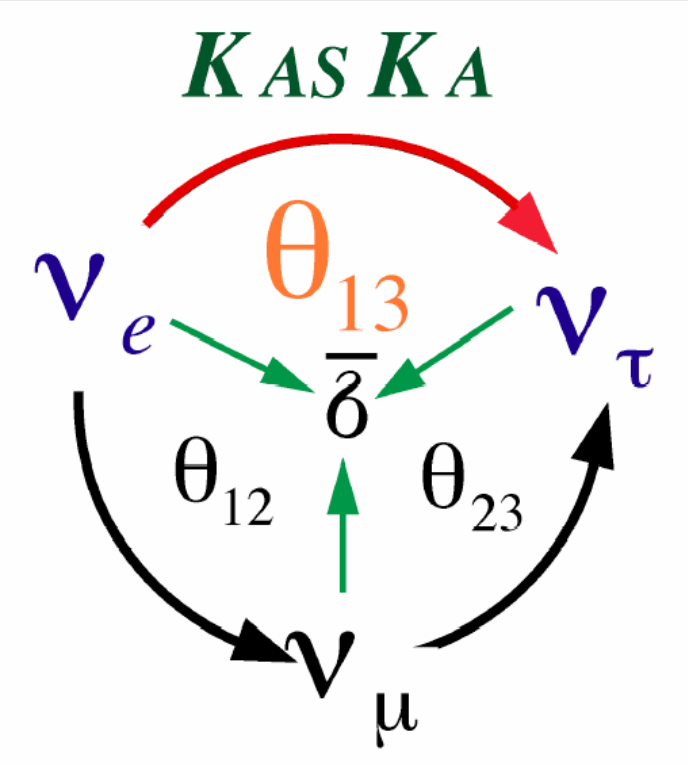
θ_{13} Measurements with Reactor Anti-neutrinos and the KASKA experiment



WIN'05 Neutrino Working Group
Delphi Greece
on
June 8th, 2005

Y.Fukuda
for the KASKA collaboration
Miyagi University of Education

Understanding of Neutrino Sector

- Pontecorvo-Maki-Nakagawa-Sakata mixing matrix (leptonic version of CKM matrix)

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

ν_e ν_μ ν_τ : flavor eigenstate
ν_1 ν_2 ν_3 : mass eigenstate

$$= \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}}_{\text{SK(atm}\nu\text{)} + \text{K2K}} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \underbrace{\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}}_{\text{Solar}\nu + \text{KL}}$$

Unknown (1-3) sector

- Current status

$$|U_{MNS}| \sim \begin{pmatrix} 0.7 & 0.7 & < 0.2 \\ 0.5 & 0.5 & 0.7 \\ 0.5 & 0.5 & 0.7 \end{pmatrix} \leftarrow \sin\theta_{13} e^{i\delta_l}$$

$\sin\theta_{13} < 0.2$,

δ_l: totally unknown CPV phase

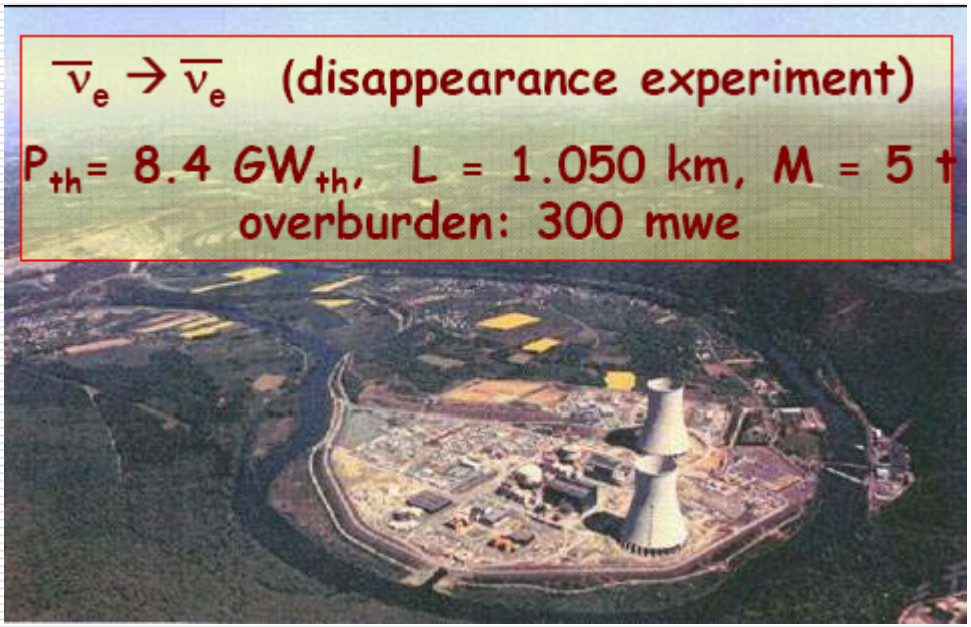
Next important step is to measure θ_{13}

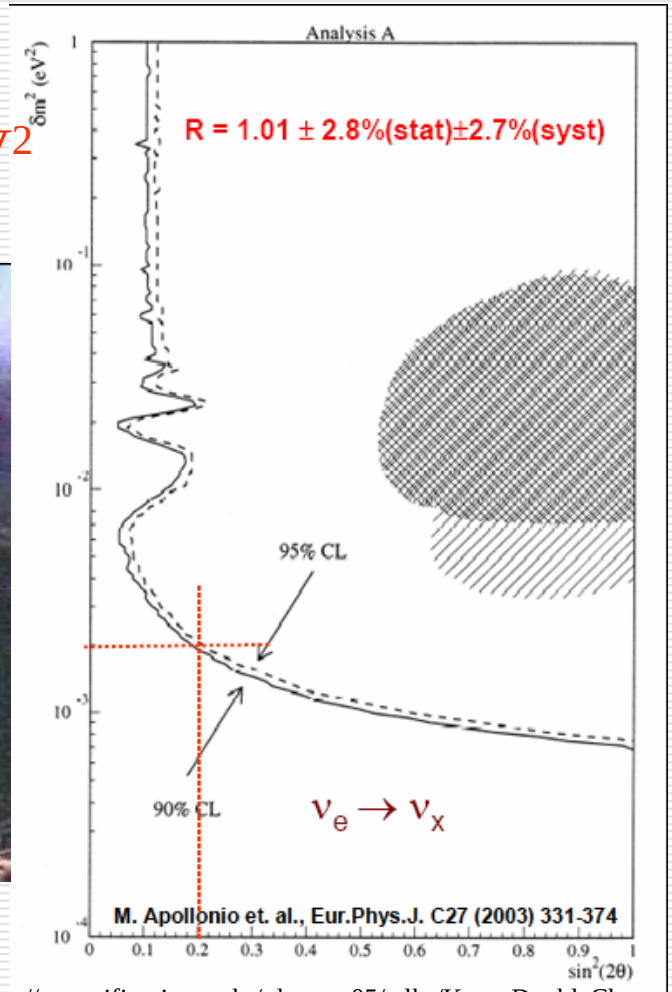
cf. finite value of $\sin^2 2\theta_{13}$ indicates the possibility of CPV phase δ_l measurement in the future

Experimental limits for (1-3) sector

- Experimental upper limit obtained by CHOOZ reactor experiment:

  $\sin^2 2\theta_{13} < 0.2$ @ $\Delta m^2_{13} = 2 \times 10^{-3} \text{eV}^2$





http://www.ifi.unicamp.br/~lenews05/talks/KerretDoubleChooz.pdf

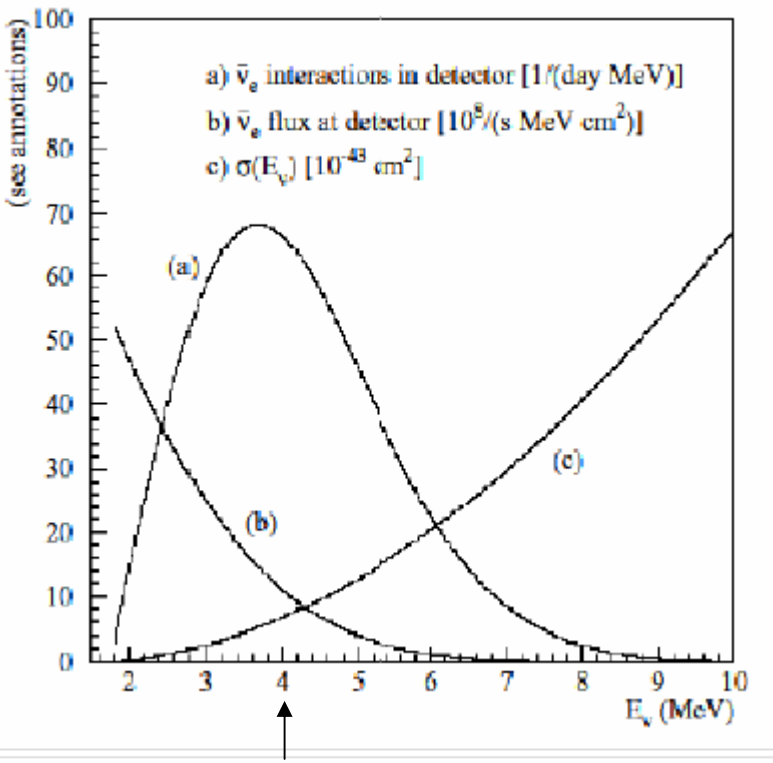
Measurement of θ_{13} using by reactor

- Neutrinos from reactor
  - Nuclear fission produce ~ $6\nu_e$ by β-decay
  - Usual 1GW reactor emits 6×10^{20} $\bar{\nu}_e$ /sec
  - Neutrino energy spectrum determined by spallation products data with 2.5% accuracy
  - Neutrino absorption by proton

