A standalone simulation program for Resistive Cylindrical Chambers (RCC) in the TANGO_RD project

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INFN, Sezione di Bari

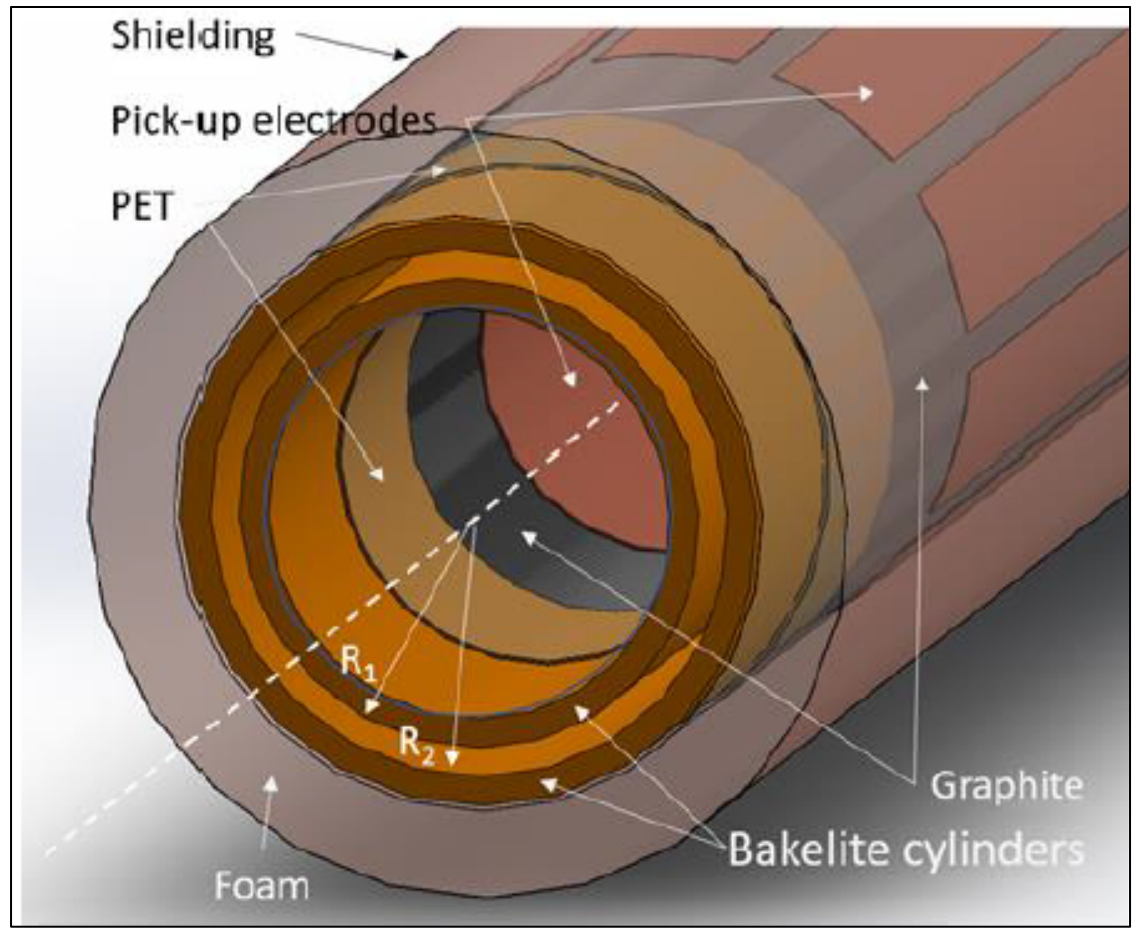
Resistive Cylindrical Chamber: RCC

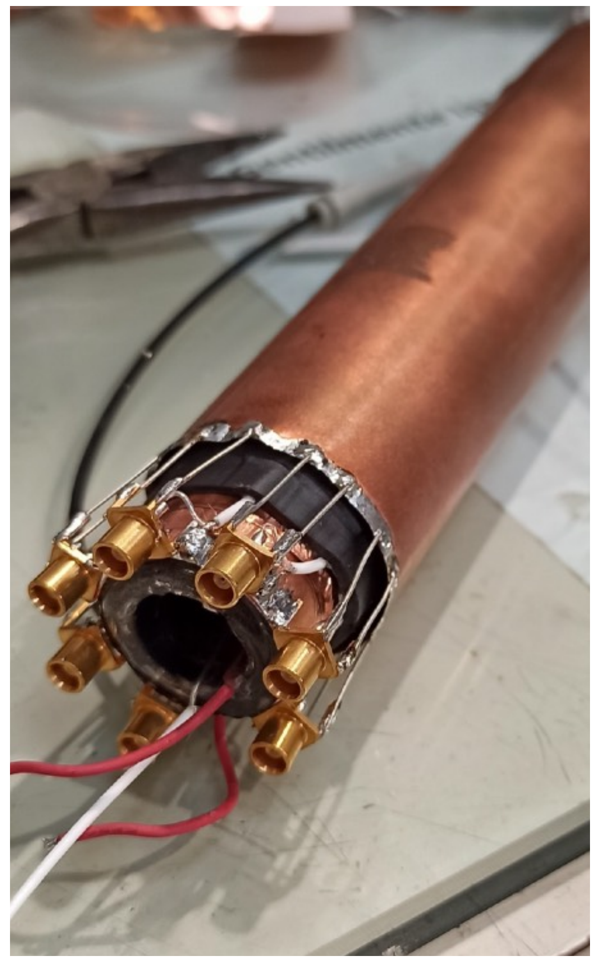
The RCC detector is a new gaseous detector introduced by **R. Cardarelli** in 2021:

R. Cardarelli, Future RPC developments, J. Instrum. 16 (2021) C05004.

R. Cardarelli, A. Rocchi et al, The Resistive Cylindrical Chamber. NIM Section A. Volume 1058,2024,168822-ISSN 0168-9002

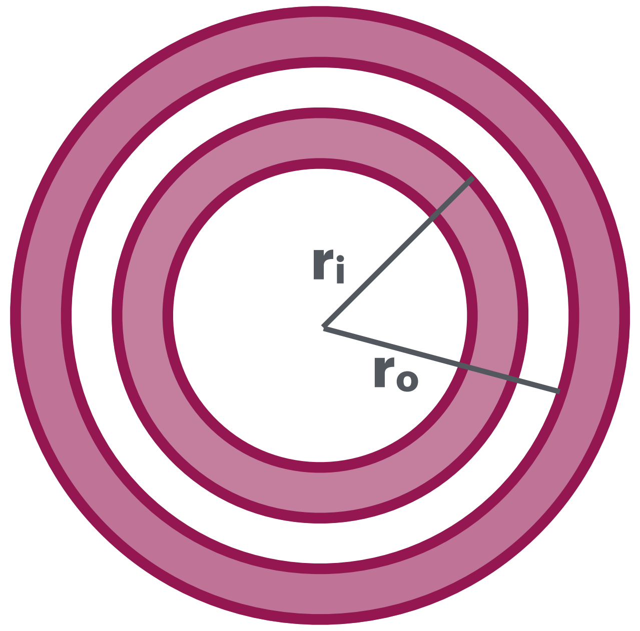
https://doi.org/10.1016/j.nima.2023.168822



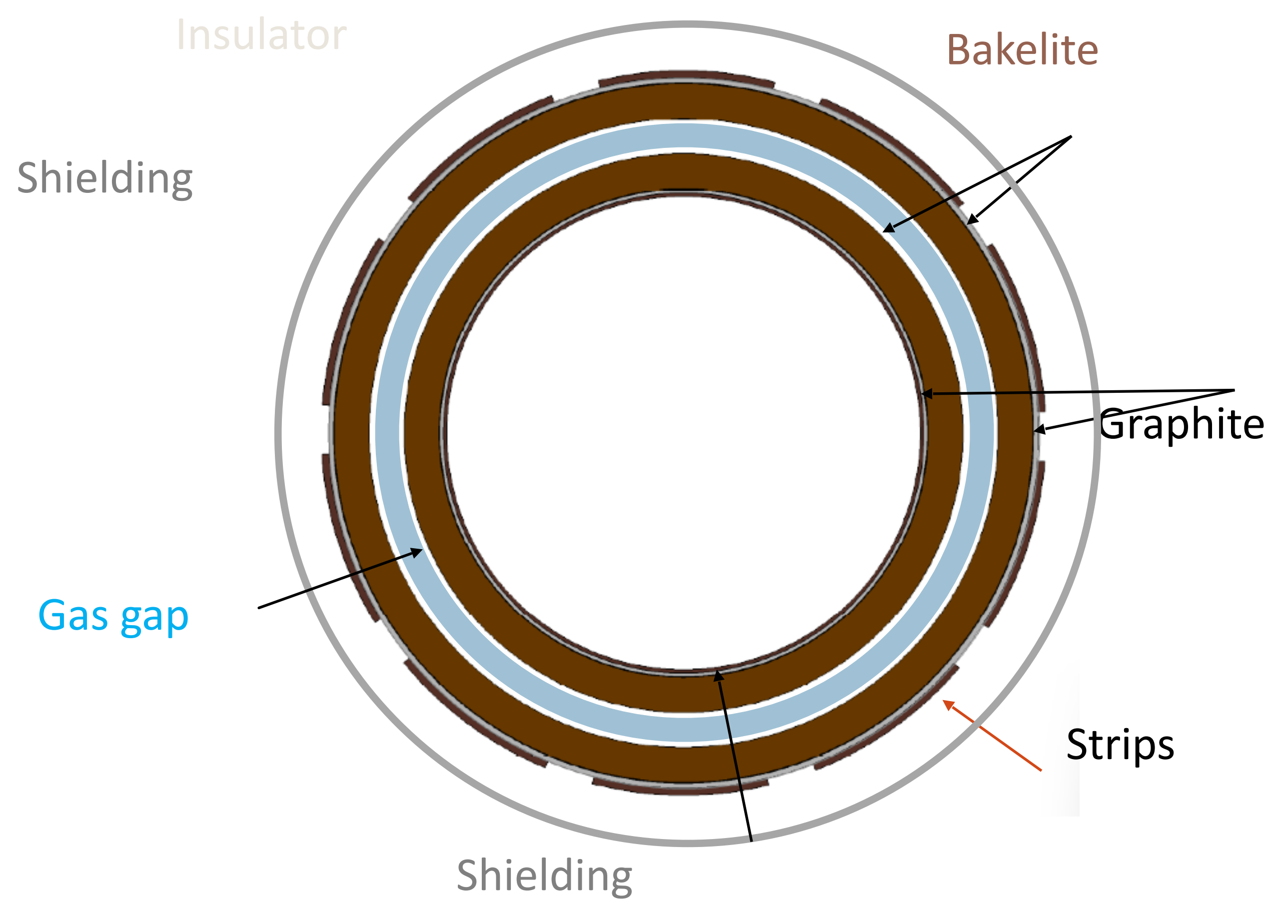


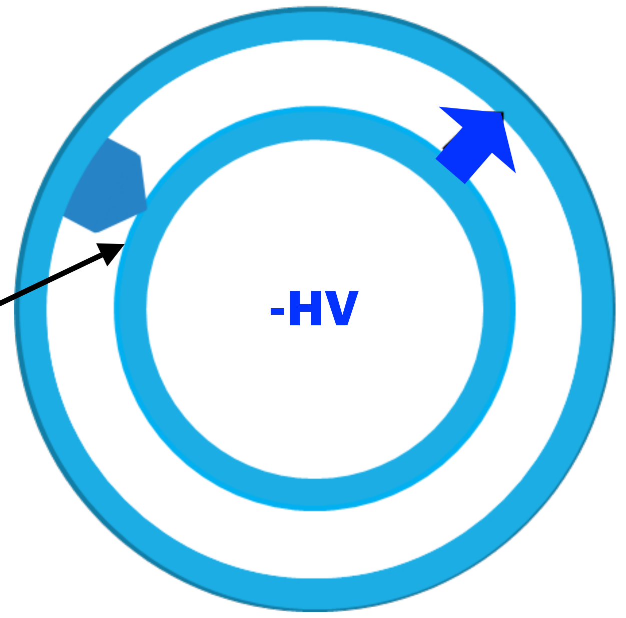
Negative polarity if the inner electrode is at negative voltage vs outer electrode

Positive polarity if the inner electrode is at positive voltage vs outer electrode

