Status of the KATRIN Experiment

Sixteenth Lomonosov Conference on Elementary Particle Physics
2013/08/23, Moscow State University

- Brief Introduction to KATRIN
- First Measurements with Spectrometer and Detector Section (Transmission Fktn, BG Spektra, Rn related BG)
- Status of Source and Transport System
Absolute Neutrino-Mass Scale

**cosmology:** role of relic-ν’s as hot dark matter \( (W_n) \)

**particle physics:** absolute neutrino mass scale \( (m_n) \)

---

**mass degeneracy**

\[ \sum_{i=1}^{3} m_i \]

\[ m_1, 2, 3 \]

---

**mass hierarchy**

\[ \sqrt{\Delta m^2} \sim m_i \]

---

**What are the masses of the three known Neutrino species?**
Neutrino Mass: Status and Perspectives

Input from Cosmology:

- measures $\Sigma m_i$ and HDM $\Omega_\nu$
- very sensitive, but model dependent!
- Planck: $\Sigma m_i < 0.23 - 1.31$ eV
  (Planck 2013 results. XVI. Cosm. param. arXiv:1303.5076v1)
- potential: $\Sigma m_i = 20-50$ meV
  (Planck, LSST, weak lensing)
Neutrino Mass: Status and Perspectives

status and potential of neutrino masses in lab experiments

kinematics of $\beta$-decay

absolute $\nu_e$-mass: $m_\nu$

model-independent

squared neutrino mass:

$$m_{\nu e}^2 = \sum_i |U_{ei}|^2 \cdot m_{\nu i}^2$$

direct, from kinematics

status: $m_\nu < 2.0$ eV

(PDG using Mainz and Troitsk results)

potential: $m_\nu = 200$ meV

MARE, Project 8, KATRIN

search for 0$\nu\beta\beta$

eff. Majorana mass $m_{\beta\beta}$

model-dependent (CP-phases)

effective Majorana mass $m_{\beta\beta}$

probe $\nu$ as Majorana particle:

status: $m_{\beta\beta} < 0.35$ eV, evidence?

potential: $m_{\beta\beta} = 20-50$ meV

GERDA, EXO, SNO+, MAJORANA, Cuore, KamLAND-Zen, ...
KATRIN experiment – overview

Source & Transport Section (STS)

tritium source: $10^{11}$ $\beta$-decays/s

ideal $\beta$-emitter

$^3$H: super-allowed

$E_0$  $18.6$ keV

t$_{1/2}$  $12.3$ y

$^3$H $\rightarrow^3$He $+$ $e^-$ $+$ $\bar{\nu}_e$


Spectrometer & Detector Section (SDS)

total background: $10^{-2}$ cps

Ideal $\beta$-emitter

$^3$He + $e^-$ + $\bar{\nu}_e$

region close to $\beta$ end point

$m(\nu_e) = 0$ eV

only 2 x $10^{-13}$ of all decays in last 1 eV

$m(\nu_e) = 1$ eV

KATRIN sensitivity

- **reference n-mass sensitivity**
  for 3 ‘full beam‘ years:
  - statistical & systematic errors
    contribute equally:
    statistics: $\sigma_{\text{stat}} = 0.018 \text{ eV}^2$
    systematics: $\sigma_{\text{syst}} < 0.017 \text{ eV}^2$

  **sensitivity** $m(\nu) = 200 \text{ meV (90\% CL)}$

  350 meV (5 $\sigma$)

- **requirements**
  - precise knowledge of systematics
    (mainly related to source properties)
  - precise knowledge of spectrometer properties
  - Very low background $\leq 10^{-2}\text{cps}$
Spectrometer commissioning

- 2013 first period of data-taking with entire spectrometer/detector
  - successful bake-out of spectrometer vessel at 300 °C
  - first light achieved May 31st
  - extensive commissioning measurements ongoing:
    - BG characteristics
    - Optimize el.-mag. Layout
    - Meas. TF with egun
    - BG removal methods

All Data Preliminary!
Transmission Function Measurement

Angular selective E-Gun:
• Ag layer (30 nm) on glas fiber,
  back-illuminated by UV-LED or LASER (260 -310 nm)

