Searching for θ_{13} mixing angle with reactor neutrinos

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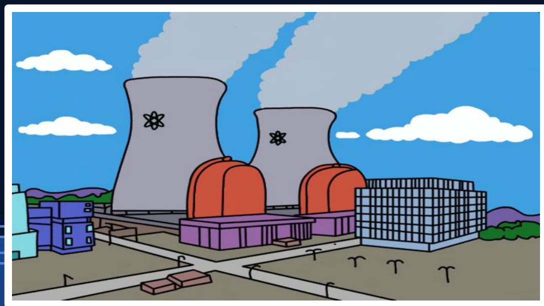
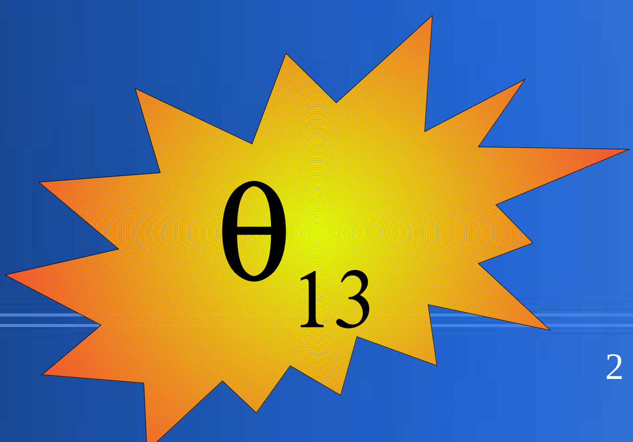
BEYOND 2010, Cape Town

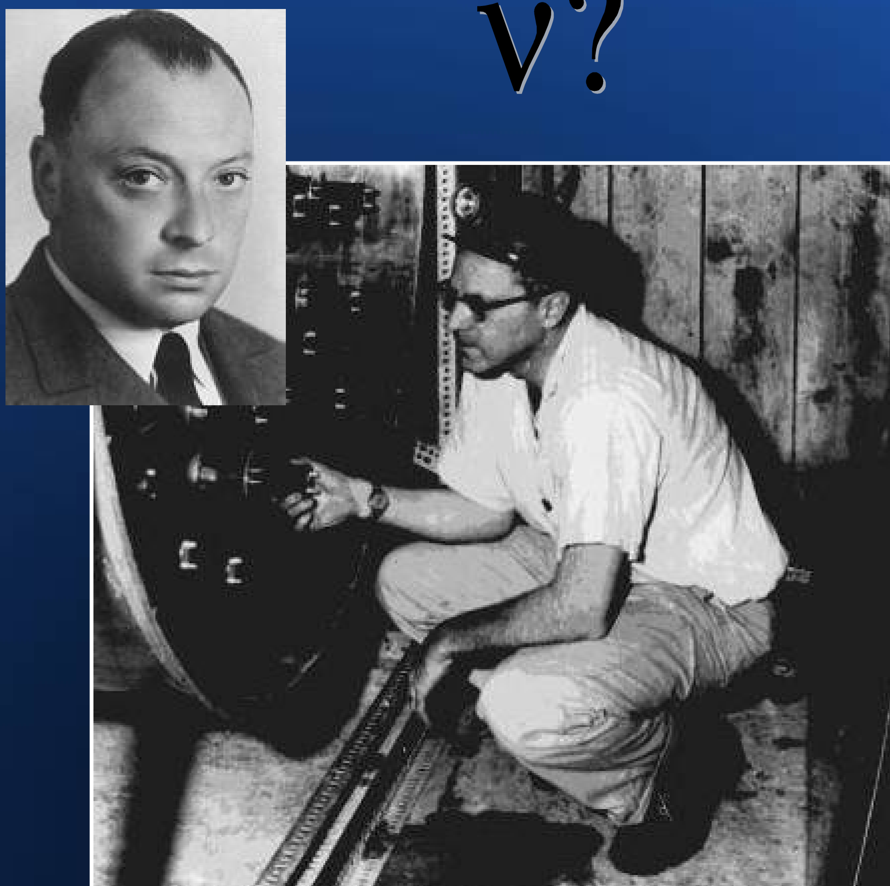


Overview

- What's next in neutrino oscillation physics
- Reactor neutrinos in the quest for θ_{13}
- Optimizing the experiments
- Reactor attempts in the search for θ_{13}
- θ_{13} Around the corner?



In the begining...



ν?

Reactors already played a major role in ν physics...

- 1956: Cowan and Reins detect reactor neutrinos
- 1990's: neutrino oscillations:

Physics Beyond the Standard Model

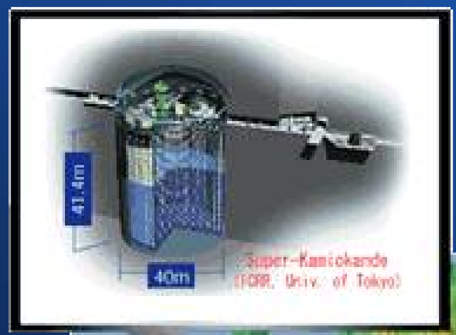
Reactors play a major role again!

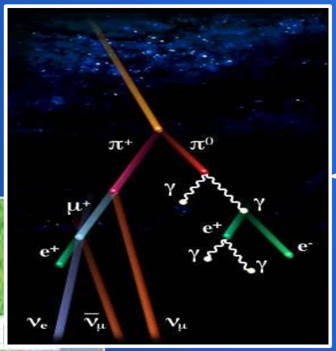
Measuring the oscillation

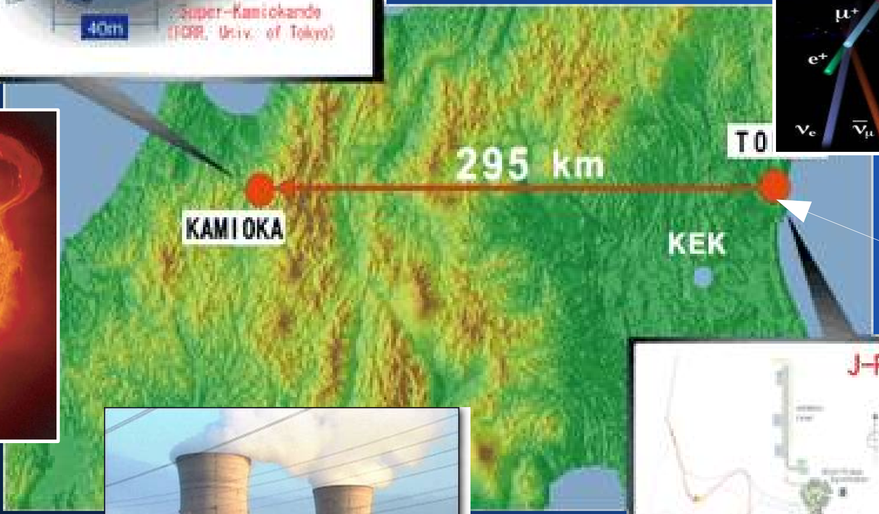
ν_α E_ν ν_β

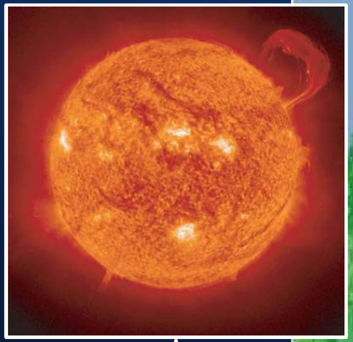
$\longrightarrow$

L









Δm_{atm} , θ_{atm}

Δm_{sol} , θ_{sol}

$\Delta m_{ij}^2 \equiv m_i^2 - m_j^2$

Exploring the neutrino mixing

$$\nu_{\alpha L} = \sum_{k=1}^{n} U_{\alpha k} \nu_{kL}$$

Oscillation parameters: $(\theta_{12}, \theta_{13}, \theta_{23})$, $(\Delta m^2_{21}, \Delta m^2_{31})$, δ

Oscillation physics

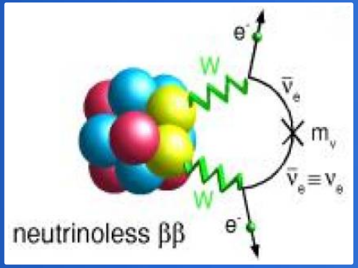
$\beta\beta0\nu$

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{21} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} e^{i\alpha_1} & 0 & 0 \\ 0 & e^{i\alpha_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Atmospheric sector

interference sector ?

