Neutrino mass (1)

cosmology, direct measurements

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Questions (1)

supernova, high energy neutrino

1. Why neutrinos release most of the supernova energy?
2. Why the detections of neutrino signal were a few hours before optical observation?
3. Is it possible to measure direction on a supernova with neutrino detectors? Which detector you would propose?
4. What are experimental goals to build large neutrino detectors?

1. Perché i neutrini rilascio la maggior parte dell'energia supernova?
2. Perché le rilevazioni di segnale di neutrini erano poche ore prima osservazione ottica?
3. E 'possibile misurare la direzione in una supernova con rivelatori di neutrini? Quale rilevatore si propone?
4. Quali sono gli obiettivi sperimentali per costruire rivelatori di neutrini di grandi dimensioni?

Questions (2)
high energy neutrino

1. Experimental principle of IceCube?
2. Which kind of irradiation is detected by the IceCube detector?
3. Advantages of high energy neutrino to study structure of the universe?

1. Principio sperimentale di IceCube?
2. Che tipo di radiazioni viene rilevato dal rivelatore IceCube?
3. Vantaggi di alta neutrino energia per studiare struttura dell'universo?

Questions (3)

detection of reactor neutrino

1. Why nuclear reactors were used to detect neutrino?
2. How reactor anti-neutrino is detected?
3. The time interval between two signals depends on?
4. What one expect to observe in a case of neutrino oscillations?
5. Why the early reactor oscillation experiments were carried out at short distance on reactors?

1. Perché i reattori nucleari sono stati usati per rilevare neutrino?
2. Come reattore antineutrino viene rilevato?
3. L'intervallo di tempo tra due segnali dipende?
4. Cosa si aspetta di osservare in un caso di oscillazioni dei neutrini?
5. Perché gli esperimenti di oscillazione primi reattori sono stati effettuati a breve distanza sulla reattori?

Questions (4)

detection of reactor neutrino oscillations

1. The main difference of KamLAND on the previous experiments?
2. Effect detected by the KamLAND experiment?
3. What is the main feature of the Daya Bay and RENO experiments?
4. Aims of the Daya Bay and RENO experiments?
5. Goal of the next generation reactor neutrino experiments?
6. Principle of sterile neutrino search?

1. La differenza principale KamLAND sugli esperimenti precedenti?
2. Effetto rilevato dall'esperimento KamLAND?
3. Qual è la caratteristica principale degli esperimenti Daya Bay e Reno?
4. Finalità degli esperimenti Daya Bay e Reno?
5. Obiettivo degli esperimenti reattore neutrini di nuova generazione?
6. Principio di Ricerca neutrino sterile?

Neutrino mass

approaches to estimate the absolute neutrino mass scale

Cosmology, Neutrinoless double β decay, Direct measurements

- The experiments with solar, atmospheric, reactor, and accelerator neutrinos have provided compelling evidences for flavour neutrino oscillations – transitions in flight between the different flavour neutrinos ν_e, ν_μ, ν_τ, caused by nonzero neutrino masses and neutrino mixing, when flavor neutrinos ν_{lL} are superposition of left handed massive neutrinos ν_{jL} with masses m_j :

$$\nu_{lL} = \sum_{j=1}^{n} U_{lj} \nu_{jL}$$

U is the unitary Pontecorvo-Maki-Nakagawa-Sakata mixing matrix, $l = e, \mu, \tau$

[1] S. Petcov, The nature of massive neutrinos, Advances in High Energy Physics (2013) 852987

[2] R. N. Mohapatra, Origin of neutrino masses and mixings, Nucl. Phys. 91 (2001) 313

[3] Alessandro Strumia, Francesco Vissani, Neutrino masses and mixings and... arXiv:hep-ph/0606054v3 2010

Neutrino mass

approaches to estimate the absolute neutrino mass scale [1]

Importance of the absolute neutrino mass measurements

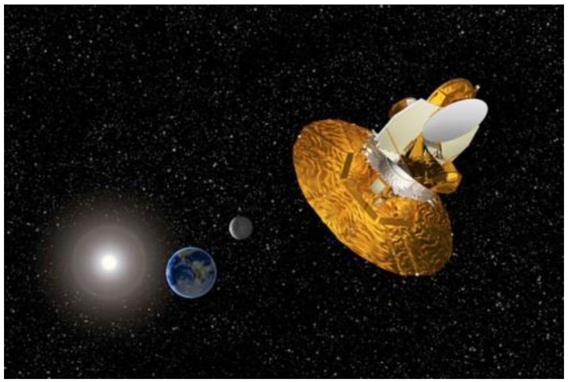
- The absolute value of the neutrino masses is very important for astrophysics and cosmology because of the role of neutrinos in structure formation due to the huge abundance of relic neutrinos left over in the universe from the big bang [2].
- In addition, the key role of neutrino masses in understanding, which of the possible extensions or new theories beyond the Standard Model of particle physics is the right one , makes the quest for the absolute value of the neutrino mass among of the most urgent questions of nuclear and particle physics.
- Three different approaches can lead to the absolute neutrino mass scale as follows: Cosmology, Neutrinoless double β decay, Direct measurements

[1] G. Drexlin et al., Current Direct Neutrino Mass Experiments, Advances in High Energy Physics (2013) 293986
[2] J. Lesgourgues, S. Pastor, Neutrino mass from cosmology, Advances in High Energy Physics (2012) 608515

Neutrino mass

approaches to estimate the absolute neutrino mass scale

Cosmology: fluctuations of the early universe density from cosmic microwave background



WMAP spacecraft

PLANCK spacecraft

Measurements of differences in the temperature of the cosmic microwave background (CMB) – the radiant heat remaining from the Big Bang – across the sky

The early fluctuations of universe density imprinted on the cosmic microwave background measured with the WMAP satellite

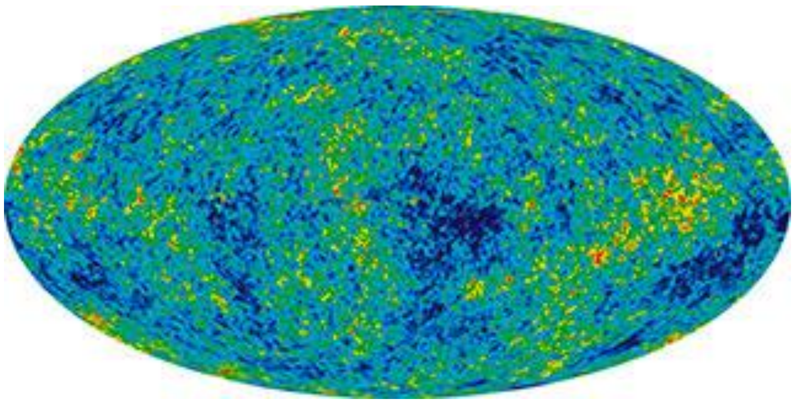
The Planck apparatus shows agreement with the WMAP results on the density and distribution of matter in the Universe.

http://map.gsfc.nasa.gov
http://www.esa.int/Our_Activities/Space_Science/Planck

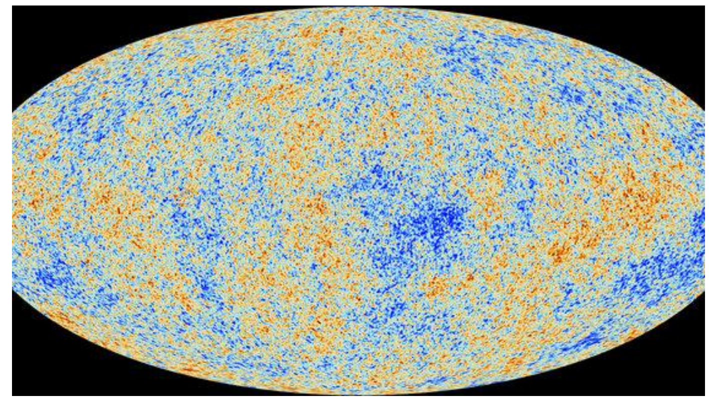
Neutrino mass

approaches to estimate the absolute neutrino mass scale

Cosmology: fluctuations of the early universe density from cosmic microwave background



WMAP's maps the afterglow of the hot, young universe when it was only 375,000 years old



Planck's map of the young universe

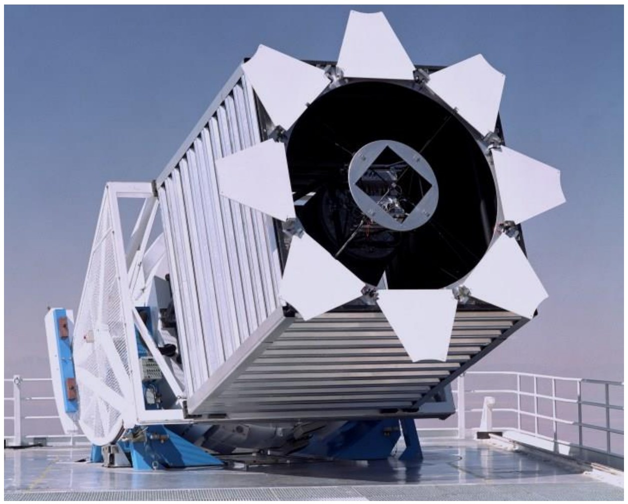
The visible structure of the universe has been formed out by fluctuations at the very early stage. Due to the large abundance of relic neutrinos and their low masses they acted as hot dark matter: neutrinos have smeared out fluctuations at small scales.

