Karlsruhe Tritium Neutrino Experiment

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University of Washington

Outline:

Brief KATRIN Introduction

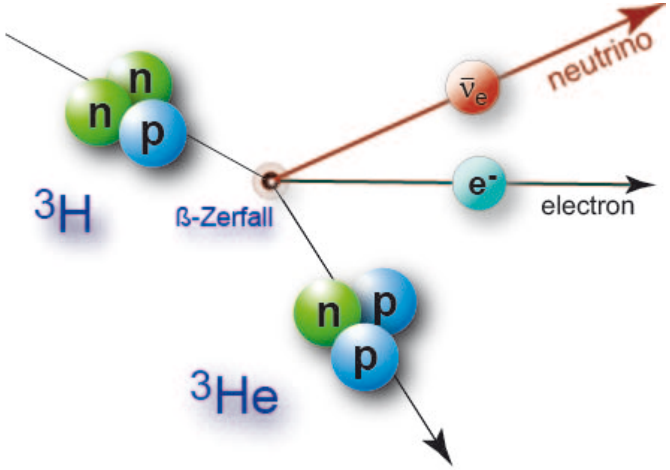
Source Considerations

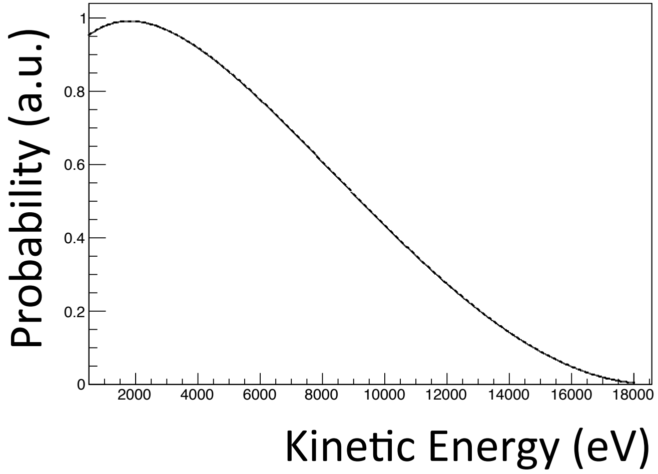
Spectrometer Commissioning

Outlook & Milestones

Neutrino Mass: Direct Measurement

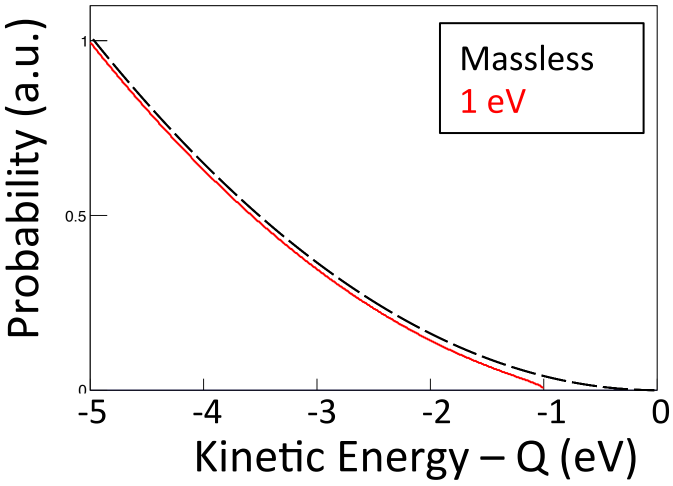
- Shape of T_2 beta spectrum near the endpoint



