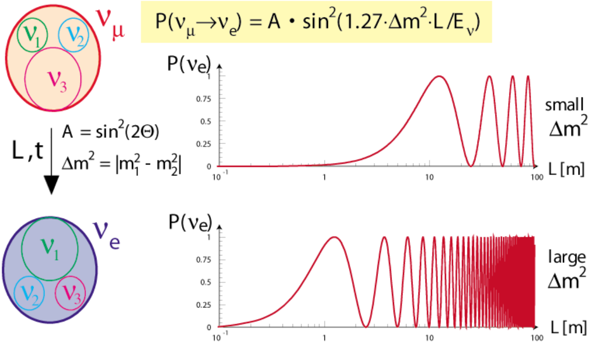
Bestimmung der Neutrino-Masse: Heidelberg Moskau Experiment und KATRIN

Emil Pavlov

Inhaltsverzeichnis

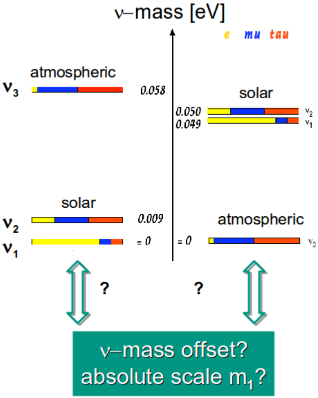
Neutrinooszilationen

- Hinweise auf massive Neutrinos
- $m \geq 0.04 - 0.07\,\mathrm{eV}$



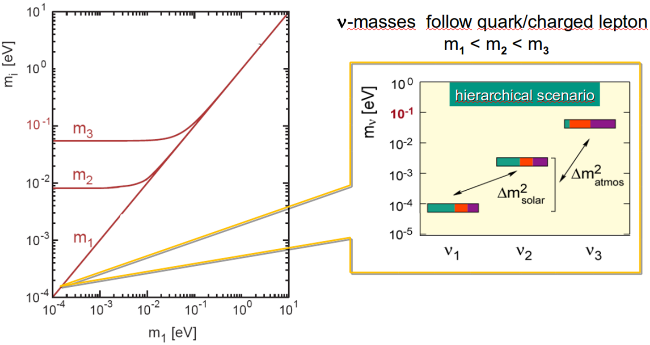
Neutrinomasse

- Keine absolute Skala



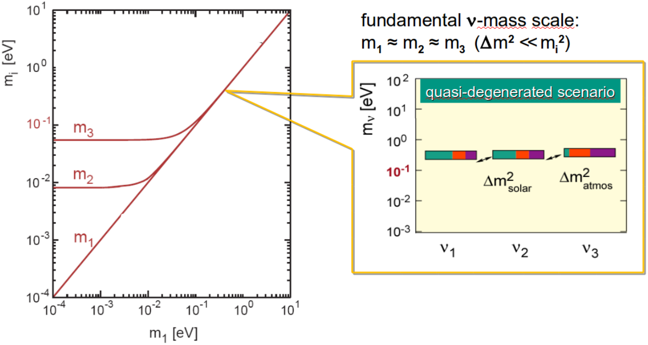
Neutrinomasse

- Keine absolute Skala
- Massenhierarchie



Neutrinomasse

- Keine absolute Skala
- Massenhierarchie



Teilchenphysik

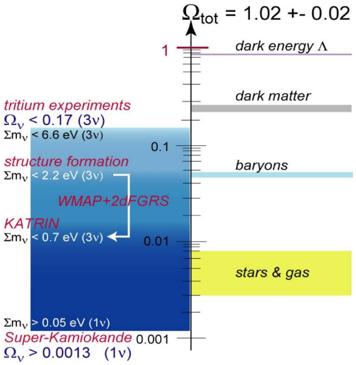
- Im Standard Model - keine Masse
- Einzige Fermionen mit unbekannte Masse
- Überprüfung von Modelle

Astrophysik

- Kandidat für Hot Dark Matter (HDM)
- Evolution von Large Scale Structures (LSS)

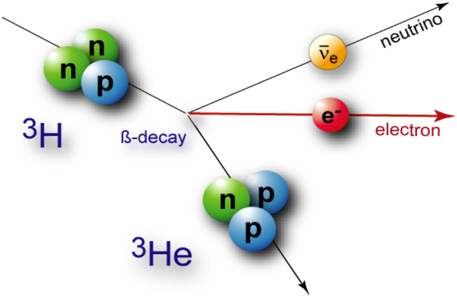
Astrophysik

- Kandidat für Hot Dark Matter (HDM)
- Evolution von Large Scale Structures (LSS)