E. Komatsu et al., Seven-YearWilkinson Microwave Anisotropy Probe (WMAP) observations: cosmological interpretation, Astrophysical Journal Supplement 192 (2011) 18

Neutrino mass

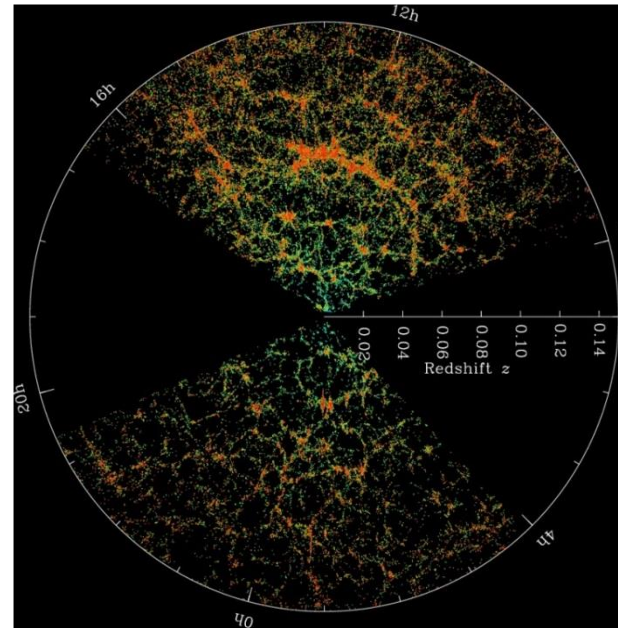
approaches to estimate the absolute neutrino mass scale

Cosmology: mapping out today's structure of the universe by large galaxy surveys



The Sloan Foundation 2.5m Telescope at Apache Point Observatory

The SDSS map of the Universe. Each dot is a galaxy; the color bar shows the local density



- SDSS is a multi-filter imaging and spectroscopic redshift survey using a dedicated 2.5-m wide-angle optical telescope at Apache Point Observatory in New Mexico, United States.

http://www.sdss.org/science/

Neutrino mass: cosmology estimations

the SDSS map of the large-scale structure of the universe

- The Sloan Digital Sky Survey has been working for more than 15 years to make the most detailed three-dimensional maps of the Universe, with deep multi-color images of one third of the sky, and spectra for more than three million astronomical objects.

http://www.sdss.org/science/

Neutrino mass

approaches to estimate the absolute neutrino mass scale

Cosmology: limit on the sum of the neutrino masses

By determining the early fluctuations imprinted on the cosmic microwave background with the WMAP and Planck satellites, and mapping out today's structure of the universe by large galaxy surveys, upper limits on the sum of the neutrino masses $\Sigma m(\nu_i)$ (total mass) can be derived.

$\Sigma m(\nu_i)$, eV	Data and Analysis	Ref.
< 0.39	Planck CMB data combined with galaxy clustering from SDSS-III (Baryon Oscillation Spectroscopic Survey)	[1]
< 0.24	Observational Hubble parameter data with 7-year WMAP data and the most recent estimate of H_0 (Hubble constant)	[2]
< 0.60	WiggleZ Dark Energy Survey high redshift galaxy sample when combined with 7-year WMAP data	[3]
< (0.2 – 1.3)	Cosmological and astrophysical measurements (review)	[4]

The limits are to some extent model and analysis dependent.

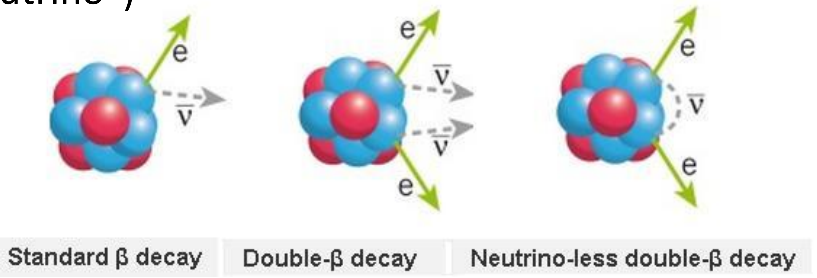
[1] E. Guisarma et al., Constraints on neutrino masses from Planck and Galaxy clustering data, Phys. Rev. D 88 (2013) 063515
[2] Moresco et al., New constraints on cosmological parameters and neutrino properties using the expansion rate of the Universe to z ~ 1.75 J Cosmology and Astropart.Phys. 53 (2012) 1207
[3] S. Riemer–Sørensen et al., WiggleZ Dark Energy Survey: Cosmological neutrino mass constraint from blue high-redshift galaxies, Phys. Rev. D 85 (2012) 081101
[4] K.N. Abazajian et al., Cosmological and astrophysical neutrino mass measurements, *Astropart. Phys.*. 35 (2011) 177

Neutrino mass

approaches to estimate the absolute neutrino mass scale

Neutrinoless double β decay

0ν2β decay could exist if the neutrino is its own antiparticle (“Majorana-neutrino” in contrast to “Dirac-neutrino”)



effective Majorana mass of neutrino $\langle m_\nu \rangle = |\Sigma U_{ej}^2 m_j|$ can be estimated by measuring the 0ν2β decay half-life $T_{1/2}^{0\nu 2\beta}$

$$(T_{1/2}^{0\nu 2\beta})^{-1} = G^{0\nu}(Q_{2\beta}, Z)\left|M^{0\nu}\right|^2 \left\langle m_\nu \right\rangle^2$$

where $G^{0\nu}(Q_{2\beta}, Z)$ is the phase space integral, $M^{0\nu}$ is the nuclear matrix element

The most sensitive 0ν2β experiments give upper limit $\langle m_\nu \rangle$ < (0.2 – 1) eV

The estimations depend on the nuclear matrix elements calculations

J.D. Vergados, H. Ejiri, F. Šimkovic, Theory of neutrinoless double-beta decay, Rep. Prog. Phys. 75 (2012) 106301
A. Giuliani and A. Poves, Neutrinoless double-beta decay, *Adv. High Energy Phys. (*2012) 857016

Neutrino mass

Direct neutrino mass determination

Principles of direct neutrino mass determination

The direct neutrino mass determination is based purely on kinematics without further assumptions. Essentially, the neutrino mass is determined by using the relativistic energy-momentum relationship $E^2 = p^2 + m^2$. Therefore it is sensitive to the neutrino mass squared $m^2(\nu)$.

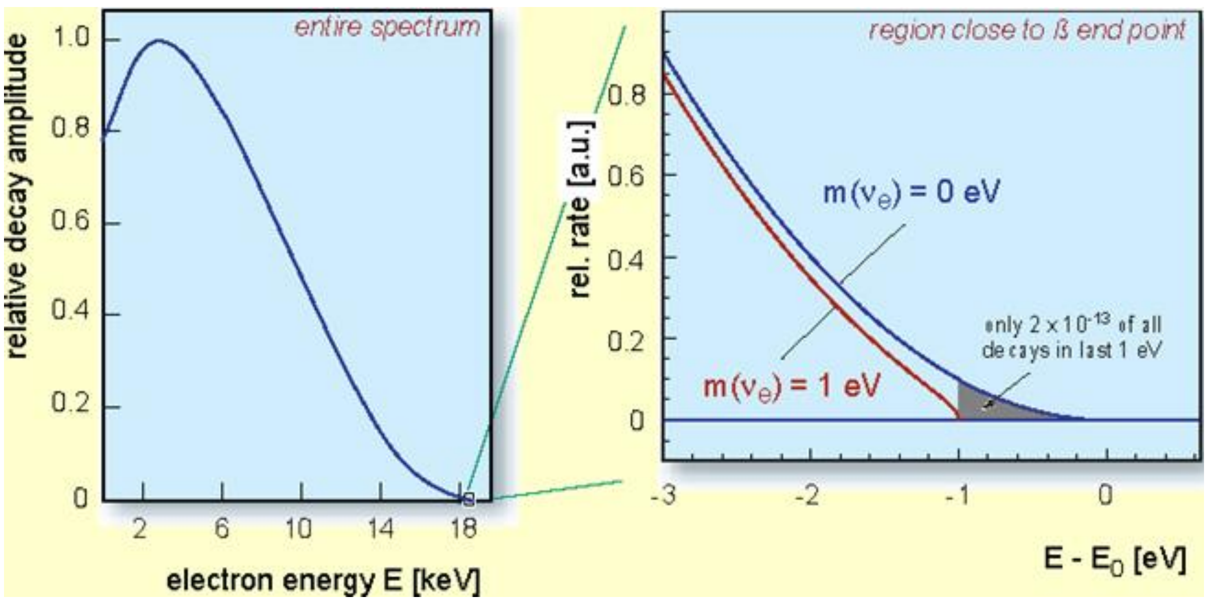
The average electron neutrino mass $m(\nu_e)^2$ can be obtained from investigation of the endpoint region of a β-decay spectrum (or an electron capture):

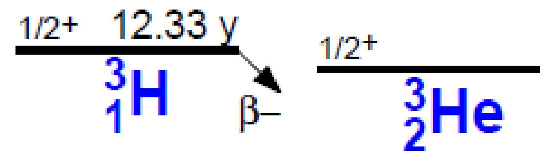
$$m(\nu_e)^2 = \sum \left|U_{ei}^2\right| m(\nu_i)^2$$

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay





Q_β = 18.590 keV

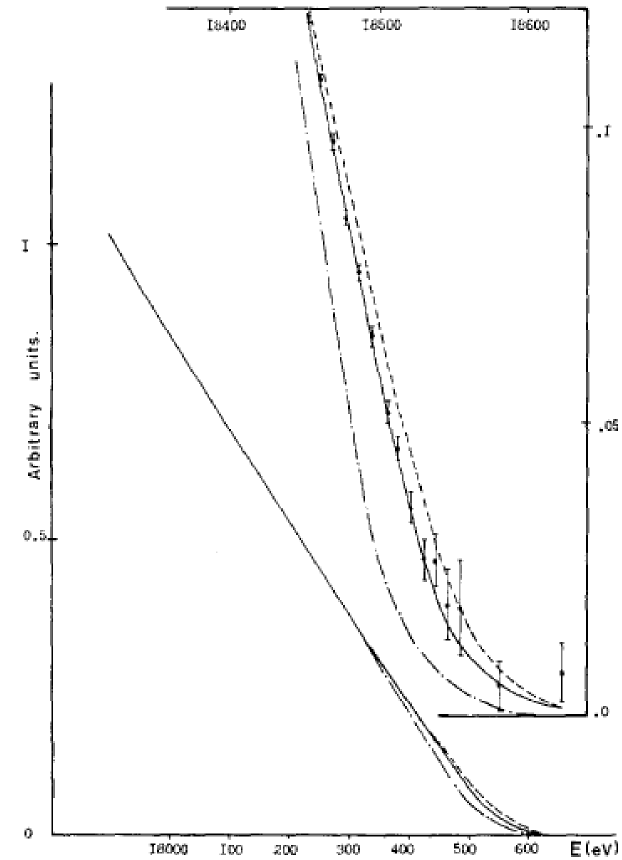
Expanded β-spectrum of an allowed or superallowed β-decay around its endpoint E_0 for $m(\nu_e)$ = 0 (red line) and for an arbitrarily chosen neutrino mass of 1 eV (blue line). In the case of tritium, the gray-shaded area corresponds to a fraction of 2×10^{-13} of all tritium β-decays.

