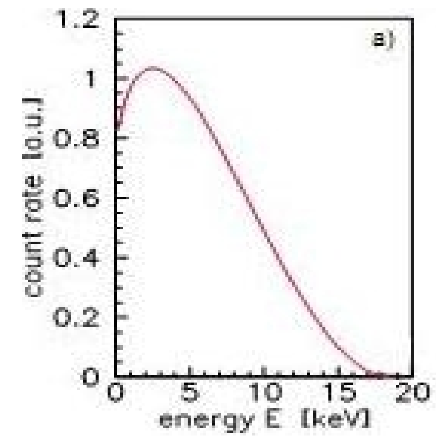
Setup and production of the wire electrode for KATRIN

Outline

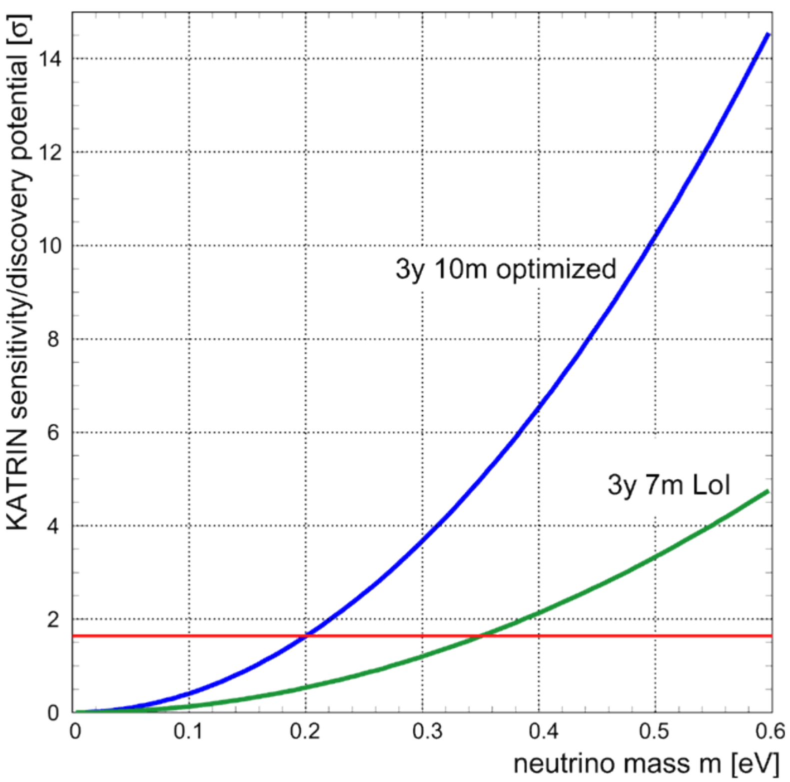
- Motivation and overview of the KATRIN experiment
- Wire electrode setup
- Wire electrode production
- Summary and outlook

Introduction

- 1930: Pauli postulates electron neutrino to explain continuous beta spectrum
- Neutrinos first assumed massless
- Neutrino oscillation experiments have proven that ν´s must have mass
  but: absolute mass scale not known
- Absolute neutrino mass important parameter for particle physics and astrophysics
- current upper limit: $m(\overline{\nu}_e) \approx 2.3 eV$ (Mainz)

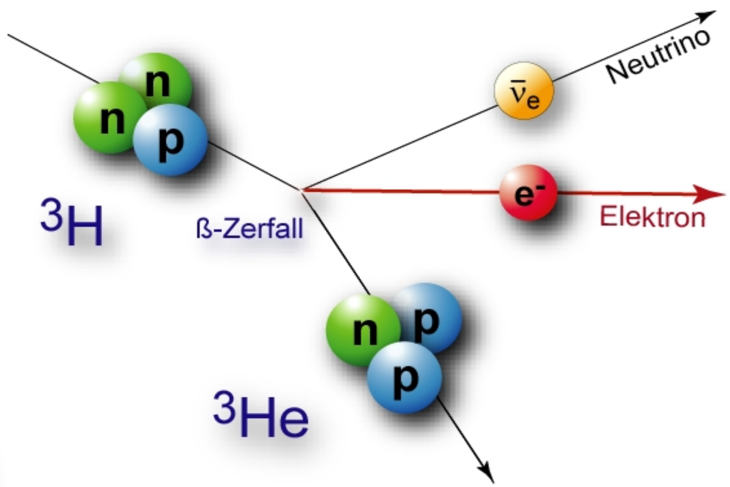


KATRIN goals with 3 years worth of data: upper limit of $m(\overline{\nu}_e)=0.2 eV$ (90% C.L.)



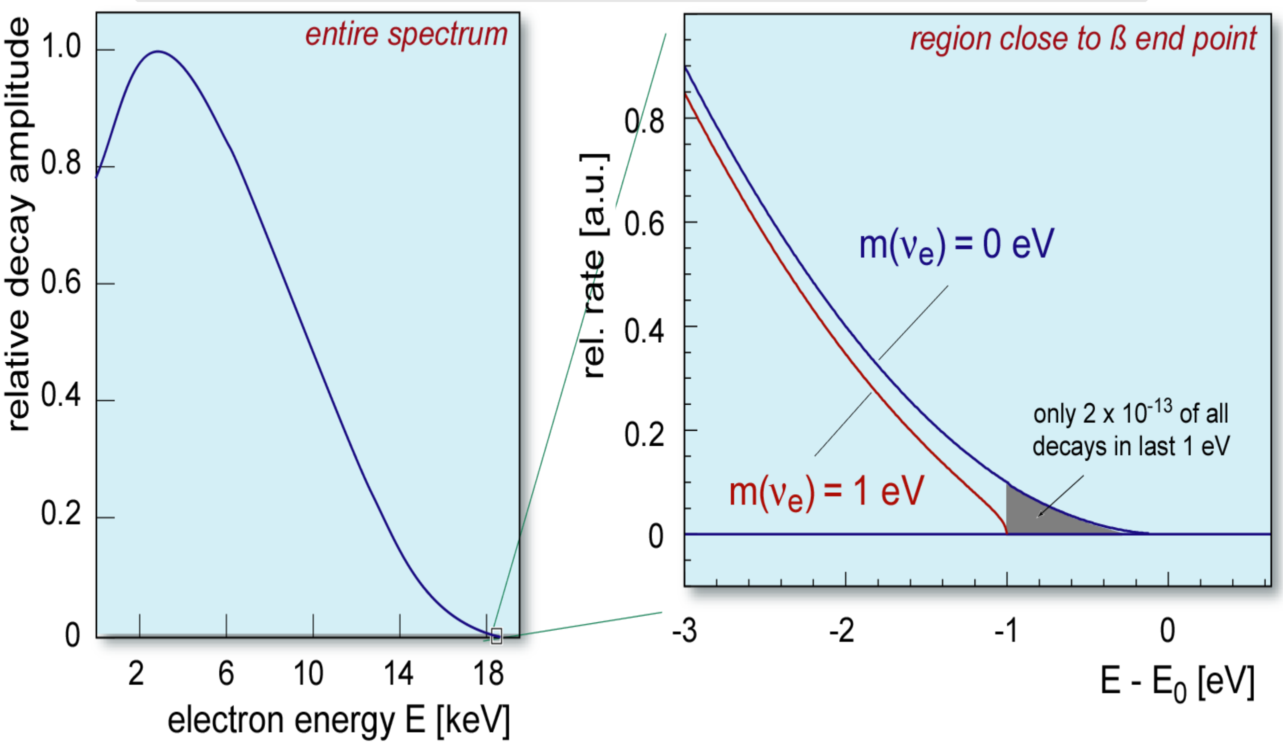
Direct neutrino mass measurement

- determination of $m(\bar{\nu}_e)$ from kinematics of Tritium beta decay
- Tritium: ideal β emitter for this purpose:
  $E_0 = 18.6$ keV $\quad T_{1/2} = 12.3$ a



