Global strategy

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Zoom

Happy 90th!

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grossenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

What do we mean by better?

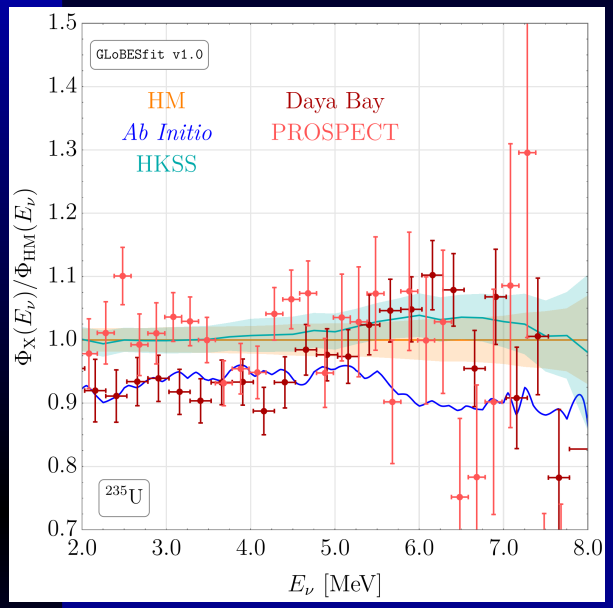
To be useful for neutrino science and/or applications:
— flux for specific reactor and fuel history
— fully elaborated error budget
— for CEvNS need to go below 2 MeV

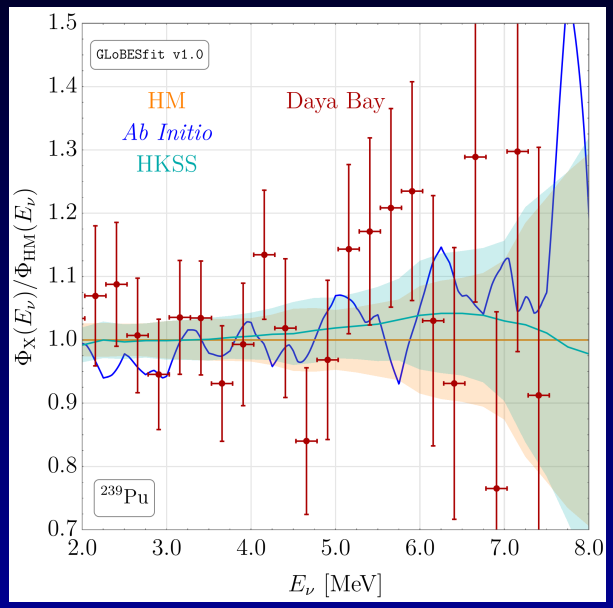
Most of the current focus is on providing a universal, equilibrium flux above 2 MeV.

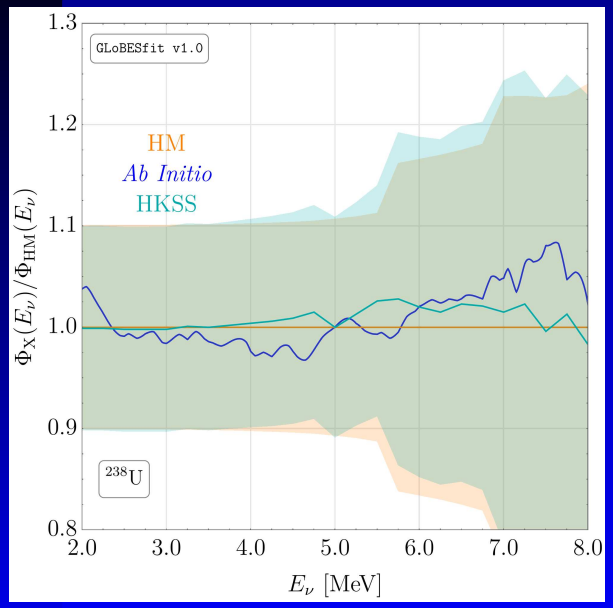
(Only ?) the Daya Bay neutrino result has a full and reliable error budget including normalization.

