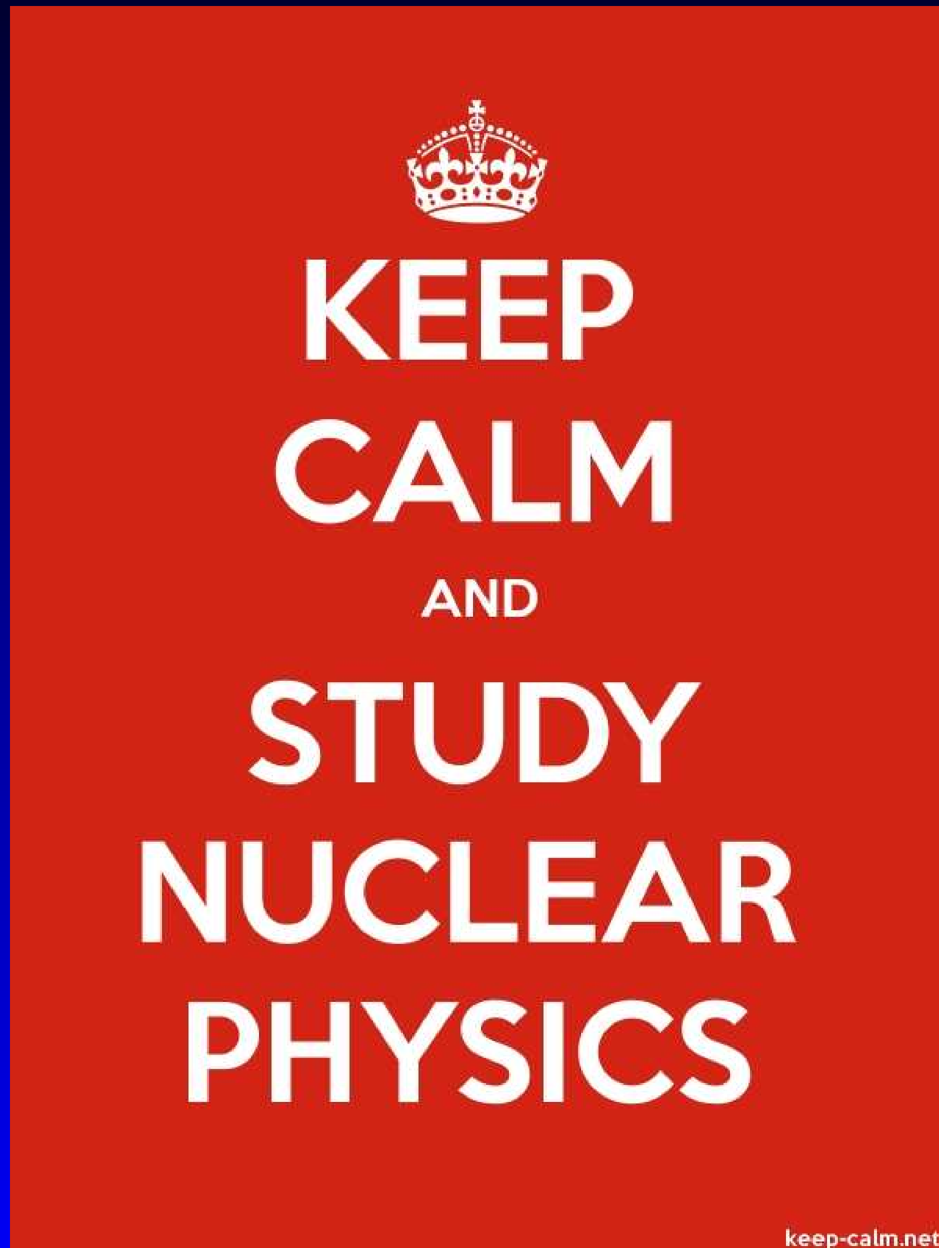
Nuclear physics and the reactor anomaly

Patrick Huber

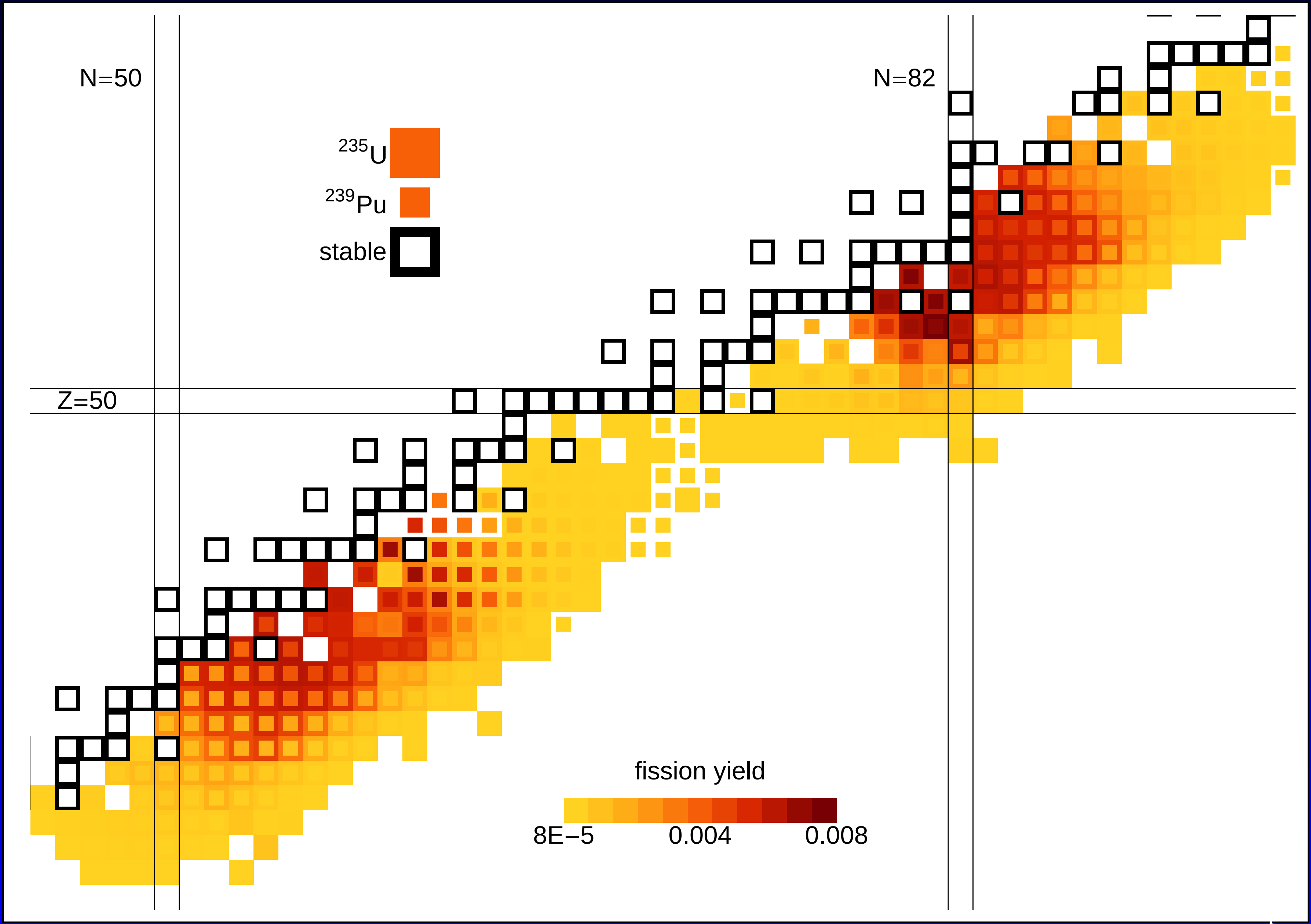
Center for Neutrino Physics – Virginia Tech

