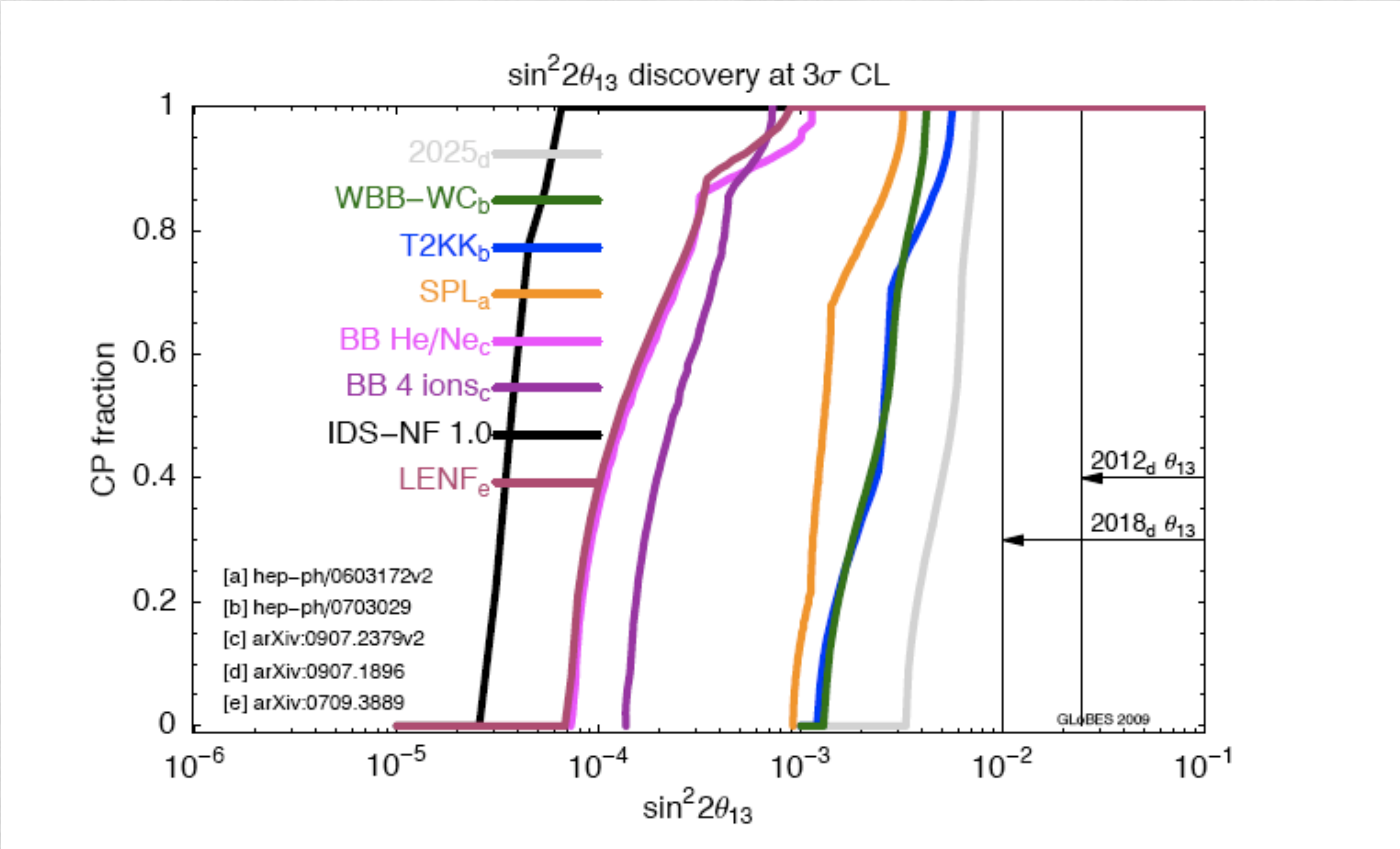
WP6 SUMMARY

Andrea Donini, IFT (UAM/CSIC) & IFIC (UV/CSIC)

PRIMARY WP6 ACTIVITY

- Our primary role in EUROnu is the comparison of the physical performances of all the facilities, with updates as soon as new inputs are available
- Latest comparison available in the arXiv can be found in the WP6 2009 Yearly Report, arXiv:1005.3146
- Comparisons are usually shown in terms of sensitivity to θ_{13}, δ and to the mass hierarchy (preferred observables, chosen at ISS)

MIXING ANGLE



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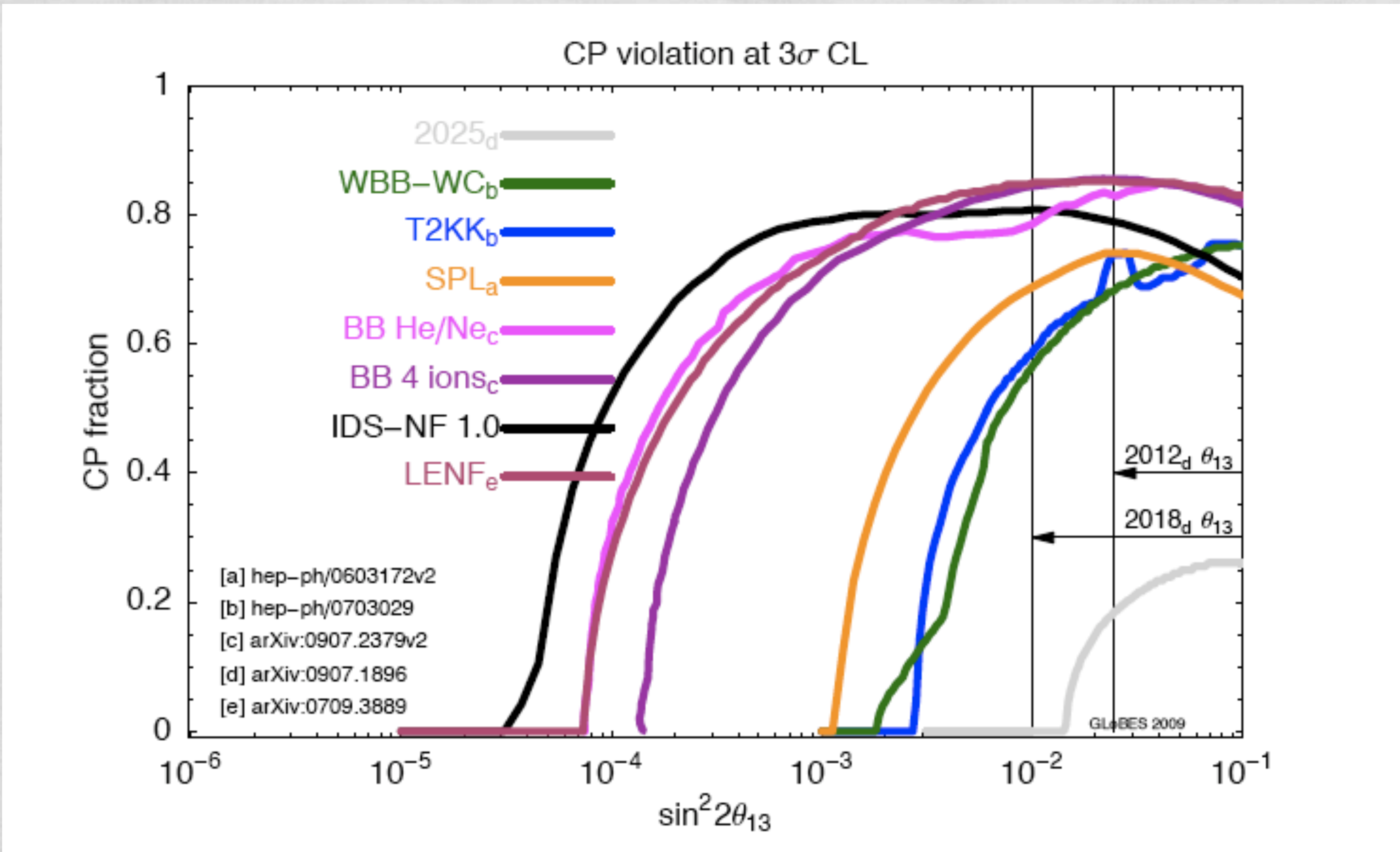
CP VIOLATING PHASE



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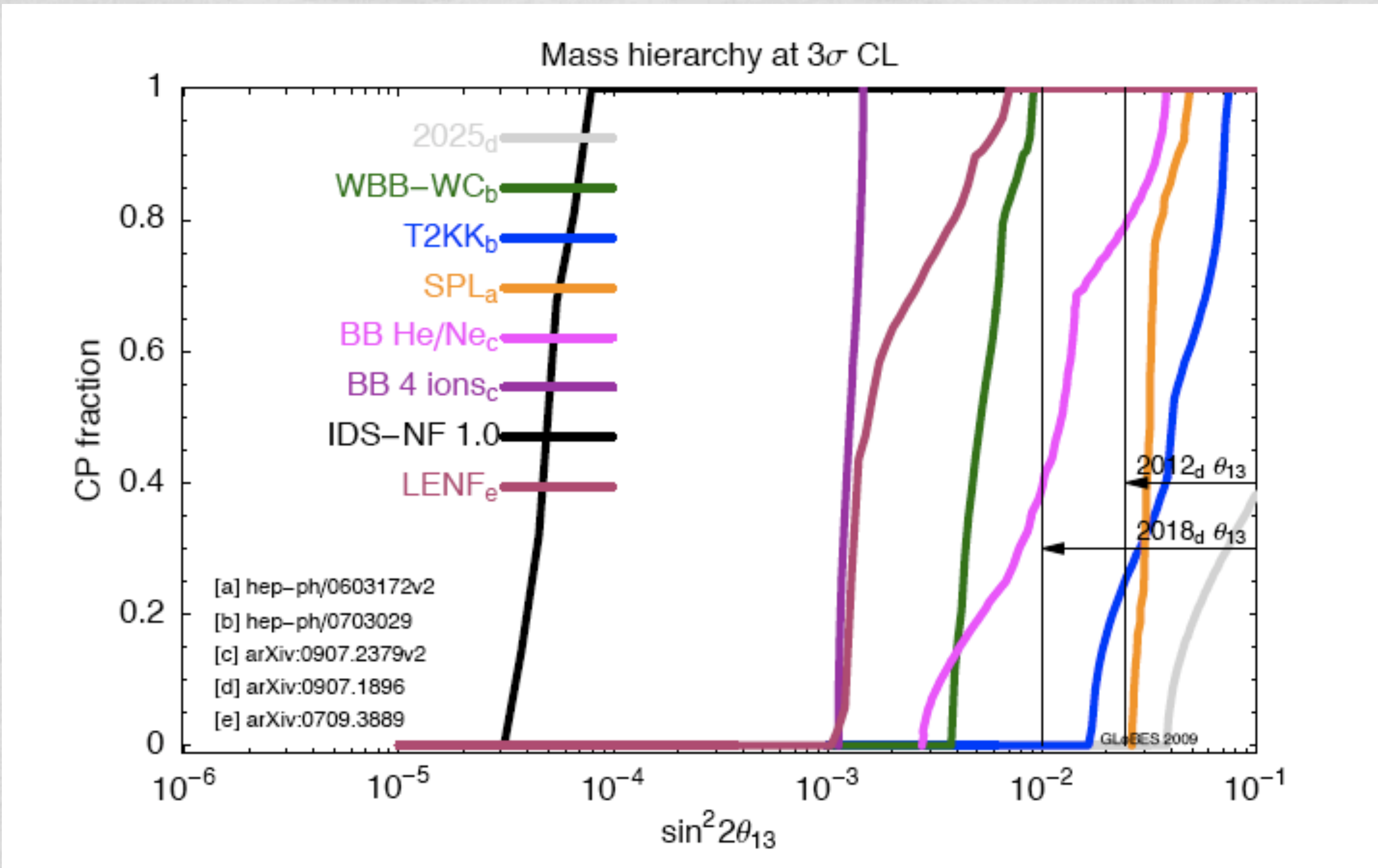
MASS HIERARCHY



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ONCOMING MILESTONES

Unified treatment of systematics (end of 2009!)

we had a very lively discussion on wednesday joint with WP5 (scheduled 20 minutes, lasted 1 hour)

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the hope is to get some "realistic" inputs for Li and B fluxes, to replace the present educated guesses on the amount of storable ions

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Impact of flavour physics measurements (end of 2010)

some work done within the WP in the context of searches for new physics beyond standard three-family oscillations

SYSTEMATIC ERRORS, I

- Input from WPs other than WP6:
  - NF and BB fluxes: $\Phi = \Phi(N,\delta\varphi,P,E)$
  - Cross-sections: $\sigma(E_i) \rightarrow \sigma(E,\{\alpha_k\})$ with $k << N_{bins}$
    (some discussion regarding if they must be the same used to compute effs or not; the answer is no)
  - these new parameters could be fitted by GLOBES, together with oscillation parameters
- For Super-Beams, the strategy should be different (T2K-like)

