Status of Double Chooz and first near detector data

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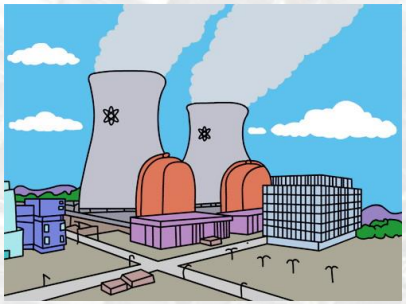
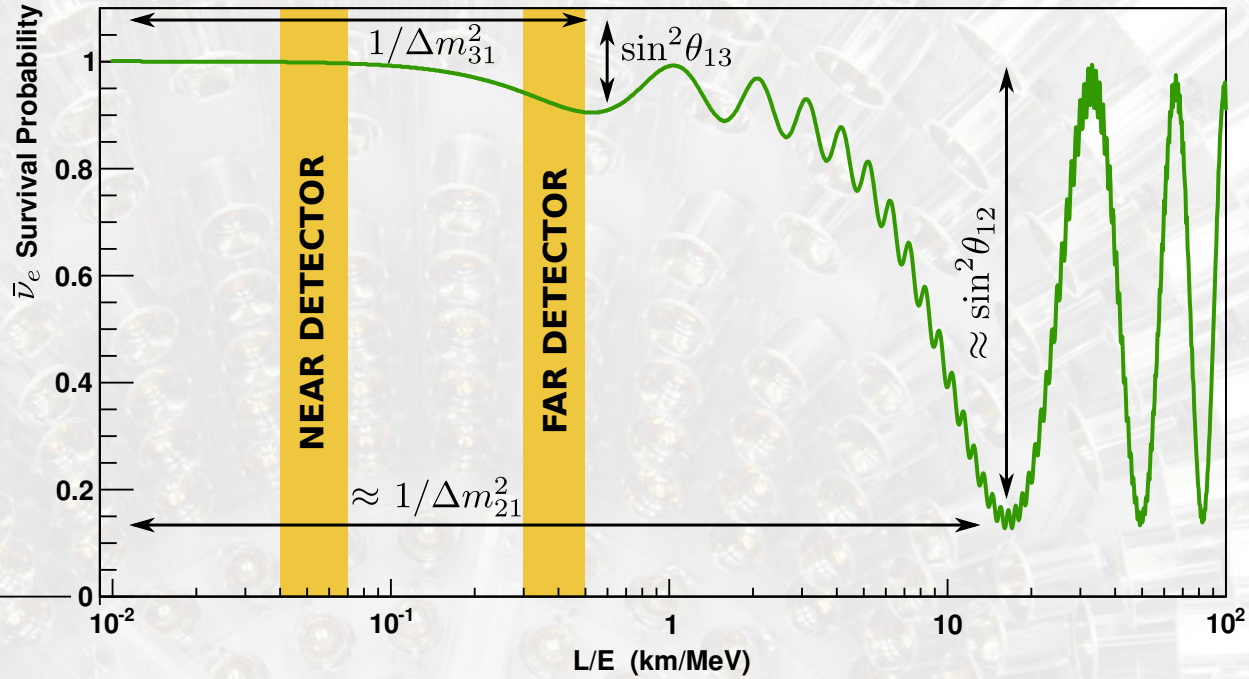
GDR Neutrino, Marseille
November 27th, 2014

Measurement of θ_{13} with reactor neutrinos

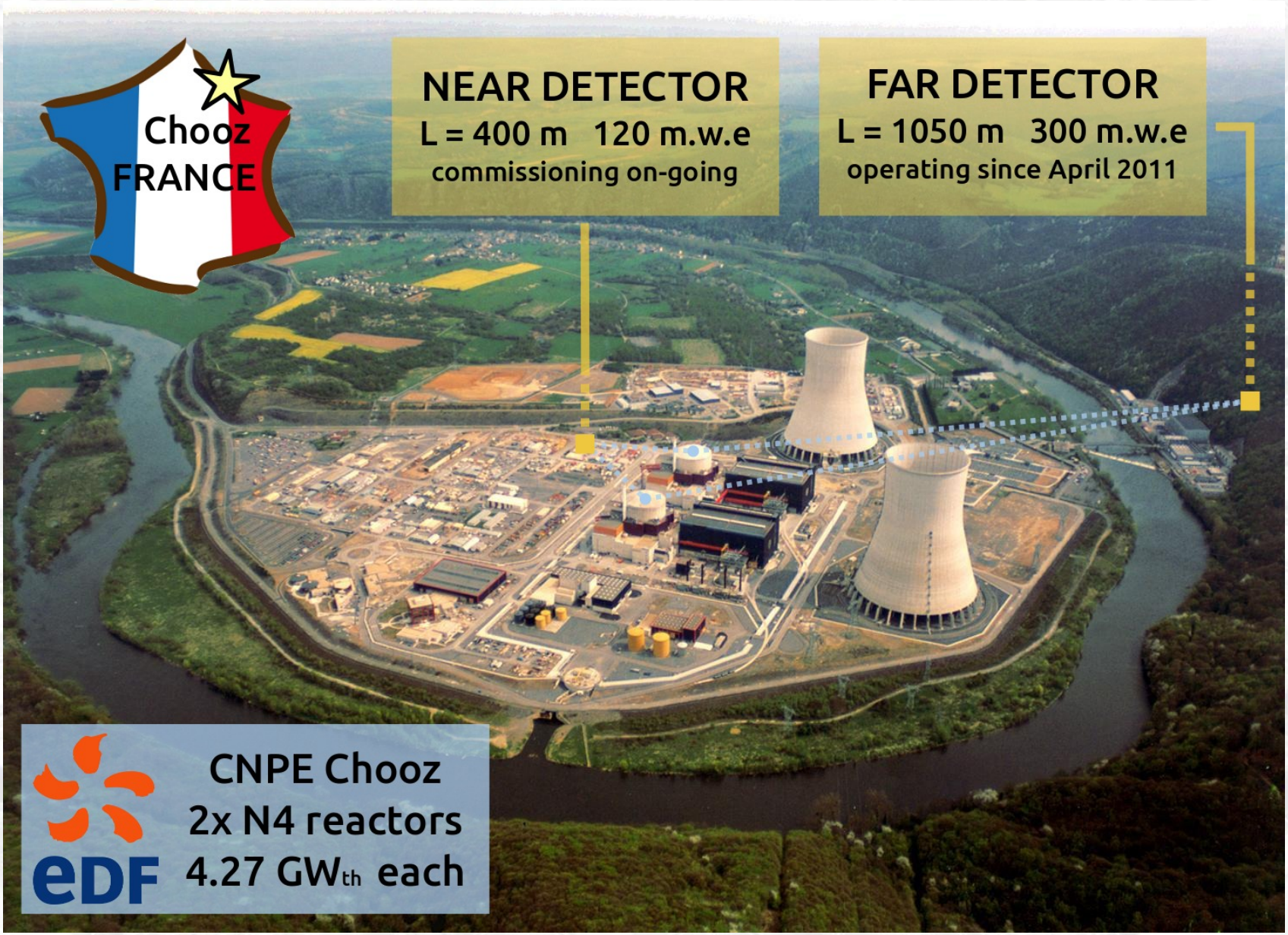




$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \sin^2(2\theta_{13}) \sin^2\left(\frac{\Delta m^2_{31} L}{4 E}\right) + O(10^{-3}) \quad \text{for } L/E \lesssim 1$$

- survival probability depends of L/E_ν $\rightarrow$ measurement based on **rate and shape** deformation
- **reactor neutrinos**: pure $\bar{\nu}_e$, high intensity ($\sim 10^{21}$ $\bar{\nu}_e$/sec), low energy $\rightarrow$ short baseline, no oscillation parameters correlation and no matter effect (**direct measurement**)
- precise measurement of θ_{13} by **2 identical detectors** (cancel flux & efficiency uncertainties)
  – far detector $\rightarrow$ disappearance of $\bar{\nu}_e$ around first minimum
  – near detector $\rightarrow$ unoscillated neutrino flux

Double Chooz experimental layout



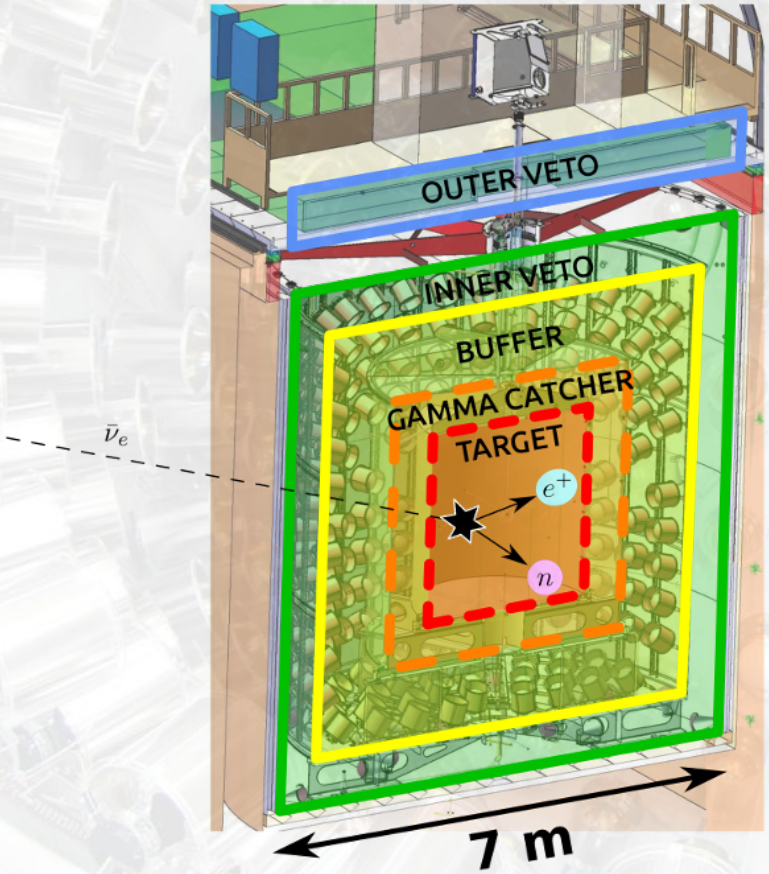
Principle of $\bar{\nu}_e$ detection

INVERSE BETA DECAY on proton (threshold > 1.8 MeV)

$$\bar{\nu}_e + p^+ \longrightarrow e^+ + n$$

prompt signal: scintillation + e^+ annihilation
$E_{prompt} \approx E(\nu_e) - 0.8$ MeV

delayed signal: γ ray(s) from neutron capture
n-Gd $E_{delayed} \approx 8.0$ MeV $\Delta T \approx 30$ μs
or n-H $E_{delayed} \approx 2.2$ MeV $\Delta T \approx 200$ μs



