Test of Lorentz Violation with LSND

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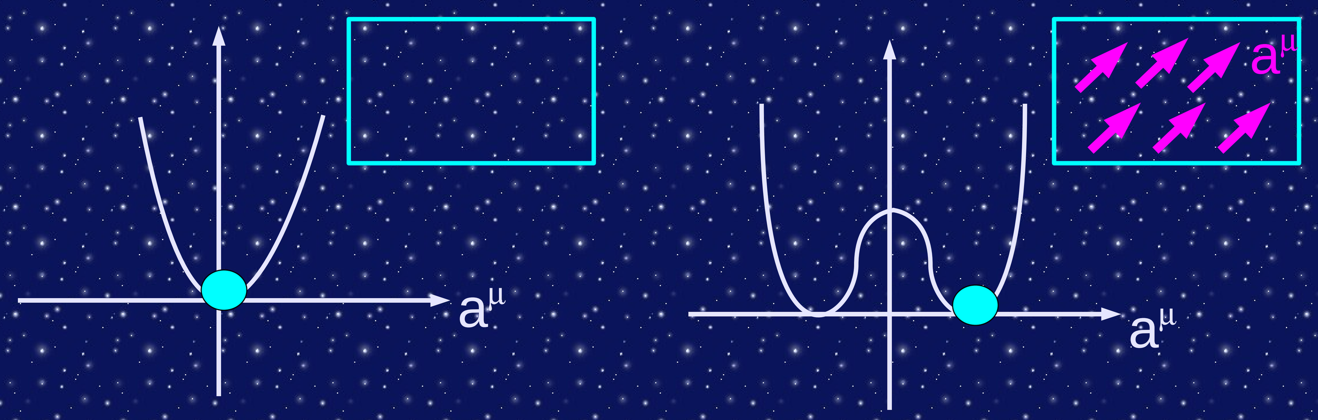
PRD,72(2005)076004

Motivation

PRD,39(1989)683

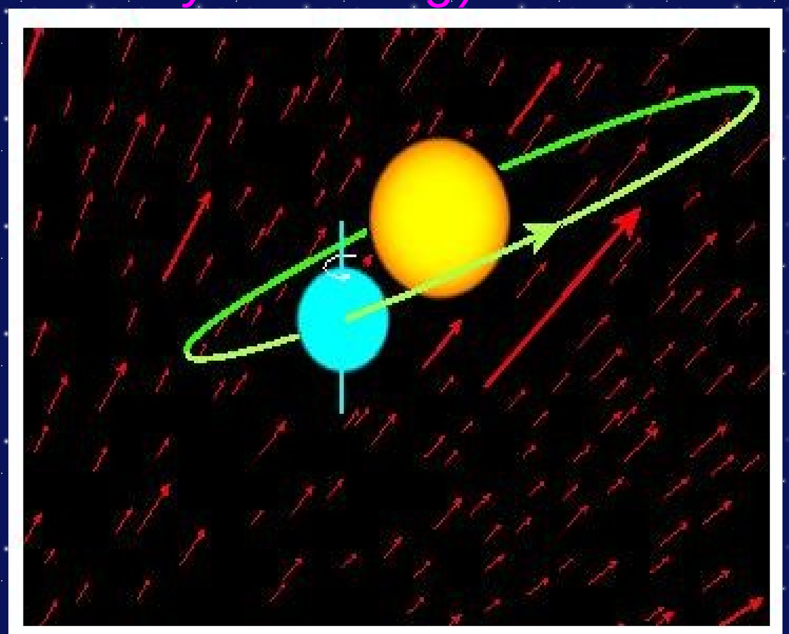
In a field theory, Spontaneous Symmetry Breaking (SSB) occurs when symmetries of the Lagrangian are not respected by the ground state of the theory



In string theory, there is a possibility that some Lorentz tensor fields acquire a nonzero vacuum expectation value (Spontaneous Lorentz symmetry Breaking)

Universe might be polarized!

Lorentz and CPT violation also occurs in other theories, including loop quantum gravity, noncommutative field theory, brane world, etc...



