3rd EUROnu Annual Meeting
January 20th, 2011
STFC Rutherford Appleton Laboratory
United Kingdom

The tau-contamination at the Neutrino Factory

Pilar Coloma

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A. Donini, J.J. Gómez Cadenas and D. Meloni, arXiV: 1005.2275 [hep-ph]
D. Indumathi and Nita Sinha, arXiv:0910.2020v2 [hep-ph]

Outline

- Tau-contamination
  - In appearance
  - In disappearance
- The revival of an old well-known effect?
- Solution: the migration matrix
  - Reconstruction of the whole signal
- Corrected results:
  - Golden: problem solved
  - Disappearance: not so easy...
- Conclusions

Basics of the NF

$$\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$$

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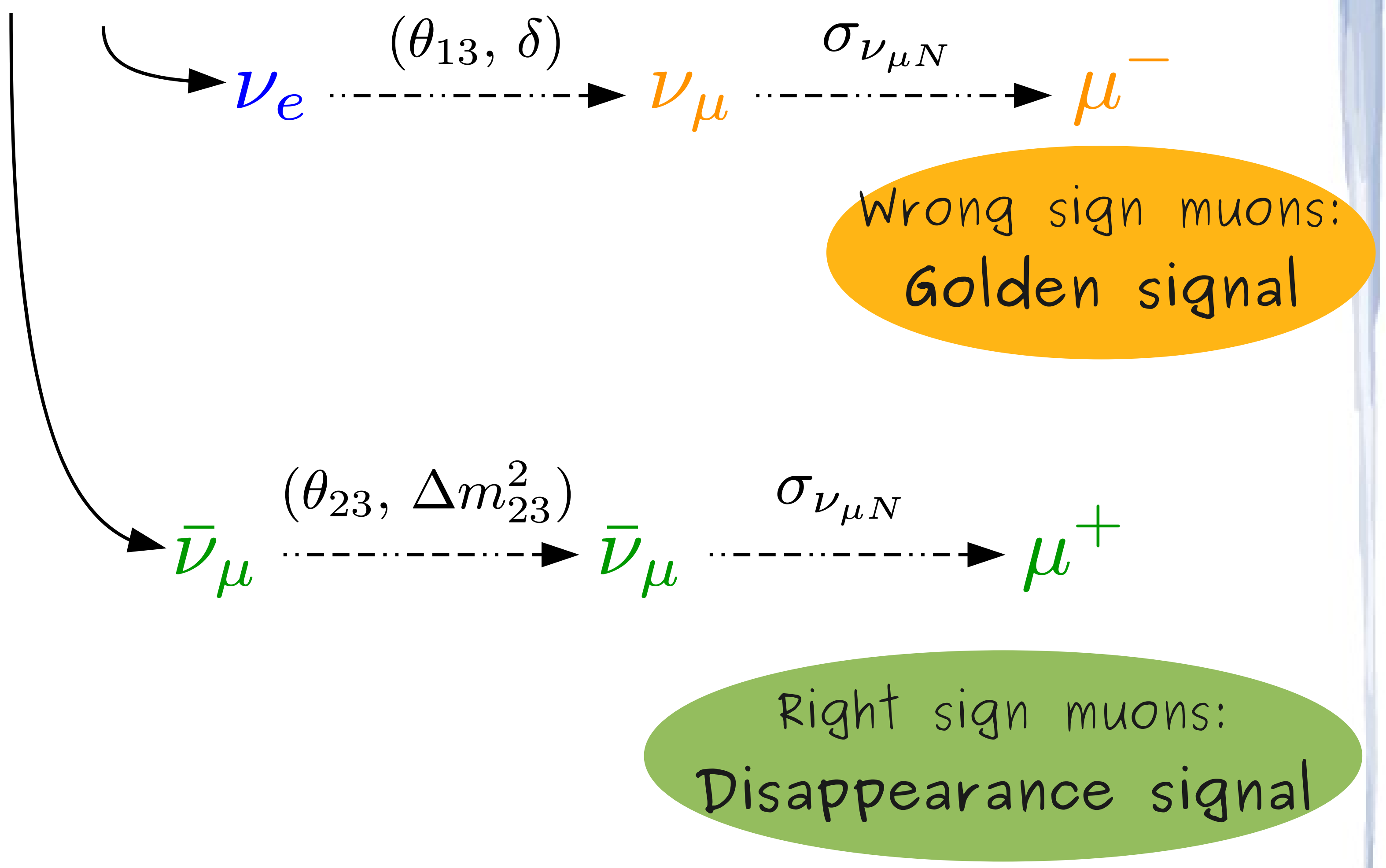
$$\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$$

$$\nu_e \xrightarrow{(\theta_{13},\, \delta)} \nu_\mu \xrightarrow{\sigma_{\nu_\mu N}} \mu^-$$

Wrong sign muons:
Golden signal

Basics of the NF

$$\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$$

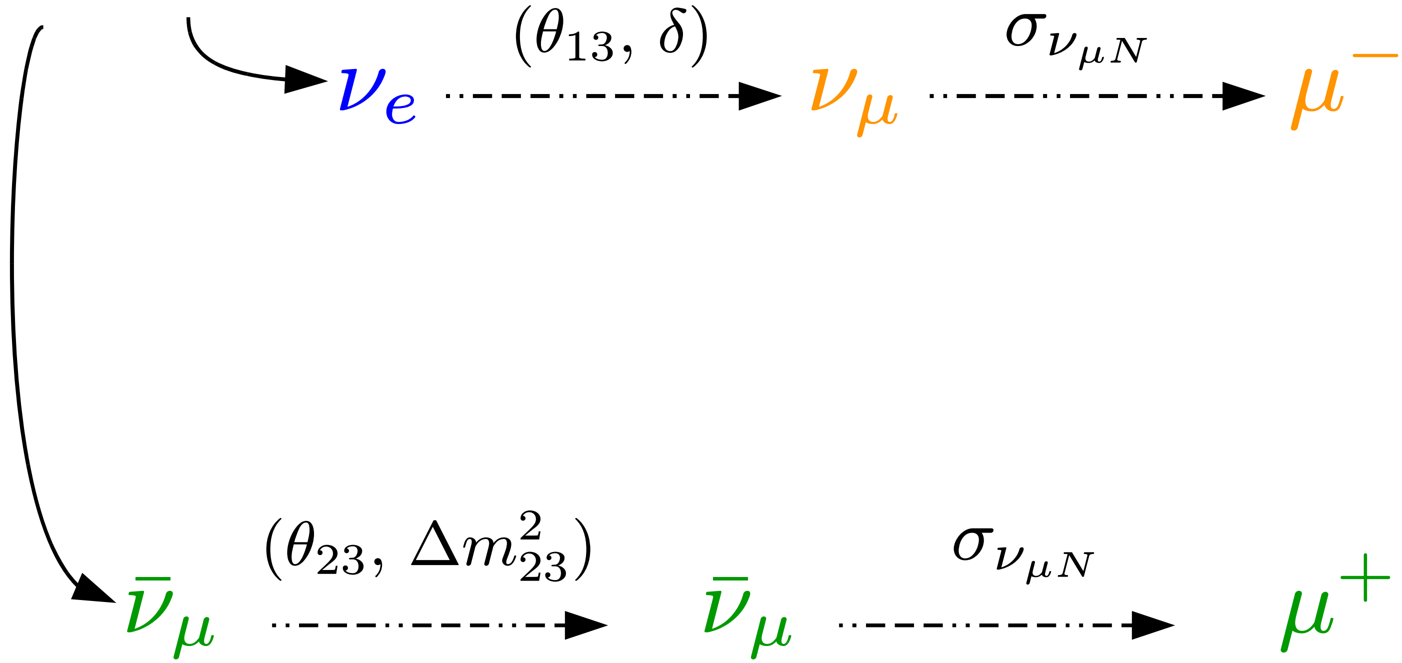


Basics of the NF

- Golden channel:
  - best channel to measure θ_{13}, δ and $sgn(\Delta m^2_{31})$
  - few events expected due to θ_{13} small
  - main backgrounds:
    - Right sign-muons;
    - CC with missed lepton + fake muons from hadrons;
    - NC + fake muons from hadrons.
- Disappearance channel:
  - Best channel to measure atmospheric parameters
  - Huge statistics at the detector

The tau-contamination

$$\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$$



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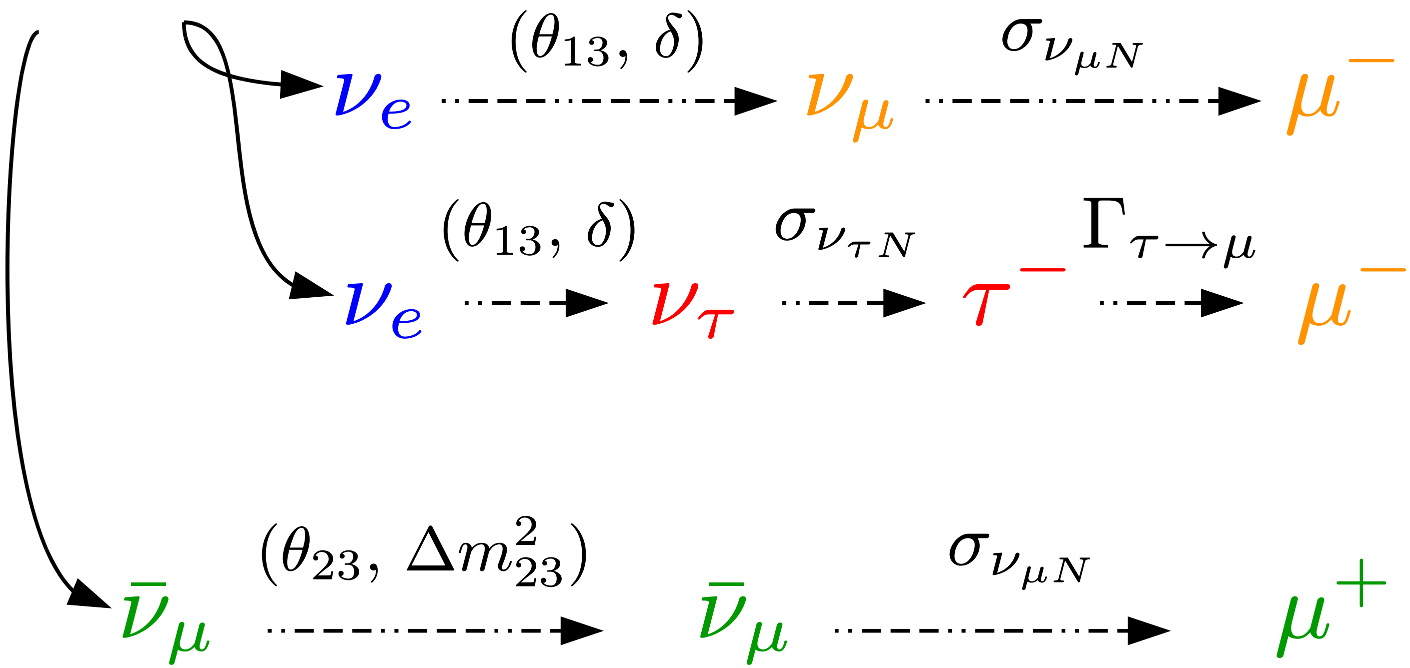
$$\mu^+ \to e^+ \bar{\nu}_\mu \nu_e$$



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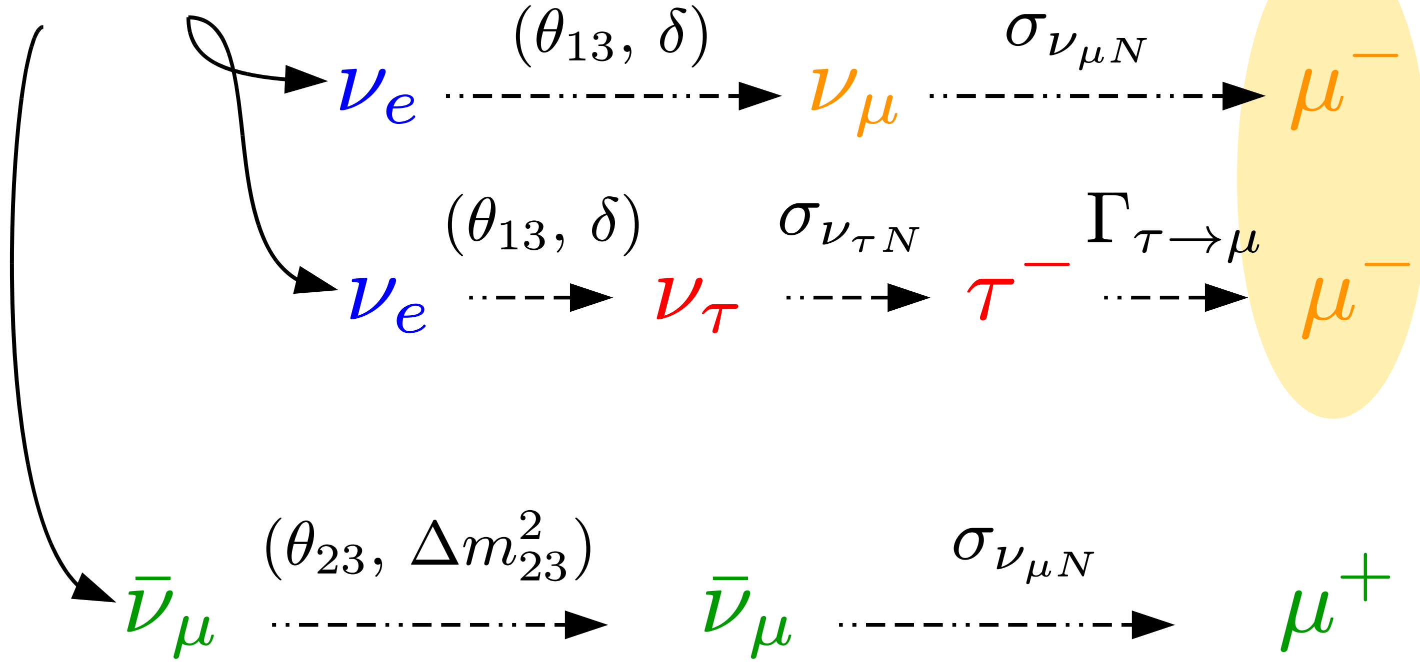

