θ_{13} The Key to CP (?)

Jim Napolitano
Rensselaer Polytechnic Institute

"The Revolution in Particle Physics is Here!"
Aspen Particle Physics Conference
17-23 January 2010

Hubble Ultra Deep Field • Infrared

HST • WFC3/IR

NASA, ESA, G. Illingworth (UCO/Lick Observatory and University of California, Santa Cruz), and the HUDF09 Team

STScI-PRC09-31

The Mass Mixing Matrix for Neutrinos

Quarks mix via the CKM matrix;
neutrinos mix via the MNSP matrix ...

$$U_{\mathrm{MNSP}} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{bmatrix} \begin{bmatrix} \cos\theta_{13} & 0 & e^{-i\delta}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta}\sin\theta_{13} & 0 & \cos\theta_{13} \end{bmatrix} \begin{bmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

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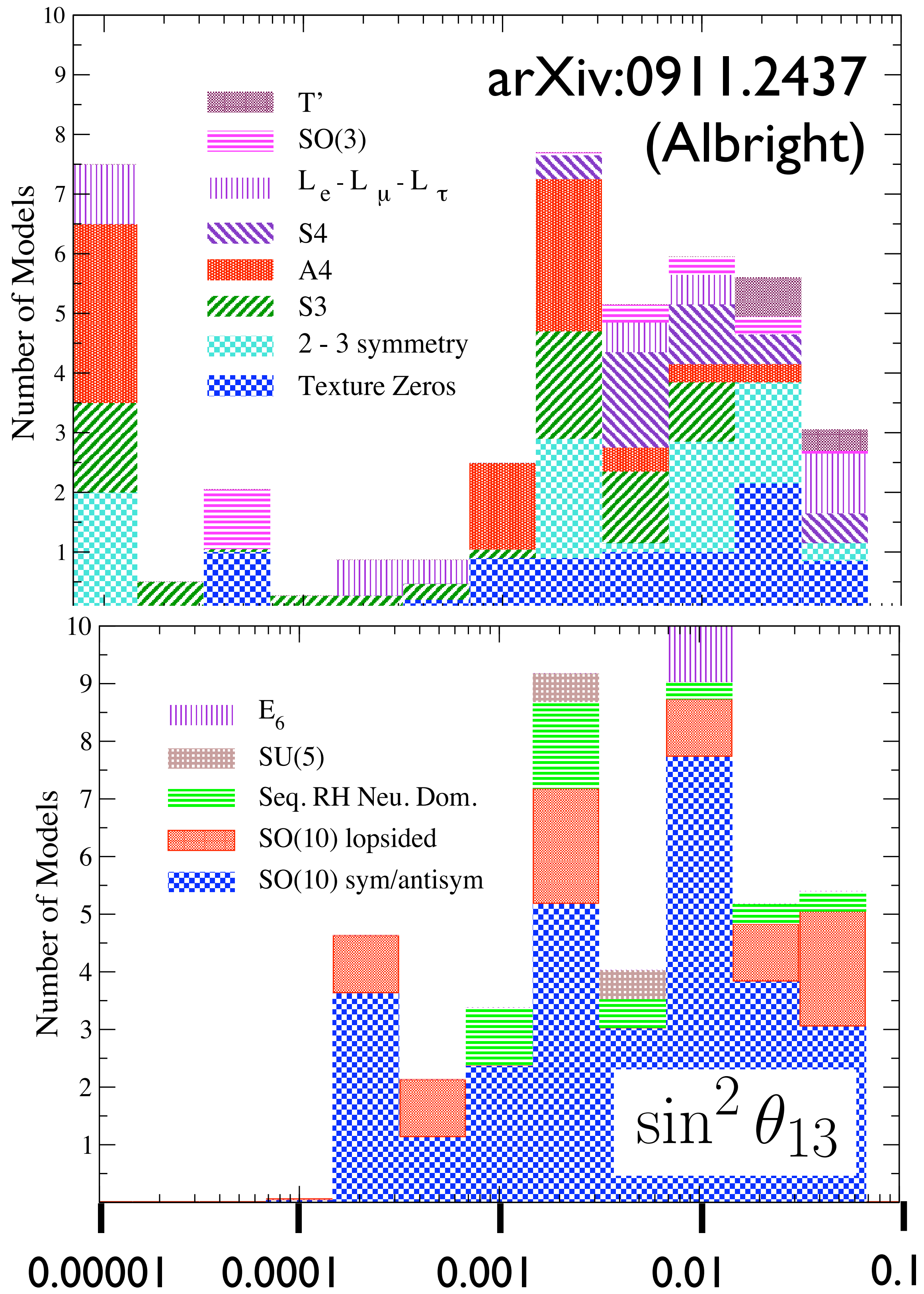
CP Violation!

The extent depends on the size of θ_{13}, but current limits are consistent with zero.

Solar neutrinos, confirmed with KamLAND

Values for θ13: Theory and Experiment



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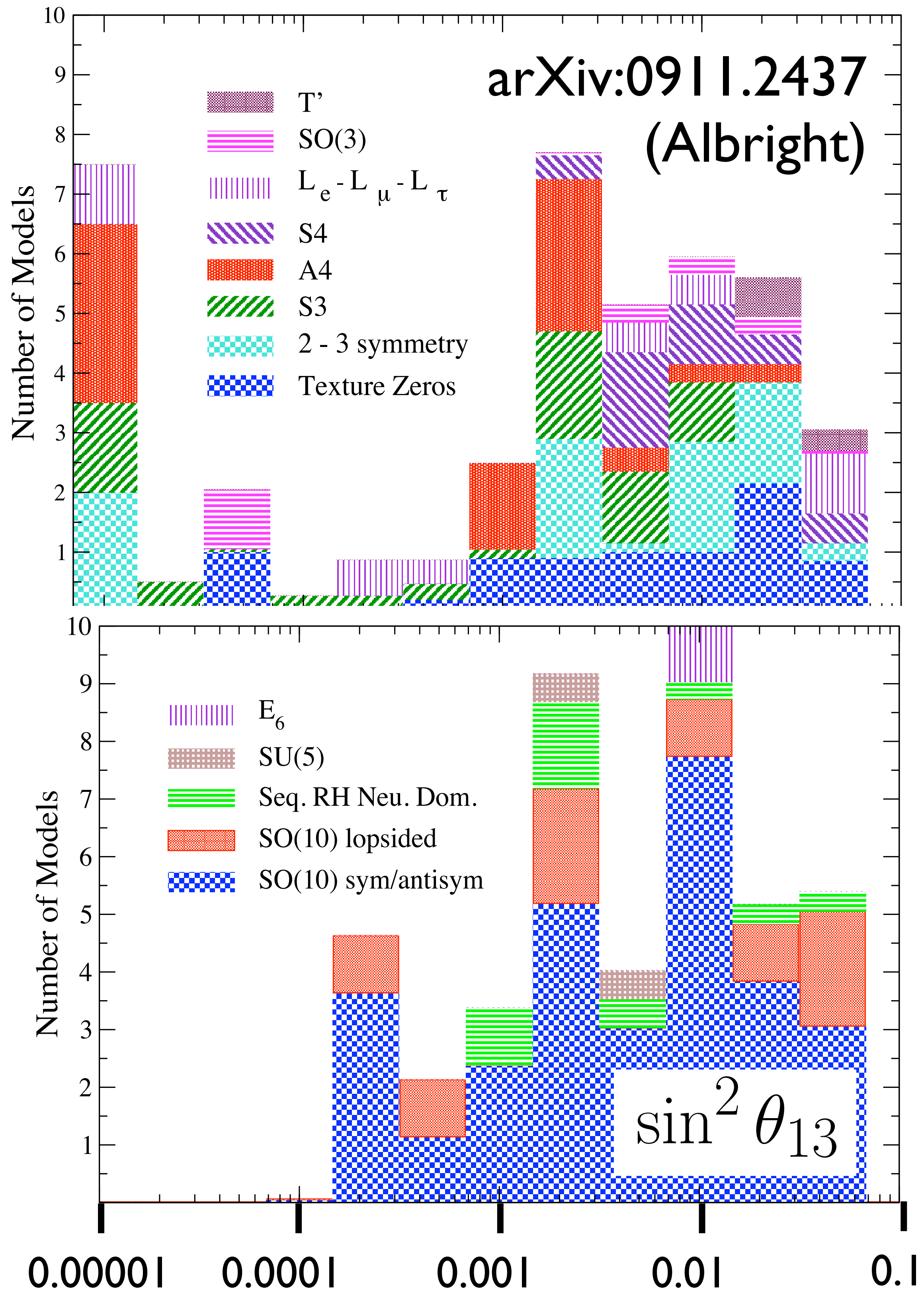
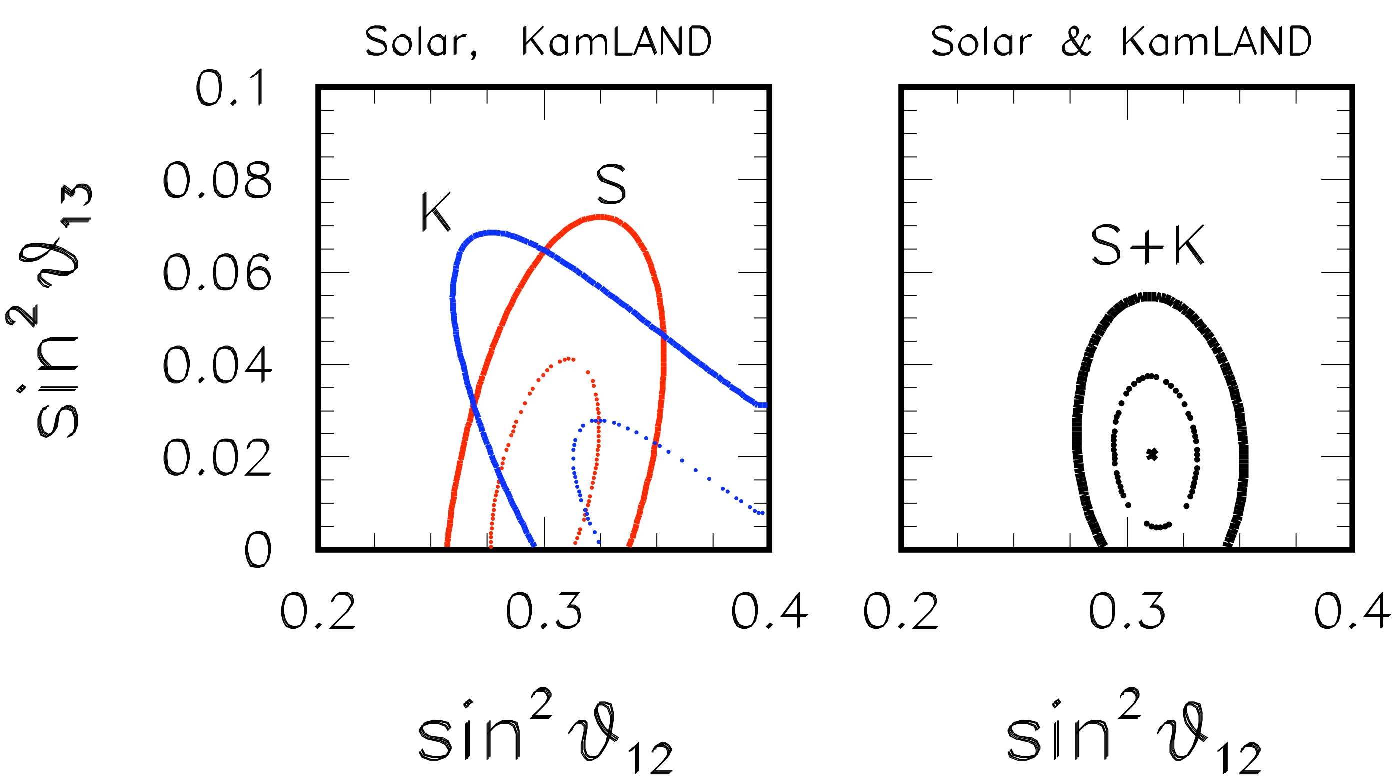


Fogli, et al, PRL 101(2008)141801



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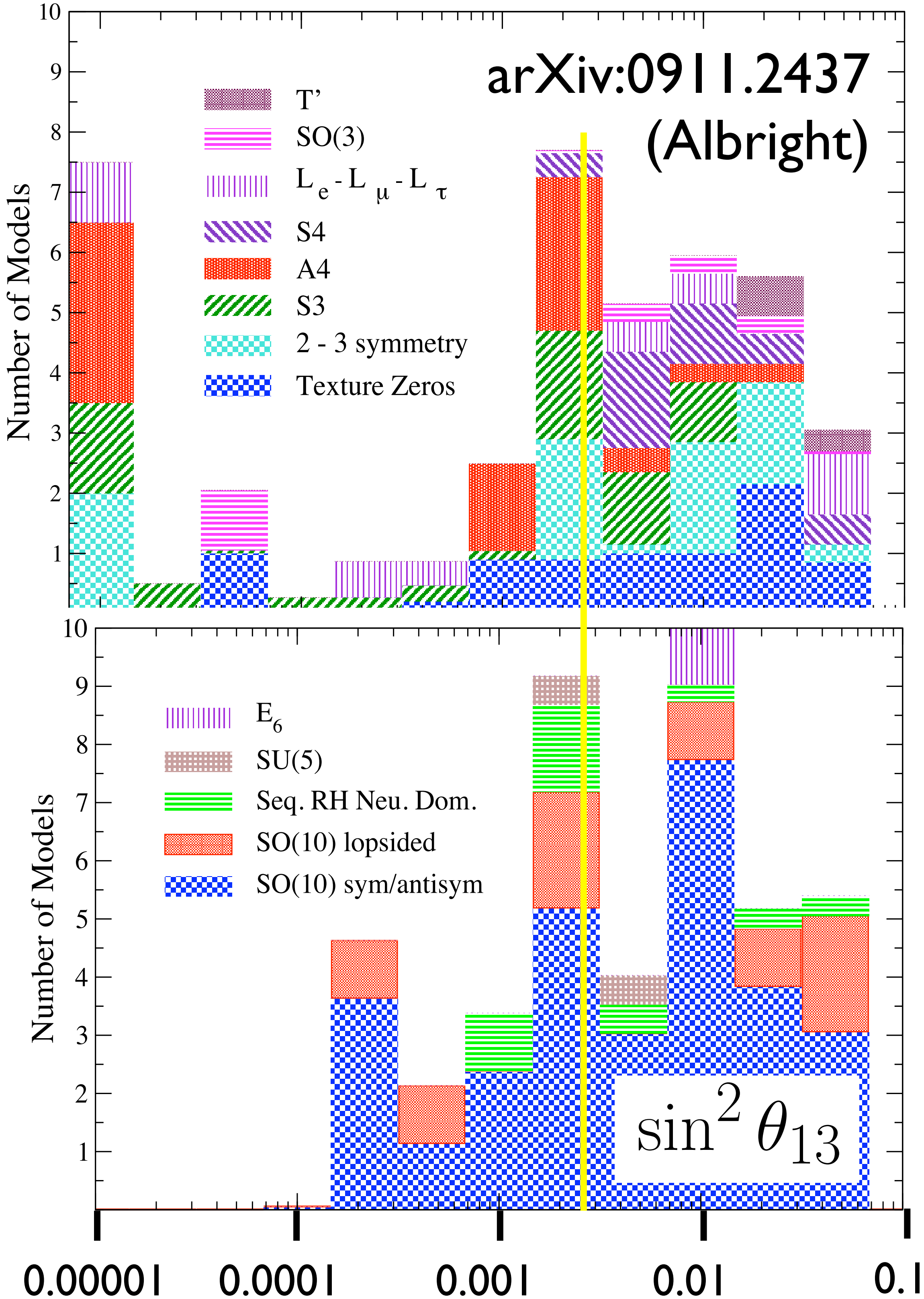