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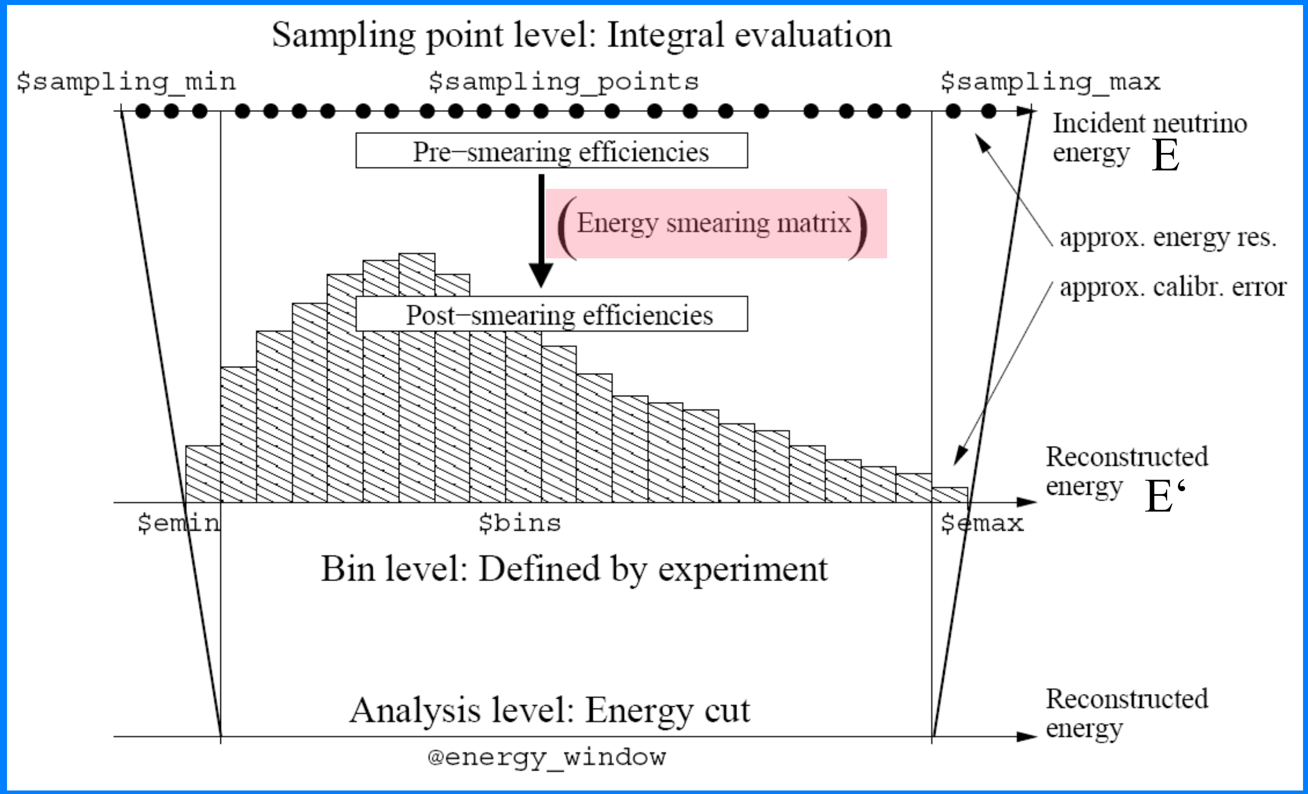
SYSTEMATIC ERRORS,2

- The second step is the replacement of efficiencies and backgrounds by migration (or response) matrices for the signal and the backgrounds (up to 6, with at least 2 negligible)
- GLOBES is prepared for this

On energy smearing



(GLoBES manual)

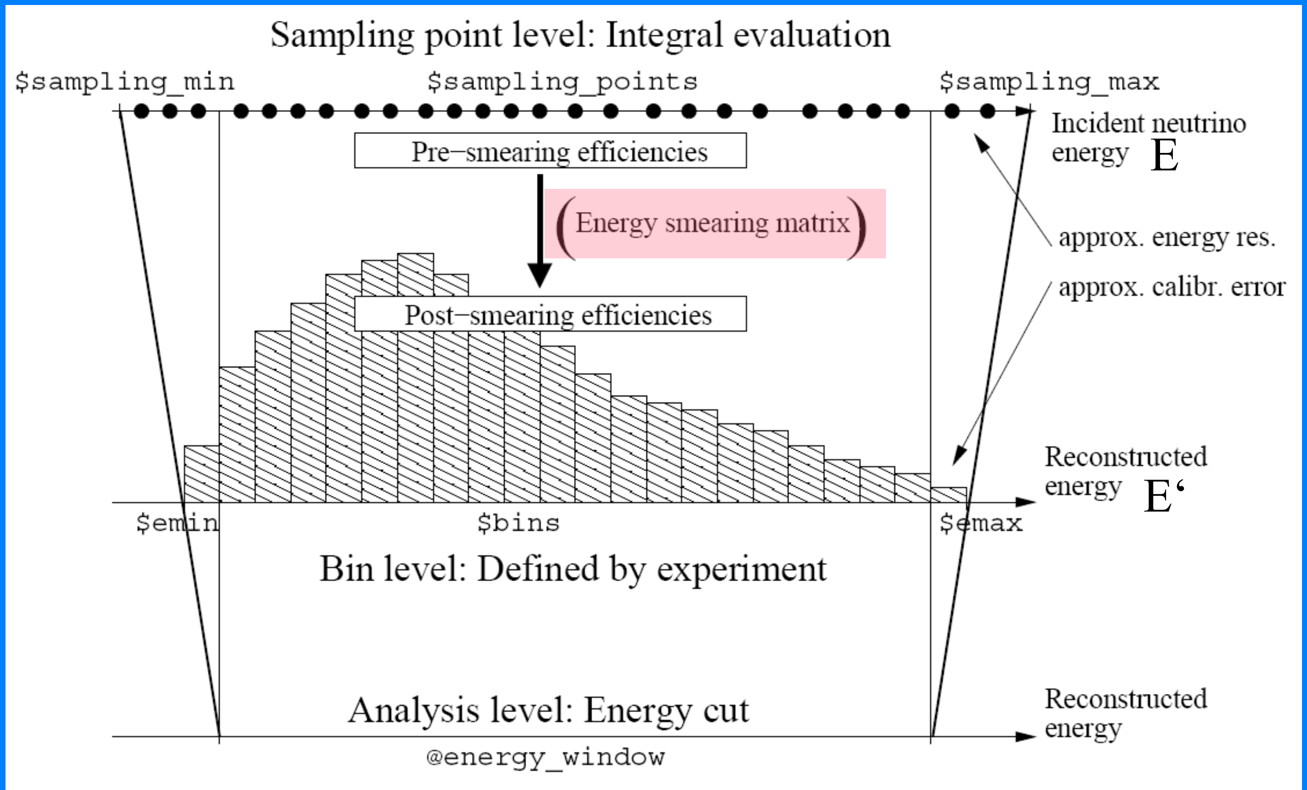
W. Winter, this meeting

On energy smearing

- Automatic energy smearing, e.g.,

$$R^c(E, E') = \frac{1}{\sigma(E)\sqrt{2\pi}} e^{-\frac{(E-E')^2}{2\sigma^2(E)}}$$

$$\sigma(E) = \alpha \cdot E + \beta \cdot \sqrt{E} + \gamma$$



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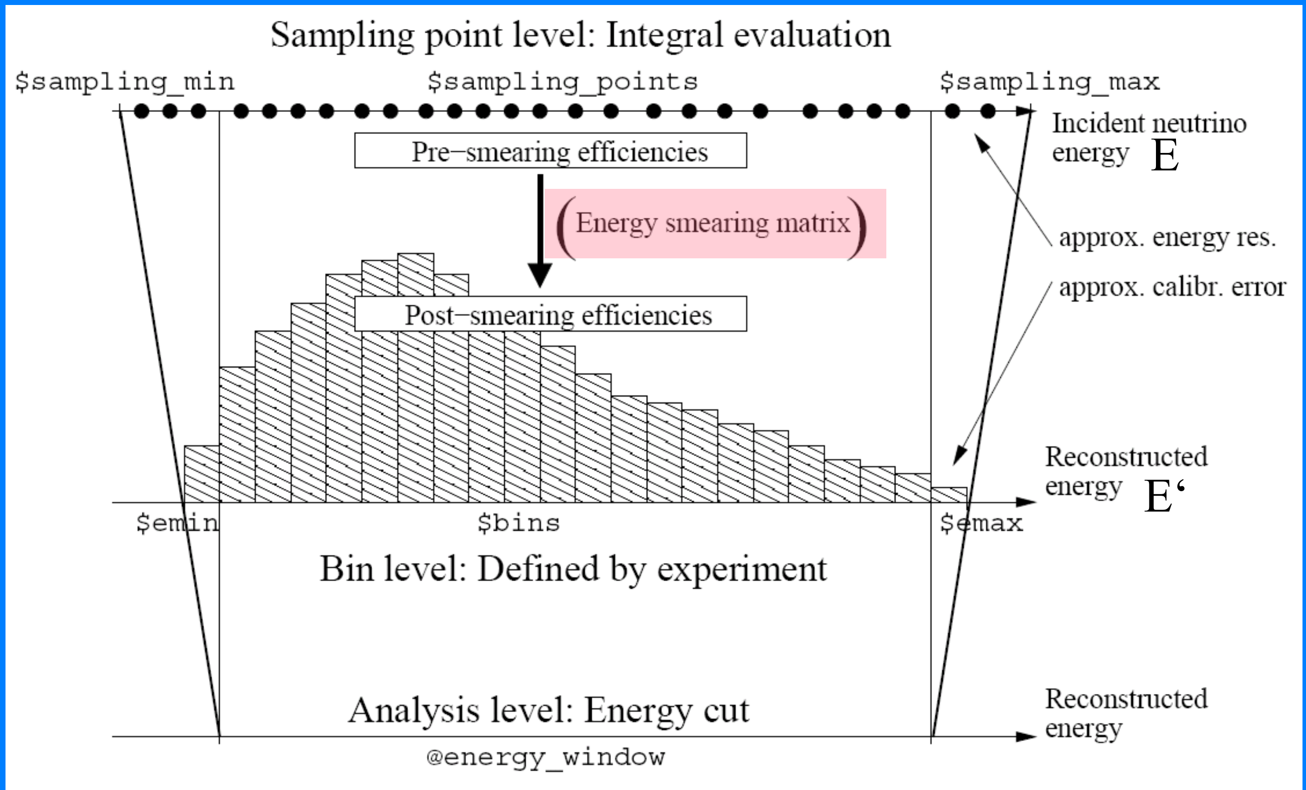

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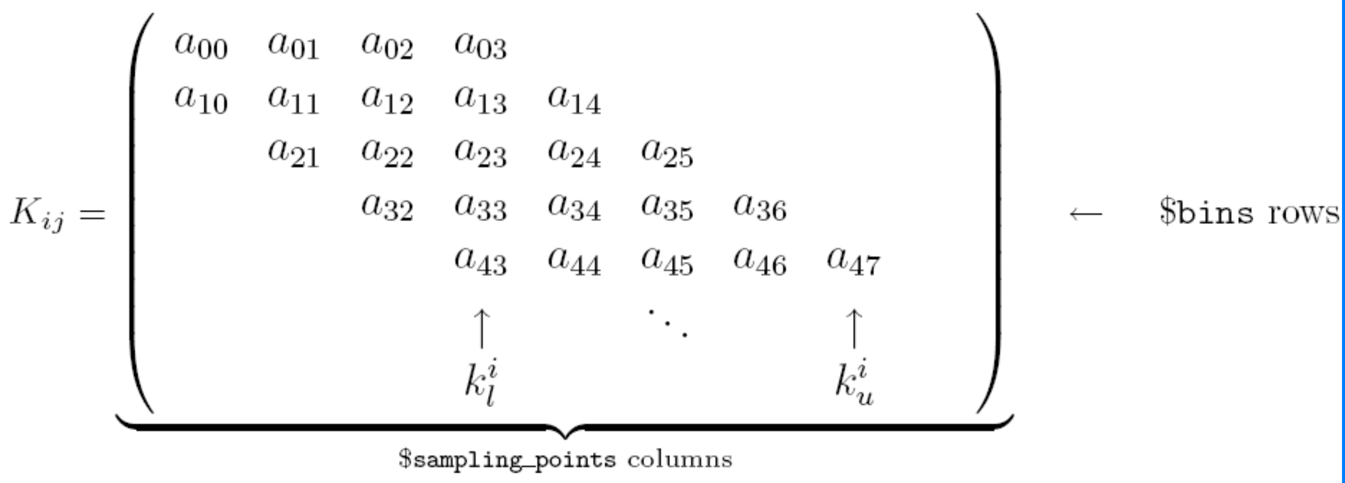
- Manual energy smearing by migration matrix



- Migration matrix to be specified in AEDL (experiment definition file)
- Not new, has been used in the past. Example: WBB-WC simulation Barger et al, hep-ph/0607177

