Which long-baseline neutrino experiment?

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Options for a U.S. long-baseline program

NOvA - I:

- off-axis beam from FNAL, L=810 Km to 25 Kt TASD
- beam energy is tuned to 1st osc. max.
- neutrino mode only

Sensitive only to $\theta_{13} \Rightarrow$ upgrade required

Possible upgrades:

NOvA - II:

- upgrade FNAL proton infrastructure (HINS)
- run in neutrino and antineutrino modes
- 2nd detector (liquid Ar TPC at original site)
- 2nd detector (50 Kt water Cherenkov)

- at same L but different OA angle (2nd osc. max.)
- at same L/E but shorter L (diff. matter effect)

Wide band beam:

- upgrade in FNAL proton infrastructure (HINS)
- run in neutrino and antineutrino modes
- 300 kt water Cherenkov detector at DUSEL
- energy spectrum information

Off-axis studied extensively. Consider WBB

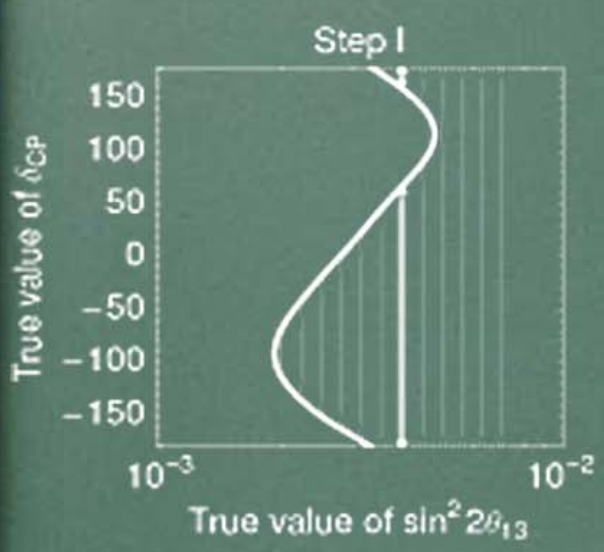
Performance indicators:

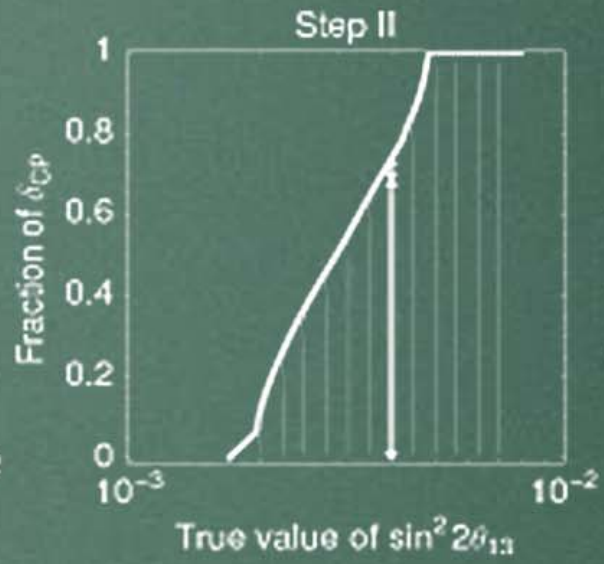
1. θ_{13} discovery potential – exclusion of $\theta_{13} = 0$

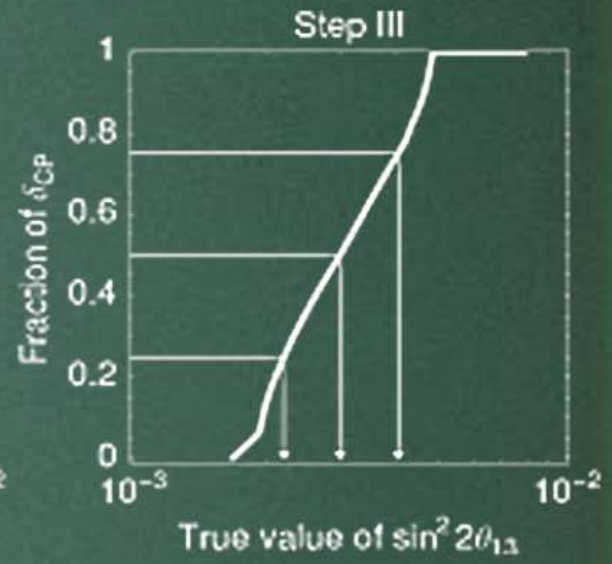
2. discovery of mass hierarchy – suppose $\Delta m^2_{31} > 0$ how well can $\Delta m^2_{31} < 0$ be excluded?

