reactor $\theta_{13}$

(*the ultimate measurement?*)

LIO Neutrinos @ Lyon (France)
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CNRS / IN2P3
Double Chooz @ APC (Paris)

Wednesday, 24 October 2012
ν-oscillations knowledge...
\[(\nu_e, \nu_\mu, \nu_\tau)^T = U (\nu_1, \nu_2, \nu_3)^T, \text{ where } U \text{ looks like}\]

\[
U = \begin{pmatrix}
1 & 0 & 0 \\
0 & c_{23} & s_{23} \\
0 & -s_{23} & c_{23}
\end{pmatrix}
\]

The "CKM"

\[
\Delta m_{31}^2
\]

\[
\Delta m_{31}^2
\]

\[
\Delta m_{21}^2
\]

"atmospheric" \(\rightarrow\) \(\theta_{23} \sim 45^\circ\)

\(\theta_{13} < 11^\circ\) & "dirac" \(\delta_{CP}\)

"solar" \(\rightarrow\) \(\theta_{12} \sim 33^\circ\)

Knowledge on \(\theta_{13}\) & \(\delta_{CP}\) [later]

Fogli et al. arXiv:1106.6028
Previous hints of $\theta_{13} > 0$
are now measurements!
(and basically independent
of old/new reactor fluxes)

Some hints of $\theta_{23} < \pi/4$
are emerging at $\sim 2\sigma$
worth exploring by means
of atm. and LBL+react. data

A possible hint of $\delta_{CP} \sim \pi$
emerging from atm. data
[Is the PMNS matrix real?]

So far, no hints for
$\mathrm{NH} \leftrightarrow \mathrm{IH}$
**NUMERICAL 1σ, 2σ, 3σ RANGES:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Best fit</th>
<th>1σ range</th>
<th>2σ range</th>
<th>3σ range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta m^2/10^{-5}$ eV$^2$</td>
<td>7.54</td>
<td>7.32 – 7.80</td>
<td>7.15 – 8.00</td>
<td>6.99 – 8.18</td>
</tr>
<tr>
<td>$\sin^2 \theta_{12}/10^{-1}$</td>
<td>3.07</td>
<td>2.91 – 3.25</td>
<td>2.75 – 3.42</td>
<td>2.59 – 3.59</td>
</tr>
<tr>
<td>$\Delta m^2/10^{-8}$ eV$^2$ (NH)</td>
<td>2.43</td>
<td>2.33 – 2.49</td>
<td>2.27 – 2.55</td>
<td>2.19 – 2.62</td>
</tr>
<tr>
<td>$\Delta m^2/10^{-3}$ eV$^2$ (IH)</td>
<td>2.42</td>
<td>2.31 – 2.49</td>
<td>2.26 – 2.53</td>
<td>2.17 – 2.61</td>
</tr>
<tr>
<td>$\sin^2 \theta_{13}/10^{-2}$ (NH)</td>
<td>2.41</td>
<td>2.16 – 2.66</td>
<td>1.93 – 2.90</td>
<td>1.69 – 3.13</td>
</tr>
<tr>
<td>$\sin^2 \theta_{13}/10^{-2}$ (IH)</td>
<td>2.44</td>
<td>2.19 – 2.67</td>
<td>1.94 – 2.91</td>
<td>1.71 – 3.15</td>
</tr>
<tr>
<td>$\sin^2 \theta_{23}/10^{-1}$ (NH)</td>
<td>3.86</td>
<td>3.65 – 4.10</td>
<td>3.48 – 4.45</td>
<td>3.31 – 6.37</td>
</tr>
<tr>
<td>$\sin^2 \theta_{23}/10^{-1}$ (IH)</td>
<td>3.92</td>
<td>3.70 – 4.31</td>
<td>3.53 – 4.84</td>
<td>5.43 – 6.41</td>
</tr>
<tr>
<td>$\delta/\pi$ (NH)</td>
<td>1.08</td>
<td>0.77 – 1.36</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>$\delta/\pi$ (IH)</td>
<td>1.09</td>
<td>0.83 – 1.47</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

