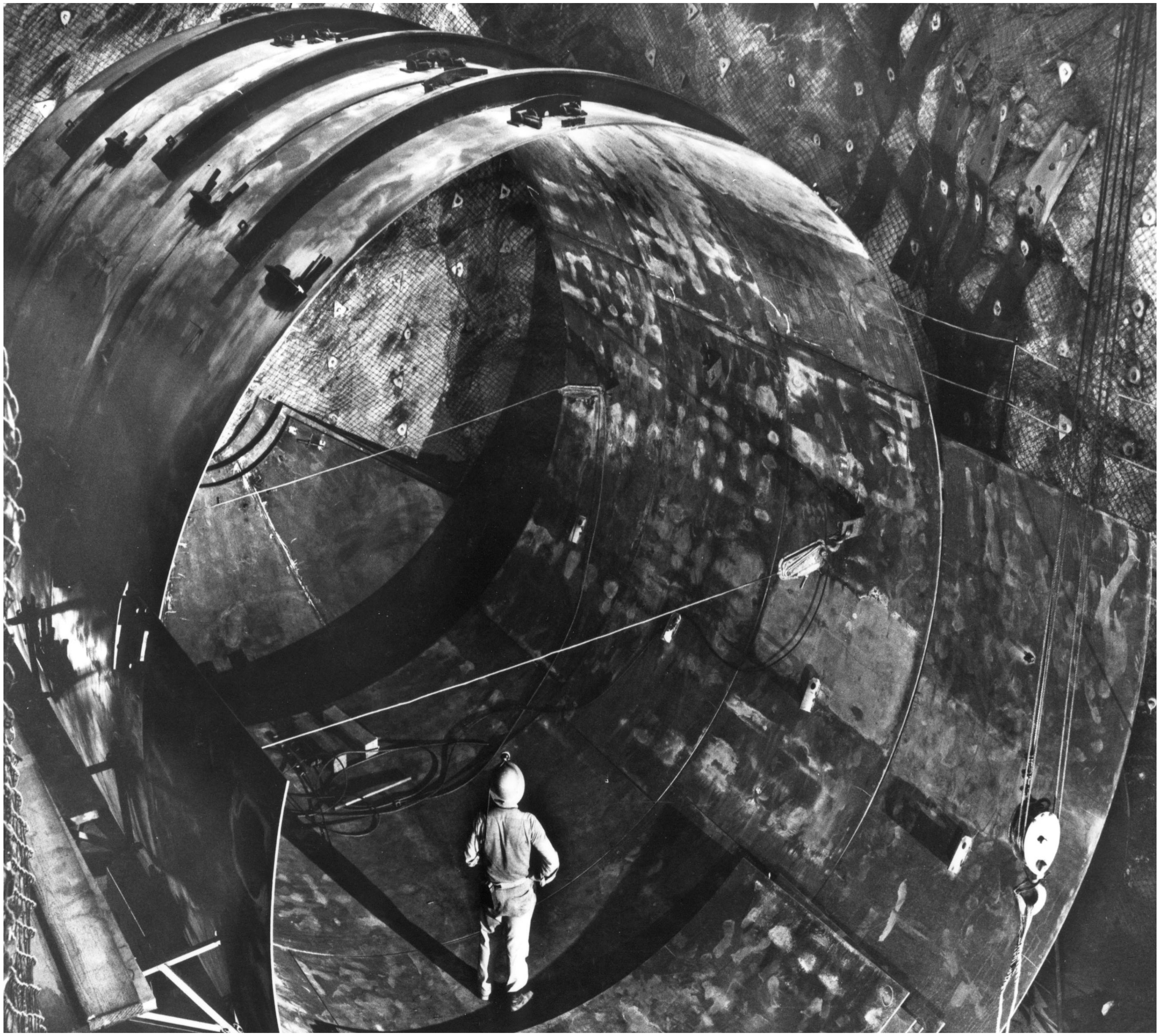
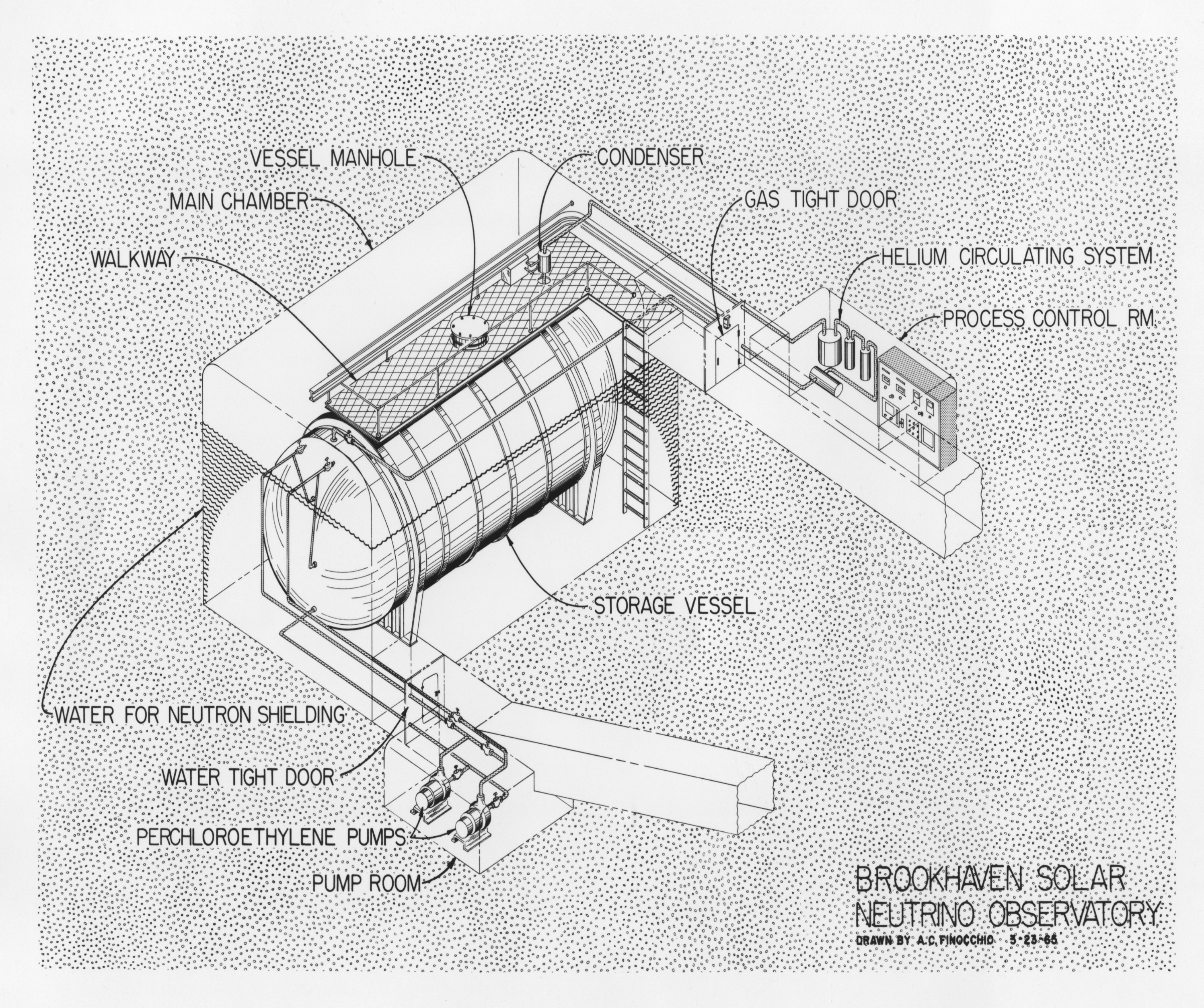
# Physics 125

