Beam neutrinos: beyond the Standard Model?

Alexander Friedland

LANL

LBNE reconfiguration workshop

Fermilab, April 26, 2012

- Beam neutrino physics:
  - CPV
  - Mass hierarchy
  - Known angles and splittings
  - ??
- Nucleon decay
- Supernova

Bread and butter

NSI: 1970s ...

- The idea is as old as the field itself

PHYSICAL REVIEW D VOLUME 17, NUMBER 9 1 MAY 1978

Neutrino oscillations in matter

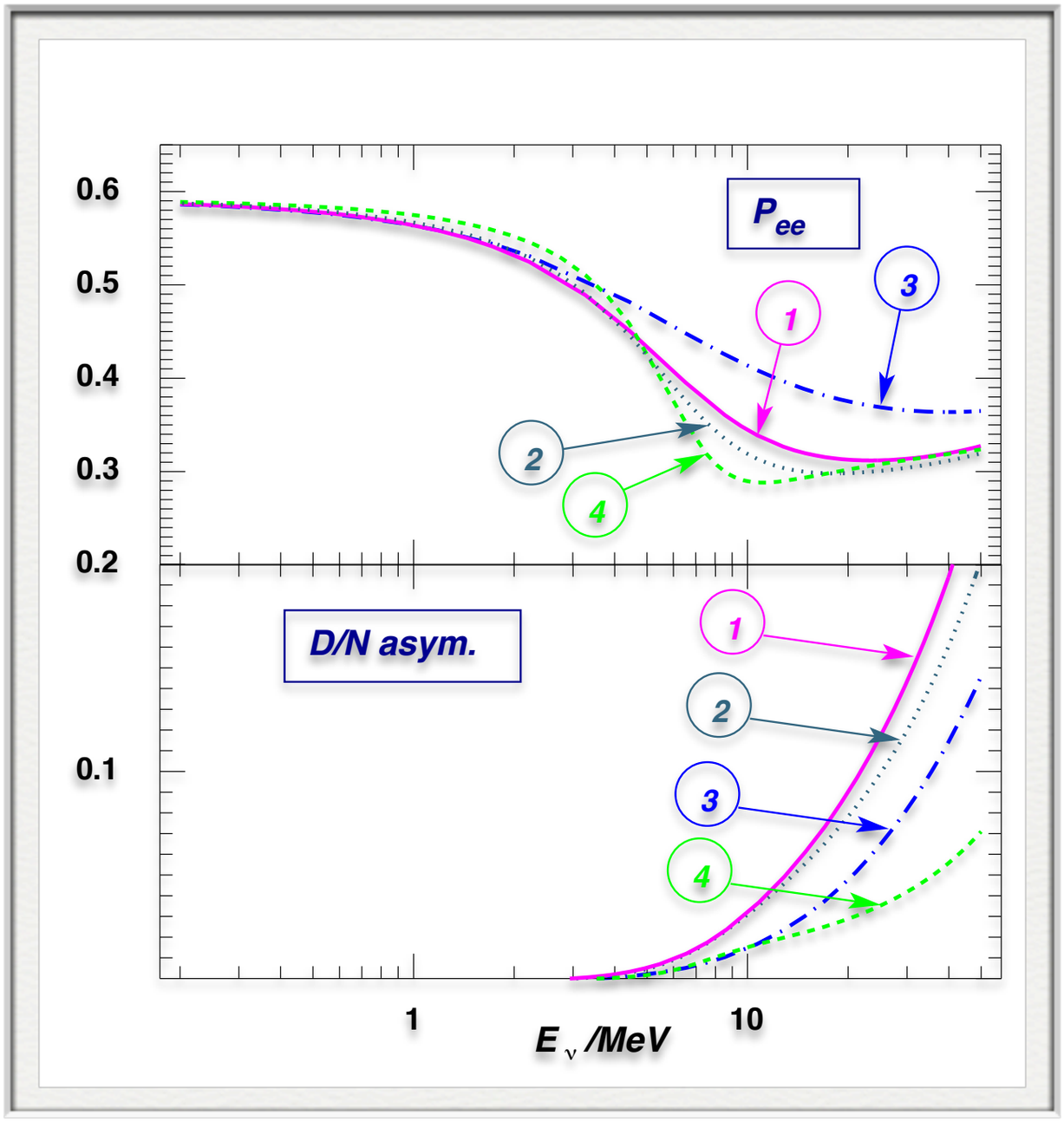
L. Wolfenstein
Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213
(Received 6 October 1977; revised manuscript received 5 December 1977)

