Compilation, Evaluation and Systematics of Beta-Delayed Neutron and Associated Half-Life Data in the A ≤ 72 Mass Region

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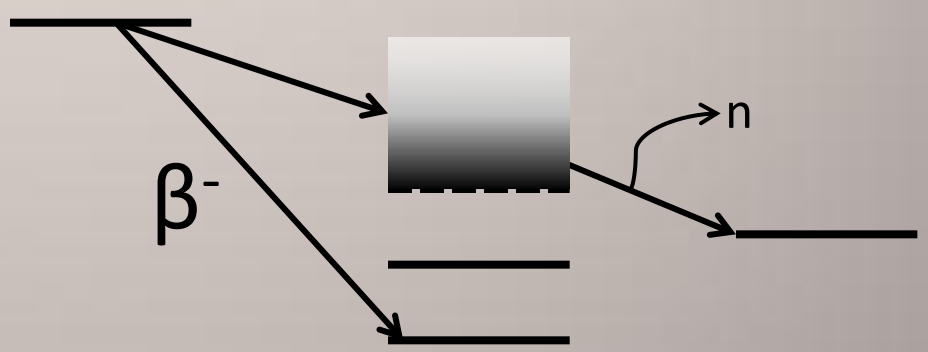
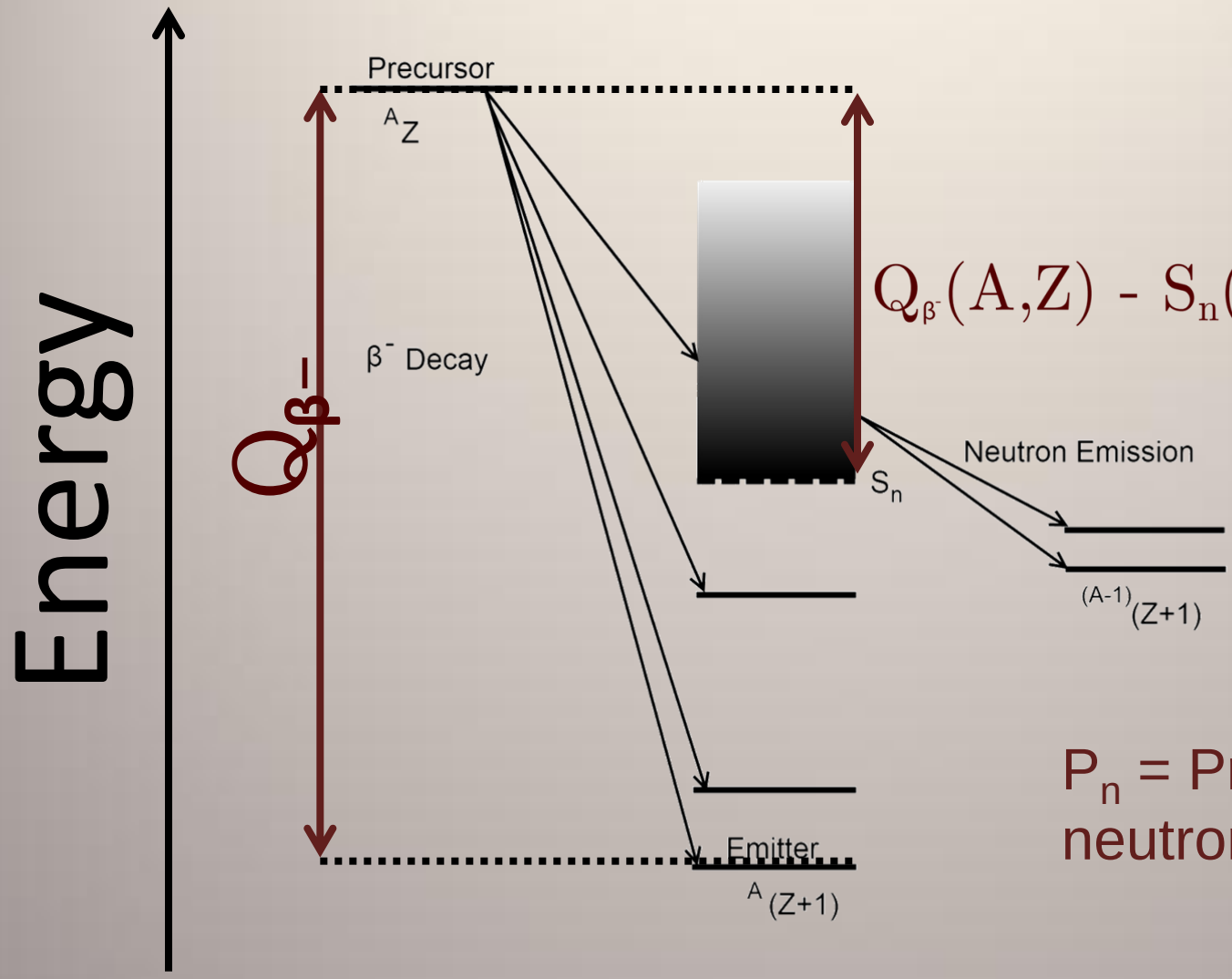
Outline

