The Reactor Antineutrino Anomaly

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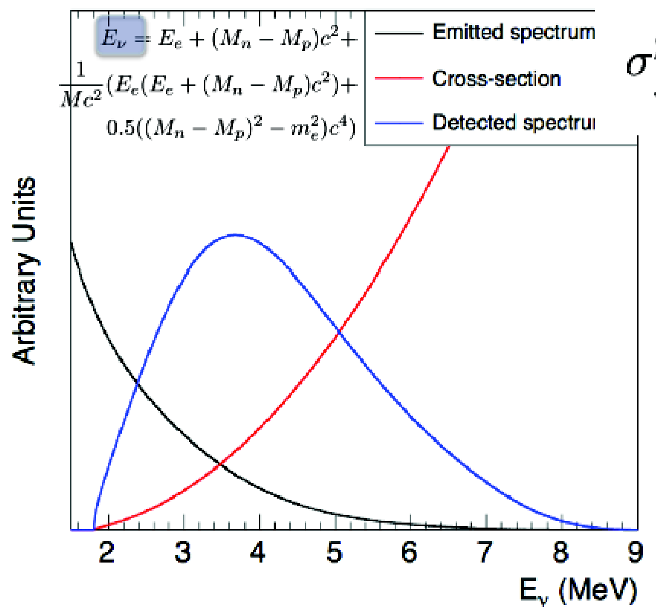
Introduction

- New spectra calculations presented by David Lhuillier in previous talk
- Increase of cross-section per fission
- Changes in other cross-section parameters (τ_n)
- → Check past measurements, and re-compute R=measured/expected
- Re-investigate shape constraints for the ILL experiment
- What does it mean for neutrino oscillations ?

- Outline:
  - The reactor anti-ν anomaly: rates in every experiment
  - The ILL shape measurement
  - Putting it all together
  - This talk contains updated material

Computing the expected rate/spectrum



$$\sigma_f^{pred} = \int_0^\infty S_{tot}(E_\nu)\sigma_{\mathrm{V-A}}(E_\nu)dE_\nu = \sum_k f_k \sigma_{f,k}^{pred}$$

- Use prescription from Fayans, Sov. J. Nucl. Phys. 42(4), 1985
  - Correct neutrino energy for proton recoil
  - Recoil, WM and radiative corrections
  - We used those of Vogel (1984), different from thos of Fayans but found to be numerically similar by Fayans himself

- Use Bugey-4's **calculations** to check ours
- Compare with reference publication of BUGEY-4 (Phys Lett B 338(1994)383) for isotopes measured by Schreckenbach et al.
- Using their inputs:
  - τ_n = 887.4 s
  - “old” spectra using 30 effective branch conversion
  - no off-equilibrium corrections

10^{-43}cm^2/fission	^{235}U	^{239}Pu	^{241}Pu
BUGEY-4	6.39±1.9%	4.18±2.4%	5.76±2.1%
This work	6.39±1.8%	4.19±2.3%	5.73±1.9%
Difference	$<10^{-3}$	0.2%	-0.5%

Final agreement to better than 0.1% on best known ^{235}U, using Bugey-4 inputs. Validates our calculation code.

The New Cross Section Per Fission

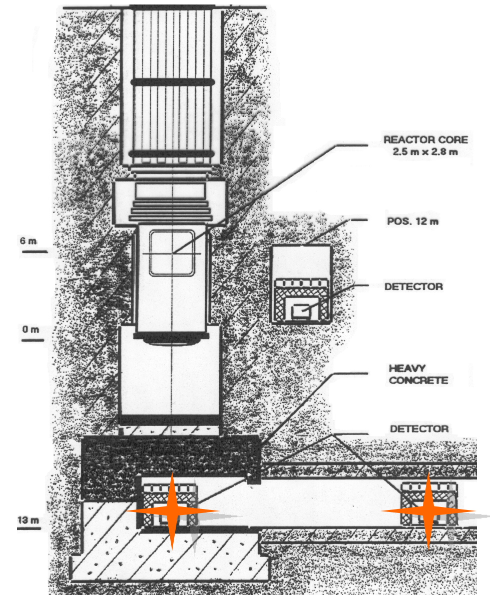
- ν-flux: ^{235}U : +2.5%, ^{239}Pu +3.1%, ^{241}Pu +3.7%, ^{238}U +9.8% (σ_f^{pred} ↗)
- Off-equilibrium corrections now included (σ_f^{pred} ↗)
- Neutron lifetime decrease by a few % (σ_f^{pred} ↗)
- Slight evolution of the phase space factor (σ_f^{pred} →)
- Slight evolution of the energy per fission per isotope (σ_f^{pred} →)
- Burnup dependence: $\sigma_f^{pred} = \sum_k f_k \sigma_{f,k}^{pred}$ (σ_f^{pred} →)

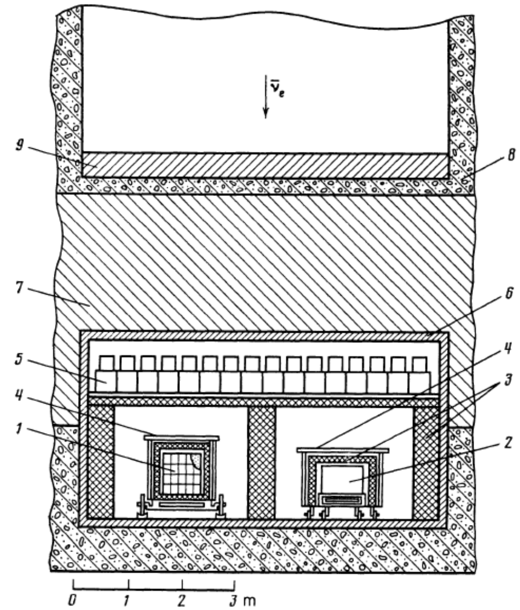
	old [3]	new
$\sigma_{f,^{235}U}^{pred}$	6.39±1.9%	6.61±2.11%
$\sigma_{f,^{239}Pu}^{pred}$	4.19±2.4%	4.34±2.45%
$\sigma_{f,^{238}U}^{pred}$	9.21±10%	10.10±8.15%
$\sigma_{f,^{241}Pu}^{pred}$	5.73±2.1%	5.97±2.15%

Short baseline experiments near nuclear reactors

The 5 ROVNO88 measurements (Sov Phys JETP67, 1988)

- Rovno VVER nuclear plant, 1983-1986
- Integral detector with PE target containing ^{3}He counters, only neutrons are detected
- Liquid Scintillator detector
- Measurements at 18m and 25 m
- Typical fuel composition: 60.7% ^{235}U, 27.7% ^{239}Pu, 7.4% ^{238}U, 4.2% ^{241}Pu, depends on position
- Neutron lifetime used in original paper: 898.8 s
- Published ratios:
  0.969, 1.001, 1.026, 1.013, 0.990
- Revised ratio with new spectra:
  0.917, 0.948, 0.972, 0.959, 0.938
- Uncertainties:
  - Stat: <0.9%
  - Syst : 7-8%
- Correlated with: Bugey-4, Rovno91 (integral measurement only), and with each other

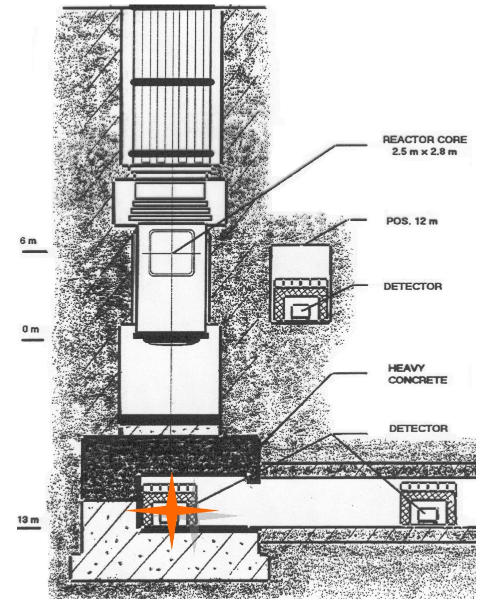


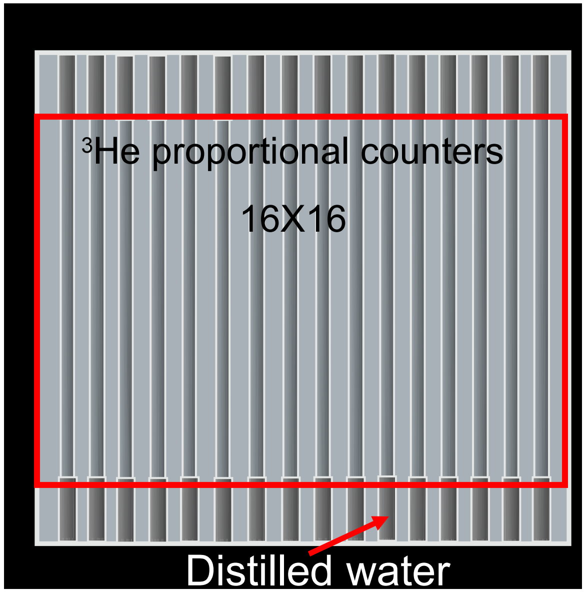


The ROVNO experiment (JETP Lett., 54, 1991, 253)

energie atomique • energies alternatives

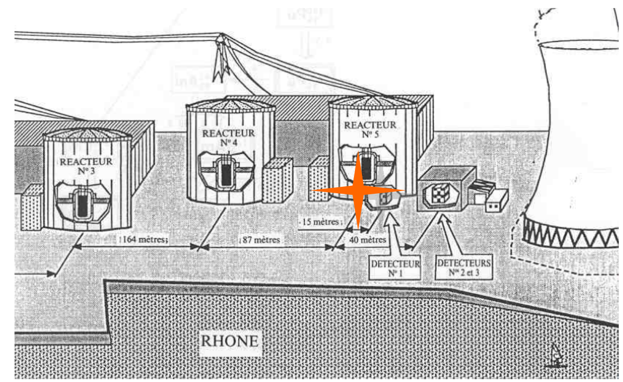
- Rovno VVER nuclear plant, late 80s
- **Upgraded** integral detector : **water target** containing ^{3}He counters, only neutrons are detected
- Fuel composition: 61.4% ^{235}U, 27.4% ^{239}Pu, 7.4% ^{238}U, 3.8% ^{241}Pu
- Neutron lifetime used in original paper: 888.6 s
- Published ratio:
  0.985±0.038
- Revised ratio with new spectra:
  0.940±0.037
- Uncertainties:
  - Stat: <1%
  - Syst : 3.8%
- Correlated with: Bugey-4 (same detector)

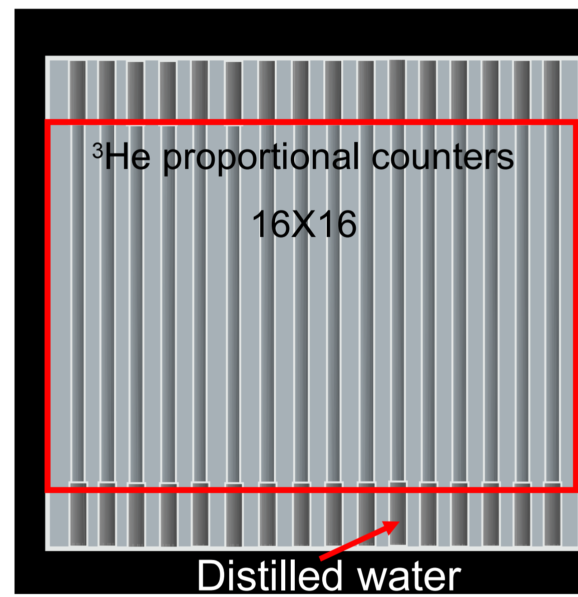




Bugey-4: most precise measurement

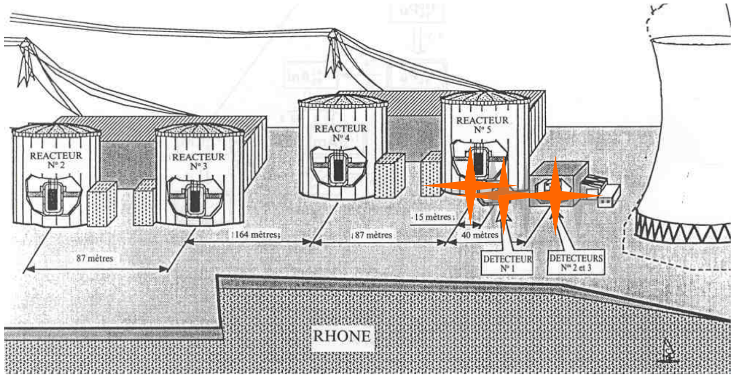
- Bugey PWR EdF plant, early 1990s
- Integral detector : water target containing ^{3}He counters, only neutrons are detected
- Fuel composition: 53.8% ^{235}U, 32.8% ^{239}Pu, 7.8% ^{238}U, 5.6% ^{241}Pu
- Neutron lifetime used in original paper: 887.4s
- **Published ratio of $\sigma_f^{measured}$ to σ_f^{pred}: 0.987±0.030**
- **Revised ratio with new spectra & updates 0.943±0.029**
- Uncertainties:
  - Stat: negligible
  - Syst : 3% (Most Sensitive Exp.)
- Correlated with: ROVNO (same detector)
- **Visible tension between this precise measurement and $\sigma_f^{pred,new}$**
- **May impact the Chooz limit**

