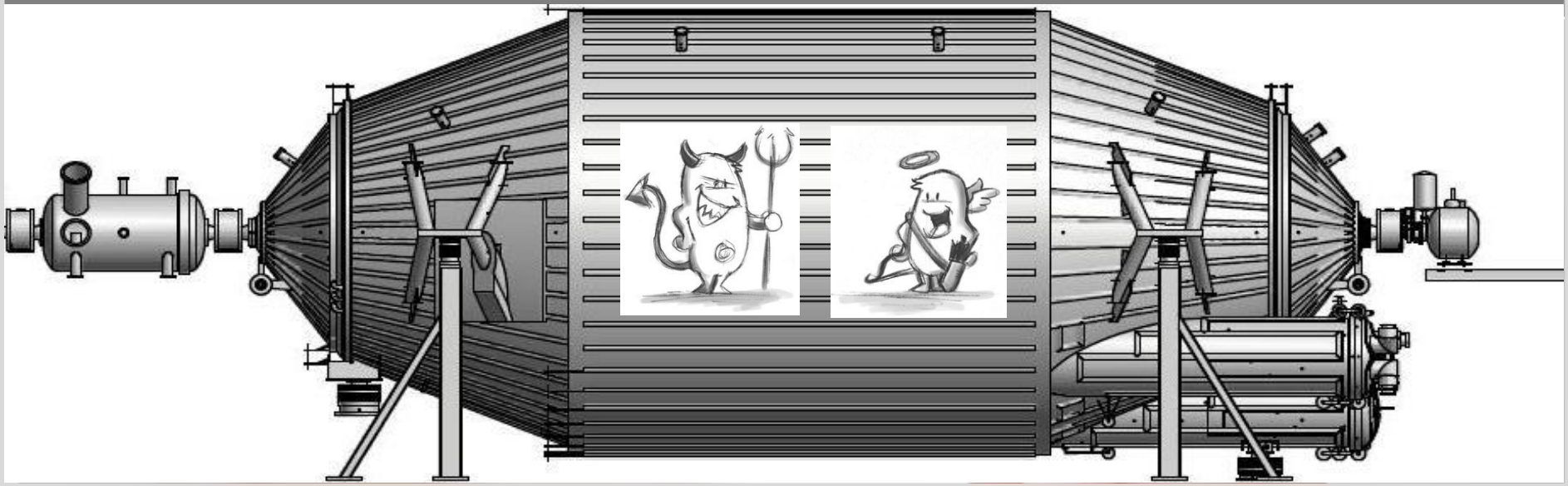
Karlsruhe Institute of Technology

bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

Electrons in the KATRIN main spectrometer – both a blessing and a curse

Nancy Wandkowsky (Institut für Kernphysik, KIT)



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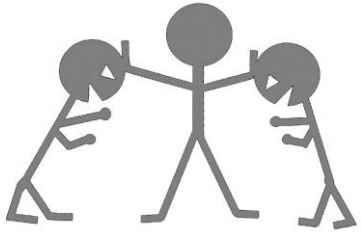
- Introduction
- The blessing: signal electrons

- The curse: background electrons

- The cure: methods to remove background



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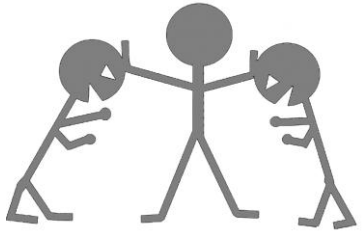
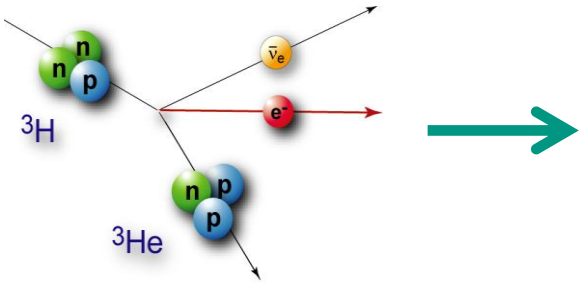
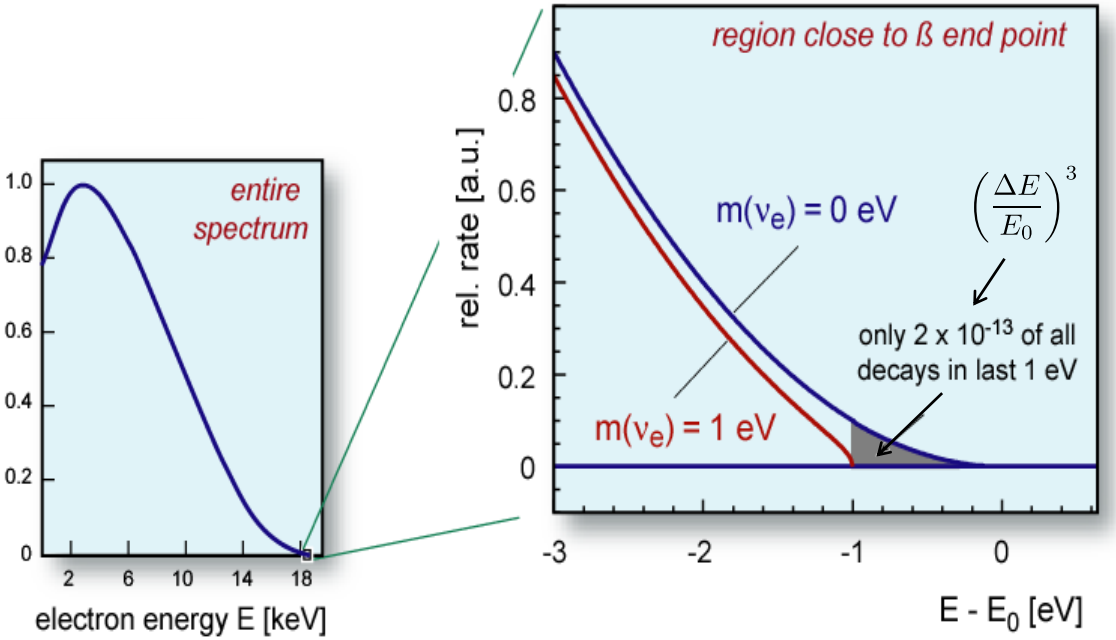


Introduction

kinematics of ß-decay
$\bar{\nu}_e$-mass: m_ν





$m_\nu \neq 0$ impact:

- shift of E_0
- changed shape
- shape to be analysed!

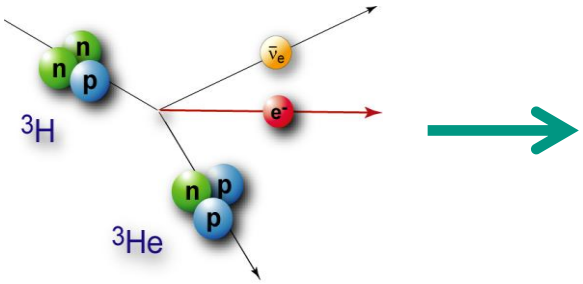
key requirements:

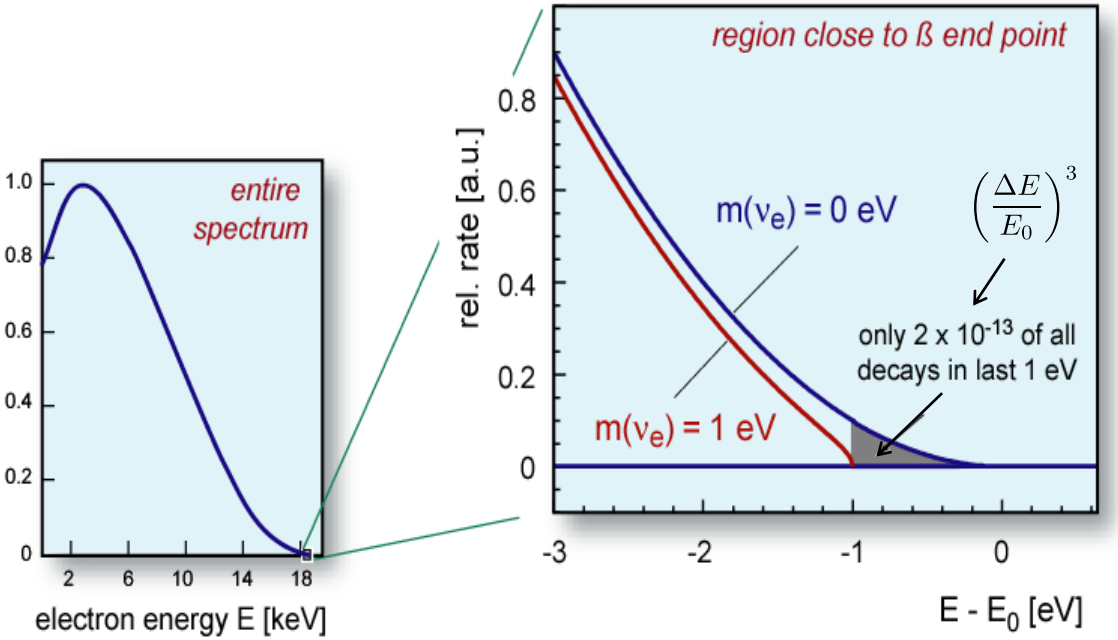
- low endpoint β source
- high count rate
- high energy resolution

- extremely low background (<10^{-2} cps)

Introduction

kinematics of ß-decay
$\bar{\nu}_e$-mass: m_ν





$m_\nu \neq 0$ impact:

- shift of E_0
- changed shape
- shape to be analysed!

→ **$m_\nu < 0.2$ eV (90% CL)**

key requirements:

- low endpoint β source
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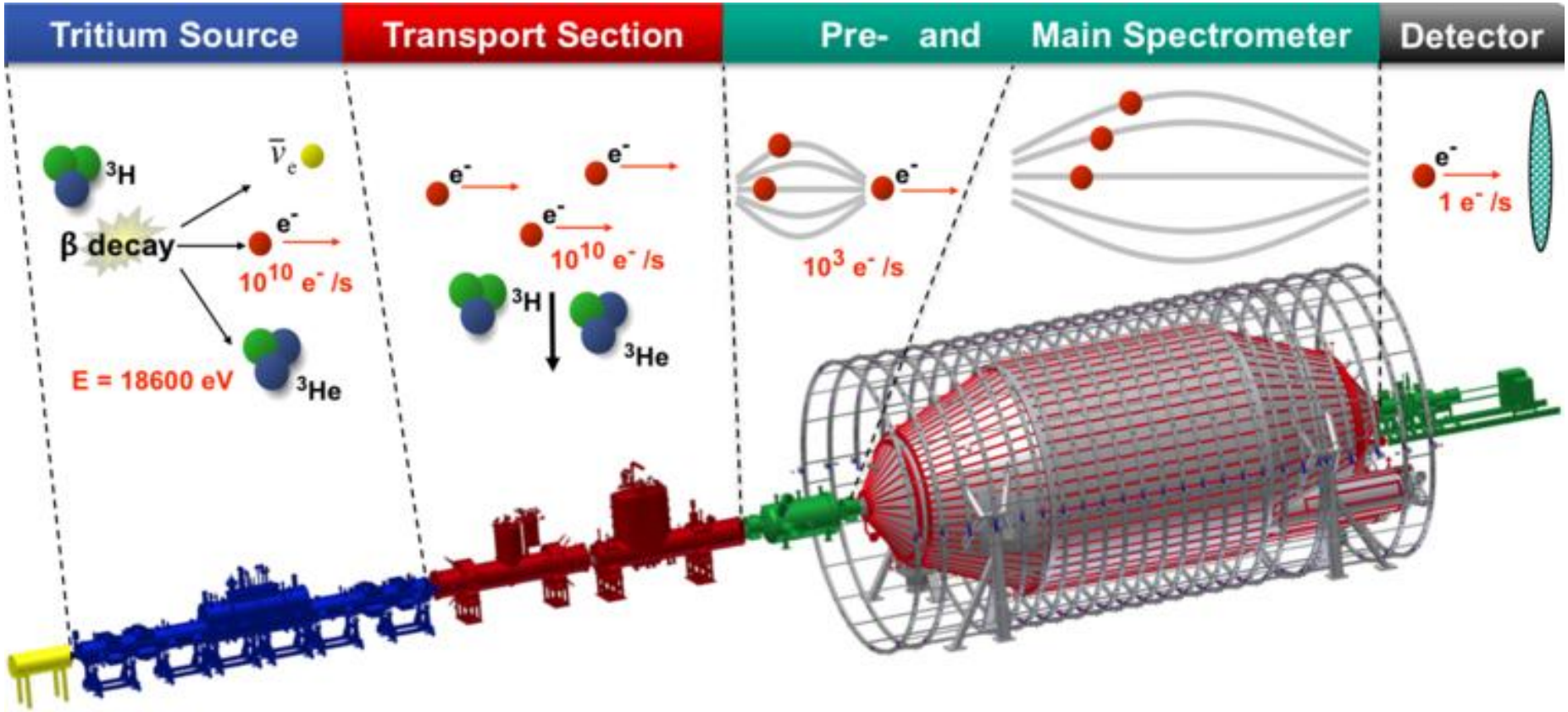
Introduction



Magnetic field guides electrons through the whole experiment!

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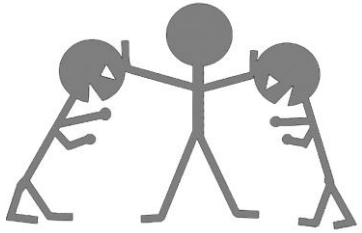
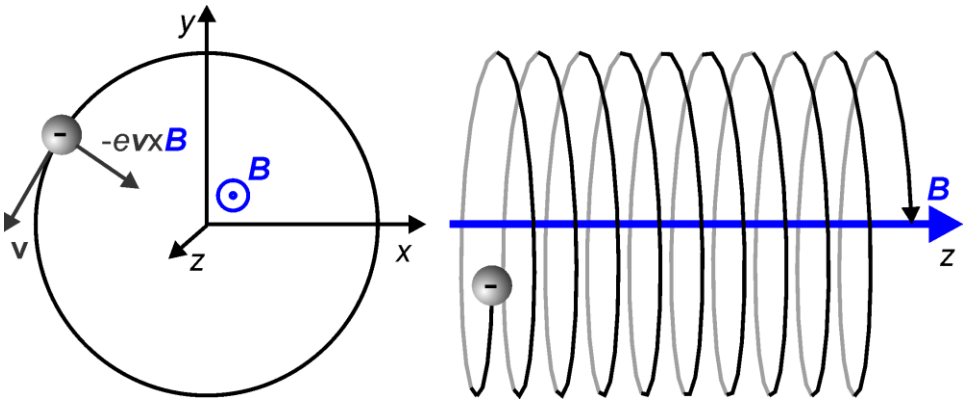


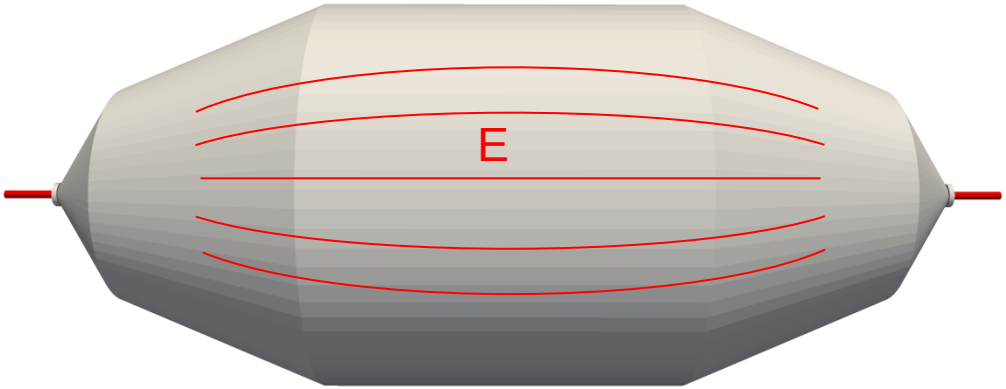
The blessing – signal electrons



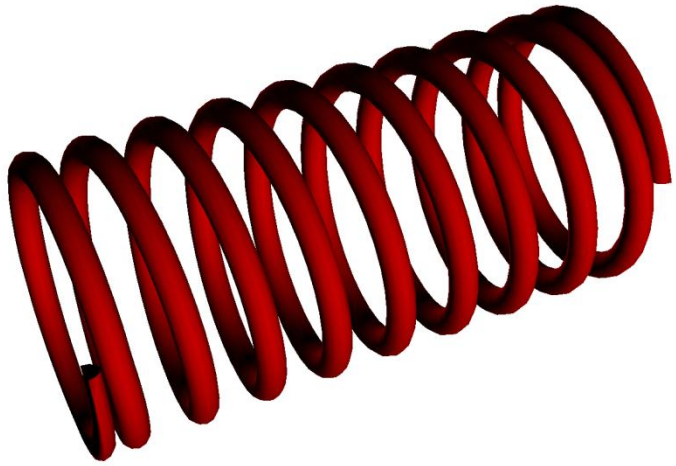
Task
filtering of electrons
according to kinetic energy