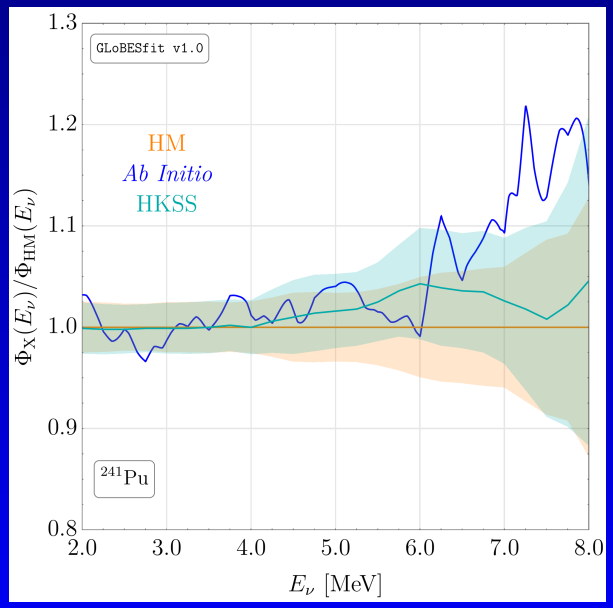
How much better depends on the specific application.

Where we are









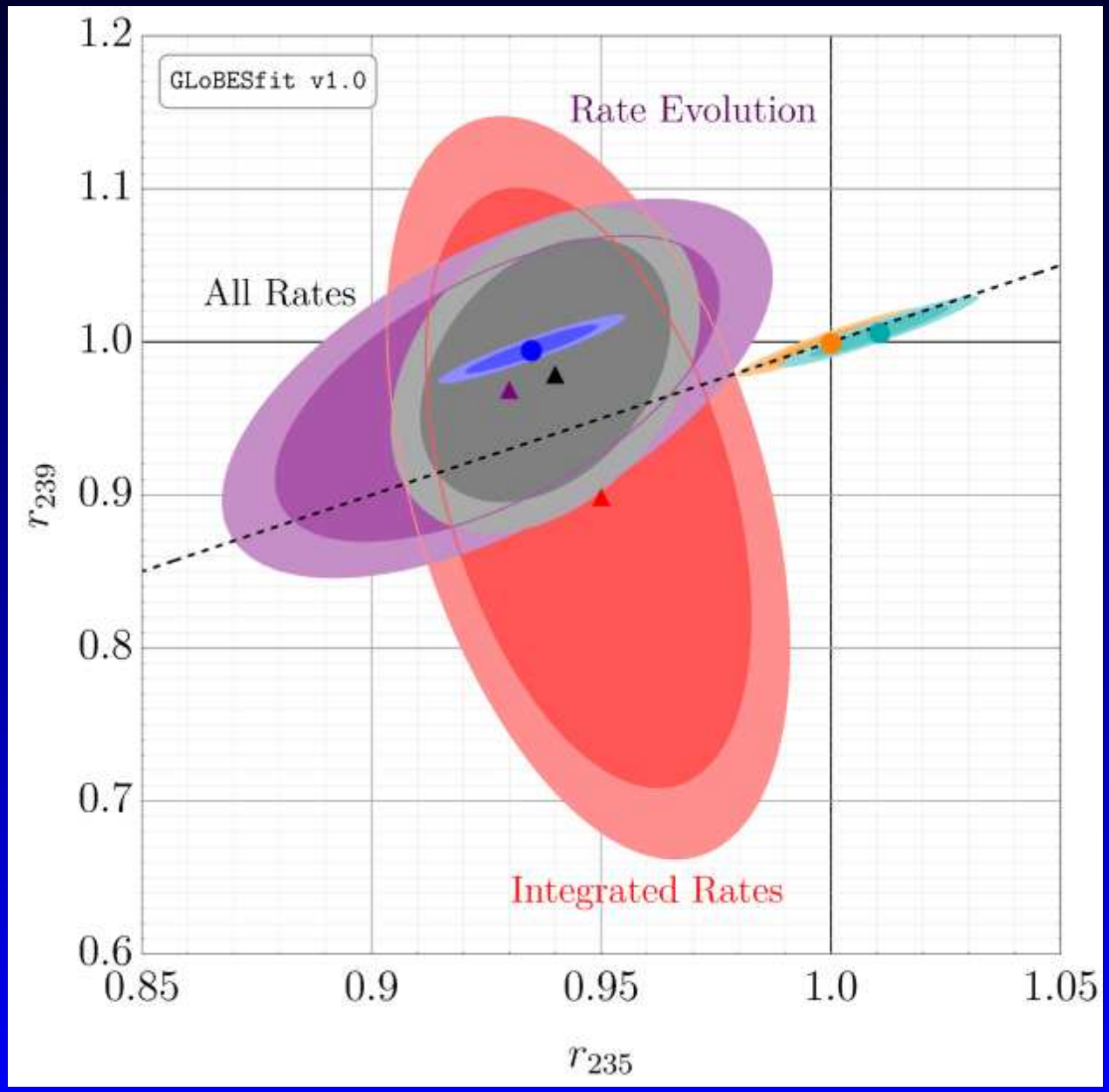
3 different flux models, data from 2 different experiments

