Short Baseline Neutrino Oscillations and Chameleon B-L Gauge interactions

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*refs:B. Feldman and A.N., JHEP 0608:002,2006, hep-ph/0603057;
A.N. and J.Walsh,arXiv:0711.1363, arXiv:0802.0762*

Outline

- LSND vs MiniBooNe:
  - energy dependent and ν vs. $\bar{\nu}$ dependent effect?
  - New MSW-like effect at short baseline from
    - gauged B-L
      - $g < 10^{-5}$
      - gauge boson mass < 30 keV
    - 3 sterile neutrinos with opposite sign B-L
    - little effect on long baseline active-active oscillations
- astrophysics constraints and “Chameleon” mechanism

LSND

- *SBL (30 m) conversion of $\bar{\nu}_\mu$ to $\bar{\nu}_e$: P=0.264±0.081%*
- *$\bar{\nu}_\mu$ from μ^+decay at rest: Energy 20 — 53 MeV*
- *An outlier in standard 3 ν model*
- *agreement with other experiments requires exotic ingredients, e.g. 2 additional sterile ν (in disagreement with cosmology)*

MiniBooNe

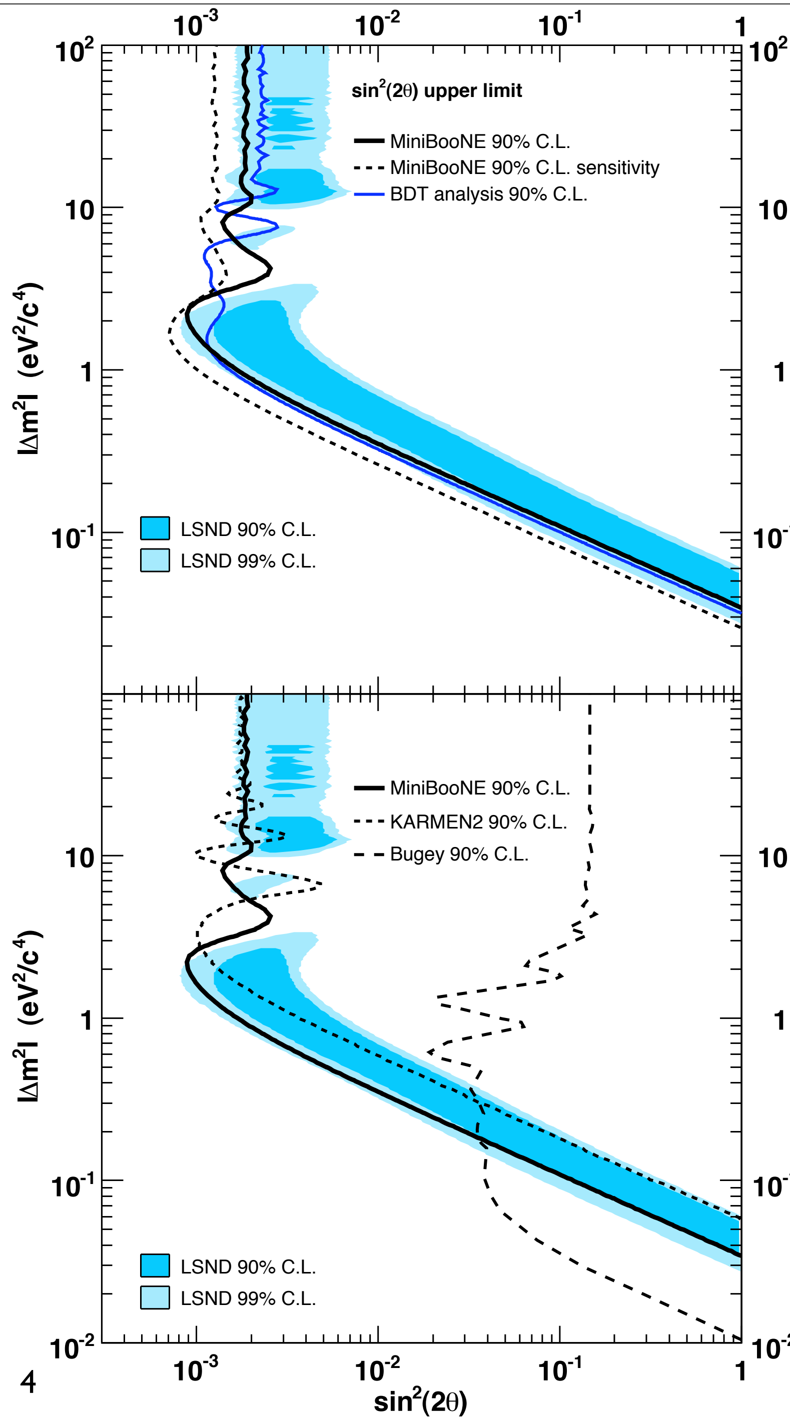
- Search for SBL (541 m) conversion of ν_μ to ν_e
- Similar L/E to LSND (analysis region 475 MeV — 3 GeV)
- first data with ν_μ's does not confirm conventional ν oscillation interpretation of LSND
- currently unexplained ν_e excess below 475 MeV which doesn't fit conventional ν oscillation interpretation

MiniBooNE, Karmen, Bugey versus LSND

End of Story?

