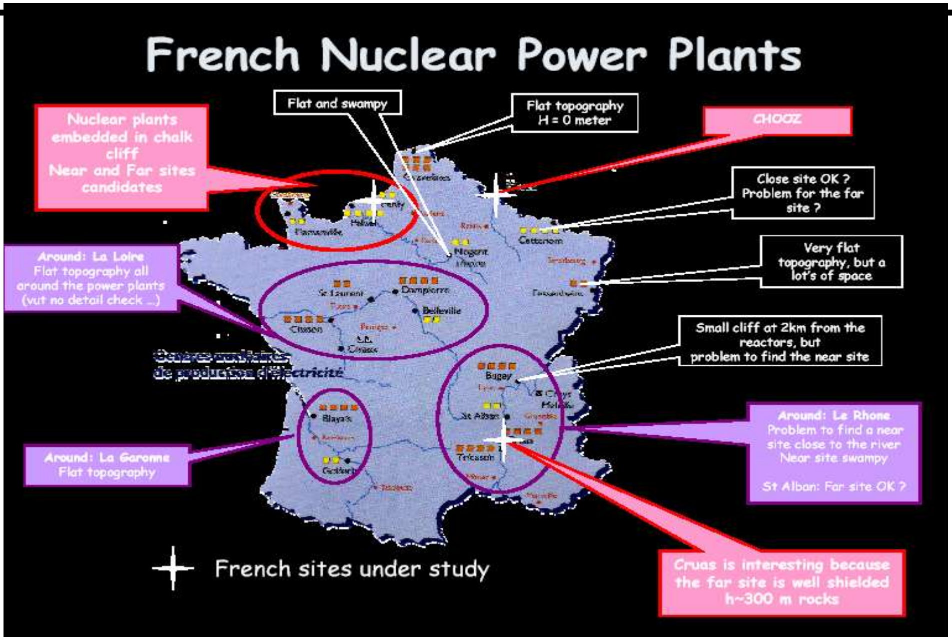
PANIC Neutrino physics planning Meeting

Santa Fe New Mexico, October 2005

The Double Chooz Double Fast Reactor Neutrino Opportunity



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Outline

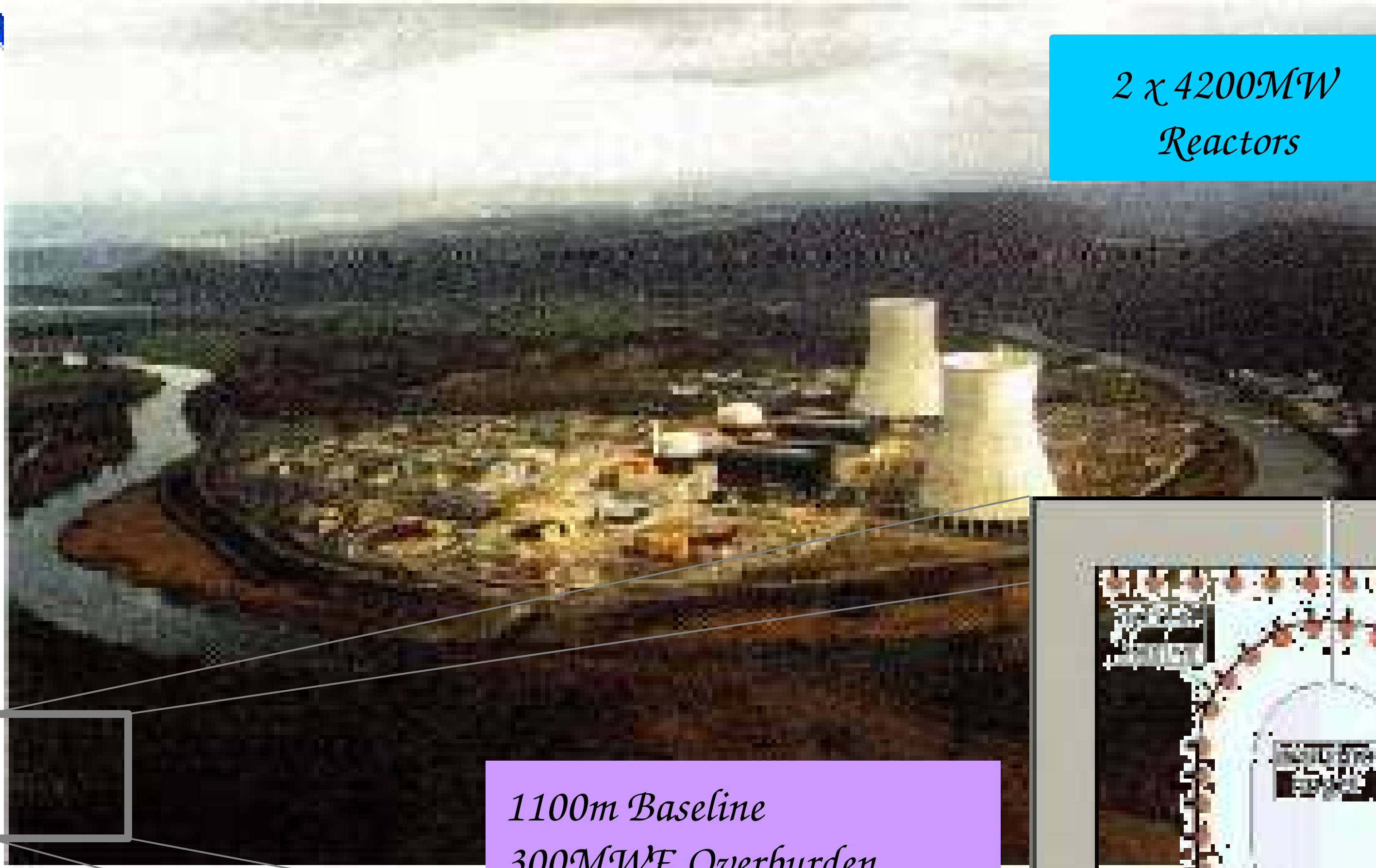
- I am going to assume others mention the importance of Θ_{13}
- CHOOZ
- Double Chooz
- Comments on Neutrino Planning relevant to the six current reactor neutrino opportunities?

CHOOZ

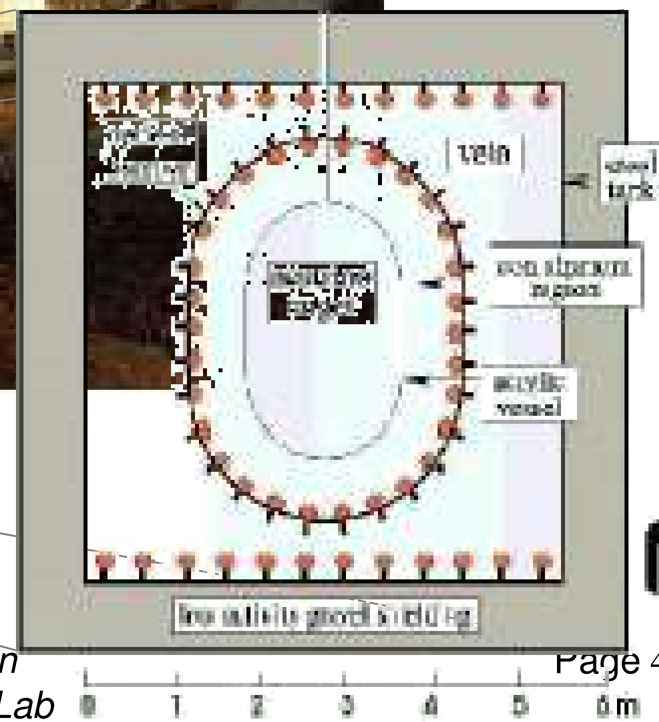
Originally built to determine if the atmospheric neutrino anomaly was due to what we now call θ_{12}.

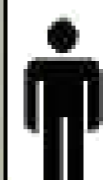
Chooz site

2 x 4200MW
Reactors



1100m Baseline
300MWE Overburden





$\bar{\nu}_e$ Signal

Neutron/positron coincidence

$\bar{\nu}_e p \rightarrow e^+ n$; Neutron/positron coincidence

200 days reactor on; 142 days reactor off

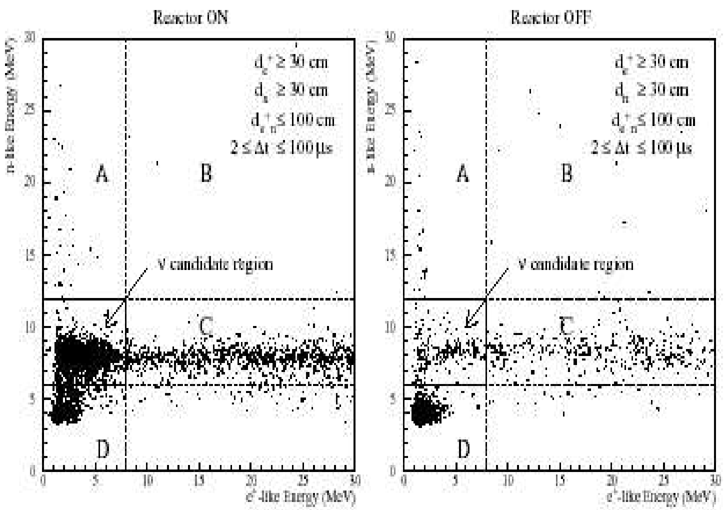


Fig. 37. Neutron versus positron energy for neutrino-like events selected from the preliminary sample by applying the "topological" cuts here indicated.