Neutrino Platform Week

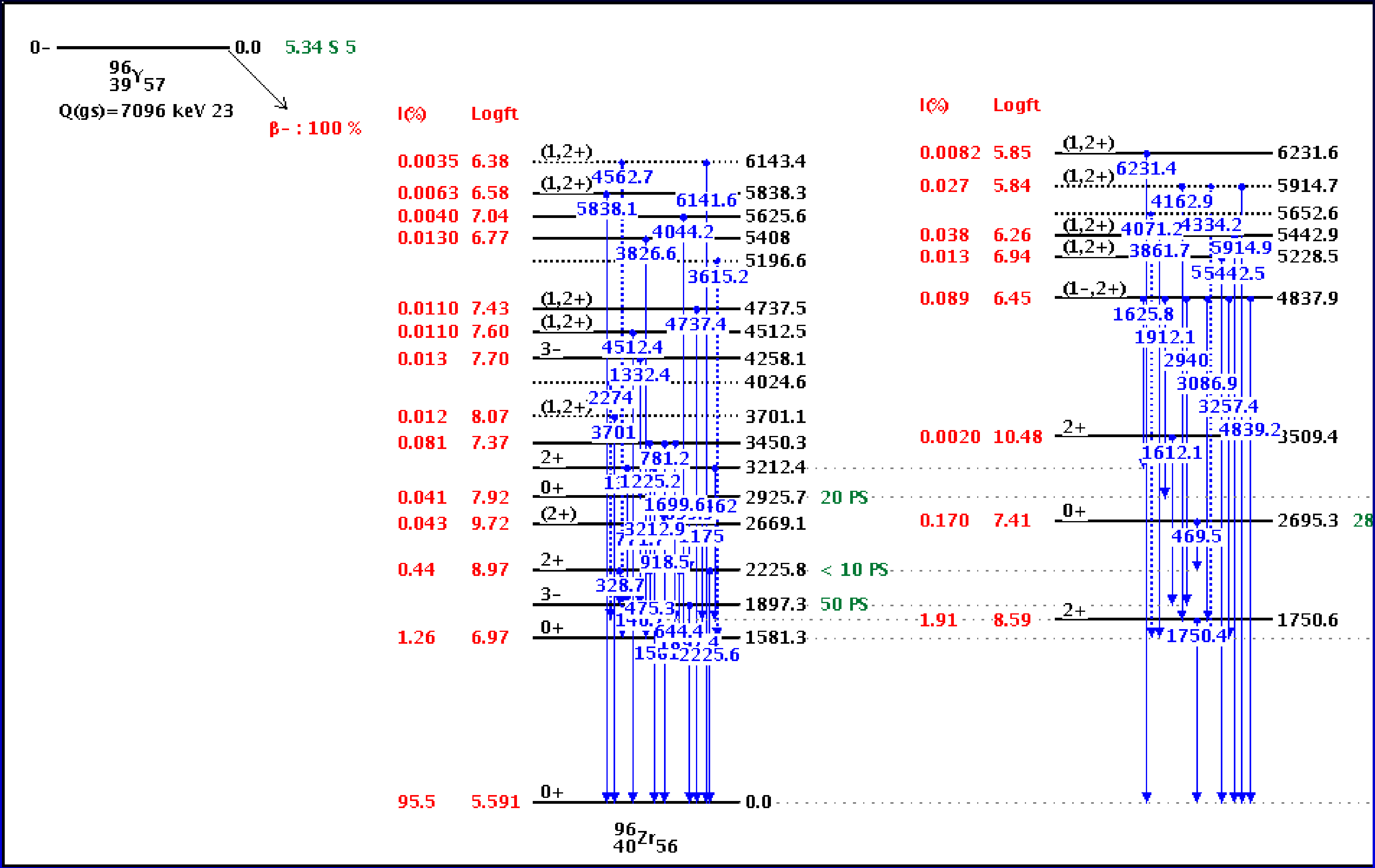
January 29 – February 2, 2018, CERN


KEEP
CALM
AND
STUDY
NUCLEAR
PHYSICS
keep-calm.net

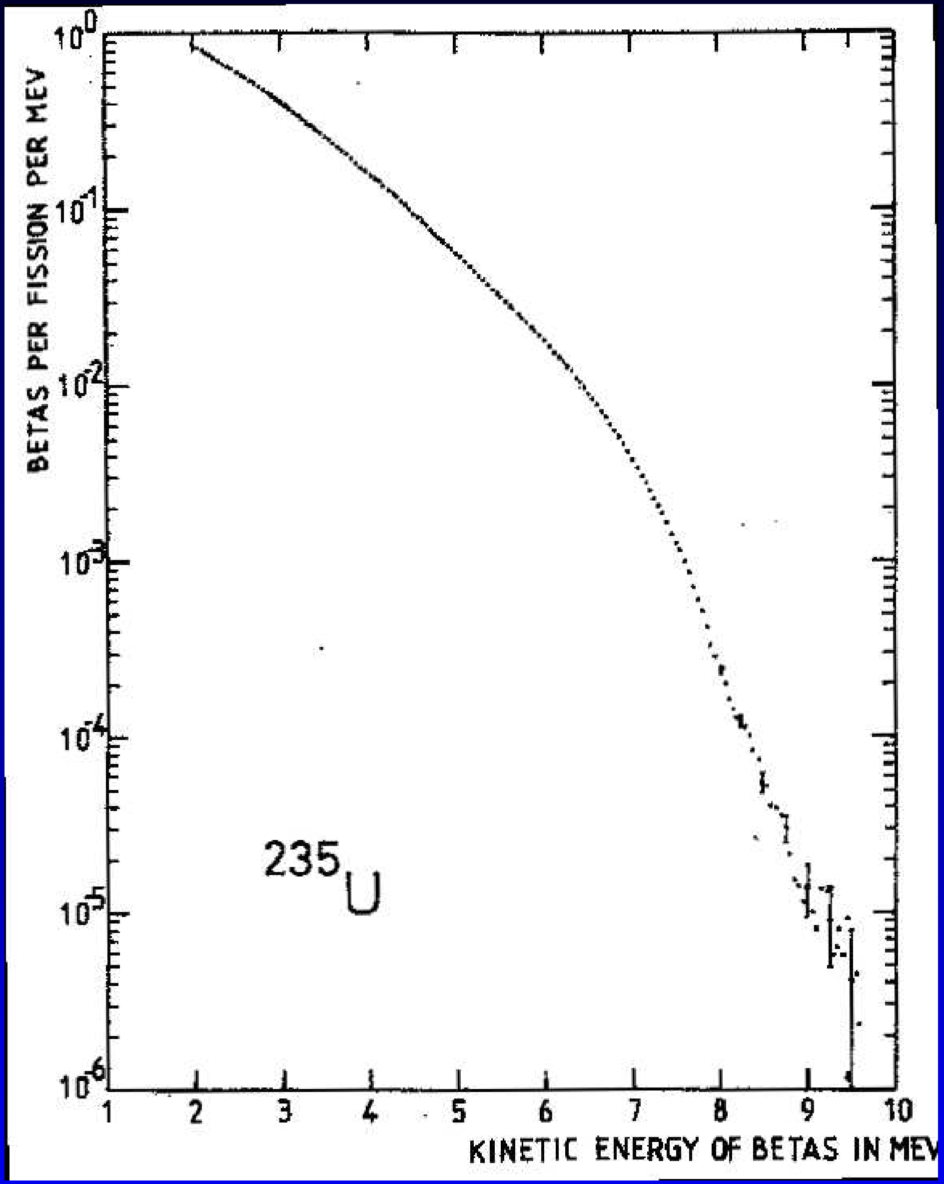
Neutrinos from fission



β-branches



β-spectrum from fission



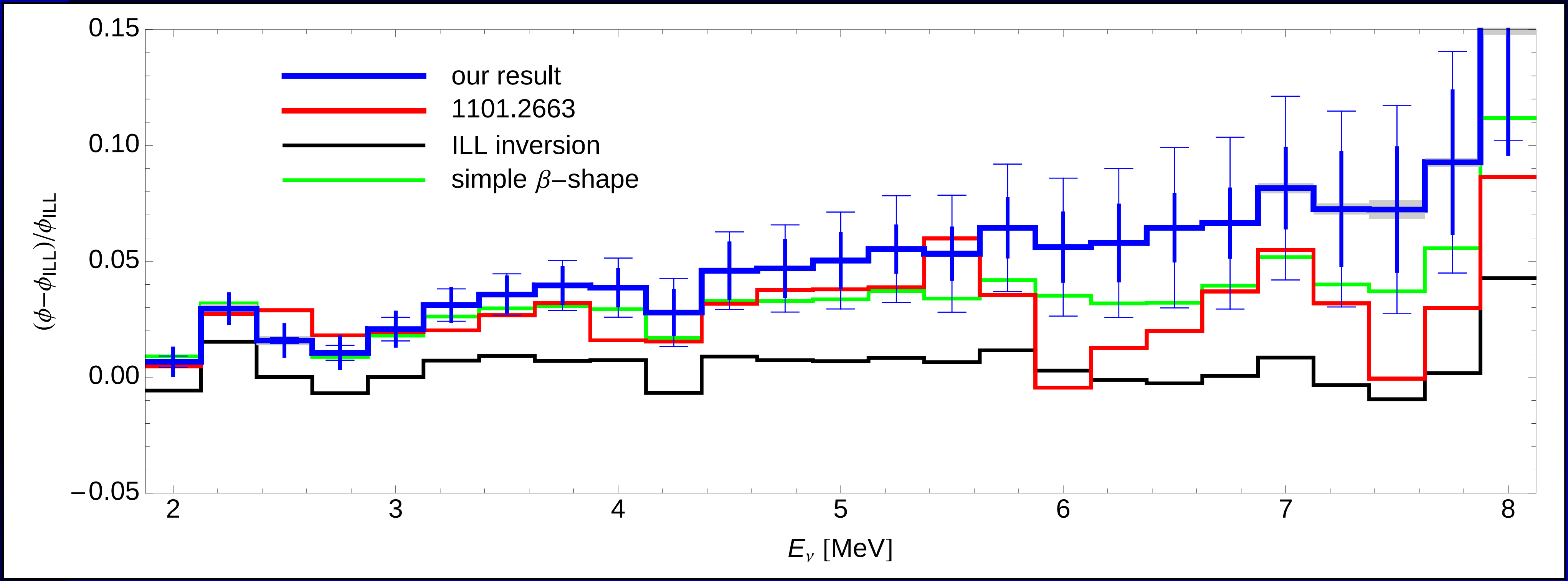
Schreckenbach, *et al.* 1985.

