Advancements in Simulating $C_3H_2F_4$-based Gas Mixtures for Resistive Plate Chambers

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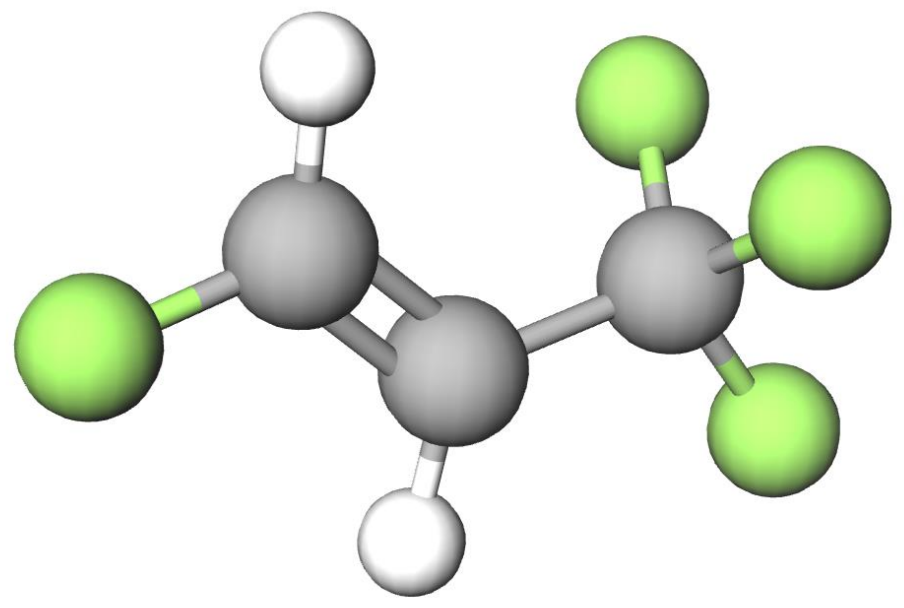
Outline

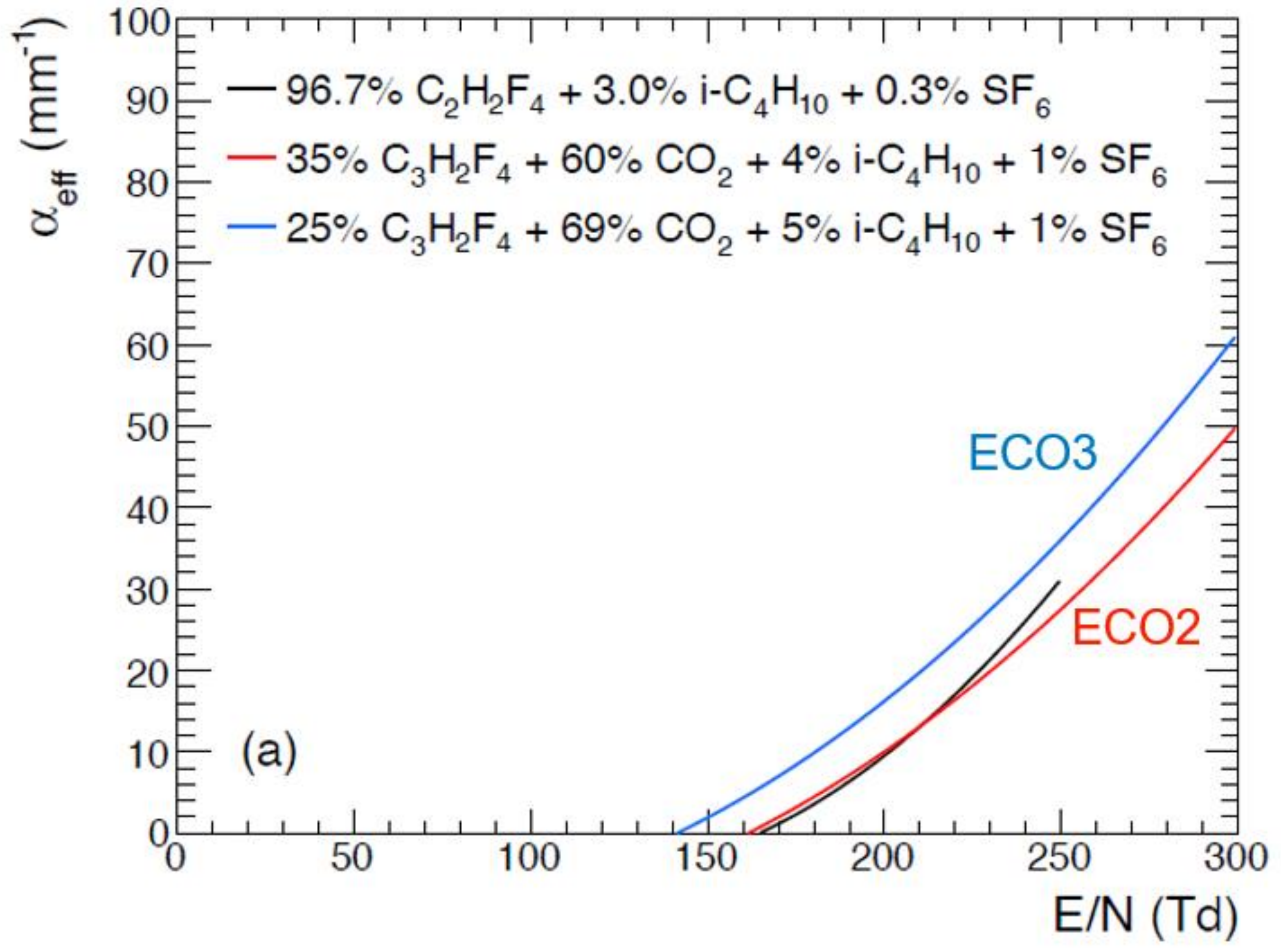
$C_3H_2F_4$ as a Promising Gas for Gaseous Particle Detectors

- Growing interest, particularly for use in Resistive Plate Chambers (RPCs)



Electron Collision Cross Sections for $C_3H_2F_4$

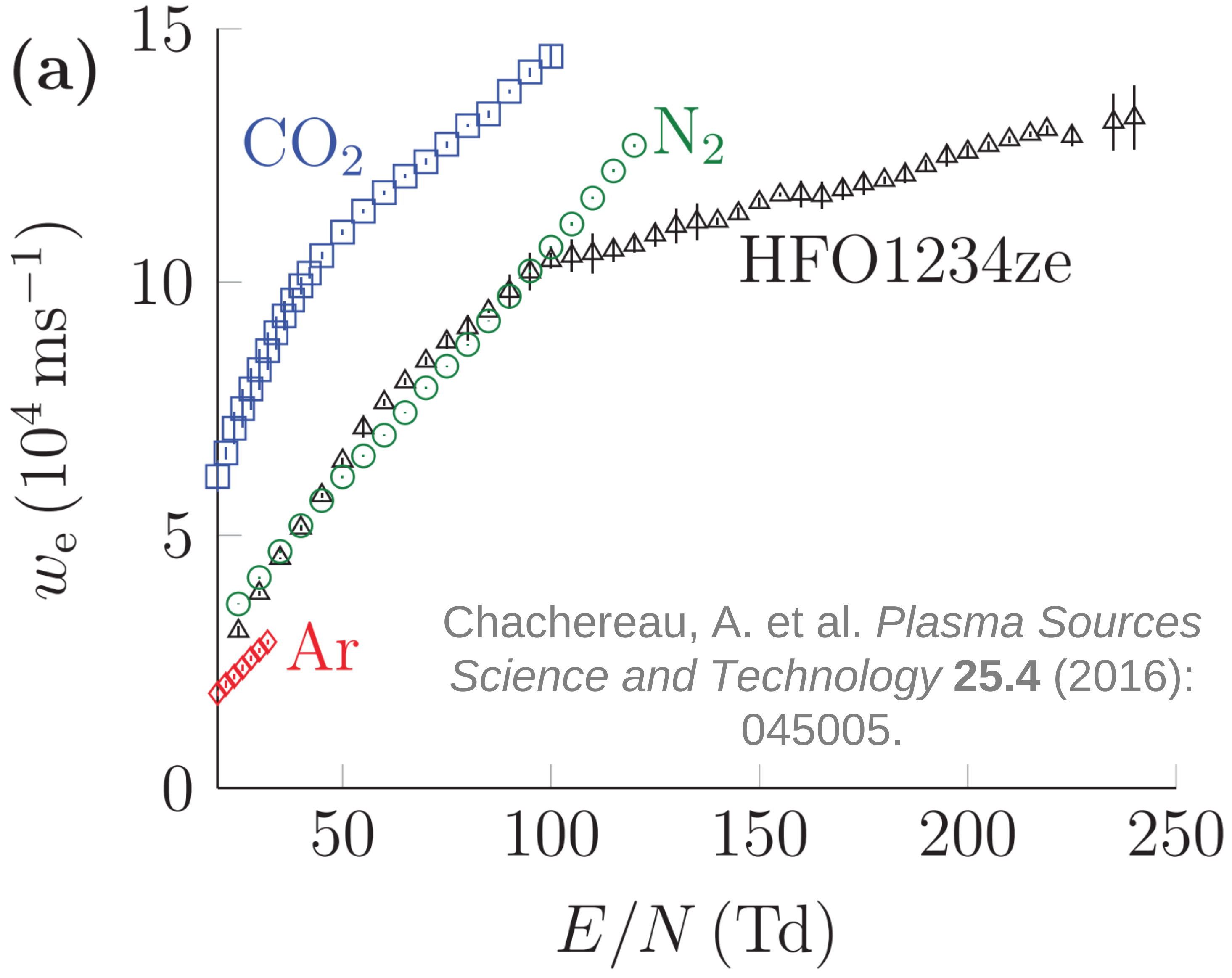
- Derived by unfolding electron swarm parameters from the literature
- Simulation results validated with Koch’s model and direct measurements in RPCs

