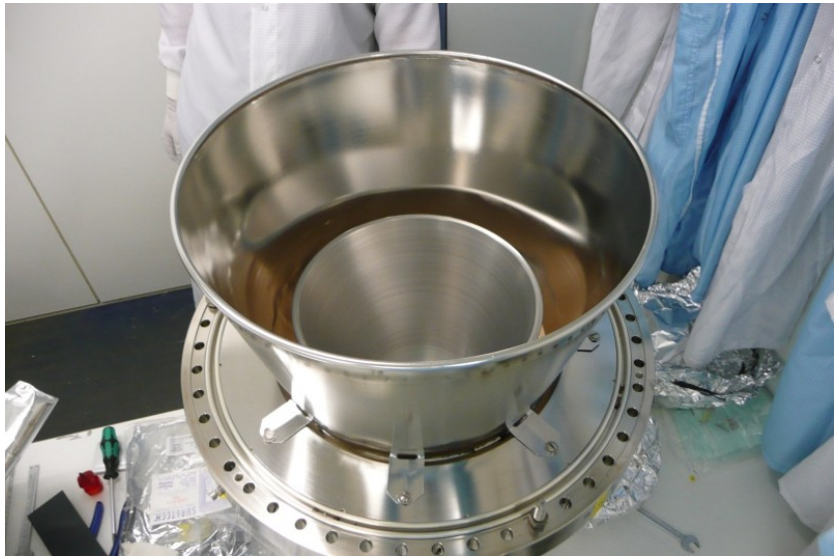
The electrode system for the KATRIN spectrometers

Outline

- Motivation
- KATRIN
- Inner electrode system
- Penning traps are bad...
- How to avoid them



Introduction – Neutrino mass in a nutshell

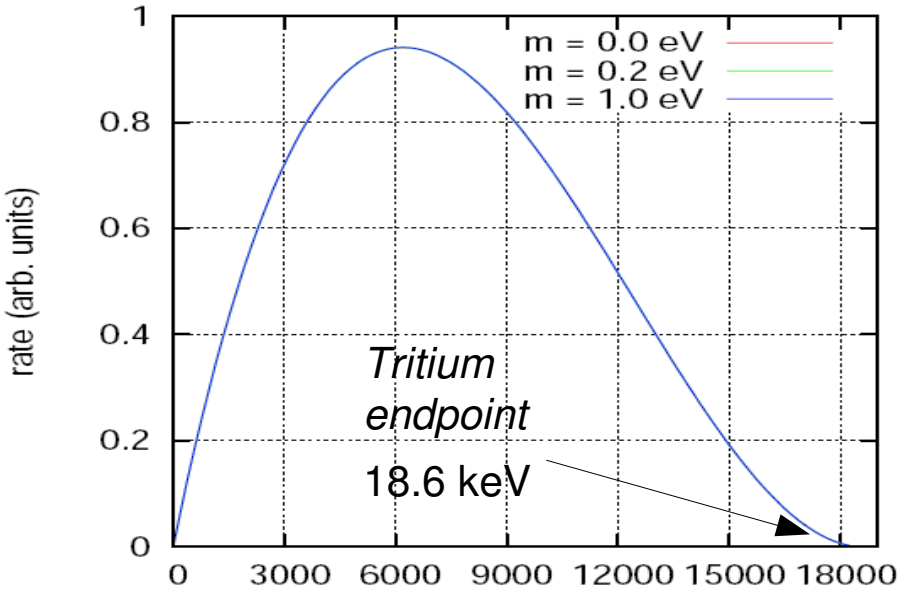
- 1998: SuperK evidence of neutrino oscillation → neutrinos have mass!

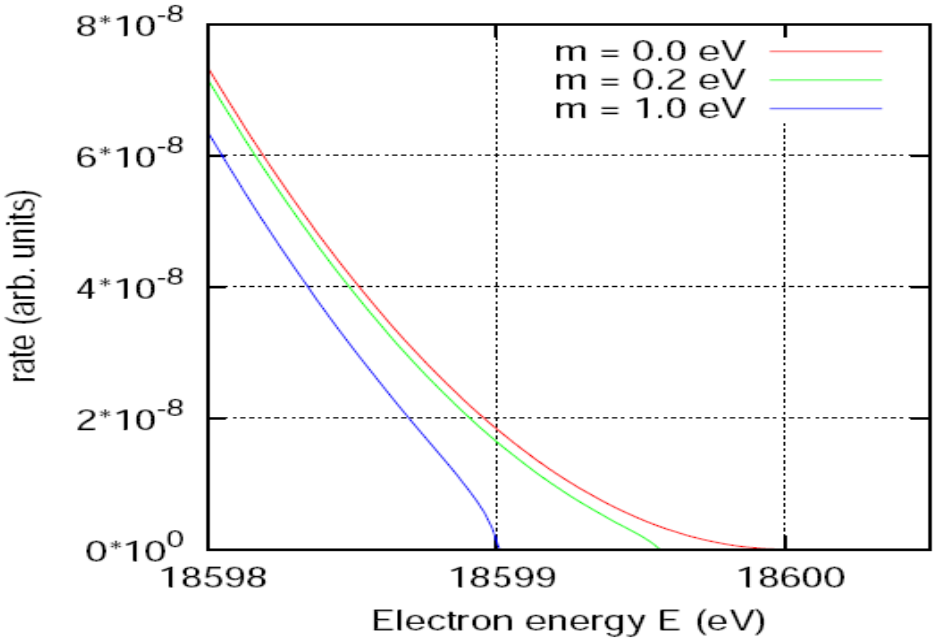
$$m_{\nu_e} = \sqrt{\sum_{i=1}^{3} |U_{ei}|^2 m_i^2}$$

- Oscillation: only $\Delta m^2 = (m_i^2 - m_j^2)$
- Absolute mass scale: e.g.
  Kinematics of beta decay
  (direct, model independent method)

- ß-spectrum sensitive to ν mass
- Use spectrometer:
  High resolution
  High luminosity
  Low background rate
  → MAC-E-filter
  (sharp integrating high pass filter)

- Current upper limit m < 2.2 eV (95% C.L.)
  Mainz, Troitsk
  → soon: KATRIN



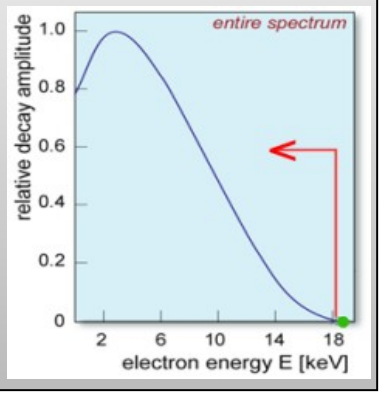


KATRIN experiment – Overview

Setup currently under construction at KIT (former FZK)

Pre-Spectrometer

- MAC-E type
- cut away uninteresting electrons
- reduce flux to 10^3 e^-/s
- p < 10^{-11} mbar

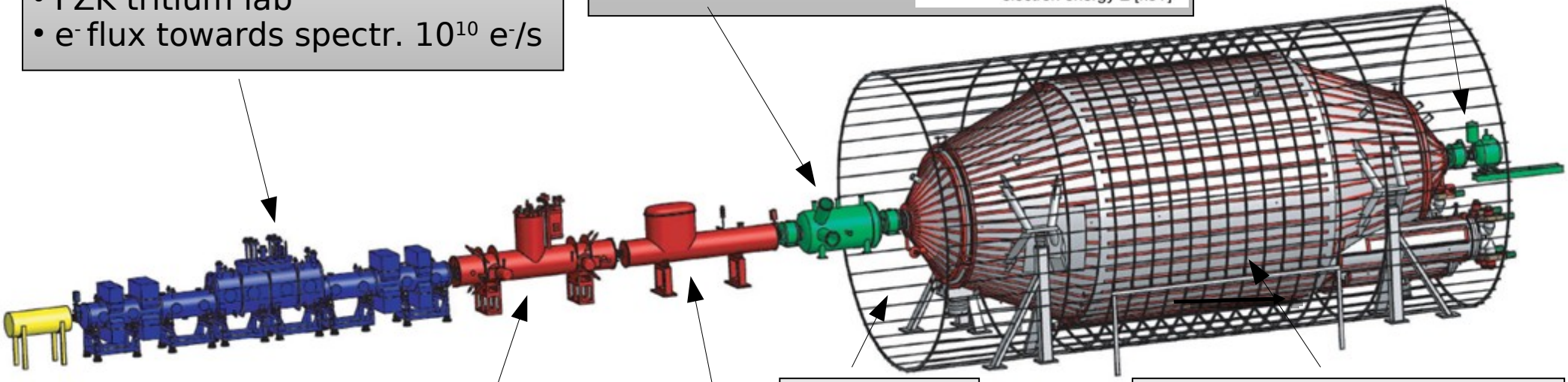


Electron detector

- segmented
- resolution ≈ 1 keV

Windowless Gaseous Tritium Source (WGTS)

- FZK tritium lab
- e^- flux towards spectr. 10^{10} e^-/s



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

Air coils

Main-Spectrometer

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- scan around endpoint
- 1 eV resolution
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KATRIN experiment – Overview

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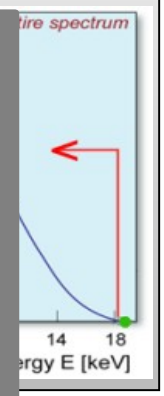
Pre-Spectrometer



KATRIN goal with 3 years worth of data:

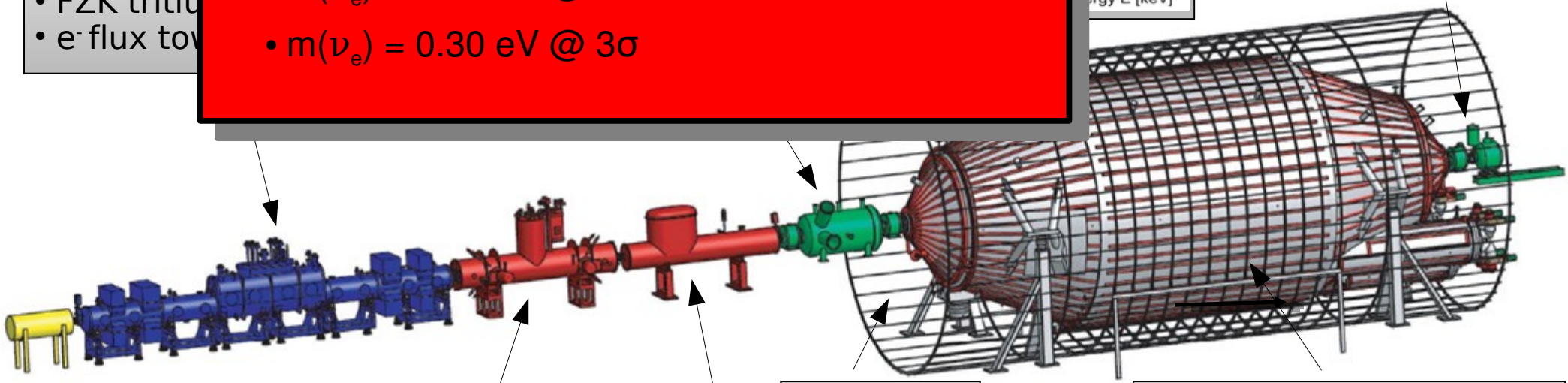
- Sensitivity 0.2eV (90% C.L.)
- Improvement by factor 10 to predecessors
- $m(\nu_e) = 0.35$ eV @ 5σ
- $m(\nu_e) = 0.30$ eV @ 3σ

