Testing CPT with the solar neutrino sector

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COST CA18108 Fourth Annual Conference
Based on 2305.06384 [hep-ph]
in collaboration with G. Barenboim, C.A. Ternes and M. Tórtola

CPT violation could manifest as **particles and antiparticles having different masses** and lifetimes.

I. With data from solar neutrinos, we set **new bounds.**

II. **Future** neutrino observatories, including JUNO, Hyper-Kamiokande and DUNE, will further **improve these limits**.

About
CPT symmetry

About **CPT symmetry**

CPT is a keystone of high energy physics which stems from requiring **Lorentz invariance, unitarity and locality**.

R. Jost, Helv.Phys.Acta 30 (1957) 409-416

CPT violation could result from

- Lorentz violation
- **Non-local Lorentz-invariant field theories**

Addazi et al, Prog.Part.Nucl.Phys. 125 (2022) 103948

About CPT symmetry

From **CPT Theorem,** particles and antiparticles have the **same mass and lifetime.**

In **some CPT breaking models,** a mass splitting between particles and antiparticles is realised.

Chaichian et al, Phys.Lett.B 699 (2011)

Chaichian et al, Eur.Phys.J.C 73 (2013) 3, 2349

About CPT symmetry and neutrino oscillations

Neutrino oscillations are sensitive to two mass splittings

$$\Delta m^2_{21} \text{ and } \Delta m^2_{31} \quad (\Delta m^2_{ij} = m^2_i - m^2_j)$$

three mixing angles

$$\theta_{12},\ \theta_{13} \text{ and } \theta_{23}$$

and a phase δ_{CP}.

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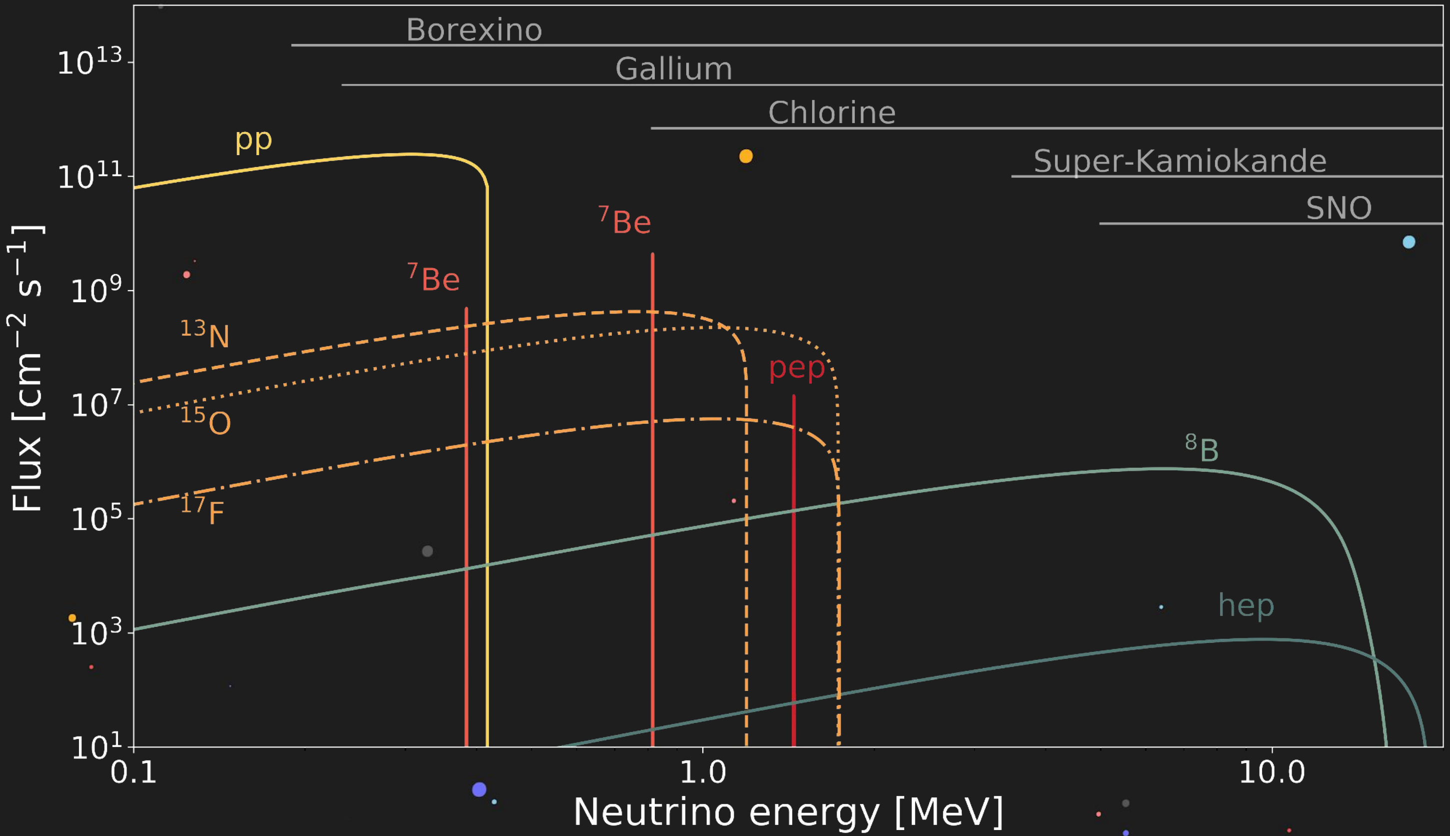
SOLAR SECTOR