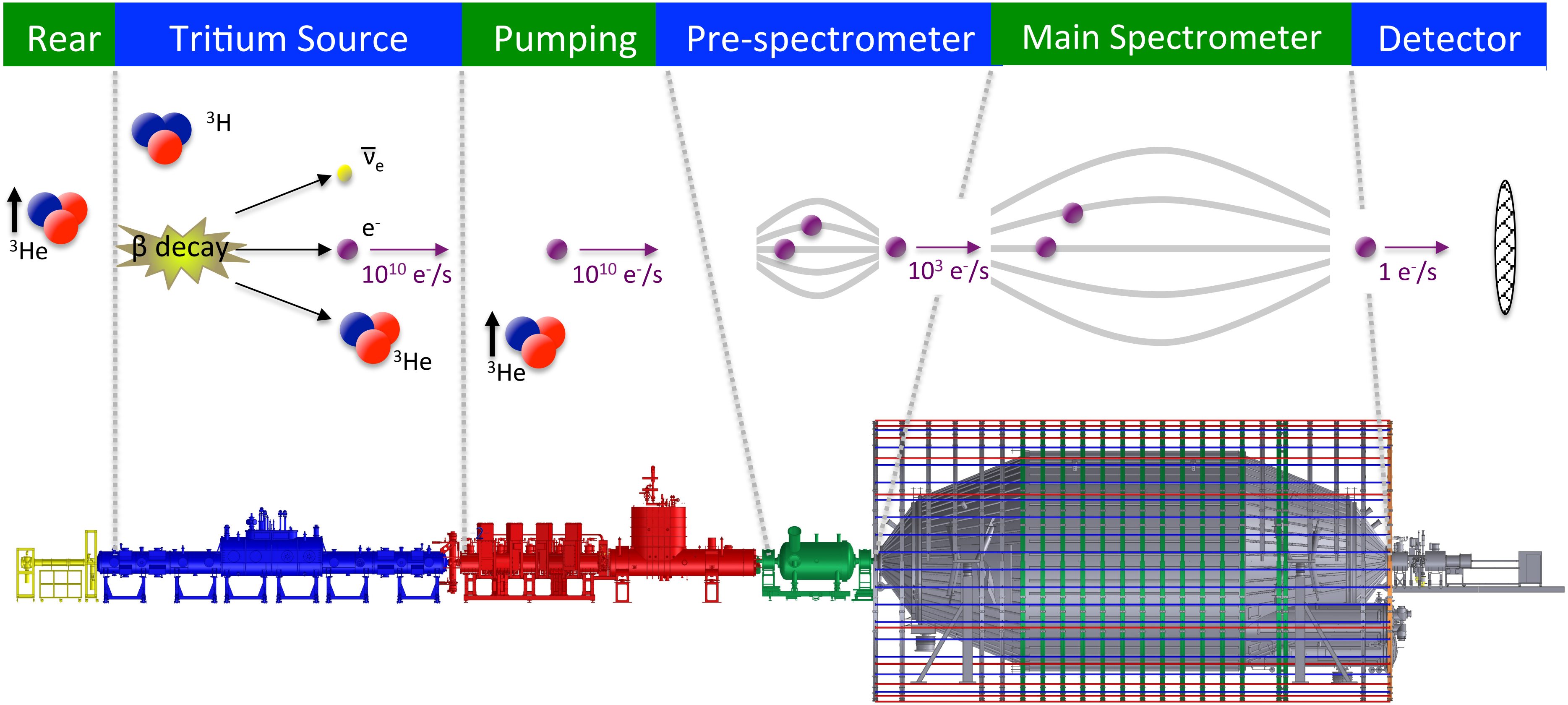


- Kinematic constraint
- Tritium (T_2)
- Best laboratory limits

$m_\nu < 2$ eV

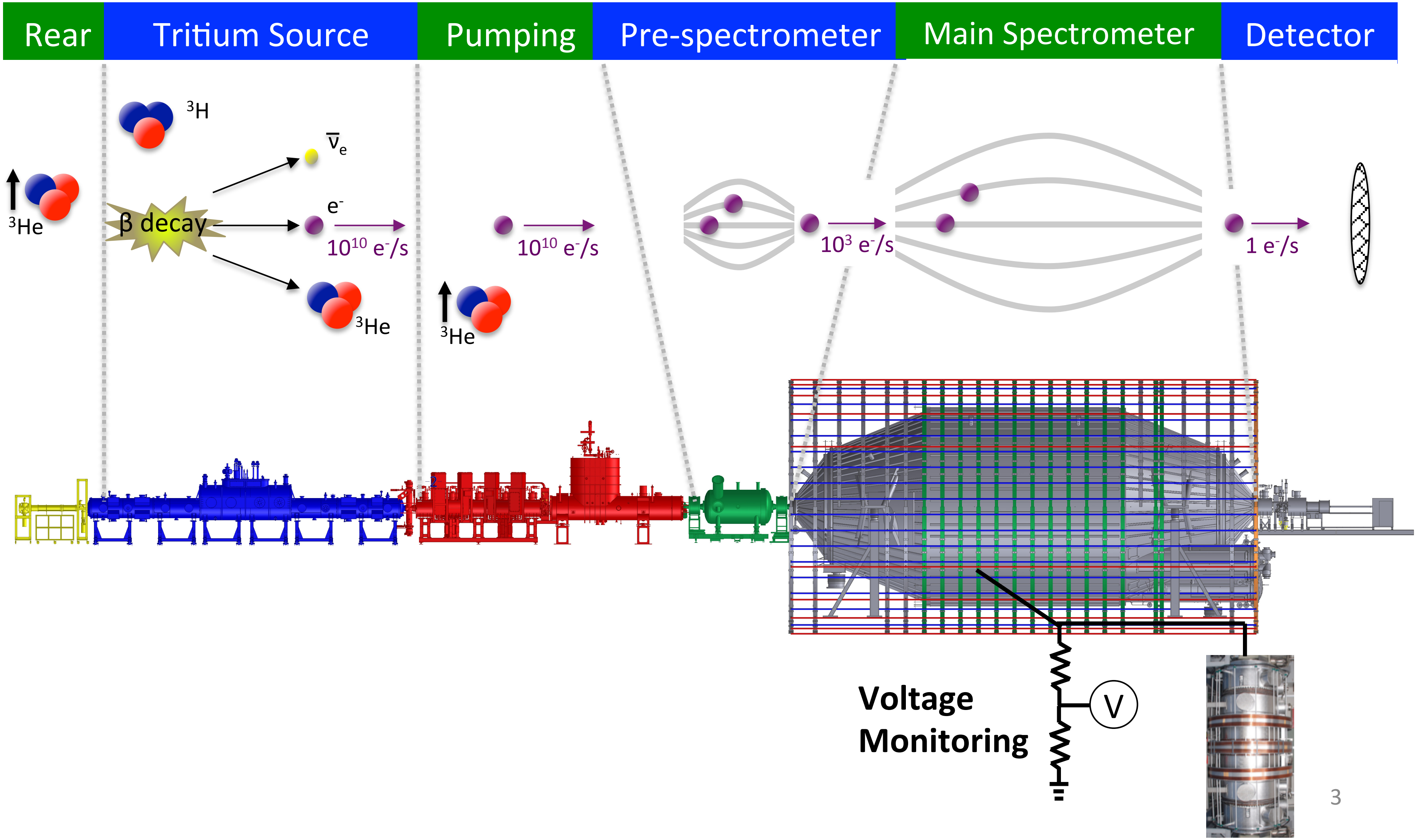


KATRIN in one figure



Pressure	10^{-3} mbar	10^{-11} mbar	10^{-11} mbar	10^{-11} mbar
Voltage	±1 kV	18.4 kV	18.574 kV	±30 kV