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: evidence for a non-zero neutrino mass

- The high energy part of the β-spectrum of tritium in the valine molecule ($C_5H_{11}NO_2$) was measured with a high precision by a toroidal β-spectrometer.
- The thickness of the source was ≈ 2/μg/cm^2 of valine.
- Energy resolution FWHM ≈ 45 eV at the end of the tritium β -spectrum.
- The results give evidence for a non-zero electron antineutrino mass [1].



[1] V. A. Lubimov et al., An estimate of the νe mass from the β-spectrum of tritium in the valine molecule, *Phys. Lett. B* 94 (1980) 266

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: early Troitsk experiment: neutrino mass ~30 eV

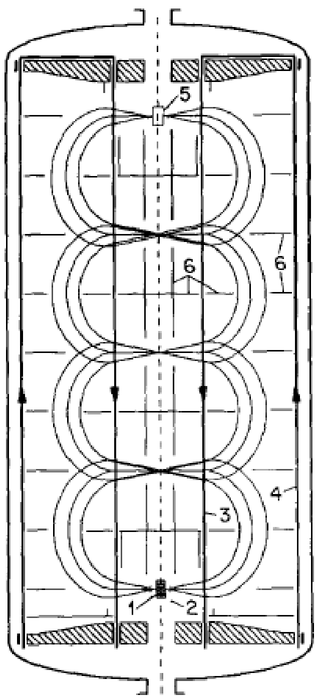
The data from the spectrum measurement of the tritium decay in a valine molecule carried out in a wide energy range (3.4 keV) with the Institute of Theoretical and Experimental Physics spectrometer are analyzed. The combined analysis of both these data and the data of the previous cycle gives the neutrino mass 30.3^{+2}_{-8} eV.

S. Boris et al., Neutrino mass from the beta spectrum in the decay of tritium, *Phys. Rev. Lett.* 58 (1987) 2019

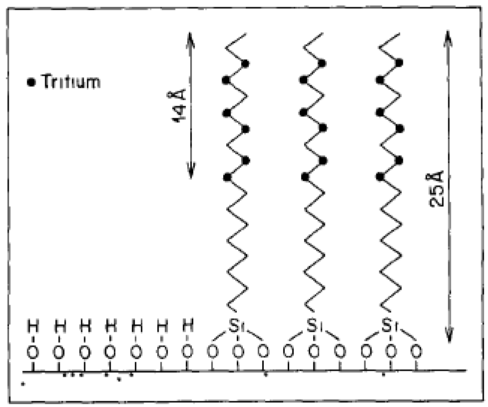
Neutrino mass

Direct neutrino mass determination

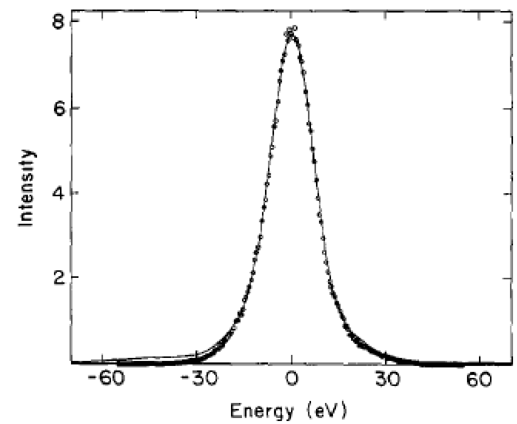
Neutrino mass from tritium β-decay: early experiments: Zurich, no evidence of ν mass



Cross section of the spectrometer (source 1, grid 2, current wires 3, 4, detector 5, battles 6)
Distance between source and detector is 2.65 m



Model of the tritium source (right) and the surface before monolayer coverage (left)



Spectrometer resolution function as measured (solid line) and as calculated by Monte Carlo simulation (points). FWHM = 17 eV

E. Holzschuh, M. Fritschi, and W. Kundig, Measurement of the electron neutrino mass from tritium β-decay, *Physics Letters B* 287 (1992) 381

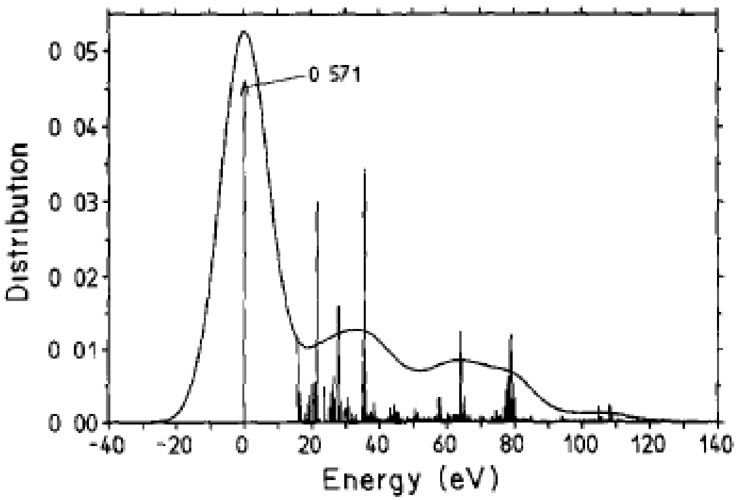
Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: early experiments: Zurich, no evidence of ν mass

Disadvantage of solid source (e.g., tritiated hydrocarbon molecules):

- energy losses due to certain thickness of the source
- need to take into account the the electromc final states of the molecules containing tritium



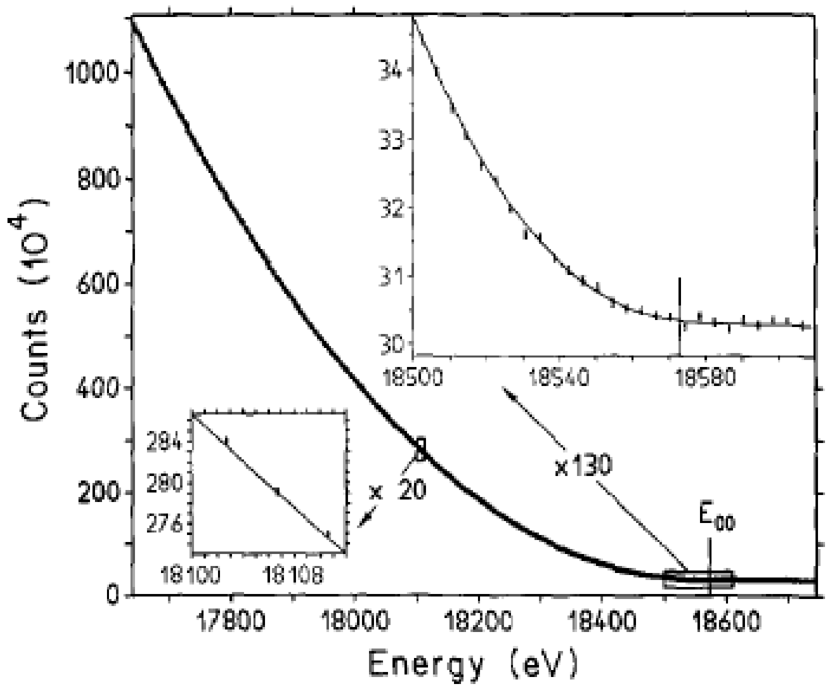
Distribution of electronic final states for CH_3-CHT-CH_3 used for the analysis. The solid line is the same distribution convoluted with a gaussian with 17 eV FWHM (approximately the spectrometer resolution). The complicated response function of the spectrometer make difficulties to analyze final spectra.

E. Holzschuh, M. Fritschi, and W. Kundig, Measurement of the electron neutrino mass from tritium β-decay, *Physics Letters B* 287 (1992) 381

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: early experiments: Zurich, no evidence of ν mass



Measured tritium spectrum from all data (points) and best fit (solid line). For E $\geq$ 18 500 eV actual counts are plotted. For lower energies the data were scaled by the counting periods Insets show parts with the vertical scale expanded by the indicated factor.

No indication of a nonzero mass my of the electron antineutrino was found. The result is m_ν^2 = -24 $\pm$ 48 $\pm$ 61 eV^2. An upper limit m_ν < 11 eV (95% confidence level) was derived.

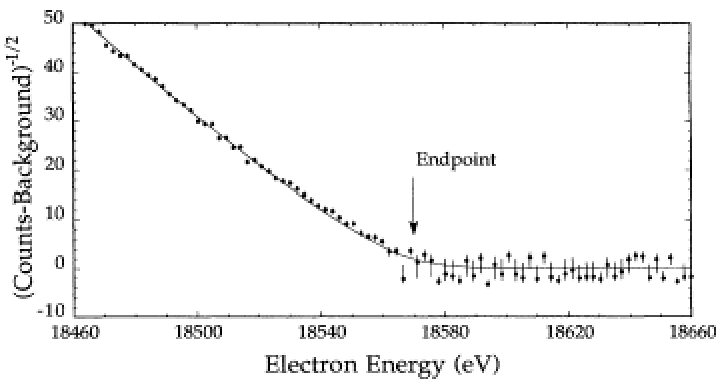
E. Holzschuh, M. Fritschi, and W. Kundig, Measurement of the electron neutrino mass from tritium β-decay, *Physics Letters B* 287 (1992) 381

Neutrino mass

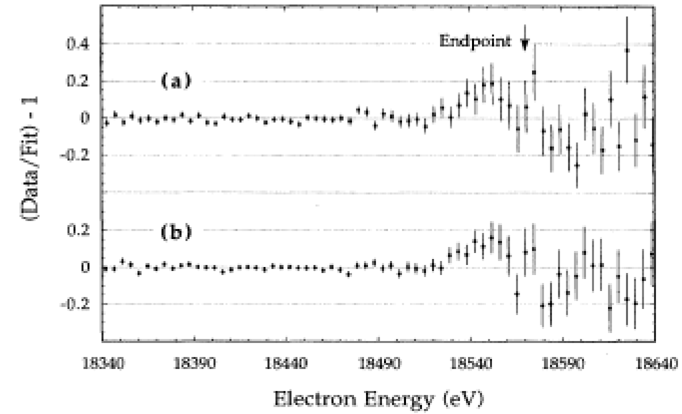
Direct neutrino mass determination

Neutrino mass from tritium β-decay: Livermore: gaseous tritium source

Windowless gaseous source of molecular tritium and a high resolution toroidal field magnetic spectrometer.



