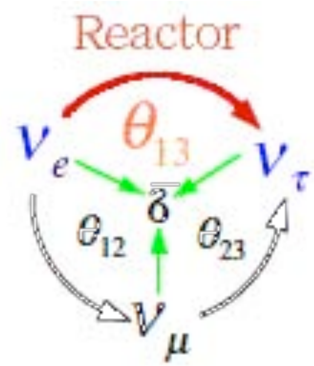
IIT Seminar,
April 6, 2005

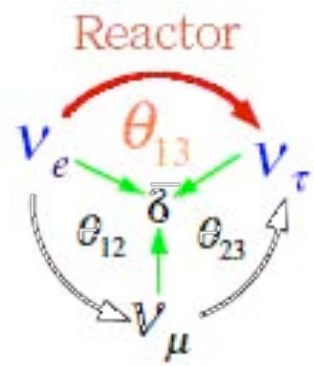
Plans for the Reactor Neutrino Experiment Double Chooz
Double Chooz US



Maury Goodman, Argonne National Lab

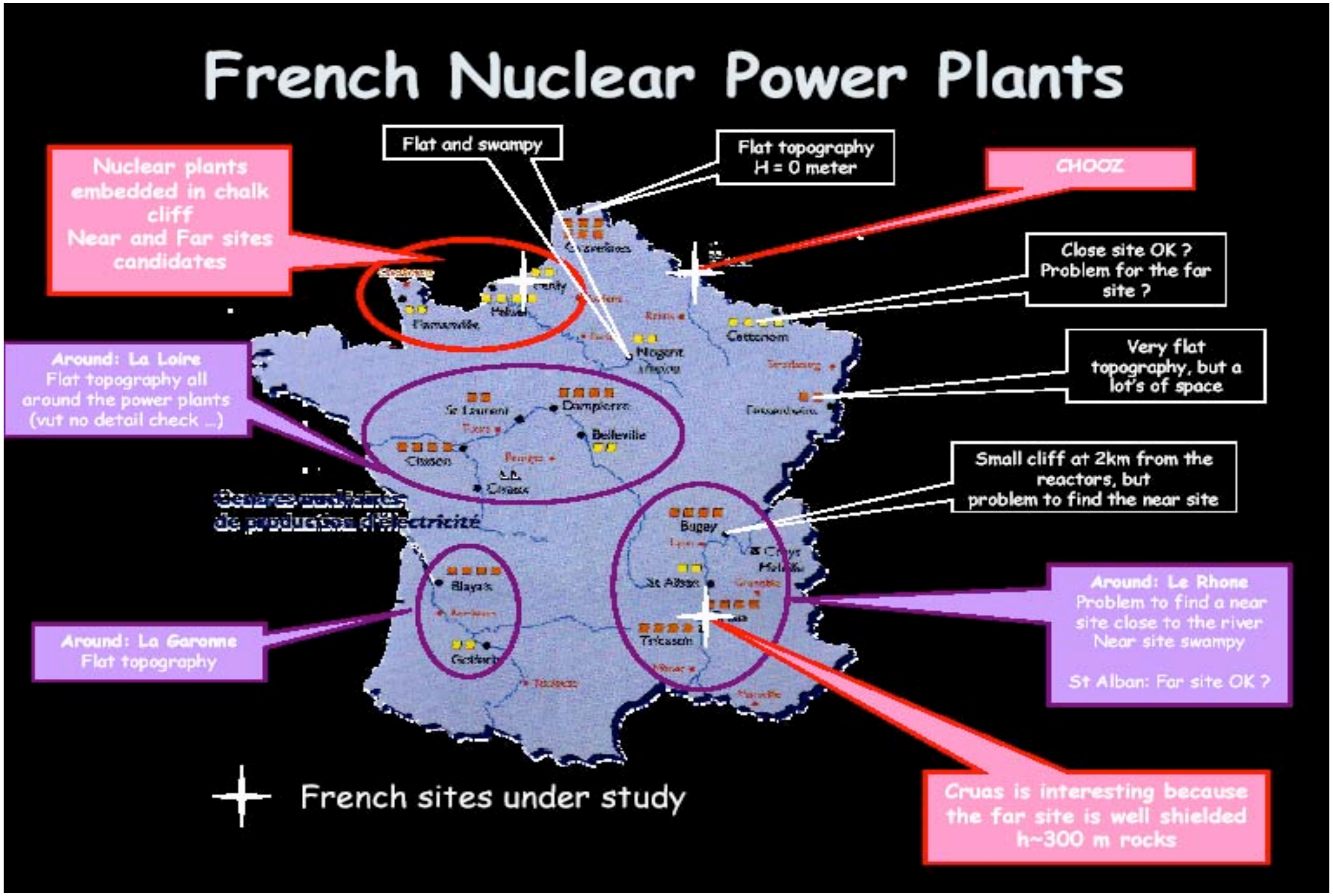
IIT Seminar,
April 6, 2005

And then Braidwood



Maury Goodman, Argonne National Lab

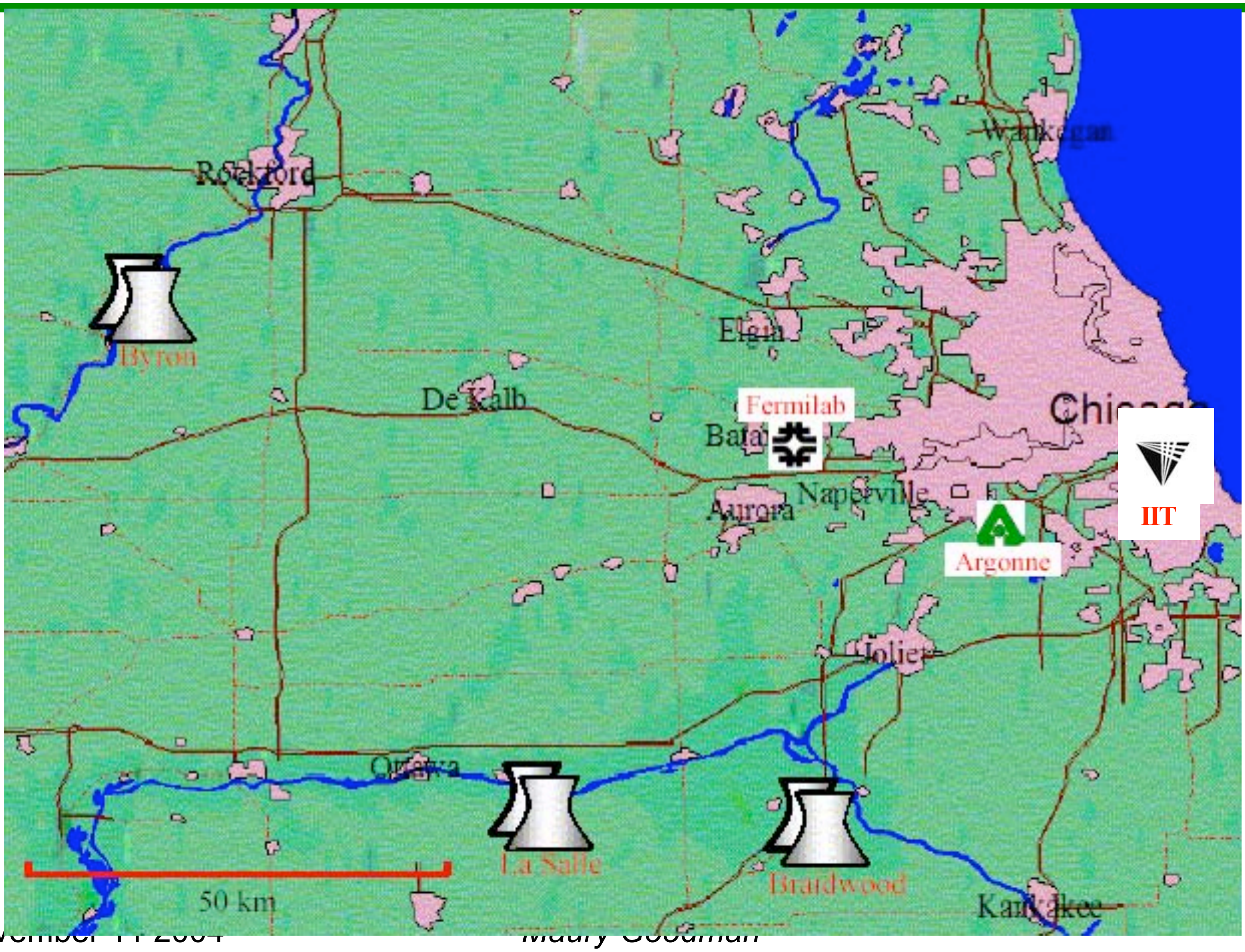
France



November 11 2004
Double-CHOOZ

Maury Goodman
Argonne National Lab

Illinois


Rockford
Waukegan
Byron
Elgin
De Kalb
Fermilab
Naperville
Aurora
Argonne
IIT
Ottawa
La Salle
Braidwood
50 km

Outline

- **Remarks about Θ_{13}**
- CHOOZ
- **Reactor ν Initiatives**
  - ▷ K2DET ▷ Diablo Canyon ▷ Kaska ▷ Daya Bay ▷Angra
- Double Chooz
- Braidwood
- Prospects/NuSAG

Maury Goodman
Argonne National Lab

Remarks about Θ_{13}

November 11 2004
Double-CHOOZ

Maury Goodman
Argonne National Lab

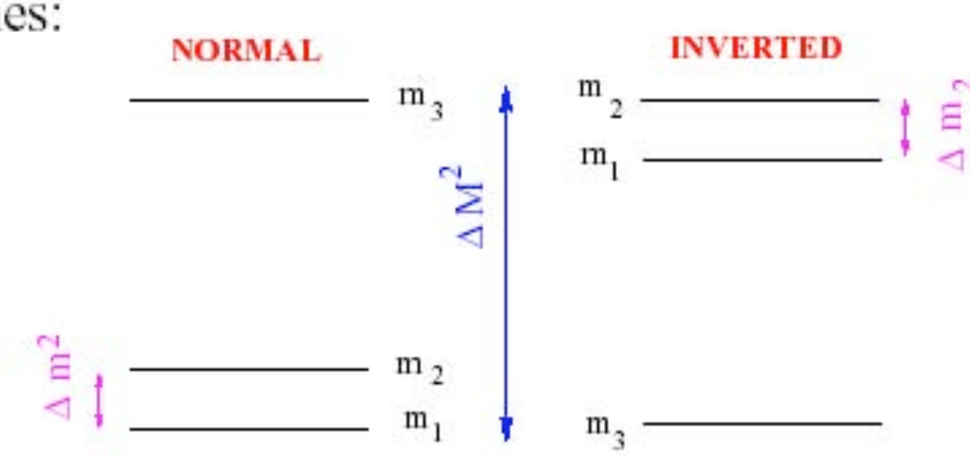
MNS matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

– U: 3 angles, 1 CP-phase + (2 Majorana phases)

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

– Two schemes:



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

Apology

- Apology to non-experts

- Θ_{13} limits are expressed several different ways
- Several factors of 2 confusion are possible

$U_{e3}^2 = \sin^2\theta_{13} \sim \frac{1}{2} \sin^2\theta_{\mu e} \sim 1/4 \sin^2 2\theta_{13}$

θ_{13} (degrees)	θ_{13} (radians)	$\sin(\theta_{13})$	$\sin^2(\theta_{13})$	$\sin^2(2\theta_{13})$
0.00000	0.00000	0.00000	0.00000	0.00000
1.00000	0.01745	0.01745	0.00030	0.00122
1.43254	0.02500	0.02500	0.00063	0.00250
1.81215	0.03163	0.03162	0.00100	0.00400
2.00000	0.03491	0.03490	0.00122	0.00487
2.02740	0.03538	0.03538	0.00125	0.00500
2.86598	0.05002	0.05000	0.00250	0.00998
3.00000	0.05236	0.05234	0.00274	0.01093
4.00000	0.06981	0.06976	0.00487	0.01937
4.05481	0.07077	0.07071	0.00500	0.01990
4.06505	0.07095	0.07089	0.00503	0.02000
4.30122	0.07507	0.07500	0.00563	0.02237
5.00000	0.08727	0.08716	0.00760	0.03015
5.73917	0.10017	0.10000	0.01000	0.03960
6.00000	0.10472	0.10453	0.01093	0.04323
6.46048	0.11276	0.11252	0.01266	0.05000
7.00000	0.12217	0.12187	0.01485	0.05853
7.03493	0.12278	0.12247	0.01500	0.05910
7.18076	0.12533	0.12500	0.01563	0.06152
7.60180	0.13268	0.13229	0.01750	0.06878
8.00000	0.13963	0.13917	0.01937	0.07598
8.13010	0.14190	0.14142	0.02000	0.07840
8.62693	0.15057	0.15000	0.02250	0.08798
9.00000	0.15708	0.15643	0.02447	0.09549
9.21747	0.16088	0.16018	0.02566	0.10000
9.97422	0.17408	0.17321	0.03000	0.11640
10.00000	0.17453	0.17365	0.03015	0.11698
10.07866	0.17591	0.17500	0.03063	0.11875
11.00000	0.19199	0.19081	0.03641	0.14033
11.53696	0.20136	0.20000	0.04000	0.15360
13.28253	0.23182	0.22975	0.05279	0.20000

Apology

- Apology to non-experts
- Apology to experts

- Θ_{13} limits are expressed several different ways
- Several factors of 2 confusion are possible

$U_{e3}^2 = \sin^2\theta_{13} \sim ½ \sin^2\theta_{\mu e} \sim 1/4 \sin^2 2\theta_{13}$

θ_{13} (degrees)	θ_{13} (radians)	$\sin(\theta_{13})$	$\sin^2(\theta_{13})$	$\sin^2(2\theta_{13})$
0.00000	0.00000	0.00000	0.00000	0.00000
1.00000	0.01745	0.01745	0.00030	0.00122
1.43254	0.02500	0.02500	0.00063	0.00250
1.81215	0.03163	0.03162	0.00100	0.00400
2.00000	0.03491	0.03490	0.00122	0.00487
2.02740	0.03538	0.03538	0.00125	0.00500
2.86598	0.05002	0.05000	0.00250	0.00998
3.00000	0.05236	0.05234	0.00274	0.01093
4.00000	0.06981	0.06976	0.00487	0.01937
4.05481	0.07077	0.07071	0.00500	0.01990
4.06505	0.07095	0.07089	0.00503	0.02000
4.30122	0.07507	0.07500	0.00563	0.02237
5.00000	0.08727	0.08716	0.00760	0.03015
5.73917	0.10017	0.10000	0.01000	0.03960
6.00000	0.10472	0.10453	0.01093	0.04323
6.46048	0.11276	0.11252	0.01266	0.05000
7.00000	0.12217	0.12187	0.01485	0.05853
7.03493	0.12278	0.12247	0.01500	0.05910
7.18076	0.12533	0.12500	0.01563	0.06152
7.60180	0.13268	0.13229	0.01750	0.06878
8.00000	0.13963	0.13917	0.01937	0.07598
8.13010	0.14190	0.14142	0.02000	0.07840
8.62693	0.15057	0.15000	0.02250	0.08798
9.00000	0.15708	0.15643	0.02447	0.09549
9.21747	0.16088	0.16018	0.02566	0.10000
9.97422	0.17408	0.17321	0.03000	0.11640
10.00000	0.17453	0.17365	0.03015	0.11698
10.07866	0.17591	0.17500	0.03063	0.11875
11.00000	0.19199	0.19081	0.03641	0.14033
11.53696	0.20136	0.20000	0.04000	0.15360
13.28253	0.23182	0.22975	0.05279	0.20000

CP violation ($\nu_\mu \rightarrow \nu_e$)
[Long-Baseline Accelerator]

- $P(\nu_\mu \rightarrow \nu_e) = P_1 + P_2 + P_3 + P_4$ {in vacuum}
  - $P_1 = \sin^2(\theta_{23}) \sin^2(2\underline{\theta_{13}}) \sin^2(1.27\ \Delta m_{31}^2\ L/E)$
  - $P_2 = \cos^2(\theta_{23}) \sin^2(2\theta_{12}) \sin^2(1.27\ \Delta m_{21}^2\ L/E)$ often negligible
  - $P_3 = -/+\ J \sin(\delta) \sin(1.27\ \Delta m_{31}^2\ L/E)$
  - $P_4 = J \cos(\delta) \cos(1.27\ \Delta m_{31}^2\ L/E)$

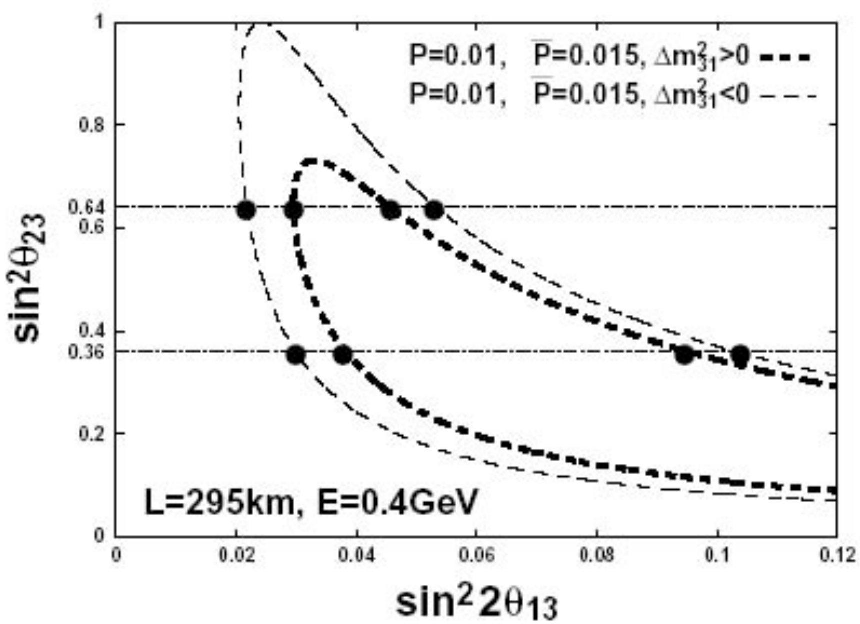
  where $J = \cos(\theta_{13}) \sin(2\theta_{12}) \sin(2\underline{\theta_{13}}) \sin(2\theta_{23}) \times$

  $\sin(1.27\ \Delta m_{31}^2\ L/E) \sin(1.27\ \Delta m_{21}^2\ L/E)$

$\overline{P}$

Correlations & degeneracies

- One perfect measurement of $P(\nu_\mu \rightarrow \nu_e)$ and $P(\overline{\nu}_\mu \rightarrow \overline{\nu}_e)$
  - ➦ 8 possible values of $\sin^2(2\theta_{13})$



Reactor/Accelerator approaches to θ_{13}

Reactor Features

- Best current limit
- Needs careful control of systematics
- Subtract two numbers
- Not sensitive to CP, matter
- Required detector sizes ~ 50 tons

Accelerator Features

- Some long-baseline beams already (almost) exist
- Signal/Background improves off-axis
- Sensitive to CP, matter →ambiguities/degeneracies
- Required detector sizes ~ 50 kilotons

If there was strong theoretical prejudice for $\theta_{13} = 0$, accelerator CP/matter sensitivity would be less relevant.