KATRIN in one figure



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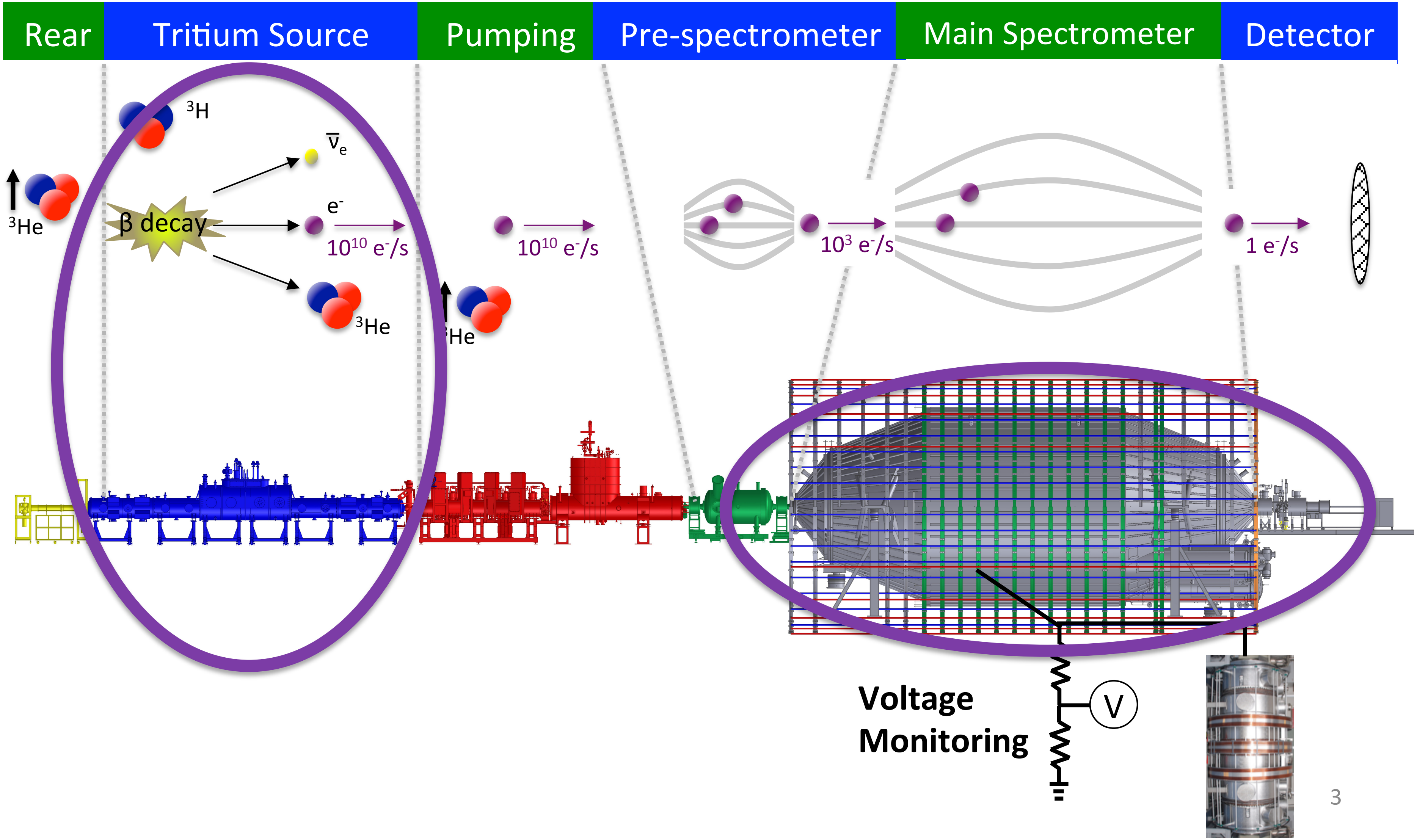
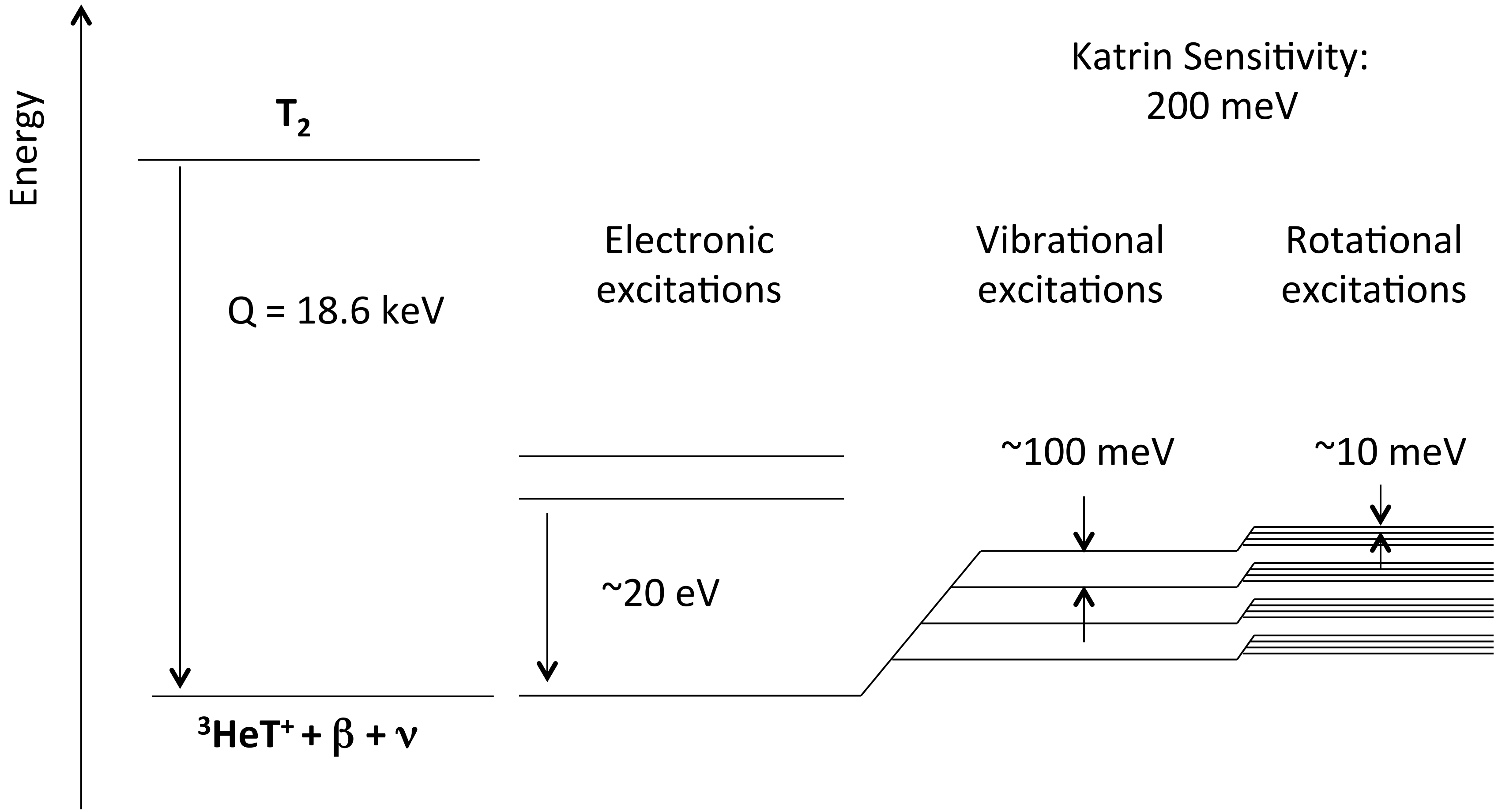


KATRIN by the Numbers

- Expected m_ν sensitivity in 5 calendar 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: 60,000 G
- Design main-spec resolution: 0.93 eV
- Main spectrometer volume: 1400 m^3

