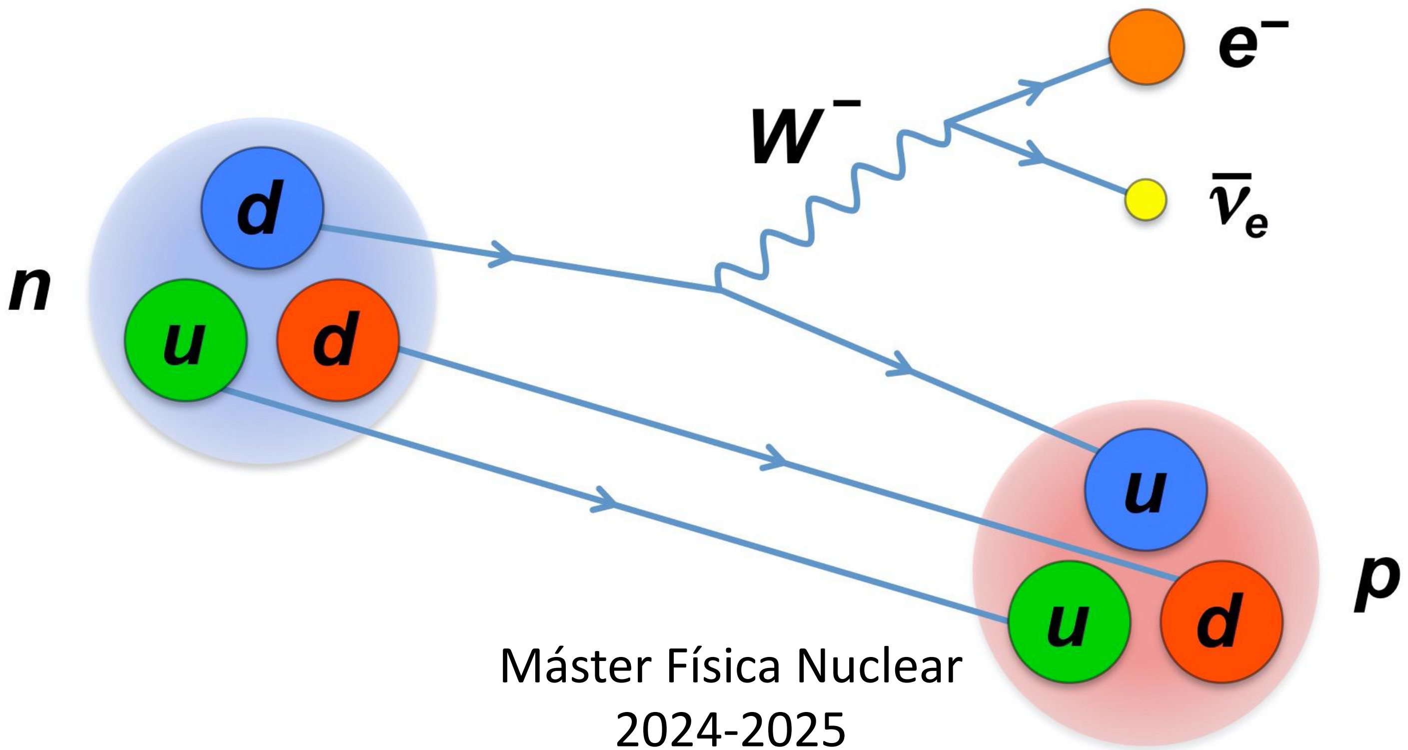
Beta decay experiments



Máster Física Nuclear
2024-2025
Bruno Olaizola
CSIC-IEM

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    - Beta particle energy spectrum
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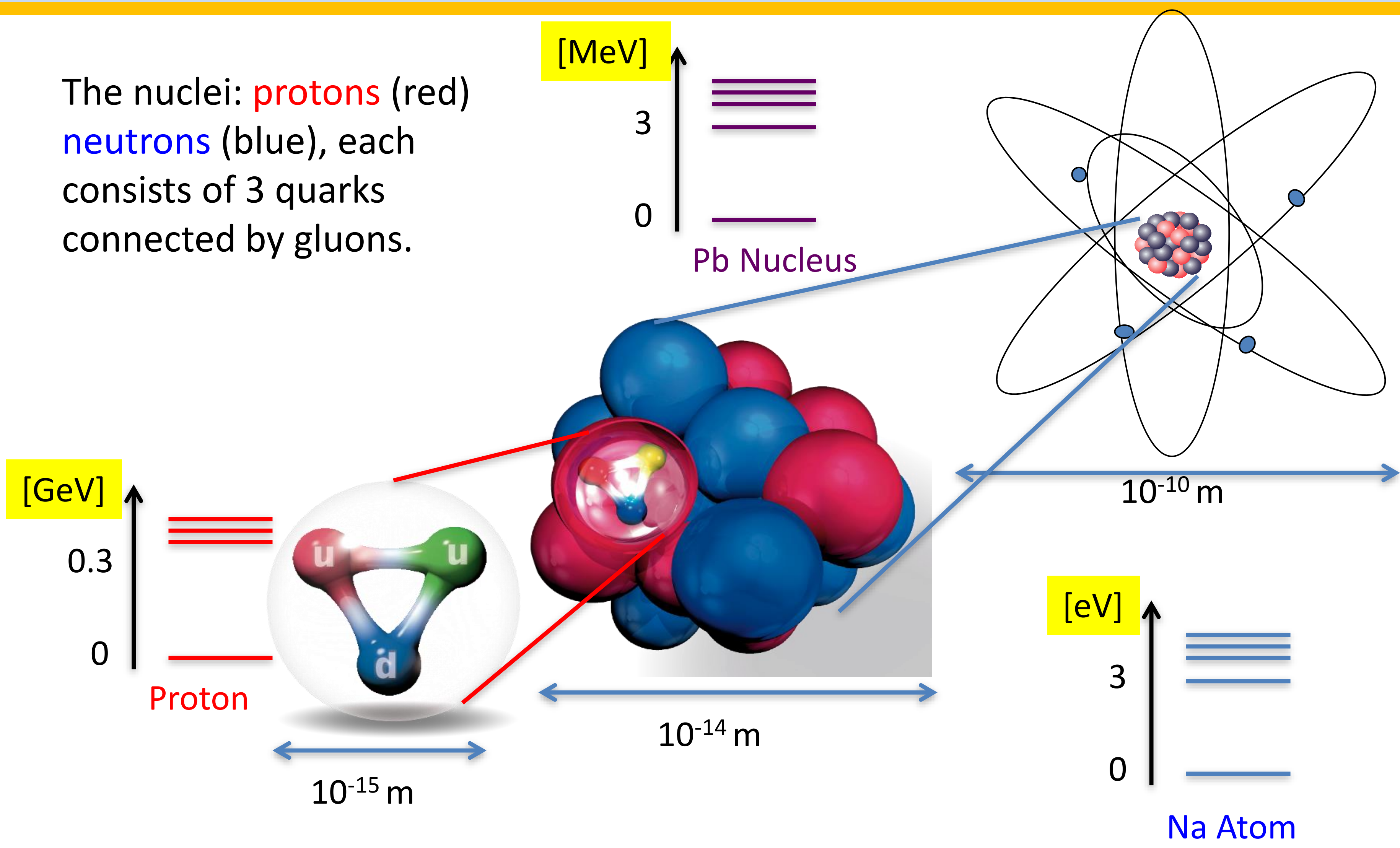
        - Main array
        - Ancillary detectors
- Some experiments using beta decay

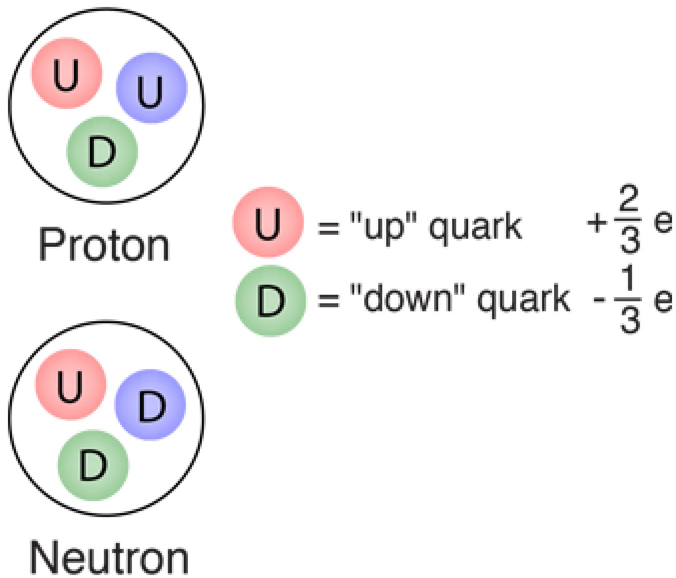
Subatomic Structure

The nuclei: protons (red) neutrons (blue), each consists of 3 quarks connected by gluons.



Particle masses

- Mass 938.3 MeV
- Mass 939.6 MeV

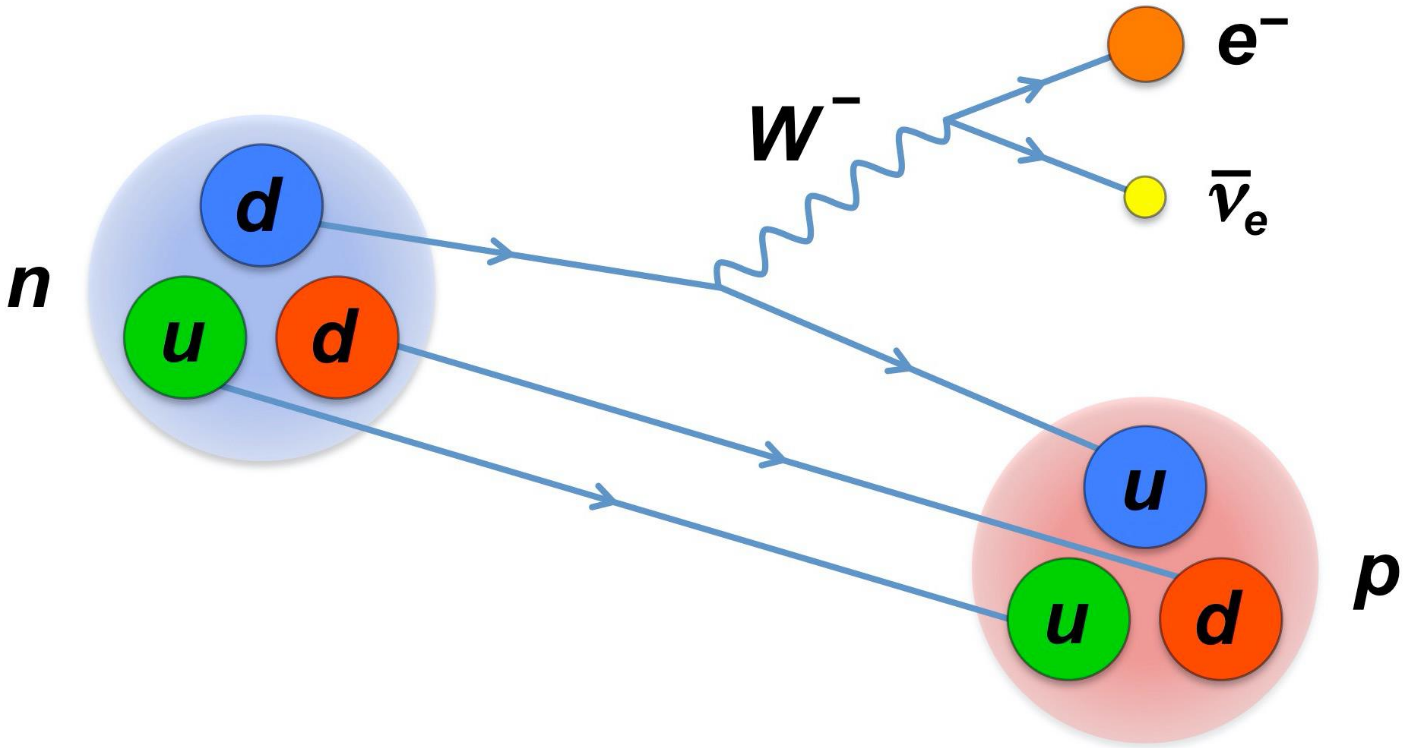


- Mass 1.8-2.7 MeV*
- Mass 4.4-5.2 MeV*

*Independent particle rest mass which, in the case of quarks, is meaningless

Quarks only add to ~10 MeV of the mass of nucleons, the rest comes from the field energy of gluons

Beta decay



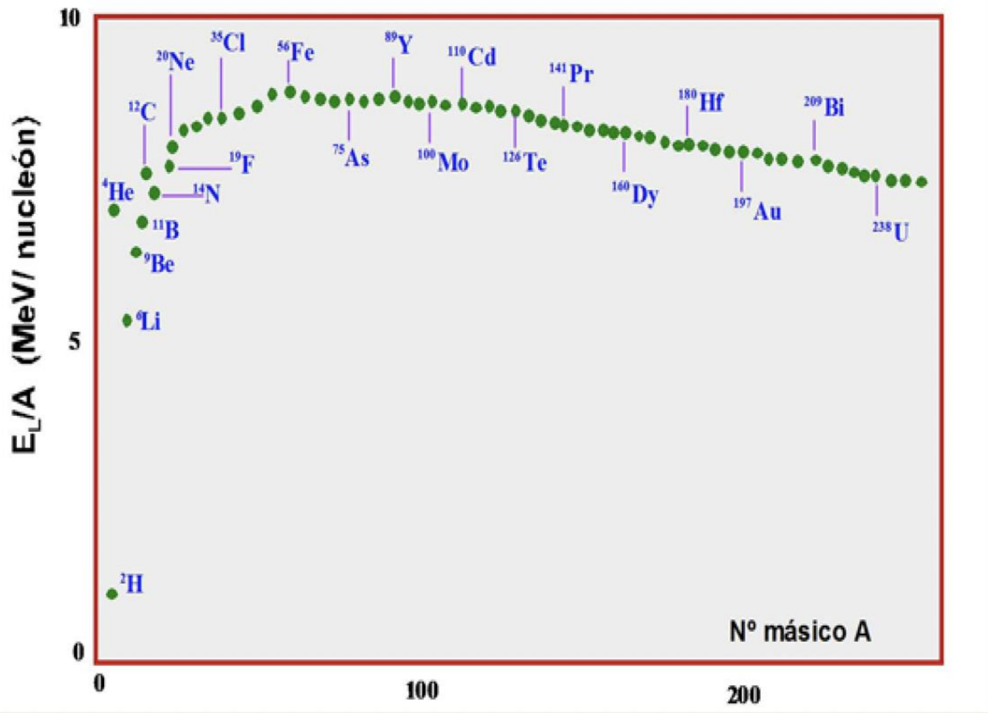
- Free neutrons decay into protons with τ~900 s
- Due to charge conservation, an electron is emitted e^-
- Due to lepton number conservation, an antineutrino is also emitted $\bar{\upsilon}_e$
- Free protons are stable

Nuclear mass

$$m_N < Z \cdot m_p + N \cdot m_n$$

$$m_N = Z \cdot m_p + N \cdot m_n - B/c^2$$

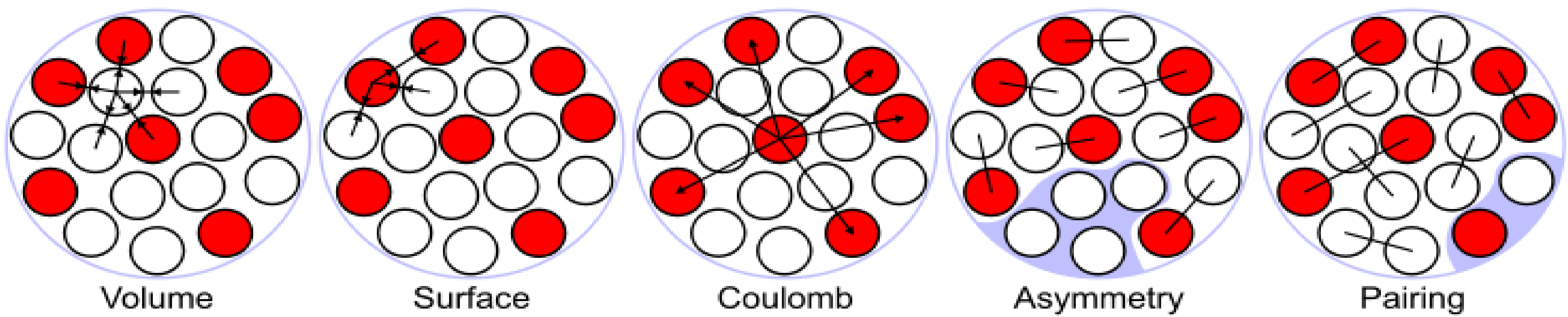
- B is the nuclear binding energy
- It is a residue of the strong interaction between quarks
- B/A~8 MeV on average
- Maximum around ^{62}Ni
- Explains stellar nuclear reactions
    - Element abundance
- Nuclear reactors



Semi-empirical mass formula

$$B(A,Z) = a_v A \;\; - a_s A^{2/3} - a_c Z(Z-1)A^{-1/3} - a_{sym}\frac{(A-2Z)^2}{A} + \delta a_p A^{-3/4}$$

$\nearrow$ volume $\uparrow$ surface $\uparrow$ Coulomb $\uparrow$ symmetry $\nwarrow$ pairing



https://en.wikipedia.org/wiki/Semi-empirical_mass_formula

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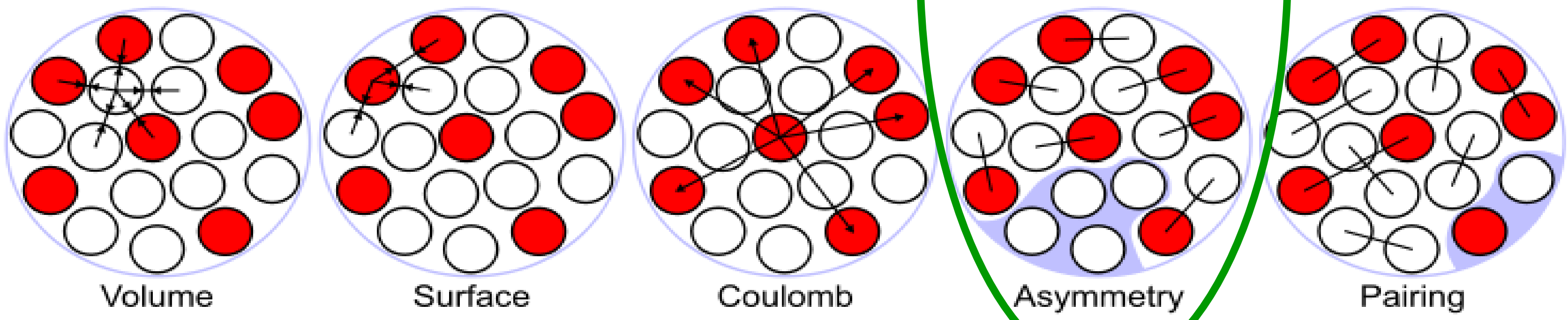
$$B(A,Z) = a_v A \; - a_s A^{2/3} - a_c Z(Z-1) A^{-1/3} - a_{sym} \frac{(A-2Z)^2}{A} + \delta a_p A^{-3/4}$$

volume ↗ surface ↑ Coulomb ↑ symmetry ↑ pairing ↖



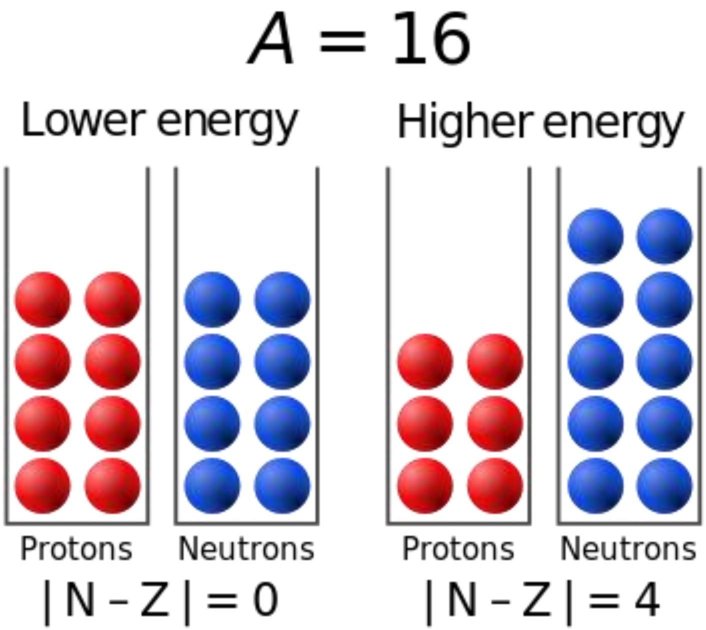
https://en.wikipedia.org/wiki/Semi-empirical_mass_formula

Assymetry term

- Also known as *Pauli term*
- It originates from the Pauli exclusion principle and the Shell structure
- An excess of neutrons would need to occupy higher energy orbitals
- It can be expressed as:

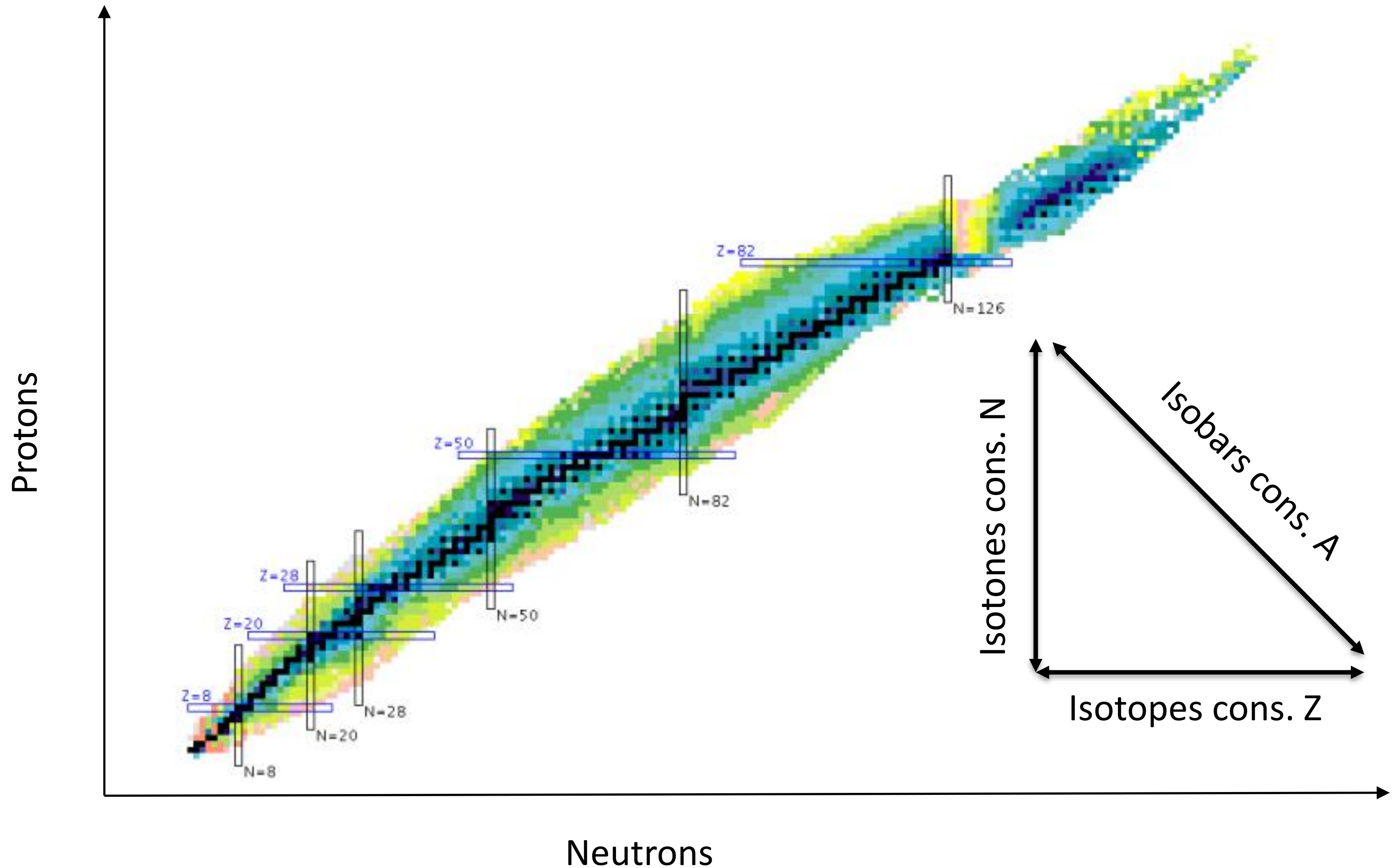
$$a_A \frac{(N-Z)^2}{A}$$

- Notice the square dependence with the difference between protons and neutrons
- This can also be derived by modeling the nucleus as a Fermi ball of nucleons



https://en.wikipedia.org/wiki/Semi-empirical_mass_formula

Nuclear chart



https://www.nndc.bnl.gov/

Nuclear stability

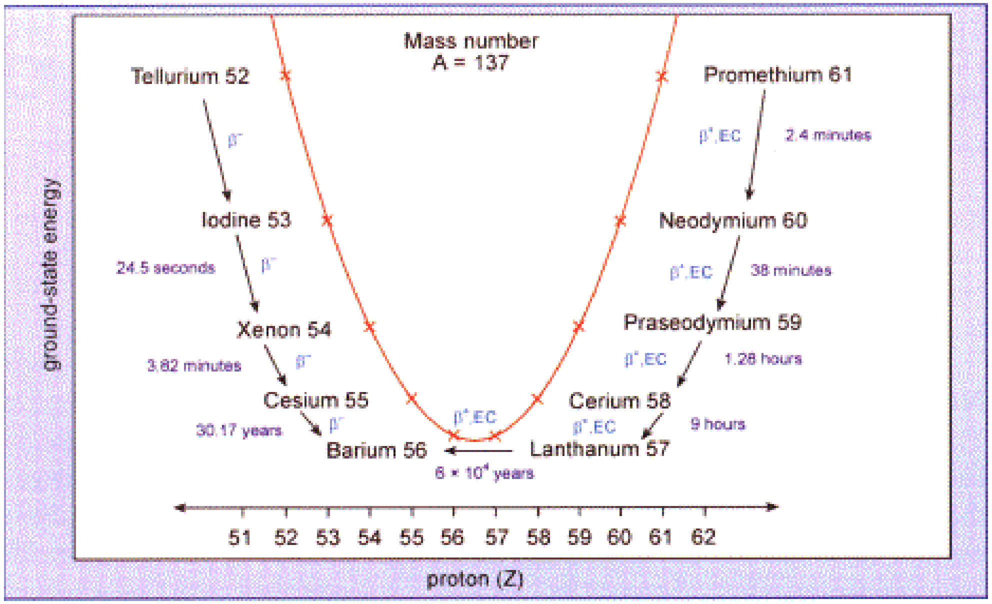
- Due to the asymmetry term, in isobar lines the masses will follow a parabola
- Nuclei will decay into the valley of stability
- This valley is not at N=Z mainly due to the Coulomb repulsion between protons
- Protons inside the nucleus can be unstable, they decay into a neutron by β^+

Thus for each A-value one can calculate the nucleus with lowest mass (largest binding energy):

For a given A a parabolic behaviour of the nuclear masses show up.

odd-A only one stable nucleus. The rest $\beta^{\pm}$ decay towards the only stable nucleus.

even A both even-even and odd-odd $\Rightarrow$2 parabolas implied by the mass equation.



Beta Decay: definition

Beta Decay: **universal term for all weak-interaction transitions between two neighboring isobars**

Takes place in 3 different forms

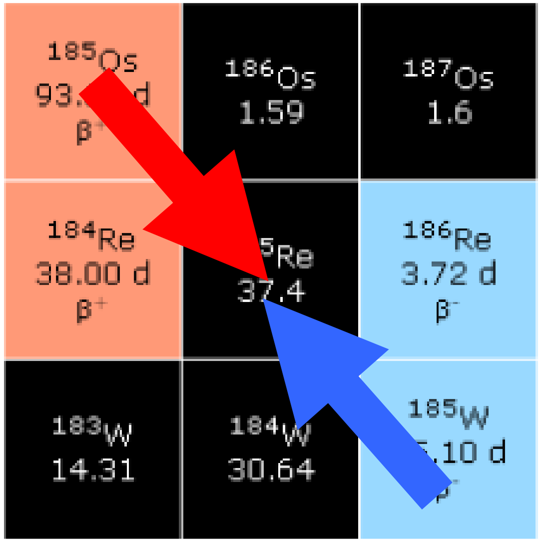
β^-, β^+ & EC (capture of an atomic electron)

β^+: p → n + e^+ + ν

$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z-1}X^{*}_{N+1} + e^{+} + \nu_{e} $$

EC: p + e^- → n + ν

$$ {}^{A}_{Z}X_{N} + e^{-} \rightarrow {}^{A}_{Z-1}X^{*}_{N+1} + \nu_{e} + X_{ray} $$



β^-: n → p + e^- + $\tilde{\nu}$

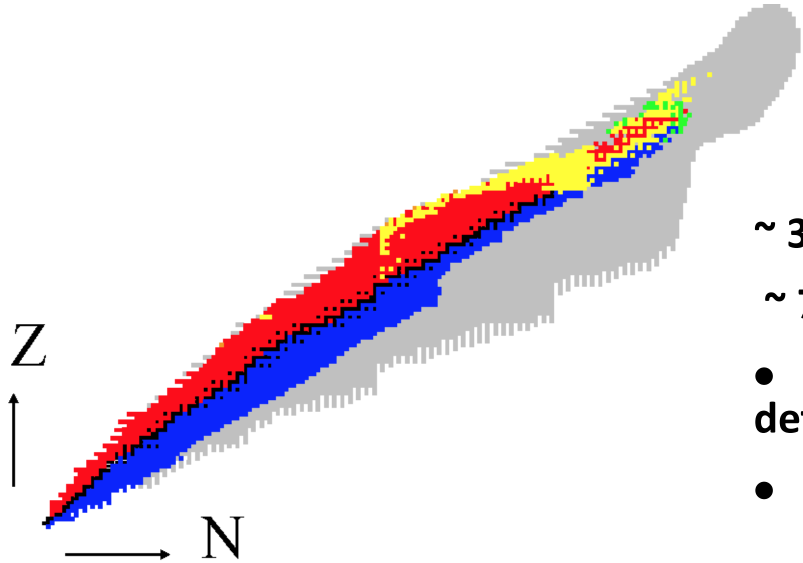
$$ {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}X^{*}_{N-1} + e^{-} + \overline{\nu}_{e} $$

a nucleon inside the nucleus is transformed into another

No preformation!

Atomic Mass Model

Relationship with Nuclear Decay Models



254 Stable nuclei
- 167 e-e
- 4 o-o (2H, 6Li, 10B, ^{14}N)
- 83 e-o

34 Primordial ($T_{1/2} > 10^9$y)

~ 3000 produced in nuclear reactions

~ 7000 predicted to be bound

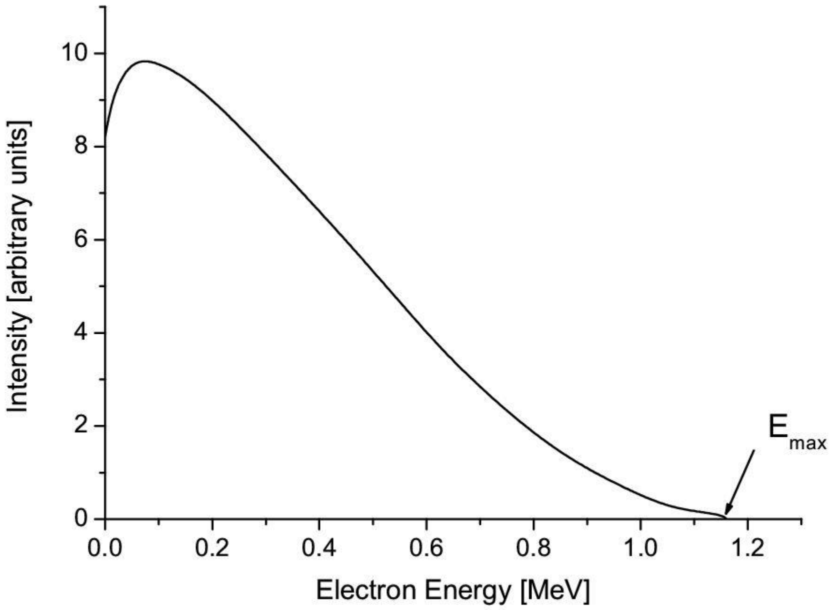
- **Decay characteristics of most radioactive nuclei determined by β-decay i.e. weak interaction**
- **For heavier nuclei → Electromagnetic interaction important →**
  - α-decay
  - fission

- **Moving away from stable nuclei by adding protons or neutrons → until the particle drip-lines (S_p = 0 or S_n = 0).**

Nuclei beyond drip-line are unbound to nucleon emission, i.e. Strong interaction cannot bind one more nucleon to the nucleus

Beta decay energy spectrum

- Energy spectrum of beta particle is continuous
- No discrete peaks
- This is why neutrinos were suggested
- 3-body decay: beta, (anti)neutrino and recoiling nucleus
- Energy mass difference is split among the 3 products
- Total energy available:



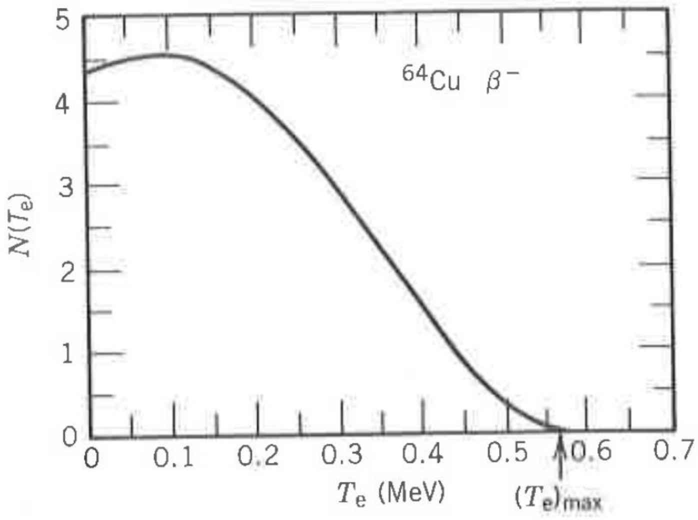
$$Q = (m_X - m_{X'} - m_\nu - m_e)c^2 = E_{X'} + E_\nu + E_e$$

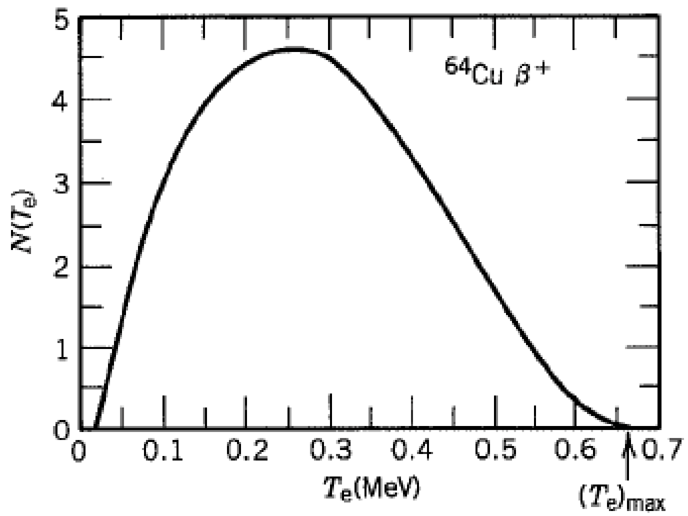
- Typical Q is from a few MeV to 20-30 MeV

Energy spectra features

- E_{max}~Q_{β}, the β particle takes all the available energy; daughter nucleus and neutrino at rest
- There is a most likely value for the β particle energy 0.1-0.4 Q_{β}
- β^- can be emitted at ~0 energy
- β^+ can not be emitted at ~0 energy
  - The attraction or repulson of the protons in the nucleus is not negligible

$$N(T_e) = \frac{C}{c^5} F(Z,Q) |V_{fi}|^2 [Q - T_e]^2 \sqrt{T_e^2 + 2T_e m_e c^2}\,(T_e + m_e c^2)$$

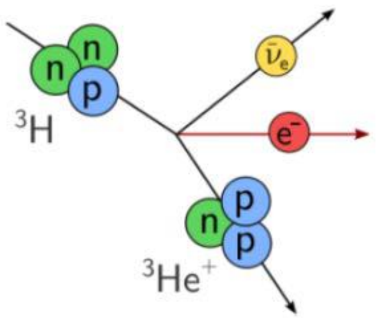




Neutrino mass measurement

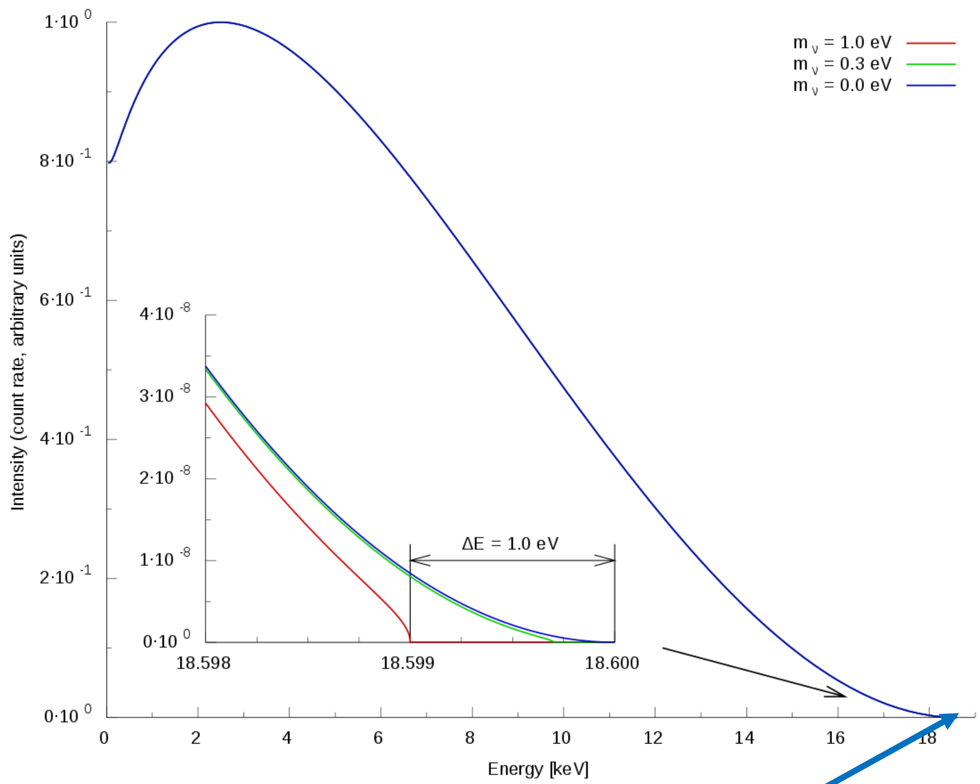
$$\frac{dN}{dE} = C \cdot F(E,Z) \cdot p(E+m_e) \cdot (E_0 - E) \cdot \sqrt{(E_0 - E)^2 - m_\nu^2}$$

$$m_{\nu_e}^2 = \sum_{i=1}^{3} |U_{ei}|^2 m_i^2$$



- If we know with great precision the nuclear masses, we know Q_β
- A precise measurement of the end point is sensitive to m_ν
- Model independent method

$$T_2 \rightarrow {}^3HeT^+ + e^- + \bar{\nu}_e$$



Q_β=18.59202 (6) keV

https://indico.cern.ch/event/572149/contributions/2488095/attachments/1446803/2228876/ALPS2017_fraenkle.pdf

KATRIN (Karlsruhe Tritium Neutrino Experiment)

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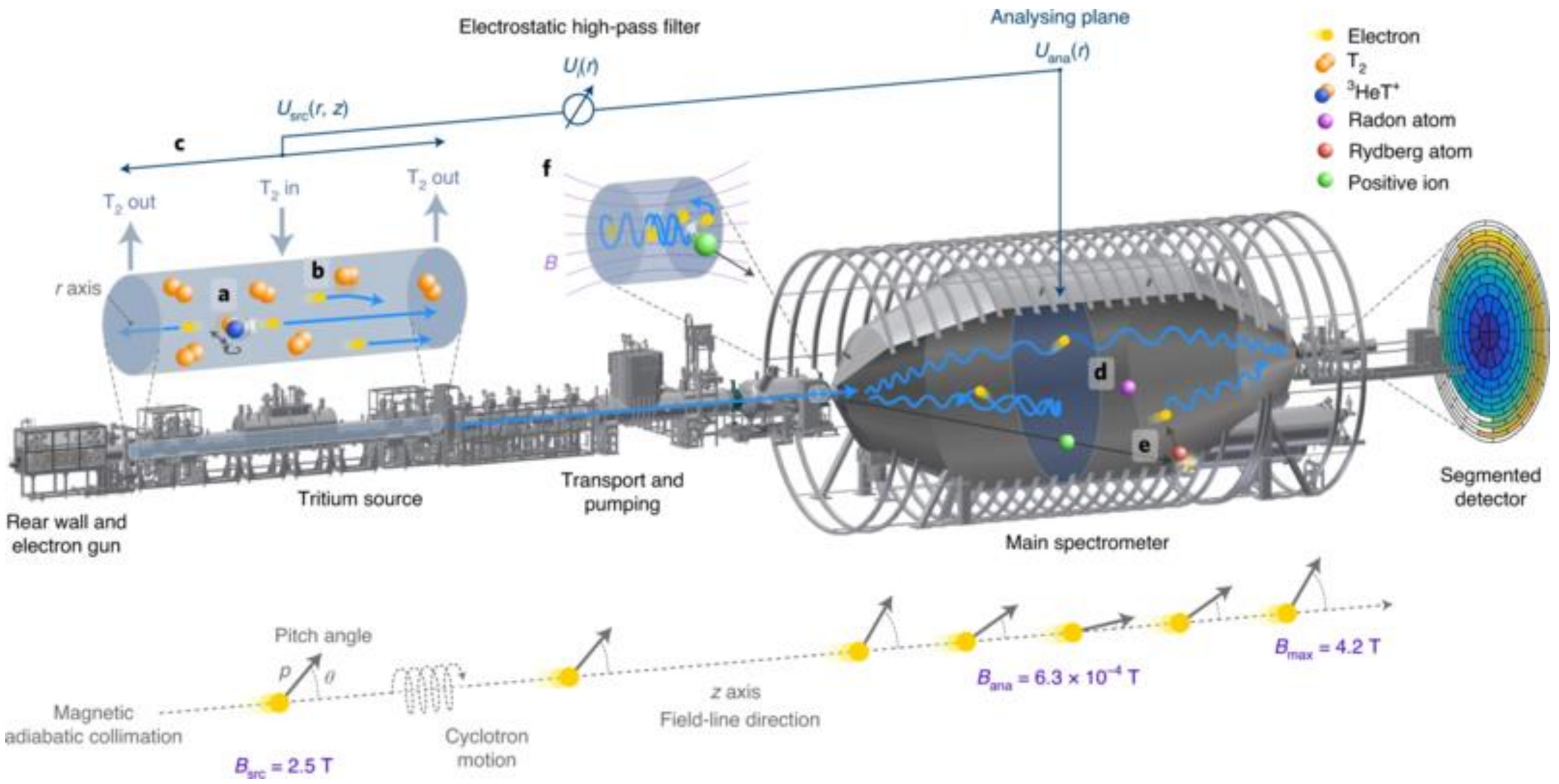
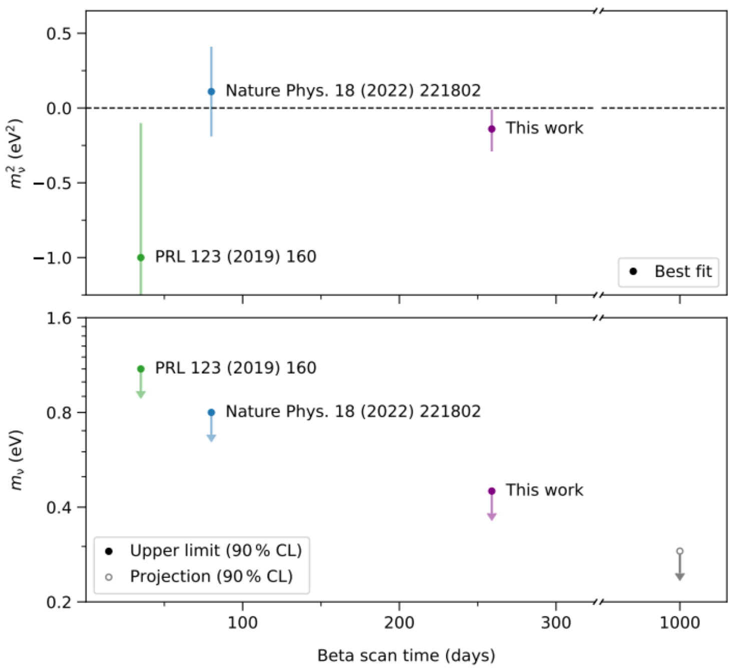


