Solar neutrino anomaly and NSI

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Background Mitigation Strategies Workshop

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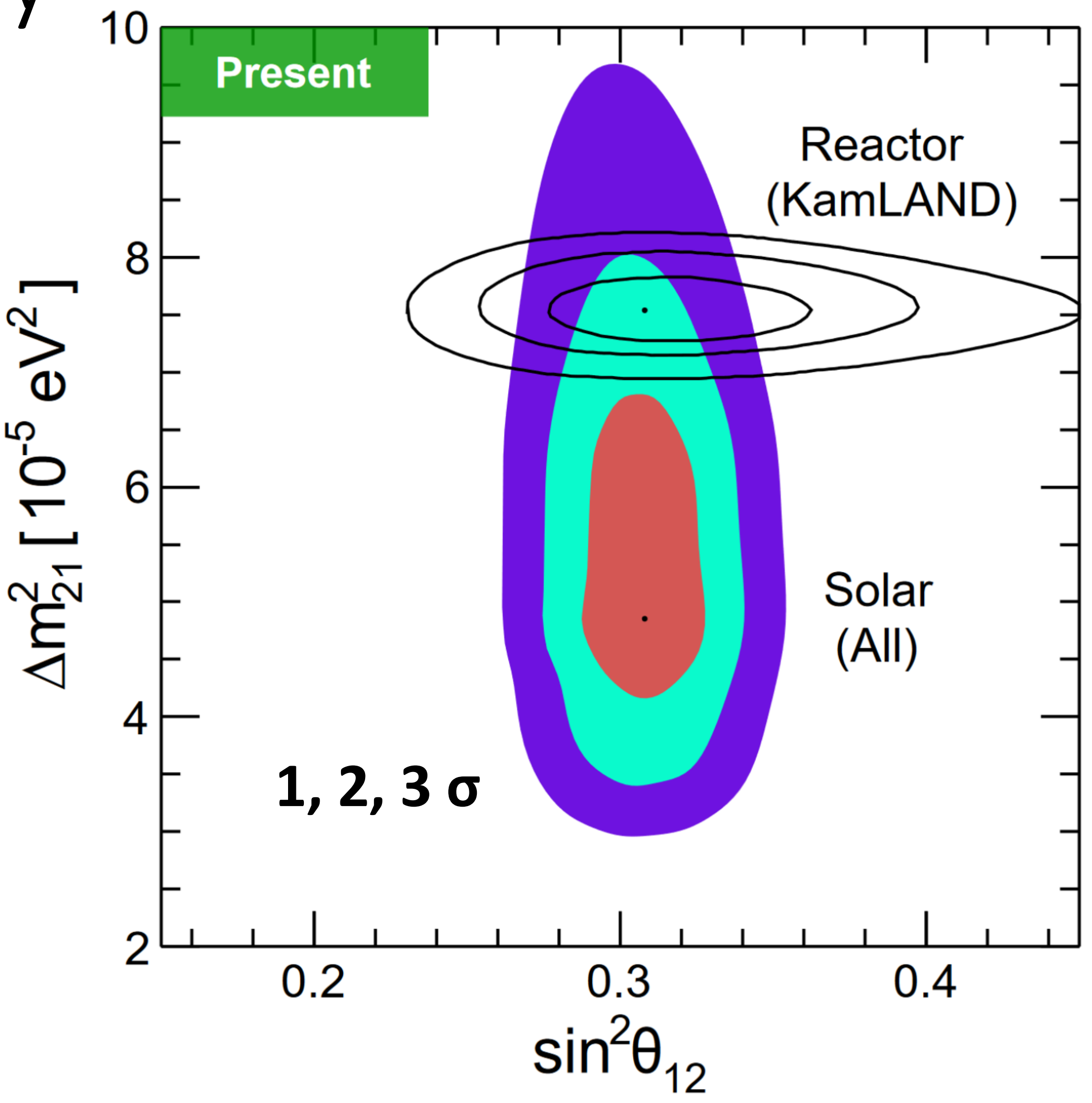
Outline

- Solar neutrino anomaly
- Neutral-current NSI in Sun
- Current NSI constraints
- Resulting solar ν_e survival probability with NSI
- How well could DUNE do?
  - Estimated DUNE sensitivity
- Conclusions

Solar neutrino anomaly

F. Capozzi, S.W. Li, G. Zhu, J.F. Beacom (2018)
arXiv:1808.08232

- ~2σ discrepancy in solar Δm^2 measured by solar experiments and KamLAND



Neutral-current NSI in Sun

O.G. Miranda, M.A. Tórtola, J.W.F. Valle (2006)
arXiv:hep-ph/0406280
(extended with up-quark NSI)

- 2-flavor model

SM vacuum oscillations + matter effect **NSI**

  - $H = \begin{pmatrix} -\frac{\Delta m^2}{4E}\cos 2\theta + \sqrt{2}G_F N_e & \frac{\Delta m^2}{4E}\sin 2\theta \\ \frac{\Delta m^2}{4E}\sin 2\theta & \frac{\Delta m^2}{4E}\cos 2\theta \end{pmatrix} + \sqrt{2}G_F(N_d + N_u)\begin{pmatrix} 0 & \varepsilon \\ \varepsilon & \varepsilon' \end{pmatrix}$

  - Measurement: $P(\nu_e \to \nu_e) = \frac{1}{2}[1 + \cos 2\theta \cos 2\theta_m]$

    - $\cos 2\theta_m = \frac{\Delta m^2 \cos 2\theta - 2\sqrt{2}EG_F\left(N_e - \varepsilon'(N_d + N_u)\right)}{[\Delta m^2]_{matter}}$
      - $[\Delta \mathrm{m}^2]^2_{matter} = \left[\Delta m^2 \cos 2\theta - 2\sqrt{2}EG_F\left(N_e - \varepsilon'(N_d + N_u)\right)\right]^2 + \left[\Delta \mathrm{m}^2 \sin 2\theta + 4\sqrt{2}\varepsilon EG_F(N_d + N_u)\right]^2$

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NSI$_1$ **ε = 0**

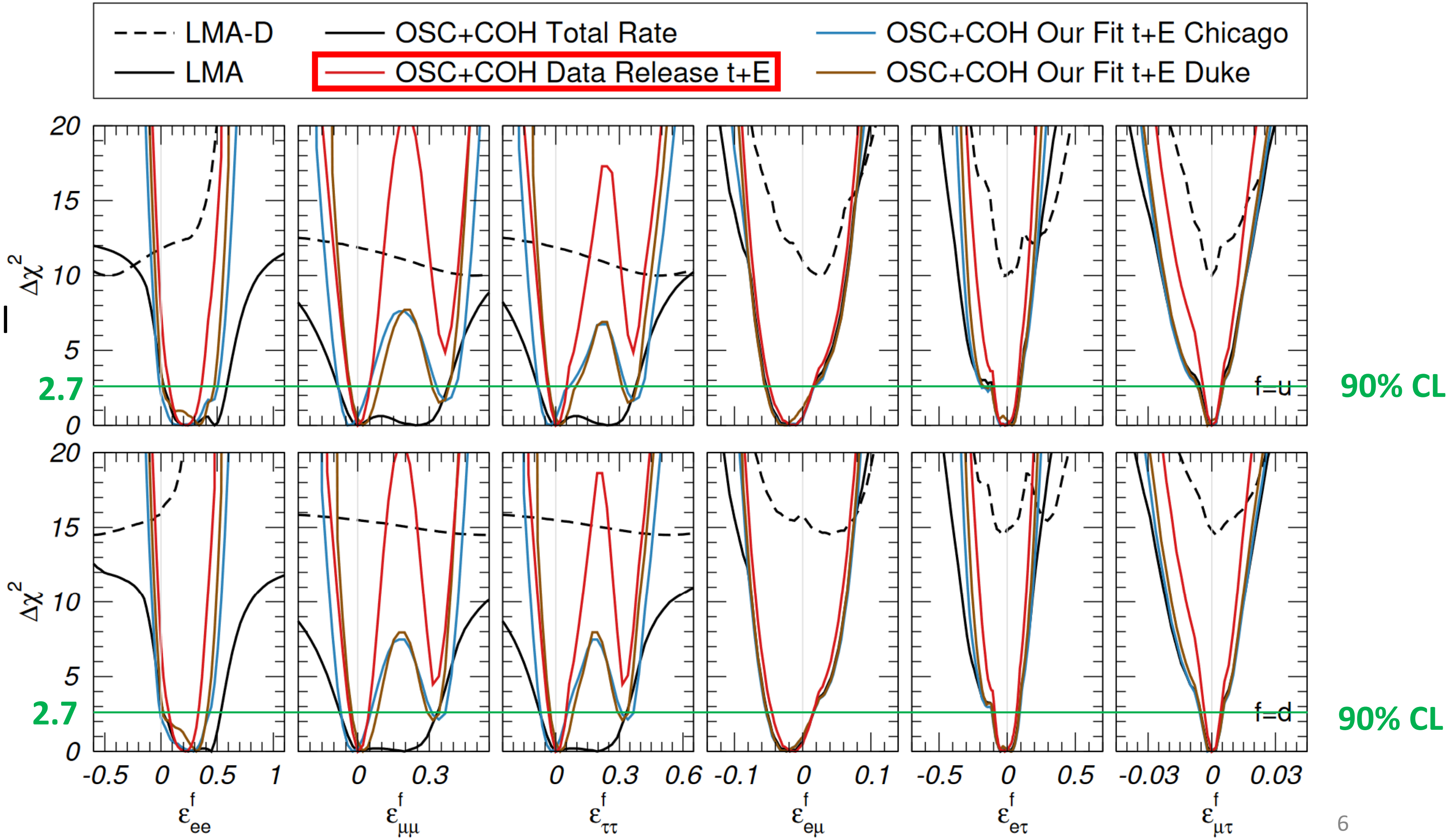
  - $[\Delta \text{m}^2]^2_{matter} = \left[\Delta m^2 \cos 2\theta - 2\sqrt{2}EG_F\left(N_e - \varepsilon'(N_d + N_u)\right)\right]^2 + \left[\Delta \text{m}^2 \sin 2\theta + 4\sqrt{2}\varepsilon E G_F(N_d + N_u)\right]^2$