Molecular T_2 Beta Decay Levels



Energy

Katrin Sensitivity:
200 meV

T_2

Q = 18.6 keV

$^{3}HeT^{+} + \beta + \nu$

Electronic
excitations

~20 eV

Vibrational
excitations

~100 meV

Rotational
excitations

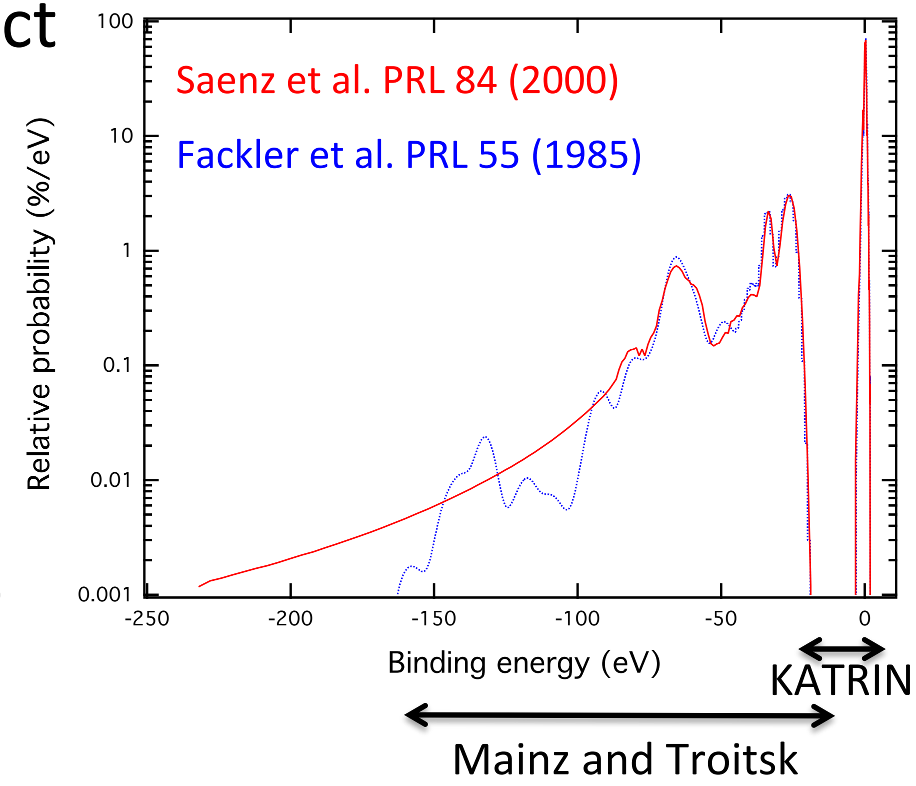
~10 meV

Molecular Source Considerations

- Molecular excitations affect beta spectrum!

$$\Delta m_\nu^2 \simeq -2\Delta\sigma_{\mathrm{FSD}}^2$$

- *Ab initio* final-state distribution calculations
  - Standard geminal basis
  - A. Saenz (Humboldt-Berlin)
- Combine distributions for each state, species, …



Details in arXiv:1502.03497

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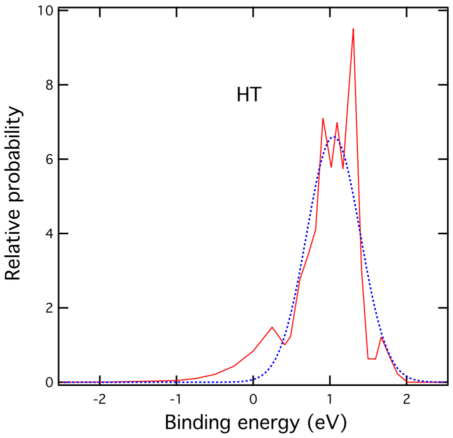

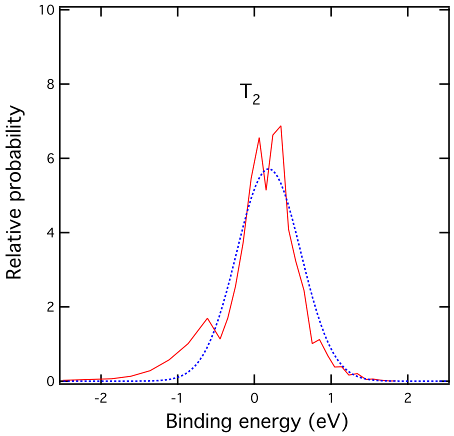

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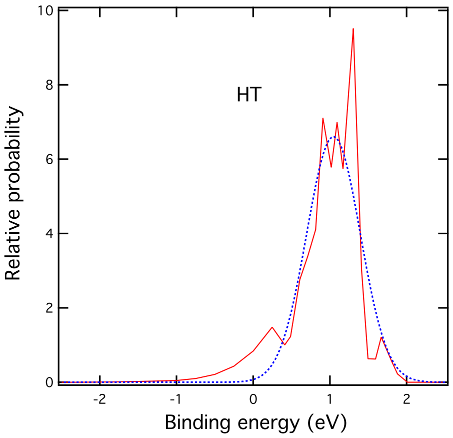
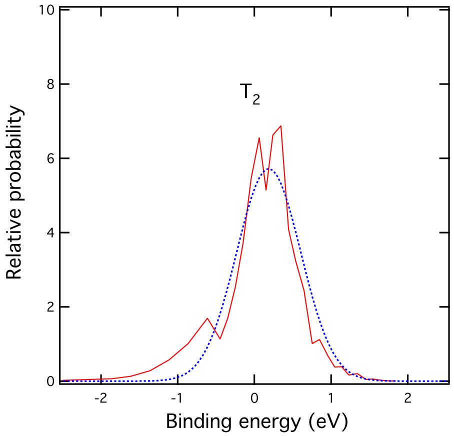
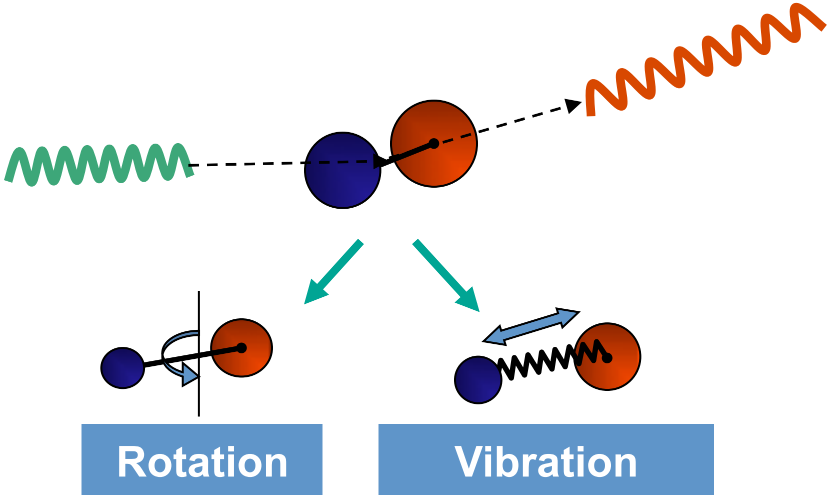




Need to know both the **isotopic** and **rotational state** gas composition very well.