5/10/2010

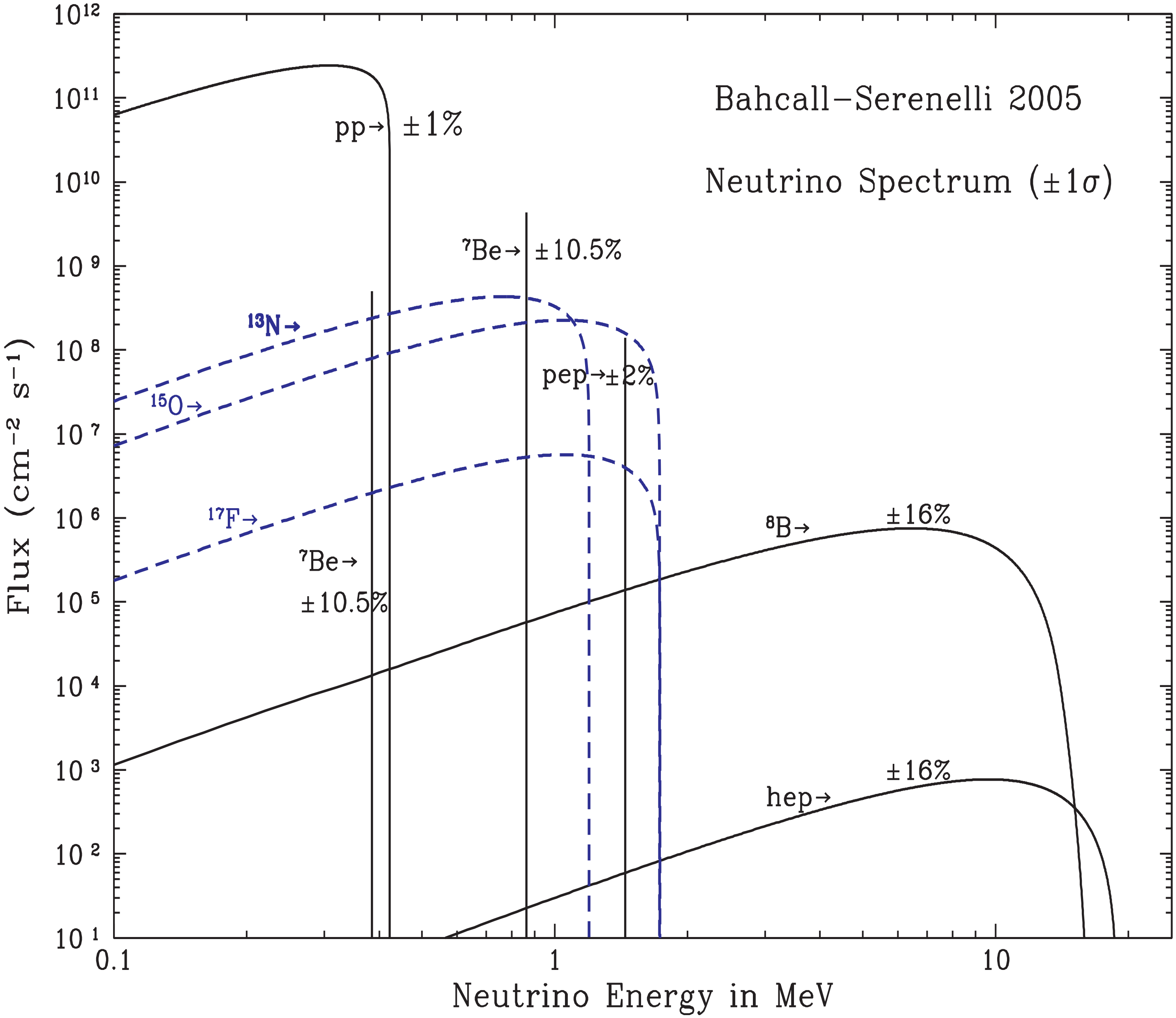
# Davis Tank – Near Deadwood



# Davis Experiment



# Solar Neutrino Flux



# The Search Plot

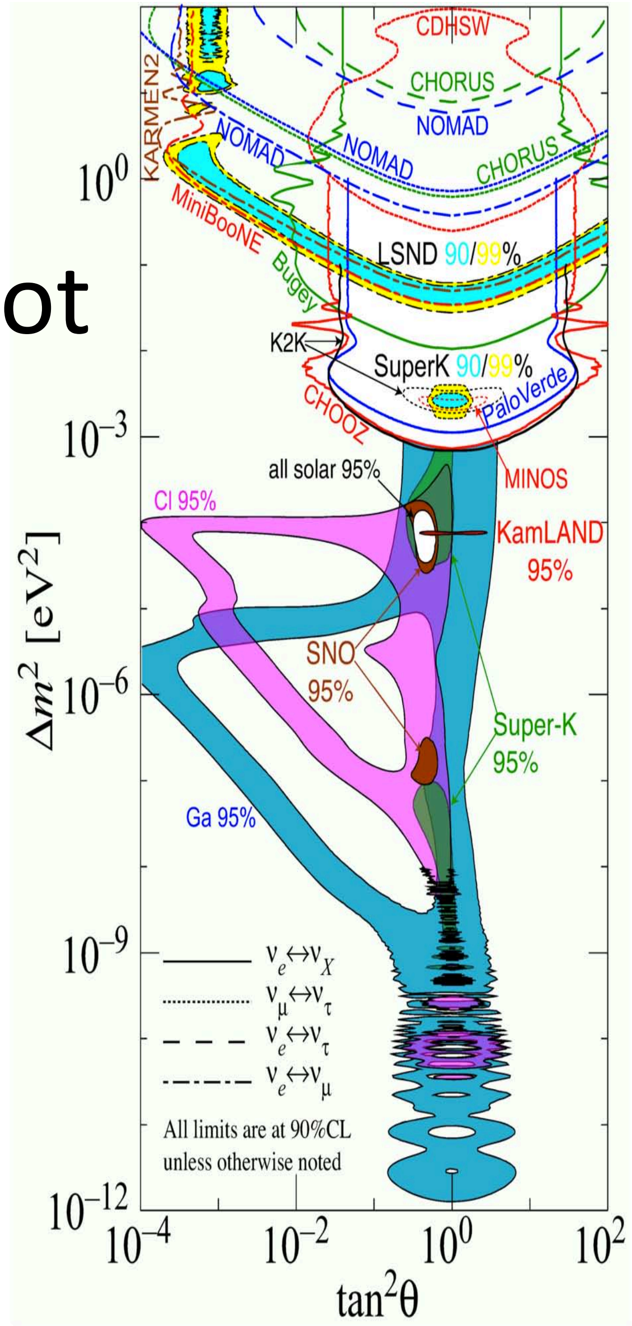


**Figure 13.4:** The regions of squared-mass splitting and mixing angle favored or excluded by various experiments. This figure was contributed by H. Murayama (University of California, Berkeley). References to the data used in the figure can be found at http://hitoshi.berkeley.edu/neutrino/.

