Non-standard neutrino interaction search with IceCube DeepCore

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JG|U

Non-standard neutrino interactions (NSI)

- NC scattering on first-generation charged fermions relevant for neutrino propagation (coherent forward scattering)
- NSI emerge from wide variety of neutrino mass models
- described by effective 4-fermion Lagrangian:

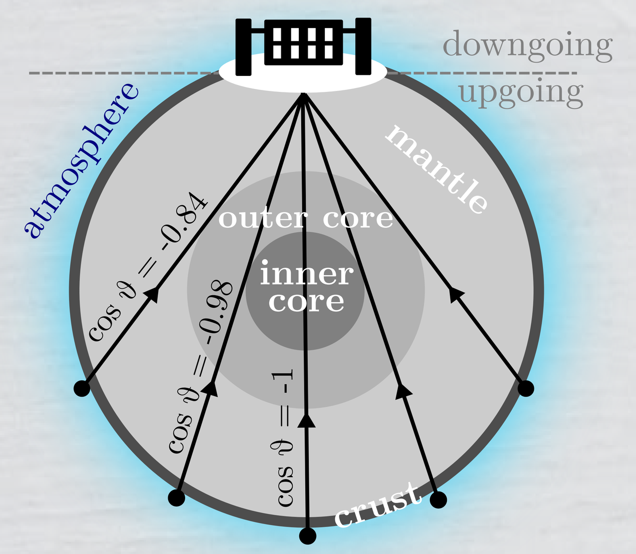
$$\mathscr{L}^{\mathrm{NC}}_{\mathrm{NSI}} = -2\sqrt{2}G_F \sum_{f=e,u,d} \left[\bar{\nu}_\alpha \gamma^\mu L \nu_\beta\right]\left[\bar{f}\gamma_\mu\left(\varepsilon^{fL}_{\alpha\beta}L + \varepsilon^{fR}_{\alpha\beta}R\right)f\right]$$

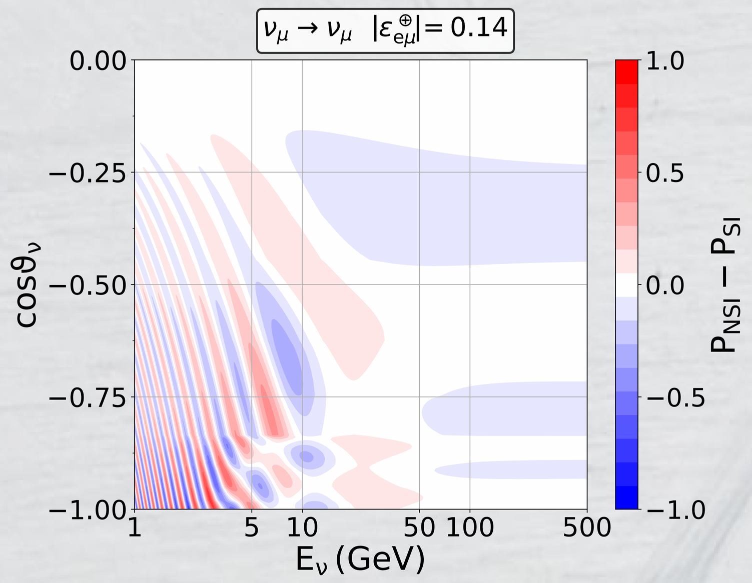
NSI imprint on oscillation probabilities

$\varepsilon^{\oplus}_{\alpha\beta} \approx \varepsilon^{eV}_{\alpha\beta} + 3\left(\varepsilon^{uV}_{\alpha\beta}+\varepsilon^{dV}_{\alpha\beta}\right)$ (vector couplings)

- Hamiltonian for propagation in Earth matter:

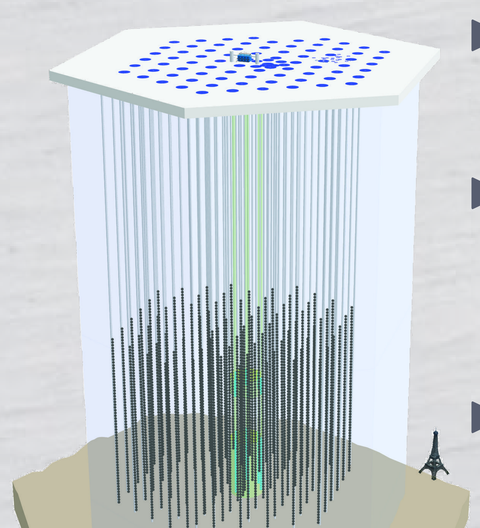
$$H_\nu(E_\nu,x) = \underbrace{\frac{1}{2E_\nu}U\mathrm{diag}\left(0,\Delta m^2_{21},\Delta m^2_{31}\right)U^\dagger}_{\text{vacuum}} + V_e(x)\left(\underbrace{\mathrm{diag}(1,0,0)}_{\text{SI}} + \underbrace{\begin{pmatrix}\varepsilon^\oplus_{ee}-\varepsilon^\oplus_{\mu\mu} & \varepsilon^\oplus_{e\mu} & \varepsilon^\oplus_{e\tau}\\ \varepsilon^{\oplus *}_{e\mu} & 0 & \varepsilon^\oplus_{\mu\tau}\\ \varepsilon^{\oplus *}_{e\tau} & \varepsilon^{\oplus *}_{\mu\tau} & \varepsilon^\oplus_{\tau\tau}-\varepsilon^\oplus_{\mu\mu}\end{pmatrix}}_{\text{NSI}}\right)$$

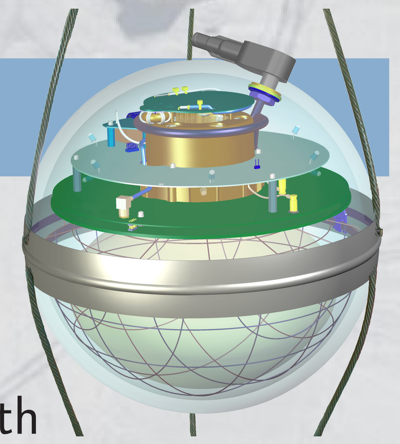




- atmospheric neutrinos at baselines between 20 km and Earth diameter encounter different matter density profiles
- difference in ν_μ survival probabilities for flavor-changing NSI $\varepsilon^\oplus_{e\mu}$ of given strength

IceCube and DeepCore





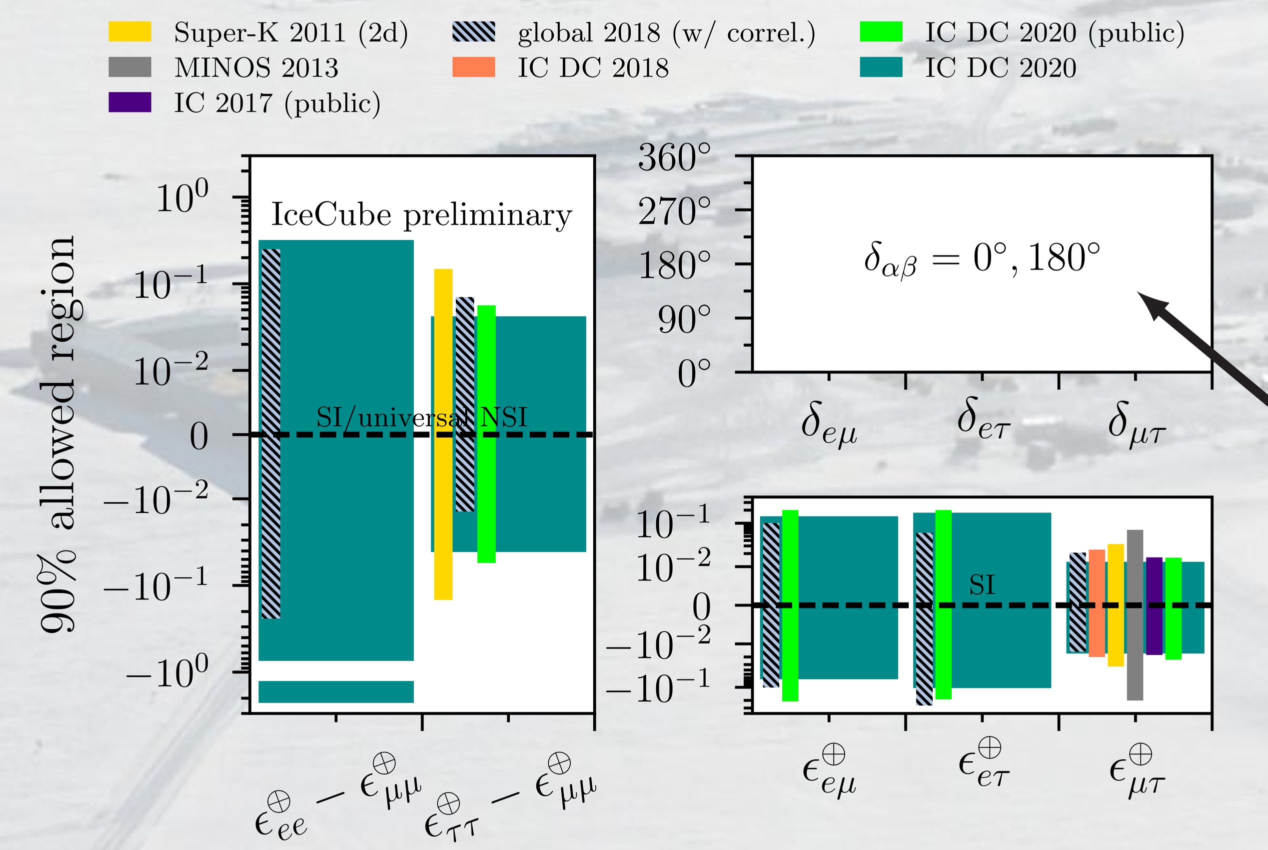
- 1 km^3 Cherenkov detector at Geographic South Pole
- 5160 optical modules equipped with downward-looking PMTs in 1.5 km–2.5 km deep glacial ice, distributed across 86 vertical strings
- **DeepCore** sub-array with low energy threshold ($\sim$ 5 GeV)
- $\nu_\mu, \bar{\nu}_\mu$ CC identification capabilities (track-like events)