The Kurie plot of the end point region for molecular tritium. The solid curve is a fit to the data of run (b) with zero neutrino mass. The subtracted background is 26 counts/channel.



The ratio of the data to the fit functions for two runs (a) and (b) which had different spectrometer settings. **The anomalous structure in the beta decay spectrum in the last 55 eV closest to the end point causes the negative value for square of the neutrino mass.**

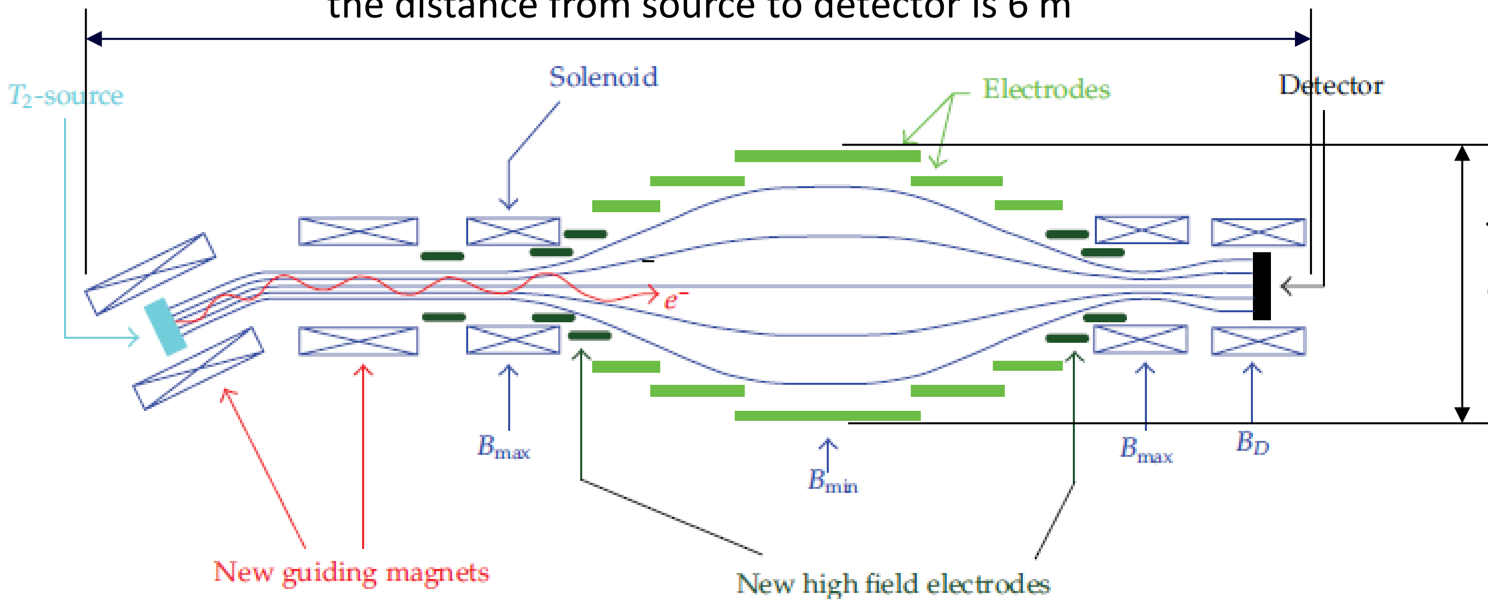
W. Stoeffl and D.J. Decman, Anomalous structure in the β decay of gaseous molecular tritium, *Physical Review Letters* 75 (1995) 3237

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: Mainz experiment

the distance from source to detector is 6 m



the outer diameter is 1m

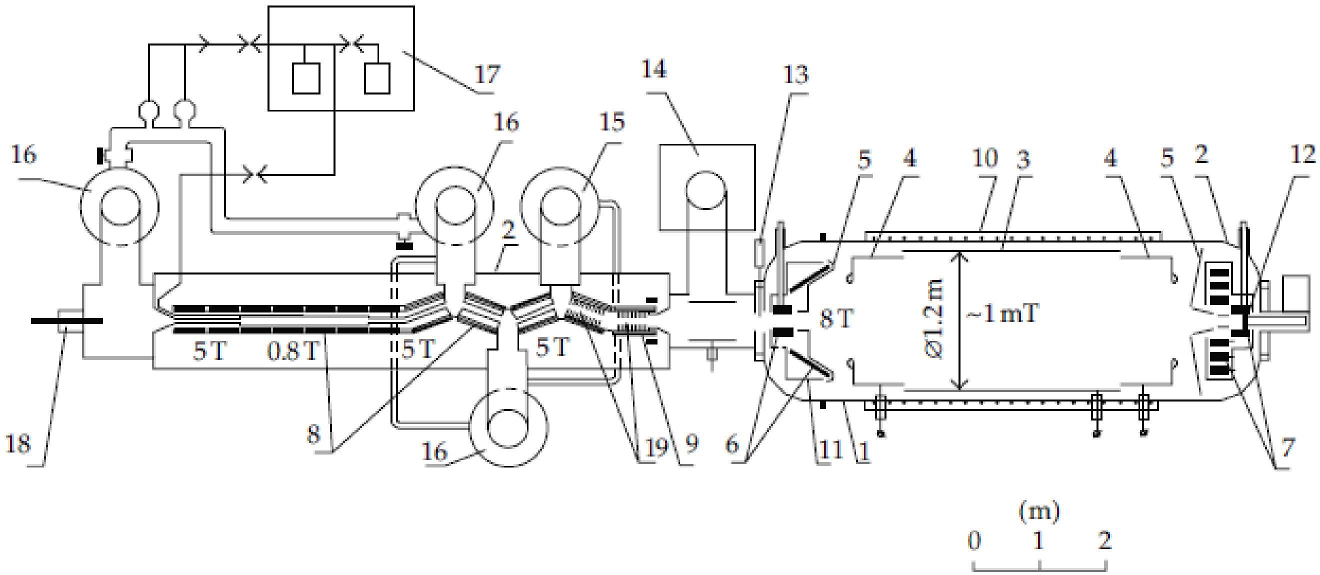
The upgraded Mainz setup shown schematically.

C. Kraus et al., Final results from phase II of the Mainz neutrino mass search in tritium β decay, Eur. Phys. J C 40 (2005) 447.

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: Troitsk experiments



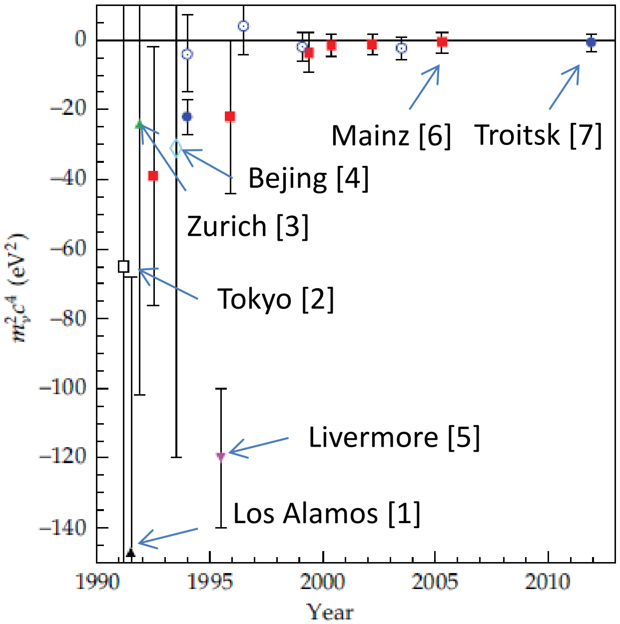
The TroitskNeutrinoMass Experiment: vacuumvessel ofMAC-E-Filter (1) and ofwindowless gaseous tritiumsource (2), retarding electrodes (3, 4), ground electrode (5), superconducting solenoids (6–9), warm solenoid (10), LN2 shield (11), Si(Li) detector (12), emergency valve (13),magnetodischarge pump (14),mercury diffusion pumps (15-16) tritium purification system(17), electron gun (18), and argon trap (19).

[7] V. N. Aseev et al., Upper limit on the electron antineutrino mass from the Troitsk experiment, Phys. Rev. D 84 (2011) 112003

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: early experiments



Results of tritium β-decay experiments on the observable $m^2(\nu_e)$.The experiments at Los Alamos, Zurich, Tokyo, Beijing, and Livermore used magnetic spectrometers; the tritium experiments at Mainz [1] and Troitsk [2] applied electrostatic spectrometers of the MAC-E-Filter type.

[1] R.G.H. Robertson et al., Limit on anti-ν_e mass from the observation of the β decay of molecular tritium, *PRL.* 67 (1991) 957

[2] H. Kawakami et al., "New upper bound on the electron anti-neutrino mass," *PLB* 256 (1991) 105

[3] E. Holzschuh et al., Measurement of the electron neutrino mass from tritium β-decay, *PLB* 287 (1992) 381

[4] C. R.Ching et al., Apossible explanation of the negative values of $m^2\nu_e$ obtained from the β spectrum shape analyses, *Int. J Mod. Phys. A* 10 (1995) 2841

[5] W. Stoeffl and D.J. Decman, Anomalous structure in the β decay of gaseous molecular tritium, *PRL* 75 (1995) 3237

[6] C. Kraus et al., Final results from phase II of the Mainz neutrino mass search in tritium β decay, Eur. Phys. J C 40 (2005) 447.

[7] V. N. Aseev et al., Upper limit on the electron antineutrino mass from the Troitsk experiment, Phys. Rev. D 84 (2011) 112003

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: explanation of negative values for $m^2(\nu_e)$

The negative values of $m^2(\nu_e)$ have no physical meaning. The main reasons:

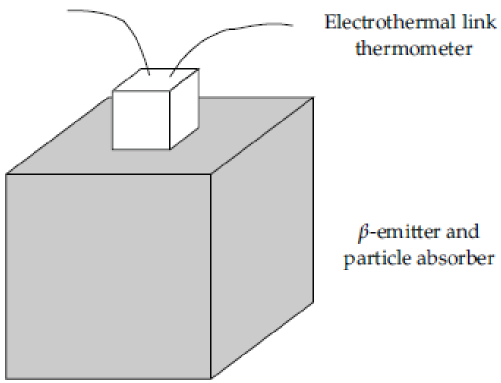
Some experiments (also Mainz) used as tritium source a film of molecular tritium quench condensed onto aluminum or graphite substrates. Although the film was prepared as a homogenous thin film with flat surface, detailed studies showed that the film was not stable: it underwent a temperature-activated roughening transition into an inhomogeneous film by forming microcrystals. Thus, unexpected large inelastic scattering probabilities were obtained, which were not taken into account in previous analyses. This extra energy losses were only significant when analyzing larger energy intervals below the endpoint.