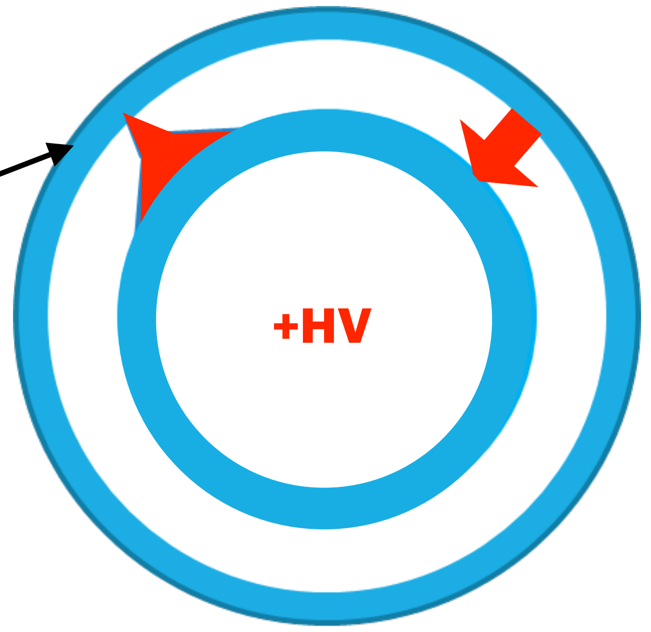


$$E(r) = \frac{V}{r \cdot ln\frac{r_o}{r_i}}$$

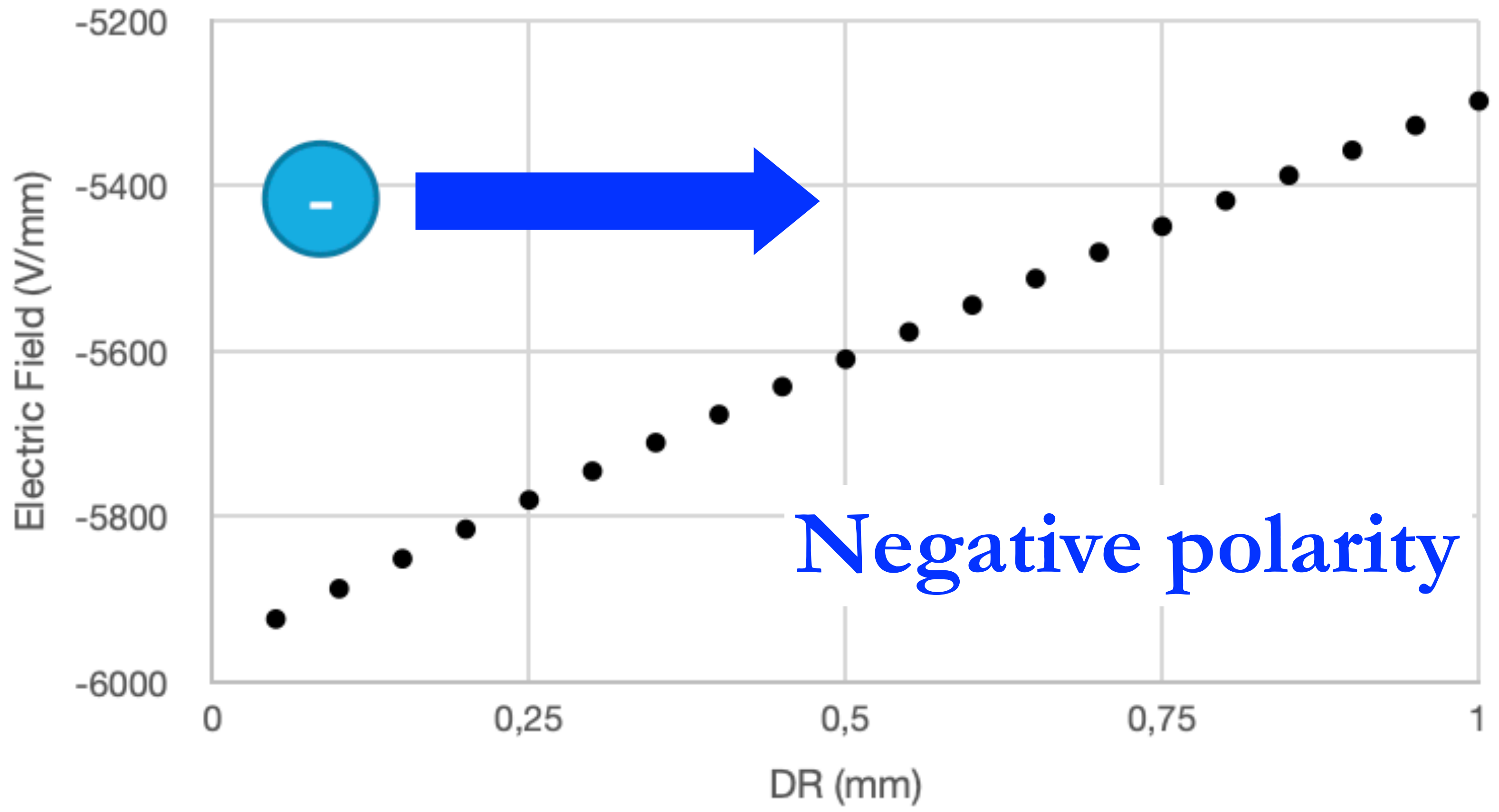


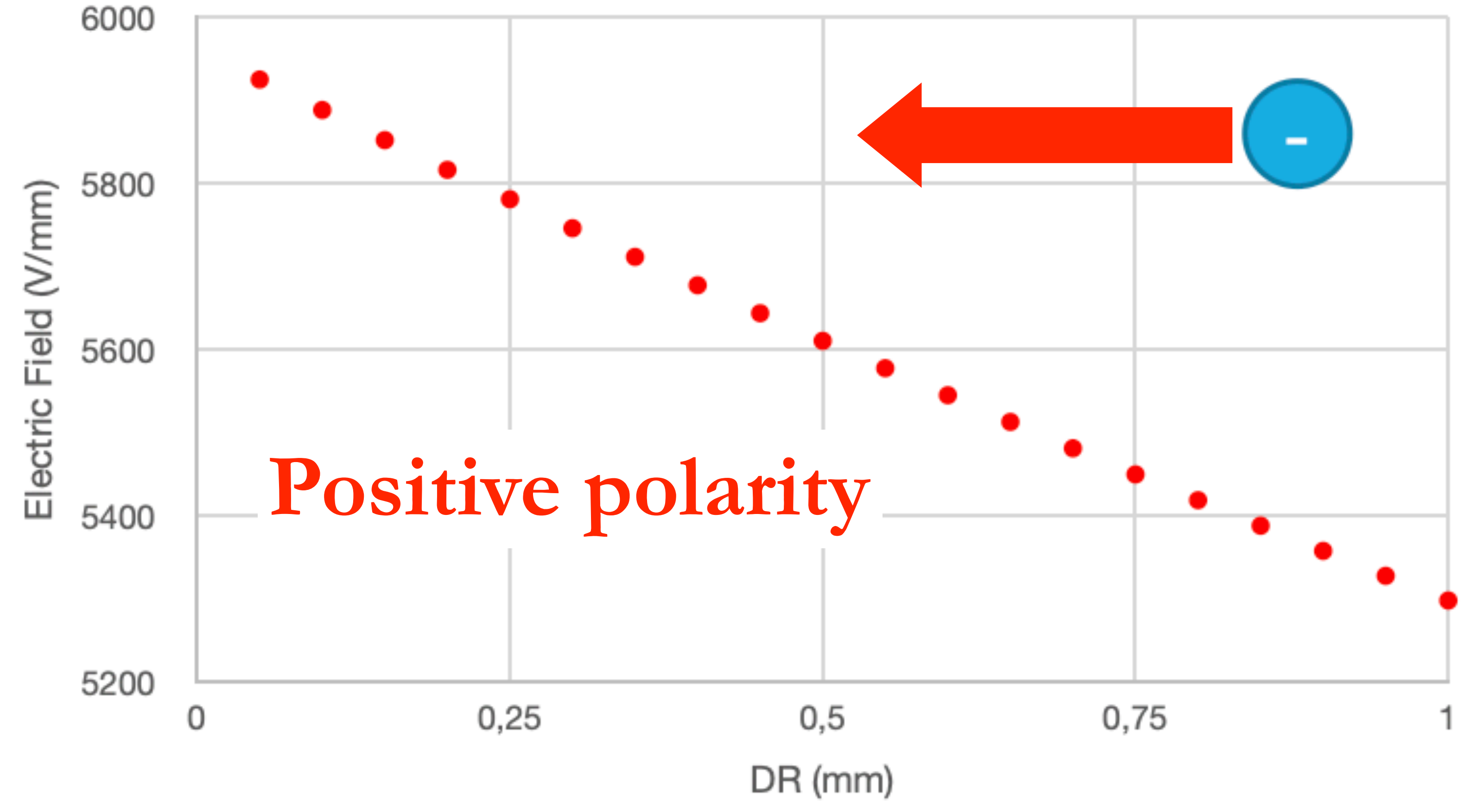


Multiplication followed by drift



Drift followed by multiplication





Resistive Cylindrical Chamber: RCC

The RCC detector is a new gaseous detector introduced by R. Cardarelli in 2020 - 2022.

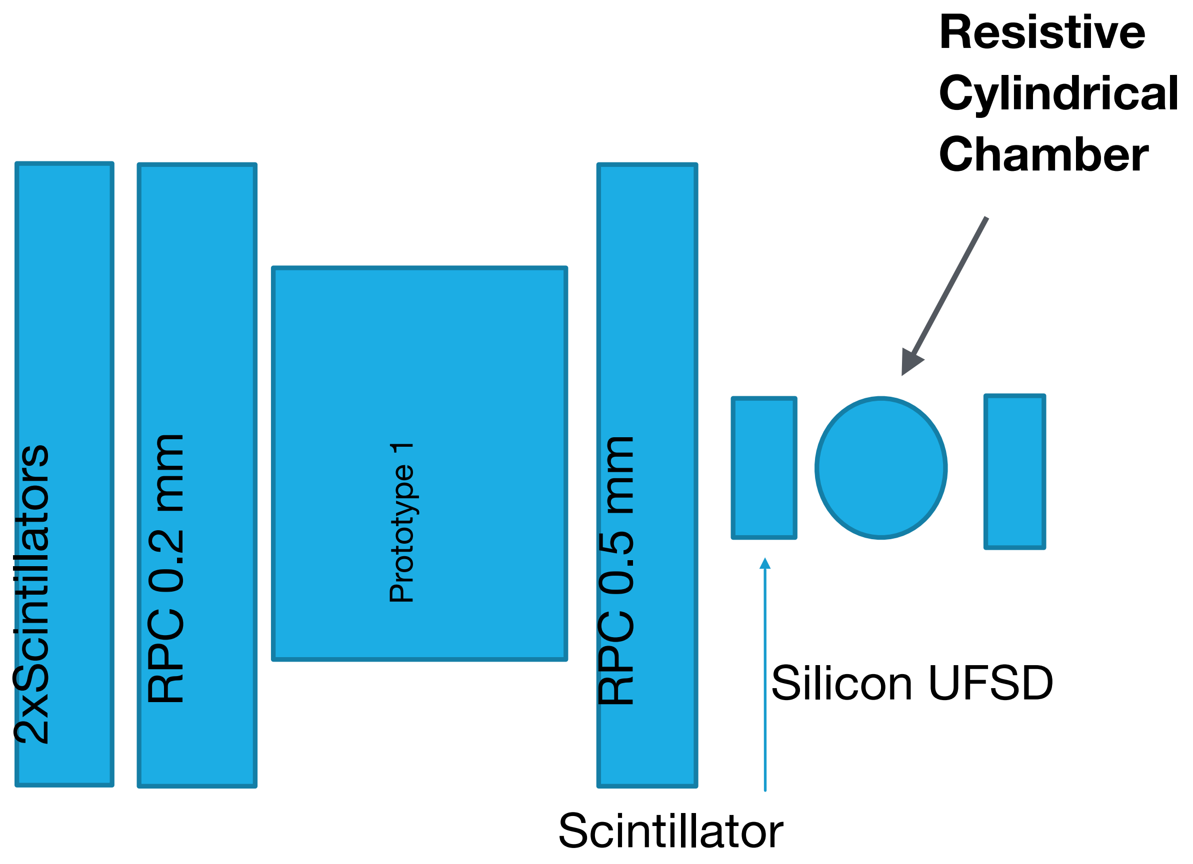
[**R. Cardarelli, A. Rocchi et al**, **The Resistive Cylindrical Chamber**. NIM Section A. Volume 1058,2024,168822-ISSN 0168-9002]

https://doi.org/10.1016/j.nima.2023.168822

Experimentally characterized: [**A. Rocchi et al**, "**Efficiency and time resolution of a thin gap Resistive Cylindrical Chamber**." Contribution to RPC2024 Conference

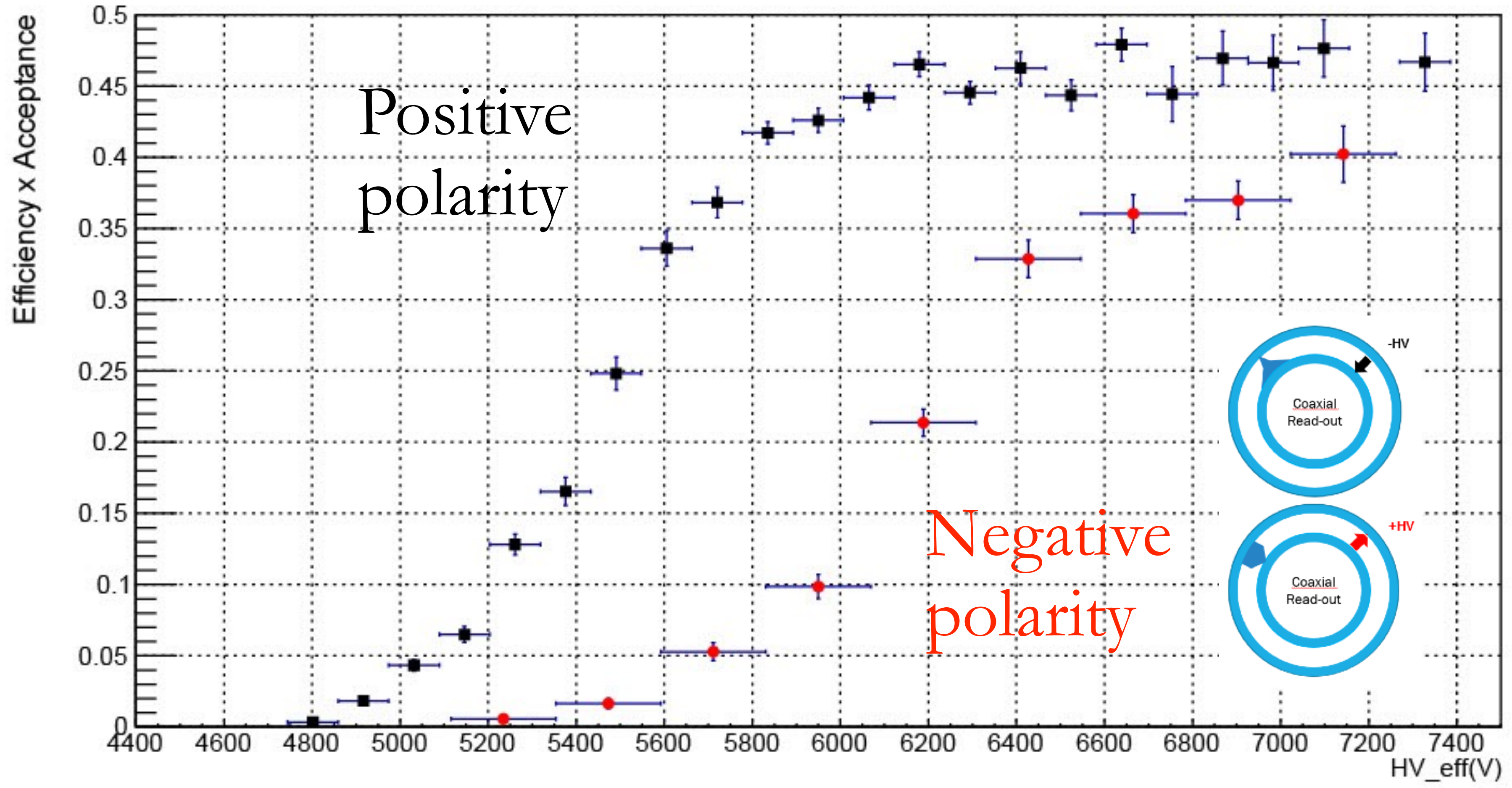
https://doi.org/10.15161/oar.it/8vsjx-d8c51]

