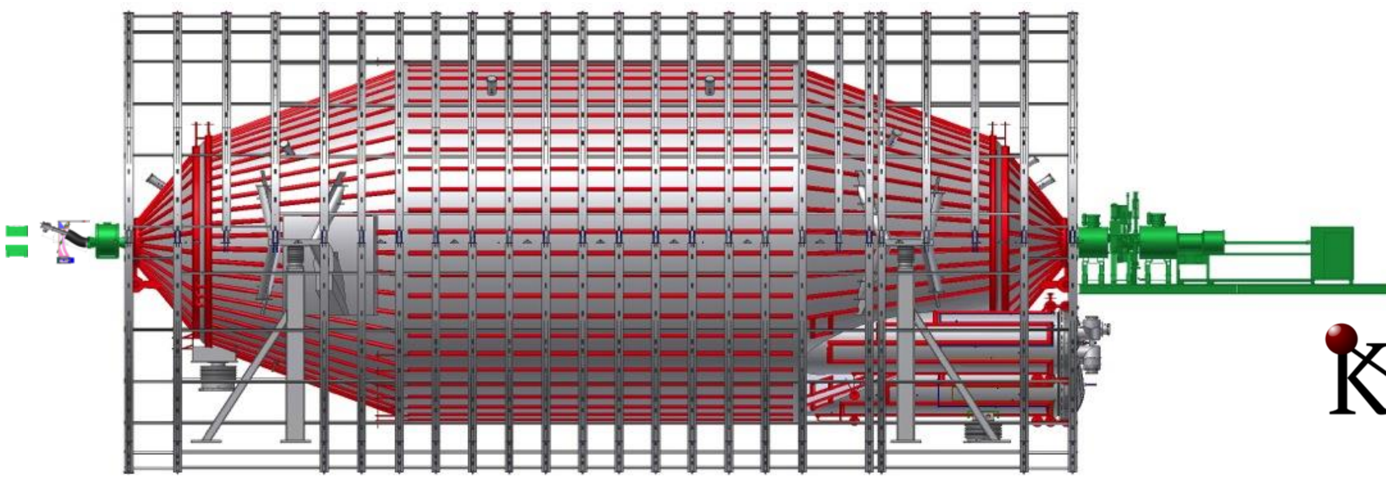
Transmission measurements at the KATRIN main spectrometer

Stefan Groh

GK-Workshop Bad Liebenzell, October 2013

Karlsruhe Institute of Technology (KIT) – Institute for Experimental nuclear Physics (IEKP)



Outline

- How does KATRIN work
- Commissioning of spectrometer and detector
- Alignment of eGun and Detector
- Transmission function measurement
- Radial potential scan
- Transmission function at high rate

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Model independent measurement of the neutrino mass with a sensitivity of 200 meV (90% C.L.)

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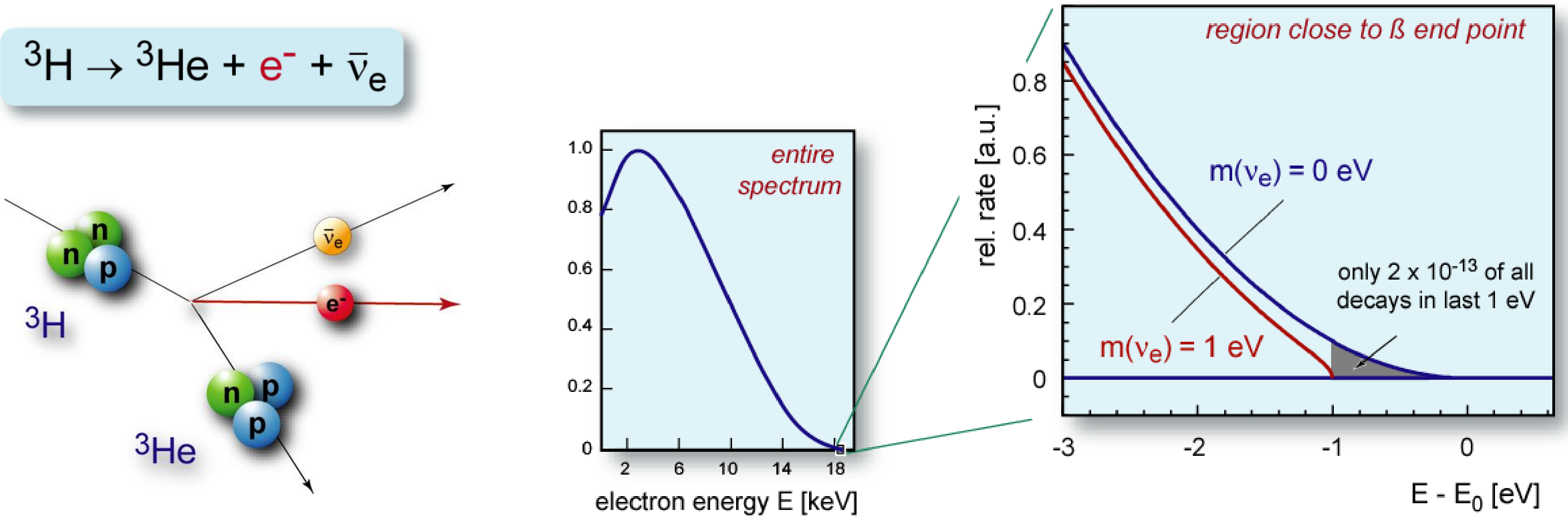
Tritium beta decay

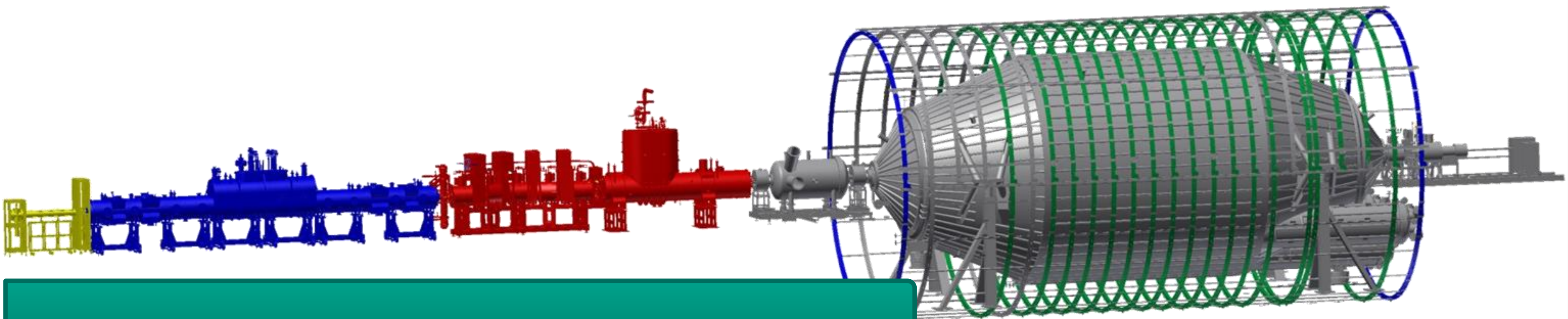
$^{3}H \rightarrow {}^{3}He + e^{-} + \bar{\nu}_e$



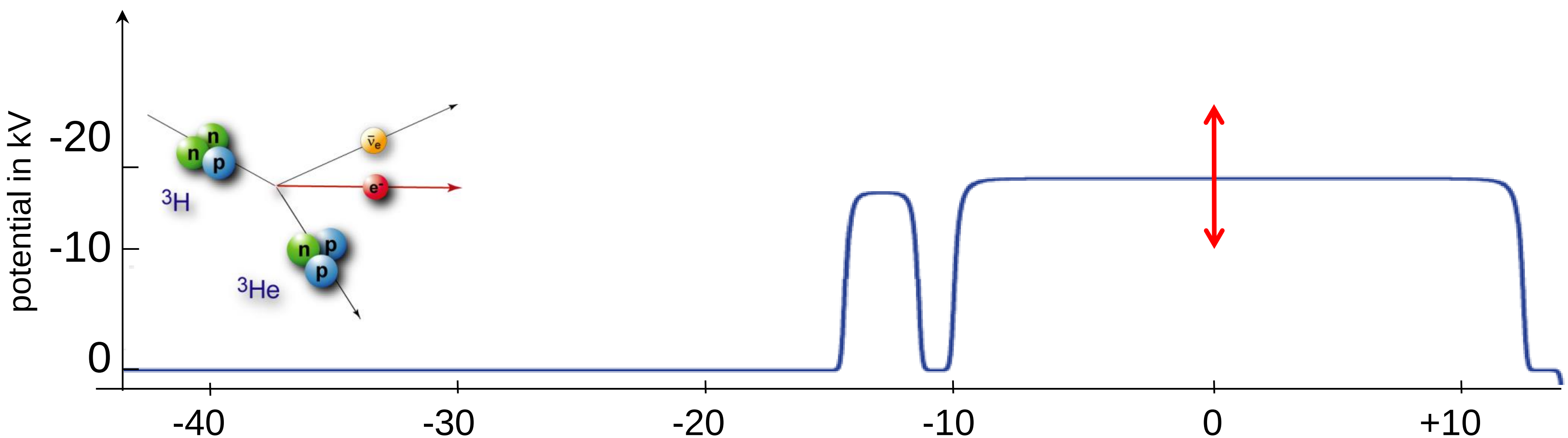
Neutrino mass takes away energy that changes shape of electron spectrum

Precise spectroscopy of beta decay electrons necessary

Experimental Setup



How to measure the energy of the electrons?



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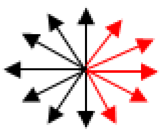
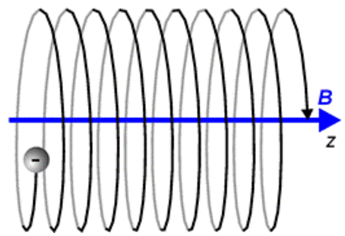
Why the big spectrometer?

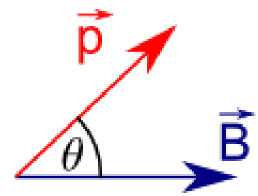
Source: isotropic e^- emission



Cyclotron motion along field line



Fixed polar angle between p and B



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

Electric field only filters long. comp.

Problem: How to filter the electrons according to their kinetic energy?

Solution: Decrease the polar angle of the electrons at the analyzing point

μ is conserved in an adiabatic motion

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

reduce magnetic field at the analyzing point

$$E_{\perp} \rightarrow E_{||}$$

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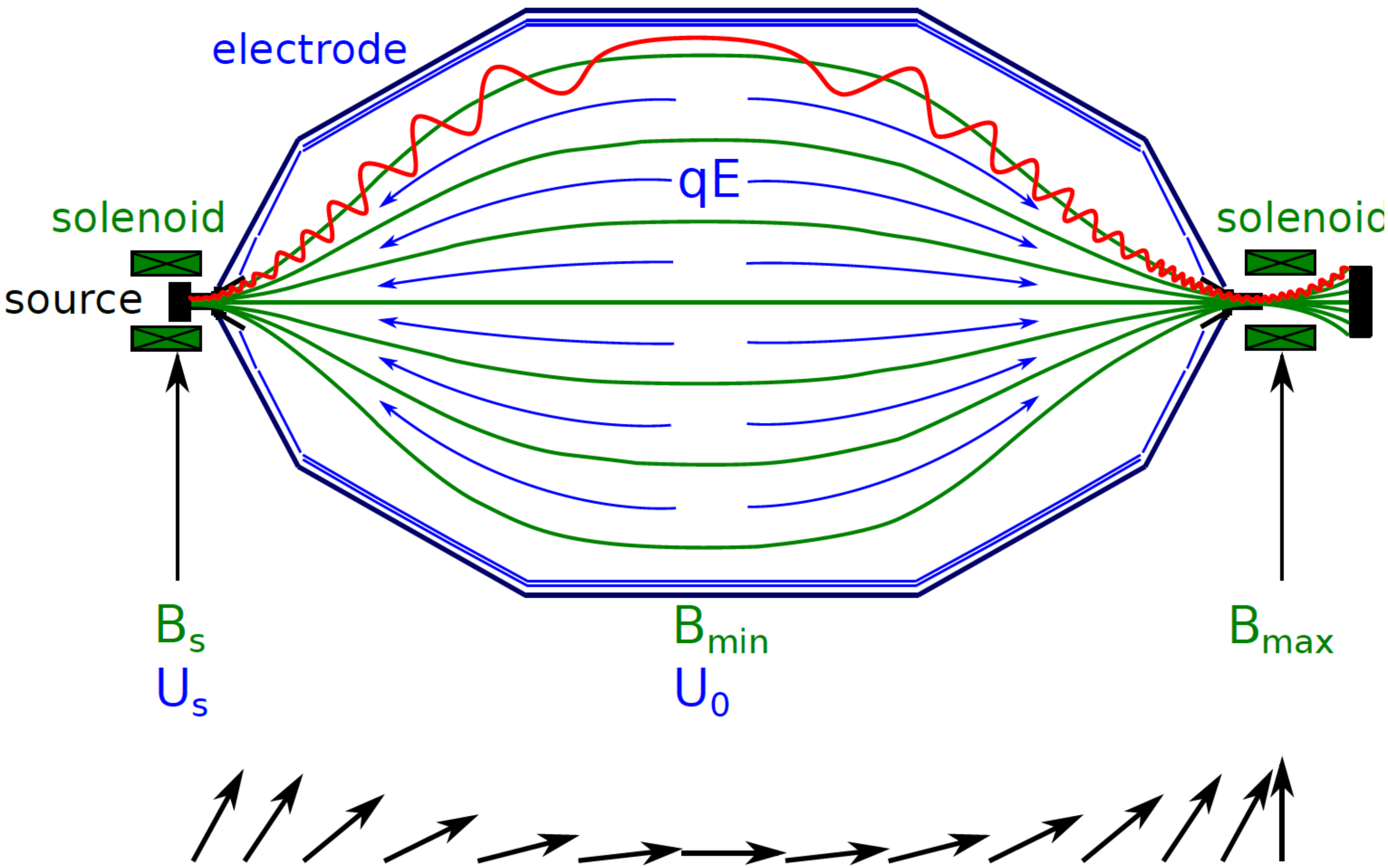
The MAC-E-Filter principle



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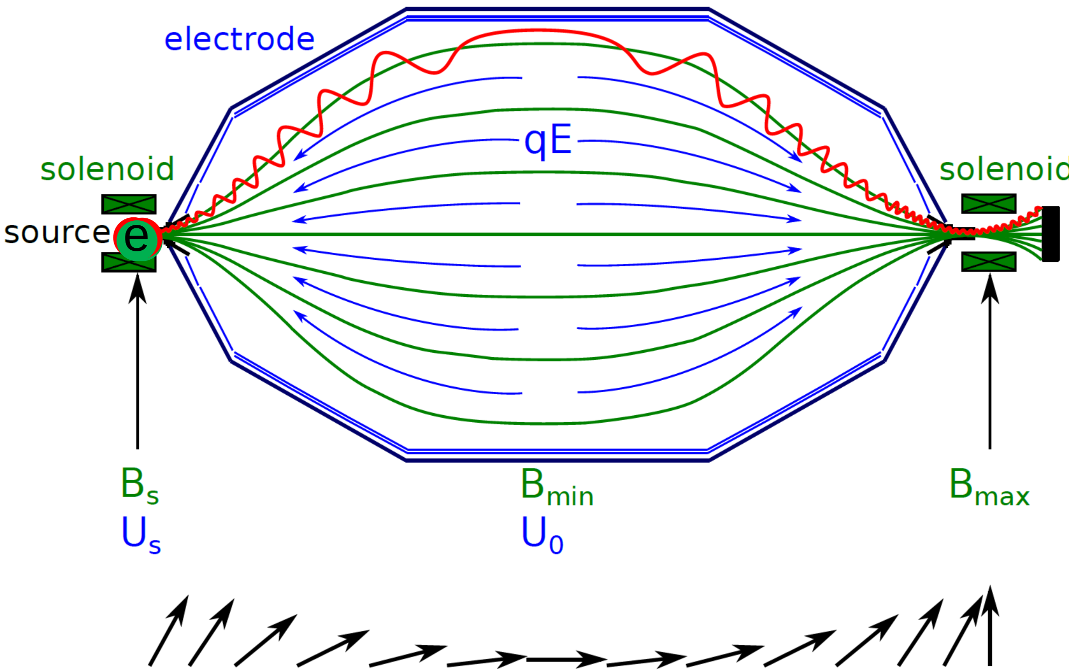
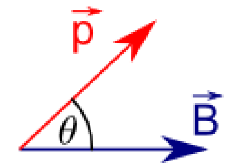
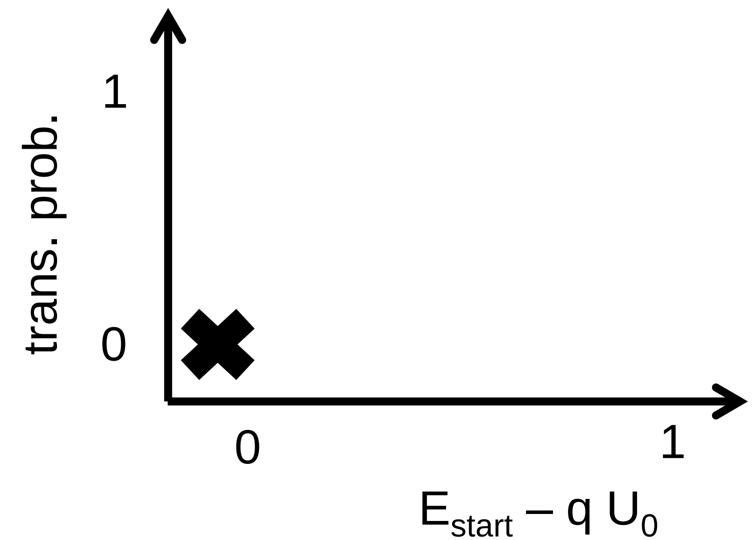
The energy resolution