Simplified form of the β spectrum:

$$\frac{dN}{dE_\beta} \propto (E_0 - E)\sqrt{(E_0 - E)^2 - m^2(\nu_e)c^4}$$



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

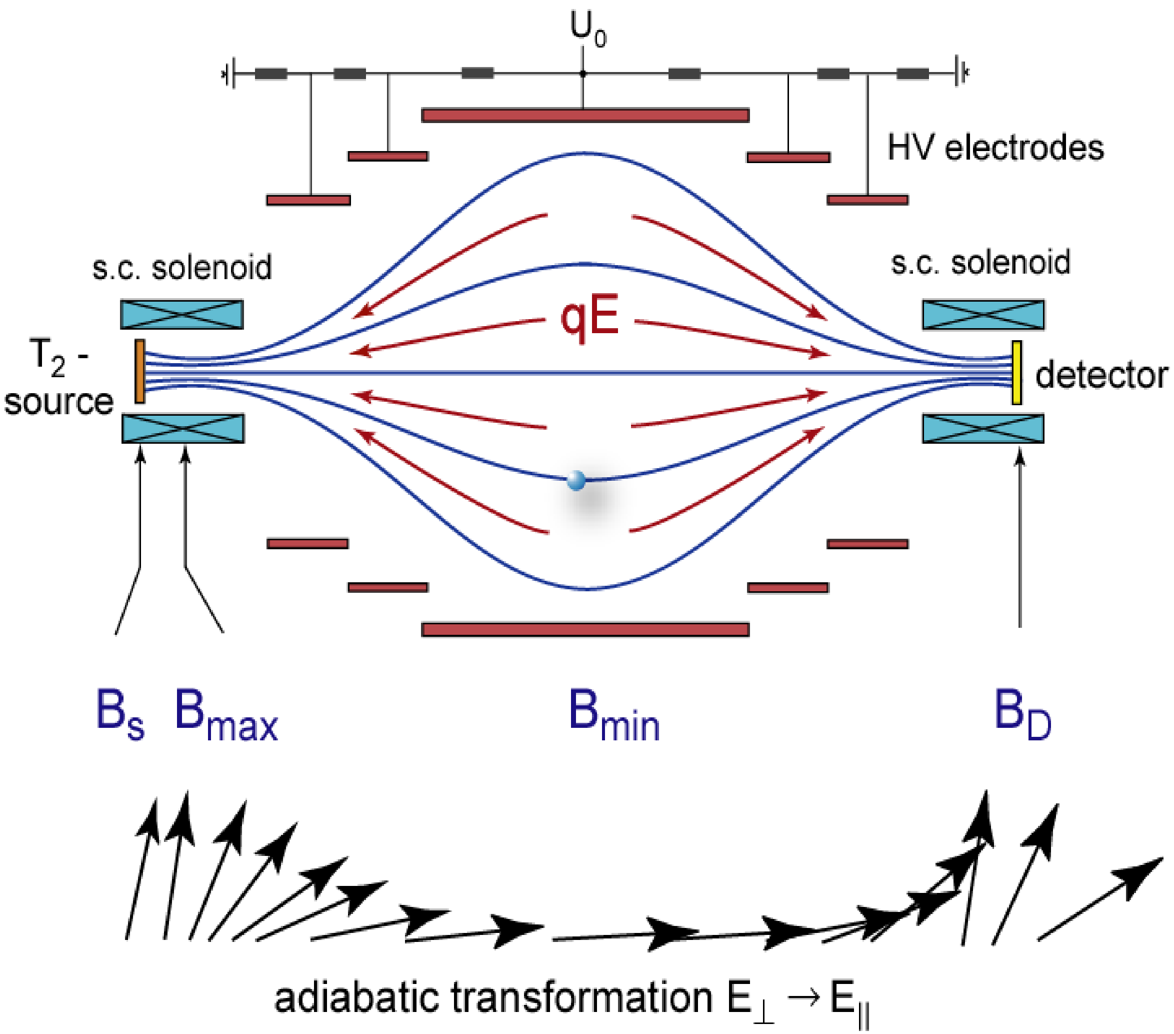
Requirements:

- high energy resolution
- large solid angle ($\Delta\Omega \sim 2\pi$)
- low background rate

→ **use MAC-E filter**

MAC-E filter

Magnetic Adiabatic Collimation with Electrostatic Filter



- electrons gyrate around magnetic field lines
- only electrons with $E_{||} > eU_0$ can pass the MAC-E filter

  $\longrightarrow$ **Energy resolution depends on ΔU_0 and on $E_\perp$**

- B drops by a factor 20000 from solenoid to analyzing plane,

  $\mu = E_\perp / B = \text{const.} \longrightarrow E_\perp \rightarrow E_{||}$

- $\Delta E = E \frac{B_{min}}{B_{max}} \approx 1\text{eV}$
- MAC-E filter acts as a high pass filter with a sharp transition function

A. Picard et al., Nucl. Instr. Meth. B 63 (1992)

KATRIN

KArlsruhe TRItium Neutrino experiment

Windowless Gaseous Tritium Source (WGTS)

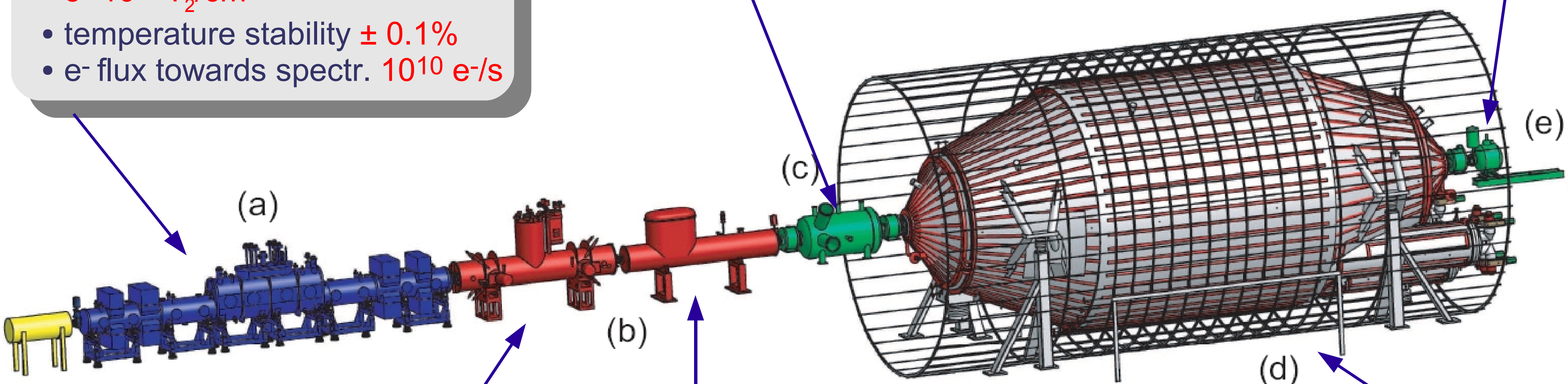
- Tritium flow rate of 5×10^{19} molecules/s (40 g of T_2 / day)
- column density ρd: 5×10^{17} T_2/cm^2
- temperature stability ± 0.1%
- e^- flux towards spectr. 10^{10} e^-/s

Pre-Spectrometer (MAC-E)

- retardation voltage 18.3 kV
- reduce flux to 10^3 e^-/s
- $p < 10^{-11}$ mbar

Electron detector

- segmented
- ≈ 1 keV resolution
- B = 5.6 T
- veto shield



Differential pumping section

- e^- guided along beamline by strong magnetic fields
- T_2 removed by TMPs in kinks

