The potential to resolve spectral anomalies with different reactor experiments

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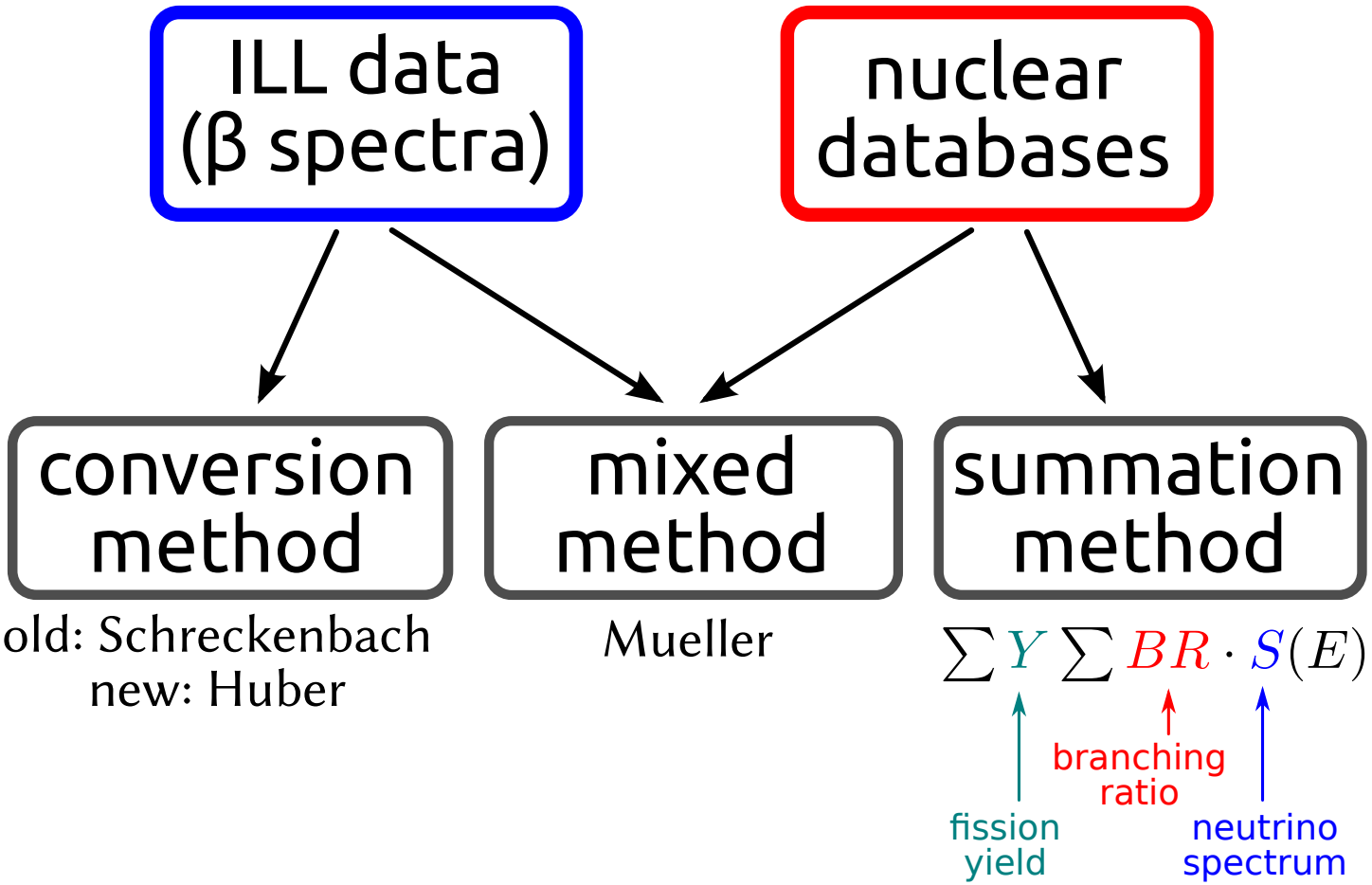
AAP 2015, 8th December

Contents

$\bar{\nu}_e$ Spectrum Predictions

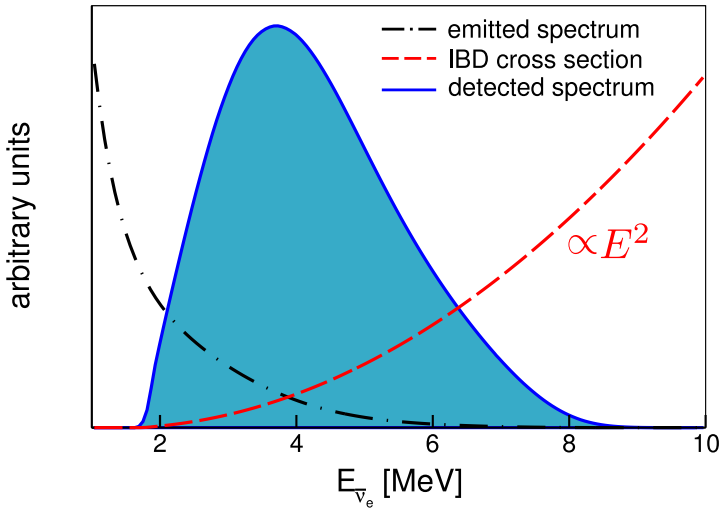


T. Mueller et al., Phys. Rev. C83, 054615 (2011)
P. Huber, Phys. Rev. C84, 024617 (2011)
A. A. Hahn, K. Schreckenbach et al.,
Phys. Let. B218,365 (1989) + refs. therein

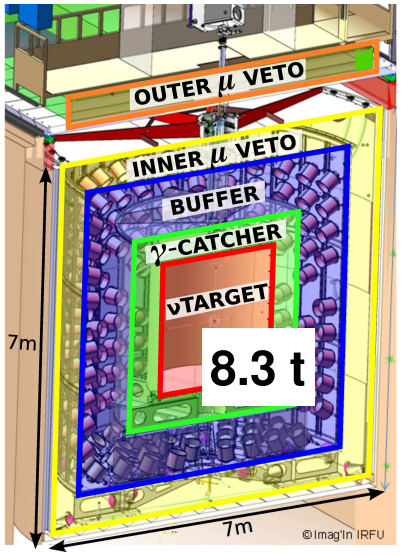
θ_{13} Reactor Experiments

current high precision reactor experiments:

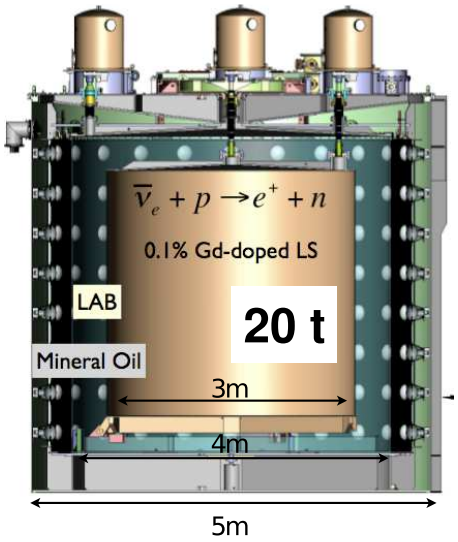
- inverse beta decay reaction
- organic liquid scintillator
- loaded with 1 g/L Gd
- measurement of θ_{13} using $\bar{\nu}_e$ rate and spectral shape



