Neutrino Factories & β-Beams

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Neutrino Factory Working Group of the APS Neutrino Study
Argonne National Laboratory
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Outline

- General Strategy

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- Commercial

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- θ_{13} sensitivity

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- Sensitivity to CP effects

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- Comparison with neutrino factory and superbeam
- Conclusion

General Strategy

Event rate calculation

- Efficiencies
- Backgrounds
- Energy response

Data

- Appearance channels
- Disappearance channels
- Energy information
- External information

General Strategy

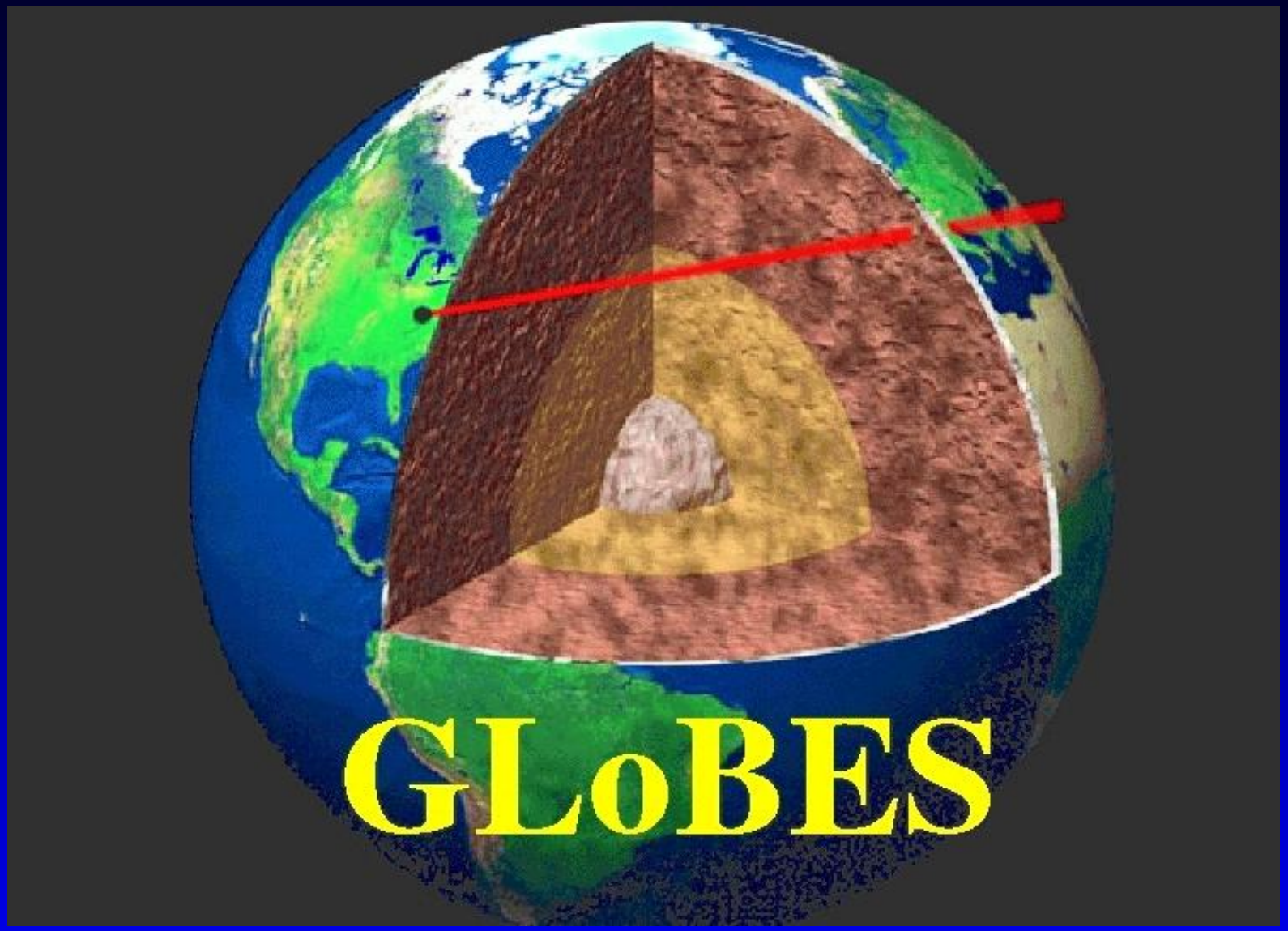
Analysis

- Systematics
- Correlations
- Matter density uncertainties
- Degeneracies

Comparison

- Parameters of interest
- Figure(s) of merit
- Risk function

Commercial



Commercial

General Long Baseline Experiment Simulator

GLoBES is a software package designed for

- Simulation
- Analysis
- Comparison

of neutrino oscillation experiments

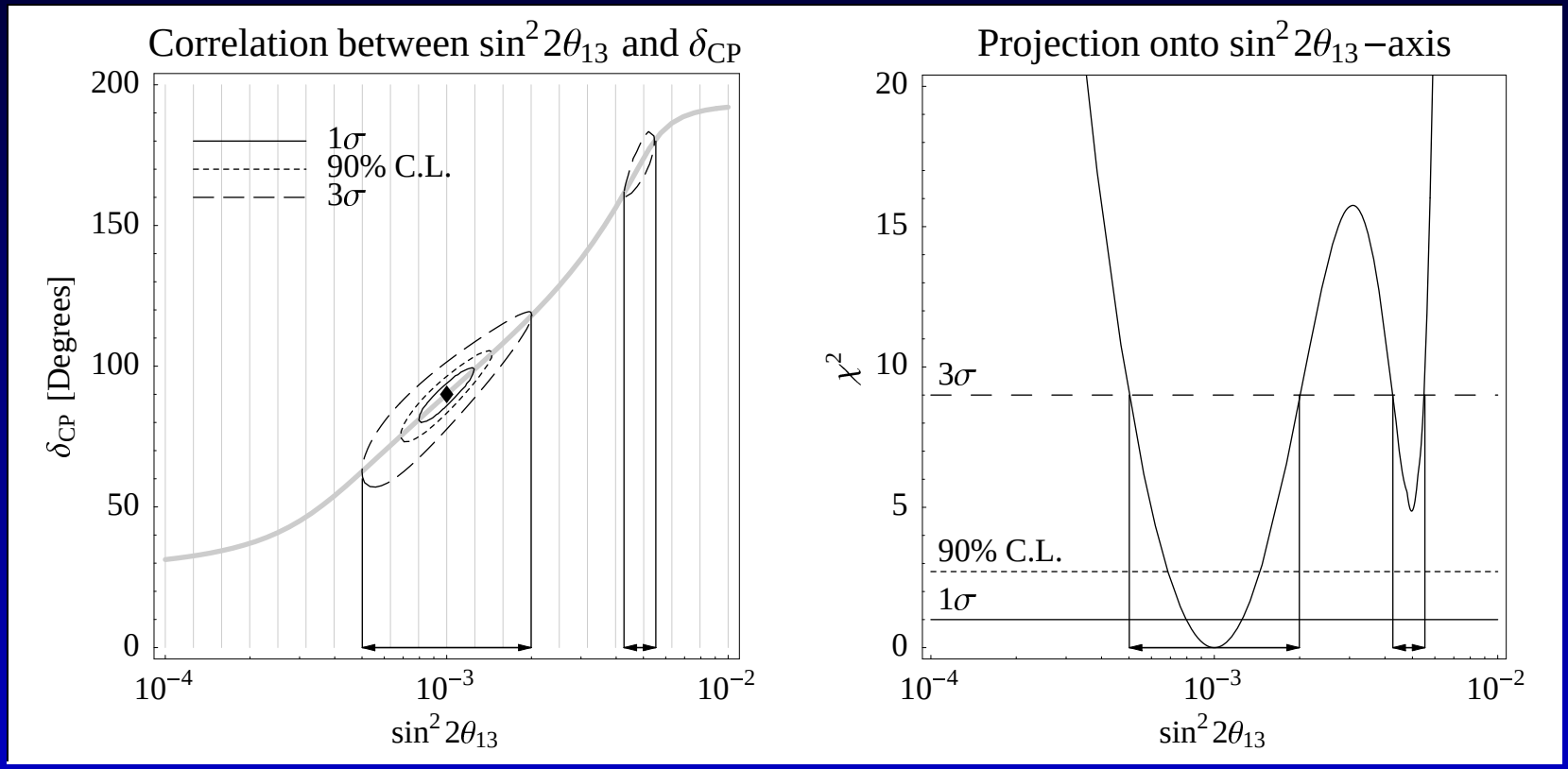
Commercial - continued

Features include

- Accurate treatment of systematical errors
- Arbitrary matter profile & uncertainties
- Arbitrary energy resolution function
- Single and multiple experiment simulation
- Simple χ^2 calculation
- Inclusion of external input
- Projection of χ^2 (minimization)
- ...

Commercial - continued

Example – χ^2 projections



Commercial - continued

GLoBES has been used for simulating

- MINOS, CNGS
- Reactor experiments
- JHF-SK
- NuMI off-axis
- JHF-HK
- Neutrino factory
- β-beam