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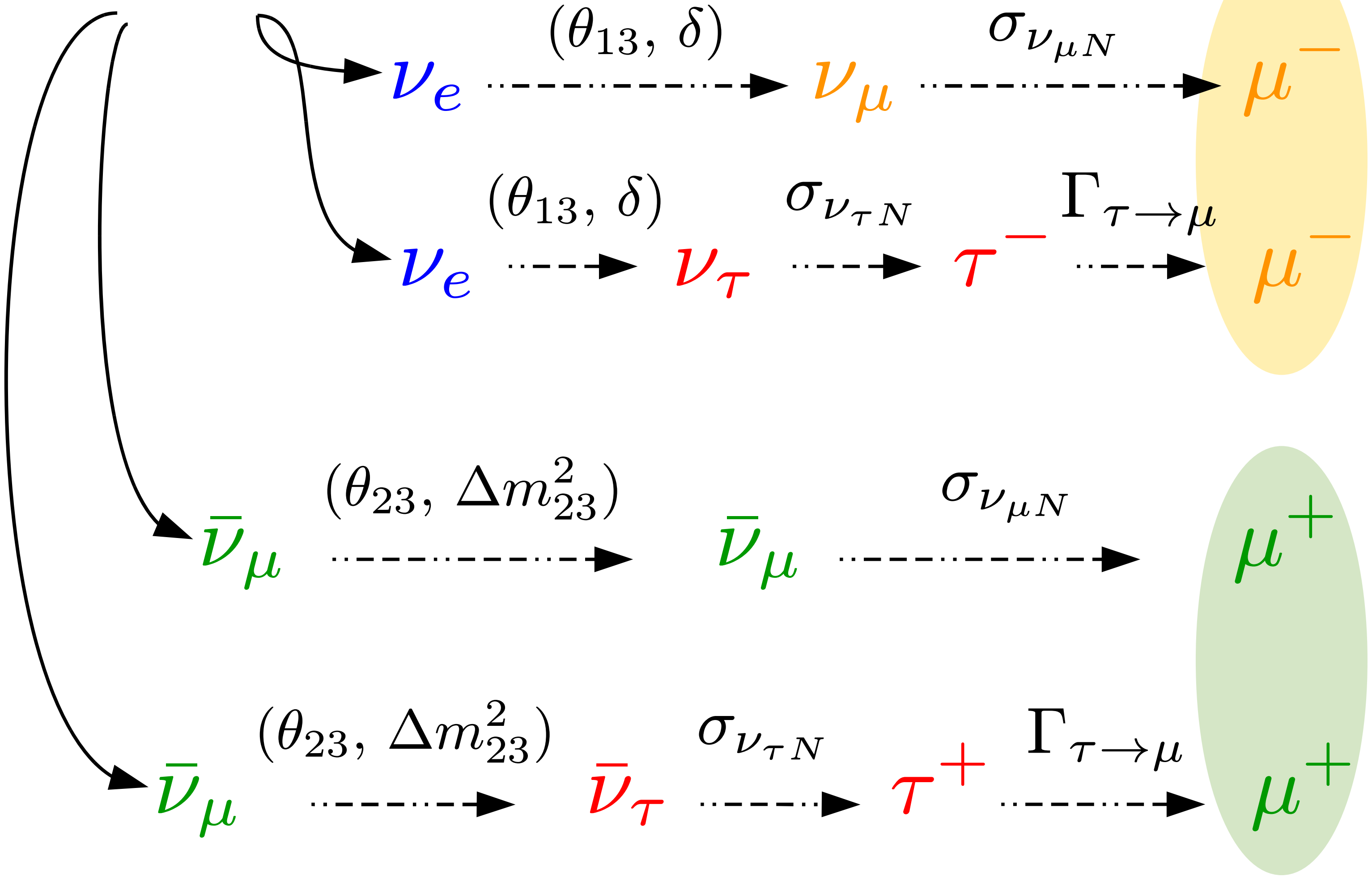

The tau-contamination

- These muons would result in a separate signal itself in ECC or LAr
- In MIND, these cannot be distinguished from the true signal
- Low energy bins mostly affected due to spectral change after the decay: resulting in a fake measurement of θ_{13}, θ_{23}

A well-known effect...

...not considered in the NF performance analyses up to 2009

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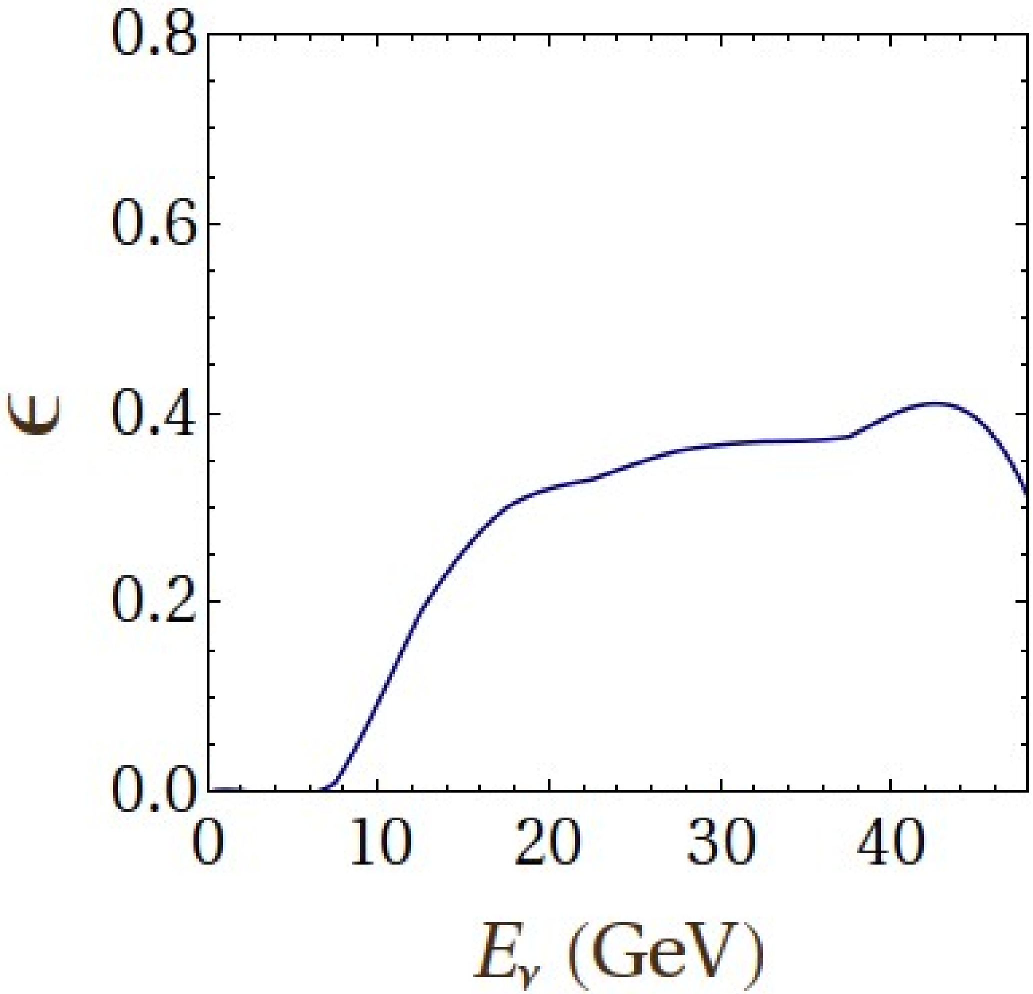
Why??

MIND (old) efficiencies

Tight kinematic cuts give a very low background fraction

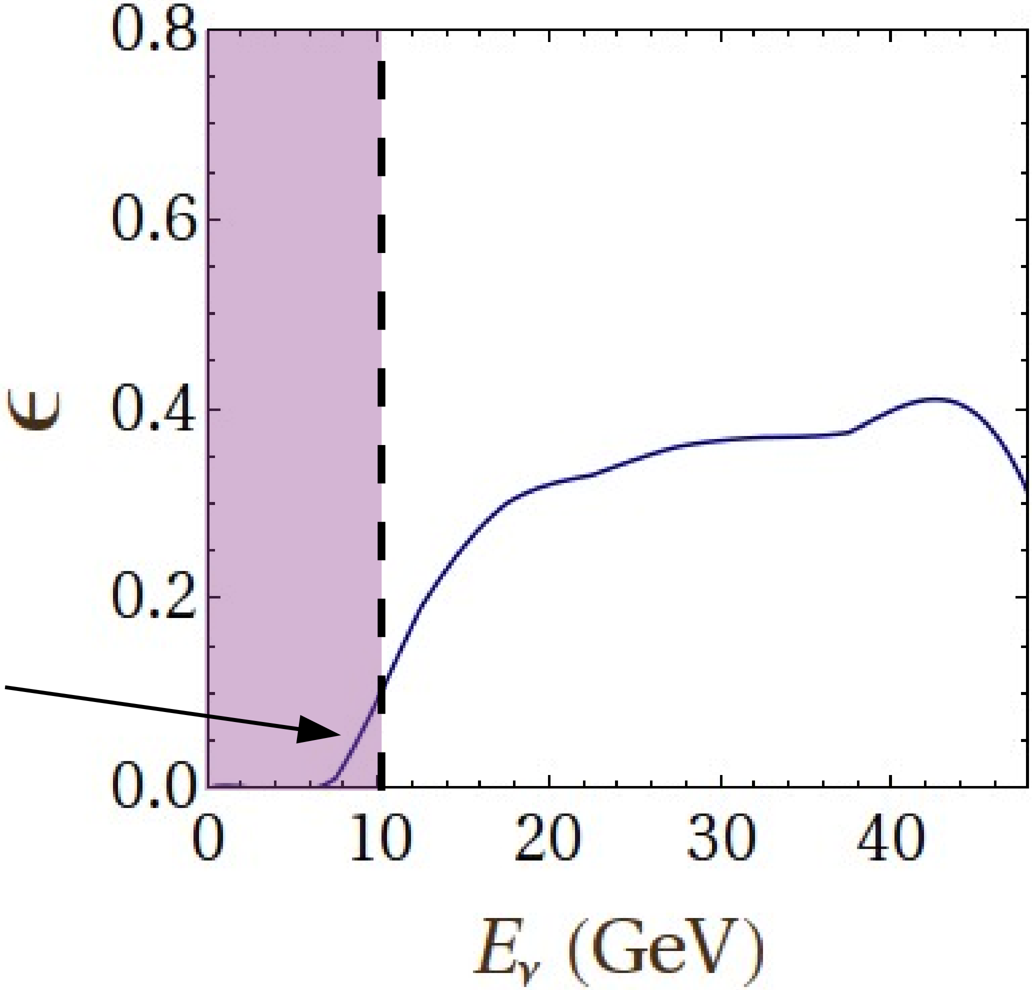


Cervera et al, hep-ph/0002108

MIND (old) efficiencies

Tight kinematic cuts give a very low background fraction

But these give very low efficiencies below 10 GeV, too...