3. CP violation – exclusion of CP conserving values, $\delta = 0, \pi$

Definition of CP fraction

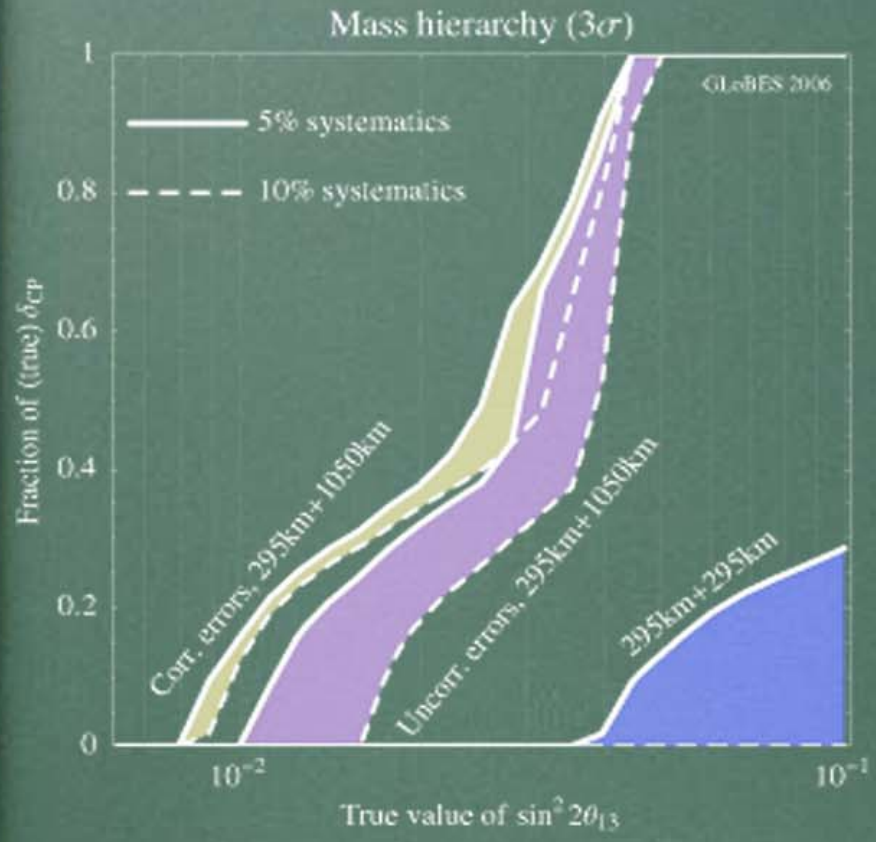


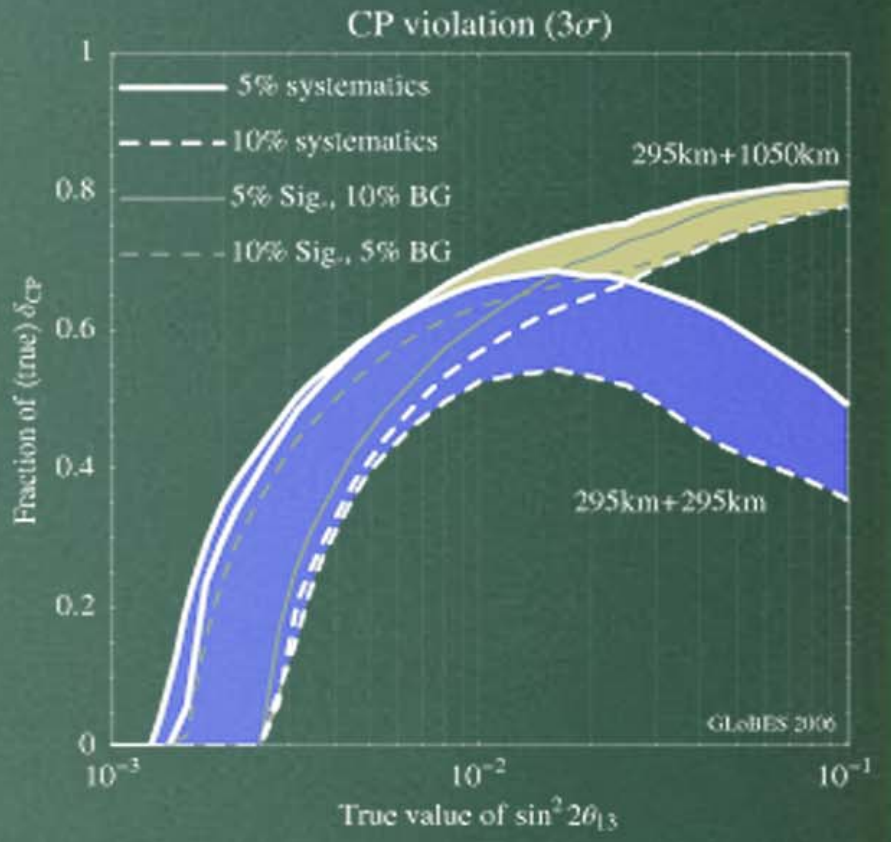




T2KK

- 4MW protons from Tokai
- same decay tunnel as for T2K
- two 270 kt WC detectors
- two baselines, 295 km and 1050 km
- same off-axis angle
- 4 years neutrinos + 4 years antineutrinos
- π^0 rejection as in T2K


Mass hierarchy (3σ)
GLoBES 2006
5% systematics
10% systematics
Corr. errors, 295km+1050km
Uncorr. errors, 295km+1050km
295km+295km
Fraction of (true) δ_{CP}
True value of $\sin^2 2\theta_{13}$
1
0.8
0.6
0.4
0.2
0
10^{-2}
10^{-1}


CP violation (3σ)
5% systematics
10% systematics
5% Sig., 10% BG
10% Sig., 5% BG
295km+1050km
295km+295km
GLoBES 2006
Fraction of (true) δ_{CP}
True value of $\sin^2 2\theta_{13}$
1
0.8
0.6
0.4
0.2
0
10^{-3}
10^{-2}
10^{-1}

