The search for leptonic CP violation

Enrique Fernández Martínez

νProbes

Mostly based on collaborations with P. Coloma

Oscillation Parameters

- What we already know (1σ)
  - Solar sector $\begin{cases} \Delta m^2_{21} = 7.45^{+0.19}_{-0.16} \cdot 10^{-5}\,\mathrm{eV}^2 \\ \sin^2\theta_{12} = 0.306^{+0.012}_{-0.012} \end{cases}$
  - Atm. sector $\begin{cases} \Delta m^2_{31} = 2.417^{+0.013}_{-0.013} \cdot 10^{-3} \,/\, -2.410^{+0.062}_{-0.062} \cdot 10^{-3}\ \mathrm{eV}^2 \\ \sin^2\theta_{23} = 0.446^{+0.007}_{-0.007} \,/\, 0.587^{+0.032}_{-0.037} \end{cases}$
  - $\sin^2\theta_{13} = 0.0229^{+0.002}_{-0.0019}$
- What we still don't know
  - $\delta = ?$
  - Mass hierarchy $s_{atm} = sign\left(\Delta m^2_{31}\right)$

M. C. Gonzalez-Garcia, M. Maltoni, J. Salvado, T. Schwetz 1209.3023 www.nu-fit.org
See also: D. V. Forero, M. Tortola, J. Valle 1205.4018
G.L. Fogli, E. Lisi, A. Marrone, D. Montanino, A. Palazzo, A.M. Rotunno 1205.5254

The Golden channel in matter

$$P\left(\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_\mu\right) = s_{23}^2 \sin^2 2\theta_{13} \left(\frac{\Delta_{atm}}{\tilde{B}_{\mp}}\right)^2 \sin^2\left(\frac{\tilde{B}_{\mp} L}{2}\right) \quad \text{"atmospheric"}$$

$$+ c_{23}^2 \sin^2 2\theta_{12} \left(\frac{\Delta_{sol}}{A}\right)^2 \sin^2\left(\frac{AL}{2}\right) \quad \text{"solar"}$$

$$\text{"interference"} + \tilde{J} \frac{\Delta_{sol}}{A} \frac{\Delta_{atm}}{\tilde{B}_{\mp}} \sin\left(\frac{AL}{2}\right) \sin\left(\frac{\tilde{B}_{\mp} L}{2}\right) \cos\left(\pm\delta - \frac{\Delta_{atm} L}{2}\right)$$

Expanded in

$$\sin 2\theta_{13} \sim 0.3 \qquad \left(\frac{\Delta_{sol} L}{2}\right) \cong 0.05$$

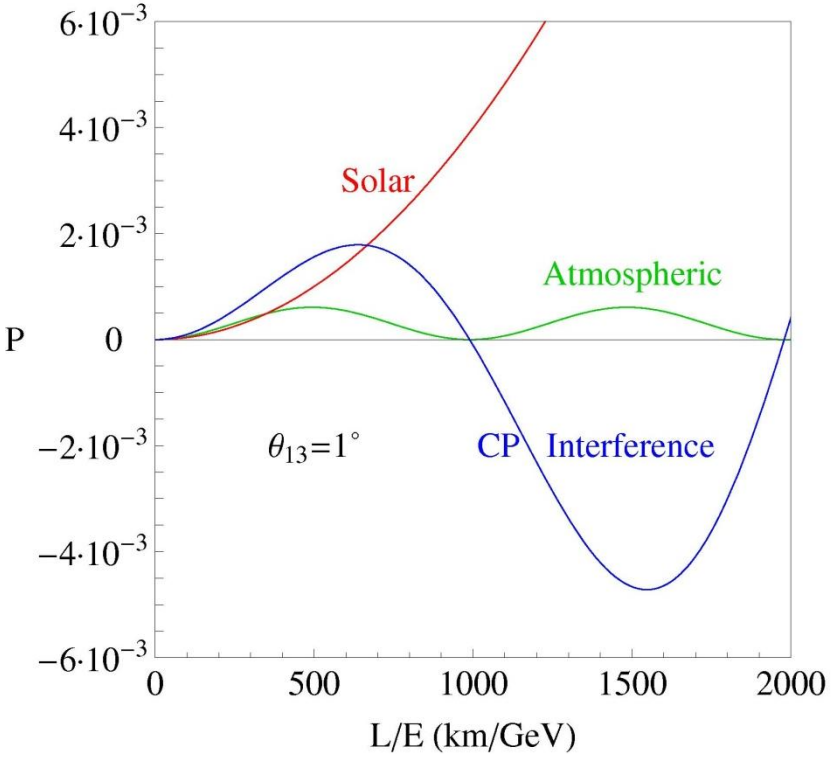
where

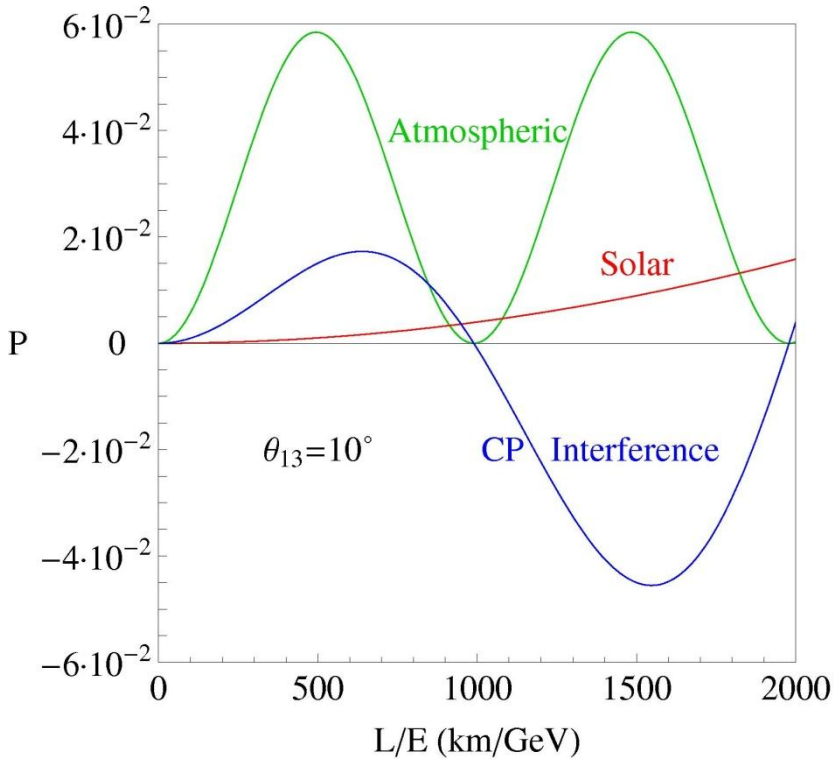
$$\tilde{J} = \cos\theta_{13} \sin 2\theta_{13} \sin 2\theta_{12} \sin 2\theta_{23} \qquad \Delta_{atm} = \frac{\Delta m_{23}^2}{2E} \qquad \Delta_{sol} = \frac{\Delta m_{12}^2}{2E}$$

$$A = \sqrt{2} G_F n_e \qquad \tilde{B}_{\mp} = \left| A \mp \Delta_{atm} \right|$$

A. Cervera *et al.* hep-ph/0002108

Optimization of facilities for large θ_{13}



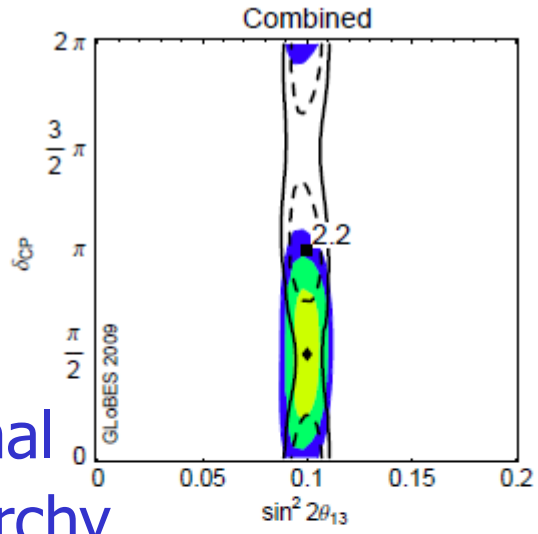


Signal systematics and not stats becomes the bottleneck for large θ_{13}, explore second peak? P. Coloma and EFM 1110.4583