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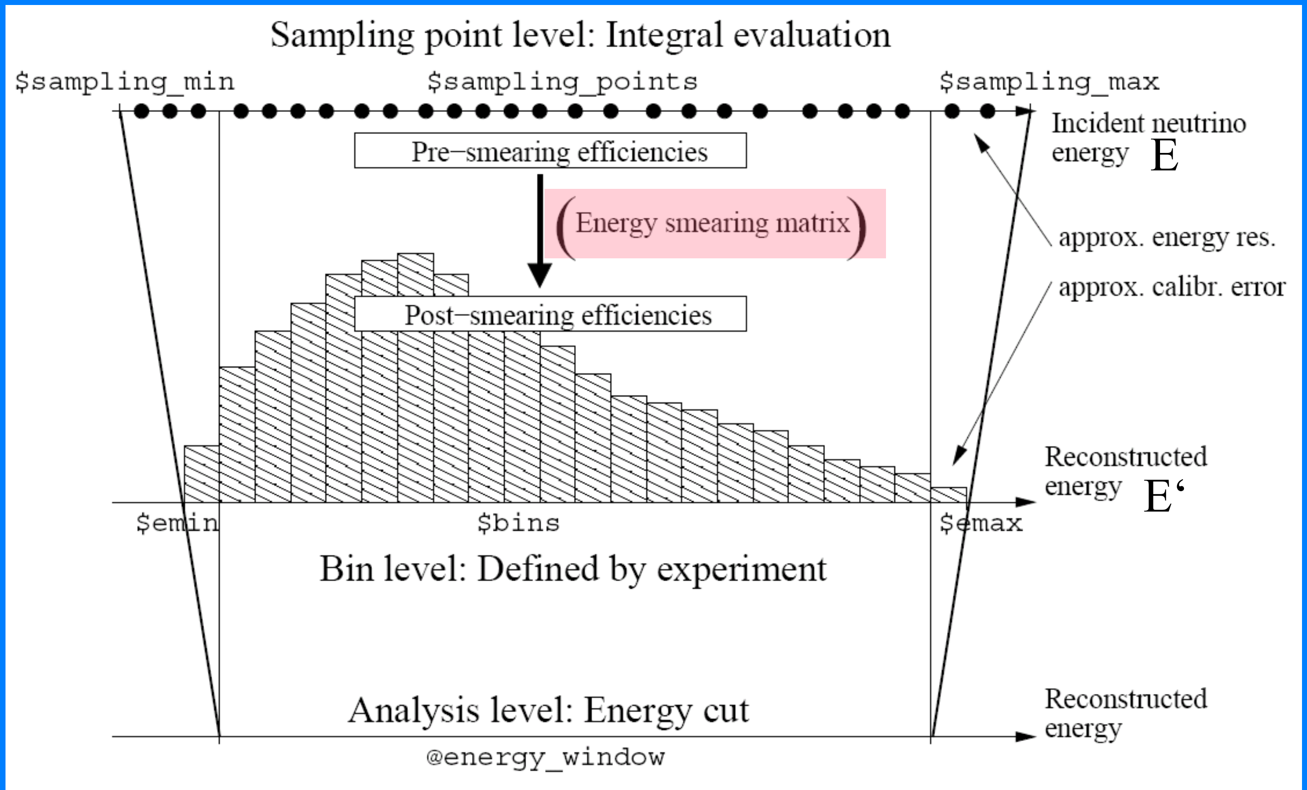

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$$K_{ij} = \underbrace{\begin{pmatrix} a_{00} & a_{01} & a_{02} & a_{03} & & & & \\ a_{10} & a_{11} & a_{12} & a_{13} & a_{14} & & & \\ & a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & & \\ & & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} & \\ & & & a_{43} & a_{44} & a_{45} & a_{46} & a_{47} \\ & & & \uparrow & & \ddots & & \uparrow \\ & & & k_l^i & & & & k_u^i \end{pmatrix}}_{\text{\$sampling\_points columns}} \quad \leftarrow \quad \text{\$bins rows}$$

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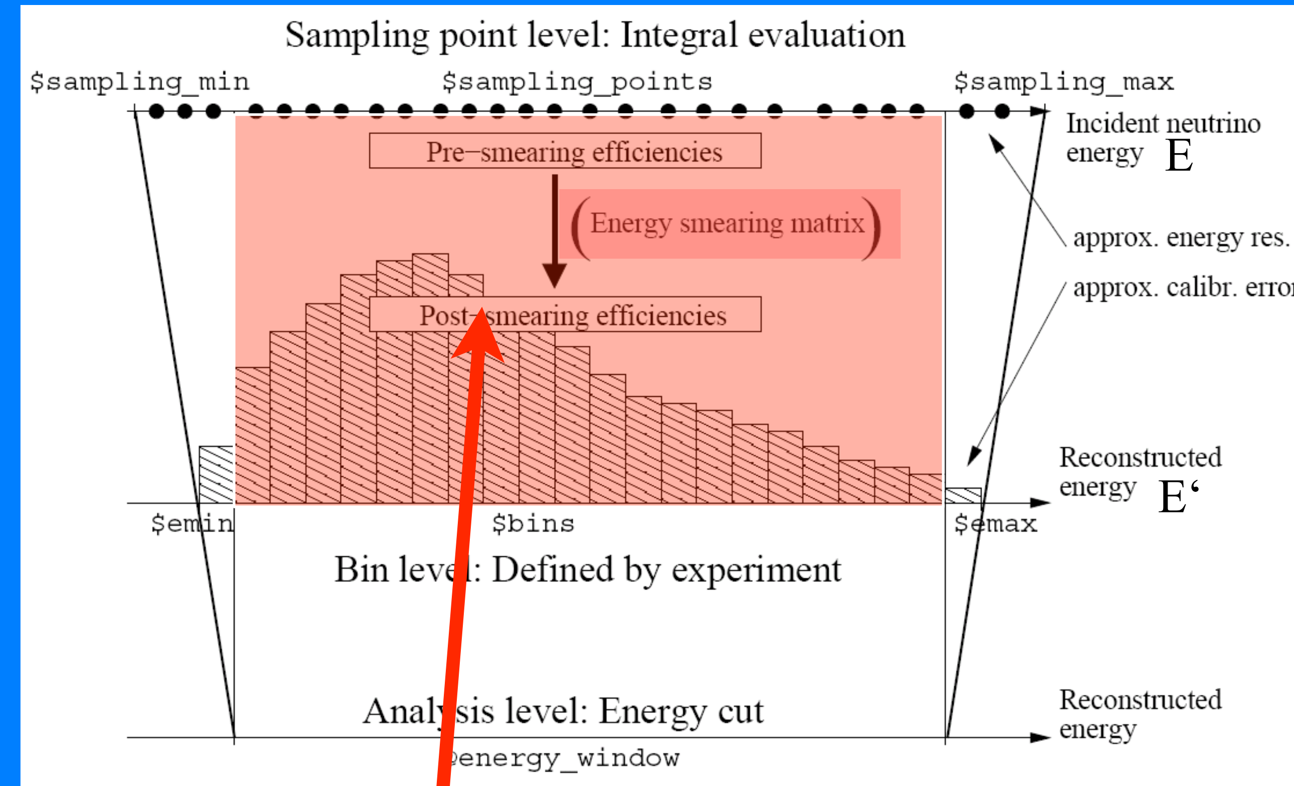

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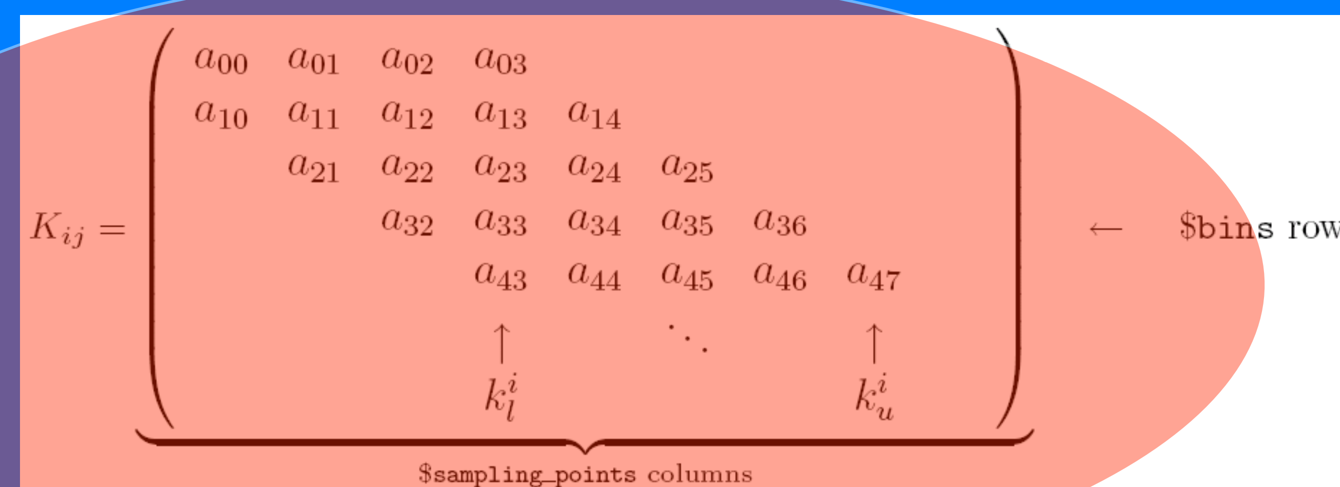

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SYSTEMATIC ERRORS,3

- At moment GLOBES cannot deal with errors in the migration matrices elements (time x $N_{sampling} \times N_{bins}$). Two proposals:
    - migmat elements can come with mean,max and min; (time x 3) estimate the impact (how to deal with correlations?)
    - replace $M(E_i,E'_j) \rightarrow M(E,E',\{\beta_k\})$ with $k=1,\ldots,N_\beta << N_{sampling} \times N_{bins}$ $\rightarrow$ (time x N_β)
    - GLOBES is not YET prepared for this second option, but it could be modified accordingly

TALKS AT STRASBOURG

- optimization and proposal of facilities (or related)
  - T. Schwetz, "Status of θ_{13}"
  - A. Donini, "Tau-contamination at the (HE) Neutrino Factory"
  - S. Pascoli, "Low Energy Neutrino Factory"
  - L. Scotto-Lavina,"High-Q low-γ Beta-Beam at LNGS"
- "new" physics beyond three-family oscillations
  - M. Maltoni, "Solar fluxes from neutrino data"
  - W. Winter, "NSI vs non-unitarity at the NF"
  - T. Ota, "New physics searches at near detectors"

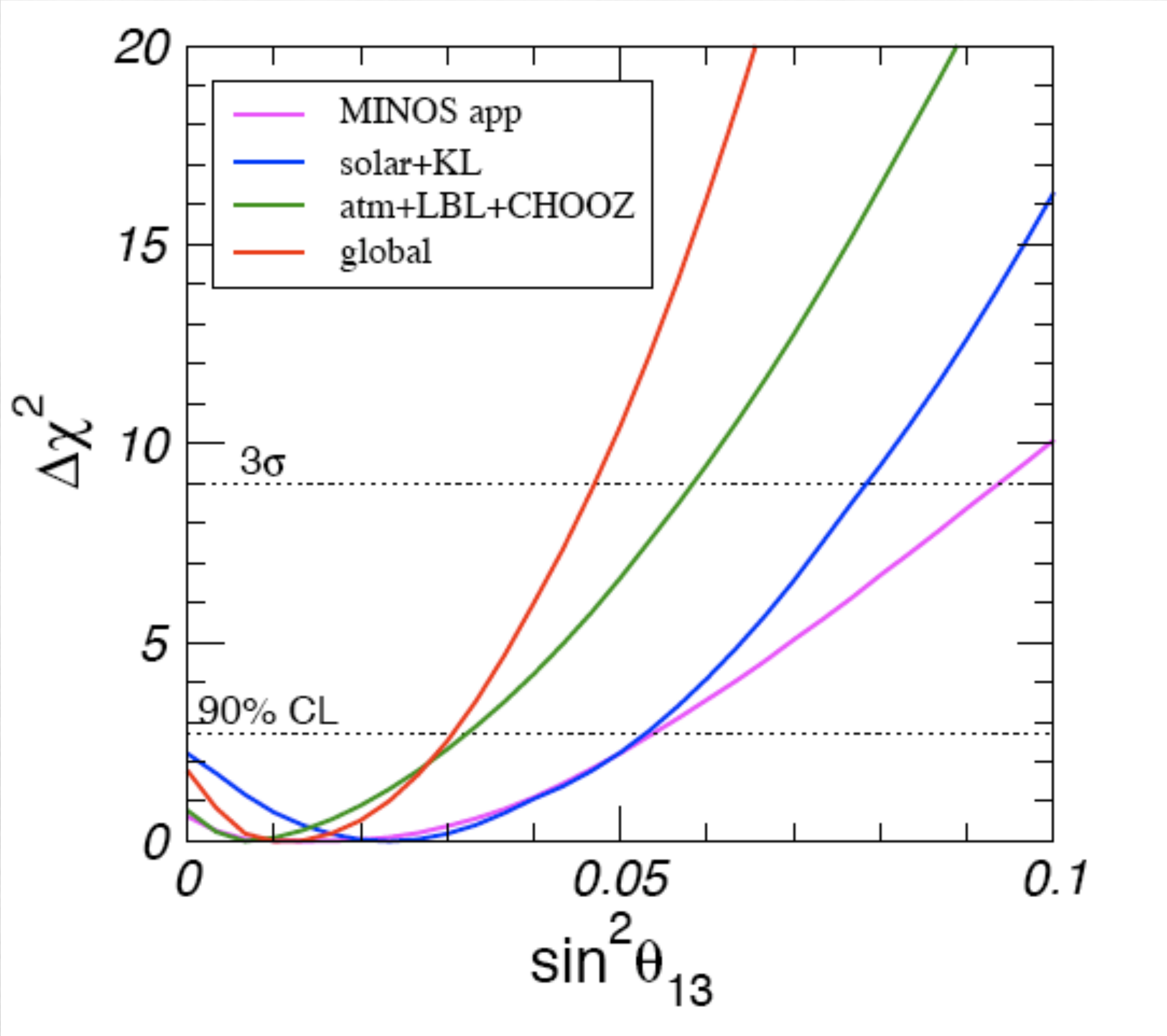
STATUS OF Θ_{13}

- Hint from solar+KamLAND data ($\sim 1.5\sigma$)
  fragile, but agreement among groups
  depends somewhat on assumptions on solar metalicity

- Hint from atmospheric data
  controversial, not confirmed by SuperK Wendell et al., 1002.3471