Laser Raman Spectroscopy

- Composition of source (T_2, DT, HT, J states)
  - Gas dynamics
  - Final state spectra
- Continuous monitoring of tritium purity
- Recent test results:
  - 0.1% precision in 20 sec
  - 3% accuracy



S. Fischer et al., *Fusion Sci. Tech.* **60** (2011) 925

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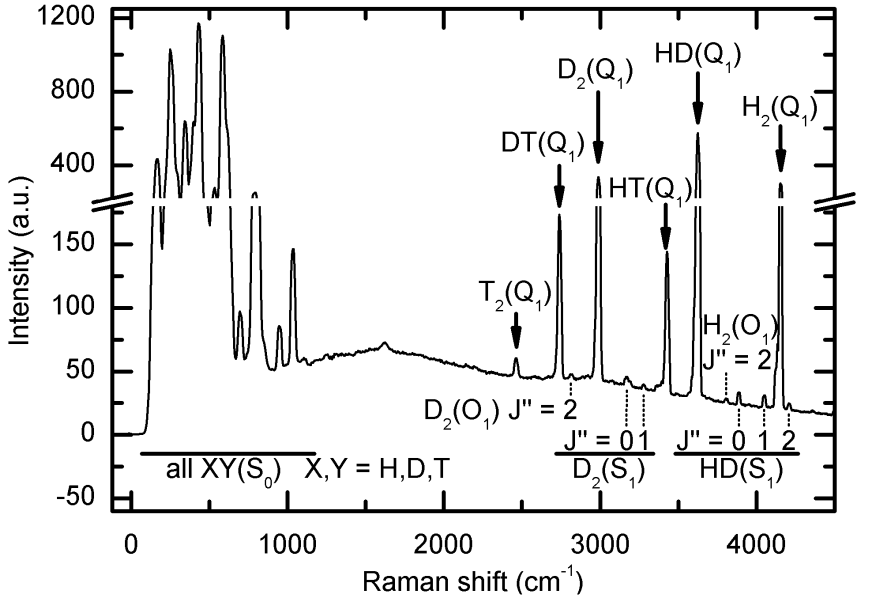

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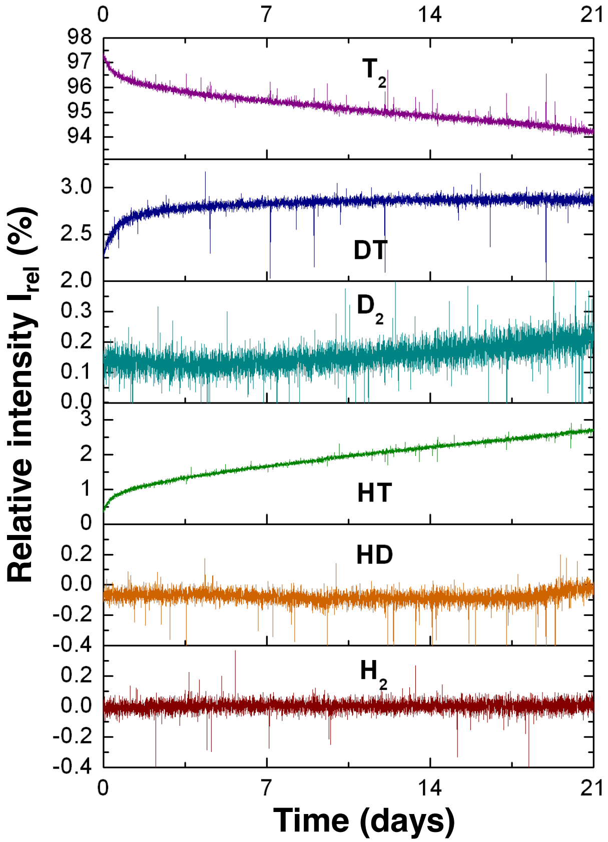

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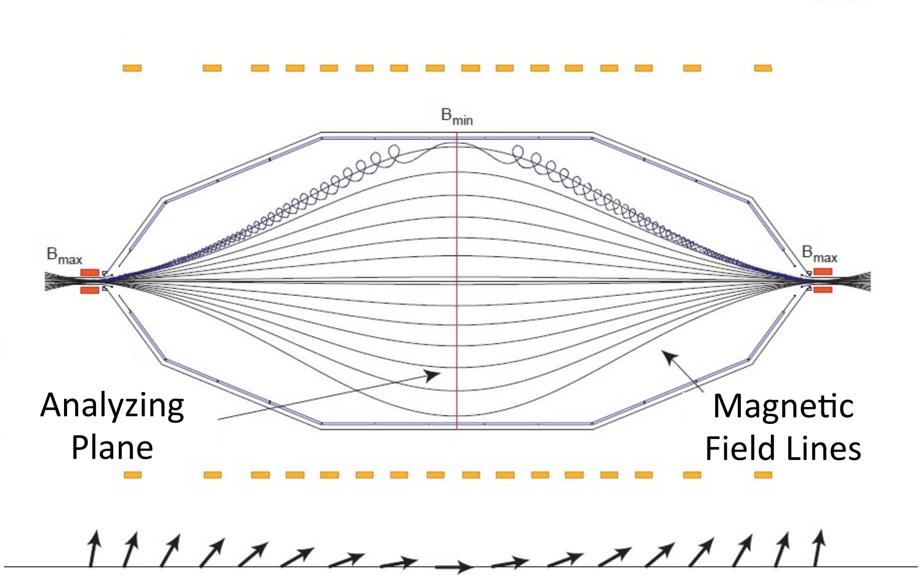
The Main Spectrometer

- Magnetic Adiabatic Collimation with an Electrostatic Filter (MAC-E)
- Wire Plane Electrode
  - 2 wire layers
  - Installation finished January 2012
- Ultrahigh Vacuum
  - Goal: 10^{-11} mbar
  - Turbo, NEG and cryo pumps