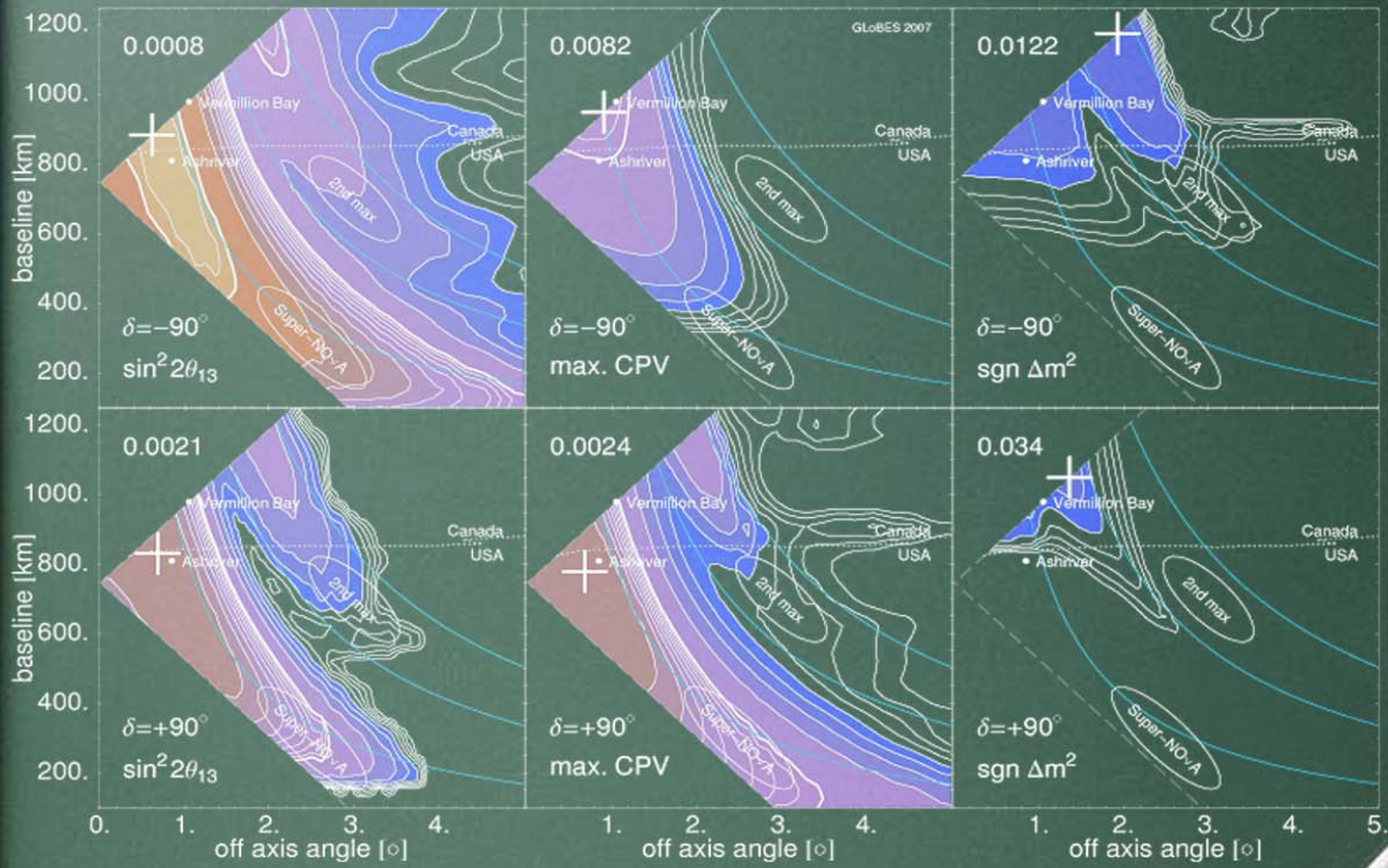
NOvA*

- 1.13 MW from MI at FNAL
- same decay tunnel as for MINOS and NOvA
- 100 kt LArTPC
- 3 years neutrinos + 3 years antineutrinos of 25kt NOvA at Ash River
- +3 years neutrinos + 3 years antineutrinos of both