Maury Goodman
Argonne National Lab

A personal observation

I started working on Fermilab-Soudan long-baseline in 1988. We had our first Fermilab-induced ν at Soudan 3 weeks ago. Since 1988,

- CHOOZ was proposed, ran and finished
- San Onofre → Palo Verde was proposed, ran, finished
- KamLAND was proposed, ran, & due to its incredible success, had its impact

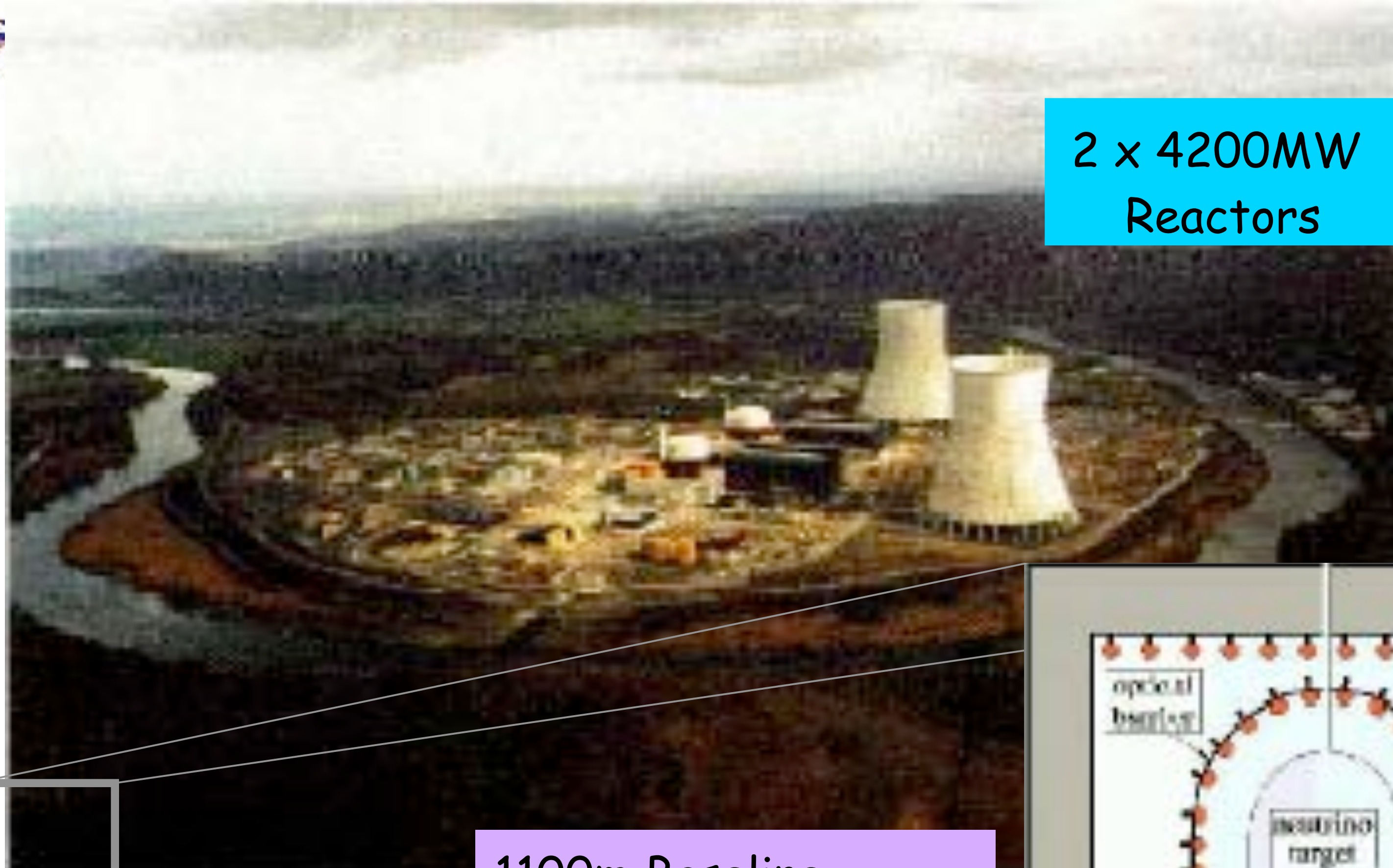
It occurs to me that neutrino physics at a reactor has some advantages w.r.t. physics impact.

Neutrino Oscillation Workshop 2004

CHOOZ

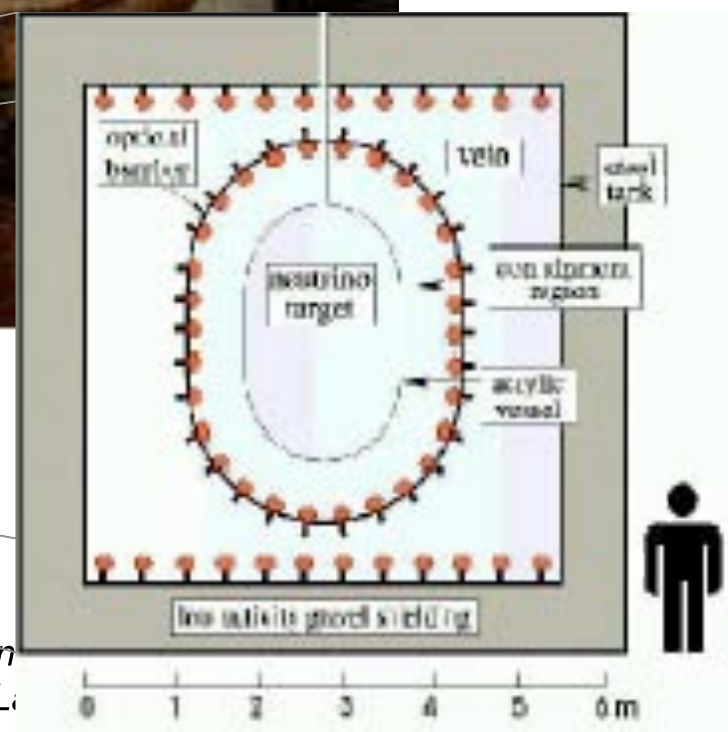
Maury Goodman
Argonne National Lab

Chooz site



2 x 4200MW
Reactors

1100m Baseline
300MWE Overburden



CHOOZ Cf source

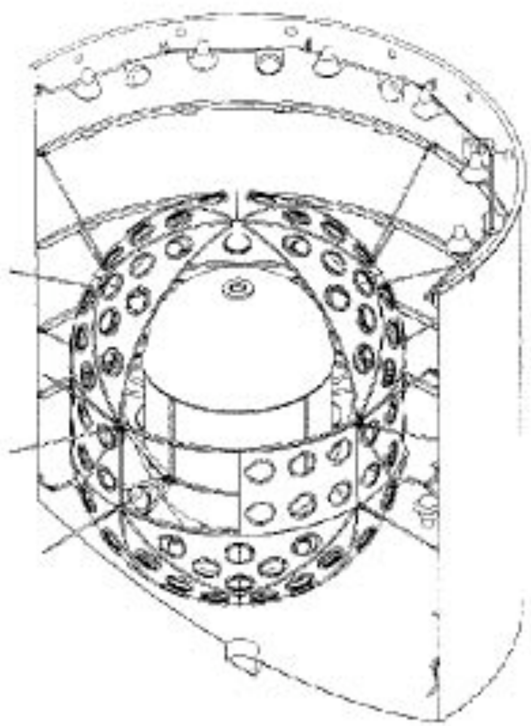


Fig. 13. Mechanical drawing of the detector; the visible holes on the geode are for the PMT housing (from [42]).

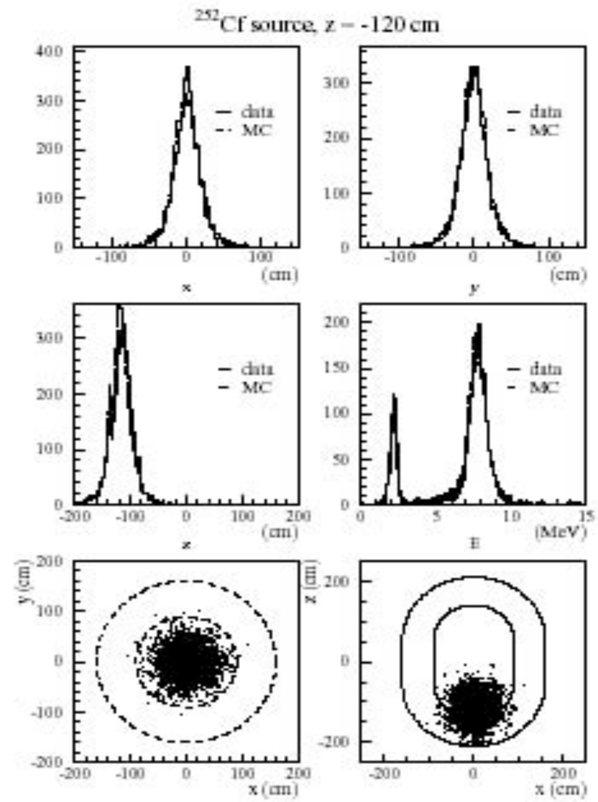


Fig. 32. Distributions of neutron events with the ^{252}Cf source at z = -120 cm. The discontinuity in the z distribution at the vessel surface is visible also in Monte Carlo generated events.

$\bar{\nu}_e$ Signal

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

Neutron/positron coincidence

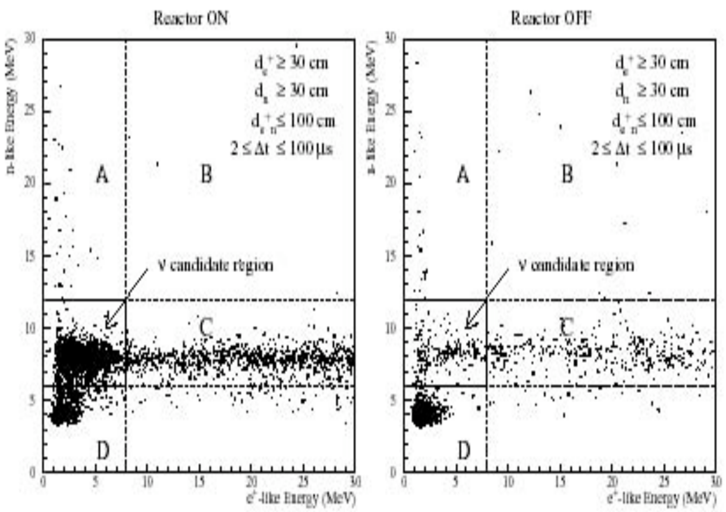


Fig. 37. Neutron versus positron energy for neutrino-like events selected from the preliminary sample by applying the "topological" cuts here indicated.

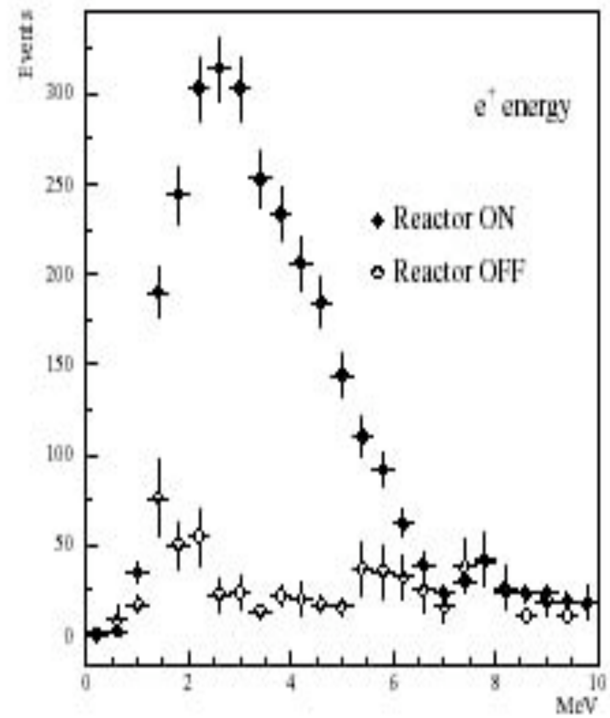


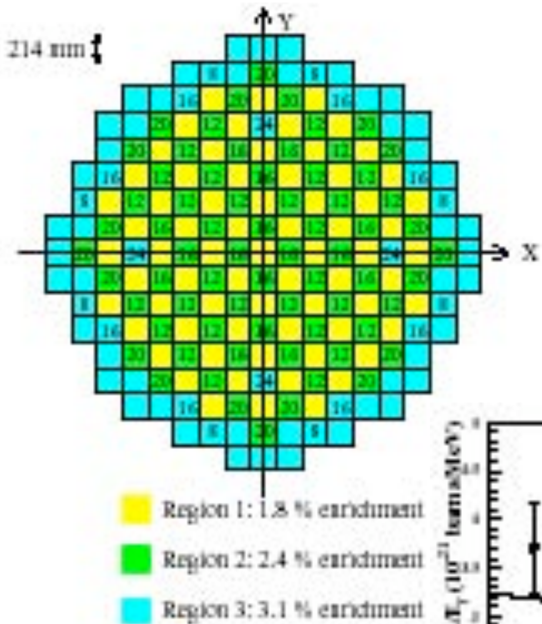
Fig. 46. Experimental positron spectra for reactor-on and reactor-periods after application of all selection criteria. The errors shown are statistical.

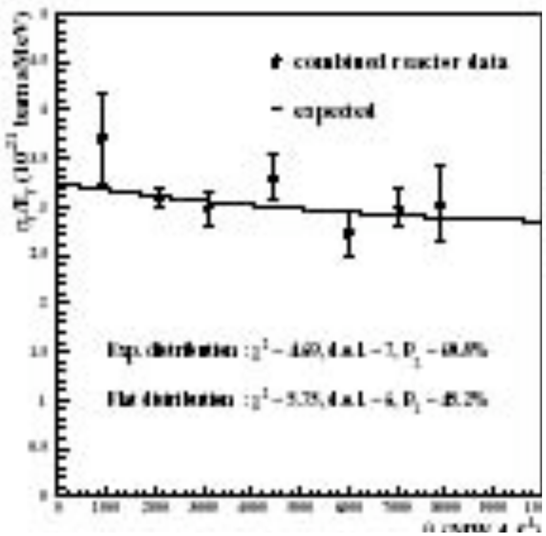
Oscillation signature

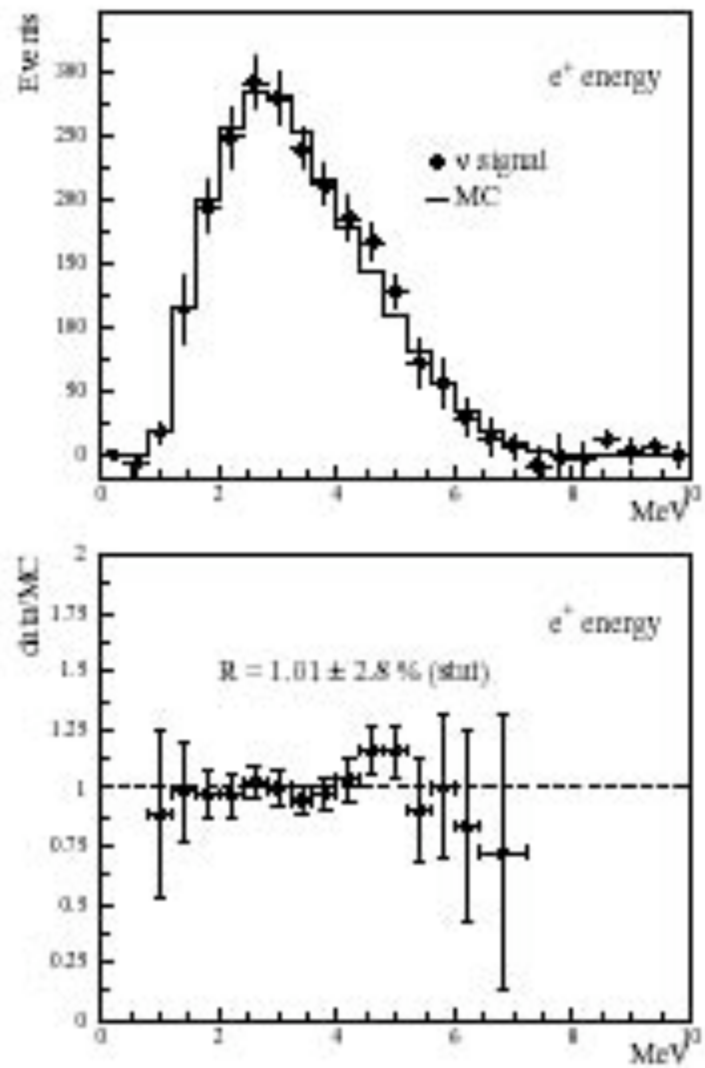
- Less antineutrinos than expected.
- A shape of the energy spectrum indicative of oscillations. (This requires more statistics)