The effect of coherent forward scattering must be taken into account when considering the oscillations of neutrinos traveling through matter. In particular, for the case of massless neutrinos for which vacuum oscillations cannot occur, oscillations can occur in matter if the neutral current has an off-diagonal piece connecting different neutrino types. Applications discussed are solar neutrinos and a proposed experiment involving transmission of neutrinos through 1000 km of rock.

- hundreds of follow-up papers

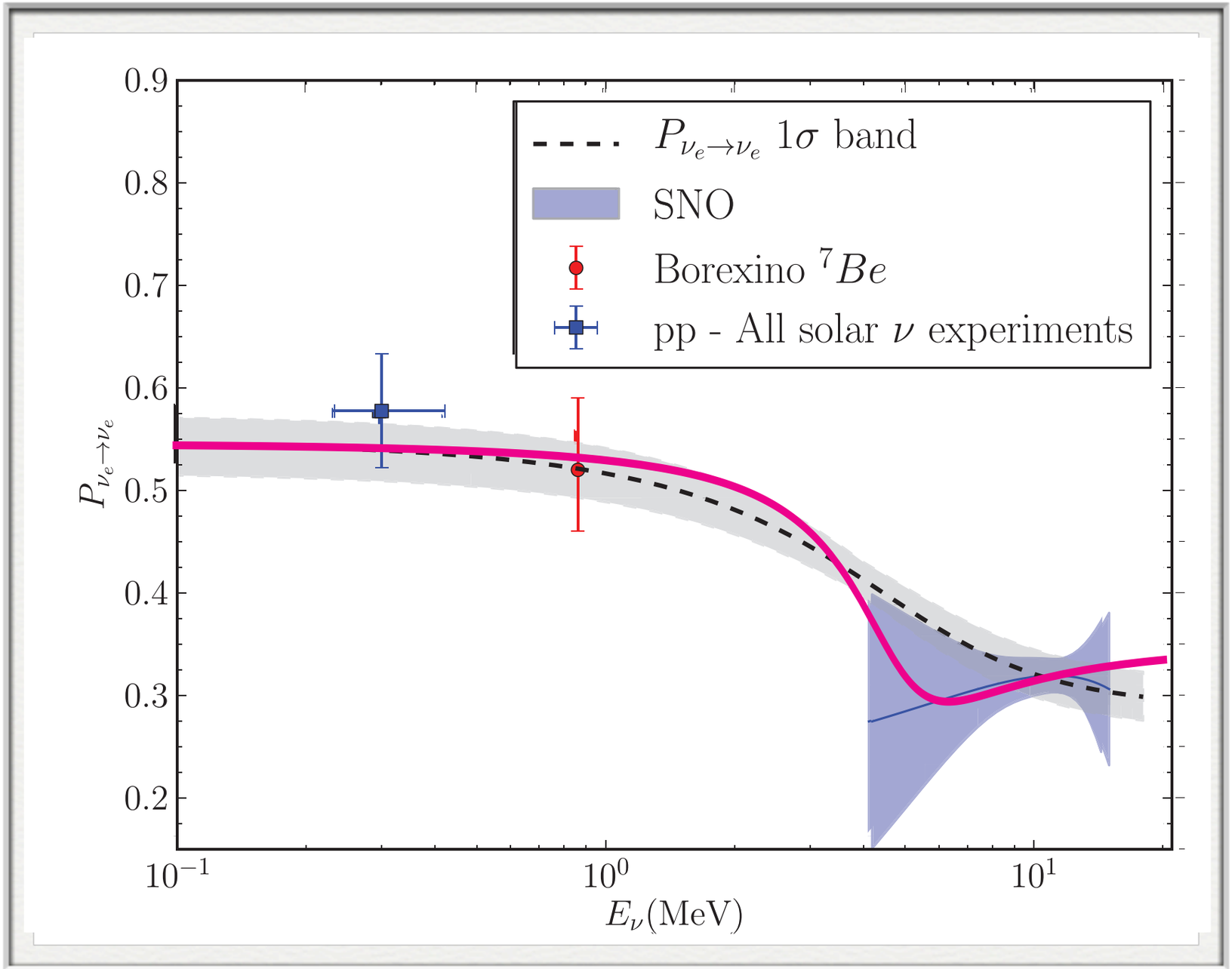
Solar neutrinos

- Small NSI change the energy dependence of the solar neutrino survival probability
  - mostly in the vacuum/matter transition regime
- Also changes the D/N asymmetry
- All one has to do is observe the upturn of the survival probability



Friedland, Lunardini, Peña-Garay, PLB (2004)

Solar neutrinos, 2011

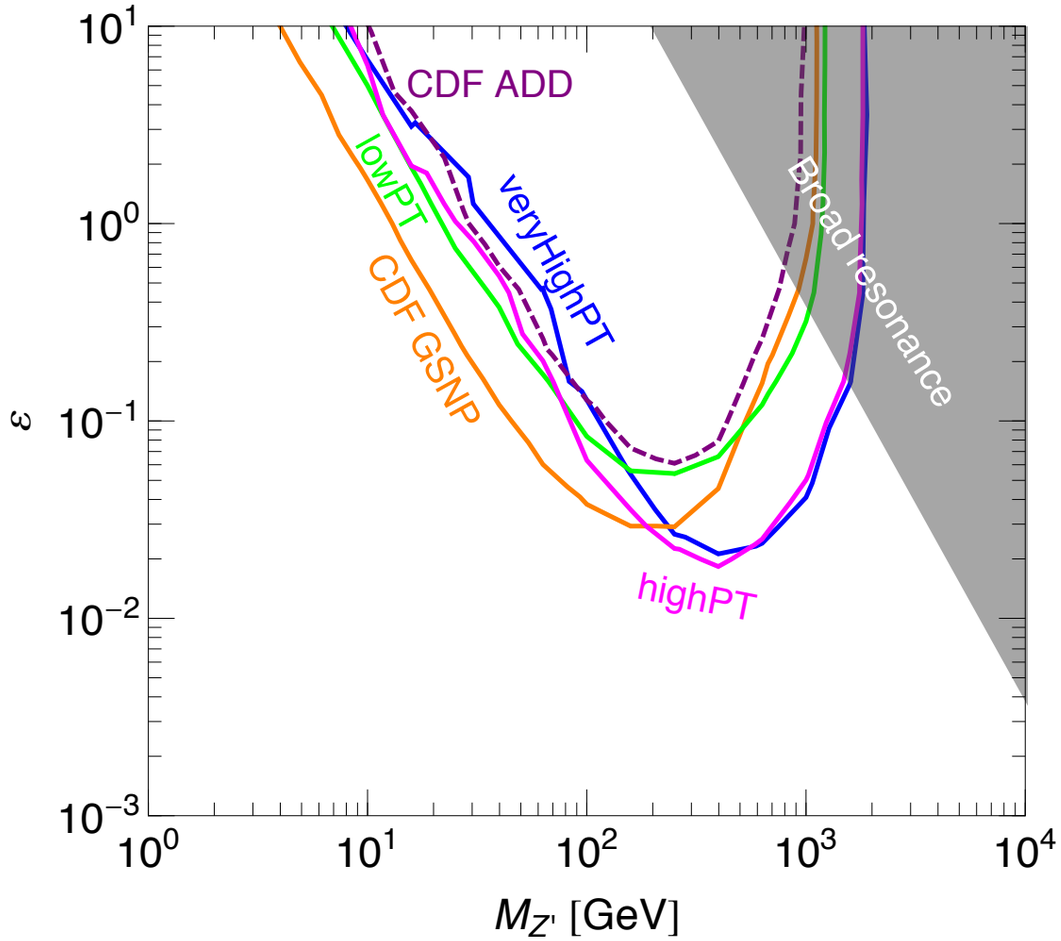


SNO 3-phase analysis 2011

Similar story with Borexino, SuperK; see Palazzo, PRD 2011

Other constraints?

