Survey of non-equilibrium effects in Electron drift and avalanches

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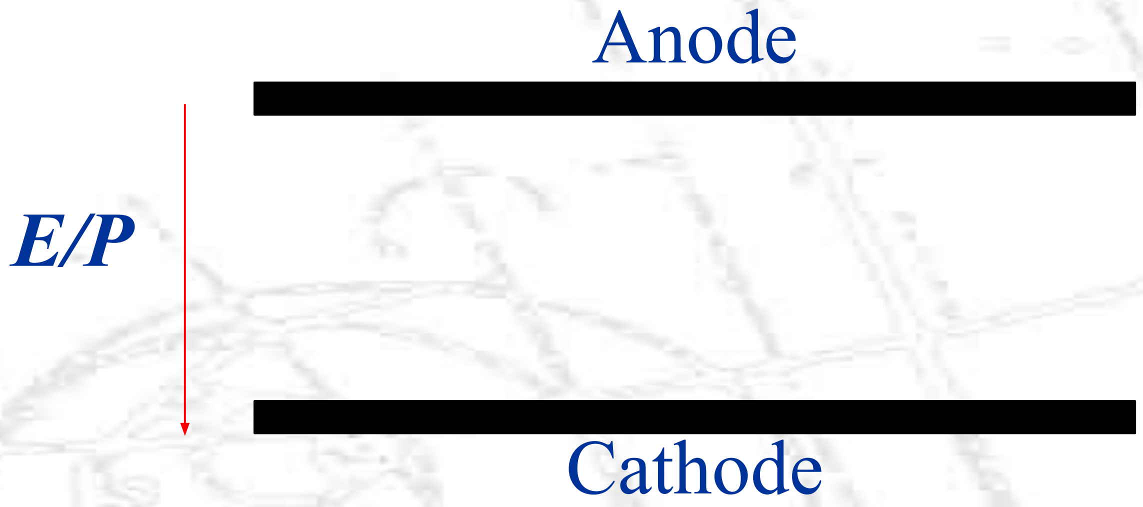
Electron - Electric Field Equilibrium

❖ **Equilibrium:** the variation of the electric field over the electron mean free path is low

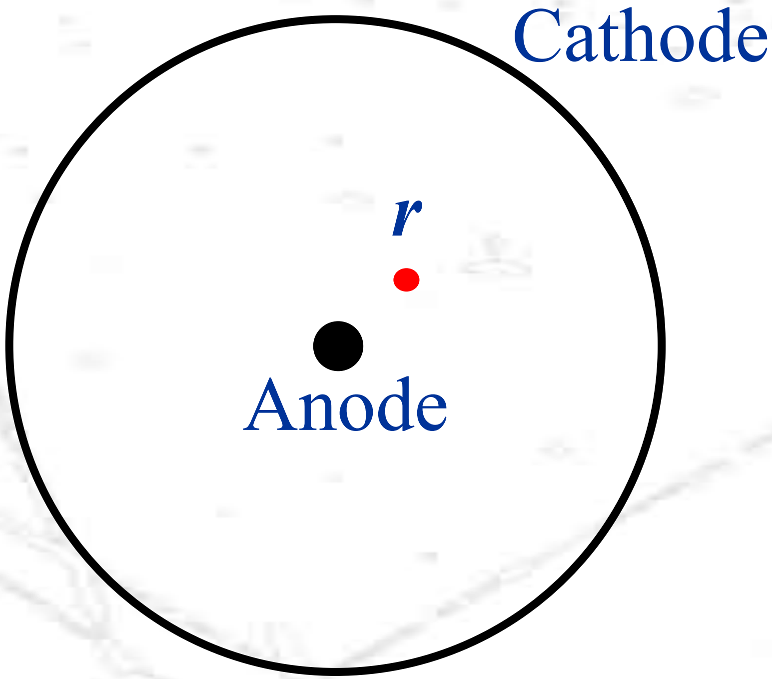
- Electron - electric field equilibrium means that the values of an electron's transport parameters (e.g. Townsend factor) are only dependent on the reduced electric field (E/P).

- In a non-uniform electric field configuration this means that at some random point ***r*** inside the field, the value of the transport parameter is equal to its value in a constant electric field of the same strength

Electron - Electric Field Equilibrium



Uniform electric field → Townsend coefficient and drift velocity are constant everywhere



Non-uniform electric field → Townsend coefficient and drift velocity are changing.

- **Equilibrium:** if at point ***r*** the value of the reduced electric field is ***E/P*** then the reduced transport parameters (like ***α/P*** **,** ***v/P***) at ***r*** is equal to its the constant value inside the parallel plate **regardless** of any other variables like pressure or dimensions of the anode - cathode.

Electron - Electric Field Equilibrium

- Equilibrium enables us to simulate detectors with non-uniform electric field by only simulation of the transport in a uniform electric field;
  - then integrating the values of the transport parameters over the non-uniform electric field values.

- For example, calculating the gas gain in single wire tube:

$$G = \exp\left(\int \alpha(r)\, dr \right)$$

- Calculating the drift time:

$$t = \int (1/v(r))\, dr$$

Non-equilibrium effect

- **Non-equilibrium** effects has been addressed for **non-uniform electric** field in the literature
- **The effect is** seen at high electric field gradients
  - If **E/p** is high the change in electric field across one free mean path can't be ignored
    - The effect causes a difference between integration calculation and actual results

- See the reference for further information : Ségur, P., Pérés, I., Boeuf, J. P., and Bordage, M. C. (1989). Microscopic calculation of the gas gain in cylindrical proportional counters. Radiation Protection Dosimetry,29(1-2), 23–30.

- Non-equilibrium effect is the deviation from the electron-electric field equilibrium, where the values of the transport parameters now depend on the electric field and the pressure separately.

- This mean that we can no longer use the integrating method to simulate e.g. gas gain in detectors with non-uniform electric fields.

- Instead we need to use microscopic tracking method to simulate the detectors without any integration.

Microscopic tracking

- Magboltz offers a Monte-Carlo simulation assuming the uniform electric field,
  - But, under the equilibrium conditions, **we can still** calculate gas gain or drift velocity for a non-uniform electric field detectors by integrating the Magboltz uniform transport parameters. (https://magboltz.web.cern.ch/magboltz)

- **How to understand non-equilibrium effect is important for a given data?**
- Garfield++ uses the same Monte-Carlo method but generalized for any field configuration called **"Microscopic Tracking",**
  - This enables us to define the dimension of the detector used (https://garfieldpp.web.cern.ch/garfieldpp/)

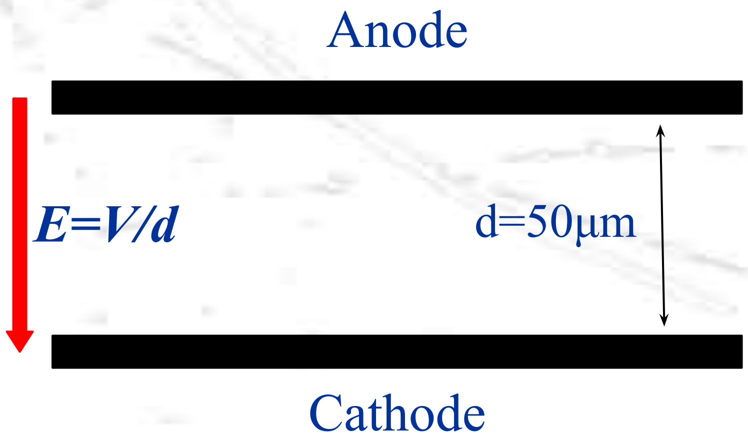
- **Comparing** these two methods (Magboltz and Microscopic Tracking) should give us an insight on non-equilibrium effect!

Simulation of Parallel Plate Detectors (PPD)

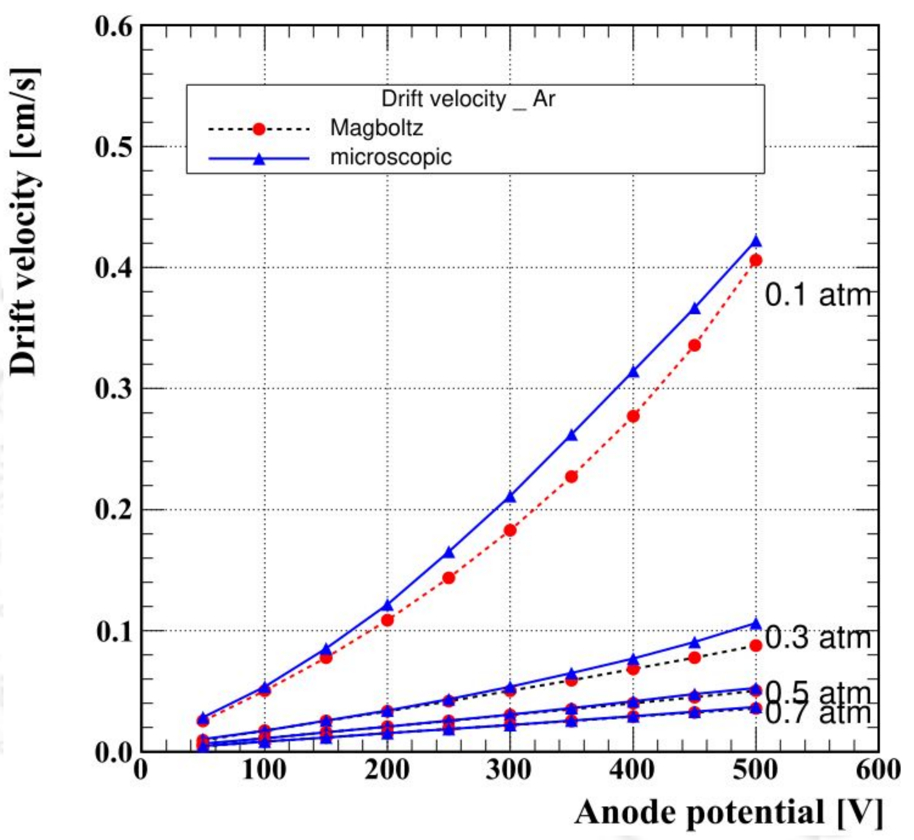
- To prove that the difference between the two method is only the non-equilibrium effect, we have first to make sure that the two methods give the same results in a uniform electric field (parallel plate detector).

