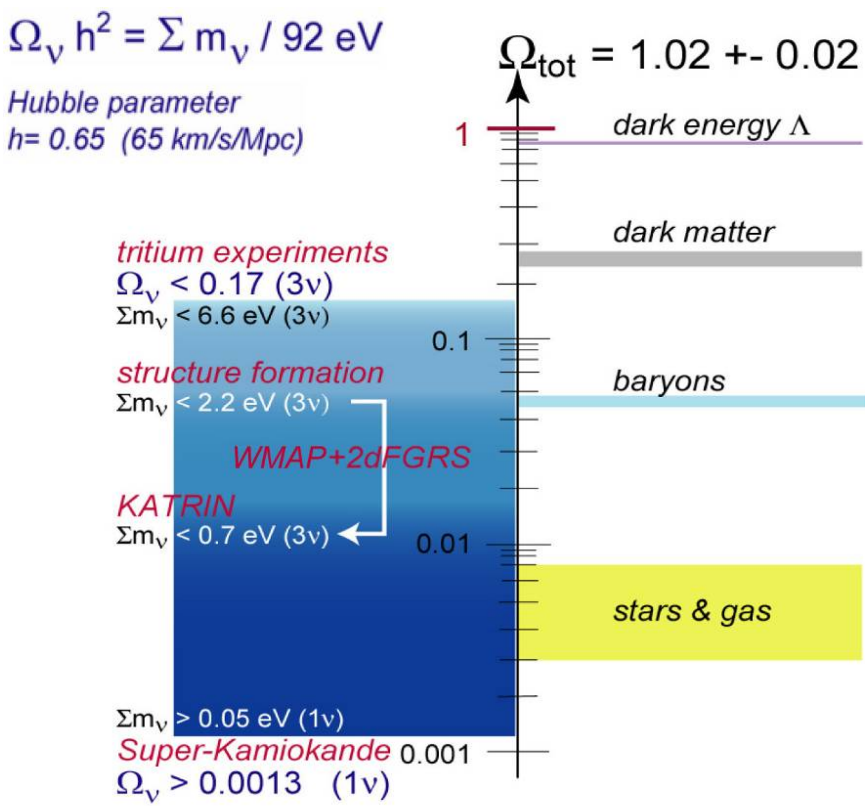
KATRIN: An experiment to determine the neutrino mass

Florian Fränkle
for the KATRIN Collaboration

Motivation from cosmology

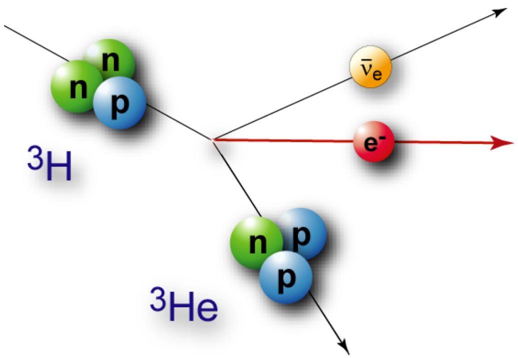
Upper limit on neutrino mass:
m_ν < 2.3eV (β-decay)

- determine absolute neutrino mass scale
- probe cosmological relevant region
- help to understand neutrino mass generation mechanism



KATRIN: only model independent determination of "electron anti-neutrino mass", sensitivity: 0.2 eV

Tritium β-decay



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

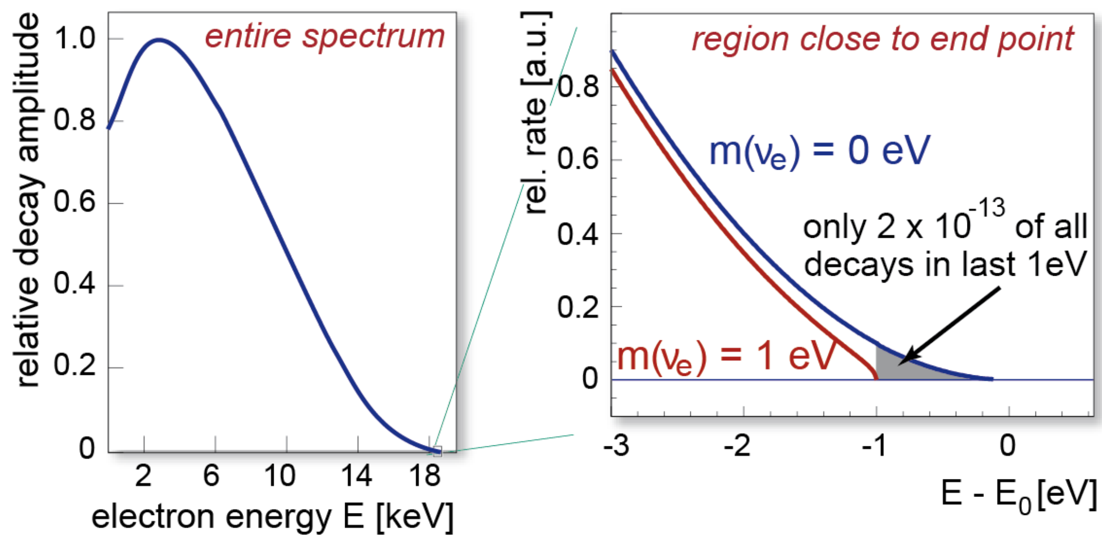
Fermi theory of β-decay:

$$\frac{dN}{dE} = C \cdot F(E,Z) \cdot p(E+m_e) \cdot (E_0 - E) \cdot \sqrt{(E_0 - E)^2 - m_\nu^2}$$

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

tritium as β emitter:

- high specific activity (half-life: 12.3 years)
- low endpoint energy E_0 (18.57 keV)
- super-allowed



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KATRIN experiment

(**KA**rlsruhe **TRI**tium **N**eutrino experiment, location: Forschungszentrum Karlsruhe)