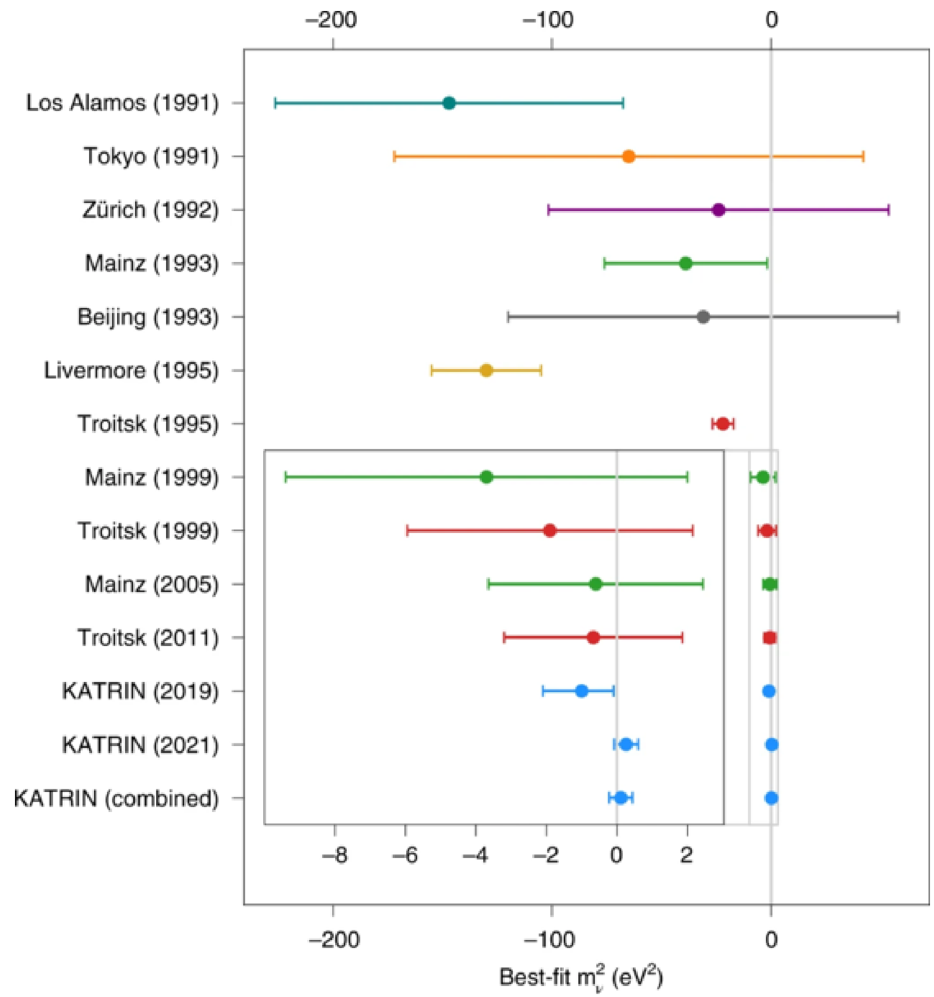
- Molecular tritium source ($T_{1/2}$=12.3 years and Q_β=18.59202 (6) keV)
- Electric field to filter low energy β particles
- Magnetic field to conduct them to the detector

KATRIN (Karlsruhe Tritium Neutrino Experiment)

- ~259 days of measurement, out of 1000 days planned
- Current upper limit of m_ν<0.45 eV
- Plan to reach m_ν<0.3 eV 90% C.L.
- Model independent measurement, but relies on theoretical calculation
  - i.e. molecular dynamics



https://arxiv.org/pdf/2406.13516



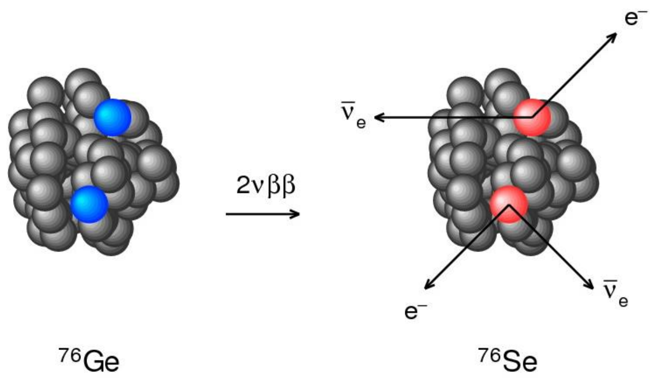
Nat. Phys. **18**, 160–166 (2022). https://doi.org/10.1038/s41567-021-01463-1

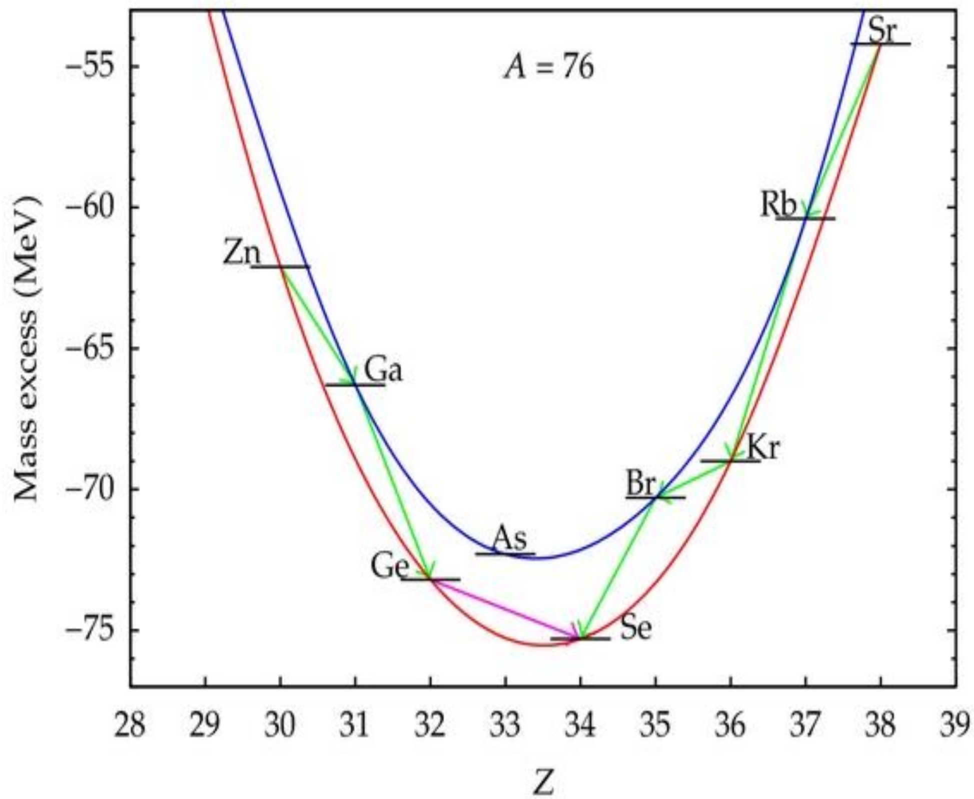
Double beta decay

- There are a few cases for which simple β decay is not energetically allowed, but double β decay is.

$$(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$$

- Has been observed in about dozen cases, i.e., $^{76}Ge \rightarrow$ ^{76}Se
- $T_{1/2}$~10^{18}-10^{21} years

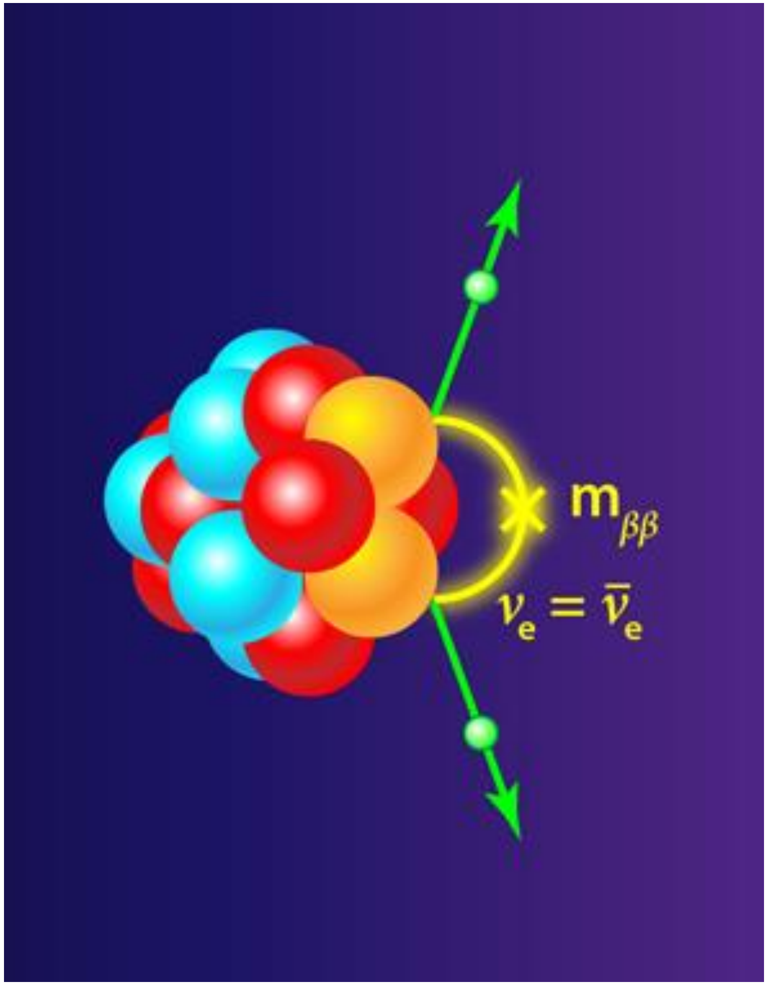




J. Mendez PhD thesis

Neutrinoless double beta decay

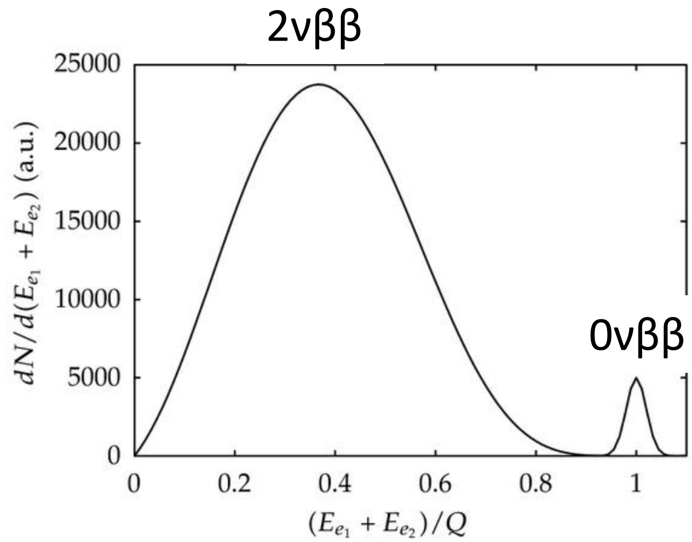
- If neutrinos have masses (they oscillate, so yes) they could be Majorana particles
- Neutrinos would be their own antiparticle $\nu_e = \bar{\nu}_e$
- This decay would violate lepton number conservation (+2 from the emitted e^-)
- Would allow for absolute measurement of m_ν
- Imply physics beyond the standard model

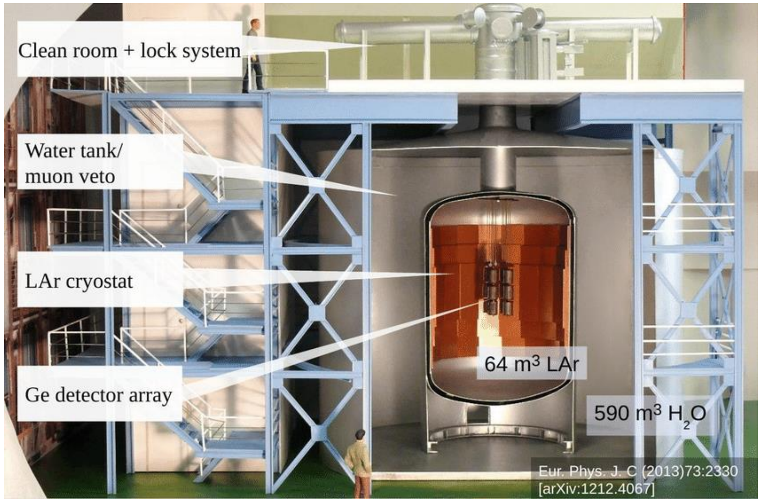


Physics 11, 30 (2018)

Neutrinoless double beta decay

- In neutrinoless double beta decay, both electrons carry all the energy
  - Sum of both energies=total energy
- Very low probability
  - Large amount of radioactive material
  - Superb sensitivity and efficiency
  - Long collection time
- Ultra low background (i.e. underground)
- No event has been observed so far
  - $T_{1/2}>10^{25}$ years (universe age ~10^{10} years)
- If there is ever a result, will need the M_{if} nuclear matrix element (see later)





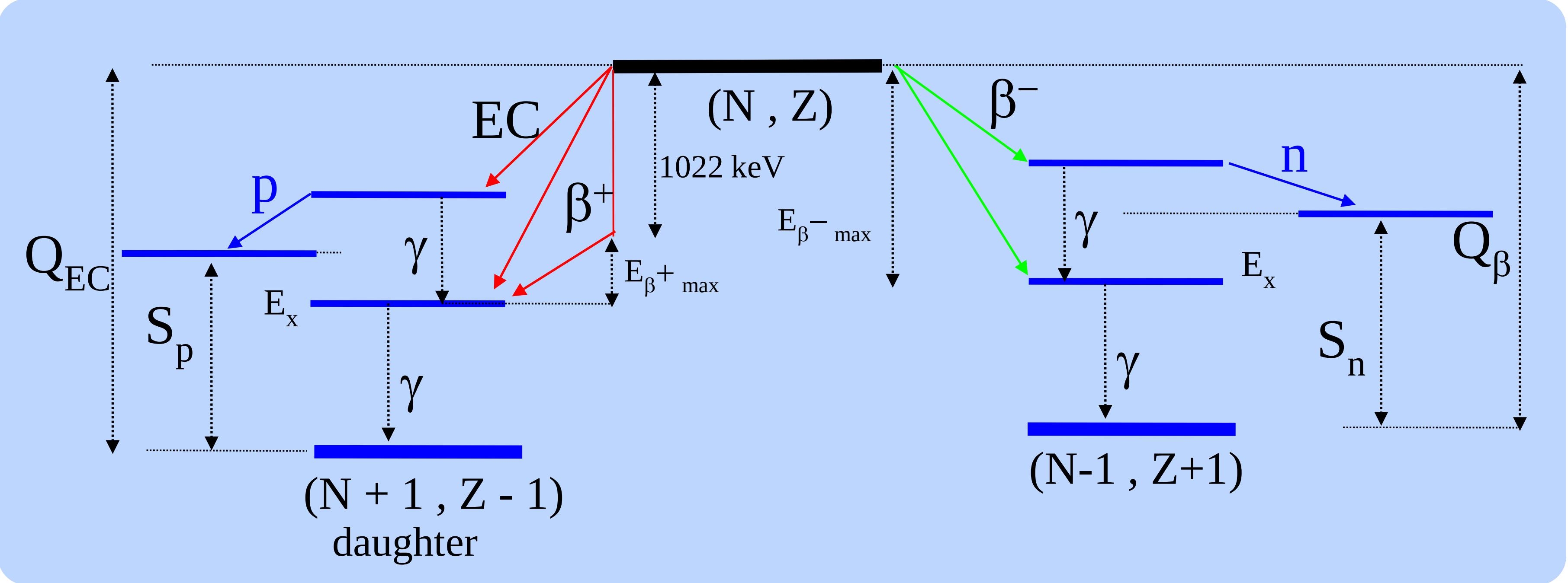
https://www.mpi-hd.mpg.de/gerda/

Beta decay process

Process mediated by the weak interaction between two isobars

$(N , Z) \xrightarrow{\beta^-} (N-1, Z+1) + e^- + \bar{\nu}$ $\qquad M(Z) - M(Z+1) = E_\beta + E_\nu + Ex$

$(N , Z) \xrightarrow{\beta^+ + EC} (N+1, Z-1) + e^+ + \nu$ $\qquad M(Z) - M(Z-1) = E_\beta + E_\nu + 1022 + Ex$



Fermi´s golden rule

$$\lambda_{if} = \frac{2\pi}{\hbar} \left|M_{if}\right|^2 \rho_f$$

Transition rate or probability of decay per second

Matrix element for the (weak) interaction

Density of final states

$$M_{if} = \langle f|M|i\rangle = \int \psi_f^* \psi_e^* \psi_\upsilon^* M \psi_i dV$$

*The one we need for neutrinoless double beta decay

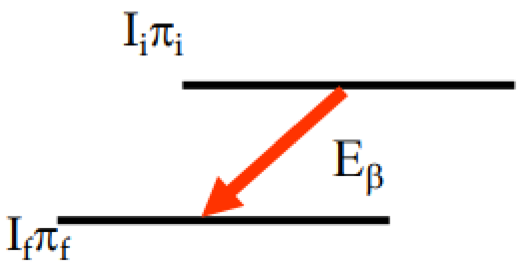
Beta decay *ft* value

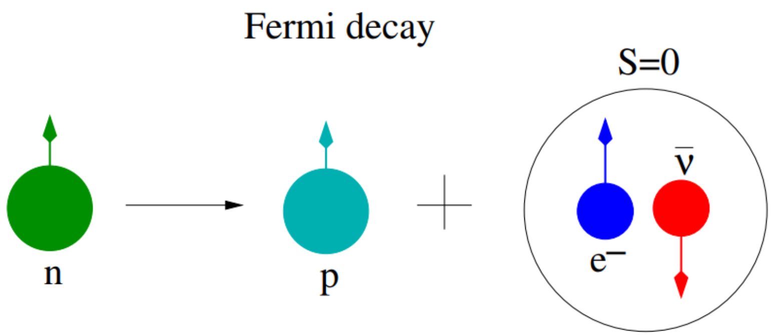
$$ft = f(Q)\frac{t_{1/2}}{BR} = \frac{2\pi^3\hbar^7\ln(2)}{g^2 m_e^5 c^4 \left|\overline{M'_{if}}\right|^2} = \frac{K}{g^2\left|\overline{M'_{if}}\right|^2}$$

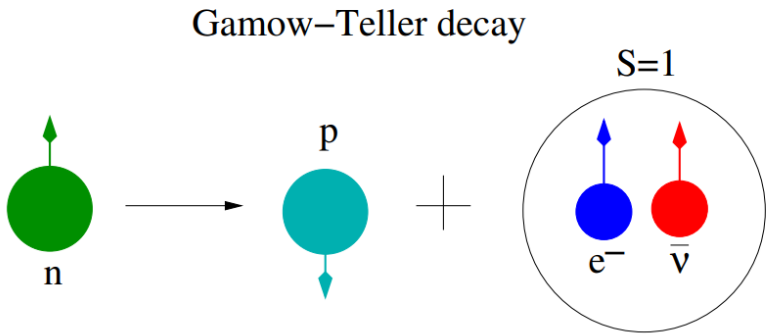
- *f* is the phase-space integral, which is related to the statistical rate factor, and is a function of the Q value. It is tabulated. It favours populating low energy states.
- Partial half-life of a specific decay branch $t_{1/2}^{\beta_i} = \frac{T_{1/2}^{exp}}{P_{\beta_i}}$
- If we measure Q, BR and $t_{1/2}$, we have log(*ft*).

