Validation of Garfield with Test-Beam Data of ATLAS Muon Drift-Tube Chambers in Magnetic Fields

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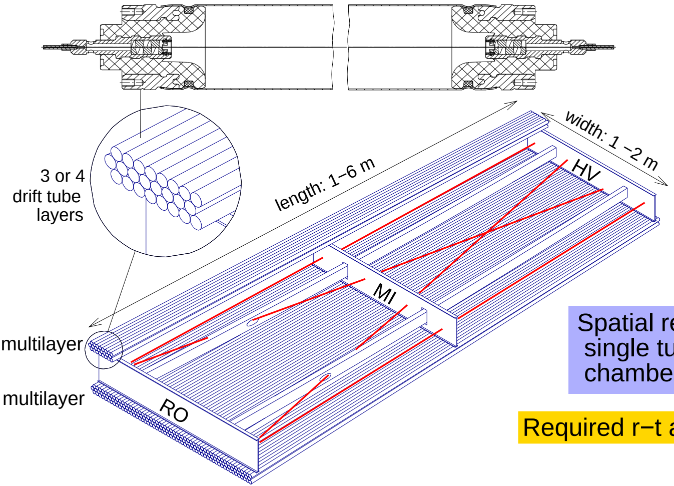
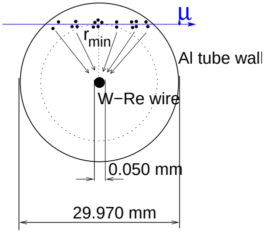
DPG-Frühjahrstagung, Heidelberg March 2006

ATLAS muon drift-tube chambers

drift tube: $Ar:CO_2$ (93:7), gas gain $2 \cdot 10^4$ (3080 V)

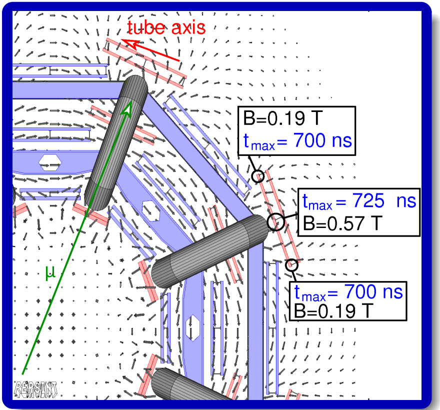




Spatial resolution:
single tube: 80 μm
chamber: 35 μm

Required r−t accuracy: 20 μm

Motivation for the study



Average magnetic field: 0.4 T.

Goal:

- conversion of drift times into drift radii with an accuracy $\leq 20\ \mu$m.

In chambers on the toroid coils:

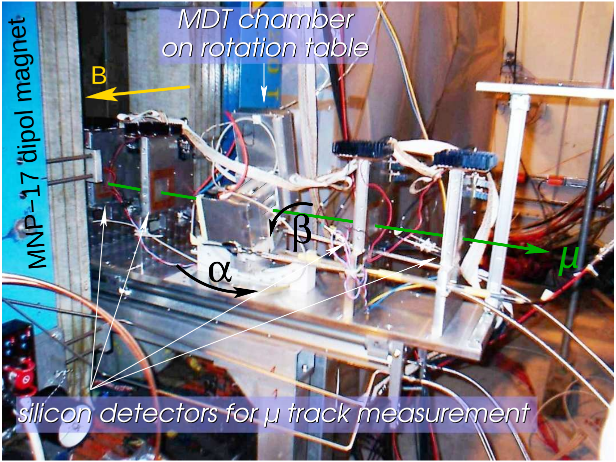
- large gradients of the magnetic field along a tube,

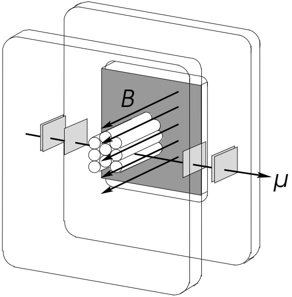
$\Rightarrow$ large variations of the maximum drift time t_{max} along a tube.

This goal requires a formula to correct for these variations with an accuracy of ∼1 ns.

Set-up for the test-beam measurements

Location: Gamma Irradiation Facility at CERN.



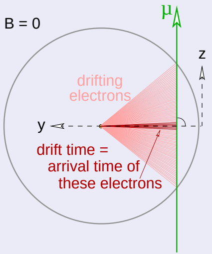


B=0.3 T, 0.6 T, 0.9 T.

Position accuracy of silicon tracker: $< 20\ \mu$m.

A simple model

Equation for the electron drift (special case: $\vec{B}\,\|$wire)



$$\ddot{y} = -\left(\frac{\dot{y}}{\tau_\epsilon}\right)^{1+\epsilon} - \frac{e}{m}E_y - \frac{e}{m}\dot{z}B$$

$$\ddot{z} = -\left(\frac{\dot{z}}{\tau_\epsilon}\right)^{1+\epsilon} - \frac{e}{m}E_z + \frac{e}{m}\dot{y}B.$$

$\underline{\epsilon = 0}$: Langevin equation.

$\underline{\epsilon > 0}$: allow for larger friction. Larger friction can be caused by inelastic electron-molecule scattering.

$E_{rot}(CO_2) \sim E_{kin}(e^-) \Rightarrow$ rotations of CO_2 can be excited.

