The KATRIN Experiment

Diana Parno

CENPA, University of Washington

Lake Louise Winter Institute

22 February 2013

- Neutrino mass: An introduction
- Measuring $m_\nu$ via tritium decay
- The KATRIN experiment
Neutrino Mass: What Do We Know?

$$\begin{bmatrix}
\nu_e \\
\nu_\mu \\
\nu_\tau
\end{bmatrix}
$$

Flavor eigenstates
Neutrino Mass: What Do We Know?

$$\begin{bmatrix}
\nu_e \\
\nu_\mu \\
\nu_\tau \\
\end{bmatrix} =
\begin{bmatrix}
U_{e1} & U_{e2} & U_{e3} \\
U_{\mu1} & U_{\mu2} & U_{\mu3} \\
U_{\tau1} & U_{\tau2} & U_{\tau3} \\
\end{bmatrix}
\begin{bmatrix}
\nu_1 \\
\nu_2 \\
\nu_3 \\
\end{bmatrix}$$

- Flavor eigenstates
- PMNS matrix
- Mass eigenstates

The KATRIN Experiment -- Diana Parno
Neutrino Mass: What Do We Know?

• One closely spaced pair

\[ \Delta m_{21}^2 = (7.5 \pm 0.2) \times 10^{-5} \text{eV}^2 \]
Neutrino Mass: What Do We Know?

• One closely spaced pair
  \[ \Delta m_{21}^2 = (7.5 \pm 0.2) \times 10^{-5} \text{ eV}^2 \]

• One separated state
  \[ \Delta m_{32}^2 = (2.32^{+0.12}_{-0.08}) \times 10^{-3} \text{ eV}^2 \]
Neutrino Mass: What Do We Know?

- One closely spaced pair
  \[ \Delta m_{21}^2 = (7.5 \pm 0.2) \times 10^{-5} \text{eV}^2 \]

- One separated state
  \[ \Delta m_{32}^2 = \left(2.32^{+0.12}_{-0.08}\right) \times 10^{-3} \text{eV}^2 \]

- Upper limit from direct measurements at Mainz and Troitsk
  \[ \sum |U_{ei}|^2 m_{vi}^2 < 2\text{eV} \]
Neutrino Mass from $^3$H Decay

- $E_0 = 18.58$ keV
- $t_{\frac{1}{2}} = 12.3$ years
Neutrino Mass from $^3$H Decay

- $E_0 = 18.58$ keV
- $t_{\frac{1}{2}} = 12.3$ years

The KATRIN Experiment -- Diana Parno
Neutrino Mass from $^3$H Decay

- $E_0 = 18.58$ keV
- $t_{1/2} = 12.3$ years

The KATRIN Experiment - Diana Parno

C. Weinheimer
KArlsruhe TRITium Neutrino Experiment

• High-resolution integrating high-pass filter
  – Same principle used to establish present limit
• Map $T_2$ beta spectrum near endpoint
KARlsruhe TRITium Neutrino Experiment

• High-resolution integrating high-pass filter
  – Same principle used to establish present limit

• Map $T_2$ beta spectrum near endpoint

• MAC-E filter:
  – Magnetic adiabatic collimation

Image: Karlsruhe Institute of Technology
KArlsruhe TRItium Neutrino Experiment

- High-resolution integrating high-pass filter
  - Same principle used to establish present limit
- Map $T_2$ beta spectrum near endpoint
- MAC-E filter:
  - Magnetic adiabatic collimation
  - Electrostatic filter (adjustable retarding potential)

Image: Karlsruhe Institute of Technology
KATRIN at a Glance

Images: Karlsruhe Institute of Technology
KATRIN at a Glance

Gaseous $T_2$ source

$^3\text{H}$, $\beta$ decay, $e^-$, $10^{10}$ $e^-$/$s$, $E = 18600$ eV, $^3\text{He}$

Images: Karlsruhe Institute of Technology

The KATRIN Experiment -- Diana Parno
KATRIN at a Glance

Gaseous $T_2$ source

Transport section

Images: Karlsruhe Institute of Technology
KATRIN at a Glance

Gaseous T$_2$ source

Transport section

Spectrometers

Images: Karlsruhe Institute of Technology
KATRIN at a Glance

Gaseous $T_2$ source

Transport section

Spectrometers

Images: Karlsruhe Institute of Technology

The KATRIN Experiment -- Diana Parno
KATRIN at a Glance

Gaseous $T_2$ source

Transport section

Spectrometers

Pre-  Main

Images: Karlsruhe Institute of Technology
KATRIN at a Glance

Gaseous $T_2$ source

Transport section

Spectrometers

Detector

Images: Karlsruhe Institute of Technology

The KATRIN Experiment -- Diana Parno
KATRIN at a Glance

Gaseous $T_2$ source

Transport section

Spectrometers

Pre-

Main

Detector

Voltage Divider

Images: Karlsruhe Institute of Technology

The KATRIN Experiment -- Diana Parno
KATRIN at a Glance

Gaseous T$_2$ source

Transport section

Spectrometers

Detector

Images: Karlsruhe Institute of Technology
KATRIN by the Numbers

• Expected $m_\nu$ sensitivity in 5 years: 0.2 eV at 90% CL
KATRIN by the Numbers