Beta decay momentum conservation

- $\vec{L}_\beta = \vec{l}_e + \vec{l}_\nu$, $\vec{S}_\beta = \vec{s}_e + \vec{s}_\nu$ and $\vec{J}_\beta = \vec{L}_\beta + \vec{S}_\beta$
- $\vec{J}_i = \vec{J}_f + \vec{L}_\beta$
- J is the total angular momentum
- L is the orbital angular momentum
- S is the spin
  - Fermi $\vec{S}_e + \vec{S}_\nu = 0$ (antiparallel)
  - Gamow-Teller $\vec{S}_e + \vec{S}_\nu = 1$ (parallel)







Beta decay selection rules

L Classification

$$L_\beta = 0 \rightarrow \quad \text{Allowed}$$
$$L_\beta = 1 \rightarrow \quad \text{First Forbidden}$$
$$L_\beta = 2 \rightarrow \quad \text{Second Forbidden}$$
$$L_\beta = 3 \rightarrow \quad \text{Third Forbidden}$$

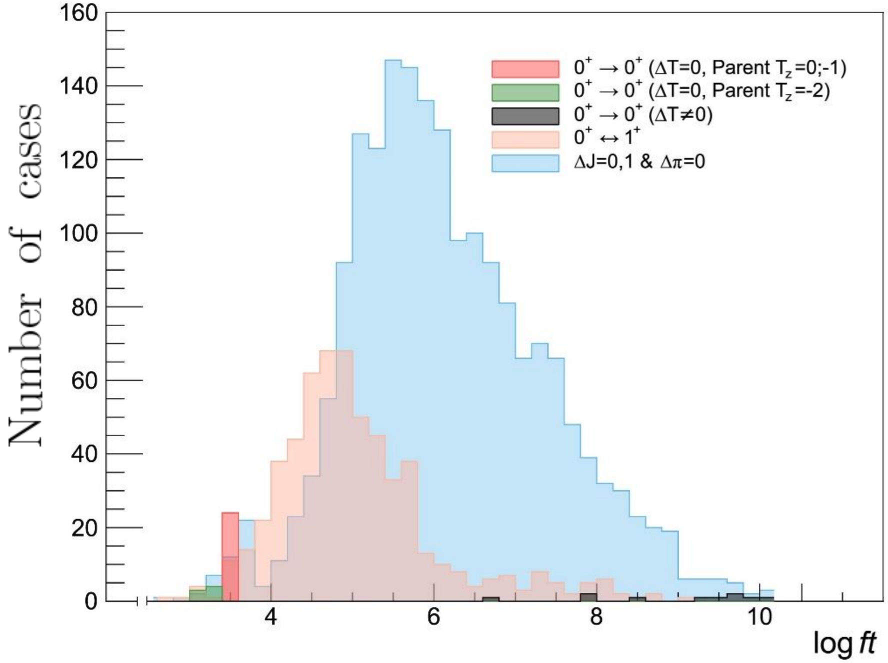
S Classification

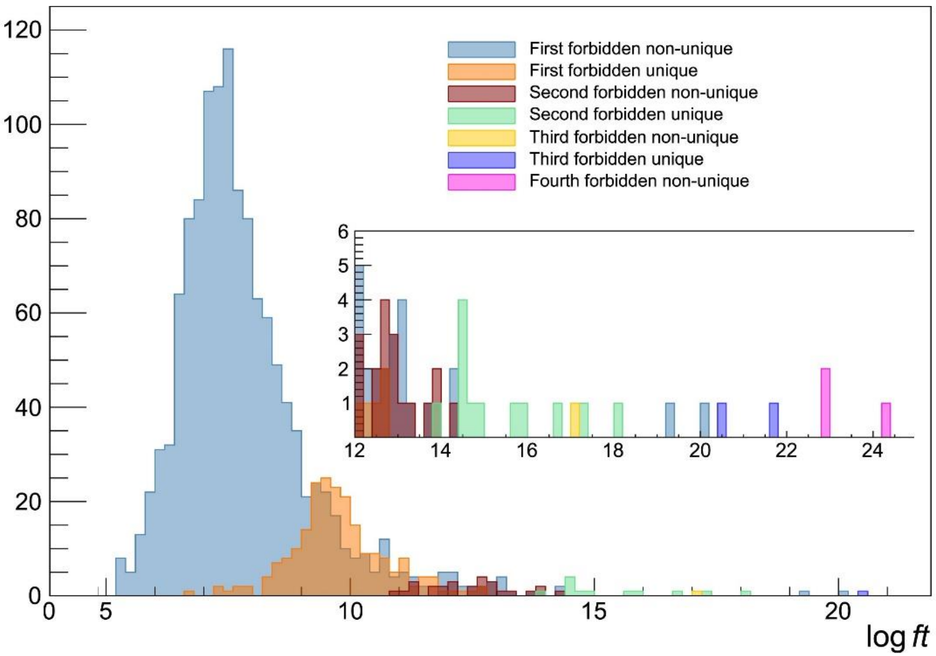
$$\vec{S}_\beta = \vec{S_{e^+}} + \vec{S_{\nu_e}} = \begin{cases} 0 & \uparrow\downarrow \text{ or } \downarrow\uparrow \quad V\,(F) \\ 1 & \uparrow\uparrow \text{ or } \downarrow\downarrow \quad A\,(GT) \end{cases}$$

- $0^+ \rightarrow 0^+$ not allowed in GT, because $S_\beta=1$ and therefore $\Delta L \neq 0$

Beta decay selection rules

S. Turkat et al., Nucl. Data Sheets 152, 101584 (2023)





- We can use log(*ft*) to infer the spin-parity of daughter nucleus states
- Learn about nuclear structure

Beta decay experiment

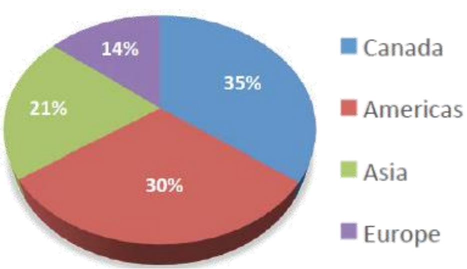
- Selection rules tell us which states we will "most likely" populate in the daughter nucleus
- Log(*ft)* favours populating low energy states
- No need to re-accelerate beams
  - Higher intensity
  - No Doppler corrections
  - Easier experiment

Beta decay experiment

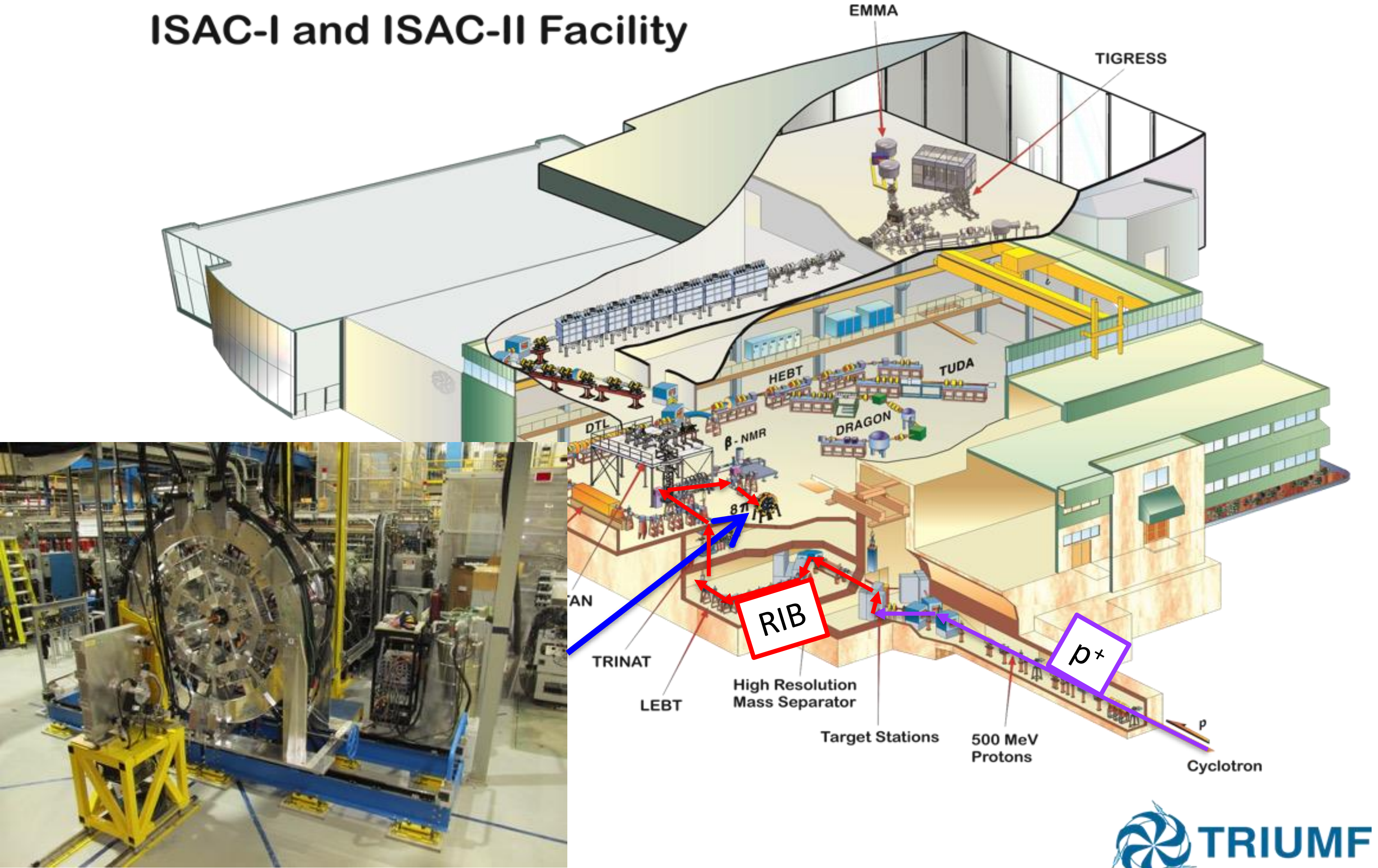
- Now we have all the ingredients to perform beta decay experiments and learn nuclear structure
- I will use GRIFFIN at TRIUMF as example, current state-of-the-art spectrometer
- More facilities are following its design

400 staff
200 students & post-doctoral researchers

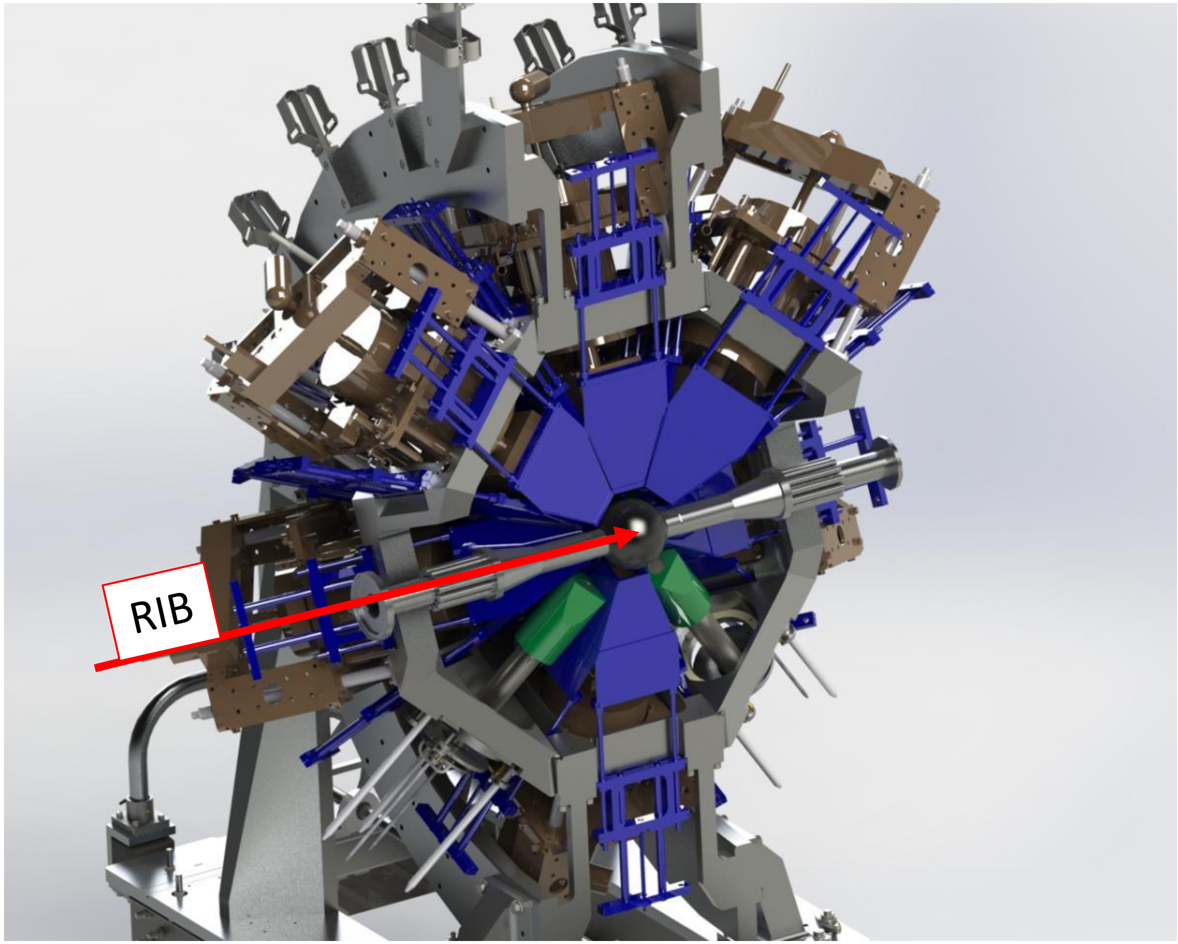
650 scientist & student researcher visits per year



ISAC@TRIUMF

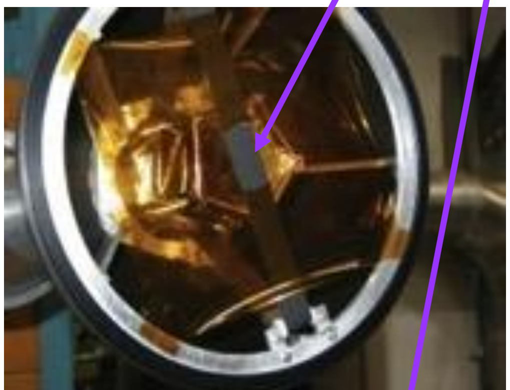

ISAC-I and ISAC-II Facility
EMMA
TIGRESS
HEBT
TUDA
DTL
β-NMR
DRAGON
8π
AN
RIB
p+
TRINAT
LEBT
High Resolution Mass Separator
Target Stations
500 MeV Protons
p
Cyclotron
TRIUMF

GRIFFIN

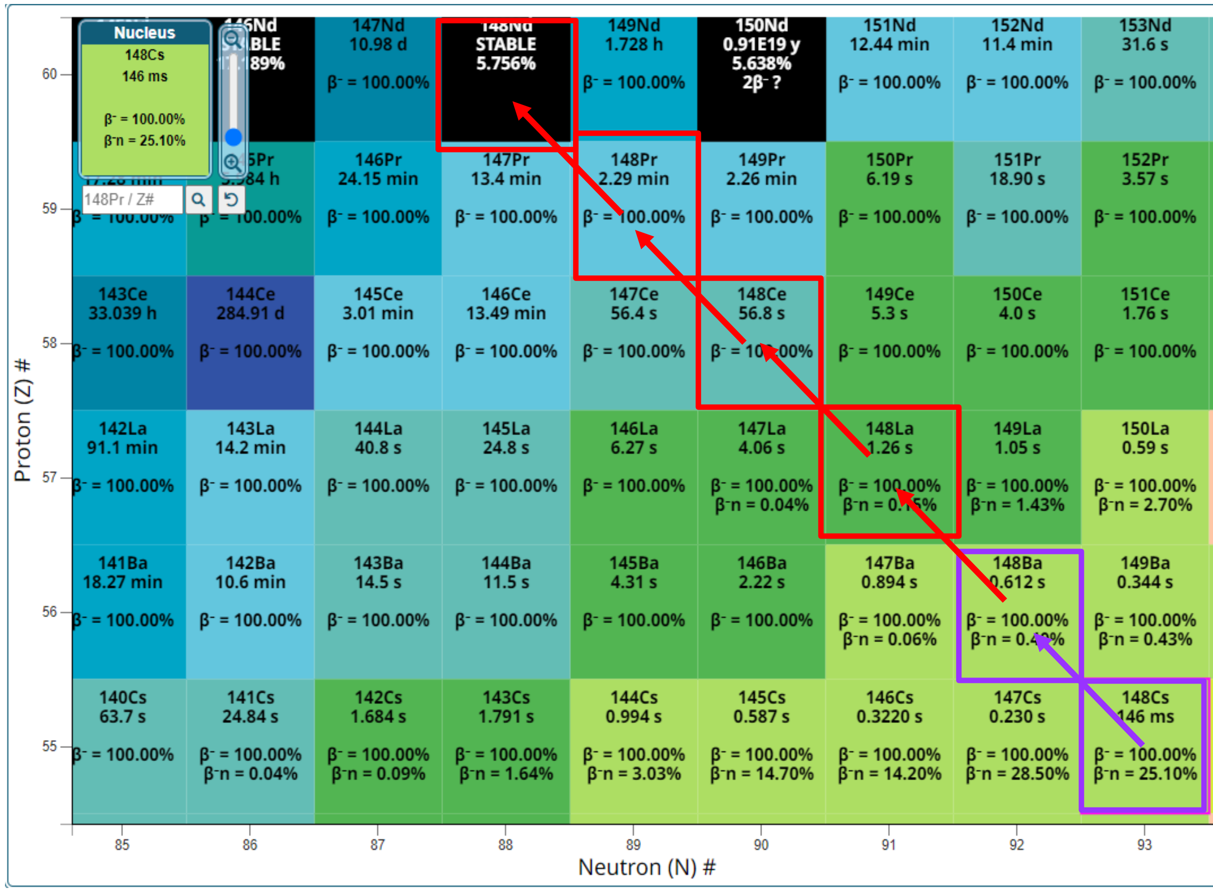


Moving tape

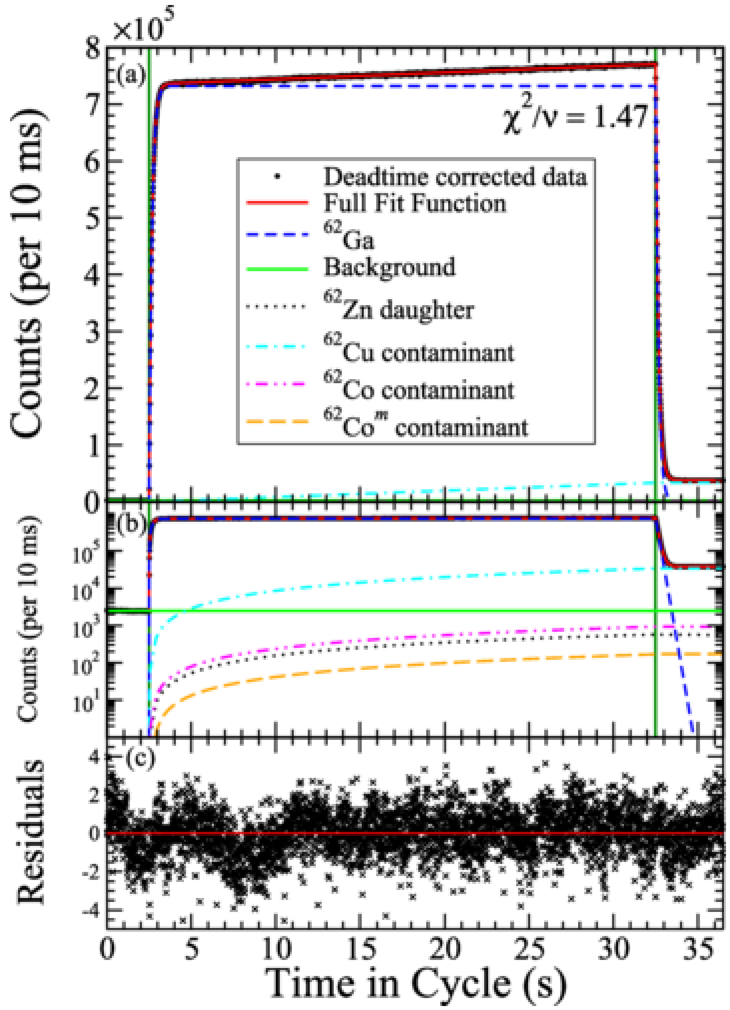
Mylar tape



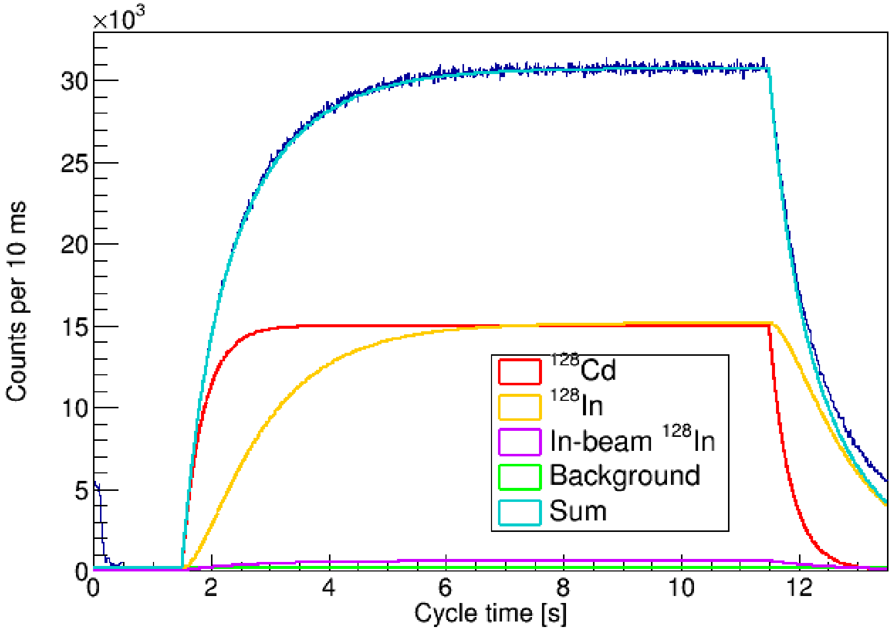
Lead wall



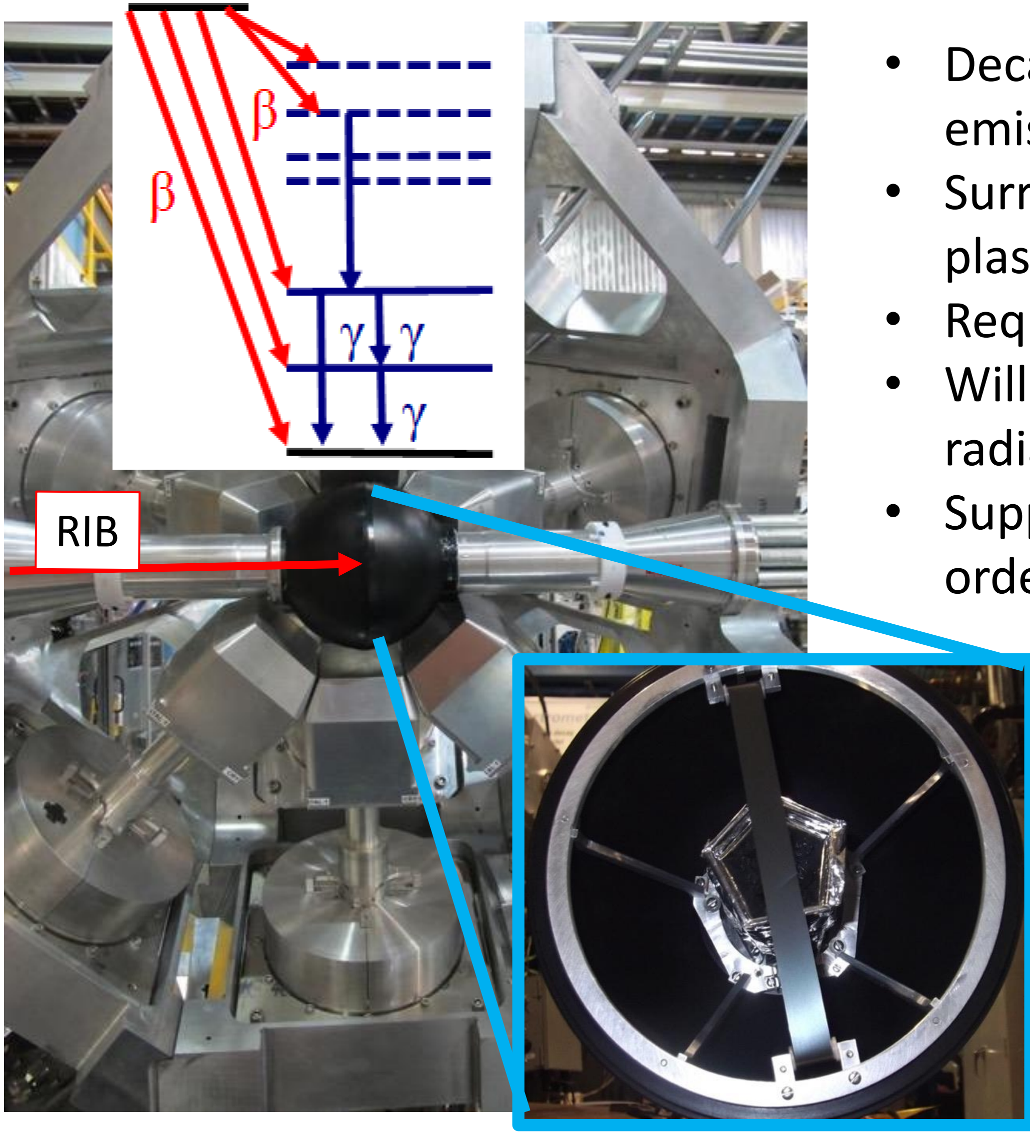
Moving tape



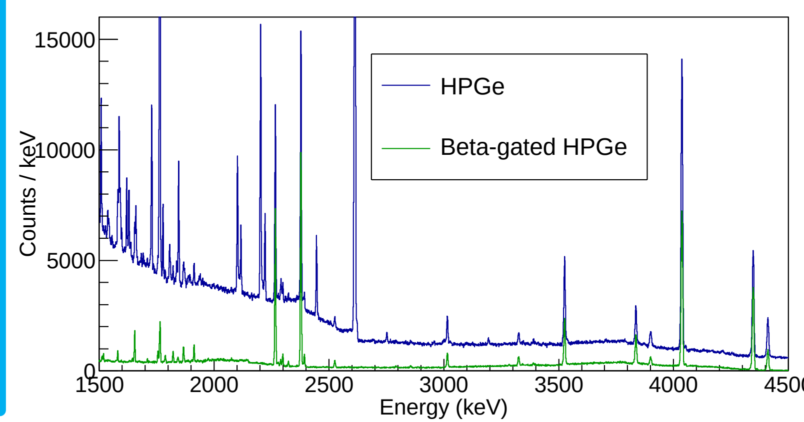
- You implant RIB for some time until your activity saturates
- Block RIB and measure decay
- Thanks to very different lifetimes, you observe different decay curves
- Move tape behind lead wall
- Start fresh implantation



