Systematics at future LBL oscillation experiments

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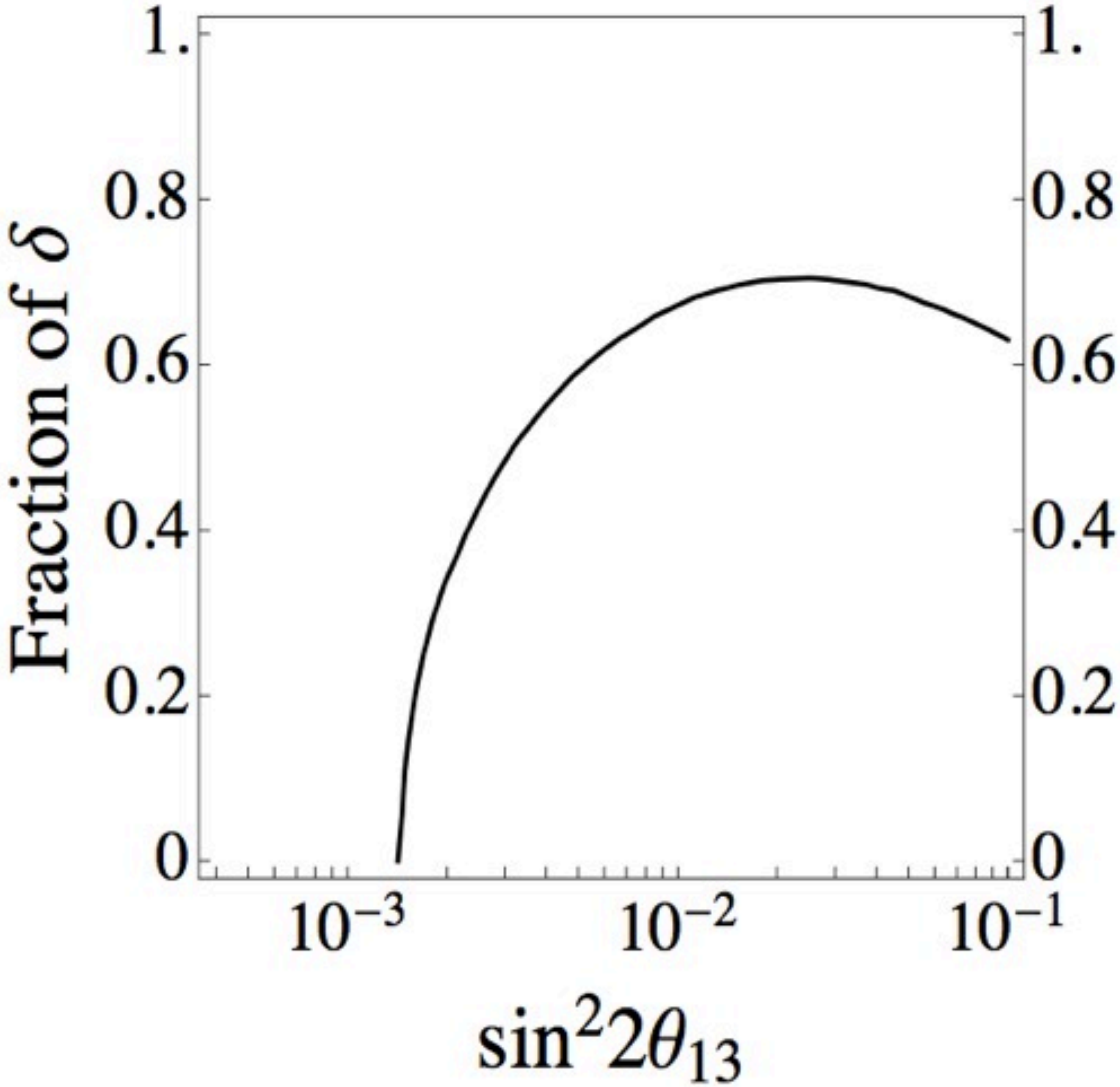
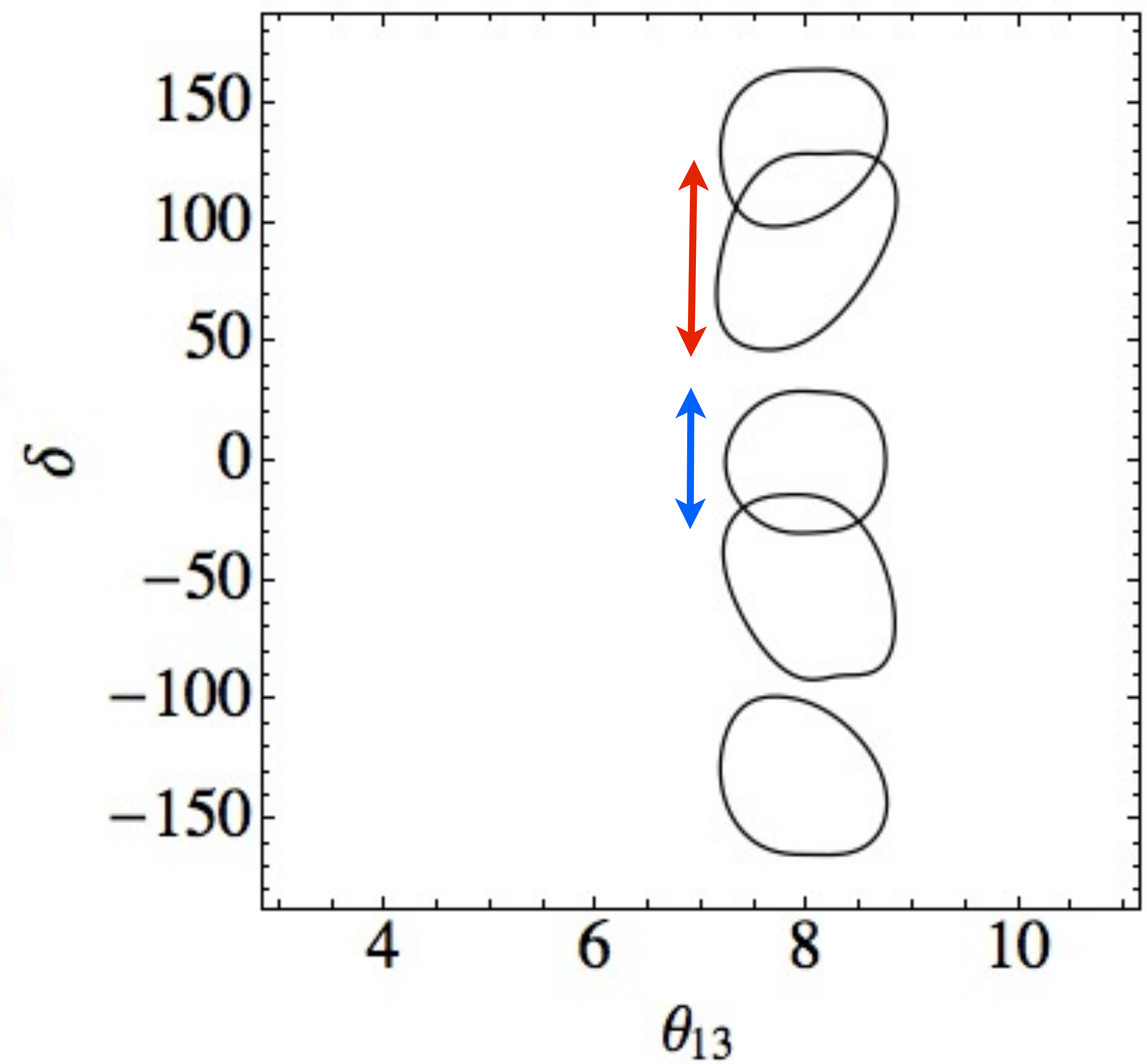
Based on the collaboration with
P. Huber, J. Kopp and W. Winter, arXiv: 1209.5973 [hep-ph]

9^{th} IDS-NF Plenary Meeting, October 9^{th} 2012
Fermi National Accelerator Laboratory

Why precision?

