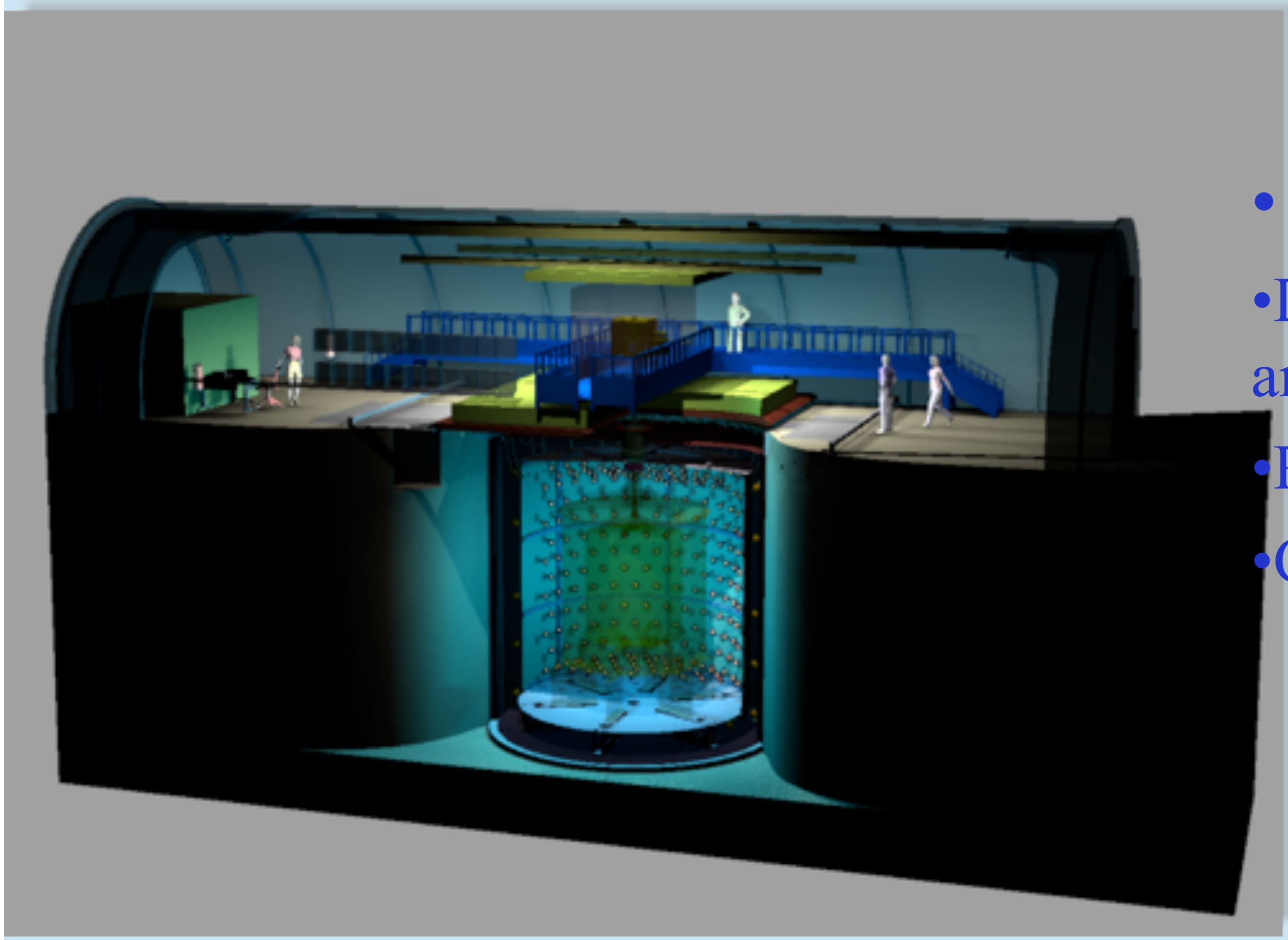
Measurement of θ_{13} at Double Chooz



- θ_{13} & ν Oscllations
- Double Chooz Concept and Detector
- Preliminary Results
- Conclusions

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SESAPS Meeting

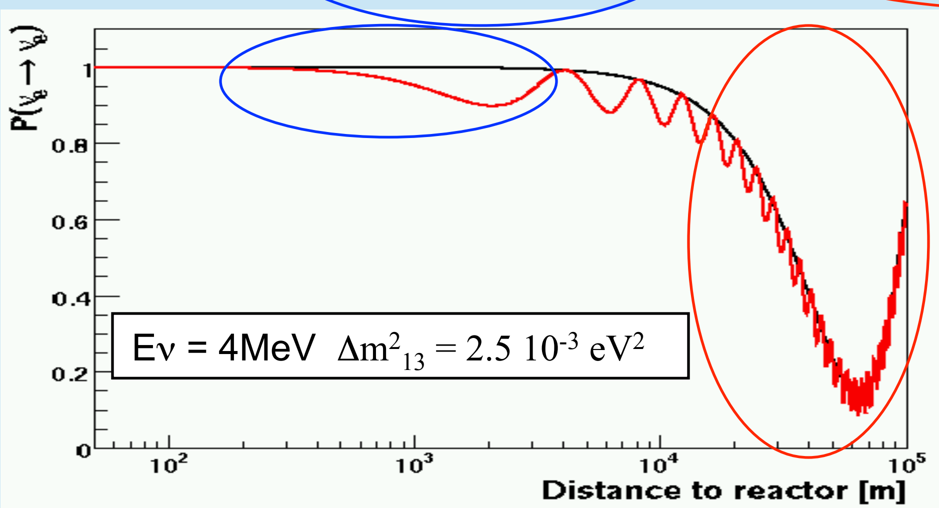
October 20th 2011

θ_{13}

- PMNS Matrix Describes the relationship between neutrino mass and flavor eigenstates.

$$= \underbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix}}_{\text{Atmospheric}} \begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix} \underbrace{\begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{\text{Solar \& Kamland}} \begin{bmatrix} e^{i\alpha_1/2} & 0 & 0 \\ 0 & e^{i\alpha_2/2} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$P(\overline{\nu}_e \to \overline{\nu}_e) = 1 - sin^2 2\theta_{13} \cdot sin^2\left(\frac{\Delta m^2_{31} \cdot L}{4E}\right) - cos^4 \theta_{13} \cdot sin^2 2\theta_{12} \cdot sin^2\left(\frac{\Delta m^2_{21} \cdot L}{4E}\right)$$



- The current limit on θ_{13} comes from the first Chooz experiment.

