Neutrino mistakes

wrong tracks and hints, hopes and failures

Fake νs

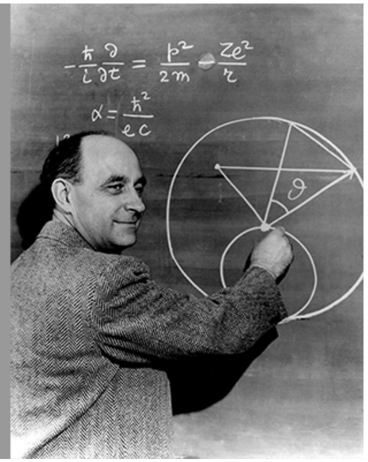
History of Neutrinos

Paris

September 2018

Wolfgang Pauli
1900 - 1958
Nobel Prize in 1945

Enrico Fermi
1901 - 1954
Nobel Prize in 1938



Neutrino mistakes

wrong tracks and hints, hopes and failures

History of Neutrinos

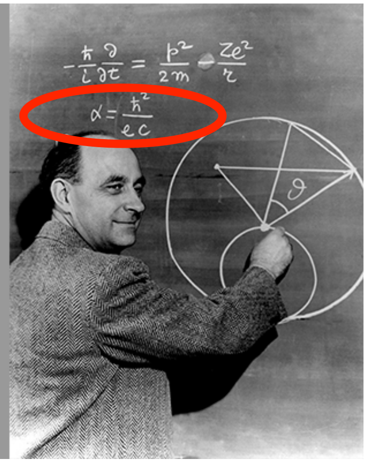
Paris

September 2018

No!
$\alpha = e^2/\hbar c$
-5

Wolfgang Pauli
1900 - 1958
Nobel Prize in 1945

Enrico Fermi
1901 - 1954
Nobel Prize in 1938



Report of $\mu \rightarrow e \gamma$

(i.e. rumor)

$\mu \rightarrow e \gamma$

- When I was a graduate student in the mid 70's, I heard a rumor that this process had been measured B ~ 10^{-8} at the SIN facility in Switzerland.
- Expected $B = 5 \times 10^{-48} [\Delta m^2_{21} (eV)^2]^2 \sin^2 \theta_{12} \cos^2 \theta_{12}$
- I never heard a talk about this and a positive result was never published
- SIN published a limit
- The only confirmation of my memory is a discussion with Robert Shrock which led me to a footnote in a paper by Bjorken and Weinberg

SIN Results

A SEARCH FOR THE DECAY $\mu^+ \rightarrow e^+\gamma$†

A. VAN DER SCHAAF and R. ENGFER

Physik-Institut der Universität Zürich, CH-8001 Zürich, Switzerland

H. P. POVEL*, W. DEY** and H. K. WALTER

Laboratorium für Hochenergiephysik, ETHZ, CH-5234 Villigen, Switzerland

and

C. PETITJEAN

SIN, CH-5234 Villigen, Switzerland

29 October 1979

Abstract. We report on the final analysis of a search for the decay $\mu^+ \rightarrow e^+\gamma$ performed at SIN. No evidence for the existence of the process has been found. An upper limit for the branching ratio of 1.0×10^{-9} (90% confidence) is presented. The measured positron–photon energy distributions are completely described by the decay $\mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu\gamma$ and accidental coincidences.

E	RARE DECAY $\mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu\gamma$; measured e^+, γ coincidence spectra; deduced upper limit for the branching ratio of $\mu^+ \rightarrow e^+\gamma$.

SIN Results

A SEARCH FOR THE DECAY $\mu^+ \to e^+\gamma$†

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E | RARE DECAY $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu \gamma$; measured e^+, γ coincidence spectra; deduced upper limit for the branching ratio of $\mu^+ \to e^+\gamma$.

$\mu \rightarrow e\ \gamma$

Mechanism for Nonconservation of Muon Number*

James D. Bjorken
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

Steven Weinberg†
Department of Physics, Stanford University, Stanford, California 94305
(Received 17 January 1977)

We consider the possibility that muon-number conservation is not a fundamental symmetry of nature. In simple SU(2)⊗U(1) gauge theories with several scalar boson doublets, muon number will still atuomatically be conserved by the intermediate-vector-boson interactions, but not by effects of virtual scalar bosons. The branching ratio for $\mu \rightarrow e + \gamma$ is estimated to be of order $(\alpha/\pi)^3$. Other μ-e transition processes are also discussed.

- [2] It would be disingenuous for us not to acknowledge that our interest in this question was kindled by an experiment now in progress at Schweizerisches Institut für Nuklearforschung [cf. *Physics Research in Switzerland*, Catalog 1975 (Swiss Physical Society, Bern, 1975), p. 207], and by rumors of a positive signal. However, our considerations here do not depend on any assumptions about the eventual outcome of this experiment; indeed, we believe that even if this measurement were to yield a null result, it would be worthwhile to push on to the greatest possible accuracy.

$\mu \rightarrow e\ \gamma$

- When I was a graduate student in the mid 70's, I heard a rumor that this process had been measured B ~ 10-8 at the SIN facility in Switzerland.
- Expected $B = 5 \times 10^{-48} [\Delta m^2_{21} (eV)^2]^2 \sin^2 \theta_{12} \cos^2 \theta_{12}$
- I never heard a talk about this and a positive result was never published
- SIN published a limit
- The only confirmation of my memory is a discussion with Robert Shrock which led me to a footnote in a paper by Bjorken and Weinberg
- This rumor led to a series of lectures at FNAL by Robert Shrock. **That** is where I learned about neutrino oscillations.

Outline

“mistakes” considered for this talk

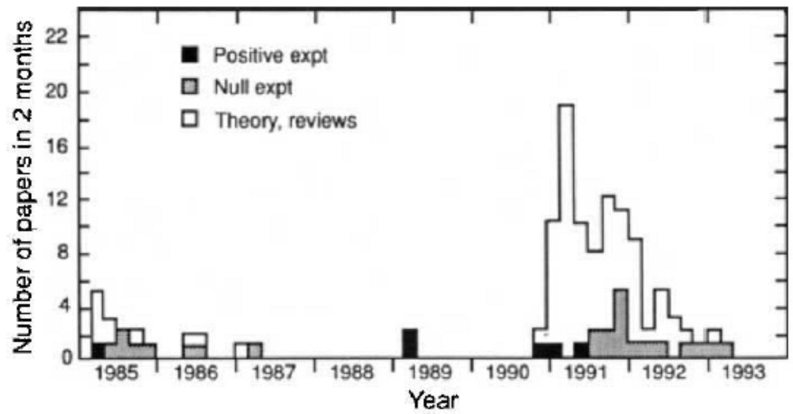
- SIN report of $\mu \rightarrow e \gamma$
- High y anomaly
- NuTeV Helium bag events
- Klapdor’s $0\nu\beta\beta$ signal
- LSND/eV “sterile” νs
- IMB limit on ν oscillations
- Alternating neutral currents
- Reines-Sobel ν oscillations
- Vanucci PS191 oscillations
- BNL 776 & 816 oscillations
- BEBC oscillations
- HPW “super” trimuons
- Oscillations in Bugey
- Majoron emission in $0\nu2\beta$ PNL/USC
- SPT vs. V-A
- Superluminal νs
- 17 keV ν
- NuTeV anomaly
- Tritium endpoint (-)m^2
- Kolar events
- Early atmospheric ν lack of polarization
- MINOS anti-ν θ_{23}
- God’s mistake
- ν grammar
- Labels for Δm^2_{ab}
- PDG m(ν) encoding
- Which ν is a particle?
- Karmen time anomaly
- Time variations in Troitsk m_ν^2
- ITEP $m(\nu_e)$ = 30 eV in 1980

What is a mistake?

- ☆A statistical fluctuation?
- ☆A systematic error?
- ☆A wrong interpretation of good data?
- ☆A theoretical misunderstanding?
- ☆…
- ☆ Was hot dark matter to explain Ω a mistake?

17 keV neutrino

17 keV timeline



- 1985 Simpson kink at 1.5 keV in tritium decay; 18.6-1.5=17.1, P = 3%
  - *Phys. Rev. Lett **54** 1891-1893*
- 1985 various negative results P < 0.3%
  - *Phys. Rev. **C32** 2215-2216*
- 1989 Hime & Simpson kink in ^{35}S; 16.9 keV, P = 0.7%
  - *Phys. Rev **D39**, 1805*
- 1991 Hime & Jelley 2 measurements in ^{35}S; 17 keV, P=0.8% 8σ
  - *Phys. Lett. **B257** 441*
- 1993 Mortara et al., definitive exclusion
  - *Phys. Rev. Lett. **70** 394*
- 1993 Hime, Identifies scattering effects as likely responsible
  - Phys. Lett B299, 165-173

17 keV

VOLUME 70, NUMBER 4 PHYSICAL REVIEW LETTERS 25 JANUARY 1993

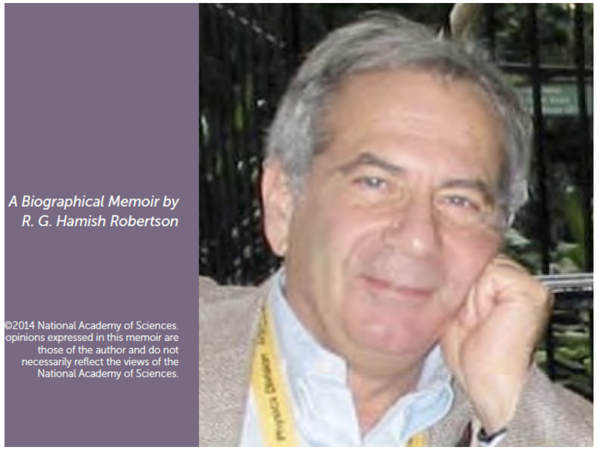
Evidence against a 17 keV Neutrino from ^{35}S Beta Decay

J. L. Mortara,[(1),(4),(a)] I. Ahmad,[(1)] K. P. Coulter,[(1)] S. J. Freedman,[(1),(2),(3),(4)] B. K. Fujikawa,[(1),(2)] J. P. Greene,[(1)] J. P. Schiffer,[(1),(4)] W. H. Trzaska,[(5),(b)] and A. R. Zeuli[(1)]

[(1)] *Argonne National Laboratory, Argonne, Illinois 60439*
[(2)] *Lawrence Berkeley Laboratory, Berkeley, California 94720*
[(3)] *University of California, Berkeley, California 94720*
[(4)] *University of Chicago, Chicago, Illinois 60637*
[(5)] *Texas A&M University, College Station, Texas 77843*

(Received 23 September 1992)

We have searched for the effect of a neutrino of mass 17 keV/c^2 in the beta decay of ^{35}S with an apparatus incorporating a high-resolution solid-state detector and a superconducting solenoid. The experimental mixing probability, $\sin^2\theta = -0.0004 \pm 0.0008(\text{stat}) \pm 0.0008(\text{syst})$, is consistent with zero, in disagreement with several previous experiments. Our sensitivity to neutrino mass is verified by measurements with a mixed source of ^{35}S and ^{14}C, which artificially produces a distortion in the beta spectrum similar to that expected from the massive neutrino.



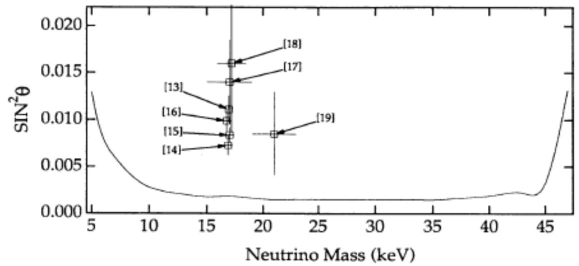


FIG. 4. The 95% C.L. upper limits on $\sin^2\theta$ from fits to the ^{35}S data for various neutrino masses. The points correspond to the results of previous positive experiments and are labeled by their reference number.

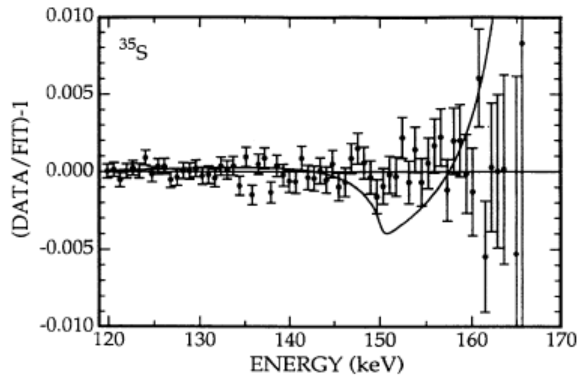


FIG. 3. Residuals from a fit to the pileup-corrected data assuming no massive neutrino ($\sin^2\theta = 0$); the reduced χ^2 for the fit is 0.88. The solid curve represents the residuals expected for decay with a 17 keV neutrino and $\sin^2\theta = 0.85\%$; the reduced χ^2 of the data is 2.82.

17 keV

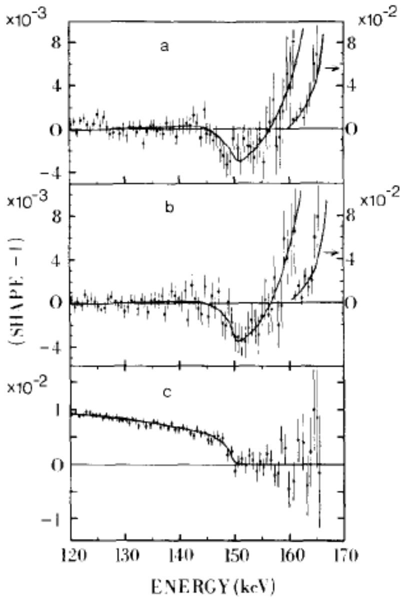


Fig. 4. Shape factors for (a) run #1 and (b) run #2 obtained by dividing the experimental spectra by the best least squares fit to the region 120–167 keV when no heavy neutrino mixing is allowed. The data plotted in (a) and (b) above 161 keV go off the scale set by the left ordinate and should be read using the scale indicated by the right ordinate. (c) Shape factor for combined data of runs #1 and #2 when normalizing a single component spectrum to the data over the region above 150 keV. The smooth curves in each case indicate the expected deviation for the emission of a 17 keV neutrino with $\sin^2\theta = 0.009$.