⇒still no explanation for LSND excess

⇒conventional 3+1 ν oscillations are bad fit to SBL even w/o MiniBooNe



What if LSND and/or MiniBooNe are ν physics?

considered so far:

- ❈ CPV + more than 3+1 *Maltoni + Schwetz*
- ❈ new background for ν_e's *Harvey+Hill*
- ❈ increased ν_e background + ν_e disappearance *Giunti+Laveder*
- ❈ more exotic *Schwetz; Pas, Pakvasa+Weiler*

Motivation for model to reconcile LSND with MiniBooNe

- Essential differences between LSND, MiniBooNE experiments
  - ν's versus $\overline{\nu}$'s
  - similar L/E, different E
- Similarity: MiniBooNE, LSND both have oscillation baselines through matter
- new physics MSW-like effect ?

A new gauge interaction?

- Anomaly free candidate is gauged B-L (with 3 sterile ‘right handed’ neutrinos)
- interesting SBL effects with Majorana masses for sterile ν’s at few eV and “miniseesaw”
- MSW effect is opposite for ν, $\bar{\nu}$
- MSW effect ~ $2\,E\,\rho_{B\text{-}L}\,g^2/M_V^2$
- $\rho_{B\text{-}L}$ nonzero and similar for LSND, MiniBooNE
- flavor diagonal for active neutrinos
  - little effect on long baseline oscillations
- MSW effect for short baseline oscillations affected by heavier sterile neutrinos

Spontaneous B-L violation and Majorana ν masses

- a "mini seesaw" with eV mass singlet N's
- λ, g, λ' $\langle\phi\rangle$ are small
- nonzero $\langle\phi\rangle$ required for active-sterile mixing

$$\begin{array}{cc} & \begin{array}{cc} \nu & \quad N \end{array} \\ M = & \begin{pmatrix} 0 & \lambda\langle H\rangle \\ \lambda^T\langle H\rangle & \lambda'\langle\phi\rangle \end{pmatrix} \begin{array}{c} \nu \\ N \end{array} \end{array}$$

$$H \approx E + \frac{M^\dagger M}{2E} + V$$

$$V = \begin{pmatrix} -VI_3 & 0 \\ 0 & VI_3 \end{pmatrix}$$

Anomalous matter effect

effective mass^2 matrix for neutrino oscillations:

$$M^2_{eff} = \begin{pmatrix} m^2 & mM \\ mM & 4VE + M^2 + m^2 \end{pmatrix}$$

- ❇ m≡ λ ⟨H⟩ ~0.2 - 0.4 eV, 3 nearly degenerate

  eigenvalues govern large mixing angle LBL oscillations in matter at high energy
- ❇ V ≡ B-L potential, (negative)positive for (anti)ν's, interesting for SBL for V ~ 10 $^{-9}$ eV
- ❇ M≡ λ ⟨ϕ⟩ ~1-2 eV, M^2 ~ 4VE for MiniBooNE energy

  region

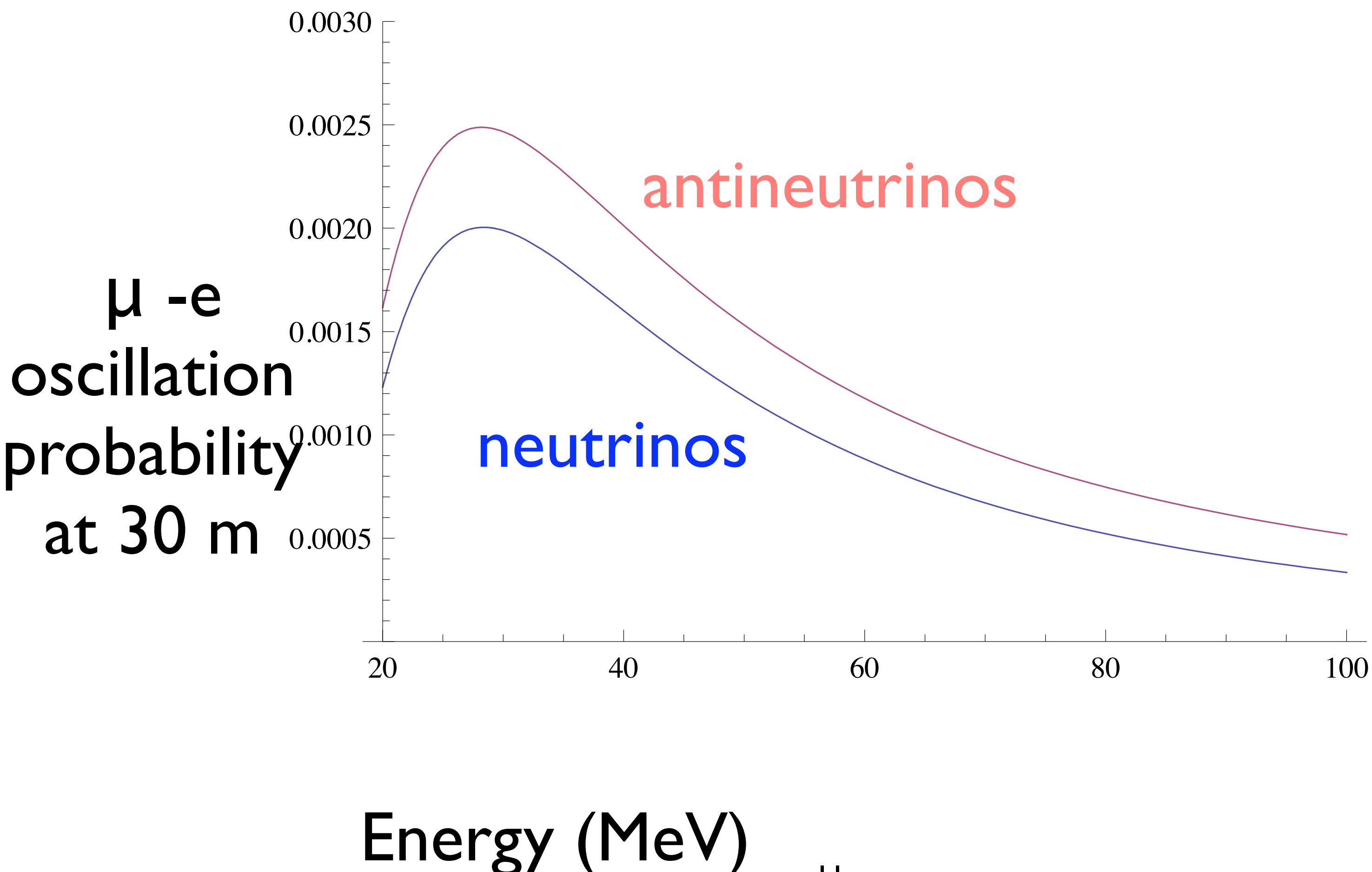
Heavy ν's mix with Effective Energy dependent mixing angle