Cryo pumping section

- T = 4K
- argon frost as cryo pump
- B = 5.6 T

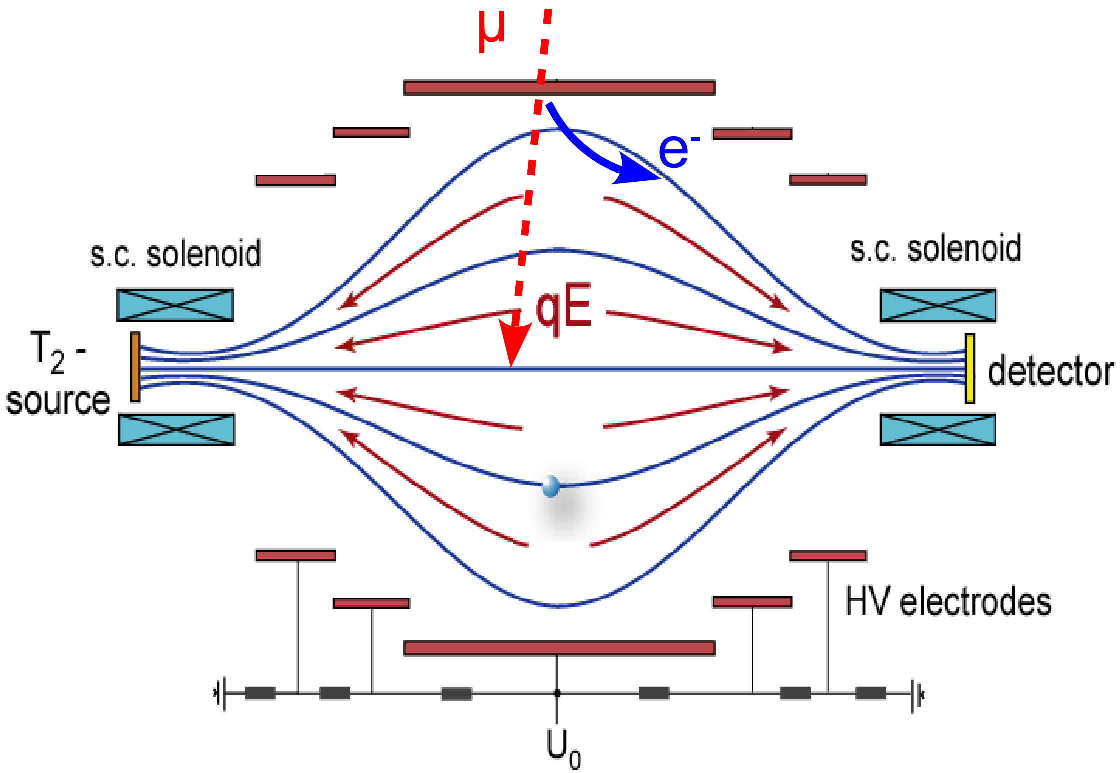
Main-Spectrometer (MAC-E)

- @ 18.6 keV (endpoint)
- 1 eV resolution
- $p < 10^{-11}$ mbar

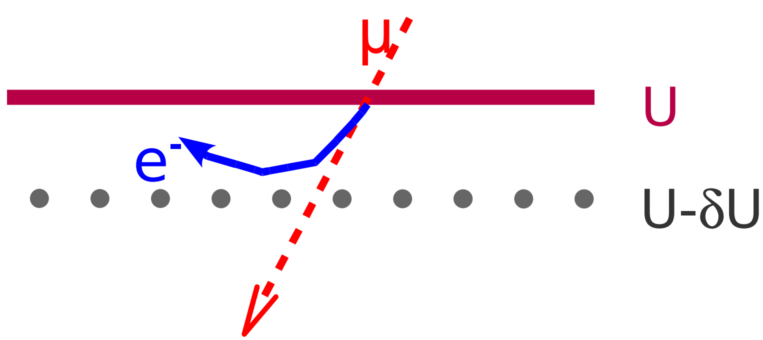
KATRIN main spectrometer

Transport of the main spectrometer: Deggendorf to Leopoldshafen

Principle of the wire electrode

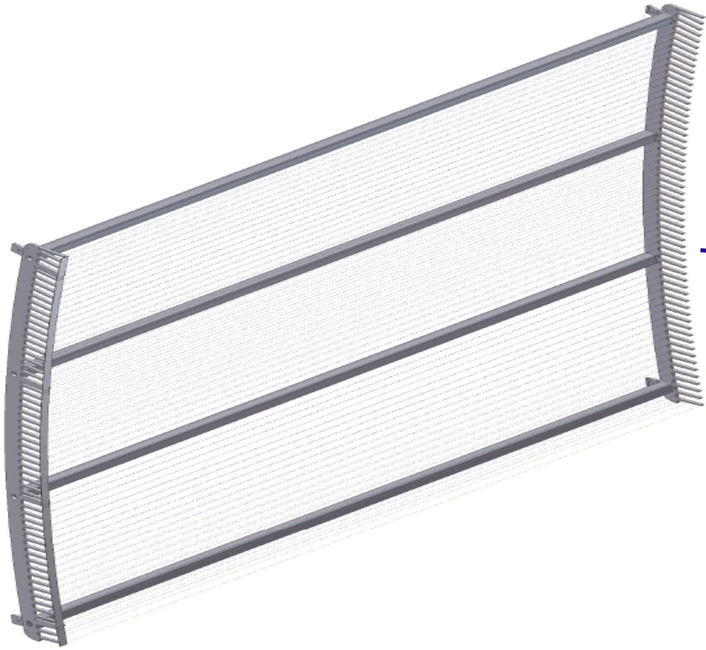


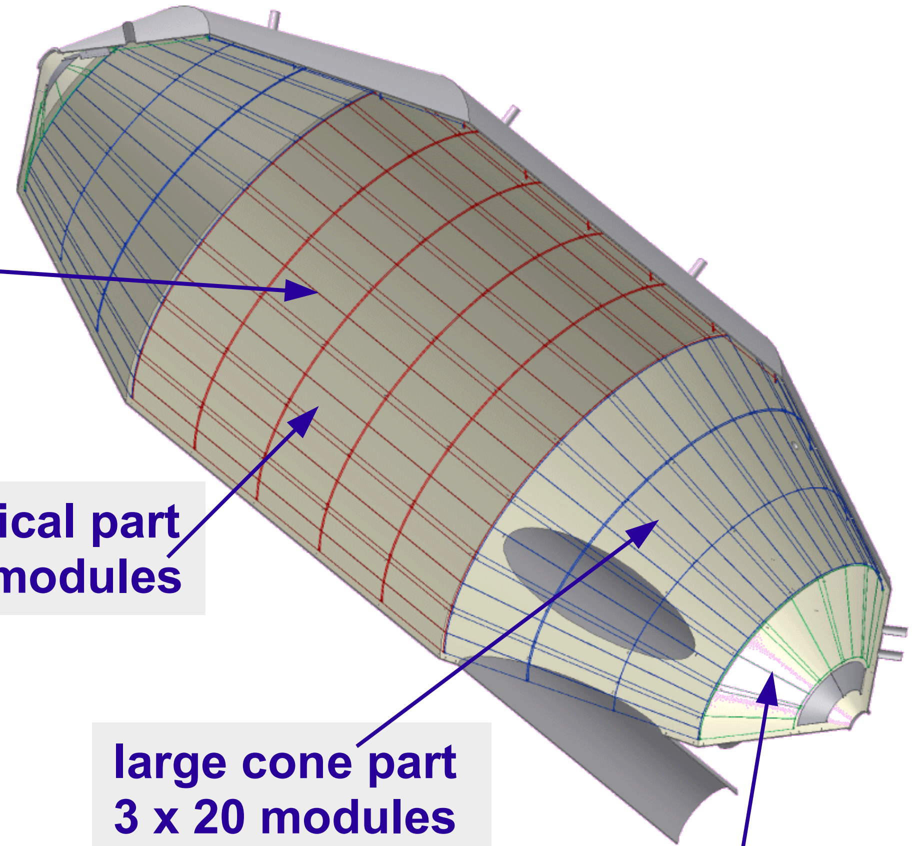
- Cosmics and radioactive contamination can mimic e^- in endpoint energy region
- $650 m^2$ surface of main spectrometer
  - ⟶ ca. 10^5 μ / s + contamination
- Reduction due to B-field: factor 10^5-10^6
- Real signal rate in the mHz region
- **Additional reduction necessary**