Except for U235:
+ the models agree within error bars
+ the models agree with neutrino data

U235 has smallest error bars, not surprising that discrepancies show up first.

Berryman, PH, 2020

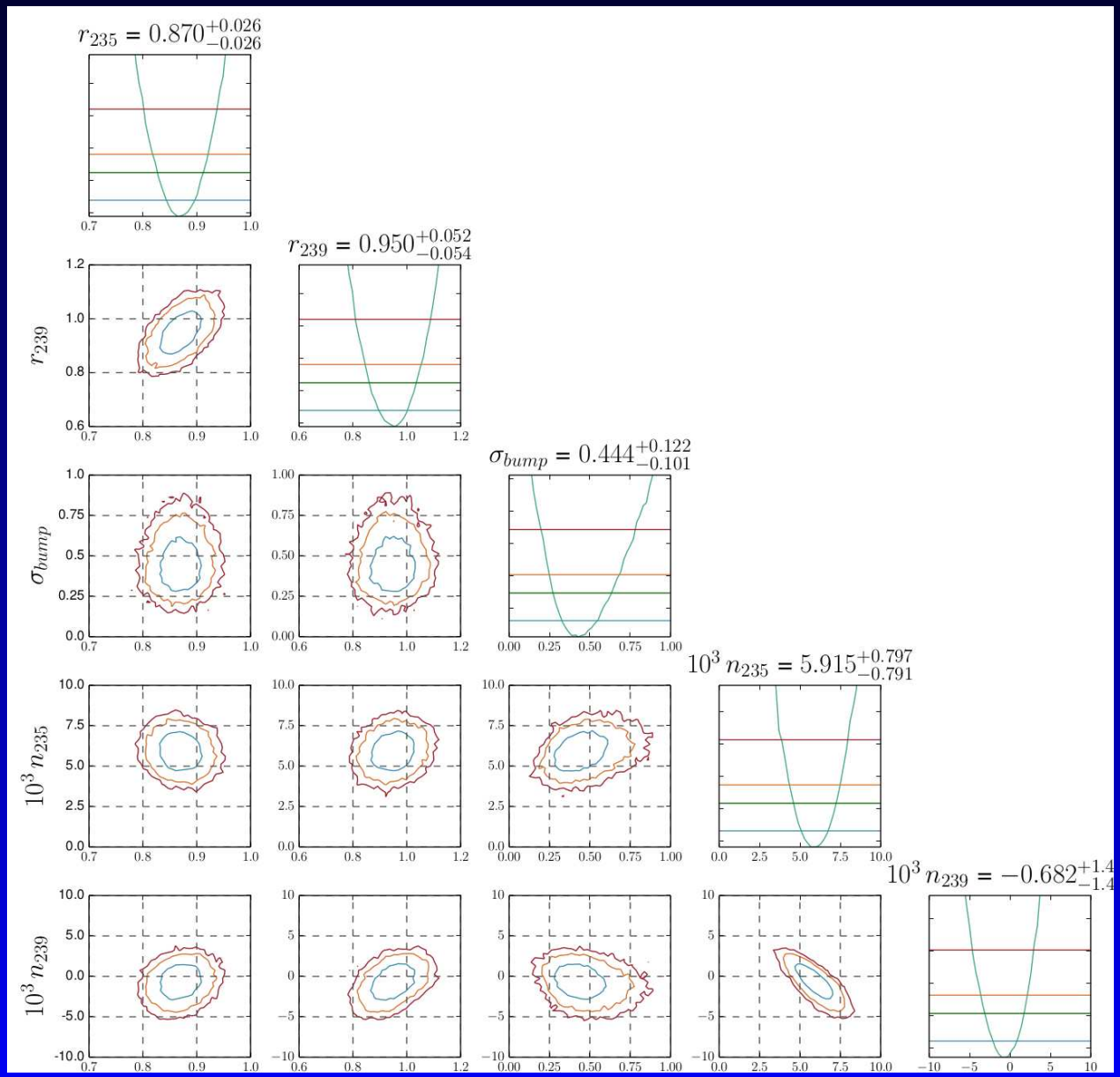
Fuel evolution



$r_{235} \neq 1$

Berryman, PH, 2020

Bumpology

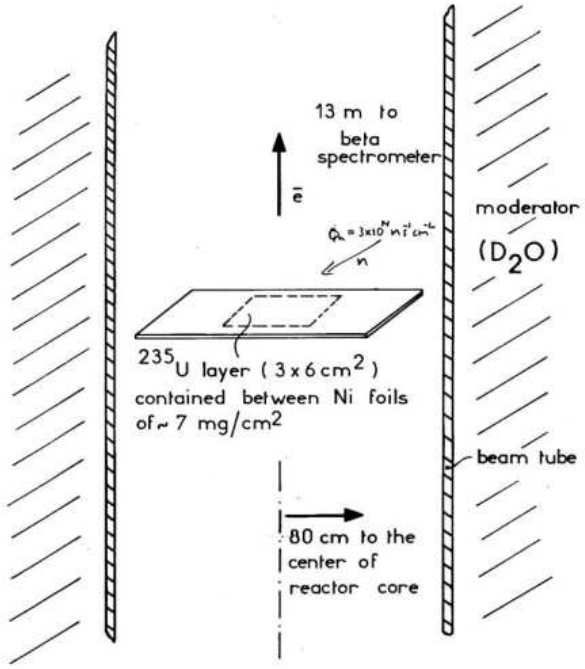


Daya Bay, RENO and PROSPECT as of 2019

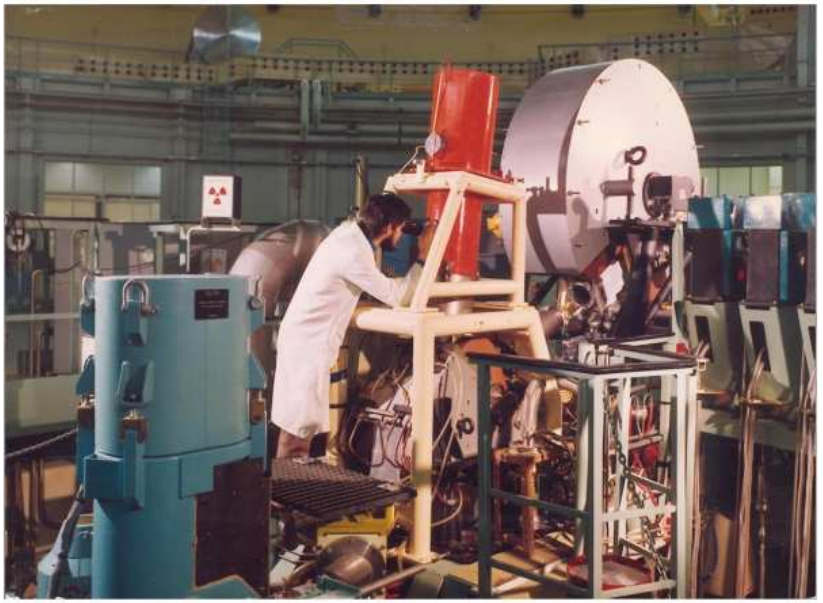
Only $n_{235} \neq 0$ with any significance

Berryman, PH, 2020

Kill BILL?



SCHEMATIC VIEW OF THE TARGET SITE



Magnetic BILL spectrometer at ILL, 1972-1991

(Electron detector in focal plane: multi chamber proportional counter in transmission, rear mounted scintillator in coincidence)

Neutron flux calibration standards different for U235 and Pu239: 207Pb and 197Au respecively.

Combined with potential differences in neutron spectrum – room for a 5% shift of U235 normalization?