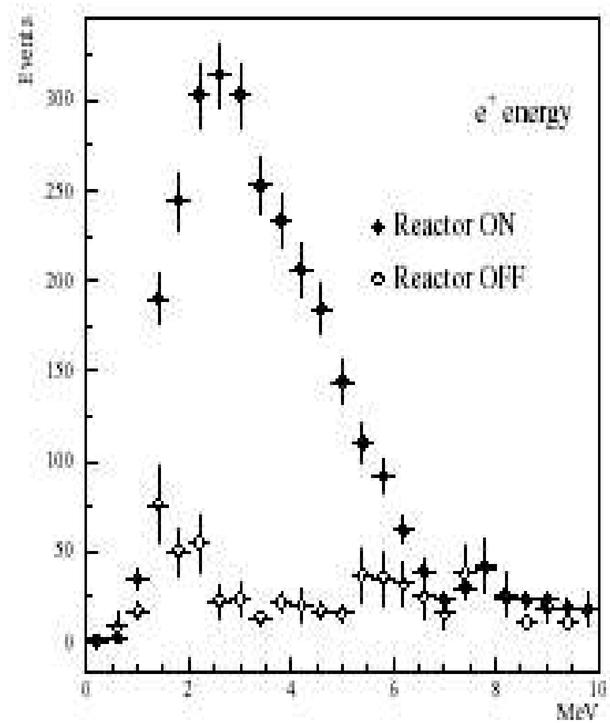
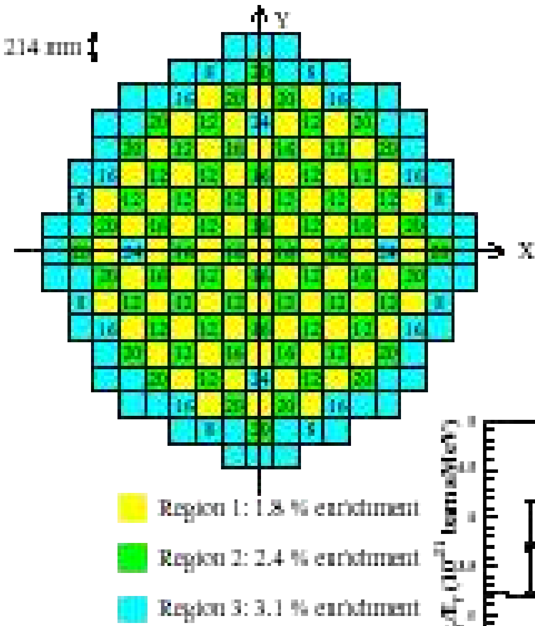
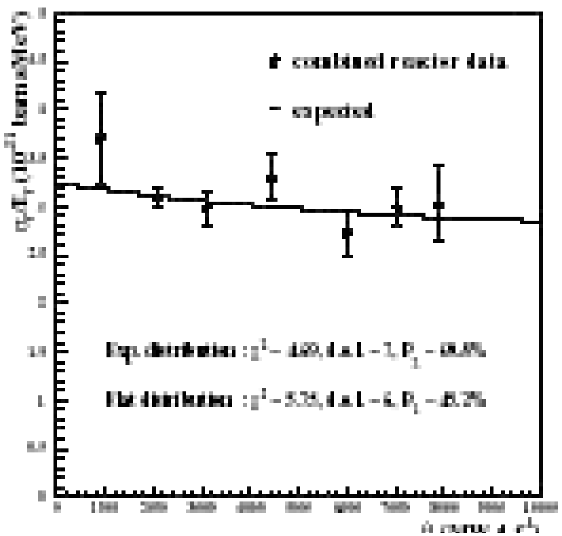
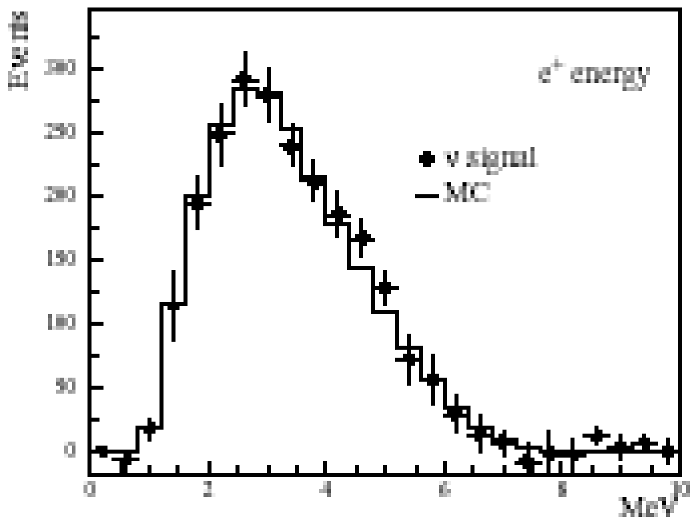


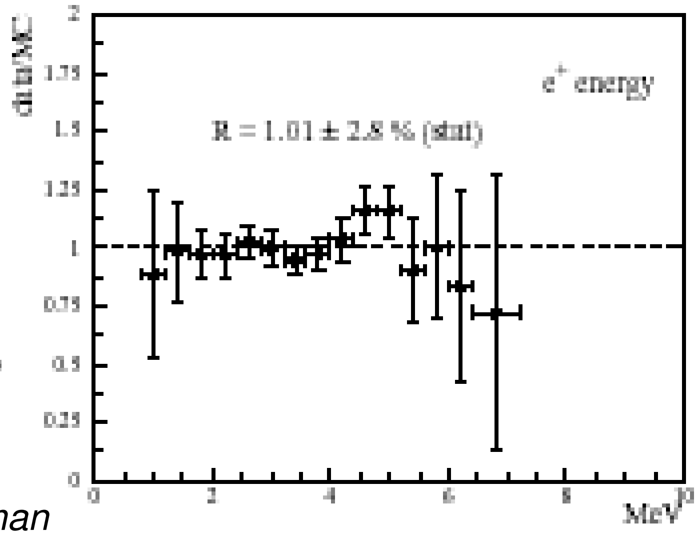
Fig. 46. Experimental positron spectra for reactor-on and reactor-periods after application of all selection criteria. The errors shown are statistical.

Systematics Limited by Reactor Flux









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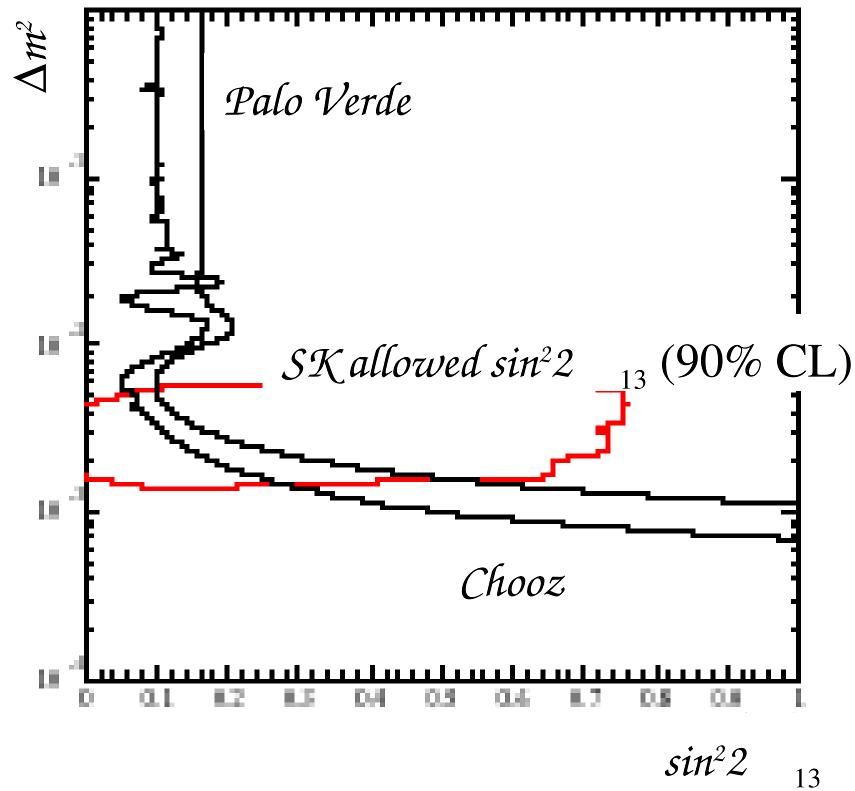
CHOOZ result

- Sin^{2}2 $_{13}$ < 0.19
  (at 2.0 10^{-3} eV^{2})

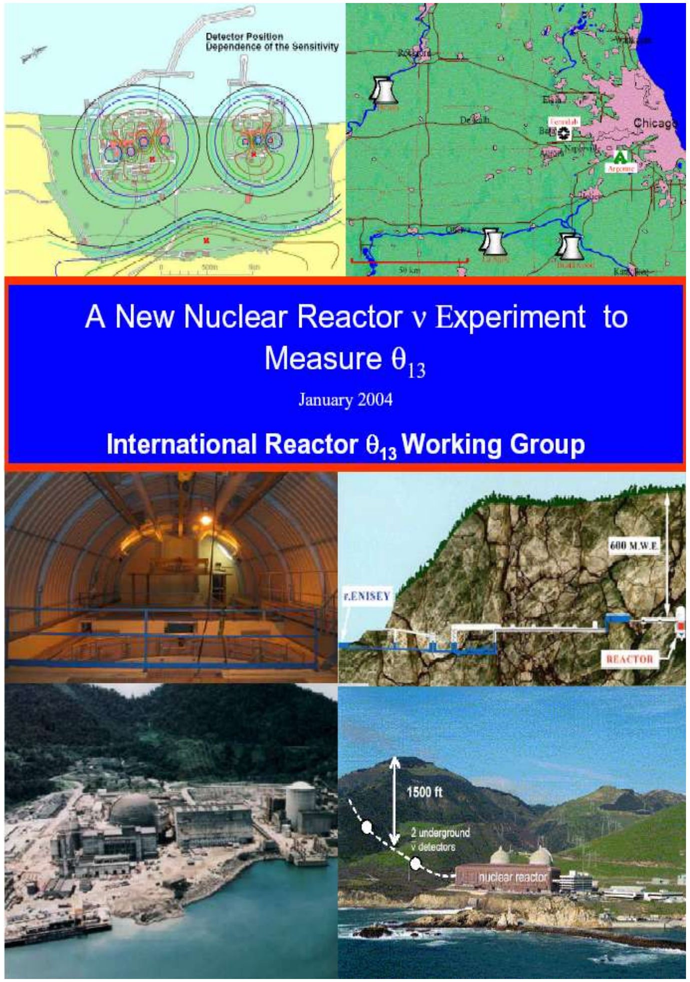


Double-CHOOZ

Jan 2004 White Paper

International Reactor neutrino Working Group

- 4 Workshops
  - Alabama 2003
  - Munich 2003
  - Niigata 2004
  - Angra 2005
- 7 Site-specific appendices
- 125 authors from 40 institutions in 9 countries



The reactor white paper estimated that civil construction would account for 2/3 of the estimated cost. To many of us, an opportunity to use an existing site is attractive & compelling.

Double Chooz Improvements

Second detector cancels reactor/cross section systematics

Steady operation of reactors ~✘4 in average ν flux

Buffer region reduces singles background

Better design allows fewer cuts

Improved veto system(s) tags background μ events

Double the fiducial volume region

Stable scintillator

⇨ 53 ν events/day (average) at far detector

⇨ 12→200 GW-ton-year!