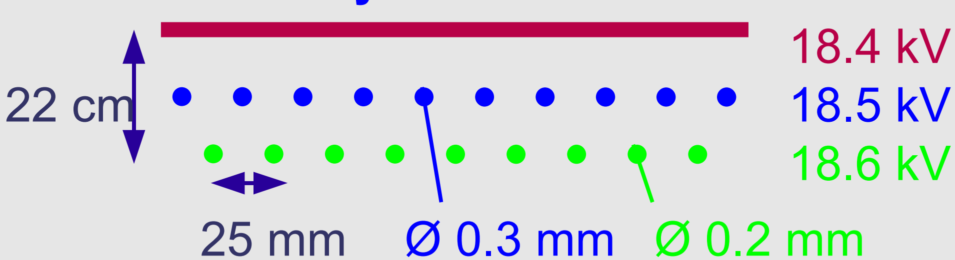
- Screening of background electrons with a wire grid on a negative potential
- Proof of principle at Mainz MAC-E filter
  - → at 200 V shielding potential the background rate was **reduced by a factor 10** with a single layer electrode

Wire electrode setup





KATRIN: double layer electrode



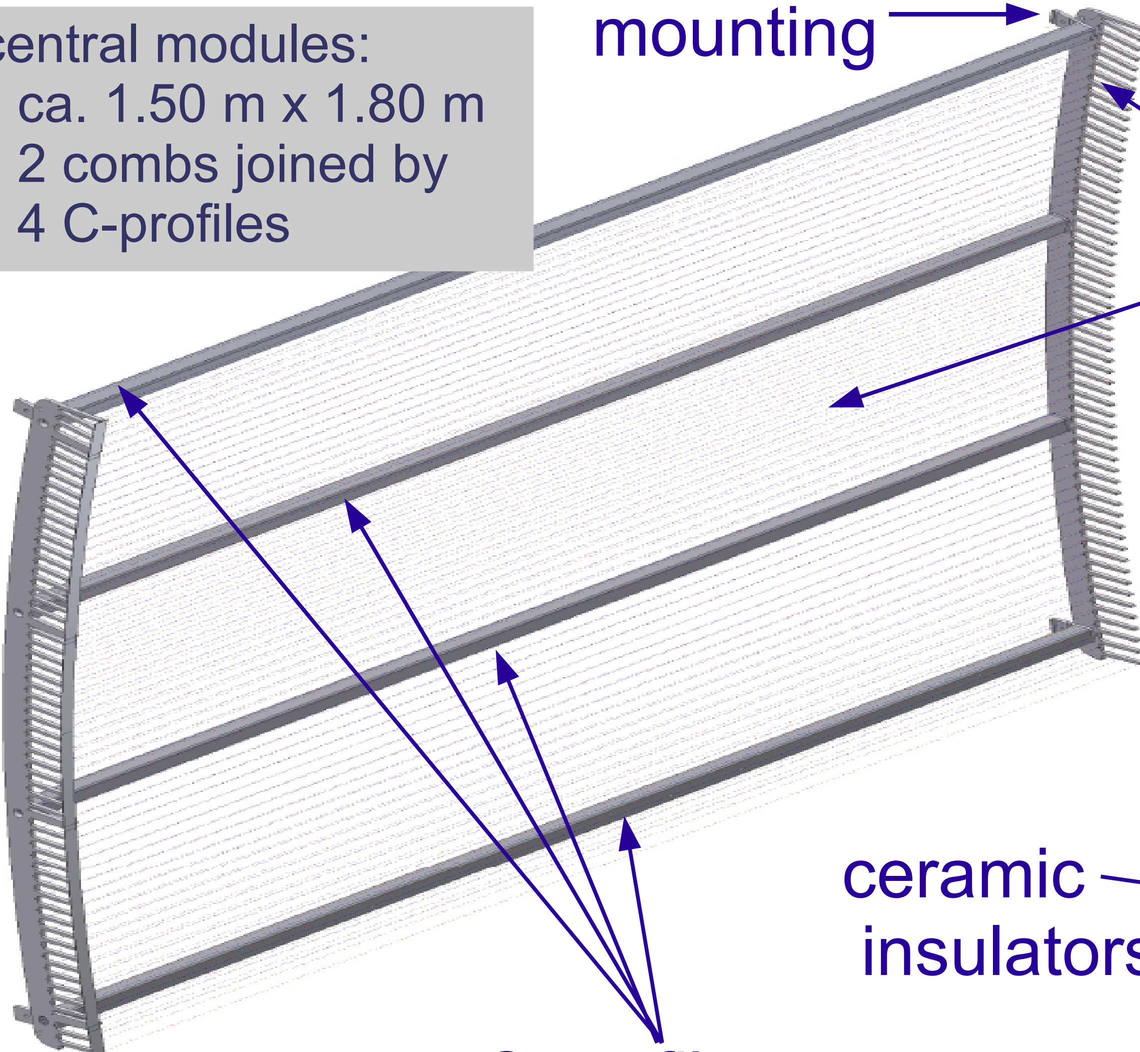
- improved shielding and electric field homogeneity

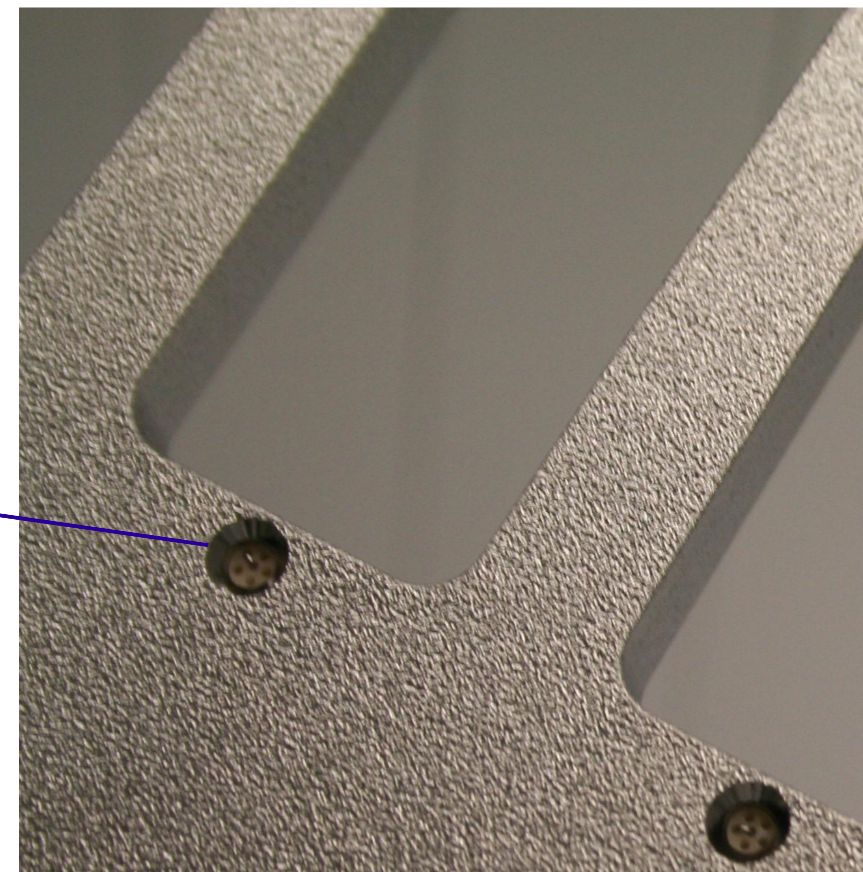
  → **expected background reduction by 10 - 100**