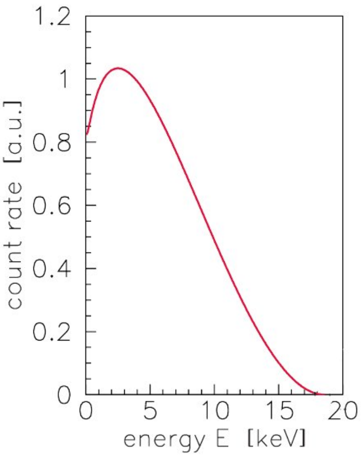
β-Zerfall

- $n \rightarrow p + e + \bar{\nu}_e$
- unterbestimmtes Problem
  - 3 Tochterteilchen
  - 2 Erhaltungsgröße



β-Zerfall

- $n \rightarrow p + e + \bar{\nu}_e$
- unterbestimmtes Problem
  - 3 Tochterteilchen
  - 2 Erhaltungsgröße
- kontinuerlisches Spektrum

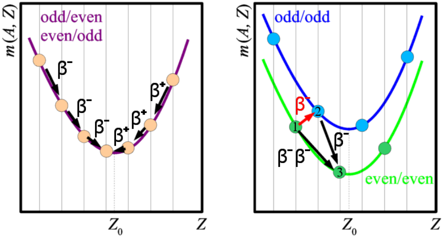


Methode zur Bestimmung der Neutrinomasse

- Neutrinolose Doppeltbetazerfall (Heidelberg Moscau)
- Normale Beta-Zerfall (KATRIN)

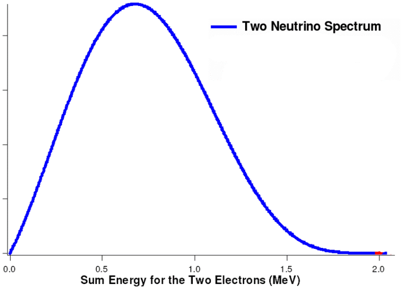
$\beta\beta 2\nu$-Zerfall

- $2n \rightarrow 2p + 2e^- + 2\bar{\nu}_e$
- lange Lebensdauer - 10^{20} a



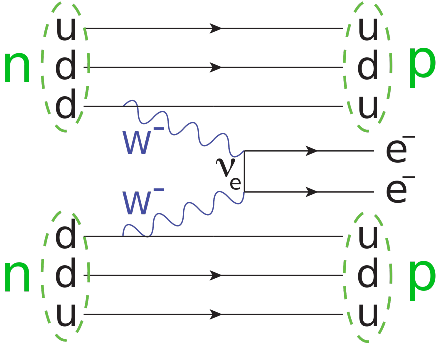
$\beta\beta 2\nu$-Zerfall

- $2n \rightarrow 2p + 2e^- + 2\bar{\nu}_e$
- lange Lebensdauer - 10^{20} a
- kontinuerlisches Spektrum



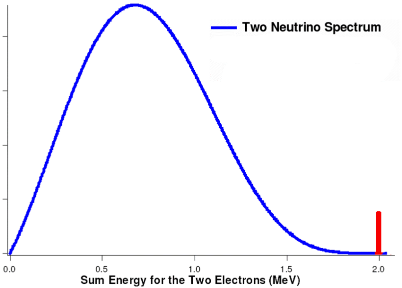
$\beta\beta 0\nu$-Zerfall

- $2n \rightarrow 2p + 2e^- + 0\bar{\nu}_e$
- Neutrino indentisch mit anti-Neutrino - Majorana Typ



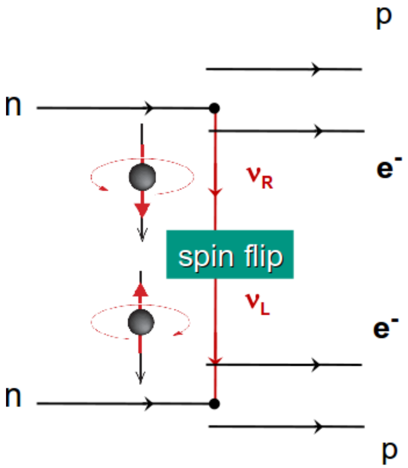
$\beta\beta 0\nu$-Zerfall

- $2n \rightarrow 2p + 2e^{-} + 0\bar{\nu}_e$
- Neutrino indentisch mit anti-Neutrino - Majorana Typ
- Peak bei Endpunktenergie



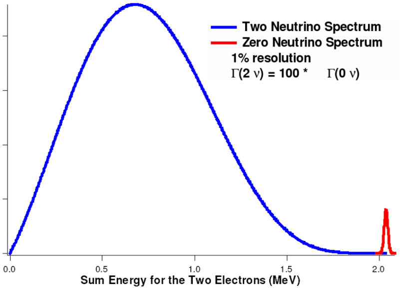
Helizität

- $h = \vec{S} \cdot \frac{\vec{p}}{|\vec{p}|}$
- Antineutrinos - rechtshändig, Neutrinos - linkshändig