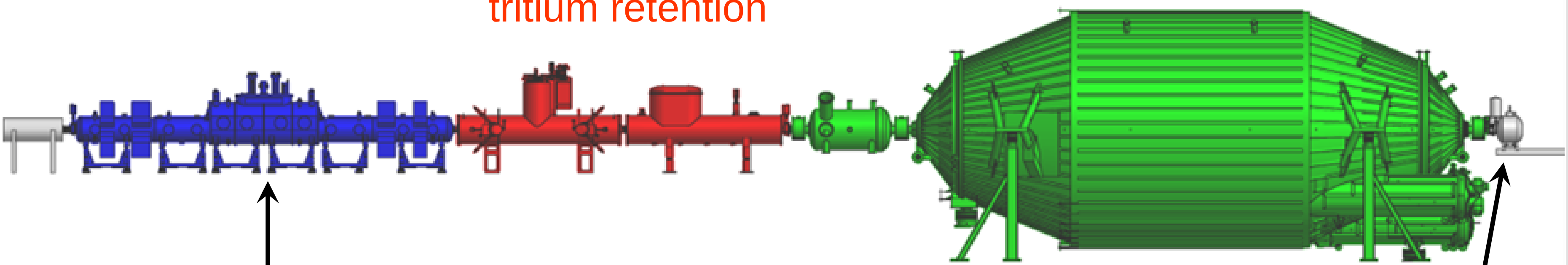
70 m

tritium decay

electron transport

tritium retention

energy analysis



β-decay rate: $\mathbf{10^{11}}$ Hz

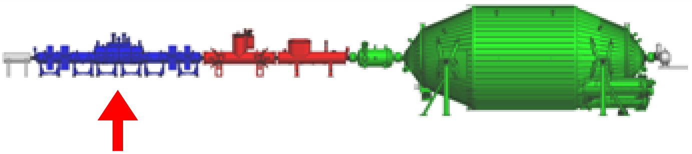
T_2 pressure: $\mathbf{10^{-6}}$ mbar

about **14** orders of magnitude

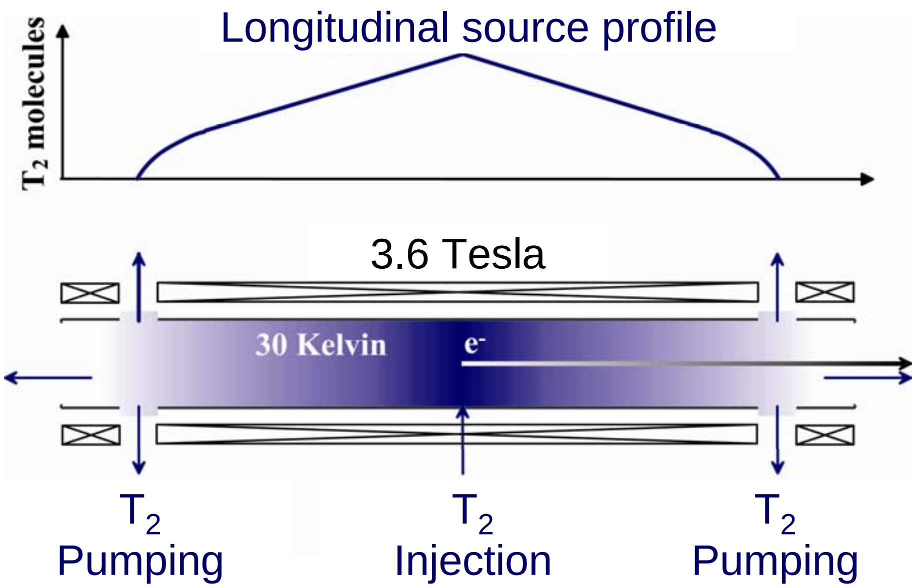
background rate: $\mathbf{10^{-2}}$ Hz

T_2 pressure: $\mathbf{10^{-20}}$ mbar

adiabatic guiding of electrons on meV level



WGTS



purpose: Delivery of 10^{11} β-decay electrons per second

requirements:

- Stability of T_2 density profile of **10^{-3}** (function of: injection rate, purity, beamtube temperature T_B, pump rate)
- T_B homogeneity ±30 mK
- T_B stability ±30 mK • h^{-1}

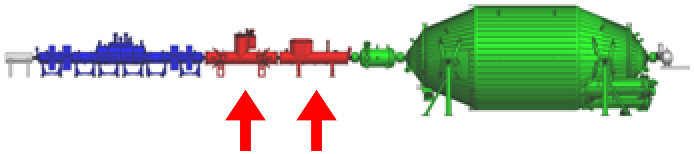
status:

- Demonstrator to test new cooling concept 2009
- Construction 2010/11
- Commissioning 2012

properties:

- Beam tube: 10m length, 90mm diameter, absolute temperature 30K
- Tritium loop: 40g T_2 / day

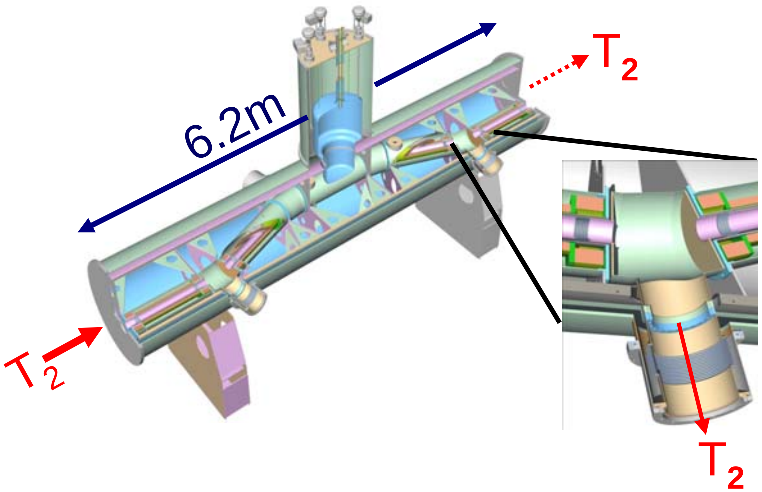
TLK provides complex infrastructure to handle tritium



tritium retention

Differential Pumping Section:

purpose: reduce T_2 flux by 10^5

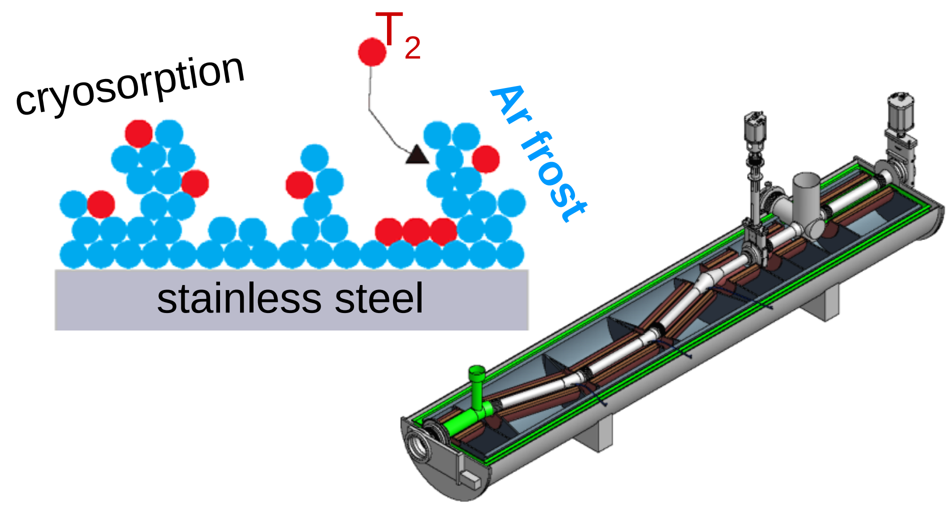


- differential pumping of T_2 (TMPs)
- magnetic guiding of electrons (5.6T)
- removal of positive ions (dipole)

status:
- Delivered to FZK **2 days ago!**
- Acceptance tests
- test program 2010

