Simulation of B field effects inside MCP-PMTs

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

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PANDA Meeting, 31.05.2022

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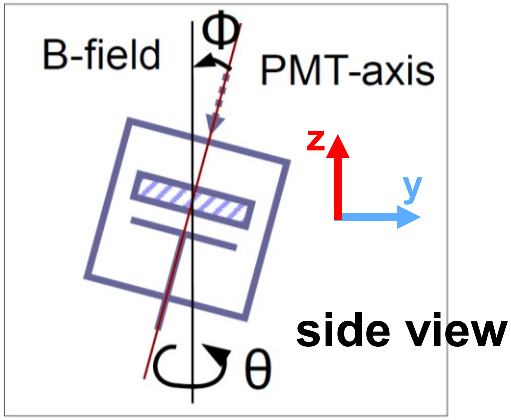
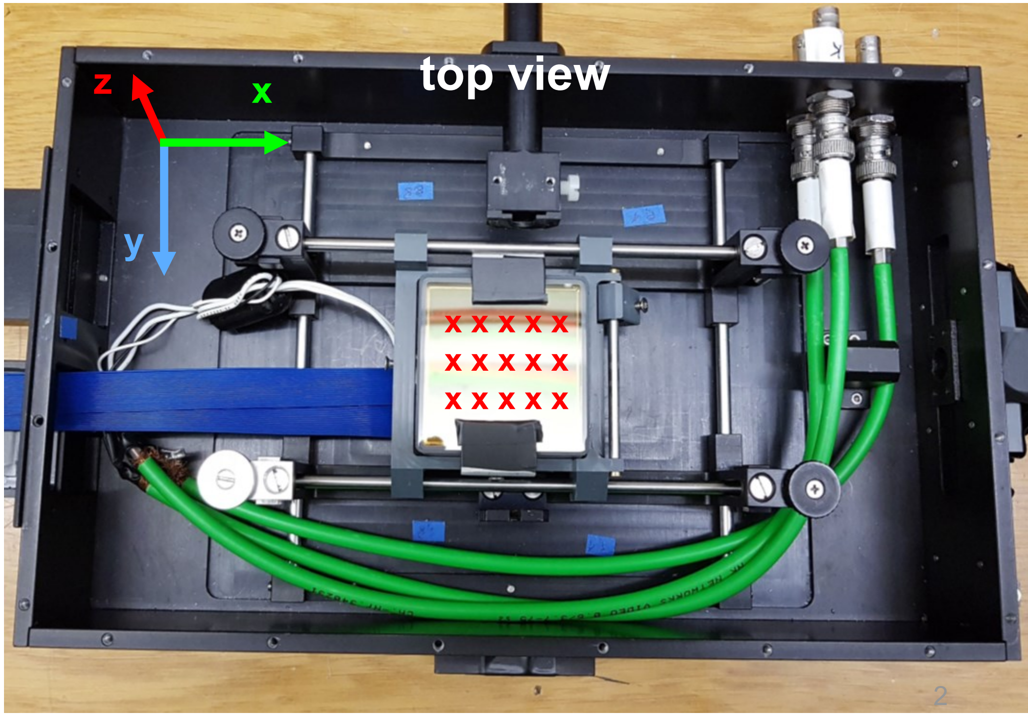
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

NATURWISSENSCHAFTLICHE FAKULTÄT

Shifts of charge cloud centroid in B field

- Measurement:
  - tilting of the tube in yz plane around x axis, scanning in y direction, B-field in z direction, E-Field along yz plane
- Expectations:
  - **geometrical shift** of charge cloud in y direction
    - ➢ electrons will follow B-field direction, depends on tilt angle, saturates at certain B-field strength
  - **lorentz shift** of charge cloud in x direction
    - ➢ electrons experience Lorentz force perpendicular to E- and B-field depending on **B-field strength** & **tilt angle** (higher Φ increases $E_\perp$ component)