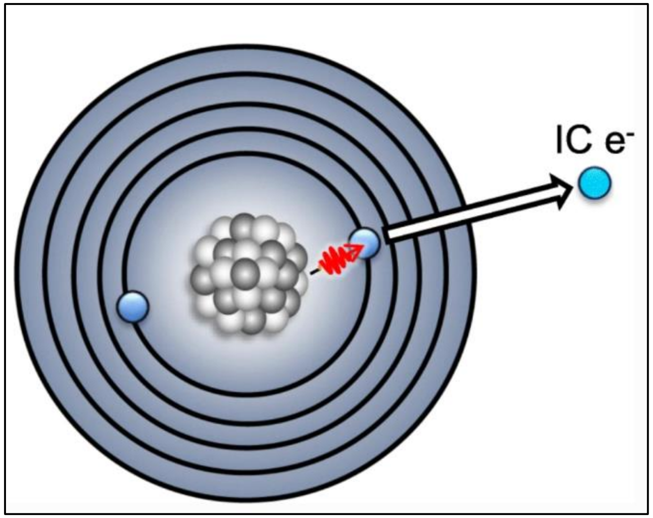
Beta tagging



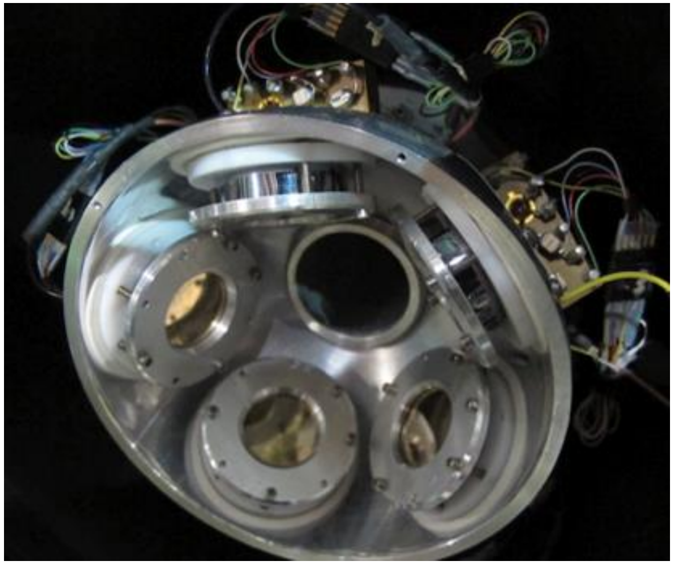
- Decay of interest begins with a β emission
- Surround point of implantation with plastic scintillators
- Require detection of a β particle
- Will not detect β particle from ambient radiation
- Suppresses room background by 5 orders of magnitude



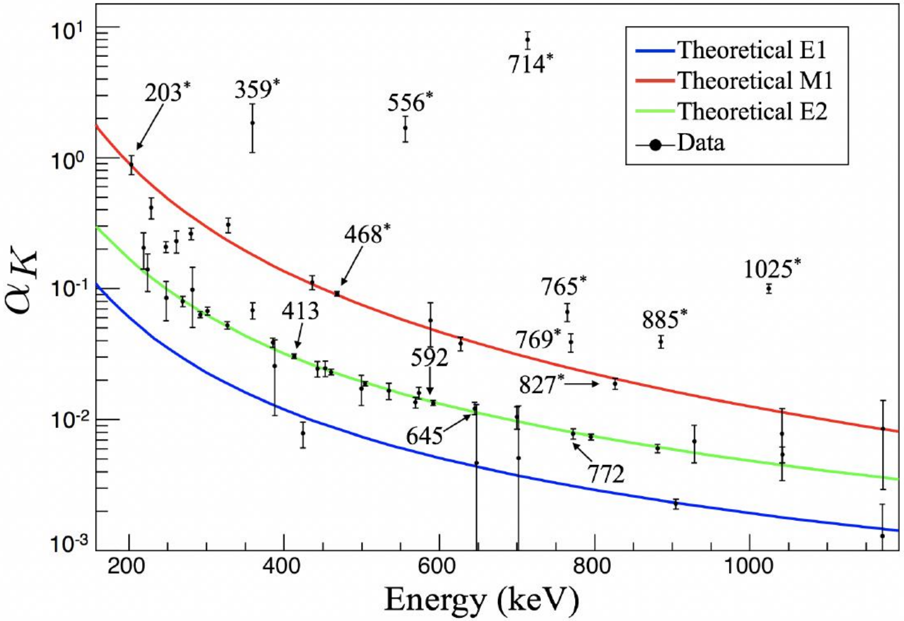
Conversion electrons



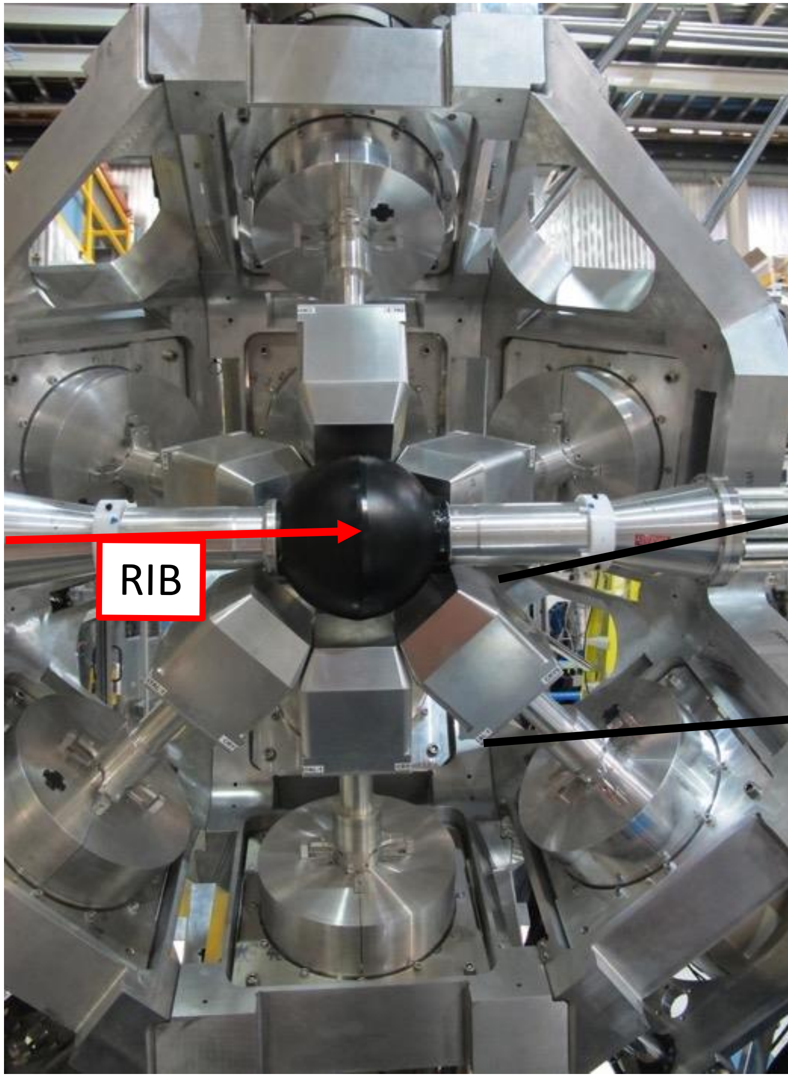
- Whenever a low energy gamma is emitted, an inner shell atomic orbital can absorb it
- Probability depends on multipolarity of gamma and energy
- Electron emitted with discrete energy
- Si detectors, cooled to reduce electronic noise
- PACES in GRIFFIN, SPEDE in IDS (CERN)

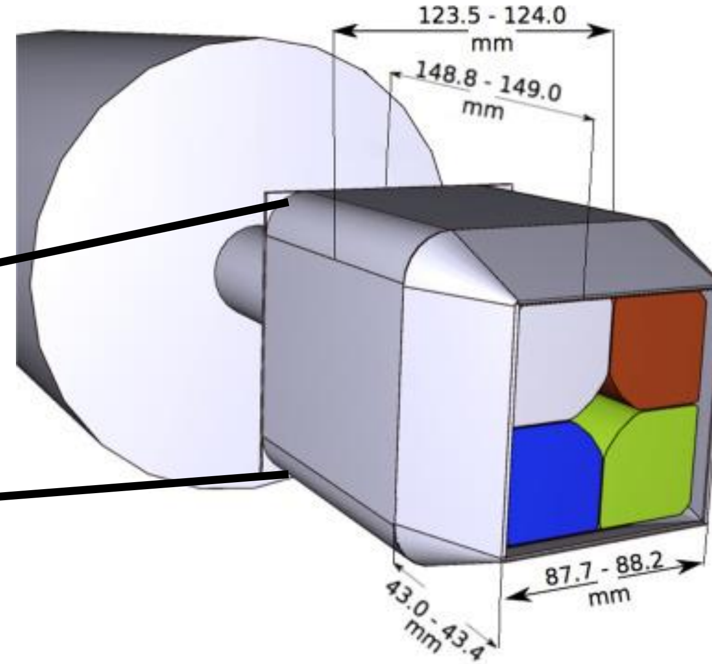


J. Park *et al.*, PRC 96, 014315 (2016).



HPGe clovers

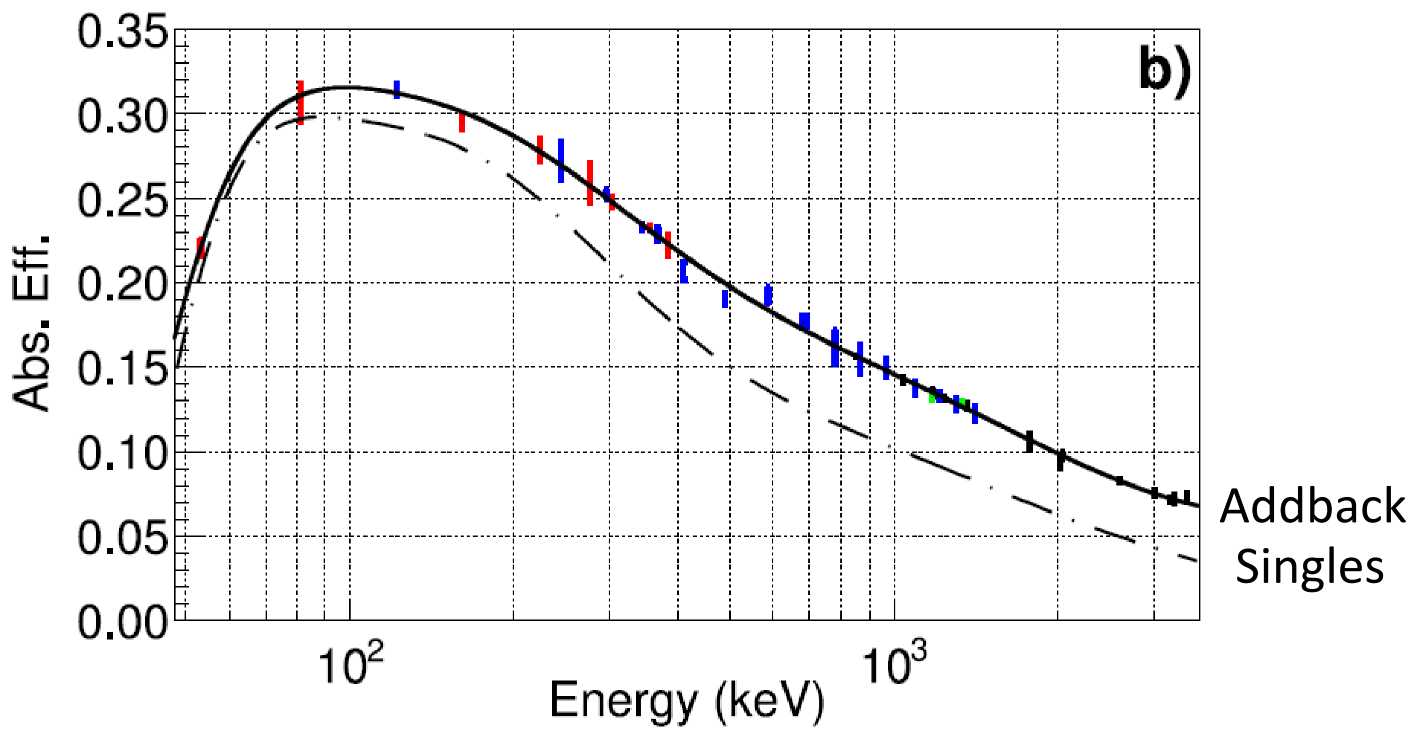




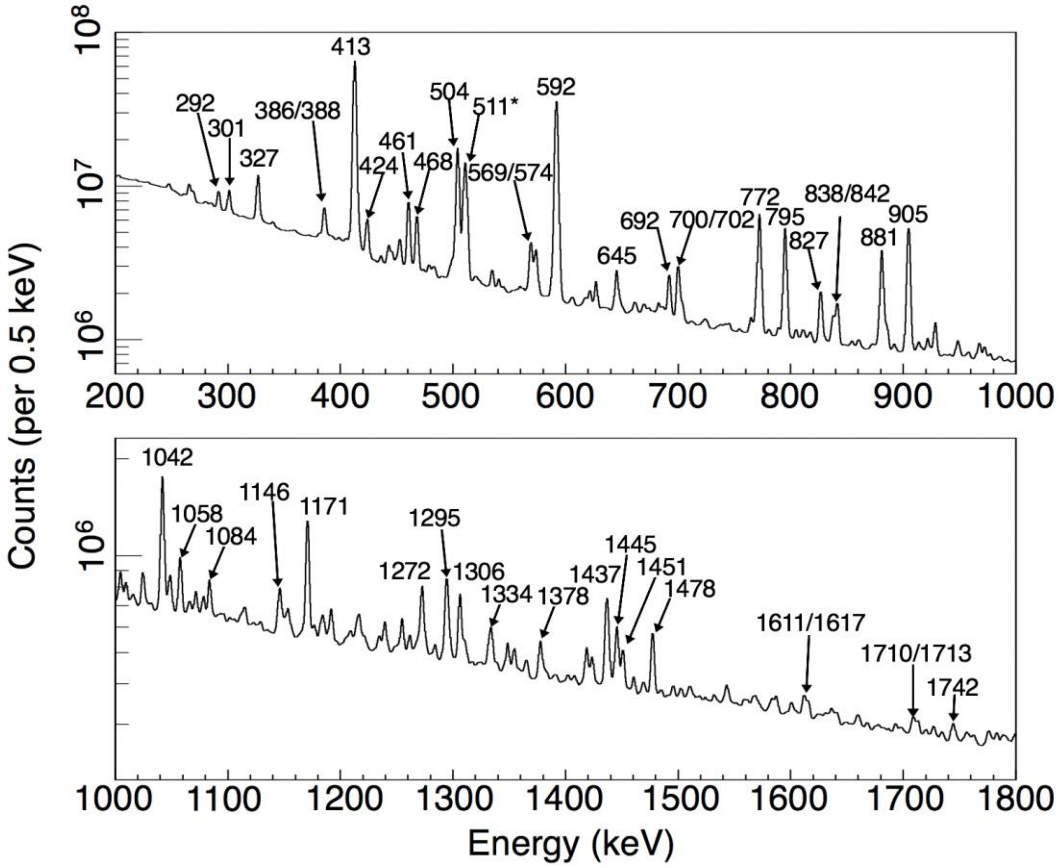
A.B. Garnsworthy, C.E. Svensson, M. Bowry et al. Nuclear Inst. and Methods in Physics Research, A 918 (2019) 9–29

HPGe clovers

- 16 clovers, 4 crystal each, 64 total
- ~30% efficiency at ~120 keV
- Energy resolution@ 1.3MeV = 1.89(6) keV



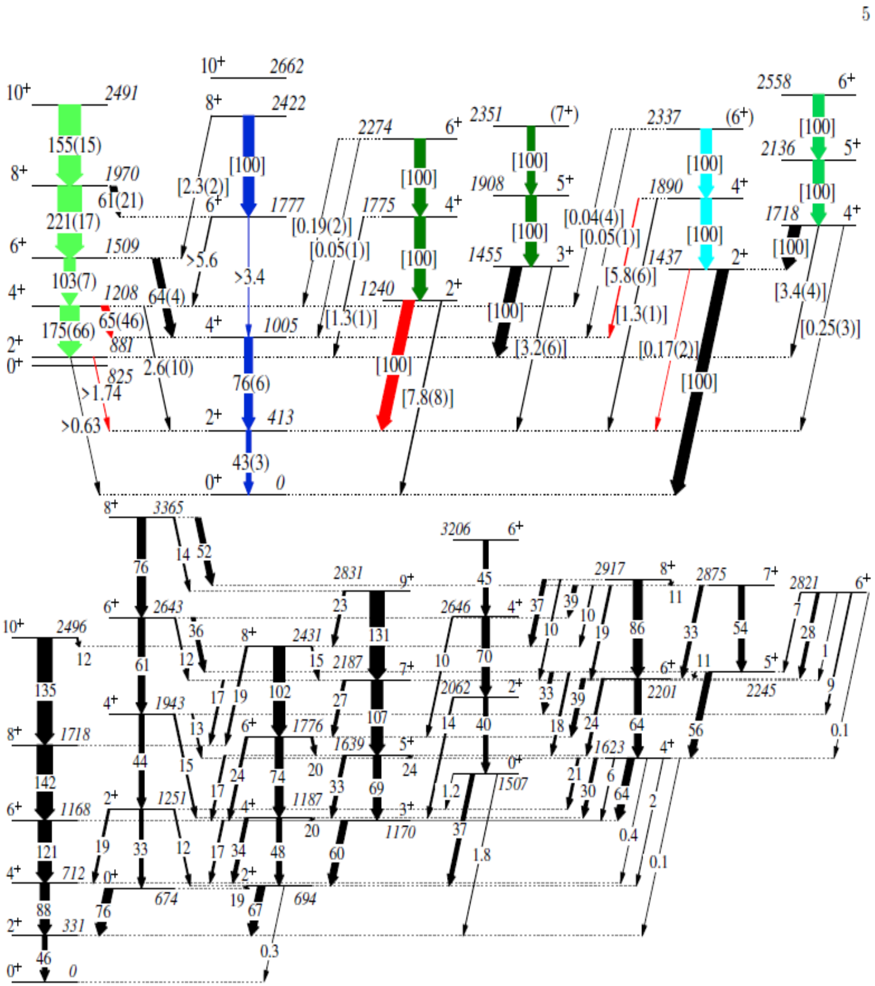
Statistics



- High efficiency allows for high statistics
- Detects more and weaker γ rays
- Wealth of information, but more complex analysis