e   θ = 0

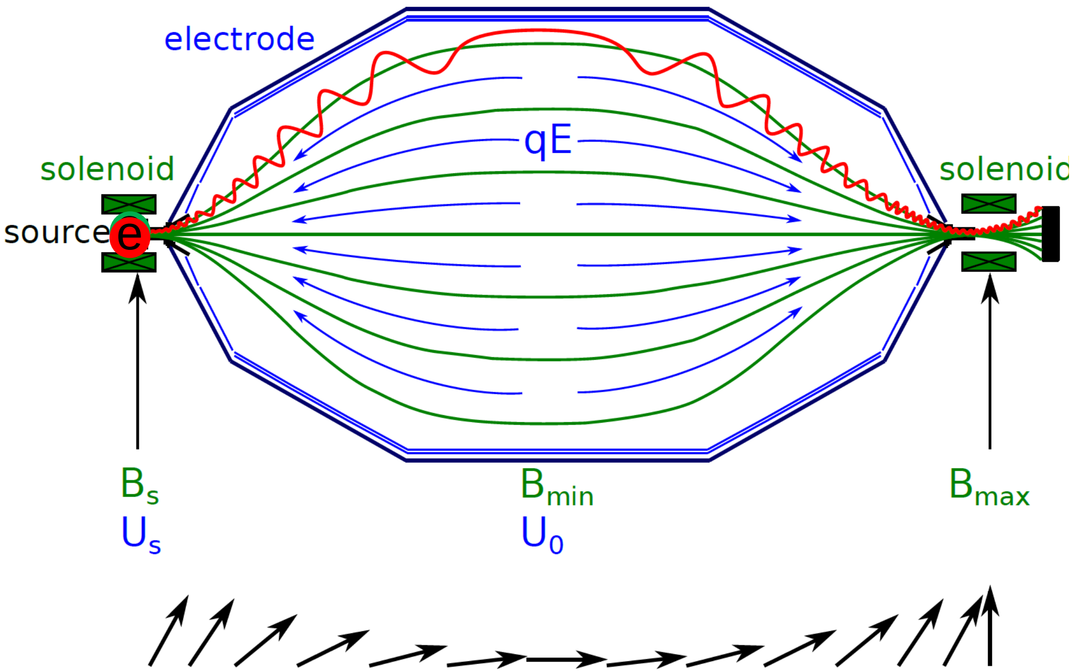
e   θ = 60

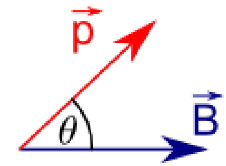


ret. potential: 18000 V

electron energy: 17999.9 eV

The energy resolution



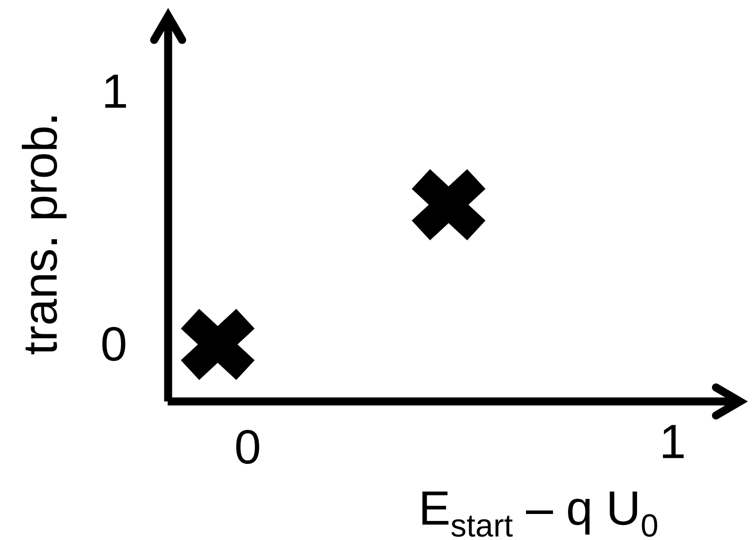


e $\theta = 0$

e $\theta = 60$

ret. potential: 18000 V

electron energy: 18000.5 eV



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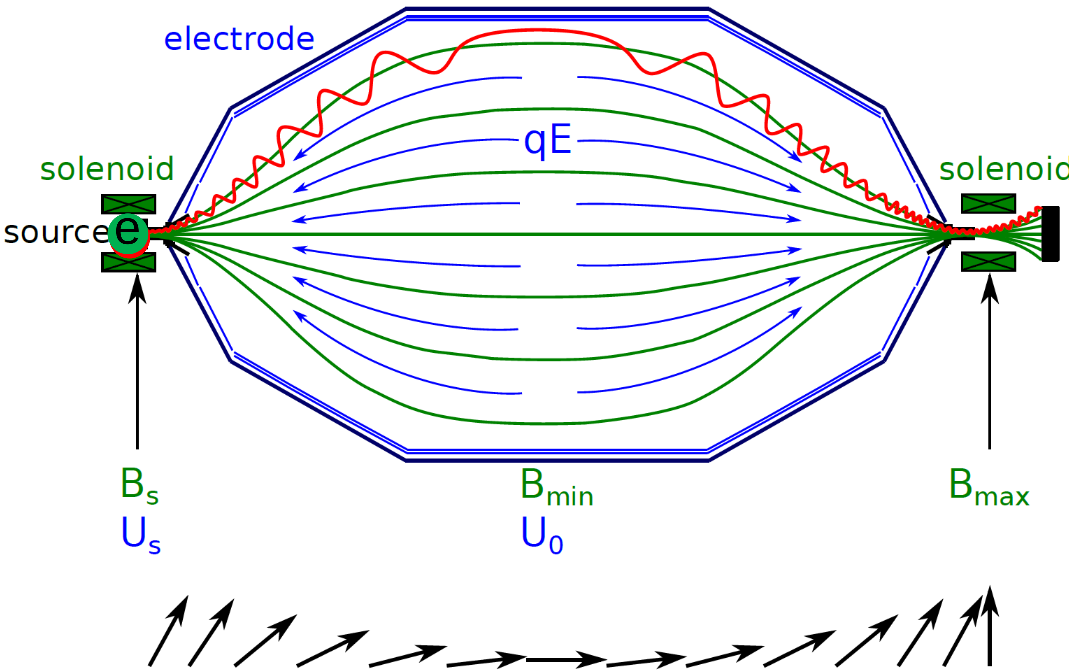
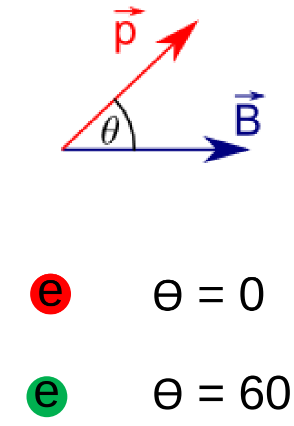
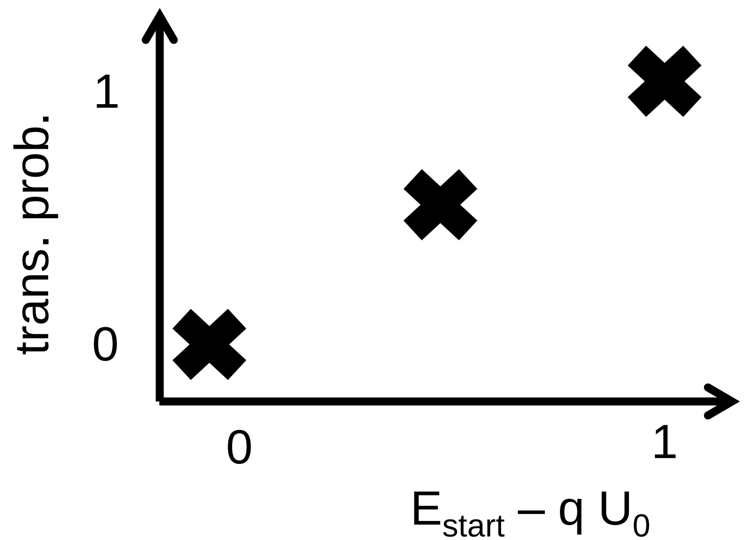
The energy resolution





ret. potential: 18000 V

electron energy: 18001.0 eV



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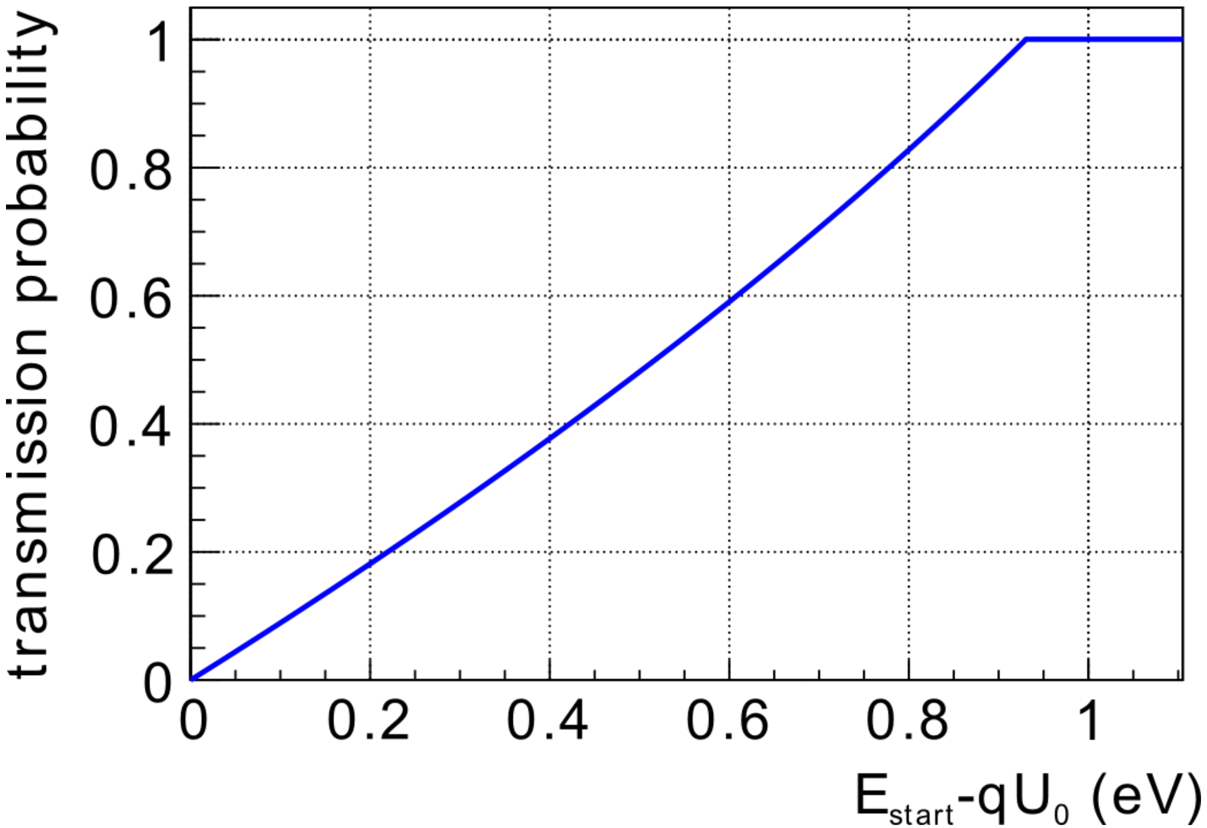
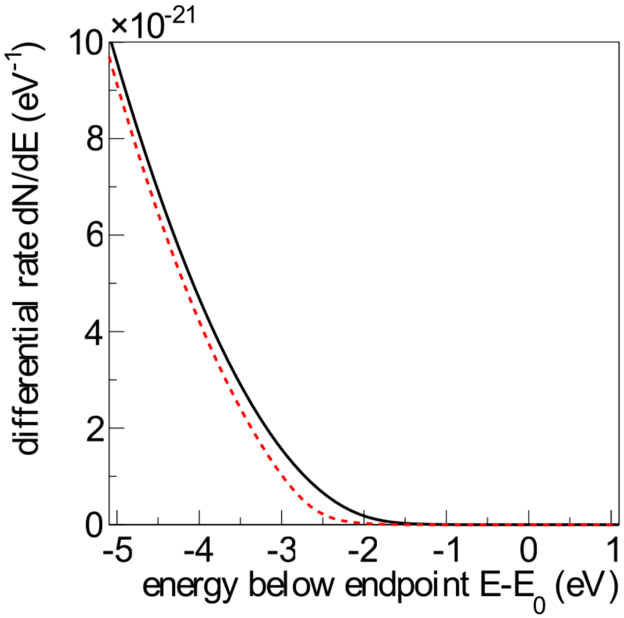
The transmission function

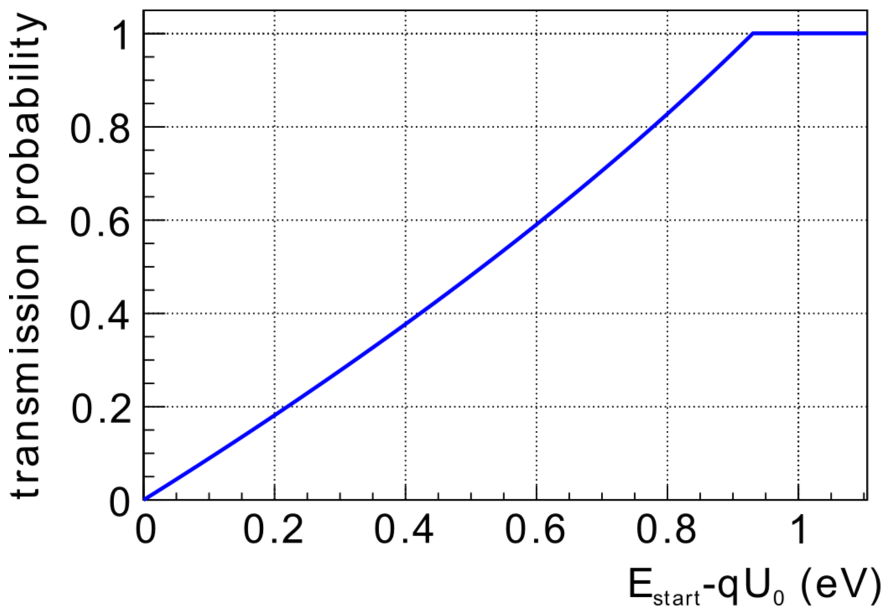


$$\Delta E = 18,6\,keV \cdot \frac{B_{min}}{B_{max}} \approx 1\,eV$$

Integral spectrum



$\otimes$



$$\mathrm{N(qU)} \approx \int_0^{E_0} \frac{dN}{dE}\,(E_0, mv^2) * T(E, qU)dE$$

Integral spectrum is convolution of differential spectrum with transmission function

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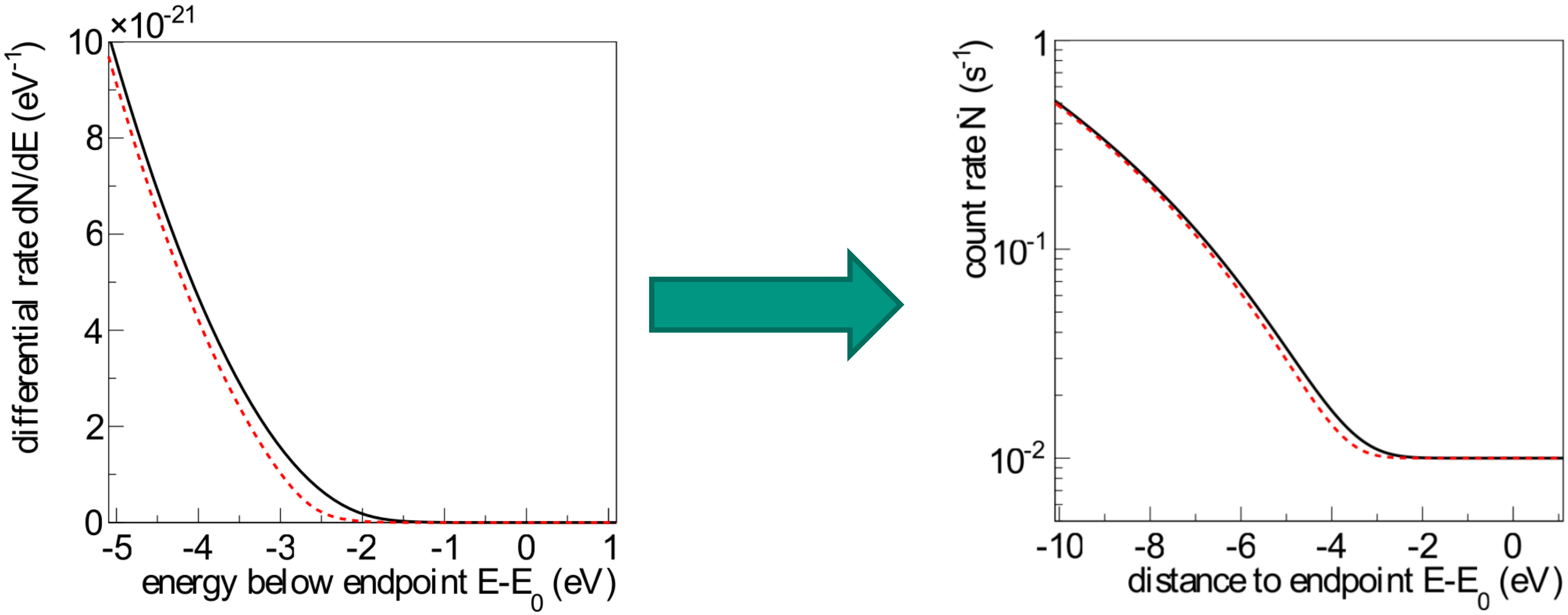
Integral spectrum



Precise knowledge and detailed understanding of the transmission function is essential for a successful neutrino mass measurement