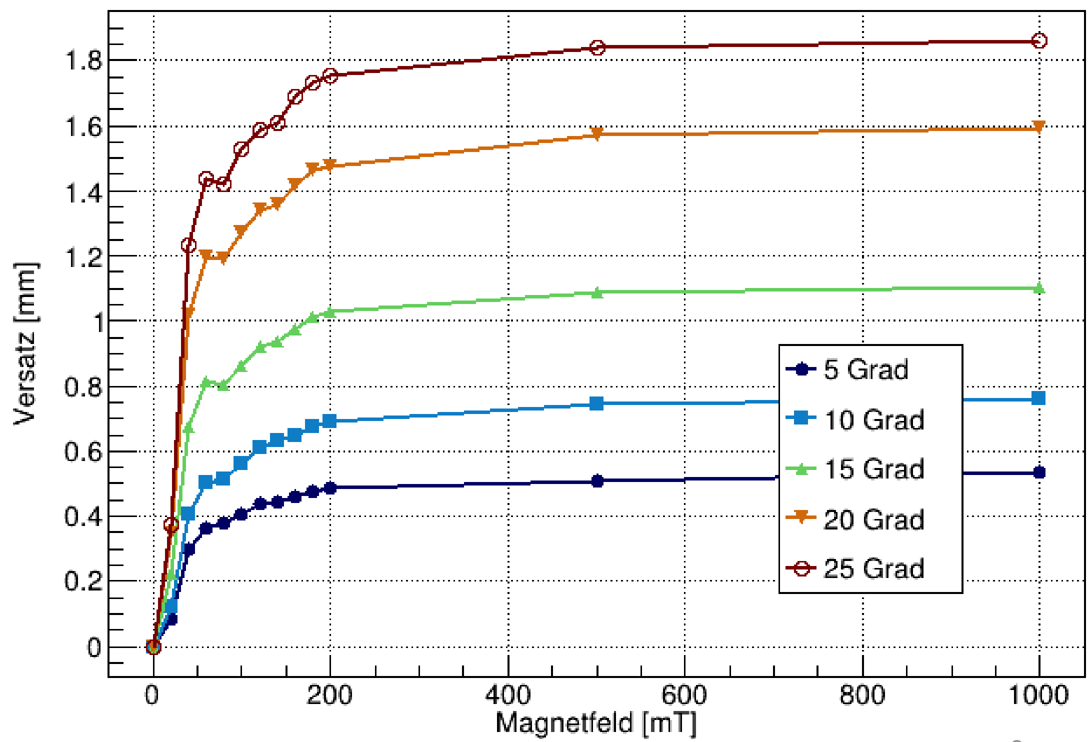




Shifts of charge cloud centroid in B-field

- below the **geometrical shift** is shown for different tilt angles
- Measured with Photonis 946P541 (3x100 pixels)
- Saturation starts at a few hundred mT
- At 25° tilt angle, saturation at ~ 1.8 mm shift → 3 – 4 pixels shift for EDD
- Also at 15° tilt angle & 1 T B-field ~ 1.1 mm shift → geometrical shift not negligible for Barrel DIRC

- Only geometrical shift was measured last time in Jülich
- For Lorentz shift measurement the tube needs to be scanned in x direction for varying tilt angles
- next time in Jülich, we will try to measure Lorentz shift



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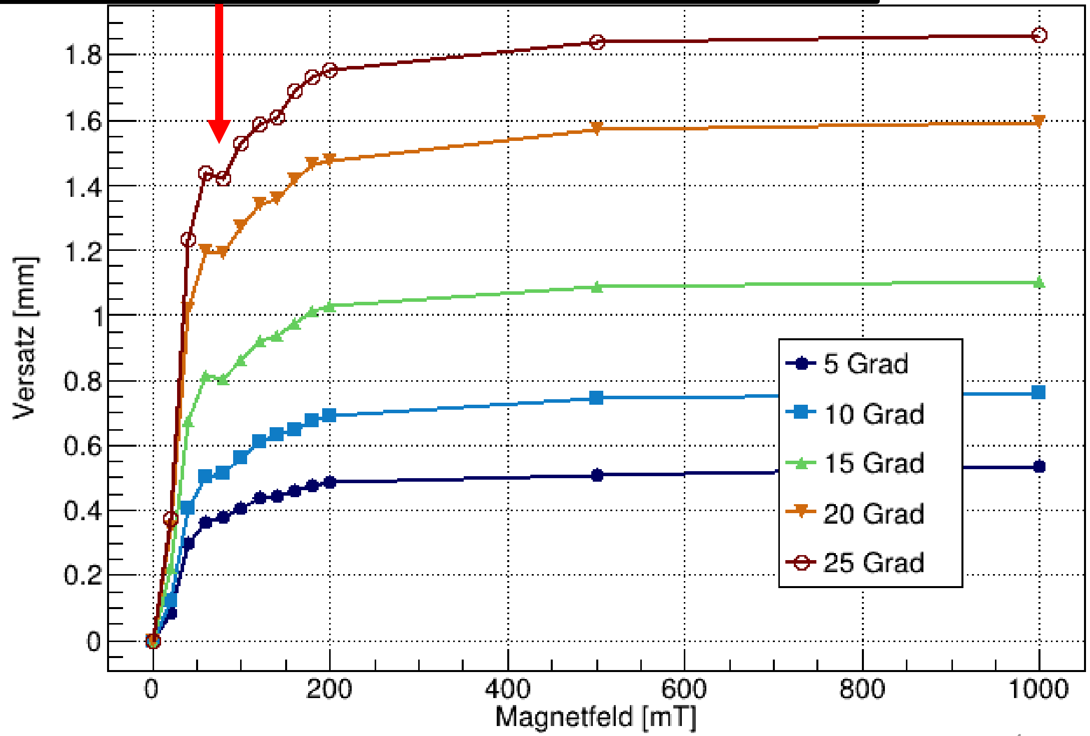
Why is there a dip at ~70 mT?