Cryogenic Pumping Section:

purpose: reduce T_2 flux by 10^7



- cryosorption of T_2 on Argon frost
- concept successfully tested (TRAP)

status:
- Technical design report is ready
- presently being manufactured at ASG
- Delivery to FZK on 10.2010
- Commissioning 2011

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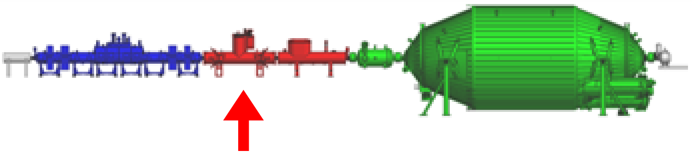
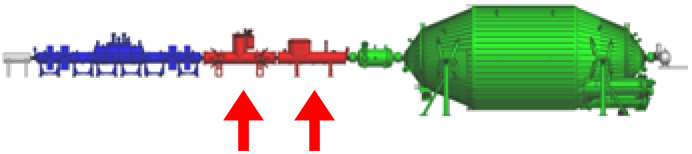


Arrival of DPS

Karlsruhe Institute of Technology



tritium retention

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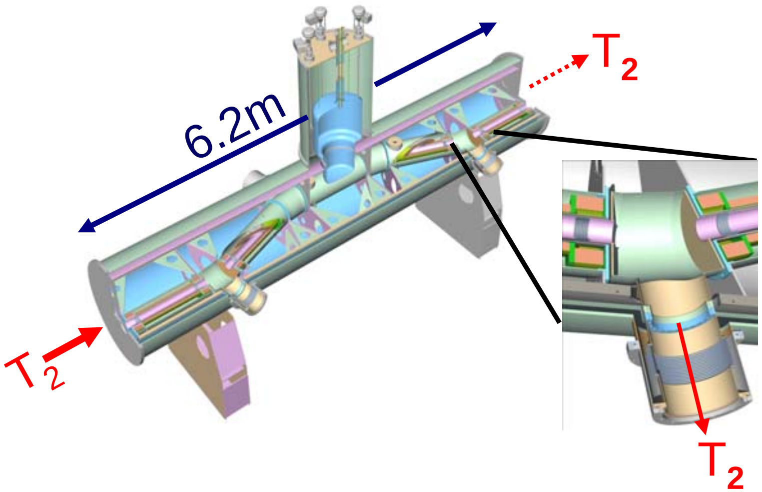

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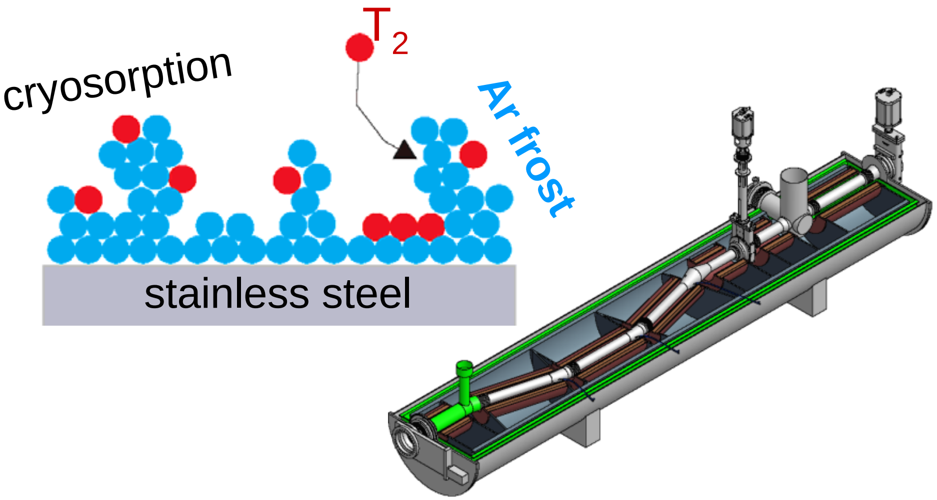

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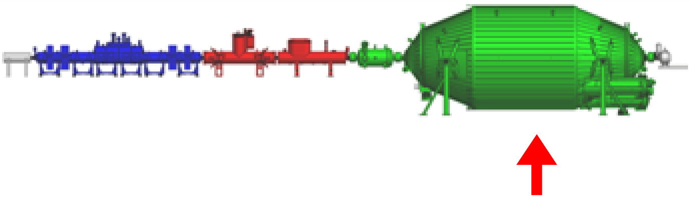


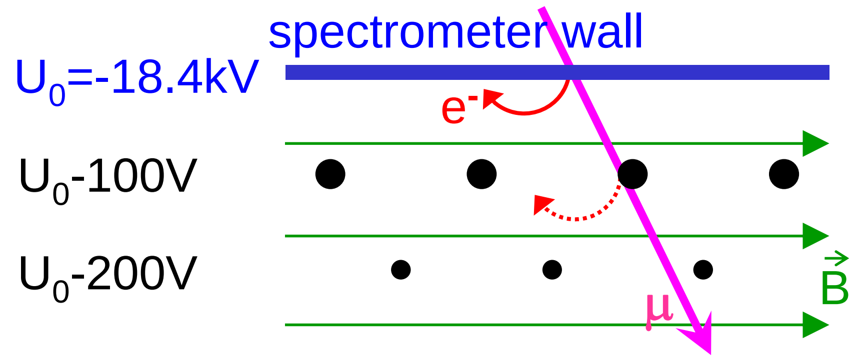
main spectrometer

purpose: energy analysis

requirements:

- energy resolution 0.93eV @ 18.6keV
- pressure < 10^{-11}mbar
- background event rate < 10mHz
- stable HV system (1ppm @ -18.6kV)

background rejection:

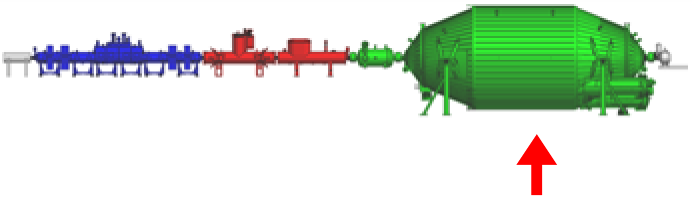


properties:

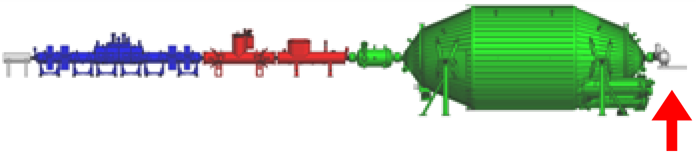
- MAC-E filter (integrating high pass filter)
- volume: 1240m³, surface: 689,6m²
- inner electrode system
- variable voltage to scan E_0 region

status:

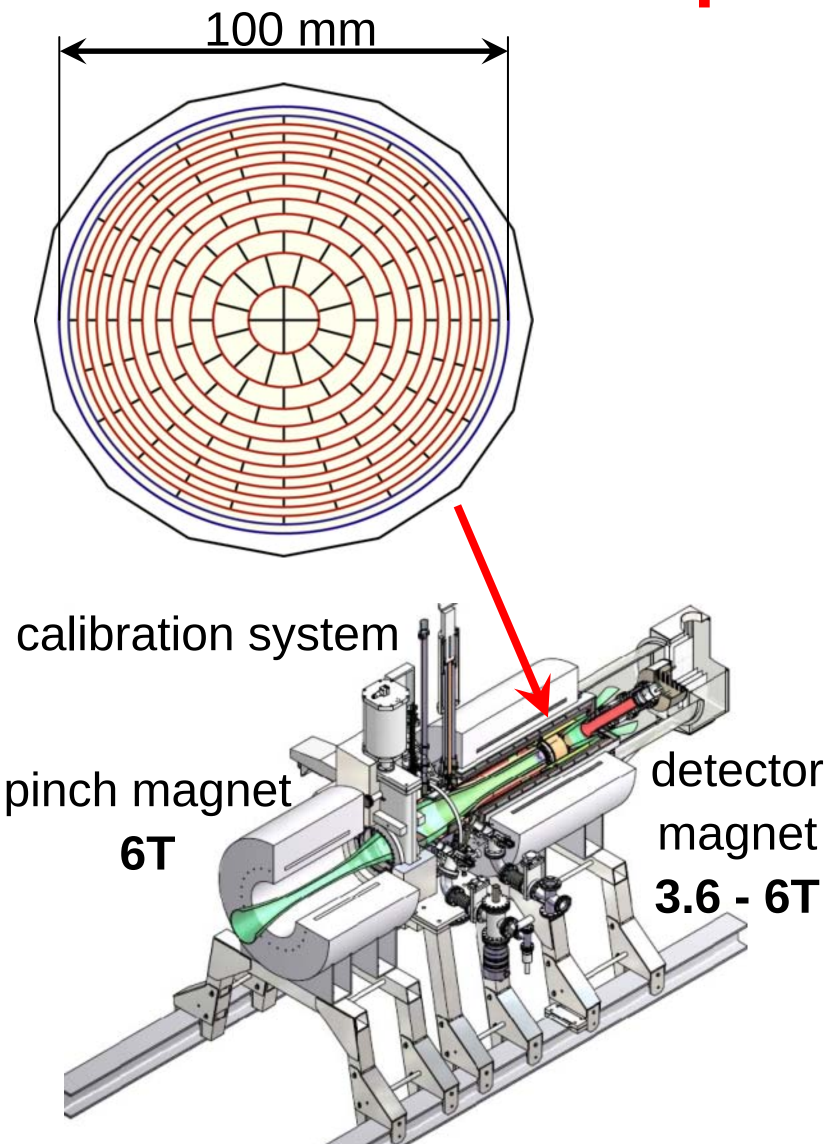
- First vacuum test without getter pump successful (10^{-10}mbar)!
- Mounting of inner electrode system
- Electro-magnetic test measurements 2010



main spectrometer



detector system

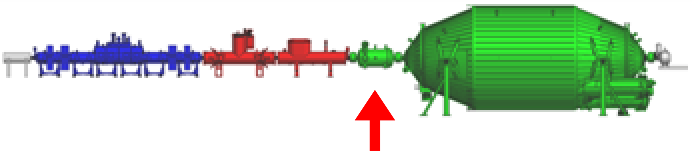


purpose: counting transmitted β-decay electrons

requirements:
- intrinsic background rate < 1mHz in RoI
- electron energy range 5 to 100keV
- energy resolution < 1keV

properties:
- segmented monolithic Silicon PIN Diode
- 148 pixels, area ~ 50mm² each
- post acceleration (up to 30kV)

status:
- Assembly and initial commissioning until 02/2010
- Delivery to FZK 03/2010

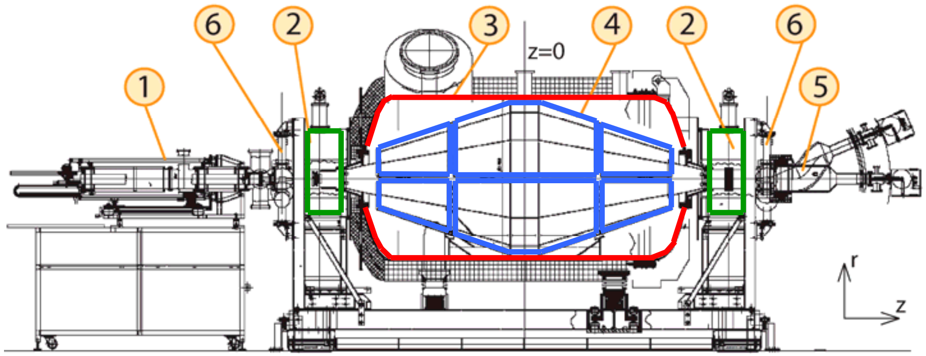


pre-spectrometer

purpose: reduce β-decay electron flux by 10^6

- MAC-E filter
- energy resolution 70eV @ -18.4keV
- pressure 10^{-11}mbar

pre-spectrometer test setup



1 detector	**2** magnets (4.5 T)
3 vessel	**4** electrode system
5 electron gun	**6** valve

prototype for main spectrometer:

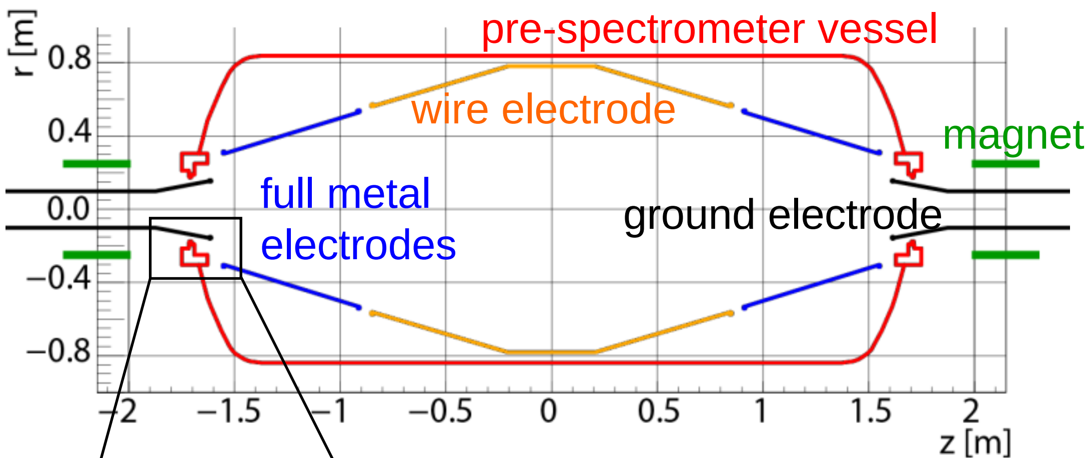
- vacuum concept successfully tested (p = 10^{-11}mbar, routinely)
- active HV stabilization tested
- test of new electromagnetic design
- background suppression
- optimization of electrode system