Commercial - continued

GLoBES is developed, documented and maintained by

- Patrick Huber
- Manfred Lindner
- Walter Winter

GLoBES will be available soon

`http://www.physik.tu-muenchen.de/~globes/`

β-Beam simulation

Spectrum in nucleus rest frame

$$\propto E_\nu^2 (Q - E_\nu) \sqrt{(Q - E_\nu)^2 - m_e^2}$$

Two isotopes

$$\begin{aligned} \bar{\nu}_e &: \quad {}^6\mathrm{He},\ Q = 3.5\,\mathrm{MeV},\ \gamma = 60, \\ \nu_e &: \quad {}^{18}\mathrm{Ne},\ Q = 3.4\,\mathrm{MeV},\ \gamma = 100 \end{aligned}$$

This corresponds to the so called low-γ setup!

β-Beam simulation

Problem: There are differences in the literature!

Unoscillated ν_e and $\bar{\nu}_e$ CC event rates per kt y

	ν_e	$\bar{\nu}_e$
J. Bouchez, *et al.* hep-ex/0310059	32.9	4.5
J. Burguet-Castell, *et al.* hep-ex/0312068	25.7	1.9

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We use the values of hep-ex/0310059 as reference!

β-Beam simulation

Signal events at $\sin^2 2\theta_{13} = 0.12$ and $\delta = 0$

	ν_e	BG	$\bar{\nu}_e$	BG
hep-ex/0310059	5130	397	612	1
our calculation	5126	397	616	1

- Total rates
- Appearance channels
- 2% systematic

- $4\,400\,\mathrm{kt\,y}$ exposure
- 5% on atm. params.
- 10% on sol. params.

$\Delta m^2_{31} = 3 \cdot 10^{-3}\,\mathrm{eV}^2$, $\Delta m^2_{21} = 7 \cdot 10^{-5}\,\mathrm{eV}^2$,

$\sin^2 2\theta_{23} = 1$ and $\sin^2 2\theta_{12} = 0.8$

Signal events

$\sin^2 2\theta_{13} = 0.1$ and $\delta = 0$

ν	β-beam	JHF-HK	NuFact-II
S	4967	13171	69985
BG	397	2140	95.2
S/BG	12.5	6.2	735

$\bar{\nu}$	β-beam	JHF-HK	NuFact-II
S	477	9377	15342
BG	1	3326	180
S/BG	477.5	2.8	85.2

θ_{13}-sensitivity

How to compute the θ_{13}-sensitivity

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- Simulate data with $\theta_{13} = 0$