- Only geometrical shift was measured last time in Jülich
- For Lorentz shift measurement the tube needs to be rotated by 90 ° & scanned in x direction for varying tilt angles
- next time in Jülich, we will try to measure Lorentz shift

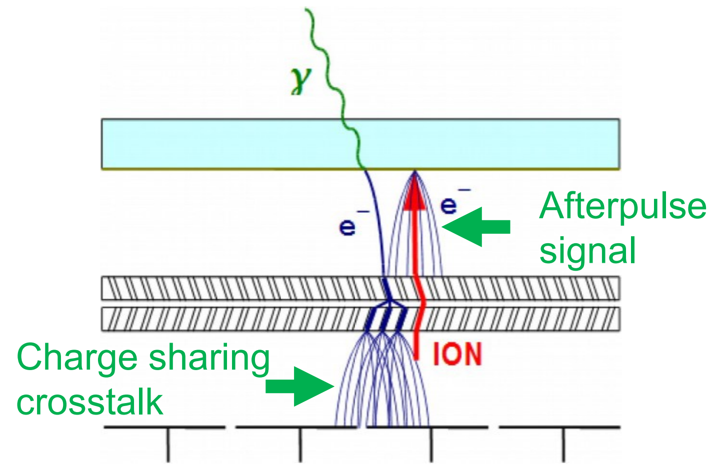


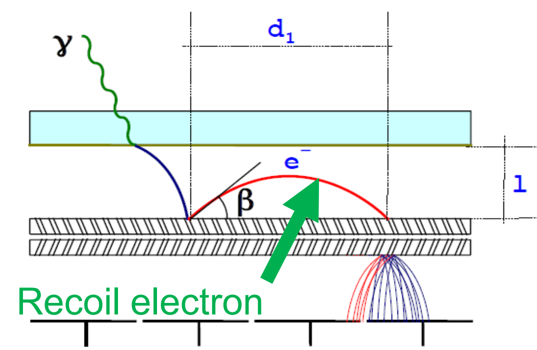
Crosstalk and range of Recoil Electrons

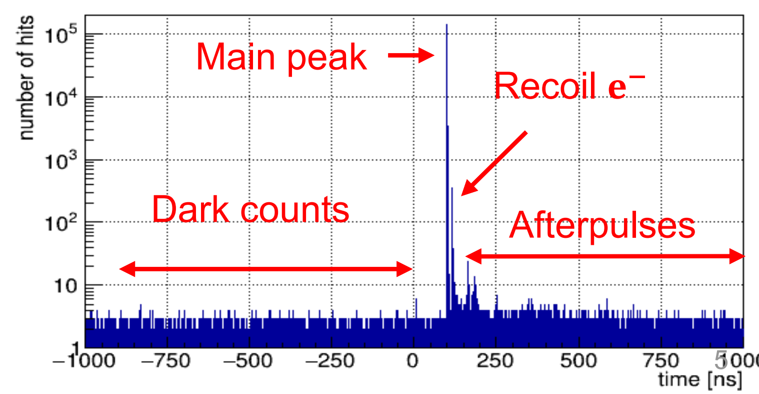
- Measured with TRB/PaDiWa3 DAQ
- After a laser trigger all hits within a certain time interval (-10 to +1 μs) are read out and stored

- Main information obtained for each channel with xy-scans:
  - x-, y-position, hit time, ToT, number of hits