Σ = 240 modules
23000 wires

Module setup

central modules:
- ca. 1.50 m x 1.80 m
- 2 combs joined by
- 4 C-profiles





Wire specifications

- wire sag and position ≤0.2mm
- outer layer 0.3mm@10N
- inner layer 0.2mm@5N
- test measurements show:
  elasticity of wires changes during
  first bake-out cycle

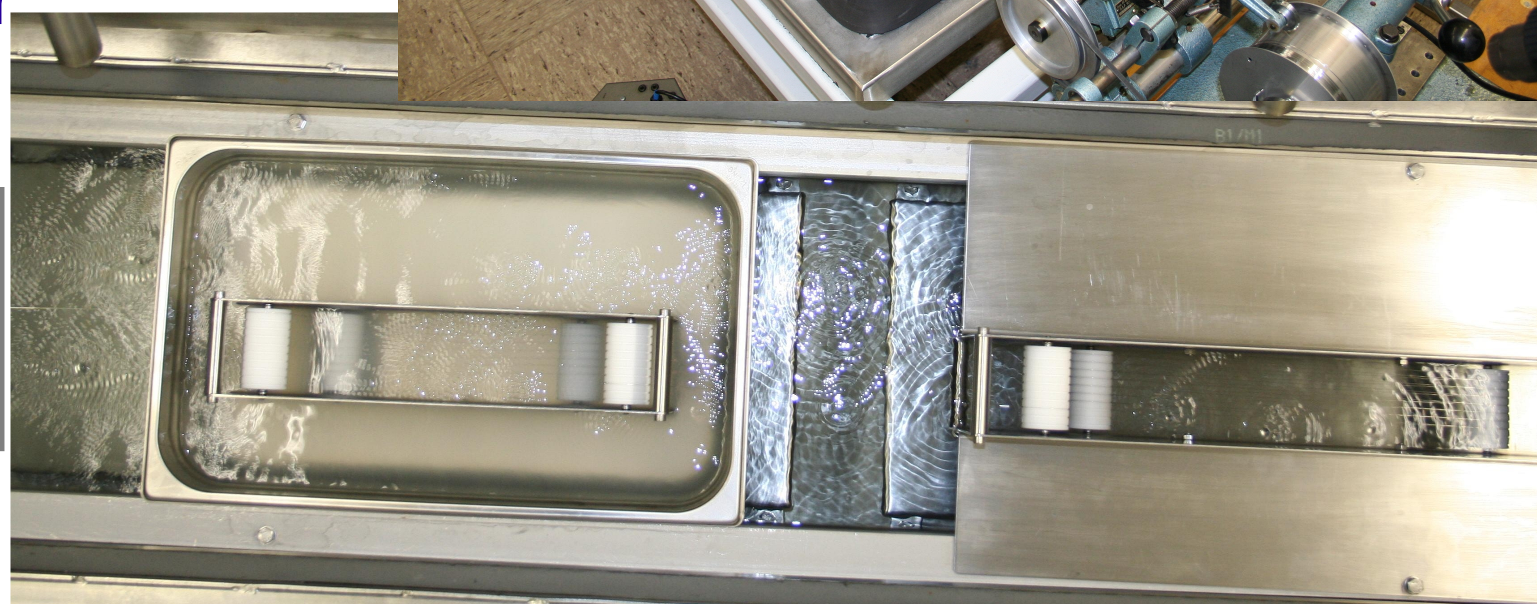
→ wires need to be tempered
  before assembly

- tempering:
  → need to rewind the wire to stainless steel coil
- wires are drawn through oil during production
  → need to clean the wires before tempering!
  → do this in one step!

Cleaning and rewireing - ultrasonic bath

- 2x 1.5kW ultrasonic bath
- can be filled with Almeco or (ultra-)pure water
- shower with ultrapure water
- wires guided through two basins filled with Almeco and pure water

wires stay
≈ 10m ≈ 1min
in each bassin

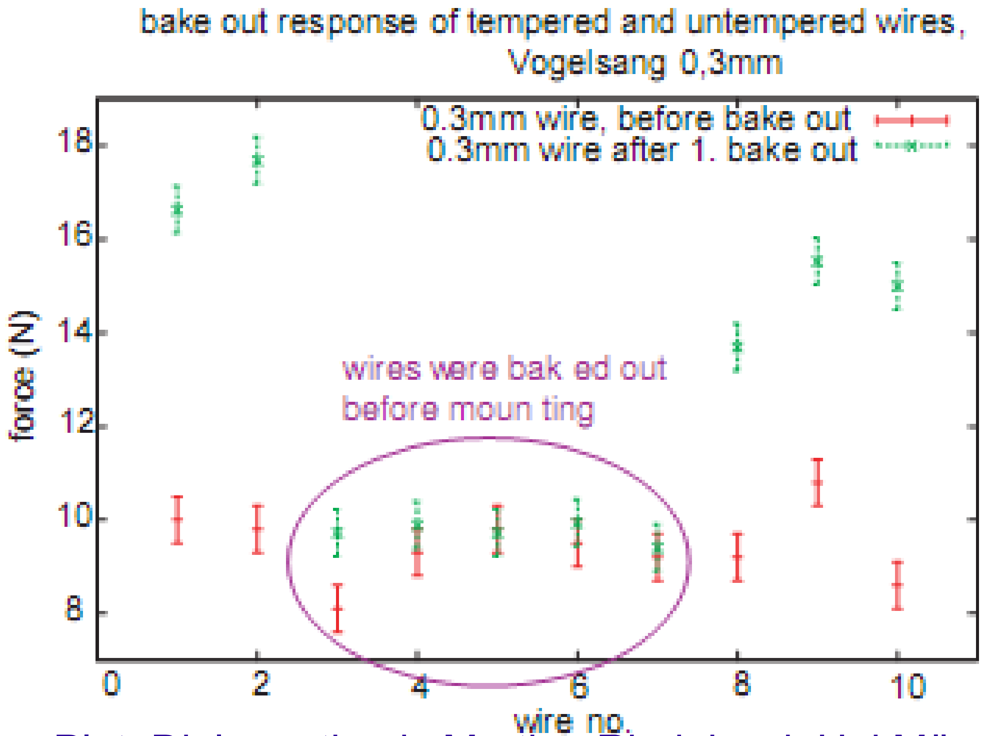


Wire production - tempering in UHV oven

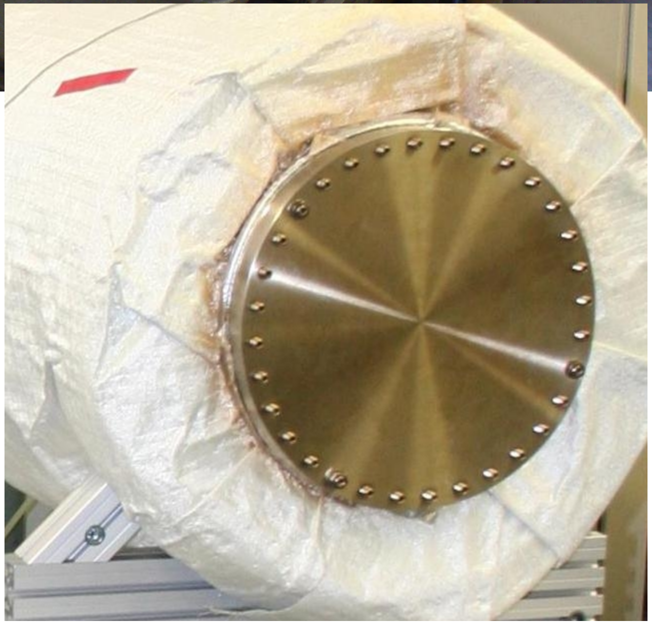
UHV oven for tempering:

2h@350°C

<u>Test:</u> mount tempered and untempered wires on test module and bake out



Plot: Diploma thesis Martina Rheinhard, Uni Münster

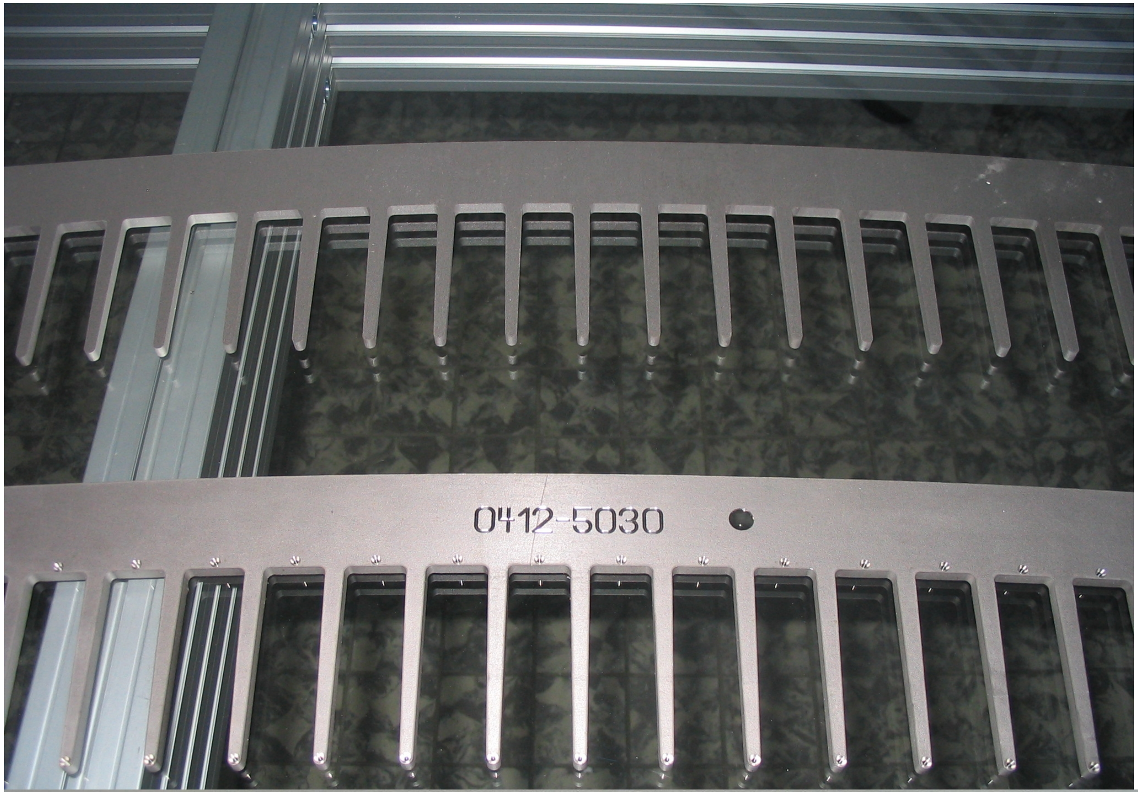


Comb production

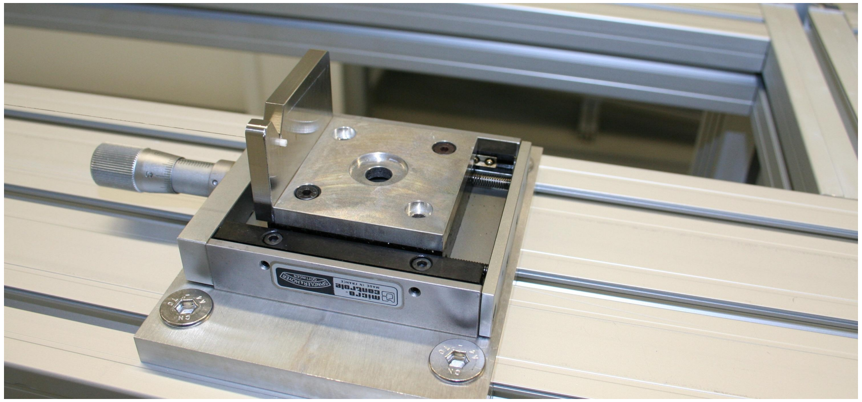
- combs cut by waterjet

- holes are drilled and
  serial number is milled in

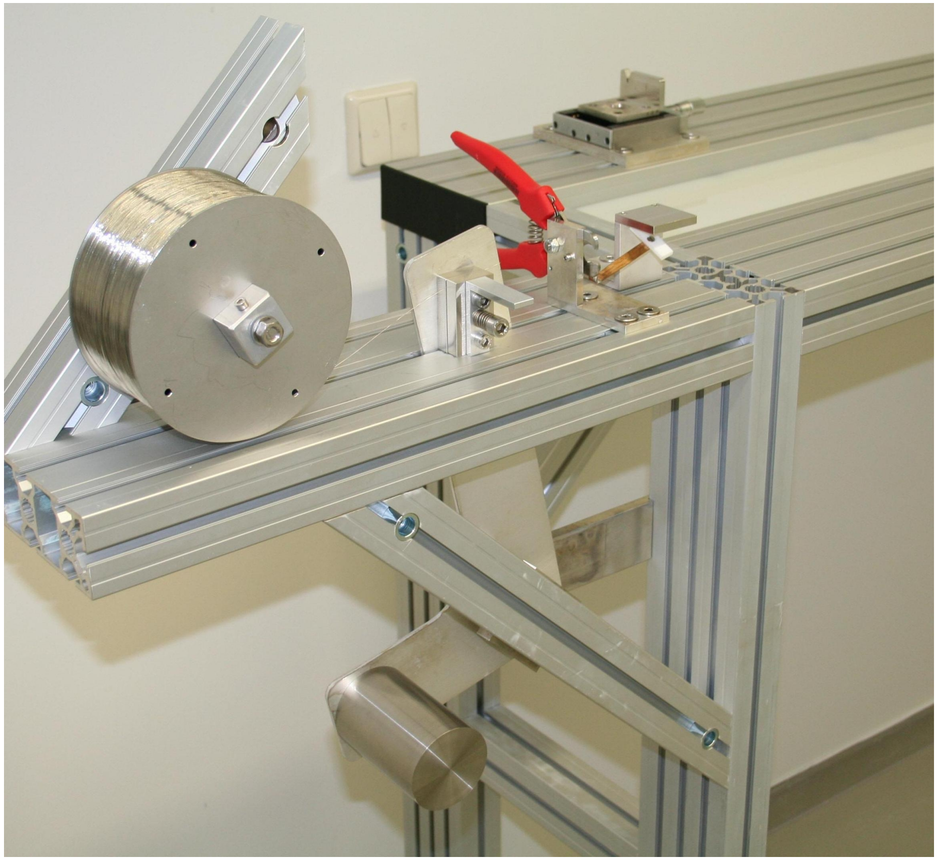
- comb gets electropolished
- cleaning of combs in
  ultrasonic bath