see poster of E. Bourbeau

New results for 3 years of data

to be published soon

- one-by-one NSI constraints obtained for:
  - flavor violation: $\varepsilon^\oplus_{\alpha\beta} = \left|\varepsilon^\oplus_{\alpha\beta}\right| e^{i\delta_{\alpha\beta}}$ $(\alpha \neq \beta)$
  - flavor non-universality: $\varepsilon^\oplus_{ee(\tau\tau)} - \varepsilon^\oplus_{\mu\mu}$ $(\in \mathbb{R})$

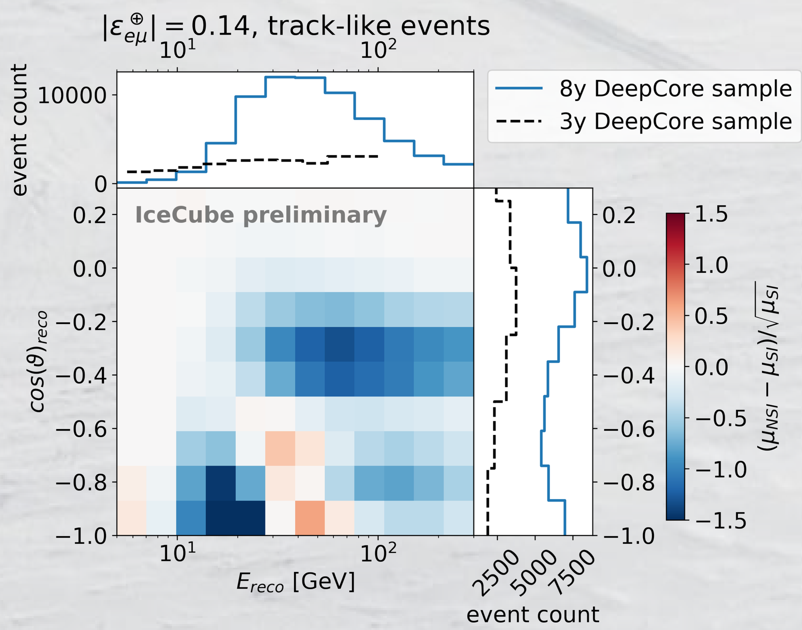


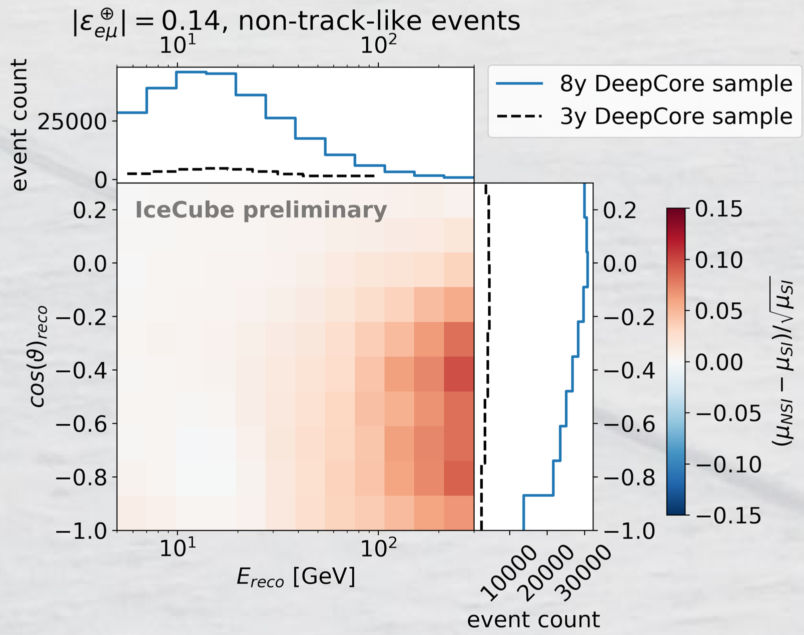
- \+ 3D matter potential fit: strength & flavor structure
  - overall strength: $\varepsilon_\oplus \in [-1.2, -0.3] \cup [0.2, 1.4]$
  - rotation angles: $\varphi_{12} \in [-9°, 8°]$, $\varphi_{13} \in [-14°, 9°]$

