Investigations of the KATRIN inter-spectrometer Penning trap

Westfälische Wilhelms-Universität Münster

KATRIN – Karlsruhe Tritium Neutrino Experiment

Bundesministerium für Bildung und Forschung

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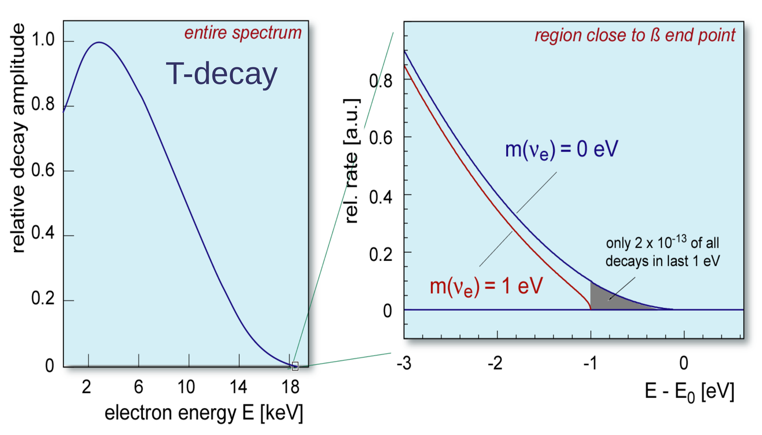
Kinematic determination of m(ν_e)

$$\frac{d\Gamma}{dE}=C\,p(E+m_e)(E_0-E)\sqrt{(E_0-E)^2-m_{\nu_e}^2}\,F(Z+1,E)\,\Theta(E_0-E-m_{\nu_e})\,S(E)$$

$$C=\frac{G_F^2}{2\pi^3}\cos^2\theta_C|M|^2$$

$$m_{\nu_e}=\sqrt{\sum_{i=1}^{3}|U_{ei}|^2 m_i^2}$$

(modified by final states, recoil corrections, radiative corrections, ...)



Requirements

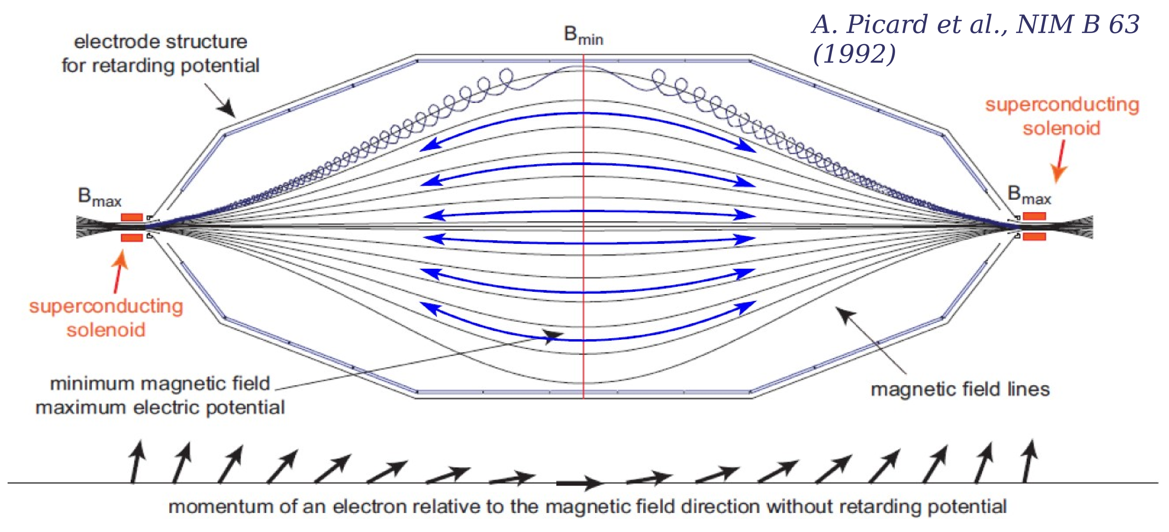
low endpoint energy
high source luminosity
high energy resolution
very low background
stability of experimental parameters on the ppm level