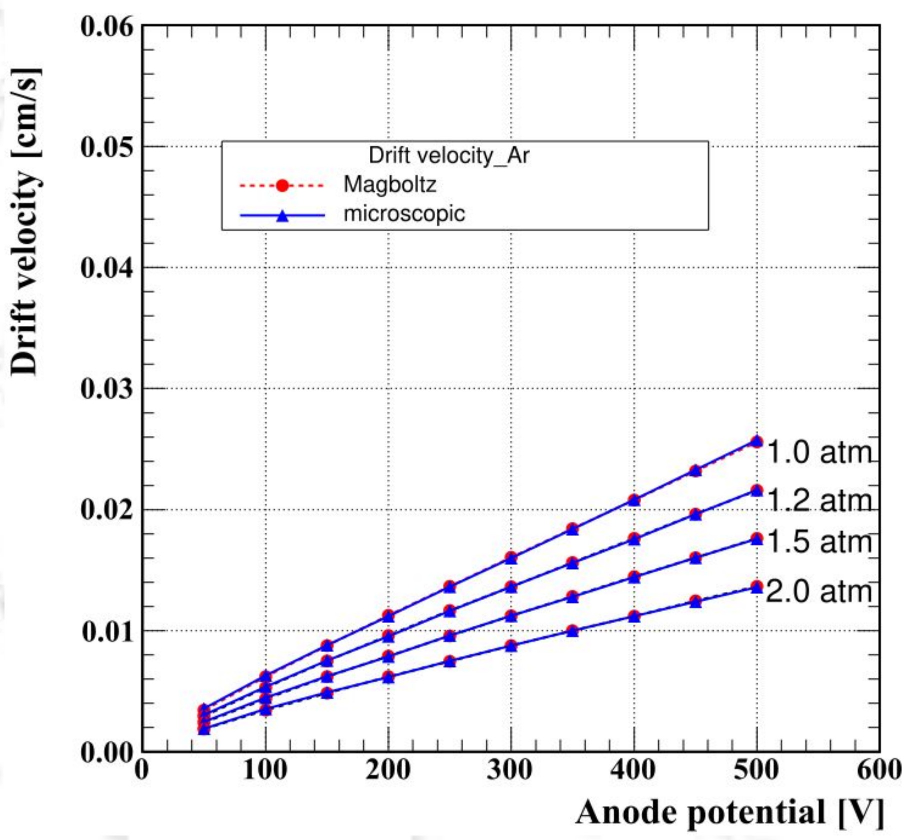
    - **Drift velocity** : should be same in uniform electric fields
    - **Gas Gain** : should be same since the electric field is constant in PPD

- The calculations were made for parallel plate detector with
    - d = 50μm gap,
    - the anode potential (V) ranged from 50-500V,
    - the pressure ranged between 0.1-2 atm
    - Gas: Ar, Ar-CO_2 (80/20), Ne-CO_2 (80/20)



Parallel Plate: Drift Velocity in Pure Ar

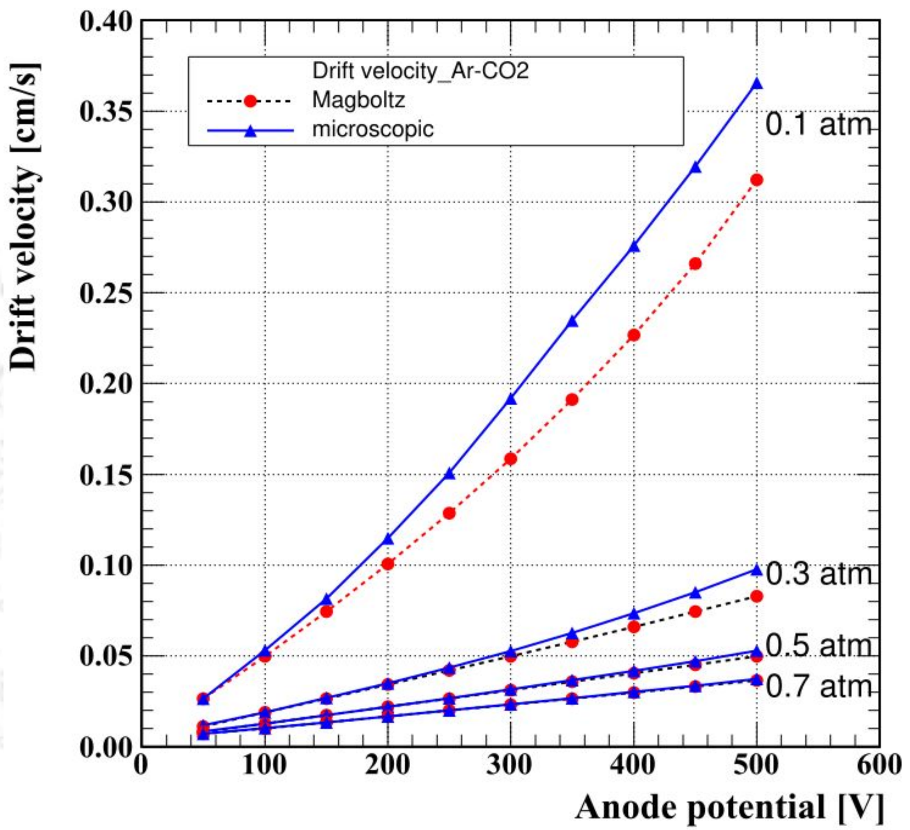


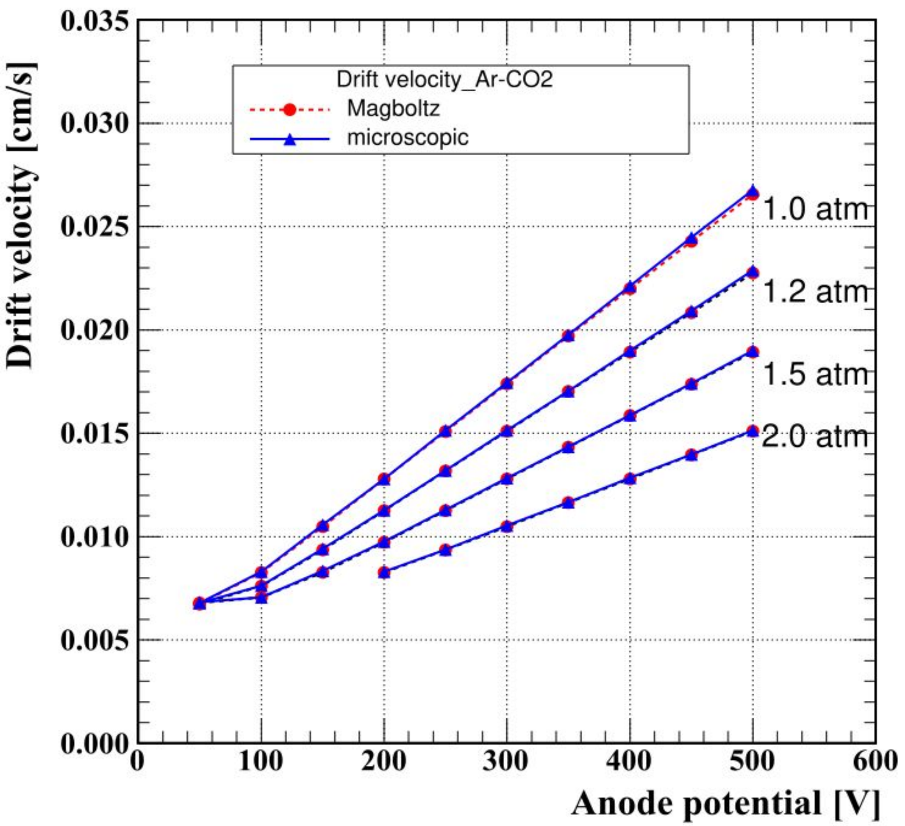


- Small discrepancies at 0.1 and 0.3 atm
- **Possible explanation:** The electrons have not yet made enough collisions to reach a state of equilibrium (relaxation time).

- Calculation overlaps are perfectly fine with both Magboltz and Microscopic approaches at high (atmospheric) pressures.