Cervera et al, hep-ph/0002108

MIND (old) efficiencies

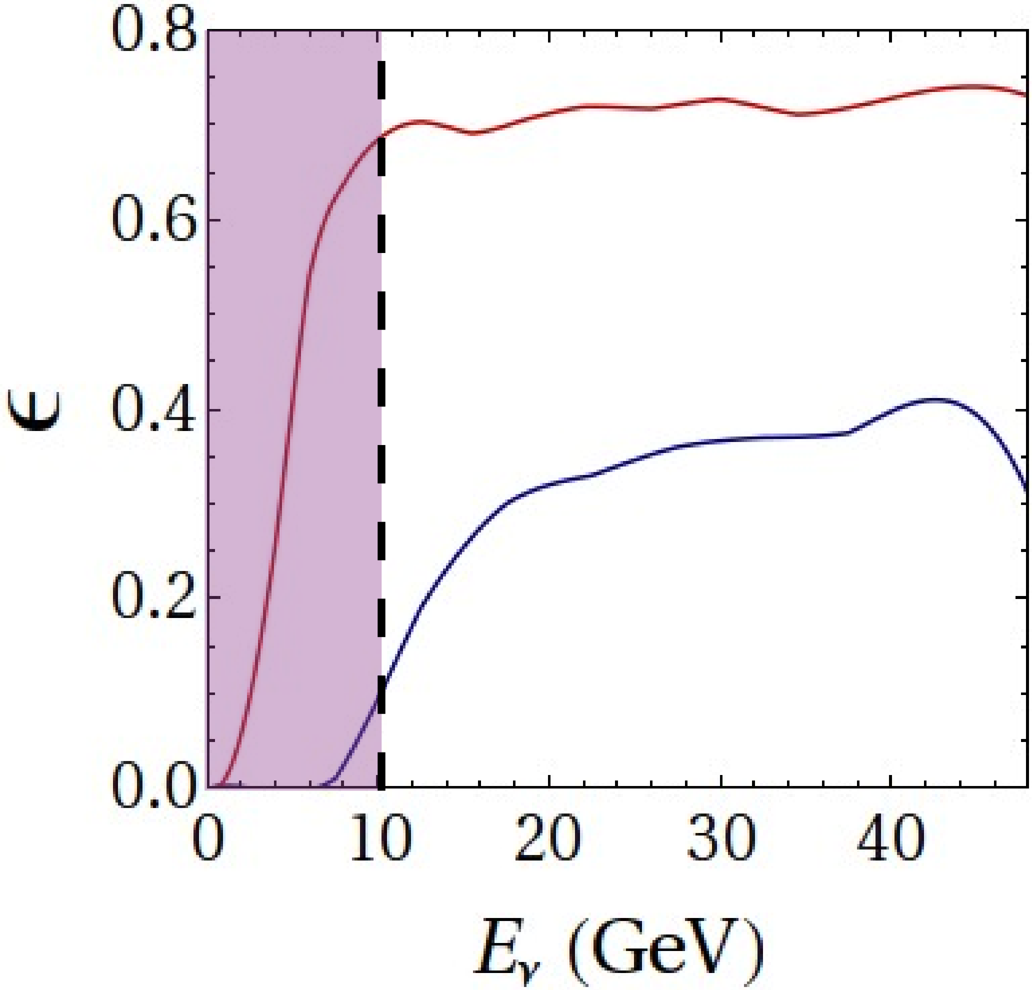
- Low energy bins will be the most affected by the tau-contamination due to spectral change after the decay
  - Efficiencies below 10 GeV are too low, so we miss the effect
- However, correlations & degeneracies appear for the 25 GeV NF.

Donini *et al*, arXiv:hep-ph/0312072

- Ways to solve them:
  - Two detectors at different baselines;
  - Wide spectral information.

MIND (new) efficiencies

Relaxing cuts, we get better efficiencies at low energies

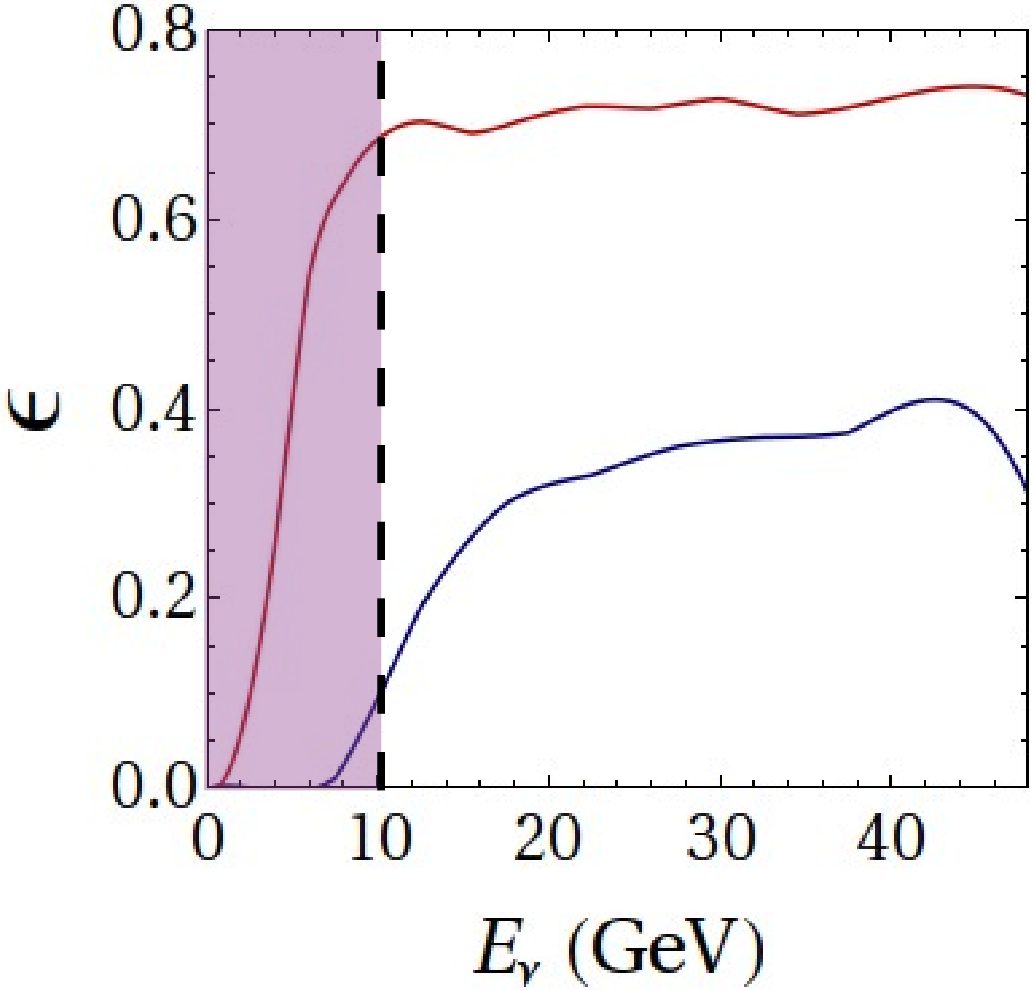


ISS Detector Report, Abe *et al*, JINST 4 (2009) T05001

MIND (new) efficiencies

Relaxing cuts, we get better efficiencies at low energies

We solve degeneracies better... But the contamination reappears!



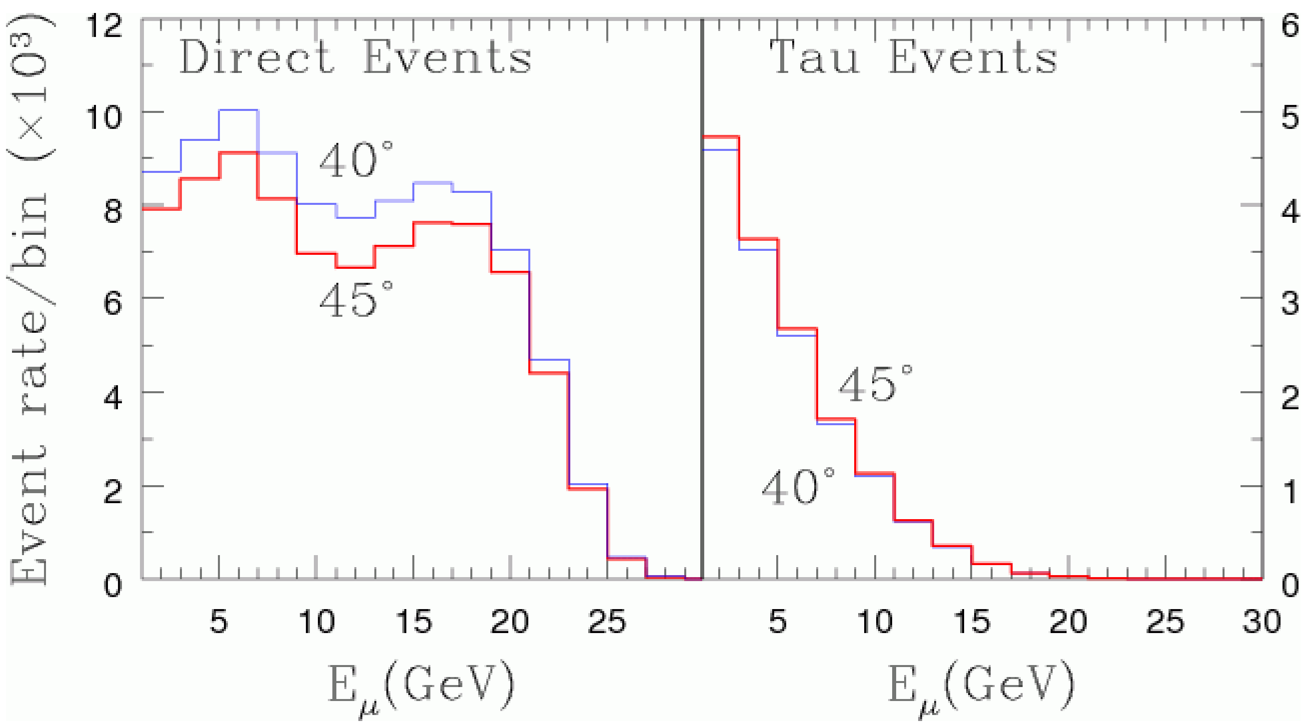
ISS Detector Report, Abe *et al*, JINST 4 (2009) T05001

Two ways to treat the problem:

1) Using the final muon energy
2) Using the reconstructed neutrino energy

Final Muon energy

- Fitting in the final muon energy:
  - Add the two samples: more signal
  - No hadronic calorimeter info: more background



Indumathi and Sinha, arXiV:0910.2020

Neutrino energy reconstruction

- Fitting in the reconstructed neutrino energy:

$$E_{\nu_\mu} \quad = \quad E_\mu + E_{hadr}$$

(Primary muons)

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$$= \overbrace{E_\mu + E_{miss}} + E_{hadr}$$

(Secondary muons)

Neutrino energy reconstruction

- Fitting in the reconstructed neutrino energy:

$$E_{\nu_\mu} = E_\mu + E_{hadr}$$ (Primary muons)

$$E_{\nu_\tau} = E_\tau + E_{hadr} =$$

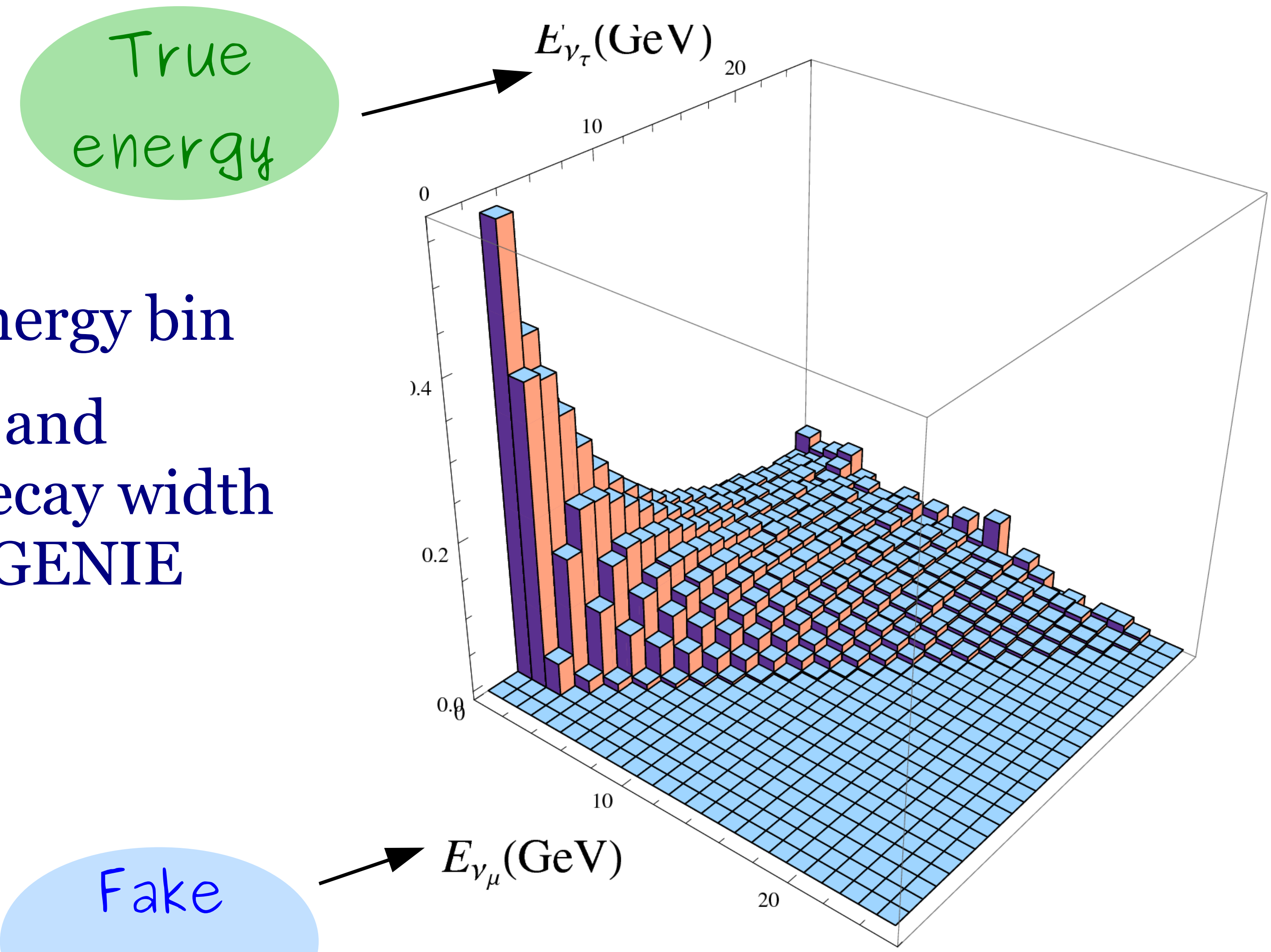
$$= \underbrace{E_\mu + \cancel{E_{miss}} + E_{hadr}}$$ (Secondary muons)

$$\text{“}E_{\nu_\mu}\text{”} = E_\mu + E_{hadr} < E_{\nu_\tau}$$

The neutrino energy is wrongly reconstructed!

