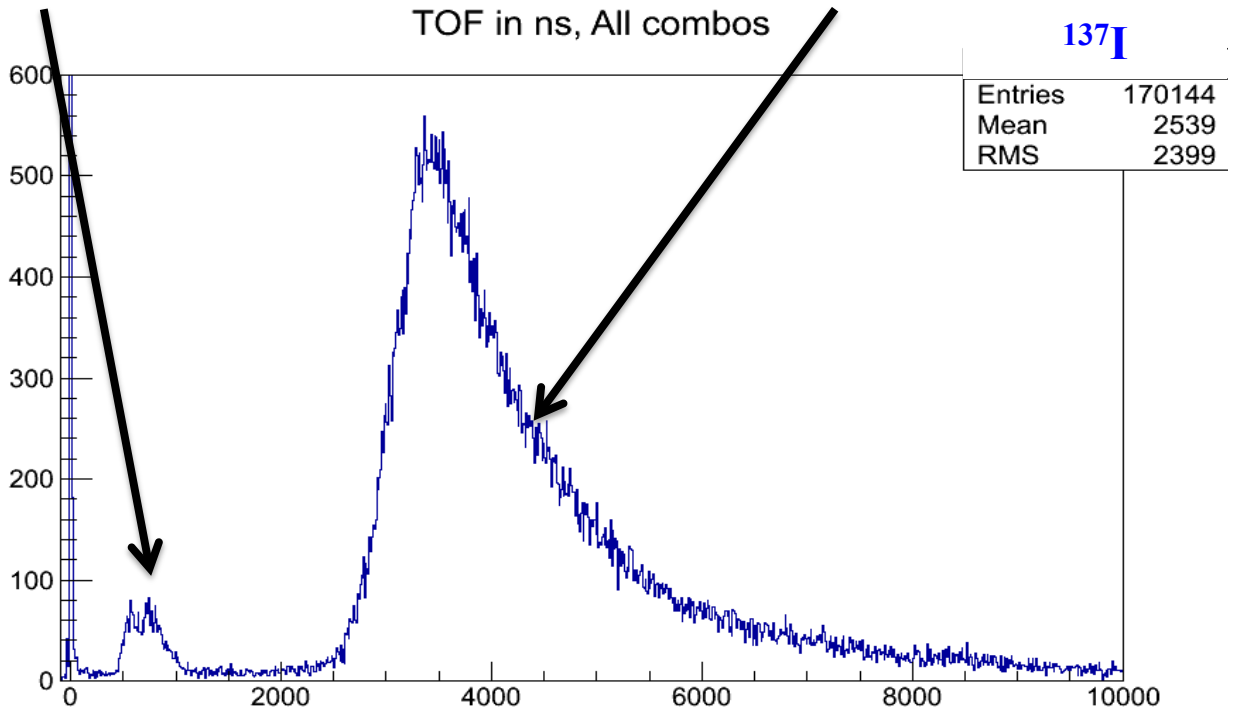
^{135}Sb



Method 3: Recoil Ions

Fast Ions (BDN)

Slow Ions (β-decay)