K. Valerius et al.,
Prototype of an angular-selective photoelectron calibration source for the KATRIN experiment,
JINST 6:P01002 (2011)

V. Hannen et. al., WWU Münster
Angular selective E-Gun:
• For a mono-energetic and mono-angular source:
  TF is step-function

\[ \mu = \frac{E_{\perp}}{B} = \text{const.} \]

Energy resolution @ 18.6 eV:
\[ \Delta E = E \cdot \frac{B_{\text{min}}}{B_{\text{max}}} = 0.93 \text{ eV} \]
Transmission function at $U_0 = -200$ V, UV-LED with 290nm
Energy resolution dominated by energy spread of the e-gun $\sim 0.09$ eV
Transmission function at $U_0 = -200$ V, UV-LED with 290nm

Energy resolution dominated by energy spread of the e-gun $\sim 0.09$ eV
First Background Measurements @ -18.6 kV

- Vessel and wire electrode on -18.6 kV
- Raw data after Energy Callibration
- Magnetic Fields: $B_{\text{max}} = 5 \text{T}$, $B_{\text{min}} = 3.8 \text{ G}$
- Only real time low energy threshold cut

Linear Scale

Preliminary!
First Background Measurements @ -18.6 kV

- Data after Cuts (Multipixel, Veto, Energy…)
- Red lines indicate the Region of Interest (ROI)
  \[ U_{\text{Vessel}} - 3\text{kV}, U_{\text{vessel}} + 2\text{kV} \]
First Background Measurements @ -18.6 kV

- Rate Trend after Cuts in the ROI
- Rate: 1116 ± 10 mcps
First Background Measurements @ -18.6 kV/-18.4 kV

- Rate Trend after Cuts in the ROI
- Vessel on -18.4 kV, wire electrode on -18.6 kV
- Rate: 757 ± 15 mcps

Repelling of electrons from the wall induced by CR works well on a sub-dominant level

Preliminary!
What do these results mean for KATRIN?
Flashback to 15th Lomonosov Conference

- **Pre-spectrometer background investigations**
  - Novel bg-source: $^{219,220}$Rn produce electrons in the keV-range, which are trapped & generate **enhanced bg-levels for up to several hours**

---

F.M. Fränkle et al., Astropart. Phys. 35 (2011) 128
Solution for the Main Spectrometer

Radon emitting from getter is blocked by LN cooled baffels by cost of 55% pumping speed For Hydrogen

NEG-pump
(3 x 1.000 m SAES St707 getter)

liquid nitrogen cooled baffle

Radon

H₂
First Baffle Test

Vessel on 0V, electrodes on -600V, $B_{\text{max}}=5\text{T}$,

Cool down of Baffle 2, Baffle 1 cold, Baffle 3 warm,

Warming up of all three Baffles

Background Suppression of a factor of 5
→ Not jet sufficient for KATRIN design sensitivity
Implications for main spectrometer

non-Poissonian nature of Rn-induced background has the potential to limit neutrino mass sensitivity of KATRIN

need novel background reduction techniques

TDR-benchmark: $r_{bg} = 0.01 \text{ cps}$

S. Mertens et al., Astropart. Phys. 41 (2013) 52
Background reduction techniques

**Active methods**
- fast removal of stored electrons by breaking of trapping condition

**Cyclotron Resonance**
- apply RF-field tuned to cyclotron frequency
  \[ \omega_{RF} = \omega_{cycl} \]
  all electron energies

**Magnetic Pulse**
- zero central B field to induce drift to wall
  high energies (E > 1 keV)

**Electrostatic Dipole**
- apply transversal dipole to drift electrons to wall
  low energies (E < 1 keV)
Background reduction techniques

- **Active methods**
  - fast removal of stored electrons by breaking of trapping condition

**Cyclotron Resonance**
- apply RF-field tuned to cyclotron frequency

\[ \omega_{RF} = \omega_{cycl} \]
all electron energies

**Magnetic Pulse + Electrostatic Dipole**

![Graph showing trapping probability vs electron energy](image)