• Expected $m_\nu$ sensitivity in 5 years: 0.2 eV at 90% CL

• Source activity: $10^{11}$ decays/second
KATRIN by the Numbers

• Expected $m_\nu$ sensitivity in 5 years: **0.2 eV** at 90% CL

• Source activity: $10^{11}$ decays/second

• Tritium reduction factor: $10^{14}$
KATRIN by the Numbers

- Expected $m_\nu$ sensitivity in 5 years: 0.2 eV at 90% CL
- Source activity: $10^{11}$ decays/second
- Tritium reduction factor: $10^{14}$
- Minimum B field: 3 G
- Maximum B field: 60 kG
KATRIN by the Numbers

- Expected $m_\nu$ sensitivity in 5 years: **0.2 eV** at 90% CL
- Source activity: $10^{11}$ decays/second
- Tritium reduction factor: $10^{14}$
- Minimum B field: 3 G
- Maximum B field: 60 kG
- Expected background: $\leq 10$ mHz in ROI
KATRIN by the Numbers

• Expected $m_\nu$ sensitivity in 5 years: **0.2 eV** at 90% CL

• Source activity: $10^{11}$ decays/second

• Tritium reduction factor: $10^{14}$

• Minimum B field: 3 G

• Maximum B field: 60 kG

• Expected background: $\leq 10$ mHz in ROI

• Expected main-spec resolution: 0.93 eV
KATRIN by the Numbers

• Expected $m_\nu$ sensitivity in 5 years: **0.2 eV** at 90% CL

• Source activity: $10^{11}$ decays/second

• Tritium reduction factor: $10^{14}$

• Minimum B field: 3 G

• Maximum B field: 60 kG

• Expected background: $\leq 10$ mHz in ROI

• Expected main-spec resolution: 0.93 eV

• Main spectrometer volume: 1400 m$^3$
The Main Spectrometer

Leopoldshafen, Germany
November 2006
The Main Spectrometer

Leopoldshafen, Germany
November 2006

Photo: Karlsruhe Institute of Technology
• Measure source composition ($T_2$, DT, HT,...)
  – Gas dynamics
  – Final state spectra
LAser Gas RAman Spectroscopy

- Measure source composition ($T_2$, DT, HT,...)
  - Gas dynamics
  - Final state spectra
- Continuous monitoring via inelastic Raman scattering
• Measure source composition ($T_2$, DT, HT,...)
  – Gas dynamics
  – Final state spectra
• Continuous monitoring via inelastic Raman scattering
• Recent test results:
  – 0.1% precision in 250 sec
  – 3% accuracy

S. Fischer et al., Fusion Sci. Tech. 60 (2011) 925
Focal-Plane Detector System

Pinch magnet 6 T

Detector magnet 3.6 T
Focal-Plane Detector System

Pinch magnet
6 T

Detector magnet
3.6 T

Post-acceleration electrode
Focal-Plane Detector System

Pinch magnet
6 T

Detector magnet
3.6 T

148-pixel PIN diode
custom from Canberra

Post-acceleration electrode
Focal-Plane Detector System

- Pinch magnet: 6 T
- Detector magnet: 3.6 T
- Calibration
- Post-acceleration electrode

**241Am spectrum**

- Cu X-rays
- 237Np
- 241Am

**148-pixel PIN diode**

**241Am spectrum**

(1.40±0.01 keV FWHM)

- Deposited energy (keV)
- Events / 50 eV
The Detector in Action
Recent Milestones

• Main spectrometer bake-out complete
  – Pressure in vessel: $6 \times 10^{-11}$ mbar

• Detector-system commissioning underway
  – 146/148 working channels
  – Energy resolution, 18.6 keV: $1.48 \pm 0.01$ keV (FWHM)
  – Magnetic field drift < 0.014%/month
The Future

- **March**: Connect main spectrometer and detector system
- **April**: Begin commissioning main spectrometer
  – Transmission measurement with electron gun
- **2014**: Completion of tritium sections
- **Late 2015**: Begin data-taking for neutrino mass
The Future

- **March**: Connect main spectrometer and detector system
  - Transmission measurement with electron gun
- **April**: Begin commissioning main spectrometer
- **2014**: Completion of tritium sections
- **Late 2015**: Begin data-taking for neutrino mass

The KATRIN Experiment -- Diana Parno
The KATRIN Collaboration

- Institute for Nuclear Research, Troitsk
- Karlsruhe Institute for Technology
- Lawrence Berkeley National Laboratory
- Max Planck Institut für Kernphysik, Heidelberg
- Nuclear Physics Institute of the ASCR
- Massachusetts Institute of Technology
- University of Applied Science, Fulda
- University of Bonn
- University of California, Santa Barbara
- University of Mainz
- University of Münster
- University of North Carolina
- University of Swansea
- University of Washington
- University of Wuppertal

150 collaborators
5 countries

Thank you!