**FRACTIONAL 1σ ACCURACY** [defined as 1/6 of ±3σ range]

- $\delta m^2$: 2.6%
- $\Delta m^2$: 3.0%
- $\sin^2 \theta_{12}$: 5.4%
- $\sin^2 \theta_{13}$: 10%
- $\sin^2 \theta_{23}$: 14%

Note: above ranges obtained for “old” reactor fluxes. For “new” fluxes, ranges are shifted (by ~ 1/3 σ) for two parameters only: $\Delta \sin^2 \theta_{12}/10^{-1} = +0.05$ and $\Delta \sin^2 \theta_{13}/10^{-2} = +0.08$

Hierarchy differences well below 1σ for various data combinations.
Further hints for $\theta_{23}$ in 1st octant. But no significant hierarchy discrimination.
$\delta_{CP}$ global info...
Adding 2012 SK atmospheric neutrino data:

We find a preference for $\delta \sim \pi$ (helps fitting sub-GeV e-like excess in SK)
why reactors are so cool?
$P(\nu_e \rightarrow \nu_e) \sim 1 - \sin^2(2\theta_{13}) \sin^2(\Delta m^2_{32} L_o/E)$

[plot: $E = 3\text{MeV}, \sin^2(2\theta_{13}) = 0.1, \Delta m^2_{32} = 2.5 \times 10^{-3}\text{eV}^2$]

ND $\rightarrow$ reduce several systematic uncertainties (mainly flux rate & shape) wrt FD
ND $\rightarrow$ isolates from reactor anomaly (fast oscillation $\rightarrow$ average effect) [DC: Bugey4]
**why reactors?**

- **copious** (high statistics) source and **free** vs
  - highly reliable “beam” (reactor-OFF \(\implies\) very expensive, even “strike” proof)

- excellent \(\delta(E/L)\) resolution \(\implies\) disappearance experiment

- [for \(\theta_{13}\) searches] **short baselines** \(\implies\)
  - small detectors (less expensive)
  - negligible matter & “NSI” effects (global analysis input)

- high & **known cross-section** \(\implies\) **exciting situation** (so called reactor anomaly)

- **BGs** \(\implies\) overburden, shielding, radio-purity (possible “reactor OFF”)

- trivial **multi-detector extrapolation** \(\implies\) flux scales with \(1/L^2\) (isotropic)

- rich **energy calibration** \(\implies\) many radioactive sources @ few MeV

- one unknown & one observable \(\implies\) unambiguous \(\theta_{13}\) signature (measurement/limit)

  - compelling **synergy to beam results** (several unknown's) \(\implies\) **global picture!**
reactor $\theta_{13}$
• **3 experiments**: Double Chooz (DC), Daya Bay (DB) and RENO

• **$\theta_{13}$ (large) will be measured by reactors**
  - **hard to improve results** (or re-trigger dedicated experimental activity)
  - $\theta_{13}$ measurement to $\sim 5\%$ precision (eventually) $\rightarrow$ used on by everyone else!
    - high precision $\rightarrow$ multi-detector approach
    - high accuracy $\rightarrow$ several experiments (bias-free?)
  - **oscillation signature $\rightarrow$ $\theta_{13}$ via both rate & shape**
    - rate-only analysis: “any deficit” is numerically associated to $\theta_{13}$ (BG, etc)
    - all results so far are rate-driven $\rightarrow$ DC uses shape to some extent

• **beams to use the “reactor $\theta_{13}$”** $\rightarrow$ further insight in neutrino oscillations
  - $\nu_e$ appearance $\rightarrow$ first(??) appearance experiment ($\rightarrow$ 5$\sigma$s soon)
  - rich physics…
    - $O(1\%)$ precision measurement of $\Delta m^2_{32}, \theta_{23}$ (T2K, NOvA)
    - further information on $\delta$ and MH (with atmospheric)
    - over-constraint 3$\nu$ oscillation scenario $\rightarrow$ NSI, sterile, exotic stuff, etc

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common technology...
• two trigger in coincidence $\Rightarrow$ low BG
  1st: “prompt” (e+ like)
  2nd: “delay” (capture in Gd): $\sim 8$ MeV
• correlation in time and space

$\sigma_{\text{IBD}} \Rightarrow T_{\text{neutron}} = (881.5 \pm 1.5)$ s

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TARGET (scintillator + Gd)

