Measuring $\sin^22\theta_{13}$ with the Daya Bay nuclear power reactors

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• Target of the experiment
• Analysis of past experience
• Detector design
• Systematic errors
• Daya Bay as the site
• Summary
How big $\sin^2 2\theta_{13}$?

J. Bahcall et al., hep-ph/0305159

M. Maltoni et al., hep-ph/0309130

**Main approximation:** one mass scale dominance for 3 types of experimental data ($\Delta m^2_{\text{sun}} \ll \Delta m^2_{\text{atm}}$, $\nu_s$ decoupled)

$\sin^2 2\theta_{13} \sim 3\%$, Chooz limit: $\sin^2 2\theta_{13} < 10\%$
• Analysis based on 2-generation neutrinos
• Global fit with 3-generations still underway
• No good reason (symmetry) for $\sin^2 2\theta_{13} = 0$
• Even if $\sin^2 2\theta_{13} = 0$ at tree level, at low energies with radiative corrections, $\sin^2 2\theta_{13}$ will not vanish
• Theoretical models typically predict $\sin^2 2\theta_{13} \sim 0.1$-10 %

An experiment with a precision < 1% is vital
Systematic errors of past experiments

- There are three main types of errors: reactor related (~3%), background related (~2%) and detector related (~3%)
- Use two detectors, far/near to cancel reactor related errors “completely” and some of detector/background related errors
- Use movable detectors, near-far, to cancel all backgrounds and some of detector related errors
- Sufficient shielding to reduce backgrounds

Can we really do <1% ?
5t 0.1% Gd-loaded scintillators

Shielding:
300 MWE
2 m scintillator +
0.14m Fe
1km baseline

Signal: ~30/day
Eff. : ~70%

BK:
  corr.  1/day
  uncorr. 0.5/day
# Systematics

<table>
<thead>
<tr>
<th>sources</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction cross section</td>
<td>1.9</td>
</tr>
<tr>
<td>Number of protons</td>
<td>0.8</td>
</tr>
<tr>
<td>Detection efficiency</td>
<td><strong>1.5</strong></td>
</tr>
<tr>
<td>Reactor power</td>
<td>0.7</td>
</tr>
<tr>
<td>Energy released per fission</td>
<td>0.6</td>
</tr>
<tr>
<td>total</td>
<td>2.7</td>
</tr>
</tbody>
</table>
Closer look -- Detection efficiency

<table>
<thead>
<tr>
<th>selection</th>
<th>$\epsilon(%)$</th>
<th>rel. error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>positron energy*</td>
<td>97.8</td>
<td>0.8</td>
</tr>
<tr>
<td>positron-geode distance</td>
<td>99.9</td>
<td>0.1</td>
</tr>
<tr>
<td>neutron capture</td>
<td>84.6</td>
<td>1.0</td>
</tr>
<tr>
<td>capture energy containment</td>
<td>94.6</td>
<td>0.4</td>
</tr>
<tr>
<td>neutron-geode distance</td>
<td>99.5</td>
<td>0.1</td>
</tr>
<tr>
<td>neutron delay</td>
<td>93.7</td>
<td>0.4</td>
</tr>
<tr>
<td>positron-neutron distance</td>
<td>98.4</td>
<td>0.3</td>
</tr>
<tr>
<td>neutron multiplicity*</td>
<td>97.4</td>
<td>0.5</td>
</tr>
<tr>
<td>combined*</td>
<td>69.8</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*average values
Position cut

Energy cut
Experience gained

- Not stable Gd-loaded scintillator ($\lambda \approx 5 - 2\text{m}$)
- PMT directly in contact with scintillator $\Rightarrow$ too high uncorr. Background $\Rightarrow$ too high $E_{th}(1.32 \text{ MeV})$
- Good shielding $\Rightarrow$ low background
- Homogeneous detector $\Rightarrow$ Gd peak at 8 MeV
- 2m scintillator shielding gives a neutron reduction of $0.8 \times 10^6$. 
12t 0.1% Gd-loaded scintillators

Shielding:
32 MWE /1m water
0.9 km baseline

Signal: ~20/day
Eff. ~ 10%

BK:
corr.: ~ 15/day
uncorr. ~ 7/day
Very stable Gd-loaded liquid scintillator
## Systematics