- $\vartheta \approx m\,M/(4\,VE+\,M^2)$
- $\nu_\mu \Leftrightarrow \nu_e$ conversion~ ϑ^4
- bigger for anti neutrinos (negative V)
- for neutrinos, ϑ smaller at high energy

$$M^2_{eff} = \begin{pmatrix} m^2 & mM \\ mM & 4VE + M^2 + m^2 \end{pmatrix}$$

Effects of B-L potential

eg m=.3 eV, M_1 =1 eV, others heavy, V= 0.3 10^{-9} eV



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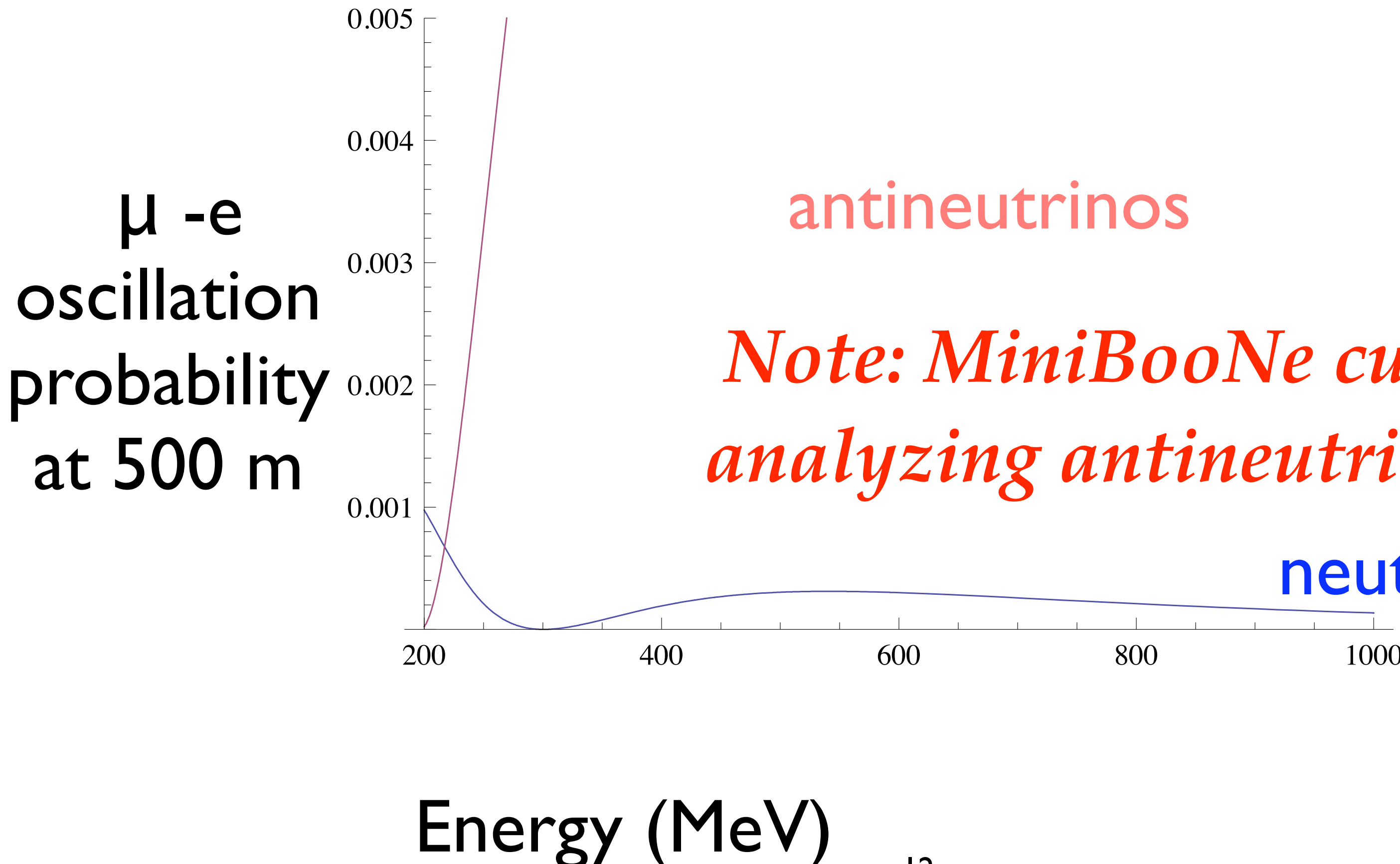
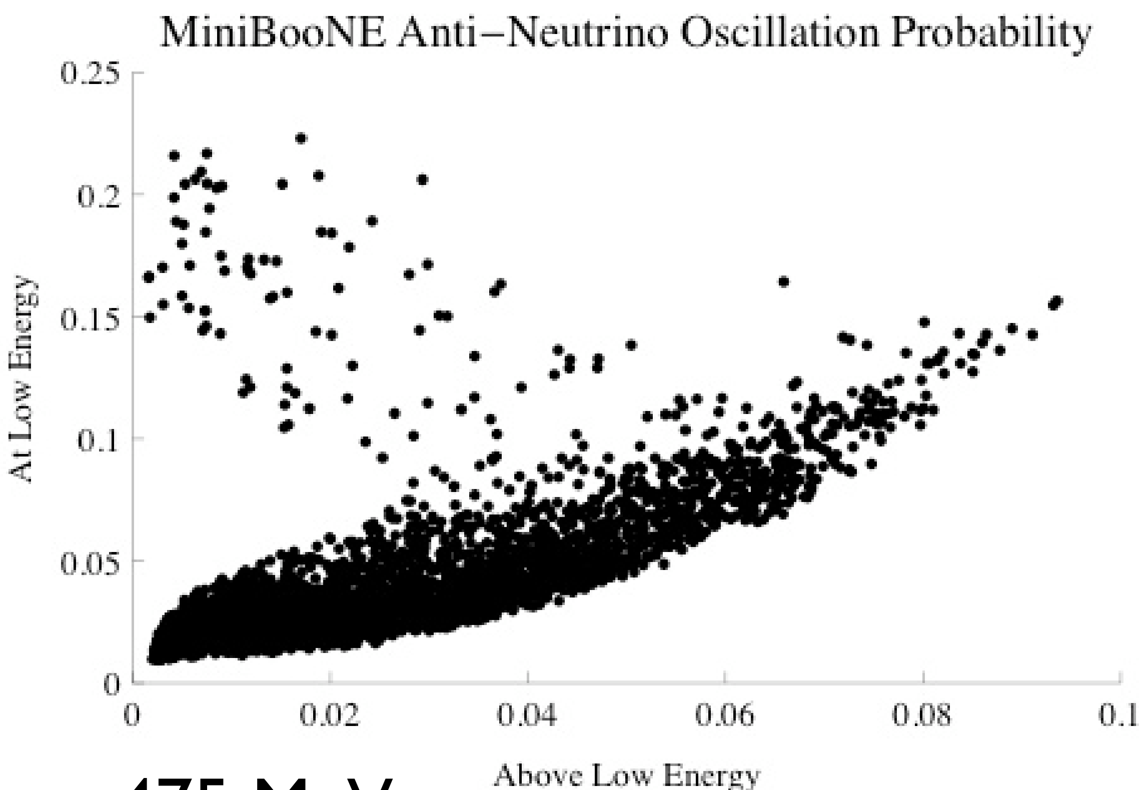


Note: MiniBooNe currently analyzing antineutrino data

Predictions for MiniBoone $\bar{\nu}$

❄ scan over model parameters in range consistent with constraints from SBL experiments, especially CHOOZ, LSND, MiniBooNe above 475 MeV

