Next generation long baseline experiments on the path to leptonic CP violation

P. Migliozzi and F. Terranova

- ✔ On−peak versus off−peak experiments
- ✔ JHF−SK in the "null result" scenario
- ✔ JHF−SK and CNGS synergies

Oscillation probability

Taylor expansion around $\alpha \equiv \Delta m^2_{21}/\Delta m^2_{31}$ and $\sin^2 2\vartheta_{13}$ for constant matter density:

$$P(\nu_\mu \to \nu_e) \simeq \sin^2 2\vartheta_{13} \sin^2\vartheta_{23} \frac{\sin^2[(1-\hat{A})\Delta]}{(1-\hat{A})^2}$$ O_1 (leading term)

$$-\alpha \sin 2\vartheta_{13}\, \xi \sin\delta_{CP} \sin\Delta \frac{\sin[\hat{A}\Delta]}{\hat{A}} \frac{\sin[(1-\hat{A})\Delta]}{(1-\hat{A})}$$ O_2 ($\sim \sin\Delta$)

$$+\alpha \sin 2\vartheta_{13}\, \xi \cos\delta_{CP} \cos\Delta \frac{\sin[\hat{A}\Delta]}{\hat{A}} \frac{\sin[(1-\hat{A})\Delta]}{(1-\hat{A})}$$ O_3 ($\sim \cos\Delta$)

$$+\alpha^2 \cos^2\vartheta_{23} \sin^2 2\vartheta_{12} \frac{\sin^2[\hat{A}\Delta]}{\hat{A}^2}$$ O_4 (suppressed by α^2)

$$\xi \equiv \cos\vartheta_{13} \sin 2\vartheta_{12} \sin 2\vartheta_{23} \sim O(1) \qquad \hat{A} \equiv 2\sqrt{2}\, G_F\, n_e \frac{E}{\Delta m^2_{31}} \qquad \Delta \equiv \frac{\Delta m^2_{31} L}{4E}$$

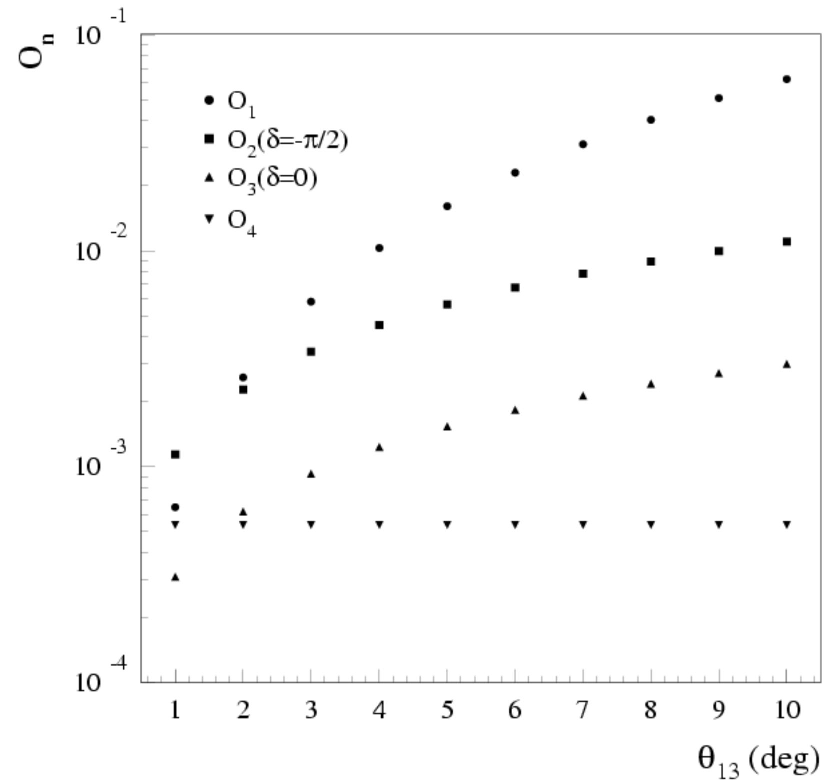
A.Cervera et al. Nucl.Phys. B579(2000)17 ; M. Freund, Phys.Rev. D64(2001)053003