Helizität

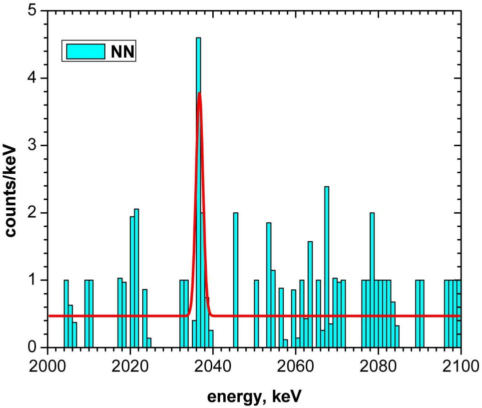
- $h = \vec{S} \cdot \frac{\vec{p}}{|\vec{p}|}$
- Antineutrinos - rechtshändig, Neutrinos - linkshändig
- $\Gamma \propto m_{\nu}^{-2}$



Resultate

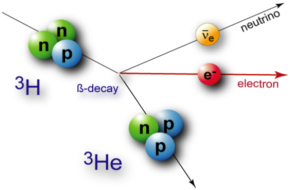
- Endpunktenergie von $^{76}Ge = 2039\,\mathrm{keV}$
- Neutrinomasse $0.2 - 0.5\,\mathrm{eV}$

Bild: H. V. KLAPDOR-KLEINGROTHAUS and I. V. KRIVOSHEIN, Modern Physics Letters A, Vol. 21, No. 20 (2006) 1547

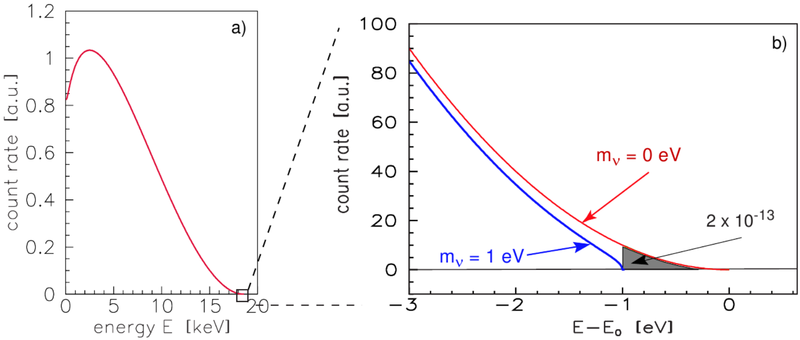


Kinematik des β-Zerfalls

- Absolute Bestimmung der Masse
- Einfache Kinematik - Energieerhaltung
- Modelunabhängig

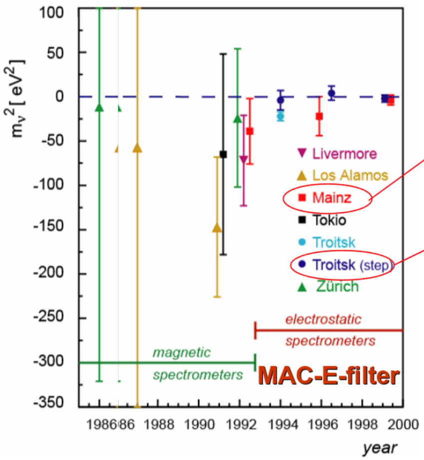


Energiespektrum



$$\frac{dN_e}{dE_e} \propto p_e \cdot \left(E_e + m_e c^2\right) \cdot (E_0 - E_e)\sqrt{(E_0 - E_e)^2 - m_\nu^2 c^4}$$

Vorherige Experiment



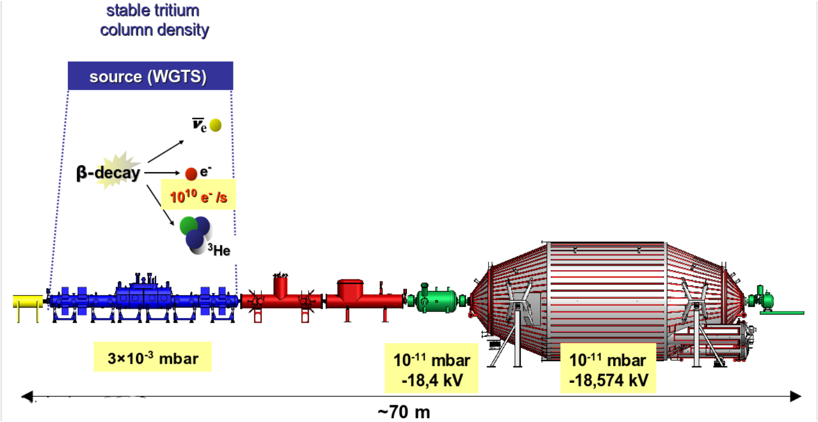
$$m_\nu^2 = -0.6 \pm 2.2_{stat} \pm 2.1_{syst}\,\mathrm{eV}^2$$
$$m_\nu \leq 2.3\,\mathrm{eV}(95\%CL)$$

$$m_\nu^2 = -1.2 \pm 2.2_{stat} \pm 2.1_{syst}\,\mathrm{eV}^2$$
$$m_\nu \leq 2.2\,\mathrm{eV}(95\%CL)$$