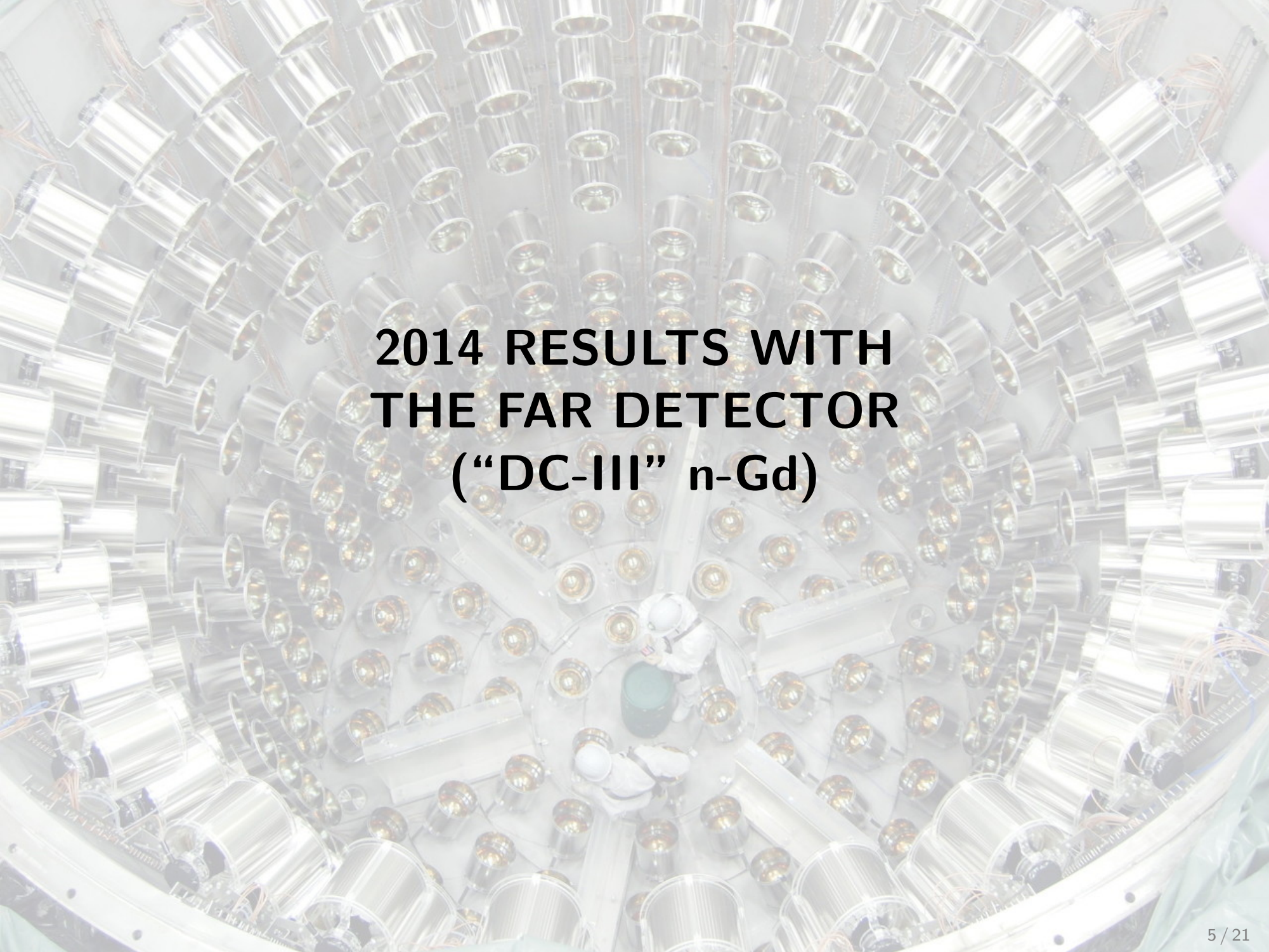
Neutrino target:
liquid scintillator PXE + Gd

Gamma catcher:
liquid scintillator PXE (no Gd)

Buffer volume:
transparent mineral oil
with 390 x 10" PMTs assembly

Inner Veto:
liquid scintillator (LAB)
with 78 x PMTs 8"

Outer Veto:
plastic scintillator strips



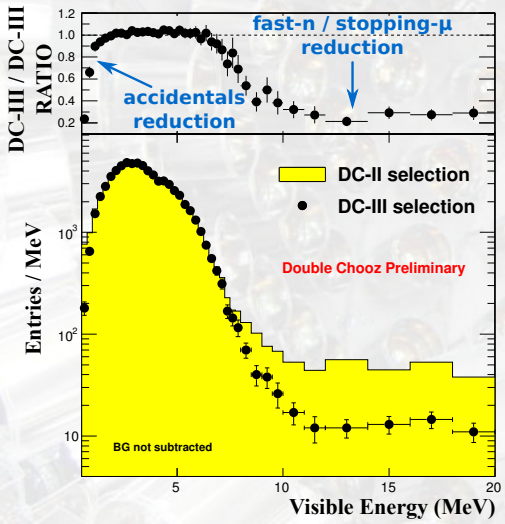
2014 RESULTS WITH THE FAR DETECTOR ("DC-III" n-Gd)

DC-III new event selection

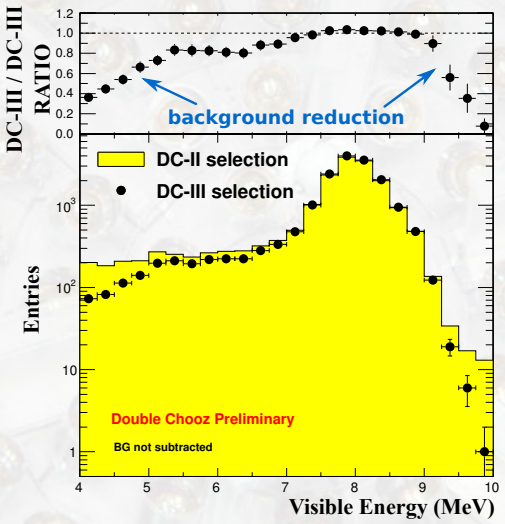
	DC-II (2012)	DC-III (2014)
Prompt Energy	0.7 – 12.2 MeV	0.5 – 20 MeV
Delayed Energy	6 – 12 MeV	4 – 10 MeV
Δ t	2 – 100 μs	0.5 – 150 μs
Δ R	n/a	$<$ 1 m
isolation window	[-100, +400] μs	[-200, +600] μs

- **muon veto:** $\Delta t_{last-\mu} > 1$ ms
- **OV veto:** no OV hit coincident with prompt
- **^{9}Li veto:** likelihood method trained with ^{12}B ^{9}Li rejection $> 50\%$ with dead time $< 0.5\%$
- **"FV" veto:** point-like characterisation of energy deposit (reject stopping muons)
- **IV veto:** reject fast-neutrons and accidentals
- **light noise:** improved criteria on charge isotropy and simultaneity of PMT signals

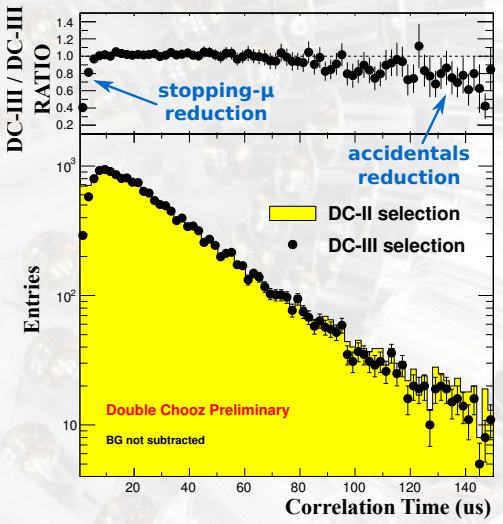
opened selection cut (more signal) + new vetos (less background)



— Prompt —

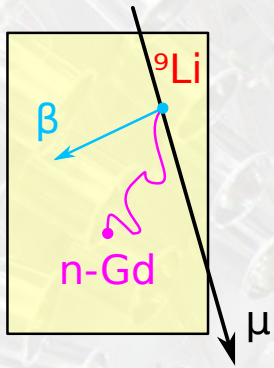


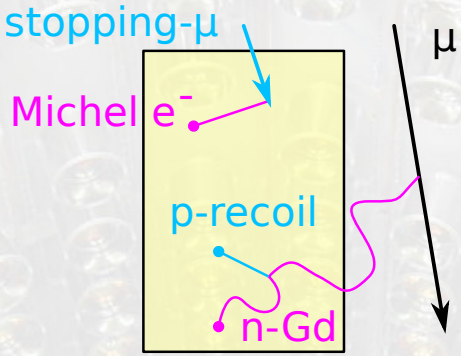
— Delayed —

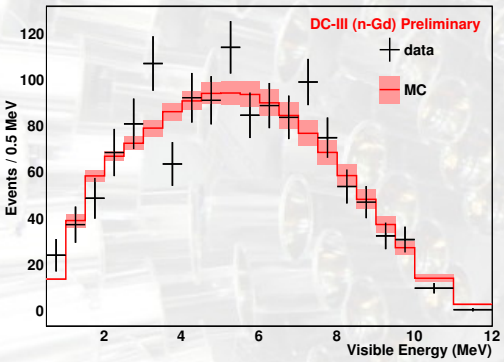


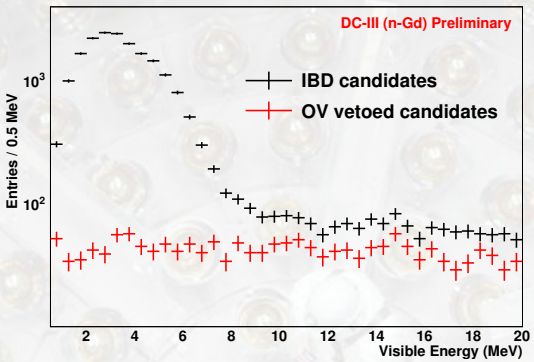
— ΔT —

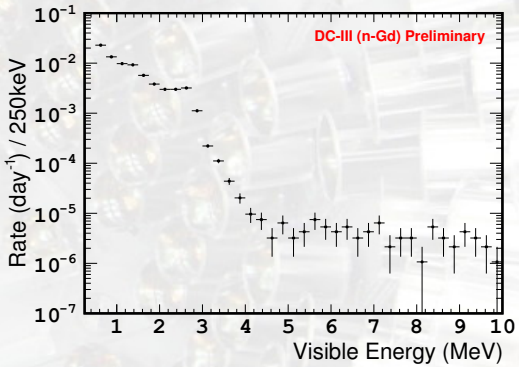
DC-III neutrino backgrounds











Cosmogenetic background

β-n emitter (mainly ^{9}Li)