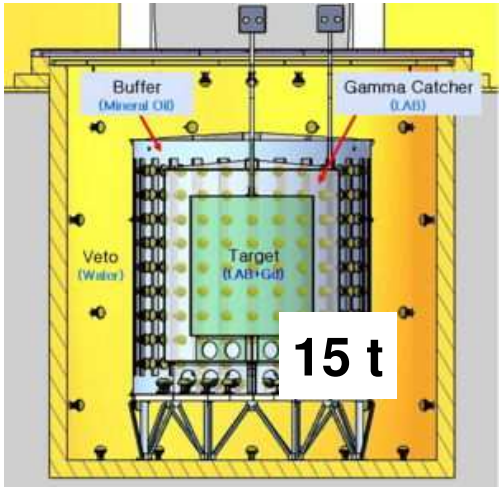
Double Chooz



Daya Bay



RENO



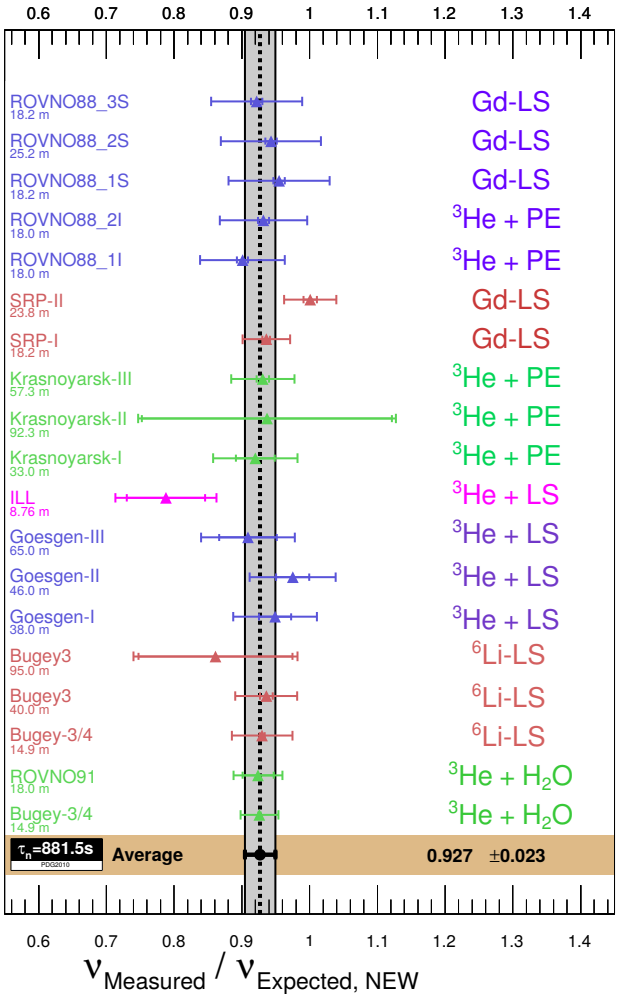
Reactor Anomalies

- Reactor Antineutrino Anomaly:
  6 % flux deficit between
  SBL reactor experiments
  and new predictions (2011)

  $\Longrightarrow$ sterile searches

- **spectral shape distortion** relative to conversion spectra at $E_\nu \sim 6\,\mathrm{MeV}$

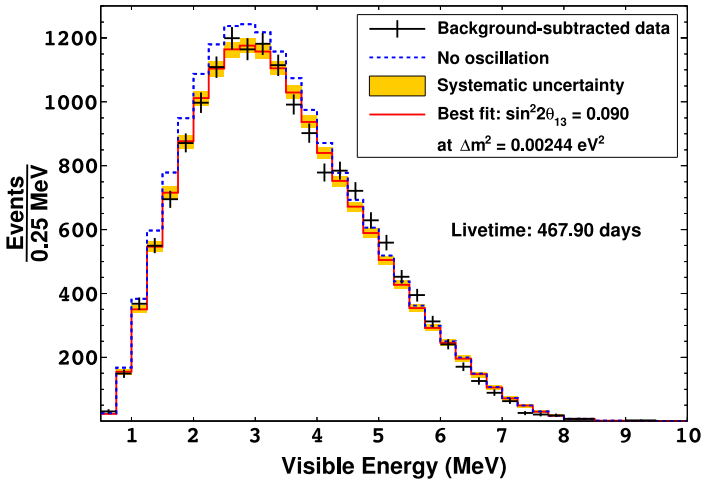
arXiv:1204.5379 [hep-ph] (2012)

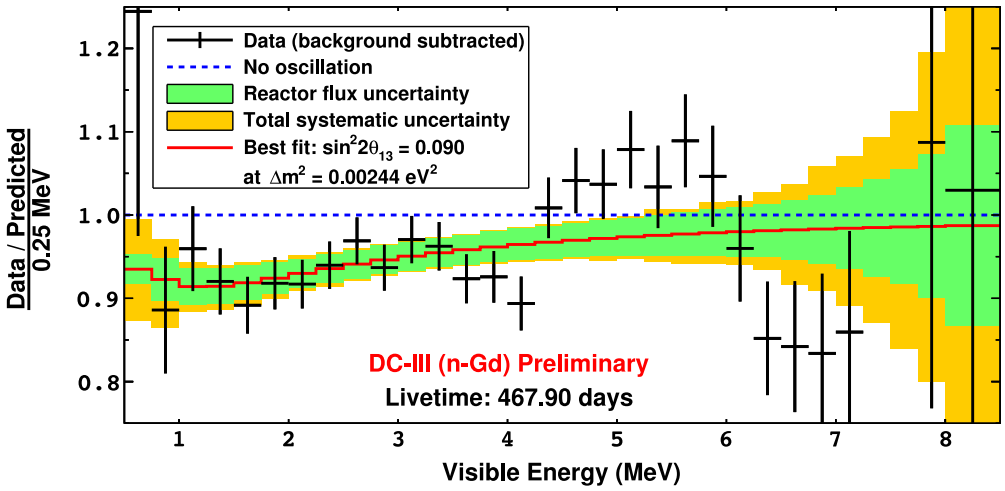


Reactor Spectrum Distortion "Anomaly 2"