We can take this total β-spectrum and convert it to a neutrino spectrum Mueller *et al.*, 2011; Huber 2011

For *allowed* decays this can be done in a controlled fashion, resulting in a 2% error.

NB: This assumes the β-spectrum data is correct.

Reactor antineutrino fluxes



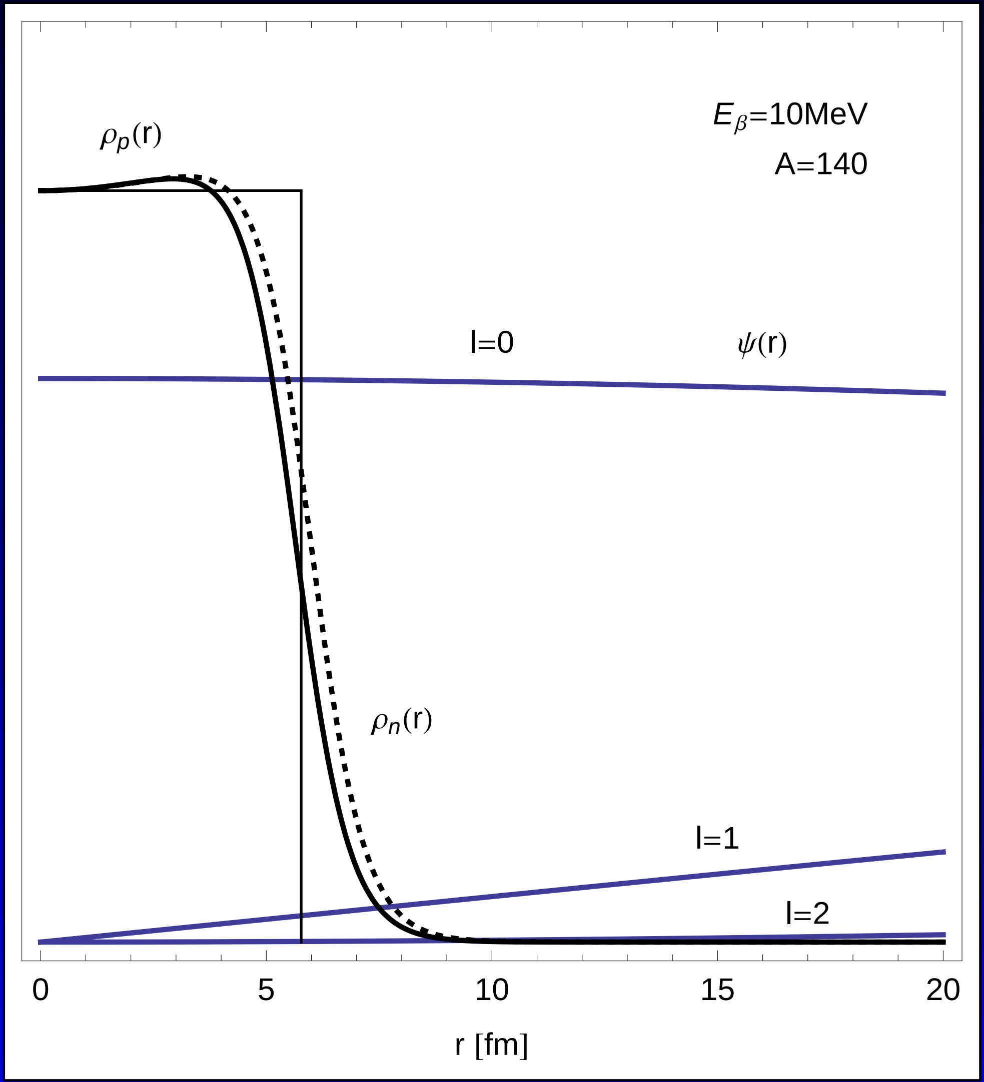
Shift with respect to ILL results, due to

