Test for Lorentz violation with MiniBooNE low energy excess

Teppei Katori
Massachusetts Institute of Technology
CPT and Lorentz symmetry 2010
Bloomington, Indiana, USA, June 30, 10

Test for Lorentz violation with MiniBooNE low energy excess

outline

1. MiniBooNE experiment
2. ν_e candidate low energy excess
3. Lorentz violating neutrino oscillation
4. SME parameters fit
5. Conclusion

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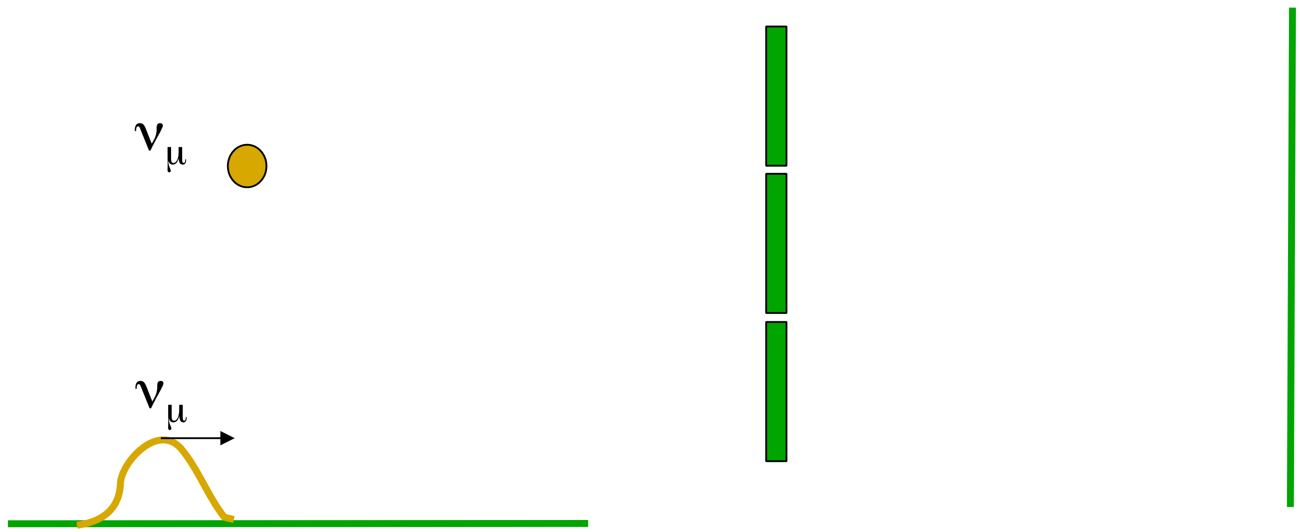
1. Lorentz violation with neutrino oscillation

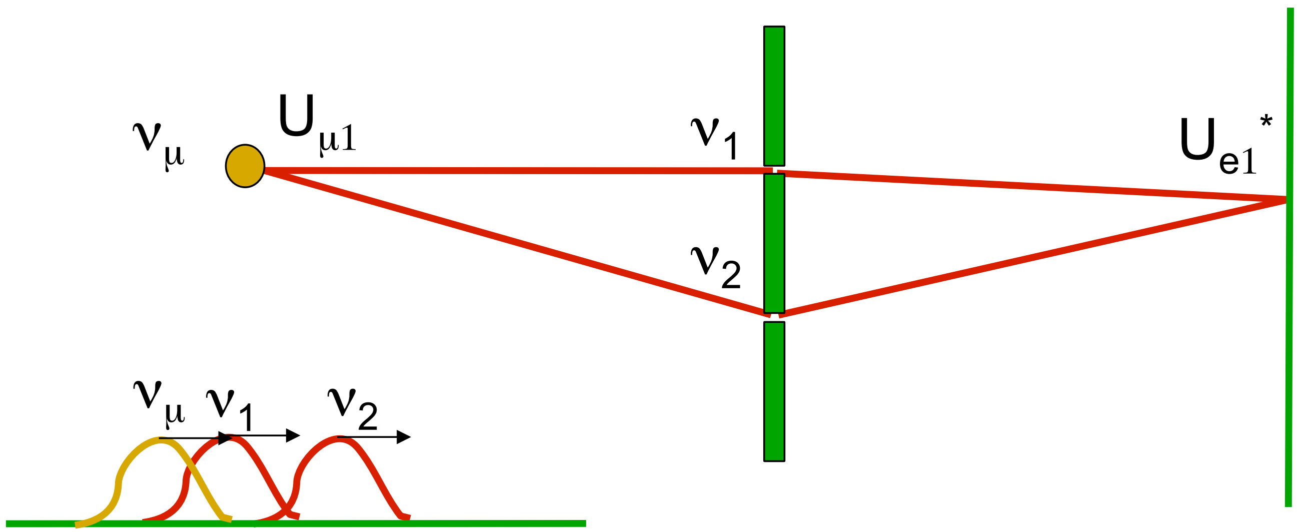
Neutrino oscillation is an interference experiment (cf. double slit experiment)



If 2 neutrino Hamiltonian eigenstates, ν_1 and ν_2, have different phase rotation, they cause quantum interference.

1. Lorentz violation with neutrino oscillation

Neutrino oscillation is an interference experiment (cf. double slit experiment)



If 2 neutrino Hamiltonian eigenstates, ν_1 and ν_2, have different phase rotation, they cause quantum interference.

If ν_1 and ν_2, have different coupling with Lorentz violating field, interference fringe (oscillation pattern) depend on the sidereal motion.

1. Lorentz violation with neutrino oscillation

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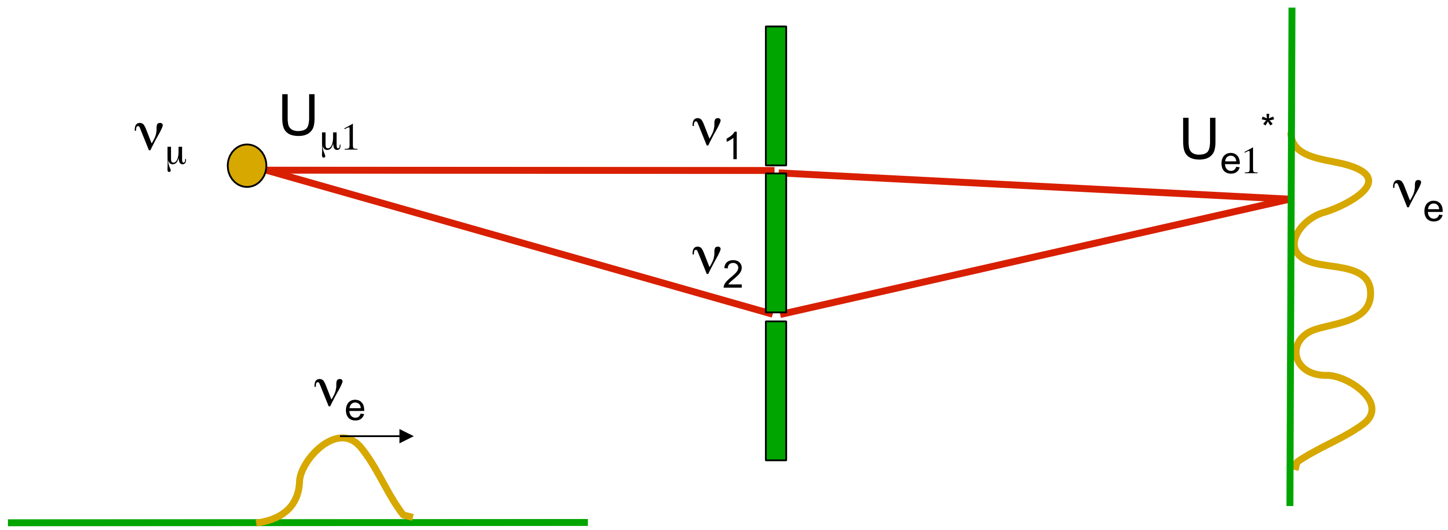


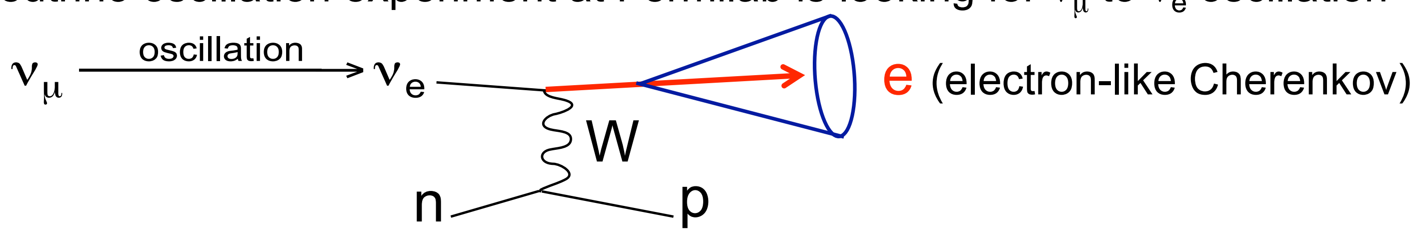
If 2 neutrino Hamiltonian eigenstates, ν_1 and ν_2, have different phase rotation, they cause quantum interference.

If ν_1 and ν_2, have different coupling with Lorentz violating field, interference fringe (oscillation pattern) depend on the sidereal motion.

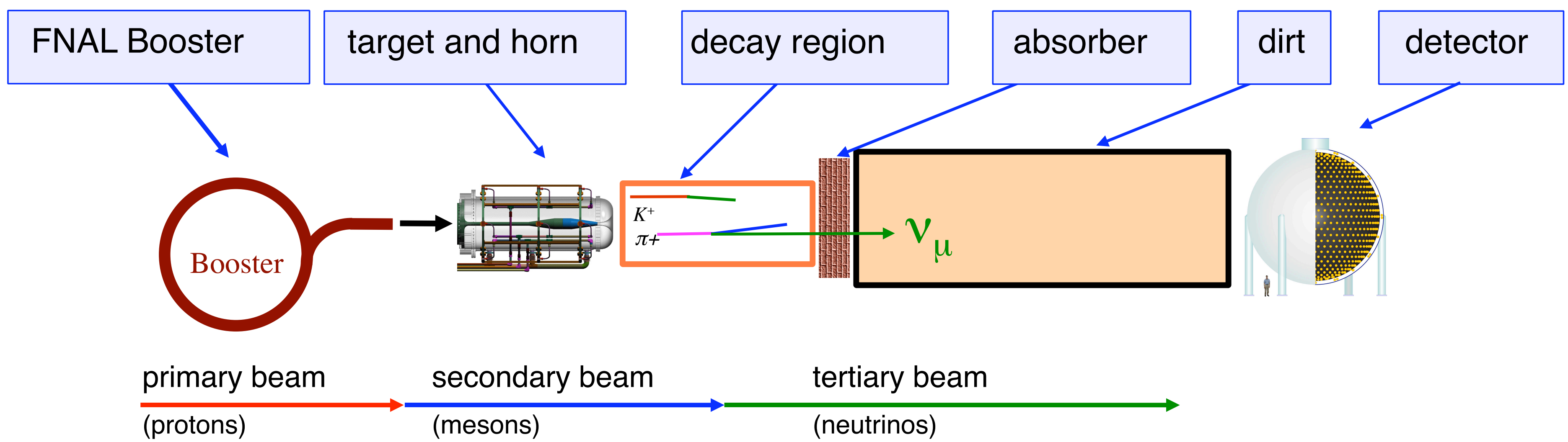
The measured scale of neutrino eigenvalue difference is comparable the target scale of Lorentz violation ($<10^{-19}$GeV).