<table>
<thead>
<tr>
<th>Sources</th>
<th>power method</th>
<th>Swap method</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+$ trigger efficiency</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>$n$ trigger efficiency</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>$\nu$ flux prediction</td>
<td>2.1</td>
<td>2.1</td>
</tr>
<tr>
<td>$\nu$ selection cuts</td>
<td>4.5</td>
<td>2.1</td>
</tr>
<tr>
<td>Background variation</td>
<td>2.1</td>
<td>N/A</td>
</tr>
<tr>
<td>$(1-\epsilon_1) B_{pn}$</td>
<td>N/A</td>
<td>3.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6.1</strong></td>
<td><strong>5.3</strong></td>
</tr>
</tbody>
</table>

Error on $\nu$ selection cuts obtained from multi-variable analysis
Experience gained

• Good Gd-loaded scintillator ($\lambda \sim 11$ m)
• Not enough shielding $\Rightarrow$ too high corr./uncorr. Background
• Segmentation makes Gd capture peak $<6$ MeV $\Rightarrow$ too high uncorr. Background
• Rn may enter the detector, problem ?
• Veto eff. is not high enough (97.5%)
• Swap method to measure/cancel backgrounds $\Rightarrow$ key to success
• 1m water shielding gives a neutron reduction of $10^6$ (lower energy, complicated event pattern).
KamLAND

1000t scintillators

Shielding:
3000 MWE/3m Water

180 km baseline

Signal: ~0.5/day
Eff. ~40%

BK:
corr.: ~0.001/day
uncorr. ~0.01/day
## Systematic errors

<table>
<thead>
<tr>
<th>Systematic errors</th>
<th>E&gt;0.9 MeV</th>
<th>E&gt;2.6 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total LS mass</td>
<td>2.13</td>
<td>2.13</td>
</tr>
<tr>
<td>Fiducial mass ratio</td>
<td>4.03</td>
<td>4.03</td>
</tr>
<tr>
<td>Energy threshold</td>
<td>--</td>
<td>2.13</td>
</tr>
<tr>
<td>Efficiency of cuts</td>
<td>2.06</td>
<td>2.06</td>
</tr>
<tr>
<td>Live time</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>Reactor power</td>
<td>2.05</td>
<td>2.05</td>
</tr>
<tr>
<td>Fuel composition</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Time lag</td>
<td>0.28</td>
<td>0.28</td>
</tr>
<tr>
<td>(\nu) spectra</td>
<td>2.25</td>
<td>2.48</td>
</tr>
<tr>
<td>Cross section</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Total</td>
<td>6.0</td>
<td>6.4</td>
</tr>
</tbody>
</table>
Large error on fiducial volume

$R_{\text{fid}} = 6.5 \text{ m}$
$R_{\text{fid}} = 5 \text{ m}$
$\Delta V_{\text{fid}} / V_{\text{fid}} = 4.6 \%$

Fiducial mass 408 ton (out of 1000)
Experience gained

• Very good shielding
• Balloon not good $\Rightarrow$ target mass not well defined
• Light transport in scintillator unknown $\Rightarrow$ particularly bad for Large detectors $\Rightarrow$ large error on position reconstruction
• Significant backgrounds from 8He/9Li
• Not good enough veto tracking system
• 3m water shielding gives a neutron reduction of $>13 \times 10^6$(high energy).
Important point to have small systematic error