Hierarchy of $O_1 \ldots O_4$ terms

- On peak, "short" baseline experiments (JHF−SK) ⇒ dominance of O_1 and O_2 terms and low sensitivity to sign (Δm^2_{31})

$$P(\nu_\mu \to \nu_e) \simeq \sin 2\vartheta_{13}(\sin 2\vartheta_{13} A_1 - \sin\delta\,\alpha\, A_2) \quad ; \quad A_1, A_2 \sim O(1)$$

- On peak, longer baseline experiments (NuMI−Off Axis) ⇒ dominance of O_1 and O_2 and higher dependence on sign(Δm^2_{31})



Off−peak experiments (e.g. CNGS)

Leading term: signal rate suppressed $|(1-\hat{A})\Delta| \ll 1$

$$\frac{\sin^2[(1-\hat{A})\Delta]}{(1-\hat{A})^2} \simeq \Delta^2$$

Matter effects cancel out at LO even if CNGS is an high energy beam

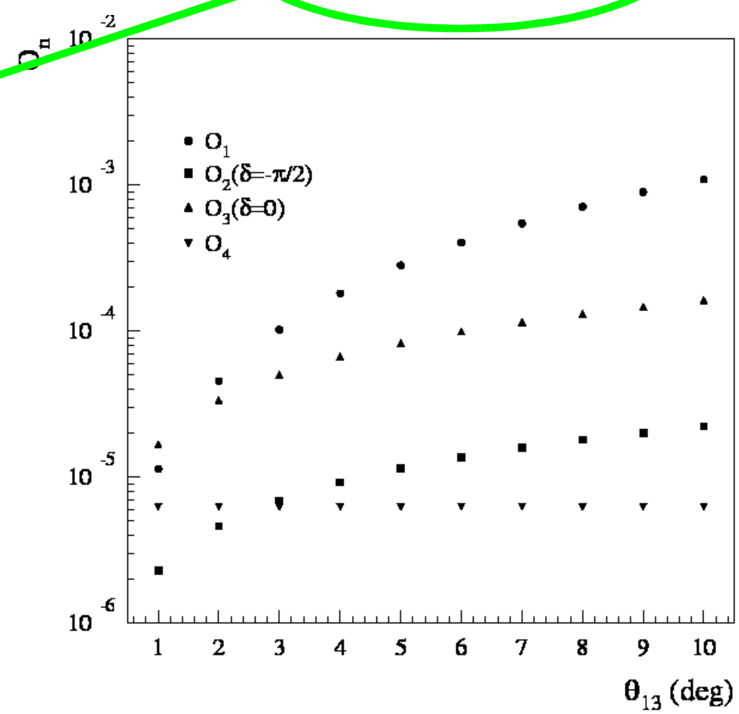
$$P(\nu_\mu \to \nu_e) \simeq \Delta^2[\sin^2 2\vartheta_{13} A_1 - \sin\delta \sin 2\vartheta_{13} \alpha \Delta A_2 + \cos\delta \sin 2\vartheta_{13} \alpha A_3 + \alpha^2 A_4]$$

Dominance of O_1 and O_3:

O_1 is CP and matter independent

O_3 is CP even and odd under

$\Delta m^2_{31} \to -\Delta m^2_{31}$ transformation



Phase I → Phase II strategy

Since the physics reach of High Intensity Superbeams (e.g. JHF−HK) and NuFact depends critically on the size of $\sin^2 2\vartheta_{13}$

