The KATRIN experiment

Status and second SDS comissioning phase

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KATRIN
Karlsruhe Tritium Neutrino Experiment

Outline

Introduction

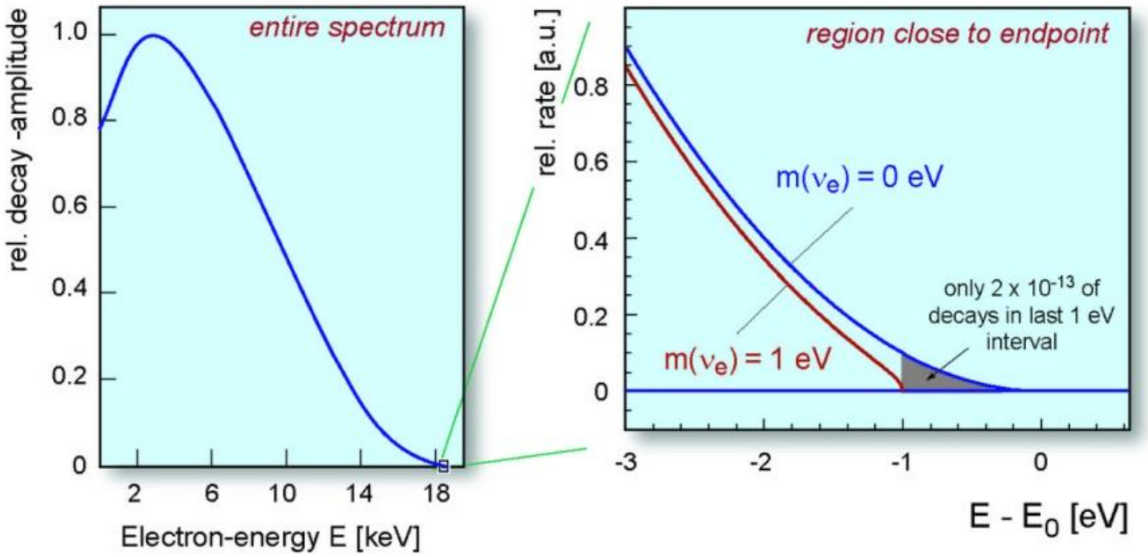
MAC-E filters and the KATRIN experiment

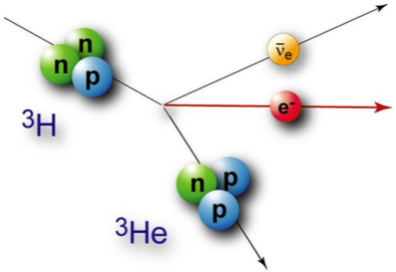
Commissioning of the Spectrometer and Detector Section (SDS)
- Background
- Electron optics

Conclusion

(Tritium) β-decay and neutrino mass

β-decay: $^{A}_{Z}X_{N} \rightarrow ^{A}_{Z+1}X_{N-1} + e^{-} + \bar{\nu}_e$





Tritium ^{3}H:

E_0 = 18.6 keV

$T_{1/2}$ = 12.3 y

Rhenium ^{187}Re:

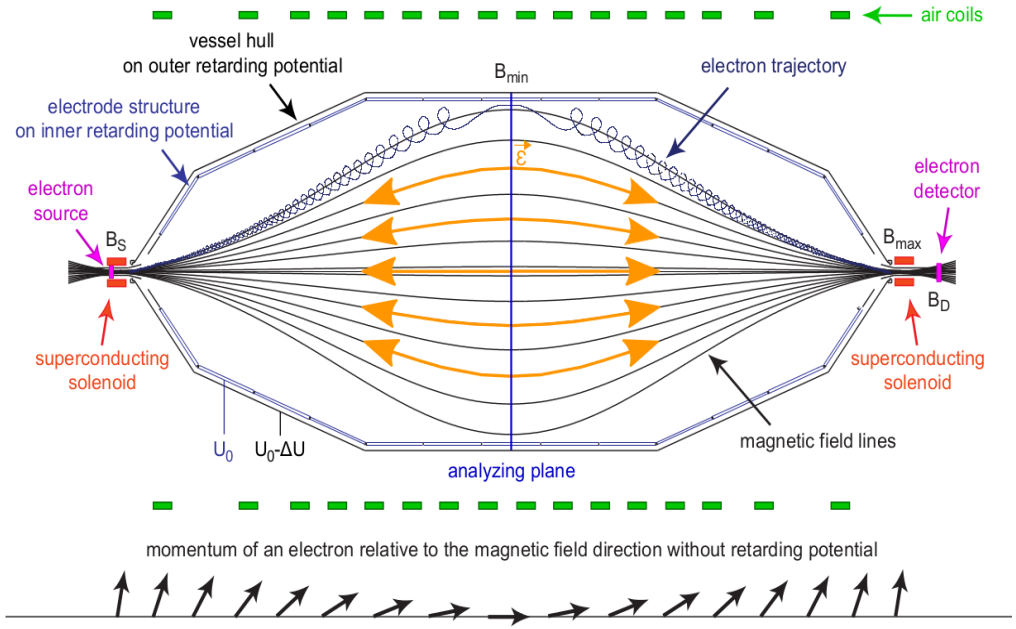
E_0 = 2.47 keV

$T_{1/2}$ = 4.3 10^{10} y

$$\frac{dN}{dE} = K\ F(E,Z)\ p\ (E_e + m_e)(E_0 - E_e)\sqrt{(E_0 - E_e)^2 - m(\bar{\nu}_e)^2}$$

MAC-E Filter

Magnetic **A**diabatic **C**ollimation and **E**lectrostatic Filter:



Magnetic guiding and collimation of e^-
- Transform $E_\perp$ to $E_{||}$

Electrostatic field for energy analysis
- Sharp transmission depending on:
  - Emission angle
  - Radius in at B_{min}

Integrated energy resolution:

$$\Delta E = E \frac{B_{min}}{B_{max}}$$

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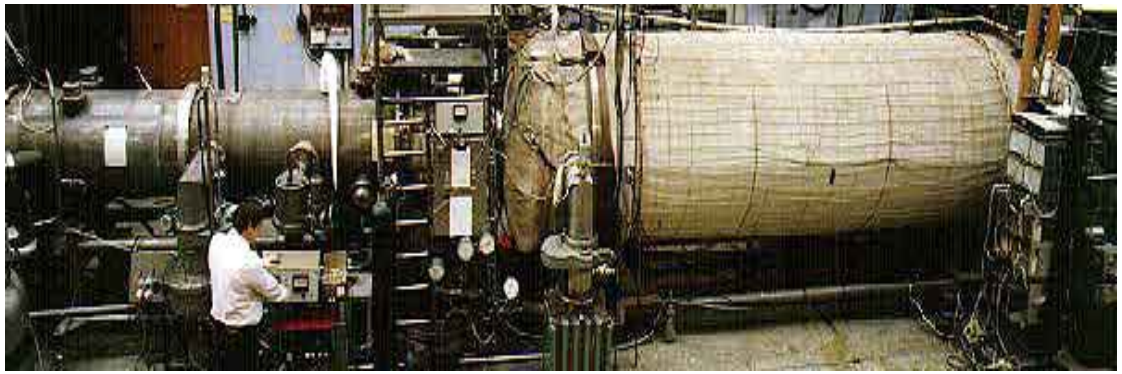
Previous MAC-E filter experiments: Troisk & Mainz

