Me
Status of Double Chooz
The required pretty picture.
I am here thanks to my double chooz colleagues.
Double Chooz is a european-japanese-american-brazilian collaboration of ~150 physicists.
The Experiment:

just to orient you as to where I/Double Chooz fit in to the discussions this week.
reactor neutrino experiment
Where in the World is Chooz?

It is located at the border with Belgium.
Fly into Brussels, drive toward Luxembourg and turn right.
The next generation in a long line of reactor neutrino experiments. Starting from the first detection of the neutrino to the LMA+MSW solution to the solar neutrino problem. Go through each picture and the plot...
Reactor Neutrinos Oscillating:

\[ P_{e,e} = 1 - \sin^2 2\theta_{12} \sin^2 (1.27 \Delta m_{12}^2 L/E) \]

\( L_0 \) is the flux averaged reactor distance, 180 km.

The Beautiful KamLAND plot.
Describe.
Reactors have been good to us.
Why are we doing this?

\[ U_{\nu} = \begin{pmatrix}
1 & 0 & 0 \\
0 & c_{\theta_{23}} & s_{\theta_{23}} \\
0 & -s_{\theta_{23}} & c_{\theta_{23}}
\end{pmatrix}
\begin{pmatrix}
c_{\theta_{13}} & 0 & s_{\theta_{13}} e^{-i\delta} \\
0 & 1 & 0 \\
-s_{\theta_{13}} e^{i\delta} & 0 & c_{\theta_{13}}
\end{pmatrix}
\begin{pmatrix}
c_{\theta_{12}} & s_{\theta_{12}} & 0 \\
-s_{\theta_{12}} & c_{\theta_{12}} & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
e^{i\alpha/2} & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 1
\end{pmatrix} \]

Atmospheric K2K, MINOS

Solar + KamLAND

Does it violate CP? Is it Majorana?

But first that pesky mixing angle!

You may have seen this one twice a million times in the last week. Atmospheric Mixing – Majorana phases (Carter Hall/ DBD lectures).
Solar+KamLAND and then the last one, that beautiful CP violating phase that could be evidence for CP violation at higher scales.
What are the current best limits?

Chooz Bound: $\sin^2\theta_{13} < 0.21$

Global Analysis: $\sin^2\theta_{13} = 0.04-0.12$
What next?

Long Baseline Does It All: 
$\theta_{13}$, CP Violation, Mass Hierarchy....

Unfortunately Long Baseline does it all ....
The Most Complicated Formula:

\[ P(\nu_e \rightarrow \nu_e) = 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m^2_{31} L}{4E} \]

\[ + \frac{1}{2} \sin^2 \theta_{12} \sin^2 \frac{\Delta m^2_{21} L}{2E} \sin^2 \frac{\Delta m^2_{31} L}{2E} \]

\[ - \left( \cos^2 \theta_{13} \sin^2 2\theta_{12} + \sin^2 \theta_{12} \sin^2 2\theta_{13} \cos \frac{\Delta m^2_{31} L}{2E} \right) \sin^2 \frac{\Delta m^2_{31} L}{4E}. \]

Near+Far is key and we will come back to that... for now reactors provide a very clean measurement.
Do you get the joke?
Know how to detect.
What do we expect.
Get the fission data per isotope per day from the 53 japanese reactors. Cross-sections w/ spectrum gives the expected spectrum. Measured by all those other experiments see Gosgen....
Most of the spectrum below 5MeV so we are talking about LS not Water C.
Loose directional information.
You can try using the vertex positions but its difficult.
Very low background....
And then there were three:
## The Three Experiments:

<table>
<thead>
<tr>
<th></th>
<th>Double Chooz</th>
<th>Daya Bay</th>
<th>RENO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Cores</td>
<td>2 Cores</td>
<td>6 Cores</td>
<td>6 Cores</td>
</tr>
<tr>
<td>Total Power</td>
<td>8.54 GW</td>
<td>11.6 GW</td>
<td>16.4 GW</td>
</tr>
<tr>
<td>Target Mass</td>
<td>8.24 tons</td>
<td>20 tons</td>
<td>15 tons</td>
</tr>
<tr>
<td>Near Distance</td>
<td>400m</td>
<td>300–500m</td>
<td>290m</td>
</tr>
<tr>
<td>Far Distance</td>
<td>1.05km</td>
<td>1.6–1.9km</td>
<td>1.4km</td>
</tr>
<tr>
<td>Far Overburden</td>
<td>300 m.w.e.</td>
<td>350 m.w.e.</td>
<td>460 m.w.e.</td>
</tr>
<tr>
<td>Events per Day</td>
<td>425/43</td>
<td>1600/400</td>
<td>5000/100</td>
</tr>
</tbody>
</table>

* Daya Bay will increase to 17.4GW in 2011, has two near sites, and uses multiple detectors per site.
Hunting $\theta_{13}$:

(Disclaimer, all comparisons are of my own imagination and do not reflect the views of my group, collaboration, etc.)

$\sin^2\theta_{13} \sim 0.01$  \hspace{1cm} $\sin^2\theta_{13} \sim 0.02$  \hspace{1cm} $\sin^2\theta_{13} \sim 0.03$
### Why the two detectors?

<table>
<thead>
<tr>
<th></th>
<th>Chooz</th>
<th>Double Chooz</th>
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</thead>
<tbody>
<tr>
<td><strong>Reactor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\nu$ flux and spectrum</td>
<td>1.9%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>Reactor Power</td>
<td>0.7-2%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td><strong>Detector</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Angle</td>
<td>0.3%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>Target Mass</td>
<td>0.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Density</td>
<td>0.3%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>H/C and Gd ratio</td>
<td>1.2%</td>
<td>&lt;0.2%</td>
</tr>
<tr>
<td>Spatial Effects</td>
<td>1.0%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>Live time</td>
<td>-</td>
<td>&lt;0.2%</td>
</tr>
<tr>
<td><strong>Analysis</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From 3-7 cuts.</td>
<td>1.5%</td>
<td>0.2-0.3%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2.7%</td>
<td>&lt;0.6%</td>
</tr>
</tbody>
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Cancel Systematics → It is much easier to quantify the difference between two detectors than to Especially the reactor systematics – dependent on the electric company.
Far detector alone reactor systematics
Both detectors – dominated by the differences between the two detectors.
Using SONGs Data to Verify Reactor Models:

San Onofre Nuclear Generating Station

SONGs reactor: 3.438 GWh output

SONGs detector: 0.64 cm liquid scintillator doped with Gd

Work of C. Jones with LLNL and Sandia NL
Spectral Evolution:

![Graph showing spectral evolution over time.](image)