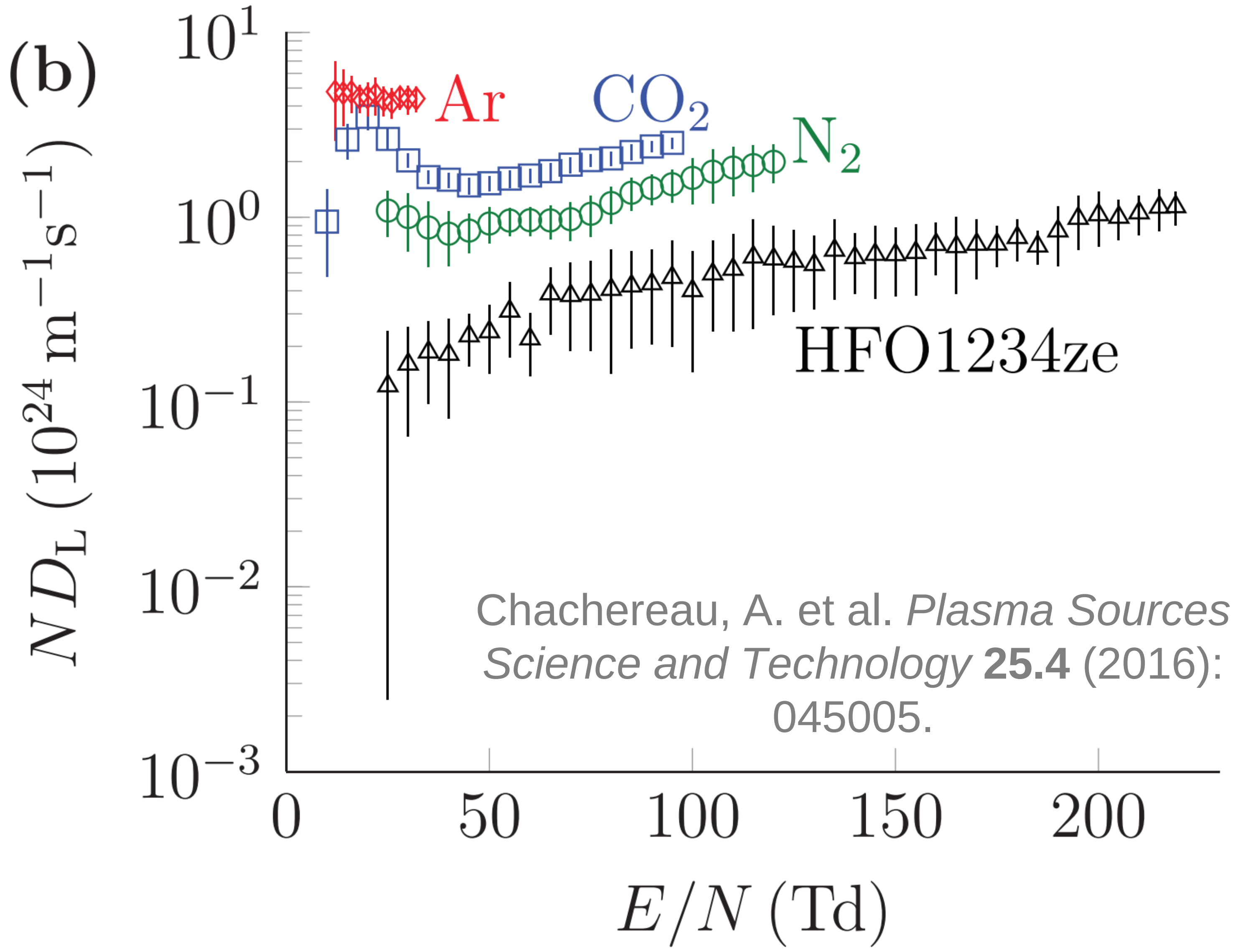


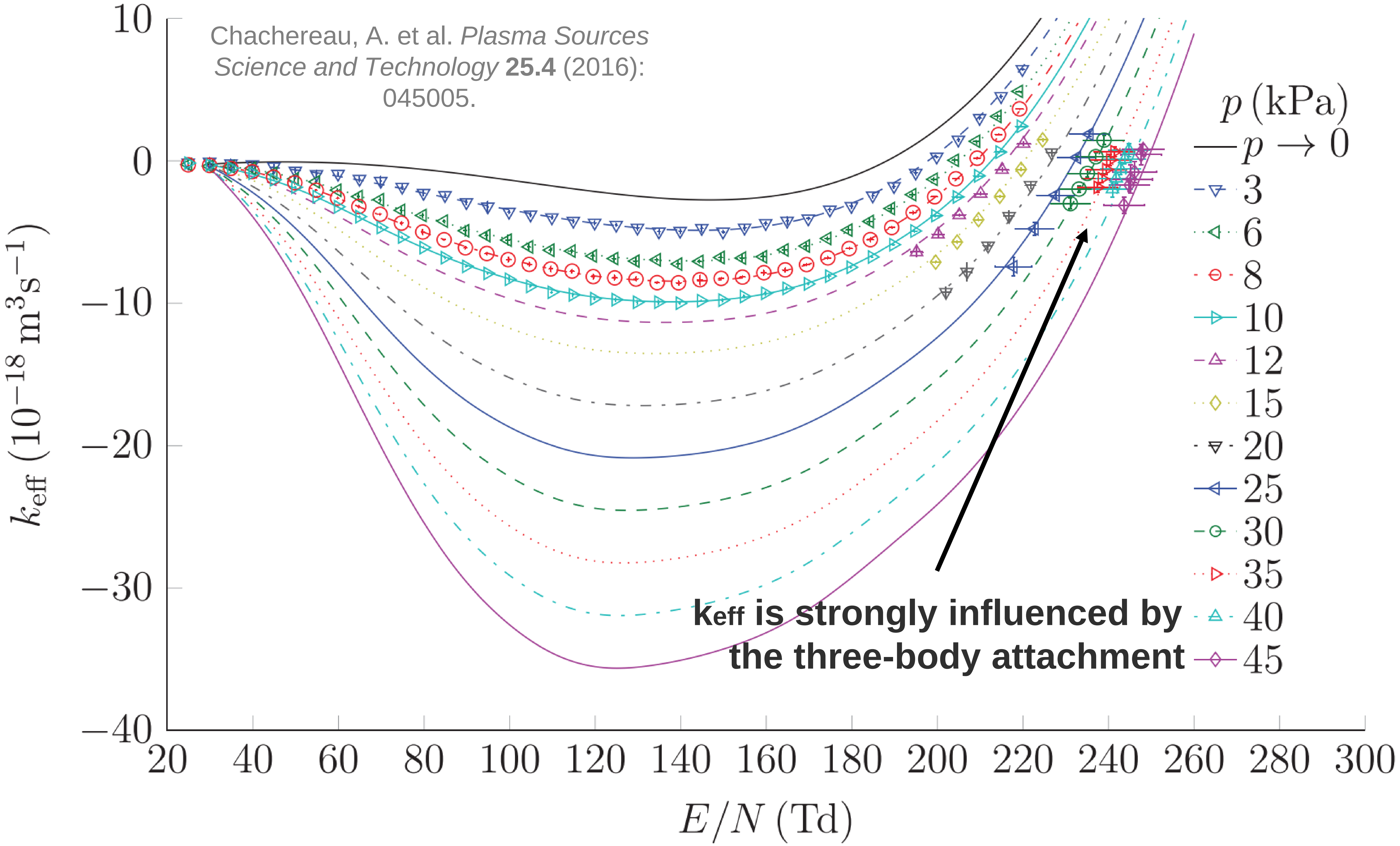
Comparative Studies of $C_3H_2F_4$-based Gas Mixtures