P. Coloma, I. Esteban, M.C. Gonzalez-Garcia, M. Maltoni (2019)
arXiv:1911.09109

Current NSI constraints

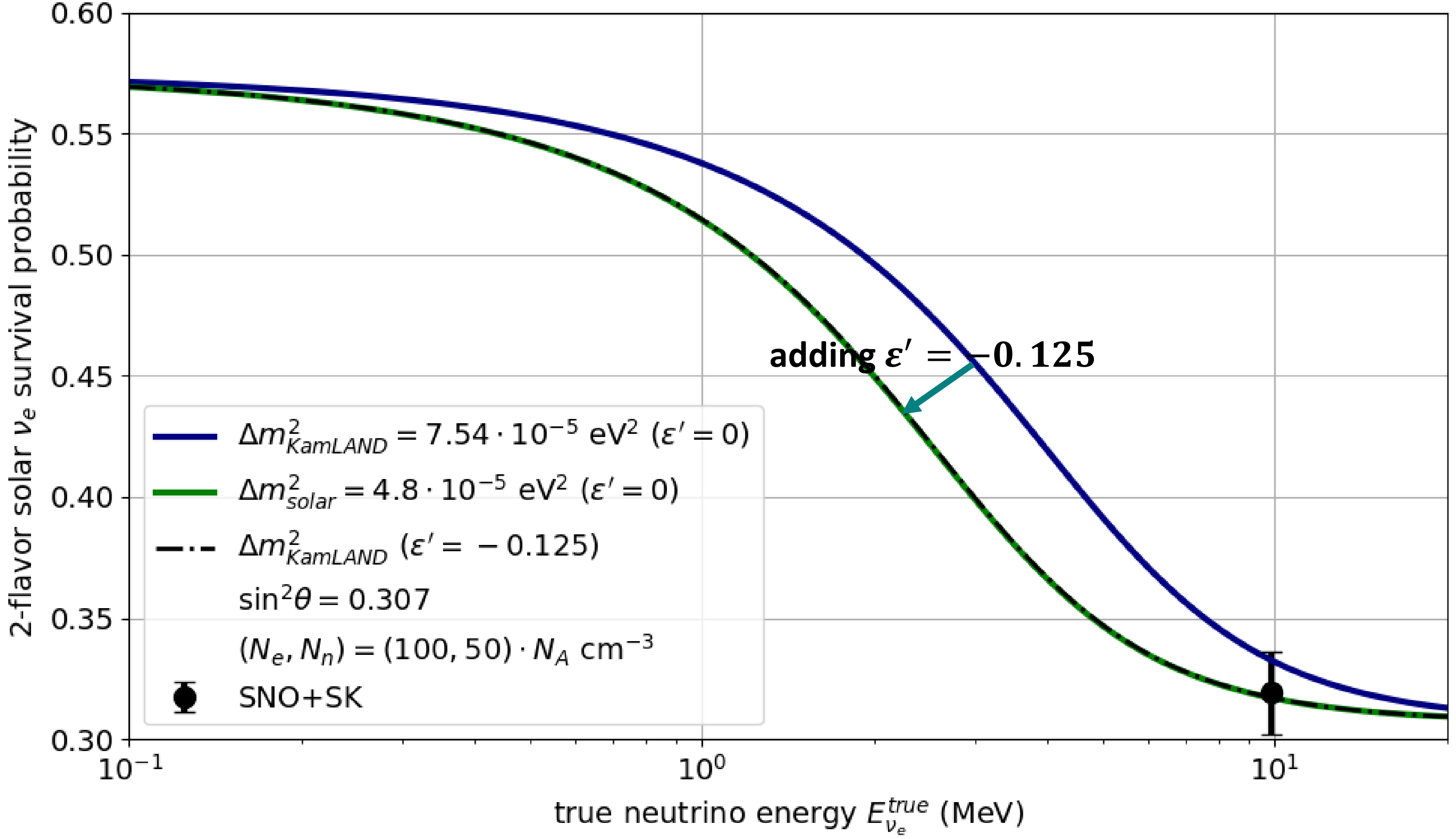
Assume red curves as current constraints

- Our simplified model
  - $\varepsilon_{ee}^{d} = \varepsilon_{ee}^{u} = -\varepsilon'$
  - $\varepsilon_{\mu\mu}^{d} = \varepsilon_{\mu\mu}^{u} = \cdots = 0$



Resulting solar ν_e survival probability with NSI

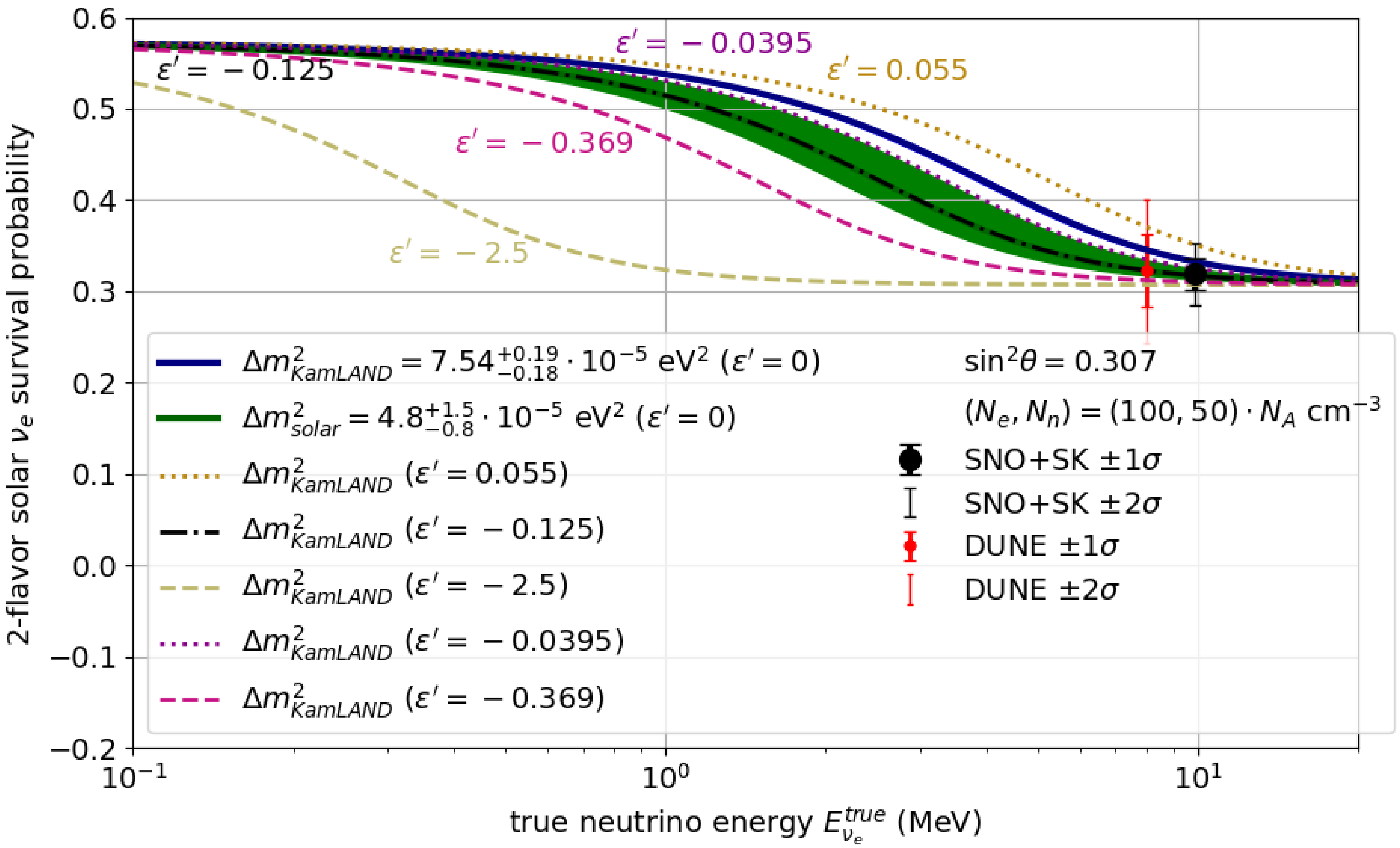
- Correcting KamLAND result (**blue**) with $\varepsilon' = -0.125$ (dot-dashed) produces same survival probability as solar fit (**green**)