a) different effective nuclear charge distribution

b) branch-by-branch application of shape corrections

Overall 2% error on IBD rate under the allowed decay assumption.

Forbidden decays



$e,\bar{\nu}$ final state can form a singlet or triplet spin state J=0 or J=1

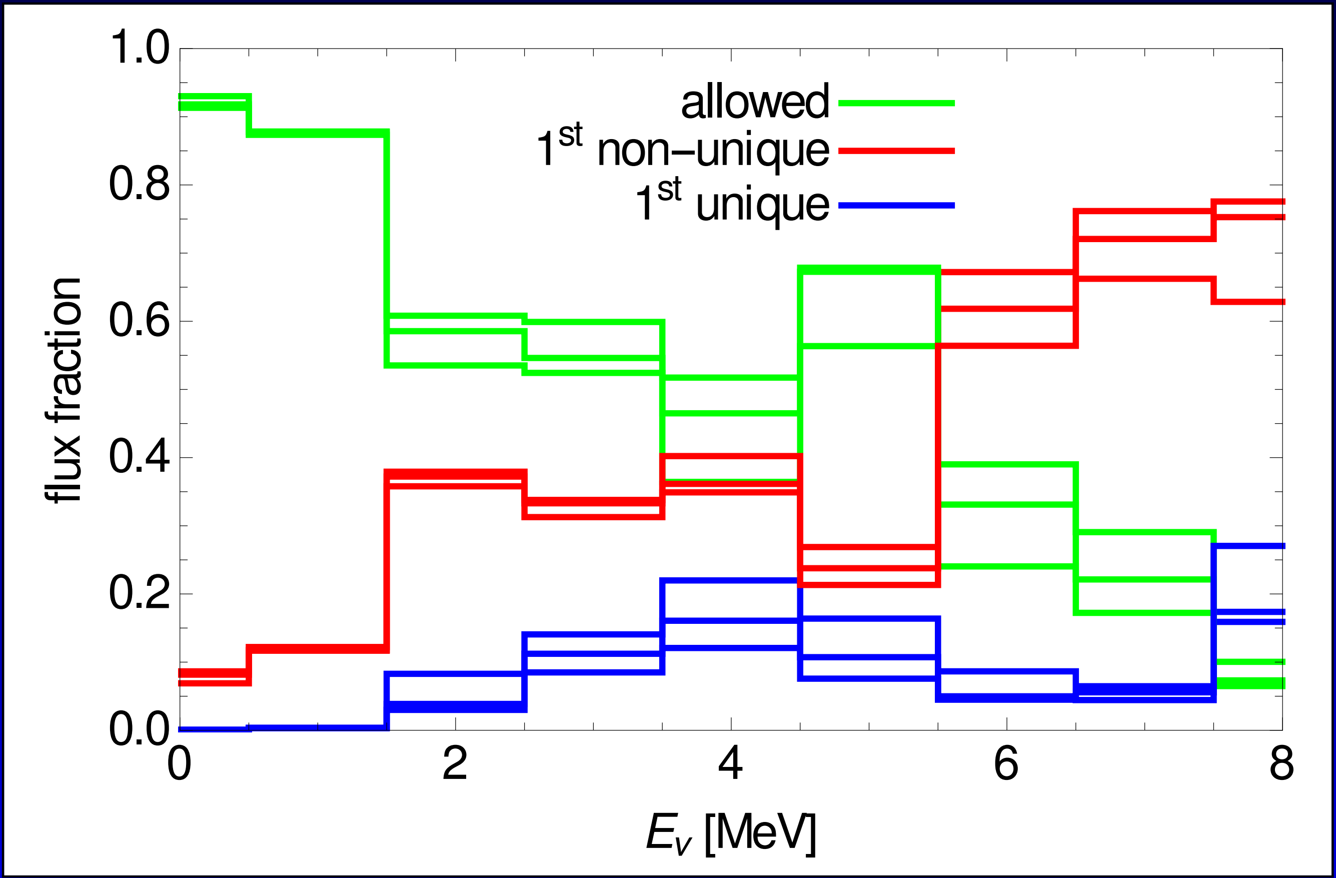
Allowed:
s-wave emission ($l = 0$)

Forbidden:
p-wave emission ($l = 1$) or $l > 1$

Significant dependence on nuclear structure in forbidden decays$\rightarrow$ large uncertainties!

Do forbidden decays play a role?