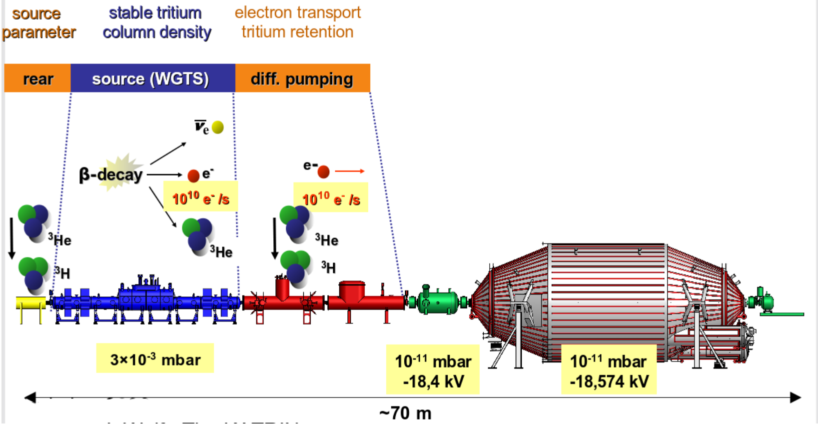
Sensitivity

m_ν < 200 meV (90% C.L.)
m_ν < 350 meV (5σ level)

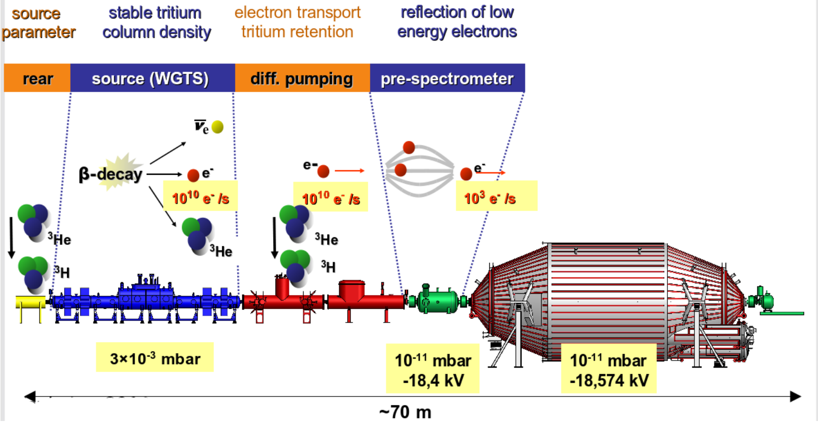
Aufbau


stable tritium
column density
source (WGTS)
$\bar{\nu}_e$
β-decay
e⁻
10^{10} e⁻/s
^{3}He
3×10^{-3} mbar
10^{-11} mbar
-18,4 kV
10^{-11} mbar
-18,574 kV
~70 m

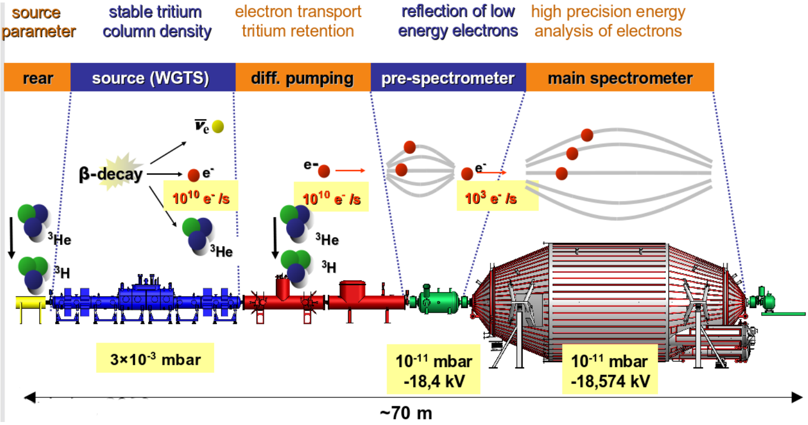
Aufbau


source
parameter
stable tritium
column density
electron transport
tritium retention
rear
source (WGTS)
diff. pumping
β-decay
e⁻
10^{10} e⁻ /s
e⁻
10^{10} e⁻ /s
³He
³H
³He
³He
³H
3×10^{-3} mbar
10^{-11} mbar
-18,4 kV
10^{-11} mbar
-18,574 kV
~70 m