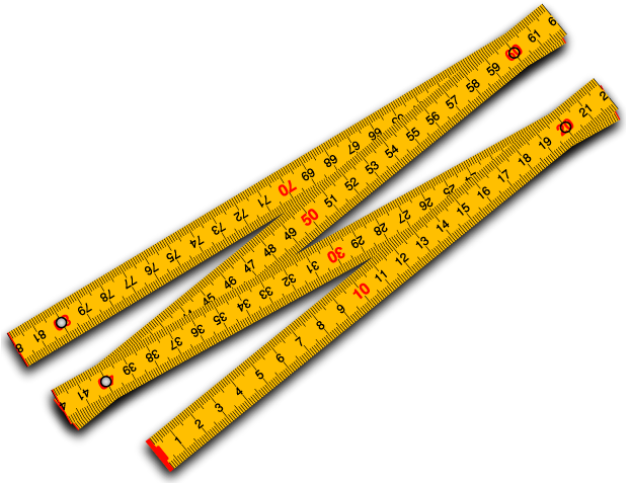
$$E_{kin} = E_{||} + E_{\perp}$$

Tool
electrostatic retarding potential
on spectrometer vessel



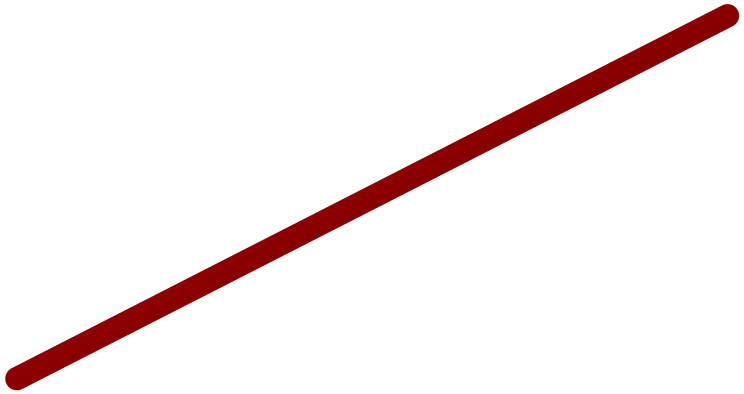
The blessing – signal electrons

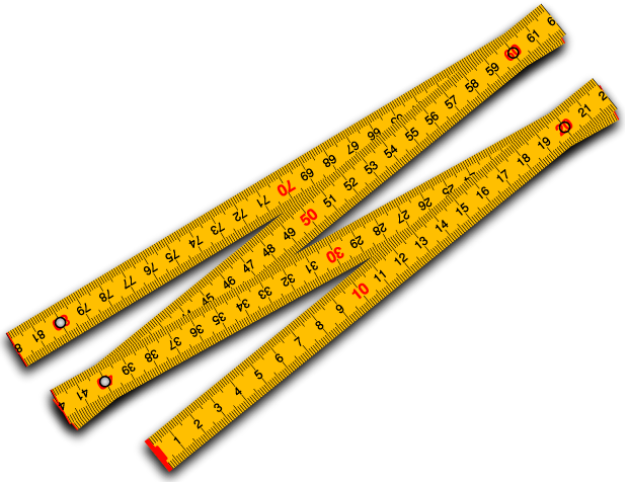




analogous problem: determination of length of spring with ruler

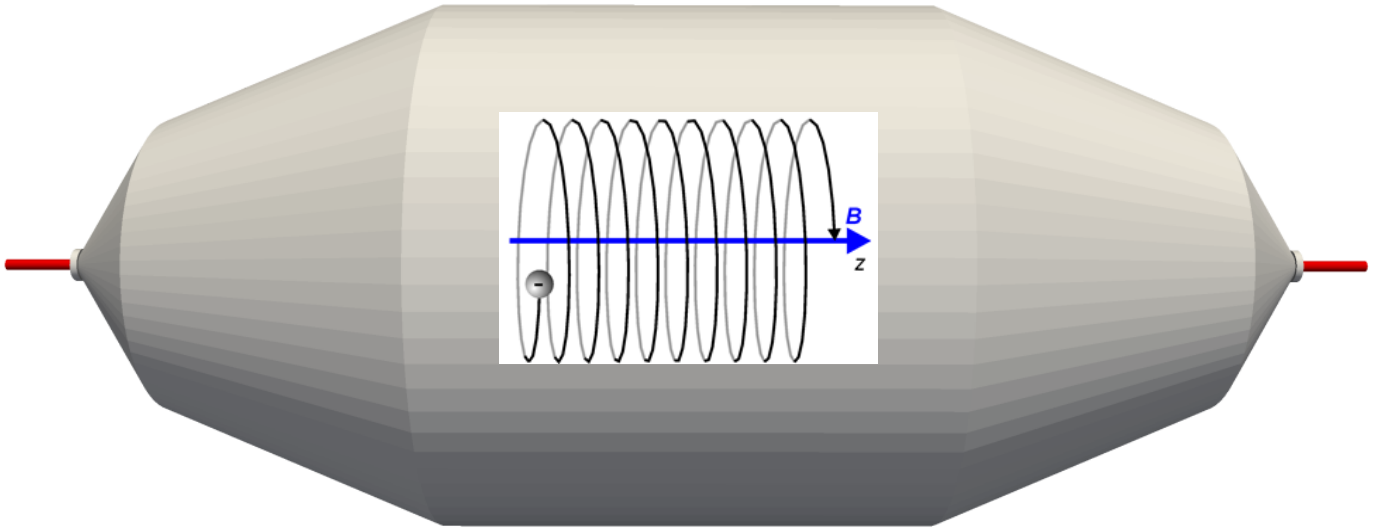
The blessing – signal electrons





solution: force the spring into a straight line

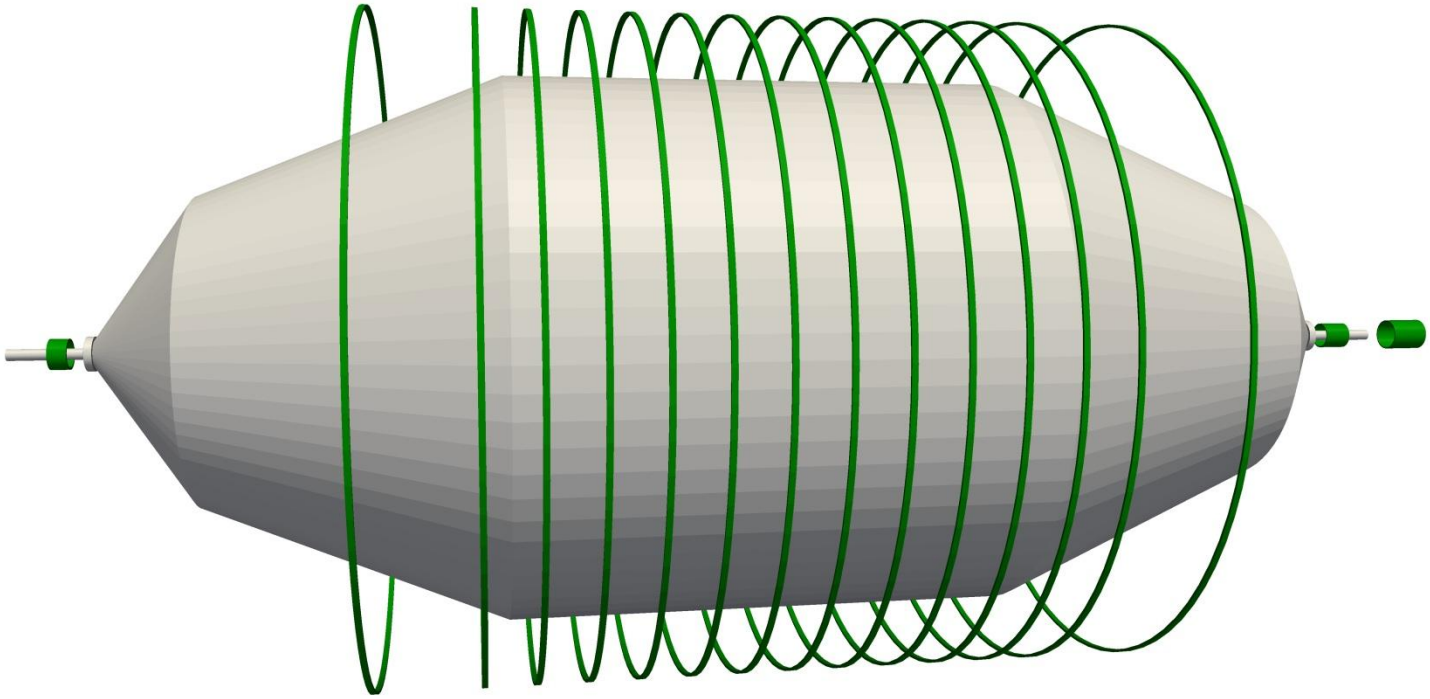
The blessing – signal electrons



The blessing – signal electrons

solution: magnetic gradient exerts force

$$\vec{F} = (\vec{\mu} \cdot \nabla)\, \vec{B}$$



The blessing – signal electrons

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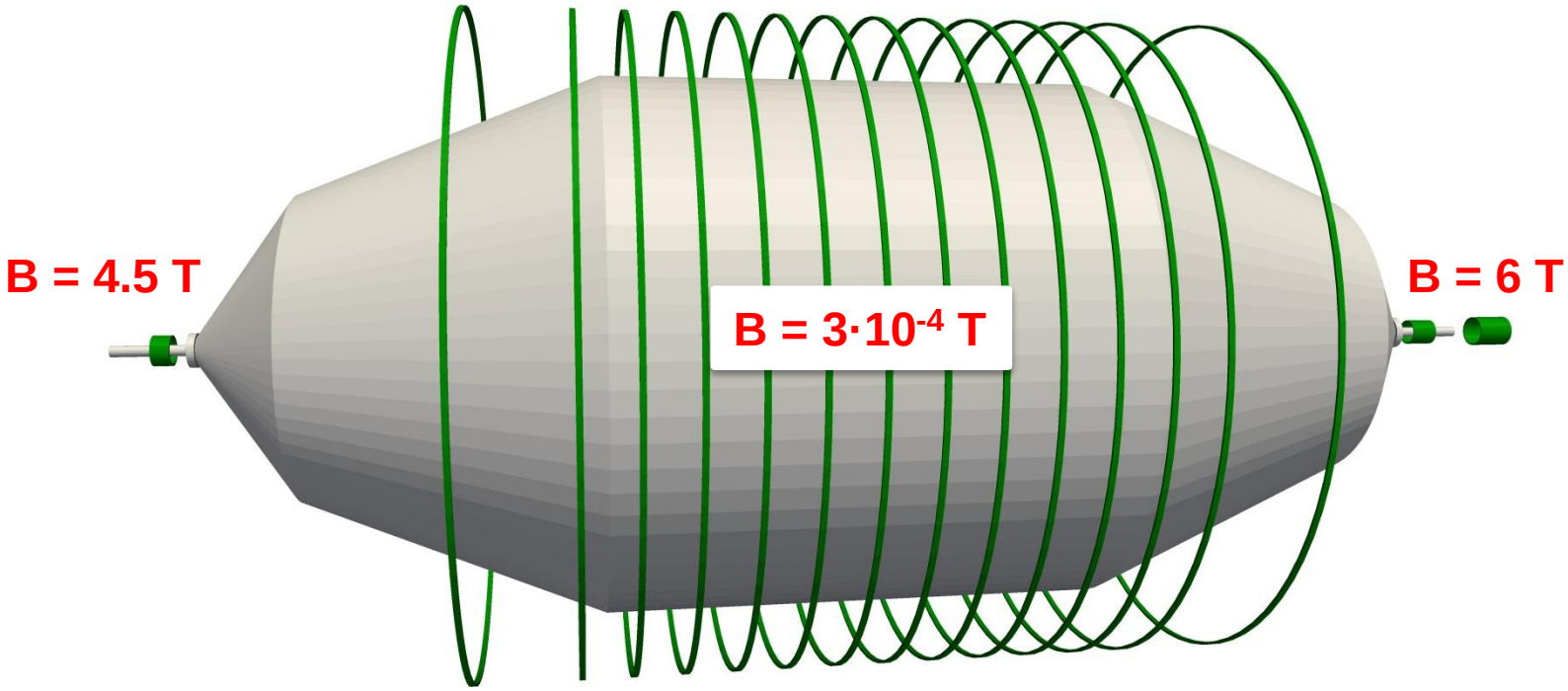
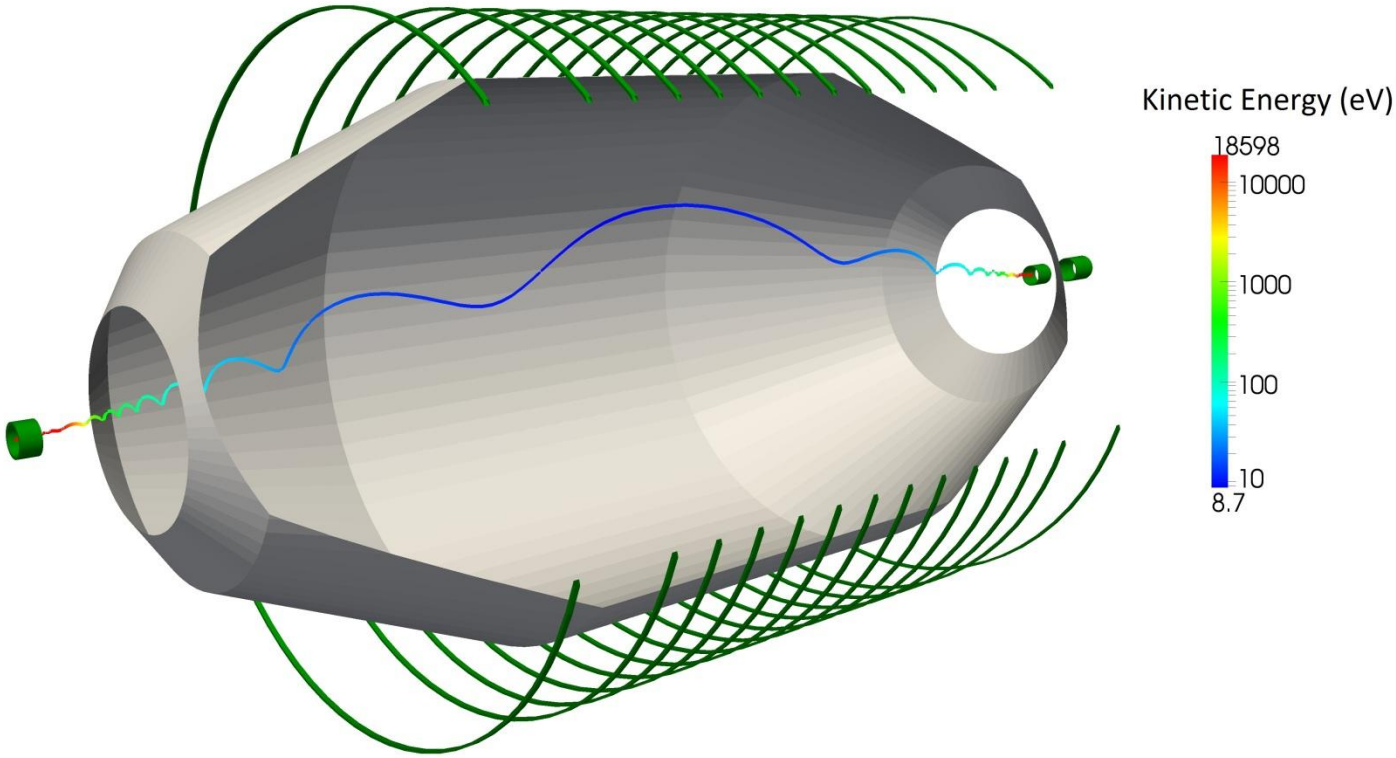