Based on JEFF fission yields and using ENSDF spin-parity assignments

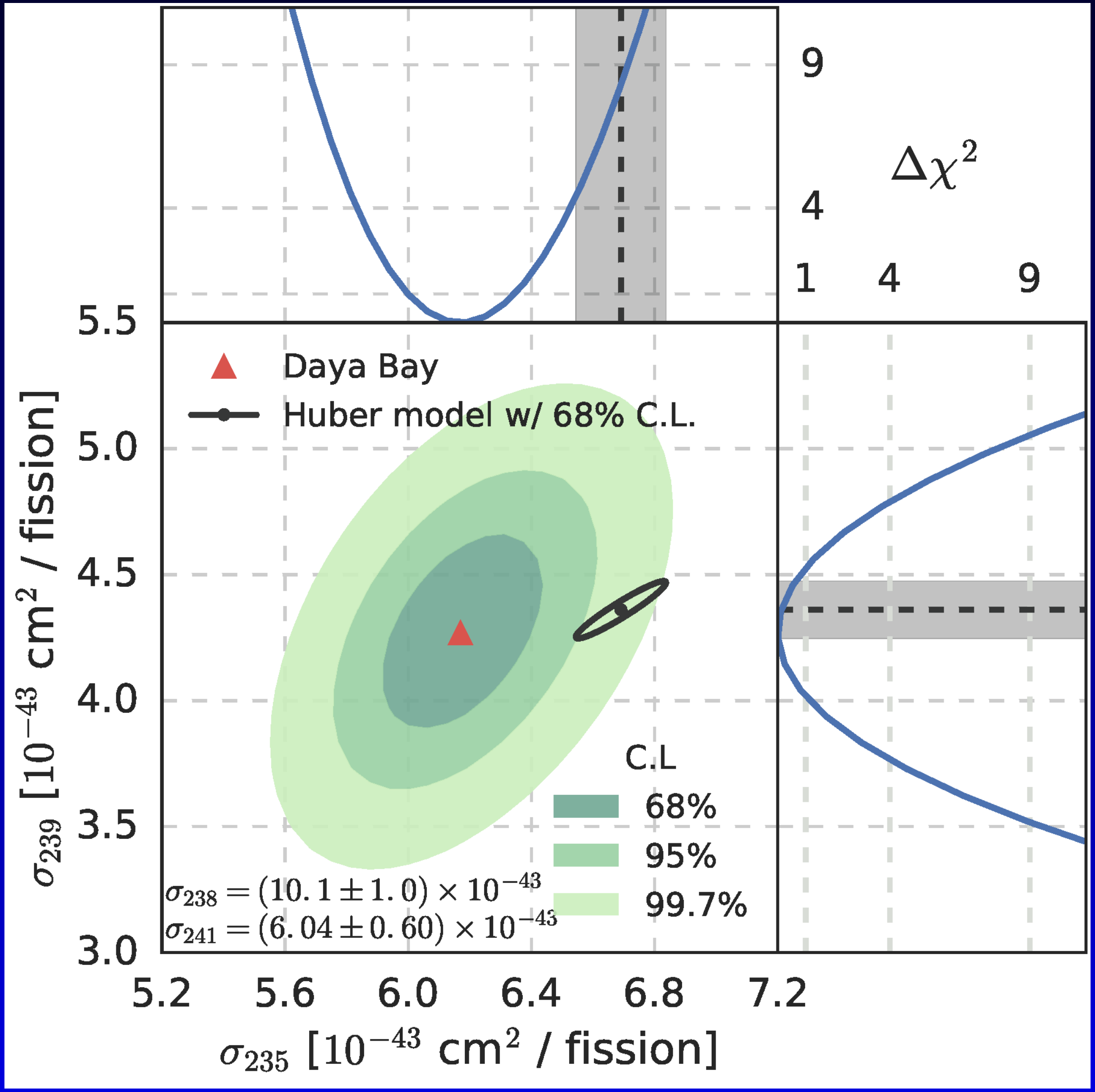


Thus, we no longer can claim a 2% uncertainty and there is room for the 5 MeV-bump.

Disclaimer

- The following slides are NOT presented on behalf of the Daya Bay collaboration.
- Entirely based on publicly available data.
- The reactor model employed is of a vanilla pressurized water reactor.
- A detailed calculation based on the actual Daya Bay reactor data will yield a different quantitative result.
- There may be other contributions.

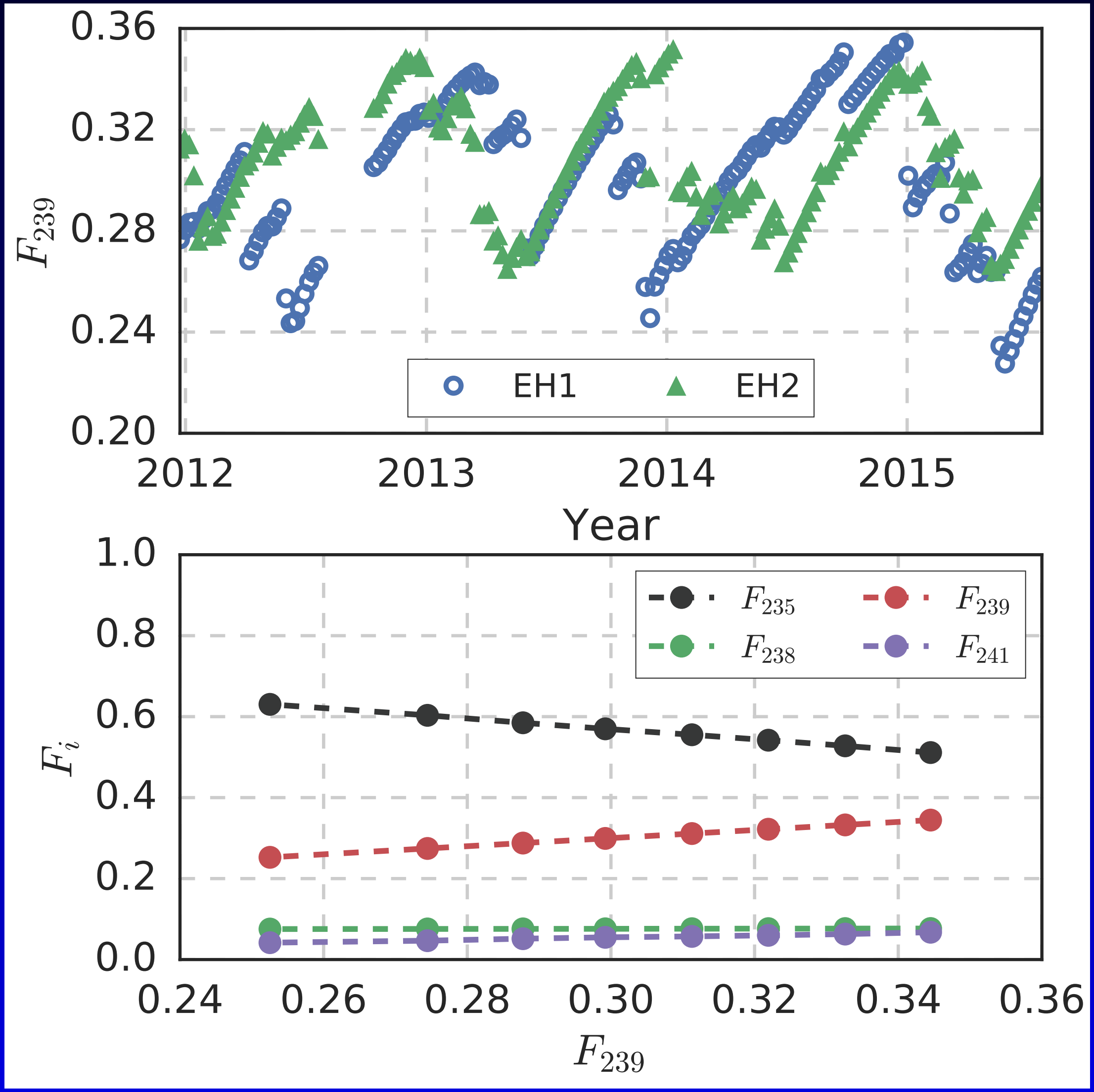
Latest result of Daya Bay



Daya Bay, 2017

Only an issue if the prediction of Pu239 in the Huber+Mueller model is correct.
Hayes *et al.*, 2017

How does this work?