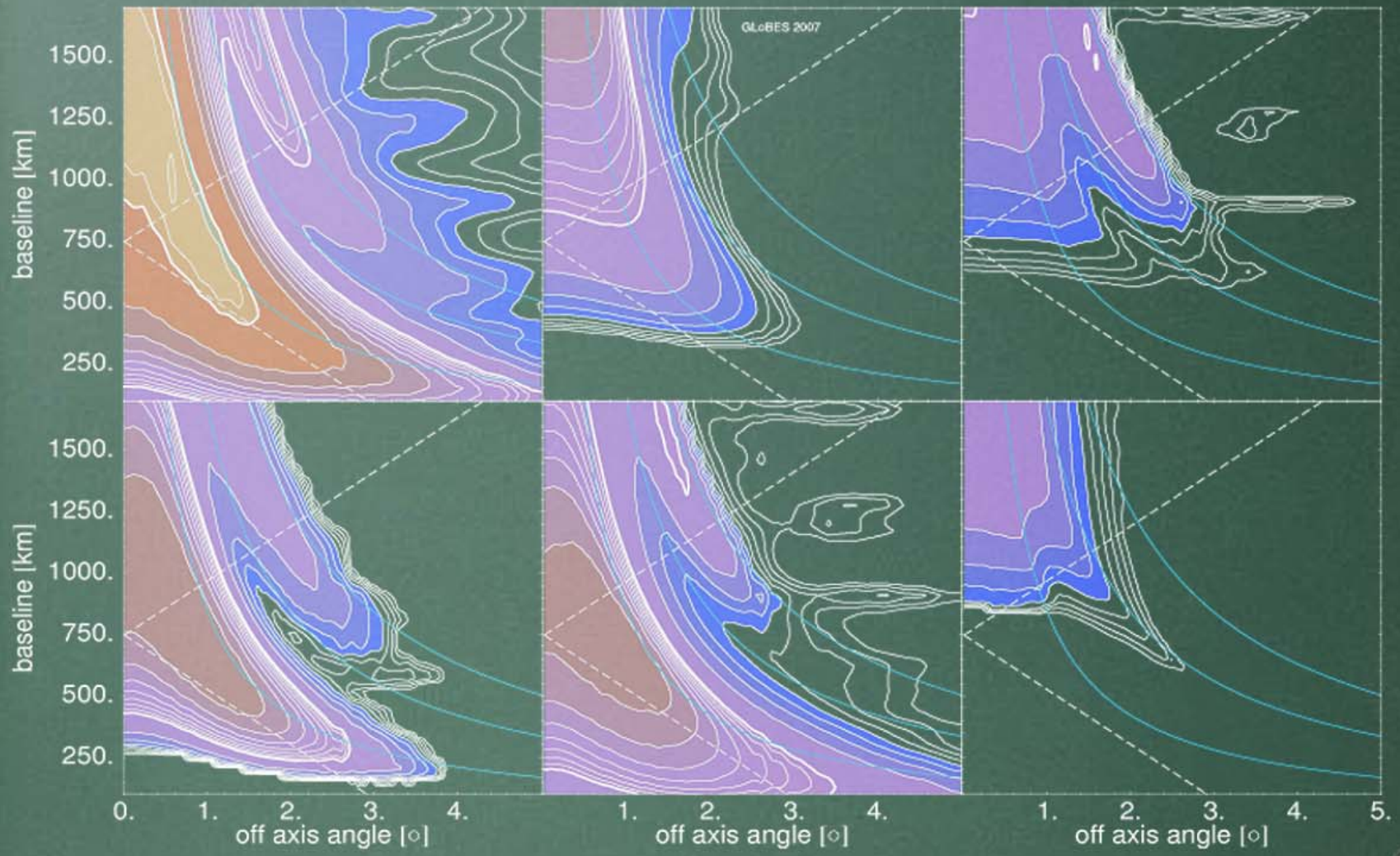
LArTPC

- 80% efficiency
- no NC background
- 5% energy resolution for QE events
- 20% energy resolution for non-QE events

Where to put NOvA*?



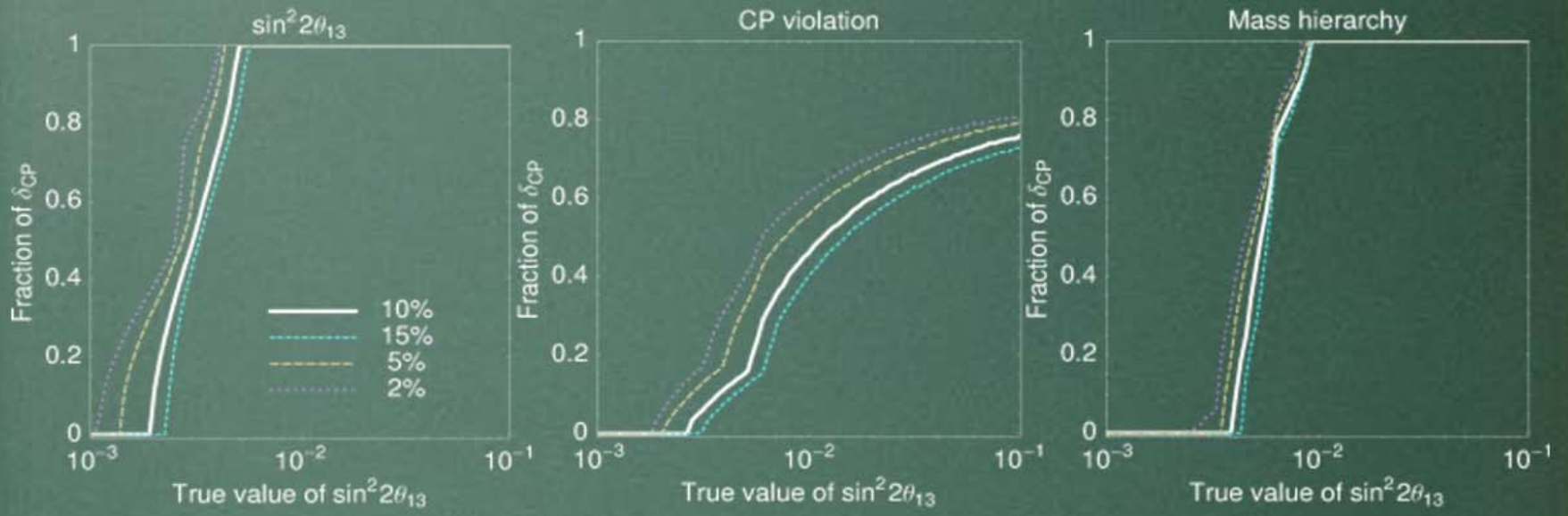
On-axis or off-axis?



WBB

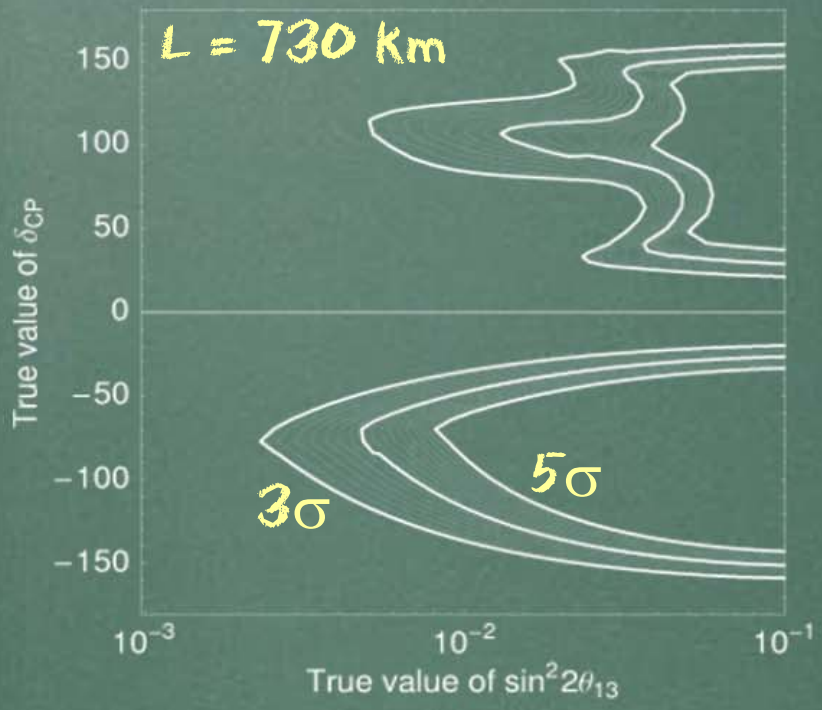
- 1(ν) + 2($\bar{\nu}$) MW at 28 GeV
- 300 kt WC detector on axis
- L = 1300 km
- 5 years neutrinos + 5 years antineutrinos
- performance based on full detector MC
- improved π^0 rejection