Parallel Plate: Drift Velocity in Ar-CO_2 (80/20)

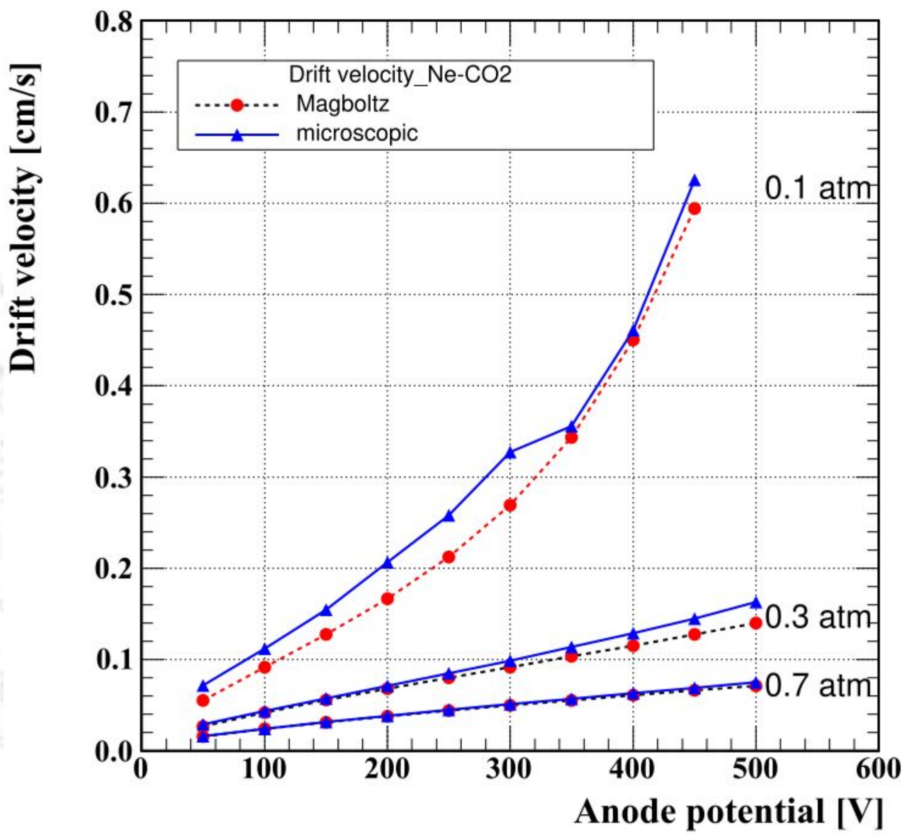


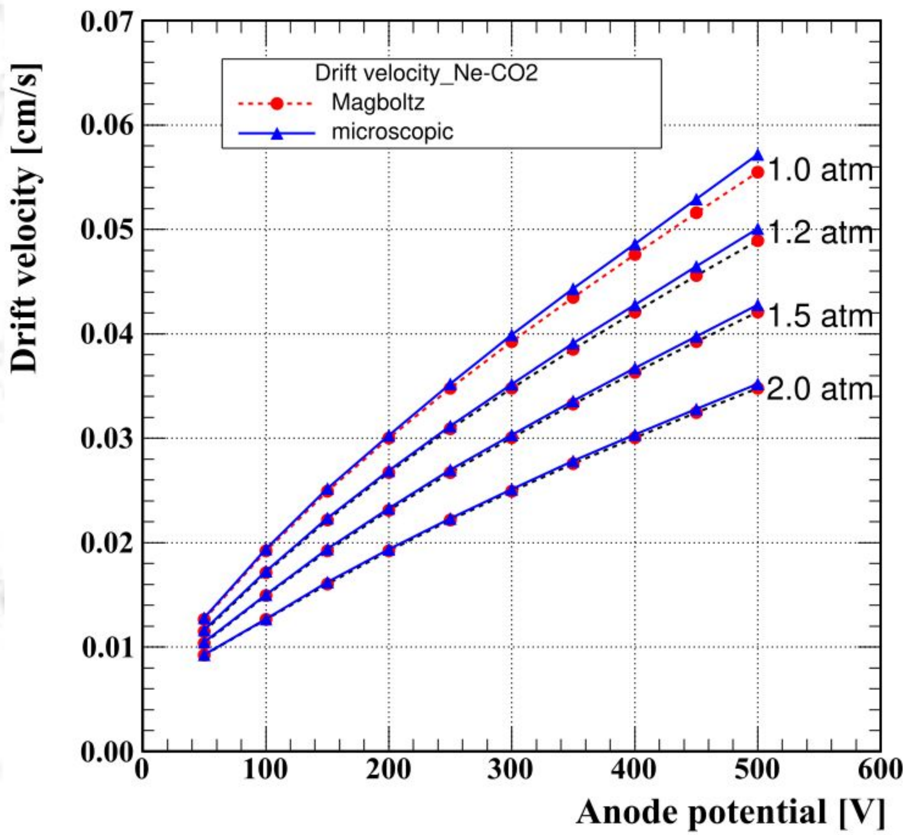


- Small discrepancies again at 0.1 and 0.3 atm
  - Still less than 15% even at 0.1 atm
- **The same explanation holds (see pure Argon)!**

- Perfectly fine overlaps again with both Magboltz and Microscopic approaches at high pressures.

Parallel Plate: Drift Velocity in Ne-CO_2 (80/20)