Himes' reinterpretation with "more complete" electron response function with "intermediate scattering"

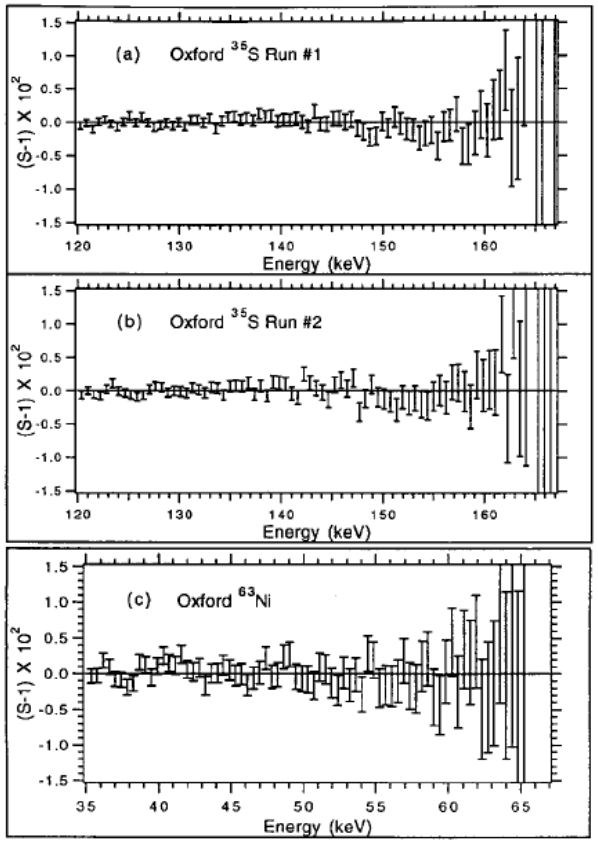


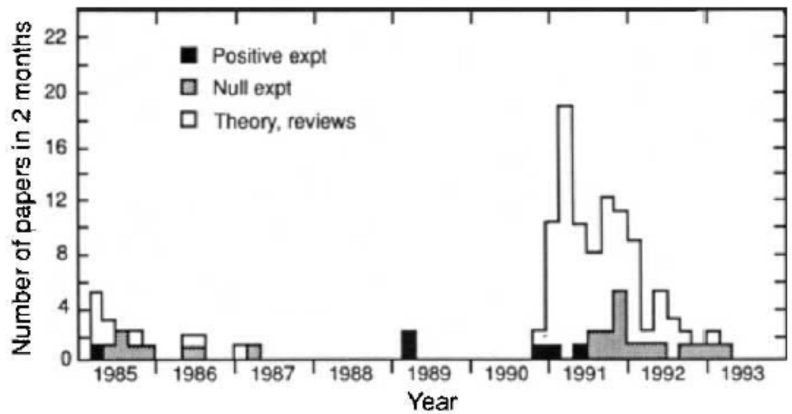
Fig. 4. Shape factors extracted from Oxford, (a) ^{35}S run#1, (b) ^{35}S run#2 and (c) ^{63}Ni, data after implementing the best fit theoretical spectrum including intermediate scattering effects and assuming a single component, massless neutrino.

17 keV

Random comment

- The last days of the 17 keV neutrino was contemporaneous with:
  - ☆The serious consideration of long-baseline experiments
  - ☆The beginning of my newsletter (May 1992)

  - ☆There was much more theoretical interest (> × 5) in the possible existence of the m_ν = 17 keV ν than atmospheric ν oscillations, m_ν = 1-100 meV



Klapdor’s
neutrinoless double beta decay

Neutrinoless Double Beta Decay

Heidelberg-Moscow Collaboration looking for $0\nu\beta\beta$ in ^{76}Germanium

- Eur.Phys.J.A12:147-154,2001; 14 authors; T > 1.9 10^{25} y @90%CL
- Mod.Phys.Lett.A16:2409-2420,2001; 4 authors; T= 1.5 -0.7 +16.8 10^{25} y @95%CL

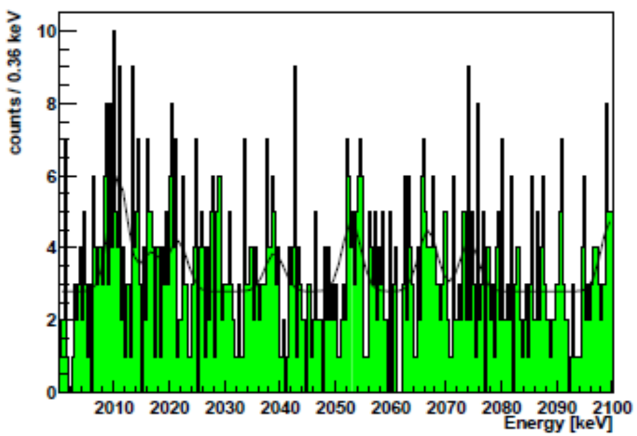


Fig. 2. The spectrum taken with the ^{76}Ge detectors Nr. 1,2,3,4,5 over the period August 1990 - May 2000 (54.9813 kg y) in the original 0.36 keV binning, in the energy range 2000 - 2100 keV. Simultaneous fit of the ^{214}Bi lines and the two high-energy lines yield a probability for a line at 2039.0 keV of 91%.

EVIDENCE FOR NEUTRINOLESS DOUBLE BETA DECAY

H.V. KLAPDOR-KLEINGROTHAUS[1,3],
A. DIETZ[1], H.L. HARNEY[1], I.V. KRIVOSHEINA[1,2]

[1] *Max-Planck-Institut für Kernphysik, Postfach 10 39 80, D-69029 Heidelberg, Germany*
[2] *Radiophysical-Research Institute, Nishnii-Novgorod, Russia*
[3] *Spokesman of the GENIUS and HEIDELBERG-MOSCOW Collaborations, e-mail: klapdor@gustav.mpi-hd.mpg.de, home page: http://www.mpi-hd.mpg.de/non_acc/*

The data of the HEIDELBERG-MOSCOW double beta decay experiment for the measuring period August 1990 - May 2000 (54.9813 kg y or 723.44 molyears), published recently, are analyzed using the potential of the Bayesian method for low counting rates. First evidence for neutrinoless double beta decay is observed giving first evidence for lepton number violation. The evidence for this decay mode is 97% (2.2σ) with the Bayesian method, and 99.8% c.l. (3.1σ) with the method recommended by the Particle Data Group. The half-life of the process is found with the Bayesian method to be $T^{0\nu}_{1/2} = (0.8 - 18.3) \times 10^{25}$ y (95% c.l.) with a best value of 1.5×10^{25} y. The deduced value of the effective neutrino mass is, with the nuclear matrix elements from [1], $\langle m \rangle$ = (0.11 - 0.56) eV (95% c.l.), with a best value of 0.39 eV. Uncertainties in the nuclear matrix elements may widen the range given for the effective neutrino mass by at most a factor 2. Our observation which at the same time means evidence that the neutrino is a Majorana particle, will be of fundamental importance for neutrino physics.

PACS. 14.69.Pq Neutrino mass and mixing - 23.40.Bw Weak-interaction and lepton (including neutrino) aspects - 23.40.-s Beta decay; double beta decay; electron and muon capture.

Neutrinoless Double Beta Decay

Early reactions

COMMENT ON "EVIDENCE FOR NEUTRINOLESS DOUBLE BETA DECAY"*

C. E. AALSETH[1], F. T. AVIGNONE III[2], A. BARABASH[3], F. BOEHM[4], R. L. BRODZINSKI[1], J. I. COLLAR[5], P. J. DOE[6], H. EJIRI[7], S. R. ELLIOTT[6,†], E. FIORINI[8], R. J. GAITSKELL[9], G. GRATTA[10], R. HAZAMA[6], K. KAZKAZ[6], G. S. KING III[2], R. T. KOUZES[1], H. S. MILEY[1], M. K. MOE[11], A. MORALES[12], J. MORALES[12], A. PIEPKE[13], R. G. H. ROBERTSON[6], W. TORNOW[14], P. VOGEL[4], R. A. WARNER[1] and J. F. WILKERSON[6]

[1]*Pacific Northwest National Laboratory, Richland, WA 99352, USA*
[2]*Department of Physics and Astronomy, University of South Carolina, Columbia, SC 29208, USA*
[3]*Institute for Theoretical and Experimental Physics, Moscow 117259, Russia*
[4]*Department of Physics, California Institute of Technology, Pasadena, CA 91125, USA*
[5]*Enrico Fermi Institute, University of Chicago, Chicago, IL 60637, USA*
[6]*Center for Experimental Nuclear Physics and Astrophysics, University of Washington, Seattle, WA 98195, USA*
[7]*International* ...
[7]*Emeritus, Research* ...
[8]*Dipartimento di* ...
[9]*Departm* ...
[10]*Physi* ...
[11]*Emeritus, Department of Physics and Astronomy, University of California, Irvine, CA 92697, USA*
[12]*Laboratory of Nuclear and High Energy Physics, University of Zaragoza, 50009 Zaragoza, Spain*
[13]*Department of Physics and Astronomy, University of Alabama, Tuscaloosa, AL 35487, USA*
[14]*Department of Physics, Duke University, Durham, NC 27708, USA*

We comment on the recent claim for the experimental observation of neutrinoless double-beta decay. We discuss several limitations in the analysis provided in that paper and conclude that there is no basis for the presented claim.

Received 22 February 2002
Revised 21 May 2002

Neutrinoless Double Beta Decay
Newsletter story

Long-Baseline news, January 2002

***** Evidence that Neutrinos are Majorana particles**

H.V. Klapdor-Kleingrothaus et al., Mod Phys Lett A 16 (2002) 2409-2420, present "Evidence for Neutrinoless Double Beta Decay". A 3.1 sigma peak is found which fits to a best value of the neutrino mass of 0.39 eV and a half life 1.5 10^25 years. See hep-ph/0201231 and an analysis in hep-ph/0201226. Prior data analysis is in hep-ph/0103062. They're using 125 moles of Ge76.

- As a result, I got a quick email from John Beacom who didn't believe the result, and said this didn't meet the standards of my newsletter. I replied I didn't have standards, I had deadlines.

Neutrinoless Double Beta Decay
Newsletter story-2

Long-Baseline news, February 2002

***** Neutrino Mass may not be .39 eV**

The recent report on evidence for neutrinoless double beta decay is disputed by the 26 authors of a comment on that paper in hep-ex/0202018. They say that the extraction of the "signal" depends upon the choice of window and the absence of a flat background, among other problems pointed out in the paper. Also hep-ph/0201291

Subject: Re: February 2002 long-baseline neutrino news
From: Hans Volker Klapdor <Hans-Volker.Klapdor-Kleingrothaus@mpi-hd.mpg.de>
Date: 3/2/2002 9:22 AM
To: Maury Goodman at Argonne <mcg@hep.anl.gov>

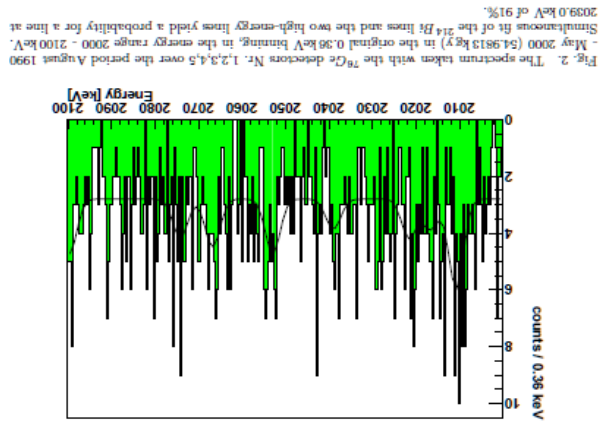
```
Dear Dr. Goodman,

I am surprised to see that you handle the 'Comment' put on the web as
hep-ex/0202018 on the same level as our published paper in Mod. Phys.
Lett. A. The 'Comment' (which is not yet published or accepted to our
knowledge) makes  n o  analysis  of our data, but just gives
hand-waving arguments. The 'Comment' was premature, these authors
forgot that we up to now published a  L e t t e r, and most of the
points
they raise (without having contacted us), are naturally treated in a
more
detailed paper.
It is highly misleading and concerning the second part of the statement
wrong, when in your Neutrino Web you state, that
"the 'signal' depends on the choice of the window and of the absence of
a
flat background".
May I propose that you better take out this unserious 'Comment' from
your
web page.
```

- I responded that my newsletter gave equal attention to the discovery of neutrino oscillations and a novel about a Neanderthal neutrino physicist.

Neutrinoless Double Beta Decay
Irrelevant facts which affect believability

- Result published before there was a preprint
- Published in a journal on which Klapdor was associated
- Significant fraction of collaboration didn't sign the paper
- Signal failed the upside-down test
- The only talk I heard from him was arrogant
- Data wasn't shared with all collaborators
- He repeatedly touted this with the DAMA DM "discovery"
- Doug Michael's view:
  "Even if it's right, it's wrong"
- It felt like a-posteriori analysis to me



Neutrinoless Double Beta Decay

Even though few in the community "believed" it, Klapdor's value became a benchmark

- EXO Phys. Rev. Lett., 109, 032505 (2012).

The result from the likelihood fit is shown in Fig. 6, along with the recent constraint for ^{136}Xe [7] and the best limit [19] and claimed detection [4] for ^{76}Ge. The present result contradicts [4] at 68% C.L. (90% C.L.) for the nominal values of all (most) matrix element calculations considered [5,20–23] and provides upper bounds to Majorana neutrino masses between 140 and 380 meV at 90% C.L..

- GERDA 2013

The long-standing claim for a $0\nu\beta\beta$ signal in ^{76}Ge is strongly disfavored, which calls for a further exploration of the degenerate Majorana neutrino mass scale. This will be pursued by GERDA phase II aiming for a sensitivity increased by a factor of about 10.