	Chooz	Double-Chooz
Reactor cross section	1.9 %	—
Number of protons	0.8 %	0.2 %
Detector efficiency	1.5 %	0.5 %
Reactor power	0.7 %	—
Energy per fission	0.6 %	—

Systematic error comparison

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Argonne National Lab

European LOI & US proposal

May 2004

Letter of Intent for Double-CHOOZ: a search for the mixing angle θ_{13}

F. Ardellier [5], I. Barabanov[10], J.C. Barrière [6], M. Bauer [7], L. Bezroukov[10], C. Buck[11], C. Cattadori [8,9], M. Cribier [1,3], F. Dalnoki-Veress [11], N. Danilov[2], H. de Kerret [1,12], A. Di Vacri [8,15], A. Etenko [13], C. Grieb [14], M. Goeger [14], Y.S. Krilov[2], D. Kryn [1,12], C. Hagner 16, W. Hampel [11], F.X. Hartmann [11], P. Huber [14], J. Jochum [7], T. Lachenmaier [14], Th. Lasserre [1,1,3], C. Lendvai [14], M. Lindner [14], F. Marie [4], G. Mention [1,12], A. Milsztajn [3], J.P. Meyer [3], D. Motta [11], L. Oberauer [14], M. Obolensky [1,12], L. Pandola [8,15], W. Potzel [14], S. Schönert [11], U. Schwan [11], T. Schwetz [14], S. Scholl [7], L. Scola [6], M. Skorokhvatov [13], S. Sukhotin [12,13], A. Letourneau [4], D. Vignaud [1,12], F. von Feilitzsch [14], W. Winter [14], E. Yanovich[10]

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[3] DSM/DAPNIA/SPP, CEA/Saclay, 91191 Gif-sur-Yvette, France

[4] DSM/DAPNIA/SPhN, CEA/Saclay, 91191 Gif-sur-Yvette, France

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[10] INR, 7a, 60th October Anniversary prospect, Moscow 117312, Russia

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[12] PCC Collège de France, 11 place Marcelin Berthelot, 75005 Paris, France

[13] RRC Kurchatov Institute, 123182 Moscow, Kurchatov sq. 1, Russia

[14] TU München. James-Franck-Str., D-85748 Garching, Germany

[15] University of L'Aquila, Piazza Vincenzo Rivera 1, 67100 L'Aquila, Italy

[16] Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany

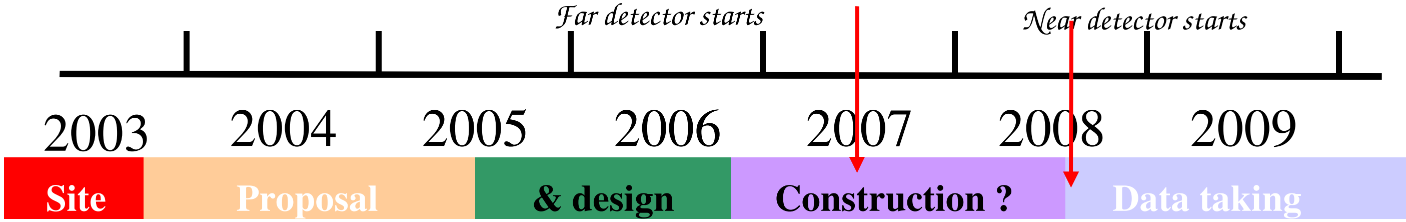
Proposal for U.S. participation in Double-CHOOZ: A New θ_{13} Experiment at the Chooz Reactor

S. Berridge[g], W. Bugg[g], J. Busenitz[a], S. Dazeley[e], G. Drake[b], Y.Efremenko[g], M. Goodman[b*], J. Grudzinski[b], V. Guarino[b], G. Horton-Smith[d], Y. Kamyshkov[g], T. Kutter[e], C. Lane[c], J. LoSecco[f], R. McNeil[e], W. Metcalf[e], D. Reyna[b], I. Stancu[a], R. Svoboda[e*], R. Talaga[b]

October 14, 2004

[a] University of Alabama, [b] Argonne National Laboratory, [c] Drexel University, [d] Kansas State University, [e] Louisiana State University, [f] University of Notre Dame, [g] University of Tennessee
* US Contacts: phsvob@lsu.edu, maury.goodman@anl.gov

Milestones



Detector Construction Can Begin In 2006

Near Laboratory

- Finalize designs in 2005
- Civil construction 2006-7

Data Taking

- Oct 07 $\sin^2 2\theta_{13}$ > (0.19) with far detector alone
- Nov 07 Near Detector Completion
- Dec 08 $\sin^2 2\theta_{13}$ > (0.05) sensitivity - 2 detectors
- Dec 10 $\sin^2 2\theta_{13}$ > (0.03)

Far site

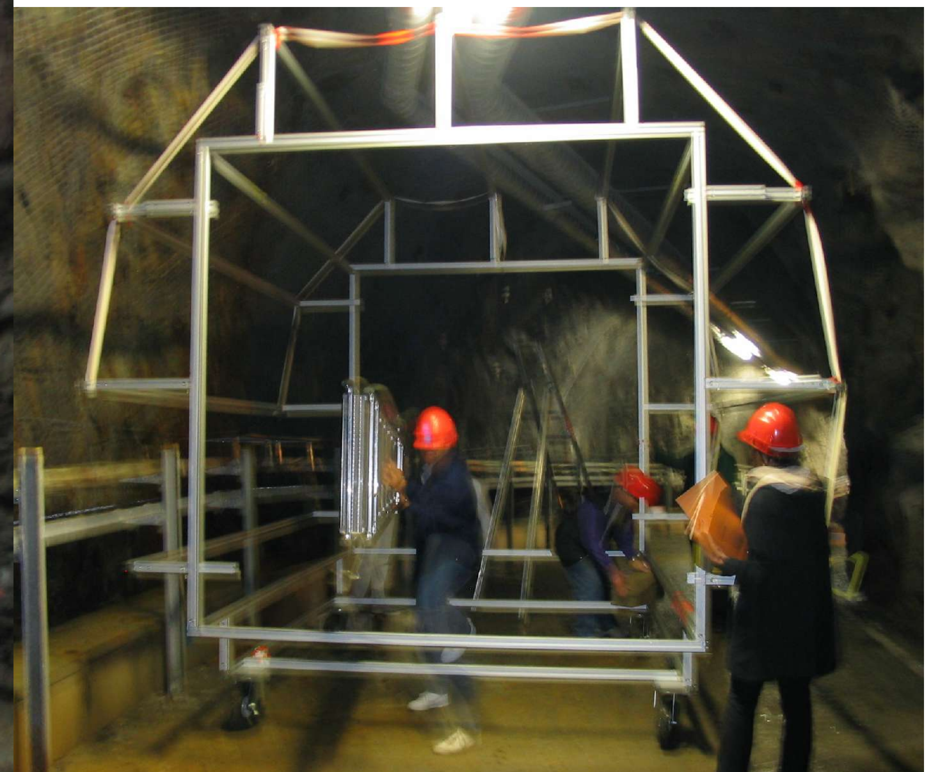
- Access through the access tunnel allowed pieces of diameter 3.6 m maximum

Crane

- Capacity : 5 tons
- Height under hook : 3.5 m

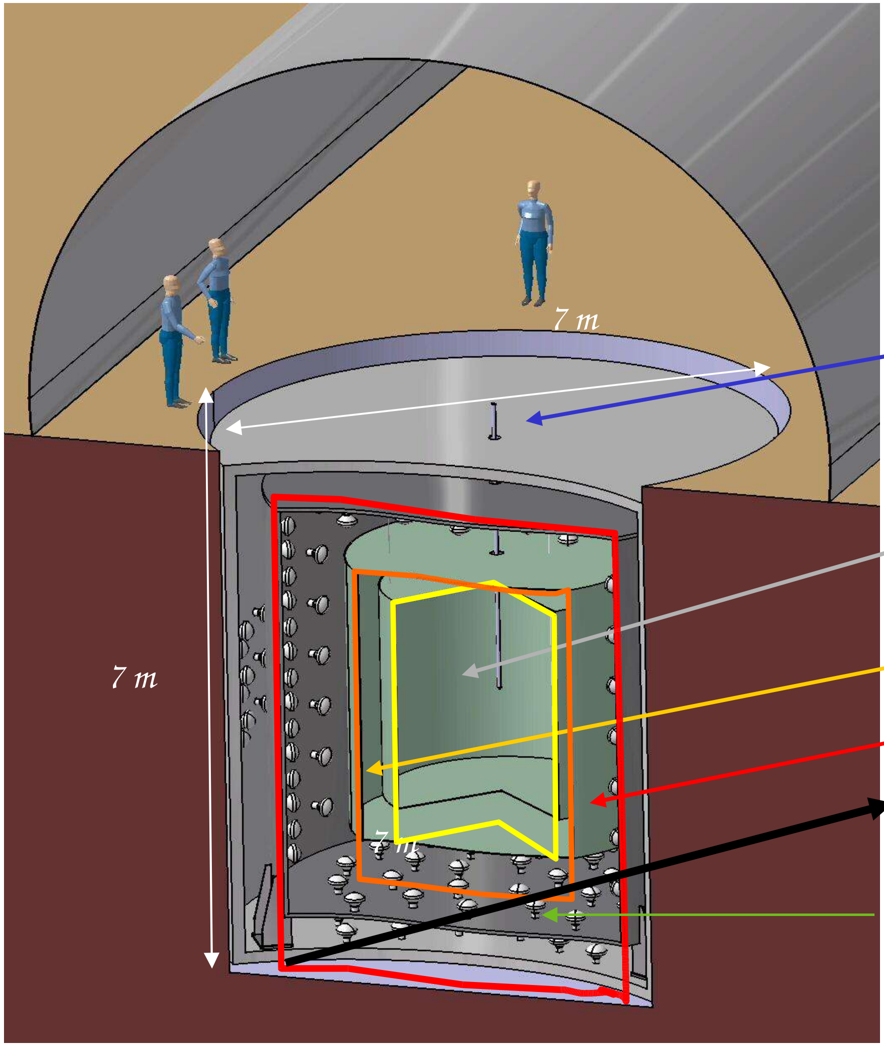
No space for storage

7 & 8 october 2004 accessibility tests



Successful !!