- Especially those tested by the **RPC ECOGAS@GIF++ collaboration**

Electron Swarm Parameters in $C_3H_2F_4$

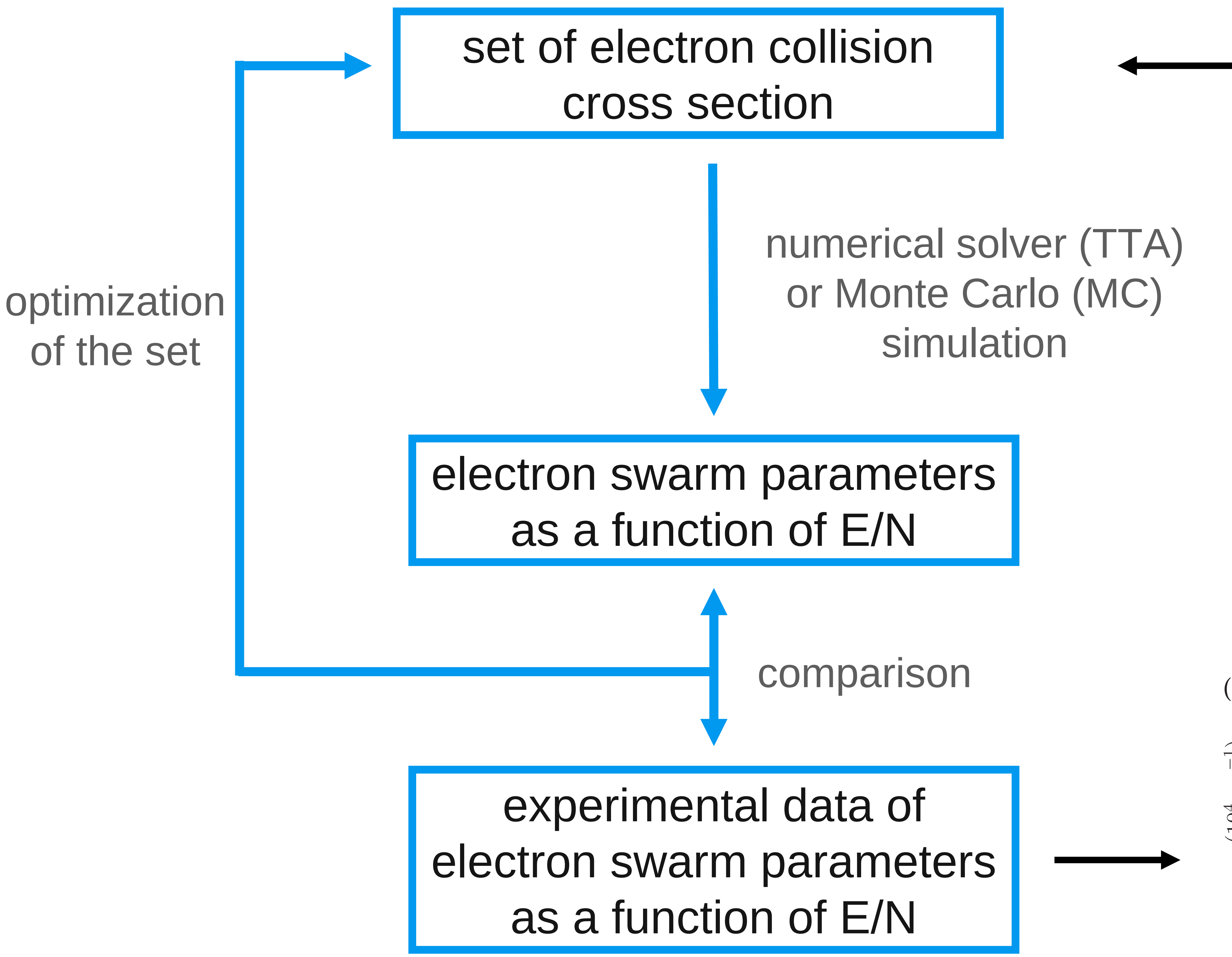


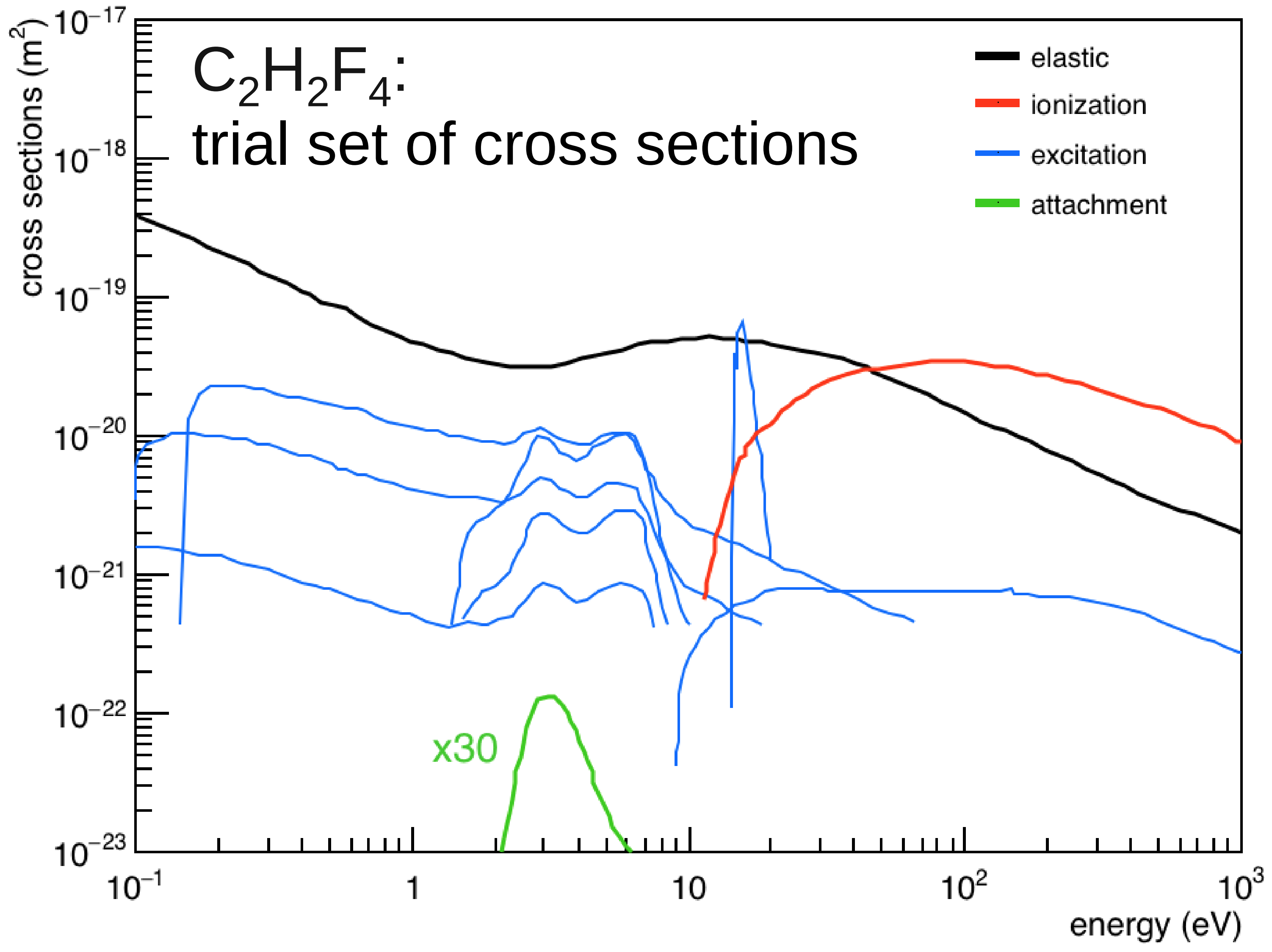




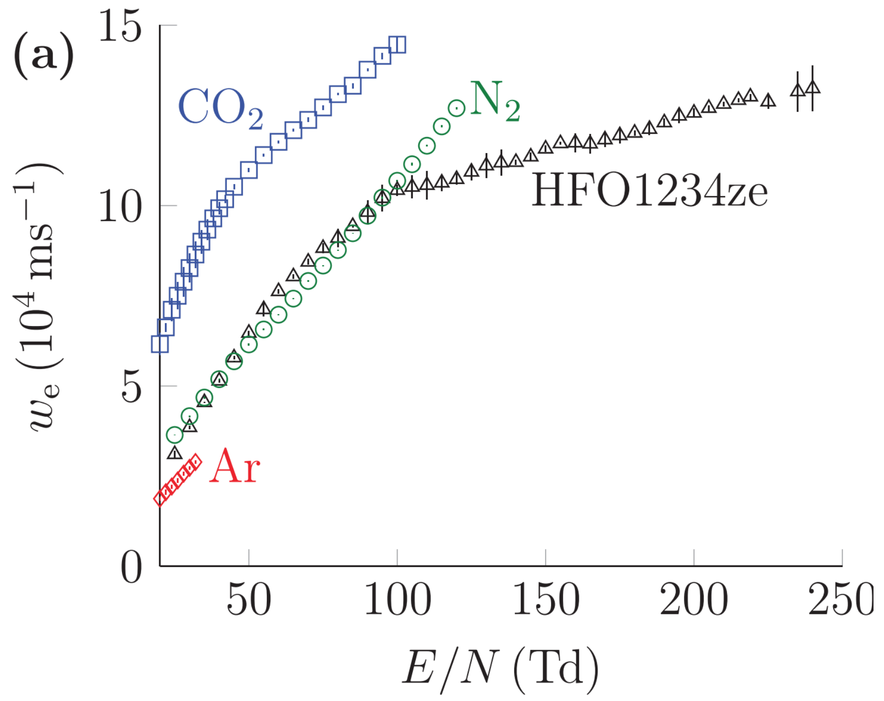
A set of electron collision cross sections for $C_3H_2F_4$ has been obtained by unfolding electron swarm parameters

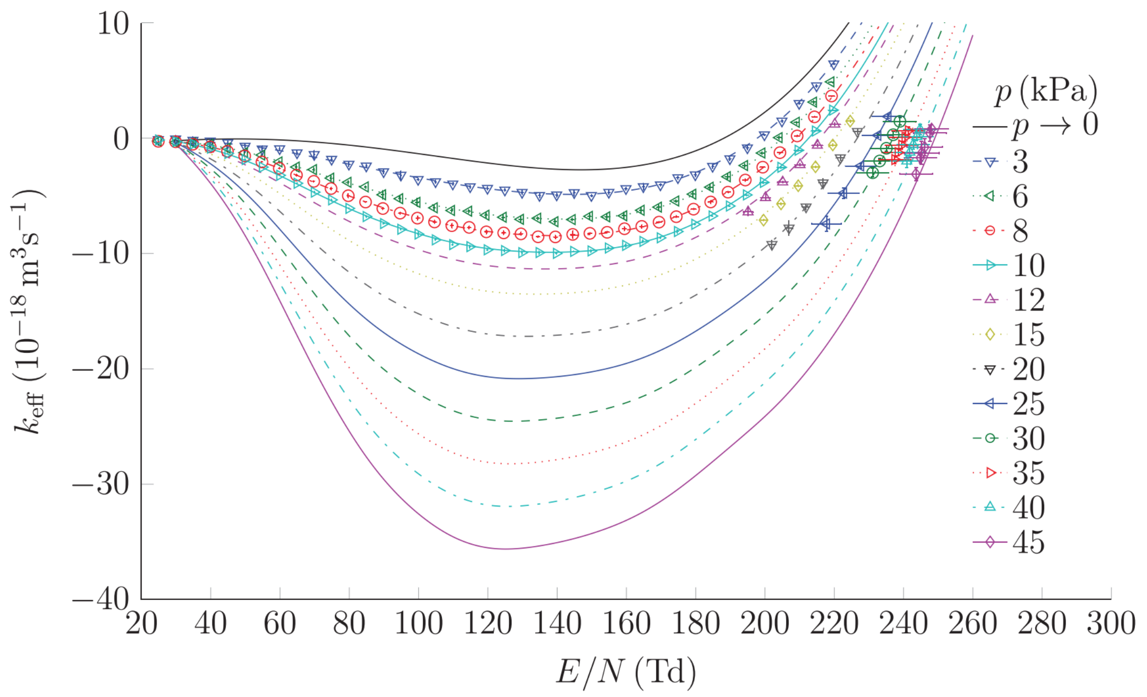
Unfolding of Electron Swarm Parameters



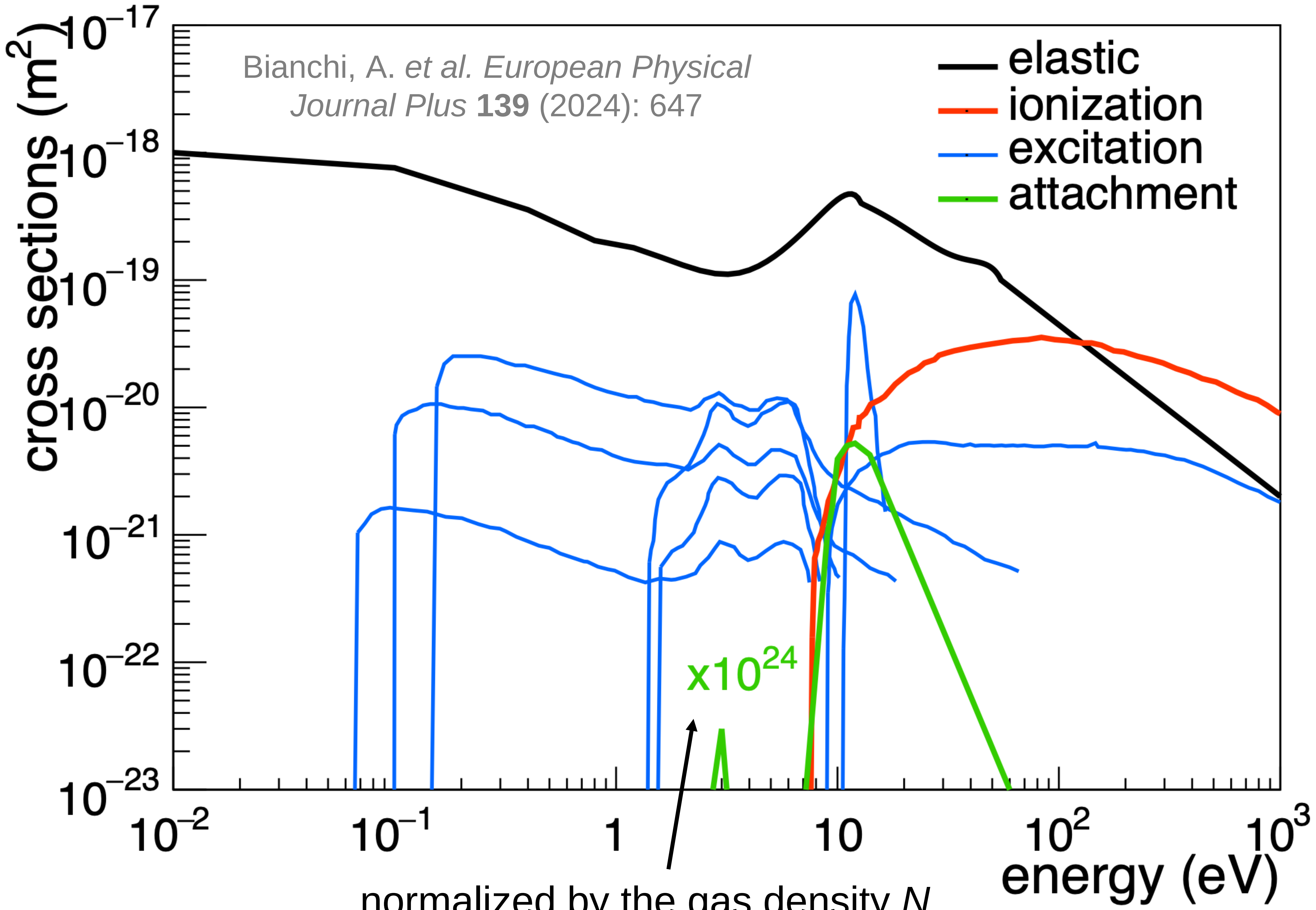


Šašić, O. *et al*. *Journal of Physics D: Applied Physics* **46.32** (2013): 325201.





