

Potential Impact of New Measurements on Reactor Spectrum and Flux Predictions

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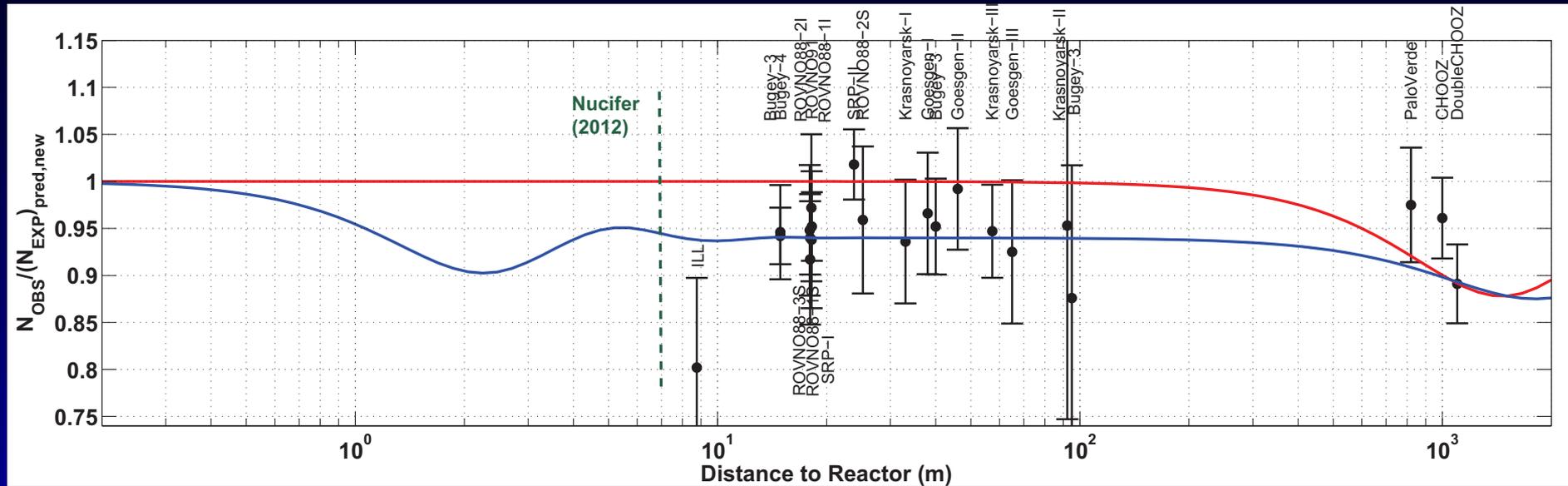
Center for Neutrino Physics – Virginia Tech

Reactor Antineutrino Spectrum and Anomaly Measurements: U.S. Planning Meeting

Lawrence Livermore National Laboratory

December 11-12, 2012

Reactor anomaly

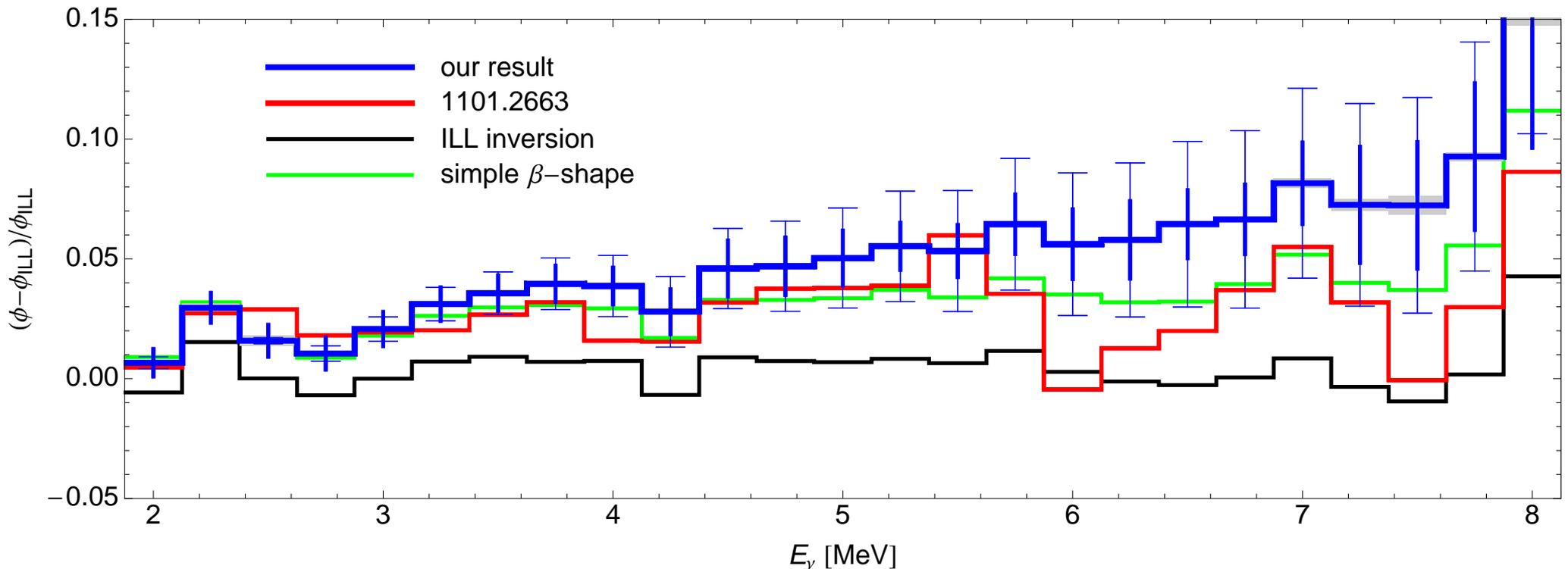


[arXiv:1101.2755](https://arxiv.org/abs/1101.2755) & [arXiv:1204.5379](https://arxiv.org/abs/1204.5379)

6% deficit of $\bar{\nu}_e$ from nuclear reactors at short distances

- 3% increase in reactor neutrino fluxes
- decrease in neutron lifetime
- inclusion of long-lived isotopes (non-equilibrium correction)