  $\sin^2 2\theta_{13} < 0.15$ @ $\Delta m^2_{13} = 2.5\ 10^{-3}\ eV^2$

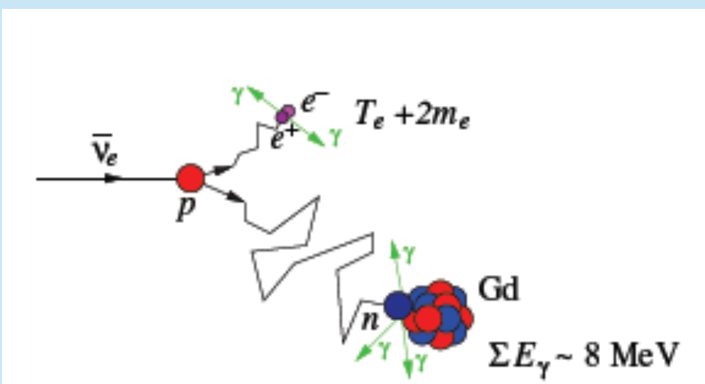
Reactor Anti-Neutrinos

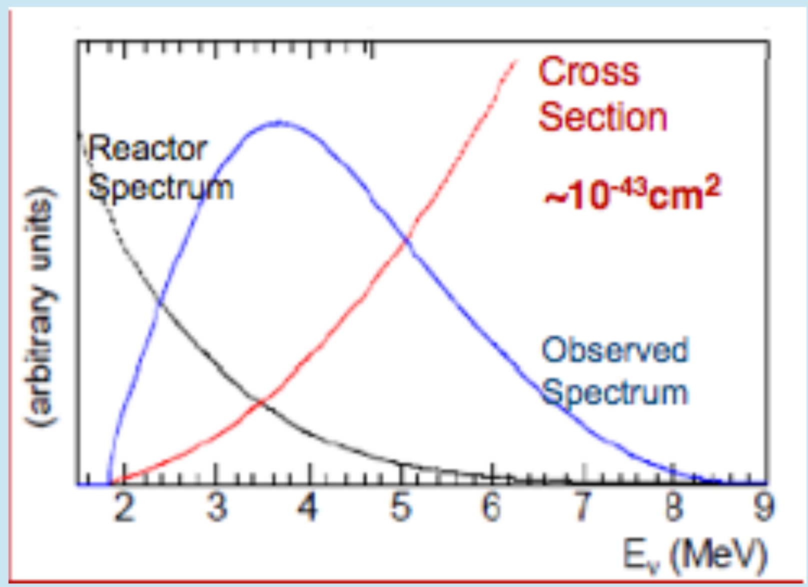
- For reactor experiments the source is electron anti-neutrinos from beta decay of unstable fission products.
- For Double Chooz: Two 4.25GW reactors

  $\sim 2 \times 10^{21}\ \nu/s$

- The electron anti-neutrinos are detected with inverse beta decay reactions.

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



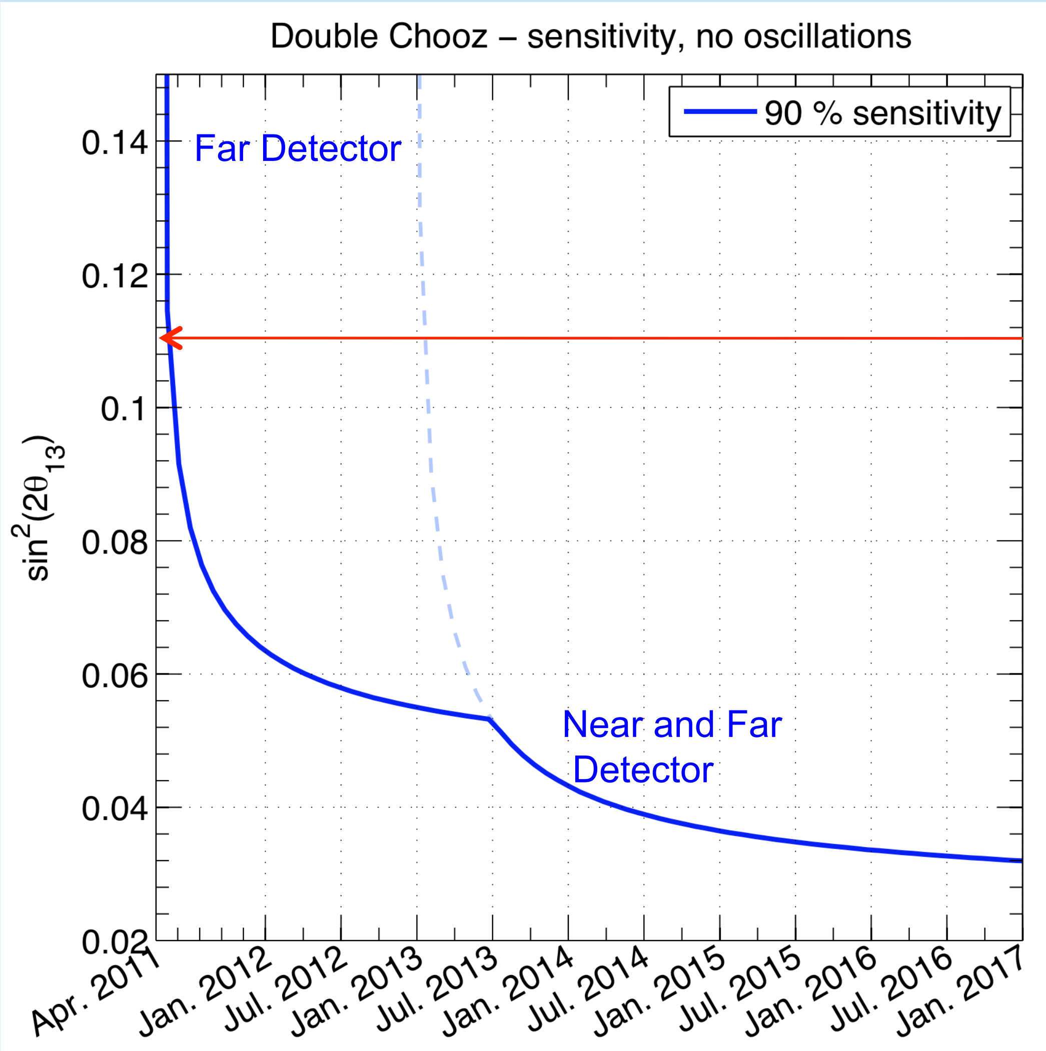


Double Chooz

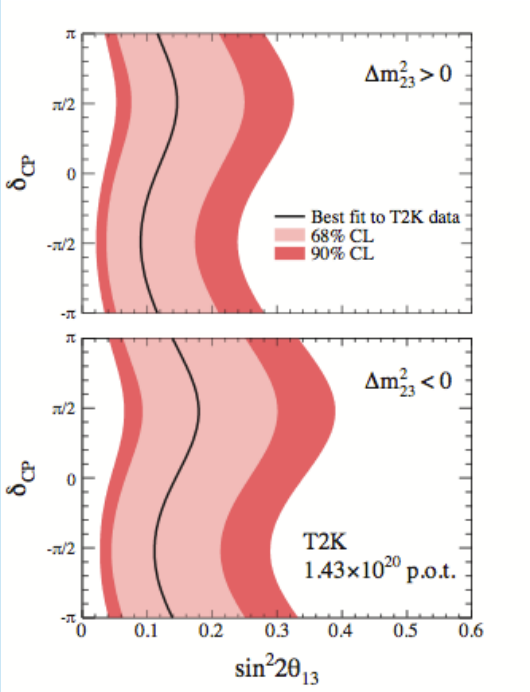
- The Double Chooz concept will build on the previous Chooz experience improving background suppression, systematic and statistical uncertainties
- Two identical detectors will be built, one at the previous Chooz site (1.05km from reactors) and a near detector (~400m from reactors).