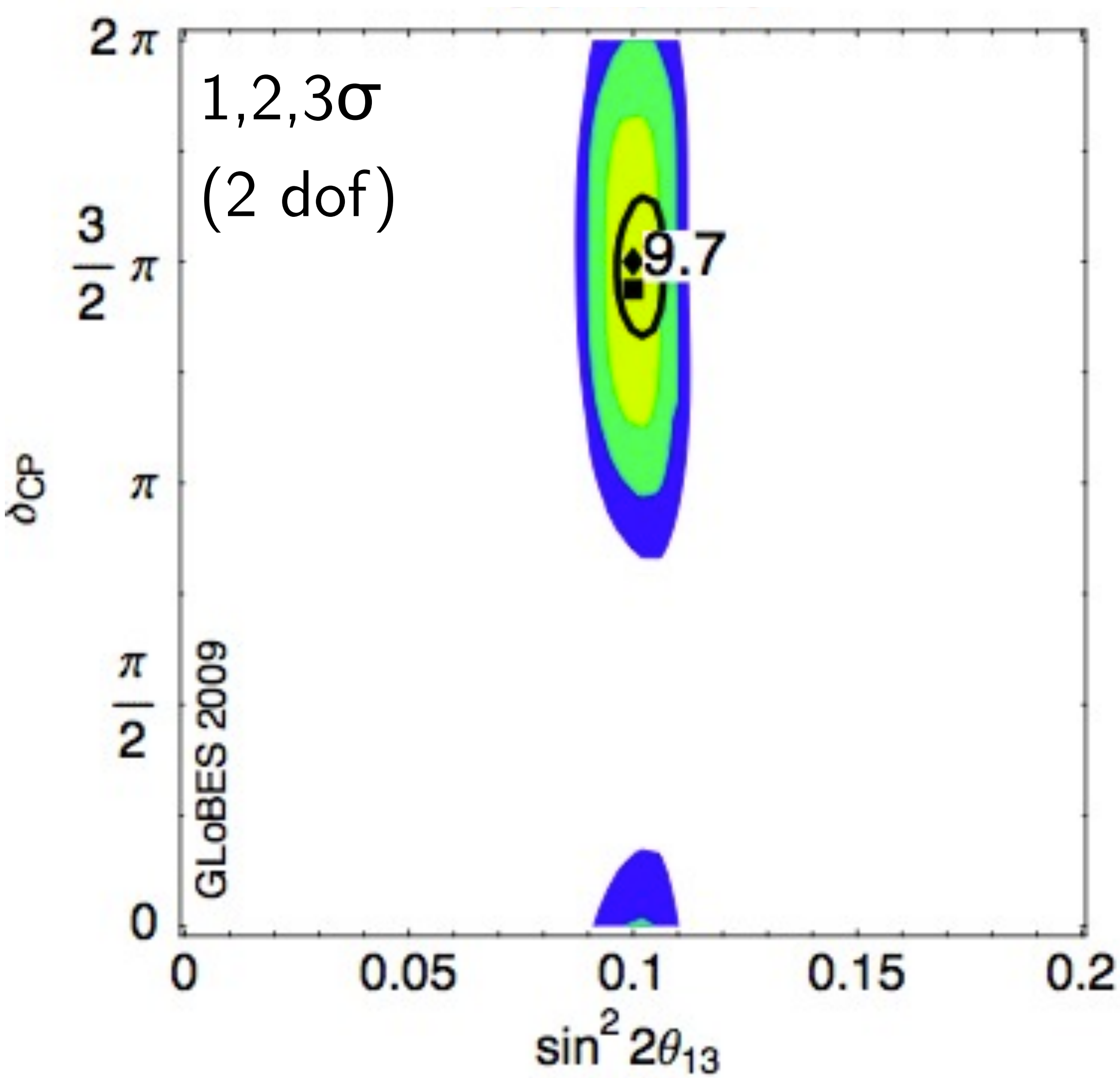
Discovery vs precision

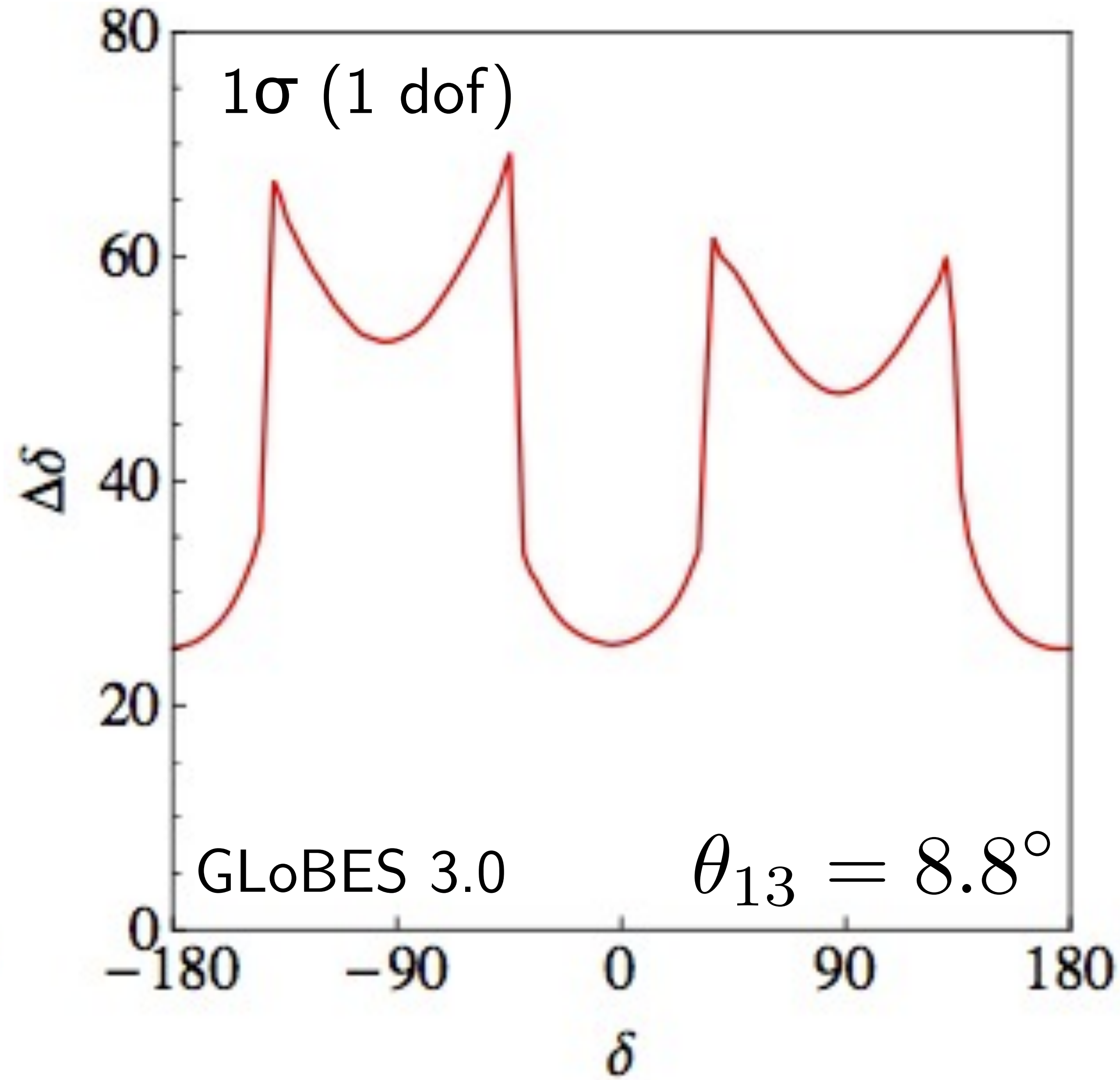




The starting point

NOvA+T2K+Daya Bay

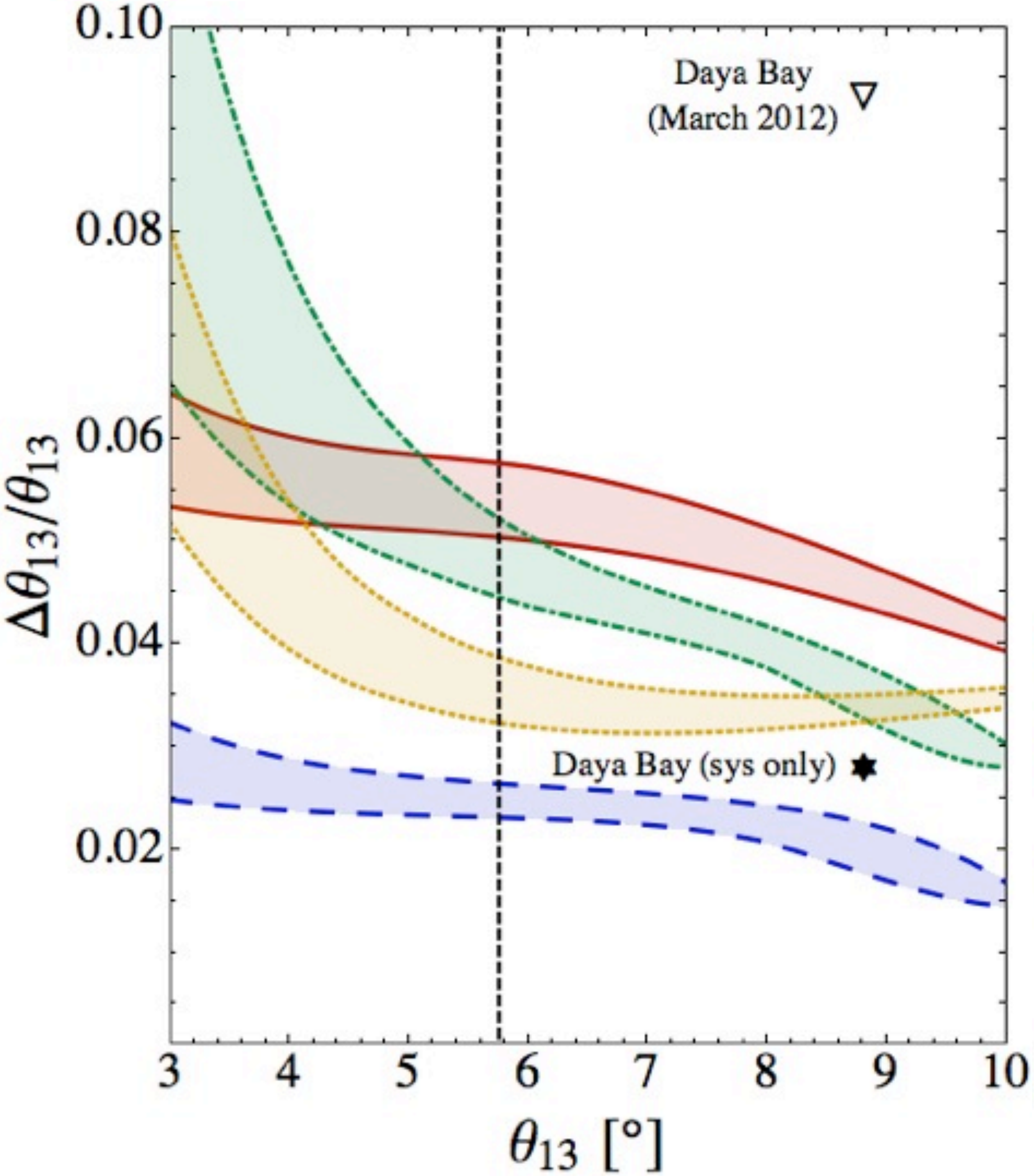


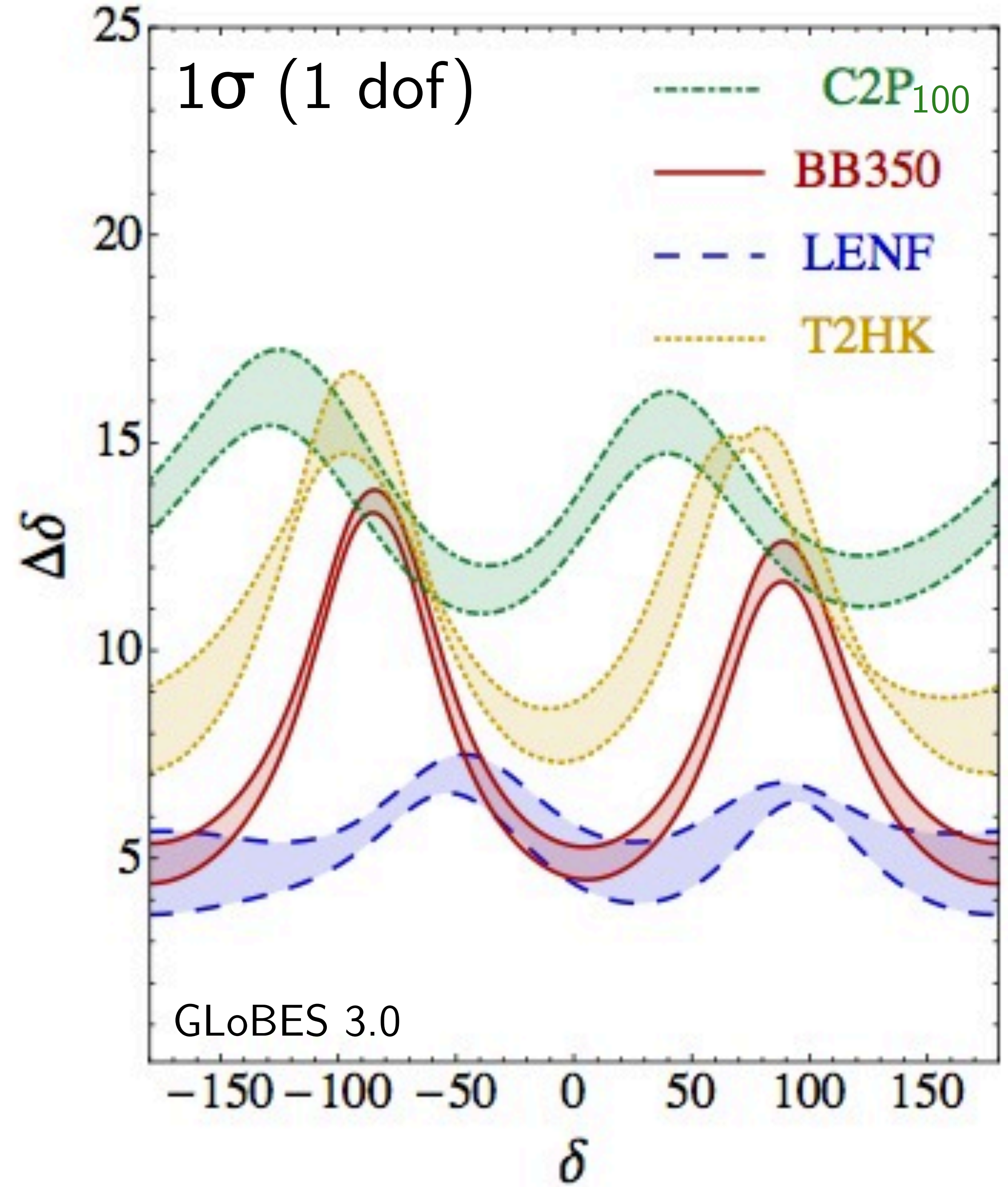


Huber, Lindner, Schwetz, Winter, 0907.1896 [hep-ph]

Coloma, Donini, Fernández-Martínez, Hernández, 1203.5651 [hep-ph]