Maury Goodman
Argonne National Lab

Systematics Limited by Reactor Flux





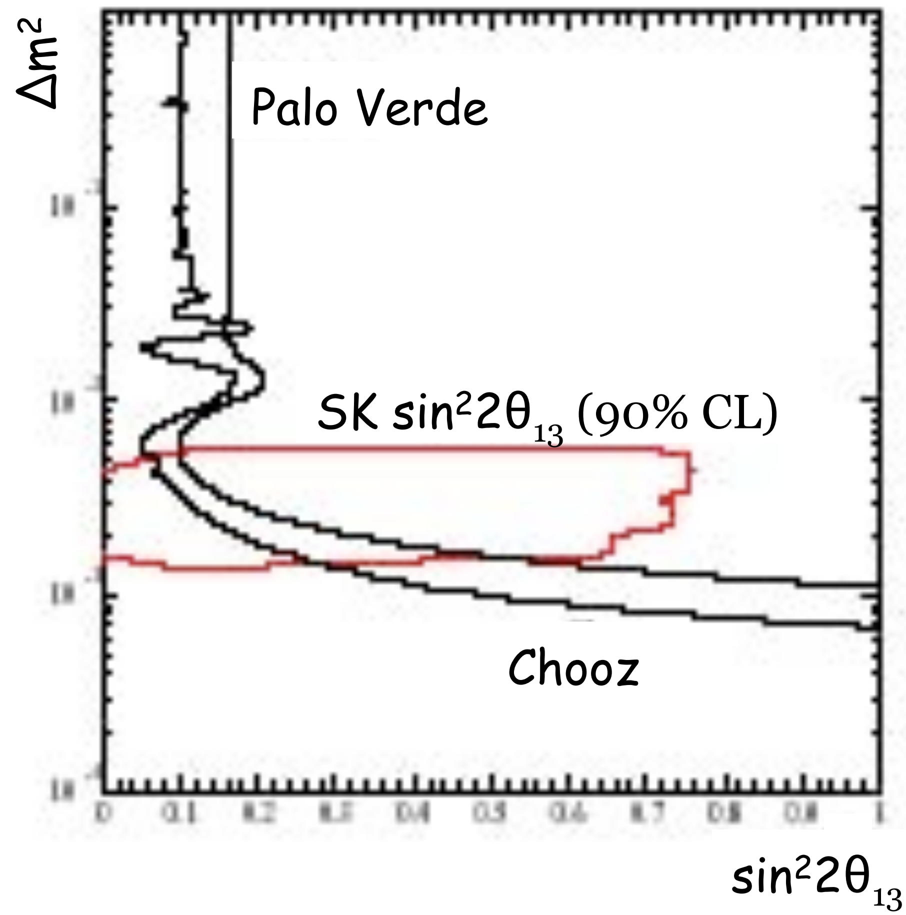


CHOOZ Limits

- $Sin^2 2\theta_{13} < 0.19$

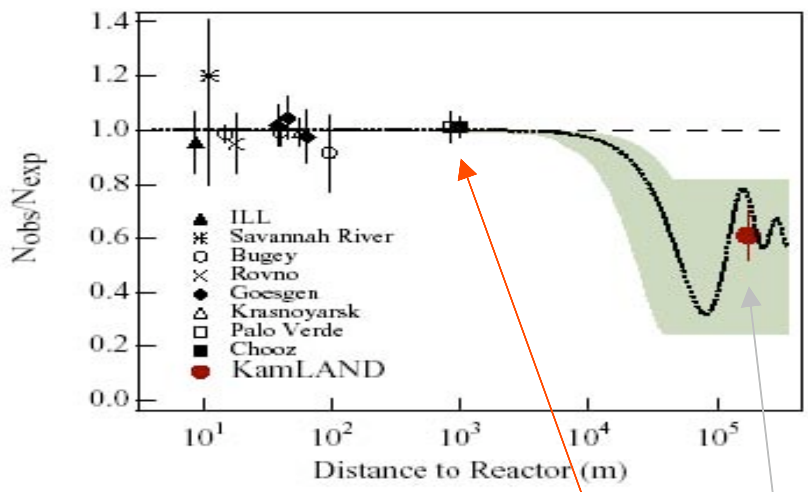
  (at 2.0 10^{-2} eV^2)

- SK and atmospheric give allowed Δm^2
- Result limited by systematics



Maury Goodman
Argonne National Lab

KamLAND



KamLAND sees a 40% deficit/shape at 200km

related to Δm^2_{21}

Search for a 1-5% deficit/shape at ~1 km

related to Δm^2_{31}

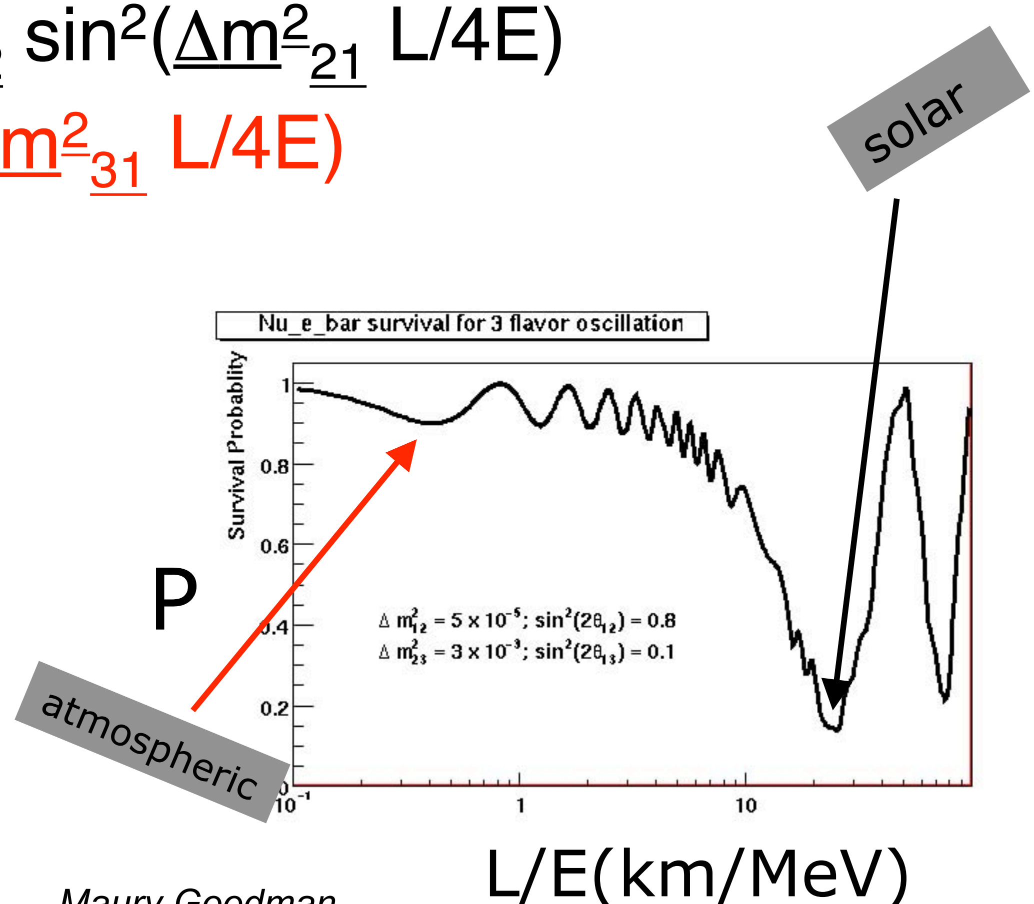
Θ_{13} from reactors?

$P(\nu_e \rightarrow \nu_e) = 1$

$- \cos^4\theta_{13} \sin^2 2\underline{\theta_{12}} \sin^2(\underline{\Delta m^2_{21}} L/4E)$

$- \sin^2 2\theta_{13} \sin2 (\underline{\Delta m^2_{31}} L/4E)$

No CP terms



Maury Goodman
Argonne National Lab

Θ_{13} Initiatives

November 11 2004
Double-CHOOZ

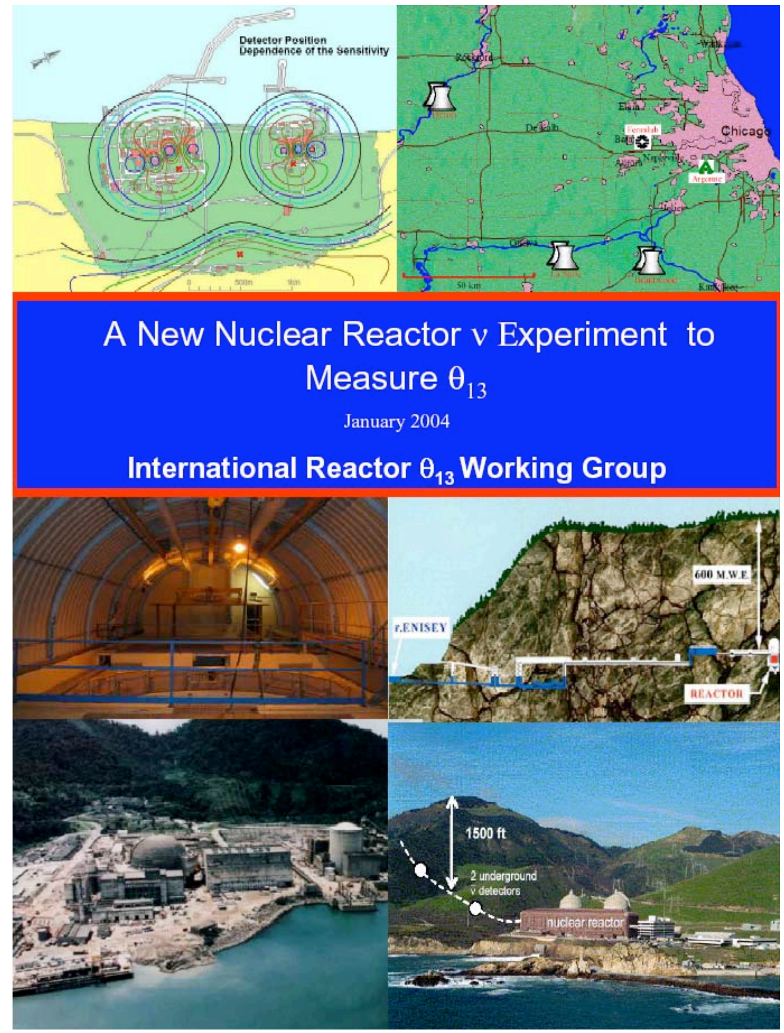
Maury Goodman
Argonne National Lab

Nuclear reactors in the world

Maury Goodman
Argonne National Lab

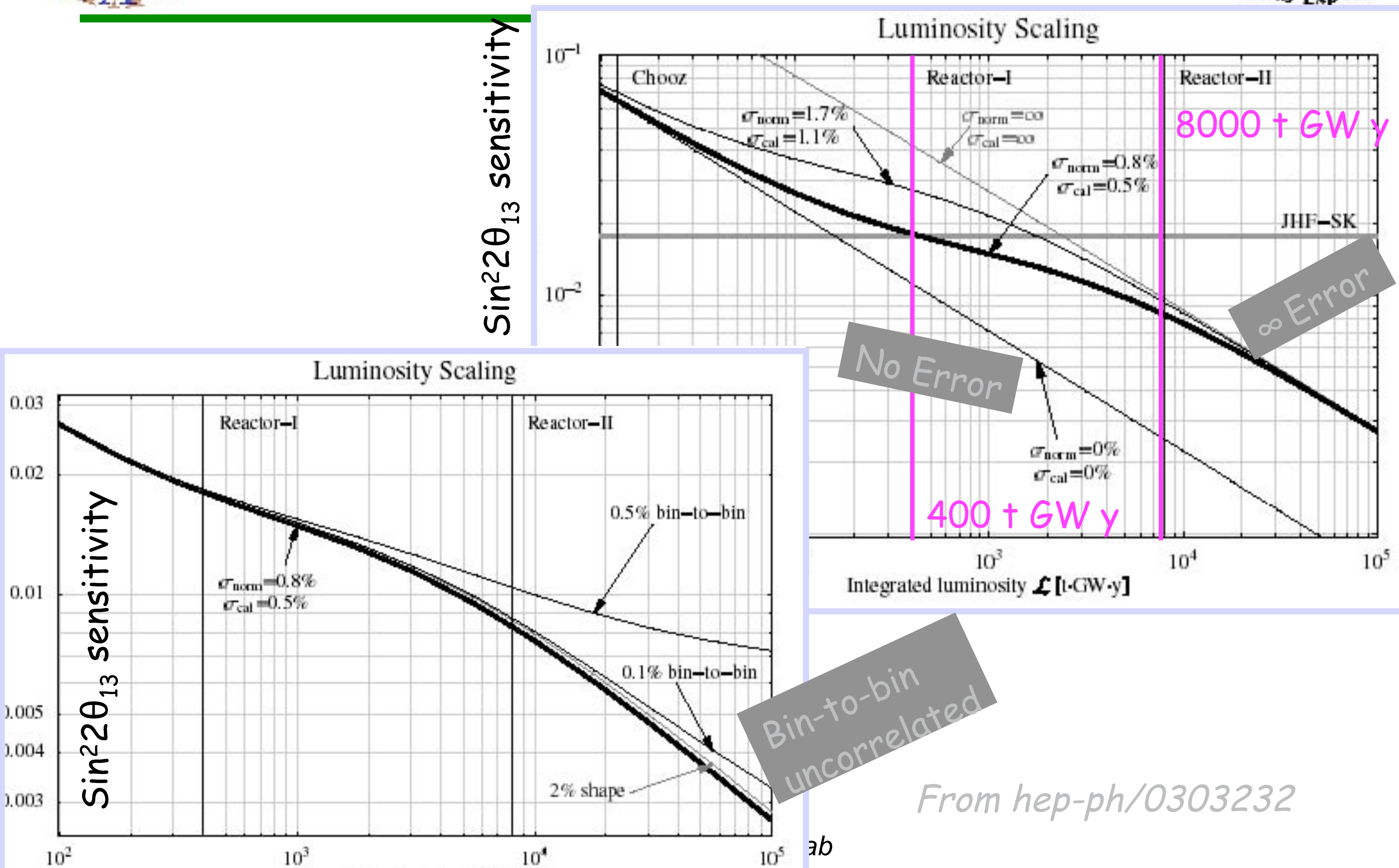
Jan 2004 White Paper

- Instigated by LBL & ANL
- 4 Workshops
  - ➔Alabama 2003
  - ➔Munich 2003
  - ➔Niigata 2004
  - ➔Angra 2005
- 7 Site-specific appendices
- 125 authors from 40 institutions in 9 countries



Maury Goodman
Argonne National Lab

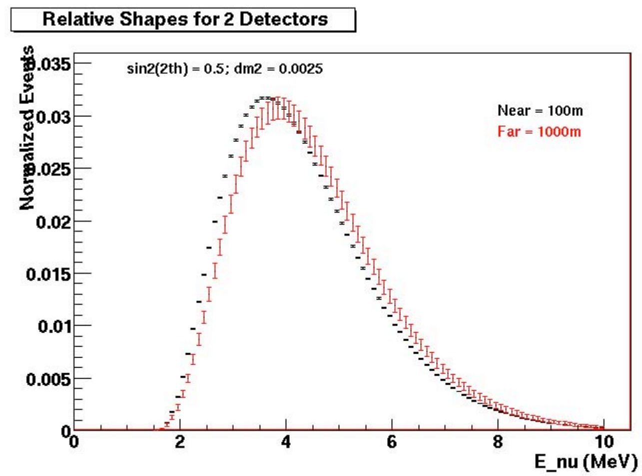
Lindner Group paper



From hep-ph/0303232

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

Optimum Location
with a close near detector

Δm^2	rate	shape
$3\ 10^{-3} eV^2$	1300m	850
$2\ 10^{-3} eV^2$	1700	1050

Maury Goodman
Argonne National Lab

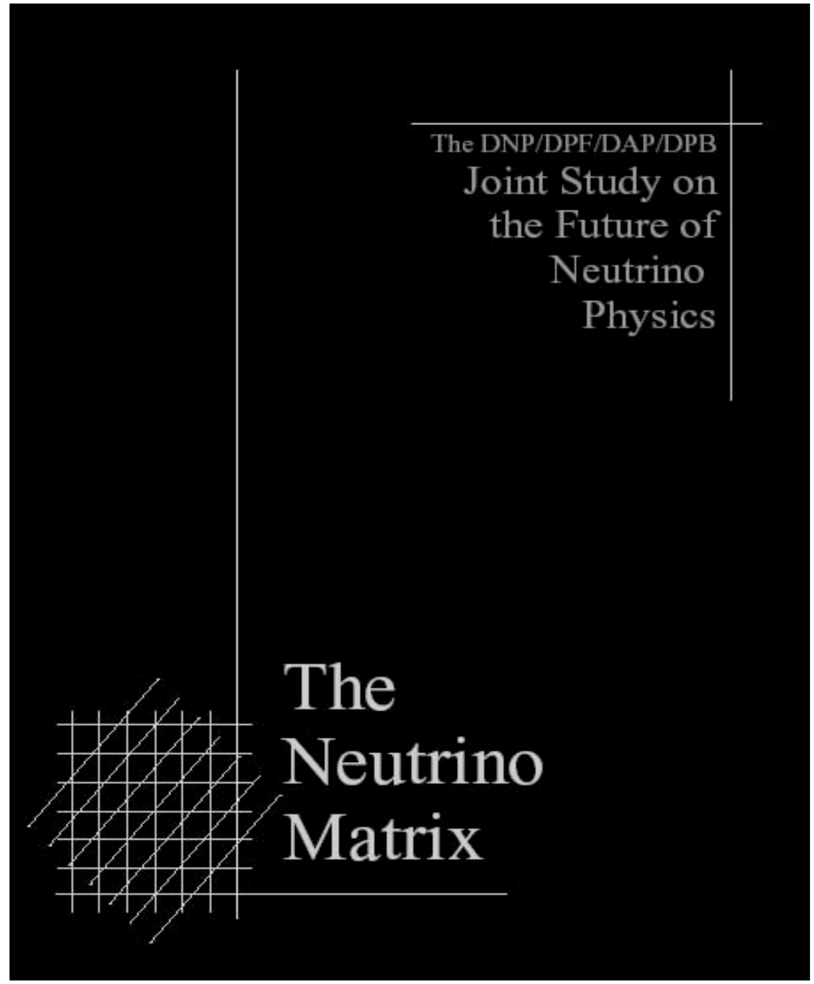
Conclusion of White Paper

- A new experiment can do better than CHOOZ by using two (or more) detectors
- There was not consensus on the how far in precision reactor experiments could be made to address – i.e. the eventual limiting systematic error was not agreed upon(0.03-0.003).
- There is clearly need to address statistical error in another round or two of experiments

