Electromagnetic Design of the Spectrometer Section of the KATRIN Experiment

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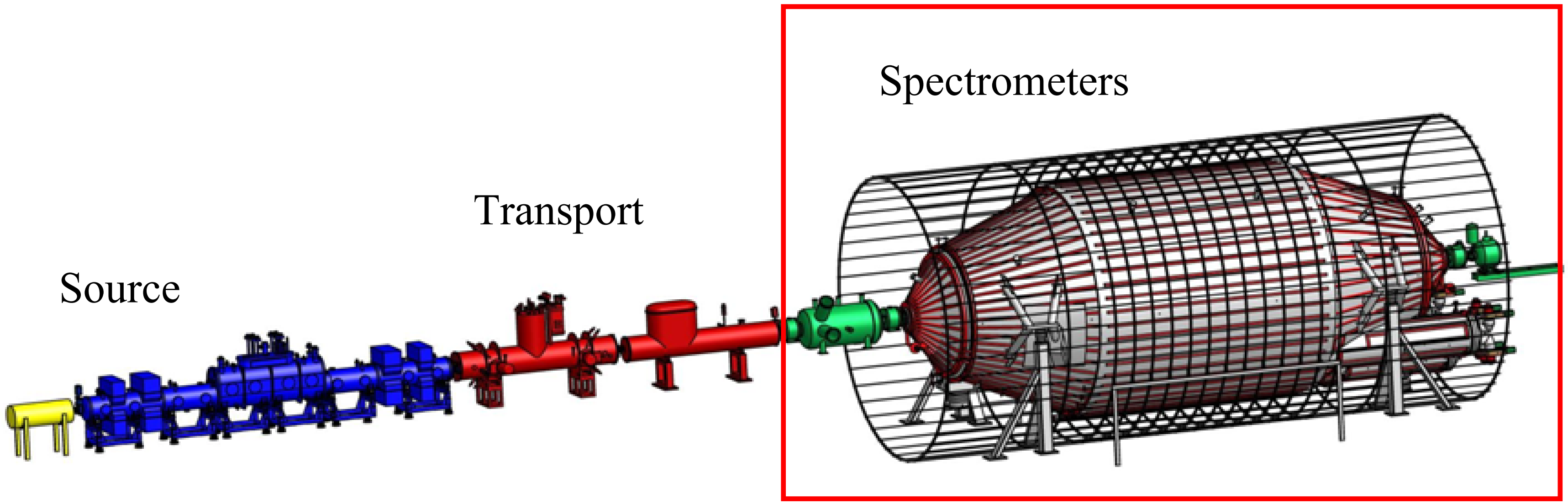
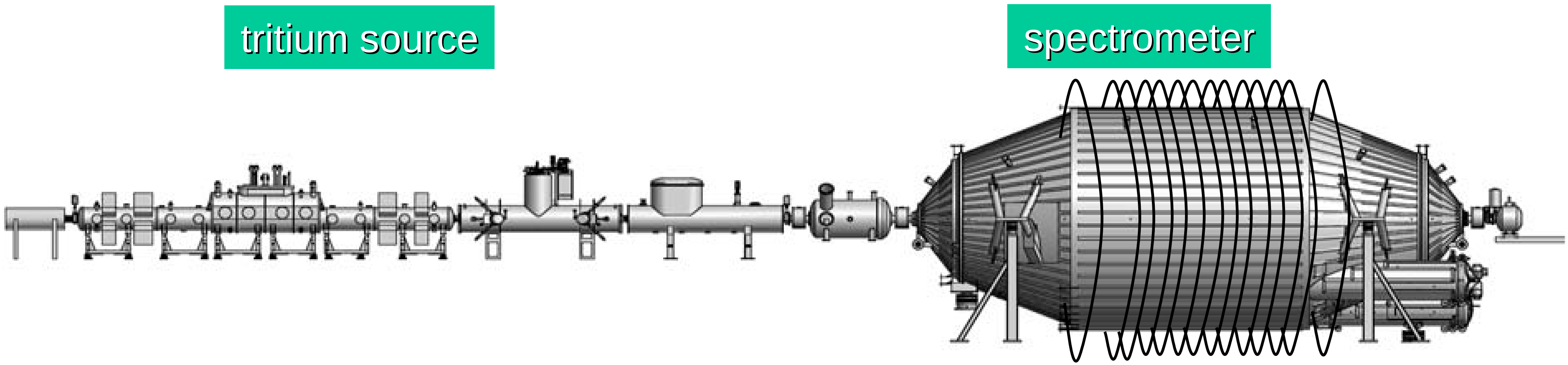
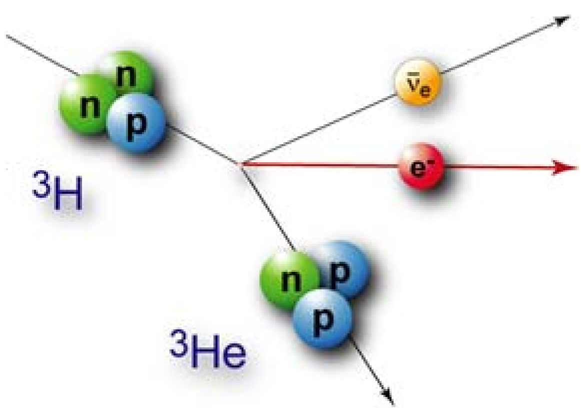
Overview

- Why do we have electric and magnetic fields at the KATRIN experiment?
- What are the challenges of the Electromagnetic Design?
- How is it realized?

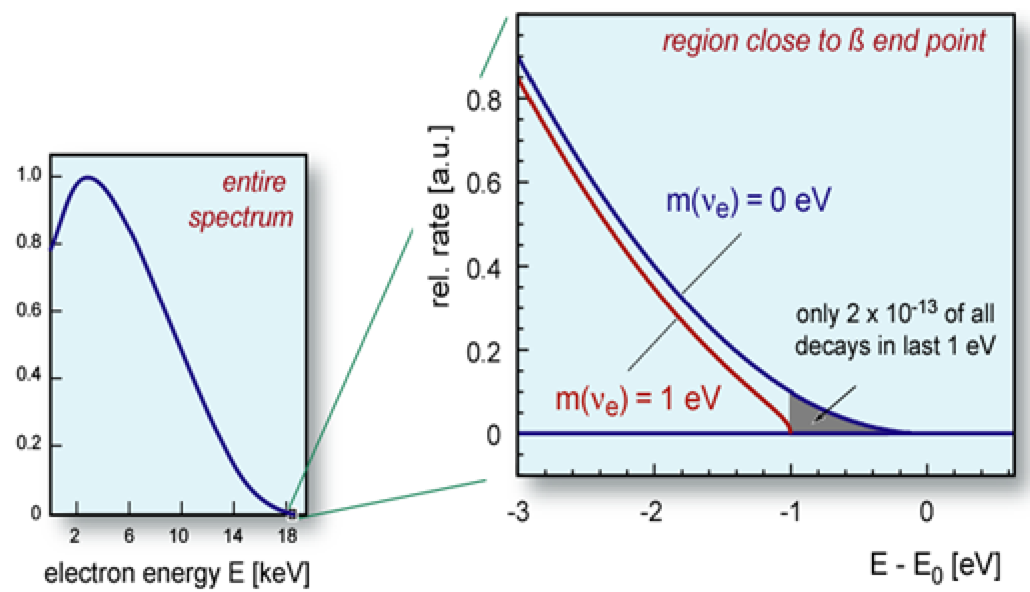


Why do we have electric and magnetic fields at the KATRIN experiment?

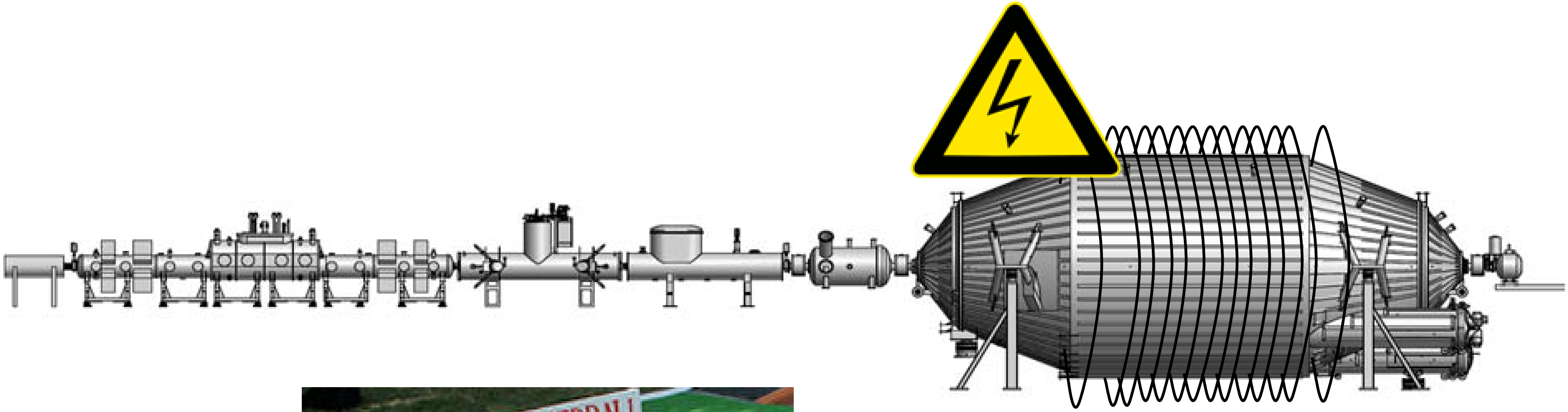




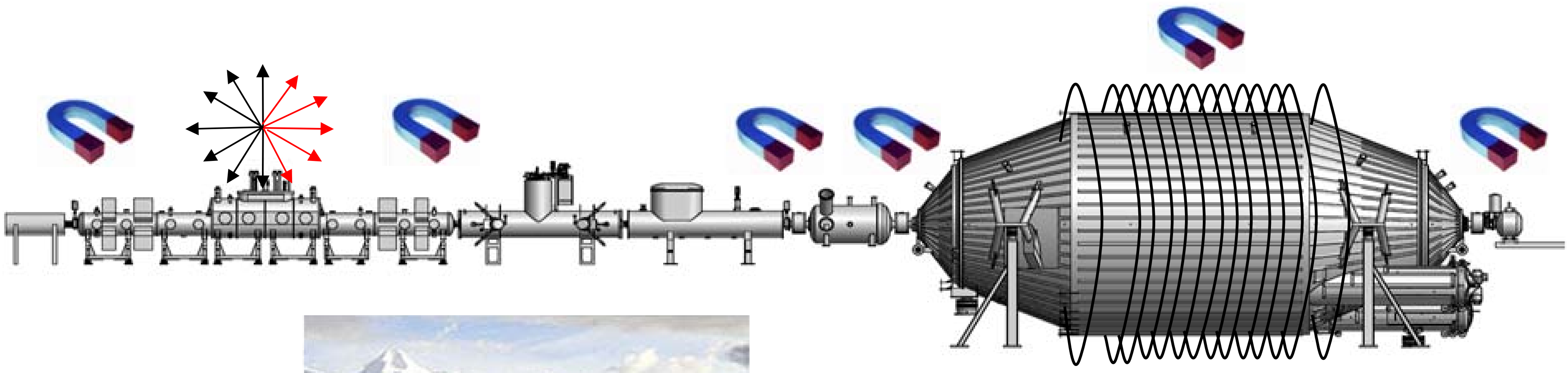
$$^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$$



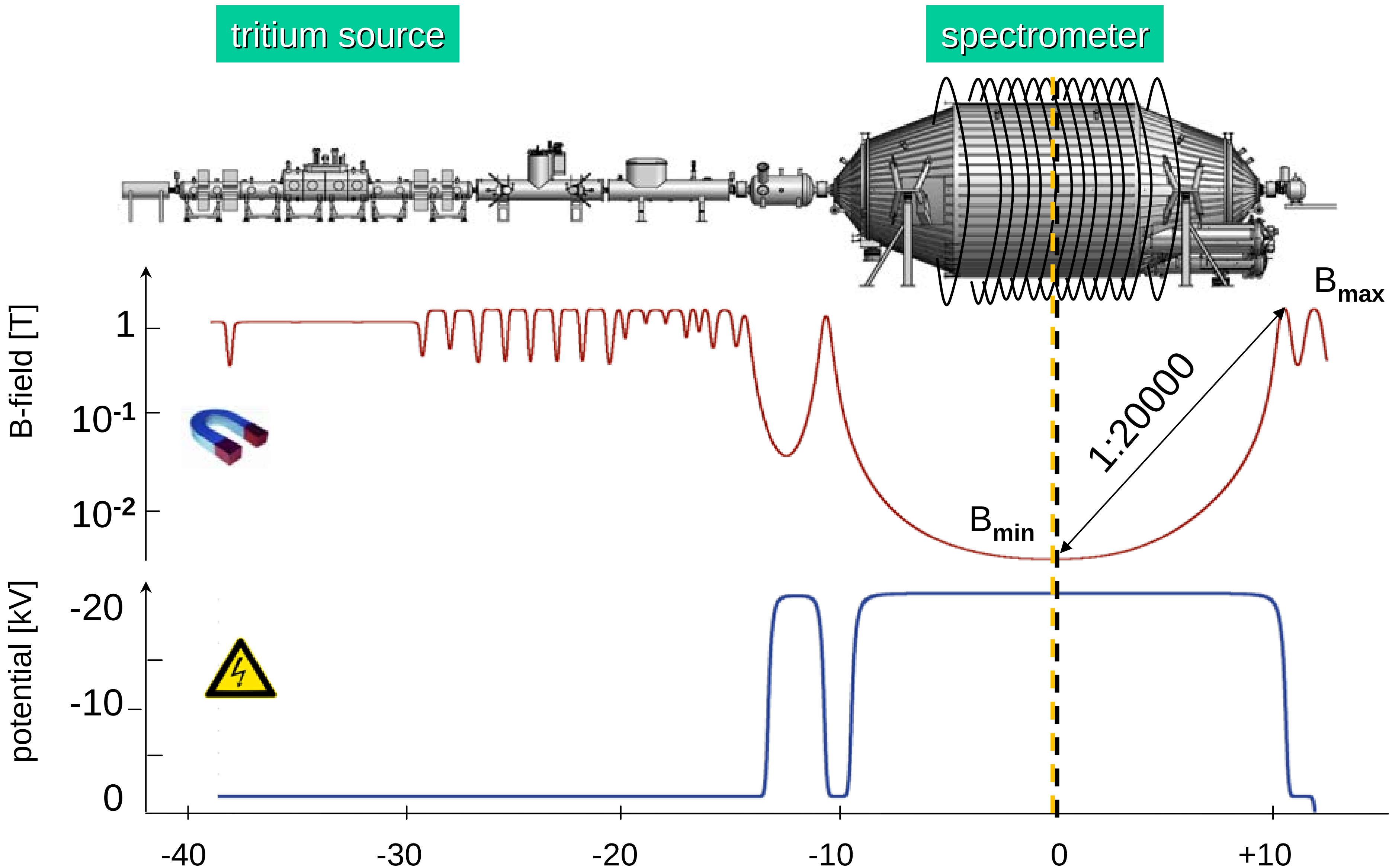
Role of the electric potential: high energy electron filter



Role of the magnetic field: guiding system



Interplay of electric potential and magnetic field



Interplay of electric potential and magnetic field

- Electron kinetic energy:

$$\boxed{E_{\text{kinetic}} = E_{\text{longitudinal}} + E_{\text{cyclotron}}}$$

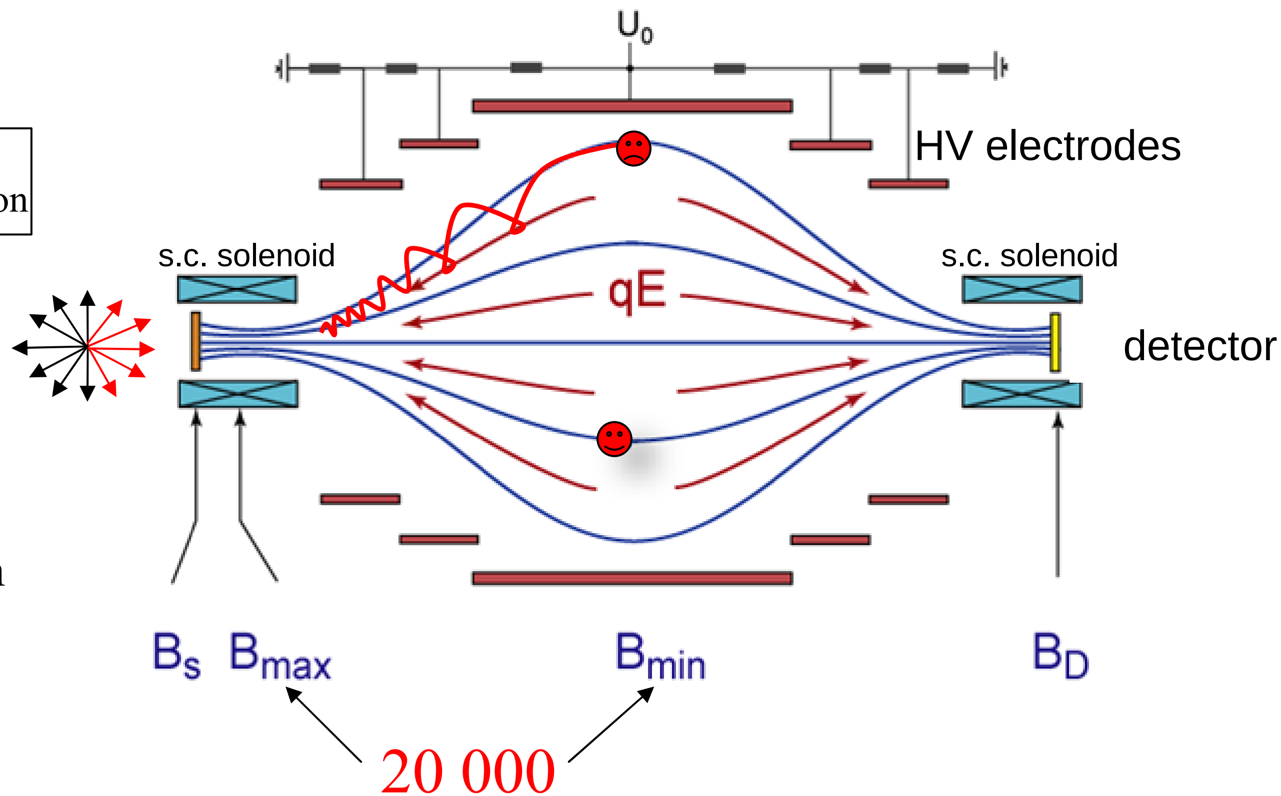
- Electron transmitted if:

$$\boxed{E_{\text{longitudinal}} > 0\,keV}$$

- Adiabatic motion of electron from high to low magnetic field:

$$\boxed{E_{\text{cyclotron}} \rightarrow E_{\text{longitudinal}}}$$

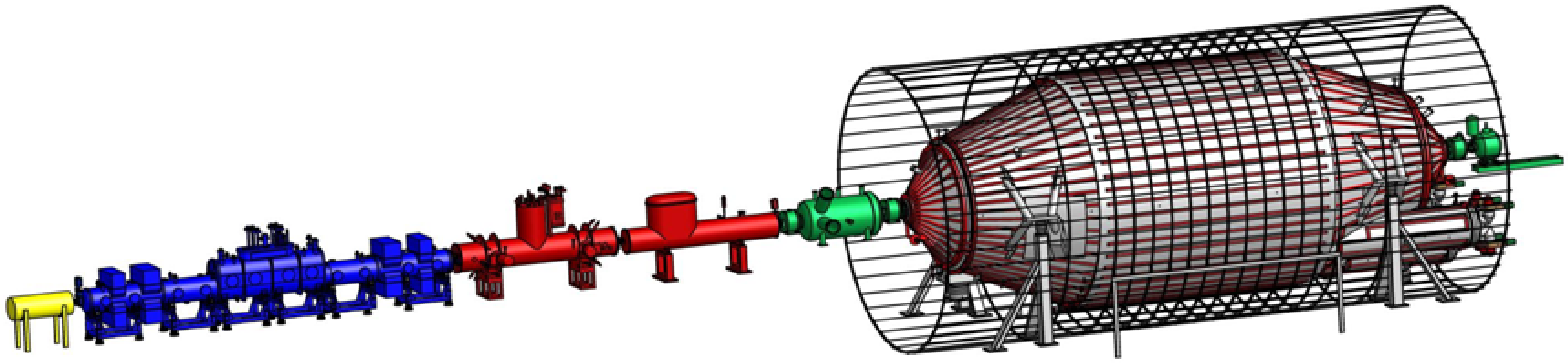
$$\boxed{E_{\text{kinetic}} \approx E_{\text{longitudinal}} > 0\,keV}$$