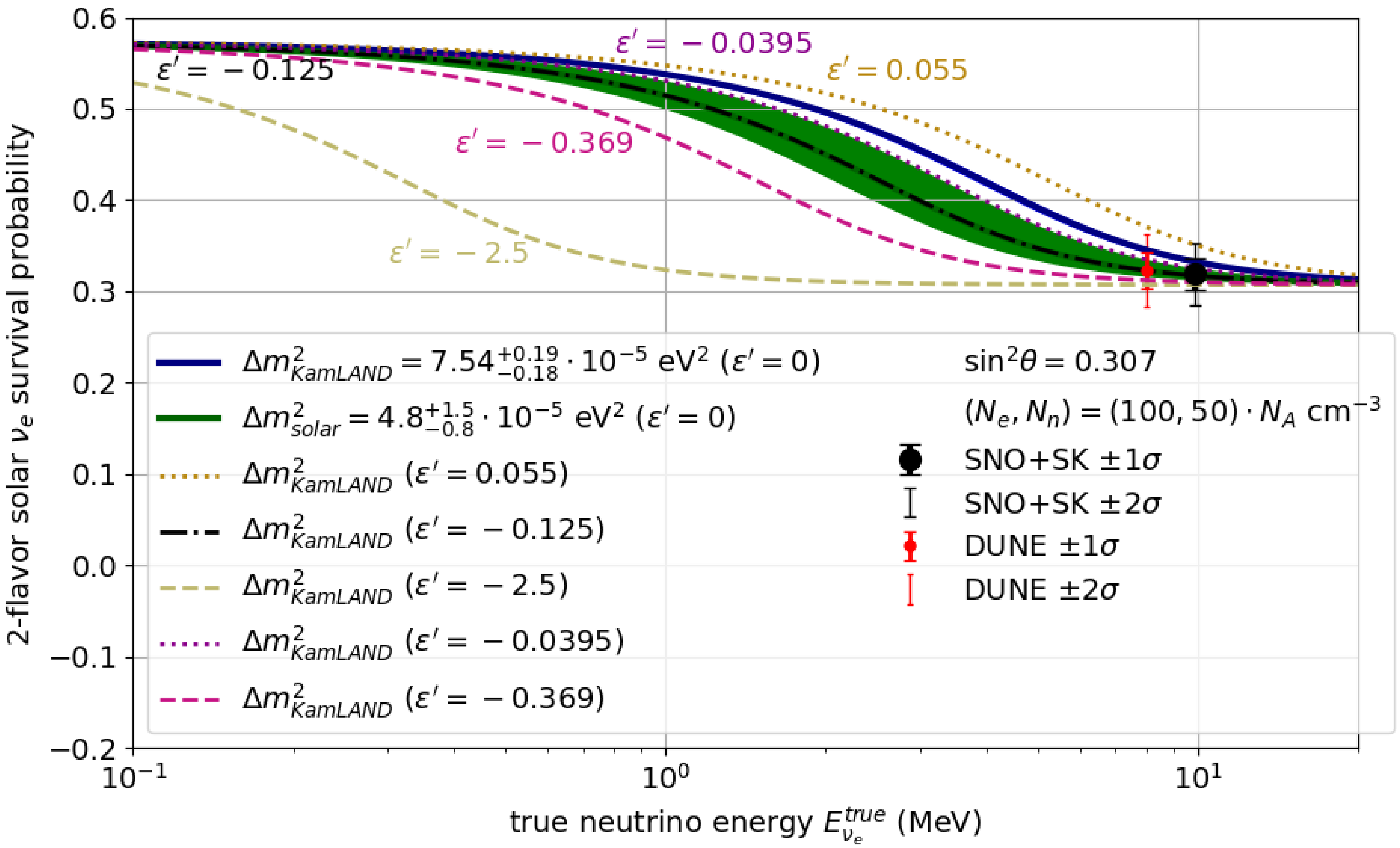
How well could DUNE do?

- SNO+SK detected ~80,000 ν's
- Assume best-case 15,000 solar ν's per 10 kt·year detected in DUNE
  - $E_{\nu}^{mean} = 8$ MeV ($E_{vis}^{threshold} = 3 - 4$ MeV)
  - Ignore systematics
- ~40 kt·years of DUNE could already validate SNO+SK
  - 10 kt·years: 0.19 SNO+SK (2.3 σ_{SNO+SK})
  - 40 kt·years: 0.75 SNO+SK (1.2 σ_{SNO+SK})
  - 160 kt·years: 3 SNO+SK (0.58 σ_{SNO+SK})
  - 400 k·t years: 7.5 SNO+SK (0.37 σ_{SNO+SK})
  - 1600 k·t years: 30 SNO+SK (0.18 σ_{SNO+SK})