Phase I experiments ⇒ high $\sin^2 2\vartheta_{13}$ sensitivity

signal ⇒ precision MNS physics at SB/NuFact

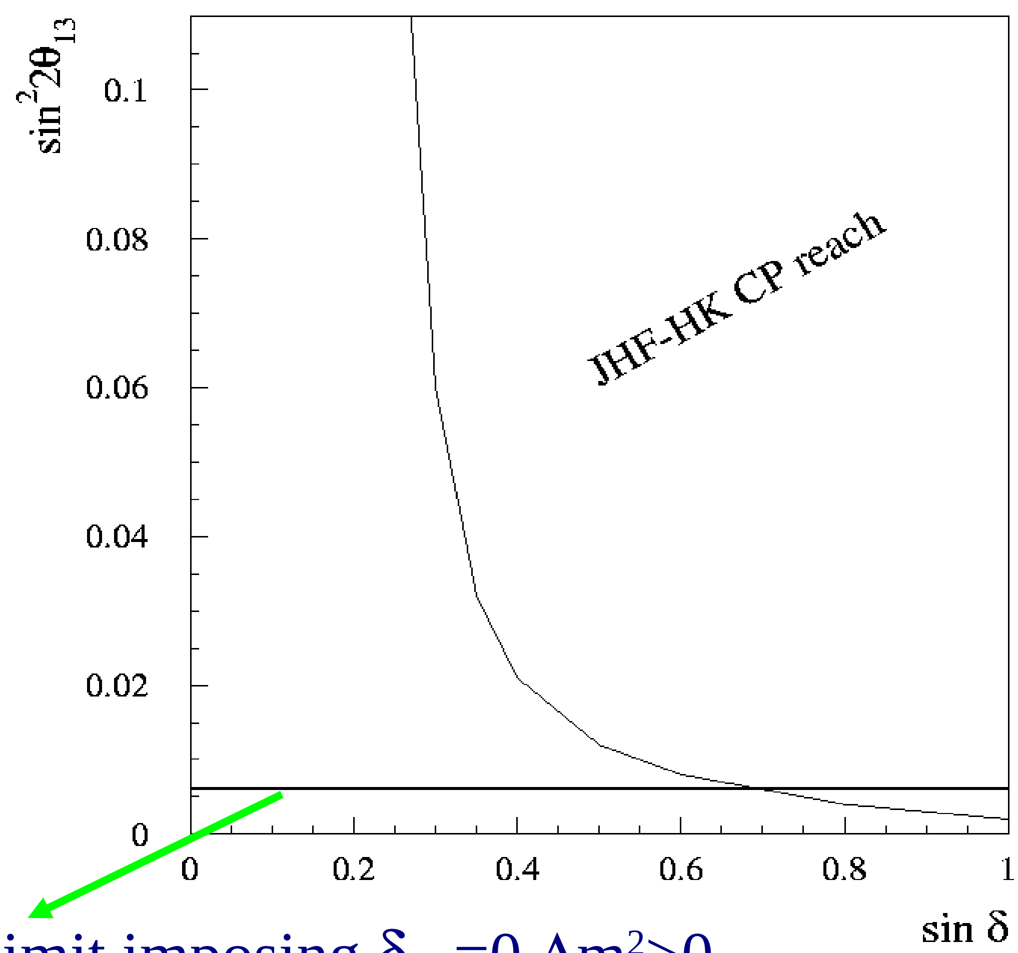
null result ⇒ discourage the SB/NuFact physics programme

Three ways to build a good phase I experiment:

- A "pure" $\sin^2 2\vartheta_{13}$ experiments (e.g. Reactors)
- An experiment sensitive to δ but able to disentangle $\delta - \vartheta_{13}$ cancellation effects (JHF−SK + antineutrino runs)
- An experiment which has maximal ϑ_{13} sensitivity for maximal $\not{CP}$

How looks a pure $\sin^2 2\vartheta_{13}$ experiment?