electron momentum

The blessing – signal electrons

solution: magnetic gradient exerts force

$$\vec{F}=(\vec{\mu}\cdot\nabla)\,\vec{B}$$



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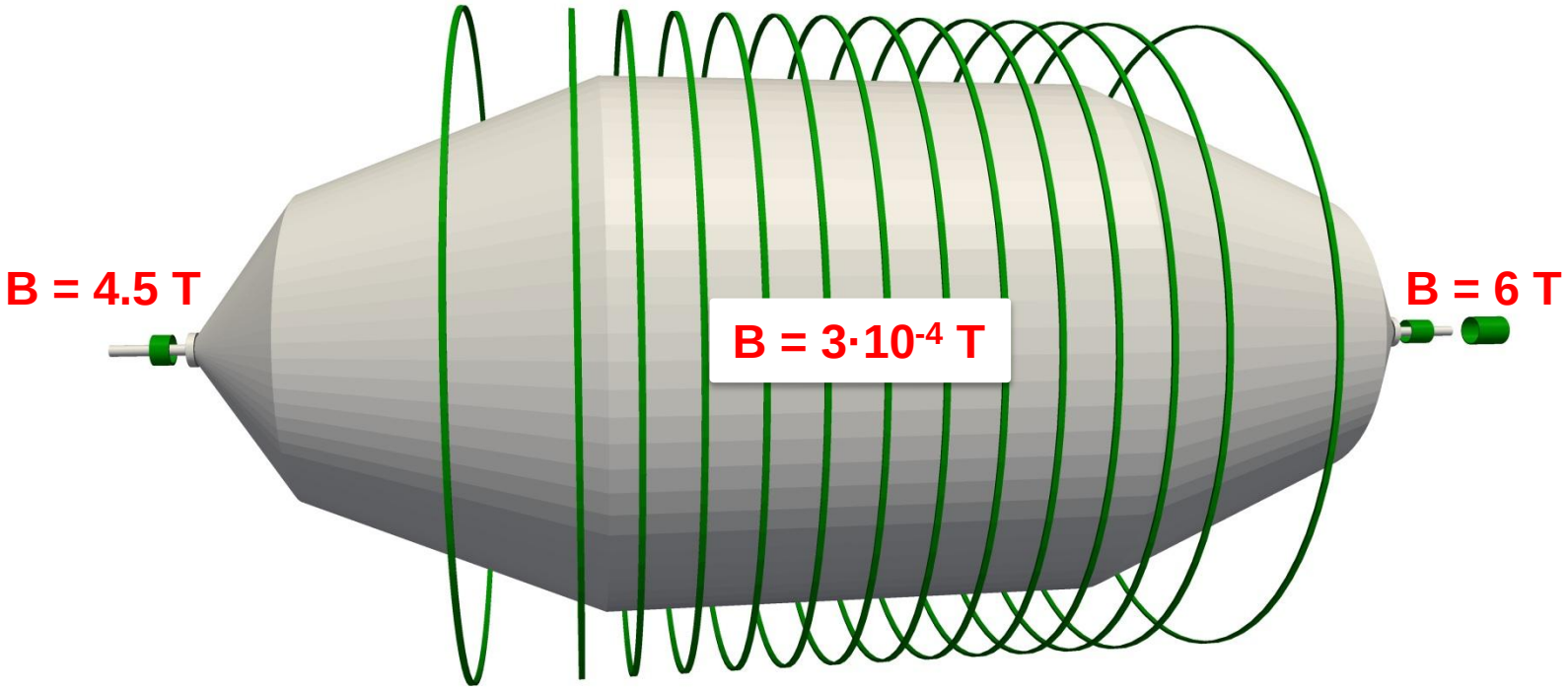


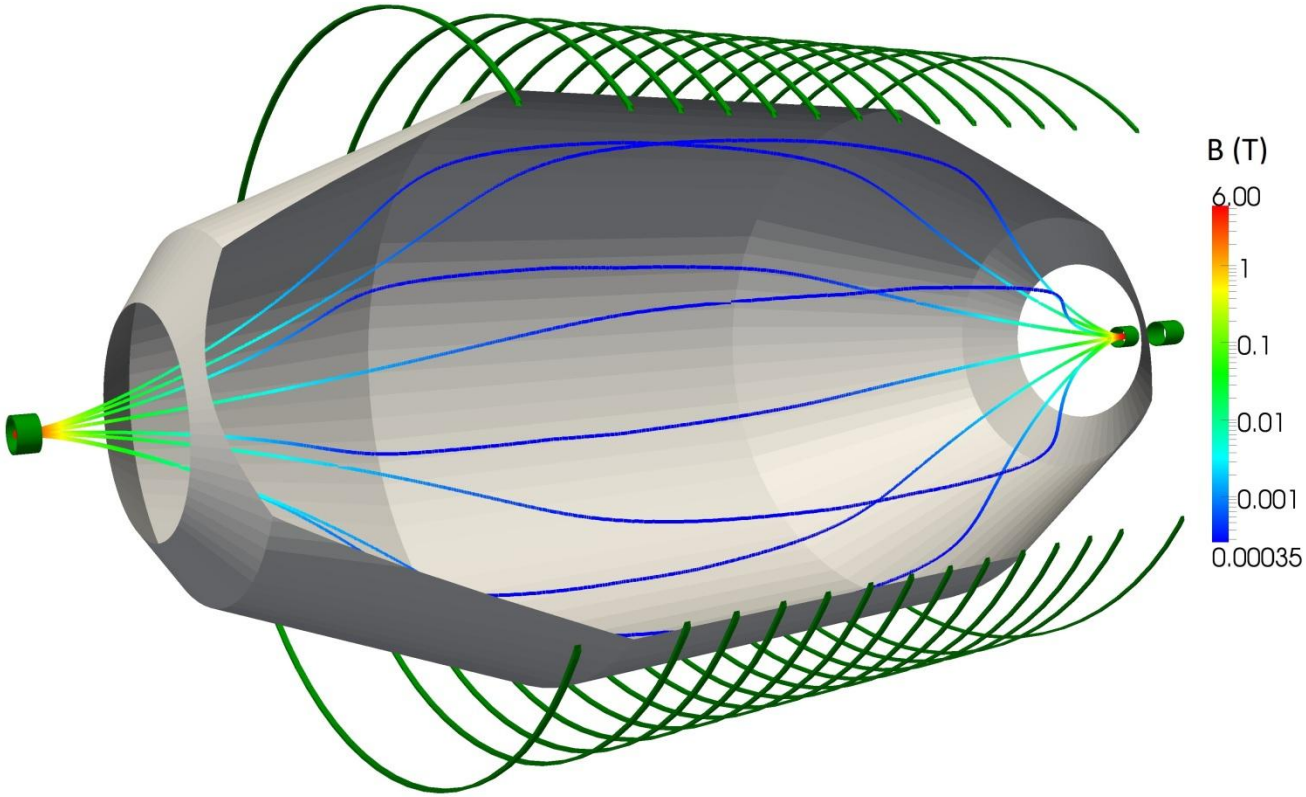
energy resolution:

$$\frac{\Delta E}{E}=\frac{B_{min}}{B_{max}}=\frac{1}{20000}$$

The blessing – signal electrons

solution: magnetic gradient exerts force

$$\vec{F} = (\vec{\mu} \cdot \nabla)\, \vec{B}$$

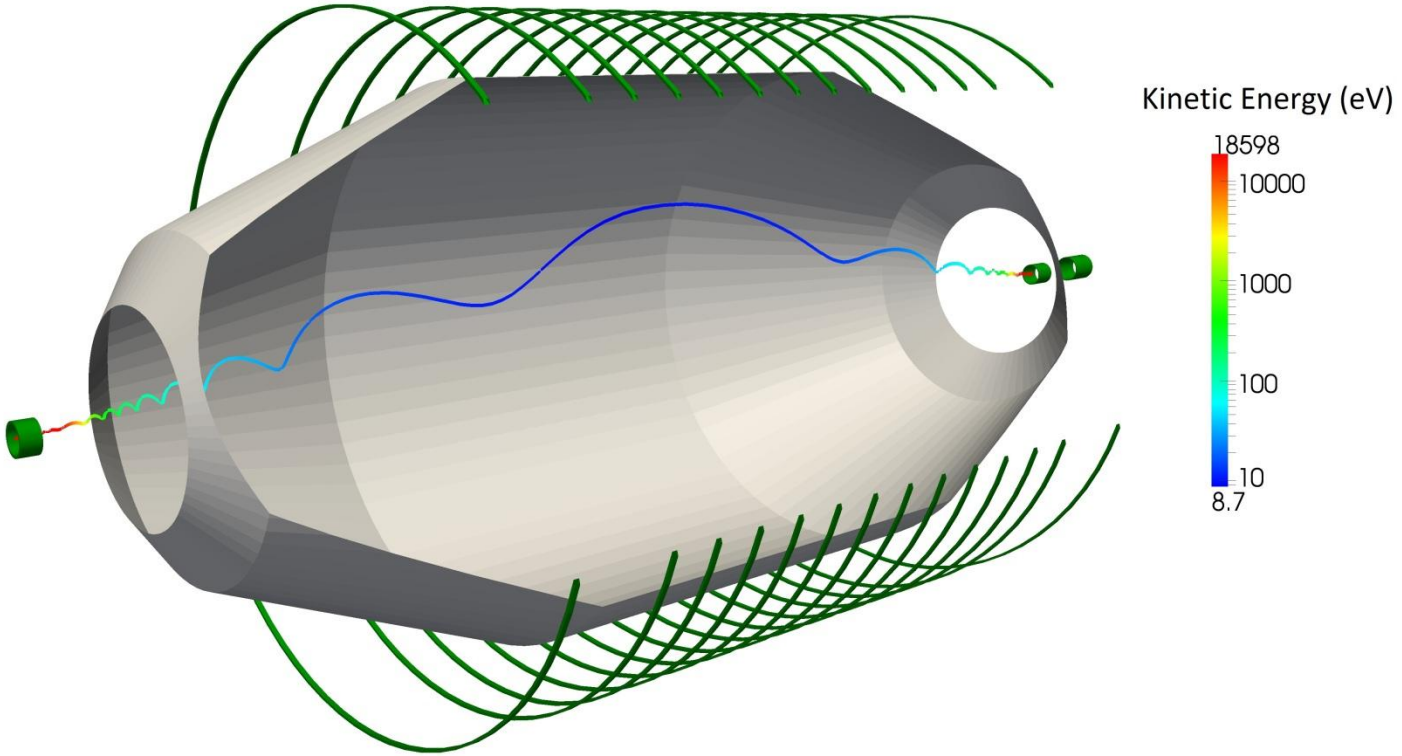


conservation of magnetic flux → increase in flux tube size → large spectrometer radius

The blessing – signal electrons

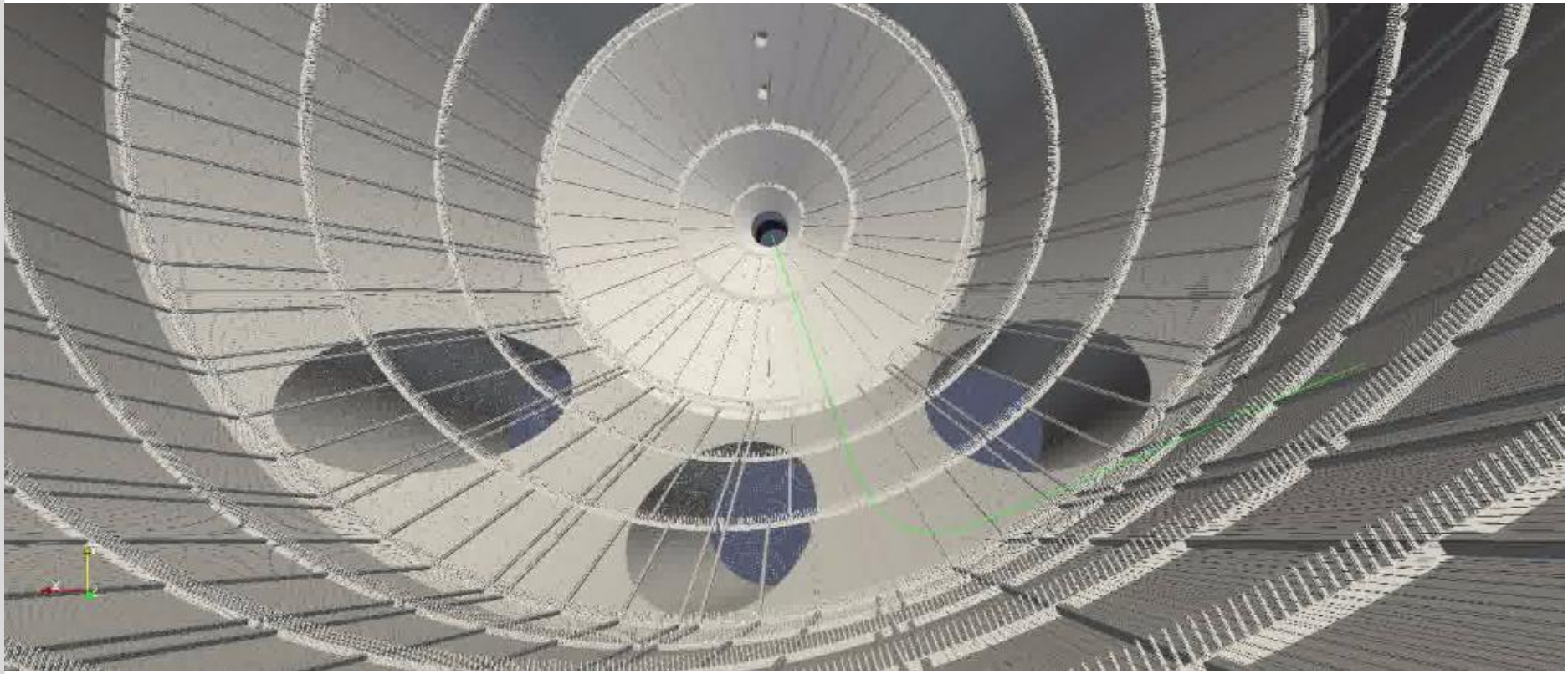
Adiabatic transformation $E_{\perp} \rightarrow E_{||}$ if:

$$\mu = \frac{E_{\perp}}{B} = const$$

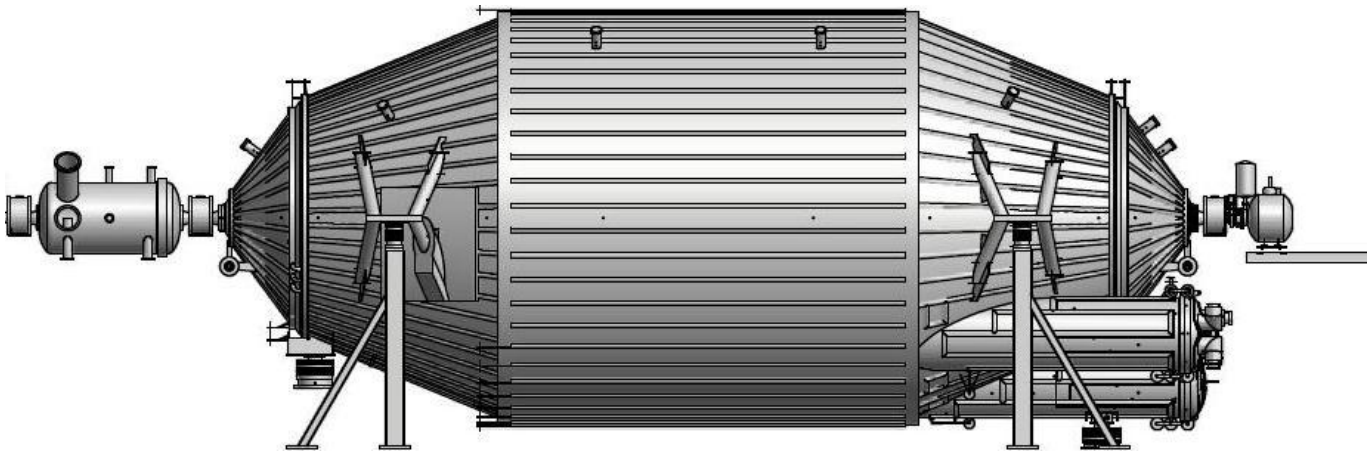


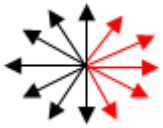
adiabatic motion → „slow“ field decrease → long spectrometer