- KamLAND-Zen 201

PRL **110,** 062502 (2013) PHYSICAL REVIEW LETTERS week ending 8 FEBRUARY 2013

Limit on Neutrinoless $\beta\beta$ Decay of ^{136}Xe from the First Phase of KamLAND-Zen and Comparison with the Positive Claim in ^{76}Ge

tions. Using those calculations, this result excludes the Majorana neutrino mass range expected from the neutrinoless double-beta decay detection claim in ^{76}Ge, reported by a part of the Heidelberg-Moscow Collaboration, at more than 97.5% C.L.

Superluminal neutrinos

- We don’t allow neutrinos in here, said the bartender.
- A faster-than-light neutrino walks into a bar.

※Neutrino

※Who’s There?

※Knock Knock

Superluminal neutrinos

- August 2007 – MINOS superluminal preprint (published 2008)
- 22 Sep 2011 – OPERA preprint -- 6 σ
- 23 Sep 2011 -- CERN seminar broadcast live on the web. PREPRINT
- 23 Sep 2011 – (original) CERN press release
- 17 Nov 2011 -- Revised preprint submitted for publication (not published)
- 25 Feb 2012 – Possible loose connector announced

Superluminal neutrinos

MINOS

It is typical within the field of High Energy Physics that we have not read a majority of our own papers. (!)

Measurement of neutrino velocity with the MINOS detectors and NuMI neutrino beam

arXiv:0706.0437v3 [hep-ex] 31 Aug 2007

(Dated: February 1, 2008)

The velocity of a ~3 GeV neutrino beam is measured by comparing detection times at the Near and Far detectors of the MINOS experiment, separated by 734 km. A total of 473 Far Detector neutrino events was used to measure $(v-c)/c = 5.1 \pm 2.9 \times 10^{-5}$ (at 68% C.L.). By correlating the measured energies of 258 charged-current neutrino events to their arrival times at the Far Detector, a limit is imposed on the neutrino mass of $m_\nu < 50$ MeV/c^2 (99% C.L.).

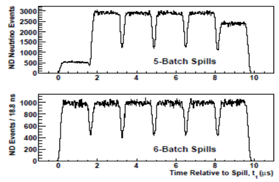


FIG. 1: Neutrino event time distribution measured at the MINOS Near Detector. The top plot corresponds to events in 5-batch spills $P_1^5(t_1)$ while the bottom plot corresponds to 6-batch spills $P_1^6(t_1)$.

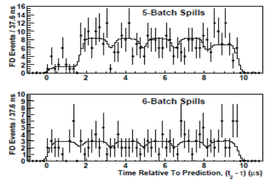


FIG. 2: Time distribution of FD events relative to prediction after fitting the time-of-flight. The top plot shows events in 5-batch spills, the bottom 6-batch spills. The normalized expectation curves $P_2^5(t)$ and $P_2^6(t)$ are shown as the solid lines.

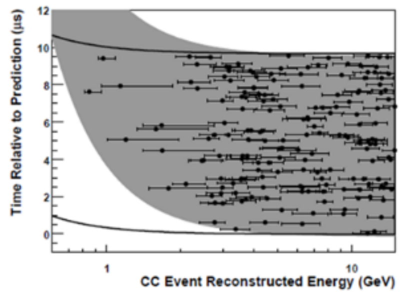


FIG. 3: The time and reconstructed energy for contained ν_μ charged current events. The points show the measured times of events and reconstructed energy E_{reco}. The horizontal error bars indicate the ~1σ energy uncertainty. The gray filled region indicates the allowed range of times predicted by a neutrino with $m_\nu = 50$ MeV/c^2. The solid lines indicate the allowed range predicted $m_\nu = 17$ MeV/c^2.

Superluminal neutrinos

Measurement of the neutrino velocity with the OPERA detector in the CNGS beam

The OPERA neutrino experiment at the underground Gran Sasso Laboratory has measured the velocity of neutrinos from the CERN CNGS beam over a baseline of about 730 km with much higher accuracy than previous studies conducted with accelerator neutrinos. The measurement is based on high-statistics data taken by OPERA in the years 2009, 2010 and 2011. Dedicated upgrades of the CNGS timing system and of the OPERA detector, as well as a high precision geodesy campaign for the measurement of the neutrino baseline, allowed reaching comparable systematic and statistical accuracies. An early arrival time of CNGS muon neutrinos with respect to the one computed assuming the speed of light in vacuum of (60.7 ± 6.9 (stat.) ± 7.4 (sys.)) ns was measured. This anomaly corresponds to a relative difference of the muon neutrino velocity with respect to the speed of light $(v-c)/c = (2.48 \pm 0.28 \text{ (stat.)} \pm 0.30 \text{ (sys.)}) \times 10^{-5}$.

- OPERA: Oscillation Project with Emulsion Tracking Apparatus
- CNGS: CERN Neutrinos to Gran Sasso

Superluminal neutrinos

My 2011 comments

- No neutrino's velocity was measured
- Three ways to make a mistake:
  - Clocks (t)
  - Surveying (distance)
  - Beam physics assumptions
- My opinion – OPERA is wrong
  - Further, if OPERA is "right" we don't know what "it" is, so we can't test "it"

Superluminal neutrinos

ORIGINAL PRESS RELEASE

Geneva, 23 September 2011. The OPERA[1] experiment, which observes a neutrino beam from CERN[2] 730 km away at Italy's INFN Gran Sasso Laboratory, will present new results in a seminar at CERN this afternoon at 16:00 CEST. The seminar will be webcast at http://webcast.cern.ch. Journalists wishing to ask questions may do so via twitter using the hash tag #nuquestions, or via the usual CERN press office channels.

The OPERA result is based on the observation of over 15000 neutrino events measured at Gran Sasso, and appears to indicate that the neutrinos travel at a velocity 20 parts per million above the speed of light, nature's cosmic speed limit. Given the potential far-reaching consequences of such a result, independent measurements are needed before the effect can either be refuted or firmly established. This is why the OPERA collaboration has decided to open the result to broader scrutiny. The collaboration's result is available on the preprint server arxiv.org: http://arxiv.org/abs/1109.4897.

The OPERA measurement is at odds with well-established laws of nature, though science frequently progresses by overthrowing the established paradigms. For this reason, many searches have been made for deviations from Einstein's theory of relativity, so far not finding any such evidence. The strong constraints arising from these observations makes an interpretation of the OPERA measurement in terms of modification of Einstein's theory unlikely, and give further strong reason to seek new independent measurements.

"This result comes as a complete surprise," said OPERA spokesperson, Antonio Ereditato of the University of Bern. *"After many months of studies and cross checks we have not found any instrumental effect that could explain the result of the measurement. While OPERA researchers will continue their studies, we are also looking forward to independent measurements to fully assess the nature of this observation."*

"When an experiment finds an apparently unbelievable result and can find no artefact of the measurement to account for it, it's normal procedure to invite broader scrutiny, and this is exactly what the OPERA collaboration is doing, it's good scientific practice," said CERN Research Director Sergio Bertolucci. *"If this measurement is confirmed, it might change our view of physics, but we need to be sure that there are no other, more mundane, explanations. That will require independent measurements."*

In order to perform this study, the OPERA Collaboration teamed up with experts in metrology from CERN and other institutions to perform a series of high precision measurements of the distance between the source and the detector, and of the neutrinos' time of flight. The distance between the origin of the neutrino beam and OPERA was measured with an uncertainty of 20 cm over the 730 km travel path. The neutrinos' time of flight was determined with an accuracy of less than 10 nanoseconds by using sophisticated instruments including advanced GPS systems and atomic clocks. The time response of all elements of the CNGS beam line and of the OPERA detector has also been measured with great precision.

"We have established synchronization between CERN and Gran Sasso that gives us nanosecond accuracy, and we've measured the distance between the two sites to 20 centimetres," said Dario Autiero, the CNRS researcher who will give this afternoon's seminar. *"Although our measurements have low systematic uncertainty and high statistical accuracy, and we place great confidence in our results, we're looking forward to comparing them with those from other experiments."*

"The potential impact on science is too large to draw immediate conclusions or attempt physics interpretations. My first reaction is that the neutrino is still surprising us with its mysteries." said Ereditato. *"Today's seminar is intended to invite scrutiny from the broader particle physics community."*

The OPERA experiment was inaugurated in 2006, with the main goal of studying the rare transformation (oscillation) of muon neutrinos into tau neutrinos. One first such event was observed in 2010, proving the unique ability of the experiment in the detection of the elusive signal of tau neutrinos.

Gedanken history

After the press release, this made worldwide front page news.

But…

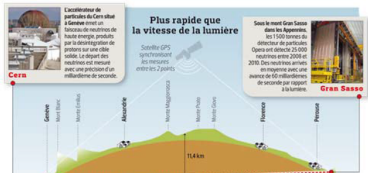
- Suppose OPERA had the same seminar but CERN had <u>not</u> issued a press release…
- Two weeks later there would have been an article in the science section of the New York Times
  - The scientific story would have been the same.
  - The worldwide fuss would not have been the same.

Relativité: Einstein contredit par des chercheurs du CNRS

Par Cyrille Vanlerberghe (http://plus.lefigaro.fr/page/cyrille-vanlerberghe) | Mis à jour le 23/09/2011 à 11:30 / Publié le 22/09/2011 à 19:55

Des chercheurs du CNRS ont montré que des particules sont capables de voyager plus vite que la lumière.

«Si c'est vrai, c'est une véritable bombe pour la physique, c'est une découverte comme il en arrive tous les siècles», commente Thibault Damour, grand spécialiste de la relativité d'Einstein à l'Ihes (Institut des hautes études scientifiques à Bures-sur-Yvette). La raison de cette effervescence est simple: une équipe de chercheurs de l'Institut de physique nucléaire de Lyon a montré que des neutrinos «superluminiques», des particules très légères, sont capables de voyager plus vite que la lumière. Un phénomène tout simplement impossible d'après la théorie de la relativité restreinte d'Einstein, qui définit la vitesse de la lumière comme une limite infranchissable pour tout objet doté d'une masse. Si les mesures de Dario Autiero et de ses collègues du CNRS à Lyon sont justes, c'est toute la physique moderne qui est à revoir. Les conséquences seraient tellement importantes que tous les spécialistes se veulent prudents et demandent que l'expérience soit reproduite ailleurs, avec une autre équipe, avant de jeter d'un coup à la poubelle tout le travail d'Einstein sur la relativité.



The Guardian

Faster than light particles found, claim scientists

Particle physicists detect neutrinos travelling faster than light, a feat forbidden by Einstein's theory of special relativity

LSND and eV sterile neutrinos

Light sterile neutrinos

Partial Timelime

☆Neutrino 1994; 8 events B = 0.9

Nucl. Phys. B (Proc. Suppl.) 38 229-234 1995

☆1st Paper 16.4+9.7-8.9 ± 3.3 excess

Phys. Rev. Lett. 75 2650-2653 1995

☆Hill paper with limit 5 events B=6.2

Phys. Rev. Lett. 75 2654-2657 1995

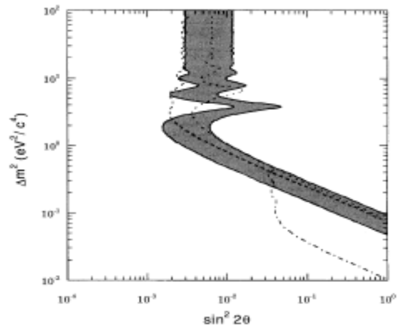


FIG. 3. Results from interpreting the excess signal from all e^+ data as due to two-generation neutrino oscillations. The two edges of the shaded band are the 90% C.L. limits of $\sin^2 2\theta$ as a function of Δm^2. Not included is the 20% systematic uncertainty in the LSND normalization. Also shown are 90% C.L. limits from Ref. [8] (dotted histogram), Ref. [9] (dashed histogram), and Ref. [10] (dot-dashed histogram).

☆2007 **MiniBooNE Results Inconsistent with Existence of "Sterile" Neutrinos**

https://www.aps.org/publications/apsnews/200706/miniboone.cfm

☆2006 Gallium Anomaly 0.79+0.09−0.10 expected rate with souce

J. N. Abdurashitov et al.,Phys.Rev.C 73(2006) 045805

☆2011 Reactor neutrino anomaly

Phys.Rev.D83:073006,2011

Light sterile neutrinos

Issues

- Inconsistency of 0.3%, 3% and 30% signals
- LSND Decay in flight signal
- Karmen's limit better than its sensitivity
- Most analyses presented based on 2-νs ($\theta_{\mu e}$)
- Cosmological limits on N_ν^{eff} & Σm_ν
- MiniBooNE's low energy excess
- 3+1 vs 3+2 vs 3+3
- Limits from MINOS+, NOvA, Ice-Cube, …
- Inconsistency of ν_e appearance and ν_μ disappearance
- What if the "Best Fit" is a bad fit
- Value of Δm^2 for low energy excess

Light sterile neutrinos

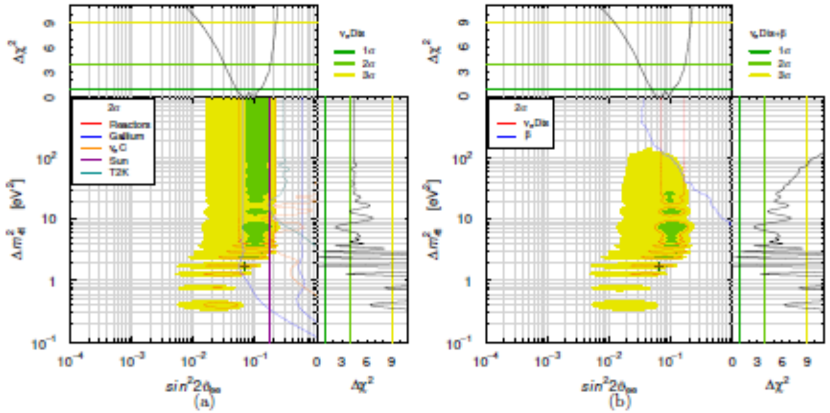


Figure 5. Allowed regions in the $\sin^2 2\vartheta_{ee}$–Δm^2_{41} plane and marginal $\Delta\chi^2$'s for $\sin^2 2\vartheta_{ee}$ and Δm^2_{41} obtained from: (a) the combined fit of ν_e and $\bar{\nu}_e$ disappearance data; (b) the combined fit of ν_e and $\bar{\nu}_e$ disappearance data and the β-decay constraints of the Mainz [83] and Troitsk [84, 85] experiments. The best-fit points corresponding to χ^2_{min} in Table 4 are indicated by crosses.