Solar sector

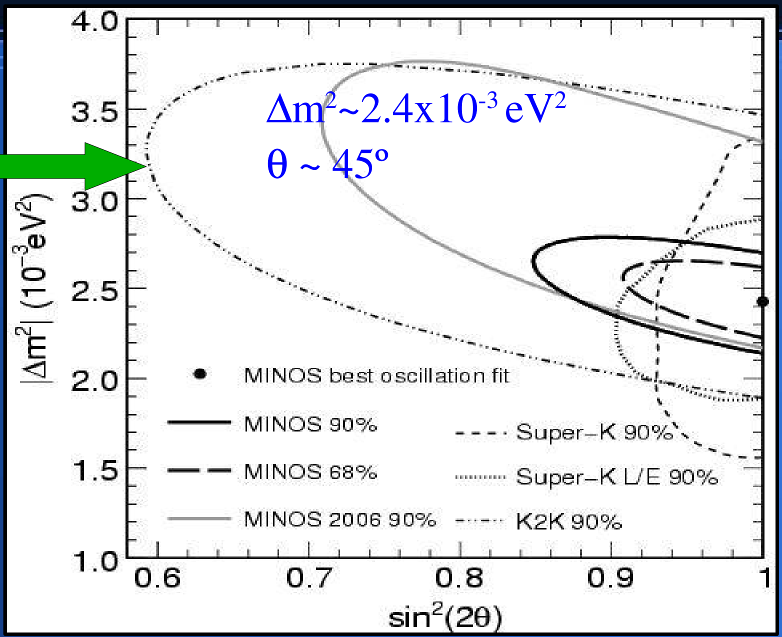


What's next?

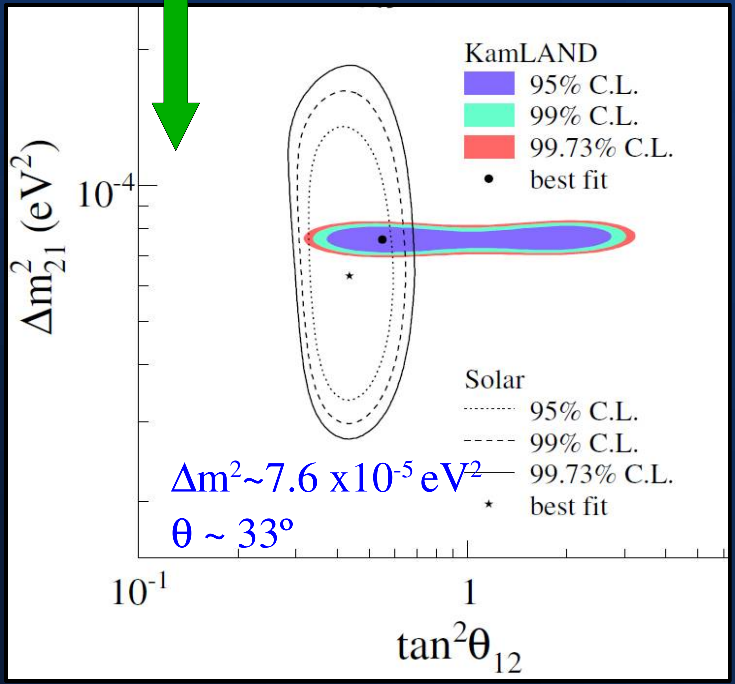
- Experimental results:

- $(|\Delta m^2_{atm}|, \theta_{atm})$ → Minos and Super-K

- $(\Delta m^2_{sol}, \theta_{sol})$ → Kamland and solar data



Phys. Rev. Lett. 101:131802,2008



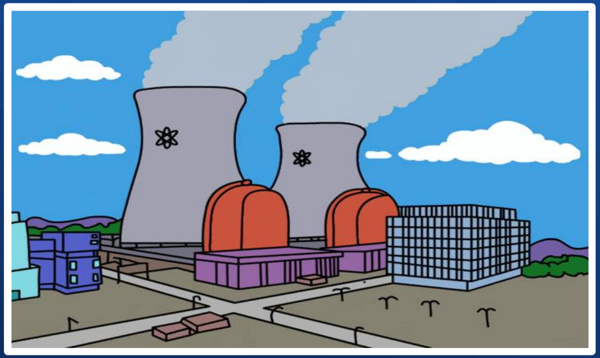
Phys. Rev. Lett. 100:221803, 2008

- **$\sin^2(2\theta_{13}) < 0.15$ → Chooz: δ?**

θ_{13}

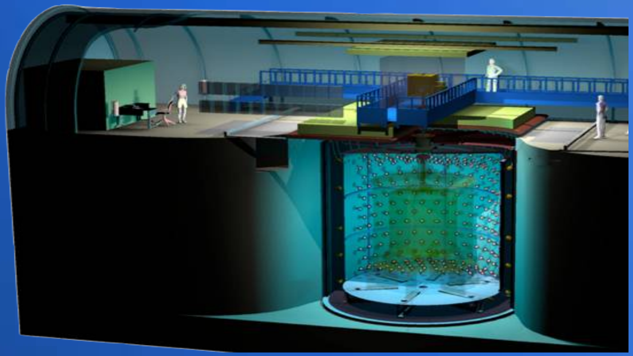
- Measurement of δ_{cp}
- Sign of Δm^2_{atm} (hierarchy)
- Design of next experiments

Why reactor neutrinos?



L ~ 1 km

P($\bar{\nu}_e \rightarrow \bar{\nu}_x$)



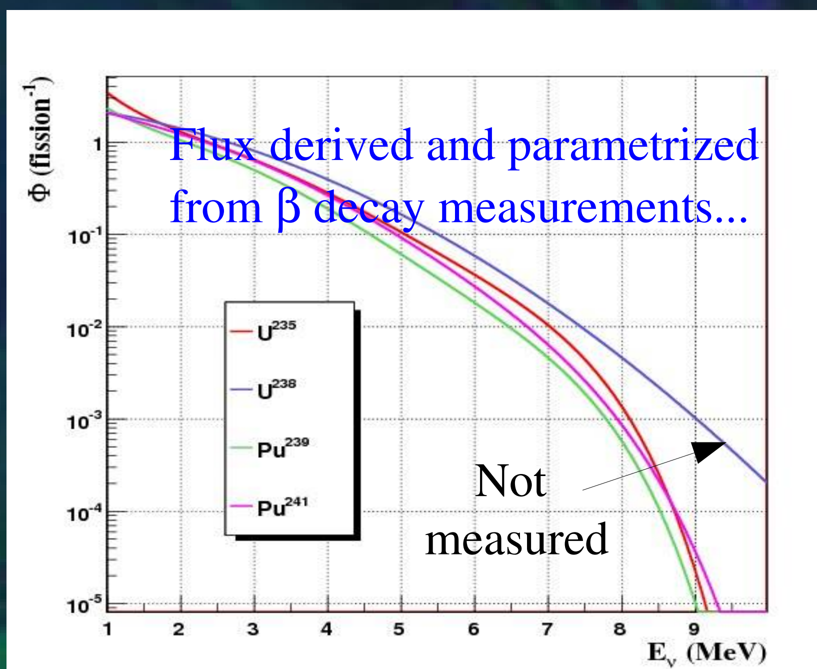
- In contrast to accelerator experiments...

$$P_{ee}(E_{\overline{\nu}_e}, L, \Delta m^2_{31}, \theta_{13}) = 1 - \sin^2(2\theta_{13}) \sin^2\left(1.27 \frac{\Delta m^2_{31}[10^{-3}\ \mathrm{eV}^2] L[\mathrm{km}]}{E_{\overline{\nu}_e}[\mathrm{MeV}]}\right)$$

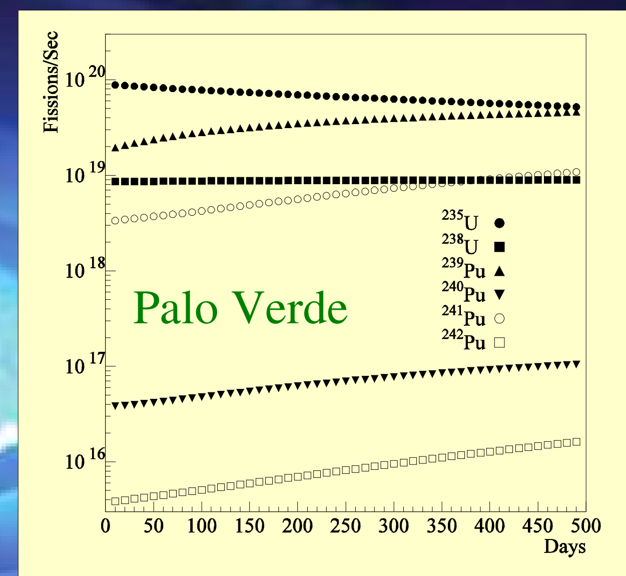
- No parameter correlations
- Nearly pure $\bar{\nu}_e$ beam
- Low energy
- No matter effects
- Cheap, as source exists
- High flux and large xsection

Reactors as ν source

ν come from fission products...