Electron Collision Cross Sections in $C_3H_2F_4$



normalized by the gas density *N*

The stable capture of electrons can occur in $C_3H_2F_4$ by:

$$e^- + C_3H_2F_4 \rightarrow A^- + B$$

dissociative attachment

or

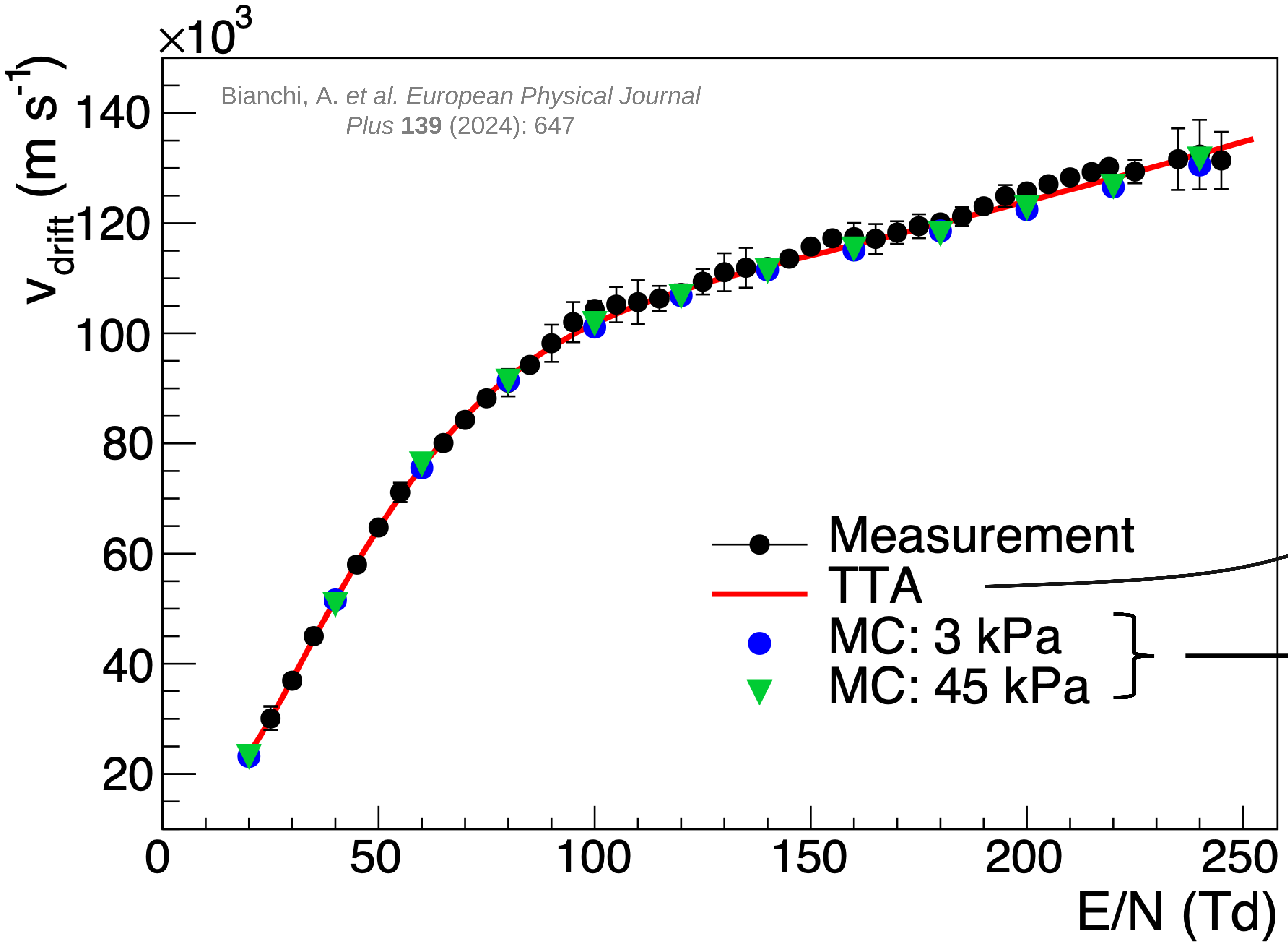
$$(C_3H_2F_4)^{-*} + C_3H_2F_4 \rightarrow (C_3H_2F_4)^- + C_3H_2F_4$$

collisional stabilization

This last process depends on the collision rate of $C_3H_2F_4$, which, in turn, is influenced by the gas density *N*

Electron swarm parameters can be obtained by solving the Boltzmann transport equation through numerical calculations or Monte Carlo simulations, starting from electron collision cross sections.

Drift Velocity in $C_3H_2F_4$



Measurements are taken from 3 kPa to 45 kPa

(no significant differences are observed)

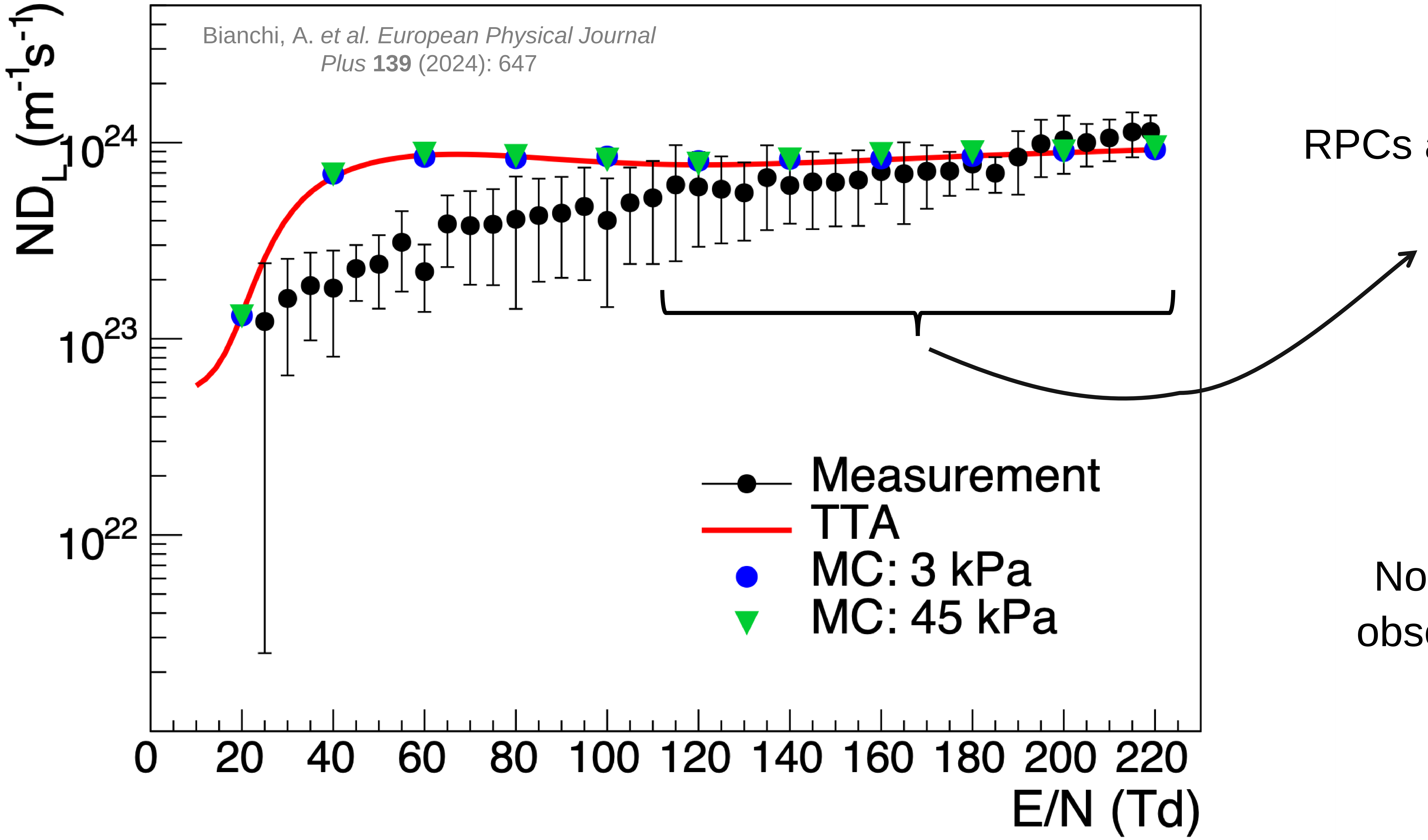
calculated by BOLSIG+ with the two-term approximation (TTA)

calculated by Monte Carlo (MC) simulations

METHES: Rabie, M. et al, *Computer Physics Communications* **203** (2016): 268-277.

MATOQ: Bianchi, A., *European Physical Journal Plus* **138** (2023), 838

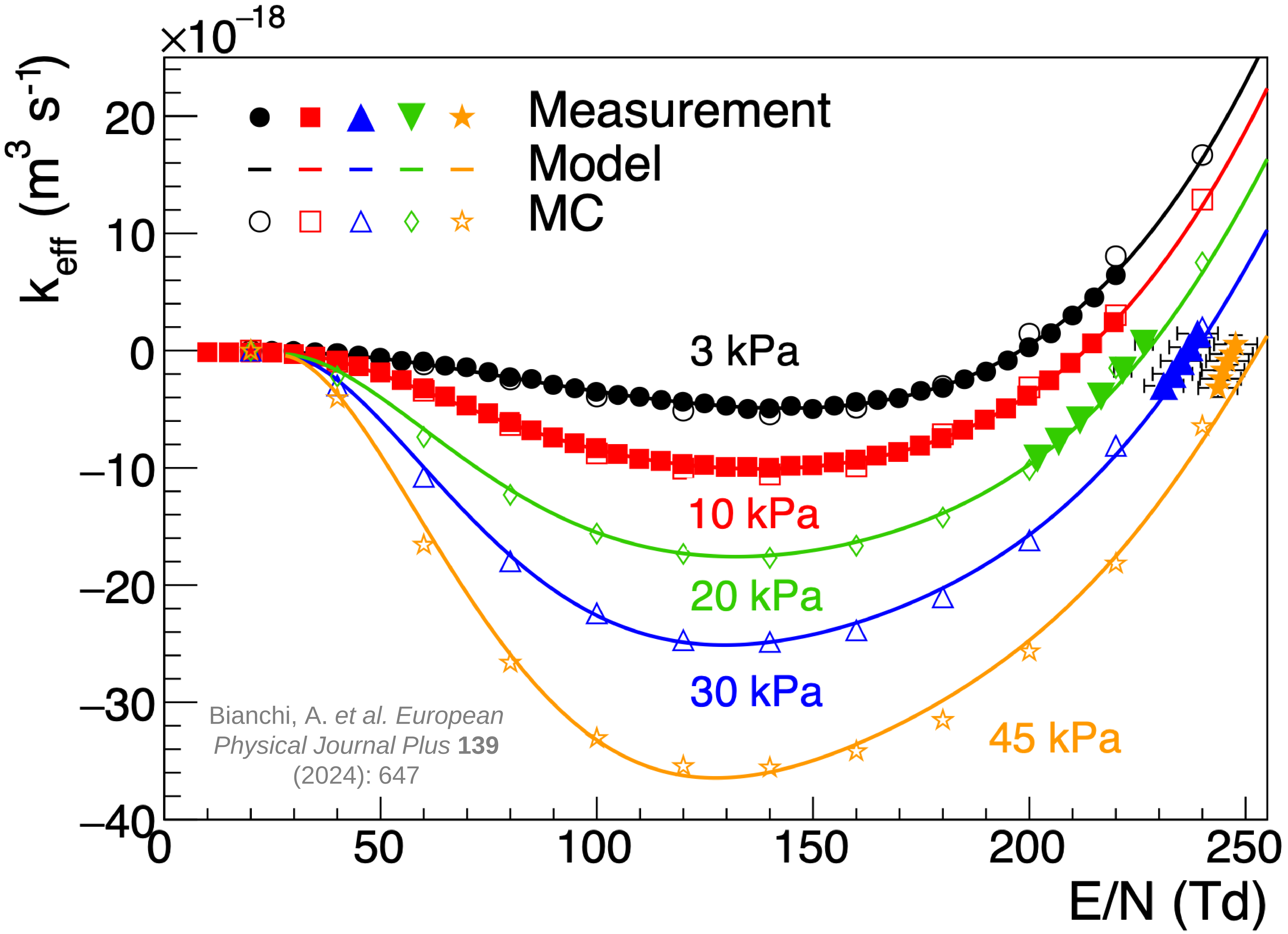
Longitudinal Diffusion Coefficient in $C_3H_2F_4$