1. MiniBooNE experiment

MiniBooNE neutrino oscillation experiment at Fermilab is looking for ν_μ to ν_e oscillation

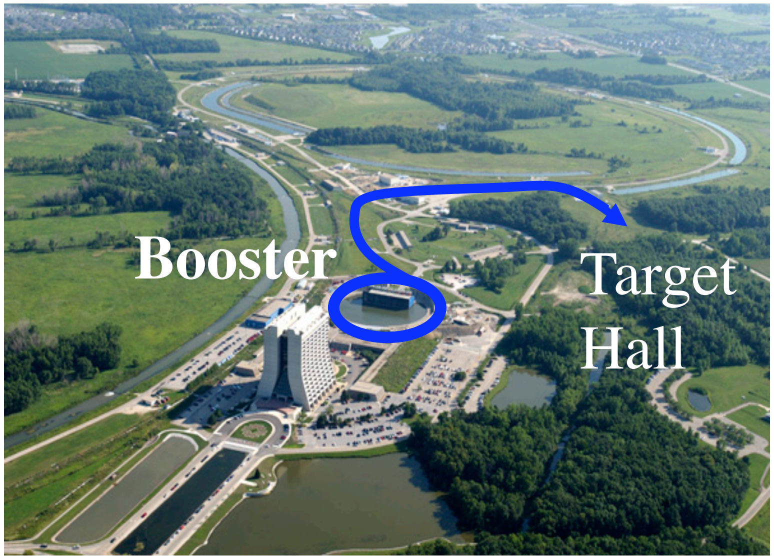


Signature of ν_e event is the single isolated electron like events

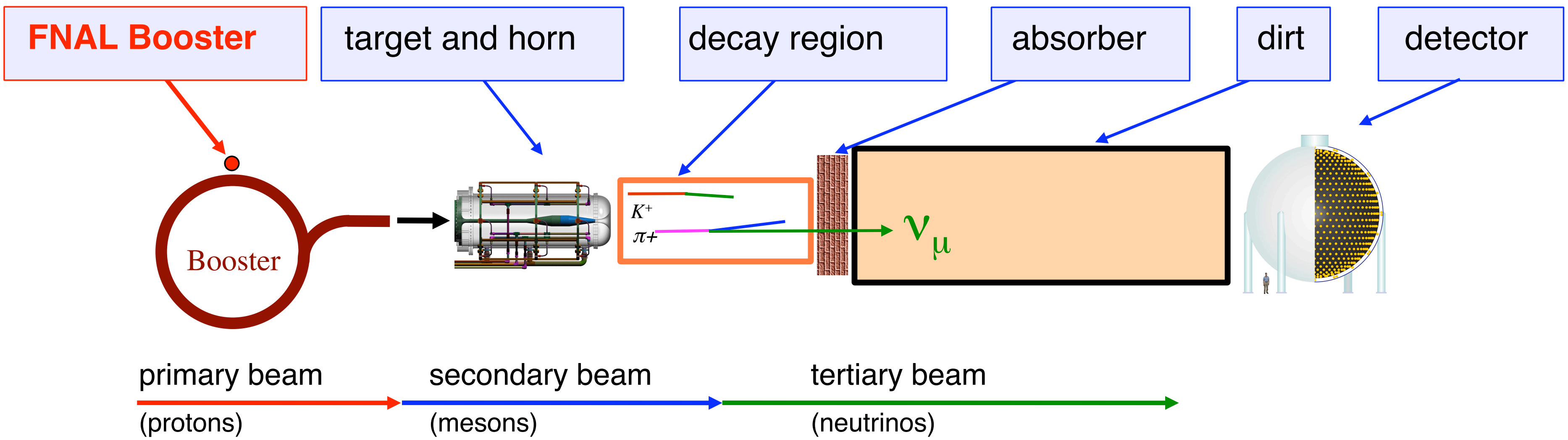


MiniBooNE collaboration,
PRD79(2009)072002

1. MiniBooNE experiment



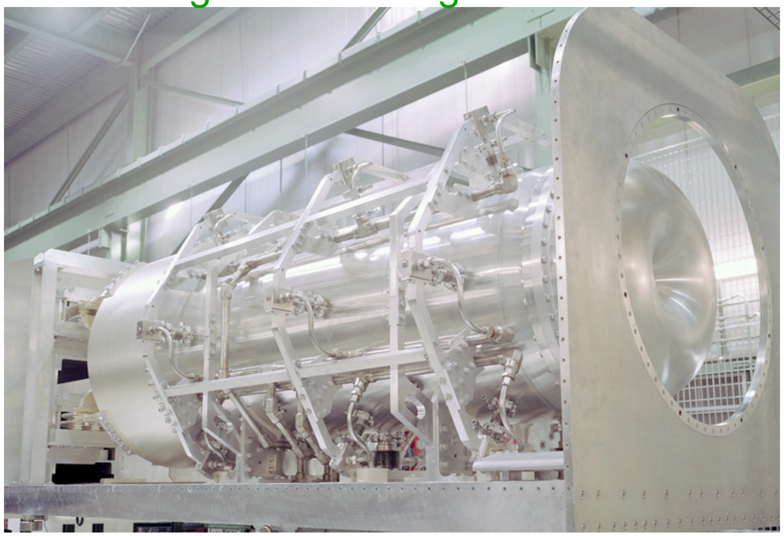
MiniBooNE extracts beam from the 8 GeV Booster



MiniBooNE collaboration,
PRD79(2009)072002

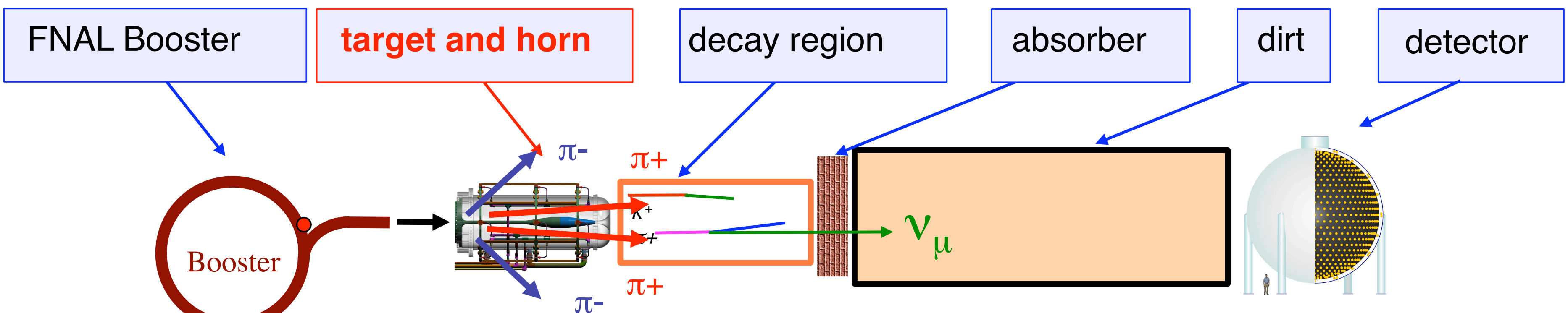
1. MiniBooNE experiment

Magnetic focusing horn



8GeV protons are delivered to a 1.7 λ Be target

within a magnetic horn (2.5 kV, 174 kA) that increases the flux by $\times$ 6

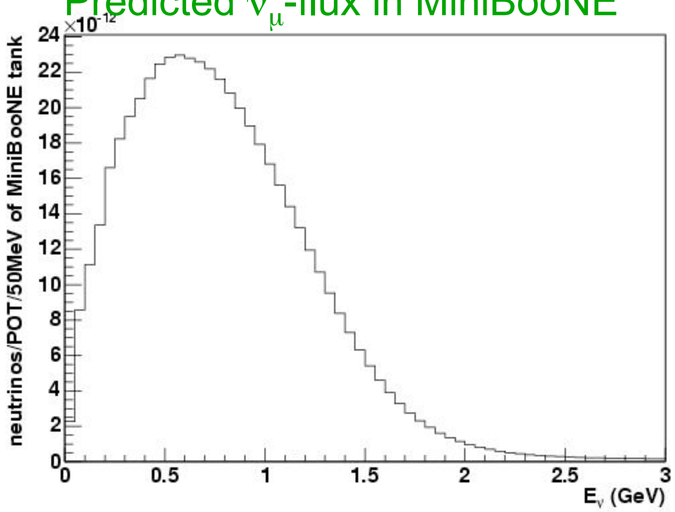


primary beam (protons) → secondary beam (mesons) → tertiary beam (neutrinos)

MiniBooNE collaboration,
PRD79(2009)072002

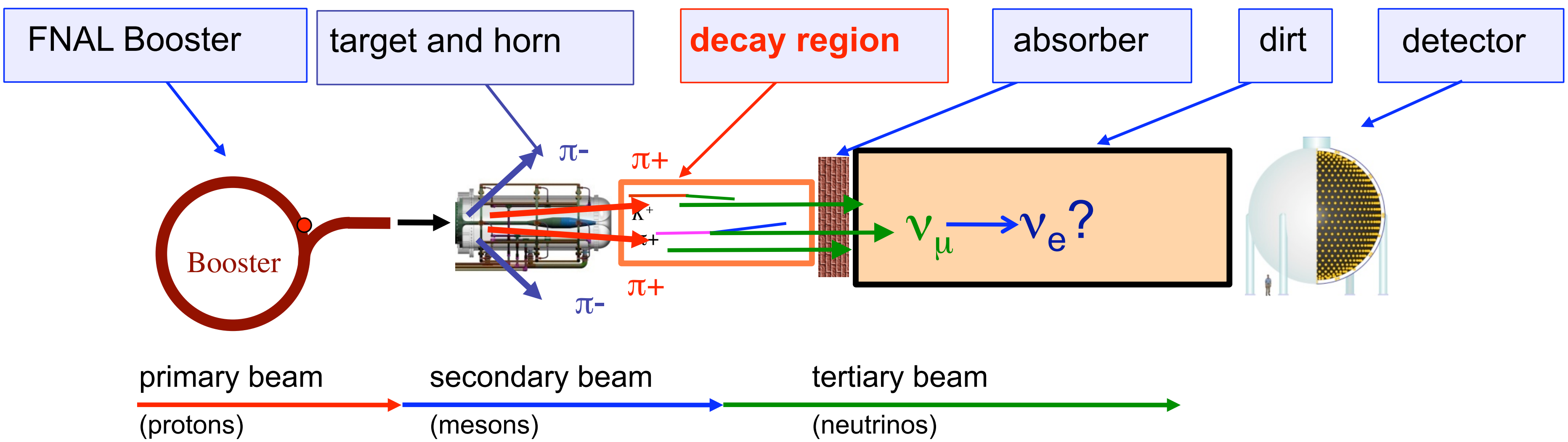
1. MiniBooNE experiment

Predicted ν_μ-flux in MiniBooNE



The decay of mesons make the neutrino beam. The neutrino beam is dominated by ν_μ (93.6%), of this, 96.7% is made by π+-decay

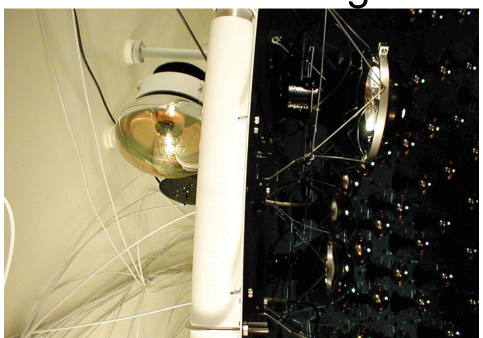
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

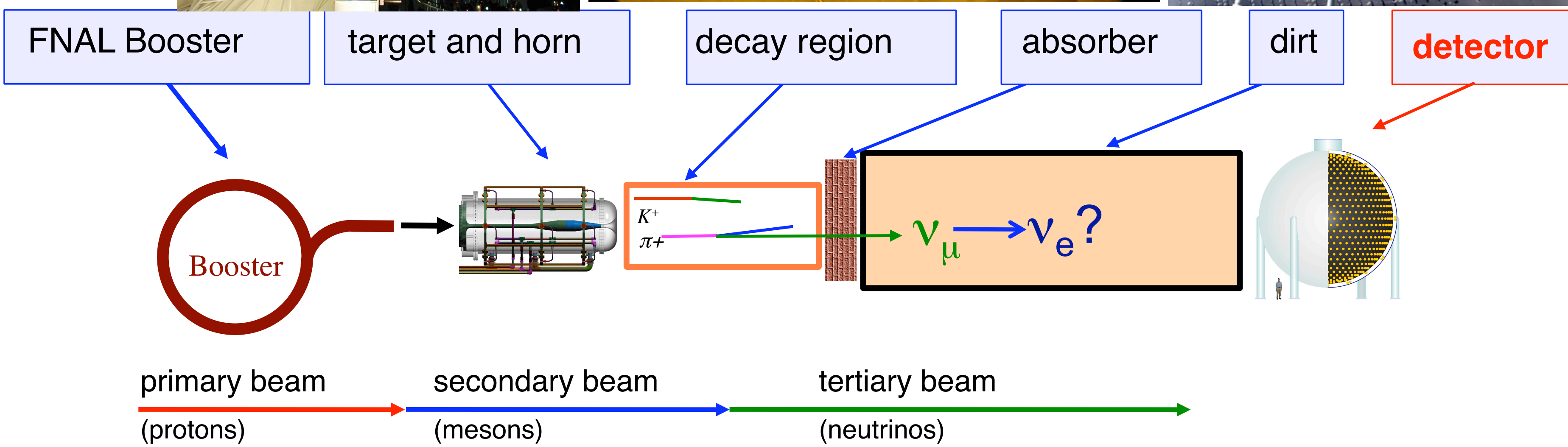


MiniBooNE collaboration,
NIM.A599(2009)28

1. MiniBooNE experiment

MiniBooNE detector is the spherical Cherenkov detector
- ν-baseline is ~520m
- filled with 800t mineral oil
-1280 of 8” PMT in inner detector
- 240 veto PMT in outer region