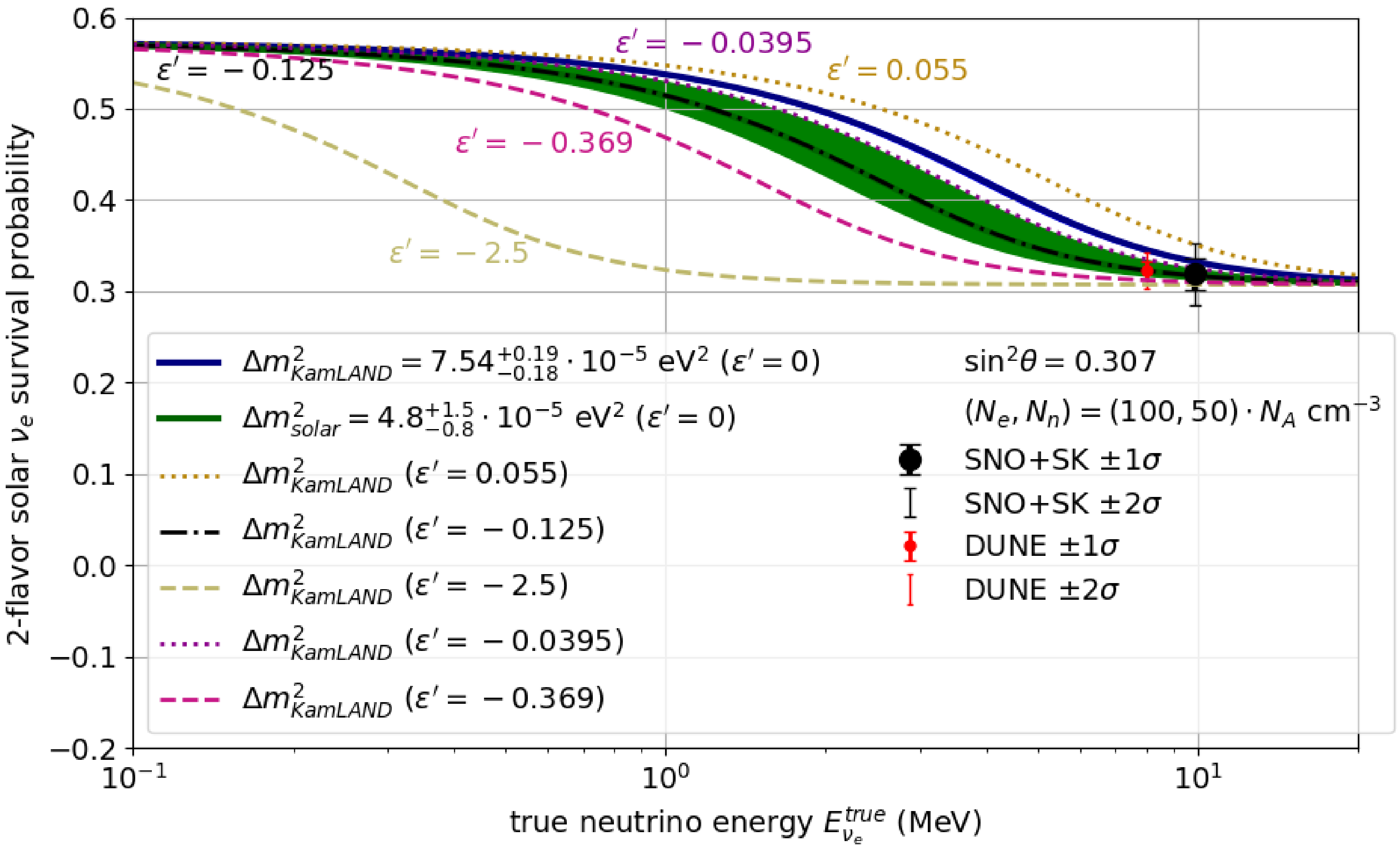
10 kt·years of DUNE



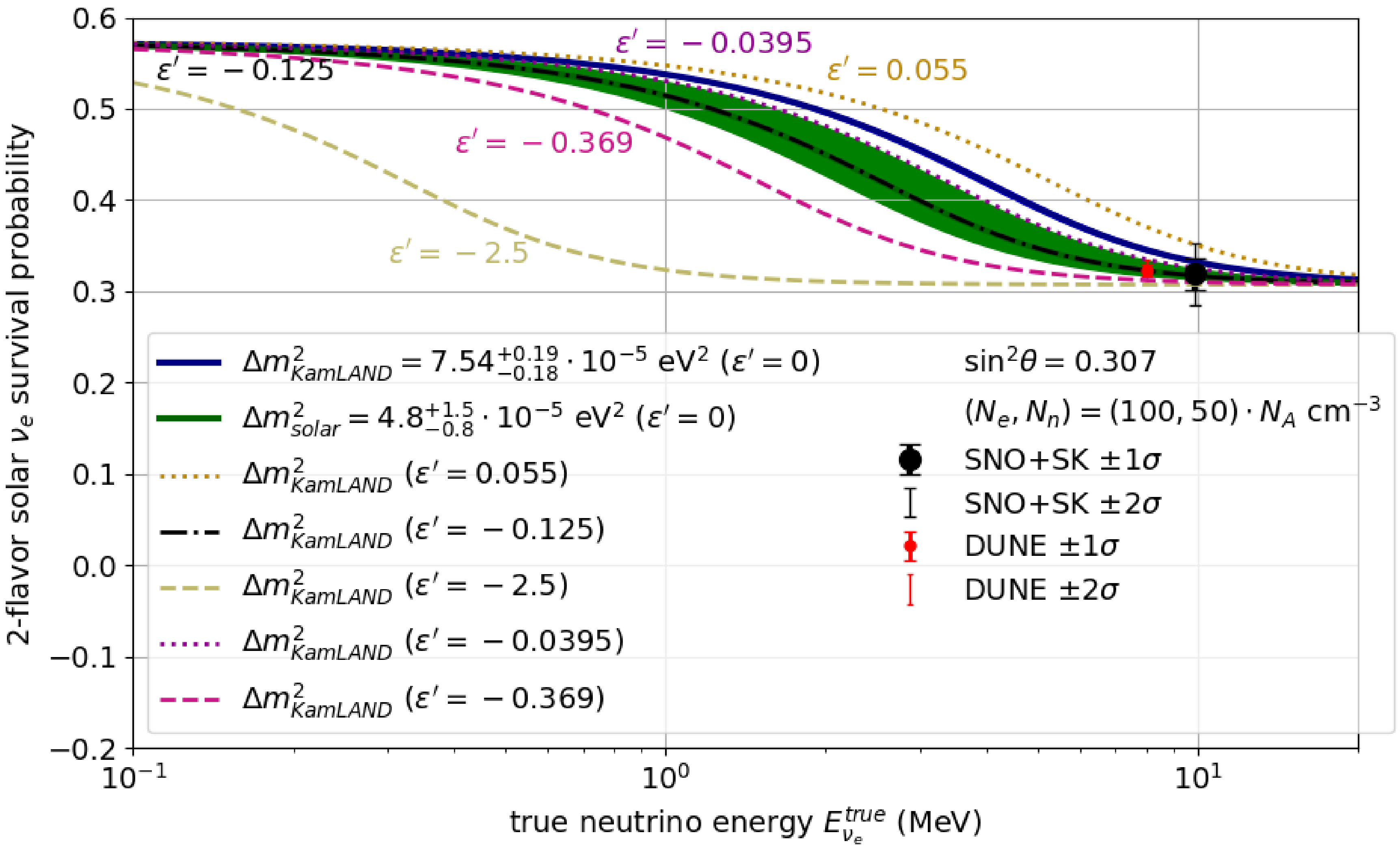
40 kt·years of DUNE



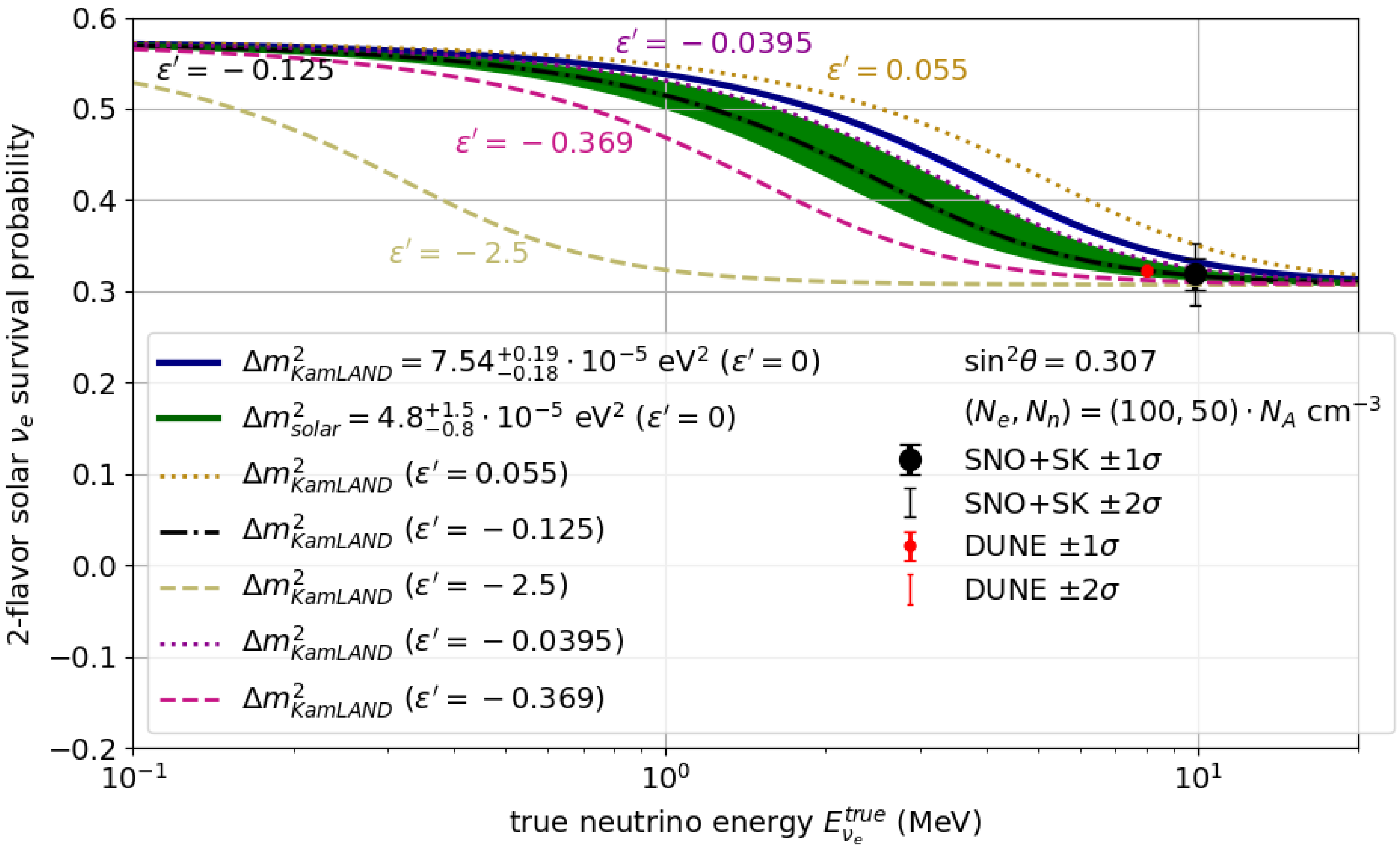
160 kt·years of DUNE



400 kt·years of DUNE

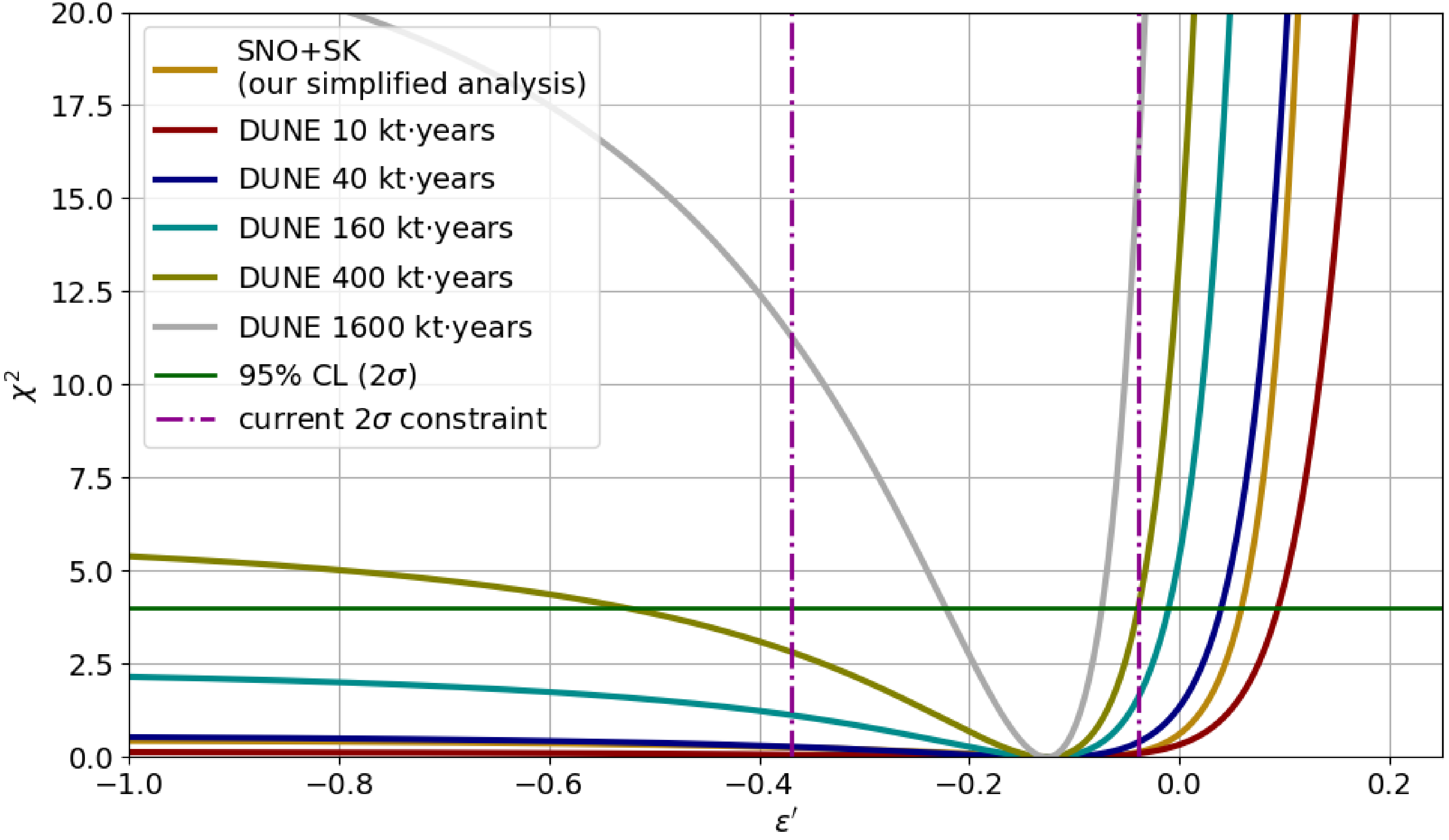


1600 kt·years of DUNE



Estimated DUNE sensitivity

- 40 kt·years improves on SNO+SK result
- 400 kt·years improves NSI limit



Conclusions

- Solar neutrino anomaly could potentially be well explained by NSI within current restrictions