Updated Global 3+1 Analysis of Short-BaseLine Neutrino Oscillations

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ABSTRACT: We present the results of an updated fit of short-baseline neutrino oscillation data in the framework of 3+1 active-sterile neutrino mixing. We first consider ν_e and $\bar{\nu}_e$ disappearance in the light of the Gallium and reactor anomalies. We discuss the implications of the recent measurement of the reactor $\bar{\nu}_e$ spectrum in the NEOS experiment, which shifts the allowed regions of the parameter space towards smaller values of $|U_{e4}|^2$. The β-decay constraints of the Mainz and Troitsk experiments allow us to limit the oscillation length between about 2 cm and 7 m at 3σ for neutrinos with an energy of 1 MeV. The corresponding oscillations can be discovered in a model-independent way in ongoing reactor and source experiments by measuring ν_e and $\bar{\nu}_e$ disappearance as a function of distance. We then consider the global fit of the data on short-baseline $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ transitions in the light of the LSND anomaly, taking into account the constraints from $\overset{(-)}{\nu}_e$ and $\overset{(-)}{\nu}_\mu$ disappearance experiments, including the recent data of the MINOS and IceCube experiments. The combination of the NEOS constraints on $|U_{e4}|^2$ and the MINOS and IceCube constraints on $|U_{\mu4}|^2$ lead to an unacceptable appearance-disappearance tension which becomes tolerable only in a pragmatic fit which neglects the MiniBooNE low-energy anomaly. The minimization of the global χ^2 in the space of the four mixing parameters Δm^2_{41}, $|U_{e4}|^2$, $|U_{\mu4}|^2$, and $|U_{\tau4}|^2$ leads to three allowed regions with narrow Δm^2_{41} widths at $\Delta m^2_{41} \approx 1.7$ (best-fit), 1.3 (at 2σ), 2.4 (at 3σ) eV^2. The effective amplitude of short-baseline $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ oscillations is limited by $0.00048 \lesssim \sin^2 2\vartheta_{e\mu} \lesssim 0.0020$ at 3σ. The restrictions of the allowed regions of the mixing parameters with respect to our previous global fits are mainly due to the NEOS constraints. We present a comparison of the allowed regions of the mixing parameters with the sensitivities of ongoing experiments, which show that it is likely that these experiments will determine in a definitive way if the reactor, Gallium and LSND anomalies are due to active-sterile neutrino oscillations or not.

Why physicist disagree

If the data doesn't agree with the null hypothesis or the alternative hypothesis, some say you need more data, while some say you need more hypotheses

Light sterile neutrinos

Big boost for Fermilab's short-baseline neutrino experiments

June 5, 2018 | Joe Lykken

Joe Lykken

For more than a decade, the particle physics community has faced a perplexing puzzle: two experiments, LSND at Los Alamos and MiniBooNE at Fermilab, found hints of neutrino behavior that did not fit the usual assumption that the universe contains three types of neutrinos that have tiny masses and oscillate.

The data from these two experiments suggest that something unusual is going on when low-energy muon neutrinos travel a short distance, less than a kilometer. The answer might be that there are additional types of neutrinos, albeit with properties different from the three "normal" types. These extras are known as sterile neutrinos. A confirmed discovery of a sterile neutrino would open up a whole new world of particles previously hidden from view.

Thanks to new results published by the MiniBooNE collaboration and presented at the Neutrino 2018 conference in Heidelberg this week, this neutrino mystery persists. The new data shows that the MiniBooNE signal has grown even stronger. Significantly stronger. The result suggests that there is almost no chance for the anomalous signal to be explained as merely a statistical fluctuation. (Read the press release from Los Alamos National Laboratory.)

http://news.fnal.gov/2018/06/big-boost-for-fermilabs-short-baseline-neutrino-experiments/

Light sterile neutrinos

In my opinion

eV sterile νs suggested by LSND have been ruled out for a long time

The SBL anomalies are real

They may have interesting or uninteresting explanations.

If you don't know what you are looking for…

- You might find it
- You might not find it
- But you cannot logically rule it out

IMB neutrino oscillation limit

IMB neutrino oscillation limit

- In 1992, IMB published a neutrino oscillation limit based on the ratio of upward-going stopping μ from atmospheric ν to upward going μ.
- This is where we now think it is.

VOLUME 69, NUMBER 7 PHYSICAL REVIEW LETTERS 17 AUGUST 1992

Search for Muon Neutrino Oscillations with the Irvine-Michigan-Brookhaven Detector

R. Becker-Szendy,[1] C. B. Bratton,[2] D. Casper,[3] S. T. Dye,[4] W. Gajewski,[5] M. Goldhaber,[6] T. J. Haines,[7] P. G. Halverson,[5] T. Jones,[8] D. Kielczewska,[9] W. R. Kropp,[5] J. G. Learned,[1] J. LoSecco,[10] G. McGrath,[1] C. McGrew,[5] J. Matthews,[3] S. Matsuno,[1] R. S. Miller,[11] M. S. Mudan,[9] L. Price,[5] F. Reines,[5] J. Schultz,[5] D. Sinclair,[3] H. W. Sobel,[5] J. Stone,[4] L. R. Sulak,[4] R. Svoboda,[11] and J. Van der Velde[3]

Muon neutrinos produced as a result of cosmic-ray interactions with the atmosphere are used to search for ν_μ oscillations into ν_τ by comparing the measured rate of upward-going muons in the Irvine-Michigan-Brookhaven detector with the expected rate. In addition, the ratio of upward-going muons which stop in the detector to those which exit is used to search for deviations from the expected spectrum. This latter technique is free of flux and cross-section normalization uncertainties. No evidence for oscillations is found. 90% C.L. limits on δm^2 are derived in the range $(1-2)\times10^{-4}$ eV^2 for $\sin^2 2\theta > 0.5$.

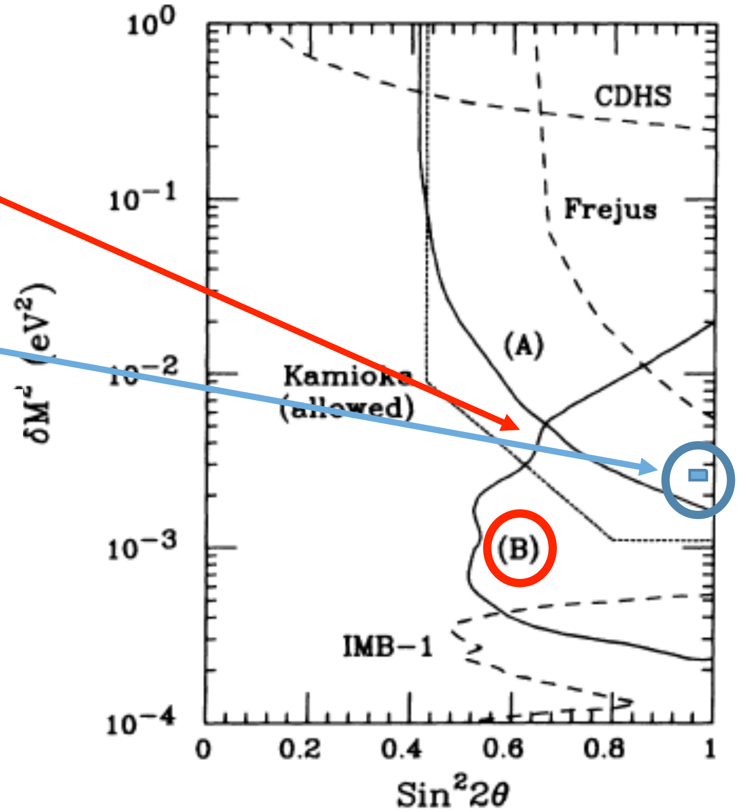

FIG. 2. 90% C.L. limits on ν_μ to ν_τ oscillations from rate (*A*) and stopping fraction (*B*). Dashed curves show limits from IMB-1 [14], Frejus [3], and CERN-Dortmund-Heidelberg-Saclay (CDHS) [15]. Dotted curve shows the allowed region from Kamiokande [16]. The Frejus limit is 95% C.L.; others are 90%.

IMB

- A retraction was never really published, but the limit was apparently quite sensitive to structure functions.
- 1999 Cosmic ray conference abstract:

SH 4.1.05

Neutrino oscillation analysis of IMB upward-going muon data with improved interaction model

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[6]*Department of Physics and Astronomy, State University of New York, Stony Brook, NY 11794-3800, USA*
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Abstract

An earlier analysis of the ratio of stopping to through-going neutrino-induced upward muons in IMB excluded neutrino oscillations in the region now favored by the Super-Kamiokande experiment. It has been suggested that the simple deep-inelastic cross-section model used in this analysis underestimates the predicted rate of upward stopping muons, and hence may mask any possible deficit caused by neutrino oscillation. The original IMB data are compared with the predictions of a more realistic cross-section model (taking into account exclusive quasi-elastic and resonant reaction channels) to determine whether they are, in fact, inconsistent with the Super-Kamiokande results.

God's mistake?

Intelligent Design of Neutrino Parameters? (~2005)

(from S. Wojcicki)

- The optimum choice for Δm^2_{21}?

Such as to give resonant transition (MSW effect) in the middle of solar energy spectrum -, $\Delta m^2_{21} = 8.2 \times 10^{-5}$ eV^2

- The optimum choice for $\sin\theta_{12}$?

Big enough for oscillations to be seen in KamLAND - ~0.8

- The optimum choice for Δm^2_{32}?

Such as to give full oscillation in the middle of the range of possible distances that atmospheric ν's travel to get to the detector - $\Delta m^2_{32} = 2.3 \times 10^{-3}$ eV^2

- The optimum choice for $\sin\theta_{23}$?

Big enough so that oscillations could be seen easily - $\theta_{23} \sim \pi/4$

- The optimum choice for $\sin\theta_{13}$?

Small enough so as not to confuse interpretation of the above - $\theta_{13} < 10^0$

- **But the acid test - will θ_{13} be big enough to see CP violation and determine mass hierarchy?**

And still?

By 2011 we learned that θ_{13} was as large as could be imagined in 2006

- ? How about the remaining parameters so that the "Intelligent Design" arguments can get longer (2012)?
  - $\delta \sim 3\pi/2$
    - to most quickly determines the hierarchy
    - to get large CP violation & answer the CP violation question
  - The inverted hierarchy, so we can tell Dirac/Majorana & maybe beta decay endpoint
  - Majorana, which seems to be more interesting so that some of our theorists will be happy (seesaw, etc.)

It appears:

✓By 2011 we learned that θ_{13} was as large as could be imagined in 2006

? How about the remaining parameters so that the "Intelligent Design" arguments can get longer (2012)?

✓ ➯ $\delta \sim 3\pi/2$
- to most quickly determines the hierarchy
- to get large CP violation & answer the CP violation question

✗ ➯ The inverted hierarchy, so we can tell Dirac/Majorana & maybe beta decay endpoint

? ➯ Majorana, which seems to be more interesting so that some of our theorists will be happy (seesaw, etc.)

Lessons?

- “The great teacher, failure is” … Yoda
- “By seeking and blundering we learn.”
  — Johann Wolfgang von Goethe
- Role of critics
  - Physicists are naturally skeptical
  - We more often ignore than actively criticize results we don’t believe
  - “Active” skeptics have not fared well
    - \- Morrison (solar nus), Miyake (Atmospheric nus)
    - \+ Stu Friedman (17 keV)

Some of my mantras

- ❈ There is no theory of systematic error
- ❈ There are an infinite number of tests of the null hypothesis
- ❈ You can’t prove anything in Physics
- ❈ The union of two confidence levels isn’t a confidence level.
- ❈ The commonly used 5σ criterion is based on several misunderstandings and is wrong.

Scientific induction *and HEP's most common mistake*

- Null hypothesis (The data can be understood without new physics)
- Alternative hypothesis (A particular new effect)
- A test statistic
- A chance probability (→ x σ effect or y% CL limit)
  - ✓ Error of the first kind (incorrect signal)
  - ✓ Error of the second kind (incorrect limit)

But all of this is only valid if the hypotheses and statistic are specified a-priori

And we do a-posteriori analysis **all the time** – we have too!

I cringe when I hear colleagues justify 5σ because "I've seen so many 3σ effects go away." An x σ effect with a-posteriori and a-priori hypothesis are calculated in exactly the same way. The meaning is totally different.

Summary and Conclusions?

- Our field (particle physics) does a poor job of
  - Presenting statistical arguments in a consistent way.
    - In particular distinguishing between a "x" σ effect calculated from an a-priori test and an "x" σ effect calculated from an a-posteriori test
  - Explaining to ourselves and others how we conclude anything based on whatever combination of data, theory and instinct that we use.

- **Nevertheless**
  - We seem to do an **excellent** collective job of taking seriously results which get vindicated and being skeptical of results which do not

- **Calling a result a mistake has a connotation of criticism.** In a scientific sense, I do <u>not</u> criticize the vast majority of these reported results.