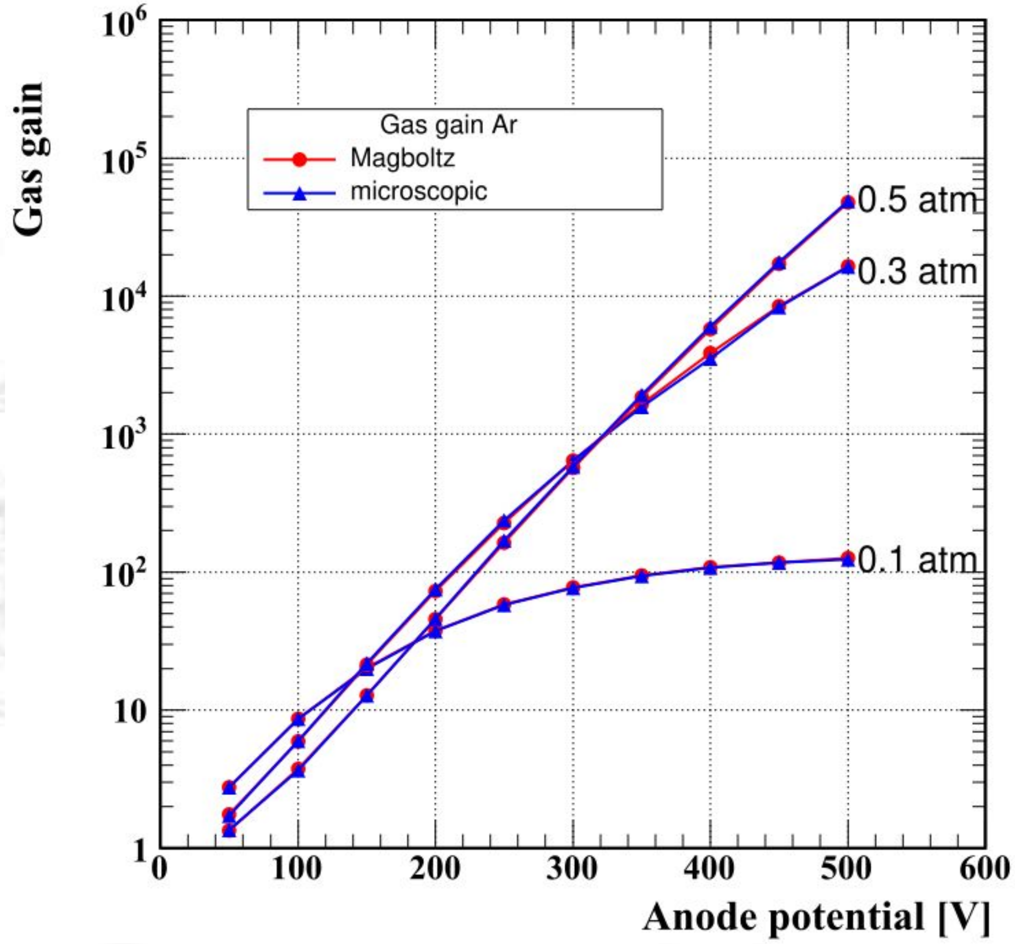


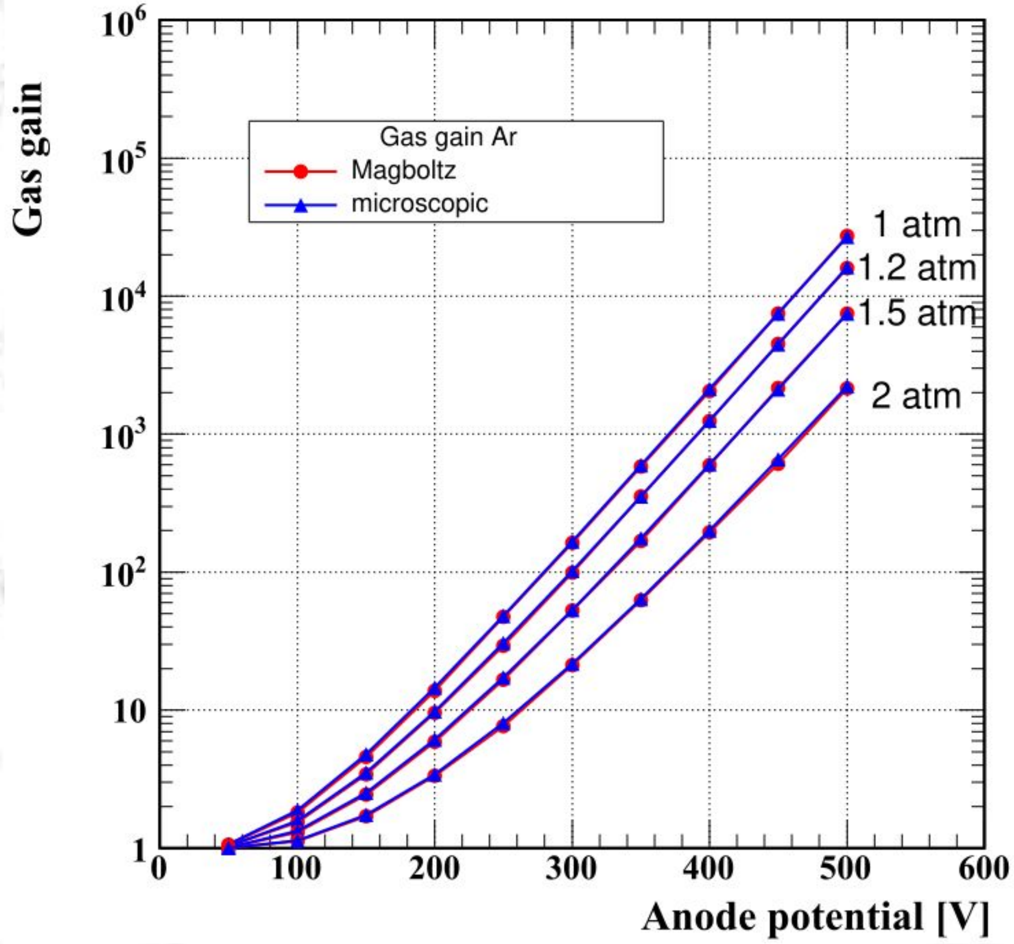


- Peculiar discrepancies again at 0.1 atm before 350V
  - Getting closer after 350V
- **The same explanation holds for the deviations!**

- Perfectly fine overlap is seen **at the highest pressure** (2 atm)
- At lower pressures, the **separations** in the calculations are still **insignificant**.

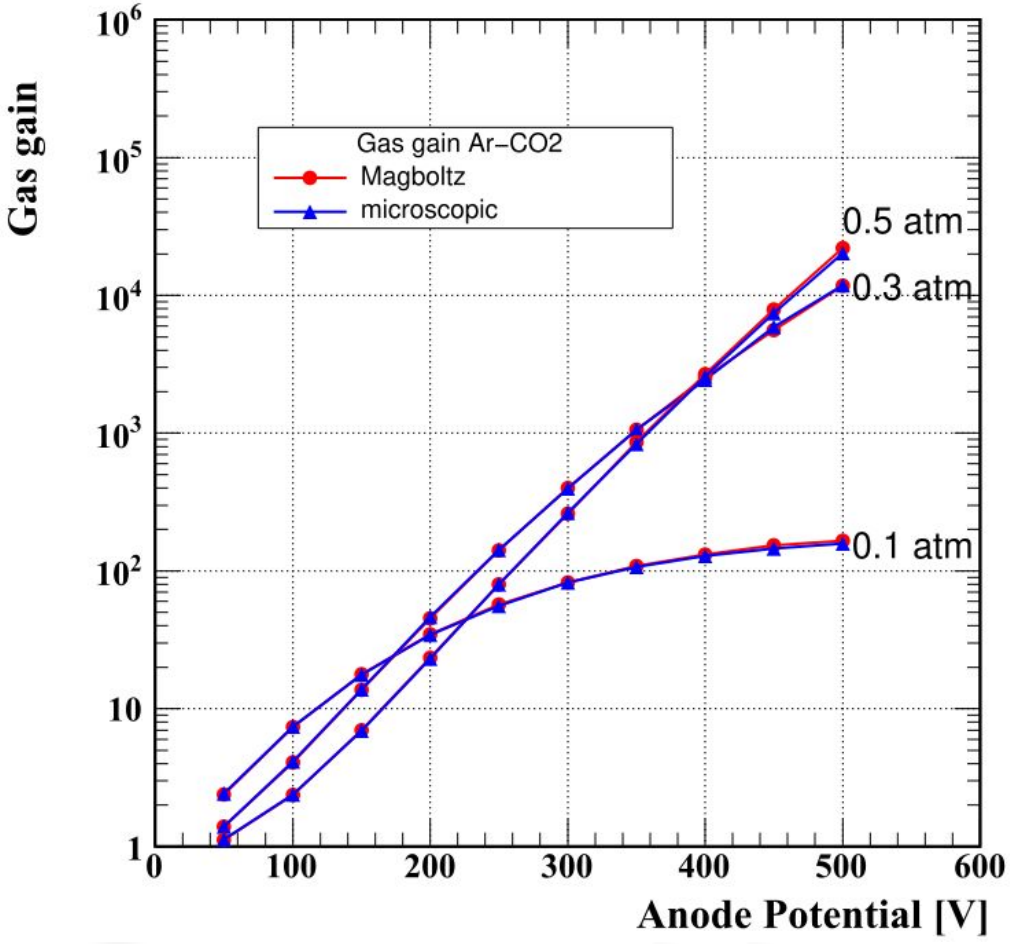
Parallel Plate: Gas Gain in Pure Ar

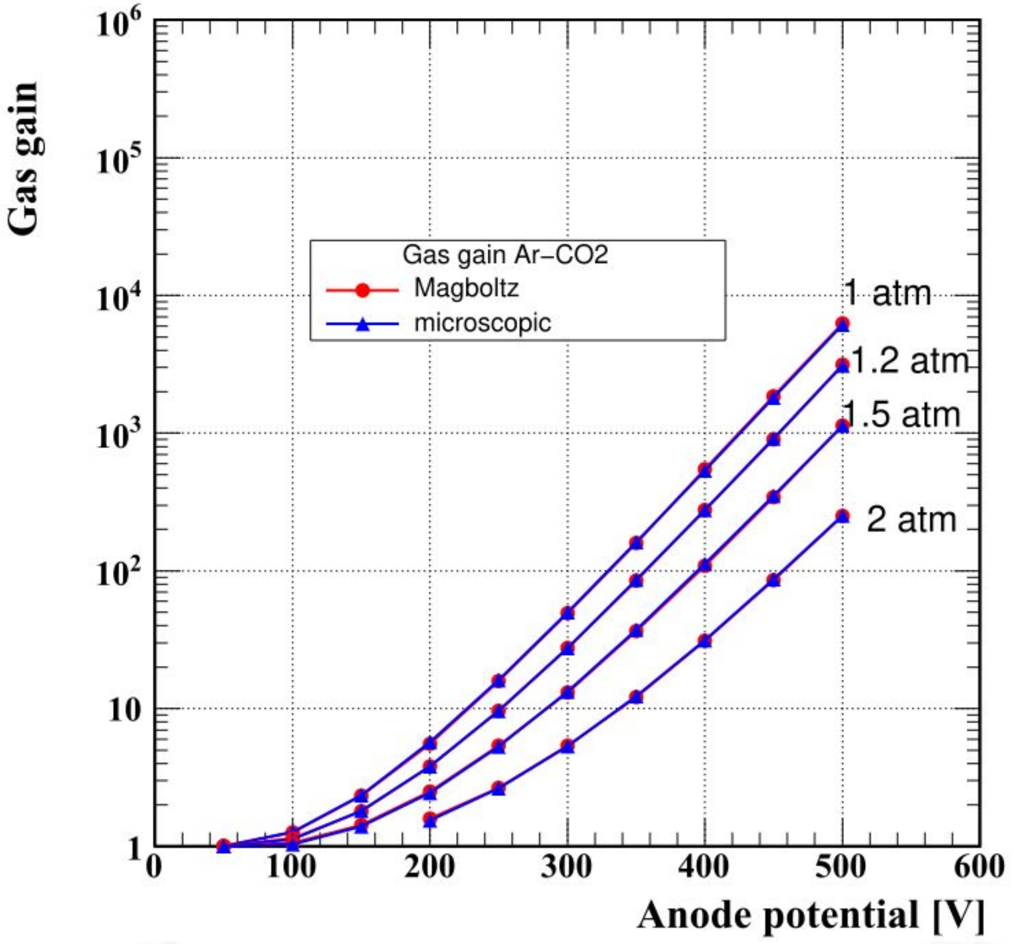




- Perfectly fine agreements for the gas gains with both Magboltz and Microscopic methods at all pressures.
- These results confirm our predictions and correspond tightly to the literature!
  - **Reminder:** For uniform electric fields, we **do not expect** to see any non-equilibrium effect on gas gain.