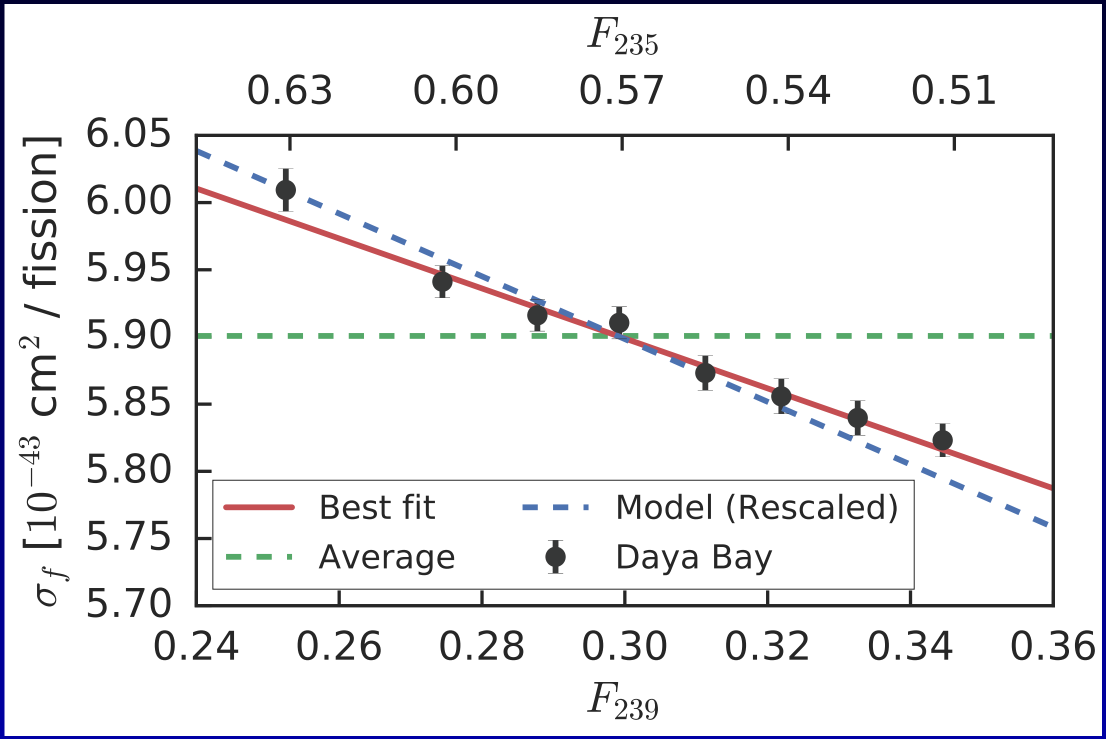
Daya Bay, 2017

Daya Bay has 6 reactor cores, small change in total burn-up

Data binned in burn-up, quantified by $F239$, fraction of fissions in ^{239}Pu.

$F239$ measures time since last refueling.

Daya Bay data



Daya Bay, 2017

Tiny mismatch between prediction and data of about 1%

Corresponds to about $3\,\sigma$

This only works if there are no other time or $F239$ dependent flux components at $\sim 0.5\%$ level.

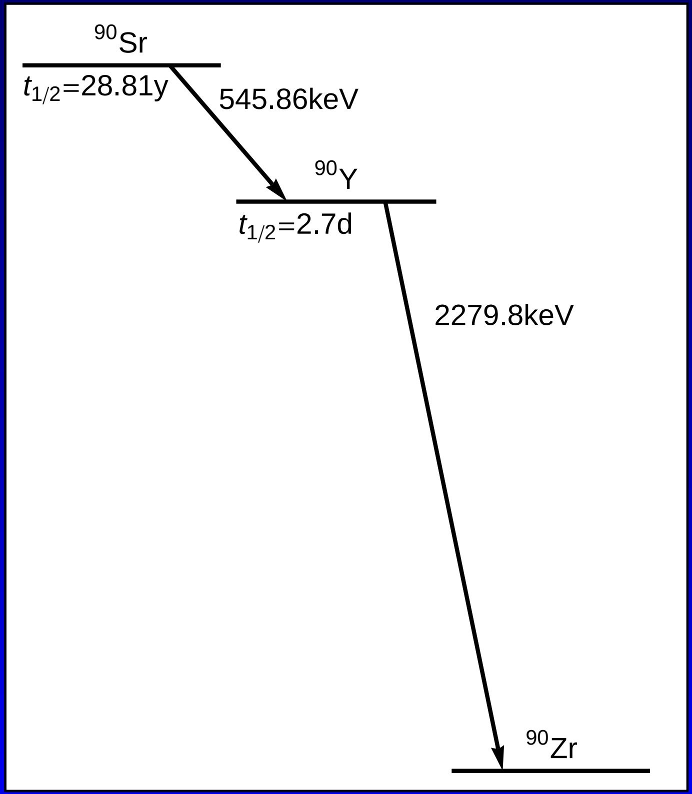
Long-lived decay chains

Some long-lived, $t_{1/2} > 12\,\text{h}$, decay chains among fission fragments produce neutrinos above $1.8\,\text{MeV}$.