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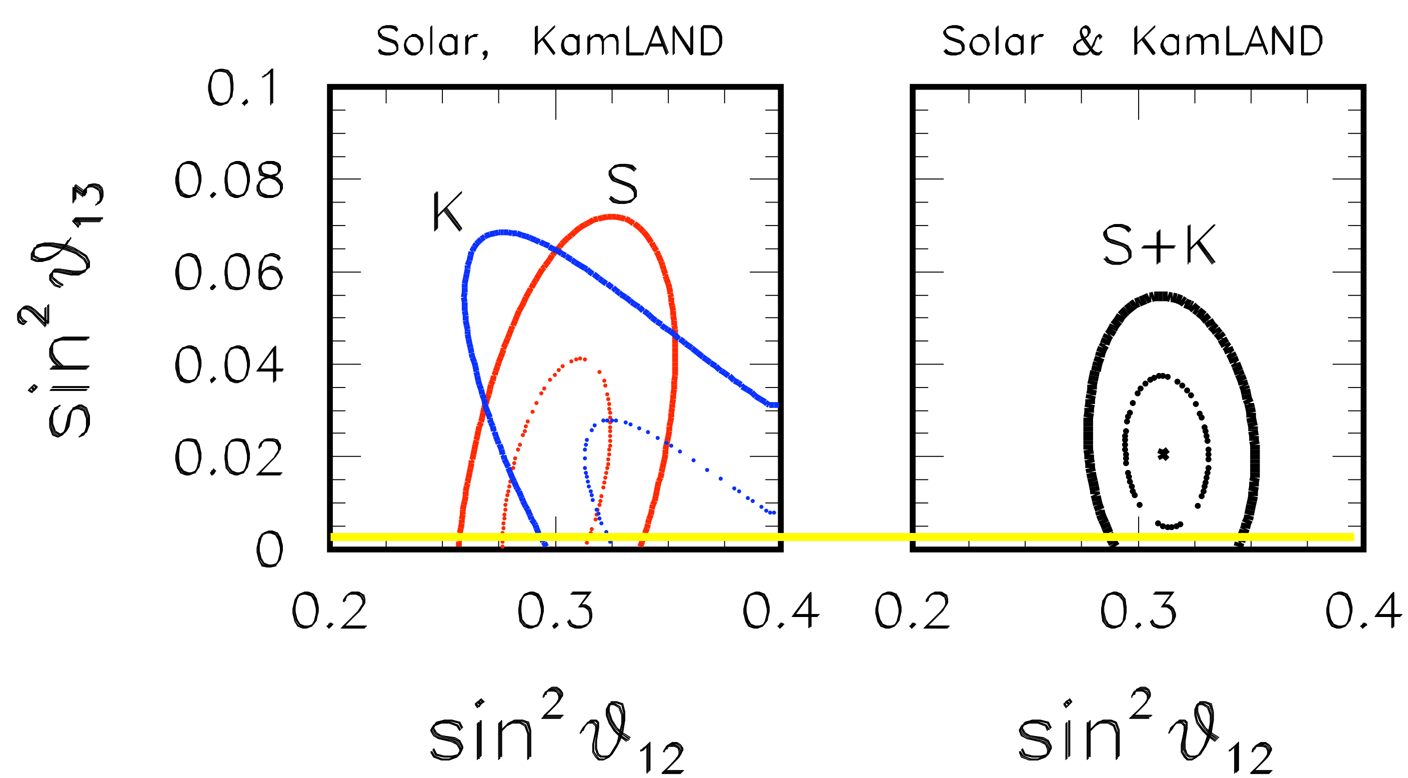

Expected sensitivity

$$\sin^2\theta_{13} \approx \frac{1}{4}\sin^2 2\theta_{13}$$

Measuring Mixing: Neutrino Oscillations

Illustrate with two flavors:

$$\begin{aligned} |\nu_\alpha\rangle &= \cos\theta_{ab}|\nu_a\rangle + \sin\theta_{ab}|\nu_b\rangle \\ |\nu_\beta\rangle &= -\sin\theta_{ab}|\nu_a\rangle + \cos\theta_{ab}|\nu_b\rangle \end{aligned}$$

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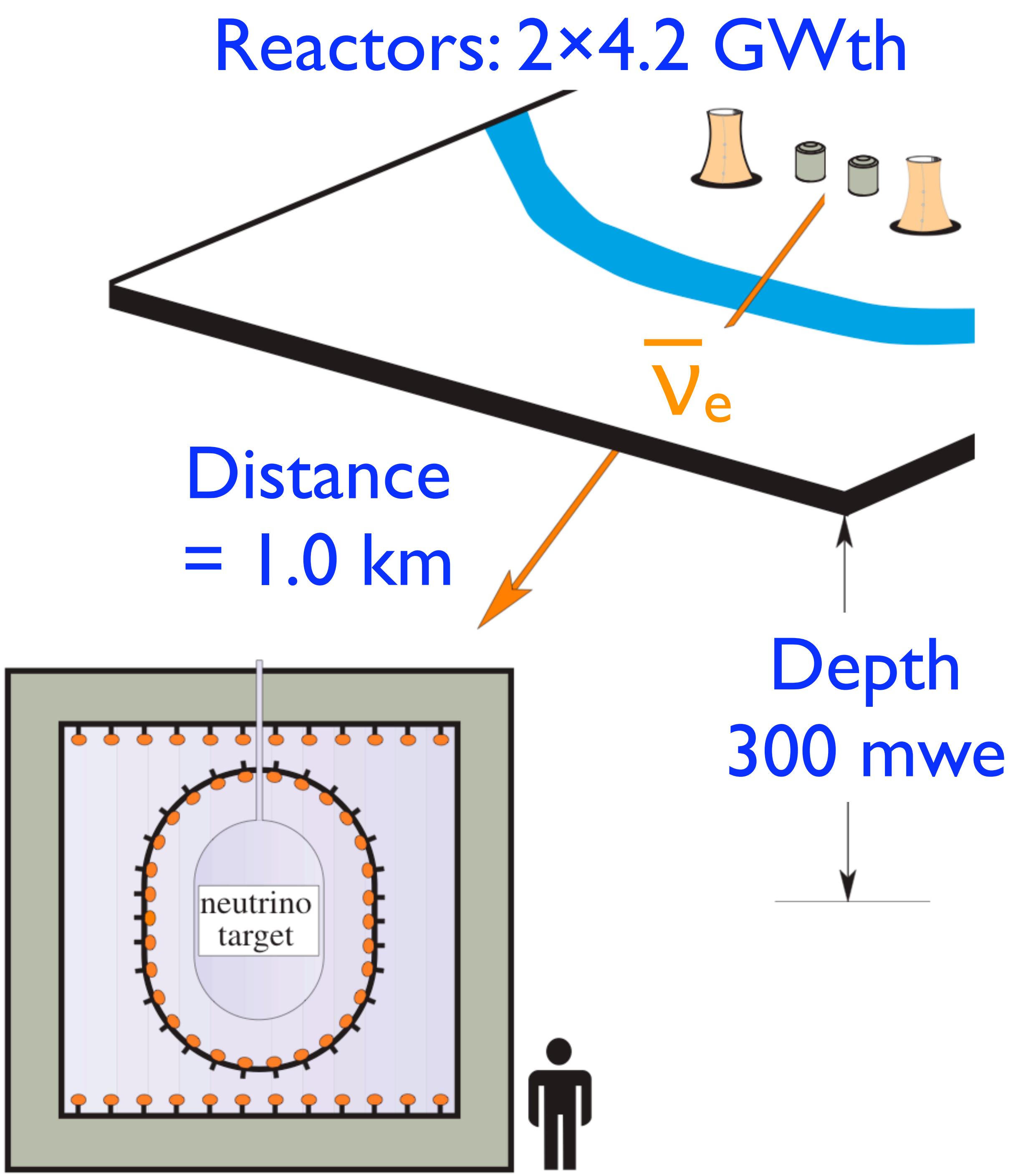
Mixing angle sets the size of the effect...

... but you need to match L and E to Δm^2 !

Measuring θ_{13} at Nuclear Reactors

Example (Chooz): Appolonio, et al., EPJ 27(2003)331



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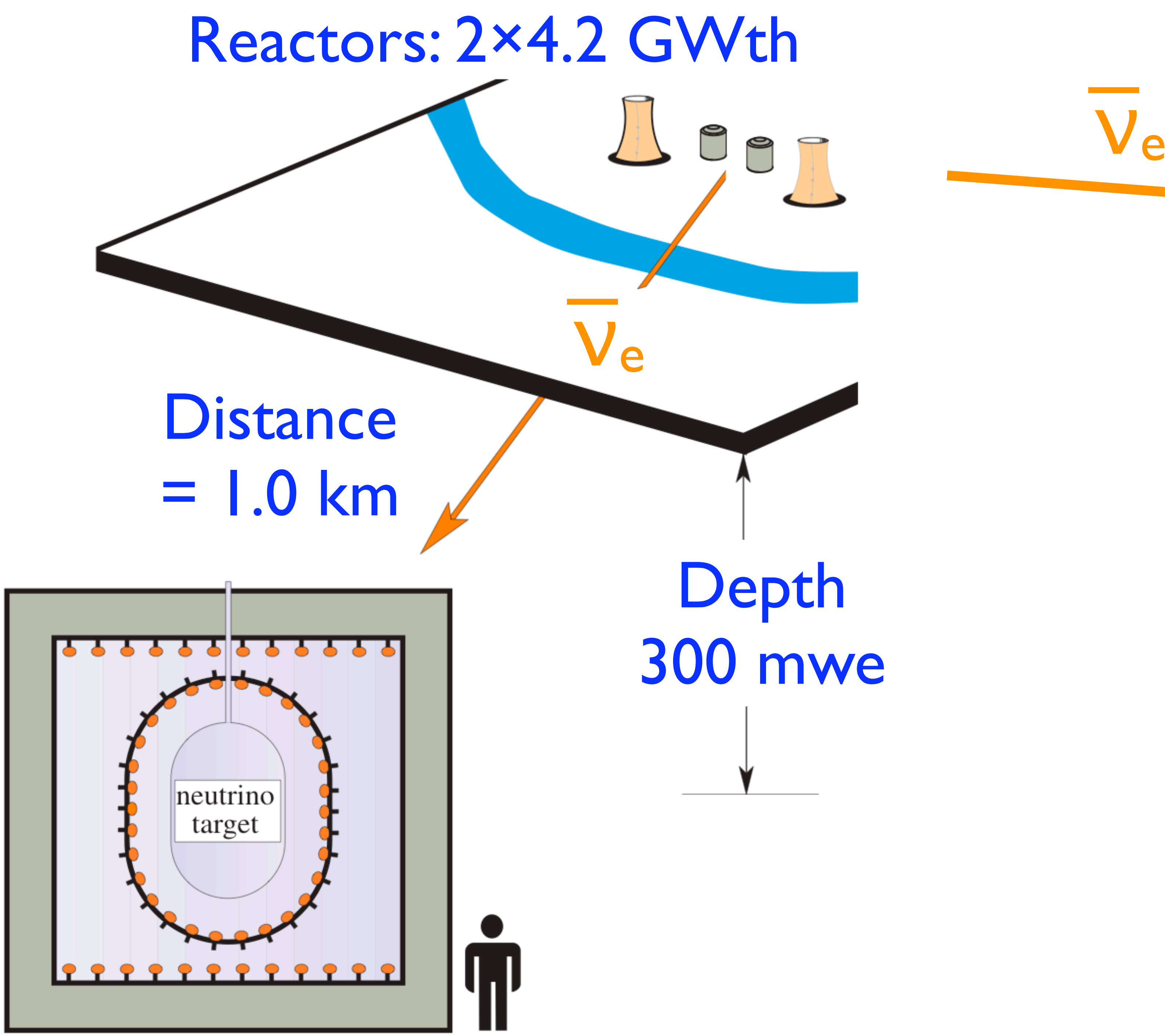

