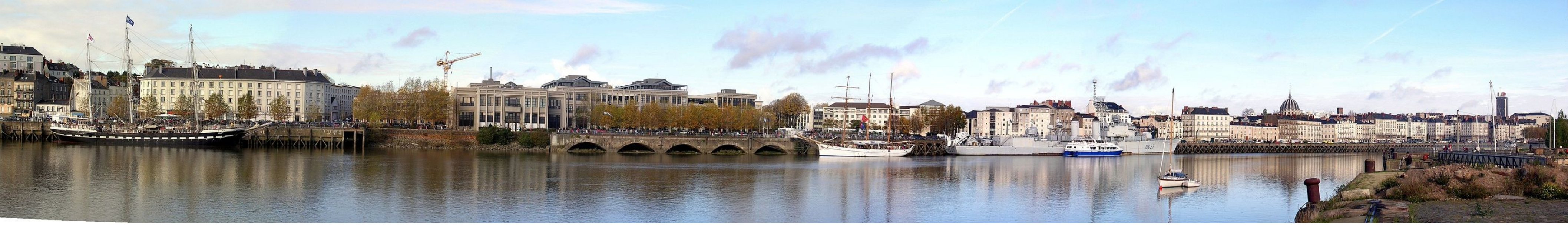


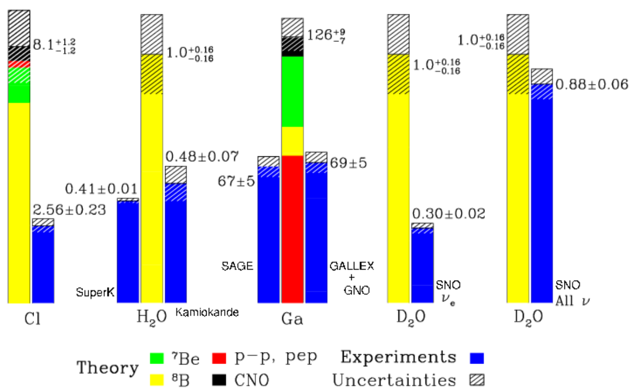
Antineutrino Spectral Excess in Double Chooz

A.S. Cucoanes and the Double Chooz Collaboration

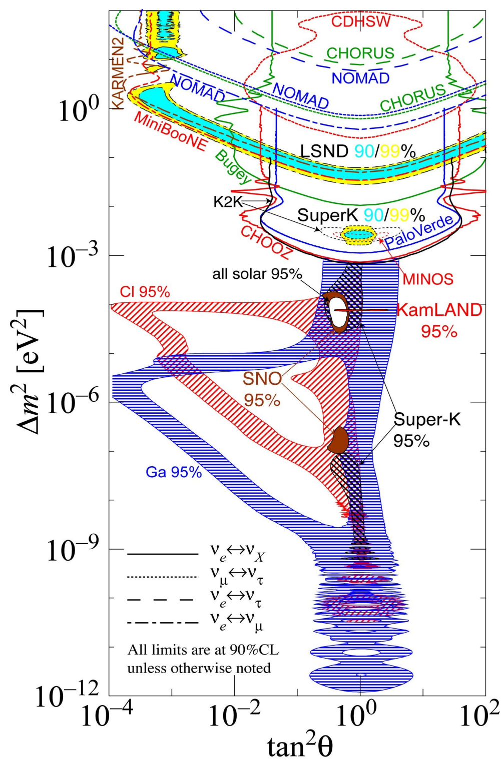
The Status of Reactor Antineutrino Flux Modeling, Nantes, Jan. 2015

Neutrino Oscillations

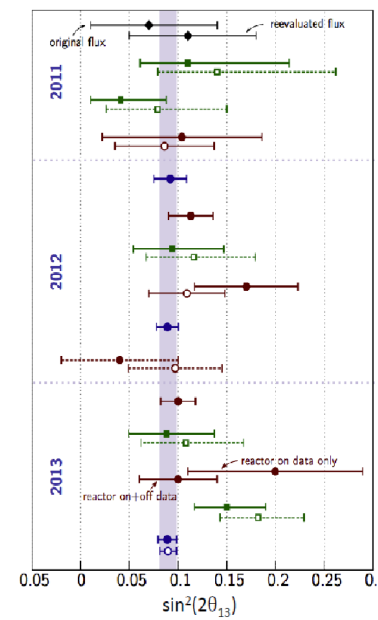
Anomalies



Searches



Precision



Here we are today !

Reactor Θ13 Experiments: some key facts

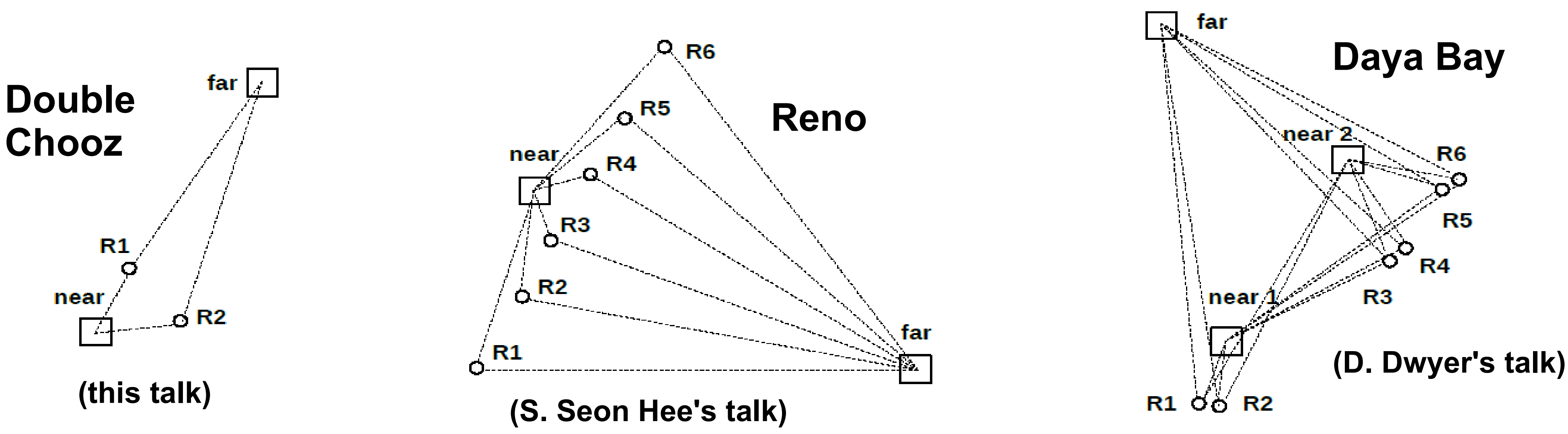
A high precision of the Θ13 value is mandatory not only *per se* but also for the future evaluation of the CP violation in the lepton sector.