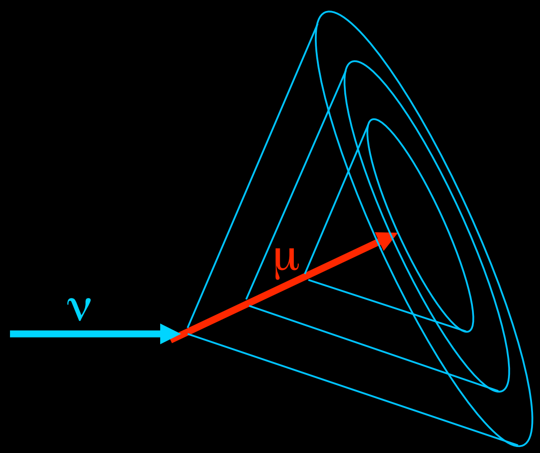


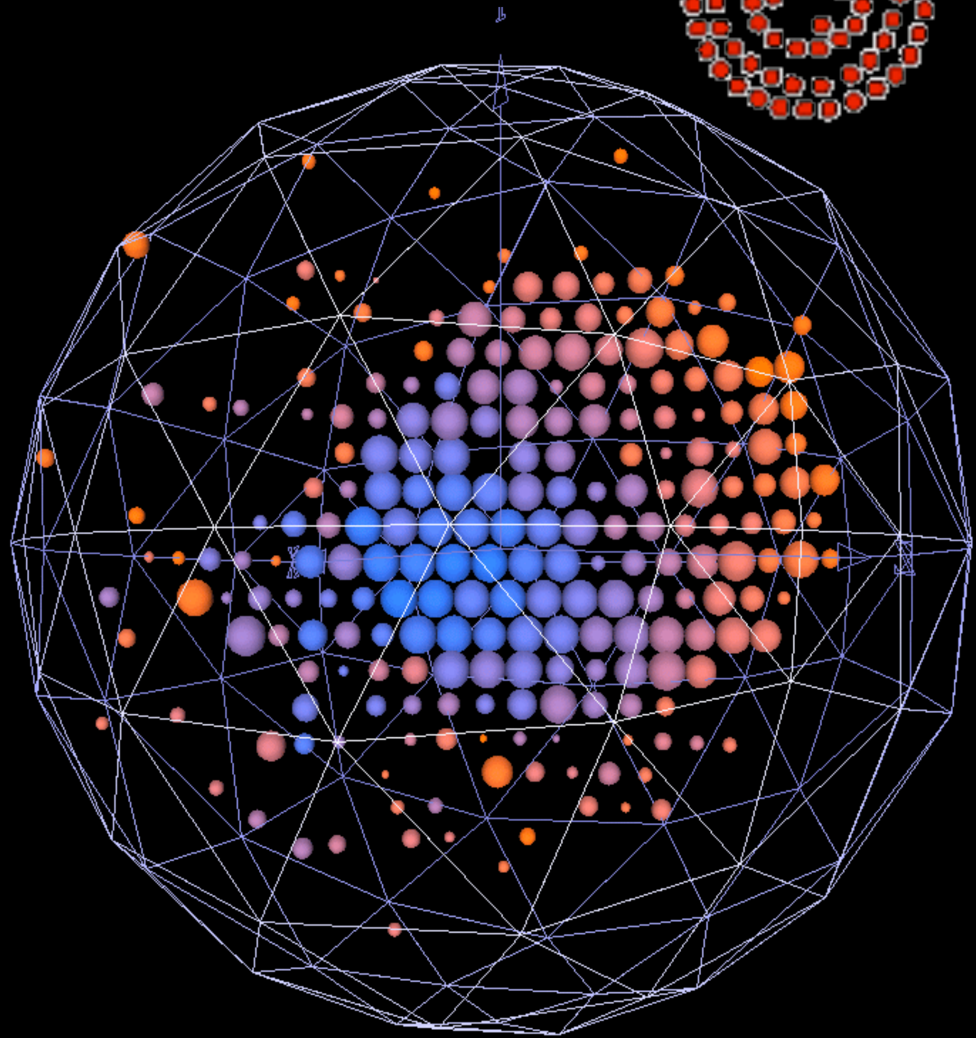


MiniBooNE collaboration, NIM.A599(2009)28

1. MiniBooNE experiment

- ***Muons***
  - ***Sharp, clear rings***
    - ***Long, straight tracks***
- Electrons
  - Scattered rings
    - Multiple scattering
    - Radiative processes





MiniBooNE collaboration,
NIM.A599(2009)28

1. MiniBooNE experiment

- Muons
  - Sharp, clear rings
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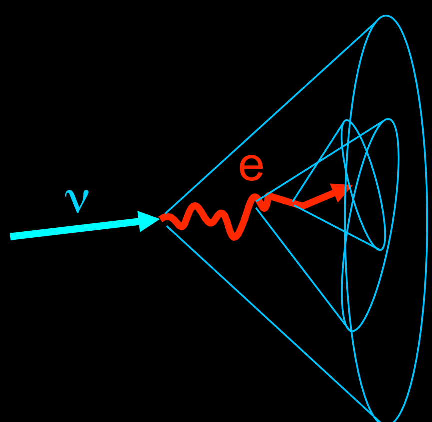

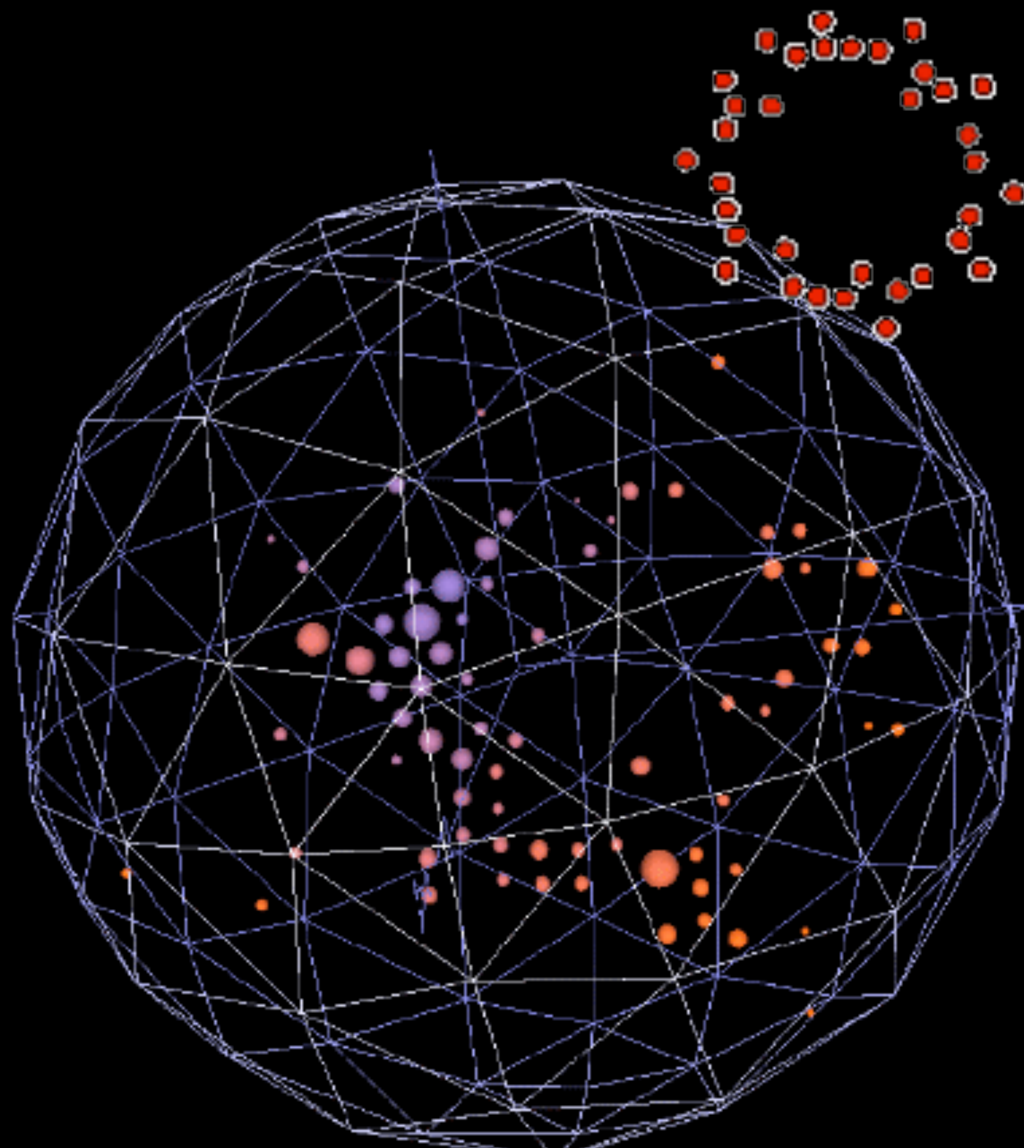

1. MiniBooNE experiment

2. ν_e candidate low energy excess

3. Lorentz violating neutrino oscillation

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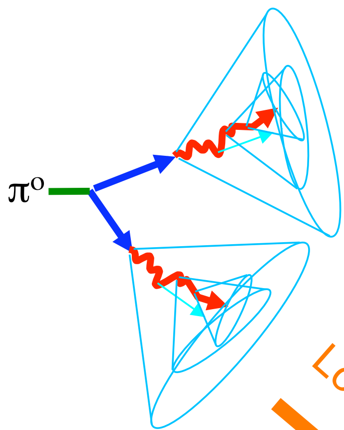
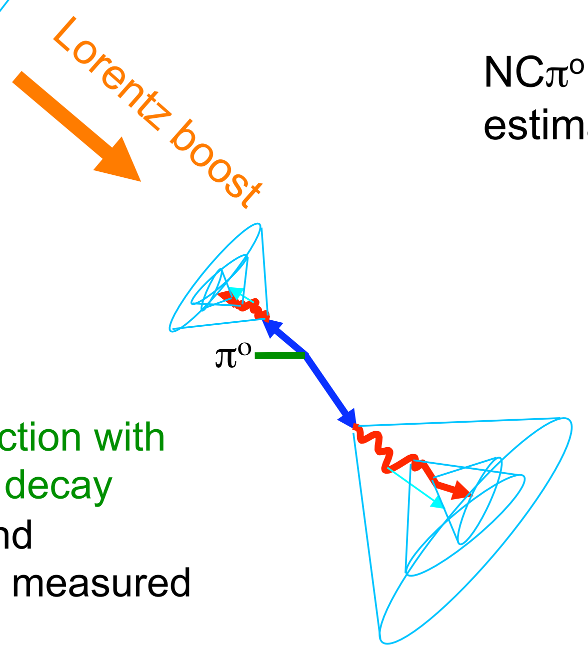
MiniBooNE collaboration
PLB664(2008)41
PRL100(2008)032301

2. ν_e candidate low energy excess

NCπ^o production
- not background
- measured





NCπ^o production with asymmetric decay
- background
- cannot be measured

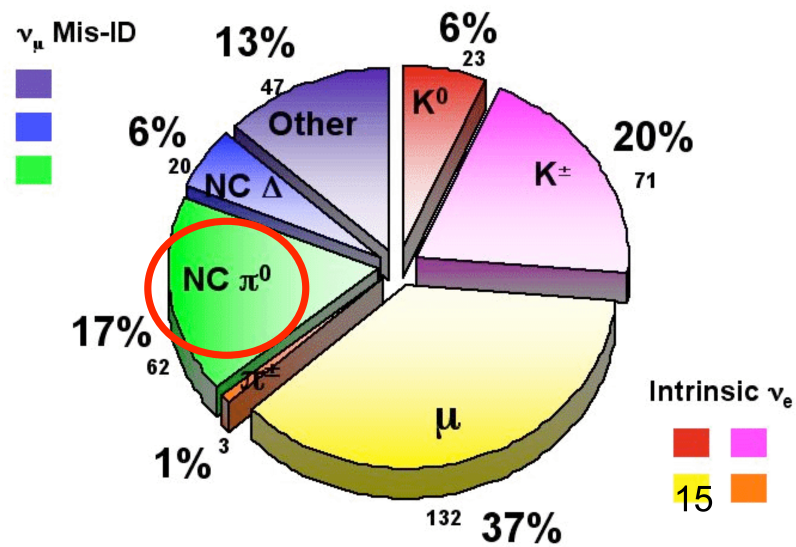
Blind analysis

MiniBooNE perform ~5 years blind analysis. ν_e candidate data is not used to tune MC. Background errors are constraint from measurements by MiniBooNE detector.

e.g.

- NCπ^o production (ν_μ misID background)
- Beam ν_e contamination (intrinsic ν_e background)

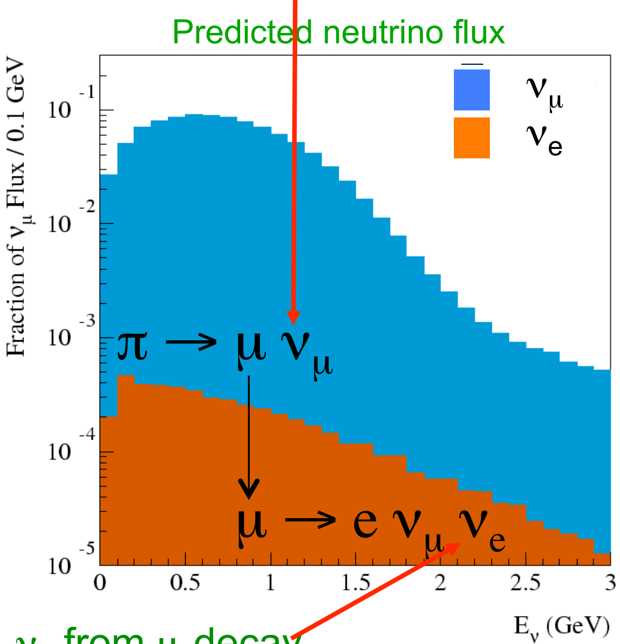
NCπ^o measurement of MiniBooNE provide precise estimation for this type of background.