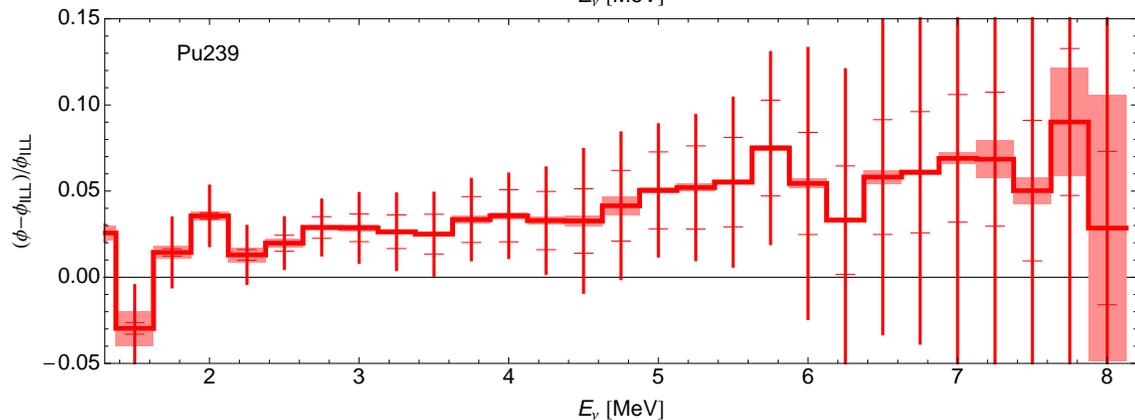
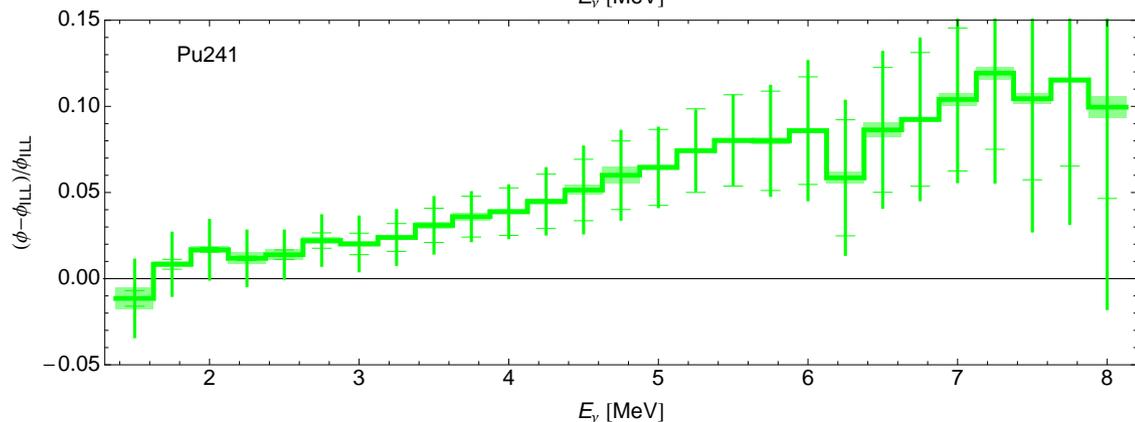
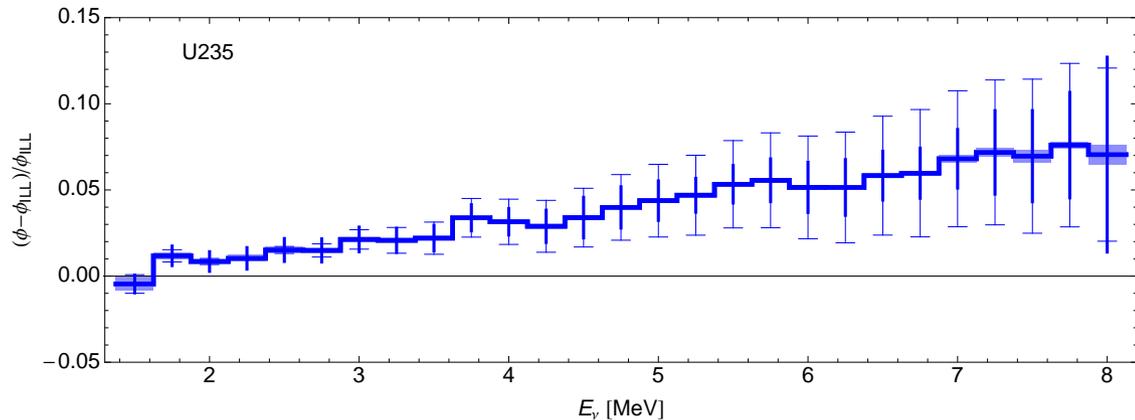
Reactor antineutrino fluxes



Shift with respect to ILL results, due to

- different effective nuclear charge distribution
- branch-by-branch application of shape corrections

Comparison of isotopes

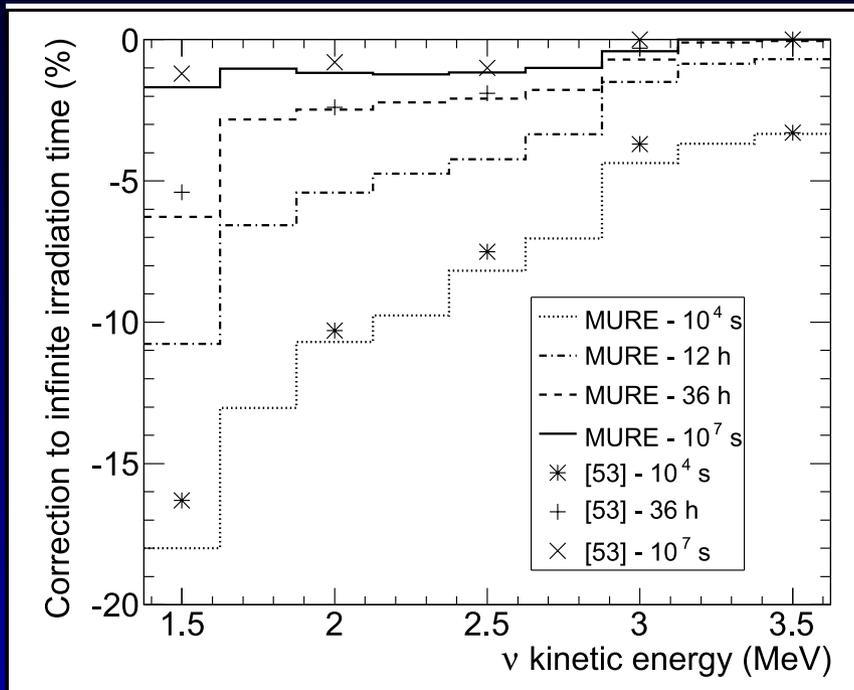


Same shift in all isotopes

Statistical errors of different size, direct consequence of different ILL data quality

^{239}Pu most problematic due to large fission fraction

Non-equilibrium corrections



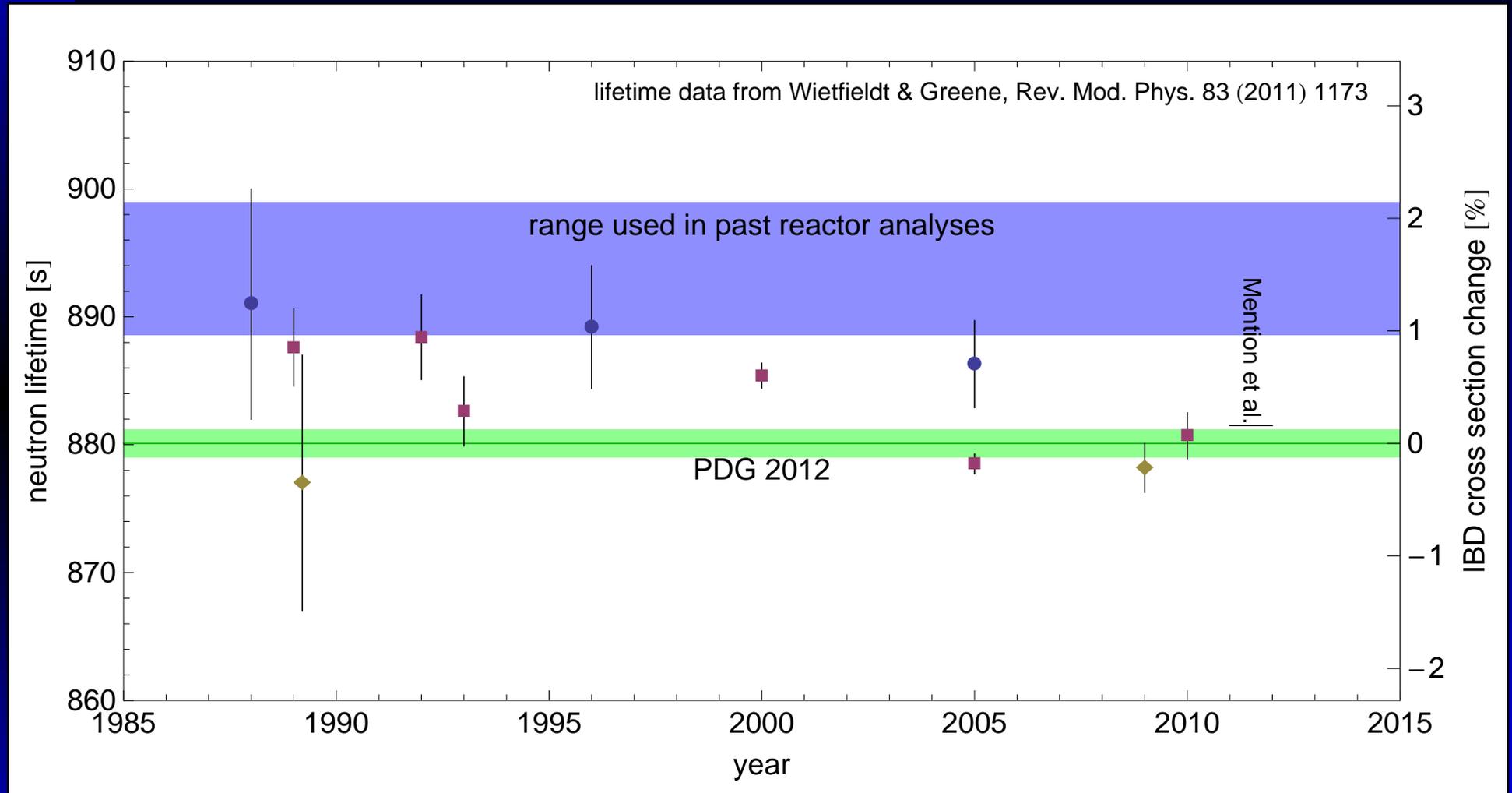
only 2 dozen isotopes
with $t_{1/2} > 12$ h above
inverse β -decay thresh-
hold