→ **MAC-E filter concept**

Tritium
E_0 = 18.6 keV, $T_{1/2}$ = 12.3 a
S(E) = 1 (super-allowed)

MAC-E filter concept

Magnetic **A**diabatic **C**ollimation with **E**lectrostatic Filter



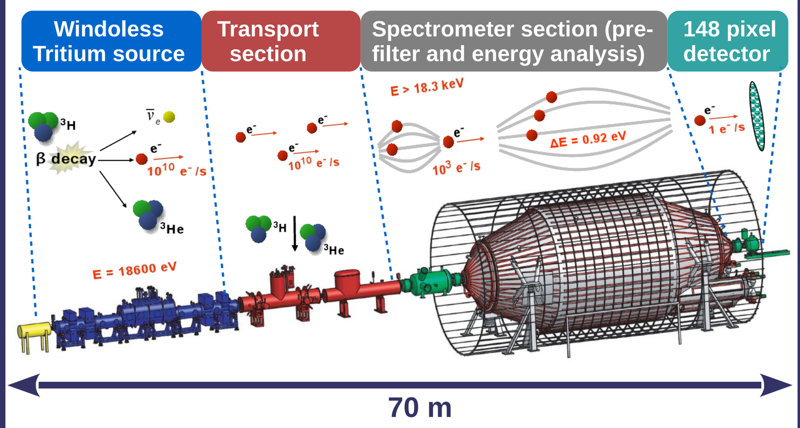
Adiabatic transport → $\mu = E_\perp / B$ = const.

B drops by $2\cdot10^4$ from solenoid to analyzing plane → $E_\perp$ → $E_\parallel$

Only electrons with $E_\parallel > eU_0$ can pass the retardation potential

Energy resolution $\Delta E = E_{\perp,max,start} \cdot B_{min} / B_{max} \approx 1$ eV

KATRIN experiment at KIT



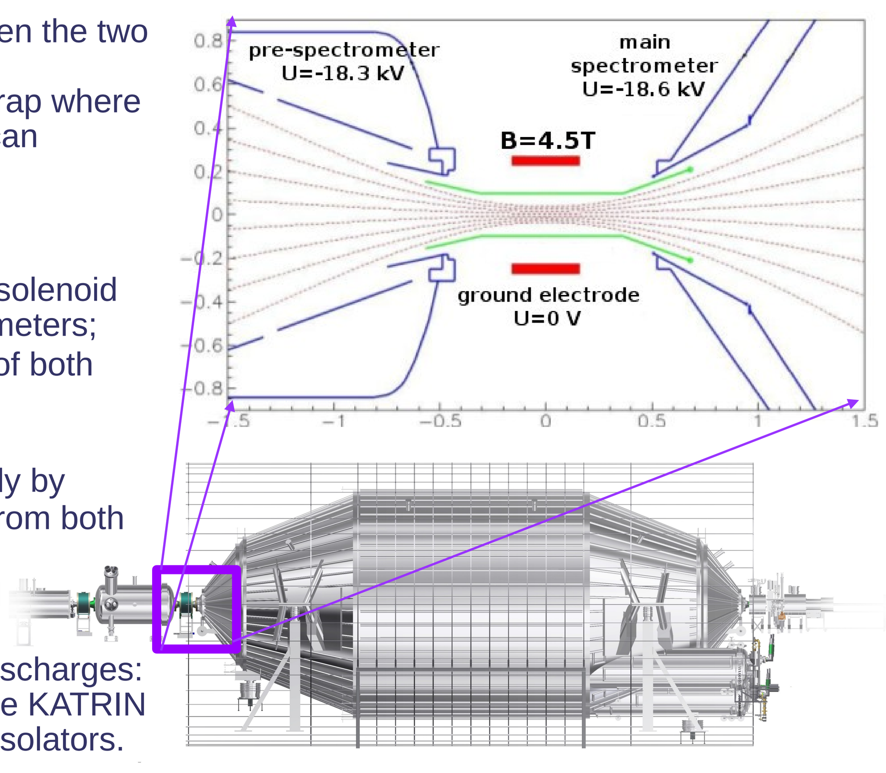
KATRIN design sensitivity:	statistical uncertainty $\sigma_{stat} \approx 0.018$ eV² systematic uncertainty $\sigma_{sys,tot} \approx 0.017$ eV²
5 year measurement (eff. 3 y of data)	→ sensitivity for upper limit 0.2 eV/c² (90% C.L.) → observable with 5σ: m(ν_e) = 0.35 eV