Outline

- How does KATRIN work
- Commissioning of spectrometer and detector
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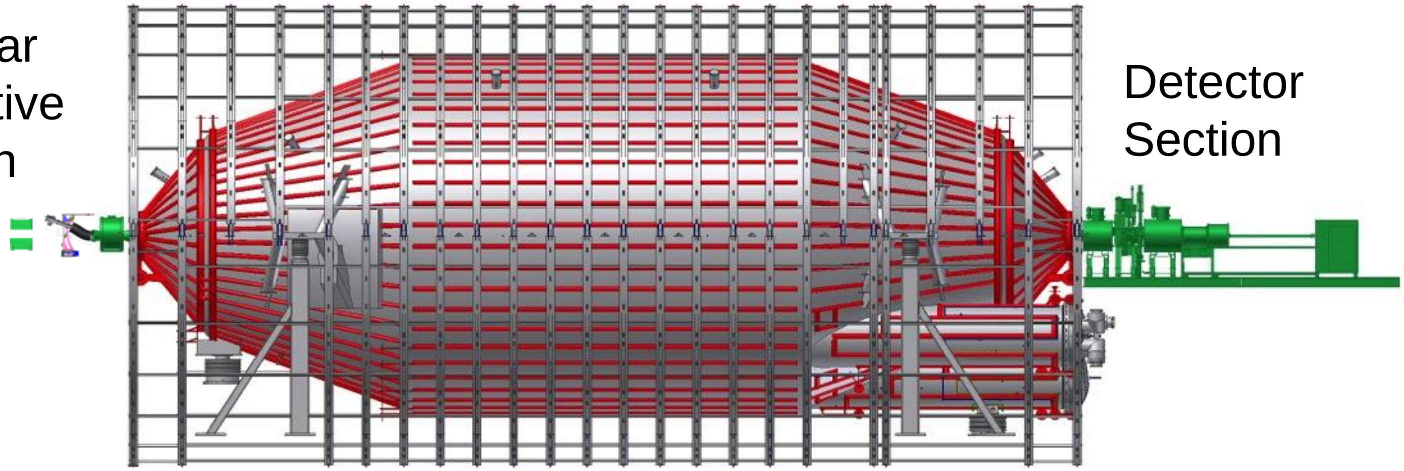
- Transmission function at high rate

Measurement phase finished last week

Commissioning of Spectrometer and Detector



Main goals:

- Test of Hardware and Slowcontrol components
- Measurement and Understanding of background
- Understanding of transmission properties
- Verification of simulations software and models

Focal plane detector system

Si-PIN Diode with 148 Pixel

See talk by J. Schwarz, later today

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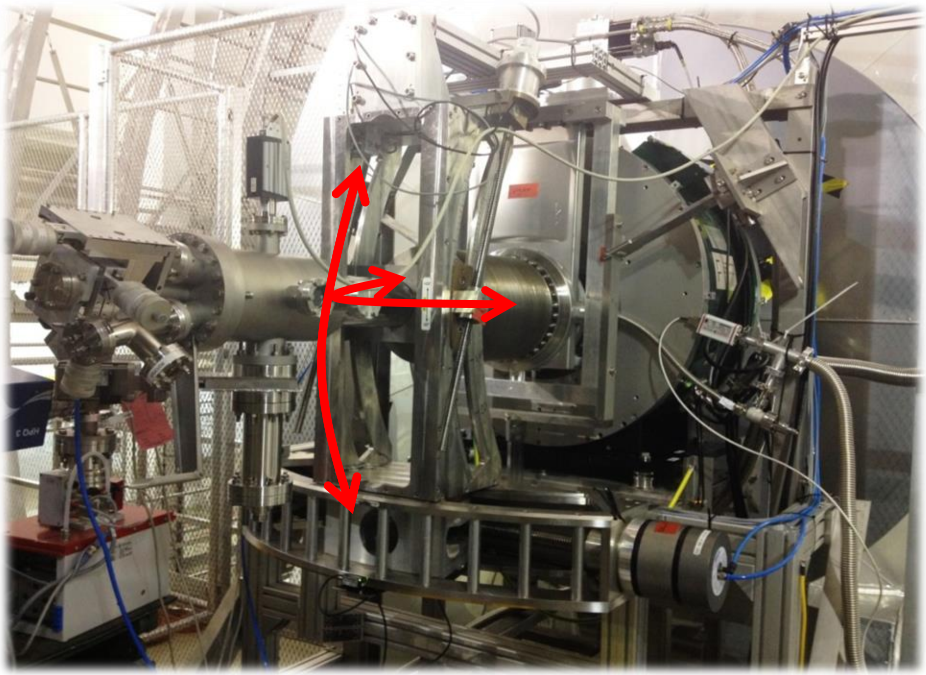
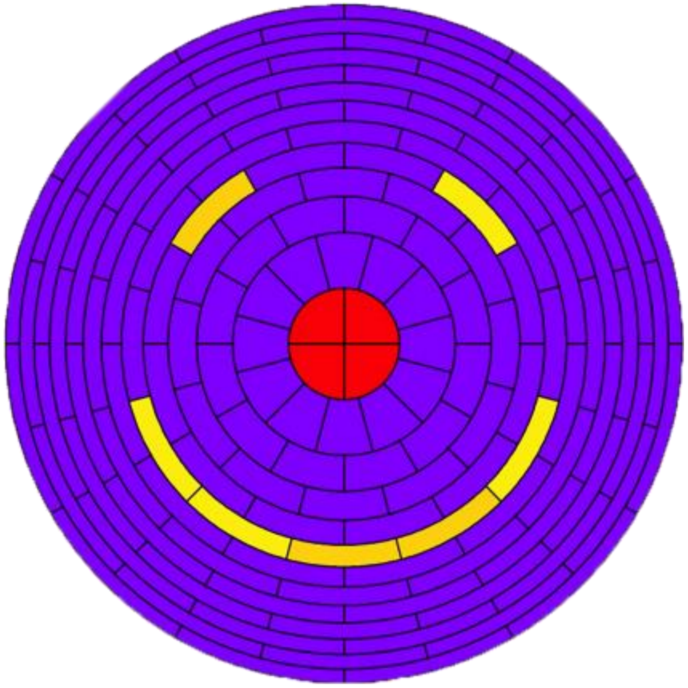
Electron Gun



Electron Gun:
- ↳Quasi monoenergetic
- ↳Pulsed for ToF measurements
- ↳Movable to cover full detector flux



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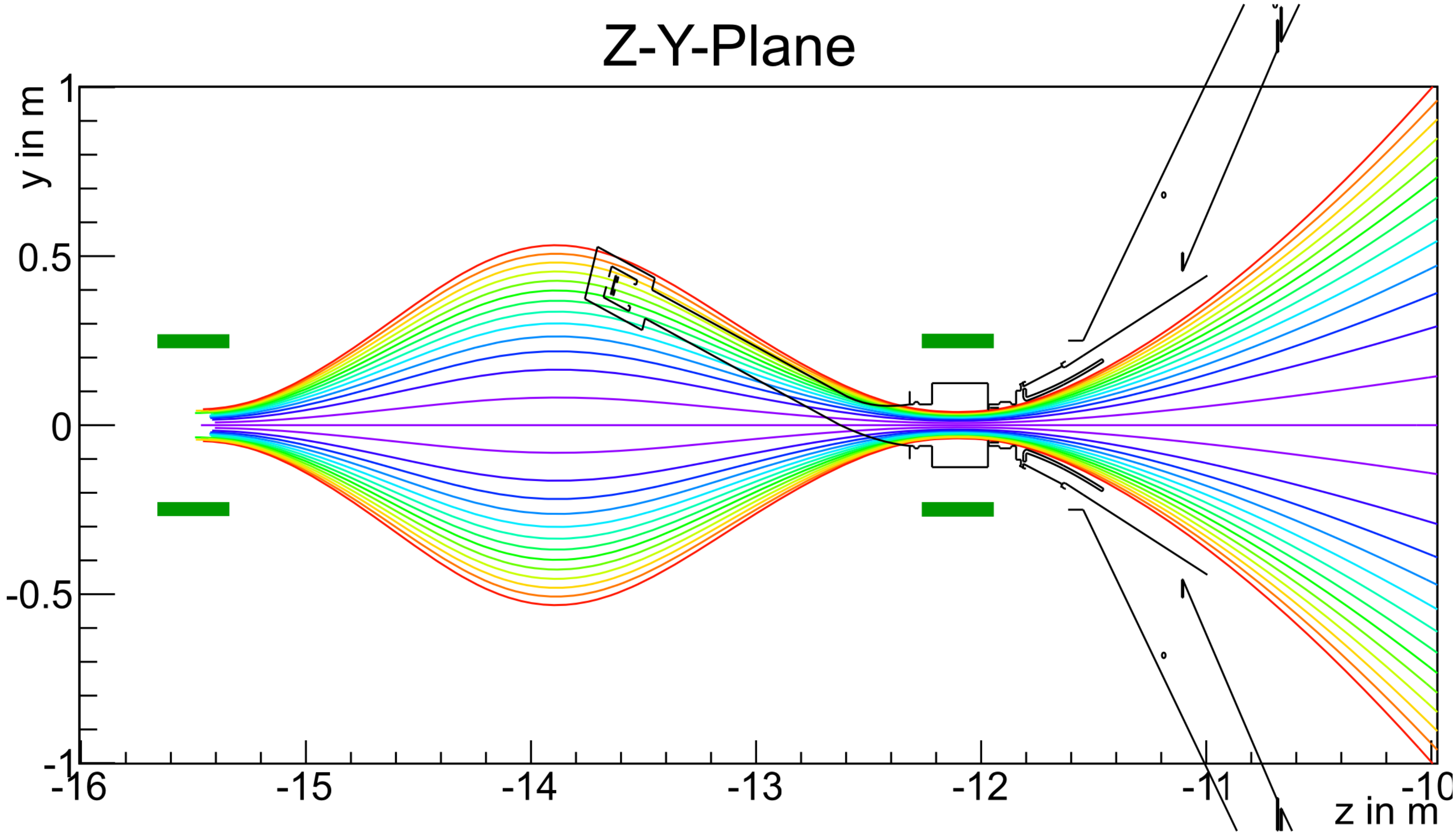
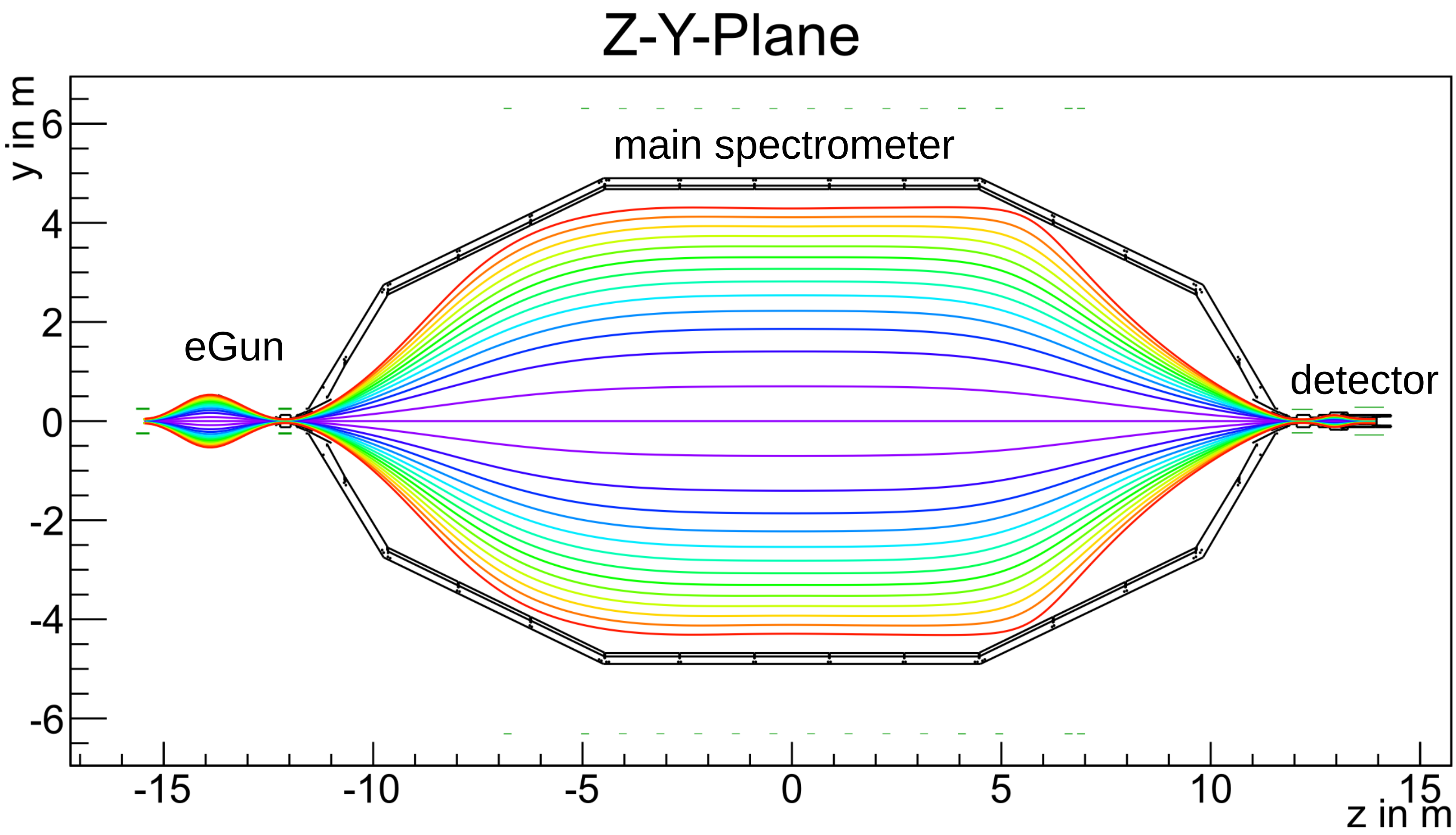
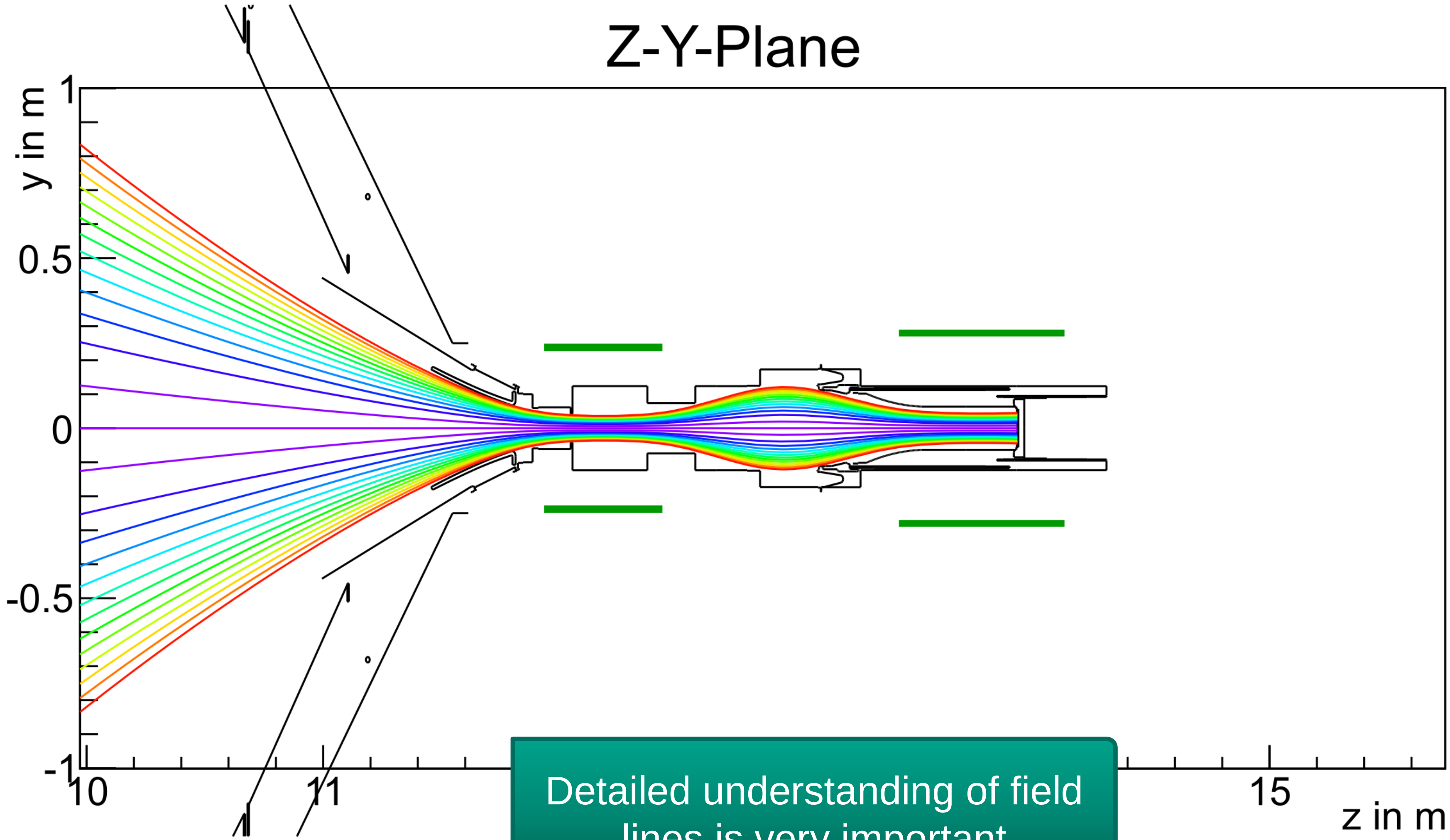
Flux tube - eGun



Flux tube

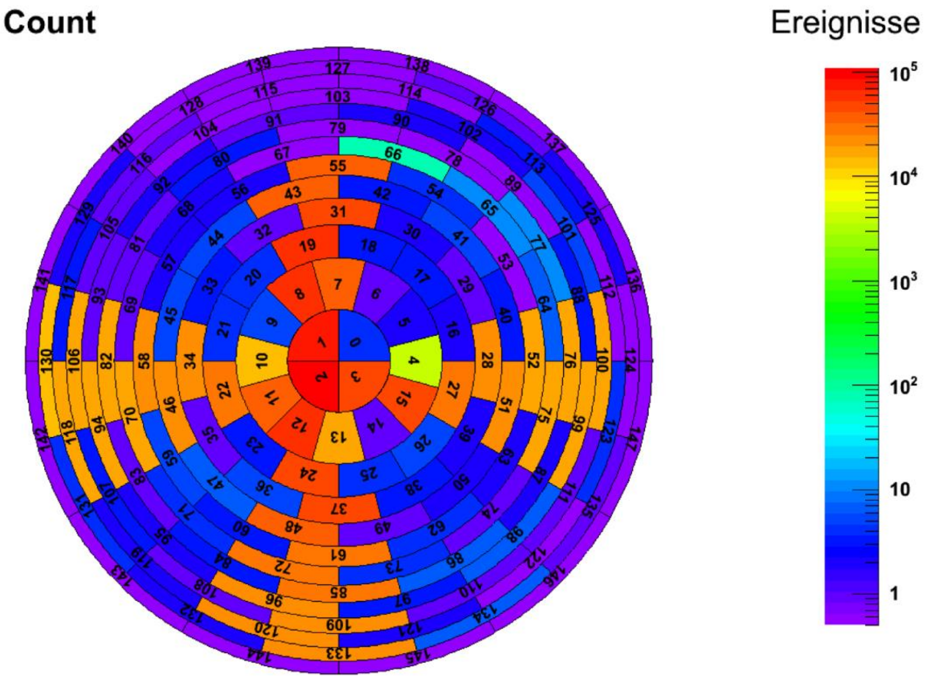

Z-Y-Plane
y in m
6
4
2
0
-2
-4
-6
main spectrometer
eGun
detector
-15
-10
-5
0
5
10
15
z in m