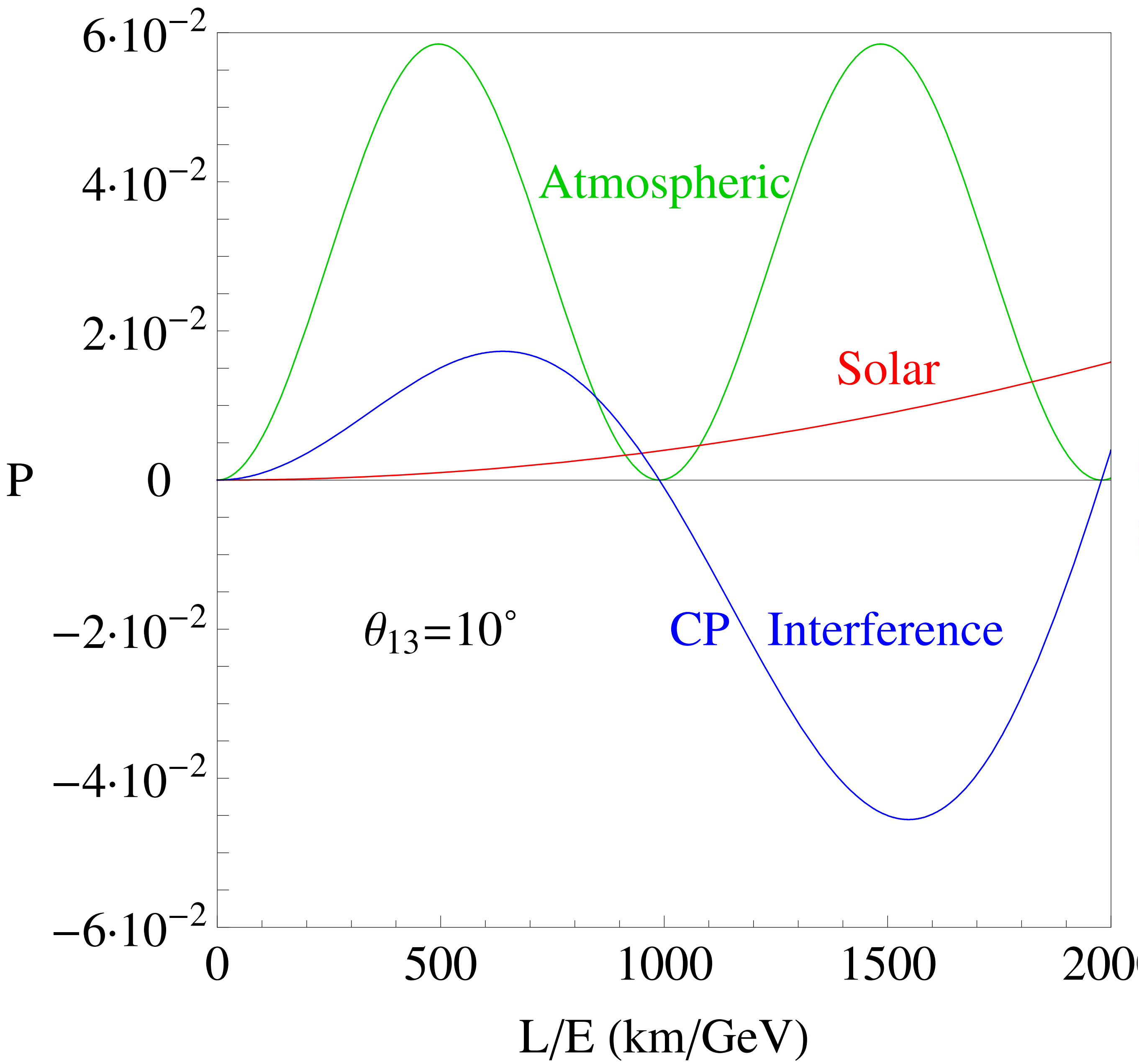
Precision

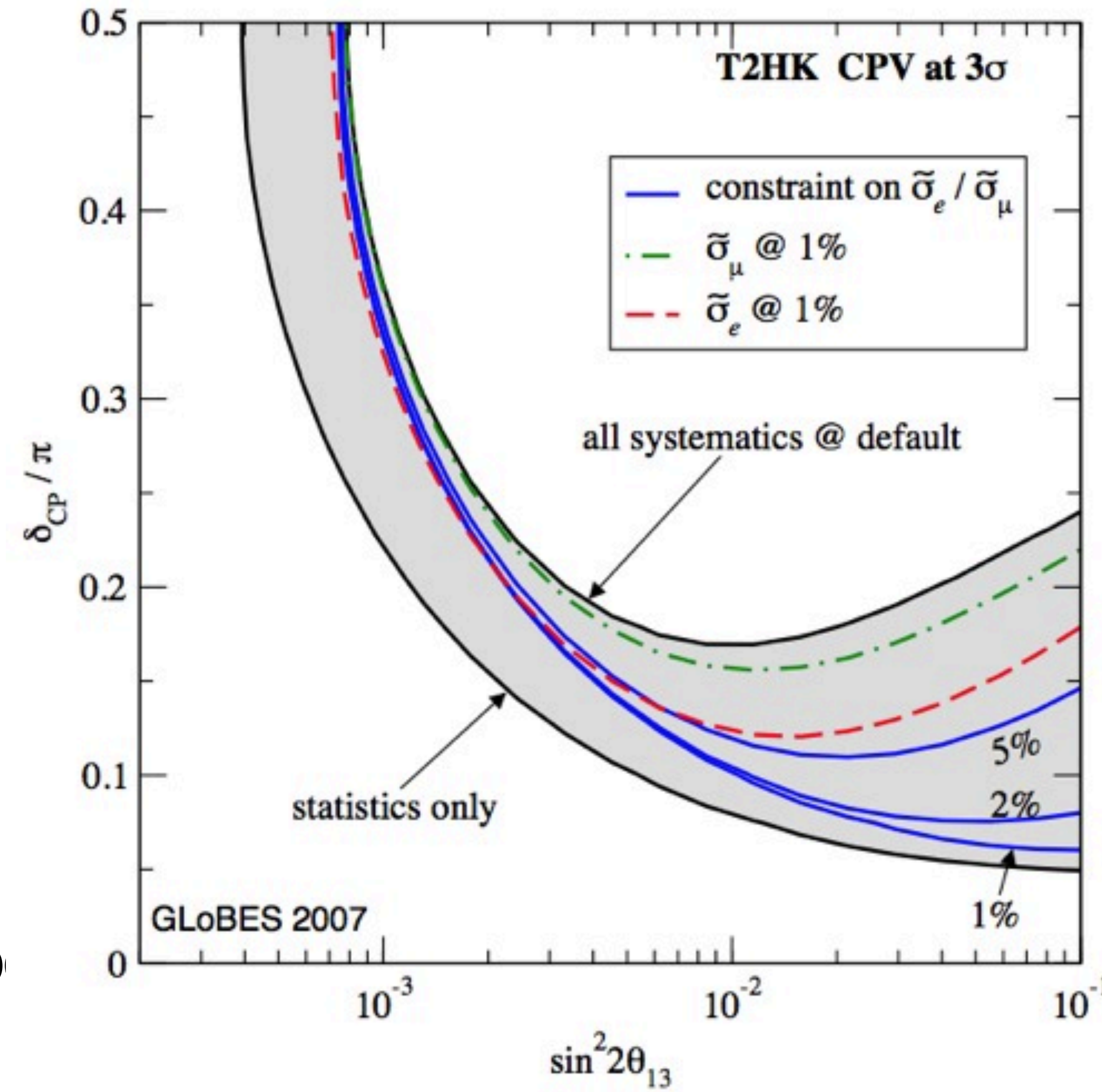




Coloma, Donini, Fernández-Martínez, Hernández, 1203.5651 [hep-ph]

Impact of systematics on CPV





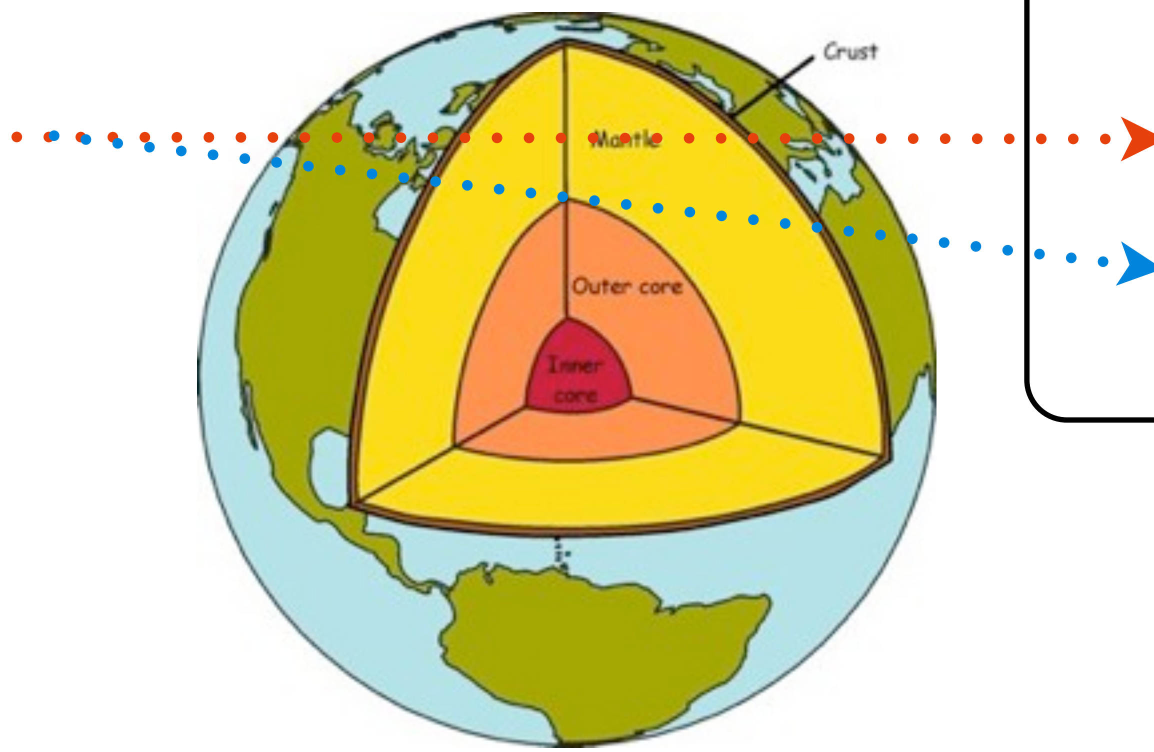
Coloma, Fernández-Martínez, 1110.4583 [hep-ph]

Huber, Mezzetto, Schwetz, 0711.2950 [hep-ph]

An example

Signal:

$$\pi^- \to \mu^- + \nu_\mu$$



CC interactions

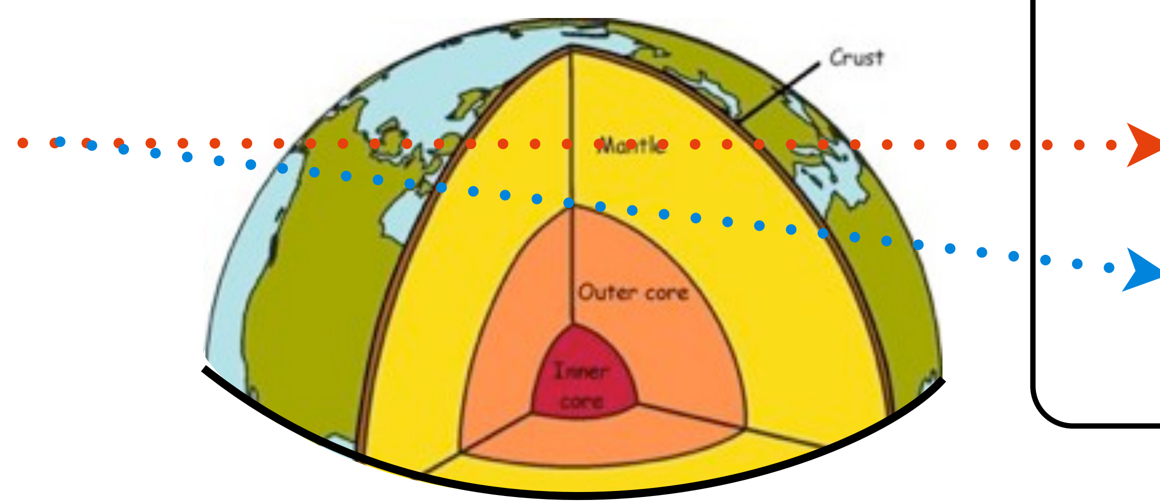
ν_e

ν_μ

An example

Signal:

$\pi^- \rightarrow \mu^- + \nu_\mu$



CC interactions

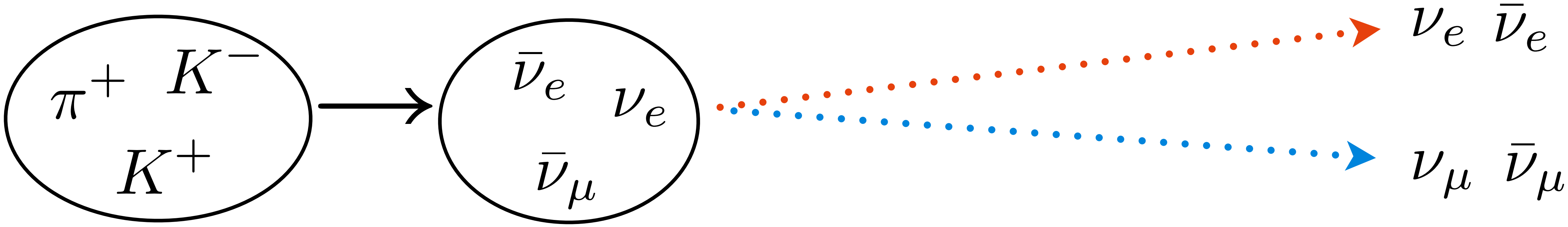
ν_e

ν_μ

Backgrounds:

NC interactions

$$\begin{cases} \pi^\pm \rightarrow \mu^\pm + E_{miss} \\ \pi^0 \rightarrow \gamma\gamma \end{cases}$$



An example

Possible ways to reduce the effect of systematics:

1) measure final flavor cross sections at a near detector. If this cannot be done, put constraints on ratios between cross sections for different flavors

2) measure intrinsic background at near detector

3) use data from disappearance channels at the far detector

An example

$$\mu^- \to e^- \bar{\nu}_e \nu_\mu$$

FD: $\bar{\nu}_e \to \bar{\nu}_\mu$

An example

$$\mu^- \to e^- \bar{\nu}_e \nu_\mu$$

FD: $\bar{\nu}_e \to \bar{\nu}_\mu$	Mu-	ν_{far}	Matter	Xsec

An example

$$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$$

	Mu-	ν_{far}	Matter	Xsec
FD: $\bar{\nu}_e \rightarrow \bar{\nu}_\mu$				
ND: $\nu_\mu \rightarrow \nu_\mu$				

An example

$$\mu^- \to e^- \bar{\nu}_e \nu_\mu$$

FD: $\bar{\nu}_e \to \bar{\nu}_\mu$	Mu-	V_{far}	Matter	Xsec
ND: $\nu_\mu \to \nu_\mu$	Mu-	V_{near}	Vac	Xsec

An example

$$\mu^- \to e^- \bar{\nu}_e \nu_\mu$$

		Mu-	V_far	Matter	Xsec
FD:	$\bar{\nu}_e \to \bar{\nu}_\mu$	Mu-	V_{far}	Matter	Xsec
ND:	$\nu_\mu \to \nu_\mu$	Mu-	V_{near}	Vac	Xsec
	$\bar{\nu}_\mu \to \bar{\nu}_\mu$	Mu+	V_{near}	Vac	Xsec

An example

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FD:	$\bar{\nu}_e \rightarrow \bar{\nu}_\mu$	Mu-	V_{far}	Matter	Xsec
ND:	$\nu_\mu \rightarrow \nu_\mu$	Mu-	V_{near}	Vac	Xsec
	$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$	Mu+	V_{near}	Vac	Xsec
FD:	$\nu_\mu \rightarrow \nu_\mu$				
	$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$				

An example

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FD:	$\bar{\nu}_e \to \bar{\nu}_\mu$	Mu-	V_{far}	Matter	Xsec
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FD:	$\nu_\mu \to \nu_\mu$	Mu-	V_{far}	Matter	Xsec
	$\bar{\nu}_\mu \to \bar{\nu}_\mu$	Mu+	V_{far}	Matter	Xsec