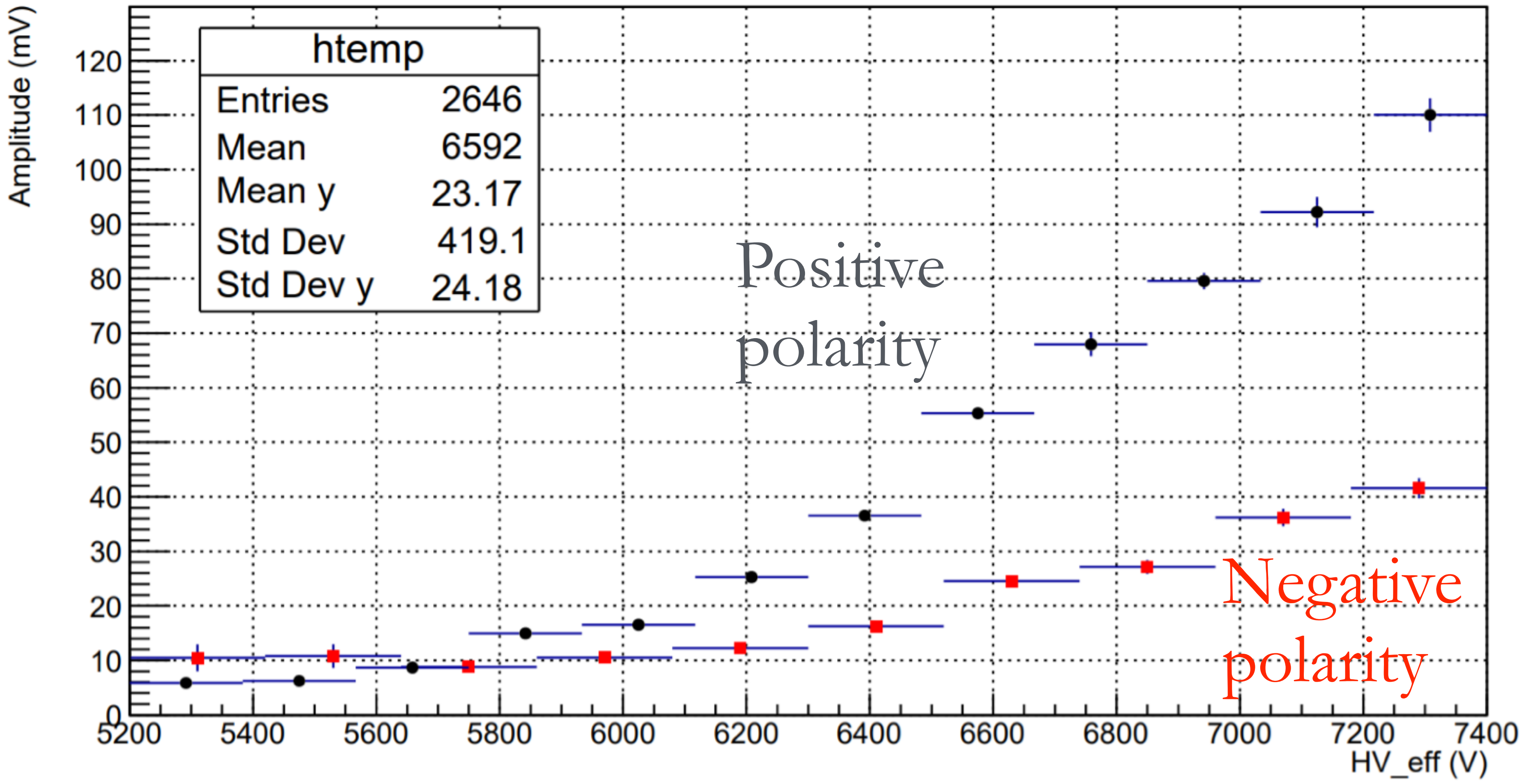
Test at CERN



First experimental results from A. Rocchi

Hybrid RCC r_i=2 mm r_o=3 mm





A. Rocchi, "**Moderation of the avalanche gas discharge through a quasi-uniform electric field device: the Resistive Cylindrical Chamber**", VCI2022 Conference.

The TANGO_RD project
(Toward A New Generation Of RPC Detectors)

- **TANGO_RD is a new project recently approved by INFN**

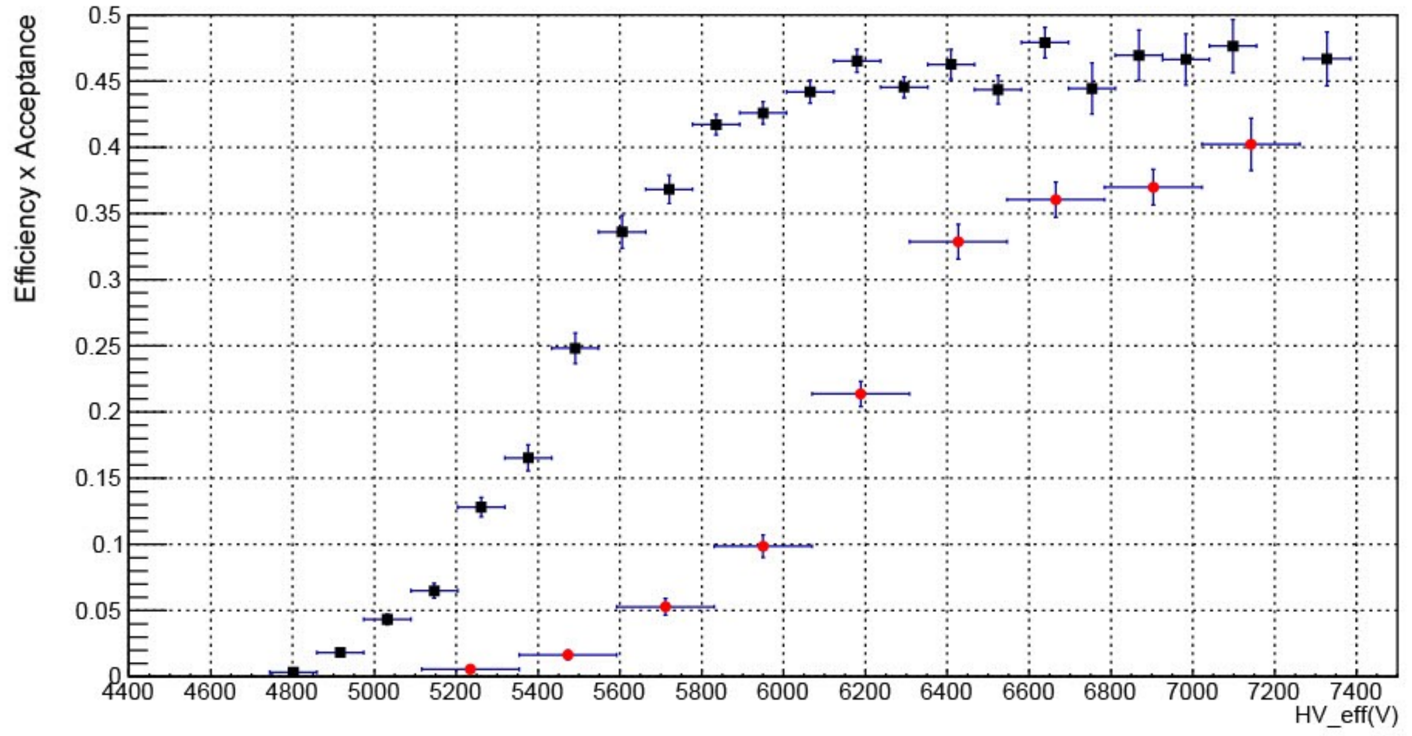
- ***ToV:*** **B. Liberti (PI)**, A. Rocchi, E. Vallocchia
- ***LNF:*** D. Piccolo, S. Bianco, A. Paoloni, S. Meola, G. Saviano, C. Vendittozzi, S. Colafranceschi*
- ***Bari:*** A. Pastore, M. Abbrescia, M. De Serio

* also James Madison University (JMU)

WP1
Characterization of underlying physical principle and performance as a function of RCC construction parameters

WP2
Development of a Simulation program for RCC and comparison with experimental data

Working principles (polarity asymmetry)



WP5
Production of large size prototypes and test with beam

System scalability
Performance

Toward green detector

WP3
Characterization of performance with ecological gas mixtures

WP4
Characterization of new electrode materials

Toward high rates

The TANGO_RD project
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Characterization of underlying physical principle and performance as a function of RCC construction paramete

[Development of a Simulation program for RCC](#)
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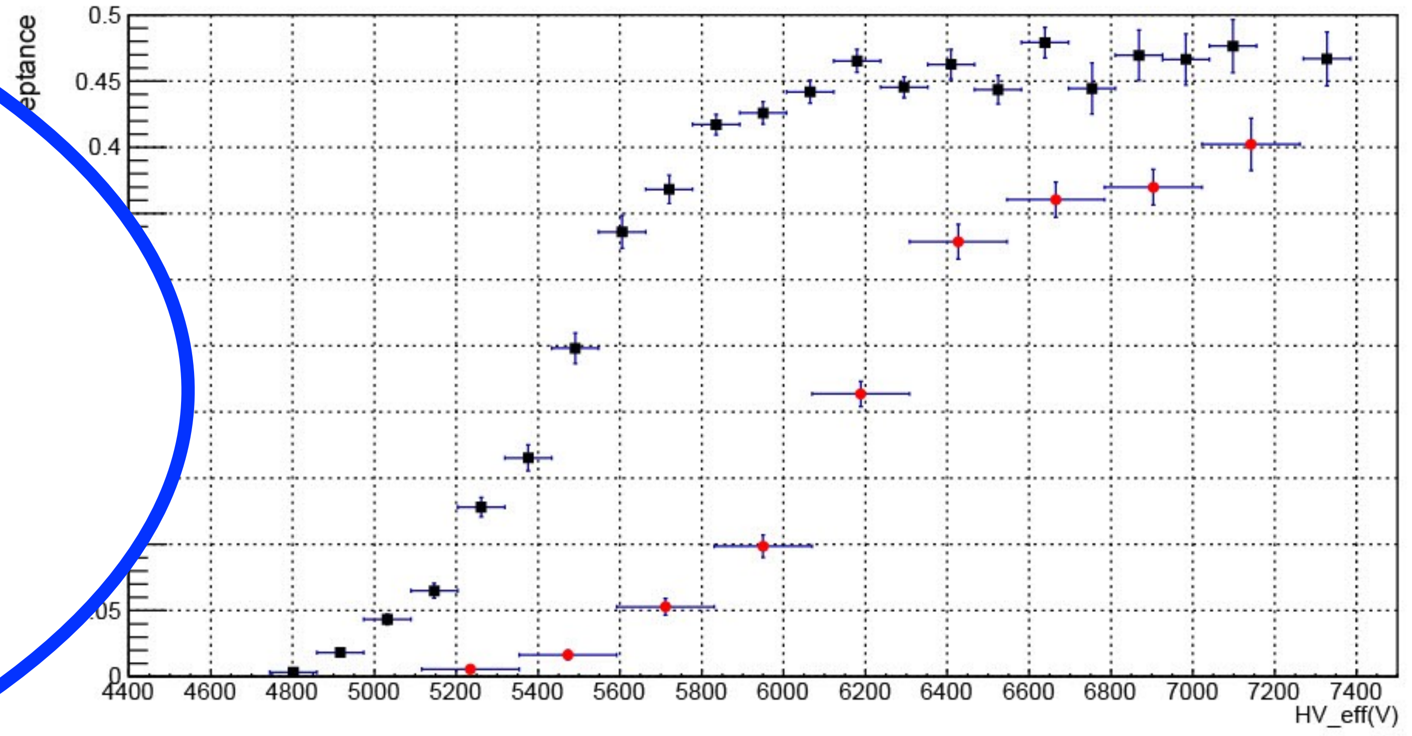


Toward green detector

Produc
prototypes an

Ω,cm",
green

Characterization of performance with ecological gas mixtures

Characterization of new electrode materials

Toward high rates

TANGO_RD

RPCs simulation

Early simulations and numerical extensions

M. Abbrescia et al. Resistive plate chambers in avalanche mode: A comparison between model predictions and experimental results. Nuclear Instruments and Methods in Physics Research Section A, 409(1-3):1–5, 1998.

M. Abbrescia et al. Simulation of resistive plate chambers in avalanche mode: Charge spectra and efficiency. Nuclear Instruments and Methods in Physics Research Section A, 431(2-3):413–427, 1999.

W. Riegler, C. Lippmann, and R. Veenhof. Detector physics and simulation of resistive plate chambers. Nuclear Instruments and Methods in Physics Research Section A, 500(1-3):144–162, 2002.

C. Lippmann and W. Riegler. Space charge effects in resistive plate chambers. Nuclear Instruments and Methods in Physics Research Section A, 517(1-3):54–76, 2004.

Microscopic approaches

R. Veenhof and contributors. Garfield++ rpc modelling tutorials. https://garfieldpp. web.cern.ch/garfieldpp/, 2020.

Streamer inclusion and new gases

D. Stocco et al. Numerical Studies on Streamer Probability in Resistive Plate Chambers for Eco-Friendly Gases. Nuclear Instruments and Methods in Physics Research Section A (2025)

TANGO_RD simulation Code goal:

A standalone simulation for RCC geometry to guide experimental studies

- **Simplified approach:** Stepwise approach with 1.5D model for correction due to space charge;
- **Fast and Flexible:** Easy comparison of several geometries and experimental layouts;
- **Sufficiently accurate:** To highlights the RCC characteristics;

Avalanche development model

$$n(x) = n_0\, e^{\int_{x_0}^{x} \alpha_{eff}(E(x'))\, dx'}$$

Avalanche Townsend Electron gain

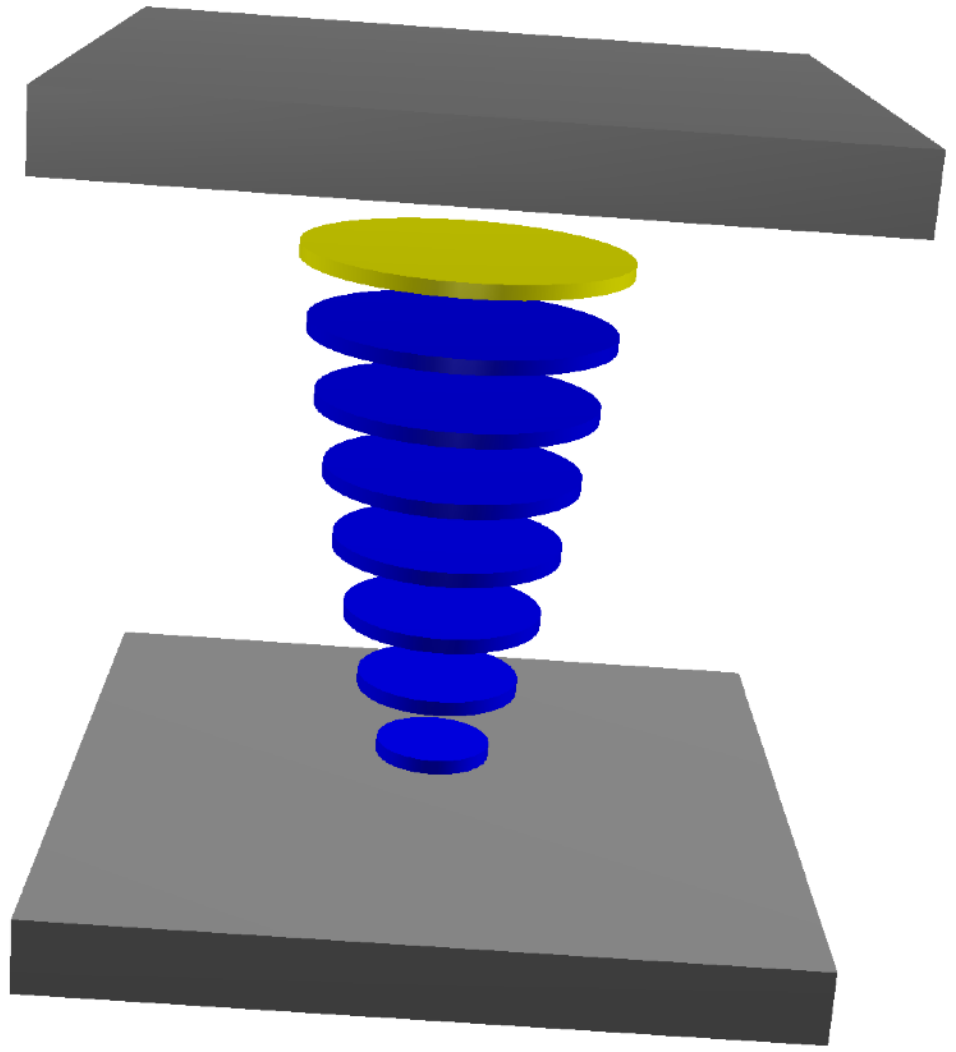
The gas gap is divided in n steps (100-1000) and for each step the electric field is considered constant: On each step evaluate n(x).