The presence of a missed experimental broadening with Gaussian width σ one expects a shift of the result on $m^2(\nu_e)$ of $\Delta m^2(\nu_e) \approx -2 \cdot \sigma^2$, which gives rise to a negative value of $m^2(\nu_e)$

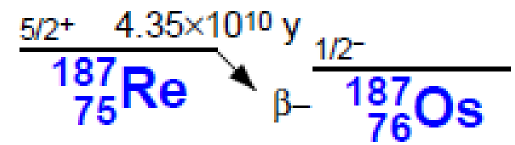
Neutrino mass

Direct neutrino mass determination: cryobolometers

Measurements of ^{187}Re β-spectrum



Scheme of a cryobolometer for direct neutrino mass measurements consisting of a ^{187}Re β-emitting crystal. The crystal serves at the same time as the particle and energy absorber.



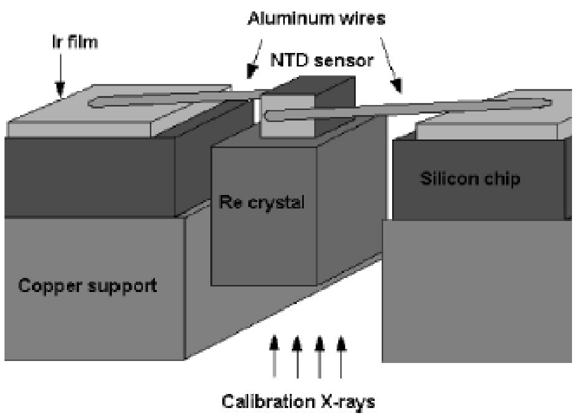
Q_β = 2.469 keV

The advantage of this approach is that many systematic uncertainties—like the electronic final state spectrum, energy losses by inelastic scattering, and so forth—drop out in first order, since all released energy except that of the neutrino is measured in the same way and summed up automatically (we assume that all deexcitation processes are faster than the integration time of a detector signal).

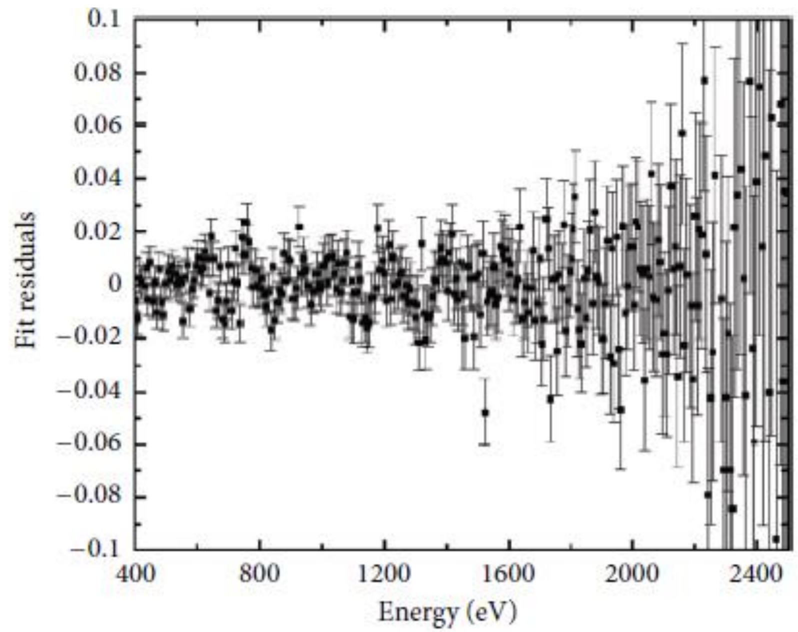
Neutrino mass

Direct neutrino mass determination: Cryobolometers

Measurements of ^{187}Re β-spectrum



The MANU experiment used a single metallic rhenium crystal of about 1.6 mg as absorber read out by a neutron transmutation doped (NTD) germanium thermistor



The residuals of the theoretically expected ^{187}Re β-spectrum that has been fitted to the data collected by the MANU experiment exhibit effects of a β-environmental fine structure (BEFS) modulation most clearly visible at low electron energies

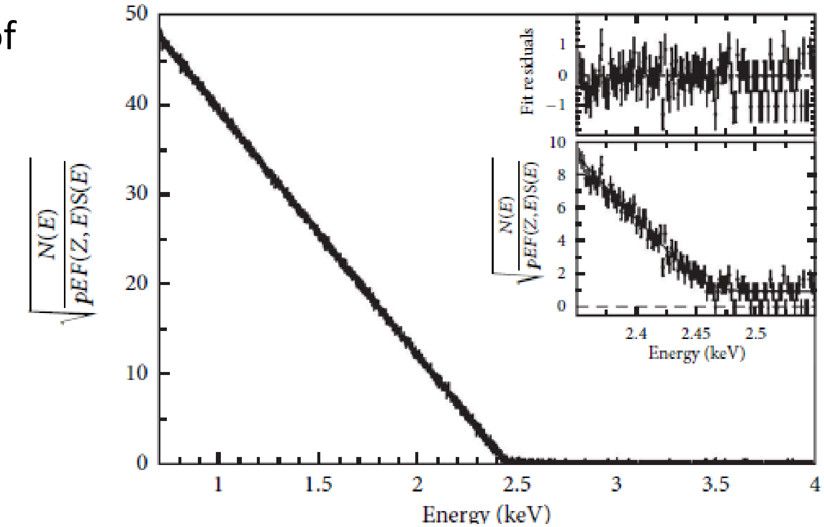
M. Galeazzi et al., End-point energy and half-life of the ^{187}Re β decay, *Physical Review C* 63 (2001) 143021

Neutrino mass

Direct neutrino mass determination

Cryobolometers: MiBeta

The experiment has been carried out with an array of eight $AgReO_4$ thermal detectors operating at a temperature of 100 mK [1]



Kurie plot of the experimental ^{187}Re β-spectrum obtained by the MiBeta collaboration [2]

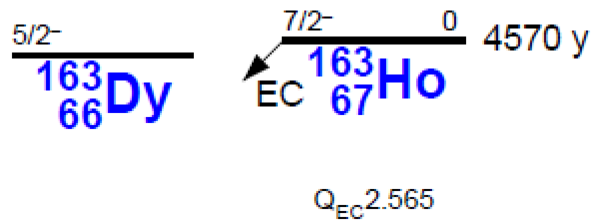
An average energy resolution of 28.5 eV FWHM was achieved. The analysis of the spectrum near the endpoint resulted in an upper limit $m(\nu_e)$ < 15 eV at 90% CL [2]

[1] C. Arnaboldi et al., Measurement of the p to s wave branching ratio of ^{187}Re β decay from beta environmental fine structure, Phys. Rev. Lett. 96 (2006) 042503
[2] M. Sisti et al., New limits from the Milano neutrino mass experiment with thermal microcalorimeters, *Nucl. Instr. Meth. A* 520 (2004) 125

Neutrino mass

Direct neutrino mass determination

Cryobolometers: electron capture (EC) decays of ^{163}Ho



A promising alternative to β-decay measurements is the study of electron capture (EC) decays of ^{163}Ho to measure the neutrino mass. The decay process considered is

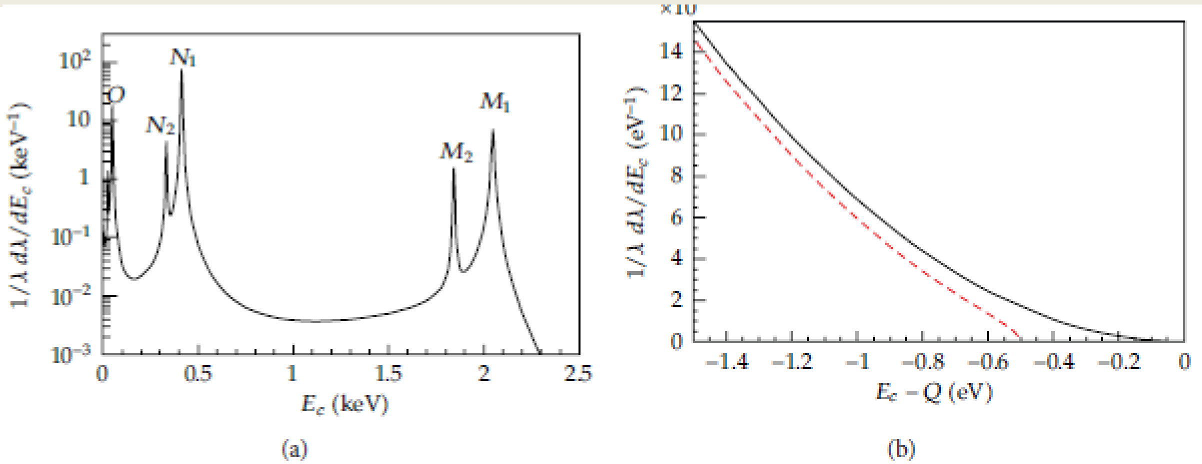
$$^{163}\mathrm{Ho}^{+} + e^{-} \rightarrow {}^{163}\mathrm{Dy}^{*}{}_{i} + \nu_e \rightarrow {}^{163}\mathrm{Dy} + E_i + \nu_e$$

The deexcitation spectrum of the intermediate state $^{163}\mathrm{Dy}^{*}{}_{i}$ is given by a series of lines at energies E_i which correspond
to the dissipated binding energy of the electron hole in the
final atom. The Q-value of the reaction is given by the mass
difference of mother and daughter nucleus in the ground state. Like the electron energy spectrum in β-decay s this
spectrum depends on the square of the neutrino mass.
The use of ^{163}Ho is favored due to its very low Q-Value in the range of 2.3 keV to 2.8 keV

Neutrino mass

Direct neutrino mass determination

Cryobolometers: electron capture (EC) decays of ^{163}Ho



Deexcitation spectrum of ^{163}Ho for Q = 2.5 keV (a). (b) shows a zoom into the endpoint region of the spectrum with the effect of a 0.5 eV neutrino mass indicated by the red dashed line

By the investigation of the electron capture of ^{163}Ho two upper limits on the average mass of the electron neutrino $m(\nu_e) < 225$ eV at 95% C.L. [1] and of $m(\nu_e) < 490$ eV at 68% C.L. [2] were set.