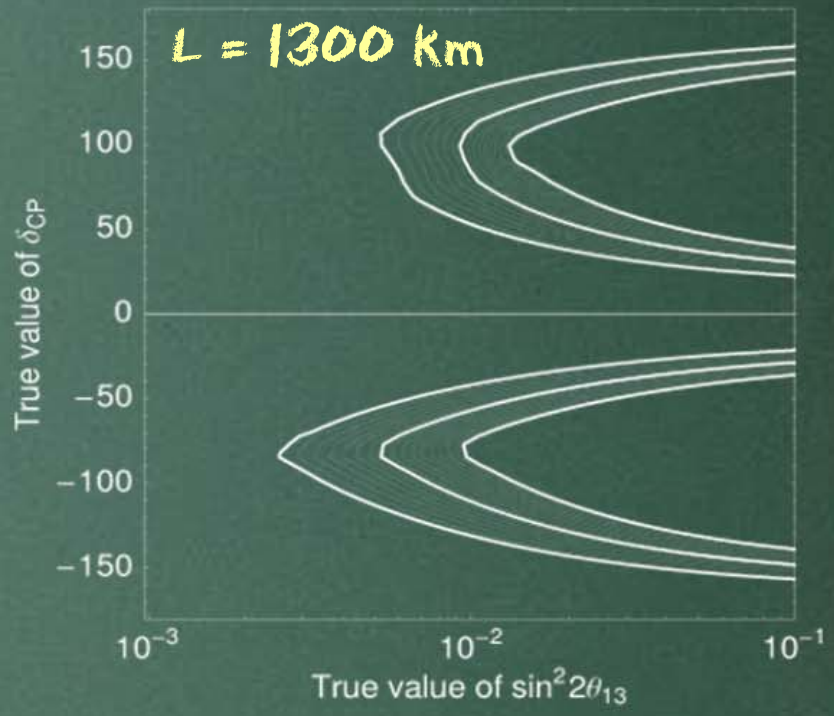
3σ sensitivities



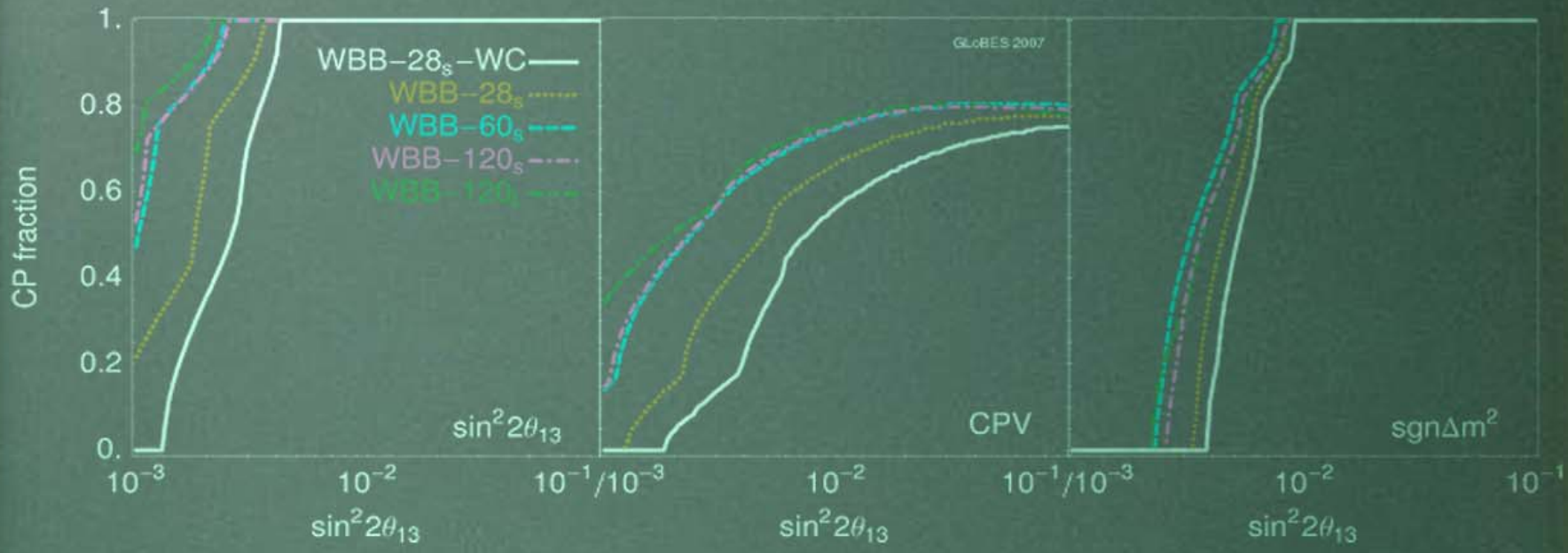
Barger, Dierckxsens, Diwan, Huber, Lewis, Marfatia, Viren (hep-ph/0607177)