- Energy threshold less than 0.9 MeV
- Homogeneous detector
- Target mass well determined → rigid container
- Target scintillator all from one batch, mixing procedures well controlled
- Not too large detector (<50t ?)
- Comprehensive calibration program
- Background well controlled → good shielding
- Be able to measure everything (Veto ineff., background, energy/position bias, …)
- A lot of unforeseen effects will occur when looking at 0.1% level
<table>
<thead>
<tr>
<th></th>
<th>Chooz</th>
<th>Palo Verde</th>
<th>KamLAND</th>
<th>Cancel ?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor power</td>
<td>0.7</td>
<td>0.7</td>
<td>2.05</td>
<td>&lt;0.2%</td>
</tr>
<tr>
<td>Reactor fuel/ν spectra</td>
<td>2.0</td>
<td>2.0</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>ν cross section</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0</td>
</tr>
<tr>
<td>No. of protons</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H/C ratio</td>
<td>0.8</td>
<td>0.8</td>
<td>1.7</td>
<td>0</td>
</tr>
<tr>
<td>Mass</td>
<td>-</td>
<td>-</td>
<td>2.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy cuts</td>
<td>0.89</td>
<td>2.1</td>
<td>0.26</td>
<td>0.2</td>
</tr>
<tr>
<td>Position cuts</td>
<td>0.32</td>
<td>3.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Time cuts</td>
<td>0.4</td>
<td>0.</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>P/Gd ratio</td>
<td>1.0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>n multiplicity</td>
<td>0.5</td>
<td>-</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>background</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>correlated</td>
<td>0.3</td>
<td>3.3</td>
<td>1.8</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>uncorrelated</td>
<td>0.3</td>
<td>1.8</td>
<td>0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Trigger</td>
<td>0</td>
<td>2.9</td>
<td>0</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>livetime</td>
<td>0</td>
<td>0.2</td>
<td>0.2</td>
<td>&lt;0.1</td>
</tr>
</tbody>
</table>
Possibly best systematic errors

- Reactor $<$ 0.2%
- Background $<$ 0.2%
- Energy cut $\sim$ 0.2%
- Position cut $\sim$ 0.2%
- Time cut $<$ 0.1%
- Livetime $\sim$ 0.1%
- Other unexpected $<$0.2%
- Total $<$ 0.5%
Background related error

• Just to have enough shielding and active veto
• How much is enough?
  – Uncorrelated backgrounds: U/Th/K/Rn
  – Correlated backgrounds: \( n \propto E_\mu^{0.75} \)

Neutrons: go deep and buffer shielding
Y.F. Wang et al., PRD64(2001)0013012

\(^8\)He/\(^9\)Li: go deep
n-production well reproduced by FLUKA

FLUKA predictions are in good agreement with current experimental data.
n-measurement by high energy neutrons and/or tagged muons

- n by tagged muons need to know tagging eff. precisely
- Veto ineff. for:
  - $\mu$ spallation in buffer
  - $\mu$ capture in buffer

Table 6
Muon-induced background rates in BOREXINO, calculated for different energy regions that are relevant for solar neutrino physics.

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Muon-induced background rates in BOREXINO given in counts/(day × 100 tons) for the different energy regions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Full energy range</td>
</tr>
<tr>
<td>11C</td>
<td>14.55 ± 1.49</td>
</tr>
<tr>
<td>7Be</td>
<td>0.34 ± 0.04</td>
</tr>
<tr>
<td>11Be</td>
<td>&lt;0.034</td>
</tr>
<tr>
<td>10C</td>
<td>1.95 ± 0.21</td>
</tr>
<tr>
<td>8Li</td>
<td>0.070 ± 0.017</td>
</tr>
<tr>
<td>6He</td>
<td>0.26 ± 0.03</td>
</tr>
<tr>
<td>8B</td>
<td>0.11 ± 0.02</td>
</tr>
<tr>
<td>9C</td>
<td>0.077 ± 0.025</td>
</tr>
<tr>
<td>9Li + 8He</td>
<td>0.034 ± 0.007</td>
</tr>
</tbody>
</table>

*The rates are given in counts/day normalized to 100 tons of target mass.
Detector design: multiple modules

- Many modules, ~10t each, 100-200 8” PMT/module
- 1-2 at near, 4-8 at far, small enough for movable calibration
- Correlated error cancelled by far/near
- Uncorrelated error can be reduced
- Event rate:
  - near: ~500-2000/day/module
  - Far: ~40/day/module
- 100 days calibration at the near pit
  - 0.2-0.5% statistical error
- Two reference modules 100 days, others ~10 days calibration
Advantages with multiple modules

• Smaller modules have less unknowns
• Smaller modules, less sensitive to scintillator aging
• Multiple handling to control systematic error ($1/\sqrt{N}$)
• Easy construction
• Easy movable detector
• Scalable
• Easy to correct mistakes

• Higher cost
• More trouble with calibration
Schematics of a multi-module detector
Structure of the module

• Three layers module structure
  I. target: Gd-loaded scintillator
  II. γ-ray catcher: normal scintillator
  III. Buffer shielding: oil

• Advantages:
  – Well defined fiducial volume
  – No cut on position ➔ small systematics