$\Rightarrow$ Inelastic electron-molecule scattering is expected for Ar:CO_2(93:7).

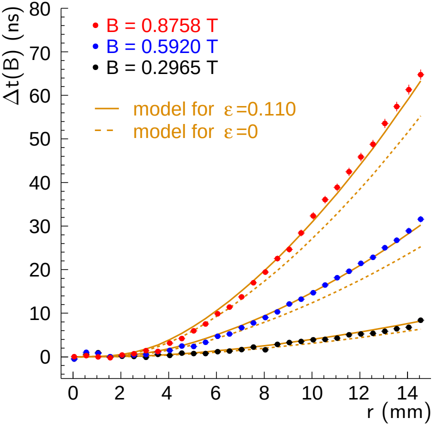
Predictions by the simple model

Solution of the differential equation

$$
\begin{aligned}
t(r,\vec{B}) = &\ t(r,\vec{B}=0) &+\Delta t(r,\vec{B}) \\
\approx &\ t(r,\vec{B}=0) &+ \\
& B^{2-\epsilon} & \cdot \int\limits_{r_{min}}^{r} \frac{v_{B=0}^{1-\epsilon}(r')}{E^{2-\epsilon}(r')}\, dr'.
\end{aligned}
$$

Accuracy of the approximation for $\Delta t(r,\vec{B})$: $\approx$1%.

Comparison with test-beam measurements



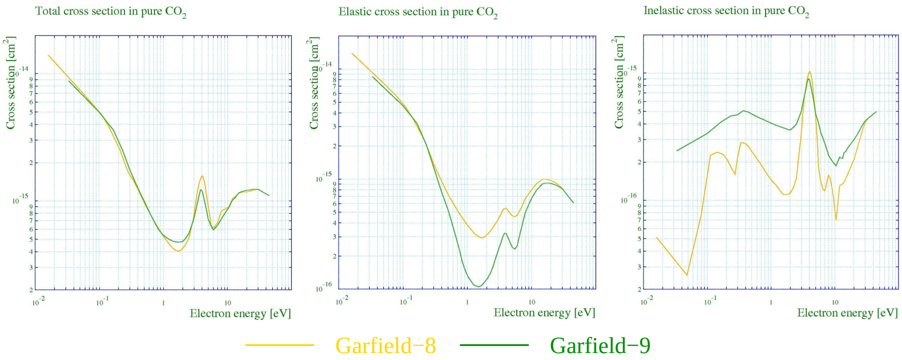
- Langevin equation with linear friction term ($\epsilon = 1$) insufficient to describe the measurements.
- Inelastic scattering of drifting electrons off CO_2 molecules must be taken into account!

Role of Garfield simulations

- Inelastic scattering of drifting electrons off CO_2 molecules are important.
- Since CO_2 has no dipole moment rotational excitations can only exist on top of vibrational excitations.
  CO_2 molecules are thermally excited to vibrational states.
- Test-beam measurments are taken at a single CO_2 content (7%) and a single temperature.
  Expect temperature spread in ATLAS: 15 K.
- Reliable Garfield calculations are needed to extrapolate from the test-beam operating point to other operating points, especially different temperatures.

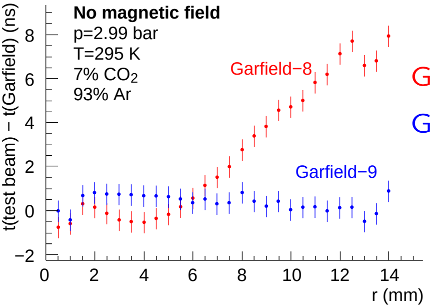
Garfield versions

- The predictions of the two latest Garfield versions were compared with our test-beam measurements: Garfield-8 and Garfield-9.
- Main difference: Garfield-9 uses new calculations of cross sections for electron-CO_2 scattering.



Comparison of Garfield with Measurements

First case: no magnetic field



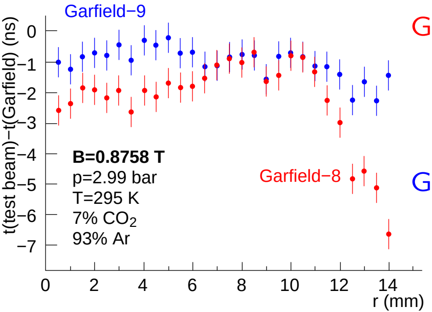
Garfield-8: Drift velocity to high!

Garfield-9: Excellent agreement between test-beam measurement and data!

Garfield-8 can be matched to test-beam data by increasing the CO_2 content to (the wrong value of) 7.1%.

Comparison of Garfield with Measurements

Second case: magnetic field switched on



Garfield-8: Too small drift velocity even after matching of $t(r)$ at B=0 by adjusting the CO_2 content!

Garfield-9: Good agreement between test-beam measurement and data!

Summary

- Test-beam studies of the space-drift-time relationship of ATLAS MDT chambers in magnetic fields show that inelastic collisions of drift electrons with the CO_2 molecules of the drift gas must be taken into account.
- Comparisons of the test-beam measurements with the predictions of the two latest Garfield versions show that only the most recent version (9) treats collisions with CO_2 molecules appropriately.