  } 90% CL

New high-statistics sample: 8 years of data

Enhanced event statistics in relevant regions of energy and zenith





- **energy range** extended up to 300 GeV, increasing sensitivity to flavor-violating NSI couplings (and control over systematics)
- binned χ^2 fit in energy, event type (track-like/cascade-like) and cos(zenith) with nuisance parameters **s**

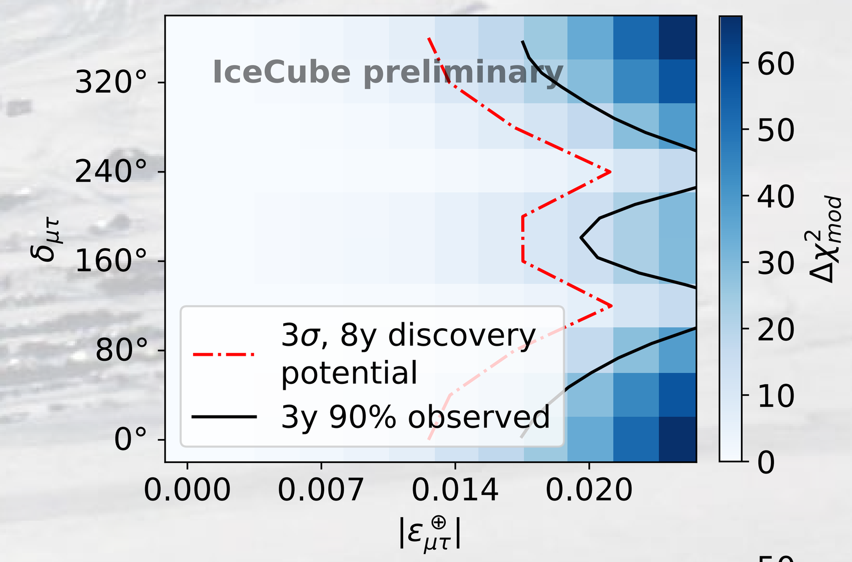
$$\chi^2_{\mathrm{mod}} = \sum_i^{\mathrm{bins}} \frac{\left(\mu_i^{\mathrm{data}} - \mu_i^{\mathrm{MC}}\right)^2}{\mu_i^{\mathrm{MC}} + \left(\sigma_i^{\mathrm{MC}}\right)^2} + \sum_j^{N_{\mathrm{prior}}} \frac{\left(s_j - s_j^{\mathrm{central}}\right)^2}{\sigma^2_{s_j}}$$