Maury Goodman
Argonne National Lab

APS multi-divisional ν study

- One of (two) high priority recommendations is for a concerted program to measure θ_{13} including:
  - ➔ A reactor experiment
  - ➔ An accelerator experiment (with NOνA in mind).
- Report available just today (11/11) at http://www.aps.org/neutrino/



Maury Goodman
Argonne National Lab

After 4 workshops, 6 Reactor possibilities

- Braidwood
- Double Chooz
- Angra

- KASKA
- YoungGwang
- Daya Bay

No
Do

Currently Proposed sites/experiments

Site (proposal)	Power (GW)	Baseline Near/Far (m)	Detector Near/Far(t)	Overburden Near/Far (MWE)
Angra dos Reis (Brazil)	6	300/1500	50/500	200/1700
Braidwood (US)	7	200/1500	130/130	450/450
Double-CHOOZ (France)	7	200/1050	10/10	60/300
Daya Bay (China)	11	300/1500	45/45	200/1000
Diablo Canyon (US)	6.4	400/1800	25/50	100/700
Kashiwazaki (Japan)	24.3	300/1300	8.5/8.5	120/350
Krasnoyarsk (Russia)	3.2	115/1000	46/46	600/600

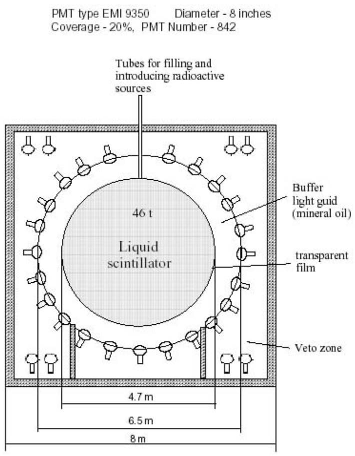
Currently Proposed sites/experiments

Site (proposal)	Power (GW)	Baseline Near/Far (m)	Detector Near/Far(t)	Overburden Near/Far (MWE)
Angra dos Reis (Brazil)	6	300/1500	50/500	200/1700
Braidwood (US)	7	200/1500	130/130	450/450
Double-CHOOZ (France)	7	200/1050	10/10	60/300
Daya Bay (China)	11	300/1500	45/45	200/1000
Diablo Canyon (US)	6.4	400/1800	25/50	100/700
Kashiwazaki (Japan)	24.3	300/1300	8.5/8.5	120/350
Krasnoyarsk (Russia)	3.2	115/1000	46/46	600/600

possibilities

Maury Goodman
Argonne National Lab

KR2DET



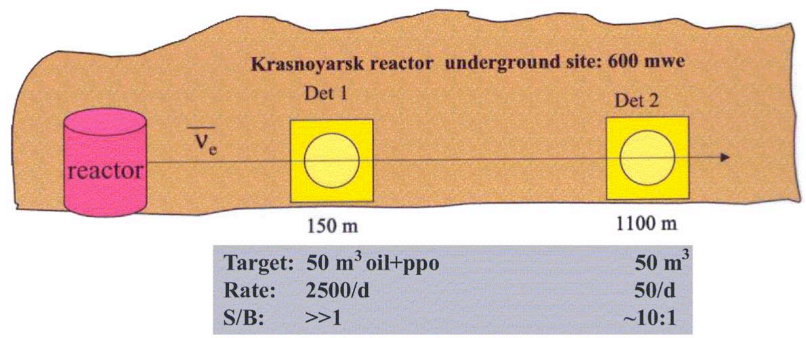
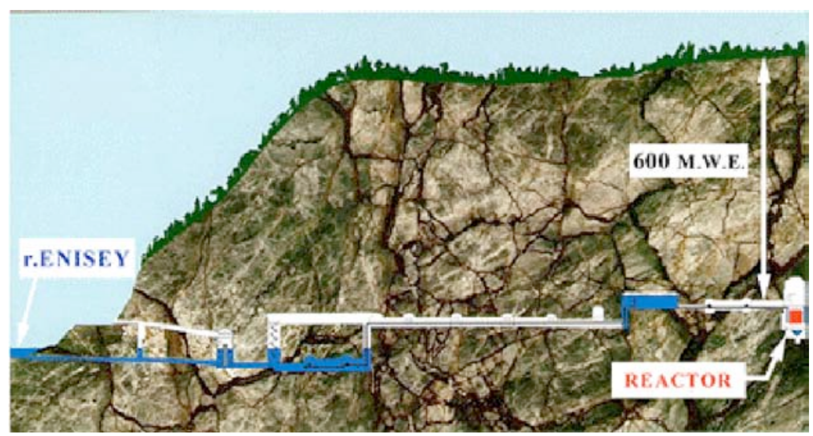


Table 1:

Parameter	Distance, m	Target, mass, ton	$N(e^+,n)$, day^{-1}	$N(e^+,n)$, year^{-1*}	Backgr., day^{-1} correl.	accid.**
Far detector	1000	46	55	$16.5 \cdot 10^3$	5	~0.3
Near detector	115	46	4200	$12.5 \cdot 10^5$	5	~0.3

* 300 days/year at full power.
** due to internal radioactivity of the detector materials only.

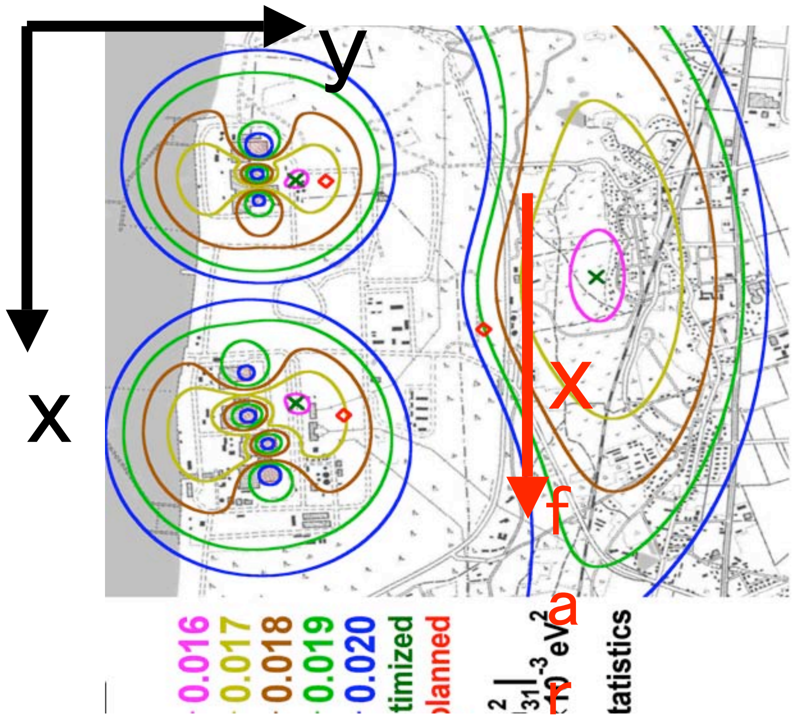


Diablo Canyon

- Geological Evaluation and tunnel cost estimate

Maury Goodman
Argonne National Lab

KASKA



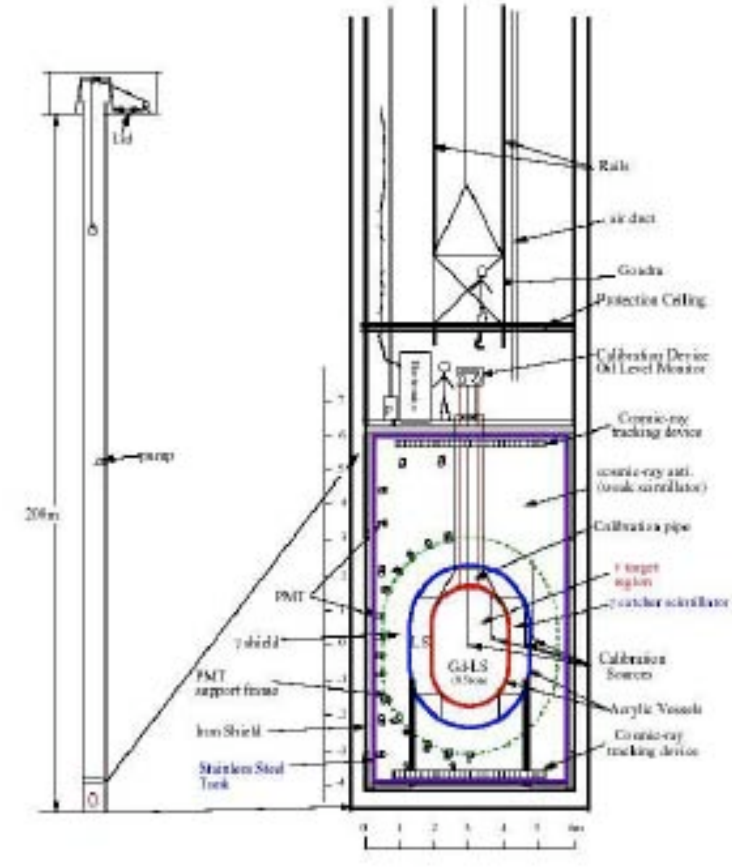


Figure [illegible]: Schematic view of the detector.

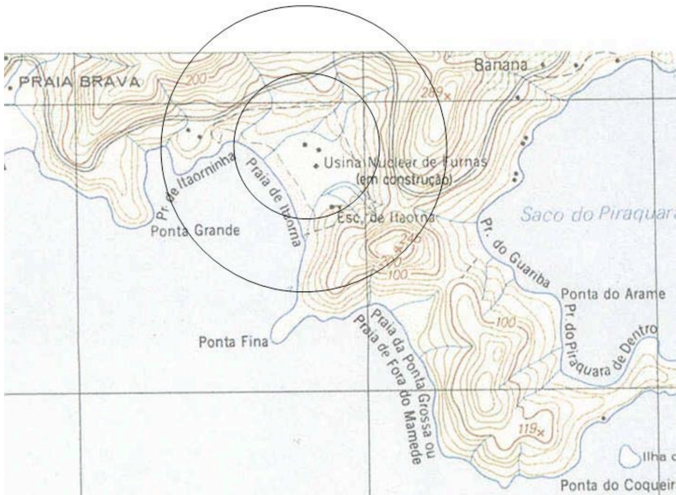
Kashiwazaki-Kariwa Nuclear Complex
7 reactors on the west coast of Japan

Maury Goodman
Argonne National Lab

Daya Bay

Far site:
D_{DB}: 2200 m
D_{LA}: 1800 m
Overburden: ~1200 m.w.e.
Detector: 4 x 10 ton
Ling Ao Near:
D: 450 m
Overburden: ~275 m.w.e.
Detector: 2 x 10 ton
Ling Dong NPP
(under const.)
Daya Bay Near:
D: 300 m
Overburden: ~250 m.w.e.
Detector: 2 x 10 ton
Ling Ao
NPP
Daya Bay
NPP

ANGRA



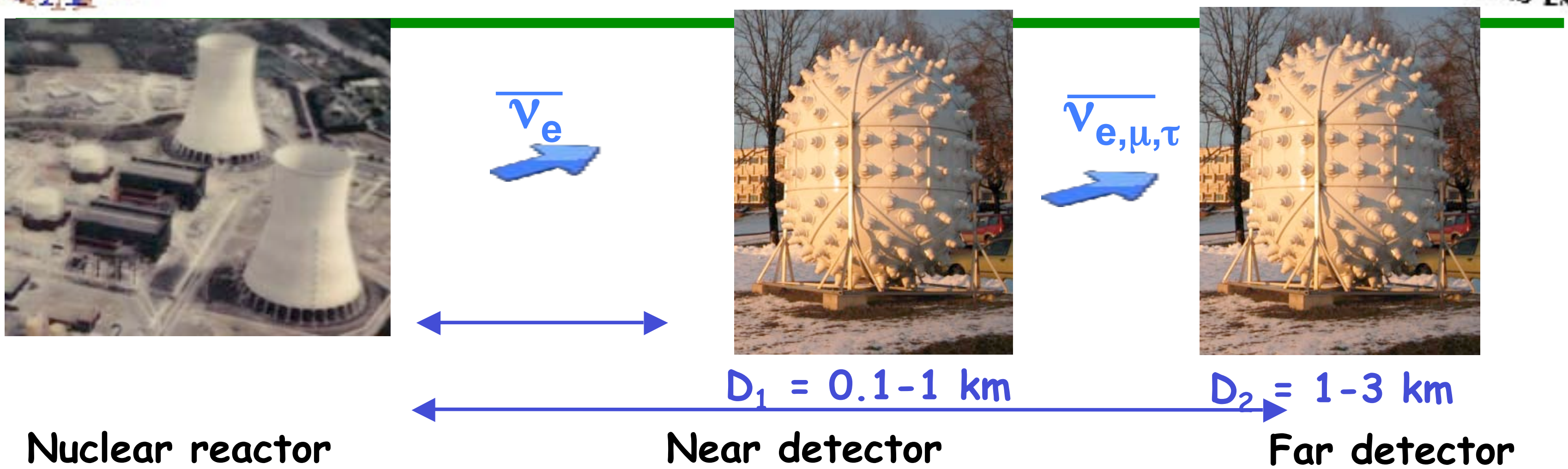
November 11 2004
Double-CHOOZ

Maury Goodman
Argonne National Lab

Double-CHOOZ

Maury Goodman
Argonne National Lab

One nuclear plant & two detectors

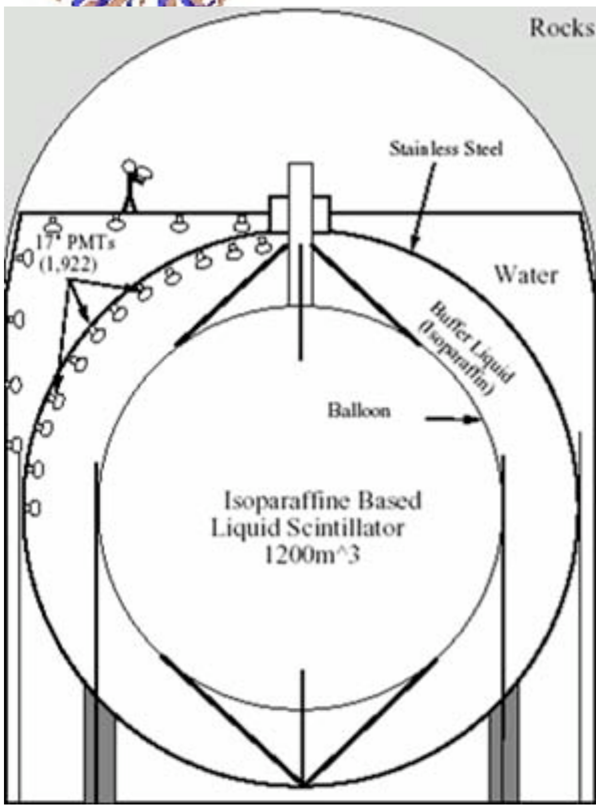


- ✓ Isotropic ν_e flux (uranium & plutonium fission fragments)
- ✓ Detection tag : ν_e + p → e^+ + n, <E>~ 4 MeV, Threshold ~1.8 MeV
- ✓ Disappearance experiment: rate suppression+shape distortion between 2 detectors
- ✓ 2 IDENTICAL detectors
  - o Minimise the uncertainties on reactor flux & spectrum (2 % in CHOOZ)
  - o Cancel cross section uncertainties
  - o Challenge: relative normalisation between the two detectors < 1% !