Systematic errors	Absolute	Relative
Production σ	1.9 %	-
Reactor power	0.7 %	-
Energy per fission	0.6 %	-
Detector efficiency	1.5 %	0.5 %
Number of protons	0.8 %	0.2 %
Total	2.7	0.6

Double Chooz Sensitivity



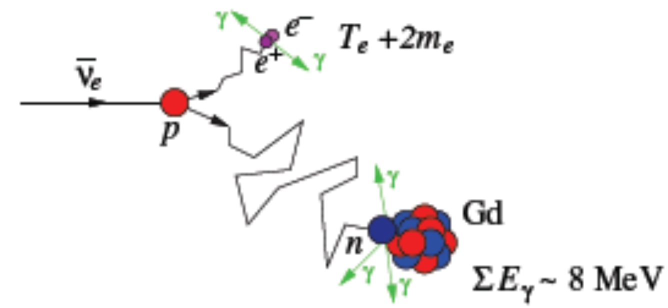
arXiv:1106.2822v2

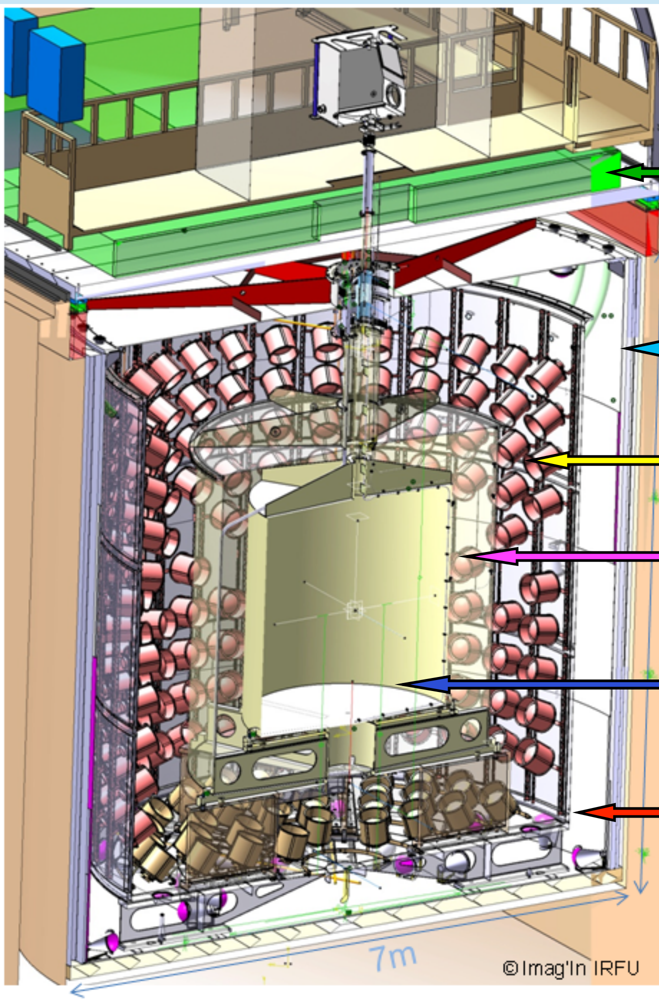


- T2K best fit $\sin^2 2\theta_{13} = 0.11$ (θ_{23}=45deg, $\Delta m^2_{13} = 2.5\ 10^{-3}\ eV^2$)

Detector Design

- Reactor electron anti-neutrinos are detected by inverse beta decay reactions inside the target area.





Outer Muon Veto:

Scintillator Plastic

15cm Steel Shielding

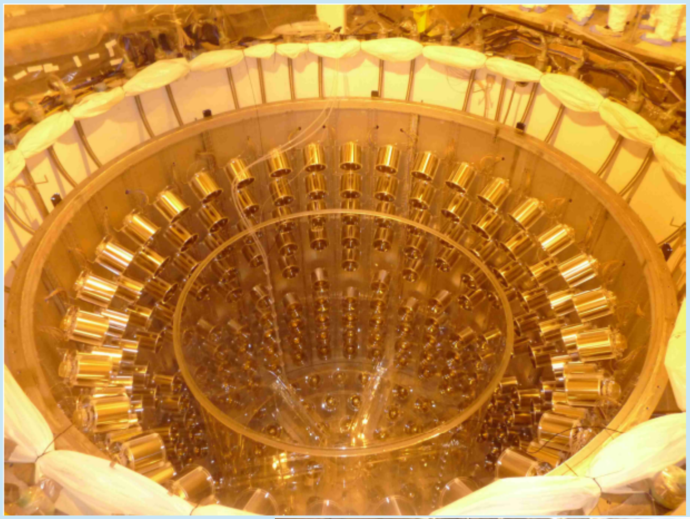
Buffer Area: 110m3 non-scint. mineral oil

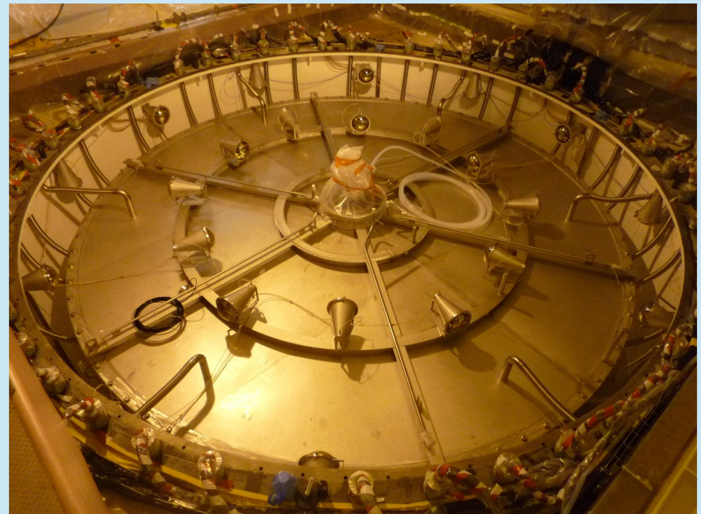
Gamma Catcher: 22.3m3 liquid scintillator

