Oscillazioni di neutrini ai reattori

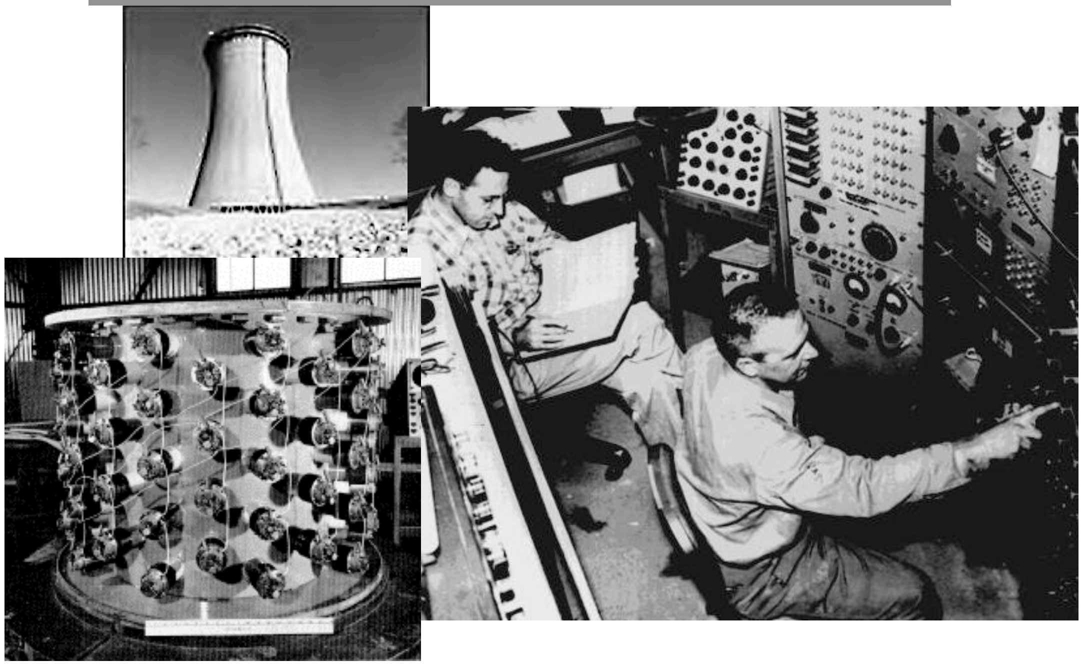
Alessandra Tonazzo - Paris7 & APC

- **Neutrini da reattori e misura di oscillazioni**
- **Un cenno a Δm^2_{12} e KamLAND**
- **Misura di θ_{13}**
  - **Double Chooz**
  - **Daya Bay, RENO, Angra ….**
- **Un'idea per la gerarchia di massa**

The discovery of the neutrino

1955- **Cowan and Reines**: detection of the neutrino ($\bar{\nu}_e$), with an experiment at the Savannah River nuclear power plant.

"The Neutrino", F. Reines and C.L. Cowan, Jr., Nature 178, 446 (1956)



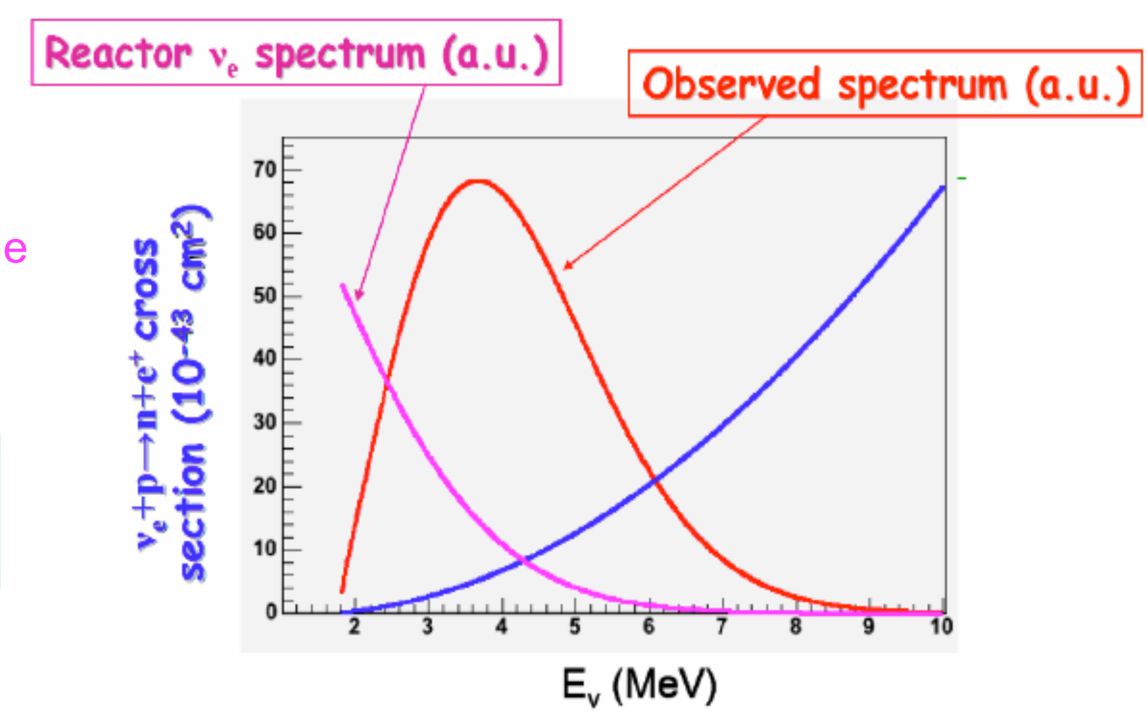
Reactor neutrinos

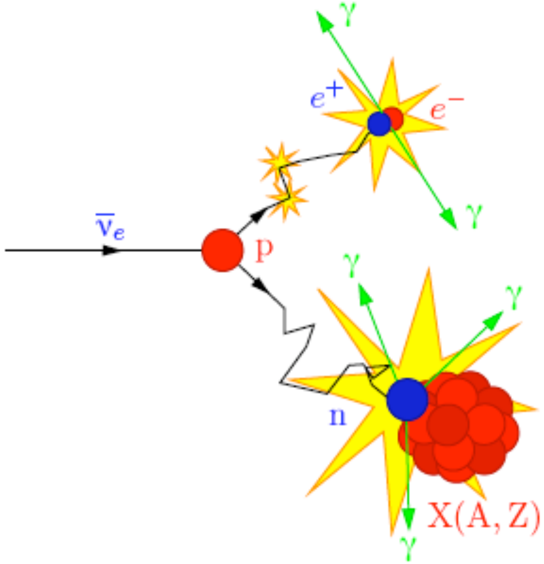
$$N_\nu\left(s^{-1}\right) = 6N_{Fiss}\left(s^{-1}\right) \approx 2\times10^{11}P\left(s^{-1}\right)$$

P=8GW $\Rightarrow N_\nu \sim 10^{21} s^{-1}$ on all solid angle

Detection by "inverse beta"

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





Prompt photons from **e^+** annihilation

$E_e = E_\nu + 1.8$ MeV + $O(E_e/m_n)$

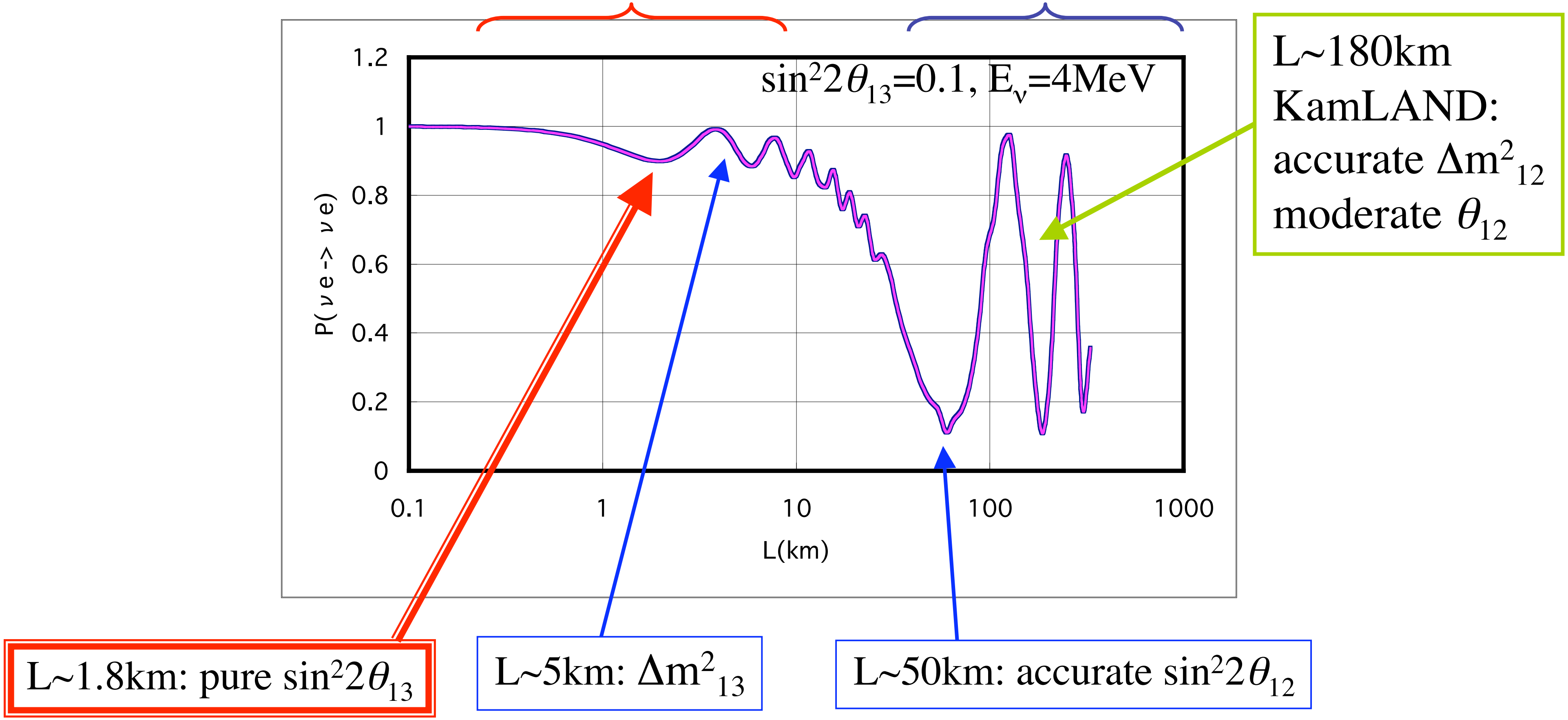
Delayed photons from **n** capture on H or on dedicated nuclei

(Gd: $\Delta t \sim 30\ \mu s$ E ~ 8 MeV)

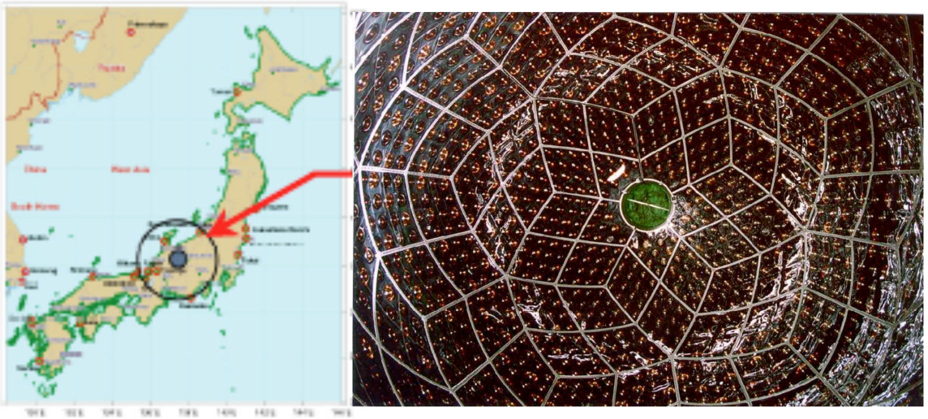
Oscillations with reactor νs

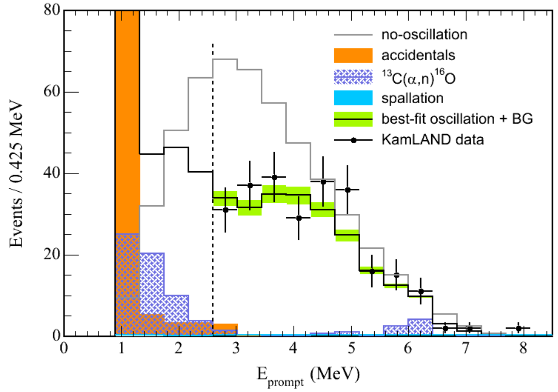
$\langle E_\nu \rangle$~ few MeV ⇒ Disappearance experiments