MiniBooNE collaboration
PLB664(2008)41
PRL100(2008)032301

2. ν_e candidate low energy excess

muon neutrino
- not background
- measured



ν_e from μ-decay
- background
- cannot be measured

Blind analysis

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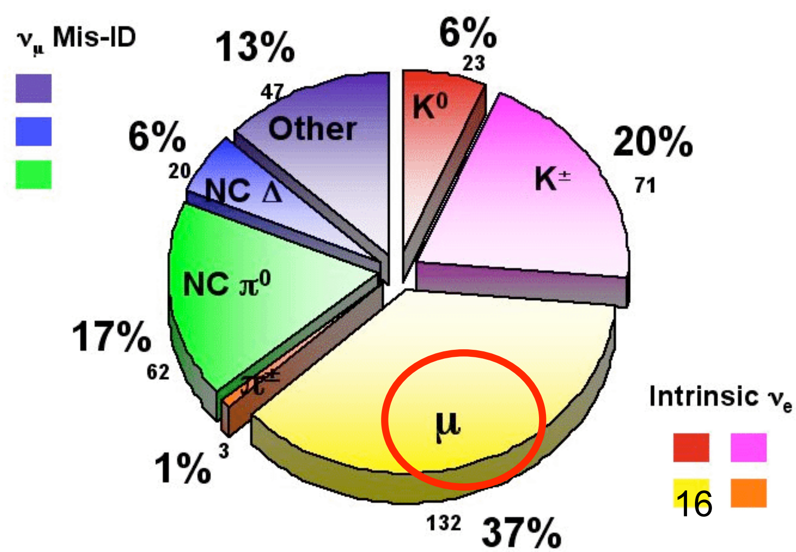
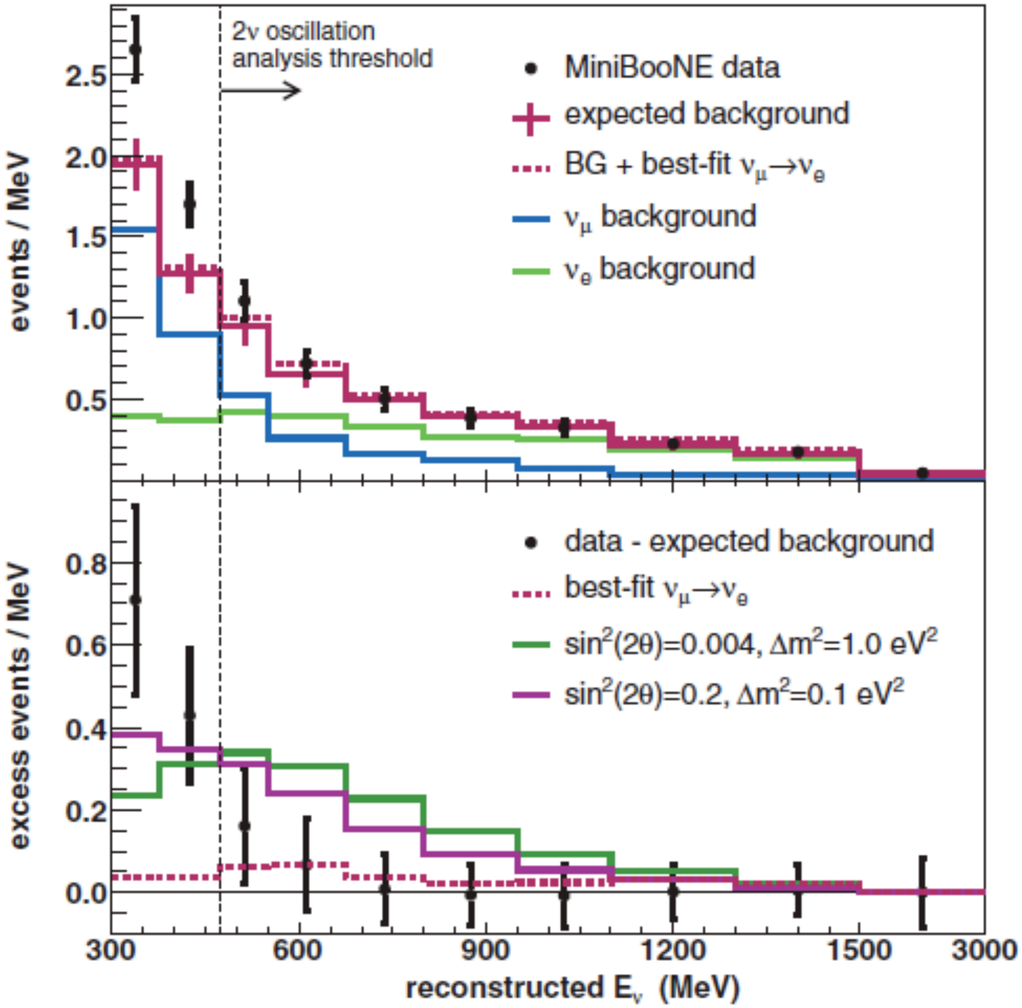
e.g.
- NCπ^o production (ν_μ misID background)
- Beam ν_e contamination (intrinsic ν_e background)

ν_μ measurement of MiniBooNE provide precise prediction of ν_e from μ-decay



MiniBooNE collaboration,
PRL98(2007)231801

2. ν_e candidate low energy excess



MiniBooNE first oscillation result

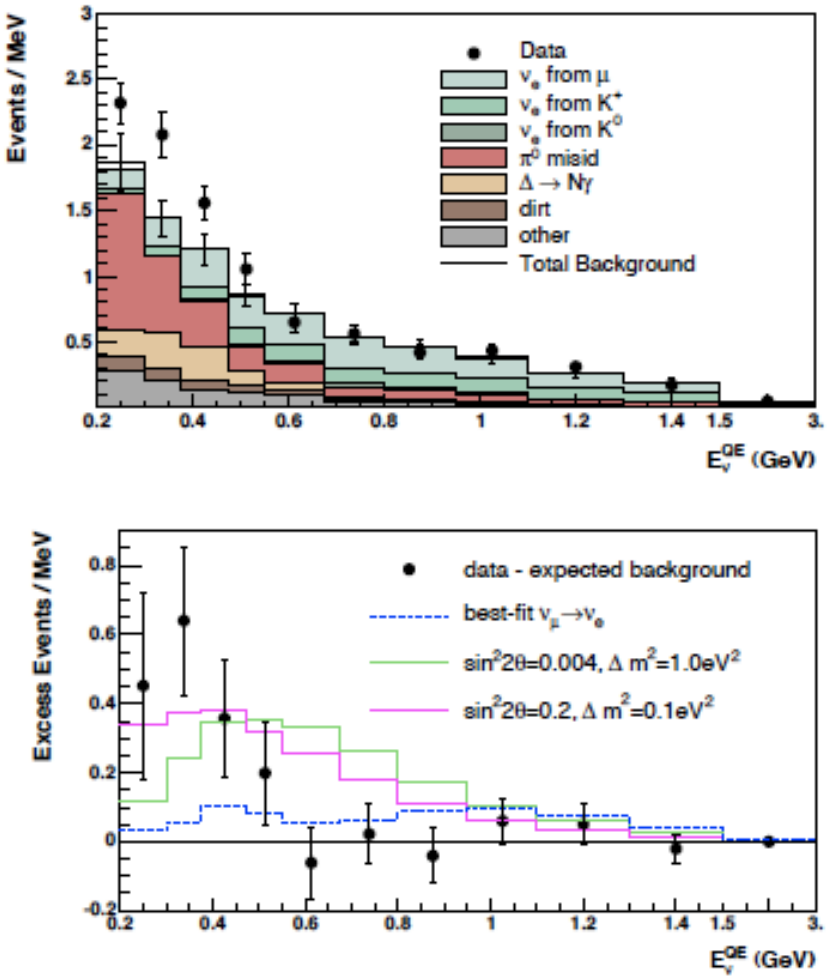
There is no ν_e candidate excess in the analysis region (where the LSND signal is expected from 1 sterile neutrino interpretation).

However there is visible excess at low energy region, which is inconsistent with two massive neutrino oscillation hypothesis.

Is this excess real physics?

MiniBooNE collaboration,
PRL102(2009)101802

2. ν_e candidate low energy excess



New MiniBooNE oscillation result

After ~1 year careful reanalysis, again no excess in oscillation candidate region, but low energy excess is confirmed.

The energy dependence of ν_e low energy excess is not consistent with ~1/E, hence it is not consistent with two massive neutrino oscillation hypothesis.

Lorentz violating neutrino oscillation has various energy dependences, therefore it is interesting to test Lorentz violation!

1. MiniBooNE experiment

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4. SME parameters fit

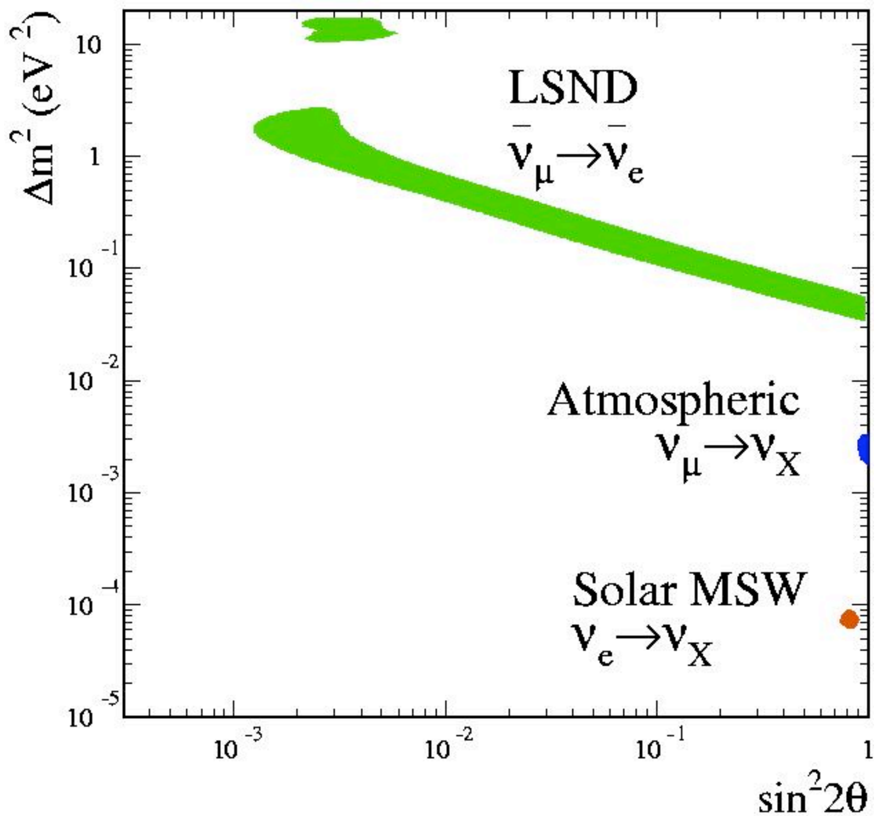
5. Conclusion

Kostelecky and Mewes
PRD69(2004)016005

3. Lorentz violating neutrino oscillation

The examples of model independent features that represent characteristic signals of Lorentz violation for neutrino oscillation

(1) Spectral anomalies
(2) L-E conflict
(3) Sidereal variation



Any signals cannot be mapped on Δm^2-$\sin^2 2\theta$ plane (MS-diagram) could be Lorentz violation, since under the Lorentz violation, MS diagram is no longer useful way to classify neutrino oscillations

LSND is the example of this class of signal.

Kostelecky and Mewes
PRD69(2004)016005

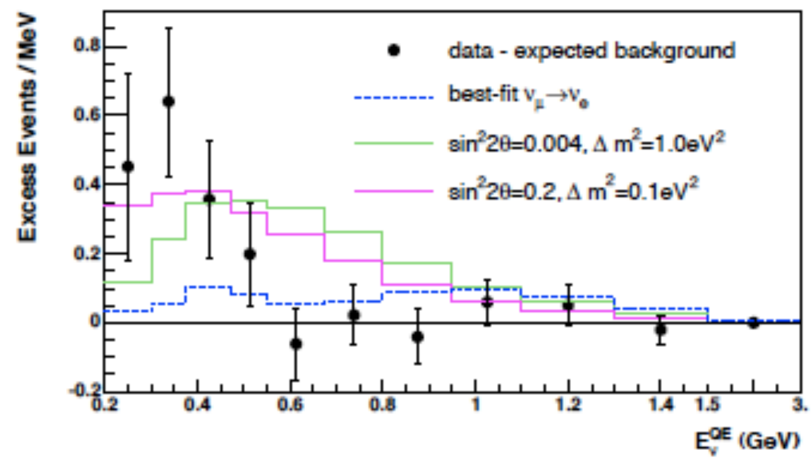
3. Lorentz violating neutrino oscillation

The examples of model independent features that represent characteristic signals of Lorentz violation for neutrino oscillation

(1) Spectral anomalies
(2) L-E conflict
(3) Sidereal variation

Any signals do not have 1/E oscillatory dependence could be Lorentz violation. Lorentz violating neutrino oscillation can have various type of energy dependences.