Electron momentum transformation

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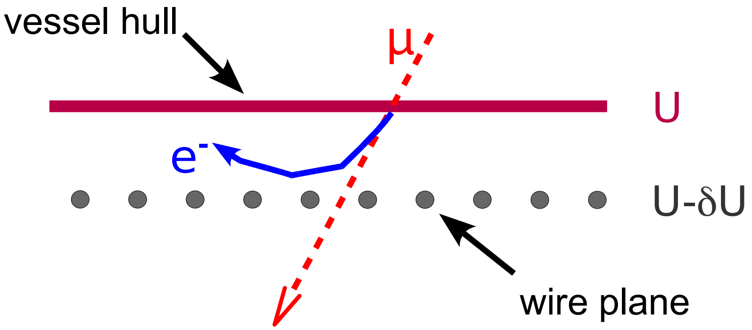

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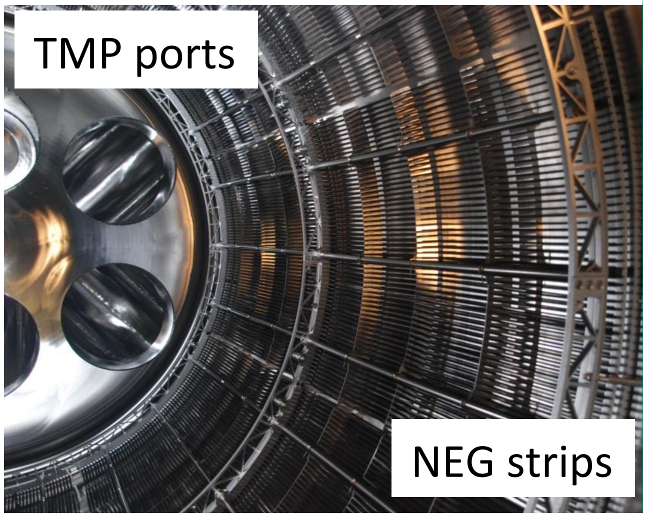
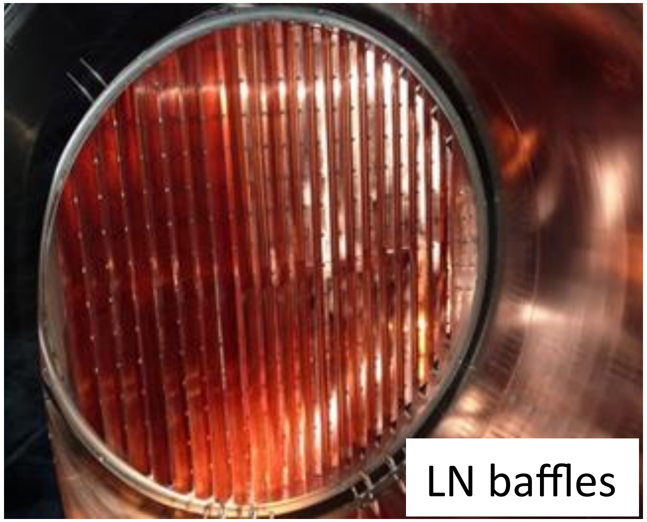
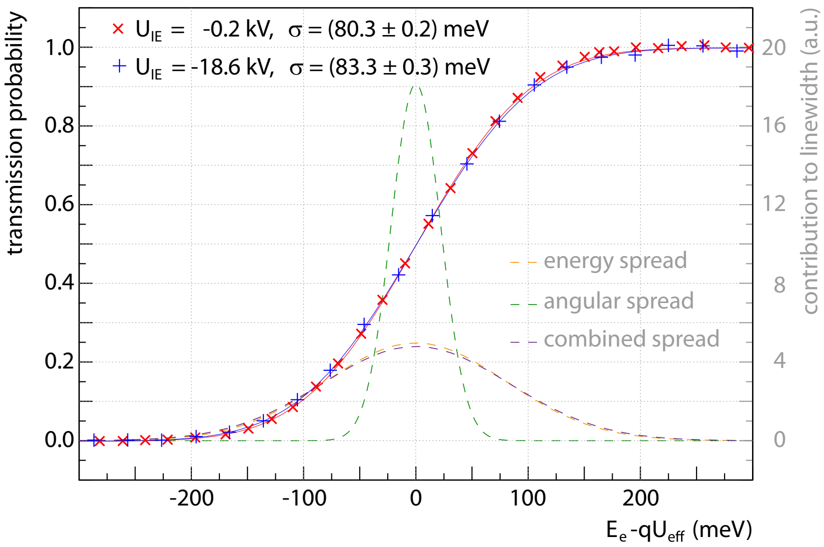


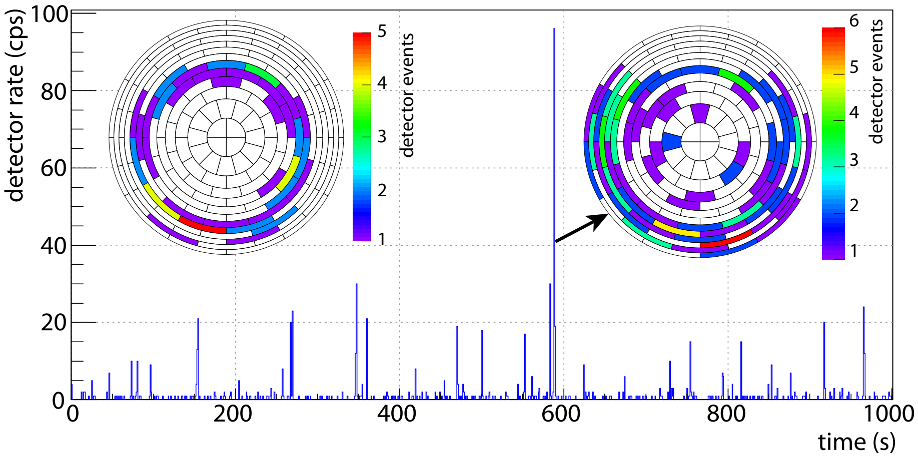


Spectrometer Commissioning

- Vacuum performance
  - Achieved 10^{-10} mbar
  - NEG and LN baffle repairs
- Transmission tests
  - No Penning discharges
  - Works as MAC-E Filter
  - Angular selective e-gun
- First look at Backgrounds
  - Radon, cosmics, etc.