Troisk experiment:

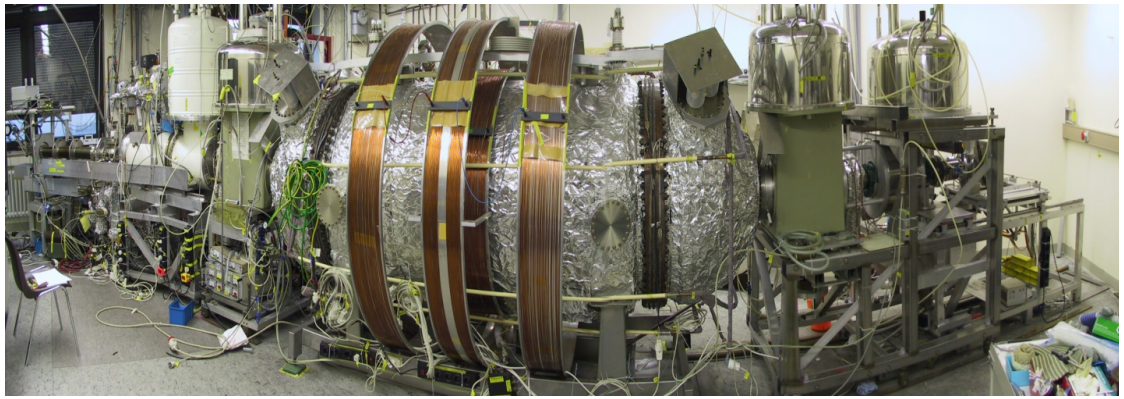


Re-analysis 2011:

$$m^2(\nu_e) = (-0.67 \pm 1.89 \pm 1.68)\ eV^2$$
$$m(\nu_e) < 2.05\ eV$$

V.N. Aseev et al., Phys. Rev. D 84 (2011) 112003

Mainz experiment:

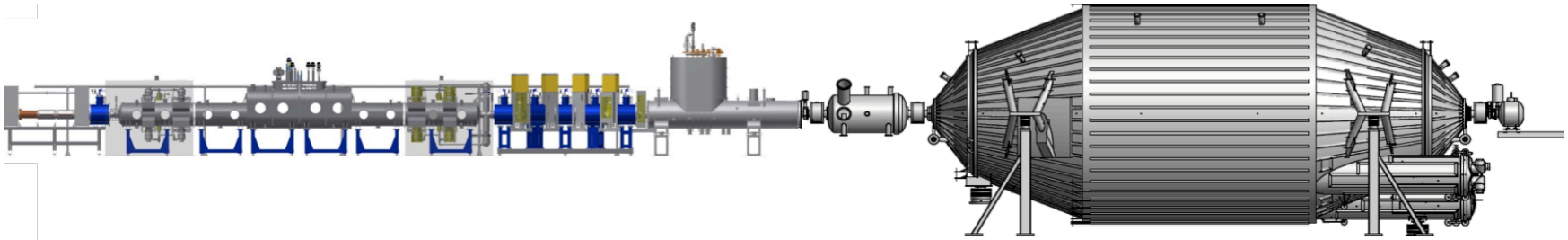


Final result 2004:

$$m^2(\nu_e) = (-0.6 \pm 2.2 \pm 2.1)\ eV^2$$
$$m(\nu_e) < 2.3\ eV$$

C. Kraus et al., Eur. Phys. J. C 40 (2005) 447

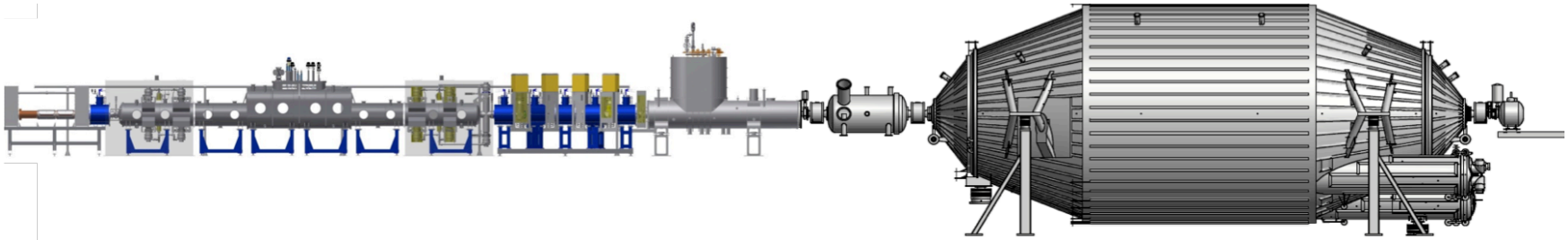
The KATRIN experiment



The **KA**rlsruhe **TRI**tium **N**eutrino experiment:
Next generation direct neutrino mass experiment at KIT
International collaboration: ~150 members
15 Institutions in 5 countries: D, US, ES, CZ, RUS

Member Institutions:

The KATRIN experiment



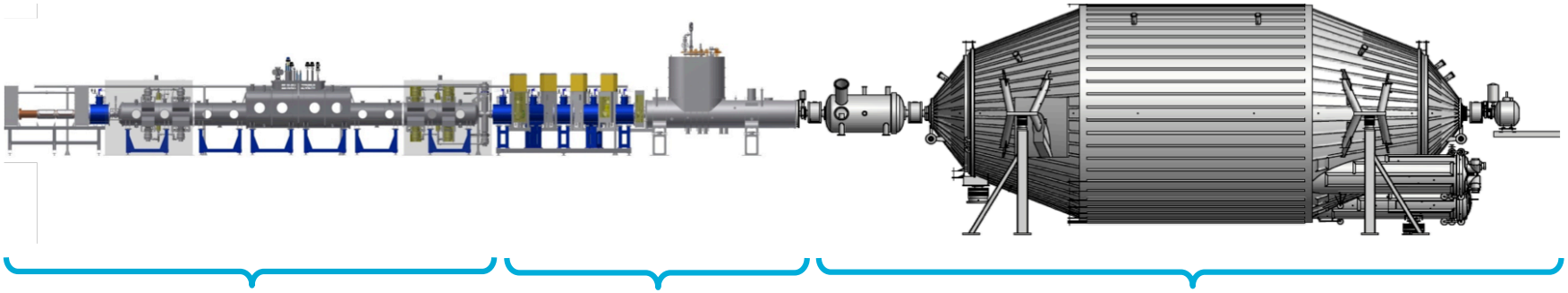
KATRIN sensitivity:

- 3 full years of beam time:
- systematic and statistical error about equal:
  - σ_{stat} = 0.018 eV^2
  - σ_{syst} < 0.017 eV^2
- Sensitivity:
  - m(v) = 200 meV (90 % C.L.)
    = 350 meV (5 σ)

KATRIN beyond m(v):

- sterile neutrinos:
  - light (eV-range)
    - ➢ reactor anomaly
  - heavy (keV-range)
    - ➢ warm dark matter
- Technological advances:
  - Vacuum technology
  - Field calculation & Particle tracking simulation
- etc.

The KATRIN experiment



Source section:
High intensity, highly stable T_2 source

WGTS

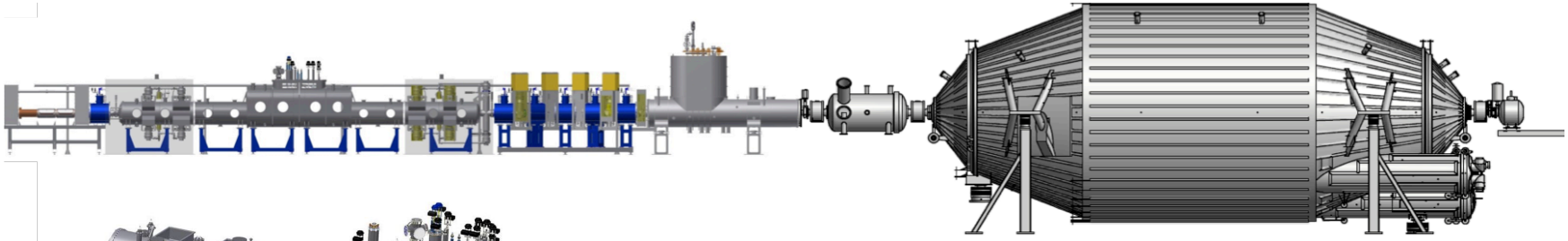
Transport section:
Tritium retention by a factor 10^{14}

DPS, CPS

Spectrometer and detector section:
Electron analysis and detection

PreSpec, MainSpec, FPD

The KATRIN experiment

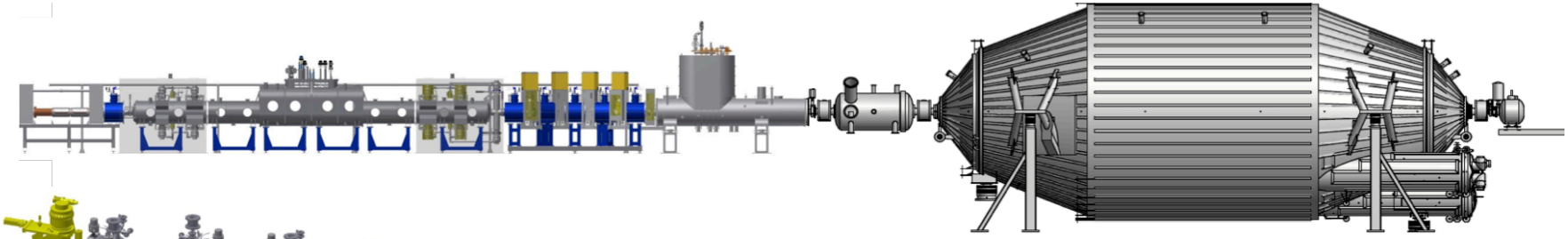


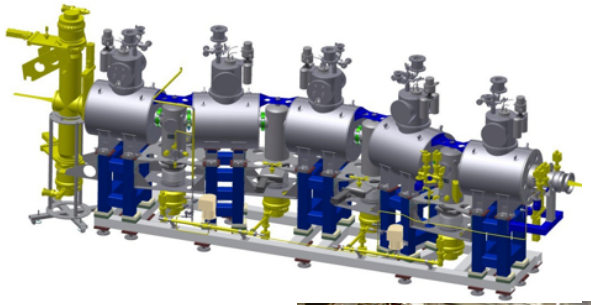
Windowless gaseous tritium source (WGTS)

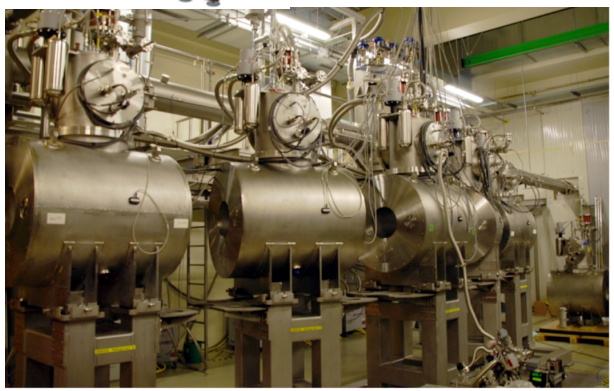
- 10 m long, ⦰ 9 cm tube
- Free flowing T_2 gas
- 1.7 x 10^{11} Bq
- Stable on 10^{-3} level on
  - Inlet pressure
  - Temperature
  - Magnetic field
- Largest source of systematics

- Delivery to KIT in August 2015

The KATRIN experiment





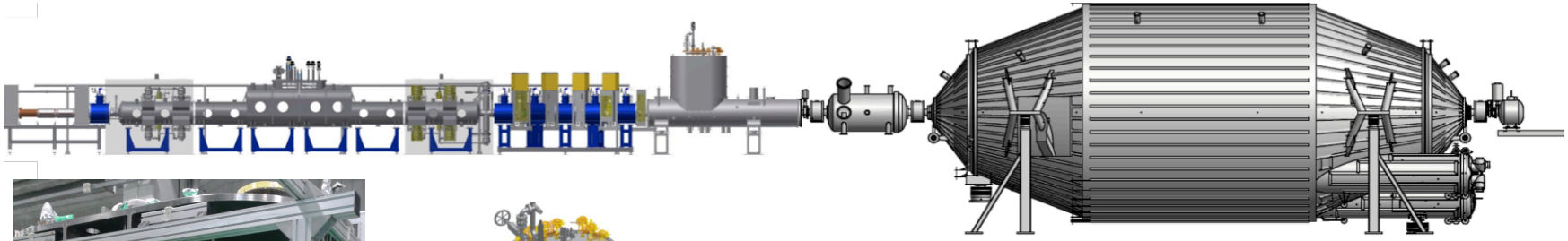


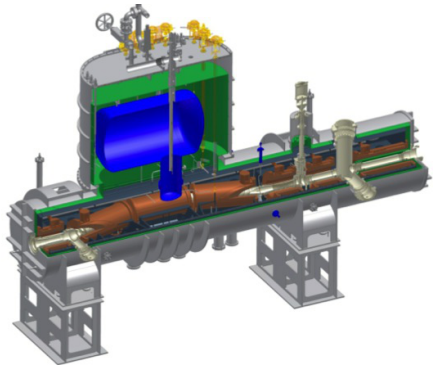
Differential pumping section (DPS)