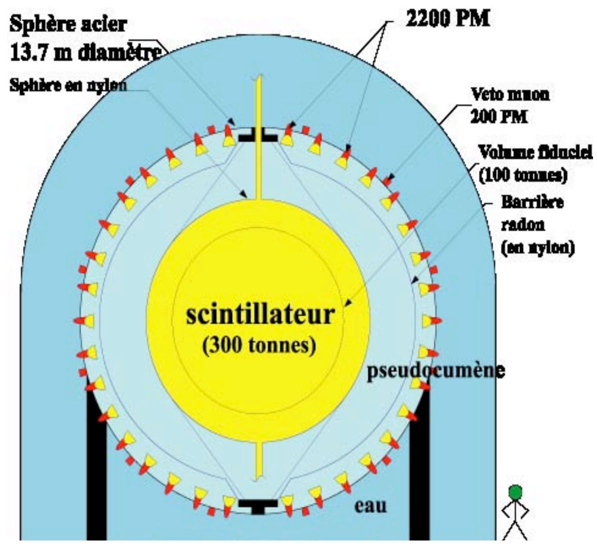
Maury Goodman
Argonne National Lab

Detector size scale

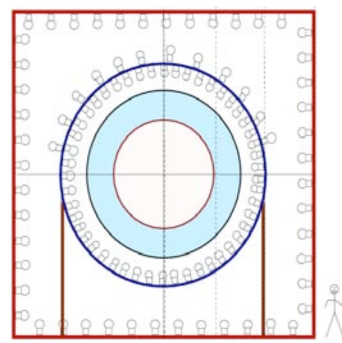
X 2



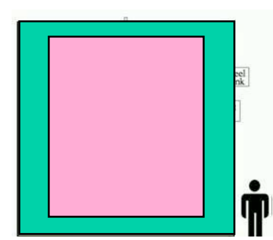
KamLAND
1000 t



Borexino
300 t



Reactor/θ_{13} Example ~20 t



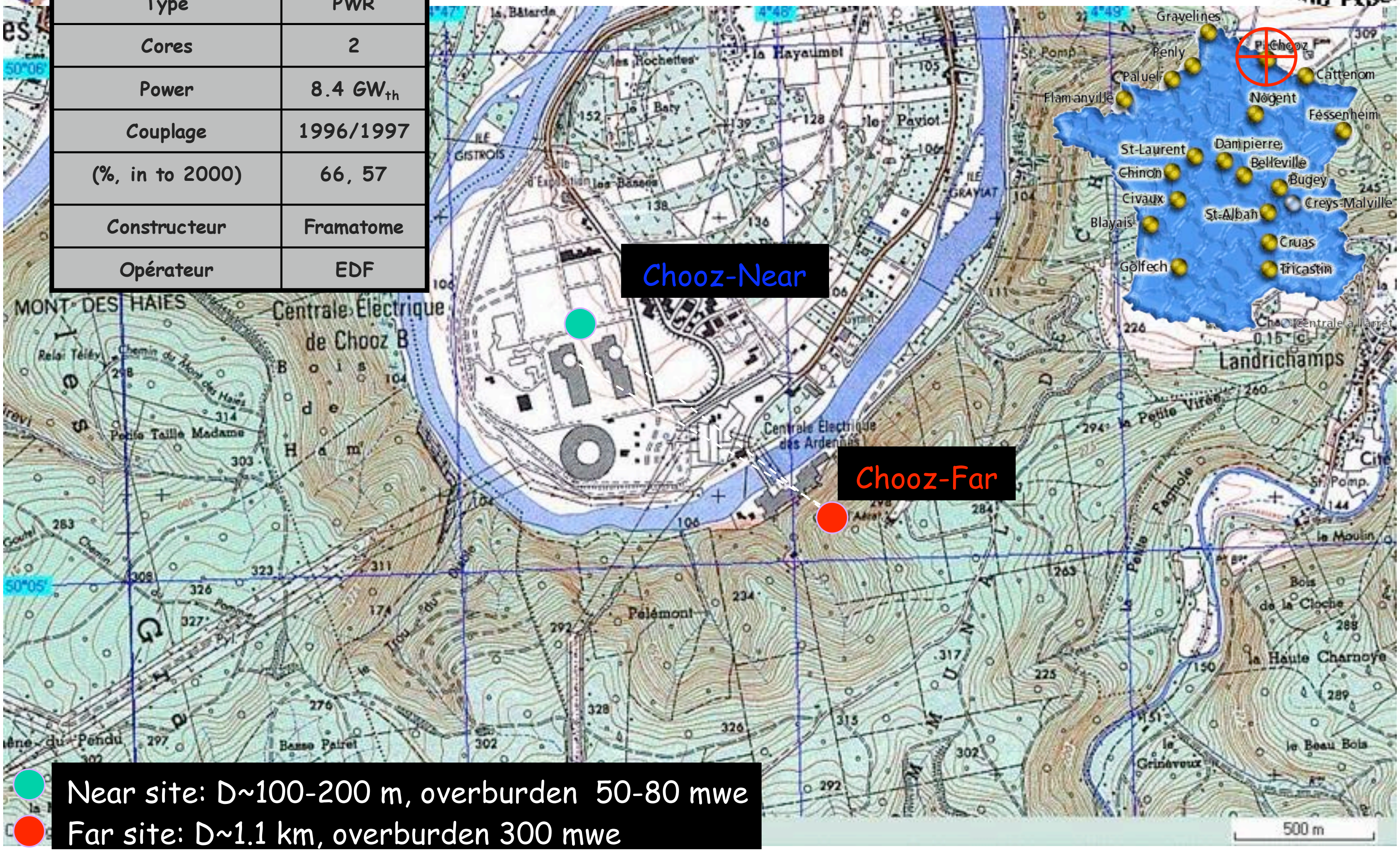
Double CHOOZ & KASKA (10 tons)

Angra, Daya-Bay, Braidwood

Maury Goodman
Argonne National Lab

Double-Chooz (France)

Type	PWR
Cores	2
Power	8.4 GW_{th}
Couplage	1996/1997
(%, in to 2000)	66, 57
Constructeur	Framatome
Opérateur	EDF



Near site: D~100-200 m, overburden 50-80 mwe
Far site: D~1.1 km, overburden 300 mwe

November 11 2004
Double-CHOOZ

Maury Goodman
Argonne National Lab

Far site

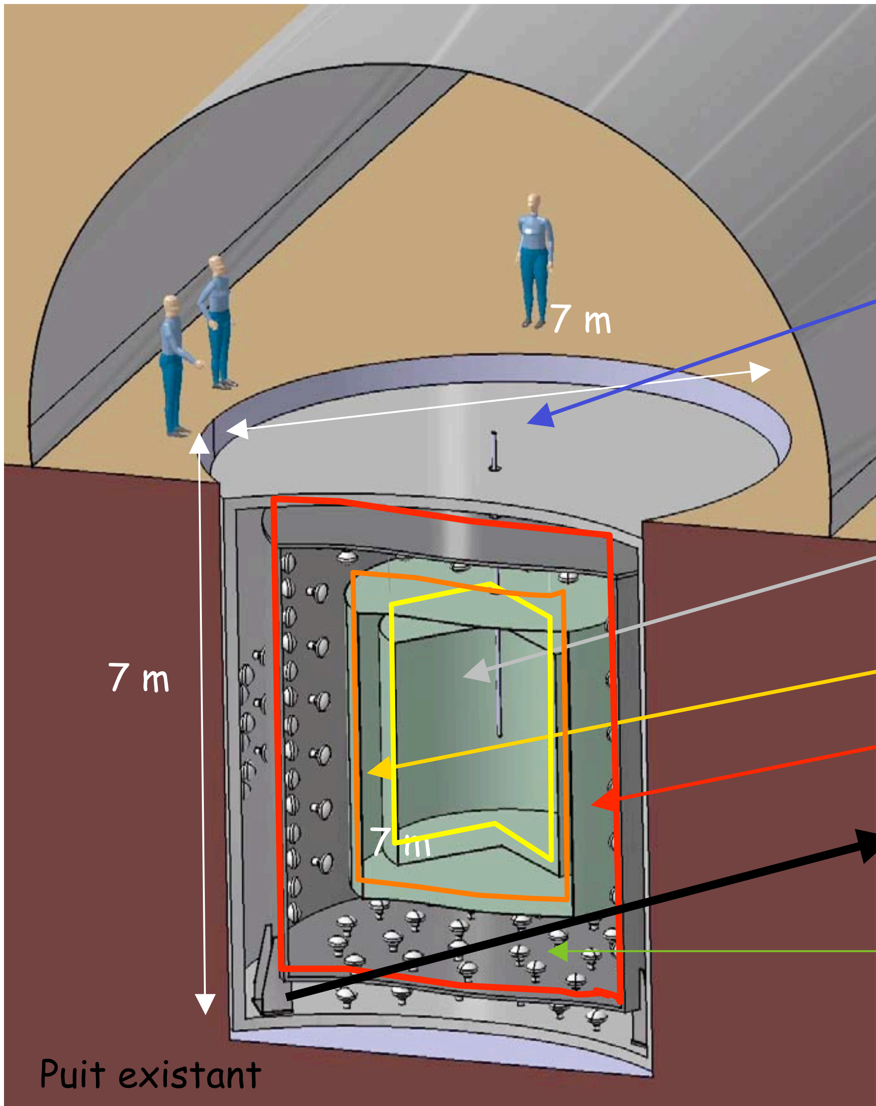
- Access through the access tunnel allowed pieces of diameter <u>3.6 m maximum</u>

Crane

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

No space for storage

Double-CHOOZ (far) Detector



Aim : to take data in 2008 with 2 detectors @ Chooz

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

Target- Gd loaded scintillatopr

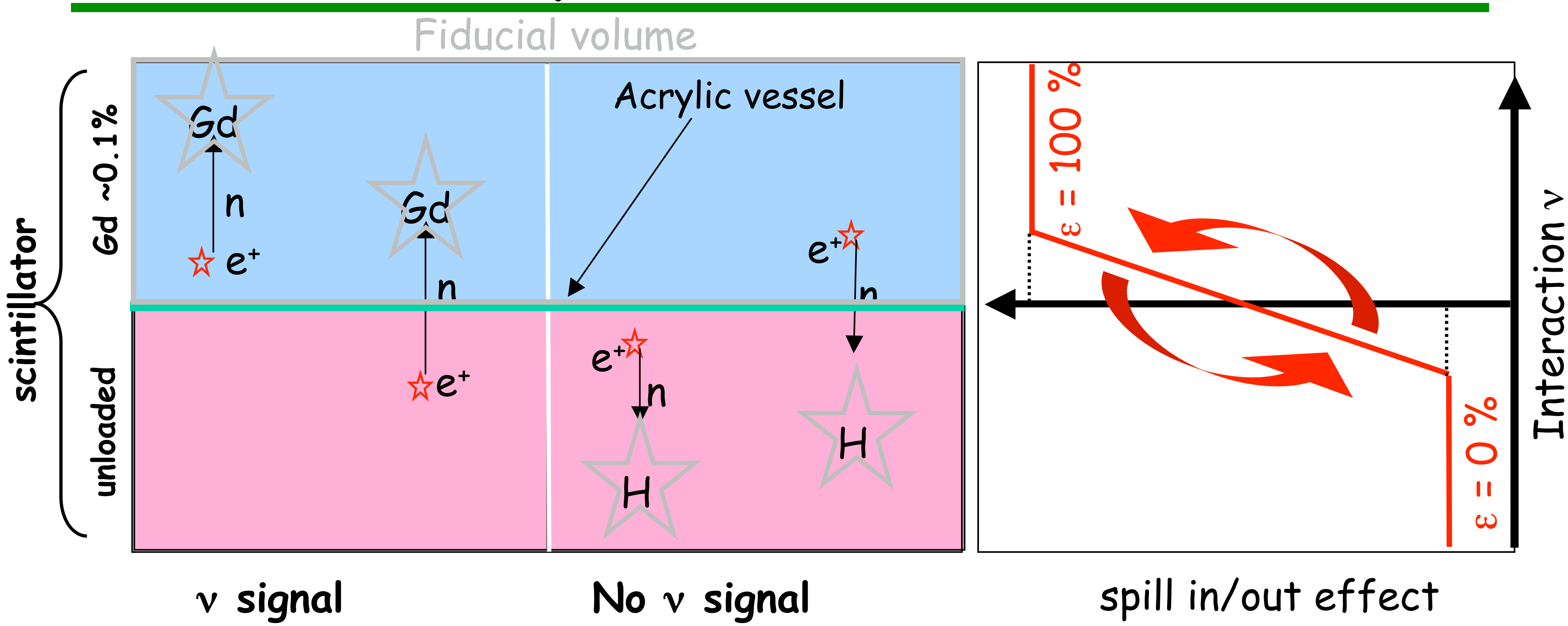
Gamma catcher: scintillator with no Gd

BUFFER Mineral Oil with no scintillator

Optically separated inner veto to tag muons

Modular Frame to support photomultipliers

Improvement with γ catcher



A ~1% irreducible systematic error from the spill in/out effect

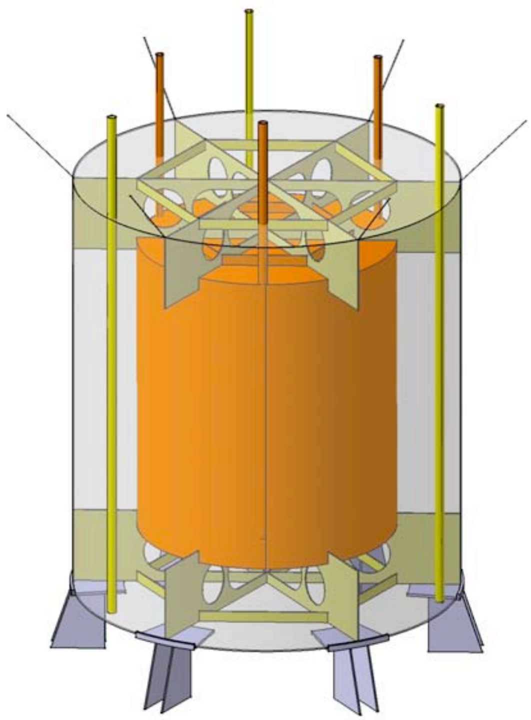
Boundary effect ➔ 2 identical inner vessels

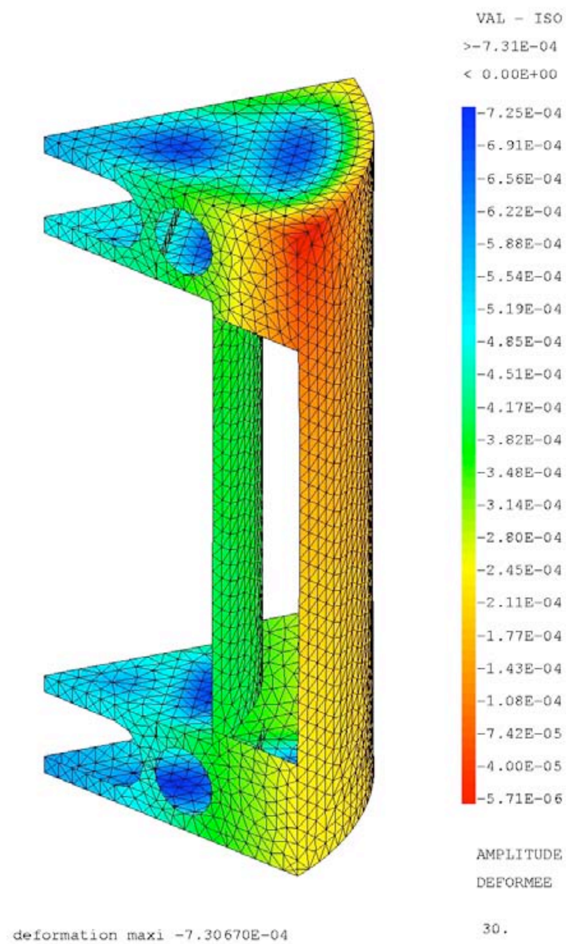
Threshold can be lowered from CHOOZ without a fiducial volume cut.

Maury Goodman
Argonne National Lab

Acrylic Vessel Design

3.6 m (d) x 4 m (h)

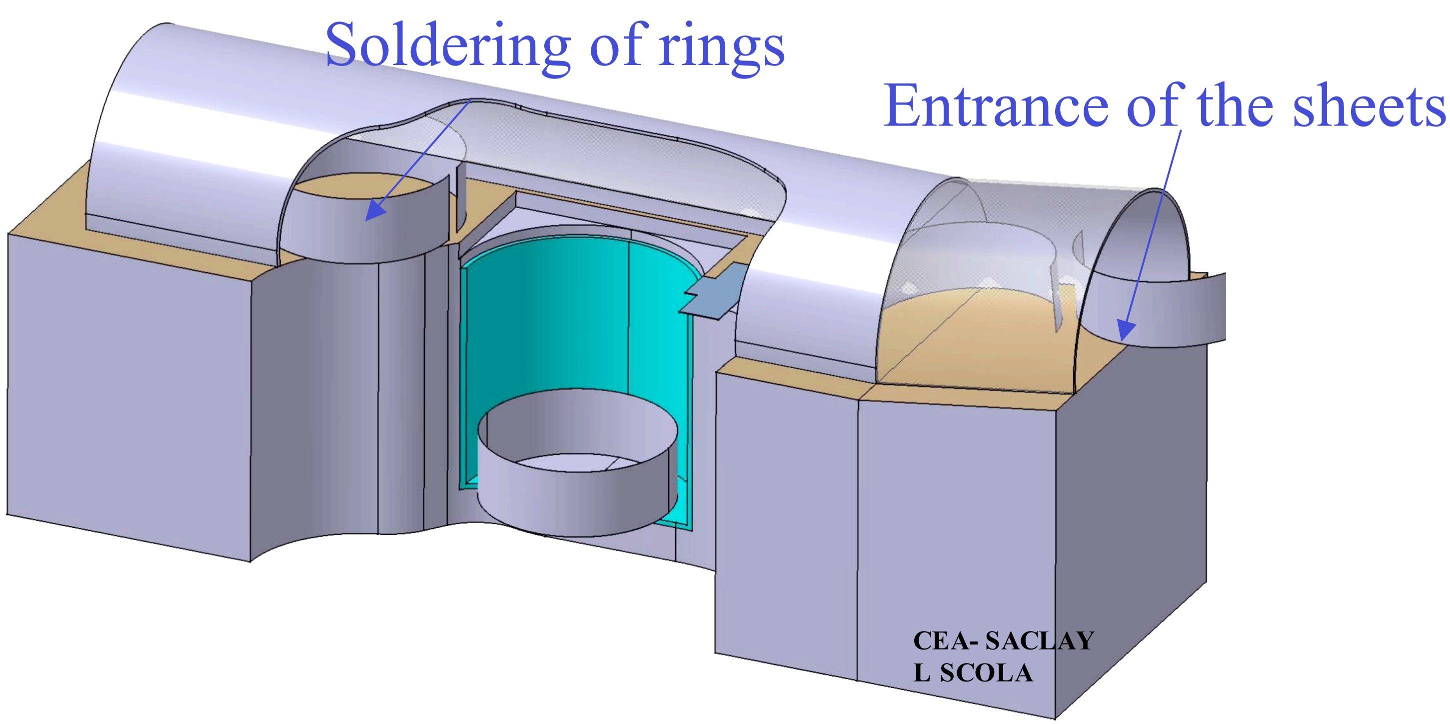




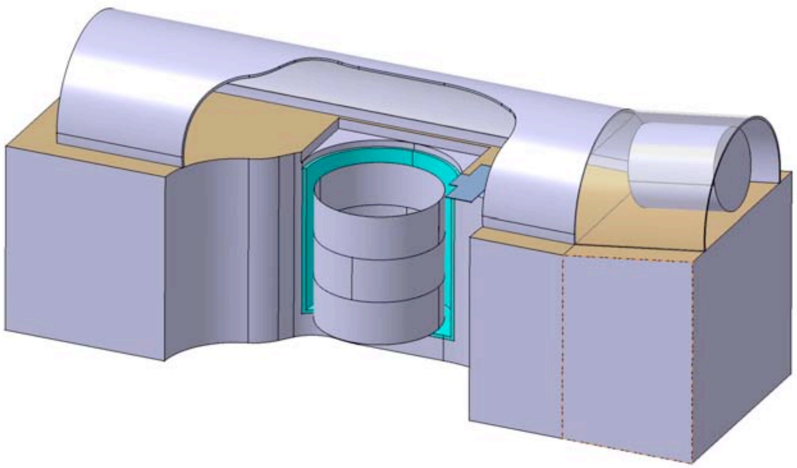
Maury Goodman
Argonne National Lab

Assembly

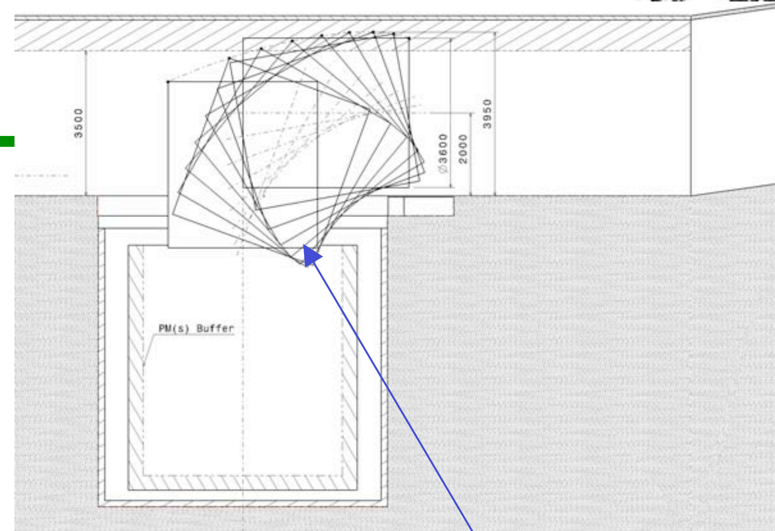
- **Assembly of the buffer vessel**
- Soldering between stainless steel sheets would be done on site