- ν Flux depends on fuel composition:



- ν Flux known to only 2%

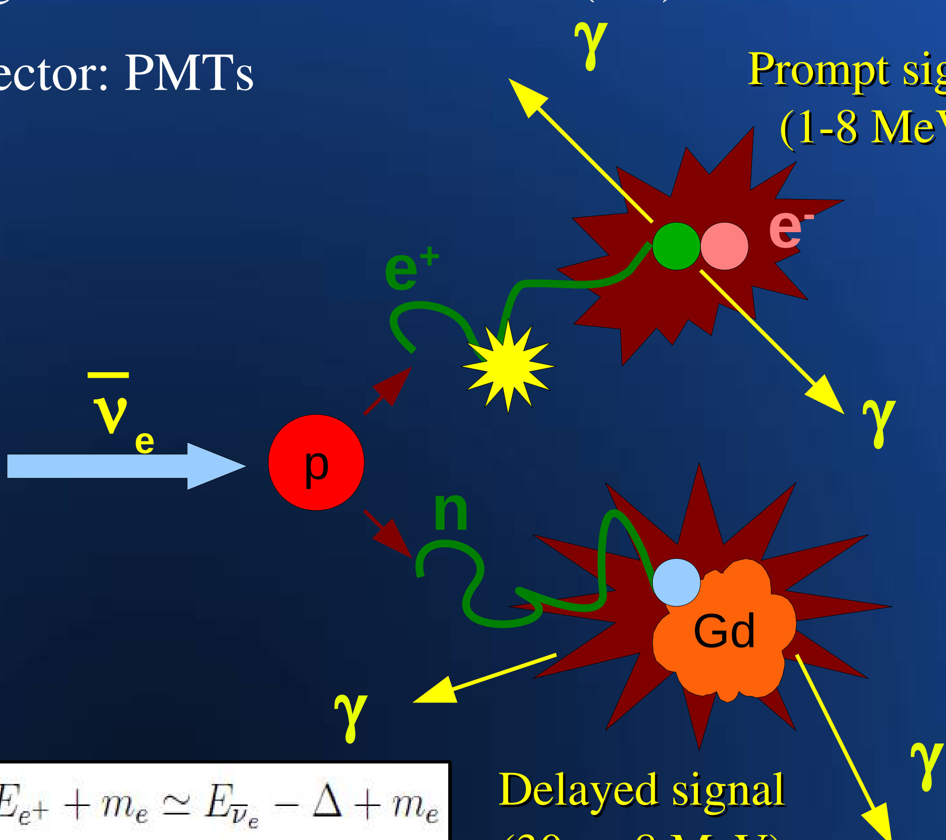
- **High flux: 1GW$_{th}$ ~ 2×10^{20} $\bar{\nu}_e$ / s**

Detecting reactor neutrinos

IBD: $\overline{\nu}_e + p \rightarrow e^+ + n$

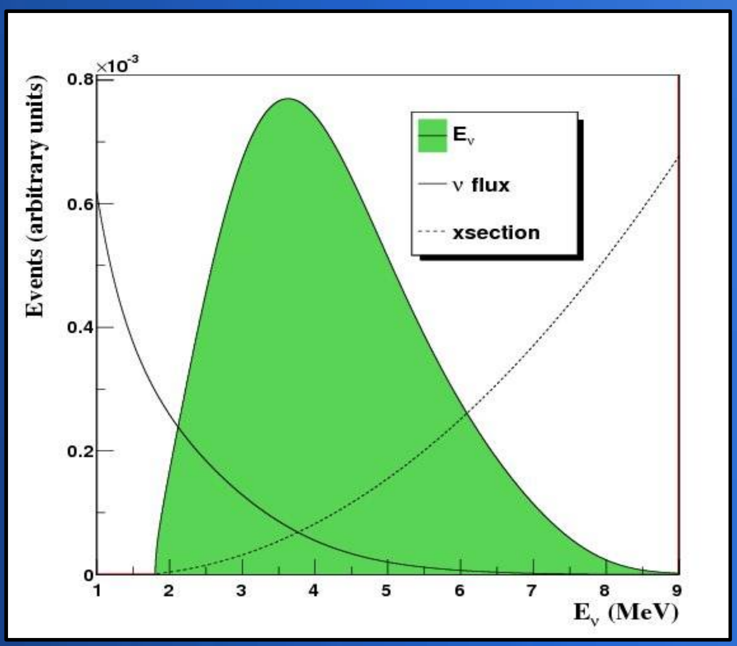
Th: 1.8 MeV. **Disappearance!**

- Target: scintillator + n-catcher (Gd)
- Detector: PMTs



$$E_{\rm vis} = E_{e^+} + m_e \simeq E_{\overline{\nu}_e} - \Delta + m_e$$

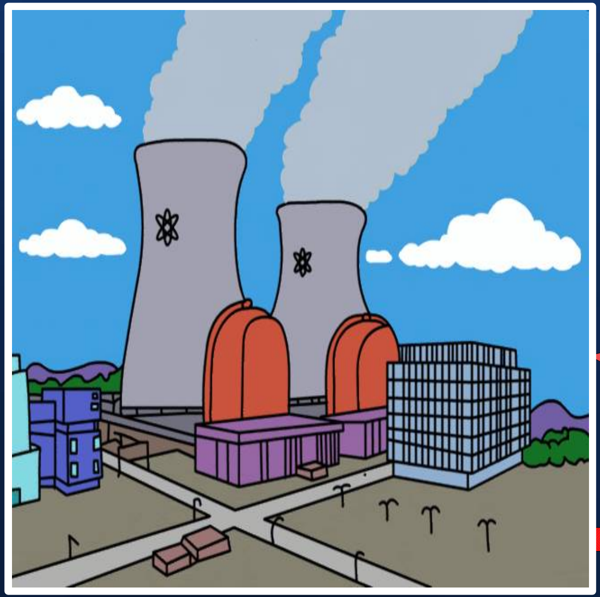
E_ν spectrum

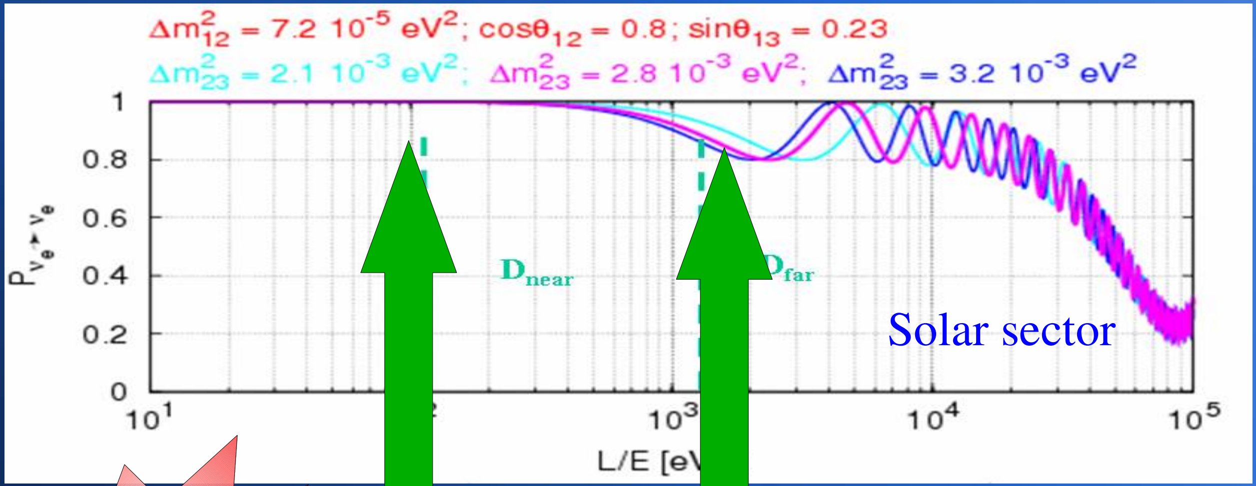


Setting up the experiment

Reactor neutrinos:

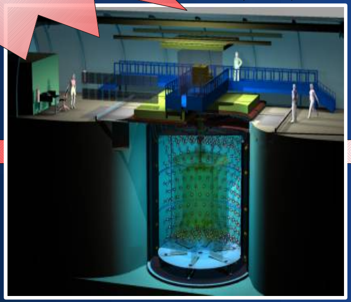
$\langle E_\nu \rangle \sim 4$ MeV

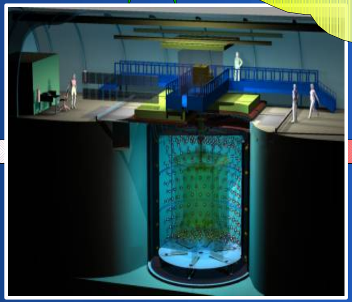




Systematics!