- 5 superconducting solenoids @ 5.6 T
- Active pumping with 4 TMPs
- Chicane setup
- Tritium retention by 10^5

- Magnets set-up at KIT
- Magnet tests and beam line assembly currently ongoing

The KATRIN experiment



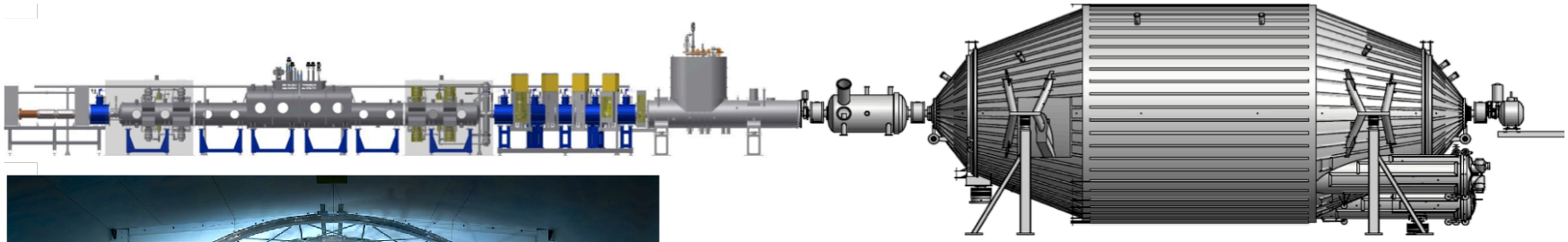


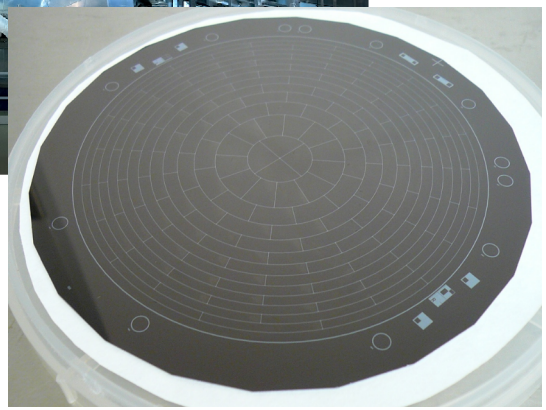
Cryogenic pumping section (CPS)

- 7 magnets @ 5.6 T
- Chicane setup
- Cryo-pumping of residual gas
- Argon frost on surface @ 3-4.5 K
- Tritium retention > 10^7

- Manufacturing in final steps
- Delivery to KIT in May 2015

The KATRIN experiment





Spectrometer and detector section

- Tandem spectrometer setup

Pre-Spectrometer

- Pre-filter 10^{11} $e^-/s \Rightarrow 10^3$ e^-/s
- Used for R&D for Main Spec

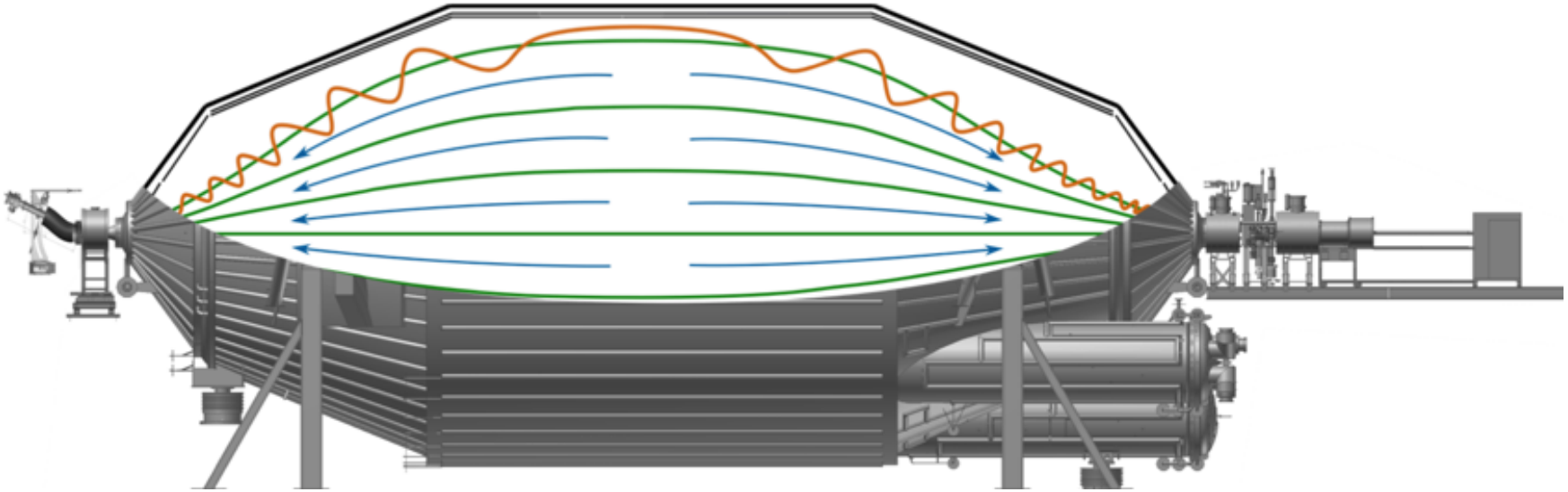
Main Spectrometer

- Main energy analysis
- ΔE = 0.93 eV

Focal plane detector (FPD)

