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# On the updated R134a cross-section and respective trigger RPC simulation

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*Project Presentation: 1st DRD1 Collaboration Meeting*

*31 January 2024*

High Voltage Laboratory

# Collaboration

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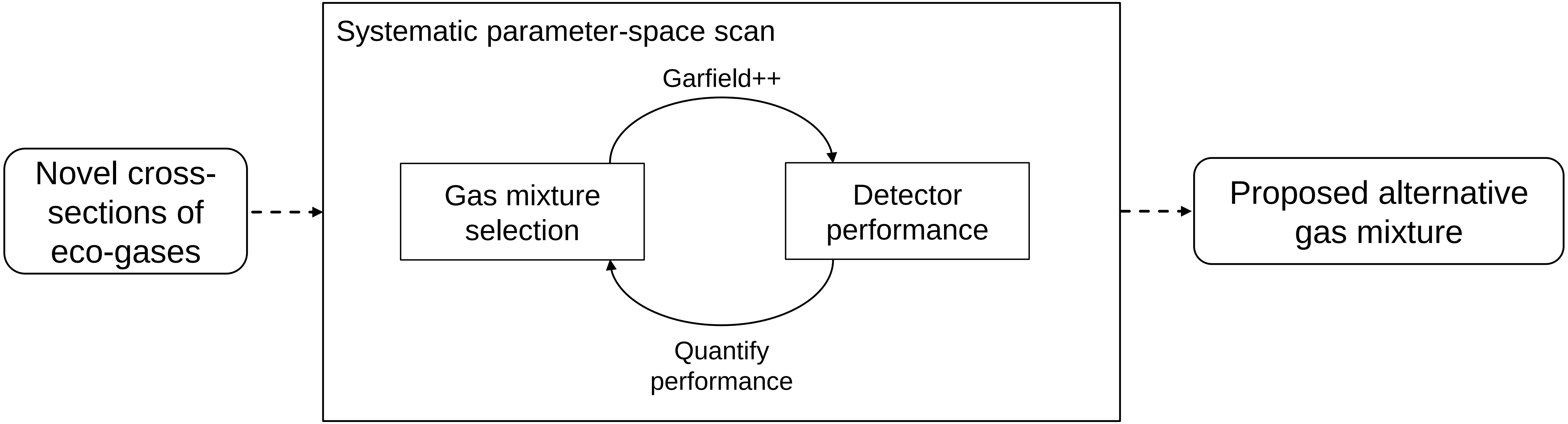
# Project Objective

**Research Goal**

Numerical prediction of performance of the trigger RPC setup using various alternative **eco-friendly** gas mixtures. Identify optimal mixtures and validate them through lab-scale experiments.



Publication by *Metting van Rijn, Biagi and Franck* expected soon

# R134a Cross-Section Update

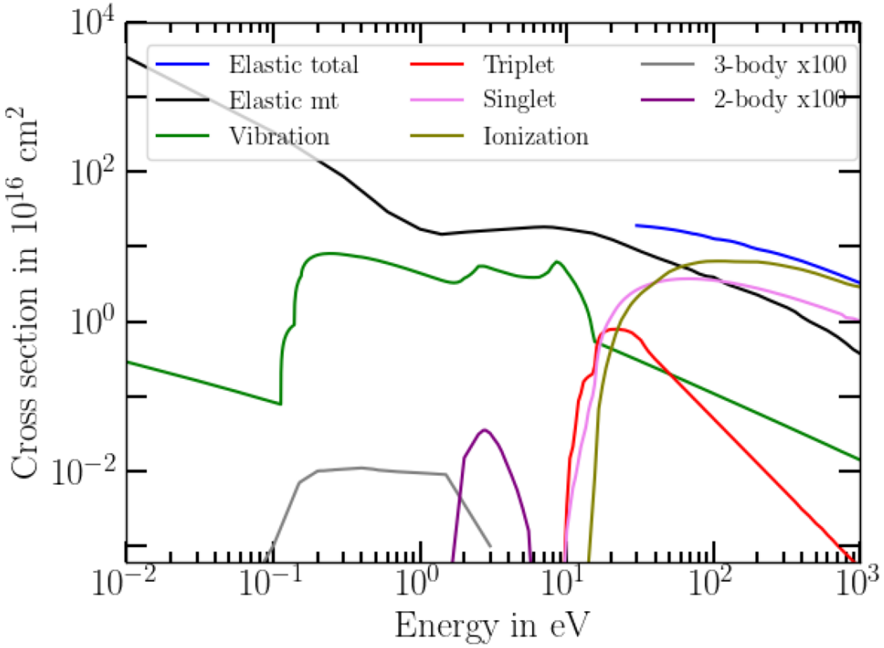



Figure: Cross section of R134a. Ionization accounts for gross ionization.

- Vibrational amplitudes adjusted
- First vibrational resonance reduced in energy
- Ionization threshold updated
- Excitation split into dipole allowed and triplet levels

⇒ Townsend coefficient of standard mixture increases by more than 10% at trigger RPC fields!