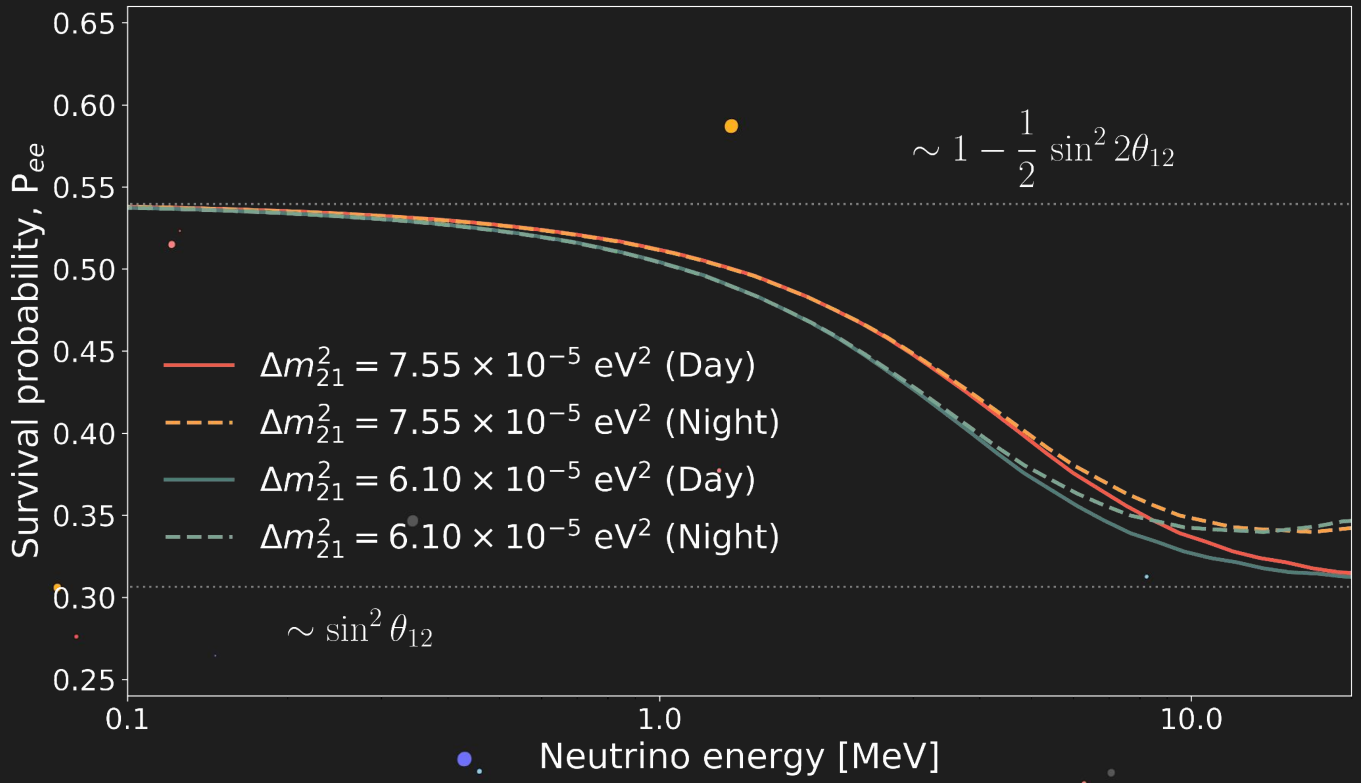
About

solar neutrinos

Solar neutrino **flux**



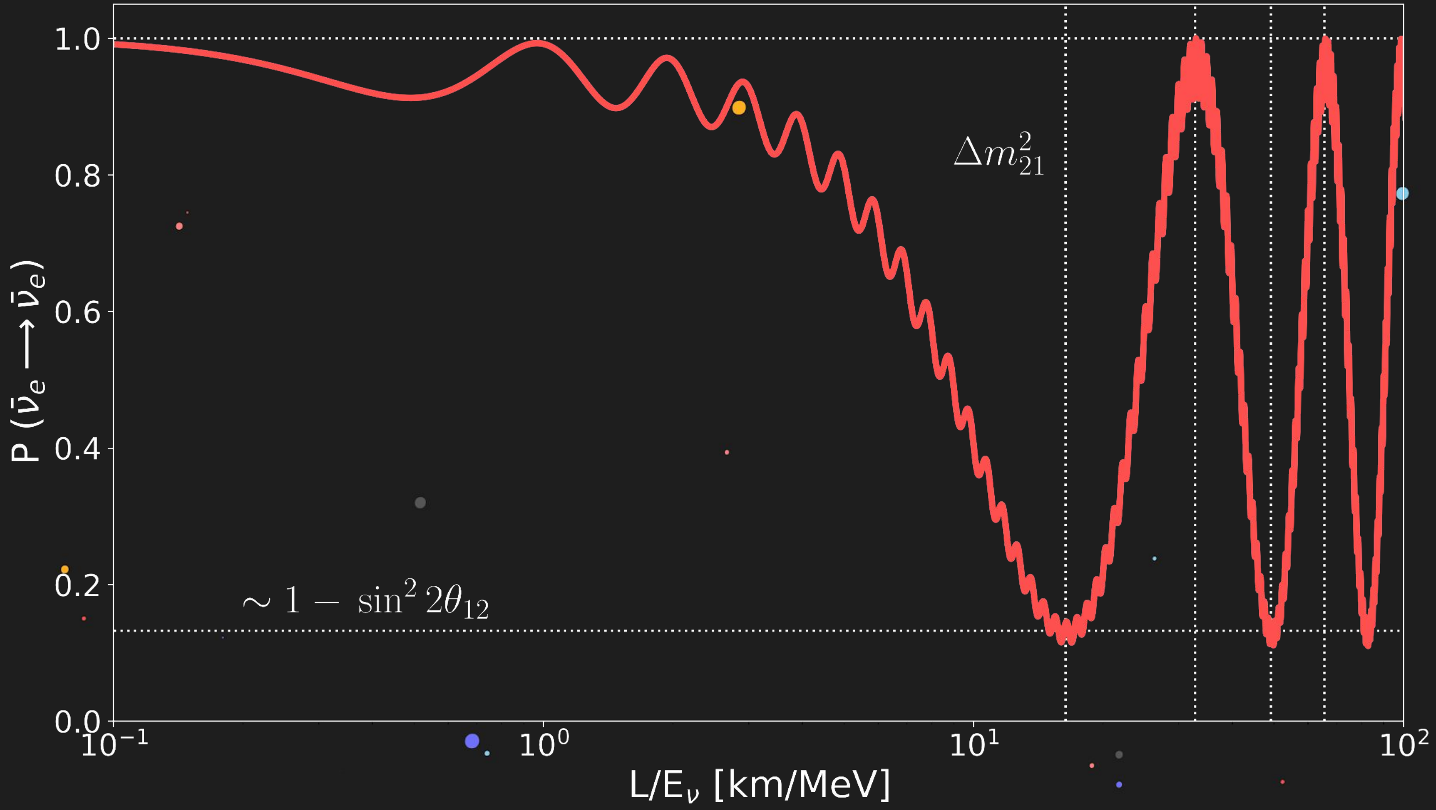
Solar neutrino **electron survival probability**