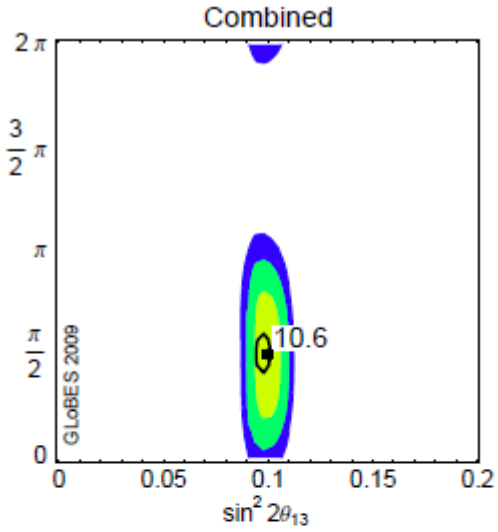
Sensitivities with present experiments

1, 2 and 3 σ

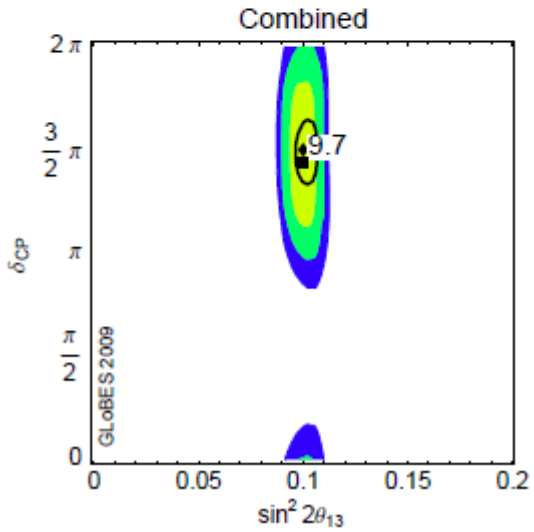
Normal hierarchy

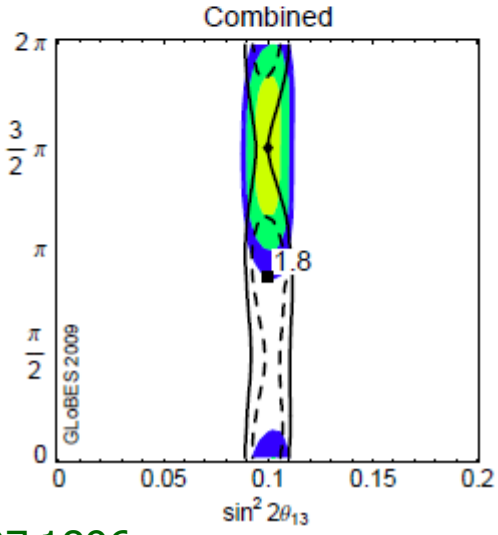


T2K+
Nova+
Daya Bay



Inverted hierarchy





From P. Huber *et al.* 0907.1896

Sensitivities with present experiments

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1 σ, 90%, 2 σ, 99% and 3 σ

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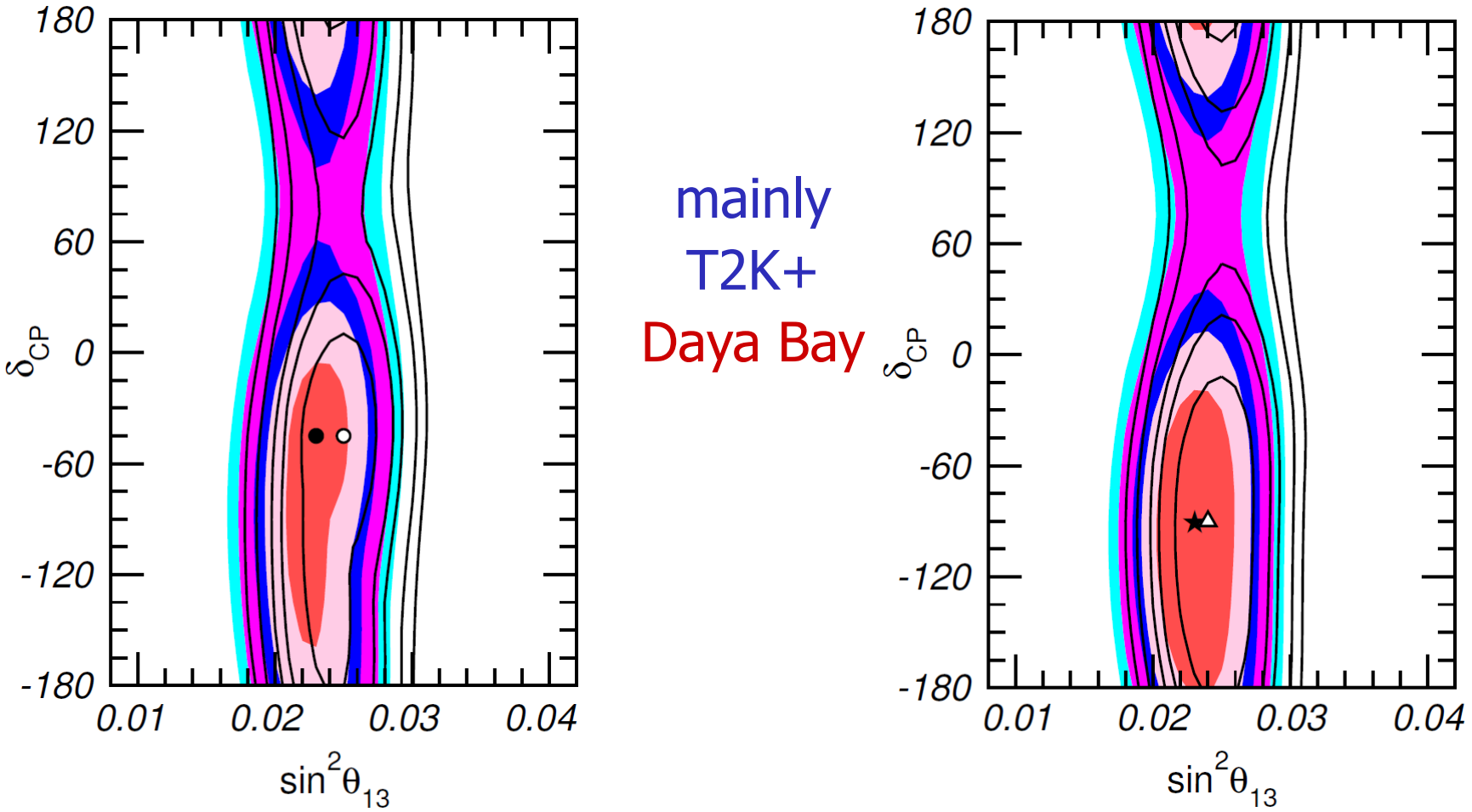

mainly T2K+ Daya Bay

From M. C. Gonzalez-Garcia, M. Maltoni, J. Salvado, T. Schwetz 1209.3023 www.nu-fit.org

Shoplist of future facilities

	detector vol. (kt)/type	dist. (km)	power (MW)	proton driver energy (GeV)	years $\nu/\bar{\nu}$
ESSνSB-360	500/WC	360	5	2.0/3.0	2/8
ESSνSB-540	500/WC	540	5	2.0/3.0	2/8
Hyper-K	560/WC	295	0.75	30	3/7
LBNE-10	10/LAr	1290	0.72	120	5/5
LBNE-PX	34/LAr	1290	2.2	120	5/5
LBNO-EoI	20/LAr	2300	0.7	400	5/5
IDS-NF	100/MIND	2000	4	10*	10**
NuMAX	10/LAr (magnetized)	1300	1	5*	5/5

E. Baussan et al 1309.7022

Shoplist of future facilities

Big WC detectors, low energies, small matter effects

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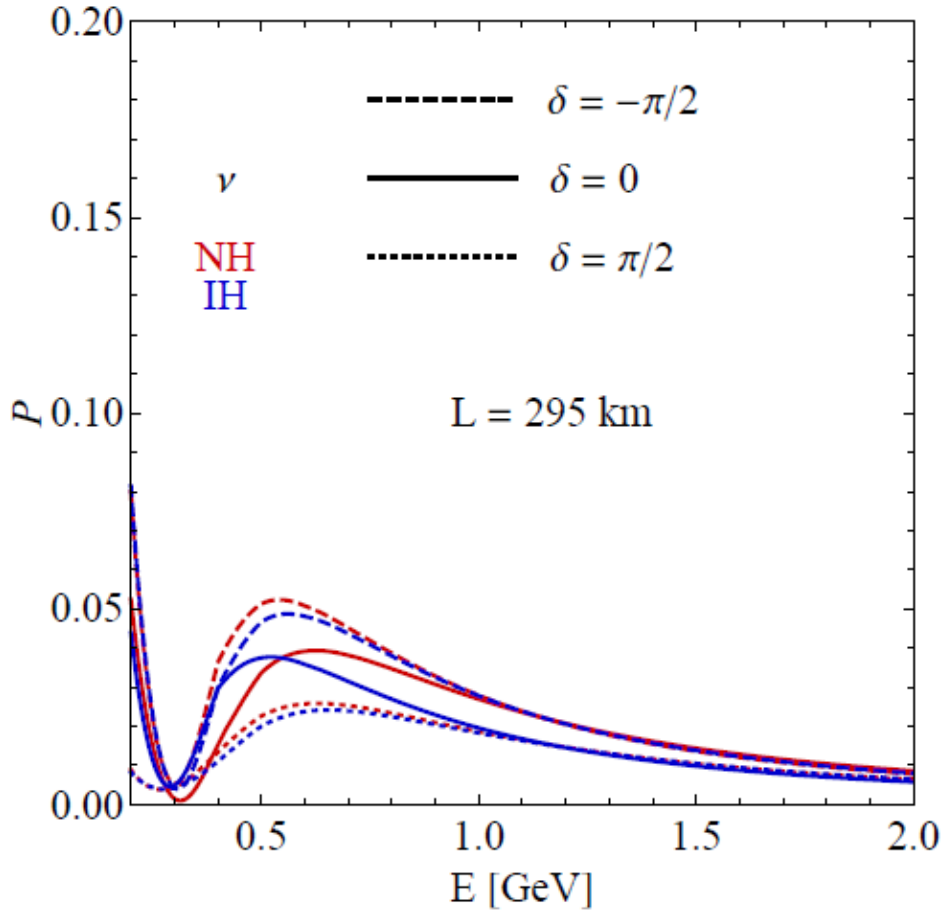
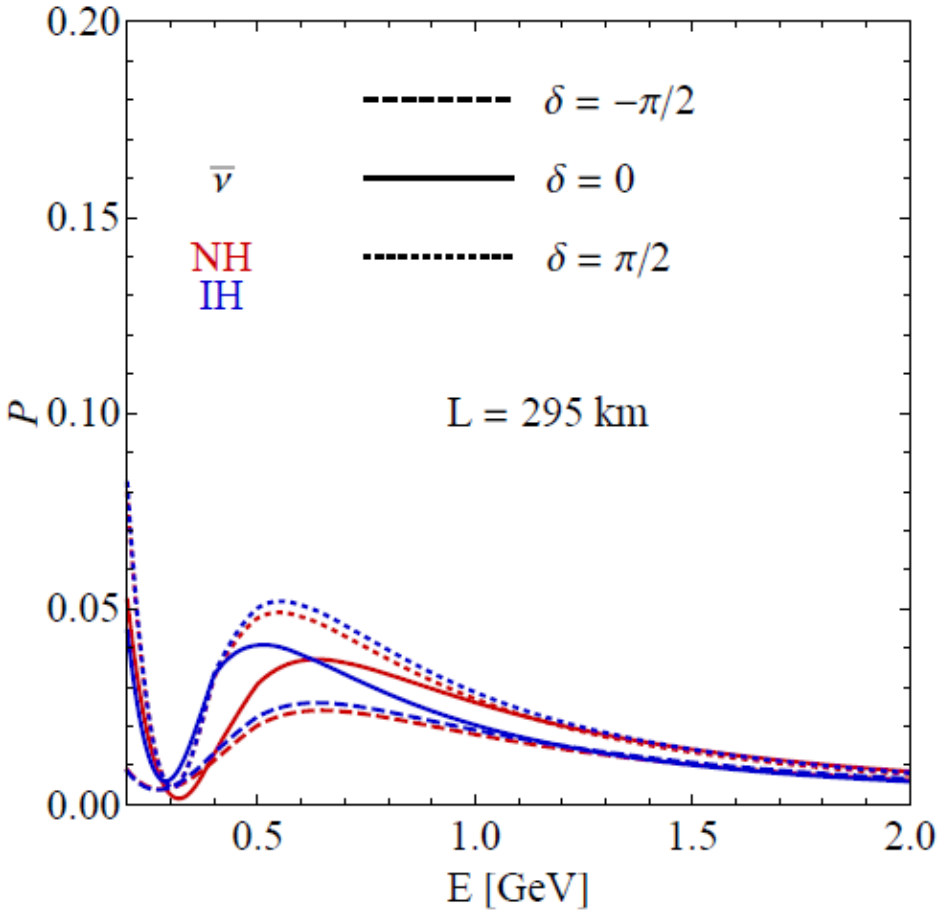
LAr detectors, high energies and broad beams, big matter effects