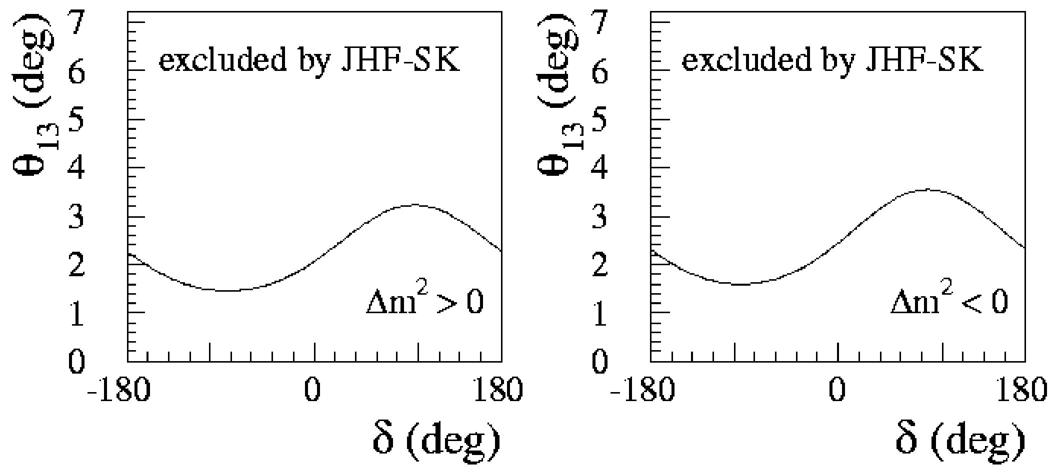
T.Nakaya @ ν2002



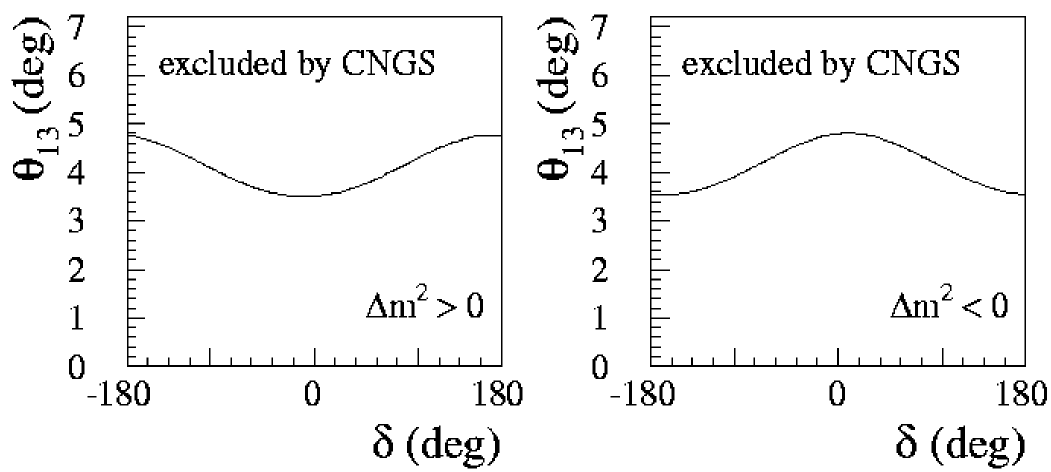
JHF−SK limit imposing $\delta_{CP}=0$ $\Delta m^2>0$

What happens in real life?