- Beta-delayed neutron (β-n) decay process
- Compilation and evaluation procedures
- Results and examples
- Systematic trends



Beta-Delayed Neutron Emission Process



$$Q_{\beta^-}(A,Z) - S_n(A,Z+1) = Q_{\beta^- n}$$

P_n = Probability of neutron emission

Beta-Delayed Neutron Emission Process

- Multiple neutrons may be emitted for decays with Q_{β^-} greater than S_{2n} or S_{3n}

$$S_{xn}(A,Z) = M(A-x,Z) + xn - M(A,Z)$$

$$Q_{\beta-2n} = Q_{\beta^-}(A,Z) - S_{2n}(A,Z+1)$$

$$Q_{\beta-3n} = Q_{\beta^-}(A,Z) - S_{3n}(A,Z+1)$$

P_{xn} = Probability of emitting x neutrons

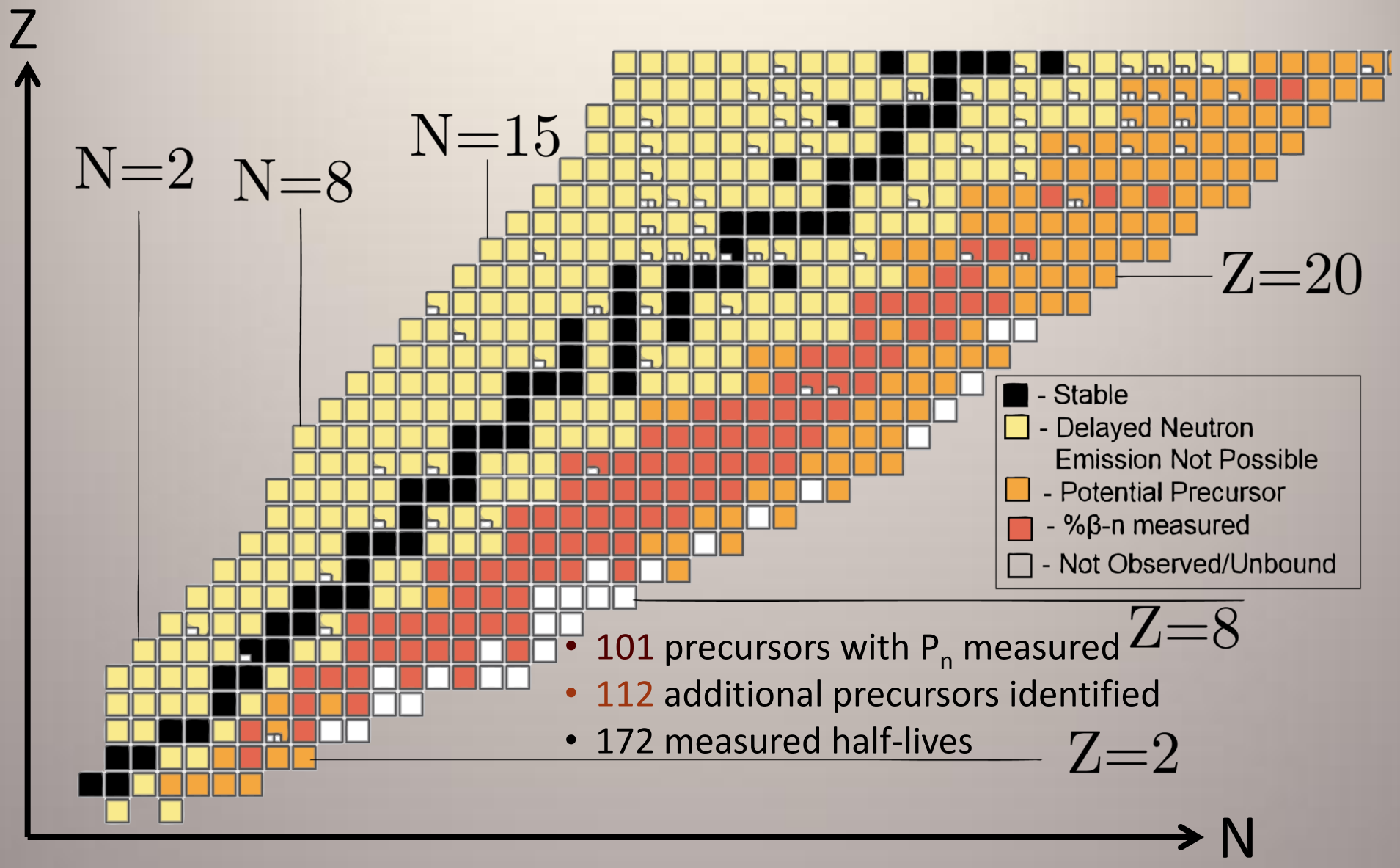
Compilation of β-n Decay Data

- Begin in low mass region, eventually complete entire chart
  - Previous topical evaluations of beta-delayed neutron data (2002Pf04,1993Ru01) dealt with fission region, A > 72
  - For A ≤ 72 no such topical evaluation exists; an earlier compilation considered only 5 nuclides: L. Tomlinson, ADNDT 12, 179 (1973)
- Contribute to IAEA Coordinated Research Project on a "Reference Database for Beta-Delayed Neutron Emission"
- Nuclei identified as potential beta-delayed neutron emitters based on $Q_{\beta\text{-}n} > 0$ in mass evaluation of G. Audi et al. (2011AuZZ)