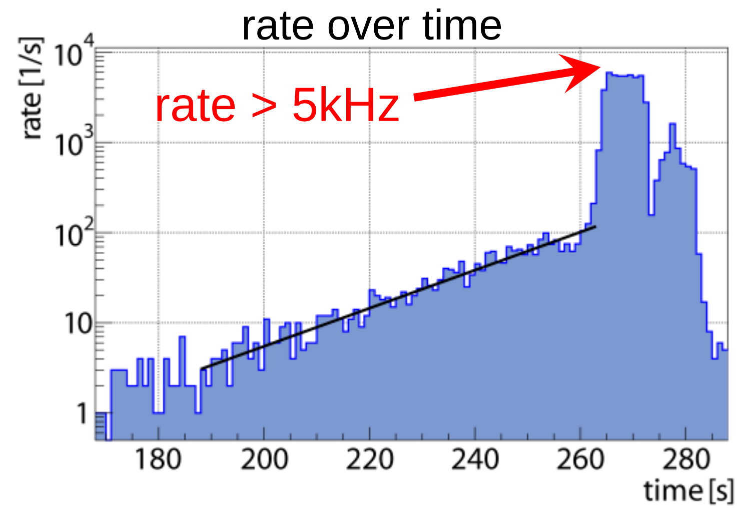
status:

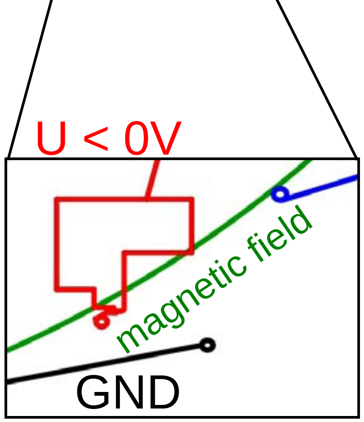
- end of test measurements 12/2009
- relocation of pre-spectrometer to main spectrometer hall 2010

Penning trap

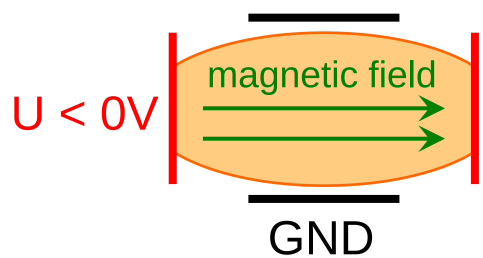
Combination of electric and magnetic fields can create Penning traps







Penning Trap:

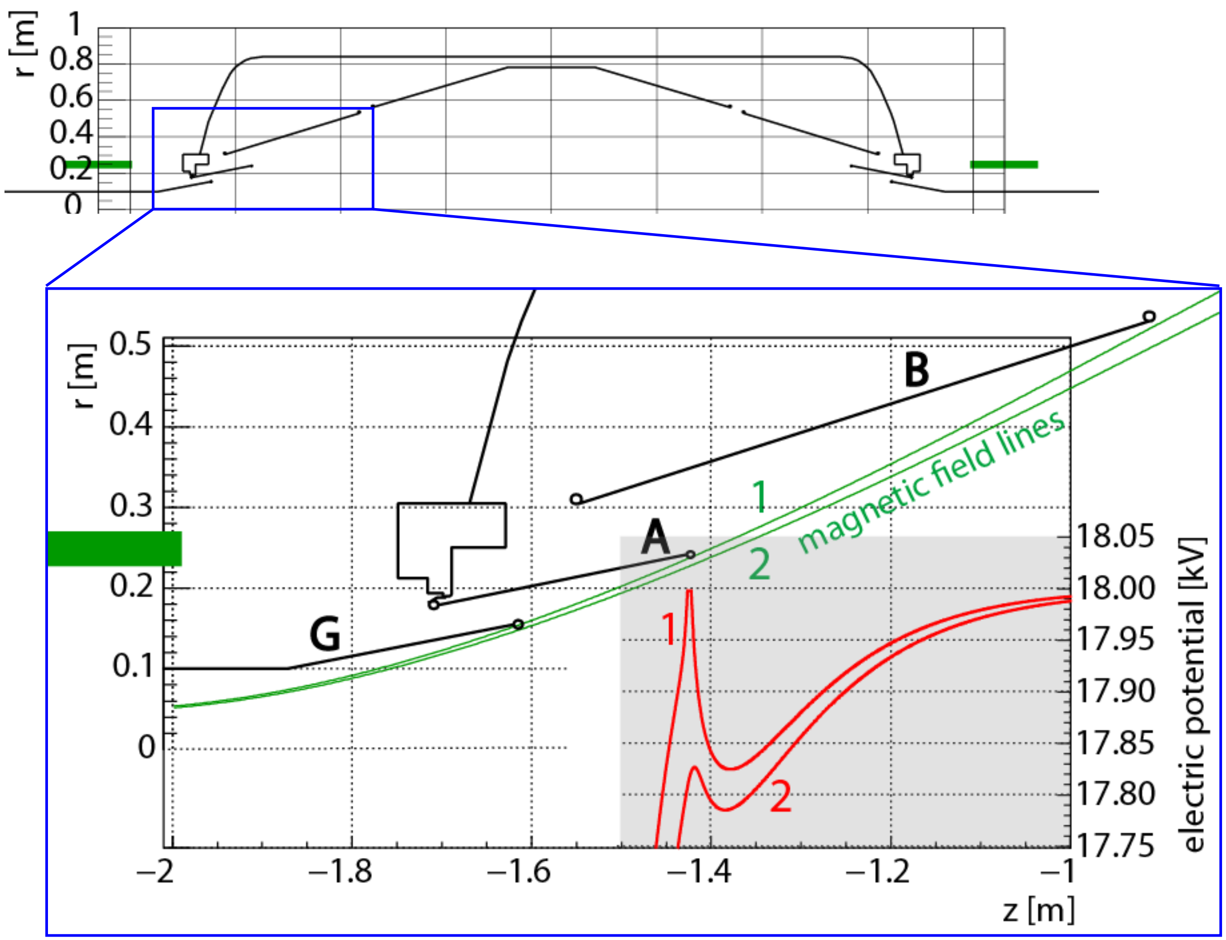


- Detailed investigations of Penning traps
- Check of parameter space: pressure, potential, magnetic field

→ Penning discharge can be major background source!