- 0.97 $^{+0.41}_{-0.16}$ /day

DC-II: 1.25 ± 0.54 /day

Correlated background

fast neutrons, stopping-μ

- 0.60 ± 0.05 /day

DC-II: 0.67 ± 0.20 /day

Accidental background

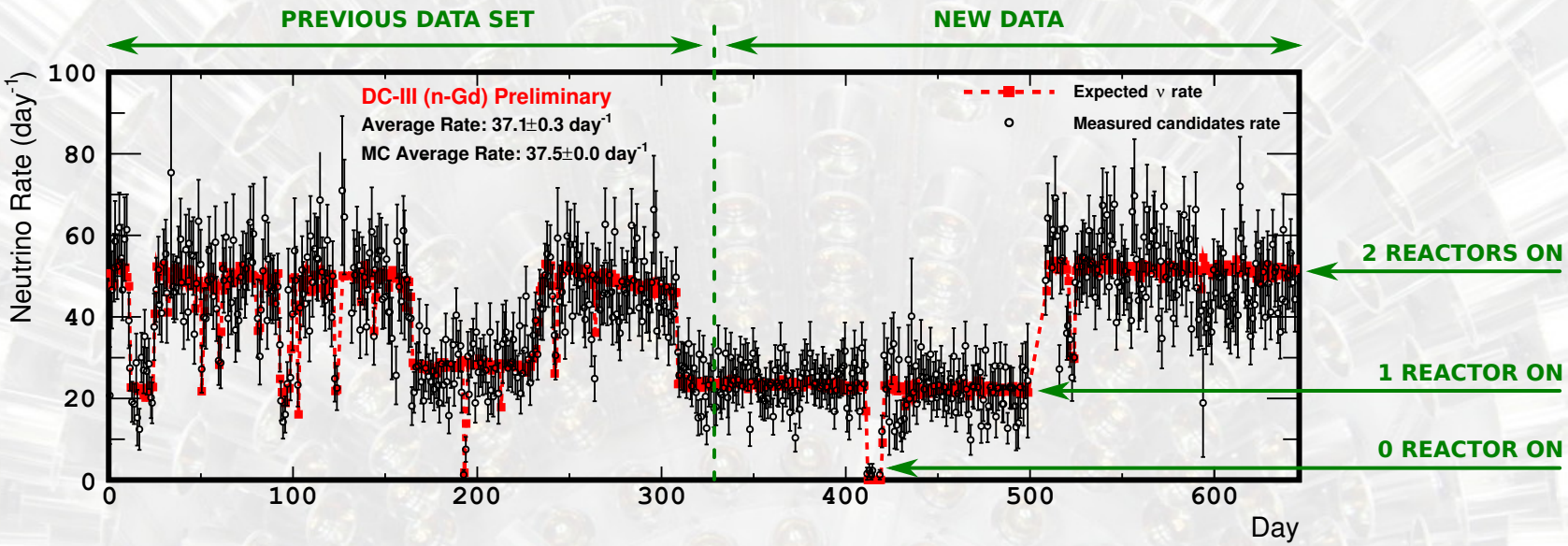
natural radioactivity

- 0.070 ± 0.005 /day

DC-II: 0.261 ± 0.002 /day

less background + more precise measurement of rate and shape

DC-III neutrino candidates

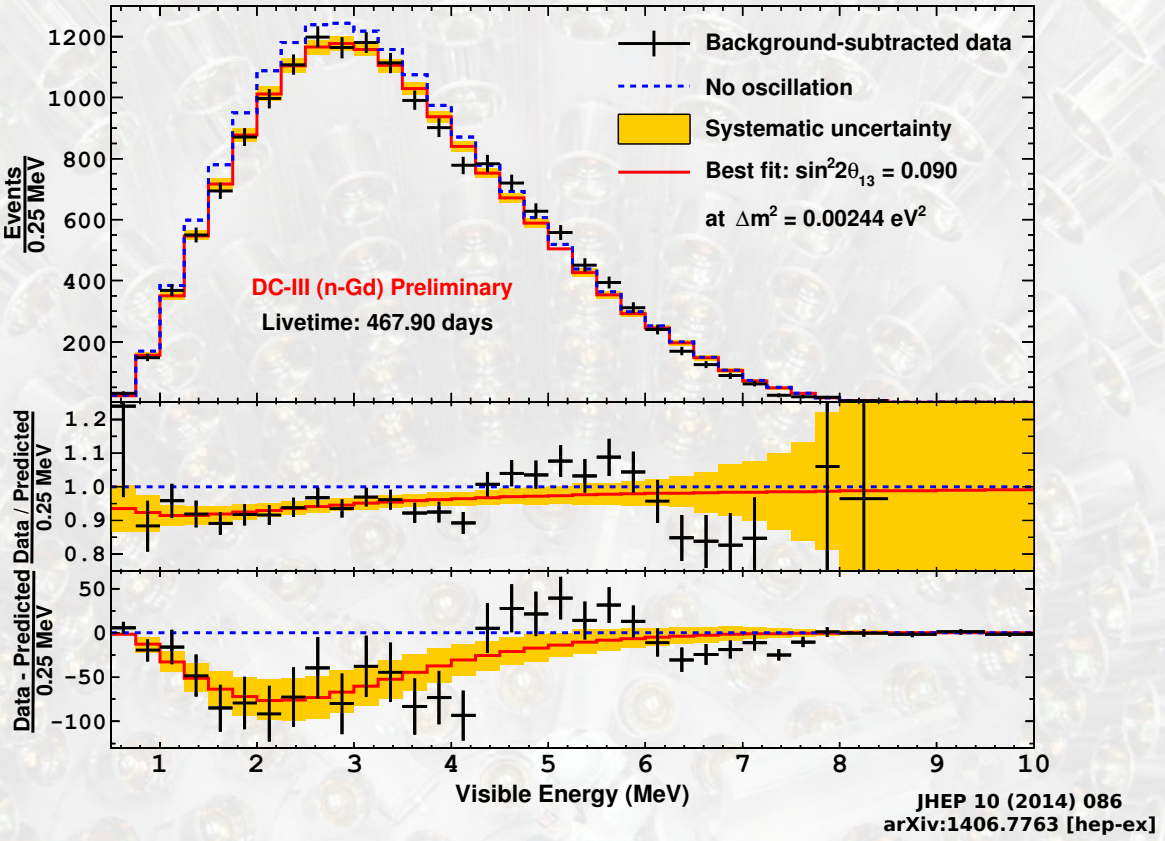


New Gd data set

- data from April 2011 to January 2013
- live time: 467.9 days (previously: 227.9 days)
  $\rightarrow$ including 7.5 days of two reactors OFF data
- 17'358 neutrinos candidates (previously: 8'249 candidates)

statistics of neutrino candidates is doubled

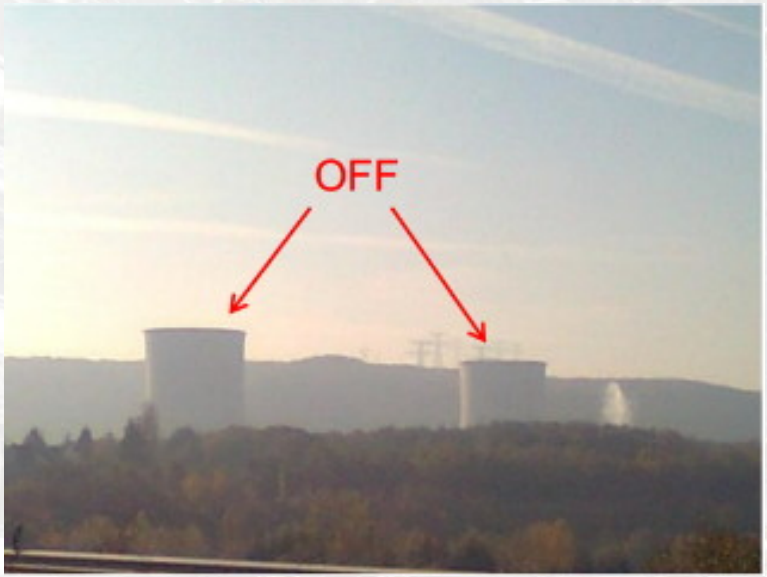
2014 Rate + Shape results (Gd)

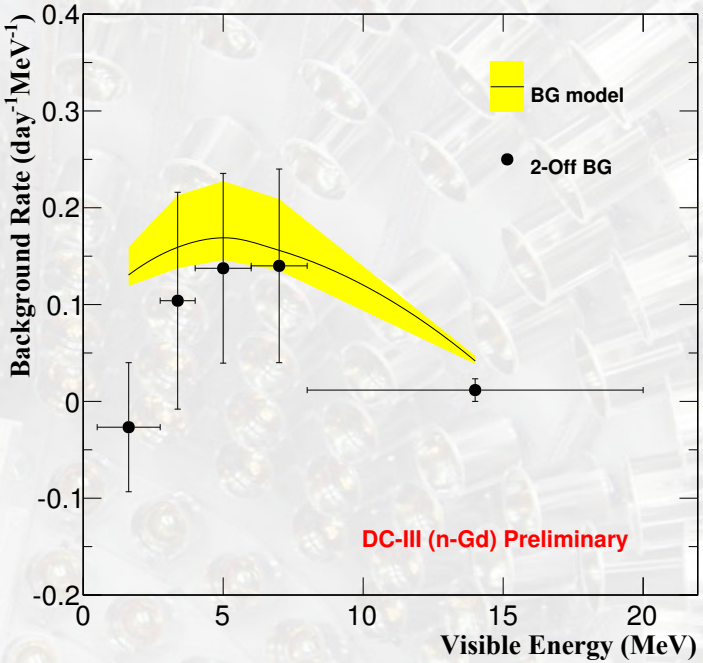


$$\sin^2(2\theta_{13}) = 0.090\ ^{+0.035}_{-0.028}$$ previous results: 0.109 ± 0.039

- excellent spectral distortion in 0.5 – 4 MeV (region constraining θ_{13} fit)
- origin of E/L structure $>$ 4 MeV under investigation integrated effect negligible on θ_{13}