E. Baussan et al 1309.7022

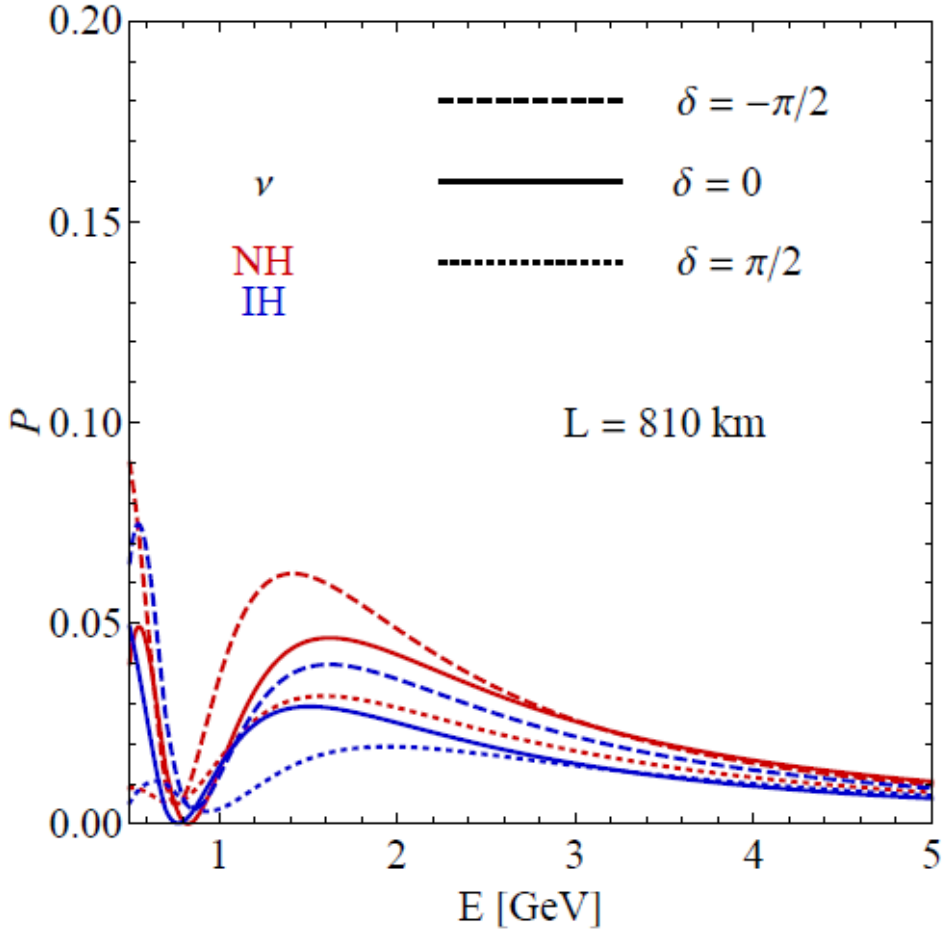
Probabilities

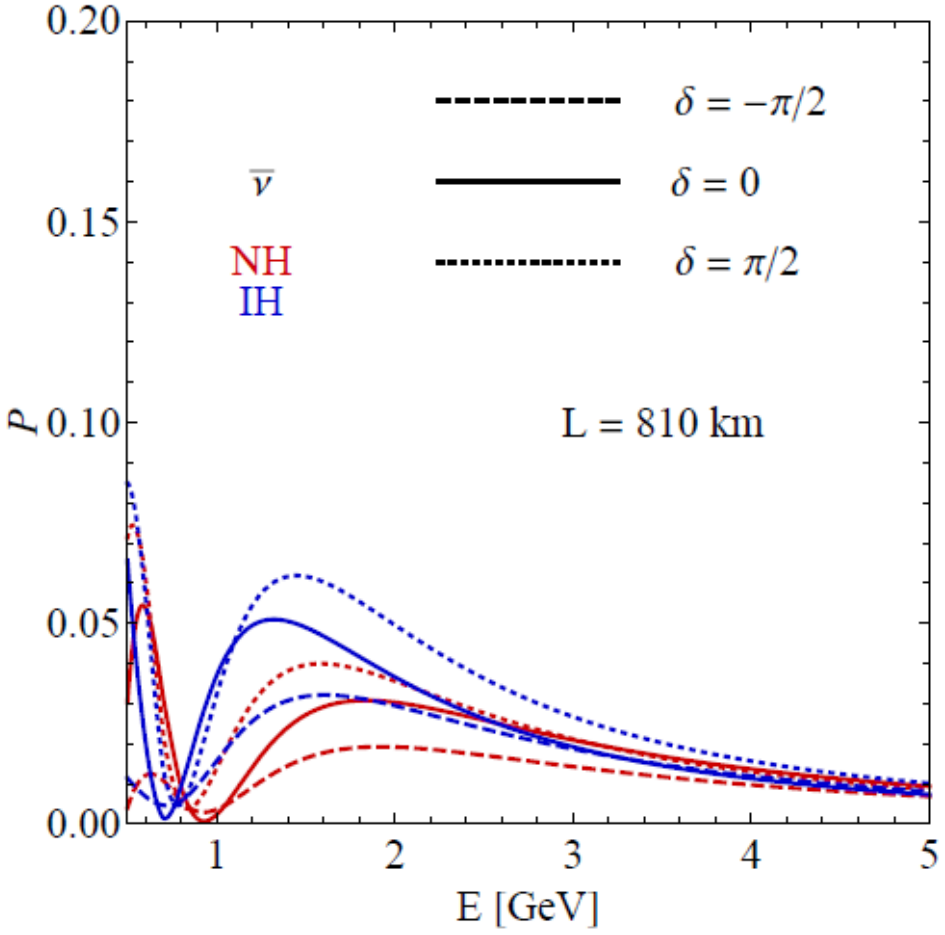




Plot from the Physics Briefing Book: Input for the Strategy Group to the European Strategy for Particle Physics

Probabilities





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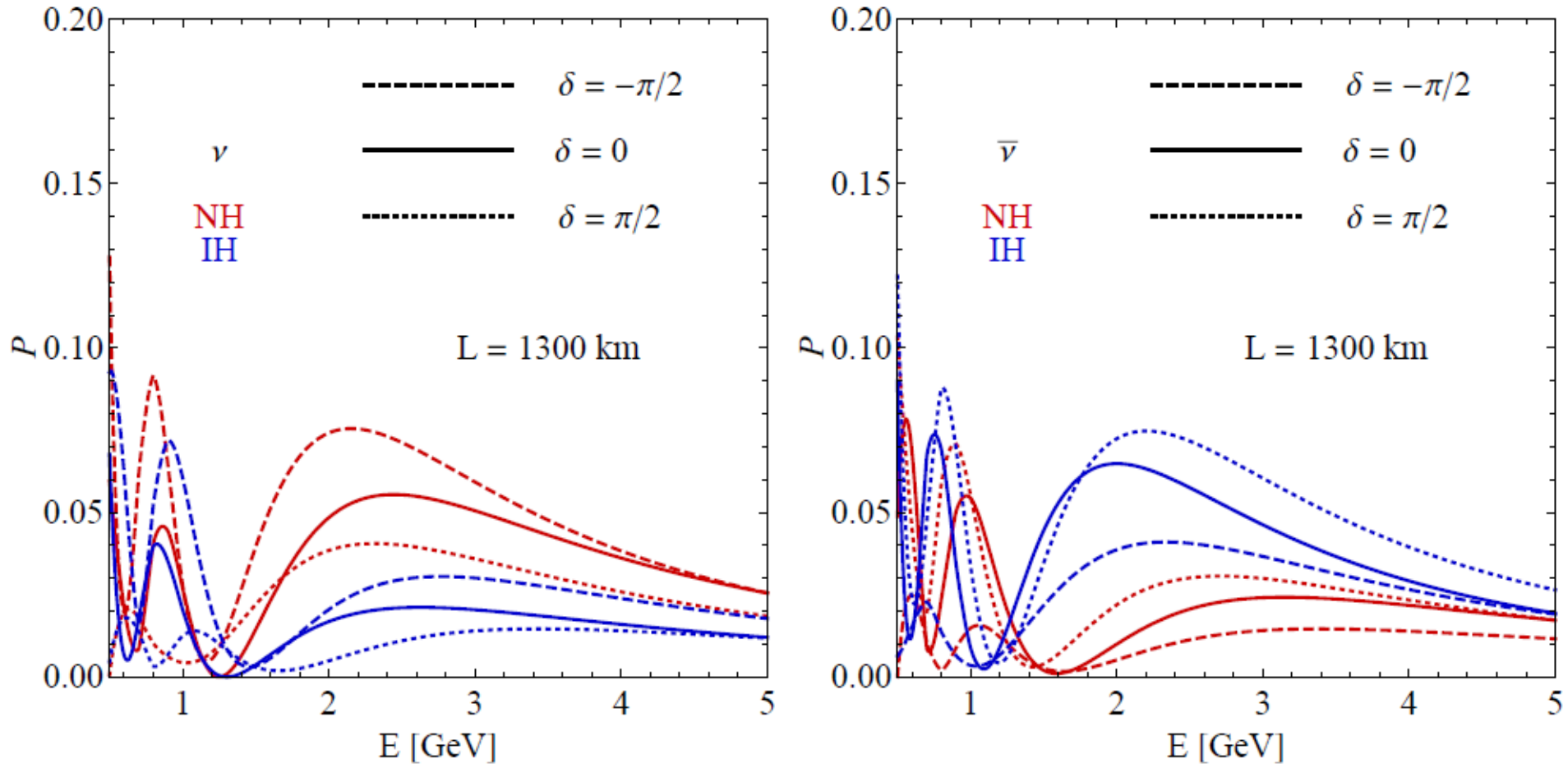

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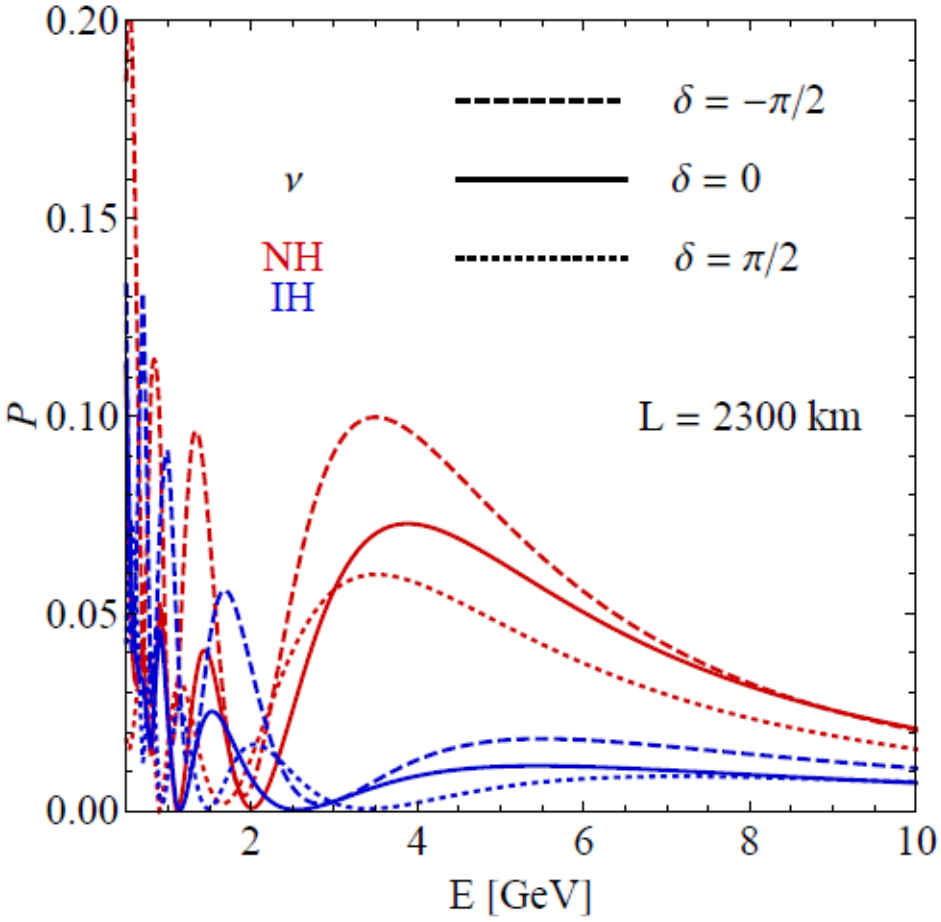