- 148 Pixel Si-PIN diode
- $\Delta E \sim 1$ keV

Spectrometer and Detector commissioning



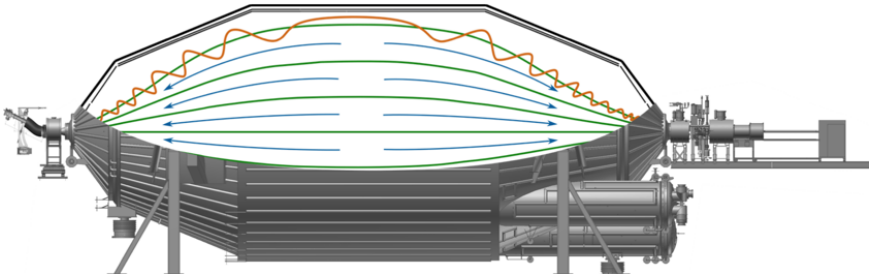
Subsystems:

- Main spectrometer
- Focal plane detector
- Angular selective e^--source

Tests:

- Hardware, Software, Slow Control
- Background
- Transmission Properties

Spectrometer and Detector commissioning



Vacuum system:

- p < 1e-9 mbar **w/o baking**
- 3 lN_2 cooled baffles

High voltage system:

- running w/o major problems

Inner electrode:

- Some electric shorts between inner and outer wire layer

➢ most measurements in single layer mode

Magnet system:

- Pinch magnet only @ 5 T

➢ New Pinch just arrived at KIT

E-Gun:

- runs nicely after some improveme

Focal plane detector:

- w/o muon veto
- two minor repairs necessary

Software and slow control:

- New systems commissioned
- w/o major failures

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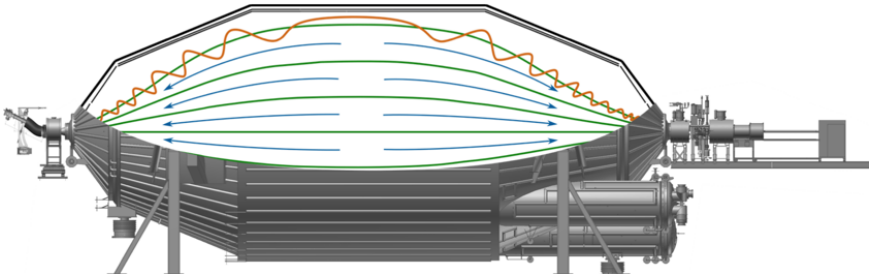
Spectrometer and Detector commissioning

Background: Stored particles

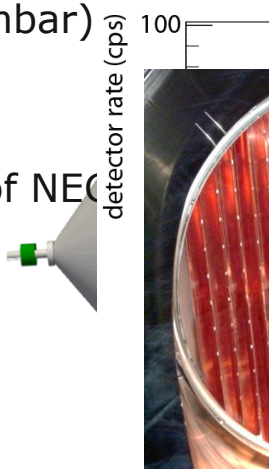
Sources:

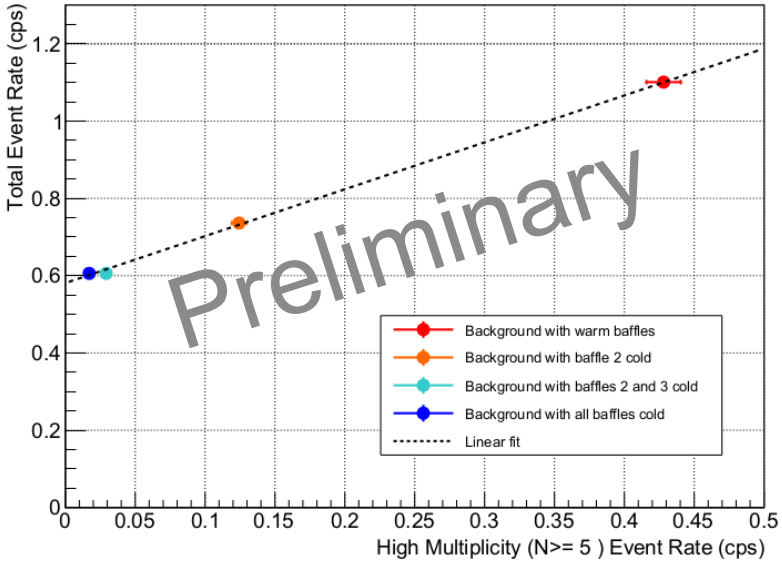
- Radioactive decays in volume
- Secondary processes
- ^{219,220}Rn emanating from NEG pumps



Identification:

- Elevated pressure (~10^{-8} mbar)
- High multiplicity events





Countermeasure:

- lN_2 cooled baffles in front of NEG pumps

Results:

- Rn BG level negligible

detector events

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Spectrometer and Detector commissioning

Background: secondary e^- from vessel wall/inner electrode

Sources:

- Cosmic rays
- Radioactive decays on surface

Identification:

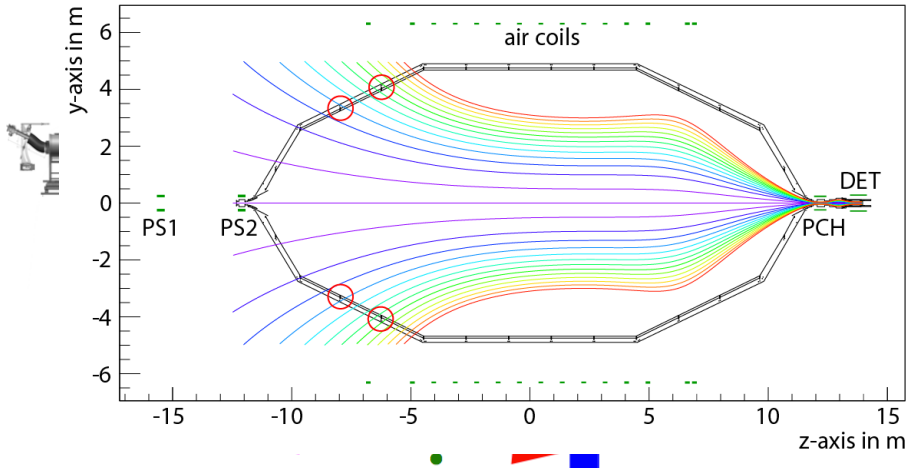
- Radial dependence of BG rate
- Specific test measurements