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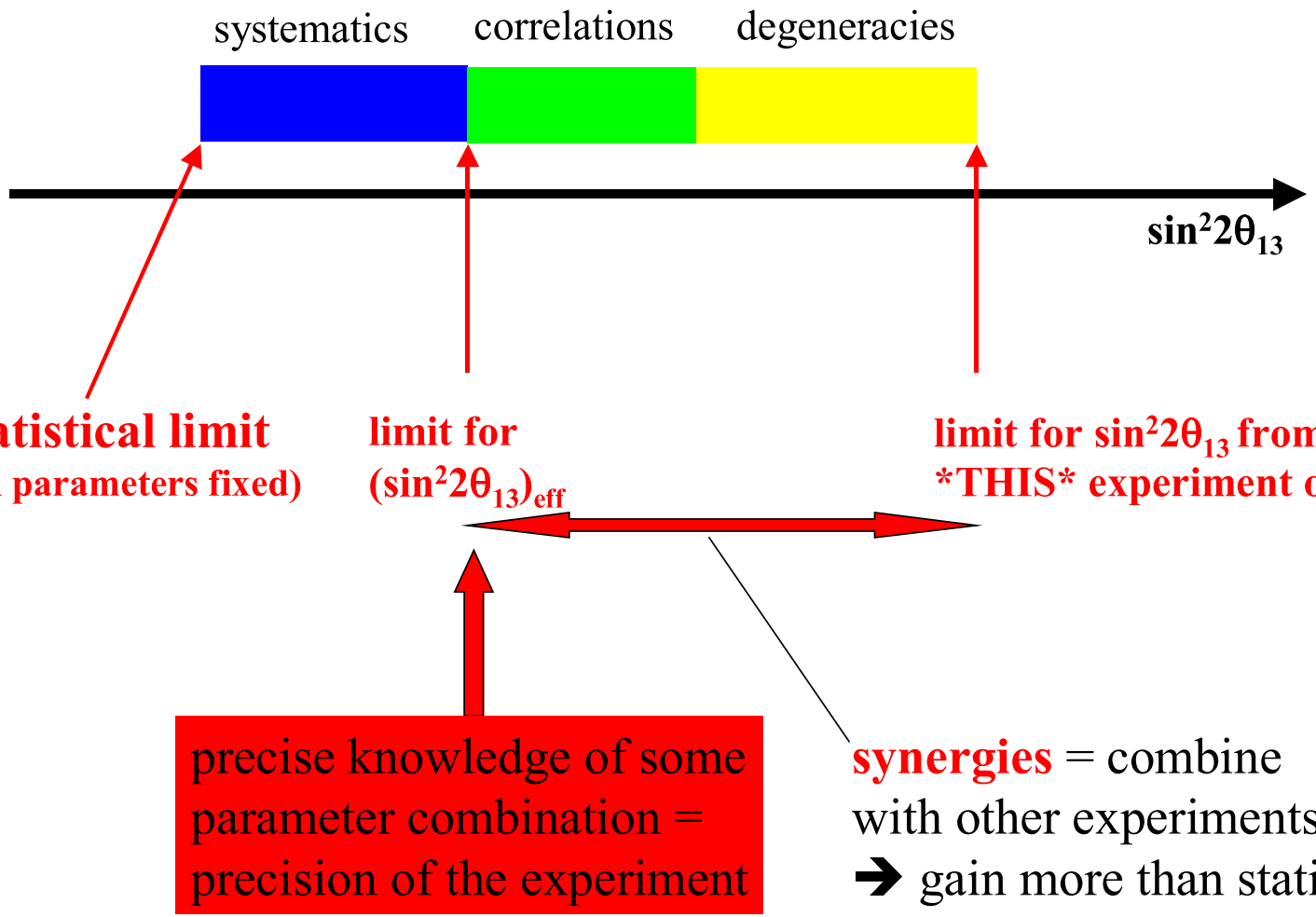
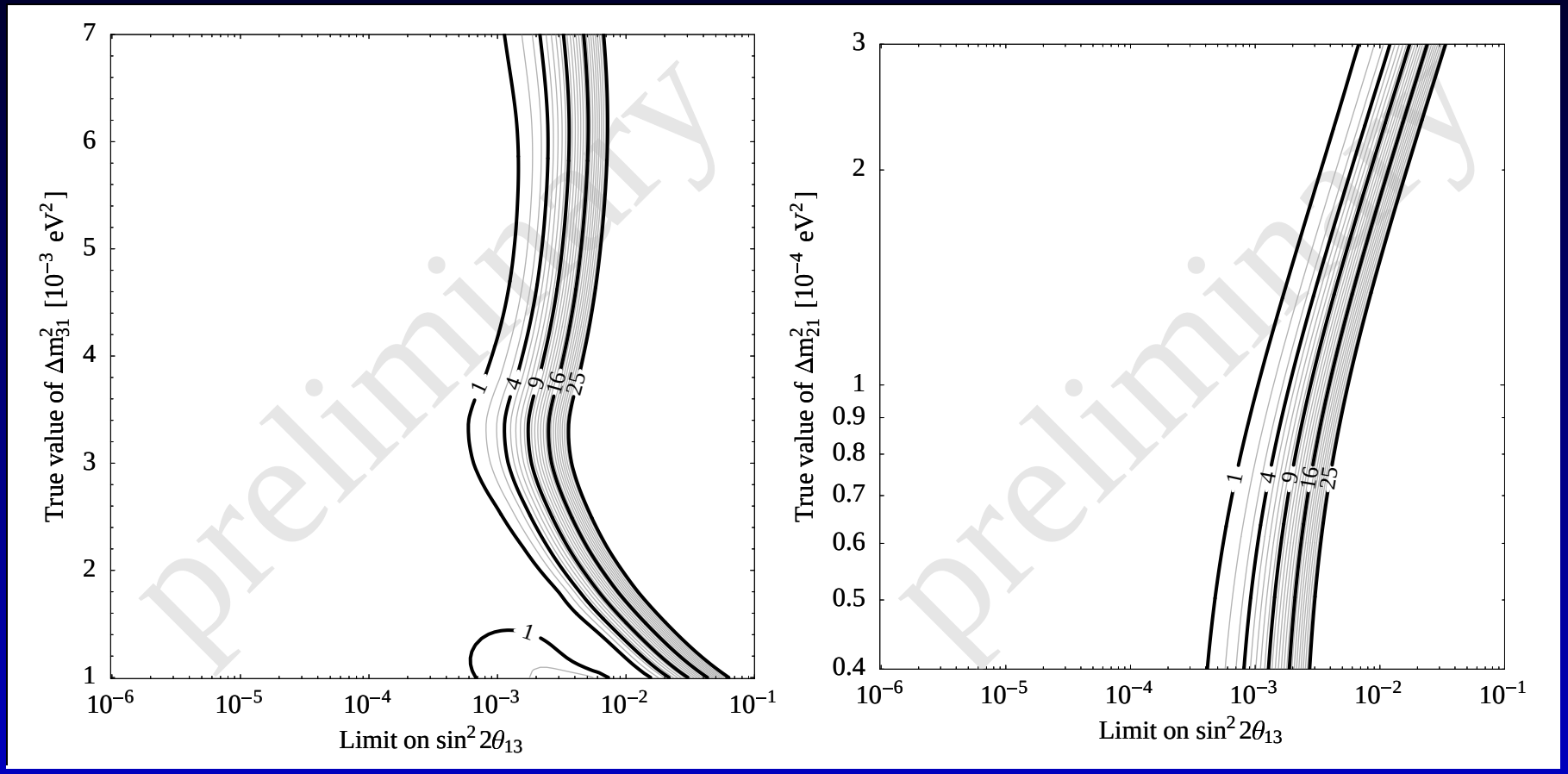
- Include correlations
- Include degeneracies