Target area: 10.3m^3 liquid scintillator doped with Gd

Inner Veto: 90m^3 liquid scintillator

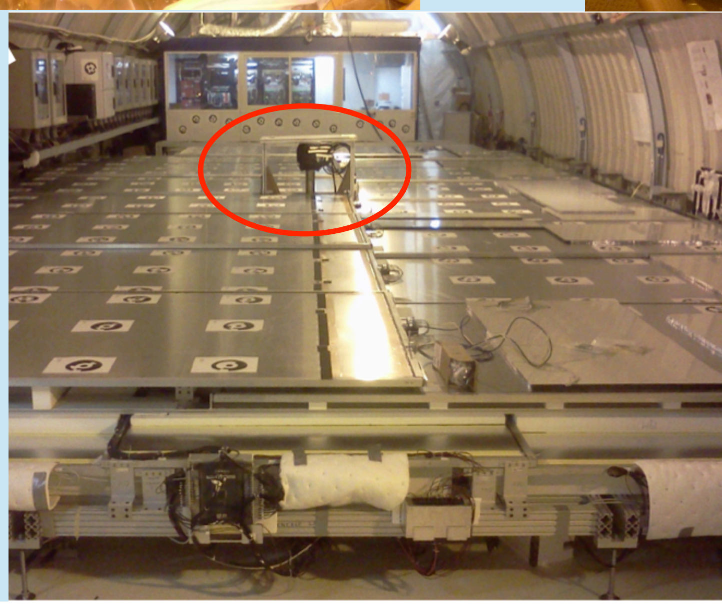
Far Detector Construction





Buffer Vessel Lid and IV PMTs

Inner Detector PMTs and Acrylic vessel

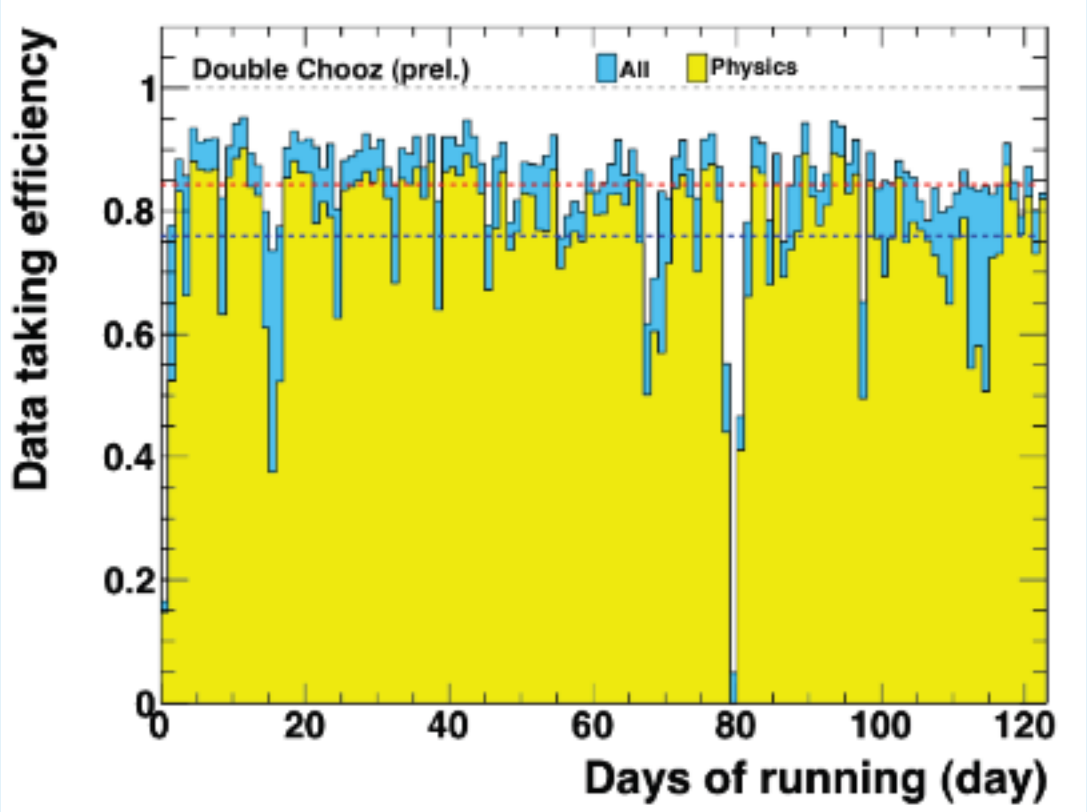


Outer Veto and Chimney

Civil Construction of the Near Lab is ongoing

Preliminary Data

- Stable Data taking at the Far Detector begain April 13, 2011

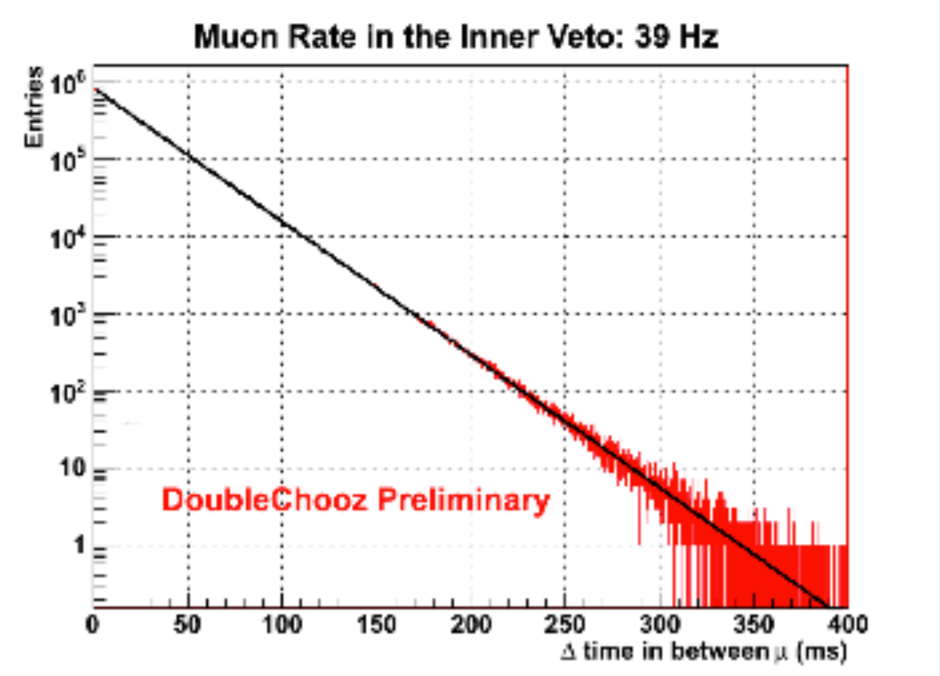


Now over 100 days of physics data.

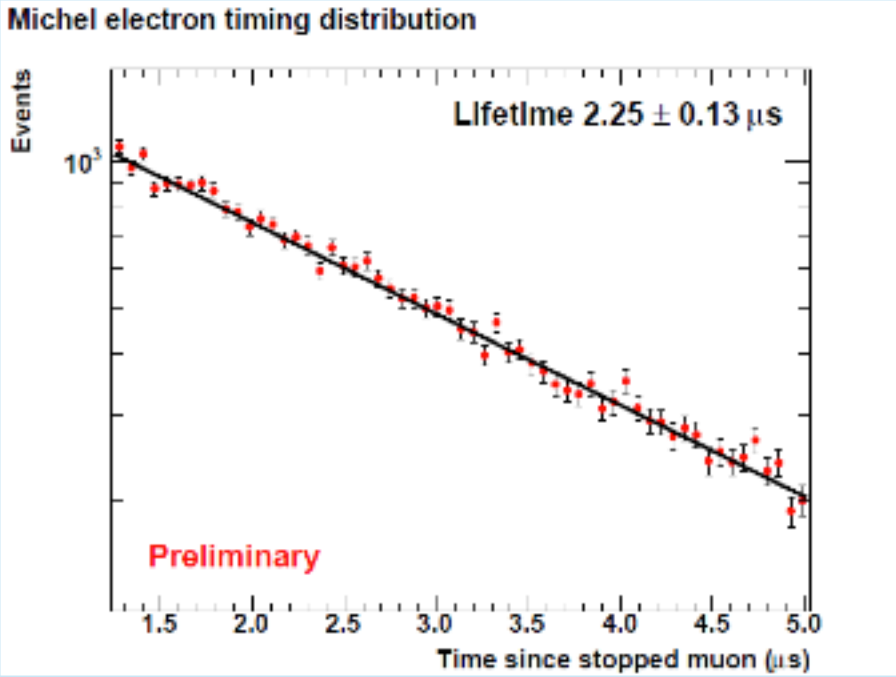
~75% physics data efficiency
~10% calibration data