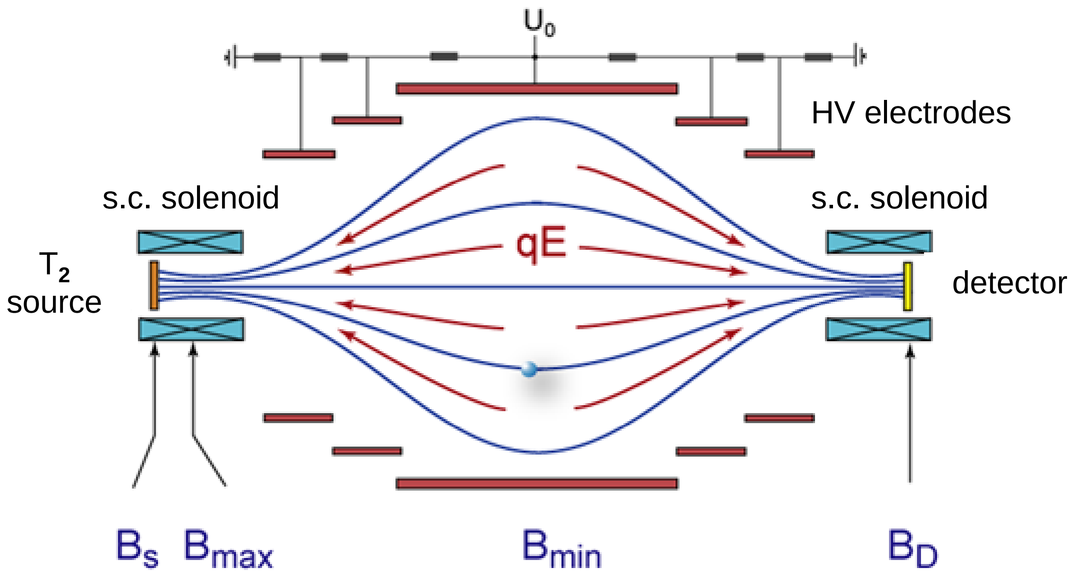
MAC-E-Filter-Principle:
Magnetic Adiabatic Collimation and Eletric filter

Overview

- Why do we have electric and magnetic fields at the KATRIN Experiment?
  - High energy electron filter (electric potential)
  - Guiding and energy transformation (magnetic field)
- What are the challenges of the Electromagnetic Design?
- How is it realized?



1^{st} Goal: Realize the MAC-E-Filter principle in the optimal way

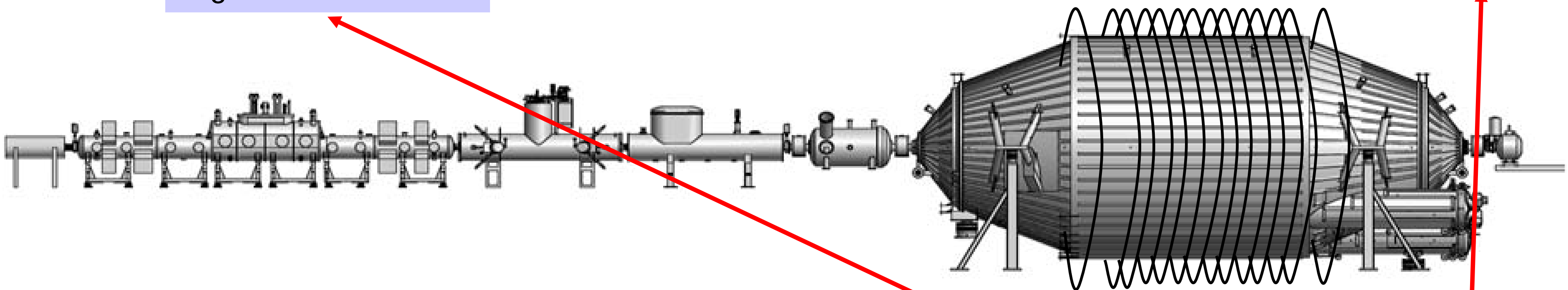


- Homogeneous electric potential in analyzing plane
- Homogeneous magnetic field in analyzing plane
- Slowly increasing electric potential relative to decrease of magnetic field
- Slowly decreasing magnetic field to assure adiabaticity

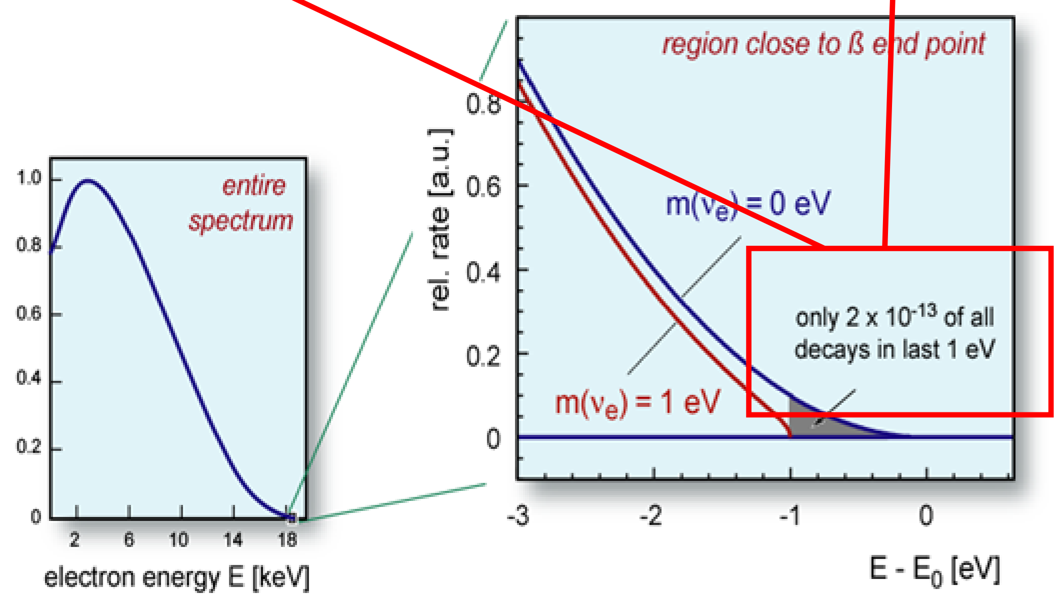
2^{nd} Goal: Reduce Background

$N_e/s = 10^{-2}$
1 Electron/min

$N_e/s = 10^{11}$

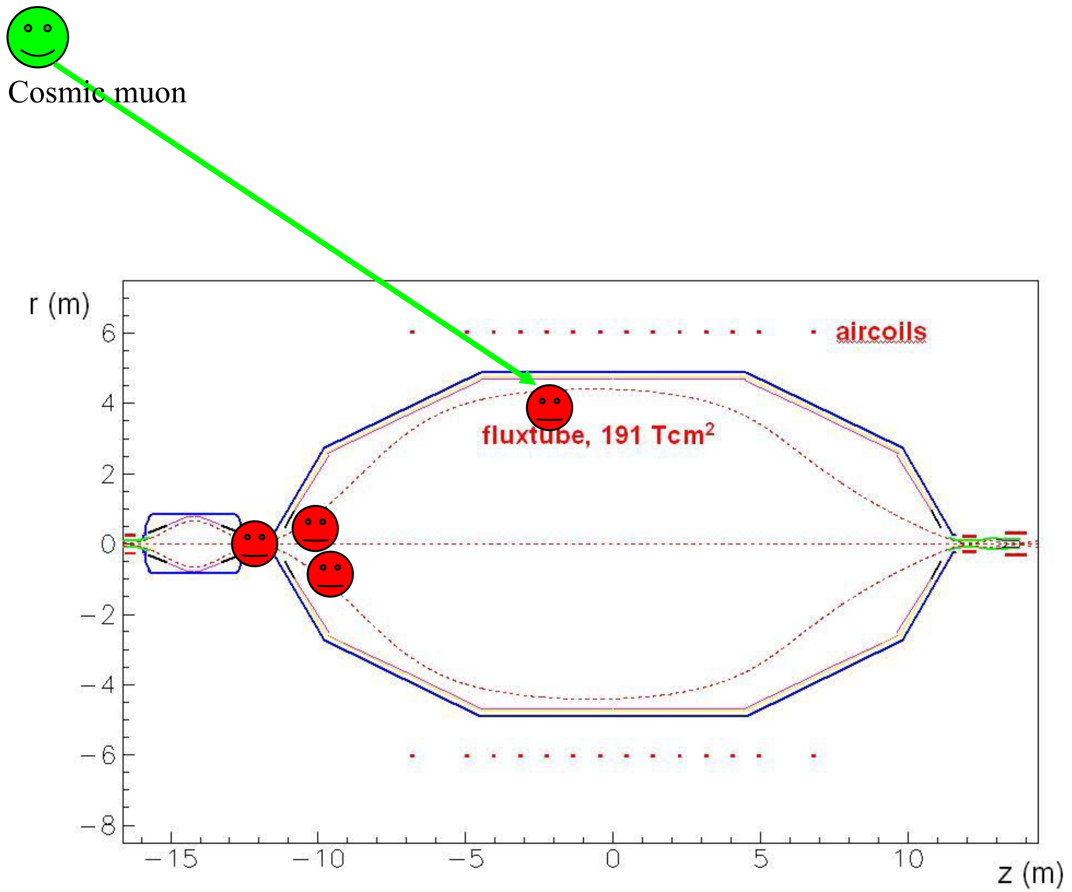


Probability: 10^{-7}



Background Sources

1. Electrons being emitted from the inner surface of the wall
2. Stored Electrons in penning traps

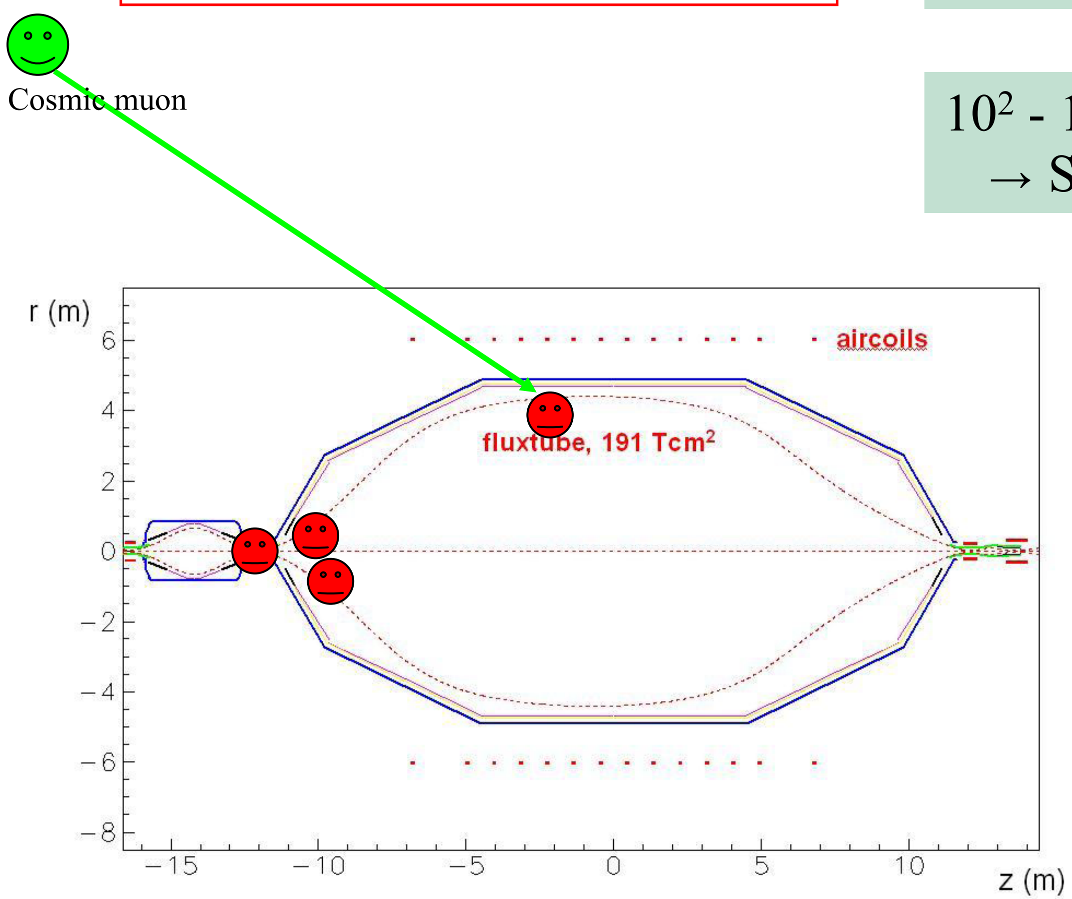


Reduce background with the Electromagnetic Design

Desired background level:
10^{-2} electrons/s
= 10 mHz

10^5 electrons/s from the wall
→ Magnetic shielding (10^5)
→ Wire electrodes (10^2) (Talk by Kathrin Valerius)

10^2 - 10^{15} electrons/s from penning traps
→ Specially designed electrodes



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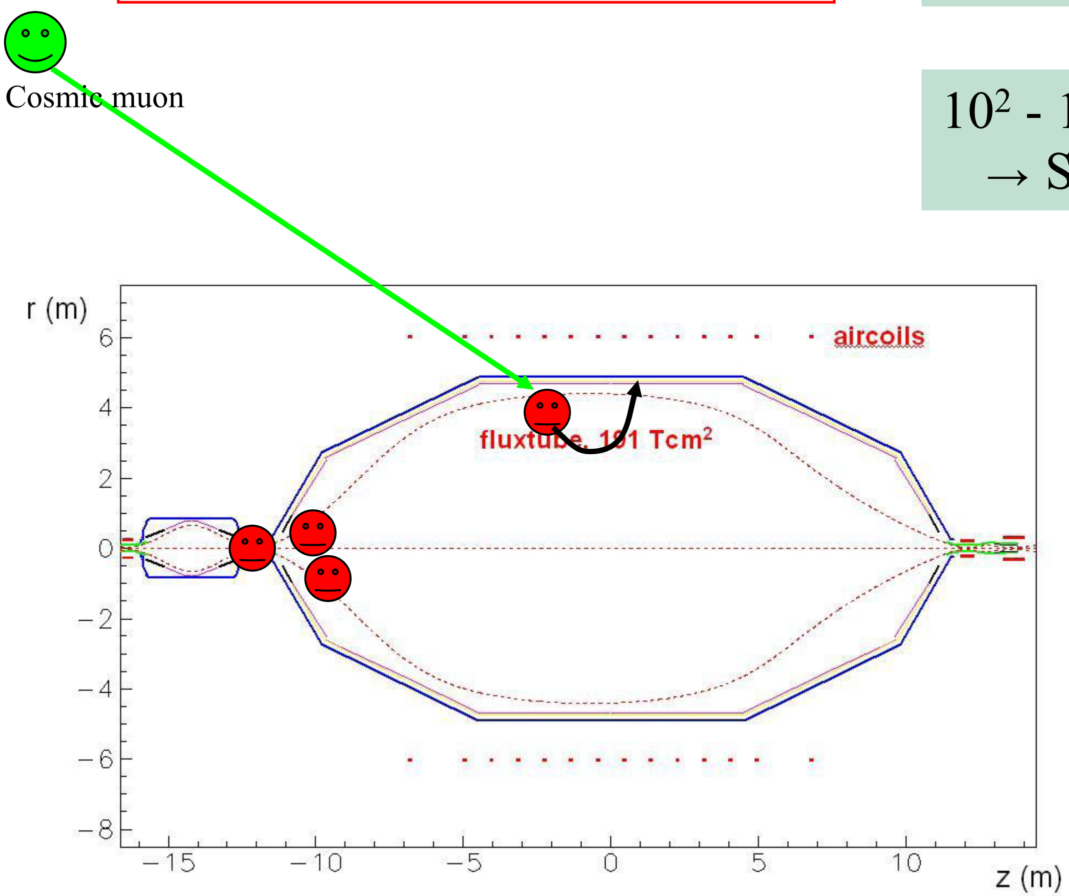

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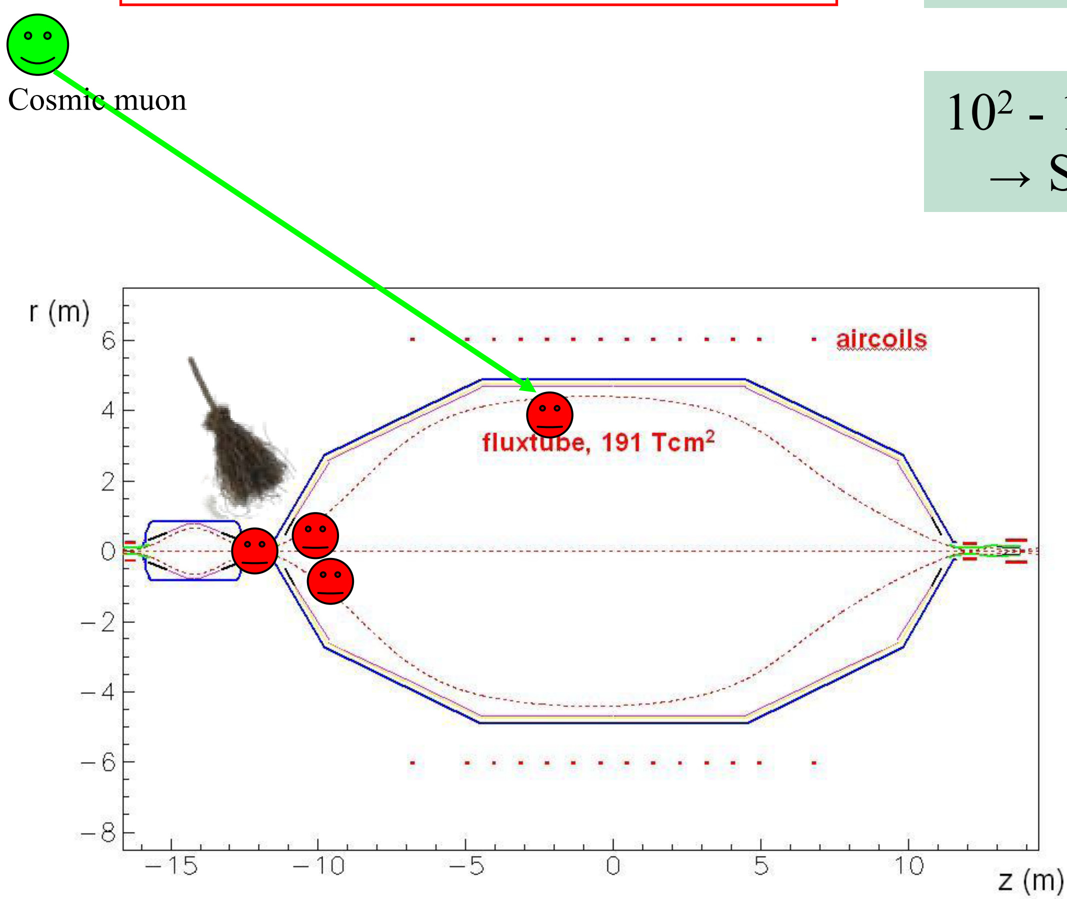