Below 475 MeV

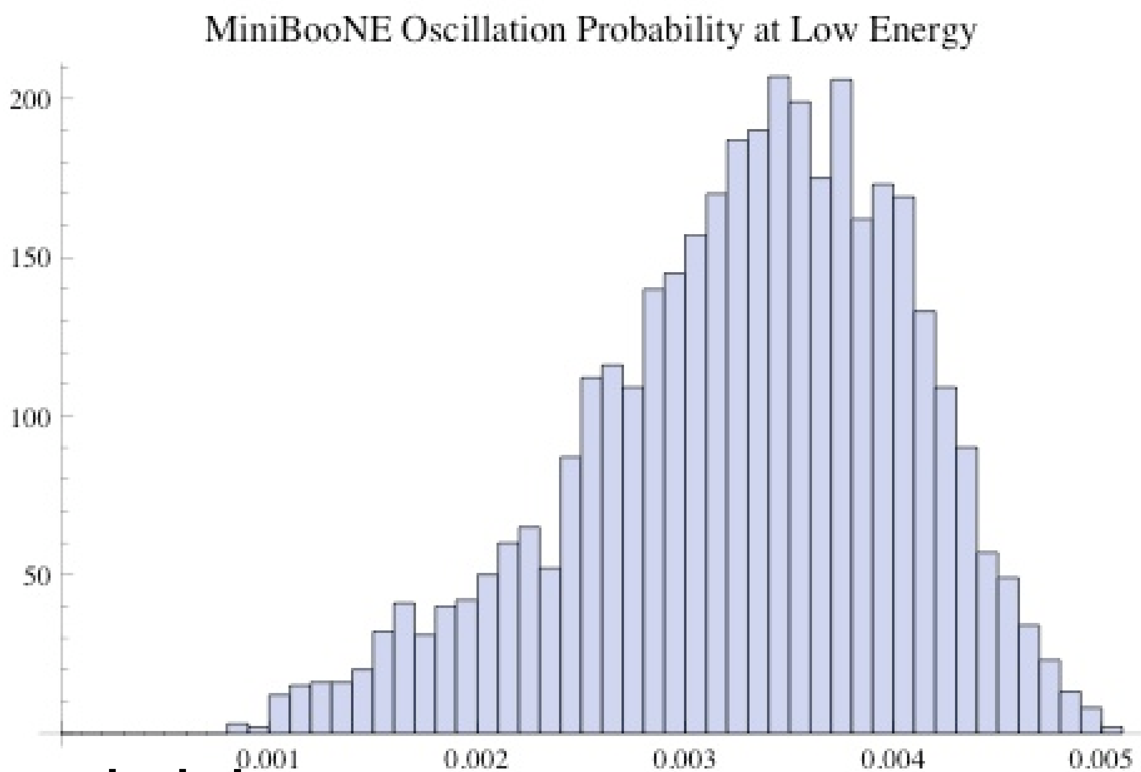


Above 475 MeV

Low energy ν_e excess?

- excess corresponds to 1% probability
- excess we get is always less than 40%

number points



Oscillation probability

Experimental Constraints

- MSW potential $\propto g^2/m_V^2$
- need $g^2/m_V^2 \sim$ 100 times larger than usual MSW effect from usual weak interactions
- need $g/m_V \sim 1/(30\ \text{GeV})$
- precision EW: $g<10^{-4} \Rightarrow m_V < 300$ keV

New forces shorter range than μm?

- Particle Physics constraints:rare decays
  - positronium→X+ Υ
  - π^0→X + Υ, K→X +ππ
  - Υ →XX, X+ Υ, X+ππ...

weaker constraints so far

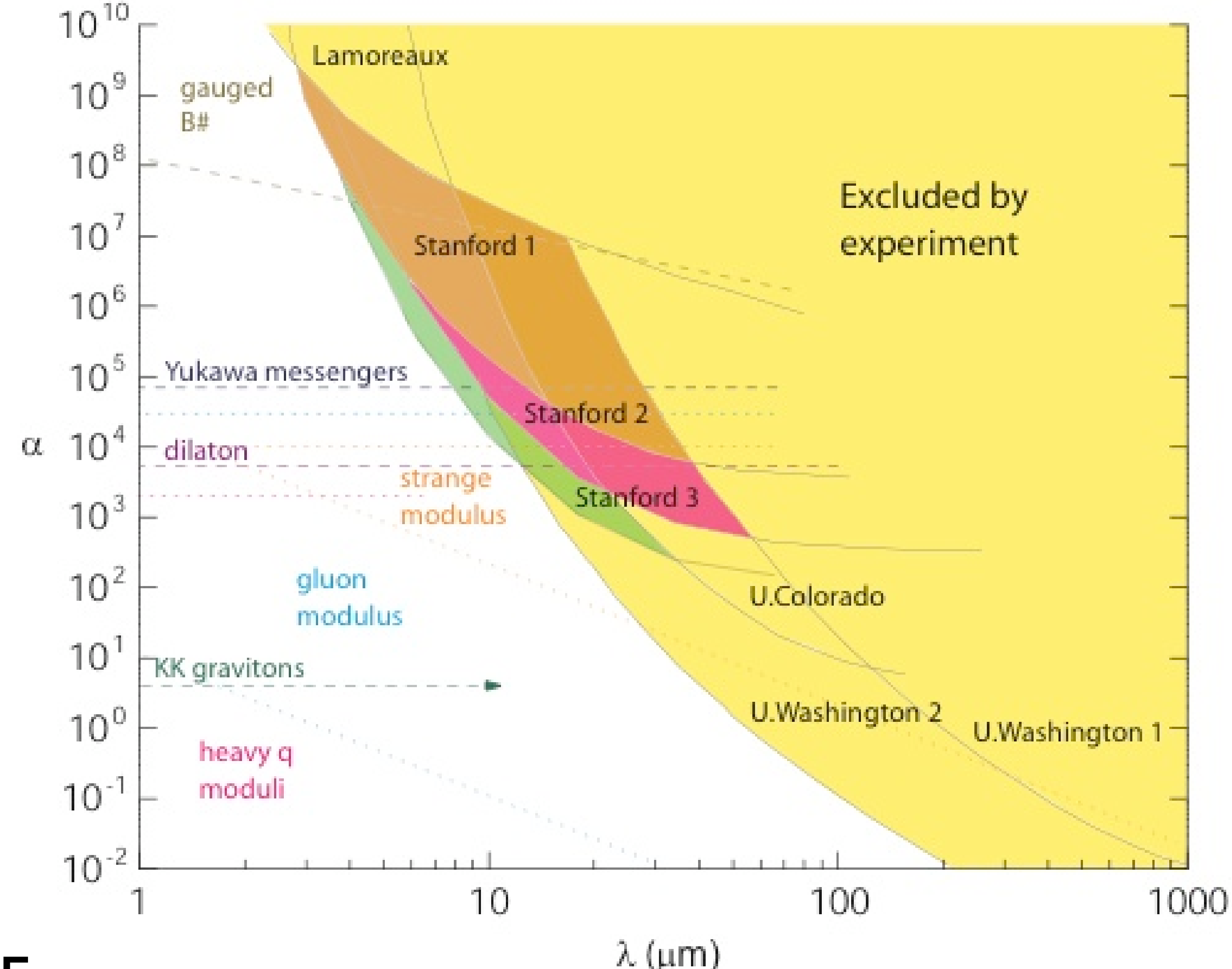
- atomic physics: $(g-2)_e$: $g<10^{-5}$ for range $<(\text{MeV})^{-1}$ ⇒ $m_V < 30$ keV