Oscillation!



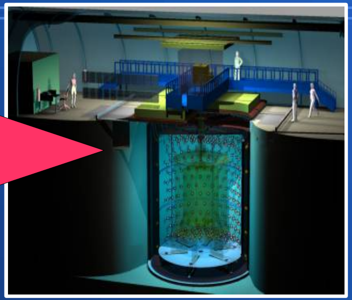


~ 100 m

~ 1 km

Expected oscillation signal

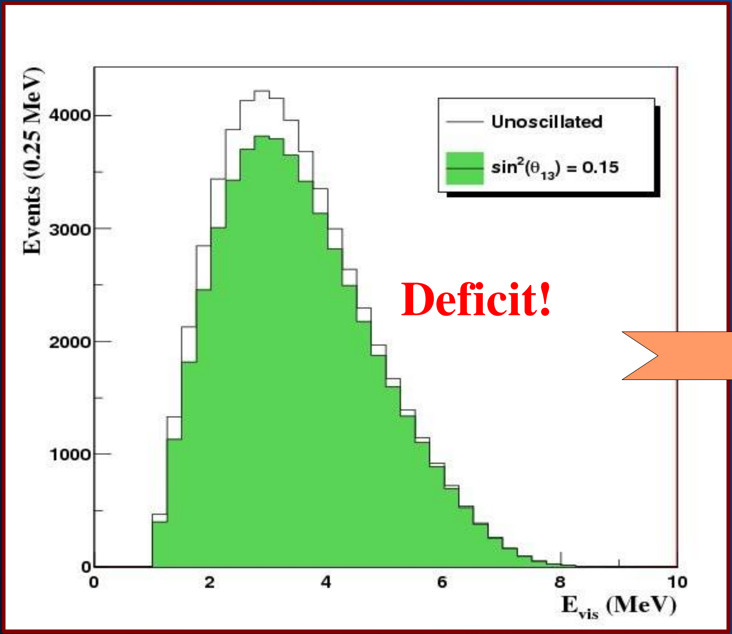
1 km

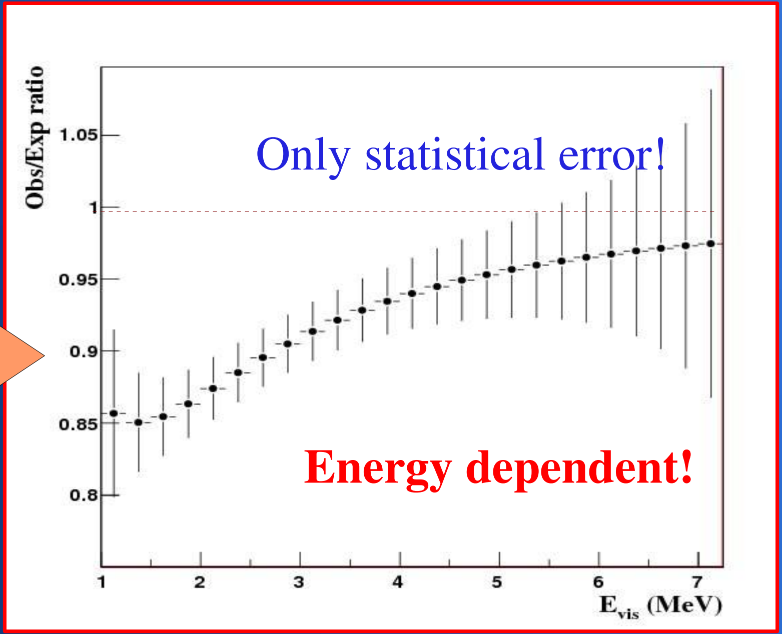


- $8x10^{29}$ free protons
- Detection efficiency 80%

3 years:

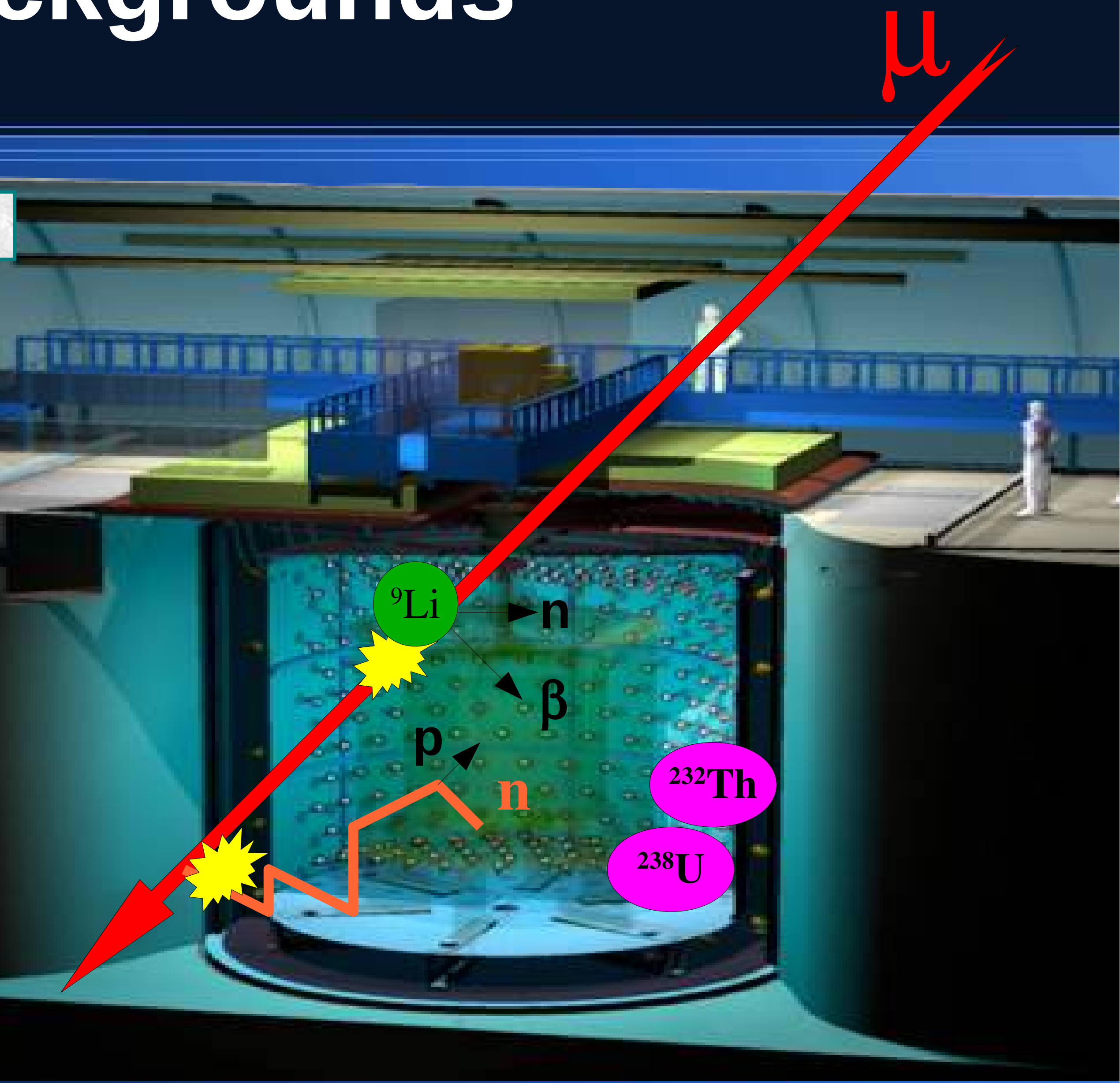
~ 50.000 events expected





Backgrounds

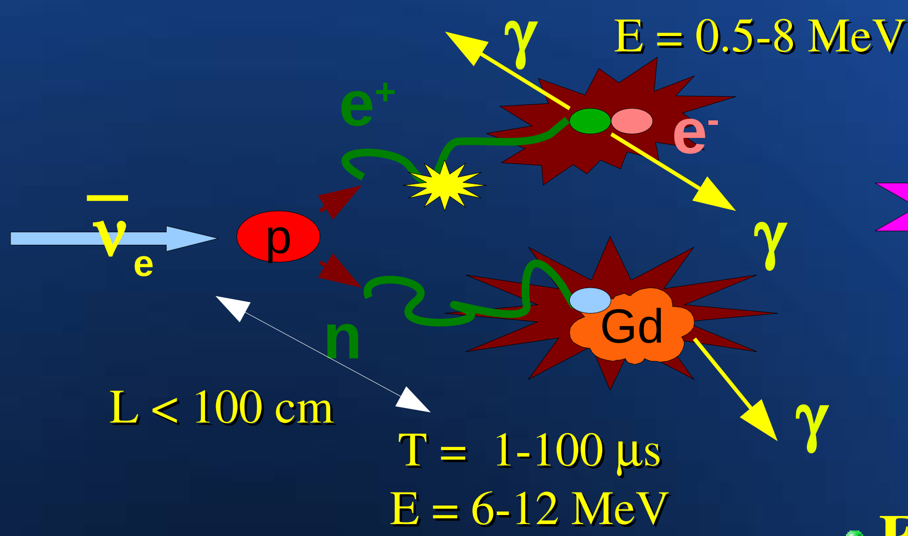
Goal on subtraction error: <1%



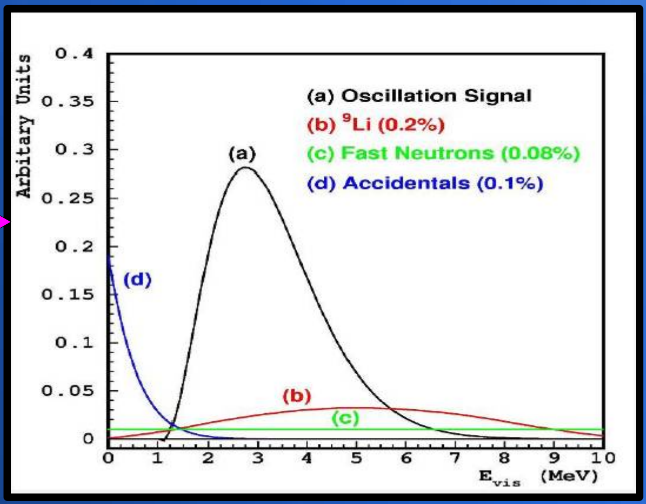
- Uncorrelated: ^{232}Th and ^{238}U
- Correlated:
  - Muon spallation: ^{9}Li
  - Fast neutrons

Analyzing the data

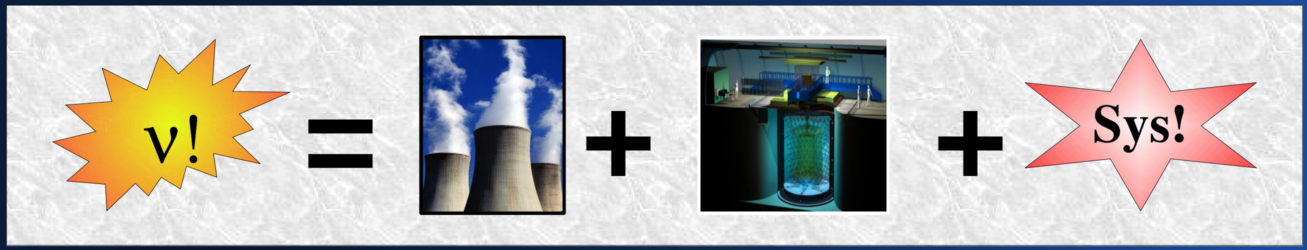
- **Identify neutrino events (cuts):**



- Subtract **backgrounds:**



- **Extract oscillation signal:**

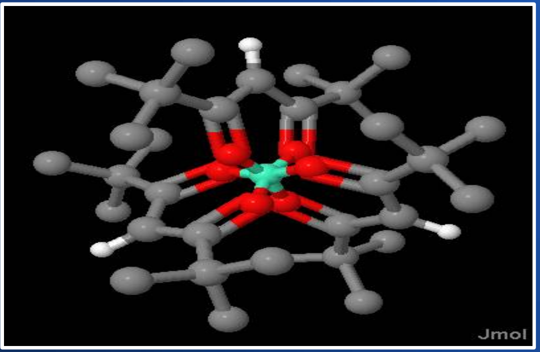


$$\chi^2 = \chi^2_{stats} + \Sigma\, \chi^2_{sys}$$

Experimental challenges

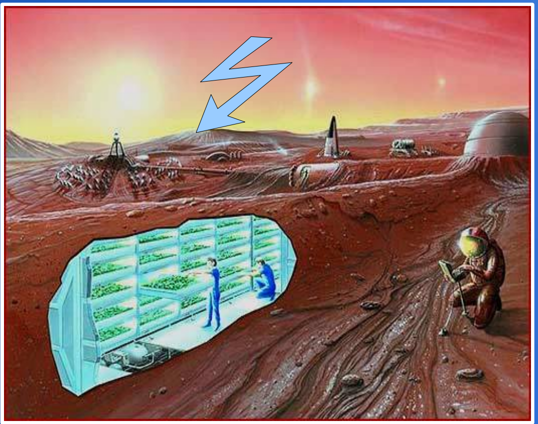
Reactor Flux

Doped scintillator



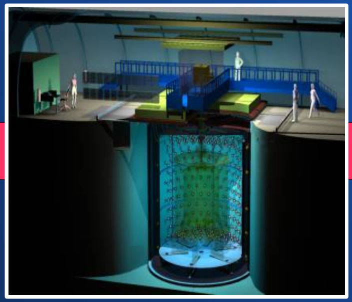
Radio-cleanliness

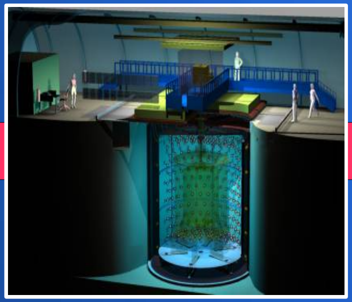
Backgrounds



Systematics!

Fighting the systematics





- Flux shape: ~ 2%
- Flux rate: ~2%

- Energy scale: ~ 0.5%
- Free H in target: ~0.5%
- Cross-section : ~0.1%

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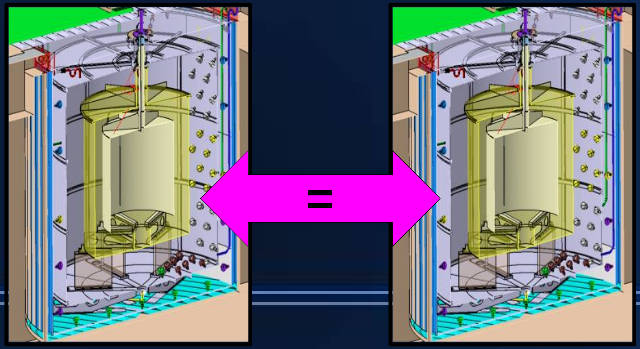
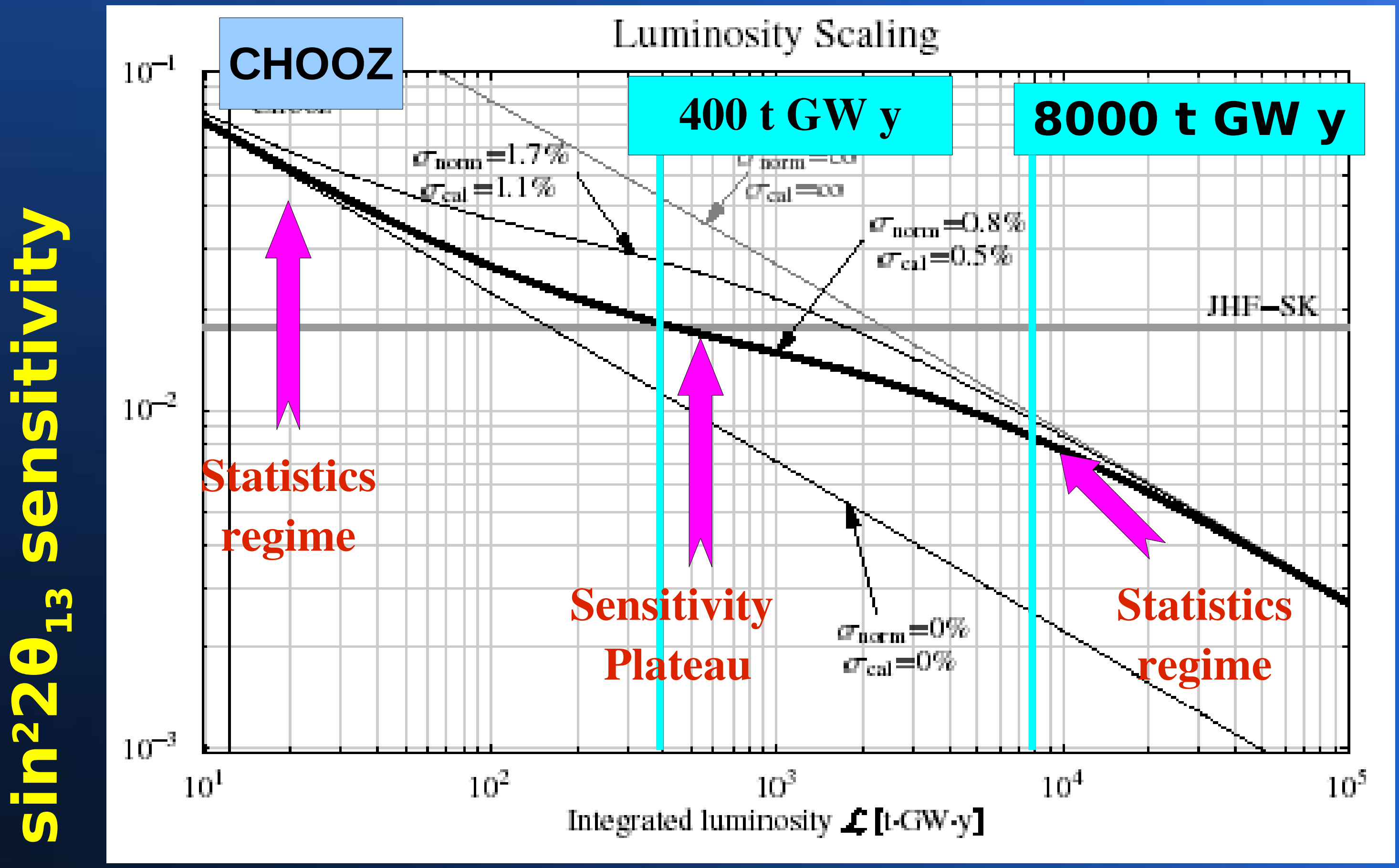
- Free H in target: ~0.5%
- Cross-section : ~0.1%