Penning trap between pre- and main spectometers

The configuration between the two KATRIN spectrometers constitutes a Penning trap where background electrons can accumulate.

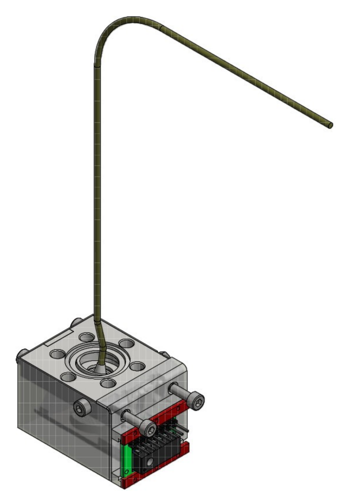
The trap is formed by:
- Magnetic field of the solenoid between the spectrometers;
- Retarding potentials of both spectrometers.

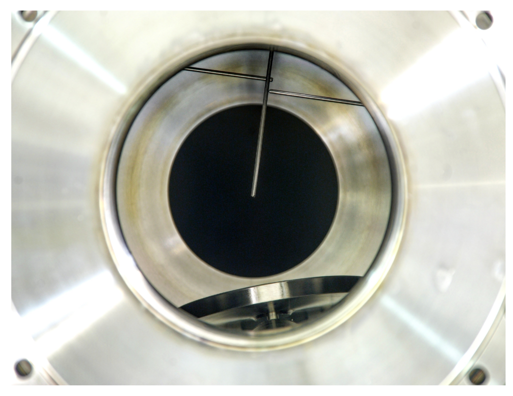
The trap is fed dominantly by background electrons from both spectrometers.
- Creation of additional background;
- Danger of Penning discharges: possibly damaging the KATRIN detector and nearby isolators.



Penning wiper concept

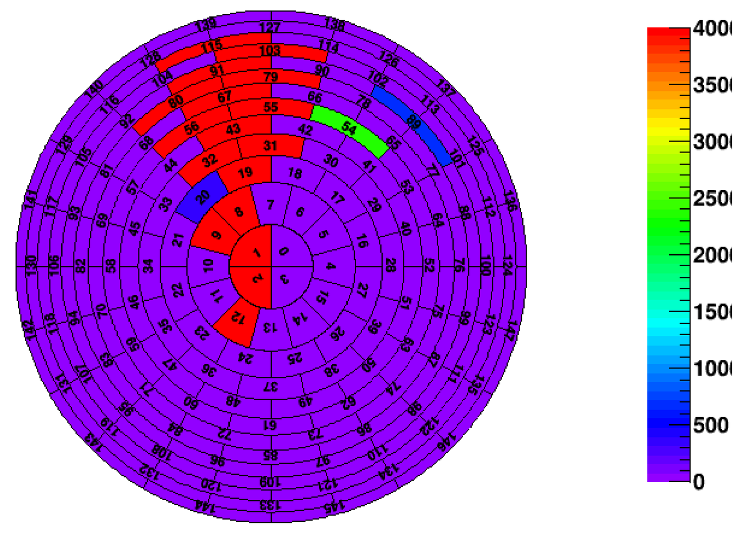
Metal rod (titanium Grade 5) to empty the Penning trap:
- Collects trapped particles when being moved into flux tube;
- Mechanical movement by a pneumatic muscle;
- Can be operated in different modes with different frequencies via ORCA (object-oriented realtime control and acquisition) software through a pulser;
- 3 penning wipers for the KATRIN measurement time;
- Photo-diode sensor gives signal when the wiper is staying inside the fluxtube.