MiniBooNE signal falls into this class.



effective Hamiltonian of neutrino oscillation (direction averaged)

usual term (3X3)   additional terms (3X3)

$$(h_{eff})_{ab} \sim \frac{1}{2E}(m^2)_{ab} + (a)_{ab} + (c)_{ab}E + \cdots$$

Kostelecky and Mewes
PRD69(2004)016005

3. Lorentz violating neutrino oscillation

The examples of model independent features that represent characteristic signals of Lorentz violation for neutrino oscillation

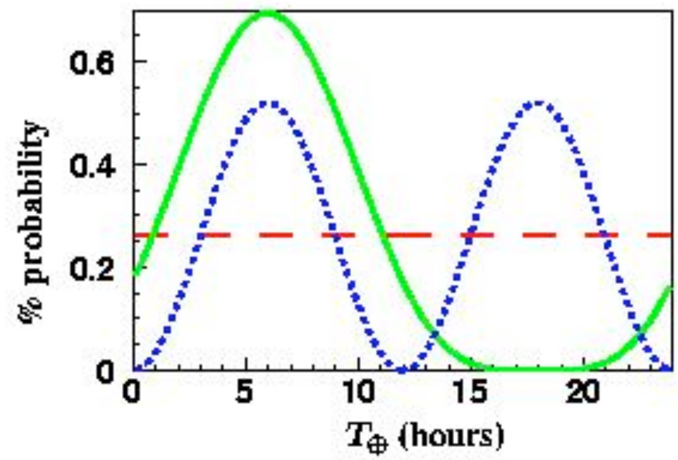
(1) Spectral anomalies
(2) L-E conflict
(3) Periodic variation

sidereal variation of the neutrino oscillation signal is the signal of Lorentz violation

This signal is the exclusive smoking gun of Lorentz violation.

Test for Lorentz violation in MiniBooNE is to find sidereal time variation from low energy excess ν_e candidate data

example of sidereal variation for LSND signal



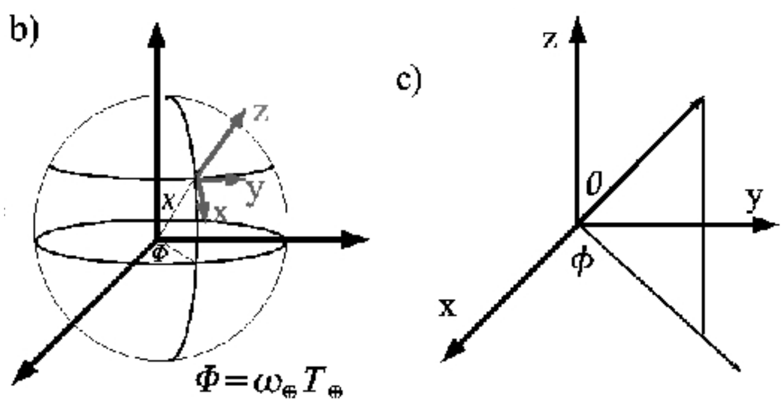
LSND collaboration,
PRD72(2005)076004

3. Lorentz violating neutrino oscillation

Test for Lorentz violation in MiniBooNE follows LSND sidereal time analysis

(1) fix the coordinate system
(2) write down Lagrangian including Lorentz violating terms under the formalism
(3) write down the observables using this Lagrangian

LANSCE to LSND detector is almost east to west
χ = 54.1°, colatitude of detector
θ = 99.0°, zenith angle of beam
ϕ = 82.6°, azimuthal angle of beam



3. Lorentz violating neutrino oscillation

Test for Lorentz violation in MiniBooNE follows LSND sidereal time analysis

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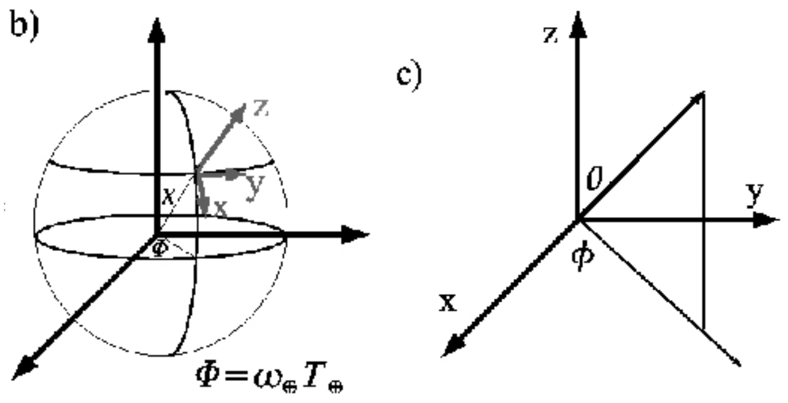
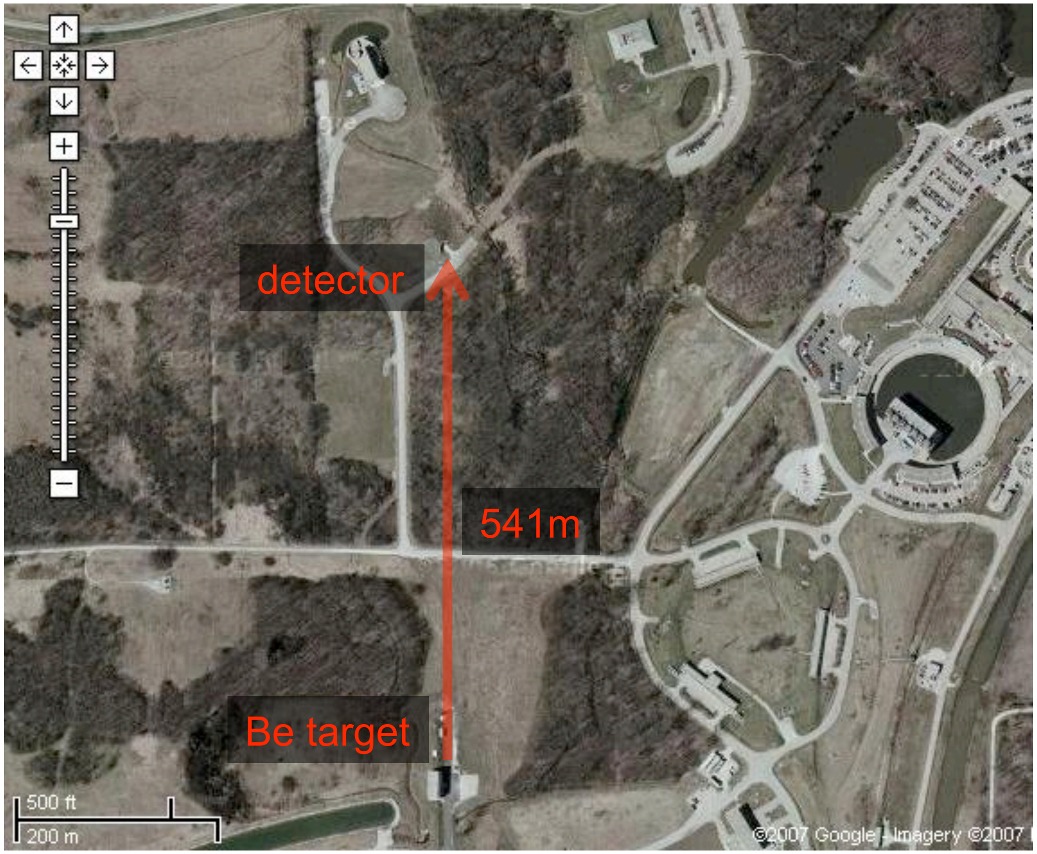
Booster neutrino beamline is almost south to north
χ = 48.2°, colatitude of detector
θ = 90.0°, zenith angle of beam
ϕ = 180°, azimuthal angle of beam





Kostelecky and Mewes
PRD69(2004)016005

3. Lorentz violating neutrino oscillation

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Modified Dirac Equation (MDE)

$$i(\Gamma^{\nu}_{AB}\partial_{\nu} - M_{AB})\nu_{B} = 0$$

SME parameters

$$\Gamma^{\nu}_{AB} = \gamma^{\nu}\delta_{AB} + c^{\mu\nu}_{AB}\gamma_{\mu} + d^{\mu\nu}_{AB}\gamma_{\mu}\gamma_{5} + e^{\nu}_{AB} + if^{\nu}_{AB}\gamma_{5} + \frac{1}{2}g^{\lambda\mu\nu}_{AB}\sigma_{\lambda\mu}$$

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

CPT odd: e^{ν}_{AB}, f^{ν}_{AB}, $g^{\lambda\mu\nu}_{AB}$, a^{μ}_{AB}, b^{μ}_{AB}

CPT even: $c^{\mu\nu}_{AB}$, $d^{\mu\nu}_{AB}$, $H^{\mu\nu}_{AB}$

- Lagrangian depends is direction dependant
- >100 free parameters

Kostelecky and Mewes
PRD70(2004)076002

3. Lorentz violating neutrino oscillation

Test for Lorentz violation in MiniBooNE follows LSND sidereal time analysis

(1) fix the coordinate system
(2) write down Lagrangian including Lorentz violating terms under the formalism
(3) write down the observables using this Lagrangian

Sidereal variation of neutrino oscillation probability for MiniBooNE

sidereal frequency $w_\oplus = \frac{2\pi}{23h56m4.1s}$

sidereal time $T_\oplus$

$$P_{\nu_e \to \nu_\mu} \sim \frac{|(h_{eff})_{e\mu}|^2 L^2}{(\hbar c)^2}$$

$$= \left(\frac{L}{\hbar c}\right)^2 |(C)_{e\mu} + (A_s)_{e\mu} \sin w_\oplus T_\oplus + (A_c)_{e\mu} \cos w_\oplus T_\oplus + (B_s)_{e\mu} \sin 2w_\oplus T_\oplus + (B_c)_{e\mu} \cos 2w_\oplus T_\oplus|^2$$

- Neutrino oscillation probability depends on coordinate (sidereal time)
- 14 SME parameters make 5 parameters (5 parameter fitting problem)

Kostelecky and Mewes
PRD70(2004)076002

3. Lorentz violating neutrino oscillation

$(a_L)^\mu = a^\mu + b^\mu$
$(c_L)^{\mu\nu} = c^{\mu\nu} + d^{\mu\nu}$

Expression of 5 observables (14 SME parameters)

- CPT-odd vector, 4 SMEs, $(a_L)^T$, $(a_L)^X$, $(a_L)^Y$, $(a_L)^Z$
- CPT-even tensor, 10 SMEs, $(c_L)^{TT}$, $(c_L)^{TX}$, $(c_L)^{TY}$, $(c_L)^{TZ}$, $(c_L)^{XX}$, $(c_L)^{XY}$, $(c_L)^{XZ}$, $(c_L)^{YY}$, $(c_L)^{YZ}$, $(c_L)^{ZZ}$

$$(C)_{e\mu} = (a_L)^T_{e\mu} - N^Z(a_L)^Z_{e\mu} + E\left[-\frac{1}{2}(3 - N^Z N^Z)(c_L)^{TT}_{e\mu} + 2N^Z(c_L)^{TZ}_{e\mu} + \frac{1}{2}(1 - 3N^Z N^Z)(c_L)^{ZZ}_{e\mu}\right]$$

$$(A_s)_{e\mu} = N^Y(a_L)^X_{e\mu} - N^X(a_L)^Y_{e\mu} + E\left[-2N^Y(c_L)^{TX}_{e\mu} + 2N^X(c_L)^{TY}_{e\mu} + 2N^Y N^Z(c_L)^{XZ}_{e\mu} - 2N^X N^Z(c_L)^{YZ}_{e\mu}\right]$$

$$(A_c)_{e\mu} = -N^X(a_L)^X_{e\mu} - N^Y(a_L)^Y_{e\mu} + E\left[2N^X(c_L)^{TX}_{e\mu} + 2N^Y(c_L)^{TY}_{e\mu} - 2N^X N^Z(c_L)^{XZ}_{e\mu} - 2N^Y N^Z(c_L)^{YZ}_{e\mu}\right]$$

$$(B_s)_{e\mu} = E\left[N^X N^Y\left((c_L)^{XX}_{e\mu} - (c_L)^{YY}_{e\mu}\right) - (N^X N^X - N^Y N^Y)(c_L)^{XY}_{e\mu}\right]$$

$$(B_c)_{e\mu} = E\left[-\frac{1}{2}(N^X N^X - N^Y N^Y)\left((c_L)^{XX}_{e\mu} - (c_L)^{YY}_{e\mu}\right) - 2N^X N^Y(c_L)^{XY}_{e\mu}\right]$$

Coordinate vector

$$\begin{pmatrix} N^X \\ N^Y \\ N^Z \end{pmatrix} = \begin{pmatrix} \cos\chi\sin\theta\cos\phi - \sin\chi\cos\theta \\ \sin\theta\sin\phi \\ -\sin\chi\sin\theta\cos\phi - \cos\chi\cos\theta \end{pmatrix}$$

Neutrino oscillation depends on coordinate of experiments and sidereal time
(χ = 48.2°, θ = 90.0°, ϕ = 180°)