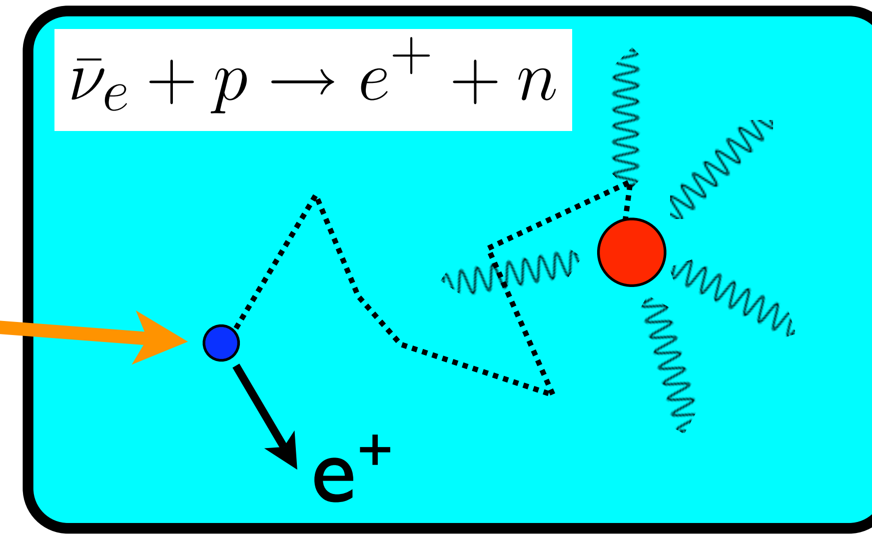

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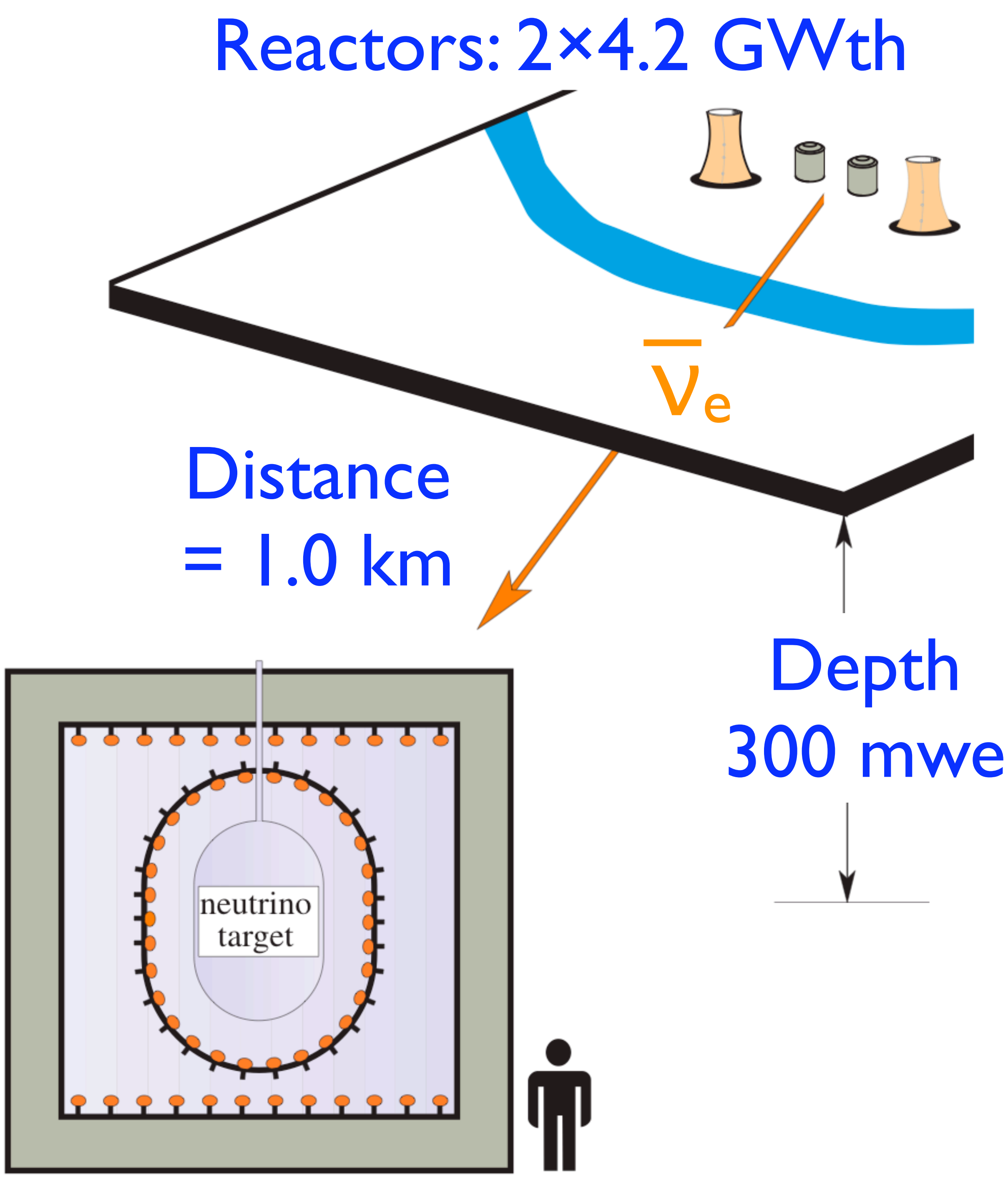

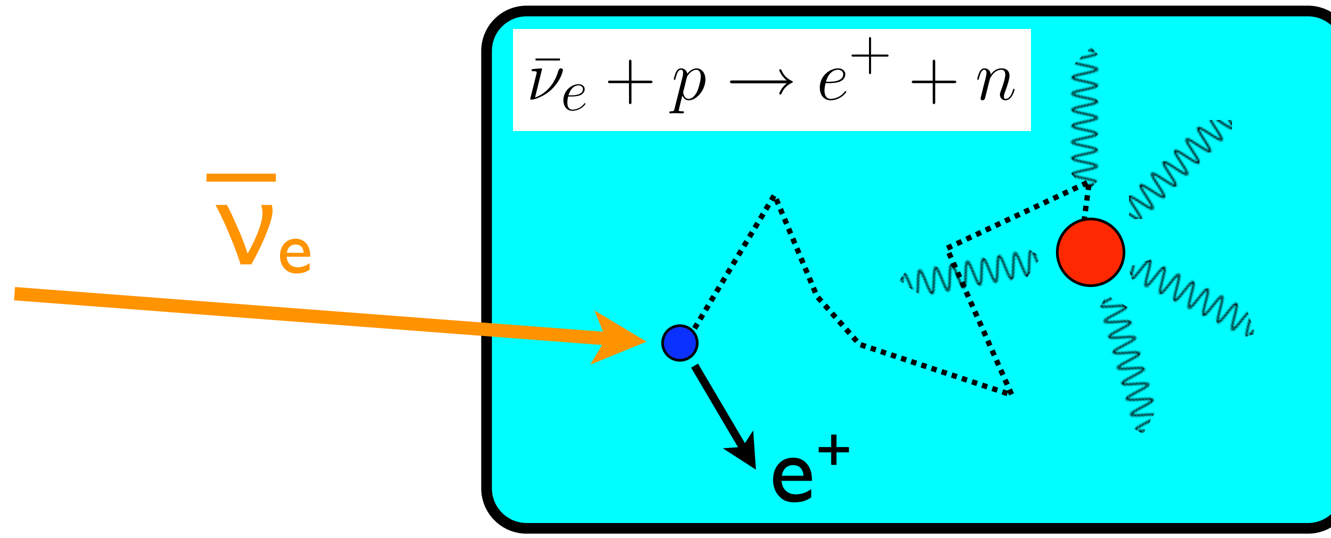

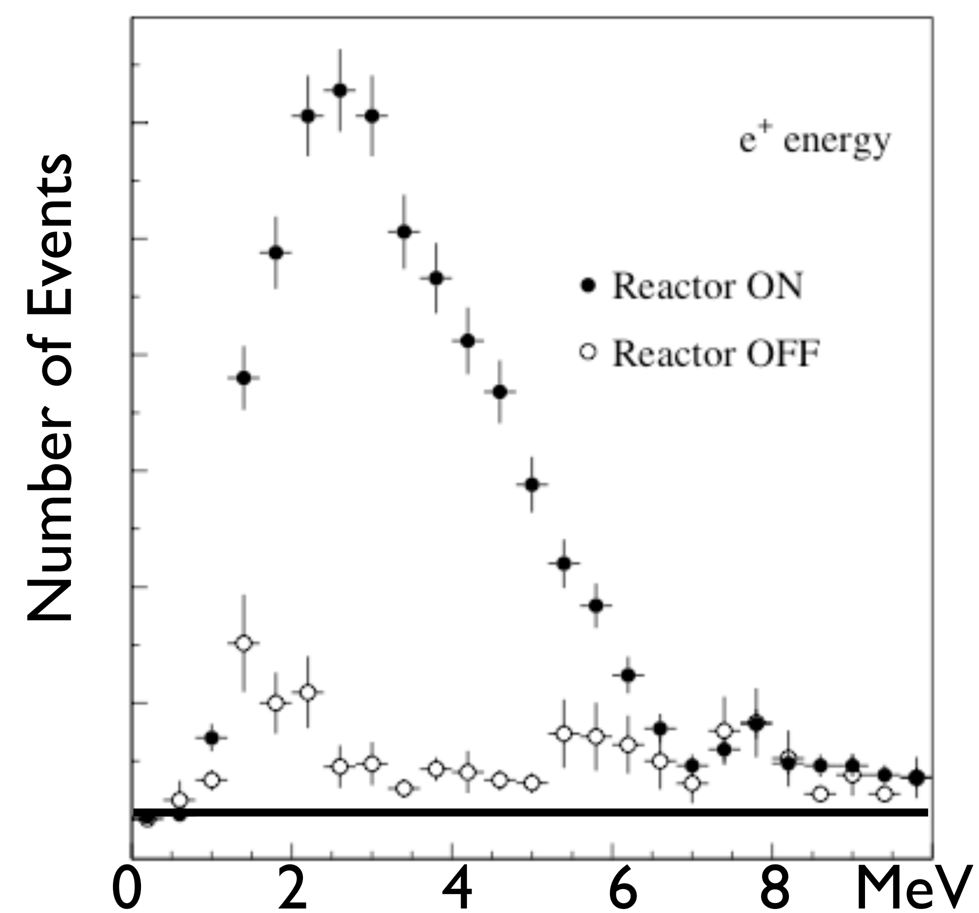

Measuring θ_{13} at Nuclear Reactors

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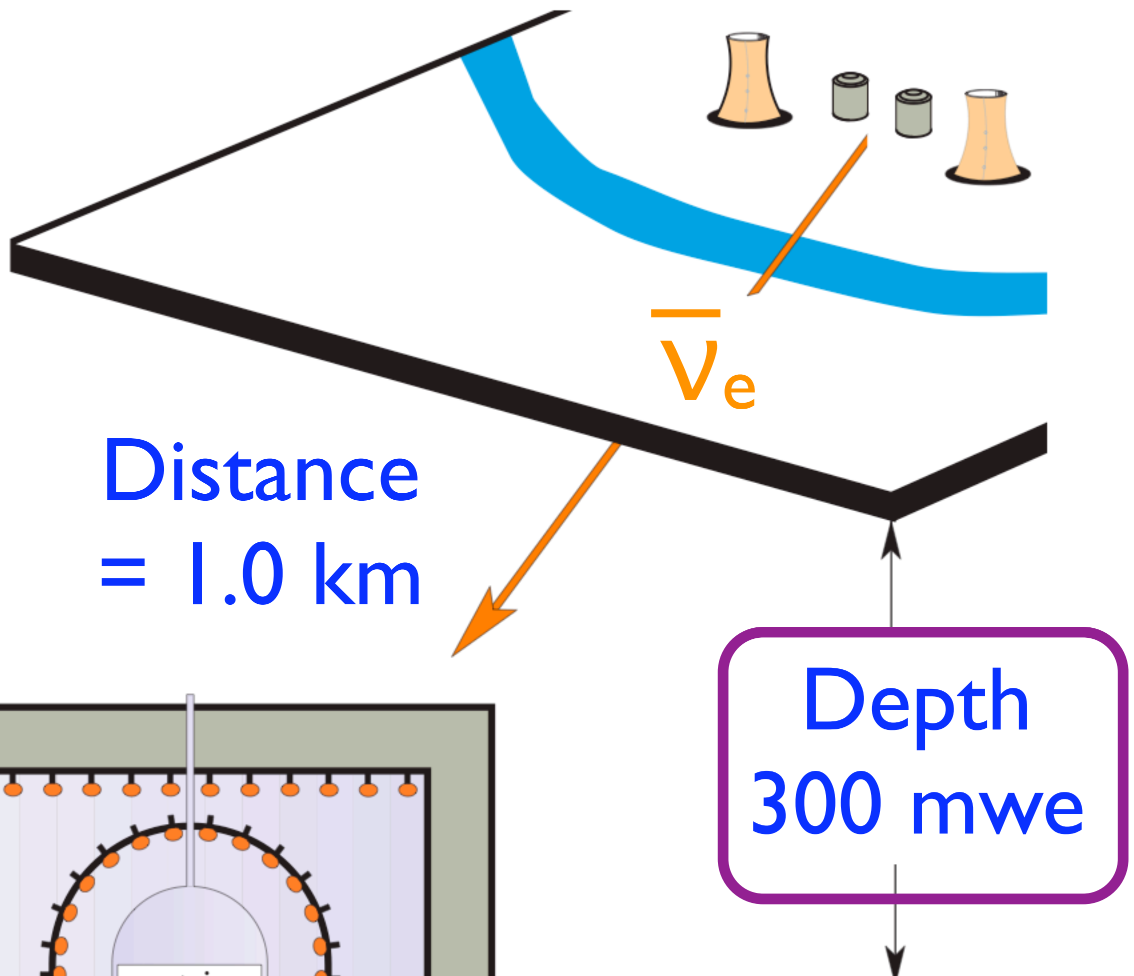
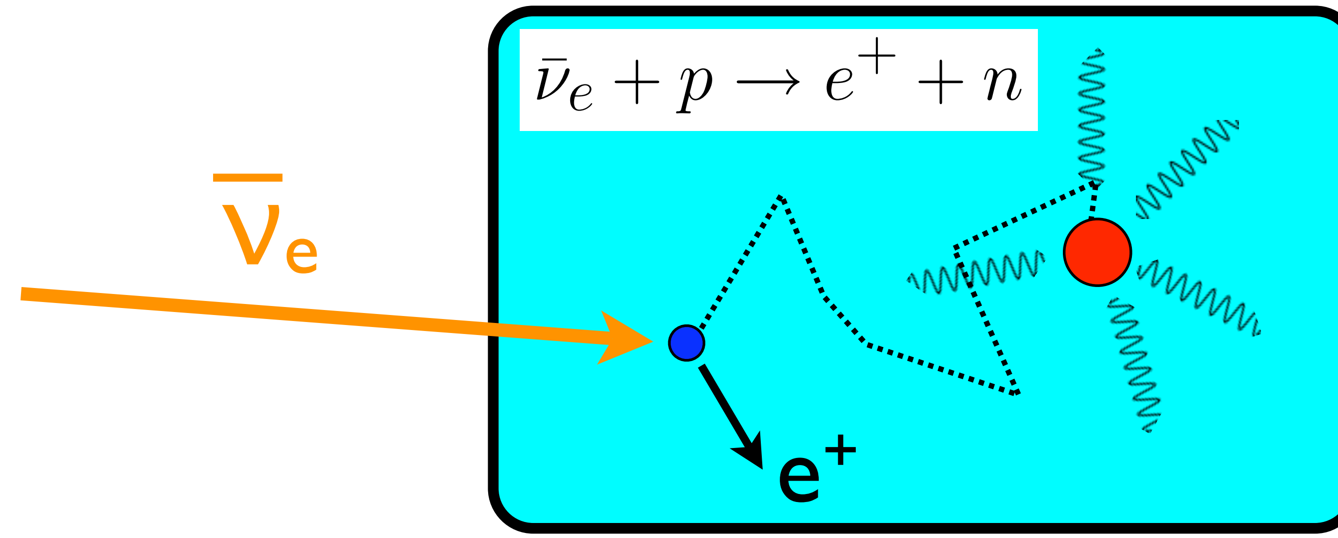
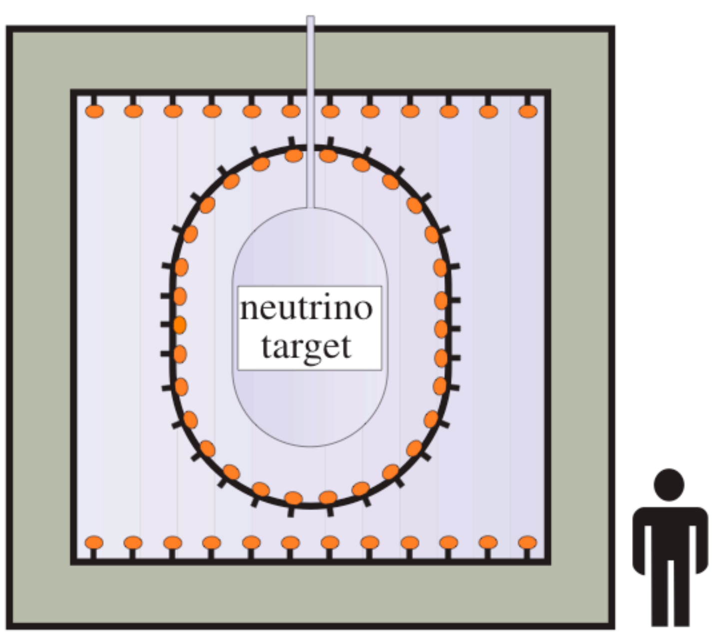
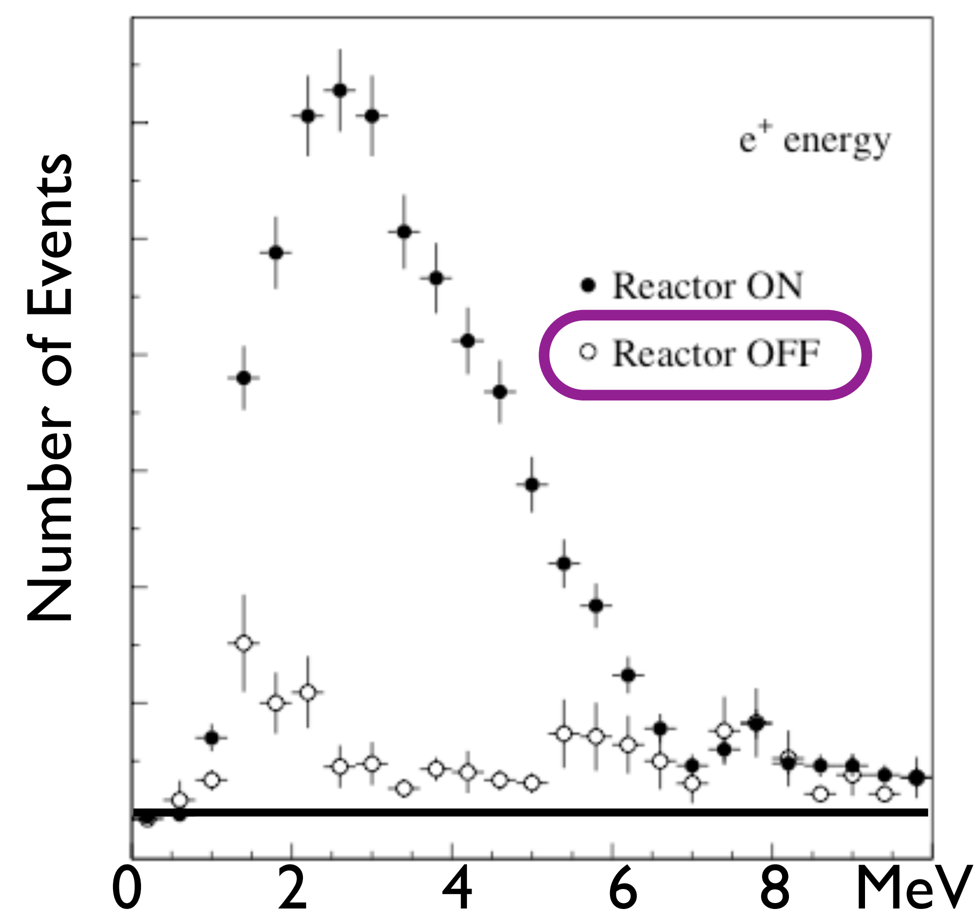
Reactors: 2×4.2 GWth