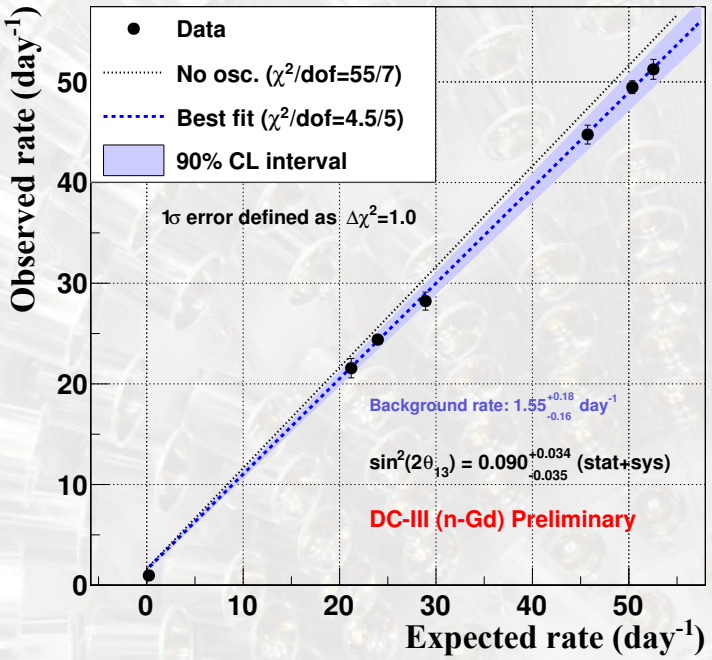
2014 Two reactors OFF results

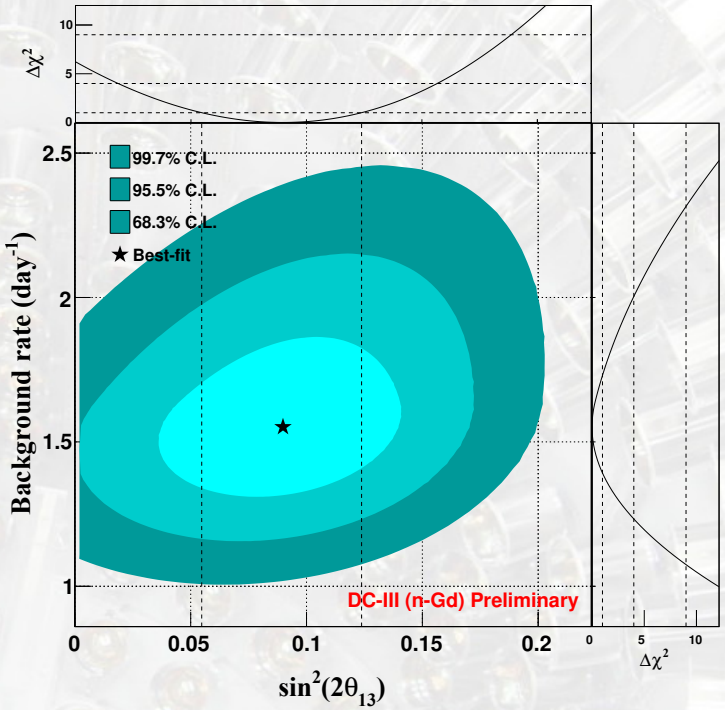




- only experiment with 7.5 days of data with all reactors OFF
  $\rightarrow$ unique opportunity to measure background
- observed events rate: 0.97 ± 0.37 /day vs expected: $1.78\ ^{+0.43}_{-0.19}$ /day
- good agreement in 4 – 8 MeV region
- small deficit of data outside $\rightarrow$ disfavor missing/unknown background

2014 Reactor Rate Modulation analysis





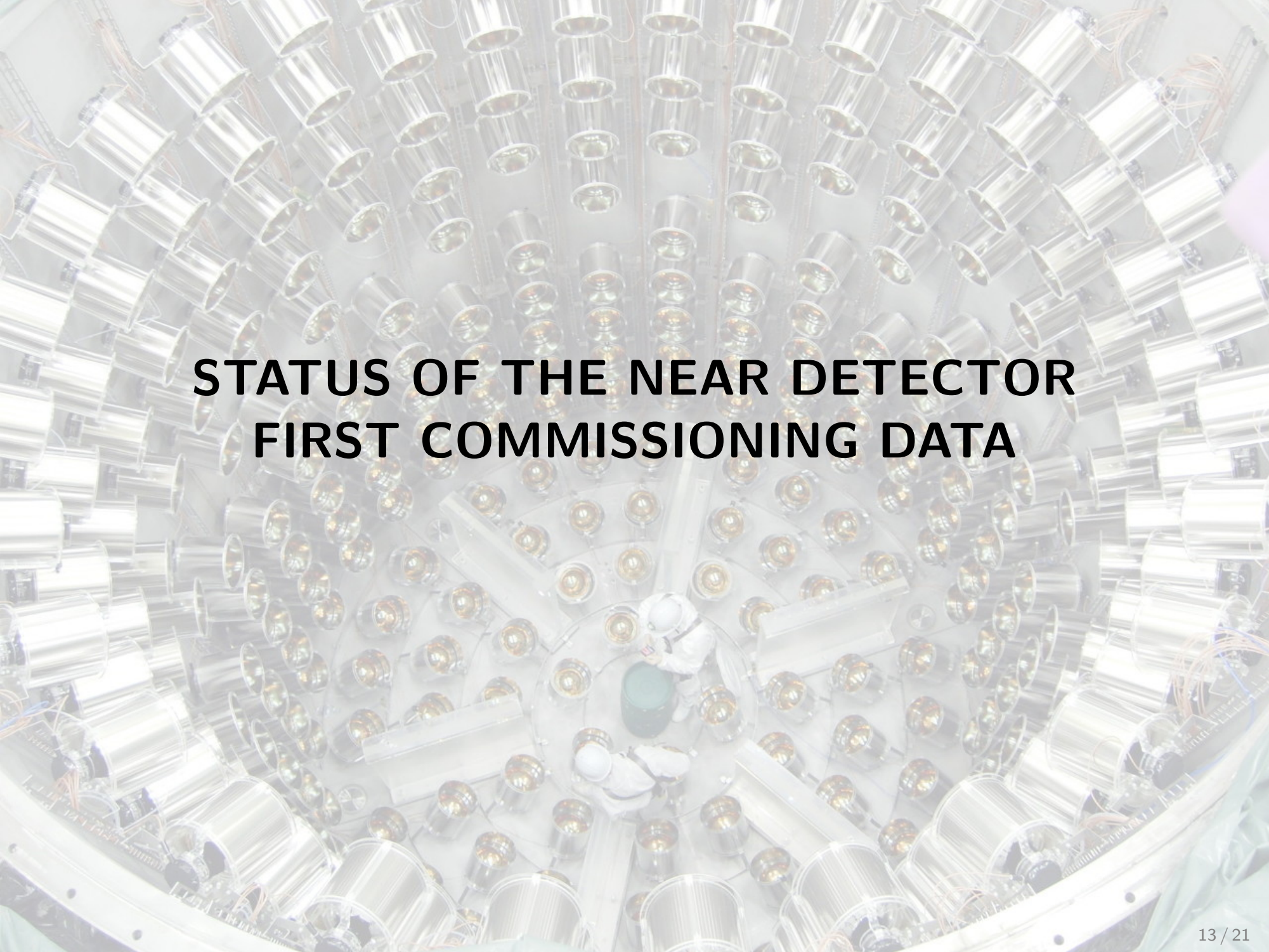
- exploit the 100 % variation in reactor power unique with Double Chooz
- independent measurement of θ_{13} (slope) and background (intercept):

$$\sin^2(2\theta_{13}) = 0.090\ ^{+0.034}_{-0.035} \qquad \text{background rate} = 1.55\ ^{+0.18}_{-0.16}\ /\text{day}$$

- consistent with rate+shape fit and OFF-OFF data
- most precise "rate-only" measurement

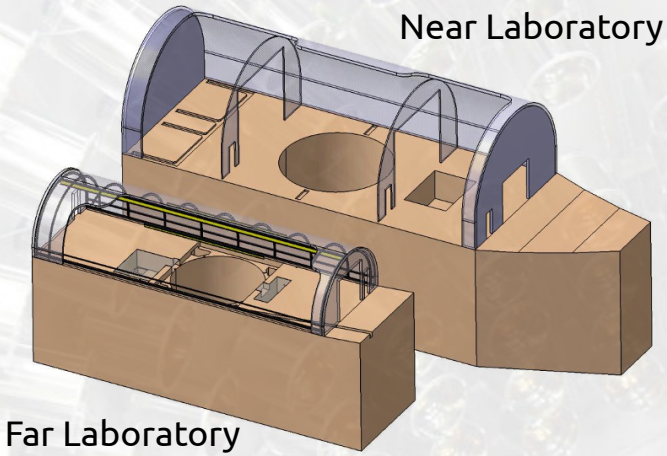
More 2014 results ...

- **Precision Muon Reconstruction in Double Chooz**
  Nucl. Inst. Meth. A 764 (2014) 330 arXiv:1405.6227
- **Improved measurements of the neutrino mixing angle θ_{13} ...**
  JHEP 10 (2014) 086 arXiv:1406.7763
- **Ortho-positronium observation in the Double Chooz Experiment**
  JHEP 10 (2014) 032 arXiv:1407.6913 $\longrightarrow$ **Timothée's talk this afternoon**
- finalising an improved n-H analysis using DC-III data set



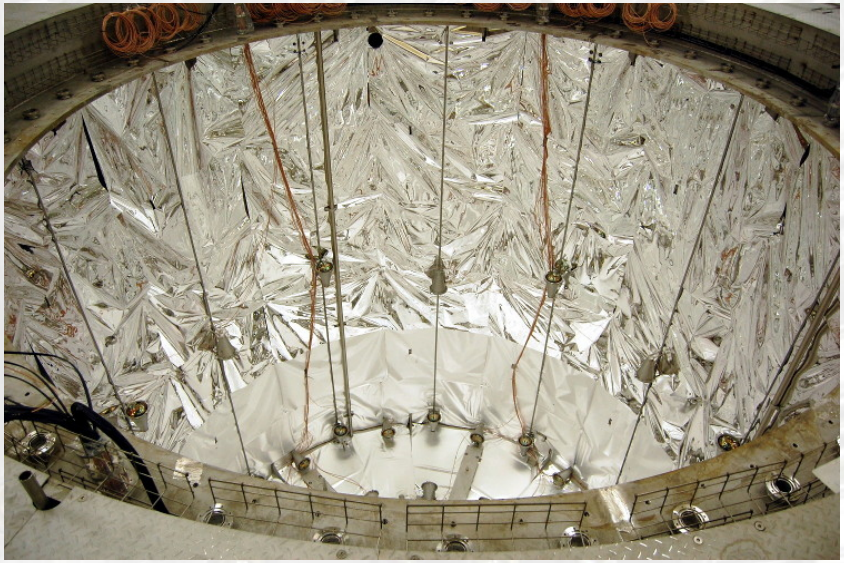
STATUS OF THE NEAR DETECTOR FIRST COMMISSIONING DATA

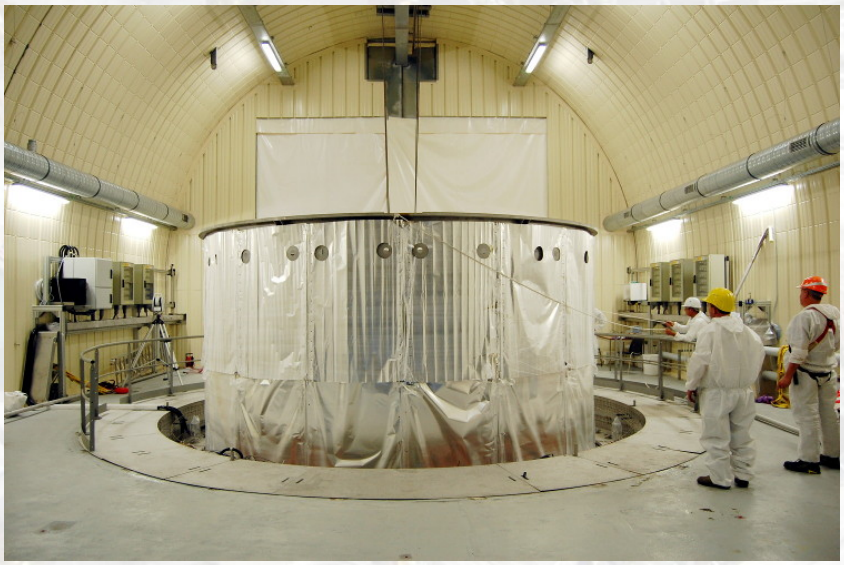
Near Laboratory



- larger laboratory divided into 3 clean rooms
  to parrallelise integration tasks for $\approx$ 1 year construction
- larger pit to afford a 1 m thickness water shielding around the detector
- digging of tunnel + underground laboratory started in 2011
- laboratory fully delivered on May 2013 $\rightarrow$ beginning of the detector integration