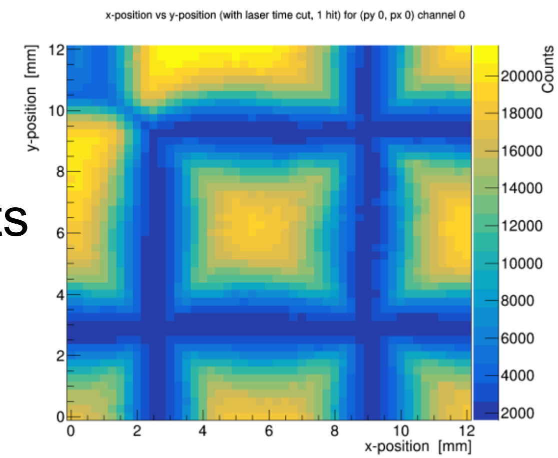
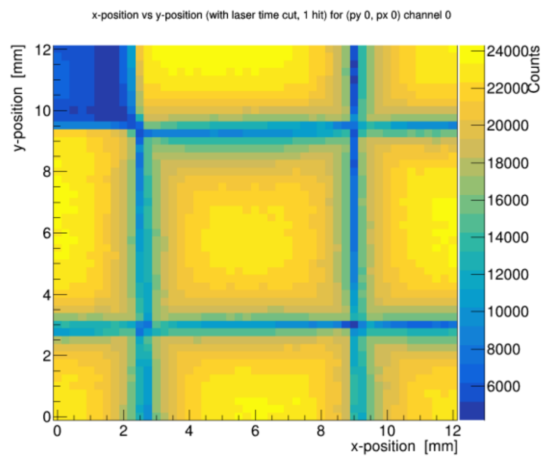
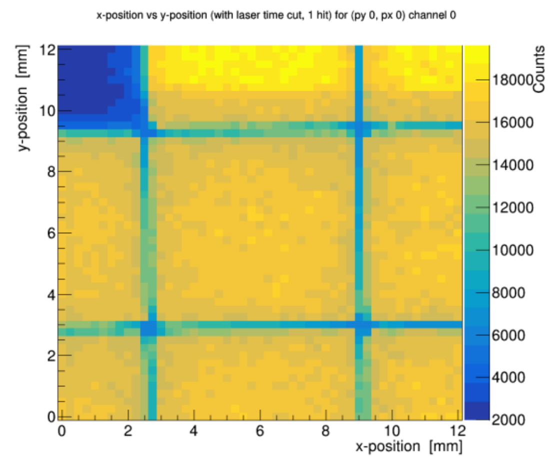
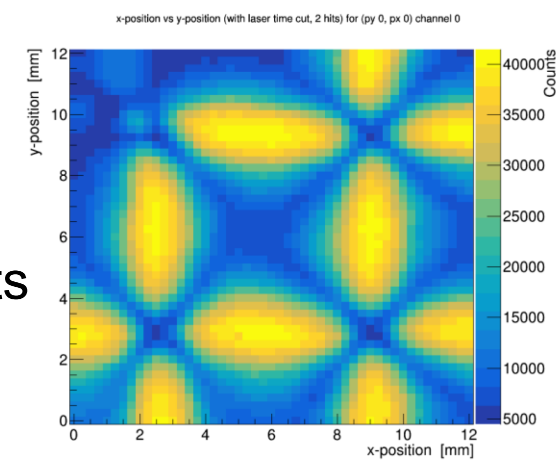
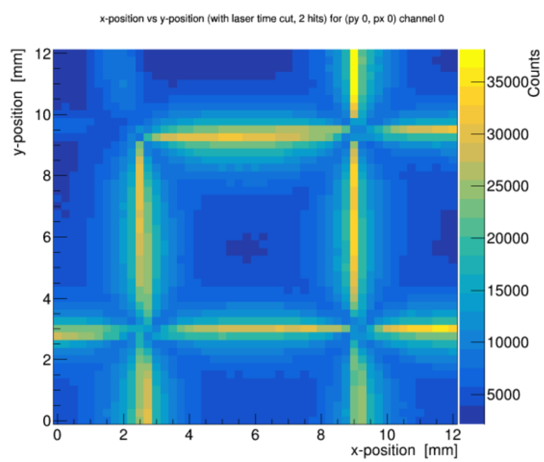
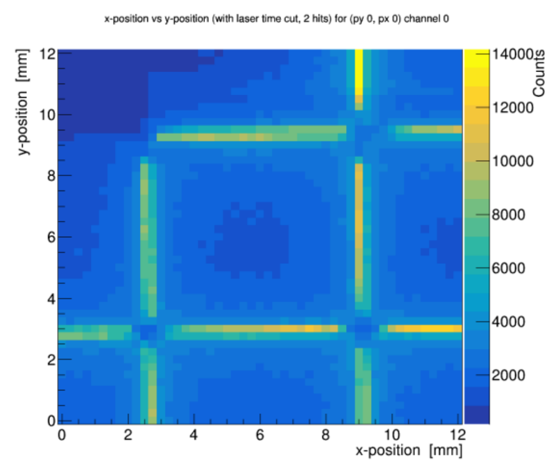
- Higher level information deduced:
  - Charge sharing crosstalk (≥ 2 hits at same time on neighbouring channels), fit Gauss distribution to 2 hit distributions to obtain upper limit of charge cloud width
  - Recoil electron distributions → back bouncing electrons at MCP entry (spatial information and time delay)
- Observations:
  - Charge cloud width reduced with B field
  - Range of recoil electrons reduced with B field
- Assumption: electrons spiral along B field lines







Example of charge sharing crosstalk: Photonis 9002192

	20mT	200mT	1000mT
1 hit events			
2 hit events			

Simulation of Equations of motion

- Motivation: want to understand observed effects
- Simulate electron traces inside MCP-PMT with numerical approach
- Lorentz force: $\overrightarrow{F_L} = q \cdot \left(\vec{E} + \vec{v} \times \vec{B}\right)$
- Equations of motion:
  - $\vec{x}(t + \Delta t) = \vec{x}(t) + \vec{v}(t) \cdot \Delta t$
  - $\vec{v}(t + \Delta t) = \vec{v}(t) + \vec{a}(t) \cdot \Delta t$
- With $\vec{a} = \frac{\vec{F}}{m}$ and B field along y-z plane:
  - $v_x(t + \Delta t) = v_x(t) + \frac{e}{m}\left(v_y(t) \cdot B_z - v_z(t) \cdot B_y\right) \cdot \Delta t$
  - $v_y(t + \Delta t) = v_y(t) - \frac{e}{m} \cdot v_x(t) \cdot B_z \cdot \Delta t$
  - $v_z(t + \Delta t) = v_z(t) + \frac{e}{m} \cdot \left(v_x(t) \cdot B_y + E_z\right) \cdot \Delta t$