Window
Tritium

- FZK tritiu
- e^- flux to

Electron detector

- segmented
- resolution ≈ 1 keV



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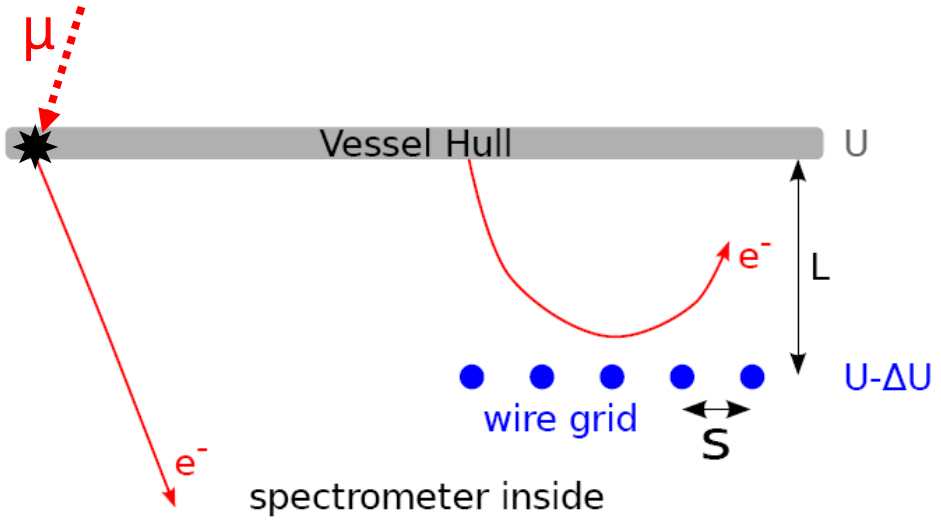
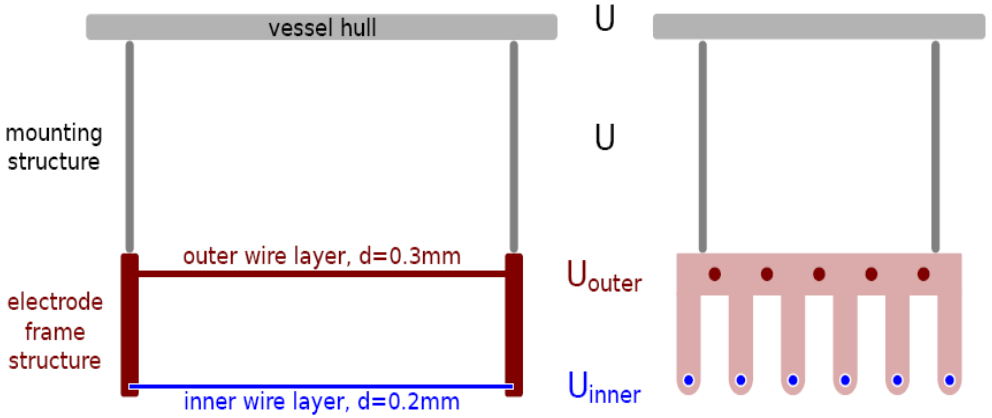
Inner wire electrode – Motivation





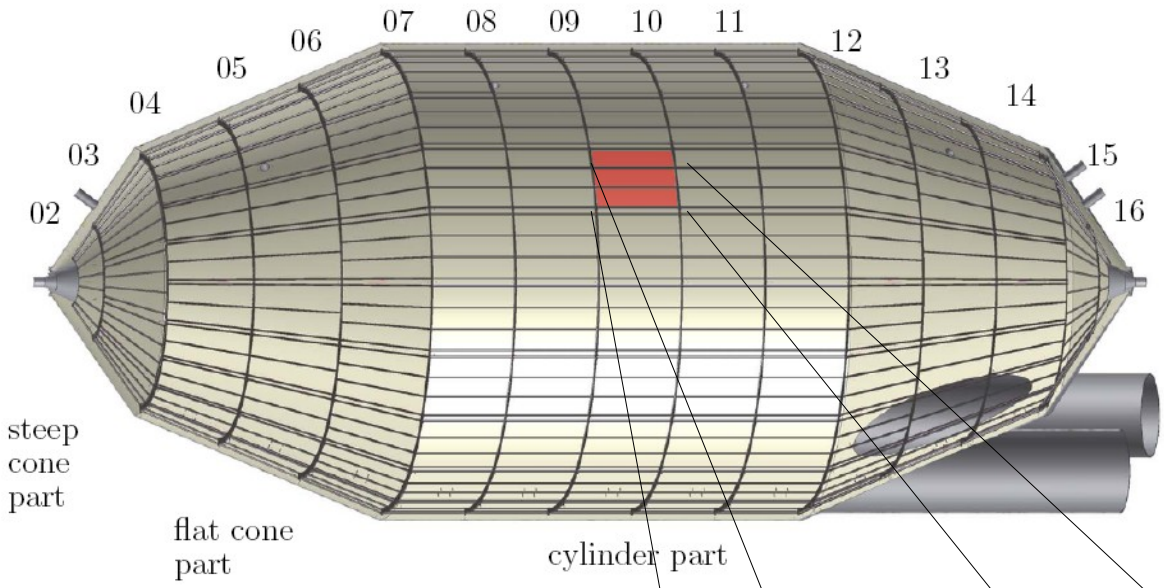
- Low background rate needed: main spectrometer: <10mHz
- Cosmics and radioactive contamination can mimic e^- in endpoint energy region
- 650m² surface of main spectrometer
  → ca. 10^5 μ / s + contamination
- Magnetic shielding by factor 10^5-10^6

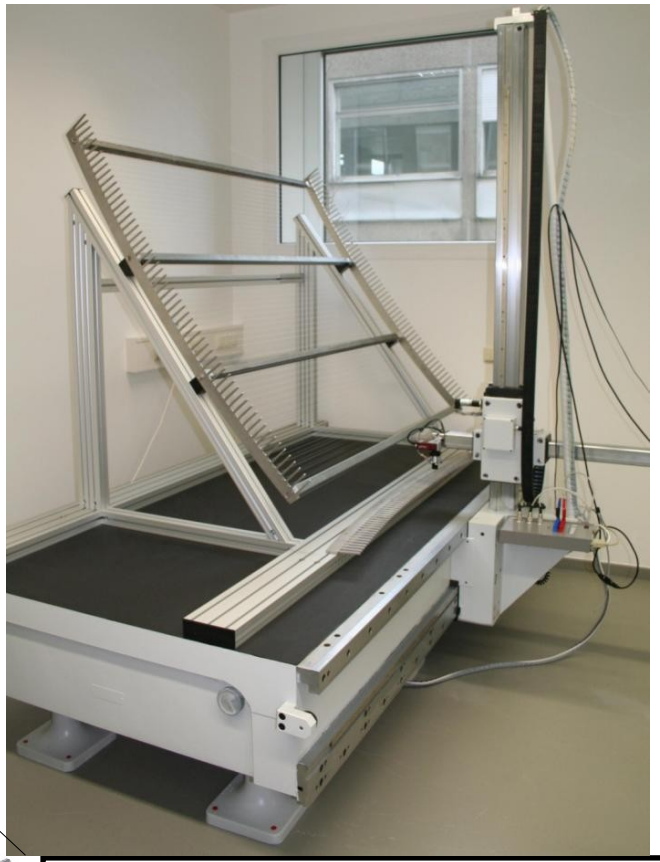
→ Additional reduction necessary!

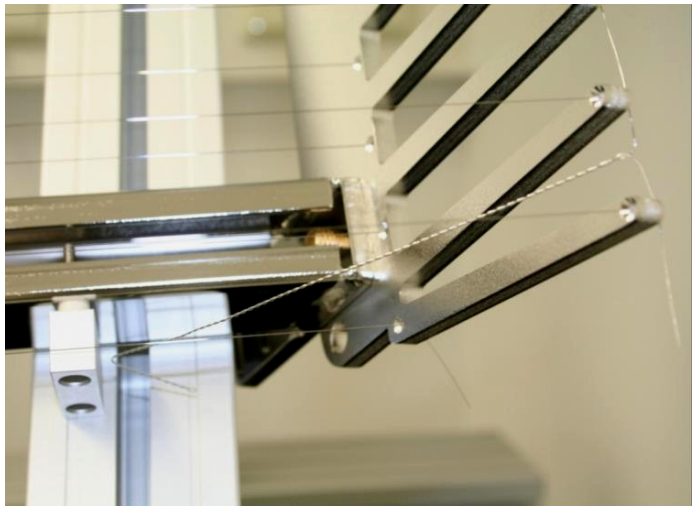
- Screening of background electrons with a wire grid on a negative potential
- Also: inner elctrode system to shape electric fields!

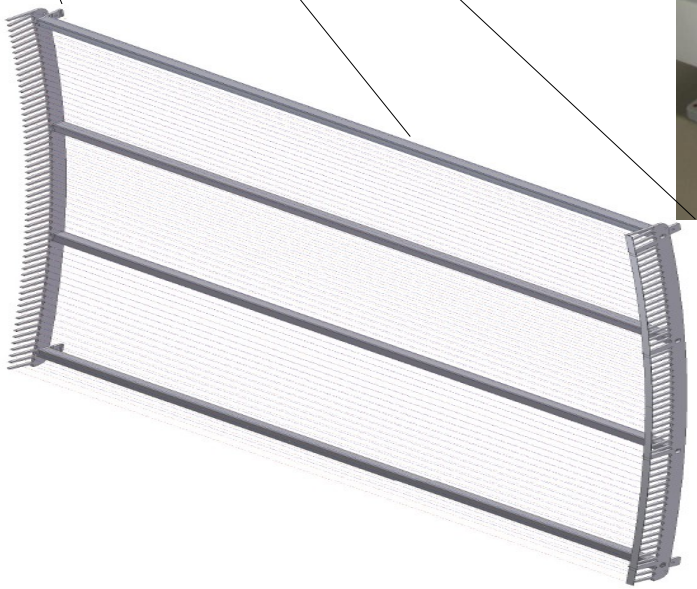
- KATRIN: Dual layer electrode for
  - improved screening factor
  - better field homogeneity