Overview

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  - High energy electron filter (electric potential)
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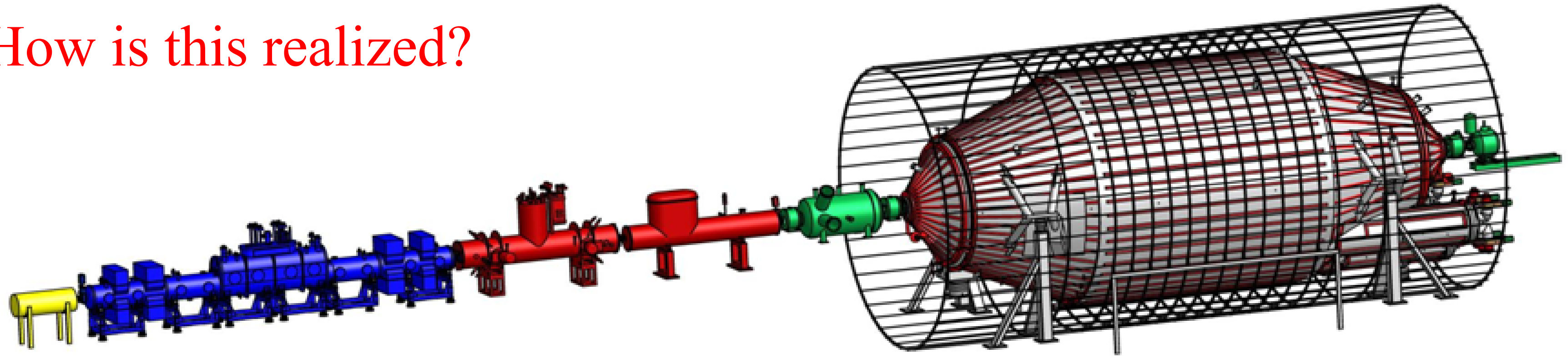
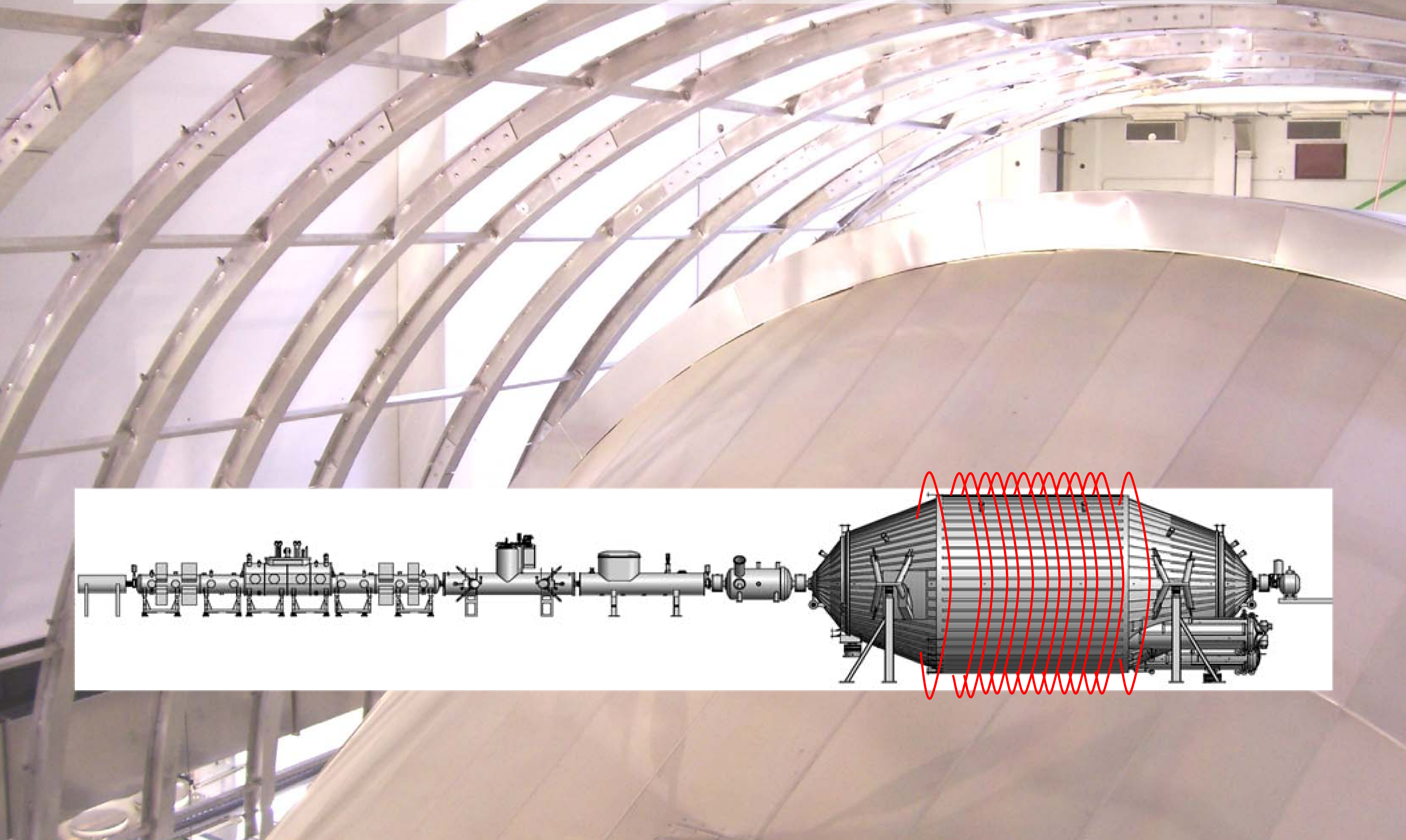
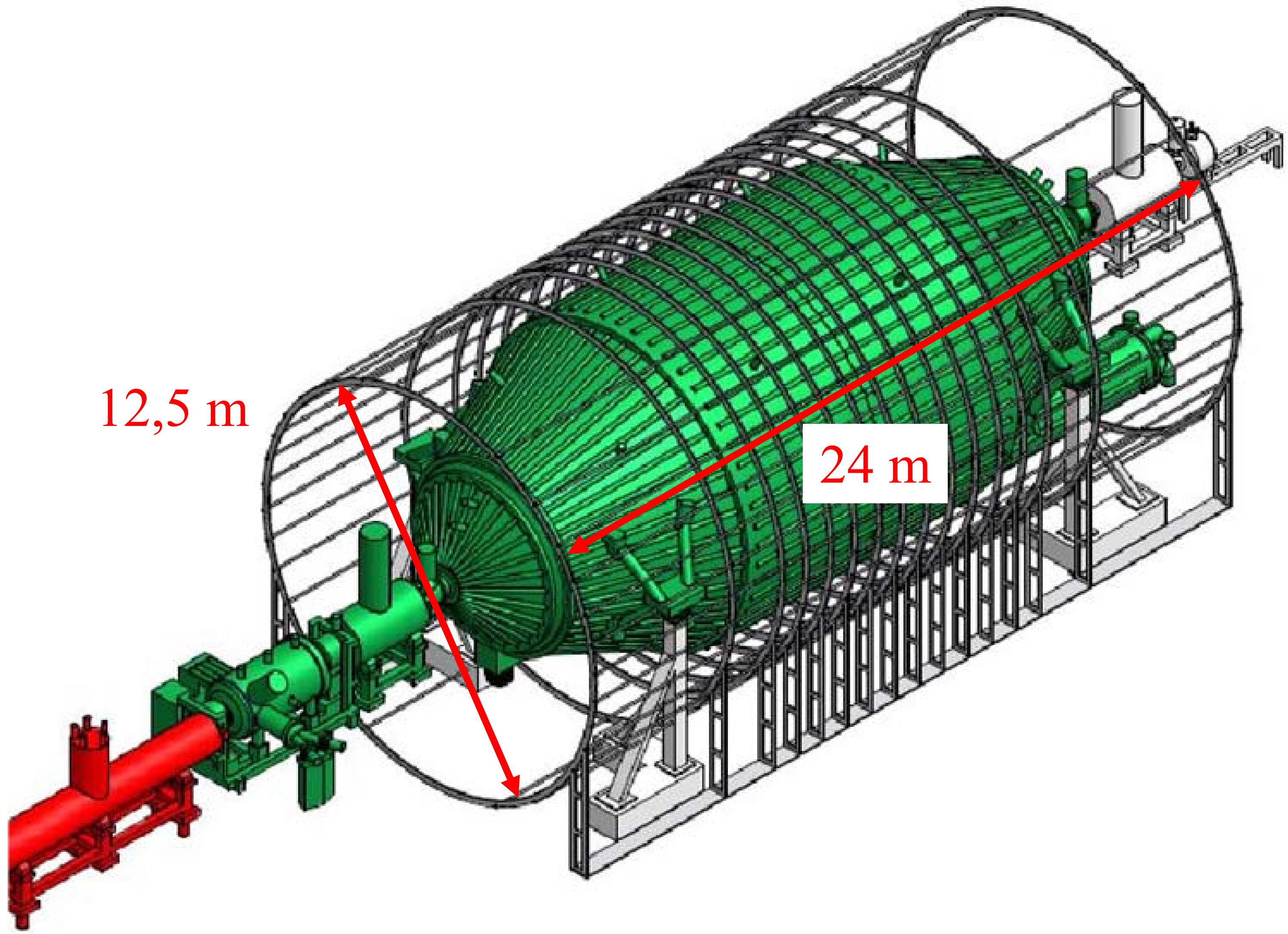
  - Realize MAC-E-Filter in optimal way
  - Reduce Background
- How is this realized?