$\bar{\nu}_e + p \rightarrow e^+ + n$ ($E_e = E_\nu - 1.8\text{MeV}$)

$e^+ + e^- \rightarrow 2\gamma$ (0.511MeV)

$E_{signal} = E_\nu - 0.8\text{MeV} > 1.0\text{MeV}$



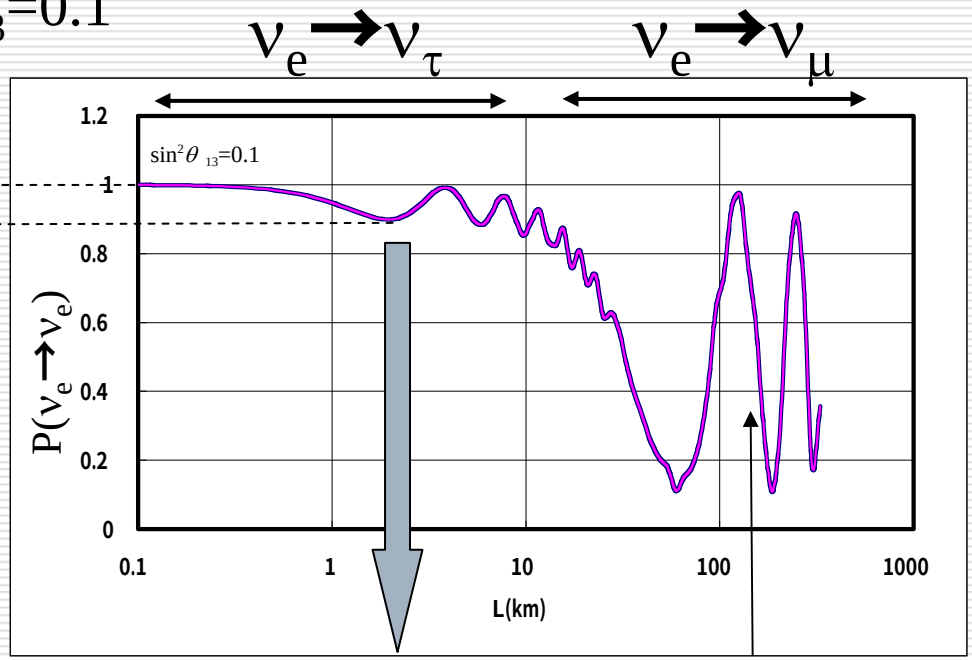
How to measure the θ_{13}

- Disappearance $\bar{\nu}_e$ from reactor

  $P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \sin^2(\Delta m^2_{13} L/4E) + O(10^{-3})$ (as Δm_{12}~solarν)

  cf. E=4MeV and $\sin^2 2\theta_{13}=0.1$

$\sin^2 2\theta_{13}$



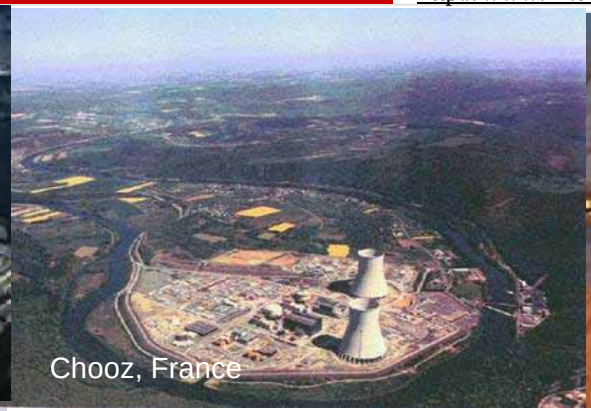
Measure this small deficit.
Due to $\Delta m^2_{12} < \Delta m^2_{23(13)}$,
this is almost pure θ_{13} measurement

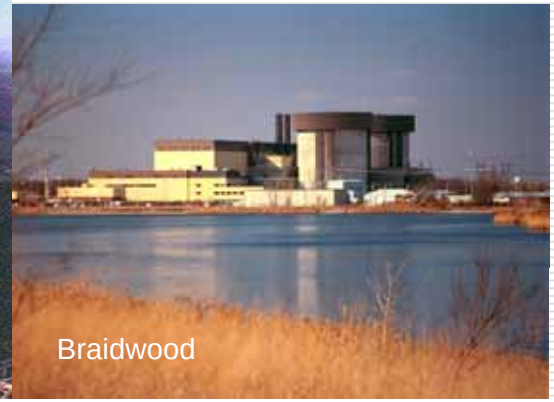
Need 1% accuracy for the measument

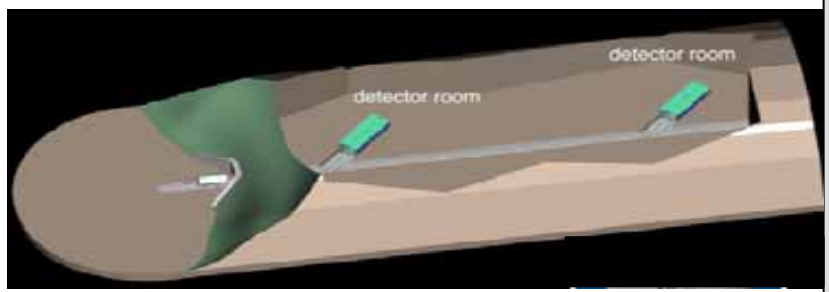
1~2km for reactor $\bar{\nu}_e$ KamLAND

θ_{13} projects

http://www.ifi.unicamp.br/~lene05/talks/Freedman_DeyaBay.ppt







Summary for θ_{13} project

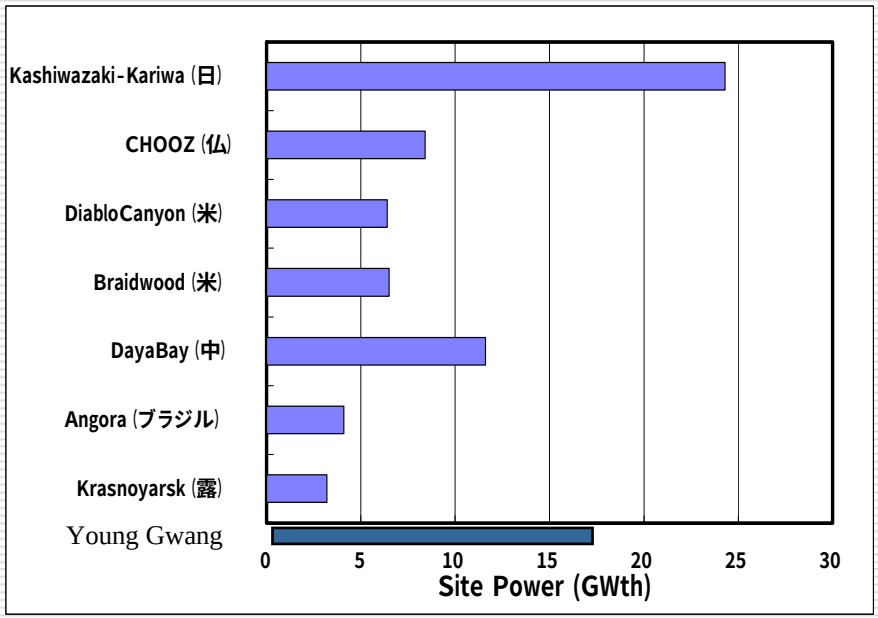
Characteristics

	merit	demerit	sensitivity
Double-Chooz	old tunnel (realistic) , know how	L might short systematic error?	$0.02@\sigma_{sys}$ ~0.6% 5yrs
KASKA	largest reactor, small detector, know how	man power? budget?	$0.015@\sigma_{sys}$ ~0.5% 3yrs
Braidwood	large and movable detector (cross calib.)	security? expensive?	< 0.01 shape+cnt.
Daya-bay	cheep construction cost (tunnel etc)	budget?	~0.01
Angra	?	Funding?	
Young Gwang	?	?	