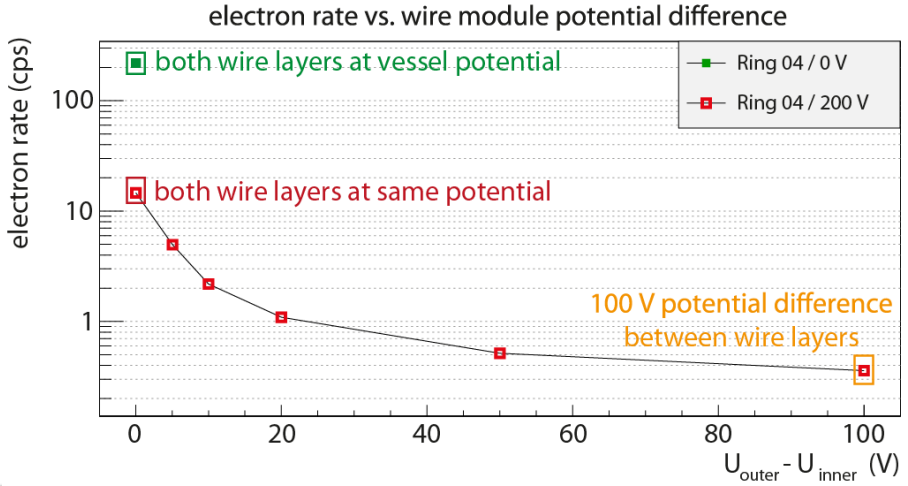
Countermeasure:

- magnetic shielding
- electric shielding with double layer inner electrode

Results:

- Shielding very effective, but remaining BG





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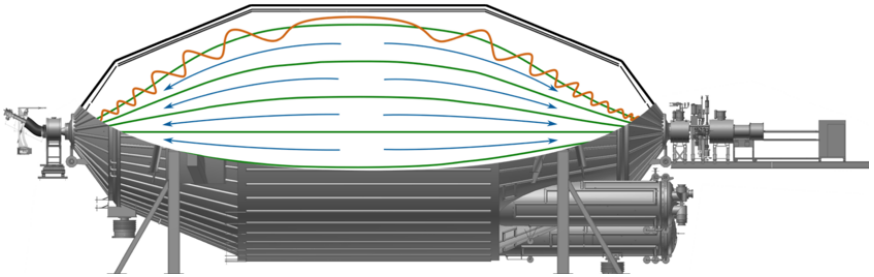
Spectrometer and Detector commissioning

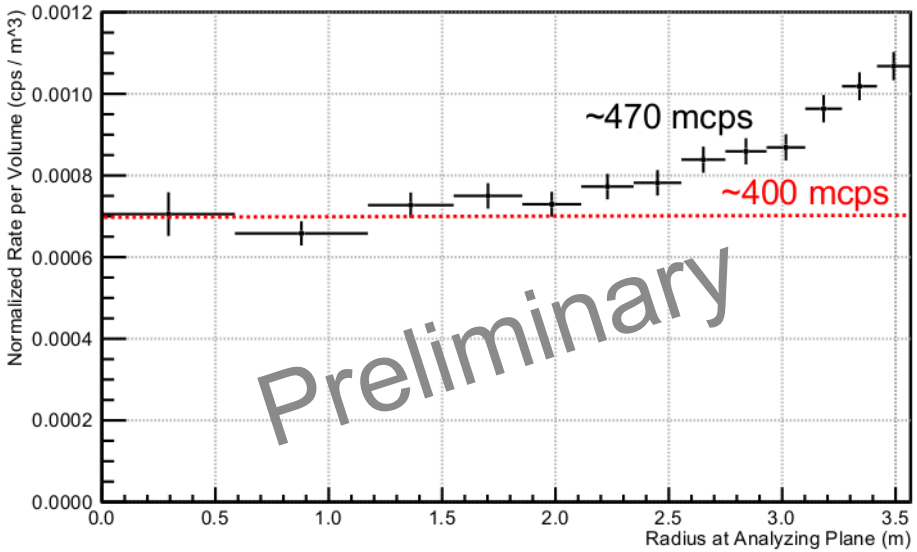
Total Background:

- ~400 mcps
  - design goal: 10 mcps
- volume dependent (flux tube)
- radially dependent part:
  - pressure dependent
  - IE fine tuning

But:

- Spectrometer not baked
  - ➢ lower pressure
  - ➢ different surface conditions



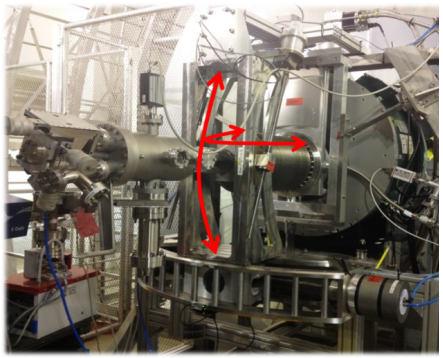


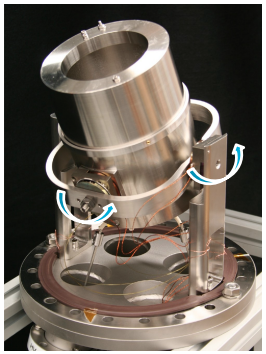
Spectrometer and Detector commissioning

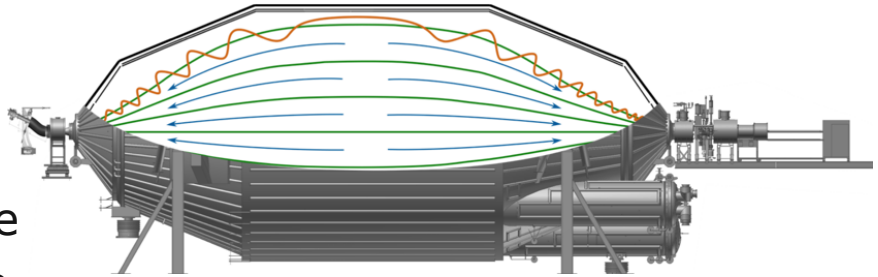
Electron Optics

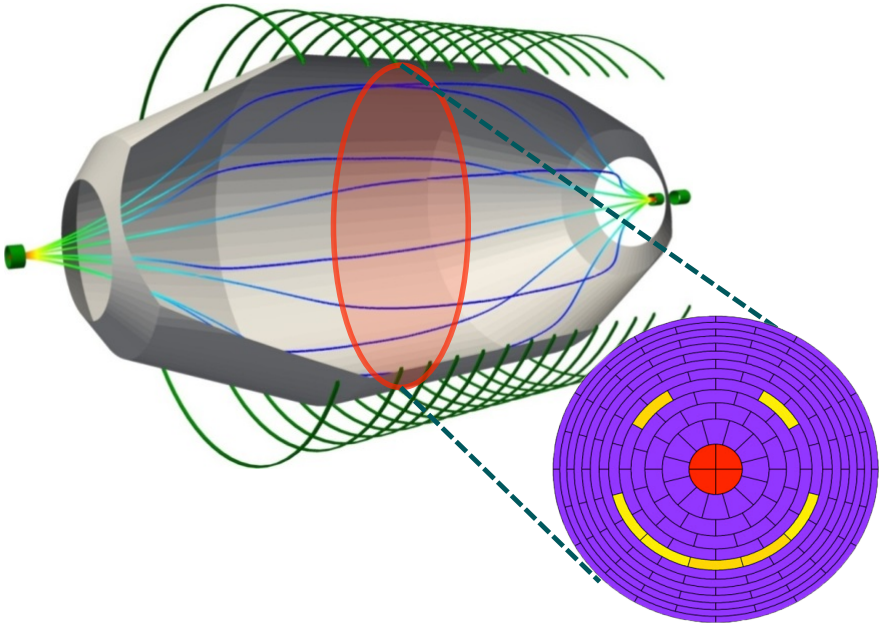
Angular selective e^--source:

- quasi mono-energetic photo-e^- created with UV-light on Au surface
- fast non-adiabatic acceleration of e- in non-parallel $\vec{E}$ and $\vec{B}$ fields
- 4 axis movement:
  - 2 axis to cover flux tube
  - 2 axis to change pitch angle







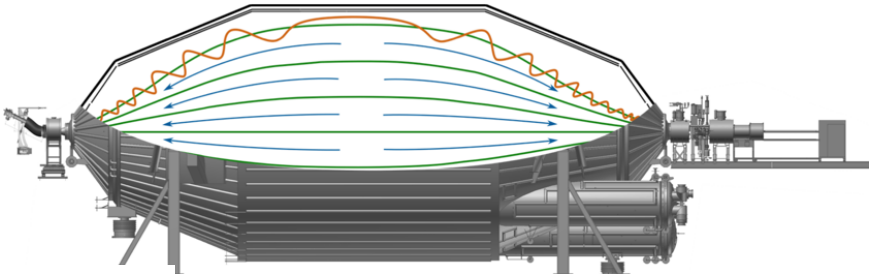


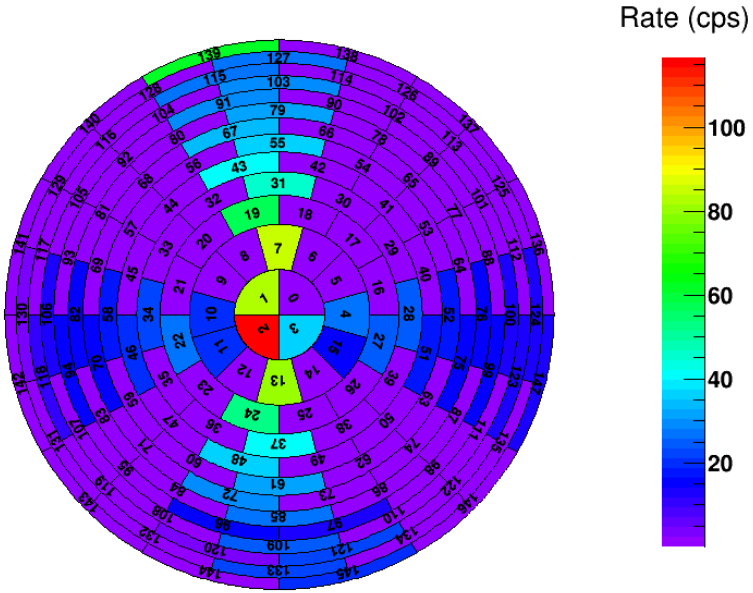
Spectrometer and Detector commissioning

Electron Optics

Alignment:

- Whole wafer can be covered





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Spectrometer and Detector commissioning

Electron Optics

Alignment:

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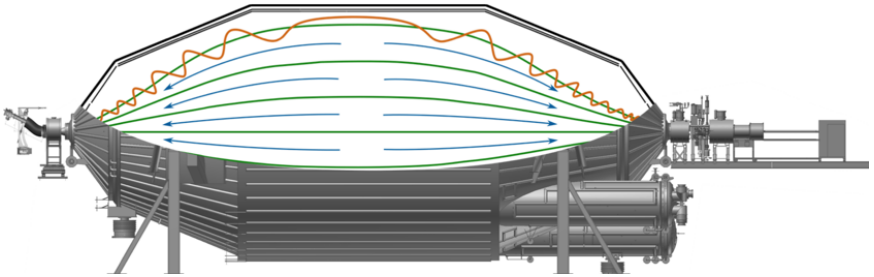
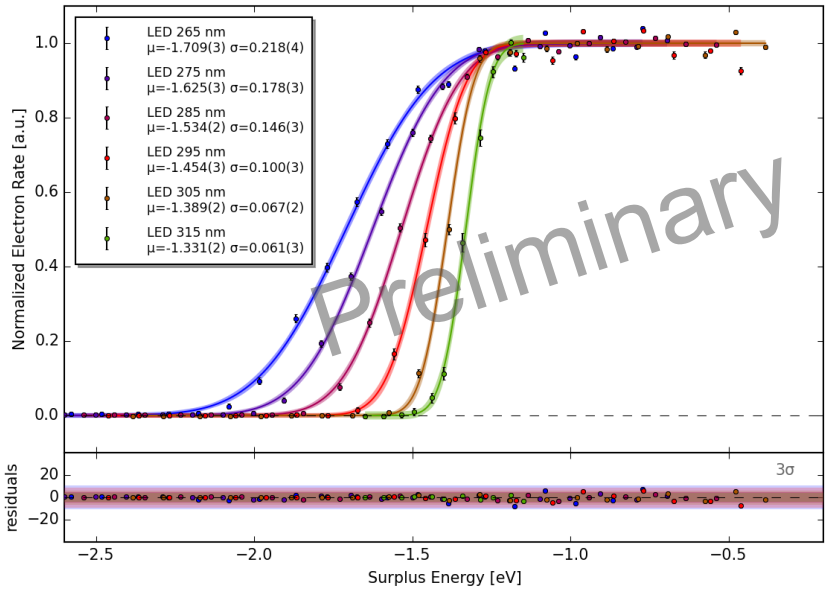
Low voltage characterization:

- Energy distribution of emitted e⁻
  - 0.05 < σ < 0.25 eV
  - depends on UV wavelength