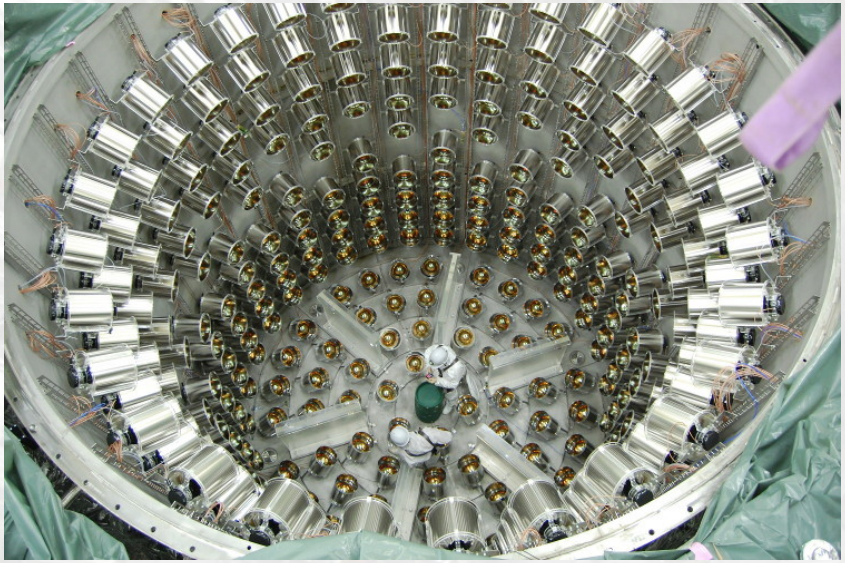
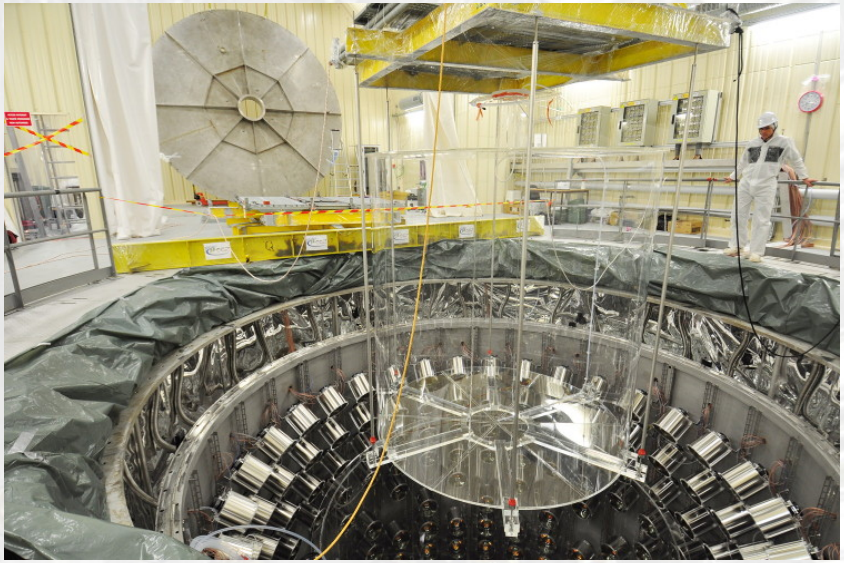
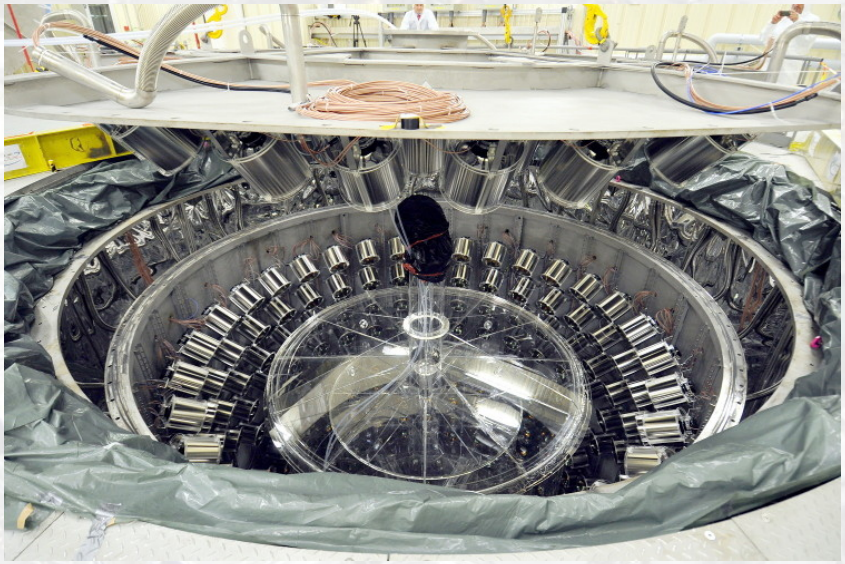
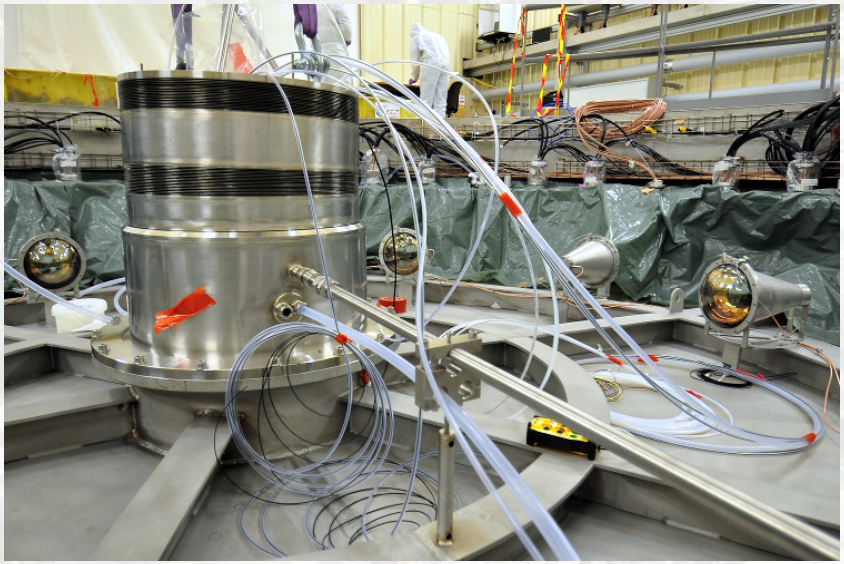
Near detector integration (1/3)



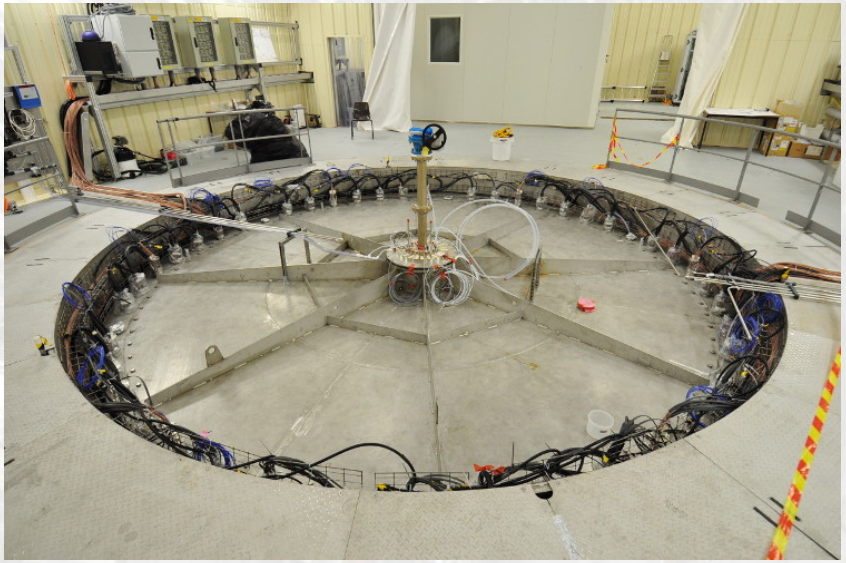
Inner-Veto vessel $\rightarrow$ **Inner-Veto PMTs** $\rightarrow$ **Inner-Detector vessel**

Near detector integration (2/3)

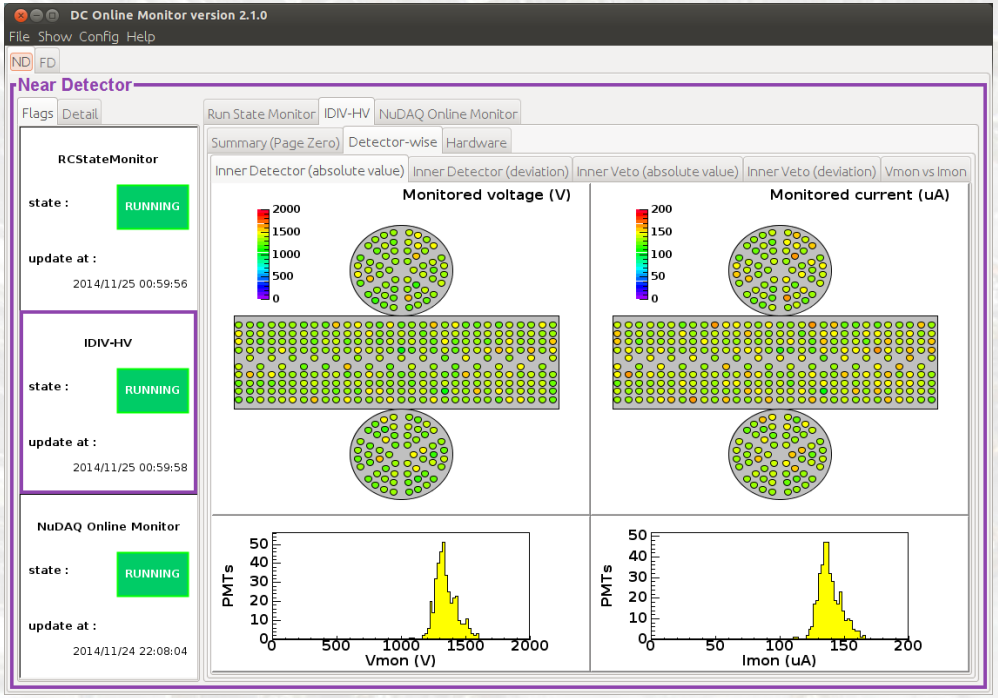
Inner-Detector PMTs → acrylics vessels → chimney connections

