Determining Δm^2_{31} With Reactors

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Neutrino Mixing Parameters

- For three neutrino generations, neutrino oscillation depends on
  - three mixing angles and a Dirac CP-violating phase in the Pontecorvo-Maki-Nakagawa-Sakata matrix parametrized as

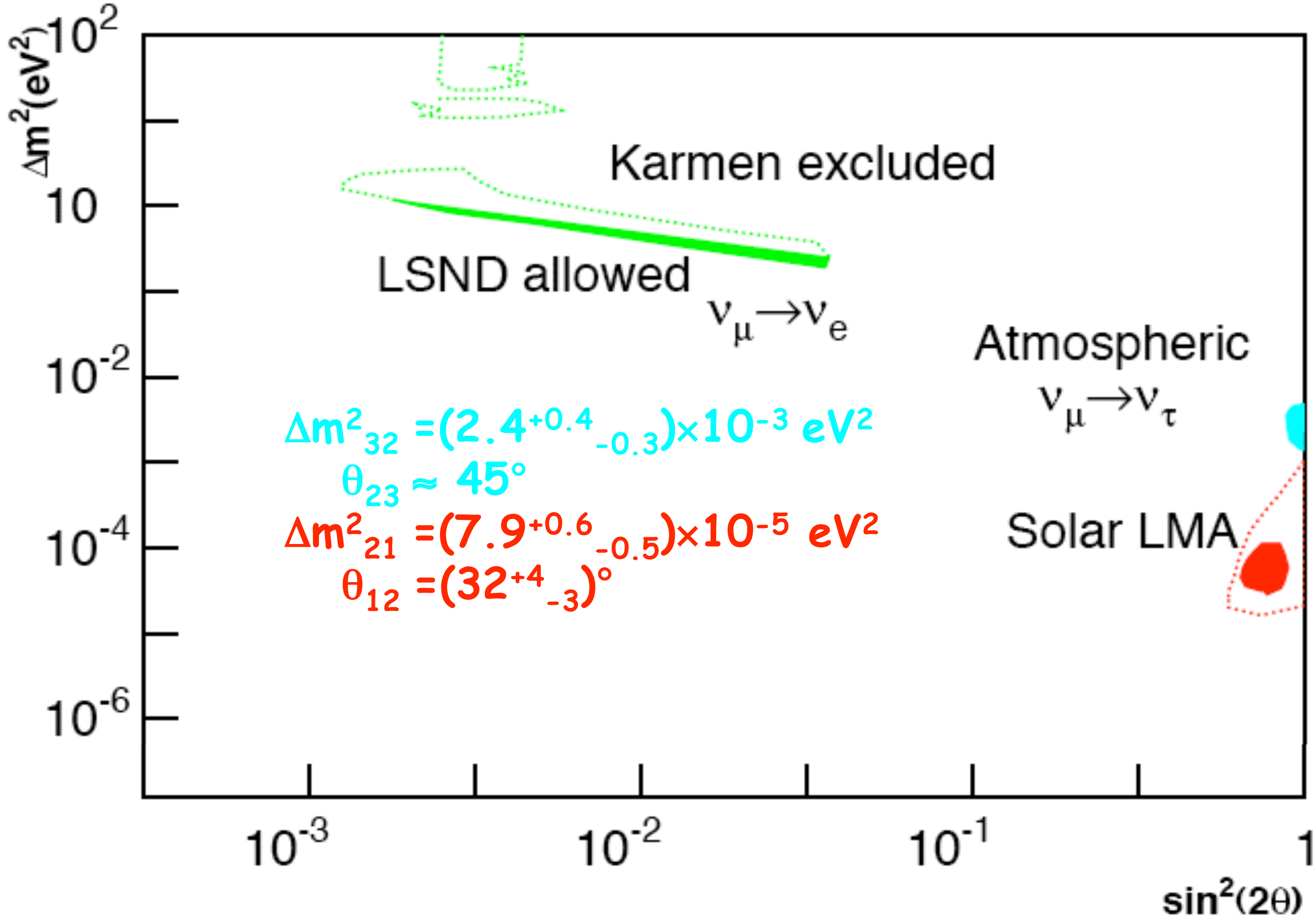
$$\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{12} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}$$

solar ν reactor $\bar{\nu}$	reactor $\bar{\nu}$ accelerator LBL ν	atmospheric ν accelerator LBL ν