1. MiniBooNE experiment

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5. Conclusion

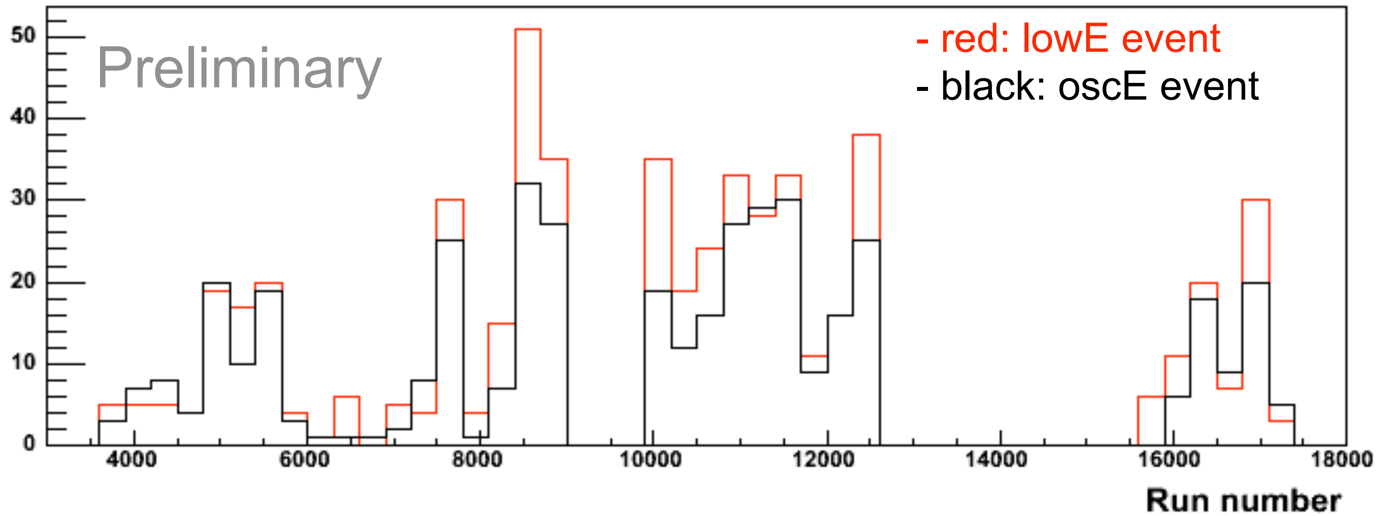
4. SME parameter fit

Data set

- We use neutrino mode data from Mar. 2003 – Jan. 2006 (run 3539-12842), and Oct. 2007 – Apr. 2008 (run 15833-17160), total 6.361E20 POT.
- 544 event in low energy region, "lowE" (200MeV<$E\nu^{QE}$<475MeV), and,
- 420 event in oscillation region, "oscE" (475<$E\nu^{QE}$<1300MeV).
- All results in this talk are preliminary.

lowE event and oscE event distribute equally in all run period.
Unbinned K-S test: P(lowE,oscE)=0.73 (compatible)

Event distribution over runs



4. SME parameter fit

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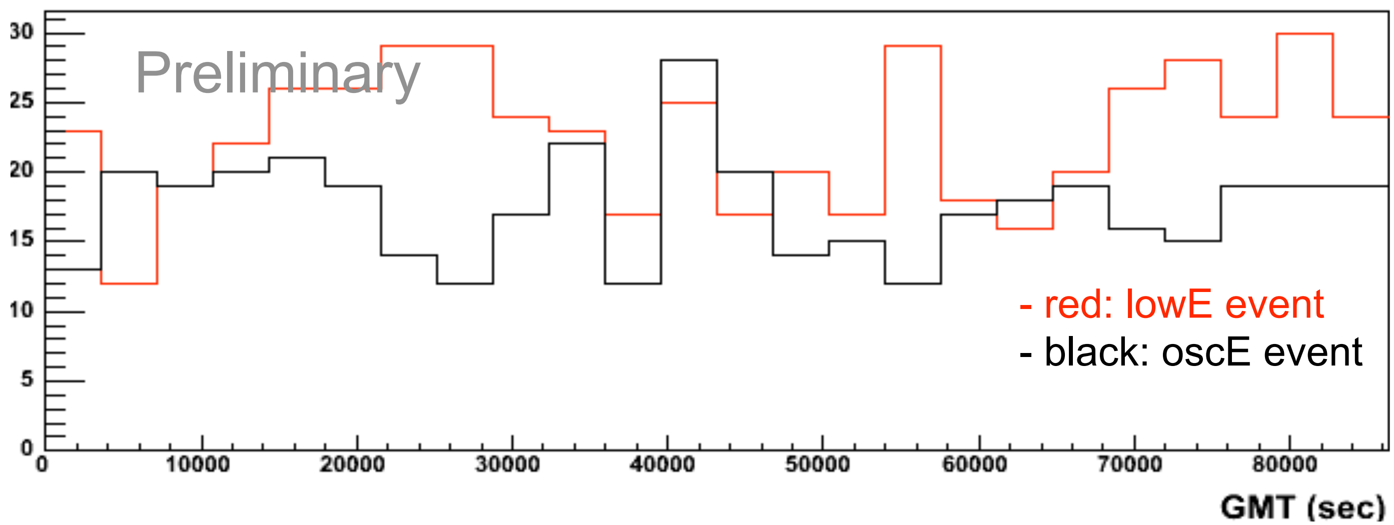
lowE event and oscE event distribute equally in GMT time.
Unbinned K-S test: P(lowE,oscE)=0.76 (compatible)

Event distribution over GMT time



4. SME parameter fit

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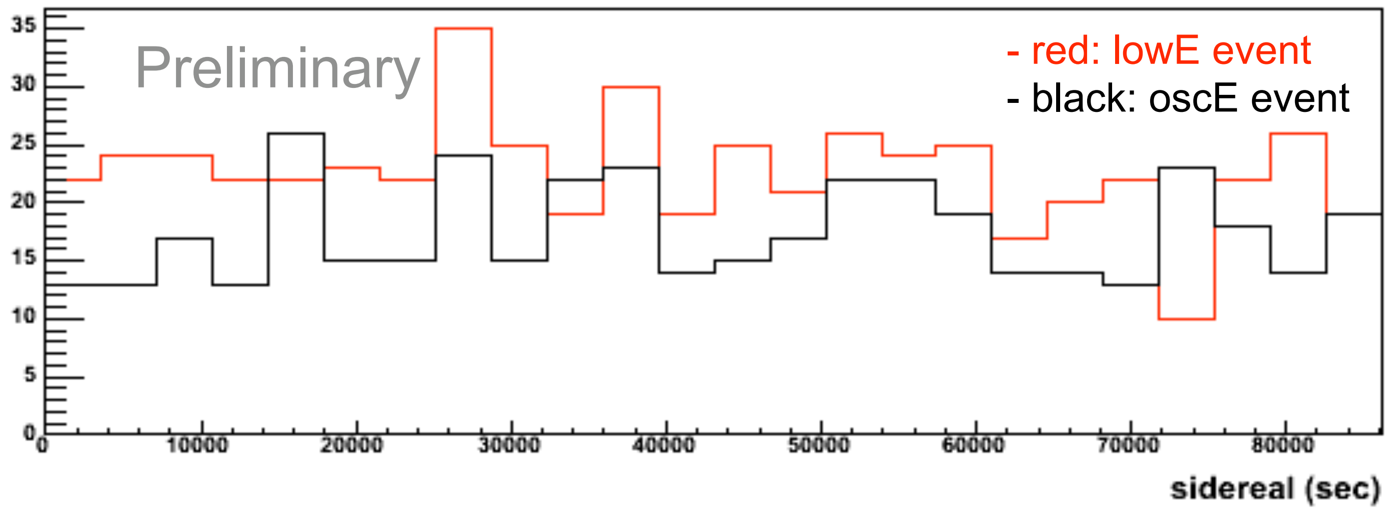
Unbinned K-S test: P(lowE,oscE)=0.59 (compatible)

Event distribution over sidereal time



4. SME parameter fit

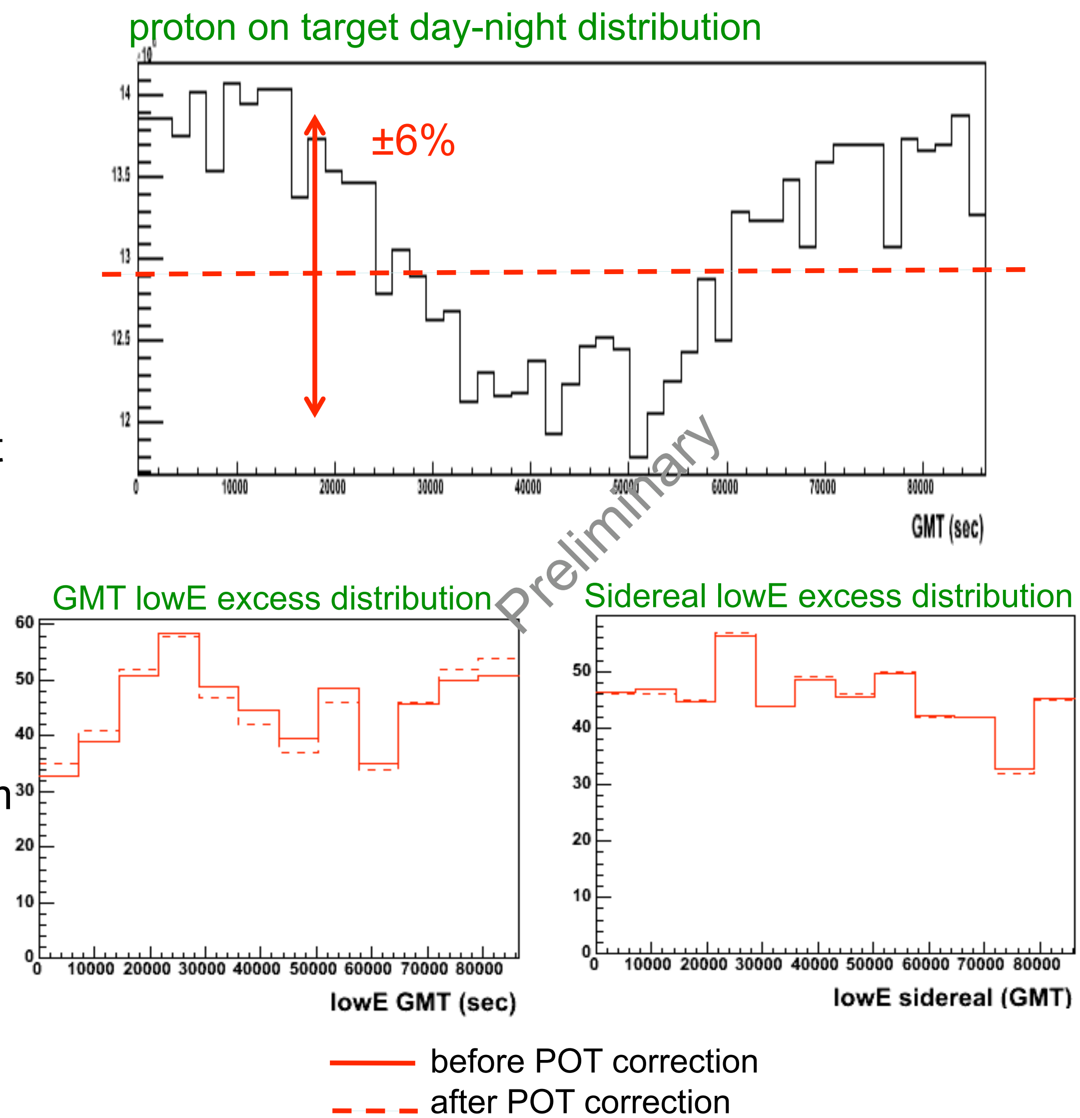
Systematic error study

Time varying backgrounds are potentially dangerous…

- Detector
Detector response may have day-night effect (temperature, etc), however effect is expected to be small

- Beam
Proton beam follows Fermilab accelerator complex run plan, namely MiniBooNE receive high intensity beam on night, and low on day time.
Maximum variation is ±6%, but this effect is washed out in sidereal time distribution.

Full systematic error study is ongoing



4. SME parameter fit

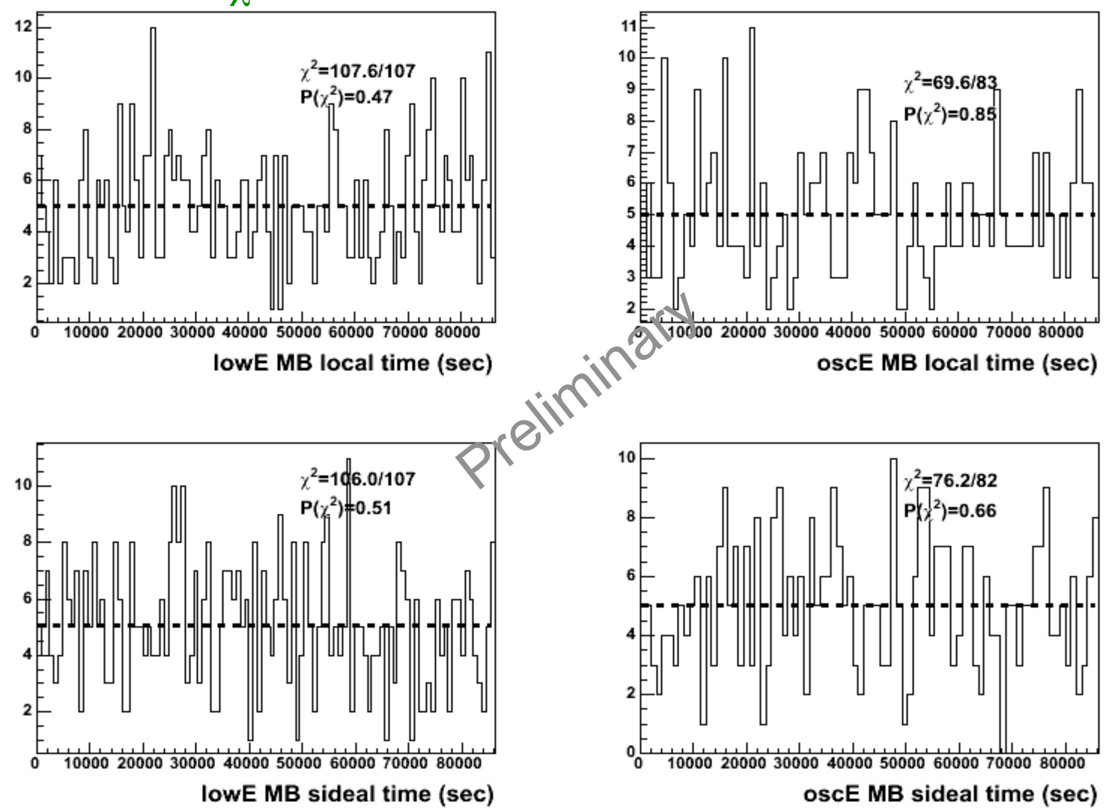
Before SME parameter fit…

Statistical test
- Null hypothesis (=no time variation) is tested to 4 samples

1. lowE GMT
2. oscE GMT
3. lowE sidereal time
4. oscE sidereal time

- Pearson's c2 test
- K-S test

Pearson's χ^2 test



4. SME parameter fit

Before SME parameter fit…

Statistical test
- Null hypothesis (=no time variation) is tested to 4 samples

	lowE GMT	oscE GMT	lowE sidereal	oscE sidereal
Pearson's χ^2 test				
d.o.f	107	83	107	82
χ^2	107.6	69.6	106.0	76.2
$P(\chi^2)$	0.47	0.85	0.51	0.66
unbinned K-S test				
P(K-S)	0.42	0.81	0.13	0.64