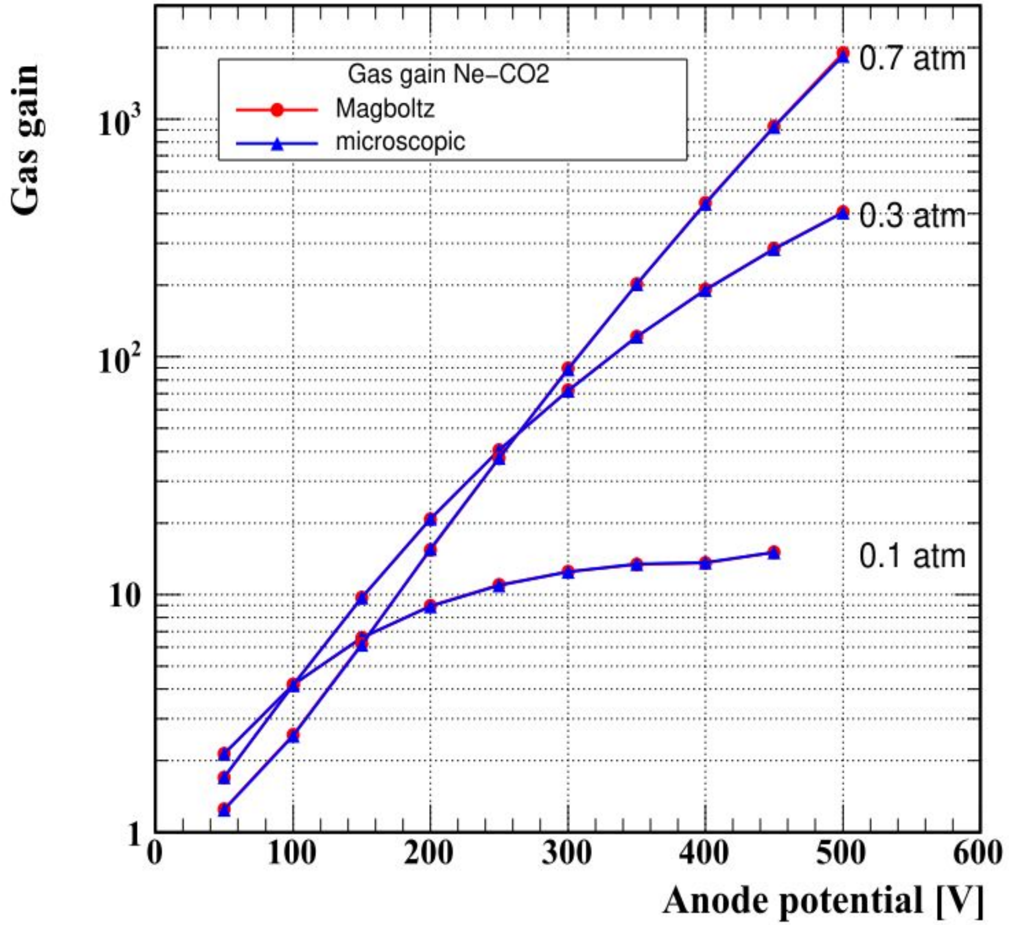
Parallel Plate: Gas Gain in Ar-CO_2 (80/20)

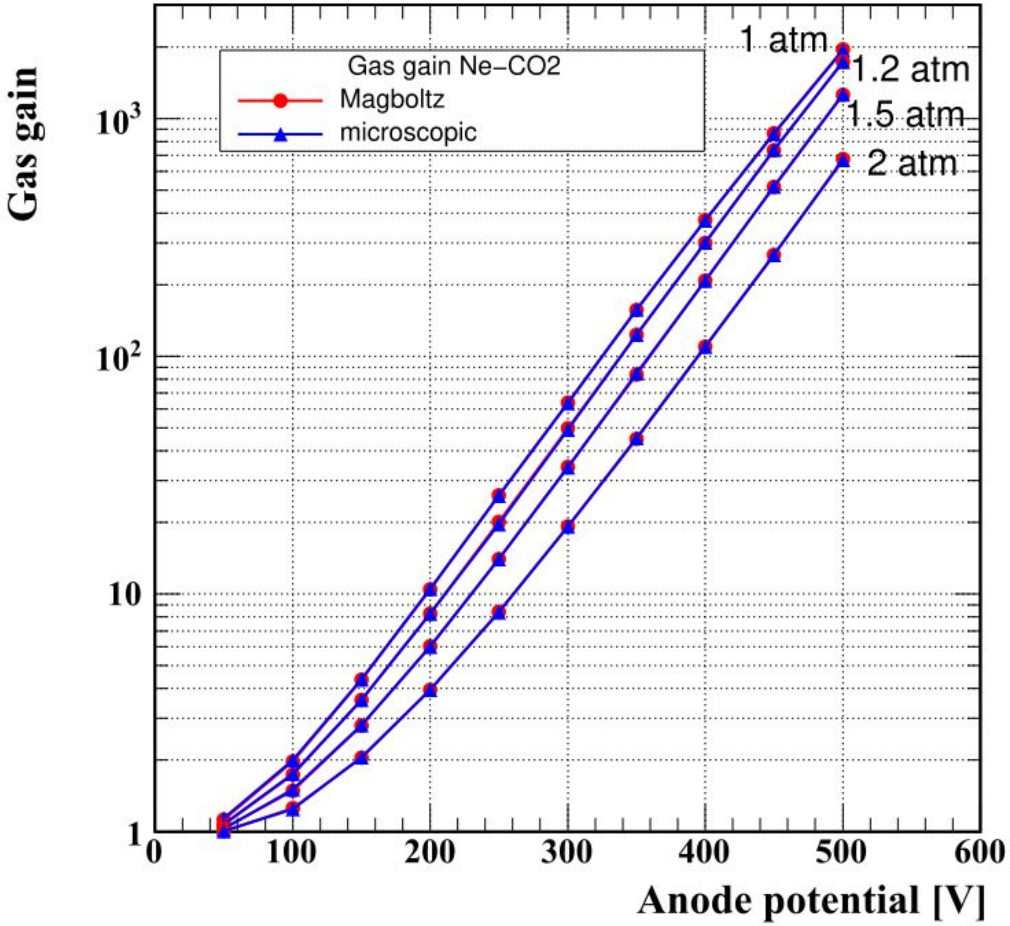




- Perfectly fine agreements for the gas gains in **Ar-CO_2** mixtures.
  - The results prove that there is absolutely **no non-equilibrium effect!**

Parallel Plate: Gas Gain in Ne-CO_2 (80/20)

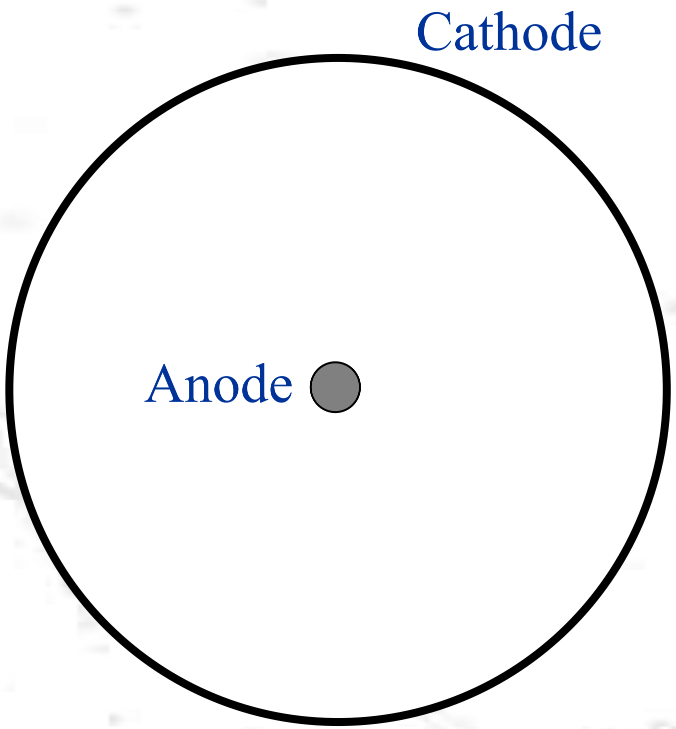


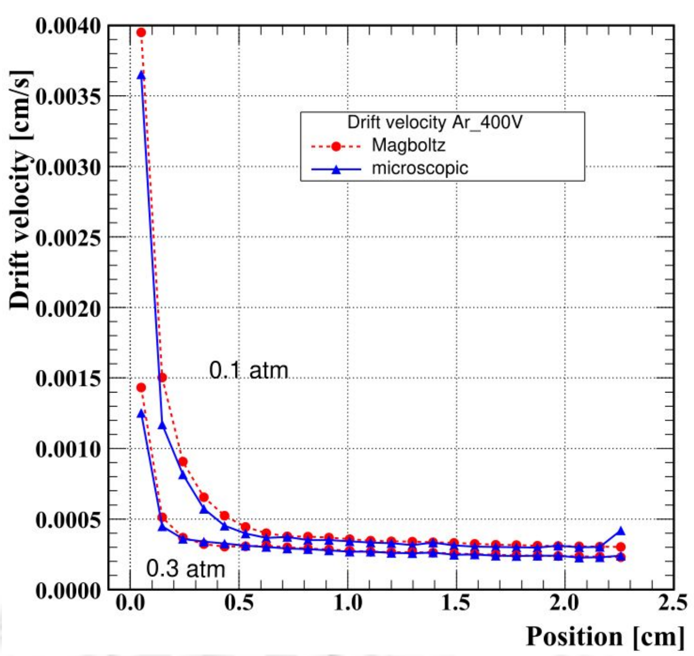


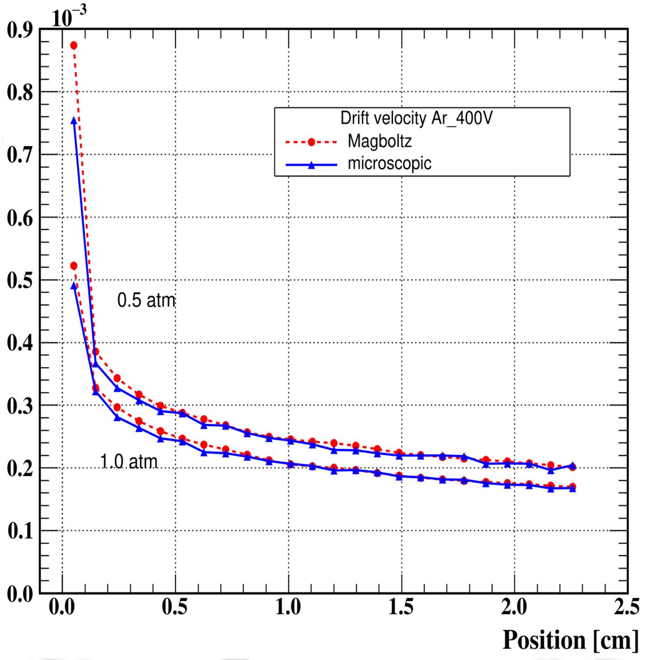
- Perfectly fine agreements for the gas gains in **Ne-CO_2** mixtures.
  - Again, **no non-equilibrium** effect is observed!