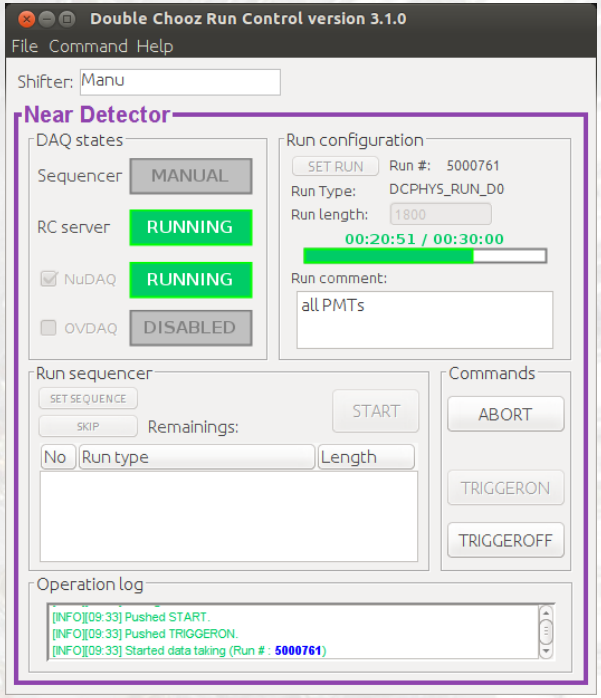
Near detector integration (3/3)



detector closed $\rightarrow$ **filling** $\rightarrow$ **top shielding** $\rightarrow$ **DAQ/electronics**

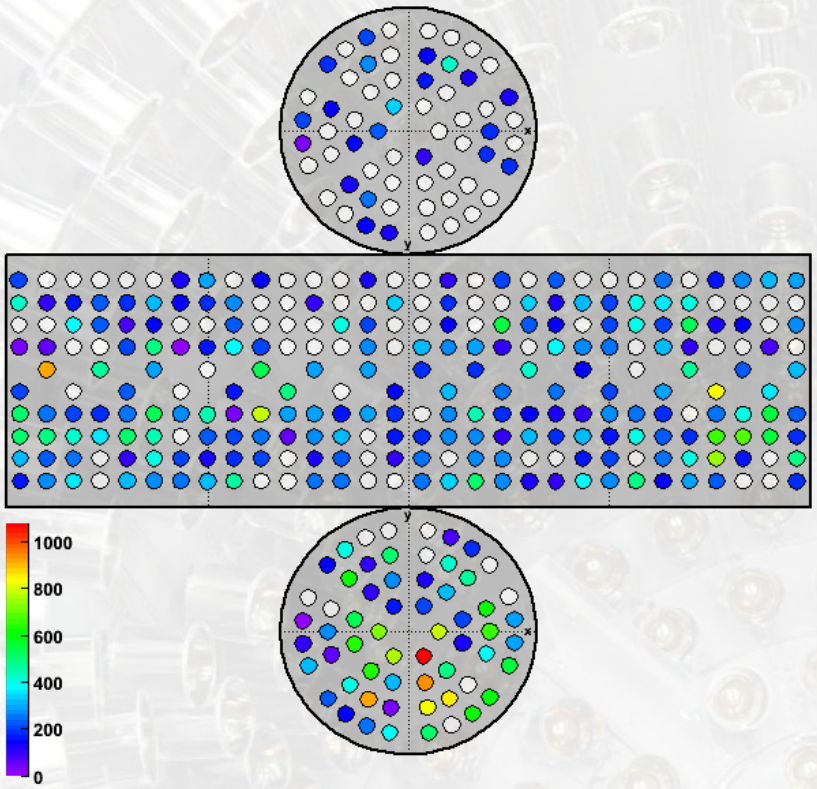
Near detector commissioning status

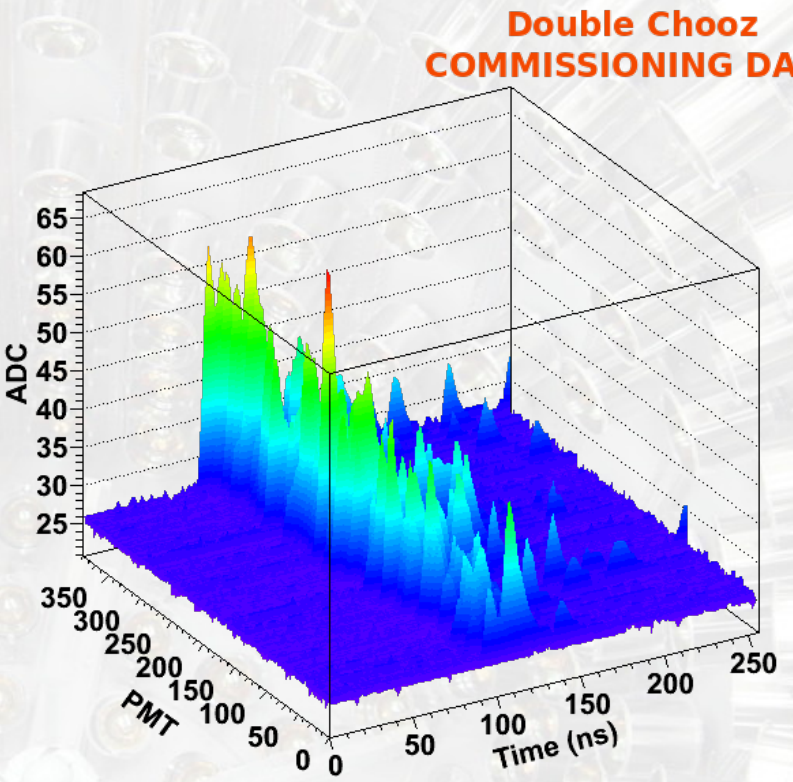




- detector is alive (ON) and stable for few weeks now
- start training shifters handling 2 detectors with new GUIs
- working on data reduction scheme by DAQ: replace PMTs waveforms by reduced data (PMT charge, tstart, ..) for muon events tagged by trigger ($>$ 200 Hz)
- preparation of an automated data reconstruction at CC/IN2P3

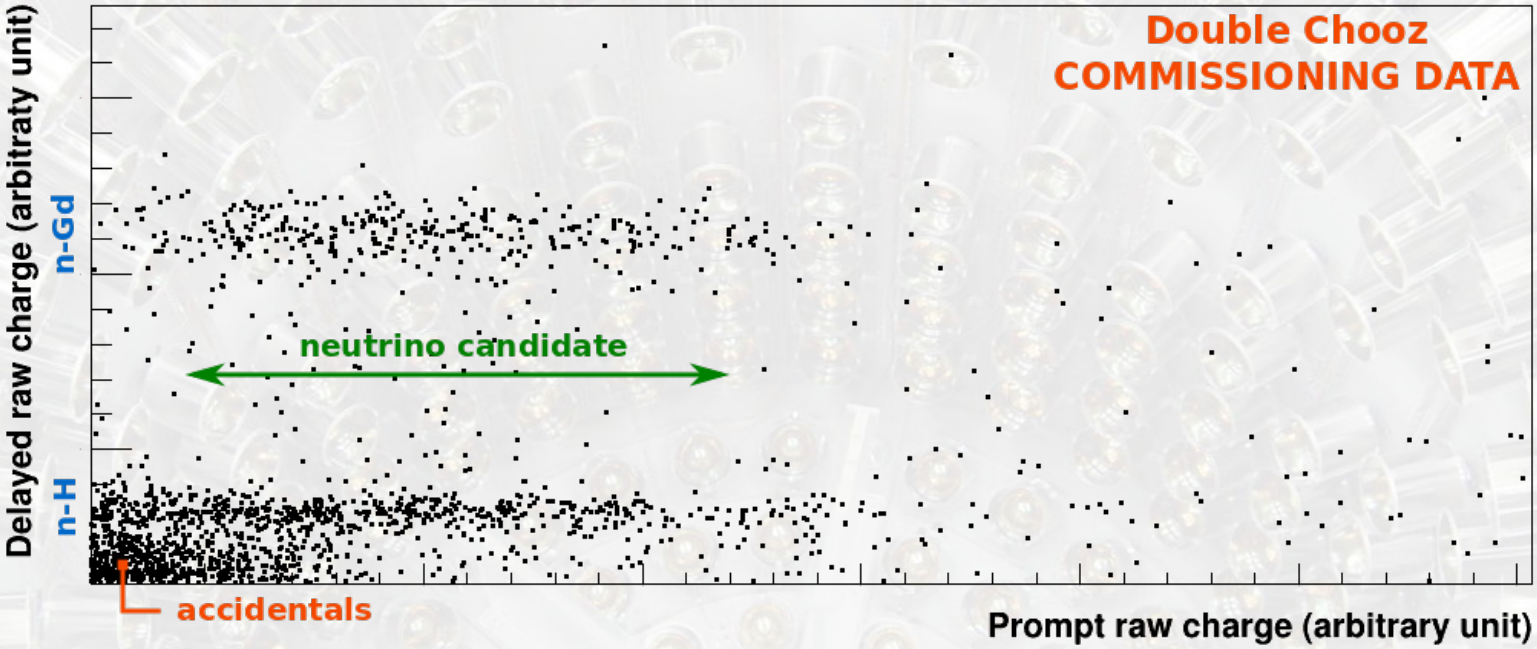
Observation of first “near” neutrinos





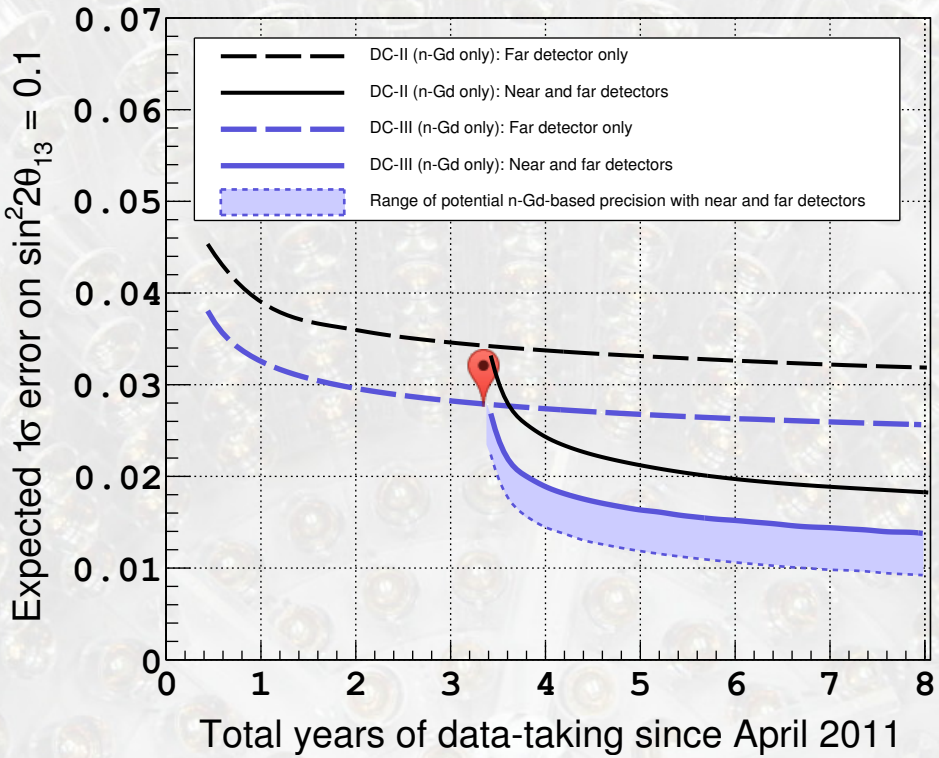
- first neutrinos candidates were seen!
  basic selection based on DC-III cut: muon veto, Δt prompt-delay, isolation window

Observation of first “near” neutrinos



- first neutrinos candidates were seen!
  basic selection based on DC-III cut: muon veto, Δt prompt-delay, isolation window
- clear and clean IBD signal (no calibration + no advanced reconstruction!)