Main spectrometer - Inner wire electrode







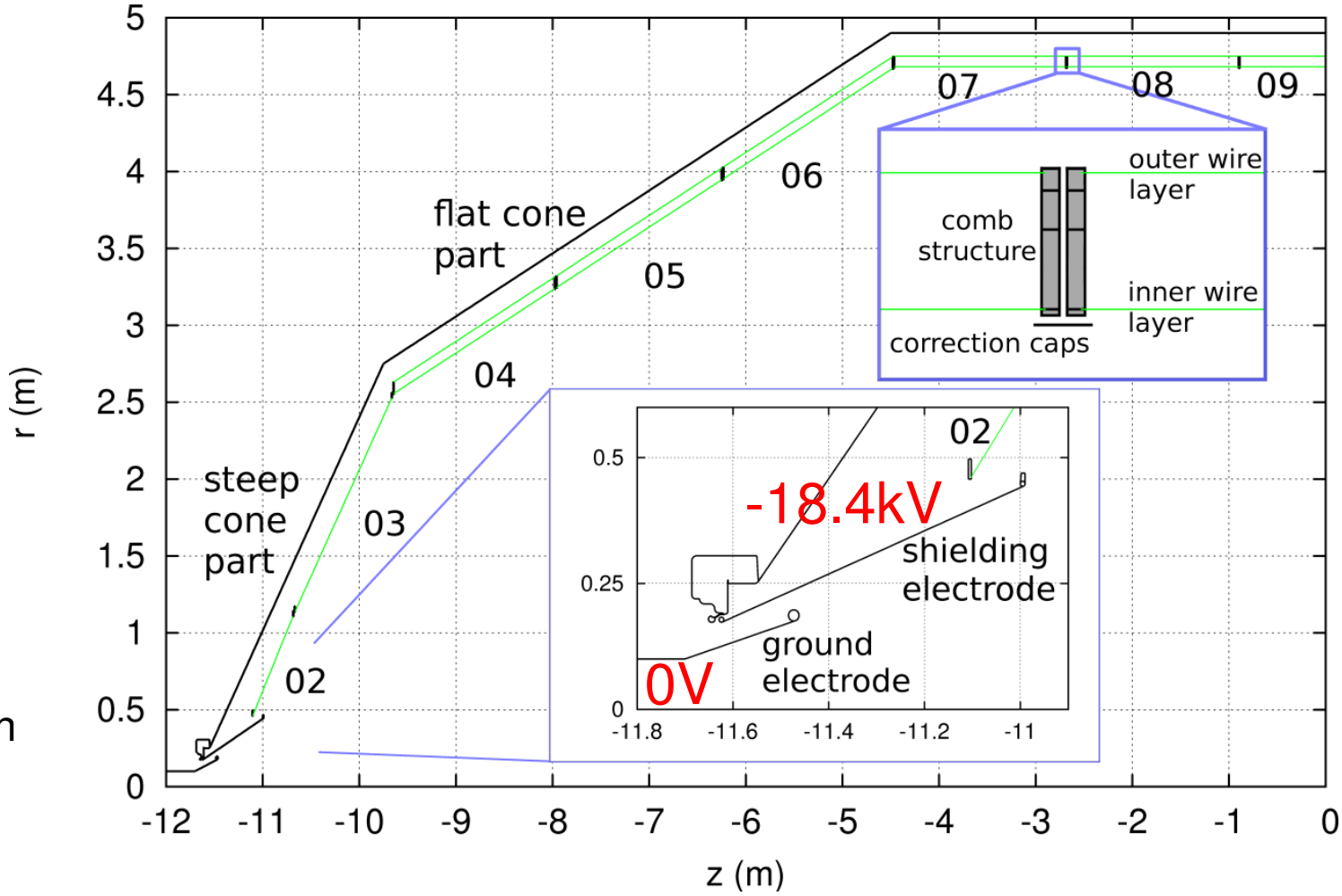


- **Total: 248 modules → ≈ 23000 wires**
- **Production and QA in Münster**
- **Installation of first modules just started**

Main spectrometer – Electrode design

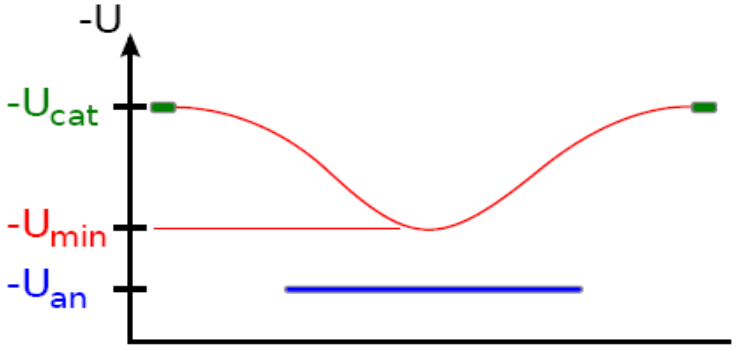
- Dual layer electrodes
- Single layer electrodes
- Conical metal electrodes

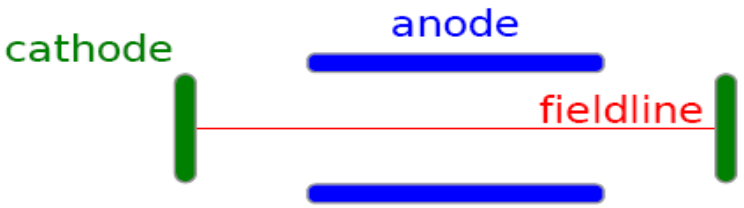
→ But why exactly like this?

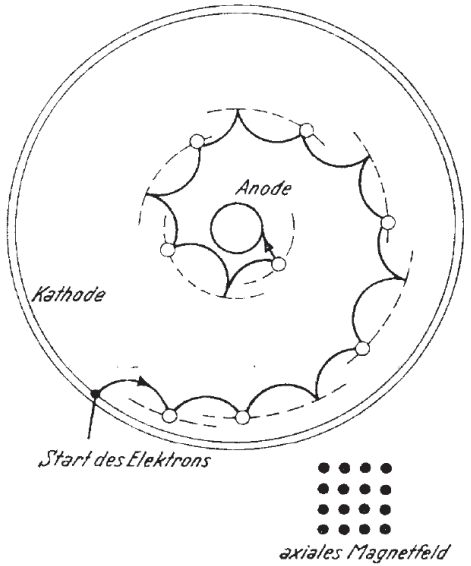


Optimized for:
- Transmission properties
- Avoid too early retardation
- Adiabatic transport
- Low electric field strength
- ...
- Avoid particle traps, e.g. Penning traps

Penning traps – A very short introduction







- Potential well in el. field
- electrons can be trapped if they loose enough kinetic energy (collisions...)
- But: to create background one needs more...

... electric field and magnetic guidance!

→ Cyclotron motion + magnetron drift + el. field

- Pathlength raises, higher “equivalent pressure”
  → ionisations more probable
  → secondary ions
- Electrons stored, positive ions accelerated to cathode
  → creation of additional electrons
  → again accelerated to trap
  → self-sustained discharge effect!

- Trap ignition e.g. by space charge effects (negative charged plasma inside trap)

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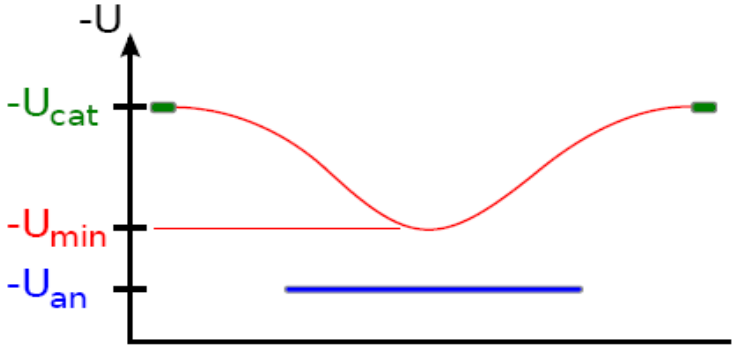

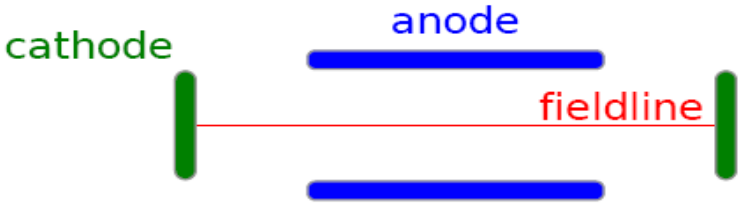

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Solution to supress trap:

- ionisation only possible for $U_{trap} > E_{ion}$
- UHV: H_2 most prominent
- $E_{ion}(H_2) \approx 15.4eV$
- Avoid trap locations!
- Keep traps shallow enough!
  → accurate simulations needed!

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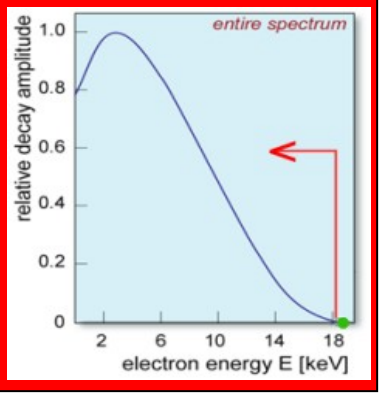

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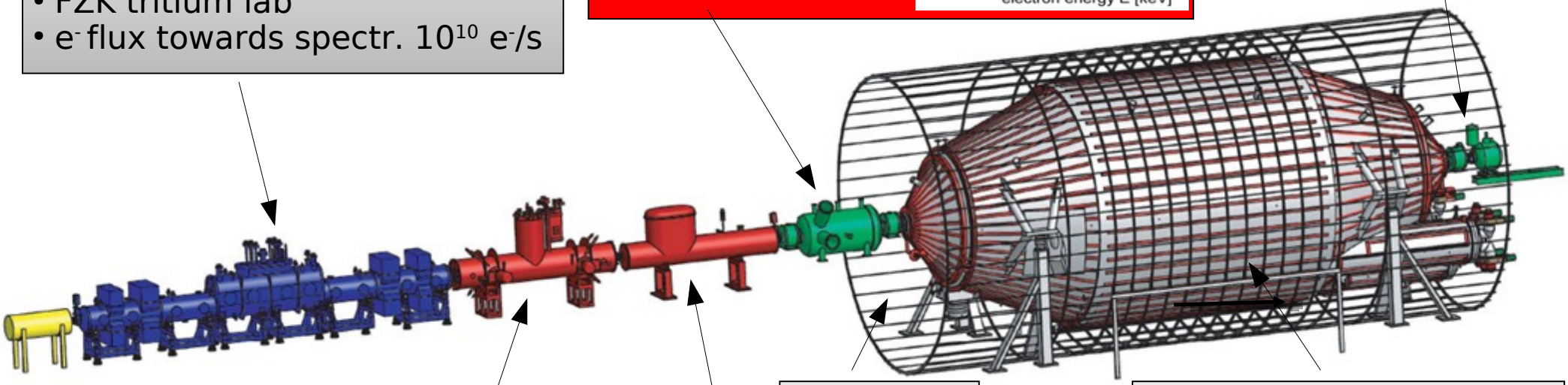