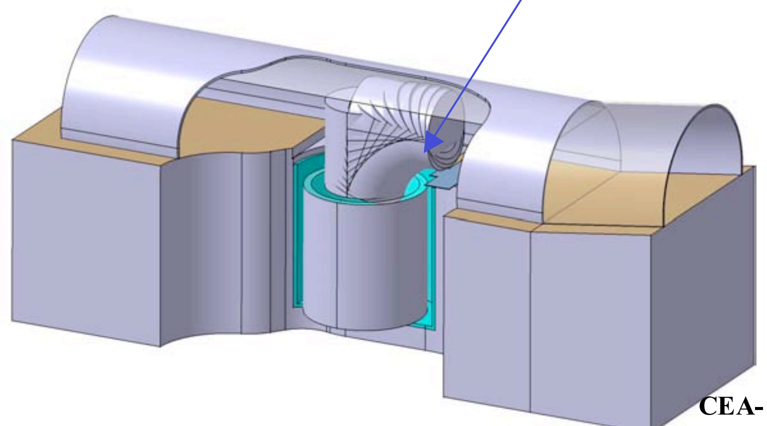
Acrylic assembly



Double acrylics vessel throught the far lab. tunnel



Specific facilities have to be developed for this step



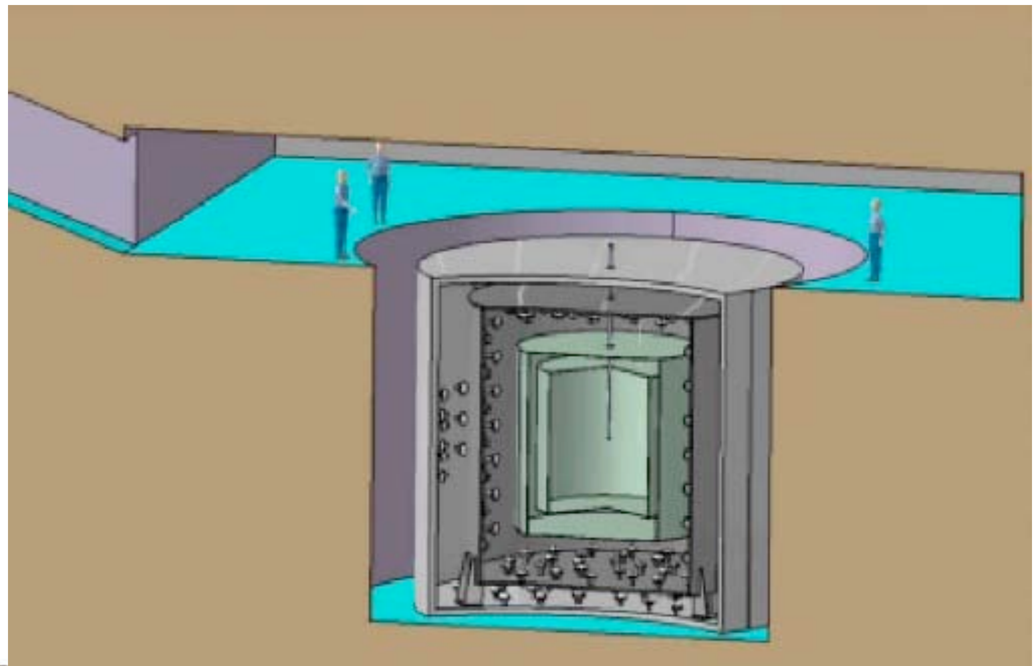
CEA- SACLAY
L SCOLA

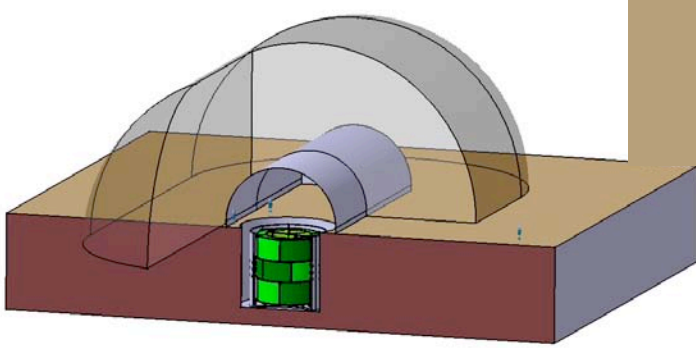
7 & 8 october 2004 accessibility tests

Successful !!

Near lab conceptual design

- Identical detector
- Except for additional outer veto
- Possibly larger inner veto





Maury Goodman
Argonne National Lab

Backgrounds

- Near detector overburden is chosen to keep signal/background above 100
- Largest background is fast neutrons
- Largest uncertainty in background comes from spallation of Li9 & He8

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.

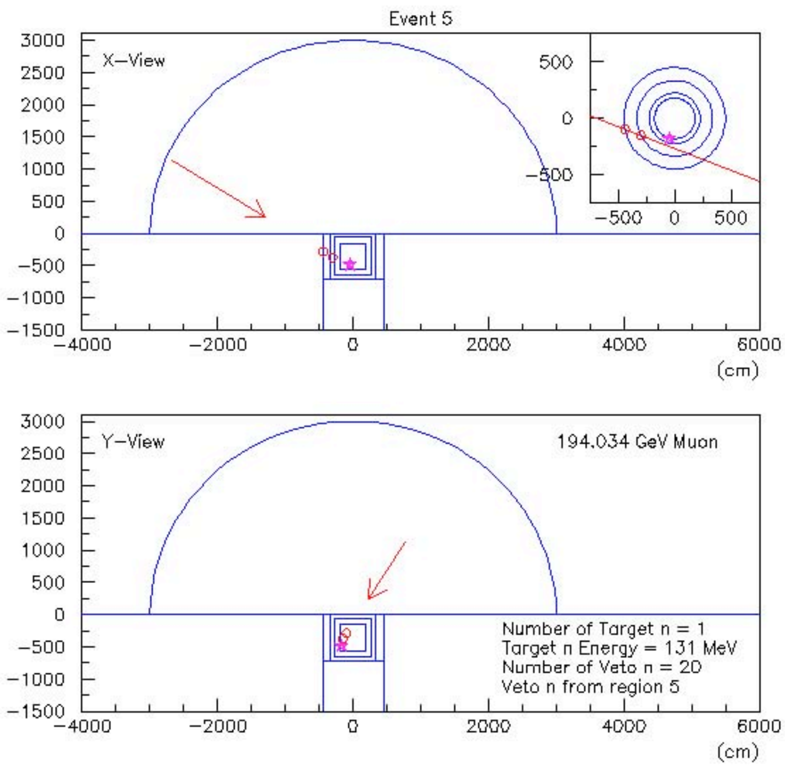
Near site

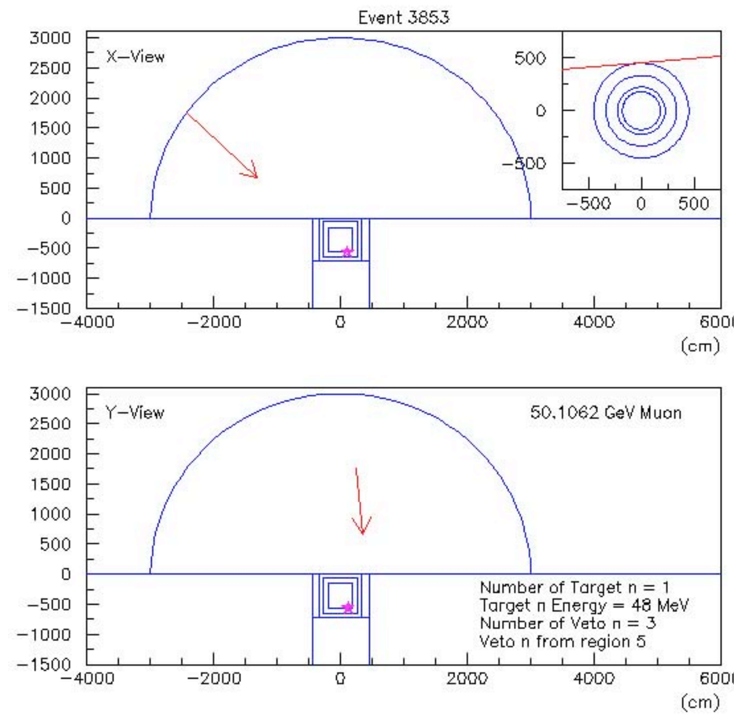
November 11 2004
Double-CHOOZ

Maury Goodman
Argonne National Lab

Veto simulation examples

☑ ☒



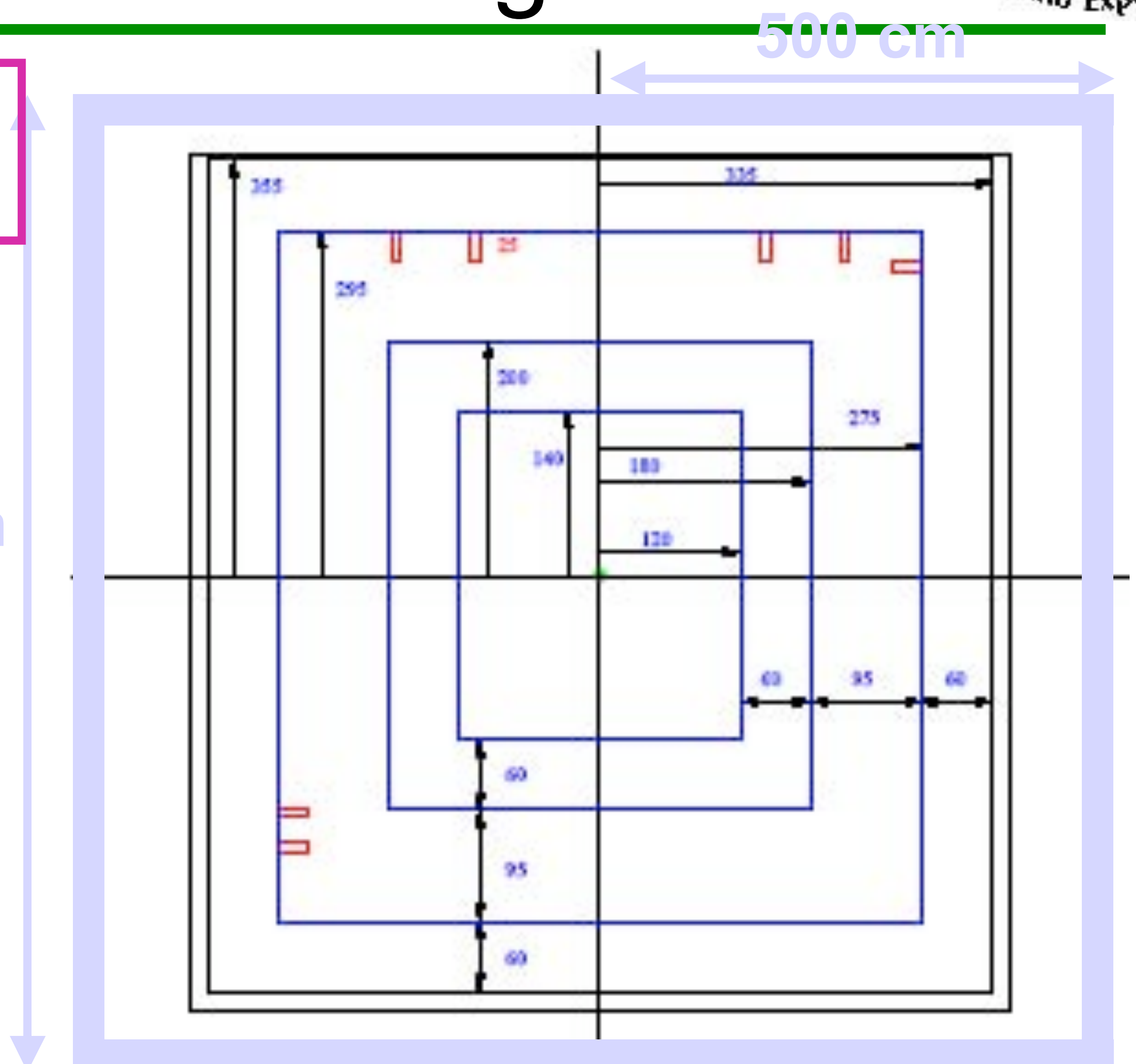


Maury Goodman
Argonne National Lab

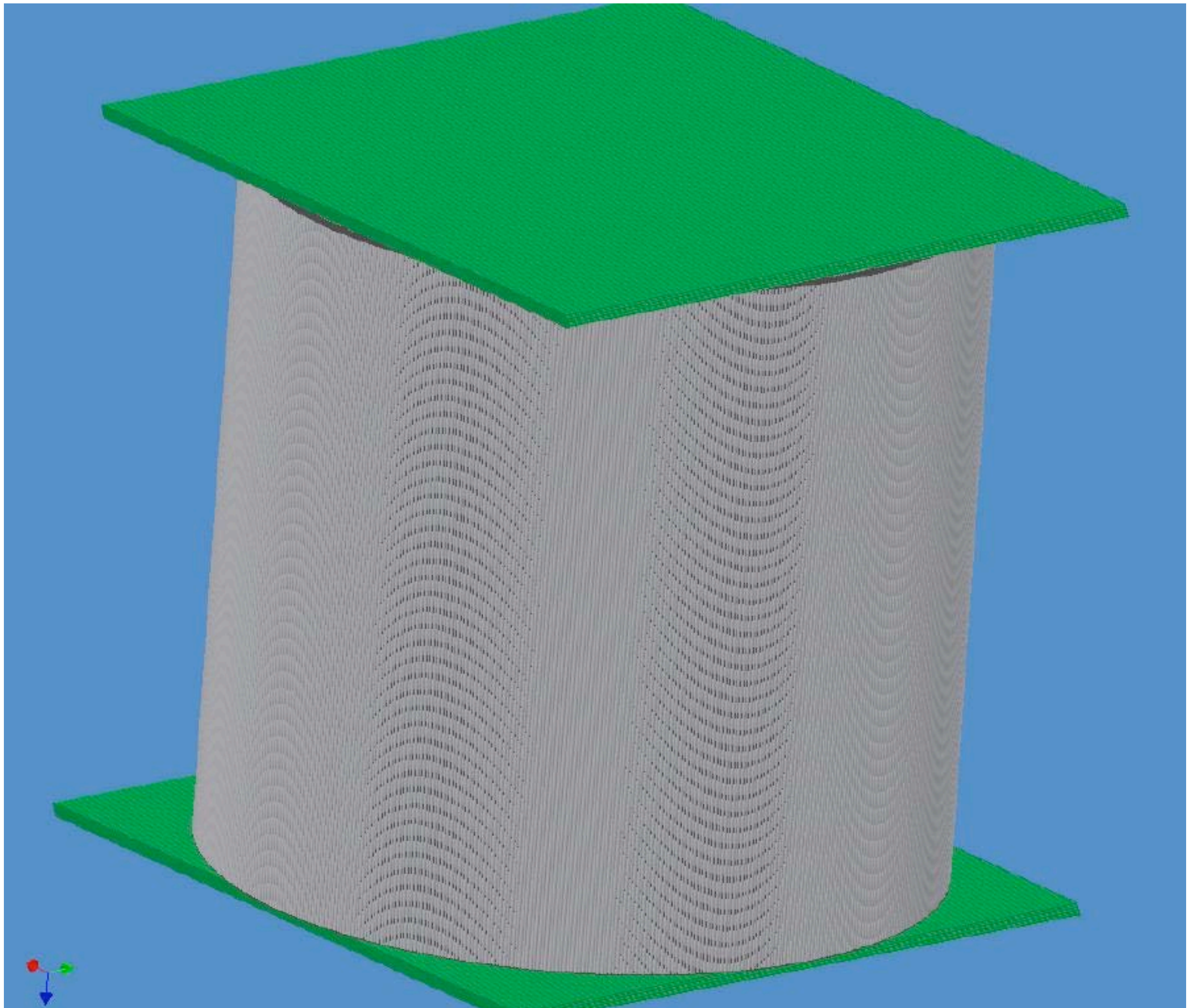
Outer Veto
Total Coverage?