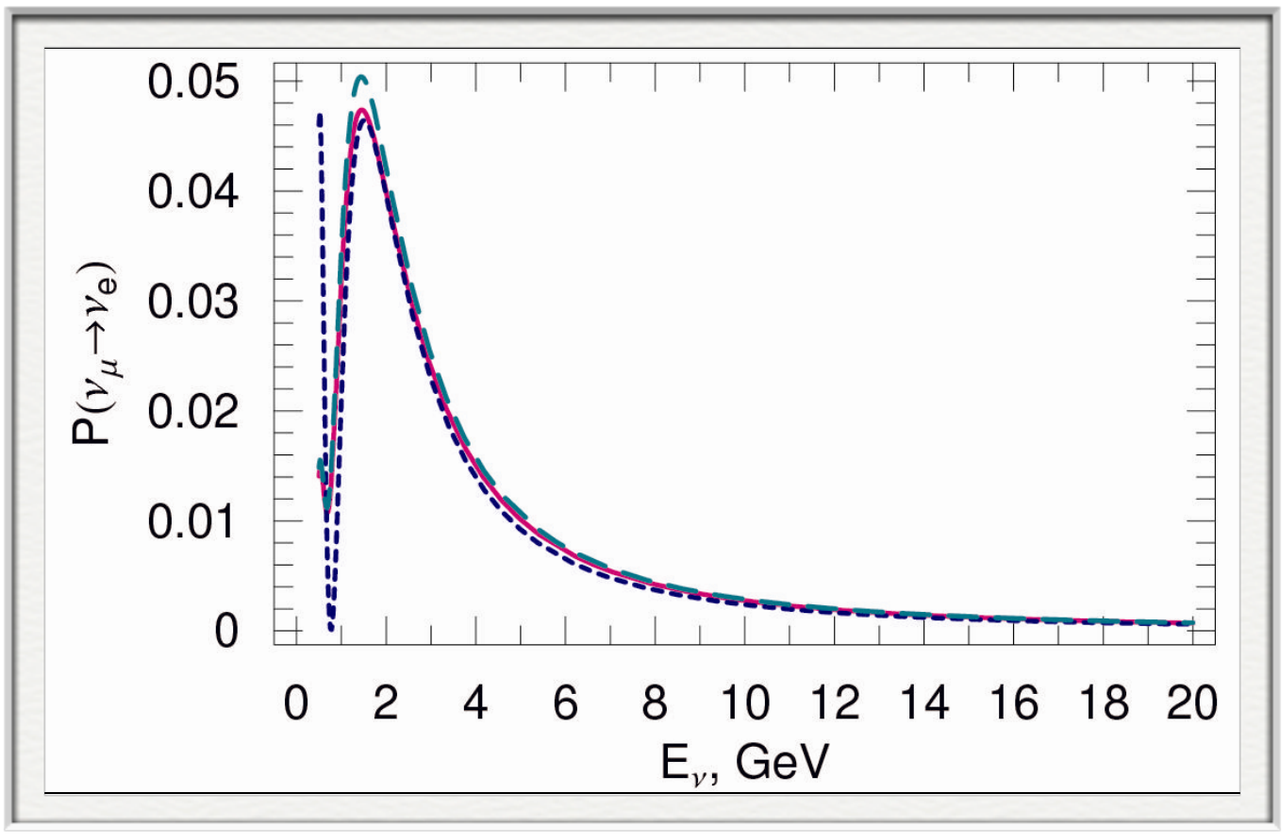
- SuperK atmospheric neutrinos allow $\varepsilon_{e\tau} \sim 0.5$ without any tuning among other parameters
  - even more with tuning
- At the LHC and Tevatron, in "monojet" events, neutrino NSI look like dark matter or extra dimensions
  - These events provide a useful constraint, especially if the new physics scale is in the hundred TeV range, but weaker if it's above or below