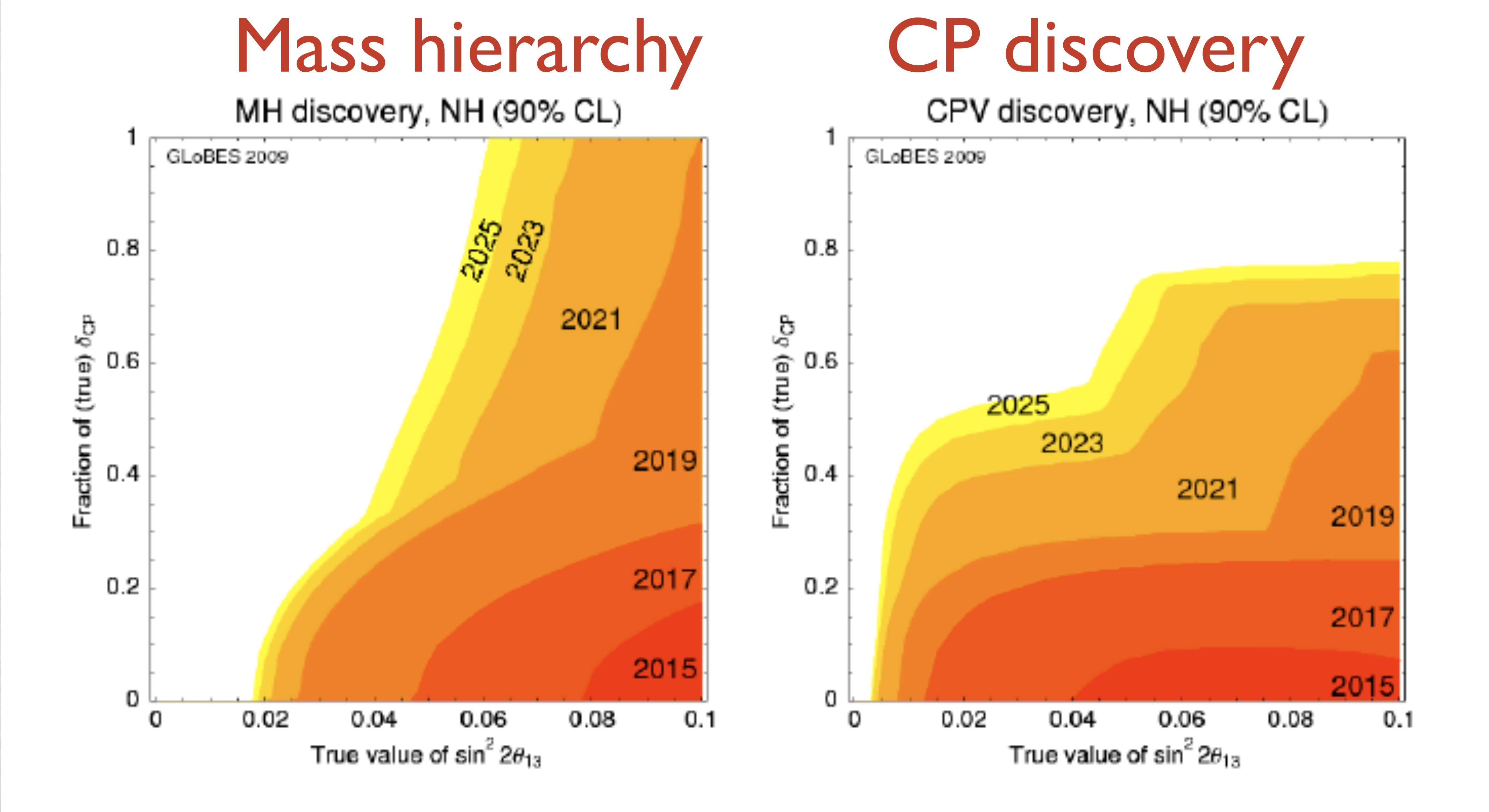
- MINOS appearance data ($\nu_\mu \to \nu_e$)
  initial $\sim 1.5\sigma$ hint has recently decreased to $\sim 0.7\sigma$

best-fit and 1σ errors	significance
$\sin^2\theta_{13} = 0.02 \pm 0.01$	2σ
$\sin^2\theta_{13} = 0.0095^{+0.013}_{-0.007}$	1.3σ
$\sin^2\theta_{13} = 0.008^{+0.012}_{-0.007}$	1.1σ
$\sin^2\theta_{13} = 0.013^{+0.013}_{-0.010}$	1.5σ
$\sin^2\theta_{13} = 0.010^{+0.013}_{-0.008}$	1.3σ



STATUS OF Θ_{13}

MH & CPV with T2K & NOvA & DayaB



Huber, Lindner, TS, Winter, 0907.1896

TAU CONTAMINATION, I

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

Wrong-sign muons

In MIND, this signal adds to the golden muon sample

TAU CONTAMINATION, I

$\nu_e \longrightarrow \nu_\tau \longrightarrow \tau^- \longrightarrow \mu^-$

(θ_{13},δ) $\sigma_{\tau N}$ $d\Gamma_{\tau\to\mu}$

Wrong-sign muons

In MIND, this signal adds to the golden muon sample

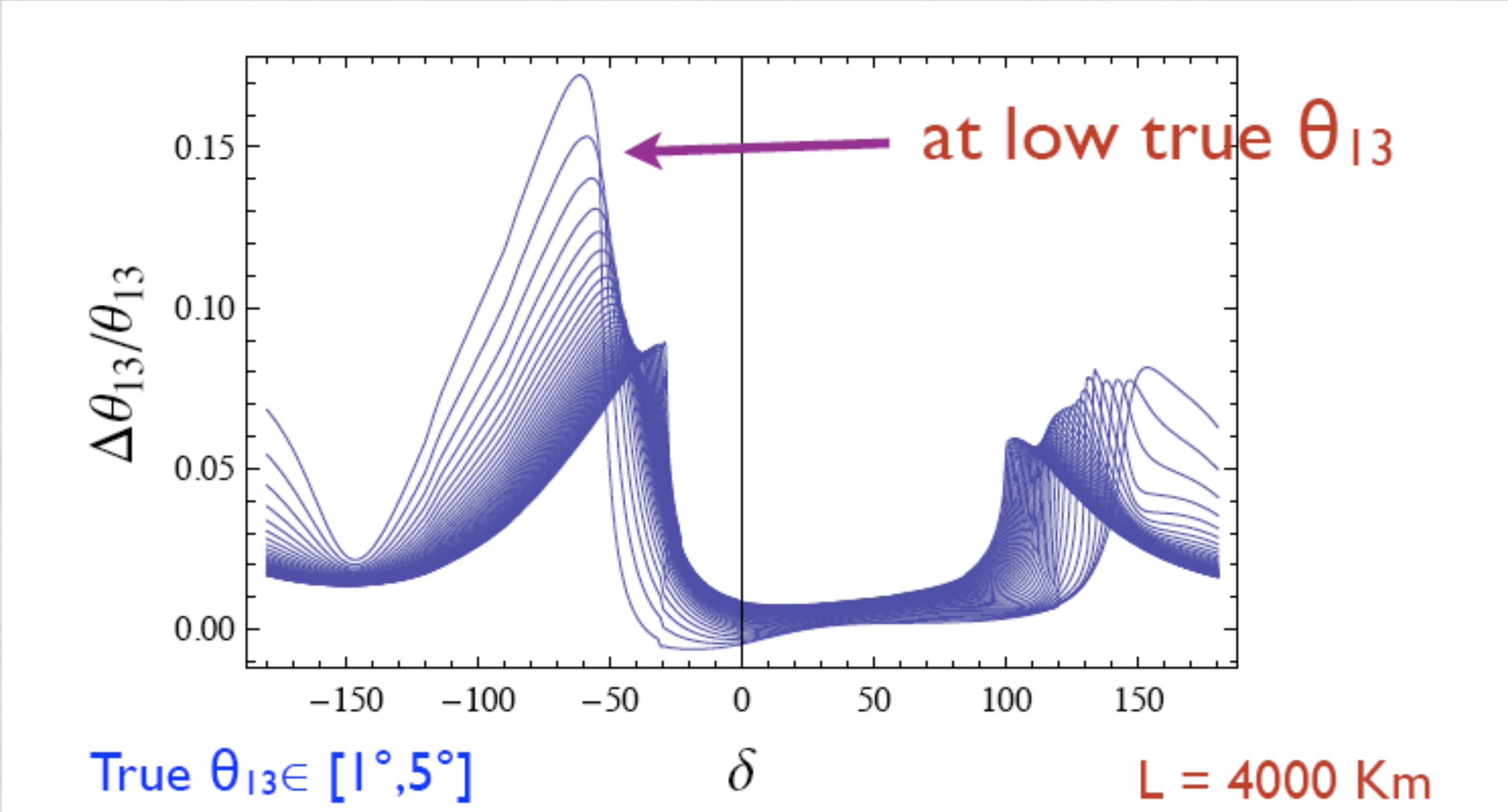
$E_{\nu\tau} = E_\tau + E_{hadr} = (E_\mu + E_{miss}) + E_{hadr}$ (silver muons)

$\Downarrow$

"$E_{\nu\mu}$" $= E_\mu + E_{hadr} < E_{\nu\tau}$

The neutrino energy is wrongly reconstructed!

