Revisiting the nuclear β decay input in the reactor anomaly

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What's it about in 3 steps:

Where is the anomaly?

Antineutrino's from β^- decay of reactor fission fragments

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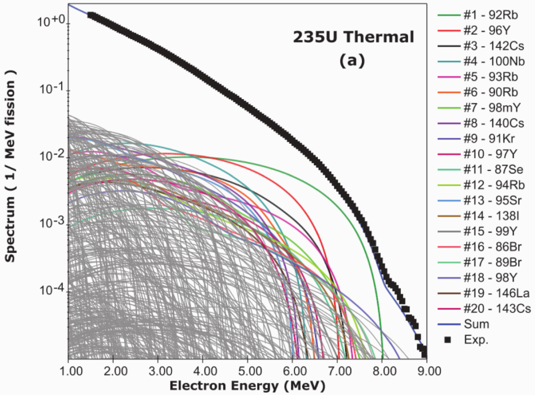
When new physics lurks, look out for quirks!

Antineutrino origin

Fission fragments from ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu have many β^- branches, but can only measure cumulative spectrum.

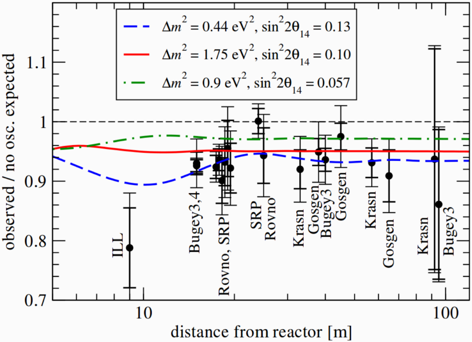


Conversion of all β branches is **tremendous** challenge

A. A. Sonzogni *et al.*, PRC **91** (2015) 011301(R)

Deficiency and particle physics proposal

Current deficiency in neutrino count rate at 94% (2-3σ)



Very exciting, but. . . it is real?

Deficiency and particle physics proposal

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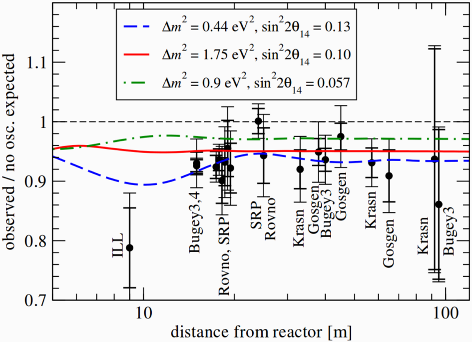


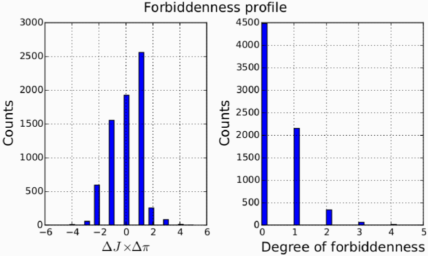
Very exciting, but. . . it is real?

Understanding of all corrections & nuclear structure is **crucial**!

An *et al.* (Daya Bay Collab.), PRL 118 (2017) 251801 & J. Kopp et al., JHEP 05

β participant sketch

Nuclear β decay is complicated



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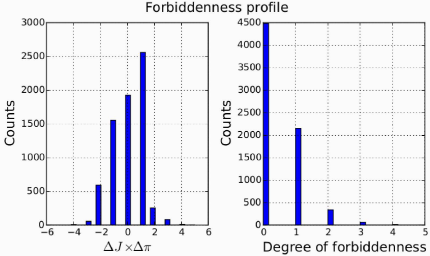

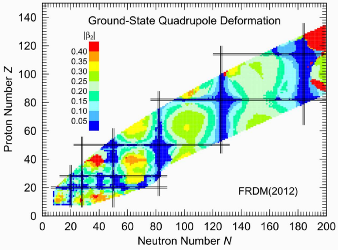

Both greatly influence the spectrum shape!

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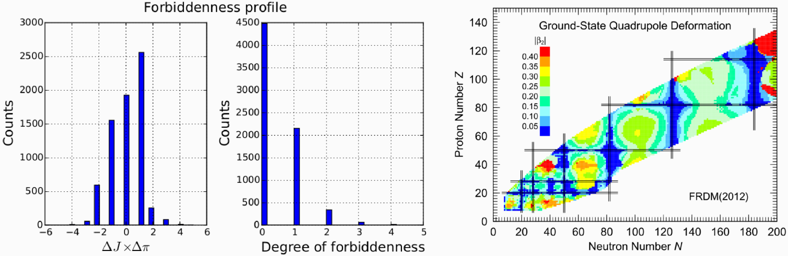
Nuclear β decay is complicated



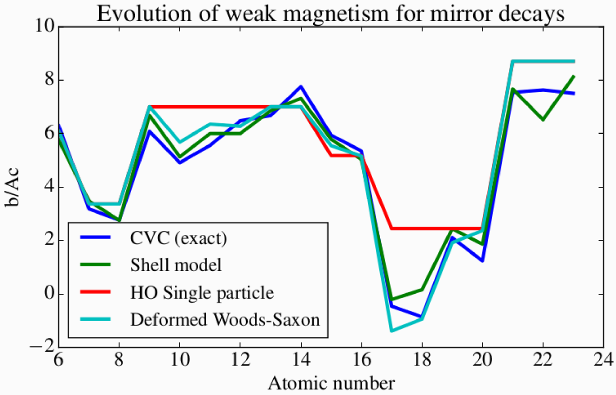
Both greatly influence the spectrum shape!