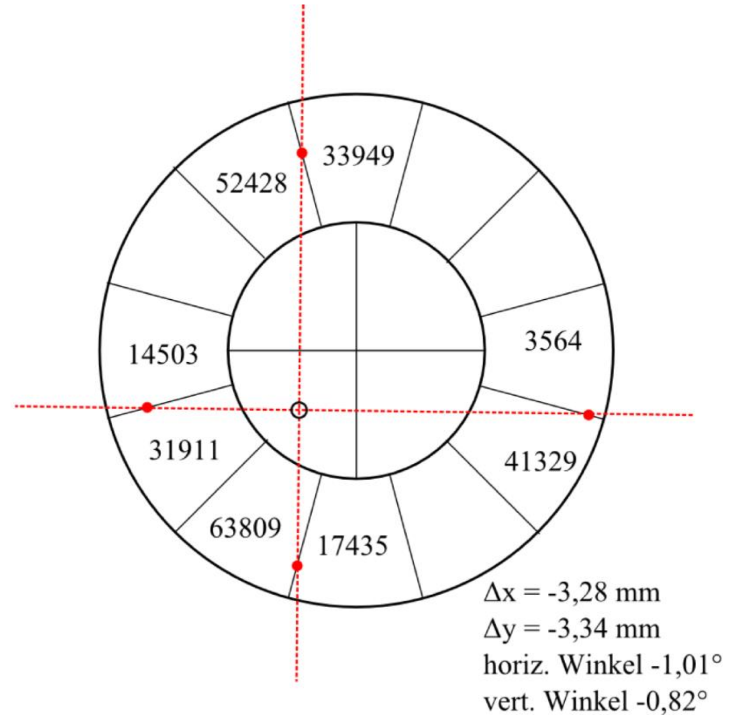
Flux tube - detector



Detailed understanding of field lines is very important

eGun-Detector alignment





Misalignment of eGun and detector needs to be taken into account in the analysis

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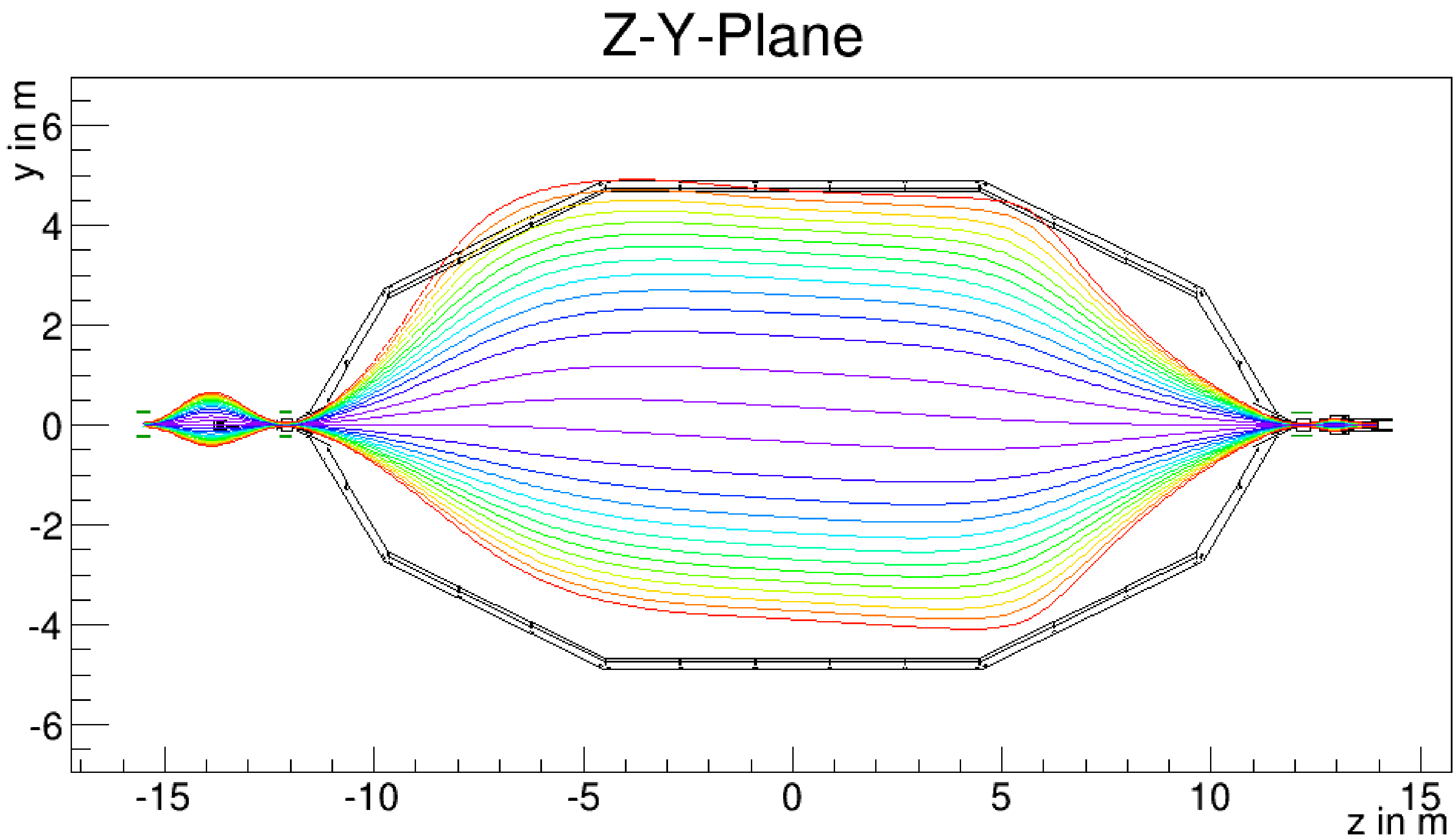
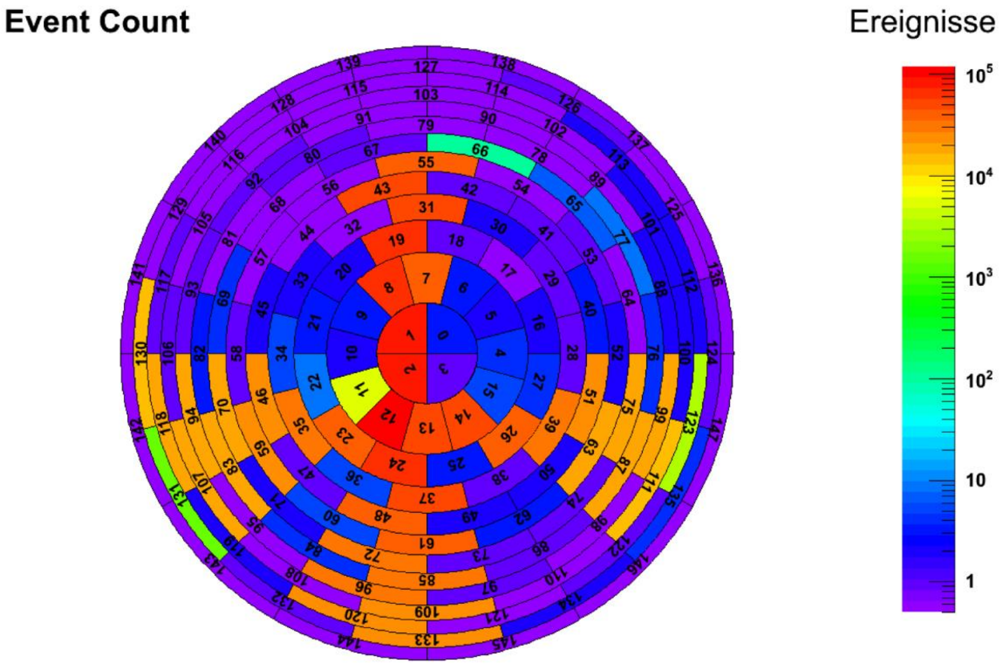
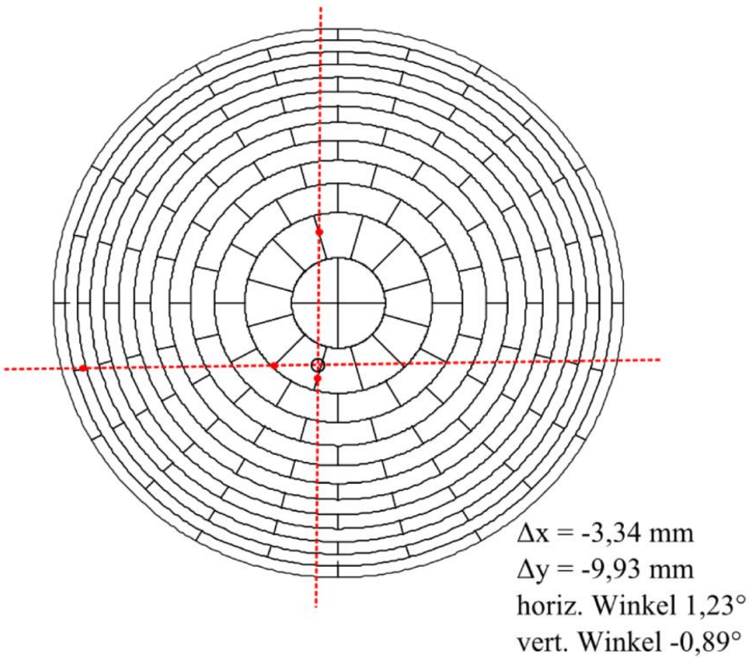
Different magnetic coil setup



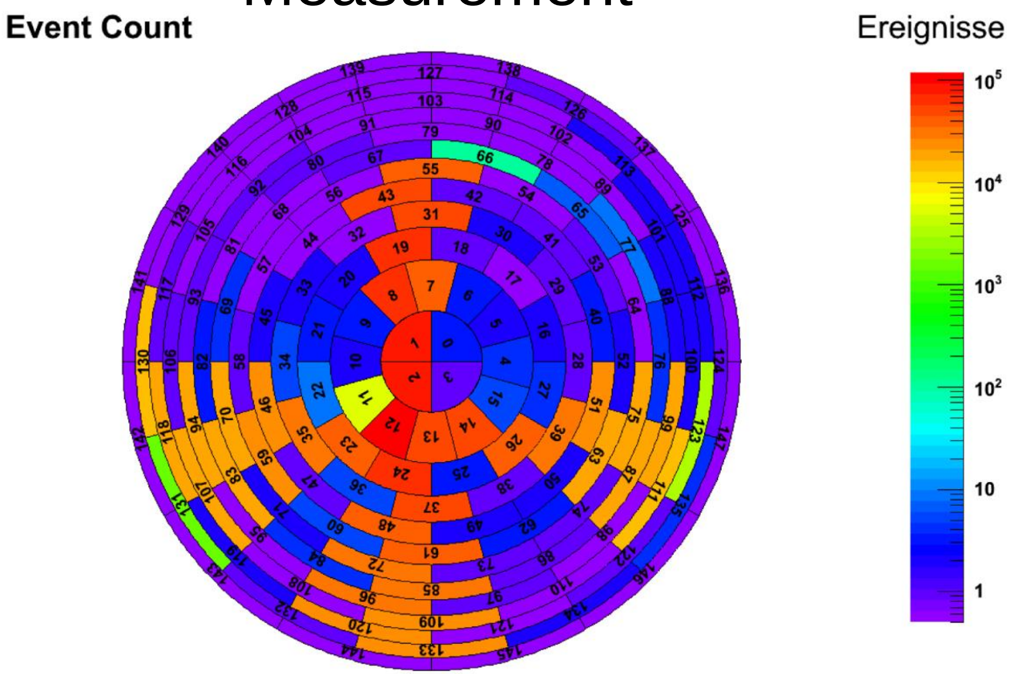
Different magnetic coil setup



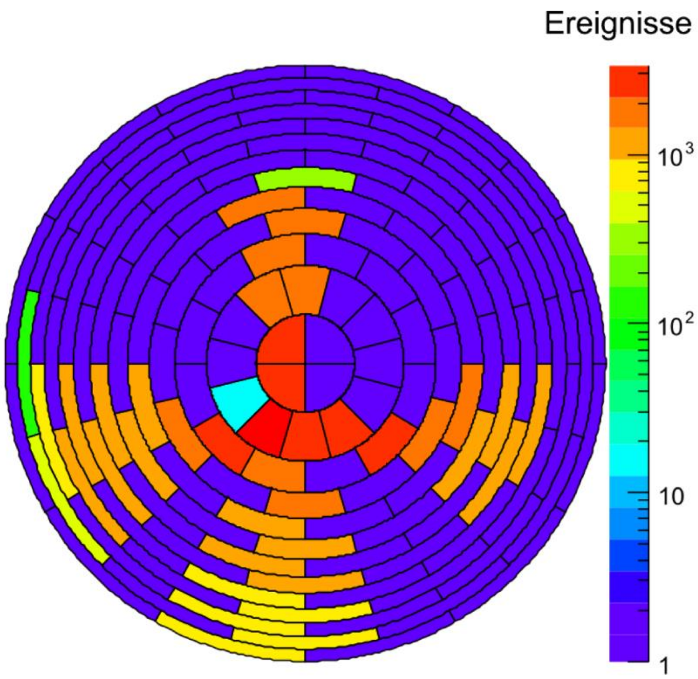


Comparison with simulation

Measurement



Simulation



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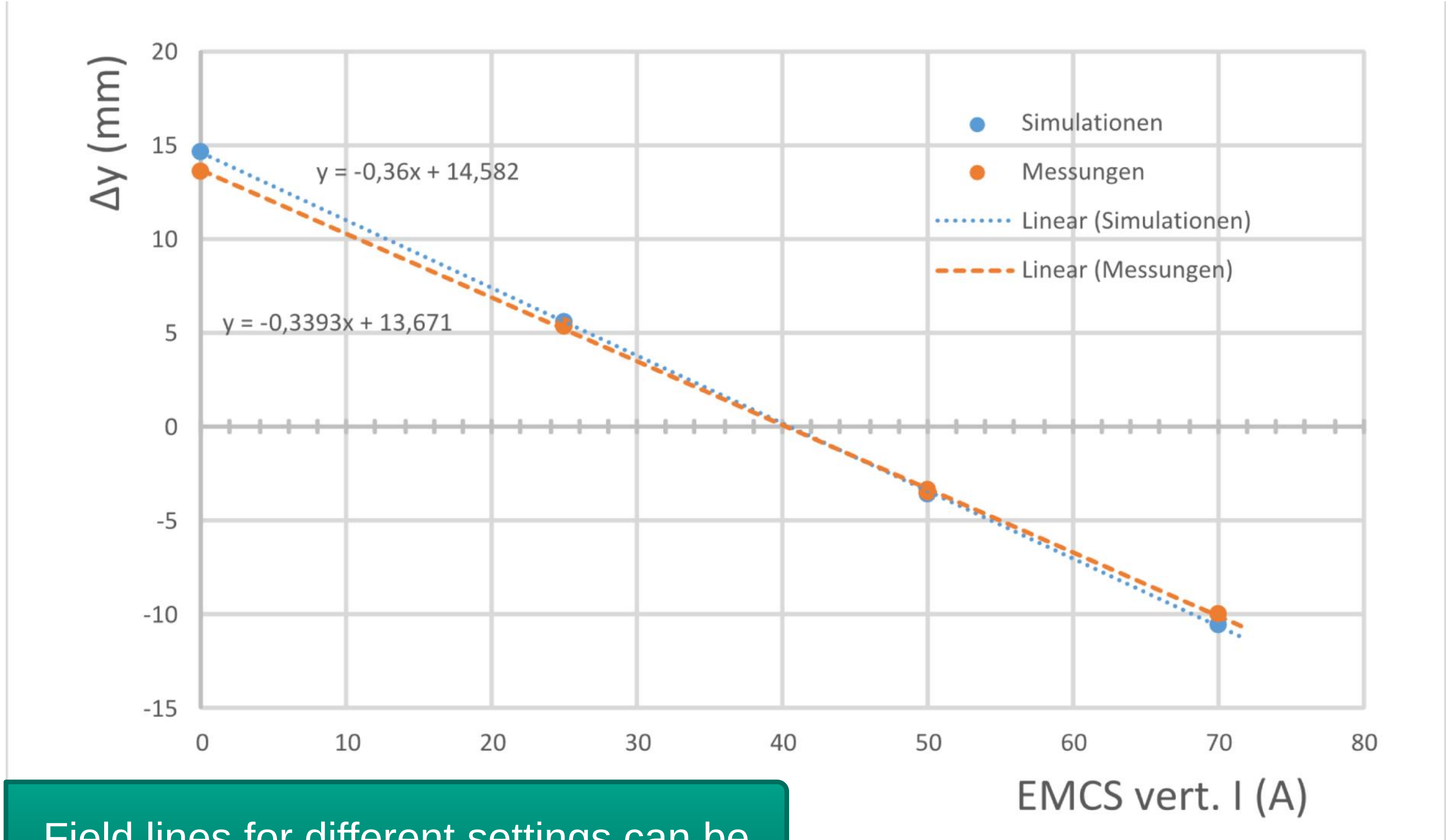
Comparison with simulation