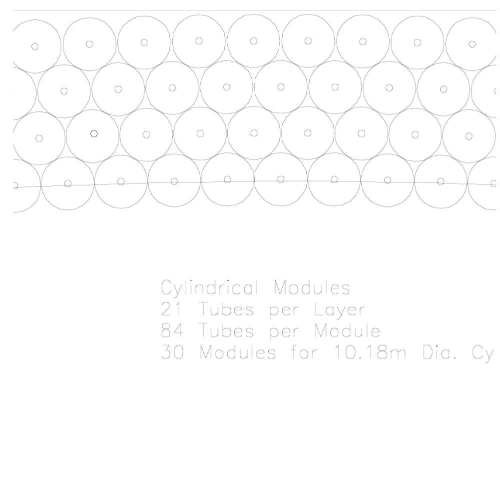
Surface Area
408 m^2

- Coverage of larger volume to reduce neutron backgrounds
- Cover 99% of direct muons through the target region.
- Use at least 2 layers
  - ↳High efficiency
  - ↳Redundancy
- Tracking/Pointing



Proportional Chambers

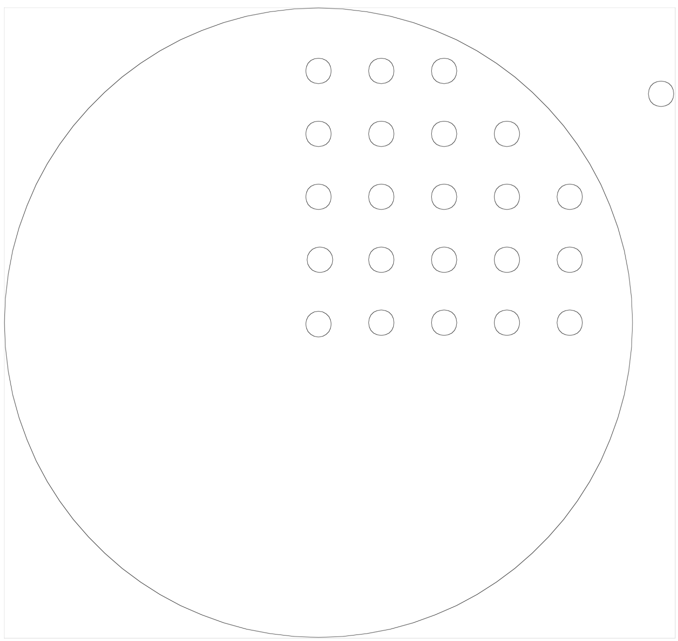




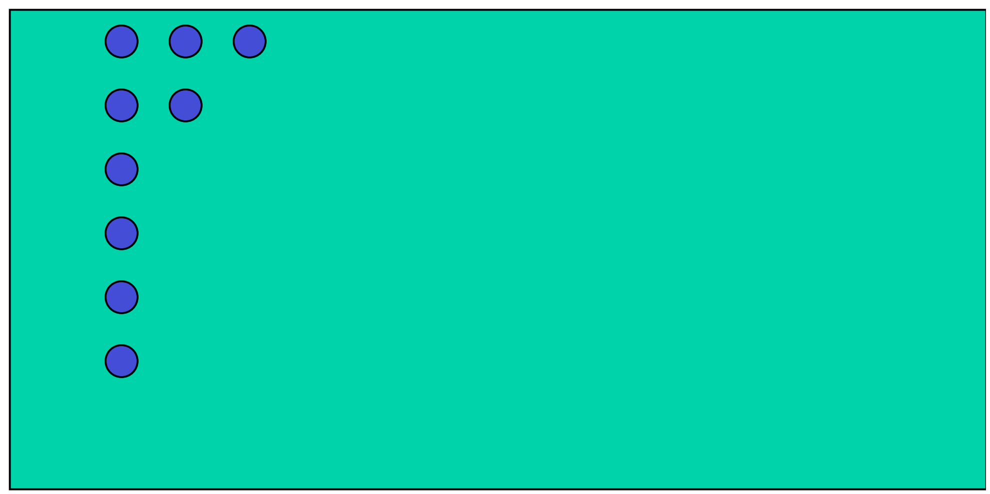
Maury Goodman
Argonne National Lab

Phototubes

- Top and Bottom



- Side



8 inch PMTs

- 512 near + 512 far + 16 spare = 1040 tubes
- 12.9% coverage
- Assures 200 MeV/pe
- Hamamatsu background calculations:

Per PMT

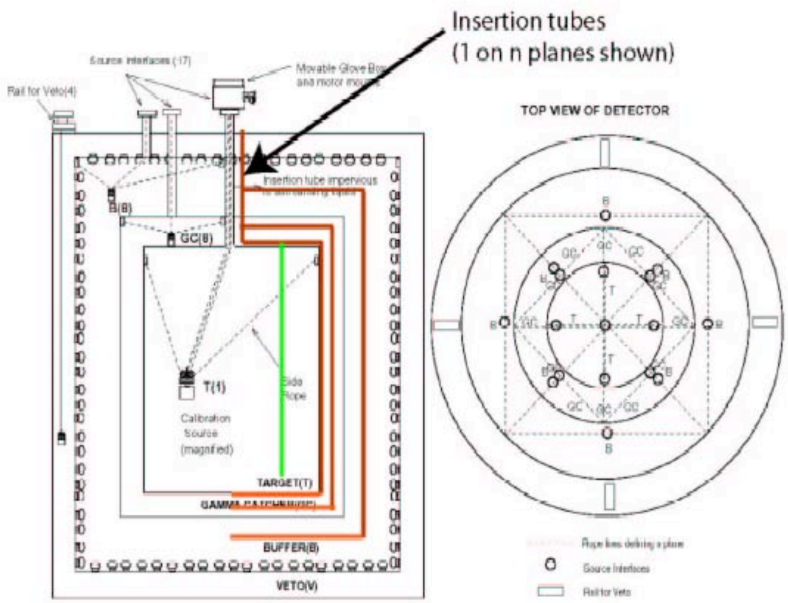
40-K	2.5 Bq
U	2.5 Bq
Th	1.0 Bq

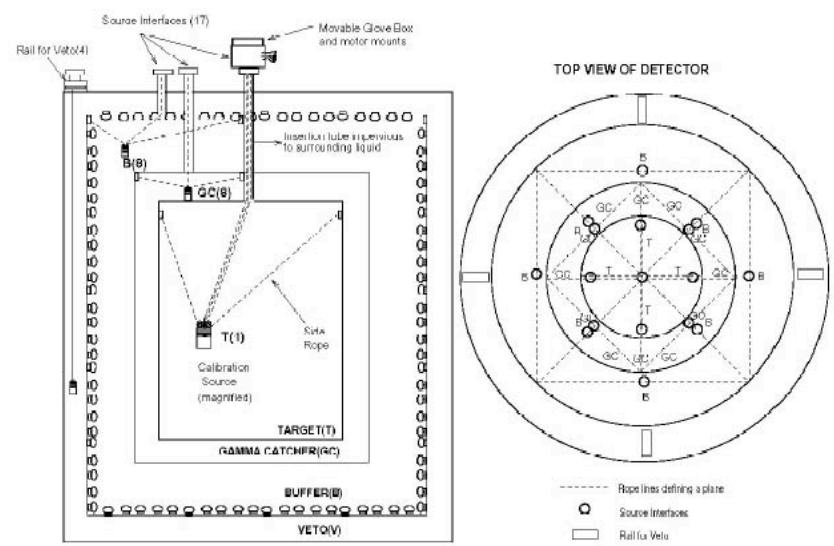
	6.0 Bq/PMT

Maury Goodman
Argonne National Lab

Calibration Deployment

- Source Tubes
- Levers & pulleys





Calibration Sources

Technique	Calibrations
Optical Fibers, Diffusive Laser ball	Timing and Charge Slopes and Pedestals, attenuation length of detector components
Neutron Sources: Am-Be, ^{252}Cf	Neutron response, relative and absolute efficiency, capture time
Positron Sources: ^{22}Na, ^{68}Ge	e^+ response, energy scale, trigger thresh.
Gamma Sources:	Energy linearity, stability, resolution, spatial and temporal variations.
^{137}Cs	β^-, 0.662 MeV
^{22}Na	β^+, 1.275 MeV + annih
^{54}Mn	EC, 0.835 MeV
^{65}Zn	1.35 MeV
^{60}Co	EC, 1.173, 1.33 MeV
^{68}Ge	EC, β^+ 1.899 MeV + annih
^{88}Y	EC, 0.898, 1.836 MeV
H neutron capture	2.223 MeV
^{241}Am-^{9}Be	(α,n) 4.44 MeV (^{12}C)
Gd neutron capture	Spectrum in 8 MeV window
^{12}C neutron capture	4.97 MeV
^{228}Th	2.615 MeV
^{40}K	EC, β^+, β^-, 11% 1.46 MeV

Table 3: Table showing the different techniques that are available to calibrate the Double-CHOOZ experiment.

Systematic Errors

	After CHOOZ	Double-CHOOZ Goal
Solid angle	0.2%	0.2%
Volume	0.2%	0.2%
Density	0.1%	0.1%
Ratio H/C	0.1%	0.1%
Neutron efficiency	0.2%	0.1%
Neutron energy	0.2%	0.2%
Spatial effects	neglect	neglect
Time cut	0.1%	0.1%
Dead time(veto)	0.25%	$< 0.25\%$
Acquisition	0.1%	0.1%
Distance cut	0.3%	$< 0.2\%$
Grand total	0.6%	$< 0.6\%$

Table 10: The column "After CHOOZ" lists the systematic errors that can be achieve without improvement of the CHOOZ published systematic uncertainties Referenc [17]. In Double-CHOOZ, we estimate the total systematic error on the normalizatio between the detectors to be less than 0.6%.

	CHOOZ	Double-CHOOZ	
selection cut	rel. error (%)	rel. error (%)	Comment
positron energy*	0.8	0	not used
positron-geode distance	0.1	0	not used
neutron capture	1.0	0.2	Cf calibration
capture energy containment	0.4	0.2	Energy calibration
neutron-geode distance	0.1	0	not used
neutron delay	0.4	0.1	—
positron-neutron distance	0.3	$0 - 0.2$	0 if not used
neutron multiplicity*	0.5	0	not used
combined*	1.5	0.2-0.3	—

*average values

Table 8: Summary of the neutrino selection cut uncertainties. CHOOZ values have been taken from[17].

	CHOOZ	Double-CHOOZ
Reactor power	0.7%	negligible
Energy per fission	0.6%	negligible
$\bar{\nu}_e$/fission	0.2%	negligible
Neutrino cross section	0.1%	negligible
Number of protons/cm^3	0.8%	0.2%
Neutron time capture	0.4%	negligible
Neutron efficiency	0.85%	0.2%
Neutron energy cut (E_γ from Gd)	0.4%	0.2%

Table 9: Summary of systematic errors that cancel or are significantly decreased in Double-CHOOZ.

Main improvements over CHOOZ

- Larger Detector and full power for both reactors allows higher Luminosity
- Two detectors cancels many systematic errors
- Gamma catcher/Buffer allows the elimination of the fiducial volume cut

Maury Goodman
Argonne National Lab

Letter of Intent

Letter of Intent for Double-CHOOZ:

a search for the mixing angle θ_{13}

APC, Paris - RAS, Moscow - DAPNIA, Saclay - EKU-Tübingen - INFN, Assergi & Milano - INR, Moscow -MPI, Heidelberg -RRC, Kurchatov - TUM-München - University of l'Aquila -Universität Hamburg

Version 5.0

April 28, 2004

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]

[1] APC, 11 place Marcelin Berthelot, 75005 Paris, France

[2] IPC of RAS, 31, Leninsky prospect, Moscow, Russia

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

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

[5] DSM/DAPNIA/SEDI, CEA/Saclay, 91191 Gif-sur-Yvette, France

[6] DSM/DAPNIA/SIS, CEA/Saclay, 91191 Gif-sur-Yvette, France

[7] Eberhard Karls Universität, Wilhelmstr. D-72074 Tübingen, Germany

[8] INFN, LGNS, I-67010 Assergi (AQ), Italy

[9] INFN Milano, Via Celoria 16, 20133 Milano, Italy

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

[11] MPI für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany

[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

CHOOZ-US

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

+ Notre Dame and 2 more @ Tenn -- Applications from Livermore & Los Alamos

[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

Funding

- Approved by Two French Physics Funding Agencies
- US proposal – DOE-HEP October 2004
- German University proposal under development
- German Lab will provide Scintillator (MPI)
- Local Government agency has provided a chateau
- State Government will probably provide ~1M€
- An Italian Group is having initial discussions with INFN
- Russian Group will provide calibration sources.

Funding - 2

- January 2005 – EdF will allow the experiment, but will not fund the near lab. French funding agencies will pay for the near lab in principle.
- CHOOZ-US proposal was received by DOE in October 2004. Sent for review in January 2005
- HEPAP/NSAC subpanel or SAG (Scientific Advisory Group) will review US reactor proposals during 2005, after February HEPAP
- Also, $0\nu\beta\beta$ & accelerator experiments, but there will be three groups(?)

Funding(3)

- Full funding is not currently in place.
- Conventional wisdom is that this experiment will happen.
- Conventional wisdom is probably right.
- Cost ~9 M € + near lab civil constr.

Maury Goodman
Argonne National Lab

US Request

PMTs	$2.11M
Outer Veto	1.32
Front End Electronics	0.23
High Voltage	0.42
Slow Controls	0.09
Calibration Deployment	0.24
Laser	0.05
Management	0.35
Total	$4.86M

Maury Goodman
Argonne National Lab

Work in Progress

- PMT mounting schemes
- Electronics Design
- Gd loaded Scintillator optical stability tests
- Software Development
- Engineering Evaluation for near site by EdF
- 13 inch tubes versus 8 inch tubes

Maury Goodman
Argonne National Lab

Milestones
(with current schedule)

- May 04-Jun 05 Project Definition
- 2005 Full Approval (assumption)
- Jun 05 Call for Bids
- Jun 05-Oct 07 Production
- Mid 06 Start on site installation
- May 07 Far Detector Completion
- 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)

Maury Goodman
Argonne National Lab

Braidwood

Maury Goodman
Argonne National Lab

Braidwood

- 2 near & 2 far detectors r=3.5m
- L ~ 200m & 1500m.
- Depth: 450 mwe (180 m real depth)
- R&D Proposal 05, Full ~1 yr
- 2 shafts cheaper! than horizontal access
- Good initial relations with EXELON

Braidwood Reactor Collaboration

- **Argonne Nat. Lab.:** M. Goodman, V. Guarino, L. Price, D. Reyna
- **Brookhaven Nat. Lab.:** R. Hahn, M. Yeh, A Garnov, Z. Chang, C. Musikas
- **U. of Chicago:** E. Abouzaid, K. Anderson, E. Blucher, M. Hurowitz, A. Kaboth, D. McKeen, J. Pilcher, J. Seger, M. Worcester
- **Columbia:** J. Conrad, Z. Djurcic, J. Link, K. McConnel, M. Shaevitz, G. Zeller
- **Fermilab:** L. Bartoszek, D. Finley, H. Jostlein, C. Laughton, R. Stefanski
- **Kansas State:** T. Bolton, C. Borjas, J. Foster, G. Horton-Smith, N. Kinzie, J. Kondikas, D. Onoprienko, N. Stanton, D. Thompson
- **U. of Michigan:** M. Longo, B. Roe
- **MIT:** P. Fisher, R. Cowan, L. Osborne, G. Sciolla, S. Sekula, F. Taylor, T. Walker, R. Yamamoto
- **Oxford:** G. Barr, S. Biller, N. Jelley, G. Orebi-Gann, S. Peeters, N. Tagg
- **U. of Pittsburgh:** D. Dhar, N. Madison, D. Naples, V. Paolone, C. Pankow
- **St. Mary's University:** P. Nienaber
- **Sussex:** L. Harris
- **U. of Texas:** A. Anthony, M. Huang, J. Jerz, J. Klein, A. Rahman, S. Seibert
- **U. of Washington:** J. Formaggio

November 11 2004
Double-CHOOZ

Maury Goodman
Argonne National Lab

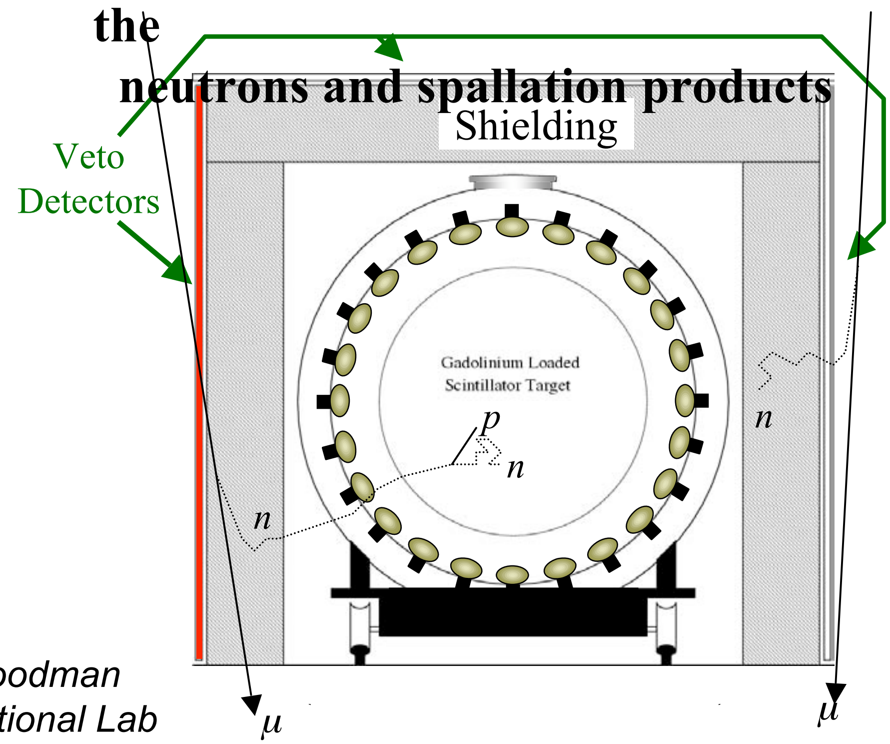
Braidwood Baseline

Design Goals: Flexibility, Redundancy, and Cross Checks

– Four identical 65 ton detectors
  - Outside Radius = 3.5 m
  - Fid. Radius = 2.6 m
– Two zones (Inner: Gd Scint, Outer: Pure oil)
  - Good access for calibrations
  - Increased fiducial mass
– Redundant detectors at each site
  - Cross checks and flexibility
– Moveable detectors
  - Allows direct cross calibration at near site
– Flat overburden at 450 mwe depth
  - Equivalent to 580 mwe mountain
  - 5 Hz muon rate in 6.5 m radius
  - Deep near detector allows access to unique additional physics (Janet's talk)

– Mitigate Correlated Background with extensive, active veto system
  - Fast neutrons from muons
  - ^{9}Li and ^{8}He produced from muon

Braidwood Strategy:
Identify and veto the few shower producing muons which produce the neutrons and spallation products



Baseline Cost and Schedule Estimates

- Baseline Cost Estimate:
  - Civil Costs: (From Hilton and Assoc. consulting firm)
    - Const.+EDIA $34M
    - Contingency $8.5M
  - Detector and Veto System (From Bartoszek Eng. and Argonne)
    - Four Detectors $17M with Veto systems
    - Contingency $5M
    - Other with cont. $1M
- Schedule:
  - 2004: R&D proposal submission.
  - 2005: Full proposal

- There has been little value engineering applied to these cost estimates.
  - Likely cost savings in developing an integrated plan for shafts, detectors, and access.
- Results of bore holes and geology studies reduces the needed contingency
- Project also lends itself to operational phasing with near and far shafts and multiple detectors

Engineering/R&D Proposal (Submitted to NSF and DOE)

- Requests funding to complete the design and engineering of the baseline project.
  - Civil engineering design leading to RFP for a "Design and Build"
  - Detector engineering leading to full "Design Report"
  - Final development of stable Gd loaded scintillator
- Amount requested
  - Civil Engineering $525k
  - Detector

Exelon Letter of support:
- Enthusiastic about project
- Claim security and site access issues not a problem
- 1st step was MOU on bore holes

Exelon Nuclear

September 21, 2004

To Whom It May Concern:

On behalf of Exelon Generation Company, LLC ("Exelon"), I am writing to express Exelon's support for the plans of the Braidwood Collaboration. Representatives of Exelon have had several meetings with scientists of the Braidwood Collaboration to discuss their proposal to use the Braidwood Nuclear Power Station to make precision measurements of neutrino properties. Exelon is enthusiastic about the opportunity to participate in this timely scientific endeavor.