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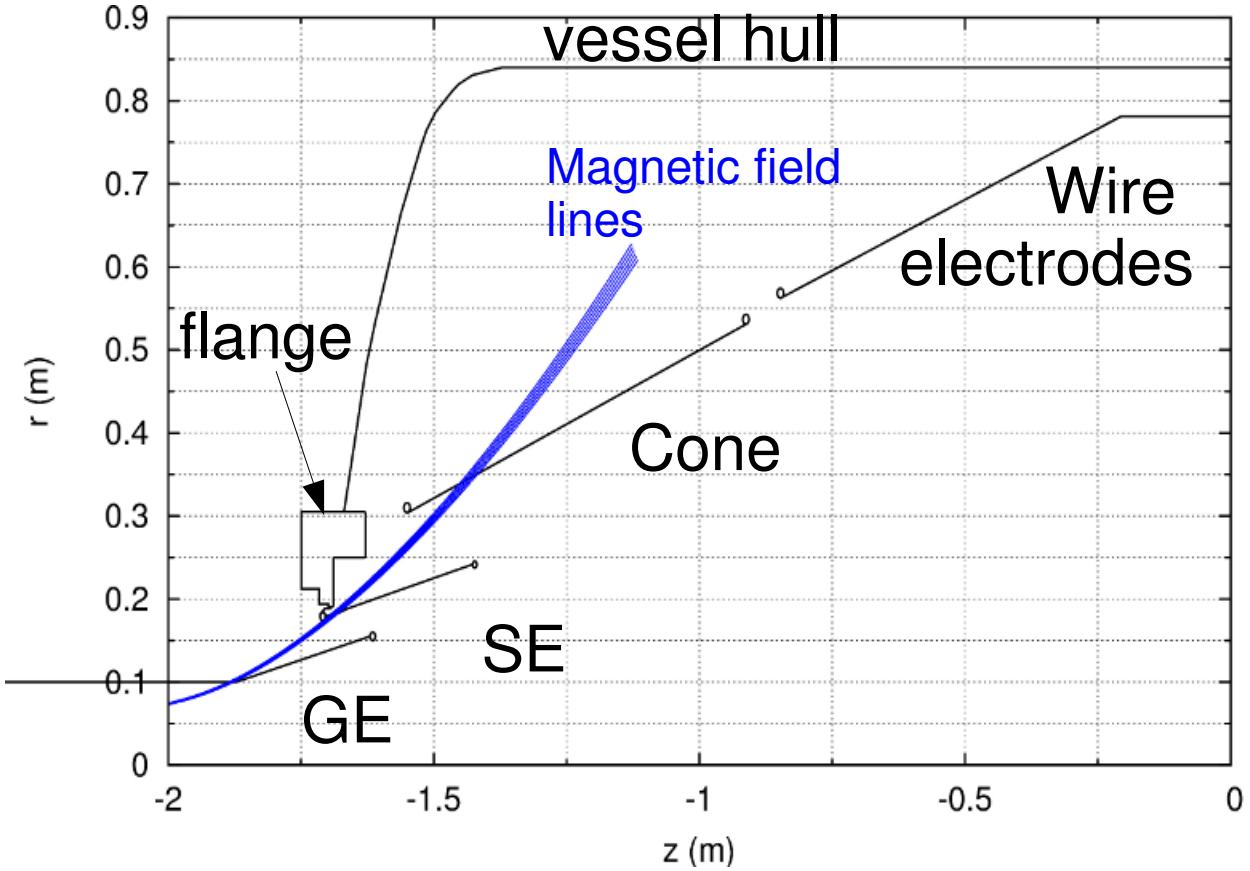
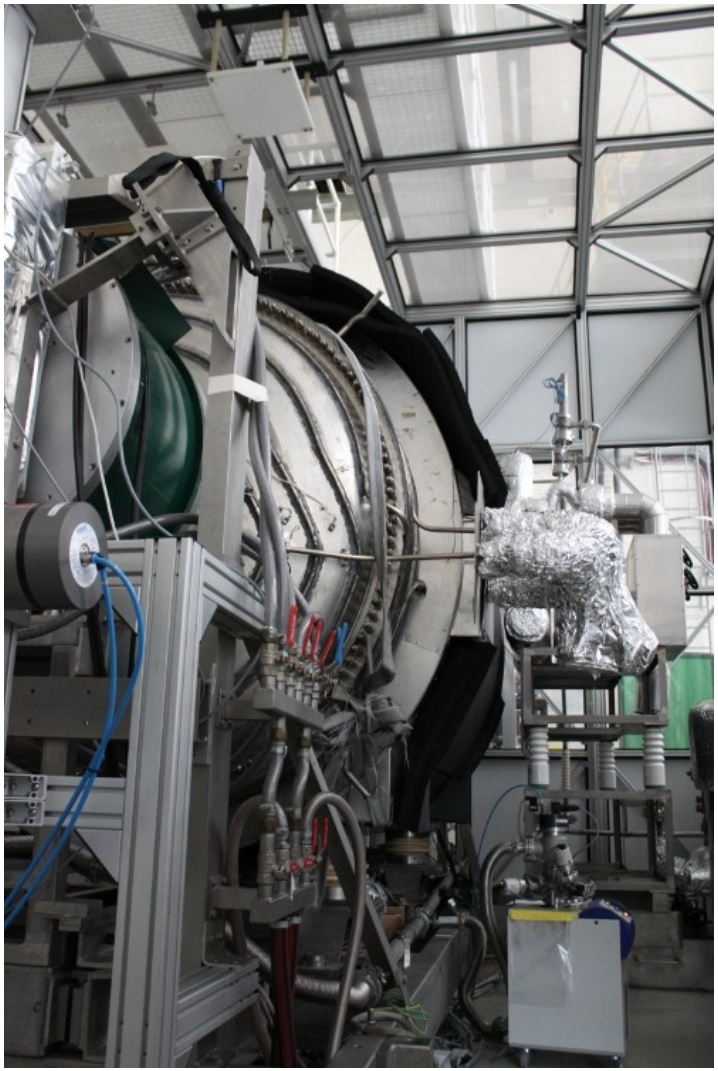
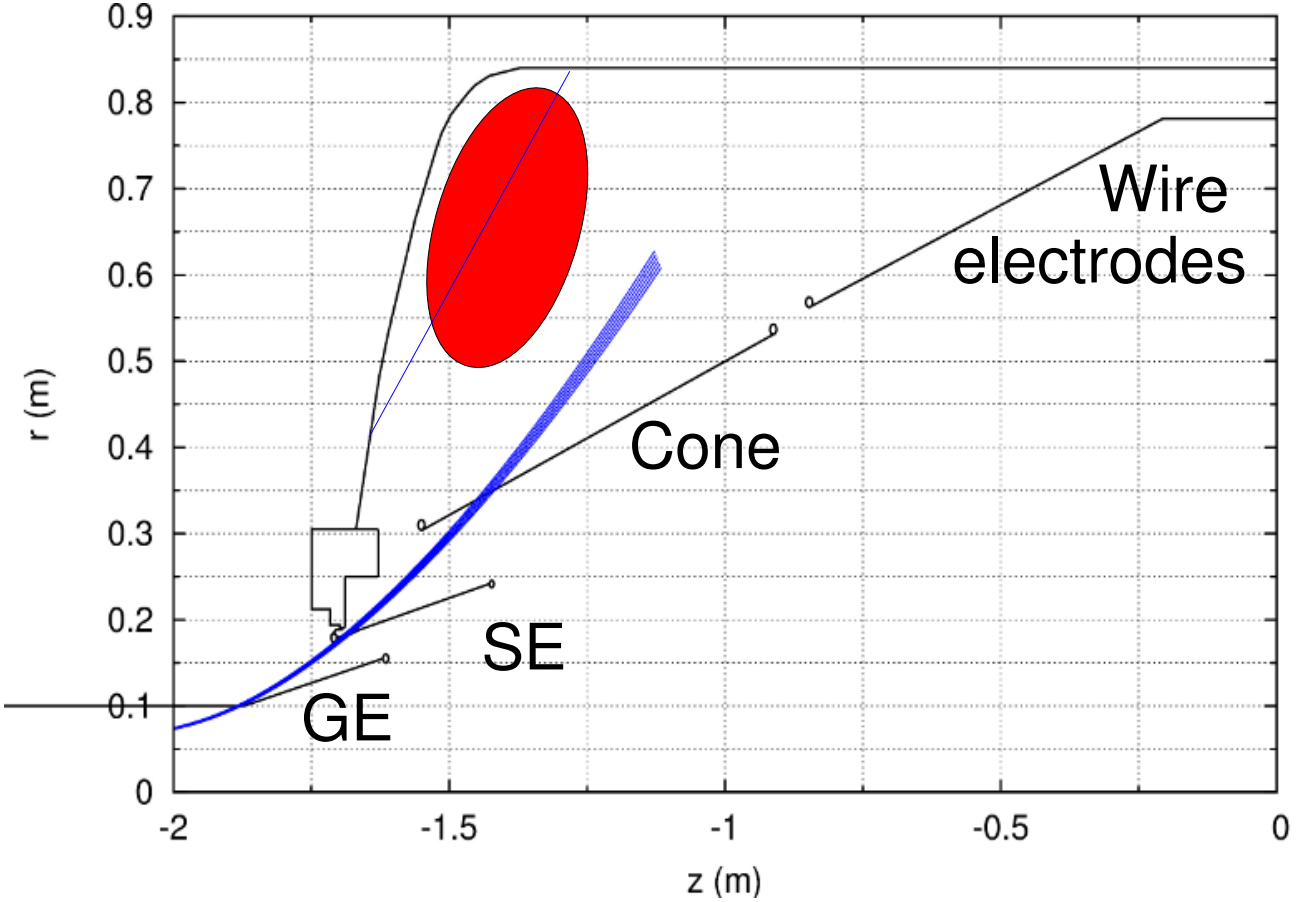
Prespectrometer electrode system - Overview

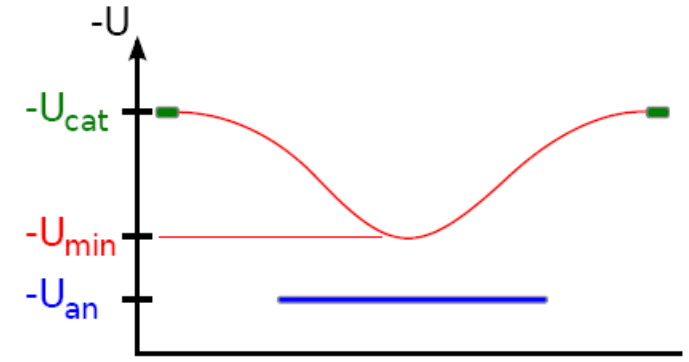


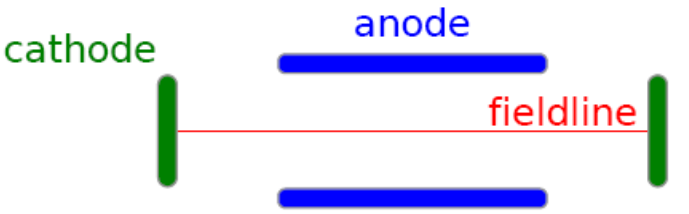


- Pre spectrometer two purposes:
  - Test setup for main spectrometer
  - Filter in final beamline
- Symmetric setup → look at 1/2 of spectrometer
- Length: 3.378m, Diameter 1.7m
- Pressure: down to $p \approx 10^{-10}$ mbar
- Electrode system? → Simulations!