Double Chooz far detector

JHEP10(2014)086



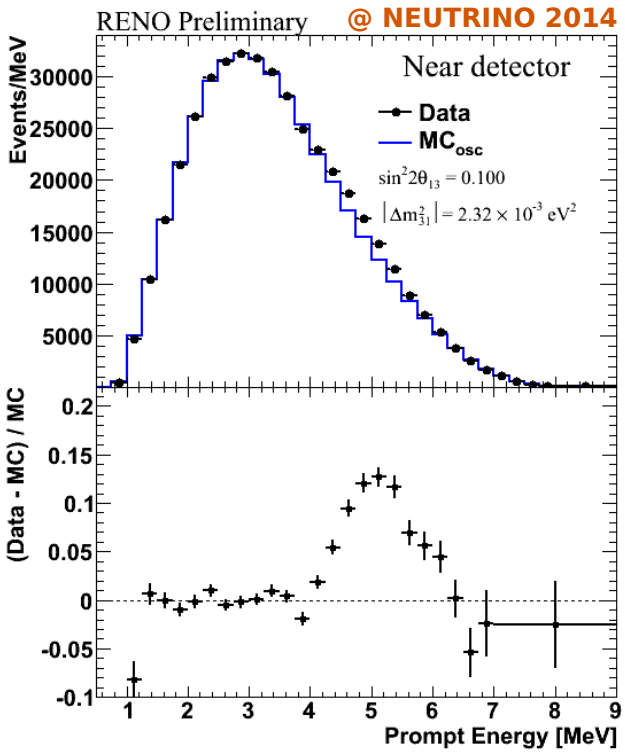


- spectral distortion above $E_{\text{vis}} = 4\,\text{MeV}$ observed by the DC experiment in 2014
- several crosschecks have shown
  - **correlation of excess with reactor power at $3\,\sigma$**
  - energy scale tested over full energy range
  - unknown background disfavoured
  - θ_{13} measurement is not affected

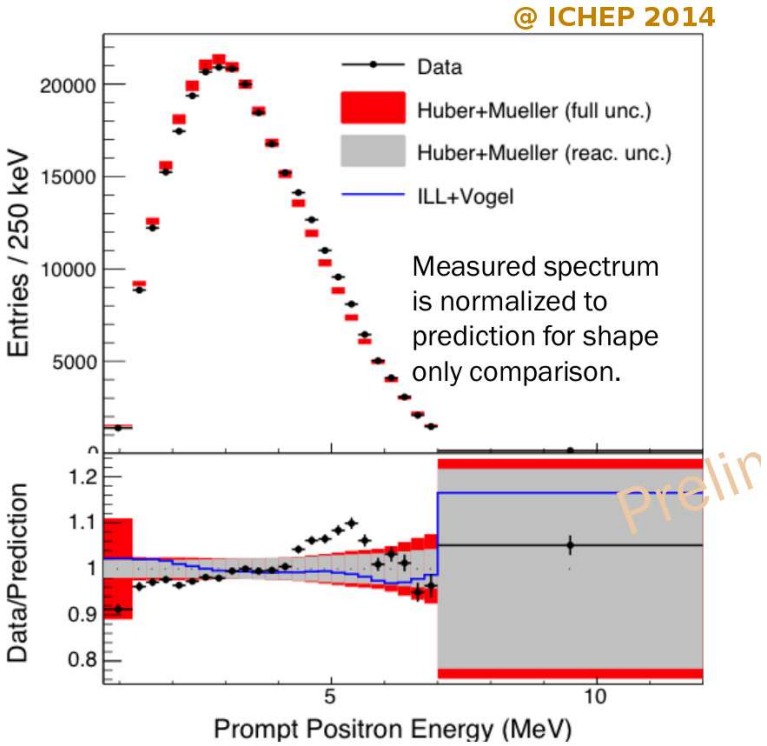
Spectral Distortion at km-Baseline Experiments

- observation of DC of the distortion was confirmed by other reactor-ν experiments

RENO



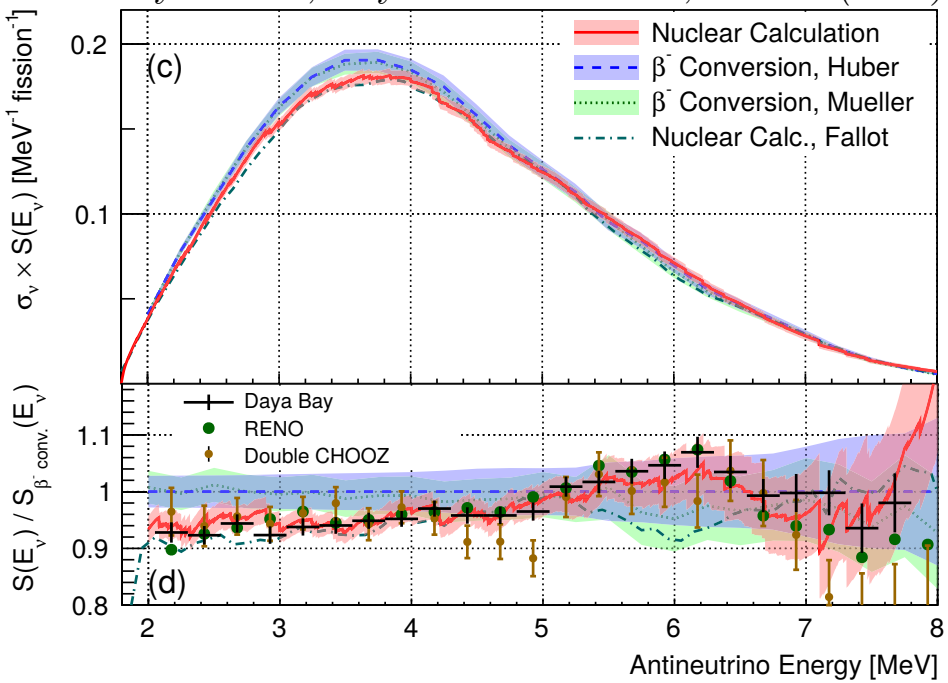
Daya Bay



Spectral Distortion in Predicted Spectrum (1)

- bump in the summation method spectra at 5-7 MeV
- at higher energies few decay branches constitute ~50 % of the total spectrum

D. Dwyer et al., Phys. Rev. Lett. 114, 012502 (2015)



Note: Dwyer's spectrum is incomplete and dominant contributions to systematic errors are missing