Migration matrix

- 10^6 ν_τ per energy bin
- Cross section and differential decay width $\tau \rightarrow \mu$ with GENIE



Donini *et al*, arXiV:1005.2275[hep-ph]

The whole signal

- Once we have computed the migration matrix M_{ij}, we can compute theoretically the entire signal:

$$N_i^{tot} = N_i^{\mu} + \sum_j M_{ij} N_j^{\tau \to \mu}$$

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$$\left(N_i^{obs} = \epsilon N_i^{tot} \right)$$

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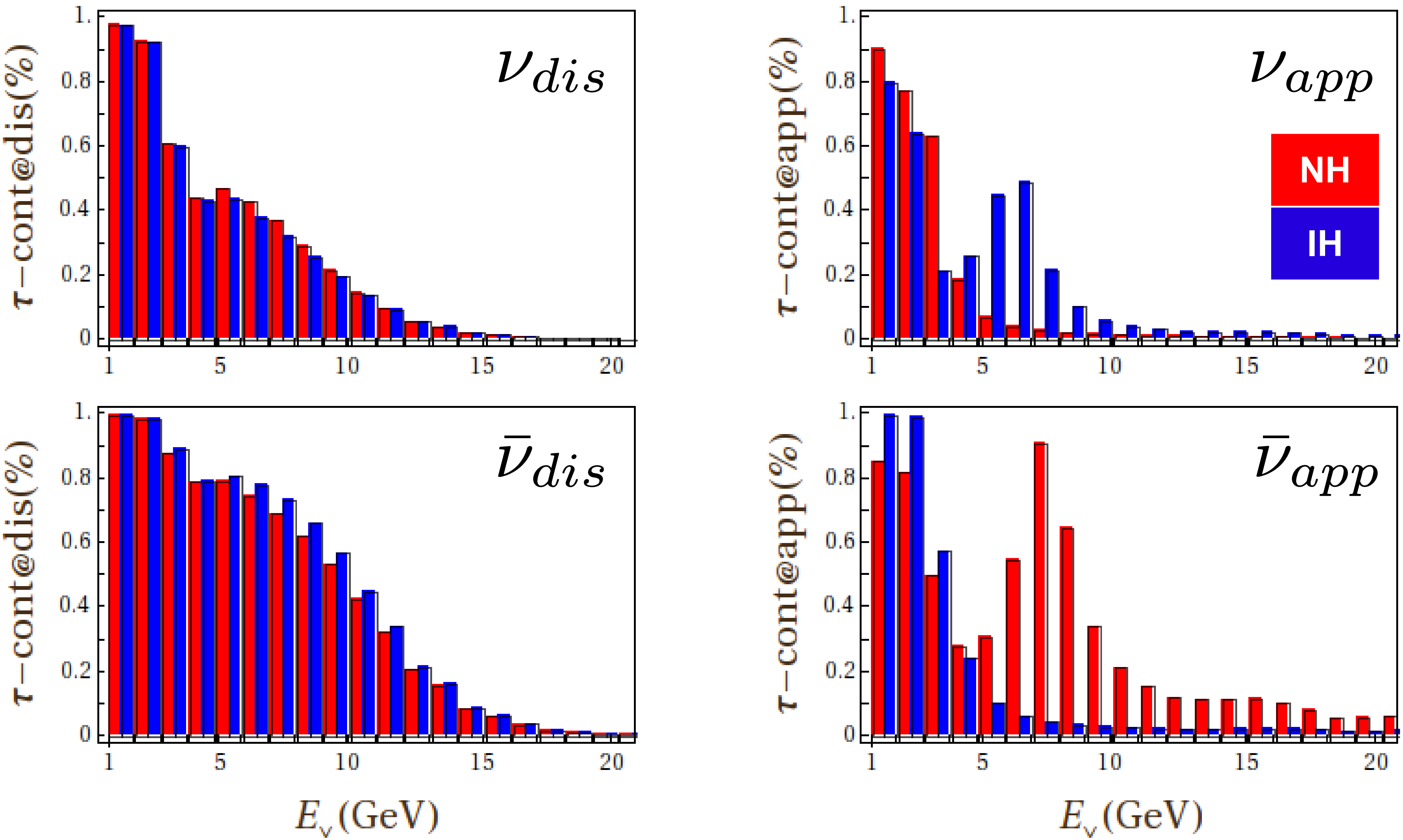
Primary muons

Migration matrix

Secondary muons

How many events will we have?

GLoBES 3.0



What if we do not take these events into account in the analysis?

Can we fit the data?

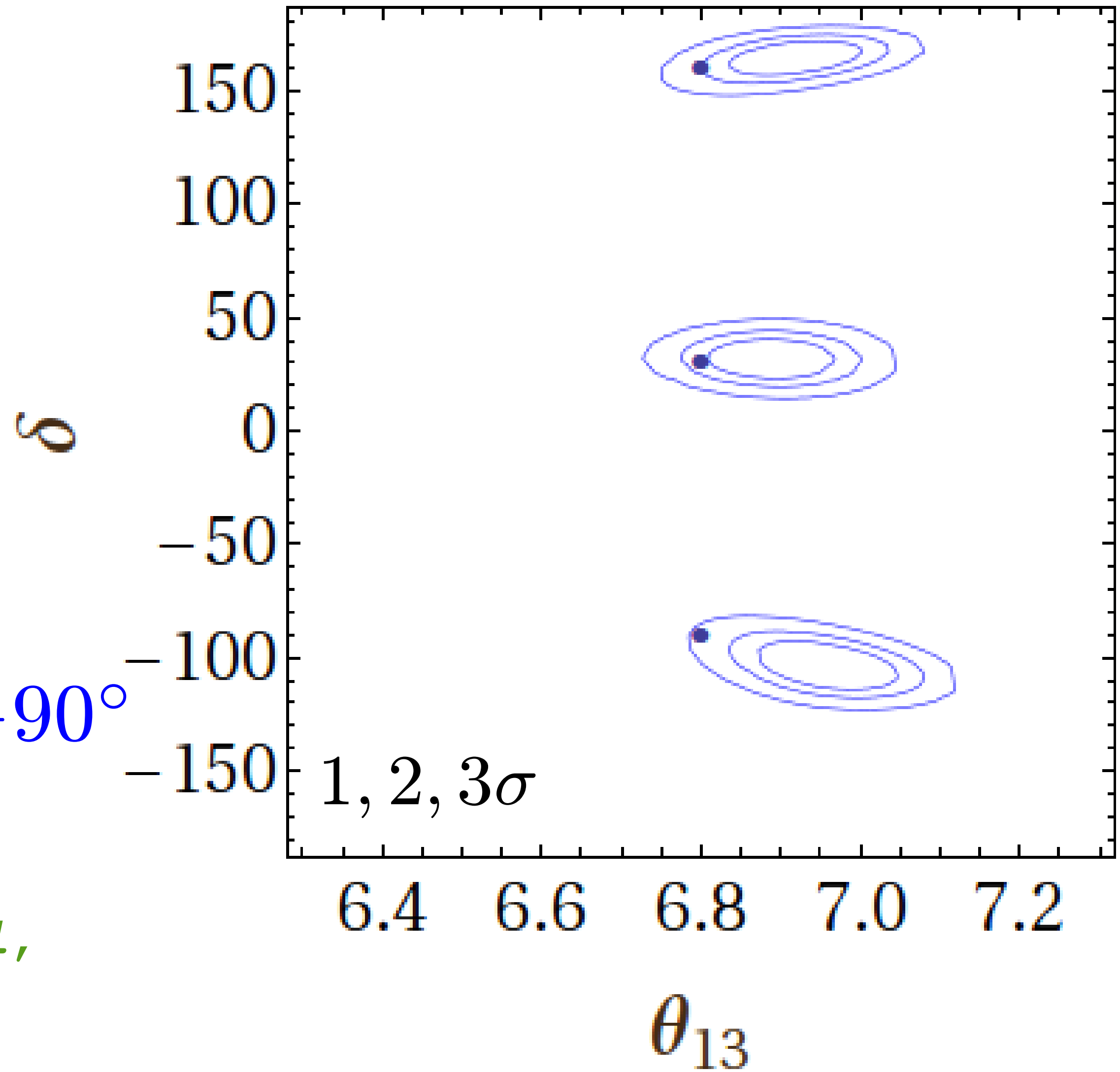
Donini *et al*, arXiV: 1005.2275 [hep-ph]

Trying to fit the data without taking the taus into account...

(no background, 2% systematics)

$$\theta_{23} = 42^\circ$$
$$\delta = 160^\circ, 30^\circ, -90^\circ$$
$$\theta_{13} = 6.8^\circ$$

M.C.Gonzalez-Garcia *et al*, arXiv:1001.4524 [hep-ph])