In reactor experiments, the precision of the Θ13 is given by the precision of the antineutrino spectrum **measurements** and the precision of the antineutrino spectrum **prediction**.

In Near/Far setups (Daya Bay, Reno, DC phase 2) **the contribution of antineutrino spectrum prediction** to the Θ13 evaluation is less important w.r.t. Far-only setups (DC phase 1) **but still present** (arXiv:1501.00356).

What about the reliability of the prediction given a precise antineutrino measurement of the reactor experiments ?

Reactor Θ13 experiments: the scene today



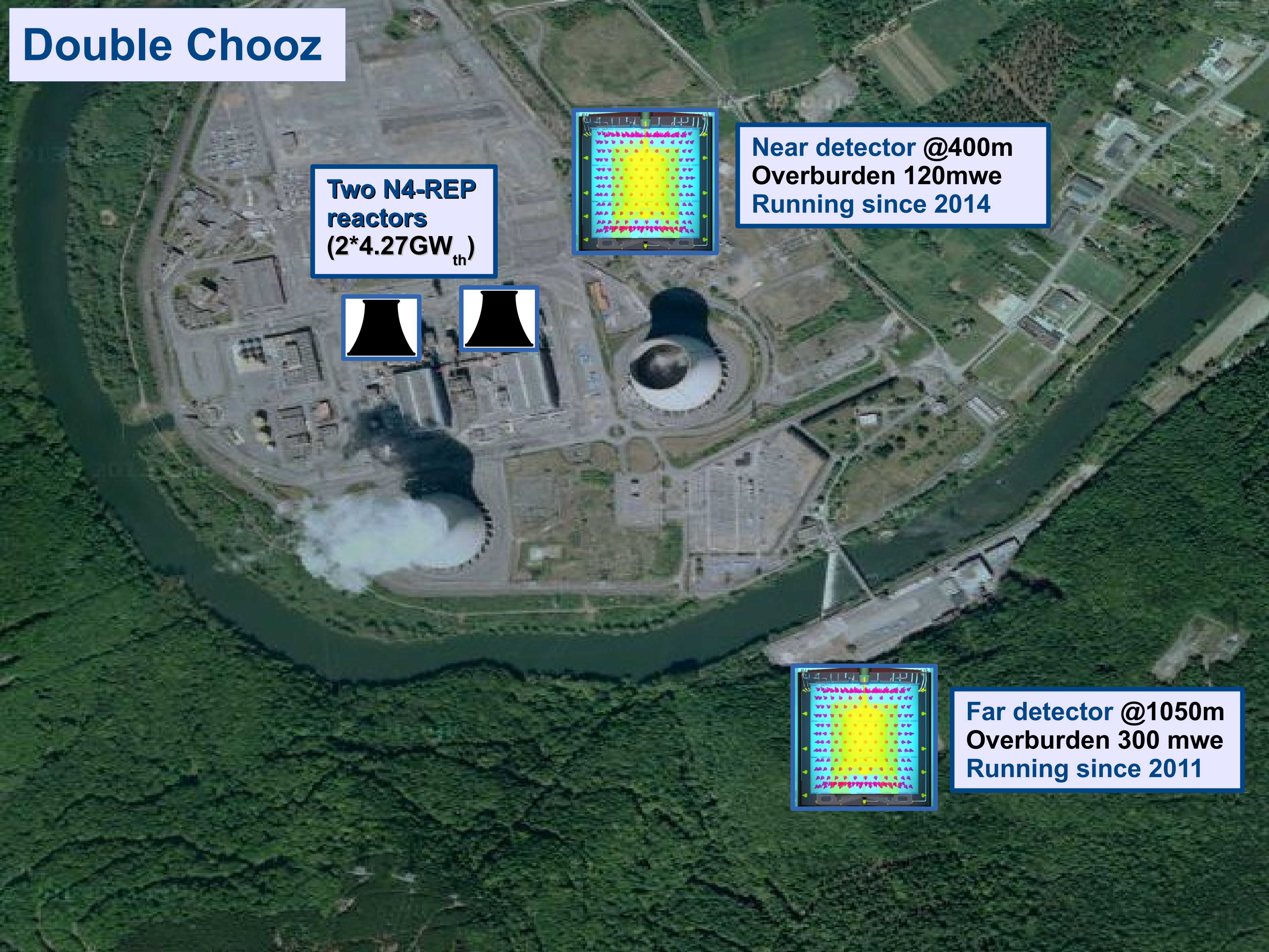
3 reactor experiments with similar setups currently taking data: DC, RE and DB

Common features: Near/Far setups (DC since 2014), detectors design and reactors (PWR), calibration

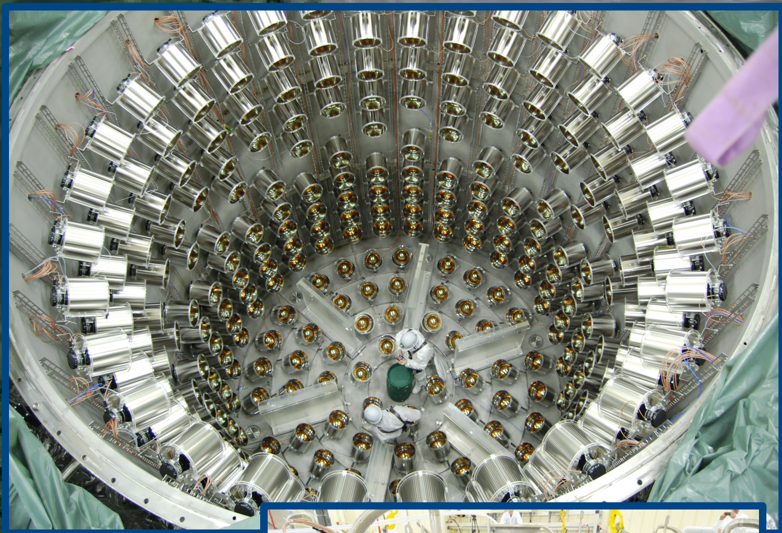
Differences: Number of reactors, readout, energy reconstruction.