- astrophysics: Strongest Constraint from energy loss in red giants: $g<10^{-14}$ for mass $<(30\ \text{keV})^{-1}$ ⇒ $m_V < 3\times10^{-4}$ eV *Grifols, Masso, Peris*

New forces from light bosons

Inverse mass 0.1eV meV

α≡Strength relative to gravity



Range of Force

From arXiv:0802.2350

Evading Red Giant cooling constraint: ‘Chameleon’ Vector Boson

- need to avoid B-L gauge boson cooling of red giant stars
- density in stellar core $\sim 2\times10^5$ gm/cm^3
- Varying mass for vector boson in this extreme environment?

Chameleon forces

Chameleon forces arise from boson fields with nonlinear equations of motion

All forces are chameleons

(although nonlinearity sometimes negligible)

Chameleon forces can be challenging to detect because their effective range and strength depends on the local environment

Barrow, Mota, Khoury, Weltman, Gubser, Brax, van de Bruck, Davies, ...Feldman, A.E.N., A.E.N, Walsh

Chameleon effect for gauged B-L

- Higgs mechanism requires B-L charged scalar
- B-L charged scalar can give additional screening of B-L in matter (new boson is much heavier inside matter)
  - note interesting chameleon effects for either sign of mass squared term (e.g. force could be infinite range in vacuum but short range near the earth)

Evading Astro Constraints on gauged B-L

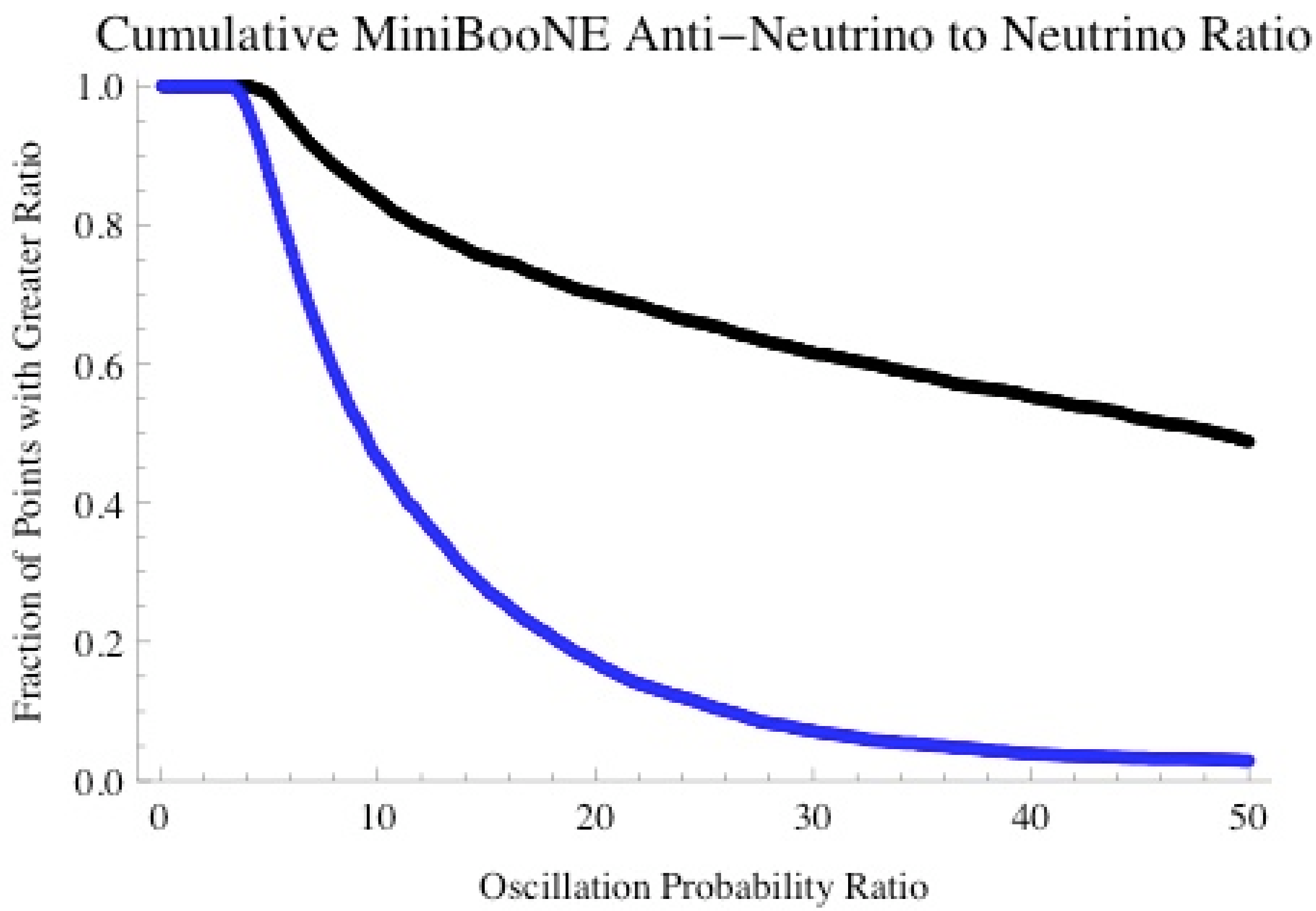
- Abelian Higgs model at high density $m_V \sim \rho^{1/3}$
  - for red giant: $(\rho_{core}/\rho_{earth})^{1/3} \sim 50$
  - allows new gauge boson on earth to be as much as 50 times lighter than stellar evolution bound for given coupling
  - 50000 times lighter than SN bound