A. F., Graesser, Shoemaker, Vecchi, arXiv:1111.5331

MINOS

- The flavor-changing NSI cause small nu-e appearance
- This could fake the effect of theta13 pretty closely
- One might think that only large NSI can be probed, but that's not so, **because theta13 is measured to be large**



$\sin^2 2\theta_{13} = 0.07$ or

$\sin^2 2\theta_{13} = 0 +$ NSI $\varepsilon_{e\tau} \sim 1$

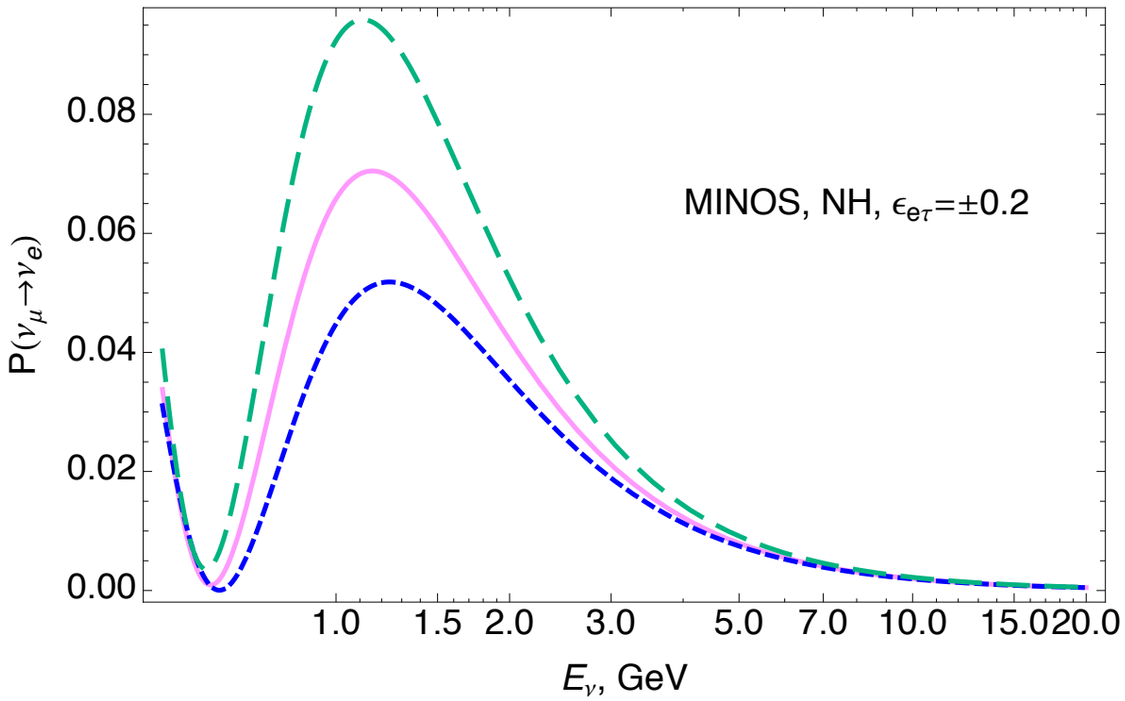
Friedland, Lunardini, PRD 2006

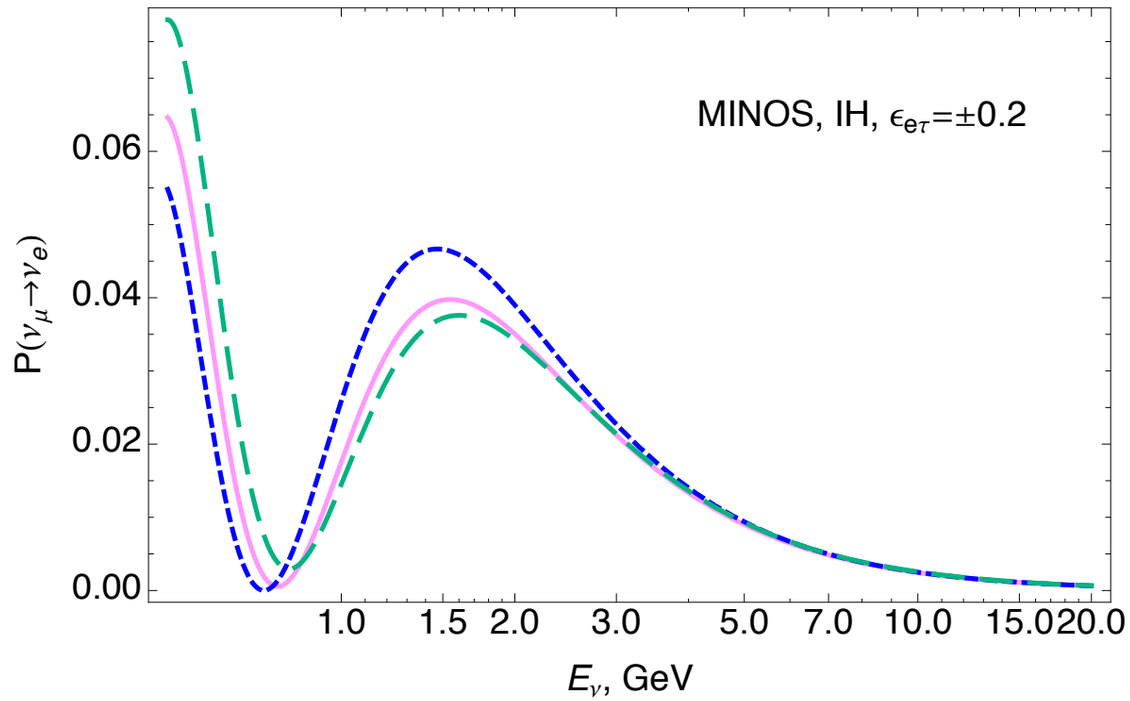
Approximate analytical formula