Double-CHOOZ (far) Detector



We will start data-taking in 2007 with the far detector

Shielding steel and external vessel (studies, réalisation, intégration → IN2P3/ PCC)

Target- Gd loaded scintillator

Gamma catcher: scintillator with no Gd

BUFFER Mineral Oil with no scintillator

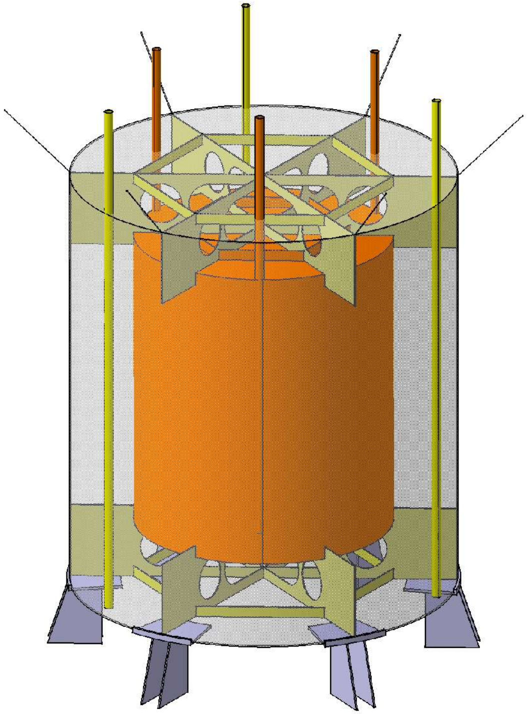
Optically separated inner veto to tag muons

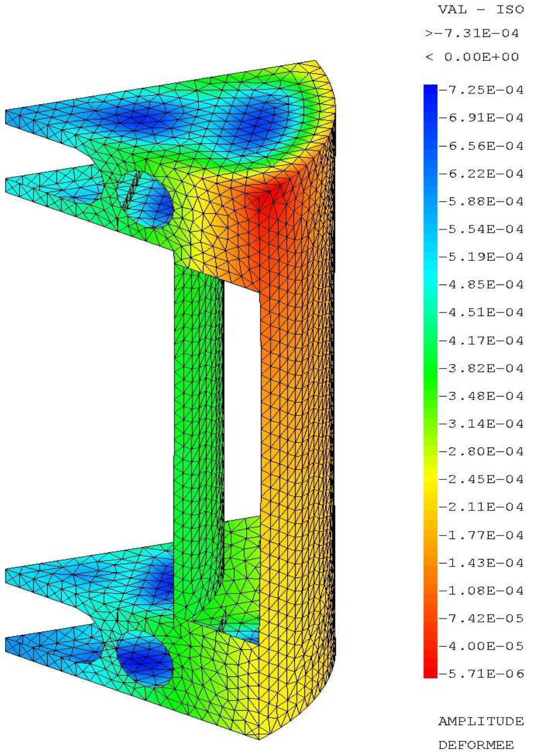
Modular Frame to support photomultipliers

Puit existant

Acrylic Vessel Design

The full detector will be
3.6 m (d) x 4 m (h)





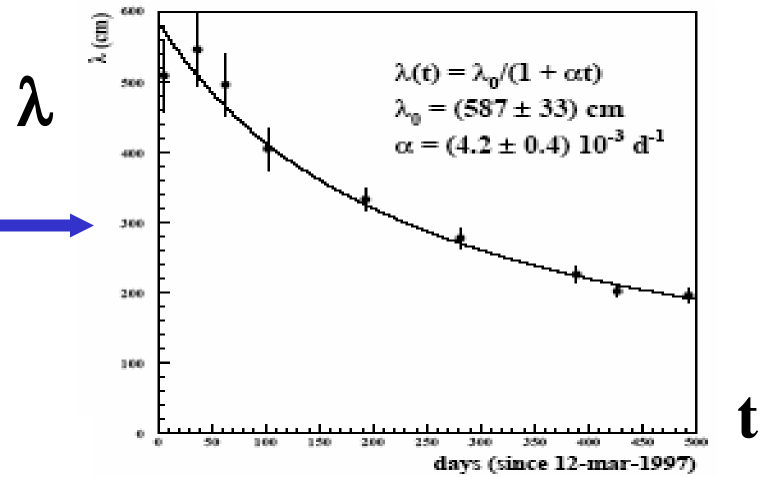
Deformation analysis from Saclay

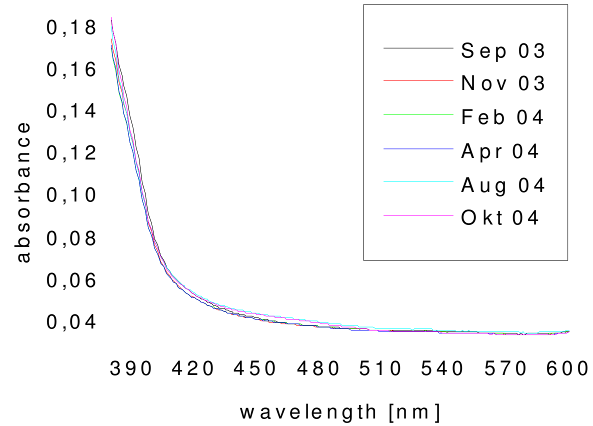
1/5 scale prototype

- Completed Summer 2005
- Will be filled soon

Scintillator progress

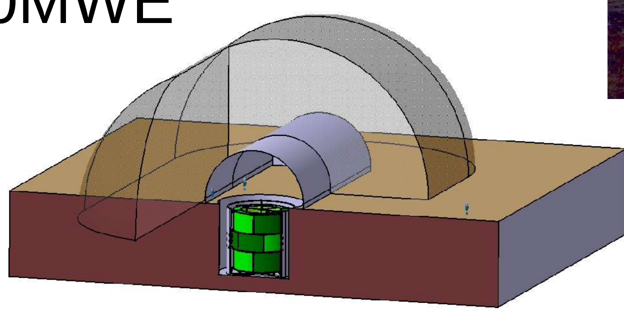
- Degradation of the attenuation length caused trouble for CHOOZ.
- After several years of research, MPI-Heidelberg has manufactured optically stable Gd loaded oils, such as Gd CBX or Betadiketones in PXE
- Currently producing 200 ℓ.
- They will optimize this scintillator and provide for Double Chooz.





Near lab conceptual design

- Identical fiducial detector and gamma catcher
- Except for additional outer veto & larger inner veto
- 60MWE



L_{near} ~100 meters, the closest near detector of any proposed experiment

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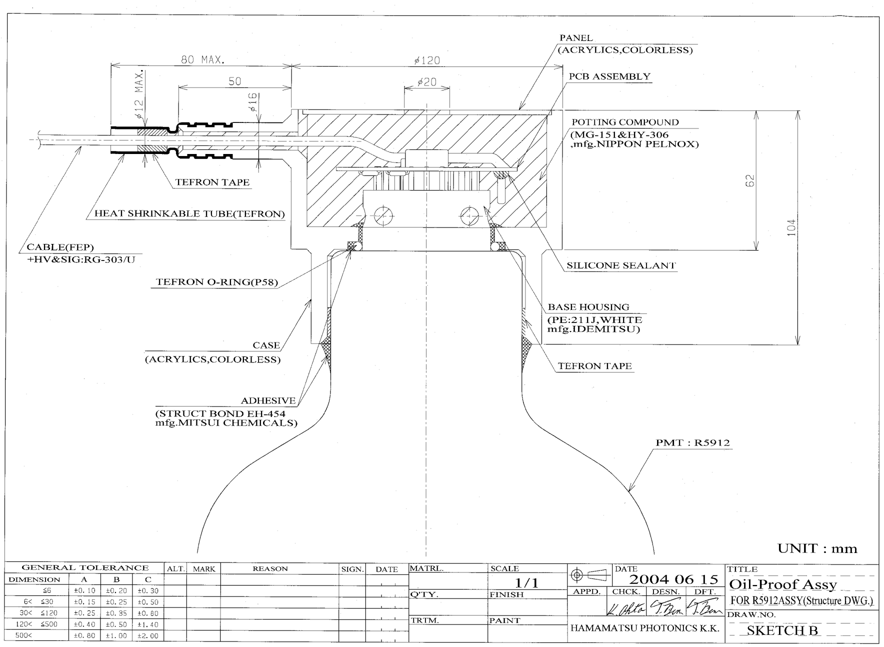
Phototubes

Baseline – 1040 tubes

12.9% phototube coverage

190 pe/ MeV (Monte Carlo)



PMT related backgrounds were about 1/3 BG at CHOOZ

Recent work on

- Cabling schemes
- Sensitivity to B fields
- Angular sensitivity
- Tilting tube options
- Phototube comparisons
- Radioactivity measurements

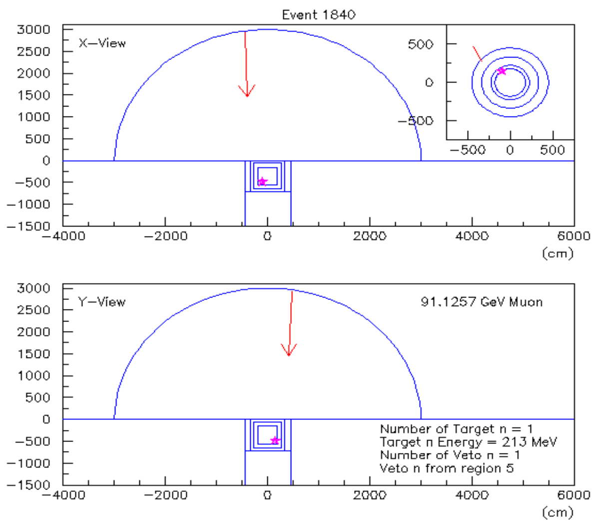
PMT's must be ordered by this fall to maintain the "rapidly deployed" schedule.

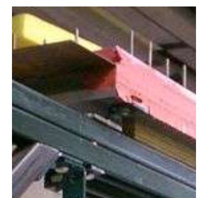
Outer Veto

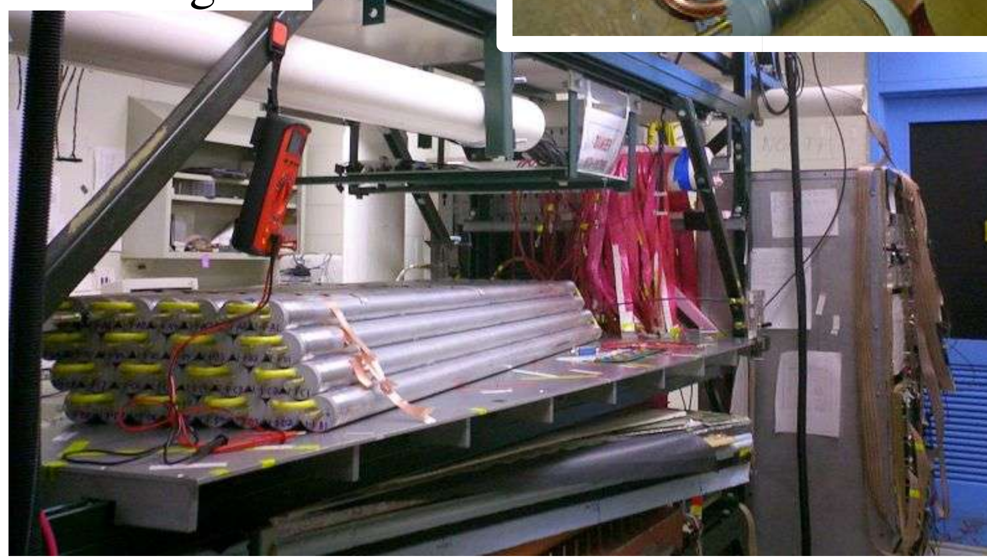
The Outer Veto provides additional tagging of μ induced background n's.