Acknowledgements

1. I am solely responsible for all mistakes in this talk about mistakes
2. For other material, I wish to thank

- ☆ Evgeny Akhmedov,
- ☆ Zelimir Djurcic
- ☆ John Losecco
- ☆ Naba Mondal,
- ☆ Jurgen Reichenbacher
- ☆ Jack Schneps
- ☆ Phil Schreiner
- ☆ Robert Shrock
- ☆ Hank Sobel
- ☆ Daniel Vignaud
- ☆ Cosmas Zachos…

Other "mistakes"

1. High y anomaly
2. NuTeV Helium bag events
3. Alternating neutral currents
4. Reines-Sobel ν oscillations
5. NuTeV anomaly
6. ITEP $m(\nu_e) = 30$ eV
7. Tritium endpoint $(-)m^2$
8. Time variations in Troitsk m_ν^2
9. Kolar events
10. Early atmospheric ν lack of polarization
11. PDG $m(\nu)$ encoding
12. MINOS anti-ν θ_{23}
13. BNL 776 & 816 oscillations
14. Oscillations in Bugey
15. Vanucci PS191 oscillations
16. HPW "super" trimuons
17. ν grammar
18. Karmen time anomaly
19. Which ν is a particle?
20. Labels for Δm^2_{ab}
21. SPT vs. V-A
22. Majoron emission in $0\nu2\beta$ PNL/USC
23. BEBC oscillations

High y anomaly

- HPW Unexpected y distributions ($y = E_{had}/E_{\nu}$) in FNAL E1 - low x
- 2 further papers
- Not seen CCFR
- Contradicted by CHARM @ CERN

VOLUME 33, NUMBER 16 PHYSICAL REVIEW LETTERS 14 OCTOBER 1974

Scaling-Variable Distributions in High-Energy Inelastic Neutrino Interactions*

B. Aubert,† A. Benvenuti, D. Cline, W. T. Ford, R. Imlay, T. Y. Ling, A. K. Mann, F. Messing, J. Pilcher,‡ D. D. Reeder, C. Rubbia, R. Stefanski, and L. Sulak
Department of Physics, Harvard University, Cambridge, Massachusetts 02138, and Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19174, and Department of Physics, University of Wisconsin, Madison, Wisconsin 53706, and Fermi National Accelerator Laboratory, Batavia, Illinois 60510
(Received 1 August 1974)

We present measured distributions in the scaling variables x and y obtained from the reactions ν_μ ($\bar{\nu}_\mu$) + nucleon → μ^- (μ^+) + hadrons at high energy. The x distributions are consistent with scale invariance. The x and y distributions are used to perform the first test of charge-symmetry invariance in high-energy neutrino interactions, assuming the validity of scale invariance. A possible *effective* deviation from charge-symmetry invariance is observed, which could be the result of new particle production.

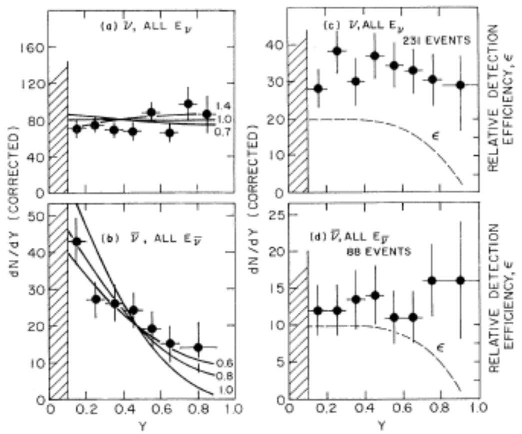

FIG. 3. Corrected experimental y distributions (a) and (b) for the region $0.6 > x \geq 0.1$, and (c) and (d) for the region $x < 0.1$. Points at $y = 0.05$ are omitted because they are sensitive to resolution corrections. Points at $y = 0.95$ in (a) and (b) are omitted because they are sensitive to efficiency corrections. Calculated curves for different values of B^{ν} and $B^{\bar{\nu}}$ are also shown in (a) and (b).

VOLUME 39, NUMBER 8 PHYSICAL REVIEW LETTERS 22 AUGUST 1977

Is There a High-y Anomaly in Antineutrino Interactions?

M. Holder, J. Knobloch, J. May, H. P. Paar, P. Palazzi, D. Schlatter, J. Steinberger, H. Suter, H. Wahl, and E. G. H. Williams
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P. Bloch, B. Devaux, M. Grimm, J. Maillard, B. Peyaud, J. Rander, A. Savoy-Navarro, and R. Turlay
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(Received 12 July 1977)

Accepted without review at the request of E. Picasso under policy announced 26 April 1976

We have analyzed data taken in the CERN narrow-band neutrino and antineutrino beams with regard to the "high-y anomaly" observed by previous experiments at Fermilab. At neutrino energies between 30 and 200 GeV, the $\bar{\nu}$ and ν charged-current cross-section ratios and muon-inelasticity distributions disagree with the earlier results. In particular, there is no evidence for energy-dependent effects in the antineutrino data which constitute an important aspect of the alleged anomaly.

NuTEV Helium bag events

- 3 events with a background of 0.04 appeared to vertex in a Helium bag in front of NuTEV.
- Kinematics didn't match the alternative hypothesis (decay of a supersymmetric particle.)
- Int. J. Mod. Phys. A16S1B, 761, 2001.

Observation of Anomalous Dimuon Events in the NuTeV Decay Detector
(Preliminary)

T. Adams[4], A. Alton[4], S. Avvakumov[8], L. de Barbaro[5], P. de Barbaro[8], R. H. Bernstein[3], A. Bodek[8], T. Bolton[4], J. Brau[6], D. Buchholz[5], H. Budd[8], L. Bugel[3], J. Conrad[2], R. B. Drucker[6], B. T. Fleming[2], R. Frey[6], J. Formaggio[2], J. Goldman[4], M. Goncharov[4], D. A. Harris[8], R. A. Johnson[1], J. H. Kim[2], S. Koutsoliotas[2], M. J. Lamm[3], W. Marsh[3], D. Mason[6], J. McDonald[7], C. McNulty[2], K. S. McFarland[3], D. Naples[7], P. Nienaber[3], A. Romosan[2], W. K. Sakumoto[8], H. Schellman[5], M. H. Shaevitz[2], P. Spentzouris[2], E. G. Stern[2], N. Suwonjandee[1], M. Vakili[1], A. Vaitaitis[2], U. K. Yang[8], J. Yu[3], G. P. Zeller[5], and E. D. Zimmerman[2]

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[8] *University of Rochester, Rochester, NY 14627*

(September 1, 2000)

A search for long-lived neutral particles (N^0) which decay into at least one muon has been performed using an instrumented decay channel at the E815 (NuTeV) experiment at Fermilab. The decay channel was composed of helium bags interspersed with drift chambers, and was used in conjunction with the NuTeV neutrino detector to search for N^0 decays. The data were examined for particles decaying into the muonic final states $\mu\mu$, μe, and $\mu\pi$. Three $\mu\mu$ events were observed over an expected background of 0.040 ± 0.009 events; no events were observed in the other modes. Although the observed events share some characteristics with neutrino interactions, the observed rate is a factor of 75 greater than expected. No Standard Model process appears to be consistent with this observation.

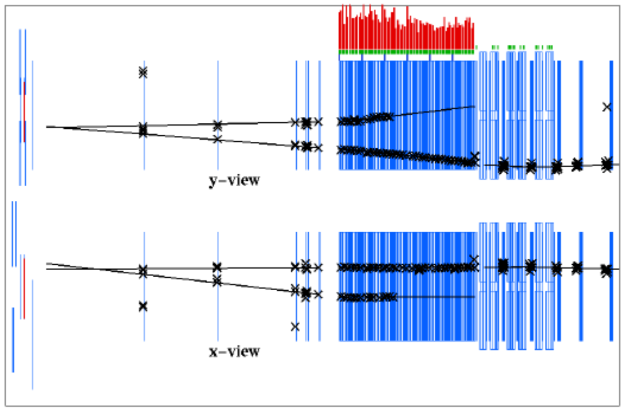


FIG. 9. Run/Event 6133/3846: $\mu\mu(\nu)$ data event passing final cuts.

Alternating neutral currents

Surely covered in D. Haidt's talk, this session

- Observation of Neutrino Like Interactions Without Muon or Electron in the Gargamelle Neutrino Experiment
- Phys. Lett. B46 (1973) 138-140
- Nucl. Phys. B73 (1974) 1-22

2·2. *Criticism and final acceptance.* – The discovery of neutrino-induced muonless events was reported to the Electron-Photon Conference at Bonn at the end of August 1973. The Harvard-Pennsylvania-Wisconsin Group (HPW) reported also muonless events observed in a counter experiment (EA1) at the NAL (today Fermi Laboratory) neutrino beam with energies in the 100 GeV regime. In one of the parallel sessions the claim was critically discussed, but at the end of the conference the general belief was that weak neutral currents were discovered. However, a hot summer and fall were to come. Rather soon critical voices started questioning the Gargamelle result and tried to blame for that the treatment of the neutron cascade. They argued that an underestimate of the neutron background would trivially mean the observation of merely neutron interactions. Such arguments were invalidated by the members of Gargamelle stressing the fact, that all aspects of neutron backgound calculation relied on data and were well under control. Nevertheless, the disbelief persisted and even became stronger, when it got known that HPW withdrew the effect in a subsequent run with their modified detector.

From D. Haidt & A. Pullia, "The Weak Neutral Current, Discovery and impact" Rivista del Nuovo Cimento, 2013

Reines Sobel ν oscillations

- Single detector reactor experiment
- Compared CC/NC rates

PHYSICAL REVIEW LETTERS

VOLUME 45 | 20 OCTOBER 1980 | NUMBER 16

Evidence for Neutrino Instability

F. Reines, H. W. Sobel, and E. Pasierb
Department of Physics, University of California at Irvine, Irvine, California 92717
(Received 24 April 1980)

This Letter reports indications of neutrino instability obtained from data taken on the charged- and neutral-current branches of the reaction

$$\bar{\nu}_e + d \to n + n + e^+ \quad (ccd)$$
$$\bar{\nu}_e + d \to n + p + \bar{\nu}_e \quad (ncd)$$

at 11.2 m from a 2000-MW reactor. These results at the (2–3)-standard-deviation level, based on the departure of the measured ratio (ccd/ncd) from the expected value, make clear the importance of further experimentation to measure the $\bar{\nu}_e$ spectrum versus distance.

- H. Sobel "It has been a while, but if I remember correctly one of the cross sections we were using changed significantly.

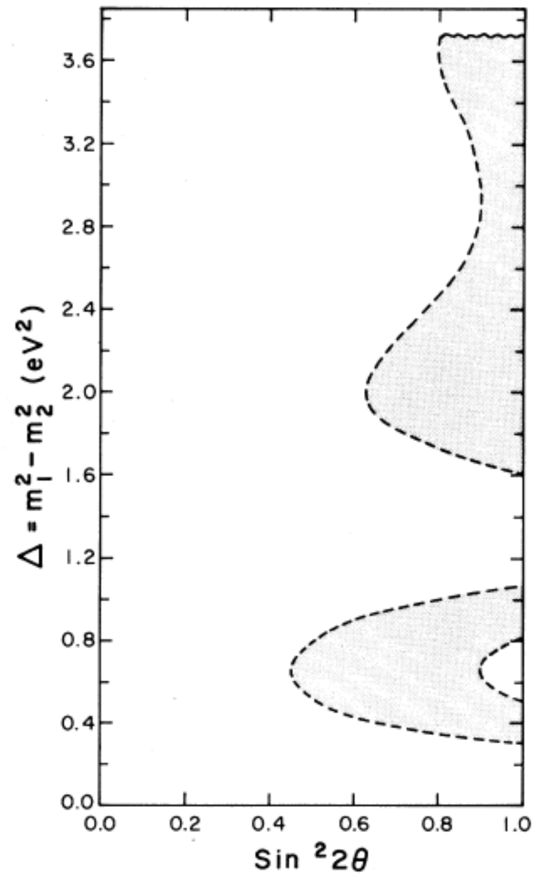


FIG. 1. Allowed regions of Δ and $\sin^2 2\theta$ for $\mathcal{R} = 0.38 \pm 0.21$.

NuTeV anomaly

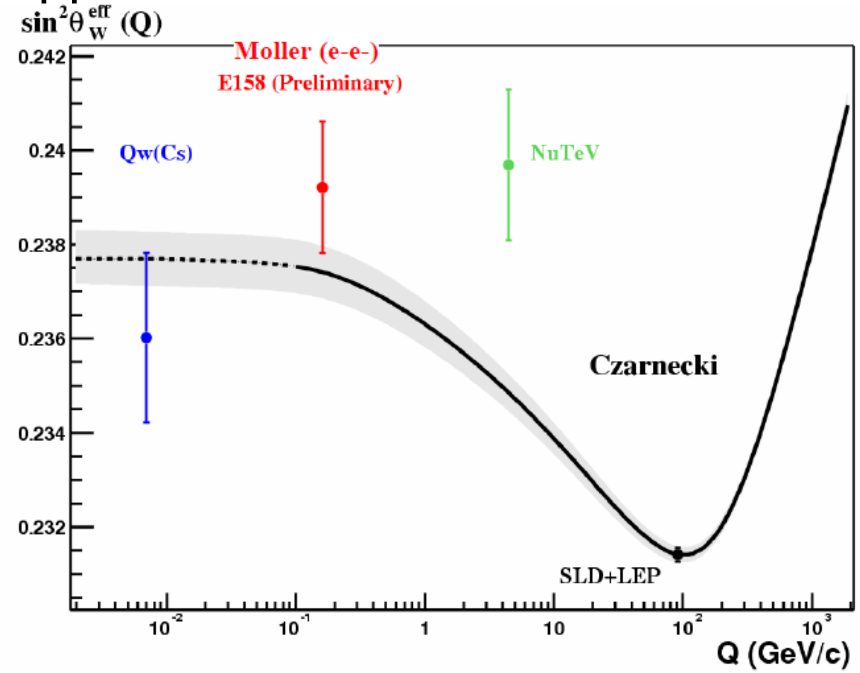
Measure

$$R^{\nu(\bar{\nu})} = \frac{\sigma_{NC}^{\nu(\bar{\nu})}}{\sigma_{CC}^{\nu(\bar{\nu})}} = \rho^2 \left(\frac{1}{2} - \sin^2\theta_W + \frac{5}{9}\sin^4\theta_W (1 + \frac{\sigma_{CC}^{\bar{\nu}(\nu)}}{\sigma_{CC}^{\nu(\bar{\nu})}}) \right)$$

	Short (NC) Events	Long (CC) Events	R_{exp}=Short/Long
Neutrino	457K	1167K	0.3916 ± 0.0007
Antineutrino	101K	250K	0.4050± 0.0016

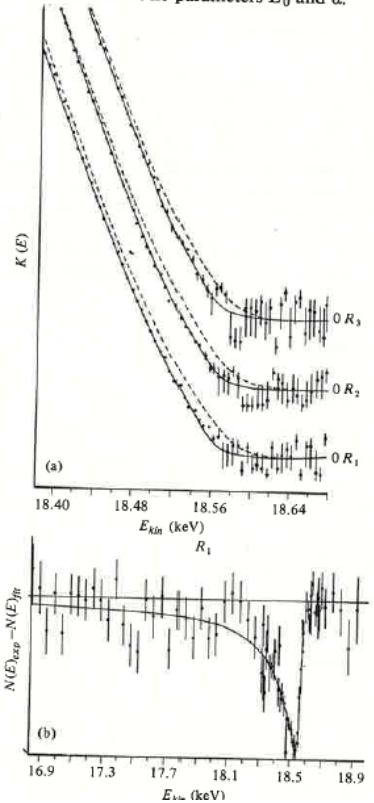
Toby vs. Godzilla

- Follow-up experiment not approved



30 eV ITEP m(ν)

Figure 2.5. (a) Observed tritium beta spectrum (Kurie plot) near the endpoint for three runs (R_1,R_2,R_3) from the ITEP experiment of Boris et al. (85). The solid curves are overall fits based on the valine final state. The dashed curves are calculated spectra for $m_\nu = 0$. (b) Difference between "best fit" to the experimental data and calculated spectrum for $m_\nu = 0$. The best fit was achieved for a set of E_0, α and $m_\nu = 34.8$ eV. The $m_\nu = 0$ horizontal line is based on the same parameters E_0 and α.