An example

$$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$$

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Simulation details

Simulation details

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

theoretical constraint

Simulation details

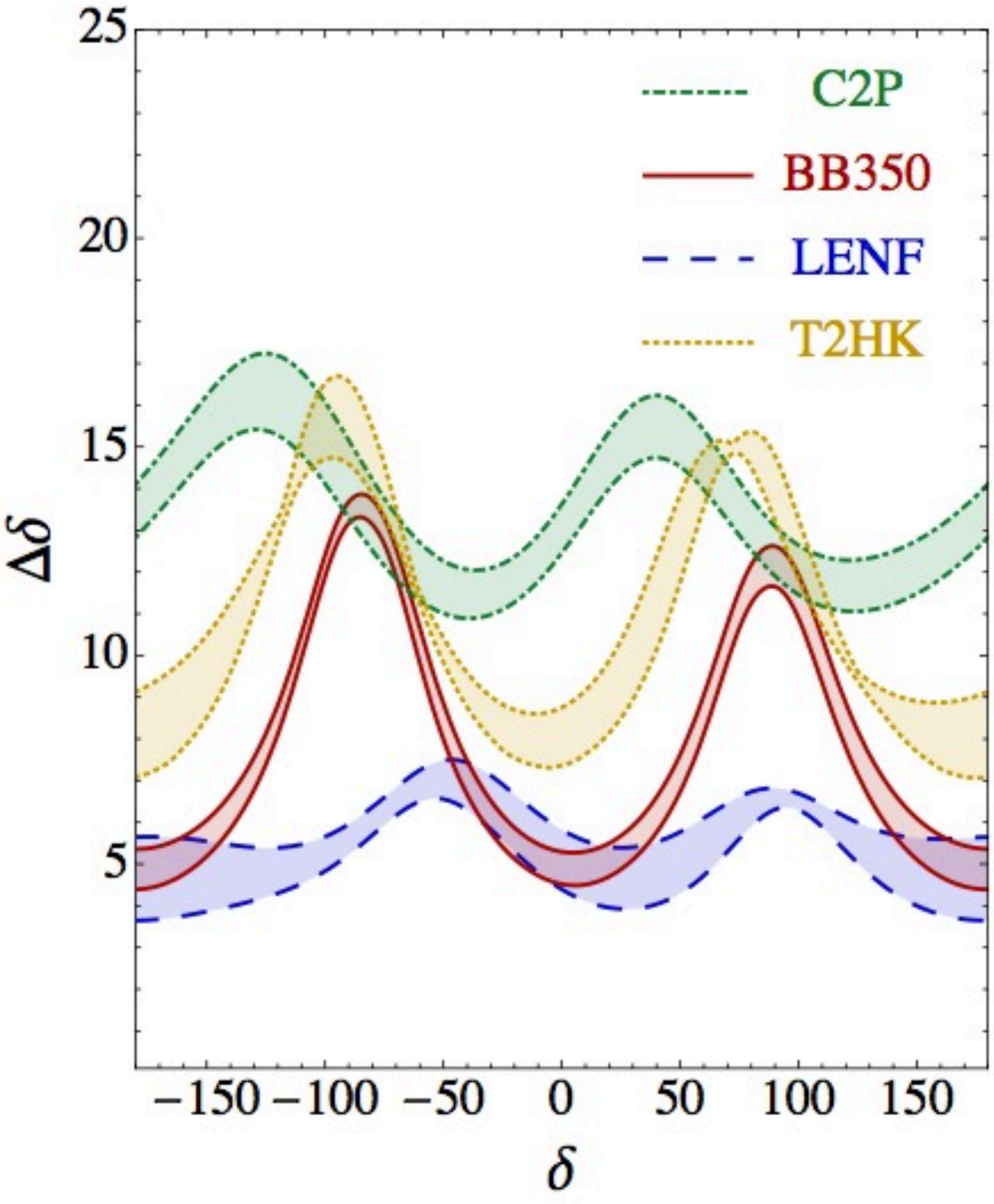
$$\chi^2 = \sum_{r,i} 2\left(T_{r,i}(\vec{\Theta},\vec{\xi}) - O_{r,i} + O_{r,i}\ln\frac{O_{r,i}}{T_{r,i}(\vec{\Theta},\vec{\xi})}\right) + \sum_k \left(\frac{\xi_k}{\sigma_k}\right)^2$$

- GLoBES software used hep-ph/0407333, hep-ph/0701187
- Input values in agreement with best fits 1205.5254 [hep-ph], 1205.4018 [hep-ph]
- Marginalization over solar and atmospheric params performed assuming 1σ gaussian priors 1108.1376 [hep-ph]
- No degeneracies have been accounted for: atmospheric angle set to maximal, normal hierarchy
- $\sin^2 2\theta_{13} = 0.1$
- 1σ (1 dof) unless stated otherwise

The setups

	Setup	E_ν^{peak}	L	OA	Detector	kt	MW	Decays/yr	$(t_\nu, t_{\bar{\nu}})$
Benchmark	BB350	1.2	650	–	WC	500	–	$1.1(2.8)\times10^{18}$	(5,5)
	NF10	5.0	2 000	–	MIND	100	–	7×10^{20}	(10,10)
	WBB	4.5	2 300	–	LAr	100	0.8	–	(5,5)
	T2HK	0.6	295	2.5°	WC	560	1.66	–	(1.5,3.5)
Alternative	BB100	0.3	130	–	WC	500	–	$1.1(2.8)\times10^{18}$	(5,5)
	+ SPL			–			4	–	(2,8)
	NF5	2.5	1 290	–	MIND	100	–	7×10^{20}	(10,10)
	$\text{LBNE}_{\text{mini}}$	4.0	1 290	–	LAr	10	0.7	–	(5,5)
	NOνA$^+$	2.0	810	0.8°	LAr	30	0.7	–	(5,5)
2020	T2K	0.6	295	2.5°	WC	22.5	0.75	–	(5,5)
	NOνA	2.0	810	0.8°	TASD	15	0.7	–	(4,4)

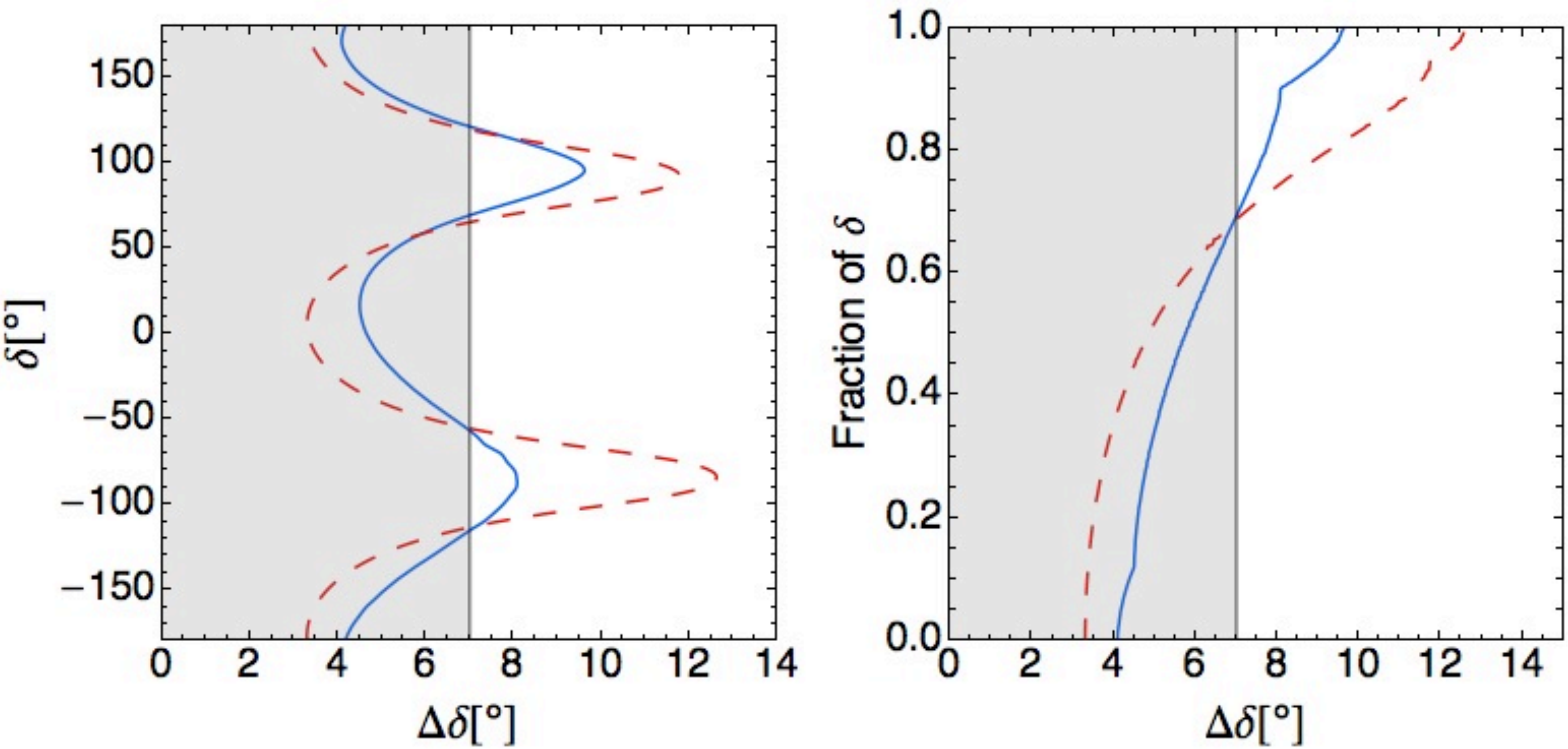
Precision



very different behaviour for all facilities

Coloma, Donini, Fernández-Martínez, Hernández, 1203.5651 [hep-ph]