θ_{13}-sensitivity

Sensitivitiy Plots



θ_{13}-sensitivity



CP effects

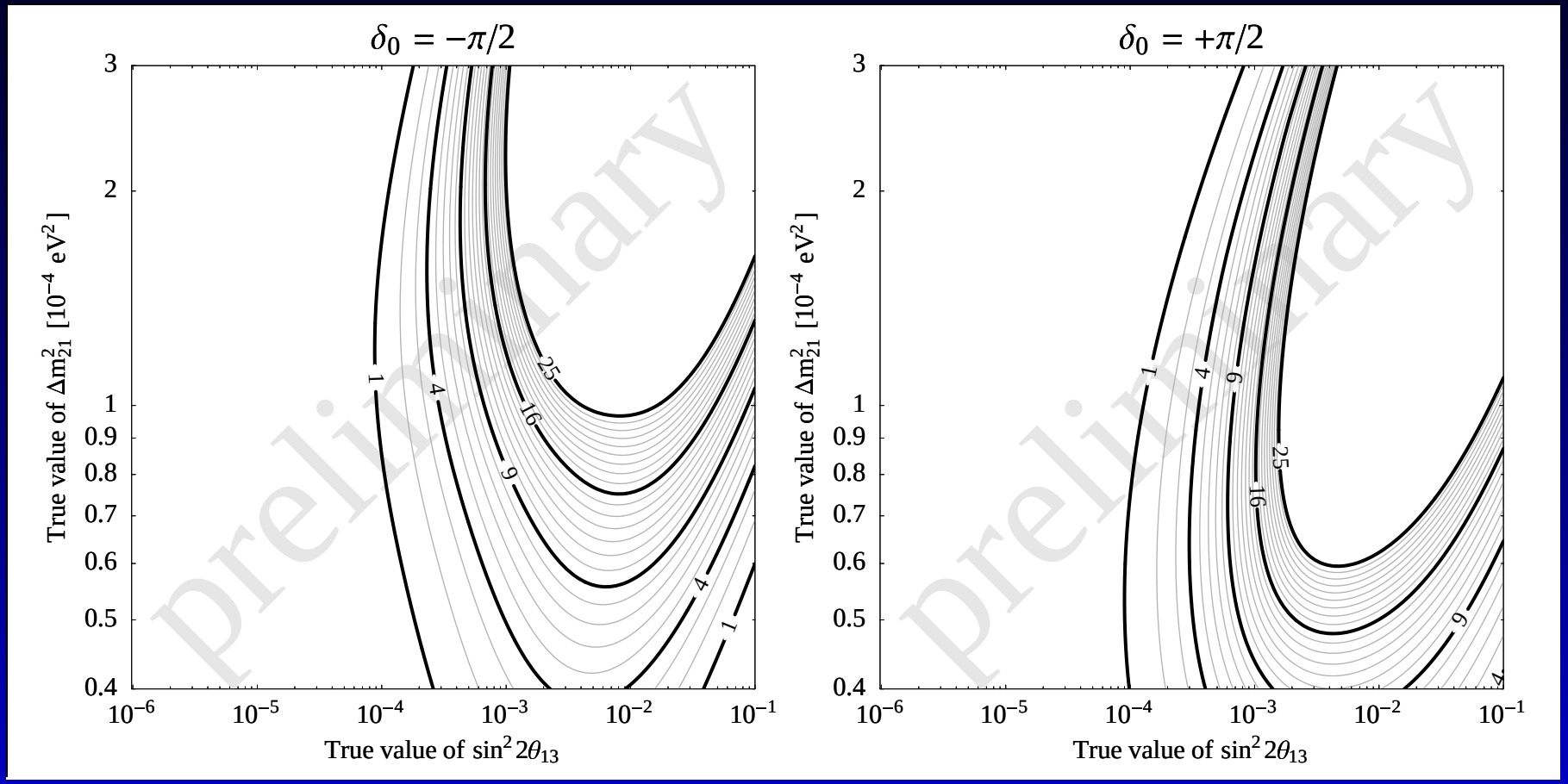
There are four special values of the CP phase δ:

- CP conservation – $\delta = 0$ and $\delta = \pi$
- maximal CP violation – $\delta = -\pi/2$ and $\delta = +\pi/2$