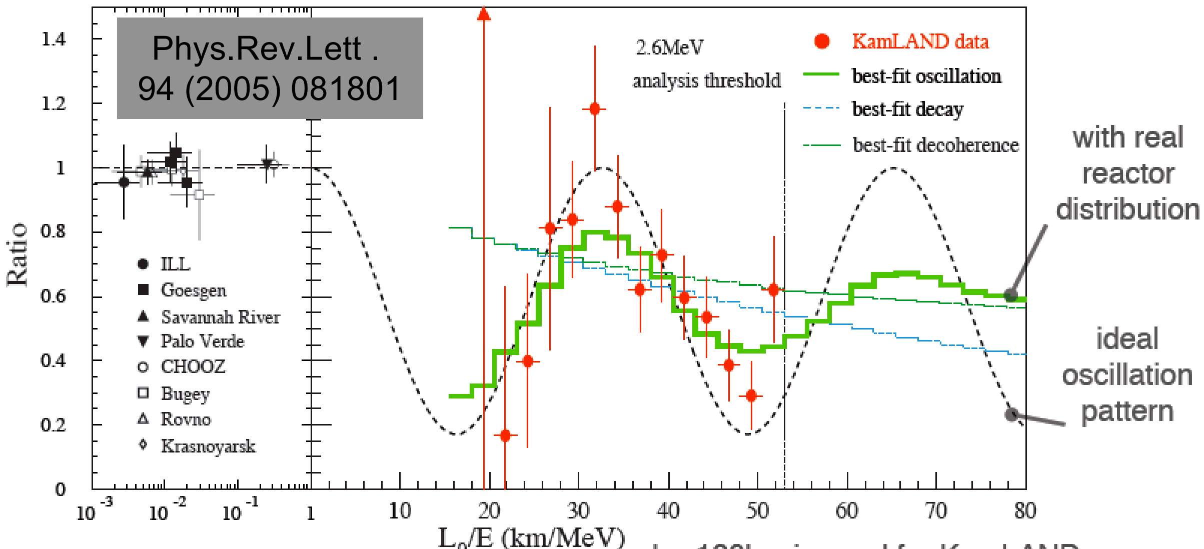
$$P(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2 \frac{\Delta m^2_{13} L}{4E} - \cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2 \frac{\Delta m^2_{12} L}{4E}$$



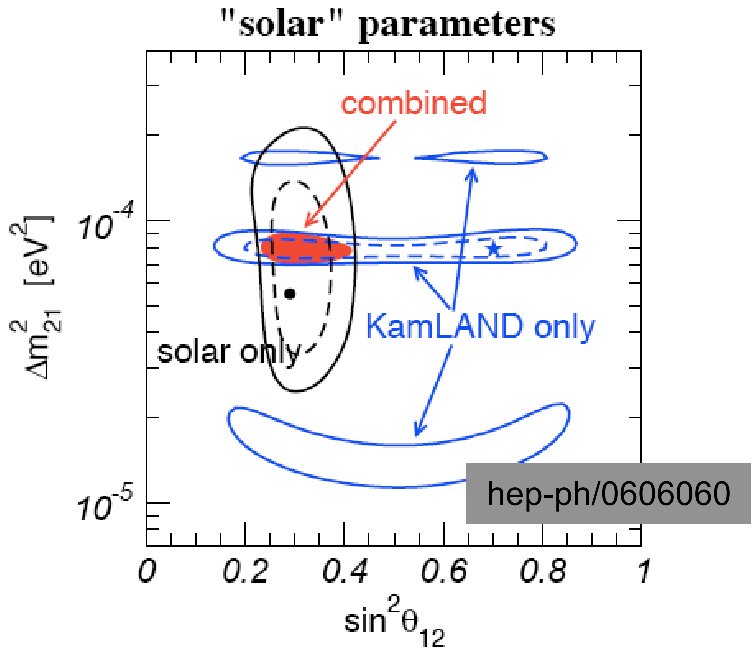
Δm_{12} @ KamLAND







L_0=180km is used for KamLAND



$$\Delta m^2 = 7.9^{+0.6}_{-0.5} \cdot 10^{-5} eV^2 \quad (2\sigma)$$

Prospects of KamLAND

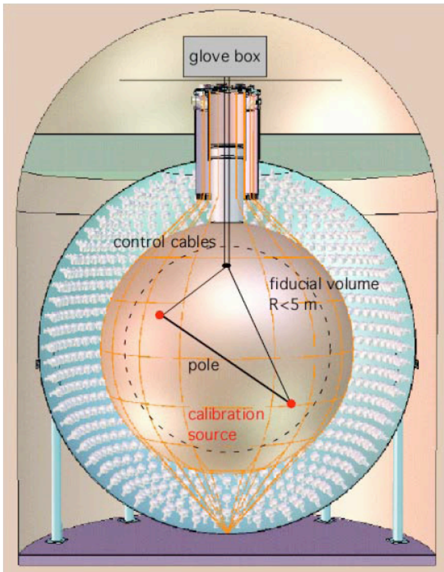
Shirai @NOW06

Reduce systematic error by a new calibration system in place of the vertical-axis calibration.

Systematic error : 6.5%

Detector	(%)
Fiducial vol.	4.7
Energy threshold	2.3
Efficiency of cuts	1.6
Live time	0.06

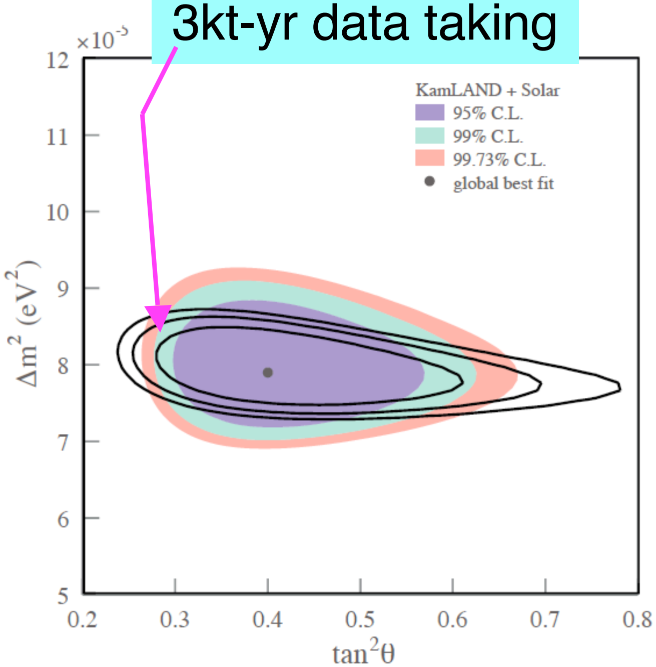
Reactor power	2.1
Fuel composition	1.0
ν_e spectra	2.5
Cross section	0.2



"4π system"

Now ready !

3% rate error
1% scale error
3kt-yr data taking

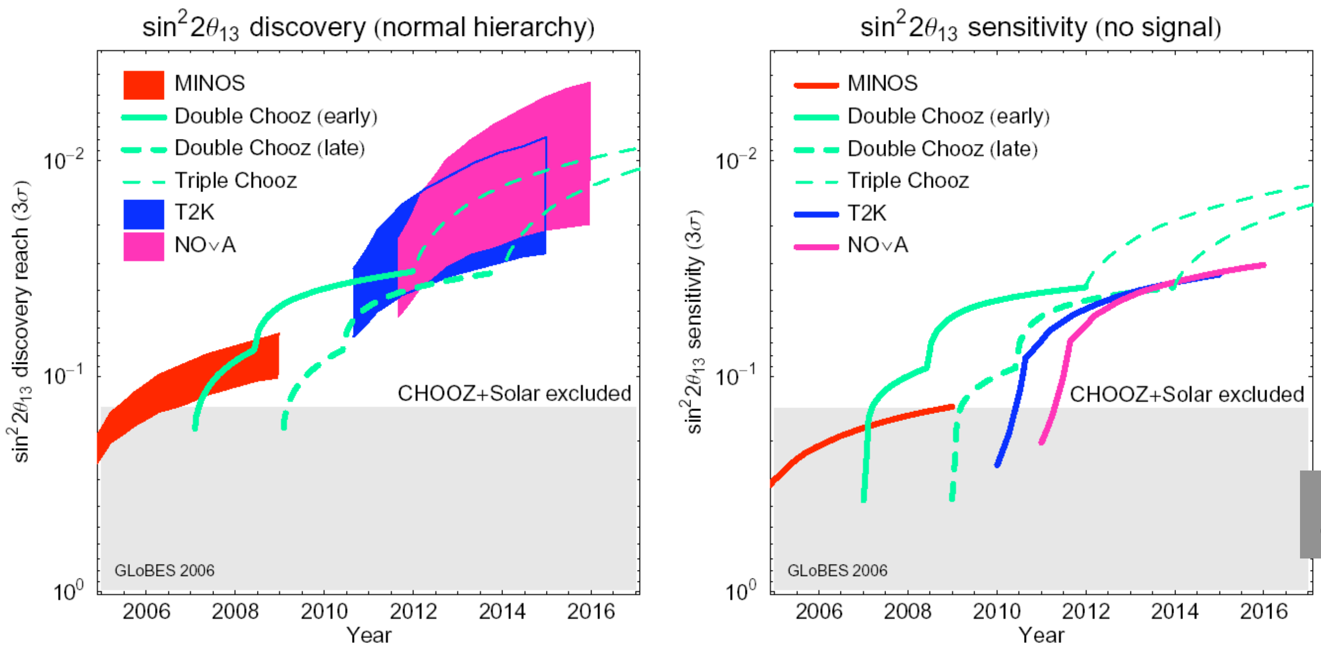


θ_{13} at reactors

- $P(\nu_e \rightarrow \nu_e)$ independent of δ-CP, weak dependence on Δm^2_{21}
- O(MeV) + small distances $\Rightarrow$ Matter effects negligible $\Rightarrow$ measurement independent of $sign(\Delta m^2_{13})$

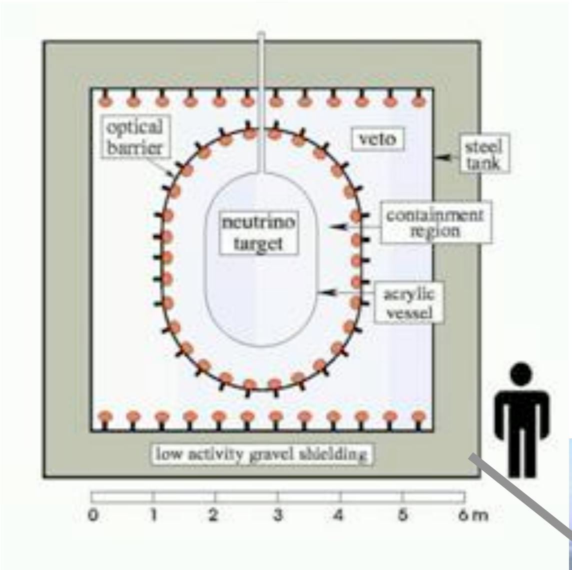
➡ "Clean" θ_{13} measurement, complementary to beams

➡ Experiments can be carried out on a short time scale and for relatively low cost $\Rightarrow$ input on decision for future beams

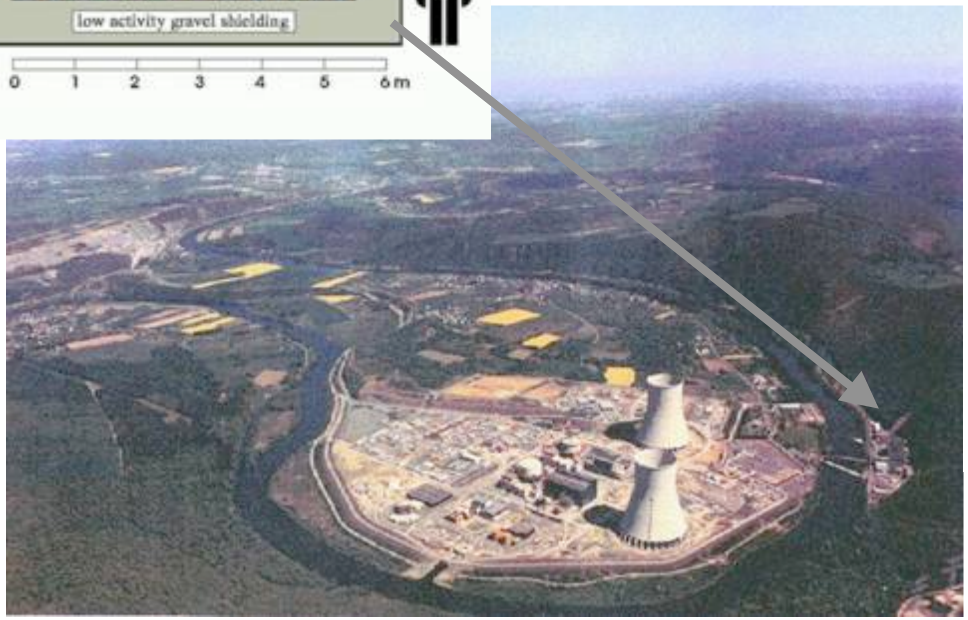


hep-ph/0601266

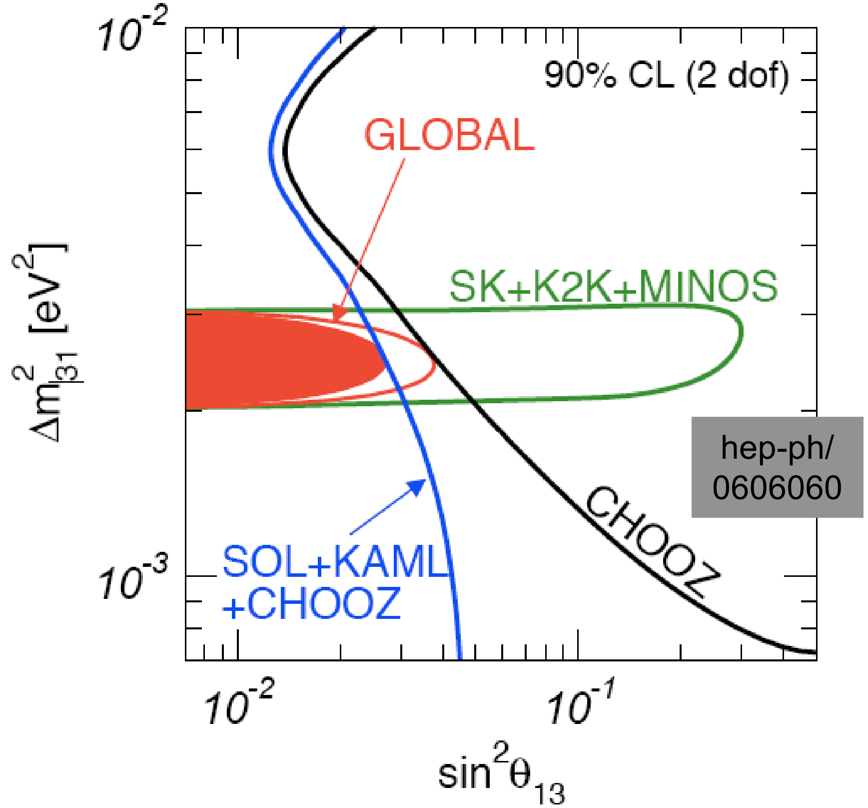
θ_{13} : what we know



The CHOOZ Experiment



M.Apollonio et. al., Eur.Phys.J. C27 (2003) 331-374



hep-ph/ 0606060

$$\sin^2\theta_{13} < 0.025 \quad (90\%CL)$$
$$\Updownarrow$$
$$\sin^2 2\theta_{13} < 0.1 \quad (90\%CL)$$

How can we improve?