Muon Data

- Muon rates from Inner Veto

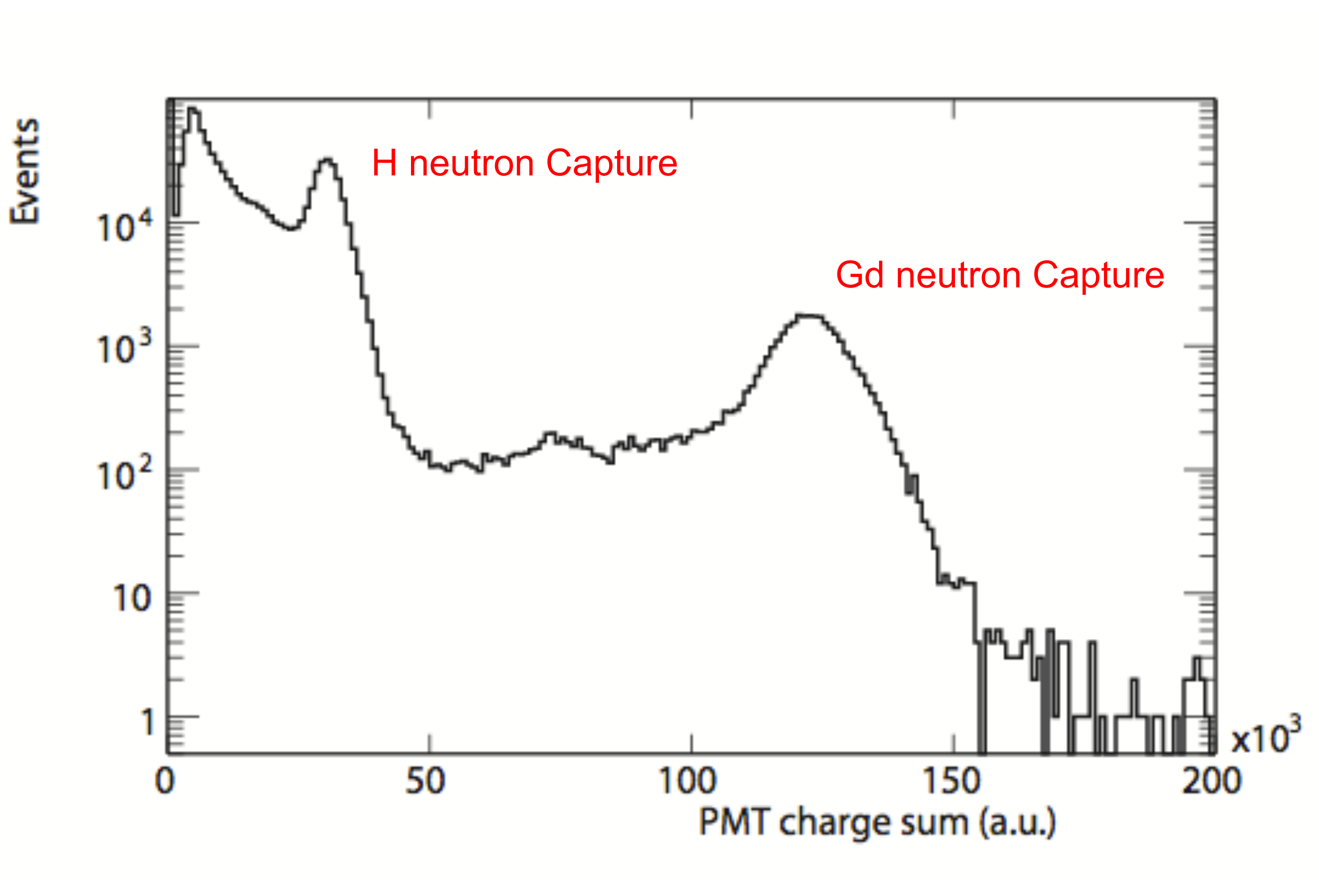


- Michel Electrons after tagged stopping Muons



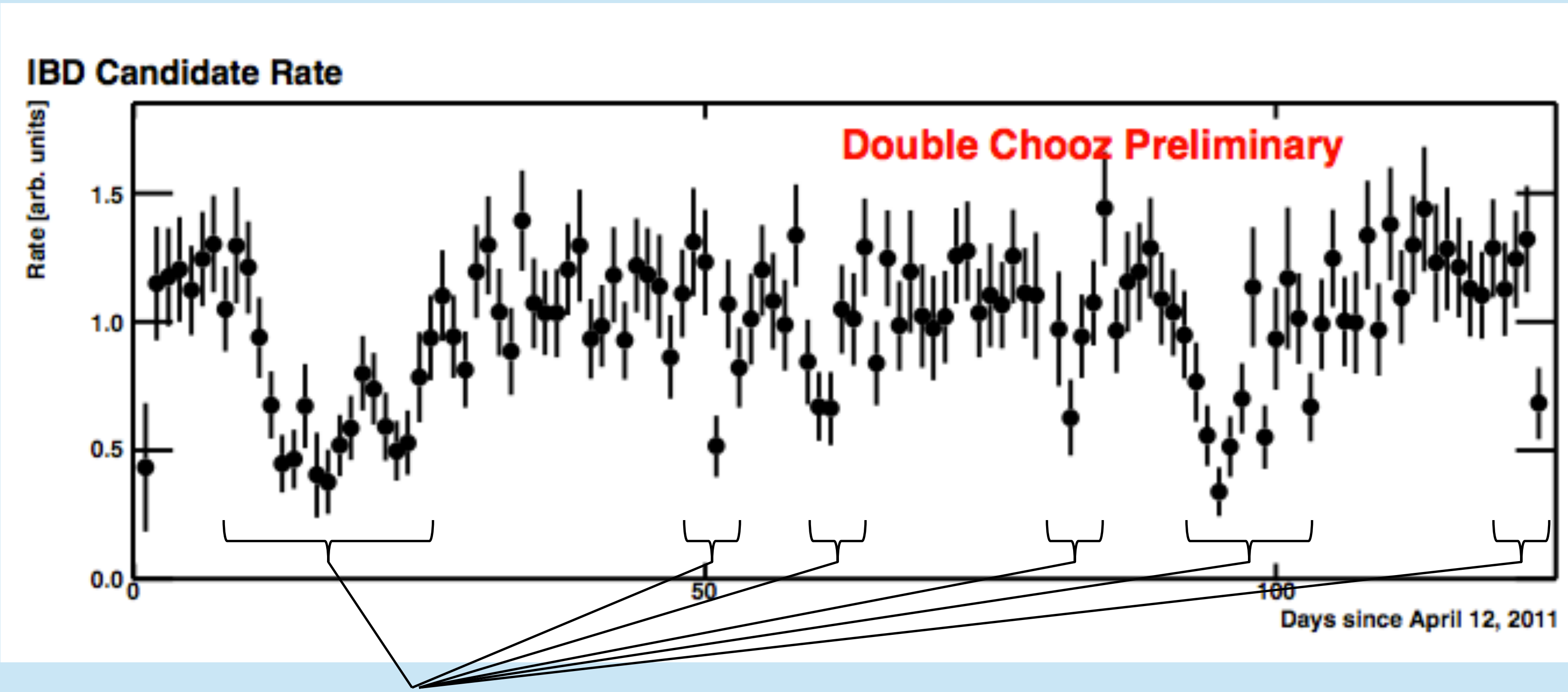
Muon Data

- Detector Events following Muons



IBD Candidates by Day

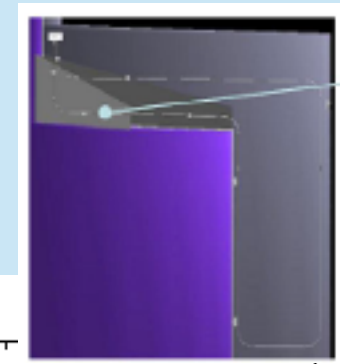
- >4000 Events with background



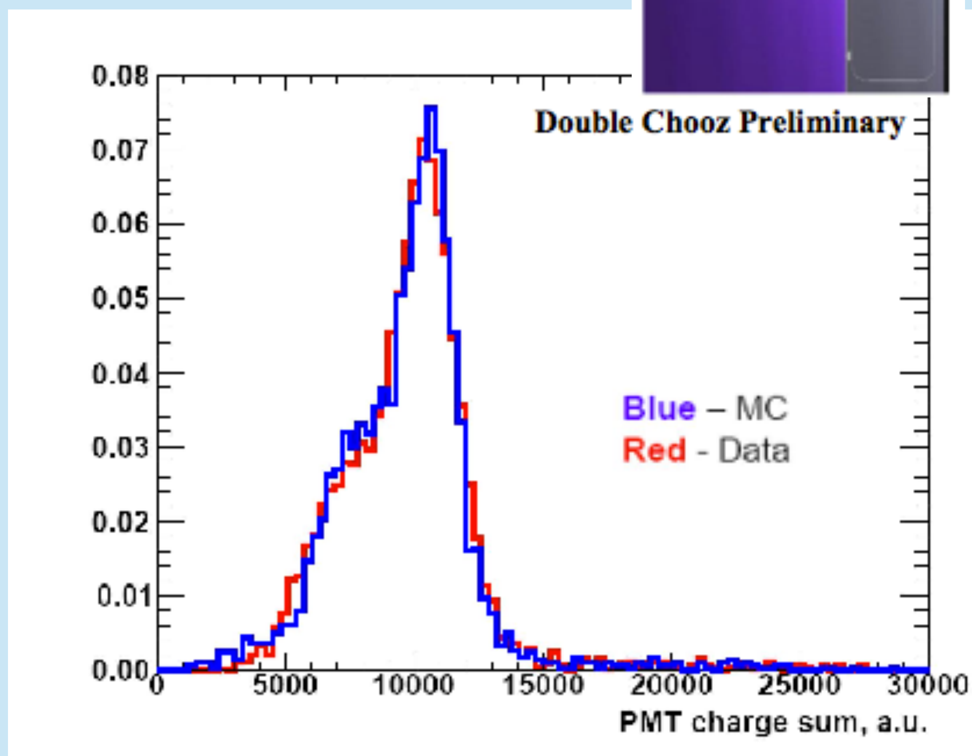
One reactor off times

Calibration Data

- ^{68}Ge calibration data in Calibration Guide Tube.