Data taken Summer 2013



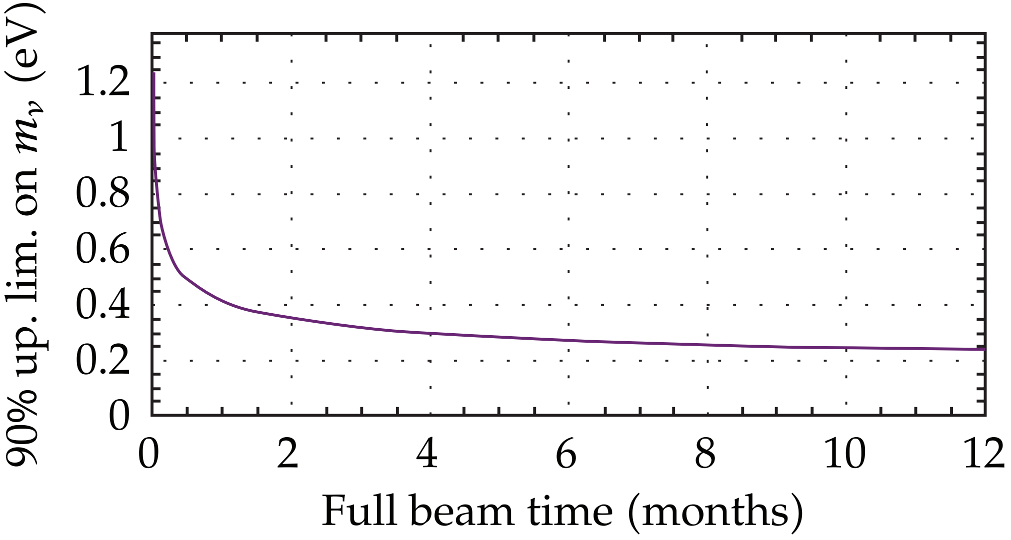


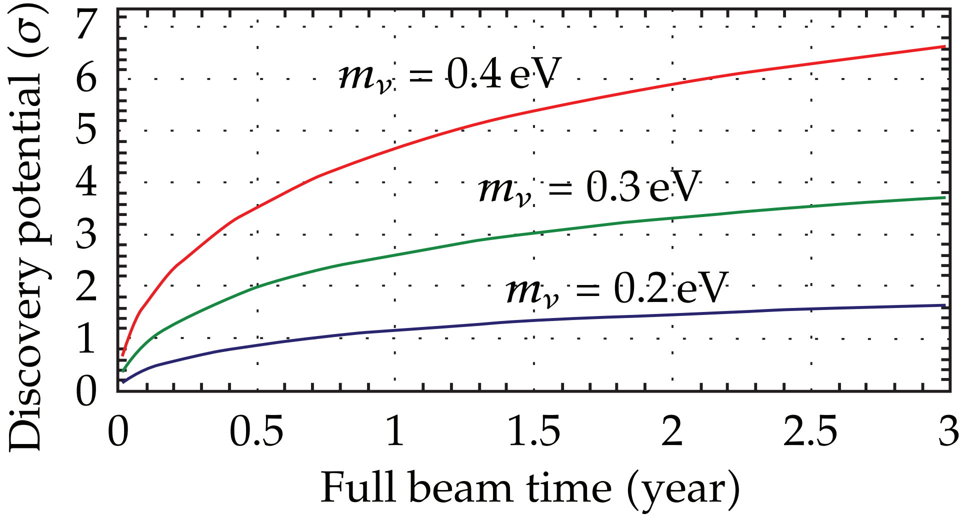
Upcoming Milestones

March 2015	End of current Spectrometer Commissioning Phase
April 2015	Delivery of Cryogenic Pumping System
August 2015	Delivery of Source (WGTS)
Middle of 2016	First test of source with tritium gas
End of 2016	Source and transport systems operational

The Future

G. Drexlin et al., Adv. High Energy Phys. ***2013*** *(2013) 293986*





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
- Universidad Complutense de Madrid
- University of Mainz
- University of Münster
- University of North Carolina
- University of Washington
- University of Wuppertal

150 collaborators
5 countries

Thank you!