$$P(\nu_\mu \to \nu_e) \simeq \left| G_1 \sin\theta_{23} \frac{\exp(i\Delta_1 L) - 1}{\Delta_1} - G_2 \cos\theta_{23} \frac{\exp(i\Delta_2 L) - 1}{\Delta_2} \right|^2 ,$$

$$\begin{aligned} G_1 &\simeq \sqrt{2} G_F N_e \epsilon_{e\tau} \cos\theta_{23} + \Delta \sin 2\theta_{13} e^{i\delta} , \\ G_2 &\simeq \sqrt{2} G_F N_e \epsilon_{e\tau} \sin\theta_{23} - \Delta_\odot \sin 2\theta_{12} . \end{aligned}$$

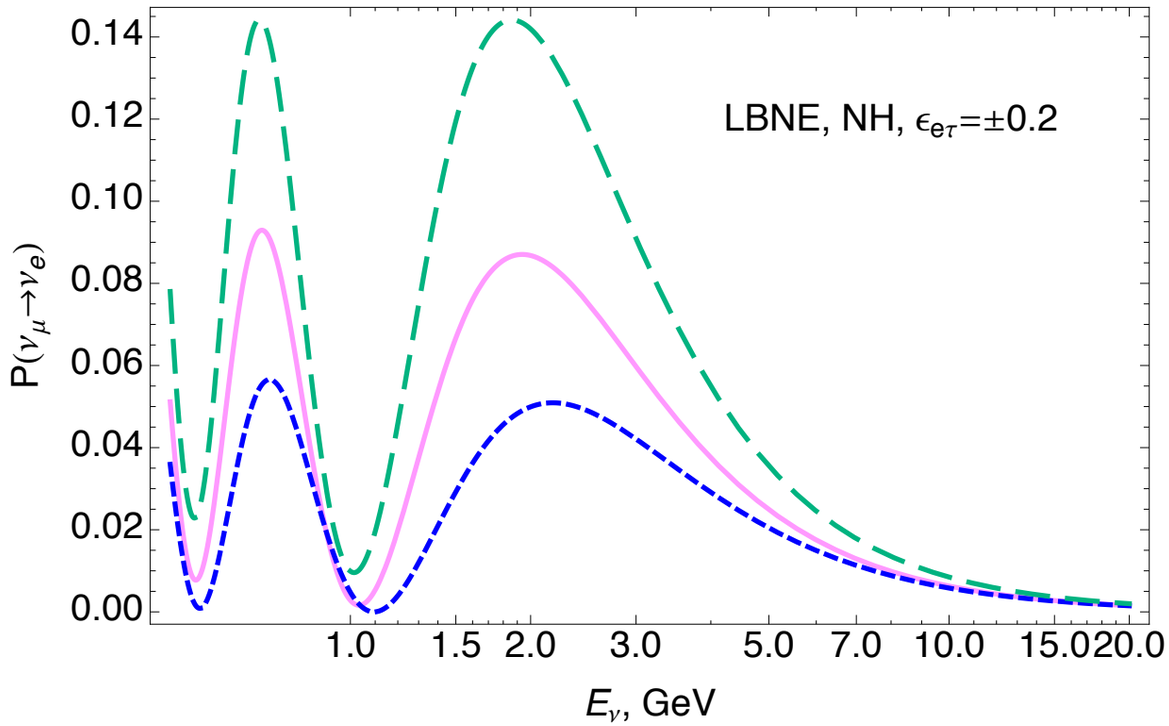
- Two channels, solar and atmospheric
- NSI amplitude appears in both
- Matter effects appear mostly in solar splitting
- NSI has its own phase; interference depends on the relative phases!