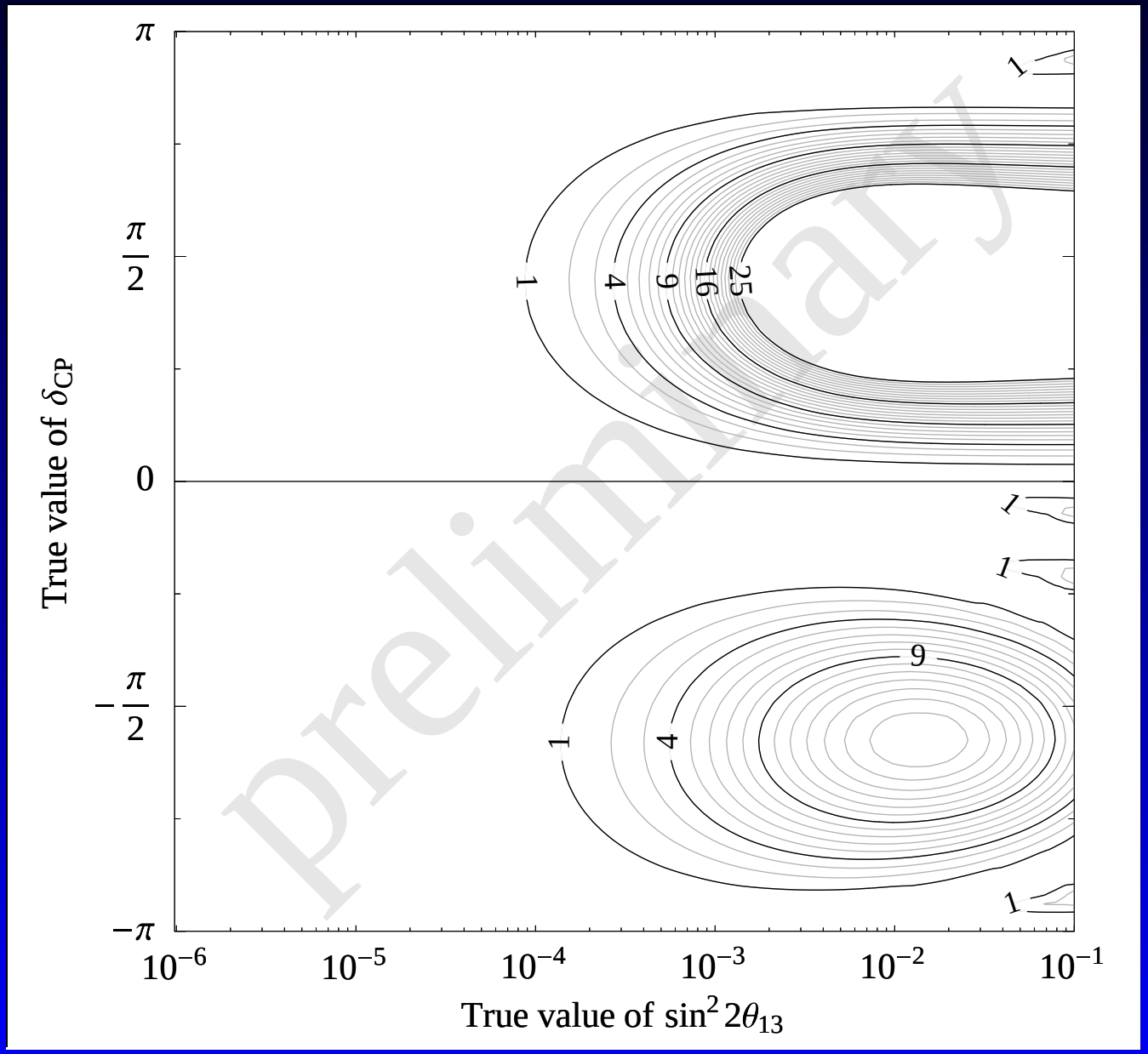
Physics potential can be described by

- Sensitivity to maximal CPV
- Sensitivity any CPV
- Accuracy in δ

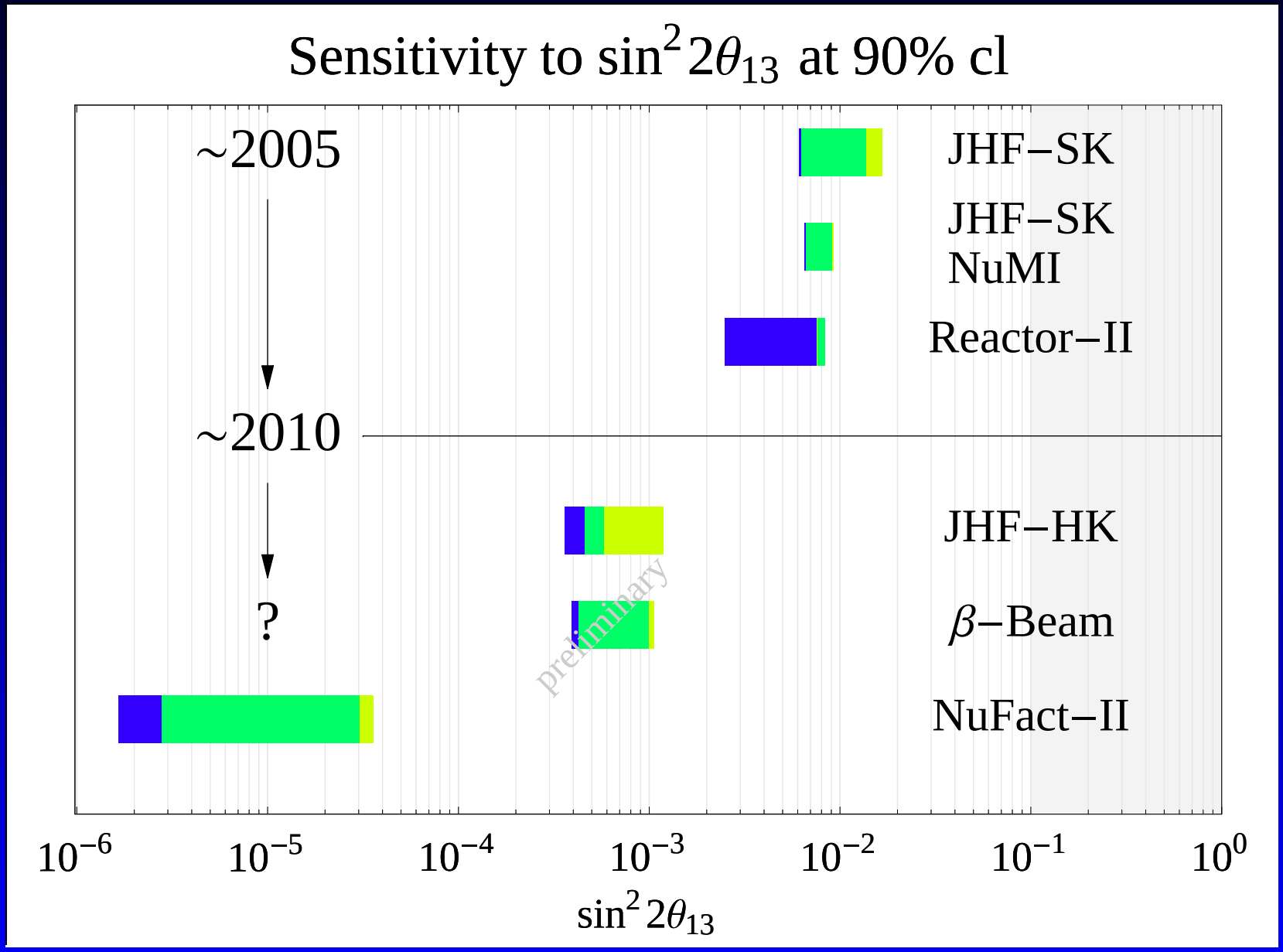
Maximal CPV


$\delta_0 = -\pi/2$
$\delta_0 = +\pi/2$
True value of Δm^2_{21} [10^{-4} eV^2]
True value of $\sin^2 2\theta_{13}$
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
4
9
16
25
6
preliminary