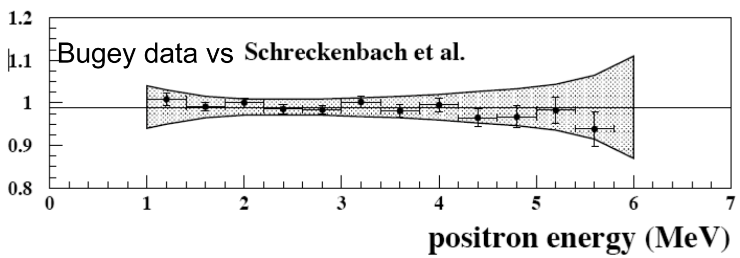
CHOOZ : R_{osc} = 1.01 ± 2.8% (stat) ± 2.7% (syst)

- **Statistics**
  - More powerful reactor (multi-core)
  - Larger detection volume
  - Longer exposure

- **Experimental error**: ν flux+spectrum and cross-section uncertainty
  - Multi-detector → relative measurement
  - Identical detectors to reduce experimental systematics (normalisation, calibration …)

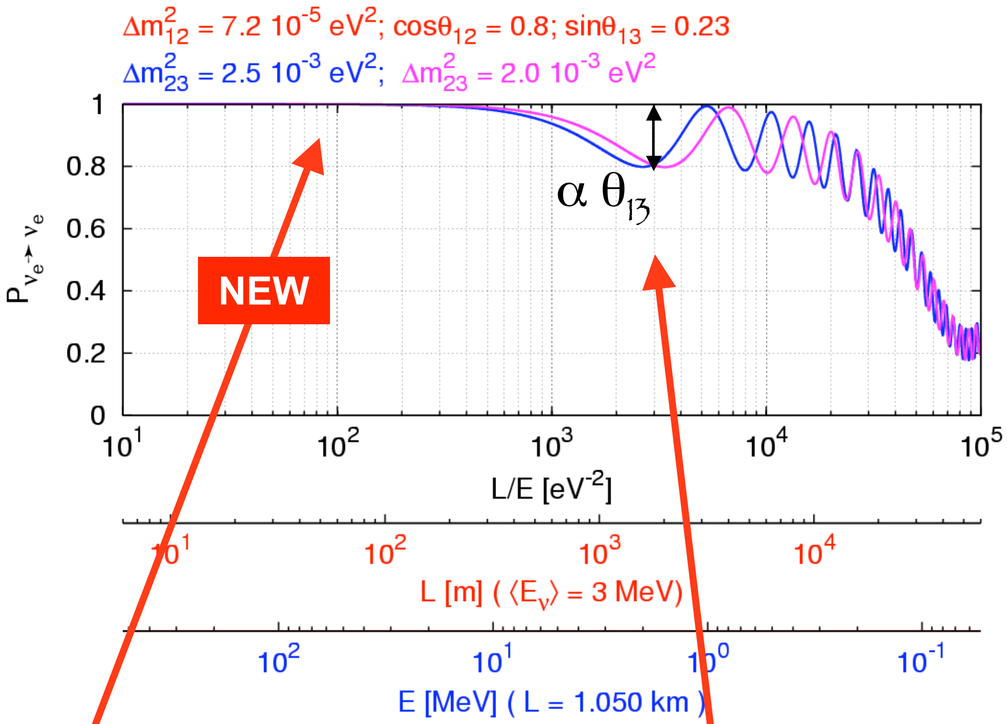
- **Background**
  - Improve detector design → larger S/B
  - Increase overburden → larger S/B
  - Improve bkg knowledge by direct measurements

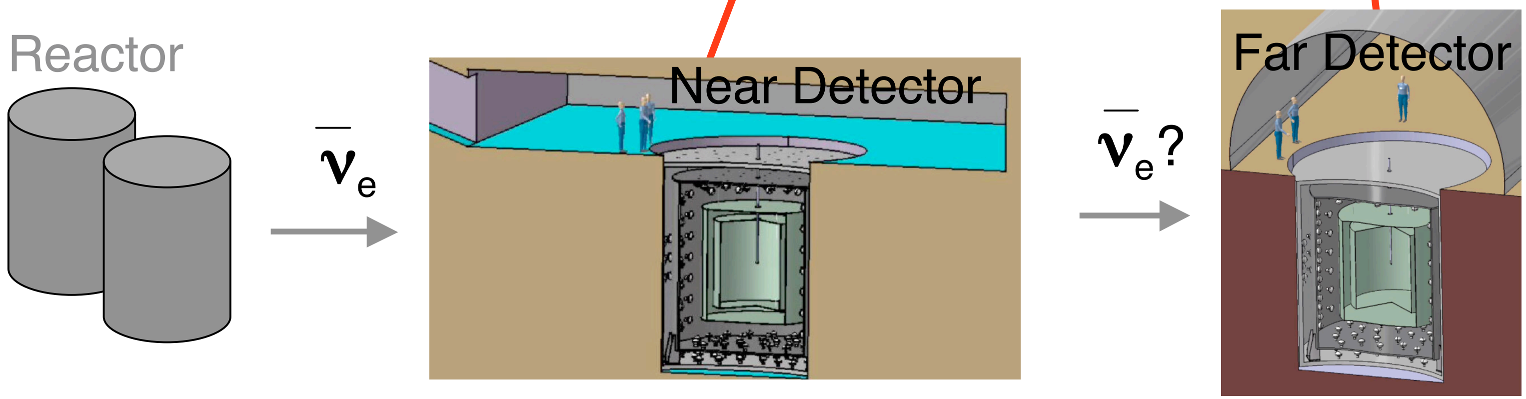
θ_{13} at reactors: new experimental concept



~~Poor knowledge of physical processes in reactors: error ~2%~~

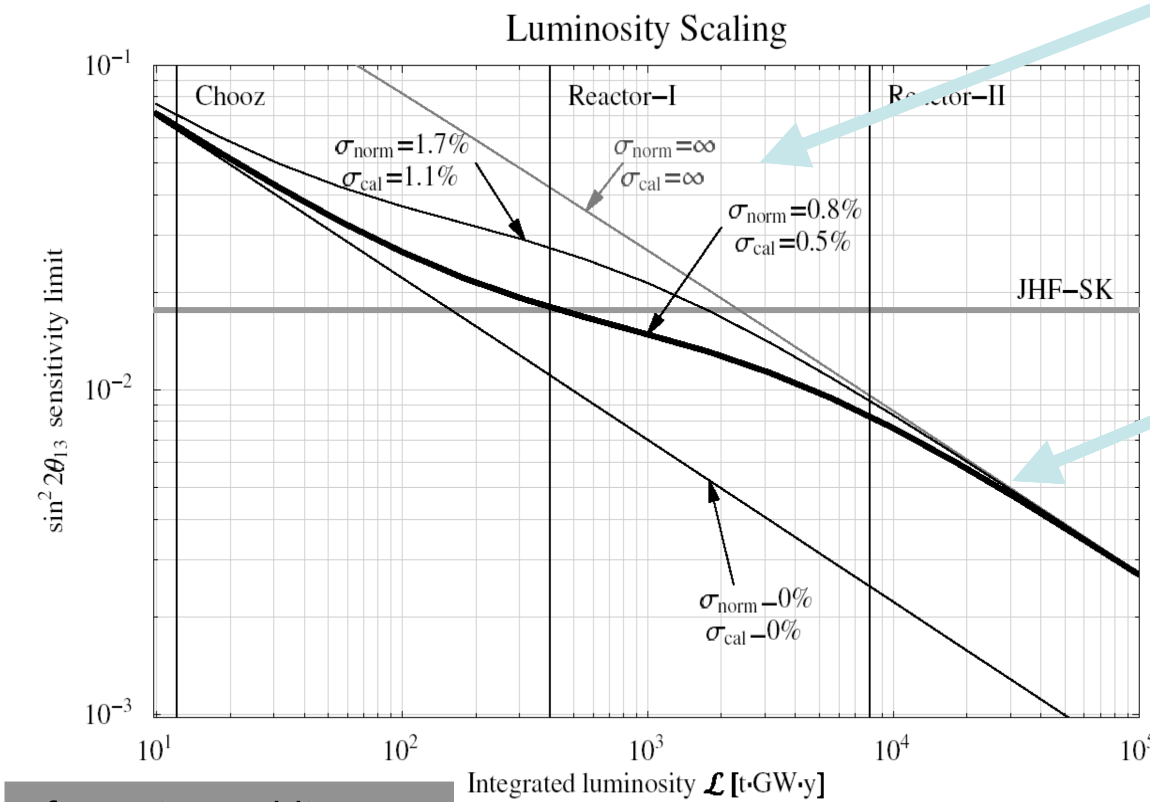
Use Near Detector

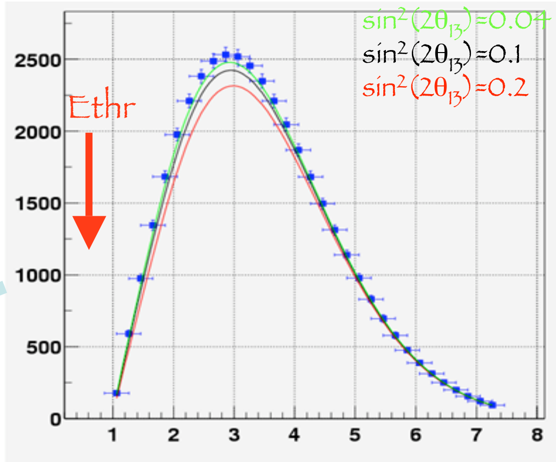


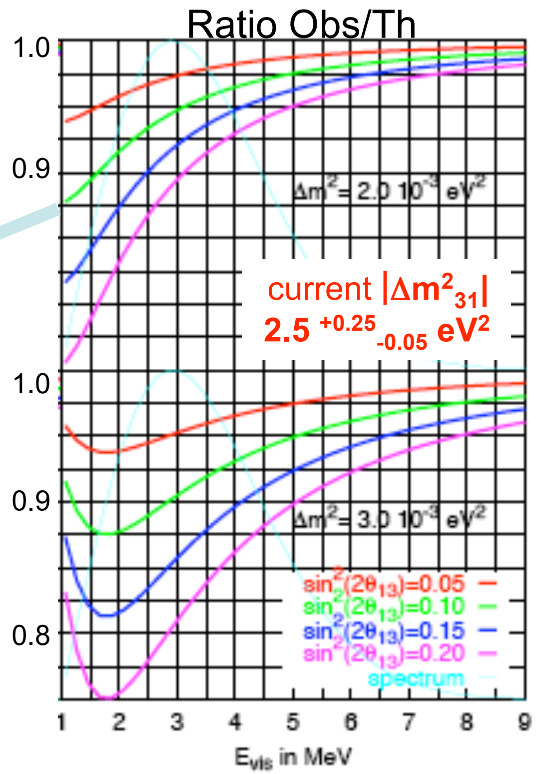


θ_{13} at reactors

Far vs Near :
two independent sets of information
Normalisation / Spectrum distortion
Dominating at intermediate / high statistics







cfr reactor ν whitepaper
hep-ex/0402041

θ_{13} at reactors : Backgrounds

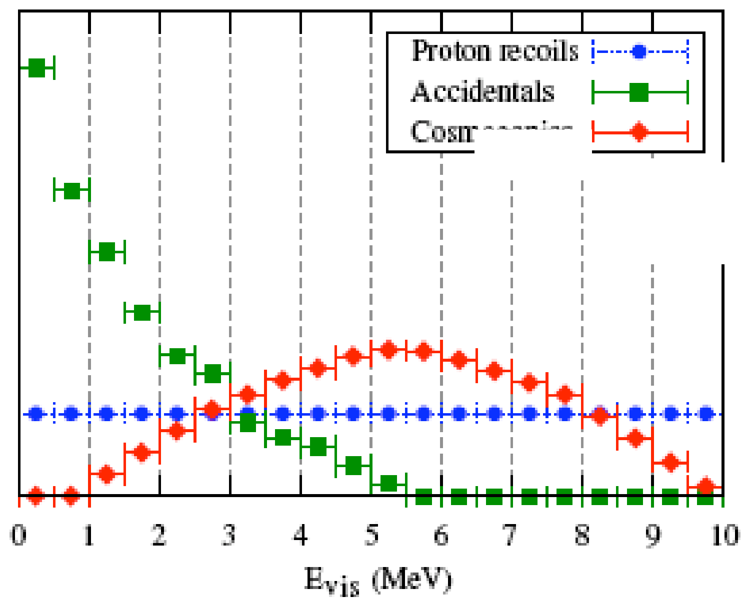
Accidental bkg:

- e^+-like signal: radioactivity from materials, PMTs, surrounding rock (^{208}Tl). (Rate=R_e)
- n signal: n from cosmic μ spallation, thermalised in detector and captured on Gd (R_n);

  γ mimicking n

⇒ Accidental coincidence

Rate = $R_e \times R_n \times \Delta t$



Bkg spectrum knowledge is critical for oscillation analysis, but difficult…

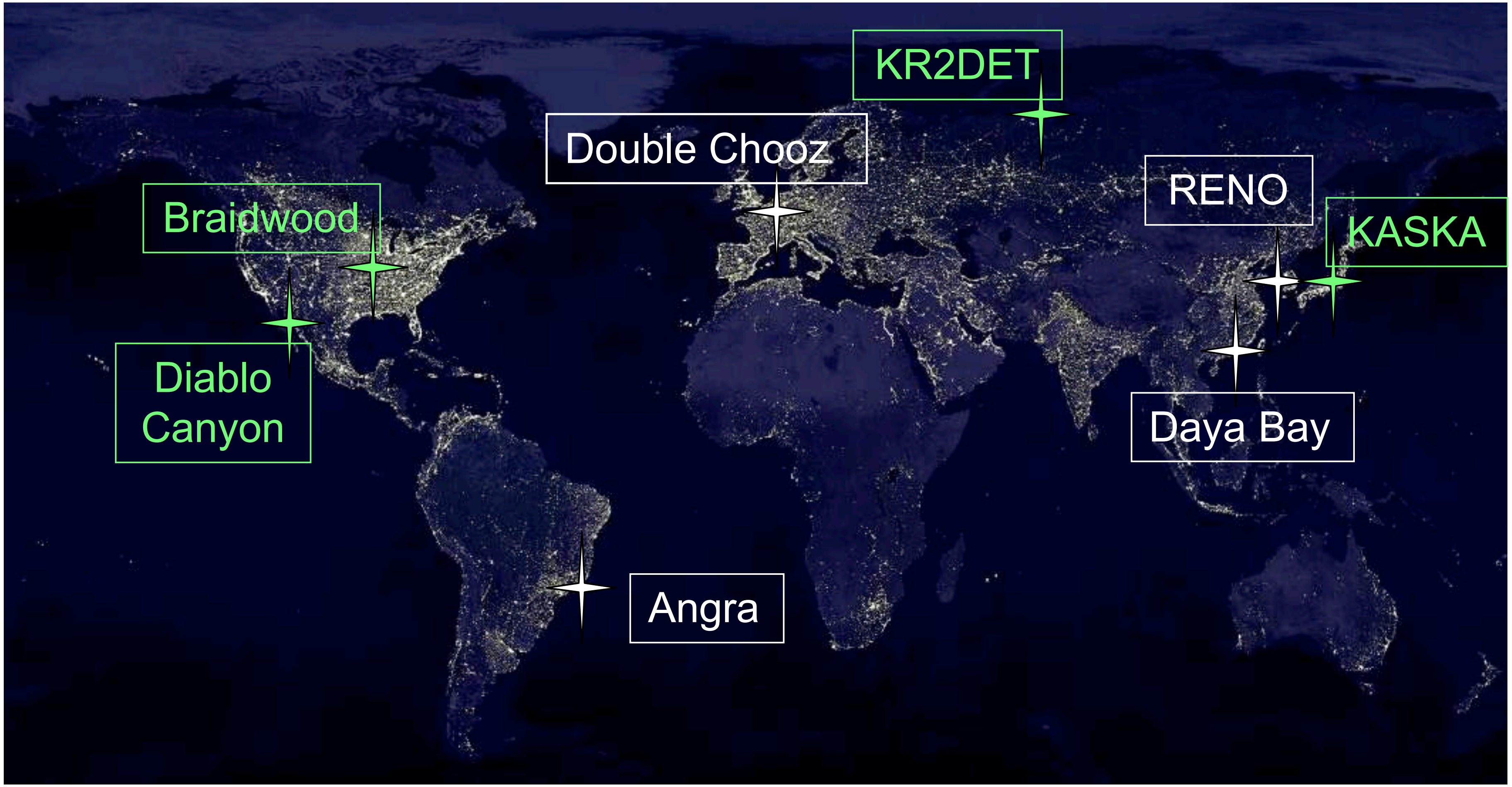
Correlated bkg:

- fast n (by cosmic μ) recoil on p (low energy) and captured on Gd
- long-lived (^{9}Li, ^{8}He) β-decaying isotopes induced by μ

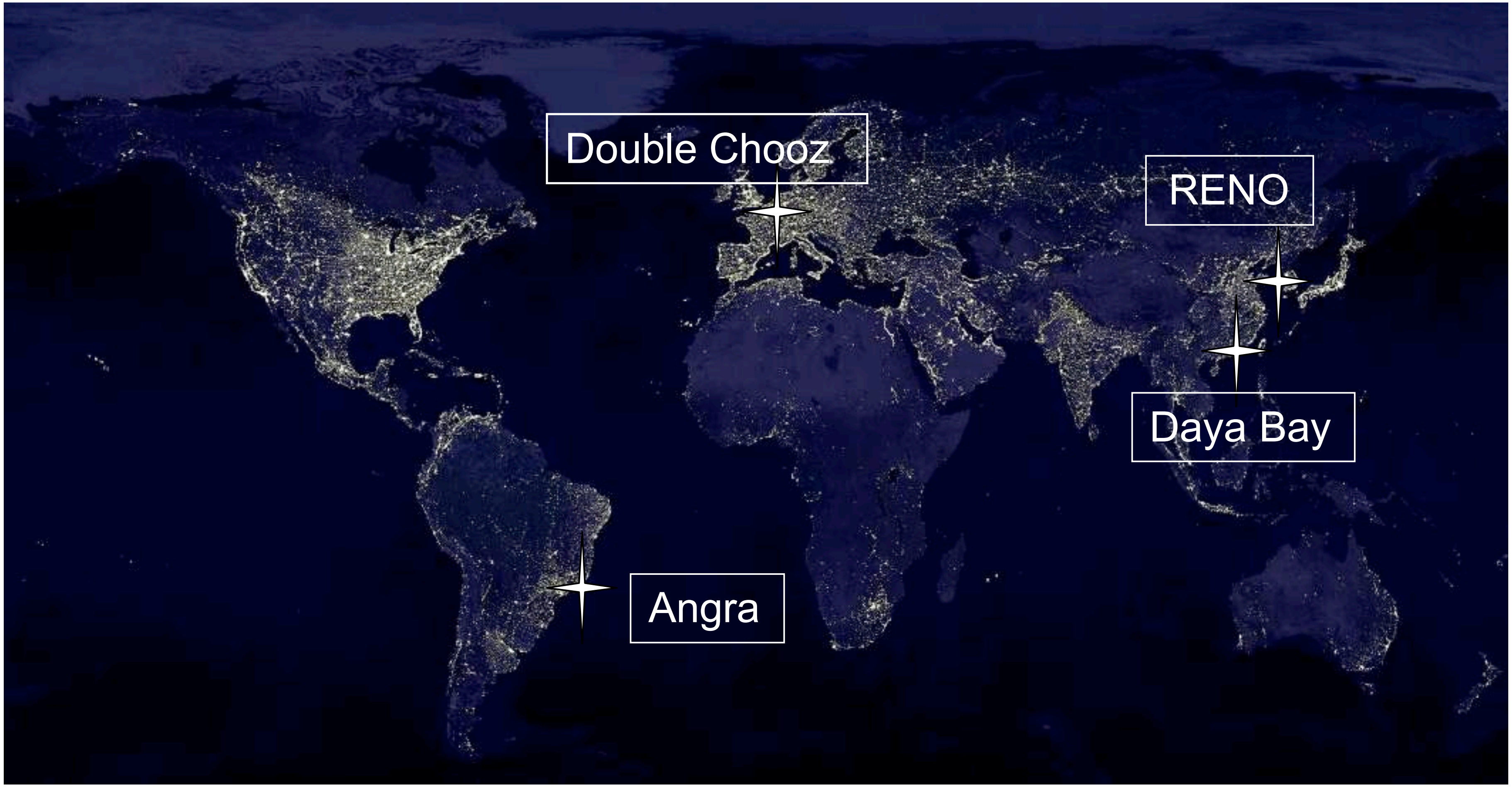
Strategy:

- Reduce bkg with overburden + detector design
- Similar S/B in Near and Far det.
- Direct measurements

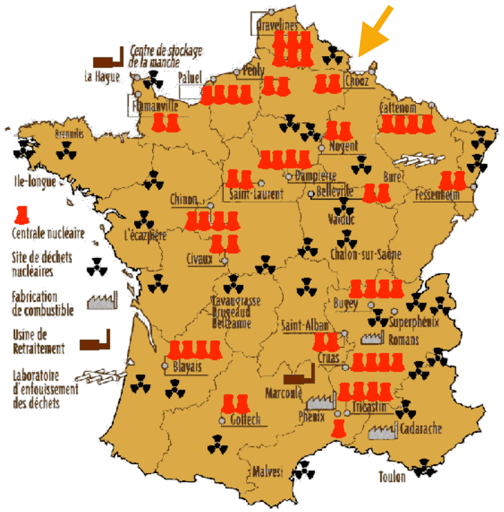
Reactor θ_{13} projects «yesterday»

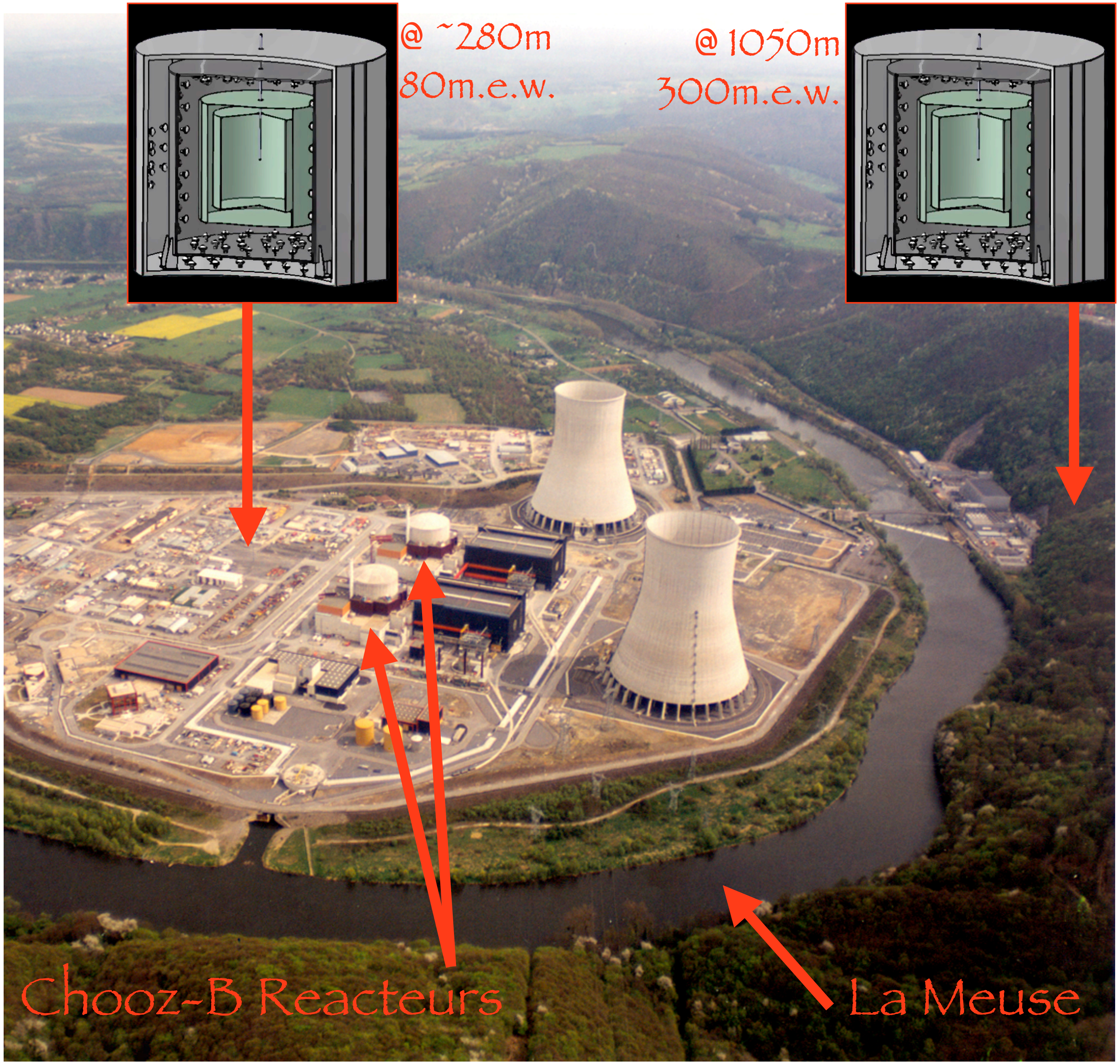


Reactor θ_{13} projects «today»