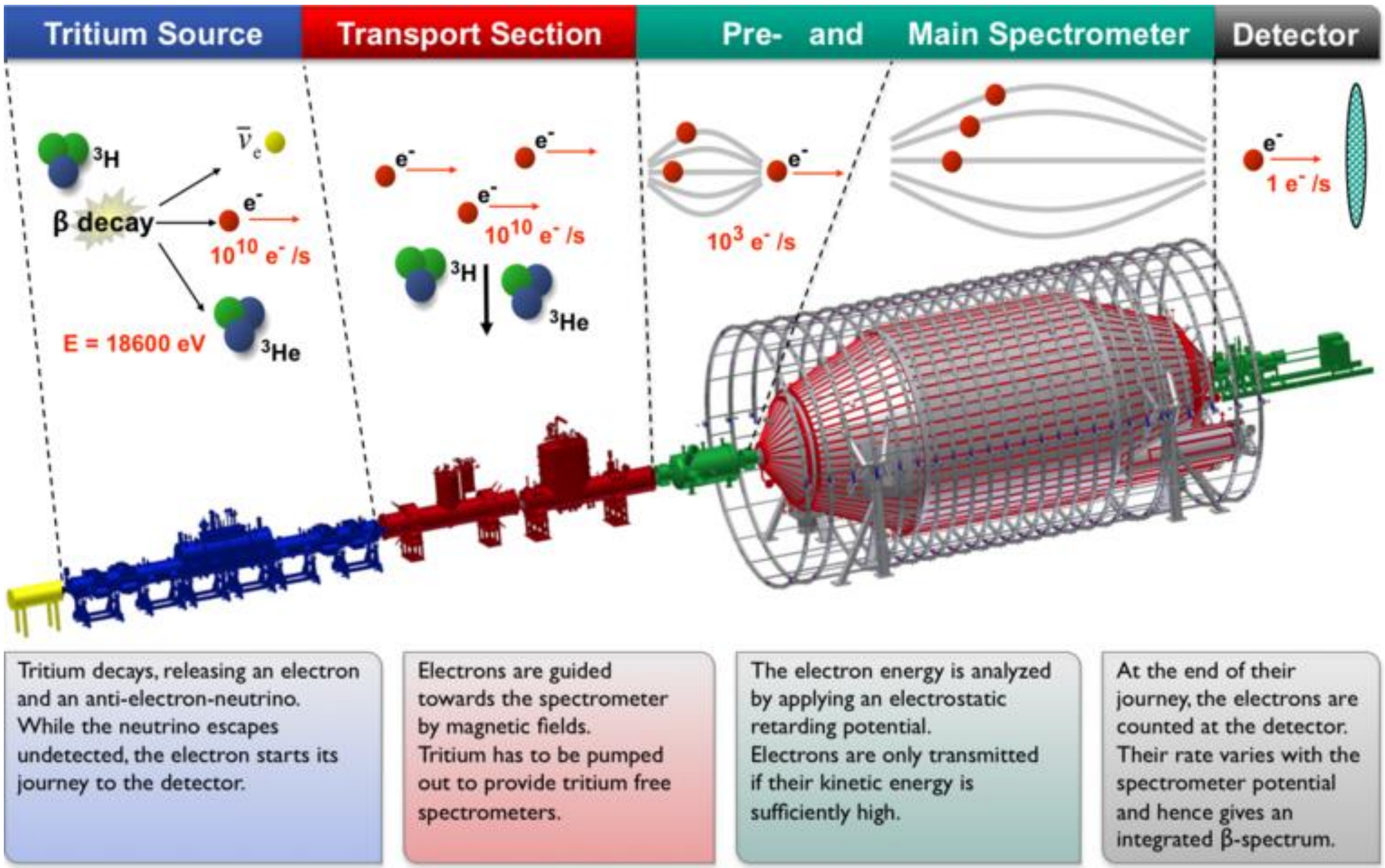
[1] P. T. Springer et al., Measurement of the neutrino mass using the inner bremsstrahlung emitted in the electron-capture decay of ^{163}Ho, Phys. Rev. A 35 (1987) 679

[2] S. Yasumi et al., The mass of the electron neutrino from electron capture in ^{163}Ho, Phys. Lett. B 334 (1994) 229

Neutrino mass

Direct neutrino mass determination: perspectives

Neutrino mass from tritium β-decay: perspectives: KATRIN



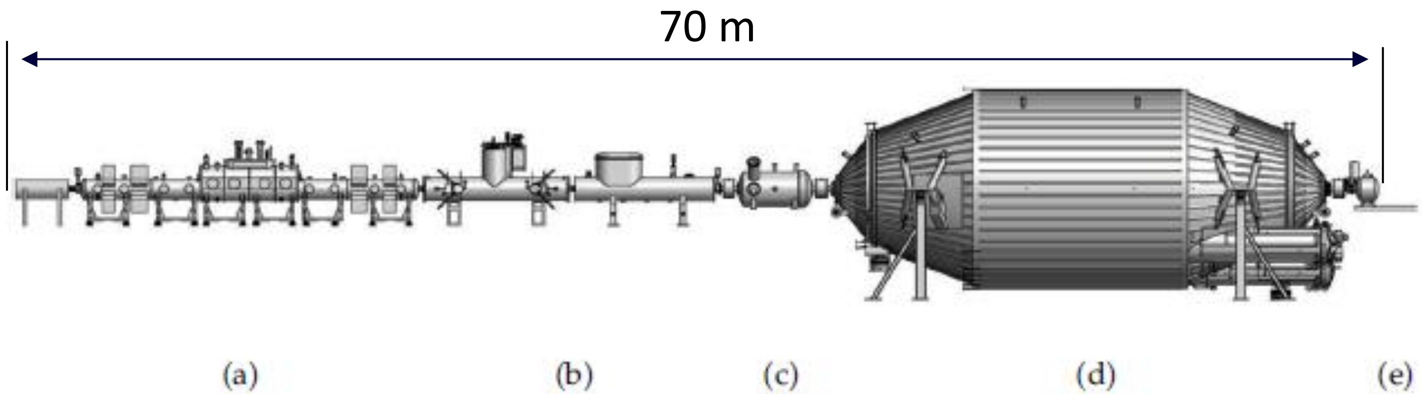
http://www.katrin.kit.edu/

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: perspectives: KATRIN

The Karlsruhe TritiumNeutrino (KATRIN) experiment currently under construction at Karlsruhe Institute of Technology, which will use the MAC-E-Filter principle to push the sensitivity down to a value of 0.2 eV. This in turn requires significant, major improvements to key experimental parameters such as source activity, energy resolution, and background rate.



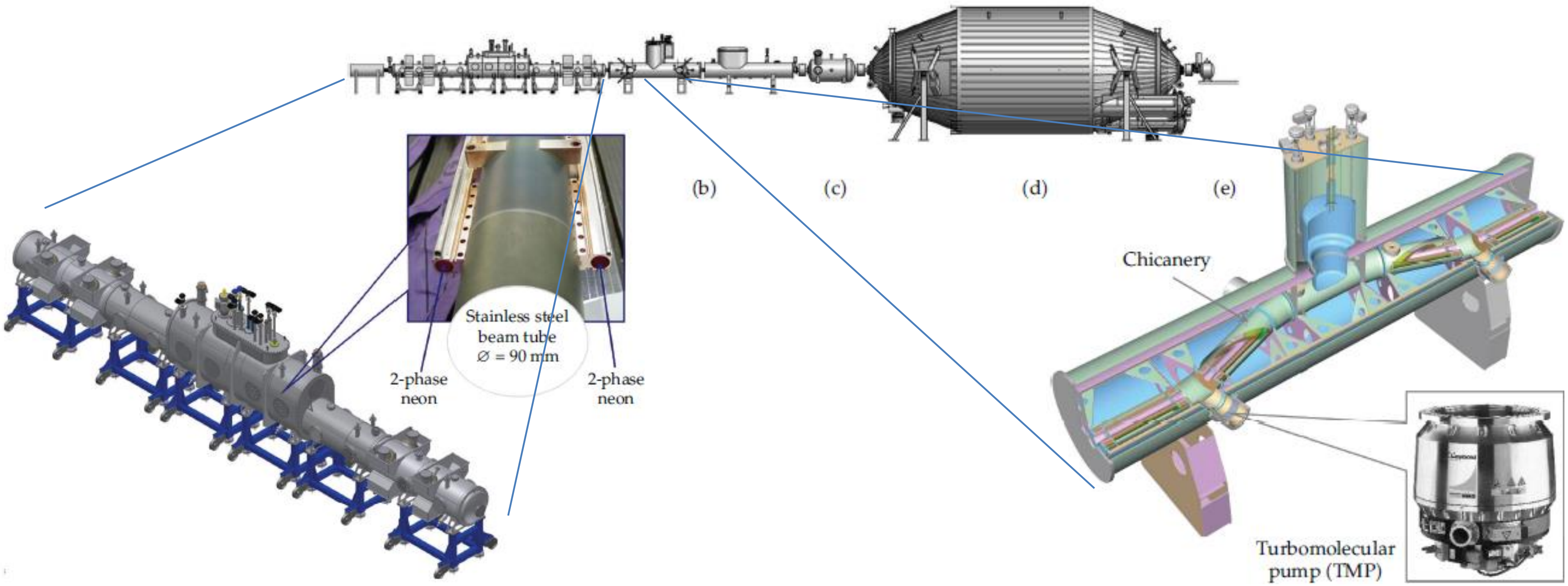
Schematic view of the complete KATRIN setup. (a) Windowless Gaseous Tritium Source (WGTS). (b) Transport section consisting of a differential (DPS2-F) and a cryogenic (CPS) pumping section. (c) Pre-spectrometer: pre-filter of β-spectrum. (d) Main spectrometer: energy analysis of β-electrons. (e) Detector: position-sensitive detection of transmitted electrons.

J. Angrik, T. Armbrust, A. Beglarian et al., "KATRIN design report 2004," Tech. Rep., Forschungszentrum, Karlsruhe, Germany, 2005.

