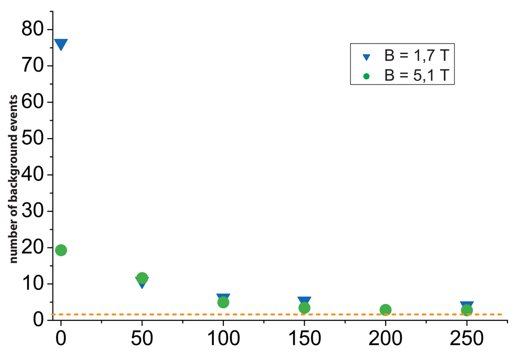
The Wire Electrode of the KATRIN Experiment

Matthias Prall, V. Hannen, B. Hillen, K. Hugenberg, H.W. Ortjohann, R. Jöhren, K. Valerius, S. Vöcking, Ch. Weinheimer, M. Zacher (University of Münster/Germany) for the KATRIN collaboration

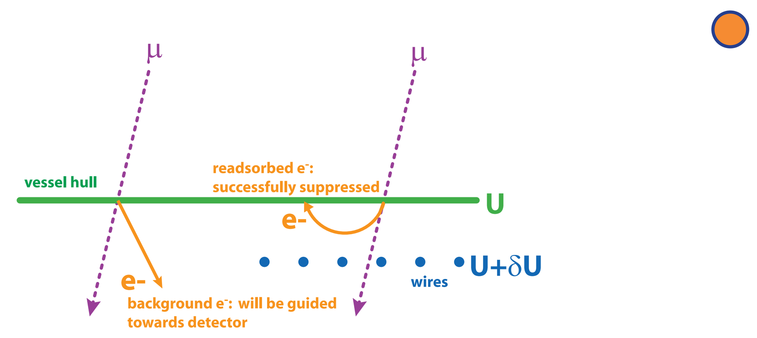
The wire electrode

Background suppression

- Signal from endpoint of tritium-β-spectrum in mHz range
- Bkg. ≈ 10^{5} μ/s from cosmics and radioactive contamination myons and radioactivity create secondary electrons in surfaces on high voltage: ≈ 10^{5} 1/s
- Lorenz force: suppression due to magnetic screening 10^{5}-10^{5} → additional bkg. suppresion mechanism needed
- Idea behind wire electrode: additionally to Lorentz force electrostatic screening of the secondary electrons
- Experiments show: factor 10 reduction of bkg. per wire layer



B. Flatt, Test of Background Suppression at the Mainz Neutrino Mass Experiment



- Voltage on wires approx. 100 V: Background due to secondary electrons is reduced significantly (order of detector background)

without wire electrode: secondary electrons give rise to background
with wire electrode: secondary electrons do not penetrate into sensitive volume

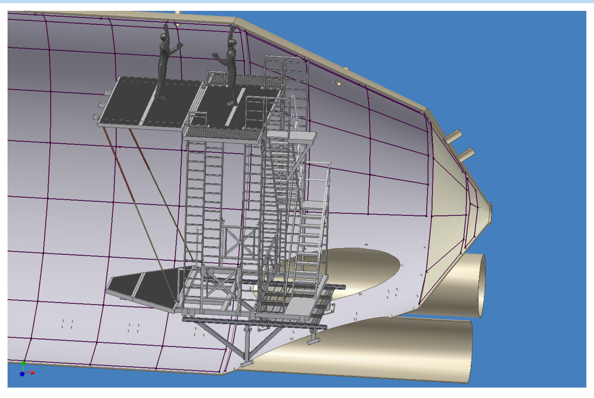
Electrode & retardation potential

- The potential behind a layer of wires is given by $U_{effective} = (1-1/S)\,U_{wire} + (1/S)\,U_{tank}$ where S >> 1 "screening factor"
- This decouples the potential inside from noise on the vessel (proven for low frequencies)
- Deviations from symmetry can be compensated with the wire electrode