Mueller, *et al.*, PRC 83 (2011)
054615

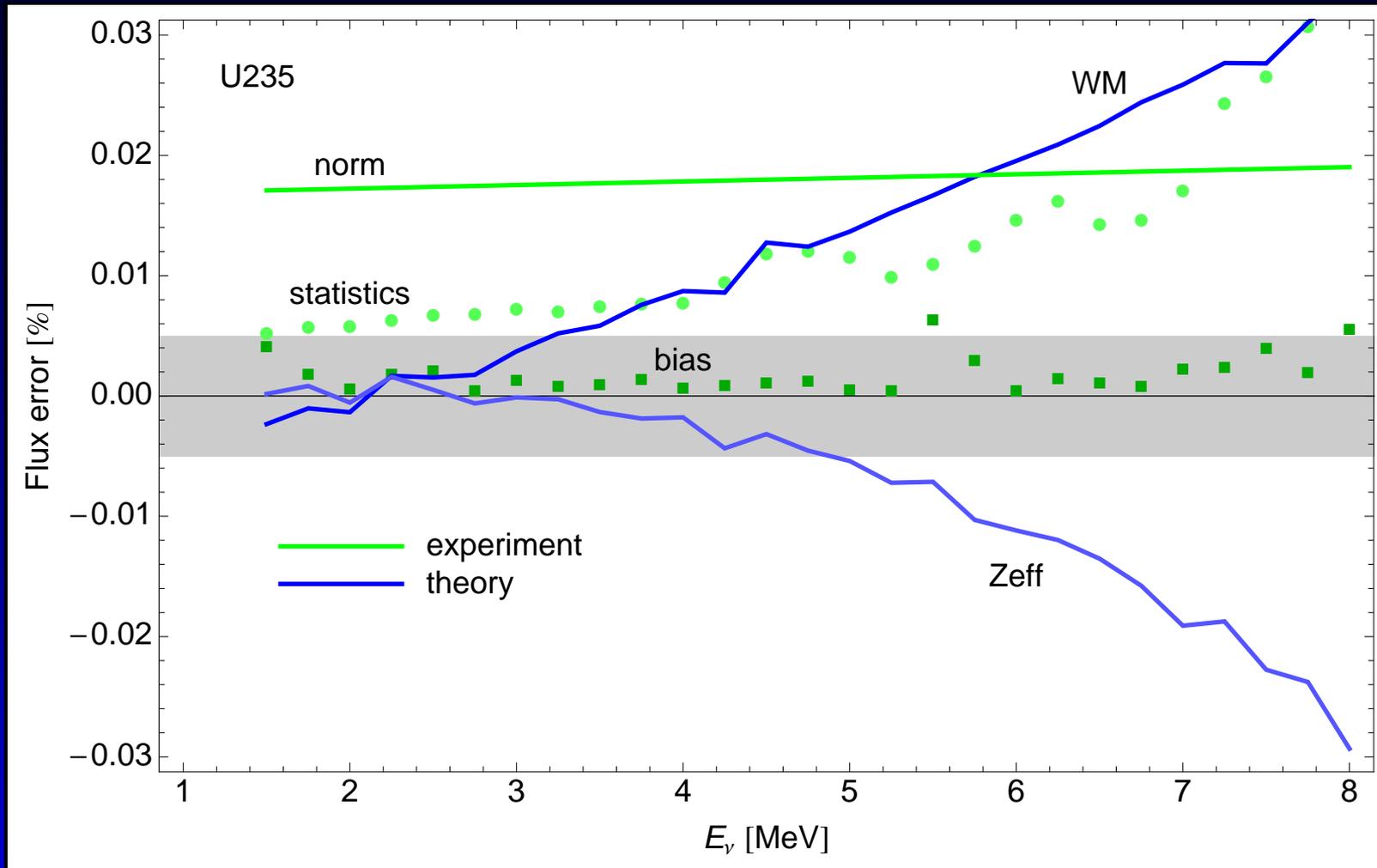
Extra shift due to long-lived isotopes

- small nuclear physics uncertainty in β -decay
- depends on detailed fuel history

Neutron lifetime

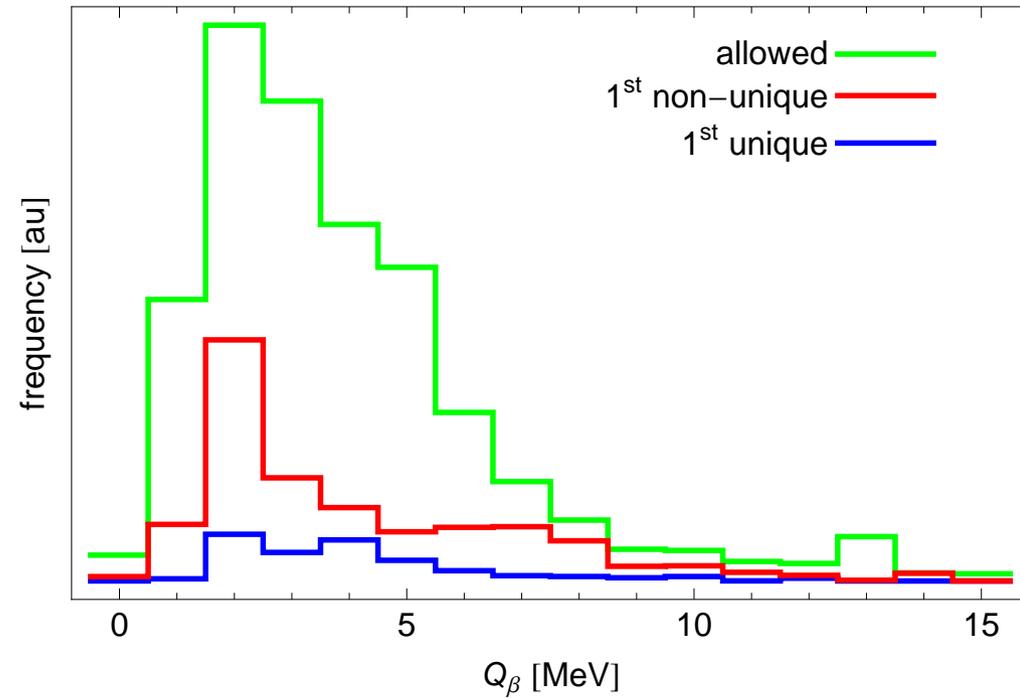
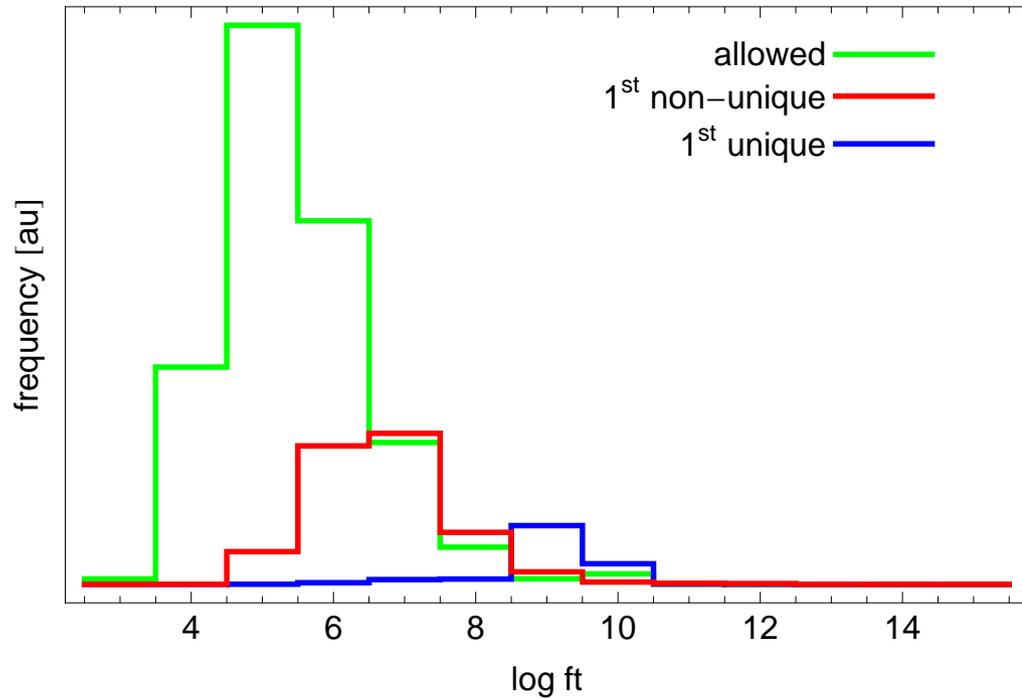