Summary

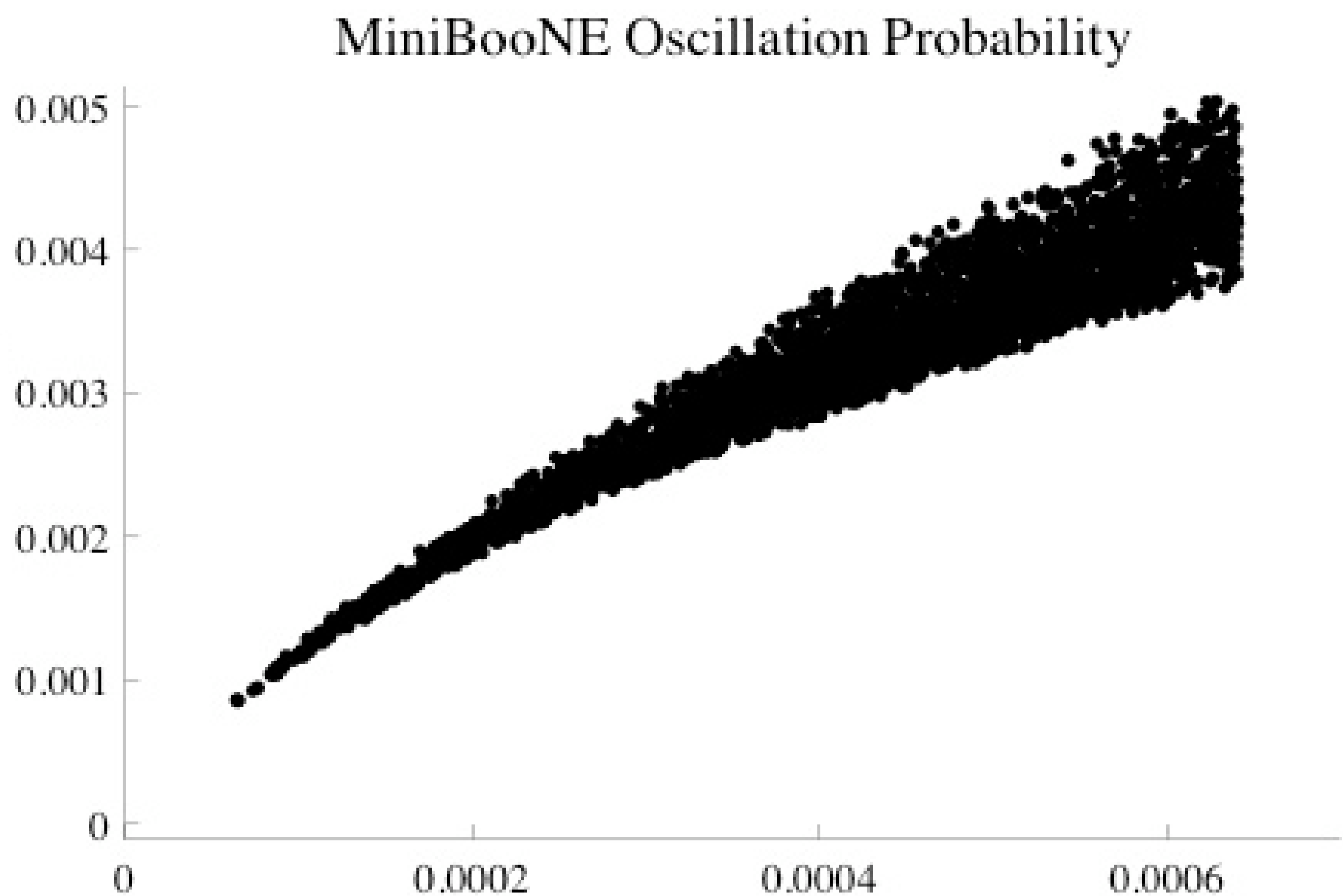
- LNSD vs MiniBooNe can be resolved via new long range B-L force giving MSW-like effect
  - can explain up to 40% of low energy MiniBooNe ν_e excess
  - suppresses SBL neutrino oscillations in MiniBooNe analysis region
  - resonance enhances anti neutrino oscillations at MiniBooNe energies
- Severe astrophysics constraints avoided
  - Vector boson with mass due to Higgs mechanism is a `chameleon', whose mass varies in extreme environments, allowing Boltzmann suppression of red giant cooling

Backup slides

anti neutrinos /neutrino oscillation expectations



MiniBooNe ν's



Below 475 MeV

Oscillation probability above 475 MeV

Neutrino oscillation effective Hamiltonian

$$\mathcal{H}'_2 = E + \frac{m^2}{2E} - V + \frac{1}{2E}\begin{pmatrix} 0 & mM_i \\ mM_i & 4VE + M_i^2 \end{pmatrix} .$$