Field lines for different settings can be very good reproduced by simulations

plots by
N. Stallkamp

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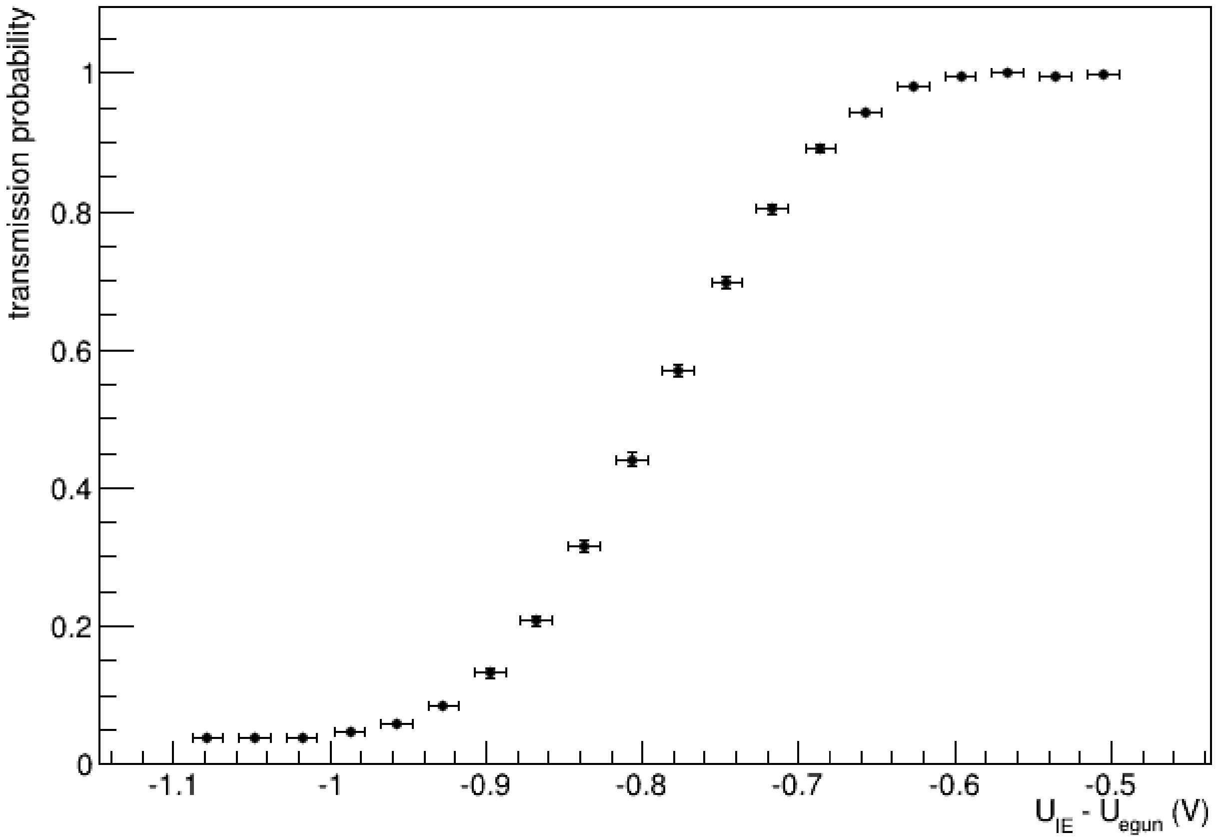
Transmission function



Spectrometer works as MAC-E-Filter – commissioning successful

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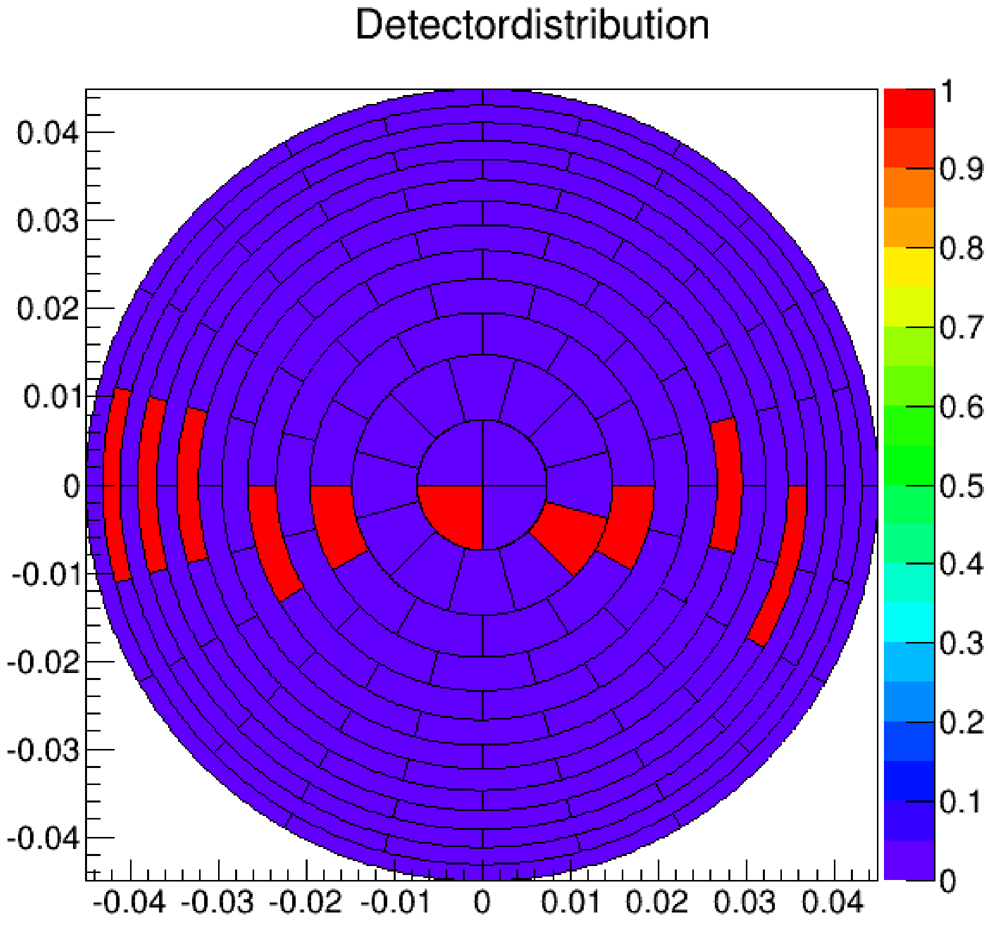
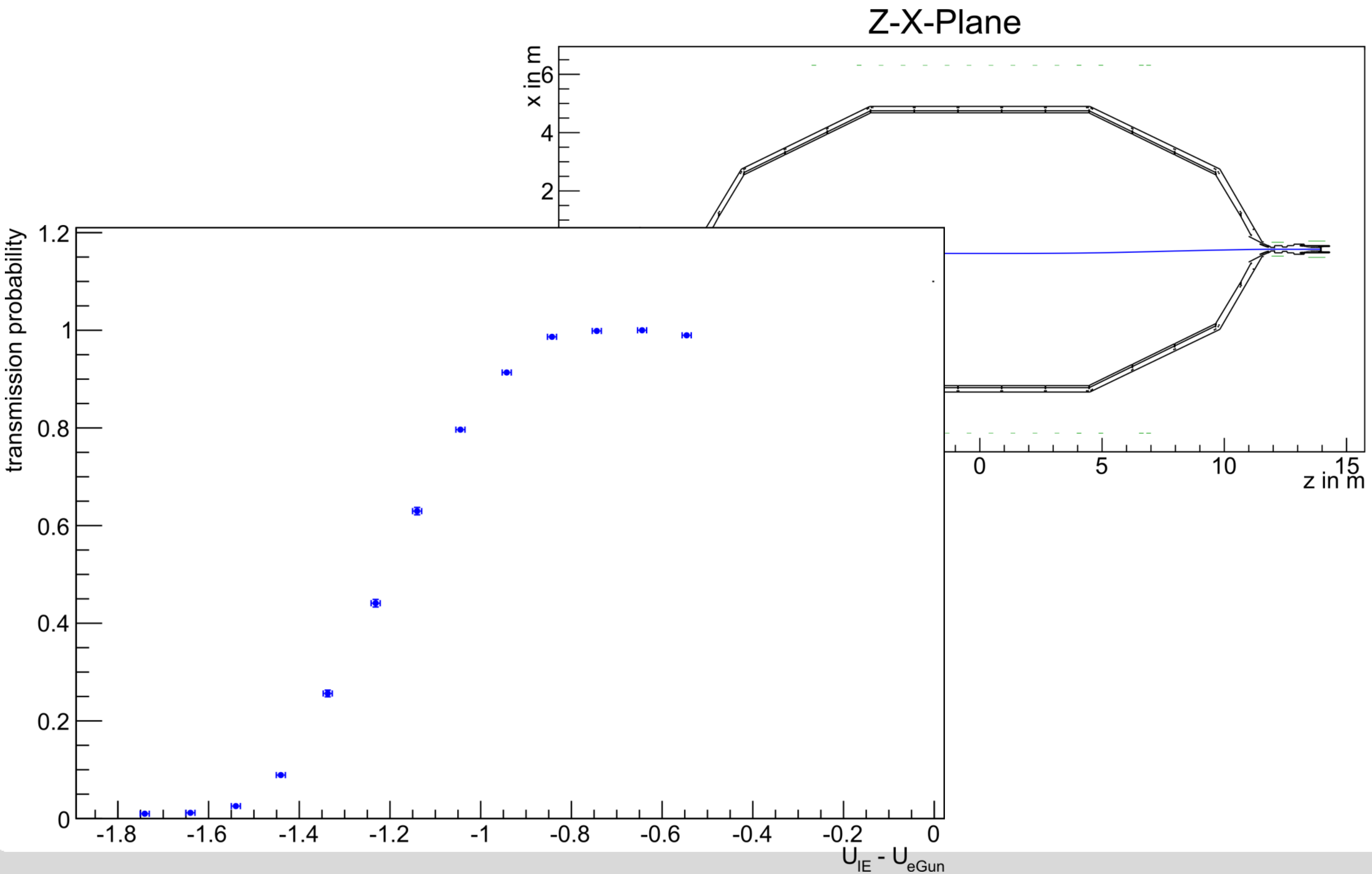
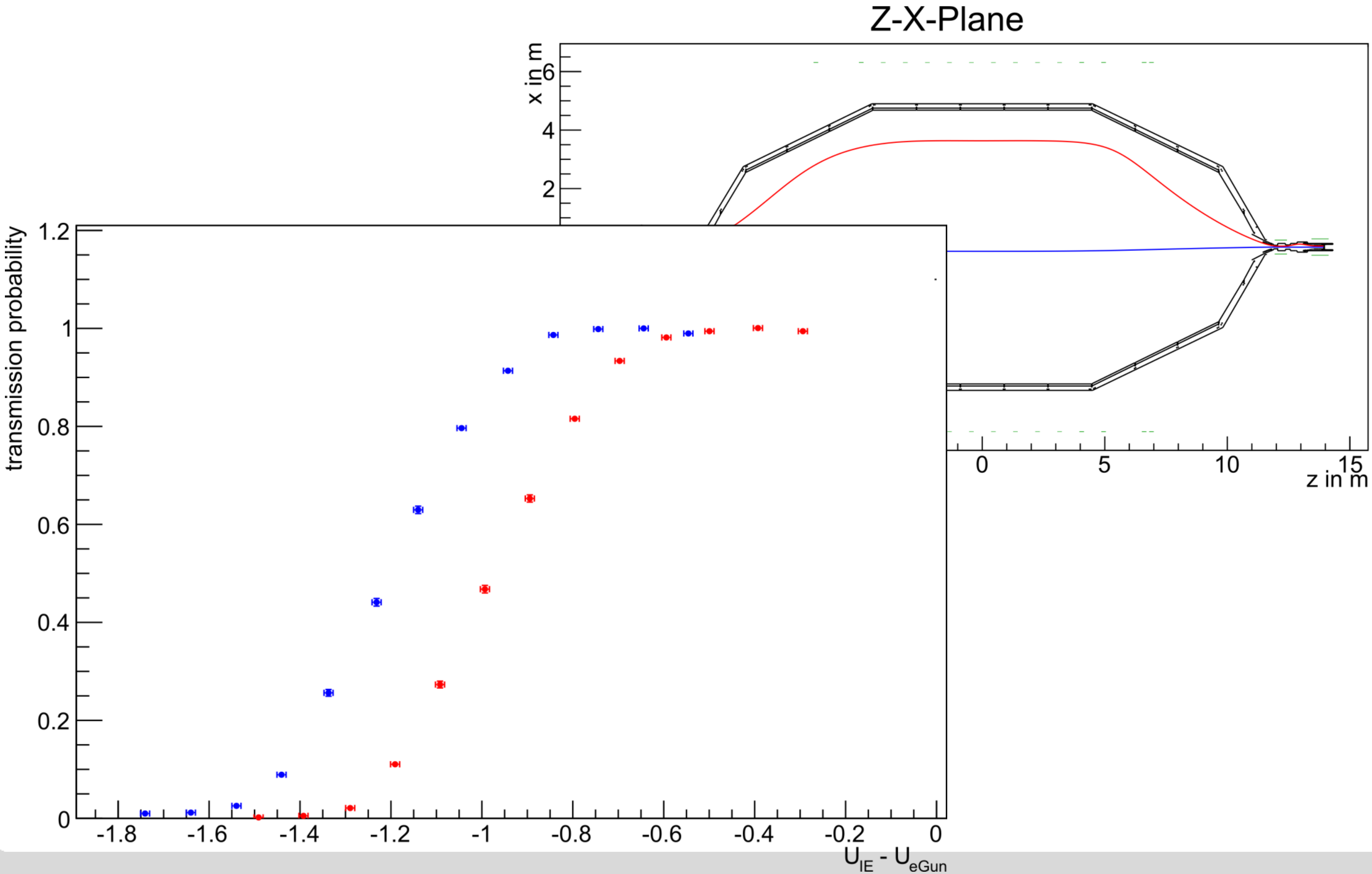
Measure TF at different radii



Radial transmission scan



Radial transmission scan



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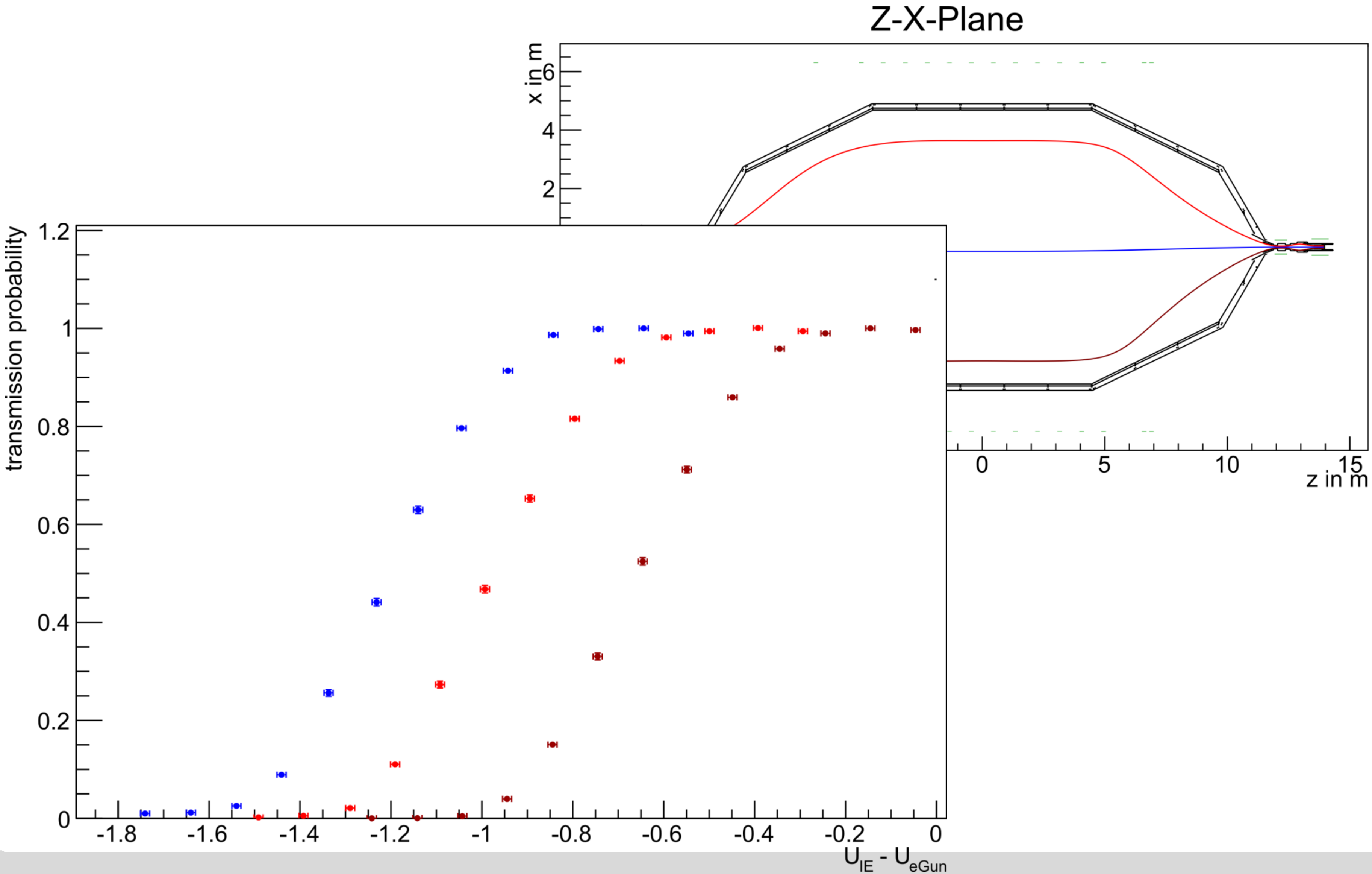
Radial transmission scan