Future prospect with near+far detector



- remarkable improvement with the new Gd analysis
- first data near the detector will improve sharply the precision
  (projection based on DC-III background model $\rightarrow$ improvement expected and in preparation)
- expect to challenge a final sensitivity of ≈ 0.01 on $\sin^2(2\theta_{13})$

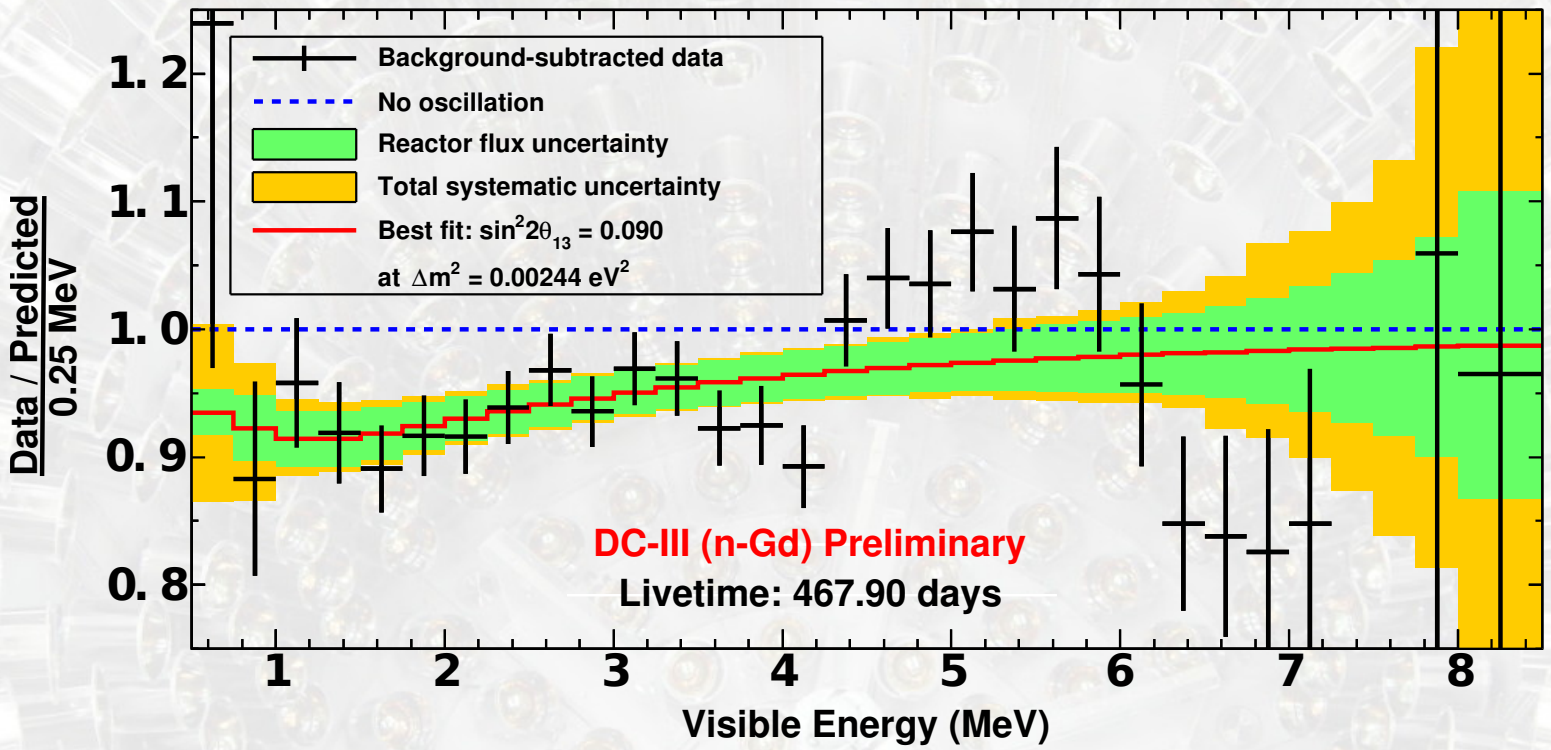
Talk summary

- **2014 results with far detector only:**
  - more statistics, better selection and background rejection
  - $\sin^2 2\theta_{13} = 0.090\ ^{+0.035}_{-0.028}$ fully consistent with previous publications
  - new improved H analysis to follow
- **near detector status:**
  - detector is completed, filled and alive
  - excellent performance at early commissioning stage
- **coming phase with 2 detectors:**
  - quick cancellation of systematics of flux and detection efficiency
  - target a final precision of ≈ 10 % on $\sin^2(2\theta_{13})$
  - investigate further the E/L structure above 4 MeV
  - more physics: reactor anomaly, sterile neutrino, reactor monitor, ...

DOUBLE CHOOZ HAS TWO DETECTORS NOW
STAY TUNE FOR UPCOMING 2015 RESULTS!

BACKUP

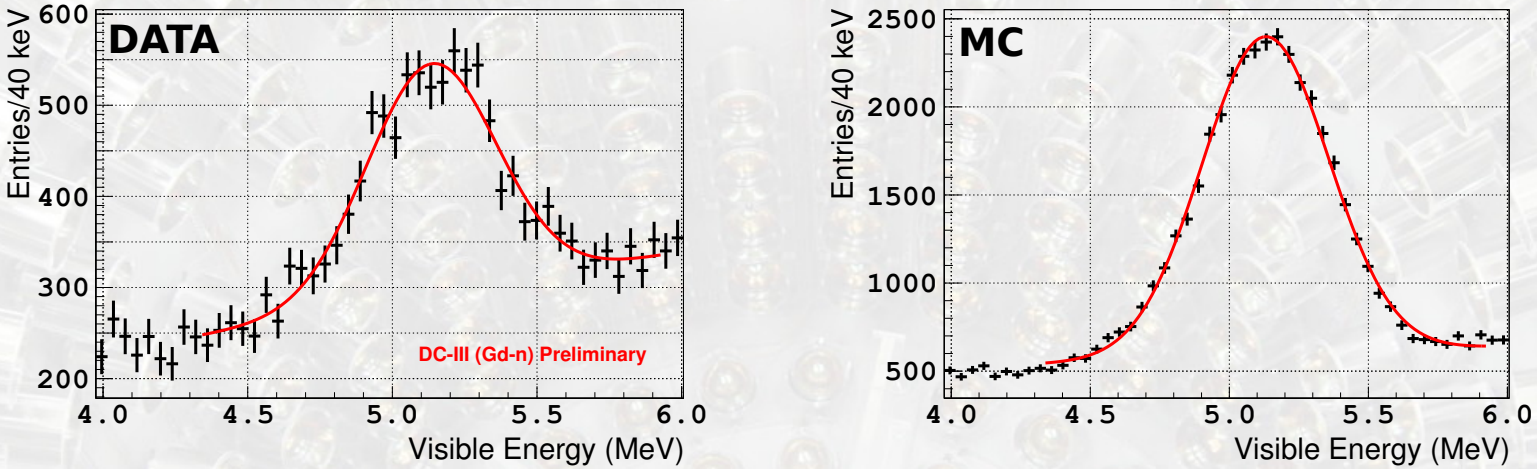
E/L structure investigation: robustness of rate+shape fit



- test rate+shape fit with an additional/hypothetical background:
  n-C-capture-like peak ($\approx$ 5 MeV) with several normalisations and shapes
- largest deviation observed: 0.3 σ on $\sin^2(2\theta_{13})$, 0.1 σ on ^{9}Li rate, $< 0.1\ \sigma$ on others

$\rightarrow$ **negligible impact on** θ_{13}

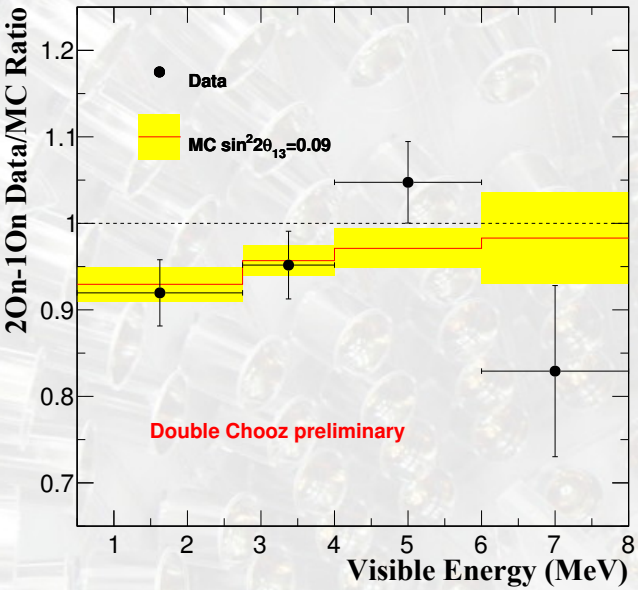
E/L structure investigation: possible culprits