\( \gamma \)-Catcher (scintillator)

\( \mu \)-Detectors (scint or water)

Buffer (oil)

each experiment chose different sizes per detector…

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• 3 experiments performed very similar analysis (almost same selection strategy)
  • differences arise in BG reduction: DC and DB (detector/site dependent)
    • RENO ➞ no BG reduction strategy
  • different instrumental noise reduction and calibration (definition MeV)
• PMT light noise (or flashers) rejection (singles ➞ accidental)
• tagged $\mu$ (or $\mu$ related physics)
  • veto 1ms upon each $\mu$ (most fast-n eliminated)
• prompt ➞ [0.7~12.0] MeV
• delay ➞ [6.0~12.0] MeV
• time-correlation cut used
  • no space-correlation used for cut
• showering-$\mu$ ID (tagged on total energy)
  • veto ~ 1s upon each $\mu_{\text{shower}}$ (reduce Li candidates ~ 1/2)
• veto on some activity on external $\mu$ detectors
  • reduce fast-n and stopped-$\mu$
- no BG subtraction \(\Rightarrow\) 2 reactors (2 ON, 1 ON and 2 OFF)
- signal dominated and signal prediction excellent evolution tracking
• **statistics**
  - no problem → eventually all experiments **plenty** (>2× σ\text{stat} = σ\text{syst})
  - with large θ\text{13} → even faster than expected (biggest, 2 detectors, etc)

• **systematics I: inter-detector systematics (and MC)**
  - ND eliminates uncertainties → reactor knowledge & common detection
  - highest precision → excellent detector understanding (**calibration** and **MC**)

• **systematics II: backgrounds rates & shapes**
  - each site → different backgrounds (both rate and shape)
    - ND more signal but also more BG (a priori not only normalisation)
  - **BG spectra measurement** with reactor ON → very challenging
    - BG (un)knowledge → systematics [but statistics dominated → improving]

• **warning: high-precision physics** (i.e. systematics at “per-mil” level)
  - **first word** (**fast**) → impressive θ\text{13} measurement “overnight”
  - **final legacy** (**slow**) → cross-checks for best θ\text{13} world knowledge
• **Double Chooz** (1112.6353, 1207.6632, 1210.3748, etc)
  • the (slow) pioneer: first detector design (influenced the field)
    • 1 detector (building of ND) → European physics signature?
  • first result: $\theta_{13}$ large (Nov. 11) rate+shape analysis
    • best 1 detector results ever → better than design
  • Bugey4 ("ND")+FD: current results (1 detector → challenging)

• **RENO** (1204.0626, Nu2012)
  • first multi-detector running in the world → results after 229 days
  • remarkable effort/success for a small collaboration (almost entirely Korean)

• **Daya Bay** (1203.1669, Nu2012)
  • huge multi-detector complex → FD running since 25th December 2011
  • ultimate $\theta_{13}$ detector → final configuration running since Sept. 2012
  • most precise measurement of $\theta_{13}$ (even with 55 days)
BG systematics...
**BG measurement:** rate (much easier) & shape (statistics limited knowledge)
- CHOOZ BGs ➞ no say on Li (reactor OFF) ➞ KamLAND observed it!

**method 1:** measure each dedicated BG (sample) component with reactor ON
- **cons:** sub-sample (different selection) & approximations
  - correction/scaling ➞ hard to validate accuracy (precision easy)

**method 2:** fit $\theta_{13}$ and all BGs (shape analysis) with reactor ON [**only DC**]
- **pro:** use all knowledge a priori (method 1) ➞ propagate to $\theta_{13}$ (correlations)
- **cons:** hard to interpret pull-info (degeneracies) and lack of knowledge still

**method 3:** direct measurement of total BG (rate) [**only DC**]
- **pro:** a dream possibility (like CHOOZ) ➞ easy to validate rate measurements
- **cons:** stats limited ➞ hard to infer BG shape information

**method 4:** observed vs expected correlation plot (next slides) [**only DC**]
- **pro:** combined and direct use of reactor ON and OFF data ➞ powerful!
- **cons:** not used yet (➔ not systematics accounted) ➞ soon!!
individual measurement... (all experiments)
accidental BG...
decay $\beta$-$n$ [$\tau \sim 100\text{ms}$]

cosmogenic BG...