The blessing – signal electrons

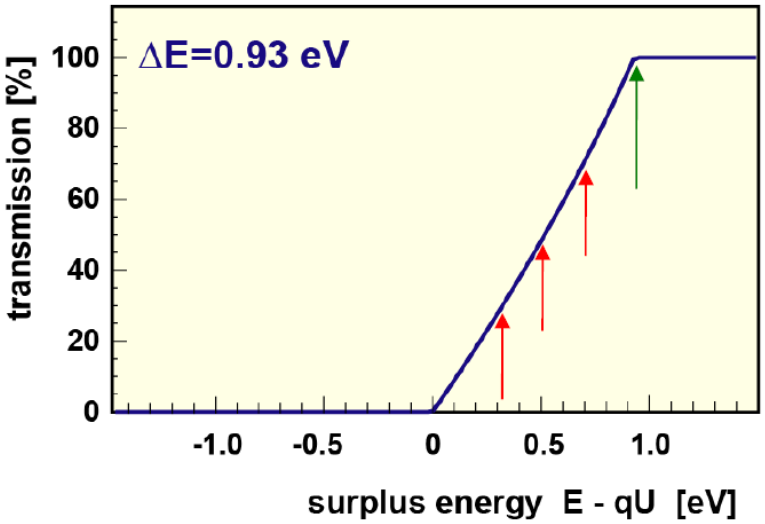


The blessing – signal electrons





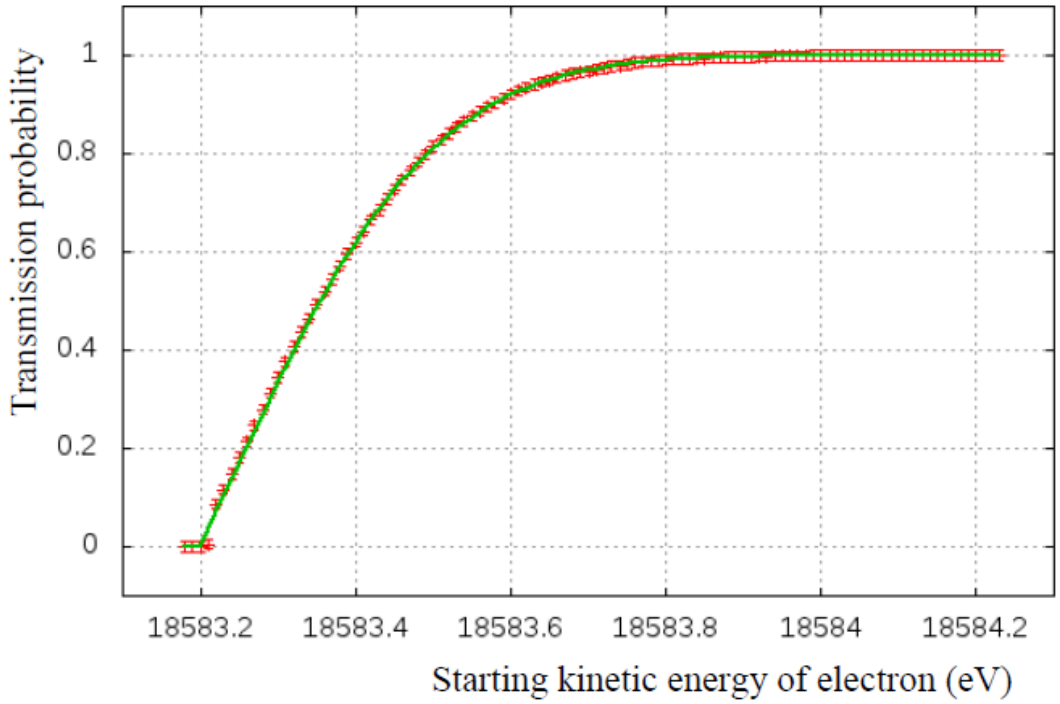
source: isotropic electron emission



spectrometer: transmission function

The blessing – signal electrons

Transmission function can be determined by Monte Carlo simulations!



Comparison with analytic calculation shows ‰ agreement!

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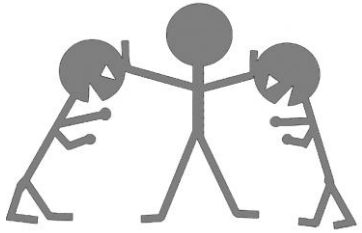
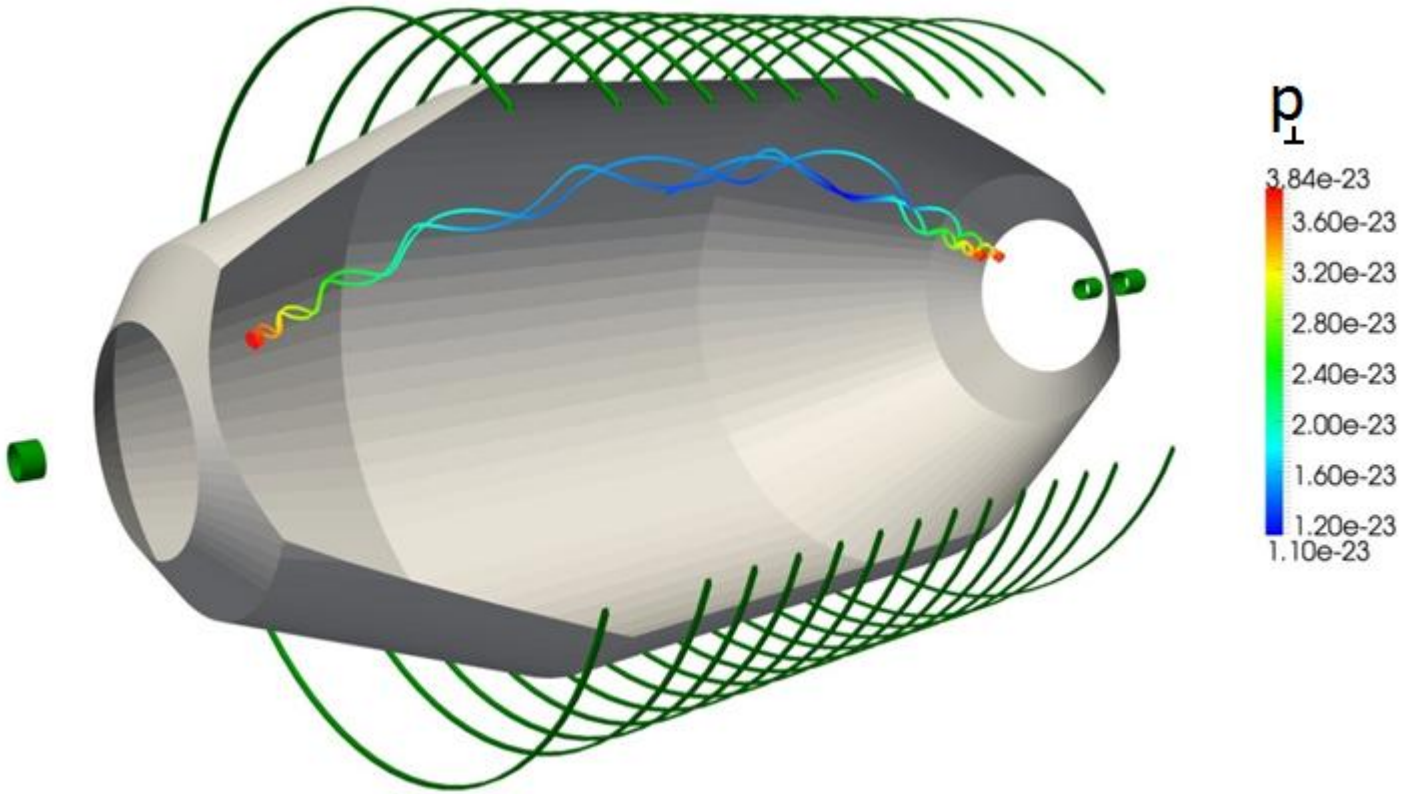


The curse – background electrons

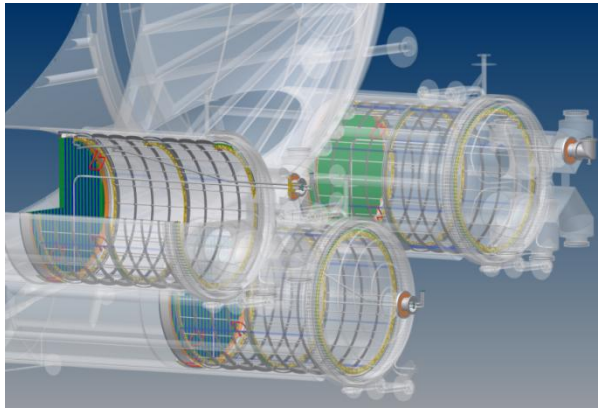
- Magnetic bottle → stored electrons (if originating inside)



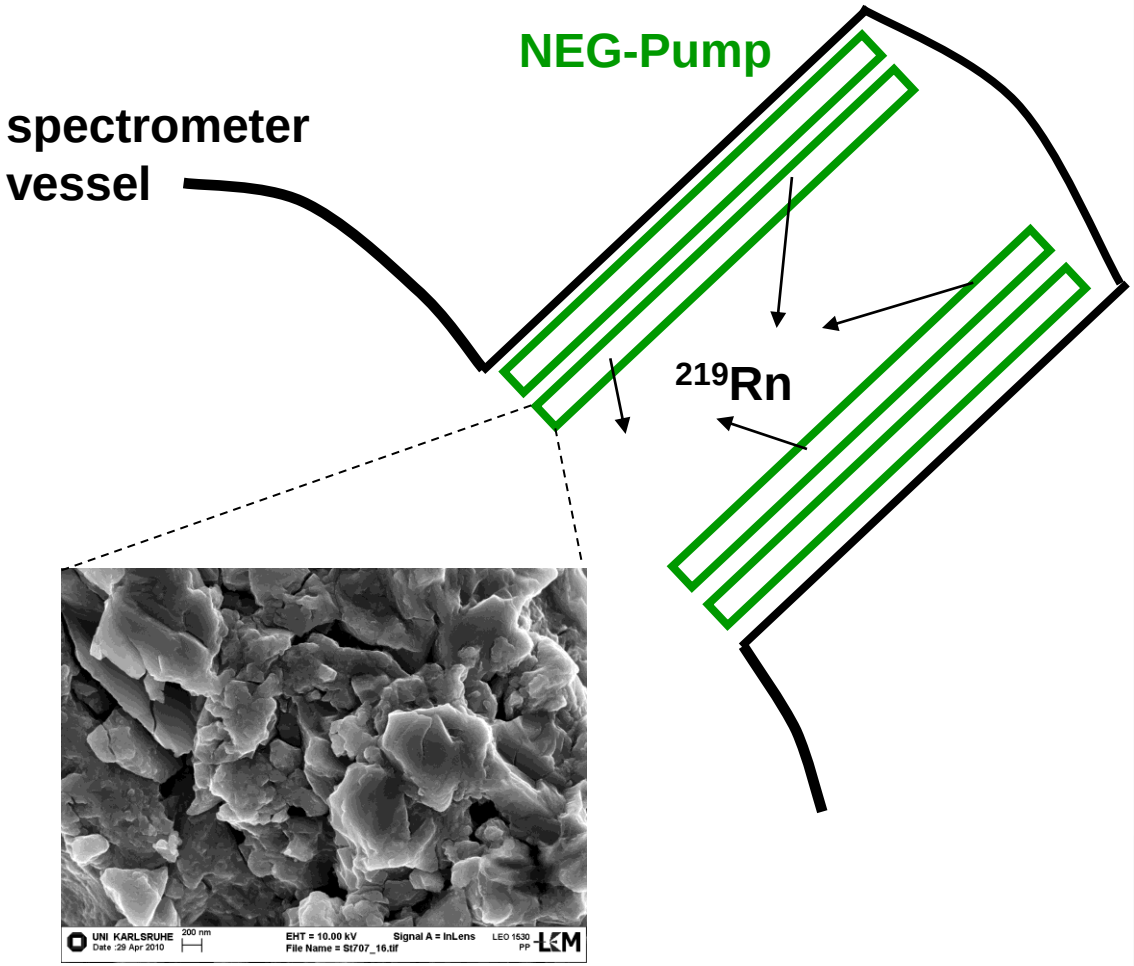
electron momentum

The curse – background electrons

source for background:
radon from getter pump

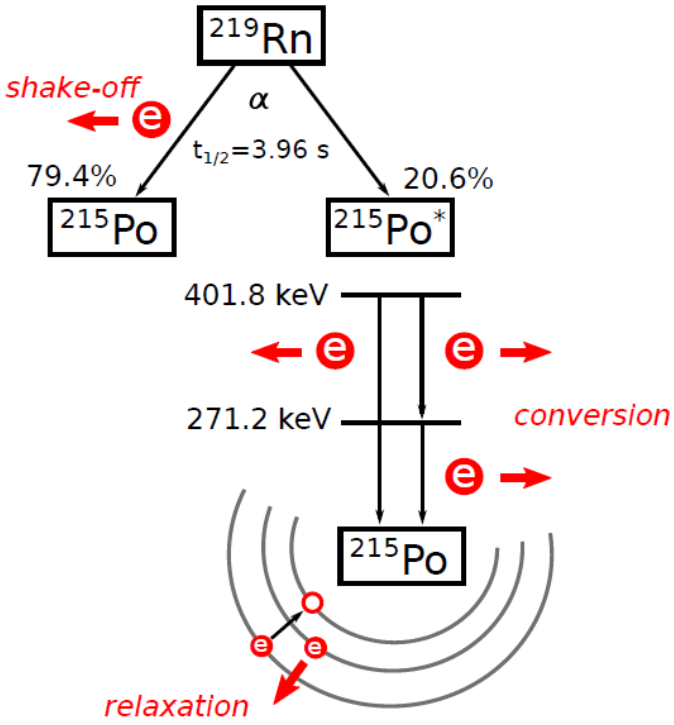


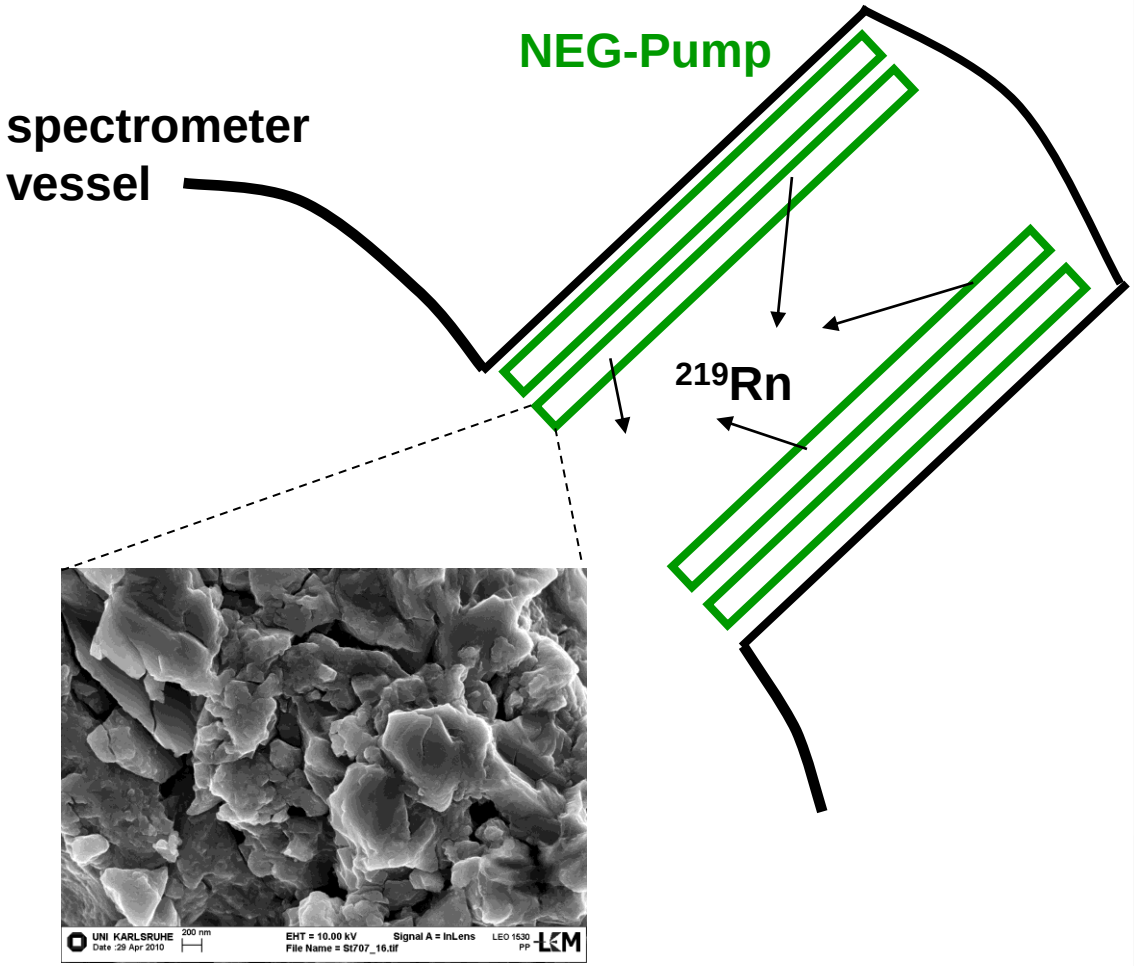
pump ports @ main spec
equipped with 3km of getter