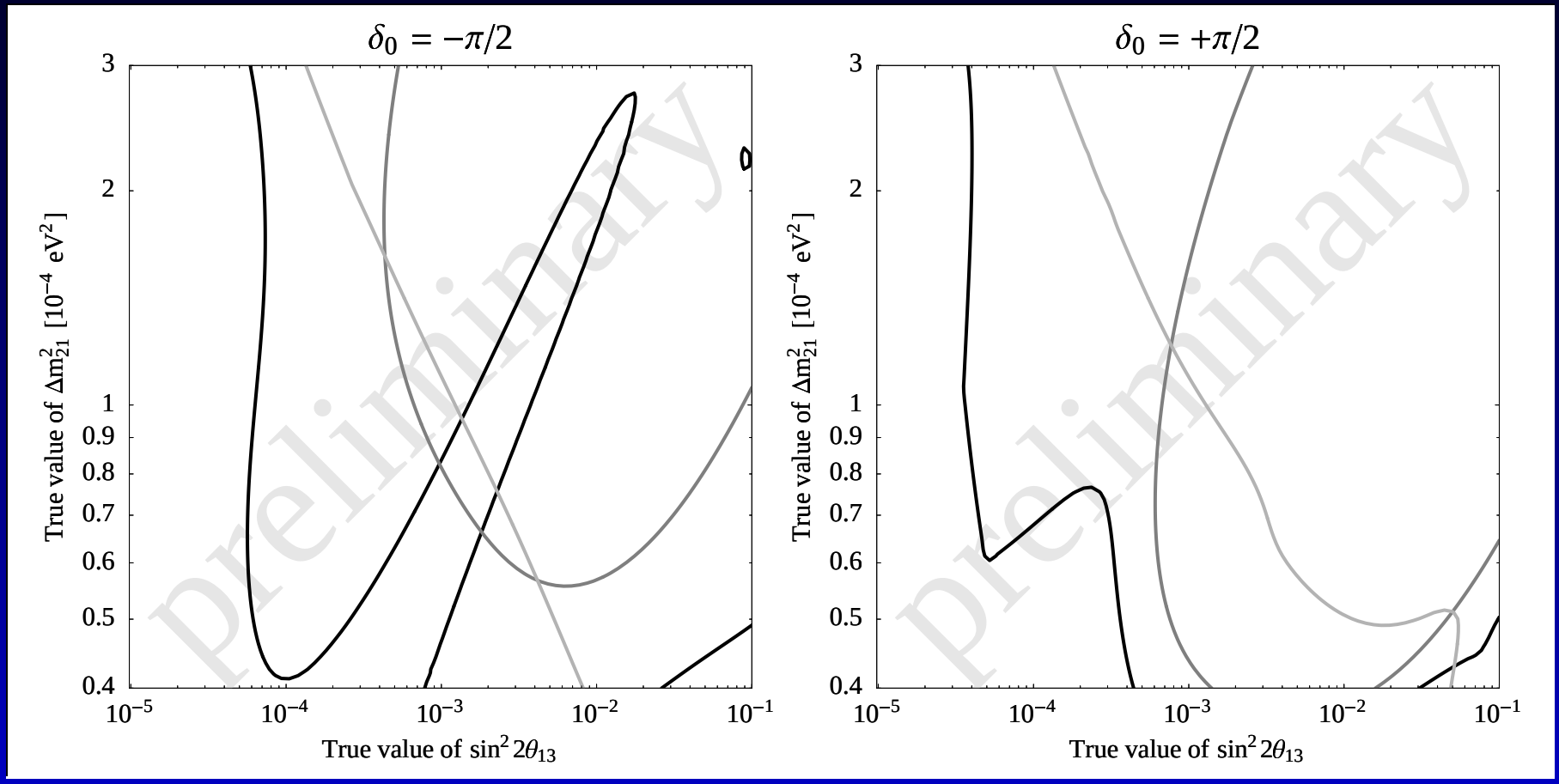
Any CPV


π
π/2
0
−π/2
−π
True value of δ_{CP}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
True value of $\sin^2 2\theta_{13}$
1
4
9
16
25
preliminary