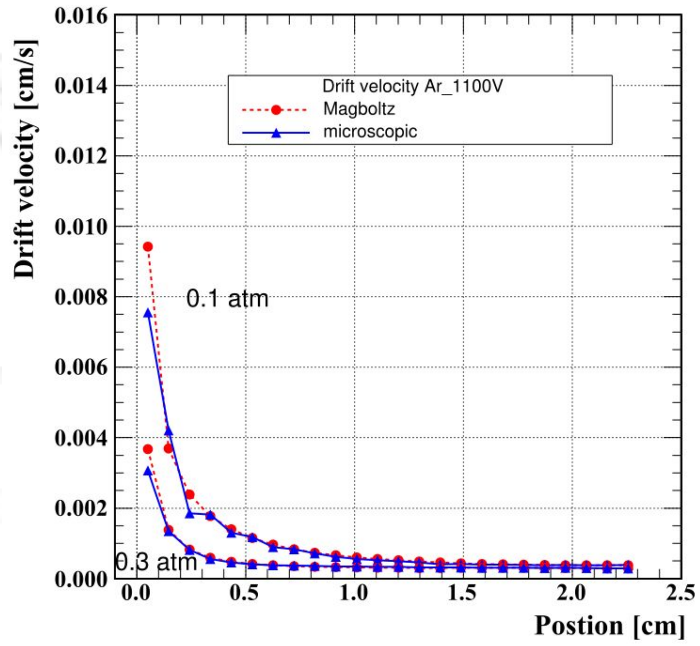
Simulations in Single Wire Tube

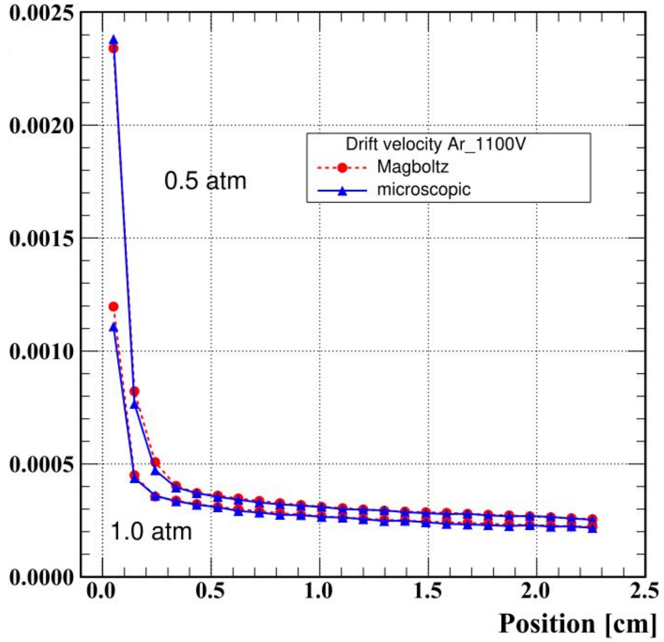
- Assumed a simple single wire detector
- r_{anode} = 25µm and $r_{cathode}$ = 2.5 cm,
- Anode potential ranging from 200-1100V
  - The same range for all the calculations
- Comparisons:
  - Different gas pressures
  - The same gases are investigated
    - Pure Ar, 80% Ar, Ne + 20% CO_2