- ☆ From Boehm & Vogel, "The physics of massive neutrinos"
- ☆ Fit to 30.0 ± 1.9 ev
- ☆ But

The ITEP measurement, while not contradicting Bergkvist's results, is the only experiment to date that has provided positive evidence for a finite neutrino mass. Over the course of this series of experiments, the values reported for the mass have changed only little and appear to have been unaffected by several drastic changes in procedures such as improvement of the resolution or inclusion of the Lorentzian width (Simpson 83). While this seems at first reassuring, it is, on closer inspection, rather difficult to understand. As mentioned above, the resulting spectrum depends strongly on the structure of the low energy tail in the resolution function, as well as on the procedure for determining the extrapolated endpoint. In an analysis, endpoint and mass are strongly correlated, and a small change in the extrapolated endpoint energy, such as that resulting from a distortion of the spectrum (the α term), may change the mass in a significant way.

Tritium negative m^2

- Mainz

$m^2 = -3.7 \pm 5.3_{fit} \pm 3.1_{syst}$ eV^2/c^4

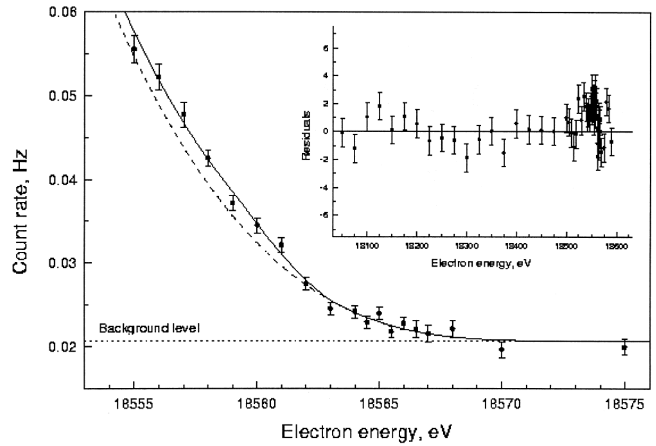
Physics Letters B 460 (1999) 219-226

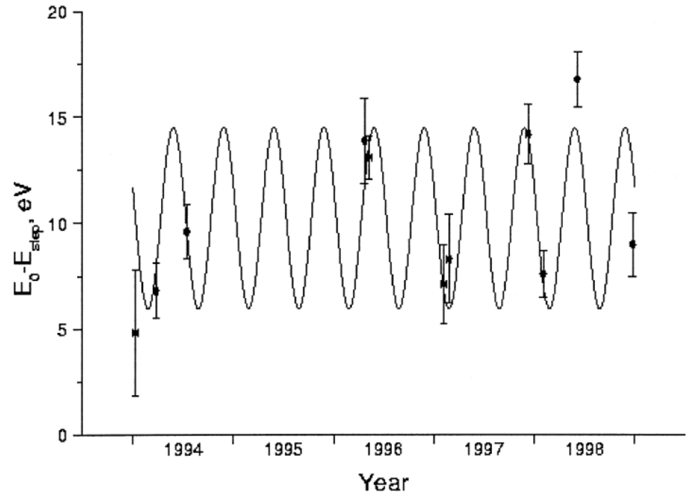
- Troitsk

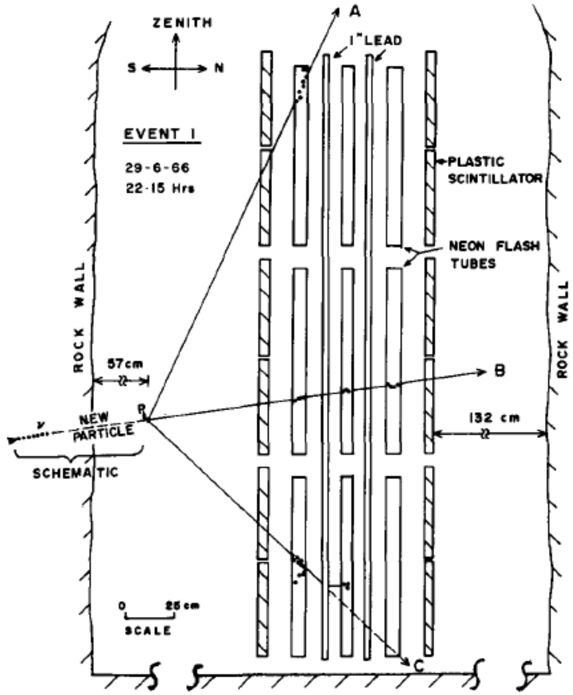
$m^2 = -1.9 \pm 3.4_{fit} \pm 2.2_{syst}$ eV^2/c^4

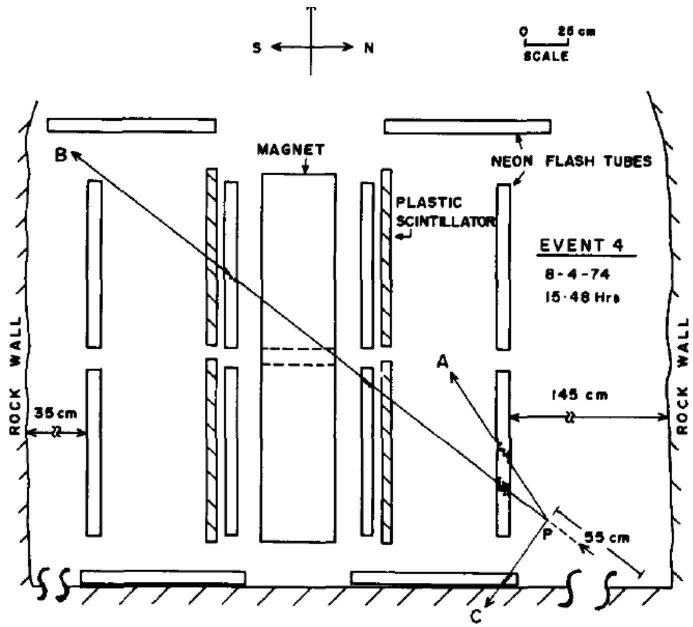
Physics Letters B 460 (1999) 227-235

- And several others, leading to speculation then about tachyons.
- *"As was discussed at the KATRIN inauguration a few days ago, this is now thought to possibly have been due to inadequate inclusion of the effects of the fact that the tritium diatomic molecules have rotational and vibrational excitations and the decays populate excited states of the resultant tritium-Helium-3 diatomic molecules." R. Schrock*
- Troitsk also saw a possible periodicitry of the step position with a period of a half year.









Kolar Events

Volume 57B, number 1 PHYSICS LETTERS 9 June 1975

EVIDENCE FOR THE PRODUCTION OF A NEW PARTICLE IN NEUTRINO INTERACTIONS

M.R. KRISHNASWAMY, M.G.K. MENON and V.S. NARASIMHAM

Tata Institute of Fundamental Research, Bombay, India

N. ITO, S. KAWAKAMI and S. MIYAKE*

Osaka City University, Osaka, Japan

Received 29 May 1975

We present here evidence, based on 5 events recorded in cosmic ray experiments deep underground, for the production of new, massive ($\gtrsim$ 2 GeV) and long lived ($\tau \sim 10^{-9}$ sec) particles in neutrino interactions with rock nuclei.

- 5 events seen in KGF which seem to vertice in air
- Never contradicted
- I'm not aware anyone tried
- Background difficult

Lack of polarization in atmospheric ν calculations

- The original atmospheric neutrino flux calculations used for the "ratio of ratios" did not take into account the fact that the muon is polarized.
- Cf Gaisser Stanev & Barr, Phys. Rev D. 38 (1988) 85. with Gaisser et al., Phys. Lett. B 214 (1988) 147.

RATIO OF ν_e/ν_μ IN ATMOSPHERIC NEUTRINOS

Stephen BARR [a], T.K GAISSER [a], Paolo LIPARI [b] and Serap TILAV [a]
[a] *Bartol Research Institute, University of Delaware, Newark, DE 19716, USA*
[b] *Dipartimento di Fisica e Sezione INFN, University of Rome I, Piazzale Aldo Moro 2, I-00185 Rome, Italy*

Received 12 August 1988

When the effect of muon polarization is included, the calculated ratio ν_e/ν_μ for atmospheric neutrinos with energies above ~200 MeV is increased by 10–20% compared to the result when polarization is neglected. We give an analytic derivation of this ratio for the artificial case of a power law differential spectrum of parent pions propagating in an atmosphere in which all pions and muons decay. This is sufficient to estimate the effect on the calculated ratio of electron-like to muon-like events induced by neutrino interactions in large underground detectors.

PDG m(ν) encoding

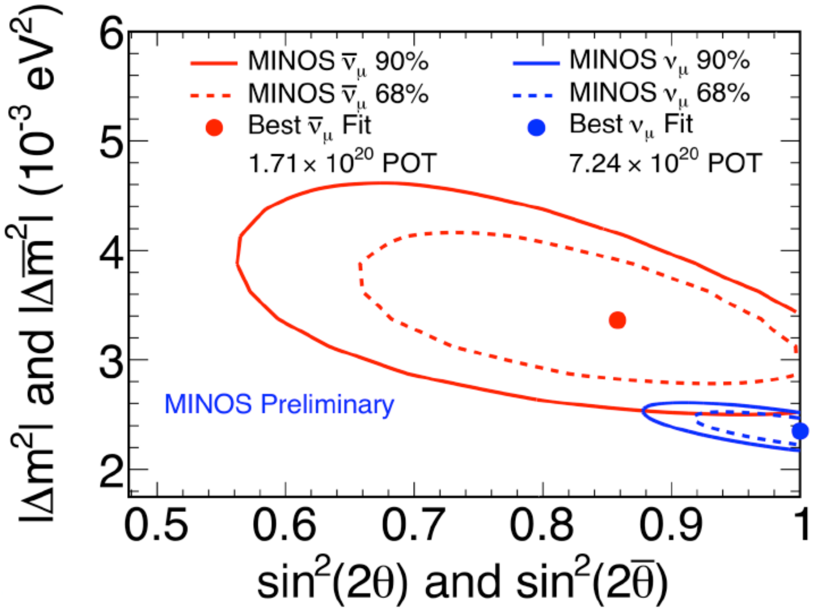
- Mainz & Troitsk reported measurements/limits on the "mass of the electron neutrino". That's like saying "the hole that the electron went through in the two slit experiment".
- An experiment at LEP looked at the kinematics for $\tau \to 3\pi\nu$ & $\tau \to 5\pi\nu$.

The event with the largest effective mass from pions puts an upper limit on the mass of the neutrino. This was reported as the mass of the ν_τ. It is actually an upper limit on the mass of the lightest neutrino.

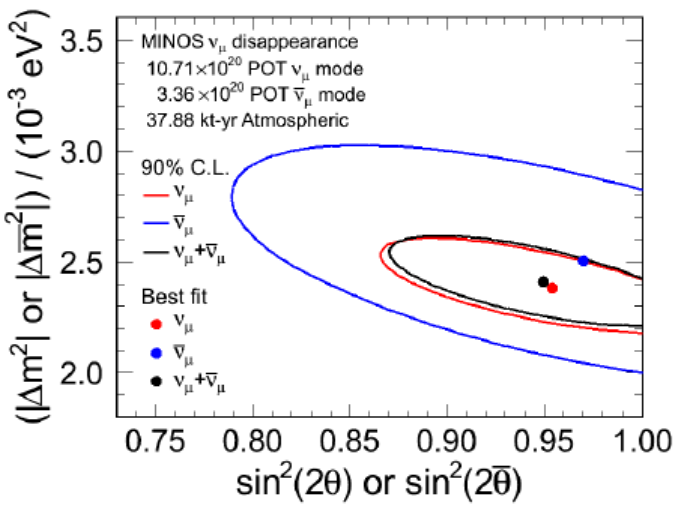
The right way to think of this was described in Shrock Physics Letters 96B p159 (1980). The language of the PDG's RPP was cleaned up in 2003. But some of the "limits" are wrong, though irrelevant.

MINOS anti-ν θ_{23}

MINOS analyzed nu and nubar separately and conducted a blind analysis for both of them. When the numbers looked different, MINOS invented an a-posteriori test and quoted the difference as 2% chance P or about 2.4 σ.
MINOS then got more nubar running and the discrepancy disappeared.