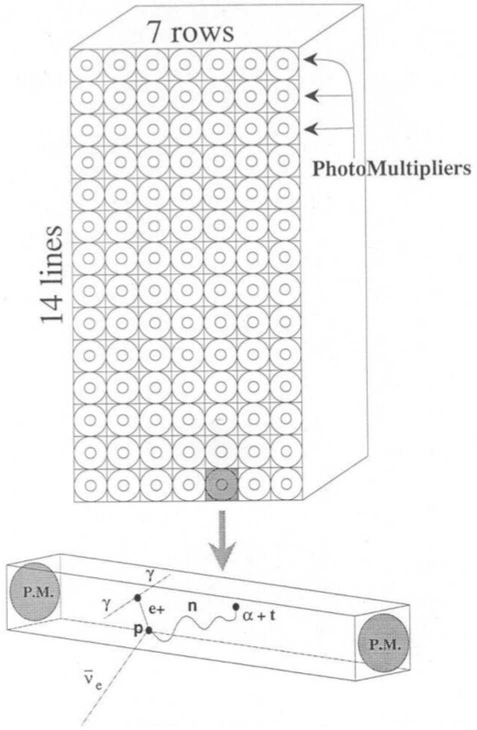




The Bugey-3 experiment (Nucl Phys B434, 504, 1995)

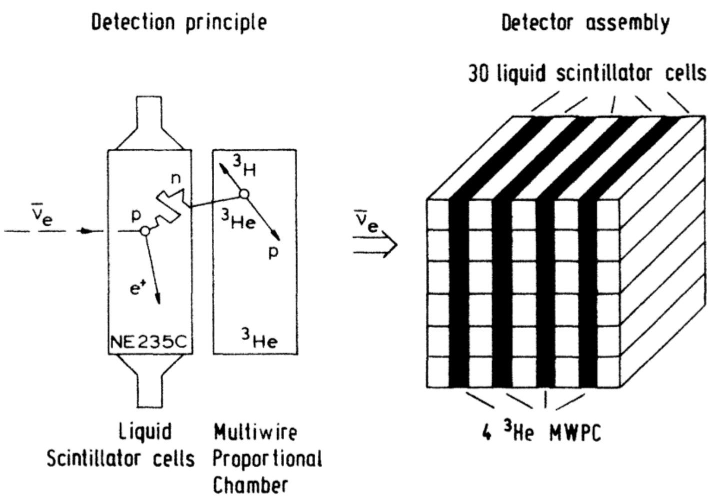
- Bugey PWR reactor, EdF
- 3 identical liquid scintillator segmented detectors doped with ^{6}Li for n capture
- Fuel composition typical of PWR – 53.8% ^{235}U, 32.8% ^{239}Pu, 7.8% ^{238}U, 5.6% ^{241}Pu
- Neutron lifetime in original paper: 889 s
- Published ratios at 14m, 42m and 95m: 0.988±0.050, 0.994±0.051, 0.915±0.13
- Revised ratios with new spectra: 0.940±0.047, 0.943±0.048, 0.873±0.12
- Uncertainties:
  - Stat: 0.4%, 1.0%, 13.2%
  - Syst : 5.0%
- Correlated with: none, but the three measurements are correlated together





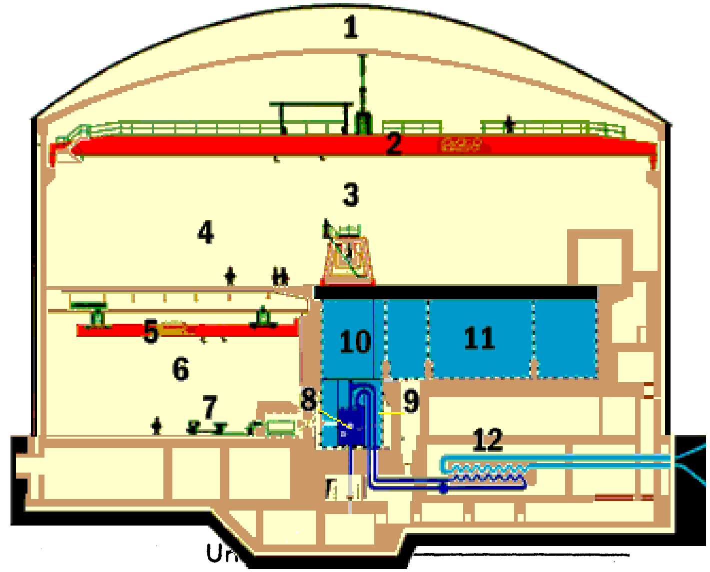
The Gösgen experiment (Phys Rev D34, 2621, 1986)

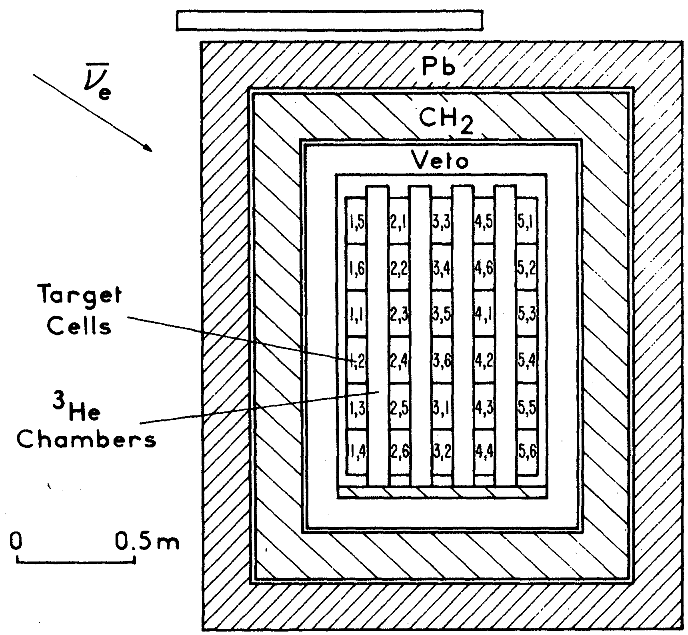
- Gösgen PWR, Switzerland, 1981-1984
- liquid scintillator segmented detector
  + ^{3}He counters for neutron capture
- Detector placed at 37.9m, 45.9m, 64.7m
- 3 fuel compositions published. Typical:
  61.9% ^{235}U, 27.2% ^{239}Pu, 6.7% ^{238}U, 4.2% ^{241}Pu
- Neutron lifetime used in original paper: 897 s
- Published ratios:
  1.018±0.066, 1.045±0.068, 0.975±0.074
- Revised ratios with new spectra:
  0.966±0.062,0.991±0.064, 0.924±0.070
- Uncertainties:
  - Stat: 2.4%, 2.4%, 4.7%
  - Syst : 6.0%
- Correlated with ILL + 3 measurements are correlated together



The ILL experiment (Phys Rev D24, 1981, 1097)

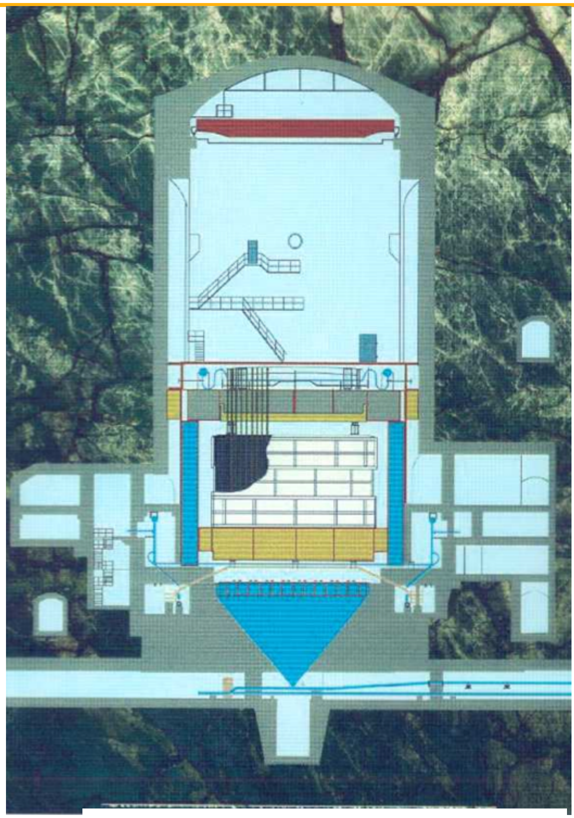
- ILL RR in Grenoble, 1979-1980
- Liquid scintillator segmented detector + ^{3}He counters for neutron capture
- Detector placed at 8.76(15) m
- Fuel composition: almost pure ^{235}U
- Data reanalyzed in 1995 by sub-group of collaboration to correct 10% error in reactor power
- Neutron lifetime: 889 s in 95
- Published ratio:
  0.832±0.079 (1995)
- Revised ratio with new spectra:
  0.801±0.076
- Uncertainties:
  - Stat: 3.5%
  - Syst : 8.9%
- Correlated with Gosgen

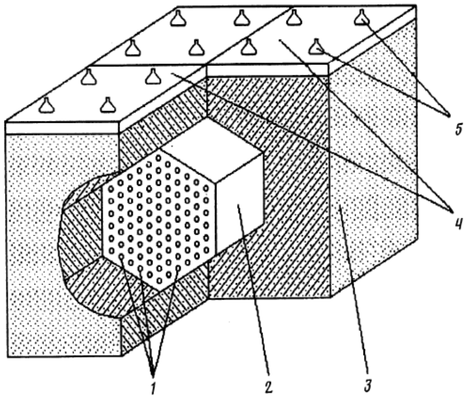




The Krasnoyarsk measurements

- Krasnoyarsk reactor in Russia
- Integral detector filled with PE+ ^{3}He counters for neutron capture
- Detector placed at 33m, 92m from 2 reactors (1987) and 57.3m from 2 reactors (1994)
- Fuel composition: mainly ^{235}U
- Neutron lifetime in original paper: 899 s
- Published ratios: 1.013±0.066, 1.031±0.068, 0.989±0.074
- Revised ratios with new spectra: 0.944±0.062,0.954±0.064, 0.954±0.070
- Uncertainties:
  - Stat: 3.6%, 1% at 57m, 19.9% at 92.3m
  - Syst : 4.8% to 5.5% (corr)
- Correlated together (same detector, WINS)



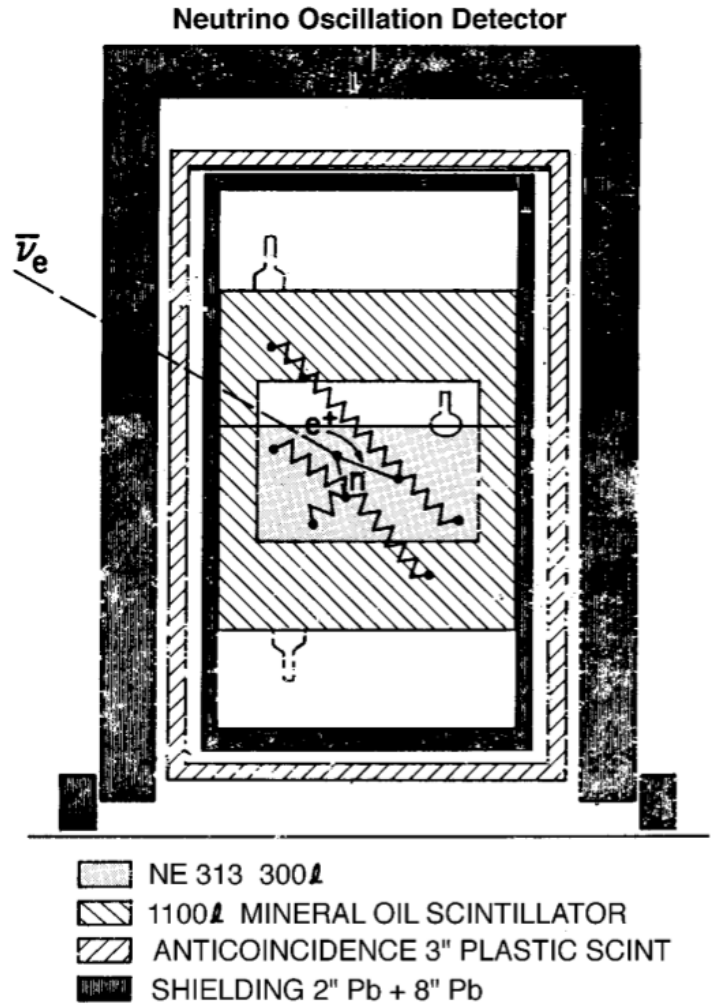


NEW

The (last) Savannah River experiments

- Savannah River, USA, late 80s - early 90s
- liquid scintillator doped with 0.5% Gd
- Detector placed at 18.2m and 23.8 m
- Fuel composition: difference with pure ^{235}U below 1.5%
- Neutron lifetime used in original paper: 887 s
- Published ratios: 0.987±0.037,1.055±0.040
- Revised ratios with new spectra: 0.953±0.036,1.019±0.039
- Uncertainties:
  - Stat: 0.6% and 1.0%
  - Syst : 3.7%
- Correlated together

(PRD53, 6054, 1996)