Prespectrometer electrode system - Overview



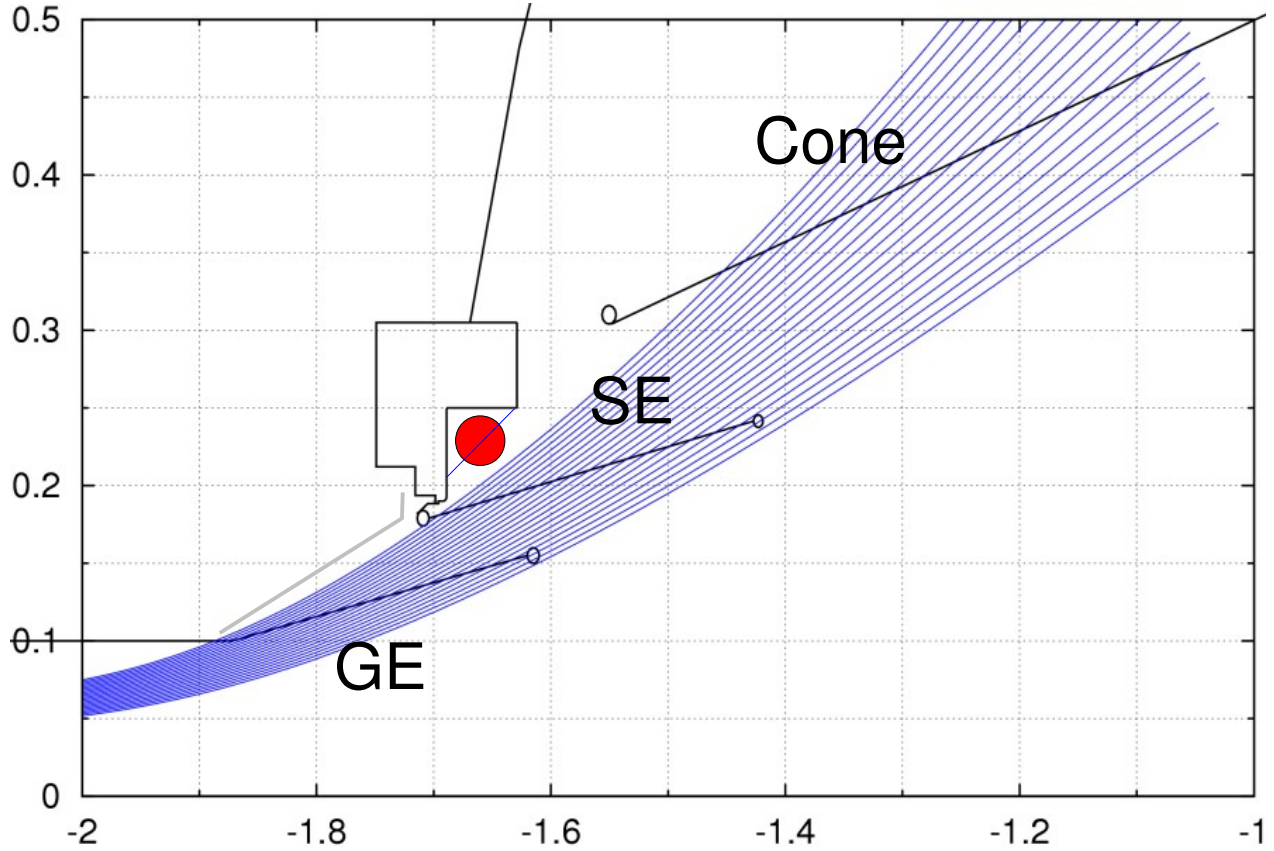


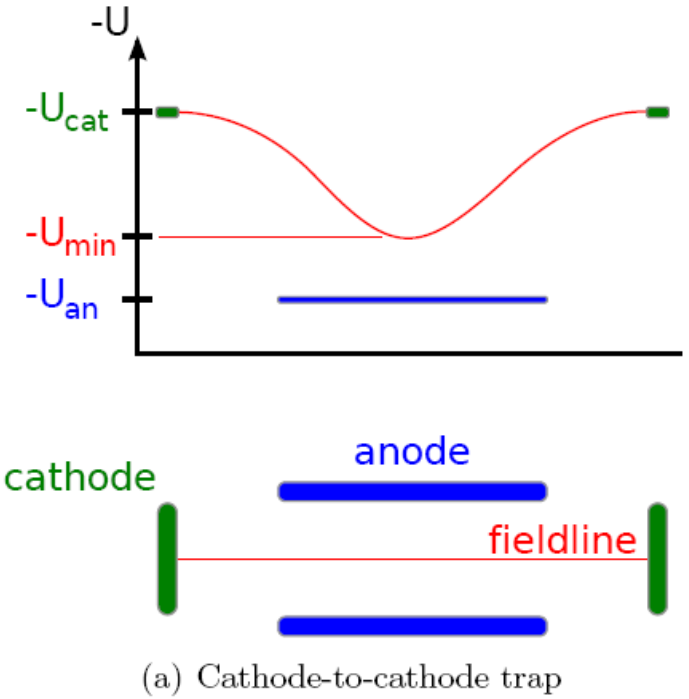


(a) Cathode-to-cathode trap

- Important for traps: magnetic fieldlines and electric fields
- Avoid Penning traps! → Simulations → Geometry
- Cone electrodes to cover spatially huge (~m³) Penning traps
- But: Spectrometer not operable!
  → maybe smaller traps are responsible?!

Prespectrometer electrode system - Overview

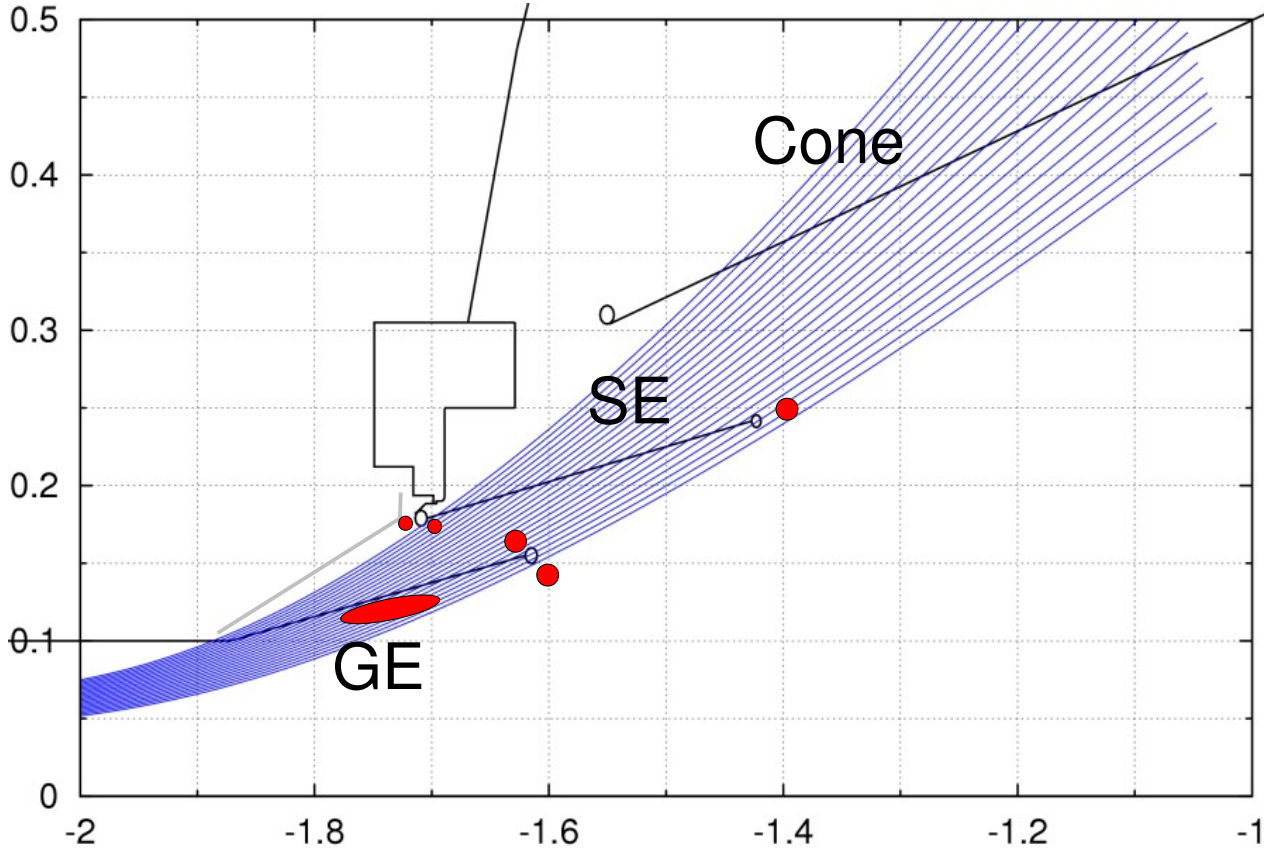


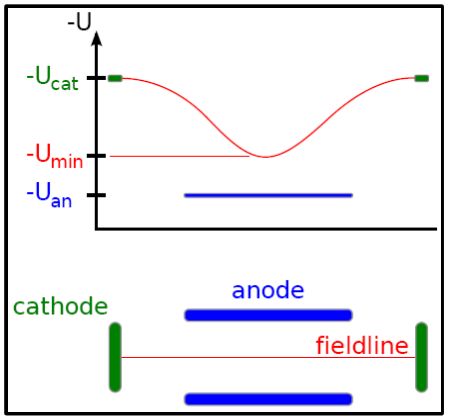


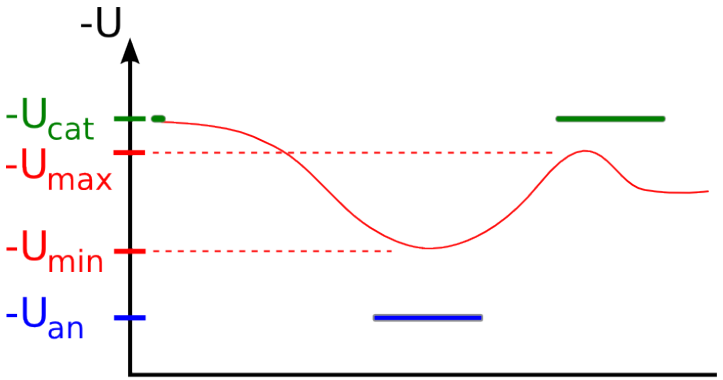
(a) Cathode-to-cathode trap

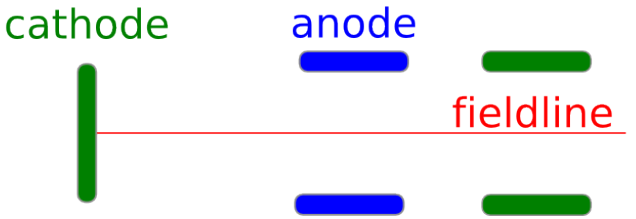
- Improvements in simulations...
- Smaller Penning traps exist (~ dm³)
- Introduction of Shielding electrode (SE)
- Now: Measurements possible!
- Increased background rates at high B fields
- Even smaller Penning traps as possible source?

Pre-spectrometer electrode system – Trap locations









- Experimental evidence points to entrance/exit region as background source
- Precise simulations
- Search for small traps
- Also look at cathode-to-vacuum traps...

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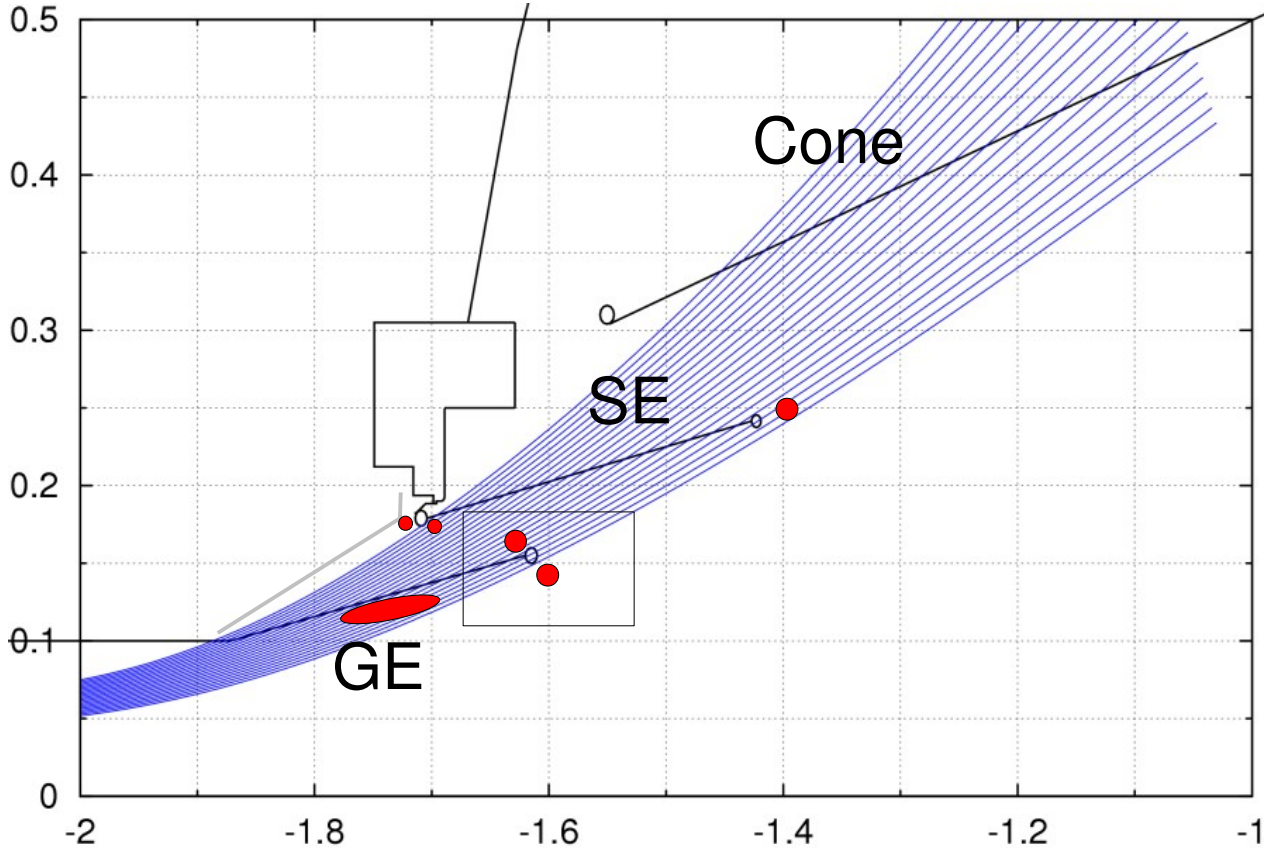