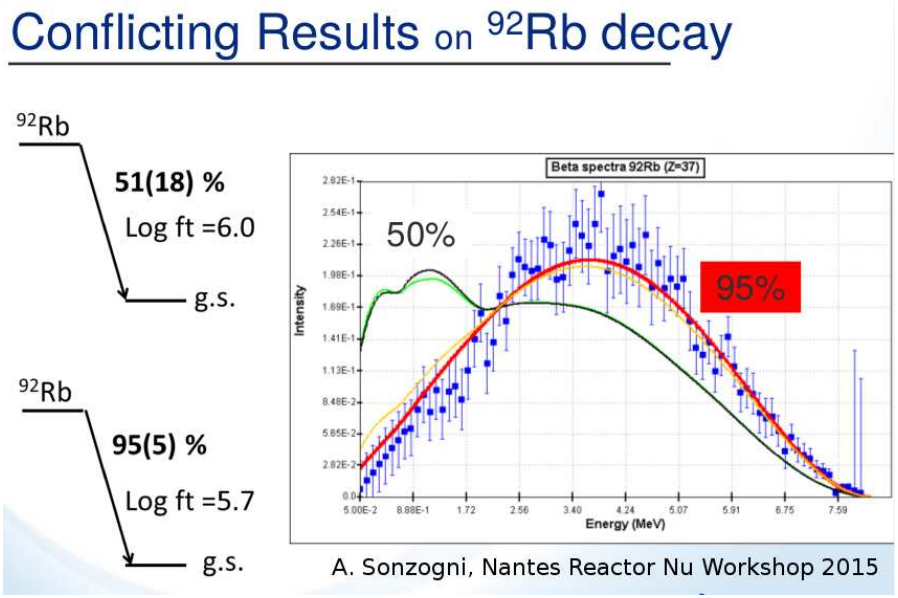
most prominent β-branches for $E > 4\,\mathrm{MeV}$

	4 - 5 MeV	5 - 6 MeV	6 - 7 MeV	7 - 8 MeV
^{92}Rb	4.74%	11.49%	24.27%	37.98%
^{96}Y	5.56%	10.75%	14.10%	-
^{142}Cs	3.35%	6.02%	7.93%	3.52%
^{100}Nb	5.52%	6.03%	-	-
^{93}Rb	2.34%	4.17%	6.78%	4.21%
^{98m}Y	2.43%	3.16%	4.57%	4.95%
^{135}Te	4.01%	3.58%	-	-
^{104m}Nb	0.72%	1.82%	4.15%	7.76%
^{90}Rb	1.90%	2.59%	1.40%	-
^{95}Sr	2.65%	2.96%	-	-
^{94}Rb	1.32%	2.06%	2.84%	3.96%

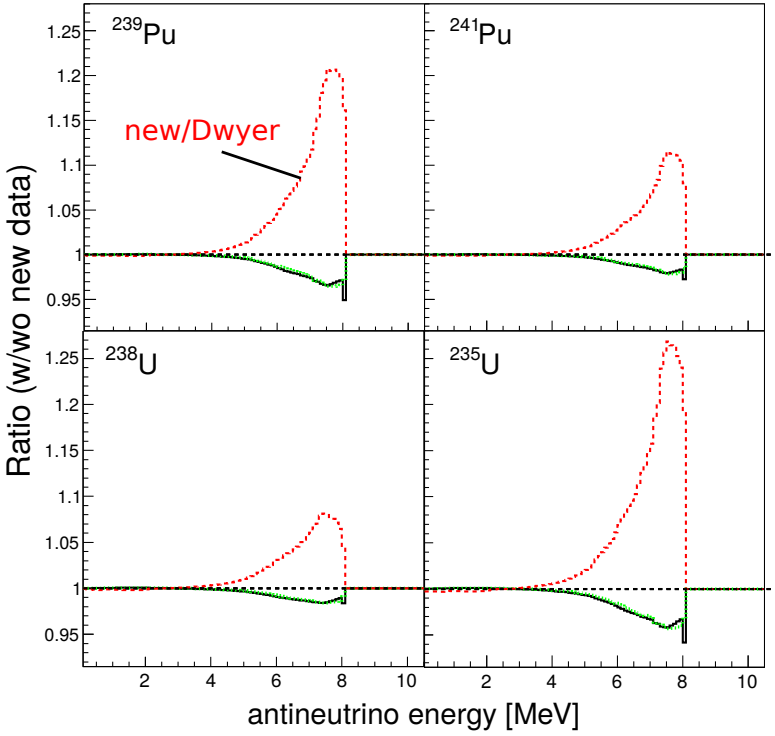
M. Fallot et al., PRL 109, 20254 (2012)

but: New Data Input on ^{92}Rb

- new data on ^{92}Rb lead to change in BR of GS → GS transition



A. Zakari-Issoufou et al., arXiv:1504.05812 [nucl-ex] (2015)



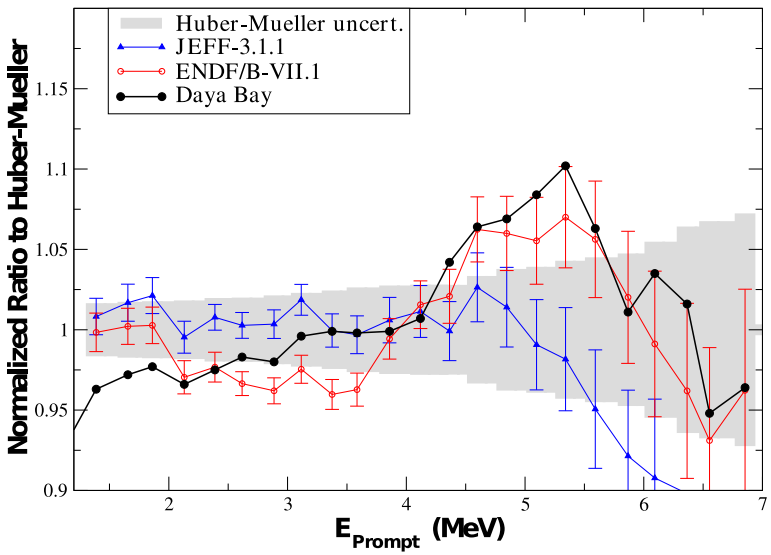
- Dwyer's conclusions change with new data
- results very sensitive to database info → further measurements needed

Spectral Distortion in Predicted Spectrum (2)

publication by Hayes et al. (2015)

- disfavoured as main origin of the distortion:
  - non-fission ν sources
  - correction terms of forbidden decays
- fission yield **databases** (ENDF & JEFF):
  - disagreement of $\sim 20\,\%$ for some nuclei
  - change the shape of prediction
- considerations:
  - correlation of the distortion and ^{238}**U**
  - influence of the neutron energy spectrum inside a reactor core

Phys.Rev.D92,033015 (2015)



Spectral Distortion in Predicted Spectrum (3)

- limitations of summation method:
  - missing information → large uncertainties
  - spectral shape depends on the choice of database
  - absolute normalization of β-spectra lower compared to ILL data