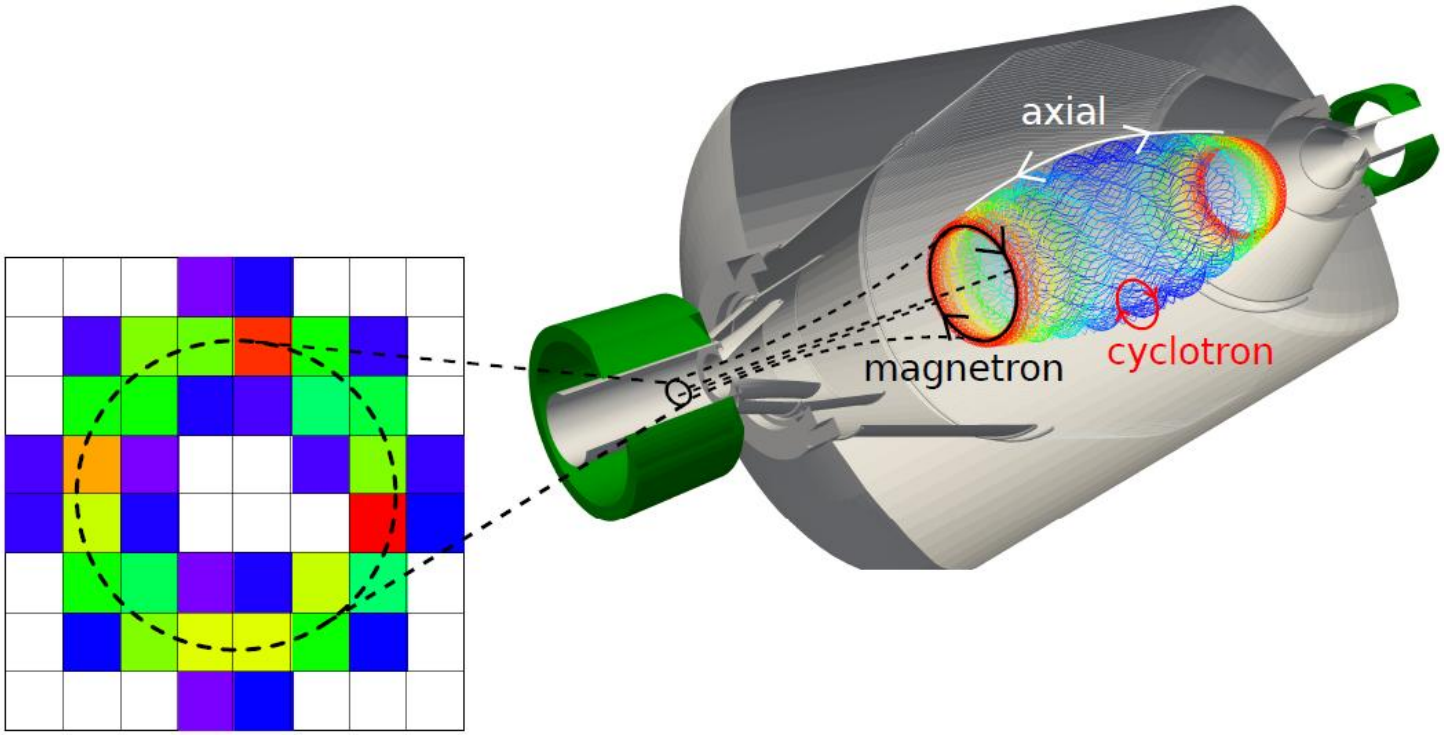
The curse – background electrons

source for background:
radon from getter pump





The curse – background electrons

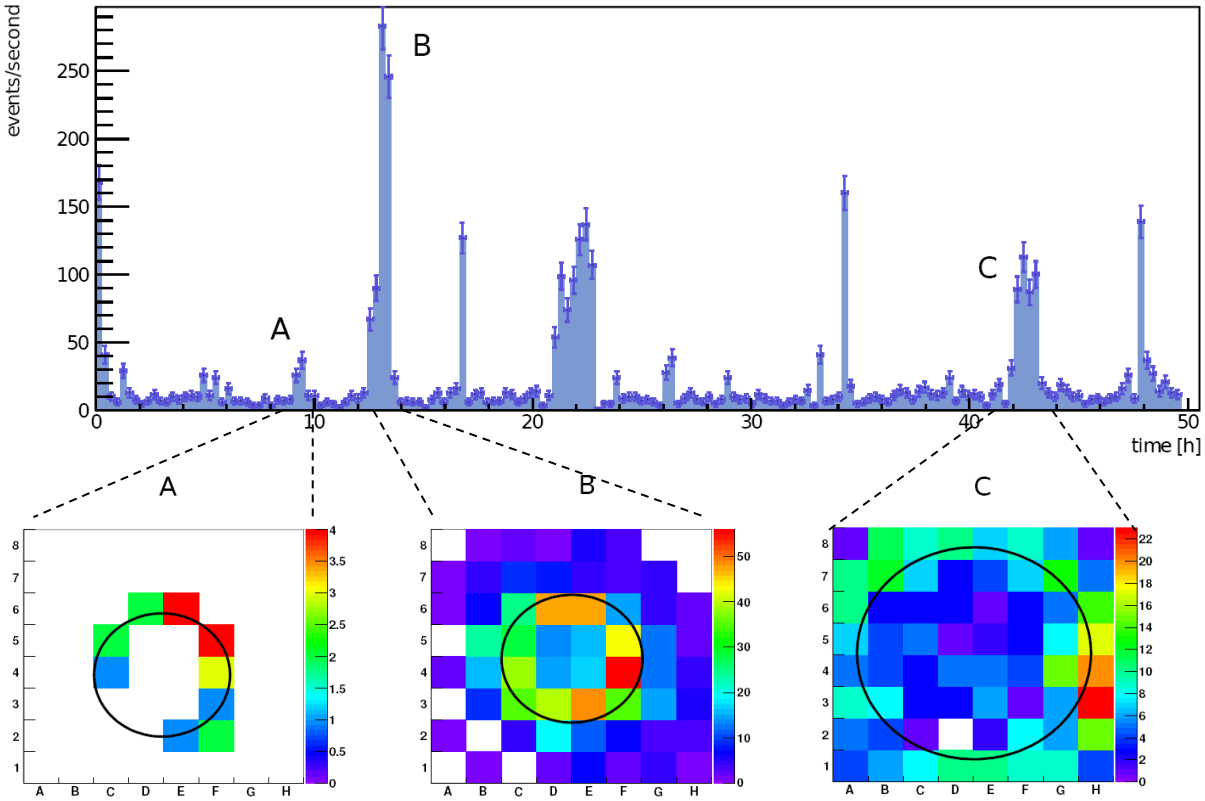


Magnetron drift: $$\vec{v} = -\frac{cE}{eB^3} \cdot \vec{B} \times \nabla_{\perp}\vec{B} + \frac{c}{B^2} \cdot \vec{E} \times \vec{B}$$

ionization → secondary electrons → characteristic ring structure

The curse – background electrons

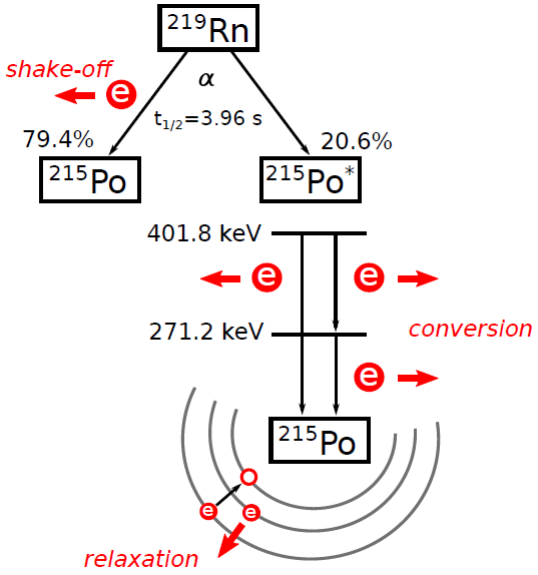
pre-spectrometer measurements:

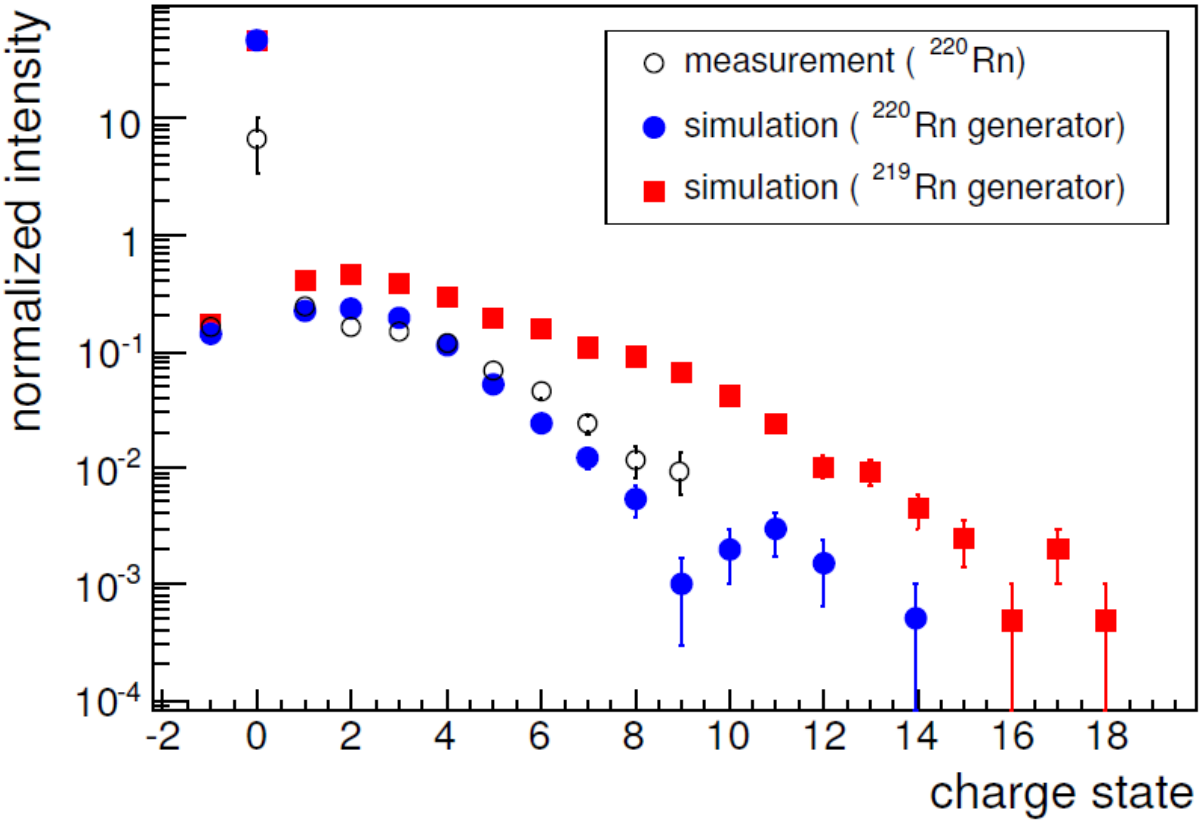


→ data used to develop background model

The curse – background electrons

Development of radon event generator: many electrons per event

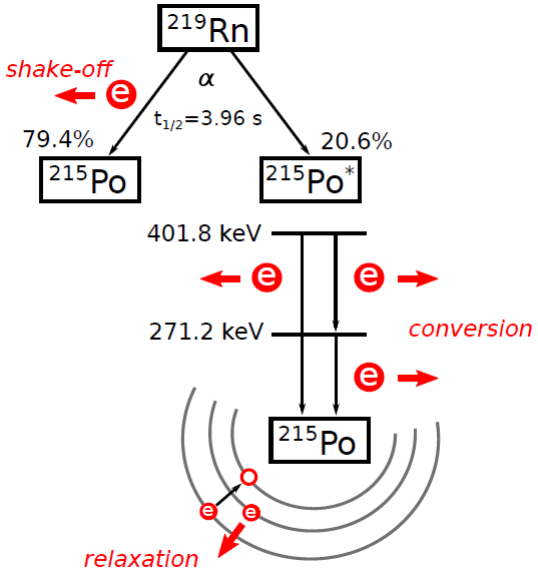


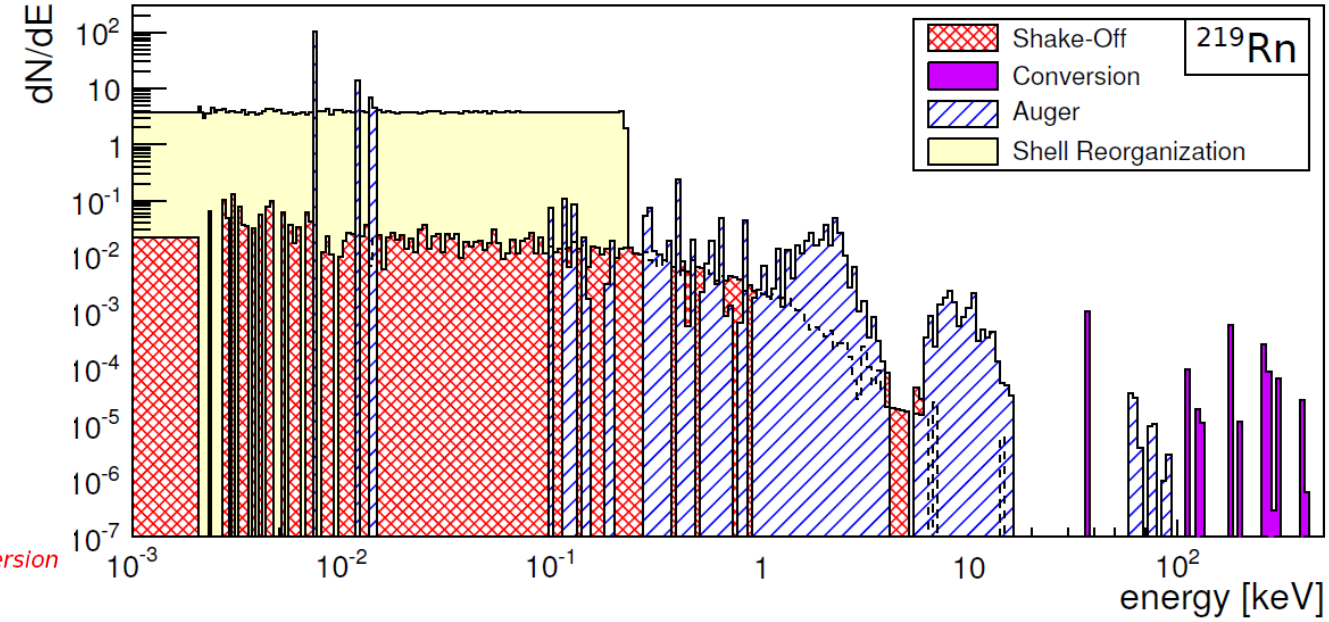


Good agreement with independent measurement!