- **Relative normalization and energy scale** (~0.5%)

Impact of systematics

Optimize the analysis according to the luminosity scaling…



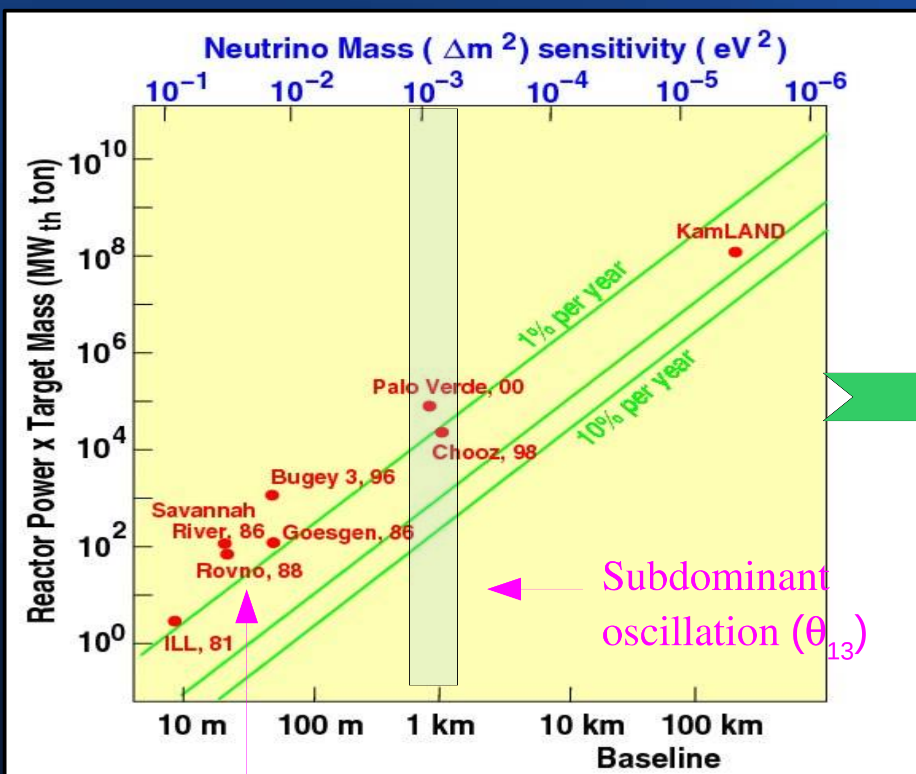
Integrated luminosity *L* (t ·G·W·y)

From hep-ph/0303232

What we know about θ_{13}

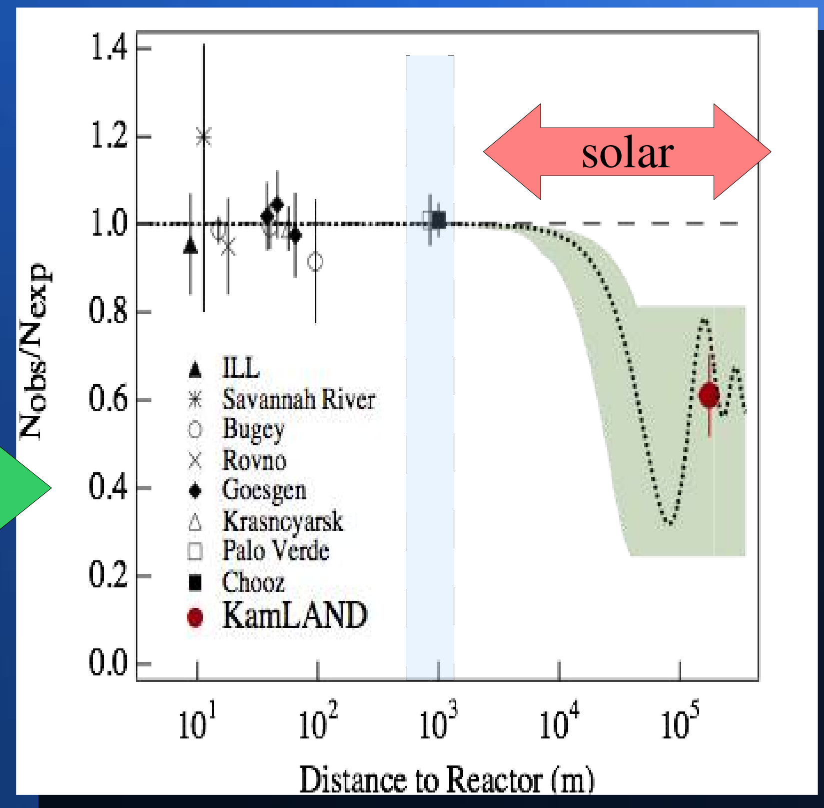
- Past reactor experiments...

Gratta et Al. Rev. Mod. Phys, 74, 2002



Subdominant oscillation (θ_{13})

Measurement of reactor flux



Phys. Rev. Lett. 90, 021802 (2003)

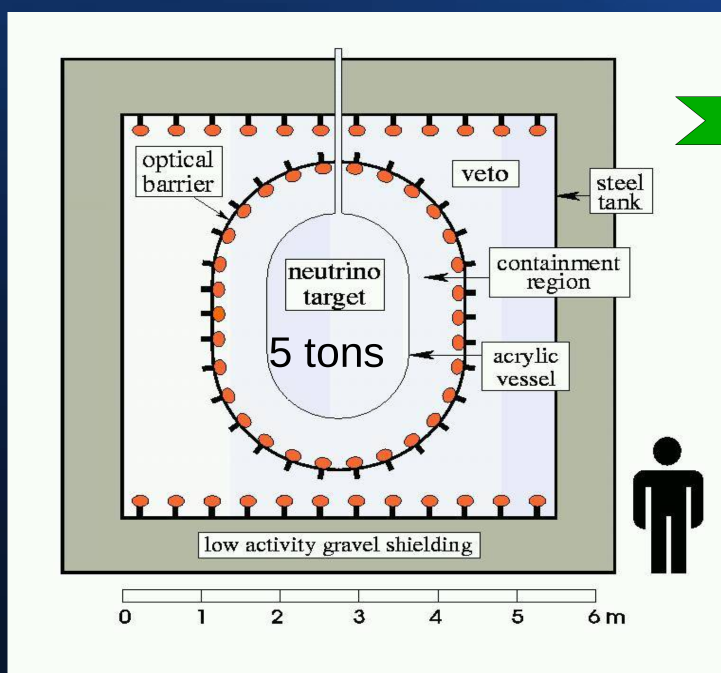
- From CHOOZ: $\sin^2(2\theta_{13}) < 0.15$