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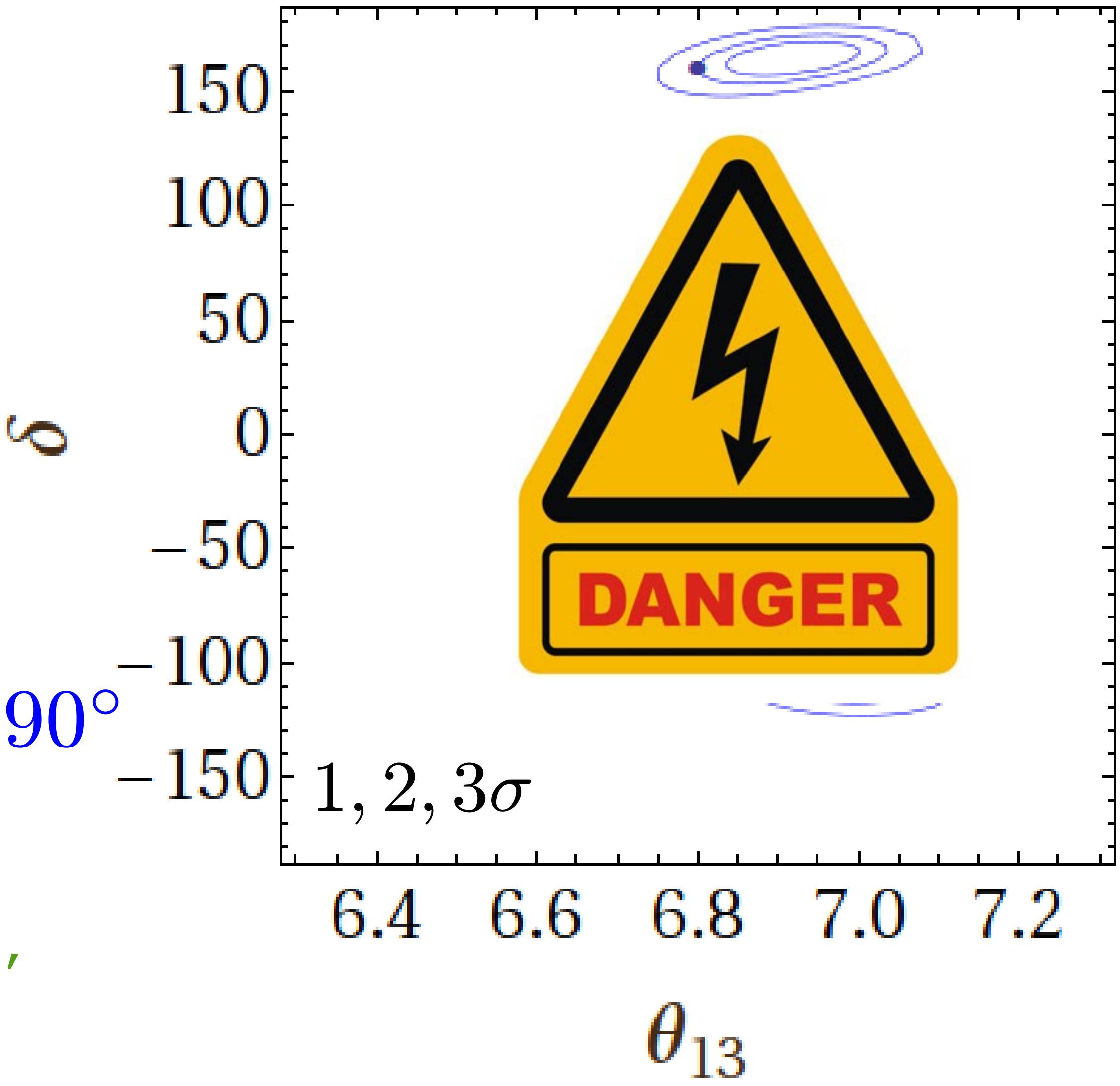
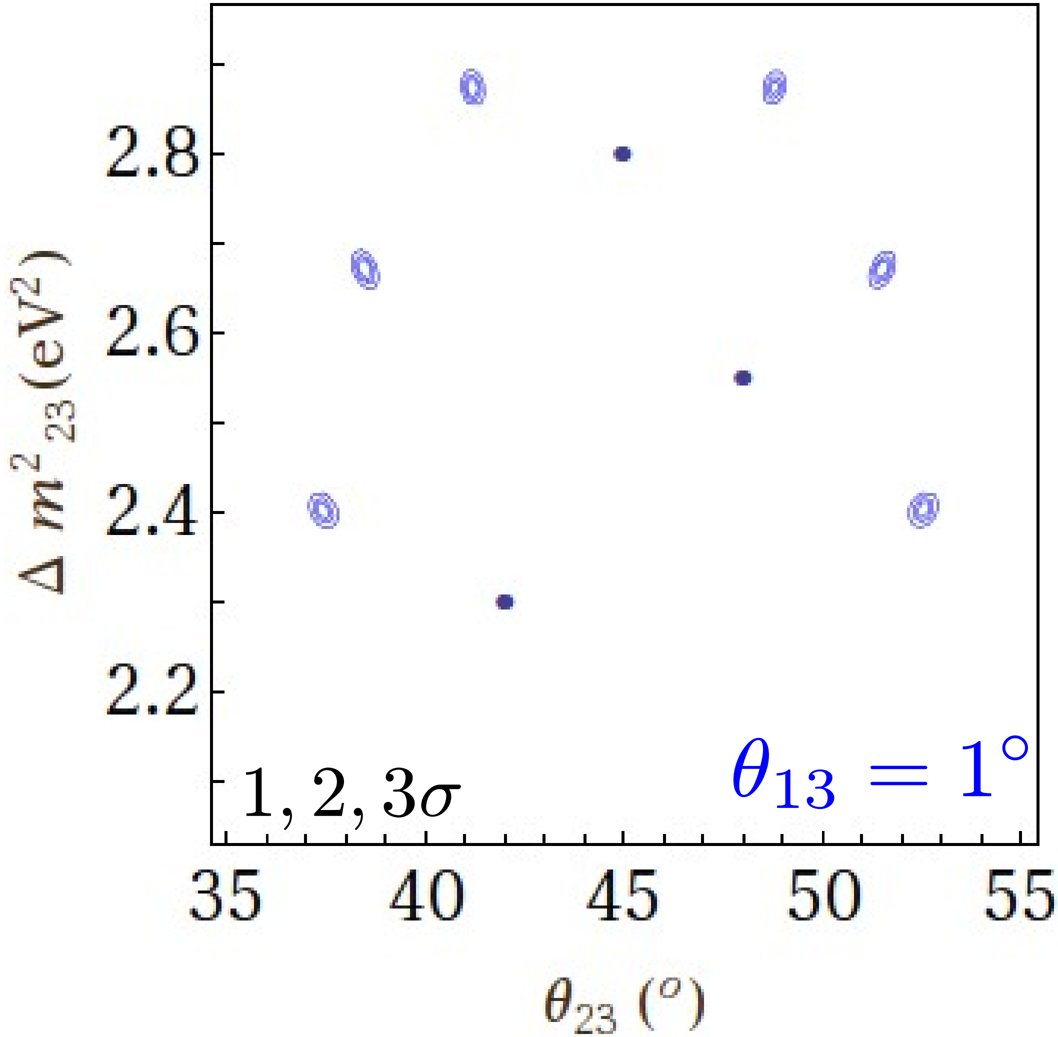


Can we fit the data?

In disappearance, the situation is much worse due to larger statistics…

(no background, 2% systematics)



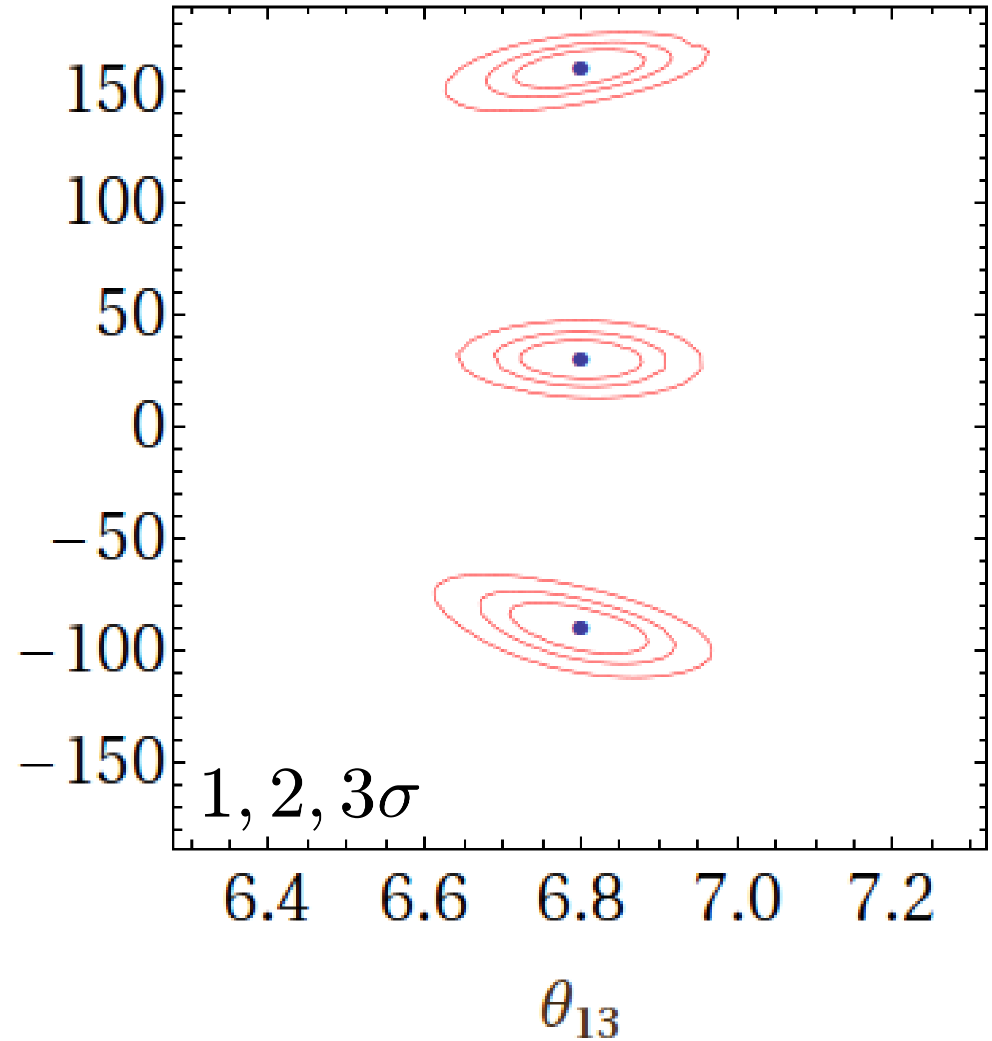
PC, A. Donini, J. J. Gomez Cadenas, D. Meloni, in preparation

Ok, this doesn't seem to be working...

Let's take taus into account!

Can we fit the appearance data?

Donini *et al*, arXiV: 1005.2275 [hep-ph]



Fitting the data including the events coming from true contamination

(no background, 2% systematics)