vessel	$U = U_0$
outer layer	$U = U_0 - dU$
inner layer	$U = U_0 - 2dU$

e^- inside see effective potential

Installation in the Main Spectrometer

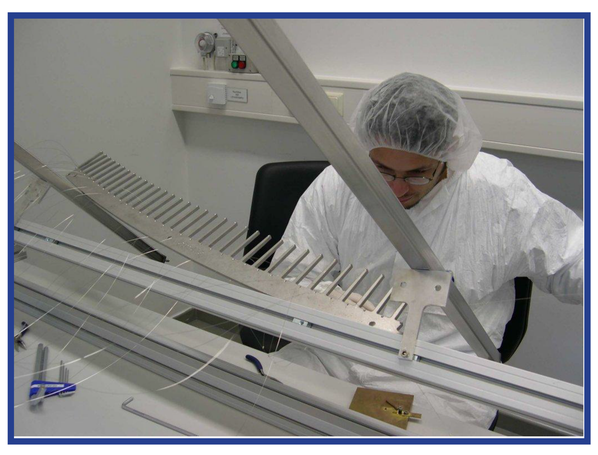


- Individual wire modules will be sled from the top of the spectrometer into their final position along circumferential rails
- A special clean room compatible scaffolding was built with which every module can be mounted / accessed

Requirements on the wire electrode

- **Wire electrode defines retardation potential:** Simulations show that a sag of > 0.2 mm leads to early retardation which reduces the resolution of the main spectrometer → mount the wires with tension (O(10 N)) and control this value
- **UHV-Compatibility:** The vacuum inside the main spectrometer will be 10^{-11} mbar and the surface of the electrode with its support structure is comparable to the surface of the main spectrometer itself → ensure low outgassing rate of 10^{-12} mbar*l/cm^2*s and guarantee mechanical precision after bake-out
- **Nonmagnetic Material:** The material with the smallest magnetic susceptibility was selected.
- **High Voltage Compatibility:** The surface of the wire has to be smooth and cleaned. The diameter of the wires hast be large large enough in order to keep the maximum field strength under a critical value.
- **Minimized volume, surface & weight:** Volume and surface of the electrode are minimized in order to ensure a minimized outgassing rate from the electrode and to avoid secondary electrons as well as electrons from radioactive decays originating from the electrode. The weight of each module is kept under 20 kg to facilitate easy mounting.
- **Reliable high voltage distribution:** The wires of the electrode are being supplied with up to 12 different voltages at a time. These voltages will be routed inside the spectrometer through 10 flanges and are then distributed via special connectors amoung the individual modules. These connections are part of the modules and do not require any tools.
- **Feasibility of installation:** The main spectrometer is equipped with a system of azimithal rails. This makes the installation of 240 modules possible. Each module is fixed on a small sled on which it is being drawn to its final position. This procedure ensures that the wires of the modules are not damaged during installation.

Production at University of Münster



- Production of frame parts at companies
- Control contour of samples with 3d measurement machine
- Drilling of the holes for the ceramics at company
- Electropolishing at company
- Cleaning in ultrasonic bath (P3 Almeco & ultrapure water)
- Control positions of holes with 3d measurement machine
- Assembly of modules in class 10.000 clean room
- Final check on 3d measurement machine (wire alignment & wire tension)
- Shipment of modules together with quality certificates (database entry & summary as hard copy)

Mass production has started in march 2008

We have produced two rings of the electrode

Two modules per day is feasible

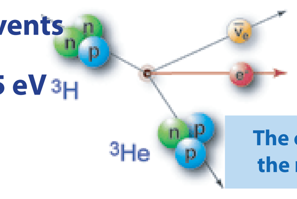
Expected completion of whole electrode: Jan 2009

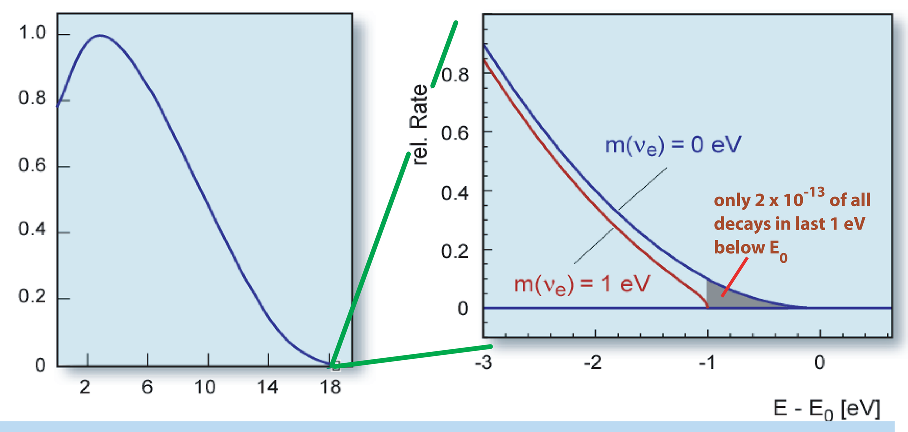
Beginn of installation in main spectrometer: March 2009