# Earth-based reactor experiment

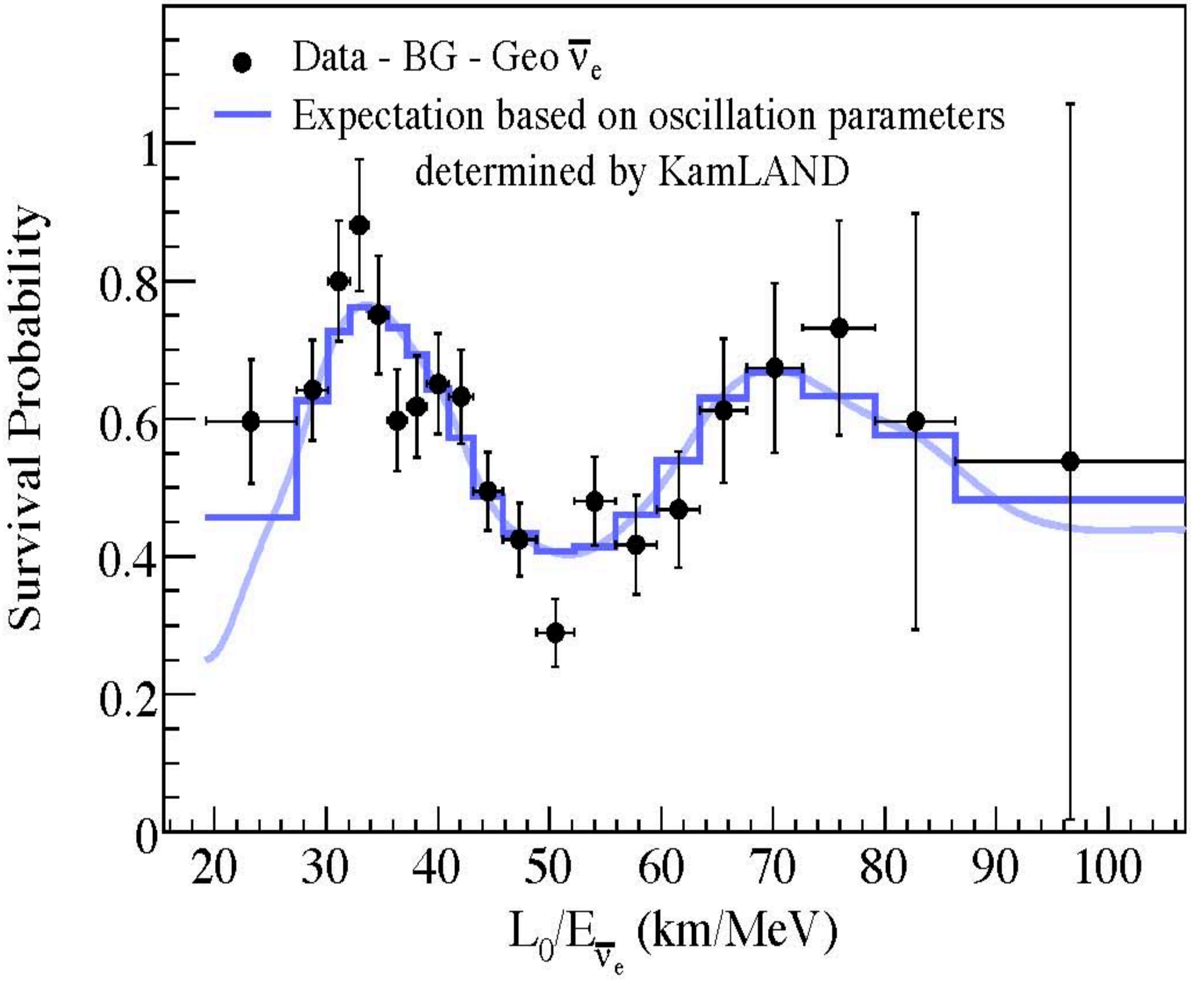
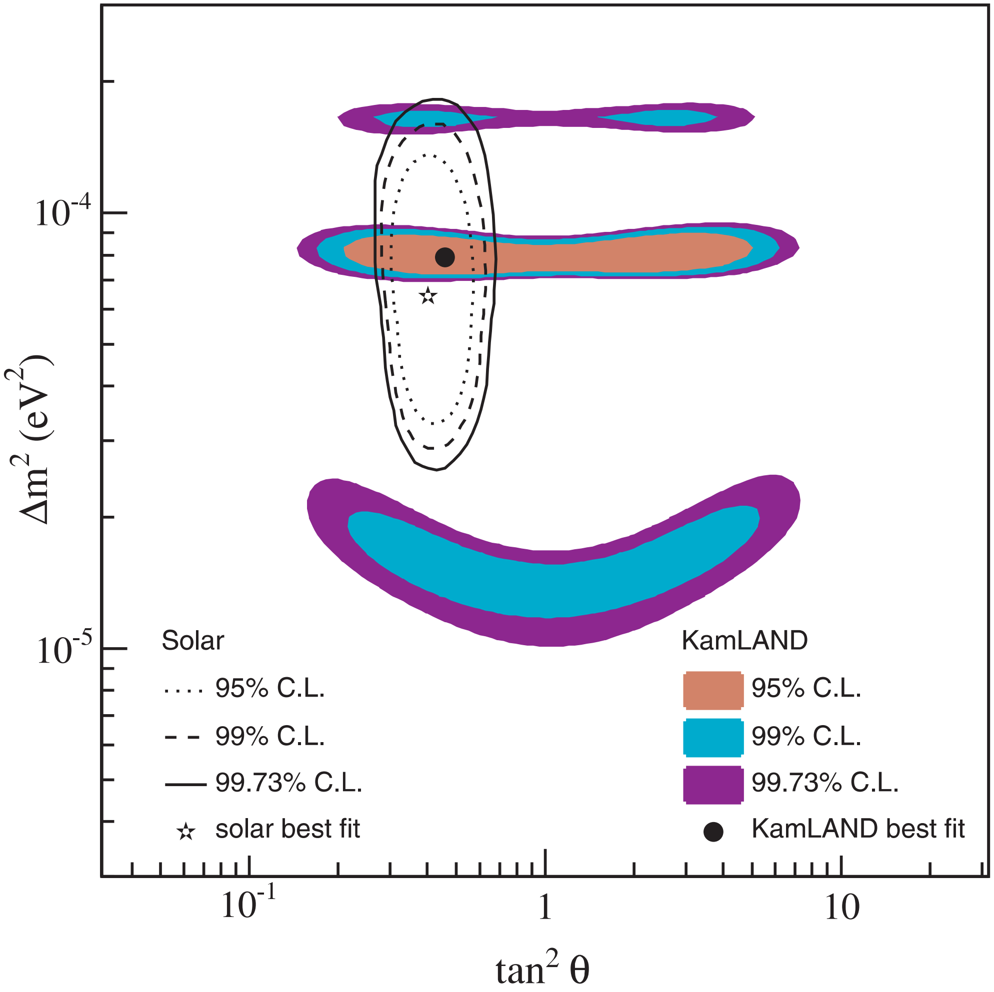


**Figure 13.2:** Ratio of the background- and geo-neutrino subtracted $\overline{\nu_e}$ spectrum to the no-oscillation expectation as a function of $L_0/E$ [28]. See text for explanation.