- Nuclei further limited to those observed experimentally
- Searched for references with measurements of half-life, $T_{1/2}$, and neutron emission probabilities, including 2n and 3n emissions

Compilation and Evaluation Procedures

- Compilation consists of documentation of all measurements including:
  - Which quantity was measured ($T_{1/2}$, P_{1n}, P_{2n}, etc.)
  - The method by which it was measured
  - Whether or not a neutron spectrum was measured and reported
  - Comments concerning the methodology of the experiment and reliability of the result
- The evaluation is done by considering the comments on methodology of the experiments to determine which results are most reliable and using an averaging procedure (e.g. weighted average) when several independent measurements may be considered equally reliable
- When an average is taken, quoted uncertainty in the recommended value is never lower than the smallest uncertainty cited in the data set of measured values
- Full documentation is also kept concerning how the evaluated result was obtained (e.g. which results were considered for averaging)

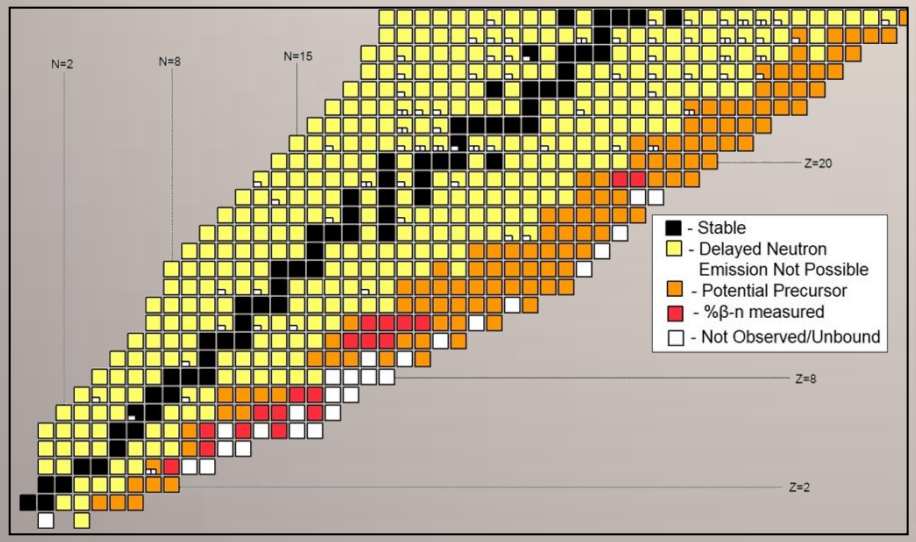
Potential Precursors and Experimental Data