The curse – background electrons

Development of radon event generator: energy spectrum

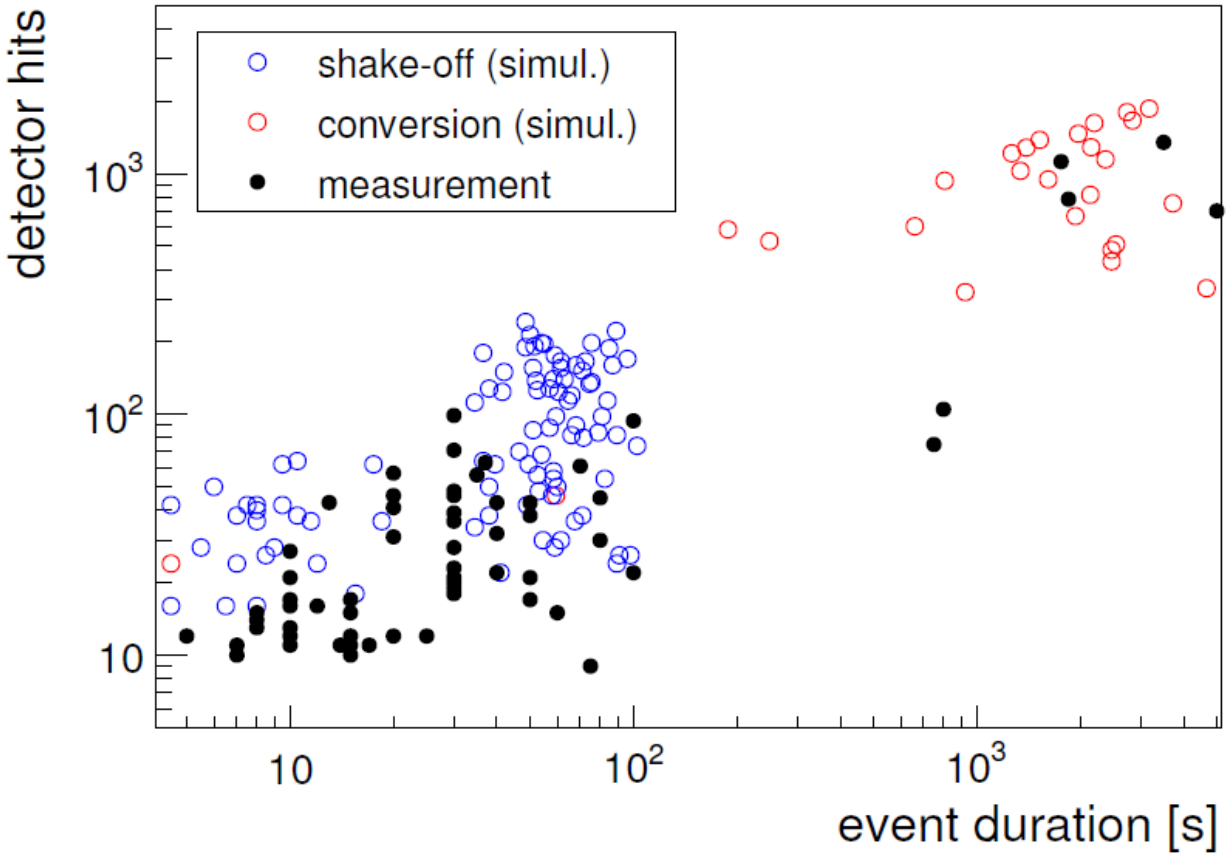




More energy → more secondary electrons

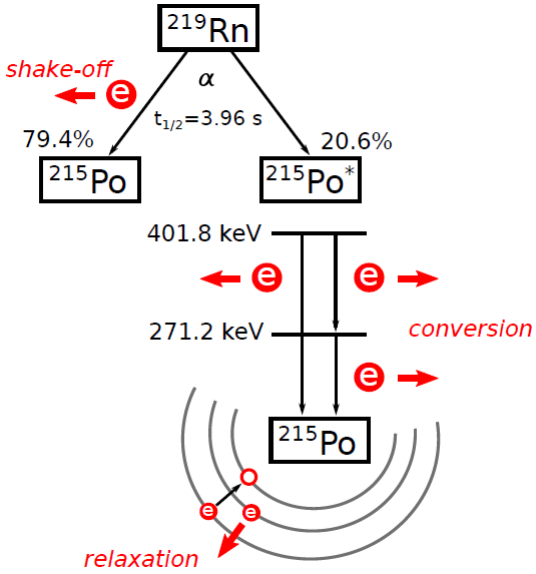
The curse – background electrons

Comparison to pre-spectrometer measurements

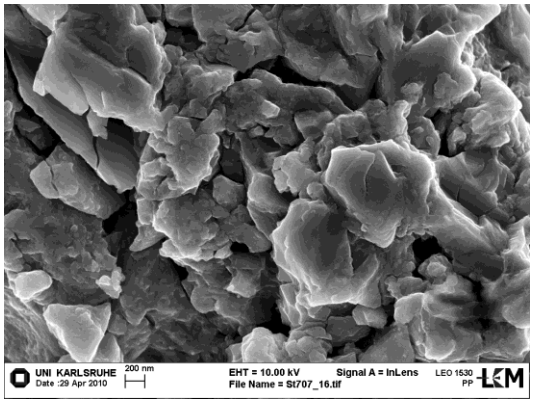


The curse – background electrons

Use model for predictions for main spectrometer (Monte Carlo):



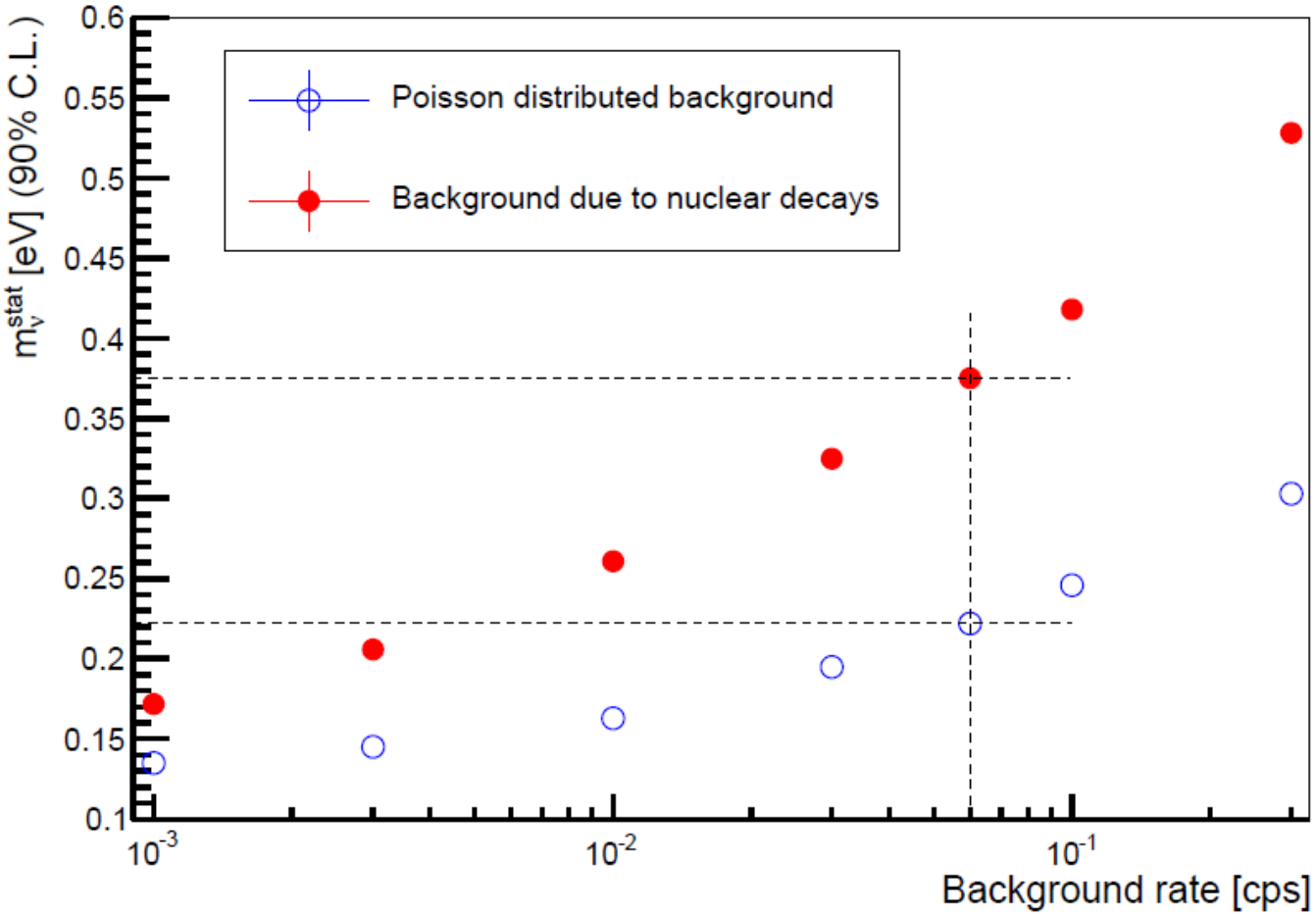
model for electron emission in α-decay



calculations for expected rate of radon decays

Monte Carlo results: $6 \cdot 10^{-2}$ cps expected

The curse – background electrons



$6 \cdot 10^{-2}$ cps, non-poissonian distribution → sensitivity reduction by factor of ~2

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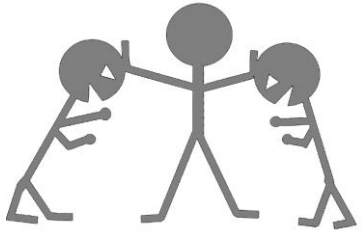
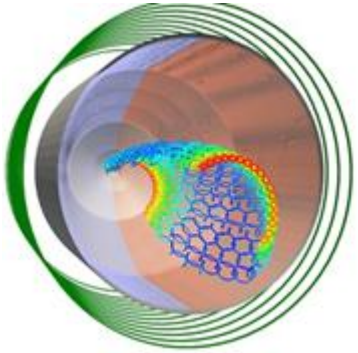


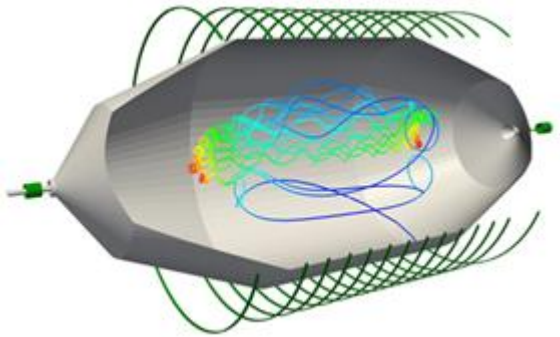
The cure – background removal

Sensitivity reduction not acceptable
→ methods to remove background required

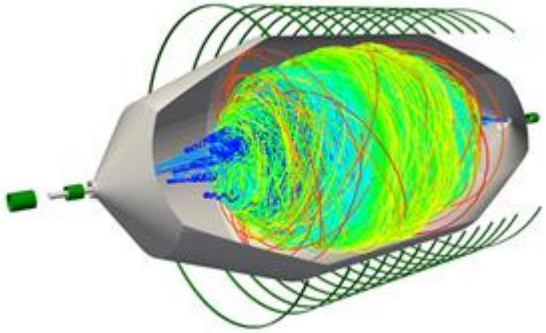
3 methods under investigation:



Electric dipole



Magnetic pulse

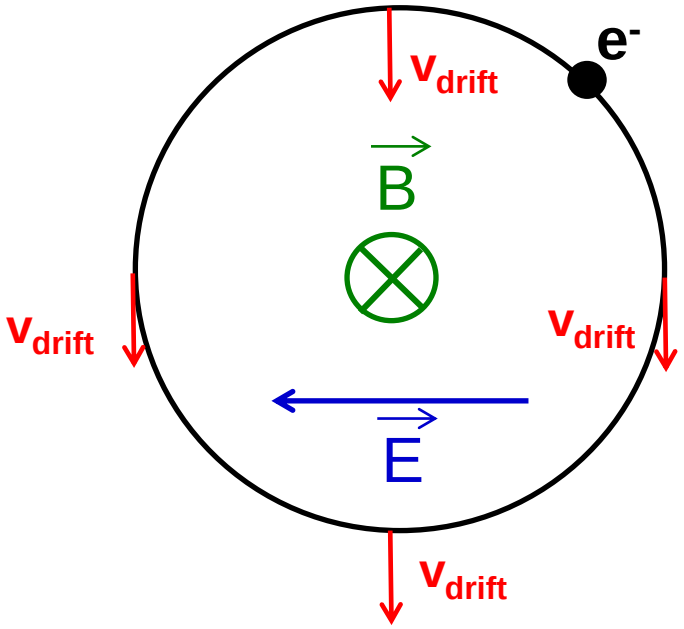


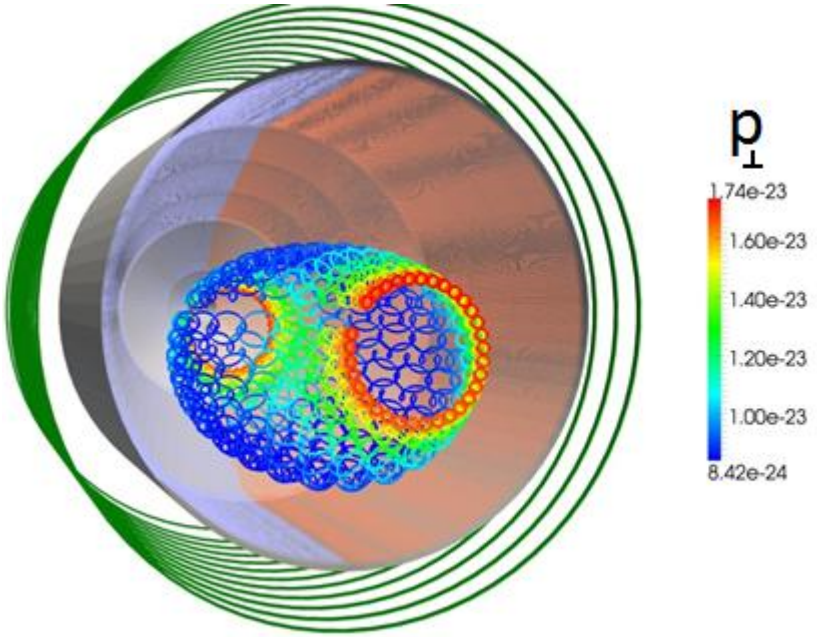
Electron Cyclotron resonance

The cure – background removal

- Electric dipole

$$\vec{v} = \frac{c}{B^2} \cdot \vec{E} \times \vec{B}$$



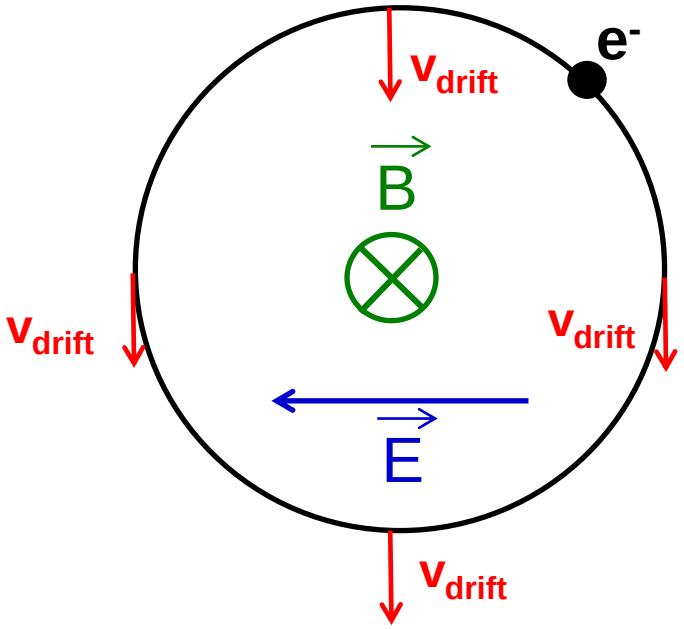


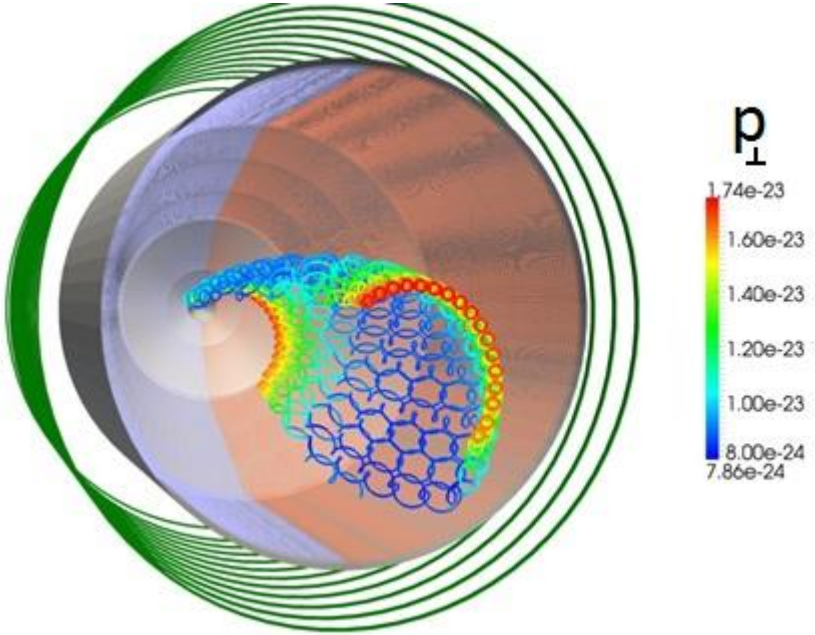
50 V/m → drift in radial direction

The cure – background removal

- Electric dipole

$$\vec{v} = \frac{c}{B^2} \cdot \vec{E} \times \vec{B}$$

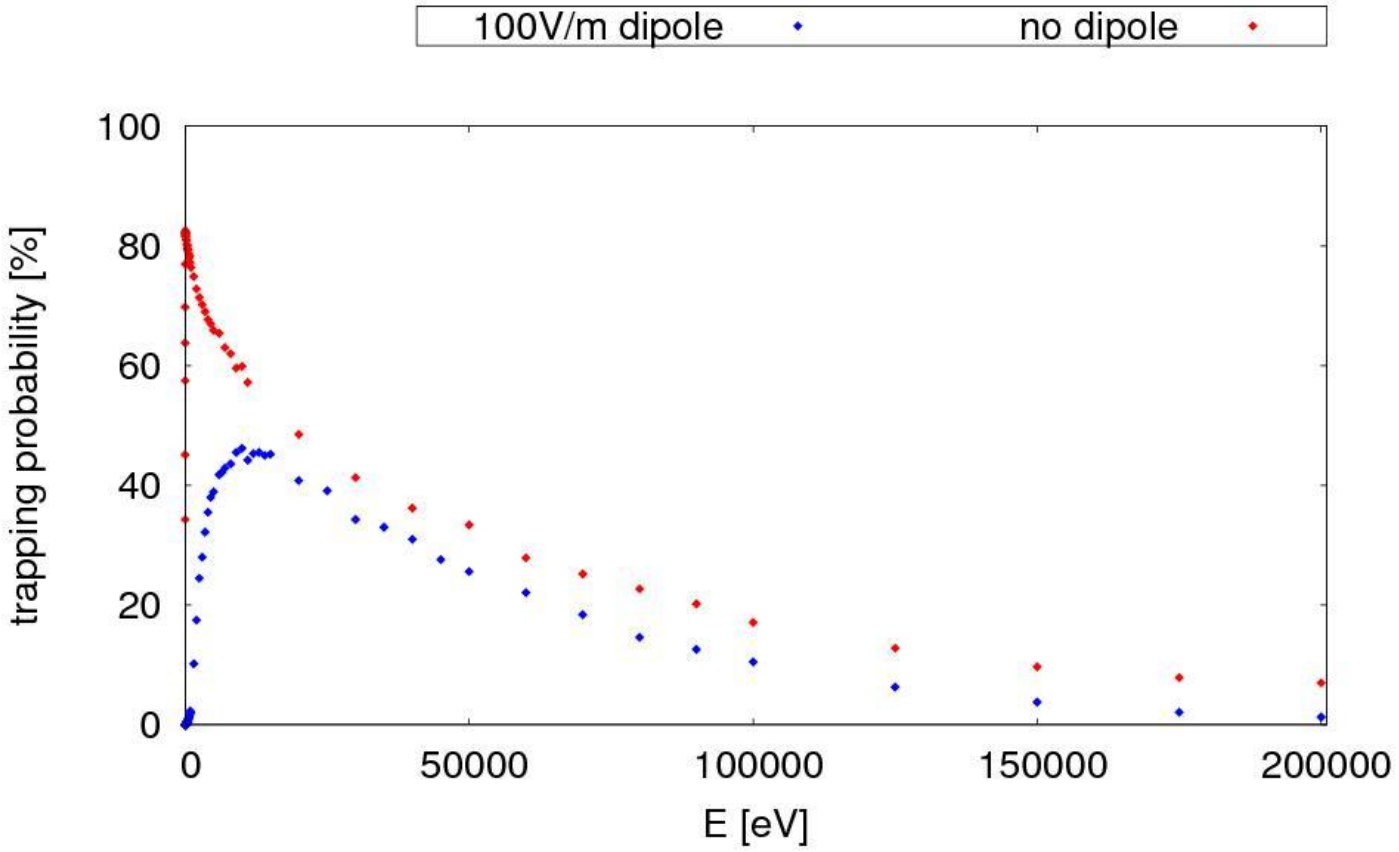




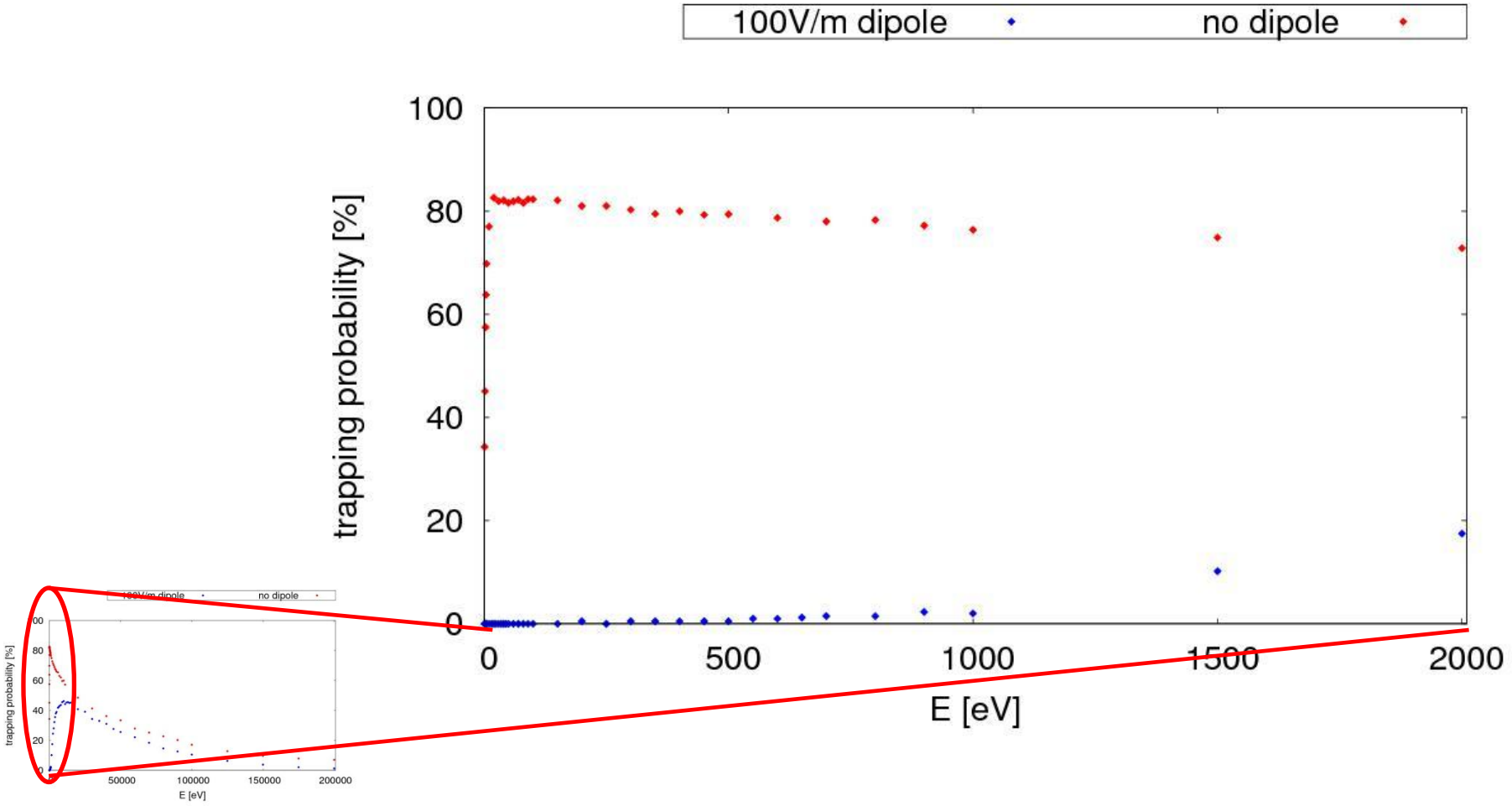
100 V/m → drift in radial direction → electron hits wall

The cure – background removal

Monte Carlo results:



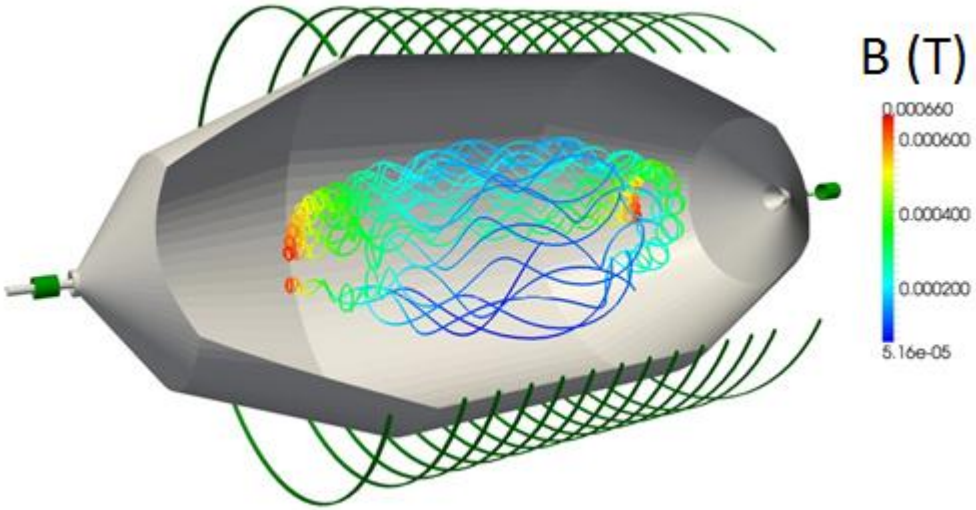
The cure – background removal



Dipole only efficient for E < 1keV → other methods necessary

The cure – background removal

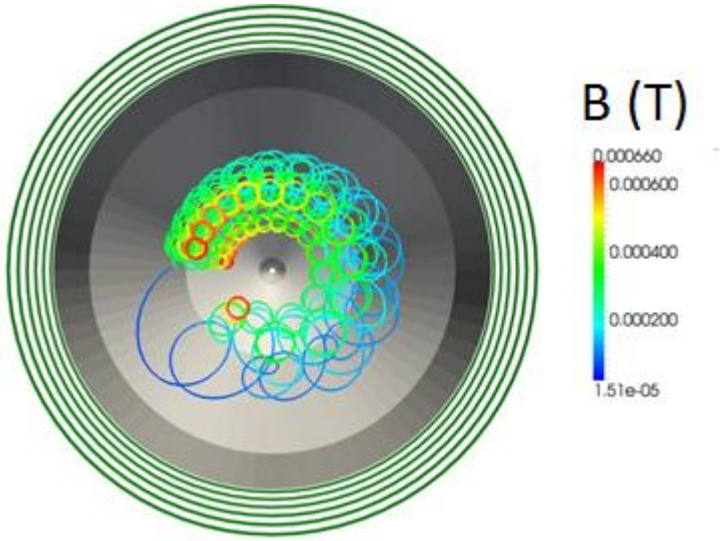
- Magnetic pulse



Reduction of magnetic field
→ increased cyclotron radius

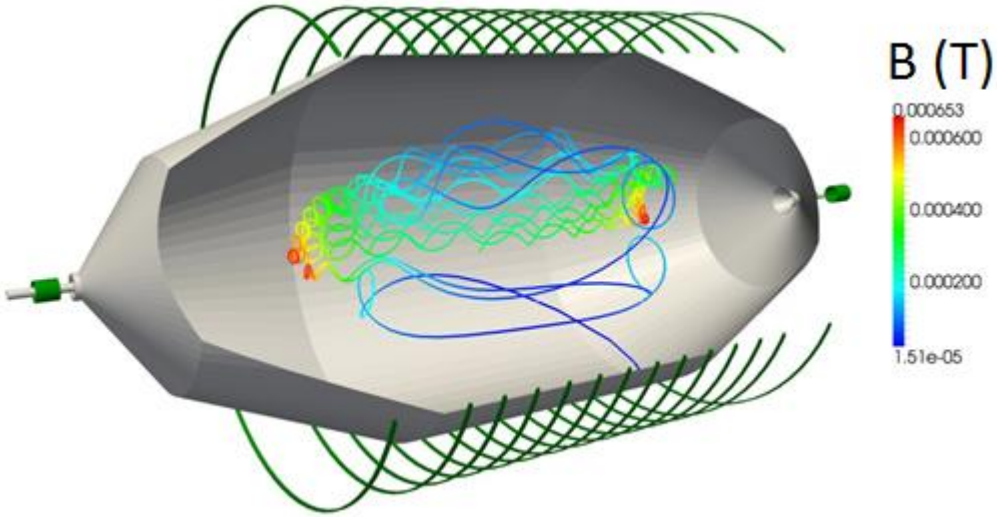
$$r = \frac{mv}{qB}$$

(non-relat.)



The cure – background removal

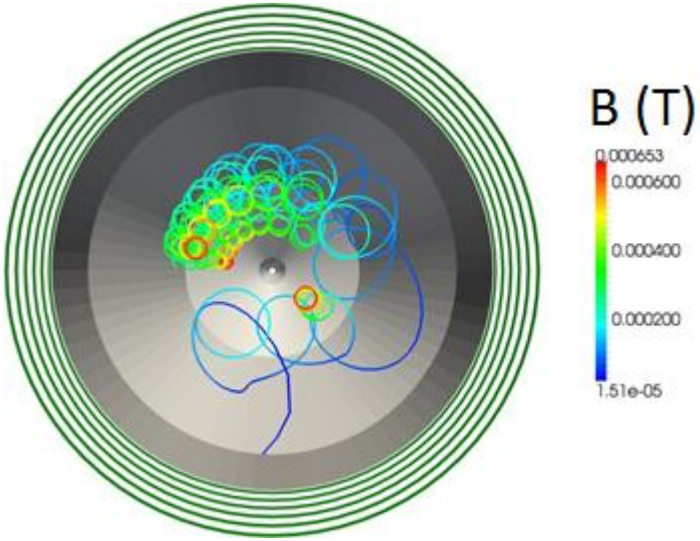
- Magnetic pulse



Reduction of magnetic field
→ increased cyclotron radius

$$r = \frac{mv}{qB}$$ (non-relat.)

→ electrons hit wall

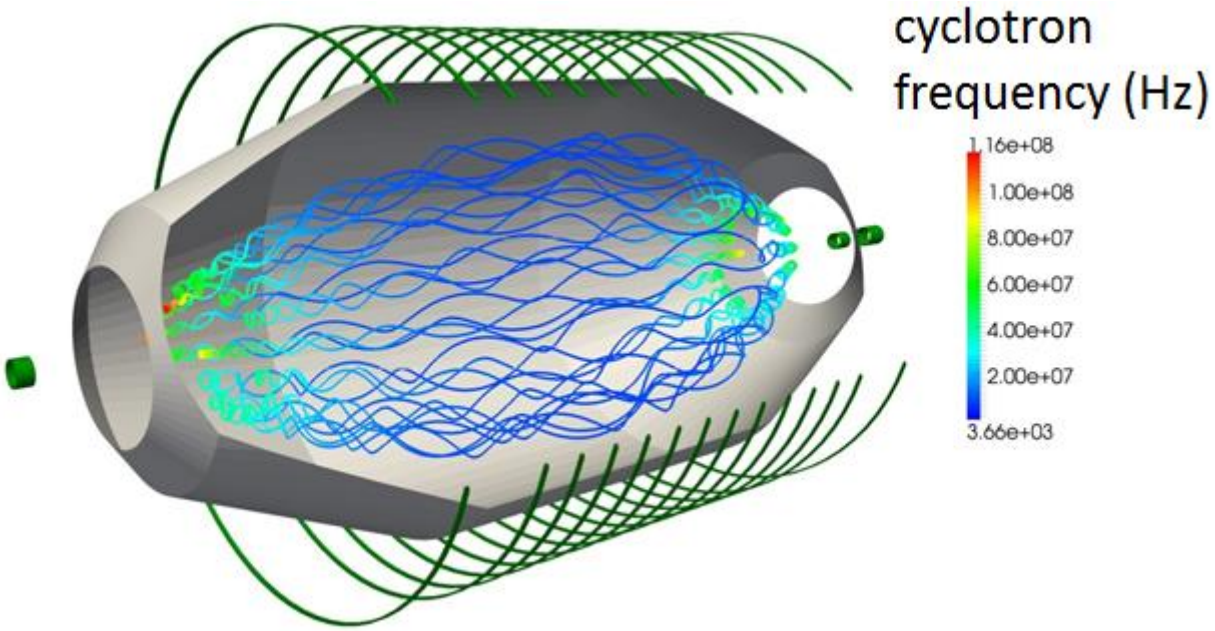


The cure – background removal

- Electron Cyclotron Resonance (ECR)