A. Letourneau, A. Onillon, AAP 2018

Two ways to predict

Summation calculations

Fission yields
Beta yields

Problem: databases are insufficient & difficulty of assigning an error budget

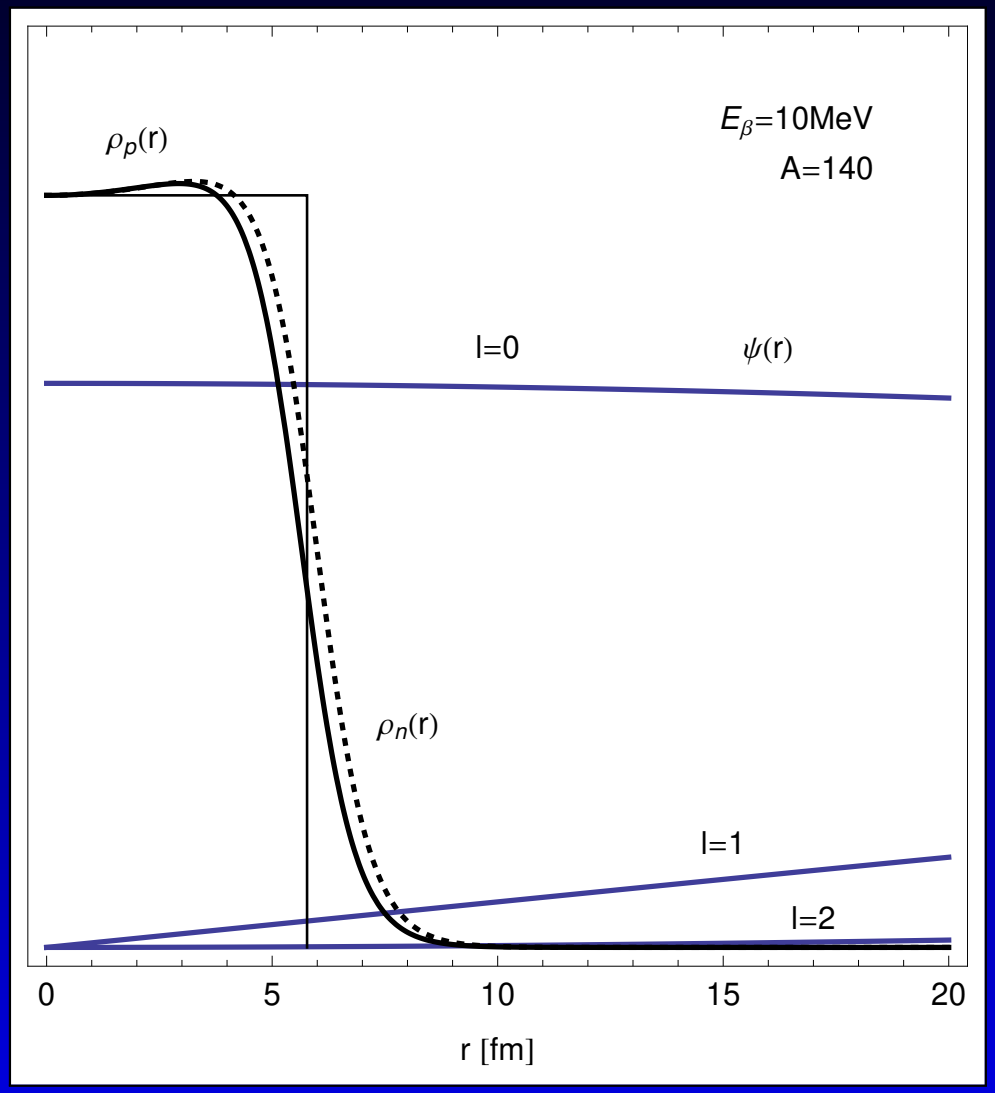
Conversion calculations

Cummulative beta spectra
Z_{eff} from databases

Problem: single set of cummulative beta spectra & forbidden corrections have to rely on databases

In both approaches, one has to deal with:
- Forbidden decays
- Weak magnetism corrections
- Non-equilibrium corrections
- Structural materials in the reactor