1st Example: Aircoil System

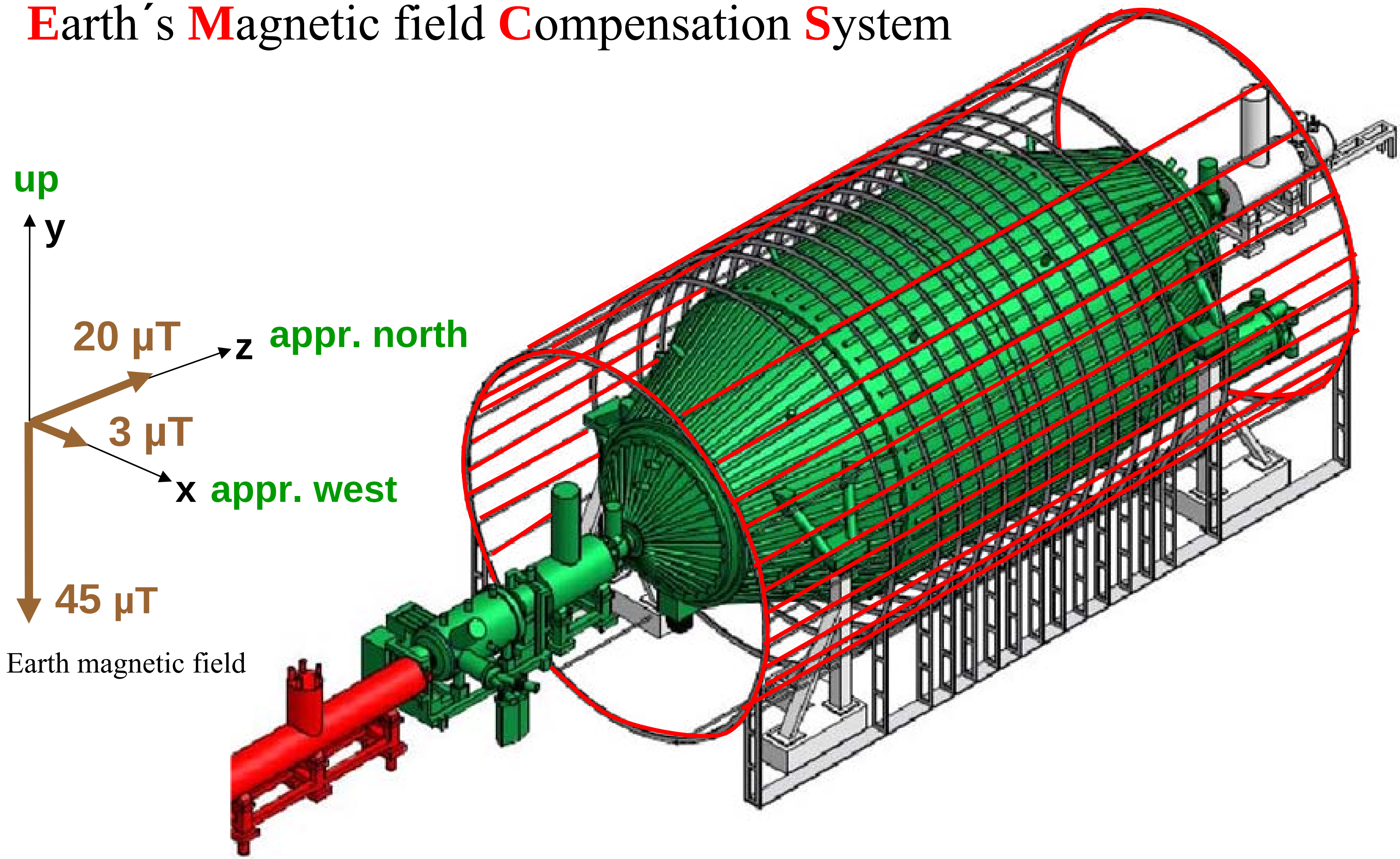


Technical realization



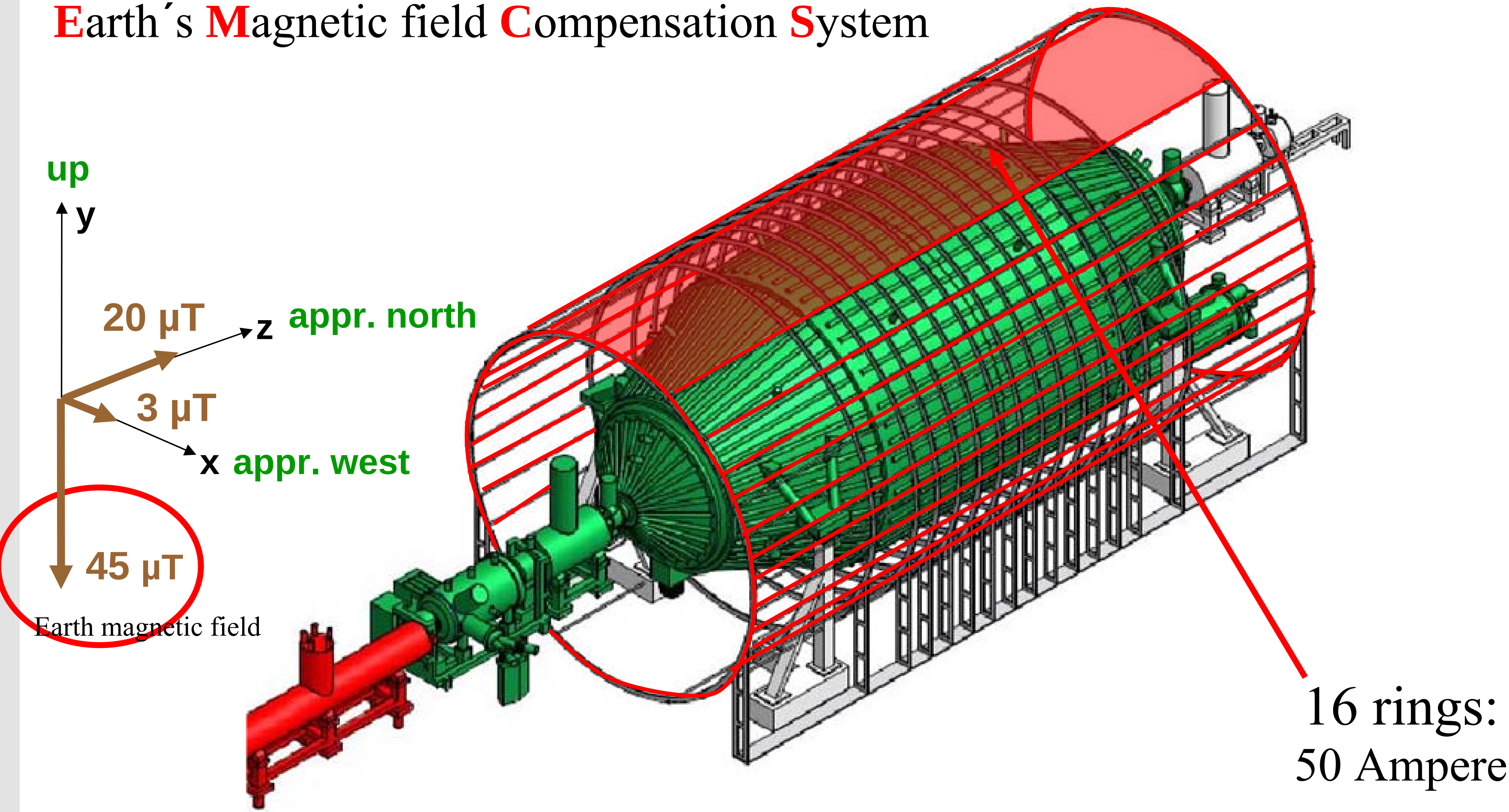
Technical realization

Earth´s **M**agnetic field **C**ompensation **S**ystem



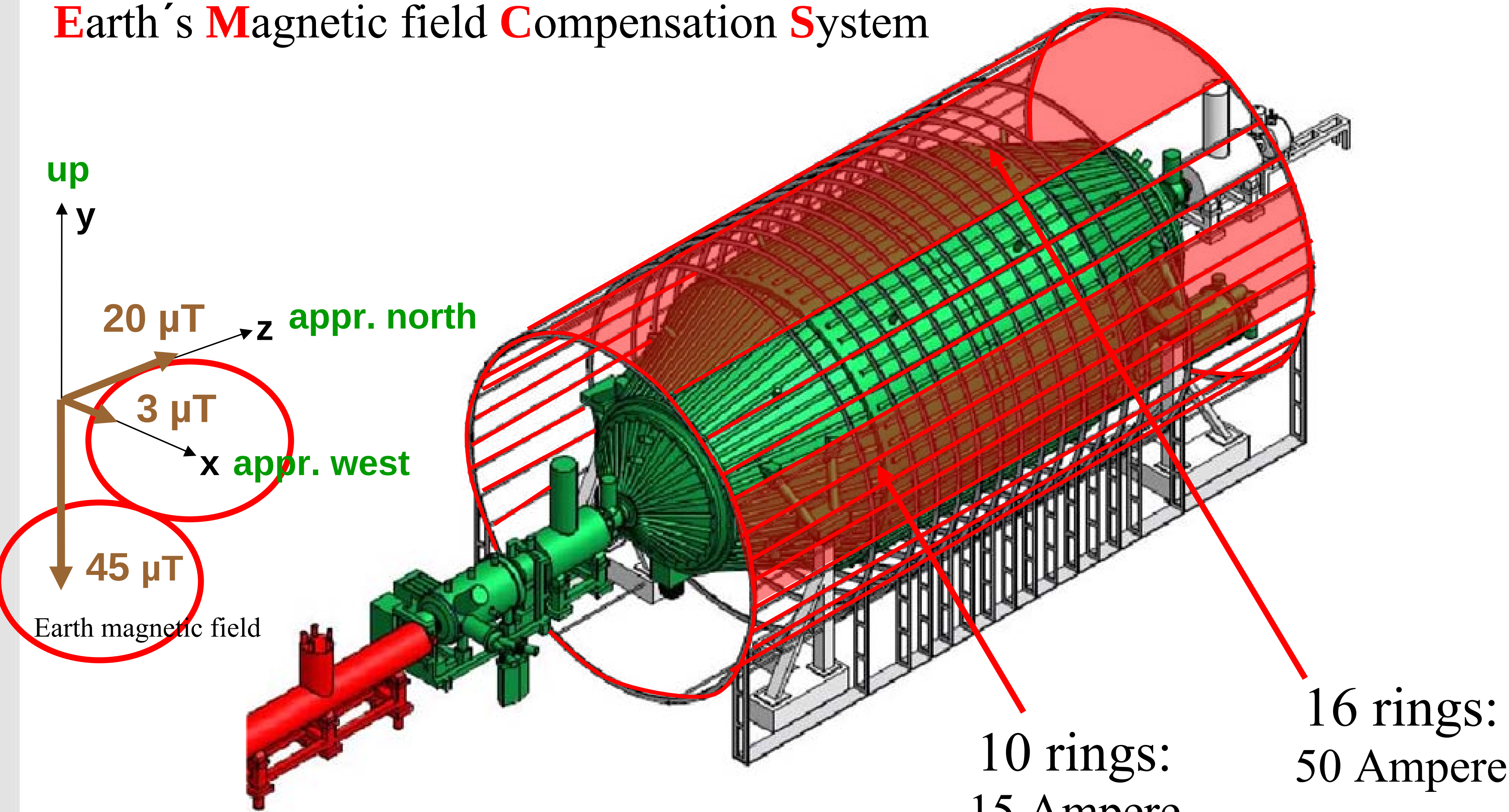
Technical realization

Earth´s Magnetic field Compensation System



Technical realization

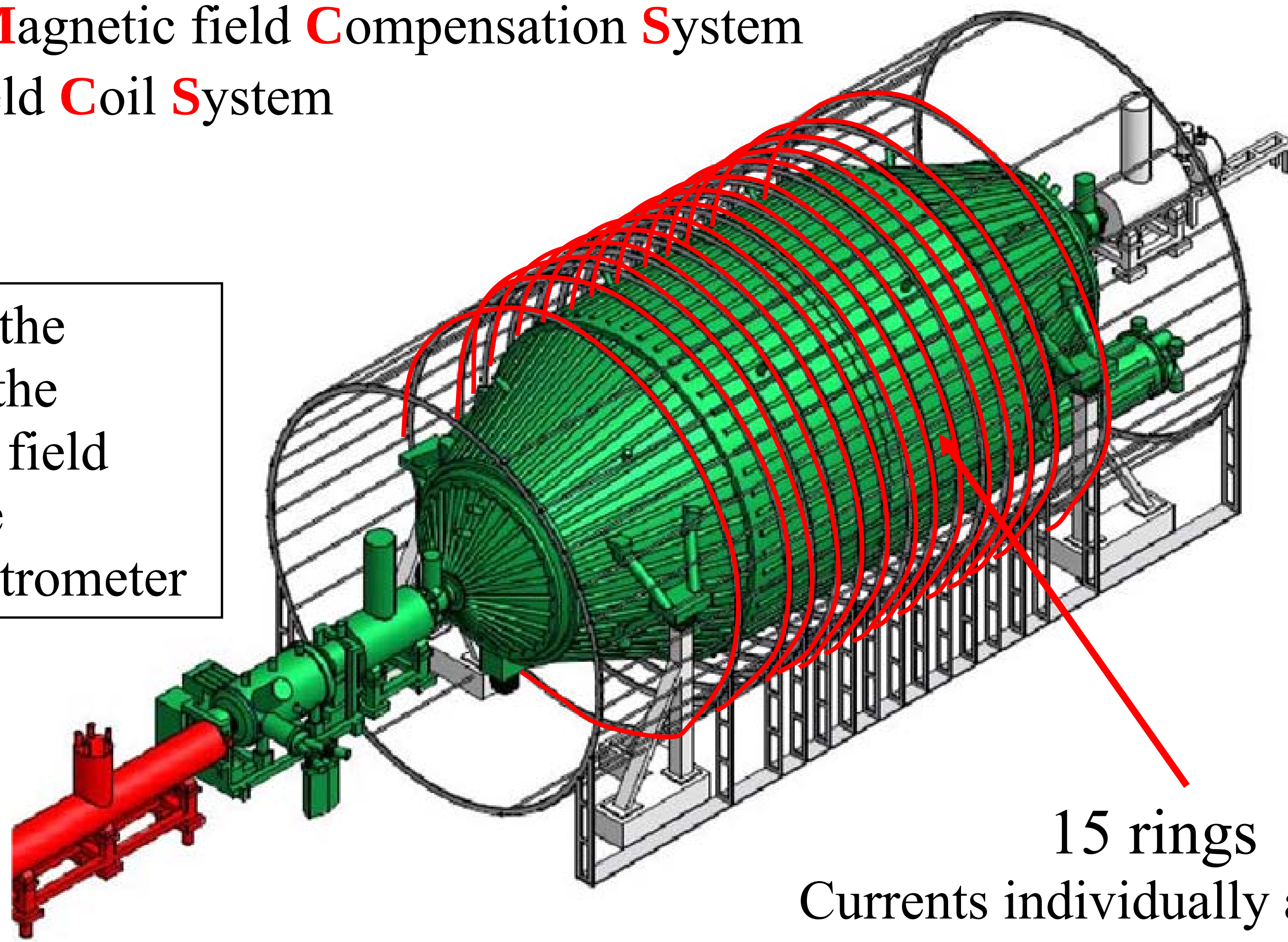
Earth´s Magnetic field Compensation System



Technical realization

Earth´s **M**agnetic field **C**ompensation **S**ystem
\+ **L**ow **F**ield **C**oil **S**ystem