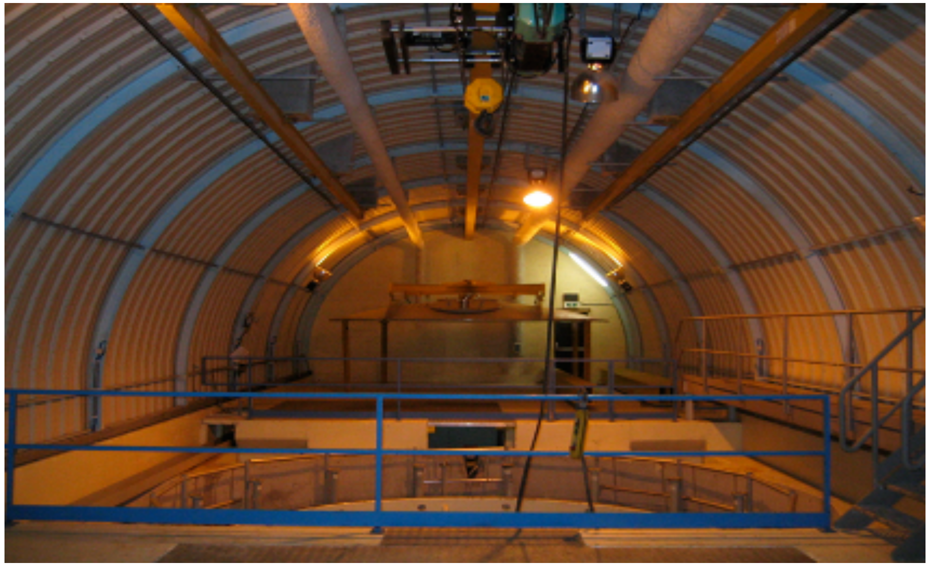


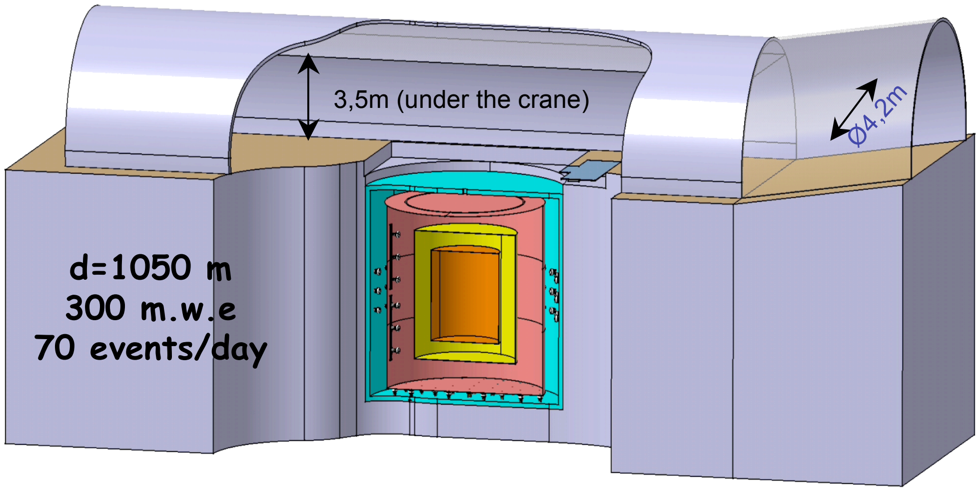
(Double-)Chooz site in the Ardennes



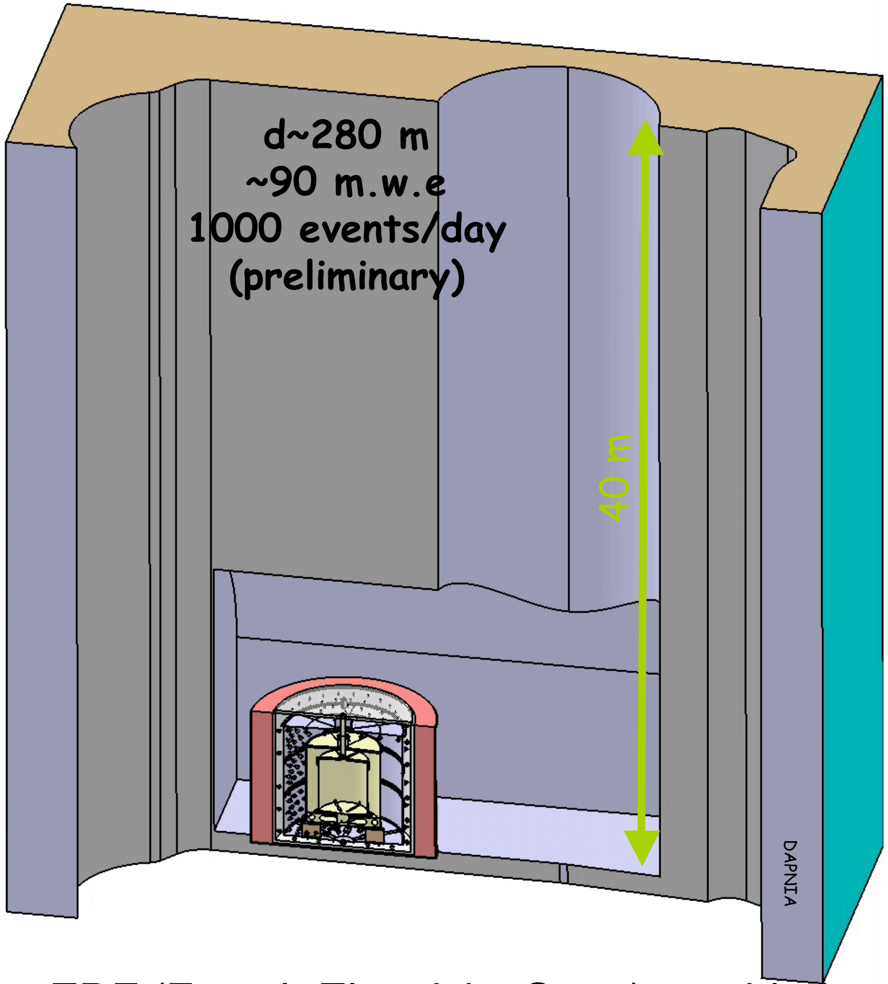


Far and near lab



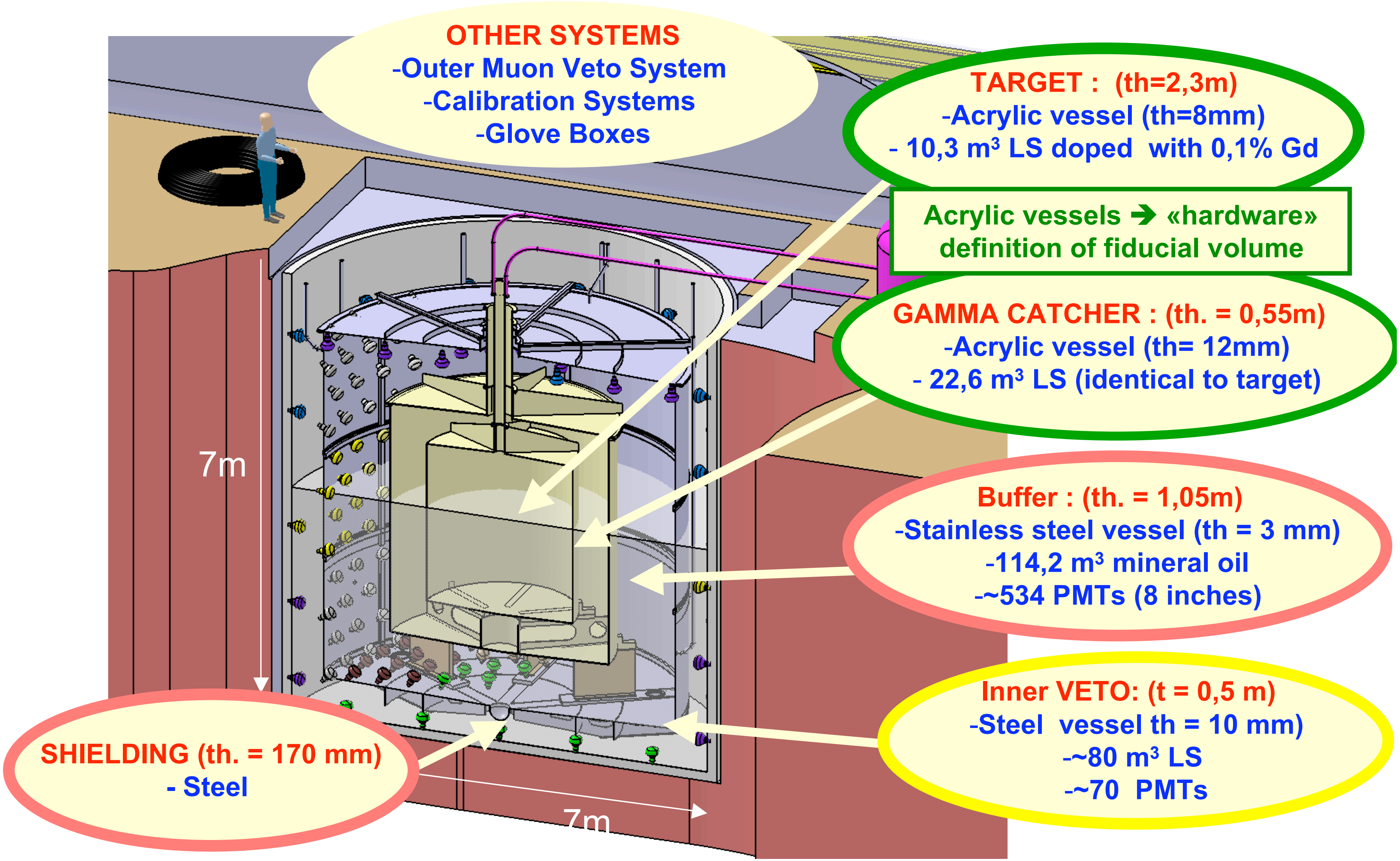


- Start of integration 2006
- Ready for detector installation



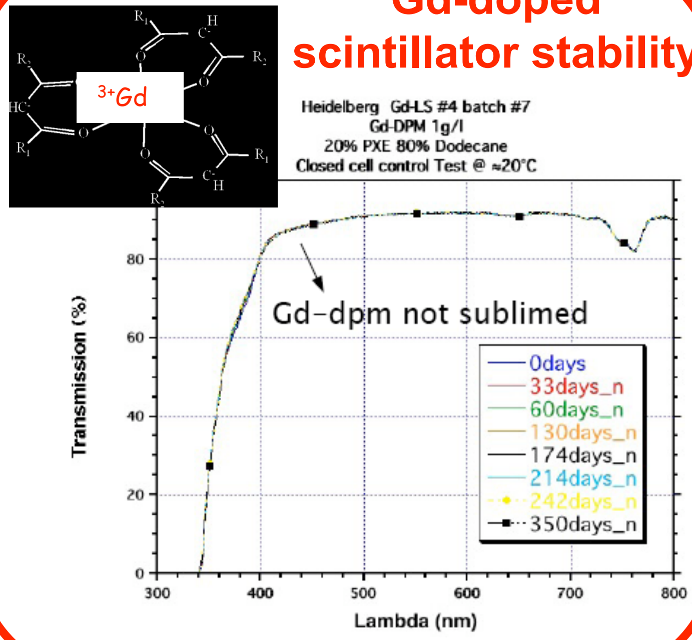
- EDF (French Electricity Corp.) provided first civil engineering study in January
- Final designs to be completed in 2007
- Lab ready in 3 years: 2009

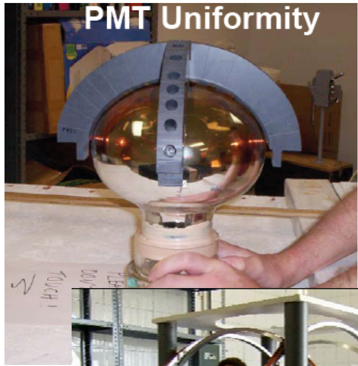
The detector(s)