Forbidden decays



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

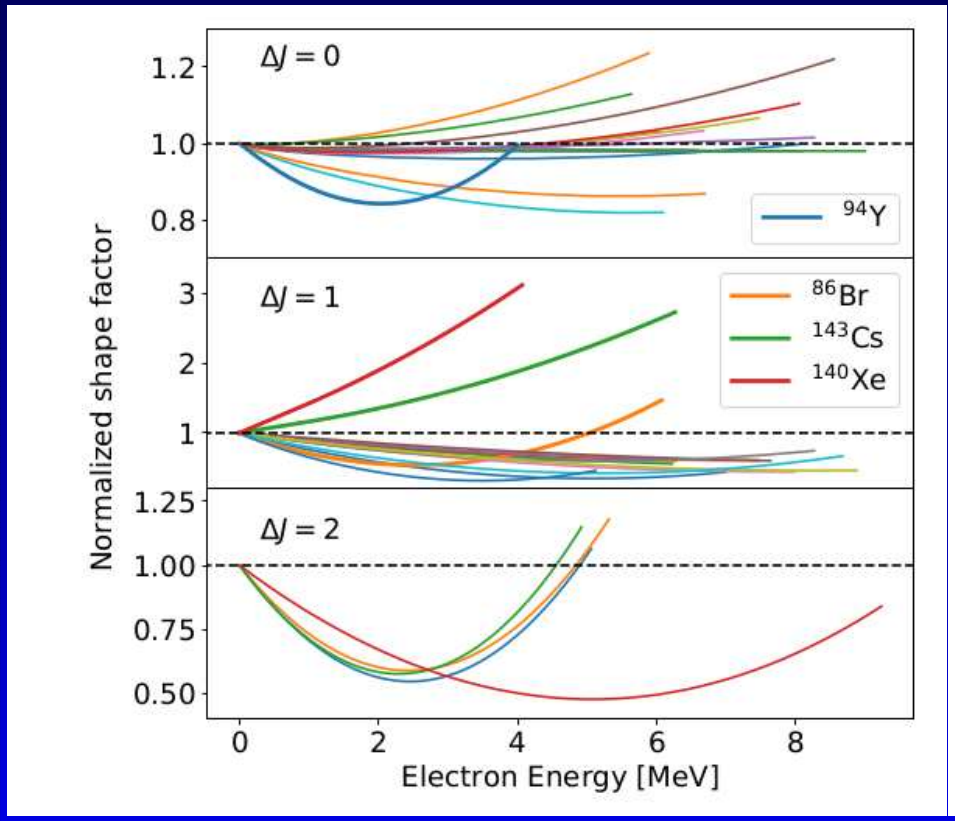
Allowed:
s-wave emission ($l = 0$)

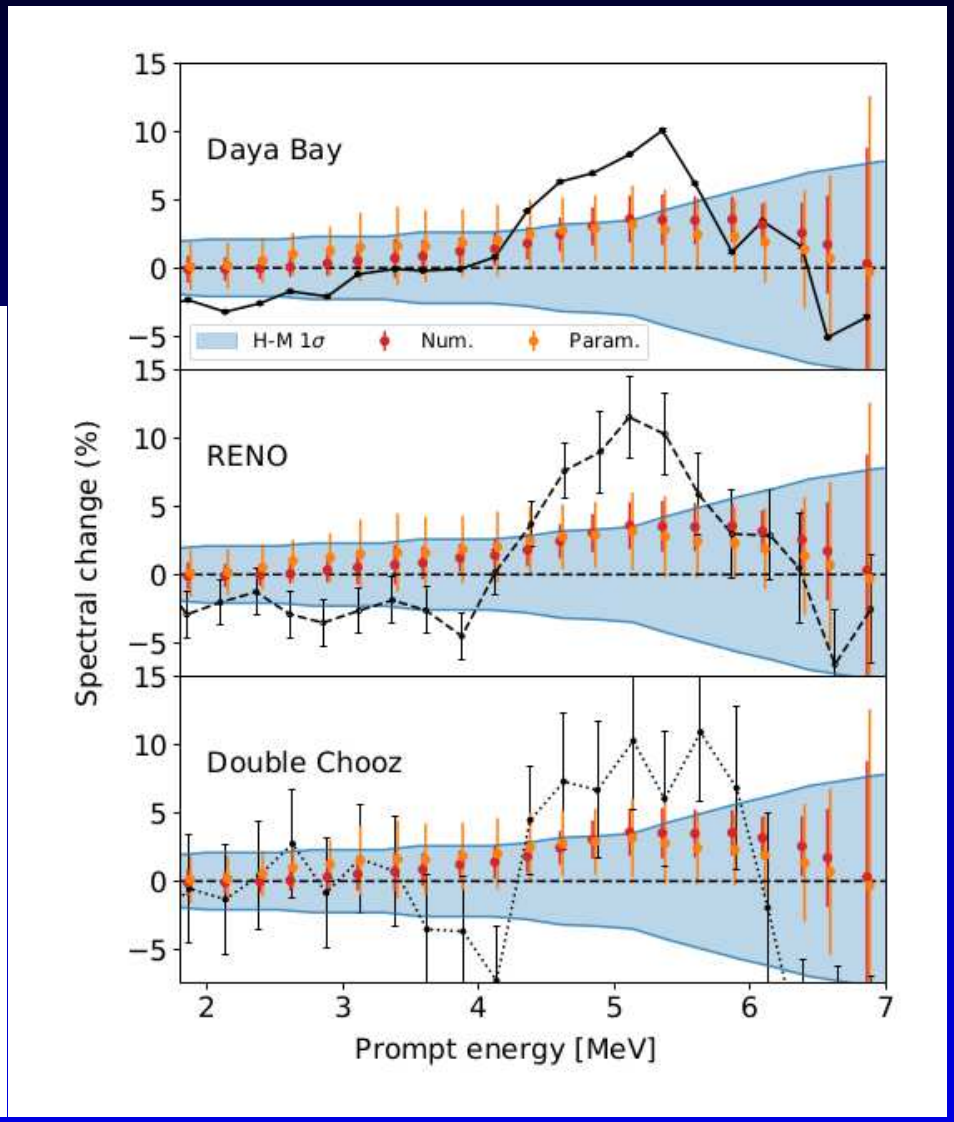
Forbidden:
p-wave emission ($l = 1$) or $l > 1$