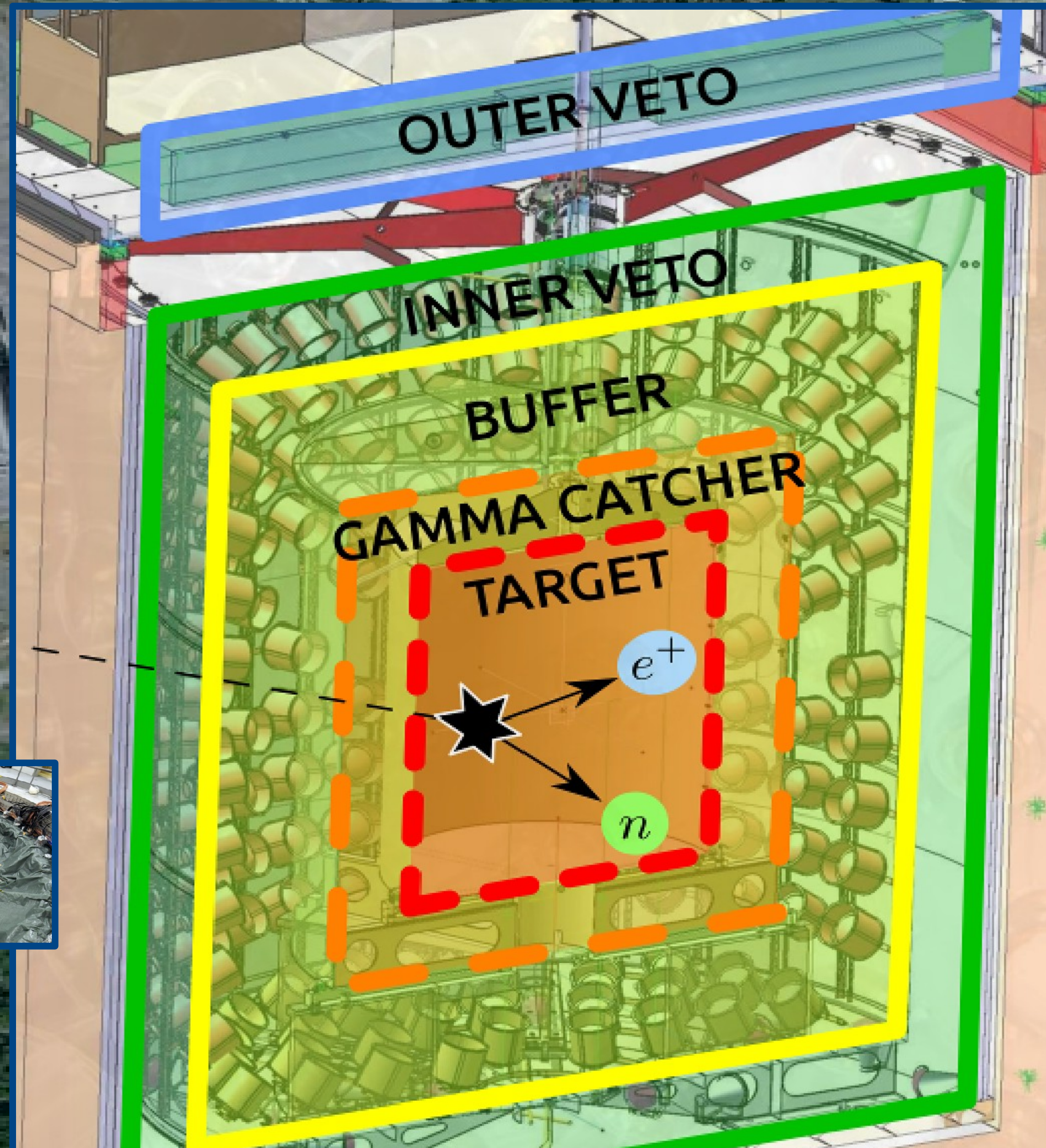
The cross-validation of results is mandatory.

