The KATRIN Neutrino Mass Measurement: Experiment, Status, and Outlook

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Outline

• Neutrino mass measurements

• KATRIN Apparatus
  • Components
  • MAC-E Spectrometer
  • First Light and Krypton Measurements

• Status of First Tritium Running

• Summary and outlook
Neutrino Mass Measurements

• 4 approaches to neutrino mass scale:

  1. (very) long baseline/ToF

  2. Neutrinoless double $\beta$ decay

  3. Kinematic methods

  4. Inferred from CMB/structure
Neutrino Mass Measurements

- 4 approaches to neutrino mass scale:

1. (very) long baseline/ToF
2. Neutrinoless double $\beta$ decay
3. Kinematic methods
4. Inferred from CMB/structure
\[ ^3\text{H} \rightarrow ^3\text{He} + e^- + \bar{\nu} \]

Tritium decay $\beta$-spectrum

Spectrum shape sensitive to effective electron $\nu$ mass

\[ m_{\nu}^2 \equiv \sum_j |U_{ej}|^2 m_j^2 \]
KATRIN, in a nutshell

(KArlsruhe TRItium Neutrino)

- Goal: precision absolute neutrino mass measurement
- Design sensitivity: 0.2eV, at 90% C.L.
- Intense molecular Tritium source (T₂)
- High-resolution (ΔE ~ 0.93eV) integrating spectrometer
- Detection of βs via segmented silicon pin diode
- Resolution via MAC-E Spectrometer
KATRIN Apparatus

Windowless Gaseous Tritium Source (WGTS)
10^{11} decay β’s/second
10^{-3} mbar T_{2}

MAC-E Pre-Spectrometer
Blocks lower energy βs

β Detector
silicon diode array

Rear Wall
For monitoring

Differential Pumping
10^{5} Tritium reduction

Cryogenic Pumping
10^{7} Tritium reduction

MAC-E Main-Spectrometer
held at \sim10^{-11} mbar
\sim10^{-20} mbar T_{2}
The MAC-E Spectrometer

(Magnetic Adiabatic Collimator with Electrostatic Filter)
The MAC-E Spectrometer

1) The Electrostatic Filter

Kinetic Energy $E = E_{\perp} + E_{||}$

Transmits $\beta$'s with $E_{||} > qU_A$

Counting rate vs $U_A$ generates integrated $\beta$ spectrum

$$F(qU_A) = \int_{qU_A}^{E_{\max}} T(qU_A, E_\beta) f(E_\beta) dE_\beta$$

Resolution

$\Delta E = E_{\perp \max}$ at analyzing plane

Need to minimize $E_{\perp \max}$

Transmission function $T(qU_A, E_\beta) vs E_\beta$
The MAC-E Spectrometer

2) The Adiabatic Magnetic Collimator

B-field guides \( \beta \)'s to detector
\[ B_{\text{max}} = 6 \, \text{T} \]
\[ B_{\text{analyzing plane}} = 0.3 \, \text{mT} \]

Adiabatic Process

orbital magnetic moment
\[ \mu = IA = \left( q \frac{V_\perp}{2\pi r} \right) \left( \pi r^2 \right) = \frac{E_\perp}{B} = \text{constant} \]

\[ \frac{\Delta E}{E} = \frac{B_A}{B_{\text{max}}} \frac{\gamma + 1}{2} = 5 \times 10^{-5} \]
\[ \Delta E = 0.93 \text{eV at 18.6 keV endpoint} \]
The MAC-E Spectrometer

Segmented Silicon Pin Diode Focal Plane Detector

Silicon Wafer

Detector in Mount

$^{241}$Am Spectrum

Pixel Hit Map
First Light and Krypton Measurements

Monitoring and associated instrumentation
First Light Campaign

- October 2016
- First electrons transmitted through the entire beam line (from rear wall to detector)
- Source of electrons: produced via photoelectric effect at the rear wall
Krypton Campaign