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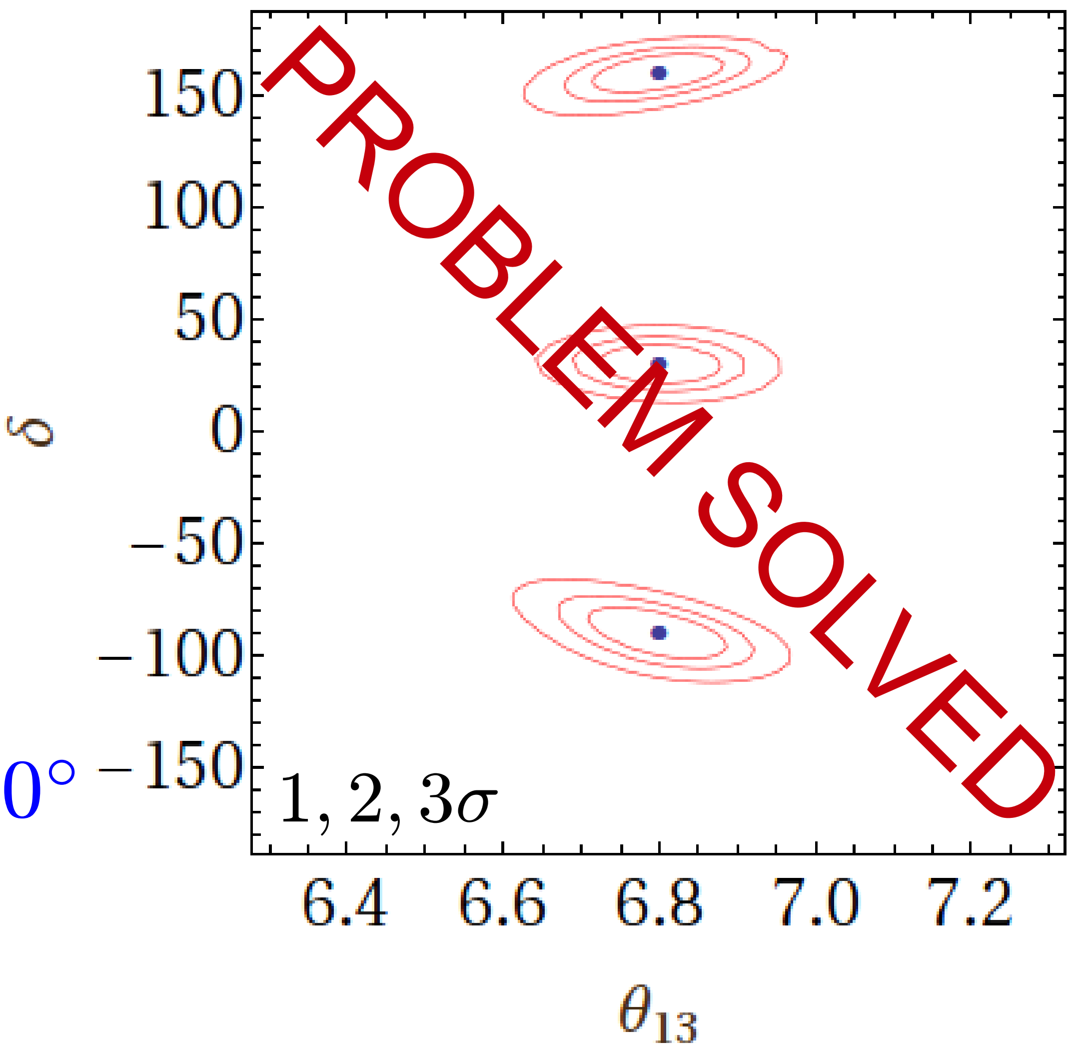
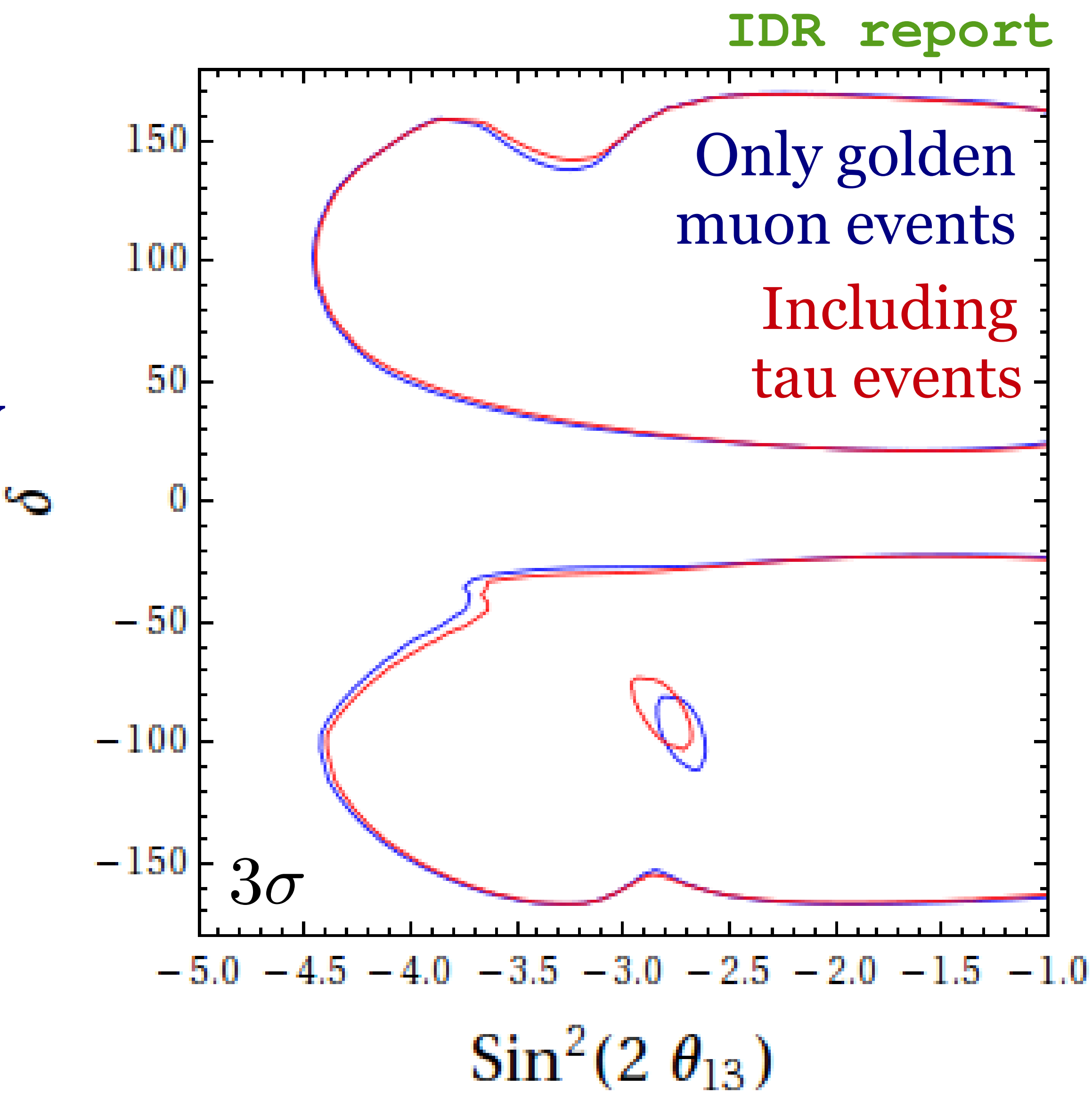
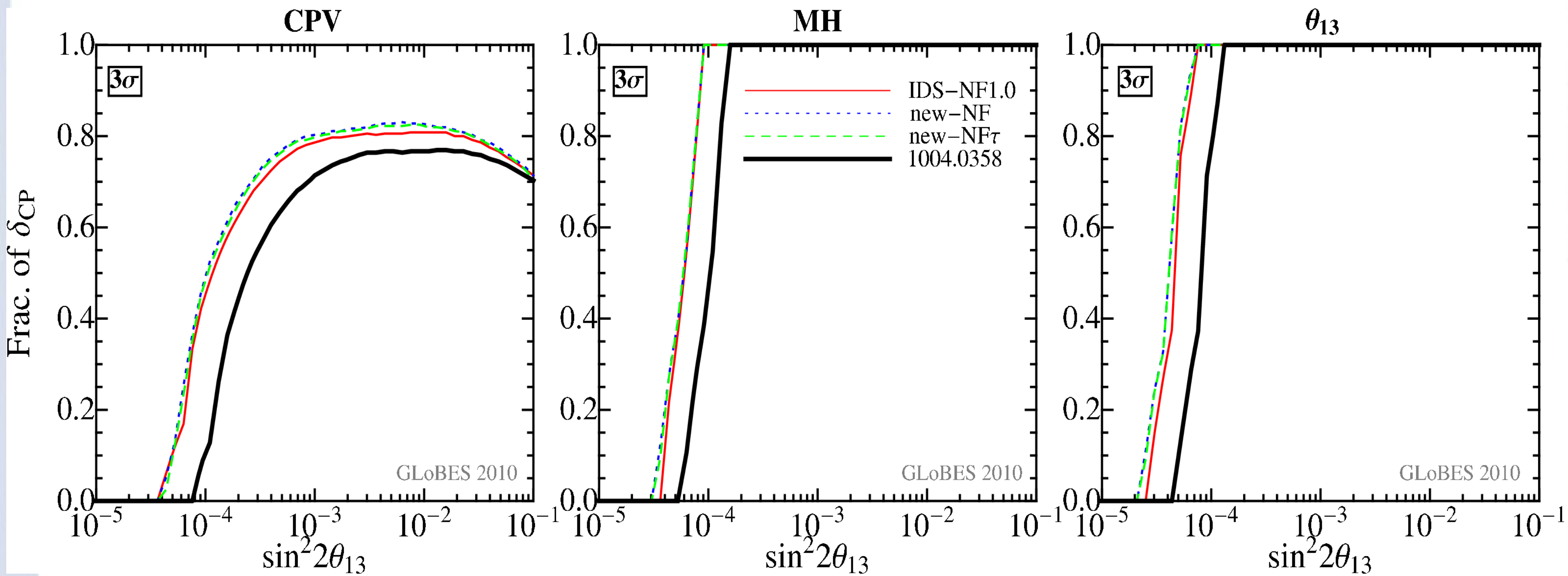


CP discovery potential

Mild effect on CP violation discovery potential



Standard observables



Huber *et al*, arXiv:1012.1872

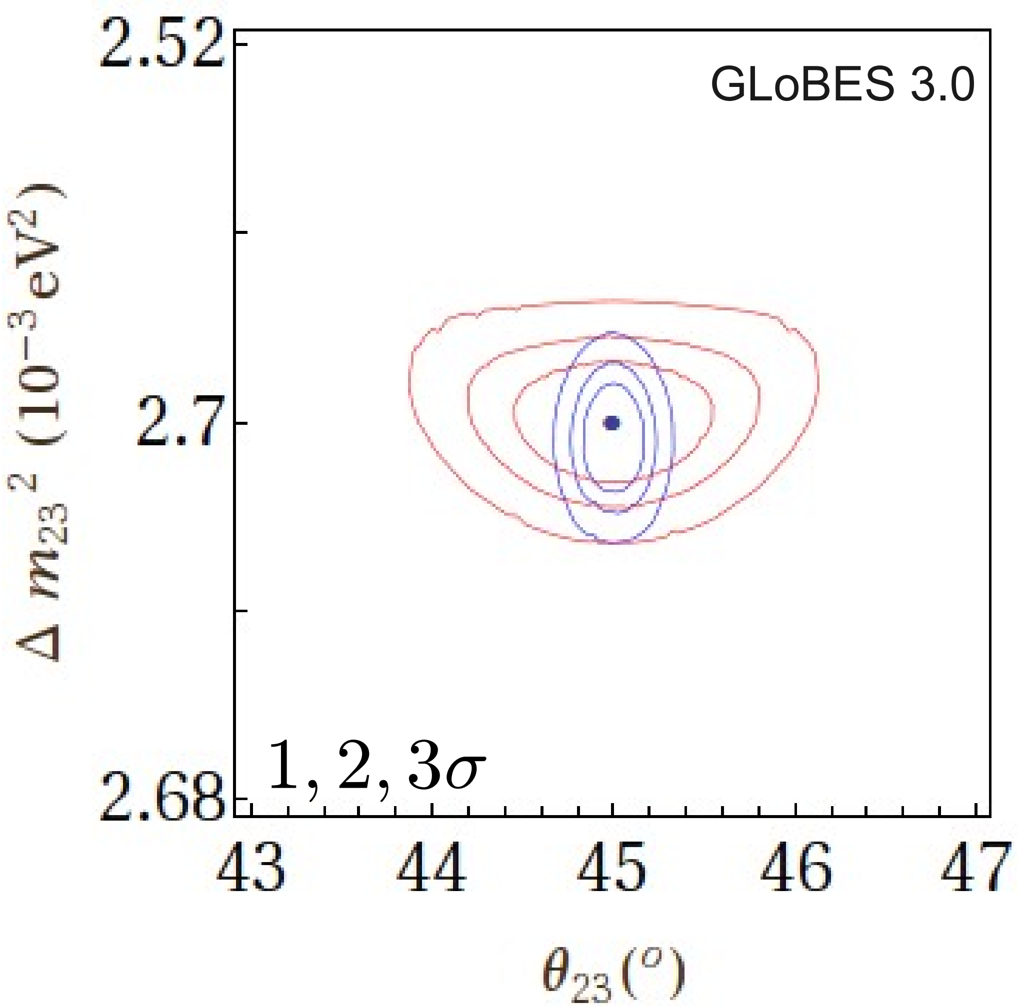
The standard observables in the golden sector remain unaffected. ✓

For disappearance…not so easy!

Consequences in disappearance

The precision measurement on atmospheric parameters is lost

(Backgrounds and systematics included)



PC, A. Donini, J. J. Gomez Cadenas, D. Meloni, in preparation

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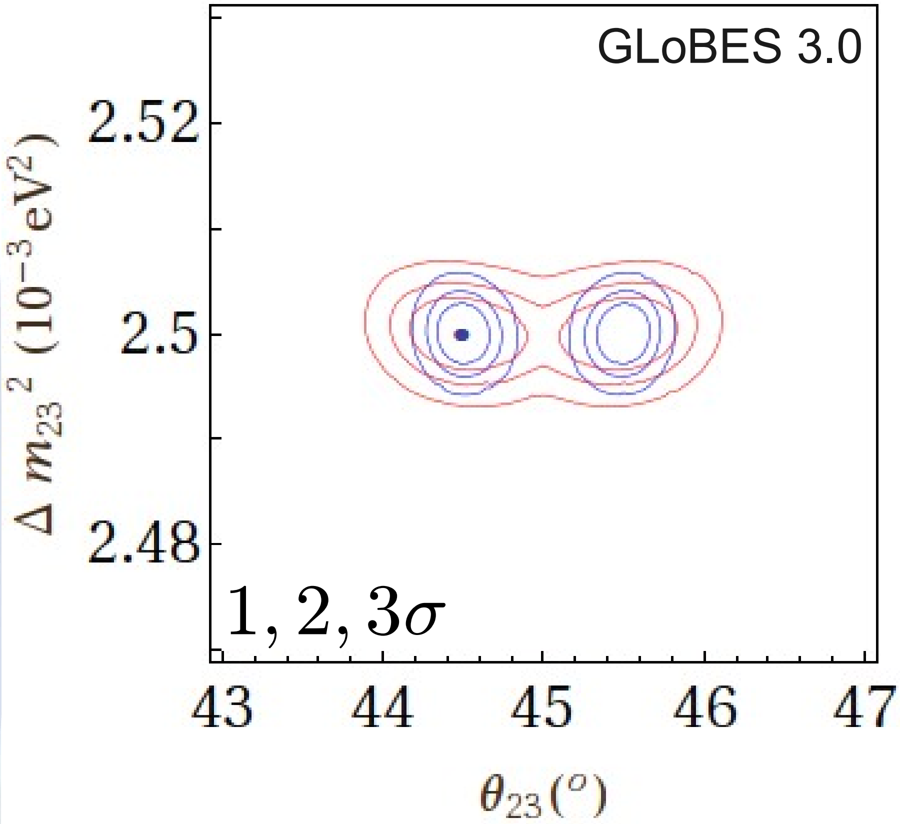
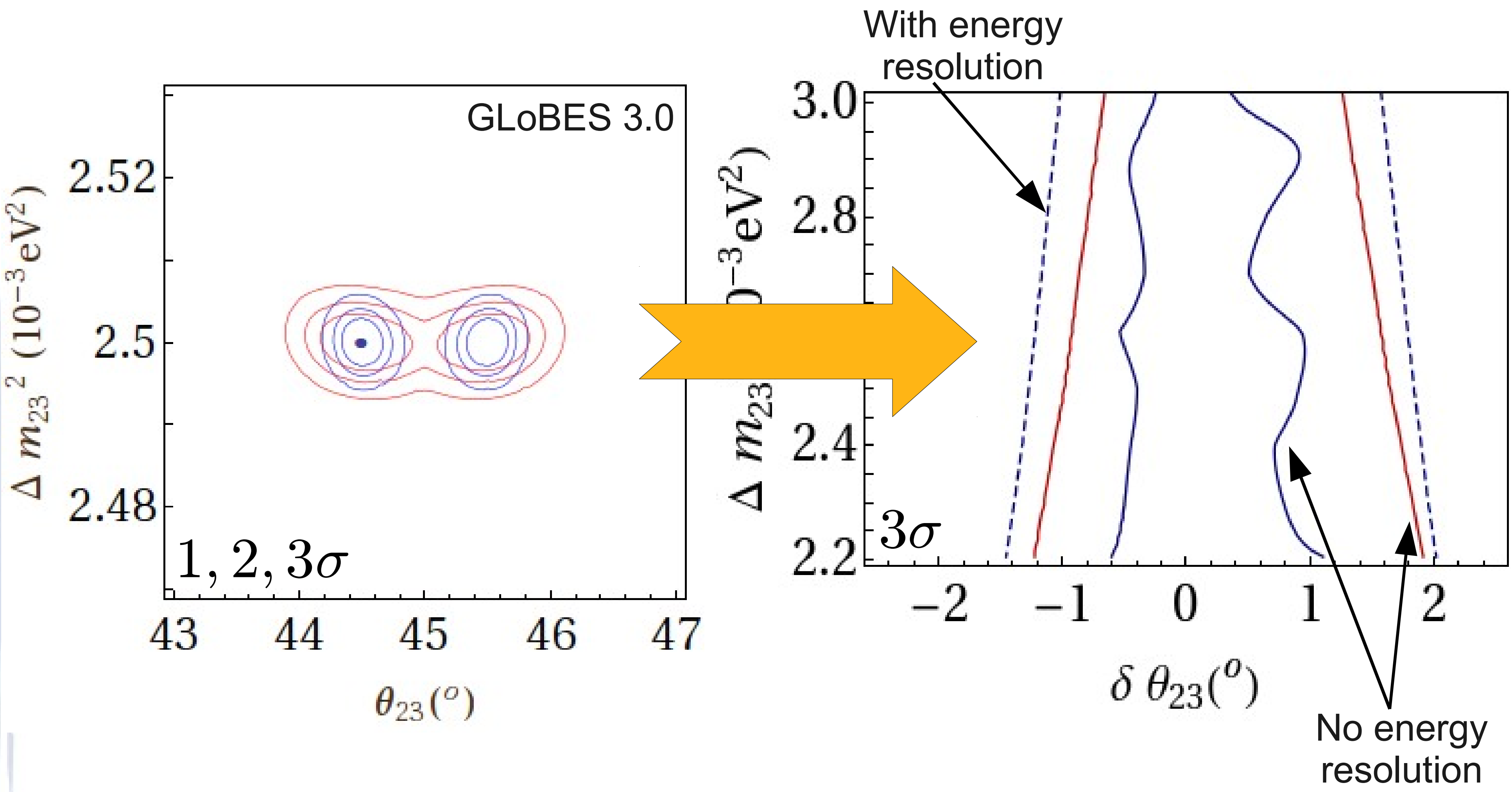