- Trapped
- Magnet pulse
- Dipole
- combined

22 23.08.2013 16th Lomonosov Conference on Elementary Particle Physics, Moscow Lutz Bornschein
Spectrometer commissioning

Next Steps:

- Transmission function @ 18.6 kV (30 kV)
- LN2 Baffle on HV
- Test of active BG suppression Techniques

→ Qualify Main Spectrometer for Tritium Operation in 2015
STS: WGTS – principle

10 m long beam tritium tube (Ø = 90 mm)

T = 30 K

$\rho d = 5 \cdot 10^{17} \text{ mol/cm}^2$

$10^{11}$ $\beta$-decays/s

Windowless Gaseous Tritium Source
STS: WGTS – principle:

**Inner loop:**
stable (±0.1%) tritium injection

**Outer loop:**
high (>95%) and stable (±0.1%) tritium purity

- Buffer vessel
- Laser Raman
- Pressure controlled buffer vessel
- Permeator
- Pump
- Waste
- Δp
- Conductance L
- WGSTS
Status Source and Transport Section:

- $10^{-3}$ stability of tritium source column density
- $10^{-3}$ isotope content in source
- $10^{-5}$ non-adiabaticity in electron transport
- $10^{-6}$ monitoring of HV-fluctuations
- $10^{-8}$ remaining ions after source
- $10^{-14}$ remaining flux of molecular tritium

many benchmark parameters reached or exceeded
**Tritium Laboratory Karlsruhe – TLK**

- **TLK**: unique large research facility at KIT for KATRIN and fusion (ITER)
  - 20 years of experience in tritium handling and processing, 24 g on-site

---

B. Bornschein et al., *Fusion Sci. Techn. 60* (2011) 1088
Status of WGTS

s.c. magnets

mechanical assembly
Status of WGTS

Present works:
- finalising of assembly procedure steps
- start mounting of WGTS after summer break, aim: finish cryostat in Q1/2015
Status of Transport Section

Tasks:
- Adiabatic guiding of electrons to the spectrometers
- Reduction of tritium flow rate by $> 10^{14}$

- differential pumping section DPS
  active pumping by TMPs

- cryogenic pumping section CPS
  cryosorption on Ar-frost

Commissioning of both systems in 2014
Summary

- Measurements with the KATRIN Spectrometer Detector System have started.
- Spectrometer works as MAC-E-Filter.
- Preliminary results of BG measurements confirm the predictions of simulations.
- BG still too high for tritium measurements. 
  → use LN2-cold Baffle to freeze out Rn and apply active counter measures.

KATRIN member institutes
Summary

- Building of Source and Transport Components (WGTS Cryostat, CPS, DPS, Rear System) is proceeding
- Many benchmark parameters reached or exceeded
- Commissioning of Transport Section in 2014
- Finish WGTS Cryostat Beginning of 2015

Thanks for your attention!

KATRIN member institutes
Back up slides
KATRIN Main Detector

- Si-PIN diode
- detection of transmitted $\beta$’s (mHz to kHz)
- low background for $T_2$ endpoint investigation
- high energy resolution:
  \[ \Delta E = 1.48(1) \text{ keV (FWHM)} \text{ at } 18.6 \text{ keV} \]
- 12 rings with 30° segmentation + 4-fold center = 148 pixels
  - minimize bg, investigate systematic effects
  - compensate field inhomogeneities of spectrometer’s analyzing plane.
KATRIN Main Detector

- detector commissioning completed
- first light from spectrometer – May 2013
Pixelviews

- Multipixel cut applied. I.e. events with a time difference below 1us on FPD are assumed to be induced by charge sharing on the wafer between neighbored pixel. In background measurements this cut should not affect the 'good events' due to the high interarrival times at a rate of ~1cps.

- Veto cut applied. I.e. events on the FPD which are in a coincidence frame of (-1us,+1us) with events of the detector veto are excluded. Small impact!

