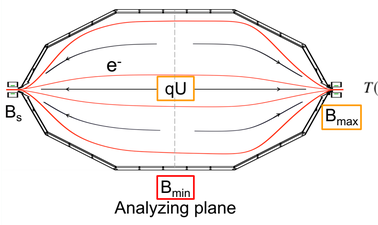
Alignment studies for the KATRIN experiment

Wonqook Choi and Marco Deffert for the KATRIN collaboration

- Transmission properties of spectrometer affected by inhomogeneities in electric potential and magnetic guiding fields
- Modeled by simulations which require precise alignment of the detector wafer, beamline and all magnets
- Data from previous measurement campaigns was used for validation of the alignment in the simulation.

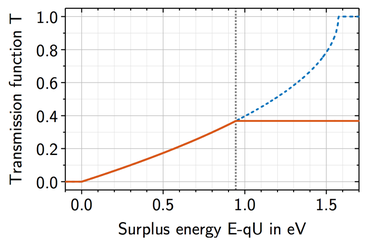
Transmission Function

Main Spectrometer



Equation of transmission function

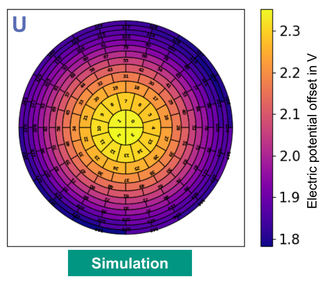
$$T(E,qU) = \begin{cases} 0 & E-qU < 0 \\ 1-\sqrt{1-\frac{E-qU}{E}\,\frac{2}{\gamma+1}\,\frac{B_{\max}}{B_{\min}}} & 0 \le E-qU \le \Delta E \\ 1-\sqrt{1-\frac{B_S}{B_{\max}}} & E-qU > \Delta E \end{cases}$$



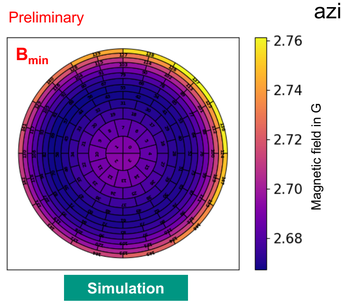
- Electric potential (**U**) and magnetic field (B_{min}) inside of the main-spectrometer can be simulated.
- More details: See J. Behrens and L. Schimpf's poster (Mo #15)

Simulation results of U and B_{min}

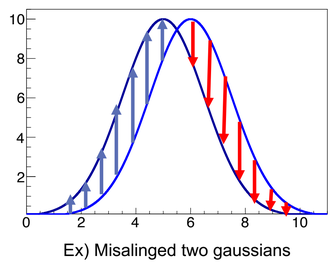
Preliminary



Preliminary

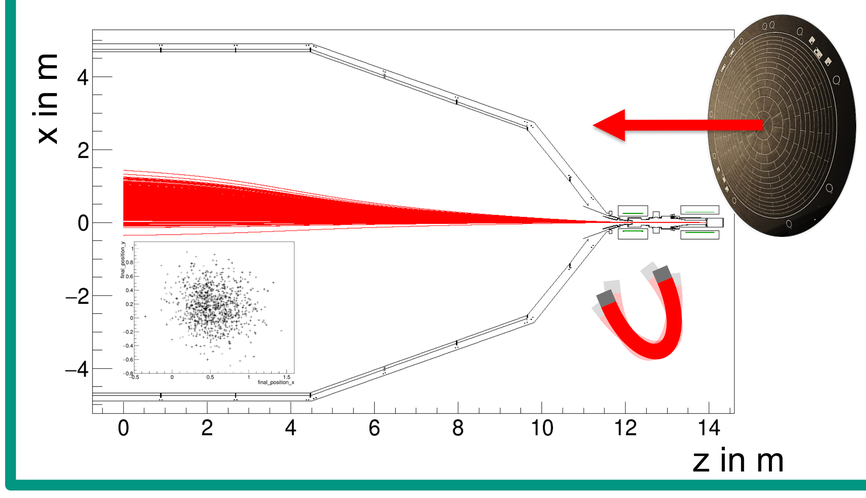


Discrepancy between simulation and real alignment causes a sinusoidal shift of measured electron energy since distribution of **U** and B_{min} is approximately azimuthal symmetric



Uncertainty on alignment simulations

- Alignment data from FaroArm, LASER tracker and magnetic field measurements go into model
- MC simulation with random alignment of beamline components and magnets within uncertainty range to get uncertainty on tracks