# RPC Simulation Results – Efficiency Curve to Validate

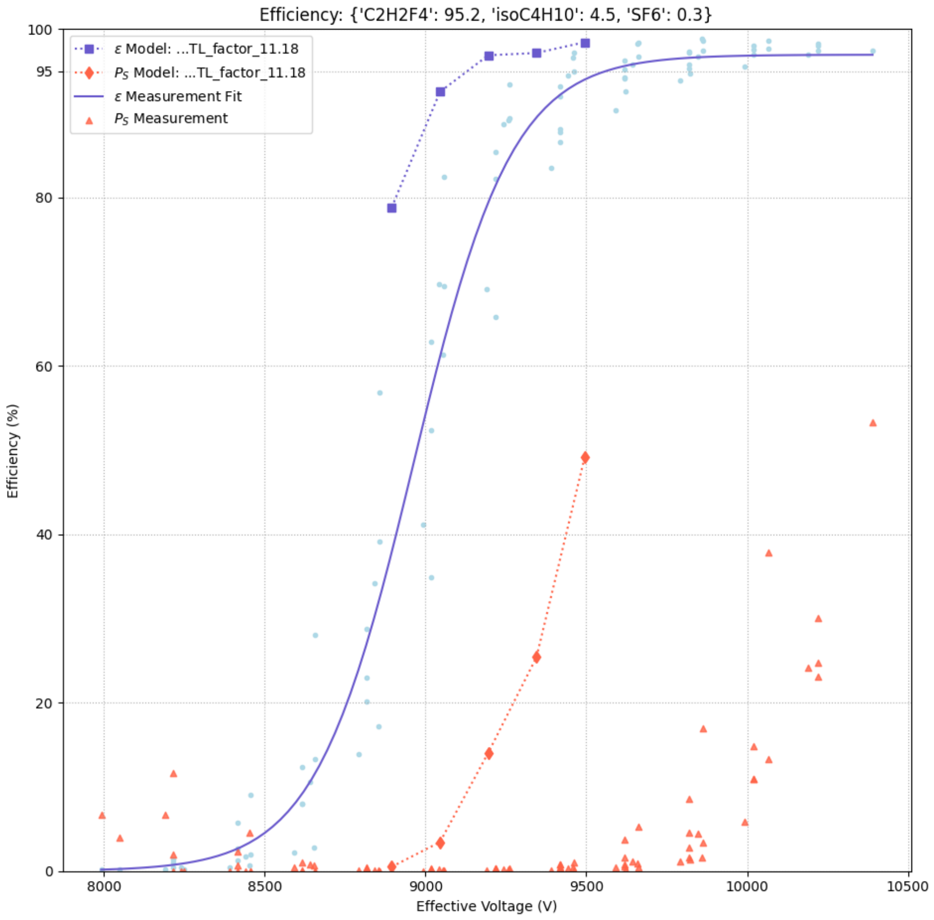
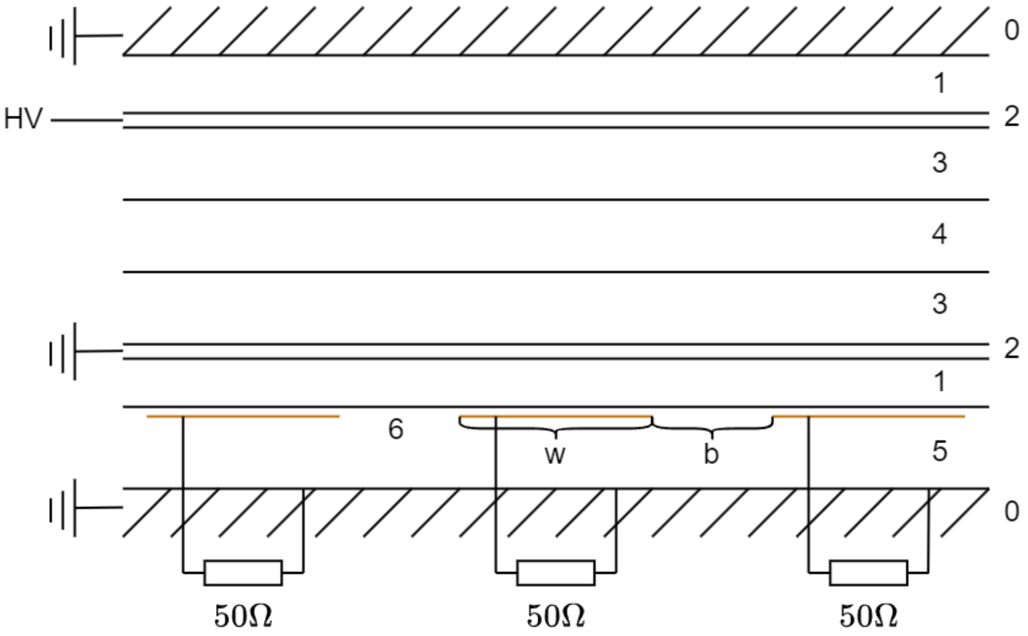



Figure: Efficiency curve of standard mixture.
Simulation (blue dotted) and measurements (blue solid).

- Updated R134a cross-sections
- Comprehensive RPC simulation
- Simulated efficiency curve for single gap (2mm) RPC is off!

→ What's going on?

# Resistive Plate Chamber (RPC) Setup




| No | Material | layer thickness | $\epsilon_r$ | $\sigma$ (S/m) |
|---|---|---|---|---|
| 0 | Metal sheet + 'foam' | - | - | - |
| 1 | Pet | 200um | 0 | 0 |
| 2 | Graphite paste | 10um | $O(1-10)$ | $0.1-0.3$ |
| 3 | Bakelite | 2mm | $8-10$ | $10^{10}$ |
| 4 | Gas gap | 2mm | 1 | 0 |
| 5 | 'foam' | ~2mm | ? | 0 |
| 6 | (Copper) Strips | $w = 2.5/2.2\text{cm}, b = 2\text{mm}$ | - | - |

Figure: RPC cross-section with table describing materials, dimensions and its properties.

# RPC Detection Principle – 7 Strip Read-Out

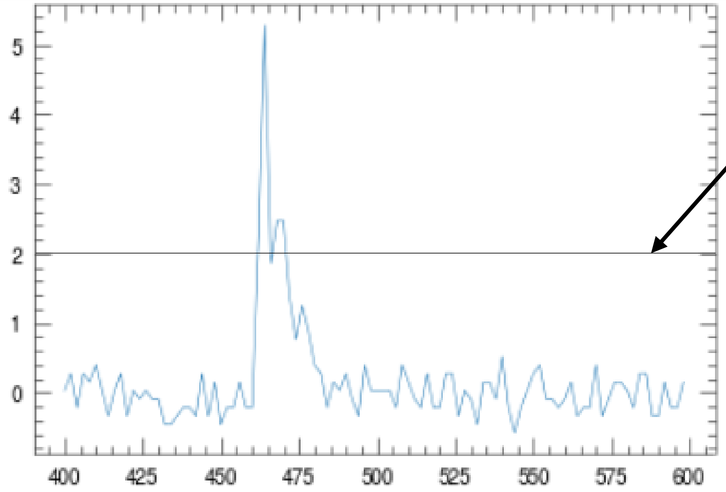



Figure: Example signal from measurements. Time resolution 2ns.

- Detection threshold at level of raw signals
  - Minimum avalanche size for std gas mixture:

$$N_{e^-} \geq 6.5 \cdot 10^6 - \frac{450}{1V} \cdot (HV - 8122V)$$

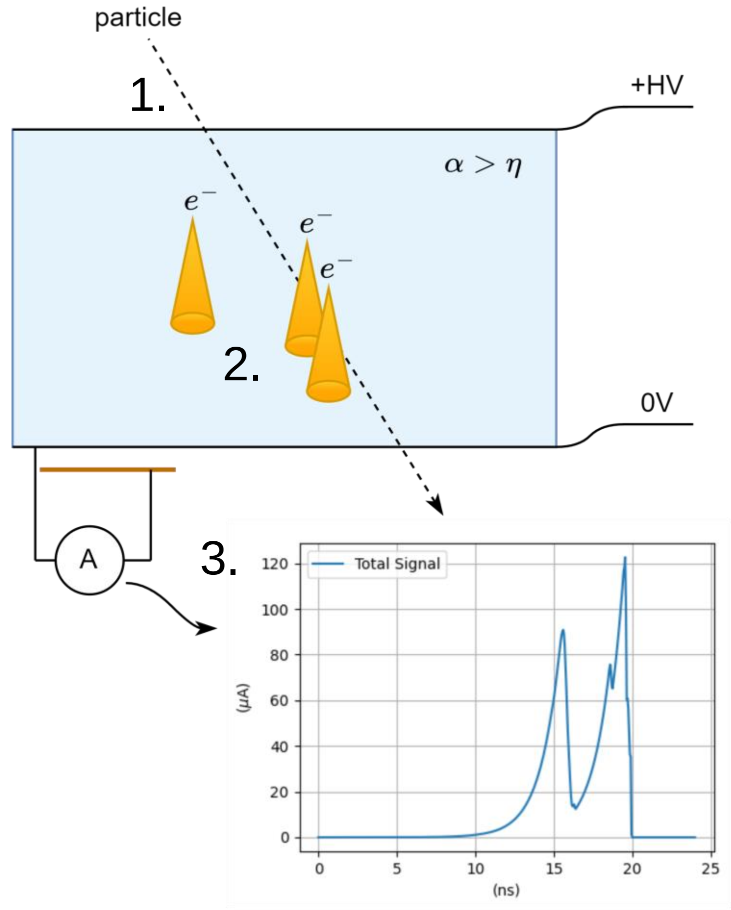
→ Need of space-charge effect …

- Streamer threshold at level of integrated signals to predict streamer probability curve

**→ Numerical model to replicate measured signals to extend search for optimal eco-friendly mixtures**

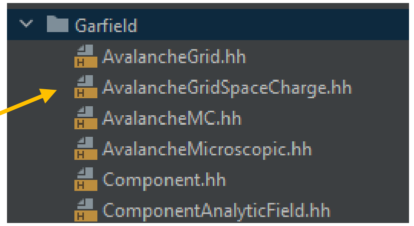
[1] C. Lippmann and W. Riegler, *Detailed RPC avalanche simulations*, NIMA 533, p. 11-15

# Simulation Principle - Pipeline




1. Primary ionization using HEED by *I. Smirnov* & swarm parameters from MAGBOLTZ by *S. Biagi*

2. Electron Transportation using 
   - AvalancheMicroscopic
   - *C. Lippmann* 2d space-charge routine [1]




3. Signal generation by characteristic weighting fields respecting the geometry of the strips

4. Signal processing using networks (multiconductor transmission line) & CAEN 2 ns sampling rate

# 2 → Space Charge Effect

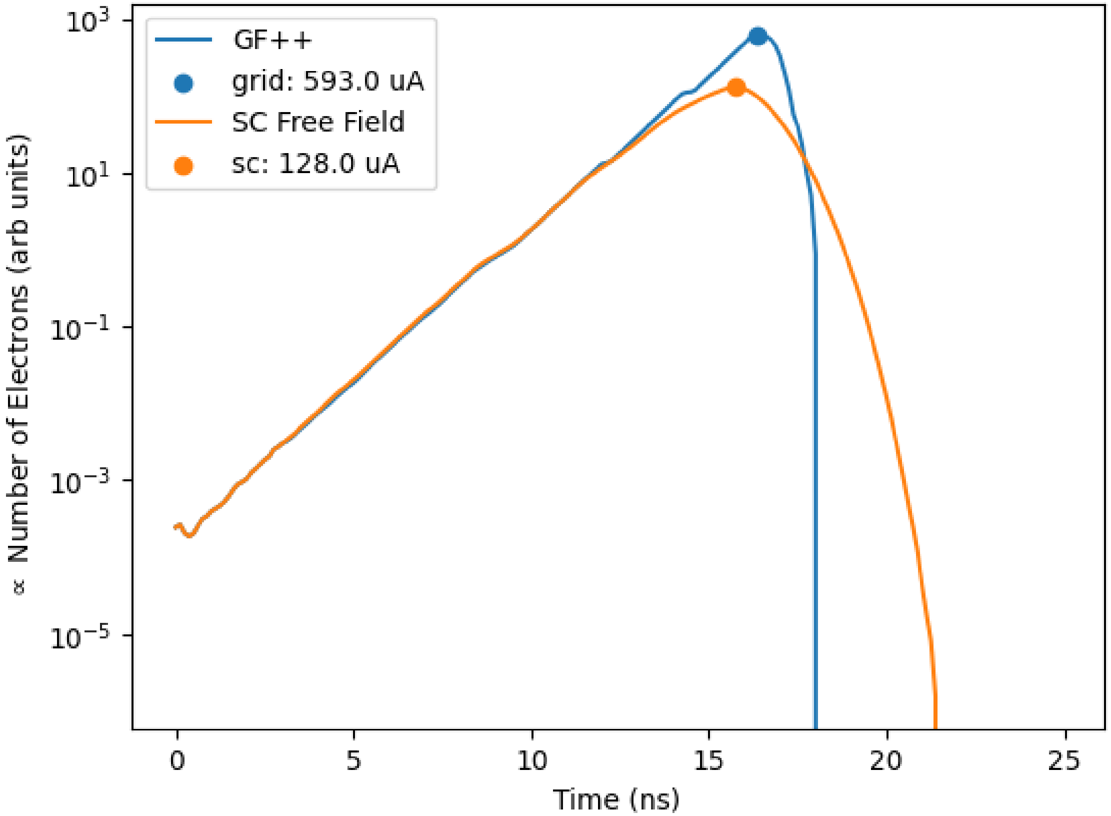



Figure: Logarithmic avalanche growth. Comparison between AvalancheGrid and Lippmann's 2d SC routine.