- Measurement with vessel and inner electrodes at 18.6 kV.
- energy ROI (U_Vessel-3keV, U_Vessel+2keV).
- Left: All pixels included.
- Right: Cut on all pixels which see the flapper valve (flappercut) or the detector vacuum chamber (detectorcut) due to the misalignment of the FPD system.
tritium retention techniques

injection

tritium bearing components

tritium free

tritium flow rate [mbar Q/s]

\(10^1\)
\(10^{-1}\)
\(10^{-3}\)
\(10^{-5}\)
\(10^{-7}\)
\(10^{-9}\)
\(10^{-11}\)
\(10^{-13}\)
\(10^{-15}\)
\(10^{-17}\)

differential & cryo- pumping
Investigation of source systematics

- **control of source systematics:**
  - near-time control/monitoring systems for key parameters
  - successful large-scale test experiments (WGTS demonstrator)
  - improved source modelling: quasi-3D gas flow

---

M. Babutzka et al., New Journal of Physics 14 (2012) 103046
Activity monitoring of the WGTS

WGTS strength = $A_Q \cdot \rho d \cdot \varepsilon_T$

Rear wall

Required stability $\leq 10^{-3}$
$t_{\text{meas}} \leq 1000$ s
Beta Induced X-ray Spectrometry (BIXS)

Si, Be, Al, Cu, Al₂O₃

\[ \text{WGTS strength} = A_Q \cdot \rho d \cdot \varepsilon_T \]

Rear wall

\[ \text{Au} > 45 \text{ nm} \]

Required stability \( \leq 10^{-3} \)

\( t_{\text{meas}} \leq 1000 \text{ s} \)
Beta Induced X-ray Spectrometry (BIXS)

Si, Be, Al, Cu, Al₂O₃

\[ e^- \rightarrow T_2 \rightarrow \gamma \]

\[ \text{WGTS strength} = A_Q \cdot \rho d \cdot \varepsilon_T \]

Gold >45 nm

Required stability \( \leq 10^{-3} \)

\[ t_{\text{meas}} \leq 1000 \text{ s} \]

Integral count rate vs. total pressure (mbar)

\[ y = (1953.0 \pm 1.8) \cdot x + (45.2 \pm 0.6) \]

\[ \varepsilon_{Q2} = (94 \pm 5)\% \]

TriReX results
BIXS mock-up TriReX (Tritium Rear Wall Experiment) shows:

- Linear detector response
- 0.1% activity changes detectable in <1000s (count rate >10^4 cps at 10^{11} Bq)
- 200 μm Be-window is an efficient permeation barrier

**BUT** memory effect was measured B/S ≈ 0.7% (after 30 days @ 1 mbar)

[Roe12] Activity monitoring of a gaseous tritium source by beta induced X-ray spectrometry
Activity change on the 0.1% level in TriReX

$A = 10^{10}$ Bq

$\Delta V/V = (0.20 \pm 0.10)\%$

$\Delta A/A = (0.29 \pm 0.09)\%$

$T_{mess} = 1000 \text{ s}$

TriReX results

$(2277.77 \pm 1.65) \text{ s}^{-1}$

$(2271.11 \pm 1.04) \text{ s}^{-1}$
Radon is not affected by electric or magnetic fields 
⇒ can decay inside the volume of the spectrometer.

A(Rn-219) ~ 8 Bq
released activity ~1‰
alpha-Decays in the Pre-Spectrometer

Spectrometers are like magnetic bottles: primary electron creates secondary electrons via ionization of residual gas molecules.

- Magnet: $I = 157\text{A}$, $B = 4.5\text{T}$
- Detector
- Pressure: $p \sim 5 \times 10^{-10}\text{mbar}$
- Tank & electrodes: $U = -18\text{kV}$
- Cone and wire: $U = -18.5\text{kV}$

A single trapped electron produces thousands of secondary electrons.
Result: Time Dependent Background

F. M. Fränkle et. al.: “Radon induced background processes in the KATRIN pre-spectrometer”, Astroparticle Physics Vol. 35, Iss. 3, October 2011, 128-134
Baffle Setup at Pre-Spectrometer

Radon emanating from the getter freeze to the cold surface of the Baffle.
Pre-Spectrometer measurements showed:

a Baffle in combination with a cold trap will be essential for successful main spectrometer experiments.

→ currently installed at the main spectrometer.

elevated Background due to Rn decay has vanished.