Discovery potential for CP violation





Proton energies and decay tunnel length



Different proposals assume different

- uptime/year
- number of years
- detector size
- beam power

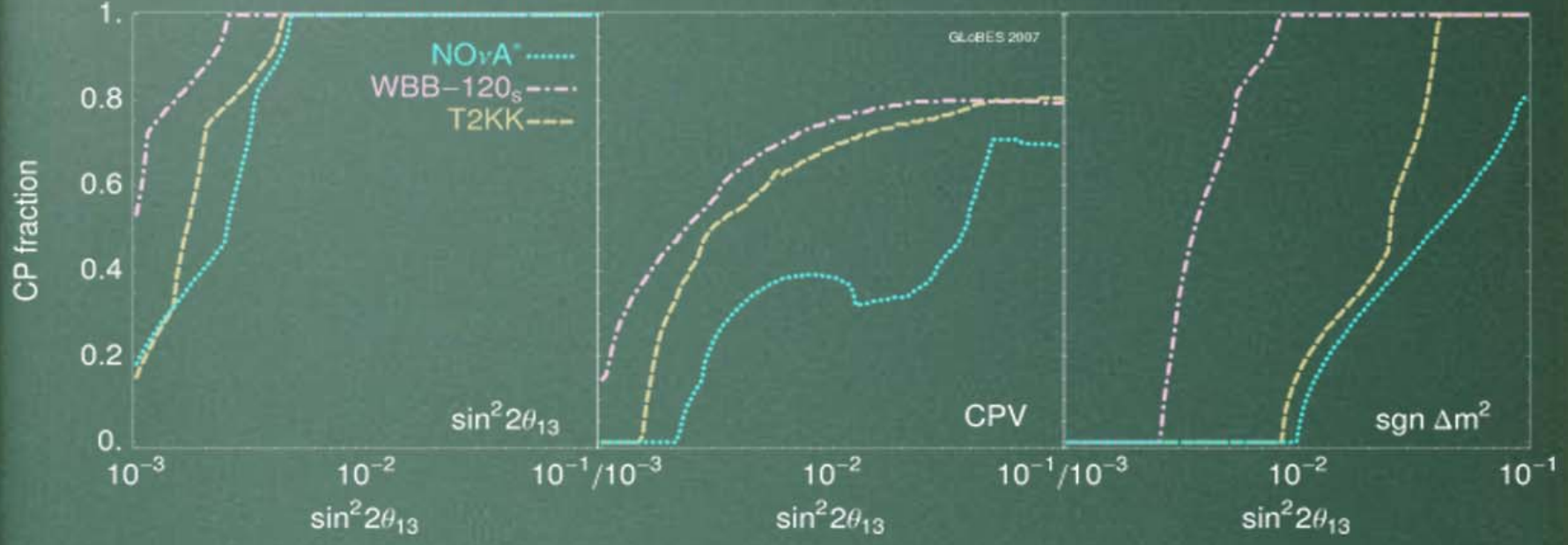
Exposure = detector mass (MMt) x target power (MMW)

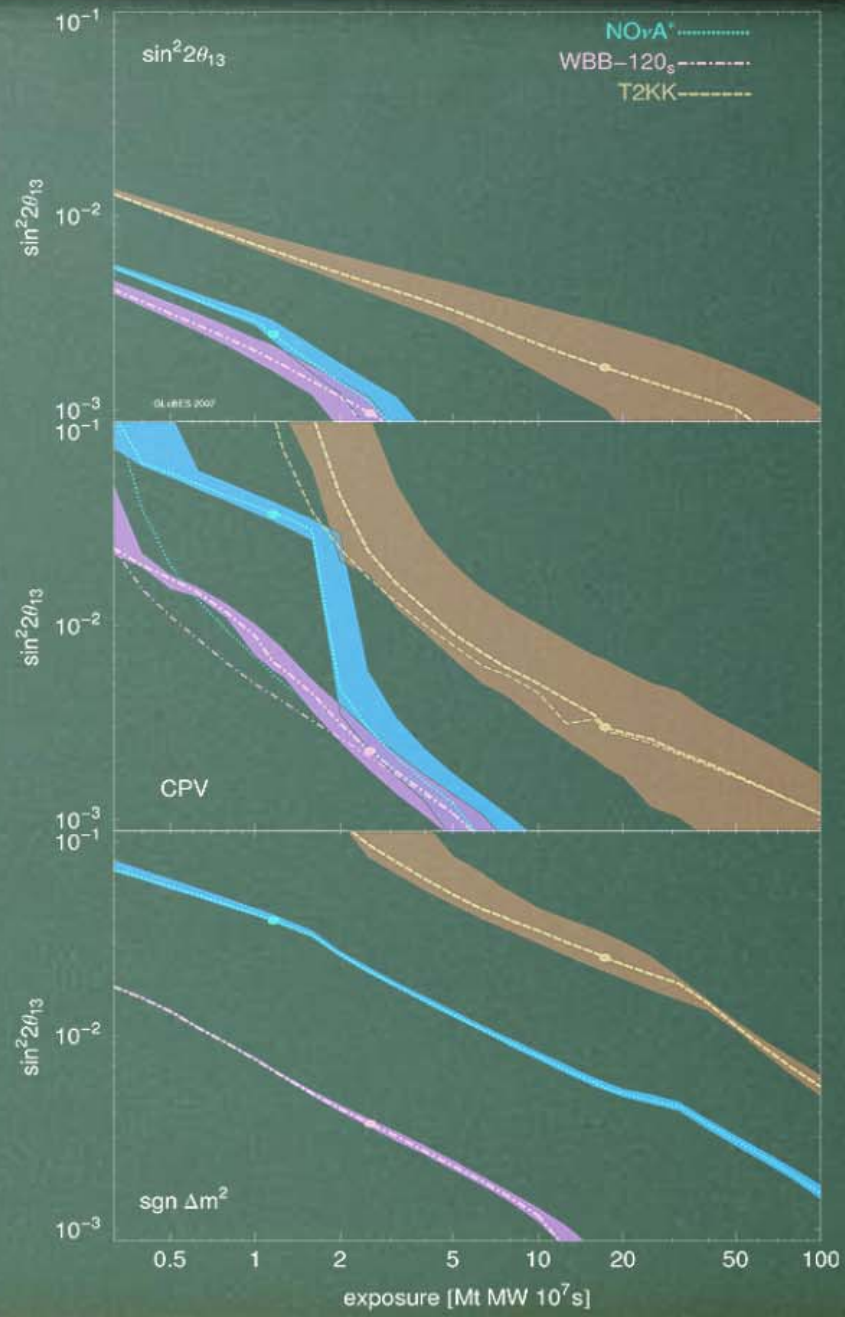
x running time (10^7s)

is a measure of integrated luminosity

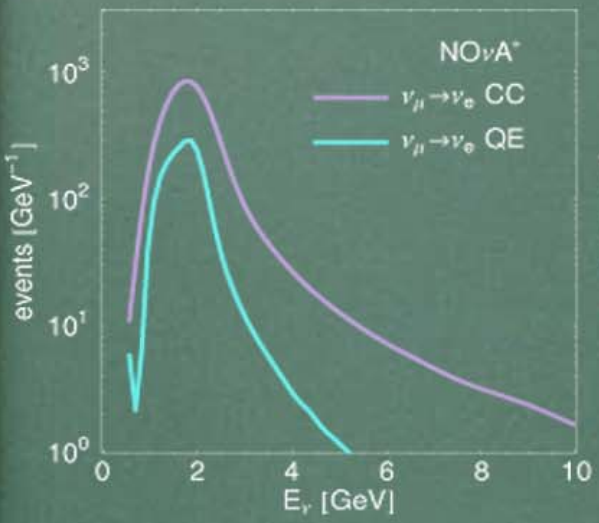
Very approximately, cost $\propto$ exposure