Positive ions evaluated on each step and considered uniformly distributed on a disk of radius a (related to transverse diffusion)

$$a = 2D_T\sqrt{x},$$

Where D_T is Transverse diffusion coefficient

Electrons evolve to the next steps according to Electric Field (alpha_eff) due to external field + space charge electric field due to positive ions (considered frozen during the avalanche)



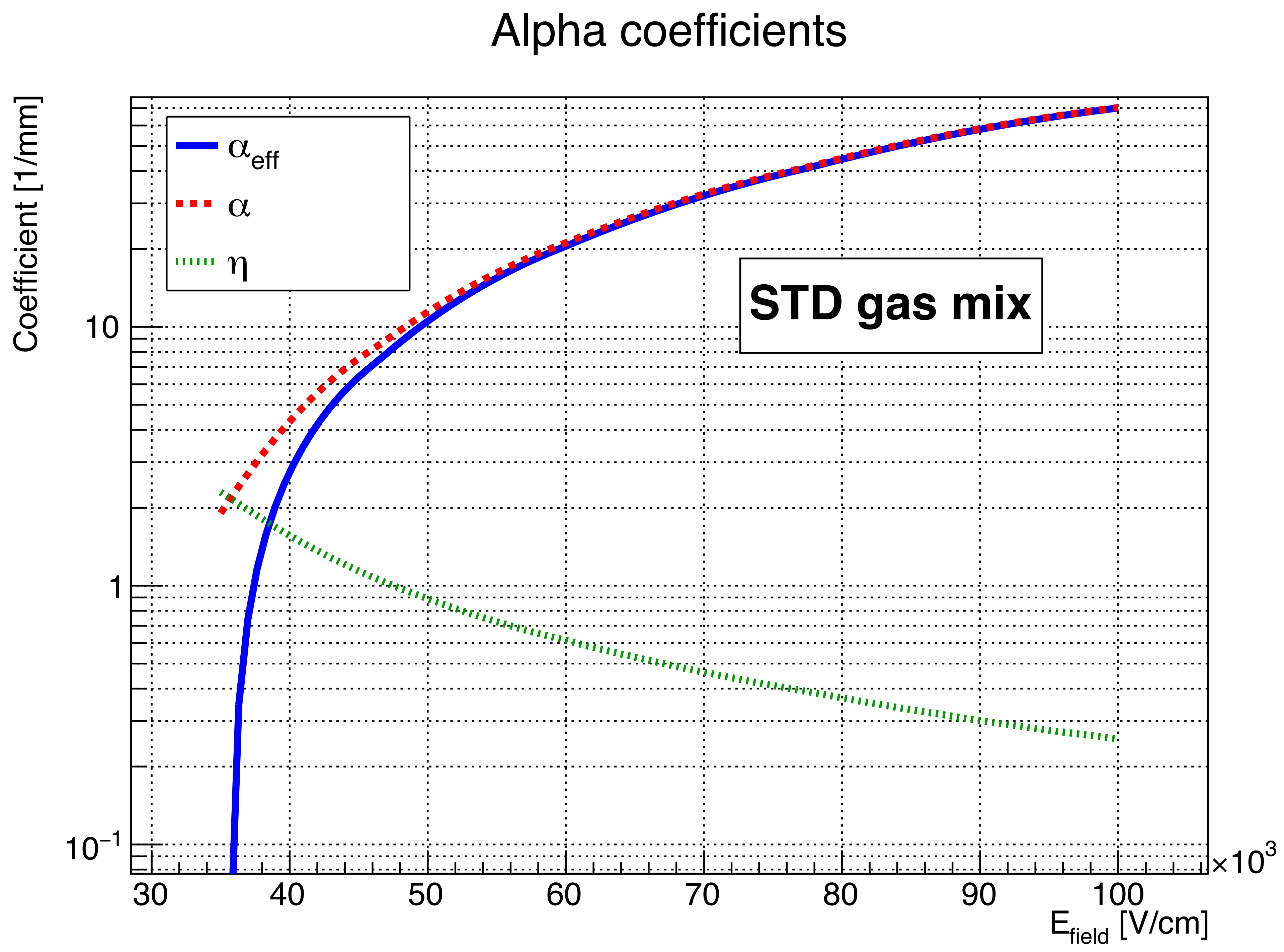
$$E(s) = \frac{\sigma}{2\epsilon_0}\left(1 - \frac{s}{\sqrt{s^2 + a^2}}\right),$$

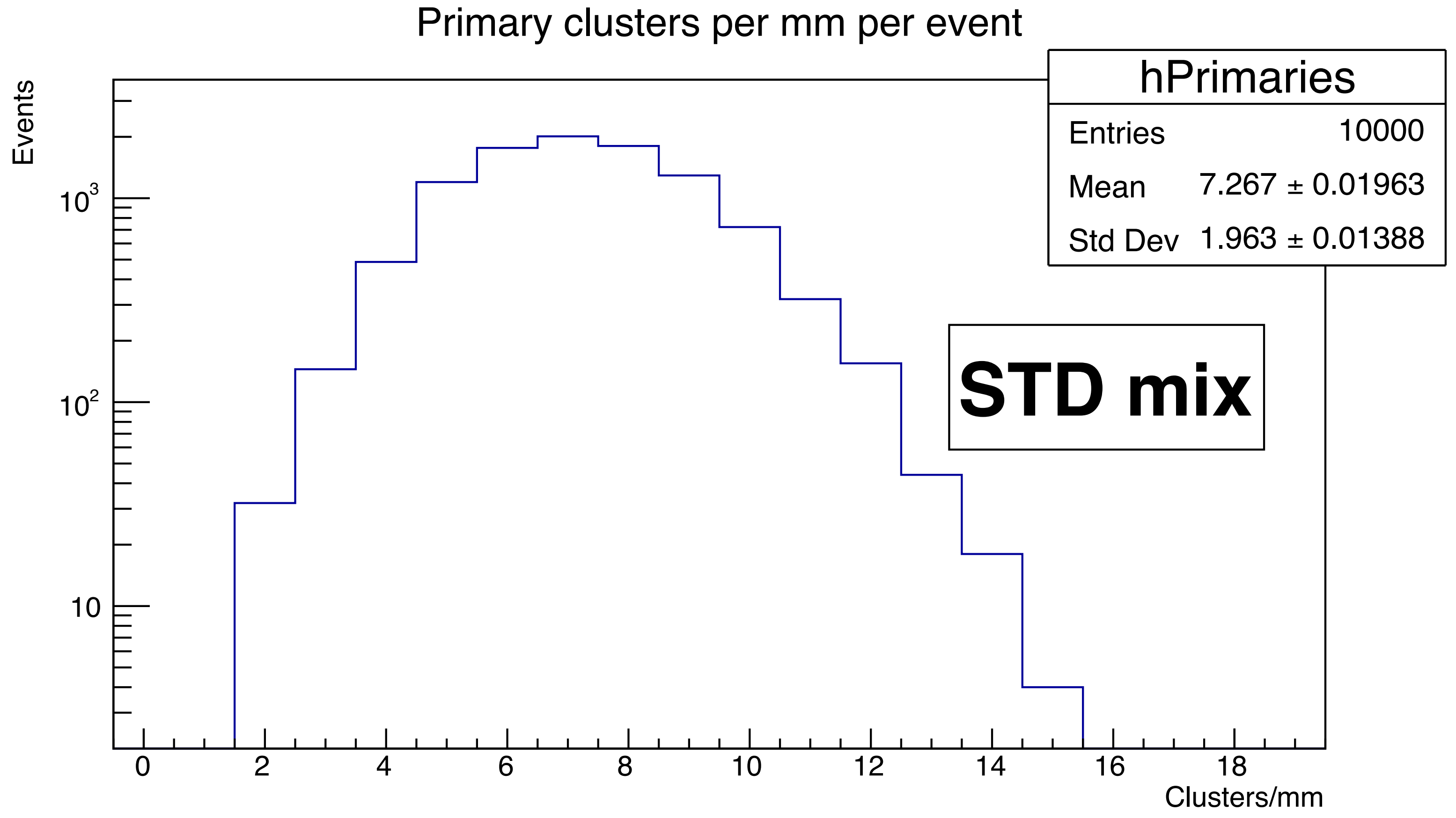
Electric field due to a uniformly charged disk at distance s

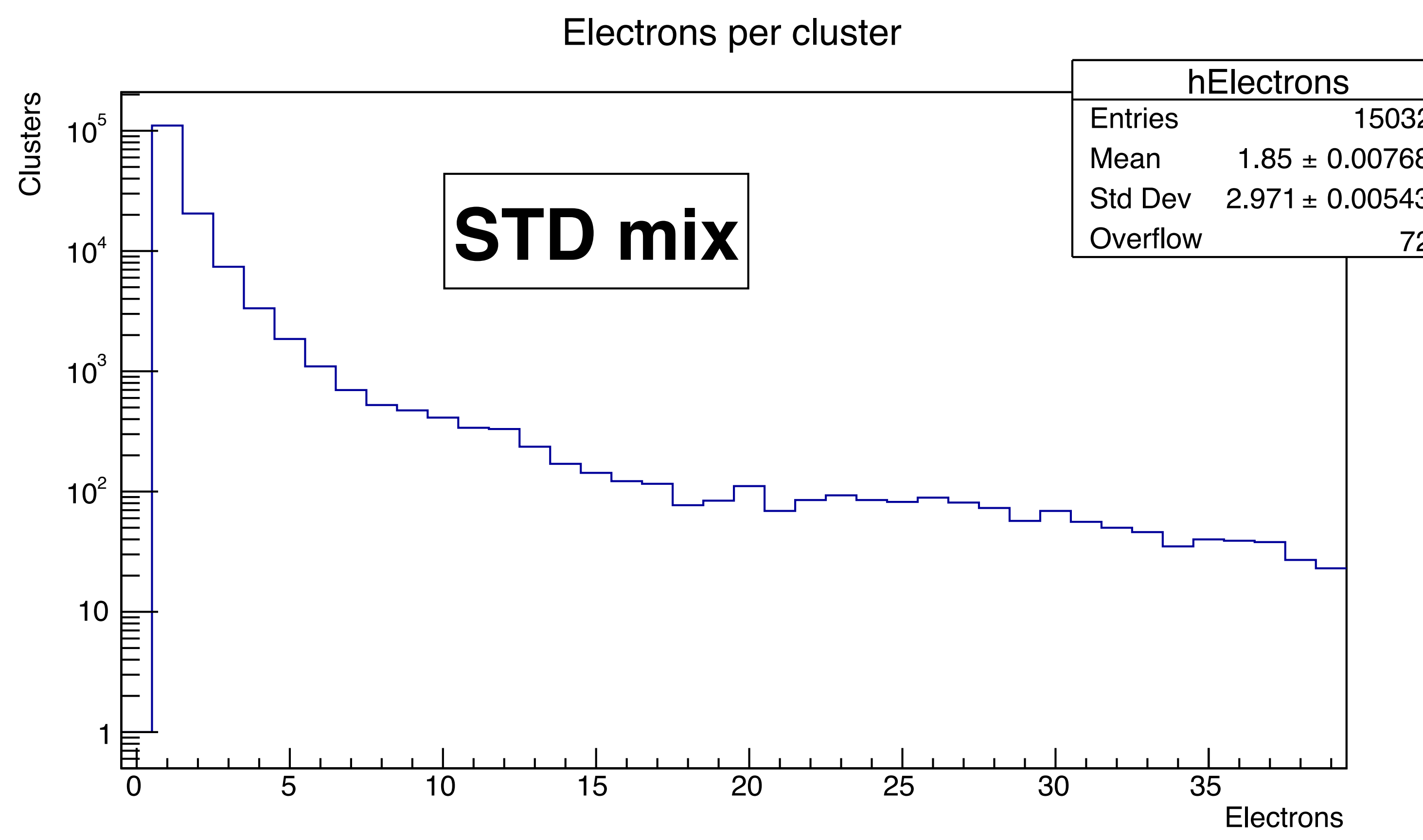
Present main limitations: All avalanches are independent, simplified space charge model, avalanche gain fluctuations not included at moment (upgraded version to include them is already available)

Simulation parameters

Main simulation parameters evaluated for standard gas mixture (STD mix: C2H2F4 95.3%, iC_4H_{10} 4.5%, SF_6 0.3%) with MAGBOLTZ. (Thanks to Piet Verwillingen providing the code for Townsend coefficient evaluation)