Precision losses affect our ability to distinguish maximal mixing

PC, A. Donini, J.J. Gomez Cadenas, D. Meloni, in preparation

Consequences in disappearance



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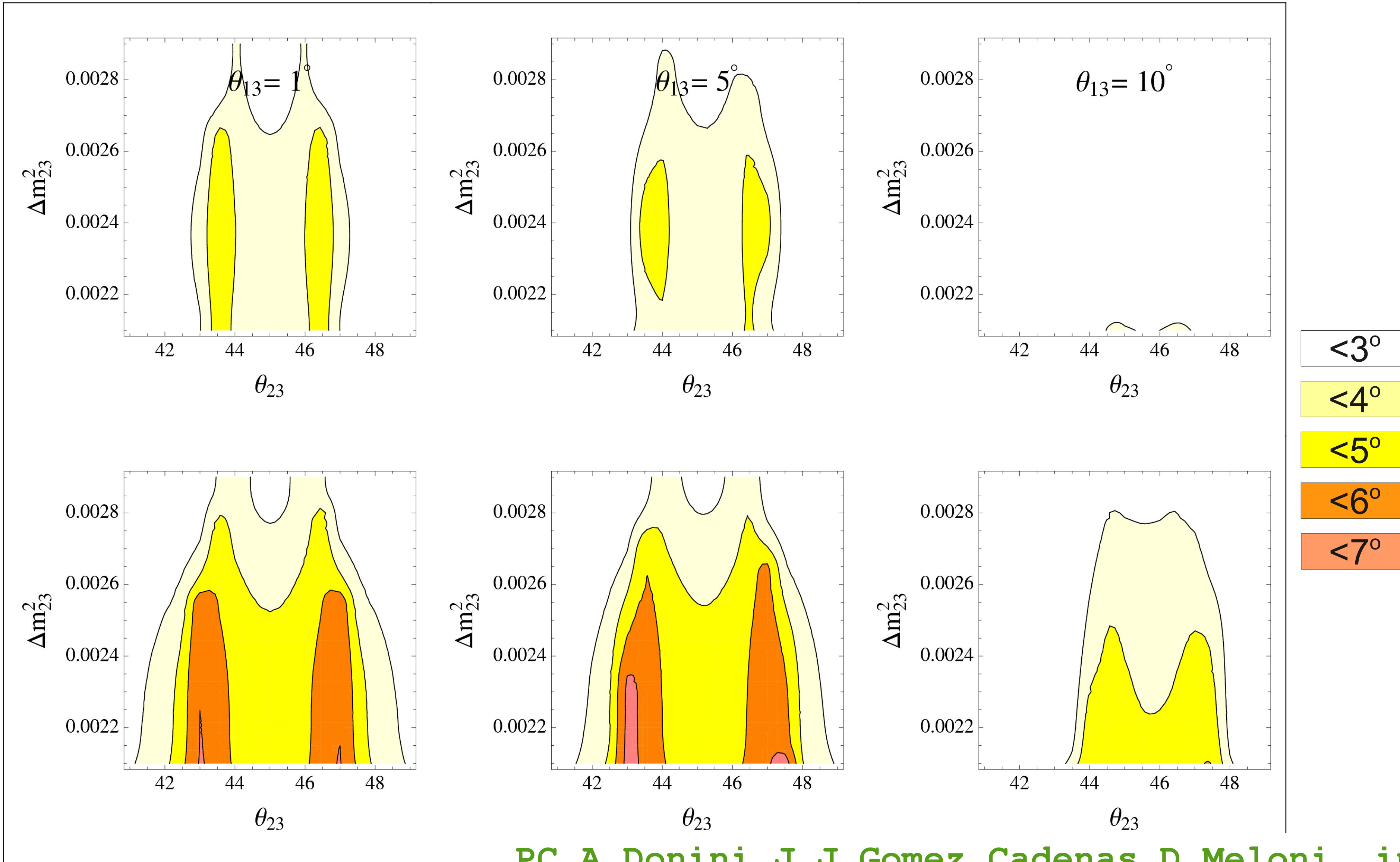
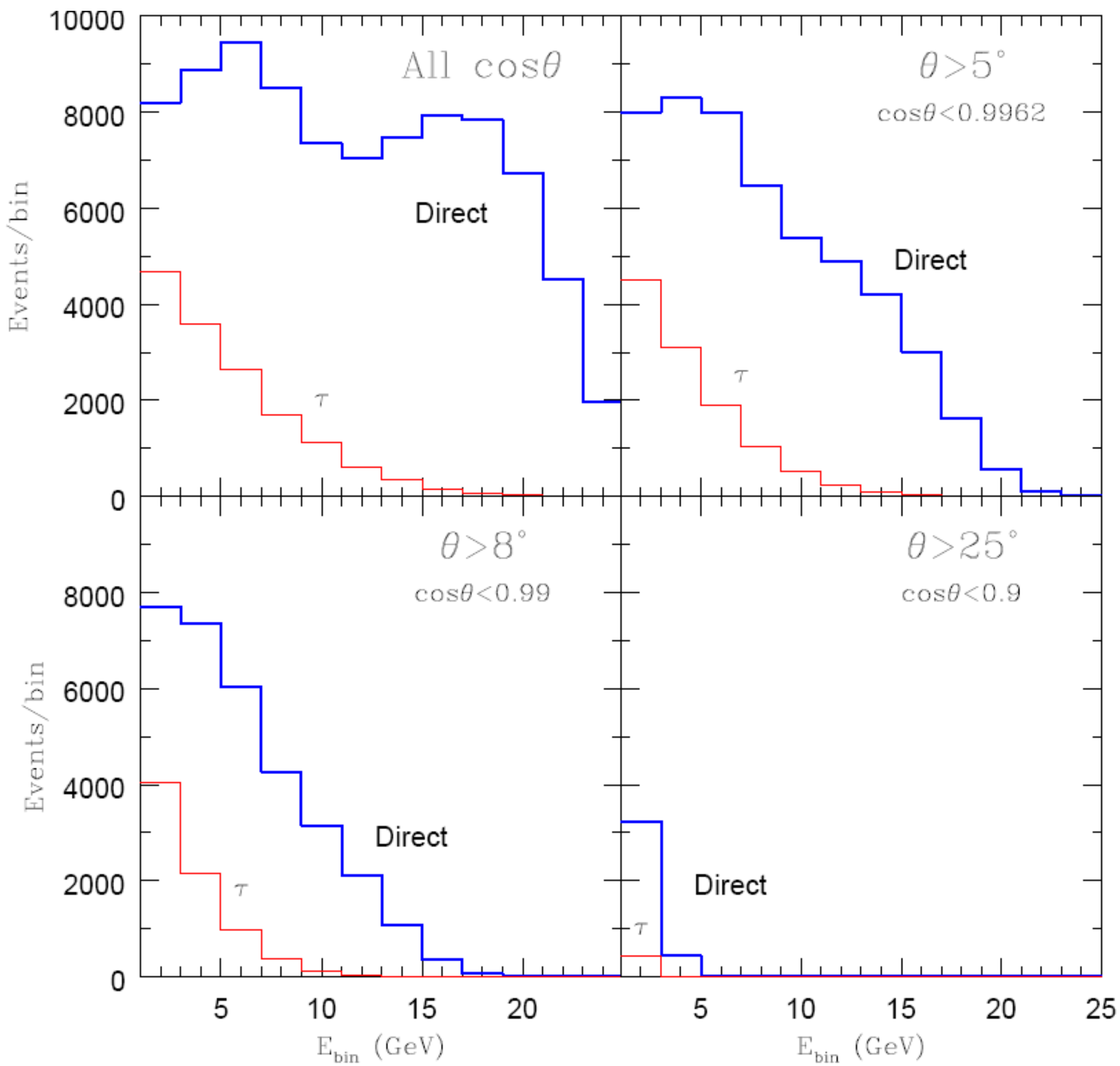


PC, A.Donini, J.J.Gomez Cadenas, D.Meloni, in preparation

Consequences in disappearance

Angular/energy cuts kill the signal without effectively reducing the contamination!



Indumathi and Sinha, arXiv:0910.2020

Conclusions

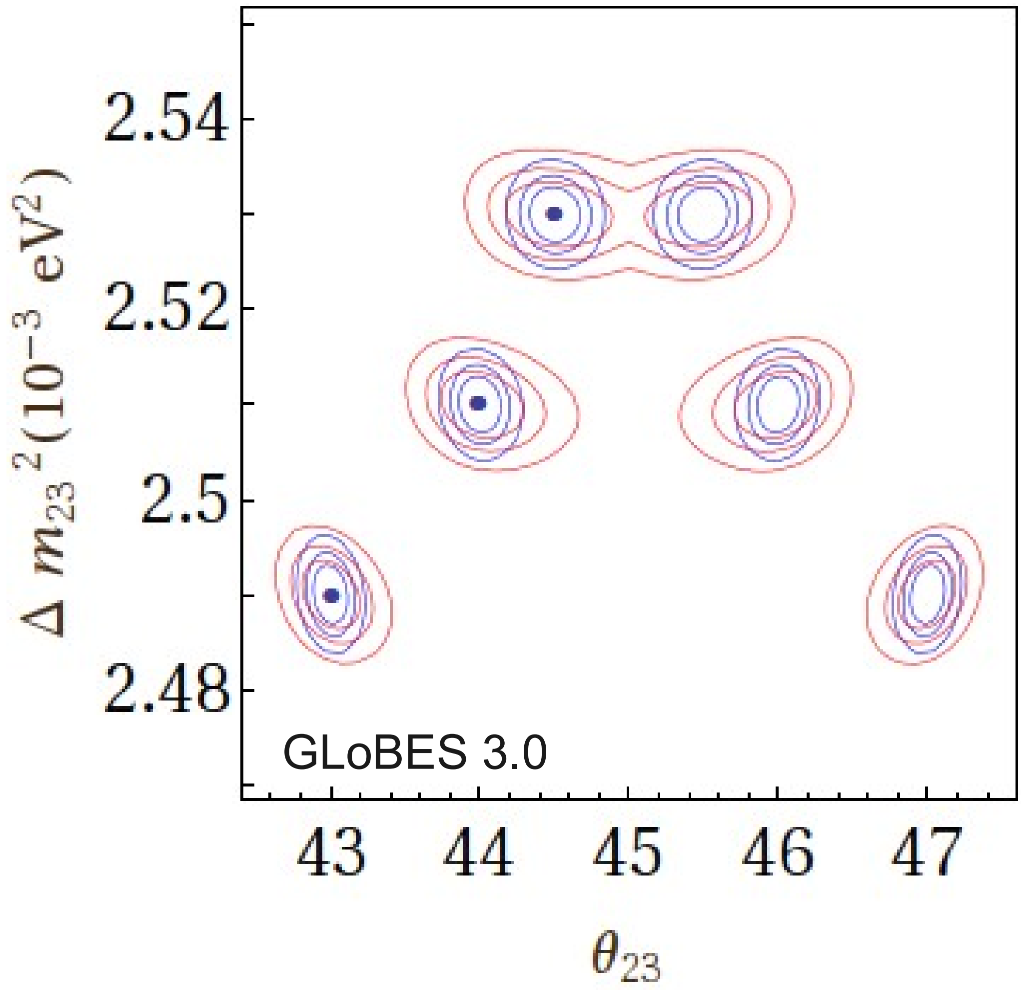
- The tau-contamination is a relevant problem at the Nufact
  - With a proper detector, separate signal itself
  - Lower energy bins are mostly affected (30-60% in appearance; 50%-90% in disappearance)
- Migration matrix solves it in appearance: no further consequences
- In disappearance, precision measurements are lost for atmospheric parameters
  - No possible cuts in E without killing the signal too
  - Maybe some cuts in Pt could be used (?)