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

Not so bad after all?

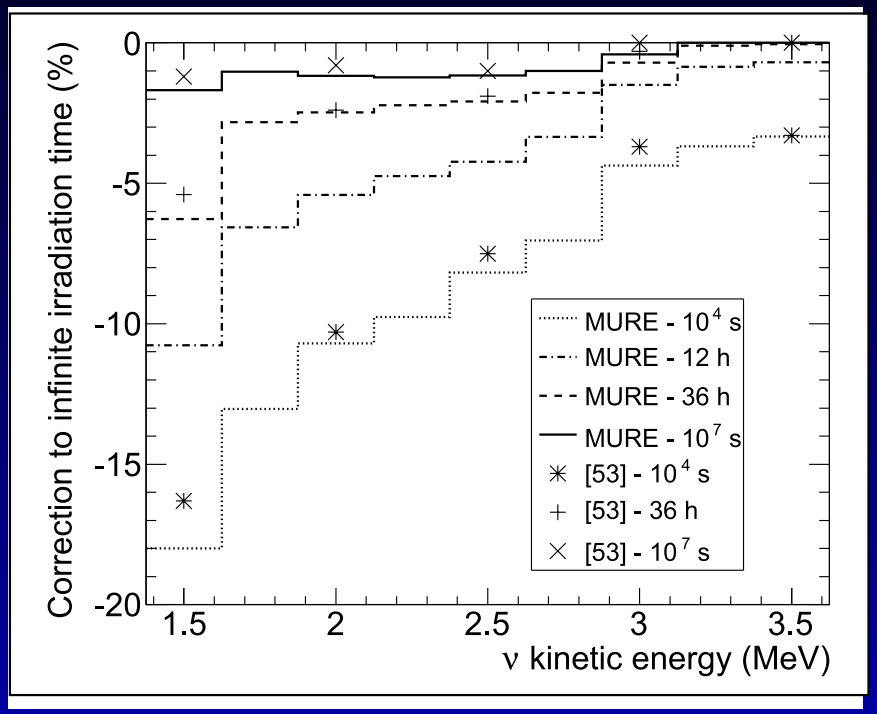
Shell model calculation of shape factors, with only a small increase in error budget.





Hayen, Kostensalo, Severijns, Suhonen 2019

Non-equilibrium



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

Only 2 dozen isotopes with $t_{1/2} > 12\,\mathrm{h}$ above inverse β-decay threshold

Still Daya Bay calculations yield different results than Mueller *et al.*

Extra shift due to long-lived isotopes

a) small nuclear physics uncertainty in β-decay
b) depends on detailed fuel history
c) much more important at low energy

Neutron capture

Breeding reactions dominate antineutrino flux around 1–1.5 MeV

$$^{238}\mathrm{U}+\mathrm{n} \rightarrow {}^{239}\mathrm{U} \xrightarrow{\beta} {}^{239}\mathrm{Np} \xrightarrow{\beta} {}^{239}\mathrm{Pu}$$

If present in core (research reactors)

$$^{27}\mathrm{Al}+\mathrm{n} \rightarrow {}^{28}\mathrm{Al} \xrightarrow{\beta} {}^{28}\mathrm{Si}$$