Additional lower order effects: Atomic, electrostatic, kinematic...

Möller *et al.*, ADNDT **109-110** (2016) 1; L.H. *et al.*, arXiv: 1709.07530

Weak magnetism in $T = 1/2$ mirrors

Main nuclear structure influence in allowed decays



Oblate deformation for ^{33}Cl, ^{35}Ar changes sign & magnitude!

Level mixing for high Z, N is non-trivial

State of the art

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Approaches split up in 2:

1. **Huber** method: virtual β branch fits

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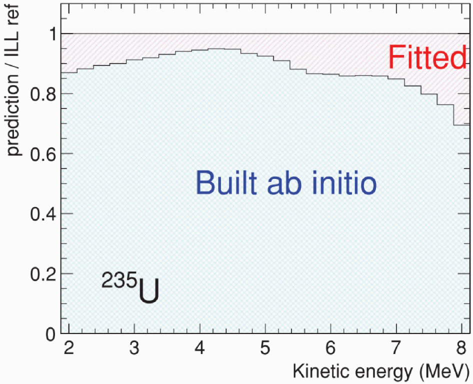
1. **Huber** method: virtual β branch fits
2. **Summation** method: Build from databases & extrapolate a la #1

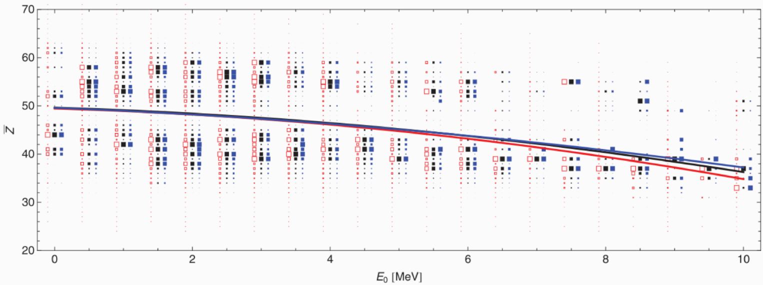


Much of *ab initio* is based on same spectral assumptions

Huber, PRC **84** (2011) 024617; Mueller *et al.*, PRC **83** (2011) 054615

Extrapolation & Virtual branches

How to construct these fictitious β branches?



Parametrised $Z(E_0)$ fit with simple polynomial

Assume allowed shape, extrapolated average nuclear matrix elements

P. Huber, PRC **84** (2011) 024617

Extrapolation & Virtual branches

Huber (extrapolation) model has many issues:

- Estimated average b/Ac from spherical mirrors, but highly transition and deformation dependent
- Incorrectly estimates $(\alpha Z)^2$ effects, $\mathrm{RNA}(\langle Z\rangle^2) \neq \langle \mathrm{RNA}(Z^2)\rangle$!
- ^{239}Pu cross section does not agree with experiment
- Only allowed transitions (dominant $0^+ \leftrightarrow 0^-$ transitions)
- Quenching of g_A is absent
- ...

Predictions are **dubious**

Planned improvements

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Central idea is more realistic uncertainty by assessing 3 main sources of error

- Fission yields
- Proper (forbidden) spectral shapes
- Database extrapolation

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Collaboration with SCK-CEN for FY uncertainties, Jyvaskyla for forbidden shape factors

Forbidden shape factors

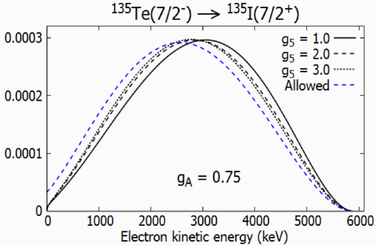
Out of thousands of β^- decays, many dominant are forbidden

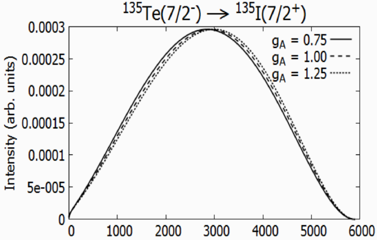
Nuclide	$J^\pi_{gs} \to J^\pi_{gs}$	Contr. (%)	GS β_2
^{96}Y	$0^- \to 0^+$	6.3	0.308
^{92}Rb	$0^- \to 0^+$	6.1	0.240
^{100}Nb	$1^+ \to 0^+$	5.5	0.412
^{135}Te	$(7/2-) \to 7/2^+$	3.7	-0.011
^{142}Cs	$0^- \to 0^+$	3.5	0.141
^{140}Cs	$1^- \to 0^+$	3.4	0.097
^{90}Rb	$0^- \to 0^+$	3.4	-0.105
^{95}Sr	$1/2^+ \to 1/2^-$	3.0	0.308
^{88}Rb	$2^- \to 0^+$	2.9	-0.073