# Solar/KAMLAND



# Atmospheric…

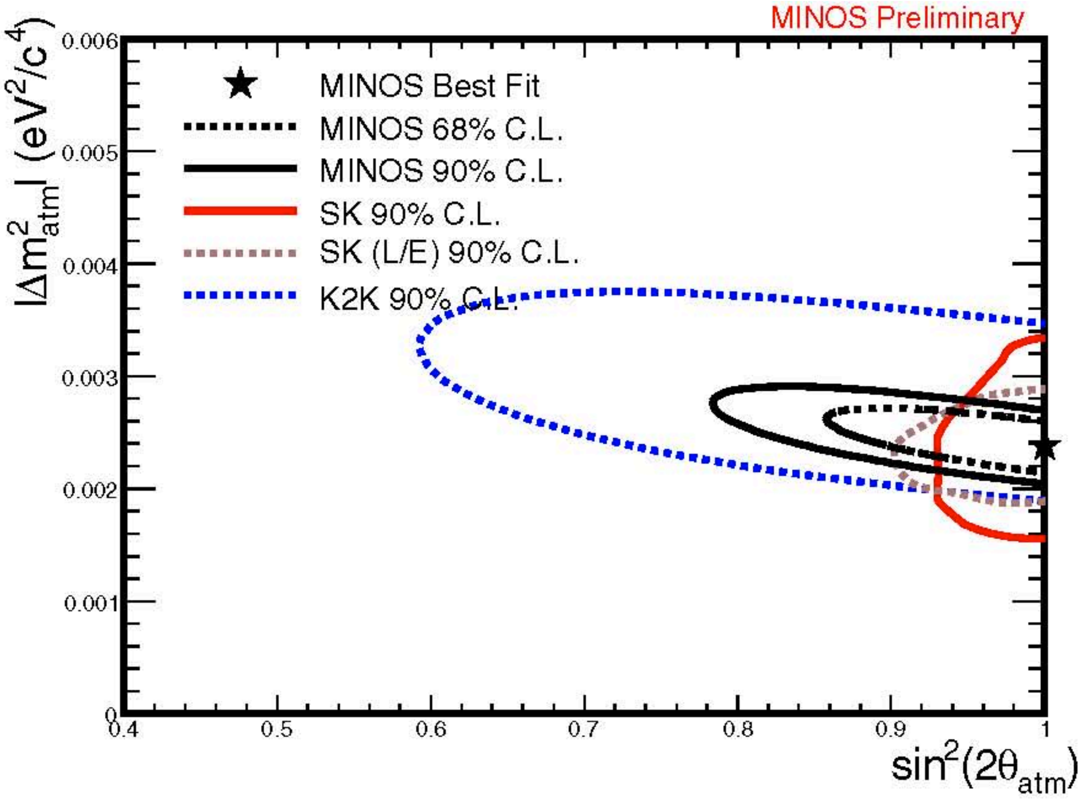


**Figure 13.1:** The region of the atmospheric oscillation parameters $\Delta m^2_{\text{atm}}$ and $\sin^2 2\theta_{\text{atm}}$ allowed by the SK, K2K, and MINOS data. The results of two different analyses of the SK ("Super K") data are shown [21].

# Electron Neutrino Appearance (RPP)

With a conventional beam, one would seek $CP$ violation, and try to determine whether the mass spectrum is normal or inverted, by studying the oscillations $\nu_\mu \to \nu_e$ and $\overline{\nu_\mu} \to \overline{\nu_e}$. The appearance probability for $\nu_e$ in a beam that is initially $\nu_\mu$ can be written for $\sin^2 2\theta_{13} < 0.2$ [53]

$$P(\nu_\mu \to \nu_e) \cong \sin^2 2\theta_{13}\, T_1 - \alpha \sin 2\theta_{13}\, T_2 + \alpha \sin 2\theta_{13}\, T_3 + \alpha^2 T_4 \quad . \tag{13.39}$$

Here, $\alpha \equiv \Delta m^2_{21}/\Delta m^2_{31}$ is the small ($\sim 1/30$) ratio between the solar and atmospheric squared-mass splittings, and

$$T_1 = \sin^2\theta_{23} \frac{\sin^2[(1-x)\Delta]}{(1-x)^2} \quad , \tag{13.40}$$

$$T_2 = \sin\delta \sin 2\theta_{12} \sin 2\theta_{23} \sin\Delta \frac{\sin(x\Delta)}{x} \frac{\sin[(1-x)\Delta]}{(1-x)} \quad , \tag{13.41}$$

$$T_3 = \cos\delta \sin 2\theta_{12} \sin 2\theta_{23} \cos\Delta \frac{\sin(x\Delta)}{x} \frac{\sin[(1-x)\Delta]}{(1-x)} \quad , \tag{13.42}$$

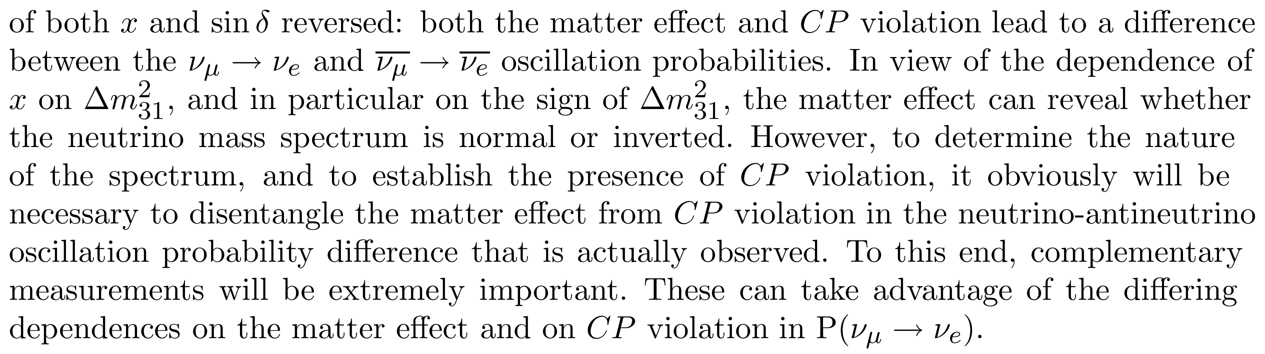
and

$$T_4 = \cos^2\theta_{23} \sin^2 2\theta_{12} \frac{\sin^2(x\Delta)}{x^2} \quad . \tag{13.43}$$

In these expressions, $\Delta \equiv \Delta m^2_{31} L/4E$ is the kinematical phase of the oscillation. The quantity $x \equiv 2\sqrt{2} G_F N_e E/\Delta m^2_{31}$, with $G_F$ the Fermi coupling constant and $N_e$ the electron number density, is a measure of the importance of the matter effect resulting from coherent forward-scattering of electron neutrinos from ambient electrons as the neutrinos travel through the earth from the source to the detector [cf. Sec. I]. In the appearance probability P$(\nu_\mu \to \nu_e)$, the $T_1$ term represents the oscillation due to the atmospheric-mass-splitting scale, the $T_4$ term represents the oscillation due to the solar-mass-splitting scale, and the $T_2$ and $T_3$ terms are the $CP$-violating and $CP$-conserving interference terms, respectively.