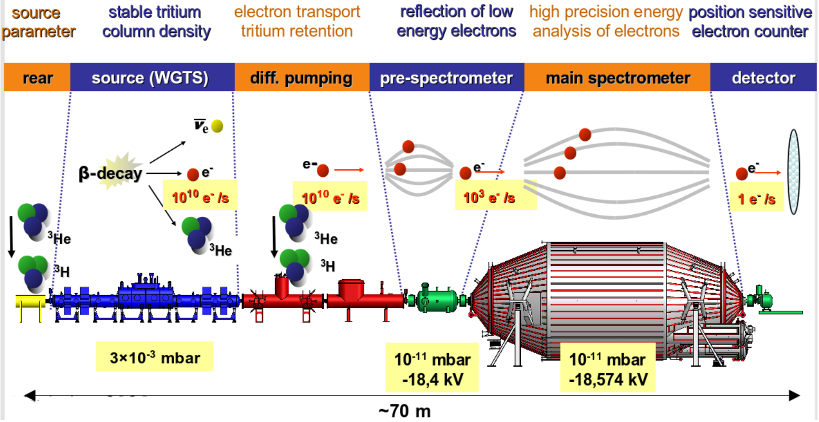
Aufbau


source parameter
stable tritium column density
electron transport tritium retention
reflection of low energy electrons
rear
source (WGTS)
diff. pumping
pre-spectrometer
β-decay
e-
10^{10} e- /s
10^{10} e- /s
10^{3} e- /s
^{3}He
^{3}H
3×10^{-3} mbar
10^{-11} mbar
-18,4 kV
10^{-11} mbar
-18,574 kV
~70 m

Aufbau


source parameter
stable tritium column density
electron transport tritium retention
reflection of low energy electrons
high precision energy analysis of electrons
rear
source (WGTS)
diff. pumping
pre-spectrometer
main spectrometer
β-decay
$\bar{\nu}_e$
e⁻
10^{10} e⁻ /s
e-
10^{10} e⁻ /s
e⁻
10^{3} e⁻ /s
^{3}He
^{3}H
^{3}He
^{3}He
^{3}H
3×10^{-3} mbar
10^{-11} mbar
-18,4 kV
10^{-11} mbar
-18,574 kV
~70 m

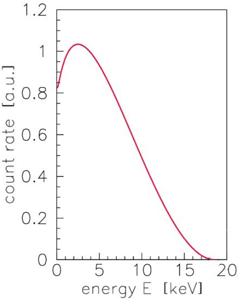
Aufbau


source parameter
stable tritium column density
electron transport tritium retention
reflection of low energy electrons
high precision energy analysis of electrons
position sensitive electron counter
rear
source (WGTS)
diff. pumping
pre-spectrometer
main spectrometer
detector
$\overline{\nu}_e$
β-decay
e⁻
10^{10} e⁻/s
e-
10^{10} e⁻/s
e⁻
10^3 e⁻/s
e⁻
1 e⁻/s
^{3}He
^{3}H
^{3}He
^{3}He
^{3}H
3×10^{-3} mbar
10^{-11} mbar
-18,4 kV
10^{-11} mbar
-18,574 kV
~70 m

Radioaktive quelle

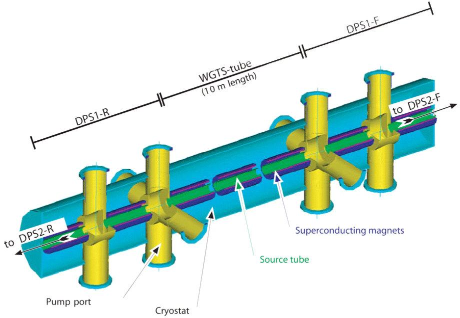
Tritium:

- große Aktivität (Lebensdauer 12,3 a)
- niedrige Endpunktenergie ($\approx 18,6\,\mathrm{keV}$)
- Spiegelkerne



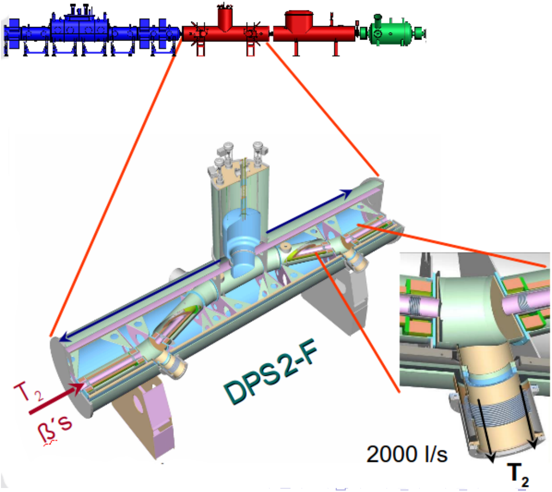
Radioaktive Quelle

- Temperatur $27\,\mathrm{K} \pm 3\,\mathrm{mK}$
- Isotropenreinheit > 95%
- $5 \times 10^{19}\,\mathrm{Molekulen/s} \pm 0,1\%$ $(40\,\mathrm{g}\,\mathrm{T_2/Tag})$
- $\Delta p = 10^{-6}\,\mathrm{mbar}$