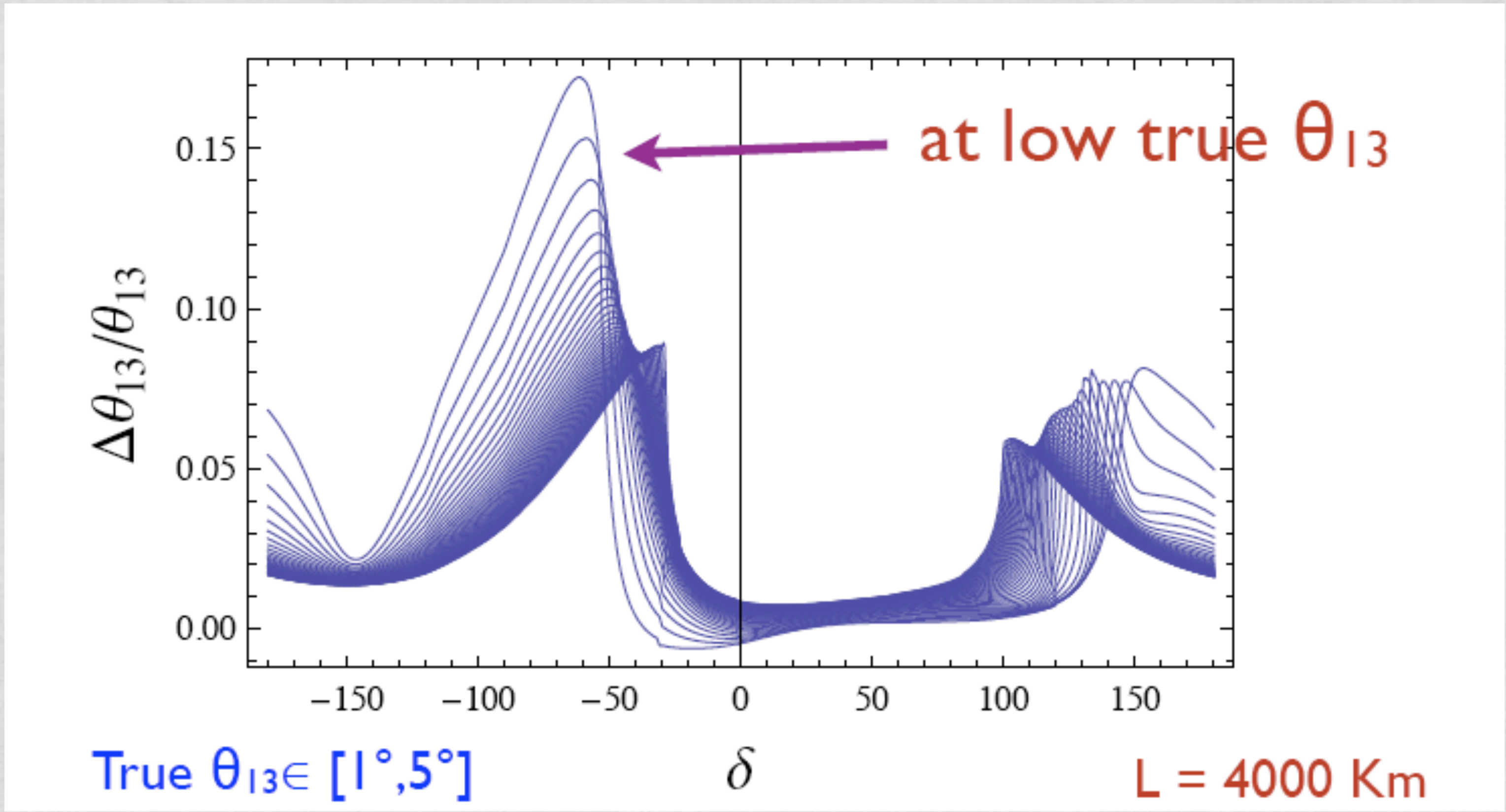
TAU CONTAMINATION,2



TAU CONTAMINATION,2

Up to 10% error in θ_{13}

Up to 40° error in δ



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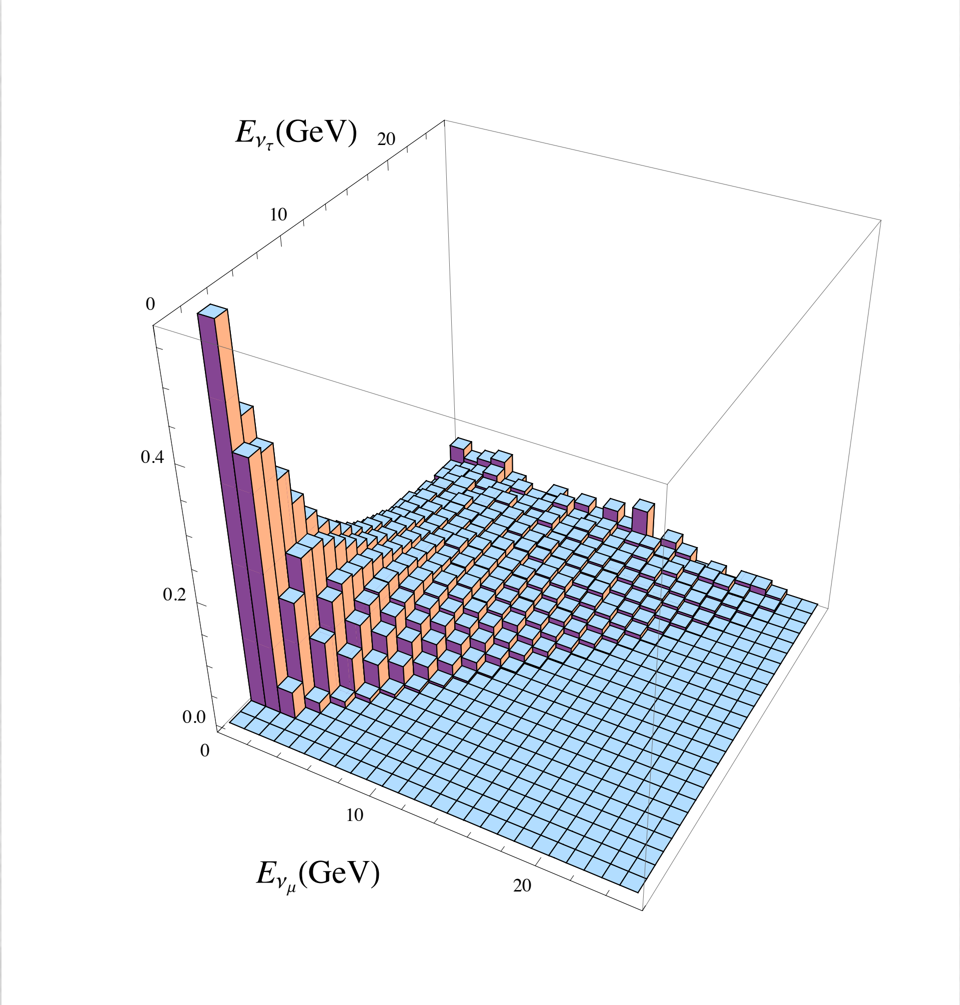

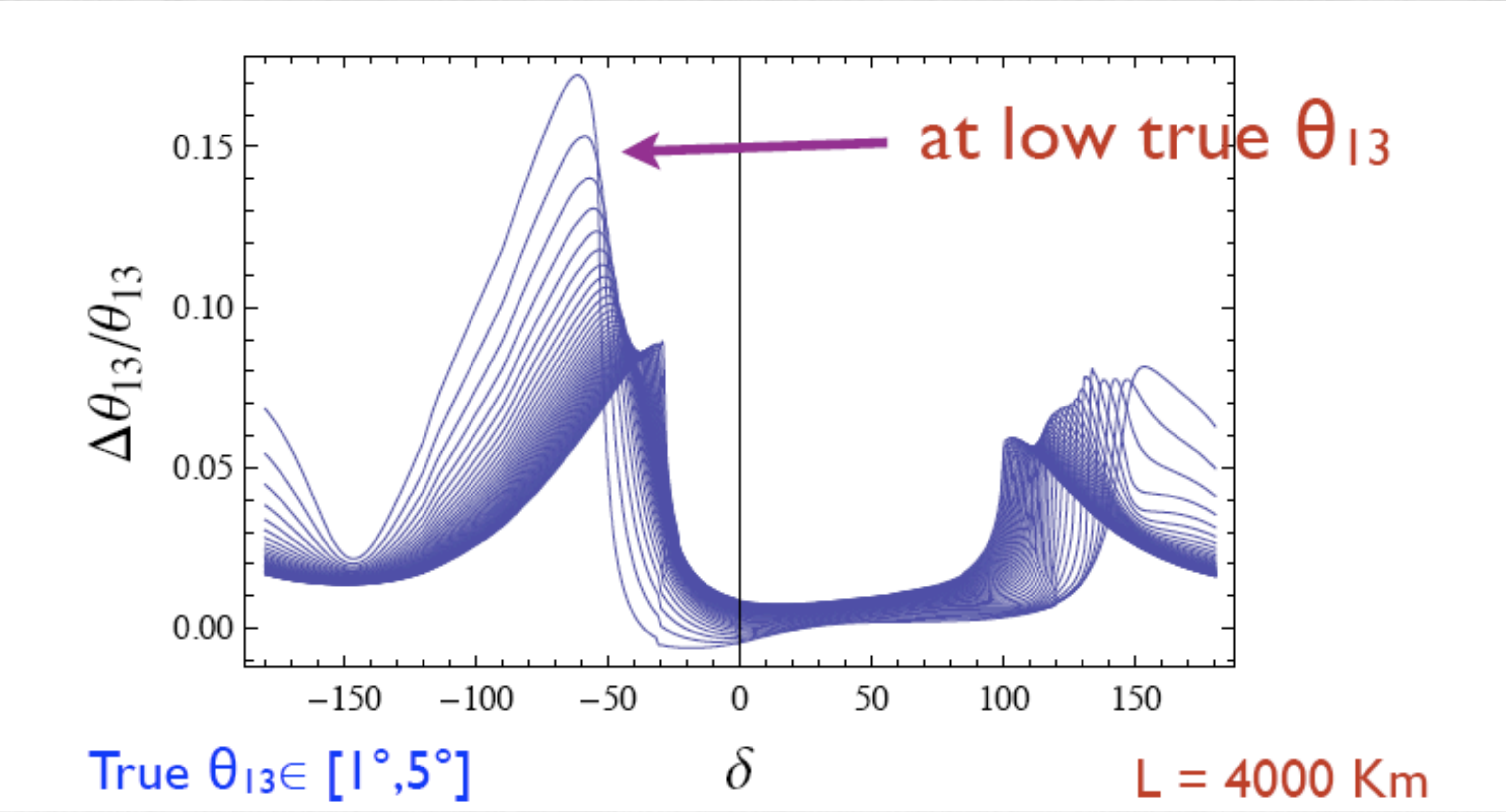

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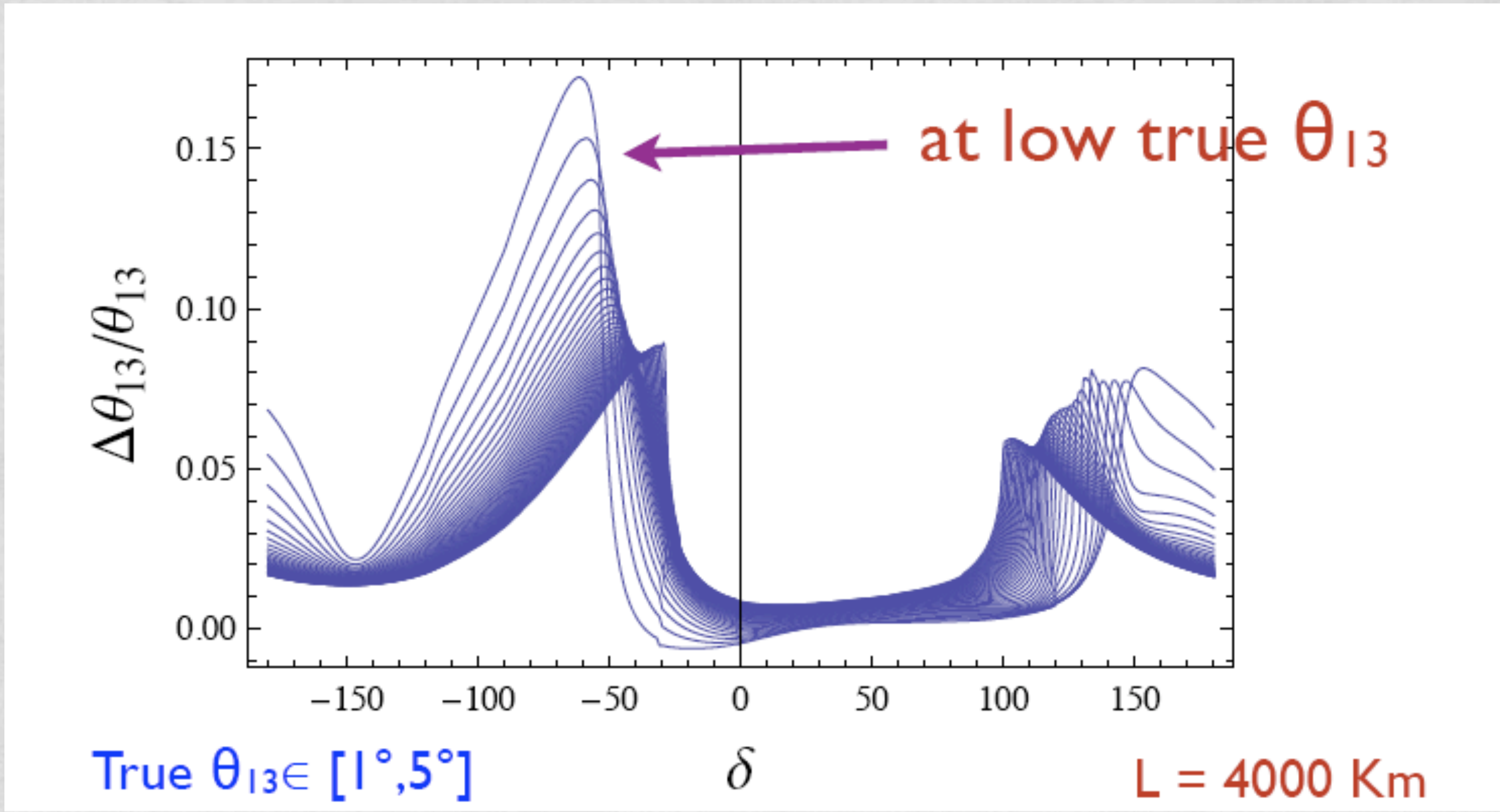
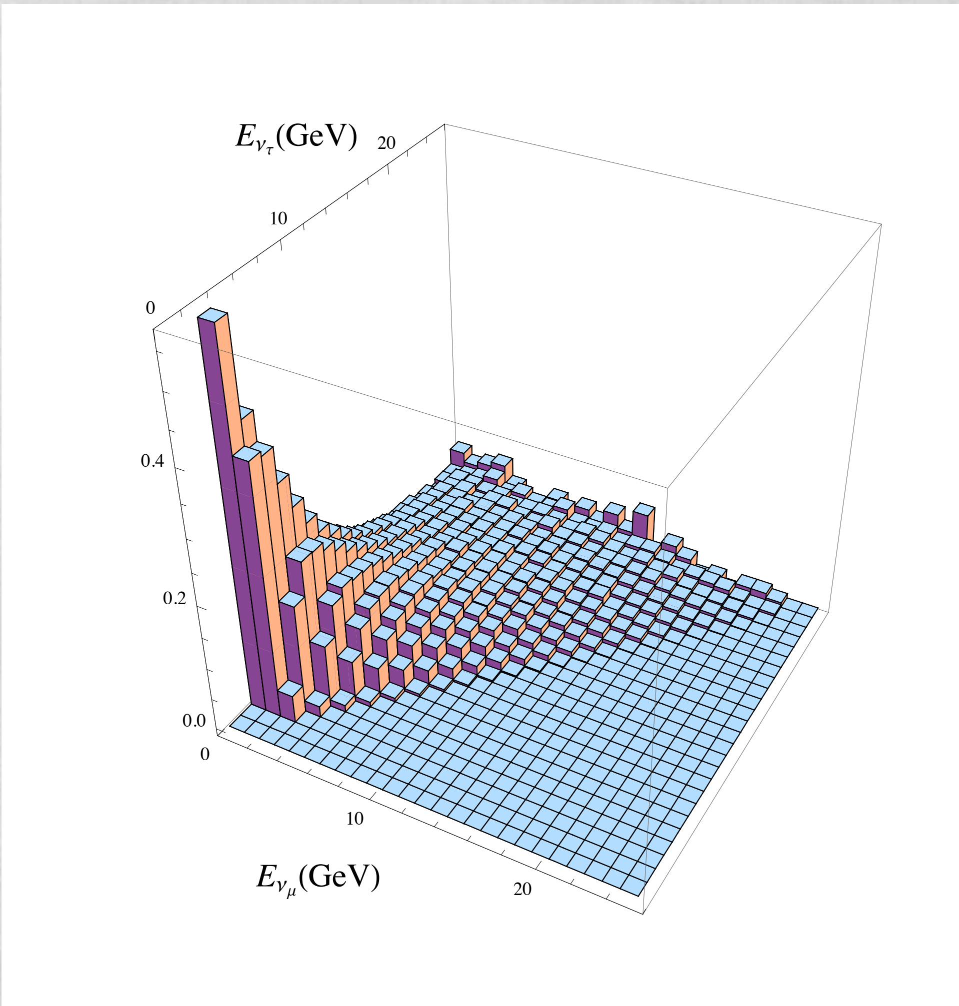