JHF−SK has the wrong pattern for $\delta>0$

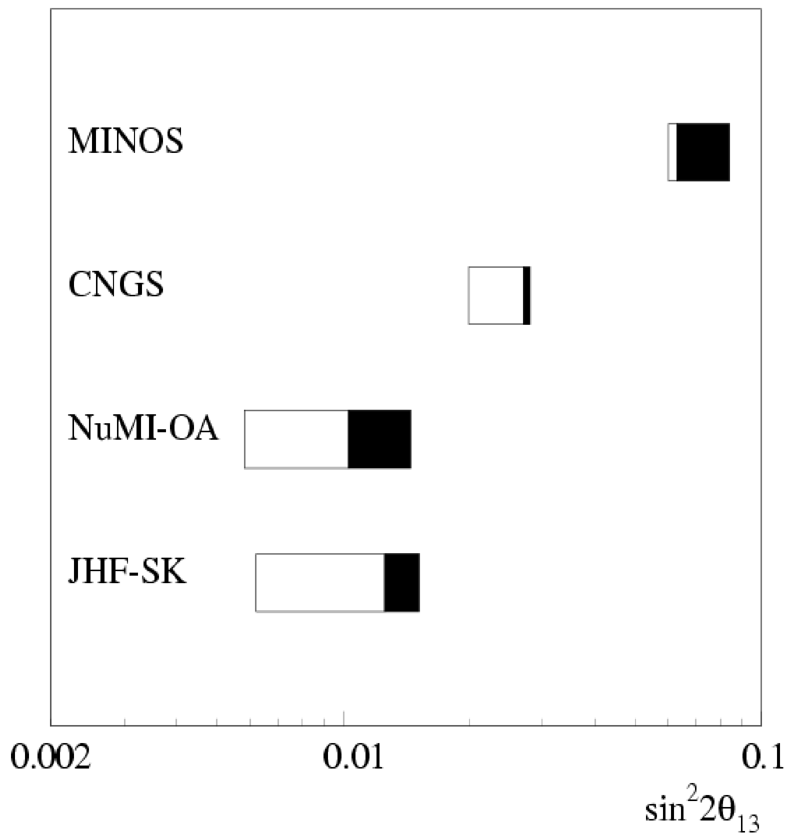


CNGS has the wrong pattern for $\Delta m^2_{31}>0$



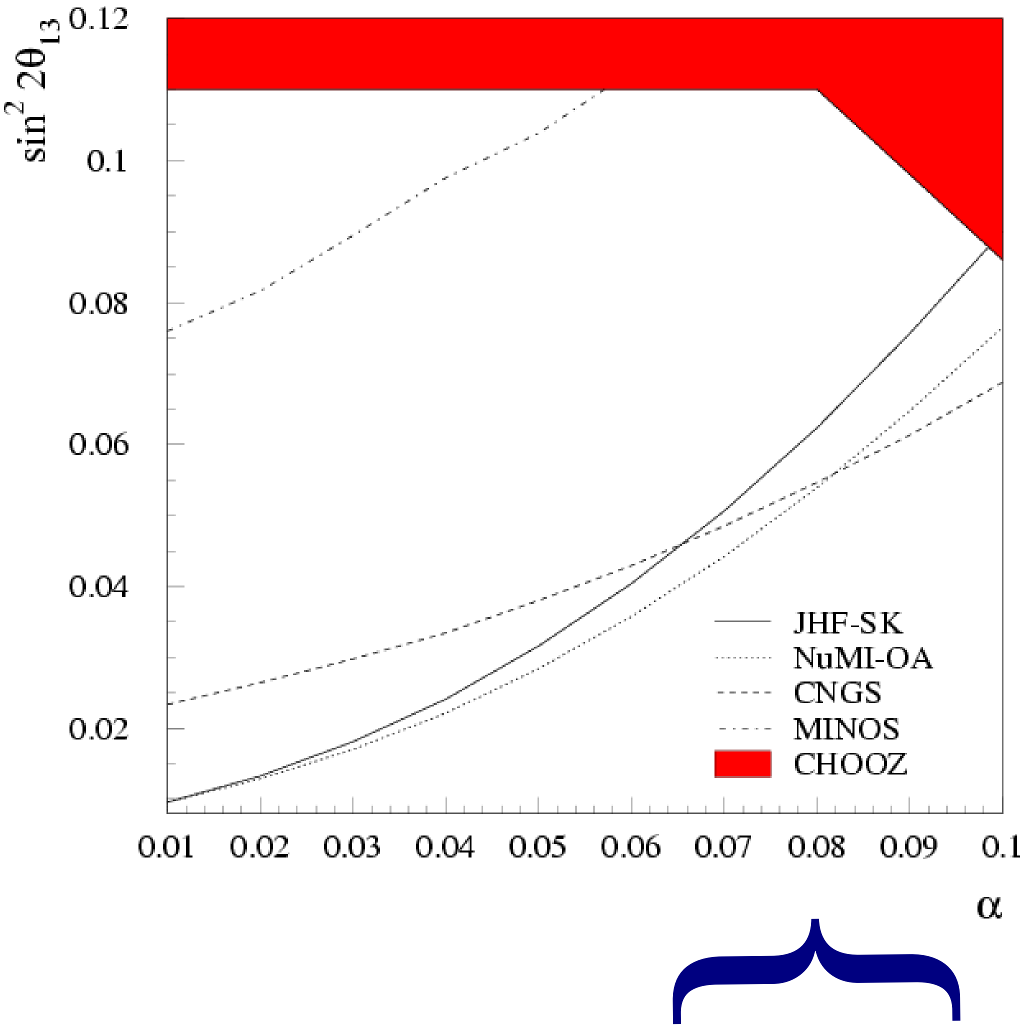
What can we say on Phase II if we observe a null result in JHF−SK?