# 4 → RPC Housing as Multiconductor Transmission Line

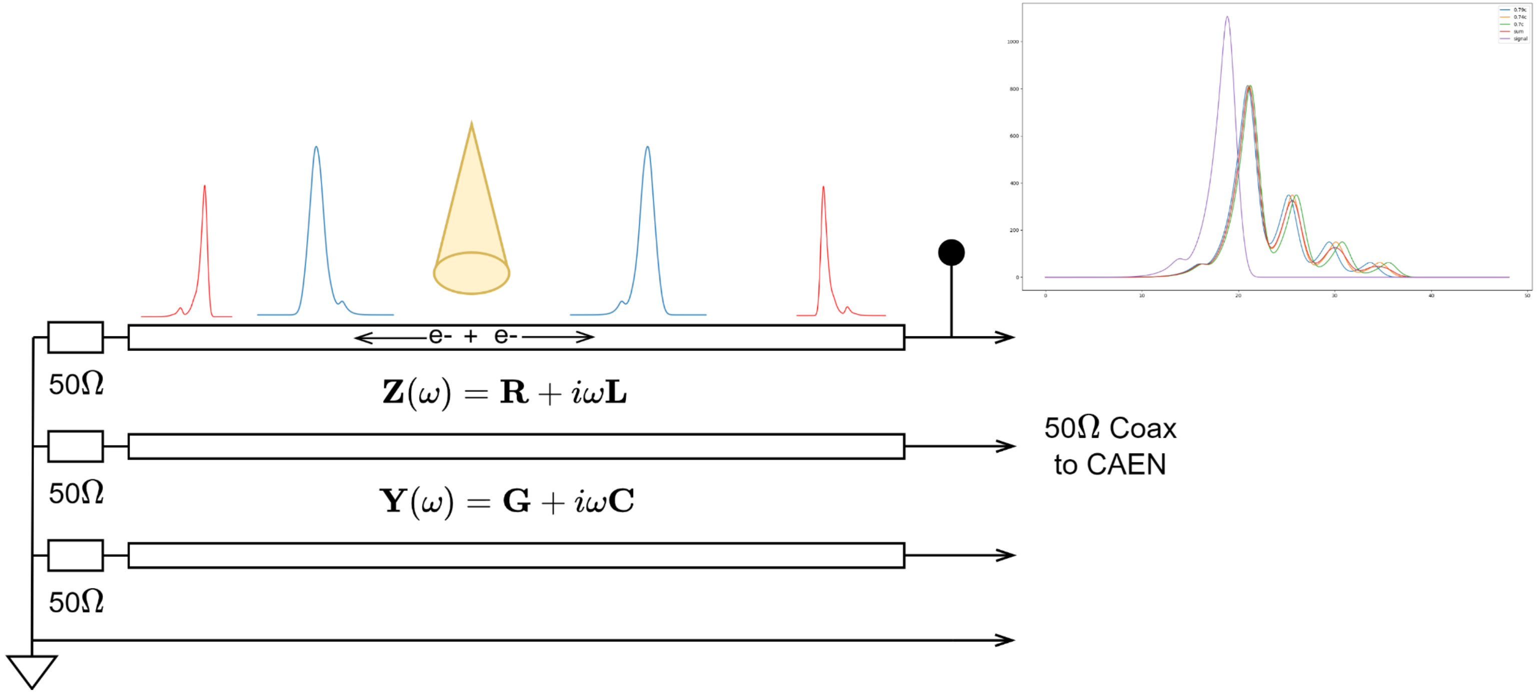



Figure: RPC strip-line network terminated with 50 Ohm resistors.

- Reflections from miss-matched impedance at both ends, results in loss of amplitude:

$$\frac{V_{amp,m}}{V_{amp,i}} \approx \frac{1+0.43}{2} \cdot \frac{21\Omega}{50\Omega} = 29\%$$

- Modal dispersion results in broader signals

- Cross-talk (~10%) results in transversal signal spread

# 4 → Characteristic Matrices: 3 Strip-Line Example

**COMSOL *Simulations:***

$$C = \begin{bmatrix} 225.3 & -27.9 & 0. \\ * & 225.3 & -27.9 \\ * & * & 225.3 \end{bmatrix} \mathrm{pF/m}$$

$$L = \begin{bmatrix} 89.7 & 3.8 & 0.2 \\ * & 89.9 & 3.8 \\ * & * & 89.7 \end{bmatrix} \mathrm{nH/m}$$

***Preliminary* VNA *Measurements:***

$$C(5.18\mathrm{MHz}) = \begin{bmatrix} 269.2 & -22.9 & -0.8 \\ * & 264.0 & -21.2 \\ * & * & 258.6 \end{bmatrix} \mathrm{pF/m} \pm 5\%$$

$$L(5.18\mathrm{MHz}) = \begin{bmatrix} 134.2 & 5.3 & 1.5 \\ * & 135.3 & 5.2 \\ * & * & 134.5 \end{bmatrix} \mathrm{nH/m} \pm 5\%$$

$$R(5.18\mathrm{MHz}) = \begin{bmatrix} 0.11 & 0.03 & 0.02 \\ * & 0.14 & 0.04 \\ * & * & 0.10 \end{bmatrix} \Omega/\mathrm{m} \pm 5\%$$

$$G(5.18\mathrm{MHz}) = \begin{bmatrix} 1.4 & -0.8 & 0.0 \\ * & 1.5 & -0.7 \\ * & * & 1.2 \end{bmatrix} 10^{-3}/\Omega\mathrm{m} \pm 10\%$$

$\Rightarrow$ $f_{bd} \sim 30\ GHz$

$Z_c \sim 21\Omega$

# Ending up in a Slight Correction of the Elastic Cross-Section

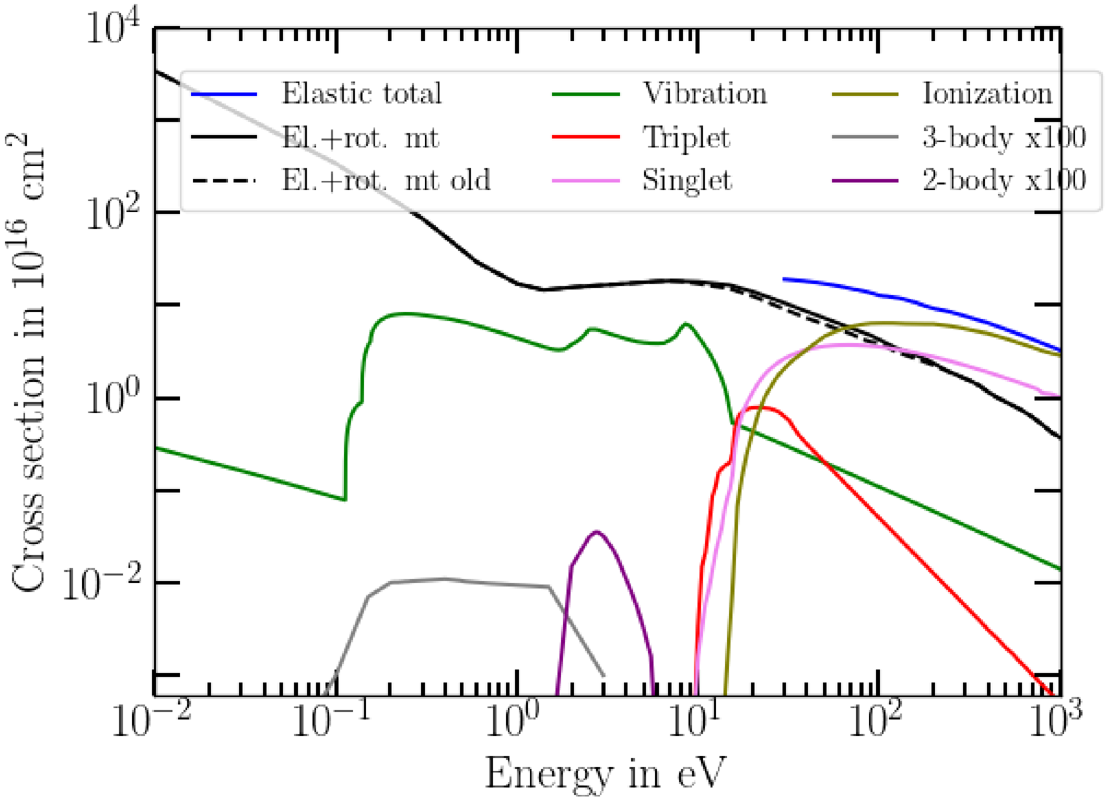



Figure: Correction on the updated cross-sections

- Elastic cross-section got a **slight** correction (Magboltz 11.19)
- Fits PT measurements better
- Reduces the previous increase of Townsend coefficient
- Due to time restriction couldn't redo the full simulation ;(