Finetune the shape of the magnetic field inside the mainspectrometer

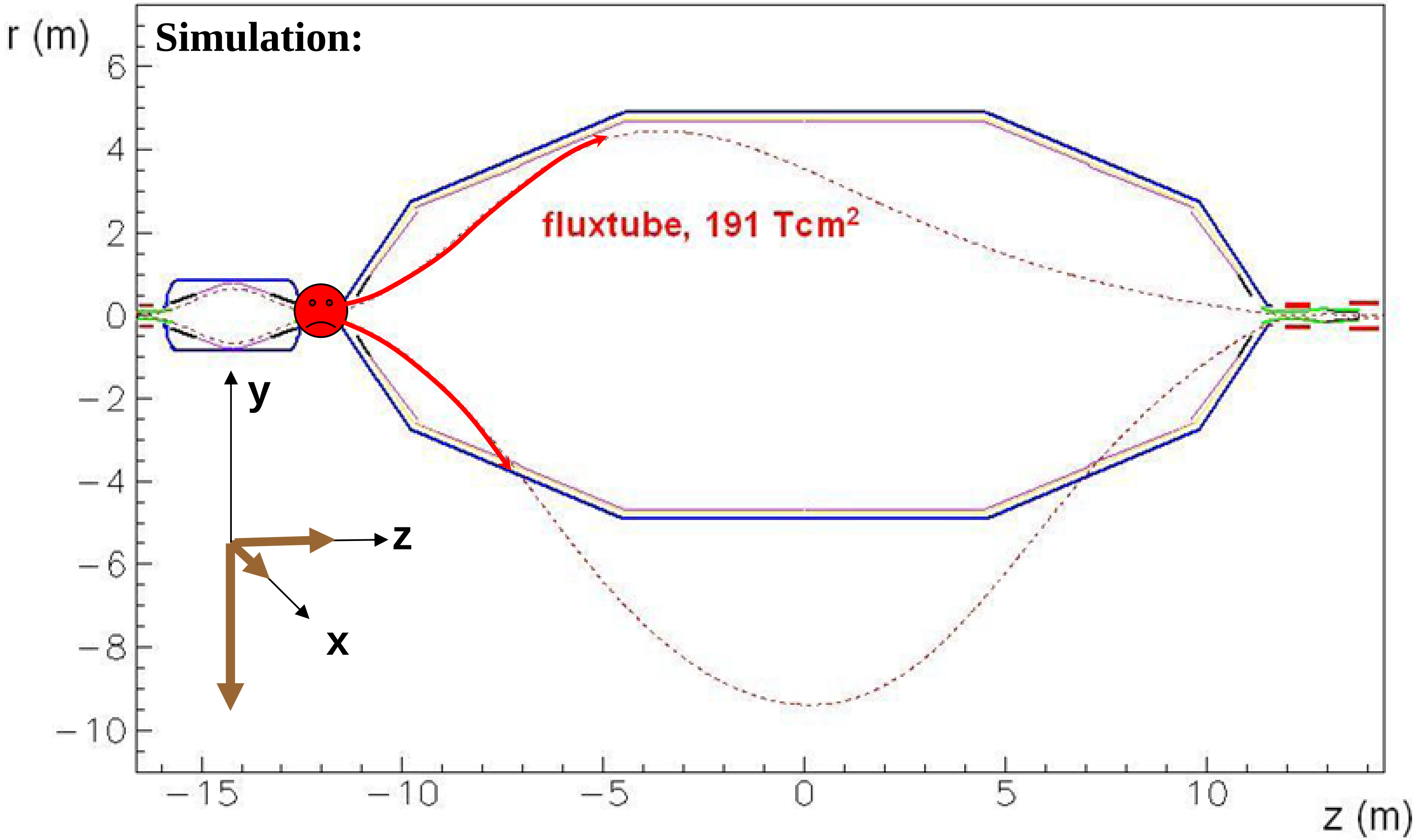


15 rings
Currents individually adjustable
max. 1500 Ampere turns

Task of Aircoil System

Without Aircoil system

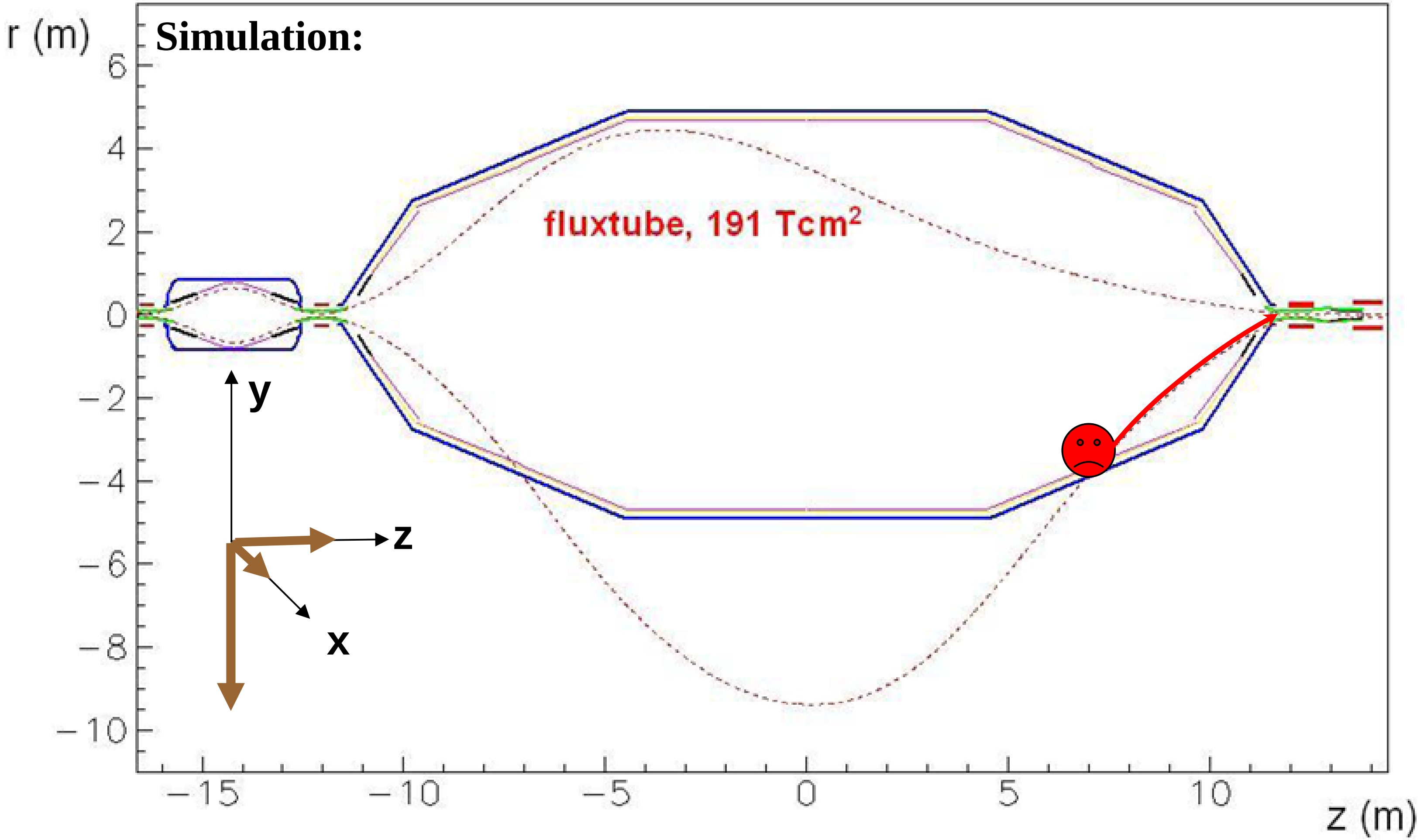
Countrate reduction



Task of Aircoil System

Without Aircoil system

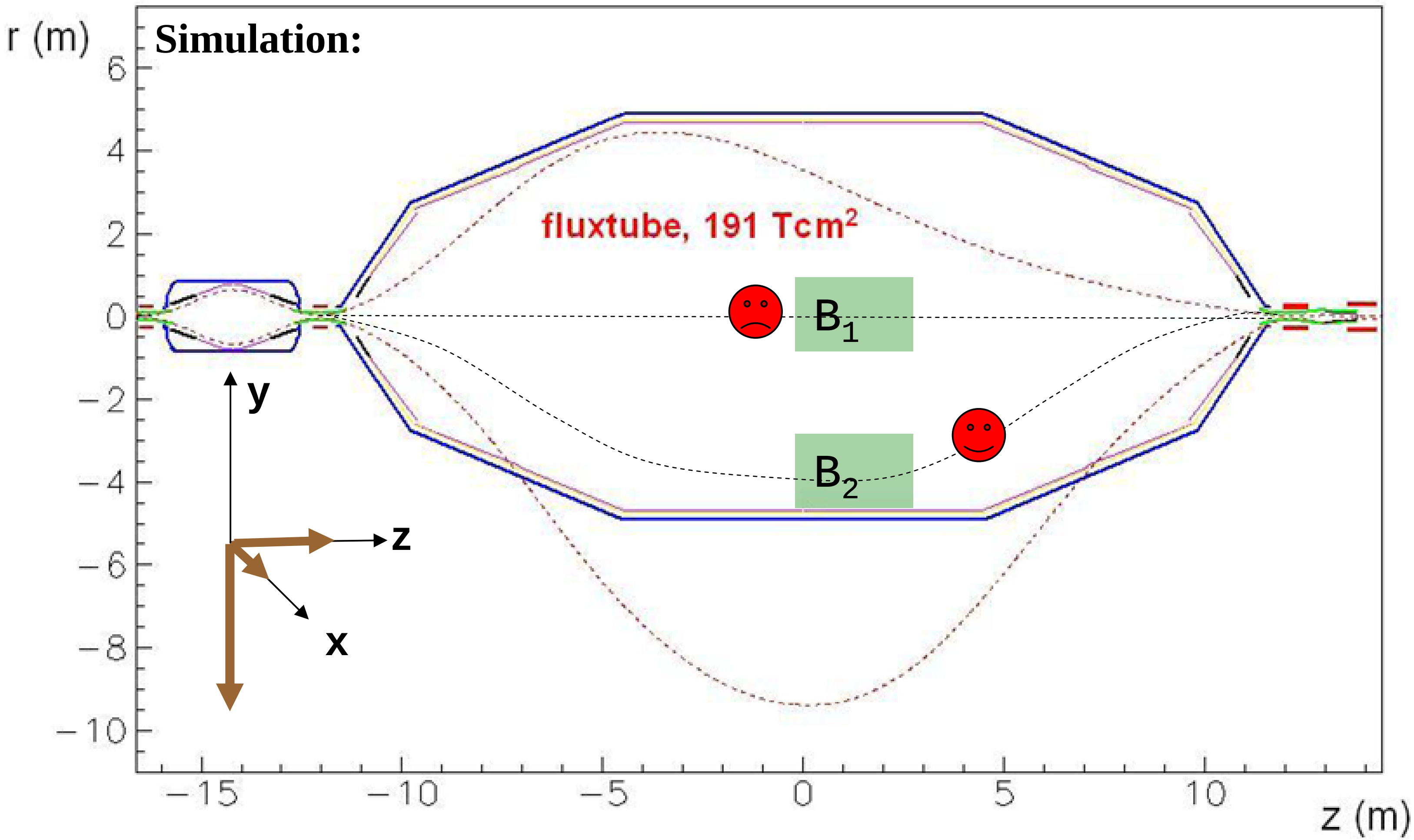
Increase of background



Task of Aircoil System

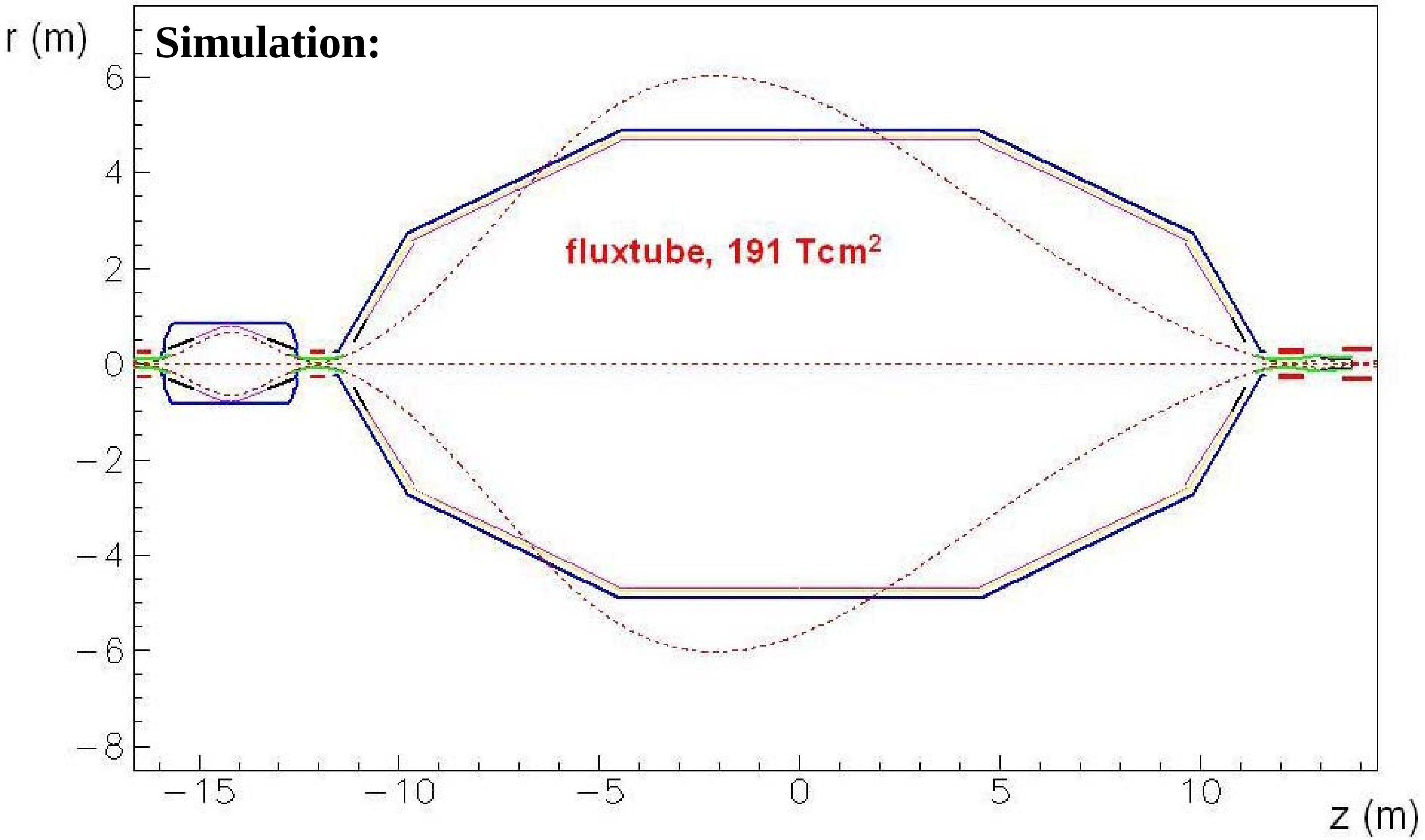
Without Aircoil system

Incorrect transmission condition



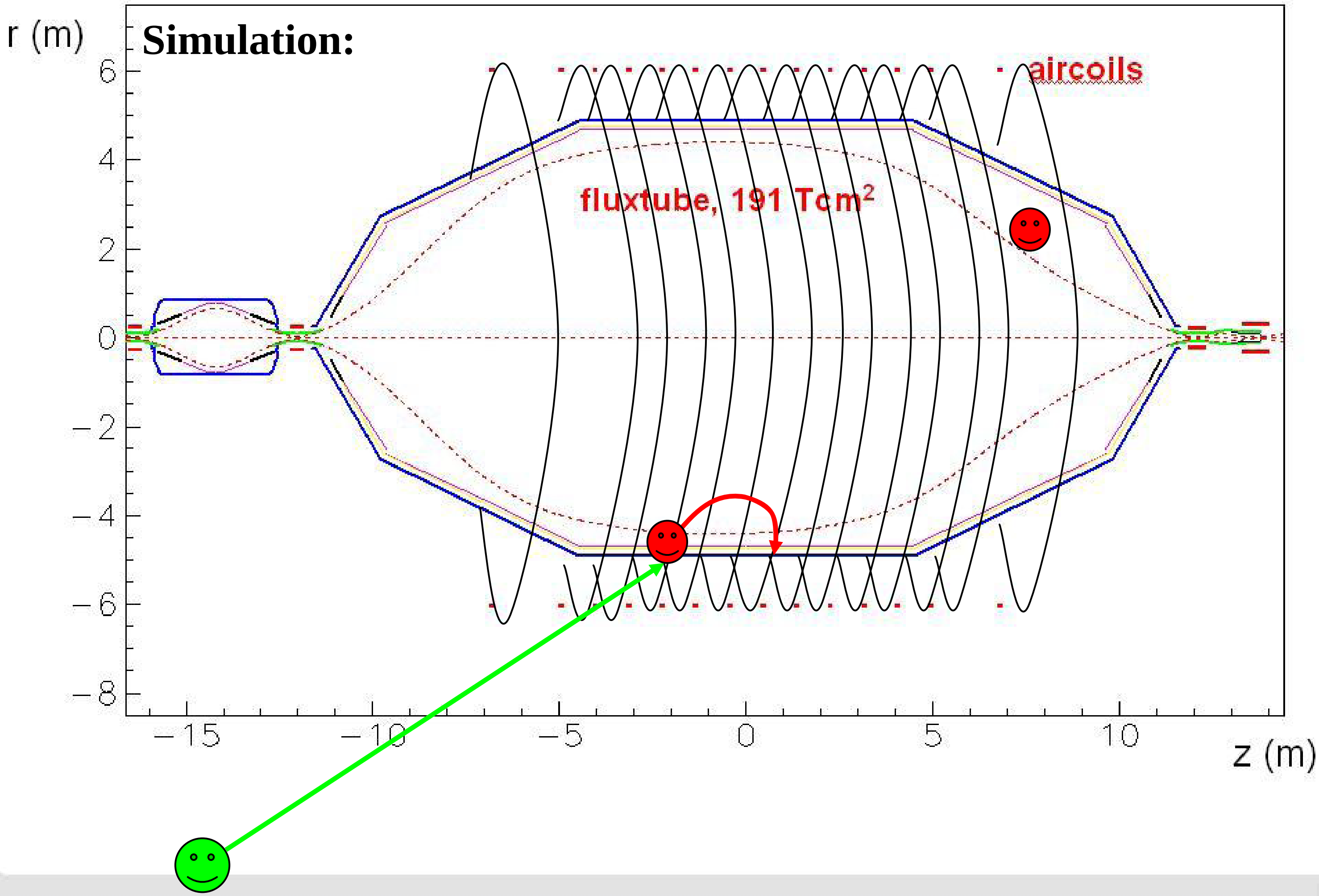
Outcome

With EMCS
(Earth´s magnetic field compensation system)



Outcome

With EMCS + LFCS
(Earth´s magnetic field compensation system + Low field coil system)

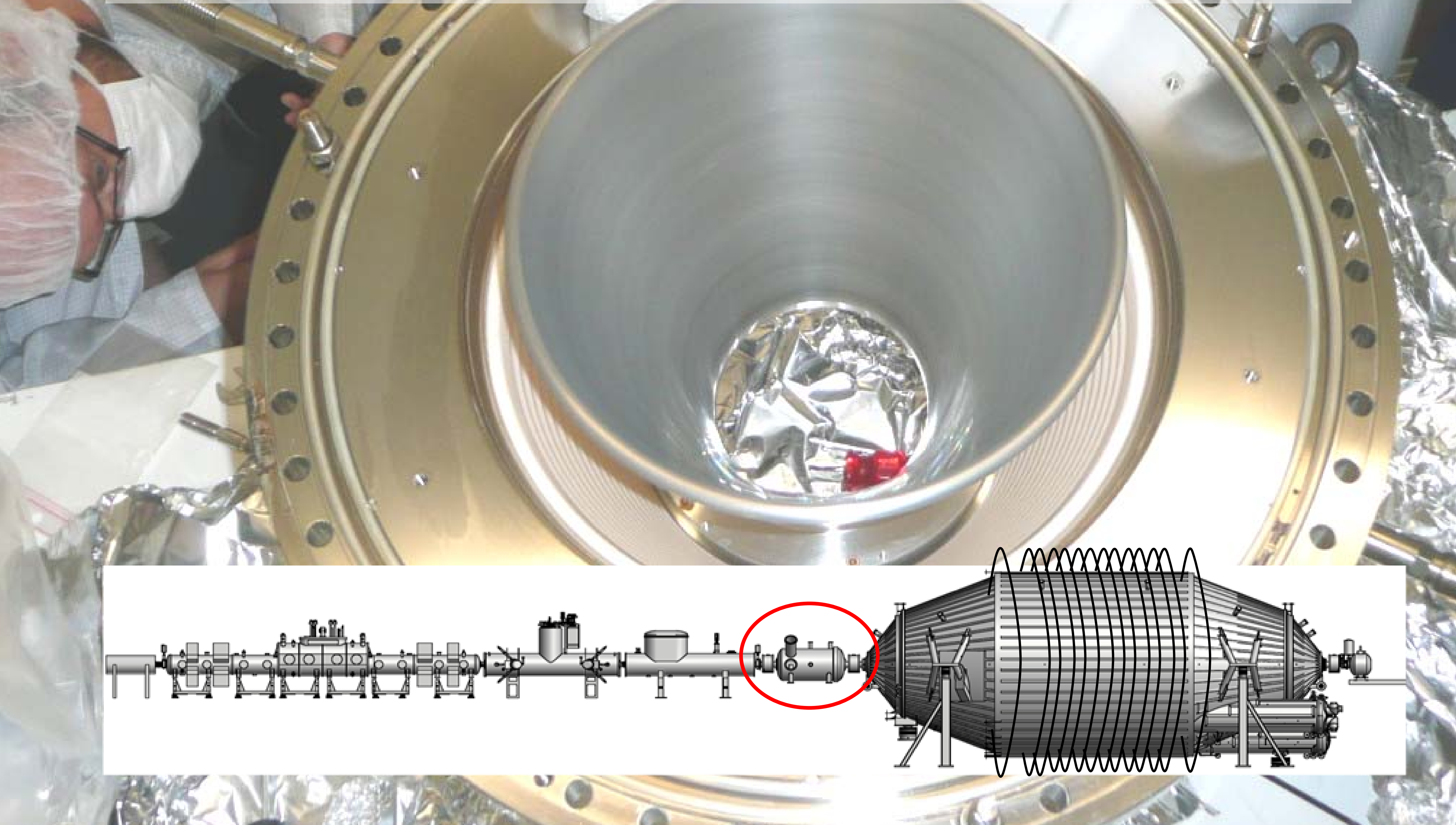


We expect:

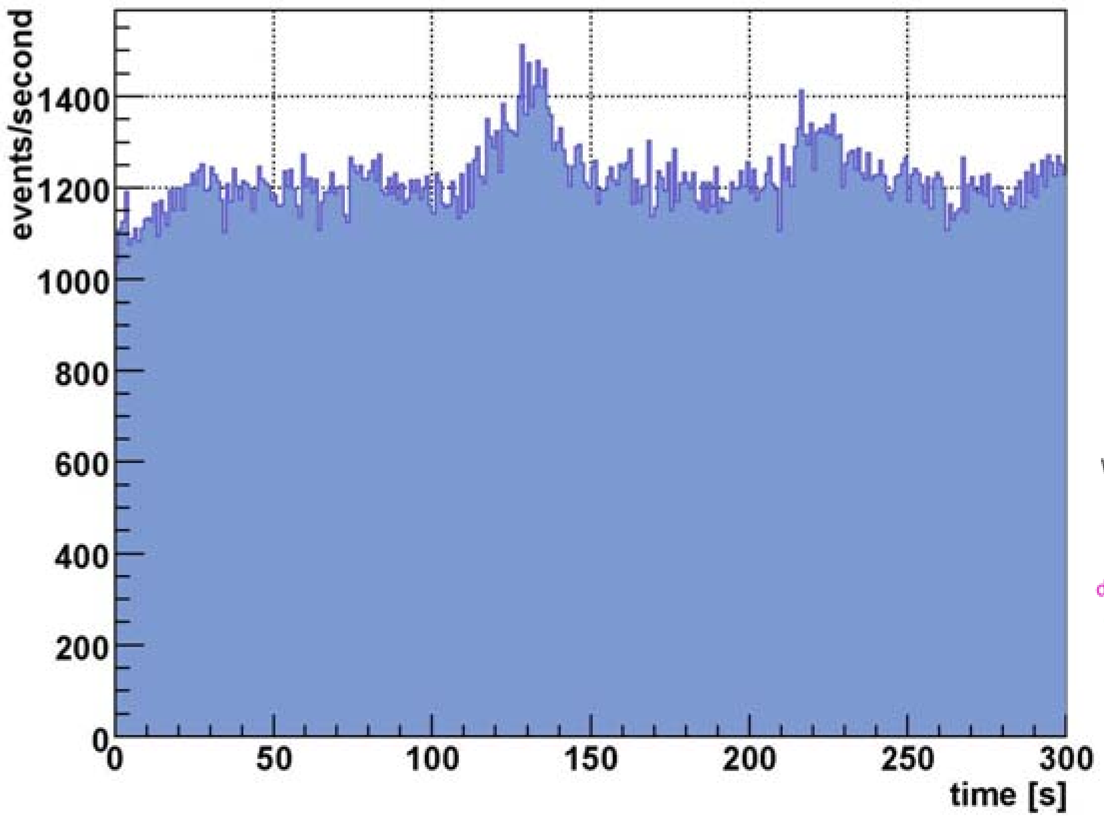
Good transmission properties

Low background

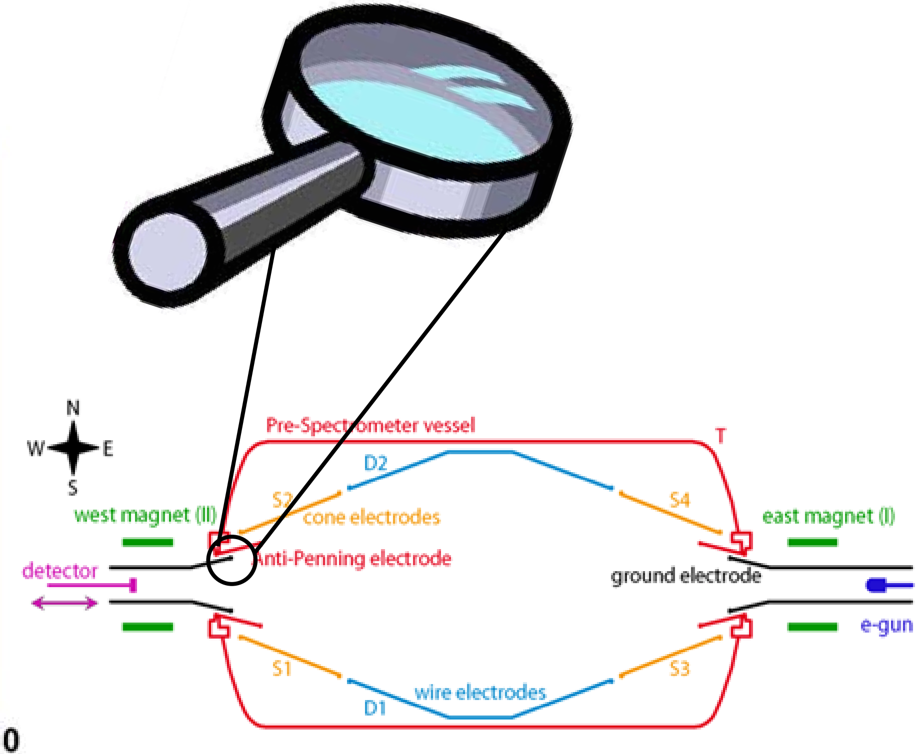
2nd Example: Special shaped ground electrode