  - mass-square differences:

$$\Delta m^2_{21} = m_2^2 - m_2^1, \quad \Delta m^2_{32}, \quad \Delta m^2_{31}$$

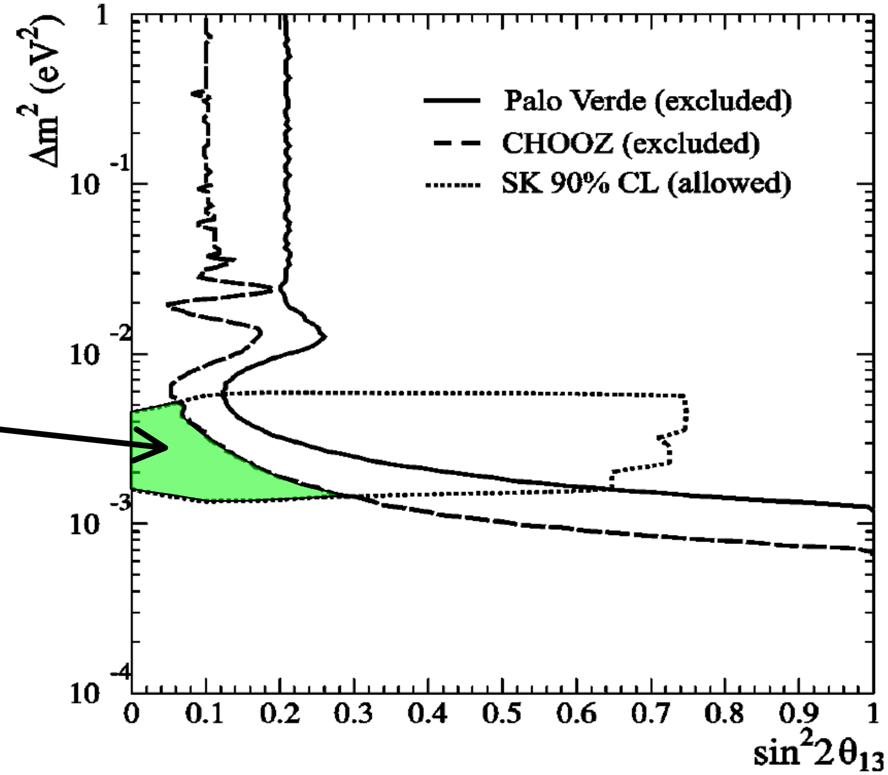
Current Status of Mixing Parameters



What are Δm^2_{31} and θ_{13} ?

Current Knowledge of θ_{13} and Δm^2_{31}

allowed region



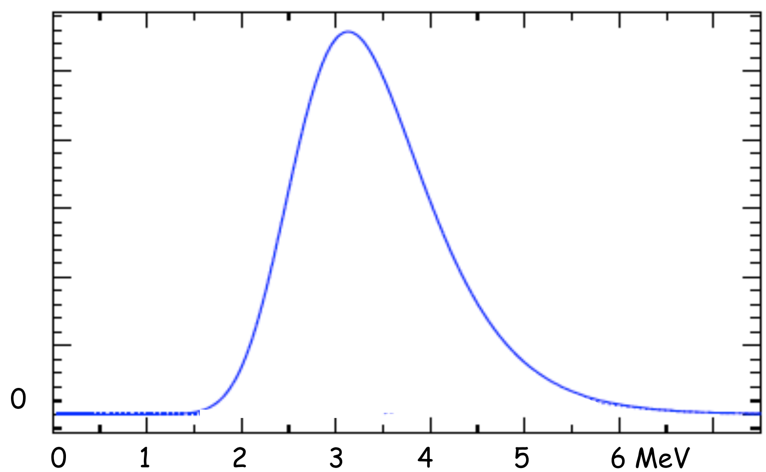
- $1.3 \times 10^{-3}\ eV^2 < \Delta m^2_{31} < 5.5 \times 10^{-3}\ eV^2$