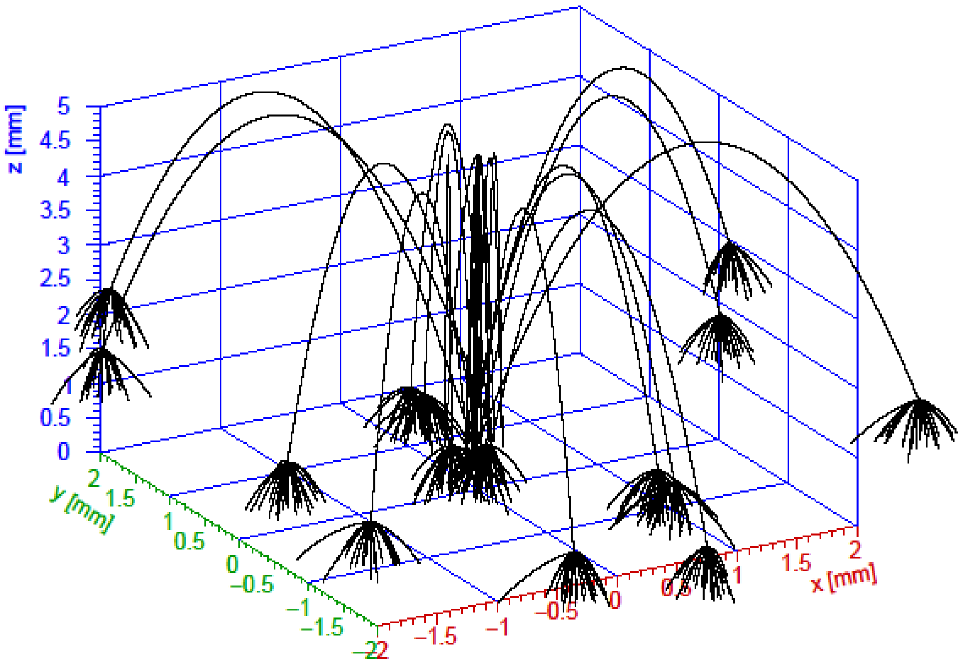
Simulation parameters

- Not simulated: electrons inside MCPs, e-e interaction
- Keep electron position and set random velocity after MCP
- Voltages are measured, distances are from internal communication with Photonis, unknown if correct for the 946P541

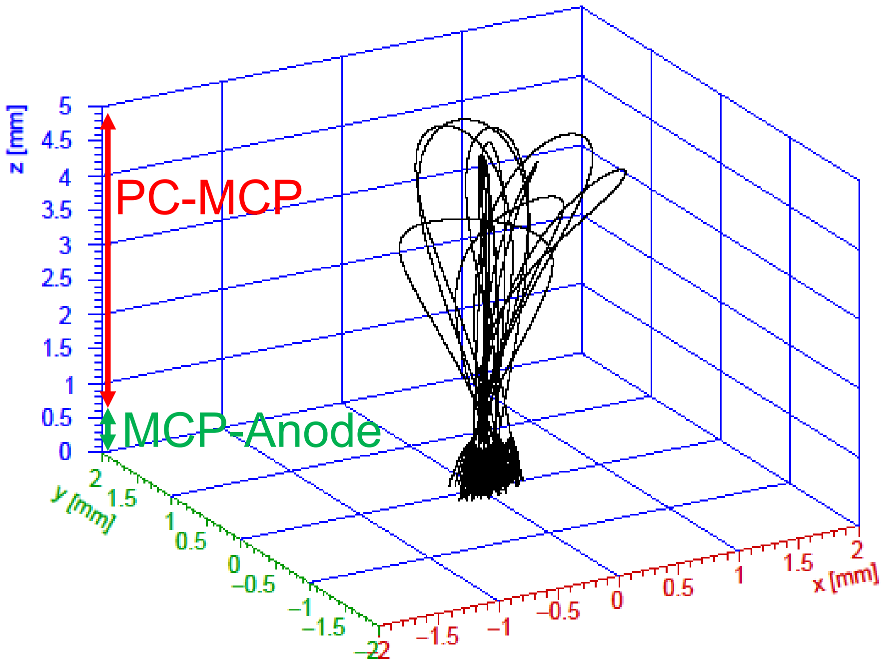
Parameter	**Value**
Step size	10^{-13} s
Voltage Cathode - MCP	871 V
Voltage - MCP - Anode	313 V
Distance Cathode - MCP	4.2 mm
Distance MCP - Anode	635 µm
Recoil probability	~10%
Amplification factor	25
Max e velocity at Cathode	10 eV
Max e velocity after MCP	100 eV

Simulation of recoil electron range in B field

- Recoil electron range already significantly reduced at small B fields
- Electrons spiral along B field lines between cathode and MCP
- Below: only recoil electrons displayed, 0 deg between B field and MCP-PMT axis, 100 events