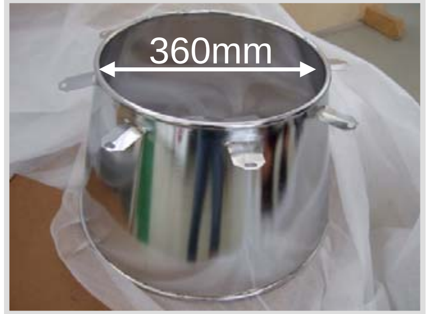
new electrodes

- new electrodes to remove Penning trap
- design also applied to main spectrometer



Anti Penning electrode

A



Ground electrode

G

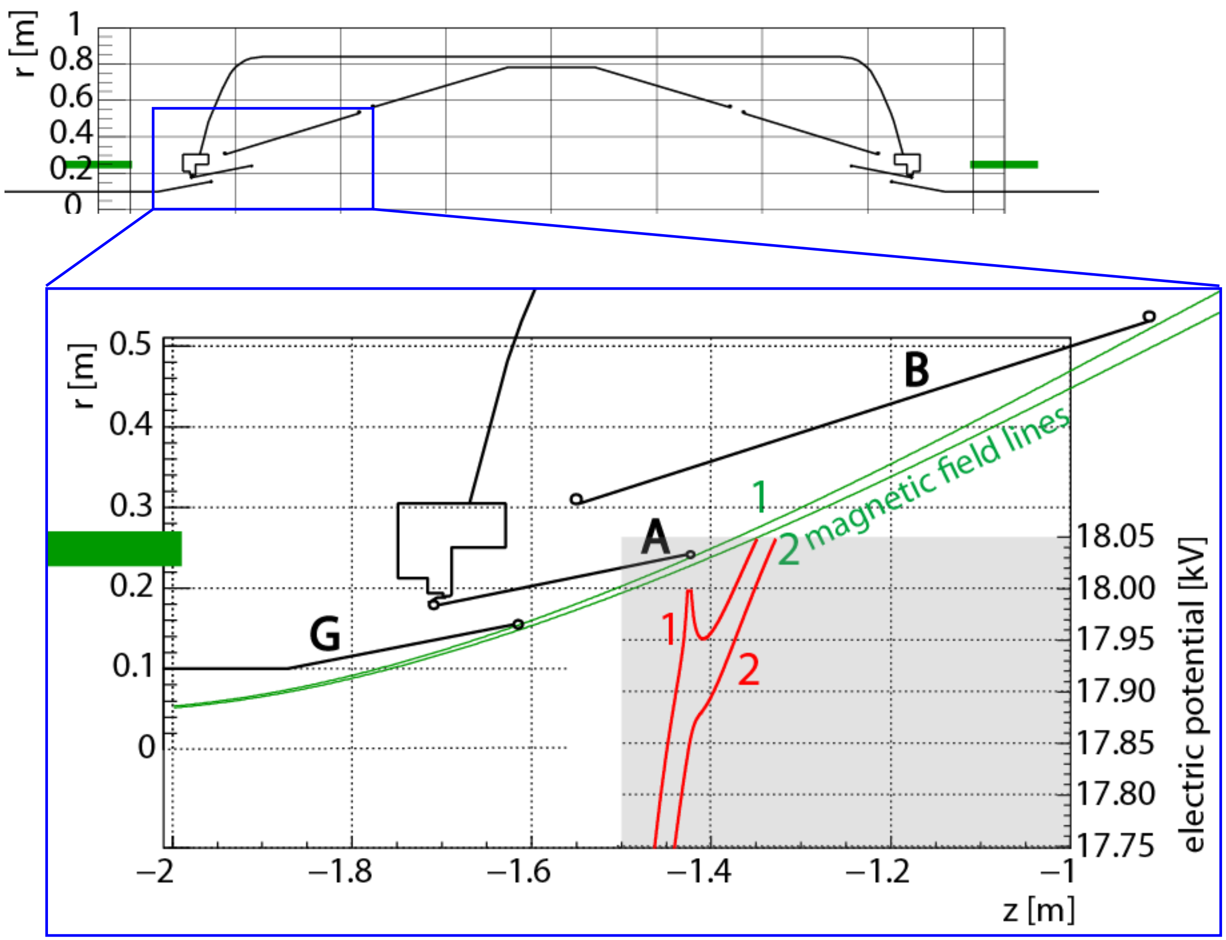
G 0kV

A -18kV

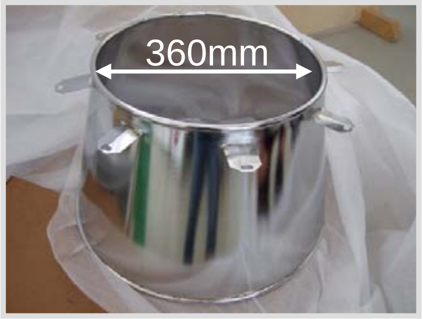
B -18kV

new electrodes

- new electrodes to remove Penning trap
- design also applied to main spectrometer