RPCs are typically operated in this electric field range

No significant differences are observed from 3 kPa to 45 kPa

Effective Ionization Rate Coefficient in $C_3H_2F_4$

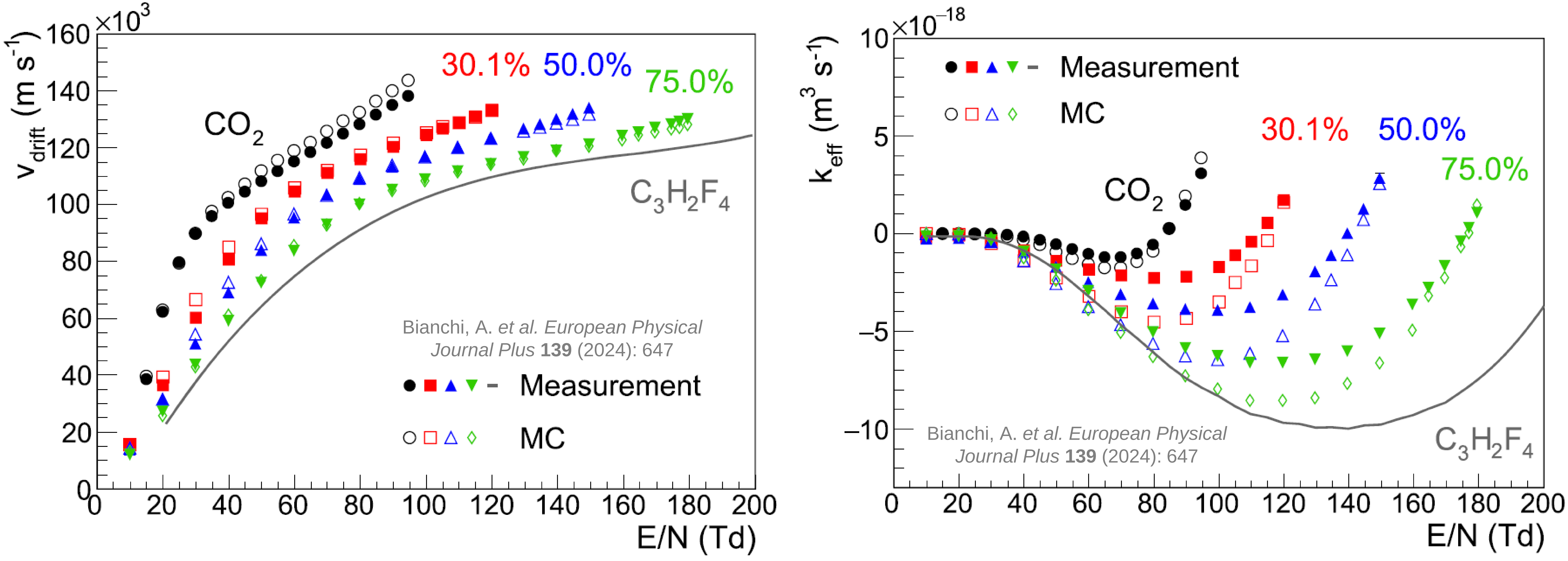


Chachereau *et al* (2016) developed a kinetic model to describe the pressure dependence of k_{eff} in $C_3H_2F_4$

This model accurately reproduces the experimental data

Monte Carlo (MC) simulations are in good agreement with the measurements and model predictions

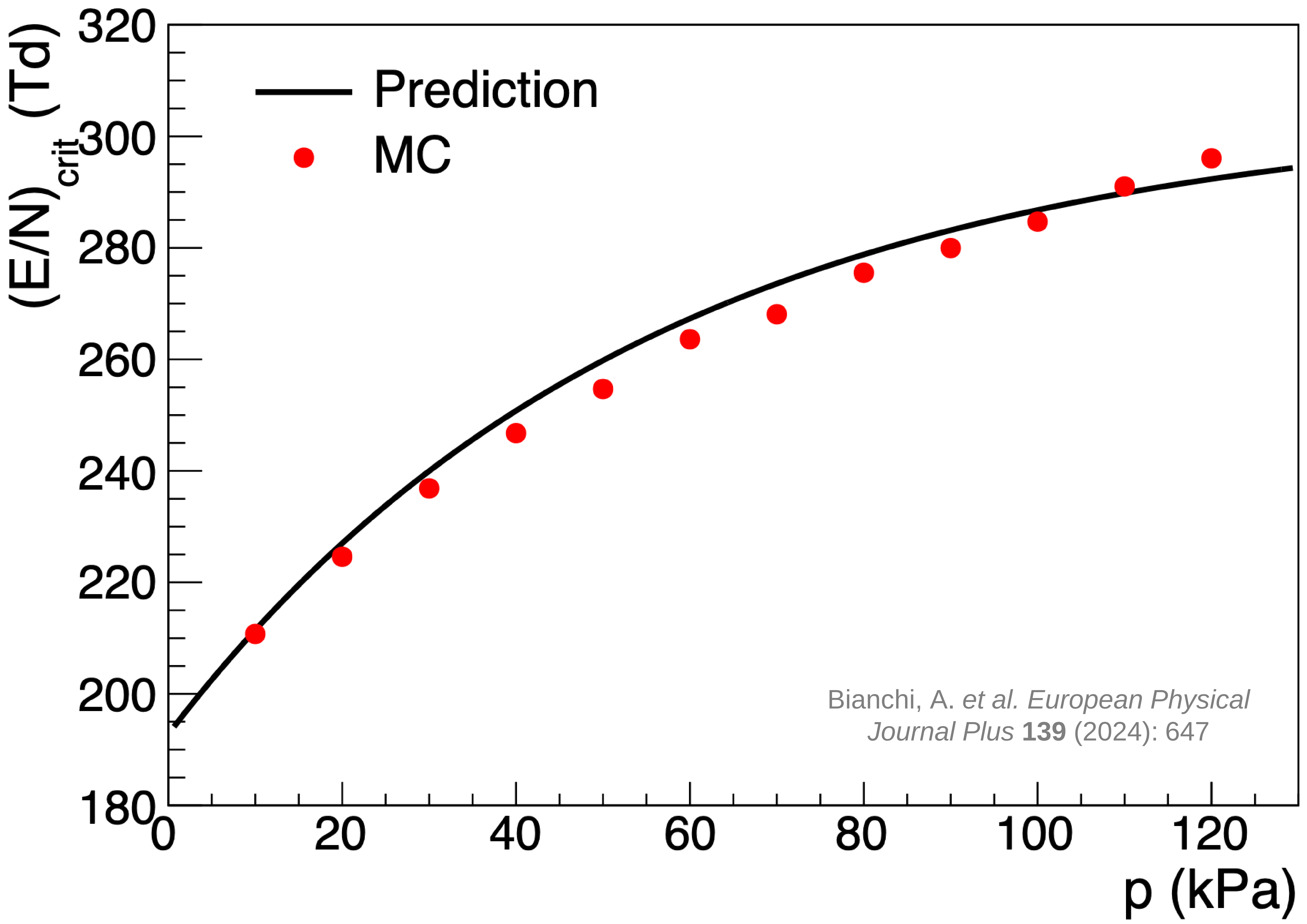
Electron Swarm Parameters in $C_3H_2F_4$ /CO_2



The addition of CO_2 generally shifts the trends upward and to the left

Cross-check: Koch's Model

Koch's model: $(E/N)_{crit} = 305\,\mathrm{Td} \cdot \left(1 - \exp\left(-\frac{p + 55\,\mathrm{kPa}}{55\,\mathrm{kPa}}\right)\right)$ → Critical electric field at which the effective ionization rate coefficient changes from negative to positive values, indicating the predominance of ionization events over electron capture

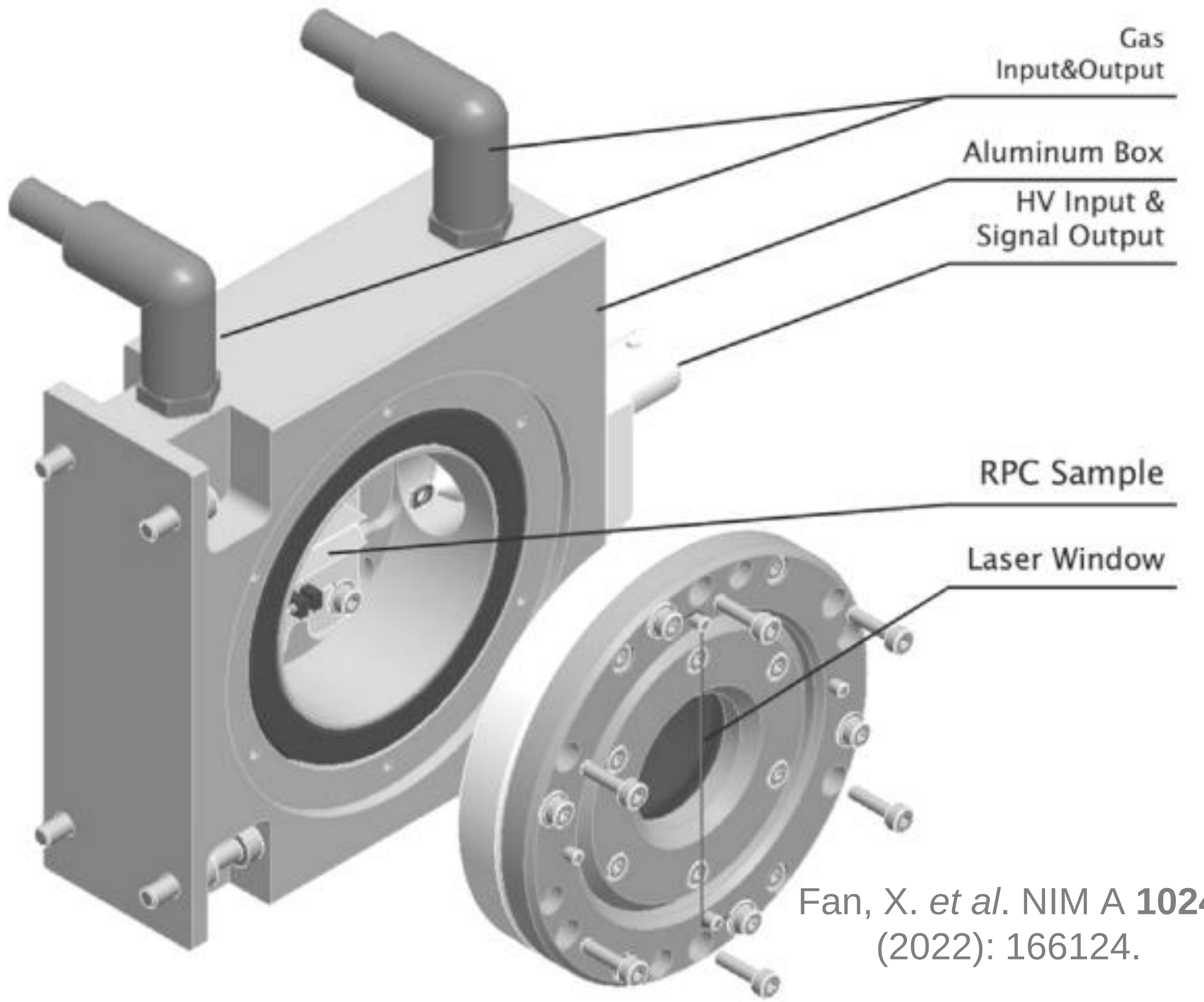


Model predictions and simulation results are in good agreement (relative error < 3%)