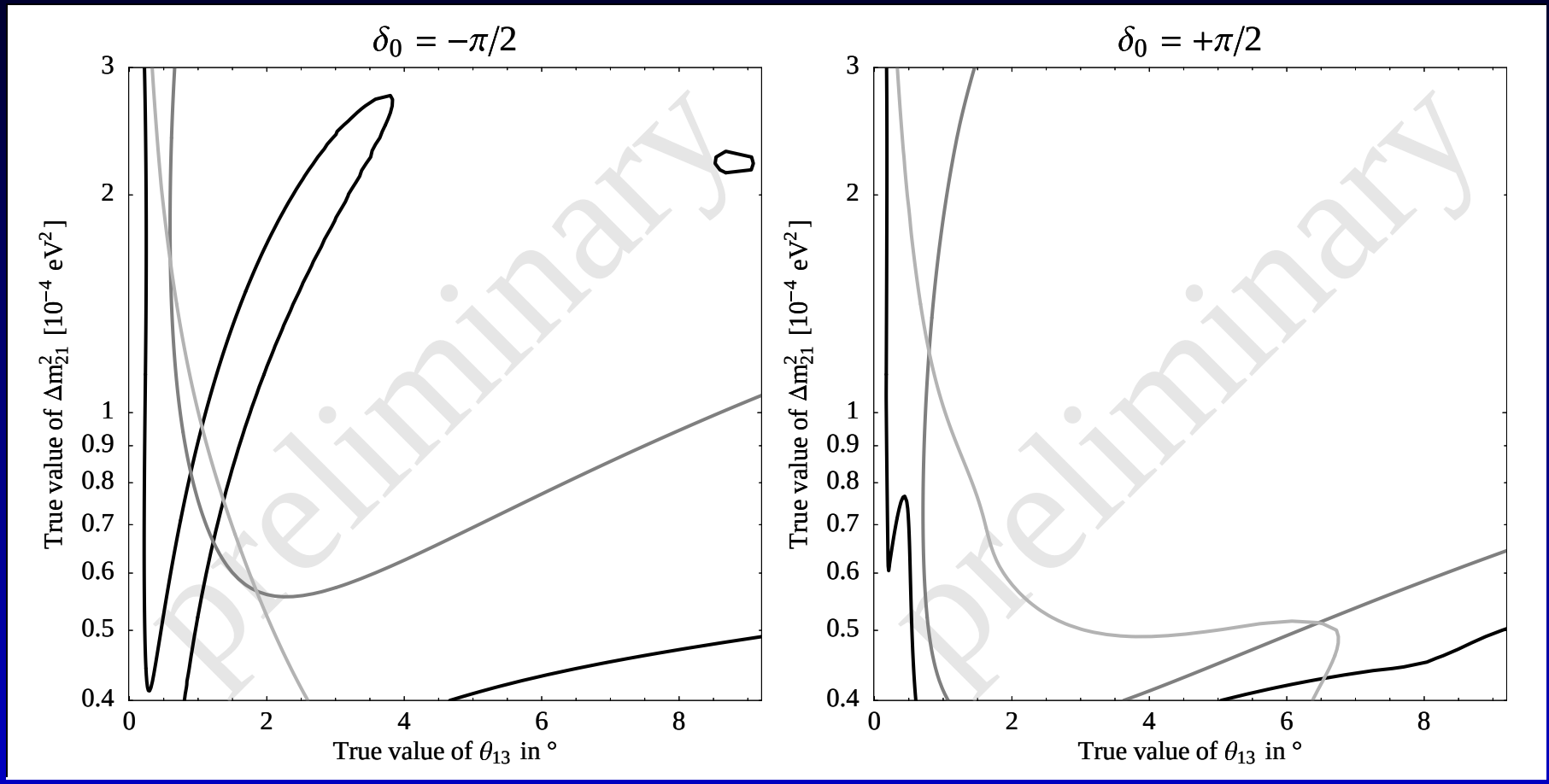
Comparison – θ_{13}-sensitivity



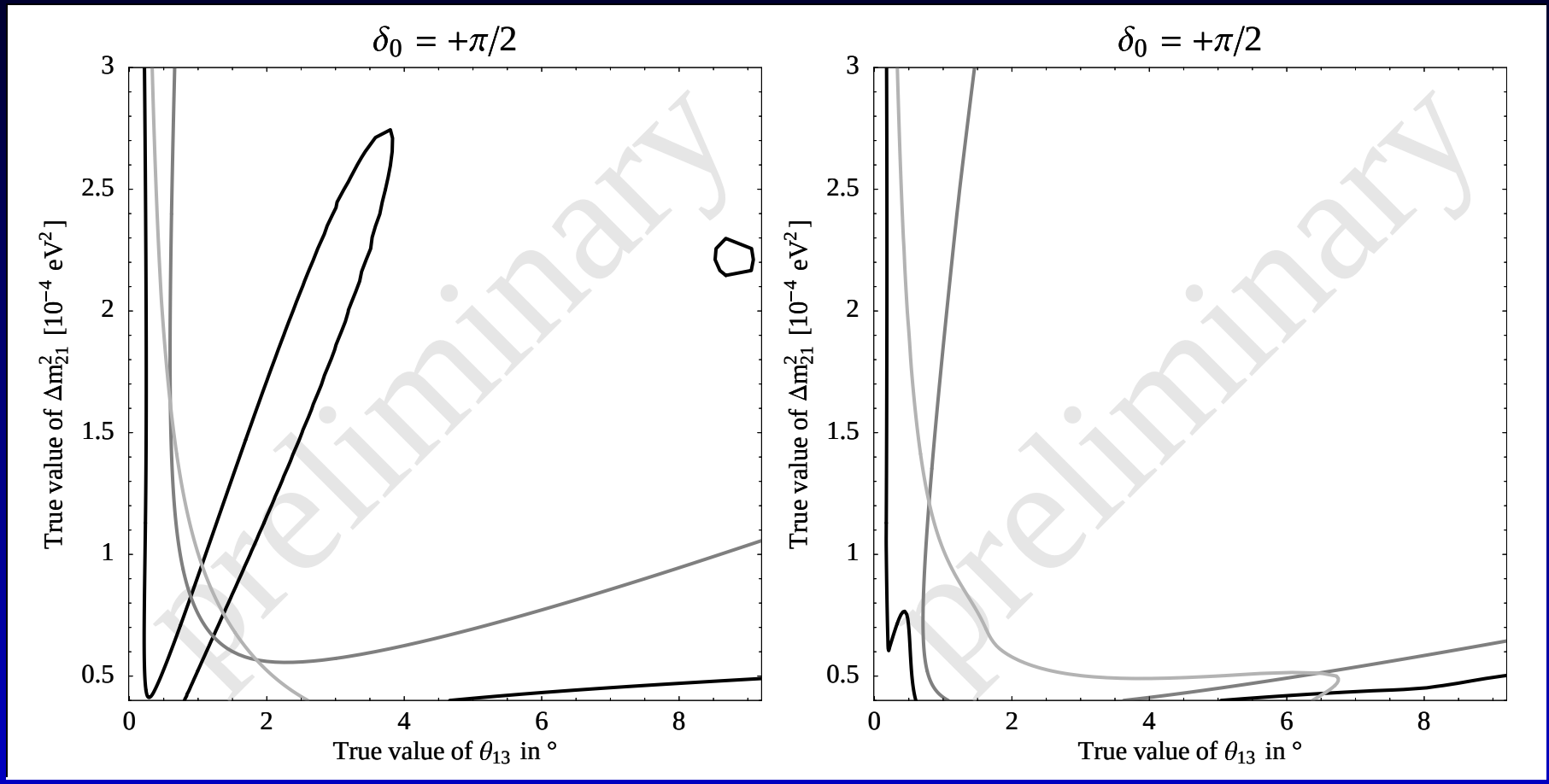
Comparison – maximal CPV



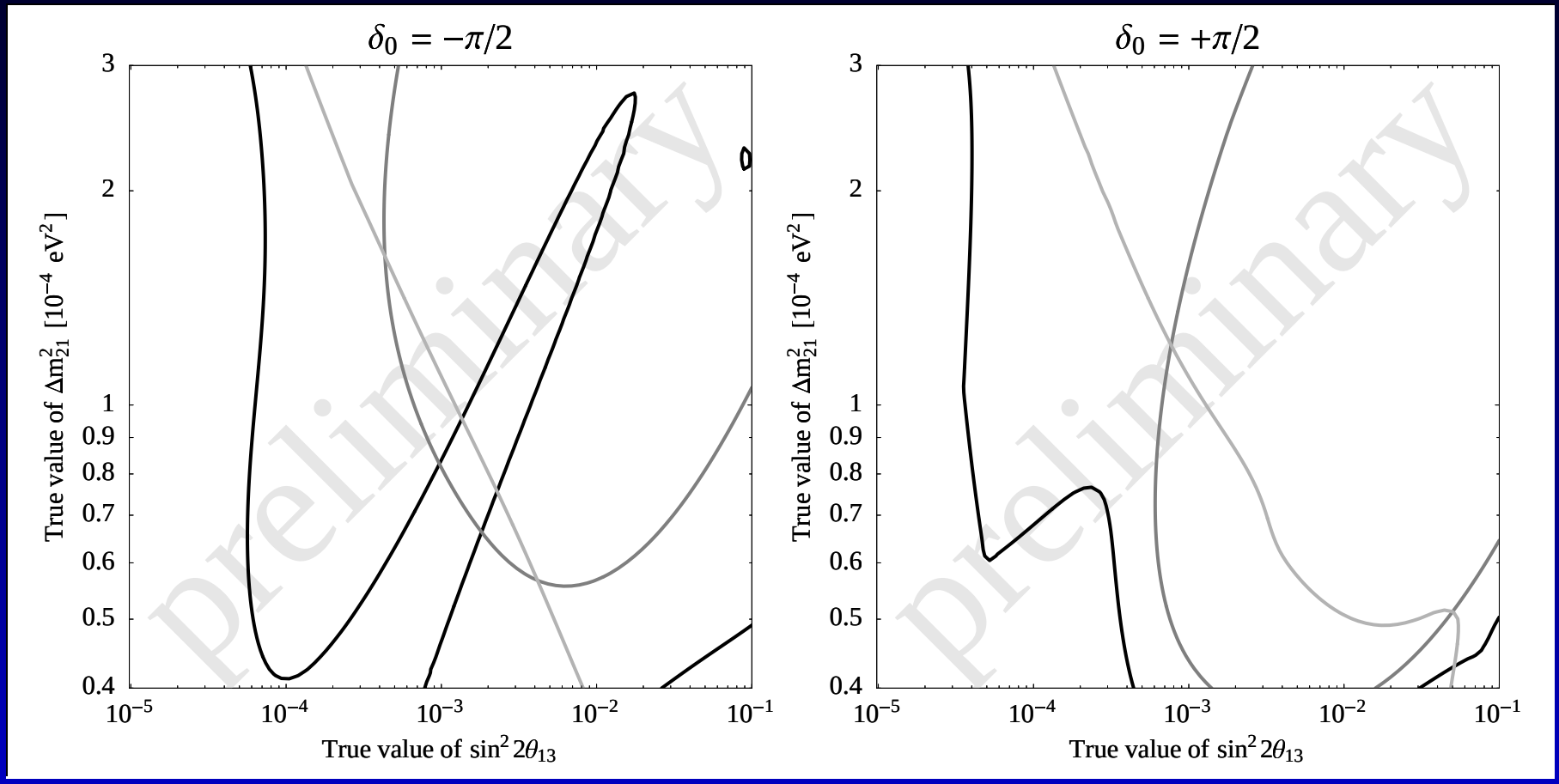
Comparison – maximal CPV