- for three neutrino flavors,
  $\Delta m^2_{31} = \Delta m^2_{32} + \Delta m^2_{21} \approx (2.5^{+0.4}_{-0.3}) \times 10^{-3}\ eV^2$

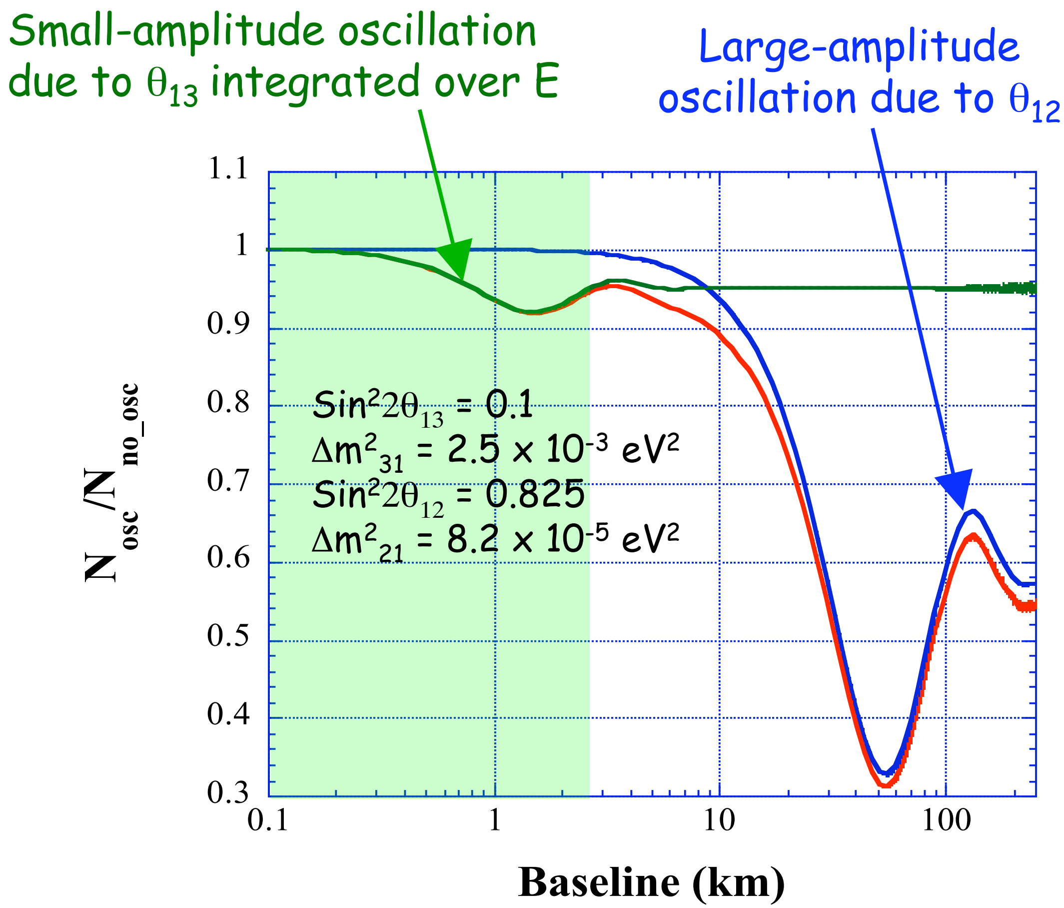
Measuring Δm^2_{31} With Nuclear Reactor

- Since reactor $\bar{\nu}_e$ are low-energy, it is a disappearance experiment:

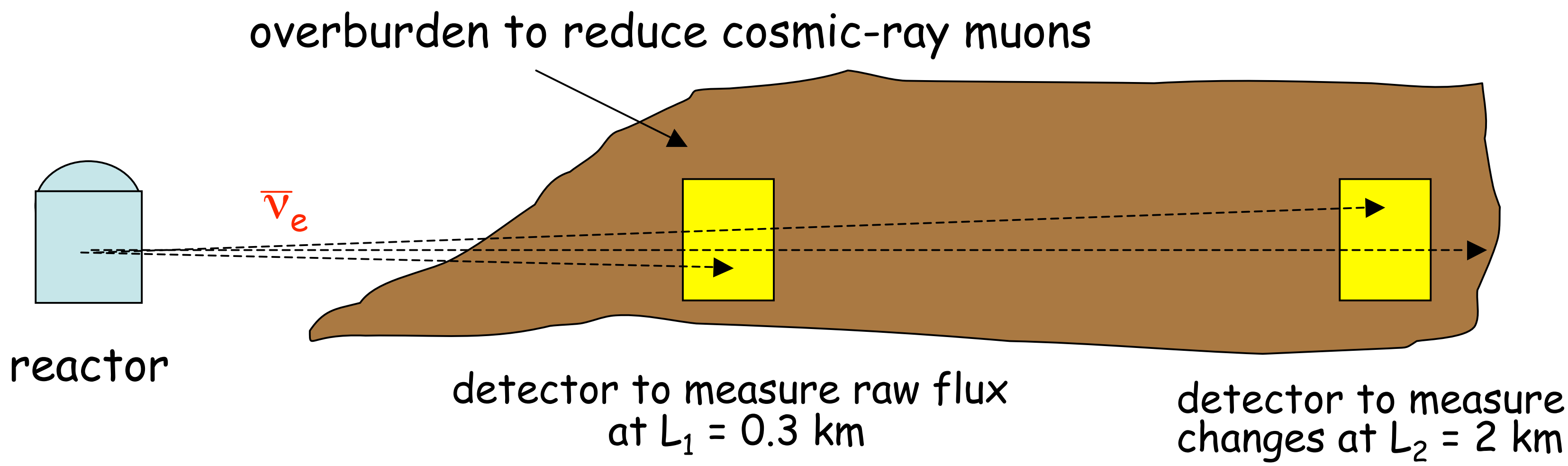
$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right)$$