($^9\text{Li}$ and $^8\text{He}$)

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correlated BG…
(fast-n & stopping-μ)

Red: Best-fit Spectrum
Grey: Tagged background events
White: IBD Signal

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**Accidental BG** (radio-purity + overburden)
- ~94% dominant in DB ➞ easy to reduce!
- appears easy to measure (if stable: rate and shape) but several components
  - all correlations well taking into account? [needs validation]

**Cosmogenic Isotopes BG** (overburden)
- ~60% dominant in DC (reduced) and RENO (not reduced)
- **unavoidable** ➞ reduced by ~1/2 (DC & DB) (hard to reduce more)
- not difficult to measure but **long integration** (~1 event per day)
  - ➞ spectral shape limited info (useful for shape analysis) [DC soon]

**Correlated BG** (overburden ➞ fast-neutrons and stopped-μs)
- DC and RENO ➞ stopping-μs (but DC will kill with μ-Veto)
- **hard to measure spectrum at low energies** (reactor ON region)
  - each detector-site (overburden and acceptance) ➞ different shapes?
    - extrapolation from >12MeV ➞ can be biassed at low-energies
  - **DC: tagging with 2 μ-detectors** (IV and OV) ➞ spectral shape
    - validated with reactor OFF data (low stats)
Correlated BG measurement

• **correlated-BG spectrum resembles $\theta_{13}$ signature** (slope-like)
  ➞ bias best value of $\theta_{13}$ if subtracted incorrectly (ND and FD)

• **naive method:** high-energy (12~30MeV) to extrapolate to low-energy
  ➞ tested in DC: this can bias the correlated BG estimation by up to 25%
  ➞ DC relies on 2 tags (2 independent $\mu$-detectors + PSD under study)

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Red: Best-fit Spectrum
Grey: Tagged background events
White: IBD Signal

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(only DC) direct measurement and validation BG...
fit both $\theta_{13}$+BGs (rate+shape) simultaneously...

- fit input (a priori) $\rightarrow$ BGs rate and shape as measured individually
- fit output (a posteriori) $\rightarrow$ fit for $\theta_{13}$ while allowing BG (rate & shape) to accommodate (within uncertainties) $\rightarrow$ newBG measurement (not independent)
- BG(after fit) < 85% BG (before fit) [$\rightarrow$ less subtraction]
- also fit $\theta_{13}$ and BGs with 3 different selections $\rightarrow$ all consistent!
DC-I Selection
(no BG reduction)

DC-II Selection
(BG reduction)

validation of BG models with 2 selections (BG changed by ~2x)
observed < expected (⇒ fluctuation? \( \sigma^{\text{stats}} < 1.5\sigma \))

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(only validation) observed vs expected rate...

- evident disappearance effect (slope $\rightarrow \theta_{13}$)
- BG total (intercept) $\rightarrow$ with and without reactor 2xFF data
- direct use of both reactor ON (1 or 2 cores) and OFF data sets
- systematics uncertainties under study $\rightarrow$ use for oscillation in future?
• cosmo & correlated **BG knowledge is statistics dominated**

• DC surprisingly (less overburden) **best BG/S** (excellent $\delta S/BG$) $\rightarrow$ high quality analysis (precise BG estimation & 3x validation/cross-checks)

• **DC/DB lowest BGs** (largest overburden and reduce Accidentals)