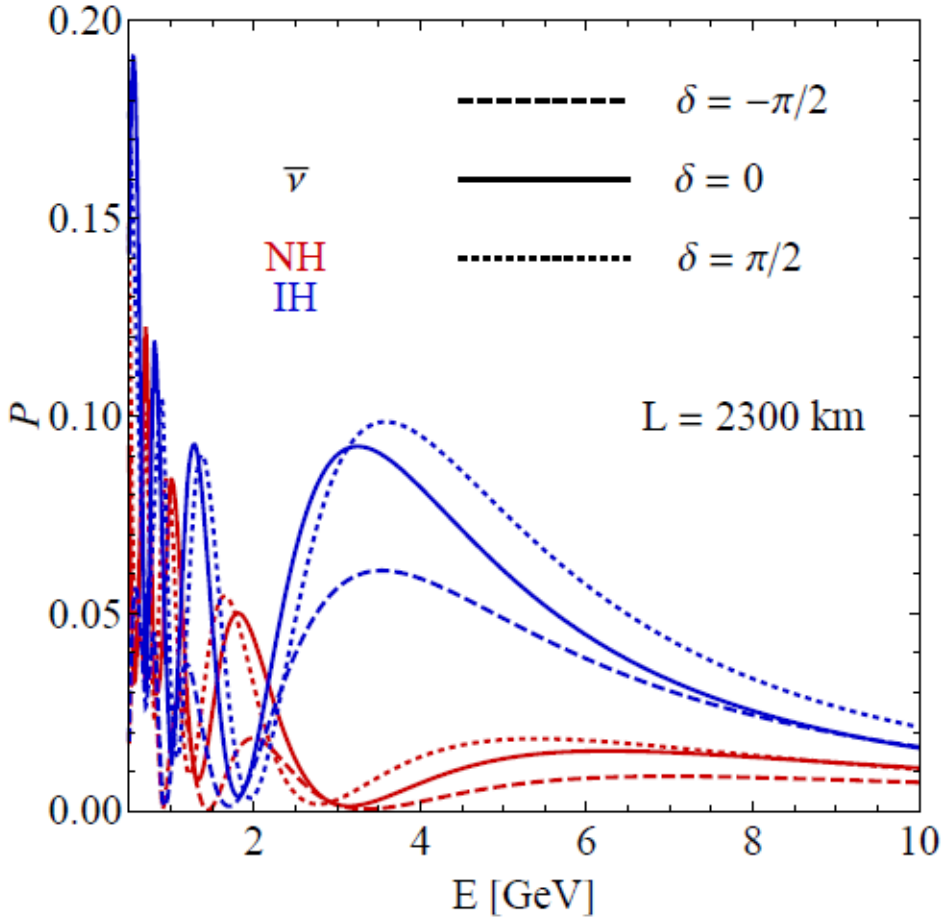

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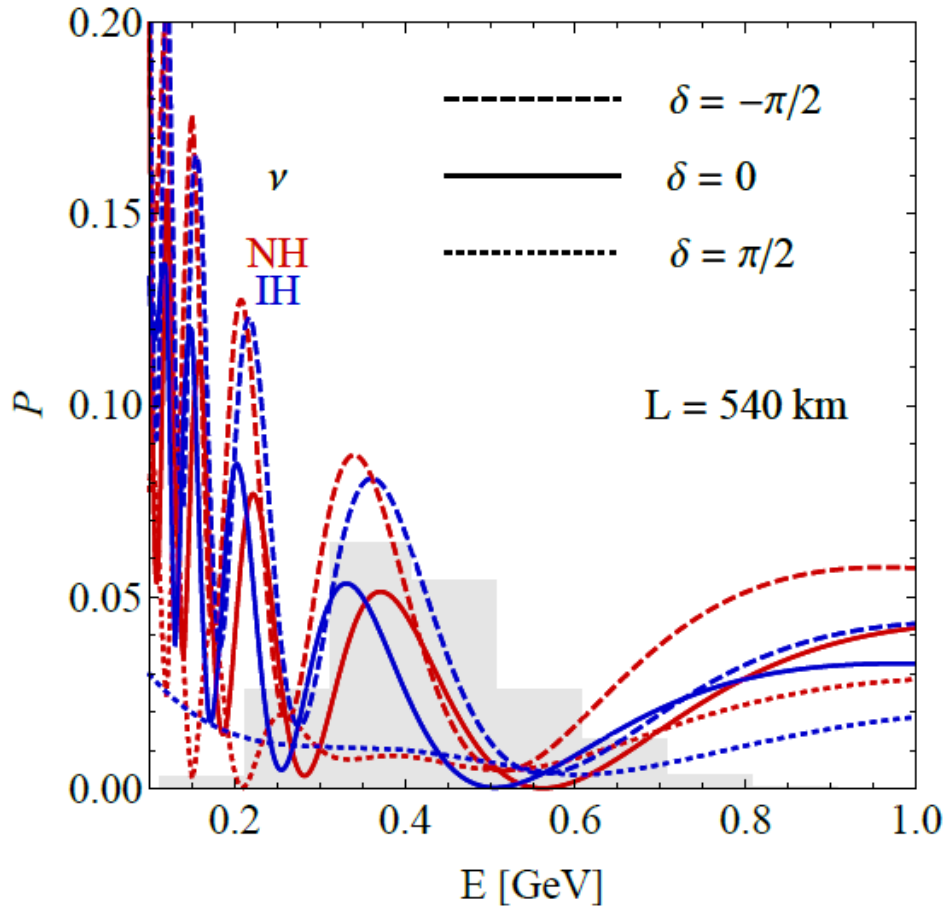
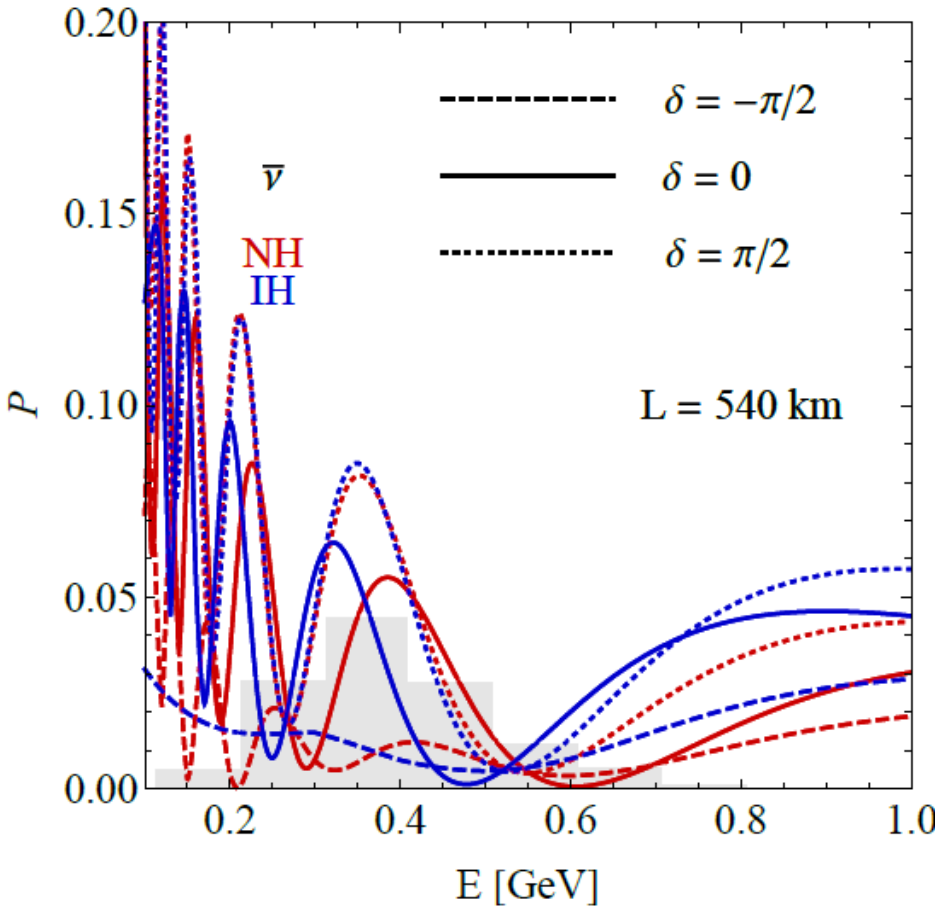
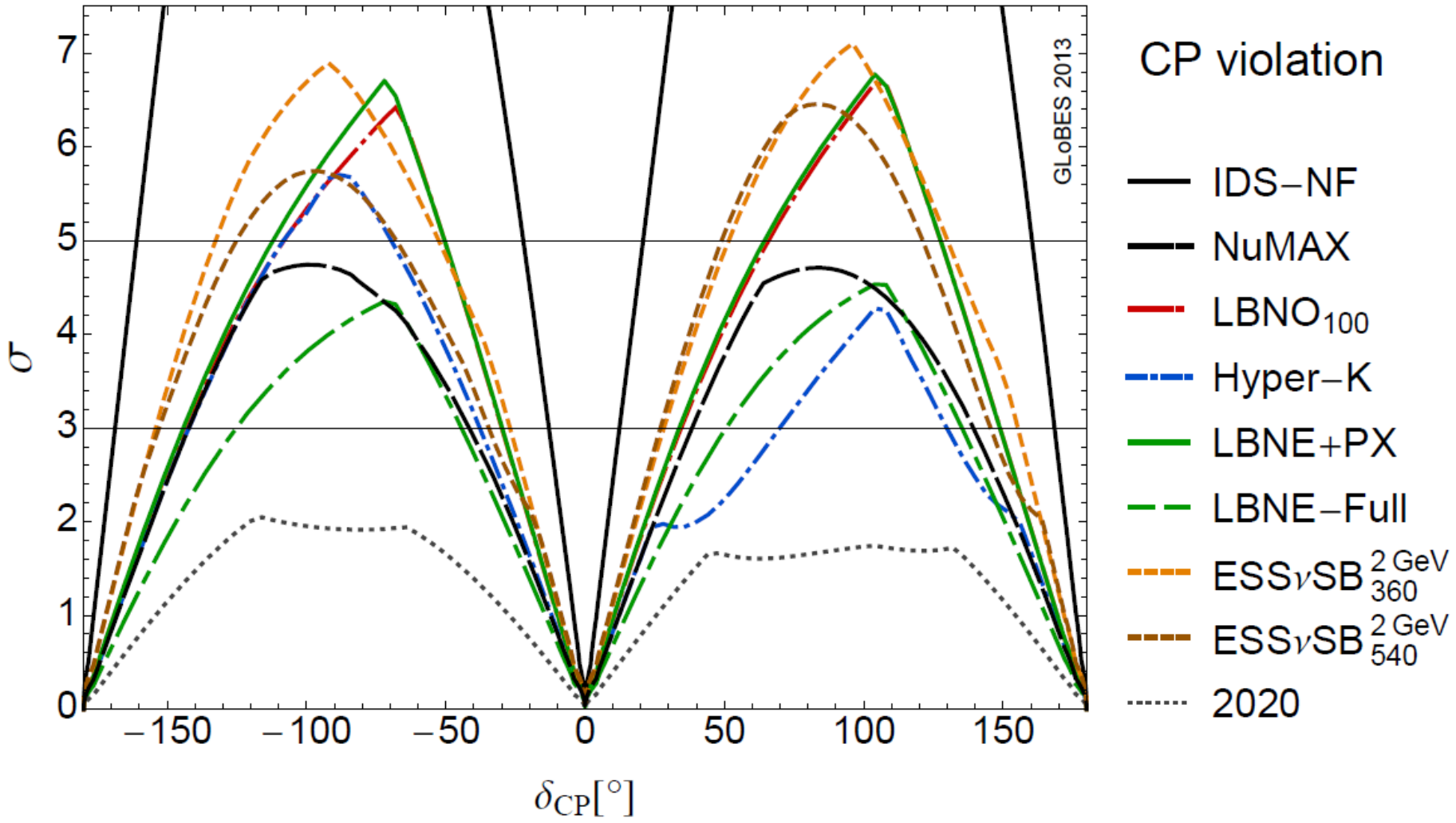