Double Chooz



Double Chooz

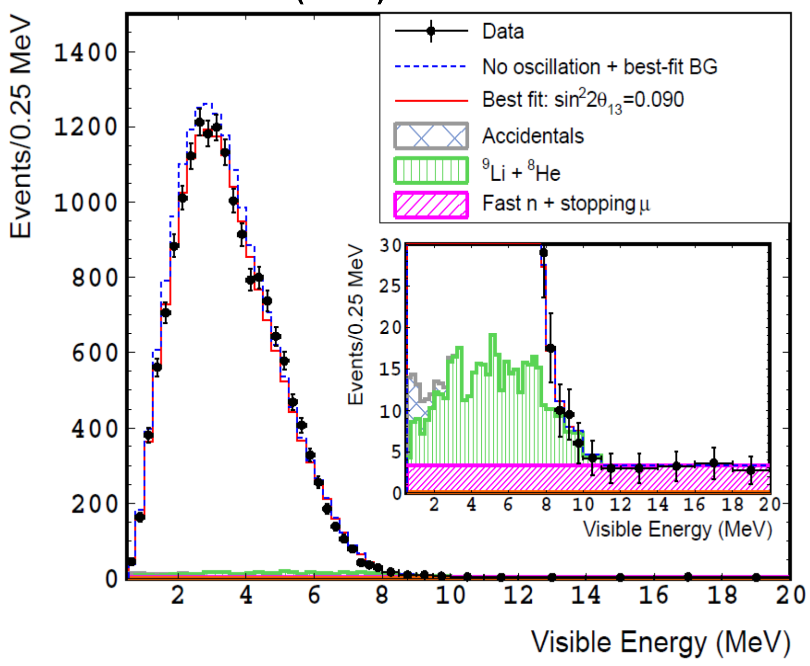




Θ13 Double Chooz Analyses

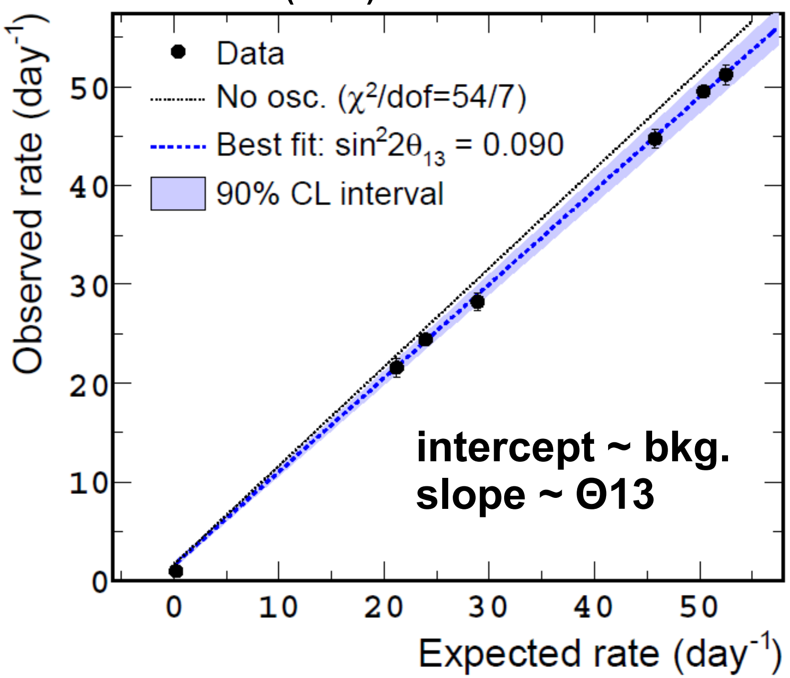
Rate+Shape (R+S) Analysis: Exploit full spectra and E/L signature of θ13 (oscillations)
The most precise θ13 measurement
3 publications: **DC1** (PRL 108, 2012), **DC2** (PRD 86, 2012), **DC3** (JHEP, 1410, 2014).

JHEP 1410 (2014)



Reactor Rate Modulation (RRM) Analysis:
θ13 and Background fitted in the same time →
Unique DC cross-check of θ13

JHEP 1410 (2014)



Analyses with neutron captures on Gd or/and H: different background, statistics, etc.

Remarkable cross-check and cross-validation possibilities.

The evolution of event selection: Gd analyses

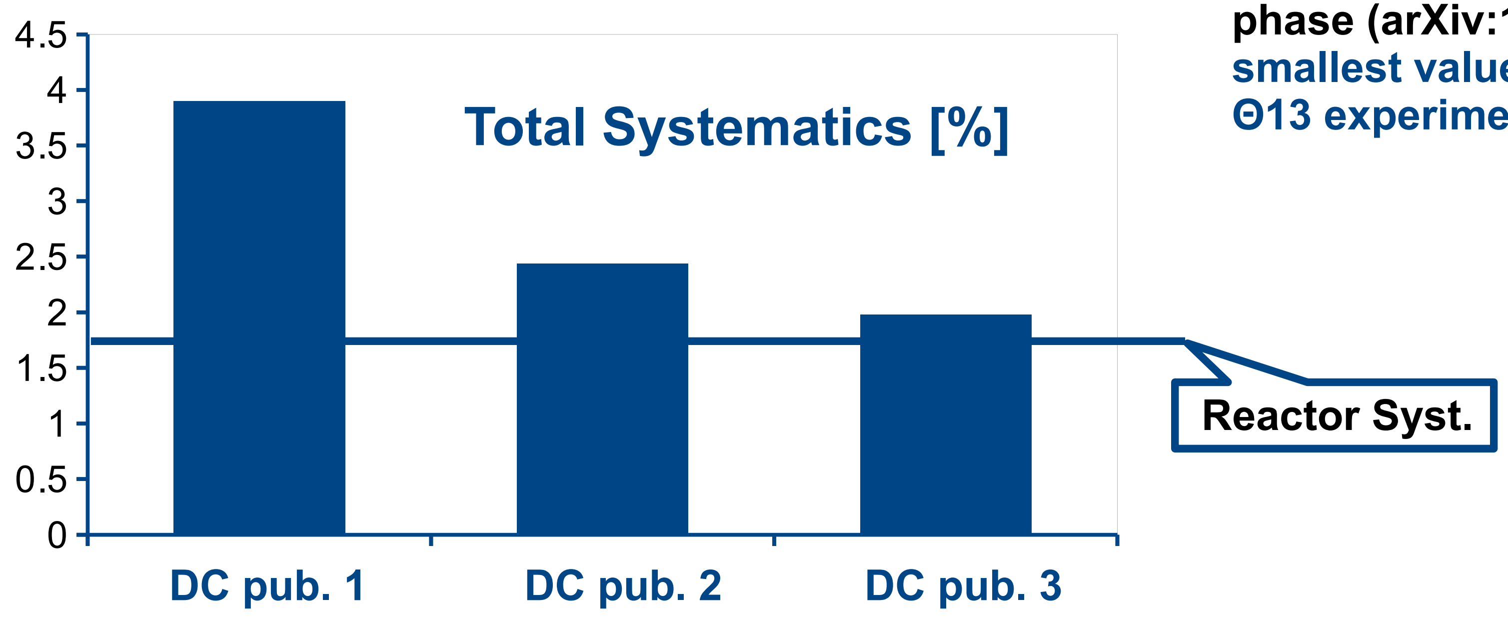
	DCpub.1	DCpub.2	DC pub 3
μ-Veto	Δt(μ) > 1ms	Δt(μ) > 1ms	Δt(μ) > 1ms
			E(ID) ≥ 20MeV & Q(IV) ≥ 30k(a.u.)
Light Noise	Qm/Qt < 0.09 & RMS(t) > 40ns	Qm/Qt < 0.09 & RMS(t) > 40ns	Qm/Qt < 0.12 2D cut RMS(t,Q) ΔQ < 30k(a.u.)
Inverse Beta Decay	Epr = [0.7, 12.2] MeV Edl = [6, 12] MeV ΔT(pr, dl) = [2, 100] μs	Epr = [0.7, 12.2] MeV Edl = [6, 12] MeV ΔT(pr, dl) = [2, 100] μs	Epr = [0.5, 20] MeV Edl = [4, 10] MeV ΔT(pr, dl) = [0.5, 150] μs
			L(pr, dl) < 1m
	Multipl. (pr, dl): [-0.1, 0.4] ms	Multipl. (pr, dl): [-0.1, 0.4] ms	Multipl. (pr, dl): [-0.2, 0.6]ms
Bakground Rejection		No OV hit	No OV hit
		Δtμ (Eμ > 600 MeV) > 0.5 s	Likelihood Li+He veto
			No IV hit cond (PMT mult, Q(IV), Δd(ID-IV), Δt(ID-IV)) FV veto

Remarkable efforts in event selection cuts and background removing.