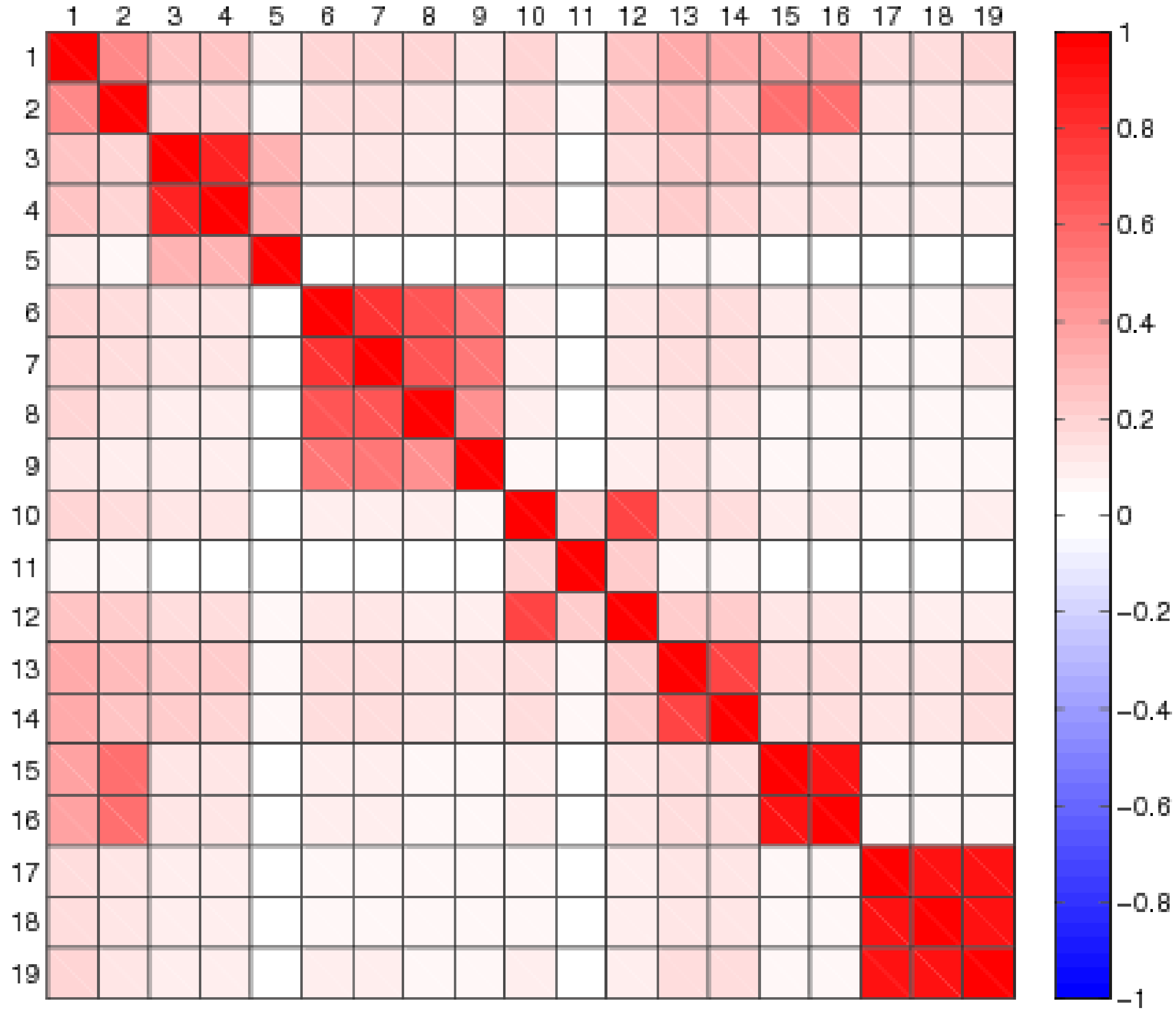
Correlations

- Correlations are difficult to take into account and will impact the result
- Our guiding principles:
  - Be conservative
  - Be stable numerically: if small changes in correlations cause large changes in result, something is off...
- We correlated experiments in the following way:
  - 2% systematic on flux 100% correlated over all measurements

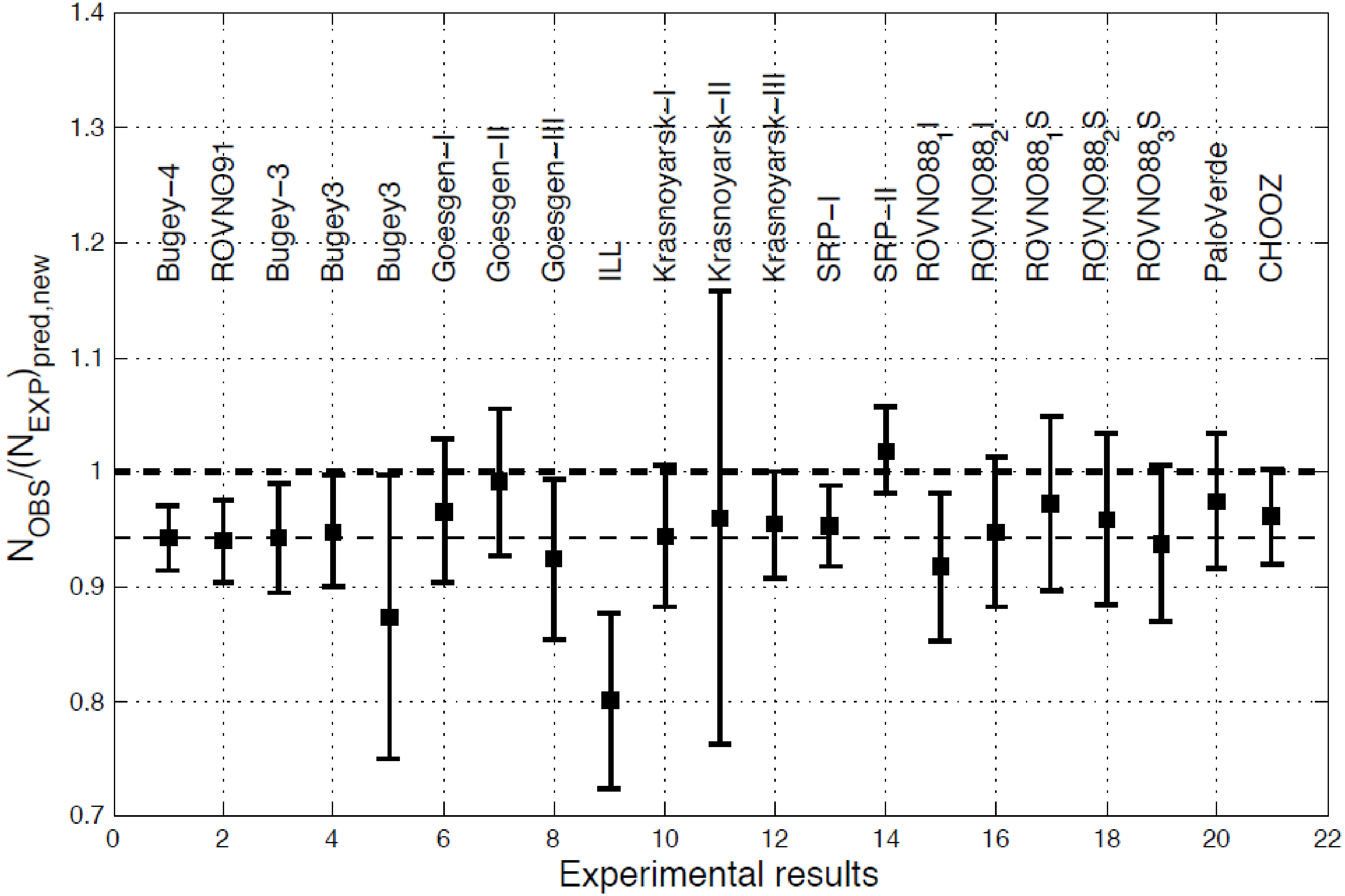
    Different from 2.7% published on arxiv:
    2% is the part corresponding to the normalization error on the ILL e- data
- Non-flux systematic error correlations across measurements:
  - Same experiment with same technology: 100% correlated
  - ILL shares 6% correlated error with Gösgen although detector slightly different. Rest of ILL error is uncorrelated.
  - Rovno88 integral measurements 100% corr. with Rovno 91 despite detector upgrade, but not with Rovno88 LS data
  - Rovno88 integral meas. 50% correlated with Bugey-4

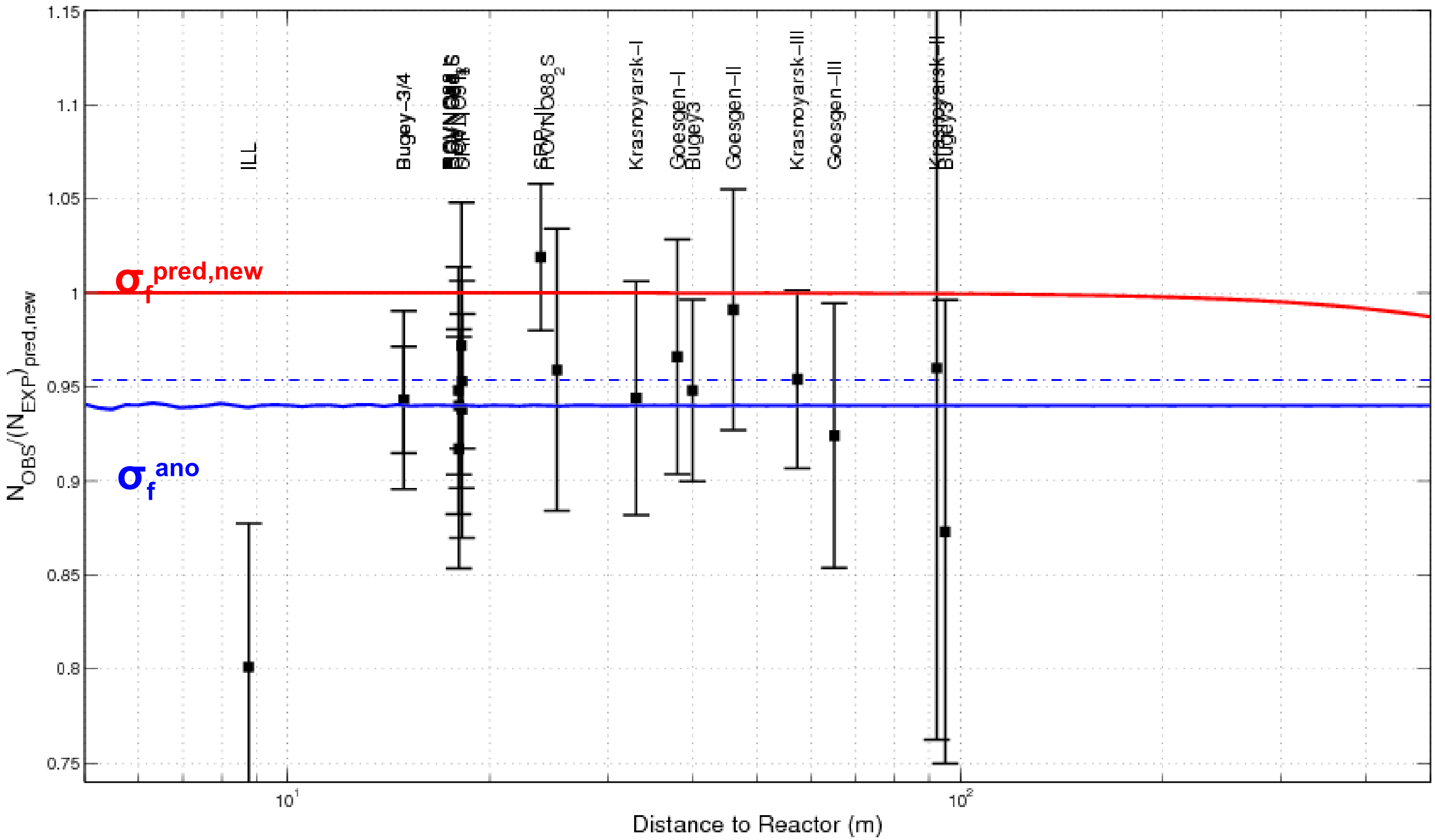
Experimental correlation matrix

- Bugey-4 15m
- Rovno91 18m
- Bugey-3 15m
- Bugey-3 40m
- Bugey-3 92m
- Goesgen 38m
- Goesgen 45m
- Goesgen 65m
- ILL 9m
- Krasno 33m
- Krasno 92m
- Krasno 57m
- SRP I 18m
- SRP II 25m
- Rovno88 1I 18m
- Rovno88 2I 18 m
- Rovno88 1S 18m
- Rovno88 2S 25m
- Rovno88 3S 18m



The reactor neutrino anomaly

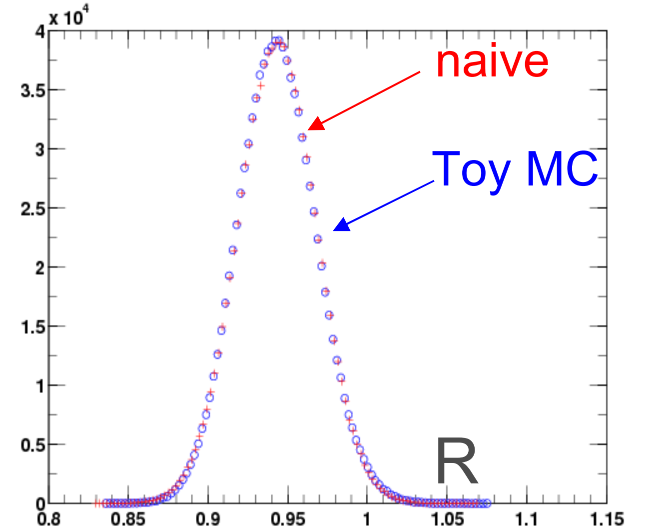


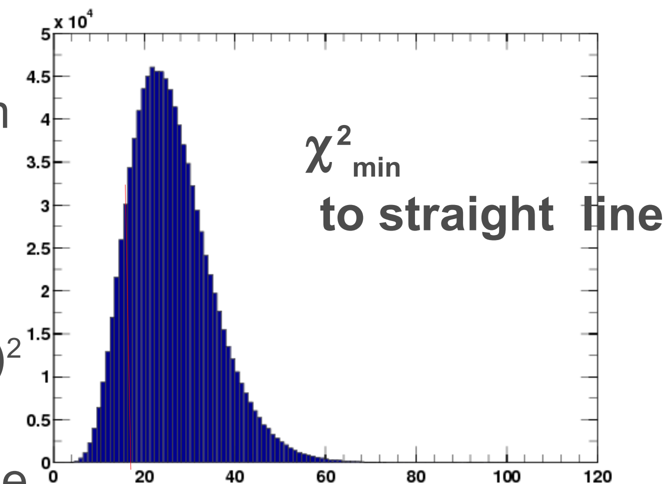

ILL
Bugey-3/4
Krasnoyarsk-I
Goesgen-I
Bugey3
Goesgen-II
Krasnoyarsk-III
Goesgen-III
Bugey3
σ_f pred,new
σ_f ano
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
N_OBS/(N_EXP)_pred,new
10^1
10^2
Distance to Reactor (m)