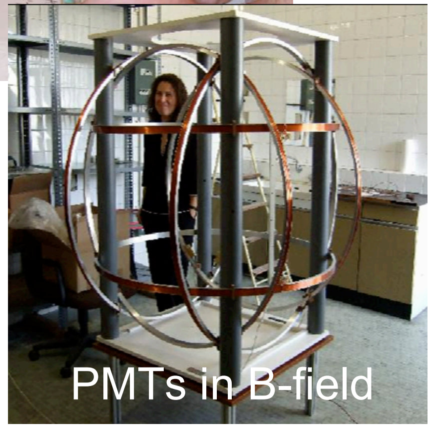


Testing + prototyping

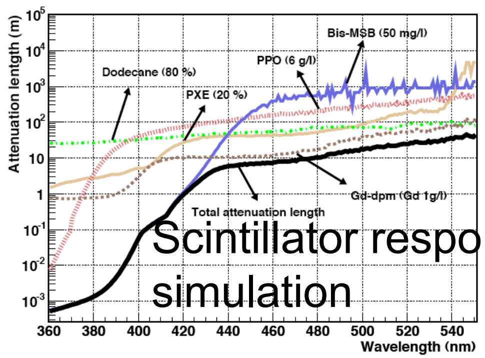
Gd-doped scintillator stability





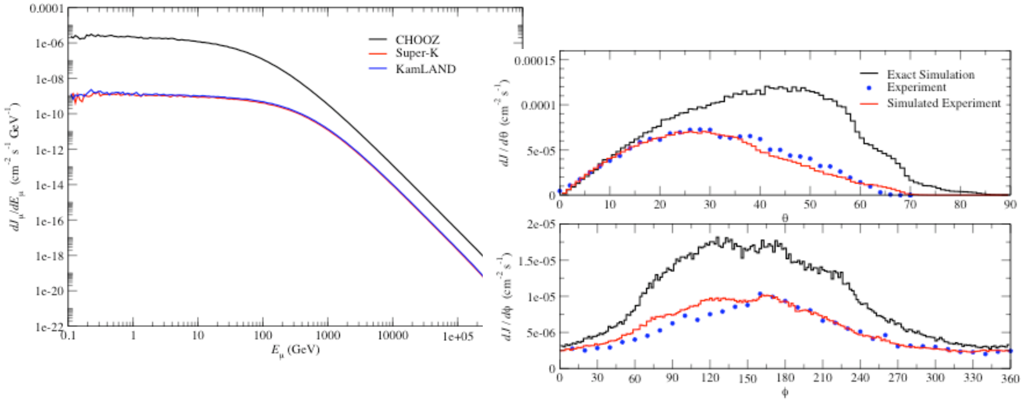


DAQ fADCs



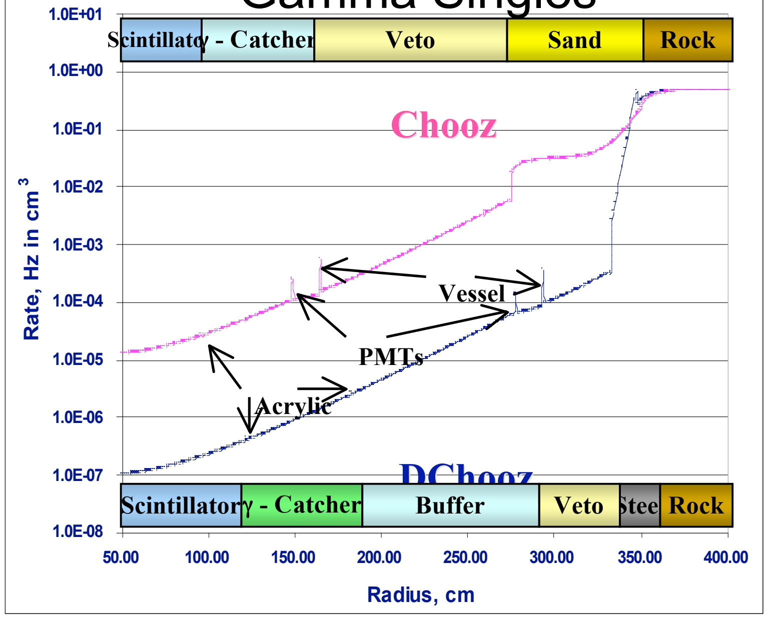
Background studies

Cosmic muons



Phys.Rev.D74:053007,2006
[hep-ph/0604078]

Gamma Singles



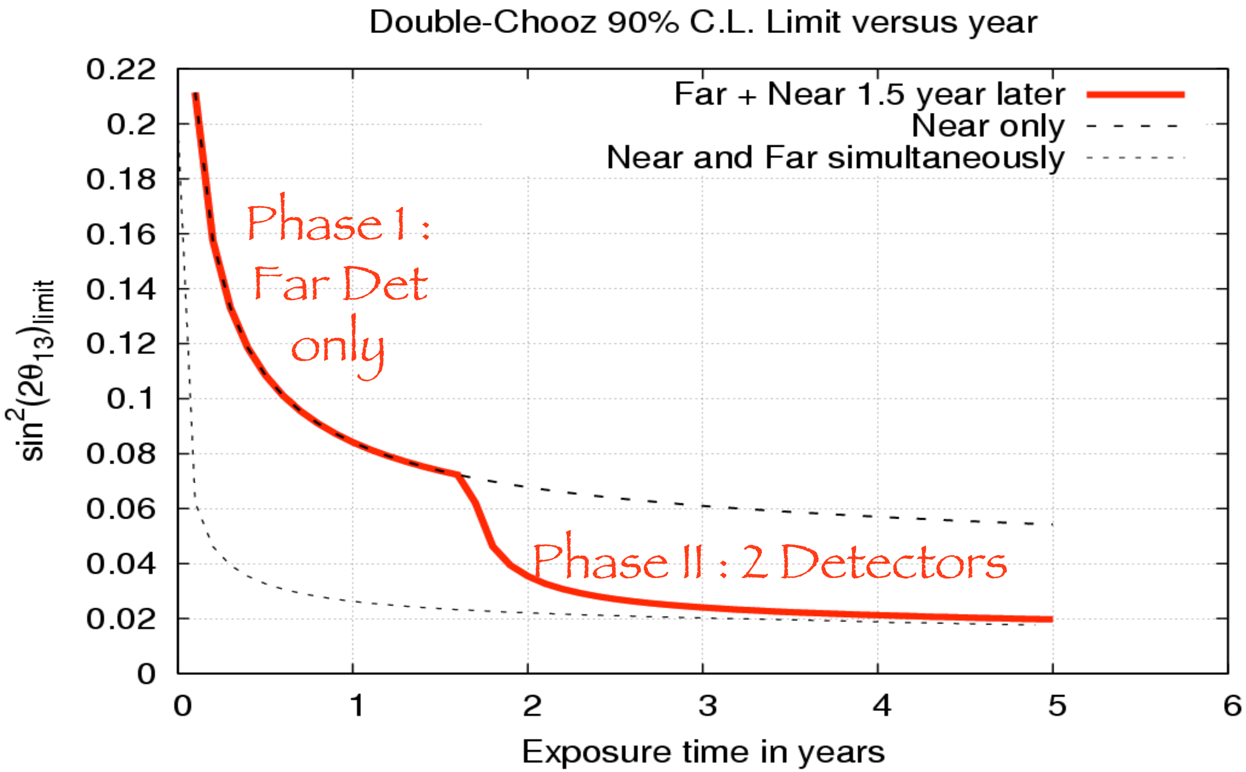
Detector	Site		Background				
			Accidental		Correlated		
			Materials	PMTs	Fast n	μ-Capture	^{9}Li
CHOOZ		Rate (d^{-1})	—	—	—	—	0.6 ± 0.4
(24 ν/d)		Rate (d^{-1})	0.42 ± 0.05		$1.01 \pm 0.04(stat) \pm 0.1(sys)$		
	Far	bkg/ν	1.6%		4%		
		Systematics	0.2%		0.4%		
Double Chooz		Rate (d^{-1})	0.5 ± 0.3	1.5 ± 0.8	0.2 ± 0.2	< 0.1	1.4 ± 0.5
(69 ν/d)	Far	bkg/ν	0.7%	2.2%	0.2%	<0.1%	1.4%
		Systematics	<0.1%	<0.1%	0.2%	<0.1%	0.7%
Double Chooz		Rate (d^{-1})	5 ± 3	17 ± 9	1.3 ± 1.3	0.4	9 ± 5
(1012 ν/d)	Near	bkg/ν	0.5%	1.7%	0.13%	<0.1%	1%
		Systematics	<0.1%	<0.1%	0.2%	<0.1%	0.2%

Systematic uncertainties

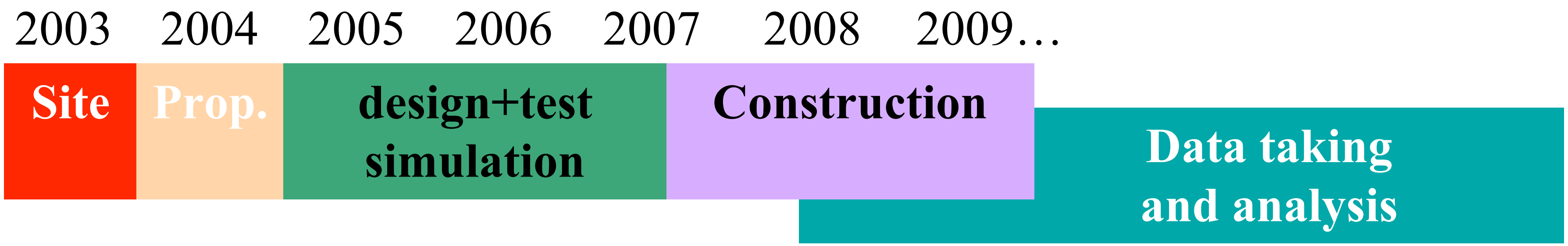
		Chooz	Double-Chooz	
Reactor-induced	ν flux and σ	1.9 %	<0.1 %	Two "identical" detectors, Low bkg
	Reactor power	0.7 %	<0.1 %	
	Energy per fission	0.6 %	<0.1 %	
Detector - induced	Solid angle	0.3 %	<0.1 %	Distance measured @ 10 cm + monitor core barycenter
	Volume	0.3 %	0.2 %	Accurate weight measurement
	Density	0.3 %	<0.1 %	Accurate T control (near/far)
	H/C ratio & Gd concentration	1.2 %	<0.1 %	Same scintillator batch + Stability
	Spatial effects	1.0 %	<0.1 %	Edge effects (Spill in/out) ~same in 2 det
	Live time	?	0.25 %	Measured with independent methods
Analysis	From 7 to 3 cuts	1.5 %	0.2 - 0.3 %	Less background => simpler selection
	Total	**2.7 %**	**< 0.6 %**	

Double Chooz schedule

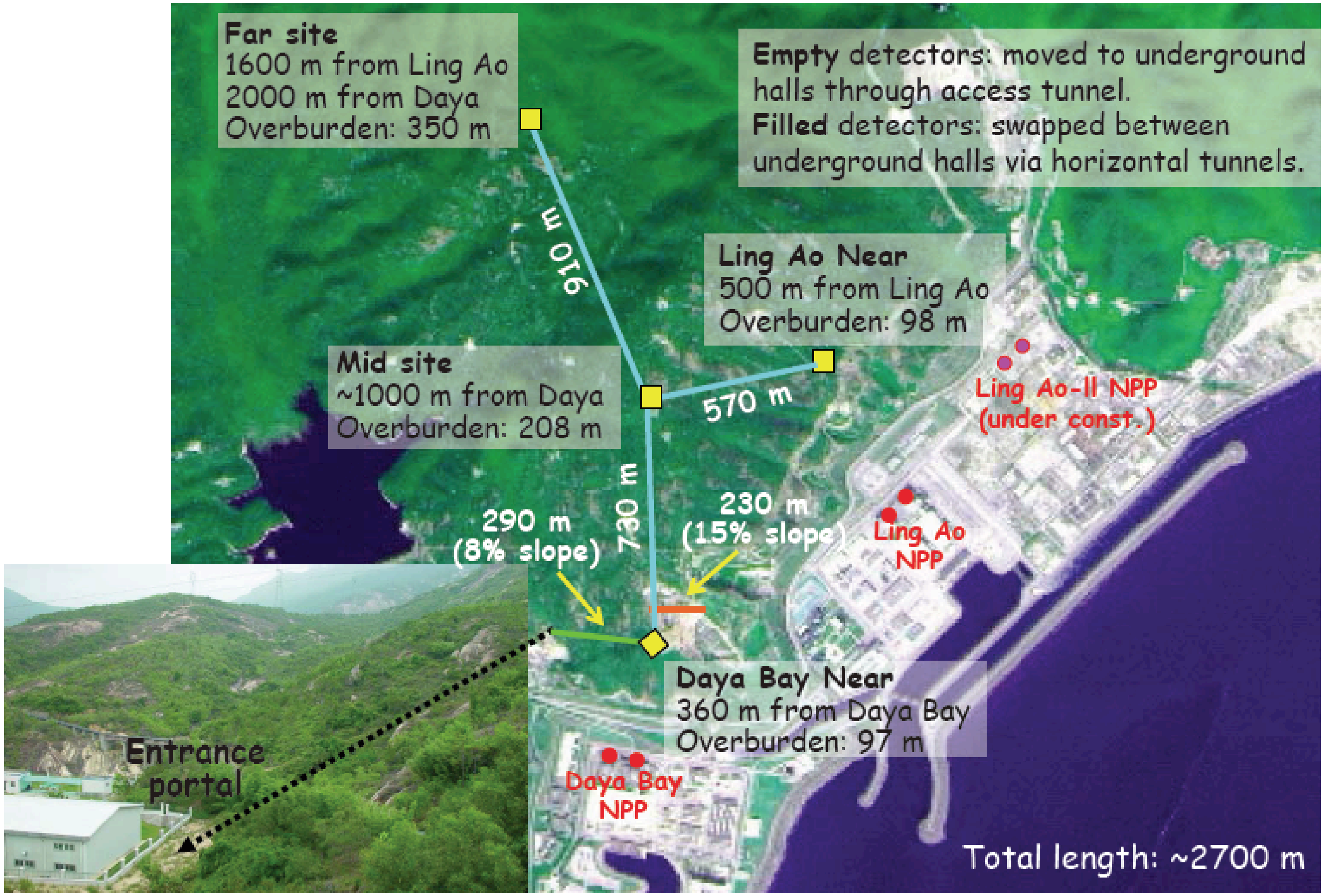
Proposal
hep-ex/0606025



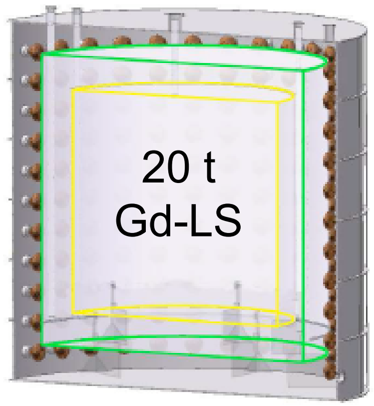
Approved & financed in France, Germany, Russia, Spain, UK (Japan? US?)