Simple renormalizable model of a B-L gauge Chameleon

- charge q scalar field $s=|s|e^{i\theta}$
- B-L gauge field B_μ
- Abelian Higgs model if m^2 negative

$$\begin{aligned}\mathcal{L} \;=\; & (\partial_\mu + iqgB_\mu)s^*(\partial^\mu - iqgB^\mu)s - m^2|s|^2 - \frac{\epsilon}{2}|s|^4 \\ & -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - gB_\mu j^\mu\end{aligned}$$

Coupled equations of motion for U(1) gauge field and Charged Scalar

- charge q scalar field $s=|s|e^{i\theta}$
- configuration $\theta=qwt$, $B_i=0$, $i=1,2,3$
- gauge invariant fields $|s|$, $\omega= w+gB_0$
- gauge invariant equations of motion for static configuration

$$\begin{aligned} \nabla^2|s| &= \left(m^2+\epsilon|s|^2-q^2\omega^2\right)|s| \\ \nabla^2\omega &= -g^2\rho+2q^2g^2\omega|s|^2 \end{aligned}$$

gauge field acts as negative m^2

scalar screens gauge field

When is chameleon effect significant for Abelian Higgs model?

- $|m|>(\varepsilon\rho)^{1/3}$, $m^2<0$: Chameleon effect minimal
- $|m|<(\varepsilon\rho)^{1/3}$: High Density Chameleon Regime

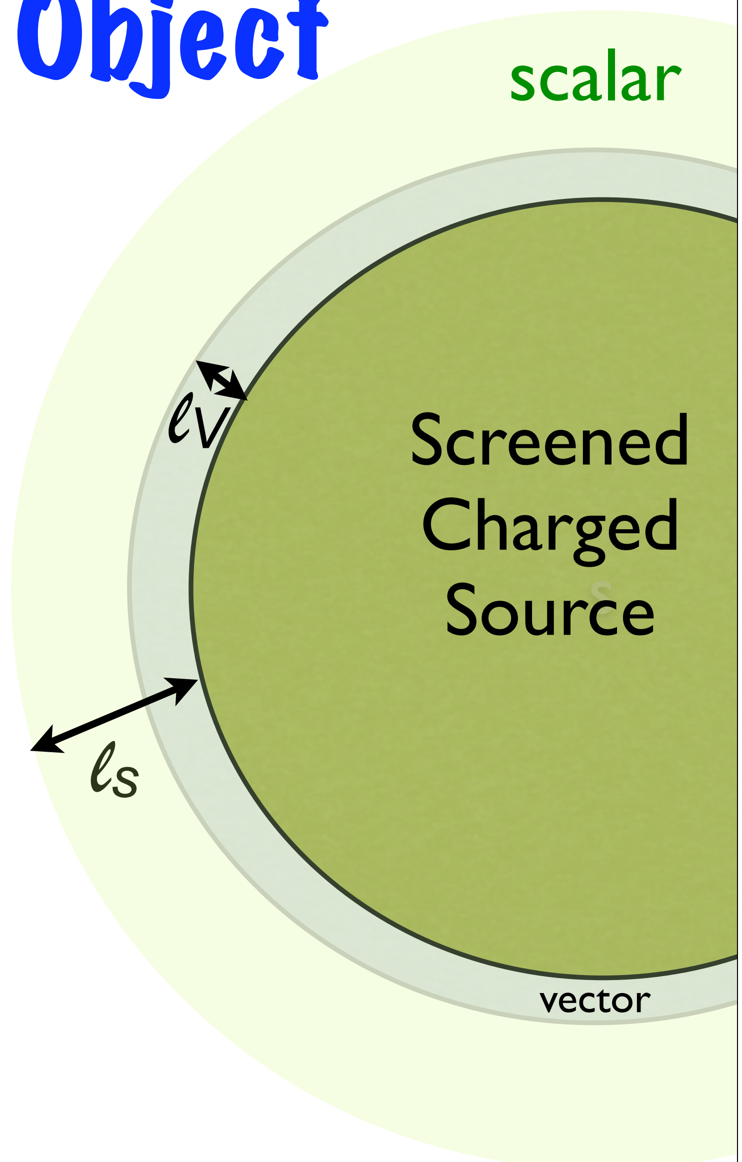
In constant density matter have solution with constant $\omega=\omega_0$

$$\omega_0 \approx \frac{(\epsilon\rho)^{\frac{1}{3}}}{q}$$
$$|s| \approx \left(\frac{\rho}{\epsilon}\right)^{\frac{1}{3}}$$

At high density gauge boson mass proportional to density$^{1/3}$

Thin Shell Near a Large Object

- vector field falls exponentially on scale ℓ_V
- scalar field falls on larger of scales ℓ_S, ℓ_V



$$\nabla^2|s| = \left(m^2 + \epsilon|s|^2 - q^2\omega^2\right)|s|$$
$$\nabla^2\omega = -g^2\rho + 2q^2g^2\omega|s|^2 .$$

The "lower"-energy region

Summer MiniBooNE update

- examining lower energy
- excess persists in 200 < E_ν < 300 MeV bin

Excess of ν_e candidates at low energy

- NEW:

this energy bin