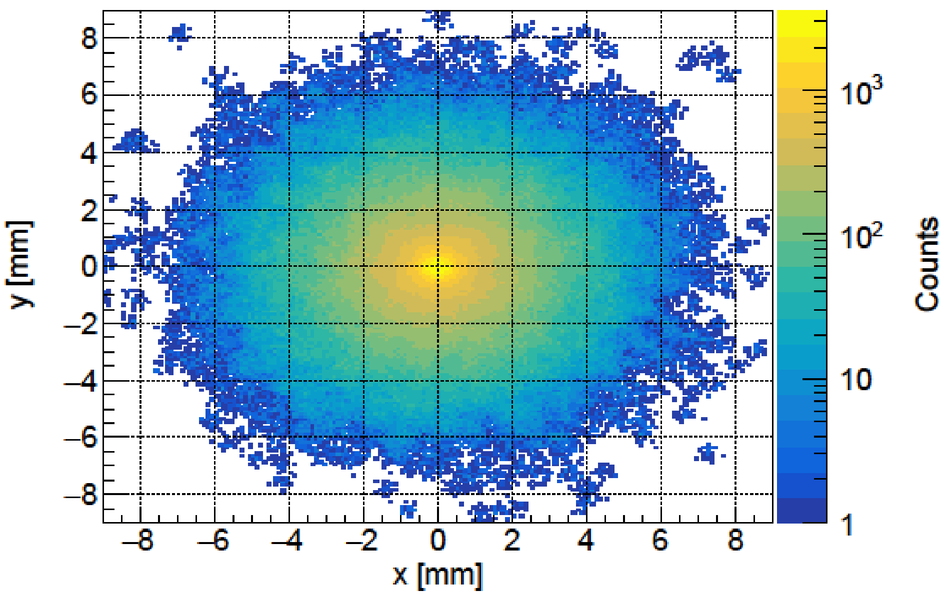
0 mT



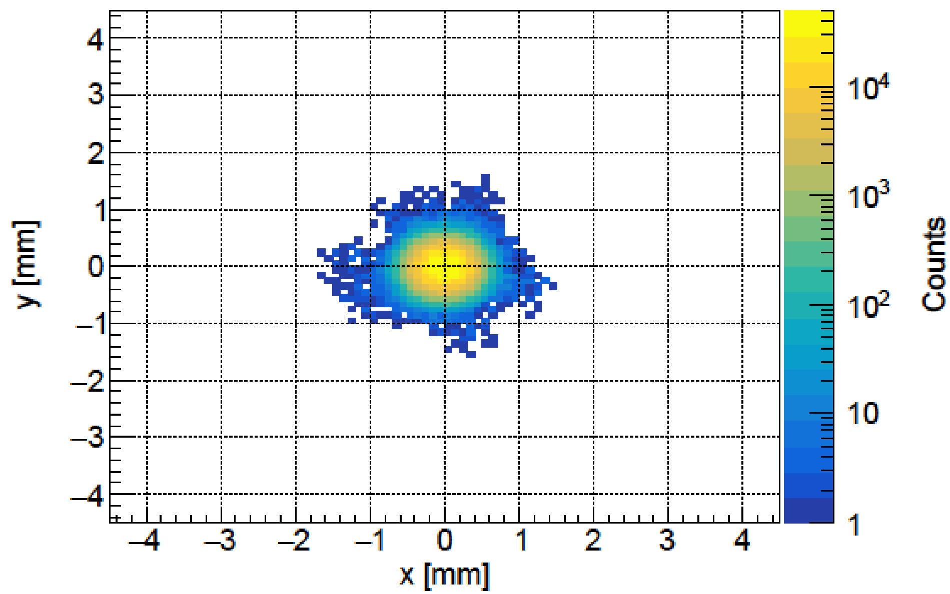
40 mT

Simulation of recoil electron range in B field

- Recoil electron range already significantly reduced at small B fields
- Electrons spiral along B field lines between cathode and MCP
- Below: only recoil electrons displayed, 0 deg between B field and MCP-PMT axis, 500k events