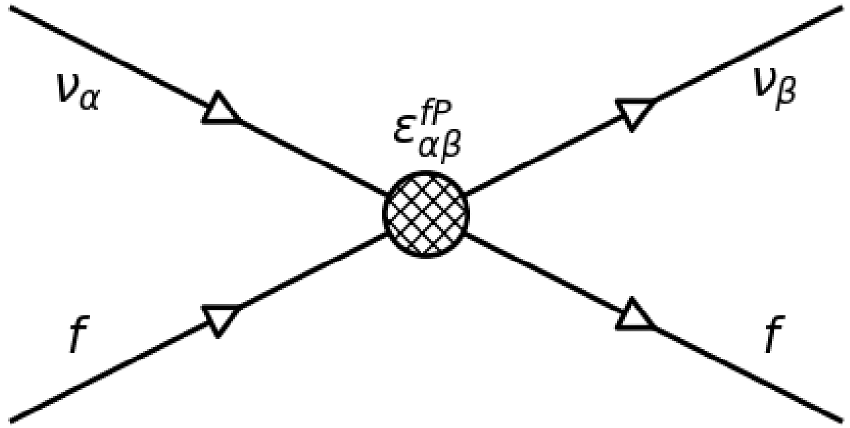
- If solar neutrino anomaly persists, after 40 kt·years of DUNE, current NSI constraints can be improved

Backup slides

NSI under consideration

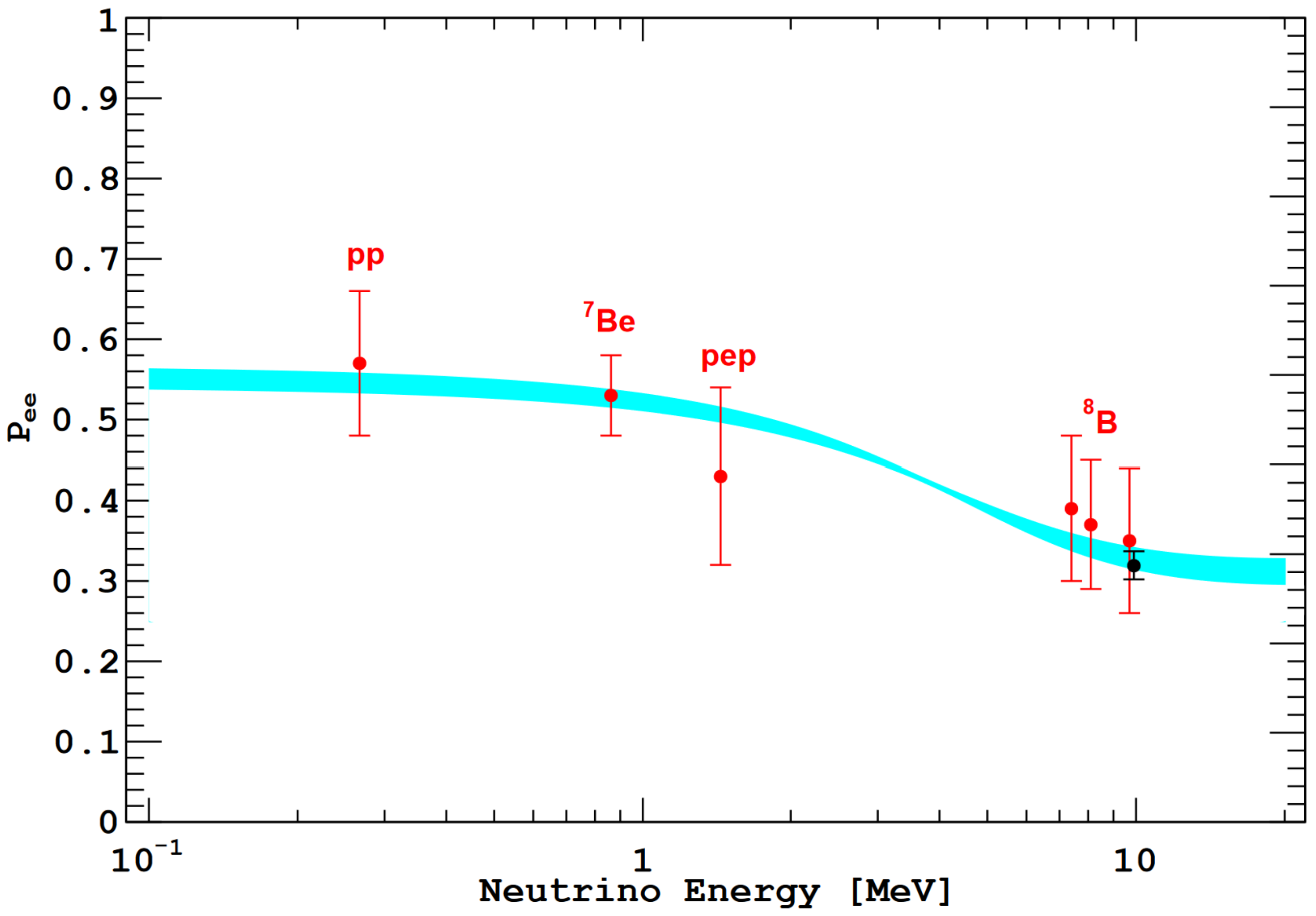
- Focusing on neutral-current models with heavy mediators ($m_{Z'}^2 \gg Q^2$)
  - $\mathcal{L}_{\alpha\beta}^{fP} = -2\sqrt{2} G_F \epsilon_{\alpha\beta}^{fP} [\bar{\nu}_\alpha \gamma^\mu (1-\gamma^5) \nu_\beta][\bar{f} \gamma_\mu P f]$