Background at prespectrometer

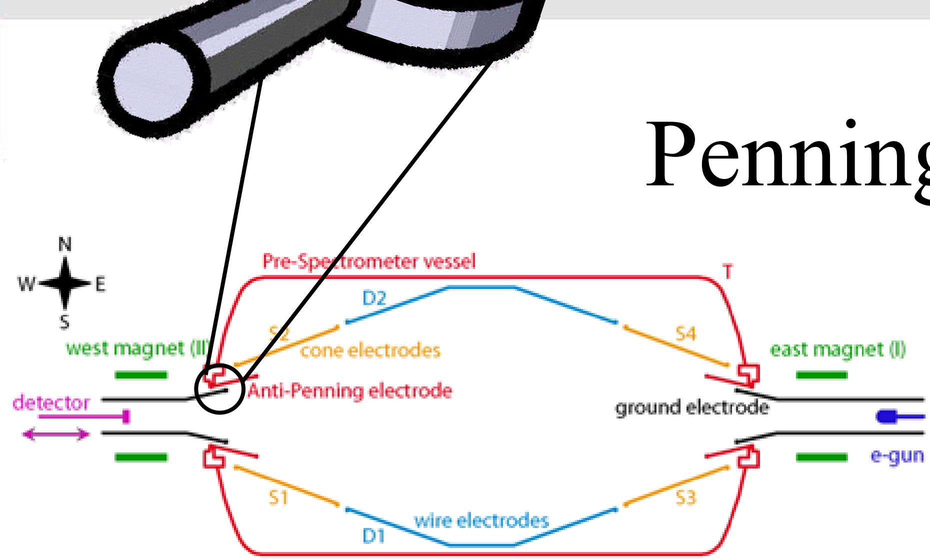


Full magnetic field
Full electric potential

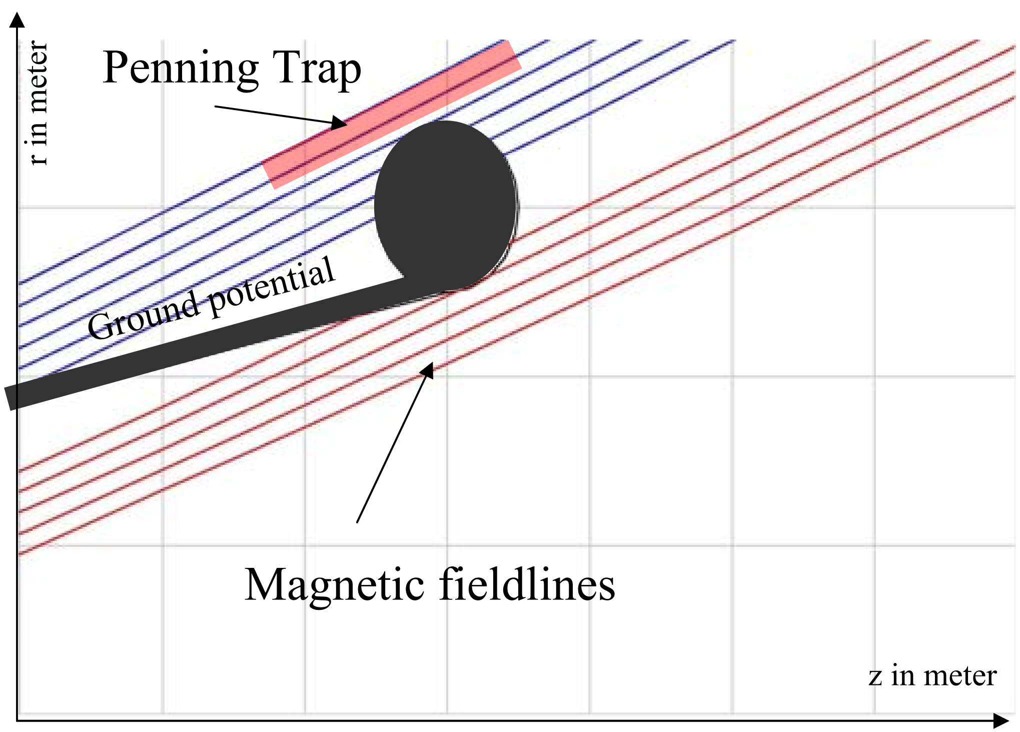


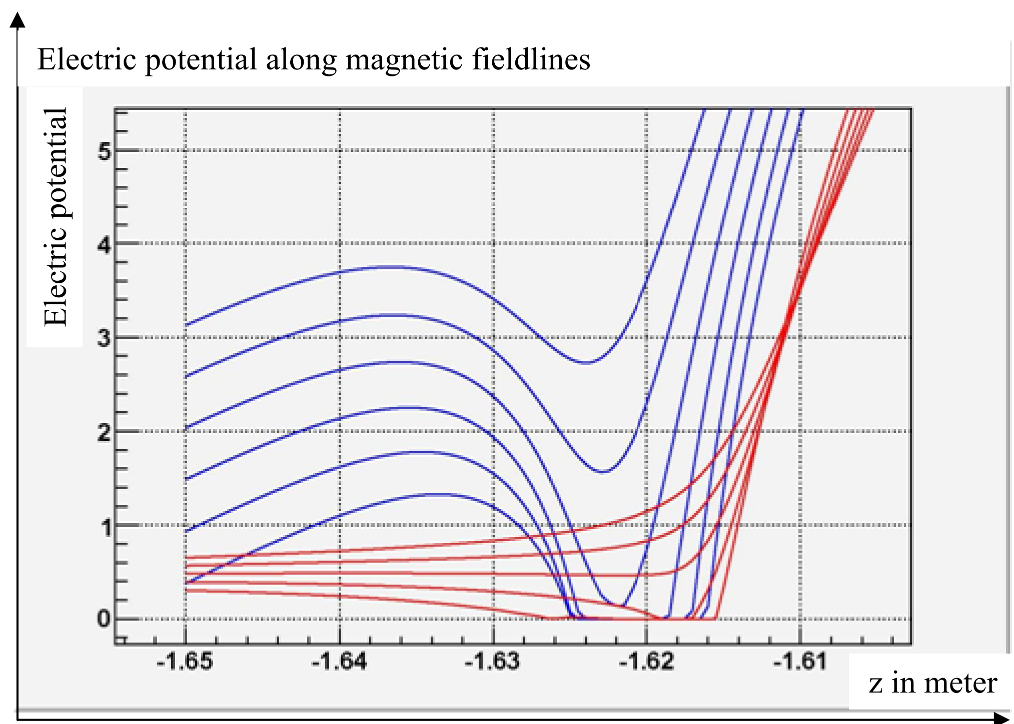
Reason for background: Tiny penning trap at exit/entrance of pre-spectrometer

Penning Trap



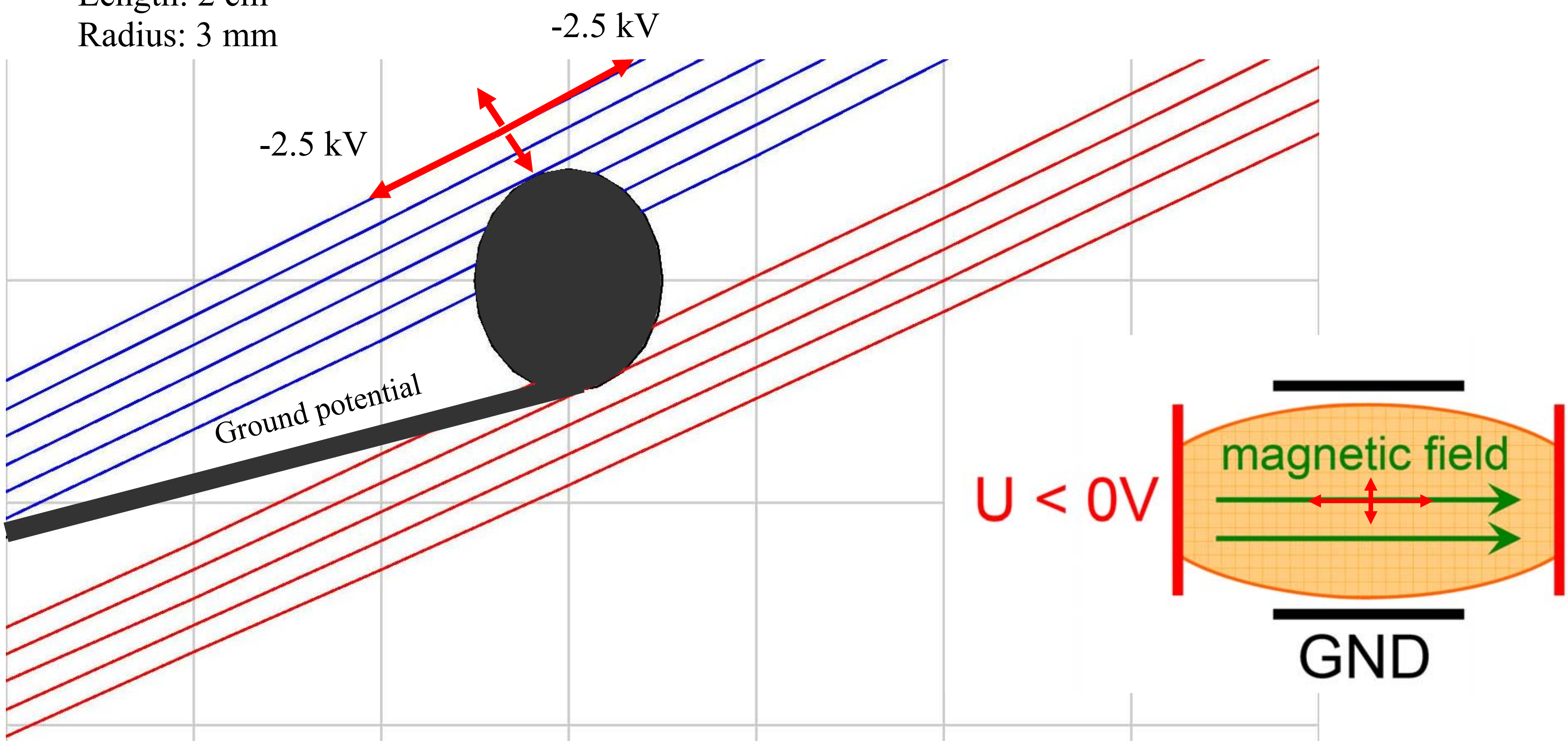
Simulation:





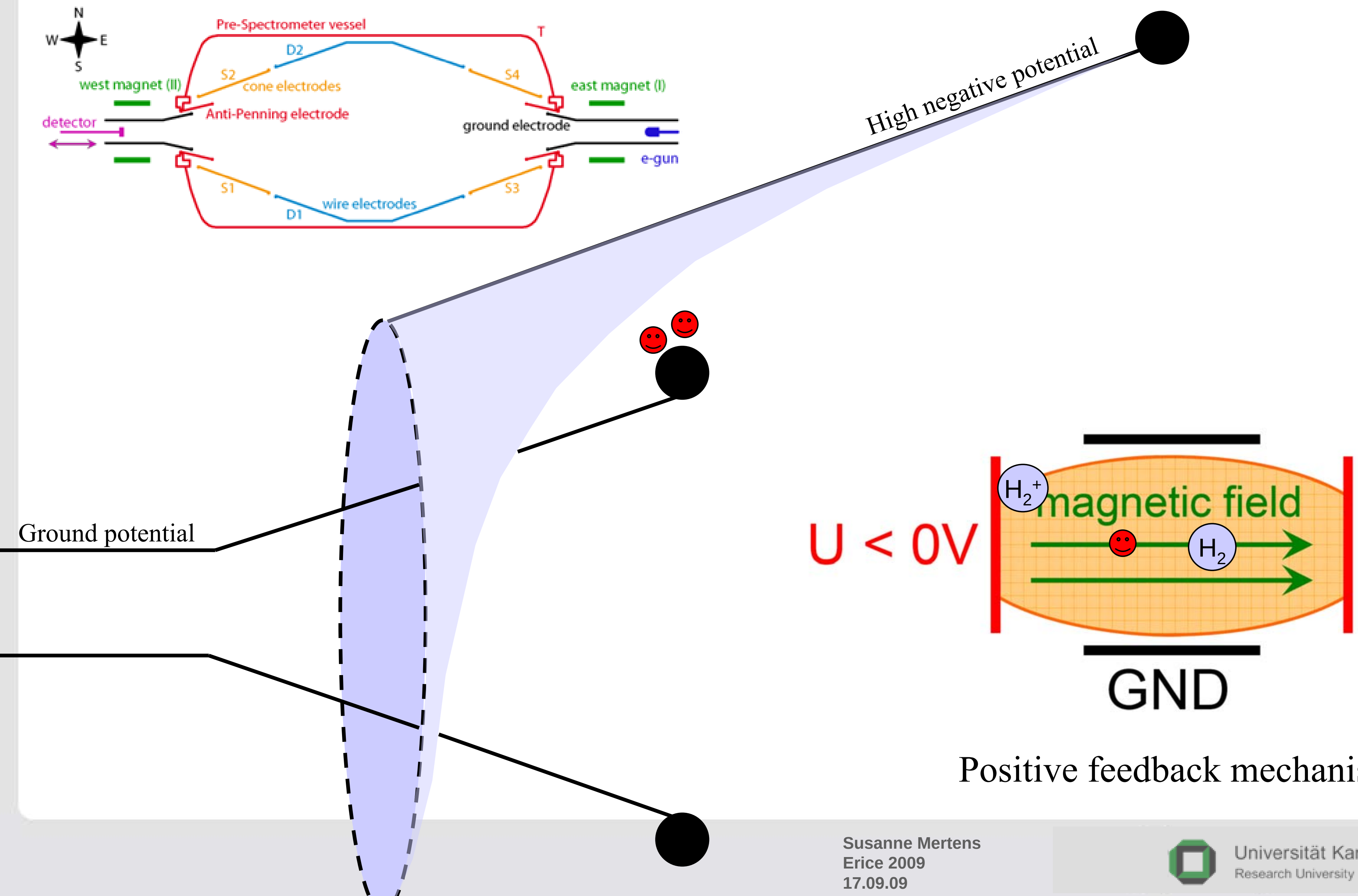
Penning Trap

Length: 2 cm
Radius: 3 mm



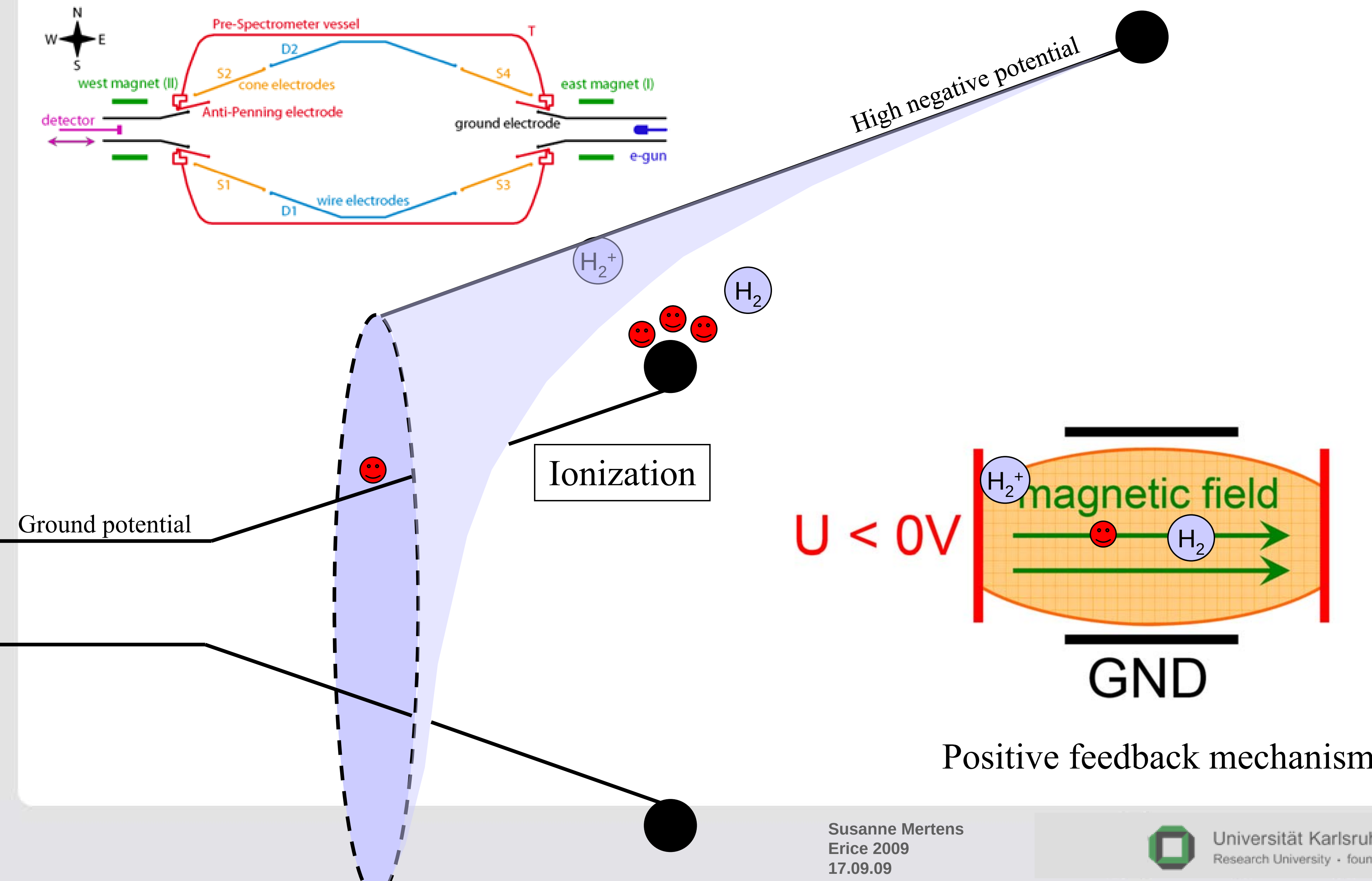
- How is the penning trap filled ?
- How does the penning trap produce background ?

How this Penning trap is filled



Positive feedback mechanism

How this Penning trap is filled



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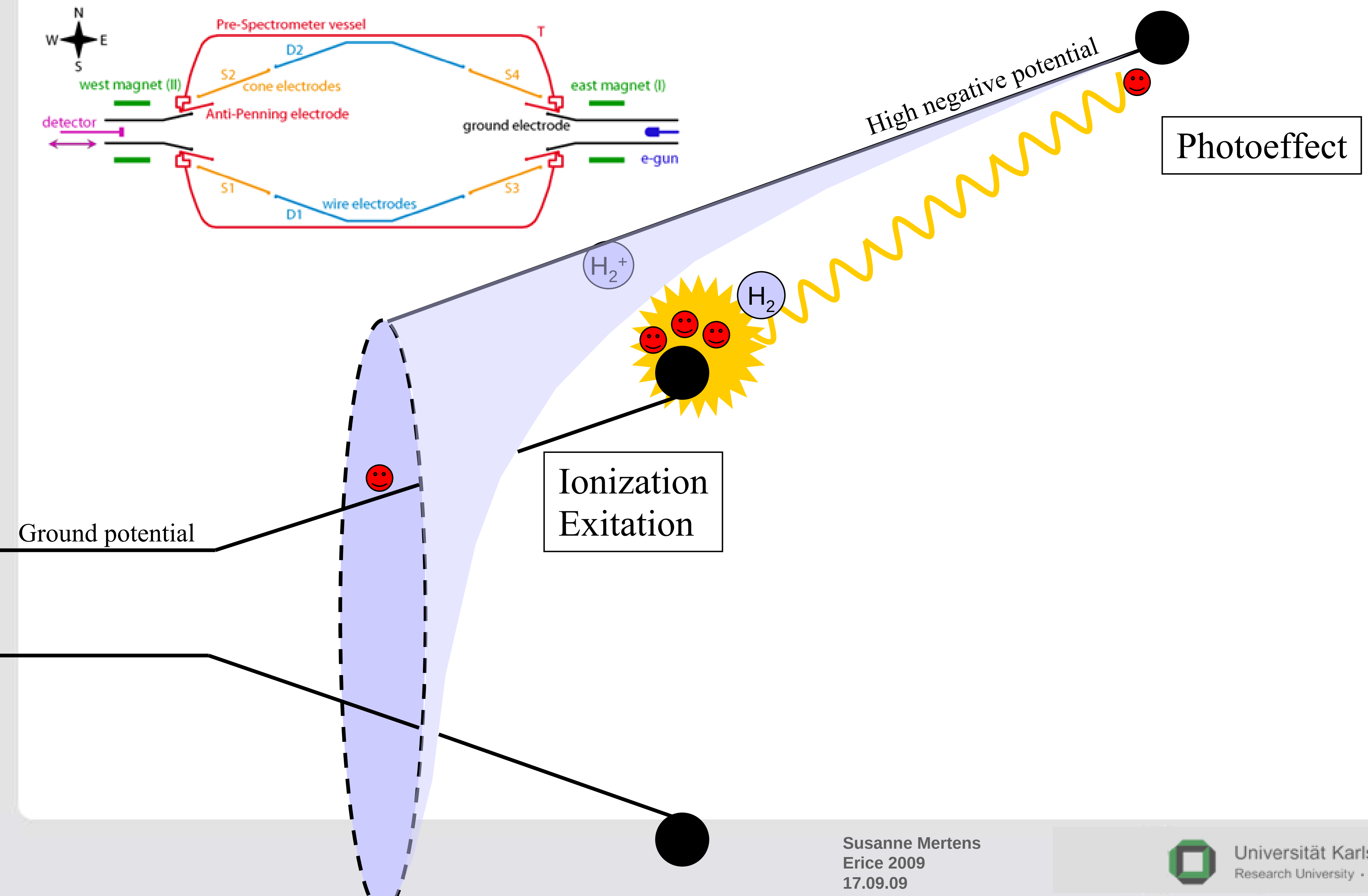