KASKA experiment

- Kashiwazaki –Kariwa nuclear power station
  - Largest power in the world (24.3GW)
  - 7 reactors in two cluster

http://www.jp.wikipedia.org



KASKA collaboration list

Niigata University: N.Tamura, M.Tanimoto, H.Miyata, H.Nakano
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T.Matsumoto, K.Sakuma, T.Nakagawa

Tokyo Institute of Technology: M.Kuze, K.Nitta, H.Furuta, J.Maeda

Kobe University: T.Hara

KEK: N.Ishihara, H.Sugiyama

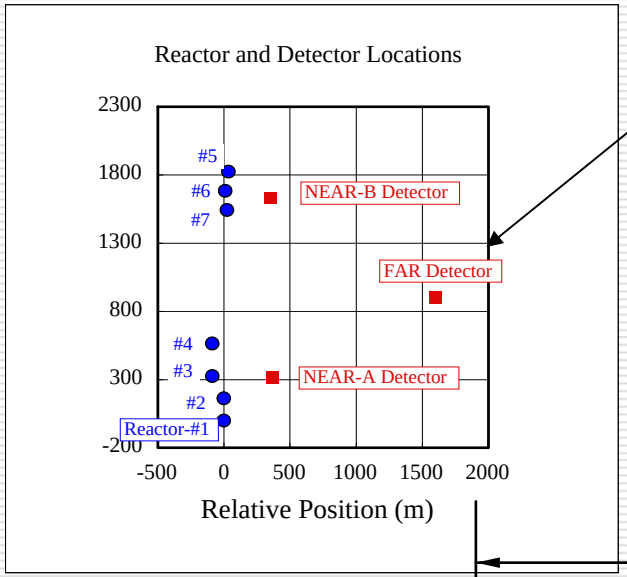
Okayama University: M.Sakuda

Miyagi University of Education: Y.Fukuda

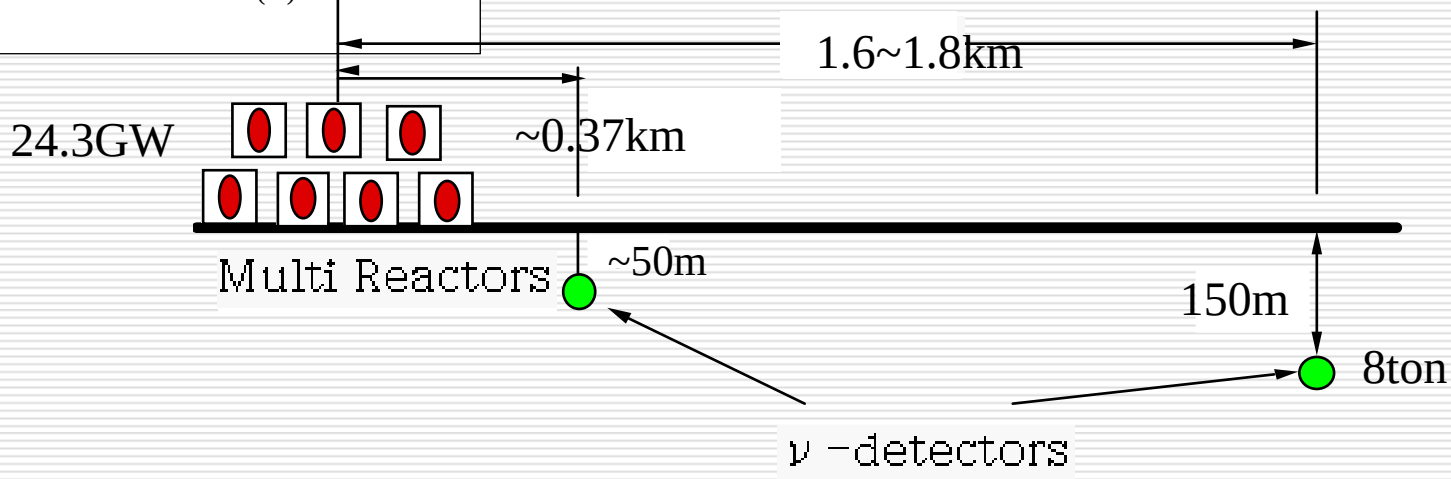
Hiroshima Institute of Technology: Y.Nagasaka

Geometry of KASKA experiment

- Location of detectors



Far detector is moved to out-side of reactor area, so that the base line could be set at 1.6 ~ 1.8km



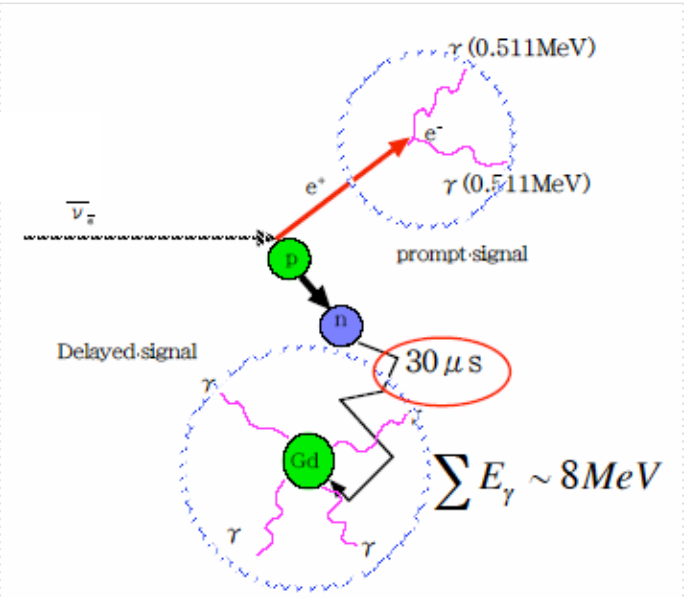
How to detect anti-ν_e

- Absorption by proton via inverse β-decay

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

$$e^+ + e^- \rightarrow 2\gamma \quad (E=E\nu-0.8MeV)$$

$$n + Gd \rightarrow Gd' + \gamma s \quad (\Sigma E_\gamma \sim 8MeV)$$



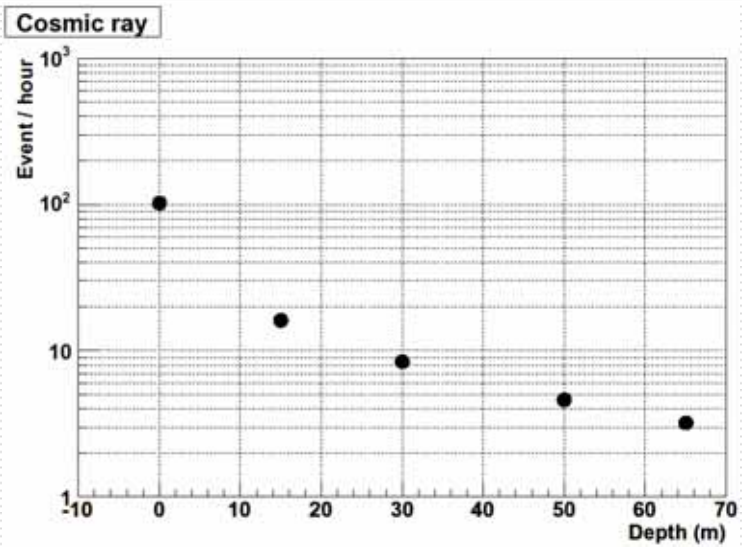
Cf. KamLAND has no Gd in LS
$n + p \rightarrow d + \gamma$ (2.2MeV)

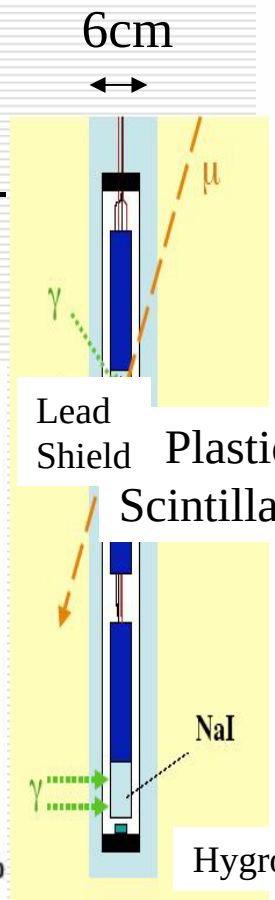
Delayed coincidence can drastically reduce the background

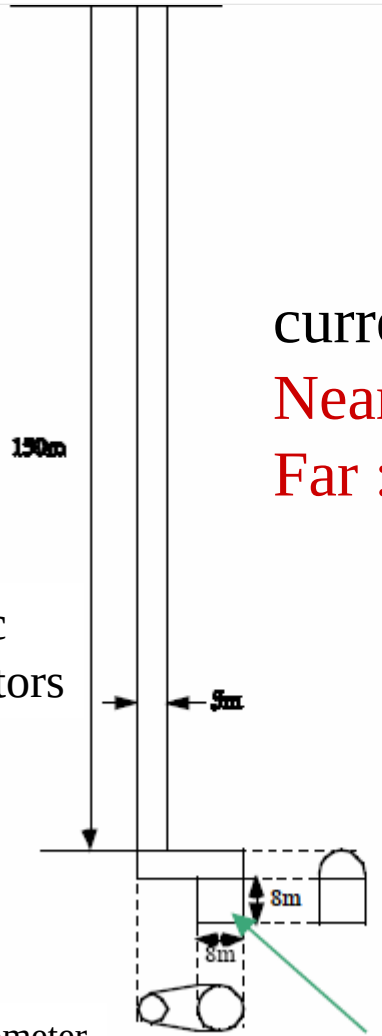
Detector under the ground

- Shaft hole
  - Aim :