40cm: 87.80%
50cm: 91.04%
70cm: 95.23%

Thickness of Layer II determined by neutrino efficiency
Structure of the module: MC simulation

- Cylinder is much better than cubic
- Small module, no vertex  \( \Rightarrow \) time not important
- Reflection at the top and the bottom of the cylinder to increase light yield

<table>
<thead>
<tr>
<th>Case</th>
<th>Total PE</th>
<th>(\Delta E/E \text{ @}8\text{MeV})</th>
<th>(\Delta R \text{ (cm)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>No refl., (\lambda=11\text{m})</td>
<td>419</td>
<td>14.2</td>
<td>11</td>
</tr>
<tr>
<td>No refl., (\lambda=7\text{m})</td>
<td>388</td>
<td>14.9</td>
<td>11</td>
</tr>
<tr>
<td>90% Refl. (\lambda=11\text{m})</td>
<td>719</td>
<td>5.3</td>
<td>17</td>
</tr>
<tr>
<td>90% Refl. (\lambda=7\text{m})</td>
<td>646</td>
<td>5.8</td>
<td>17</td>
</tr>
</tbody>
</table>

Light yield 7000/MeV, QE=20\%, QE_{D1}=60\%, 100 8” PMT
What resolution we need?

Criteria:
1) $\sigma_E @ 1\text{MeV} \rightarrow e^+ \text{ cut}$
2) $\sigma_E @ 8\text{MeV} \rightarrow n \text{ cut}$
3) Energy scale
4) Low energy backgrounds

For $5\%@8\text{MeV}$
1) ineff. at 0.9 MeV is 0.04%
2) 6MeV cut for n is $4\sigma$
3) Energy scale: $\sigma/\sqrt{N}$:
   - 1 MeV $\sim 0.2\%$,
   - 6 MeV $\sim 0.08\%$
4) Could be a problem, cheaper to work on highlighting the problem - PMT
Background - correlated

- Cosmic-muon-induced neutrons:
  - B/S < 0.005 → 0.2/day/module @ ~2km
  - Can be measured by veto tagging, accuracy < 20%
  - Veto rate < 1KHz, 2-3 layers RPC(1600-2400 m²)
  - Methods:
    - Overburden > 100 MWE
    - Active Veto, ineff. < 0.5%, known < 0.2%
    - Three scenarios:

<table>
<thead>
<tr>
<th></th>
<th>100 MWE</th>
<th>300 MWE</th>
<th>1000 MWE</th>
</tr>
</thead>
<tbody>
<tr>
<td>muon rate/m² (Hz)</td>
<td>4</td>
<td>0.4</td>
<td>0.02</td>
</tr>
<tr>
<td>n rate in rock/m³ (/day)</td>
<td>11000</td>
<td>1600</td>
<td>160</td>
</tr>
<tr>
<td>reduction required (10⁶)</td>
<td>9.2</td>
<td>1.4</td>
<td>0.14</td>
</tr>
<tr>
<td>Shielding (water equivalent) (m)</td>
<td>2.5m</td>
<td>2.1m</td>
<td>1.5m</td>
</tr>
</tbody>
</table>
Other correlated backgrounds

- $\beta$-neutron instable isotopes from cosmic $\mu$
  - $^{8}\text{He}/^{9}\text{Li}$, Br(n) = 12%/48%, $^{9}\text{Li}$ dominant
  - Production rates $= f_\mu \cdot N_A \cdot \sigma \cdot \text{Br}$

<table>
<thead>
<tr>
<th></th>
<th>100 MWE</th>
<th>300 MWE</th>
<th>1000 MWE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average $E_\mu$ (GeV)</td>
<td>36</td>
<td>64</td>
<td>160</td>
</tr>
<tr>
<td>muon rate/m$^2$ (Hz)</td>
<td>4</td>
<td>0.4</td>
<td>0.02</td>
</tr>
<tr>
<td>Cross section ($\mu$b)</td>
<td>0.61</td>
<td>0.94</td>
<td>1.86</td>
</tr>
<tr>
<td>$^{8}\text{He}/^{9}\text{Li}$ (1/day/module)</td>
<td>3.4</td>
<td>0.53</td>
<td>0.053</td>
</tr>
<tr>
<td>B/S @far(near) site(%)</td>
<td>8.5(0.7)</td>
<td>1.3(0.1)</td>
<td>0.13(0.01)</td>
</tr>
</tbody>
</table>