Anti Penning electrode

A 

Ground electrode

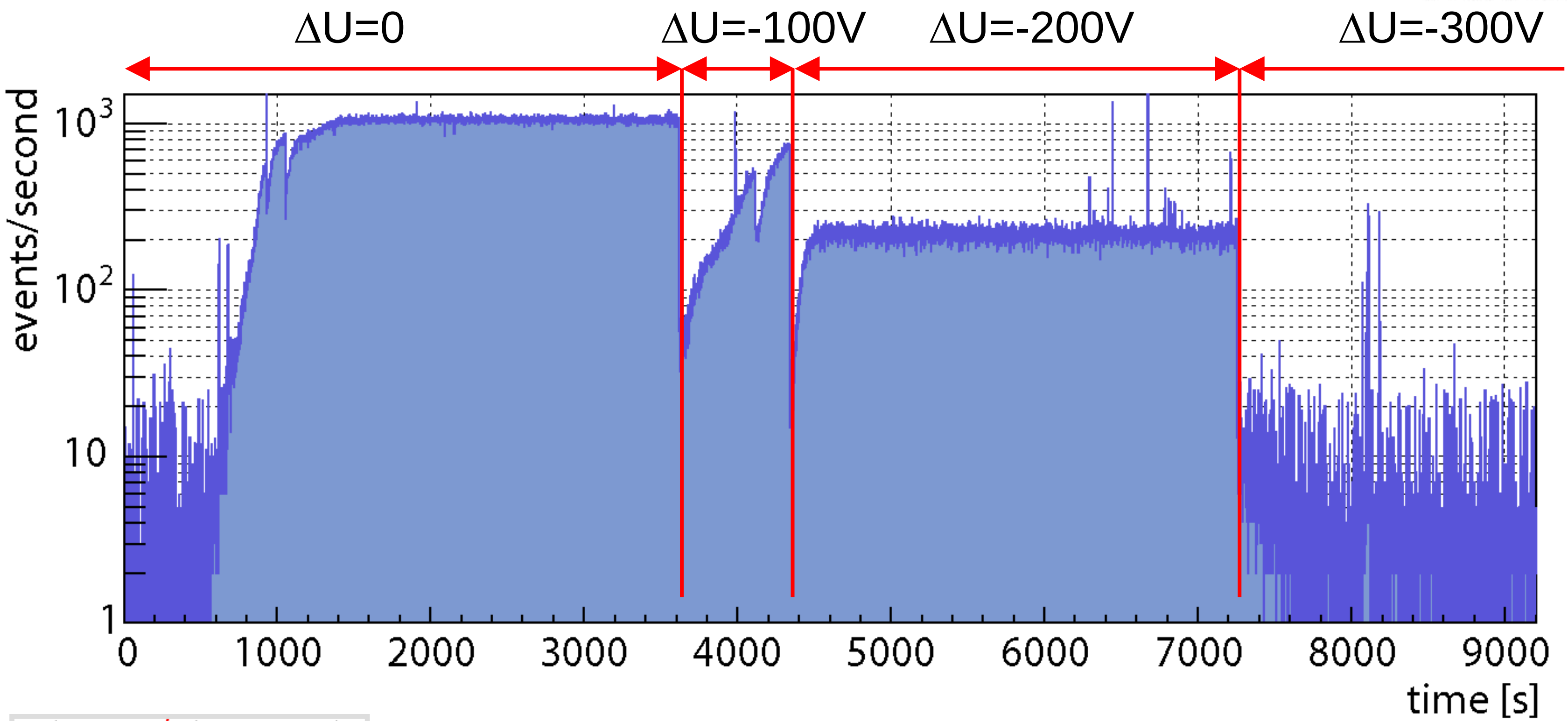
G 

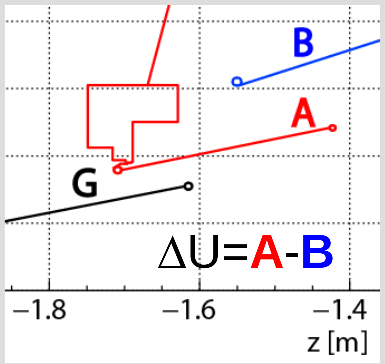
G 0kV

A -18kV

B -18.3kV

Penning discharge





- a 180V deep penning trap ignites after some minutes.
- ignition stops if **B** < **A** (as expected from calculation)

→ Penning discharge is under control!

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summary & outlook

- KATRIN will measure electron anti-neutrino mass with a sensitivity of 0.2 eV
- Tritium source: construction 2011/12
- Tritium retention:
  DPS: arrived 2 days ago, acceptance tests & test program
  CPS: TDR ready, presently being manufactured, delivery to FZK 10/2010
- Pre-spectrometer: test setup important for main spectrometer design
- Main Spectrometer: electrode installation & start of EM test program 2010
- Detector: assembly & initial commissioning, delivery to FZK 03/2010
- Assembly of components & system integration 2011/12
- Start of T_2 measurements: **summer 2012**

KATRIN collaboration

Universität Karlsruhe (TH)
Forschungsuniversität • gegründet 1825

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Westfälische Wilhelms-Universität Münster

MIT

UCL

Swansea University
Prifysgol Abertawe

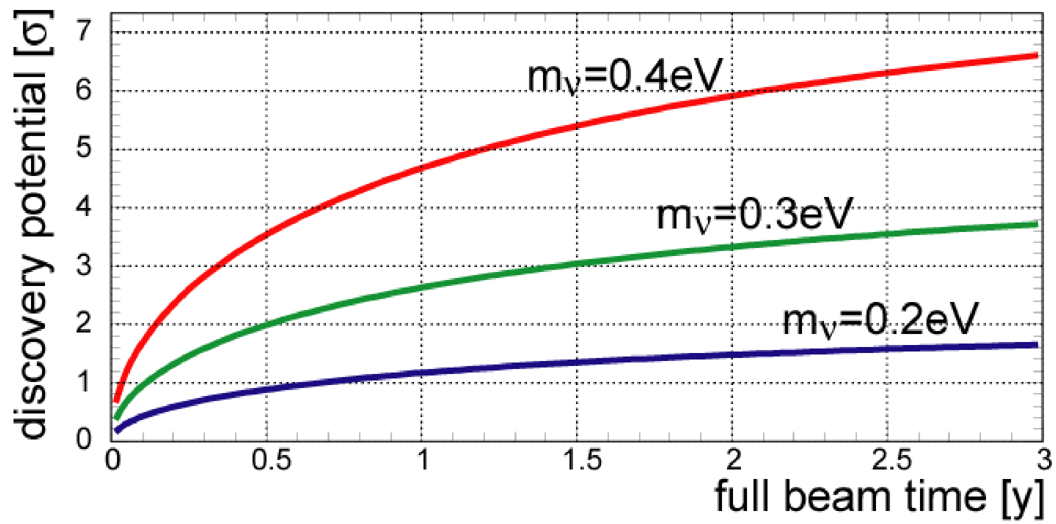
University of Washington

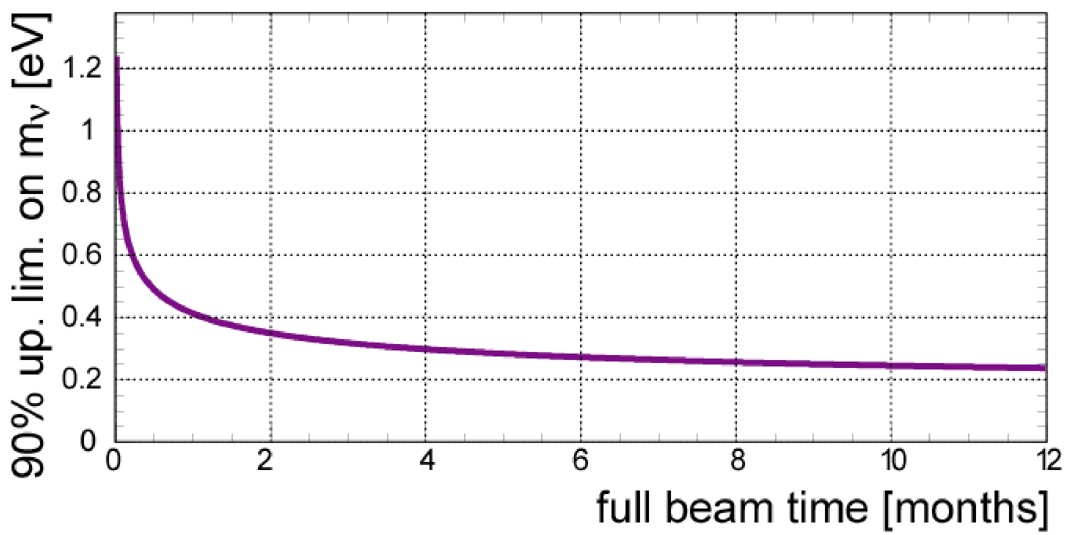
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Hochschule Fulda
University of Applied Sciences