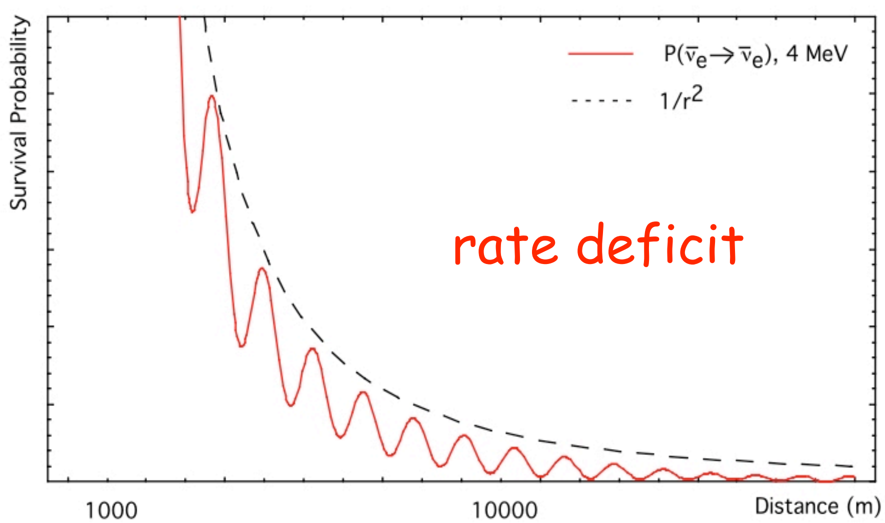


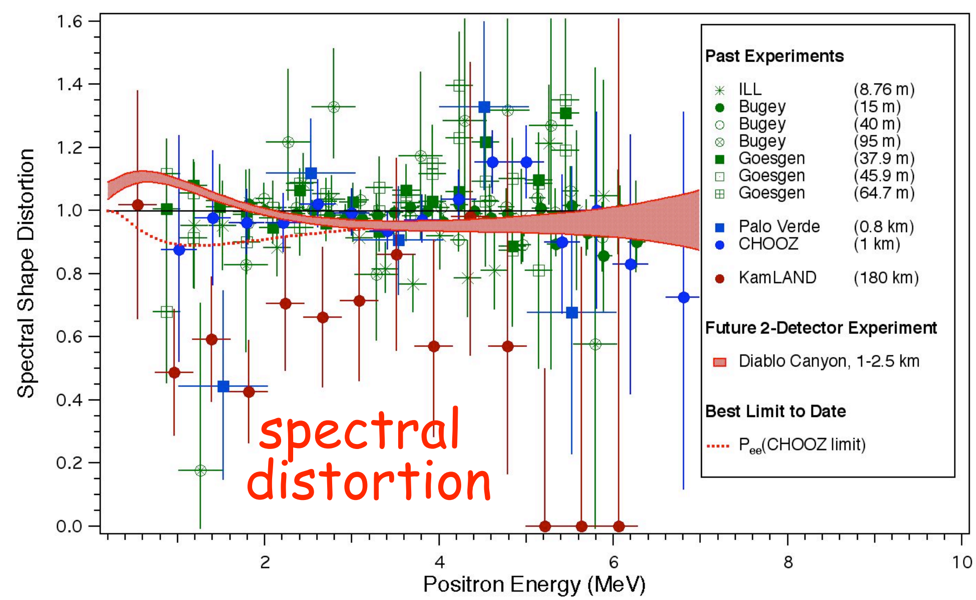
Energy spectrum of detected reactor $\bar{\nu}_e$