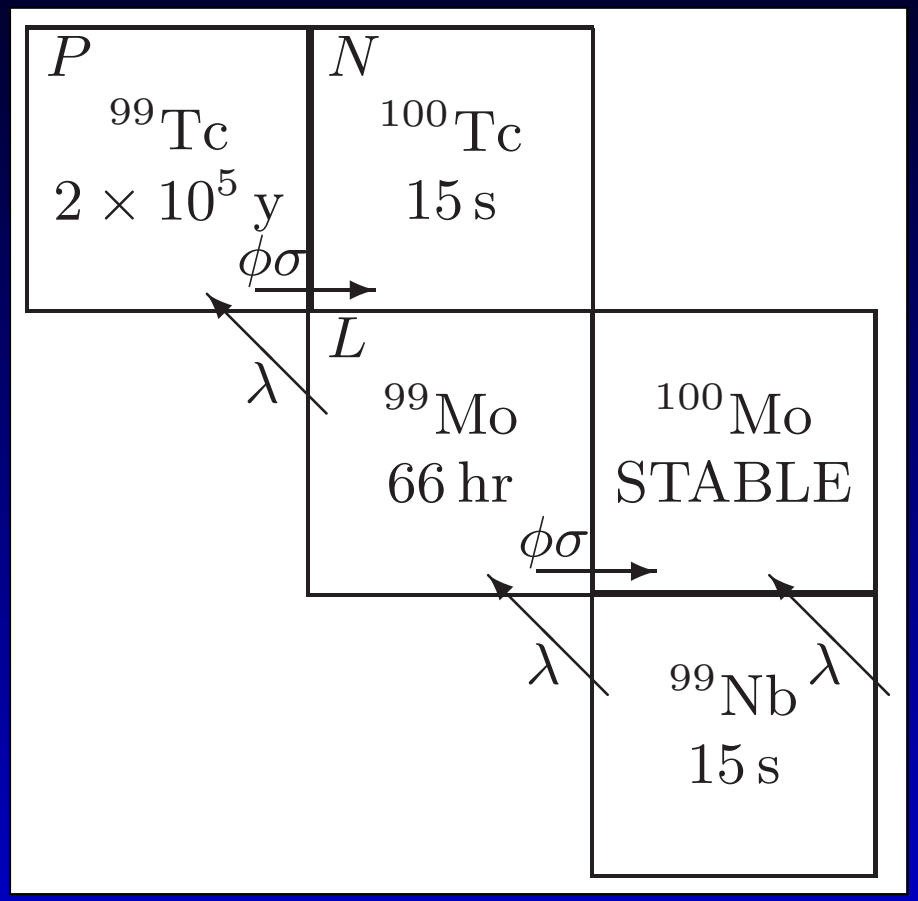
2.8 MeV antineutrino, comparable to regular flux

Conant, Mumm, Erickson, 2018

Generally, a lot of structural materials may play a role at low energies and there may even be some neutrino emitters.

Issue for CEvNS!

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

Order 1% below 3 MeV, what happens at lower energies?

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

What should we do?

Simple

+ Share relevant data in a usesable format:
  experiments and theorists
+ As much TAGS data as we can get (in a database!)
+ Continued work to clean up databases:
  beta decay and fission yields

Medium

+ Improve statistics of HEU neutrino data
+ Bumpology really requires collaborations to
  collaborate (see recent RENO/NEOS paper)
+ Common tools and methods to deal with
  reactor specific flux components
+ Reference neutrino spectra (unfolded)

What should we do?

Hard

+ Need a reliable way to compute forbidden decays
+ New cummulative beta spectra
+ Error budget for summation calculations
+ High quality Pu-enriched reactor data

The simple and medium steps, plus the Pu-enriched reactor data are necessary even in a purely data-driven approach.

IMO, this is the very minimum needed for applications to nuclear security.

Precision neutrino science may require more.

Comment

- The problem of reactor fluxes is with us since Cowan and Reines
- Major updates in the 1980's and 2011
- Flurry of activity on reactor neutrino: θ_{13}, sterile neutrinos, JUNO, safeguards, CEvNS…
- Everyone knows that the current model is wrong
- We all write papers and proposals claiming to improve reactor flux models…

I believe that some level of a coordinated and sustained effort is needed to make actual progress.