A. MacLean PhD thesis, UoGuelph 2021

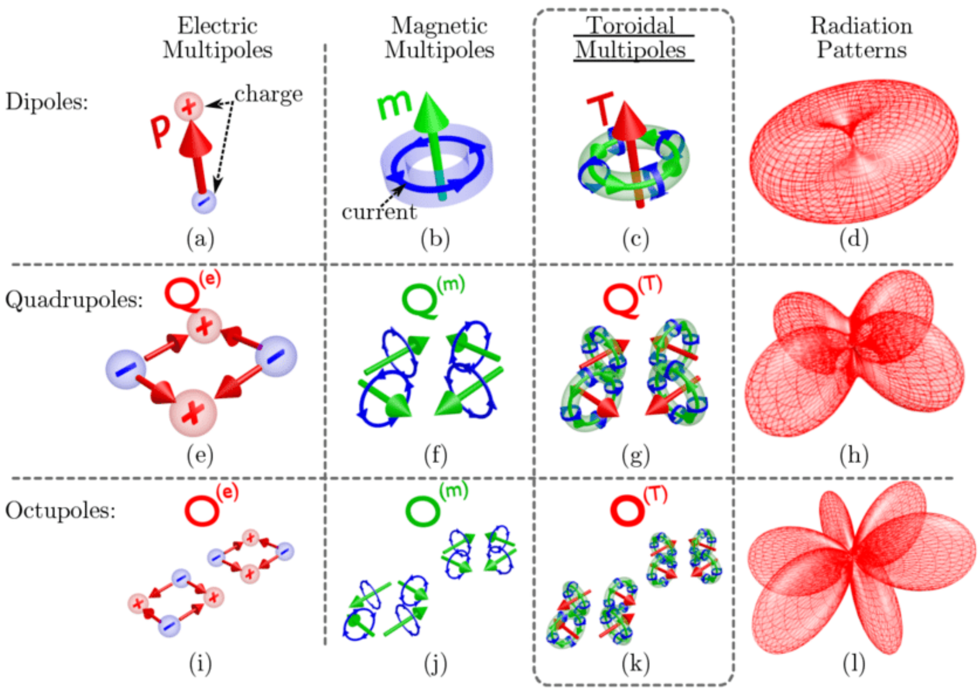
Build complex level scheme



A. MacLean PhD thesis, UoGuelph 2021

- Use γ- γ coincidences to build level scheme
- Coincidences require large statistics and efficiency
- This is a small fraction of a level scheme, can get a lot more complex
- Reveals inner structure of the nucleus

γ emission

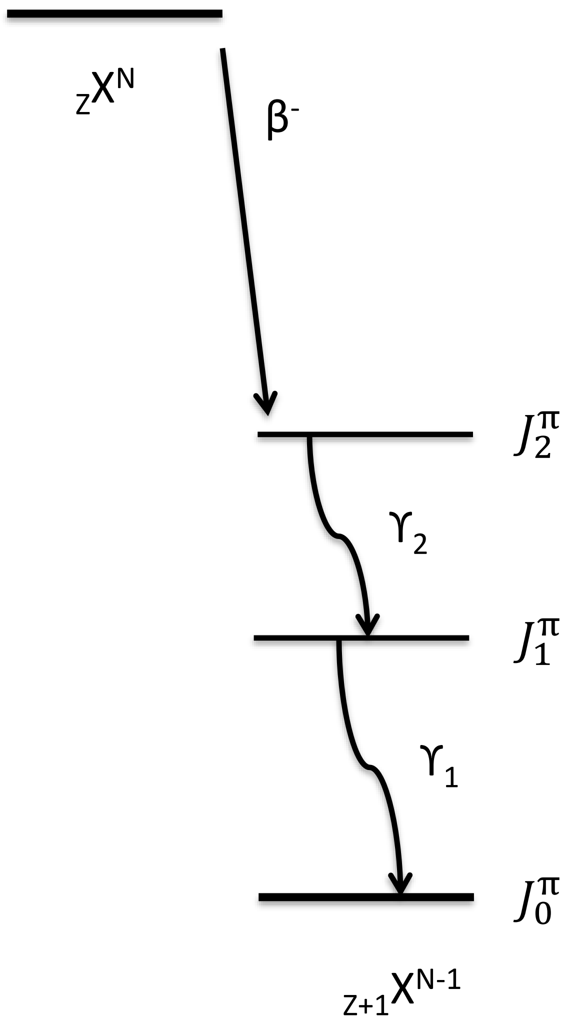


N. Papasimakis Nature Materials volume 15, pages263–271 (2016)

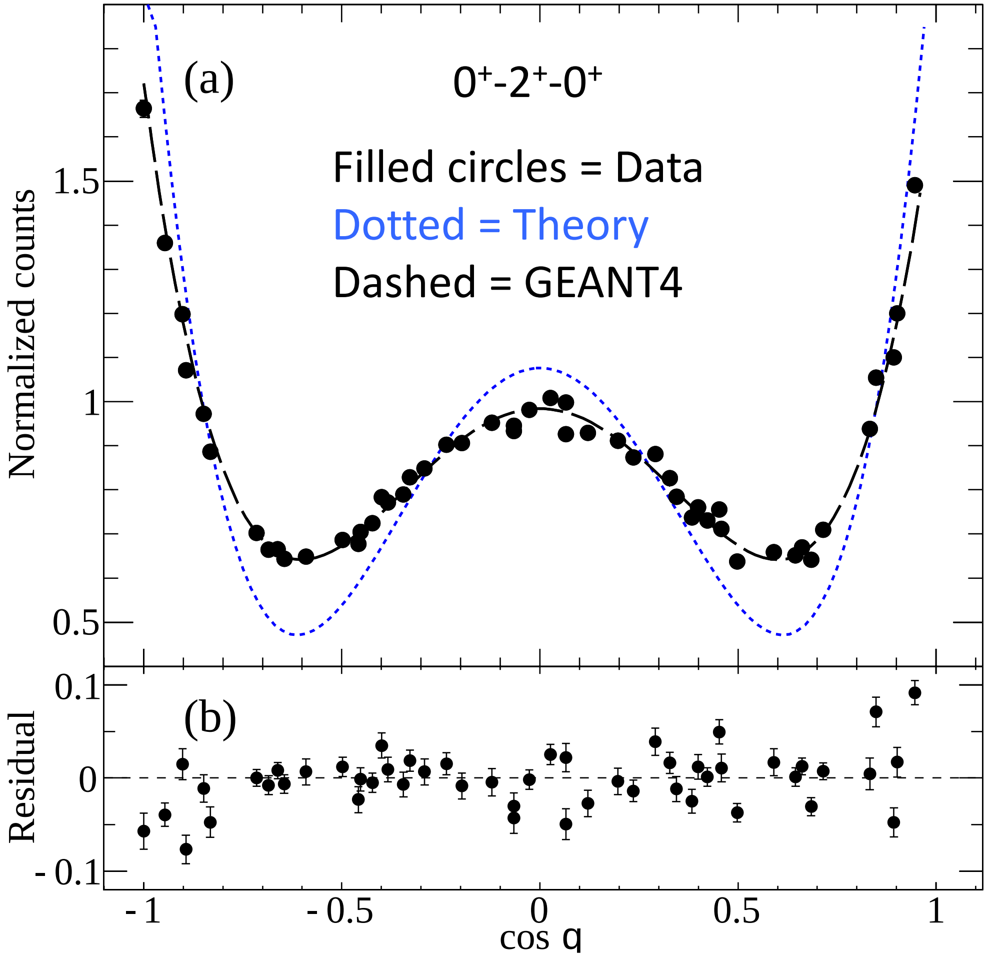
- γ-ray emission is not isotropic
- Different for a dipole than a quadrupole
- Depends on J_i, J_f and L involved
- Powerful tool to firmly assign *J* to levels and L to γ-rays

γ-γ angular correlations

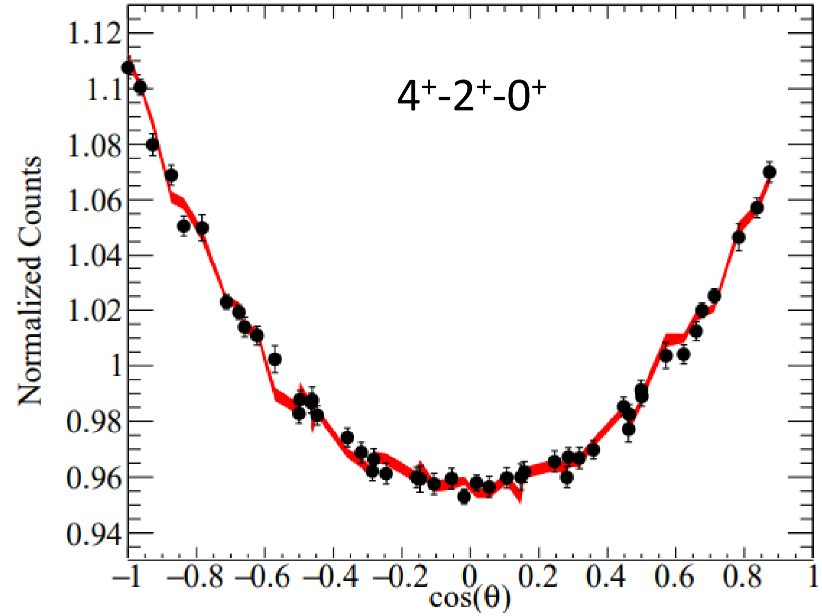
- Implanted nuclei will not be, in general, oriented (polarized)
- Effective radiation emission seems isotropic
  - Individual is not
- We can use a γ-γ cascade
  - Now we measure the angle between γ-rays
  - One γ gives us the nuclei orientation
  - The angular distribution will give us the multipolarity of the other (polarized)
- Problem: 5 incognitas and 1 equation
  - Must already know at least 4 of J^{π} and XL involded



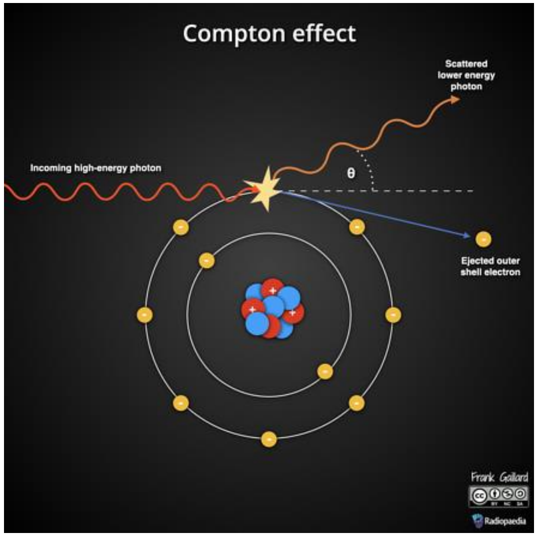
γ-γ angular correlations



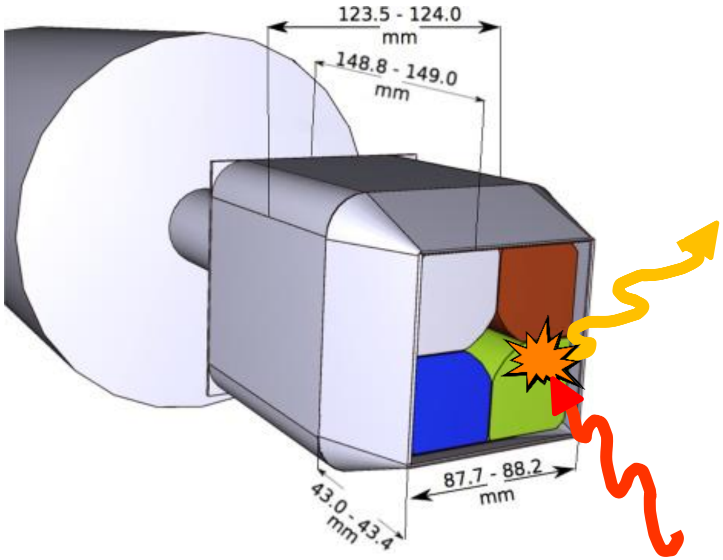
- With 64 crystals, there are 4096 pair combinations at GRIFFIN
- Very high granularity
- 52 unique angles
- Great angular resolution
- Precise angular correlations

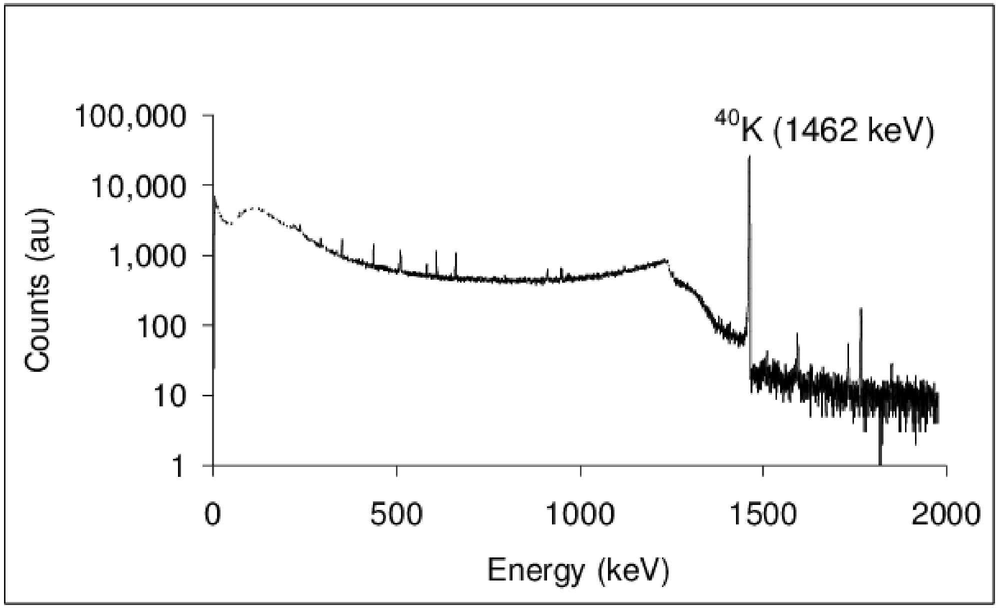


Compton scattering

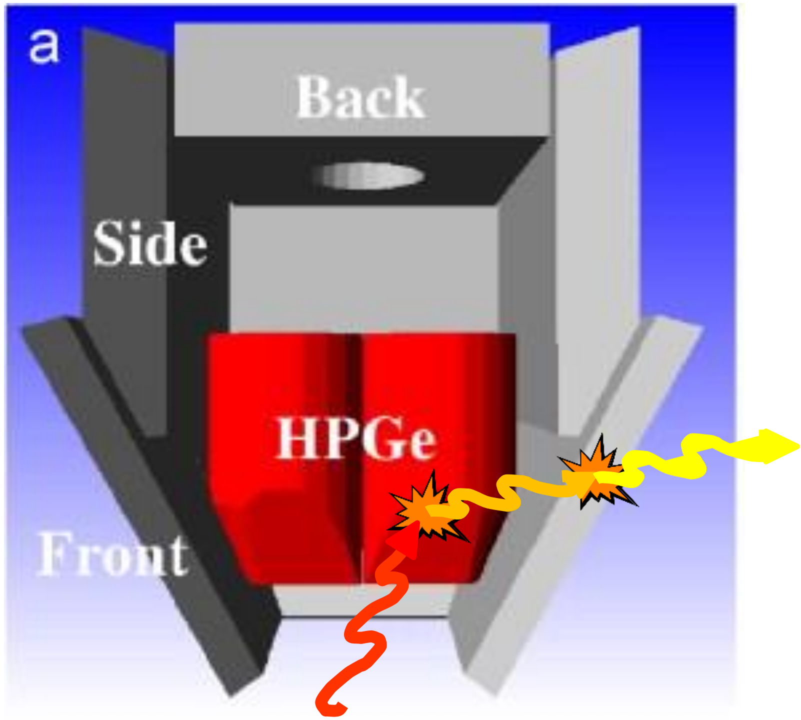


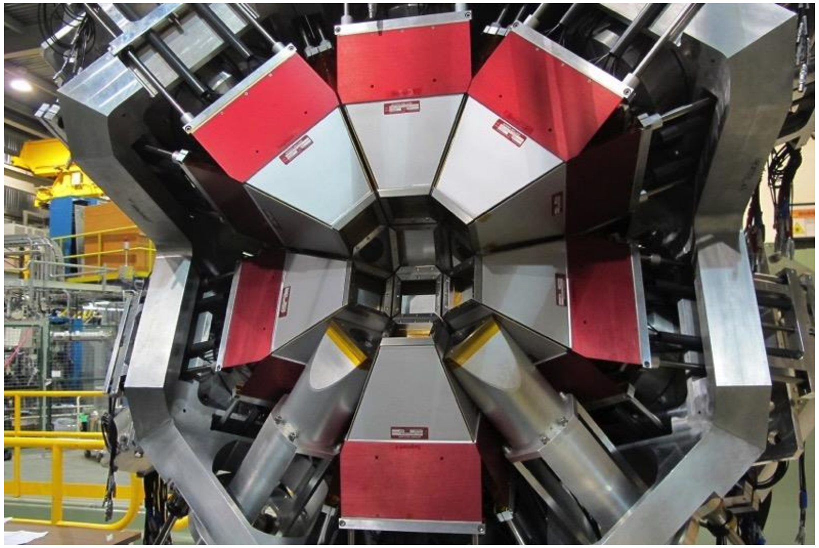
- A photon interacts with an atom depositing a fraction of its energy (not all)
- If after the Compton event, it escapes the detector, we will not detect the full energy
- Compton background complicates measurement of weaker gammas