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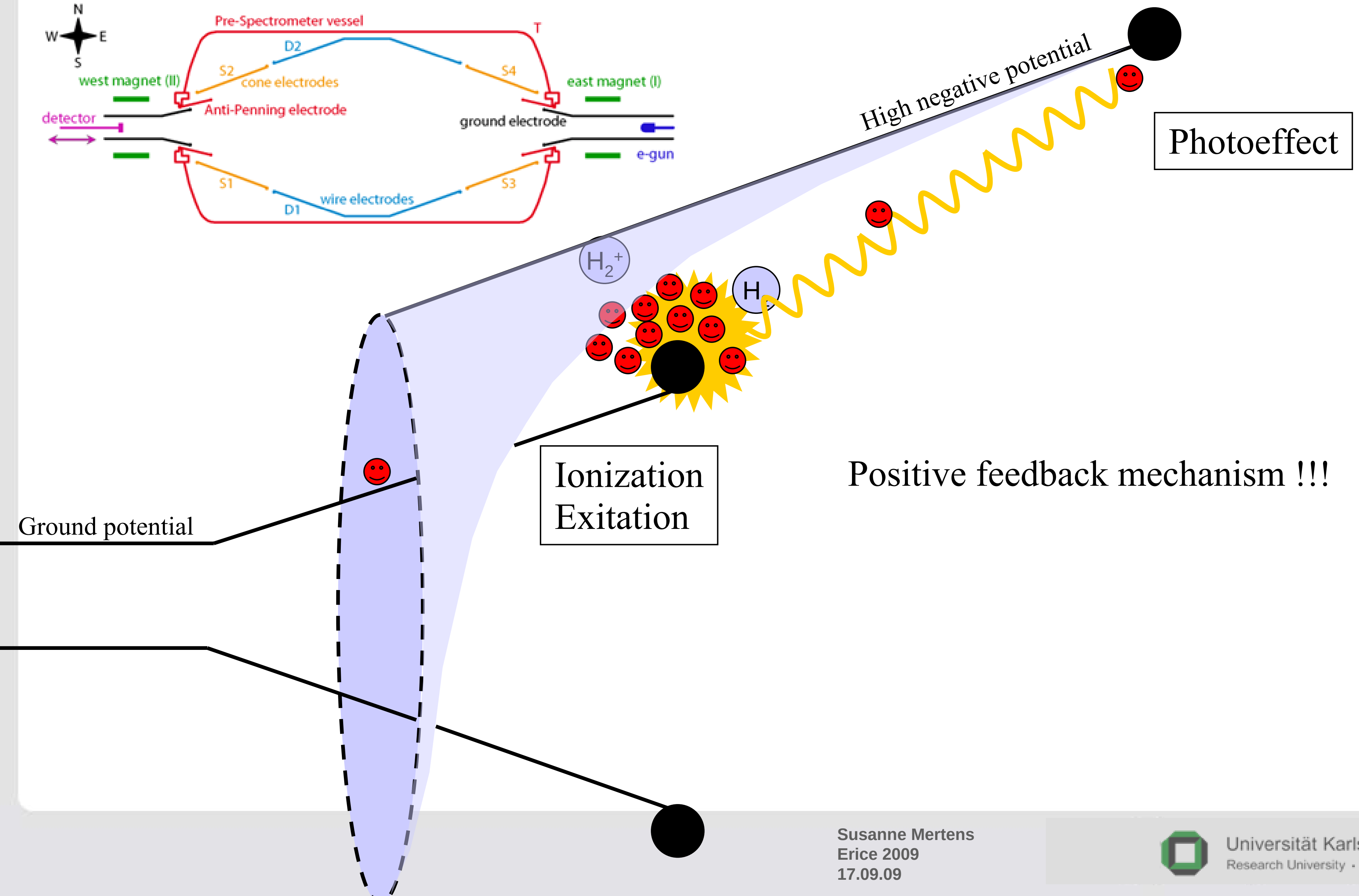
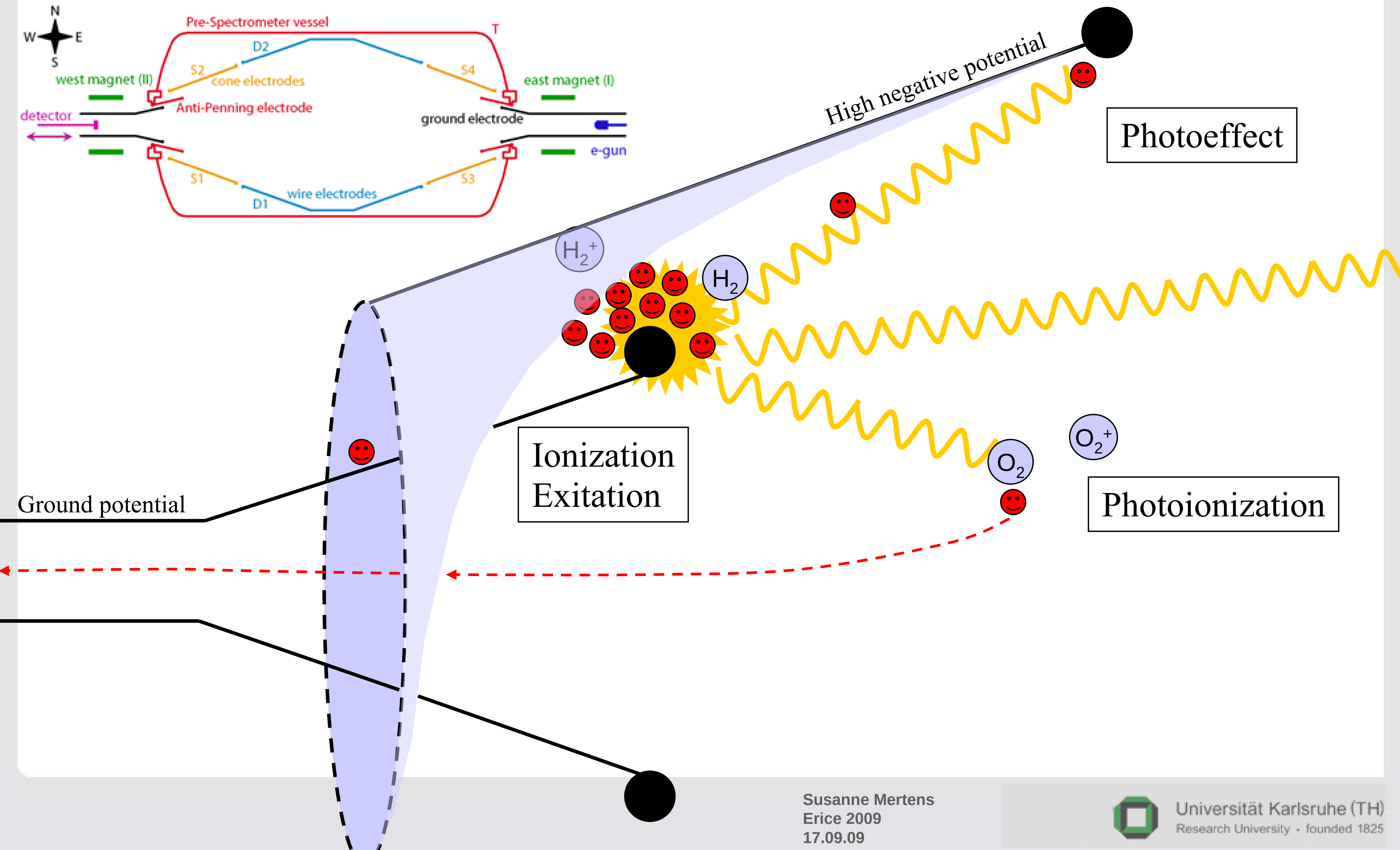


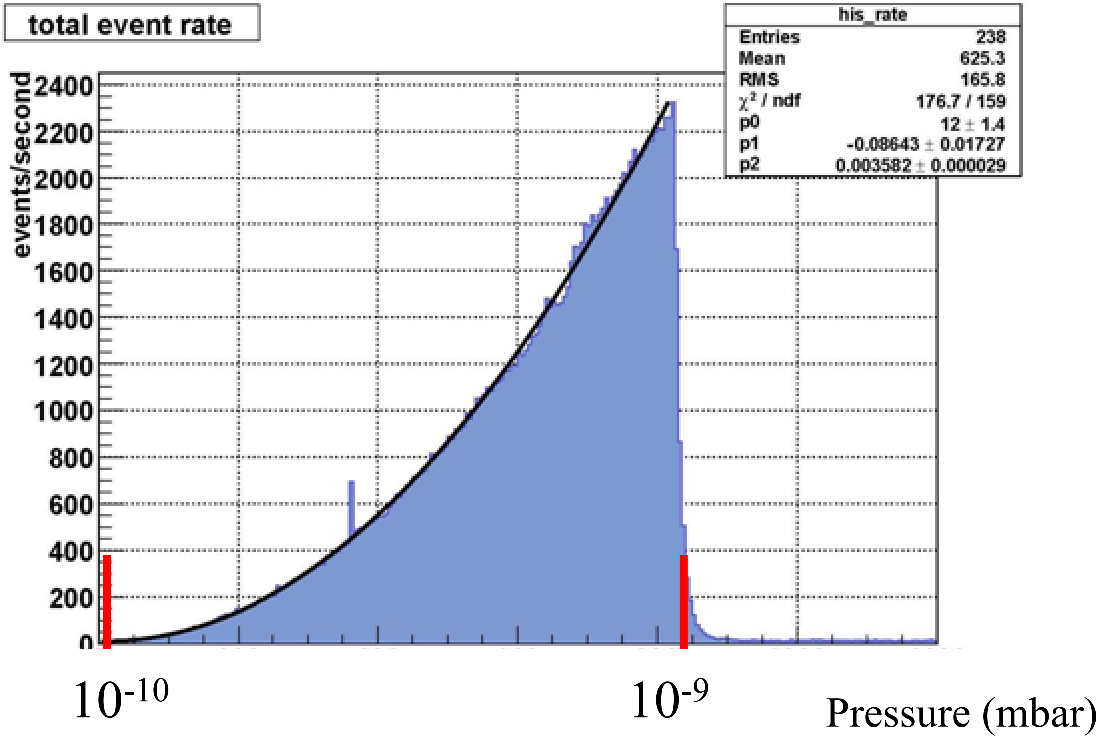
Positive feedback mechanism !!!

How this Penning trap produces background

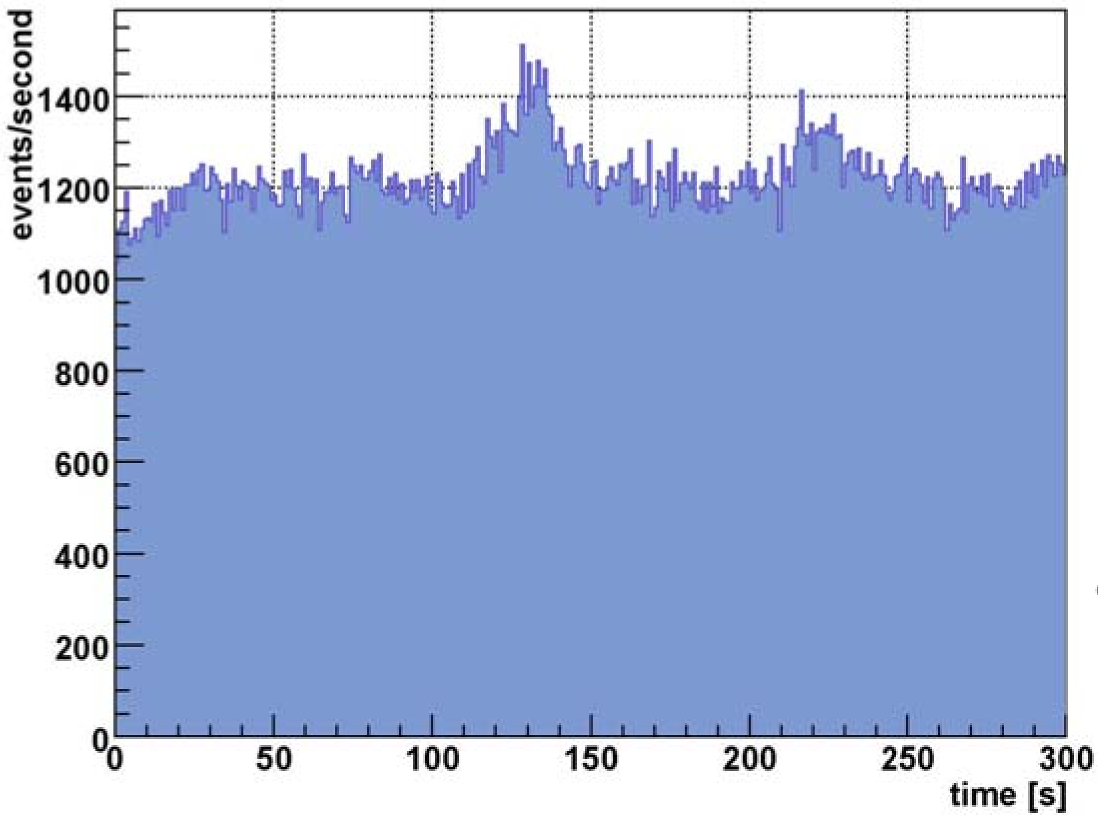


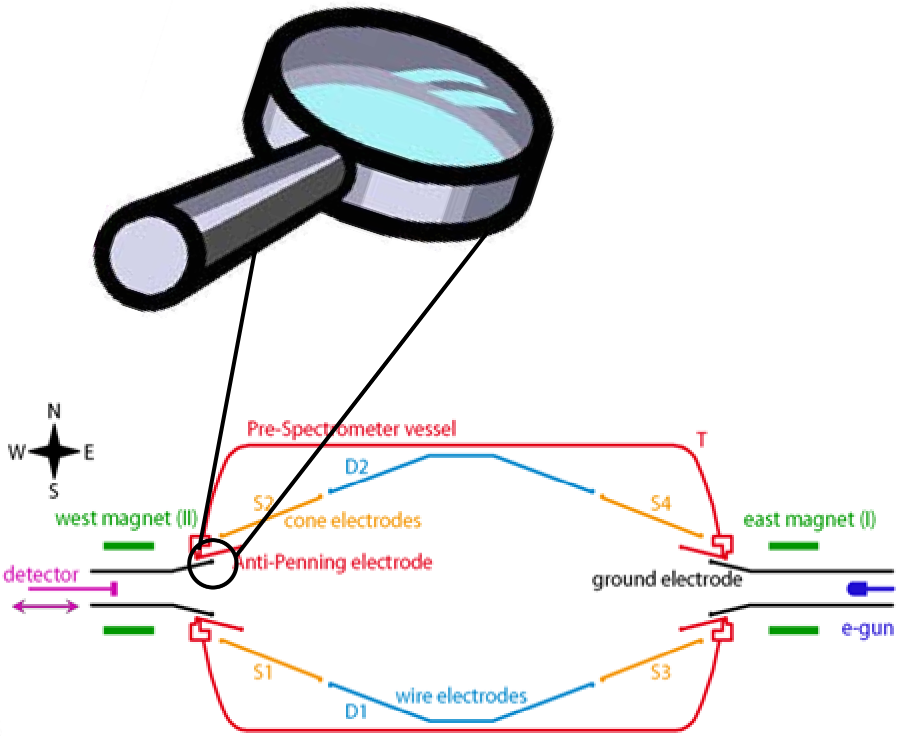
Pressure dependence

- Both filling mechanism and background production depend on pressure
- We expect a quadratic dependence on pressure



How to get rid of the background

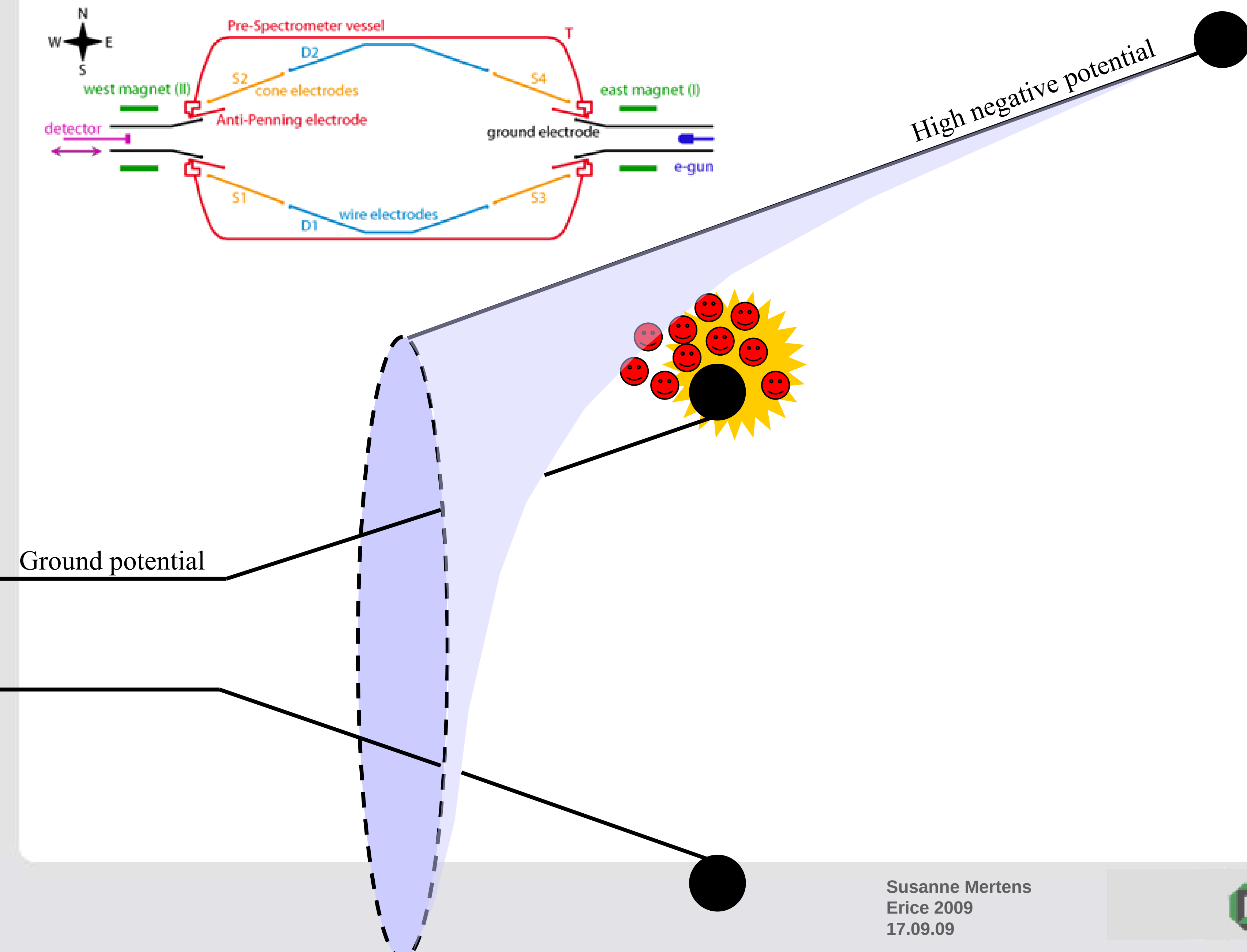




Full magnetic field
Full electric potential

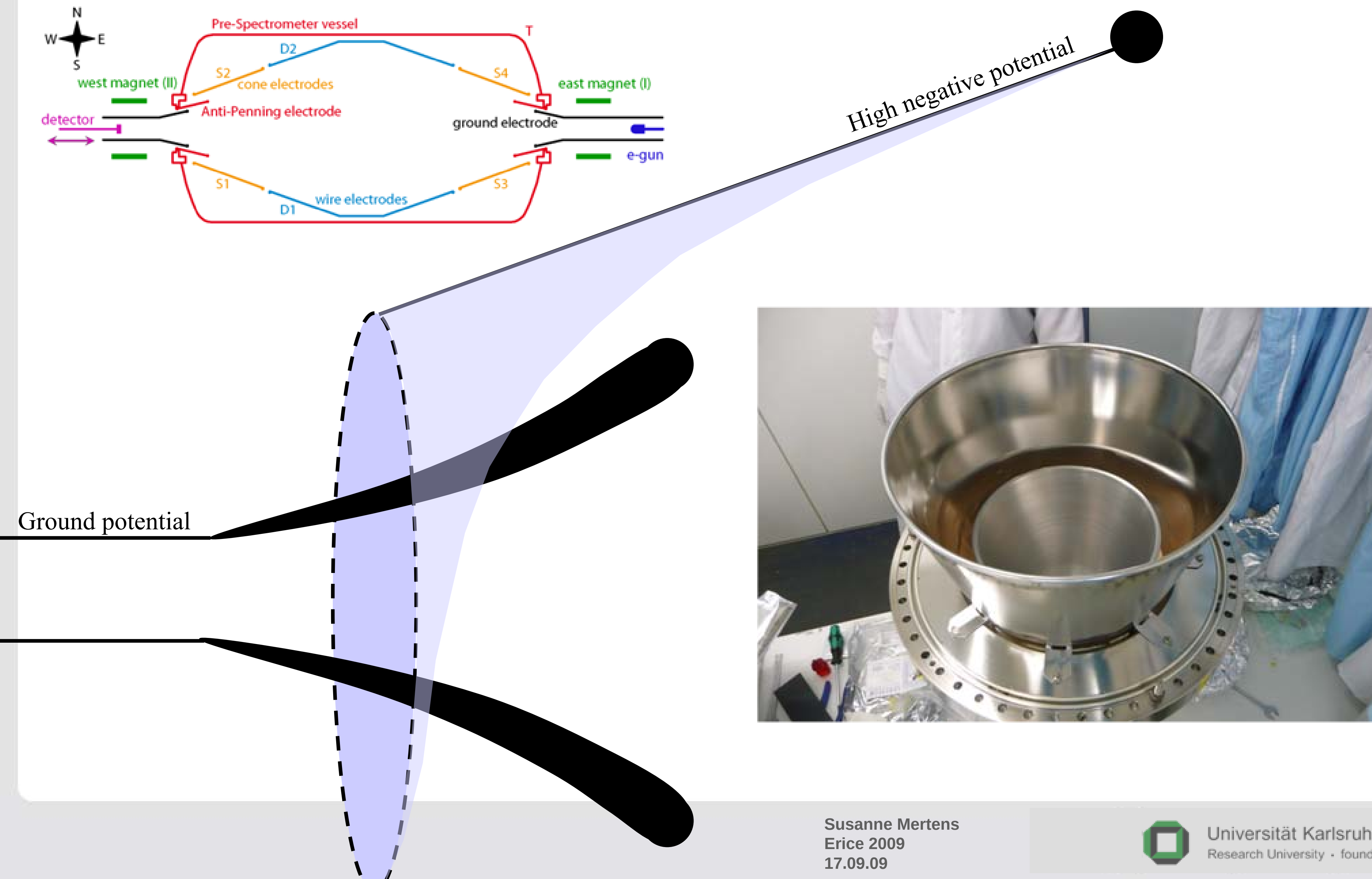
Solution: Remove penning trap with new specially shaped ground electrode