$\Longrightarrow$ experimental input needed

Reactor Experiments

Current Reactor Experiments

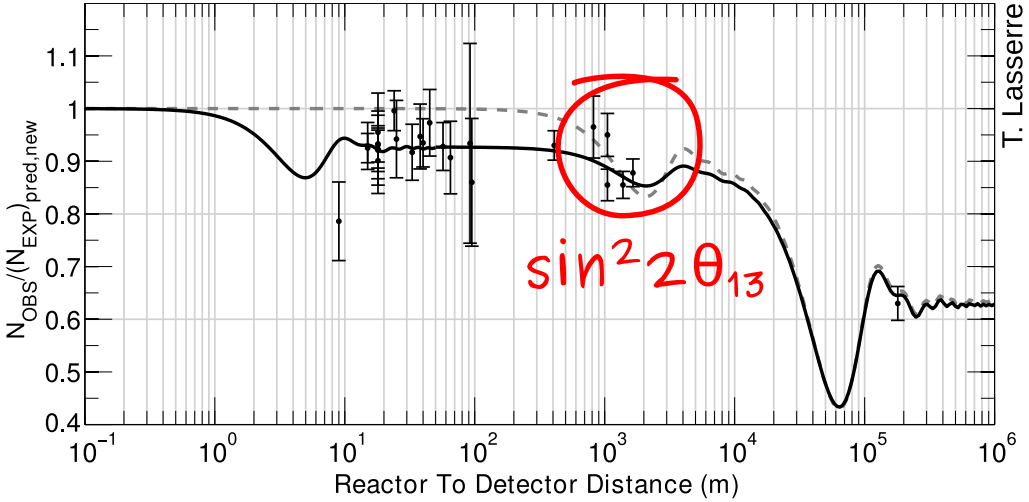
- measure the mixing angle θ_{13}
- high flux

  $\Downarrow$

  commercial reactor

  $\Downarrow$

  LEU fuel (^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu)



Reactor Experiments

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- measure the mixing angle θ_{13}
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  $\Downarrow$

  commercial reactor

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  LEU fuel (^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu)

Upcoming Reactor Experiments

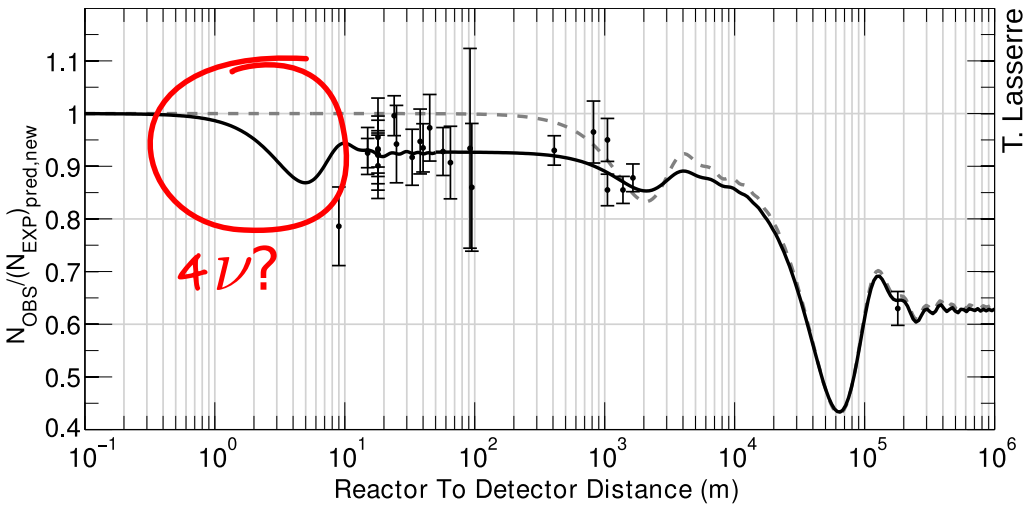
- search for eV sterile neutrinos
- compact source

  $\Downarrow$

  research reactor

  $\Downarrow$

  LEU or **HEU** fuel

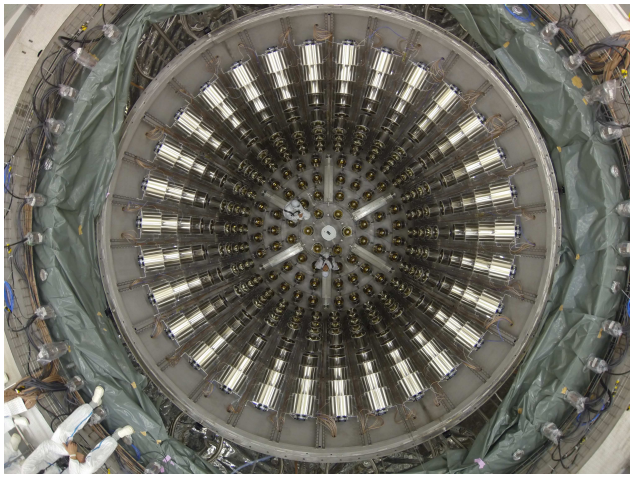


Double Chooz & Stereo

θ_{13} experiment

Double Chooz **near detector**:

- $10\,\mathrm{m}^3$ Gd-LS
- $400\,\mathrm{m}$ to $2 \times 4.3\,\mathrm{GW_{th}}$ cores
- $\sim 300\ \bar{\nu}_e$ per day
- data since end of 2014
- $\mathrm{S/B} \approx 20$
- $\sigma_E/E \sim 8\,\%$
- e-scale uncert.: sub-% level



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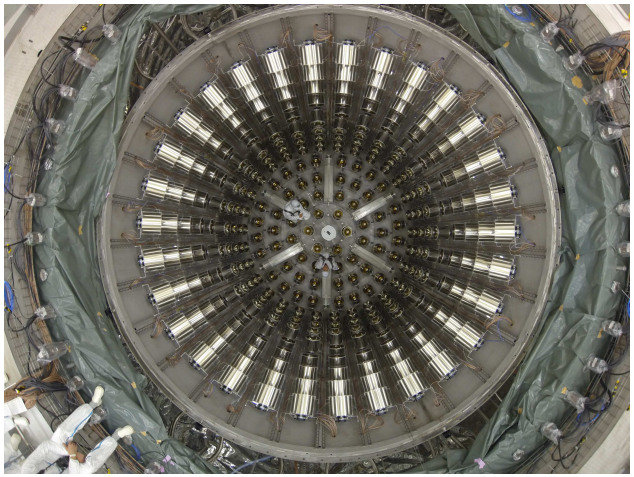
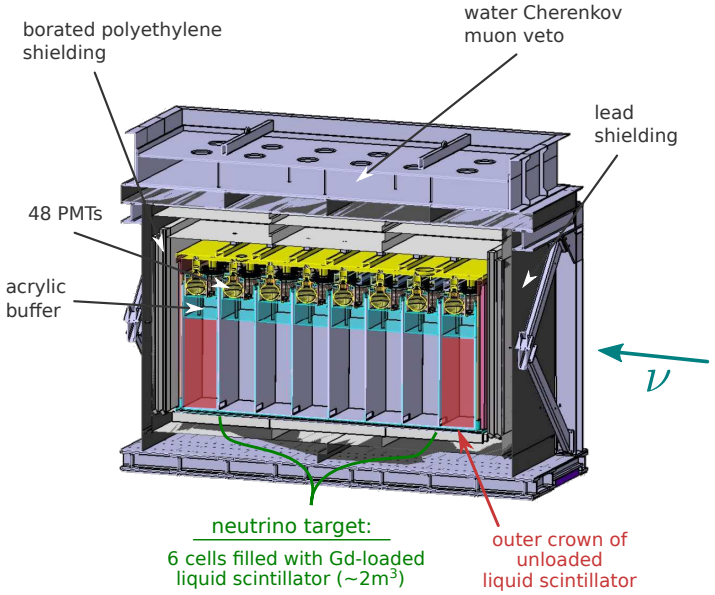


sterile ν experiment

Stereo detector:

- $2\,\mathrm{ton}$ Gd-LS
- $8\text{-}11\,\mathrm{m}$ to $50\,\mathrm{MW_{th}}$ core
- $\sim 400\ \bar{\nu}_e$ per day
- starts operation in 2016
- highly enriched in $^{235}\mathrm{U}$

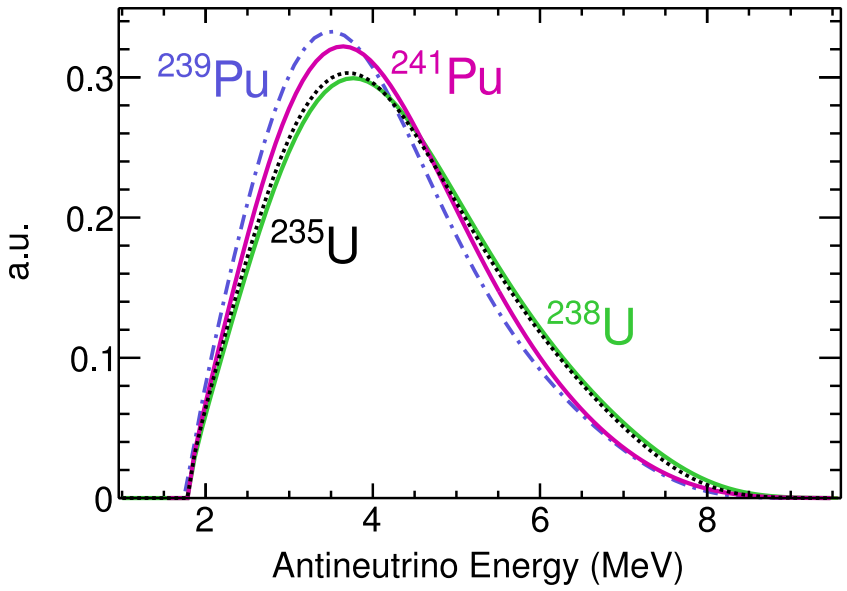


LEU vs. HEU Measurement - Assumptions

- statistics for 2 years runtime ($\sim 1.5 \cdot 10^5$ events)
- average Double Chooz **LEU** fission fraction

^{235}U	^{239}Pu	^{238}U	^{241}Pu
0.51	0.34	0.09	0.06

- Stereo: **pure ^{235}U** spectrum
- reference spectra from Huber and Haag
- gaussian excess added to the spectra

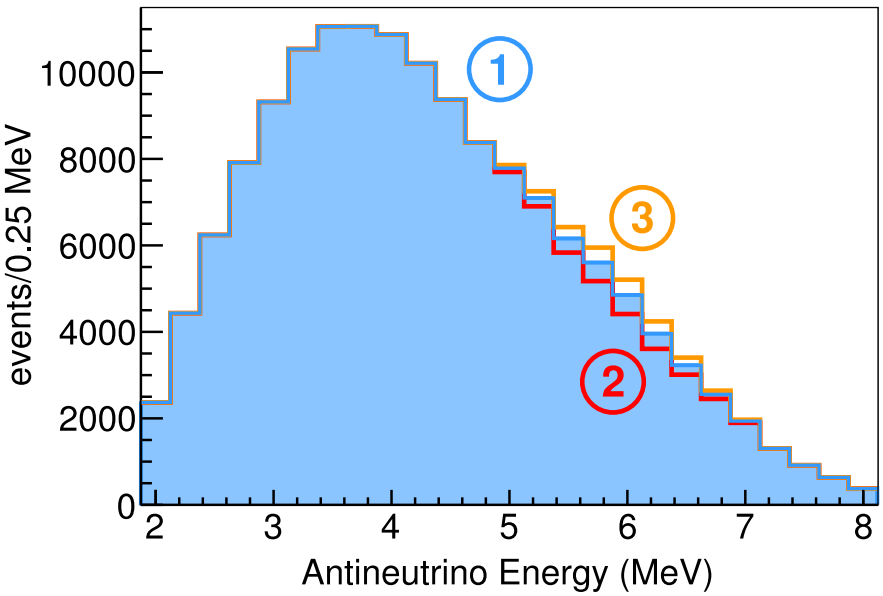


Three Hypotheses

- Double Chooz near detector:
  excess in rate and shape as for the far detector

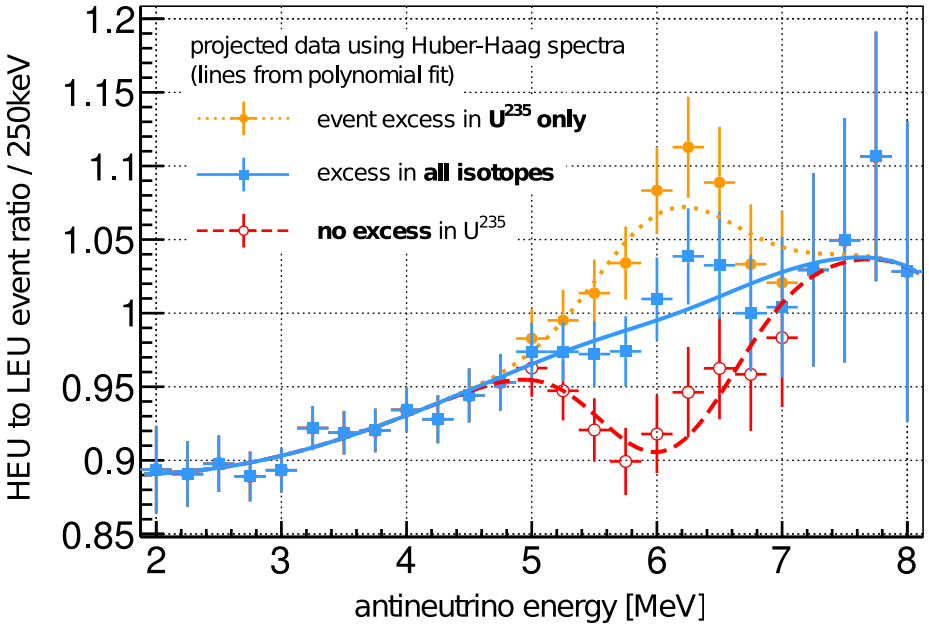
- Stereo:

1. excess as in Double Chooz
2. no excess observed
   (any other actinide but ^{235}U)
3. excess only caused by ^{235}U