# Alternative Validation: Pulsed Townsend Swarm Parameter Measurements

[1] G. Chiodini, et al., Nucl. Instr. and Meth. A 602 (2009) 757-760
[2] X. Fan, et al., Nucl. Instr. And Meth. A 1024 (2022), 166124

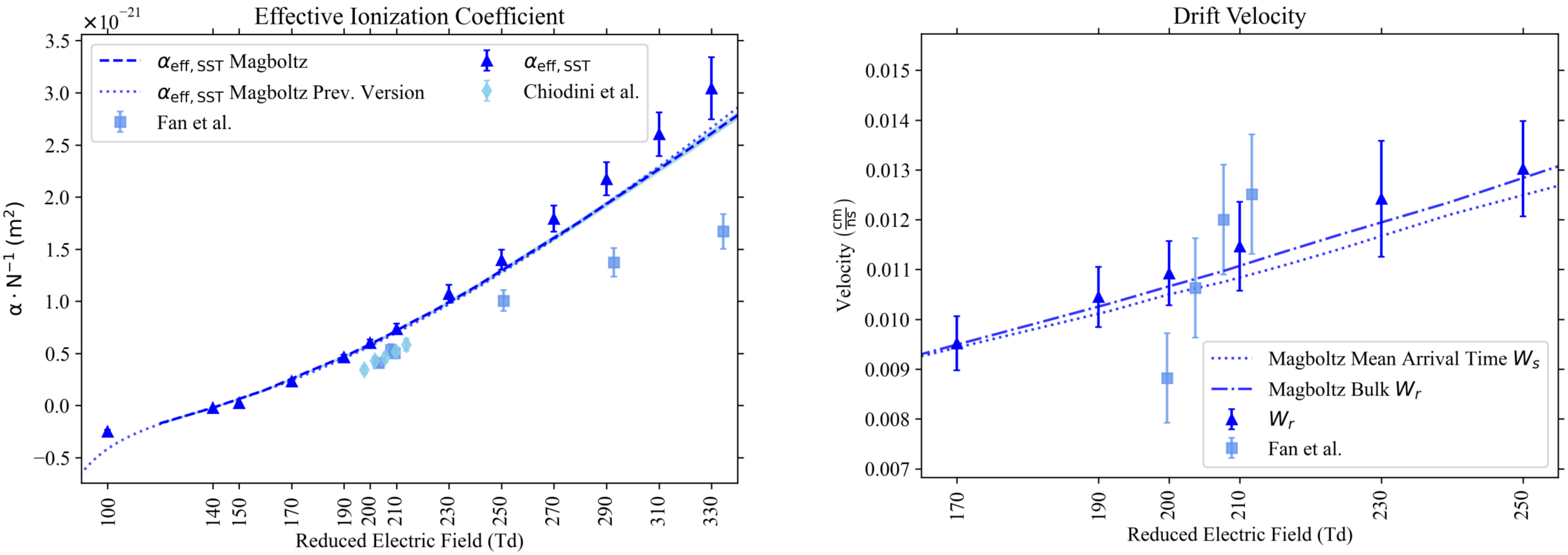



Figure: Trigger RPC standard mixture swarm parameters measured with the Pulsed Townsend Experiment. Additional pressure dependence has not been observed.

# Outlook

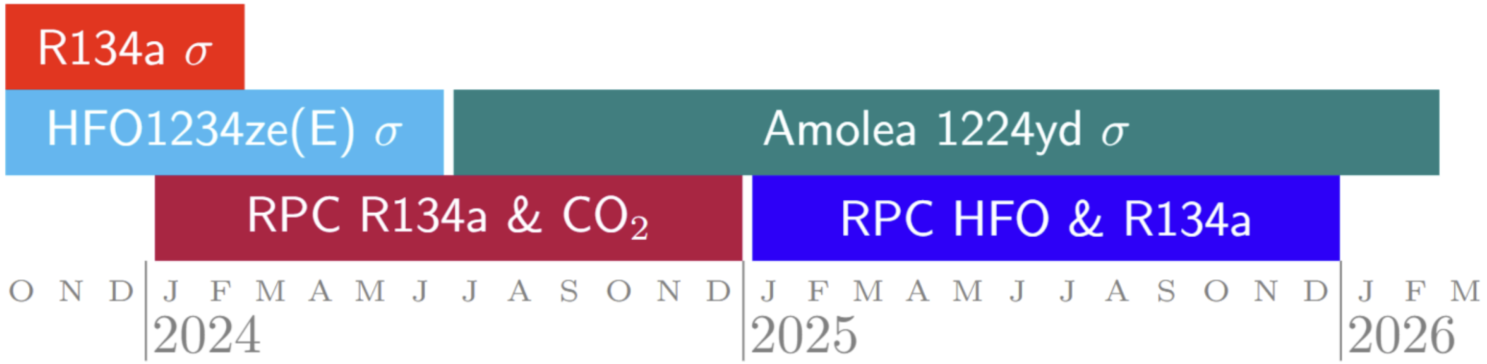



Figure: Project Timeline of the two PhD projects.

# Conclusion

R134a cross-sections received update

- Pulsed Townsend measurement of swarm parameters
- No additional pressure dependence observed at pressure up to 12kPa
- Deviation from measurements by *Fan et al.* and *Chiodini et al.*

Comprehensive trigger RPC simulation environment in developed

- C. Lippmann space-charge effect routine refactored into Garfield++
- Post-processing via multiconductor line theory significantly changes signal
- Streamer-probability curve model in development based on space-charge effect → next DRD1!