- Depth > 250 MWE@400m
- > 1000 MWE@1500m
Background - Uncorrelated

- B/S < 0.05 \implies < 2/day/module @ far site
- Can be measured by swap method, precision \sim \sqrt{B/s} = 3.5\%/day/module
- single rate @ 0.9MeV < 50Hz
  \[ 2 \cdot R_\gamma \cdot R_n \cdot \tau < 0.04/day/module \]
- Methods:
  - Low activity glass for PMT
  - 3 MWE shielding, low activity sand/aggregate or Fe ?
  - Rn concentration < 20 Bq/m\(^3\), N\(_2\) flushing ?
  - (U, Th, K) in Scintillator < 10\(^{-13}\) g/g, clean Gd
  - All mechanical structure made of low activity materials
  - Calibration gadget made of clean materials such as Teflon, ...
  - Clean everywhere, no dust, no...
Background from PMT glass

Thickness of Layer III is determined by backgrounds from PMT glass and position reconstruction

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Purity (ppb)</th>
<th>20 cm (Hz)</th>
<th>25 cm (Hz)</th>
<th>30 cm (Hz)</th>
<th>40 cm (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U (&gt;1 MeV)</td>
<td>50</td>
<td>2.7</td>
<td>2.0</td>
<td>1.4</td>
<td>0.8</td>
</tr>
<tr>
<td>$^{232}$Th (&gt;1 MeV)</td>
<td>50</td>
<td>1.2</td>
<td>0.9</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>$^{39}$K (&gt;1 MeV)</td>
<td>10</td>
<td>1.8</td>
<td>1.3</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>5.7</td>
<td>4.2</td>
<td>3.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Hamamatsu R5912: 1/3 of R1408 (used by SNO)
Total rates $<<$ 50 Hz
Radiation from PMT glass is not a problem with 20 cm shielding.
**Background from rock**

Based on measured rock purity and GEANT3 simulation

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Purity (ppm)</th>
<th>Rejection (E&gt;1 MeV) for 2.5 MWE shielding</th>
<th>Backgrounds rate (E&gt;1 MeV) (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$U</td>
<td>8.8</td>
<td>$11/3 \times 10^8$</td>
<td>5.4</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>28.7</td>
<td>$34/3 \times 10^8$</td>
<td>20.4</td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>4.5</td>
<td>$5/3 \times 10^8$</td>
<td>1.8</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>27.6</td>
</tr>
</tbody>
</table>

Total rates < 50Hz
Background from Radon

- $^{238}$U in rock: 8.78 ppm
- Rock density: 3.0 g/cm³, 10cm thick
- Rn density in the hall: 1173 atoms/cm³/day
- Rn in fresh air: 100 atoms/cm³, Kr ? atoms/cm³

A fresh air exchange of 10 volume/day is a minimum requirement $\Rightarrow$ 200 atoms/cm³

A problem to be solved
Scintillator

- Gd-loaded liquid scintillator is desirable
- PV scintillator: 11m, 55% antracene
- PV aging: 0.03%/day, Chooz aging: 0.4%/day
- PV scintillator: Gd(CH₃(CH₂)₃CH(C₂H₅)CO₂)₃
  4% 2-ethoxyethanole, 36% pseudocumene, 60% mineral oil plus PPO, BisMSb, BHT, and Gd compounds
- More pseudocumene, more stable, 50%?
- But
  - Compatibility with acrylic
  - Flush point
  - Cost
Buffer & VETO

- 2m water buffer to shield backgrounds from neutrons and γ’s from lab walls
- Active buffer as veto is even better
- 800 8” PMT from Macro available
- Inefficiency < 0.5%, known to <0.25%, in order to control neutron background uncertainty
- Need multiple handling
- RPC(>90%) + active water buffer(>95%) ⇒ total ineff. = 10%*5% = 0.5%
- Two layers RPC, each with 4cm width XY strips
RPC prototypes made in IHEP
Redundancy !
Redundancy !
Redundancy !
The site: Daya Bay power plant

• A total of 4 reactor cores in two clusters, each with a thermal power of 2.9 GW, total: 11.6 GW