    To reduce cosmic ray backgrounds
  - Measure actual cosmic-ray BG







current design

Near : ~100Hz

Far : ~10Hz

KASKA Detector

More buffer
Less oil & Less cost

ν detector Gd-LS (11.5m^3)

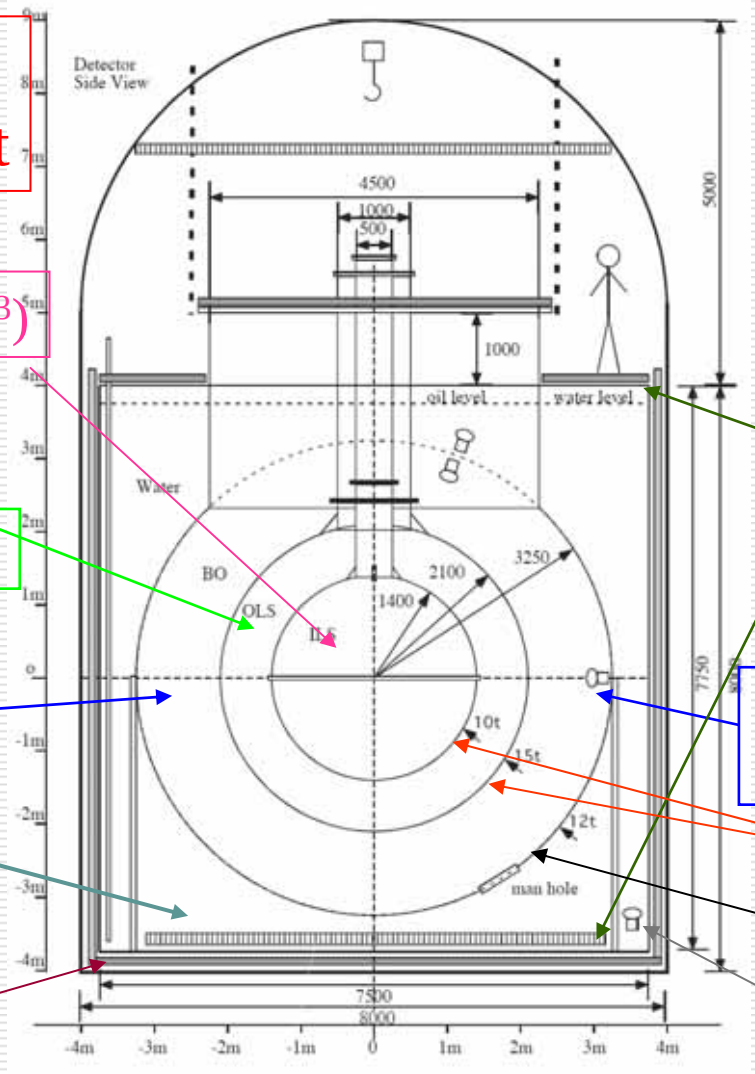
=9.2ton (ρ=0.8)

γ-catcher LS (70cm^t)

Buffer Oil(115cm^t)

Water

Fe shield(10cm^t)



Cosmic ray tracker

10”PMT*300, (13”*150)
+2”PMT*50

Acrylic vessel

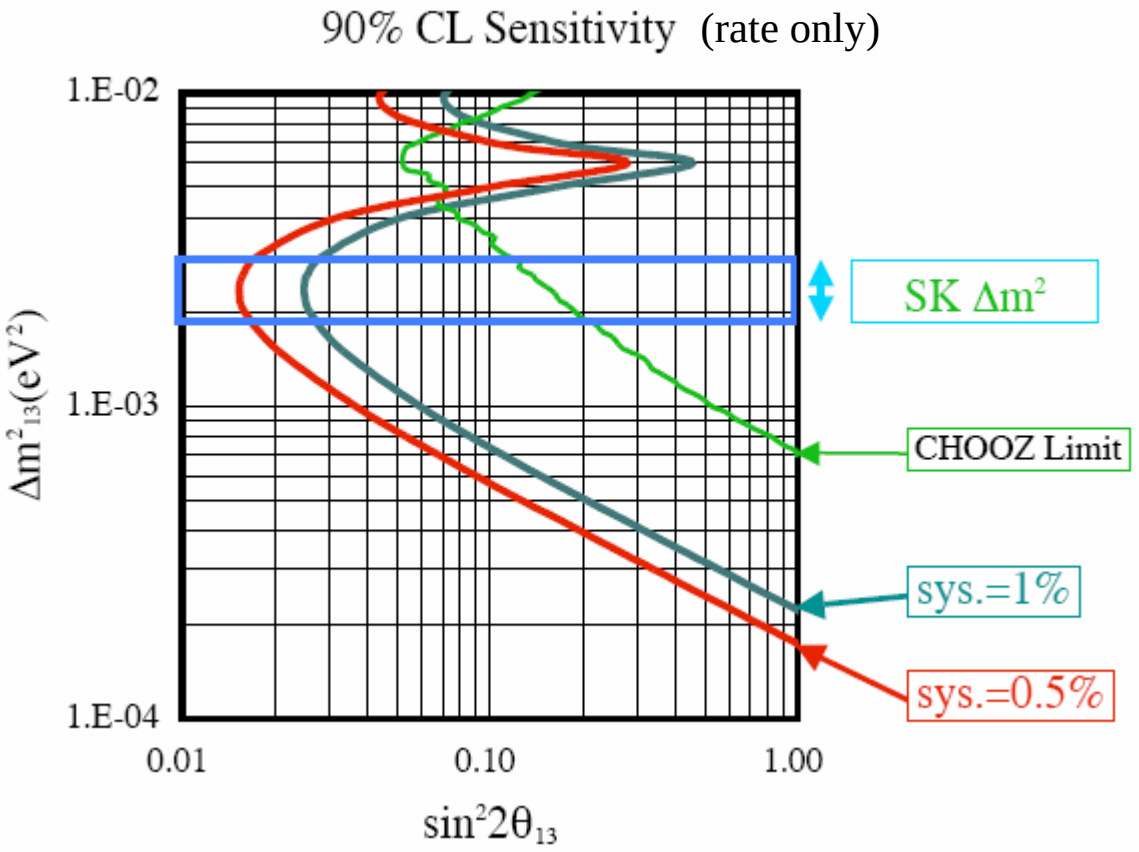
Stainless steel tank

Fe tank(1cm^t)

Expected sensitivity for KASKA

Expected event rate : 50,000/3years @ far detector

1,200,000events/3years @ near detector precise reactor-ν science



σ_{stat} ~ 0.5%
(2.8% @CHOOZ)

σ_{sys}<1%
2.7%@CHOOZ

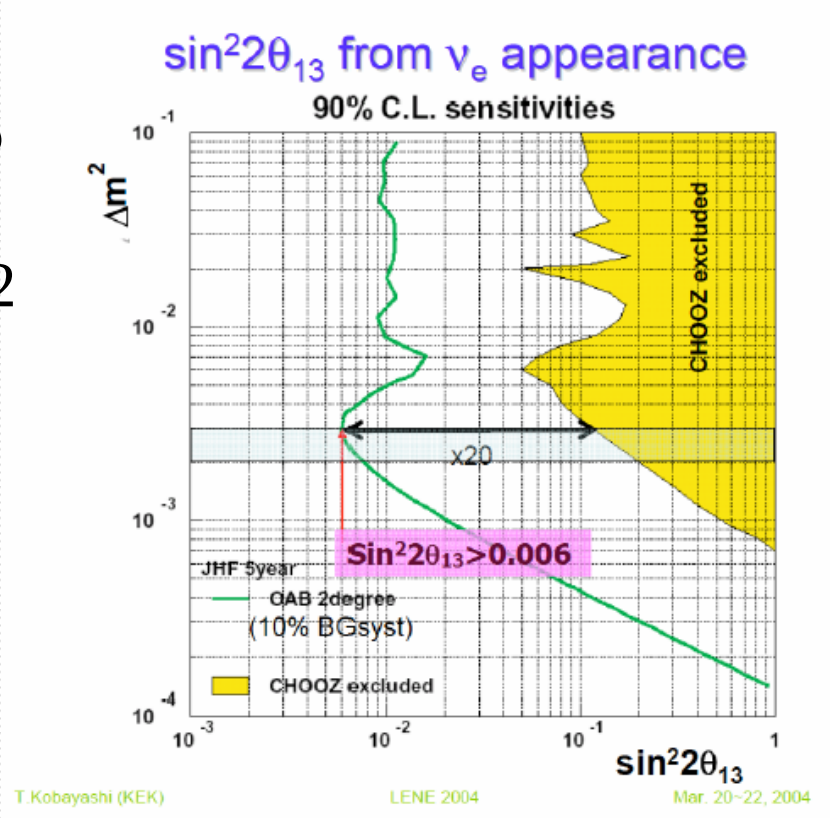
If σ_{sys} achieves 0.5%,
$\mathrm{Sin}^2 2\theta_{13}$<0.015

Why θ_{13} with reactor

- Accelerator long-base line experiment : ν_e appearance ($\nu_\mu \rightarrow \nu_e$)
  - J-PARC –SK(T2K) has sensitivity $\sin^2 2\theta_{13} < 0.006$ with 5yrs opr.
  - KASKA has $\sin^2 2\theta_{13} \sim 0.02$

Conflict them?