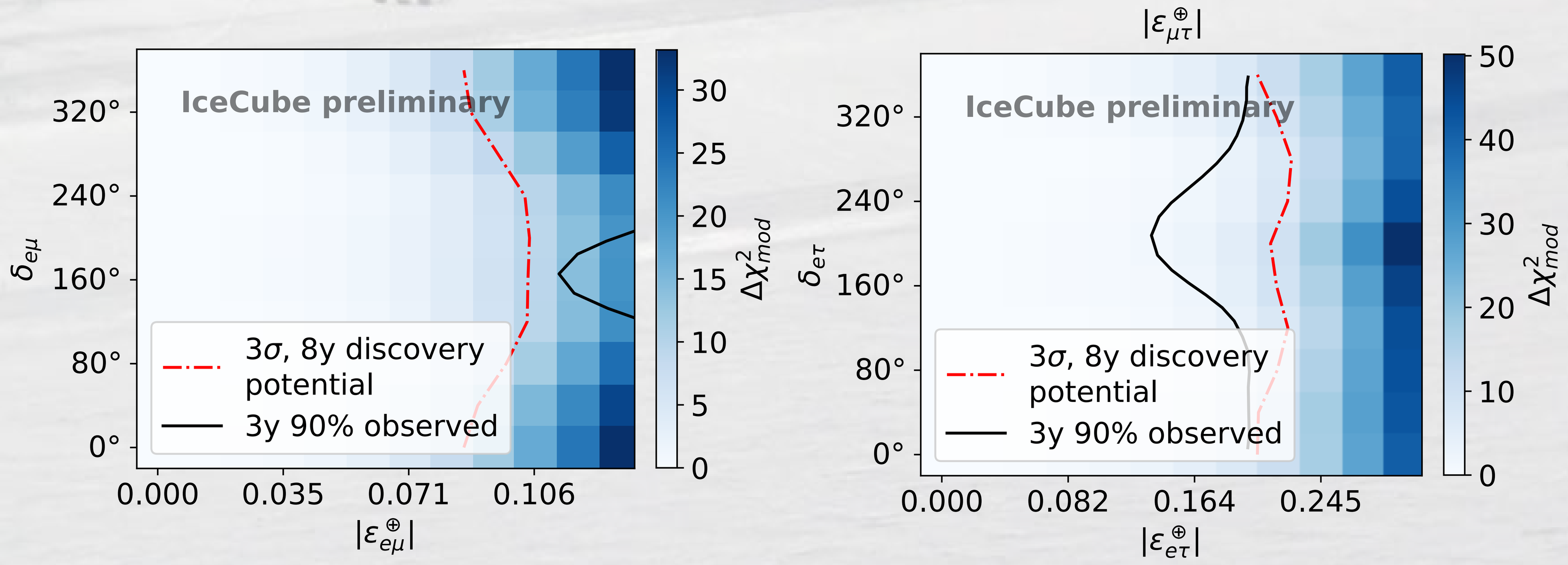
see posters of K. Leonard, T. Stuttard

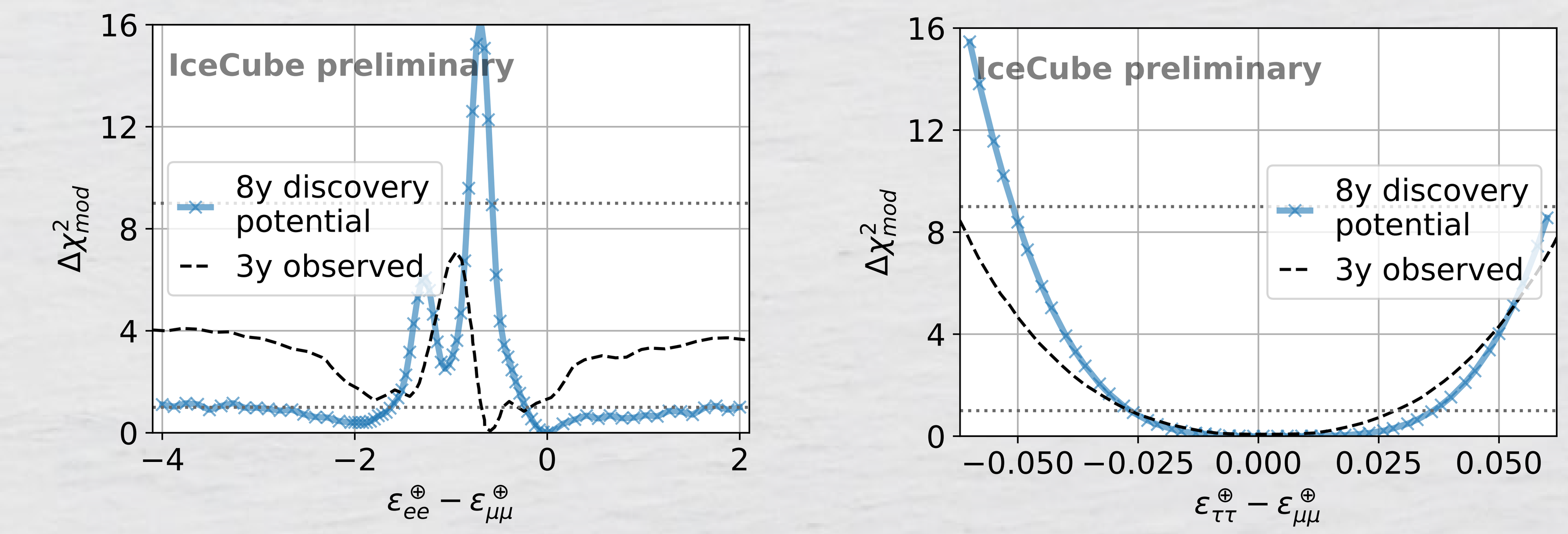
8-year discovery potential and sensitivity