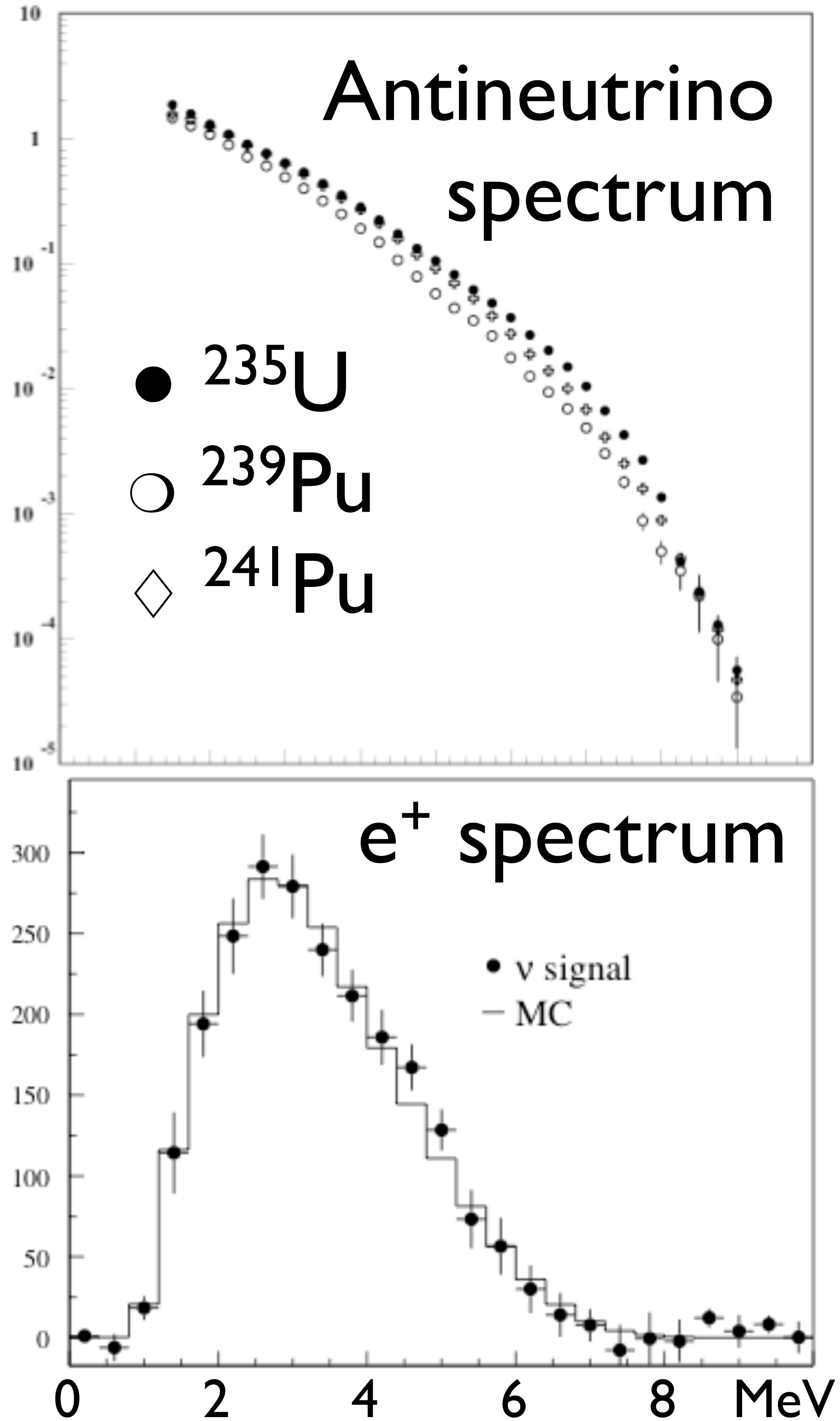








Interpreting the e^+ Energy Spectrum



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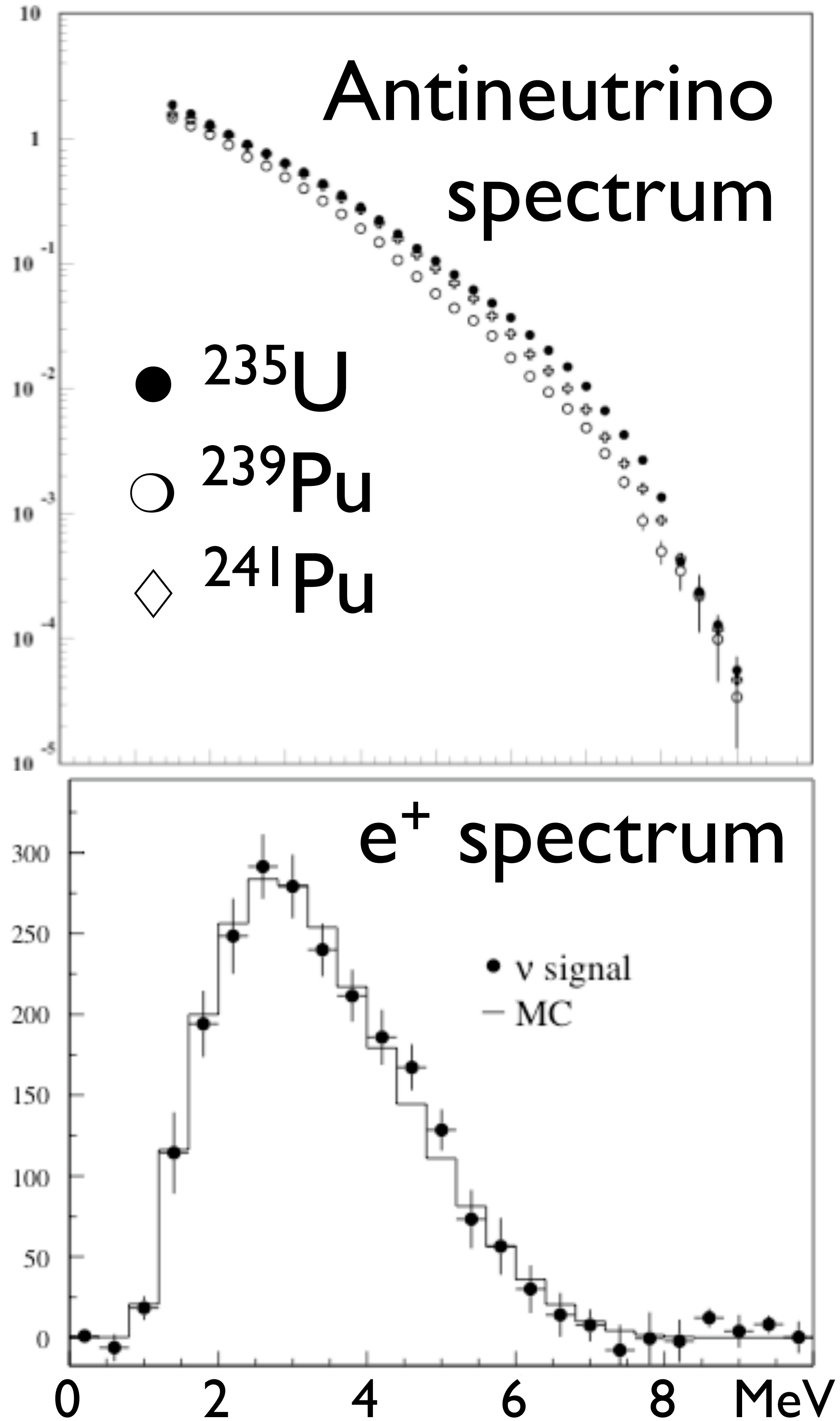