Prototype counters designed/tested

A Fluka simulation of μ's aimed at the near detector is being used to specify needed coverage

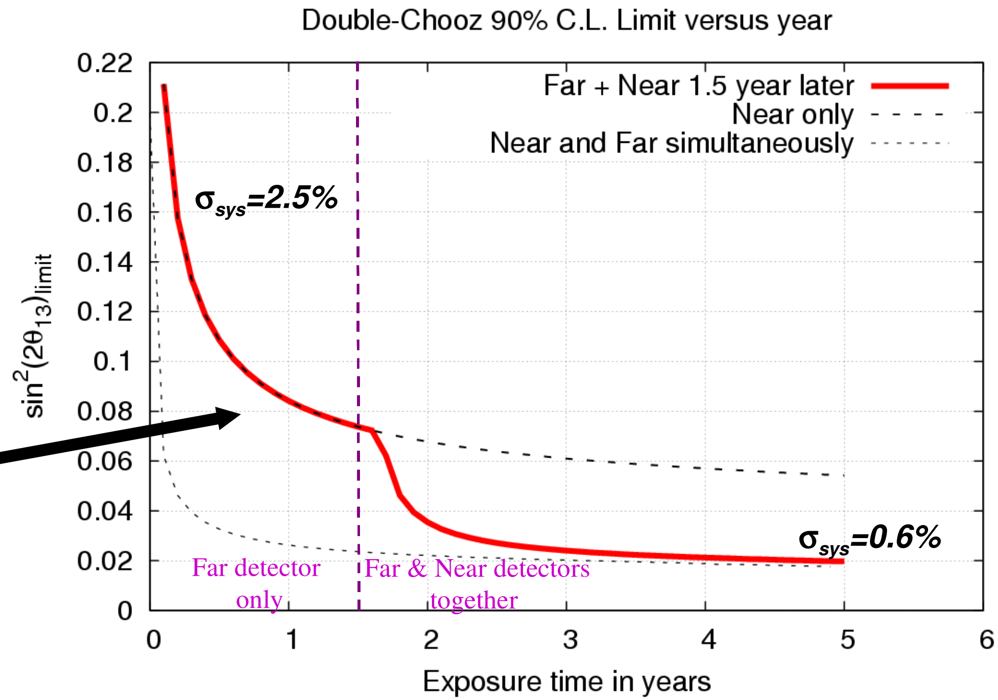






Expected Sensitivity 2007-2012

- **Far Detector starts in 2007**
- **Near detector follows 16 months later**
- **Double Chooz can surpass the original Chooz bound in 6 months**
- **90% C.L. contour if $\sin^2(2\theta_{13})=0$**
- **Δm^2_{atm} will to be measured by MINOS. (Here 2.8 10^{-3} eV^2)**



05/2007 05/2008 05/2009 05/2010

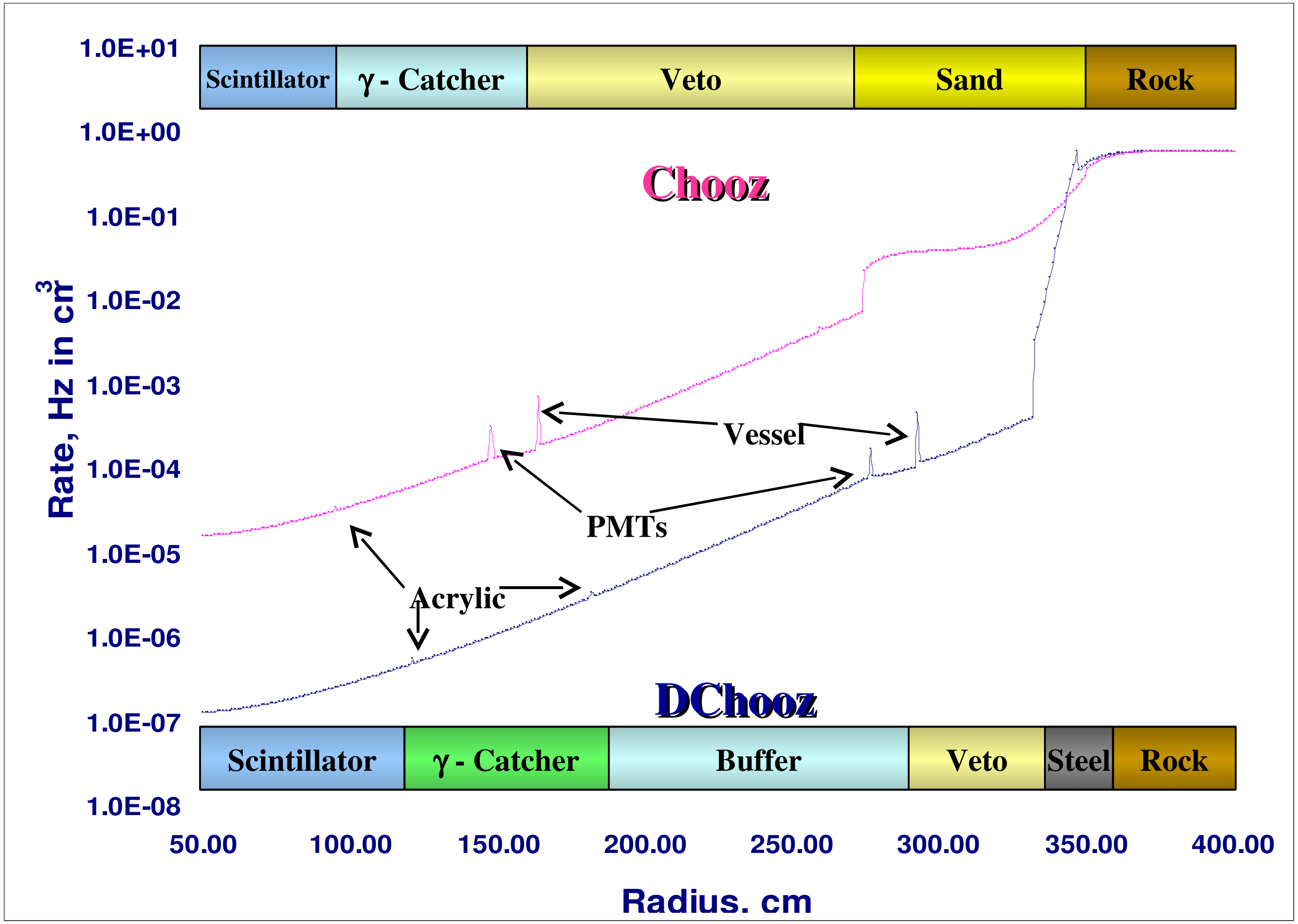
Backgrounds

- Near detector overburden is chosen to keep signal/background above 100 (The reactor signal is about 1 event per 10 seconds)
- Largest background is fast neutrons
- Largest uncertainty in background comes from spallation of Li9
- Backgrounds <u>measured</u> at CHOOZ used to calculate sensitivity

Overburden (m.w.e.)	μ rate (s^{-1})	$< E_\mu >$ (GeV)	Neutrons through going μ (s^{-1})	μ stopping rate (s^{-1})	Neutrons stopping μ (s^{-1})
40	$1.1 \cdot 10^3$	14	2	$5 \cdot 10^{-1}$	0.7
60	$5.7 \cdot 10^2$	19	1.4	$3 \cdot 10^{-1}$	0.4
80	$3.5 \cdot 10^2$	23	1	$1.2 \cdot 10^{-1}$	0.2
100	$2.4 \cdot 10^2$	26	0.7	$6 \cdot 10^{-2}$	0.08
300	$2.4 \cdot 10^1$	63	0.15	$2.5 \cdot 10^{-3}$	0.003

Table 4: Estimated neutron rate in the active detector region due to through going cosmic muons.

Modeling/reducing γ singles radioactivity

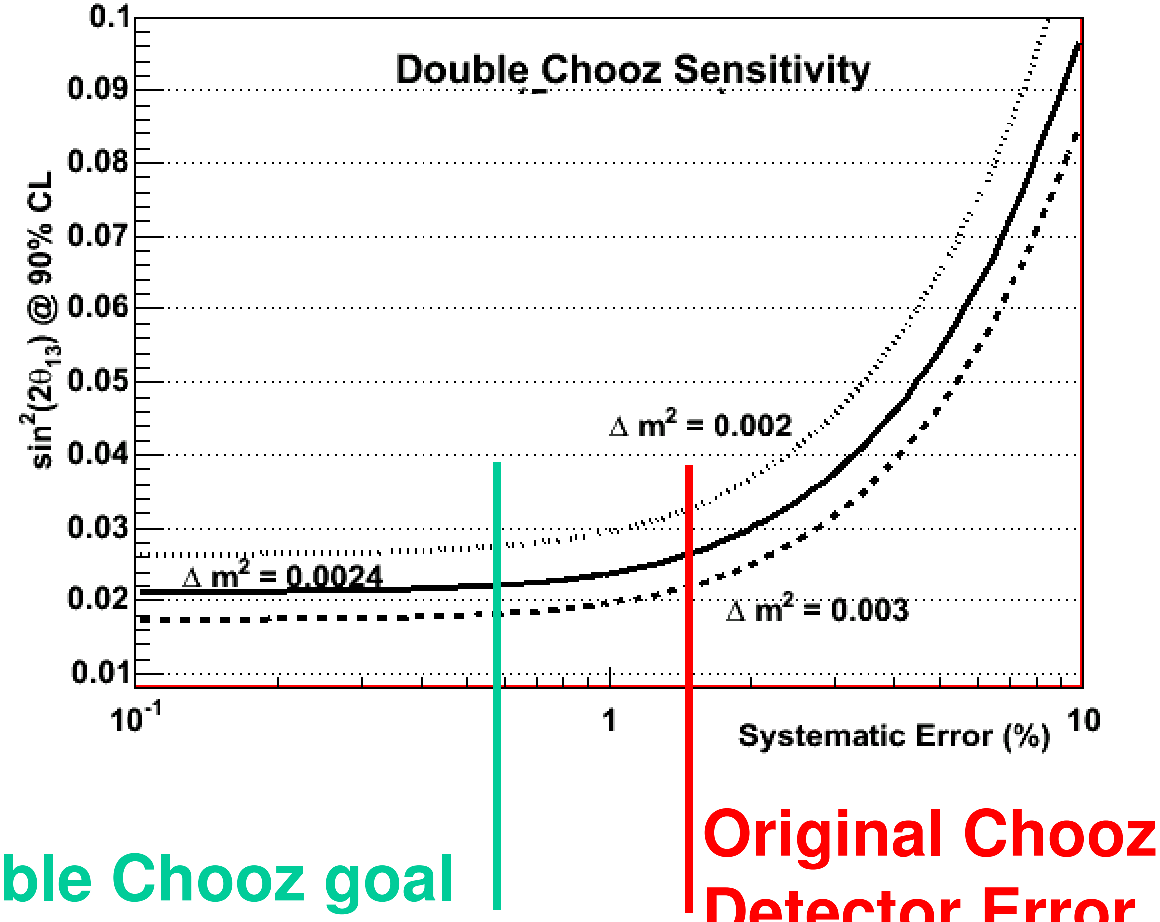


Systematic Errors

Selection Cut	Chooz error(%)	Double Chooz Relative Error(%)
Positron Energy	0.8	0
Positron-geode distance	0.1	0
Neutron capture	1.0	0.2
Capture energy containment	0.4	0.2
Neutron-geode distance	0.1	0
Neutron delay	0.4	0.1
Positron-neutron distance	0.3	0 (0.2 if used)
Neutron multiplicity	0.5	0
COMBINED	1.5	0.2 (0.3)

Selection Cut uncertainties -Total systematics 0.6%

How Good is Good Enough?