# Contact Information

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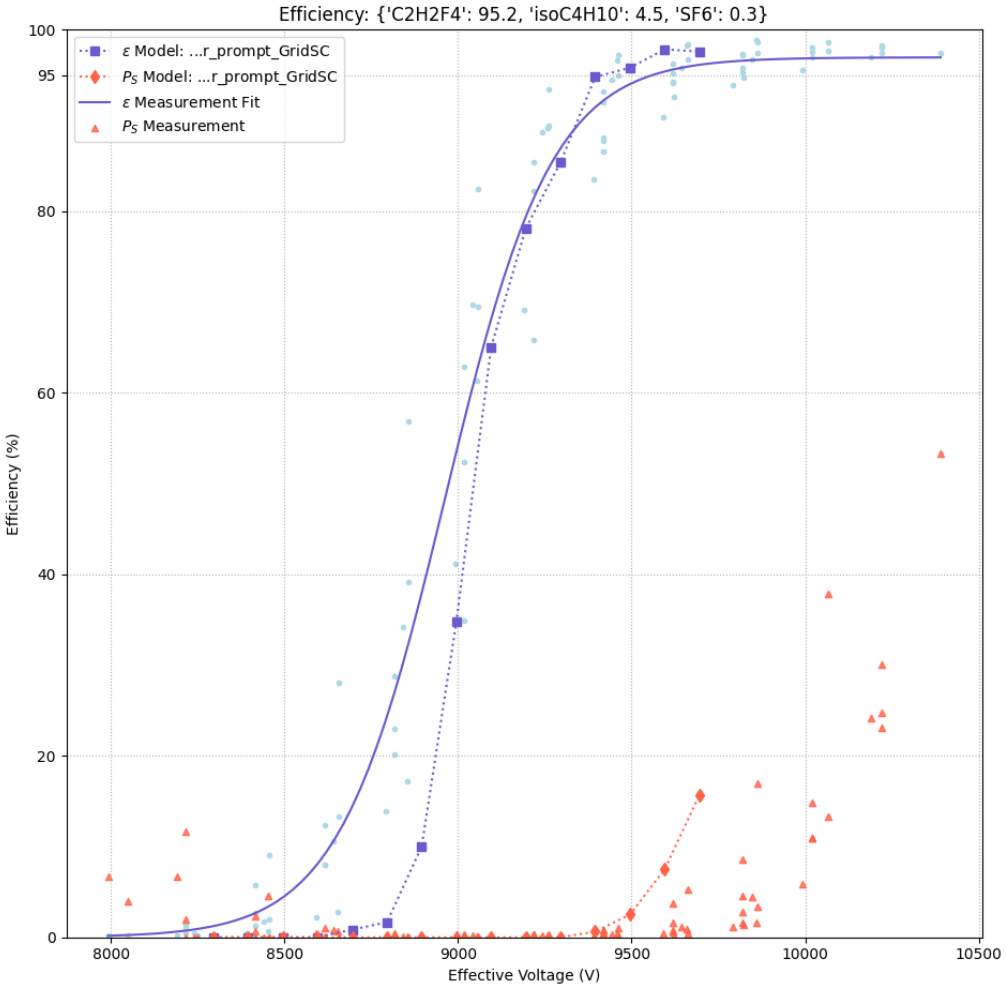
# Old R134a Cross-Section RPC Simulation



[1] G. Chiodini, et al., Nucl. Instr. and Meth. A 602 (2009) 757-760
[2] X. Fan, et al., Nucl. Instr. And Meth. A 1024 (2022), 166124

# Trigger RPC Standard Mixture Swarm Parameters

## Method: Chiodini et al., Fan et al. [1], [2]

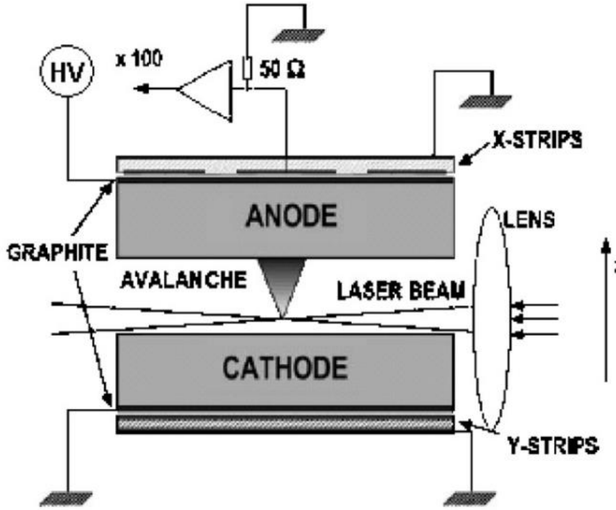
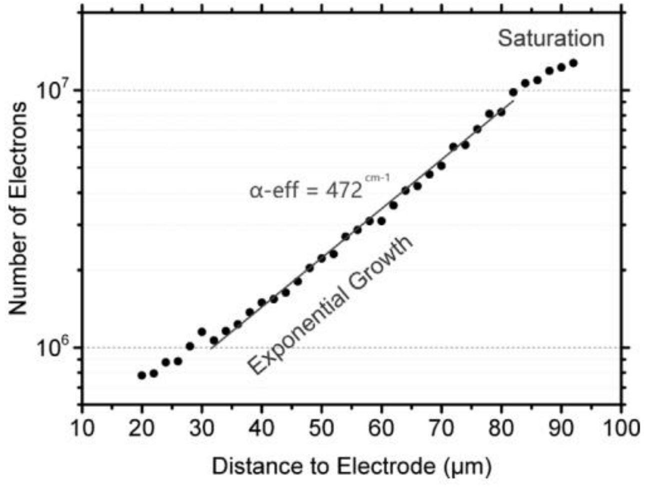



**Fig. 1.** Lateral view of the irradiated RPC.




## Pulsed Townsend Experiment

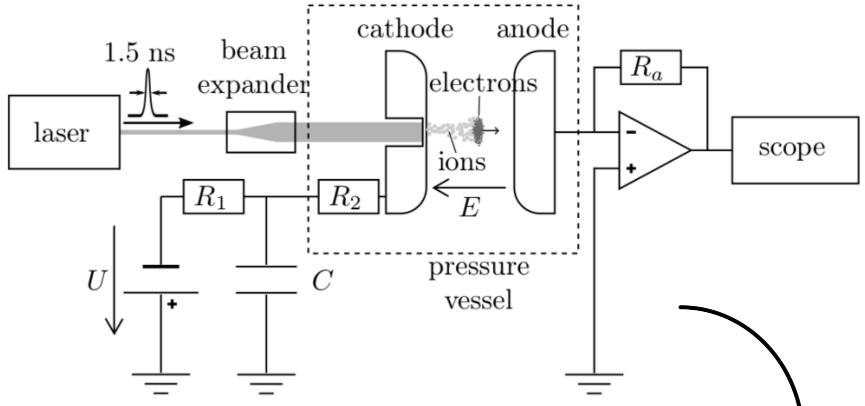



Figure: Schematic

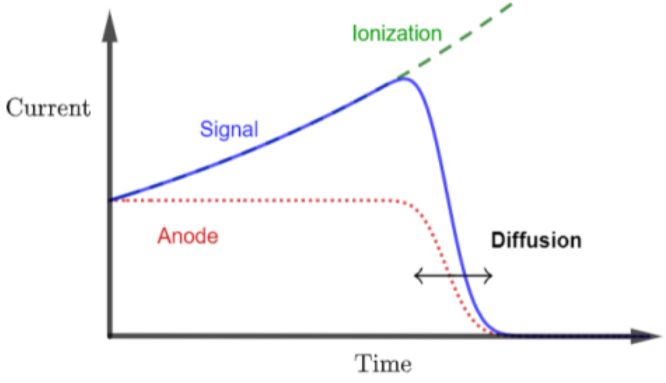



Figure: Acquired signal (blue) for an ionizing gas.