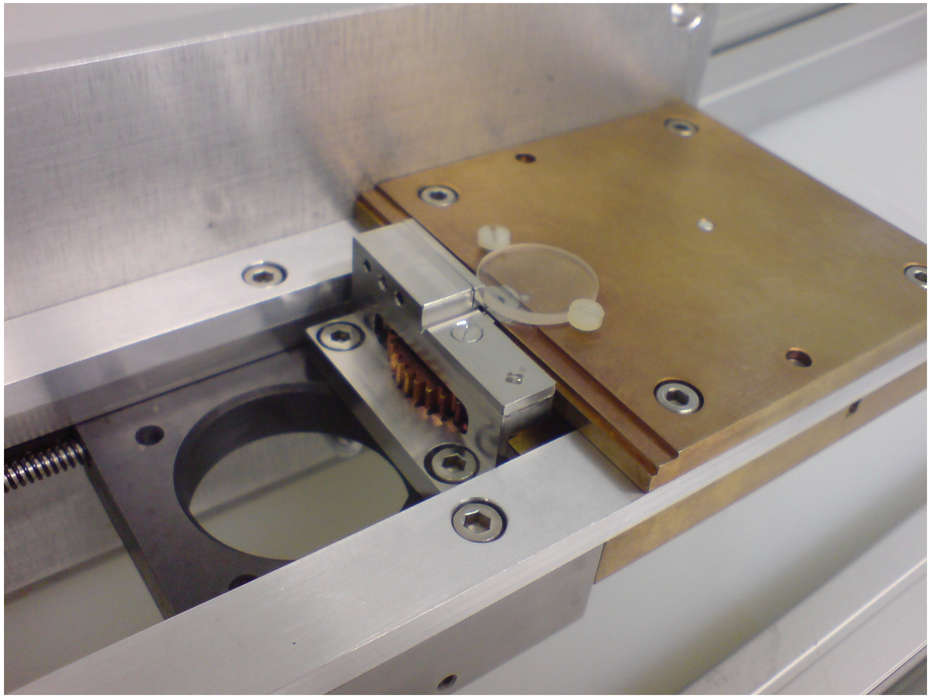


Production in the cleanroom (1/3)
Cutting the wires to desired lenght



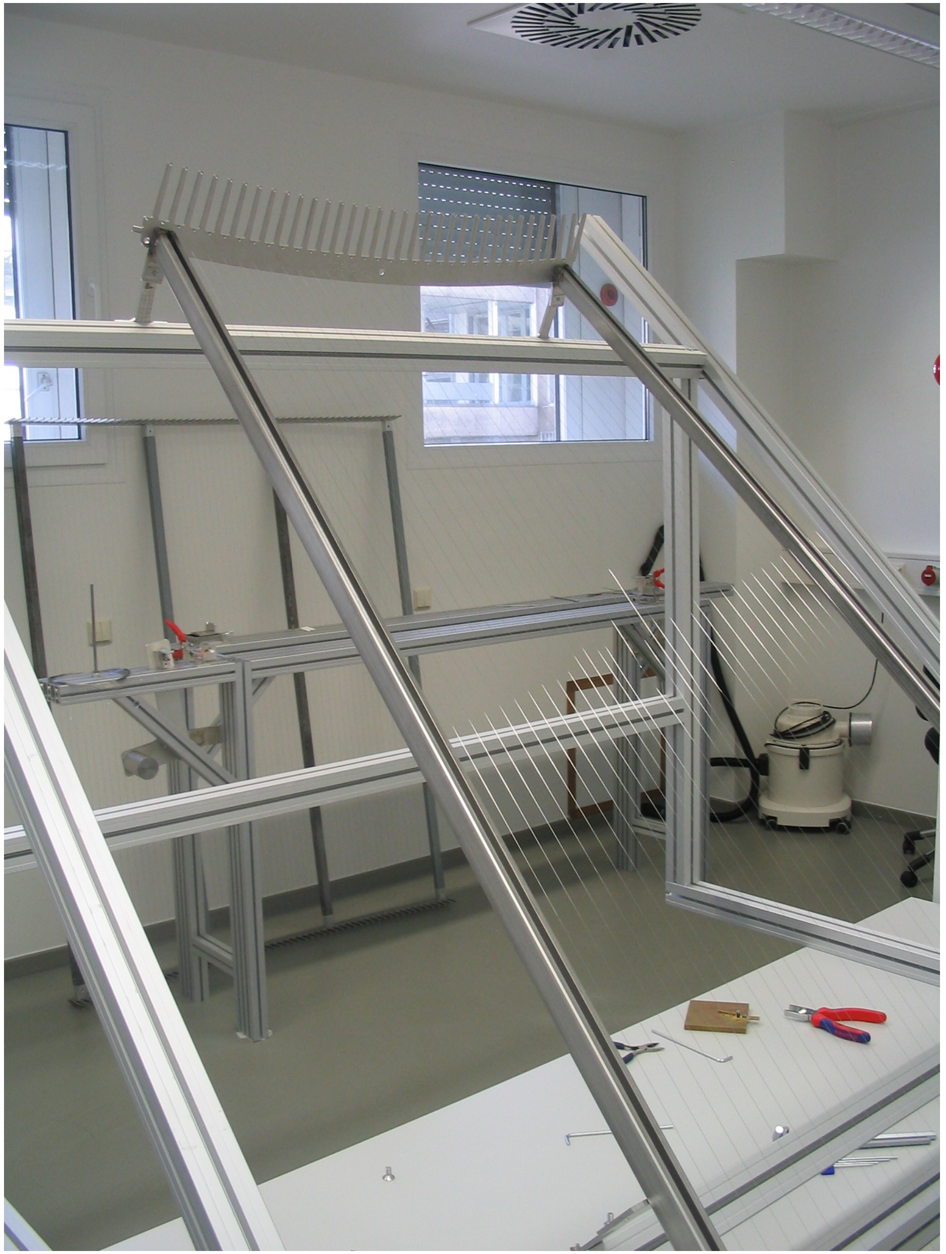
- need to stay in elastic region of the wires
- precise wire length determines tension on the module
  → cut wires under tension
  → cutting position adjusted by µm-screw