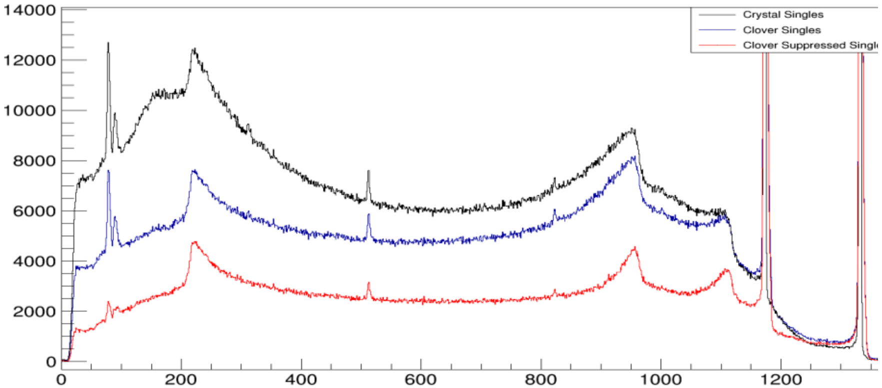


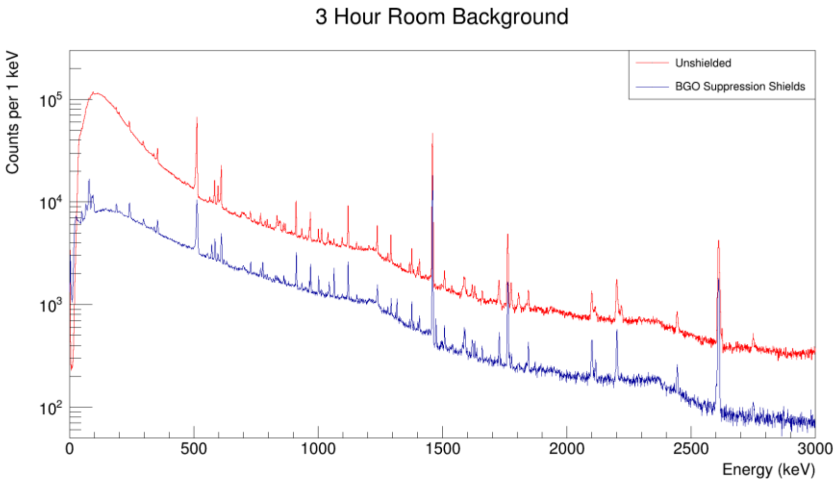


BGO Compton suppressors

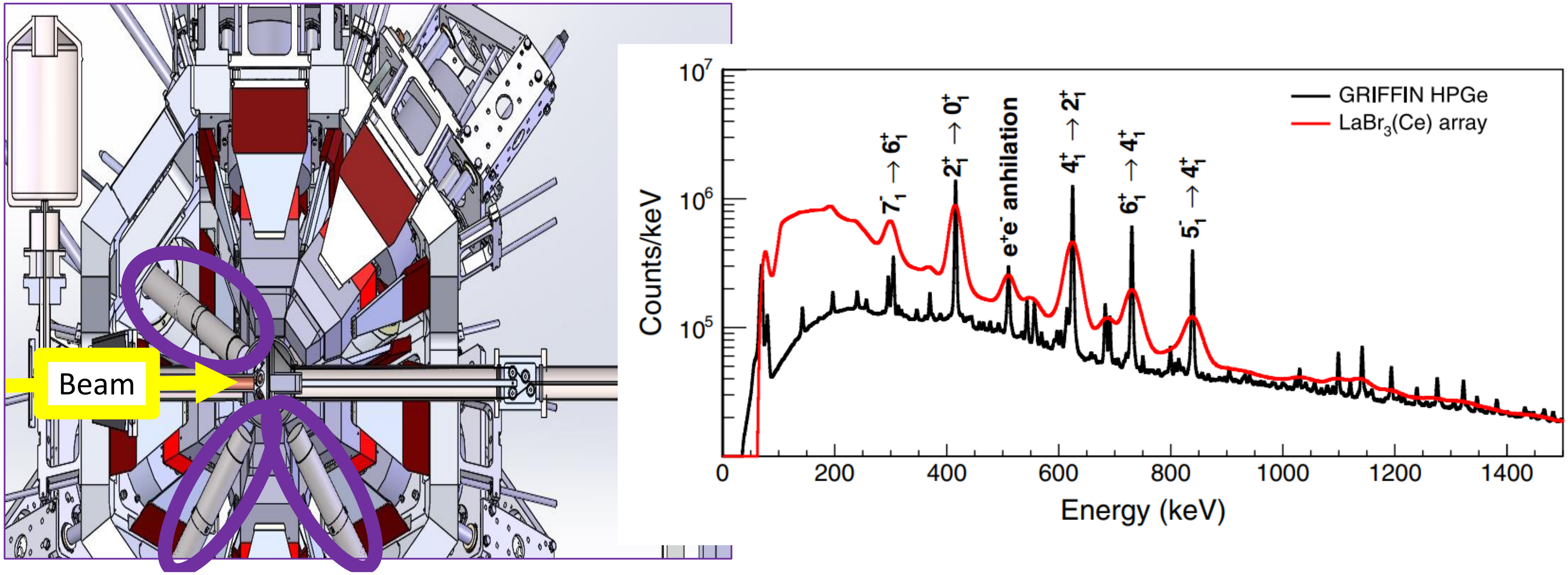


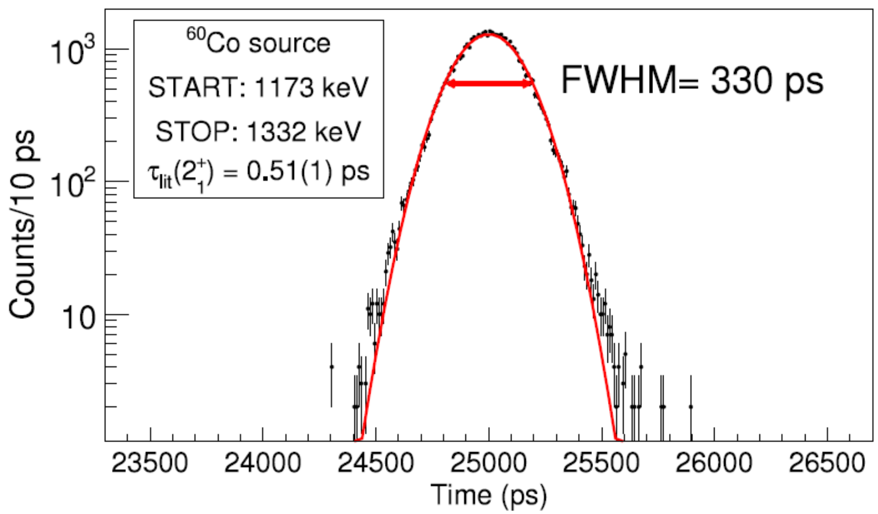






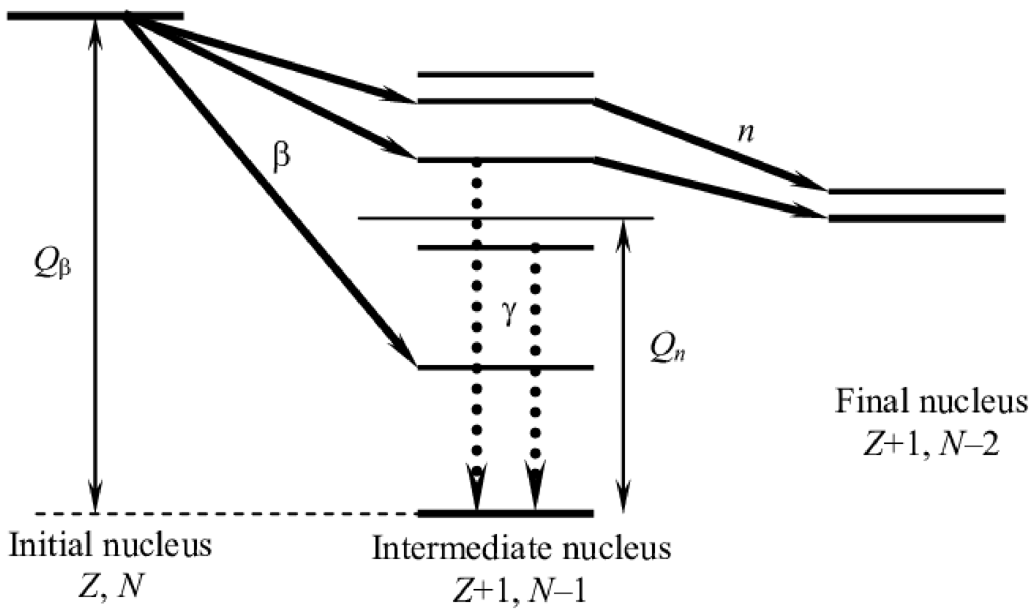
Timing with scintillators





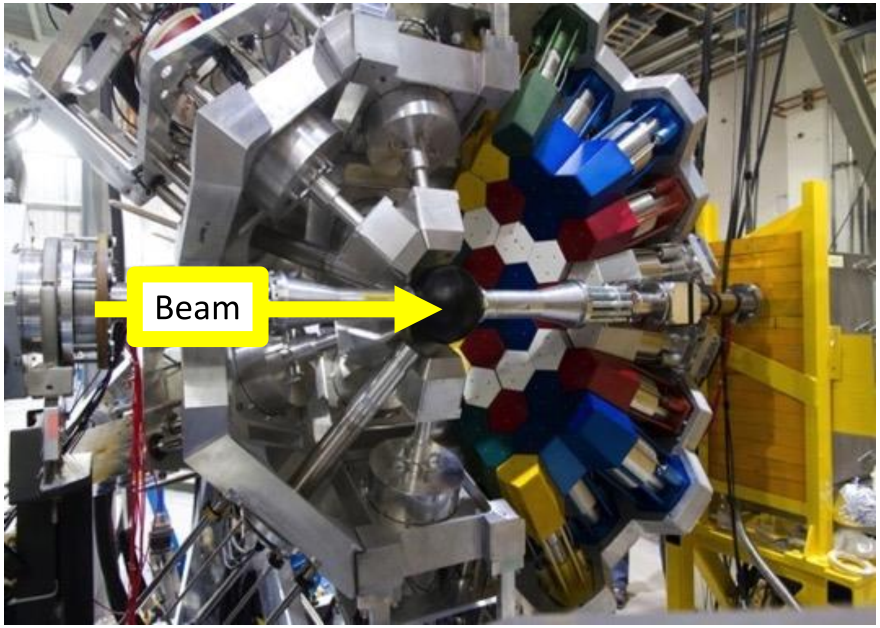
- We can add scintillators, such as $LaBr_3(Ce)$
- Worse energy resolution, superb timing properties
- Lifetime measurements down to ps

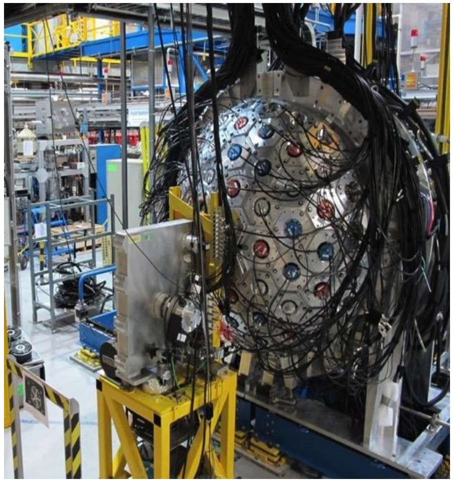
Beta delayed neutron emission



- After a beta decay, the daughter nucleus can be left in a state above the neutron separation energy
- The intermediate nucleus can emit a neutron instead of a gamma.

Neutron measurment



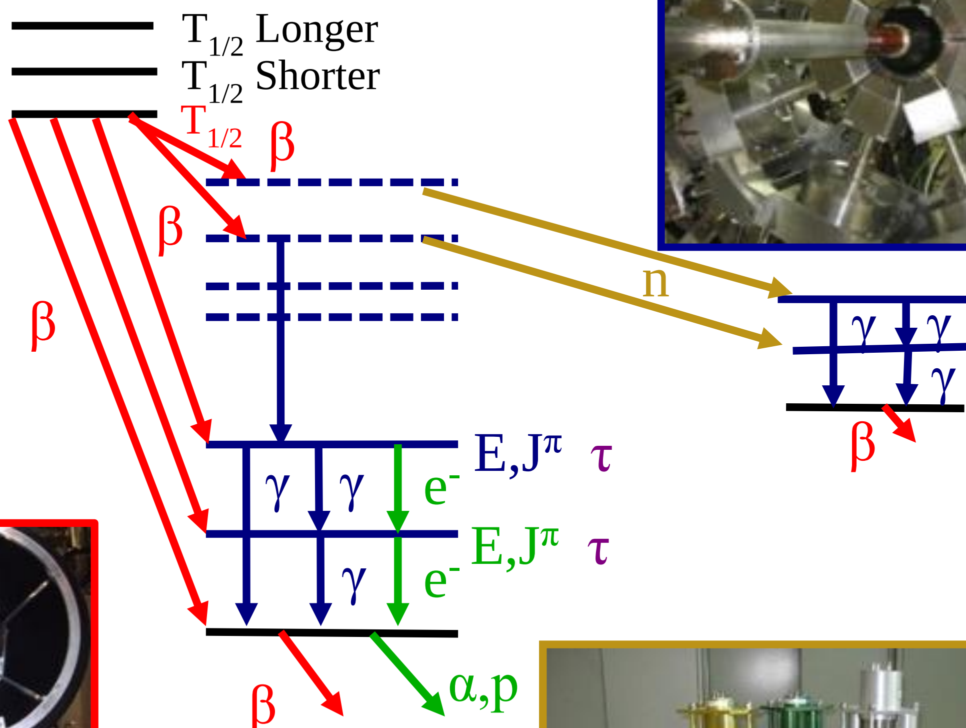


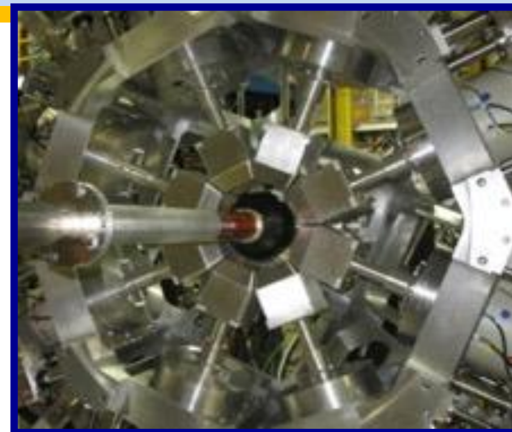
- We can use DESCANT to detect neutrons
- Liquid scintillators
- INDie (at ISOLDE) are plastic scintillators strips
- By neutron coincidences, we can distinguish if we are populating the N-1 nucleus or the N-2
- Without neutron detection, is not always trivial

Beta decay experiment

Fast, in-vacuum tape system

Enhances decay of interest





HPGe: 16 Clovers

Detect gamma rays and determines branching ratios, multipolarities and mixing ratios

$LaBr_3$:

8x$LaBr_3$

Fast-timing to measure level lifetimes

SCEPTAR: 10+10 plastic scintillators

Detects beta decays and determines branching ratios

PACES: 5 Cooled Si(Li)s

Detects Internal Conversion Electrons and alphas/protons

Beta decay experiment

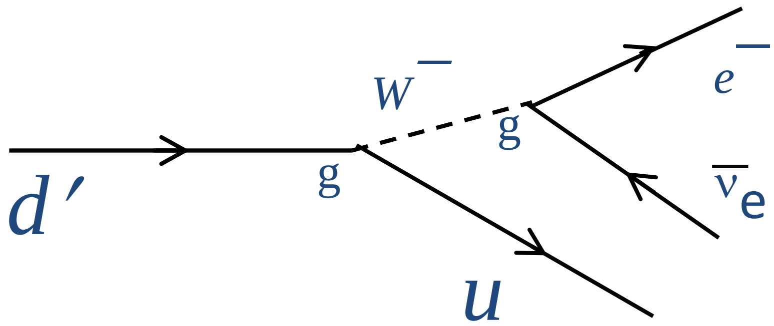
Nuclear structure

- Measure beta decay half-life
- Construct level scheme with γγ coincidences
- Assign J^{π} to excited states using:
  - Log(ft) from beta decay
  - γγ angular correlations
  - α from conversion electrons
  - B(XL) from lifetime measurements
- Firmly assigning J^{π} is key to understand the structure of a nucleus
- **NOTE:** none of this techniques is exclusive from beta decay experiments, but, in general, it would be the simplest and cleanest experiment to use them

The Standard Model of particle physics

The CKM matrix plays a central role in the Standard Model and underpins all quark flavour-changing interactions:

→ weak interaction eigenstates ≠ quark mass eigenstates



$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$|d'\rangle = V_{ud}|d\rangle + V_{us}|s\rangle + V_{ub}|b\rangle$$

In the Standard Model the CKM matrix describes a unitary transformation:

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$$

The first row of the CKM matrix provides the most demanding experimental test of the unitarity condition.

Superallowed Fermi β Decay

$$ft = \frac{K}{\left|\overline{M'_{if}}\right|^2 g^2}$$

phase space (Q-value) → f

half-life, branching ratio → t

constants → K

Weak coupling strength → g^2

matrix element → M'_{if}

For the special case of $0^+ \rightarrow 0^+$ (pure Fermi) β decays between isobaric analogue states (superallowed) the matrix element is that of an isospin ladder operator:

$$|M_{fi}|^2 = (T - T_Z)(T + T_Z + 1) = 2 \quad \text{(for } T=1\text{)}$$

Strategy: Measure superallowed ft-values, deduce G_V and V_{ud}:

$$ft = \frac{K}{2\, G_V^2}$$

Vector coupling constant → G_V

$$|V_{ud}| = G_V / G_F$$

Fermi coupling constant → G_F

Superallowed Fermi β Decay

$$Ft = ft\left(1+\delta'_R\right)\left(1+\delta_{NS}-\delta_C\right) = \frac{K}{2G_V^2\left(1+\Delta_R^V\right)} = \text{constant}$$

"Corrected" ft value

Experiment

Calculated corrections (~1%)
(nucleus dependent)

Inner radiative correction (~2.4%)
(nucleus independent)

Conserved Current Vector (CVC) Hypothesis

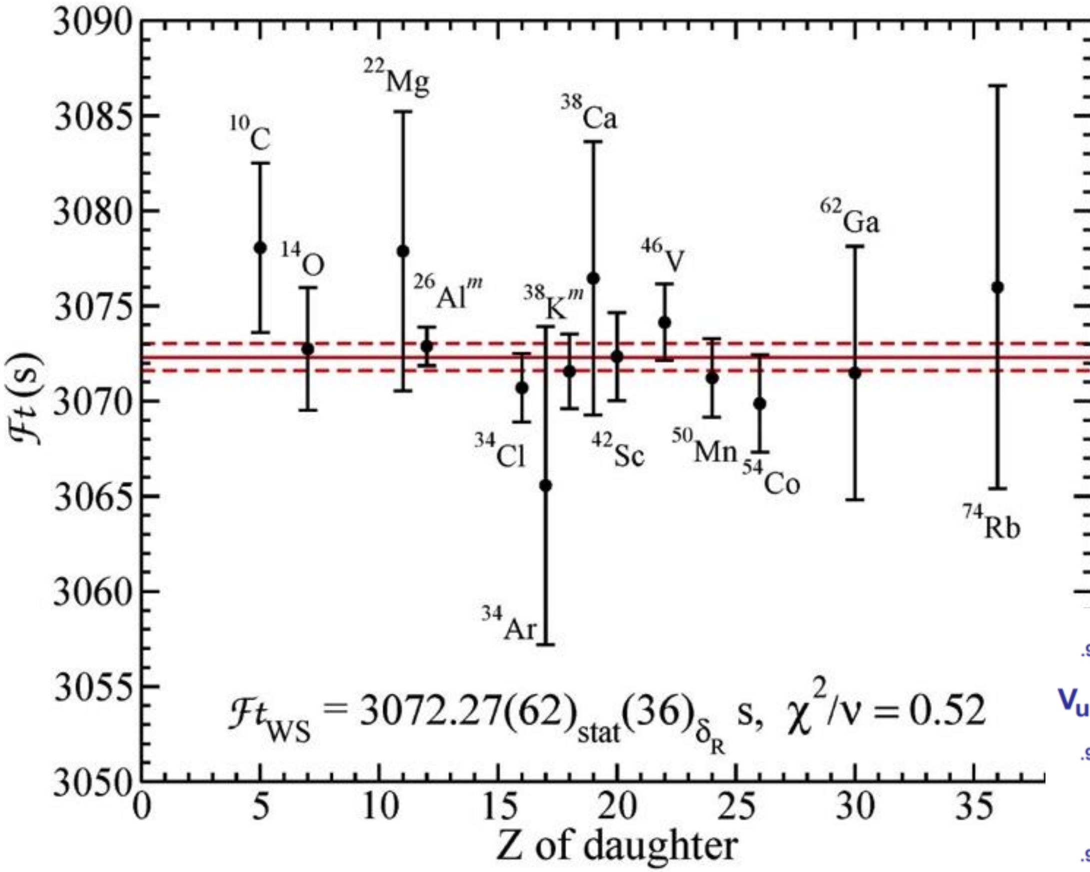
Δ_R^V = nucleus independent inner radiative correction: 2.361(38)%

δ_R = nucleus dependent radiative correction to order $Z^2\alpha^3$: ~1.4%
- depends on electron's energy and *Z* of nucleus

δ_{NS} = nuclear structure dependent radiative correction: -0.35% – 0.05%

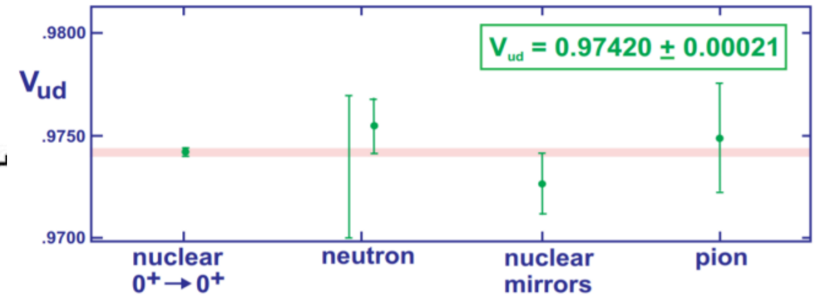
δ_C = nucleus dependent isospin-symmetry-breaking correction: 0.2% – 1.6%
- strong nuclear structure dependence