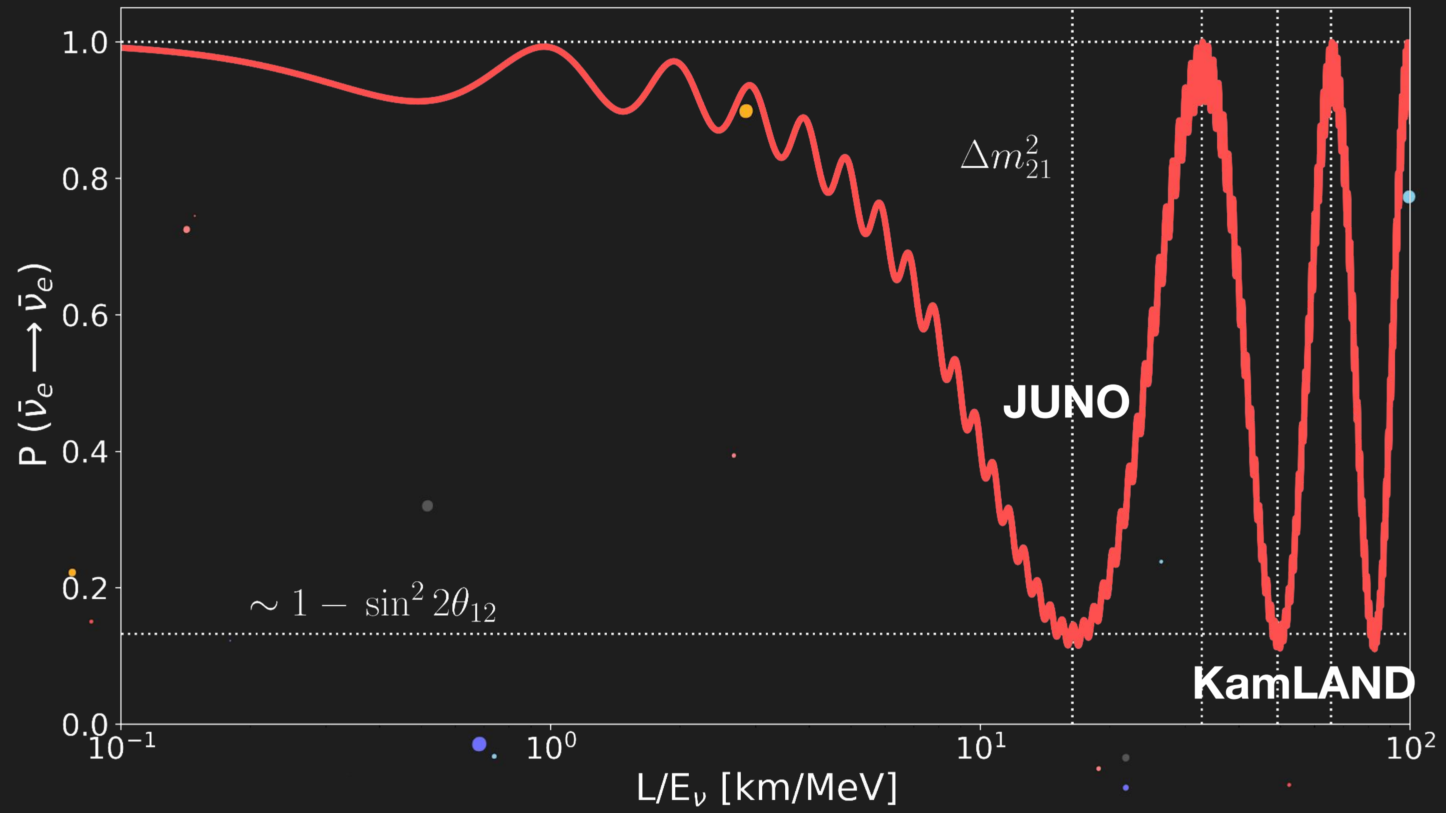
About

reactor antineutrinos

Reactor antineutrino **electron survival probability**



Reactor antineutrino **electron survival probability**



CURRENT STATUS

Limits based on data from 2020

G. Barenboim et al.
JHEP 07 (2020) 155

$$|\Delta(\Delta m_{21}^2)| = |\Delta m_{21}^2 - \Delta\bar{m}_{21}^2| < 4.7 \times 10^{-5}\ \text{eV}^2$$

$$|\Delta(\Delta m_{31}^2)| = |\Delta m_{31}^2 - \Delta\bar{m}_{31}^2| < 2.5 \times 10^{-4}\ \text{eV}^2$$

$$|\Delta(\sin^2\theta_{12})| = |\sin^2\theta_{12} - \sin^2\bar{\theta}_{12}| < 0.14$$

$$|\Delta(\sin^2\theta_{13})| = |\sin^2\theta_{13} - \sin^2\bar{\theta}_{13}| < 0.029$$

$$|\Delta(\sin^2\theta_{23})| = |\sin^2\theta_{23} - \sin^2\bar{\theta}_{23}| < 0.19$$

CURRENT STATUS

Updated limits

$$|\Delta(\Delta m^2_{21})| = |\Delta m^2_{21} - \Delta \bar{m}^2_{21}| < 3.7 \times 10^{-5}\ \mathrm{eV}^2$$

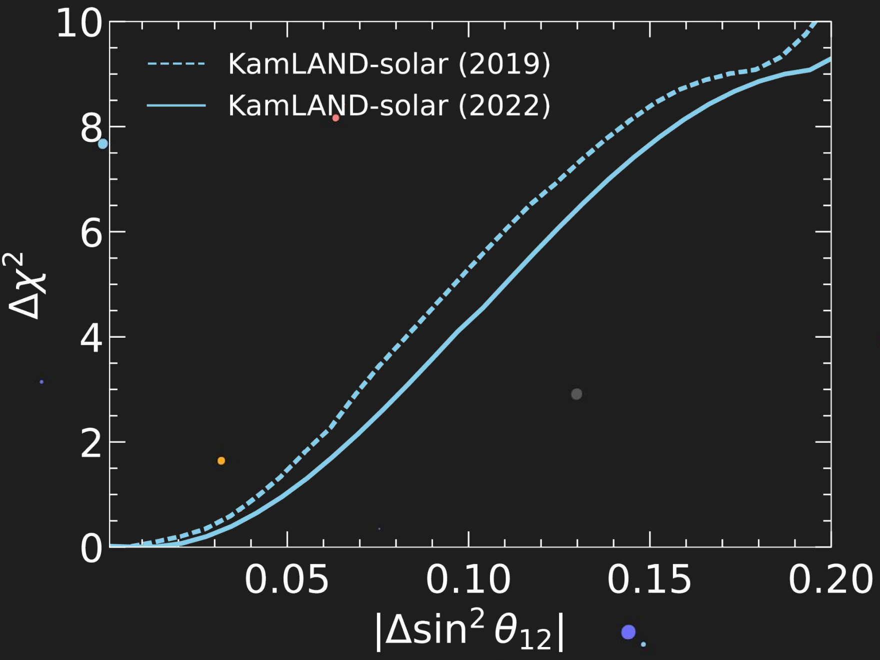
$$|\Delta(\Delta m^2_{31})| = |\Delta m^2_{31} - \Delta \bar{m}^2_{31}| < 2.5 \times 10^{-4}\ \mathrm{eV}^2$$