- Parameterized by ϵ's

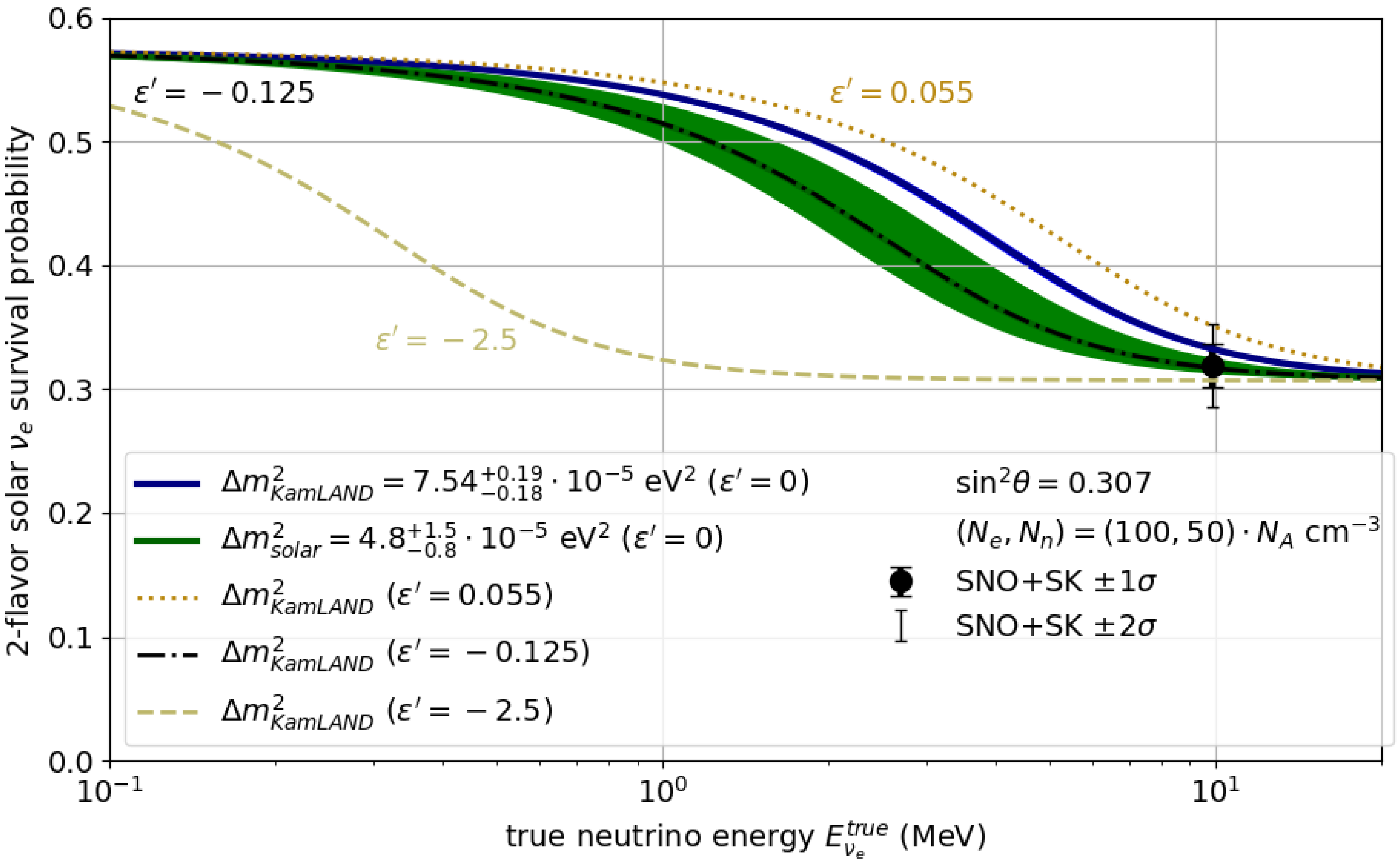


Matter oscillations

- Survival probability depends on energy
- Measurements agree with theory
- Need better statistics and more measurements in transition region