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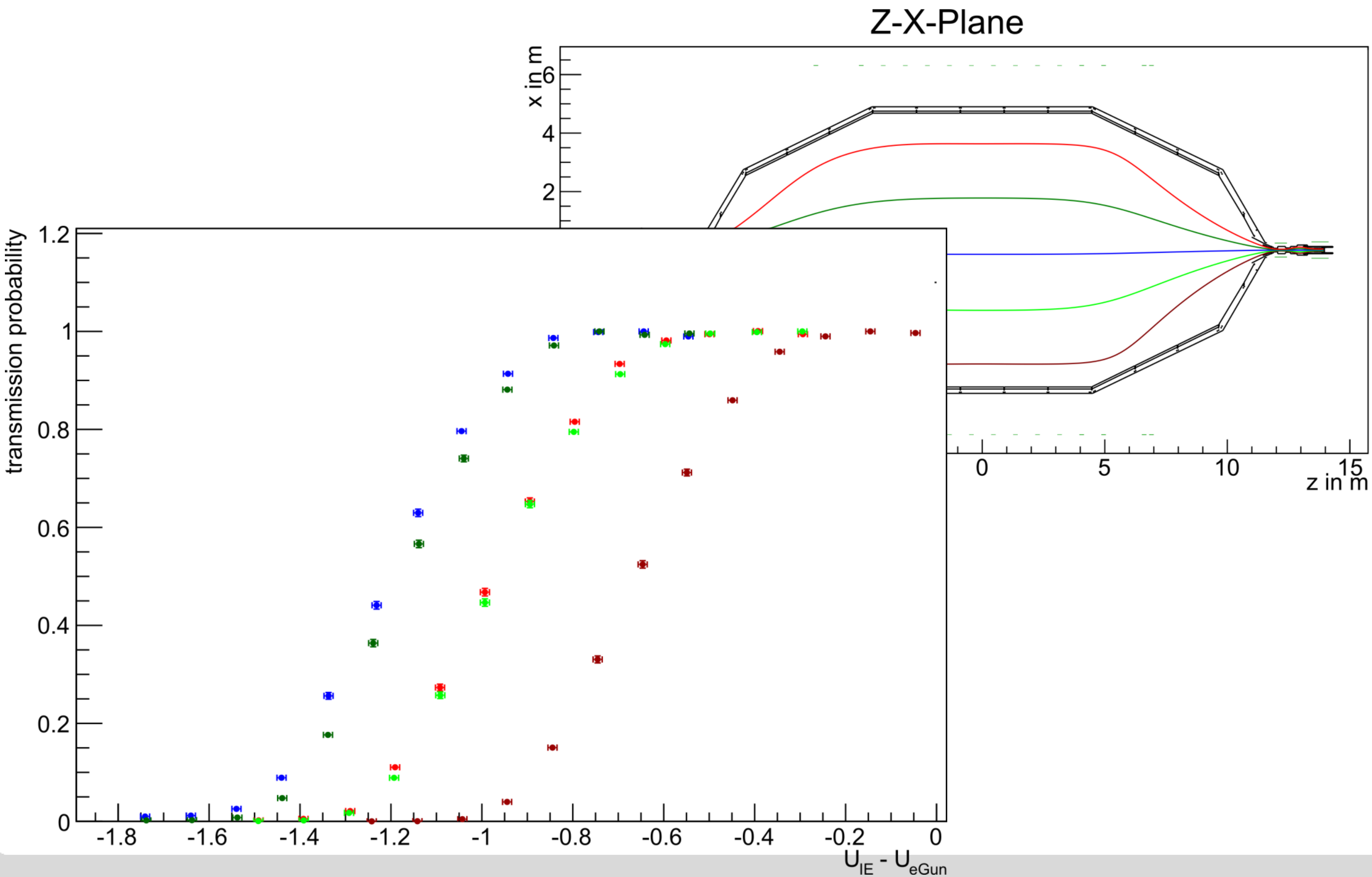
Radial transmission scan



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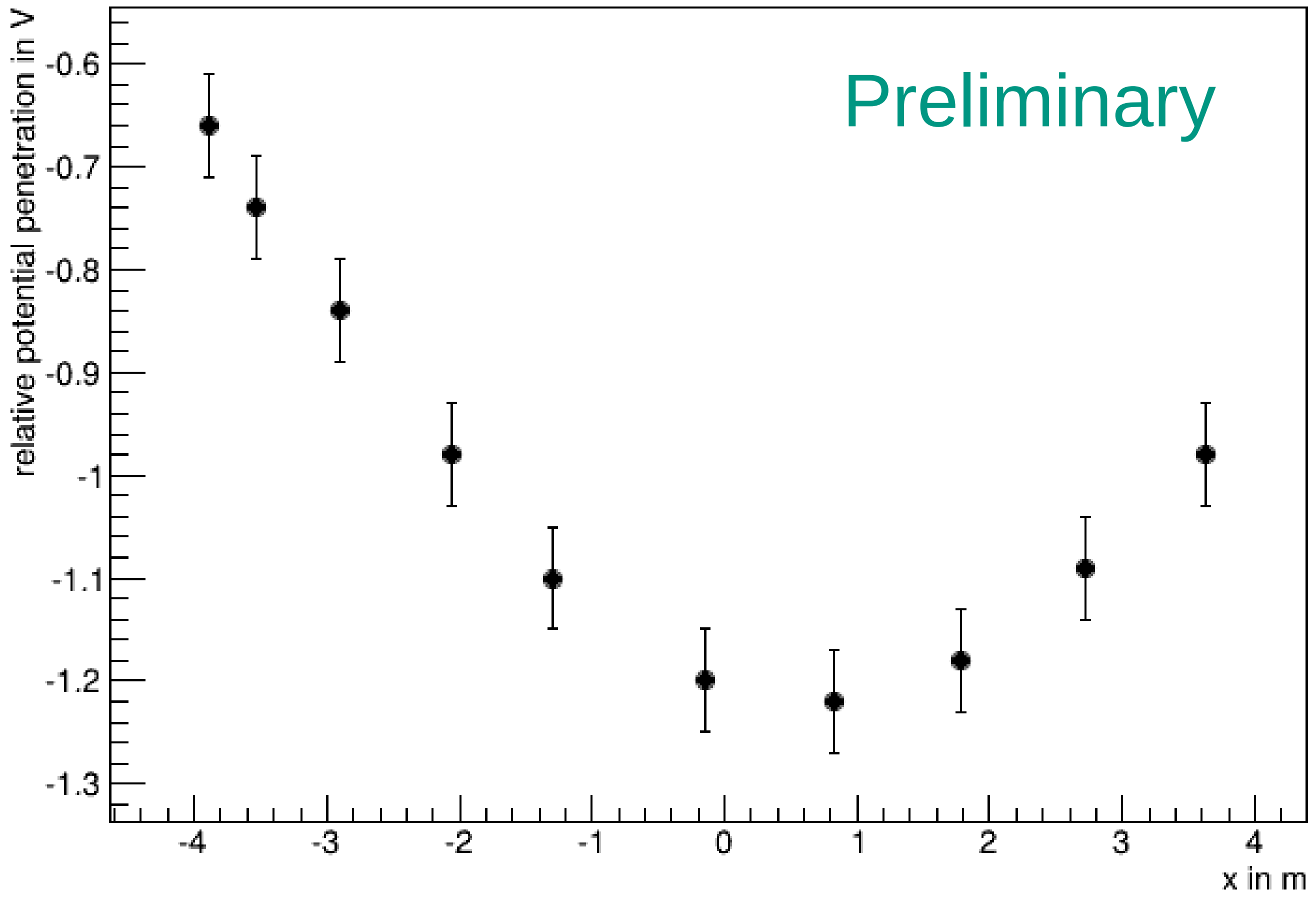
Radial potential measurement



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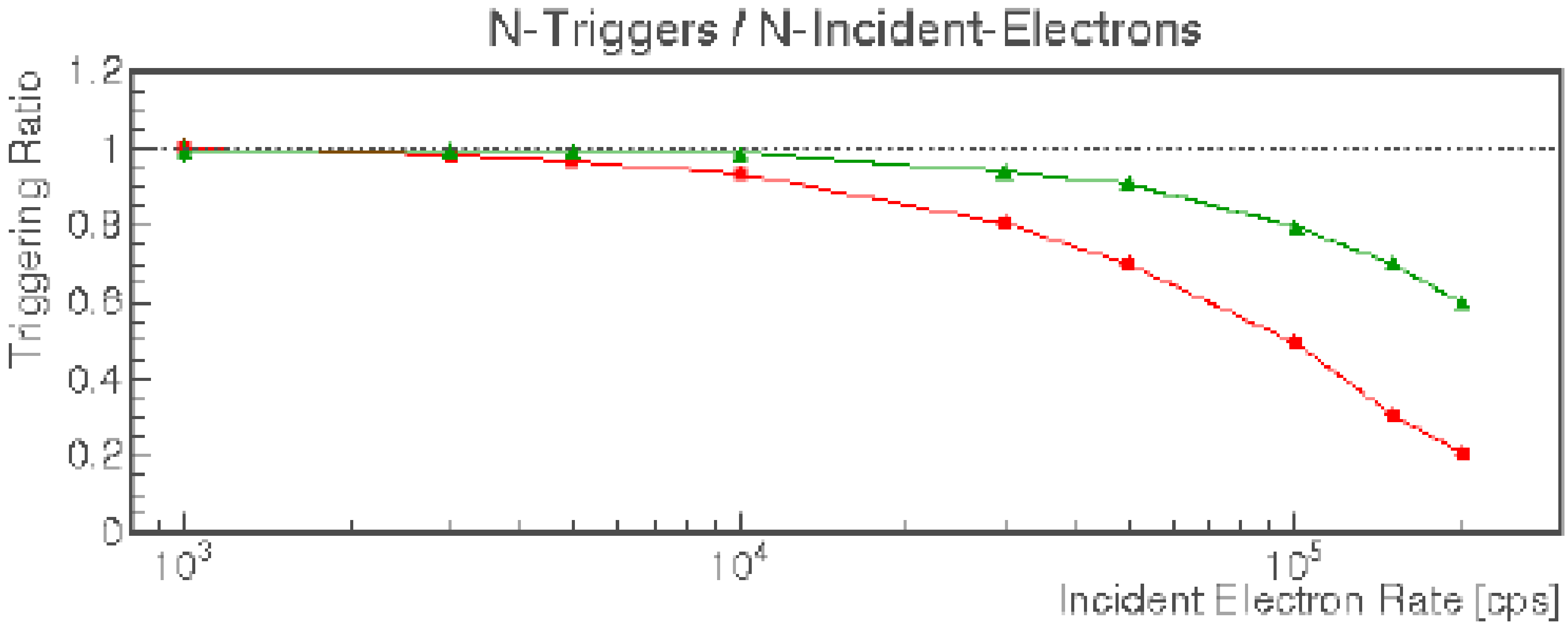
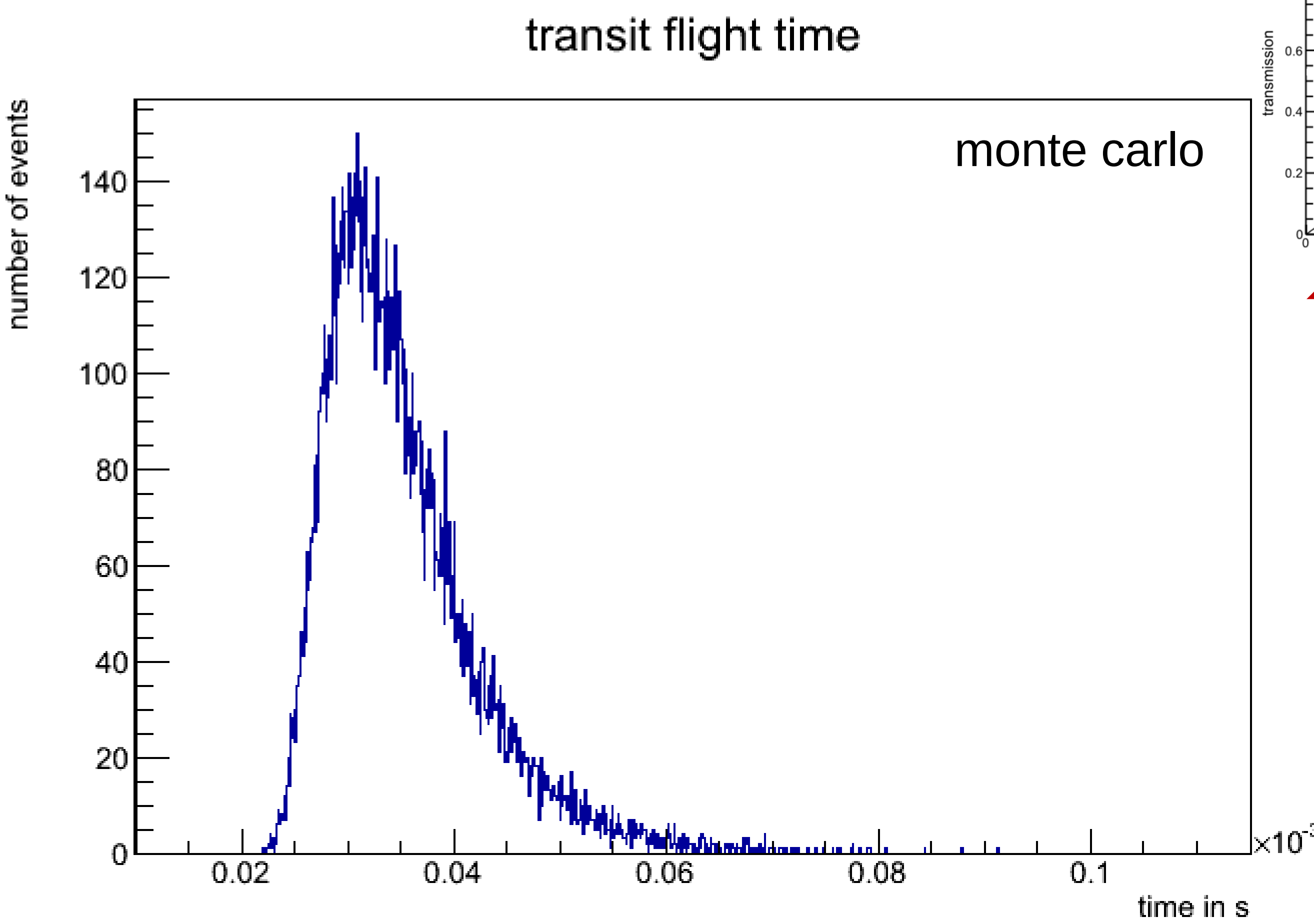
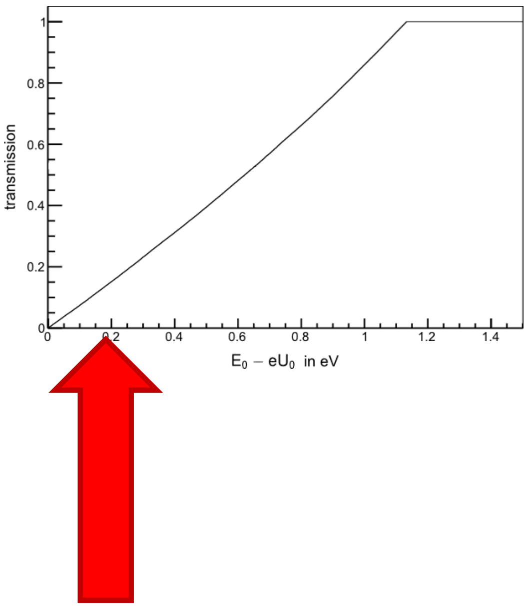
Detector efficiency at high rates



Efficiency of detector depends on rate and time profile

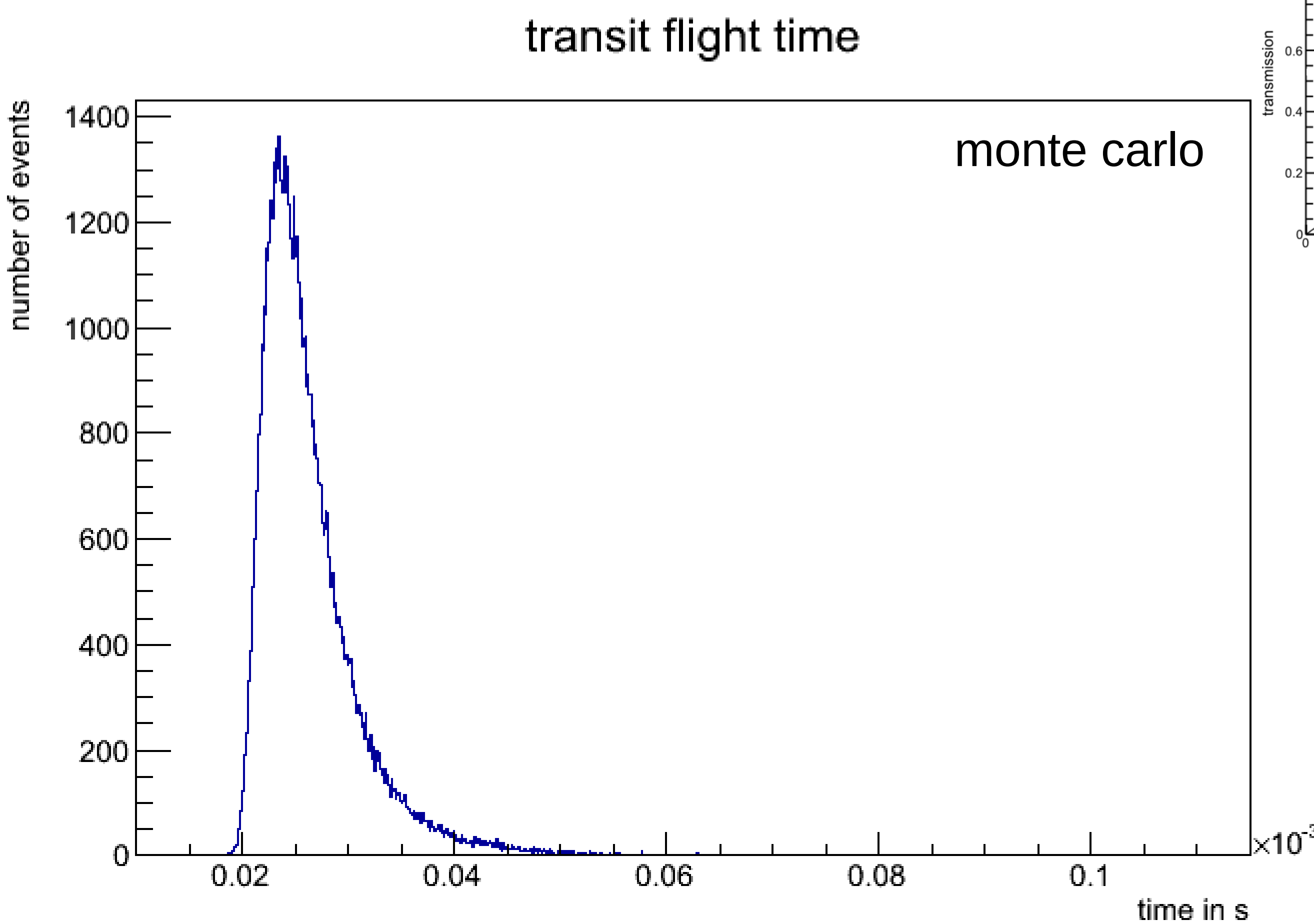
Transit flight times at different transmission points