Assuming complete ignorance on δ_{CP} and using no other information to lift the $\theta_{13}-\delta_{CP}$ ambiguity...



P.Huber et al. Nucl.Phys.B645 (2002) 3

Even worse for higher $\Delta m^2_{21}/\Delta m^2_{31}$



HLMA solution

JHF−SK should exploit its higher sensitivity even in case of null results along the line of:

T.Kajita et al. Phys.Lett. B528 (2002) 245
(anti−ν with JHF−SK)

H.Minakata et al. hep−ph/0301210
(ν with JHF−SK and anti−ν with NuMI OA... "hey guys, no kidding: YOU japanese will run with anti−ν first!")

Can we exploit the different δ_{CP} patters even in case of positive signal at JHF?

NuMI OA re−tuned: see P.Huber et al. Nucl.Phys. B654 (2003) 3
What about CNGS?

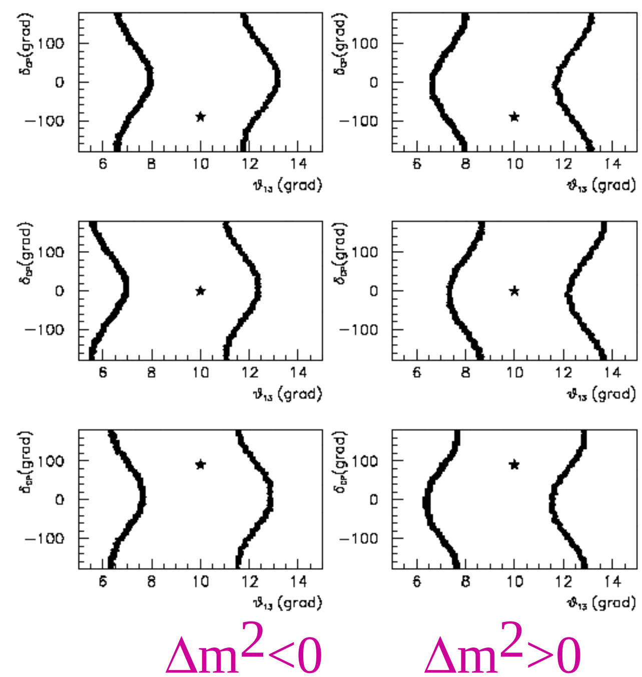
Status of CNGS at the beginning of JHF−SK

After 3 years data taking at the CNGS

- Evidence for τ appearance at $>2\sigma$ (OPERA alone)
- $Sin^2 2\theta_{13} < 0.035$ @90% C.L. (a factor 4 better than CHOOZ) in the worst case
- Indication of ν_e appearance if $\theta_{13} > 7°$