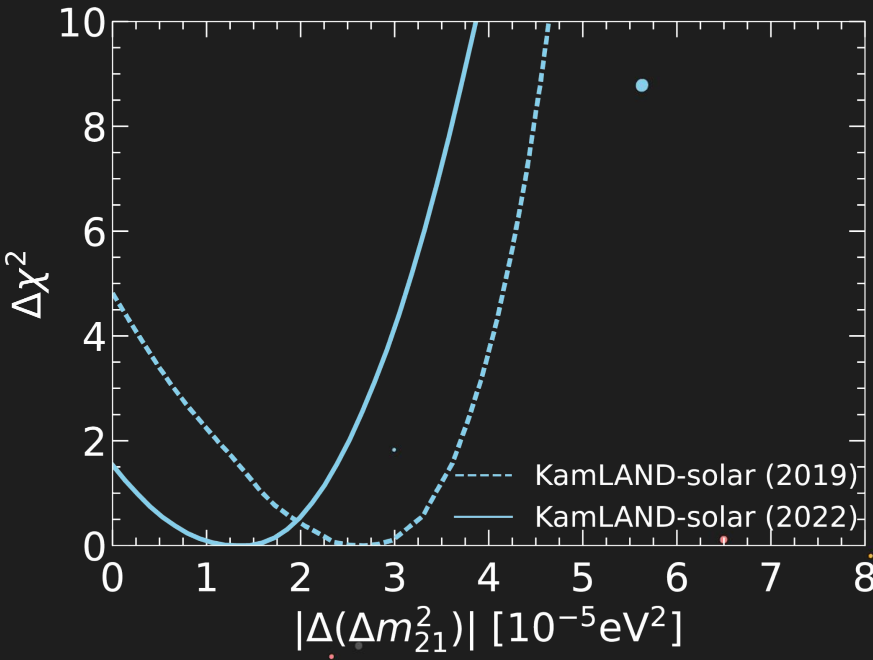
$$|\Delta(\sin^2\theta_{12})| = |\sin^2\theta_{12} - \sin^2\bar{\theta}_{12}| < 0.187$$

$$|\Delta(\sin^2\theta_{13})| = |\sin^2\theta_{13} - \sin^2\bar{\theta}_{13}| < 0.029$$

$$|\Delta(\sin^2\theta_{23})| = |\sin^2\theta_{23} - \sin^2\bar{\theta}_{23}| < 0.19$$

CURRENT STATUS





FUTURE PROSPECTS

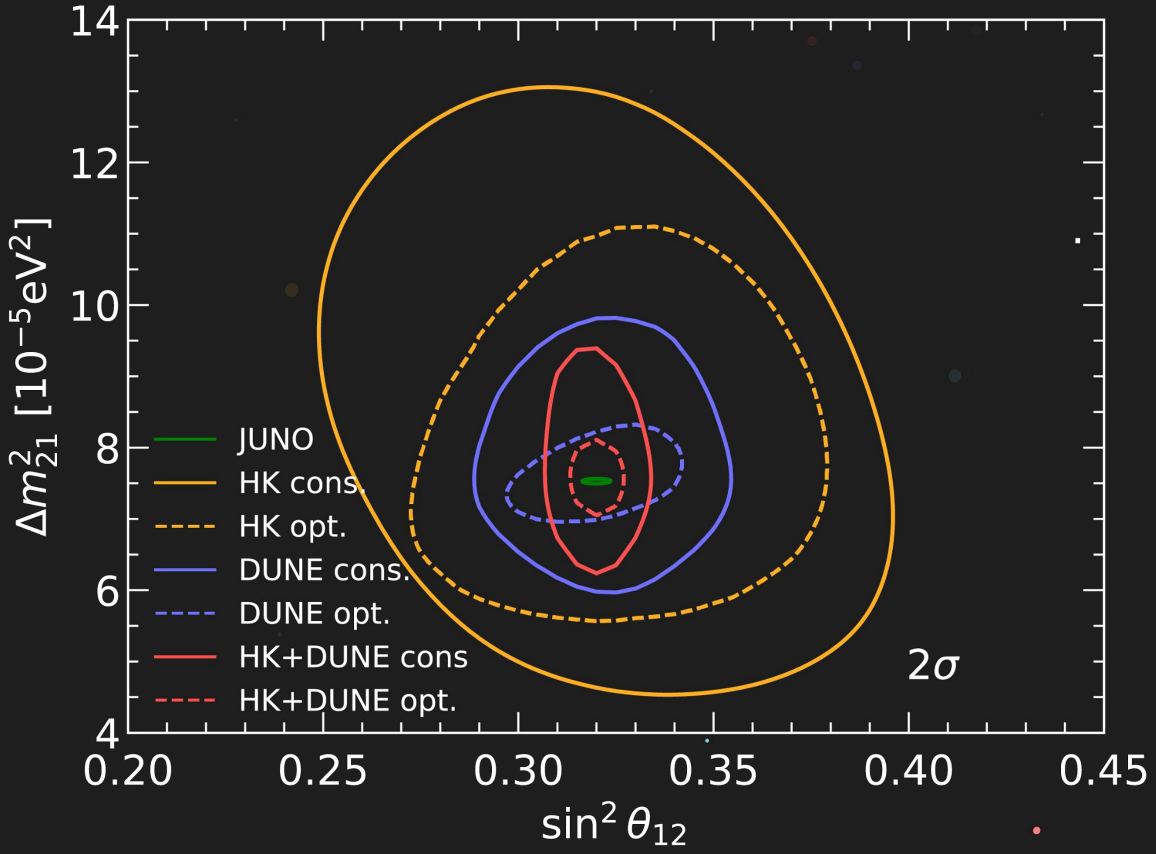
JUNO: medium baseline reactor **antineutrinos**