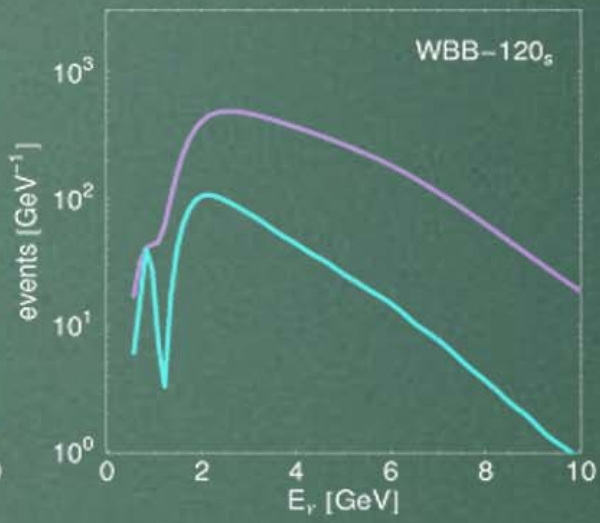
Setup	t_ν [yr]	$t_{\bar{\nu}}$ [yr]	P_{Target} [MW]	L [km]	Detector technology	m_{Det} [kt]	$\mathcal{L}$
NOνA*	3	3	1.13 ($\nu/\bar{\nu}$)	810	LArTPC	100	1.15
WBB-120$_{\text{S}}$	5	5	1 (ν) +2 ($\bar{\nu}$)	1290	LArTPC	100	2.55
T2KK	4	4	4 ($\nu/\bar{\nu}$)	295+1050	Water Cherenkov	270+270	17.28
β-beam	4	4	n/a	730	Water Cherenkov	500	n/a
NuFact	4	4	4	3000+7500	Magn. iron calor.	50+50	n/a

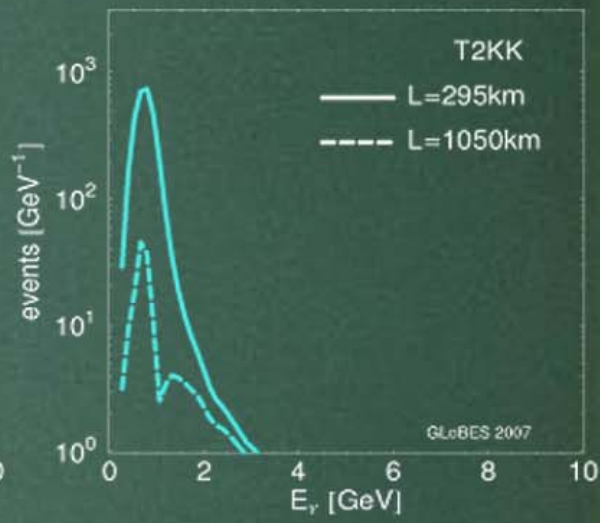

CP fraction
1.
0.8
0.6
0.4
0.2
0.
NOνA
WBB−120s
T2KK
GLoBES 2007
sin²2θ13
CPV
sgn Δm²
10⁻³
10⁻²
10⁻¹/10⁻³
10⁻¹
sin²2θ13


$\sin^2 2\theta_{13}$
NOνA
WBB–120$_s$
T2KK
GLoBES 2007
CPV
sgn Δm^2
10^{-1}
10^{-2}
10^{-3}
0.5
1
2
5
10
20
50
100
exposure [Mt MW 10^7s]

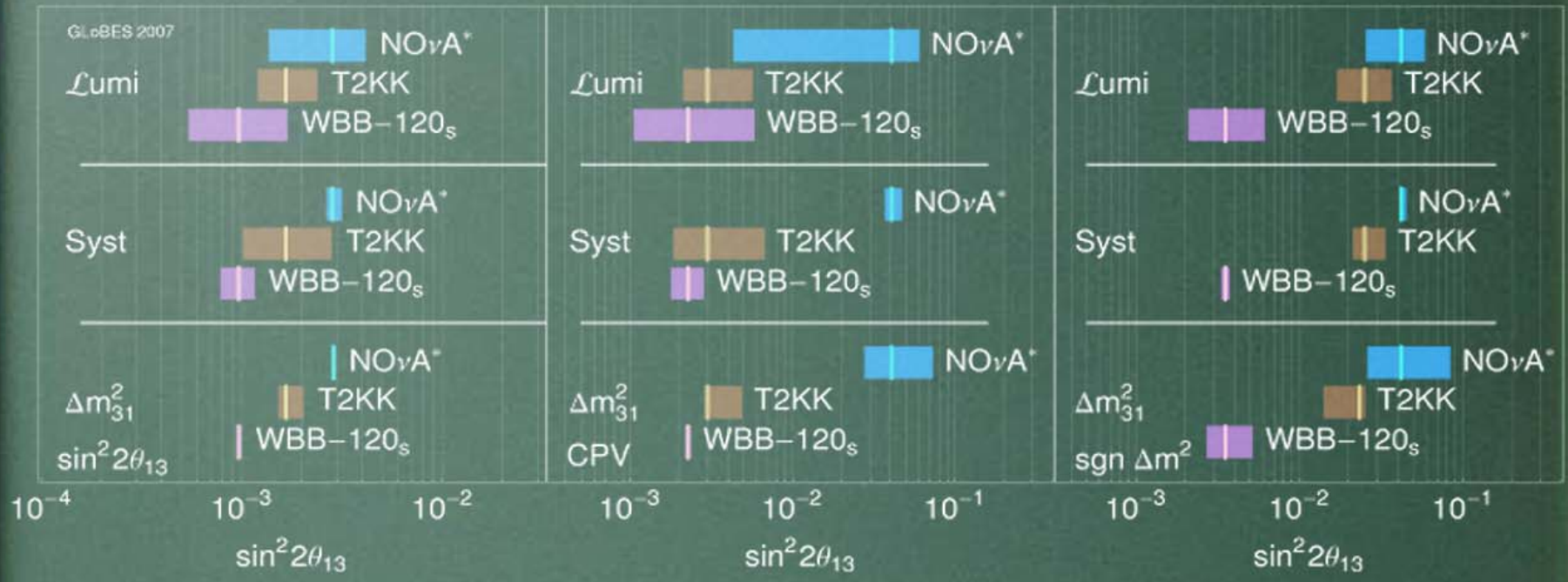
Event rates for 1 MT MW 10^7s and $\sin^2 2\theta_{13} = 0.04$