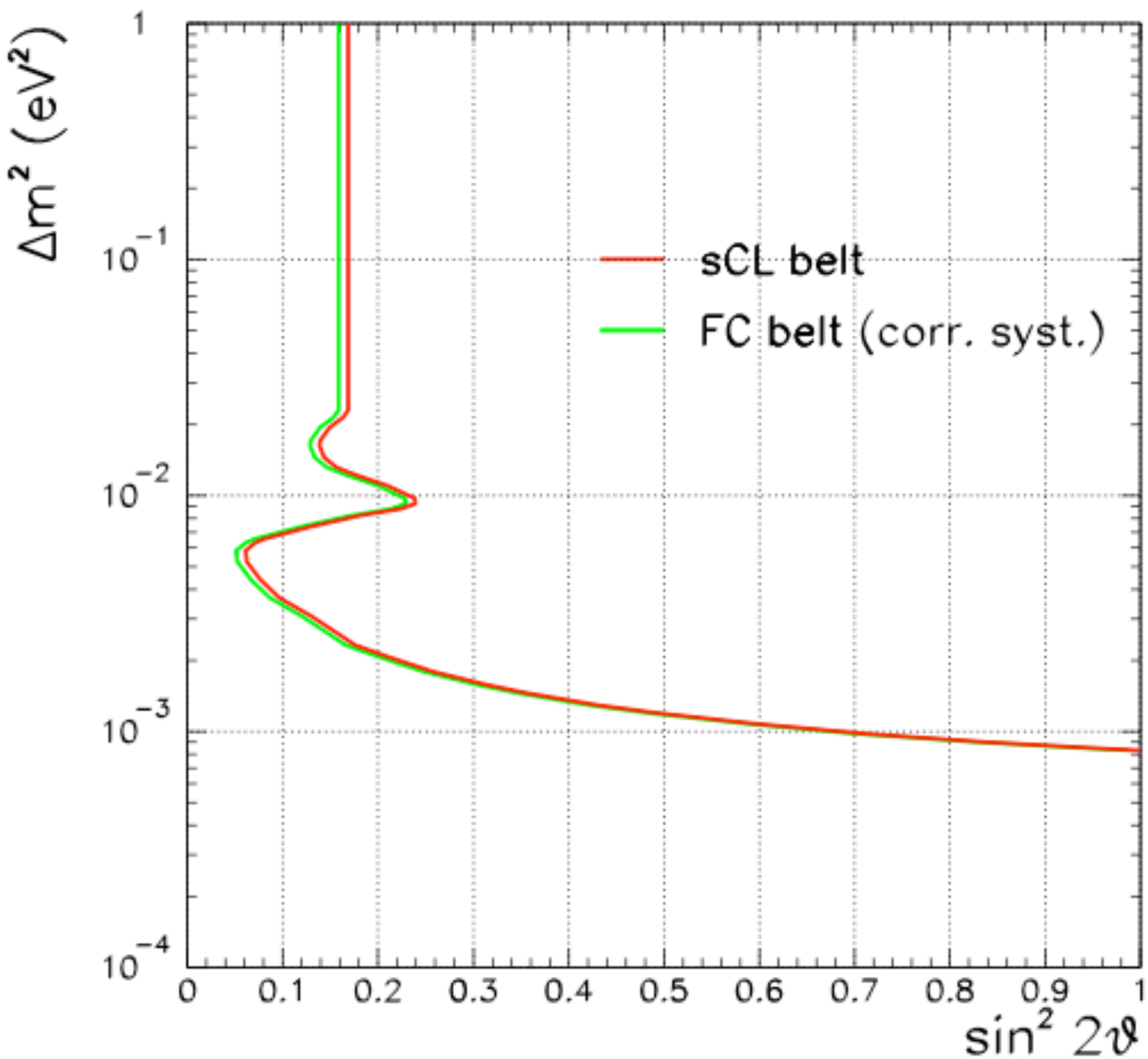

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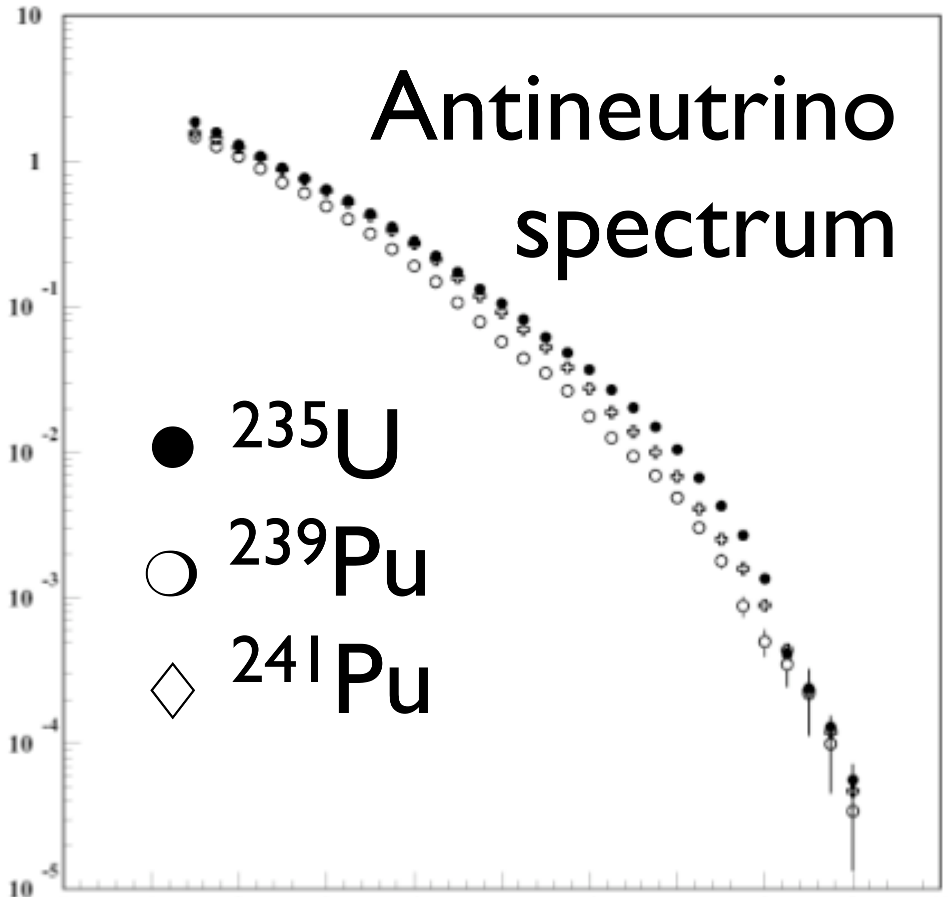
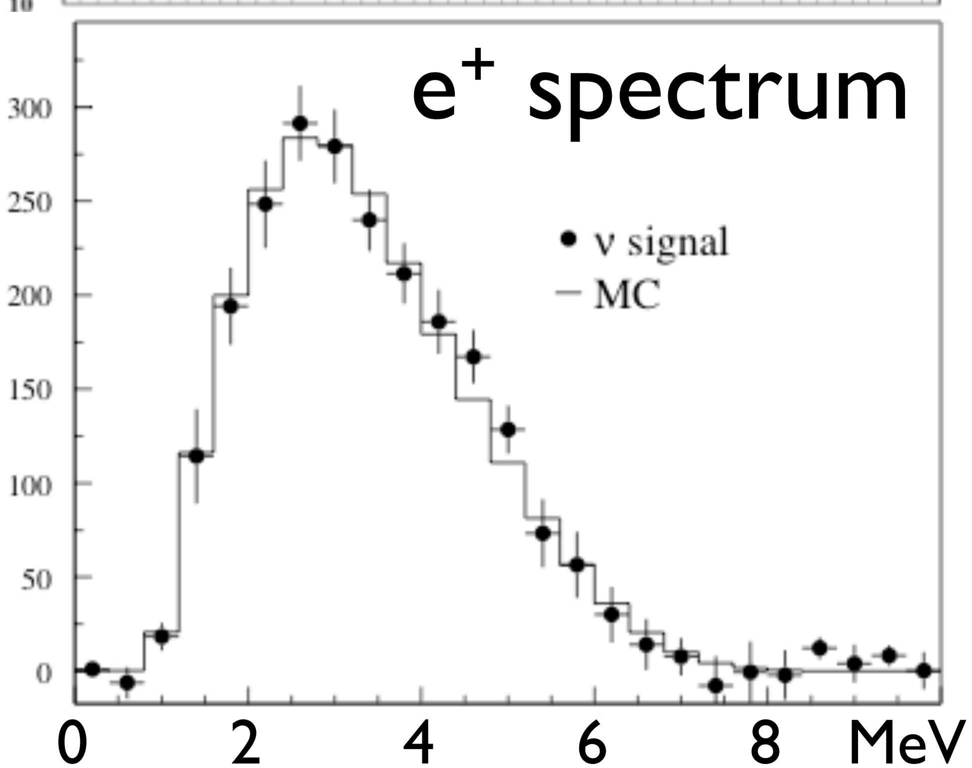
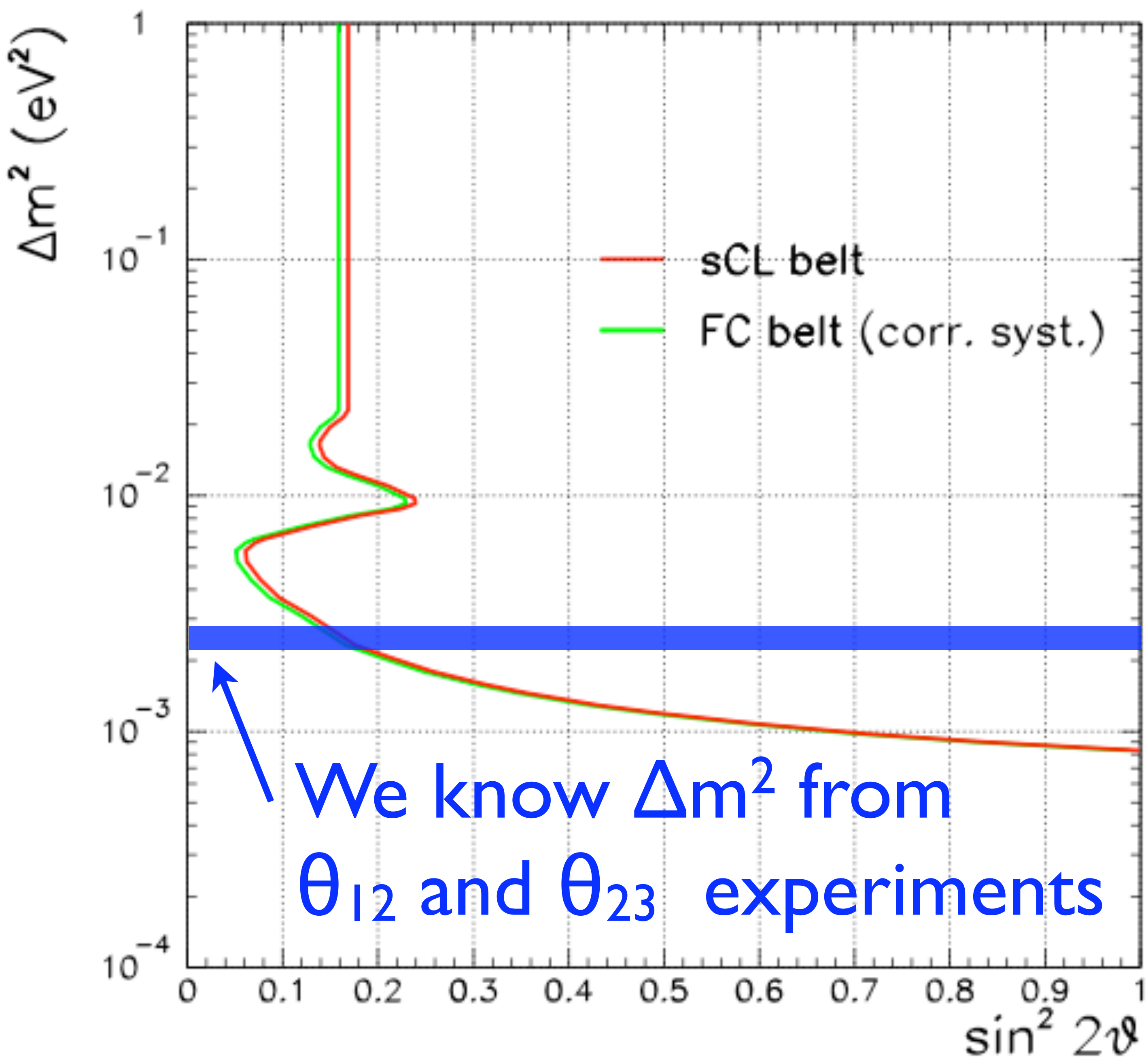
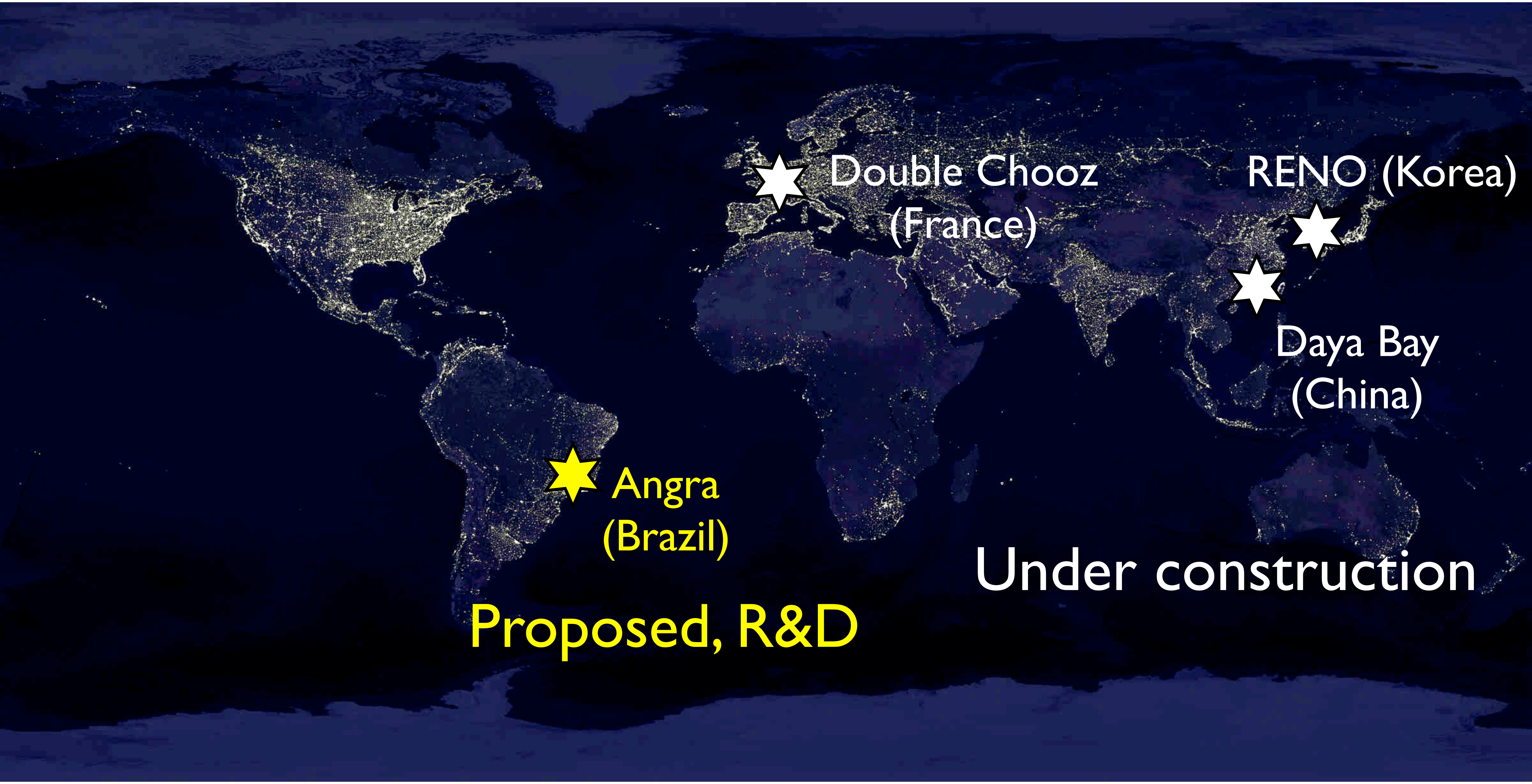