Hyper-Kamiokande: high-energy solar **neutrinos**

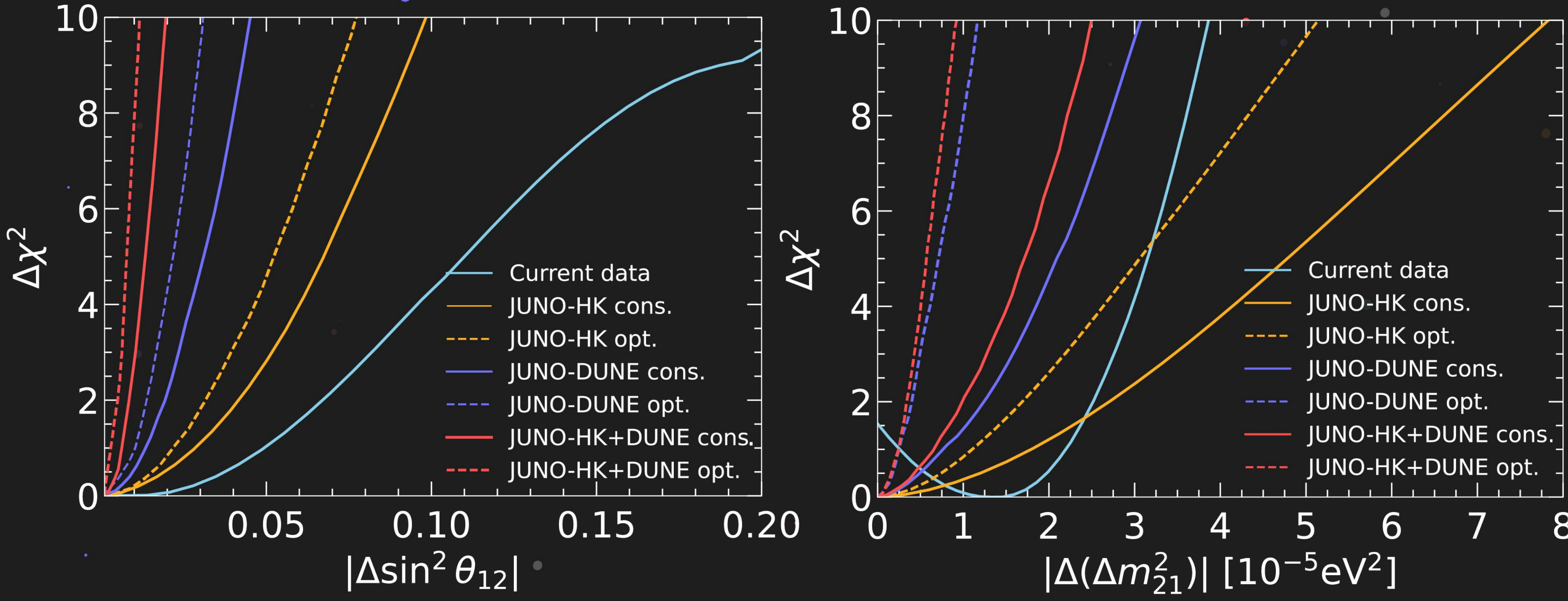
DUNE: high-energy solar **neutrinos**

Extremely **sensitive.**

We consider two sets of experimental details: **conservative** and **optimal** for each experiment.