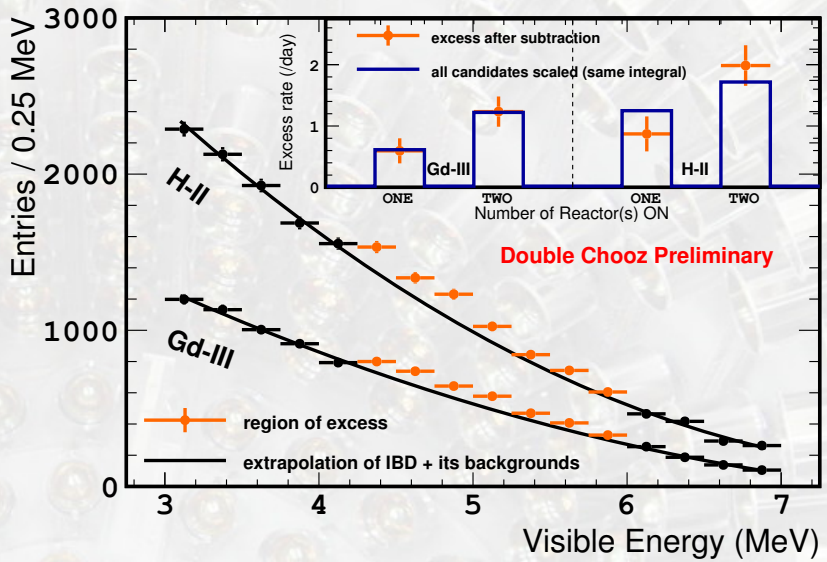
n-C peak reconstruction in GC

- **detection systematics:** no impact on shape
- **energy reconstruction:** C-n peak in GC with Δ(data,MC) < 0.5 % $\rightarrow$ disfavored
- **background:** constrained $\rightarrow$ possible but not only the sole cause
- **reactor flux:** possible

E/L structure investigation: correlation with reactor neutrino flux



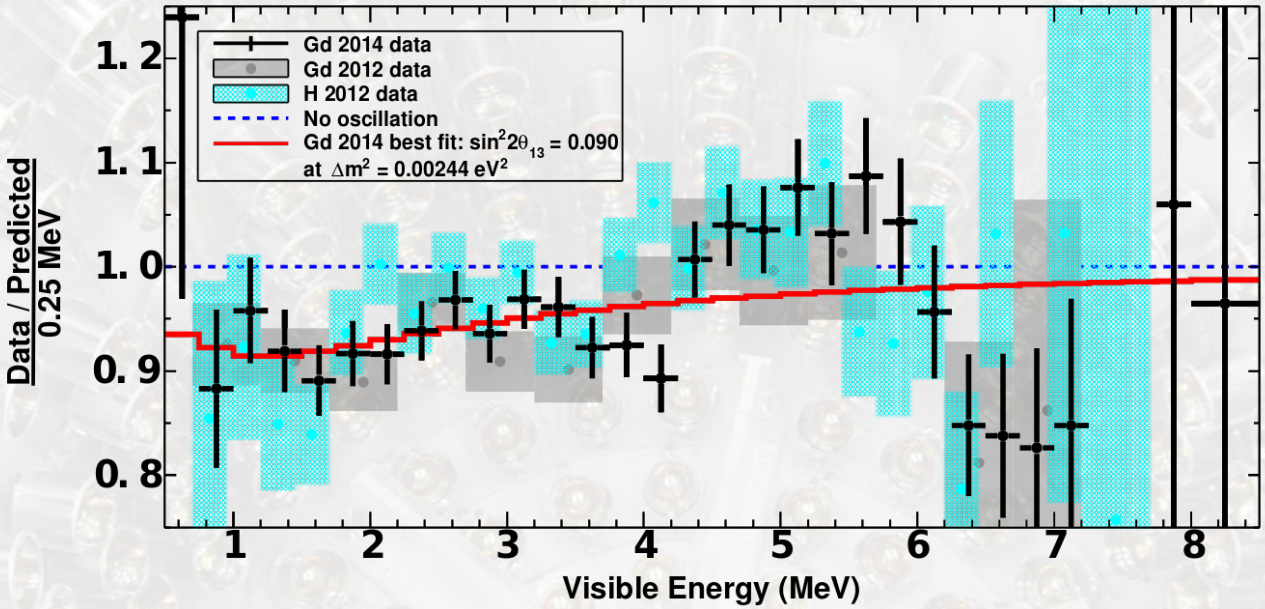
"2-ON data" – "1-ON data"



investigation of 4 – 6 MeV region (excess)

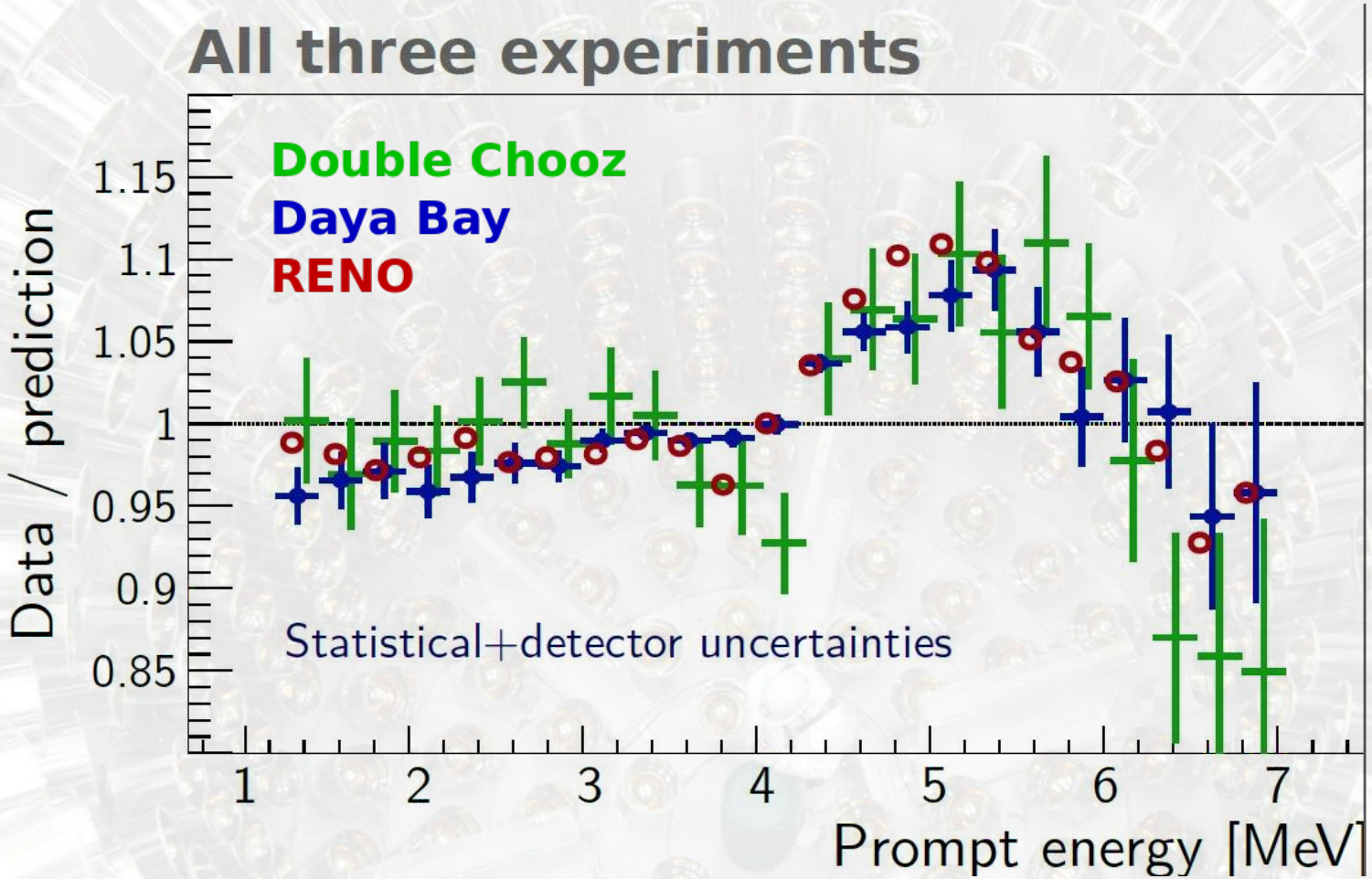
- 2 reactors ON data – 1 reactor ON data = pure 1-ON data (background free)
  → deviation consistent with observation on rate+shape fit result
- investigation of the region 4 – 6 MeV (excess of neutrino candidates):
  → rate is correlated with flux of reactor neutrinos (empirical data-driven observation)

E/L structure vs previous DC results



- same pattern observed in DC-II results
  with different selection (Gd, H) and detector volume (H)
- better resolved with DC-III (more statistics, better energy scale and less background)

E/L structure vs other experiments



- same pattern is confirmed by other reactor experiments

E/L distortion @Neutrino 2014

Reactor ν

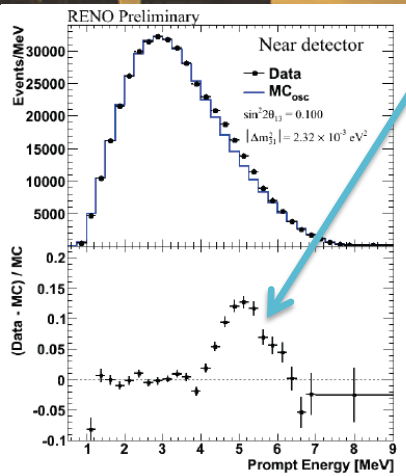
What is this?!?

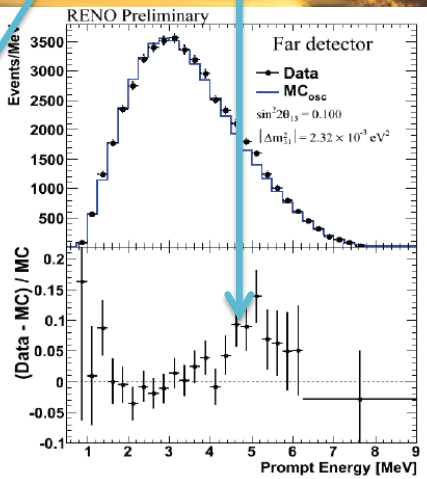
Semi - Double Chooz

New Results from RENO

XXVI International Conference on Neutrino Ph hysics

June 2-7 U.S.A.



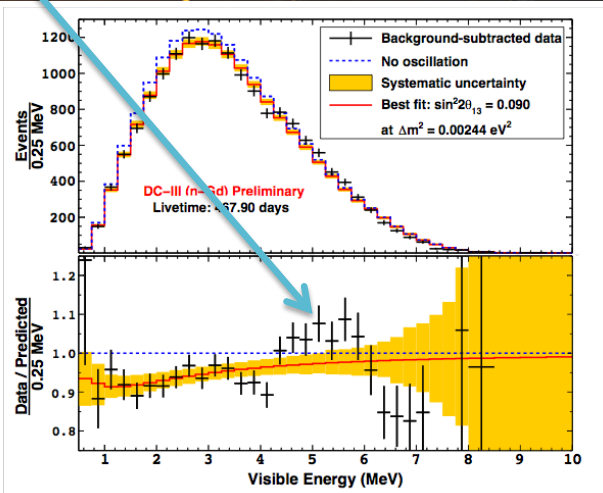


Rate only analysis ➔

Preliminary result

C data set (~800 days)

$\sin^2(2\theta_{13}) = 0.101 \pm 0.008\ (\text{stat.}) \pm 0.010\ (\text{sys.})$



Rate + shape analysis ➔

$\sin^2(2\theta_{13}) = (0.09 \pm 0.03)$

$(\chi^2/\text{n.d.f.} = 51.4/40)$

background substracted

The field benefits greatly from 3 exps!