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# RPC Experimental Setup for Validation

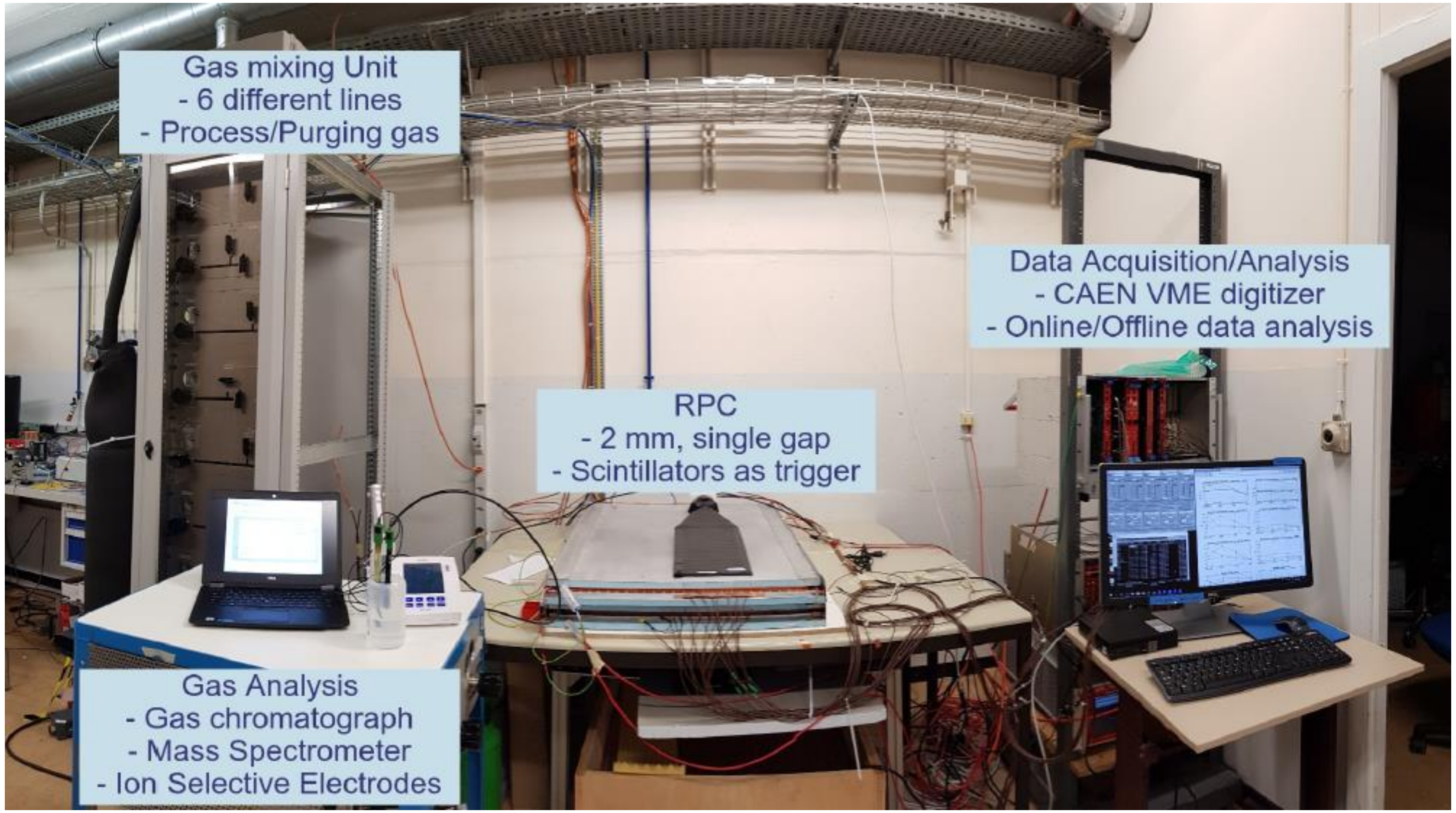
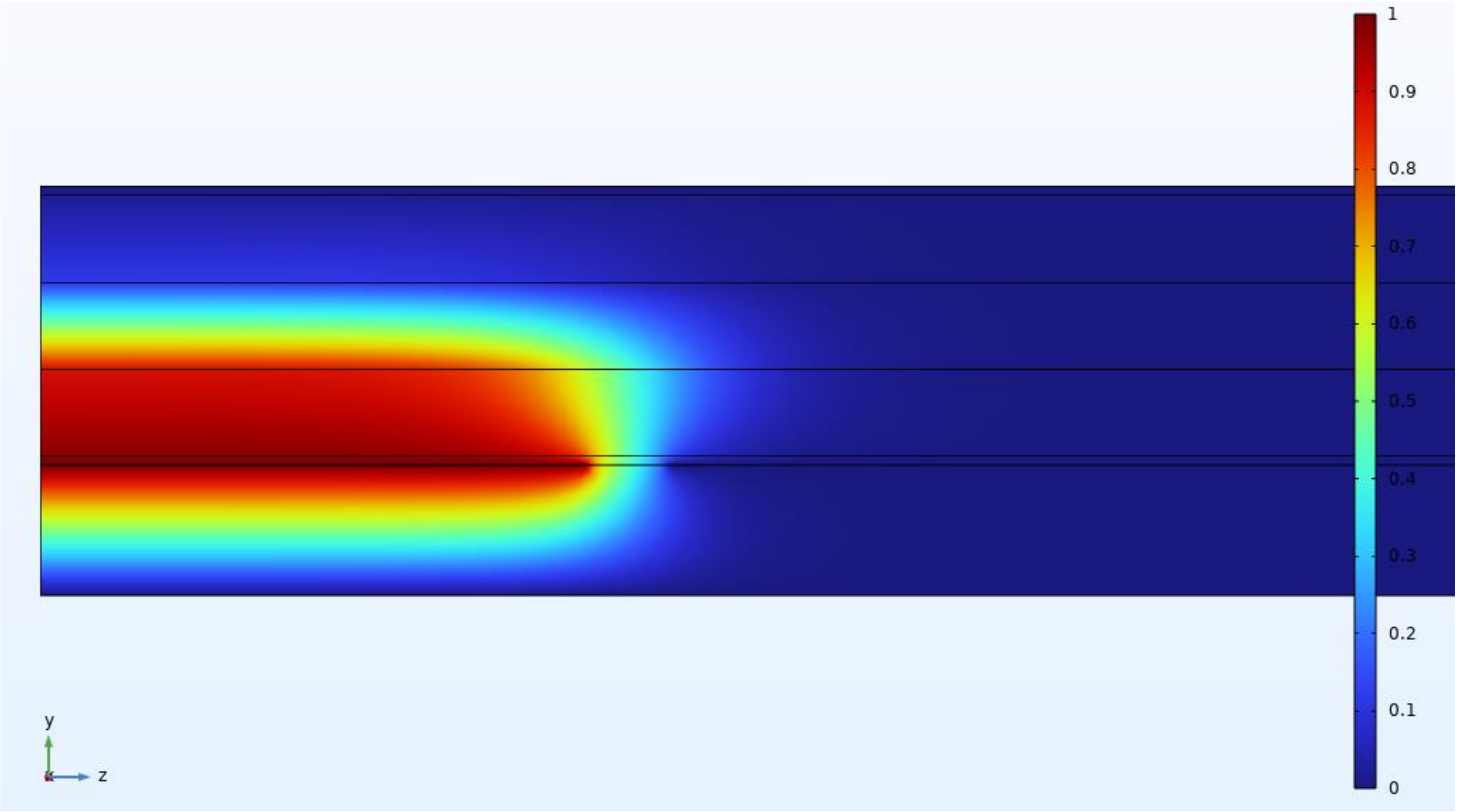
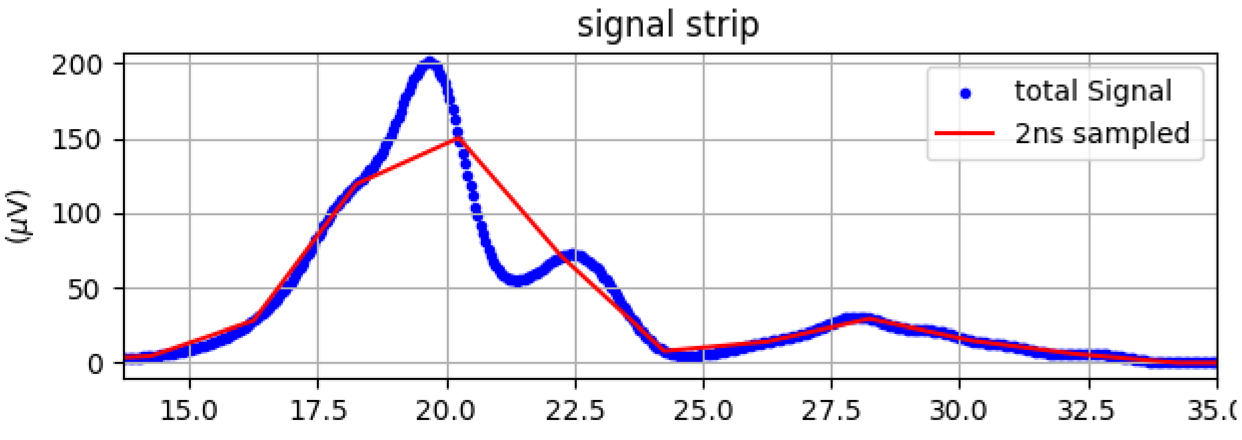