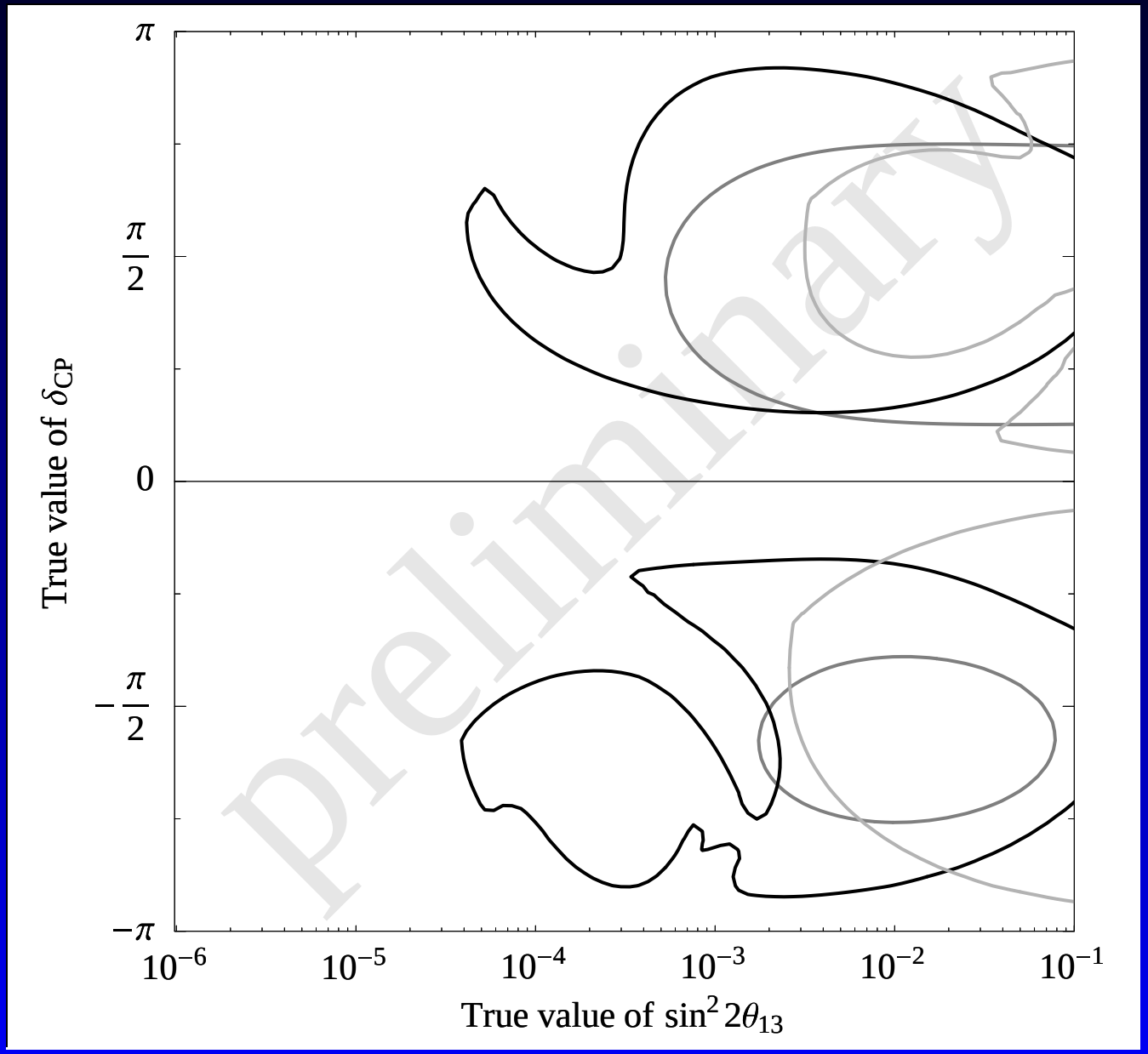
Comparison – maximal CPV



Comparison – maximal CPV



Comparison – any CPV



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there is more to come ...