Principle of the Experiment

Direct measurement of the neutrino mass

- Method: Shape of Tritium β spectrum near endpoint
- Advantage: super allowed decay, independence of nuclear matrix element → spectrum determined by kinematics only
- Short lifetime $T_{1/2}$=12.3 yr & low endpoint @ 18.6 keV → high rate in endpoint region
- Computable electron wave functions of initial and final states (e.g. excitations) No excitations in the last 23 eV
- Low Z → few inelastic scattering events
- Discovery potential: 5 sigma @ 0.35 eV Sensitivity: 90% CL upper limit if m < 0.2 eV

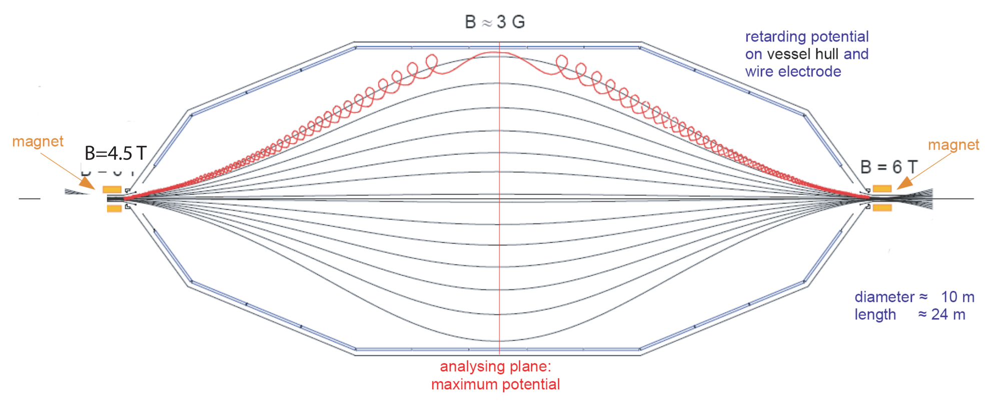




The challenge: Measure the deformation of the beta-spectrum due to the tiny neutrino mass the rate in the endpoint region in in the mHz regime → background suppression is vital

Principle of the MAC-E Filter

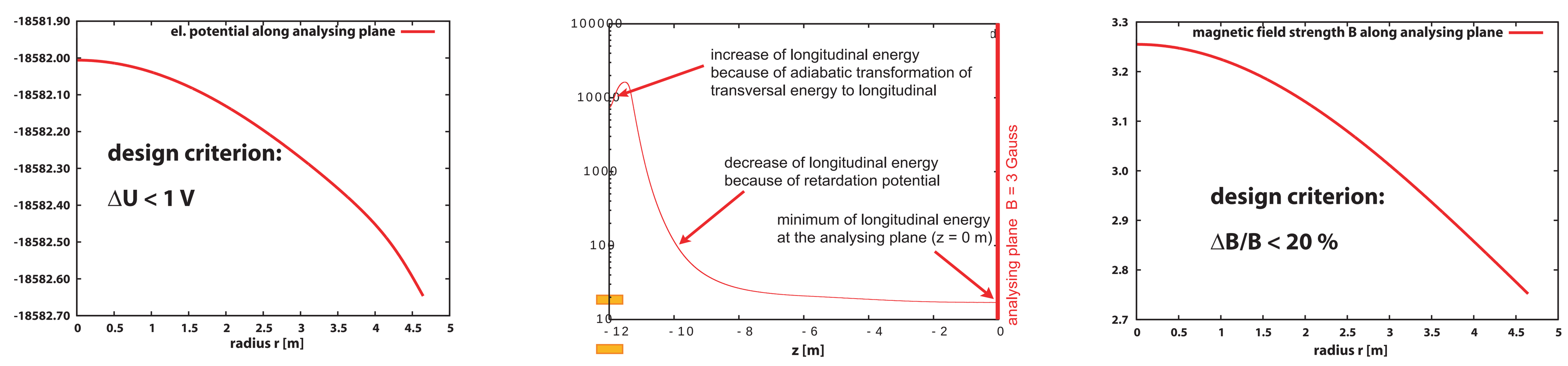
- $\mu = \oint p\,dq = E_\perp/B$ "orbital angular momentum" is a adiabatic invariant (in nonrelativistic limit)
- $E_\perp$ is being transformed into $E_\parallel$
- $E_\parallel$ is analyzed by retarding potential
- Resolution: $\Delta E/E = B_{min}/B_{max}$=1:20000
- B & E meticulouly tuned such that adiabaticity is guaranteed