The probability for the corresponding antineutrino oscillation, P$(\overline{\nu_\mu} \to \overline{\nu_e})$, is the same as the probability P$(\nu_\mu \to \nu_e)$ given by Eqs. (13.39)–(13.43), but with the signs in front

# Electron Neutrino Appearance (2) (RPP)

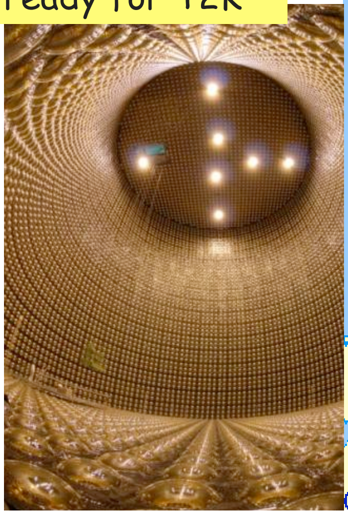


of both $x$ and $\sin\delta$ reversed: both the matter effect and $CP$ violation lead to a difference between the $\nu_\mu \to \nu_e$ and $\overline{\nu_\mu} \to \overline{\nu_e}$ oscillation probabilities. In view of the dependence of $x$ on $\Delta m^2_{31}$, and in particular on the sign of $\Delta m^2_{31}$, the matter effect can reveal whether the neutrino mass spectrum is normal or inverted. However, to determine the nature of the spectrum, and to establish the presence of $CP$ violation, it obviously will be necessary to disentangle the matter effect from $CP$ violation in the neutrino-antineutrino oscillation probability difference that is actually observed. To this end, complementary measurements will be extremely important. These can take advantage of the differing dependences on the matter effect and on $CP$ violation in $\mathrm{P}(\nu_\mu \to \nu_e)$.

# Tokai to Kamiokande - Sakashita

## T2K Experiment

Supre-K
ready for T2K



*Long base-line ν oscillation experiment in Japan*

**J-PARC@Tokai**

**Super-K
50kton**

New accelerator(~MW),
ν beam-line & detector

T2K first beam commissioning
in Apr-May '09

T2K features to enhance the sensitivity

- **Super-K(SK) as main neutrino detector** :
  22.5kton(fiducial) water cherenkov detector & good PID (e/μ) performance
- **Off-axis beam** (intense & narrow-band low energy neutrino beam) ⟶ next slide
- **Neutrino energy reconstruction** :
  CCQE interactions dominate at T2K beam energy

# Tokai to Kamiokande - Sakashita

## Next step of ν oscillation experiment

Neutrino Oscillation Experiment

$U_{e3} = s_{13}e^{-i\delta}$

**NEUTRINOS**

$$U_{MNSP} \sim \begin{pmatrix} 0.8 & 0.5 & \boxed{?} \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

- **discover a finite $\theta_{13}$**
  - determine $|U_{e3}|$
    → **important role for future neutrino experiments**
    - **CPV in lepton sector**
      → hint on Baryon# asymmetry of Universe
    - mass hierarchy
- **precise measurement**
  - Is $\theta_{23}$ maximal ?

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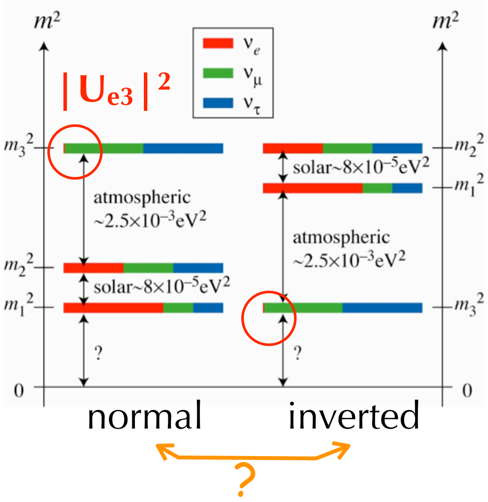
**0νββ decay exp.**
- Dirac or Majorana