Scientific American (Sept.2004)
Science (Feb. 11, 2005)

Sidereal Time Variation

The signature of Lorentz Violation is sidereal time variation of physics observables, like neutrino oscillation, in a fixed coordinate system.

Standard Model Extension (SME)

PRD,55(1997)6760;58(1998)1160

SME is the minimal extension of Standard Model including Particle Lorentz and CPT violation

Modified Dirac Equation

$$i(\Gamma^{\mu}_{AB}\partial_{\mu}-M_{AB})\nu_B=0$$

SME parameters

$$\Gamma^{\mu}_{AB}=\gamma^{\mu}\delta_{AB}+c^{\mu\nu}_{AB}\gamma_{\nu}+d^{\mu\nu}_{AB}\gamma_{\nu}\gamma_5+e^{\mu}_{AB}+if^{\mu}_{AB}\gamma_5+\frac{1}{2}g^{\mu\nu\lambda}_{AB}\sigma_{\nu\lambda}$$

$$M_{AB}=m_{AB}+im_{5AB}\gamma_5+a^{\mu}_{AB}\gamma_{\mu}+b^{\mu}_{AB}\gamma_{\mu}\gamma_5+\frac{1}{2}H^{\mu\nu}_{AB}\sigma_{\mu\nu}$$

Lorentz and CPT violating field (CPT-odd fields)

Lorentz violating field (CPT-even fields)

PRD,69(2004)016005; 70(2004)076002

Oscillation probability for LSND with CPT-odd fields

$$P_{\bar{\nu}_{\mu}\rightarrow\bar{\nu}_e}\simeq\frac{L^2}{(\hbar c)^2}\left|(C)_{e\bar{\mu}}+(A_s)_{e\bar{\mu}}\sin\omega_{\oplus}T_{\oplus}+(A_c)_{e\bar{\mu}}\cos\omega_{\oplus}T_{\oplus}\right|^2$$

$$(C)_{e\bar{\mu}}=[-(a+b)^T_{e\bar{\mu}}+N^Z(a+b)^Z_{e\bar{\mu}}]$$
$$(A_s)_{e\bar{\mu}}=[-N^Y(a+b)^X_{e\bar{\mu}}+N^X(a+b)^Y_{e\bar{\mu}}]$$
$$(A_c)_{e\bar{\mu}}=[N^X(a+b)^X_{e\bar{\mu}}+N^Y(a+b)^Y_{e\bar{\mu}}]$$