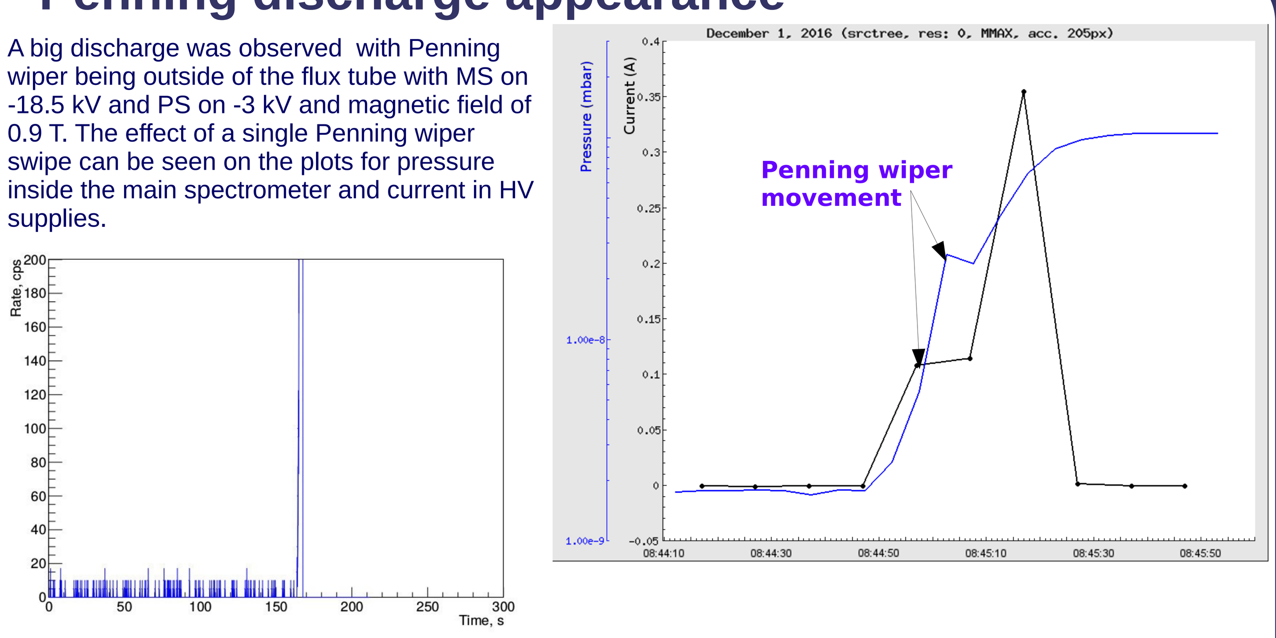
Affected pixels on the focal plane detector

Total rates on FPD detector of two measurements with rear wall illumination by UV light source with Penning wiper inside and outside of the flux tube were subtracted to see which pixels are shadowed when the wiper is inside the flux tube.