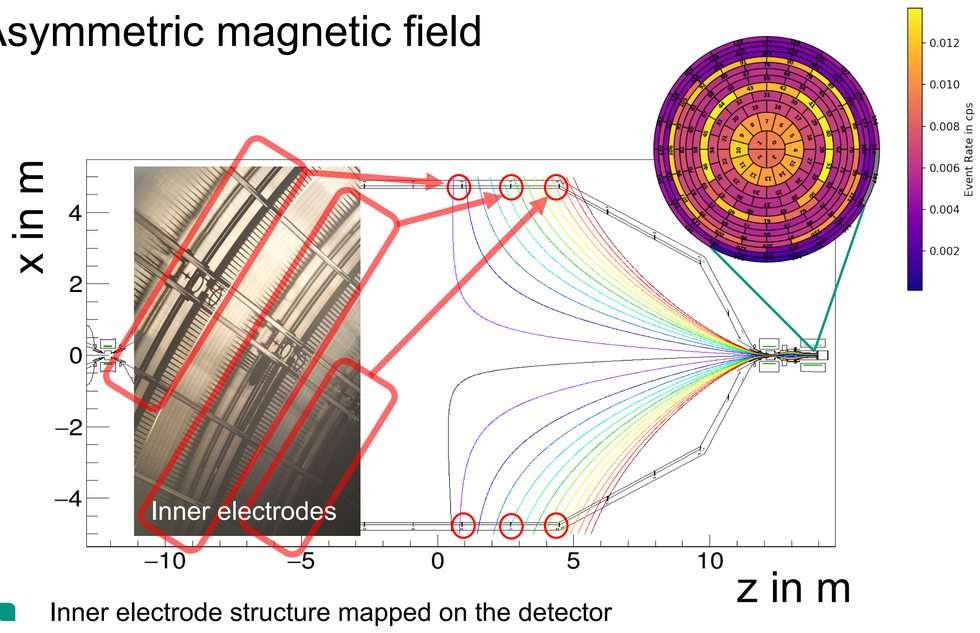


- Uncertainty dependant on magnetic field settig (1G setting shown)
- Reverse direction: position on detector

x = (-0.6 ± 0.9) mm
y = (-2.4 ± 1.0) mm

Validation of the alignment by measurements

Asymmetric magnetic field

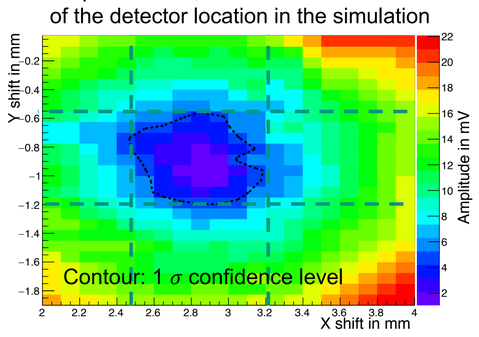


- Inner electrode structure mapped on the detector
- Ring centers give information about the alignment between spectrometer and detector

Krypton Line

More details: See M. Slezák's poster (Mo #13)

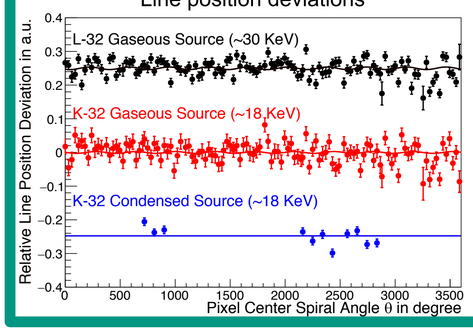
Amplitude vs X,Y shifts of the detector location in the simulation



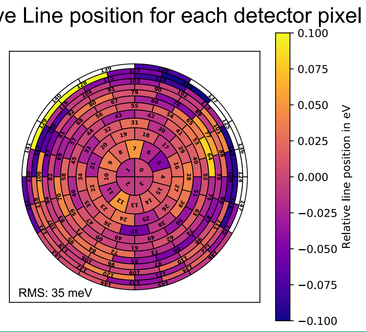
- Amplitude of sinusoidal structure scanned with certain shifts of detector in Simulation
- Center of contour is taken for additional alignment
- Work in progress