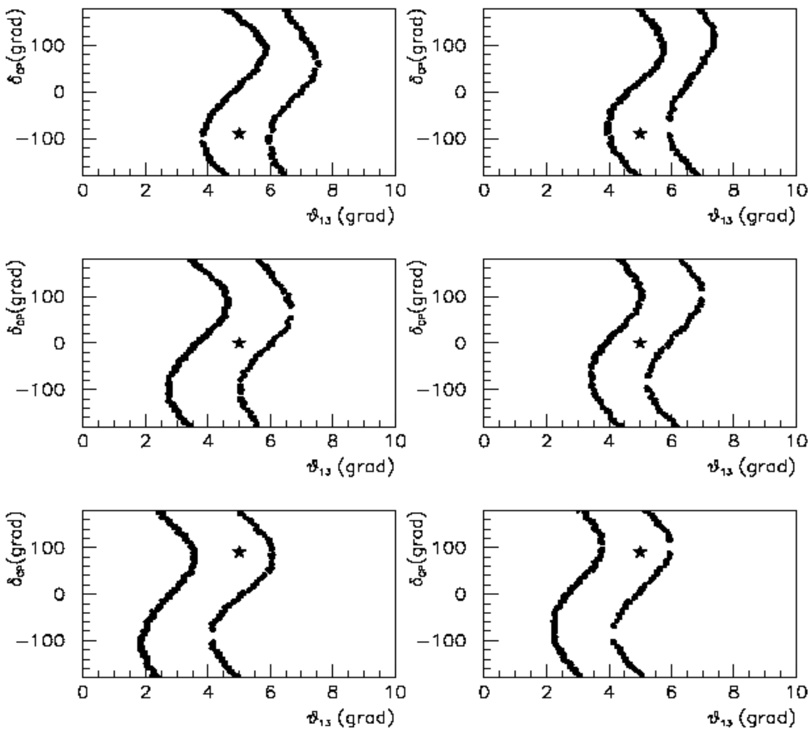
$\theta_{13}\|_{true}$	$\theta_{13}\|_{min}$	$\theta_{13}\|_{max}$	
1°	−−−	5.5°	−−−
2.5°	−−−	5.8°	−−−
5.0°	−−−	7.0°	−−−
7.5°	1.2°	11.4°	(7.5+3.9−6.3)°
10°	5.6°	13.7°	(10.+3.7−4.4)°

90% C.L. allowed region



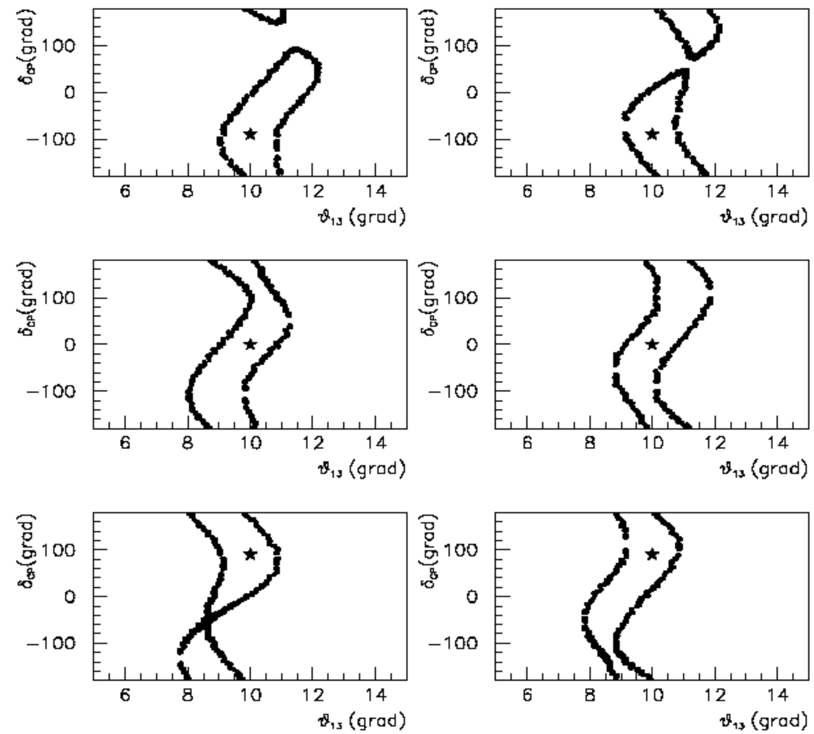
Allowed regions for JHF−SK(5 years) + CNGS(8years)