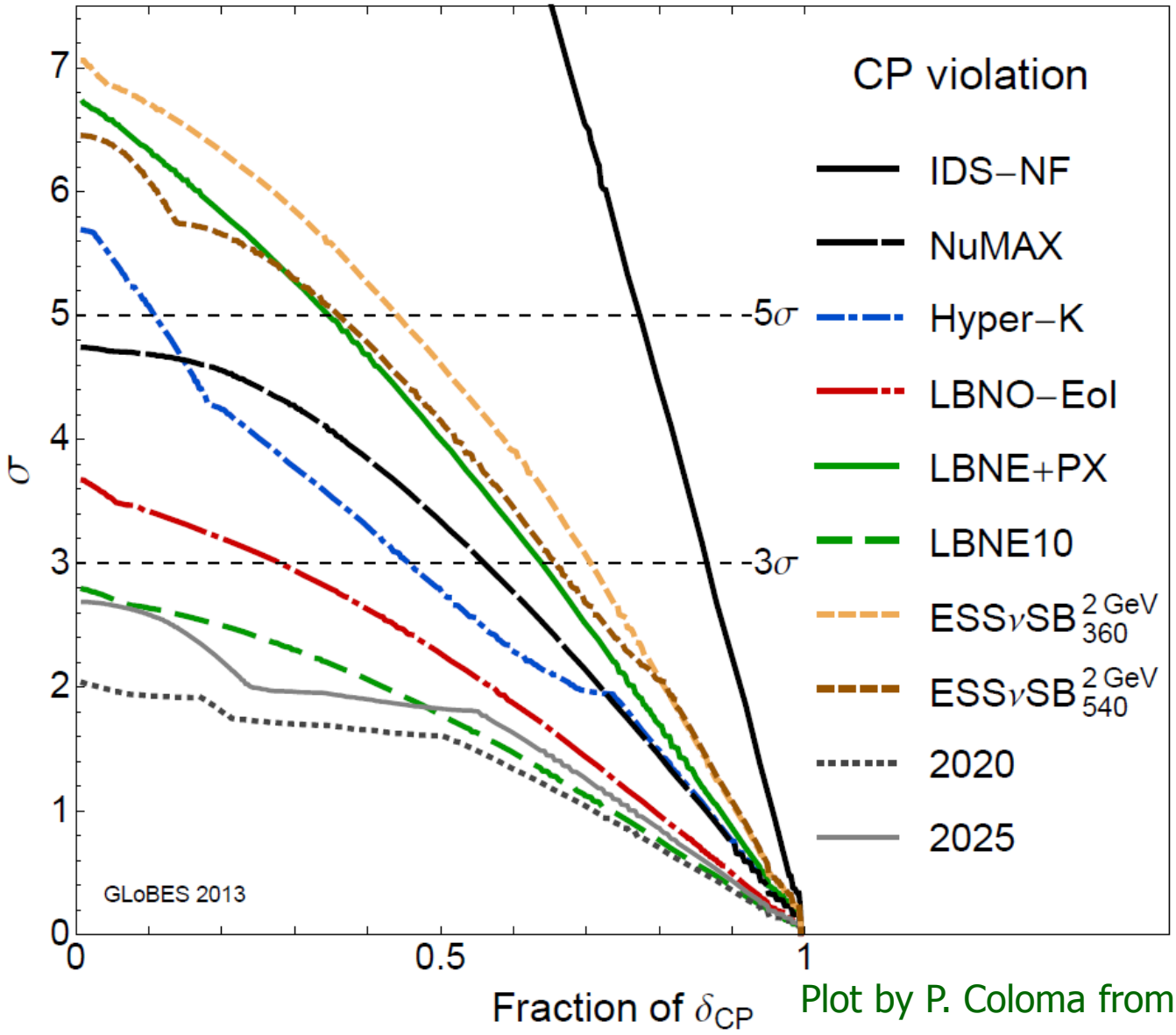


Sensitivities to CPV



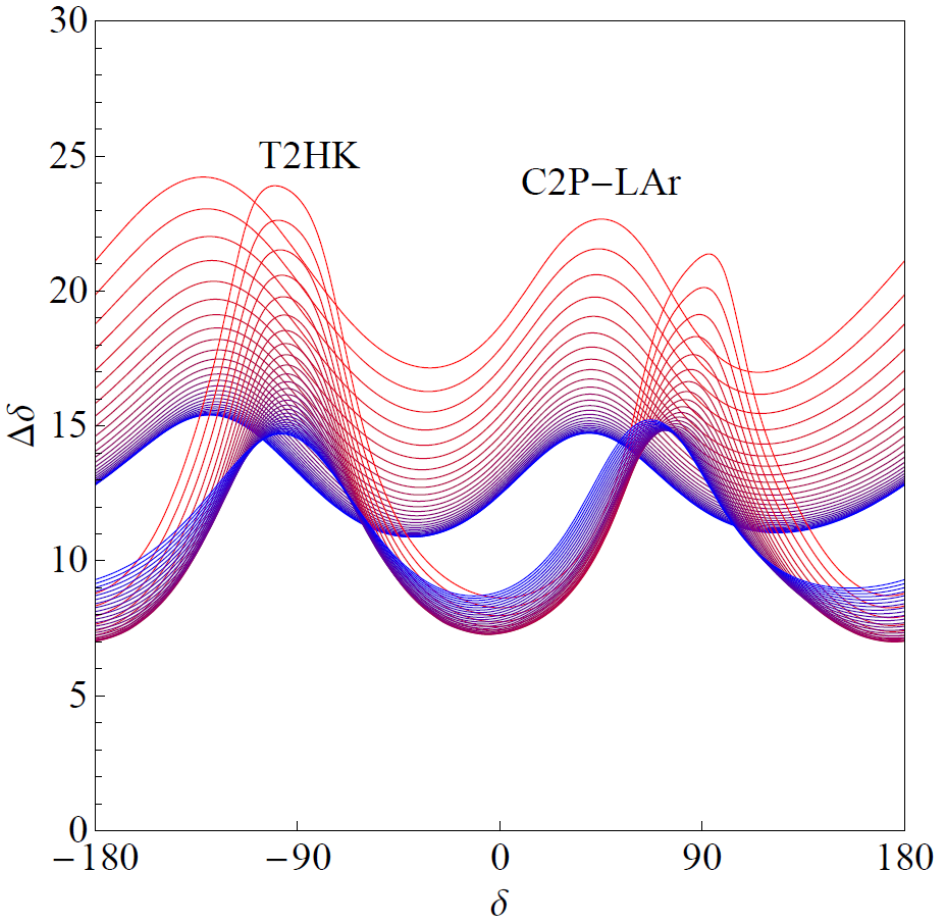
Plot by P. Coloma

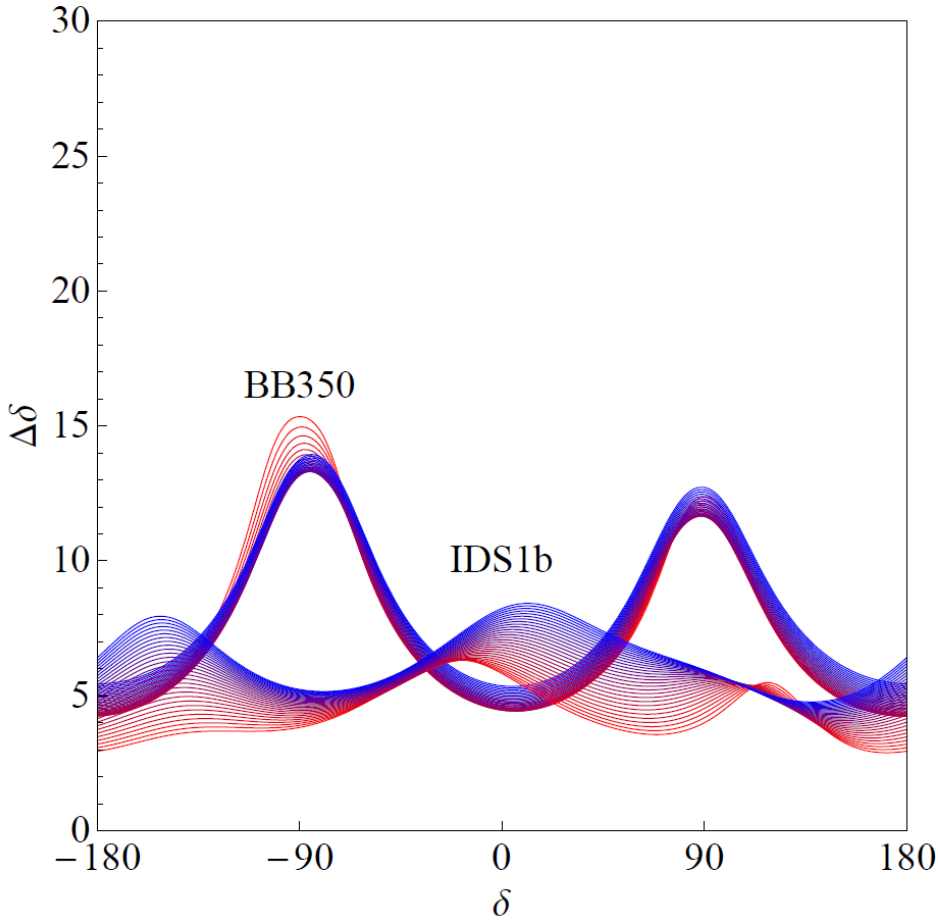
Sensitivities to CPV



Plot by P. Coloma from 1309.7022

Precision





θ_{13}: 3º - 10º

P. Coloma, A. Donini, EFM and P. Hernandez 1203.5651

Conclusions

- The large value of θ_{13} discovered opens the window to the measurement of the neutrino mass hierarchy and leptonic CP violation.

- T2K and Nova will provide the first ~90% CL indications over the next years. In order to reach discovery, upgraded or new facilities will be needed.

- The optimization strategy for CPV changes for large θ_{13}: importance of systematic errors and the second oscillation peak over statistics and backgrounds.

Sensitivities with future experiments

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4. Repeat for as many "true values" as you want and plot

Probabilities

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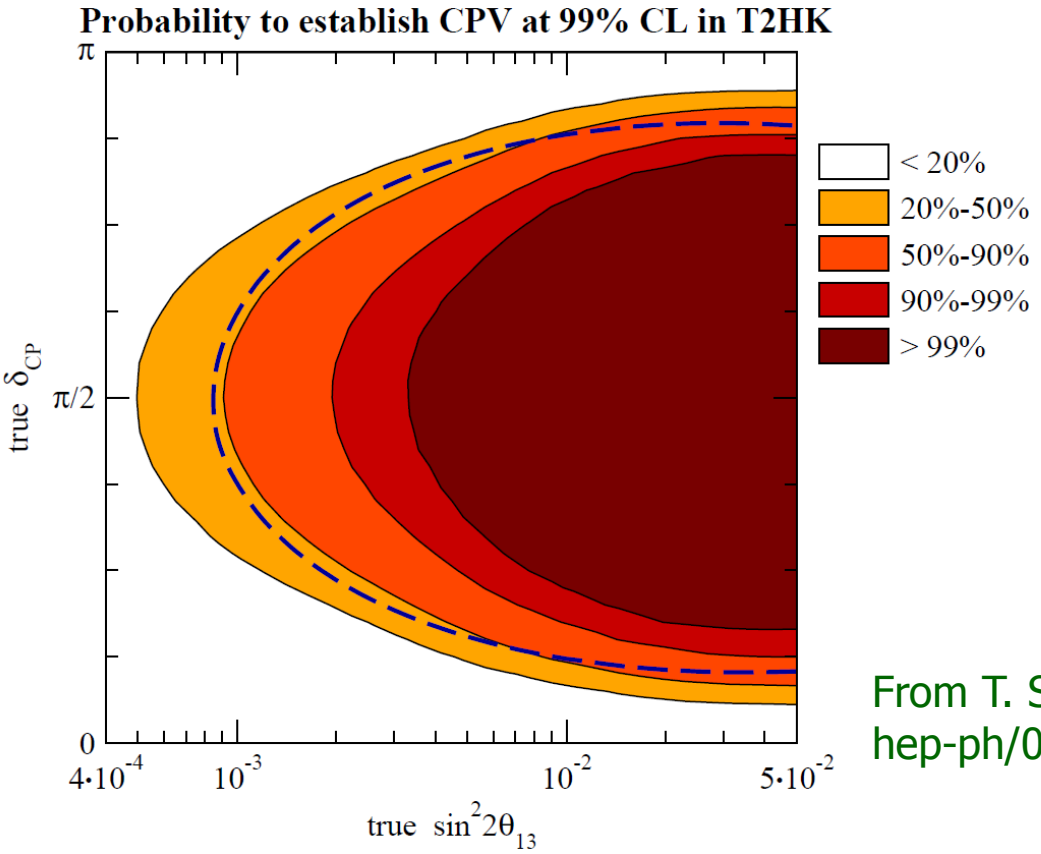

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From T. Schwetz
hep-ph/0612223

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The first could get lucky, the second unlucky…