The fluxes & their errors



Below 3.5 MeV theory errors are below 0.5%
Experimental errors can be improved by repeating the ILL measurements

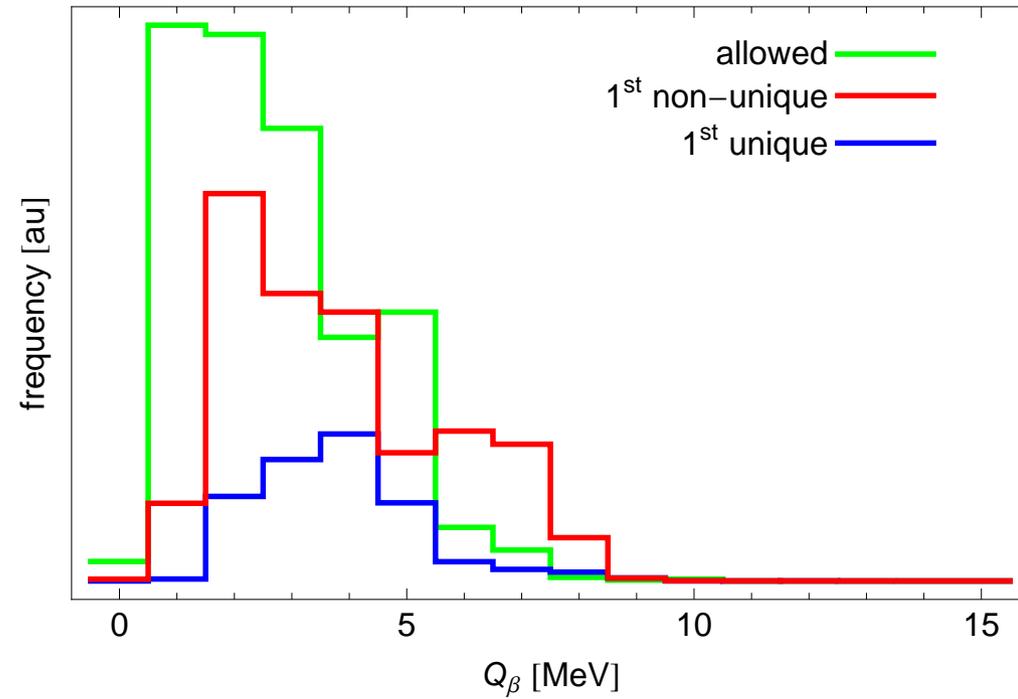
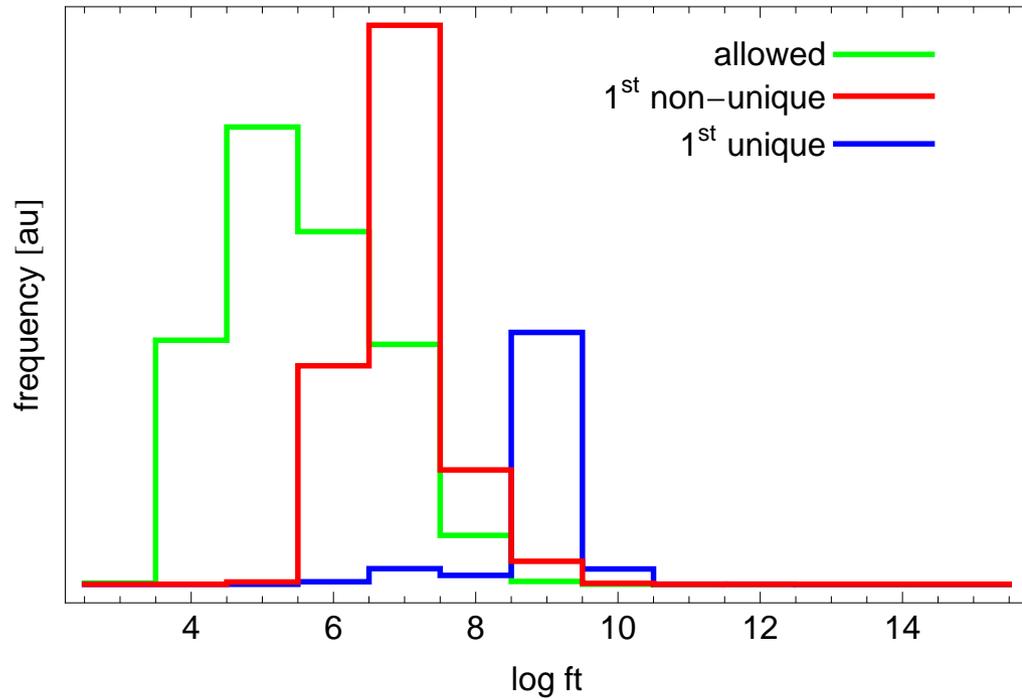
Unknown unknowns – large ft ?



E. Christensen, PH, P. Jaffke, in preparation

Shown is the distribution of $\log ft$ and Q_β throughout the ENSDF data base. Indeed, this confirms that there should be very few allowed decays with $\log ft > 6$.

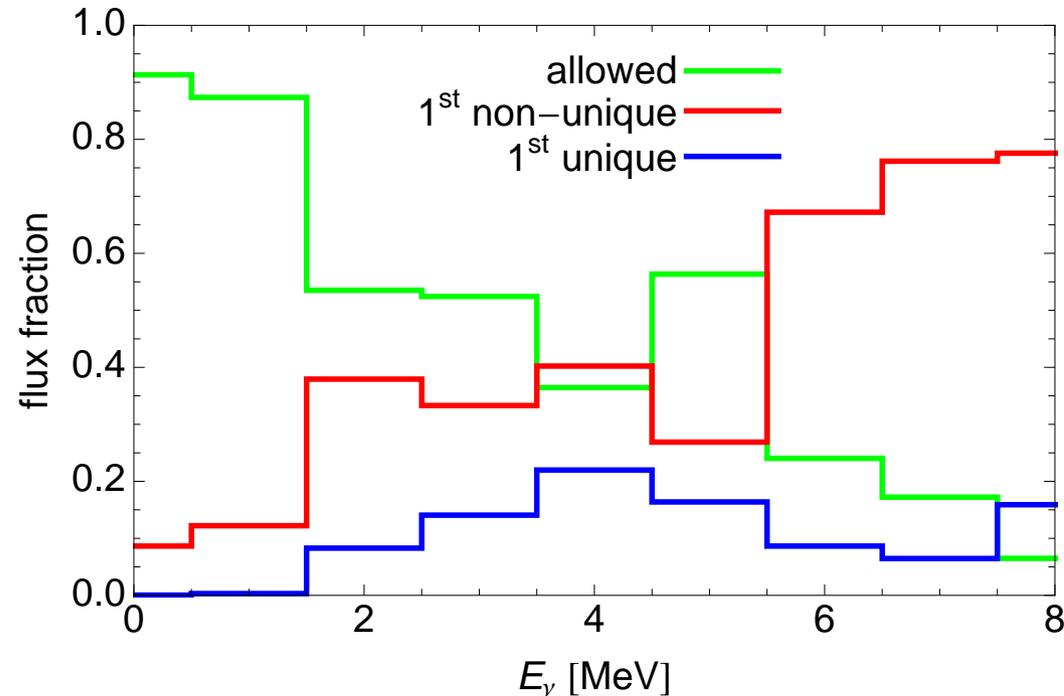
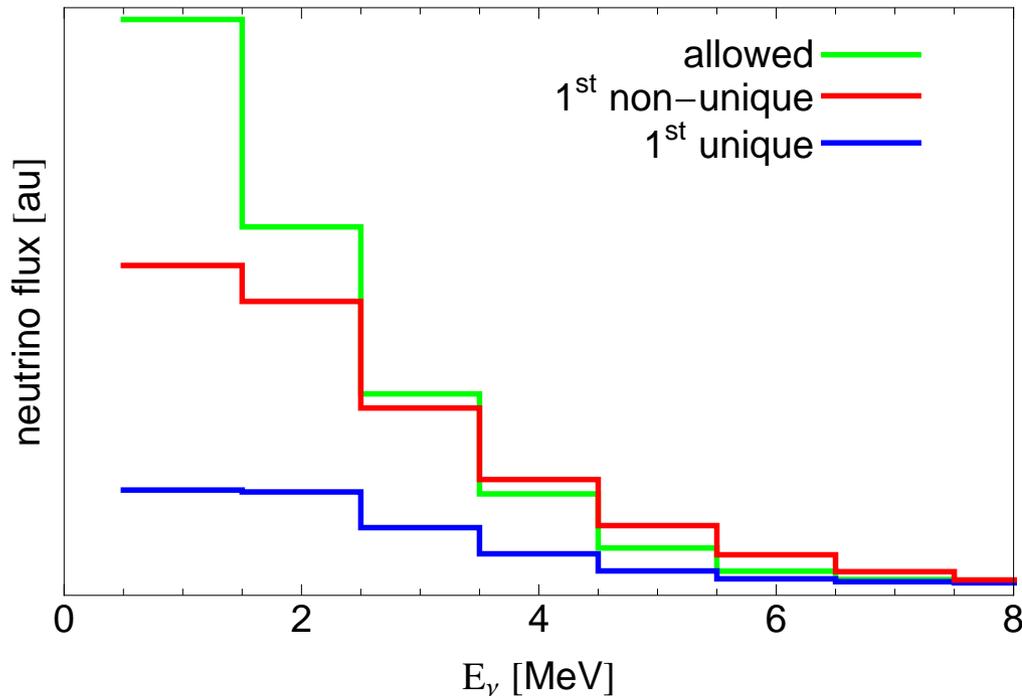
Unknown unknowns – large ft !