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Backup slides

Radon Background

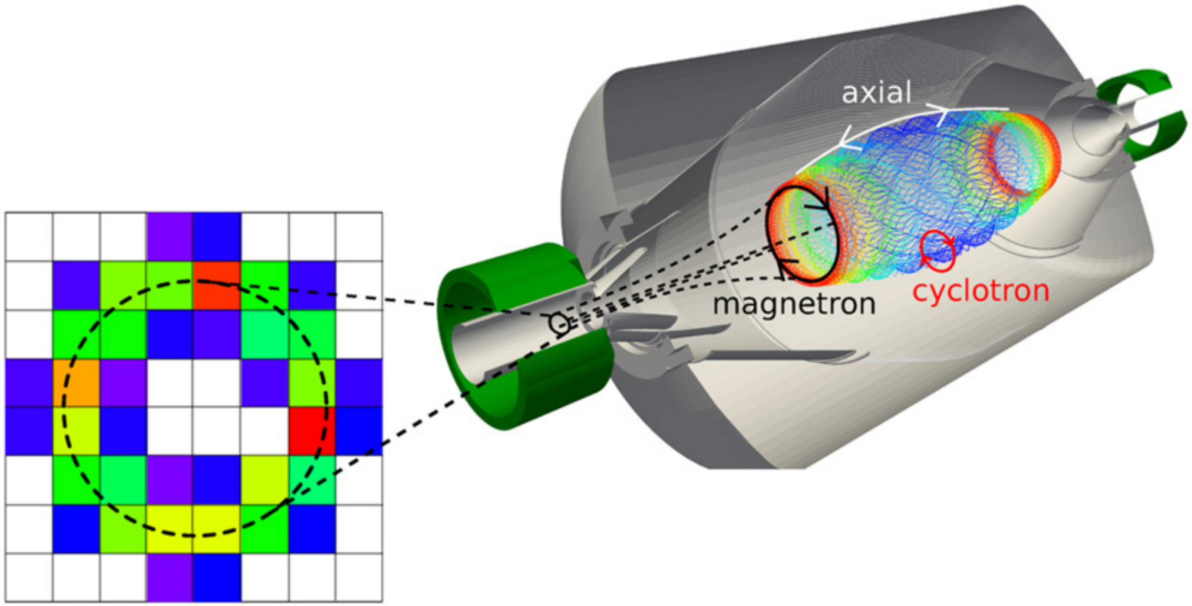
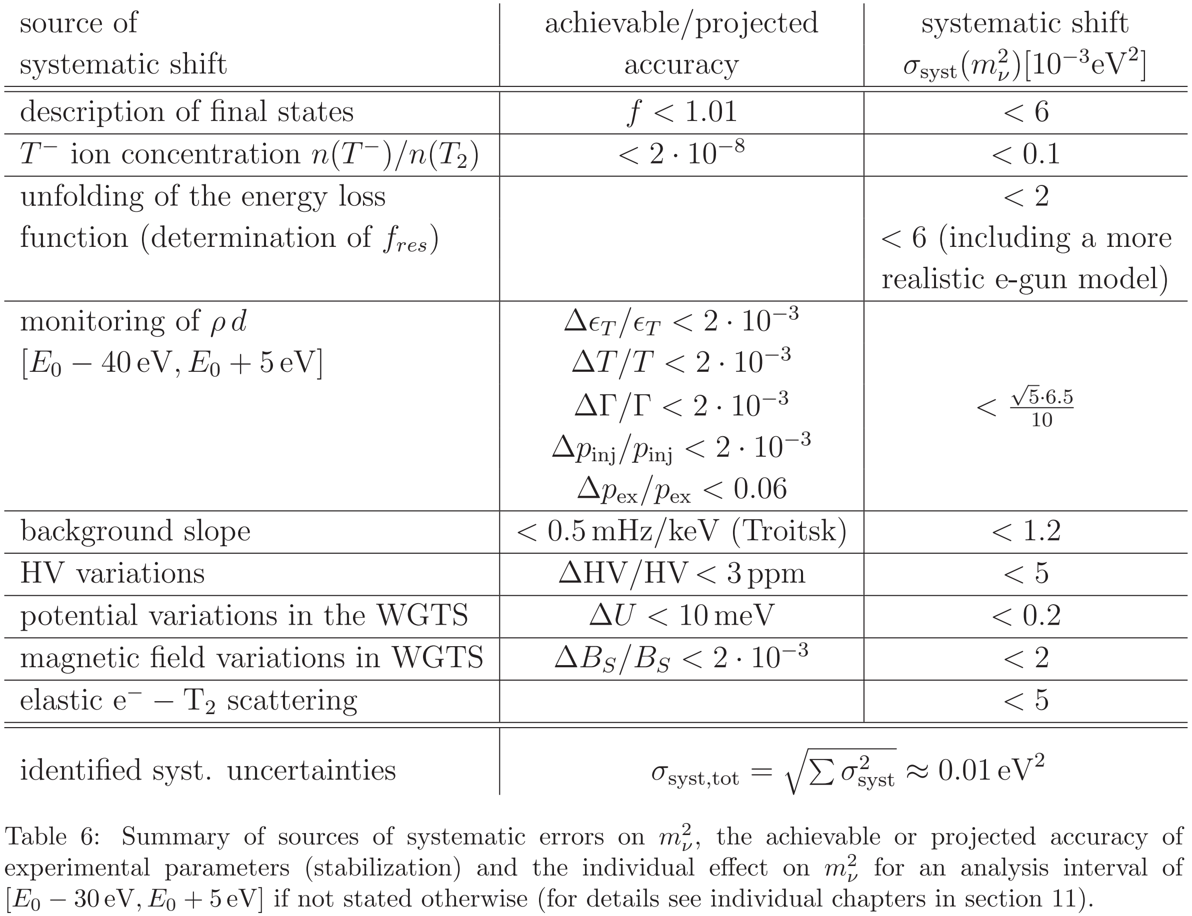


Figure 4. Simulated trajectory of a single trapped electron with start energy $E = 1000$ eV. The electron motion consists of a very fast cyclotron motion around the magnetic field line, a fast axial motion and a slower magnetron motion around the beam axis. Secondary electrons generated by the primary electron along its path are therefore seen as rings on the pixel detector. One can identify the main hit region (green to red colors, corresponding to a large number of hits) and a surrounding fuzzy region (blue, only a few hits) due to the cyclotron motion of the primary electron. The same signature was found within the measurements of [16], where figure 6 shows some example events.

N. Wandkowsky *et al.*, J. Phys. G: Nucl. Part. Phys. **40** (2013) 085102

KATRIN Systematics



source of systematic shift	achievable/projected accuracy	systematic shift $\sigma_{\text{syst}}(m_\nu^2)[10^{-3}\text{eV}^2]$
description of final states	$f < 1.01$	< 6
T^- ion concentration $n(T^-)/n(T_2)$	$< 2 \cdot 10^{-8}$	< 0.1
unfolding of the energy loss function (determination of f_{res})		< 2 < 6 (including a more realistic e-gun model)
monitoring of $\rho\, d$ $[E_0 - 40\,\text{eV}, E_0 + 5\,\text{eV}]$	$\Delta\epsilon_T/\epsilon_T < 2 \cdot 10^{-3}$ $\Delta T/T < 2 \cdot 10^{-3}$ $\Delta\Gamma/\Gamma < 2 \cdot 10^{-3}$ $\Delta p_{\text{inj}}/p_{\text{inj}} < 2 \cdot 10^{-3}$ $\Delta p_{\text{ex}}/p_{\text{ex}} < 0.06$	$< \frac{\sqrt{5} \cdot 6.5}{10}$
background slope	$< 0.5\,\text{mHz/keV}$ (Troitsk)	< 1.2
HV variations	$\Delta\text{HV}/\text{HV} < 3\,\text{ppm}$	< 5
potential variations in the WGTS	$\Delta U < 10\,\text{meV}$	< 0.2
magnetic field variations in WGTS	$\Delta B_S/B_S < 2 \cdot 10^{-3}$	< 2
elastic $\text{e}^- - \text{T}_2$ scattering		< 5
identified syst. uncertainties	$\sigma_{\text{syst,tot}} = \sqrt{\sum \sigma_{\text{syst}}^2} \approx 0.01\,\text{eV}^2$	

Table 6: Summary of sources of systematic errors on m_ν^2, the achievable or projected accuracy of experimental parameters (stabilization) and the individual effect on m_ν^2 for an analysis interval of $[E_0 - 30\,\text{eV}, E_0 + 5\,\text{eV}]$ if not stated otherwise (for details see individual chapters in section 11).

Total systematic error budget: 0.017 eV^2