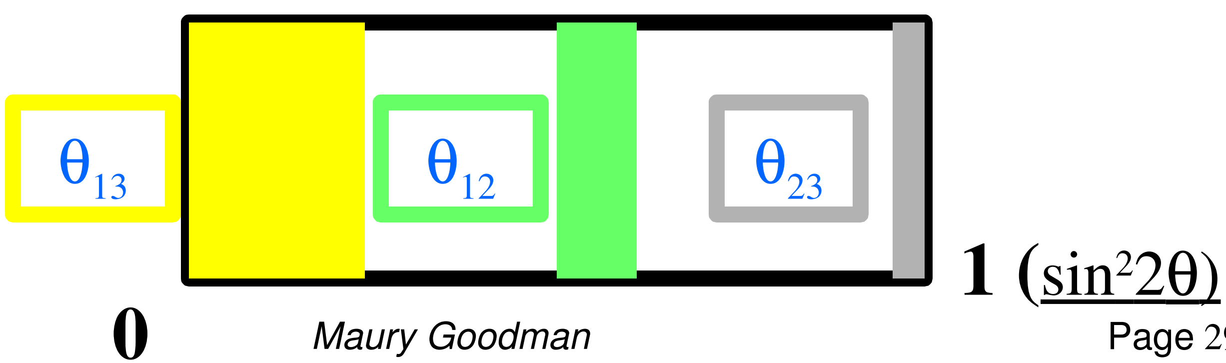
Status

- French Detector Costs Approved by Two French Physics Funding Agencies
- Near Lab (~5M €) approved pending cost study
- Agreement with Electricite de France to host site and provide engineering
- US proposal – DOE-HEP for $4.8M before NuSAG
- German University proposal under development
- German Lab will provide Scintillator (MPI)
- Local Government agency has provided a chateau

Planning Thoughts

3 Angles

- $\theta_{12} \sim 30^o$ measured in solar neutrino experiments, confirmed by KamLAND reactor neutrino experiment
- $\theta_{23} \sim 45^o$ measured in atmospheric neutrino experiments (particularly Super-K), confirmed by K2K
- $\theta_{13} < 12^o$ limited by CHOOZ reactor neutrino experiment



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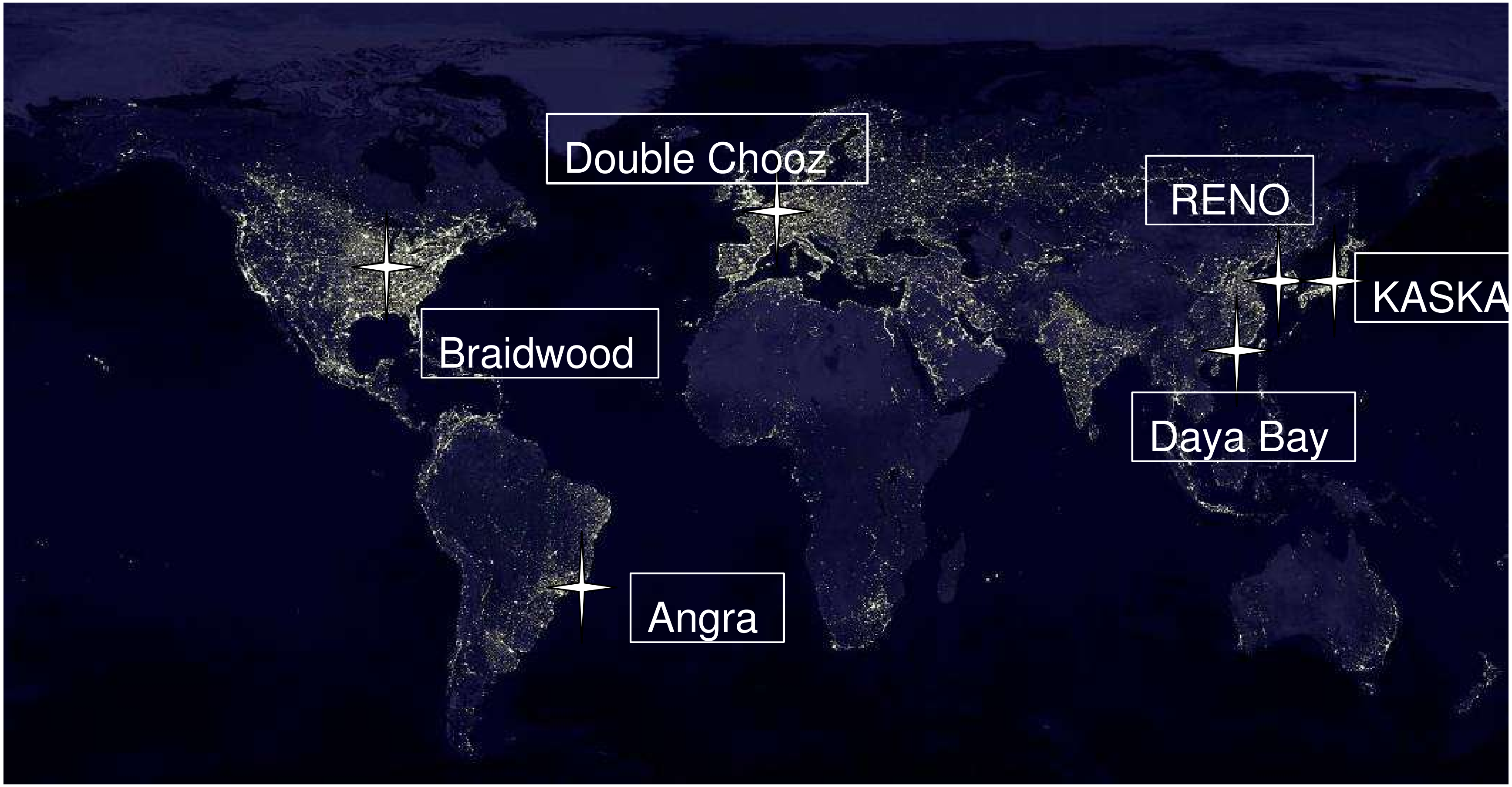
Where should we go?



Reactor ν 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
Braidwood	7.2	6.5	Illinois US	0.27/[65×2]/464 1.51/[65×2]/464
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
KASKA	24.3	19.4	Japan	0.35/6/90 [×2] 1.6/[6×2]/260
RENO	17.3	16.4	Korea	0.15/20/230 1.5/20/675

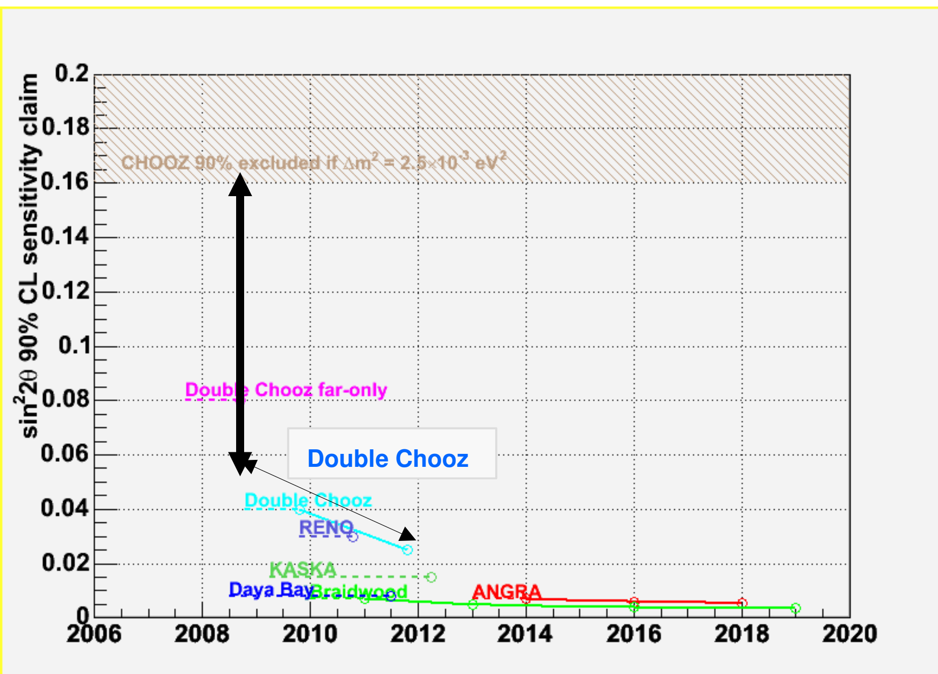
Reactor ν experiment physics

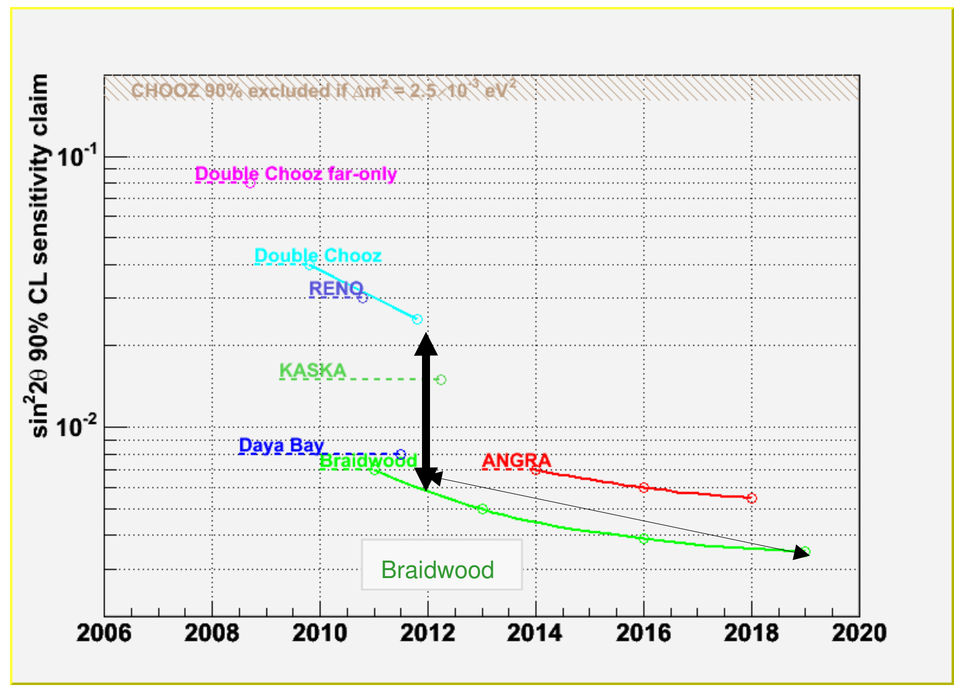
Reactor	Optimistic start date	GW-t-yr (yr)	90% CL $\sin^2 2\theta_{13}$ sensitivity	for Δm^2 (10^{-3}eV^2)	efficiencies	Far event rate
ANGRA	2013(full)	3900(1) 9000(3) 15000(5)	0.0070 0.0060 0.0055	2.5	0.8×0.9	350,000/yr
Braidwood	2010	845(1) 2535(3) 7605(9)	0.007 0.005 0.0035	2.5	0.75	41,000/yr
Daya 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
KASKA	Mar 09	493(3)	0.015	2.5	0.8×0.88	24,000/yr
RENO	Late 09	340(1)	0.03	2.0	0.8	18,000/yr