Sonzogni *et al.*, PRC **91** (2015) 011301(R)

Forbidden shape factors

Differences can be dramatic





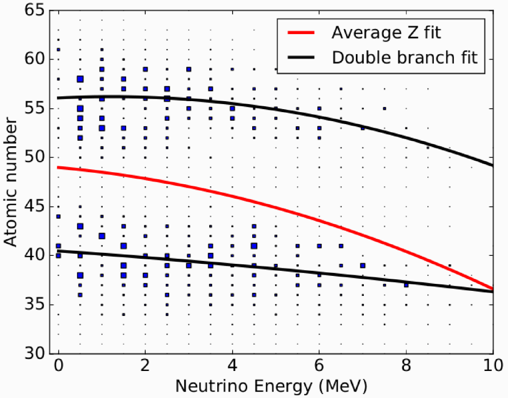
Additional uncertainty from g_A and γ_5 renormalization

Results by Joel Kostensalo (Jyvaskyla)

Database extrapolation

Database contains much more information to use

Trivial extension to improve $(\alpha Z)^2$ behaviour, fixed weights



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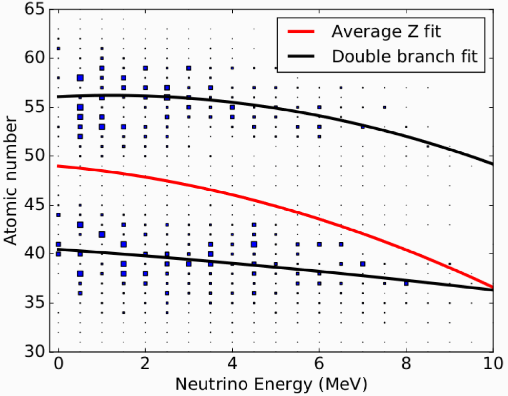
Employ Machine Learning clustering algorithms to find better patterns



Clustering & Machine Learning

Nuclear β decays live in high-dimensional vector spaces

- Z, A
- Branching Ratio, E_0, daughter excitation
- $\Delta J^{\Delta\pi}$ (forbiddenness, unique)
- Initial and final deformation
- ...

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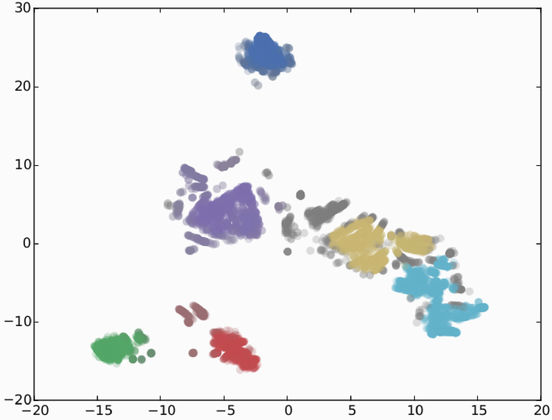
Clusters in high dimensions are smeared in 2D projections

Clustering visualisation

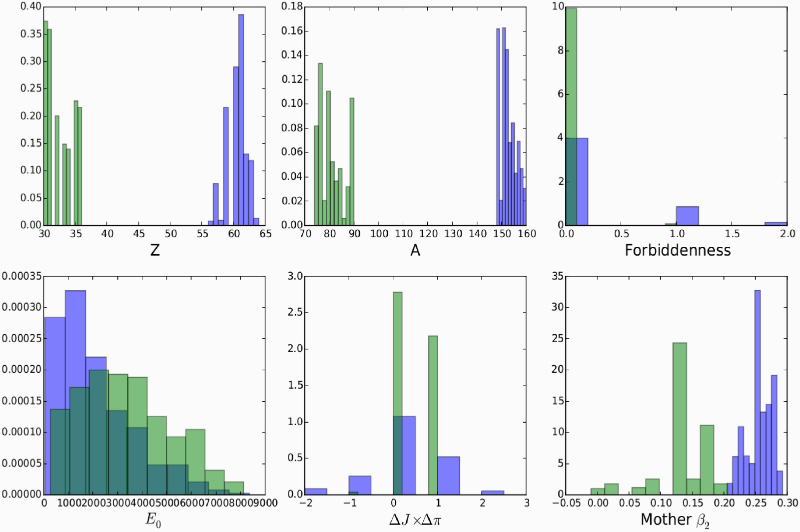
Use dimensional reduction (t-SNE) to visualise results



Clear clusters, intercluster distance irrelevant here

Intercluster comparison

Example comparison for 2 clusters



Large differences visible for simple histograms!

Monte Carlo sampling

How to combine these results?

Instead of a single $Z(E_0)$ fit, use Monte Carlo to sample

- Clusters
- Fission yields
- Other known or estimated errors

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Build a **distribution** of anomaly $\rightarrow$ better uncertainty estimate

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Triple-pronged approach to better assess (mean, σ)

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Nuclear β decays live in high-dimensional clusters, use of Machine Learning to investigate


"It's a
dangerous
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