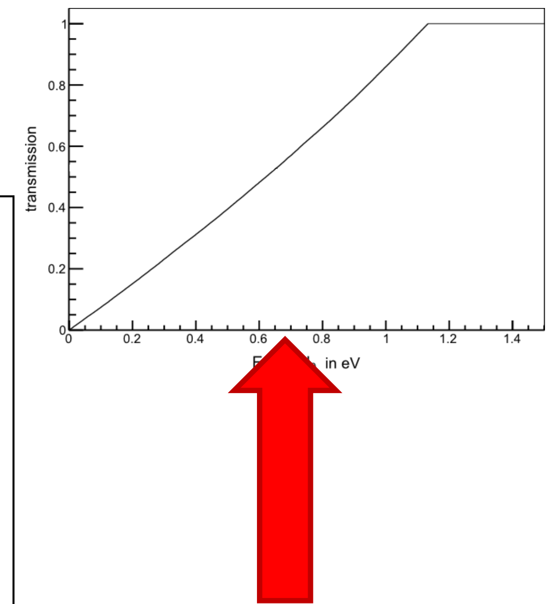




$\Delta t \approx 40\ \mu s$

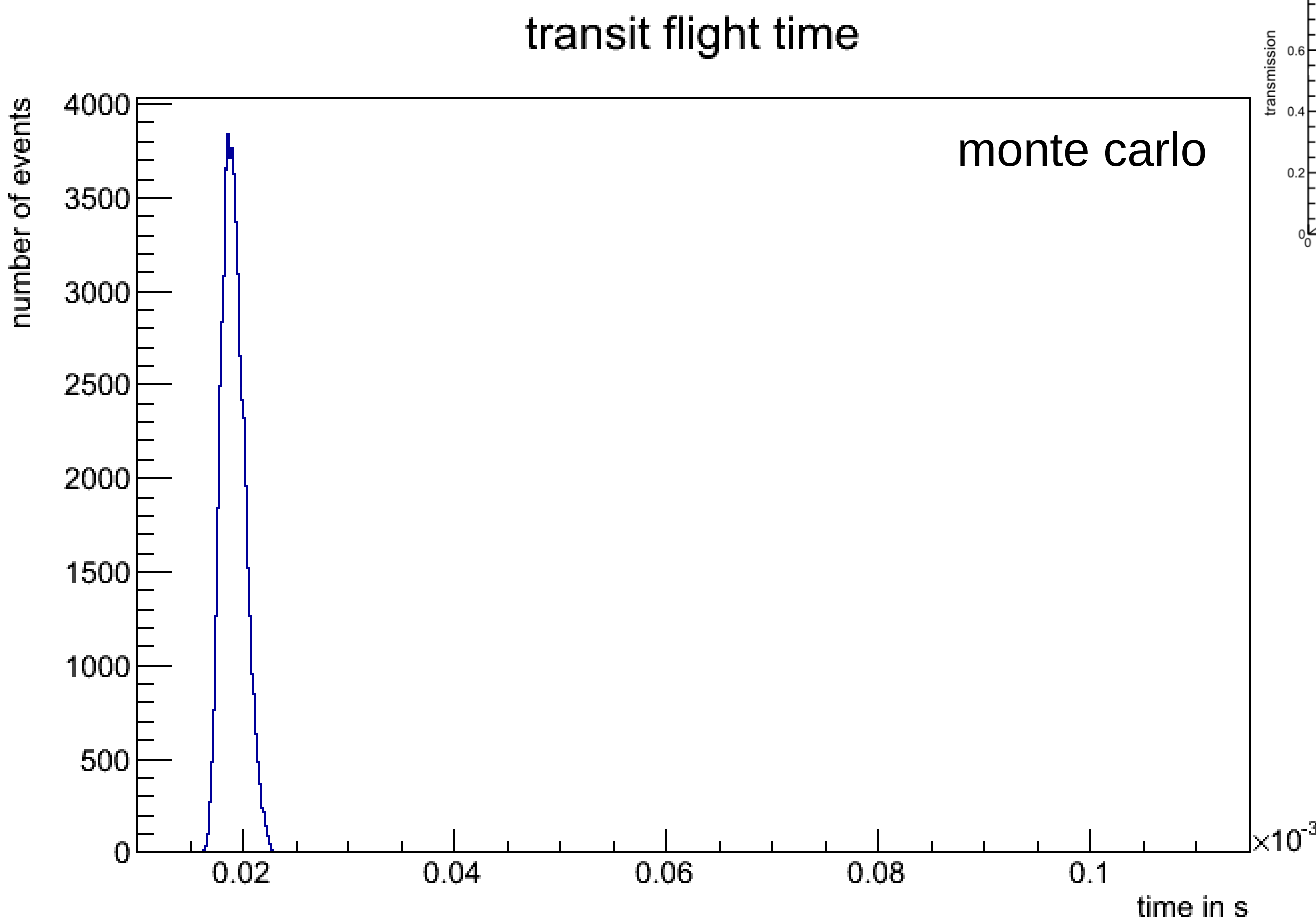
Transit flight times at different transmission points

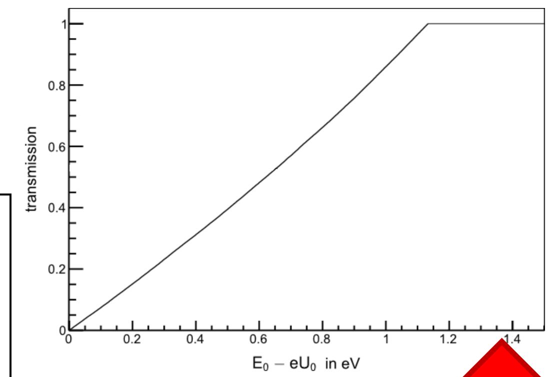




$\Delta t \approx 20\ \mu s$

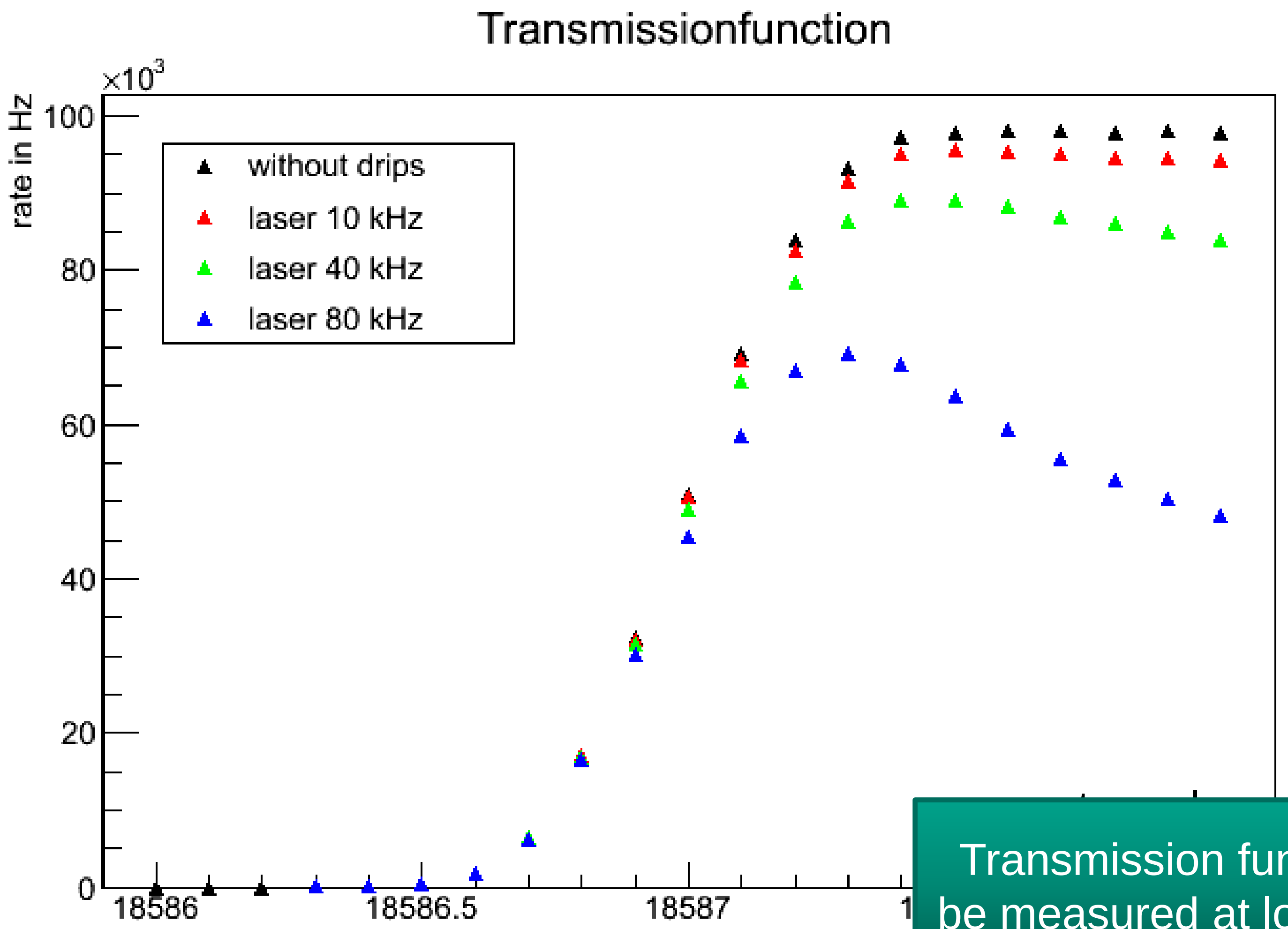
Transit flight times at different transmission points





$\Delta t \approx 5\ \mu s$

Influence on transmission function



Transmission functions can only be measured at low rate (<5 kcps)

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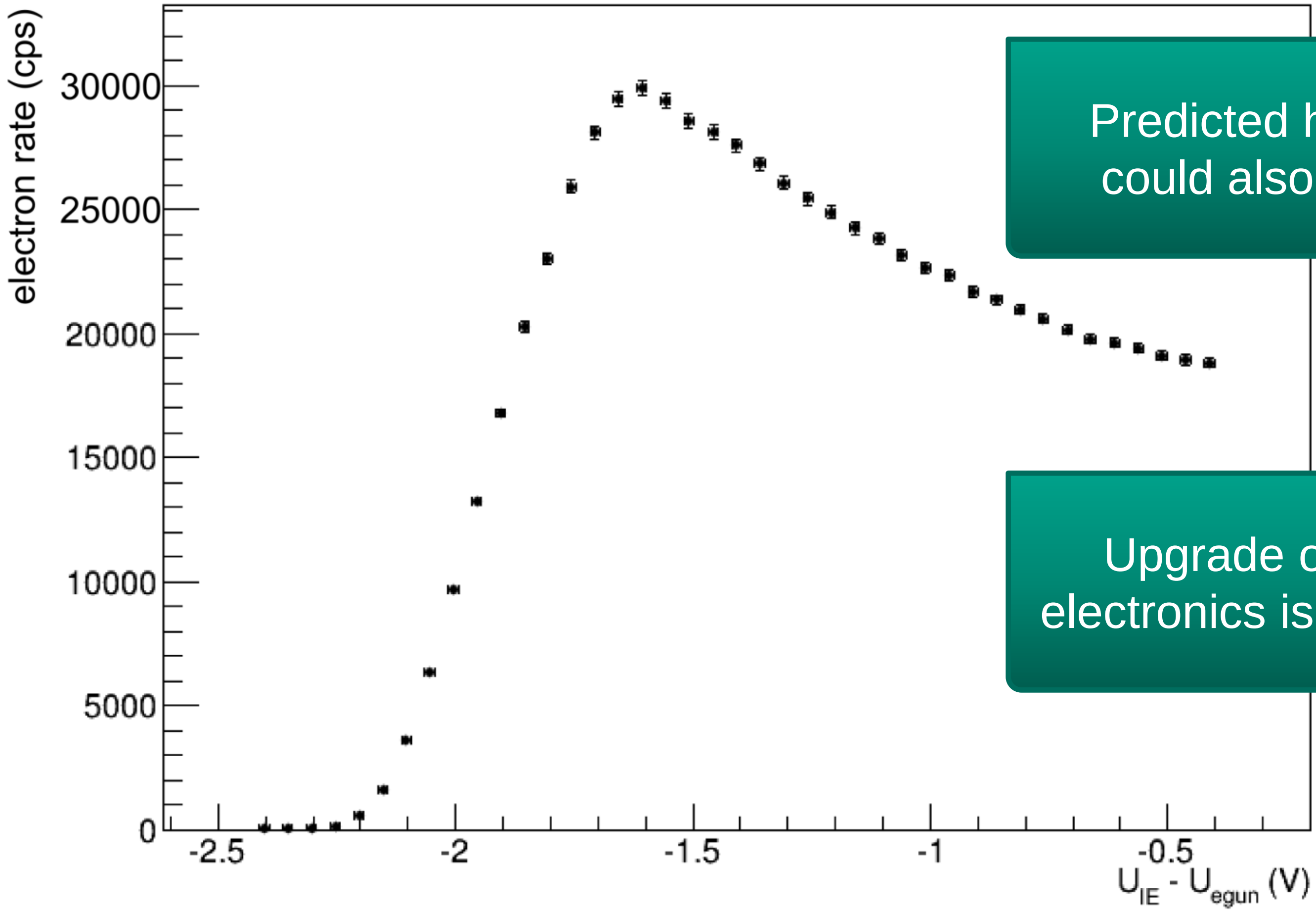
TF Measurement at high rate



Predicted high rate effect could also be measured

Upgrade of the detector electronics is already planned

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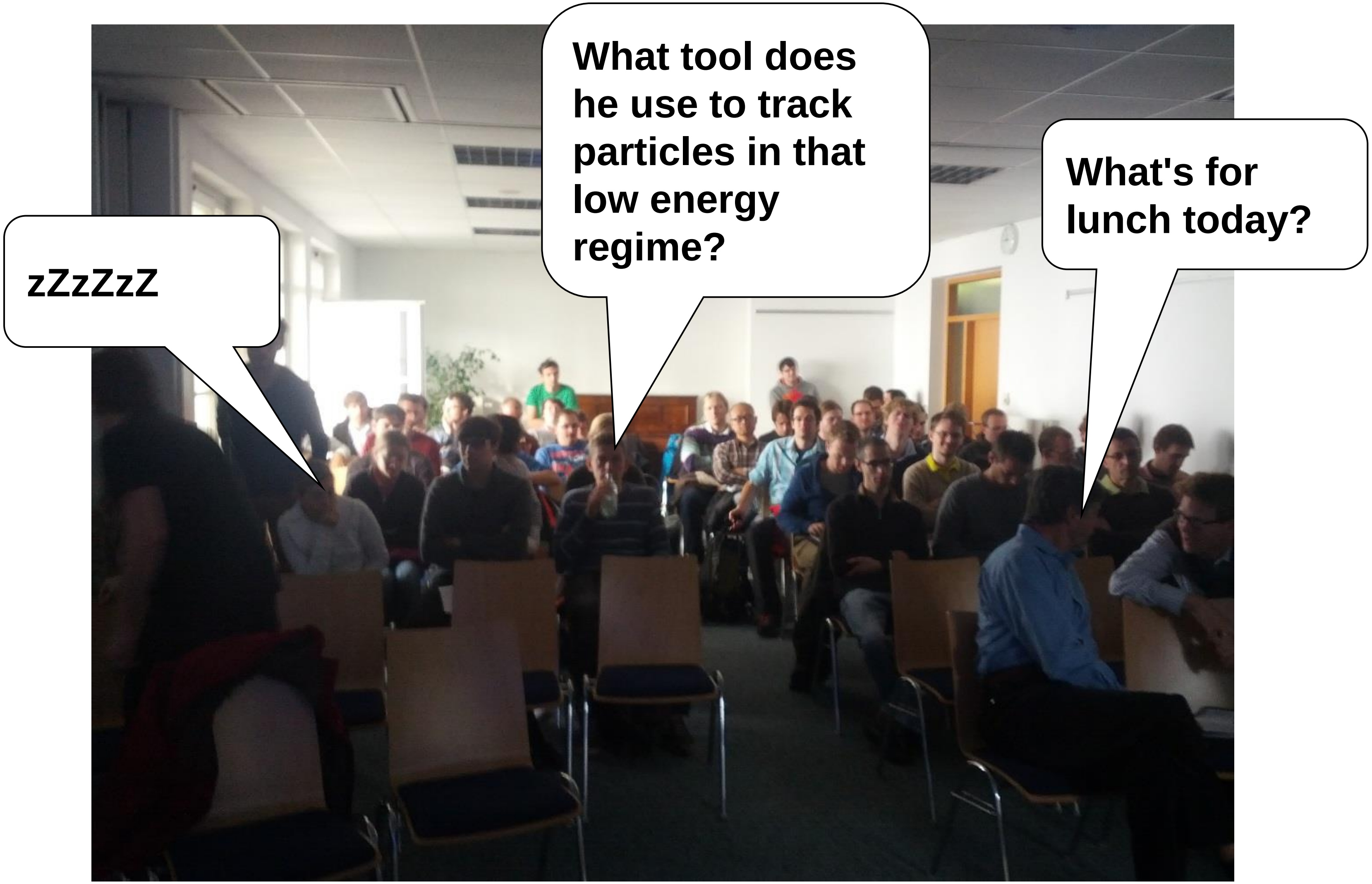
Conclusion

- KATRIN uses the MAC-E-Filter technique to measure an integrated electron spectrum
- Detailed knowledge of transmission function is important for neutrino mass analysis
- Successful commissioning of the spectrometer and detector section
- Electron gun can be used for transmission function measurements and potential mapping
- Predicted “high rate”-effects of the transmission function could be confirmed by measurements

Open questions?