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<table>
<thead>
<tr>
<th>experiment (@FD)</th>
<th>accidental [day$^{-1}$]</th>
<th>correlated [day$^{-1}$]</th>
<th>cosmo [day$^{-1}$]</th>
<th>BG</th>
<th>$\delta BG$</th>
<th>$\delta BG/BG$ (%)</th>
<th>max. signal</th>
<th>BG/S (%)</th>
<th>$\delta BG/S$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC-I</td>
<td>0.35±0.02</td>
<td>0.93±0.26</td>
<td>2.10±0.57</td>
<td>3.38</td>
<td>0.63</td>
<td>18.5</td>
<td>45</td>
<td>7.5</td>
<td>1.4</td>
</tr>
<tr>
<td>DC-II</td>
<td>0.261±0.002</td>
<td>0.67±0.20</td>
<td>1.25±0.54</td>
<td>2.18</td>
<td>0.58</td>
<td>26.4</td>
<td>45</td>
<td>4.8</td>
<td>1.3</td>
</tr>
<tr>
<td>DC-II (fit)</td>
<td>0.261±0.002</td>
<td>0.64±0.13</td>
<td>1.00±0.29</td>
<td>1.90</td>
<td>0.32</td>
<td>16.7</td>
<td>45</td>
<td>4.2</td>
<td>0.7</td>
</tr>
<tr>
<td>DC-II (OFF*)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>1.00</td>
<td>0.40</td>
<td>40.0</td>
<td>45</td>
<td>2.2</td>
<td>0.9</td>
</tr>
<tr>
<td>RENO</td>
<td>0.68±0.03</td>
<td>0.97±0.06</td>
<td>2.59±0.75</td>
<td>4.24</td>
<td>0.75</td>
<td>17.8</td>
<td>80</td>
<td>5.3</td>
<td>0.9</td>
</tr>
<tr>
<td>DB (3xFD)</td>
<td>~3.30±0.03</td>
<td>~0.04±0.04</td>
<td>~0.16±0.11</td>
<td>10.50</td>
<td>0.21</td>
<td>2.0</td>
<td>80</td>
<td>13.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>
DC Energy Spectra...

Neutrinos
Fast-Neutrons/μ-Capture
Cosmogenic (Li) [He dashed]
Accidentals

θ\text{13} E/L rise
θ\text{13} E/L dip
Normalisation (Signal)

Normalisation (HE BG)

Prompt Visible Energy (MeV)

Below Readout Threshold

Log Number of Entries

0.X ~2.0 ~6.0 ~8.0 <50

θ\text{13} E/L rise

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DC (June’12)  
DB (March’12)  
RENO (April’12)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\sin^2(2\theta_{13})$</th>
<th>Exposure (days)</th>
<th>arXiv</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC-I(rate+shape)</td>
<td>$0.086 \pm 0.051 (0.041^{\text{stat}} \pm 0.030^{\text{sys}})$</td>
<td>96.8</td>
<td>1112.6353</td>
</tr>
<tr>
<td>DB(rate only)</td>
<td>$0.092 \pm 0.017 (0.016^{\text{stat}} \pm 0.005^{\text{sys}})$</td>
<td>55</td>
<td>1203.1669</td>
</tr>
<tr>
<td>RENO(rate only)</td>
<td>$0.113 \pm 0.023 (0.013^{\text{stat}} \pm 0.019^{\text{sys}})$</td>
<td>229</td>
<td>1204.0626</td>
</tr>
<tr>
<td>DC-II(rate only)</td>
<td>$0.170 \pm 0.053 (0.035^{\text{stat}} \pm 0.040^{\text{sys}})$</td>
<td>251</td>
<td>1207.6632</td>
</tr>
<tr>
<td>DC-II(rate+shape)</td>
<td>$0.109 \pm 0.039 (0.030^{\text{stat}} \pm 0.025^{\text{sys}})$</td>
<td>251</td>
<td>1207.6632</td>
</tr>
<tr>
<td>DB-II(rate only)</td>
<td>$0.089 \pm 0.011 (0.010^{\text{stat}} \pm 0.005^{\text{sys}})$</td>
<td>126</td>
<td>Nu2012</td>
</tr>
</tbody>
</table>

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• **different baselines** (assuming MINOS-driven $\Delta m^2$)…
  • DC a bit **too short** → hard to see the rise on E/L
  • RENO and DB longer → should expect to see E/L (if BGs well understood)
  • RENO and DB: many baselines → more diffused E/L pattern?

• **E/L shape** (neutrino oscillation expectation) → **a must to measure** $\theta_{13}$
  • **BG rate & spectra** (subtracted FD and ND)
    • important: lowest S/BG (DC) and also $\delta$BG/S (DB)
  • **energy systematics** (non-linearities, MC, etc)

• **RENO & DB** → **rate analysis** (“any deficit” assumed to be $\theta_{13}$)
  • **no oscillations shape compatibility** → p-value, $\chi^2$/ndf,…
  • RENO’s spectral shape is unique (oscillations only?)
  • all experiments show some “effect” at high energies (in deficit rate)

• **DC** → **full spectral to fit $\theta_{13}$+BG** (constrain both)
  • else (rate only) DC will measure a larger $\sin^2(2\theta_{13})=0.17\pm0.05$ ($1.5\sigma$ tension)
  • **DC consistent with MINOS** [hard to constraint $\Delta m^2$]
rate-driven uncertainties table...