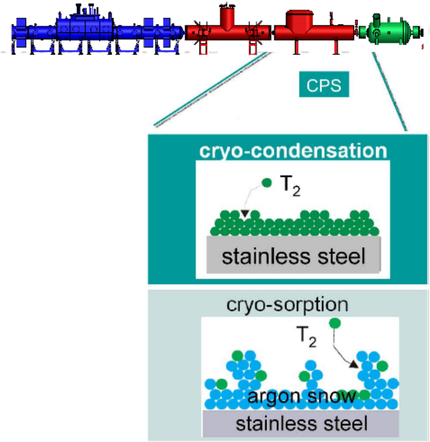
Differential Pumping Section

Reduzierungsfaktor 10^7



Cryogenic Pumping Section

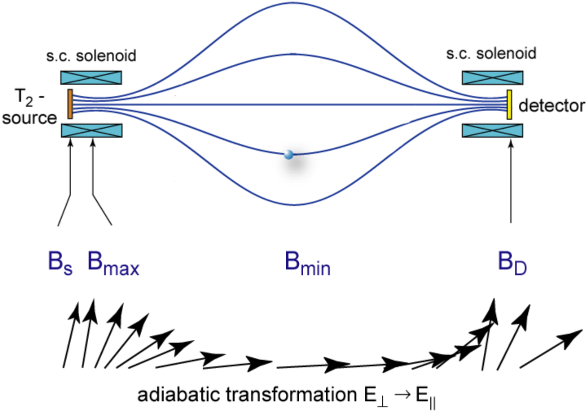
Reduzierungsfaktor 10^7



MAC-E Filter

$$\mu = \frac{p_\perp^2}{2m_e B} = const$$

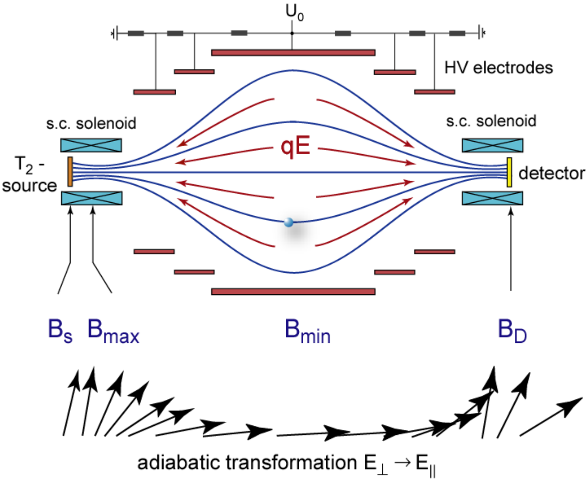
$$\Delta E = \frac{B_{min}}{B_{max}} E = 0,93\,\mathrm{eV}$$



MAC-E Filter

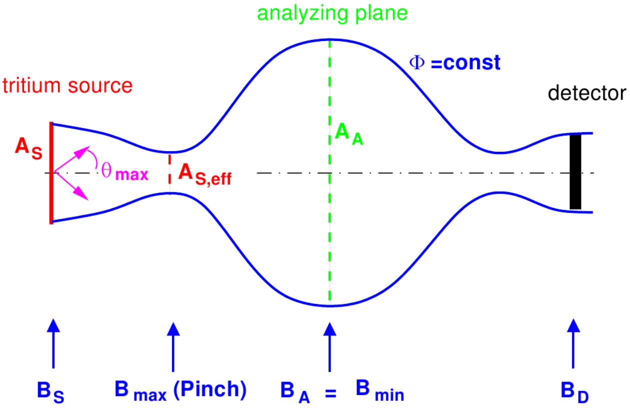
$$\mu = \frac{p_\perp^2}{2m_e B} = const$$