July 2017

- 2 week run
- System checks include HV calibration and stability

$^{83m}\text{Kr}$ provides pseudo-monoenergetic conversion electrons

$^{83\text{Rb}} \quad T_{1/2}=86.2\text{d}$

$^{83\text{mKr}} \quad T_{1/2}=1.83\text{h}$

- $M,N...$
- L Shell
- K Shell

Atomic Bindings

Nuclear Levels

$^{83\text{Kr g.s.}} \quad 9/2^+ \quad 9.4\text{ keV}$

$^{83\text{Kr}} \quad 7/2^+ \quad T_{1/2}=154\text{ ns}$

$^{83\text{mKr}} \quad 1/2^- \quad T_{1/2}=32.1\text{ keV}$
Krypton Campaign

\[ ^{83m}\text{Kr} \rightarrow ^{83}\text{Kr g.s.} \]

- \( ^{83m}\text{Kr} \) (1/2-)
- \( T_{1/2} = 183\text{h} \)
- 32.1 keV decay
- 7/2+ state, \( T_{1/2} = 154\text{ns} \)
- 9.4 keV transition

Nuclear Levels

17.8 keV, 30.4 keV, 31.9 keV transitions

32.1 keV de-excitations
Krypton Campaign

\[ ^{83m}\text{Kr} \quad ^{83}\text{Kr} \text{ g.s.} \]

\[ T_{1/2} = 1.83 \text{h} \quad T_{1/2} = 154 \text{ ns} \]

Nuclear Levels

\[ 32.1 \text{ keV de-excitation} \quad 9.4 \text{ keV de-excitation} \]
Krypton Campaign

83mKr $^{1/2-} \quad T_{1/2} = 1.83h$

32.1 keV

7/2+ $\quad T_{1/2} = 154$ ns

9.4 keV

83Kr g.s. $^{9/2+}$

Nuclear Levels

K-32, L-32, M-32...

L Shell

K Shell

M1, N...

32.1 keV de-excitations

17.8 keV

30.4 keV

31.9 keV

9.4 keV de-excitations

L-9.4, M-9.4

M1-9.4...

L Shell

K Shell

M, N...

L1-32, L2-32...

M1-32, M2-32...

L-9.4, M-9.4

M1-9.4...
Two Kr Sources Utilized
(+One used in monitor spectrometer)

1) Condensed $^{83\text{m}}$Kr source (CKrS):

- Thin film of $^{83}$Rb (activity ~MBq) condensed on cold HOPG substrate, decays into $^{83\text{m}}$Kr
- Has thin, spot-like spatial distribution which can be moved around in the flux tube
Two Kr Sources

2) Gaseous $^{83}\text{mKr}$ source (gKrS):

- $^{83}\text{Rb}$ (activity $\sim$ 1 GBq) absorbed into zeolite beads (act as molecular sieve), releasing $^{83}\text{mKr}$ in its gaseous form into the WGTS
- Has homogeneous spatial distribution
- At a later time, can coexist with Tritium in the WGTS for on-the-spot calibrations
(Preliminary) Kr Results

High resolution line scan

Excellent energy stability

Line position stable, within design limit ($\pm 60\text{meV}$), shown here for $\sim 1$ week of L3-32 line scans using GKrS
(Preliminary) Kr Results

See also:

M. Arenz et al.,
**First Transmission of Electrons and Ions through the KATRIN beamline**
DOI: 10.1088/1748-0221/13/04/P04020

M. Arenz et al.,
**Calibration of high voltages at the ppm level by the difference of $^{83}\text{m} \text{Kr}$ conversion electron lines at the KATRIN experiment**
Journal: EPJC 78 P368 (2018)
DOI: 10.1140/epjc/s10052-018-5832-y

Watch for:
~ half dozen papers in final stages of KATRIN review
Status of First Tritium Running and Outlook

• **May 18 (9:48 am CEDT):** Very First Tritium
  ➡ Ion-Safety and sub-system check out
  ➡ $\text{D}_2$, $\text{D-T}$ & $\text{T}_2$ molecules
  ➡ ~1% Tritium

• **May 19:** First Energy Spectrum Measurement!

• **Ongoing:** First Tritium

• **June 7:** Commissioning results to be presented at **Neutrino 2018** by Prof. Diana Parno
Summary and Outlook

• **June 11**: KATRIN inauguration

• **Within the next year:**
  - Additional commissioning and Kr measurements
  - Initial Tritium datasets
  - Phase 0 sterile neutrino search begins
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Thank You!