- No : $\nu_\mu \rightarrow \nu_e$ appearance experiment can not measure pure θ_{13} ($\bar{\nu}_e$ disappearance experiment can do it)

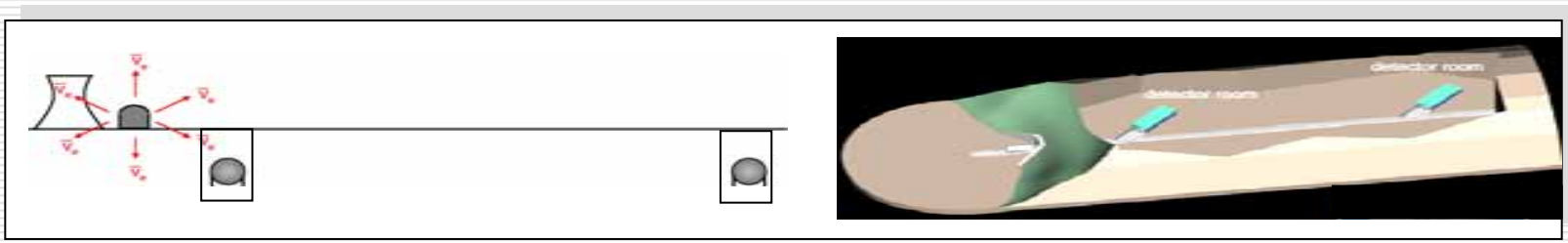


θ_{13} measurement by reactor

- Reactor experiment as clean lab.

$$P_{ee} \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m_{31}^2 L}{4E_\nu}\right) - \underbrace{\cos^4\theta_{13} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m_{21}^2 L}{4E_\nu}\right)}_{O(10^{-3})}$$

  - $\bar{\nu}_e \rightarrow \bar{\nu}_e$ disappearance experiment
  - Measurement rate (deviated from $1/r^2$ dependence) and spectral distortion
  - Multi-detectors
  - O(1km) base-line : no matter effect



http://www.ifi.unicamp.br/~lene05/talks/Freedman_DeyaBay.ppt

θ_{13} measurement by accelerator

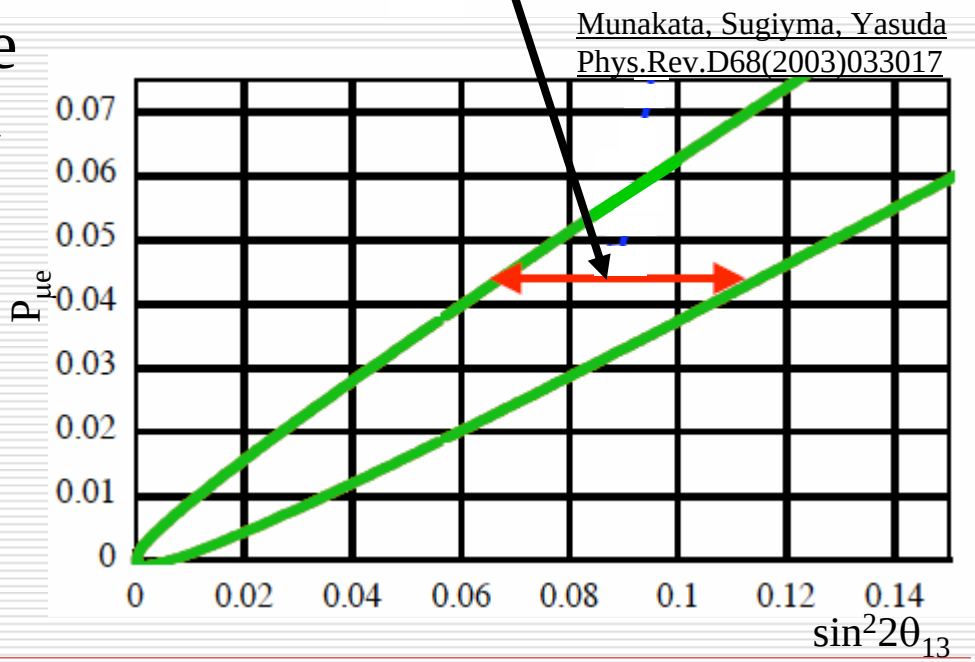
- Intrinsic ambiguity (CP phase)

$$P(\nu_\mu \to \nu_e) = \sin^2 2\theta_{13} \sin^2 \theta_{23} - \frac{\pi}{2} \frac{\Delta m^2_{12} \sin 2\theta_{12}}{\Delta m^2_{23}} \sin 2\theta_{13} \sin 2\theta_{23} \sin \delta$$

$$\sim \frac{1}{2} \sin^2 2\theta_{13} \left(1 \pm \frac{0.08}{\sin 2\theta_{13}} \sin \delta \right) \qquad -1<\sin\delta<1$$

here, $\sin^2(\Delta m^2_{31} L/4E) \sim 1$

- $\nu_\mu \to \nu_e$ appearance
  $P_{\mu e}$ has ambiguity due to $\sin\delta$
- O(100-1000km) long-baseline : matter effect



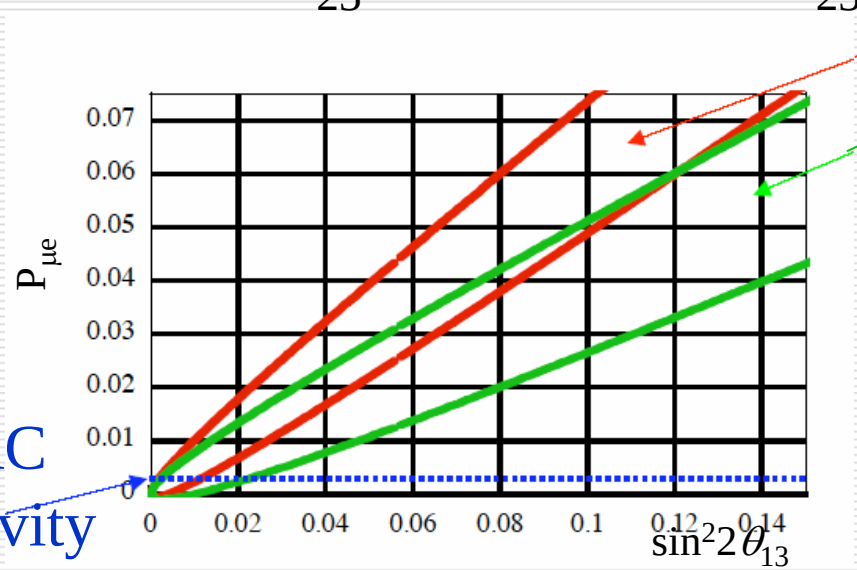
θ_{13} measurement by accelerator

- Intrinsic ambiguity 2 (θ_{23} degeneracy)

$$P(\nu_\mu \to \nu_e) = \sin^2 2\theta_{13} \sin^2 \theta_{23} - \frac{\pi}{2} \frac{\Delta m^2_{12} \sin 2\theta_{12}}{\Delta m^2_{23}} \sin 2\theta_{13} \sin 2\theta_{23} \sin \delta$$

$$\sin^2 2\theta_{13} \frac{1}{2}\left(1 \pm \sqrt{1 - \sin^2 2\theta_{23}}\right)$$