Daya Bay



Proposal
hep-ex/0701029



Reactor:
4 cores, 11.6 GWth
6 cores, 17.6 GWth in 2011

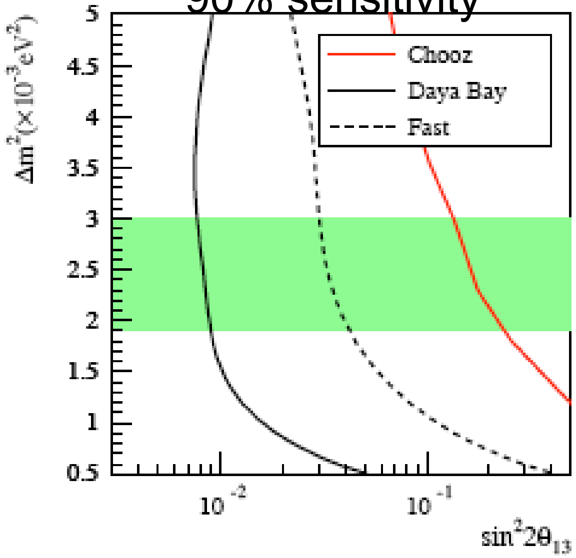
Identical detectors
Multiple modules at each site
Movable (swap to check syst.)

Daya Bay status and exp. sensitivity

- CAS officially approved the project
- Chinese Atomic Energy Agency and the Daya Bay nuclear power plant are very supportive to the project
- Funding agencies in China are supportive, R&D funding in China approved and available
- R&D funding from DOE approved
- Site survey including bore holes completed
- R&D started in collaborating institutions, the prototype is operational
- Proposals to governments under review

- Start civil engineering summer 2007
- Near+mid ("fast") Sept. 2009
- Near+far ("full) June 2010

90% sensitivity

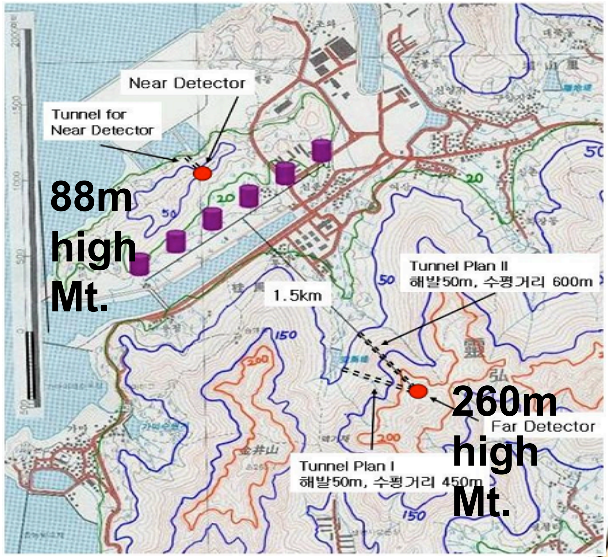


Systematics related to complexity of site need to be kept under control
cfr arXiv:0704.0498

Systematic Uncertainty Assumptions:	Baseline	Goal	Goal with swapping
90% CL Limit:	0.008	0.007	0.006

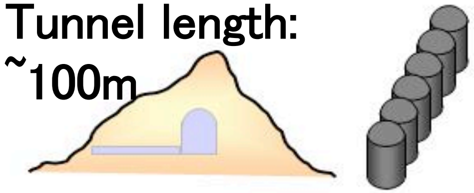
RENO

Reactor Experiment for Neutrino Oscillations at YoungGwang, South Korea

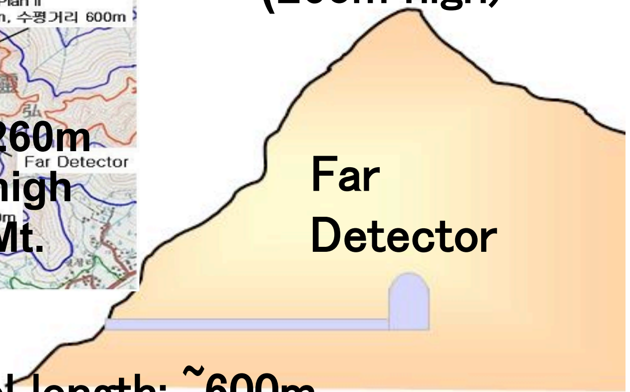


(88m high)
Near Detector

Tunnel length: ~100m



(260m high)



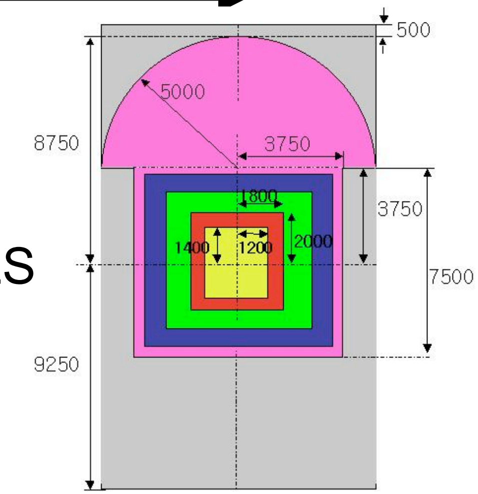
Tunnel length: ~600m

150m

~1.5 km

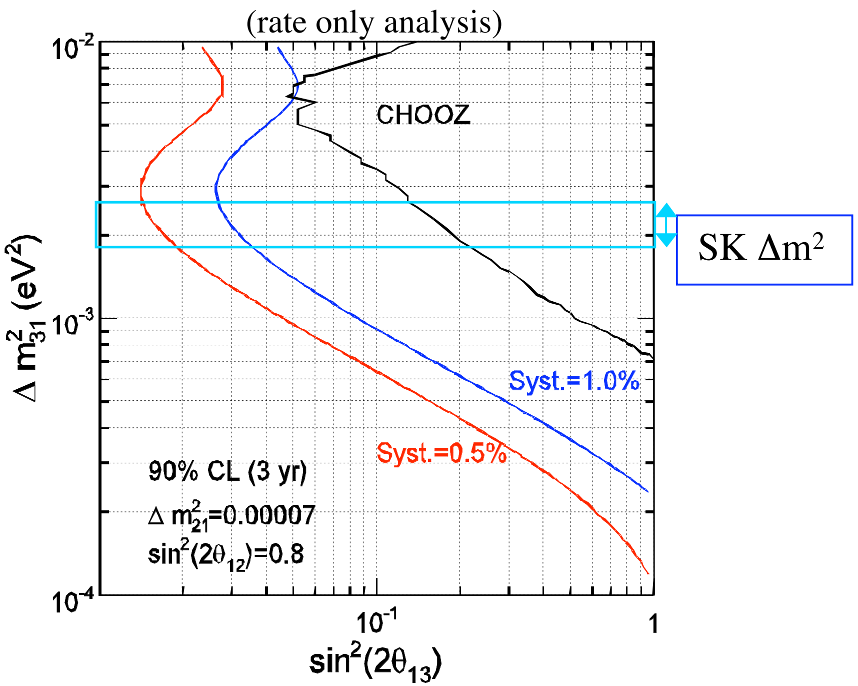
6 reactor cores
(but for 4 of them systematics is as large as gain in statistics…)
cfr arXiv:0704.0498

1 detector =
20 (or 15?) kt Gd-LS



RENO status and exp. sensitivity

1. **Civil Construction & Underground Facility**
→ Obtained support from local government & residents
→ YK Power Plant Co. allowed to use their e state
→ Bidding for survey & tunnel design comple ted (Feb 2007)
→ Civil engineering work is expected to start in this summer
2. **Detector Design**
→ Full detector detector design completed with extensive MC
→ TDR under preparation (to be ready in A pril 2007)
3. **Prototype** completed
Mockup Detector in construction
4. **Gd+Liquid Scintillator R&D**
Under performance study of various samples

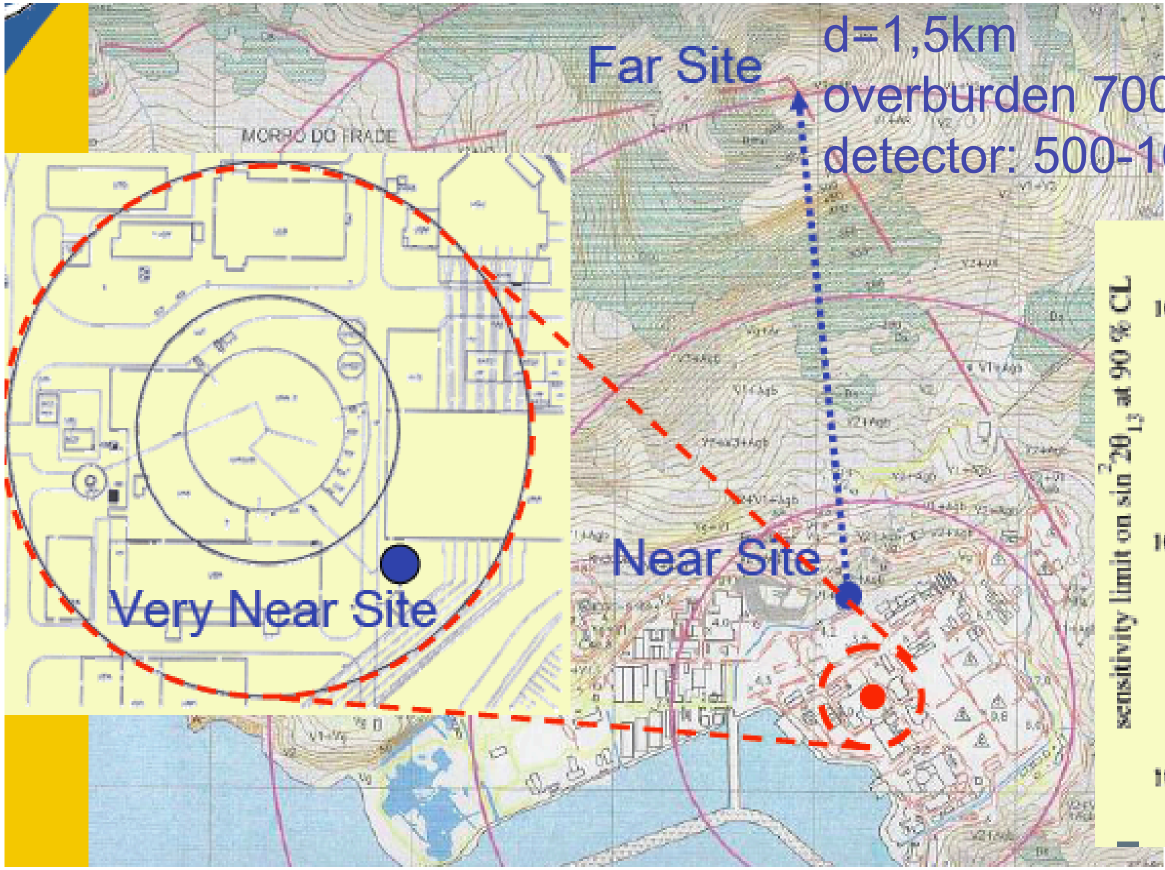


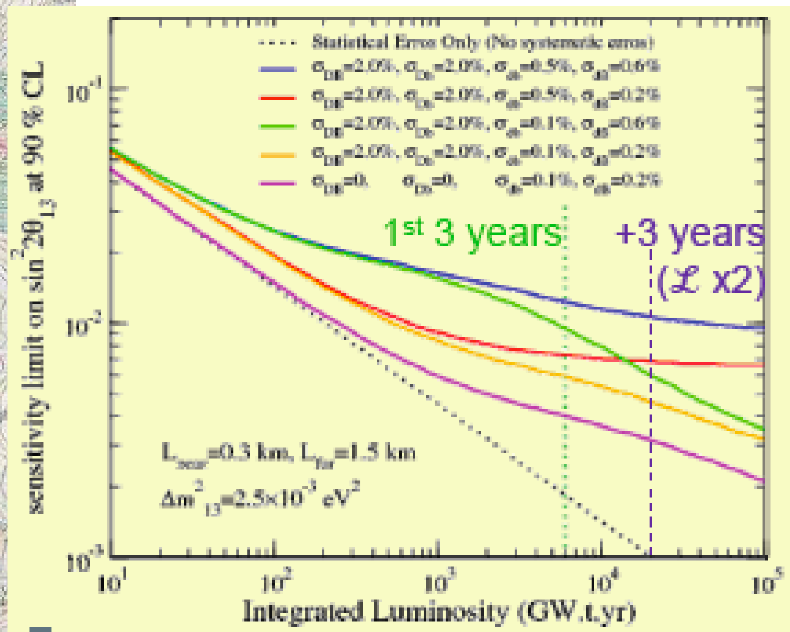
M.Goodman, NoVe07

ANGRA

Angra dos Reis, Brazil

2nd generation experiment aiming at
- very high statistics (improve use of full spectral info)
- reducing systematic errors to an absolute minimum



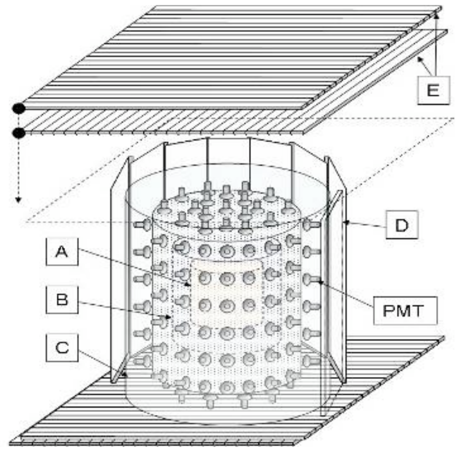


ANGRA

- **Workshop on the ANGRA detector design** (CBPF - May 16-19, 2006, Rio de Janeiro – BR)
- Now establishing a formal agreement with Eletronuclear for permanent access to the site.
- Already authorized to place a 20′ container next to the reactor.
  - Muon background measurements (MINOS type counters)
  - Liquid scintillator detector prototype
  - Internet connection with CBPF and UNICAMP for remote monitoring
- Detailed project submitted in December 2006 to the Minister of Science and Technology. Total amount requested: $400,000 USD