E. Christensen, PH, P. Jaffke, in preparation

Here we weight each β -emitter by its fission yield, which emphasizes both large values of $\log ft$ as well as forbidden decays. For forbidden decays the previous discussions do generally not apply!

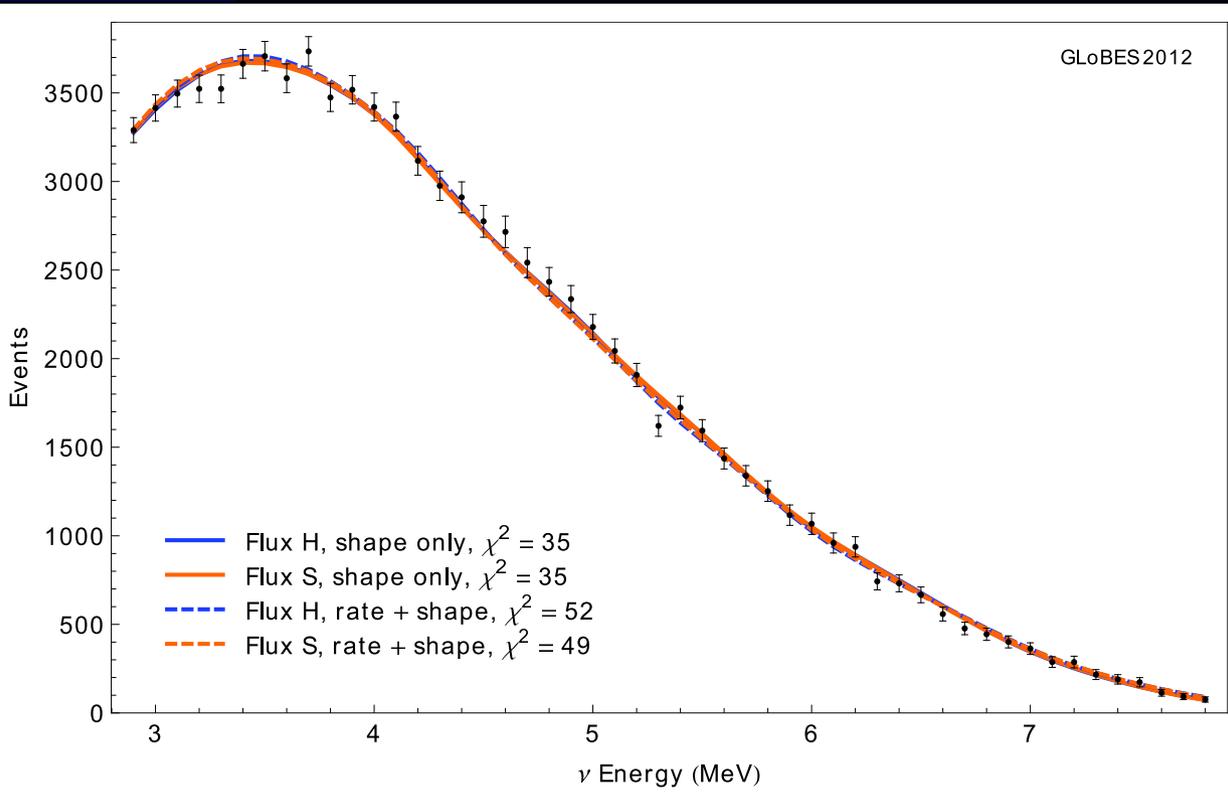
Unknown unknowns – forbiddenness!



E. Christensen, PH, P. Jaffke, in preparation

Conversion to neutrinos and the IBD cross section enhance the contributions from large $\log ft$ and forbidden decays even more \Rightarrow room for significant theory uncertainties – however, low energies are much less affected.

Using existing data



Fit for the slope parameter (aka WM correction)

Result $1.4_{-1.8}^{+1.6} \%$ MeV^{-1}

Standard theory predicts $0.5 \pm 0.5 \%$ MeV^{-1}

Application of CVC on a set of test nuclei yields (PH, PRC 84, 024617)

$0.67 \pm 0.26 \%$ MeV^{-1} ($ft < 10^6$)

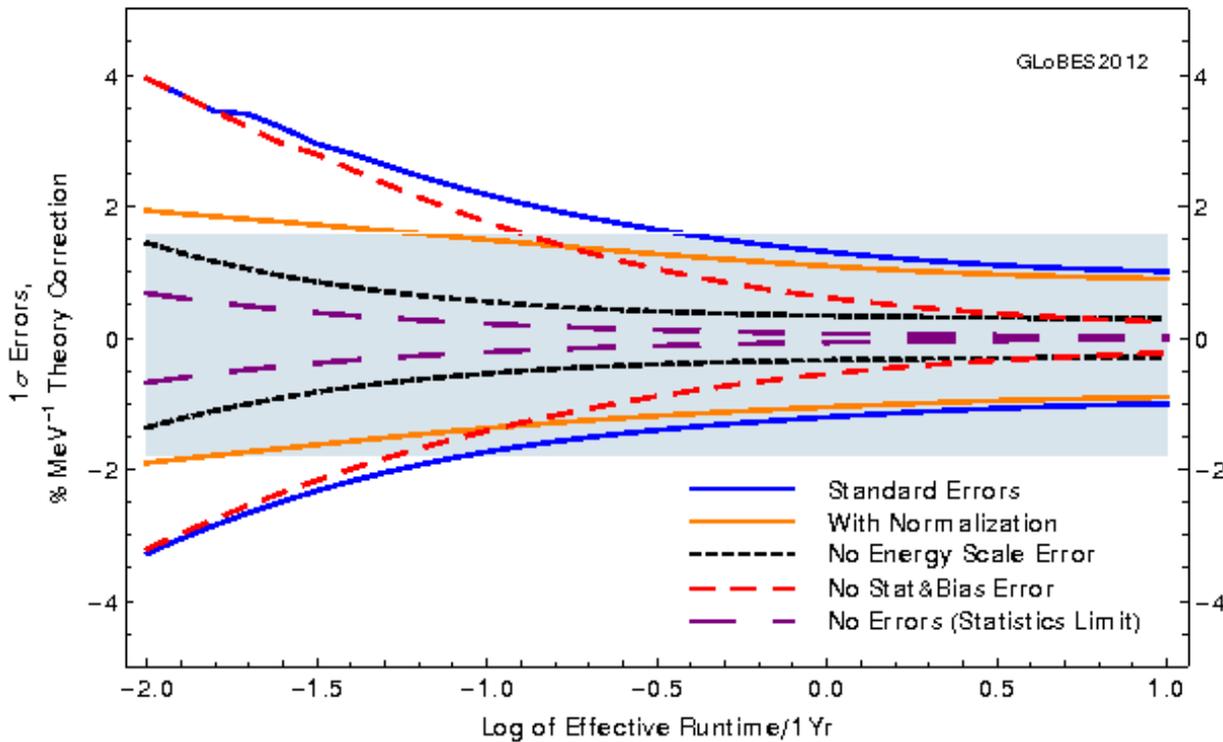
$4.78 \pm 10.5 \%$ MeV^{-1} ($ft < 10^{10}$)