If $\sin^2 2\theta_{23}$=0.95 then $\sin^2 \theta_{23}$=0.61 or 0.39

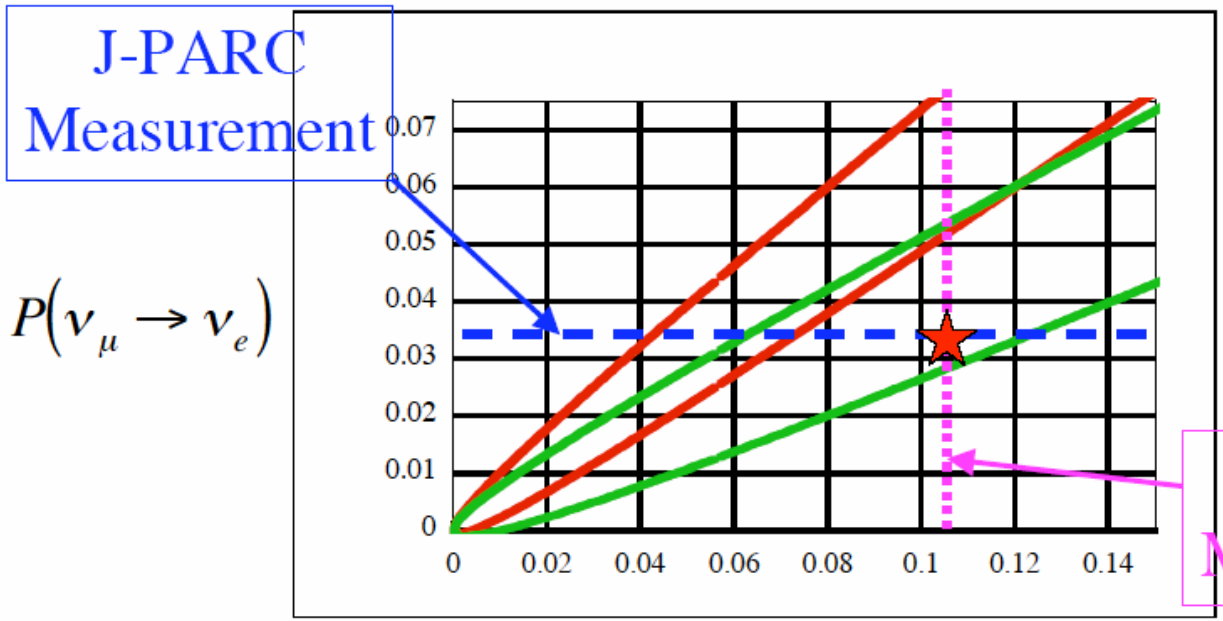


J-PARC sensitivity

Munakata, Sugiyma, Yasuda
Phys.Rev.D68(2003)033017

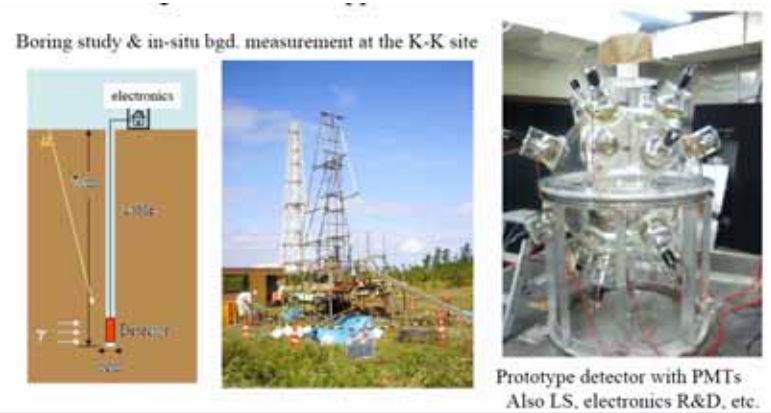
θ_{13} measurement by reactor and accelerator

- Both experiments are complementary
  - Both results complete physics issue

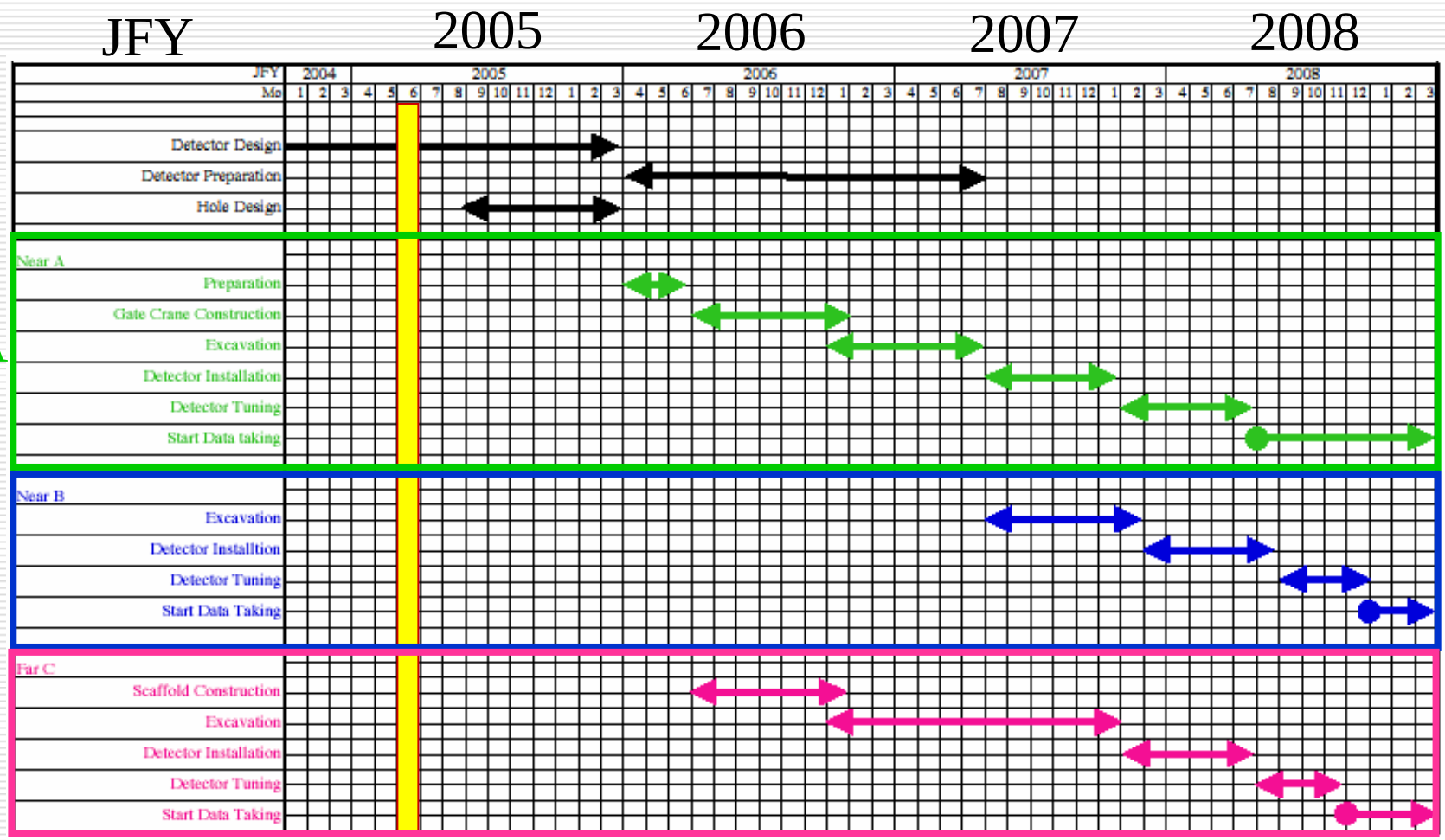


R&D for KASKA project

- R&D budgets have been approved in JFY2004~2005
  - Boring study at near-B site
  - Prototype detector
  - Electronics development
  - LS developments (another budget 2005-2006)
  - Detector and Shaft hole design study
  - Cosmic-ray detector development (2005-2006)



Possible schedule



Cost ? : JFY2005 Budget request ~$30M

Other reactor θ_{13} experiment

- Double CHOOZ

http://www.ifi.unicamp.br/~lenews05/programws05.html/talks/StatusDoubleChooz_Angra.pdf.gz