**Tritium β decay exp.**
- absolute mass scale

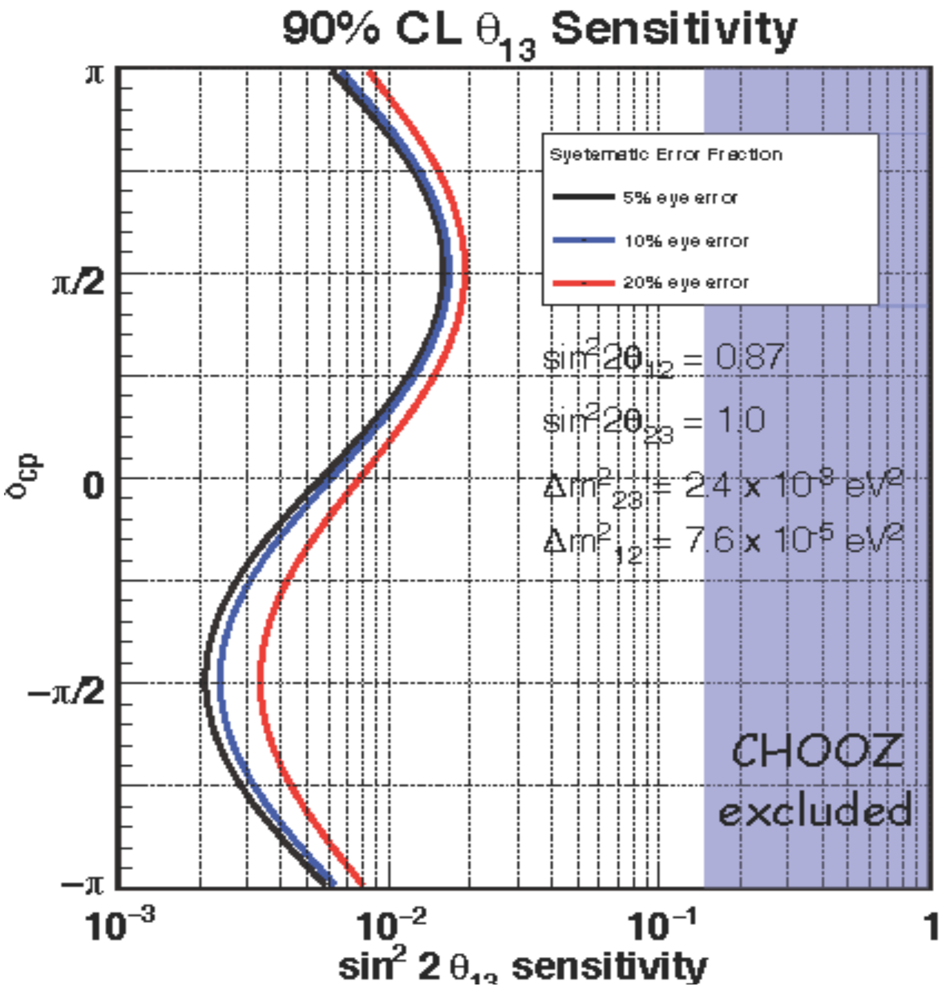


# Nova – starts about 2013

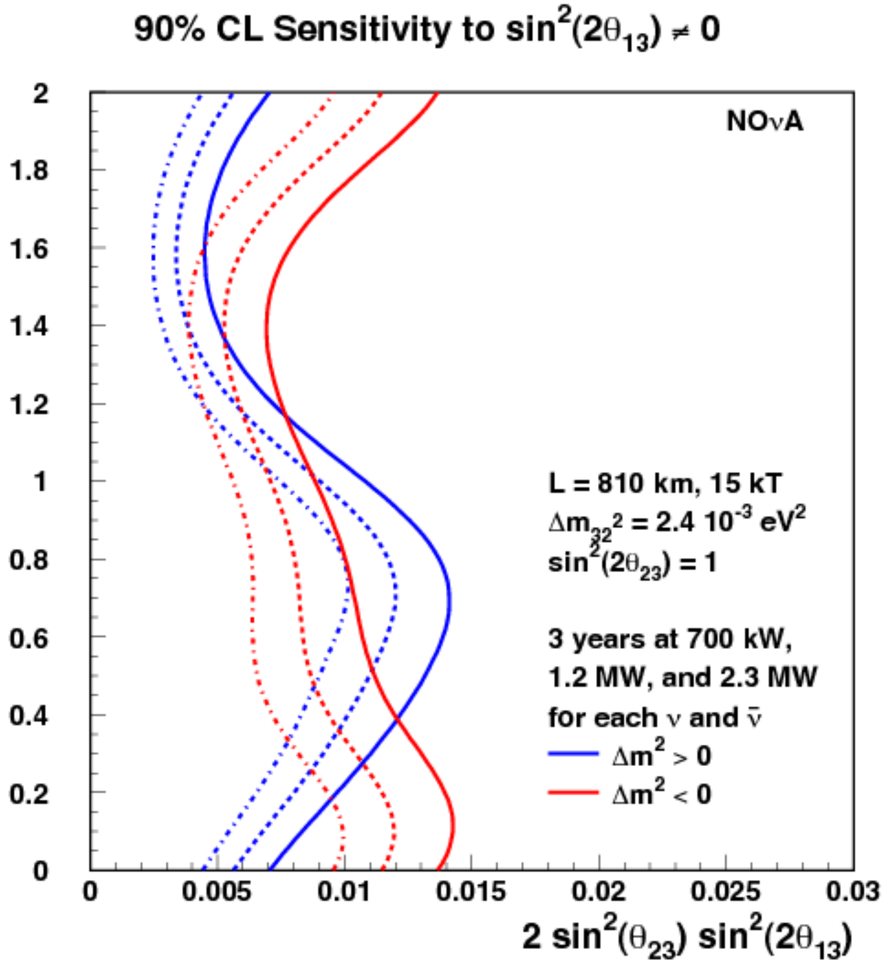
# The `Money Plots'