Preliminary

All samples are consistent with flat

However, data is not inconsistent with small variation, so we proceed to fit

4. SME parameter fit

Unbinned likelihood method

- It has the maximum statistic power
- Assuming low energy excess is Lorentz violation, extract Lorentz violation parameters (SME parameters) from unbinned likelihood fit.

$$\mathrm{LogL} = -(\mu_{sig}[\mathrm{SMEs}] + \mu_{bkgd}) + \sum_{i=1}^{n} [\mu_{sig}[\mathrm{SMEs}] \cdot \omega_{sig}[\mathrm{SMEs}, E_{\nu}^{QE}, T_{\oplus}] + \mu_{bkgd} \cdot \omega_{bkgd}]$$

μ_{sig}[SMEs] : predicted number of signal event, function of SME parameters (=14).
μ_{bkgd}: predicted number of background event, from MiniBooNE public data
$\omega_{sig}[\mathrm{SMEs}, E_{\nu}^{QE}, T]$: probability density function (PDF) of signal distribution with sidereal time, function of SMEs and reconstructed neutrino energy.
ω_{bkgd}: PDF of background (=const, background is assumed time independent).

4. SME parameter fit

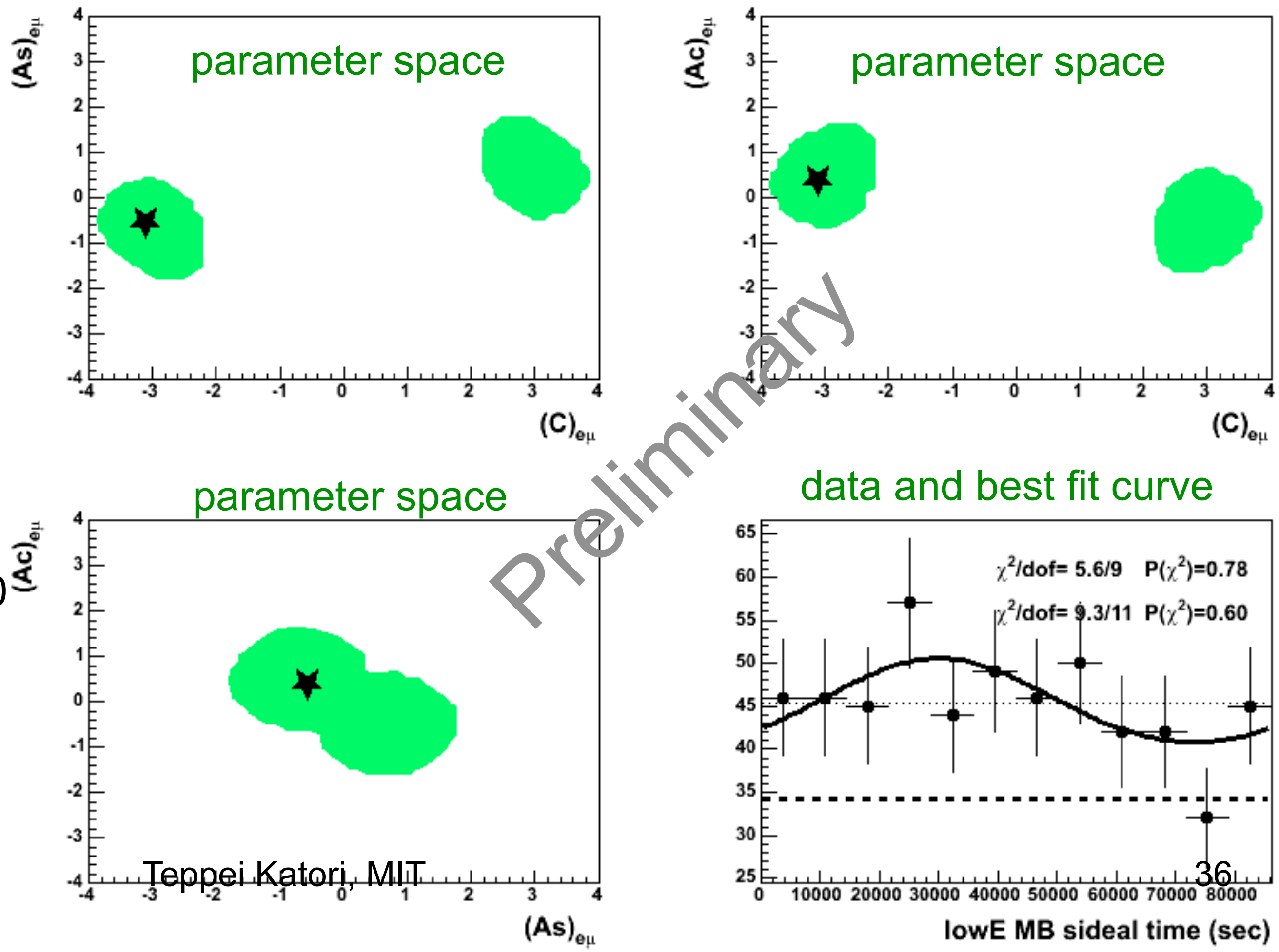
low energy excess
(200MeV<Eν^{QE}<475MeV

Unbinned likelihood method, simultaneous fit result
- simultaneous 3 parameter fit for low energy excess
- 3 parameter fit can be interpreted nature has CPT-odd only
- duplicate solution exist with opposite sign

Since data has good χ^2 with flat hypothesis, fit improve goodness-of-fit only little.

After fit
χ^2/dof=5.7/9, P(χ^2)=0.77

Flat hypothesis
χ^2/dof=9.3/11, P(χ^2)=0.60



4. SME parameter fit

low energy excess
(200MeV<$E\nu^{QE}$<475MeV

Unbinned likelihood method, simultaneous fit result

- simultaneous 3 parameter fit for low energy excess
- 3 parameter fit can be interpreted nature has CPT-odd only
- duplicate solution exist with opposite sign

Unit is 10^{-20}GeV

parameter	SME parameters	fit value	error
$(C)_{e\mu}$	$(a_L)^T+0.75(a_L)^Z+0.35[-1.22(C_L)^{TT}-1.49(C_L)^{TZ}-0.33(C_L)^{ZZ}]$	-3.1	0.9
$(As)_{e\mu}$	$0.67(a_L)^Y+0.35[-1.33(C_L)^{TY}-0.99(C_L)^{YZ}]$	-0.6	1.2
$(Ac)_{e\mu}$	$0.67(a_L)^X+0.35[-1.33(C_L)^{TX}-0.99(C_L)^{XZ}]$	0.4	1.3
$(Bs)_{e\mu}$	$0.35[-0.45(C_L)^{XY}]$	---	---
$(Bc)_{e\mu}$	$0.35[-0.22((C_L)^{XX}-(C_L)^{YY})]$	---	---

Preliminary

Only $(C)_{e\mu}$ (sidereal time independent term) is statistically significantly non-zero

extraction for $(a_L)^\mu$ and $(C_L)^{\mu\nu}$ is rather simple due to special coordinate of MiniBooNE

4. SME parameter fit

Unbinned likelihood method, simultaneous fit result

low energy excess
(200MeV<$E\nu^{QE}$<475MeV

- each SME parameters are obtained by setting others zero.

- 5 statistically significant parameters correspond to sidereal time independent solution.

	fit value (GeV)	statistic error (GeV)
$(a_L)^T$	-3.1×10^{-20}	0.9×10^{-20}
$(a_L)^X$	0.6×10^{-20}	1.9×10^{-20}
$(a_L)^Y$	-0.9×10^{-20}	1.8×10^{-20}
$(a_L)^Z$	-4.2×10^{-20}	1.2×10^{-20}

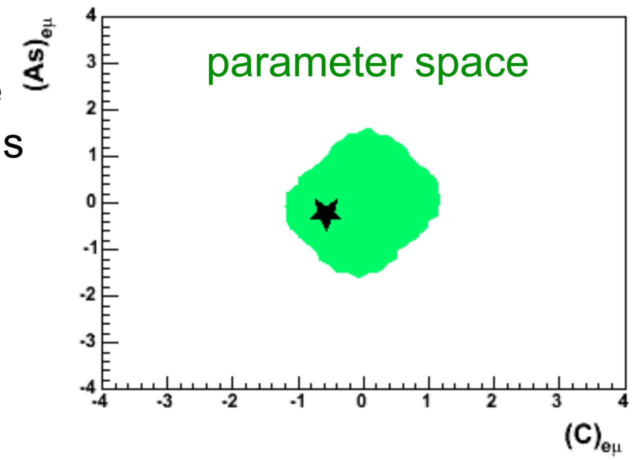
	fit value	statistic error
$(c_L)^{TT}$	7.2×10^{-20}	2.1×10^{-20}
$(c_L)^{TX}$	-0.9×10^{-20}	2.8×10^{-20}
$(c_L)^{TY}$	1.3×10^{-20}	2.6×10^{-20}
$(c_L)^{TZ}$	5.9×10^{-20}	1.7×10^{-20}
$(c_L)^{XX}$	---	---
$(c_L)^{XY}$	---	---
$(c_L)^{XZ}$	-1.1×10^{-20}	3.7×10^{-20}
$(c_L)^{YY}$	---	---
$(c_L)^{YZ}$	1.7×10^{-20}	3.4×10^{-20}
$(c_L)^{ZZ}$	2.6×10^{-19}	0.8×10^{-19}

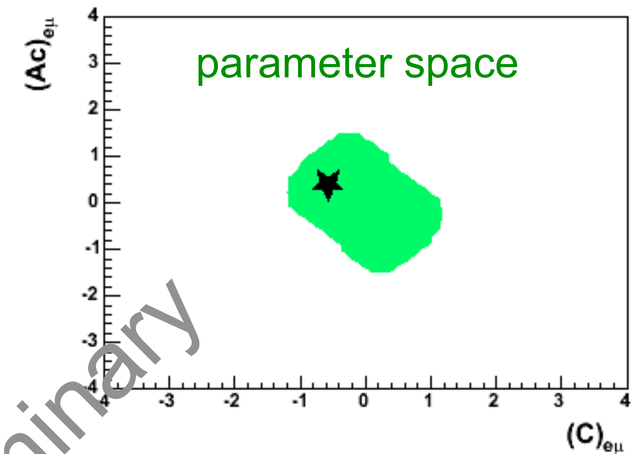
4. SME parameter fit

oscillation candidate
(475MeV<Eν^{QE}<1300MeV

Unbinned likelihood method, simultaneous fit result
- simultaneous 3 parameter fit for oscillation candidate
- 3 parameter fit can be interpreted nature has CPT-odd only
- duplicate solution exist with opposite sign

Since data has very little excess, best fit solution is consistent with zero.