Concept of Double Chooz experiment

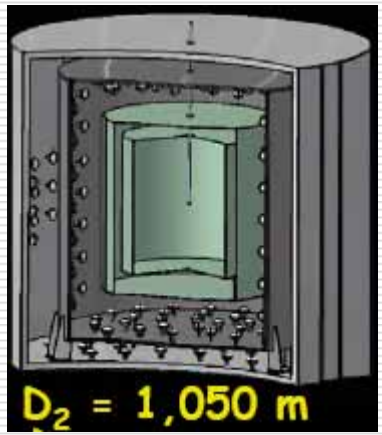
- $\bar{\nu}_e$ disappearance

8.4GW Chooz PWR stations

ν_e

Near detector

$\nu_{e,\mu,\tau}$

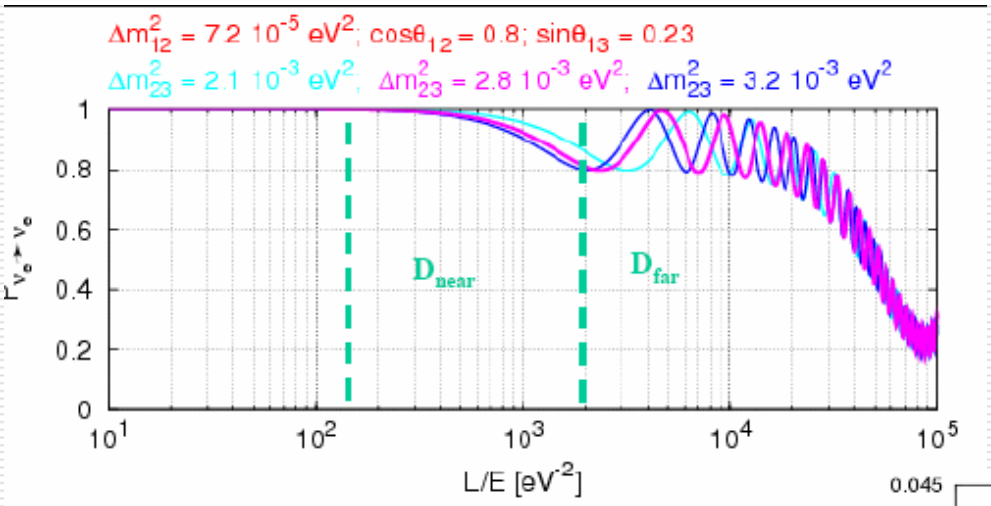


Far detector

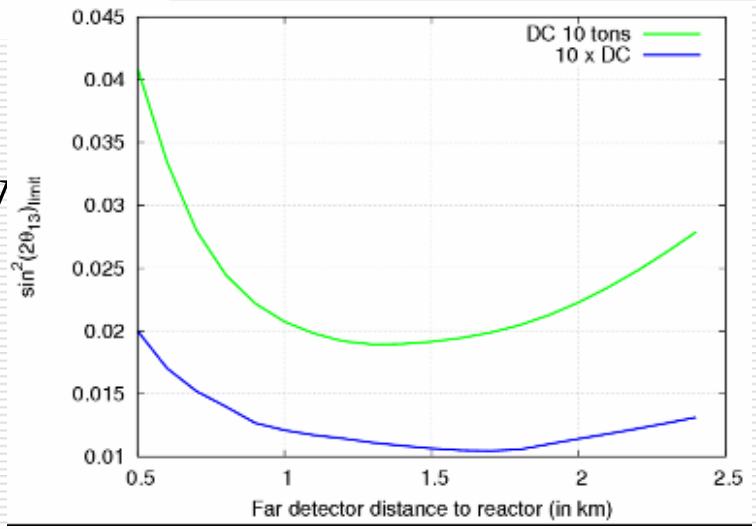
- Tuned sensitivity by optimal base line and 10t for far detector ($\sin^2 2\theta_{13} \sim 0.018$ @1.35km , 0.02 @ 1.1-1.7km assuming $\Delta m^2_{13} = 2.8 \times 10^{-3} \mathrm{eV}^2$ + 3years)

Expected sensitivity

- 10t far detector



- $\sin^2 2\theta_{13}$ ~0.02 @ 1.1-1.7km assuming Δm^2_{13}=2.8×10^{-3}eV + 3year
- Flat sensitivity for 100tons, but…



Improve of Chooz

- Statistical error (σ_{stat}= 2.7% @ Chooz)

	CHOOZ	Double-Chooz
Target volume	5,55 m^3	12,67 m^3
Target composition	6,77 10^{28} H/m^3	6,82 10^{28} H/m^3
Data taking period	Few months	3-5 years
Event rate	2700	CHOOZ-far : 60 000/3 y CHOOZ-near: >3 10^6/3 y
Statistical error	2,7%	0,4%

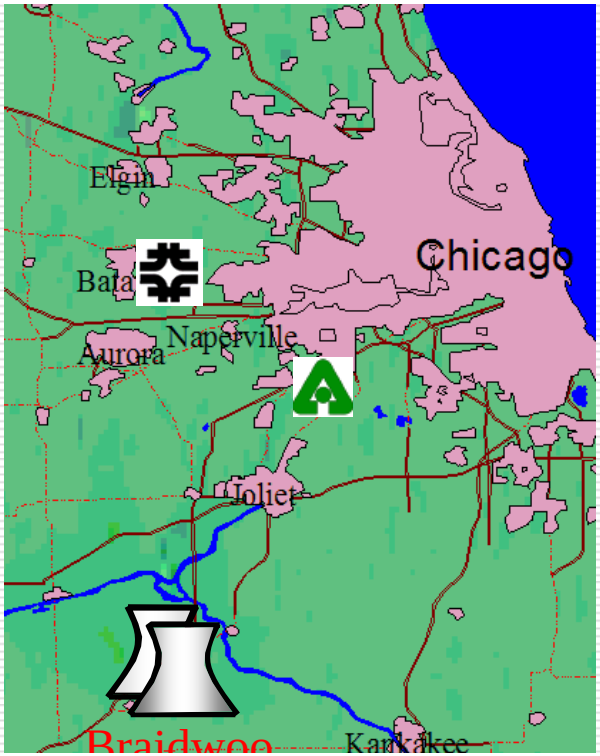
- Systematic error (σ_{sys} = 2.8% @ Chooz)
  - two identical detector make $\sigma_{relative}$=0.6%
  - Dead time ~50% @ near detector …

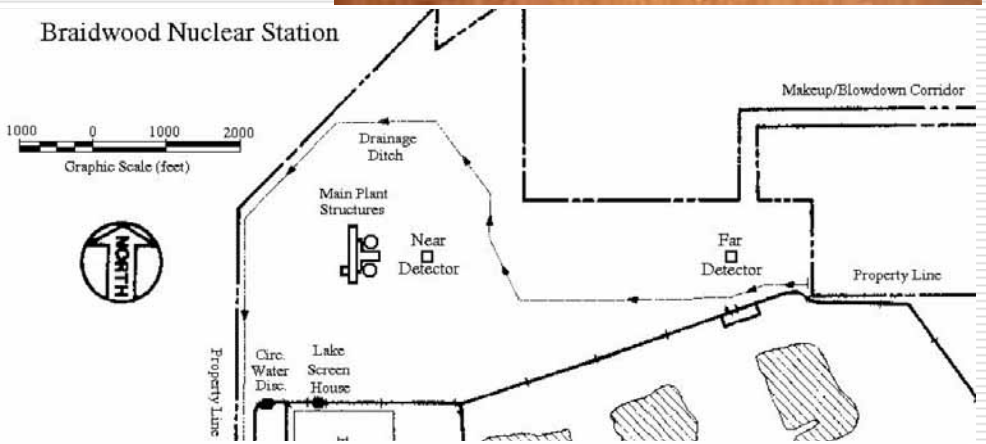
	Chooz	Double-Chooz
Reactor cross section	1.9 %	—
Number of protons	0.8 %	0.2 %
Detector efficiency	1.5 %	0.5 %
Reactor power	0.7 %	—
Energy per fission	0.6 %	—

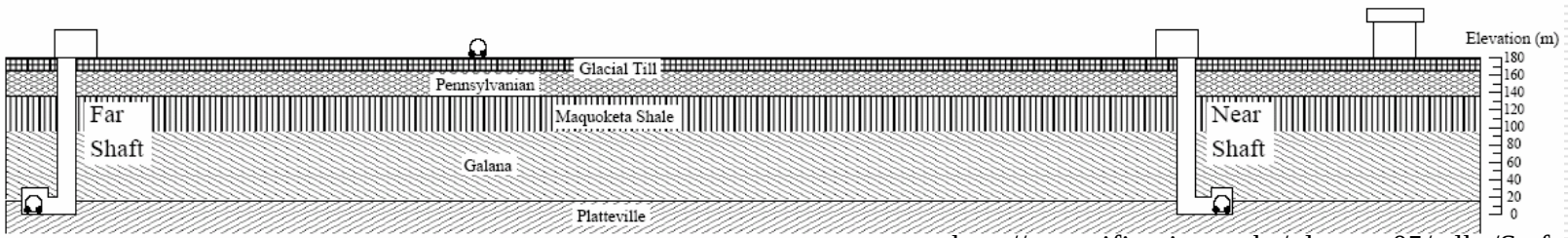
Braidwood

http://mwtheta13.uchicago.edu/

- Experimental site



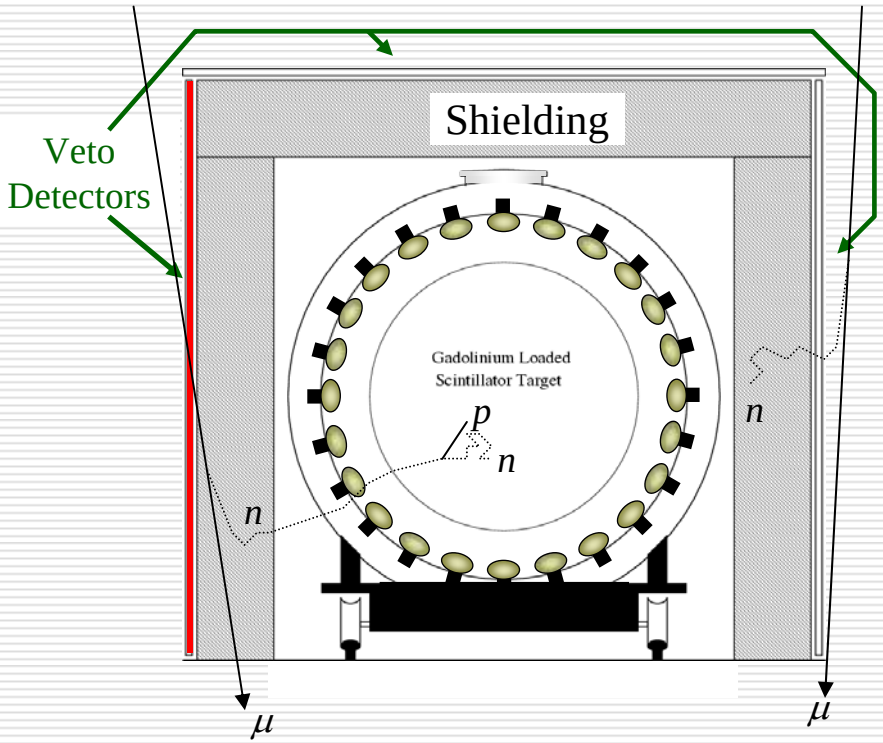




http://www.ifi.unicamp.br/~lenews05/talks/Stefanski1.ppt

Detector of Braidwood

- Fiducial volume : 5.2m radius with Gd-LS
- Buffer volume : 7m radius with mineral oil
- 1000 8”PMT with 25% coverage
- Movable detector (direct cross calibration)
- Identify and veto the few shower producing muons which produce the neutrons and spallation products