Possible NSI constraint from SNO+SK

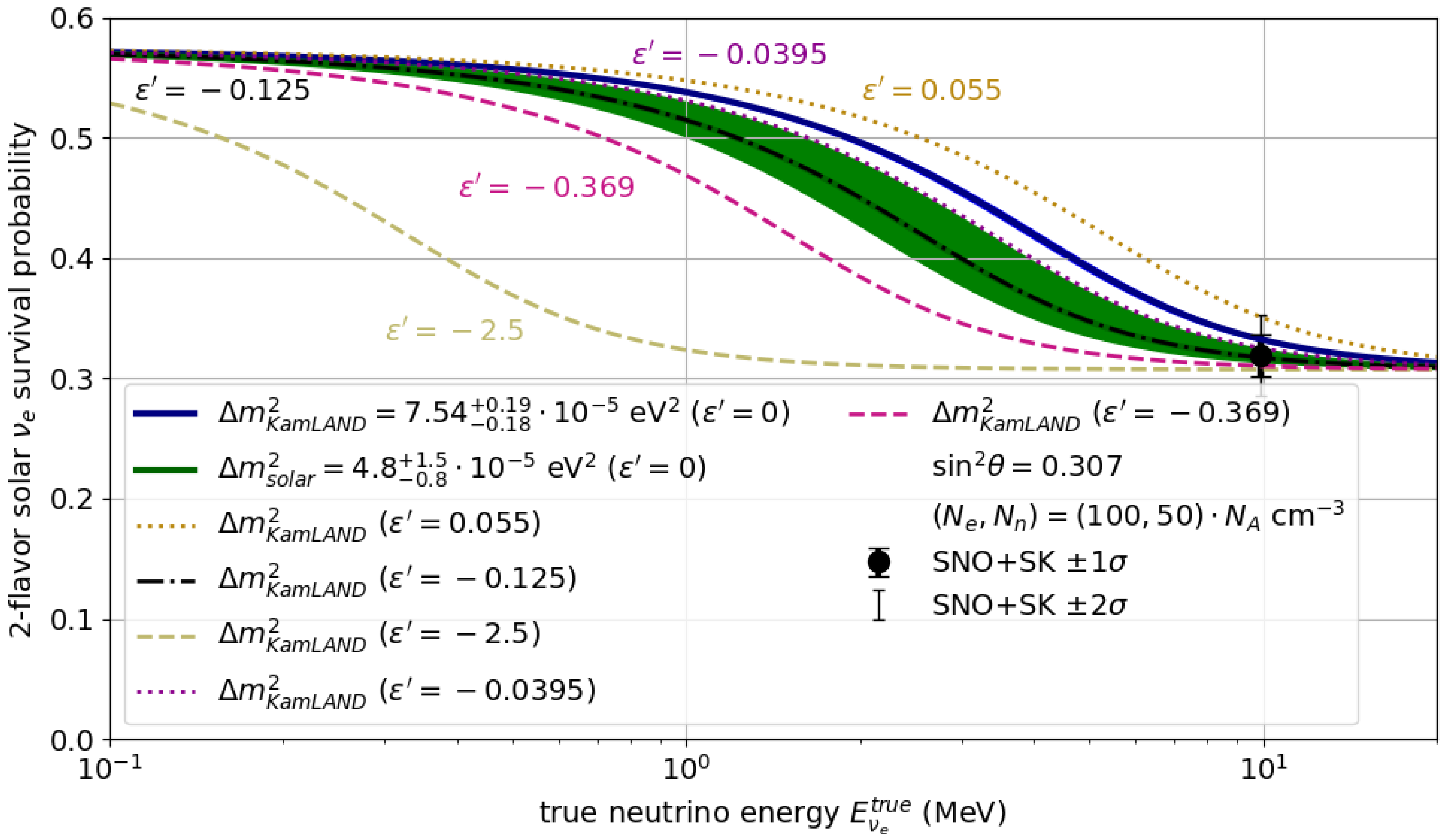


P. Coloma et al. (2019)
https://arxiv.org/pdf/1911.09109.pdf

Current NSI constraints: 2σ

ε_{ee}^{u}	$[+0.043, +0.384]$
$\varepsilon_{\mu\mu}^{u}$	$[-0.050, +0.062]$
$\varepsilon_{\tau\tau}^{u}$	$[-0.050, +0.065]$
$\varepsilon_{e\mu}^{u}$	$[-0.055, +0.027]$
$\varepsilon_{e\tau}^{u}$	$[-0.141, +0.090]$
$\varepsilon_{\mu\tau}^{u}$	$[-0.006, +0.006]$
ε_{ee}^{d}	$[+0.036, +0.354]$
$\varepsilon_{\mu\mu}^{d}$	$[-0.046, +0.057]$
$\varepsilon_{\tau\tau}^{d}$	$[-0.046, +0.059]$
$\varepsilon_{e\mu}^{d}$	$[-0.052, +0.024]$
$\varepsilon_{e\tau}^{d}$	$[-0.106, +0.082]$
$\varepsilon_{\mu\tau}^{d}$	$[-0.005, +0.005]$

Adding current NSI constraint



P. Coloma et al. (2019)
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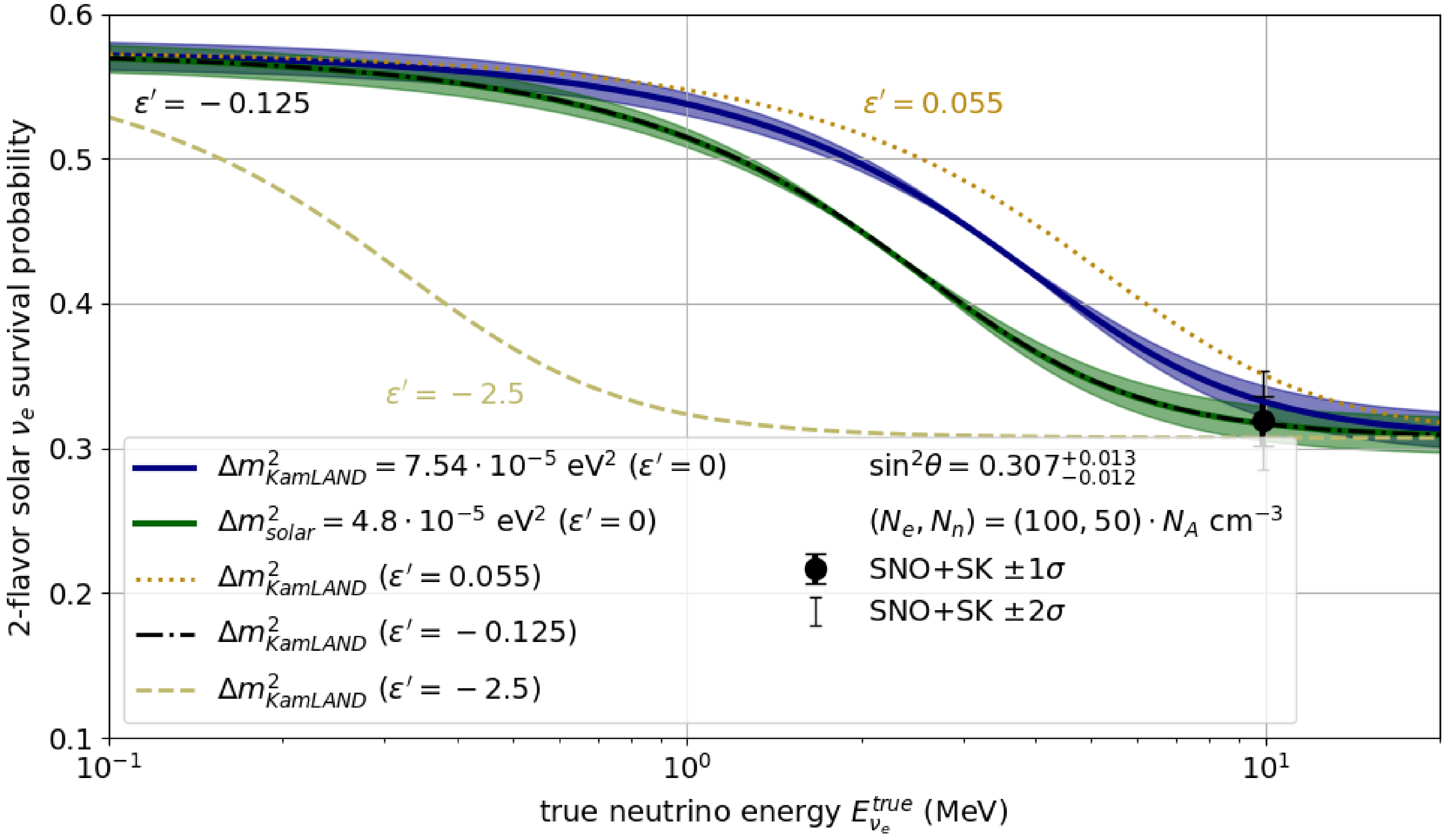
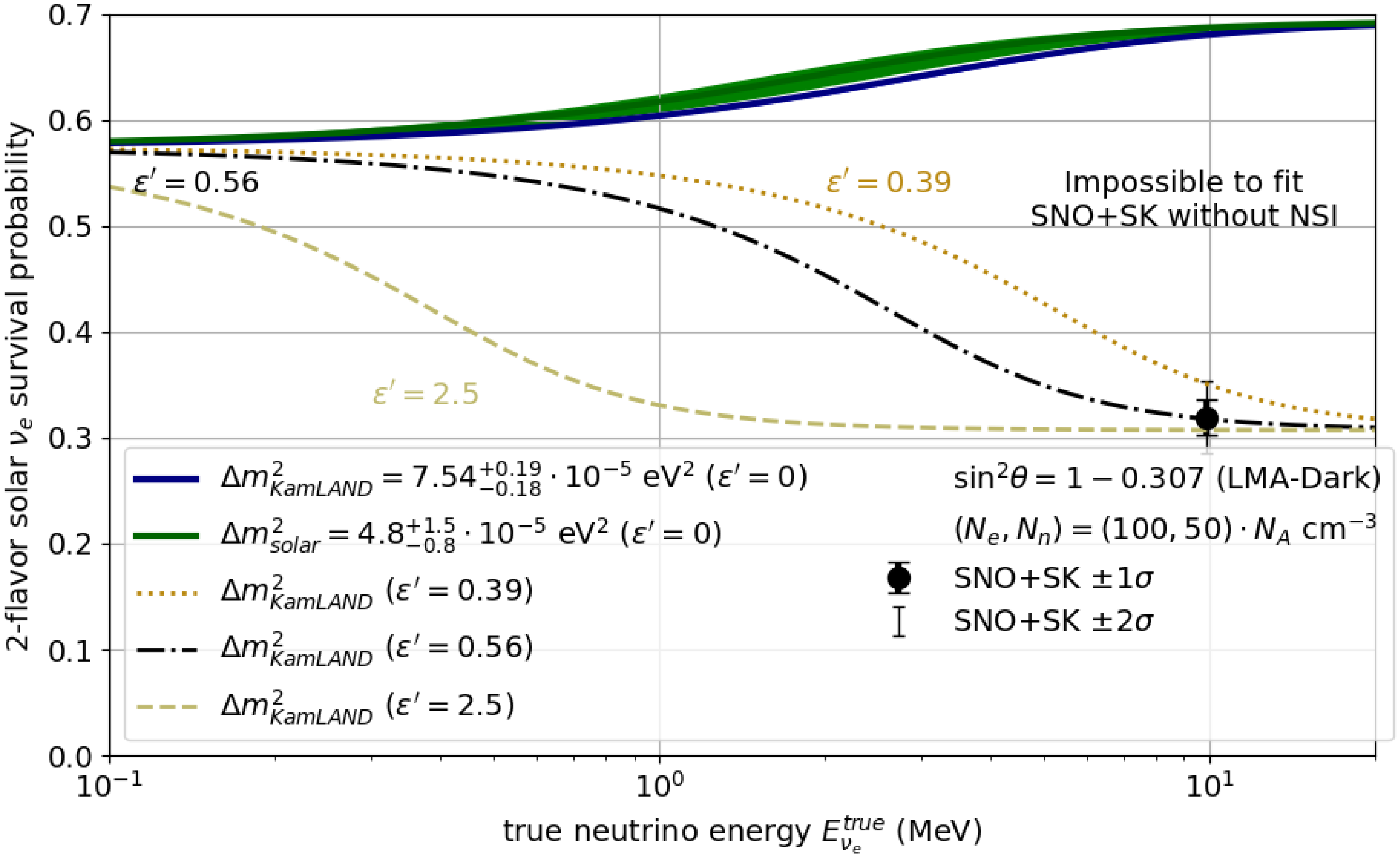
Current NSI constraints: 2σ