$$\Delta E = \frac{B_{min}}{B_{max}} E = 0,93\,\mathrm{eV}$$



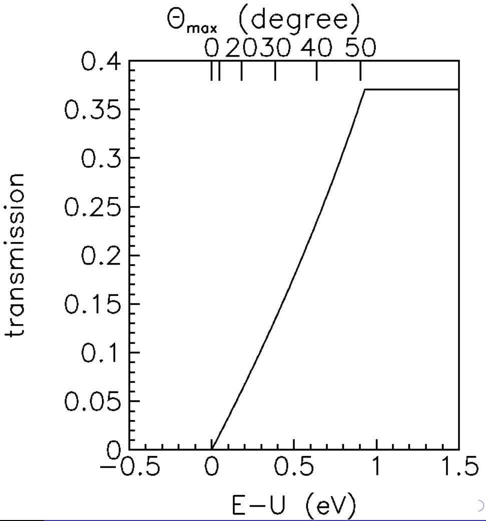
Magnetischer Spiegel

$$sin\theta_{max} = \sqrt{\frac{B_s}{B_{max}}}$$

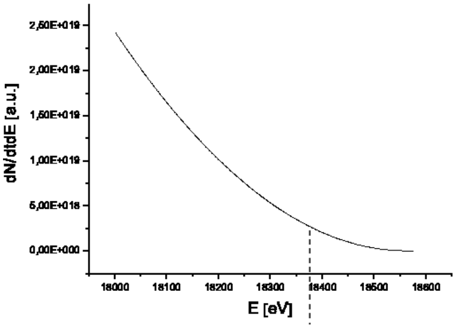


Transmissionfunktion

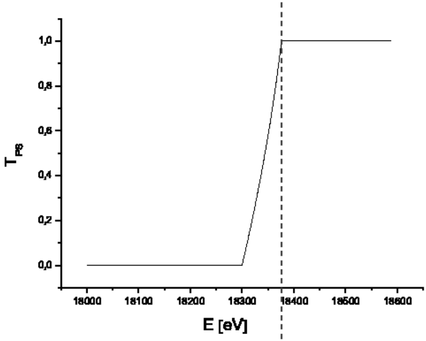
Integrierender Hochpassfilter



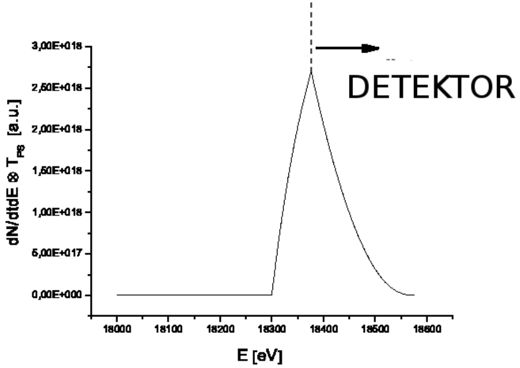
Ausgangssignal



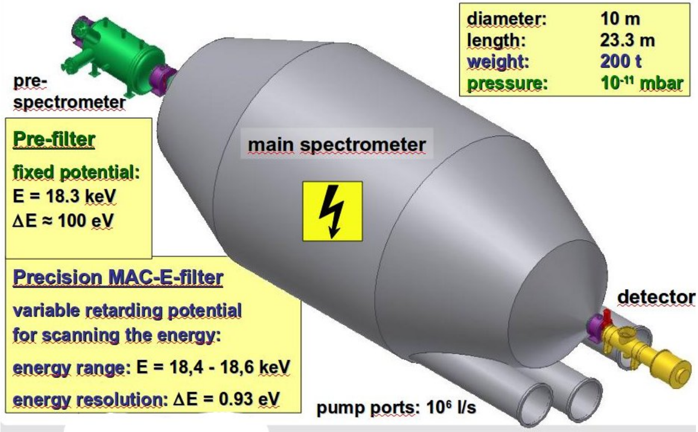
Ausgangssignal



Ausgangssignal

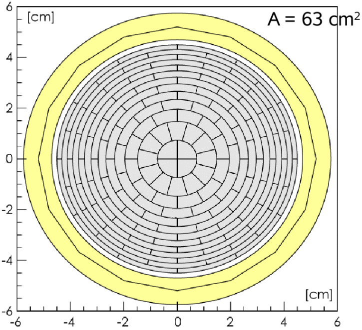


Spektrometer



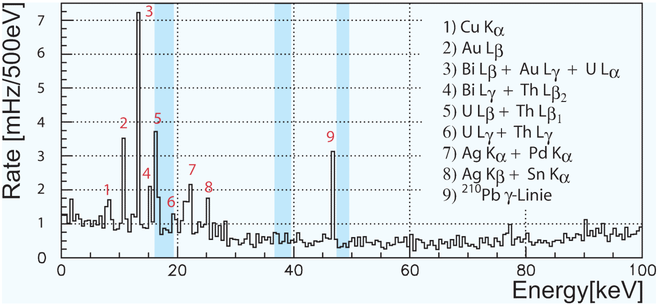
Detektor

- PIN Dioden
- Energieauflösung 600 eV
- Ortsauflösung
  - Inhomogenitäten des Verzögerungspotentials
  - Homogenität der Tritium-quelle
  - Hintergrund von außerhalb des gewünschten Magnetfeldes