T2K

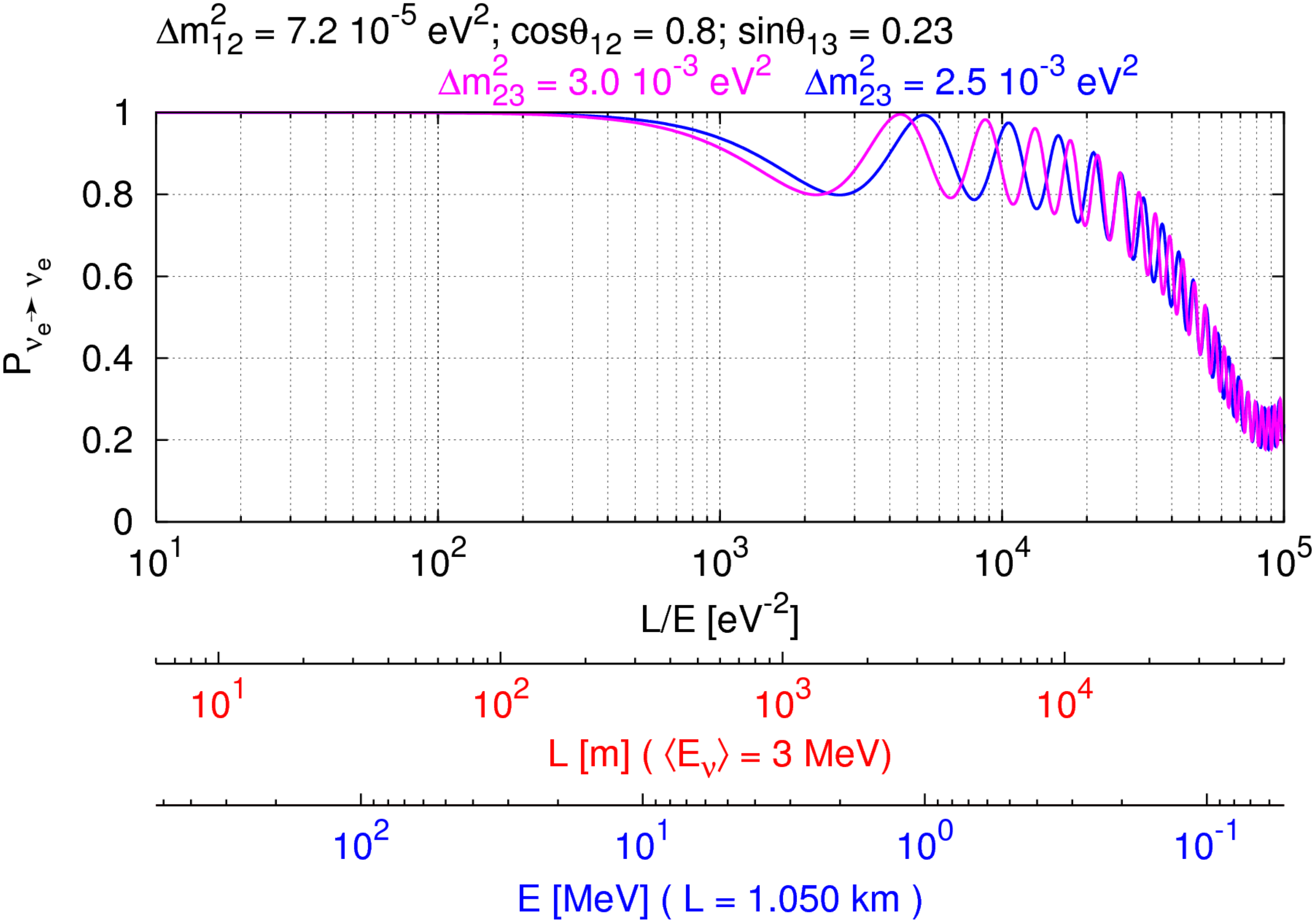
> x10 improvement from CHOOZ limit



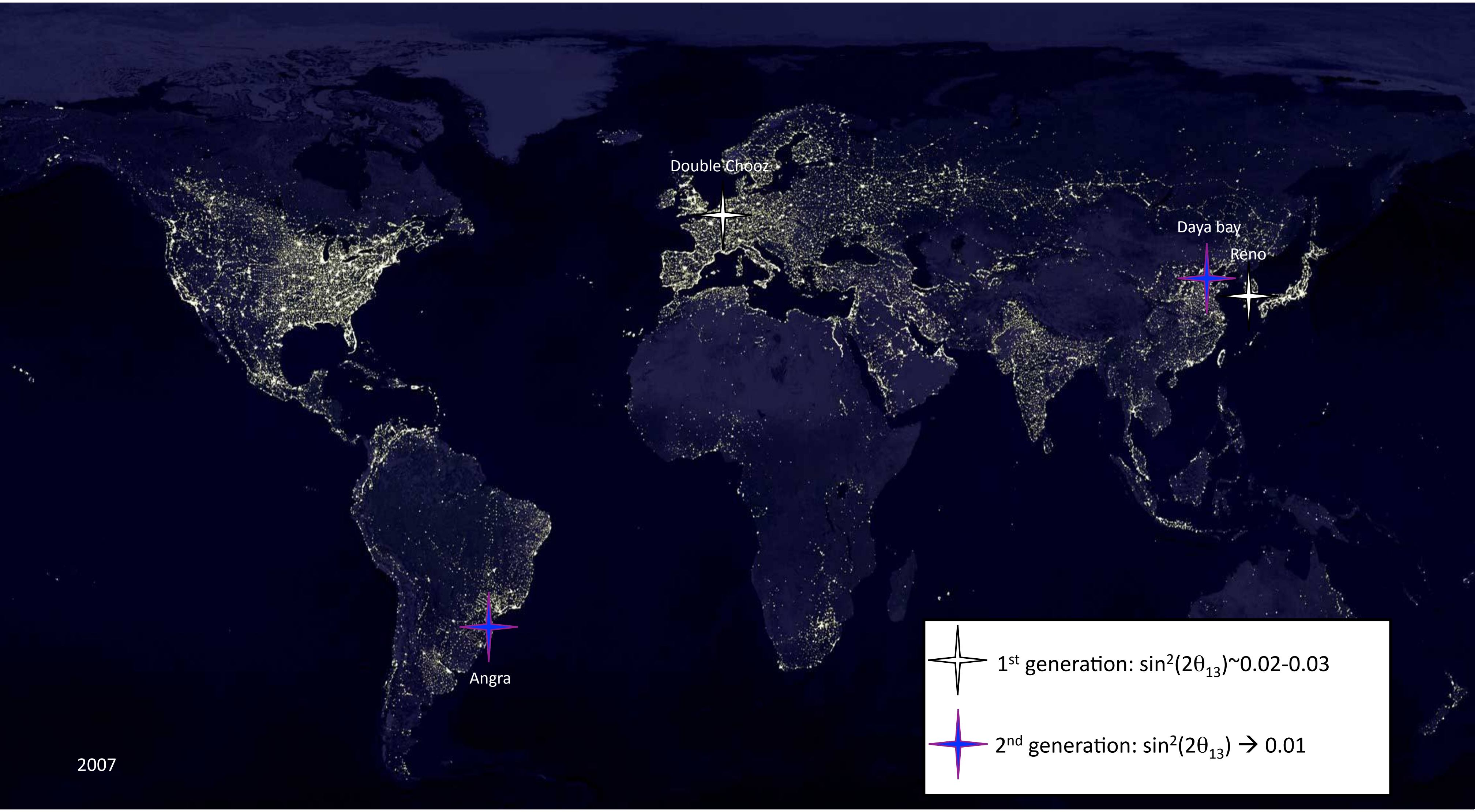
Nova



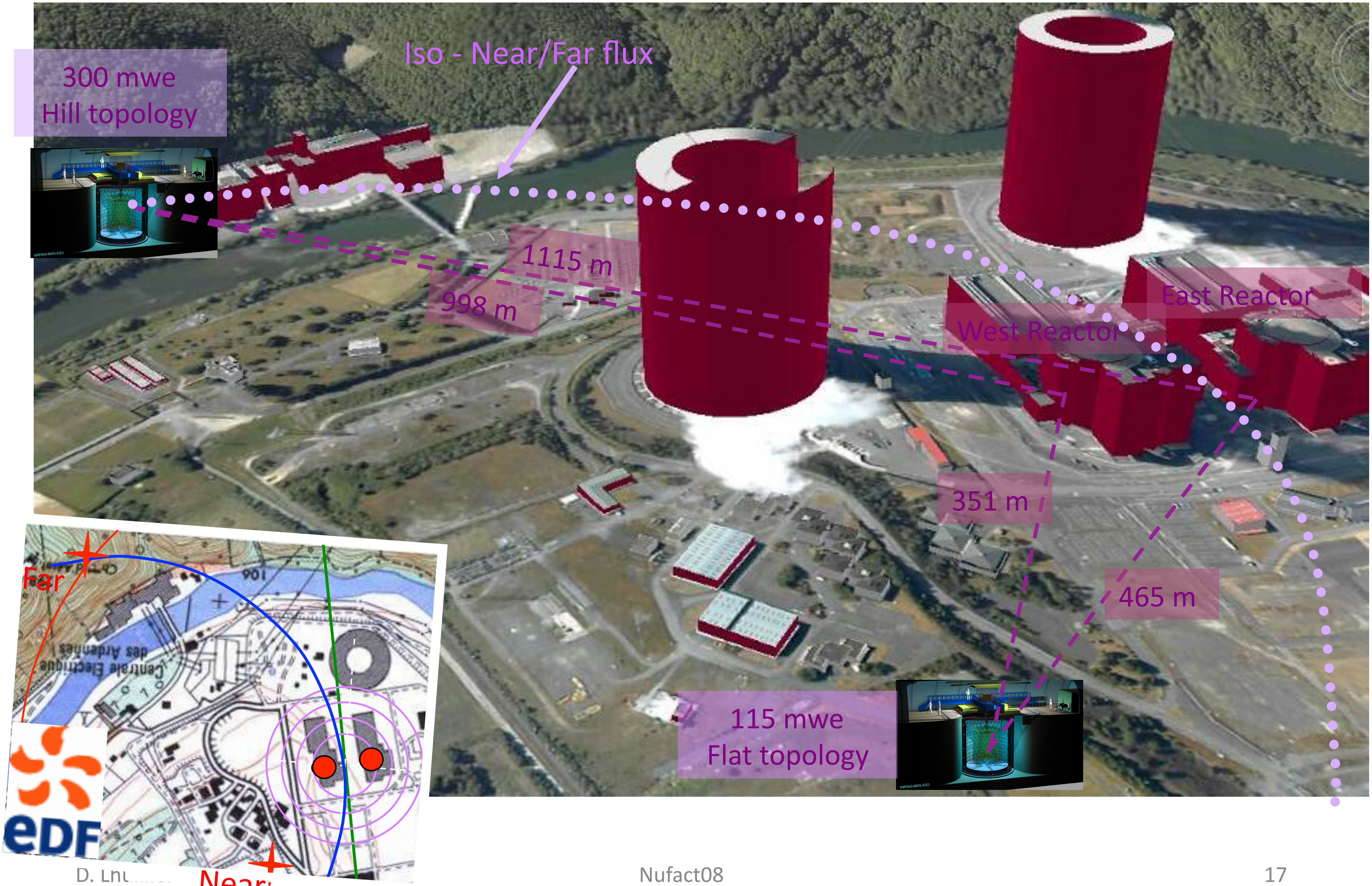
# Electron antineutrino disapperance



# Looking for Sites



# Site in French Ardennes



300 mwe
Hill topology

Iso - Near/Far flux

115 mwe
Flat topology

# Daya Bay…

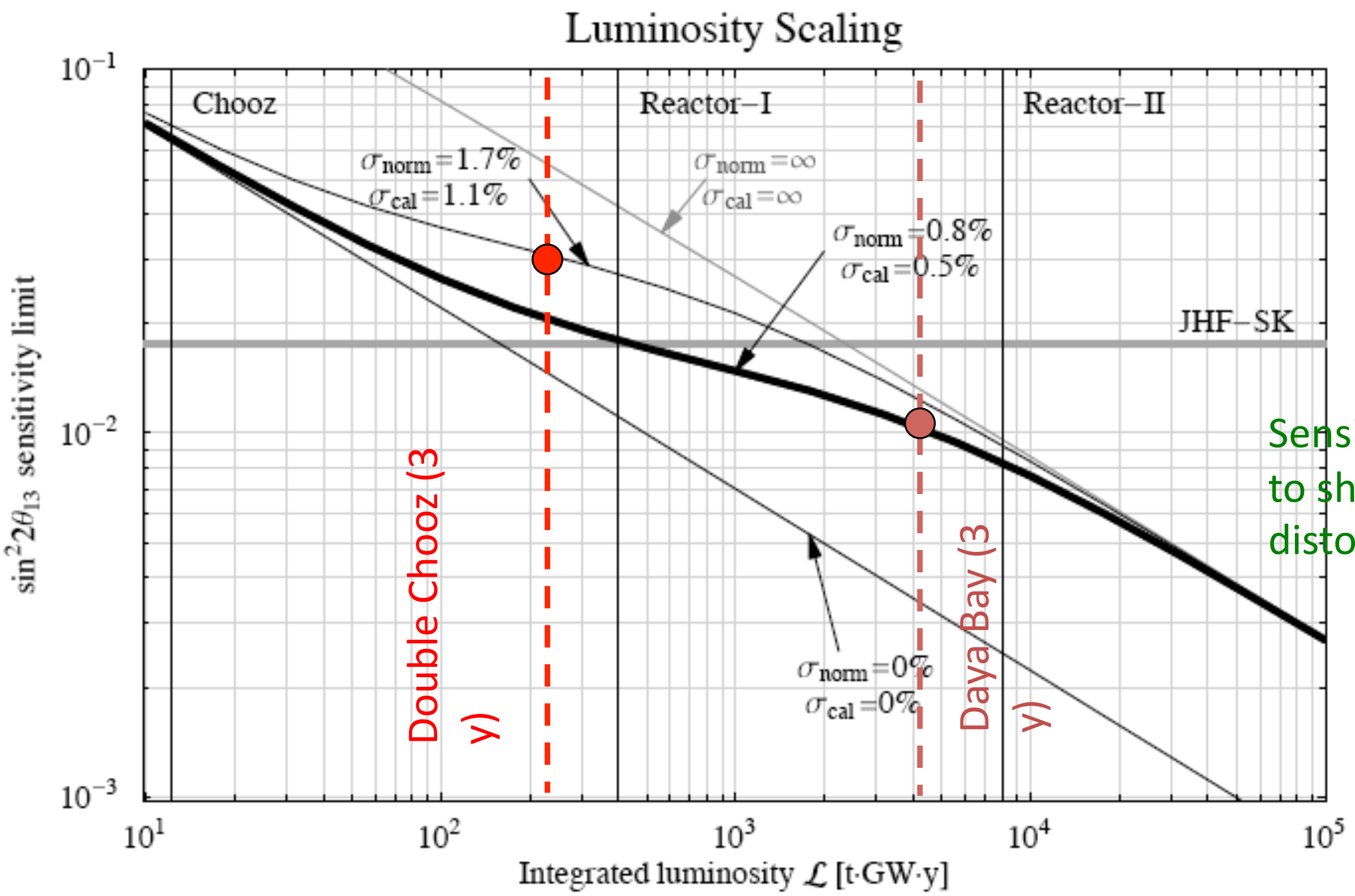

km
5
10
15
mi
4
8
Microsoft® MapPoint®
Tiantangwei
Longgang
Aotou
Guanlan
Pingshan
Shiyan
G U A N G D O N G
Niudipu
Longhua
Henggang
Buji
Kuiyong
Dapeng
Daya Bay
Nantou
Yantian
Xin'an
Shenzhen
Sha Tau Kok
Shatoujiao
Tai Pang Wan
Tong O
Zhujiang Kou
Jiujie
Pak Shek Au
Man Uk Pin
Tung Wan
Lai Tau Shek
Cheung Wo
22° 30'
Fanling
Shekou
San Tin
San Wai
Ting Kok