Naturally the two things are correlated

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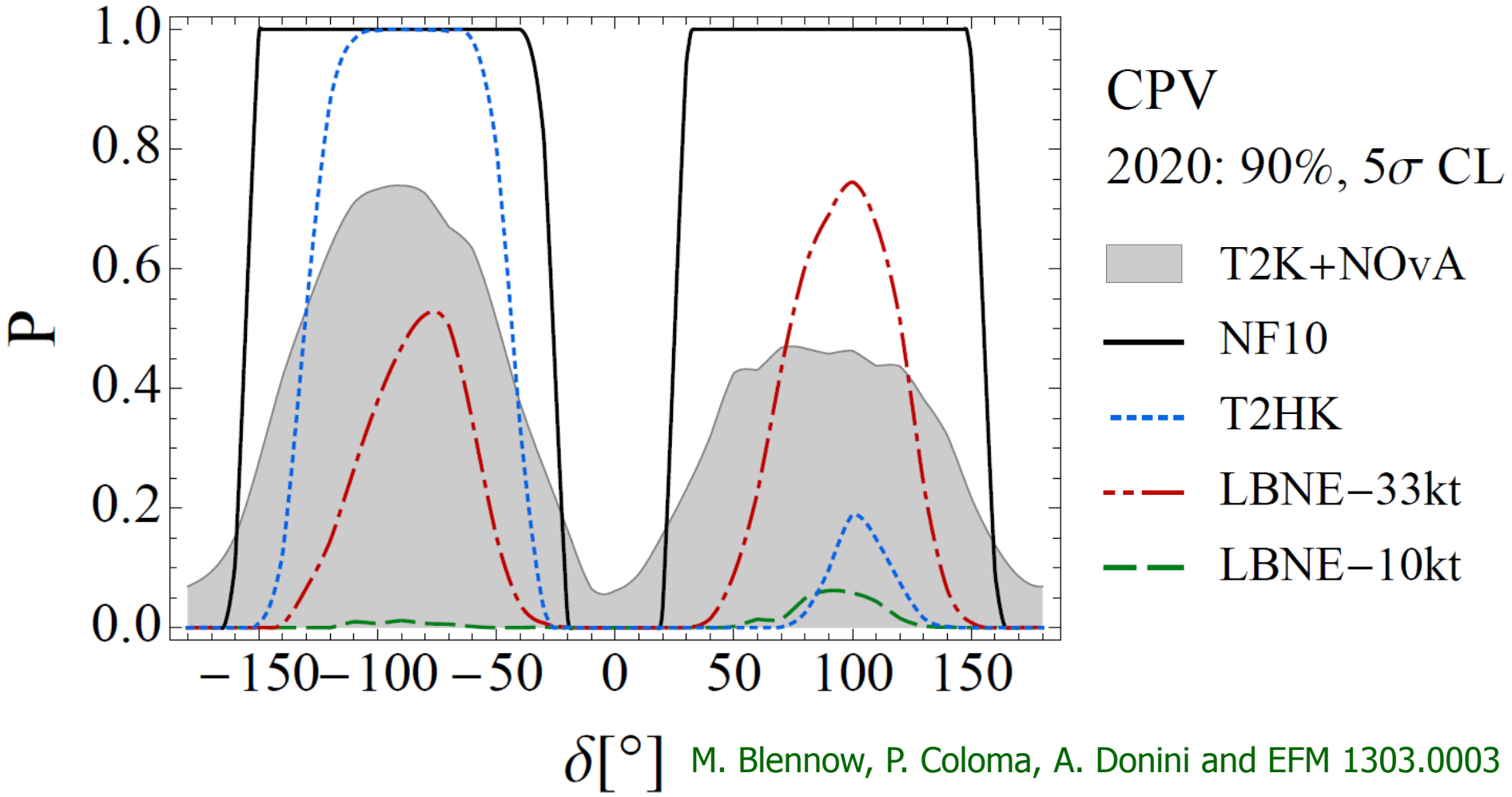
2. Generate a large (~1000) number of realizations of that experiment with the expected mean and deviation

3. Compute the χ^2 between each realization and the "null hypothesis" and check if the target CL was reached for that realization. Count how many, that gives and estimation of the success probability.

4. Repeat for as many "true values" as you want and plot

Probabilities for CPV discovery



M. Blennow, P. Coloma, A. Donini and EFM 1303.0003

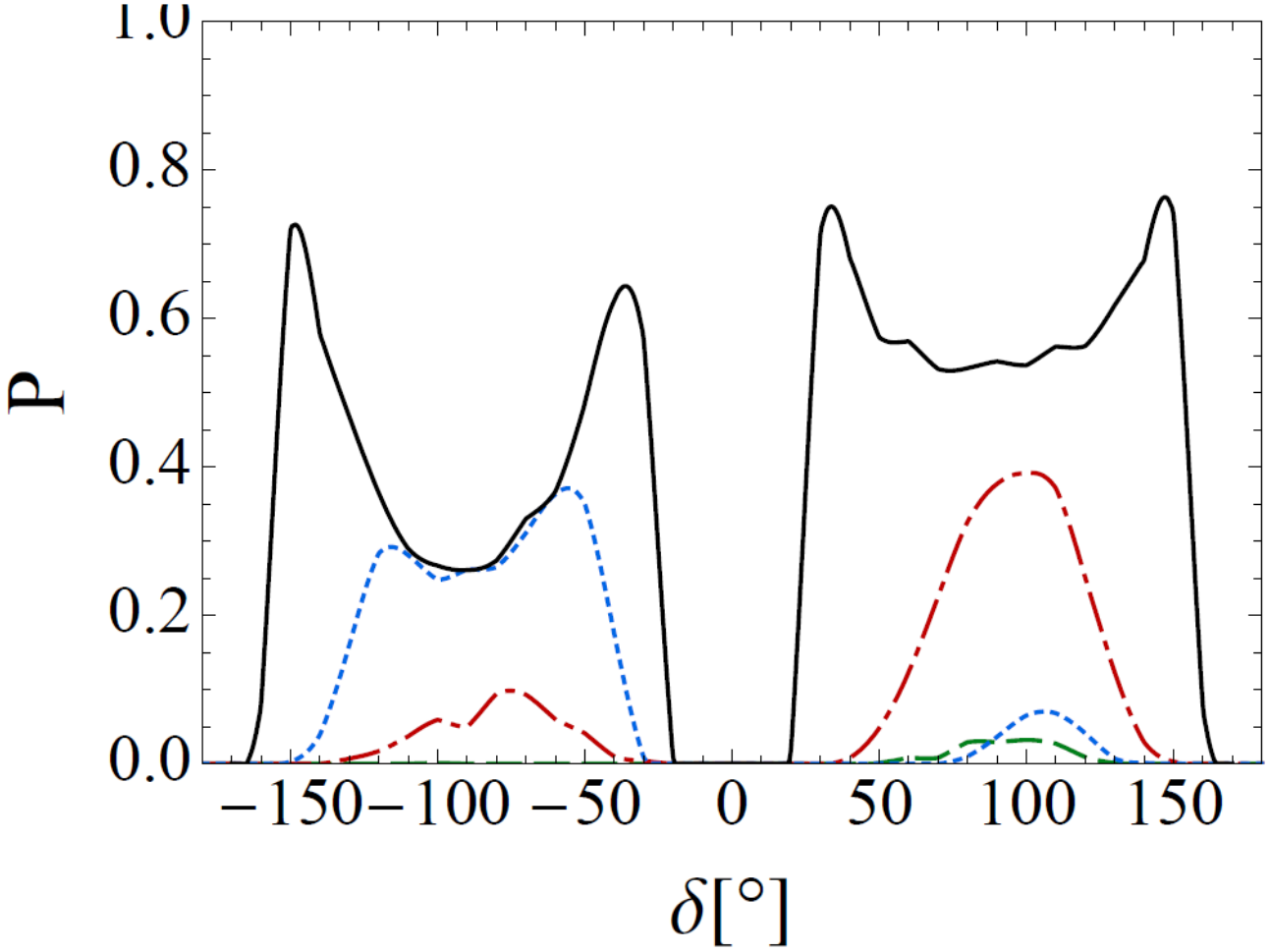
90 % CL for T2K+NOνA, 5 σ for the rest

Sensitivity peaked around ±90º for all

Probabilities for CPV discovery

Sensitivity peaked around ±90º for all

If T2K+NOνA dont see, will the others see?



M. Blennow, P. Coloma, A. Donini and EFM 1303.0003

CPV

2020: 90%, 5σ CL

T2K+NOvA

NF10

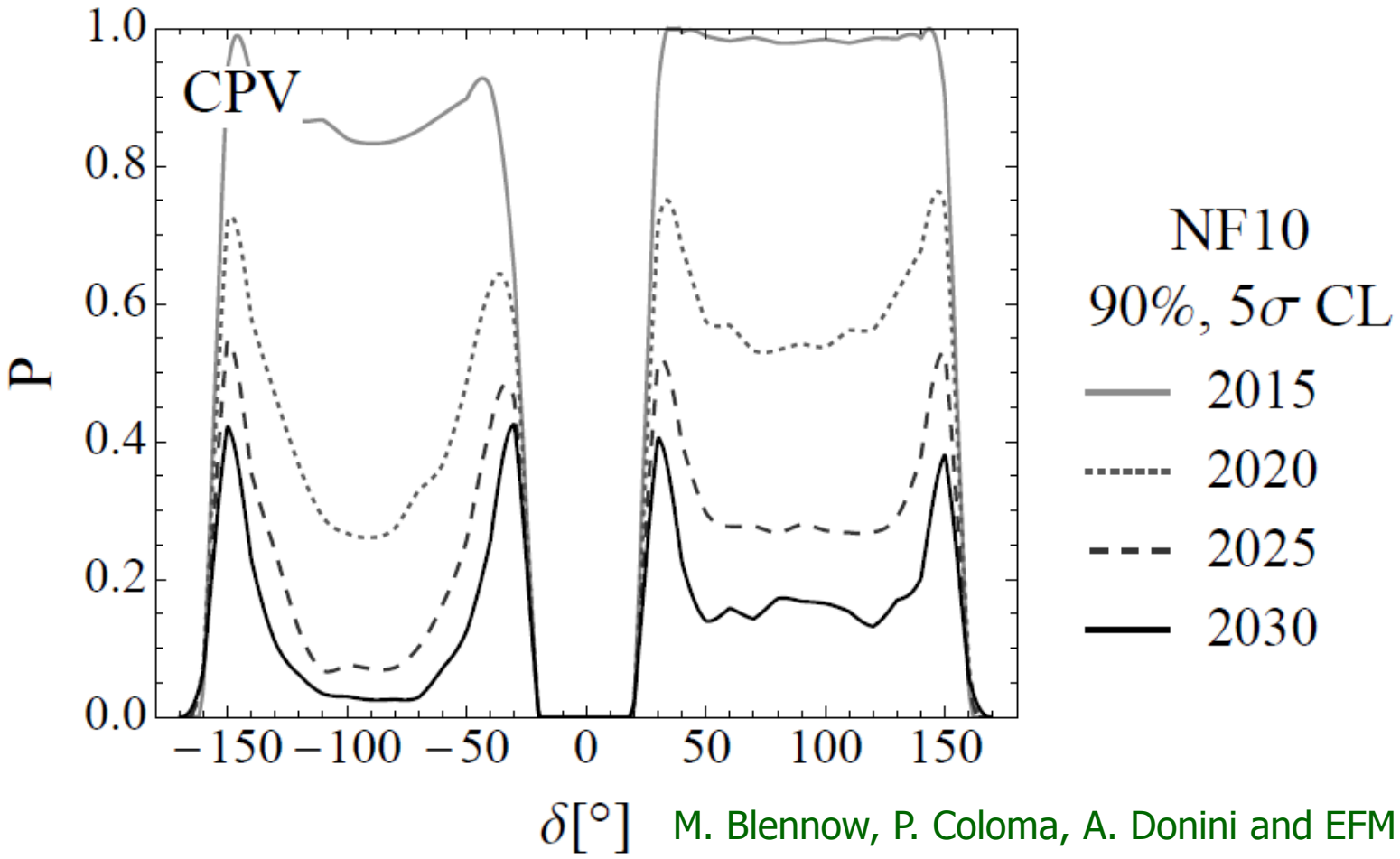
T2HK

LBNE−33kt

LBNE−10kt

Joint probability of not having a 90% CL hint at T2K+NOνA and 5 σ discovery at new facility

Probabilities for CPV discovery



M. Blennow, P. Coloma, A. Donini and EFM 1303.0003

Joint probability of not having a 90% CL hint at T2K+NOνA and 5 σ discovery at new facility. Less and less likely when increasing T2K+NOνA running time if no hint.