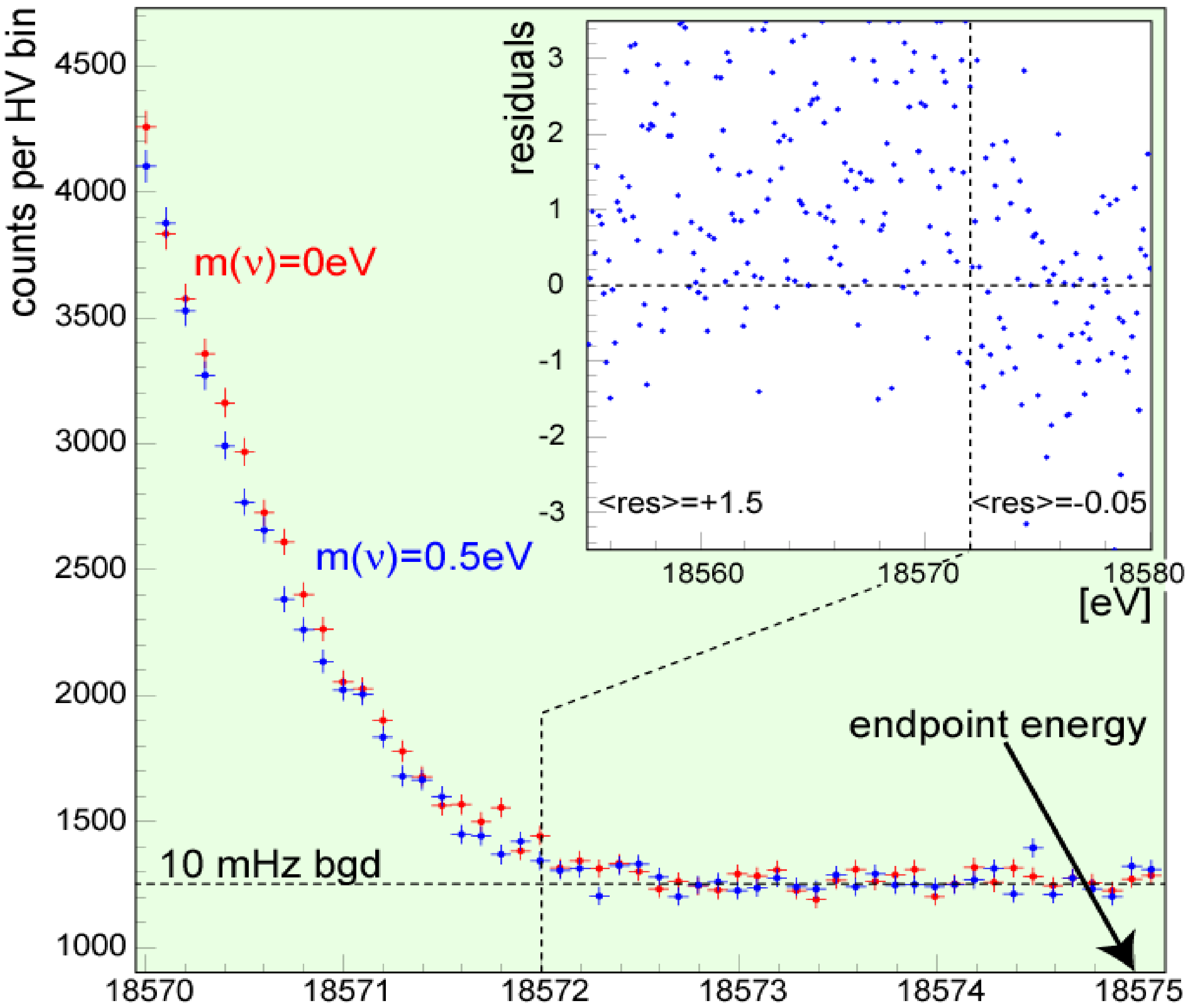
The University of North Carolina at Chapel Hill

discovery potential



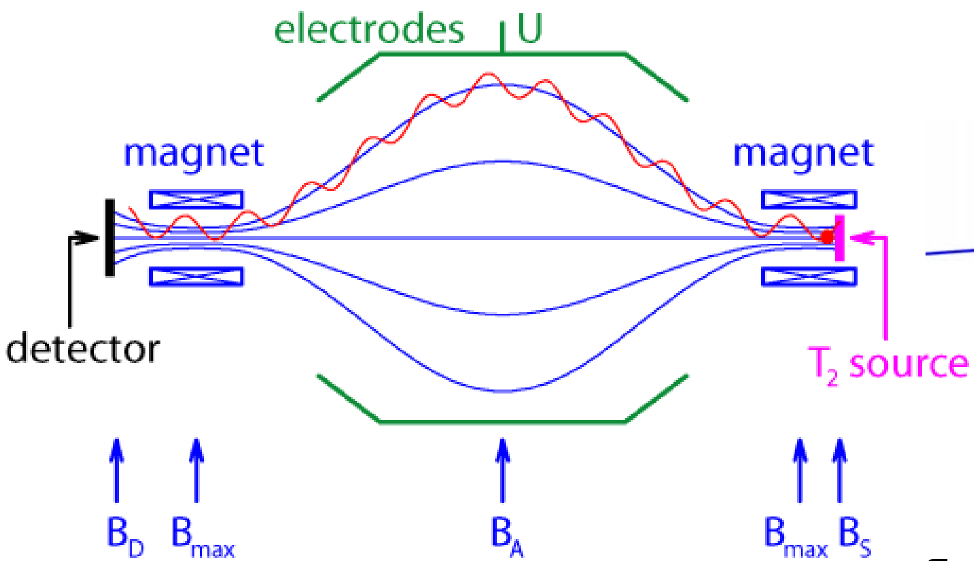


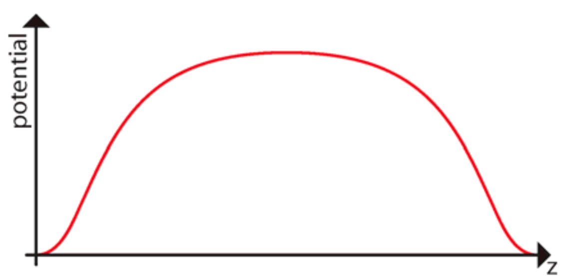
energy spectra

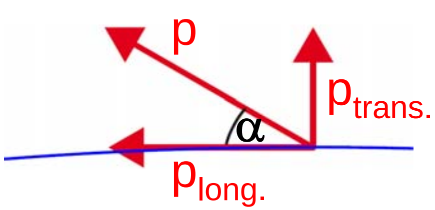


MAC-E filter

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







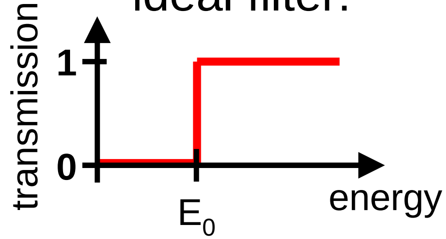
Magnetic moment:

$$\mu = \frac{E_t}{B} = const$$

Energy resolution:

$$\Delta E = \frac{B_A}{B_{max}} E_t$$

ideal filter:



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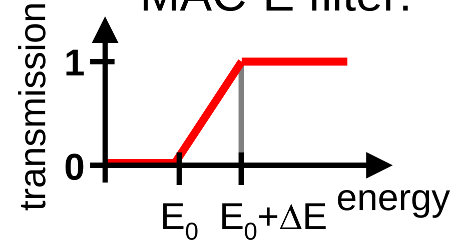

transmission if $E > E_0 + E_t{*}B_A/B_{max}{*}\sin^2(\alpha)$