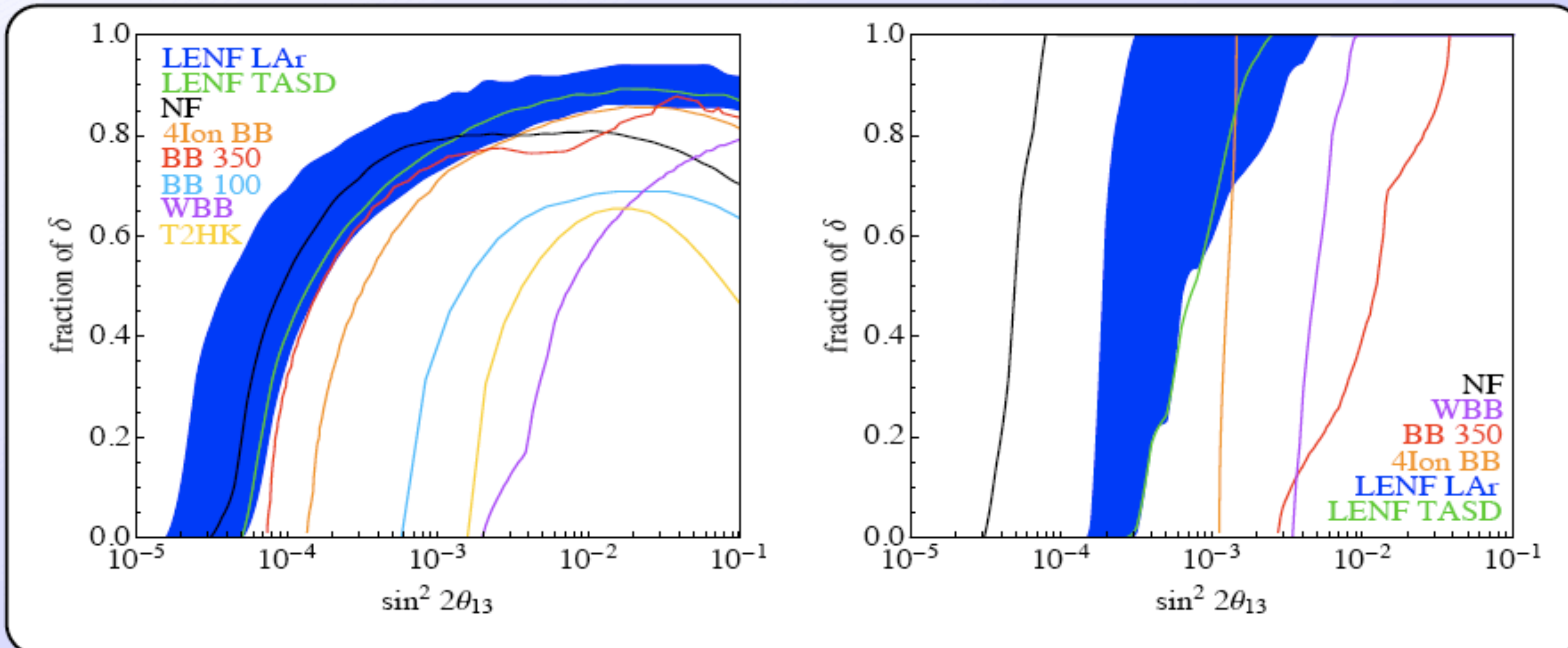


$$N^i_{obs} = N^i_\mu + \Sigma_j \, M_{ij} \, N^j_{\tau\rightarrow\mu}$$

Computed the migration matrix M_{ij}, subtracted the tau contamination

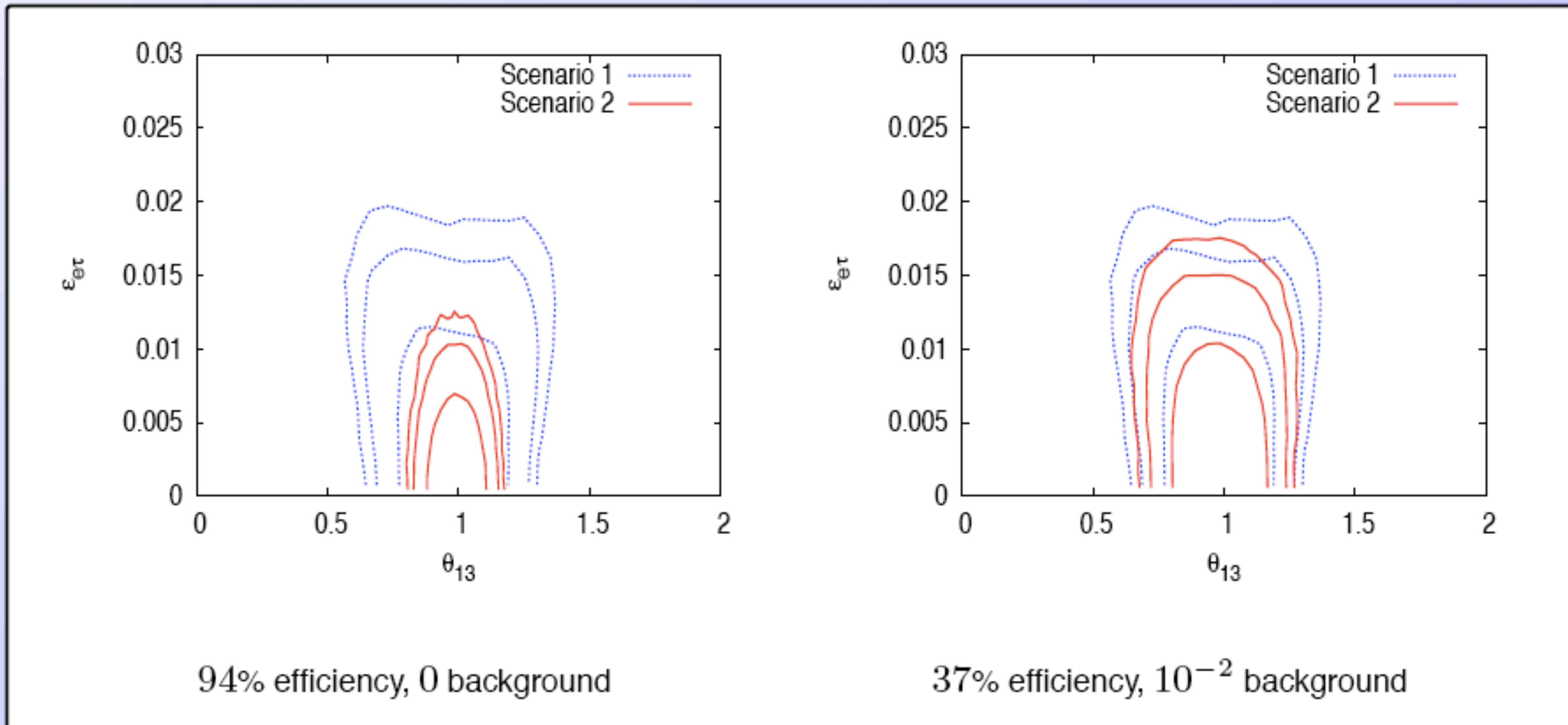
LOW ENERGY NUFACT, I

Sensitivity to the CPV and type of neutrino mass hierarchy



- **Larger neutrino flux**: 5×10^{20} and 1.4×10^{21} muon decay per year

LOW ENERGY NUFACT,2

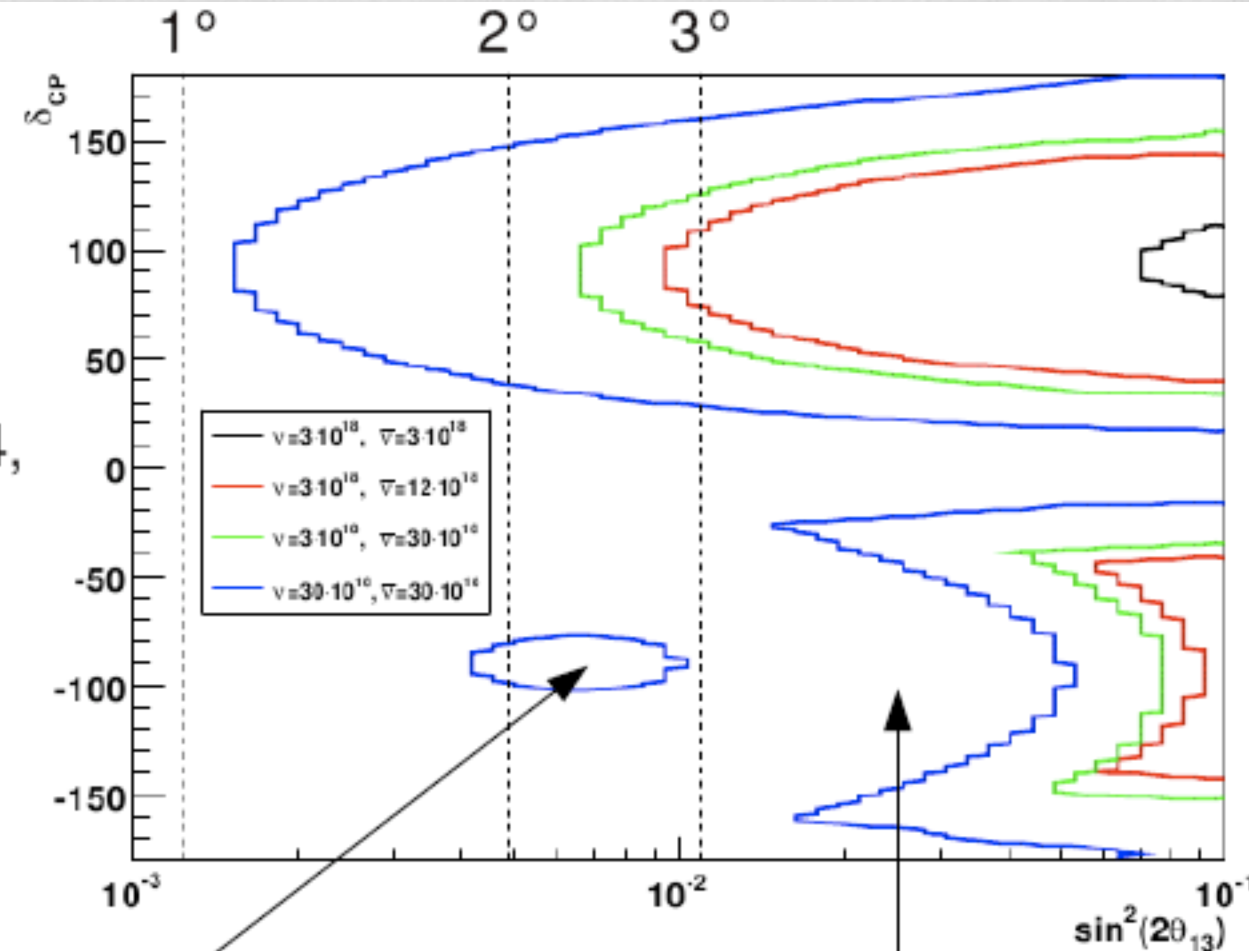


Some sensitivity to matter NSI (of course, worse than HENF)

HIGH-Q LOW-Γ BB, I

1) baseline
2) $\bar{\nu}$ flux increased by 4: great improvement
3) $\bar{\nu}$ flux further increased ($10F_0$): poor improvement
4) ν flux increased by 10: great improvement

After increasing anti-neutrino flux by a factor ~4, we cannot improve so much unless we don't increase neutrino flux as well



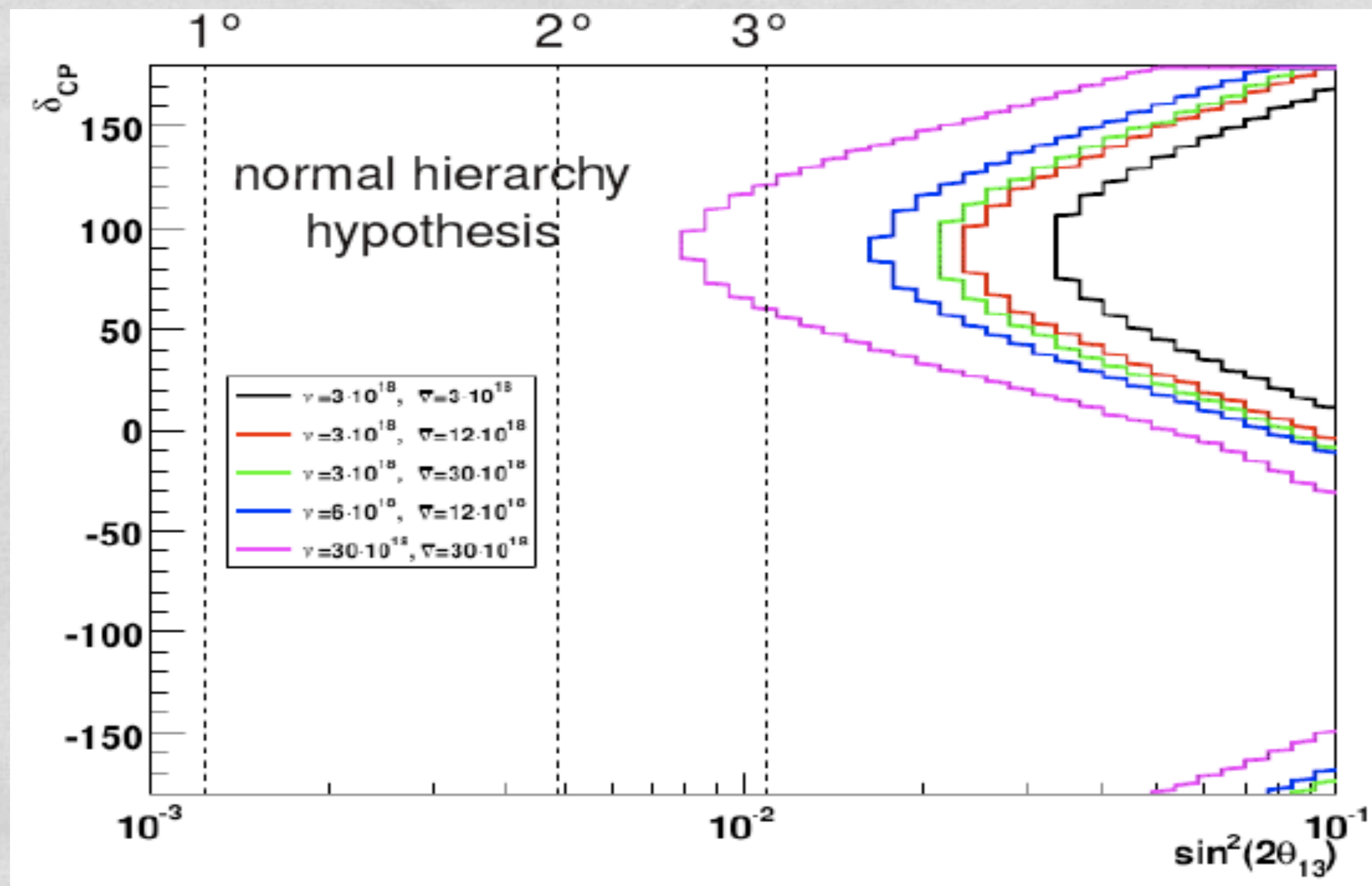
With $F^{\bar{\nu}} = 3 \times 10^{19}$, $F^{\nu} = 6 \times 10^{18}$ and if $\theta_{13} > 3°$, then a $\delta_{CP}>0$ can be measured in 60% of the parameter space