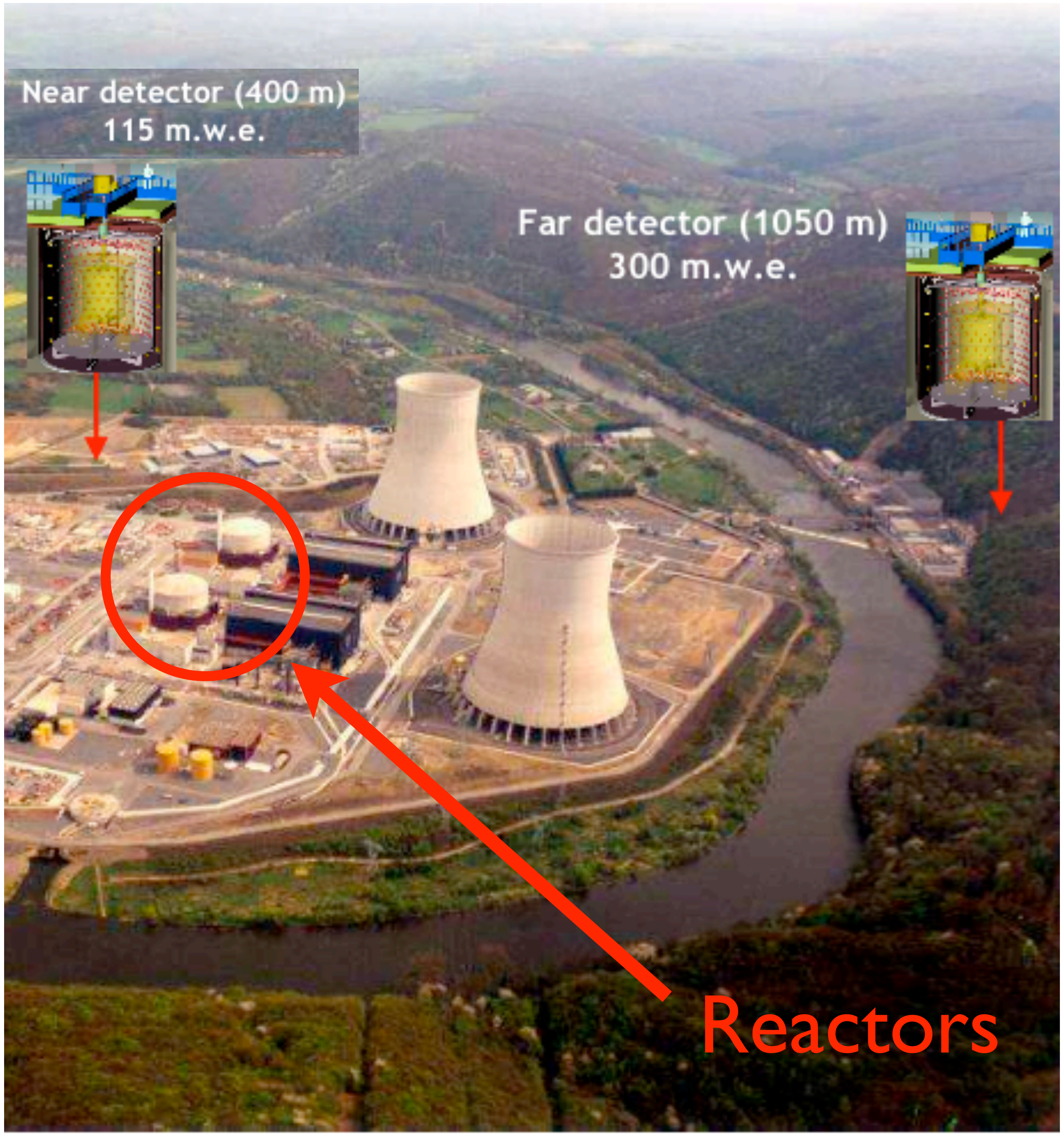
The correct baseline optimizes sensitivity!

Current θ_{13} Reactor Experiments



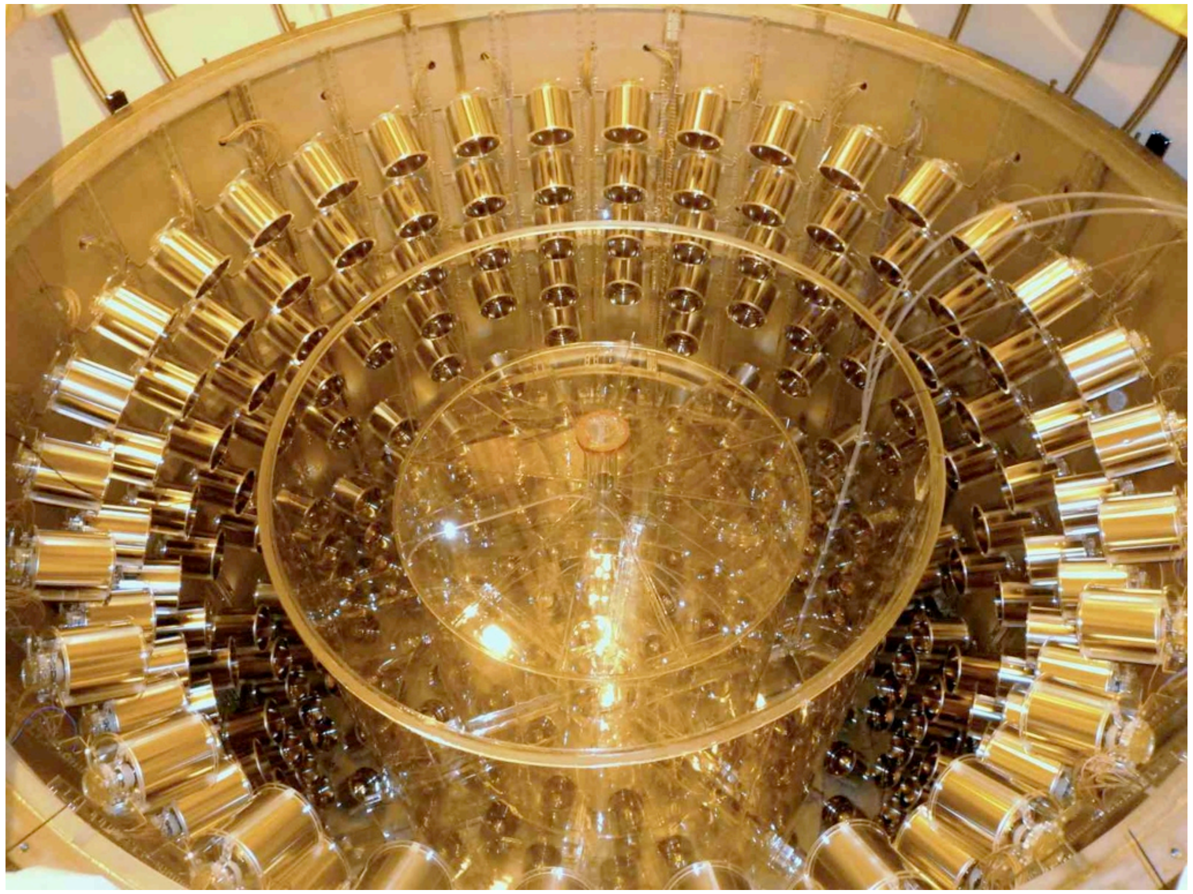
The Innovation: A "Near" Detector to Monitor the Flux

Double Chooz



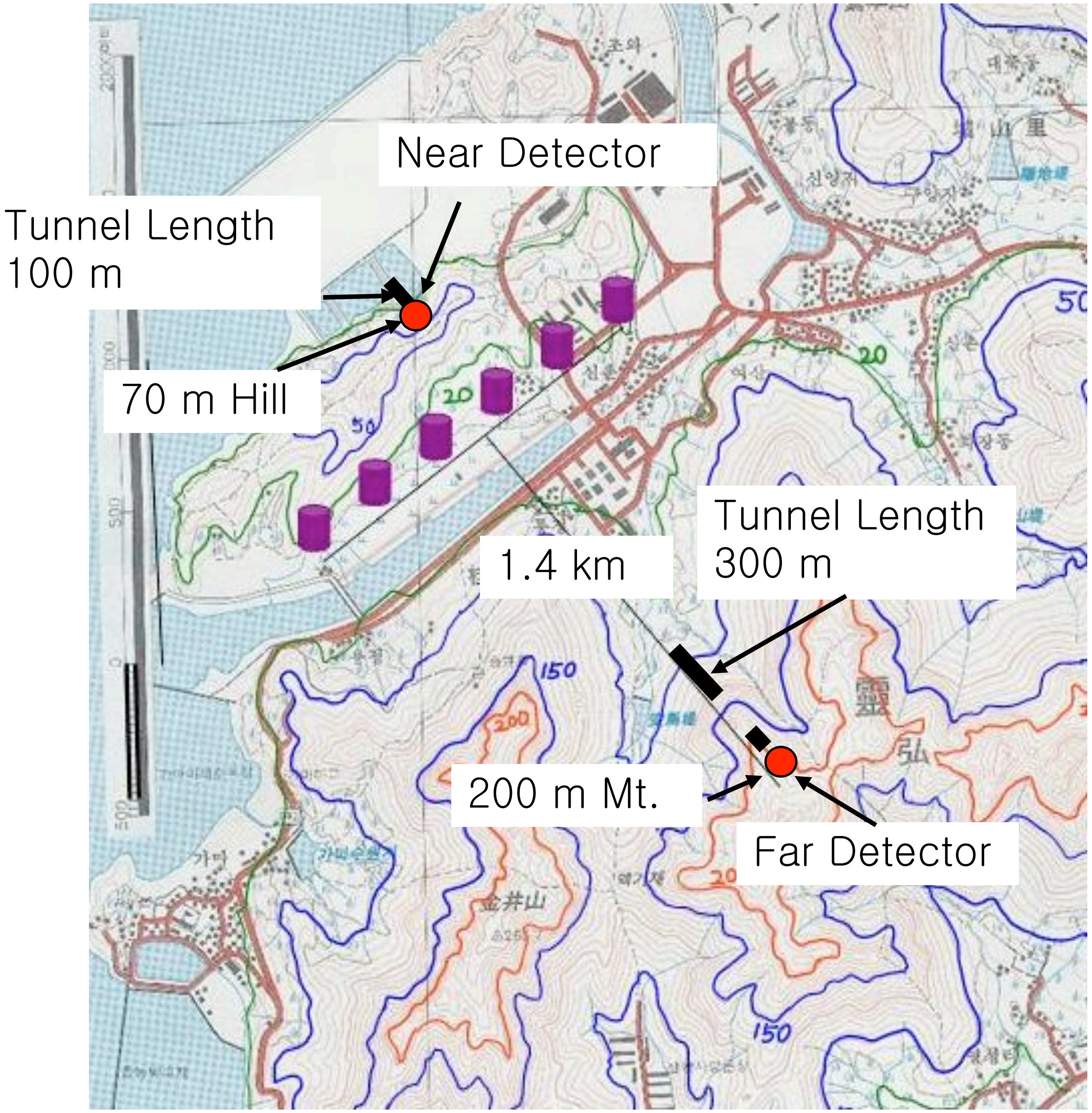
I. Gil-Botella,
J.Phys. Conf. 171(2009)012067

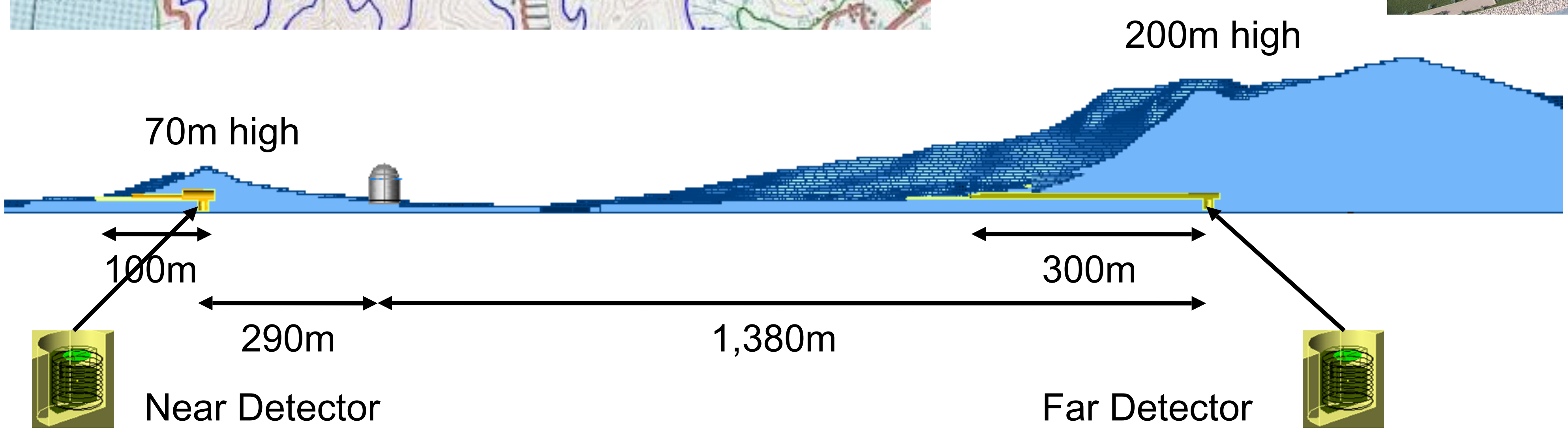
Far detector vessel with PMTs installed



RENO

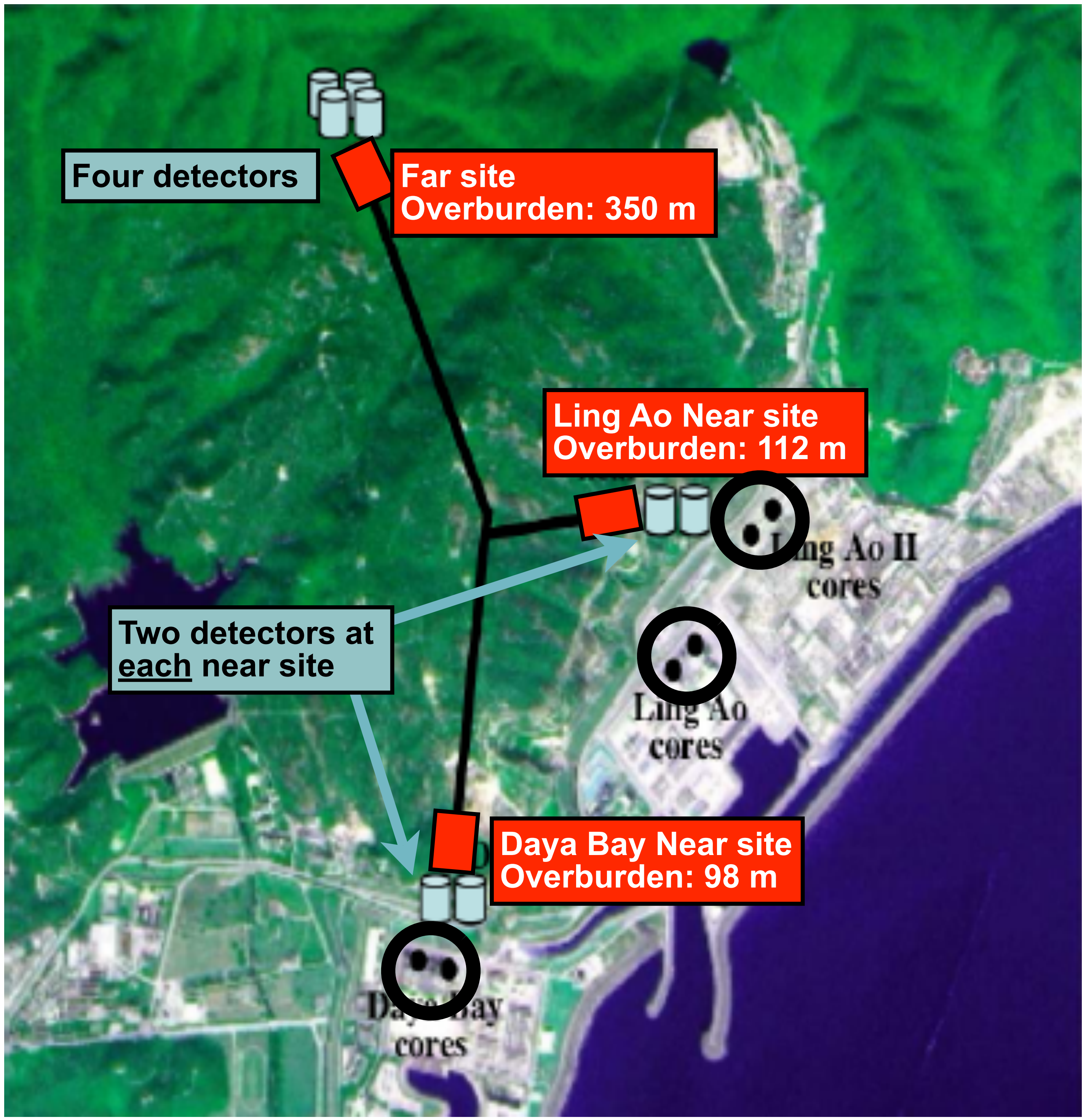
S.B.Kim, J.Phys. Conf. 120(2008)052025
Y.Oh, Nucl.Phys.B (Proc) 188(2009)109
(See also DBD 2007 and TAUP 2007)