- We use least-squares estimators and χ^2 distributions to get confidence bounds
- Our data points are ratios of gaussians:
  - Numerator: measurement, gaussian with stat & syst error
  - Denominator: theoretical calculation, assumed to have Gaussian fluctuation of 2
  - Are the ratios normallydistributed ?
  - Toy MC w/ correlated denominator with 2% fluctuation → 10^6 events
  - Numerators correlated using previous matrix
  - Estimate weighted average R of 19 random points with correlations.
  - P-value for (R >= 1) : 1.3% (2.22σ) compared to naive Gaussian 2.29σ.
  - Our contours are reweighted by $(2.22/2.29)^2$ to take this slight non-normality into account

χ^2_{min} of data to straight line in the 18% quantile

→ Data not incompatible with fluctuations





The reactor rate anomaly

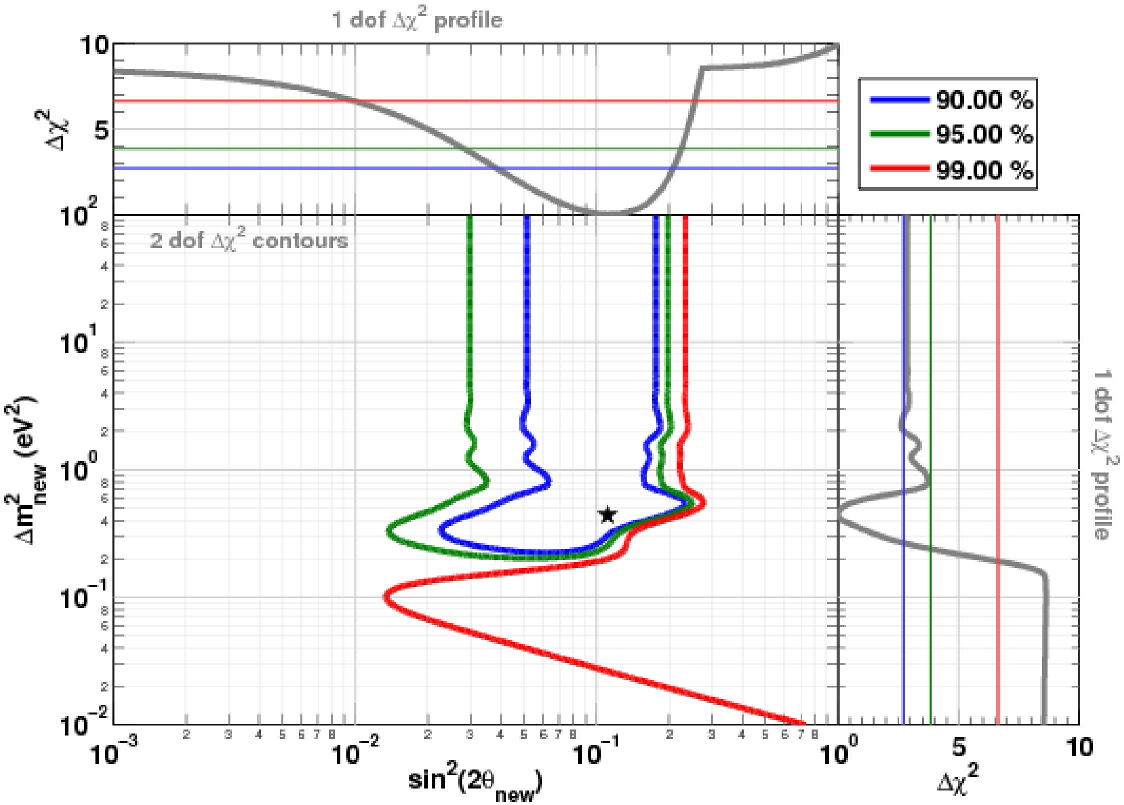
- Each short baseline experiment < 100m from a reactor observed a deficit of anti-ν_e compared to the new expectation
- The effect is statistically significant at more than 2 σ
- Effect partly due to re-evaluation of cross-section parameters, especially updated neutron lifetime
- Three possibilities:
  - Our calculations are wrong.
    We don't think so… we encourage nuclear physics groups to cross-check independently
  - Bias in all short-baseline experiments near reactors : unlikely!
    Different fuel compositions & detection techniques advocate against trivial bias
  - New physics at very short baselines, explaining a deficit of anti-ν_e :

Oscillation towards a 4th, sterile ν ?

a 4th oscillation mode with θ_{new} and Δm^2_{new}

The reactor rate anomaly

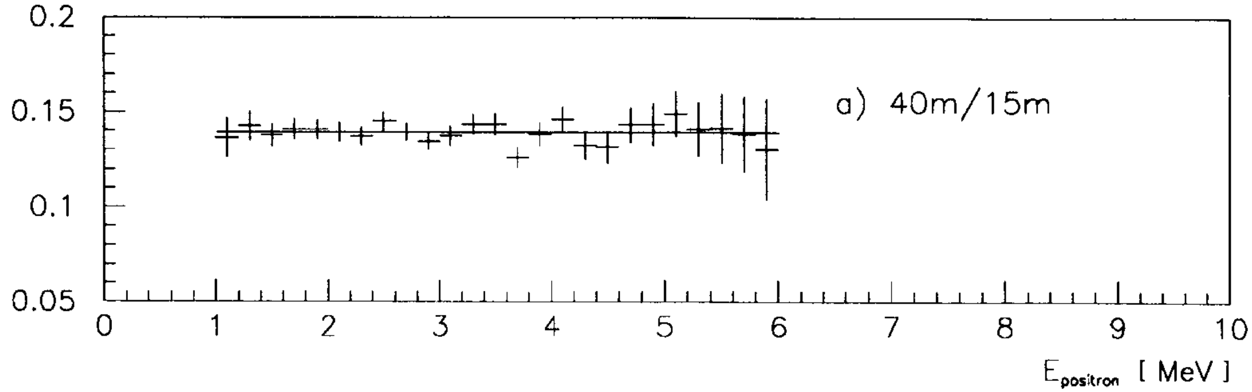
- Combine all rate measurements, no spectral-shape information
- Fit to anti-ν_e disappearance hypothesis



- Absence of oscillations disfavored at 98.64% C.L.
- Next step: include shape analyses of experiments with best shape information

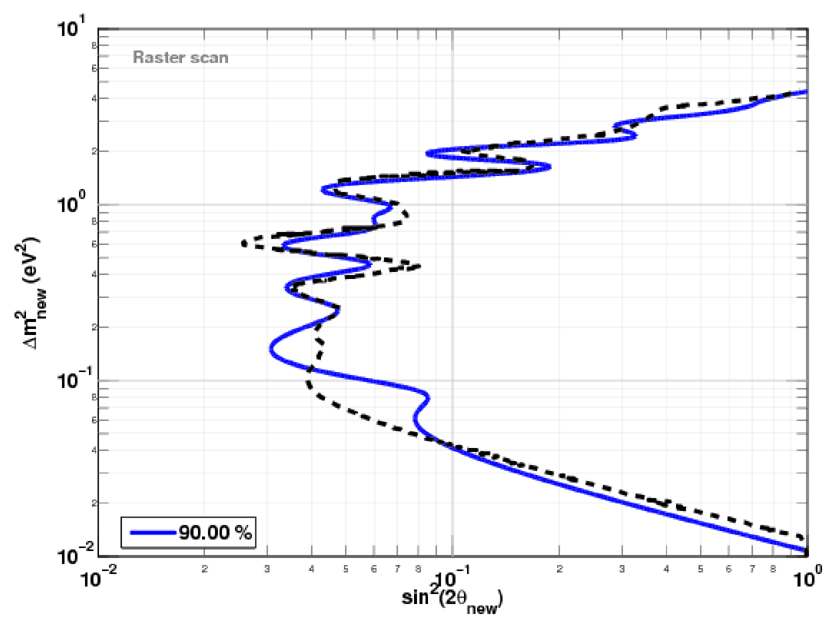
Spectral shape analysis of Bugey-3

- Bugey-3 spectral measurements at 15 m, 40 m, 90 m
  - Best constraint from high statistics R=15m/40m ratio



$$\chi^2 = \sum_{i=1}^{N=25} \left(\frac{(1+a)R^i_{th} - R^i_{obs}}{\sigma_i} \right)^2 + \left(\frac{a}{\sigma_a} \right)^2$$

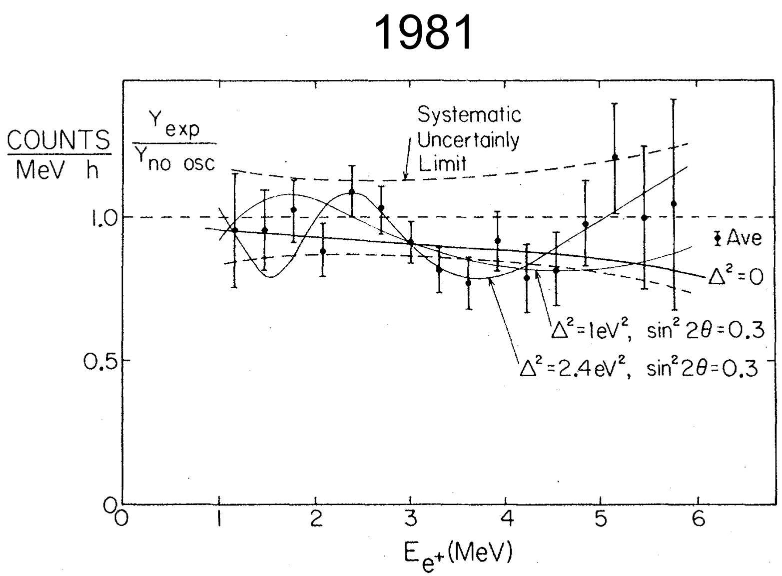
- 2% relative systematic error

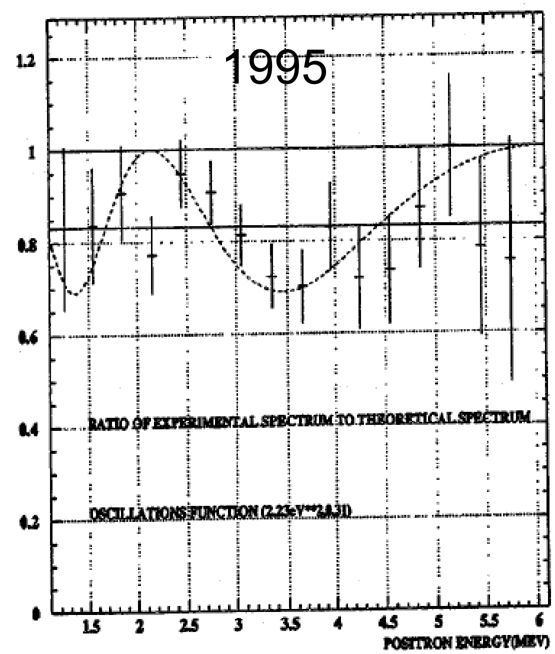


- Reproduction of the collaboration's raster-scan analysis
- Use of a global-scan in combined analysis

The 1981 ILL measurement

- Reactor at ILL with almost pure ^{235}U, with small core
- Detector 8m from core
- Reanalysis in 1995 by part of the collaboration to account for overestimation of flux at ILL reactor
  Affects the rate but not the shape analysis





Large errors, but looks like an oscillation pattern by eye ?

Details of our reanalysis of the ILL shape

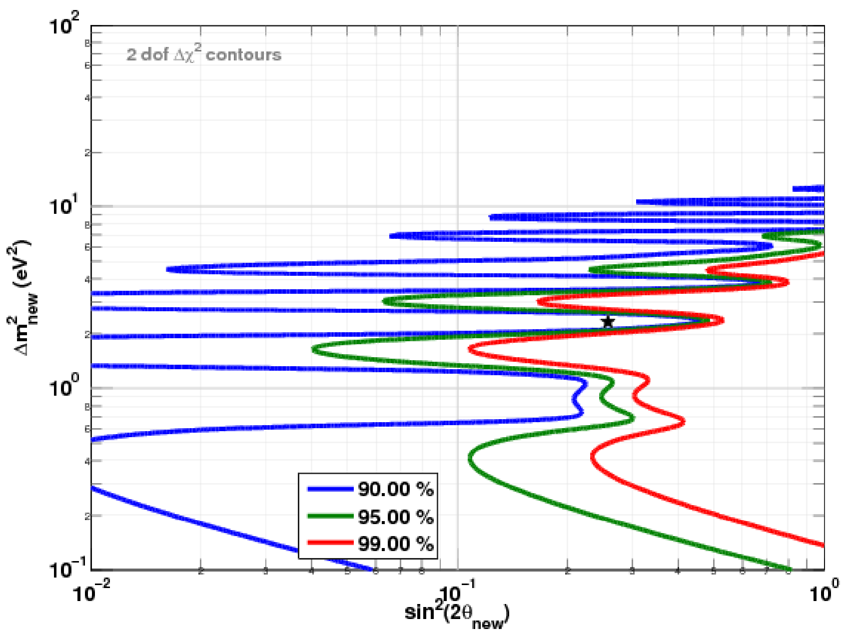
Estimator sensitive to shape only by minimization over parameter a:

$$\chi^2_{\mathrm{ILL,shape}} = \sum_{i=1}^{N=16} \left(\frac{(1+a)R^i_{th} - R^i_{obs}}{\sigma_i} \right)^2$$

- Difficult to assess the systematic error needed to reproduce the results of 1981 & 1995
- 1981: 2% energy scale error on shape
  11% systematic on normalization → does not affect shape fit
- 1995: 8.87% error on normalization, no shape error is reported
  Contour plot difficult to interpret
- Our first approach: simple fit to shape, with stat error only in each bin
- Unknown systematics: error on distance to the core ?