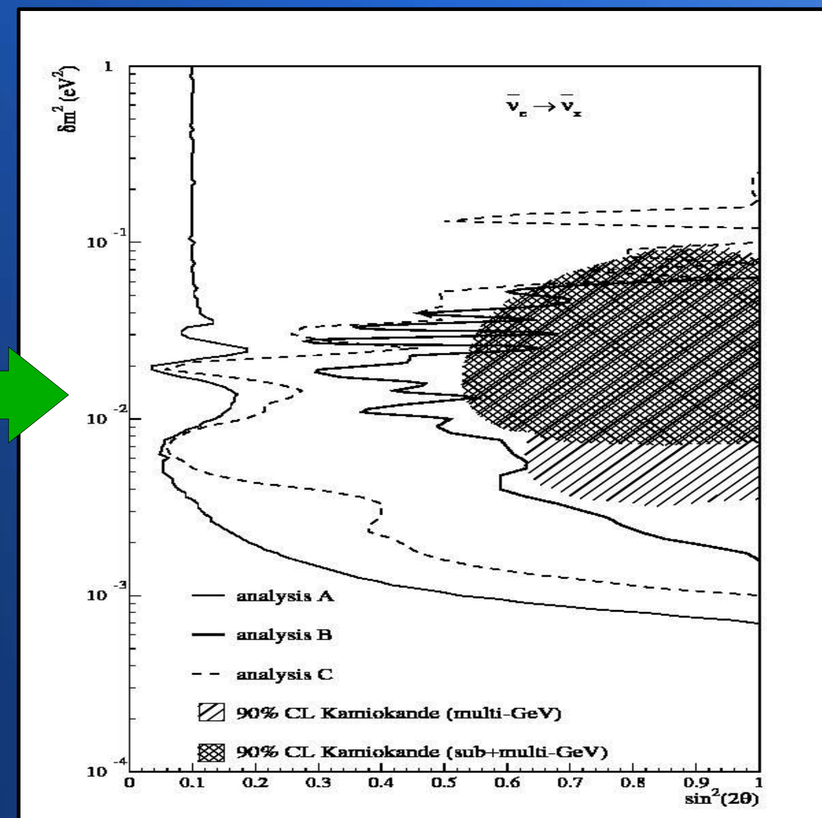
What we know about θ_{13}

The CHOOZ experiment

- Chooz Power Plant: 2x2.45 GW_{th}
- Only far detector: 1 km

IBD: $\bar{\nu}_e + p \rightarrow e^+ + n$



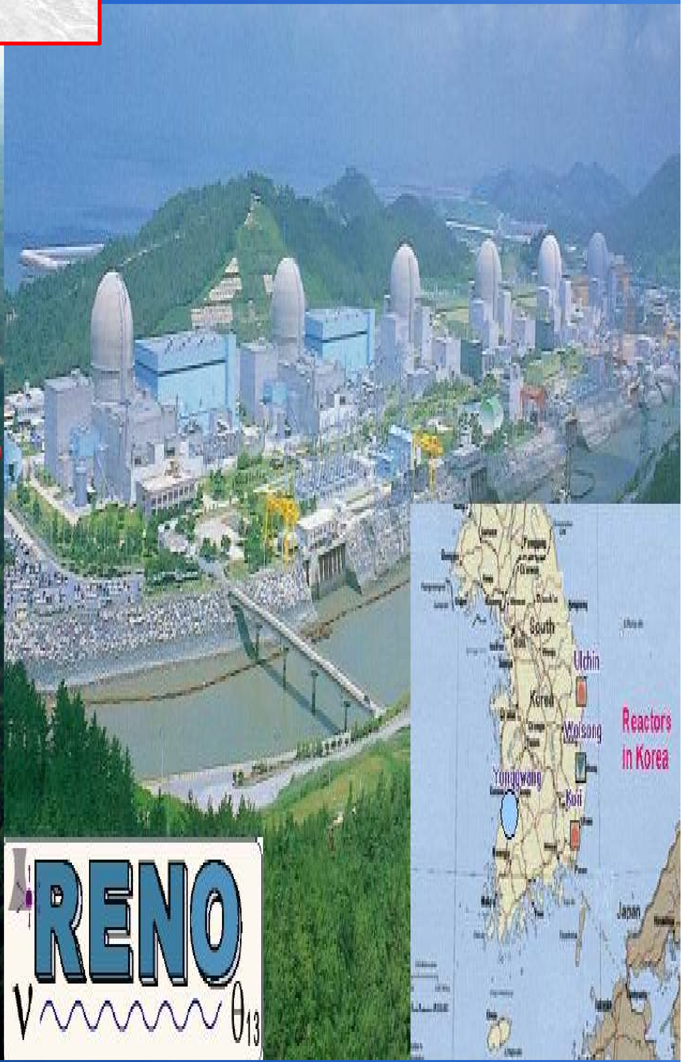


hep-ex/0301017

- Current experiments *scale up* the technology!

New Generation Experiments

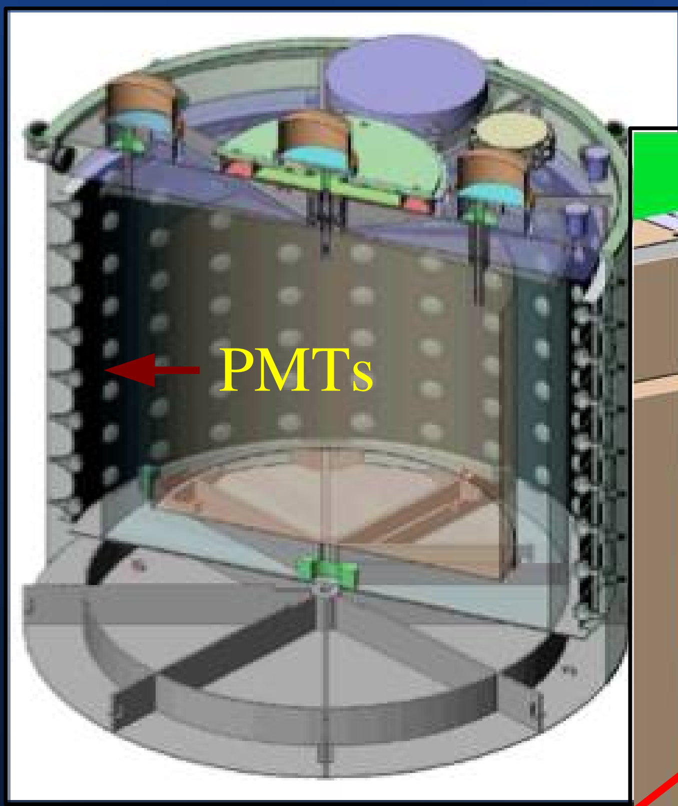
Multi-detector setups!