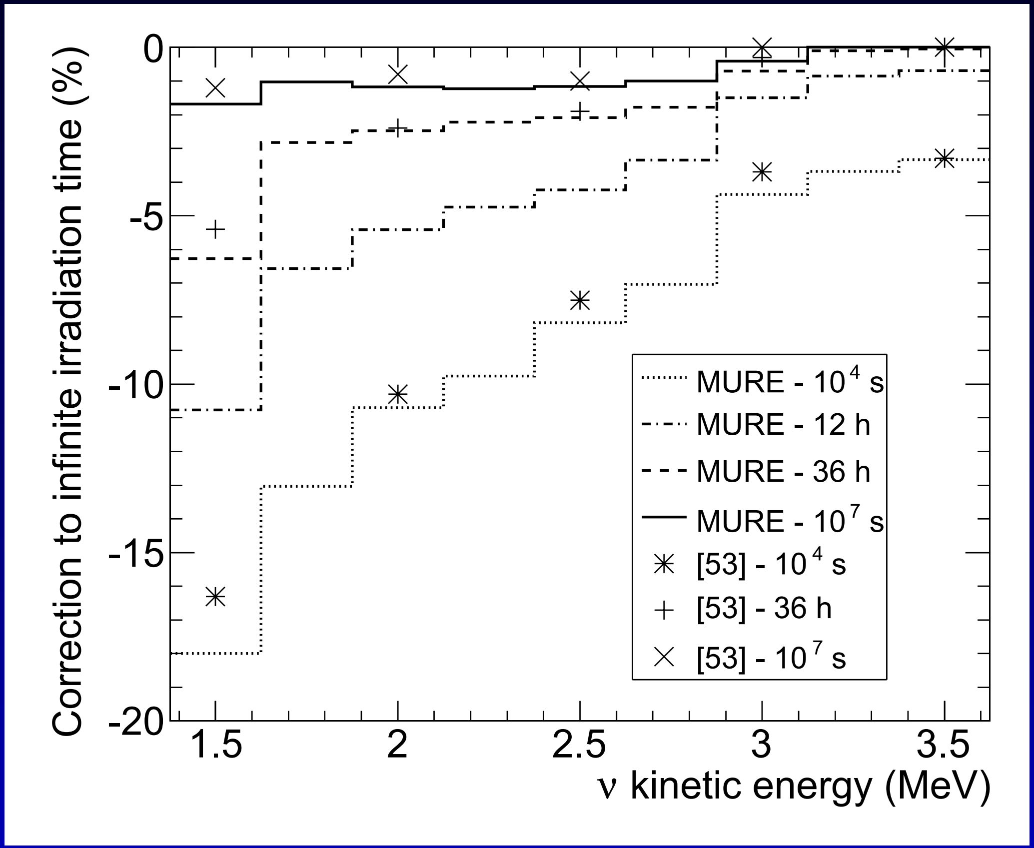
Isotope	^{90}Sr	^{106}Ru	^{144}Ce
Half life	29 y	372 d	285 d

Compute abundance using reactor burn-up codes and the associated nuclear data

Compute ν-spectra using (well) known β-feeding functions and endpoints



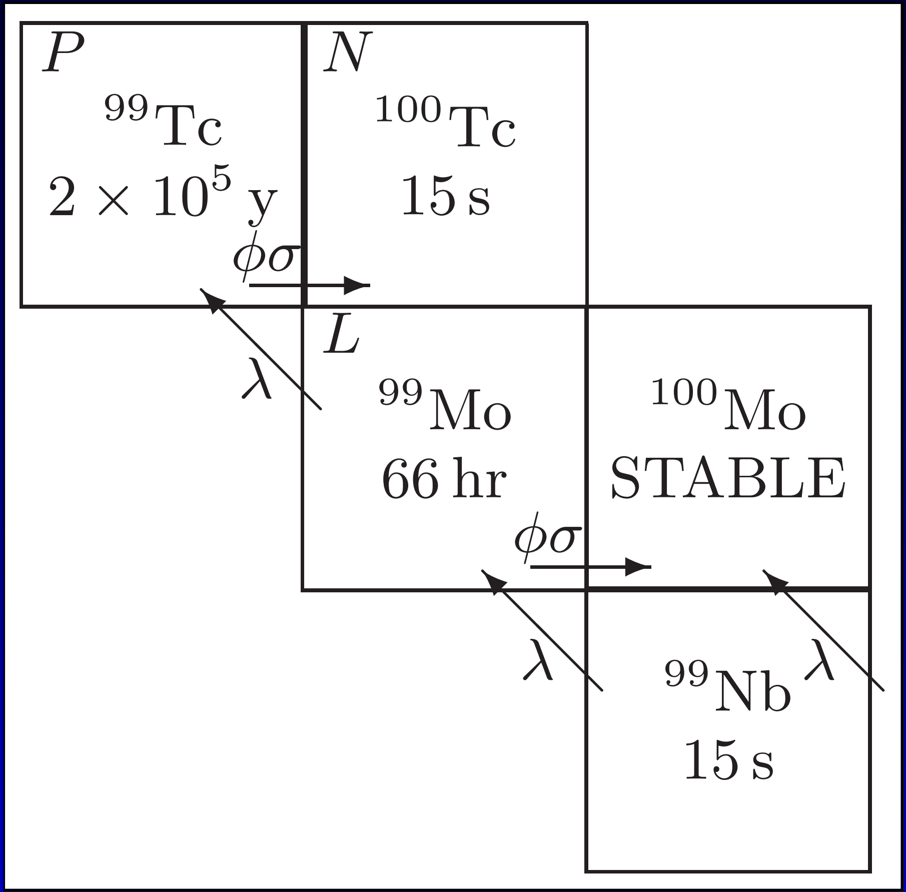
Non-equilibrium correction



Mueller *et al.*, 2011

The β-spectra at ILL were taken for irradiation periods of 12-48 h, so long-lived isotopes never reached equilibrium. Order 1% in total rate.