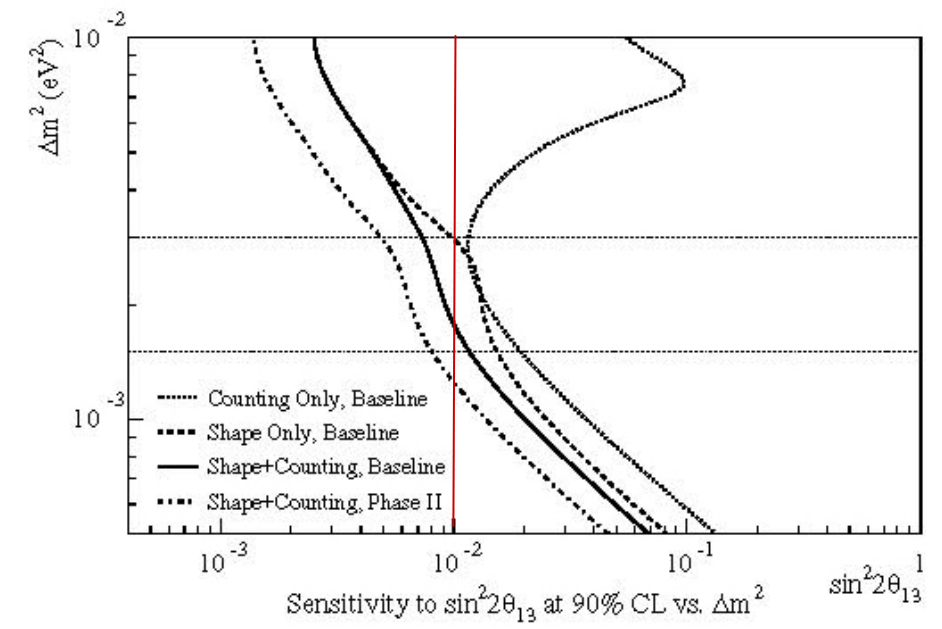


http://www.ifi.unicamp.br/~lenews05/talks/Stefanski1.ppt

Uncertainty and Sensitivity of Braidwood

- Sensitivity

http://www.ifi.unicamp.br/~lenews05/talks/Stefanski1.ppt



- Unceitainty
  - Calibrate near/far eff. vol…
  - Multi-layer veto

Source of Uncertainty	%
Near to Far Detector Relative Normalization	0.6
Far Detector Statistics	0.2
Near Detector Statistics	0.04
Backgrounds	0.5

Cost estimation and schedule for Braidwood

- Schedule
  - 2004: R&D proposal submission.
  - 2005: Full proposal submission
  - 2007: Project approval; start construction
  - 2009: Start data-taking
- Cost
  - Estimated 4 detector $18M +$5M = $23M
  - Estimated civil construction $34M + $8.5M = $42.5M
  - Total : $65.5M

Daya Bay

- Experiment site

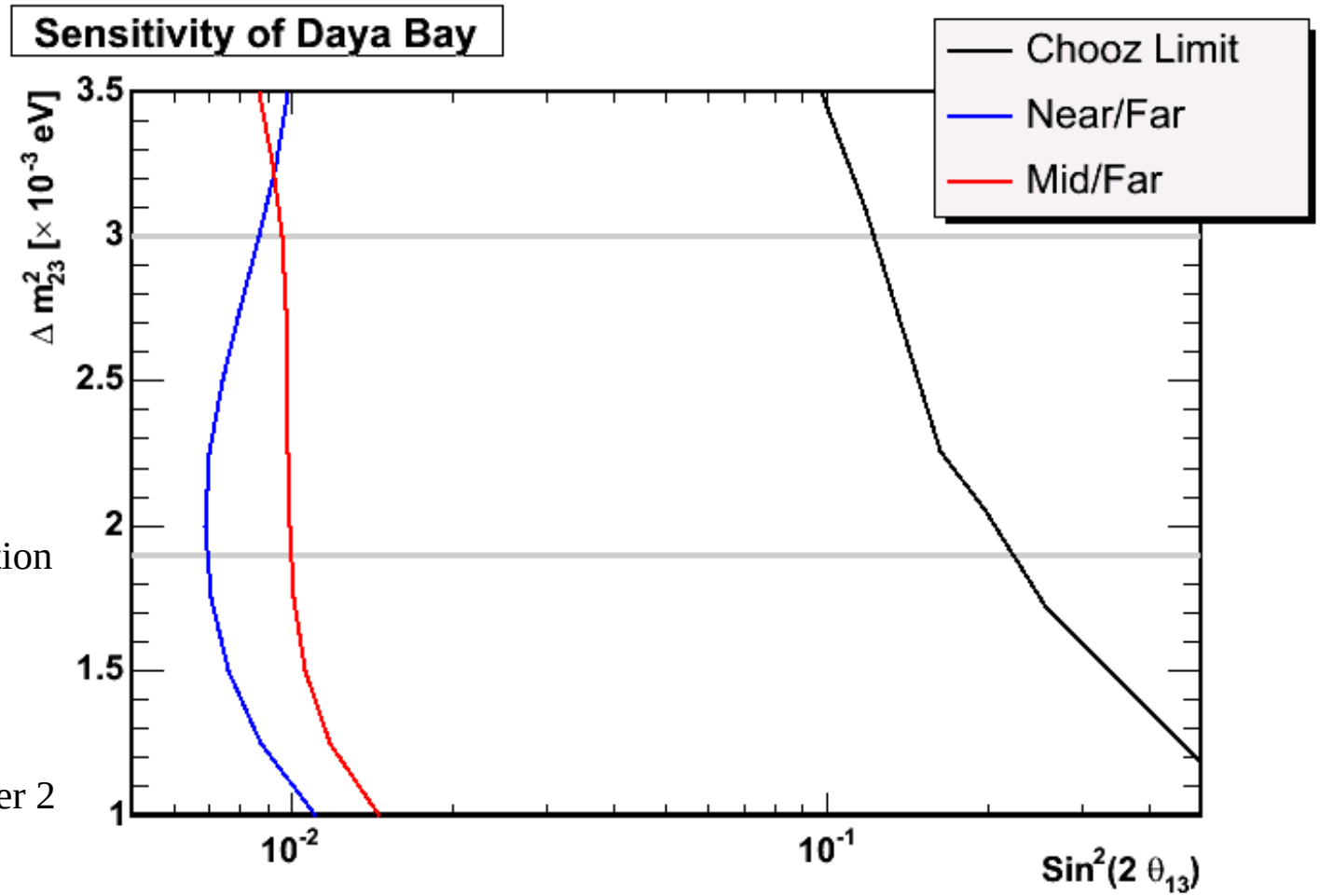
http://www.ifi.unicamp.br/~lenews05/talks/Freedman_DeyaBay.ppt

Concept:

- Minimize correlated BG
- Use horizontal tunnel
- Multi-detectors

Sensitivity of the Daya Bay

- Baselines at Daya Bay allow near/far and mid/far analysis



- volume: 5✕40 tons
- shape+rate information
- reactor systematics
  mid/far: 0.2%
  near/far: 0.08%
- 3 years of running

(cores 5+6 turn on after 2 years)

http://www.ifi.unicamp.br/~lenews05/talks/Freedman_DeyaBay.ppt

Schedule and status of Daya Bay

- Schedule
  - Summer 2005 completed geological survey
  - 2006 begin civil construction
  - Early 2007 complete tunnels and underground laboratories for near site
  - 2007 construction of tunnels for mid- and far site
  - 2008 complete tunnels and experimental halls
  - 2008/2009 begin data taking with all facilities operation
- Status
  - Good cooperation from the Daya Bay Nuclear power plant.
  - R&D agreement between US and China.
  - Have formed a proto-collaboration.
  - Two collaboration meetings (Dec 2004 and Jan 2005).
  - LOI / proposal in preparation

Summary

- Reactor medium base-line experiment could be complementary with accelerator long base-line experiment for θ_{13} physics.
- Most powerful reactor Kashiwazaki-Kariwa station (Tokyo Electronic Power Co.) agree with our project.
- Collaboration is growing up and welcome to your participation.
- Discussing actual design for 3 identical detector and location for far detector, shaft hall, construction methods…
- Getting R&D fund, need REAL budget!
- KASKA will start from JFY2008, if it's on schedule