Measuring Δm^2_{31} With a Generic Setup







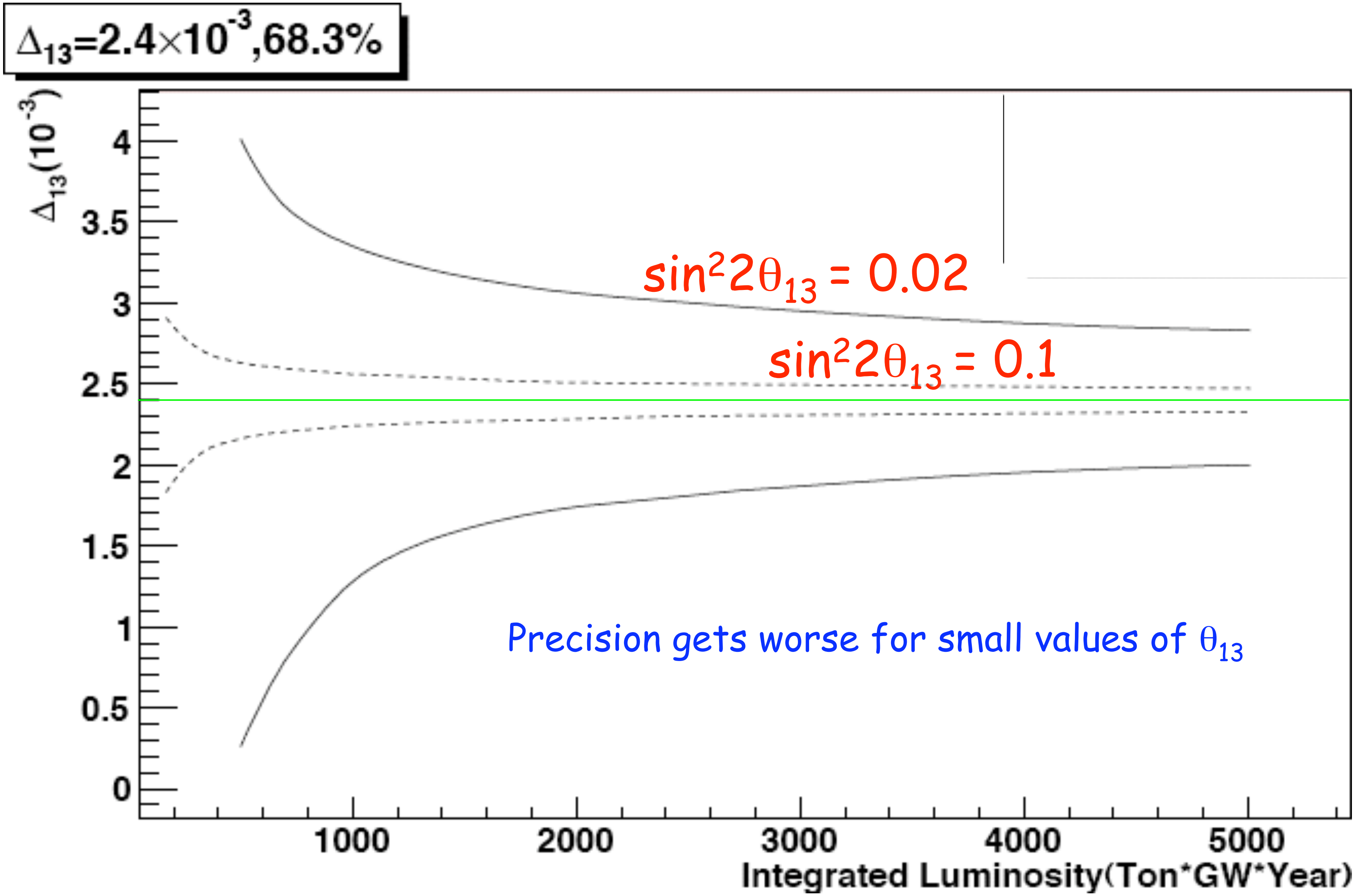
Calculation

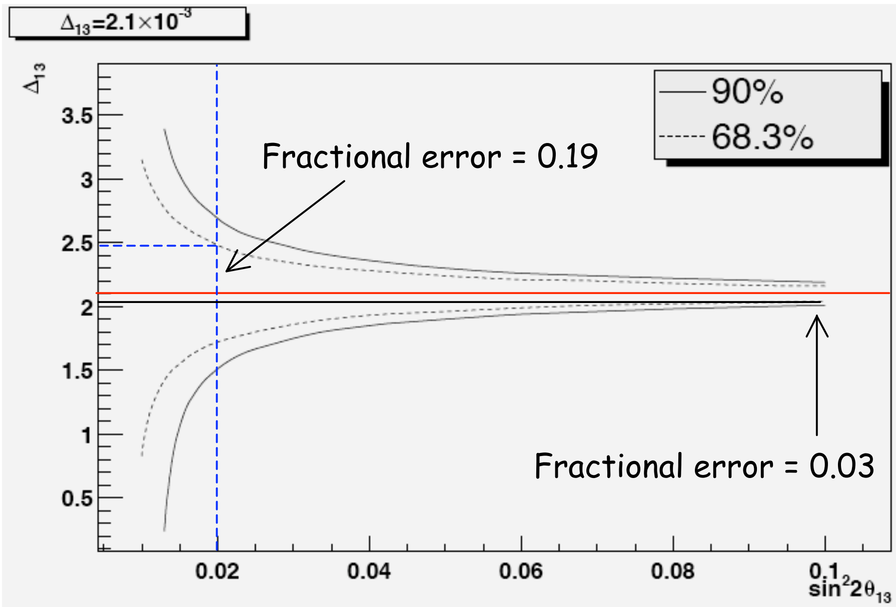
$$\chi^2 = \sum_i \frac{\left[M_i - T_i(1 + \alpha_D + \alpha_c + \sum_r \frac{T_i^r}{T_i}\alpha_r) \right]^2}{T_i + T_i^2\sigma_d^2 + B_i + B_i^2\sigma_B^2} + \frac{\alpha_D^2}{\sigma_D^2} + \frac{\alpha_c^2}{\sigma_c^2} + \sum_r \frac{\alpha_r^2}{\sigma_r^2}$$

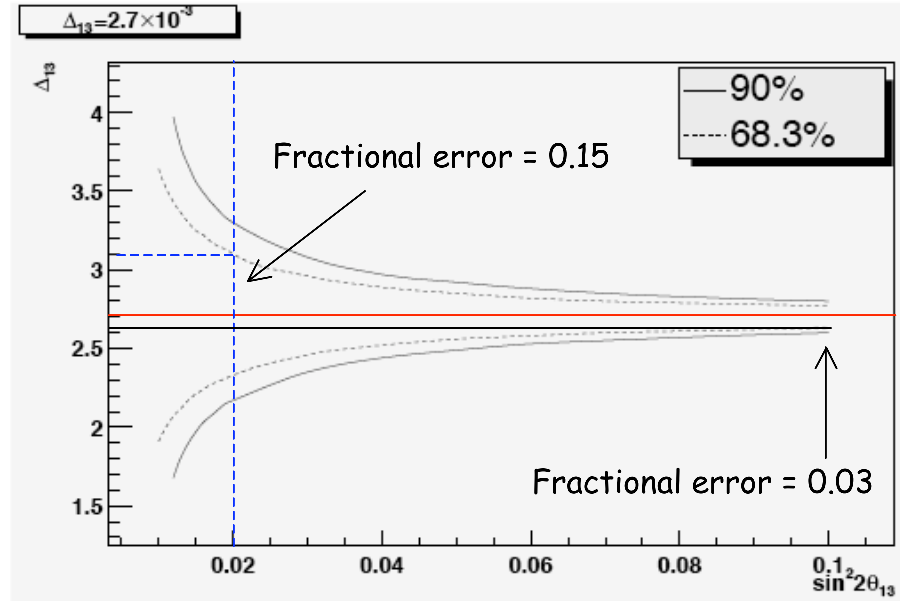
detector uncor.	background	Detector	Reactor	Reactor
0.005	1	cor = 0.03	cor= 0.02	Uncor=0.02