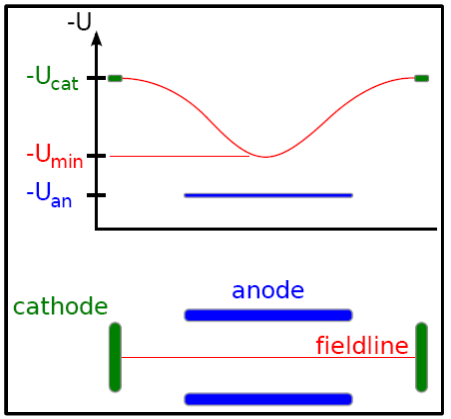

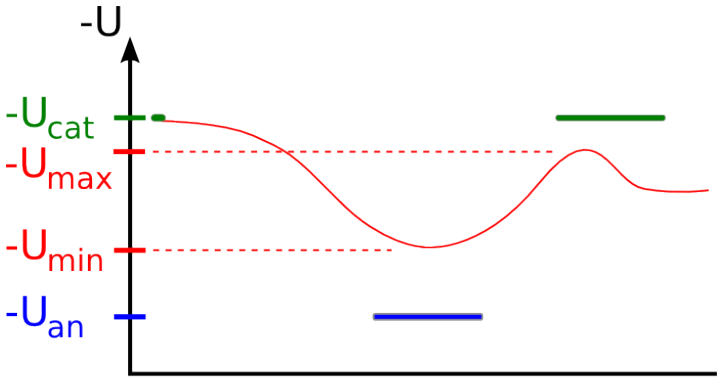

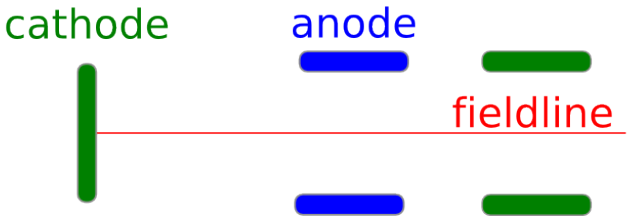

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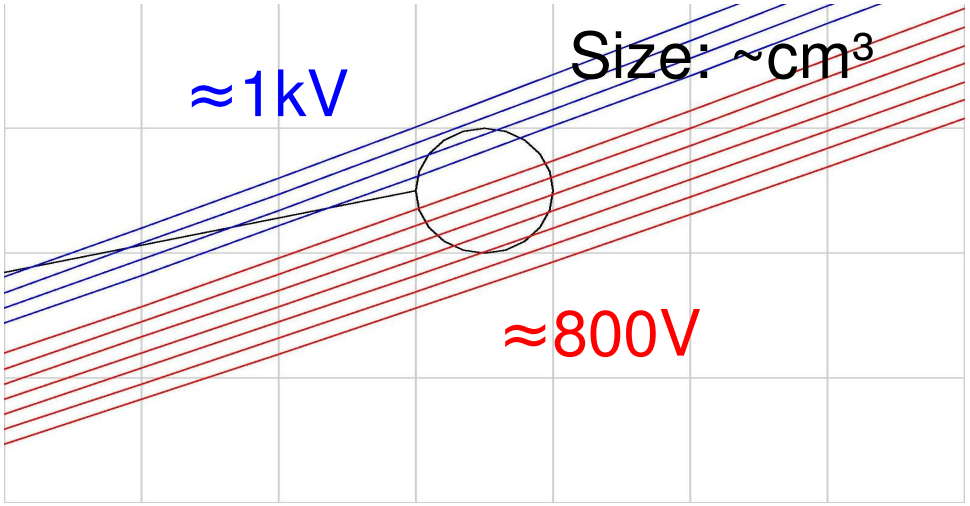
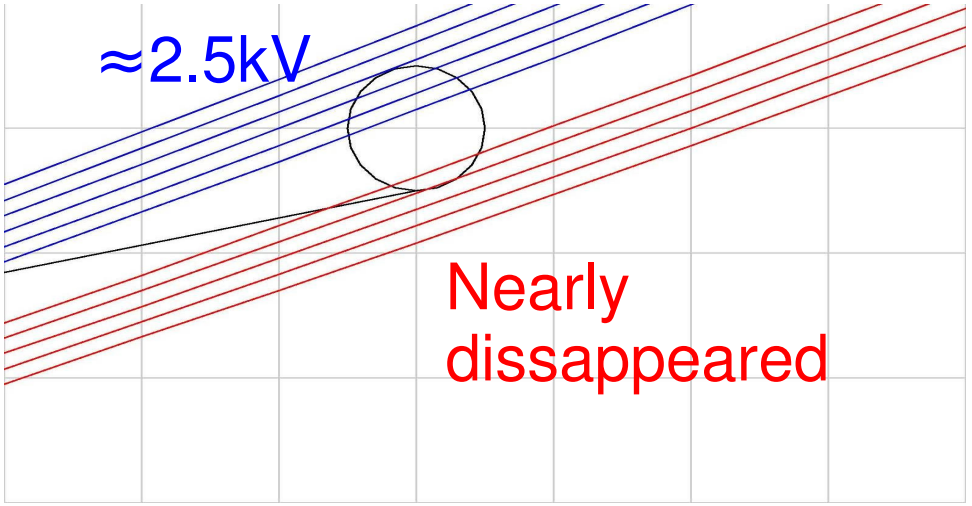
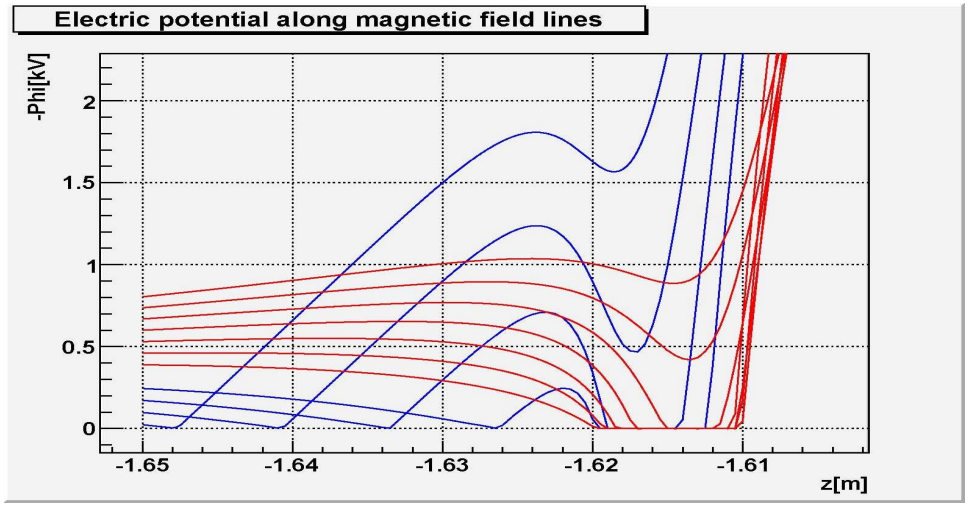
PS electrode system
Ground electrode end traps

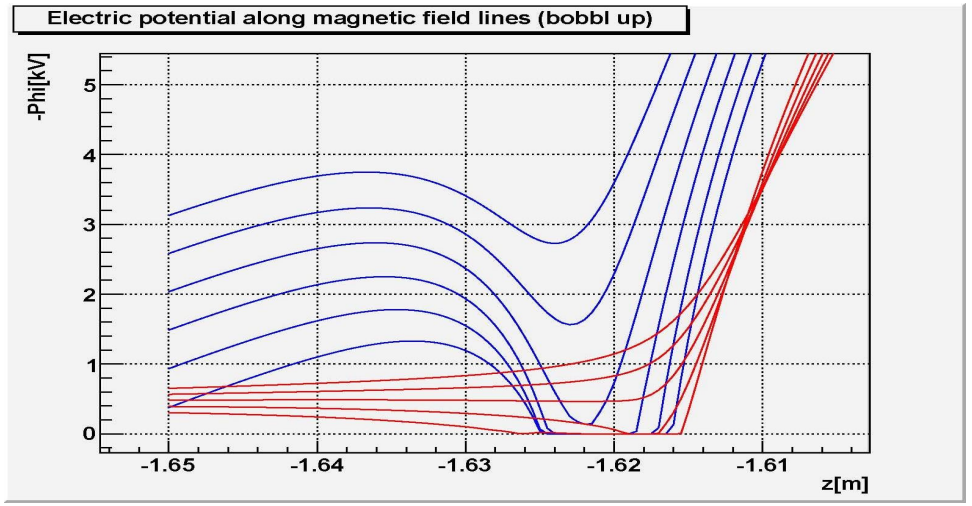
Old setup (Mk 2)



Modified setup (Mk 3)
+ wire comb at inner side of GE







Plots from Susanne Mertens / Ferenc Glück

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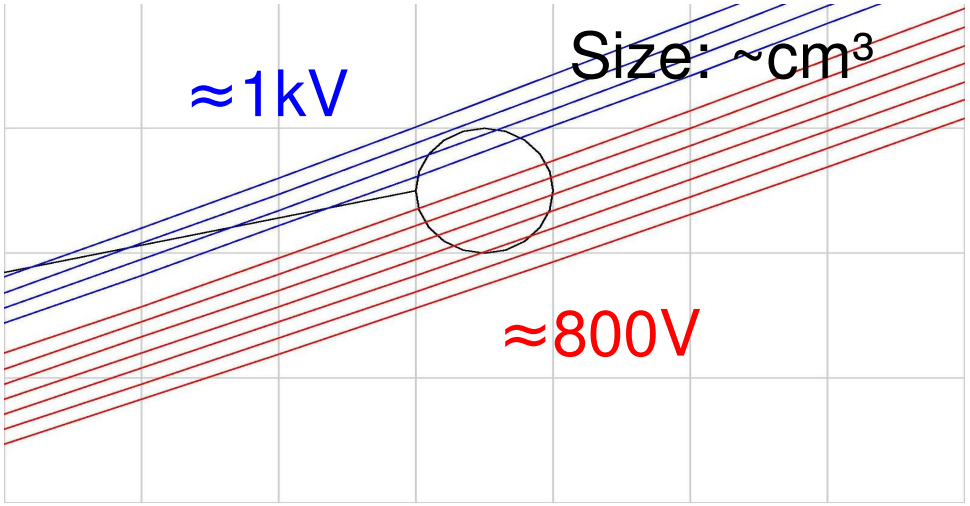