E. Christensen, PH, P. Jaffke, in preparation

Bugey-3 background subtracted data at 15m

Y. Declais, *et al.*, NPB434, 503 (1995)

Future measurements



Fit for the slope parameter as a function of exposure, where 1 corresponds to $5.8 \text{ GW}_{\text{th}}$, detector mass of 40 tons, a distance of 400 m and a runtime of 1 year.

Blue shaded region corresponds error band from Bugey-3 fit.

E. Christensen, PH, P. Jaffke, in preparation

Combination of ILL errors on flux and detector effects (energy scale!) limit this measurement.

Corollary

Reactor anomaly is a 6-7% **rate** deficit

- 1/4 stems from the neutron lifetime – other detection reactions?
- 1/4 stems from non-equilibrium corrections – depends on detailed fuel history, well understood nuclear & reactor physics (?)
- 1/2 stems from the new fluxes
 - less than 0.5% theory errors below 3.5 MeV
 - most nuclear physics uncertainties decrease with the endpoint energy
 - ILL data needs to be improved for all four fissile isotopes – 25 times as much statistics required, 50 keV resolution sufficient
 - future reactor shape measurements are difficult (but worthwhile!)

New β -measurements would be very beneficial.

Inverse Tritium decay (ITD)

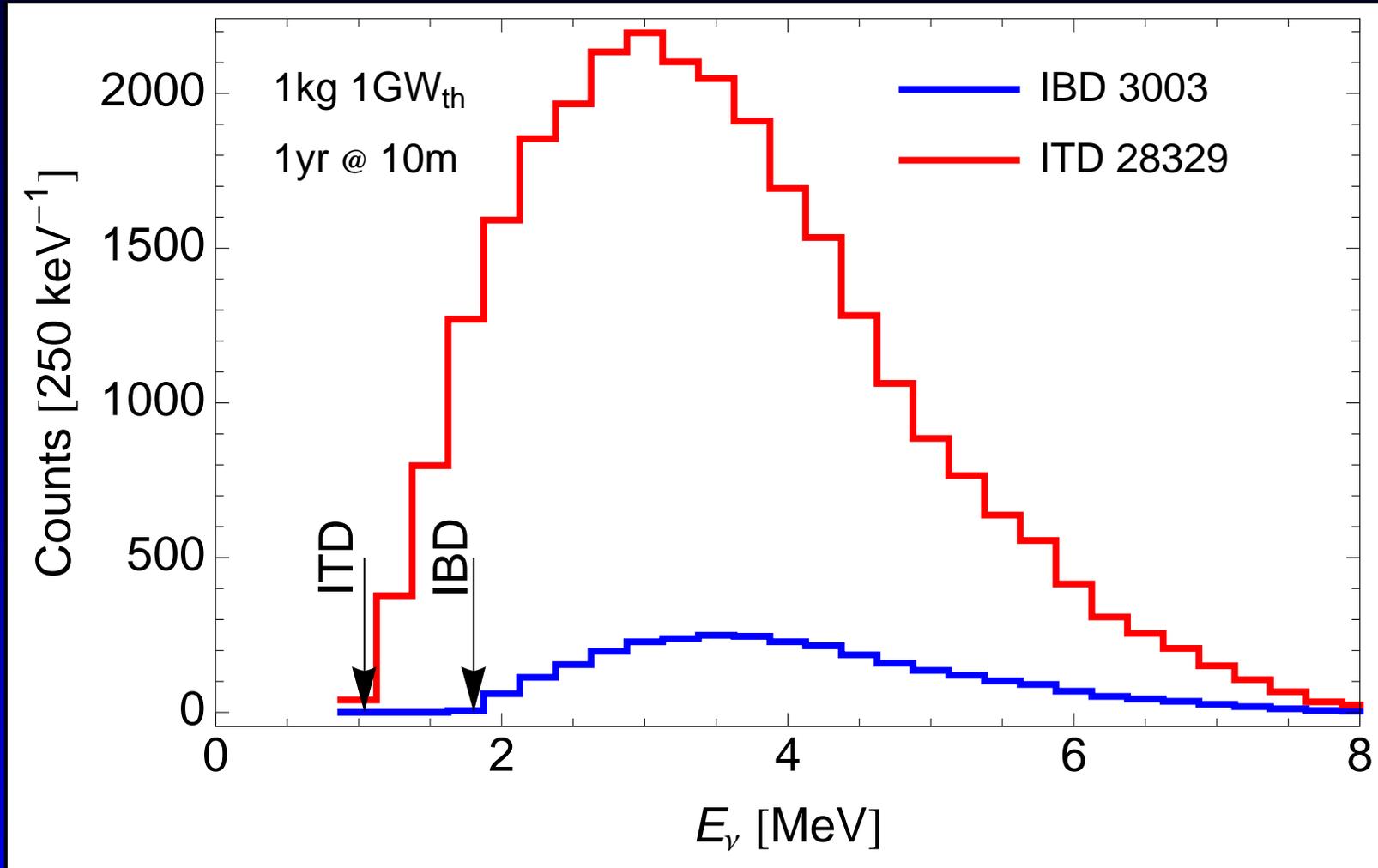


- 760 keV lower threshold than inverse β -decay (IBD)
- $\log ft$ of ITD is nearly the same as for IBD \Rightarrow large cross section
- Half-life of ${}^3\text{H}$ is known to be $4500 \pm 8 \text{ d}$ (0.17%)
- Phase space factor is known to high precision as well

Overall a cross section error for ITD of 0.25% seems possible \Rightarrow eliminates the contribution to the RAA from the neutron lifetime