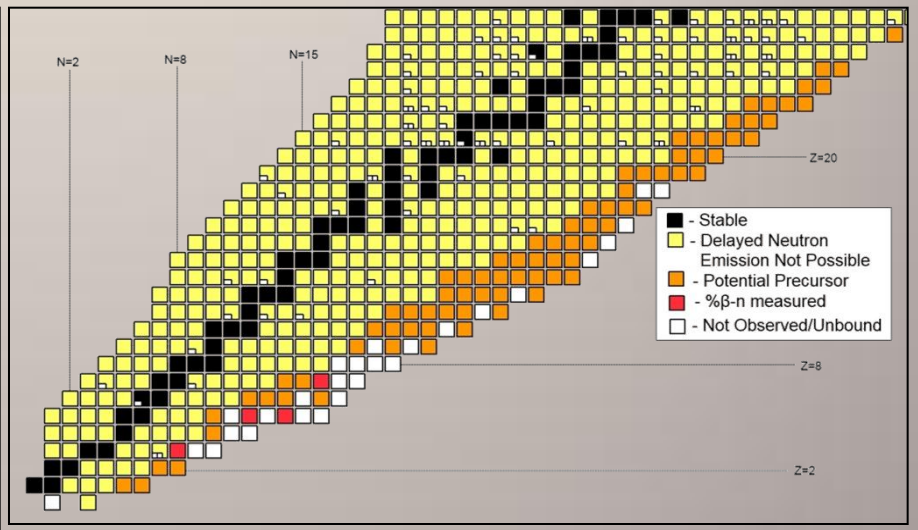
- 101 precursors with P_n measured
- 112 additional precursors identified
- 172 measured half-lives

Potential Precursors and Experimental Data

	Delayed two-neutron	Delayed three-neutron
Potential number of precursors (2011AuZZ)	115	80
Number of measured emission probabilities	19	4



Two-Neutron Emission



Three-Neutron Emission

Example: ^{31}Mg

- Important from relevance to ‘island of inversion’
- Literature search yields four references:
  - 1979De02
  - 1984La03
  - 2005Ma86
  - 2008ReZZ/1995ReZZ
- All have $T_{1/2}$ measurements and two have P_n

Example: ^{31}Mg

Reference	$T_{1/2}$ (ms)	Comments
1979De02	250(30)	Gamma intensity decay curve, only 4 data points
1984La03	230(20)	Multiscaling beta coincident neutron counts
2005Ma86	237(25)	Beta-ion time correlation, ~10 half-lives measured, Chi-Square minimization fit
2008ReZZ/1995ReZZ	235(25)	Beta-ion time correlation

Example: ^{31}Mg

Reference	P_{1n} (%)	Comments
1979De02	-	
1984La03	1.7(3)	Ratio Beta-n coincidences to total beta count
2005Ma86	-	
2008ReZZ/1995ReZZ	6.2(19)	Beta and neutron counting; neutron counter efficiency assumed to be same as for ^{16}C

Example: ^{31}Mg

- Adopted:
  - $T_{1/2}$ = 236(20) ms; weighted average of 1979De02, 1984La03, 2005Ma86, and 2008ReZZ/1995ReZZ
  - Note: weighted average gives uncertainty of 12
  - P_n = 6.2(19) %; From 2008ReZZ/1995ReZZ. In disagreement with 1984La03
  - Somewhat arbitrary choice, however 1995ReZZ covers the unweighted average of the two, 4.0(22) %, within uncertainty Systematics support higher measurement, theory supports lower measurement
  - Same values adopted in most recent ENSDF
  - Case where new measurement is needed to clarify situation

Systematic Trends

- 53% of potential precursors have not been experimentally studied
- Look for trends in the data to extrapolate in order to supplement experimental data in applications