Linear & log sensitivity

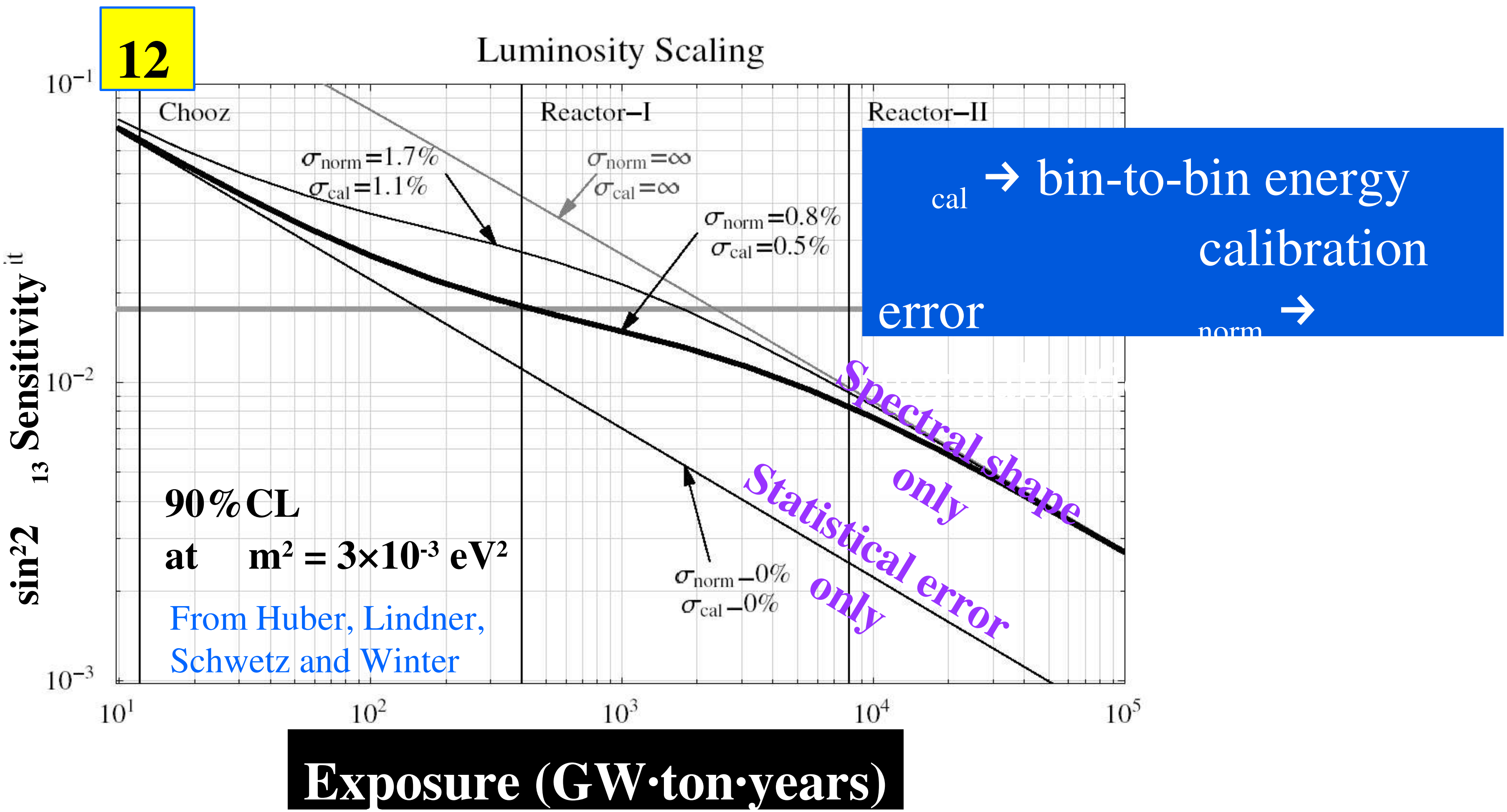
If all experiments proceed with their optimistic schedule and expected sensitivity…

↕ First non-zero evidence





Shape vs. Rate
A Luminosity Transition

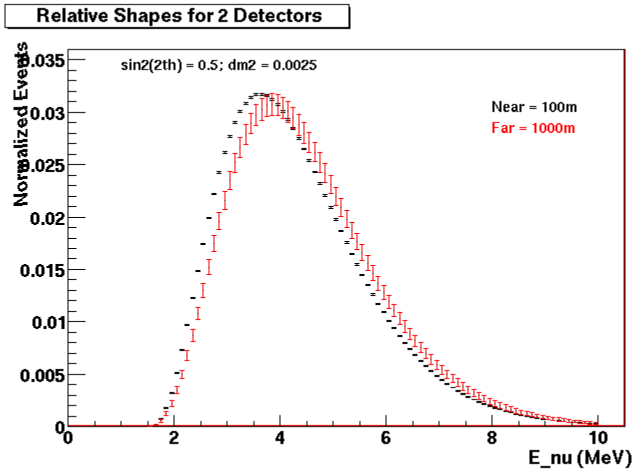


Rate & shape tests

To maximize the statistical power of the "rate" test, want the oscillation max at the peak.

To maximize the statistical power of the "shape" test, want an oscillation minimum at the peak.

The "shape" test requires more statistics.



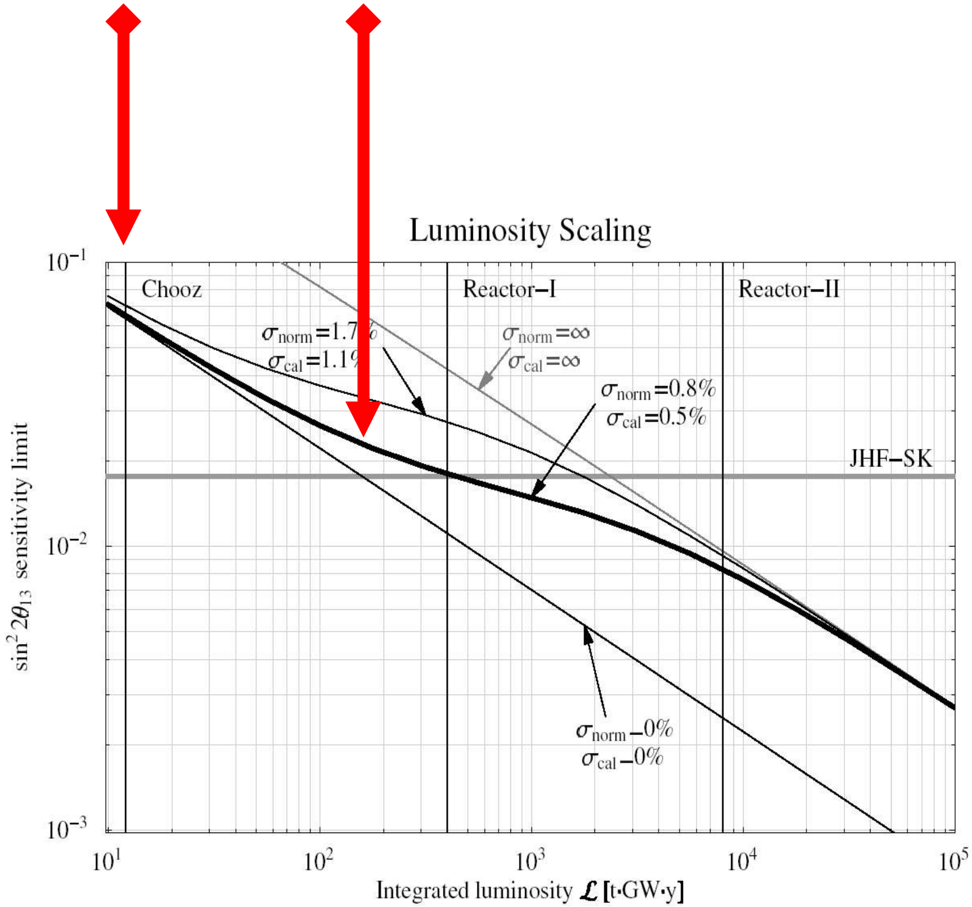
- Each experiment will do both
- Optimization of distances depends on Δm^2 & GW-t-yr

I. Get to the Transition

- Strategy #1

(Double Chooz, RENO)

There is considerable parameter space available to quickly improve the current limit.