BACKUP

Consequences in disappearance

The precision measurement on atmospheric parameters is lost

(Backgrounds and systematics included)



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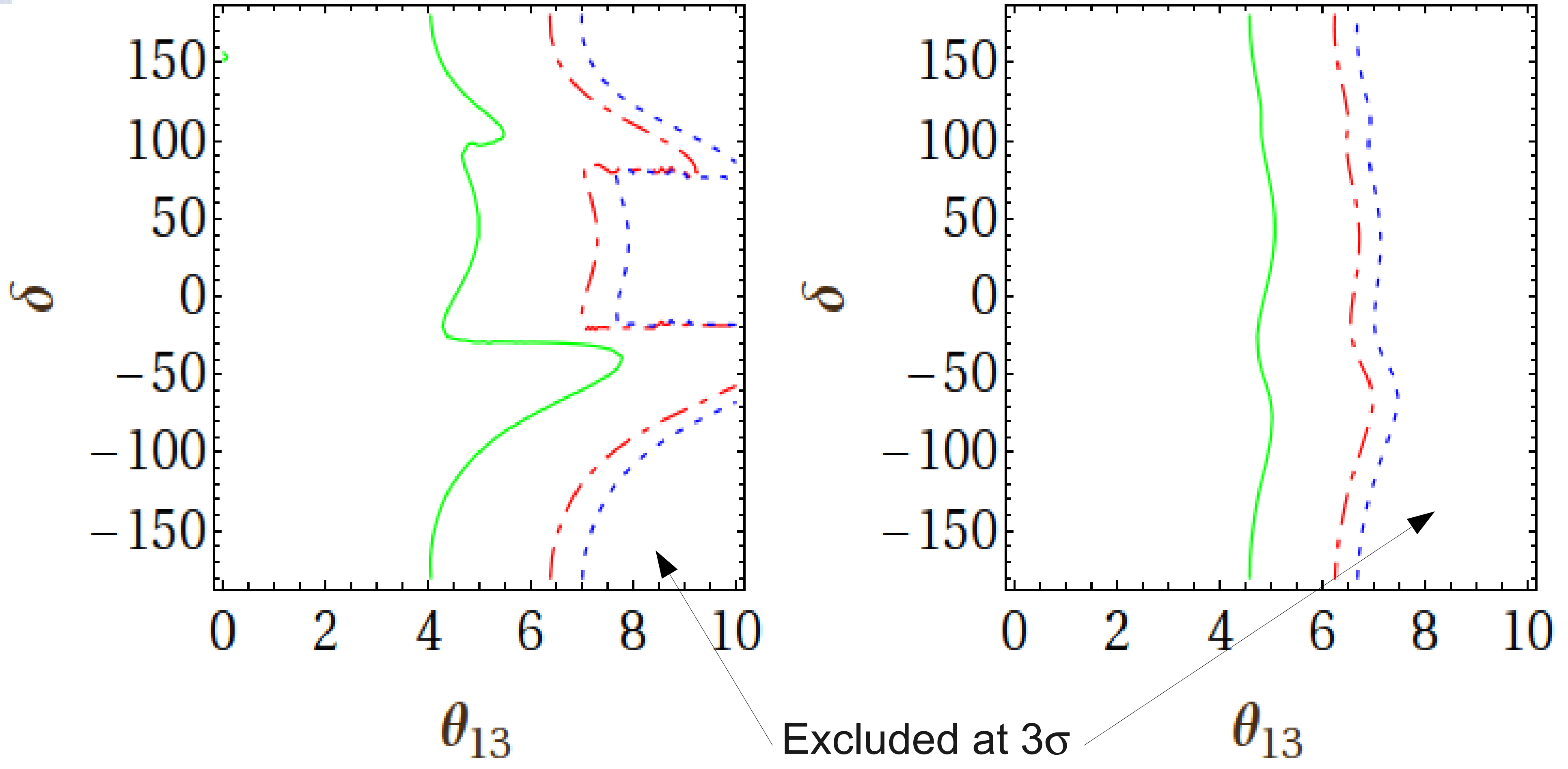
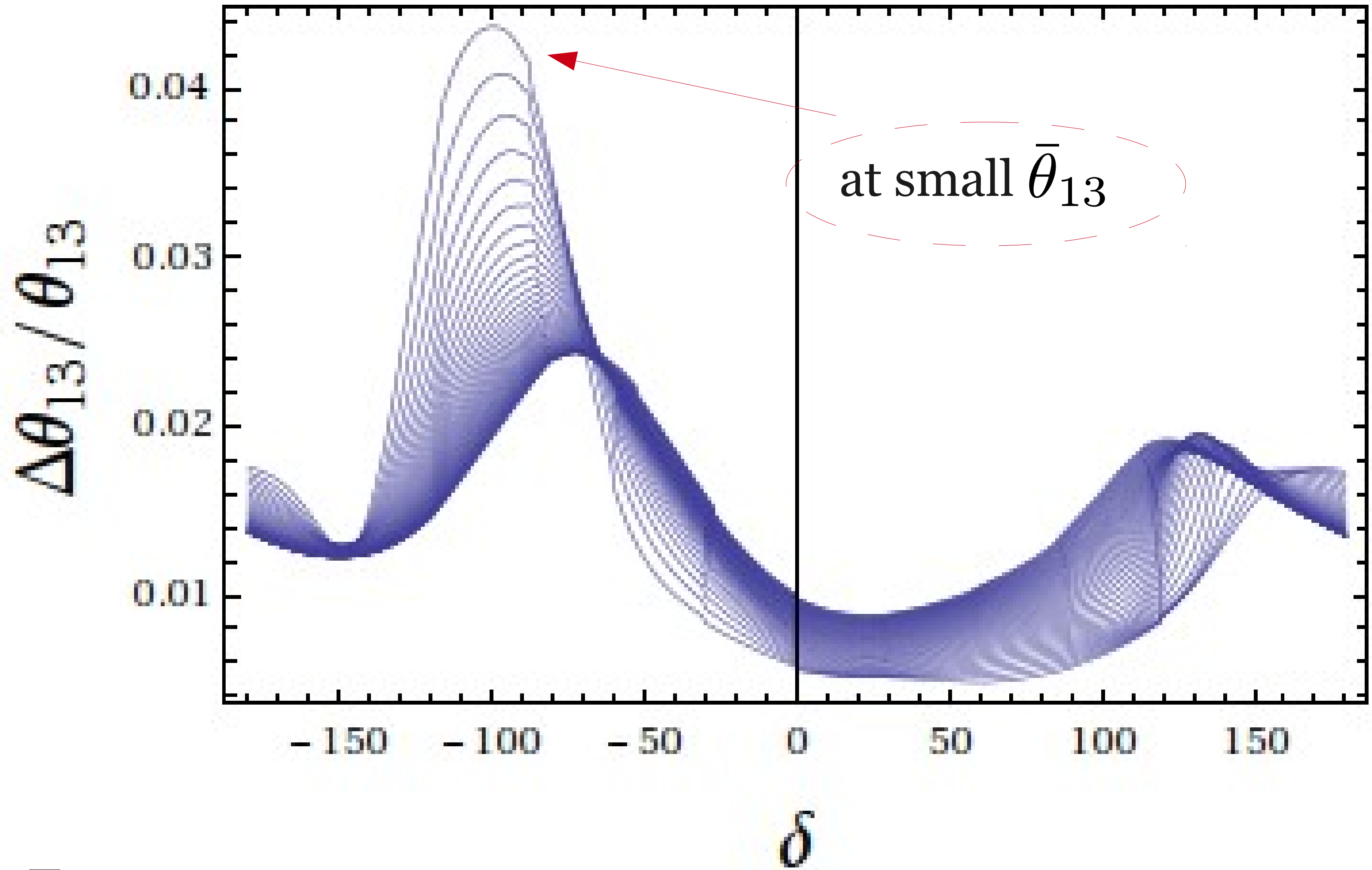
Can we fit the data?



L=4000 km

L=4000+7500 km

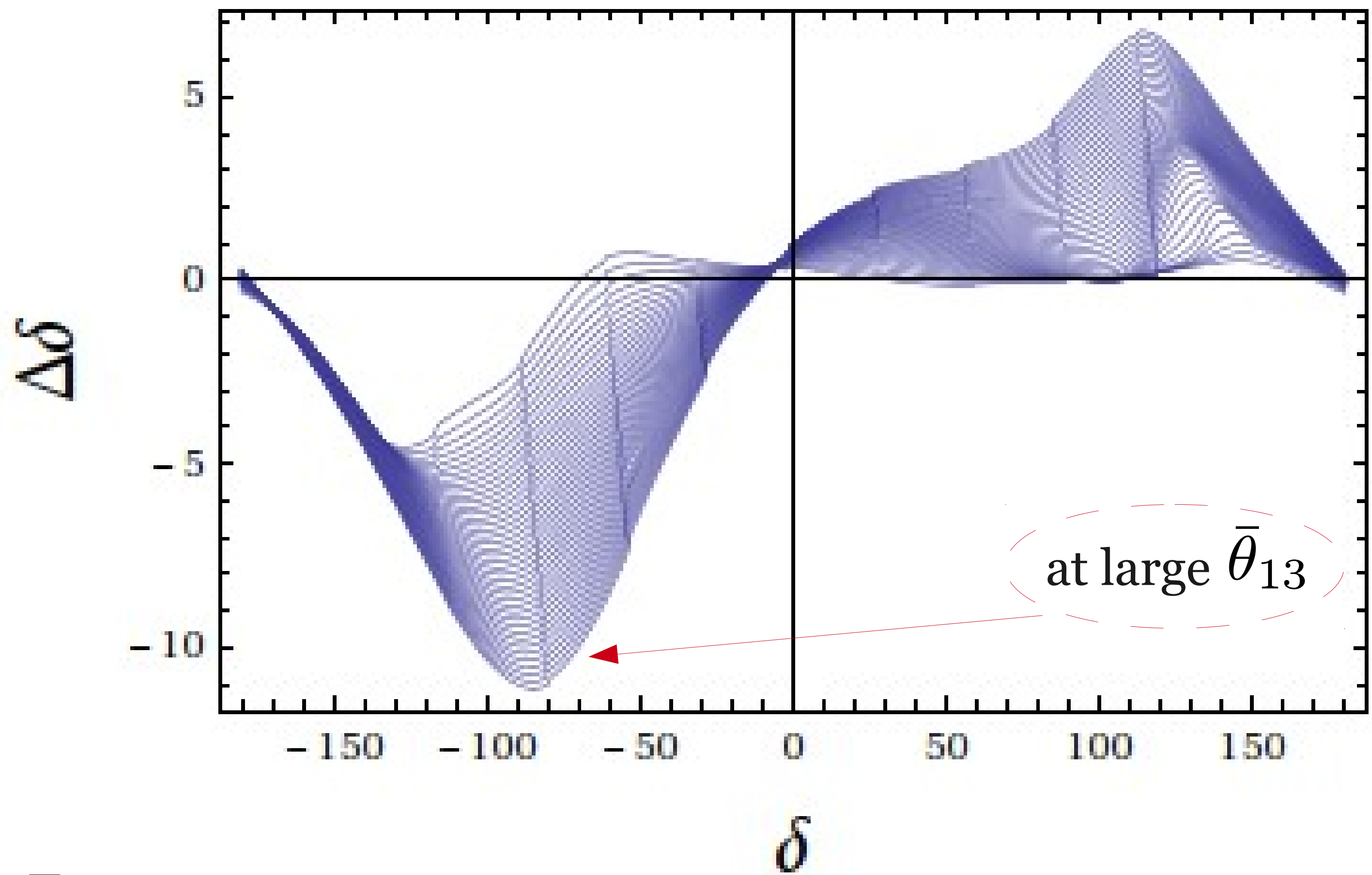
Shift in best-fit values in θ_{13}



$\bar{\theta}_{13} \in [1^\circ, 5^\circ]$

L=4000+7500 km

Shift in best-fit values in δ



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