Non-linear isotopes



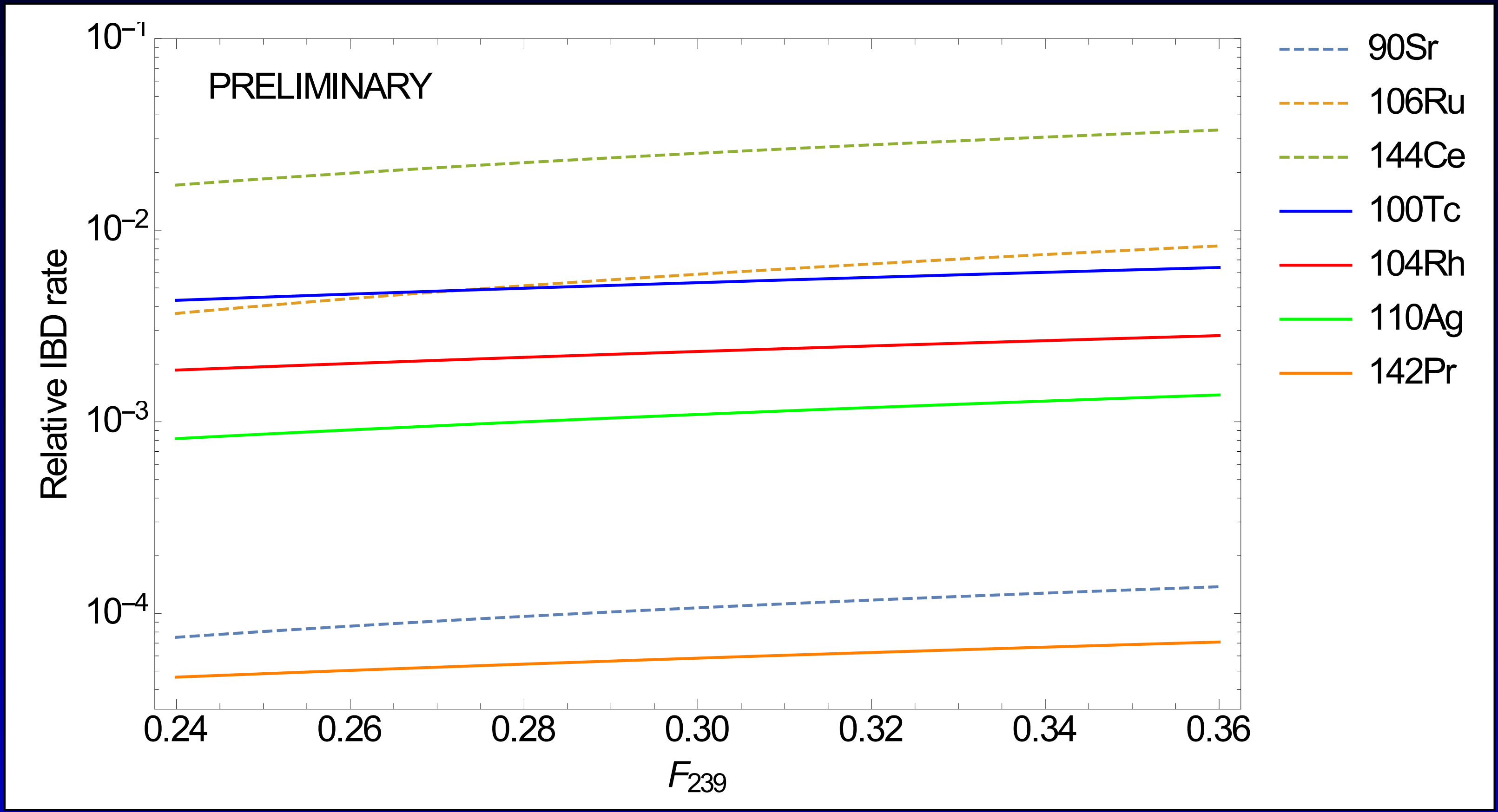
Jaffke, Huber, 2015

Out of 20 $\beta\beta$-isotopes made in fission, only 4 contribute to IBD rates in reactors:

^{100}Tc, ^{104}Rh, ^{110}Ag, ^{142}Pr

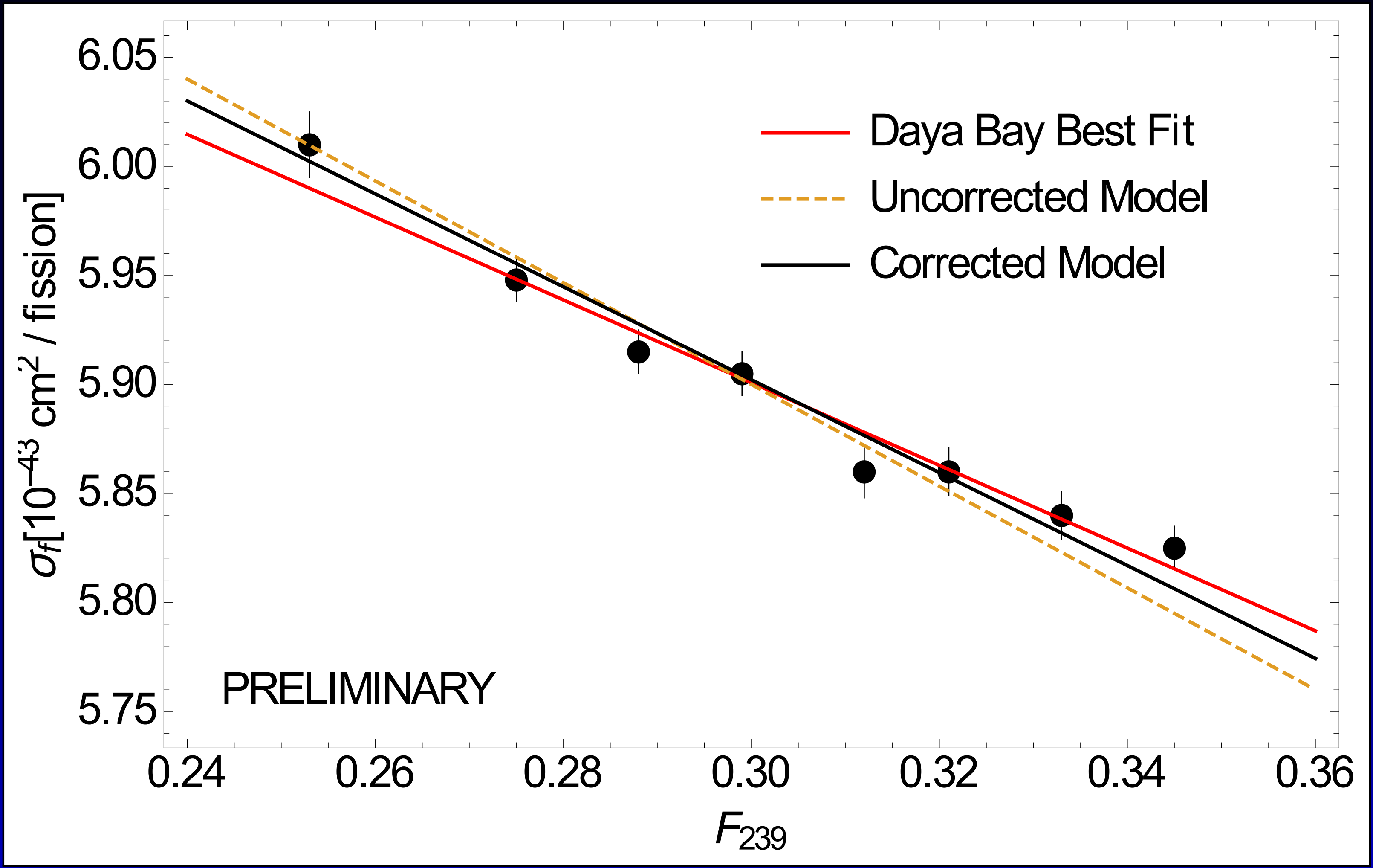
$$\Gamma_{nonlinear} \propto \underbrace{\Sigma_{\text{fiss}} \phi Z_P T_{\text{irr}}}_{\text{atoms of P}} \sigma_P^c \phi \propto T_{\text{irr}} \phi^2 \propto T_{\text{irr}}$$

Size of resulting corrections



Huber, Sharma, in progress

dashed – non-equilibrium isotopes
solid – non-linear isotopes



Huber, Sharma, in progress

	χ^2	$\sqrt{\Delta\chi^2}$
best fit	5.8	
uncorrected model	15.0	3σ
corrected model	8.5	1.6σ

Summary

- Nuclear physics is important.
- Nuclear physics is complicated.
- Quantifying errors is difficult – though not (always) impossible.
- Nuclear uncertainties cut both ways in the interpretation of reactor data:
    - hard to quantify significance of reactor IBD rate deficit.
    - hard to use high-precision burn-up data to put limit on light steriles.

Ideally, we should look for oscillation in ratios of measured quantities – DANSS and NEOS are seing hints of that.