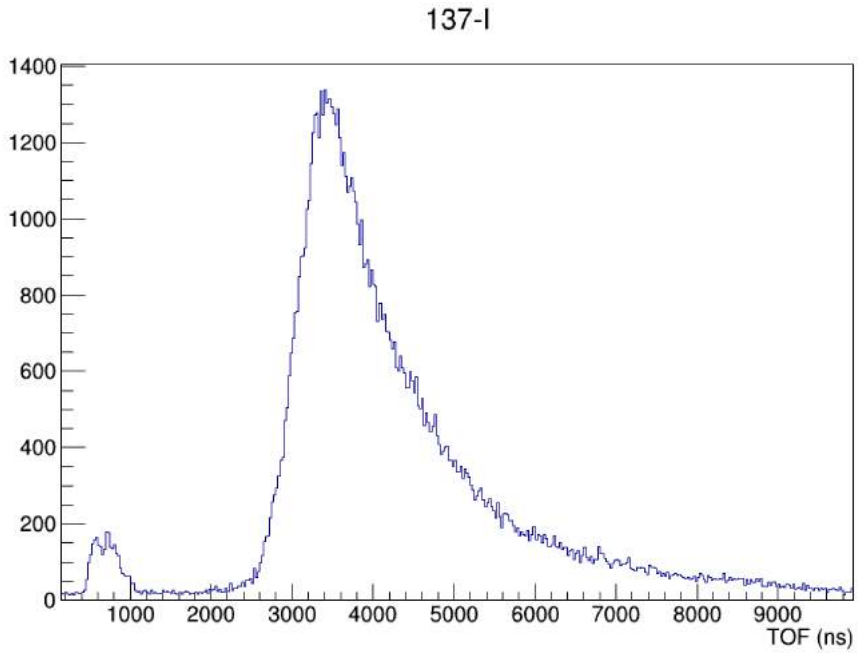
Method 3: Seeing the Difference

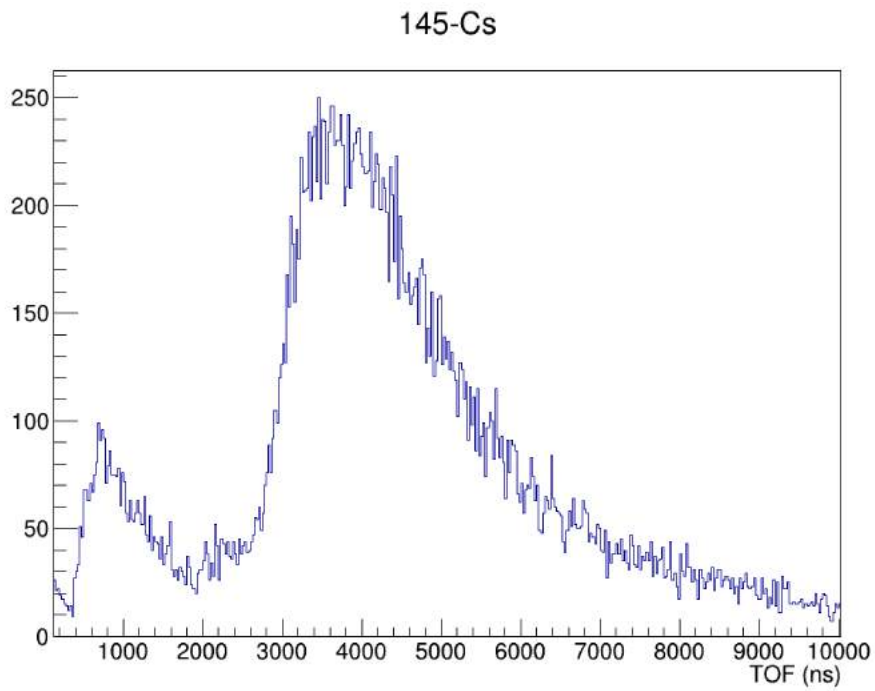
^{137}I Literature Value:

P_n = 7.14 %

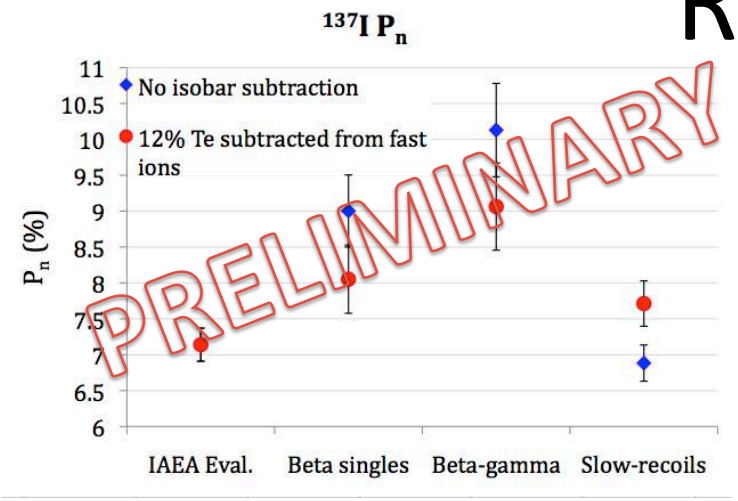
^{145}Cs Literature Value:

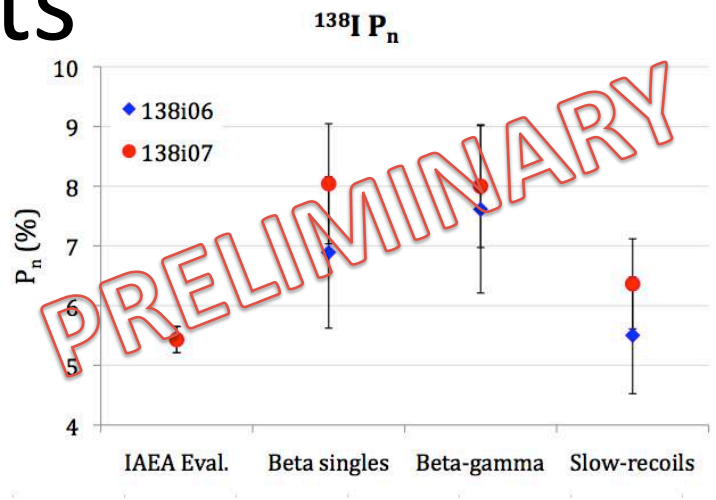
P_n =14.50 %

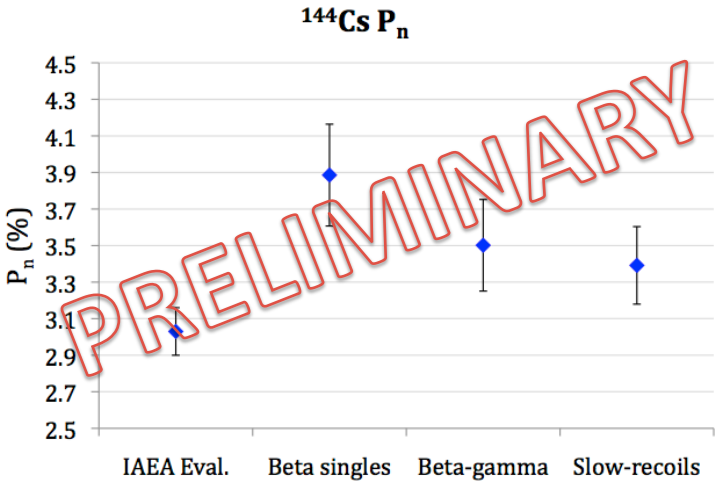


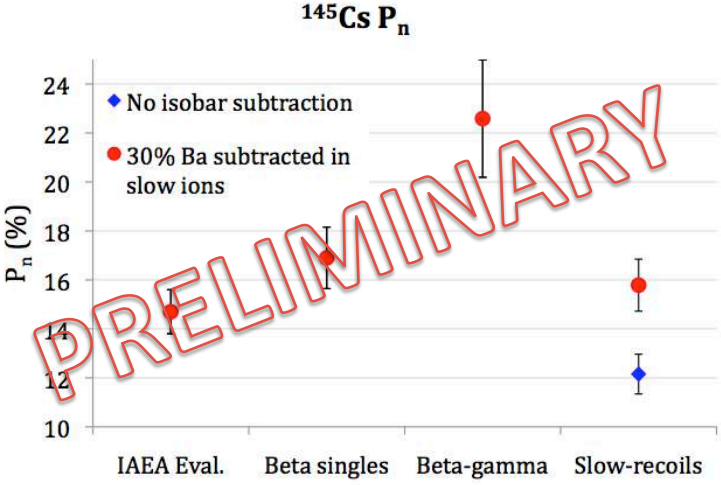


Results







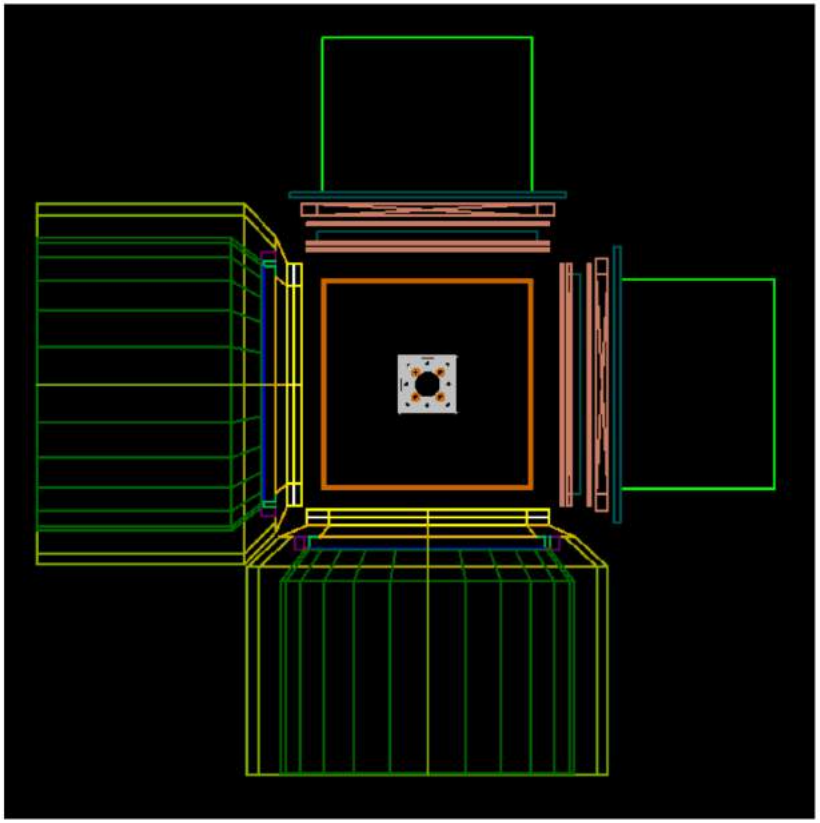


Calculations done by A. Czeszumska

Future Plans

Finalize analysis of previous experiment isotopes: $^{134,135,136}Sb$, $^{137,138,140}I$, $^{144,145}Cs$

Next Generation Trap: $^{134,135,136}Sn$



Collaborators + Acknowledgements

University of Notre Dame
S. Y. Strauss
A. Aprahamian
K. Siegl
Argonne National Laboratory
M. T. Burkey*
S. A. Caldwell*
C. J. Chiara
J. A. Clark
A. F. Levand
A. Perez Galvan
G. Savard*
Lawrence Livermore National Laboratory
A. Czeszumska§
N. D. Scielzo
B. S. Wang§
R. M. Yee§
University of Maryland
J. L. Harker
Louisiana State University
S. T. Marley
University of Manitoba
G. E. Morgan[1]
University of California – Berkeley
E. B. Norman
McGill University
R. J. Orford[1]

*Also associated with University of Chicago

§Also associated with Lawrence Livermore National Laboratory

[1]Also associated with Argonne National Laboratory

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