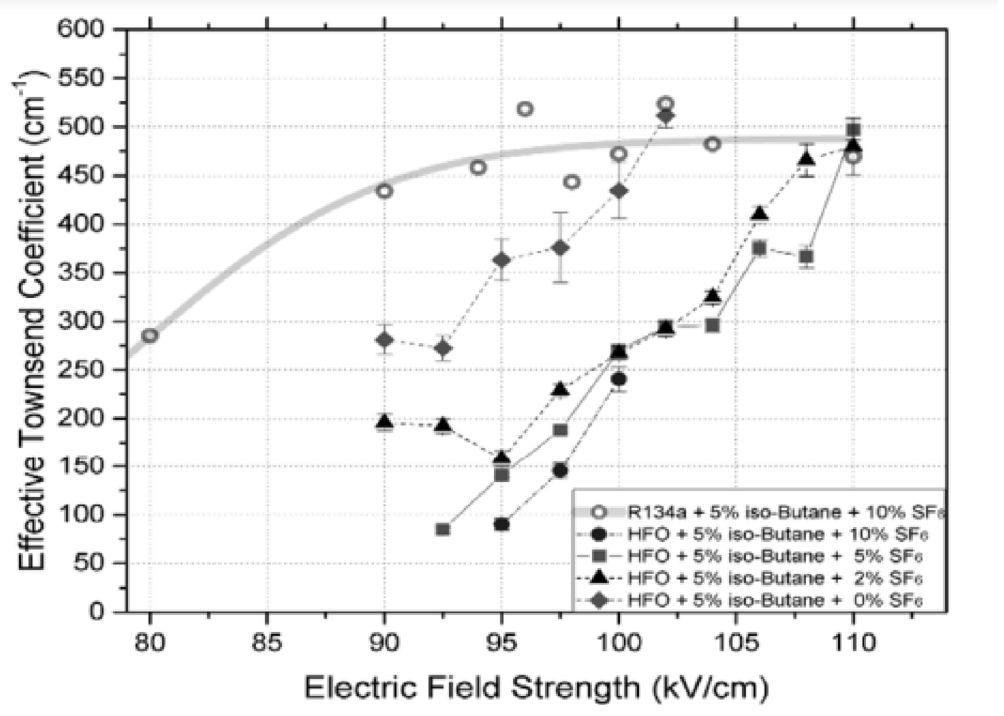
At atmospheric pressure, $(E/N)_{crit}$ is approximately 280 Td, and it decreases as the relative pressure of $C_3H_2F_4$ is reduced

Cross-check: Experimental Data by X. Fan *et al*

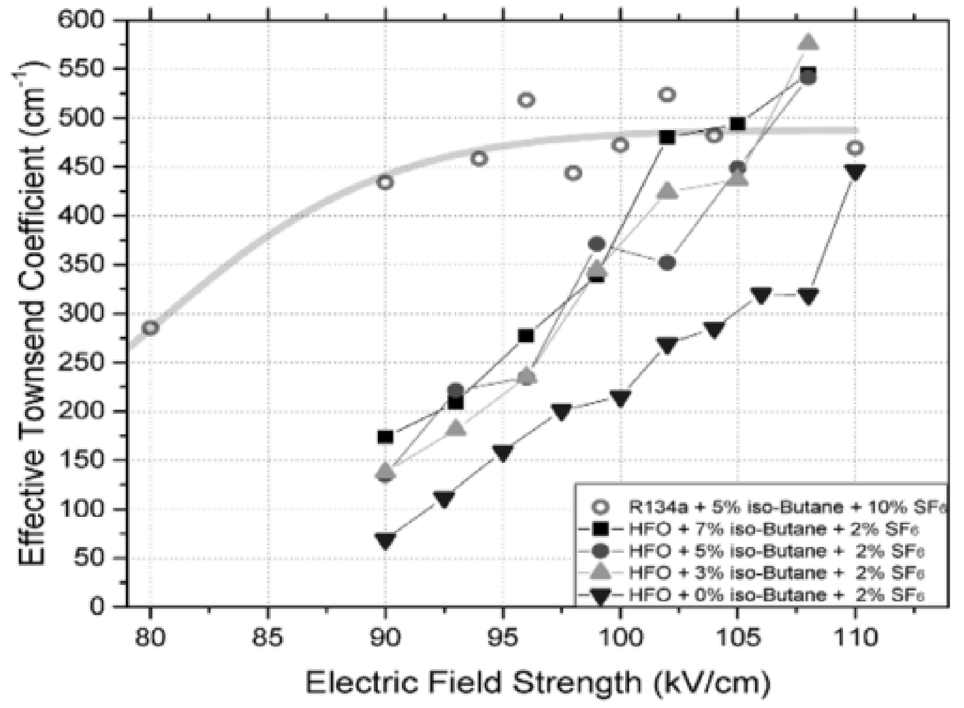
Experimental data acquired in a resistive plate chamber through the ionization of the gas mixture inside it, using a laser beam.



Fan, X. *et al*. NIM A **1024** (2022): 166124.



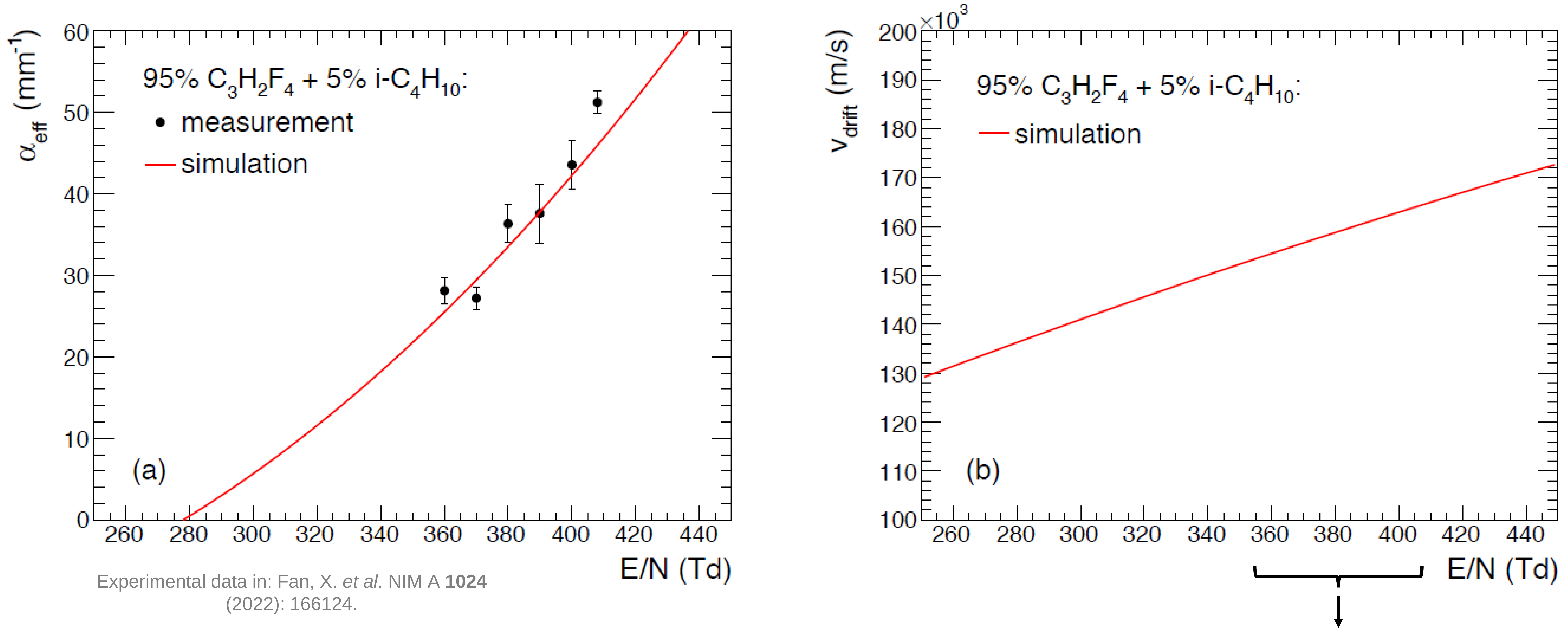
(a) With various percentage of SF_6.



Fan, X. *et al*. NIM A **1024** (2022): 166124.

According to analytic models of RPC behavior: the effective ionization rate coefficient (α_{eff}) plays a crucial role in evaluating the efficiency of RPCs, and together with the electron drift velocity (v_{drift}), it is also critical for estimating the time resolution.