The evolution of systematics

All err. in %.	DC 1	DC 2	DC 3	Estim. Near/Far
Reactors	1.7			~ 0.1
Detection	2.0	1.0	0.6	~ 0.2
Background	2.9	1.5	0.8	~ 0.3
Total syst.	3.9	2.4	1.9	
Statistics	1.6	1.1	0.8	

Up to now (all the presented results) Double Chooz run in Far-only config. → significant contribution of the reactor induced systematics.



The reactor induced systematics will be strongly suppressed in Far/Near phase (arXiv:1501.00356) → smallest value among the Θ13 experiments is expected.

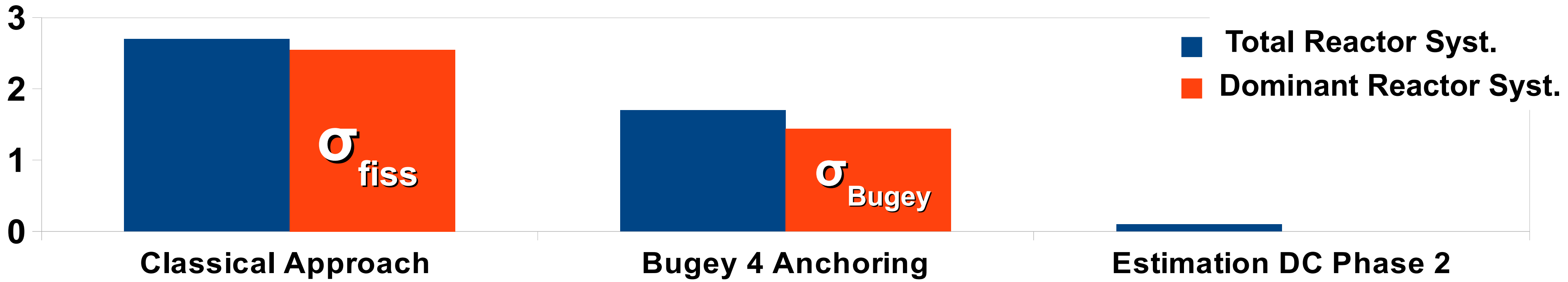
Many efforts up to now for controlling the detection & background related systematics

Antineutrino spectrum prediction

The reactor antineutrino spectrum is computed from the electron spectrum of the fission products of the main core isotopes and many corrections: (finite nuclear size, radiative corr., screening effects, induced currents, etc).

Mixed approach using nuclear databases + virtual branches to reproduce the ILL fission β spectra. (Mueller et al, Phys. Rev. C83 (2011), Huber, Phys.Rev. C84 (2011))

For DC3, new 238U spectra from Haag et al. (PRL 112 (2014))



Estimation dominated by the error of the mean IBD X-section per fission

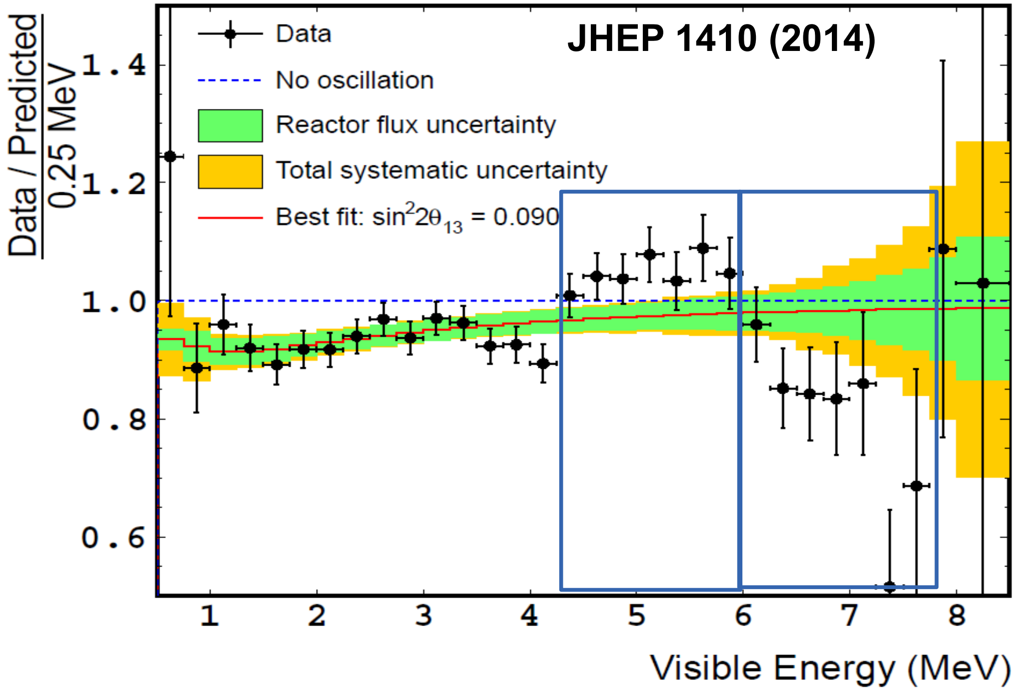
The mean IBD X-section per fission anchored to the Bugey 4 measurement