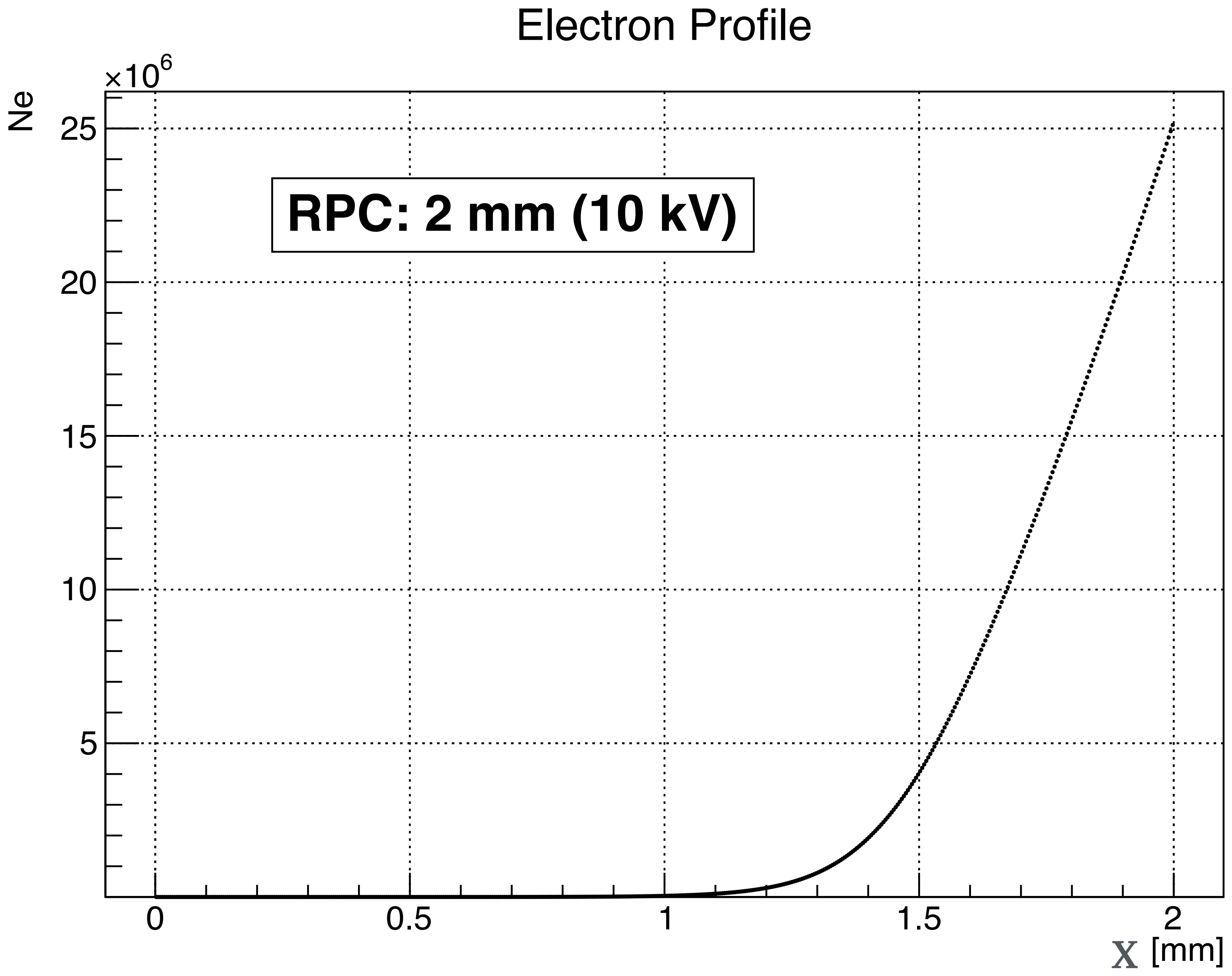
Transverse diffusion coefficient from MagBoltz almost constant with E: $\mathbf{D_T = 0.012}\sqrt{cm}$

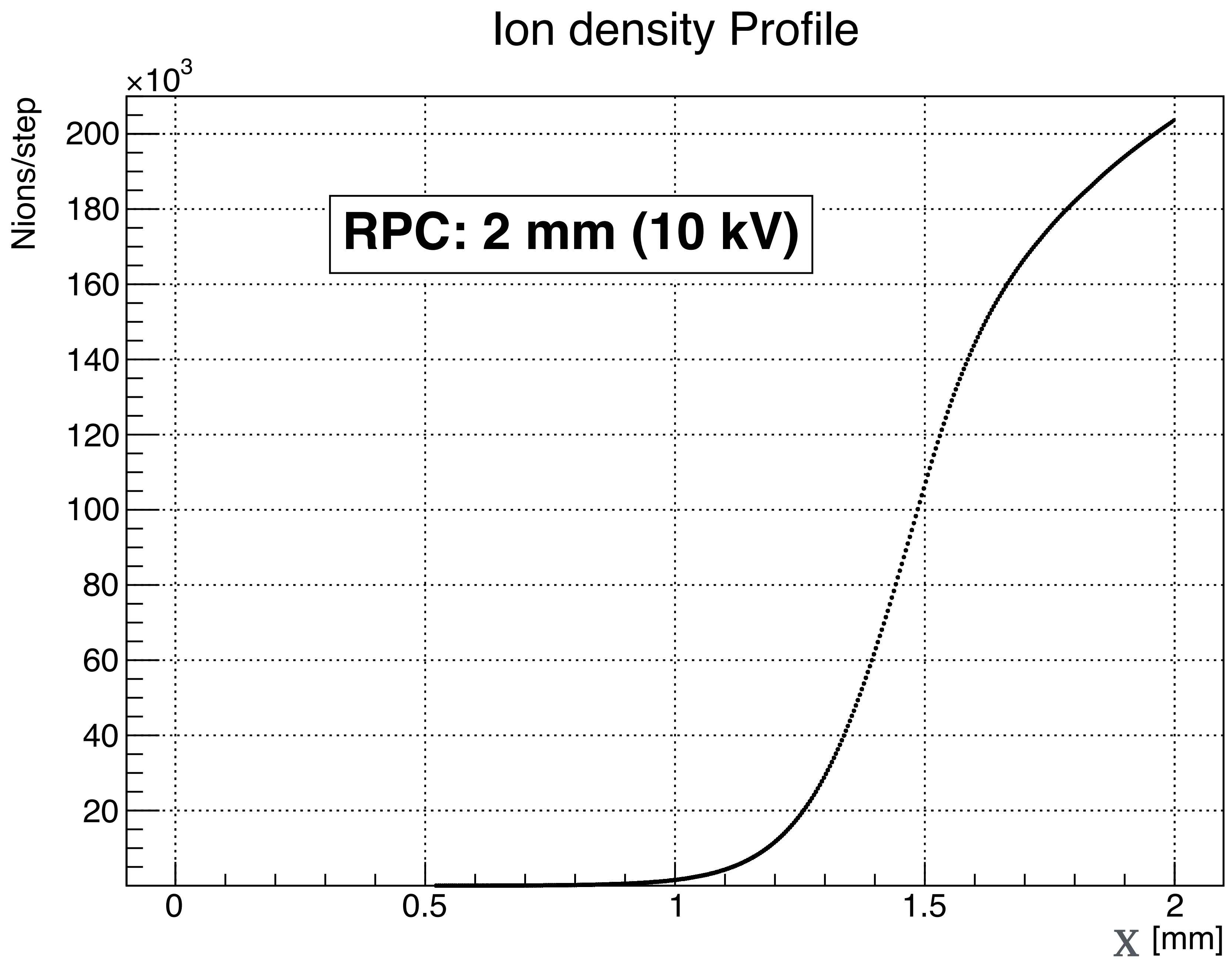
Caveat: rescaling of a factor 1.43 to normalize α_{eff} @ 50kV/cm to 10 mm^{-1} according to [G. Chiodini, et al., Studies of electron drift velocity and charge spectra in RPC by a UV laser source, Nucl. Instrum. Methods Phys. Res. A 602 (3) (2009) 757–760.]

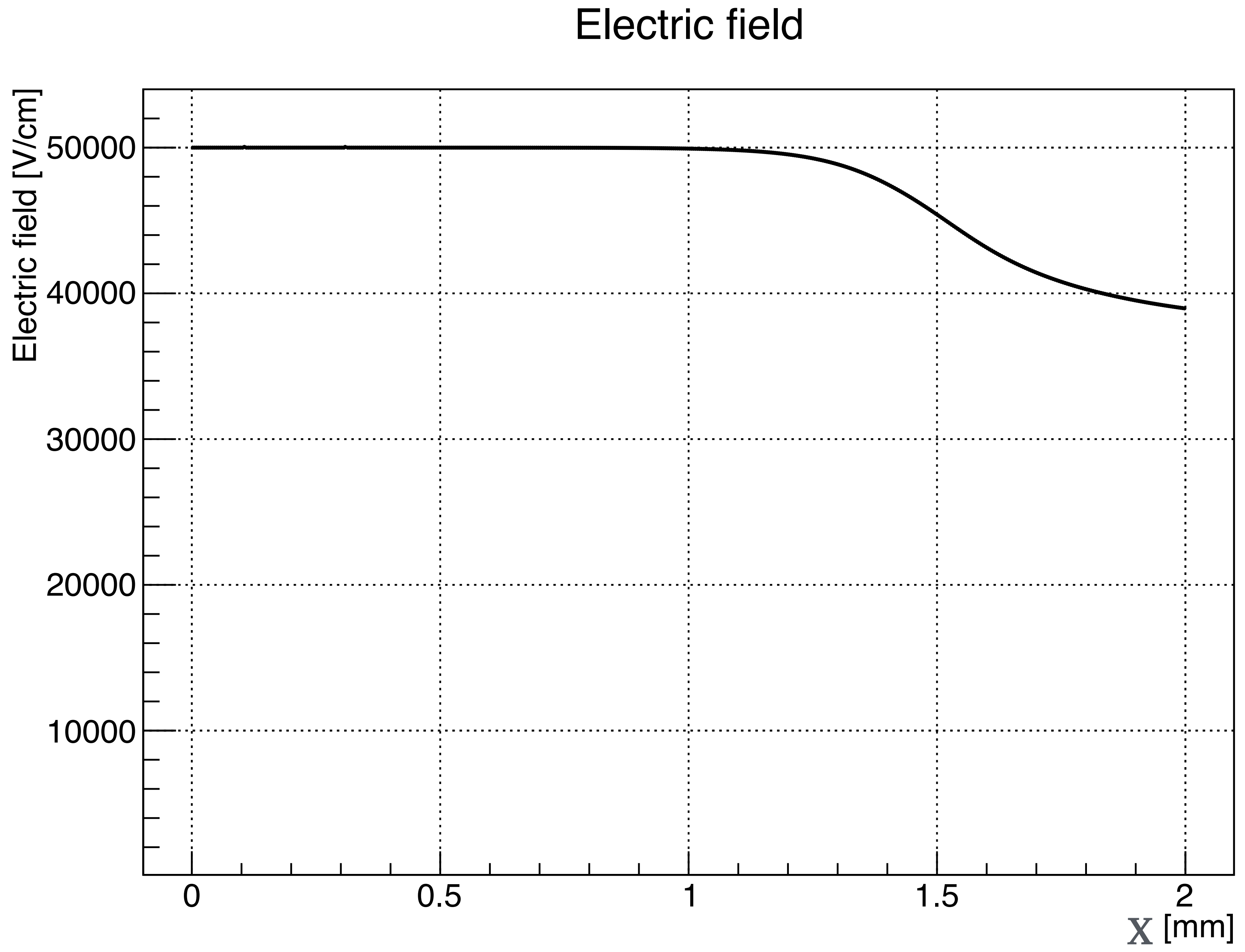
More recent data point to higher values more consistent with Magboltz values: [Dario Stocco, Marnik Metting van Rijn, and Christian M. Franck. Pulsed Townsend electron and ion swarm parameter measurements of the trigger rpc standard mixture.1001:165–257, 2021.]

Avalanche evolution for RPC (2 mm)

Example of avalanche evolution starting from the cathode for an RPC 2 mm gas gap @ 10 kV