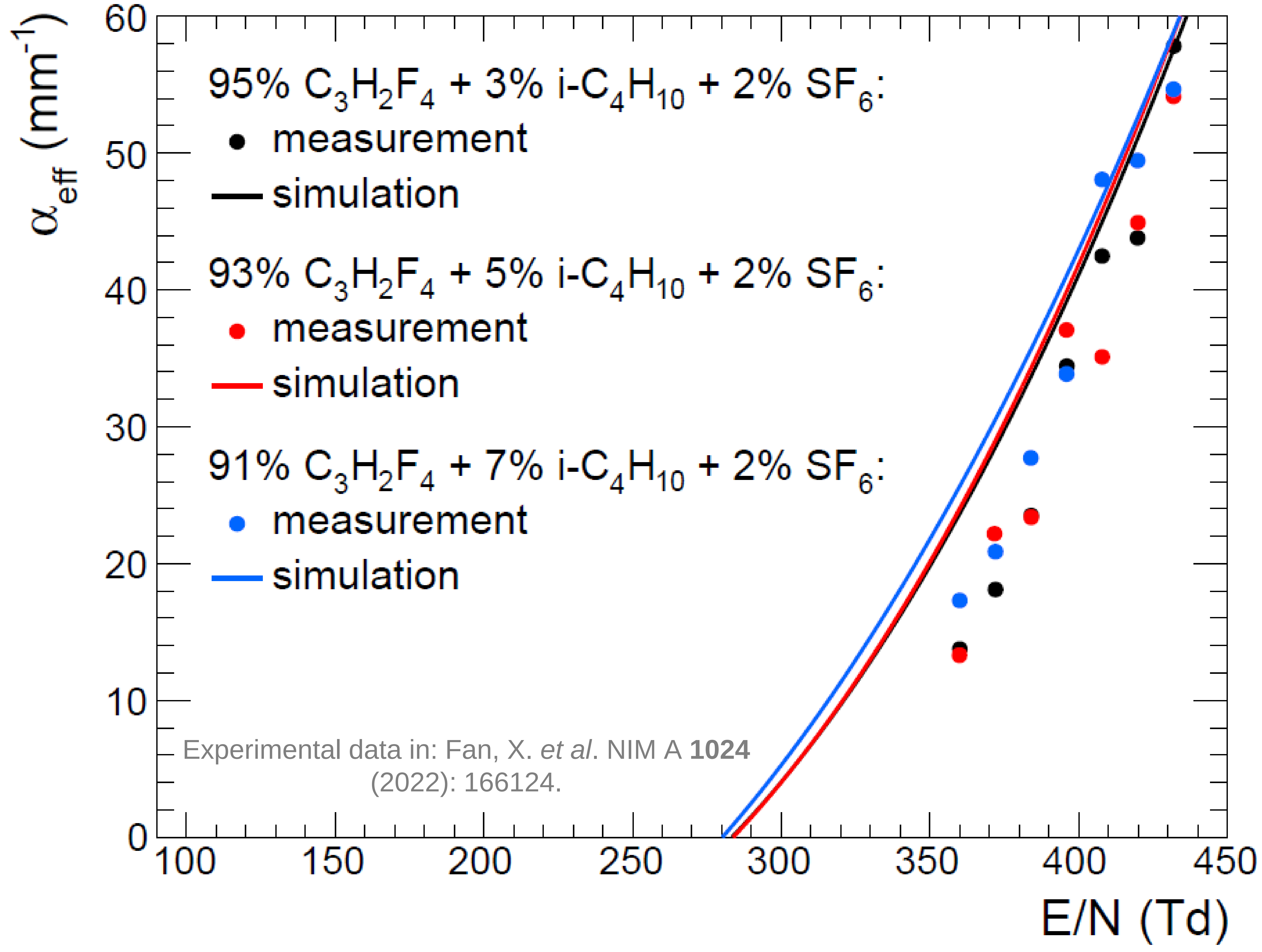
Cross-check in 95% $C_3H_2F_4$ and 5% *i*-C_4H_{10}



Experimental data in: Fan, X. *et al*. NIM A **1024** (2022): 166124.

X. Fan *et al* (2022): *"For all the test points, the electron drift velocity is around* ***200 μm/ns****"*

Cross-check: Addition of 2% SF_6



Some fluctuations are observed in the experimental data

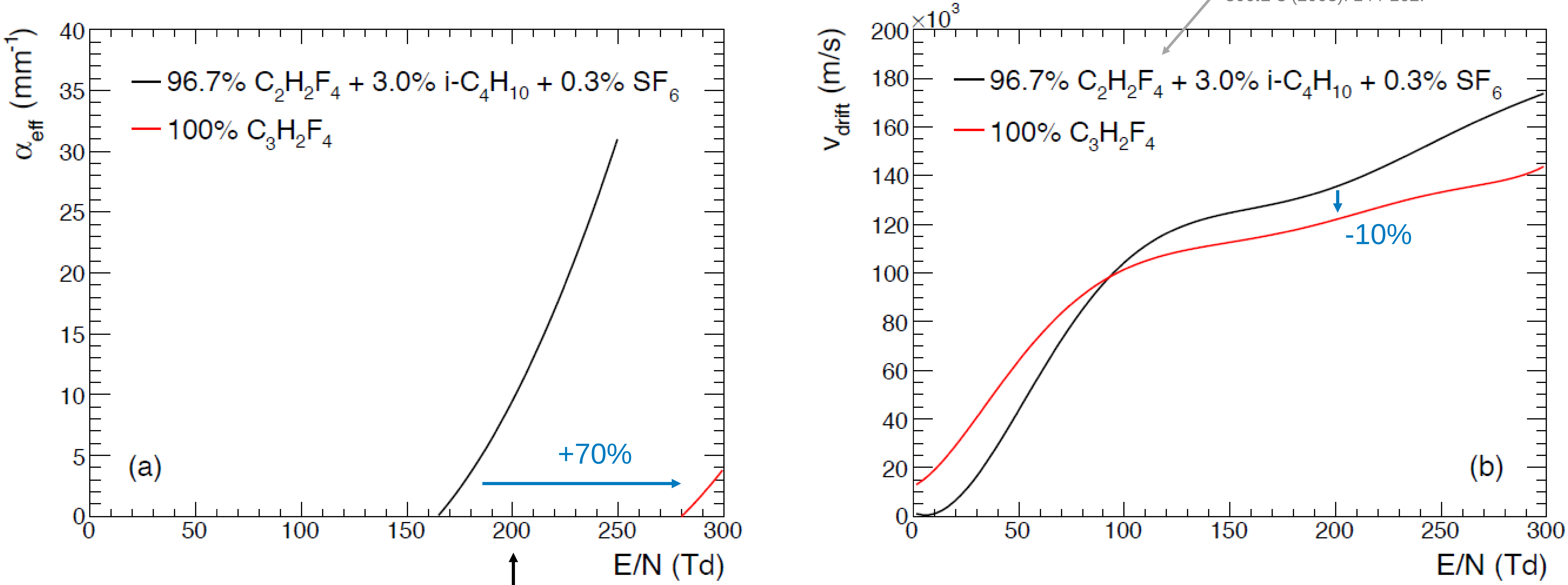
The agreement between simulation results and experimental data improves at higher field values.

No measurements of drift velocity are available

In general, simulation results are in substantial agreement with predictions of the Koch's model and measurements of electron swarm parameters in RPCs. This reinforces the reliability of cross sections found in this study

Comparison with Standard Mixture

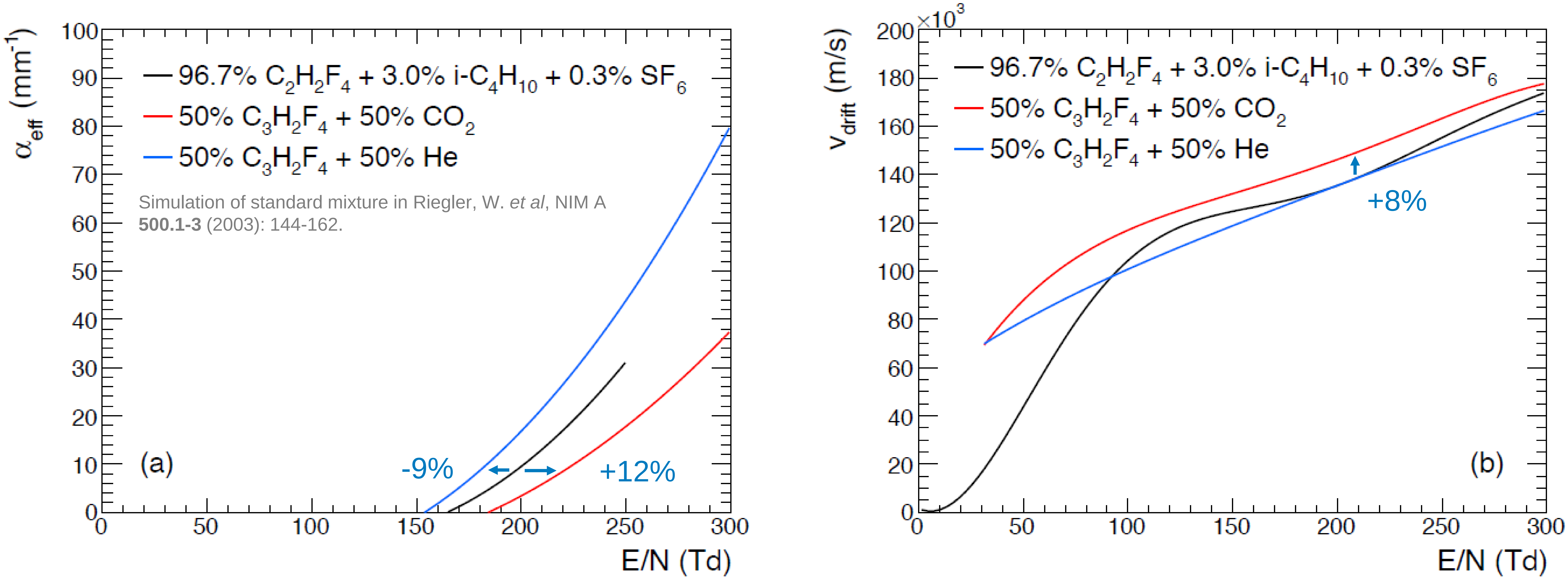
Simulation of standard mixture in Riegler, W. *et al*, NIM A **500.1-3** (2003): 144-162.



2-mm single-gap RPCs are typically operated at **200 Td**

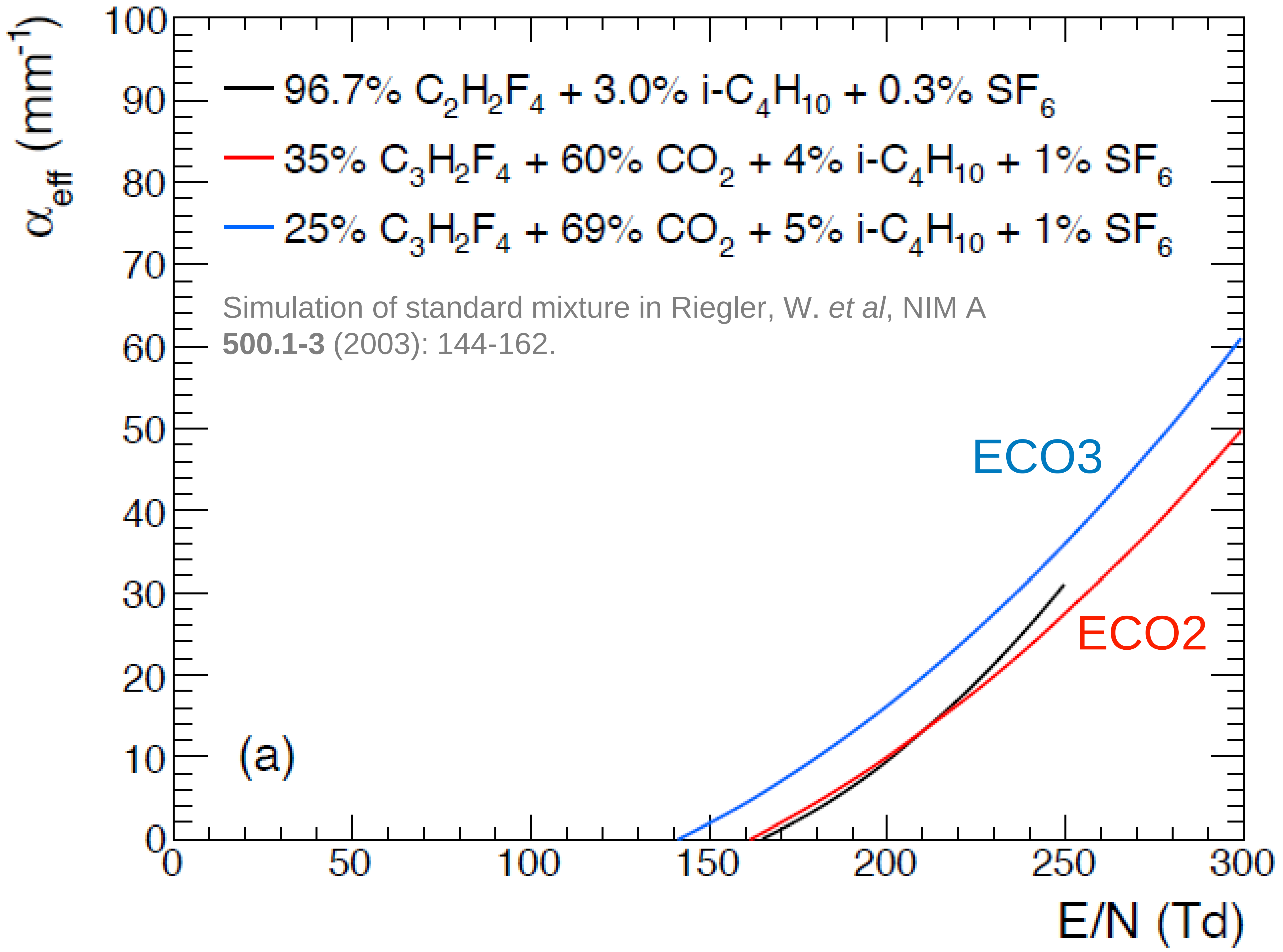
(1 Td ≈ 50 V)