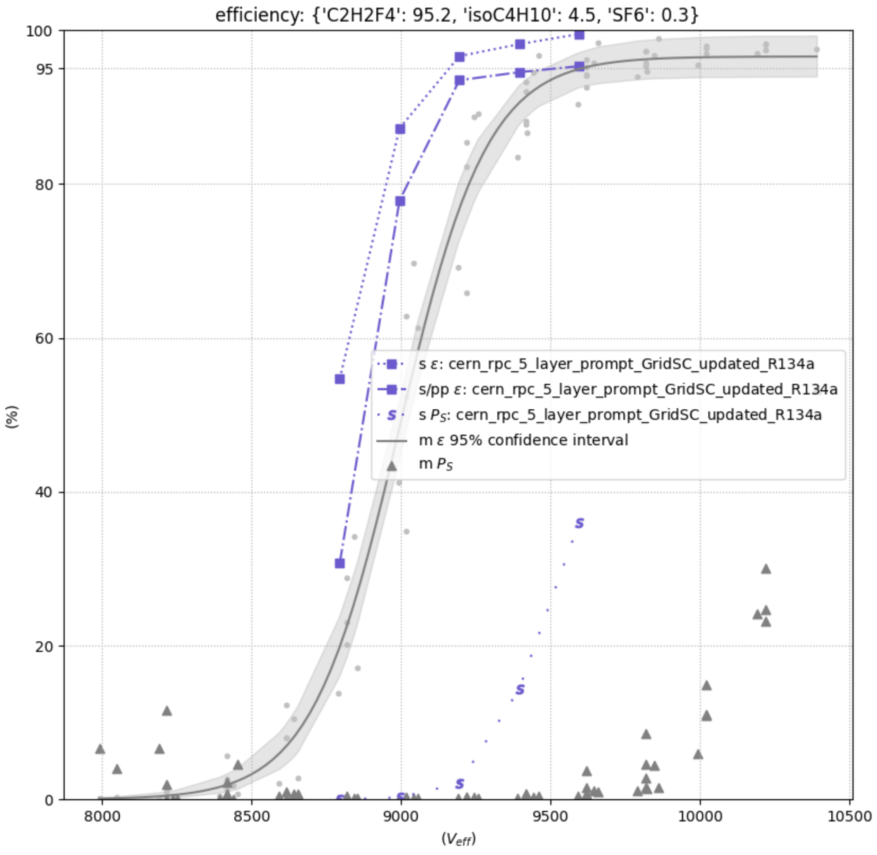

Figure: Experimental Setup [G. Rigoletti, Doctoral Thesis, 2022]

# Weighting Field of Strip



# 2ns Sampling



# Estimating the Streamer-Probability (Streamer-Inception)

## (Current) Definition Streamer Transition

An electron avalanche transitions to a streamer if the electron number a single avalanche reaches a value between $N_{crit}^{e^-} \sim 10^7 - 10^8$.

## (Updated) Definition Streamer Transition

An electron avalanche transitions to a streamer if the avalanche induced electric field distorts the background field enough, i.e. there exists a number $f$ (which may be field dependent) for each geometry $G$ and *gas* s.t.,

$$\max_{t \in T,\, x \in G} \left| \vec{E}_{bckg} + \vec{E}_{sc} \right| (x,t) > f_{G,\,gas}(V) \cdot |\vec{E}_{bckg}| \;\; \Rightarrow Transition.$$