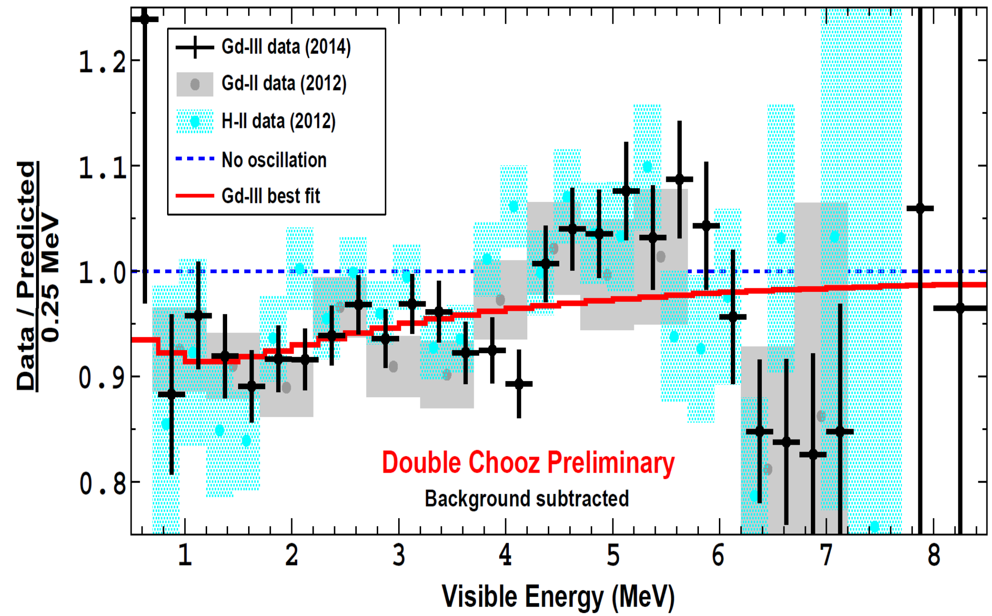
Residual reactor error for the Near-Far phase

Bugey4 measurement acts as effective Near detector for Far only phase.

For Near/Far phase, the reactor induced systematics will not be dominant.

Observed [4,8] MeV Data/MC structure





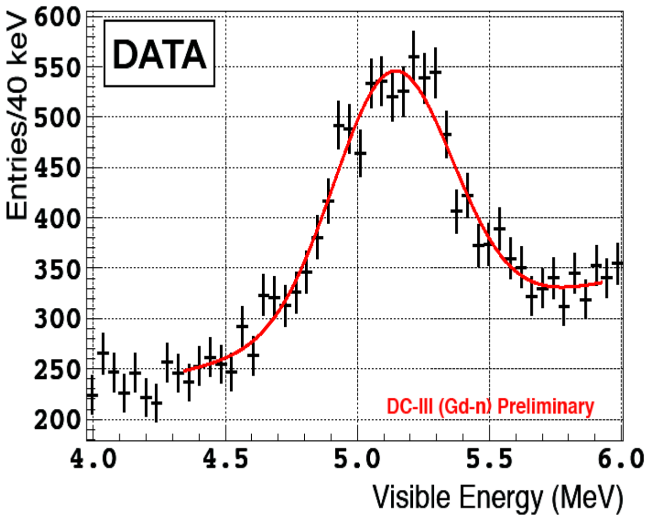
~3σ excess [4,6] and 1.6σ deficit [6,8]. → more room in the future (stat. and reactor syst. dominated)

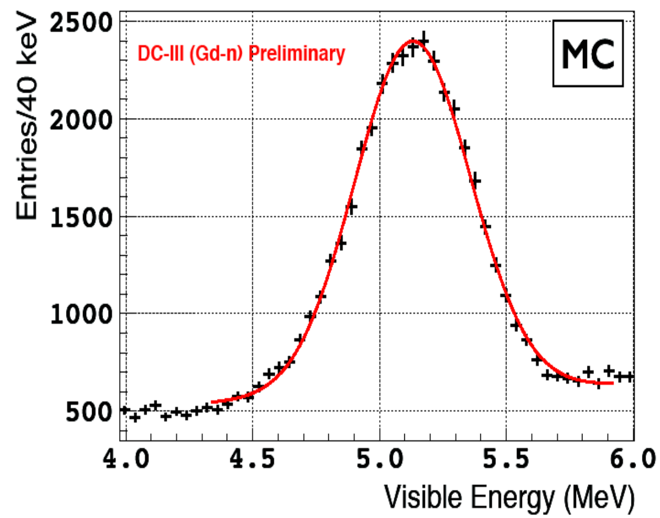
Observation in the same time with the others Θ13 experiments (despite poorest stat.) → bias excluded.

More statistics increases the clarity, however, seen also in past analysis (porer: statistics, bkg reduction, energy scale) and for n-Gd and n-H analyses (different: volume, response background).

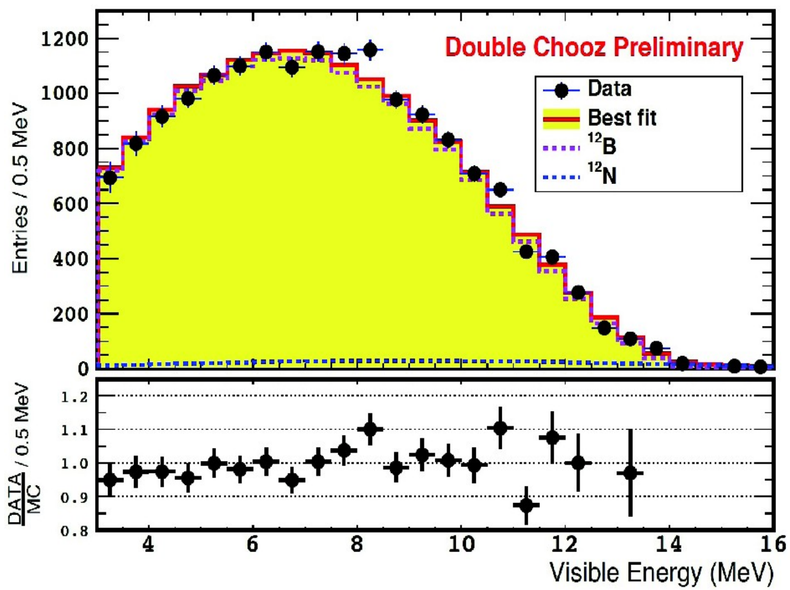
No impact on Θ13: agreement btw. RRM and R+S analyses, agreement Data/MC <4MeV

1-st Suspect: Energy scale





At ~5MeV: Remarkable (0.5%) agreement Data/MC of the n-C peak.



No consistent distortion Data/MC observed in β-decays of 12B.

Strong confirmations of the energy scale over the full range (scintillator or electronics driven effects were investigated and discarded).