Superallowed Fermi β Decay

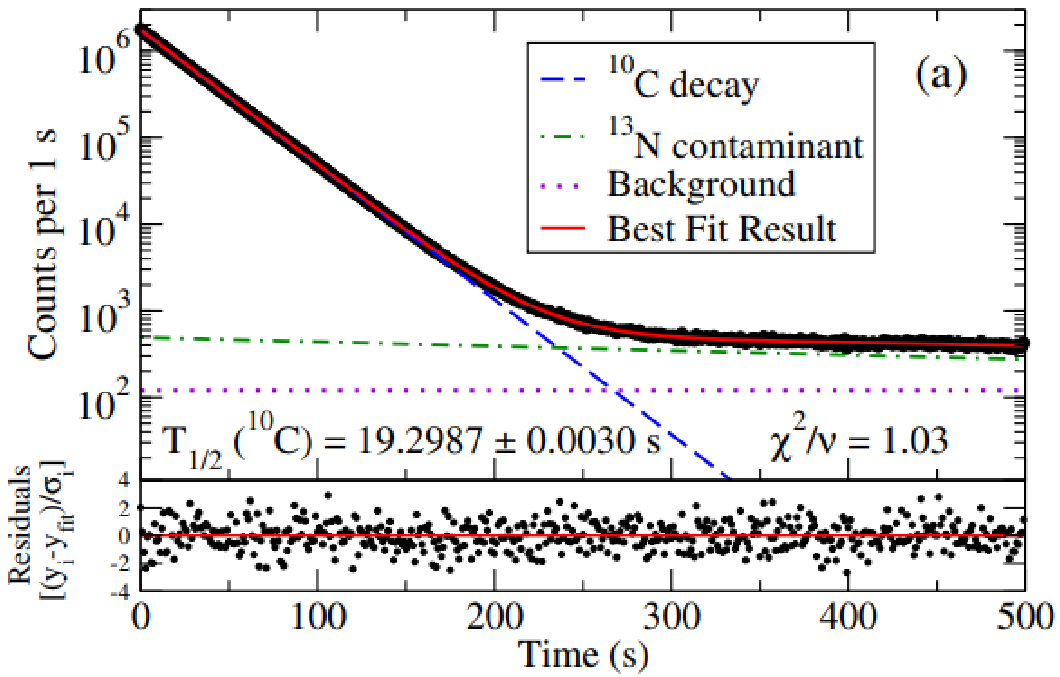


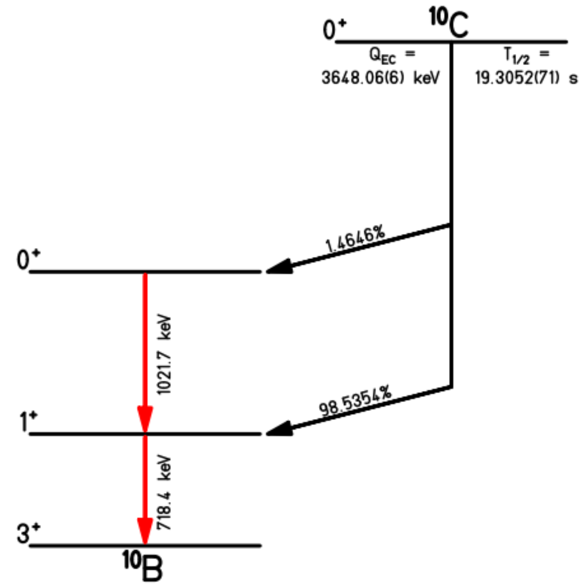
$|V_{ud}| = 0.97417 \pm 0.00021$

Hardy and Towner,
Phys. Rev. C ***91****, 025501 (2015)*



Beta decay experiment

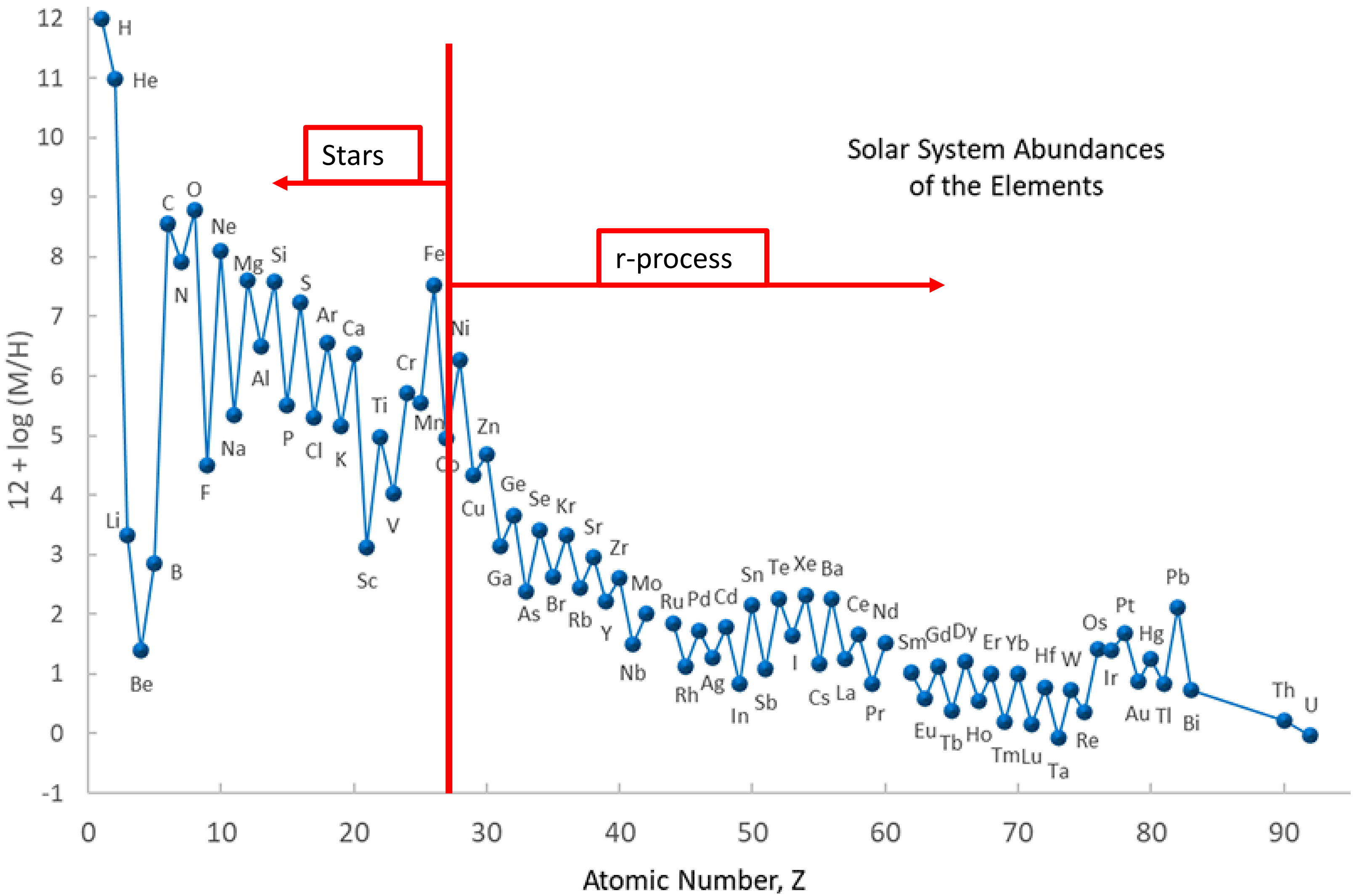




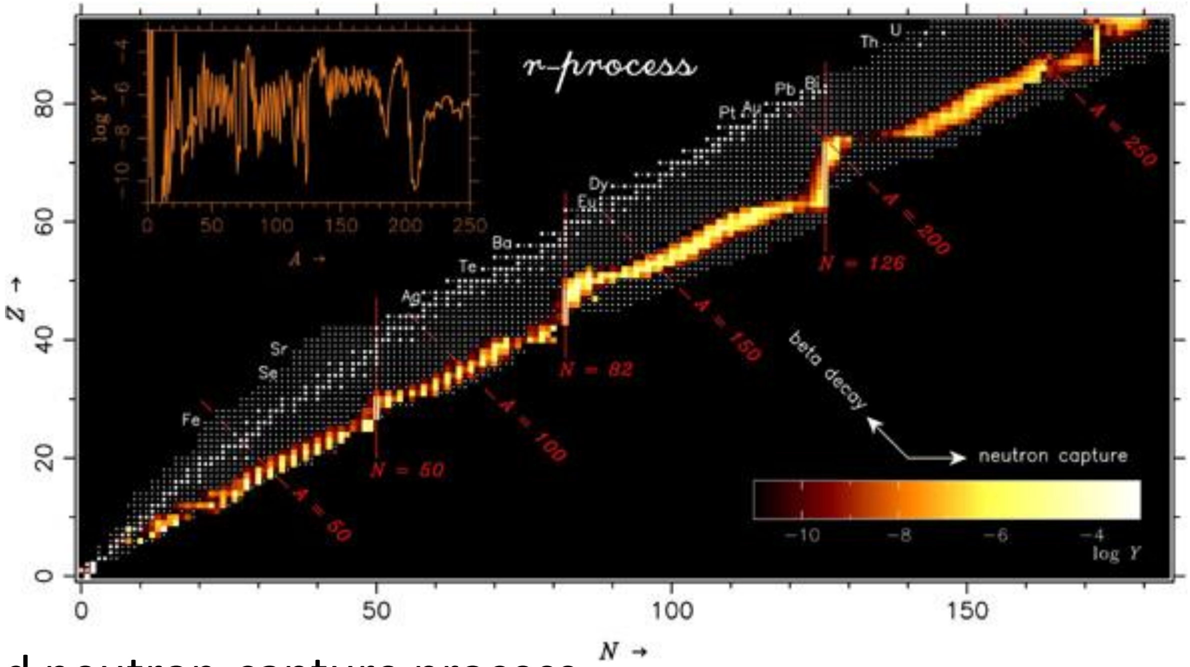
- The job of nuclear physics is to precisely measure Q_β, $T_{1/2}$ and branching ratio
- Extract Ft better than 1 part in 10^4
- If $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \neq 1$ would imply physics beyond the standard model

M. R. Dunlop et al. Phys. Rev. Lett. 116, 172501 (2016)

Beta decay experiment: astrophysics



r-process

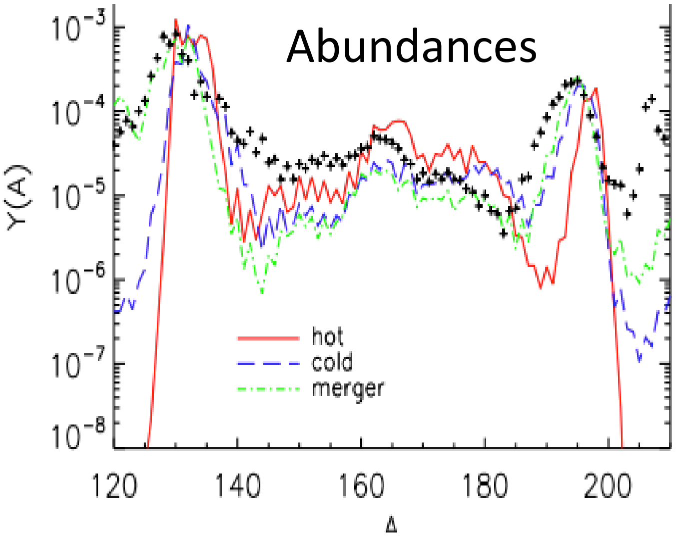


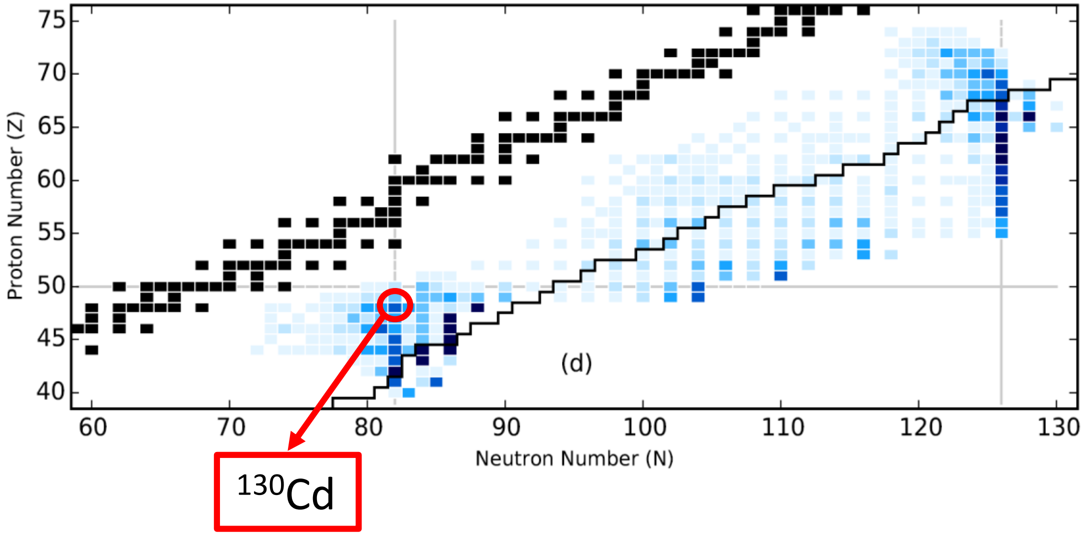
- Rapid neutron-capture process
- Neutron star mergers?
- Competition between beta decay and neutron absorption
- Most relevant observables:
  - Beta decay half life (g.s. and isomers)
  - Neutron emission
  - Neutron capture cross section

http://www.ph.sophia.ac.jp/~shinya/research/research.html

Half-Lives of Neutron-Rich $^{128\text{-}130}Cd$

Nuclei near N = 82 are responsible for the A ~ 130 r-process abundance peak. These 'waiting point' nuclei are important in calculations of all astrophyical environments.

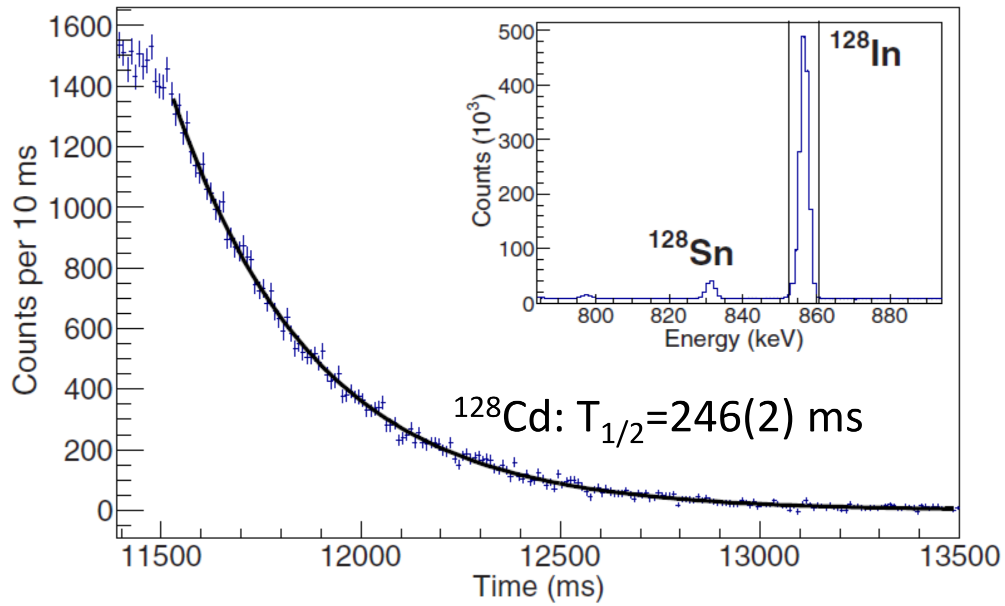


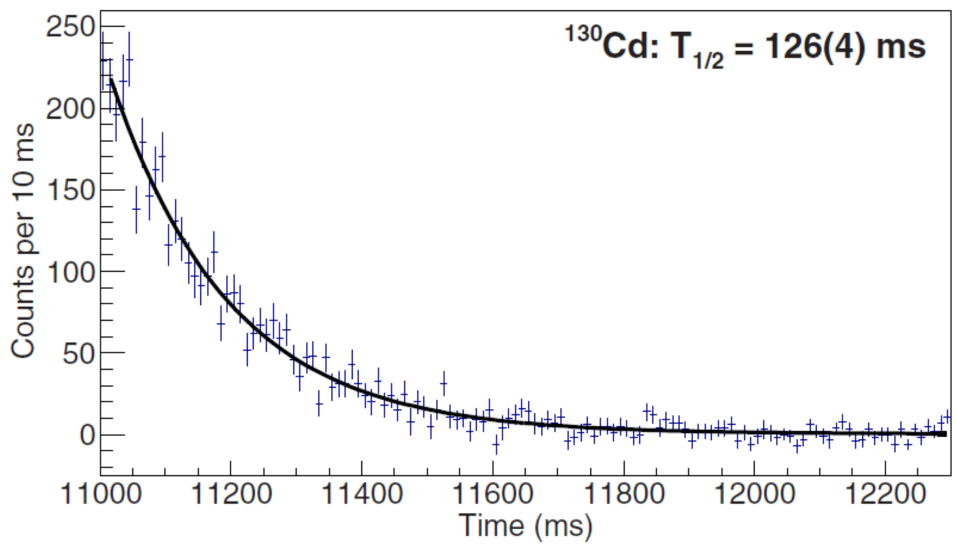


G. Lorusso et al. PRL 114 192501 (2015)

M. Mumpower et al., Prog. Part. Nucl. Phys. 86, 86 (2016)

Half-Lives of Neutron-Rich $^{128\text{-}130}Cd$

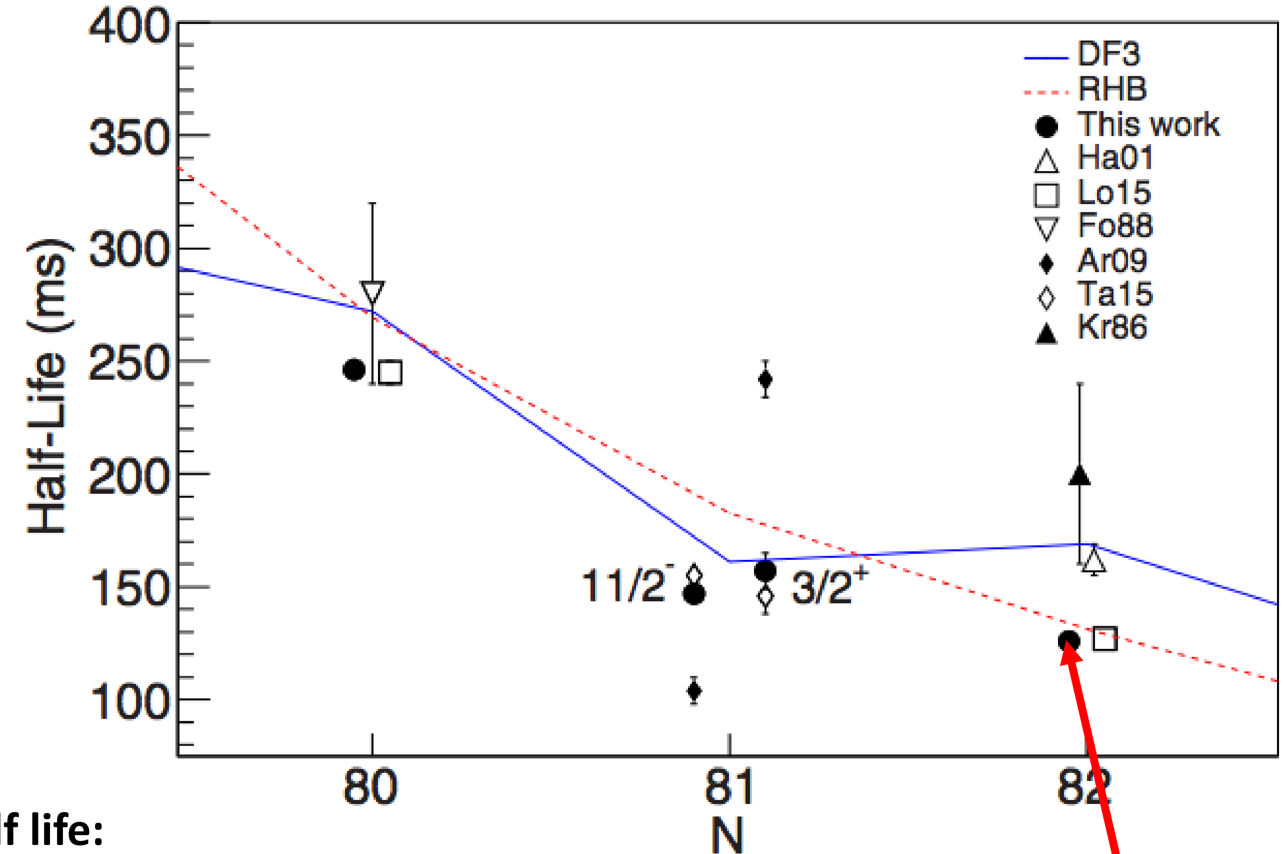




- Lifetimes were measured in β-γ coincidences
- HPGe gate cleans the spectra
- Lifetime is extracted from SCEPTAR (β) activity

R. Dunlop et al., PRC 93, 062801(R) (2016).

Beta decay experiment



^{130}Cd half life:

195 (35) ms K.-L. Kratz *et al.*, Z. Phys.A325, 489 (1986).
162 (7) ms M. Hannawald *et al.*, NPA 688, 578 (2001).

127 (2) ms G. Lorusso *et al.* PRL 114 192501 (2015).
126 (4) ms R. Dunlop *et al.*, PRC 93, 062801(R) (2016).

SM half-lives prediction below N=82

Nucleus	Measured Half-life (ms) [2]	SM ($q = 0.66$) (ms) [5]	Scaled SM ($q = 0.75$) (ms)
^{131}In	261(3)	247.53	194.1
^{130}Cd	127(2)	164.29	127
^{129}Ag	52(4)	69.81	54.03
^{128}Pd	35(3)	47.25	36.57
^{127}Rh	20^{+20}_{-7}	27.98	21.67

- Previous SM prediction were ~25% off
- New quenching precisely reproduces lifetimes
- Affects the N=82 waiting point and the A~130 peak abundance
- Creates significant discrepancy for ^{131}In
- R. Dunlop *et al.* Phys. Rev. C **93**, 062801(R) (2016)

Beta decay experiments

- One of the cleanest and most precise probes we have in nuclear physics
- Versatile experiments able to measure multiple observables simultaneously
- Relevant for astrophysics
- Powerful tool to search for physics beyond the Standard Model

Useful References

Books

- ✓ "Handbook of nuclear spectroscopy", J. Kantele, 1995
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- ✓ "Alpha-, Beta- and Gamma-ray Spectroscopy", Ed. K. Siegbahn, 1965
- ✓ "Introductory Nuclear Physics", K. S. Krane, 1988
- ✓ "Basic Ideas and Concepts in Nuclear Physics" K. Heyde IOP Publ. Ltd. 1994
- ✓ "Particle Emission from Nuclei" Ed. D.N. Poenaru & M.S. Ivaçcu, CRD 1989 Vol I, II, III
- ✓ "Subatomic Physics", Ernest M. Henley and Alejandro García, 3rd Edition, 2007, World Scientifc Publishing,

Journal Articles

- ✓ Euroschool on Exotic Beams, Lectures Notes: "Decay Studies of N~Z Nuclei", E. Roeckl, Vol I, "Beta Decay of exotic Nuclei", B. Rubio & W. Gelletly, and B. Blank"1-2p radioactivity" in Vol III
- ✓ B. Blank and M.J.G. Borge, Prog Part and Nuc. Phys 60 (2008) 403
- ✓ M. Pfützner, L.V. Grigorenco, M. Karny & K. Riisager, Rev. Mod. Phys 84 (2012)567
- ✓ G. Benzoni, Eur. Phys. J plus 131 (2016) 99
- ✓ A. Algora et al., Eur. Phys A 57 (2021) 85
- ✓ École Joliot-Curie de Physique Nucleaire, 2002

Bibliography courtesy of MJ Borge

CSIC

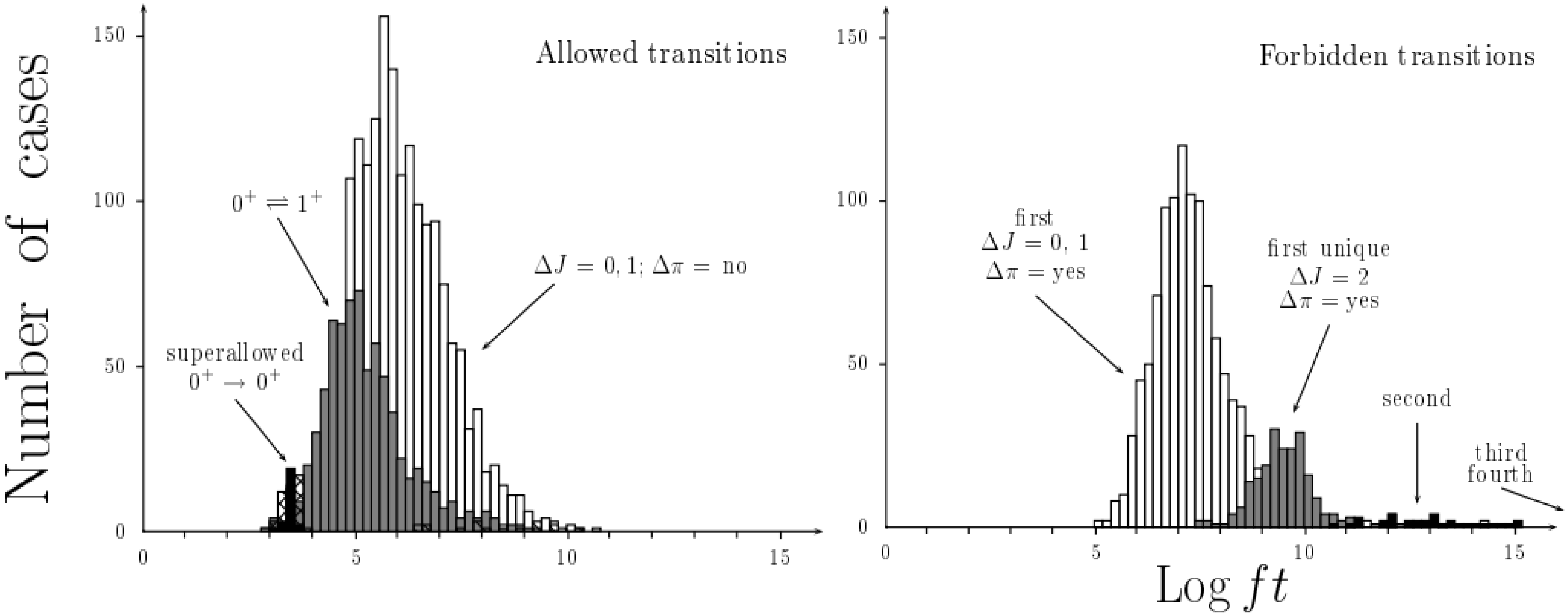
Plenty of information available on the Web

IEM

Any questions?

Beta decay selection rules

B. Singh et al., Nucl. Data Sheets 84, 487 (1998)



- We can use log(*ft*) to infer the spin-parity of daughter nucleus states
- Learn about nuclear structure

Beta decay experiment