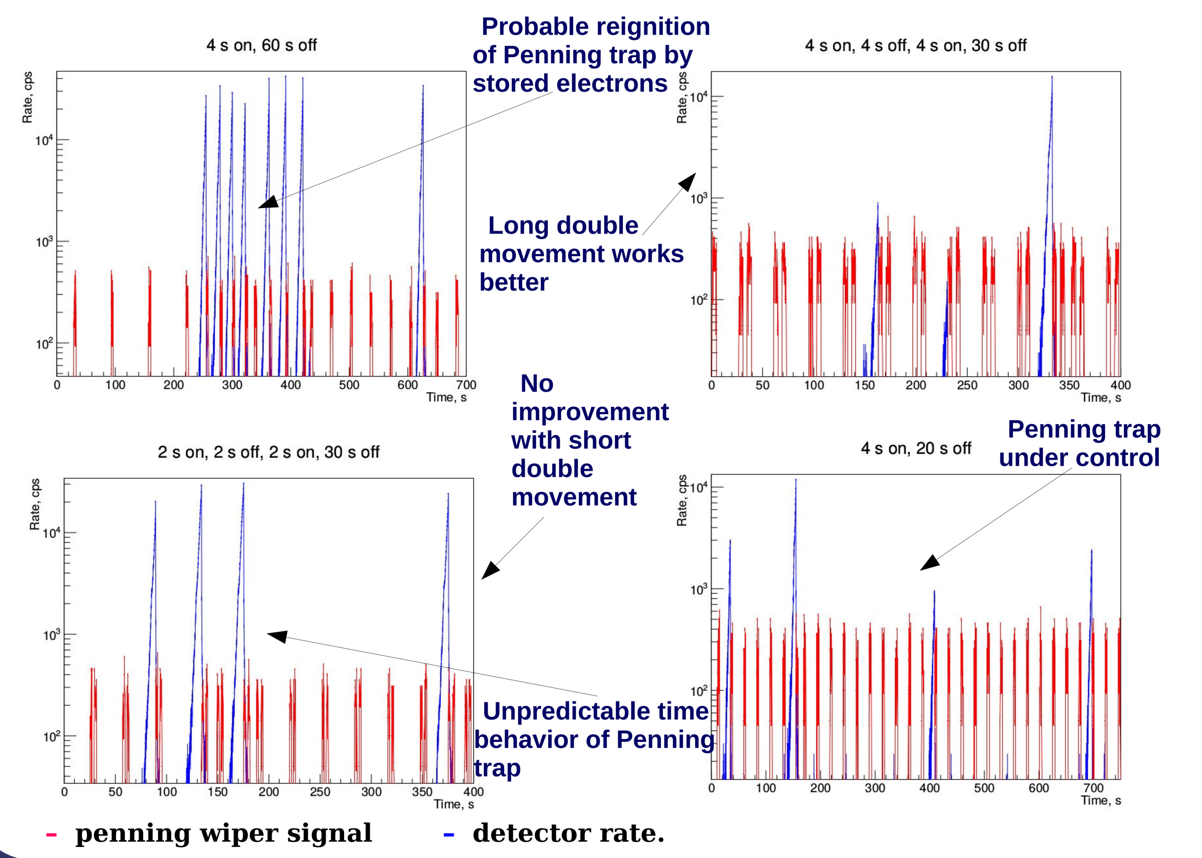
Penning discharge appearance

A big discharge was observed with Penning wiper being outside of the flux tube with MS on -18.5 kV and PS on -3 kV and magnetic field of 0.9 T. The effect of a single Penning wiper swipe can be seen on the plots for pressure inside the main spectrometer and current in HV supplies.



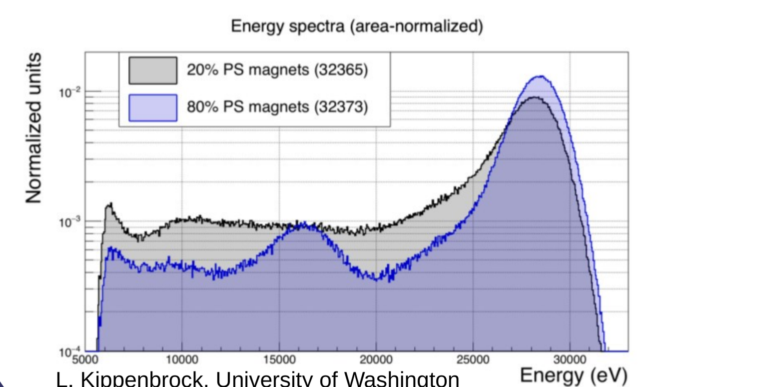
The measurements were performed in two sets, with 0.9 T and 3.6 T (which corresponds to 20% and 80% of designed value of 4.5 T) field of the inter-spectrometer solenoid.
It was observed, that with higher magnetic field discharges start to appear at lower pre-spectrometer potentials which is an expectable behavior connected to the mutual compensation of electric and magnetic fields in a Penning trap.