$\theta_{13}=5°$



$\Delta m^2<0$ $\Delta m^2>0$

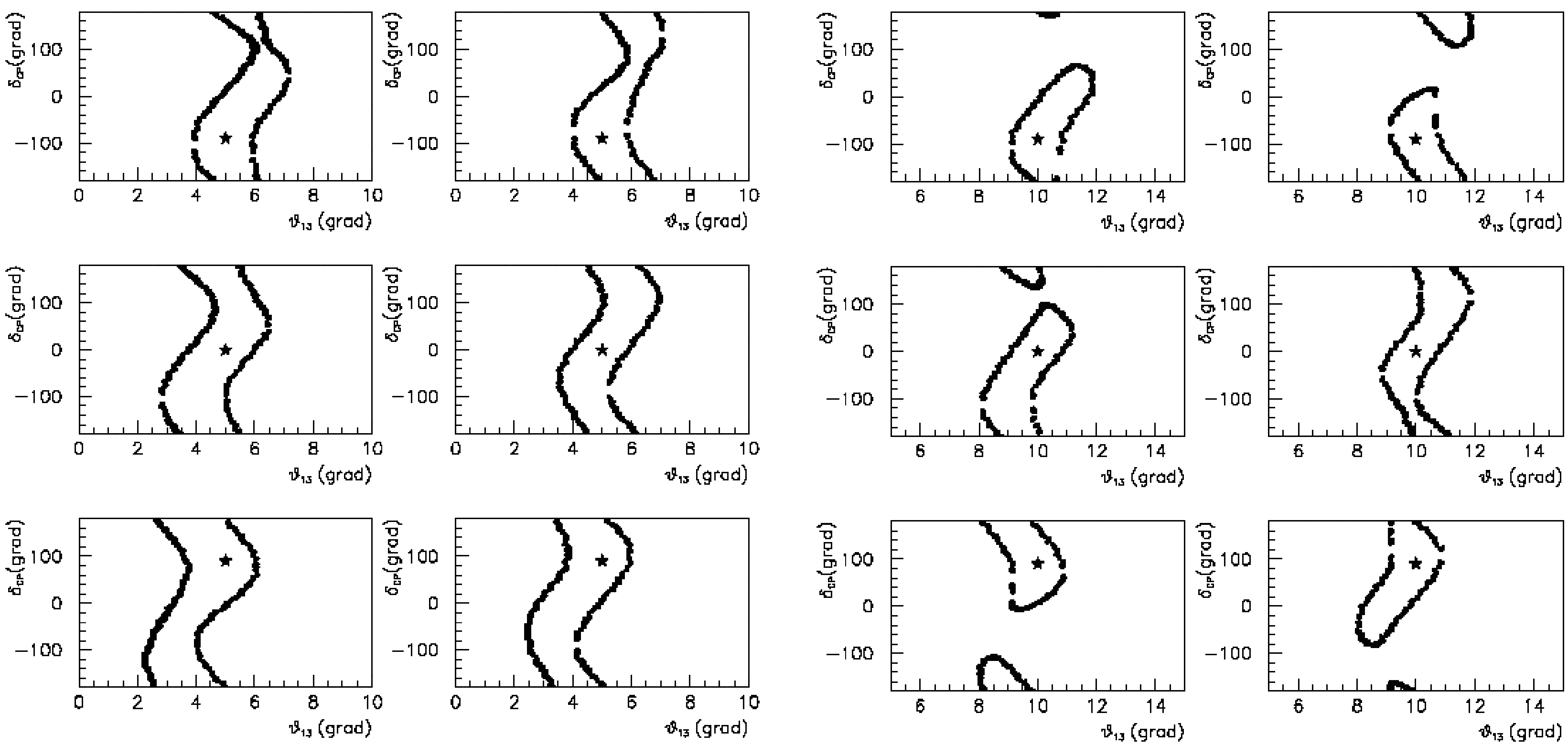
$\theta_{13}=10°$



$\Delta m^2<0$ $\Delta m^2>0$

What about an anti−neutrino run at the CNGS?

Here we assumed CNGS 3 years ν and 6 years anti−ν



Conclusions

- Off−peak beams like CNGS or a re−tuned NuMI−OffAxis explore peculiar regions of the nm ne oscillation probability that could complement on−peak experiments

- Comparisons between JHF−SK and CNGS in case of null result give the most convincing evidence that the JHF−SK data taking should be better optimized to fully profit of its overwhelming physics potential

- If θ_{13}>7°, after three years data taking CNGS could give a first indication of ν_e appearance. Moreover, the CNGS is an off−peak beam, therefore it has a different pattern from JHF−SK ⇒ they can be used synergically