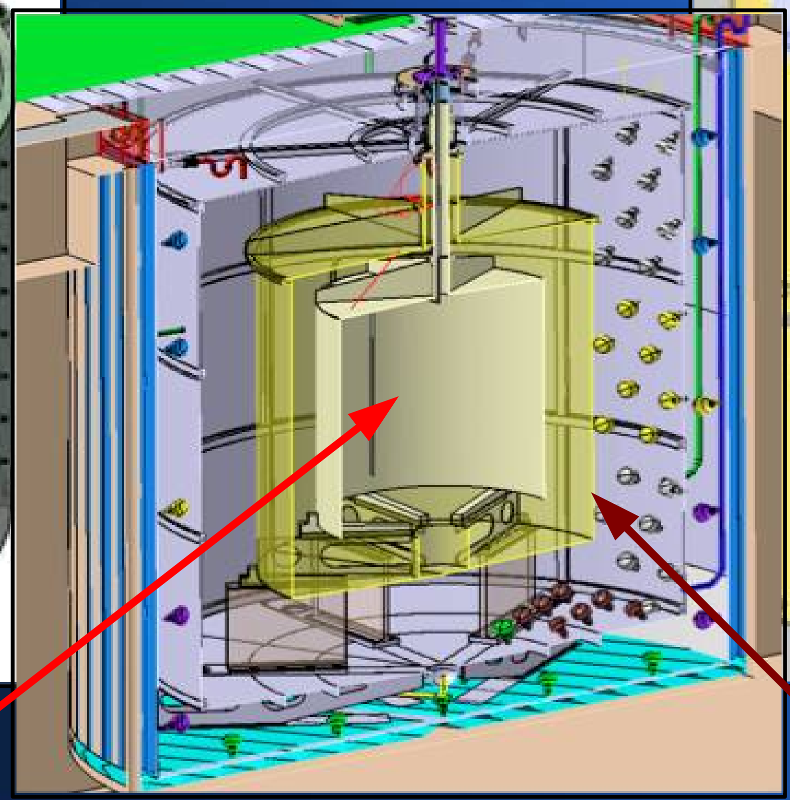
Detector technology

IBD: $\bar{\nu}_e + p \rightarrow e^+ + n$

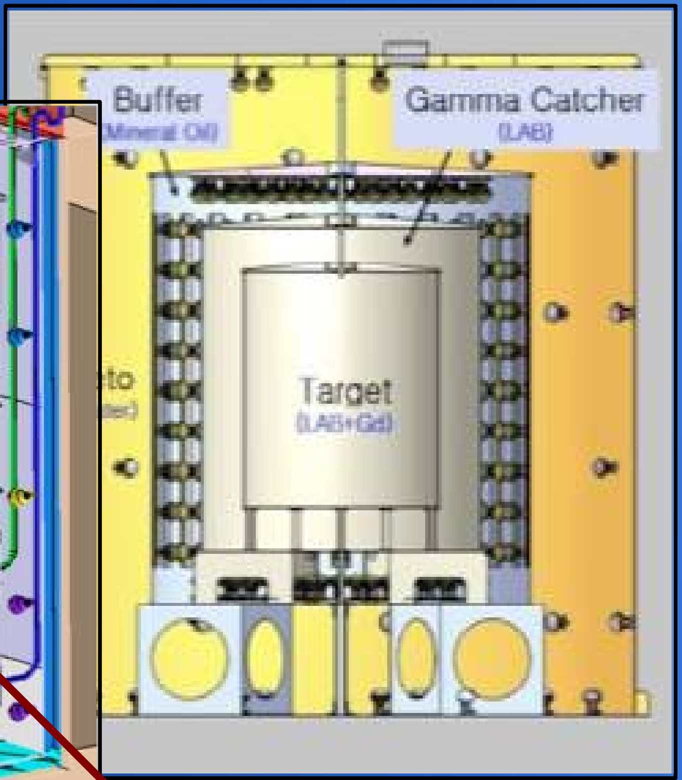
Daya Bay



Double Chooz



RENO



Target: scin + Gd

Gamma catcher

Comparing the experiments

Power	Target
8.6 GW	8.24 tons

Near	Far
400 m/115 wme	1.05 km/300 wme

Power	Target (x2x4)
17.4 GW	20 tons

Near (x2)	Far
360-500 m/ 260 mwe	1.6-2.0 km/910 wme

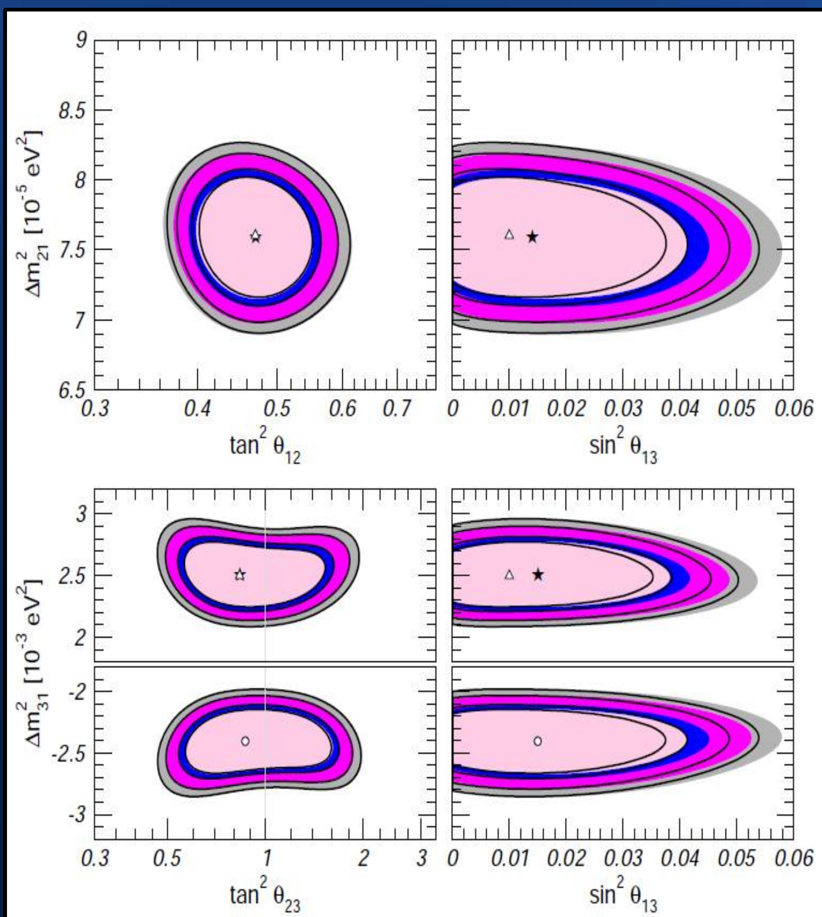
Power	Target
17.3 GW	16 tons

Near	Far
290 m/130 wme	1.38 km/460 wme

	σ_{stats} (%)	σ_{sys} (%)	s^2_{13lim} (90% CL)
D. Chooz	0.5	0.6	**0.03**
Reno	0.3	0.5	**0.02**
Daya Bay	0.2	0.4	**0.01**

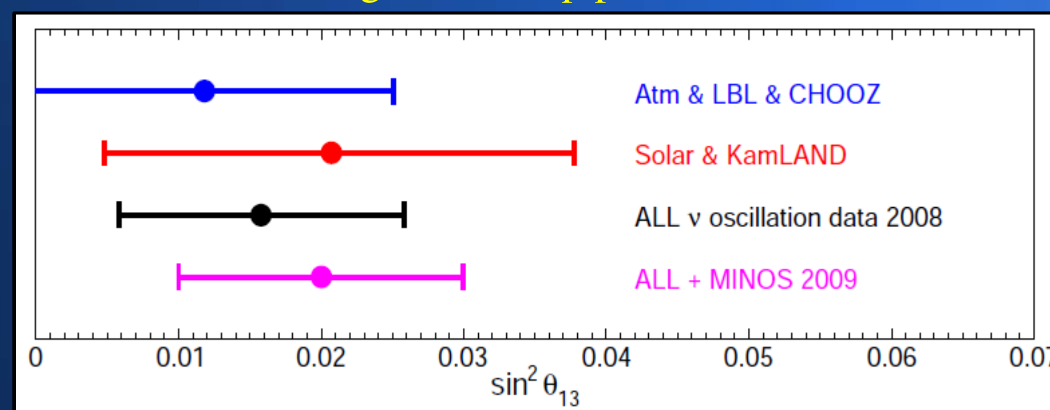
θ_{13} around the corner?

Gonzalez-Garcia et Al., hep/ph 1001.4524



- Global fit for 3-flavour scenario
  - Preference for $\theta_{13} \neq 0$
- First hint of θ_{13} : $\sin^2(\theta_{13}) \sim 0.01\text{-}0.02$

G.L. Fogli et Al, hep/ph 0905.3549v2



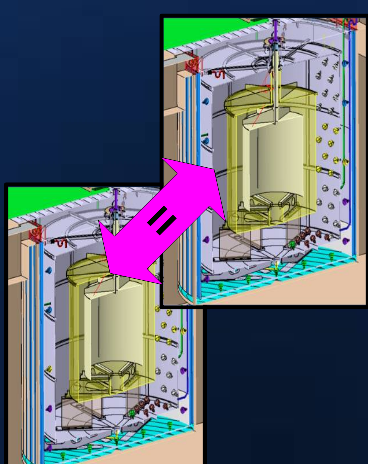
Reactors will be there in 2 years!

Summary

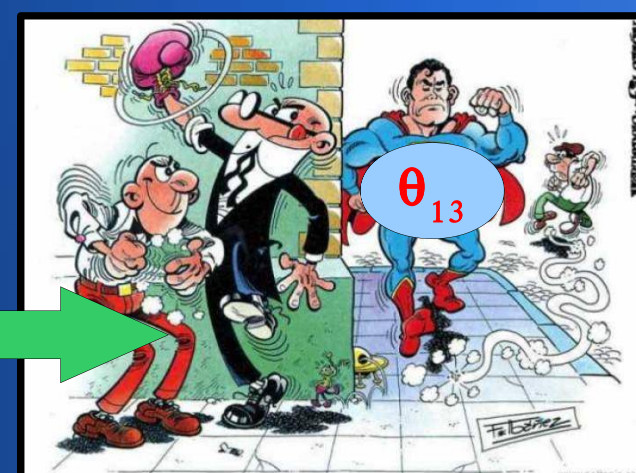
ν!

θ_{13}?

CP?



2011?




Thank you!