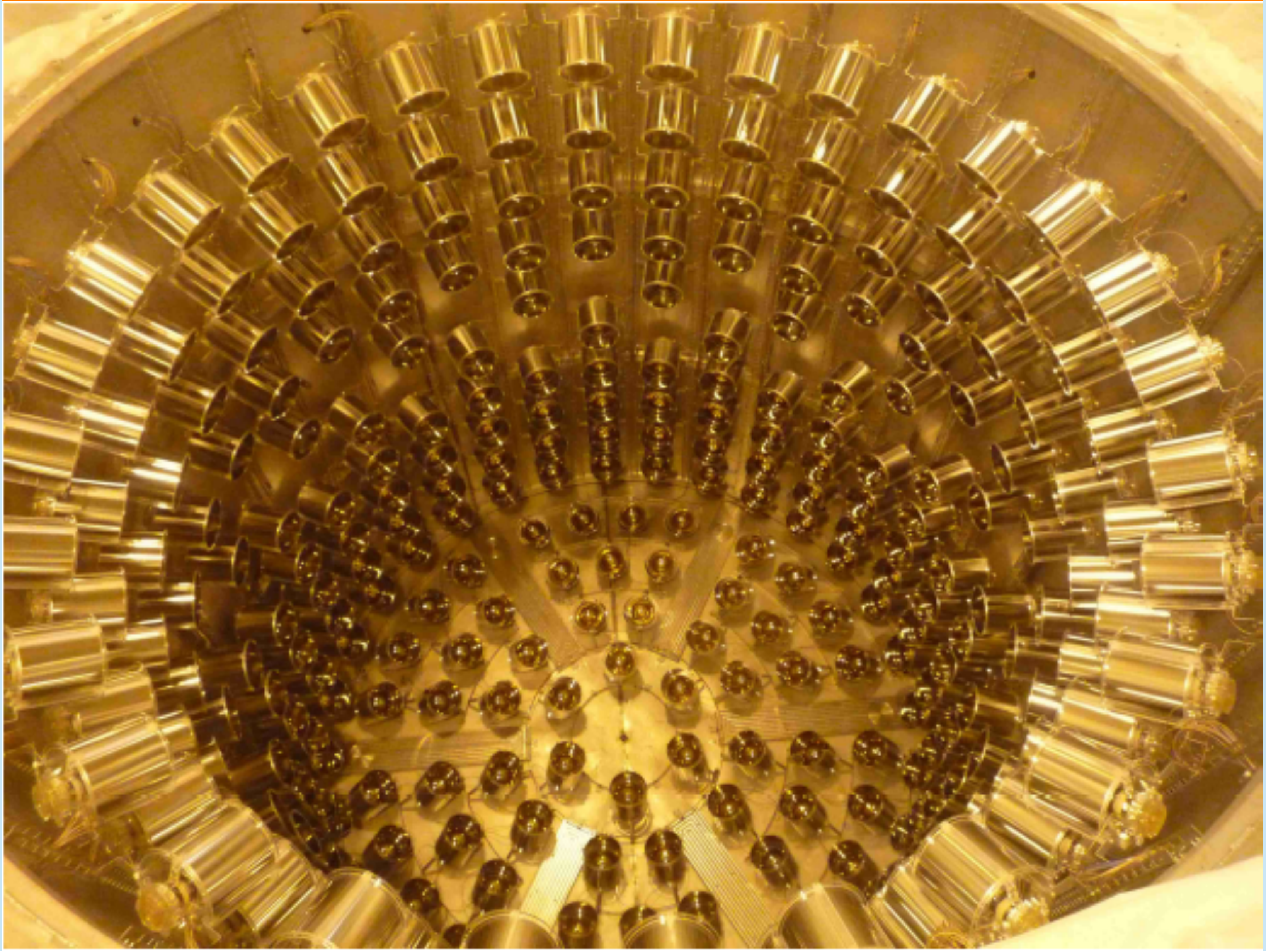
- Other Calibrations inclue:
  - Light injection system
  - Z-axsis Deployments
  - ^{137}Cs, ^{60}Co, ^{252}Cf



Conclusion

- Double Chooz Far Detector has been running stable since April of this year.
- The discover potential is promising for far detector data only.
- A “clean” measurement of θ_{13} will be important for long baseline discoveries.
- First results from Double Chooz are coming soon!

Thank You



Measurement of Theta-13

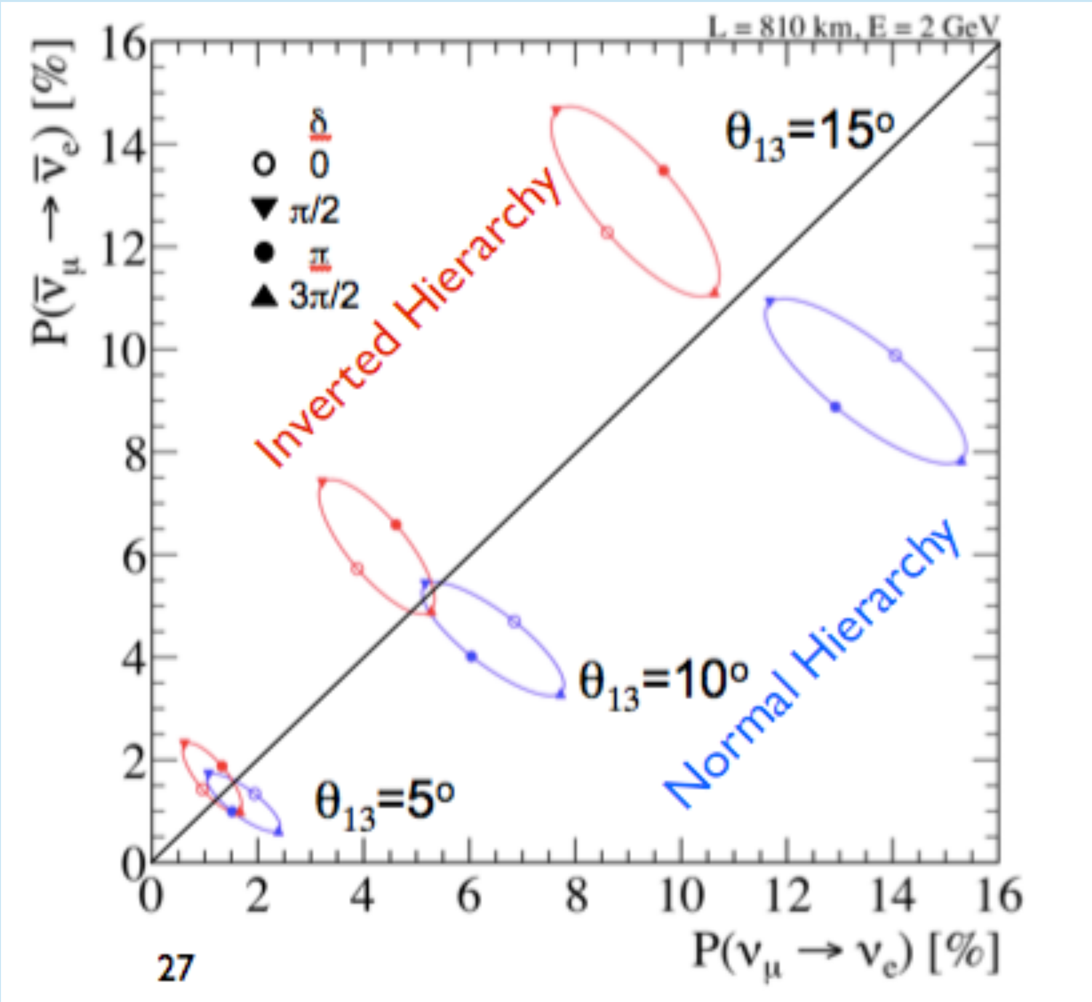
- Reactor anti-neutrino experiments have the opportunity for a "clean" measurement of θ_{13}.