FUTURE PROSPECTS



FUTURE PROSPECTS

From **neutrinos**:

	$\lvert\Delta \sin^2\theta_{12}\rvert$	$\lvert\Delta(\Delta m^2_{21})\rvert$ $[10^{-5}\,\mathrm{eV}^2]$
current bound	0.187	3.7
JUNO + HK + DUNE conservative	0.018	2.4
JUNO + HK + DUNE optimal	0.011	0.8

Current limit from the **kaon system**:

$$|m^2(K^0) - m^2(\overline{K}^0)| < 0.25\ \mathrm{eV}^2$$

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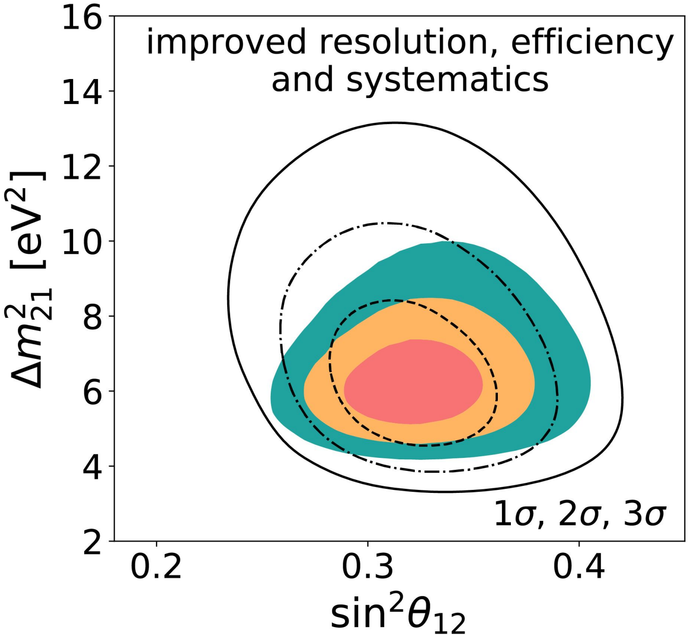
QUANTUM · GRAVITY · MULTI · MESSENGER