How well can SI be excluded at a given NSI truth hypothesis?

- discovery potential for each fitted NSI parameter
- $\varepsilon^\oplus_{e\mu}$ and $\varepsilon^\oplus_{\mu\tau}$: 3σ discovery potential for 8y sample within 3y sample's observed 90% exclusion limit

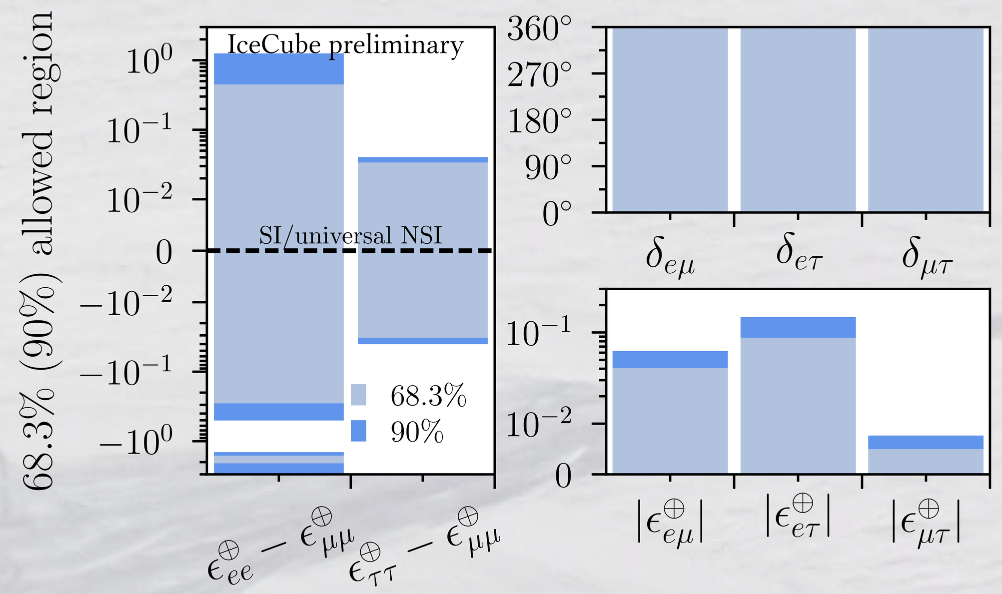






8y sensitivity: MC-based NSI exclusion power in absence of NSI

- assume complex parameters
- expect **strongest model-independent bounds** on flavor-violation and non-universality NSI strengths for Earth matter so far



References

[1] P. S. Bhupal Dev *et al.*, SciPost Phys. Proc. 2, 001 (2019), [2] M. G. Aartsen *et al.* (IceCube Collaboration), JINST 12 (03), P03012, [3] G. Mitsuka *et al.* (Super-Kamiokande Collaboration), Phys. Rev. D 84, 113008 (2011), [4] P. Adamson *et al.* (MINOS Collaboration), Phys. Rev. D 88, 072011 (2013), [5] J. Salvado *et al.*, J. High Energy Phys. 2017 (1), 141, [6] I. Esteban *et al.*, J. High Energy Phys. 2018 (8), 180, [7] M. G. Aartsen *et al.* (IceCube Collaboration), Phys. Rev. D 97, 072009 (2018), [8] S. V. Demidov, J. High Energy Phys. 2020 (3), 105

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