We understand that the proposed experiment will include detectors approximately 200 m (outside the security perimeter) and 1500 m from the reactor cores. The detectors will be placed in caverns at the bottom of approximately 10 m diameter, 180 m deep shafts at these positions. The experiment will also be designed to allow surface transportation (either by rail or crawler) of the detectors between the near and far shafts. The construction of the experiment will last 2-3 years, and data collection could extend for 10 years. The cost of civil construction and all experimental apparatus will be borne by funding agencies supporting the research. We are confident that security and site access issues related to this plan can be addressed in a way acceptable to both Exelon and the experimenters.

As a first step in this program, Exelon and The University of Chicago have concluded a Memorandum of Understanding to drill bore holes to full depth at the near and far shaft positions. These bore holes will provide necessary geological information to proceed with the civil engineering design for the full project.

We look forward to continued collaboration between Exelon and members of the Braidwood Collaboration.

Sincerely,

Charles Pardee
Senior Vice President
Nuclear Services

Engineering/R&D Proposal (Submitted to NSF and DOE)

- Requests funding to complete the design and engineering of the baseline project.
  - Civil engineering design leading to RFP for a "Design and Build"
  - Detector engineering leading to full "Design Report"
  - Final development of stable Gd loaded scintillator
- Amount requested
  - Civil Engineering $525k
  - Detector Engineering $408k
  - Liquid Scint. $28k
  - Edu. and Outreach $78k

Exelon Letter of support:
- Enthusiastic about project
- Claim security and site access issues not a problem
- 1st step was MOU on bore holes

Exelon Nuclear

September 21, 2004

To Whom It May Concern:

On behalf of Exelon Generation Company, LLC ("Exelon"), I am writing to express Exelon's support for the plans of the Braidwood Collaboration. Representatives of Exelon have had several meetings with scientists of the Braidwood Collaboration to discuss their proposal to use the Braidwood Nuclear Power Station to make precision measurements of neutrino properties. Exelon is enthusiastic about the opportunity to participate in this timely scientific endeavor.

We understand that the proposed experiment will include detectors approximately 200 m (outside the security perimeter) and 1500 m from the reactor cores. The detectors will be placed in caverns at the bottom of approximately 10 m diameter, 180 m deep shafts at these positions. The experiment will also be designed to allow surface transportation (either by rail or crawler) of the detectors between the near and far shafts. The construction of the experiment will last 2-3 years, and data collection could extend for 10 years. The cost of civil construction and all experimental apparatus will be borne by funding agencies supporting the research. We are confident that security and site access issues related to this plan can be addressed in a way acceptable to both Exelon and the experimenters.

As a first step in this program, Exelon and The University of Chicago have concluded a Memorandum of Understanding to drill bore holes to full depth at the near and far shaft positions. These bore holes will provide necessary geological information to proceed with the civil engineering design for the full project.

We look forward to continued collaboration between Exelon and members of the Braidwood Collaboration.

Sincerely,

Charles Pardee
Senior Vice President
Nuclear Services

Double-CHOOZ

Argonne National Lab

NuSAG
Questions & answers?

November 11 2004
Double-CHOOZ

Maury Goodman
Argonne National Lab

ν – the right experiments at the right time

New Initiatives

- In order to inform the Department of HEP's intent to pursue several new scientific topics, we plan to prepare draft requests for approval of CD-0 "Statement of Mission Need", including
  - A generic reactor-based neutrino experiment to measure θ_{13}
  - A generic off-axis accelerator-based neutrino experiment for θ_{13} and to resolve the neutrino mass hierarchy
  - A generic high intensity neutrino beam facility for neutrino CP-violation experiments
  - A generic neutrinoless double beta decay experiment to probe the Majorana nature of neutrinos
  - A generic underground experiment to search for direct evidence of dark matter
  - A generic ground-based dark energy experiment
- In order to be ready to move forward expeditiously, this process will be in parallel with a Scientific Advisory Group (SAG) and P5 process that I will describe tomorrow.

Question

- Why should the U.S. participate in an experiment that can only achieve 0.03 when the APS study goal was for 0.01 and (much) better experiments are on the horizon?

Maury Goodman
Argonne National Lab

Starting to Answer

- Planispherium Neutrinorum is fairly flat, so the horizon is not that close.

θ_{13} Predictions

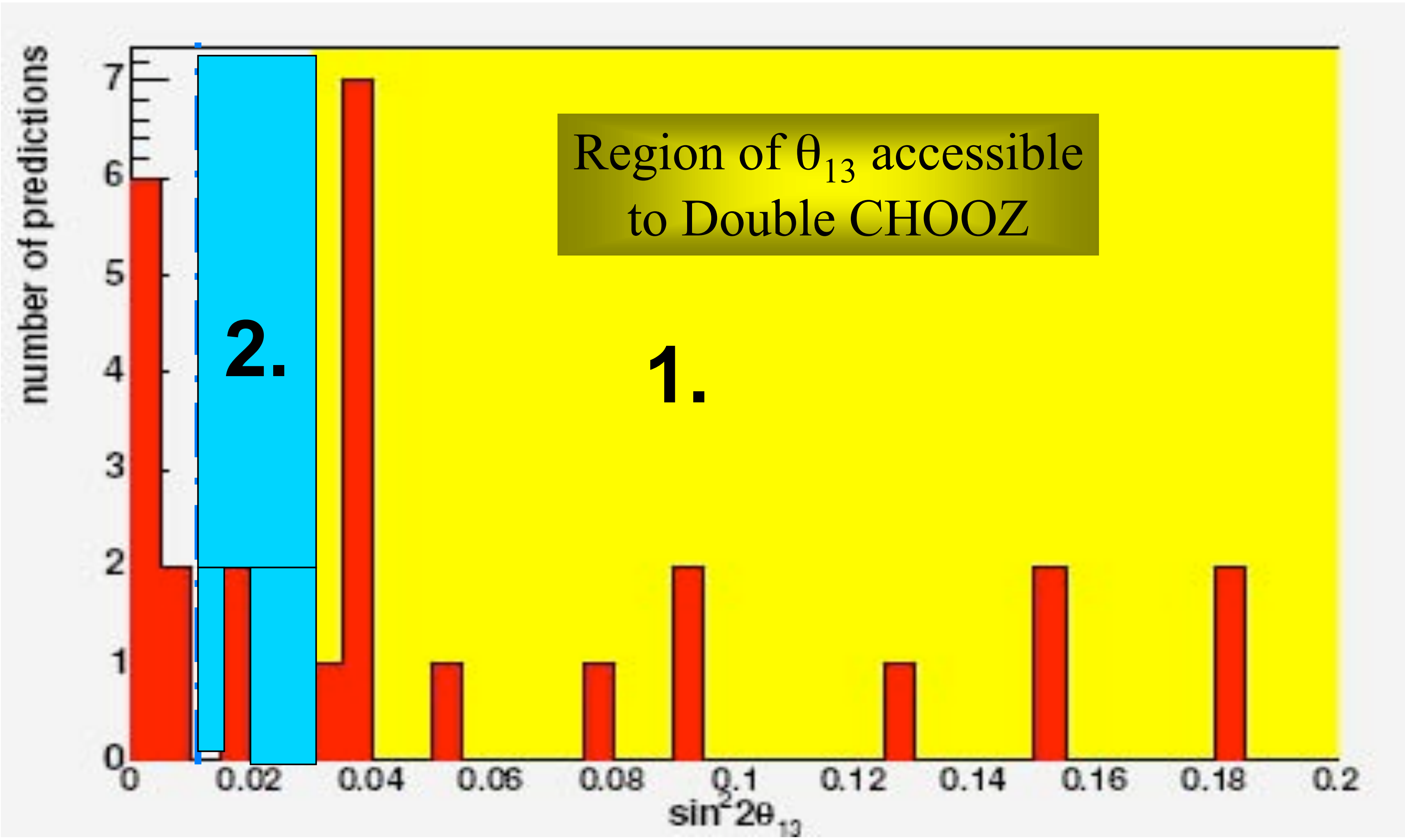
Reference	$\sin\theta_{13}$	$\sin^2 2\theta_{13}$
SO(10)		
Goh, Mohapatra, Ng [40]	0.18	0.13
Orbifold SO(10)		
Asaka, Buchmüller, Covi [41]	0.1	0.04
SO(10) + flavor symmetry		
Babu, Pati, Wilczek [42]	$5.5 \cdot 10^{-4}$	$1.2 \cdot 10^{-6}$
Blazek, Raby, Tobe [43]	0.05	0.01
Kitano, Mimura [44]	0.22	0.18
Albright, Barr [45]	0.014	$7.8 \cdot 10^{-4}$
Maekawa [46]	0.22	0.18
Ross, Velasco-Sevilla [47]	0.07	0.02
Chen, Mahanthappa [48]	0.15	0.09
Raby [49]	0.1	0.04
SO(10) + texture		
Buchmüller, Wyler [50]	0.1	0.04
Bando, Obara [51]	0.01 .. 0.06	$4 \cdot 10^{-4}$ .. 0.01
Flavor symmetries		
Grimus, Lavoura [52, 53]	0	0
Grimus, Lavoura [52]	0.3	0.3
Babu, Ma, Valle [54]	0.14	0.08
Kuchimanchi, Mohapatra [55]	0.08 .. 0.4	0.03 .. 0.5
Ohlsson, Seidl [56]	0.07 .. 0.14	0.02 .. 0.08
King, Ross [57]	0.2	0.15
Textures		
Honda, Kaneko, Tanimoto [58]	0.08 .. 0.20	0.03 .. 0.15
Lebed, Martin [59]	0.1	0.04
Bando, Kaneko, Obara, Tanimoto [60]	0.01 .. 0.05	$4 \cdot 10^{-4}$ .. 0.01
Ibarra, Ross [61]	0.2	0.15
3×2 *see-saw*		
Appelquist, Piai, Shrock [62, 63]	0.05	0.01
Frampton, Glashow, Yanagida [64]	0.1	0.04
Mei, Xing [65] (normal hierarchy)	0.07	0.02
(inverted hierarchy)	> 0.006	$> 1.6 \cdot 10^{-4}$
Anarchy		
de Gouvêa, Murayama [66]	> 0.1	> 0.04
Renormalization group enhancement		
Mohapatra, Parida, Rajasekaran [67]	0.08 .. 0.1	0.03 .. 0.04

Table 1: Incomplete selection of predictions for θ_{13}. The numbers should considered as order of magnitude statements.

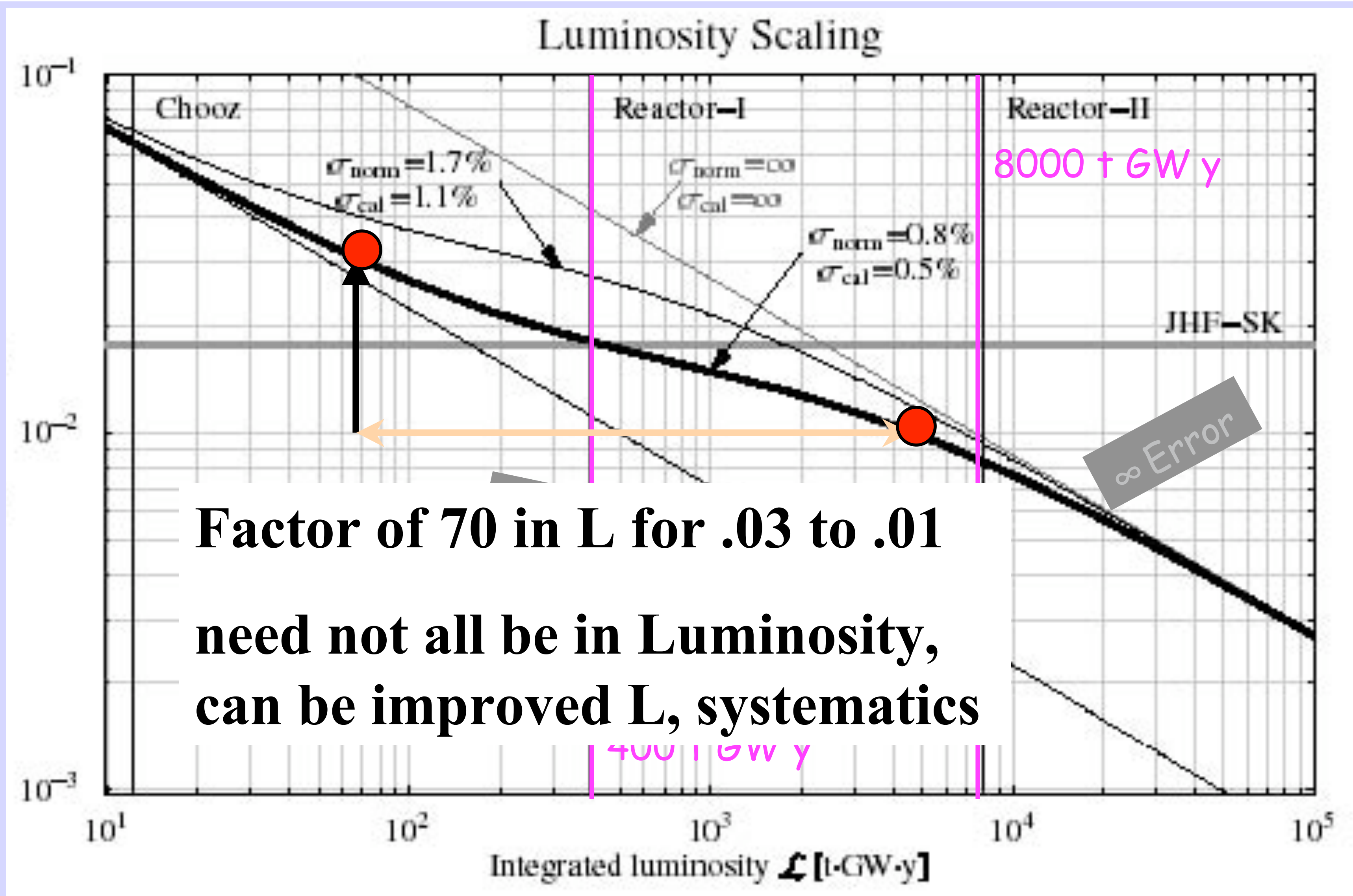
- θ_{13} is in reach
- A generally accepted observation of non-zero θ_{13} will take :
  - 2 experiments *or*
  - 2 techniques (rate & shape)

Maury Goodman
Argonne National Lab

θ_{13} Predictions, steps



.03 to .01



Factor of 70 in L for .03 to .01

need not all be in Luminosity, can be improved L, systematics

- An experiment to measure 0.01 is 70 times harder than an experiment to measure 0.03.

- An experiment sensitive to 0.03 is a crucial step on the way to an experiment (which we want) which is sensitive to 0.01.

Maury Goodman
Argonne National Lab

Question

- Why should the U.S. participate in an experiment to achieve 0.01 when a much cheaper experiment can reach 0.03?

Maury Goodman
Argonne National Lab

Starting to Answer

- 0.01 is reasonably achievable for (much) less cost than an accelerator experiment
- If you measure something with Double Chooz, it will be important for long-baseline experiment to measure it more accurately
- If you don't measure something with DC, you'll want to push as far as you reasonably can with a more ambitious experiment
- θ_{13} is important

Conclusion

- Double-CHOOZ is one of several ideas for new experiments to measure θ_{13} in nuclear reactors
- In some sense, it is the furthest along.
- If fully approved in 2005
  - Will reach CHOOZ $\sin^2 2\theta_{13}$ (0.19) limit in 4 months from far-detector turnon in 2007
  - $\sin^2 2\theta_{13} > 0.05$ in 2009
  - $\sin^2 2\theta_{13} > 0.03$ in 2010-2011
- Braidwood is the right next step

Maury Goodman
Argonne National Lab

Advertisement(s)

- Free monthly neutrino rumor newsletter -- ~100 lines, send "subscribe" to maury.goodman@anl.gov or see http://www.hep.anl.gov/ndk/longbnews/

  Join 1342 subscribers.

- Neutrino Oscillation Industry Web Page
  http://www.neutrinooscillation.org/

Maury Goodman
Argonne National Lab