Shuen Wan
San Hing Tsuen
Kau Lau Wan
Yung Shue Au
Hau Hoi Wan
Yuen Long
Lin Fa Tei
Tai Po
Wu Lei Kiu
XIAOSANMEN DAO
Wu Kwai Sha
Tuen Mun
HONG KONG SAR (CHINA)
Wong Yi Chau
Sam Shing Hui
Tsuen Wan
Sha Tsiu
Sai Kung
Pak A
Sham Wan Tsuen
Cheung Sha Wan
Pik Uk
Fu Tau Pun Chau
Kai Tak International Airport
Pa Tau Kwu
Kowloon
Yau Tong
Wo Sheung Au
KENNEDY TOWN
HAPPY VALLEY
TAI YUE SHAN
Sunset Peak
Victoria Peak 554 m (1818 ft)
Hong Kong
Tai O
Mount Collinson
Tong Fuk
Yi O San Tsuen
Stanley Mount
South China Sea
Fa Peng
Mount Stenhouse
Siu A Chau Tsuen
©2003 Microsoft Corp.
114°
114° 30'

# Perpectives @ Reactors

*P.Huber, M.Lindner, T.Schwetz and W.Winter*

*Nucl.Phys.B665:487-519,2003*

Giant detectors?



Sensitive to shape distorsion