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: perspectives: KATRIN



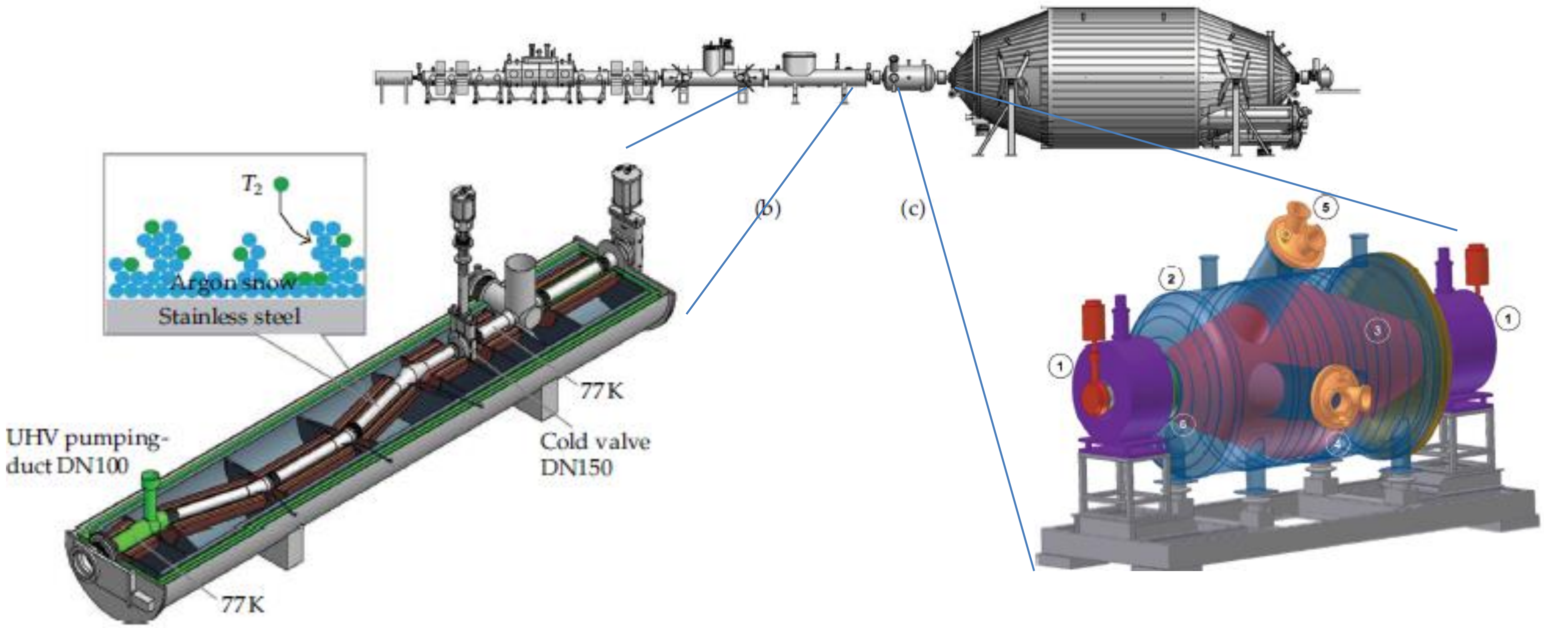
Schematic view of the 16 m long Windowless Gaseous Tritium Source (WGTS) cryostat. The inlet shows the beam tube with the two phase liquid neon cooling system

Schematic view of the 6.96 m long Transport section consisting of a differential (DPS2-F) and a cryogenic (CPS) pumping section cryostat.

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: perspectives: KATRIN



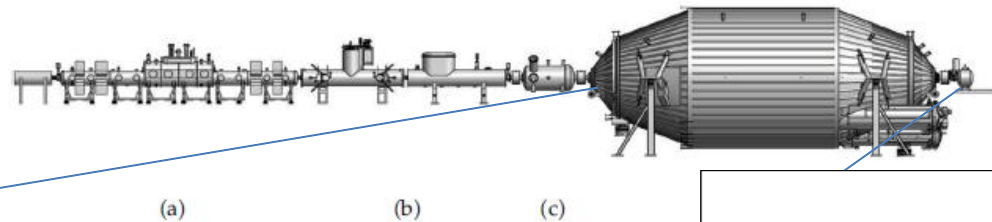
Schematic view of the seven beam tube elements of the cryogenic pumping section (CPS). The inner surface of the cryopump elements is covered with argon snow to capture the remaining tritium molecules.

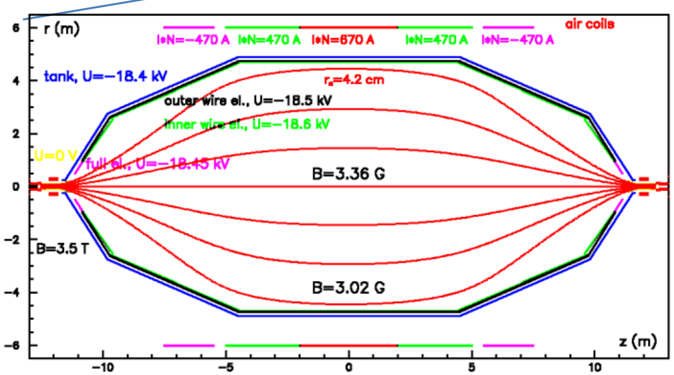
Schematic view of pre-spectrometer. (1) superconducting solenoids, (2) prespectrometer vessel, (3) inner electrode system, (4) 90∘ pump port, (5) 45∘ pump port, (6) insulator.

Neutrino mass

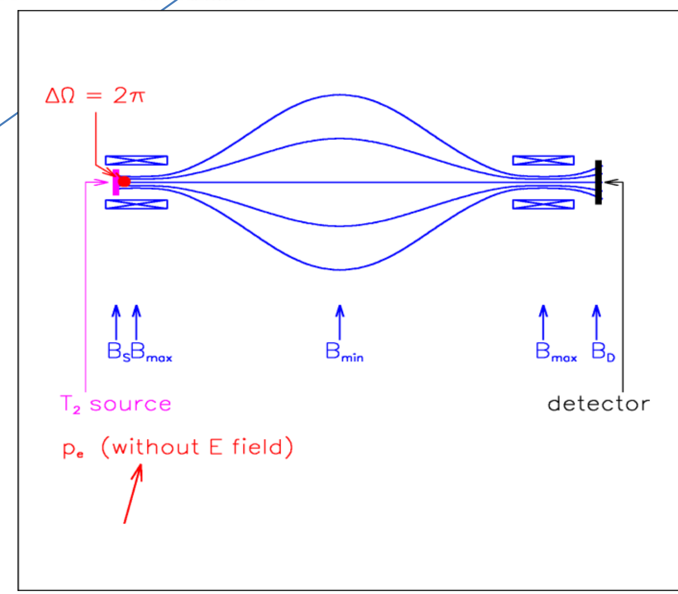
Direct neutrino mass determination

Neutrino mass from tritium β-decay: perspectives: KATRIN





The main spectrometer scheme



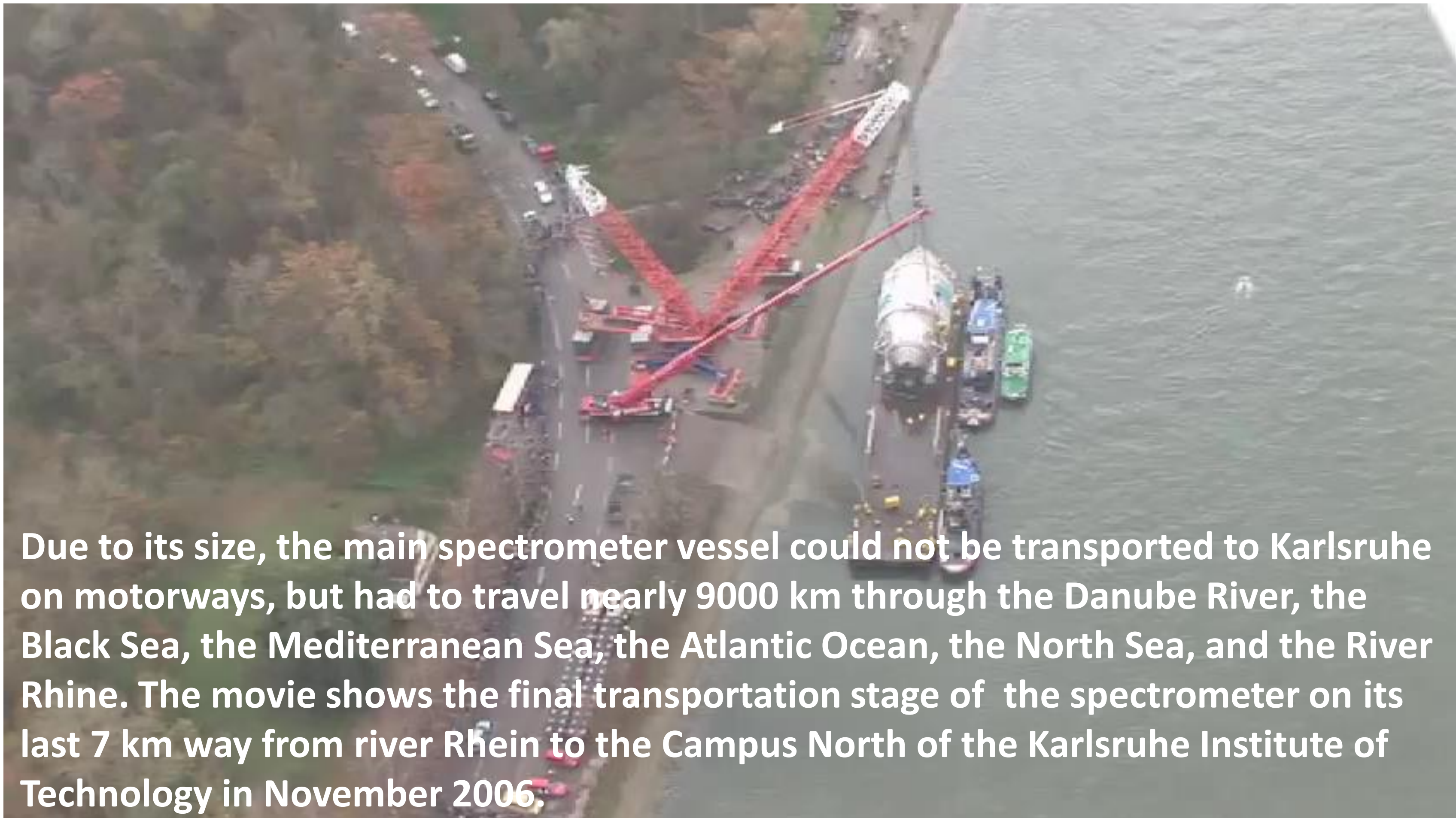
The exceedingly large dimensions of the main spectrometer are essential to operate it as an extremely precise high-energy filter with an energy resolution of ΔE = 0.93 eV

The high sensitivity of the KATRIN experiments will be reached by a special type of spectrometers, so-called **MAC-E-Filters** (<u>M</u>agnetic <u>A</u>diabatic <u>C</u>ollimation combined with an <u>E</u>lectrostatic Filter).