CP-violation sensitivity reappears at smaller θ_{13} values

"π-transit" effect: sign clones moves to a CP-conserving region of δ space

HIGH-Q Γ=100 BB, 2

With a **magnetized iron detector**, a combined analysis between **Beta beam** and **atmospheric neutrinos** can improve the sensitivity on the mass hierarchy (as noted in *A. Donini et al., Eur. Phys. J. C 53 (2008) 599*)



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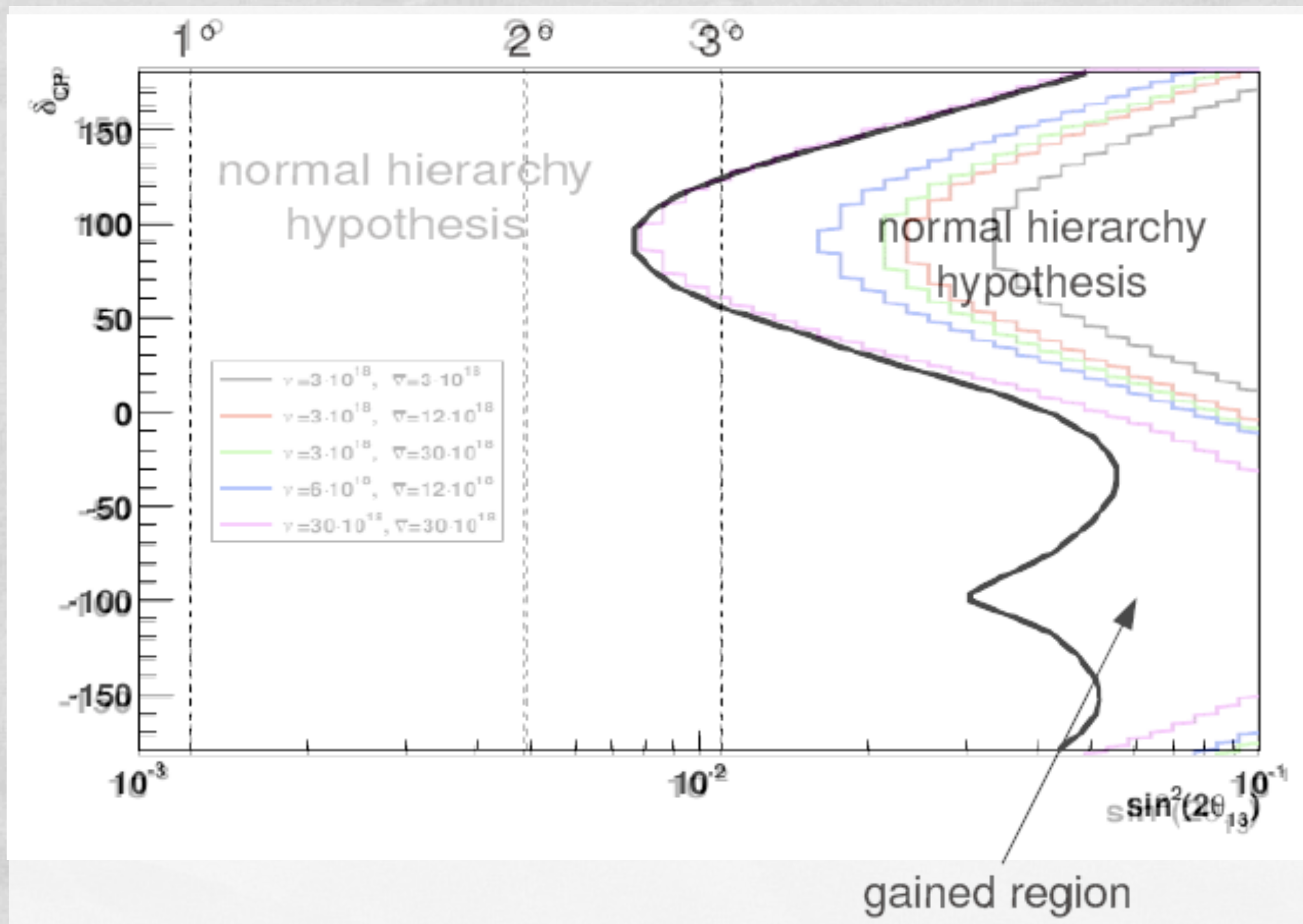

SOLAR FLUXES, I

- The solar chemical composition is encoded in its surface spectrum;
- however, its extraction requires an accurate modelling of the solar atmosphere;
- two atmospheric models: old-1D (GS98) and new-3D (AGS05, AGSS09);

- the structure of the solar interior is accurately measured by **helioseismology**;

⇒ **new abundances from AGS models are incompatible with helioseismology.**

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The solar ABUNDANCE problem

Proposal:

- in particular, CNO ν's are sensitive to the amount of "metals" (= anything but H & He);

⇒ solar neutrinos can provide direct information on the metallicity in the solar interior.

SOLAR FLUXES, 2

- solar luminosity:

$$\frac{L_{\text{pp-chain}}}{L_\odot} = 0.98^{+0.15}_{-0.14}\,[\pm 0.40]\,,$$

$$\frac{L_{\text{CNO}}}{L_\odot} = 0.015^{+0.005}_{-0.007}\,[^{+0.013}_{-0.014}]\,,$$

- from which we derive:

$$\frac{L_\odot(\text{neutrino-inferred})}{L_\odot} = 1.00 \pm 0.14\,[^{+0.37}_{-0.34}]\,.$$

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Which Standard Solar Model?

- Present data inconclusive because:
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  - not enough sensitivity anyway;
- statistical test: $P_{\text{agr}} = \begin{cases} 43\% \text{ for GS,} \\ 20\% \text{ for AGS;} \end{cases}$
- wishlist: measure CNO at $O(30\%)$ level.

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- the neutrino-inferred luminosity perfectly agrees with the measured one and it is known with a 1σ uncertainty of 14%;
- the low value of the ^{8}B flux at SK and SNO points towards low metallicity models;
- the measurement of ^{7}Be in Borexino favor high metallicity models;
- altogether there is a slight preference for models with higher metallicities;

NSI VS NON-UNITARITY (NU), I

- Effective operator picture if mediators integrated out:

$$\mathscr{L} = \mathscr{L}_{\rm SM} + \delta\mathscr{L}^{d=5}_{\rm eff} + \delta\mathscr{L}^{d=6}_{\rm eff} + \cdots\,, \quad \text{with} \quad \delta\mathscr{L}^{d}_{\rm eff} \propto \frac{1}{\Lambda^{d-4}}\mathcal{O}^d$$

ν mass

d=6, 8, 10, ...: NSI, NU

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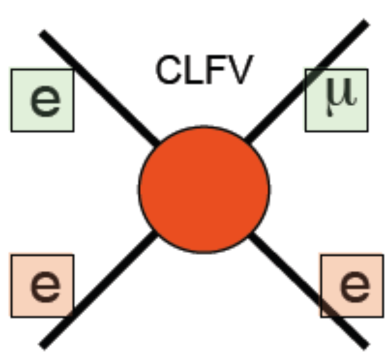
Ex.:



- Strong bounds

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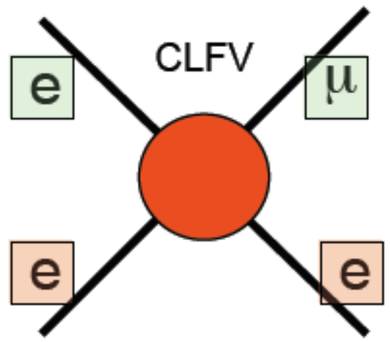
$$\mathscr{L} = \mathscr{L}_{\rm SM} + \delta\mathscr{L}^{d=5}_{\rm eff} + \delta\mathscr{L}^{d=6}_{\rm eff} + \cdots\,, \quad \text{with} \quad \delta\mathscr{L}^{d}_{\rm eff} \propto \frac{1}{\Lambda^{d-4}}\mathcal{O}^d$$

ν mass | d=6, 8, 10, ...: NSI, NU

$$P_{\nu_\alpha\to\nu_\beta} = \left|\langle \nu^d_\beta | e^{-iHL} | \nu^s_\alpha\rangle\right|^2$$

$$P_{\nu_\alpha\to\nu_\beta} = \left|\langle \nu_\beta | e^{-i(H+V_{\rm NSI})L} | \nu_\alpha\rangle\right|^2$$

Ex.:



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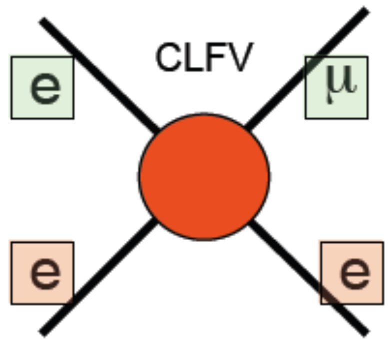

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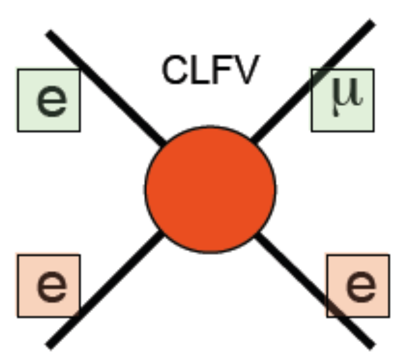

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scalar-mediated NSI

$$\delta\mathcal{L}_{\mathrm{eff}} = \left(\overline{L^c} \cdot L \right) \left(\overline{L} \cdot L^c \right)$$

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- Can one identify these/distinguish these?
- Theory: Can one distinguish between fermions and scalars as heavy mediators (simplest interpretation)?

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NF + SB can lift the ambiguity

NEW PHYSICS AT NEAR DET, I

Proposal: tau-detector (OPERA-like) at NUMI

at the beam source: $\pi^+ \xrightarrow{\epsilon^s_{\mu\tau}} \mu^+ \nu_\tau$

$\downarrow$

$\nu_\tau N \xrightarrow{\text{SM}} \tau^- X$:at a detector

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$\downarrow$ osc

$\nu_\tau N \xrightarrow{\text{SM}} \tau^- X$:at a detector

relevant operators

$$(\mathcal{O}_{ED})^\beta_\alpha = [\overline{L}^\beta E_\alpha][\overline{D}Q],$$
$$(\mathcal{O}_{EU})^\beta_\alpha = [\overline{L}^\beta E_\alpha](\mathrm{i}\tau^2)[\overline{Q}U],$$

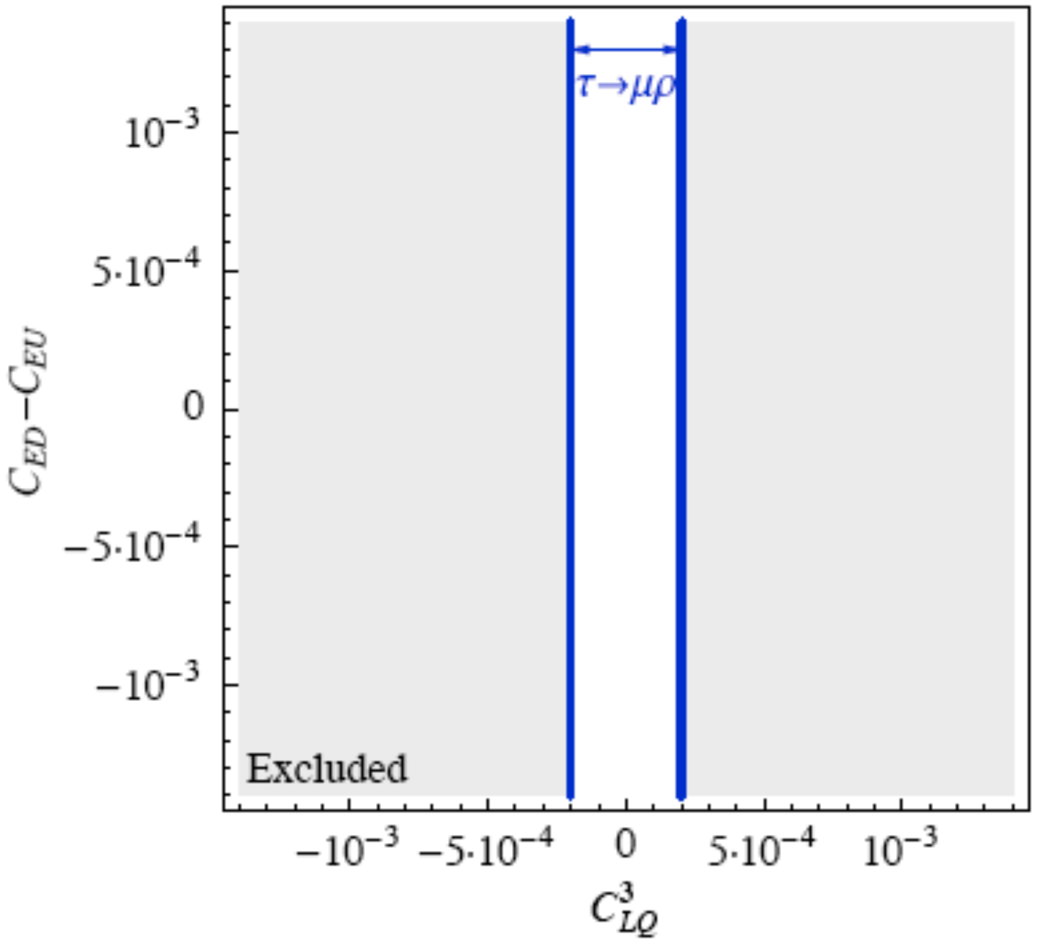
$$(\mathcal{O}^{\mathbf{1}}_{LQ})^\beta_\alpha = [\overline{L}^\beta \gamma^\rho L_\alpha][\overline{Q}\gamma_\rho Q],$$
$$(\mathcal{O}^{\mathbf{3}}_{LQ})^\beta_\alpha = [\overline{L}^\beta \gamma^\rho \vec{\tau} L_\alpha][\overline{Q}\gamma_\rho \vec{\tau} Q],$$