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \cdot \sin^2\left(\frac{\Delta m_{31}^2 \cdot L}{4E}\right) - \cos^4\theta_{13} \cdot \sin^2 2\theta_{12} \cdot \sin^2\left(\frac{\Delta m_{21}^2 \cdot L}{4E}\right)$$

- Accelerator neutrino experiments also have the capability of measuring θ_{13} but it is coupled with the CP-violating phase and matter effects.

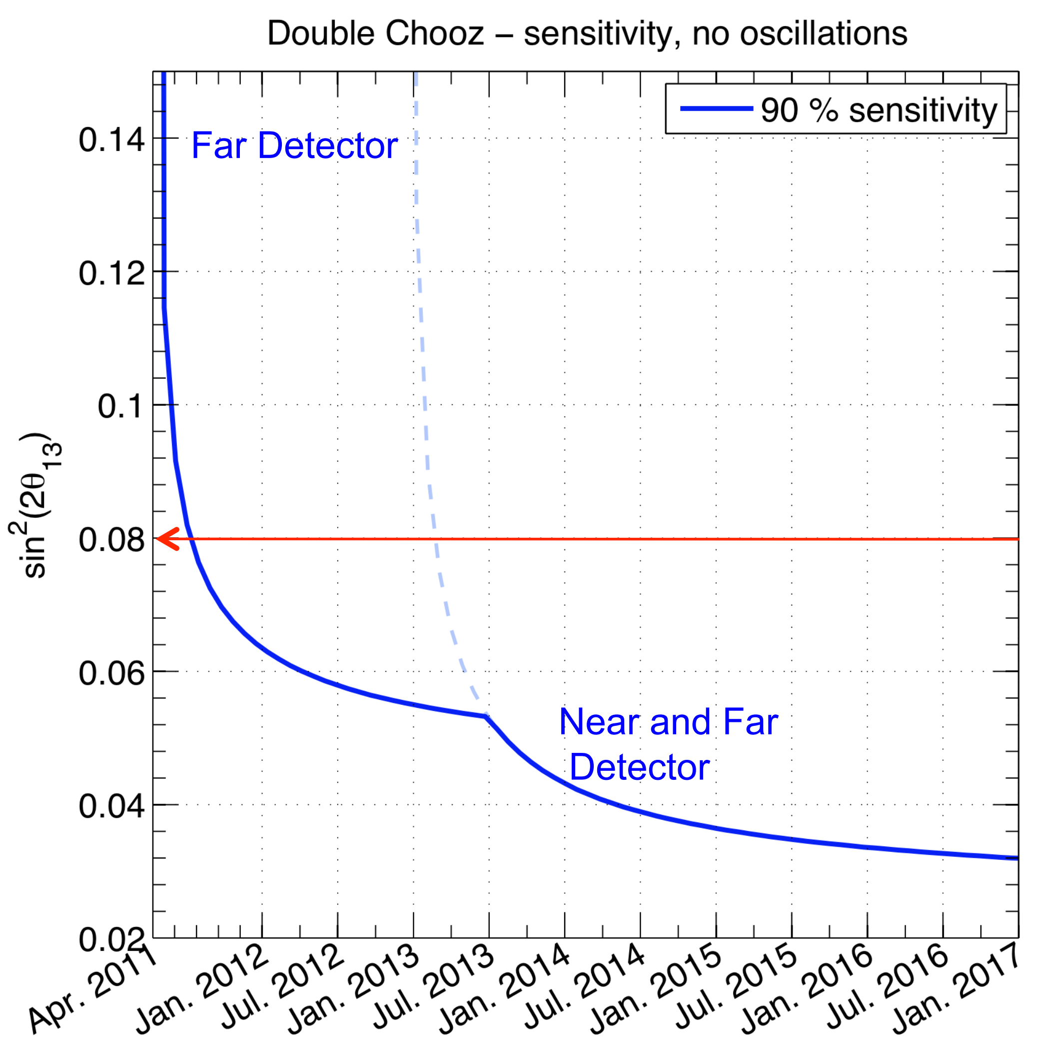
$$\begin{aligned} P(\nu_\mu \rightarrow \nu_e) \approx\ & \sin^2\theta_{23}\sin^2 2\theta_{13}\frac{\sin^2(\Delta_{31} - aL)}{(\Delta_{31} - aL)^2}\Delta_{31}^2 \\ & + 2\sin 2\theta_{13}\sin 2\theta_{23}\sin 2\theta_{12}\cos\theta_{13} \\ & * \frac{\sin(\Delta_{31} - aL)}{(\Delta_{31} - aL)}\Delta_{31}\frac{\sin(aL)}{(aL)}\Delta_{21} \\ & * (\cos\Delta_{32}\cos\delta - \sin\Delta_{32}\sin\delta) \\ & + \cos^4\theta_{13}\cos^2\theta_{23}\sin^2 2\theta_{12}\frac{\sin^2(aL)}{(aL)^2}\Delta_{21}^2 \end{aligned}$$

Accelerator Experiments



A measurement of a "large" value for θ_{13} would impact the potential for mass hierarchy and cp violating phase measurements from accelerator neutrino experiments