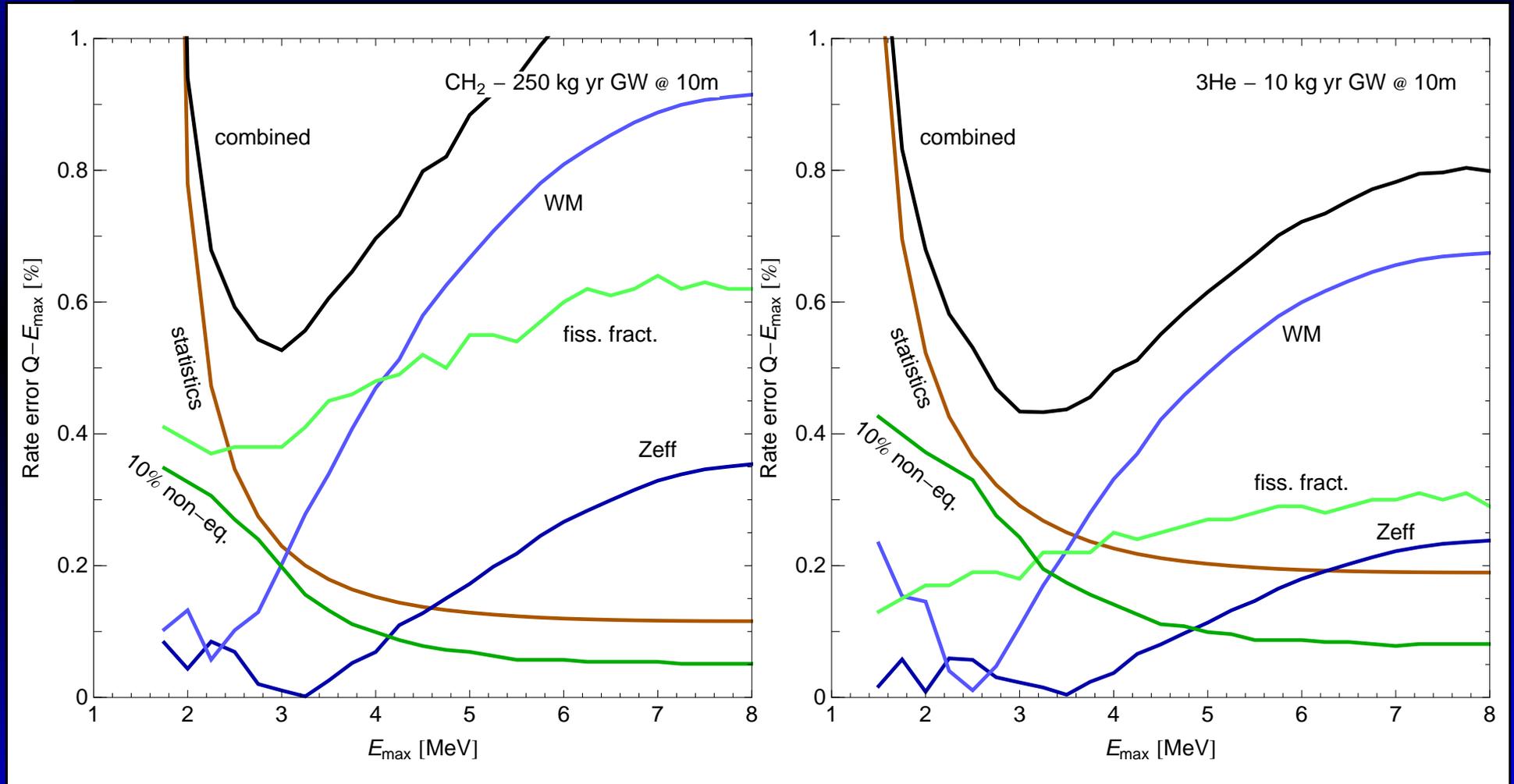
Event rates

1 kg ^3He compared to 1 kg CH_2



Adding up

Integrating signal and errors from threshold up to E_{\max}



Fission fraction impact smaller at lower energy since the difference between neutrino yields is smaller

Other error sources

IBD

- 0.5% – reactor power
- 0.25% – energy p. fiss.
- 0.2% – cross section
- 0.5% – H/C ratio
- 0.8% – Gd fraction

ITD

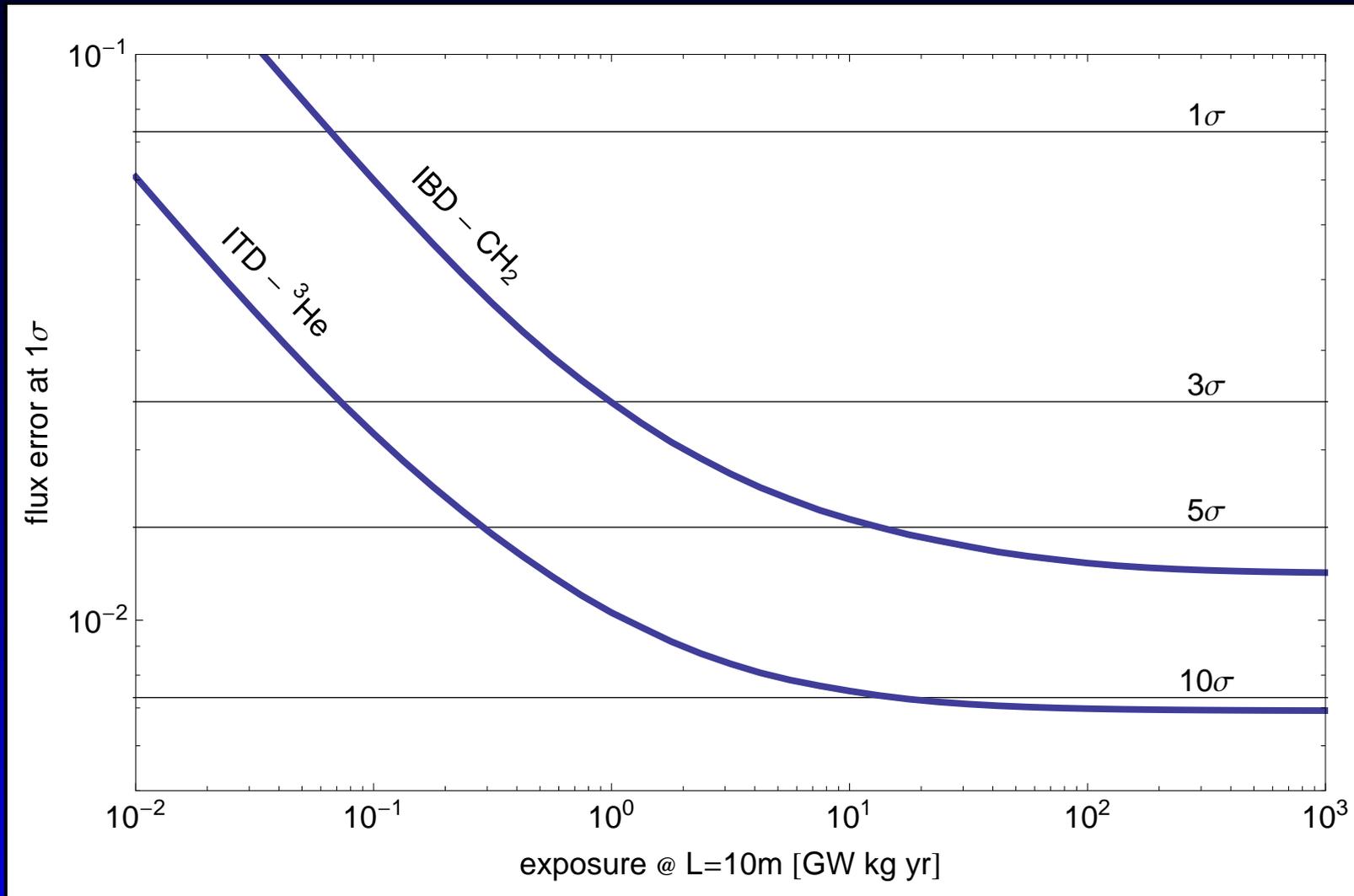
- 0.5% – reactor power
- 0.25% – energy p. fiss.
- 0.25% – cross section

+ Negligible errors from β -spectrum measurement

+ Non-equilibrium correction estimate within 10%
factor 3 improvement over current experiments

+ Geometric acceptance and barycenter of fission at short range?

How much exposure?



Saturation around 10 kg yr GW

$\Rightarrow 10\sigma$ test of the RAA?

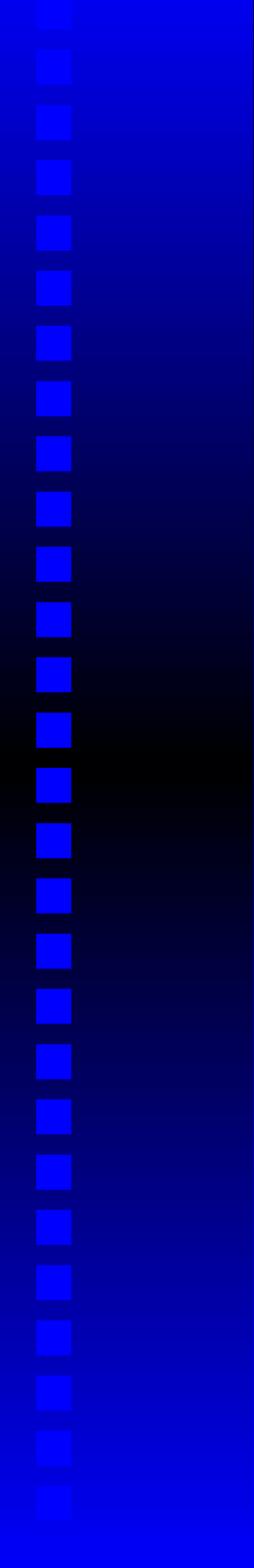
Summary

Integral β -spectrum measurements

- Improve statistics of ILL measurements by 25
- Reduce normalization error to 0.1% (0.5% probably also still OK)
- Do this for all four isotopes
- 50 keV bins are fine