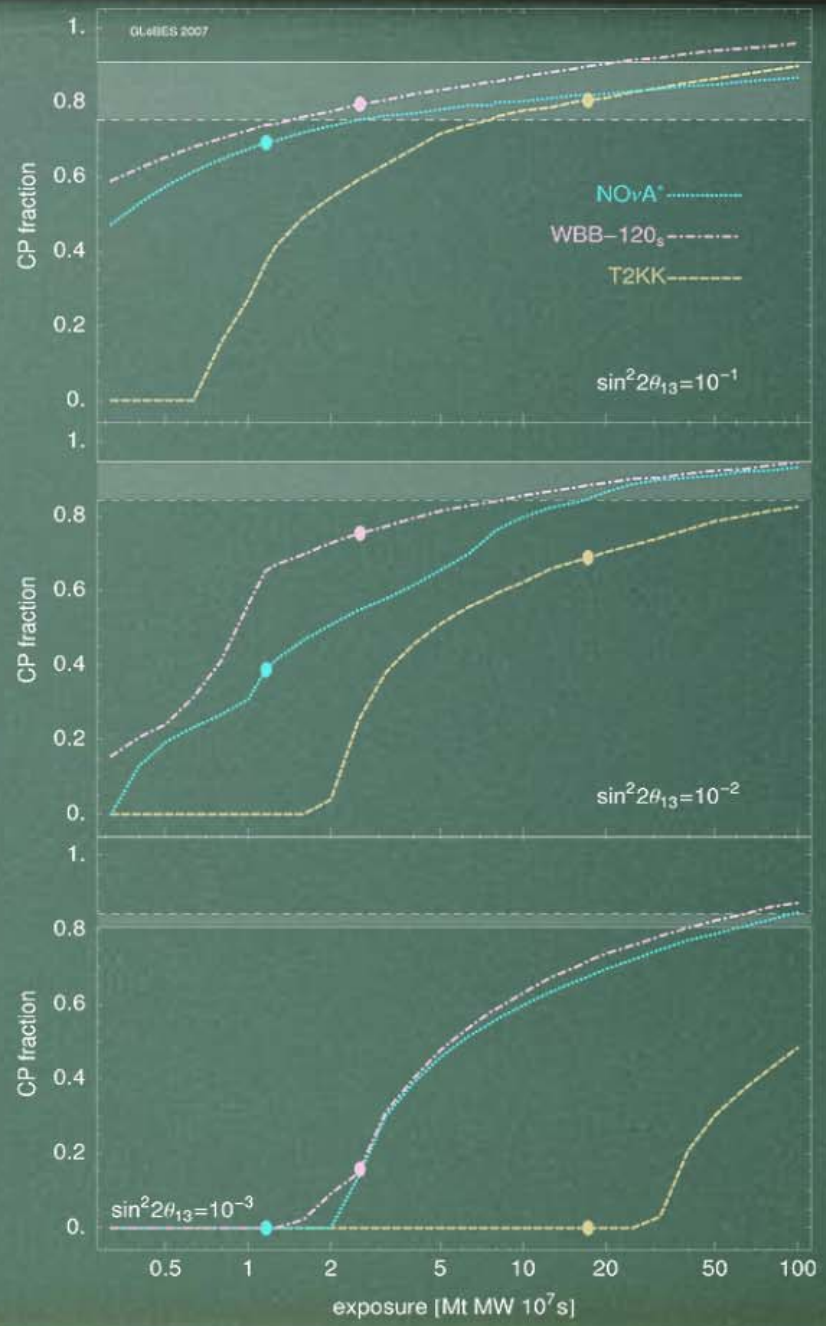


Robustness



- Exposure from 2 to 0.5 nominal value
- Systematics from 2% to 10%
- Δm^2_{31} from 2-3x10^{-3} eV^2

CPV


GLoBES 2007
CP fraction
NOνA*
WBB–120$_s$
T2KK
$\sin^2 2\theta_{13}=10^{-1}$
$\sin^2 2\theta_{13}=10^{-2}$
$\sin^2 2\theta_{13}=10^{-3}$
0.
0.2
0.4
0.6
0.8
1.
0.5
1
2
5
10
20
50
100
exposure [Mt MW 10^7s]

Summary

- Optimal NOvA* location in the U.S. is Ash River
- To be competitive for CPV, it is crucial that NOvA* gets enough exposure (> 2 Mt MW 10^7 s)
- WBB experiments can make all 3 measurements and have the most robust performance
- WBB-LAr better than WBB-WC if cost/Kt of LAr is smaller than cost/4 Kt of water
- Every strategy requires MW beams, 0.1 Mt detectors and 10 years of running (0.5 billion $)
- For $\sin^2 2\theta_{13} > 0.01$ no need for a NuFact or beta-beam