Neutrino mass

Direct neutrino mass determination

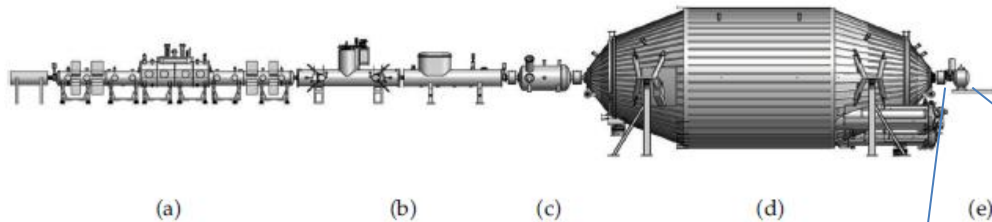
Neutrino mass from tritium β-decay, perspectives: KATRIN



Neutrino mass

Direct neutrino mass determination

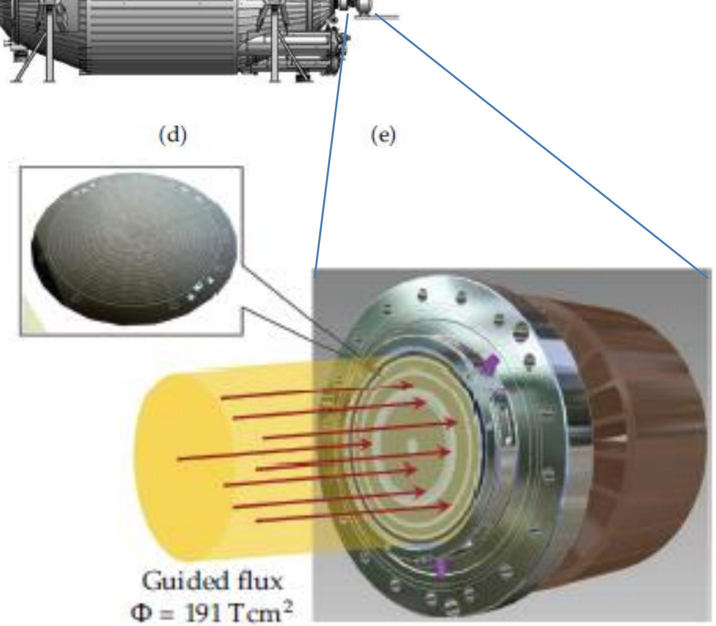
Neutrino mass from tritium β-decay: perspectives: KATRIN



Focal Plane Detector

The focal plane detector is a semiconductor-based silicon PIN diode. Its main goal is to detect transmitted electrons with a detection efficiency of >90%.

The electrons are guided along magnetic field lines to the sensitive area of the detector, which has a diameter of 10 cm. The inset shows a photograph of the detector, in which the 148 pixels are visible.

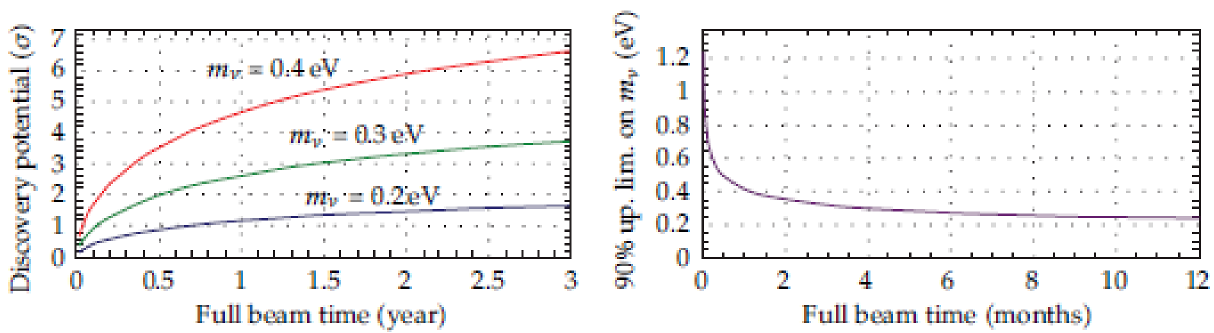


After integration of all source-related and spectrometer related components, the first runs in the final KATRIN configuration are expected in the second half of 2015. Sensitivity of the experiment (90% upper limit if neutrino mass is zero) is 0.2 eV with about equal contributions of statistical and systematical errors.

Neutrino mass

Direct neutrino mass determination

Neutrino mass from tritium β-decay: perspectives: KATRIN



(a) (b)

Discovery potential of KATRIN as function of time for different neutrino masses.
(b) Upper limit on neutrino mass at 90% C.L. as a function of time.

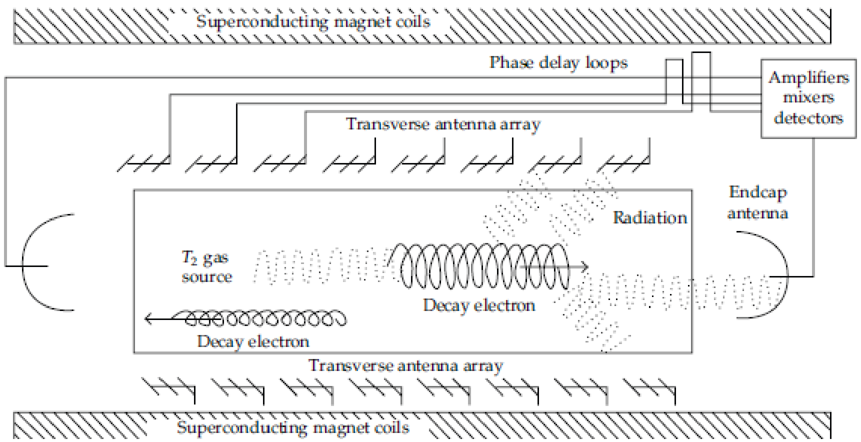
After integration of all source-related and spectrometer related components, the first runs in the final KATRIN configuration are expected in the second half of 2015. Sensitivity of the experiment (90% upper limit if neutrino mass is zero) is 0.2 eV with about equal contributions of statistical and systematical errors.

Neutrino mass

Direct neutrino mass determination: new approaches

Detection of coherent cyclotron radiation to measure energy of electrons

While spectrometer experiments based on the MAC-E filter principle currently provide the highest sensitivities in direct neutrino mass experiments, there are alternative approaches that aim for comparable performance and better scalability in the study of weak decays.



A cyclotron frequency ω of electron depends on kinetic energy of electron (E) and themagnetic field of the source (B):

$$w = \frac{qB}{m+E}$$

where q is the electron charge, m is the electron mass.

The tritium technology from the KATRIN experiment used in conjunction with microwave antennas to detect coherent cyclotron radiation emitted by individual decay electrons in a magnetic field. A β-decay spectrum can be obtained without a large electrostatic spectrometer.

B. Monreal and J. Formaggio, Relativistic cyclotron radiation detection of tritium decay electrons as a new technique for measuring the neutrino mass, *Phys. Rev. D* 80 (2009) 051301

Neutrino mass

Direct neutrino mass determination: new approaches

Microcalorimeter Arrays for a Rhenium Experiment (MARE)

The MARE collaboration is working to further the development of sensitive microcalorimeters to investigate ^{187}Re β-decay and ^{163}Ho electron capture. In MARE-1 several groups are working on alternative microcalorimeter concepts which will be tested by setting up neutrino mass experiments with sensitivities in the order of a few eV.

Besides the selection of the most sensitive detector technology, this phase will also be used to investigate the use of the EC decay of ^{163}Ho as an alternative to the study of rhenium β-decay to determine the neutrino mass.

The consideration of ^{163}Ho was triggered by persisting difficulties with superconducting metallic rhenium absorbers coupled to the sensors. Thermalization of the energy deposited in β-decays seems to be hindered by the excitation of long lived states in the rhenium absorber. The nature of these states can presently only be speculated upon. After selecting the most successful technique, a full scale experiment with sub-eV sensitivity to the neutrino mass will then be set up.

A. Nucciotti, The MARE project, Journal of Low Temperature Physics 151 (2008) 597

Conclusions (1)

1. The neutrino mass is among of the most urgent questions of nuclear and particle physics (to build extensions of the Standard Model), astrophysics and cosmology (because of the role of neutrinos in the universe structure formation)
2. Three different approaches can lead to the absolute neutrino mass scale as follows: Cosmology, Neutrinoless double β decay, Direct measurements
3. Cosmology (using cosmic microwave background and today's large structure data) gives limit on the sum of the neutrino masses on the level of $\Sigma m(\nu_i) < 0.5$ eV. The limits are to some extent model and analysis dependent
4. Neutrinoless double beta decay experiments are sensitive to the Majorana mass of neutrino (neutrino = anti-neutrino). The most sensitive $0\nu2\beta$ experiments give upper limit $\langle m_\nu \rangle < (0.2 - 1)$ eV. The estimations depend on the nuclear matrix elements calculations

Conclusions (2)

1. Direct experiments determine the average electron neutrino mass $m(\nu_e)^2$ independently on the neutrino nature (Dirac or Majorana)
2. Experiments measuring the tritium β-decay around its endpoint E_0 give the limits on the level of $m(\nu_e) < 2$ eV
3. Calorimetric experiments (Cryobolometers with ^{187}Re, ^{163}Ho) have still much lower sensitivity (a few 100 eV)
4. The KATRIN experiment (currently under construction) aims to push the sensitivity down to a value of $m(\nu_e) \sim 0.2$ eV
5. New approaches are under development (based on cryogenic microbolometeres, cyclotron frequency measurements) to push the sensitivity to sub-eV level