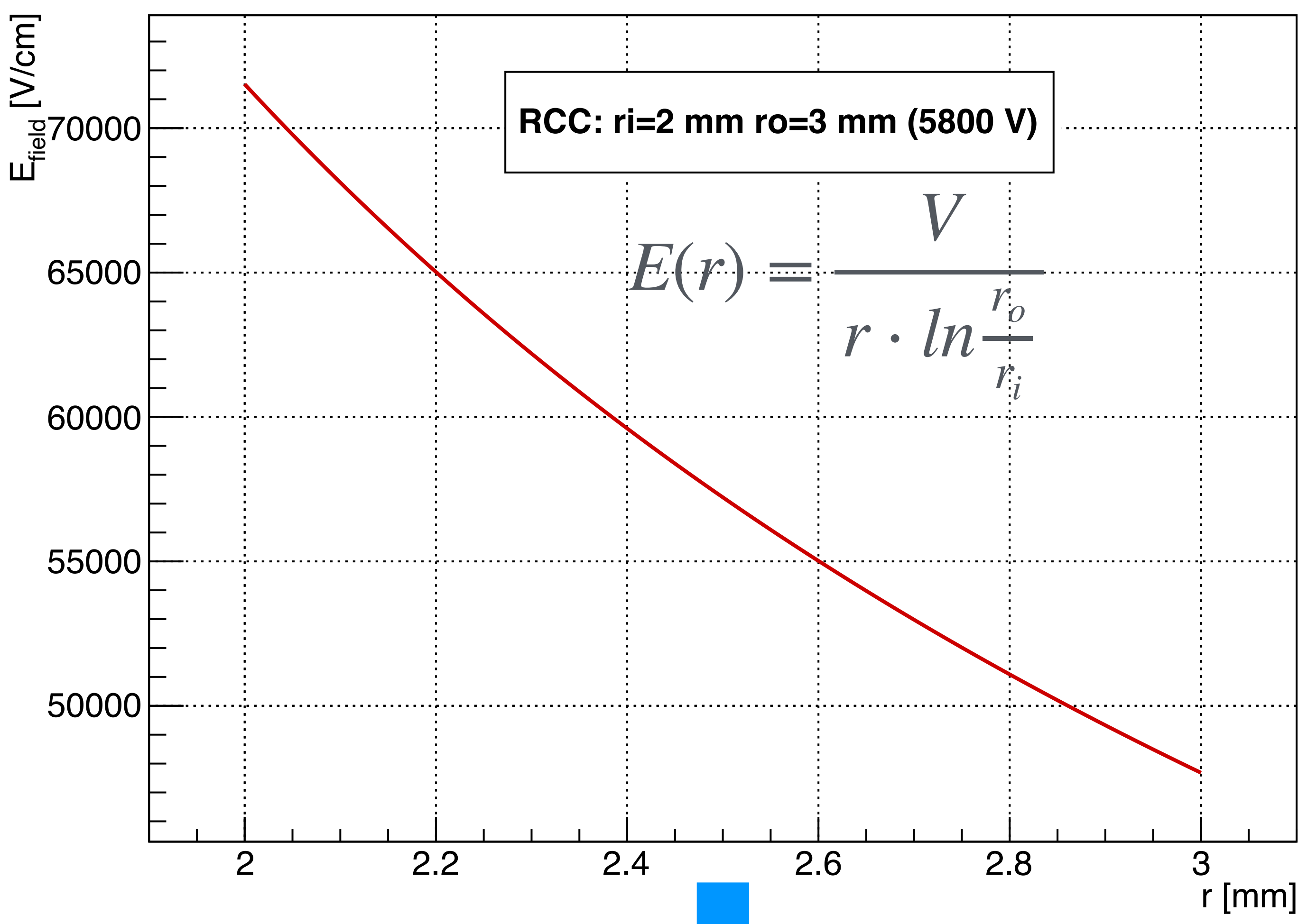


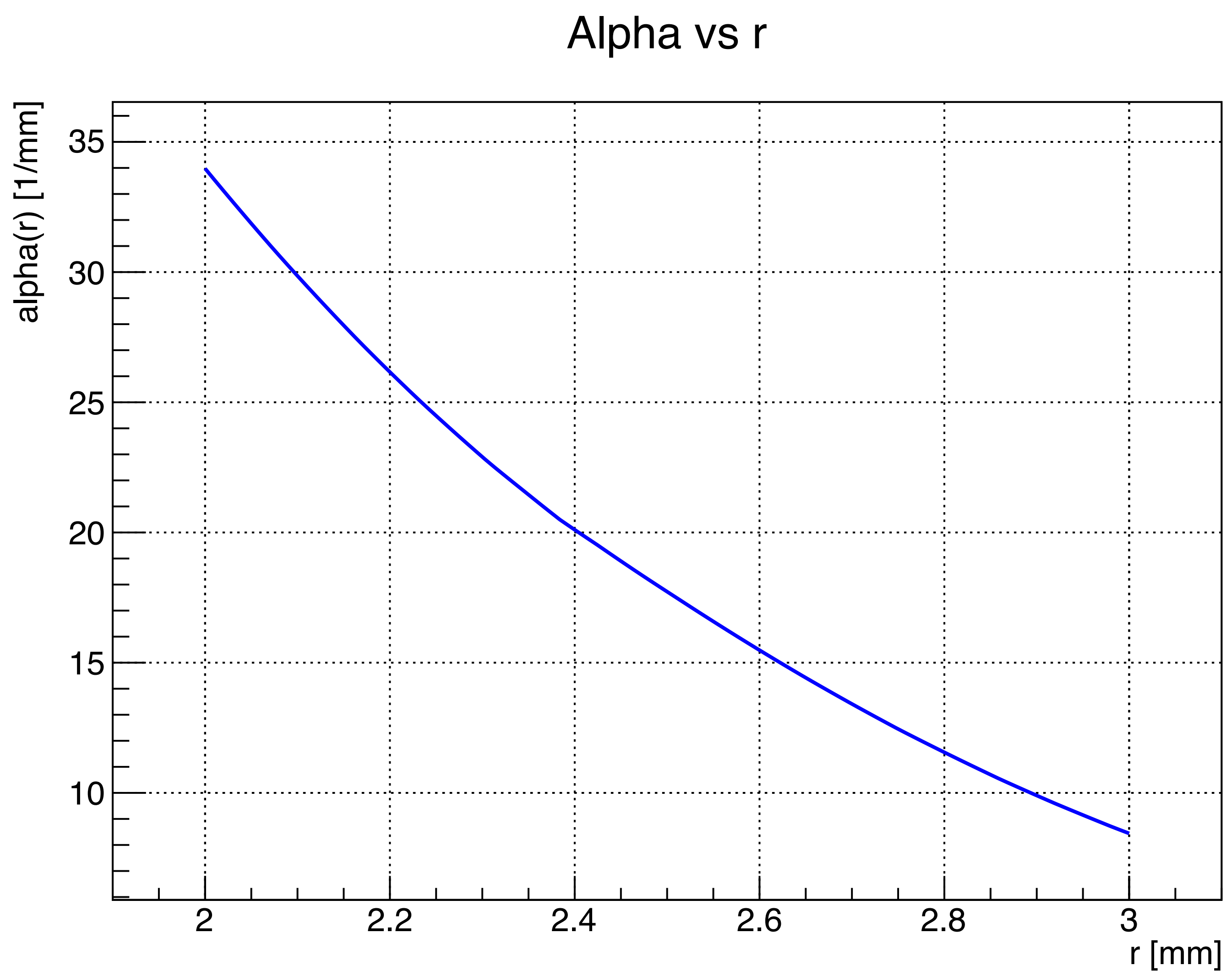


Avalanche evolution for RCC (No SC)

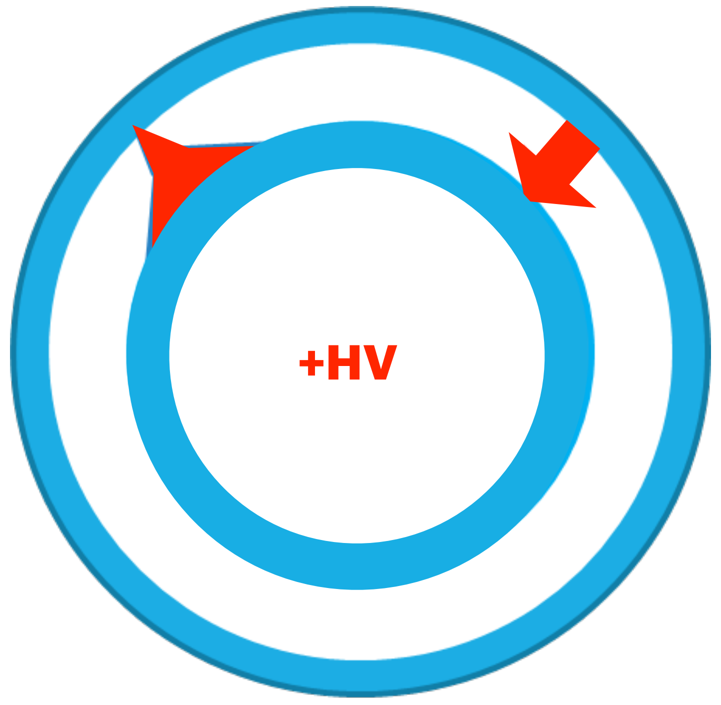
RCC example: $r_i = 2$ mm $r_o = 3$ mm V= 5800 V

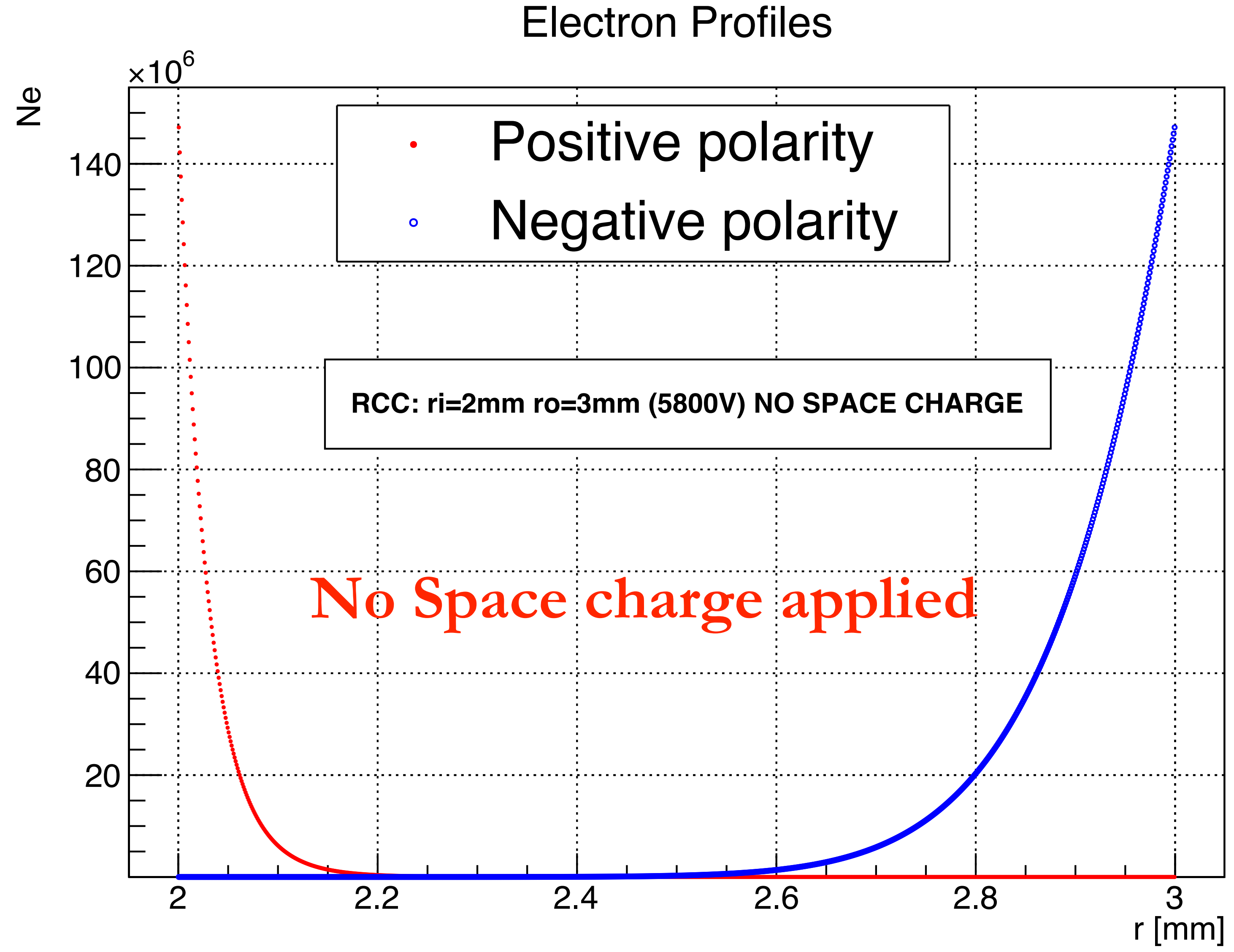
Electric field vs r

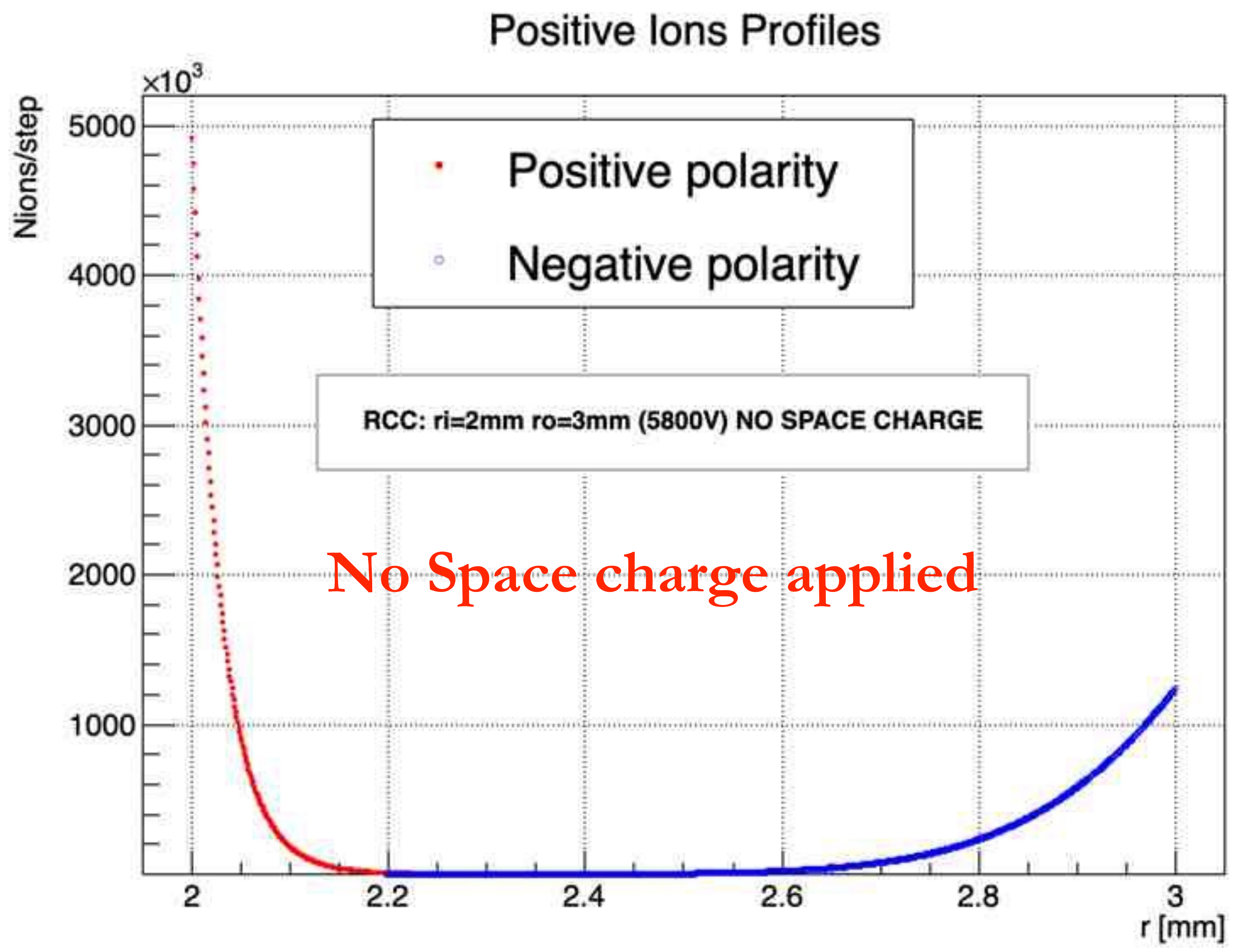




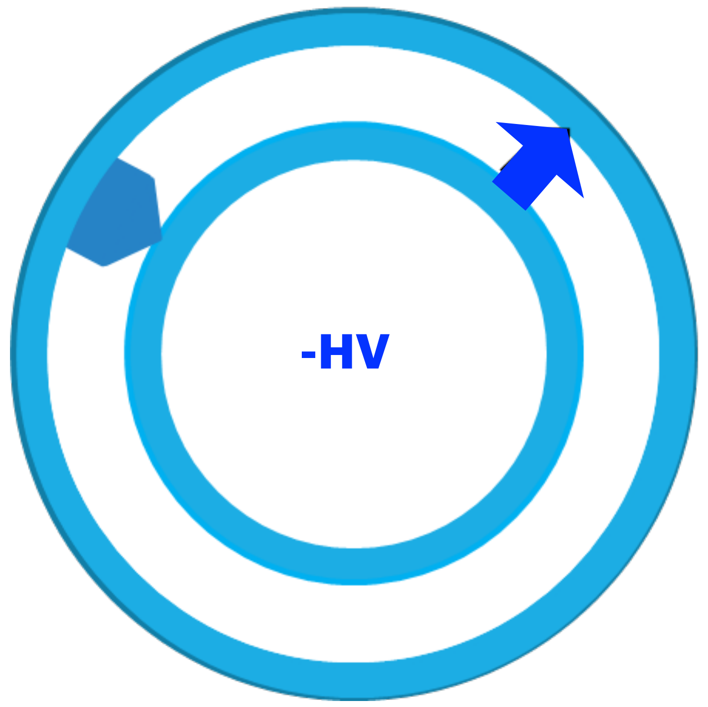
Positive polarity: avalanche from outer electrode (r=3mm) to inner (r=2mm)