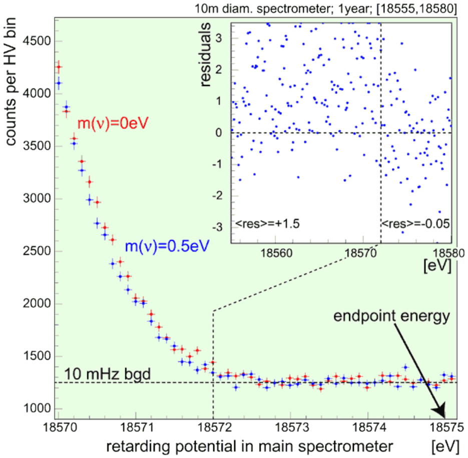


Simulierter Spektrum

- Nachbeschleunigung → kleinerer Untergrund



Simulierte Messung



Transport


UNITED KINGDOM
IRELAND
FRANCE
GERMANY
POLAND
UKRAINE
BELARUS
ROMANIA
HUNGARY
AUSTRIA
ITALY
SPAIN
PORTUGAL
GREECE
TURKEY
BULGARIA
ALGERIA
MOROCCO
TUNISIA
Mediterranean Sea
Bay of Biscay
Black Sea
Scale 1: 19,500,000
Lambert Conformal Conic Projection, standard parallels 40°N and 56°N

Transport


UNITED KINGDOM
IRELAND
Dublin
Belfast
Leeds
Manchester
Liverpool
Birmingham
Cardiff
London
Celtic Sea
Guernsey (U.K.)
Jersey (U.K.)
DENMARK
Copenhagen
Malmö
Bornholm
Kaliningrad
Gdańsk
Vilnius
Minsk
BELARUS
Hrodna
Homyel'
Hamburg
Bremen
Berlin
Poznań
POLAND
Warsaw
Łódź
Wroclaw
Brest
Kiev
Rivne
UKRAINE
Amsterdam
Rotterdam
NETH.
Essen
Cologne
Leipzig
Brussels
Lille
BEL.
Bonn
GERMANY
Frankfurt am Main
Prague
CZECH REPUBLIC
Brno
Kraków
L'viv
Chernivtsi
Paris
Luxembourg
Stuttgart
Munich
Strasbourg
Nantes
SLOVAKIA
Bratislava
Vienna
AUSTRIA
Budapest
HUNGARY
Cluj-Napoca
Iași
MOLDOVA
Chișinau
ROMANIA
Bucharest
Ljubljana
SLOVENIA
Zagreb
Algiers
Ceuta (SPAIN)
Alborán Sea
Melilla (SPAIN)
Oran
Rabat
Casablanca
MOROCCO
ALGERIA
Tunis
TUNISIA
MALTA
300 Kilometers
300 Miles
2006/10/06 11:12

Transport

Zusammenfassung

- Direkte Bestimmung der Neutrino Masse
- Eine große Ordnung besser als die bisherige Ergebnisse
- 5σ-Entdeckungspotetial für m_ν bis $0,35\,\mathrm{eV}$
- Obere Grenze von $0,2\,\mathrm{eV}$ mit 90% C.L.
- Überprüfung der Daten von Heidelberg Moskau
- Schritt zur Physik über SM

DANKE FüR DIE AUFMERKSAMKEIT

Literaturverzeichnis I

- Katrin Colloboration, Design Report, 2004
- Introduction to direct neutrino mass measurements and KATRIN by Thomas Thümmler, XXIV International Conference on Neutrino Physics and Astrophysics, Athens, Greece, June 14 - 19, 2010
- The KATRIN Experiment by Christian Weinheimer, Launch09: Neutrinos and Beyond, Heidelberg, Germany, June 9 - 12
- absolute neutrino mass by Guido Drexlin, Launch09: Neutrinos and Beyond, Heidelberg, Germany, June 9 - 12

Literaturverzeichnis II

- Detecting Neutinos by RGH Robertson, Summer School on Nuclear and Particle Astrophysics (INT 2009), Seattle (USA), Jun 29 - Jul 10, 2009 Note: Intro to KATRIN and related experiments!
- NOT Detecting Neutinos by RGH Robertson, Summer School on Nuclear and Particle Astrophysics (INT 2009), Seattle (USA), Jun 29 - Jul 10, 2009 Note: Further Intro to non-acc. neutrino experiments!

Literaturverzeichnis III

- The KATRIN neutrino mass experiment & vacuum considerations by Joachim Wolf, talk at Int.Conf. on Technology & instrum. in part.-physics (TIPP09), Tsukuba (Japan), Mar 11-17, 2009 Note: Required login information is provided!
- Designstudien fuer das KATRIN Experiment Diploma thesis, B. Flatt, Mainz, 2001
- Robert Boge, Neutrinomasse, Seminar SS 09
- H. V. KLAPDOR-KLEINGROTHAUS and I. V. KRIVOSHEIN, Modern Physics Letters A, Vol. 21, No. 20 (2006) 1547
- Wikipedia, general references