not relevant at near det

Signal

$$\left| \mathcal{A}^{\nu N\text{-scat}}_{\text{SM}} \mathcal{A}(\pi^+ \xrightarrow{\epsilon^s_{\mu\tau}} \mu^+\nu_\tau) + \mathcal{A}(\nu_\mu N \xrightarrow{\epsilon^d_{\mu\tau}} \tau^- X)\mathcal{A}^{\pi\text{-decay}}_{\text{SM}} + \mathcal{A}^{\nu N\text{-scat}}_{\text{SM}} \langle \nu_\tau | \mathrm{e}^{-\mathrm{i}HL} | \nu_\mu \rangle \mathcal{A}^{\pi\text{-decay}}_{\text{SM}} \right|^2$$

NEW PHYSICS AT NEAR DET,2



- Br($\tau \to \mu\rho$)$<6.8 \cdot 10^{-8}$
  $|\mathcal{C}^{\mathbf{3}}_{LQ}|$

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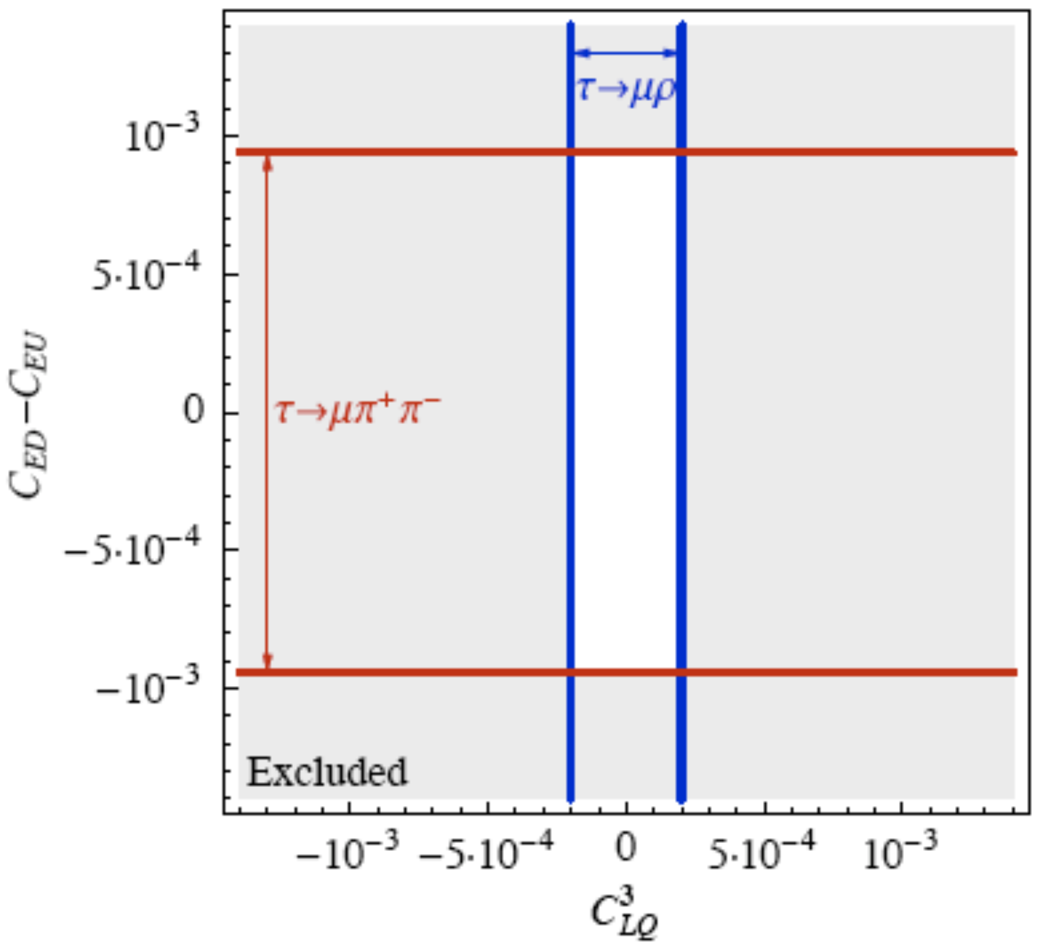

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- Br$(\tau \to \mu\pi^+\pi^-) < 2.9 \cdot 10^{-7}$
  $|\mathcal{C}_{ED} - \mathcal{C}_{EU}|$

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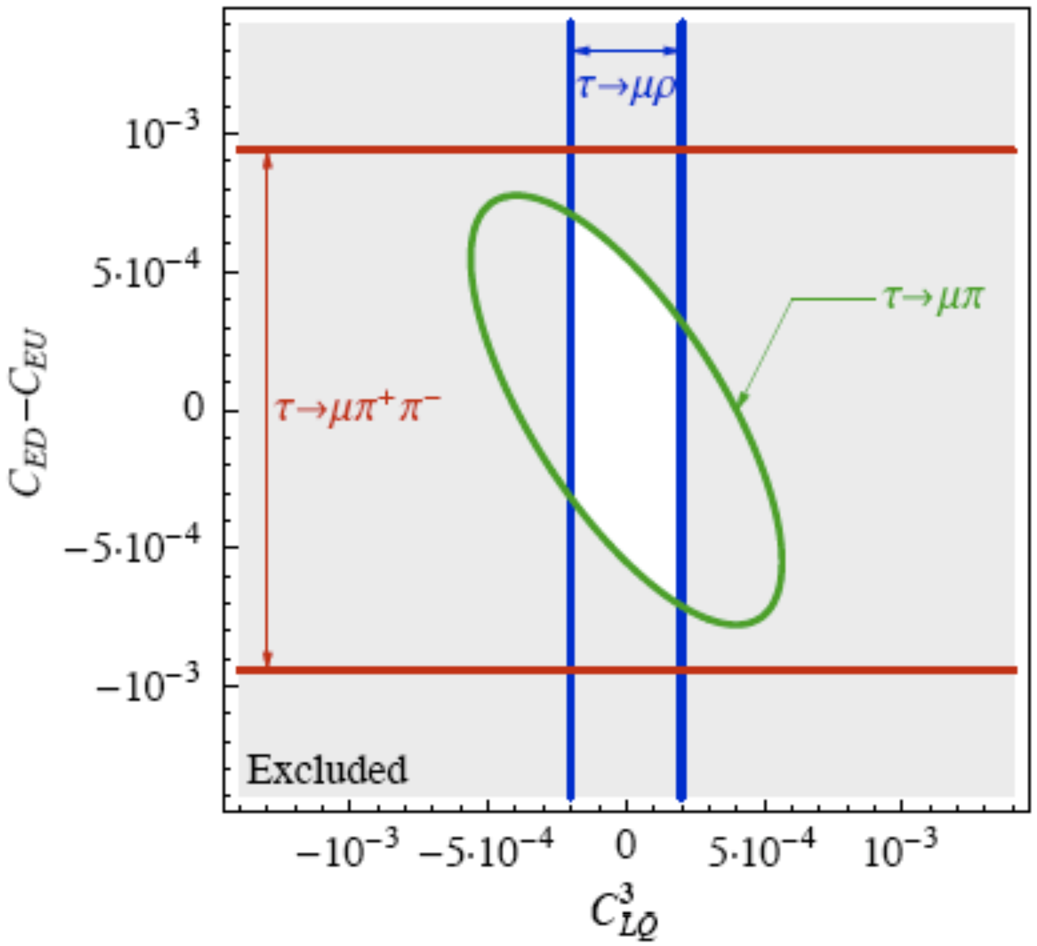

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  $\mathcal{C}^3_{LQ}$ and $(\mathcal{C}_{ED} - \mathcal{C}_{EU})$

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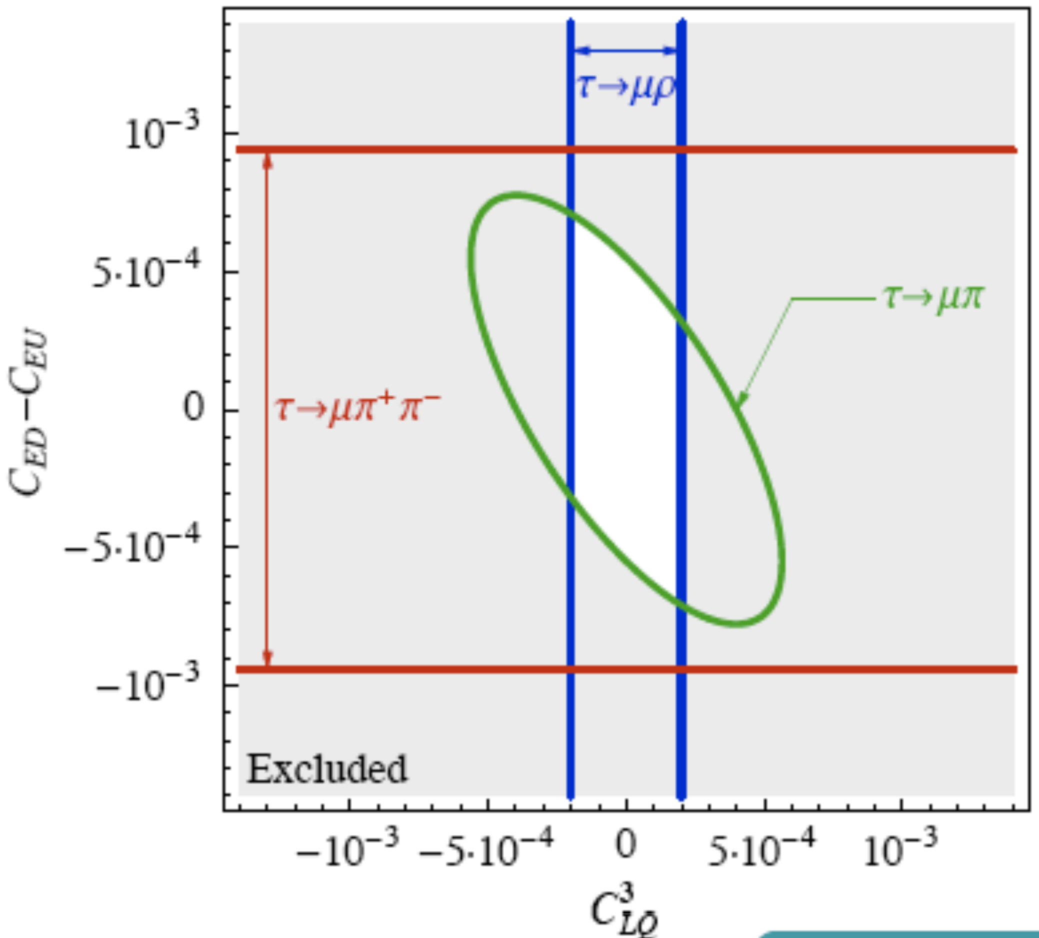

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Tau-signal / SM process

$\left|(\mathcal{C}^{\dagger}_{ED})_{\mu}{}^{\tau} - (\mathcal{C}^{\dagger}_{EU})_{\mu}{}^{\tau}\right| < 4.2 \cdot 10^{-4}$ from cLFV bounds

$\longrightarrow \Gamma(\pi^+ \to \mu^+\nu_\tau)/\Gamma_{\rm SM} < 7.9 \cdot 10^{-5}$

which is within the scope of MINSIS> $\mathcal{O}(10^{-6})$.

OVERALL WP6 ACTIVITIES

During the first half of the second EUROnu year, WP6 members have submitted 10 papers (whole first year: 10 papers)

Members are becoming aware that they are members of EUROnu and ask for preprint numbers

Papers fall in the two categories represented at this meeting:

optimization/proposals of (new) facilities (12)

"new" physics searches (8)

CONCLUSIONS

- Our primary role in EUROnu is the comparison of the physical performances of all the facilities, with updates as soon as new inputs are available (latest comparison available online in arXiv:1005.3146, WP6 2009 Yearly Report)

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- Unified treatment of systematics: discussed at length with WP5
    - flux and cross-section: we have a strategy to deal with syst errors at NF/BB
    - response matrices: GLOBES is prepared to accept them
    - errors in response matrices: we have ideas, not yet completely understood, some work to do to prepare GLOBES for them

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- Scenarios for Li and B beta-beams: discussed at length with WP4
  - only γ=100 scenario; possibility to have asymmetric fluxes (less B than Li)