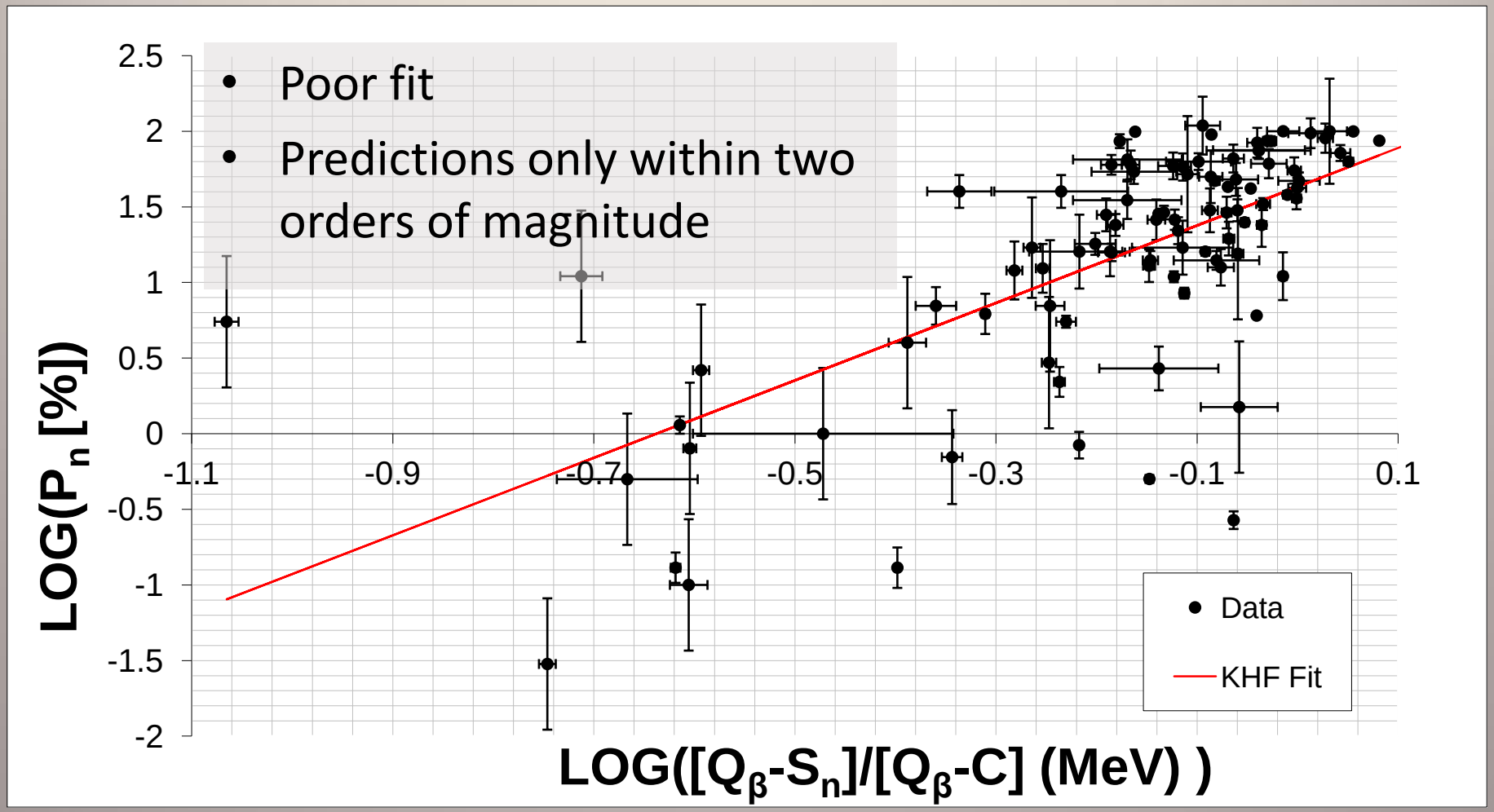
$$P_n \sim \frac{\int_{S_n}^{Q_\beta} S_\beta(E) f(Z, Q_\beta - E) dE}{\int_0^{Q_\beta} S_\beta(E) f(Z, Q_\beta - E) dE}$$

Kratz-Herrmann Formula (KHF)

$$P_n = a\left(\frac{Q_{\beta^-} - S_n}{Q_{\beta^-} - C}\right)^b$$

- a, b are parameters fitted to the measurements
- C is a cut-off parameter below which S_β is assumed to be zero
- Originally used in fission region
- Z. Physik 263, 435 (1973)

Kratz-Herrmann Formula (KHF)



Systematic Trends

- The half-life is inversely proportional to the total amount of decay activity

$$\frac{P_n}{T_{1/2}} \simeq \frac{\frac{1}{T_{1/2}}}{\int_{S_n}^{Q_\beta} S_\beta(E) f(Z, Q_\beta - E) dE}$$