Conditional probability

The results from T2K+NOνA will constrain our prior knowledge of δ for the next facilities

Negative results will make CPV values of δ less likely

$$P(\delta \mid T2K + NO\nu A)$$

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The probability of discovery of the new facility contidioned to T2K+NOνA results:

$$P(disc \mid T2K + NO\nu A) = \int P(disc \mid T2K + NO\nu A, \delta) P(\delta \mid T2K + NO\nu A) d\delta$$

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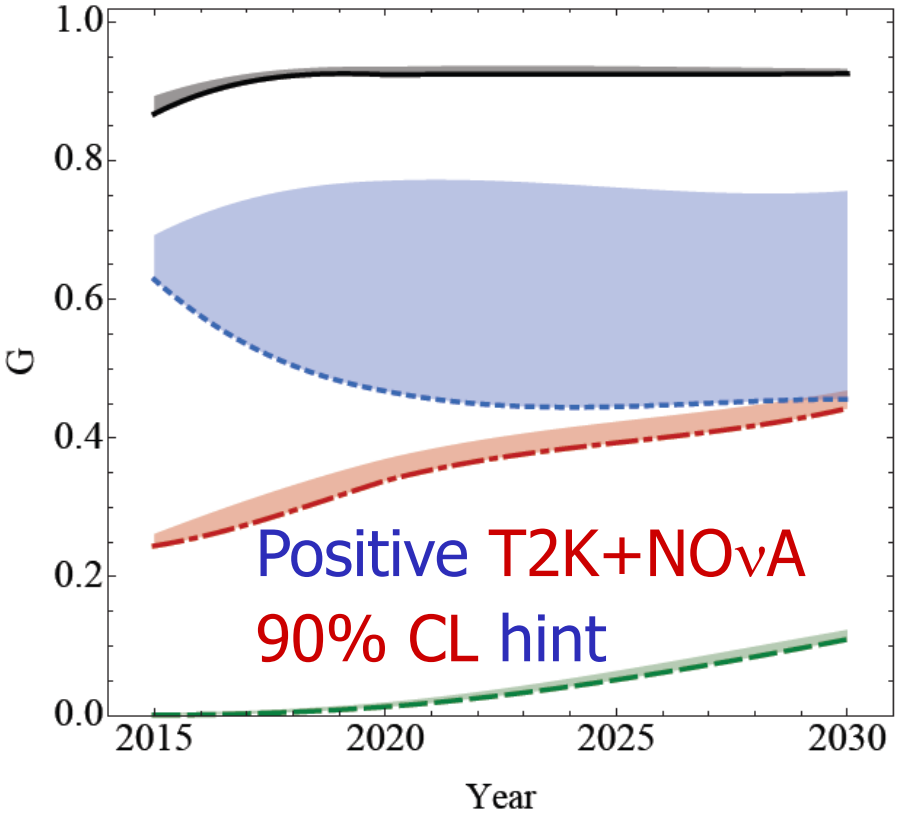
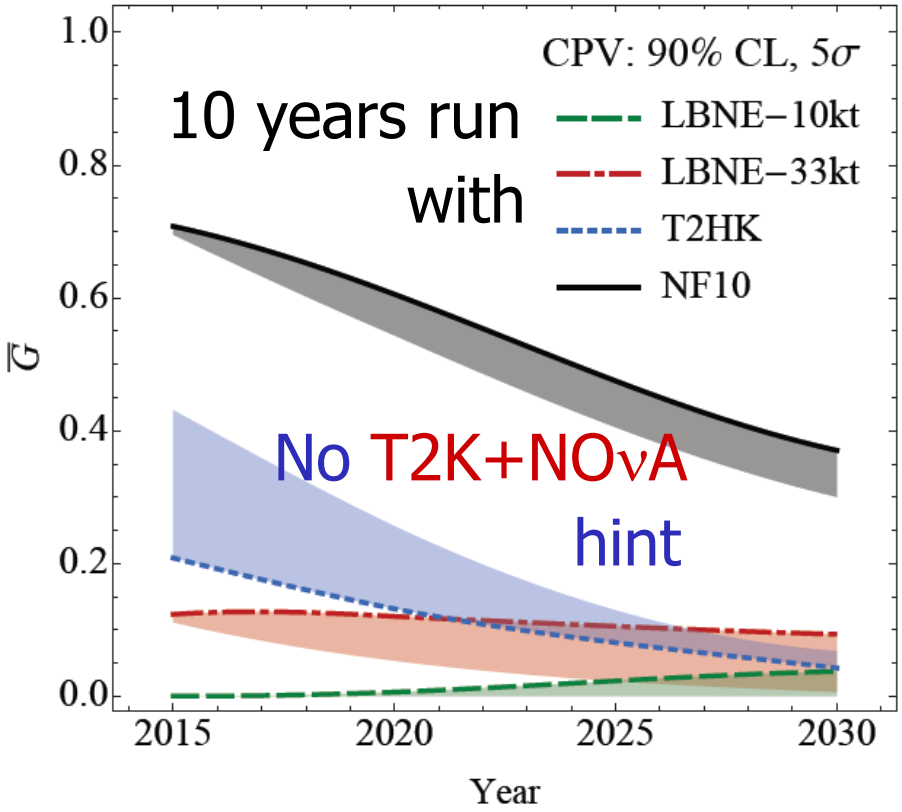
Can be easily computed from the joint prob:

$$P(disc \mid T2K + NO\nu A) = \frac{P(disc, T2K + NO\nu A)}{P(T2K + NO\nu A)}$$

Conditional probability

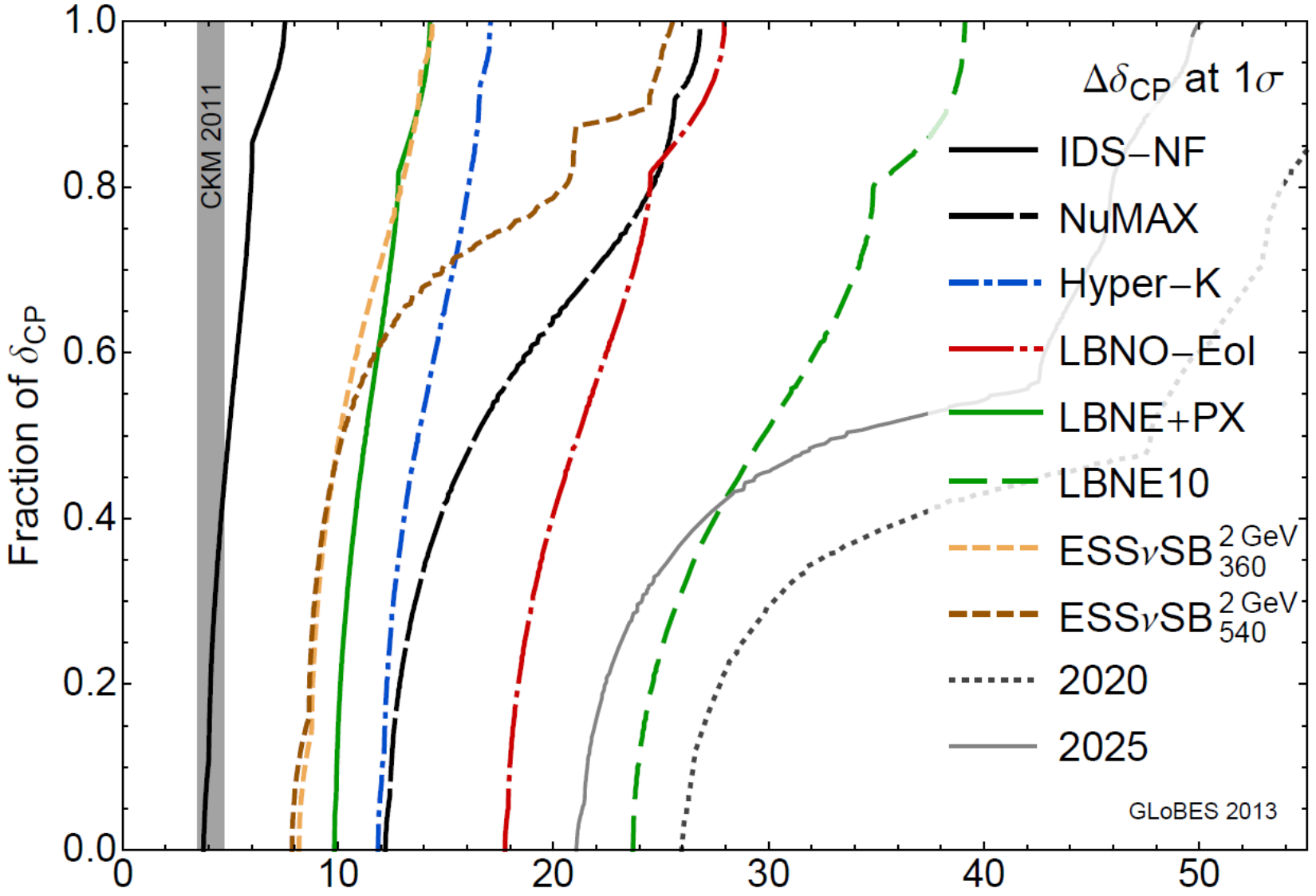




Assuming a uniform probability distribution of δ, how likely is a discovery (5σ) by a new facility if T2K+NOνA (dont) have a 90% hint by the year X? Upper (lower) end of band for (un)known hierarchy