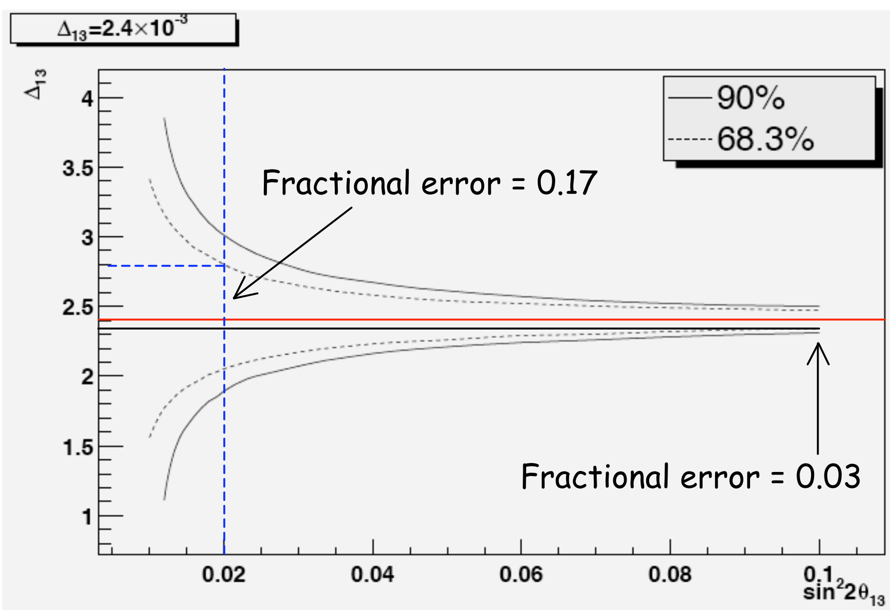
1. detector correlated error: 0.03
2. uncorrelated error of reactor: 0.02
3. error of detector is 0.005
4. error of background is 100%
5. error of energy shape is 0.02
6. error of background shape is 0.005
7. B/S of near site is 0.005
8. B/S of far site is 0.002
9. detection efficiency: 75%
10. near detector: 40 tonne
11. far detector: 100 tonne
12. reactor power: 16.7GW
13. run time: 3 years (300day/year)

Precision of Δm^2_{31}









- For a given value of θ_{13}, the precision is quite insensitive to Δm^2_{31}
- At the current limit of, reactor neutrino experiments yield a more precise value in Δm^2_{31} than

$\Delta m^2_{31} = \Delta m^2_{32} + \Delta m^2_{21} \approx (2.5^{+0.4}_{-0.3}) \times 10^{-3}\ \mathrm{eV}^2$

Conclusions

- A short-baseline reactor neutrino experiment can determine Δm^2_{31} up to $\sin^2 2\theta_{13} \sim 0.02$
- If $\sin^2 2\theta_{13} > 0.02$, Δm^2_{31} measured with a reactor can reach a precision at least as good as the one deduce from Δm^2_{32} and Δm^2_{21}
- If Δm^2_{31} measured with a reactor is significantly different from the one deduced from Δm^2_{32} and Δm^2_{21}, it will imply

    - there is(are) experimental error(s)
    - additional flavors of neutrino exist