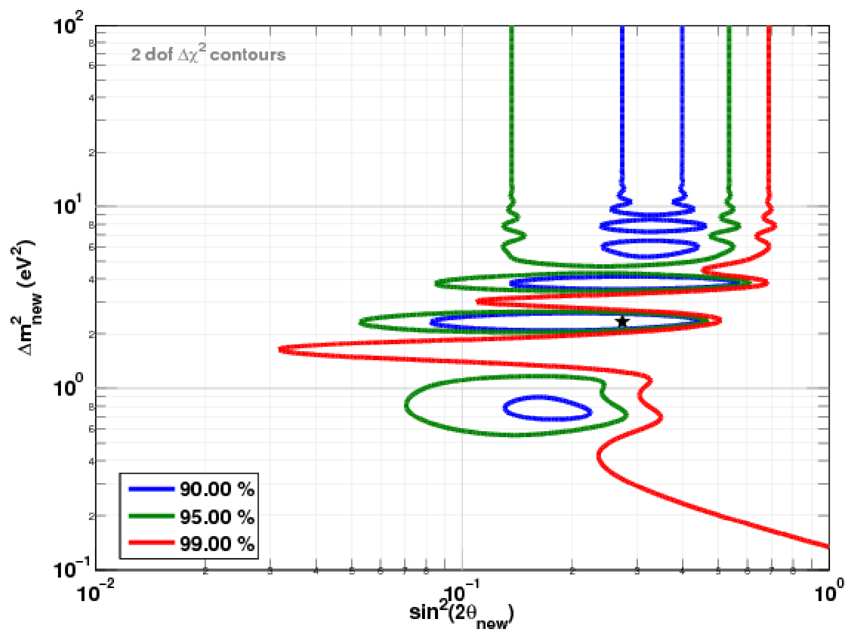
SHAPE ONLY FIT

5% systematics
uncorr. in each bin



RATE+ SHAPE FIT

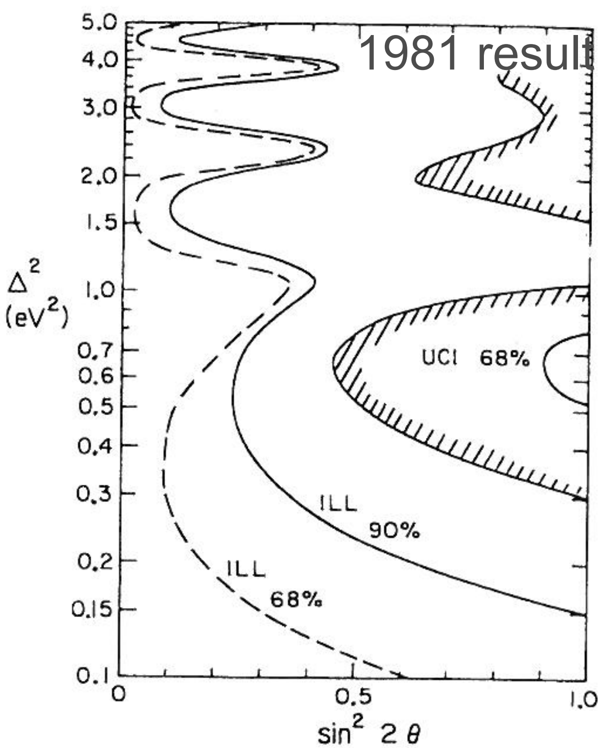
5% systematics on shape
1995 systematics on rate

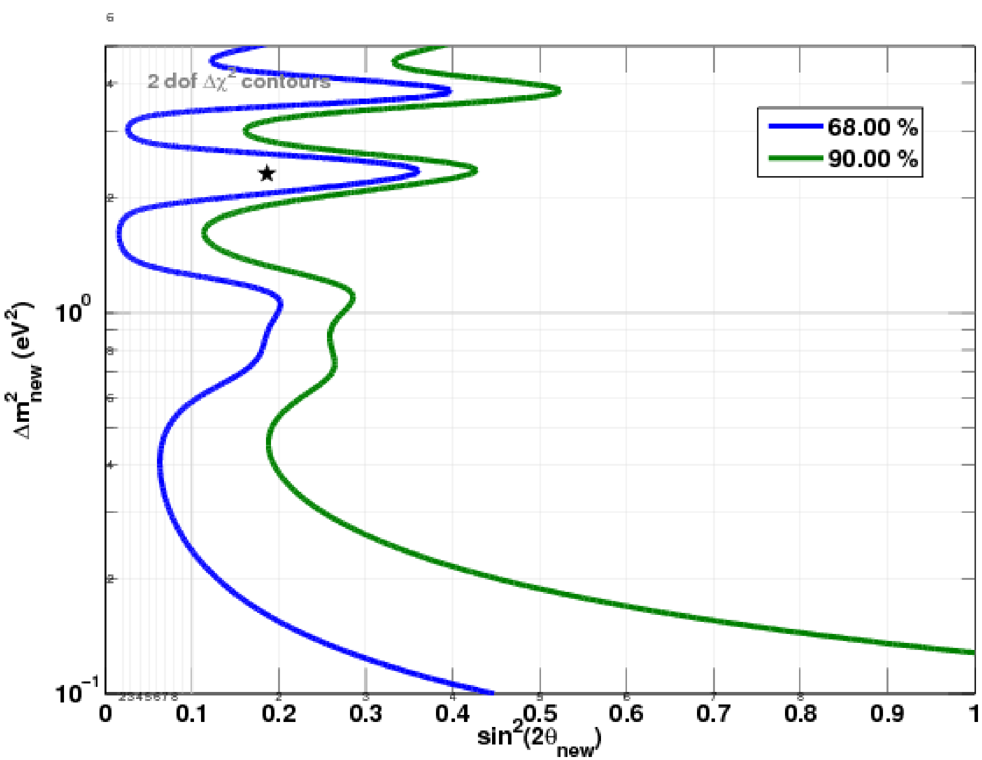


- No evidence for oscillation
- Need systematics larger than 5% on shape to reproduce ILL collaboration's contours

Our ILL analysis

- 1981: Try to reproduce published contour
- 1995: Contour plot hard to follow, reproduce claim that global fit disfavors no-oscillation at 2σ
- How ? Add uncorrelated systematic in each bin until it's large enough
- Needed error : 11%, uncorrelated, in each bin.
- We can reproduce the results quite well
- Question for ILL experts in the room: How large is the shape systematic?

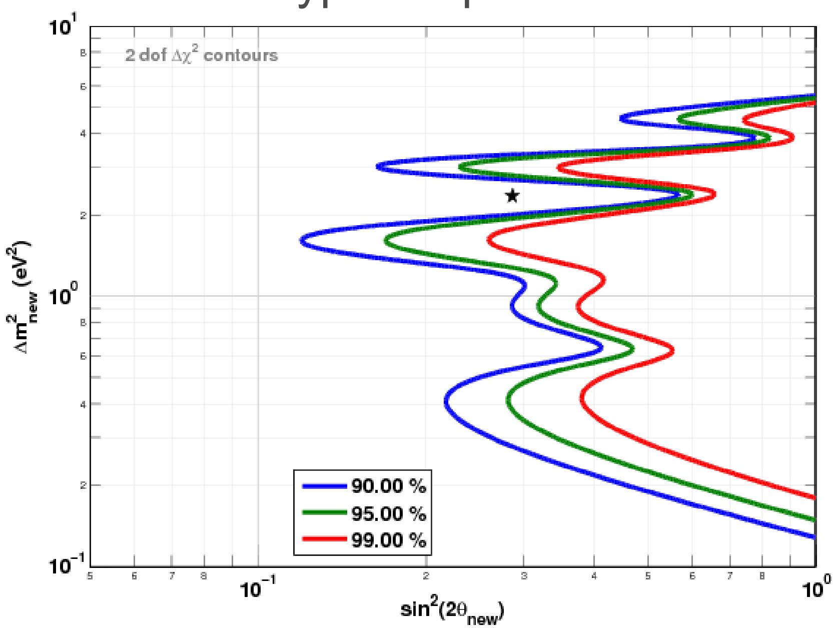


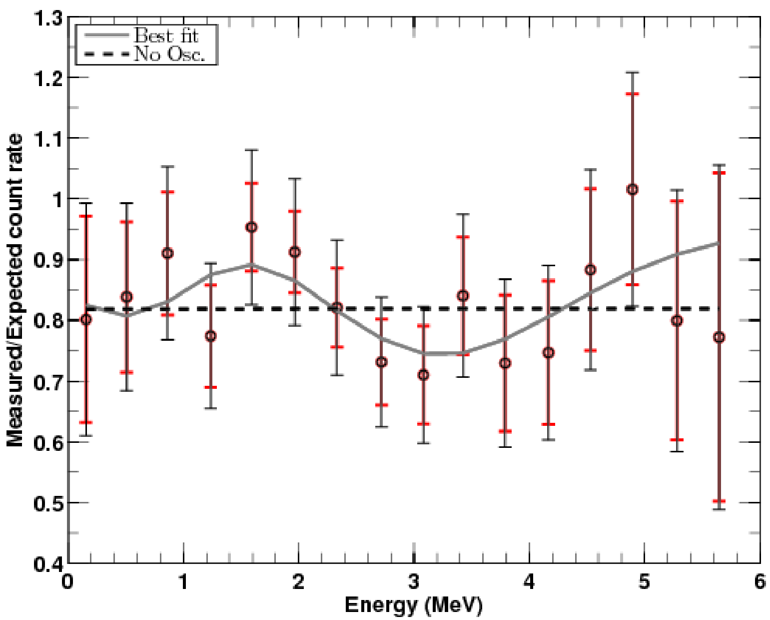


Conclusion on the ILL re-analysis (our published result)

- With the extra systematic, we reproduce the older results
- We needed to add a 11%, uncorrelated systematic in each bin in the shape only fit. Is this plausible for this experiment ?
- Running with the re-evaluated ratios, we obtain the following shape-only contour