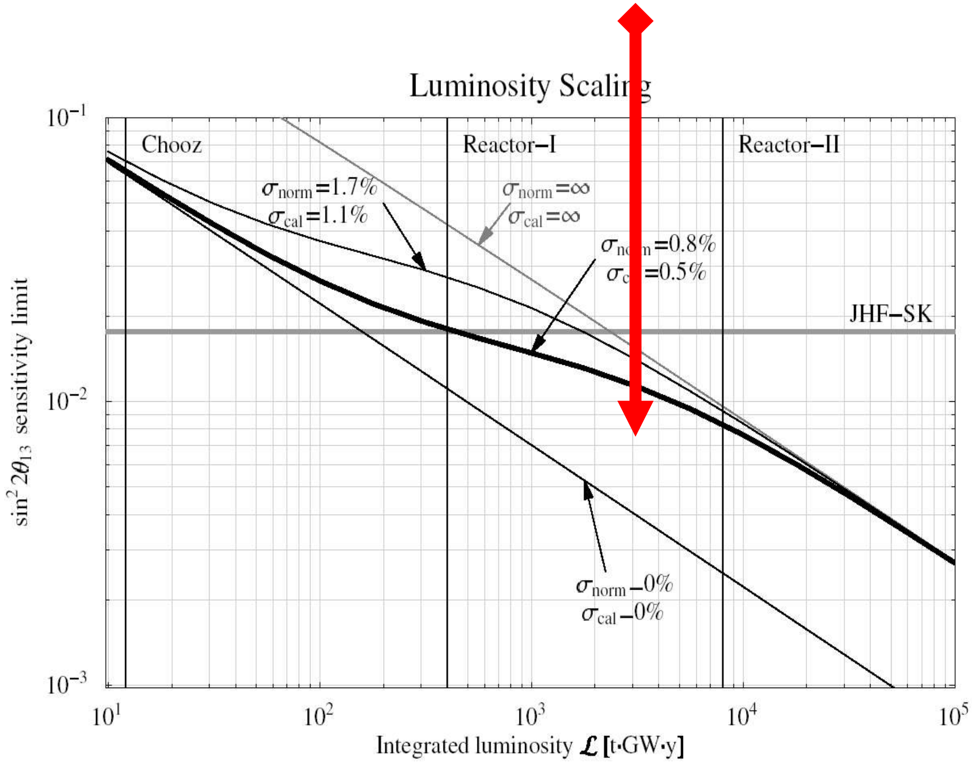


II. Beat Down the Transition

- Strategy #2

(Braidwood, Daya Bay, KASKA)

Work hard on reducing systematic errors, such as with movable detectors.

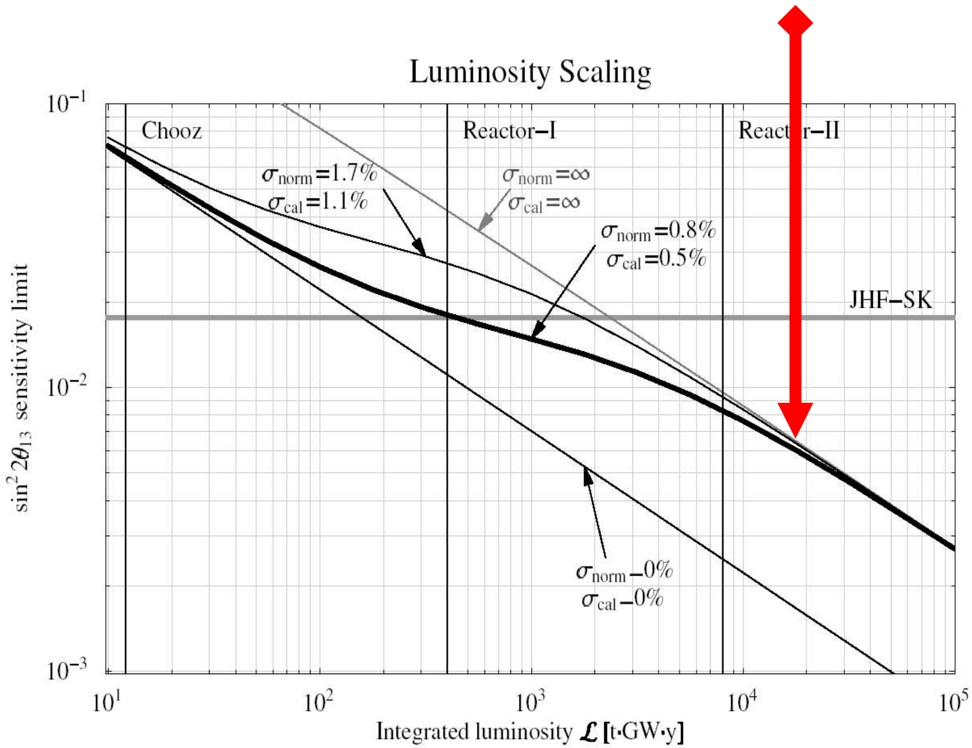


III. Pass the Transition

- Strategy #3

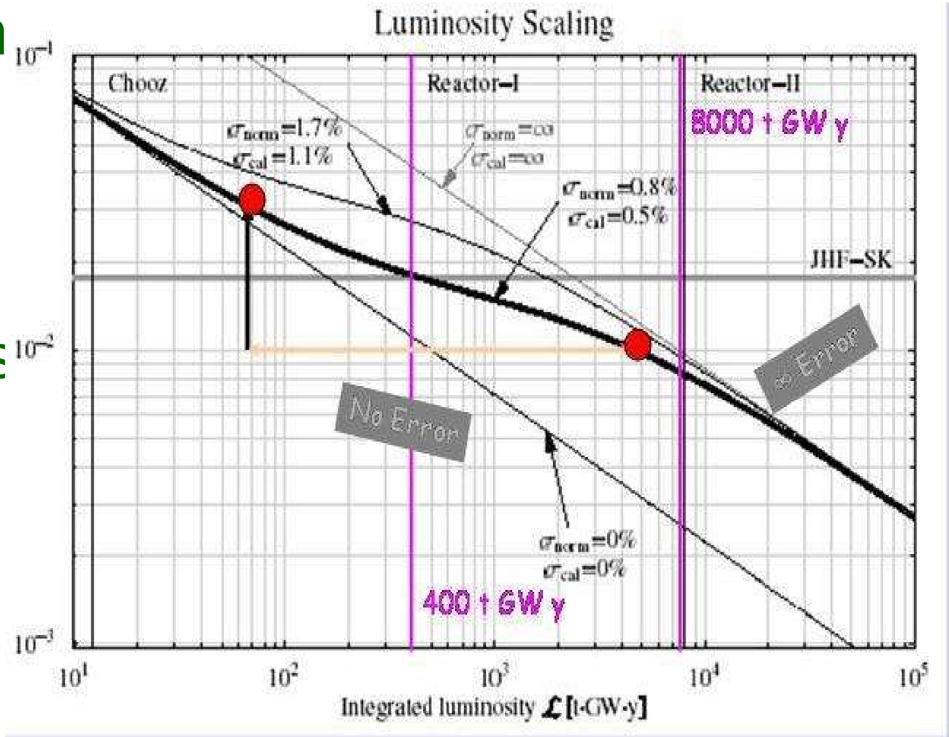
(Angra)

With larger detectors, make yourself less sensitive to systematic errors.

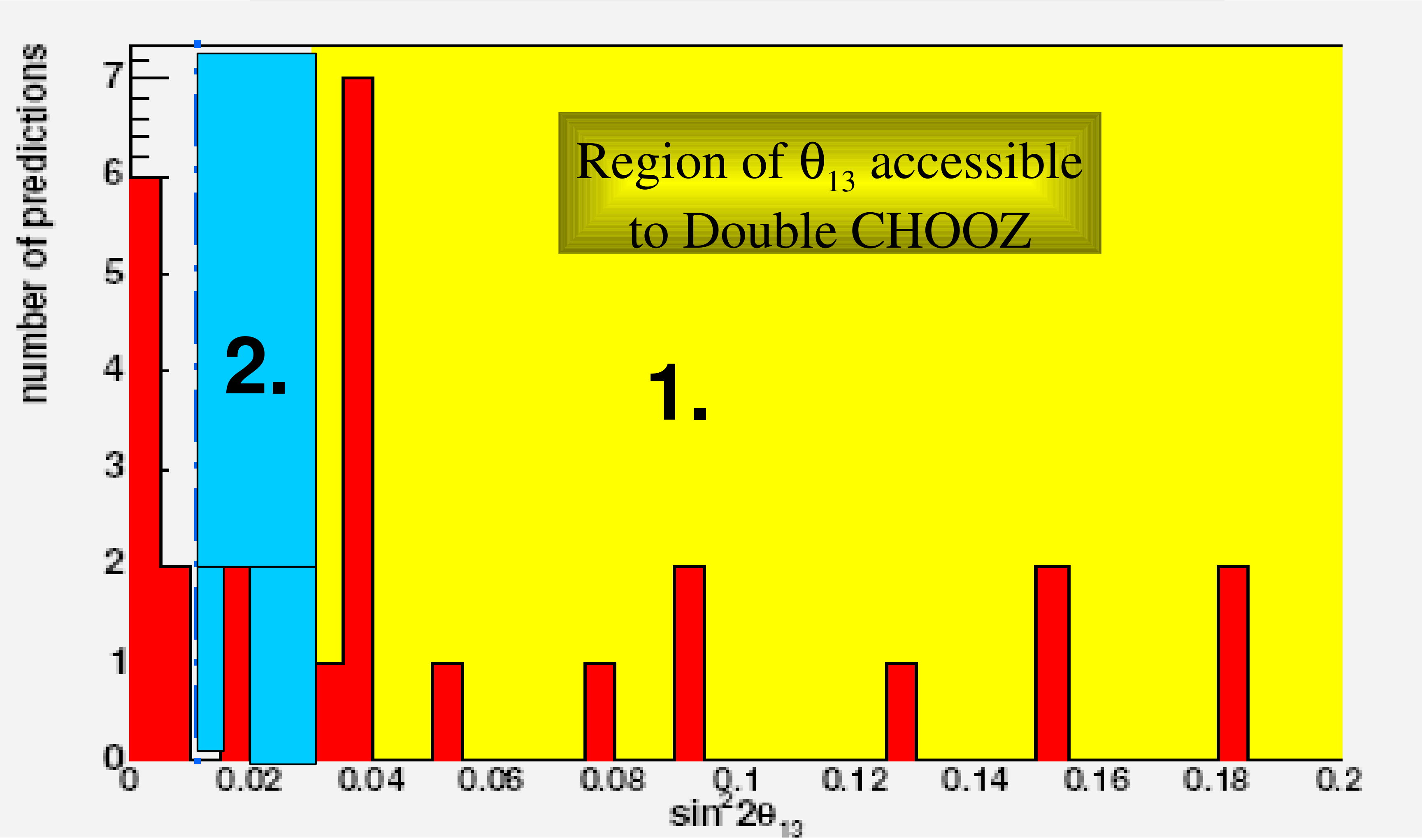


Why am I on both Braidwood & Double Chooz?

- An experiment to measure 0.03 is 70 times easier than an experiment to measure 0.01 and about 1/5th the cost .
- An experiment sensitive to 0.03 is a valuable step towards an experiment that is sensitive to 0.01.
- *Double Chooz can get to 0.03 faster than any other experiment*



θ_{13} predictions in linear space



(My) conclusions

- Double Chooz could be/should be the next first step in reactor neutrino experiments
- My (Bayesian) expectation is that the probability Double Chooz will find some evidence for a non-zero $_{13}$ is 85%.
- Other experiments should follow and will build on experiences gleaned from Double Chooz

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