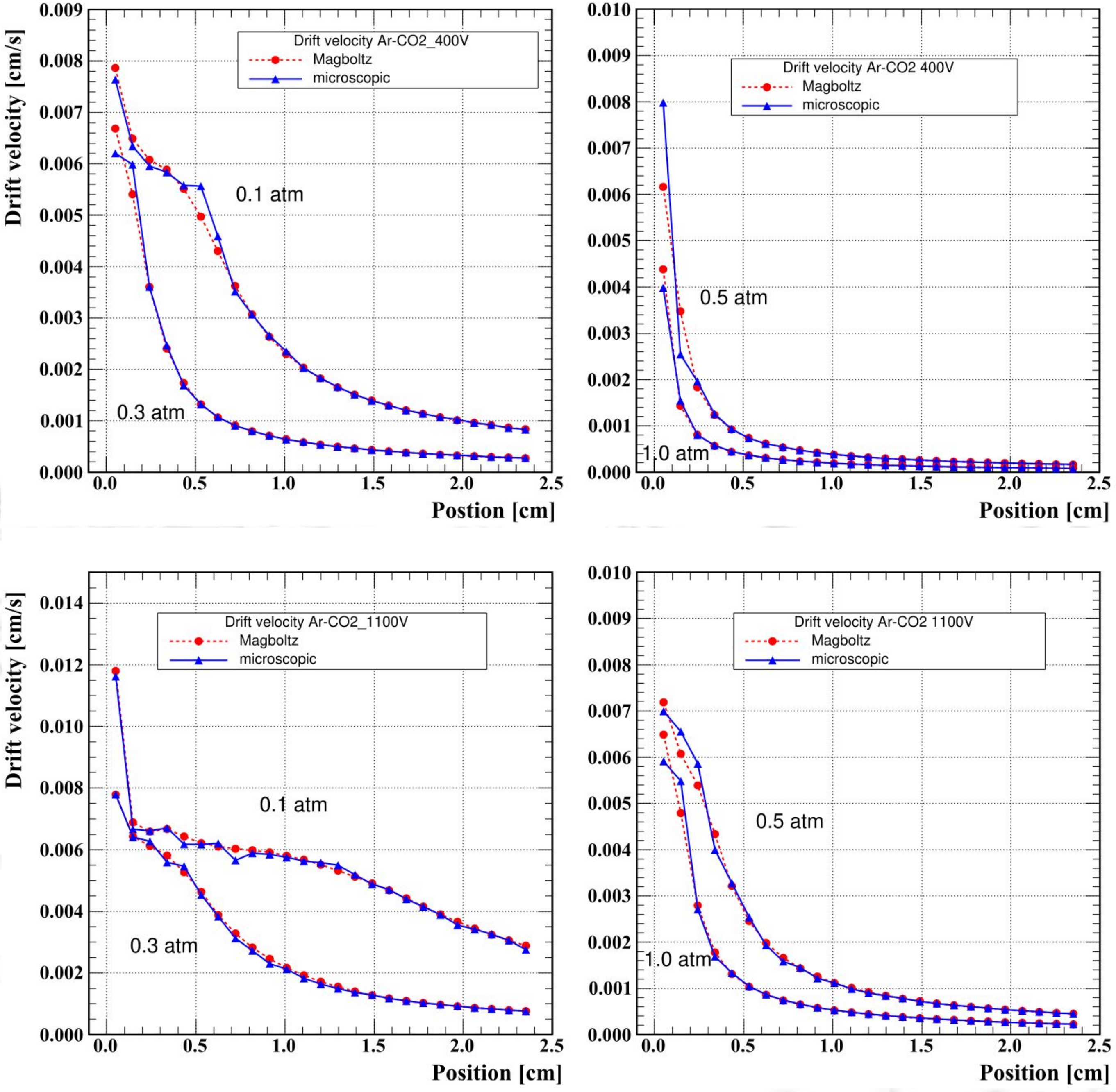






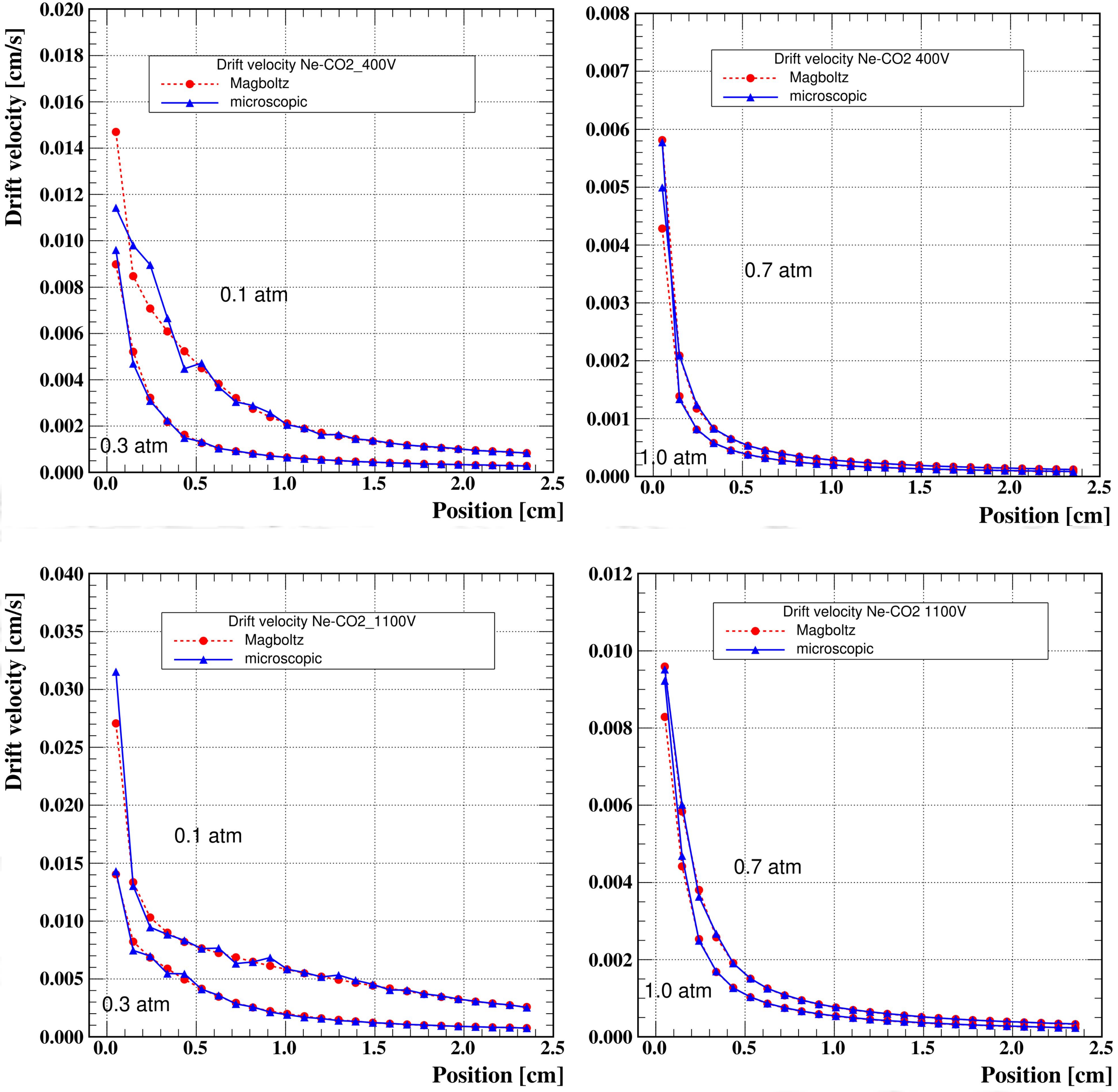
Single Wire: Drift Velocity in Pure Ar

- Both the Magboltz and Microscopic calculations provide nearly identical drift velocities.
- These agreements are the same even for the different voltages (400V and 1100 V)
- **Result:** Drift velocity is not affected by non-equilibrium effects.



Single Wire: Drift Velocity in Ar-CO_2 (80/20)

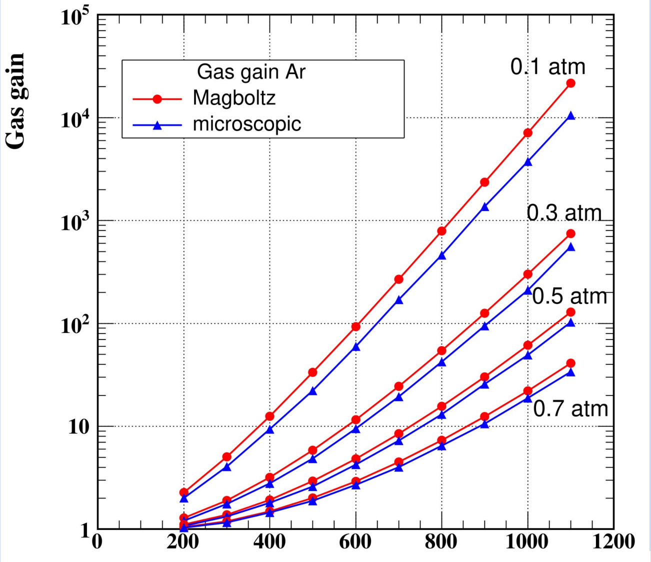
- Once again, the drift velocities are approximately the same in Ar-CO_2 mixtures.
- There is no non-equilibrium effect on the drift velocity

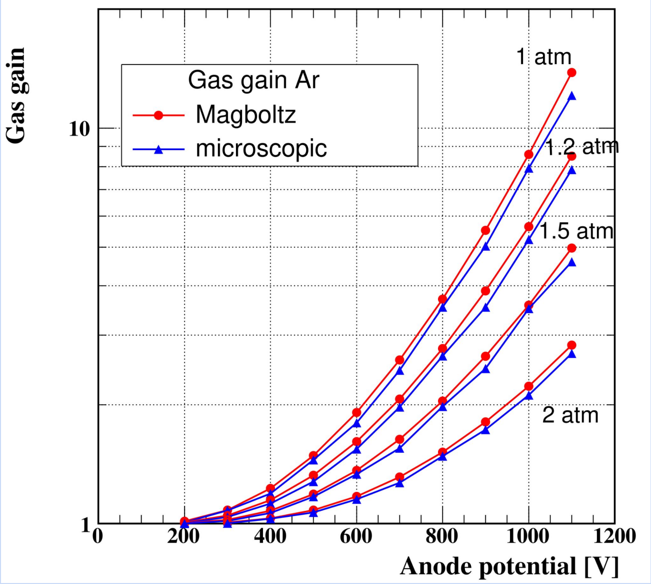


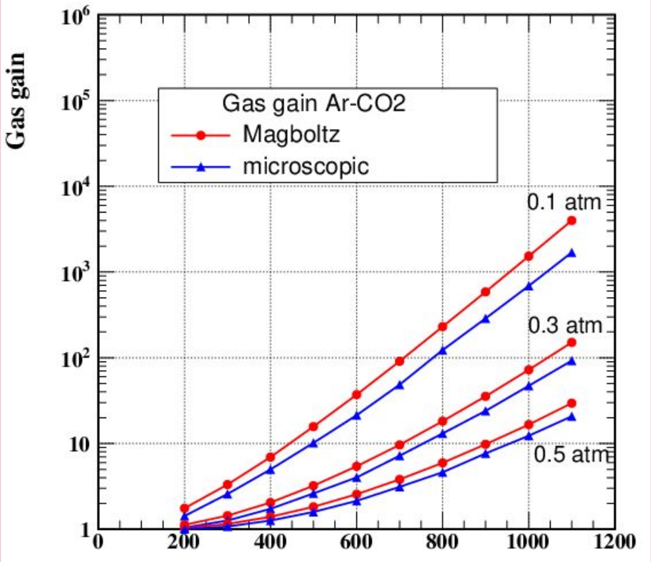
Single Wire: Drift Velocity in Ne-CO_2 (80/20)

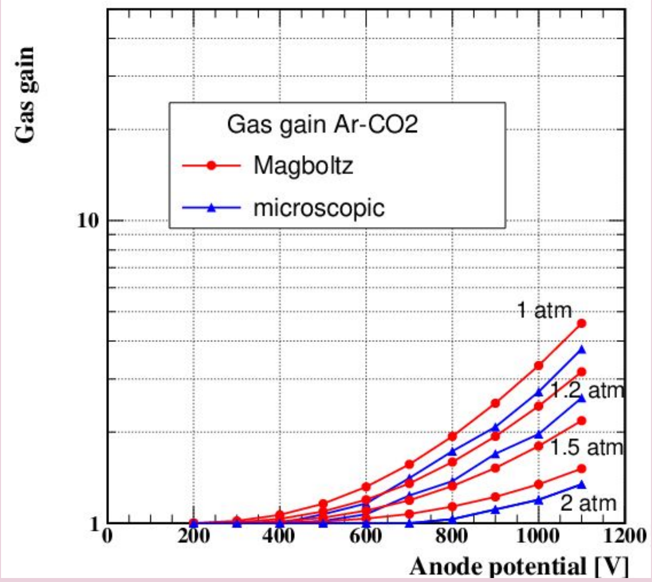
- There is not any noticeable difference for drift velocities in Ne-CO_2 mixtures.
- There is no non-equilibrium effect on the drift velocity