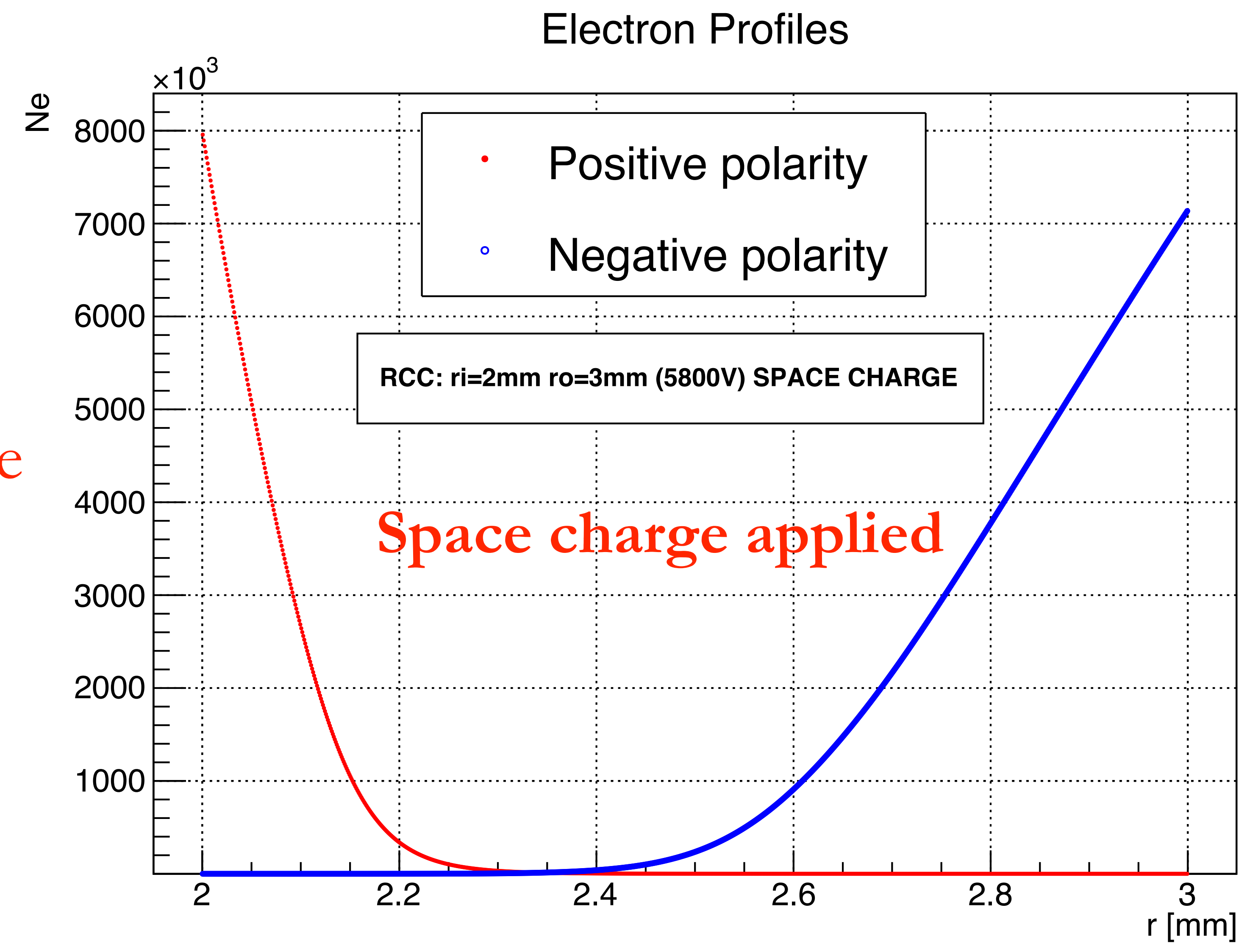


Negative polarity: avalanche from inner electrode (r=2mm) to outer (r=3mm)



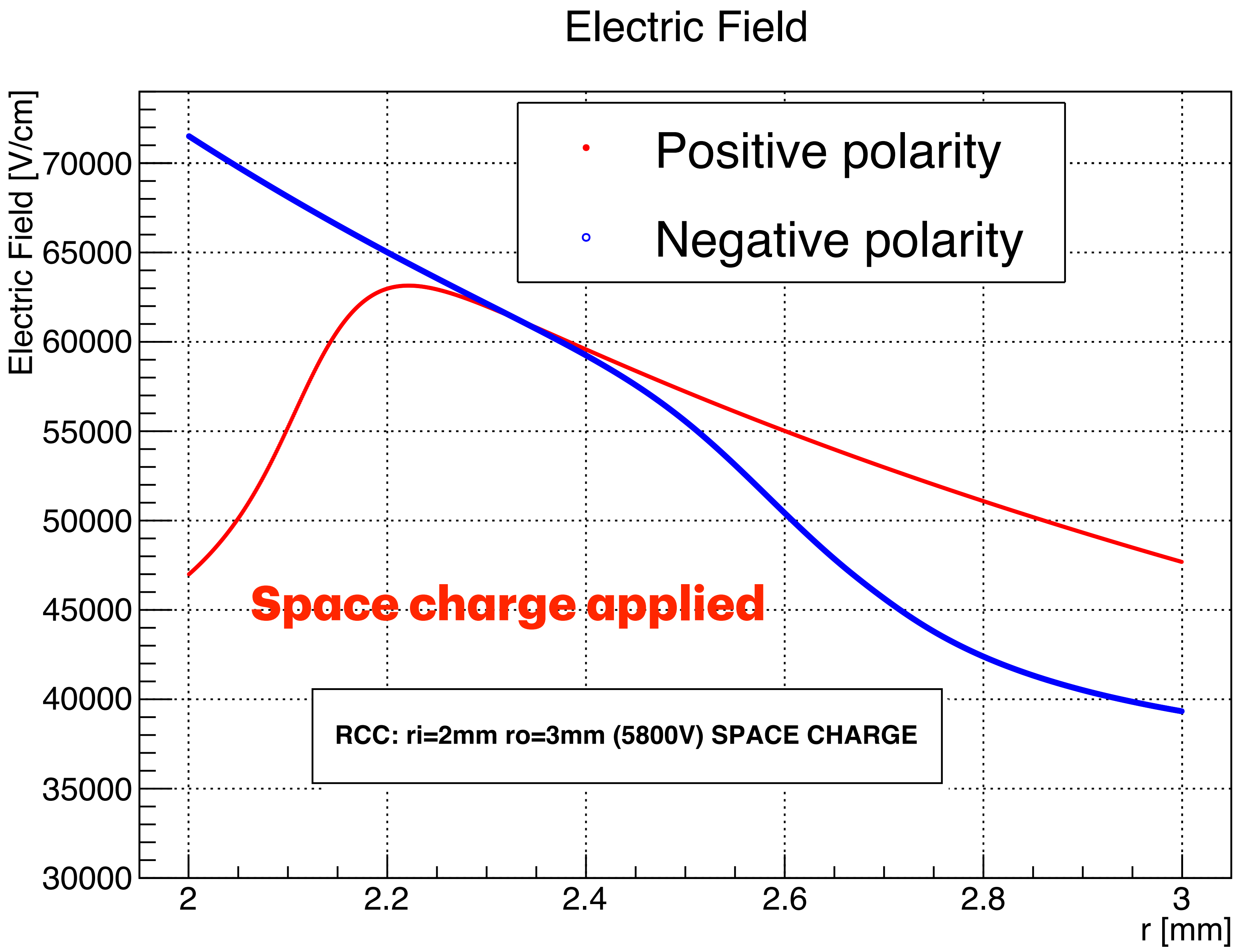
Avalanche evolution for RCC (SC)

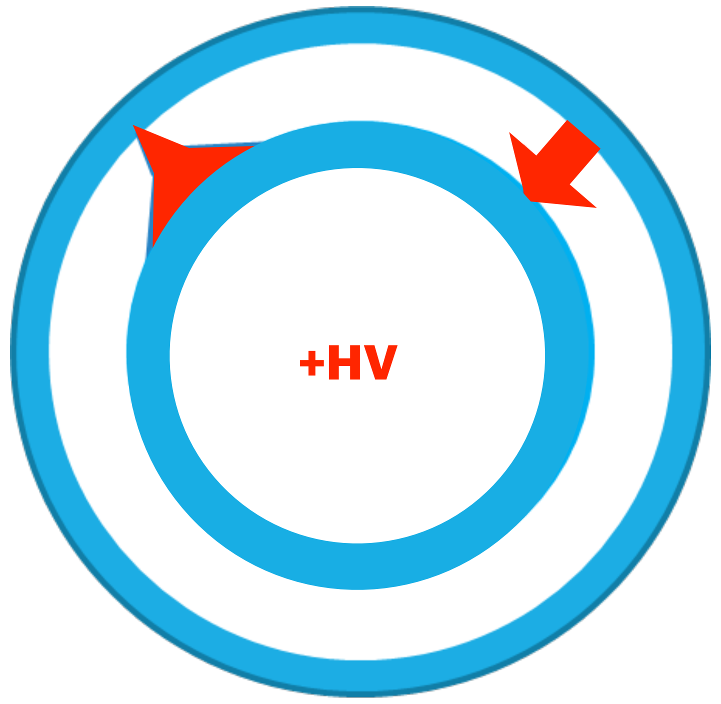
RCC example: $r_i = 2$ mm $r_o = 3$ mm

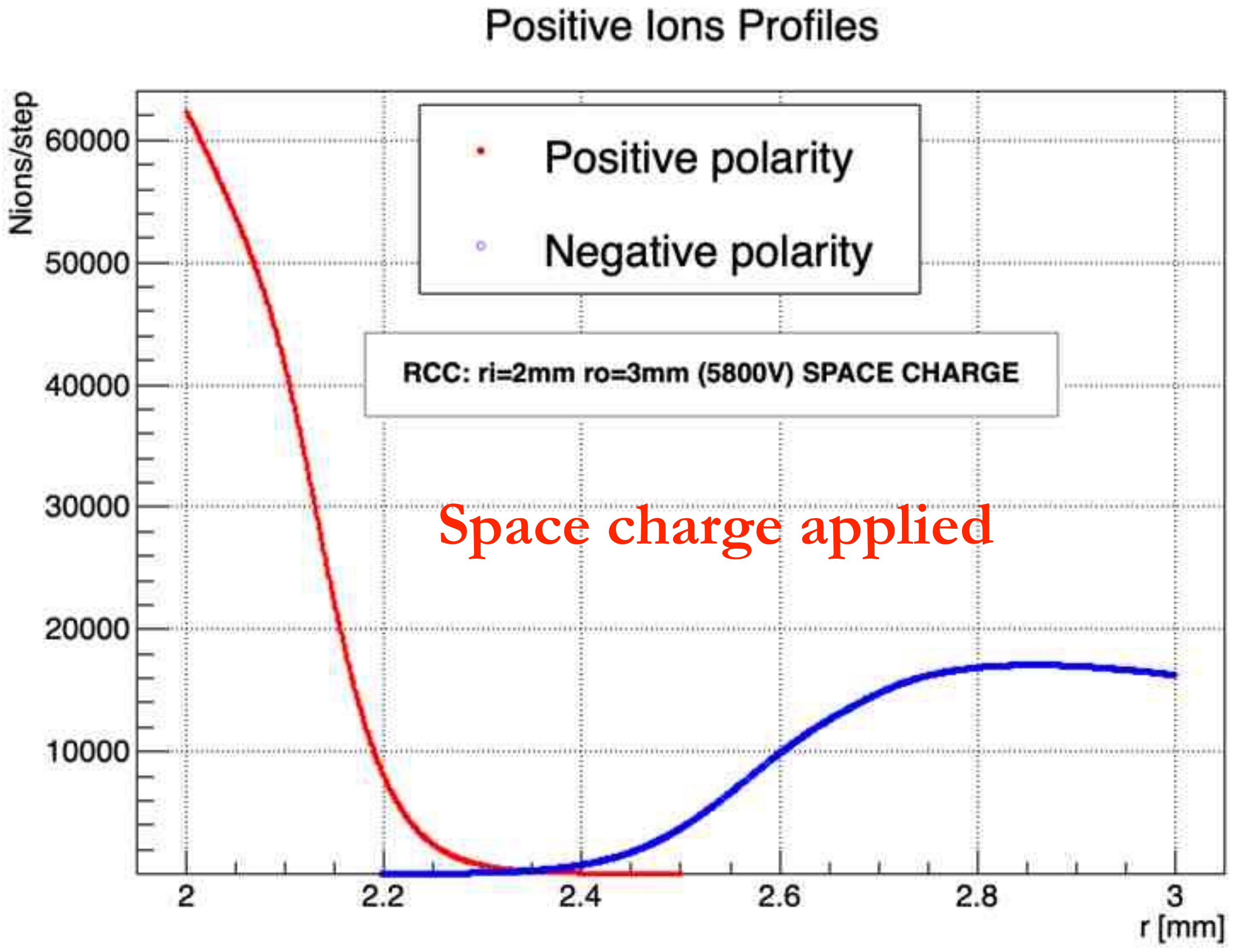


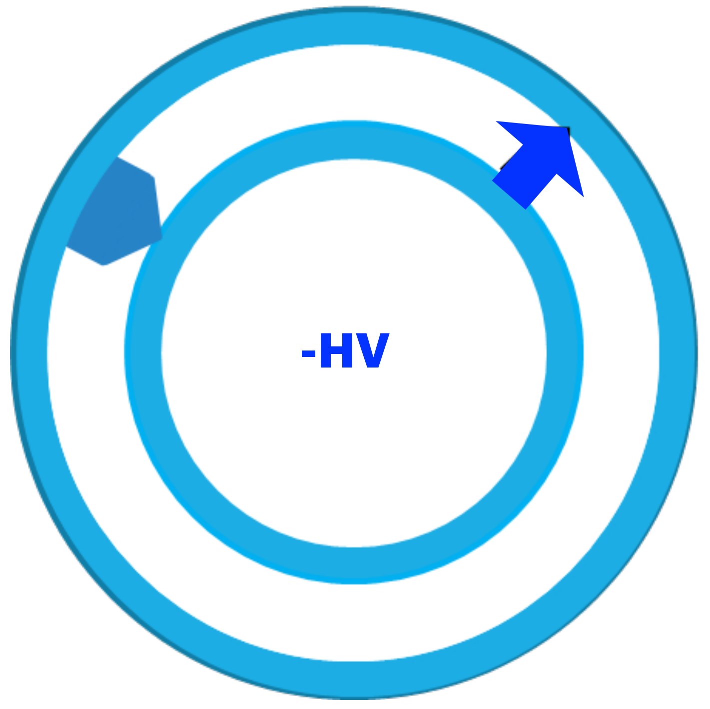
Positive polarity: avalanche from outer electrode (r=3mm) to inner (r=2mm)

Negative polarity: avalanche from inner electrode (r=2mm) to outer (r=3mm)









Induced charge

$$i(t) = q\,\mathbf{v}(t)\cdot\mathbf{E}_w(\mathbf{r}(t)), \quad \Rightarrow \quad Q_{\text{ind}} = q\int_{\mathscr{C}} n(\mathbf{r})\,\mathbf{E}_w(\mathbf{r})\cdot d\mathbf{r}\,.$$