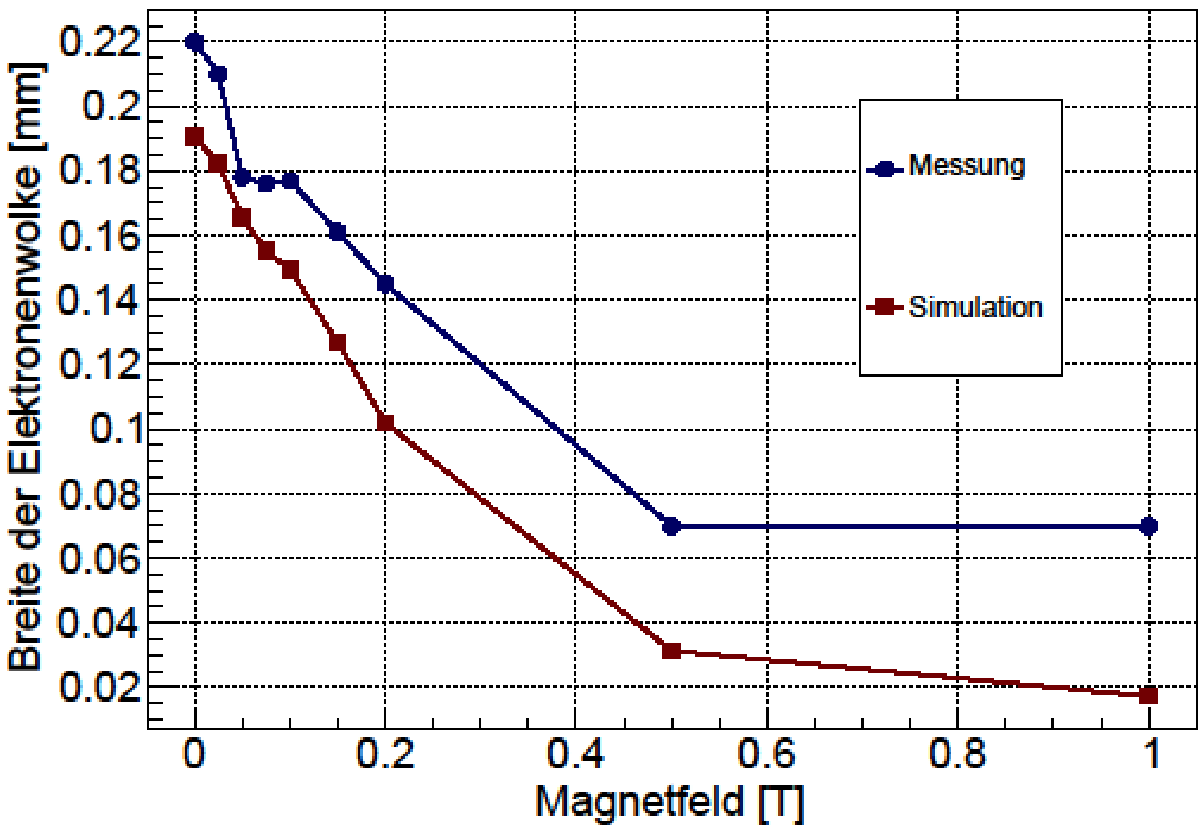
0 mT



40 mT

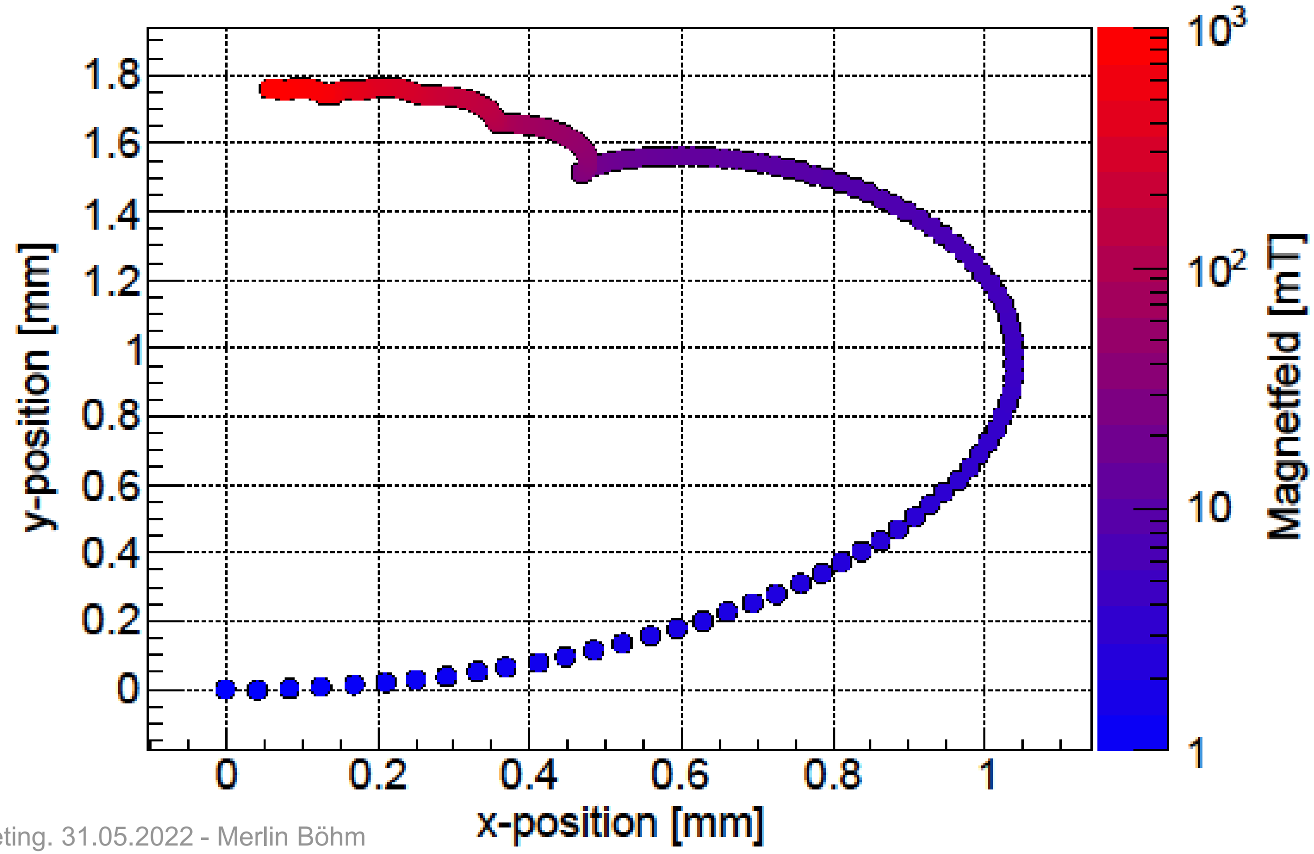
Simulation and measurement of charge cloud width

- Measurement of the upper limit of the charge cloud width (sigma)
- Laser spot size and gap between anode pads distort measured value
- Sensor: Photonis 946P541



Charge cloud shift

- Reconstructed position moves with B field
- Previous measurements were projections of y axis
- Observed dip at ~70 mT: Electrons complete one convolution
- Not yet measured: shift along x axis, max at 35 mT
- Simulation below at 20 deg