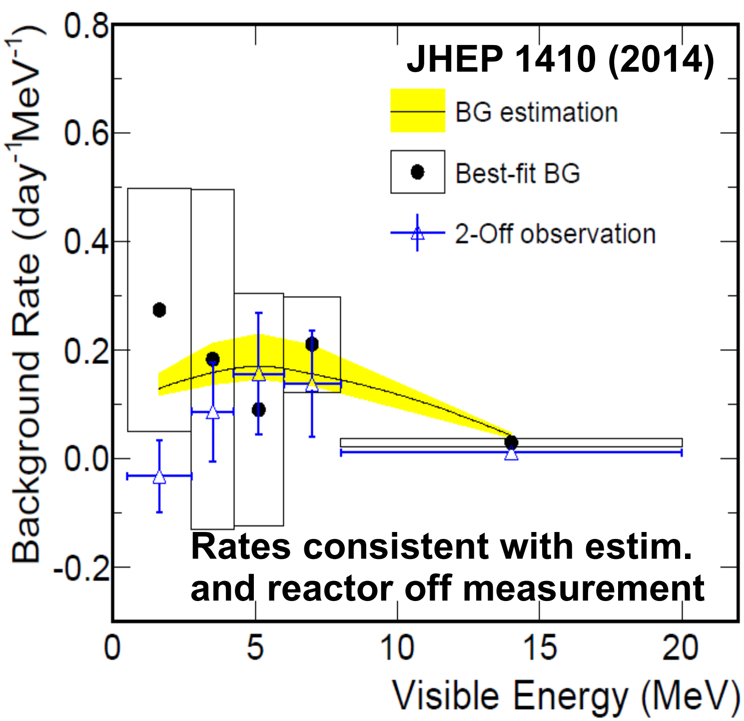
2-st Suspect: Background

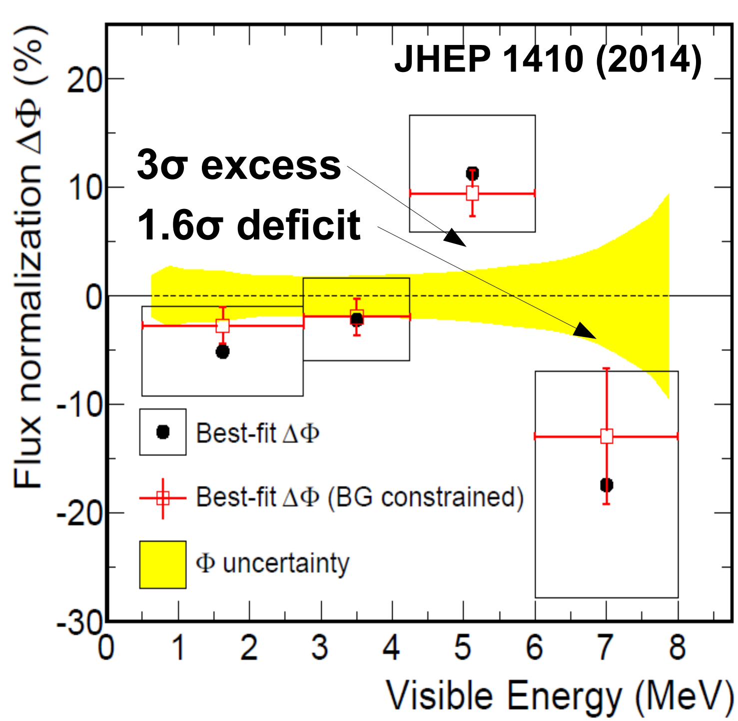
Double Chooz has the smallest number of reactors (2) among the Θ13 experiments
→ **strong influence on the statistical error**
→ **reactor off measurement, the strongest background model validation**

2 strategies for background estimation:
Exclusively → **using regular data sample**
Inclusively → **reactors Off-Off period** → **account for unknown contributions.**

2σ Tension between bkg model (exclusively) and OFF data (inclusively)
→ **no room for unknown background**

Dedicated energy binned RRM analysis capable in distinguishing the background and reactor flux hypotheses as the cause of the excess. (Θ13 value of DB plugged in).





The observed spectrum distortion originates from the reactor flux prediction, while the unknown background hypothesis is not favored.

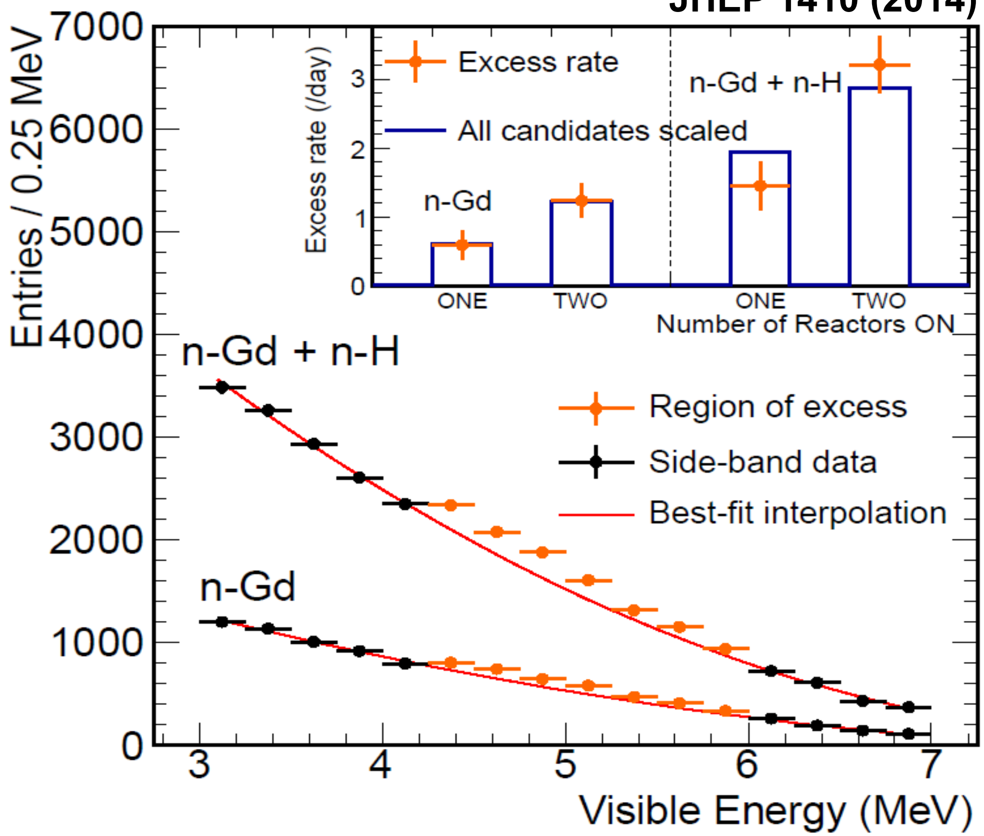
3-st Suspect: Reactor Flux

Dedicated study of the IBD rate, targeted on the region of the excess.