Induced electric field $\vec{E}=\vec{E}_0 \cdot \sin(\omega(t) \cdot t)$

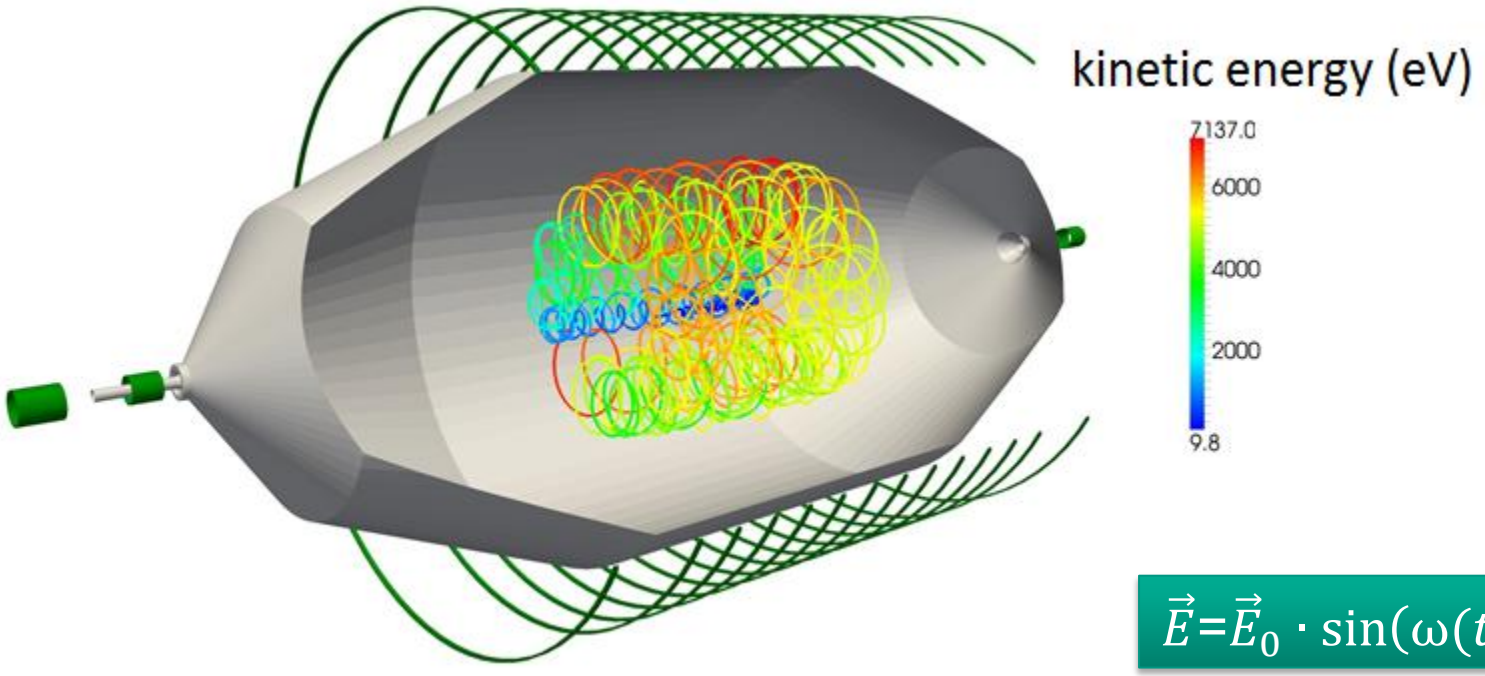
→ stochastic heating at resonance frequency $\omega_{cycl} \approx 10$ MHz



The cure – background removal

- Electron Cyclotron Resonance (ECR)

stochastic heating at resonance frequency $\omega_{cycl} \approx 10$ MHz
→ electrons gain energy



$$\vec{E} = \vec{E}_0 \cdot \sin(\omega(t) \cdot t)$$

The cure – background removal

- Electron Cyclotron Resonance (ECR)

stochastic heating at resonance frequency $\omega_{cycl} \approx 10$ MHz
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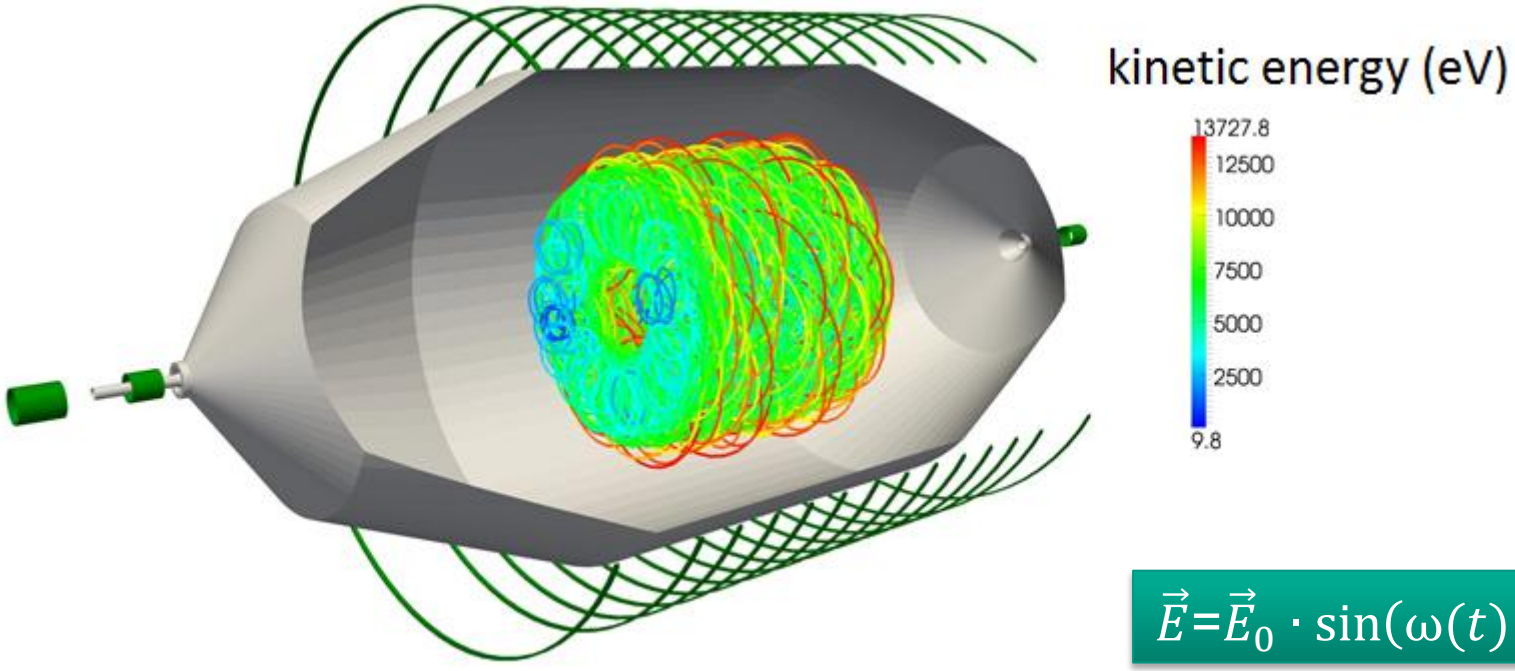

$$\vec{E} = \vec{E}_0 \cdot \sin(\omega(t) \cdot t)$$

The cure – background removal

- Electron Cyclotron Resonance (ECR)

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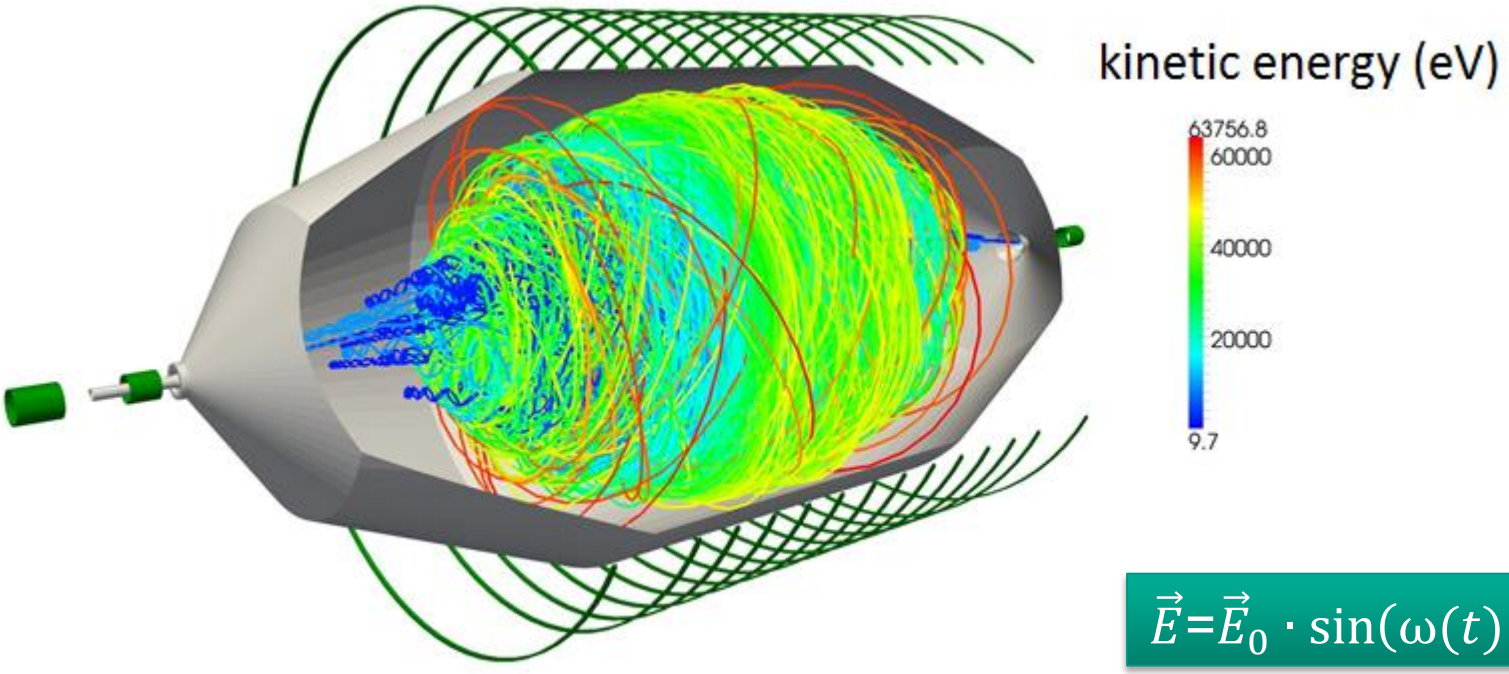
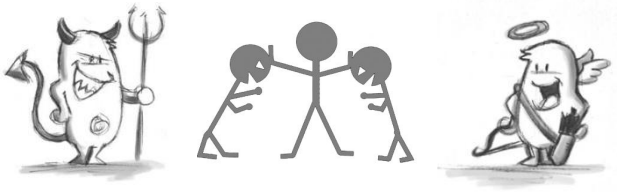


$$\vec{E} = \vec{E}_0 \cdot \sin(\omega(t) \cdot t)$$

Summary



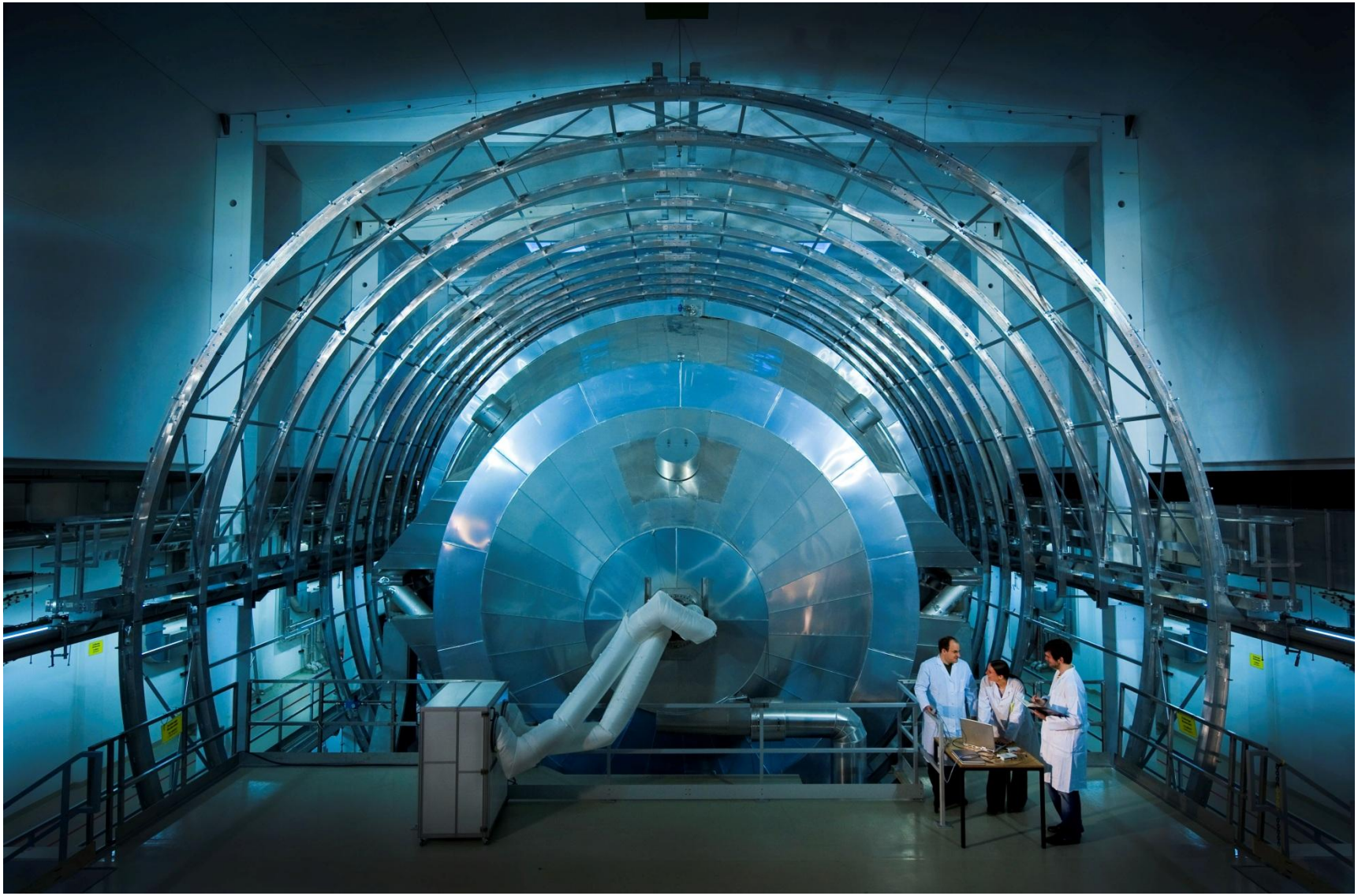
- Design sensitivity: $m_\nu < 0.2$ eV (90% CL)

- *Requirement 1*: Understanding the spectrometer
  → transmission function
- *Requirement 2*: Low background (< 10^{-2} cps)

- Background due to radon-induced stored electrons

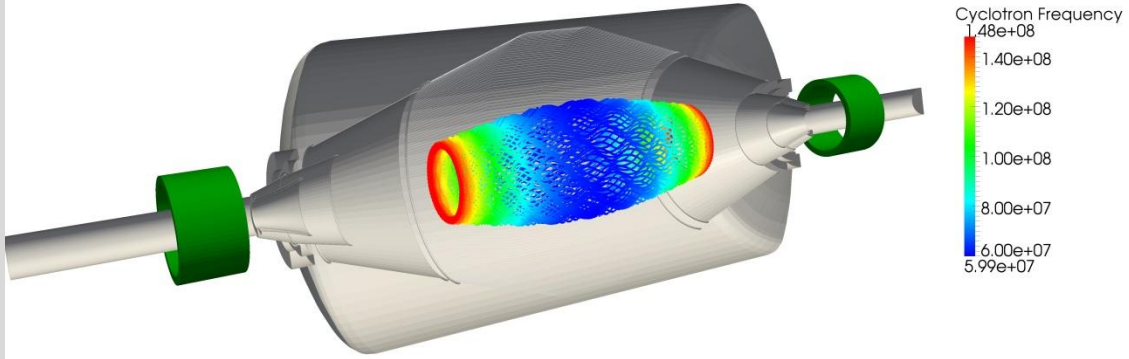
- Methods to remove background
  - Electric dipole
  - Magnetic pulse
  - Electron cyclotron resonance

Thanks for your attention!



The cure – background removal

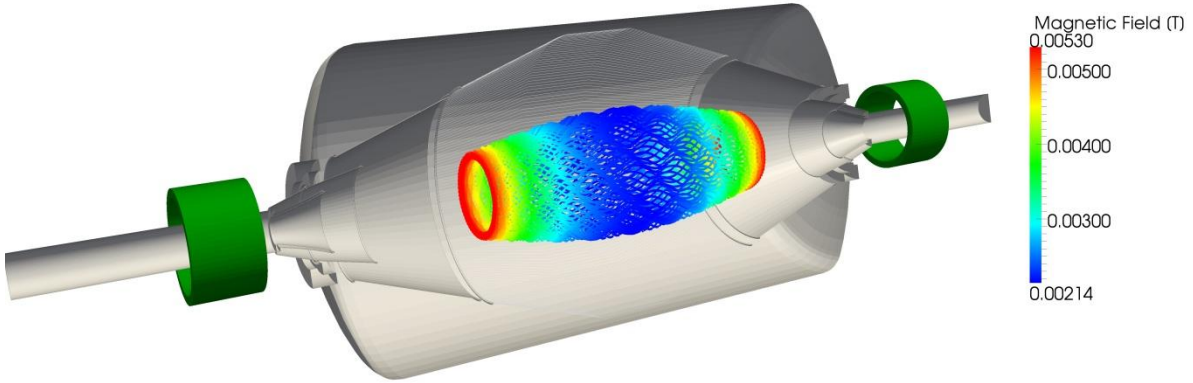
- Electron Cyclotron Resonance (ECR)



experimental test at pre-spectrometer: $\omega_{rf} \approx 62$ Mhz

$$\omega = \frac{eB}{m\gamma}$$

→ ~2.2 mT



The cure – background removal

- Electron Cyclotron Resonance (ECR)