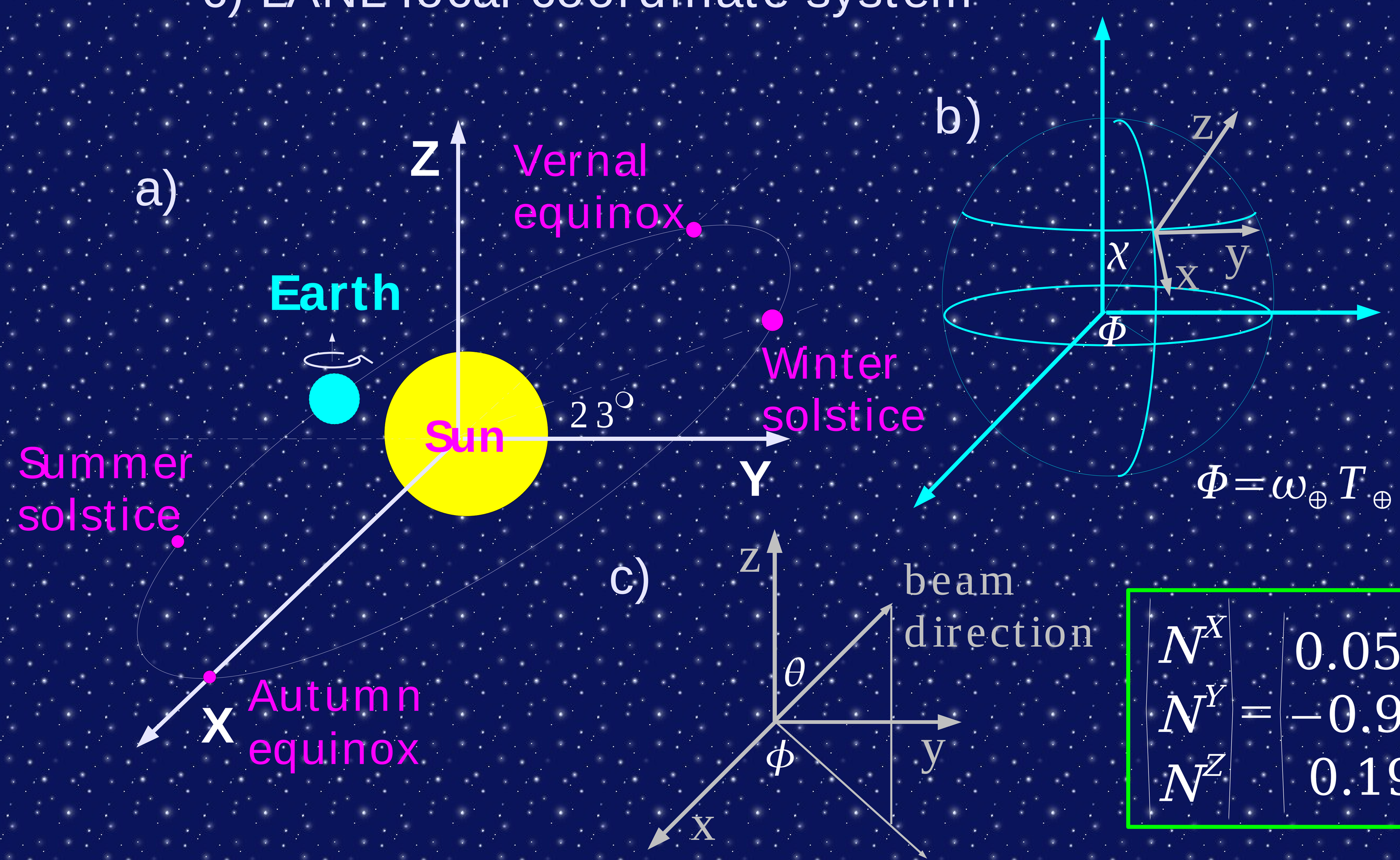
Sidereal time $T_{\oplus}$

Sidereal time frequency $\omega_{\oplus}=1/23h56m4.1s$

Direction vector of the experiment N^X, N^Y, N^Z

LSND coordinate systems

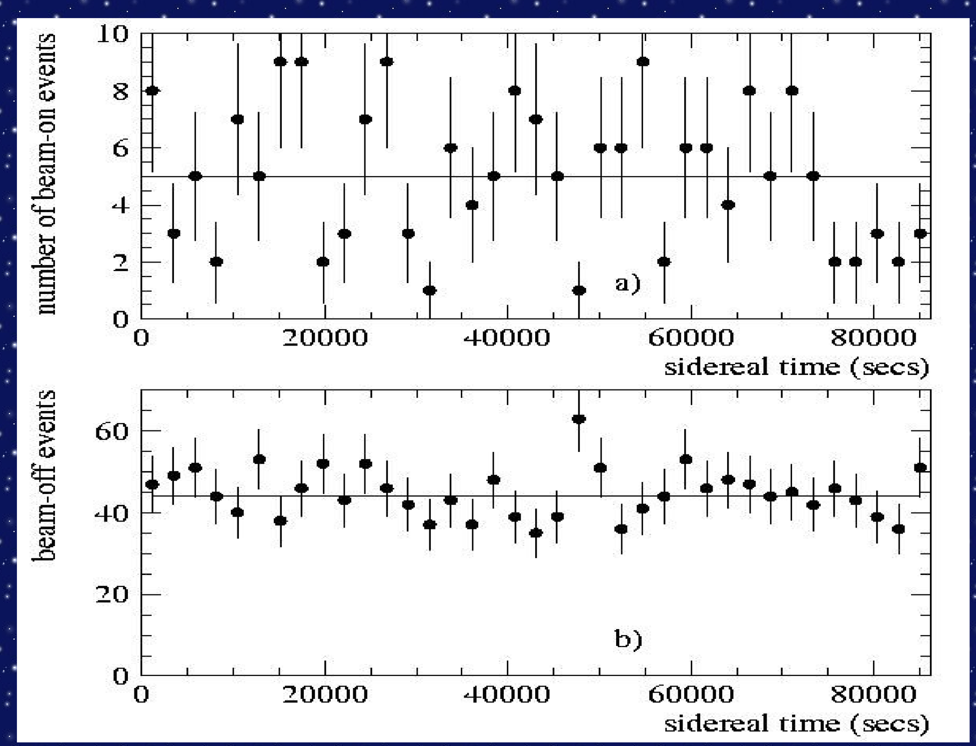
The LSND oscillation result is described in terms of 3 coordinate systems
a) Sun-centered system
b) Earth-centered system
c) LANL local coordinate system