HEU to LEU Ratio

⇒ ratio of HEU to LEU spectrum for different hypotheses

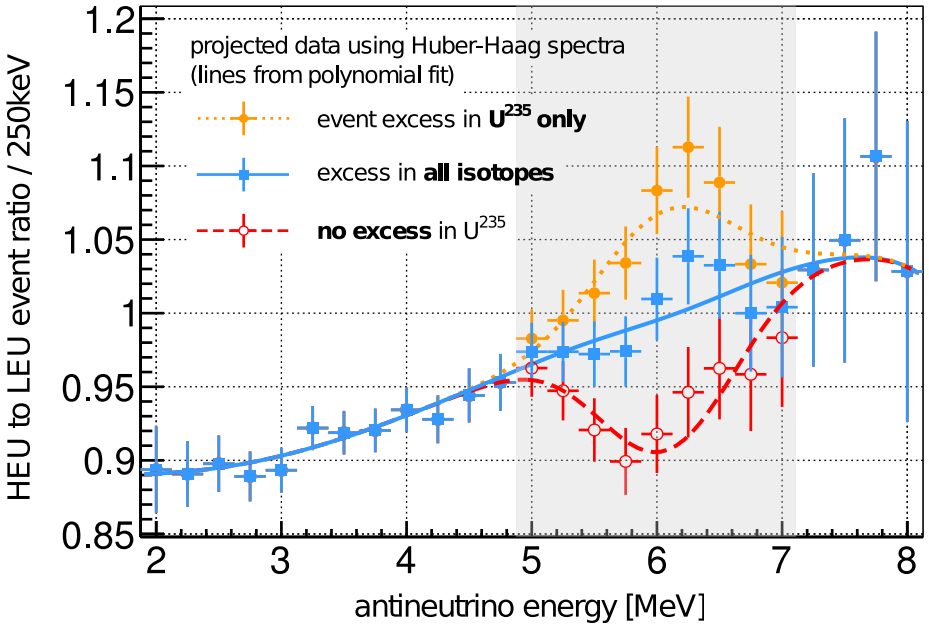


- 2 y runtime
- uncertainties: statistical + reference spectra

arXiv:1512:xxx
C. Buck, A.P. Collin, J. Haser, M. Lindner

HEU to LEU Ratio

⇒ ratio of HEU to LEU spectrum for different hypotheses



- 2 y runtime
- uncertainties: statistical + reference spectra
- significance of discrepancy $[5, 7]$ MeV:
  - only ^{235}U: $4.2\,\sigma$
  - no excess in HEU: $5.5\,\sigma$

arXiv:1512:xxx
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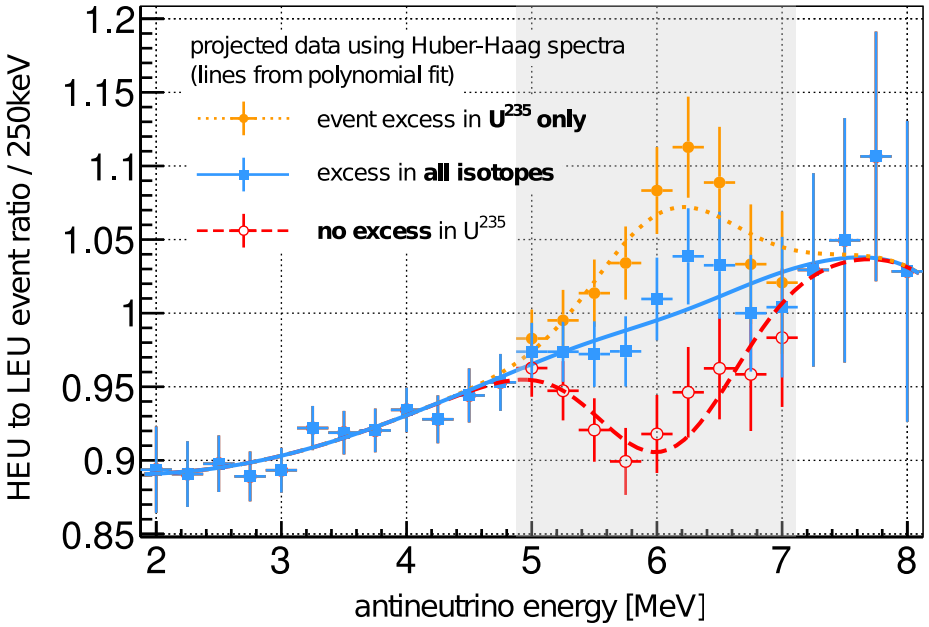
HEU to LEU Ratio

⇒ ratio of HEU to LEU spectrum for different hypotheses



- 2 y runtime
- uncertainties: statistical + reference spectra
- significance of discrepancy $[5, 7]$ MeV:
  - only ^{235}U: $4.2\,\sigma$
  - no excess in HEU: $5.5\,\sigma$
- significance including energy resolution:
  - only ^{235}U: $3.7\,\sigma$
  - no excess in HEU: $4.7\,\sigma$

arXiv:1512:xxx
C. Buck, A.P. Collin, J. Haser, M. Lindner

Conclusion

- spectral distortion relative to conversion spectra observed at $E_\nu = 6\,\mathrm{MeV}$ in currently measured reactor $\bar{\nu}$ spectra
- summation method prediction:
  - large uncertainties due to missing information
  - result depends on database
- origin of the spectral distortion still unknown

$\Longrightarrow$ more experimental input needed

- HEU to LEU data ratio could distinguish between specific hypotheses at $\sim 4\sigma$

Thank you for your attention!

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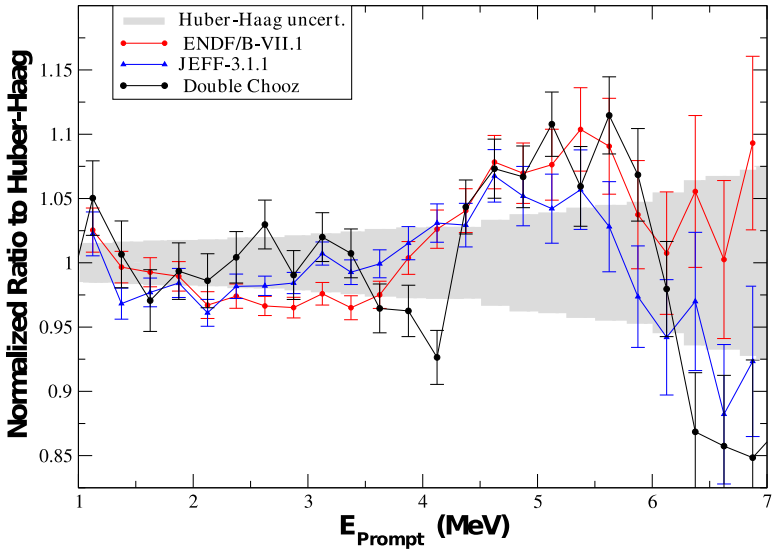
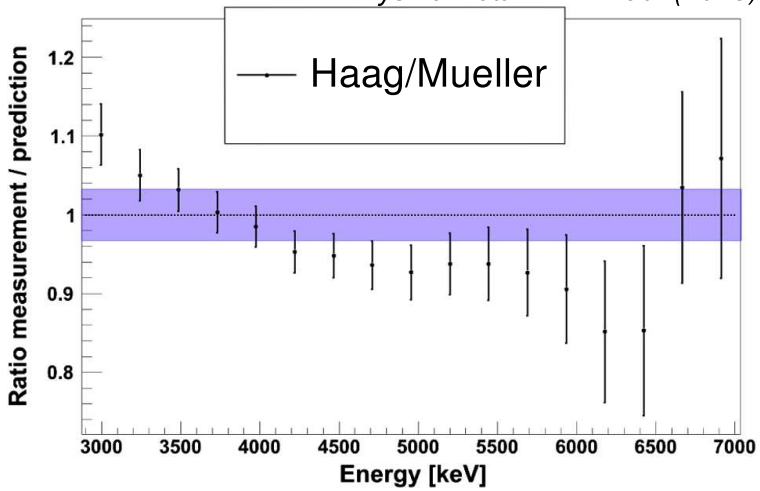
Appendix