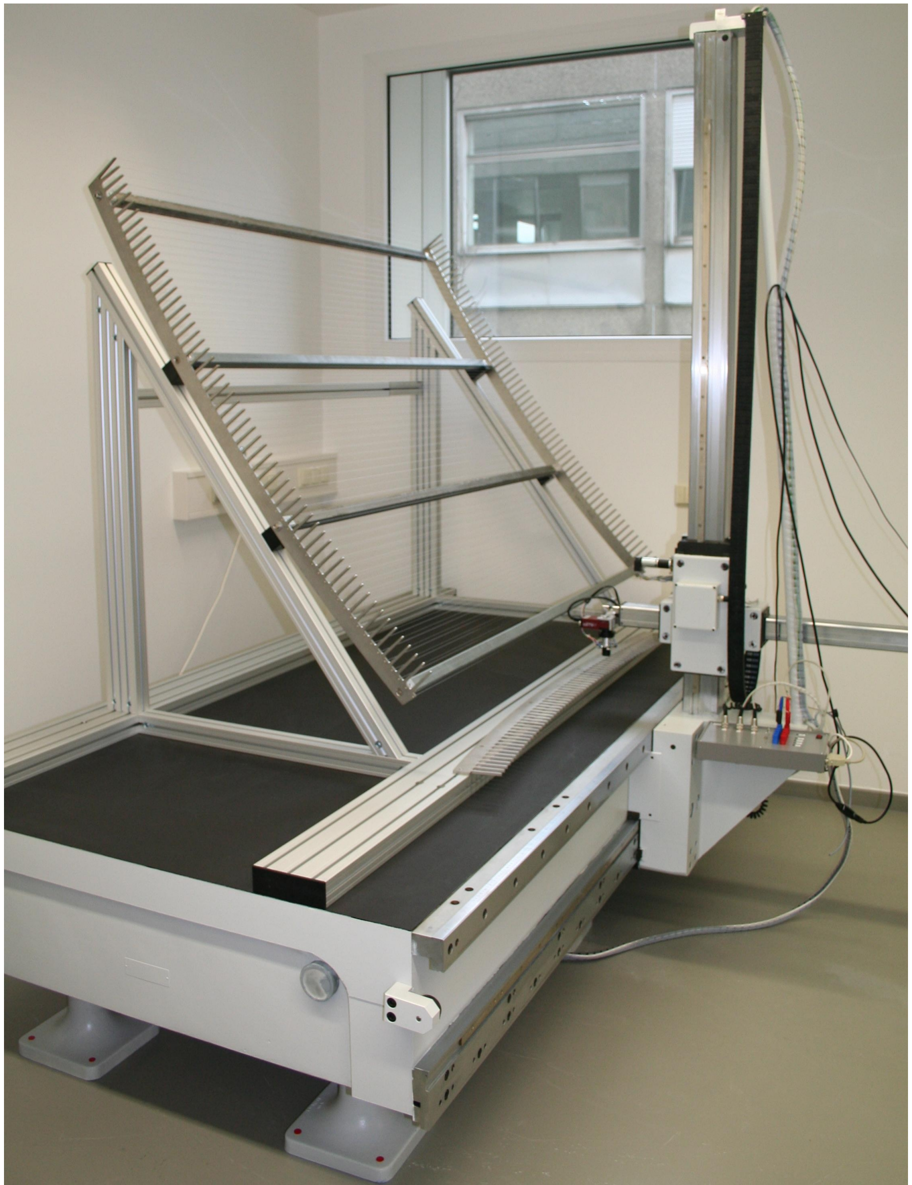


Production in the cleanroom (2/3)
Assembly

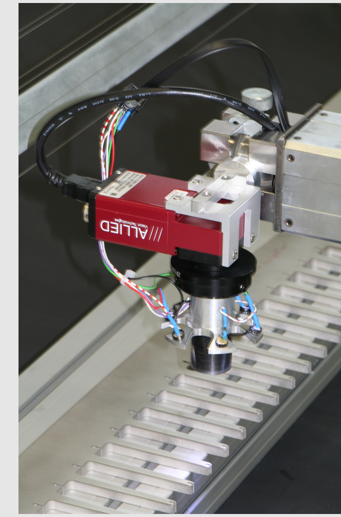
1) attach first ceramic insulator to wire
2) insert wire losely in combs
3) attach second ceramic
4) complete module by inserting c-profiles



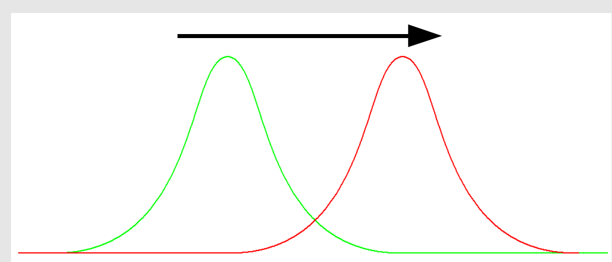
Production in the cleanroom (3/3) measurements and QA

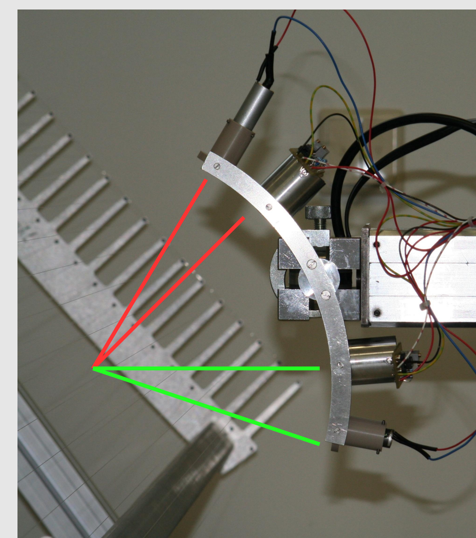


camera
- measure comb geometry using image processing software
- QA of assembled modules (ceramics)



laser sensor
- positioning of wires
- tension of wires by measurement of wire oscillation





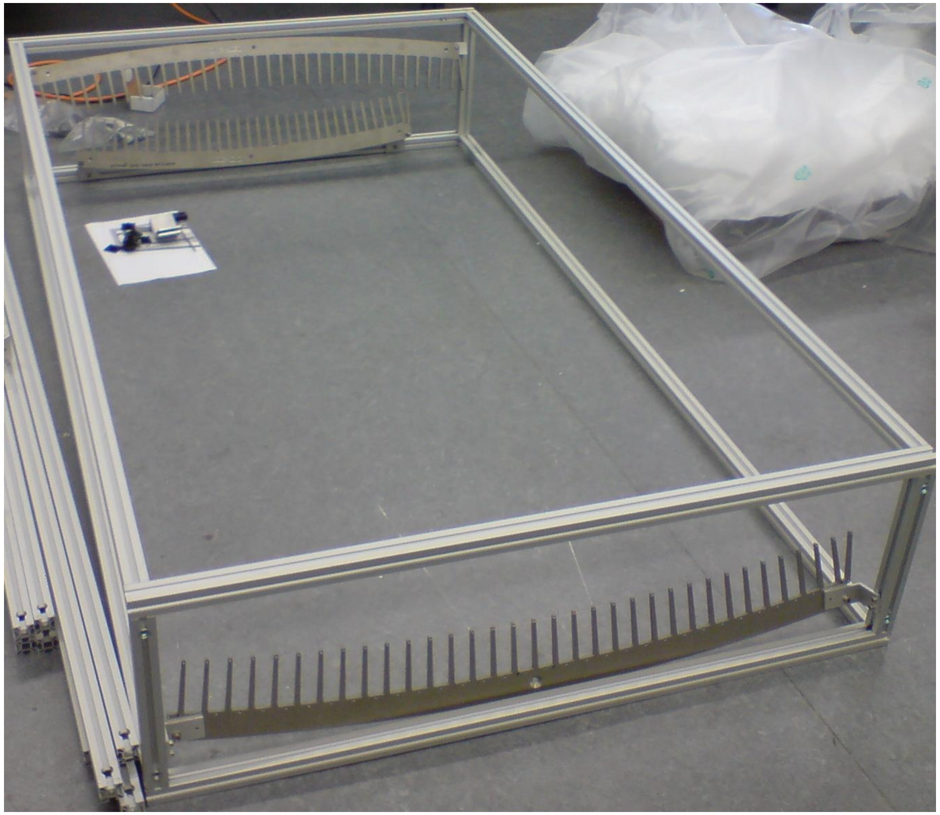
Transportation of the modules to Karlsruhe

- Mount 2 modules in one transport frame

- packaging: 3 layers of PE-foil:
  - inner clean layer, only exposed to clean room at FZK
  - middle layer, removed in the anteroom at FZK, buffer
  - outer layer, to be removed after transport to FZK

- transport to FZK via truck

- details about protecting the modules against vibrations and shocks during transport currently being planned



Summary

- KATRIN will provide highly sensitive, direct measurement of electron neutrino mass
- Dual layer wire electrode provides high background reduction and possibility to shape electric fields inside the main spectrometer
- Prototypes for the central and conical parts of the spectrometer have been produced and tested
- Mass production of electrode components is in process

The KATRIN collaboration

- ≈100 scientists
- 5 countries
- 14 institutions

The end