Electromagnetic Design of the Electrode

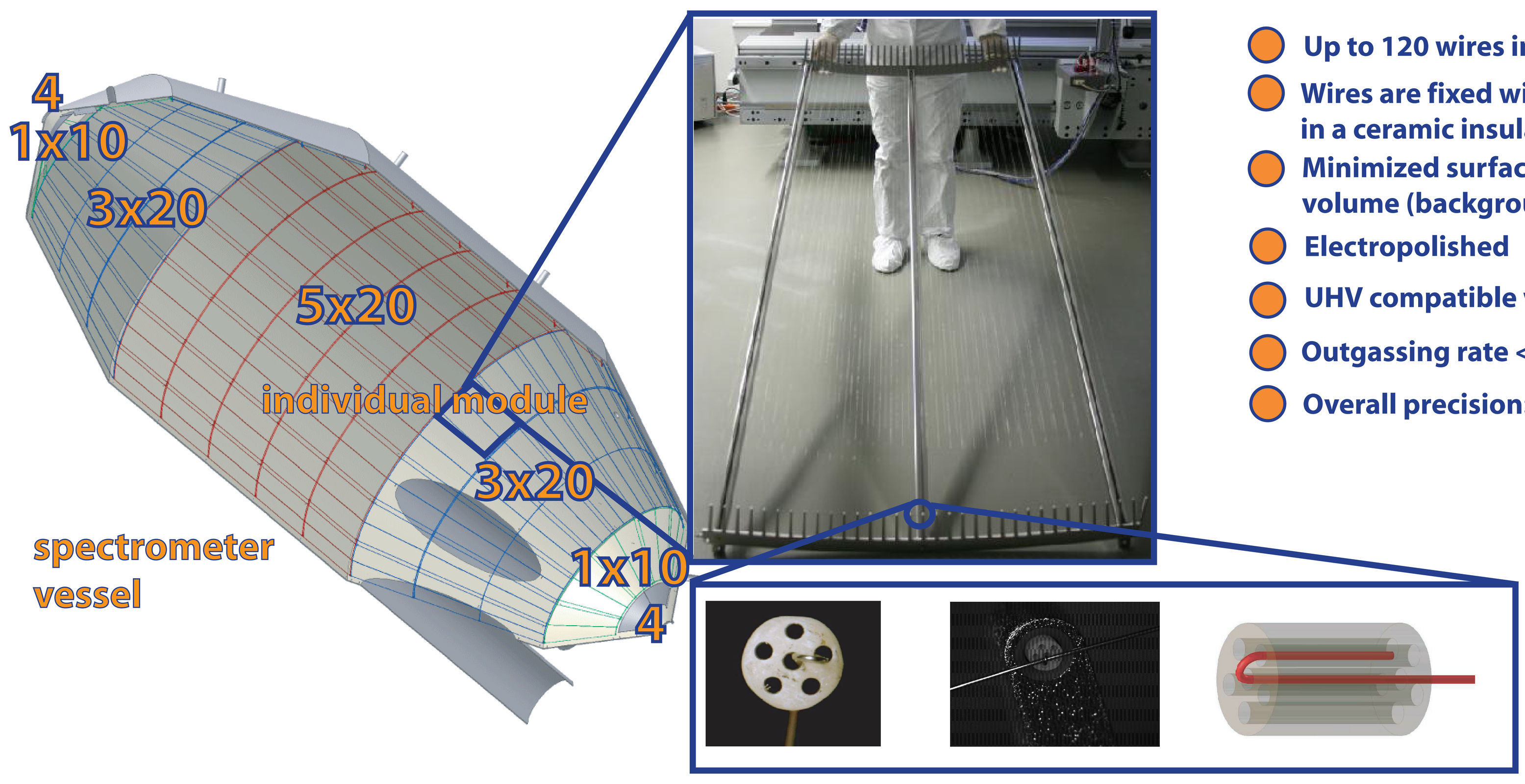
Design criteria:

- minimum of the magnetic field and maximum of the electric field should lie in the same plane
- longitudinal energy should have its minimum at z = 0 m
- potential depression in analysing plane should not exceed DU < 1 V
- magnetic field inhomogenity in analysing plane should not exceed DB/B < 20 %