PRL 107 021801 2011



PRL 110 251801 2013

Other fleeting neutrino oscillation reports

- Bugey 2 detector 3 σ effect for $\sin^2 2\theta = 0.2$, $\Delta m^2 = 0.2$ eV^2,
  - reported at Neutrino 1984
- CERN PS191 was mentioned to me but I could only find published limits
- Two contradictory (different L/E) positive results from BNL involving low energy electron excesses in a ν_μ beam*
  - BNL 776 – 23 ν_e (17) seen compared to 13.1 expected
  - BNL 816 – 110 ν_e seen compared to 53 expected

Both reported at Neutrino 1988

*This led me to predict (orally), when MiniBooNE was proposed that their search for a signal of low energy electrons in a nm beam would probably be positive, since every neutrino experiment had an excess of low energy electrons. This also may be why Bob Bernstein said that if MiniBooNE refuted LSND, everyone would believe it, but if they confirmed LSND, nobody would believe it.

Exp 1 HPW "super" 3μ

- High energy multiple muons from E1A/E310 were called "super" events at FNAL seminars
- Never published?

TRIMUON EVENTS AND THEIR INTERPRETATION

David Cline
University of Wisconsin

Neutrino experiments have always been an important part of the Fermilab program. One of the earliest results of Fermilab research was the observation of neutral currents independently of and almost simultaneously with CERN. In 1974, the first dimuons were observed. This was the first indication of charm and was reported at the London conference that summer. By now, approximately 5000 dimuon events have been observed. They occur in approximately 1% of all neutrino interactions.

Trimuon events have been produced in both Fermilab counter neutrino experiments (see Fermilab Report, April, 1977), the Caltech-Fermilab-Rockefeller collaboration (E21), and the Fermilab-Harvard-Pennsylvania-Rutgers-Wisconsin collaboration (E310). The rate of trimuon events is small, approximately 10^{-4} of the total neutrino interaction rate, and approximately 50 trimuon events have now been observed in the counter experiments. It is to be expected that they will be observed soon in bubble-chamber experiments. Two four-muon event candidates have also been recorded in the E310 experiment.

ν grammar

A hyphen is sometimes omitted when talking about a short-baseline neutrino program or the Long-Baseline Neutrino Facility. I usually describe thr rule as follows:

If I do an experiment with a long baseline, long is an adjective and baseline is a noun. There is no ambiguity and no hyphen is needed. If I do a long-baseline neutrino experiment, or work on a short-baseline neutrino program, it is the baseline that is long or short and not the neutrino, the experiment or the program. The hyphen removes this ambiguity. In fact, a long-baseline experiment will likely take a long time, and be a long long-baseline neutrino experiment. And if Ken Long from Imperial College ever builds a neutrino factory, that will be Long's long long-baseline neutrino experiment.)

Karmen time anamoly

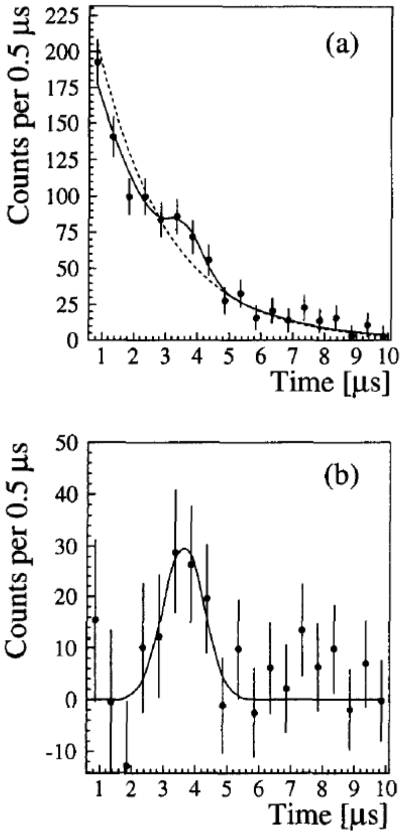


Fig. 3. (a) Distribution in time after beam-on-target of isolated events with visible energy E between 11 and 35 MeV after subtraction of cosmic background. The data are compared with χ^2-minimized fits for an exponential with a 2.2 μs time constant (dashed line) and an exponential with a 2.2 μs time constant on which is superimposed a Gaussian signal centered at 3.6 μs (solid line). (b) Time distribution of excess events left after subtraction of the exponential component with the 2.2 μs time constant, the solid line is the Gaussian signal with the parameters obtained from the χ^2-analysis of the time distribution shown in (a).

- Speculation of a slowly moving massive particle produced in the beam stop.
- β = 0.02
- 83 ± 28 events
- Phys. Lett. B348 19 1995.
- Ruled out at CERN by Daum et al
- Phys.Rev.Lett.85:1815-1818,2000
- J. Reichenbacher thesis showed that beam-correlated neutrons caused the time-anomaly.

Which neutrino is a particle?

ν_e, ν_μ and ν_τ are not particles. They are flavor eigenstates. Particles are solutions of Schrodinger's equation in free space.

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin =1/2

Flavor		Mass GeV/c^2	Electric charge
ν_L	lightest neutrino*	$(0-0.13)\times10^{-9}$	0
e	electron	0.000511	−1
ν_M	middle neutrino*	$(0.009-0.13)\times10^{-9}$	0
μ	muon	0.106	−1
ν_H	heaviest neutrino*	$(0.04-0.14)\times10^{-9}$	0
τ	tau	1.777	−1

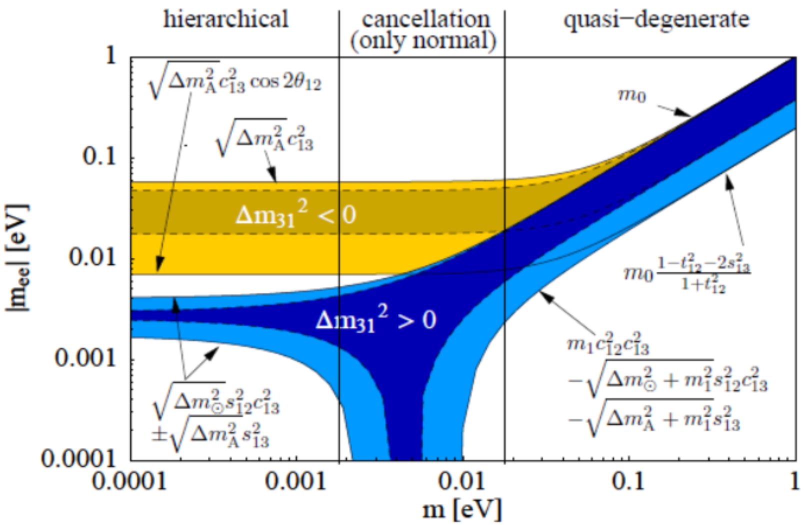
Quarks spin =1/2

Flavor		Approx. Mass GeV/c^2	Electric charge
u	up	0.002	2/3
d	down	0.005	−1/3
c	charm	1.3	2/3
s	strange	0.1	−1/3
t	top	173	2/3
b	bottom	4.2	−1/3

ν labels

Some people mistakenly always match θ_{12} with Δm^2_{12} , etc.

- θ_{12}, θ_{13}, θ_{23} are labels,
- Δm^2_{jk} are ordered (sign)



$$\Delta m^2_{12} \equiv m_1^2 - m_2^2$$
$$\Delta m^2_{21} \equiv m_2^2 - m_1^2$$
$$\Delta m^2_{13} \equiv m_1^2 - m_3^2$$
$$\Delta m^2_{31} \equiv m_3^2 - m_1^2$$
$$\Delta m^2_{23} \equiv m_2^2 - m_3^2$$
$$\Delta m^2_{32} \equiv m_3^2 - m_2^2$$

$$\Delta m^2_{21} + \Delta m^2_{32} + \Delta m^2_{13} = 0$$

SPT vs V-A

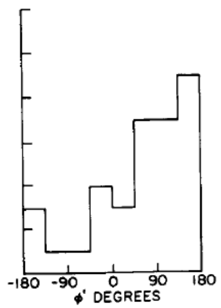
- S&T explanations of β decay of ^{6}He, BNL 1953, 1955
- There were also some early neutrino experiment results on <u>neutral currents</u> that didn't match expectations.
- (I was referred to some conference proceedings, but I couldn't find anything published.)
- These issues led to "Adler's Army" which was many postdocs at Princeton & elsewhere studying the possibility of SPT weak interactions in addition or instead of V-A.

e.g. PRD11, 1043 (1975)

& PRD10, 2216 (1974)

At first I thought this had something to do with <u>single pion CC data</u>, and I found:

with (2). However the distribution in φ' shows a 2.9 standard deviation asymmetry with respect to the $(\mu\nu)$ plane. Conservation of parity would require that this distribution be symmetric. Adler [6] has suggested that interference between the N_{33}^* and the non-resonant background could give rise to an effect of this nature.



(b)

Budagov et al., Phys. Lett. 29B p525 1969.

And other data that agreed better

P. Schreiner and F. von Hippel, PRL 30 p 339 1973

Majoron

AIP Conf. Proc. DPF meeting SLC UT, Jan 1987

Double Beta decay evidence for Majoron

Phys.Lett. B192 (1987) 460-462

Evidence against

Phys.Lett. B198 (1987) 253-254

Aregument against evidence against

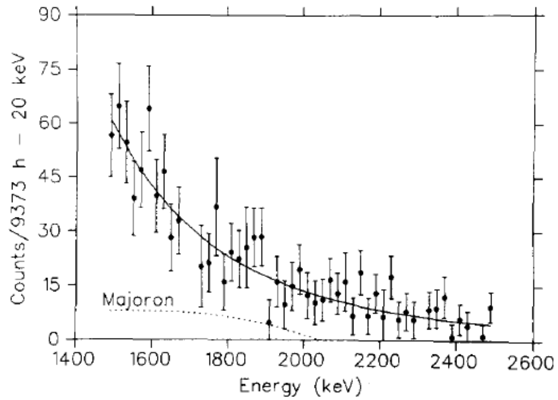


Fig. 2. Analysis of the data. The black points are those of fig. 1. The solid line is the best fit to the data points with a power law multiplied by a linear background function. The majoron spectrum for a lifetime of 6×10^{20} yr is shown by the dotted curve.

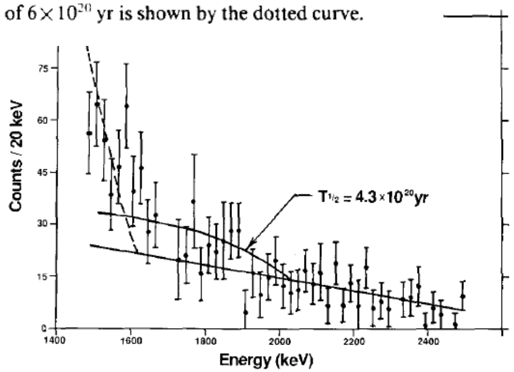


Fig. 1. The data points are those of ref. [4]. The solid lines represent the results of a maximum likelihood analysis assuming a straight line and theoretical spectrum from $0\nu\beta\beta$-decay with the emission of a majoron. The dashed curve represents the empirical shape of the spectrum due to the ^{60}Co in the copper shield.

BEBC beam dump

- A. De Rjula et al Nuclear Physics B168 (1980) 54—68

- Could be $\nu_e \rightarrow \nu_\tau$
- Not published?

(v) The recent CERN beam dump experiment [11]. The interpretation of their results in terms of neutrino oscillations is speculative (and possibly incorrect), so that we must give some details.

The experiment with the cleanest interpretation (and smallest statistics) is the BEBC bubble chamber experiment, where electrons can be directly observed. The experiments quote results for "prompt" events, from which the conventional neutrinos from π, K and μ decay are allegedly subtracted by extrapolation to an "infinite-density" target. The conventional interpretation of prompt neutrinos is that they originate almost exclusively from charmed particle decay. Barring unforeseen surprises, this implies the following relations between the fluxes of different neutrinos: $\phi(\nu_e) = \phi(\nu_\mu) \gg \phi(\nu_\tau)$ and $\phi(\bar{\nu}_e) = \phi(\bar{\nu}_\mu) \gg \phi(\bar{\nu}_\tau)$. The quoted ratio R of prompt-neutrino induced electrons and muons,

$$R = \frac{\text{no. of } (e^+ + e^-)}{\text{no. of } (\mu^+ + \mu^-)} = 0.59 \pm 0.22\,, \qquad (3.8)$$

is about two standard deviations below unity and may be an indication of ν_e oscillations. Since $\nu_\mu \to \nu_e, \nu_\tau$ oscillations seem to be absent ($P(\nu_\mu \to \nu_\mu) \sim 1$), a way to allow for $R \neq 1$ is to have $P(\nu_e \to \nu_e) < 1$.

Backup

MINOS Error calculations

	Description	Uncertainty (68% C.L.)
A	Distance between detectors	2 ns
B	ND Antenna fiber length	27 ns
C	ND electronics latencies	32 ns
D	FD Antenna fiber length	46 ns
E	FD electronics latencies	3 ns
F	GPS and transceivers	12 ns
G	Detector readout differences	9 ns
	Total (Sum in quadrature)	64 ns

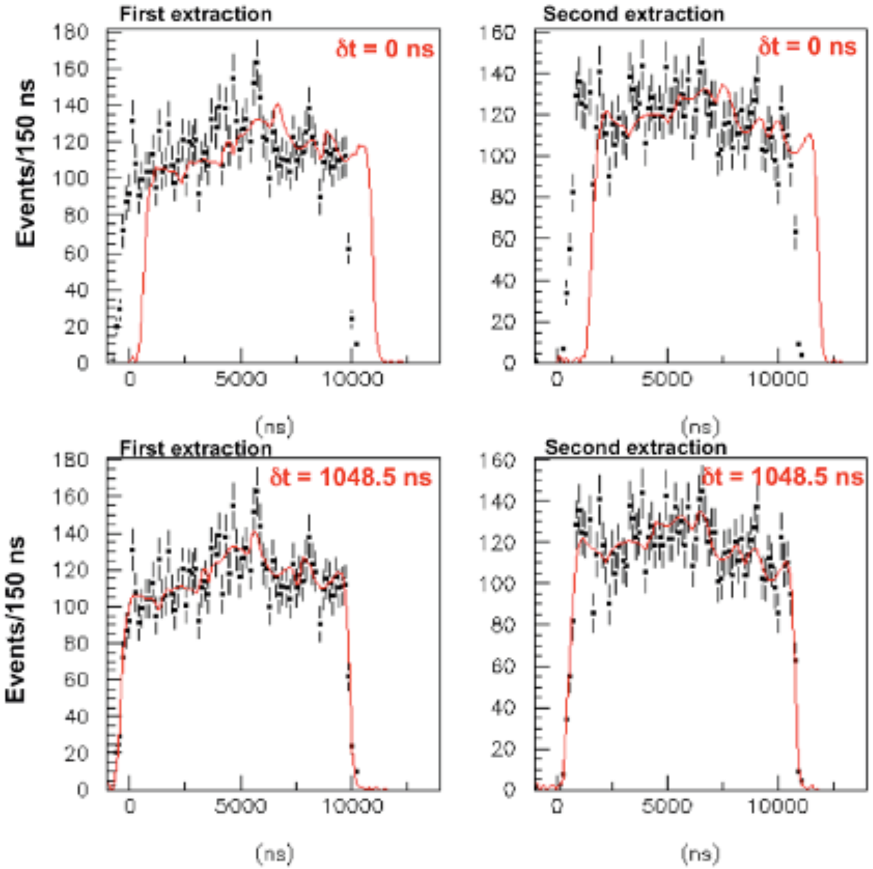
TABLE II: Sources of uncertainty in ν relative time measurement.