$$\begin{pmatrix}N^X\\N^Y\\N^Z\end{pmatrix}=\begin{pmatrix}0.053\\-0.98\\0.19\end{pmatrix}$$

Null sidereal variation hypothesis tests

Sidereal time distribution of beam-on (top) and beam-off (bottom) data



To quantify the statistical significance of any sidereal time variation, statistical tests are applied to beam-on and beam-off data.

	beam-on	beam-off
#events	186	1656
P (Pearson's χ^2) (37 bins)	0.15	0.77
P (KS test)	0.234	0.604

Beam-on data is less compatible with flat hypothesis compared to beam-off data.

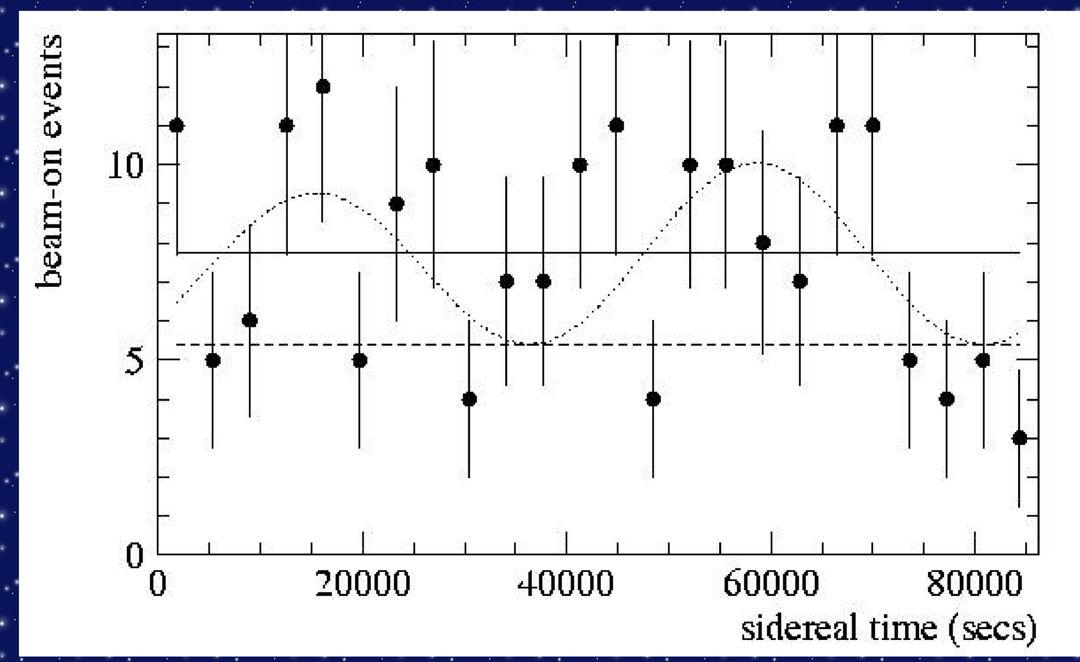
However, this is not statistically significant amount.

There is no statistically significant sidereal time variation in LSND data.