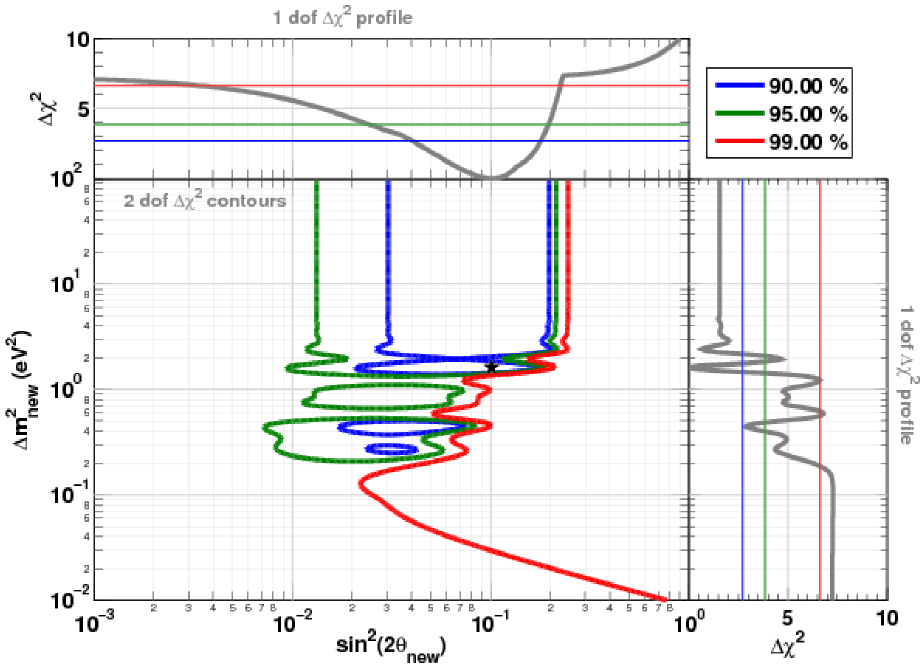
Null hyp accepted at 1 σ



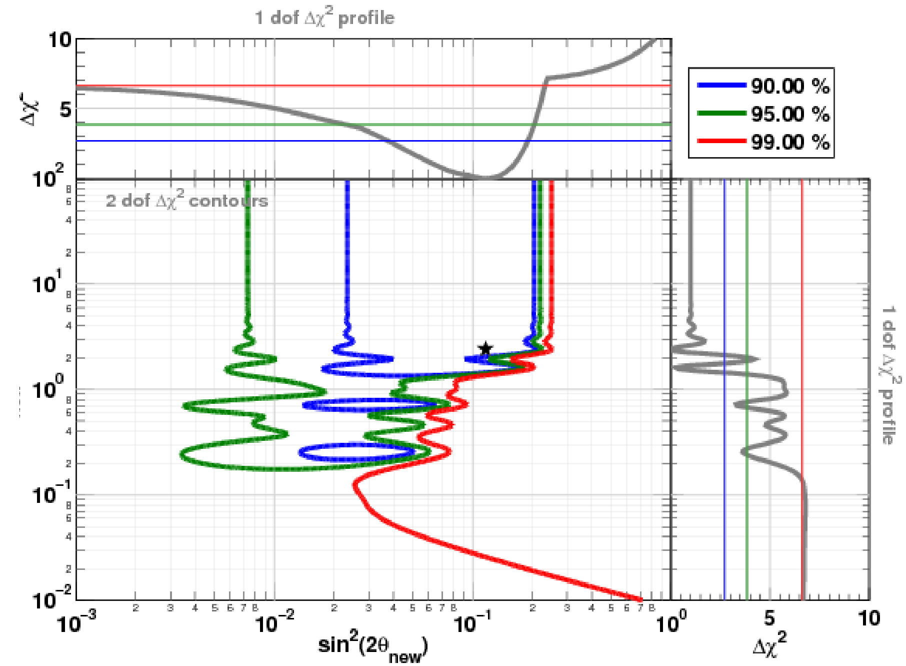


Combined Reactor rate+shape contours

Rate + Bugey-3 only



Rate + Bugey-3+ ILL



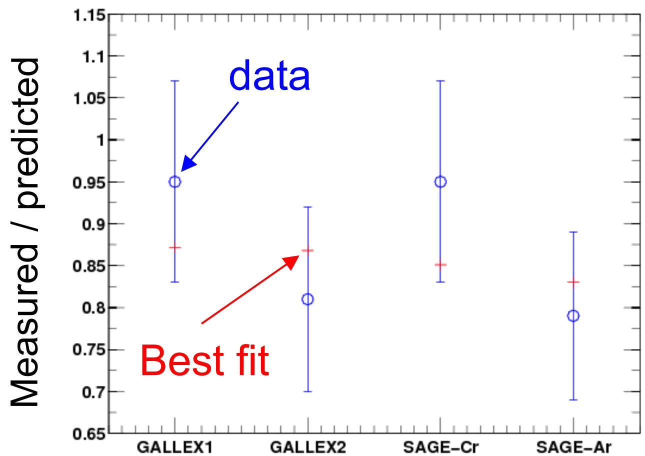
No oscillation disfavored at 96.51% CL with full rate+shape combination

Best fit: $\sin^2 2\theta \sim 0.12$, $\Delta m^2 \sim 2.4$ eV^2

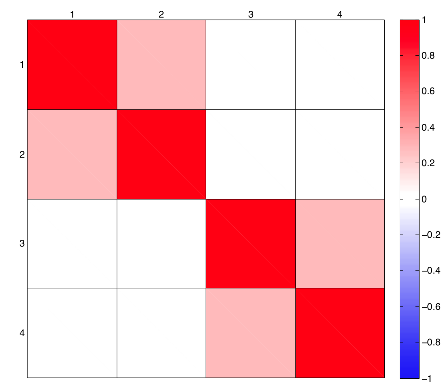
The Gallium anomaly

The Gallium anomaly

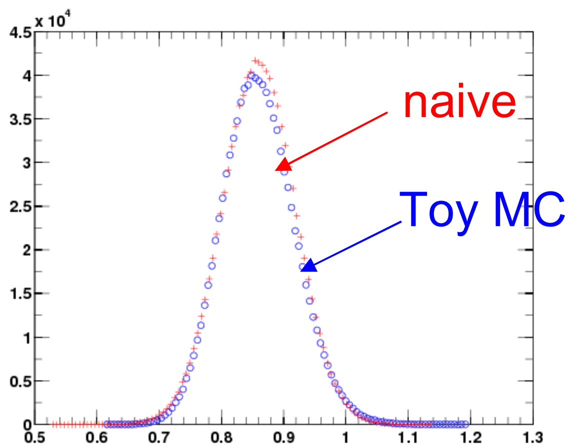
- 4 calibration runs with intense (~ MCi) neutrino (not anti-neutrino!) sources:
  - 2 runs at GALLEX with a ^{51}Cr source (750 keV ν_e emitter)
  - 1 run at SAGE with a ^{51}Cr source
  - 1 run at SAGE with a ^{37}Ar source (810 keV ν_e emitter)
  - **All observed a deficit of neutrino interactions compared to the expected activity. Hint of oscillation ?**
- Our analysis:
  - Monte-Carlo to compute mean path length of neutrino in Ga tanks, for GALLEX & SAGE
  - Correlate the 2 GALLEX runs together and the 2 SAGE runs together

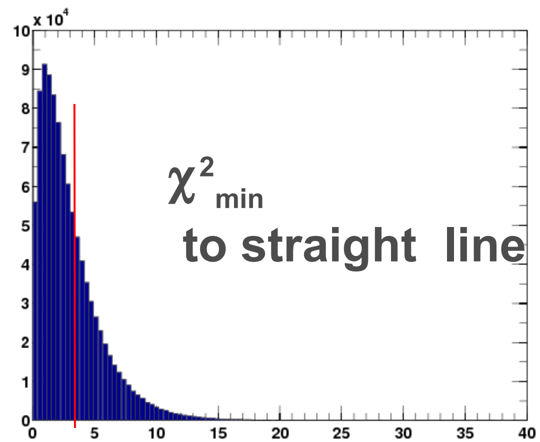


- Gallex-I
- Gallex-II
- Sage-Cr
- Sage-Ar

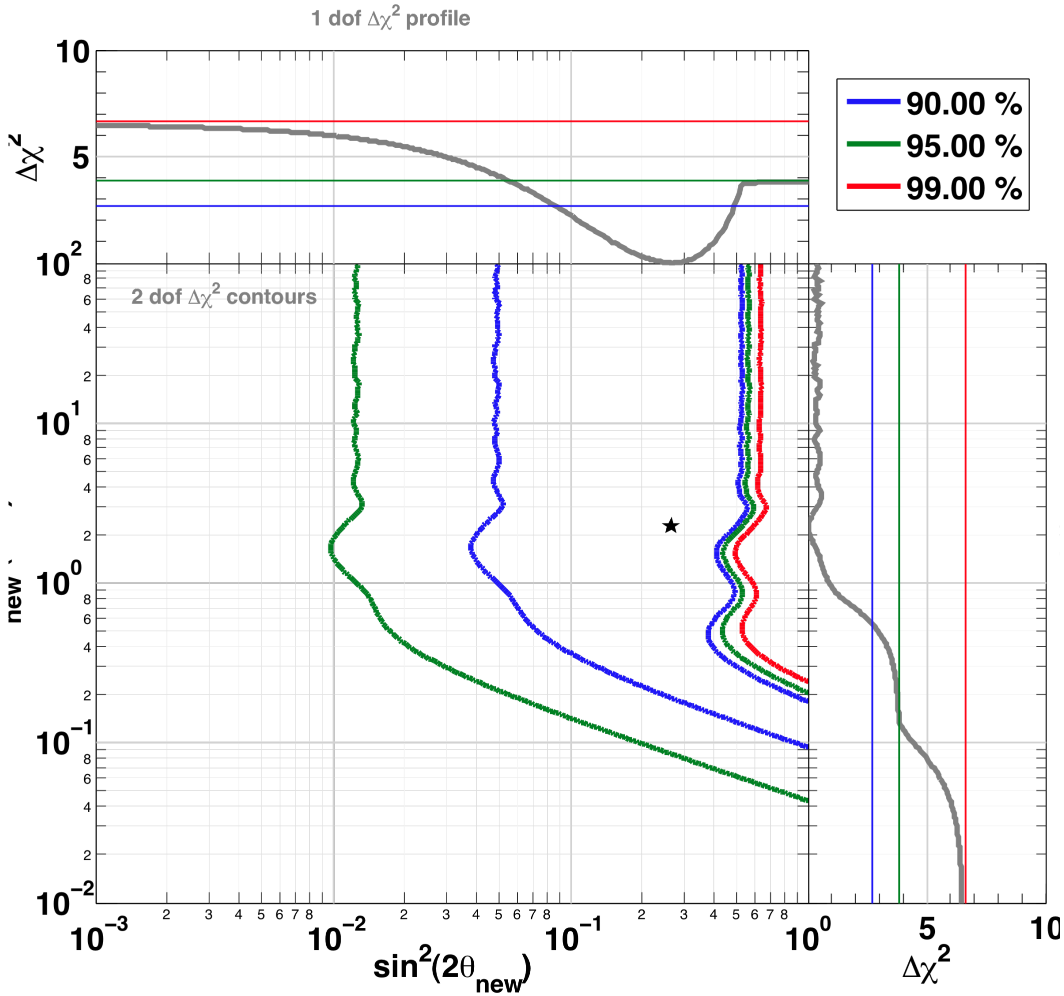


- The 4 runs are correlated together
  - Gallex runs ~10% stat error, 5.6% and 7.4% systematics
  - SAGE runs : 12% (Cr) and 8% (Ar) stat error, 5.7% and 7% syst
- Again, potential deviation from normality in ratios
- Toy MC: draw uncorrelated numerators (within stat errors) and correlated denominators according to systematics
- Fit 4 ratios by constant $\overline{R}$, including correlations
- P($\overline{R}$>1) = 1.24% (2.24σ) instead of 0.80% in Gaussian approx
- Data χ^2_{min} in 68% quantile of χ^2_{min} distribution for toyMC



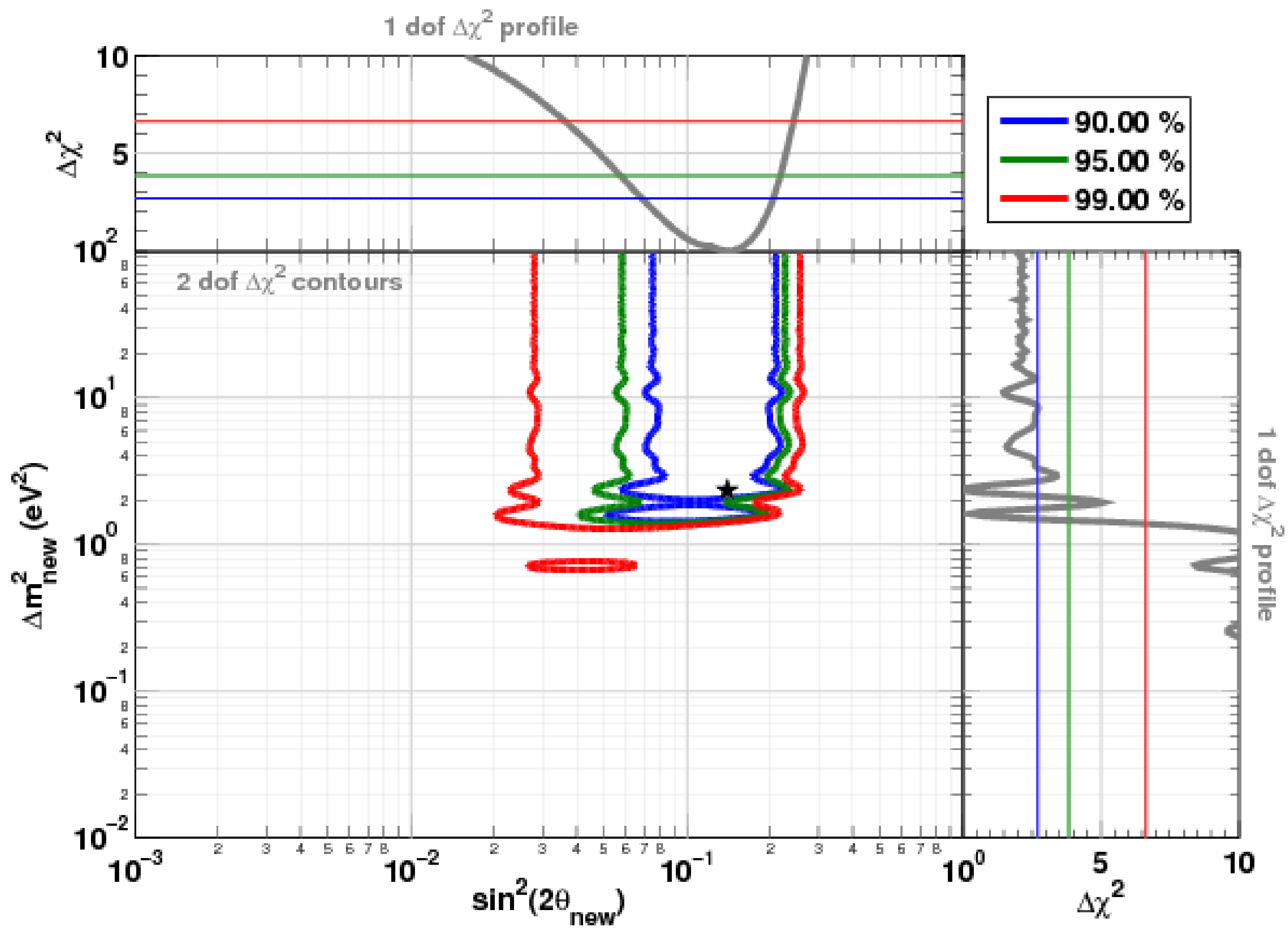


The Gallium anomaly



- Effect reported in C. Giunti & M. Laveder in PRD82 053005 (2010)
- Significance reduced by additional correlations in our analysis
- No-oscillation hypothesis disfavored at 97.7% C.L.