After alignment correction

Line position deviations

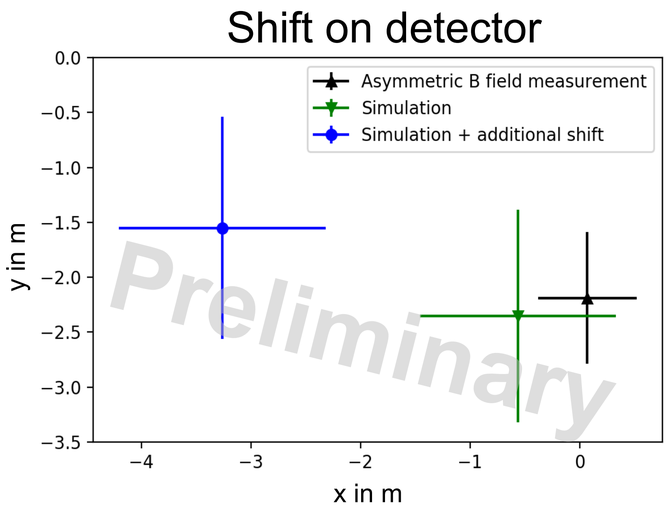


Relative Line position for each detector pixel



Results and outlook

Shift on detector



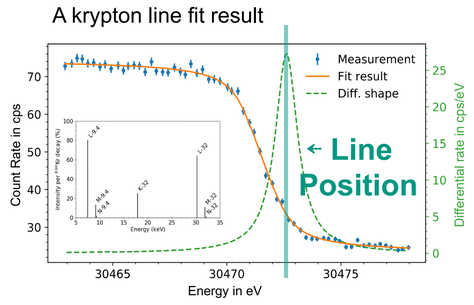
- Asymmetric magnetic field measurements and alignment simulation in good agreement
- Sinusoidal structure shown in Krypton line position distribution that could be caused by additional unknown misalignment
  - Unknown additional misalignment estimated by finding detector location in simulation with suppressed structure of gaseous Krypton L3 and K line position.
- Further investigation in progress
  - Include further alignment information in model
  - Ring fitter with machine learning algorithm
  - Work function differences (e.g. source systematics)

We acknowledge the support of Helmholtz Association (HGF), Ministry for Education and Research BMBF (05A17PM3, 05A17PX3, 05A17VK2, and 05A17WO3), Helmholtz Alliance for Astroparticle Physics (HAP), and Helmholtz Young Investigator Group (VH-NG-1055) in Germany; Ministry of Education, Youth and Sport (CANAM-LM2011019), cooperation with the JINR Dubna (3+3 grants) 2017–2019 in the Czech Republic; and the Department of Energy through grants DEFG02-97ER41020, DE-FG02-94ER40818, DE-SC0004036, DE-FG02-97ER41033, DE-FG02-97ER41041, DE-AC02-05CH11231, and DE-SC0011091 in the United States.

Karlsruhe Institute of Technology

Krypton Line

A krypton line fit result



- Structure of line positions observed during krypton measurement campaign (July 2017)

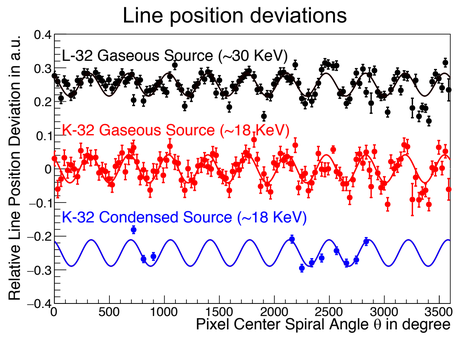
[DOI: 10.1088/1748-0221/13/04/P04020]

- Structure from discrepancy between simulation and real alignment of main spectrometer and detector.
- Magnitude of structure quantified by simple sine function:

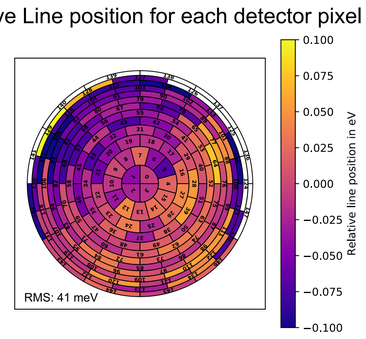
$$f(\theta; A, \varphi, b) = A \cdot \sin(\theta + \varphi) + b$$

Before alignment correction

Line position deviations



Relative Line position for each detector pixel



We acknowledge the support of Helmholtz Association (HGF), Ministry for Education and Research BMBF (05A17PM3, 05A17PX3, 05A17VK2, and 05A17WO3), Helmholtz Alliance for Astroparticle Physics (HAP), and Helmholtz Young Investigator Group (VH-NG-1055) in Germany; Ministry of Education, Youth and Sport (CANAM-LM2011019), cooperation with the JINR Dubna (3+3 grants) 2017–2019 in the Czech Republic; and the Department of Energy through grants DEFG02-97ER41020, DE-FG02-94ER40818, DE-SC0004036, DE-FG02-97ER41033, DE-FG02-97ER41041, DE-AC02-05CH11231, and DE-SC0011091 in the United States.