Charge clo

- Reconstruc
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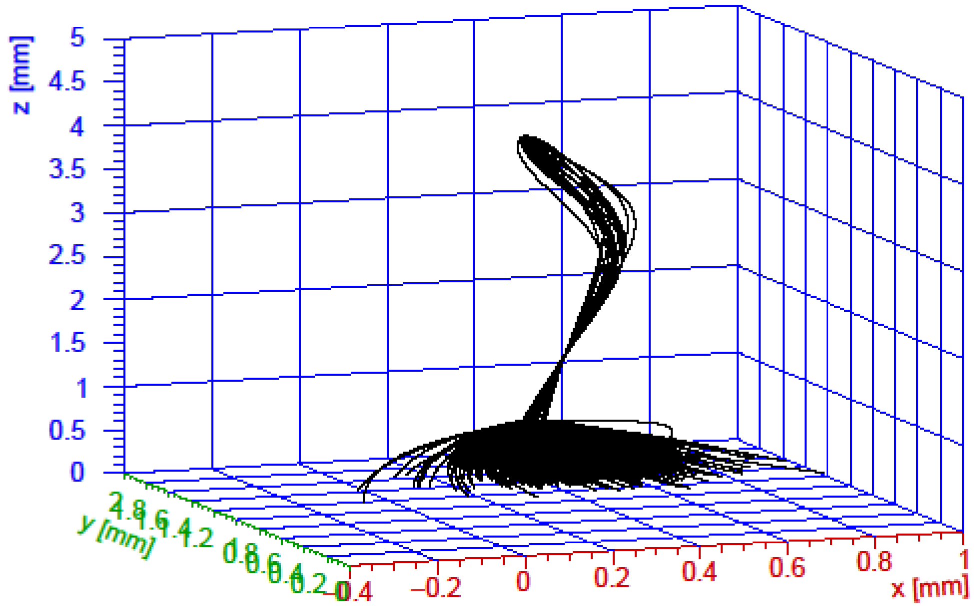
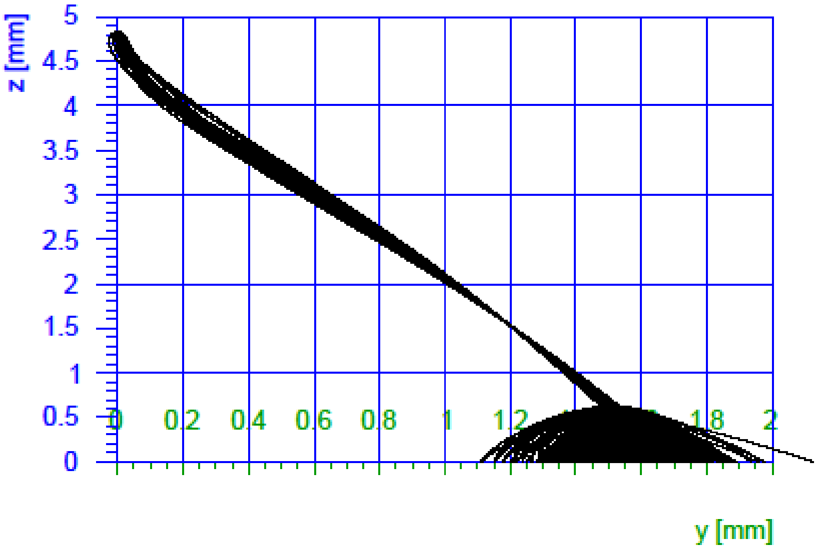
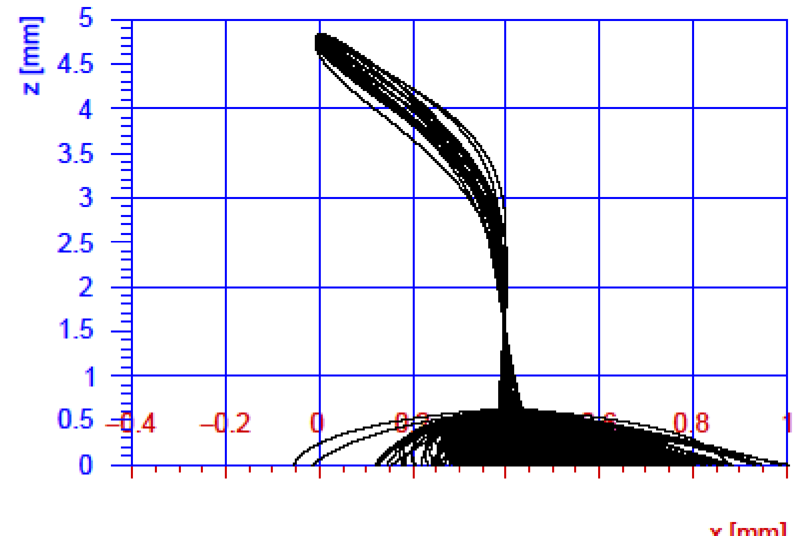


80 mT, 20 deg, no recoil electrons





Summary

- Charge cloud centroid gets significantly shifted at high B-fields and tilt angles
  - geometrical shift within E – B plane (here the **yz** plane)
  - Lorentz shift perpendicular to E – B plane (here the **x** axis)
- This needs to be taken into account for simulations & data analysis in the later experiment

- To understand the effects in the B field a simulation was written
  - Both measured charge cloud width reduction and recoil electron range can be seen in simulation
  - Dip at 70 mT understood

- Plan for next Jülich mission is to also measure the Lorentz shift component of the charge cloud centroid