<table>
<thead>
<tr>
<th>uncertainty (%)</th>
<th>DC-II (rate)</th>
<th>DC-II (shape)</th>
<th>DC-II (OFF*)</th>
<th>DC-III (FD only)</th>
<th>DC (ND)</th>
<th>RENO (abs)</th>
<th>RENO (rel)</th>
<th>DB (abs)</th>
<th>DB (rel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>flux</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>reactor</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
<td>0.8</td>
<td>2.0</td>
<td>0.9</td>
<td>3.0</td>
<td>0.8</td>
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<tr>
<td>detection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>efficiency</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
<td>0.8</td>
<td>0.2</td>
<td>1.5</td>
<td>0.2</td>
<td>1.9</td>
<td>0.2</td>
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<tr>
<td>response</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>background for rate analysis (DBG/S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>cosmogenic</td>
<td>1.49</td>
<td>0.80</td>
<td>X</td>
<td>0.28</td>
<td>0.28</td>
<td>0.71</td>
<td>0.71</td>
<td>0.27</td>
<td>0.27</td>
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<tr>
<td>correlated</td>
<td>0.55</td>
<td>0.36</td>
<td>X</td>
<td>0.06</td>
<td>0.06</td>
<td>0.08</td>
<td>0.08</td>
<td>0.10</td>
<td>0.10</td>
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<tr>
<td>accidental</td>
<td>0.01</td>
<td>0.01</td>
<td>X</td>
<td>0.00</td>
<td>0.00</td>
<td>0.04</td>
<td>0.04</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>total</td>
<td>1.59</td>
<td>0.88</td>
<td>1.10</td>
<td>0.28</td>
<td>0.28</td>
<td>0.72</td>
<td>0.72</td>
<td>0.30</td>
<td>0.30</td>
</tr>
</tbody>
</table>

BG uncertainties without shape uncertainty → (only DC) increase uncertainties...
$\sin^2 2\theta_{13}$ Measurements

- **Double Chooz Jun. 2012**
- **Double Chooz Nov. 2011**
- **Daya Bay Mar. 2012**
- **RENO April 2012**

### DB
- leading precision now 15% (still rate only)
- $\sin^2(2\theta_{13}) = 0.89 \pm 0.10_{\text{stat}} \pm 0.05_{\text{syst}}$

### RENO
- rate only measurement
- published disappearance shape ➔ features

### DC
- rate+shape analysis: $\theta_{13}$+BG constraints
- 4 ways to estimate total BGs (all consistent)
- DC final (my guesstimate by scaling from DB)
  - ND-FD ~ $(0.10 \pm 0.010_{\text{total}})$

**world-wide**: at least 2 experiments to validate accuracy of the measurement (different systematics: E/L, BGs, calibration, etc)

Wednesday, 24 October 2012
what to remember?
• **θ\textsubscript{13} measured** by reactor experiments (will dominate for long)
  - the measured value will help us to measure/constrain 3ν oscillation model
• **high precision** (uncertainty) and **high accuracy** (what’s the true value?)
• **high precision on θ\textsubscript{13}** ⇒ ~5% uncertainty within 3 years
  - multi-detector approach helps via cancellation of many uncertainties
• **high accuracy on θ\textsubscript{13}** ⇒ how to know for sure?
  - cross-check among different experiments ⇒ on-going slow process
    (transparency of collaboration is important)
  - different sites, BGs, systematics, baselines, etc help ⇒ the ONLY way?
  - rate+shape (E/L and BG-shape information) measurement of θ\textsubscript{13} a **must**
• regardless **θ\textsubscript{13} is LARGE**
  - …if you were waiting for this, **please go ahead! ;)**
  - Asia leads… (DC slowly moving, but much of this field is DC’s success)