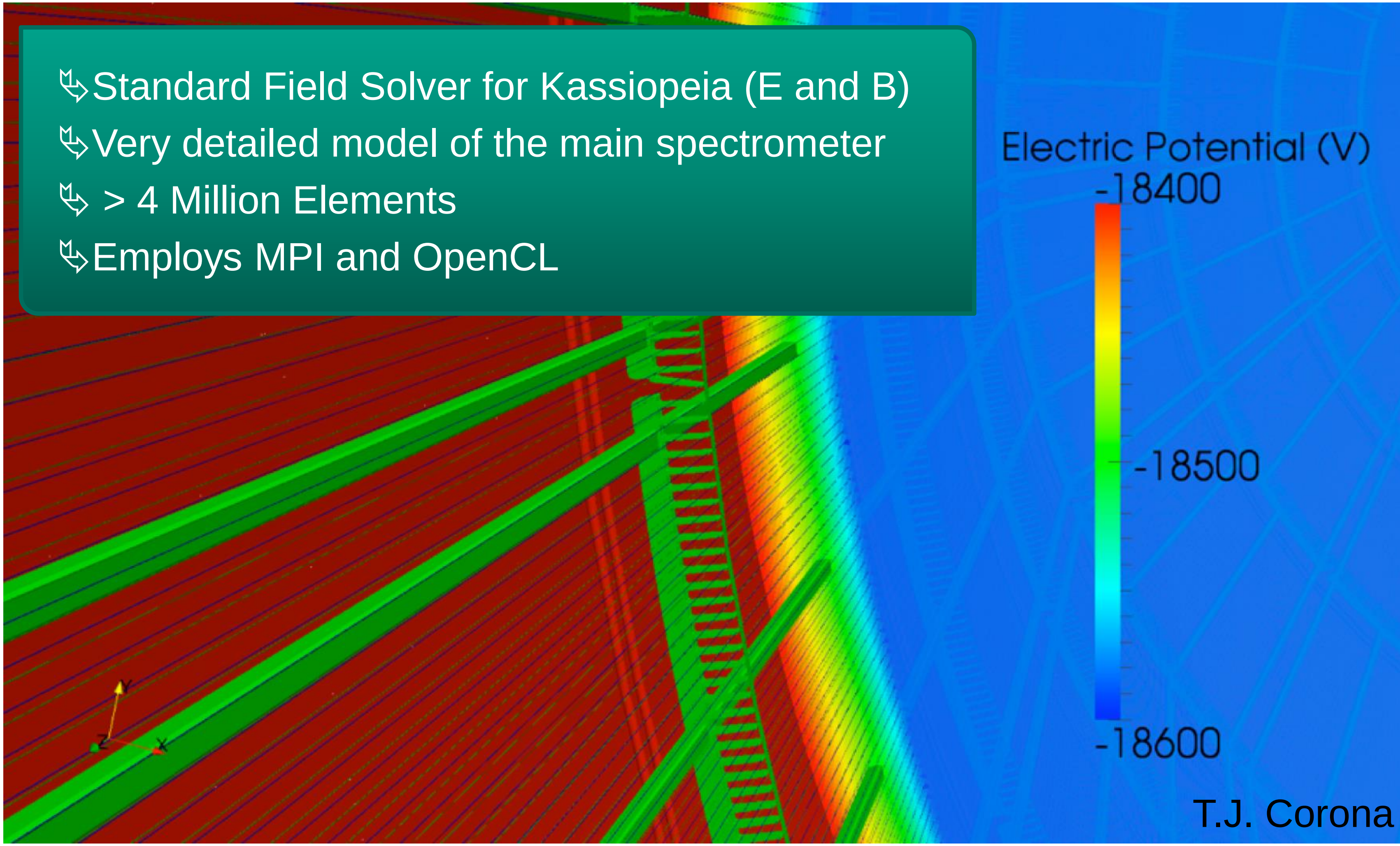
BACKUP SLIDES

Kassiopeia

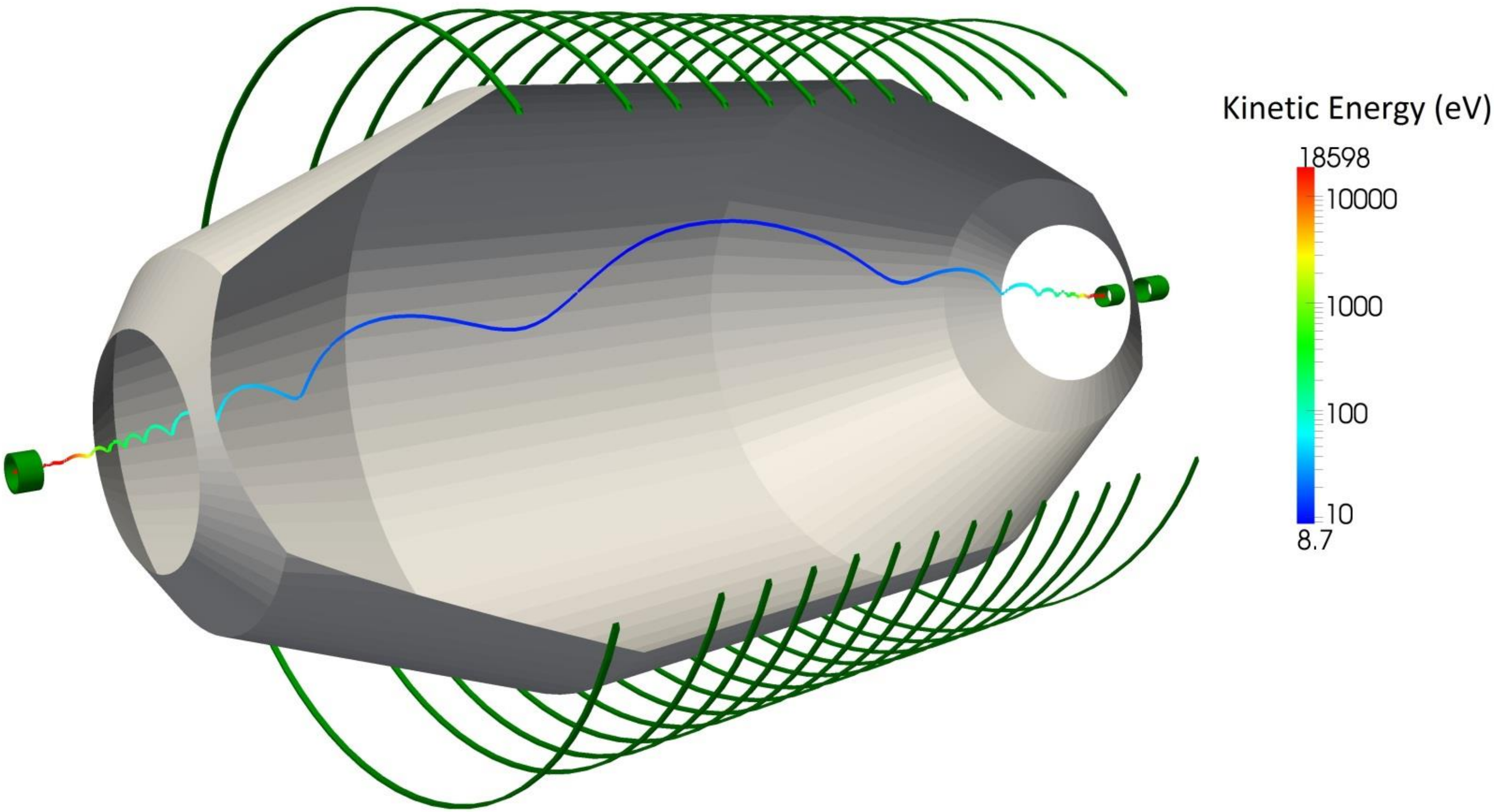
- KATRINs main particle tracking framework
- Modern C++ design
- Field solvers for electric and magnetic fields
- Particle generators
- Multiple tracking routines
- Multiple Interaction routines
- Visualization
- Easy configurable via xml files
- Interface to measurement parameters
- Full modular
- Also used by other experiments

KEMField

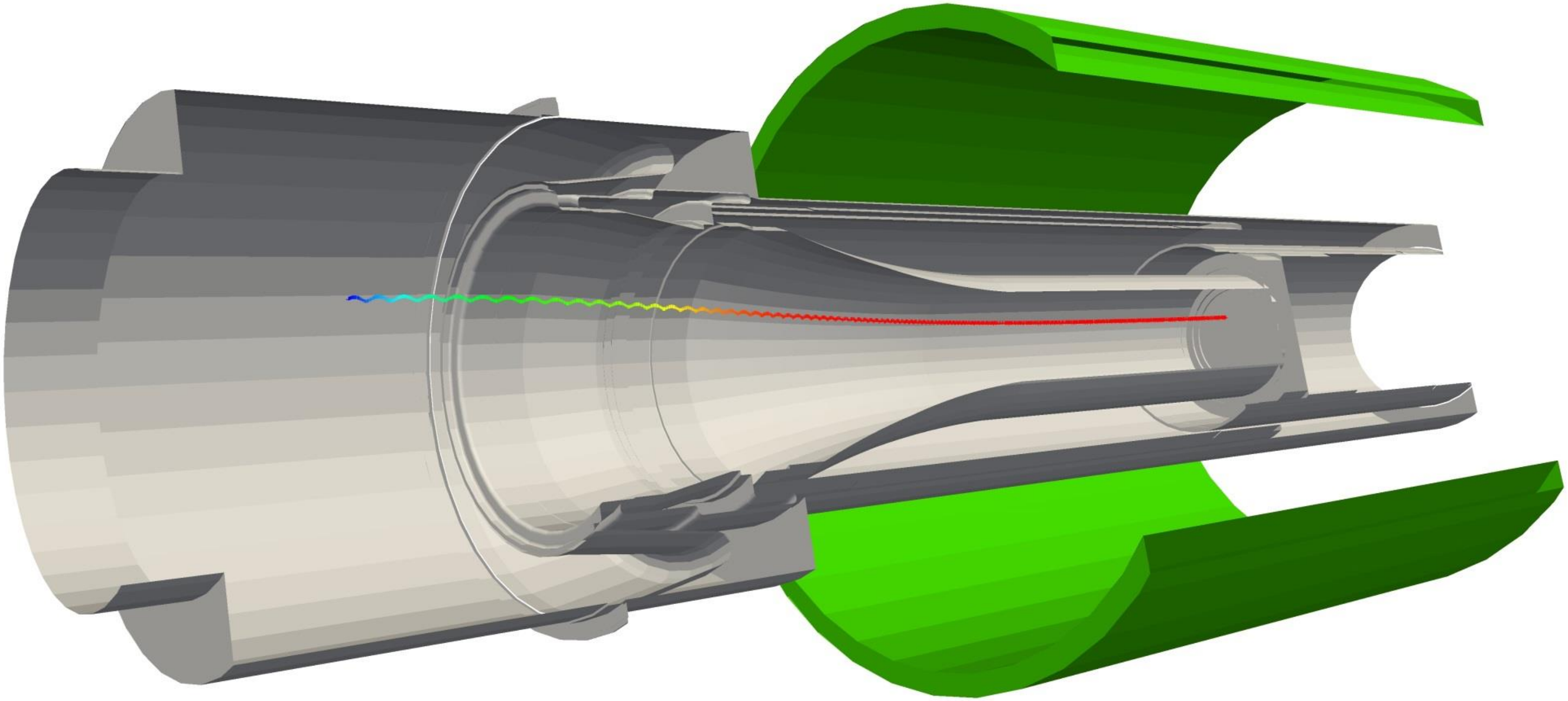
- Standard Field Solver for Kassiopeia (E and B)
- Very detailed model of the main spectrometer
- > 4 Million Elements
- Employs MPI and OpenCL



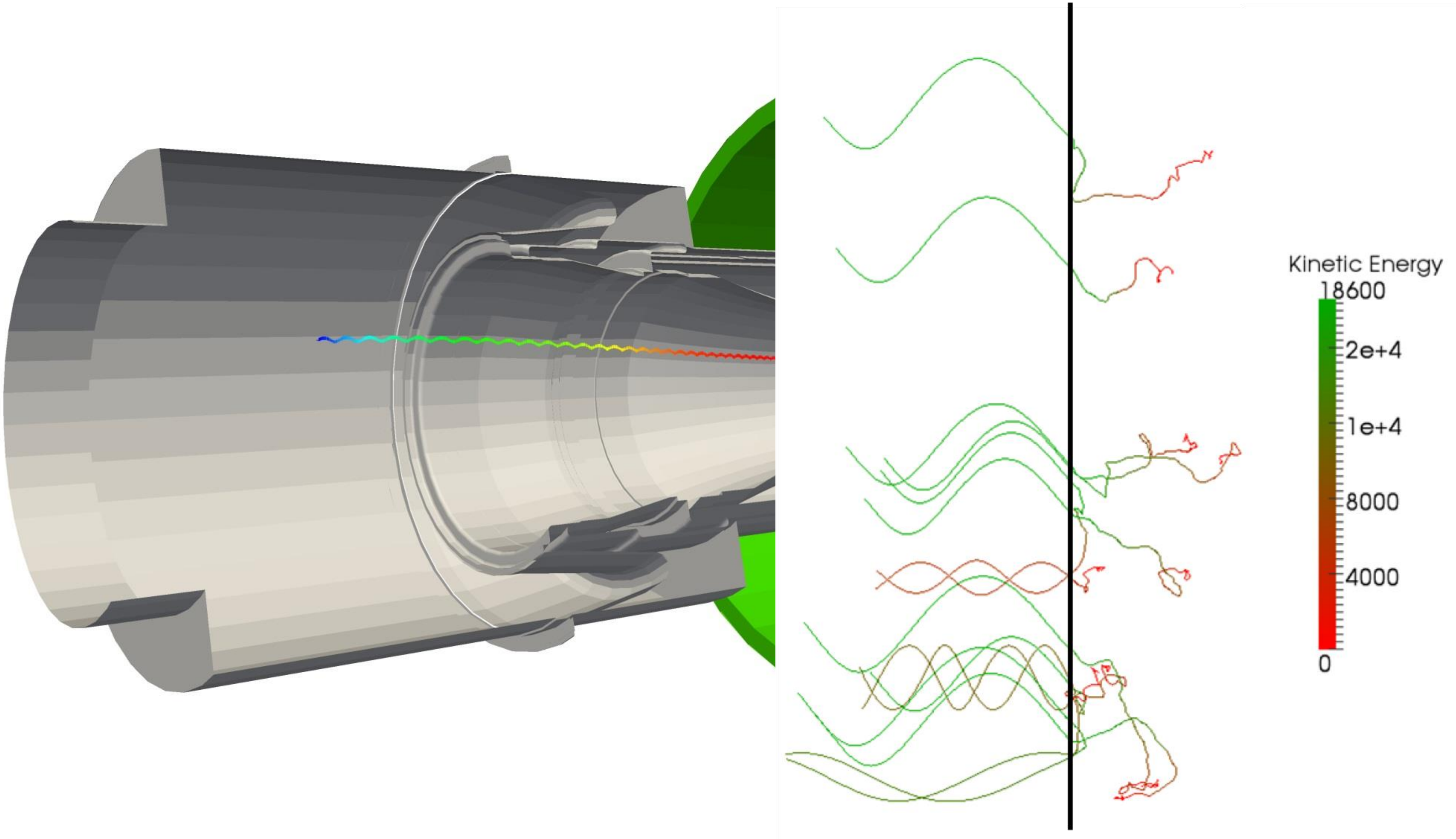
Main spectrometer



Detector



Detector



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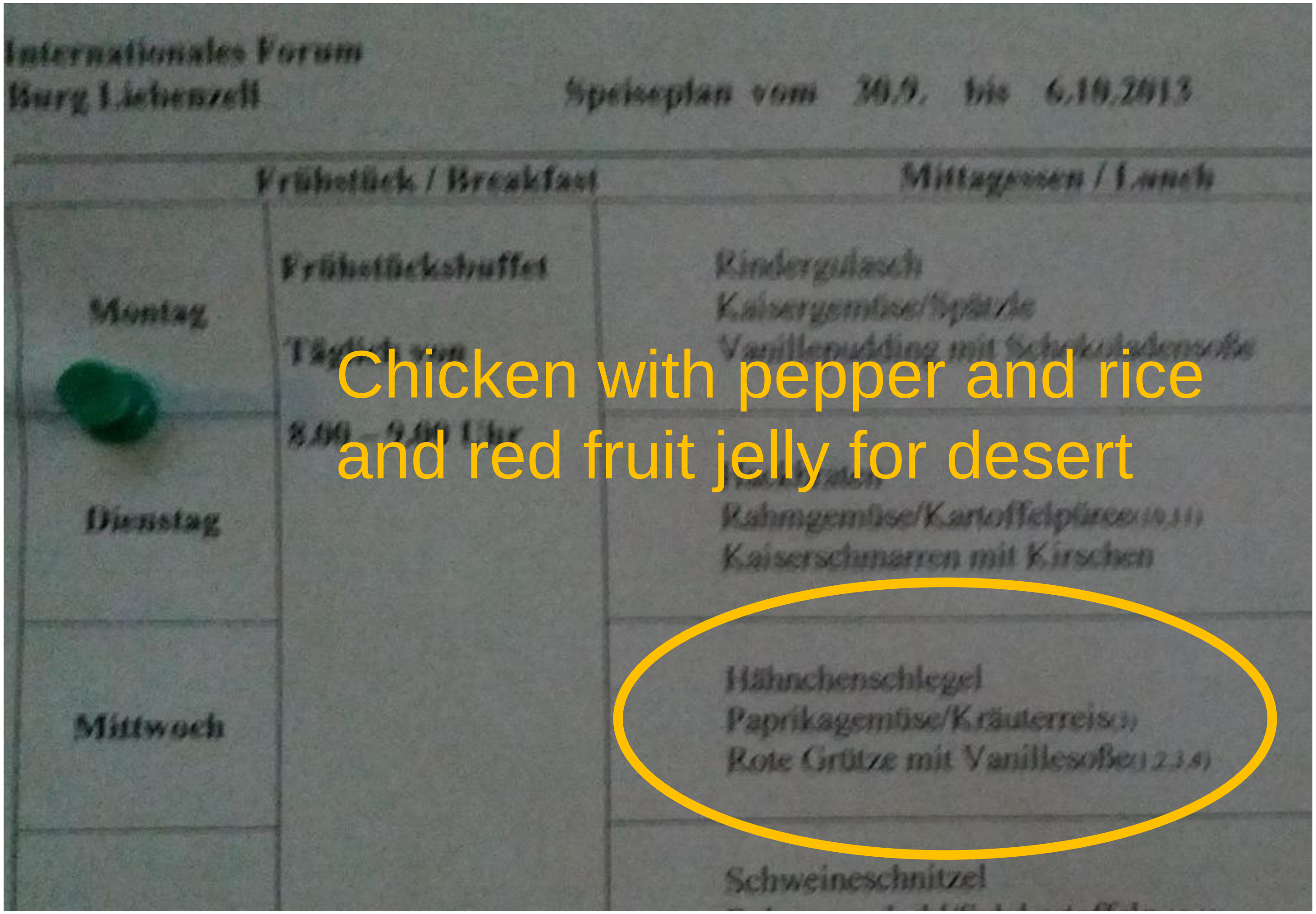
MORE BACKUP SLIDES

Lunch?



Chicken with pepper and rice and red fruit jelly for desert

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