The arrival time distribution of neutrinos at the FD is similar, but the relative jitter of the two GPS clocks further degrades the time resolution. These clocks have a maximum error of ± 200 ns relative to UTC, with a typical error of 100 ns. The uncorrelated jitter of two clocks, in addition to detector time resolution, gives a total relative (FD/ND) time uncertainty of $\sigma = 150$ ns.

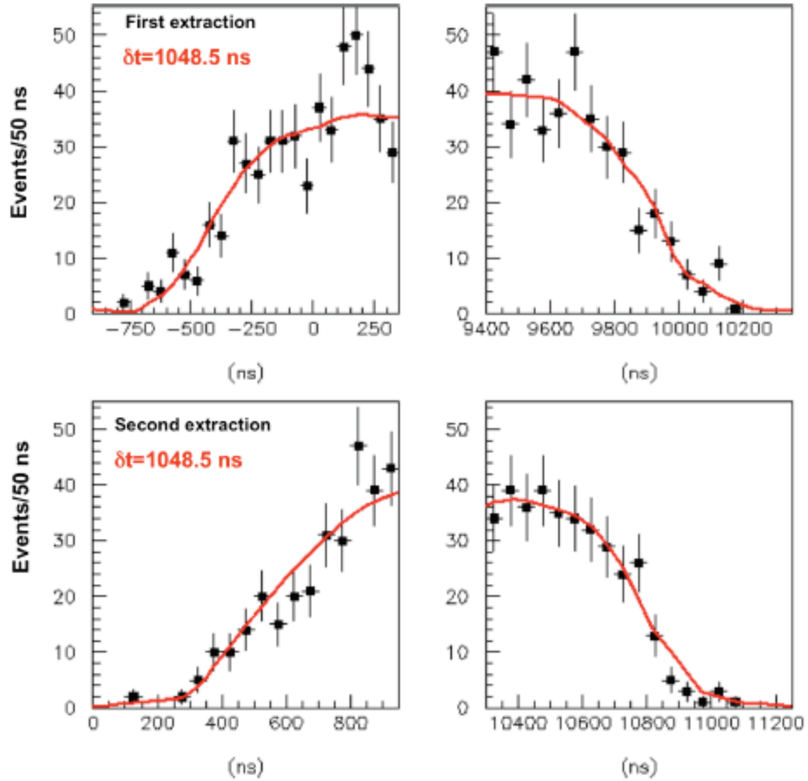
Baseline:	
Distance[a] ND to FD, L	734 298.6 $\pm$0.7 m [12]
Nominal time of flight, τ	2 449 356 $\pm$ 2 ns
MINOS Timing System:	
GPS Receivers	TrueTime model XL-AK
Antenna fiber delay	1115 ns ND, 5140 ns FD
Single Event Time Resolution	$<$40 ns
Random Clock Jitter	100 ns (typical), each site
Main Injector Parameters:	
Main Injector Cycle Time	2.2 seconds/spill (typical)
Main Injector Batches/Spill	5 or 6
Spill Duration	9.7 μs (6 batches)
Batch Duration	1582 ns
Gap Between Batches	38 ns

[a]Distance between front face of the ND and the center of the FD.

TABLE I: Relevant MINOS and NuMI Parameters



Comparison of the measured neutrino interaction time distributions (data points) and the proton PDF (red line) for the two SPS extractions before (top) and after (bottom) correcting for δt (blind) resulting from the maximum likelihood analysis.

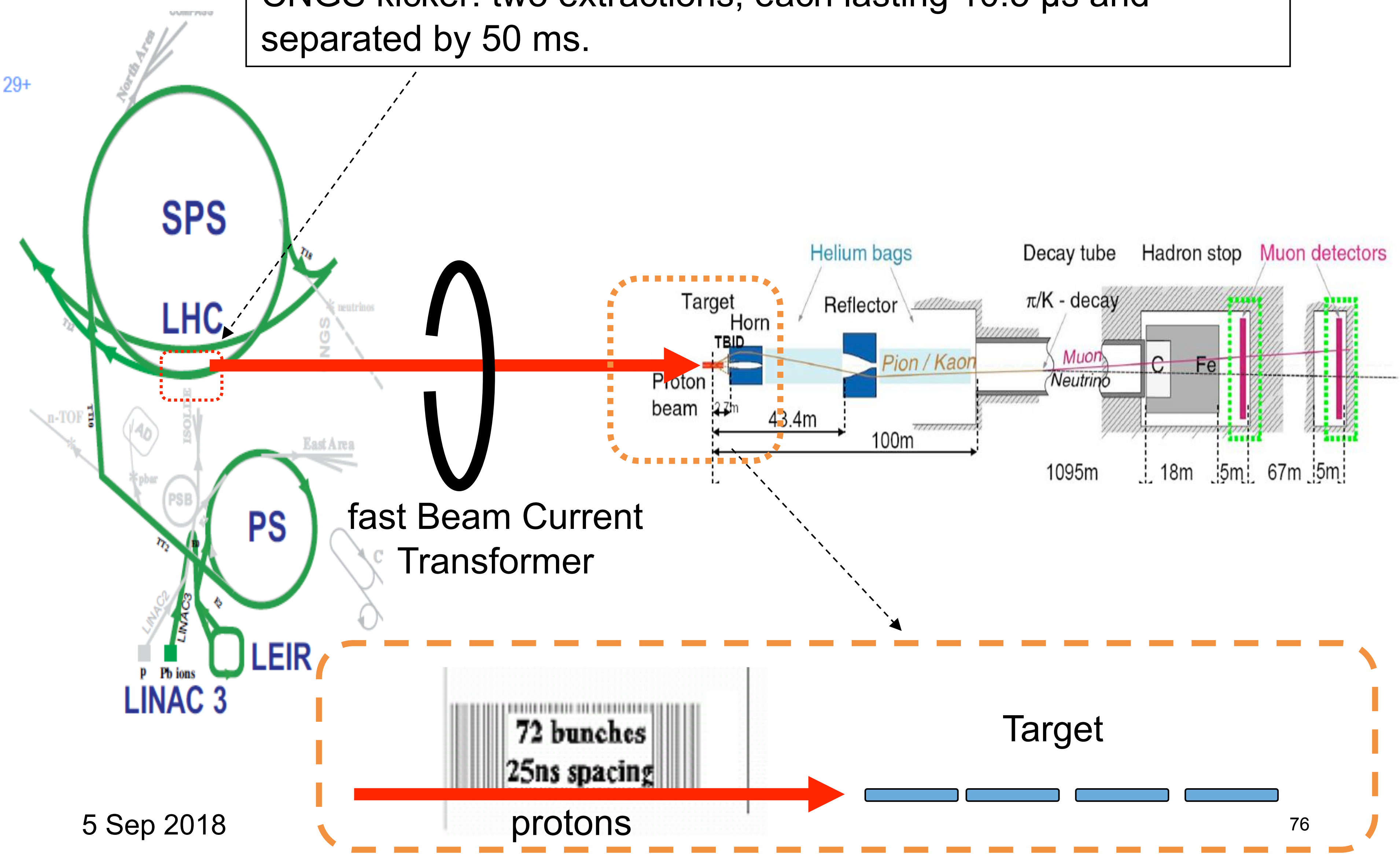


Zoom of the leading (left plots) and trailing edges (right plots) of the measured neutrino interaction time distributions (data points) and the proton PDF (red line) for the two SPS extractions after correcting for δt (blind).

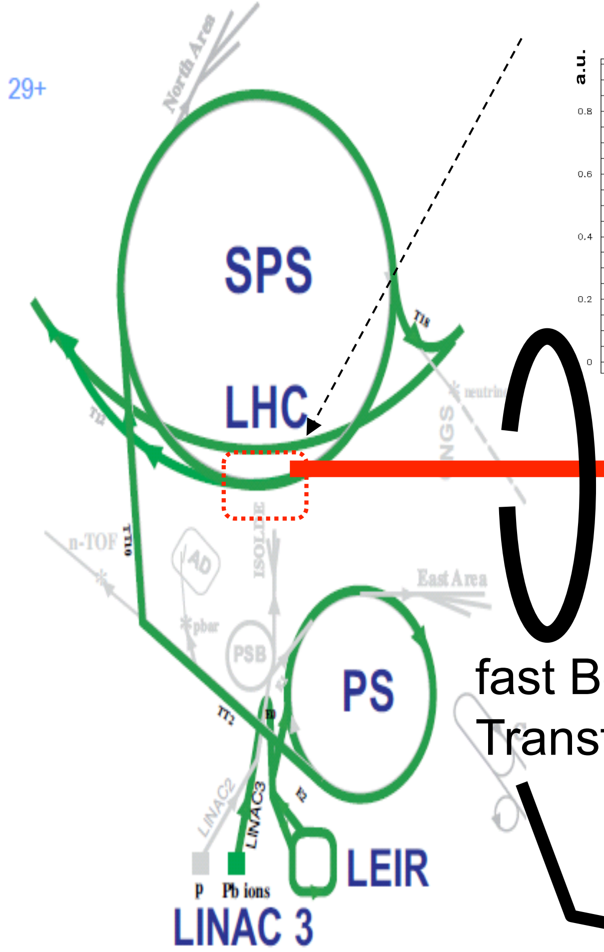
Systematic uncertainties	ns
Baseline (20 cm)	0.67
Decay point	0.2
Interaction point	2.0
UTC delay	2.0
LNGS fibres	1.0
DAQ clock transmission	1.0
FPGA calibration	1.0
FWD trigger delay	1
CNGS-OPERA GPS synchronisation	1.7
MC simulation for TT timing	3.0
TT time response	2.3
BCT calibration	5.0
Total sys. uncertainty (in quadrature)	**7.4**

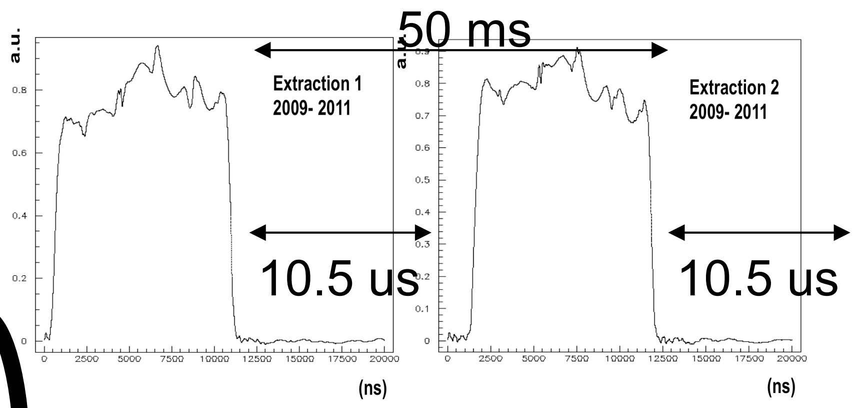
Kicker: extraction from ring to target

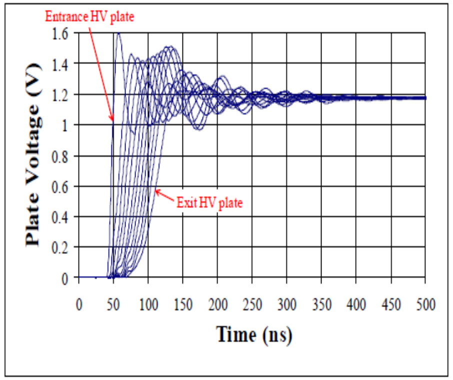
CNGS kicker: two extractions, each lasting 10.5 μs and separated by 50 ms.



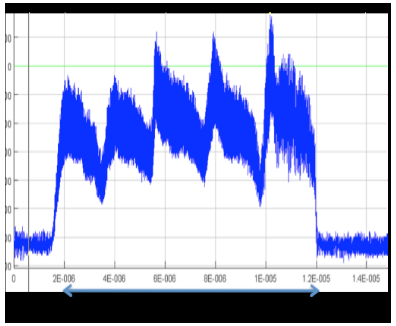
CNGS kicker: two extractions, each lasting 10.5 μs and separated by 50 ms.



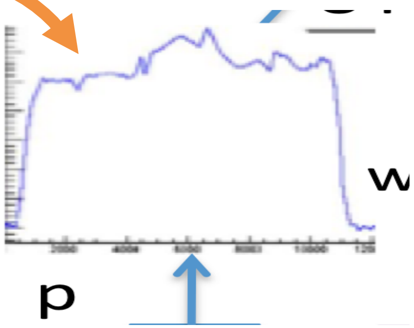




fast Beam Current Transformer



measured proton extraction with BCT



inferred probability density function (**PDF**) of the time of emission of the neutrinos within the duration of extraction.

Q: where did the ripples go?

The CNGS Beam