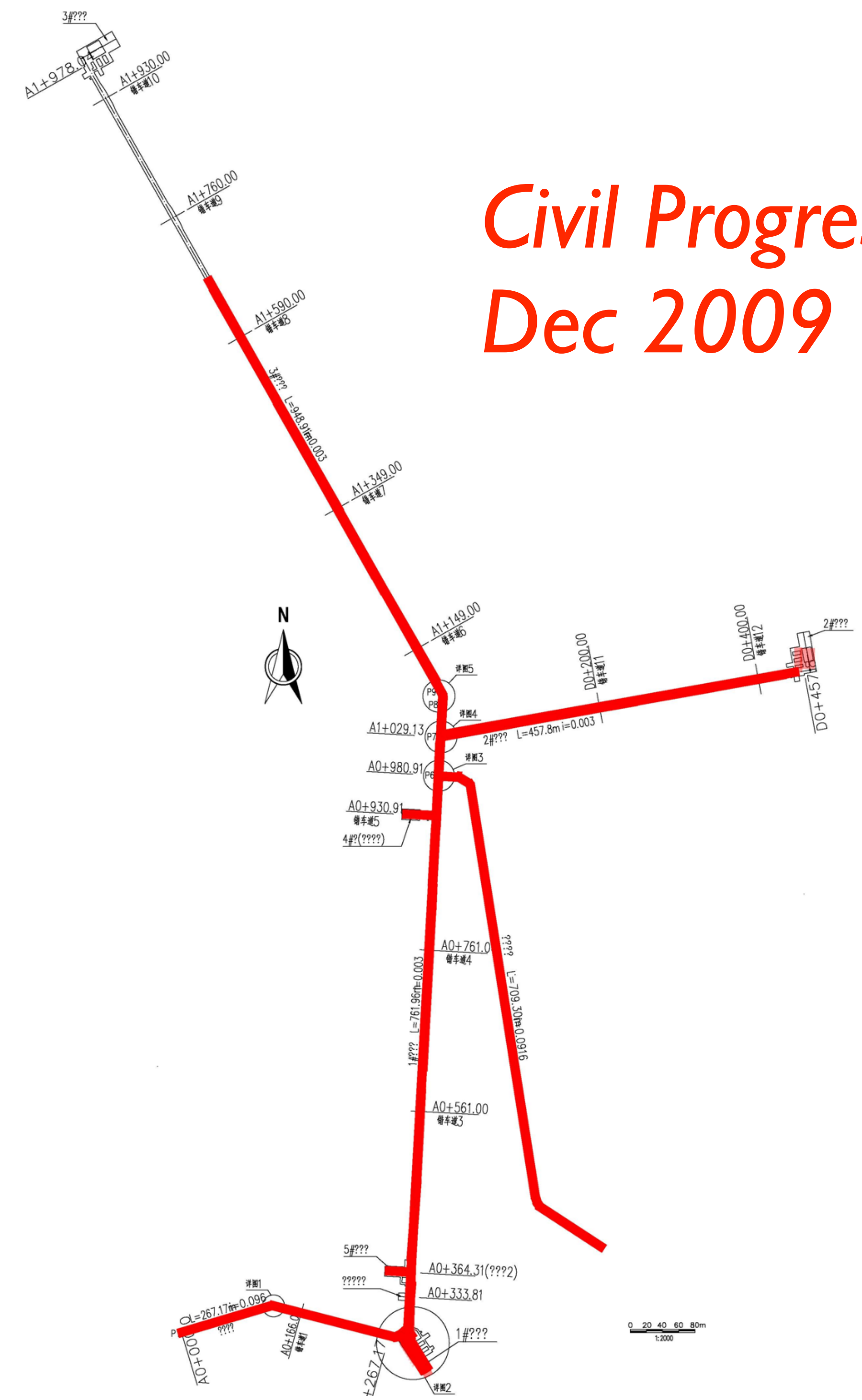




Daya Bay

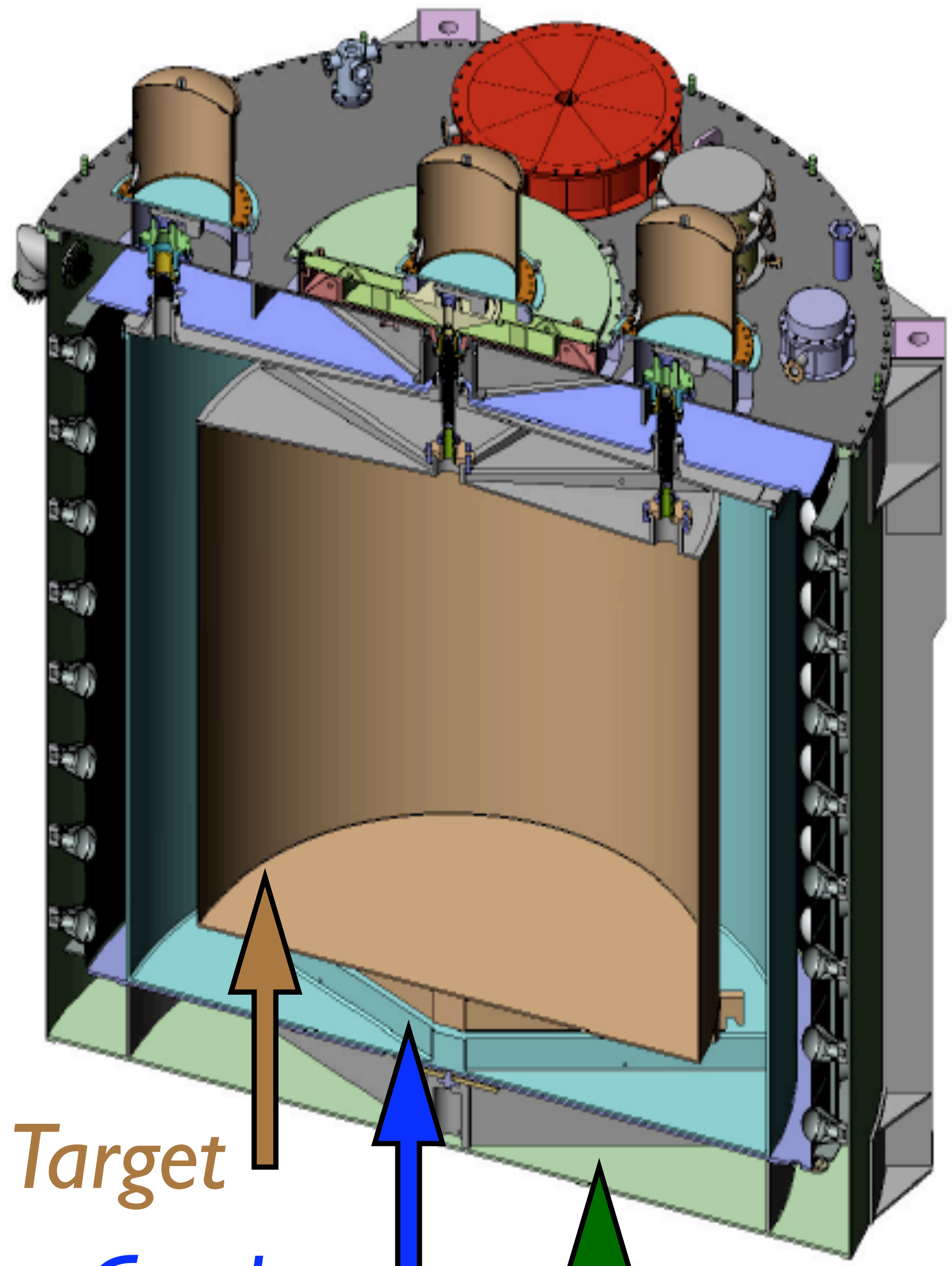
Proposal - arXiv: hep-ex/0701029
W. Wang, arXiv: hep-ex/0910.4605