M. Blennow, P. Coloma, A. Donini and EFM 1303.0003

Precision in δ



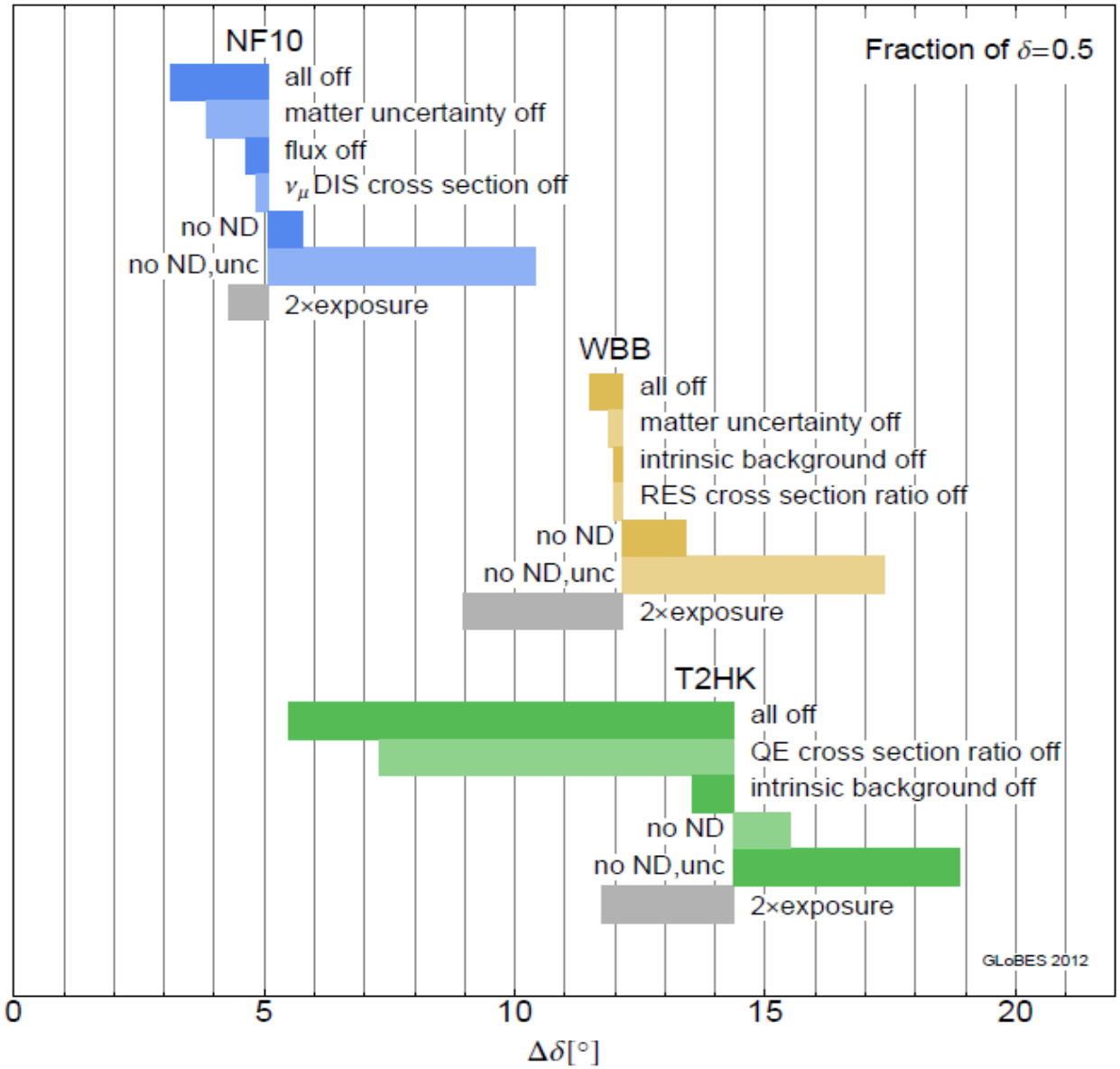
Plot by P. Coloma from 1309.7022

Systematics

	SB			NF		
Systematics	Opt.	Def.	Cons.	Opt.	Def.	Cons.
Fiducial volume ND	0.2%	0.5%	1%	0.2%	0.5%	1%
Fiducial volume FD (incl. near-far extrap.)	1%	2.5%	5%	1%	2.5%	5%
Flux error signal ν	5%	7.5%	10%	0.1%	0.5%	1%
Flux error background ν	10%	15%	20%	correlated		
Flux error signal $\bar{\nu}$	10%	15%	20%	0.1%	0.5%	1%
Flux error background $\bar{\nu}$	20%	30%	40%	correlated		
Background uncertainty	5%	7.5%	10%	10%	15%	20%
Cross secs $\times$ eff. QE†	10%	15%	20%	10%	15%	20%
Cross secs $\times$ eff. RES†	10%	15%	20%	10%	15%	20%
Cross secs $\times$ eff. DIS†	5%	7.5%	10%	5%	7.5%	10%
Effec. ratio ν_e/ν_μ QE*	3.5%	11%	–	–	–	–
Effec. ratio ν_e/ν_μ RES*	2.7%	5.4%	–	–	–	–
Effec. ratio ν_e/ν_μ DIS*	2.5%	5.1%	–	–	–	–
Matter density	1%	2%	5%	1%	2%	5%

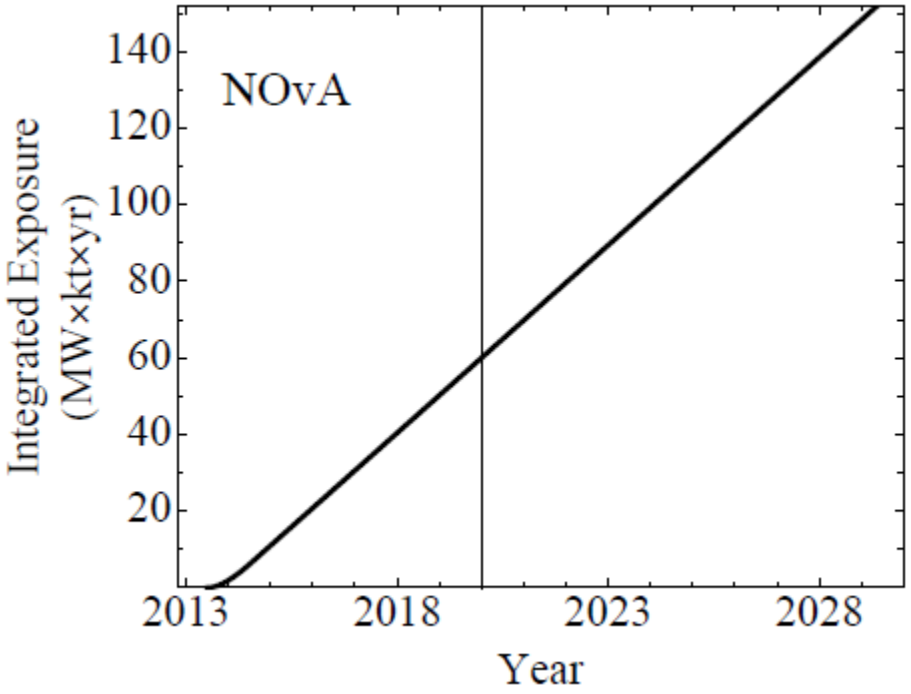
P. Coloma et al 1209.5973

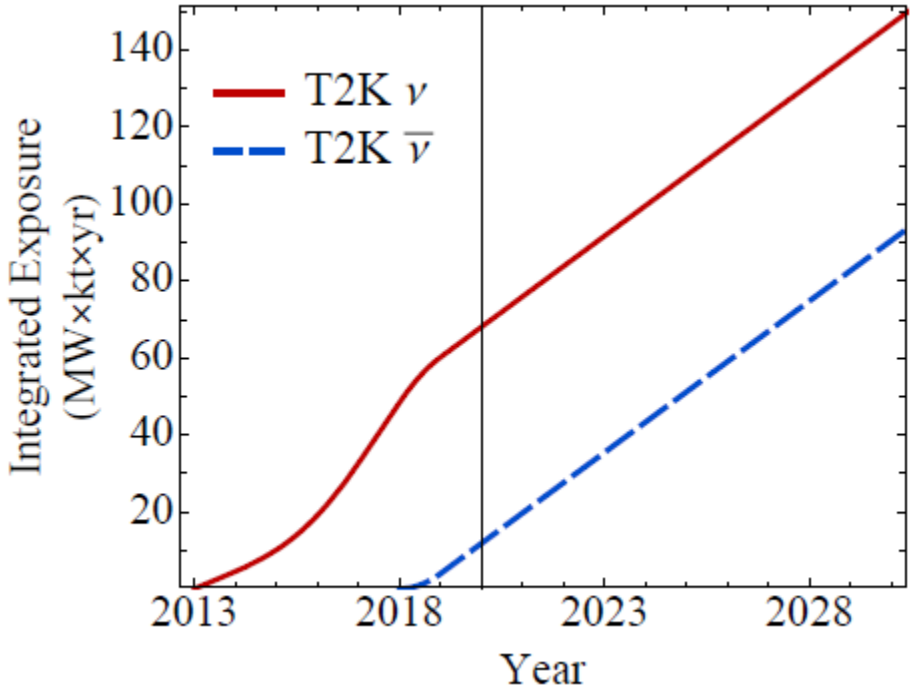
Systematics



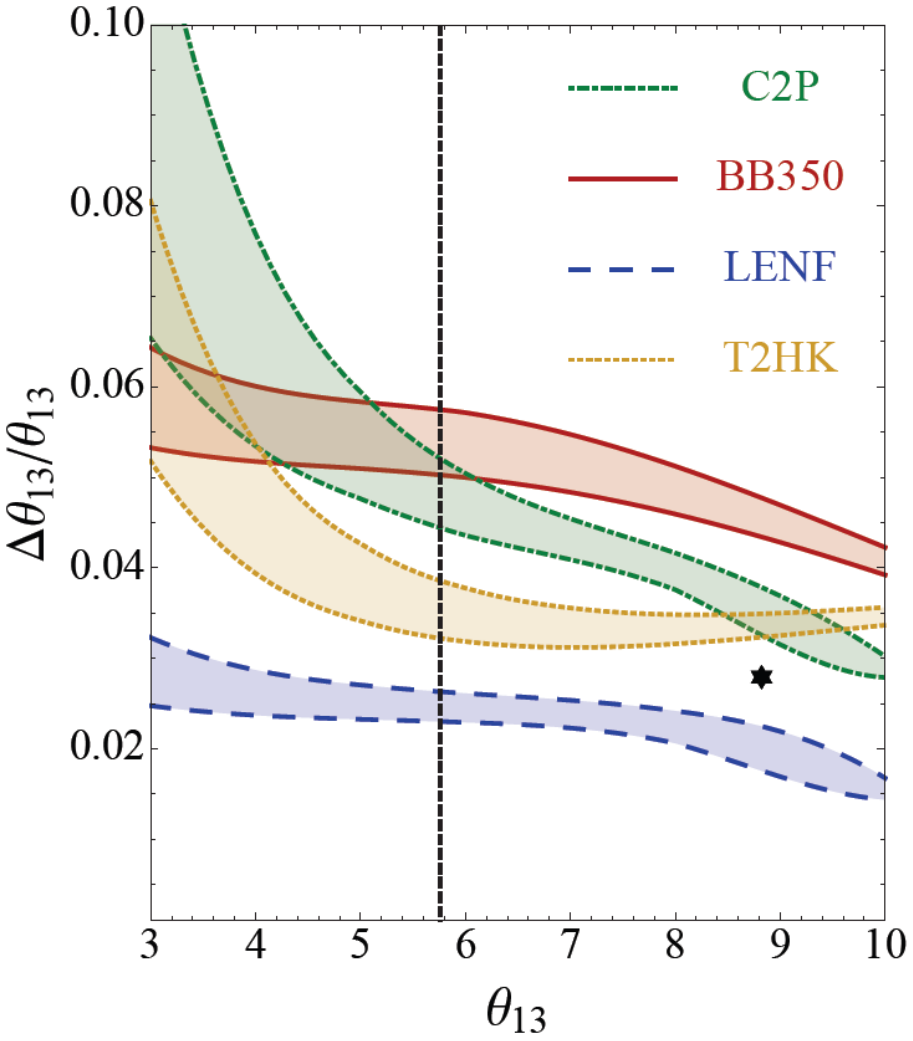
P. Coloma et al 1209.5973

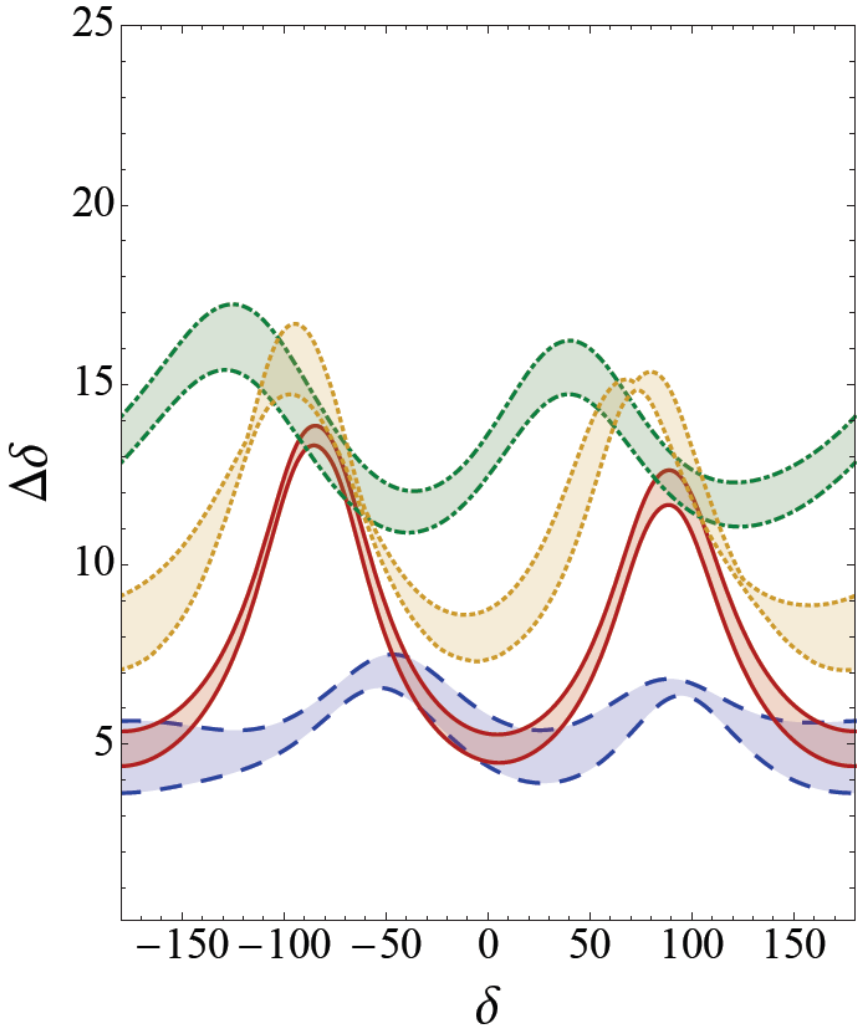
T2K+NOνA Running time





Precision





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