Tests of different Penning wiper operation modes



Spectral analysis of Penning trap background

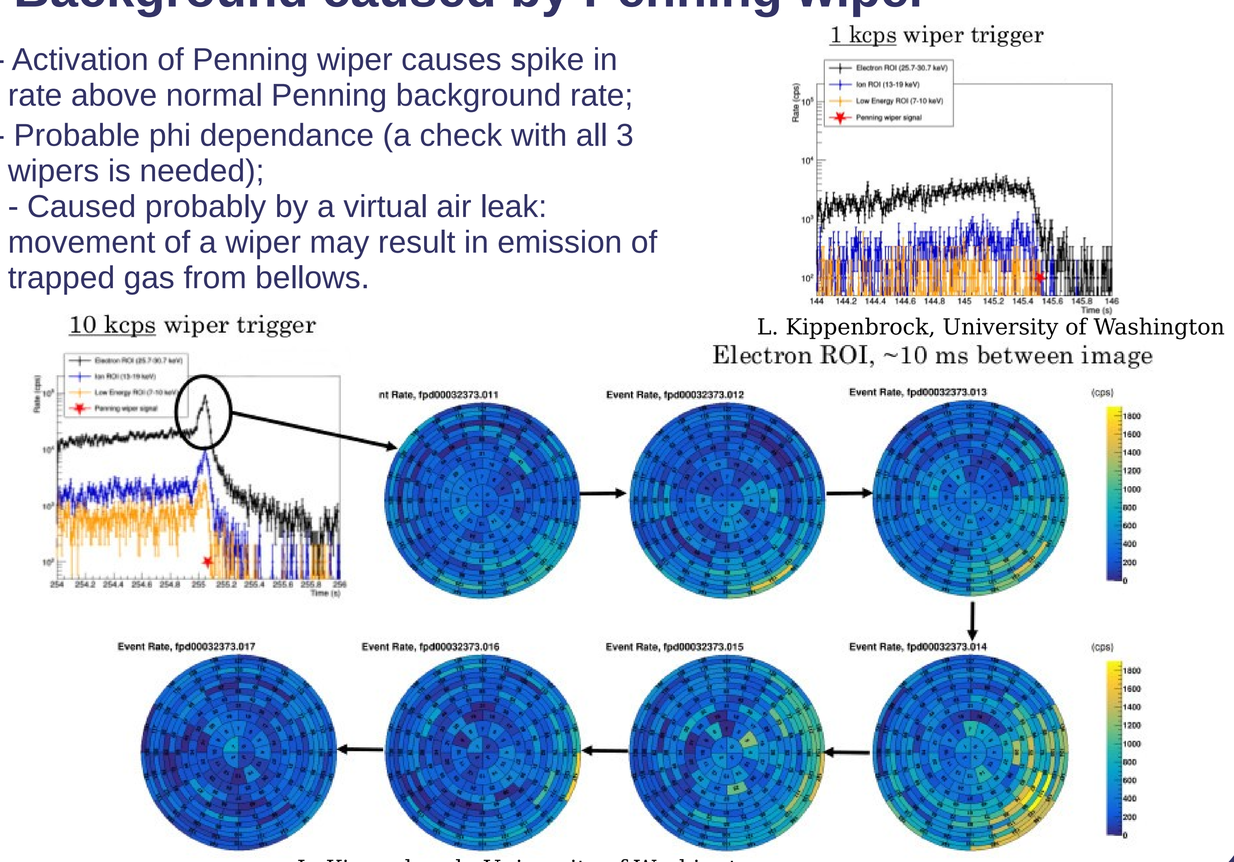
Peaks observed in background spectra:
~< 8 keV: more prominent with lower magnetic field; Due to detector/electronics noise.
~10 keV: more prominent with lower magnetic field; Probable cause from detector section.
~12 keV: more prominent with lower magnetic fields; Origin is very unclear, probably by negative ions.
~16 keV: more prominent with higher magnetic fields; Probable origin H⁻ anions.
~28 keV: more prominent with higher magnetic fields; Electron peak.