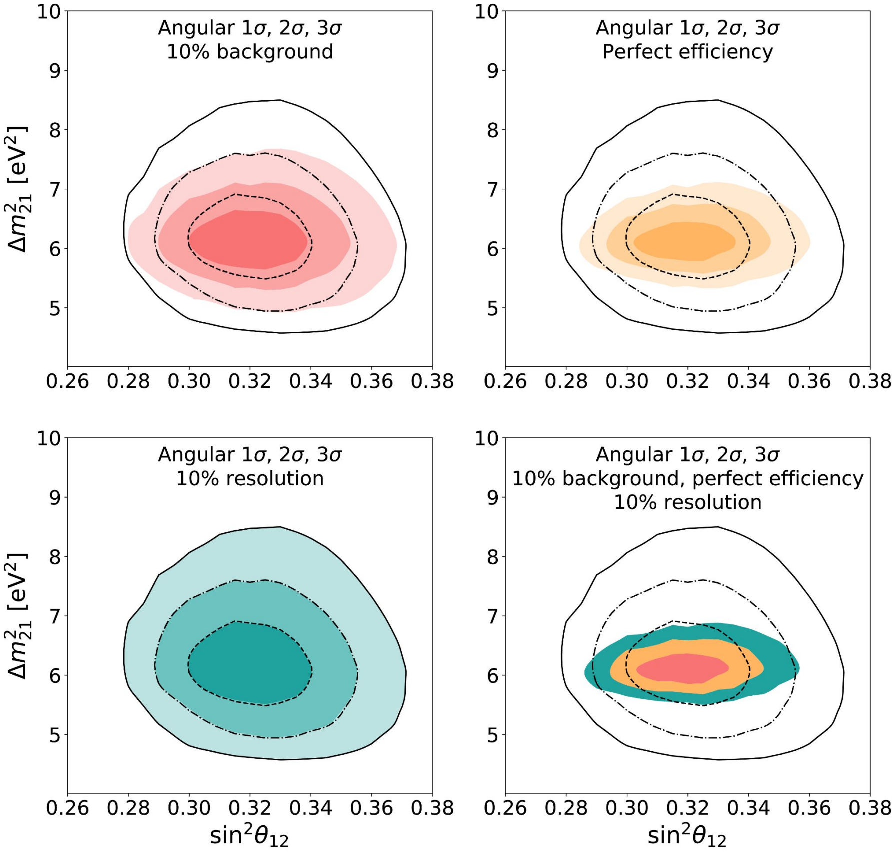
SPARE SLIDES

Hyper-Kamiokande

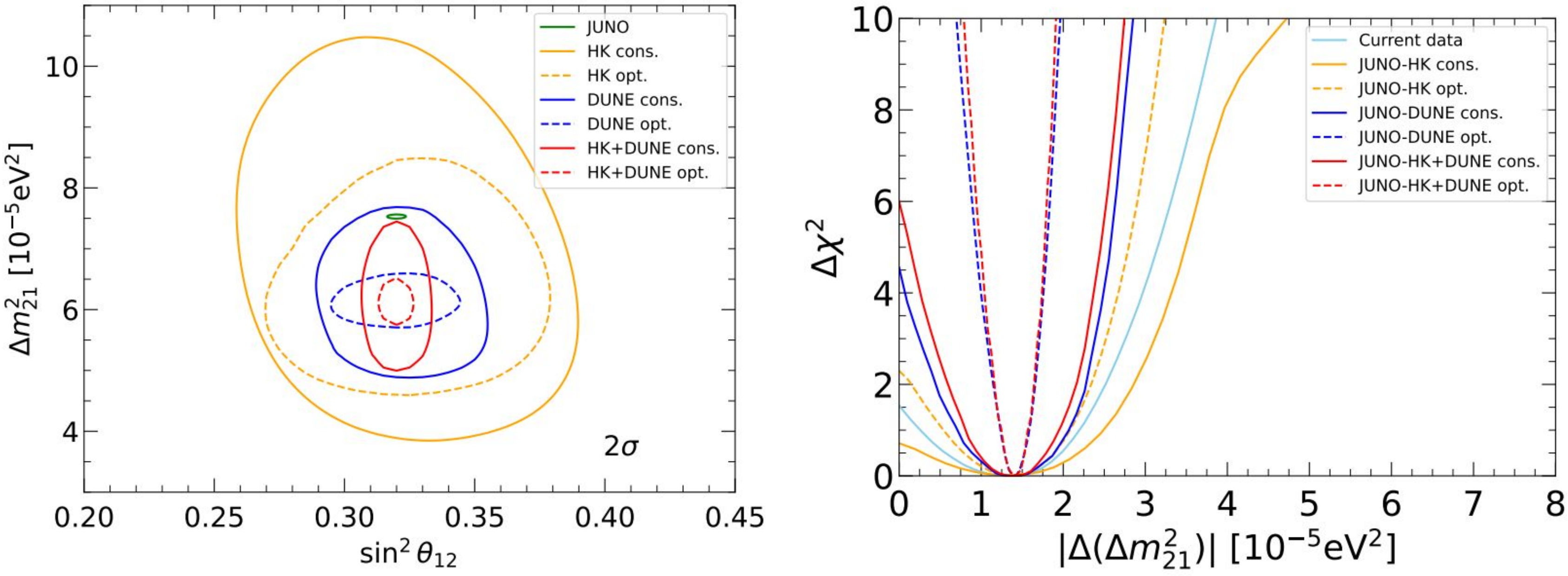


Factor 2 improvement with respect to Super-Kamiokande IV

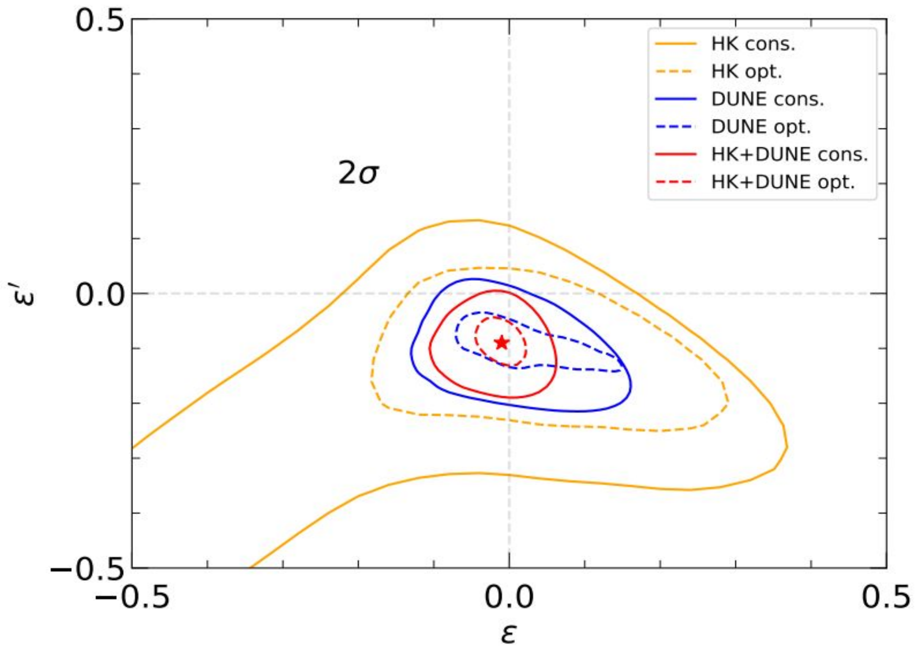
DUNE


Angular 1σ, 2σ, 3σ
10% background
Angular 1σ, 2σ, 3σ
Perfect efficiency
Angular 1σ, 2σ, 3σ
10% resolution
Angular 1σ, 2σ, 3σ
10% background, perfect efficiency
10% resolution
Δm^2_{21} [eV^2]
$\sin^2\theta_{12}$

Measuring CPT violation



Disentangling CPT and NSI



Solar neutrino **detection**

$$\nu_e + {}^{37}\mathrm{Cl} \longrightarrow {}^{37}\mathrm{Ar} + e^-$$

$$\nu_e + {}^{71}\mathrm{Ga} \longrightarrow {}^{71}\mathrm{Ge} + e^-$$

$$\nu_x + D \longrightarrow \nu_x + p + n$$

$$\nu_e + D \longrightarrow p + p + e^-$$

$$\nu_x + e^- \longrightarrow \nu_x + e^-$$

$$\nu_e + {}^{40}\mathrm{Ar} \longrightarrow {}^{40}\mathrm{K}^* + e^-$$