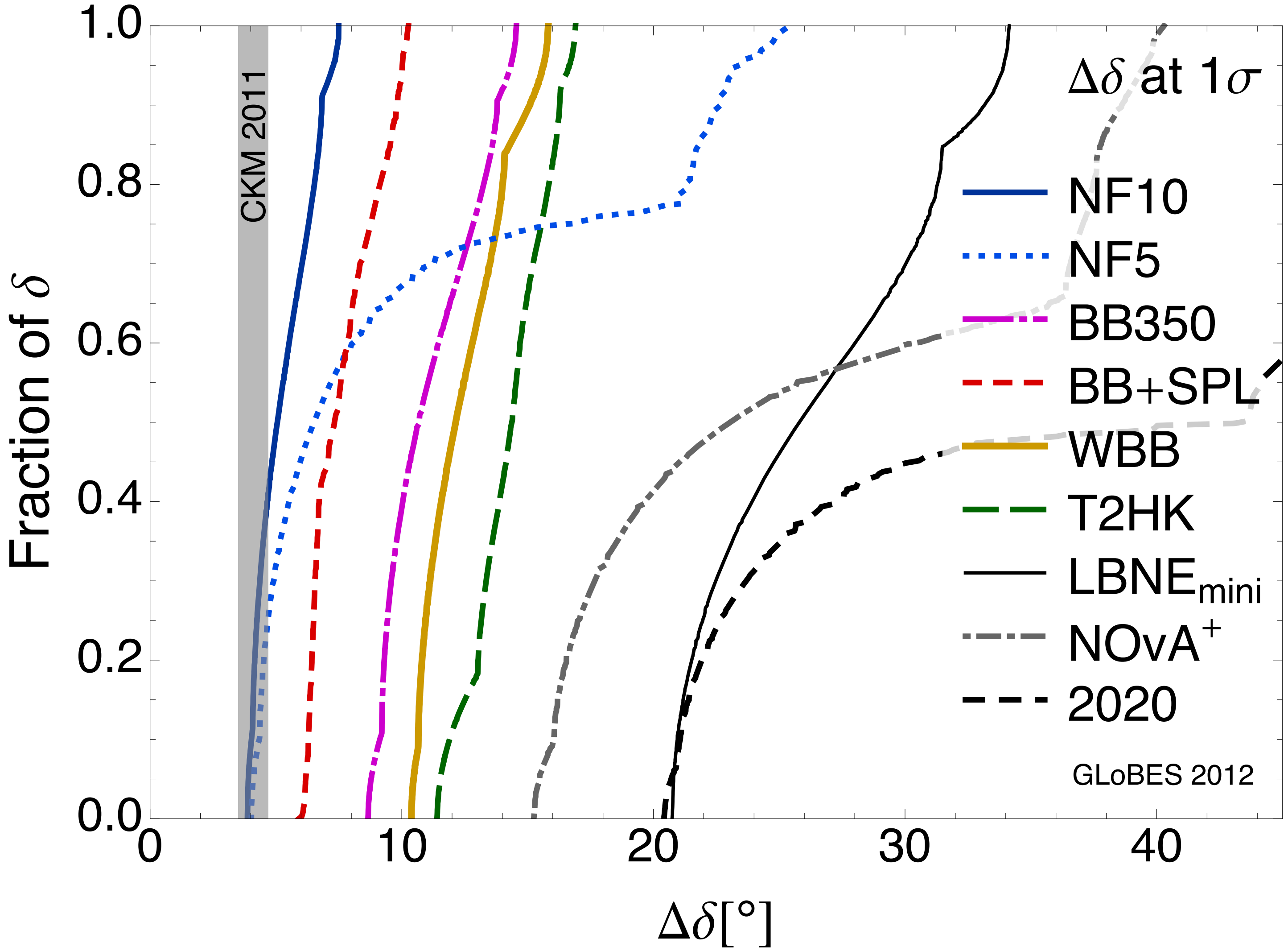
Precision and CP fraction

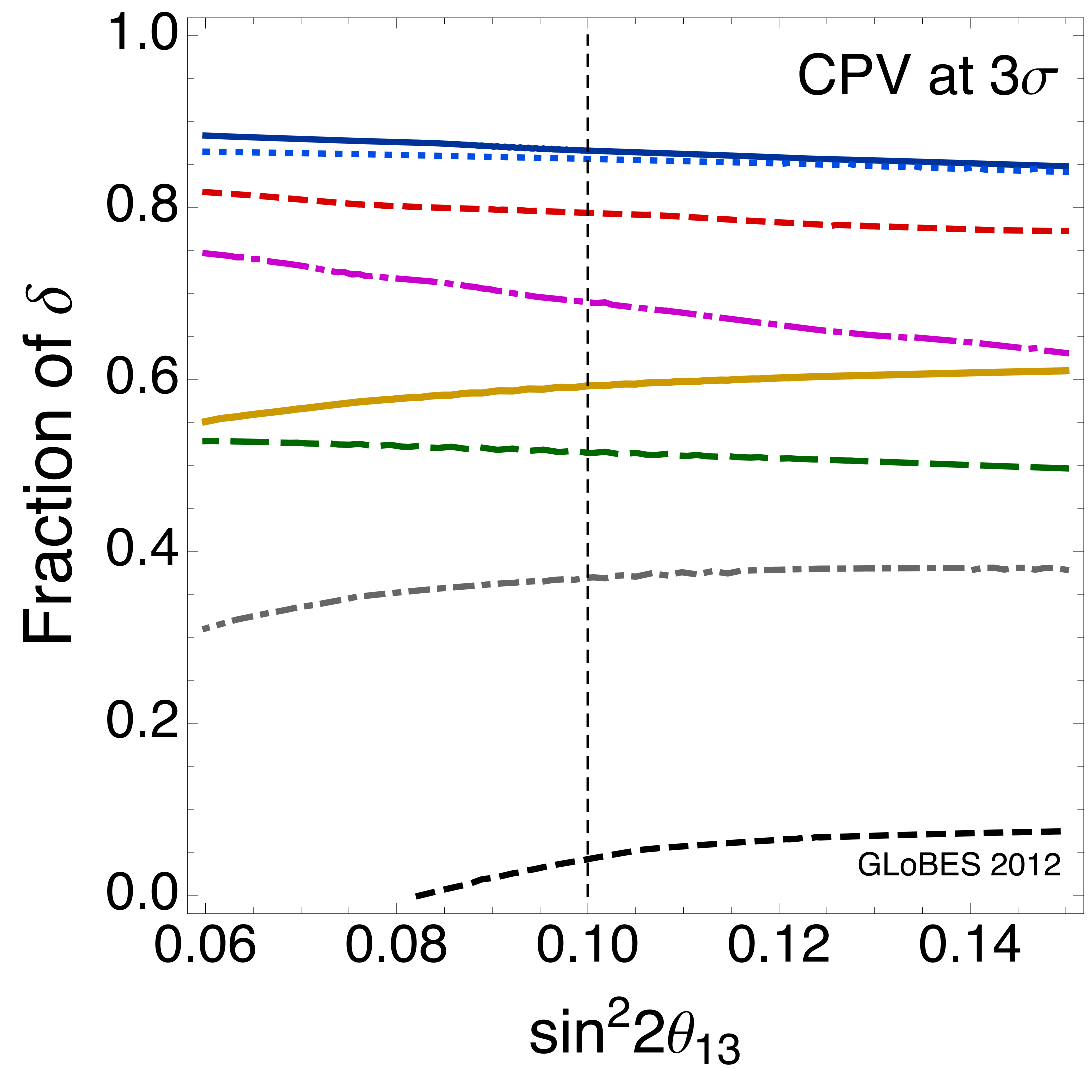


Results

General comparison

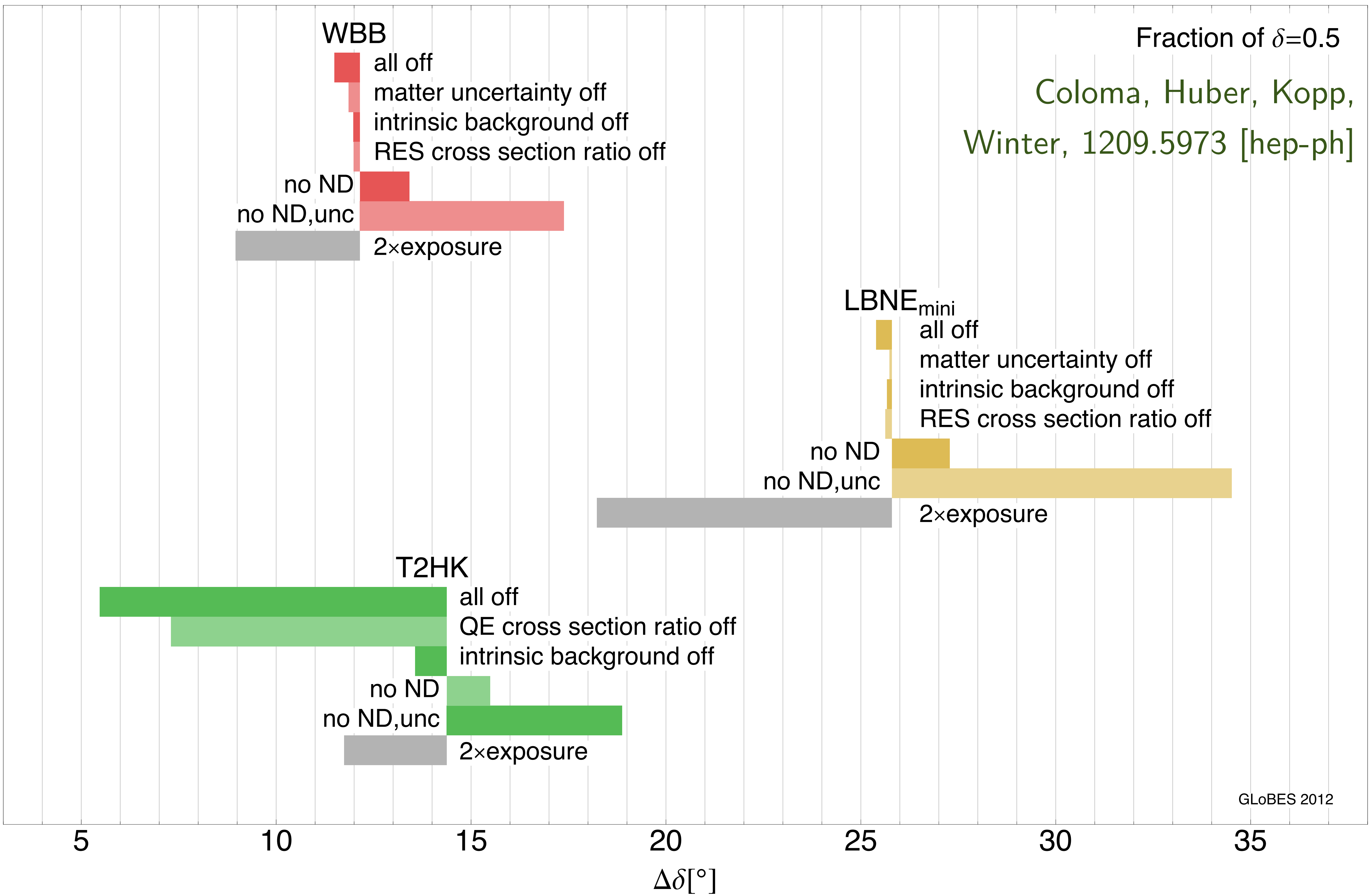
How far do we want to get?



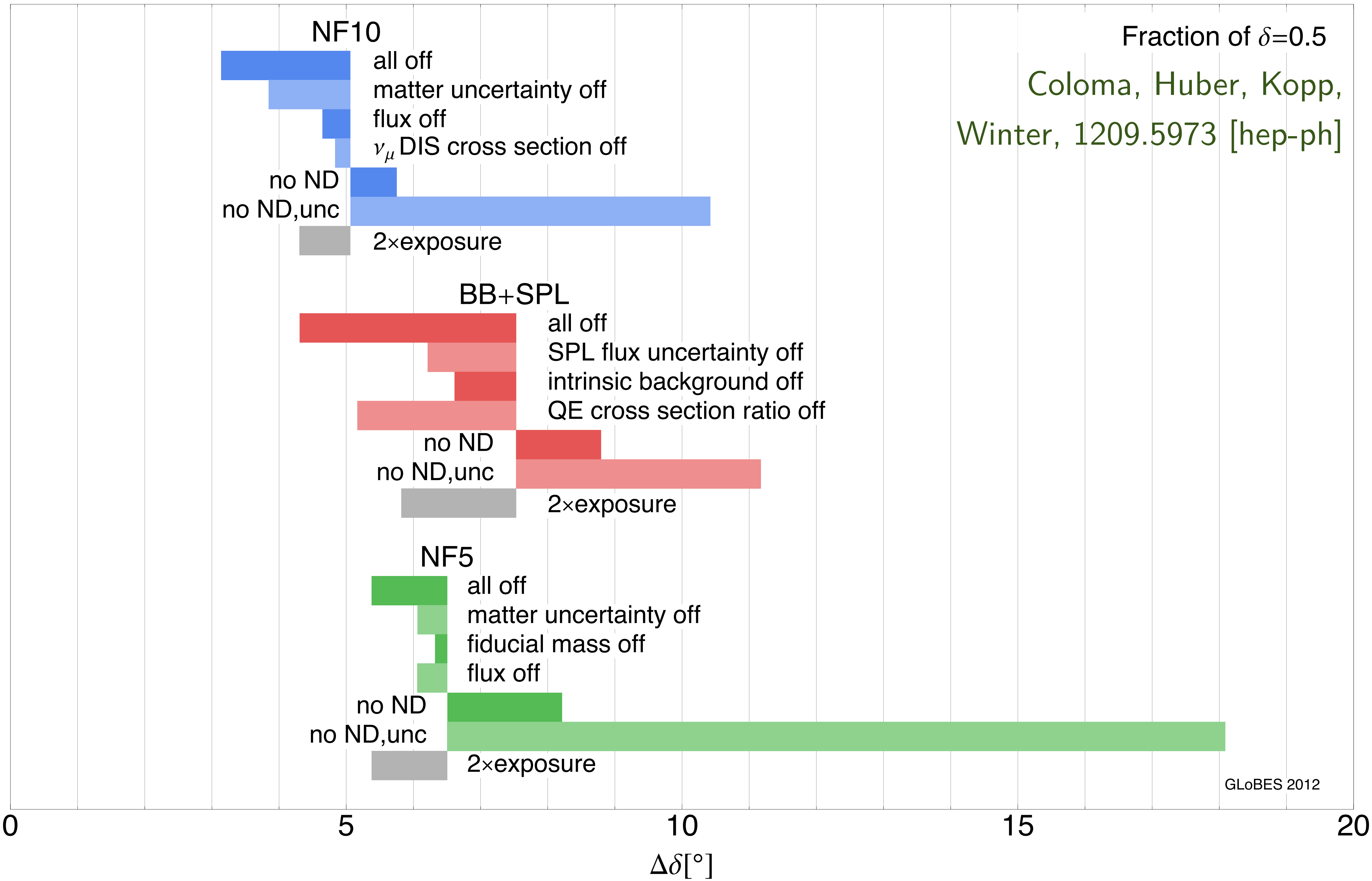


Coloma, Huber, Kopp, Winter, 1209.5973 [hep-ph]

Sys and near detectors

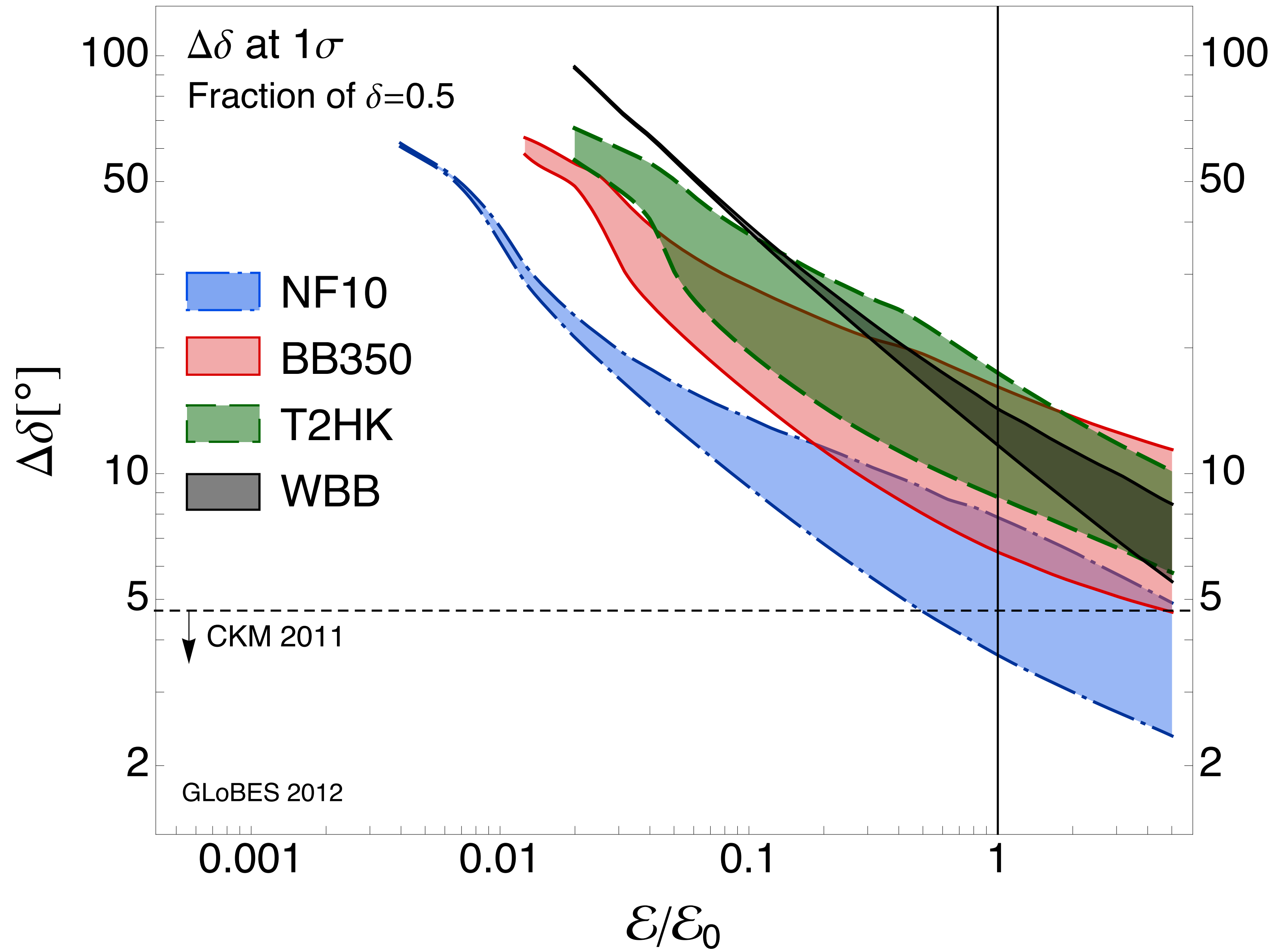


Sys and near detectors



Exposure vs systematics

Variation between optimistic and conservative assumptions:



Coloma, Huber, Kopp, Winter, 1209.5973 [hep-ph]

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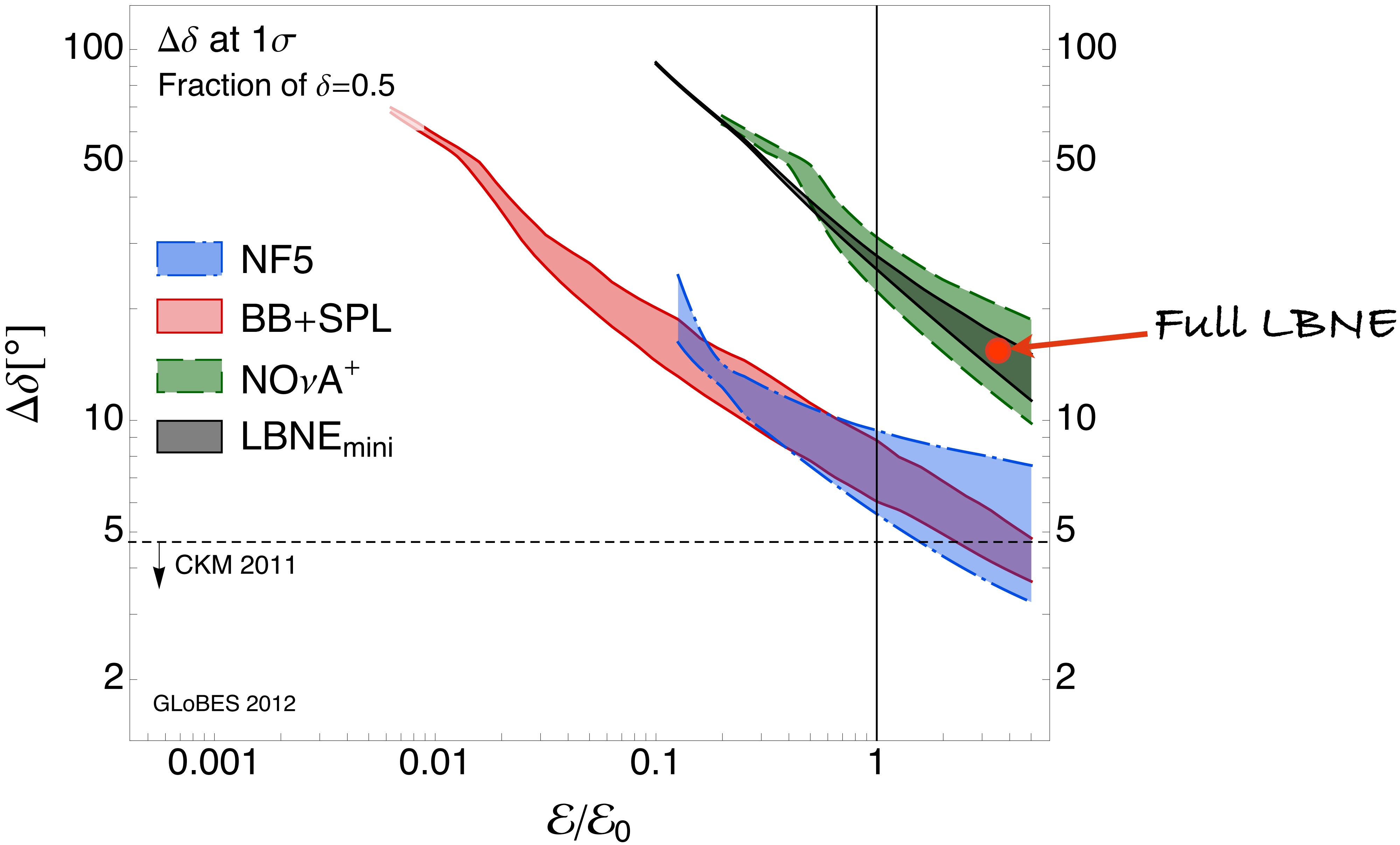


Coloma, Huber, Kopp, Winter, 1209.5973 [hep-ph]

Conclusions

- The impact of a ND does not seem so relevant if data from disappearance at the FD is used
- Low energy setups are generally more affected by systematics
  - Theoretical assumptions on cross section ratios are critical (Exception! BB+SPL)
- In some cases, it may a be better path to increase statistics than reduce systematics...
- LENF is the only facility able to achieve similar precision to quark sector
  - Matter uncertainty has a large effect for LENF

Backup

Mass hierarchy

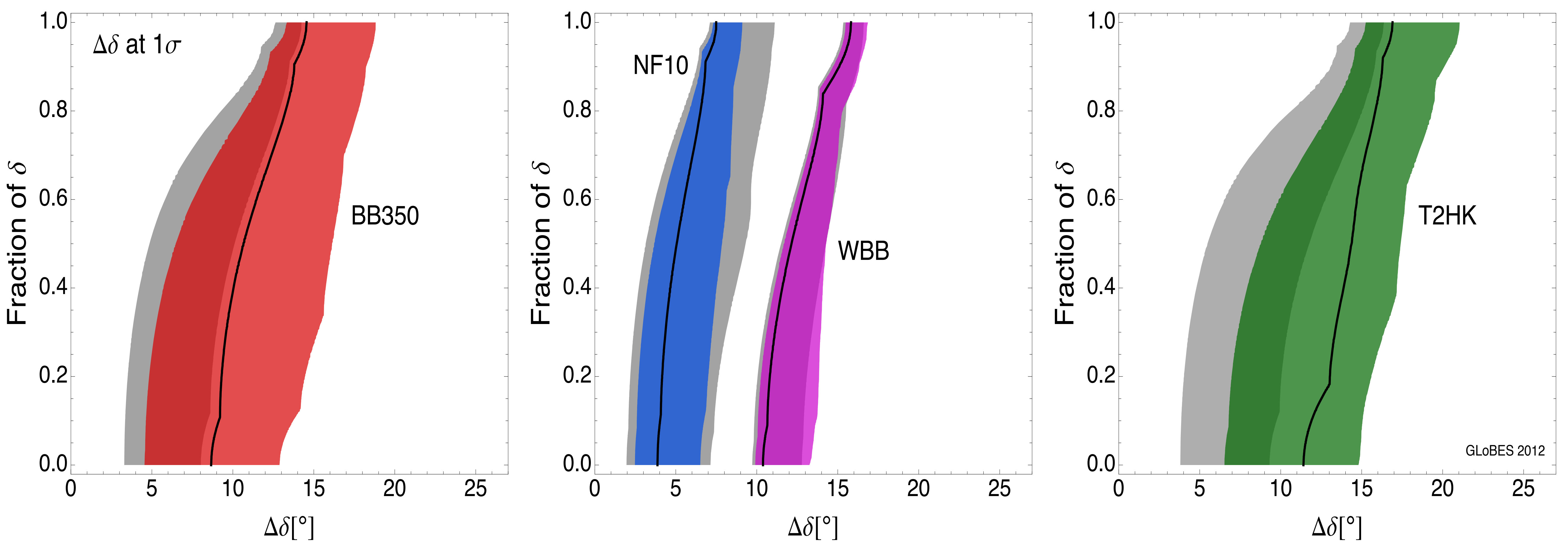
Mass hierarchy may be obtained through:

- T2K+NOvA+INO 1203.3388 [hep-ph]
- Atmospheric data at future exps 1109.3262 [hep-ex]
- PINGU 1205.7071 [hep-ph]
- Daya Bay II hep-ph/0112074
- combination of precise reactor+LBL data hep-ph/0503283
- ...

...or a combination of all of them!

Impact of systematics

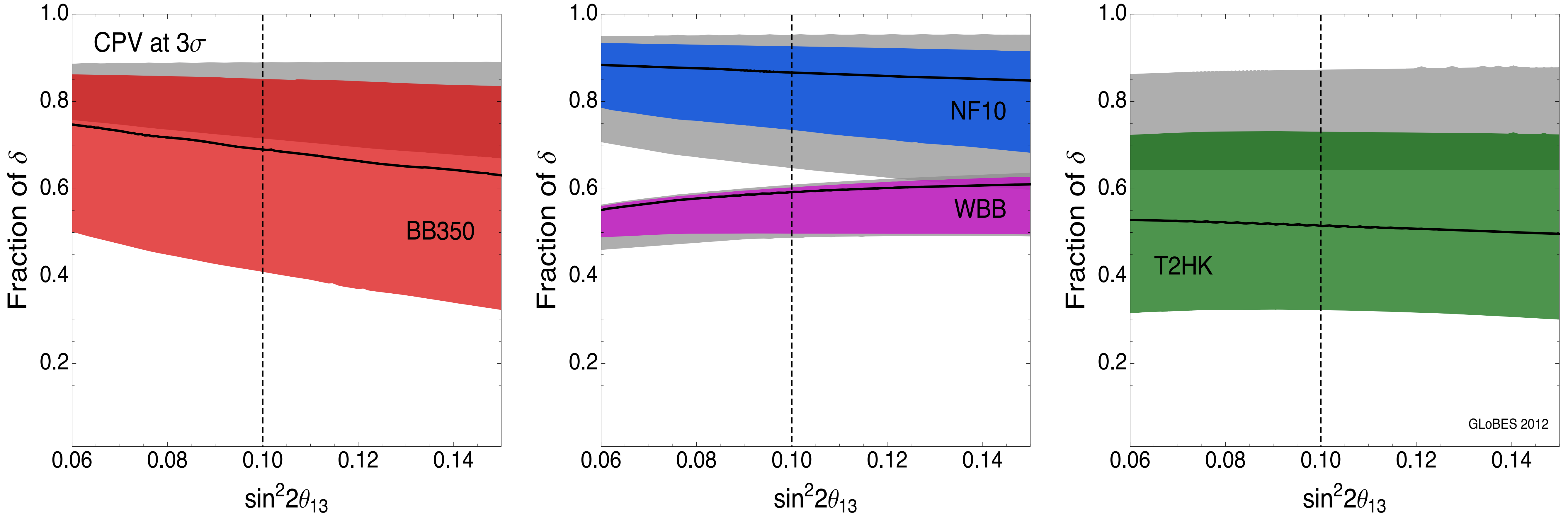
Variation between optimistic and conservative assumptions:



Coloma, Huber, Kopp, Winter, 1209.5973 [hep-ph]

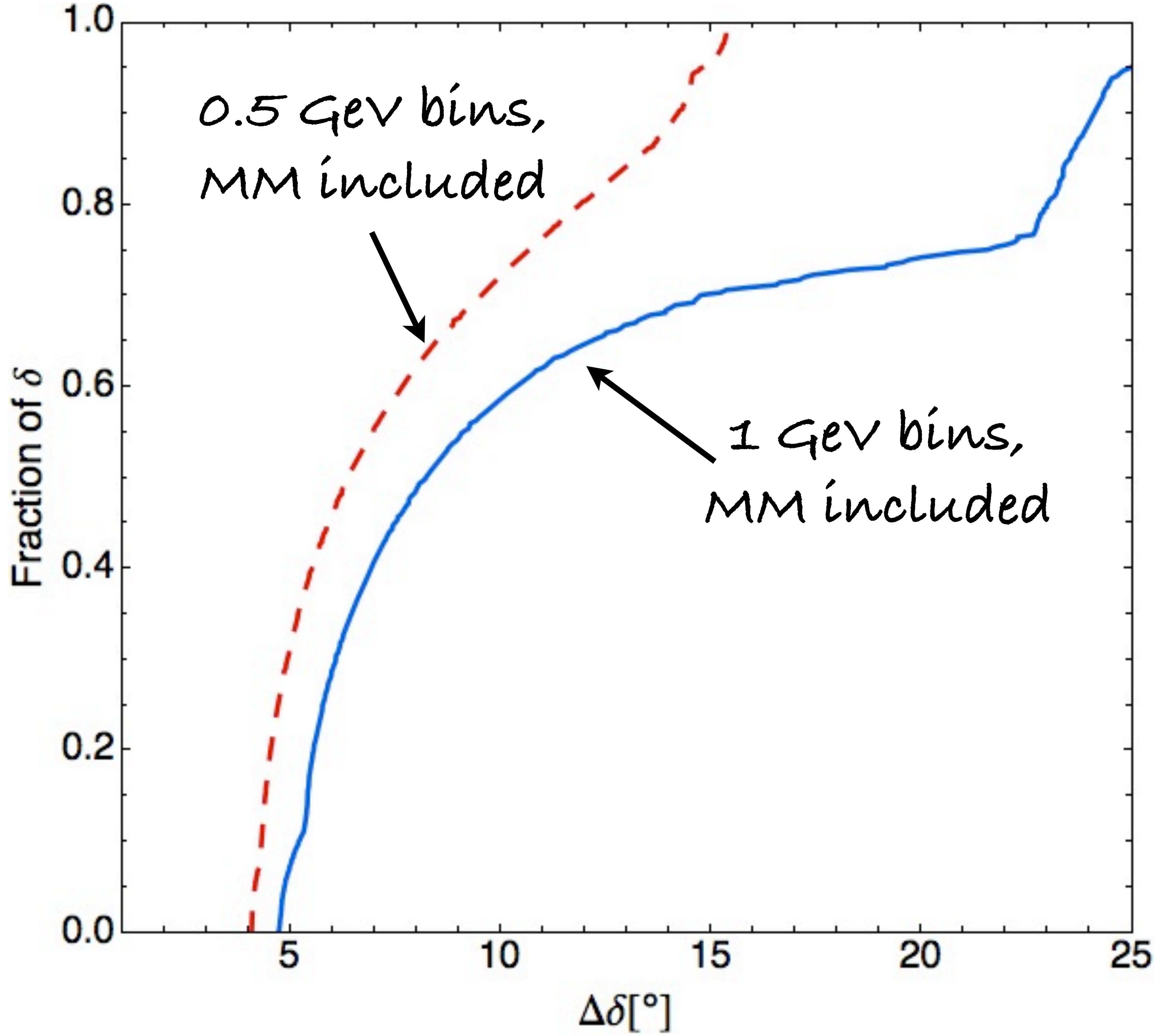
Impact of systematics

Variation between optimistic and conservative assumptions:

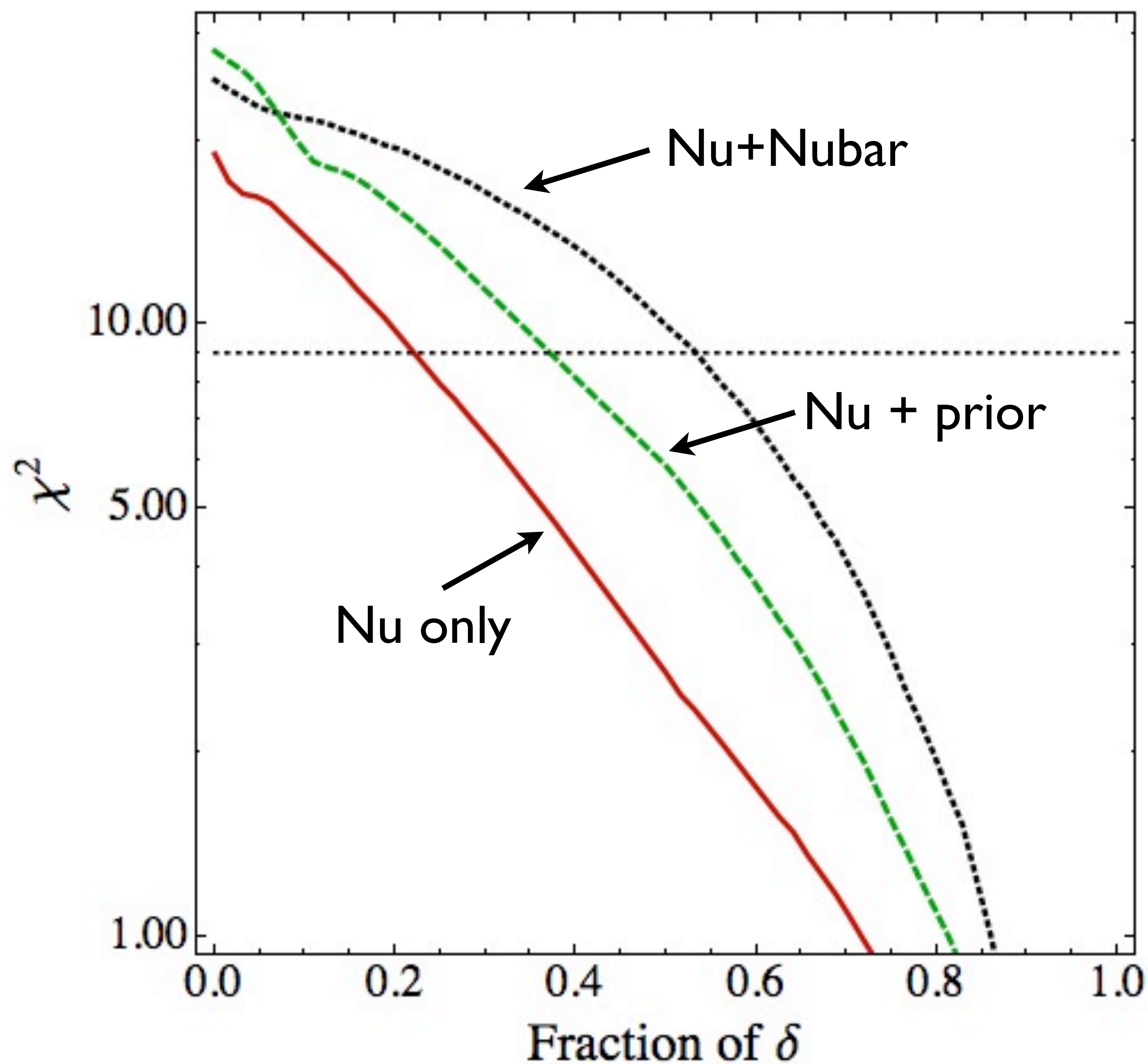


Coloma, Huber, Kopp, Winter, 1209.5973 [hep-ph]