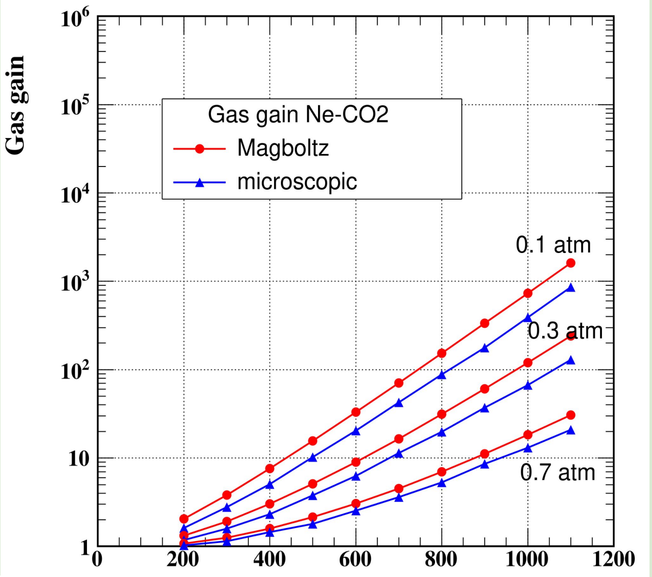
Single Wire: Gas Gain

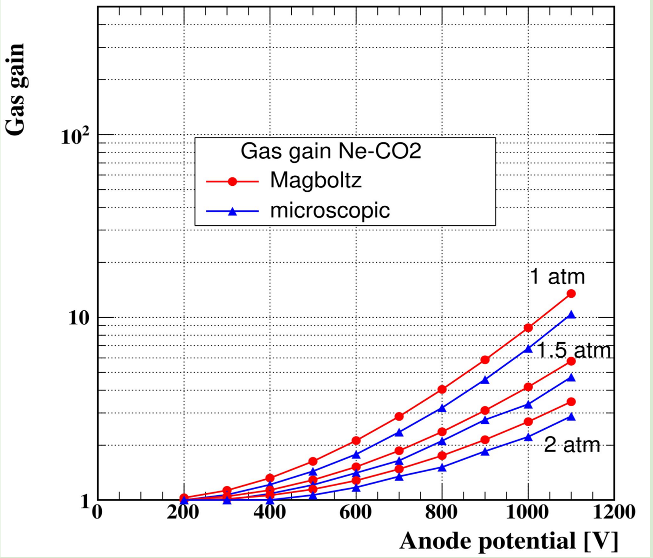












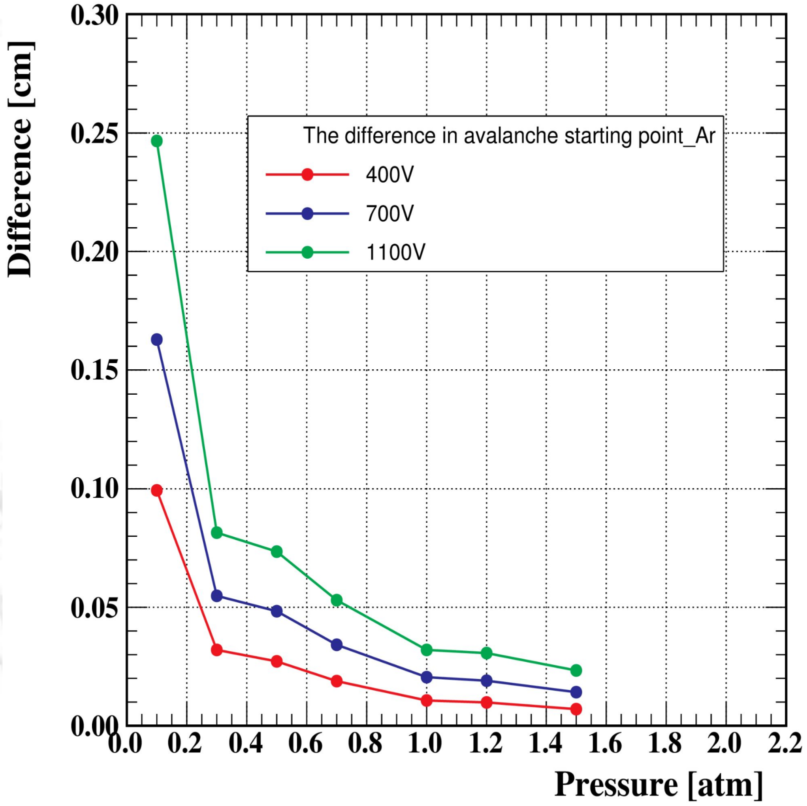
Results of single wire tube simulation

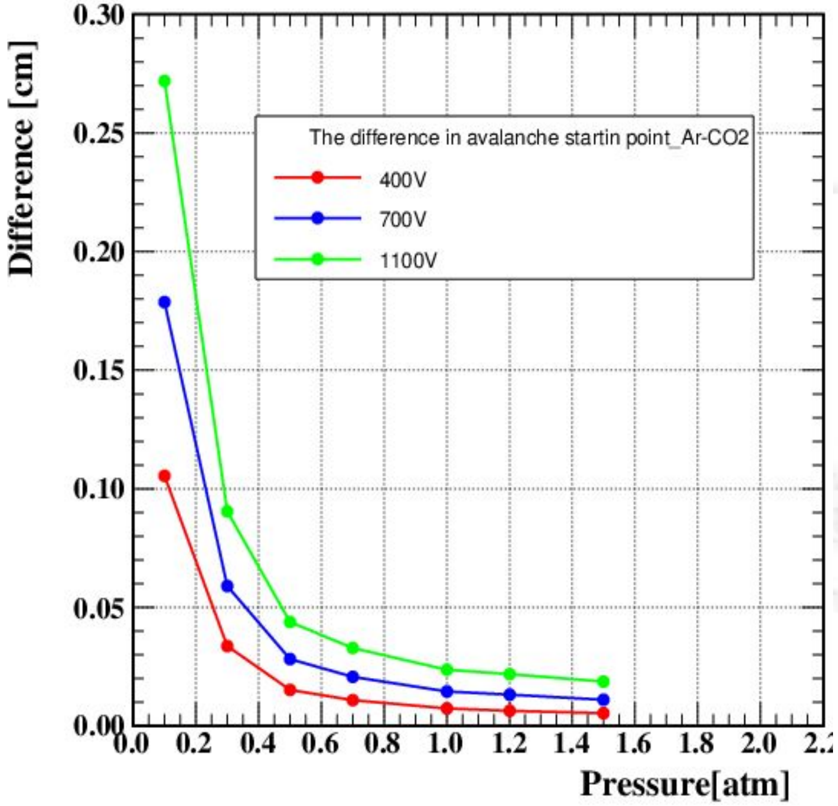
- As the previous graphs show, there's no noticeable difference in the drift velocity calculations using both methods.
  - This might point that the non-equilibrium effect of drift velocity is non-noticeable in the gas mixtures and pressures used.

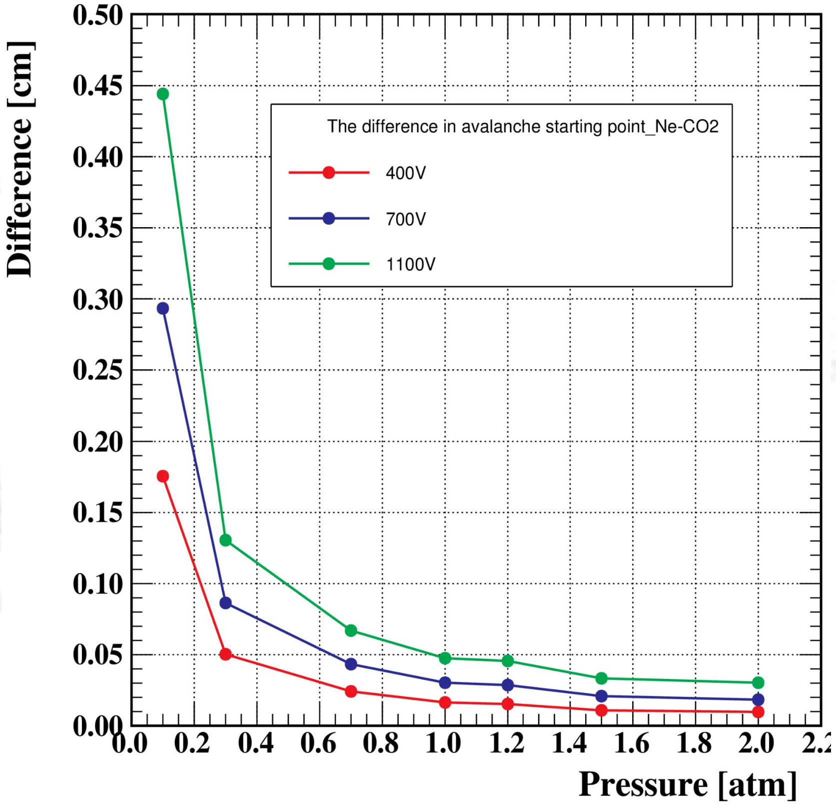
- For gas gain we see clearly that the lower the pressure the more differences there are between the two methods
  - and this differences also increase at high anode potentials.

- The position of the point where avalanche starts is also simulated to see where does the Townsend coefficient stars to differ between the two methods
  - **See the next slide!**

Avalanche starting point







- **Difference means: $r_{magboltz} - r_{microscopic}$**
- At low pressures and high anode voltages, the difference becomes larger in the same gas.

What's next?

- These Calculations show that the non-equilibrium effect is an important factor to consider when simulating gaseous detectors with non-uniform electric field.
  - Not only for much below atmospheric pressures, but even for a few atm.

- We need more calculations with more gases.
  - The type of gas combination also influences the non-equilibrium effect.
- Comparisons of simulation results to experimental data are required.
  - But we need to find out a way to isolate the non-equilibrium effect from other effects on gas gain; for example Penning effect.
    - Perhaps using non-Penning gases is a good starting point?

- Can we find a correction formula that can be added to integration method to account for the non-equilibrium effect?

Thanks and ???