Influence of new ^{238}U Spectrum

Phys.Rev.D92,033015 (2015)



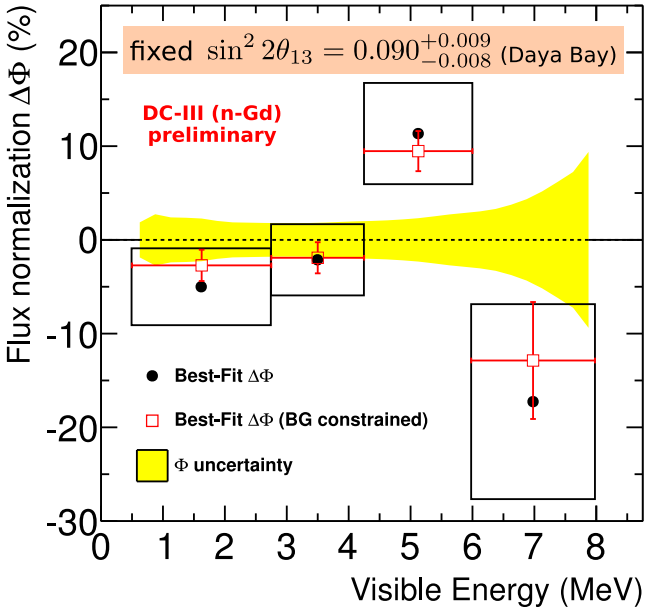
PhysRevLett.112.122501(2013)



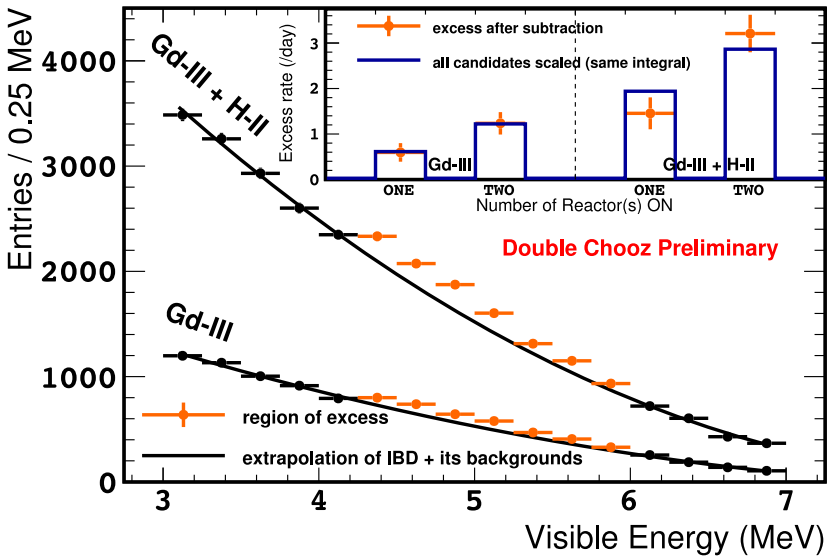
- ^{238}U β-spectrum measured by Haag (2013)
- Double Chooz uses Haag spectrum in their prediction
- distortion seen for ENDF and JEFF database
- can be explained by Haag-Mueller ratio: slope wrt E_ν

Spectrum distortion (1)

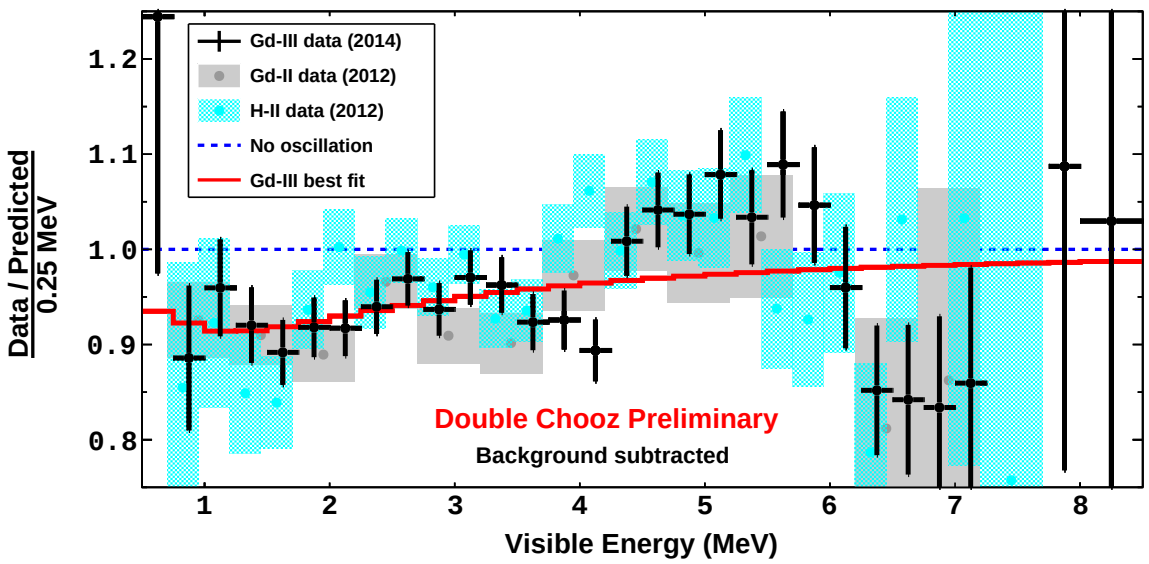
- RRM fit with free reactor normalization performed for different energy ranges
- excess at 4.25 – 6 MeV consistent with an unaccounted reactor flux
  - the significance wrt flux prediction is $3\,\sigma$ with BG constraint from our estimation



- data-driven study of this energy region:
  - correlation of excess with reactor power
  - not only limited to n-Gd sample



Spectrum distortion (2)



- same pattern observed in DC-II results with different detection channels (Gd, H) and detector volumes (Target and Gamma-Catcher)
- better resolved with DC-III (more statistics, better energy scale and less background)