Double Chooz Sensitivity



Fogli, et al., arXiv:0905.3549

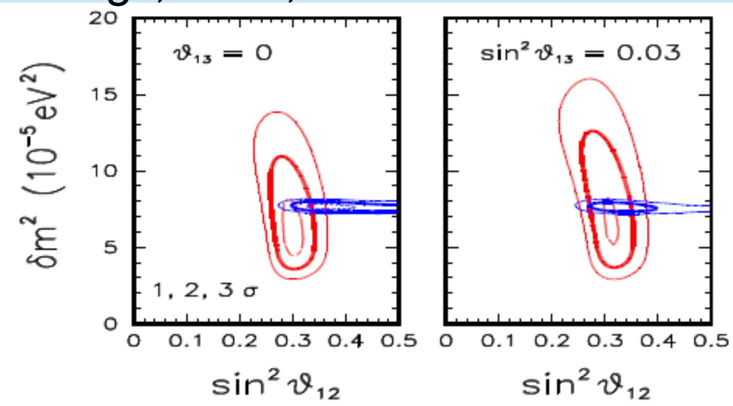
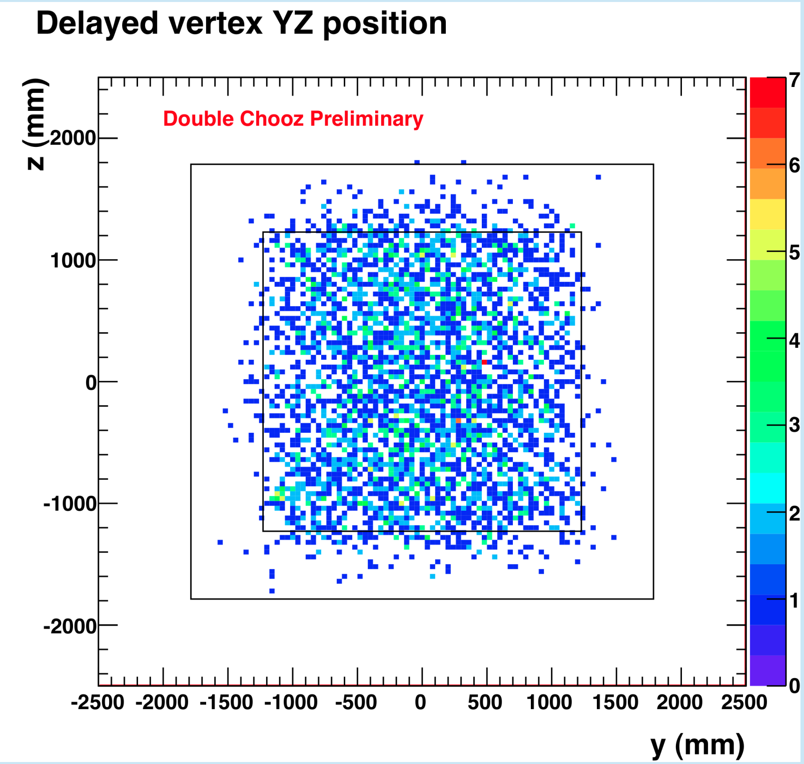


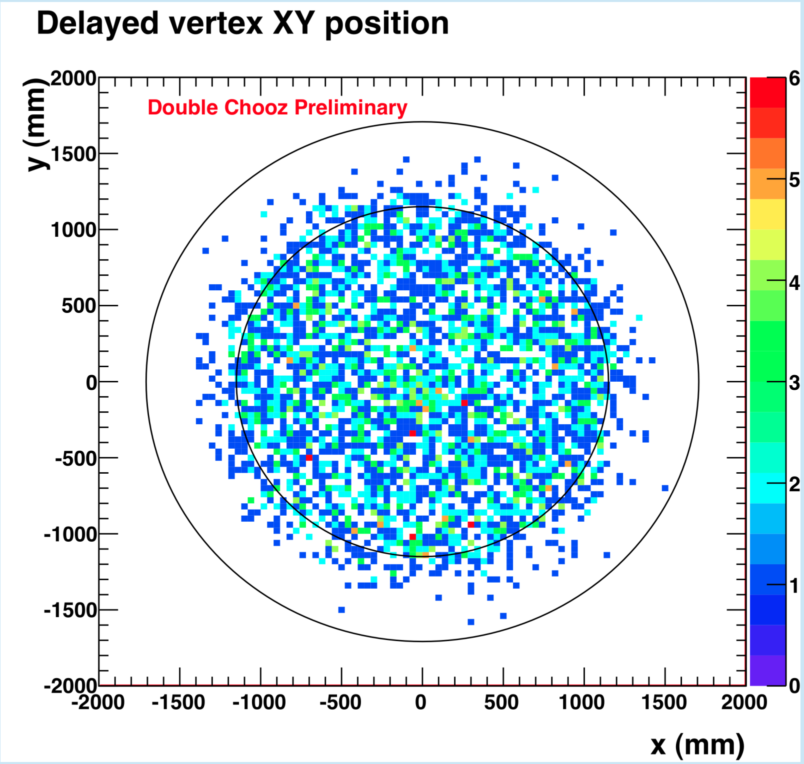
Figure 1: Comparison of n-σ regions allowed by the latest (2008) solar and KamLAND data in the $(\delta m^2, \sin^2\theta_{12})$ plane, for two fixed values of θ_{13}.

- Global analysis combining Solar and Kamland data sugests a non-zero value for theta-13.
- $\sin^2 2\theta_{13} \simeq 0.08$

Position Reconstruction

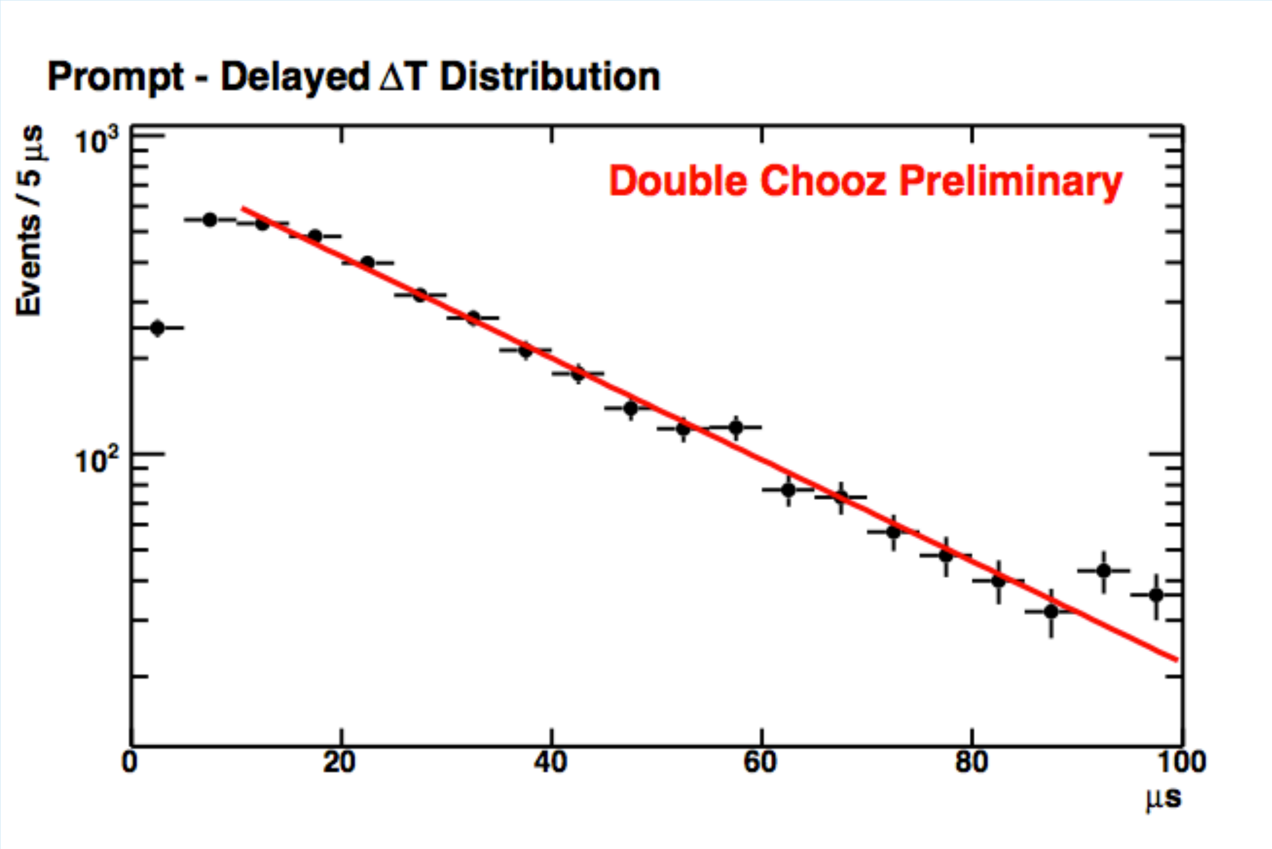
- IBD Delay event reconstructed position.





IBD Delta T

- Delta T between prompt and delay IBD events.



Delay Events