Technical realization



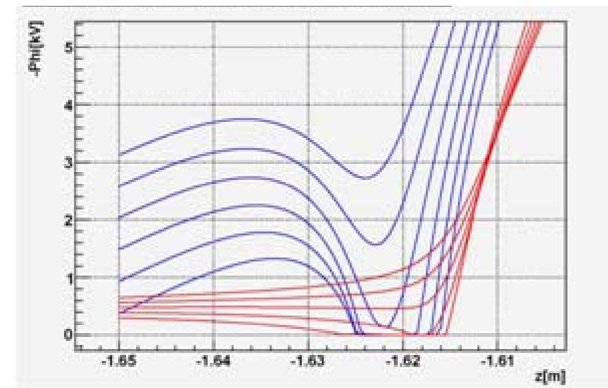
Karlsruhe Institute of Technology

Technical realization

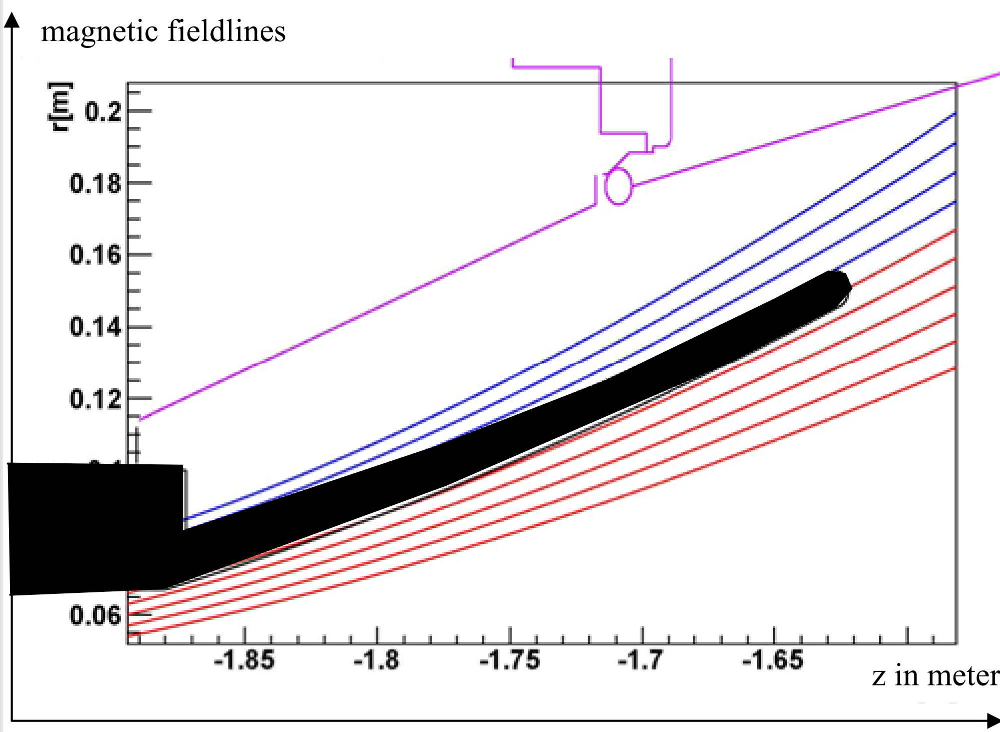


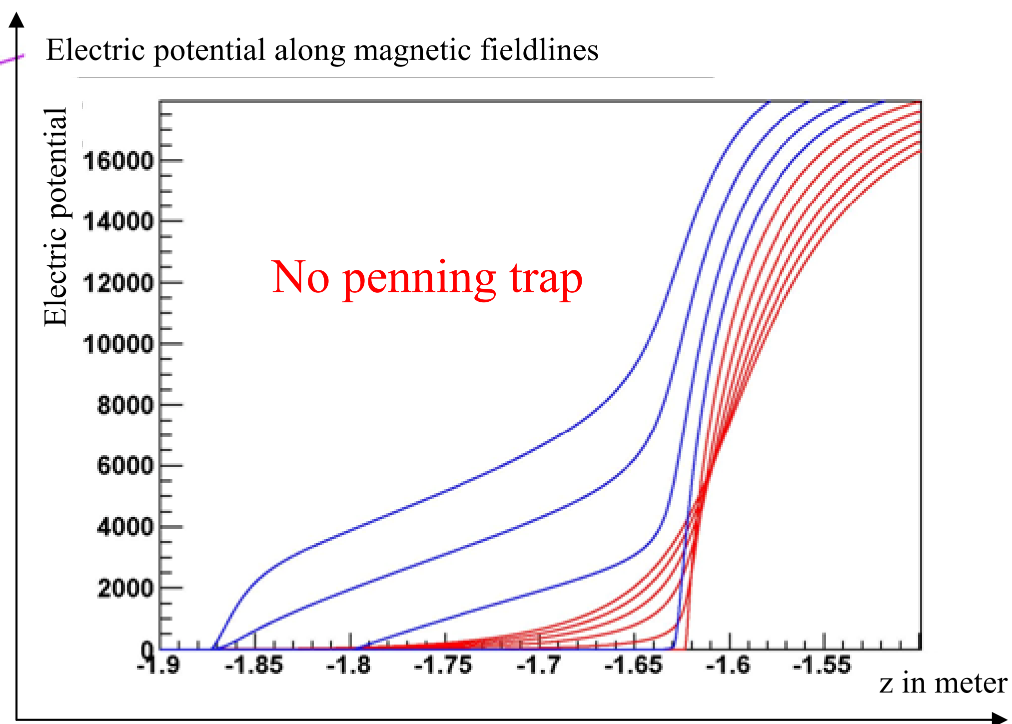
Technical realization

Before

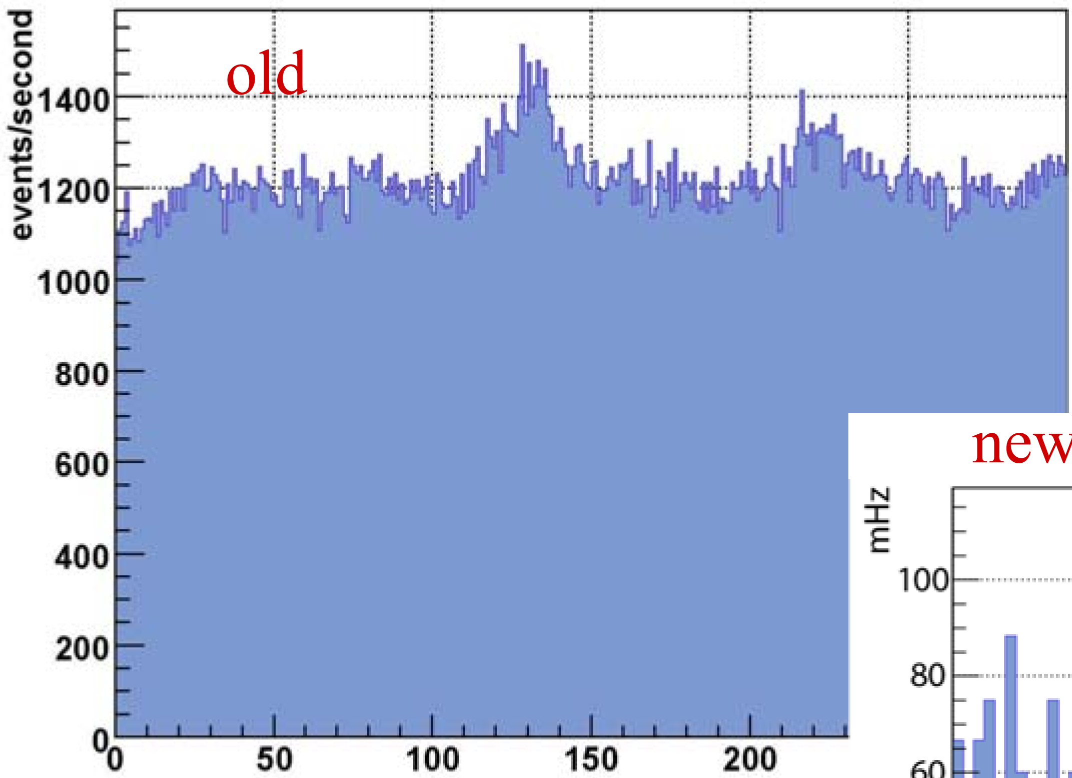


Simulation:





Result

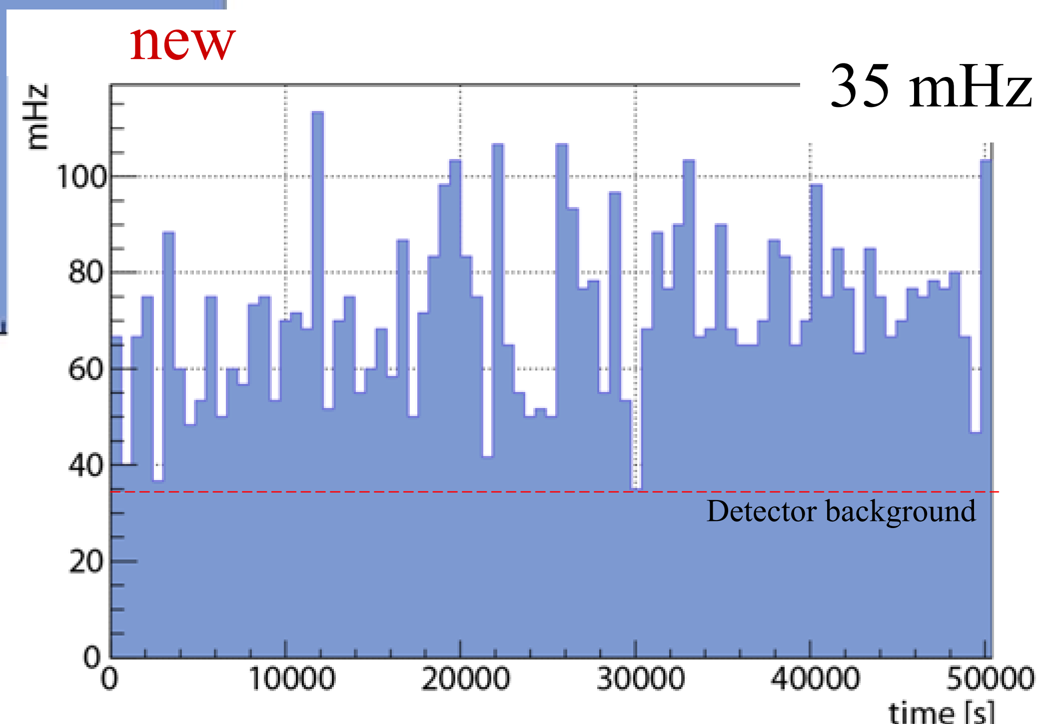


Full magnetic field
Full electric potential

1 kHz

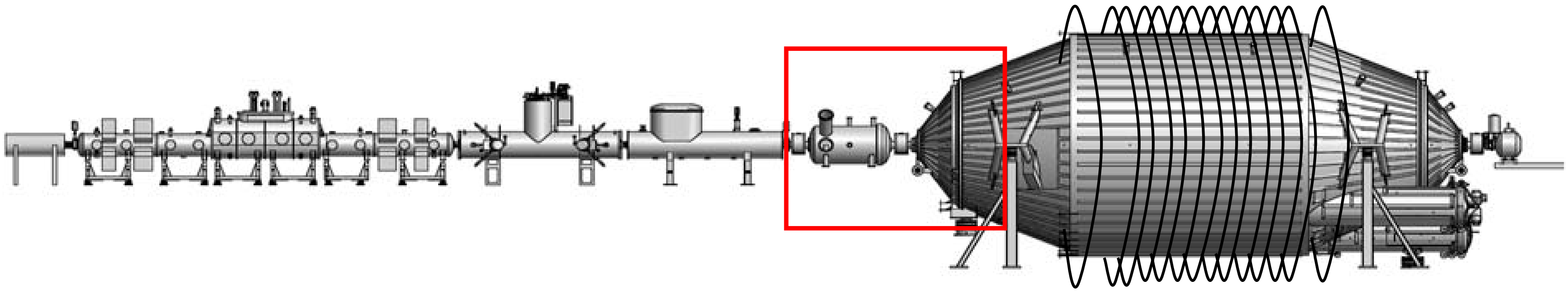
Factor: 30 000

35 mHz



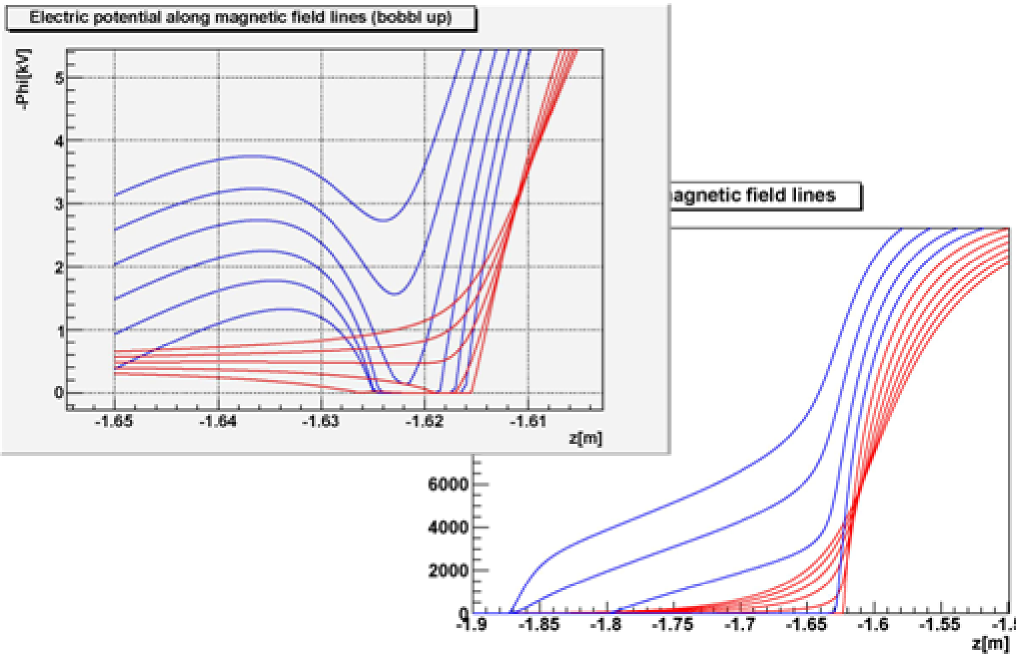
Full magnetic field
Full electric potential

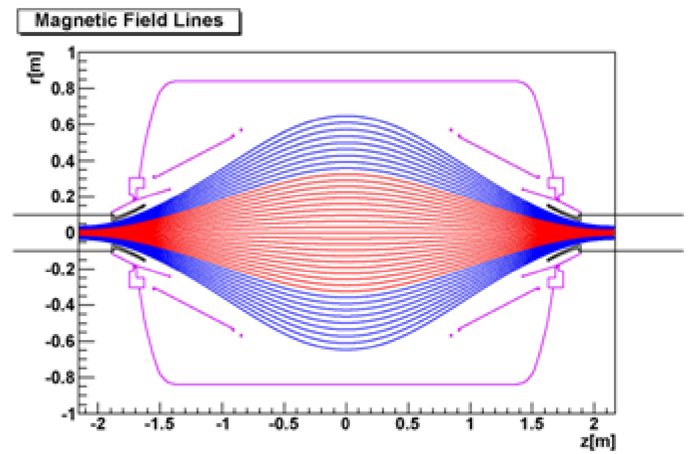
Conclusion and Outlook (I)



- By removing all penning traps we reach the desired background level: O(10 mHz)
- Prespectrometer is ready to be implemented in the whole setup
- Low background is expected for the main spectrometer
- Mainspectrometer test measurements will start next year

Conclusion and Outlook (II)





- Precise simulation is necessary to design hardware components
- Success at prespectrometer = proof of quality of the simulation programs (Ferenc Glück)
- Towards a global simulation (including all KATRIN components, e.g. Source (talk of Wolfang Käfer))

Summary

- Why do we have electric and magnetic fields in the KATRIN experiment?
  - Electric potential used as high energy electron filter
  - Magnetic field used guiding system and to transform energy

- What is the challenge of the electromagnetic design?
  - Realize MAC-E-Filter in optimal way
  - Reduce background

- How is this realized?
  - Aircoil System (good transmission properties, low background)
  - Specially shaped ground electrode (low background)

Thank you for your attention

Thanks to all the pre-spectrometer people:
Florian Fränkle, Florian Habermehl, Ferenc Glück, Michael Zacher, Lutz Bornschein and many others