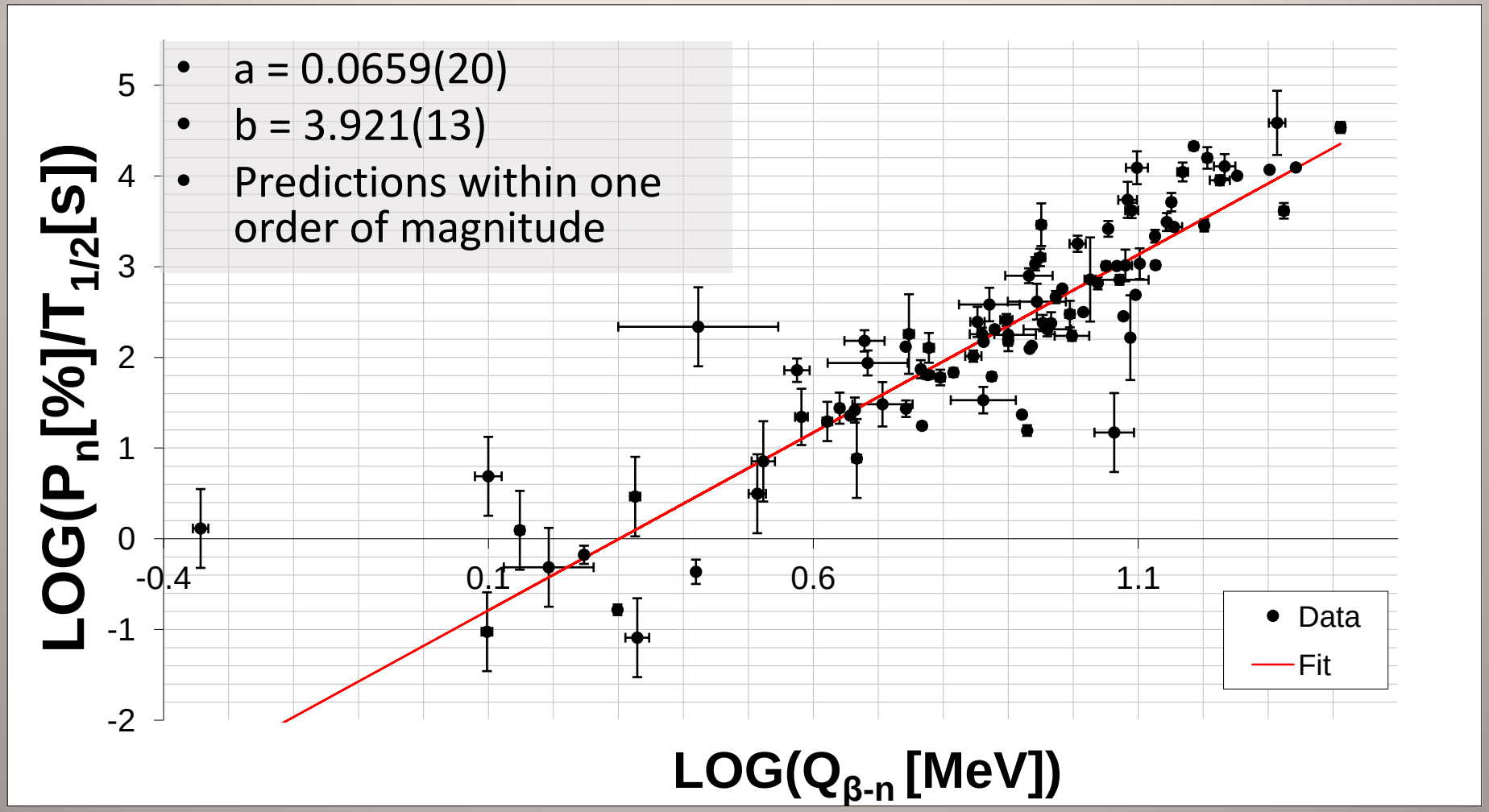
$$P_n \sim \frac{\int_{S_n}^{Q_\beta} S_\beta(E) f(Z, Q_\beta - E) dE}{\int_0^{Q_\beta} S_\beta(E) f(Z, Q_\beta - E) dE}$$

Systematic Trends

$$\frac{P_n}{T_{1/2}} = a Q_{\beta^- n}^{b}$$

- a and b are again parameters fitted to the data

Systematic Trends



Conclusion

- The beta-delayed neutron emission probabilities and/or half-lives have been compiled and evaluated for a total of 173 nuclides in the $A \leq 72$ mass region
- This evaluated data has been used to explore the systematics of beta-delayed neutron decay in this region
- The Kratz-Herrmann Formula (KHF) does not make accurate predictions in this region
- The ratio of neutron emission probability to half life shows a strong correlation with the available energy for the decay
- The neutron emission probability can be predicted within an order of magnitude when the half-life is known