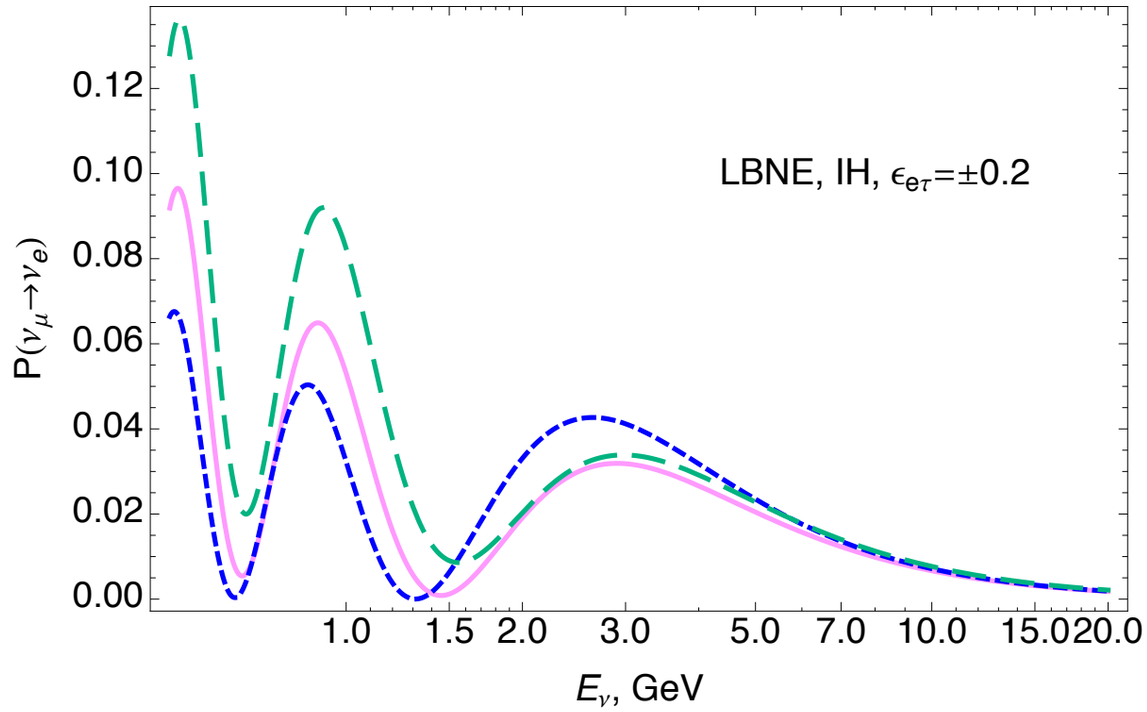




- Interference makes for a pretty large effect for NH
- Useful constraint already possible
- On the other hand, could it be seeing destructive interference? NOvA?

1300 km baseline





- More matter means greater NSI effects
- For IH, going down to the oscillation minimum and beyond would greatly help