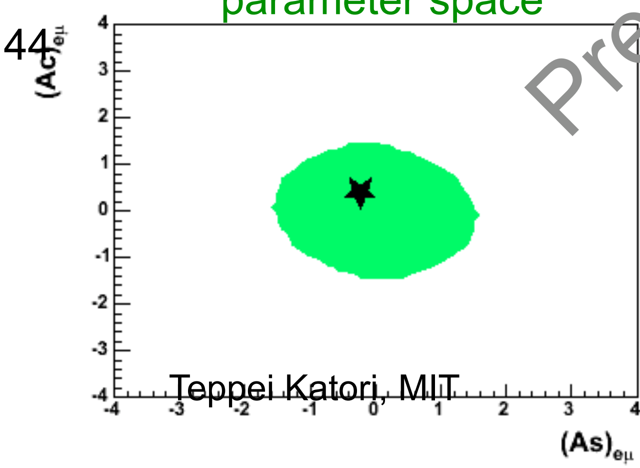


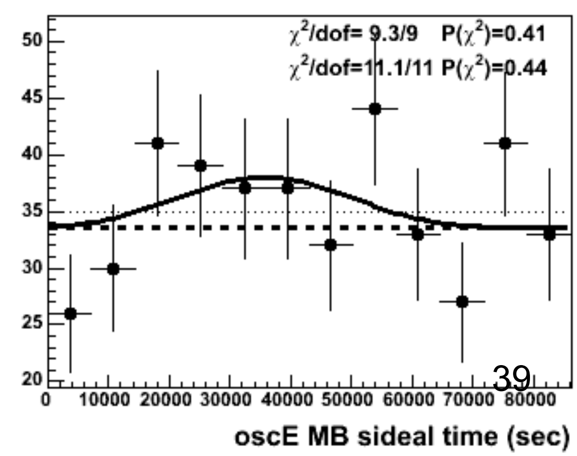


After fit
χ^2/dof=9.3/9, P(χ^2)=0.41

Flat hypothesis
χ^2/dof=11.1/11, P(χ^2)=0.44

Preliminary





4. SME parameter fit

oscillation candidate
($475MeV<E\nu^{QE}<1300MeV$

Unbinned likelihood method, simultaneous fit result

- simultaneous 3 parameter fit for oscillation candidate
- 3 parameter fit can be interpreted nature has CPT-odd only
- duplicate solution exist with opposite sign

Unit is 10^{-20}GeV

parameter	SME parameters	fit value	error
$(C)_{e\mu}$	$(a_L)^T+0.75(a_L)^Z+0.35[-1.22(C_L)^{TT}-1.49(C_L)^{TZ}-0.33(C_L)^{ZZ}]$	-0.6	1.0
$(As)_{e\mu}$	$0.67(a_L)^Y+0.35[-1.33(C_L)^{TY}-0.99(C_L)^{YZ}]$	-0.2	1.7
$(Ac)_{e\mu}$	$0.67(a_L)^X+0.35[-1.33(C_L)^{TX}-0.99(C_L)^{XZ}]$	0.4	1.4
$(Bs)_{e\mu}$	$0.35[-0.45(C_L)^{XY}]$	---	---
$(Bc)_{e\mu}$	$0.35[-0.22((C_L)^{XX}-(C_L)^{YY})]$	---	---

Preliminary

Since excess is small, all parameters are consistent with zero.

LSND collaboration,
PRD72(2005)076004

4. SME parameter fit

LSND solution
($0MeV<Ee^+<60MeV$)

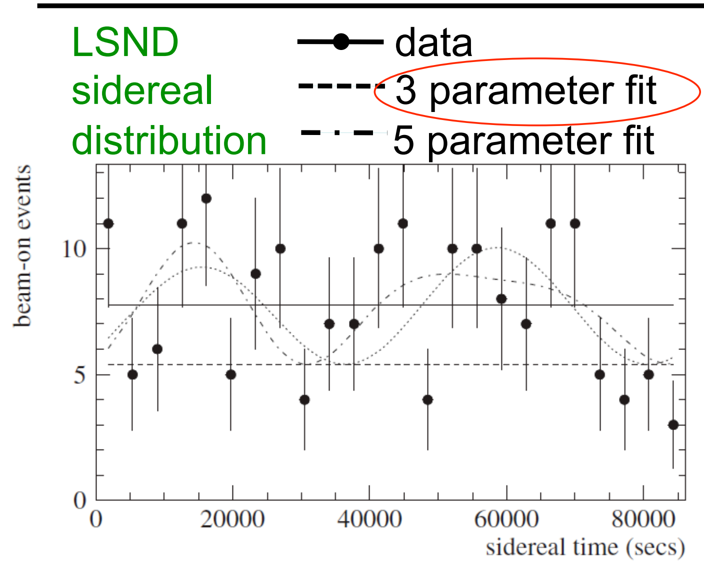
LSND result

- 3 parameter fit solution for LSND data
- there is a statistically significant sidereal time depending term

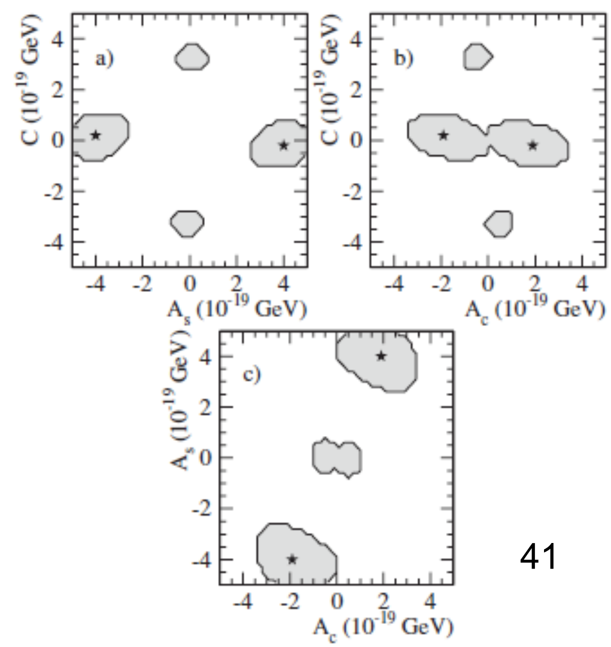
Unit is 10^{-19}GeV

parameter	SME parameters	fit value	error
$(C)_{e\mu}$	$(a_L)^T+0.19(a_L)^Z+0.04[-1.48(C_L)^{TT}-0.39(C_L)^{TZ}+0.44(C_L)^{ZZ}]$	-0.2	1.0
$(As)_{e\mu}$	$0.98(a_L)^X+0.053(a_L)^Y+0.04[-1.96(C_L)^{TX}-0.11(C_L)^{TY}-0.38(C_L)^{XZ}-0.021(C_L)^{YZ}]$	4.0	1.4
$(Ac)_{e\mu}$	$0.053(a_L)^X-0.98(a_L)^Y+0.04[-0.11(C_L)^{TX}+1.96(C_L)^{TY}-0.021(C_L)^{XZ}+0.38(C_L)^{YZ}]$	1.9	1.8
$(Bs)_{e\mu}$	$0.04[-0.052((C_L)^{XX}-(C_L)^{YY})+0.96(C_L)^{XY}]$	---	---
$(Bc)_{e\mu}$	$0.04[0.48((C_L)^{XX}-(C_L)^{YY})+0.10(C_L)^{XY}]$	---	---

LSND sidereal distribution



parameter spaces show 2 solutions in 1-sigma of the fit



LSND collaboration, PRD72(2005)076004

4. SME parameter fit

LSND result

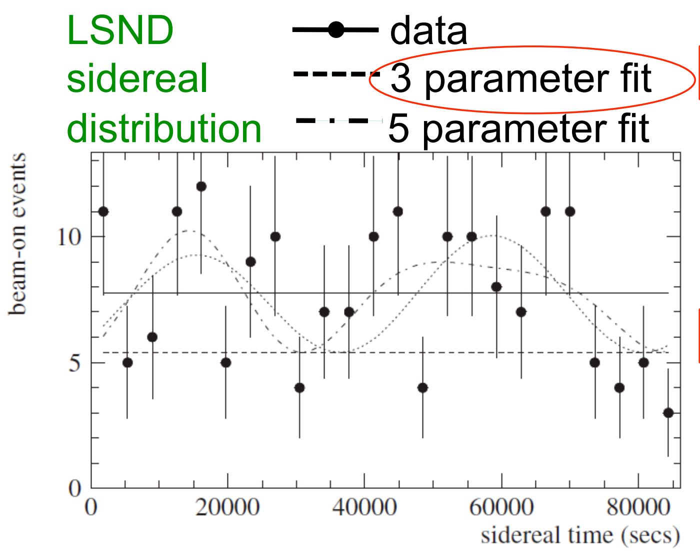
- extracted SME parameters from published result (3 parameter fit)
- 3 statistically significant SME parameters correspond to sidereal time dependent solution.

LSND solution ($0MeV<E_{e^+}<60MeV$)

	fit value (GeV)	statistic error (GeV)
$(a_L)^T$	0.2×10^{-19}	1.0×10^{-19}
$(a_L)^X$	4.2×10^{-19}	1.5×10^{-19}
$(a_L)^Y$	-1.7×10^{-19}	1.8×10^{-19}
$(a_L)^Z$	1.0×10^{-19}	5.4×10^{-19}

	fit value	statistic error
$(c_L)^{TT}$	0.3×10^{-18}	1.8×10^{-18}
$(c_L)^{TX}$	-5.2×10^{-18}	1.9×10^{-18}
$(c_L)^{TY}$	2.1×10^{-18}	2.2×10^{-18}
$(c_L)^{TZ}$	1.3×10^{-18}	6.7×10^{-18}
$(c_L)^{XX}$	---	---
$(c_L)^{XY}$	---	---
$(c_L)^{XZ}$	-2.7×10^{-17}	1.0×10^{-17}
$(c_L)^{YY}$	---	---
$(c_L)^{YZ}$	1.1×10^{-17}	1.2×10^{-17}
$(c_L)^{ZZ}$	-1.1×10^{-18}	5.9×10^{-18}

LSND sidereal distribution

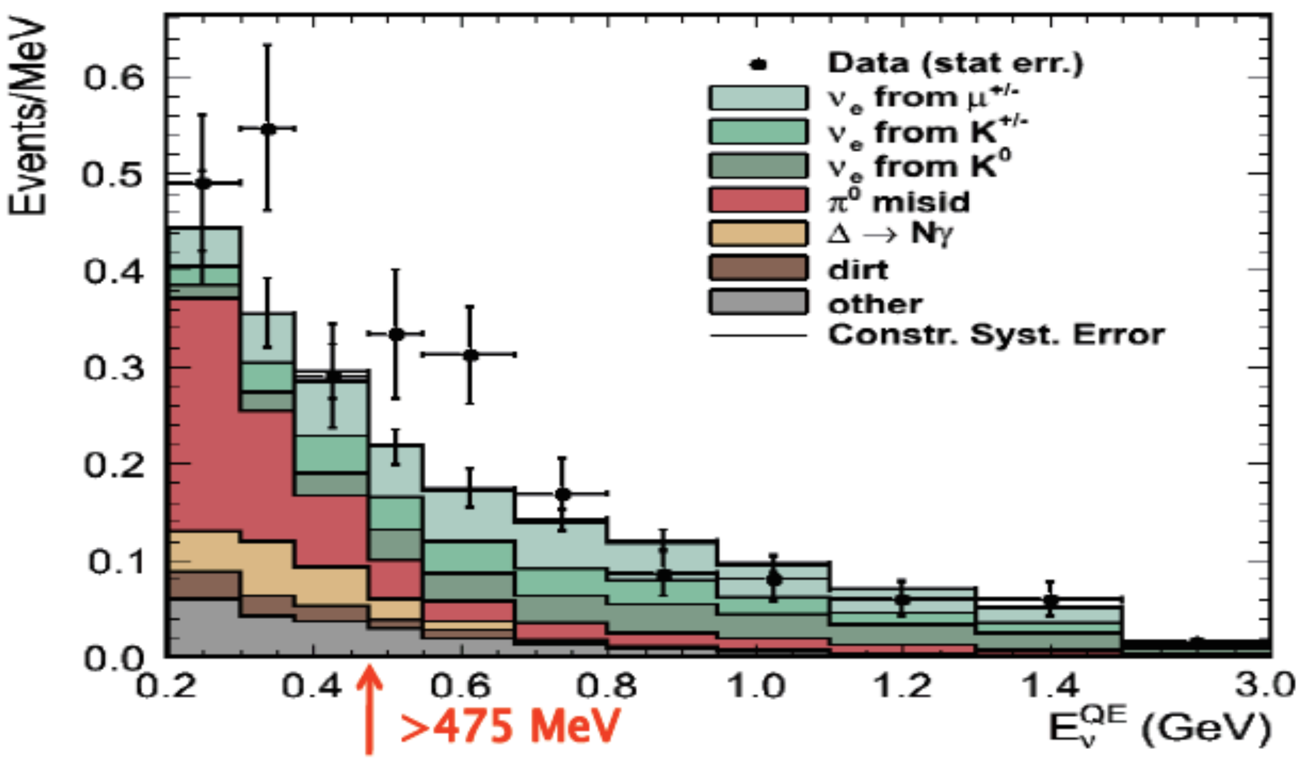


MiniBooNE collaboration,
Neutrino 2010, Athens

4. SME parameter fit

Anti-neutrino oscillation data

- We just announced new result from anti-neutrino oscillation analysis.
- There are excesses both low energy, and oscillation candidate region.
- Non-zero SME parameters are expected for both regions.



- Rex Tayloe's talk, tomorrow (July 1) morning session

10. Conclusions

Lorentz and CPT violation has been shown to occur in Planck scale physics.

MiniBooNE low energy excess ν_e data suggest Lorentz violation is an interesting solution of neutrino oscillations.

Low energy excess events are statistically consistent with no sidereal variation.

SME parameters are extracted under short baseline approximation. The flat solution is favoured. Full systematic study is ongoing.

Recently antineutrino result will be analysed under SME formalism, too.

BooNE collaboration

University of Alabama
Bucknell University
University of Cincinnati
University of Colorado
Columbia University
Embry Riddle Aeronautical University
Fermi National Accelerator Laboratory
Indiana University
University of Florida

Los Alamos National Laboratory
Louisiana State University
Massachusetts Institute of Technology
University of Michigan
Princeton University
Saint Mary's University of Minnesota
Virginia Polytechnic Institute
Yale University

Thank you for your attention!

Backup