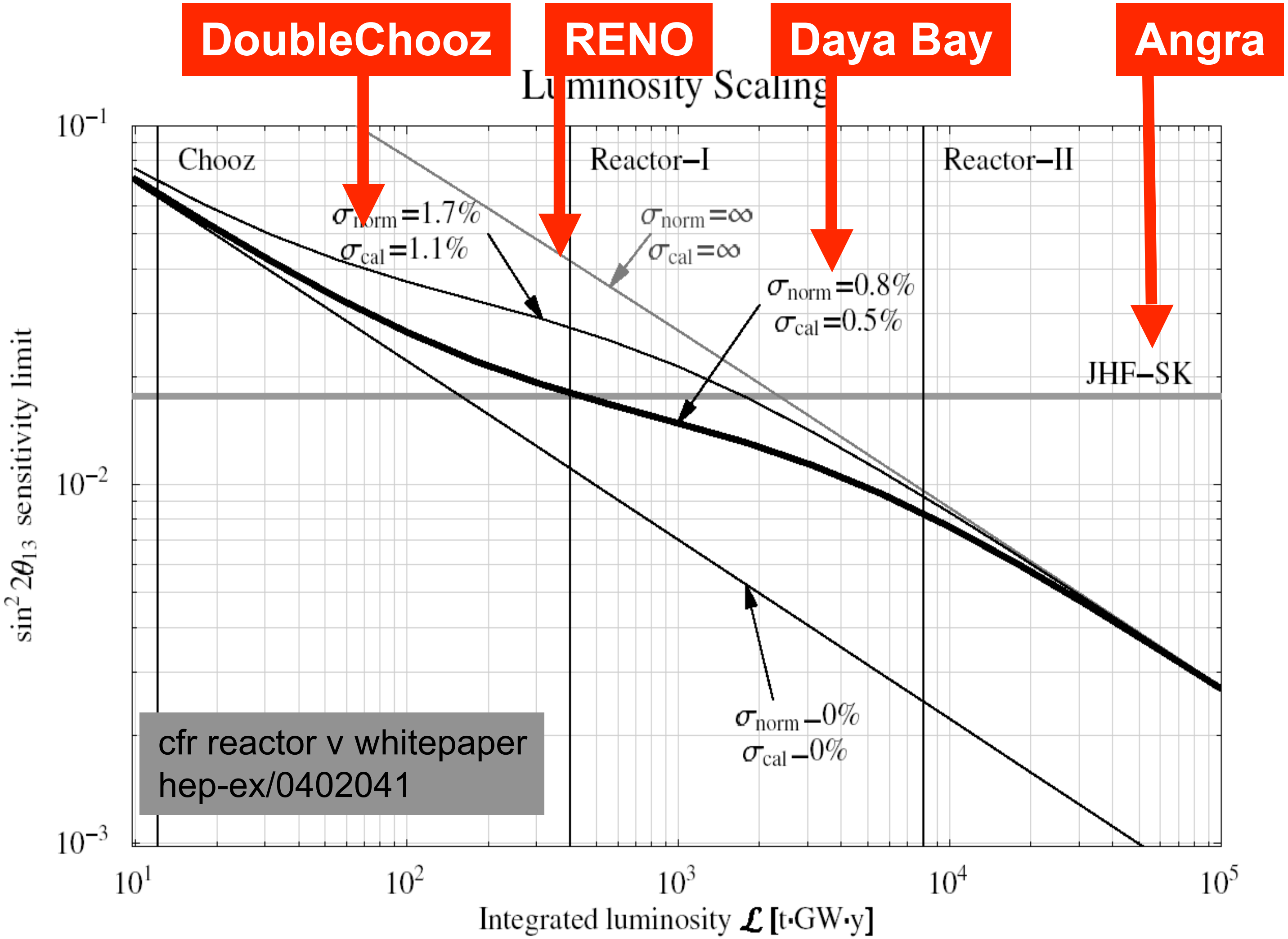
M.Goodman, NoVe07

Very Near Detector



«A construção do novo detector, que será financiada pelo governo federal via Finep (Financiadora de Estudos e Projetos), vai custar R$ 1 milhão » (28/03/07)

Luminsity scaling of sensitivity limit

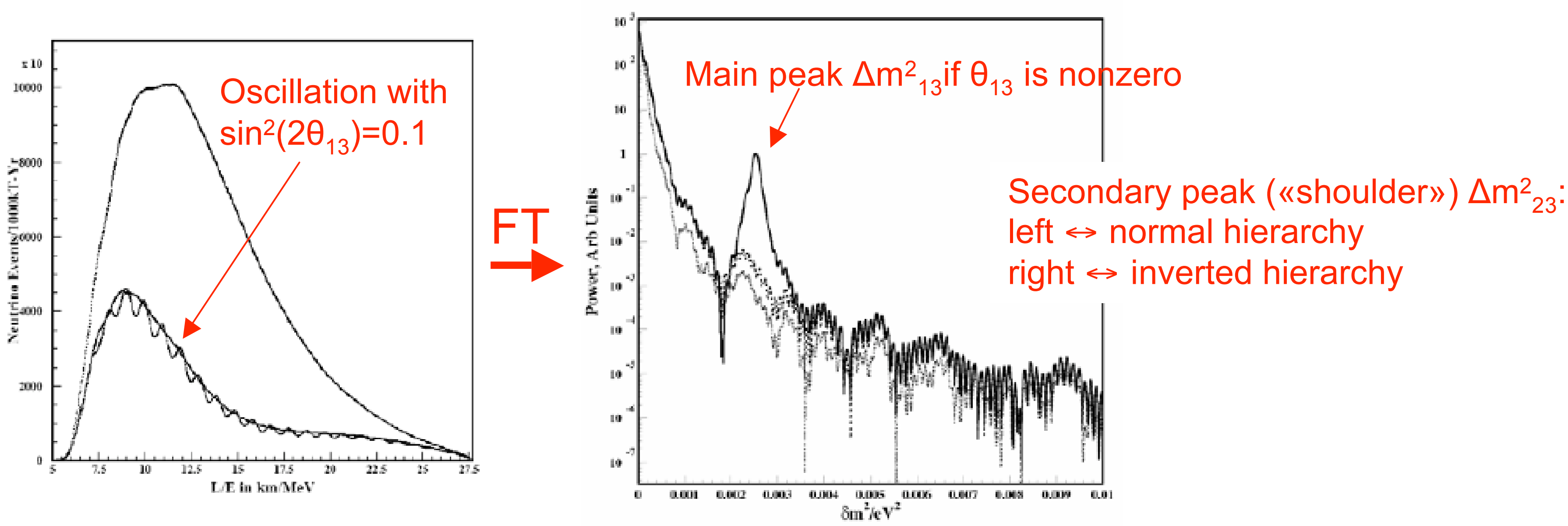


Detailed quantitative discussion of reach, with unified treatment of systematics: G.Mention, T.Lasserre, D.Motta arXiv:0704.0498v1

Mass hierarchy ?

- Mass hierarchy from Fourier transform

Learned, Dye, Pakvasa, Svoboda hep-ex/0612022



→ **Hanohano** (Hawaii)

- 10 kt, underwater, ~60 km from reactor
- Also mesure $\sin^2\theta_{12}$ to few%, $\sin^2 2\theta_{13}$ to ~0.05 and Δm^2_{13} to <1% (with 10 kt*y)

Summary and outlook

Potential for oscillation measurement at reactors is vast:

- Δm^2_{12} @KamLAND will be improved by reducing systematics
- A new idea for mass hierarchy determination has appeared
- The hottest topic: θ_{13} "quick & clean" measurement

  Four multi-detector experiments currently proposed:

  1st generation: **Double Chooz**, **RENO**

  $\rightarrow \sin^2 2\theta_{13}$<0.02-0.02 in 2011-2012

  2nd generation: **Daya Bay**, **Angra**

  $\rightarrow \sin^2 2\theta_{13}$<0.01 after 2013

Double Chooz is a pacemaker in development of detector items that will allow control of systematics to desired level.

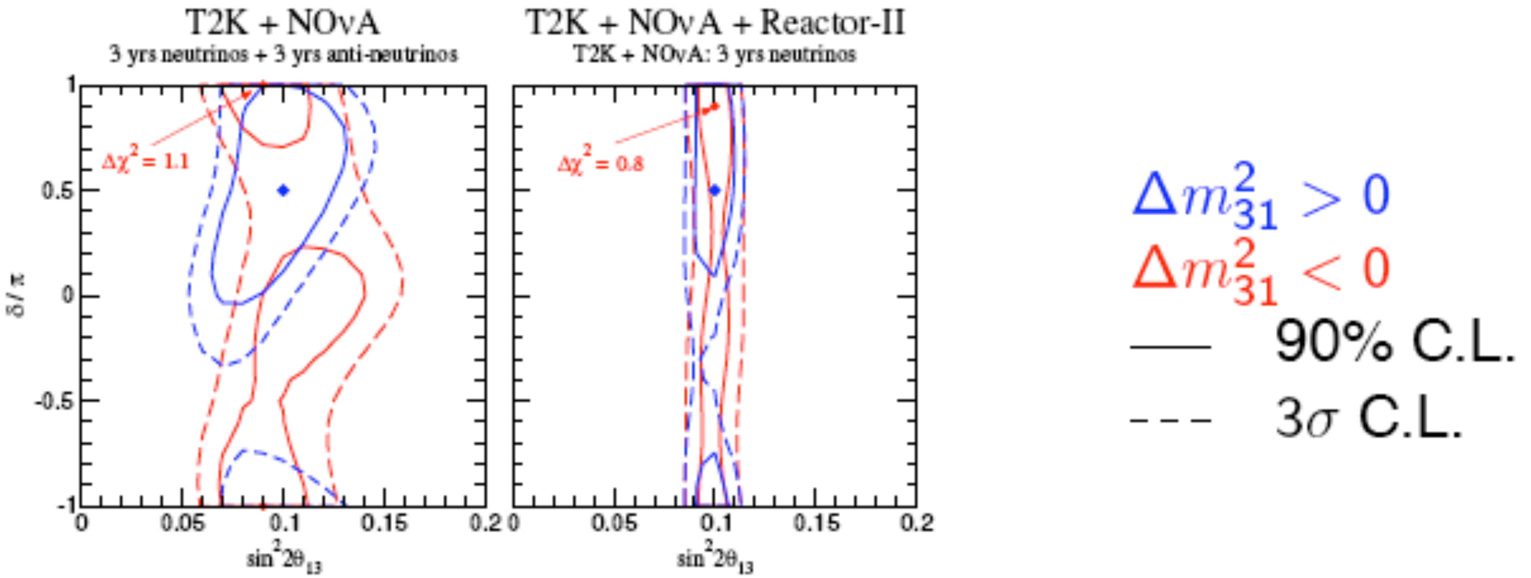
Its construction is starting soon… we're looking forward to its results !

BACKUP

Double Chooz and Superbeams

Complementarity of the two approaches

- Superbeam experiments limited by correlations and degeneracies.
- Reactor experiments can
  - Break correlations and degeneracies.
  - Replace an antineutrino running.
  - Help to optimize future accelerator experiments by constraining θ_{13}.
  - Do all this at relatively low costs.



P. Huber, M. Lindner, M. Rolinec, T. Schwetz, W. Winter, Nucl. Phys. Proc. Suppl. 145:190-193, 2005, hep-ph/0412133

Reactor ν Comparison
experiment parameters

	Power GW_{th}	<Power> GW_{th}	Location	Detectors km/ton/MWE
Angra	6.0	5.3	Brazil	0.05/1/20 0.3/50/250 1.5/500/2000
RENO	17.3	16.4	Korea	0.15/20/230 1.5/20/675
Daya Bay	11.6 (17.4 after 2010)	9.9 (14.8 after 2010)	China	0.36/40/260 0.50/40/260 1.75/[40×2]/910
Double Chooz	8.7	7.4	France	0.15/10.2/60 1.067/10.2/300

Reactor ν Comparison Physics

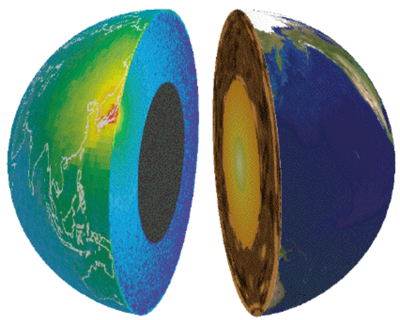
Reactor	Optimistic start date Oct 2005	GW-t-yr (yr)	90% CL $Sin^2 2\theta_{13}$ sensitivity	for Δm^2 ($10^{-3}eV^2$)	efficiencies	Far event rate
ANGRA	2013(full)	3900(1) 9000(3) 15000(5)	0.0070 0.0060 0.0055	2.5	0.8×0.9	350,000/yr
RENO	Late 09	340(1)	0.03	2.0	0.8	18,000/yr
Daya Bay	08(fast) 09(full)	3700(3)	0.008	2.5	0.75×0.83	70,000/yr 110,000/yr (before/after 2010)
Double Chooz	Oct 07(far) Oct 08(near)	29(1) 29(1+1) 80(1+3)	0.08 0.04 0.025	2.5	0.8 ×0.9	15,000/yr

Other potentials of Double Chooz

Double Chooz can do more than just ν oscillations:

- Neutrinos as a tool to monitor reactors
  - Non proliferation: νs as a new safeguard tool
  - Measurement of reactor power

- Geo-neutrinos
  - Neutrinos as “probes of the Earth’s interior”



Recent evidence:
“Experimental investigation of geologically produced antineutrinos with KamLAND”
Nature 436, 499-503 (28 July 2005)