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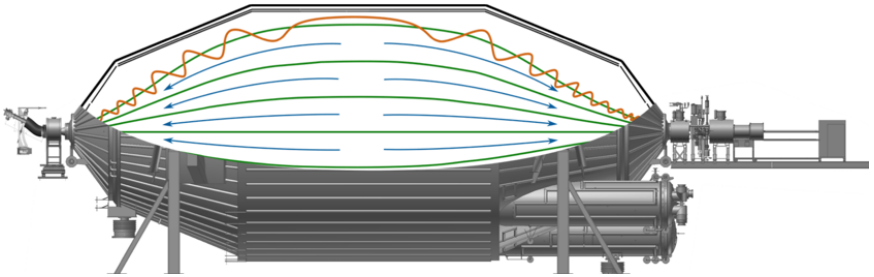
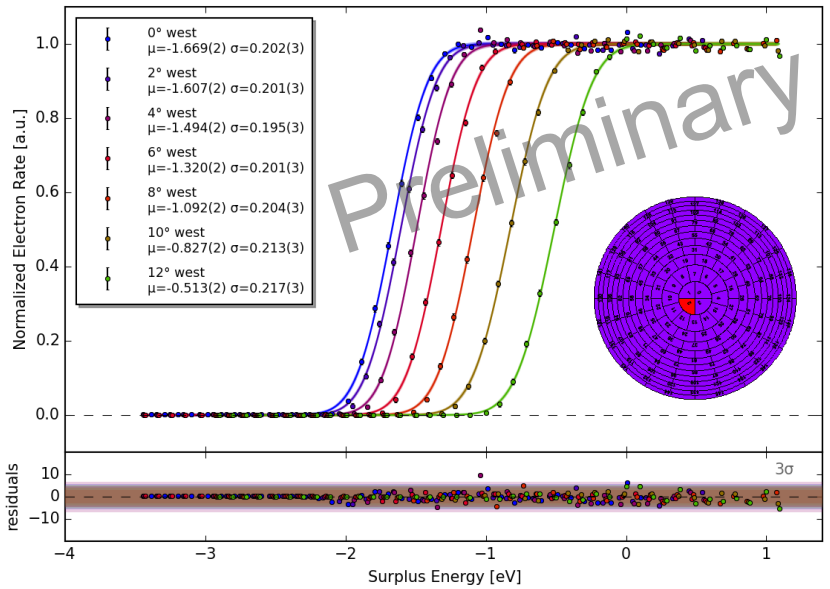
High voltage characterization:

- Angular selectivity shown
- Width: $\Delta E \approx 1.2 \text{ eV} \approx E \frac{B_{\min}}{B_{\max}}$

$E = 18.6$ keV; $B_{\min} = 0.38$ mT; $B_{\max} = 5$ T





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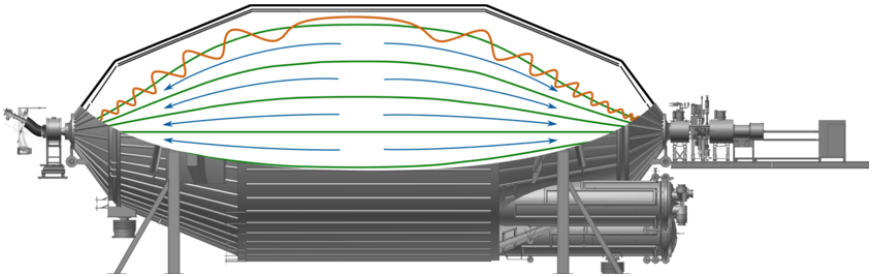
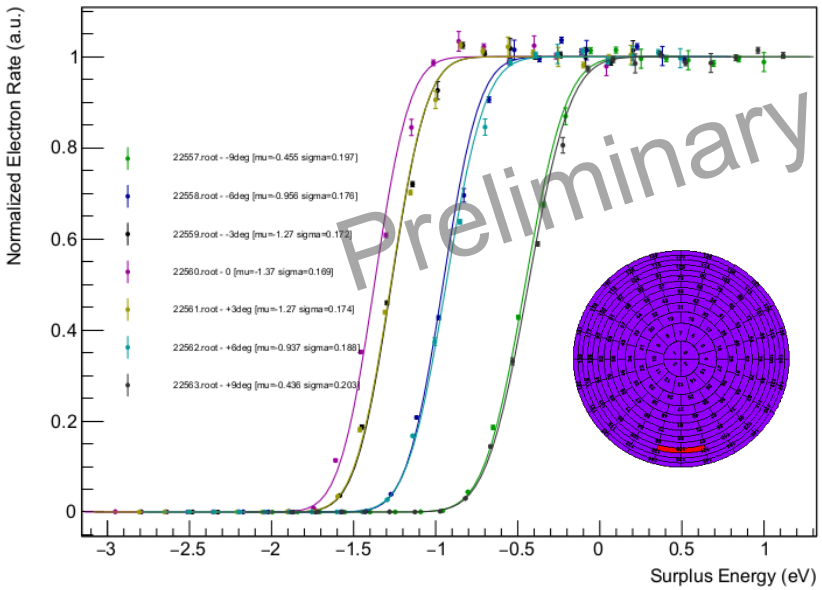
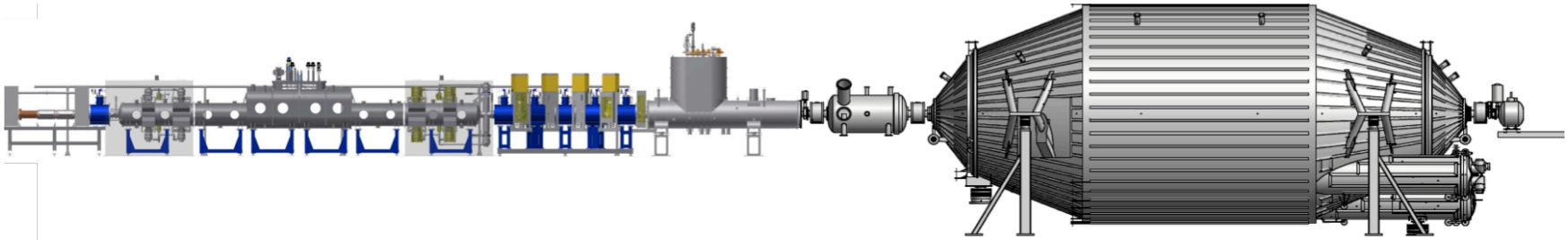
  $E = 18.6 \text{ keV}; B_{\min} = 0.38 \text{ mT}; B_{\max} = 5 \text{ T}$
- Small changes over the wafer
- Symmetric in pitch angle





Conclusions



The KATRIN experiment

- Source and transport section in the last manufacturing steps
- All parts delivered to KIT in Summer 2015
- 2nd Commissioning phase about to finish
- 3rd Commissioning phase in Spring 2016
- Physics runs start in Summer 2016

2nd Commissioning phase

- Test measurements on the spectrometer and detector section
- Hard- and software components operational w/o major problems
- Background further reduced, but still too high
- Electron optics look very promising
- **Caution:** Very preliminary results! (Some data sets < 2 weeks old) Stay tuned for more SDS-II results!

Thank you!