Binning for the LENF

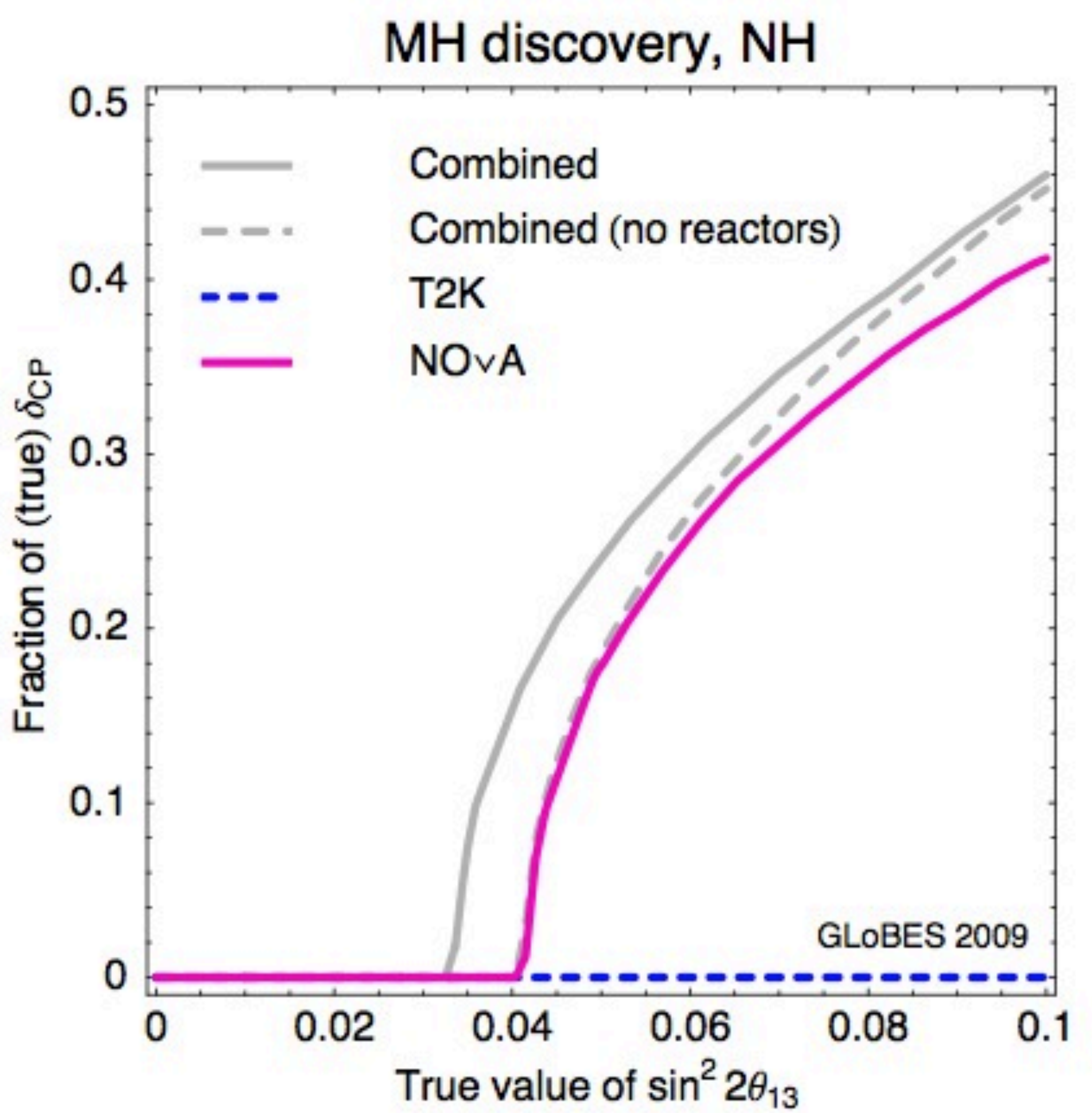


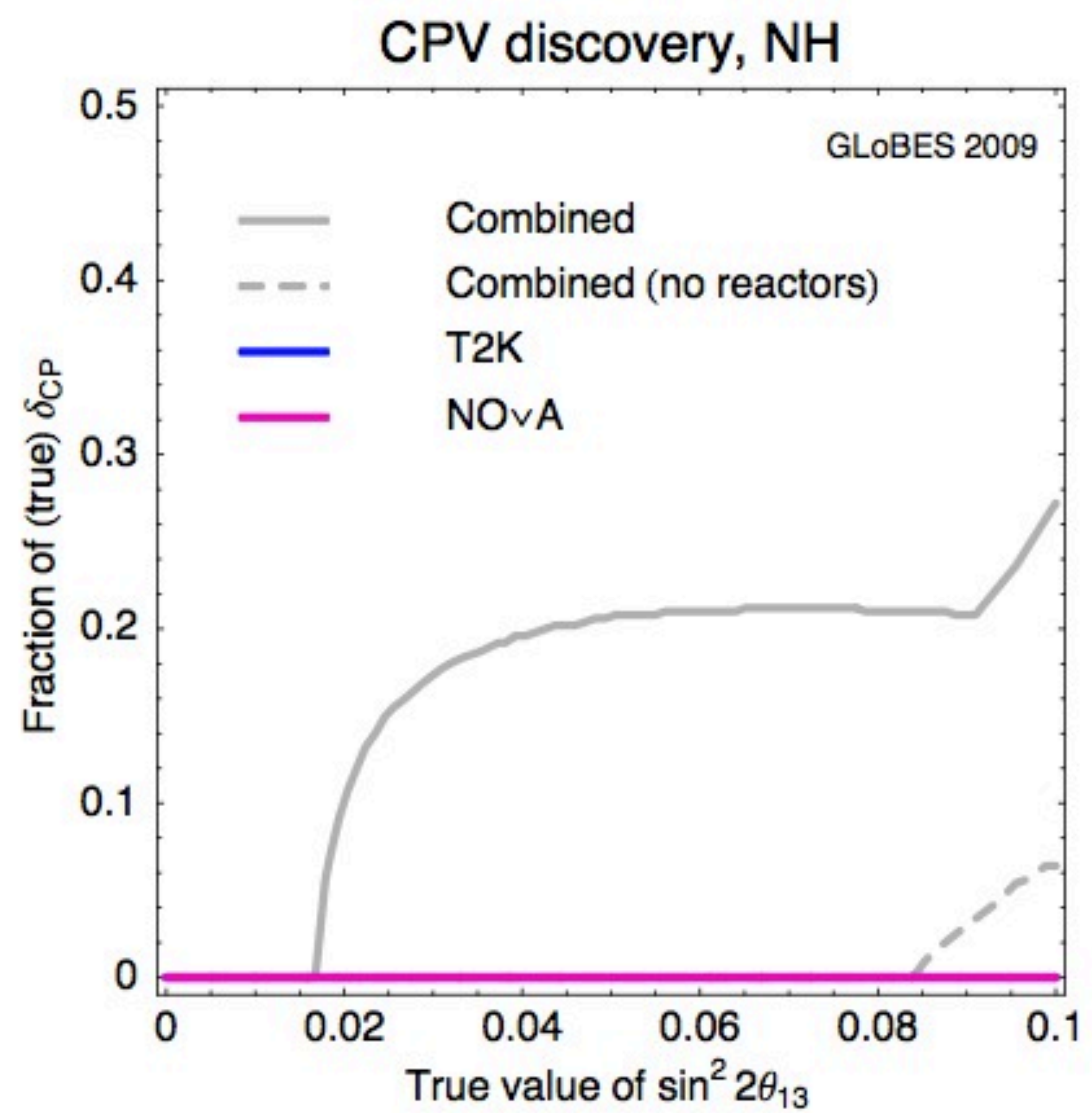
Effect of th13 prior on CPV



Present oscillation facilities

Discovery potential at the 90% CL



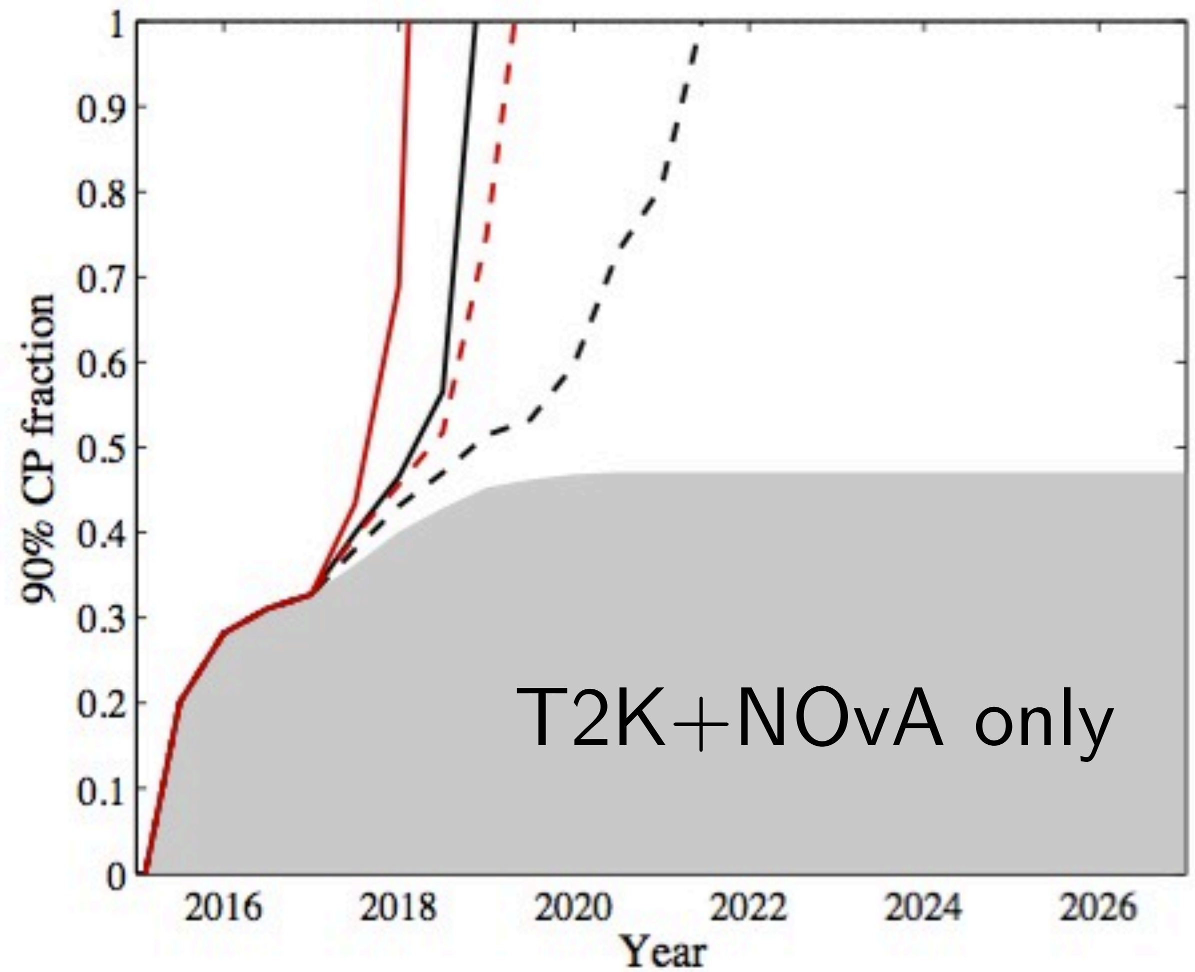


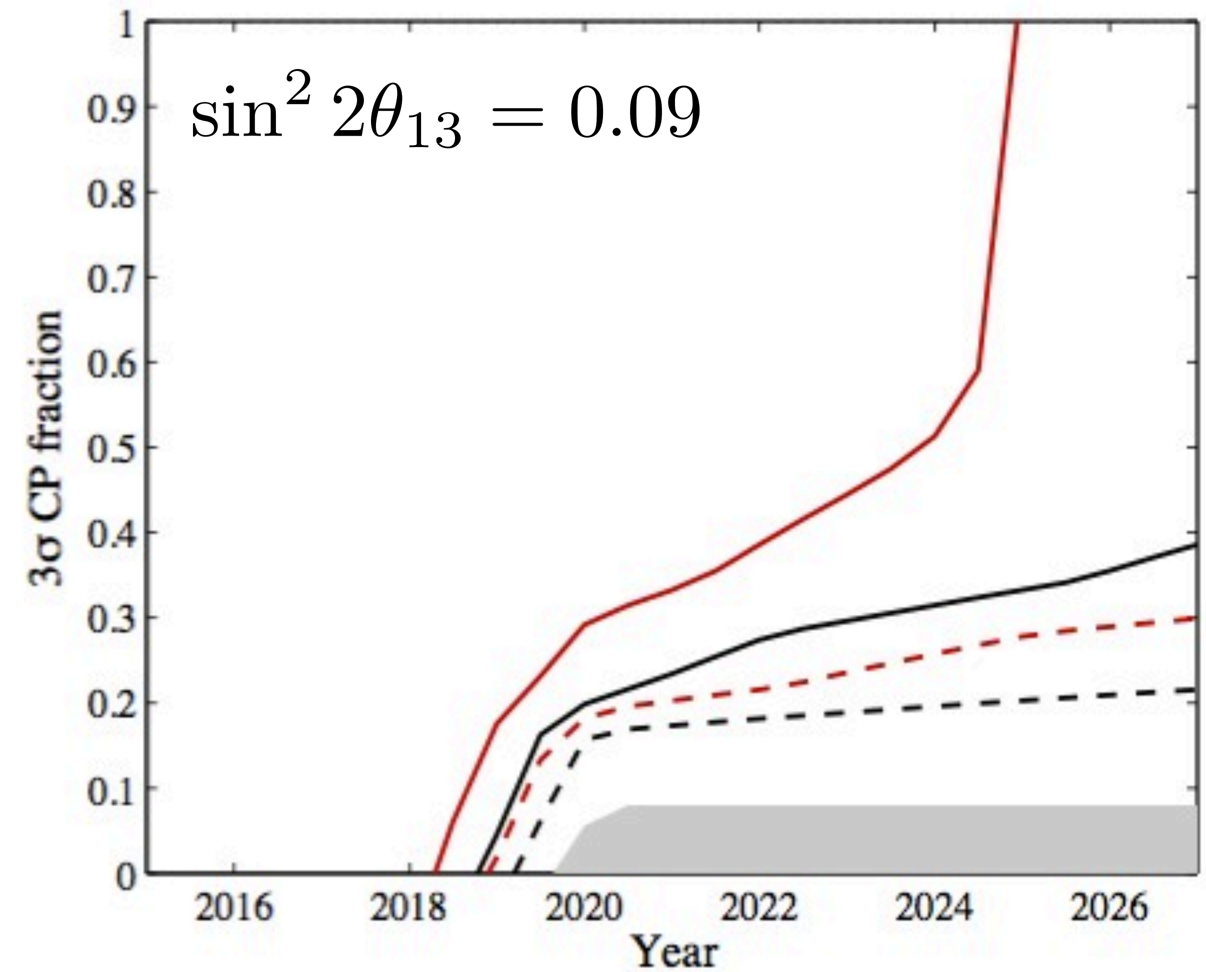
Huber, Lindner, Schwetz, Winter, 0907.1896 [hep-ph]

Present oscillation facilities

T2K+NOvA+INO

(50kt/100kt; low/high res)

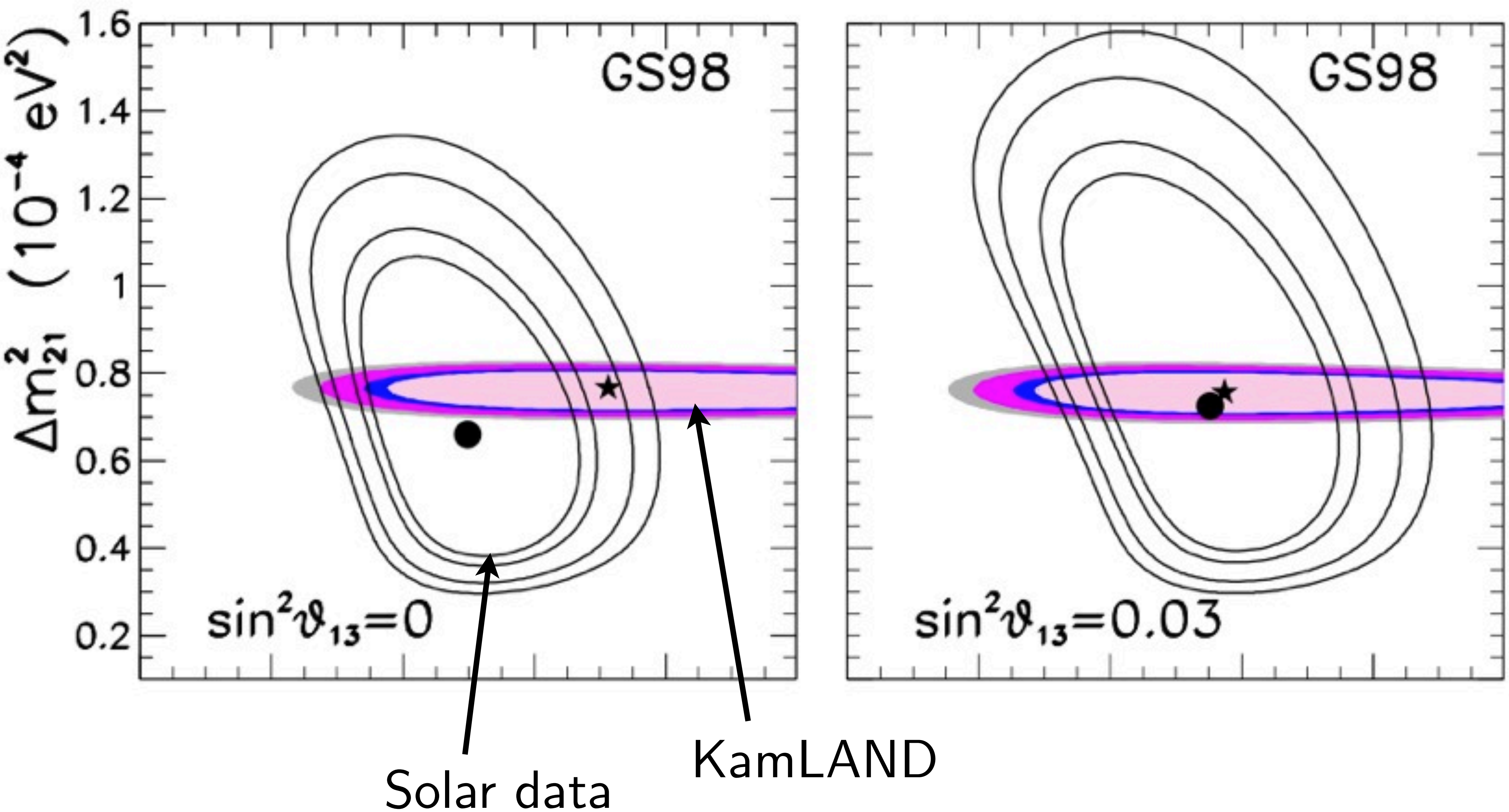




Blennow, Schwetz, 1203.3388 [hep-ph]

Previous hints on θ_{13}

Previous hints from global fits pointed to nonzero θ_{13}...



González-García, Maltoni,Salvado, 1001.4524 [hep-ph]

Currently Open Documents

- cp_MH.c
- ids-nf-3.0beta_...
- ids-nf-3.0beta-...

Last Saved: 5/30/12 12:41:35 PM
File Path ▾ : ~/Dropbox/systematics/newsys/LENF/ids-nf-3.0beta-fd.inc

ids-nf-3.0beta-fd.inc

```
>

// \mu^- running: appearance
rule(#Nu_Mu_Bar_Appearance)<
  @signal                     = 1.0@#nu_mu_bar_appQE : 1.0@#nu_mu_bar_appRES : 1.0@#nu_mu_bar_appDIS
  @sys_on_multiex_errors_sig = { #MassFar, #FluxMuMinus, #XmbQE } :
                               { #MassFar, #FluxMuMinus, #XmbRES } :
                               { #MassFar, #FluxMuMinus, #XmbDIS }

  @background                 = 1@#nu_NC_bckg : 1@#nu_mu_misCID
  @sys_on_multiex_errors_bg  = { #MassFar, #FluxMuMinus, #NCBG_mb } :
                               { #MassFar, #FluxMuMinus, #BGm  }

  @sys_on_function  = "chiMultiExp"
  @sys_off_function = "chiNoSysSpectrum"
  @energy_window = 0.1 : 10
>


// \mu^+ running: disappearance
rule(#Nu_Mu_Bar_Disappearance)<
  @signal                     = 1.0@#nu_mu_bar_disQE : 1.0@#nu_mu_bar_disRES : 1.0@#nu_mu_bar_disDIS
  @sys_on_multiex_errors_sig = { #MassFar, #FluxMuPlus, #XmbQE  } :
                               { #MassFar, #FluxMuPlus, #XmbRES } :
                               { #MassFar, #FluxMuPlus, #XmbDIS }

  @background                 = 1@#nu_bar_NC_bckg
  @sys_on_multiex_errors_bg  = { #MassFar, #FluxMuPlus, #NCBG_mb }

  @sys_on_function  = "chiMultiExp"
  @sys_off_function = "chiNoSysSpectrum"
  @energy_window = 0.1 : 10
>
```

Recent Documents

- ids-nf-3.0beta-fd.inc
- ids-nf-3.0beta_opt...
- cp_MH.c

260 | 26 | (none) | Unicode (UTF-8) | Unix (LF) | 8,130 / 660 / 290

The importance of systematics

- Up to now, each facility has made its own assumptions about systematic uncertainties. Generally,
  - BB and NF are assumed to have low sys
  - SB are assumed to have high sys
- However, this may change if a near detector is included and correlations are considered carefully

  (For instance, if final flavor cross sections can be measured at the ND)