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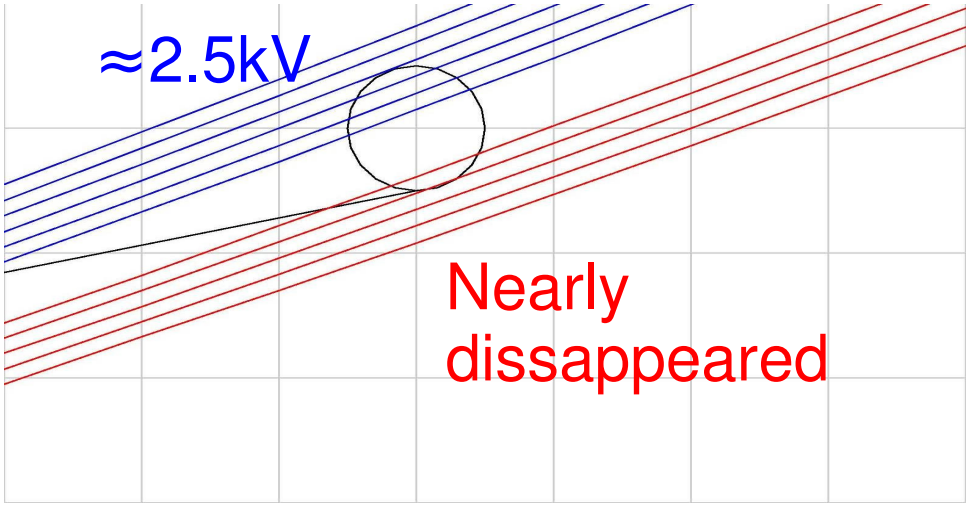
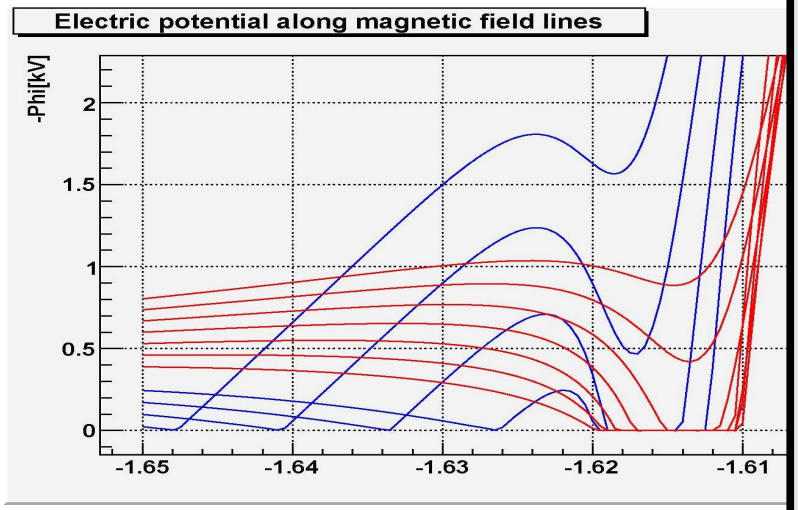




Plots from S

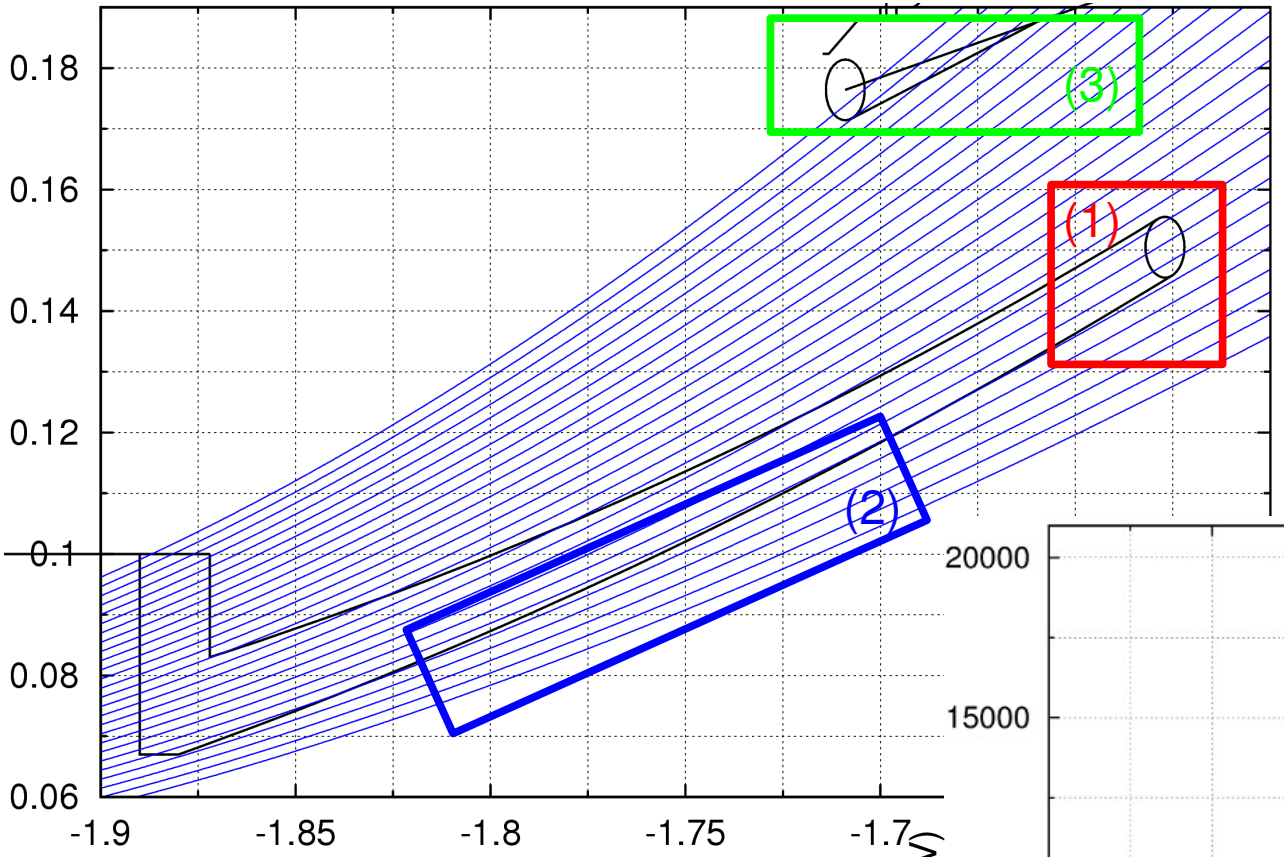
BACKGROUND INCREASED!

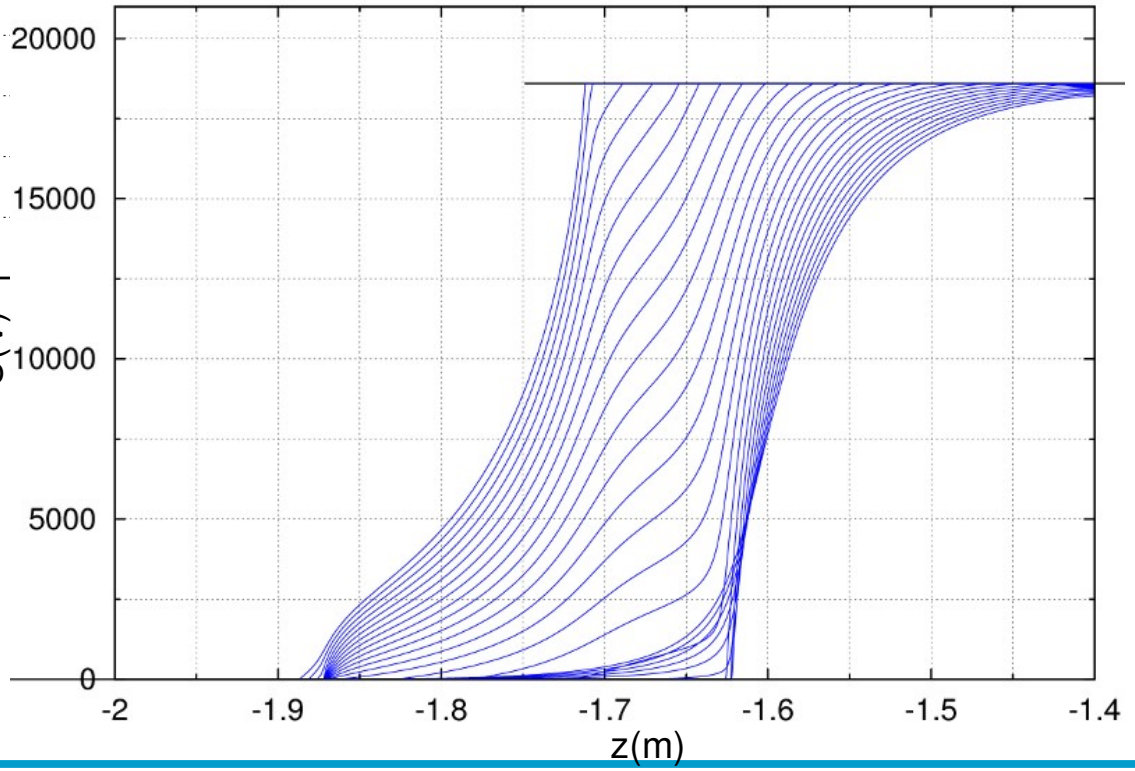
→ Evidence that the top PT causes the bulk of the background

→ Other effects might be covered from this huge background

→ Find new electrode form to solve (nearly) all known problems!

PS electrode system
New ground electrode (Mk 4)

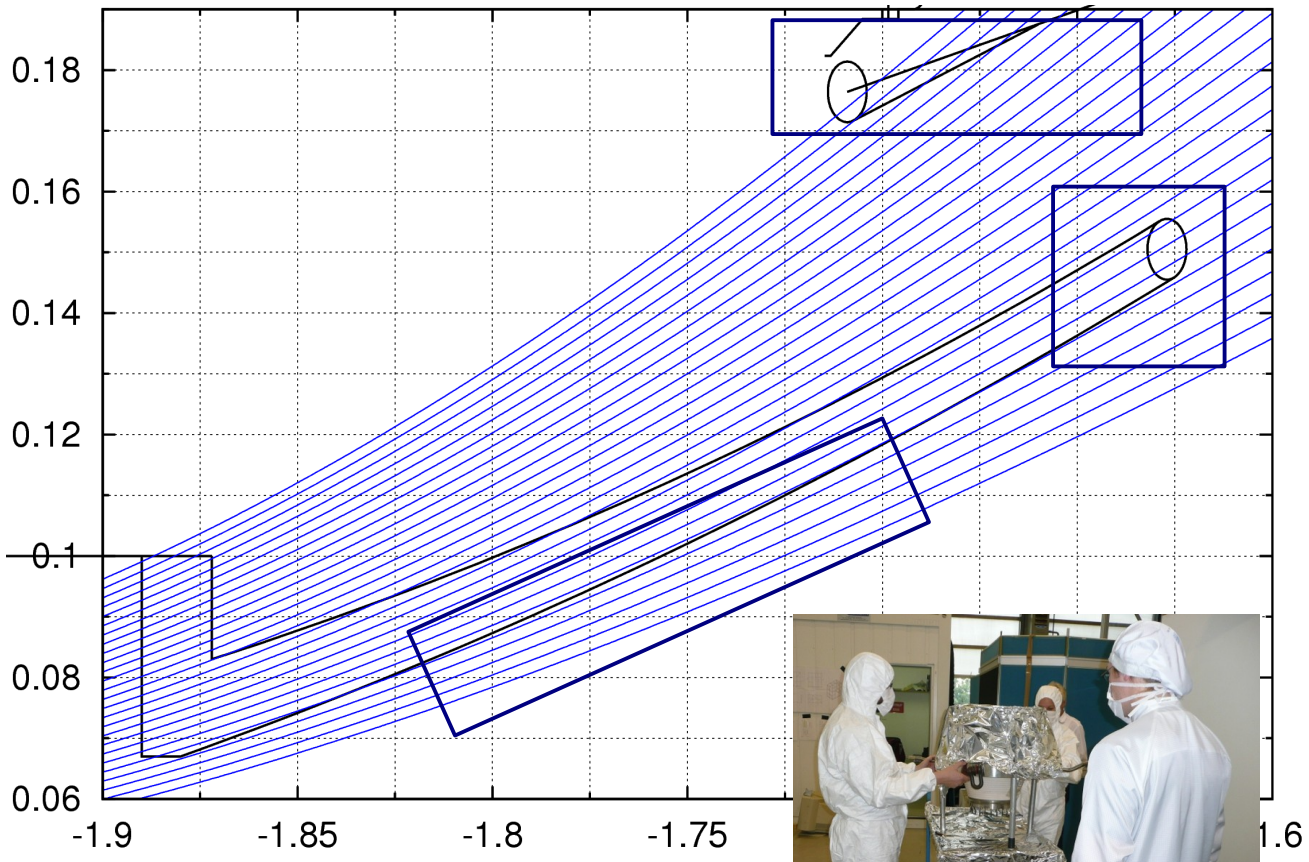


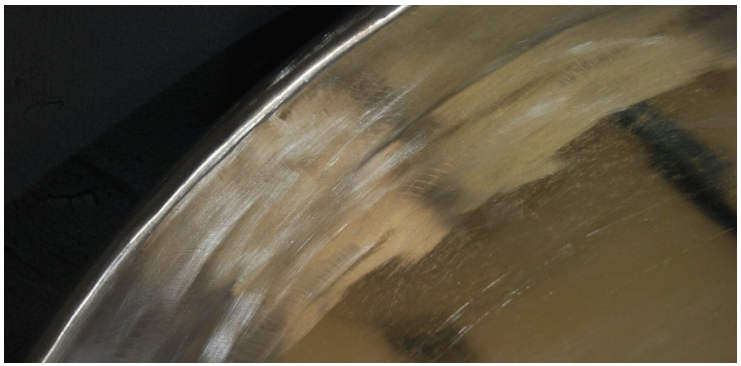


Design fulfils all criteria:

- Avoid GE end traps (1)
  (by shape of electrode end)
- Avoid ion traps (2)
  (by shape of inner side)
- Avoid „Hugenberg trap“ (3)
  (by conical sheet)

PS electrode system
New ground electrode (Mk 4)



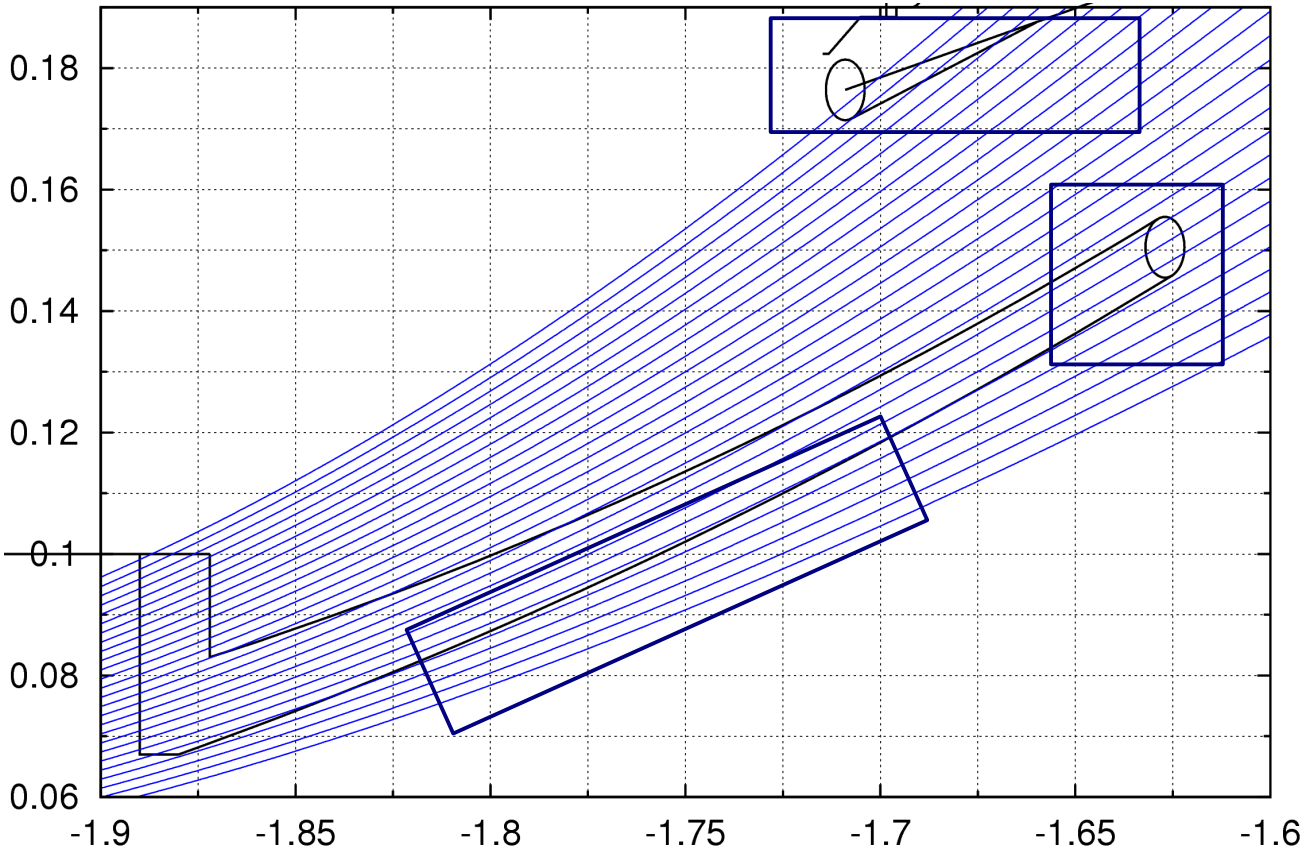


- Massive aluminium electrode
- Drilled from a block
- Bake out temperature 200°C
- Other materials needed for final beamline setup
- Fast and precise solution

→ Installed as Mk 4 setup in summer 2009

PS electrode system
New ground electrode (Mk3)

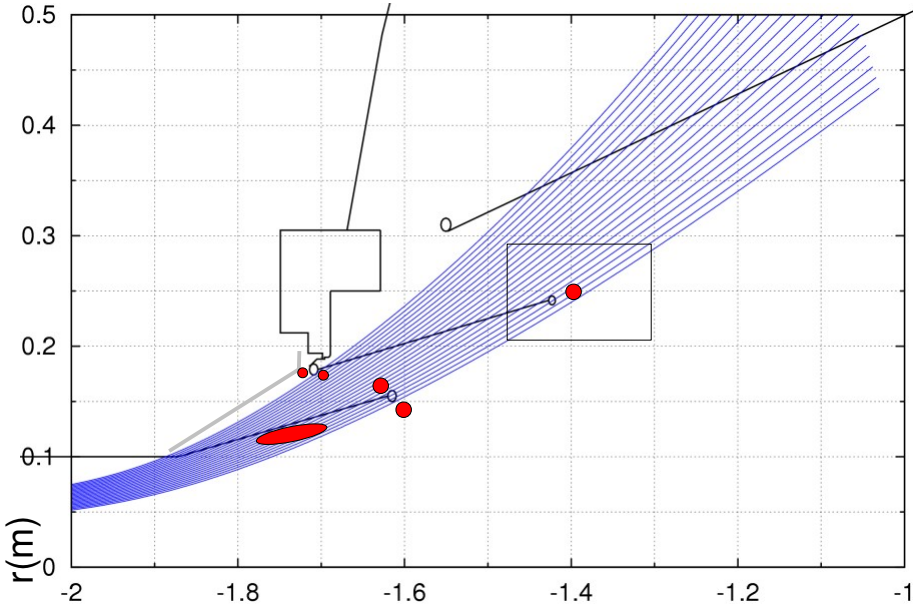
Happy Parrot

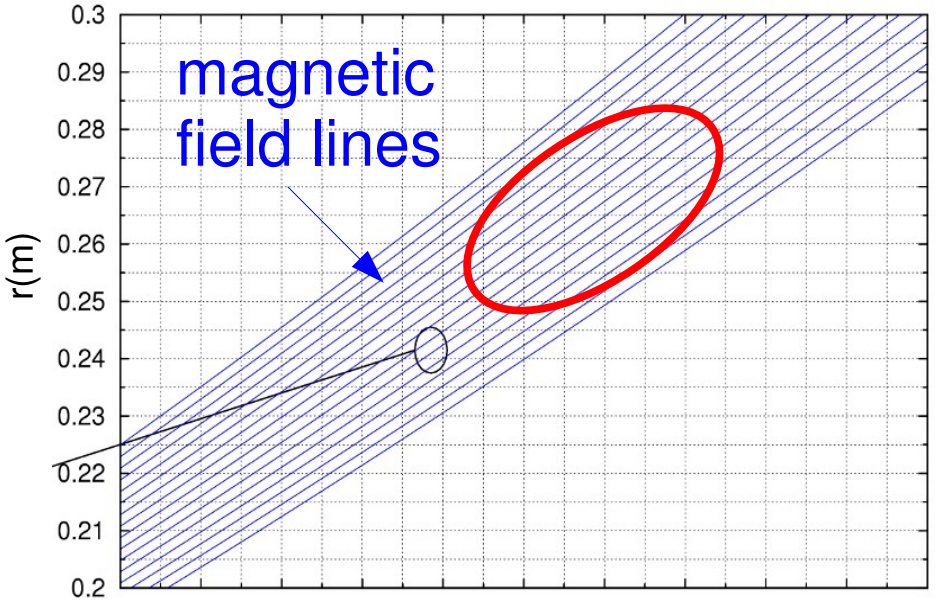


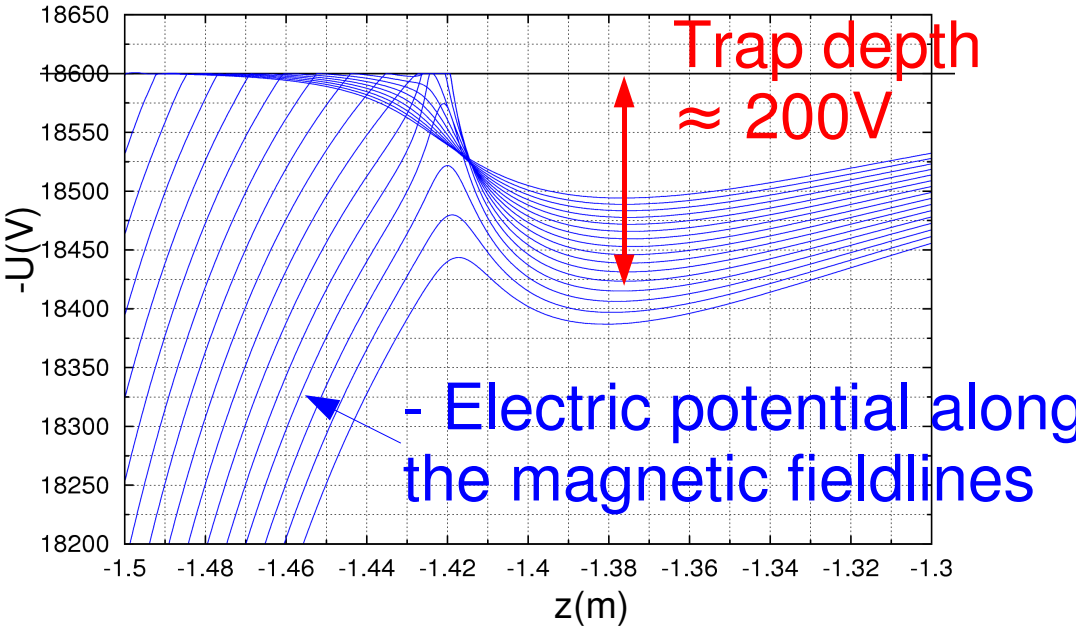
- High-B-Field background disappered!
- Trap at GE endbulge identified as main source!

→ Next task: Apply this to main spectrometer electrode system!

PS electrode system
Trap at outer end of SE







- Caused by „positive“ GE potential
- Can be solved by longer SE as at main spectrometer, but: mechanically complicated (radius > flange)
- Easier: tune cone potential to ~400V more negative

→ good way to test trap influence

Summary and outlook

- KATRIN will provide highly sensitive, direct measurement of electron neutrino mass
- Electrode system needs to be carefully designed to avoid particle traps and assure good electromagnetic properties (transmission, electric field strength, ...)
- Pre spectrometer as test setup for electrode system
- Even small Penning traps can cause serious background problems
- Pre spectrometer works...

- … interesting measurements to come!
- Apply pre spectrometer solutions for main spectrometer