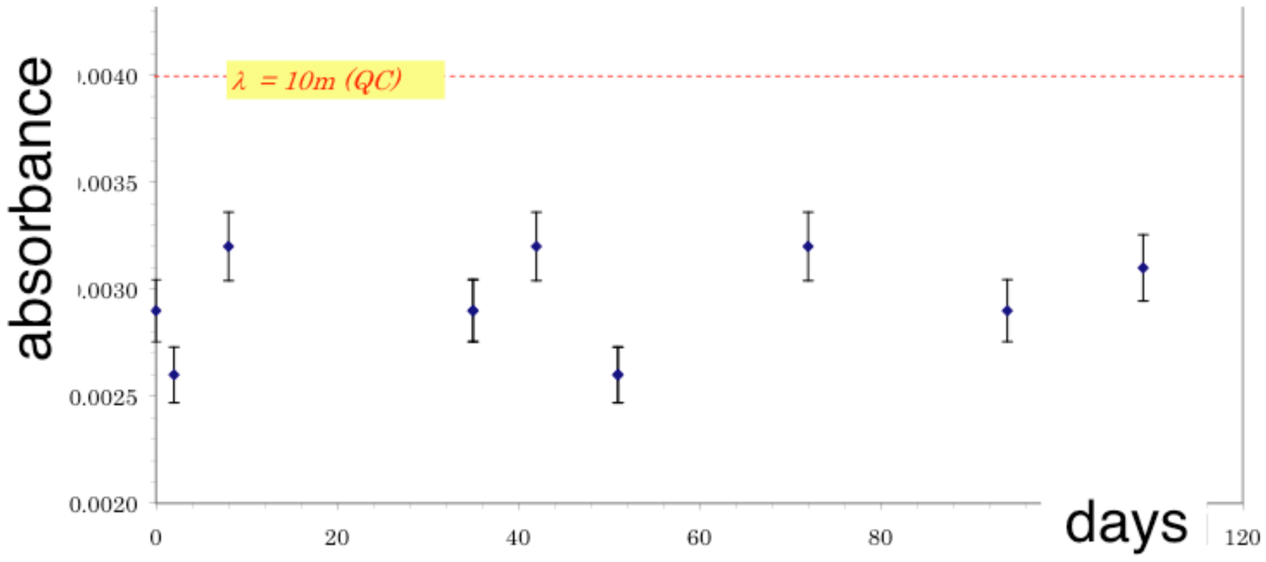
Civil Progress
Dec 2009

$\overline{\nu}_e$ Detectors: Three Zones



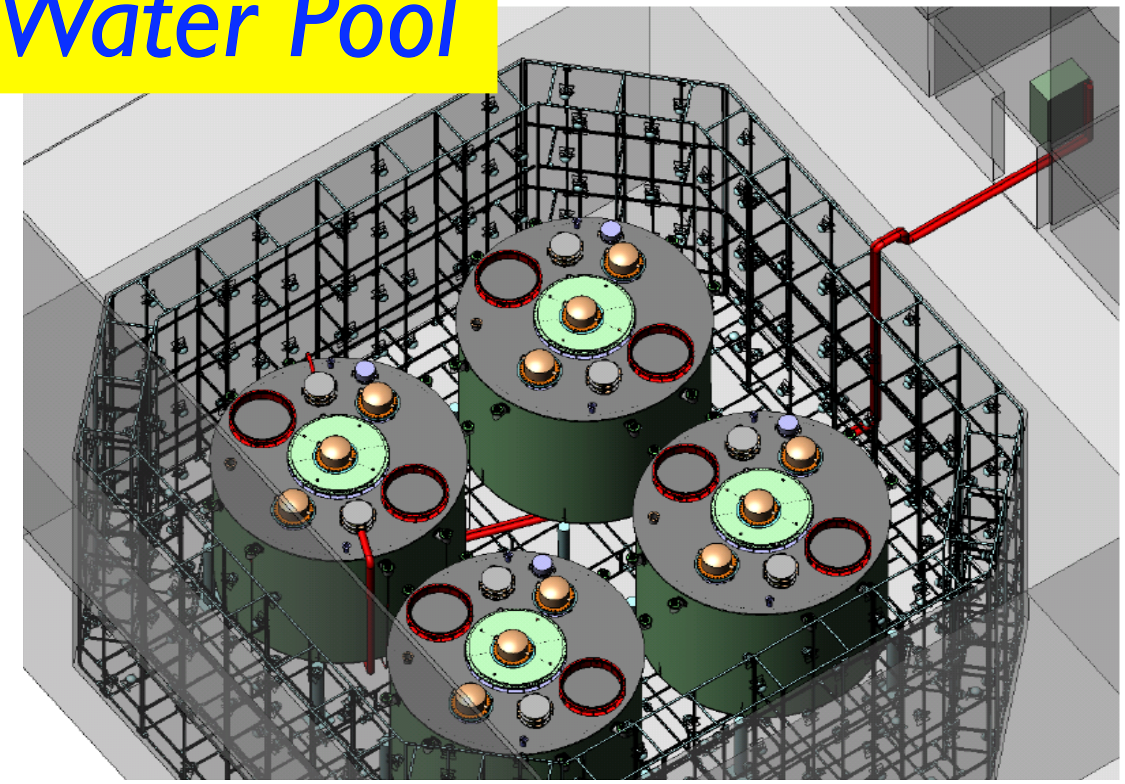
Gd-LAB Liquid Scintillator

Liquid clarity is important

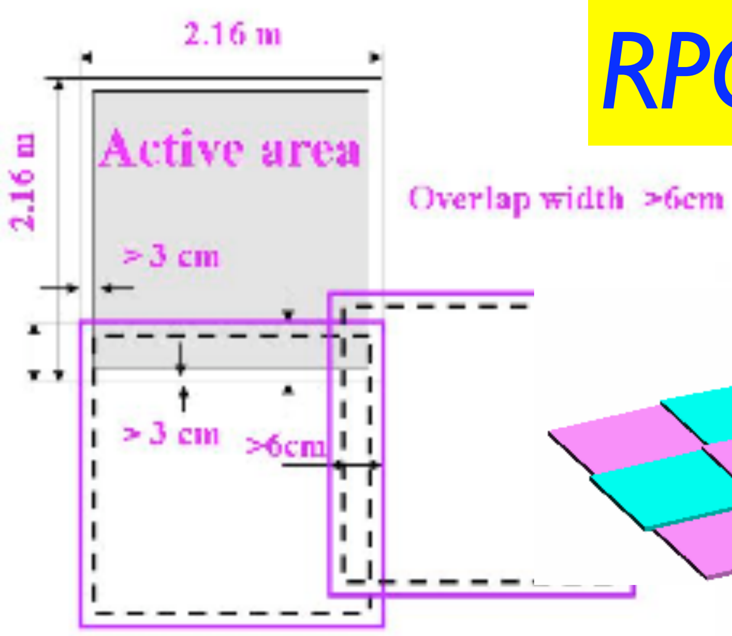


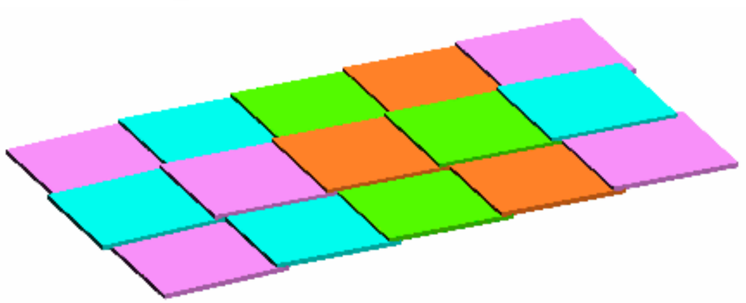
Muon Shielding

Water Pool

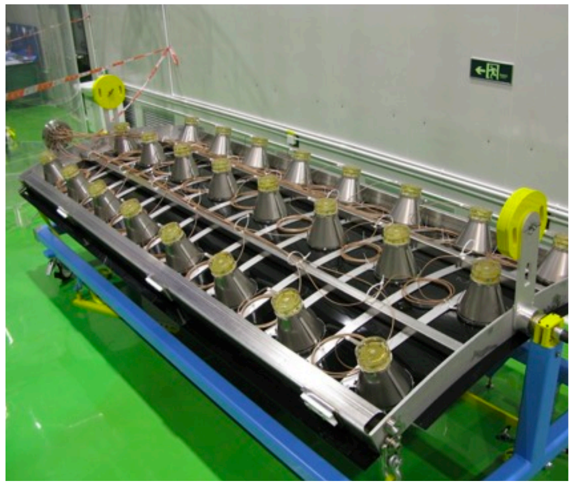


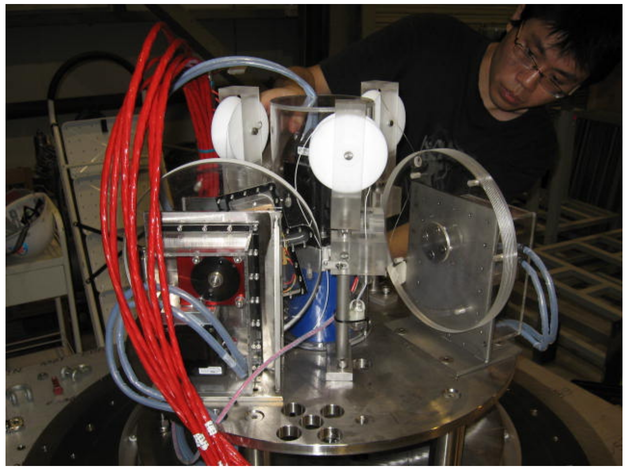
RPC Layer





Daya Bay: Progress

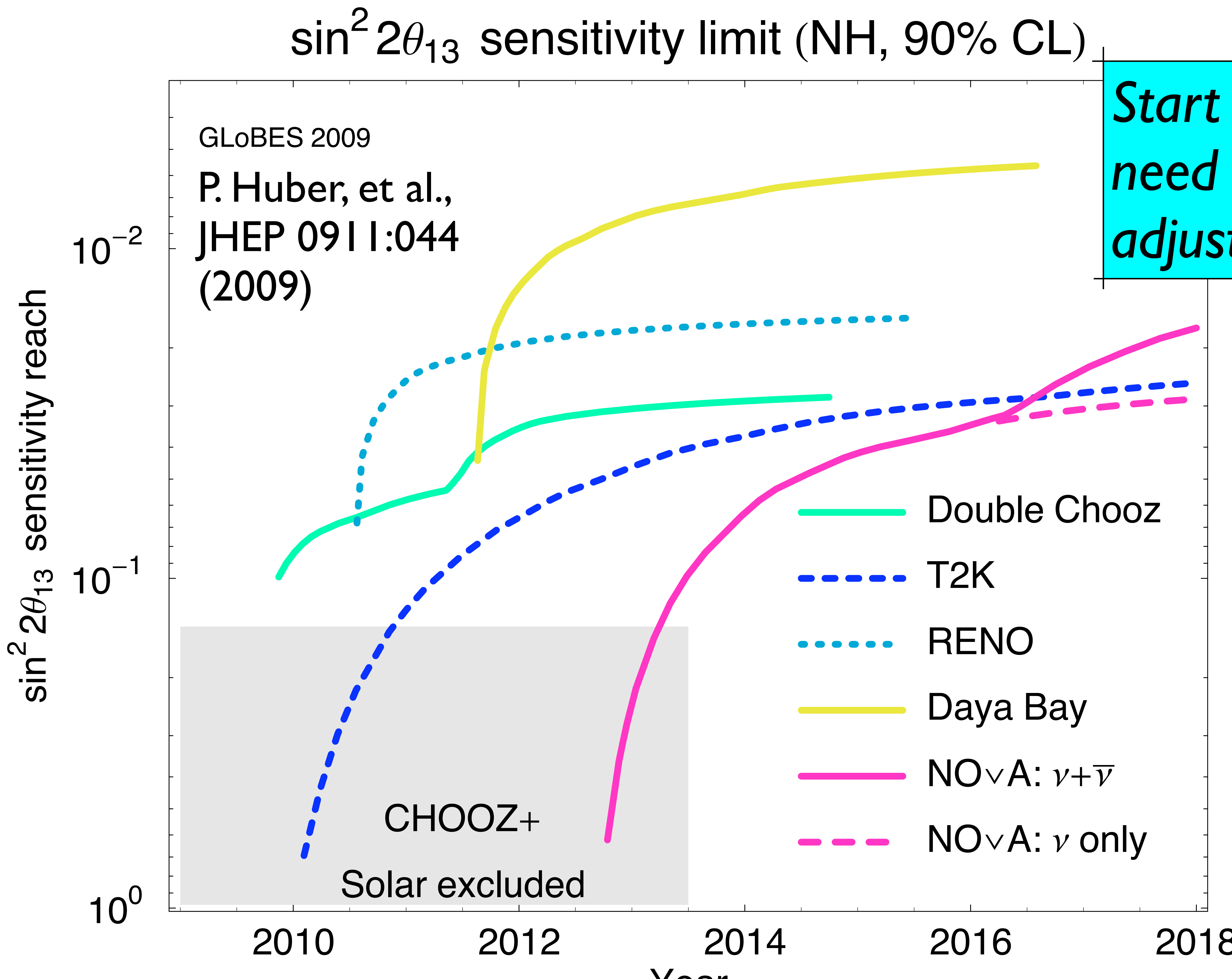




DB Near Physics Ready: 2010
Far Hall Physics Ready: 2011

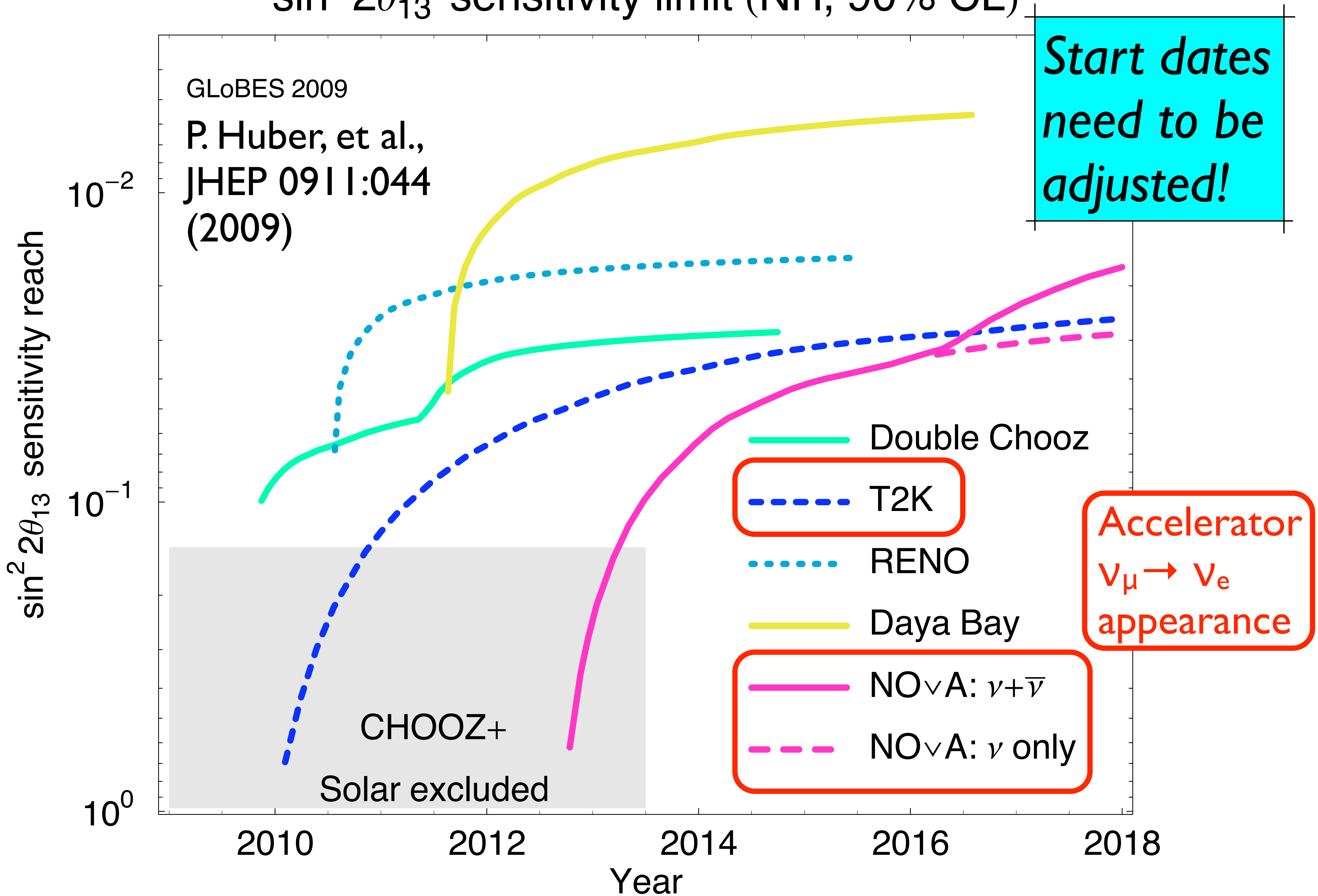
Reactor θ_{13} Experiments

	Thermal Power (GW)	Mass (Tons)	Near		Far		δ_{SYST} (%)
			Dist (m)	Depth (mwe)	Dist (m)	Depth (mwe)	
Double Chooz	8.5	2×10	400	115	1050	300	0.6
RENO	16.4	2×16	290	130	1380	460	0.5
Daya Bay	17.4	8×20	363 & 481	260	1985 & 1613	910	> 0.2 < 0.4



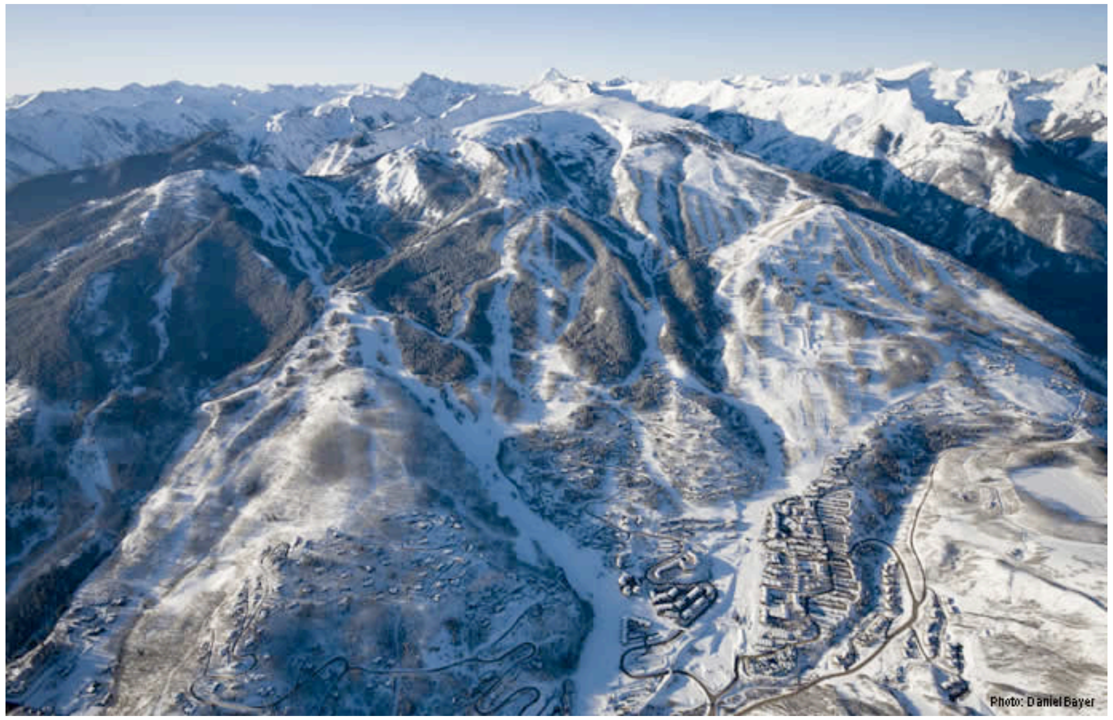
Start dates need to be adjusted!

$\sin^2 2\theta_{13}$ sensitivity limit (NH, 90% CL)



Conclusion

- Establishing $\theta_{13} \neq 0$ critical for next phase in CPV
- Expect $\approx$1% sensitivity from reactor experiments over the next few years
- Keep your fingers crossed that θ_{13} big enough for the "superbeam" experiments



Thanks!