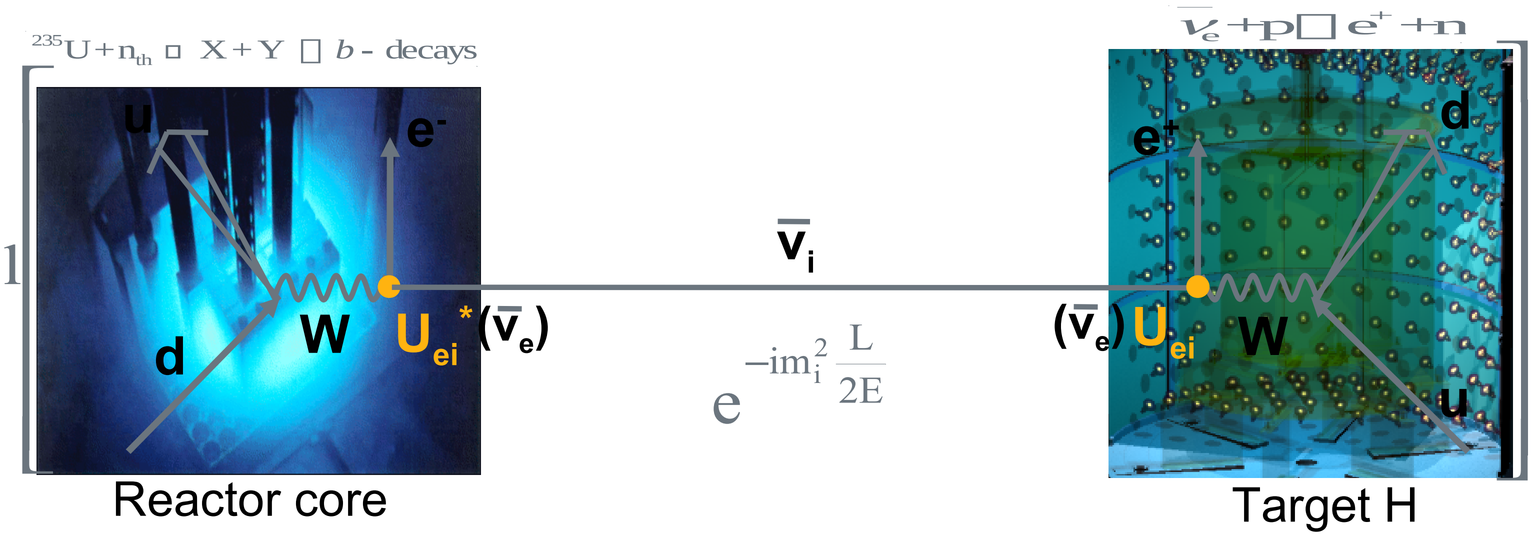
Putting it all together: reactor rates + shape + Gallium + MB



The no-oscillation hypothesis is disfavored at 99.86% CL

Long baseline reactor anti-neutrino experiments and θ_{13}

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = \left| \sum_{i=1,2,3} \mathrm{Ampl} \left[\cdots \right] \right|^2$$



$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = \left[\sum_i U_{ei}^* e^{-im_i^2 \frac{L}{2E}} U_{ei} \right]^2 = 1 - \sin^2(2\theta_{13}) \left[\sin\left(1.27 \frac{\Delta m^2_{atm}\,(eV^2) L\,(m)}{E\,(MeV)} \right) + O\left(\frac{\Delta m^2_{sol}}{\Delta m^2_{atm}}\right) \right]$$

Long baseline reactor experiments

- Experiments with baselines > 500 m
- How do you normalize the expected flux, knowing the fuel composition?

  in this slide assume Bugey-4 fuel comp.
- **If near + far detector, not an issue anymore**

Choices

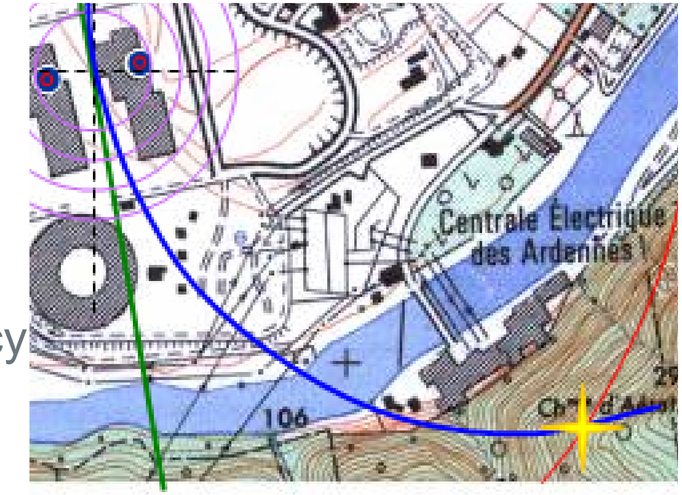
- **σ_f^{pred}**
  - Use $\sigma_f^{pred,new}$ =6.102 10^{-43} cm^2/fission ± 2.7%
  - Use $\sigma_f^{pred,old}$=5.850 10^{-43} cm^2/fission ± 2.7%
- **σ_f^{exp}**
  - Use σ_f^{exp} Bugey-4=5.750 10^{-43} cm^2/fission ± 1.4%

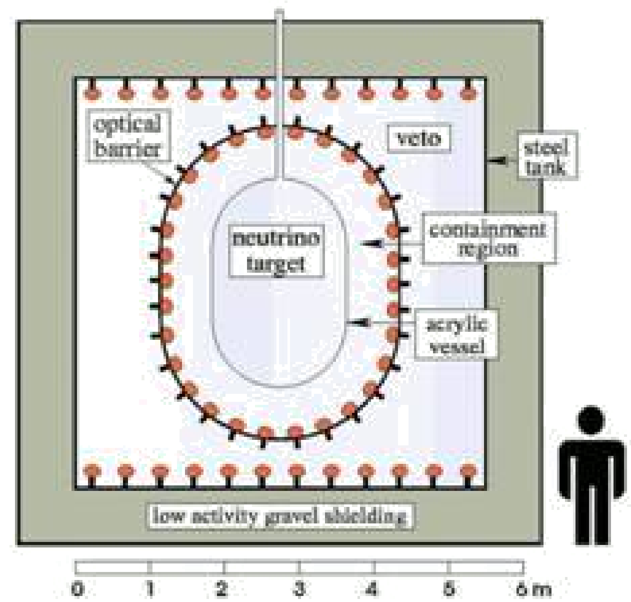
    Chooz's choice: use lower error (total 2.7% instead of 3.3%)

    Bugey-4 is a kind of "near detector" for Chooz
  - Use $<\sigma_f^{exp}> = \sigma_f^{ano}$=5.39 10^{-43} cm^2/fission ± 1% (?)

    Average over short-baseline expts.

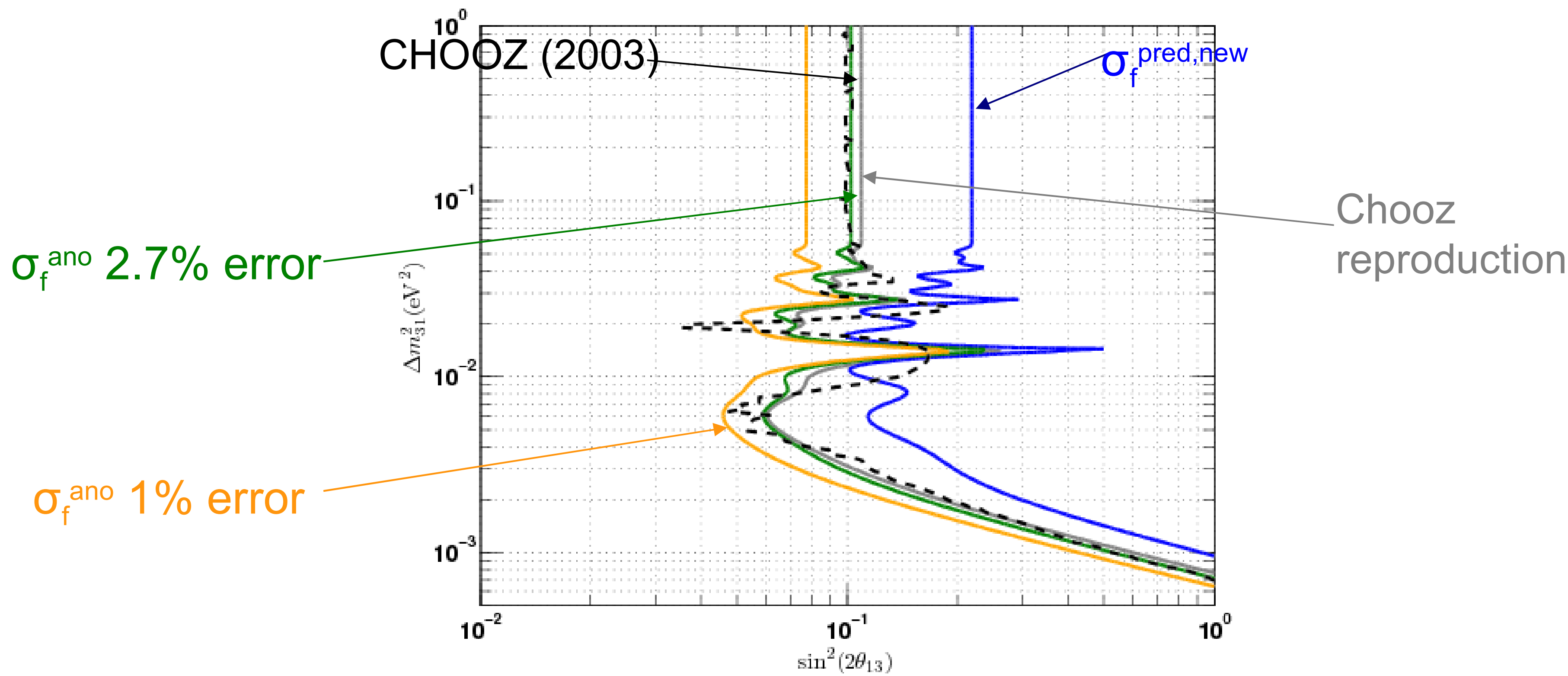
- Chooz Power Station, late 90s
- liquid scintillator doped with 1g/l Gd
  5 tons, 8.4 GW, 300 mwe
- Detector placed at 1050m for the 2 cores
- Look for an oscillation at atmospheric frequency
  θ_{13} mixing angle sensitivity, or more…
- Fuel composition typical of starting PWR – 57.1% ^{235}U, 29.5% ^{239}Pu, 7.8% ^{238}U, 5.6% ^{241}Pu
- Neutron lifetime used in original paper: 886.7 s
- **Published ratios:**
  1.01±0.043
- **Revised ratios with new spectra:**
  0.954±0.041
- Uncertainties:
  - Stat: 2.8%
  - Syst : 2.7% (3.3% in our work)





CHOOZ reanalysis

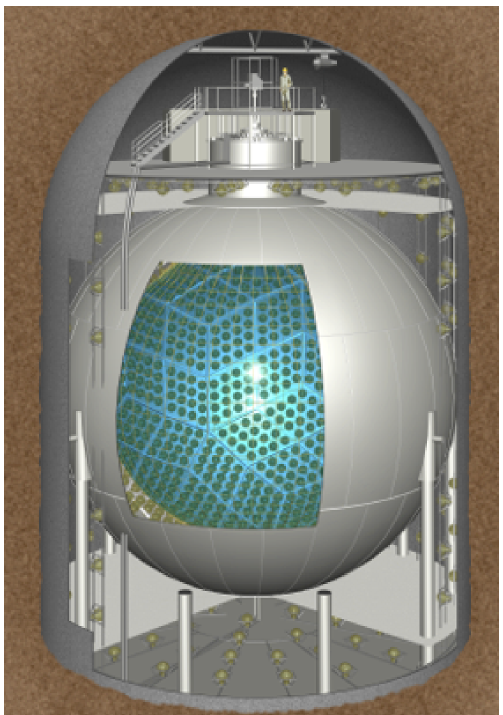
- The choice of σ_f changes the limit on θ_{13}
- Chooz original choice was σ_f^{exp} from Bugey-4 with low error
- If $\sigma_f^{pred,new}$ is used, limit is worse by factor of 2
- If σ_f^{ano} is used with 2.7%, we obtain the original limit
- If $\sigma_f^{ano,}$ which error should be used? → need expert inputs

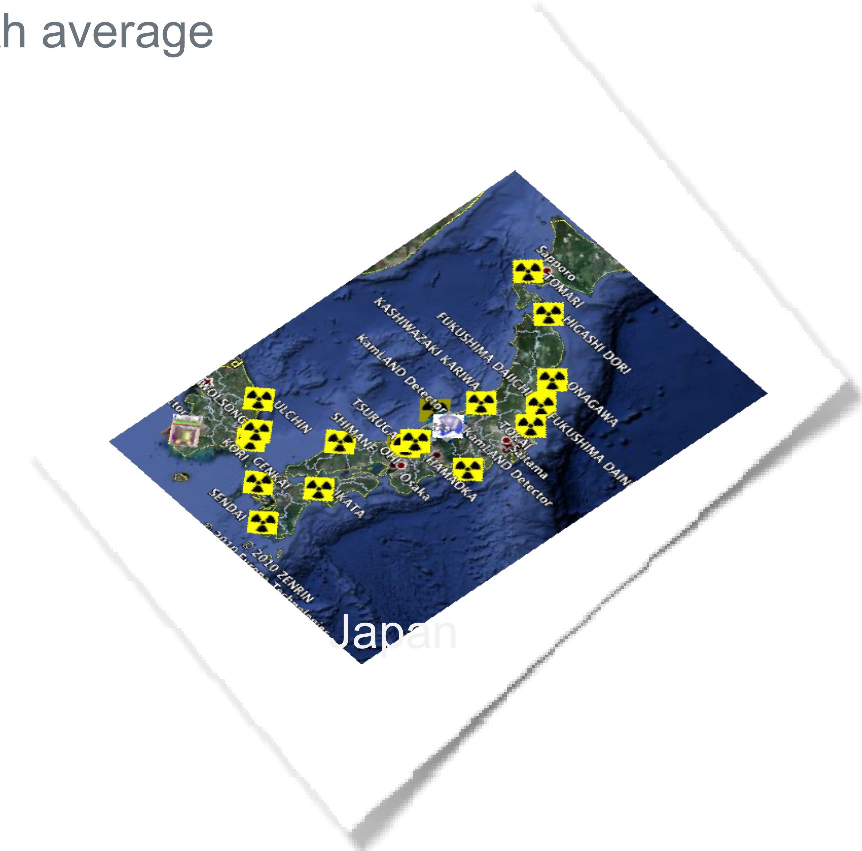


KamLAND experiment

- Reactor anti-neutrino experiment with average baseline around 180 km.
- 80% of total flux comes from reactors 140 to 210km away.