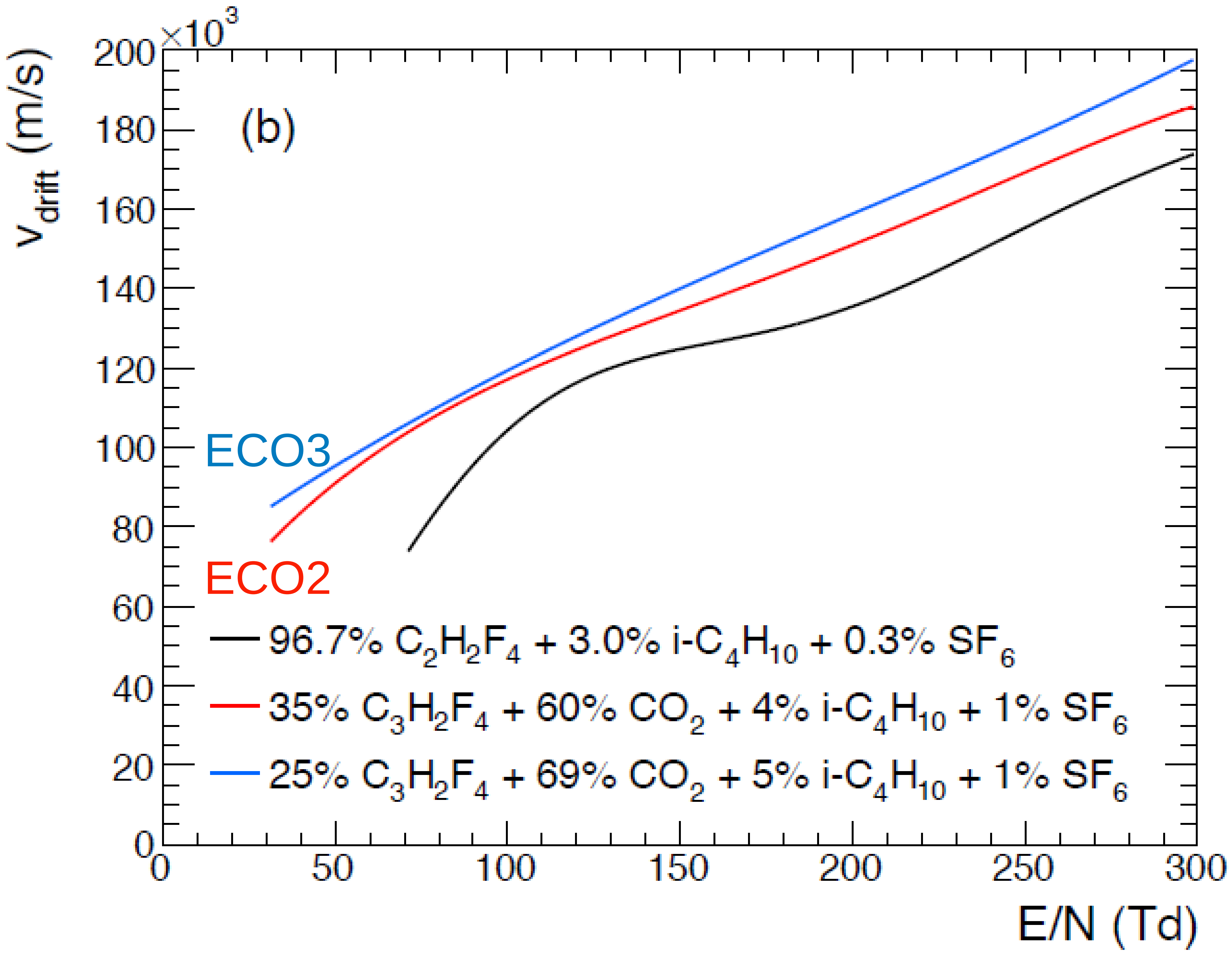
$C_3H_2F_4/CO_2$ and $C_3H_2F_4/He$ Gas Mixtures



The addition of 50% He is more effective in reducing the effective ionization coefficient compared to the addition of 50% CO_2. On the contrary, the increase in drift velocity is more significant with 50% CO_2 compared to the same percentage of He.

Gas Mixtures Tested by the *ECOGAS@GIF* Collaboration

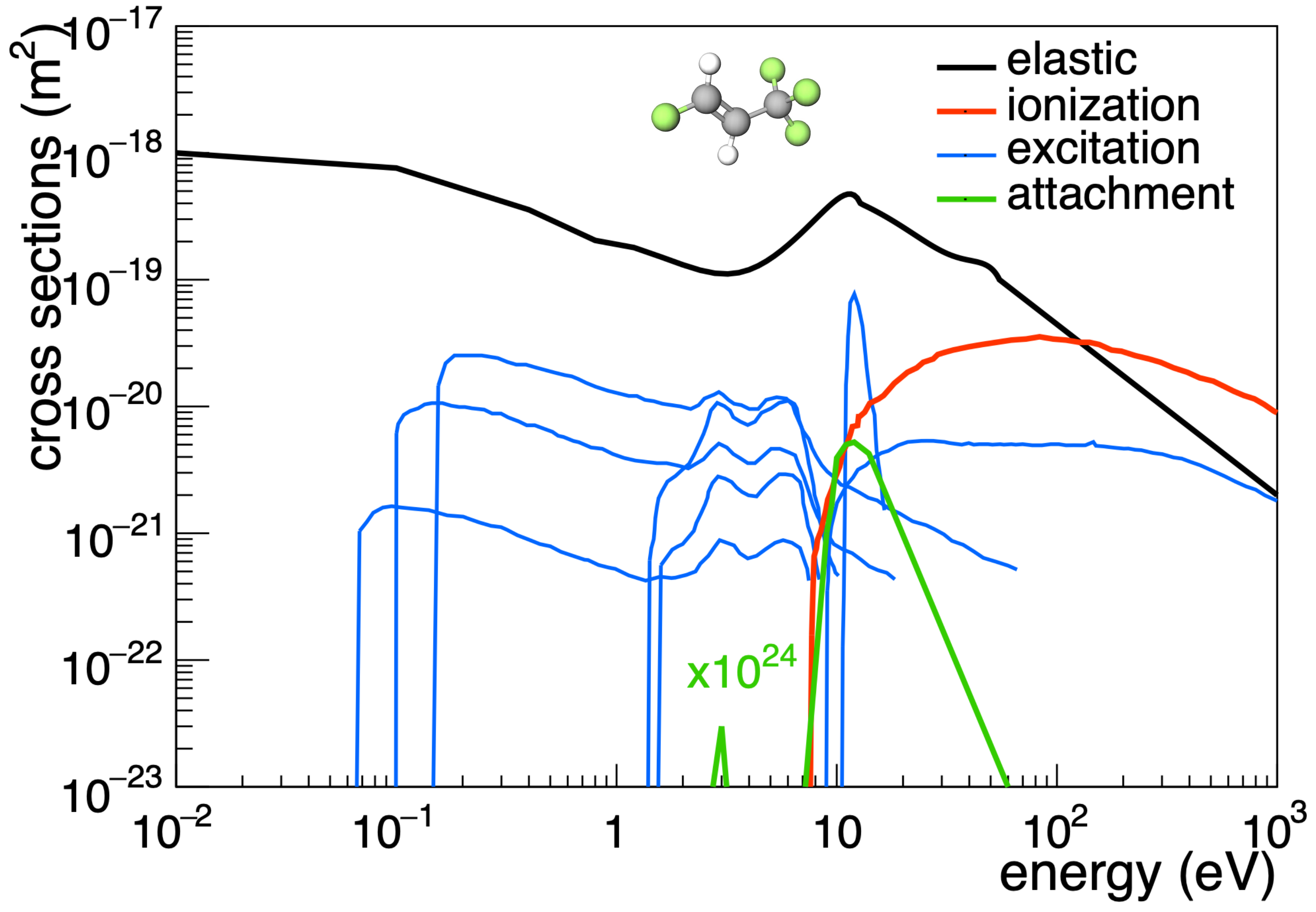




Values of the effective ionization rate coefficient in the gas mixture ECO2 are approximately the same as those in the standard mixture, while they are reduced by 10% in the gas mixture ECO3. Meanwhile, the drift velocity is increased by 10% to 20% in the ECO2 and ECO3 mixtures.

Conclusions

In the recent years, $\mathbf{C_3H_2F_4}$ has received increasing attention as a **promising gas for gaseous particle detectors**, especially for RPCs.



Electron collision cross sections for $\mathbf{C_3H_2F_4}$

- Obtained by unfolding electron swarm parameters from the literature
- Simulations in agreement with Koch's model and direct measurements in RPCs

  → Reinforces the reliability of cross sections for $\mathbf{C_3H_2F_4}$

Comparative studies of $\mathbf{C_3H_2F_4}$-based gas mixtures

- Tested by the *RPC ECOGAS@GIF*++ collaboration
- Maximum variations of up to 20% in the effective ionization coefficient and drift velocity compared to the standard mixture

Optimization strategy for RPCs: simulations of electron swarm parameters may provide an additional pathway to optimize eco-friendly gas mixtures for RPCs

More information in:

- Bianchi, A., Ferretti, A., Gagliardi, M. *et al.* **Electron collision cross sections in tetrafluoropropene HFO1234ze(E) for gas mixtures in resistive plate chambers**. *Eur. Phys. J. Plus* **139**, 647 (2024). https://doi.org/10.1140/epjp/s13360-024-05439-x
- Bianchi, A. **MATOQ: a Monte Carlo simulation of electron transport in environmental-friendly gas mixtures for Resistive Plate Chambers**. *Eur. Phys. J. Plus* **138**, 838 (2023). https://doi.org/10.1140/epjp/s13360-023-04440-0