L. Kippenbrock, University of Washington

Background caused by Penning wiper

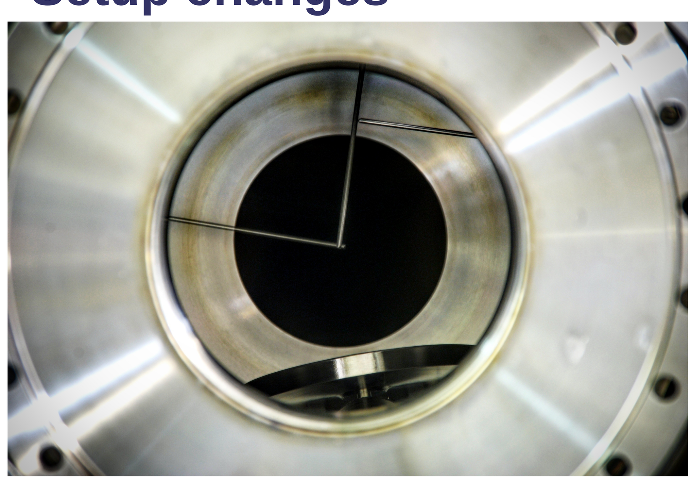
- Activation of Penning wiper causes spike in rate above normal Penning background rate;
- Probable phi dependance (a check with all 3 wipers is needed);
- Caused probably by a virtual air leak: movement of a wiper may result in emission of trapped gas from bellows.



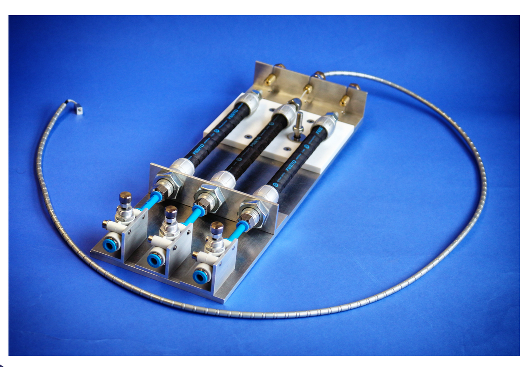
L. Kippenbrock, University of Washington
Electron ROI, ~10 ms between image

L. Kippenbrock, University of Washington

Setup changes



A wiper was moved further to the flux tube to fully cover the central pixels and therefore to better clear up the trap;
All 3 pneumatic muscles were assembled to one plate and are ready to be set up and connected on the place;
Electronic parts are assembled to one box with a readout port, 3 input ports for wiper sensor signal and 3 wiper valve ports.



Summary / Outlook

Operation of pre- and main spectrometers creates a Penning trap which causes a problem for KATRIN.

Penning wipers were designed as a measure to clear up the trapped particles from the interspectrometer region. Tests of a Penning wiper were done in a series of measurements to investigate behavior and handling of the system.

The Penning wipers showed the ability to clear up the trap and quench discharges. However, at the given conditions at the setup no suitable mode of wiper operation to completely prevent of discharges was found.

A modification for better trap clearing was done and an upgrade of the Penning wipers' setup to its final version was performed and will be installed at the spectrometer section before the next KATRIN commissioning phase.

Operation and ability of Penning wipers will be tested again at nominal magnetic fields and better pressures.

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