  ~ 1kt liquid scintillator detector





~ 4% syst. uncert. on normalization
~ 1-2% syst. on energy scale.

arXiv:1009.4771v2 [hep-ex]

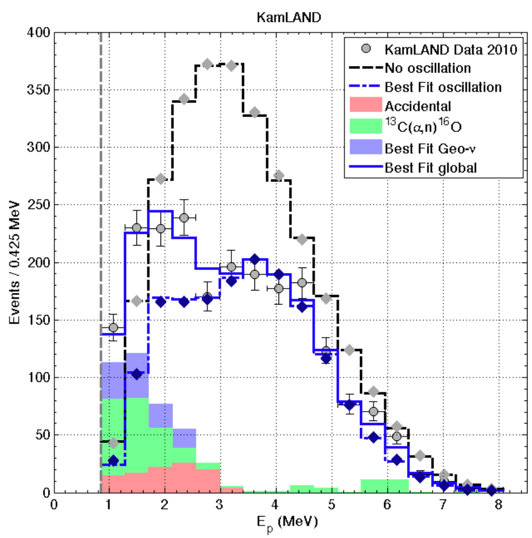
Reanalysis of KamLAND's 2010 results

arXiv:1009.4771v2 [hep-ex]

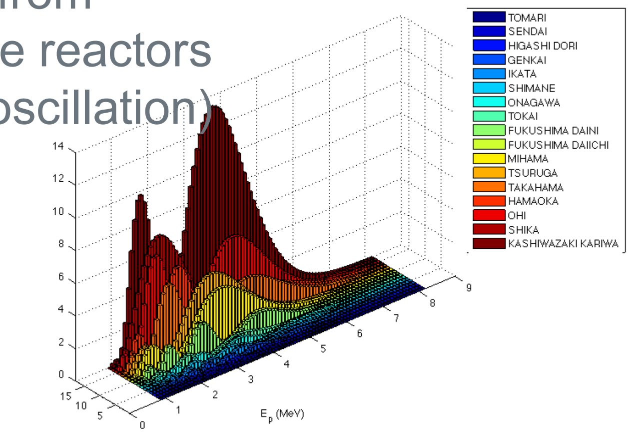
Systematics

	Detector-related (%)		Reactor-related (%)	
Δm^2_{21}	Energy scale	1.8 / 1.8	$\overline{\nu}_e$-spectra [31]	0.6 / 0.6
Rate	Fiducial volume	1.8 / 2.5	$\overline{\nu}_e$-spectra	2.4 / 2.4
	Energy scale	1.1 / 1.3	Reactor power	2.1 / 2.1
	$L_{cut}(E_p)$ eff.	0.7 / 0.8	Fuel composition	1.0 / 1.0
	Cross section	0.2 / 0.2	Long-lived nuclei	0.3 / 0.4
	Total	2.3 / 3.0	Total	3.3 / 3.4

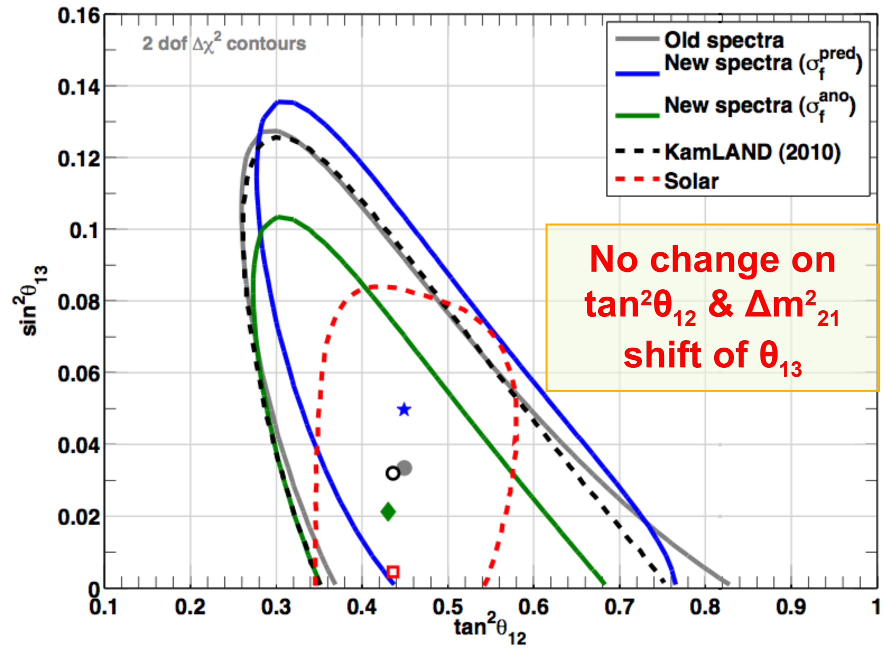
Reproduced KamLAND spectra within 1% in [1-6] MeV range



Spectra from Japanese reactors (with ν_e oscillation)



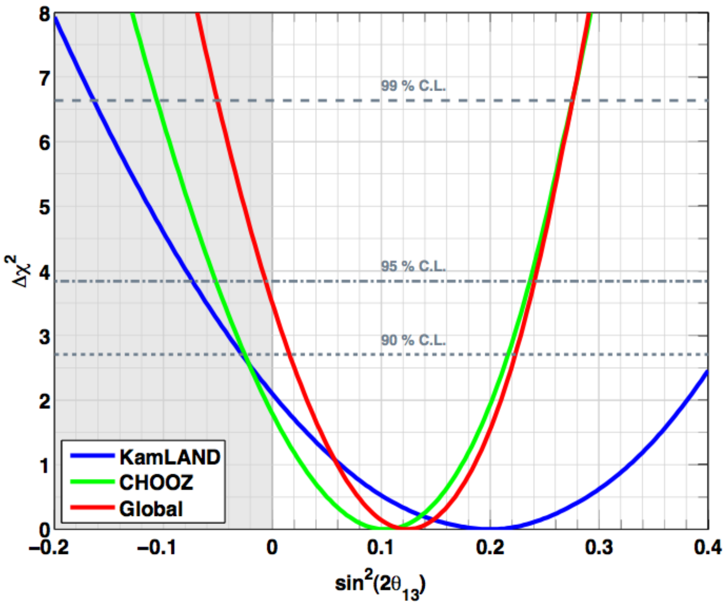
With new spectra predictions



CHOOZ and KamLAND combined limit on θ_{13}

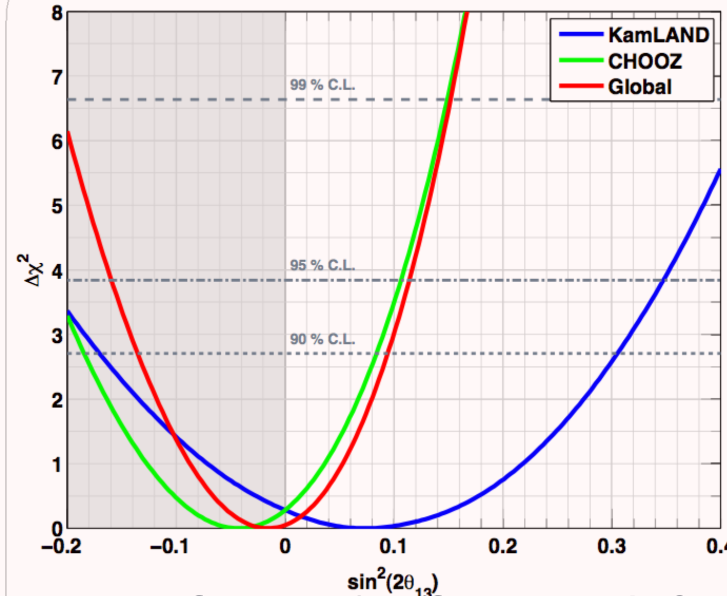
energie atomique • energies alternatives

Normalization with $\sigma_f^{pred,new}$



use of $\sigma_f^{pred,new}$, 3-ν framework & 2.7% uncertainty

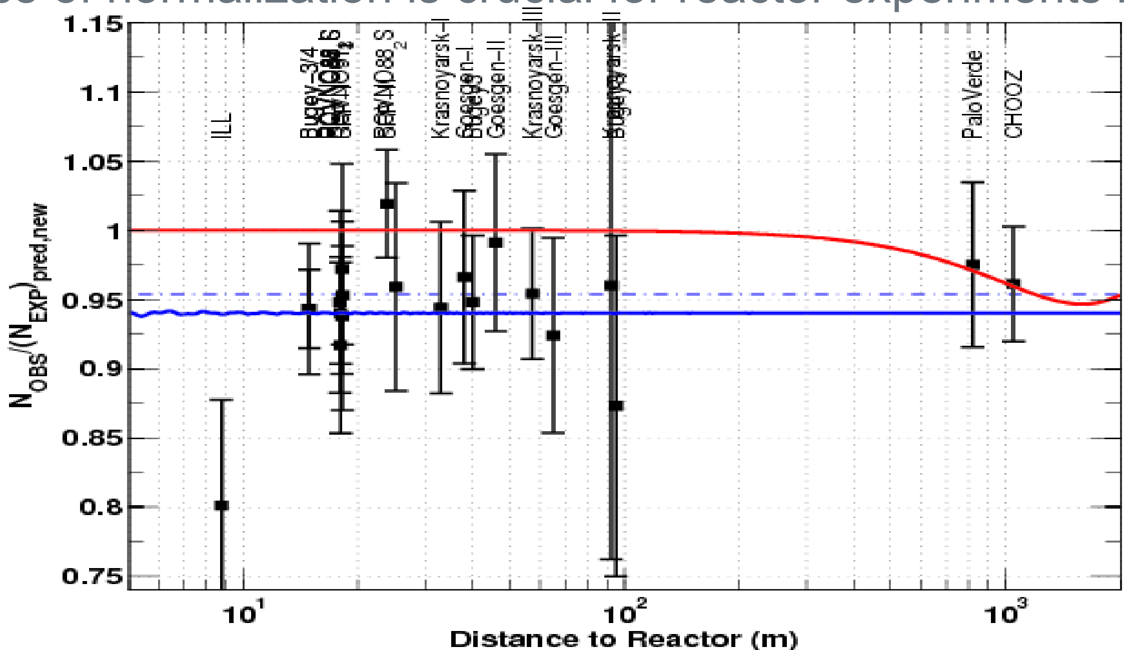
Normalization using σ_f^{ano}



use of σ_f^{ano} , 3-ν framework & 2.7% uncertainty (arbitrary…)

- **Our interpretation:**
  - No more hint on θ_{13}>0 from reactors
  - Global 90 % CL limit stays identical to published values
  - Multi-detector experiments are not affected

- The choice of normalization is crucial for reactor experiments looking for θ_{13}



- A deficit observed at long baseline can either be caused by θ_{13} or by new physics closer to the core (oscillation towards a 4th neutrino, θ_{new})

- If the sterile hypothesis from this work is proven, then using $\sigma_f^{pred,new}$ with 2.7% error is justified, together with a 3+N neutrino framework

- Using σ_f^{ano}, effects at short distances are absorbed
  - 3 neutrino framework
  - Error budget : weighted standard deviation of experimental errors ~1-2%?

Conclusion

- New calculation of anti-ν_e spectra produced at a nuclear reactor

Overall interaction rate is increased by +3.5% compared to previous calculations

- Re-analysis of (almost) all past short baseline experiments:
  - Average measured/expected ratio = 0.943±0.023
  - Reactor anti-neutrino anomaly
  - Is it new physics ? A sterile neutrino ?

- Rate+shape short-baseline data compatible with anomaly seen at Gallium experiments with MCi sources, and Miniboone ν data
  - Overall, no-oscillation hypothesis disfavored at 99.84% CL
  - Data compatible with Δm^2 >~ 1 eV2 and $\sin^2 2\theta \sim 0.1$
  - Compatible with LSND & Miniboone data ?

- Middle/Long-baseline reactor experiments: deficit from anomaly could be mis-interpreted as a hint for non-zero θ_{13}
  - Revised constraint: $\sin^2 2\theta_{13} < 0.095$ at 90%CL → No "hint"
  - Relax tension between Chooz+KamLAND and solar data

Conclusion and Outlook

- Assuming a 4th, sterile neutrino with mass ~ 1 eV exists, could it be detectable ?

- Direct β spectrum measurements: within sensitivity of KATRIN

- If Majorana, the contribution of such a state would be of interest to future $\beta\beta0\nu$ experiments

- Slightly favored by some cosmological models:
  - WMAP+BAO fit 4.34±0.87 neutrino-like radiations
  - But compatibility of 1 eV neutrino should be studied carefully (to much hot dark matter?)

- Clear experimental confirmation / infirmation is needed:
  - Nucifer: small detector, 7 m from the small Osiris core
  - Insert a MCi source into large detector with energy & spatial resolution, eg SNO+, Borexino, KamLAND