• Two more cores with a total thermal power more than 6 GW are expected to be online in 2011
Ling Ao
Reactor related error

• Use two detectors, far/near to cancel reactor related errors and some of detector related errors
• For one/two reactors, cancellation is exact
• For multiple reactors, cancellation is NOT exact
  – Multiple near detectors may be needed
  – Only uncorrelated errors contribute to final errors
  – Optimum positions can always be found with errors of 0.1-0.2%
Best location for near detectors

Near detector locations

Reactor core location

Far detector at 1800m from the center of reactor cores
Sensitivity

Near @ 350m  
Near @ 150m  
0.5% systematic error  
4 modules@far, 2 modules@near, 3 years running  

w/o stat. Error  
with stat. Error  
Far @ 1800m, near 350m
Possible staging

• Phase 0
  1 module @near

• Phase I
  2 module@near + 4 module@far

• Phase II
  2 module@near + 4 module@far +
    8 module@far*2
  ➔ sensitivity 0.5% ?
## Currently Proposed sites/experiments

<table>
<thead>
<tr>
<th>Site (proposal)</th>
<th>Power (GW)</th>
<th>Baseline Near/Far (m)</th>
<th>Detector Near/Far (t)</th>
<th>Overburden Near/Far (MWE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angra dos Reis (Brazil)</td>
<td>4.1</td>
<td>300/1300</td>
<td>25/25</td>
<td>60/600</td>
</tr>
<tr>
<td>Braidwood (US)</td>
<td>6.5</td>
<td>200/1500</td>
<td>25/50</td>
<td>250/250</td>
</tr>
<tr>
<td>Chooz-II (France)</td>
<td>8.4</td>
<td>150/1050</td>
<td>10/10</td>
<td>50/300</td>
</tr>
<tr>
<td>Daya Bay (China)</td>
<td>11.6</td>
<td>300/1500</td>
<td>25/50</td>
<td>200/1000</td>
</tr>
<tr>
<td>Diablo Canyon (US)</td>
<td>6.4</td>
<td>400/1800</td>
<td>25/50</td>
<td>100/700</td>
</tr>
<tr>
<td>Kashiwazaki (Japan)</td>
<td>24.3</td>
<td>300/1300</td>
<td>8.5/8.5</td>
<td>140/600</td>
</tr>
<tr>
<td>Krasnoyarsk (Russia)</td>
<td>3.2</td>
<td>115/1000</td>
<td>46/46</td>
<td>600/600</td>
</tr>
</tbody>
</table>
Status of the project (I)

- Chinese Atomic Energy Agency and the Daya Bay nuclear power plant are supportive to the project
- Funding agencies in China are supportive
- R&D funding applied, seeds money from IHEP available
- Conceptual design of the civil construction is finished
- Detector R&D and MC simulation started
- Collaborators in China:
  - Institute of High Energy Physics
  - China institute of atomic energy
  - Tsinghua University
  - Hong Kong University
  - Hong Kong Chinese University
Status of the project(II)

• Two workshops dedicated to this project

• People who are involved:

  K.B. Luk, Berkeley;
  B.L. Young, K. Whistnat, Iowa State;
  J. Peng, Urbana-Champaign;
  K. Lau, Houston

• Collaboration on R&D

  S. Freedman, K.B. Luk, R. Kadel, K. Heeger

  ----- Berkeley

  R. McKeown

  ------ Caltech
Status of the project(III)

• Cost estimate
  – Civil construction ~ US$ 6M
  – Detector ~ US$ 6M

• Schedule
  – 2004-2005 R&D, engineering design, secure funding
  – 2006-2007 construction
  – 2008 running
We propose to have the next meeting in Hong Kong

Organizers:
Hong University,
Chinese University of Hong Kong
IHEP

A visit to Daya Bay NPP will be organized
Summary

• Measuring Sin$^22\theta_{13}$ is a very important experiment
• Errors from reactor well under control: Near vs Far (~ 0.2%)
• Errors from backgrounds: just need “enough” shielding and go deep (~ 0.2%)
• Errors from detector: hope to be ~ 0.4%
• Daya bay power plant is one of the best site
  Sin$^22\theta_{13}$ experiment at 0.5% level is possible !
  Let’s do it !!!