Poly2 interpolation below 4.25 MeV and above 6 MeV → excess region

Analysis done with n-Gd alone and n-H additional.

JHEP 1410 (2014)

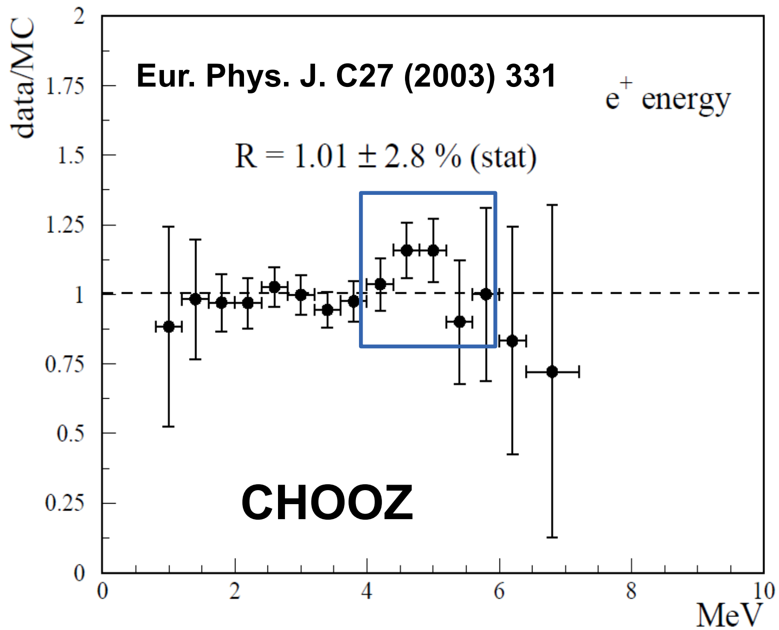


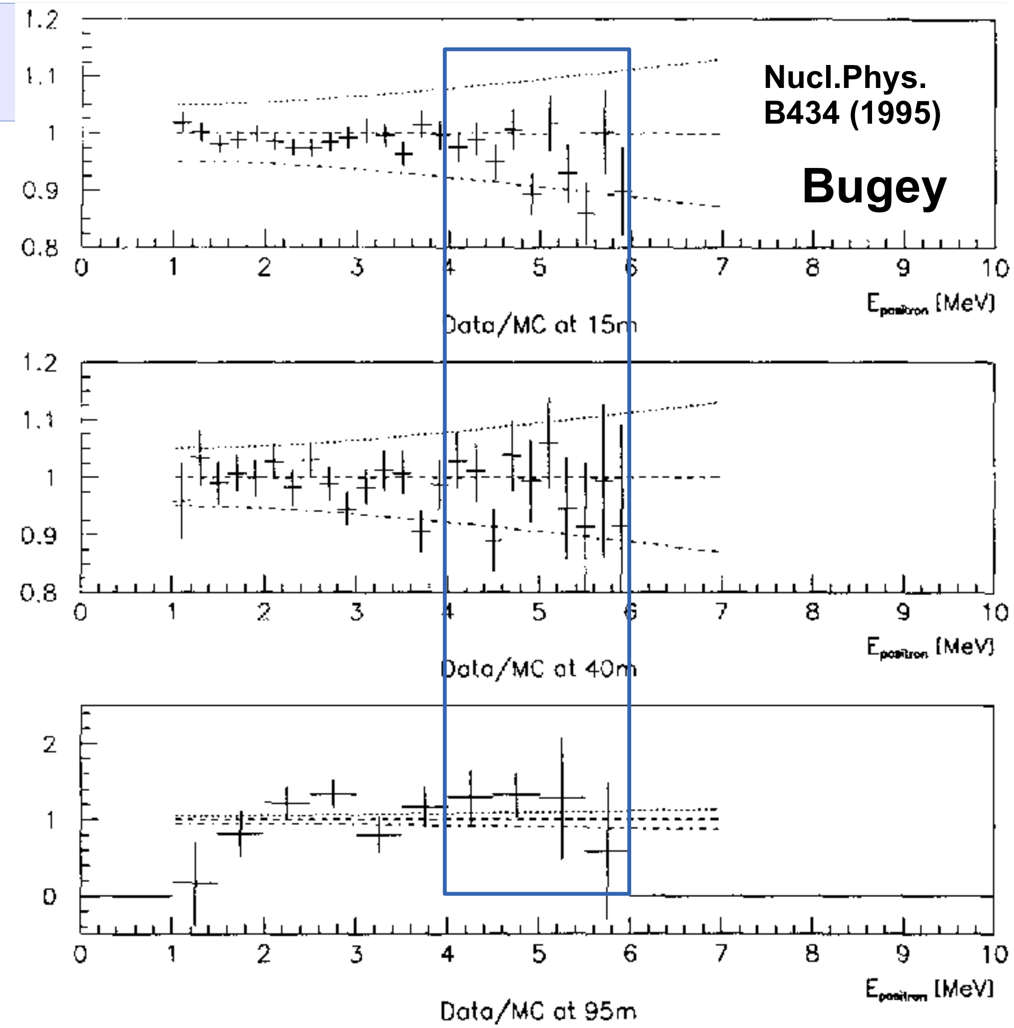
Strong correlation btw. excess and number of running reactors.

Correlation increase with statistics (n-H + n-Gd vs. n-Gd)

Background hypothesis elimination.

Beyond Double Chooz





Confirmations of the excess seen in Double Chooz, are provided also by Reno and Daya Bay → see the presentations of S. Seon Hee and D. Dwyer at this workshop.

Previous hints given by CHOOZ and Rovno (arXiv:1207.6956), not seen in Bugey.

Confirmations of the anomaly by different experiments → remove some "suspects".

Summary

Visible distortions Data/MC above 3.2 MeV which doest not seem to change the rate. The significance in Double Chooz is 3σ for [4,6] MeV and 1.6σ for [6,8] MeV.

Double Chooz (smallest detector FD only) was the one of the first experiments which highlighted this topic. → the high level of analysis

RO & RRM insensitive to shape → all DC3 $\theta 13$ results are consistent.

Strong evidences to infirm the detector and background related hypotheses.

Different detectors see the same general feature.