	Total Rate	Data Release t+E	Our Fit t+E Chicago	Our Fit t+E Duke
ε_{ee}^{u}	$[-0.012, +0.621]$	$[+0.043, +0.384]$	$[-0.032, +0.533]$	$[-0.004, +0.496]$
$\varepsilon_{\mu\mu}^{u}$	$[-0.115, +0.405]$	$[-0.050, +0.062]$	$[-0.094, +0.071] \oplus [+0.302, +0.429]$	$[-0.045, +0.108] \oplus [+0.290, +0.399]$
$\varepsilon_{\tau\tau}^{u}$	$[-0.116, +0.406]$	$[-0.050, +0.065]$	$[-0.095, +0.125] \oplus [+0.302, +0.428]$	$[-0.045, +0.141] \oplus [+0.290, +0.399]$
$\varepsilon_{e\mu}^{u}$	$[-0.059, +0.033]$	$[-0.055, +0.027]$	$[-0.060, +0.036]$	$[-0.060, +0.034]$
$\varepsilon_{e\tau}^{u}$	$[-0.250, +0.110]$	$[-0.141, +0.090]$	$[-0.243, +0.118]$	$[-0.222, +0.113]$
$\varepsilon_{\mu\tau}^{u}$	$[-0.012, +0.008]$	$[-0.006, +0.006]$	$[-0.013, +0.009]$	$[-0.012, +0.009]$
ε_{ee}^{d}	$[-0.015, +0.566]$	$[+0.036, +0.354]$	$[-0.030, +0.468]$	$[-0.006, +0.434]$
$\varepsilon_{\mu\mu}^{d}$	$[-0.104, +0.363]$	$[-0.046, +0.057]$	$[-0.083, +0.077] \oplus [+0.278, +0.384]$	$[-0.037, +0.099] \oplus [+0.267, +0.356]$
$\varepsilon_{\tau\tau}^{d}$	$[-0.104, +0.363]$	$[-0.046, +0.059]$	$[-0.083, +0.083] \oplus [+0.279, +0.383]$	$[-0.038, +0.104] \oplus [+0.268, +0.354]$
$\varepsilon_{e\mu}^{d}$	$[-0.058, +0.032]$	$[-0.052, +0.024]$	$[-0.059, +0.034]$	$[-0.058, +0.034]$
$\varepsilon_{e\tau}^{d}$	$[-0.198, +0.103]$	$[-0.106, +0.082]$	$[-0.196, +0.107]$	$[-0.181, +0.101]$
$\varepsilon_{\mu\tau}^{d}$	$[-0.008, +0.008]$	$[-0.005, +0.005]$	$[-0.008, +0.008]$	$[-0.007, +0.008]$

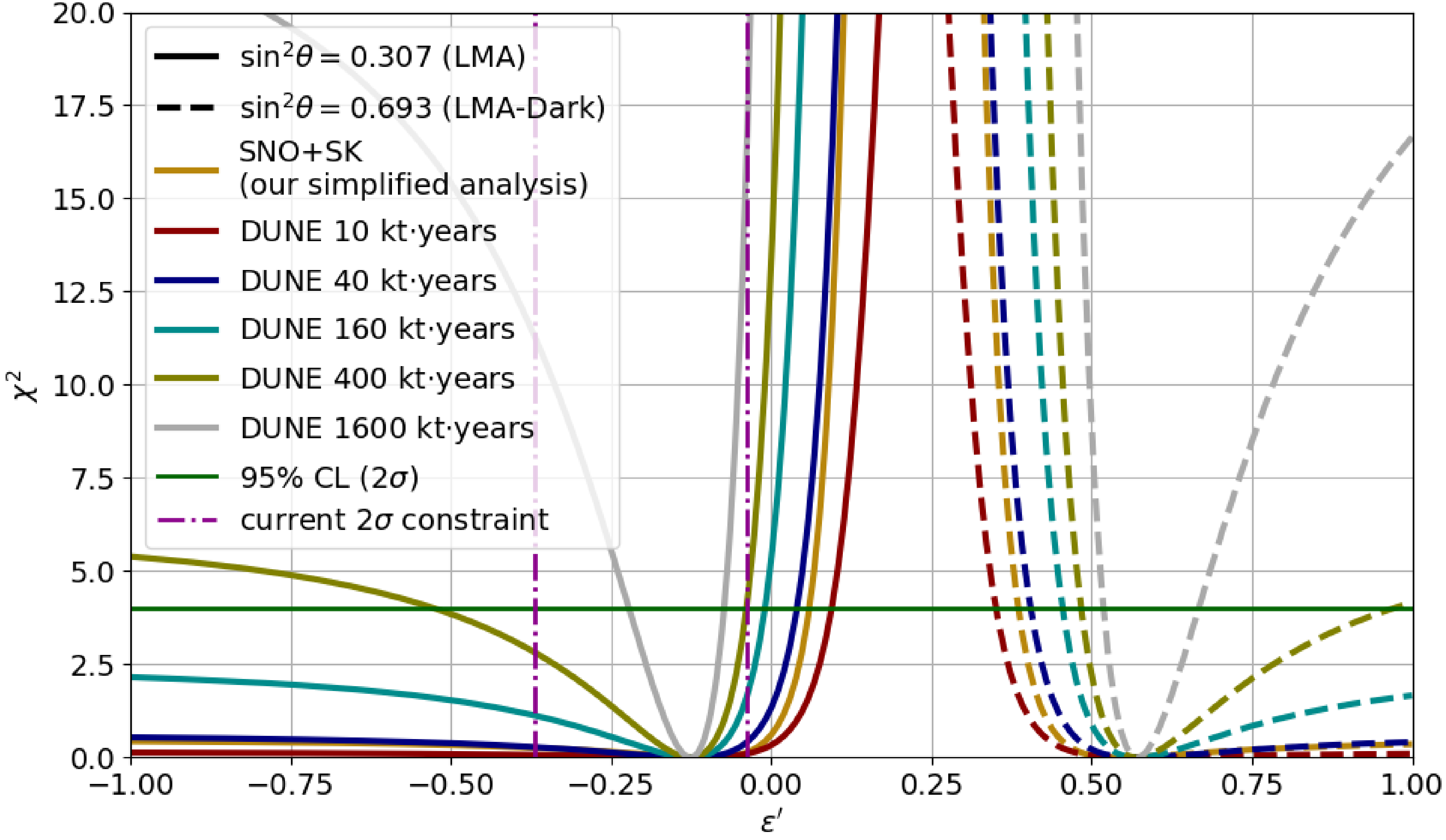
θ uncertainty



LMA-Dark solution



Estimated DUNE sensitivity (with LMA-Dark)



DUNE NSI constraint vs. exposure