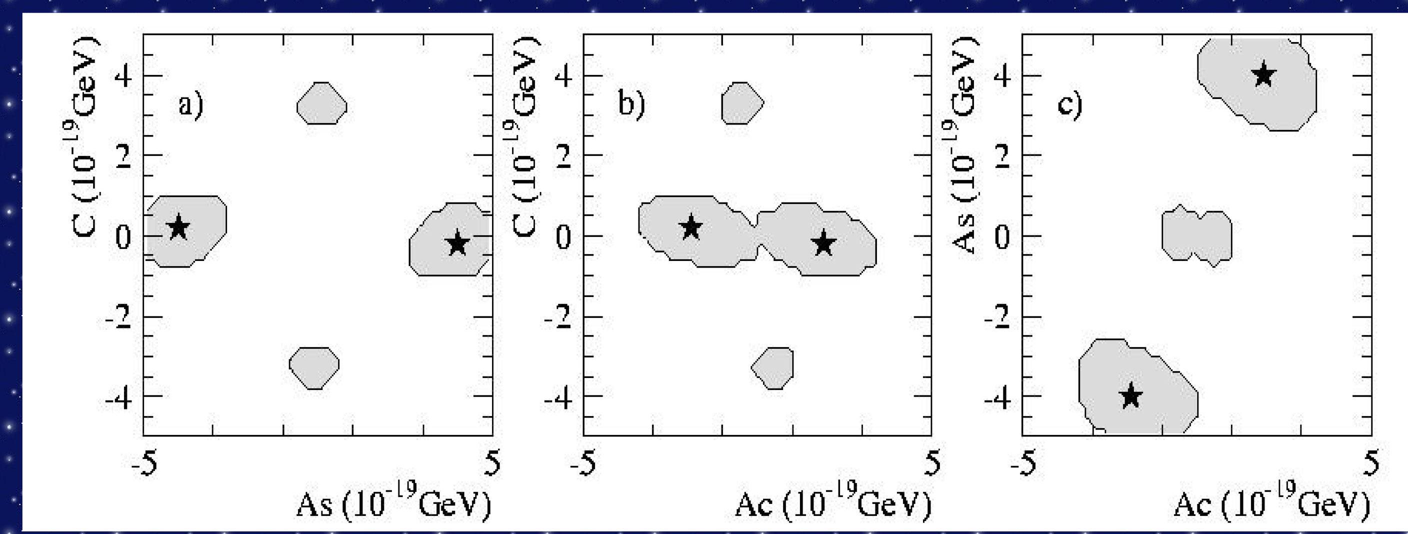
Sidereal variating model fit

Sidereal time distribution best fit lines for no time variation (solid) and including all CPT-odd Lorentz violating fields (dotted) with flat background (dashed).

Unbinned-likelihood method is used to extract the best fit parameters of this model.



2 possible solutions for CPT-odd Lorentz violation fit.



Parameter space of LSND sidereal time distribution fit using C, As, and Ac parameters (including all CPT-odd fields) with 1-sigma contour.

Solution (1)	Solution (2)
$(C)_{e\bar{\mu}}=-0.2\pm1.0\pm0.3$	$(C)_{e\bar{\mu}}=3.3\pm0.5\pm0.3$
$(A_s)_{e\bar{\mu}}=4.0\pm1.3\pm0.4$	$(A_s)_{e\bar{\mu}}=0.1\pm0.6\pm0.2$
$(A_c)_{e\bar{\mu}}=1.9\pm1.8\pm0.4$	$(A_c)_{e\bar{\mu}}=-0.5\pm0.6\pm0.2$

The solution (1) has large As value (sidereal time variation), and the solution (2) has large C (no time variation), and (1) is statistically slightly favored than (2).

This is consistent with null sidereal variation hypothesis test, where null hypothesis cannot be rejected completely.

LSND oscillation result is consistent with order ~10^{-19}GeV Lorentz violating effect.

Summary and Outlook

Lorentz Violating solution is consistent with the LSND oscillation result, but null sidereal variation scenario is not excluded.

To validate this solution, one needs to check all neutrino experiment data with this solution (Global solution of neutrino oscillation with Lorentz Violation, in preparation).

A MiniBooNE signal may exhibit similar sidereal time variation, which would be very interesting!