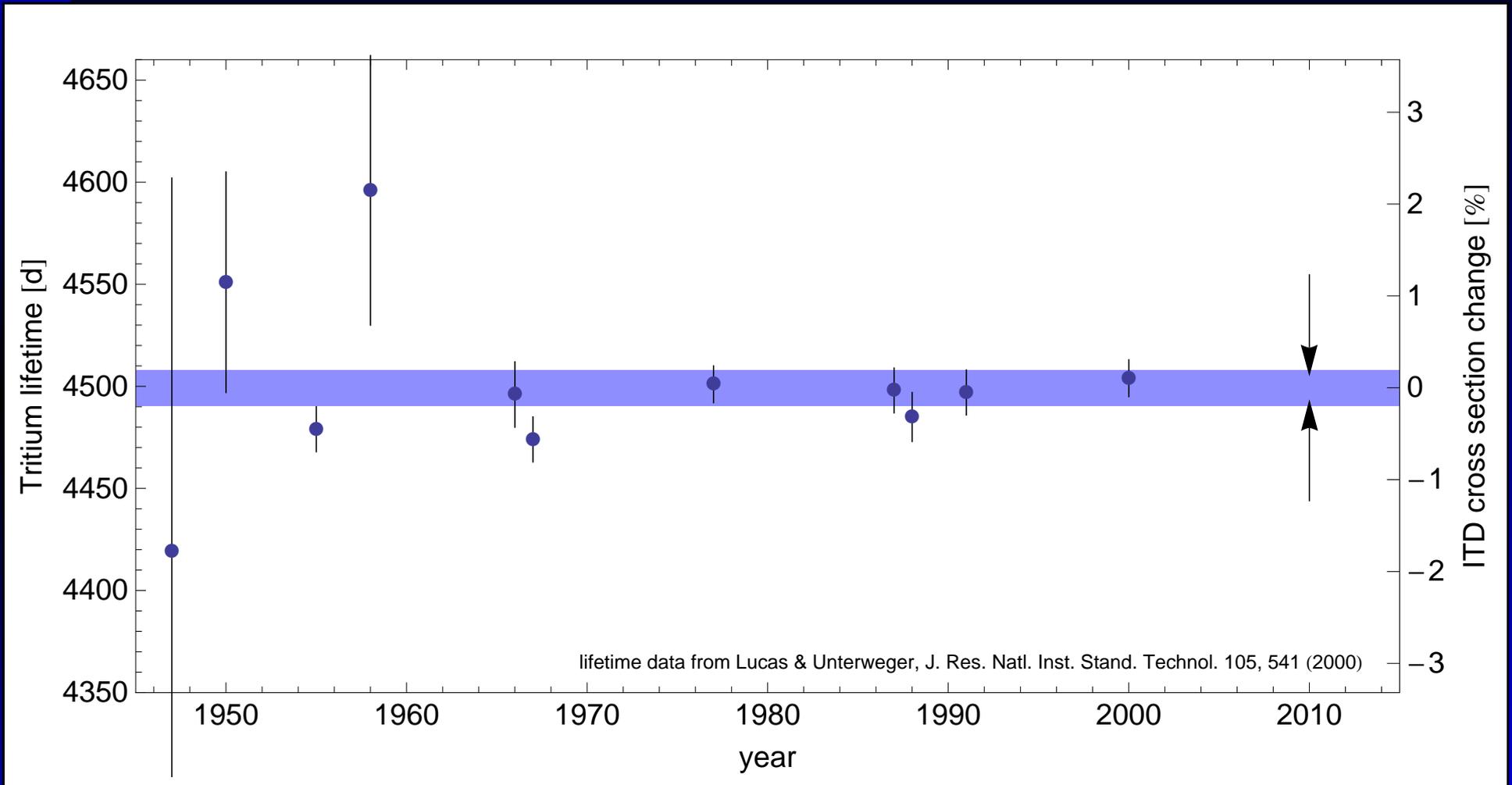
Reactor experiment

- 10 m from the core, 10 kg yr GW exposure
- focus on low energy region
- ^3He target, silver bullet for systematics?
10 σ test of the reactor anomaly?



Backup slides

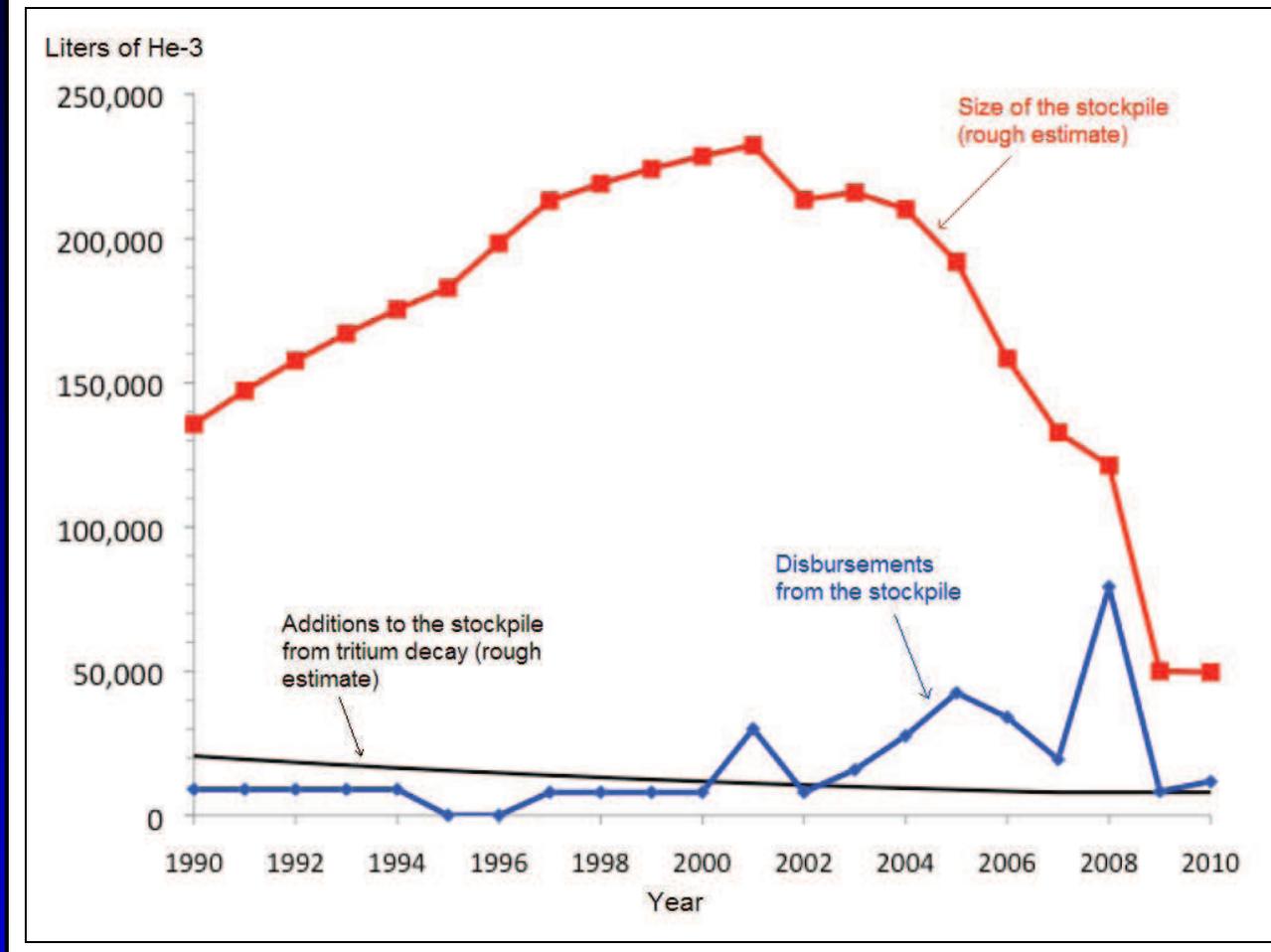
Tritium lifetime



Not quite as accurate as neutron lifetime, but much fewer systematic issues!

^3He supply in the U.S.

Figure 1. Size of the Helium-3 Stockpile, 1990-2010



Congressional Research Service, 2012

1 kg \approx 7,500 liters at \$1,000-\$2,000 per liter
 \Rightarrow lease material (like SNO did)