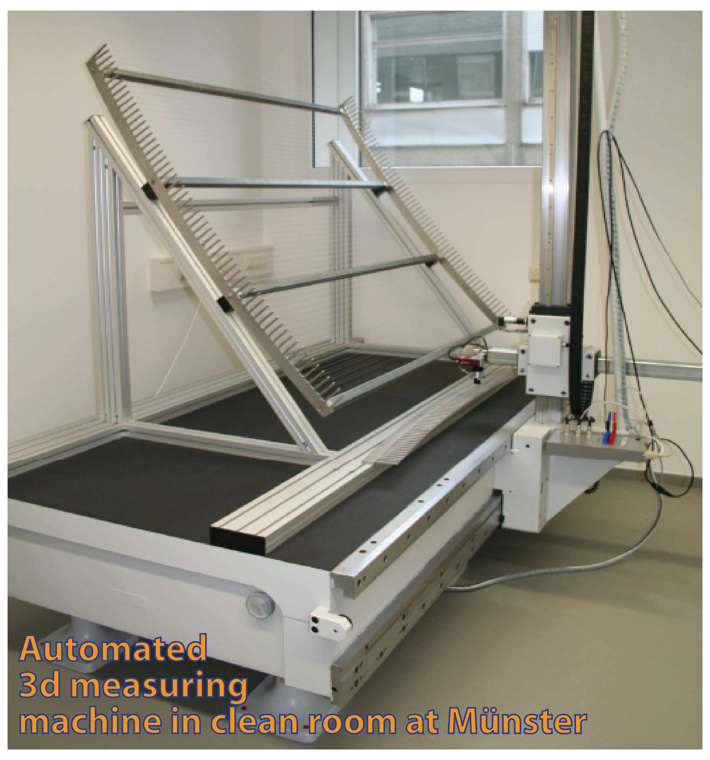
Challenging task: Complex geometry, many free parameters, BEM calculation with custom software

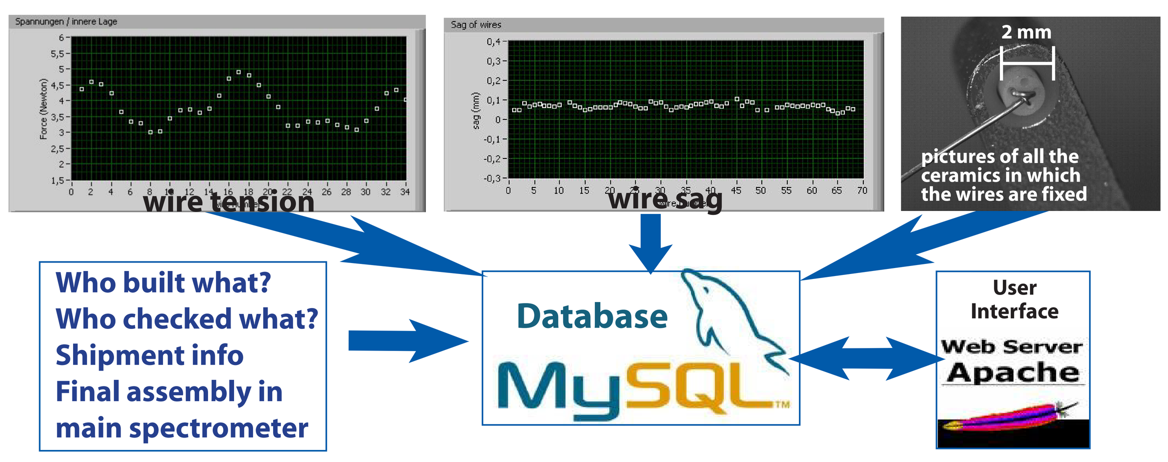
A typical wire module (one of 248)



- Up to 120 wires in two layers
- Wires are fixed with 0.1 mm precision in a ceramic insulator
- Minimized surface (vacuum) and volume (background reduction)
- Electropolished
- UHV compatible welds
- Outgassing rate < 10^{-12} mbar*l/cm^2*s
- Overall precision: 0.2 mm

Extensive Quality Assurance





- One has to make sure that not a single wire will break in the main spectrometer
- More than 70 MB (wire positions, wire tensions, pictures, processcard) per module
- A means to control if all QA measures were actually performed
- A means to reconstruct the entire history of each single module