Electrode thickness d

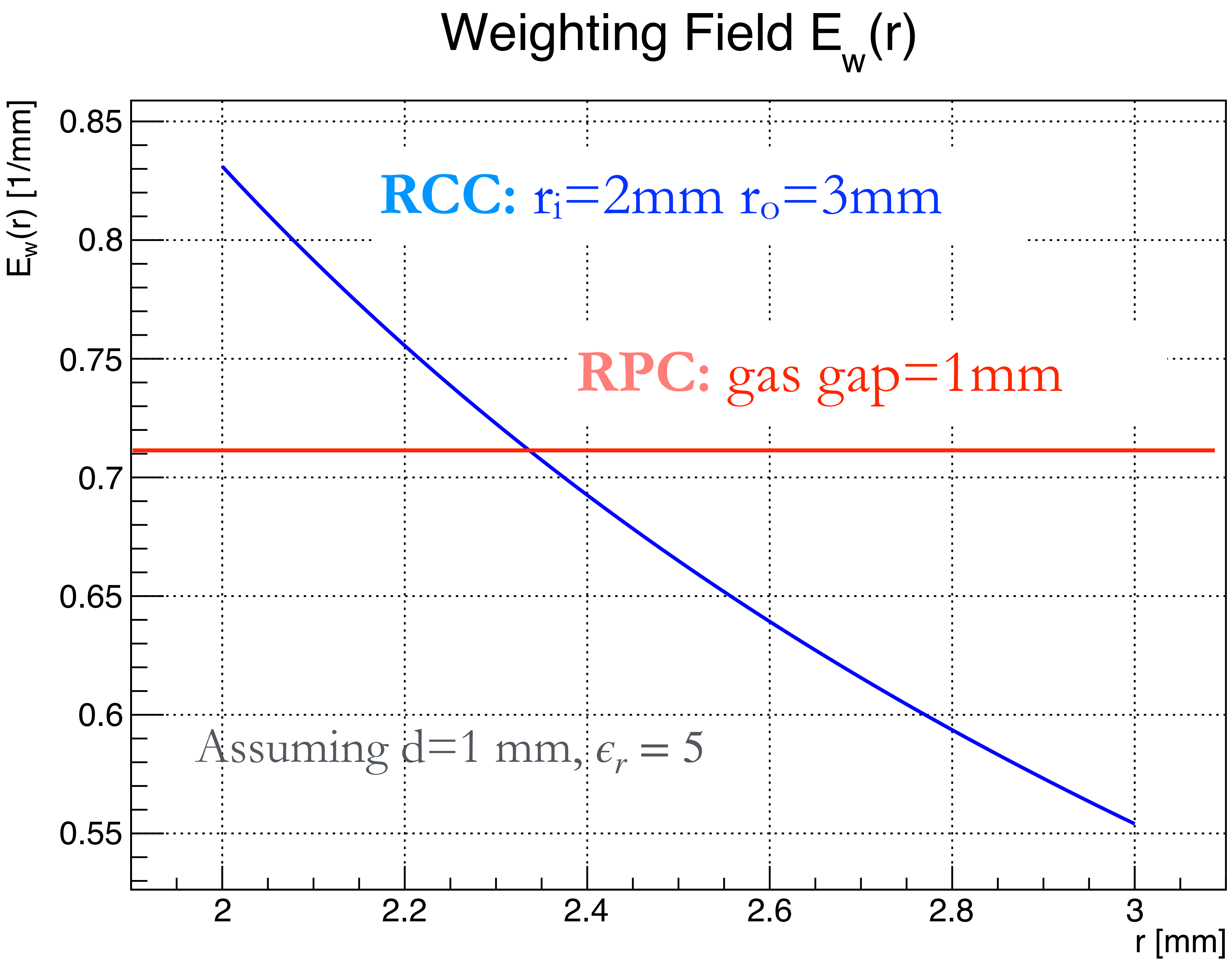
Gas gap g

Planar Geometry: **RPC**

$$E_w = \frac{1}{g + 2d/\epsilon_r}\,.$$

Cylindrical Geometry: **RCC**

$$E_w(r) = \frac{1}{r\left\{\ln\frac{r_o}{r_i} + \frac{1}{\epsilon_r}\left[\ln\frac{r_i}{r_i - d} - \ln\frac{r_o}{r_o + d}\right]\right\}}\,.$$

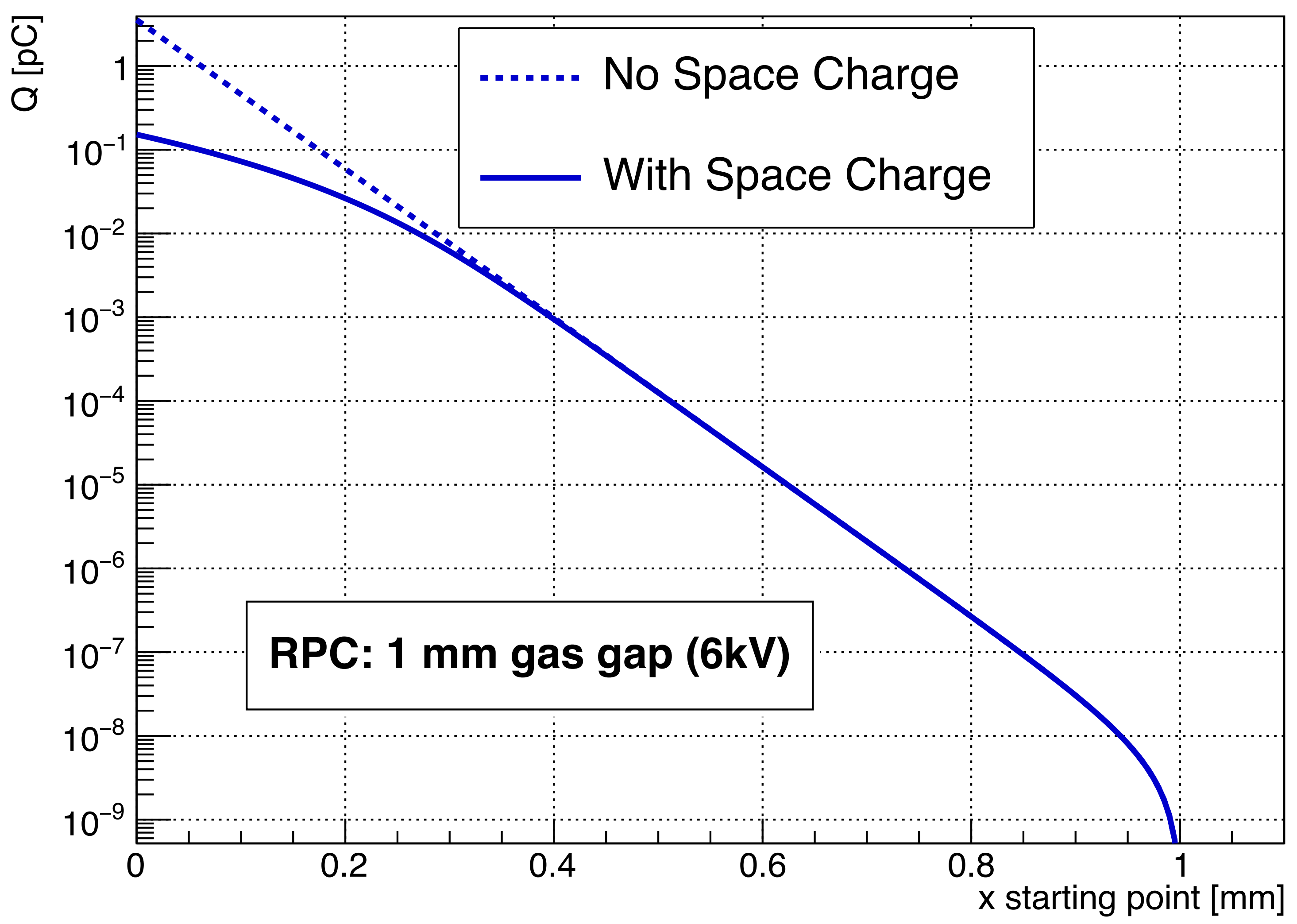


Induced charge: Comparison RPC vs RCC (1 mm gas gap)

$$i(t) = q\,\mathbf{v}(t)\cdot\mathbf{E}_w(\mathbf{r}(t)), \quad \Rightarrow \quad Q_{\text{ind}} = q\int_{\mathscr{C}} n(\mathbf{r})\,\mathbf{E}_w(\mathbf{r})\cdot d\mathbf{r}\,.$$

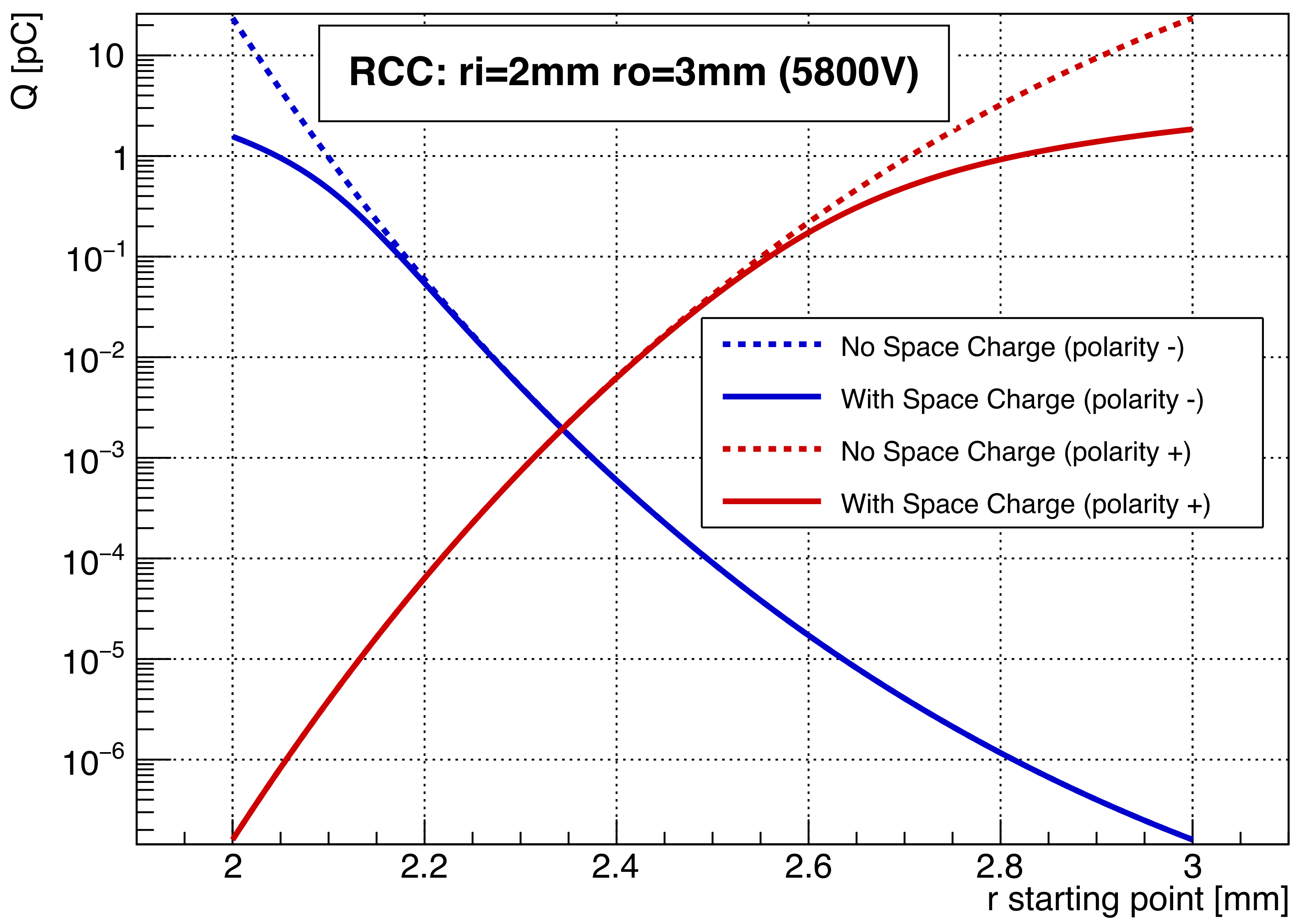
RPC: 1mm (6kV)

Induced charge vs avalanche starting point

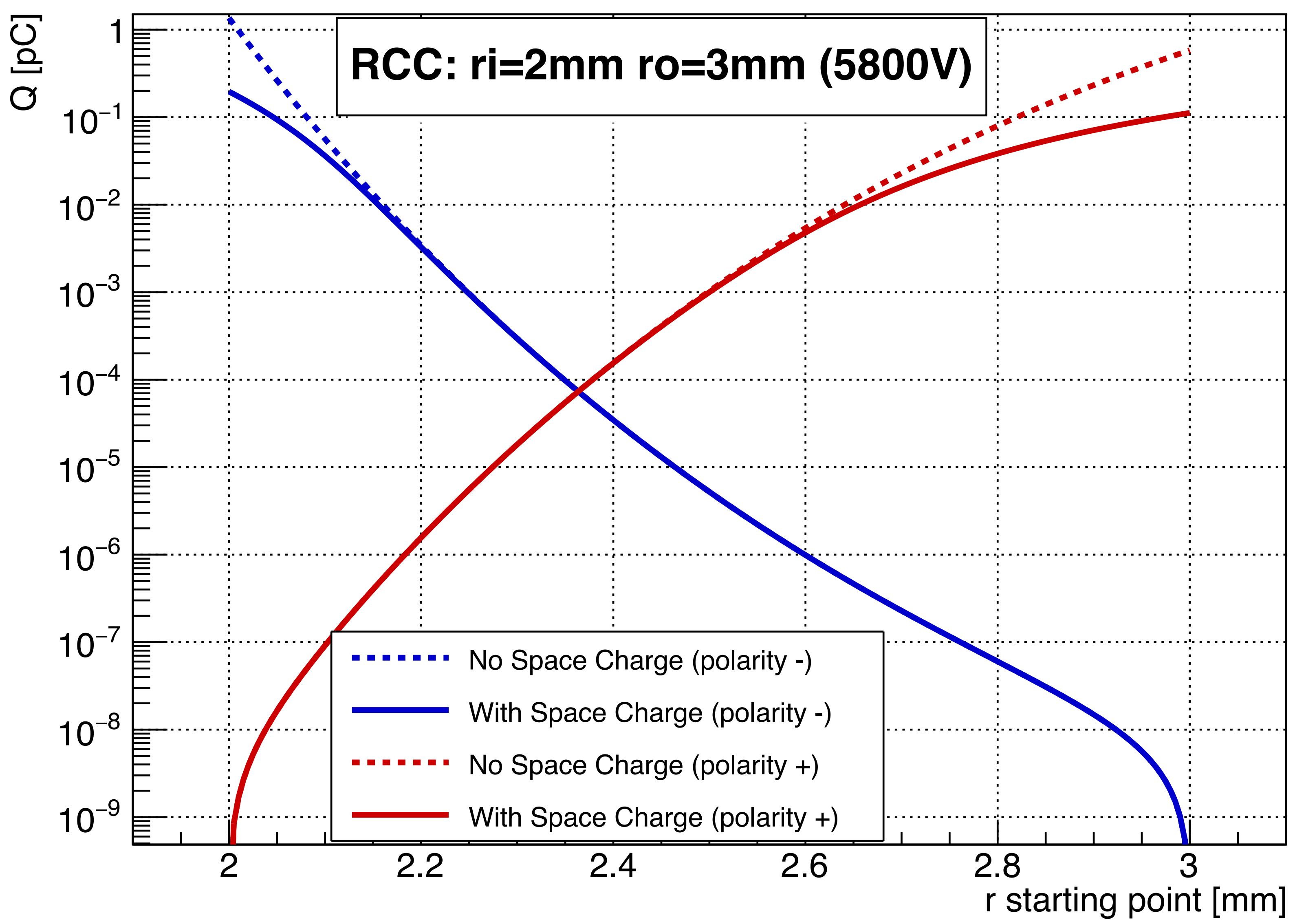


RCC: ri=2mm ro=3mm (5.8kV)

Total charge vs avalanche starting point



Induced charge vs avalanche starting point



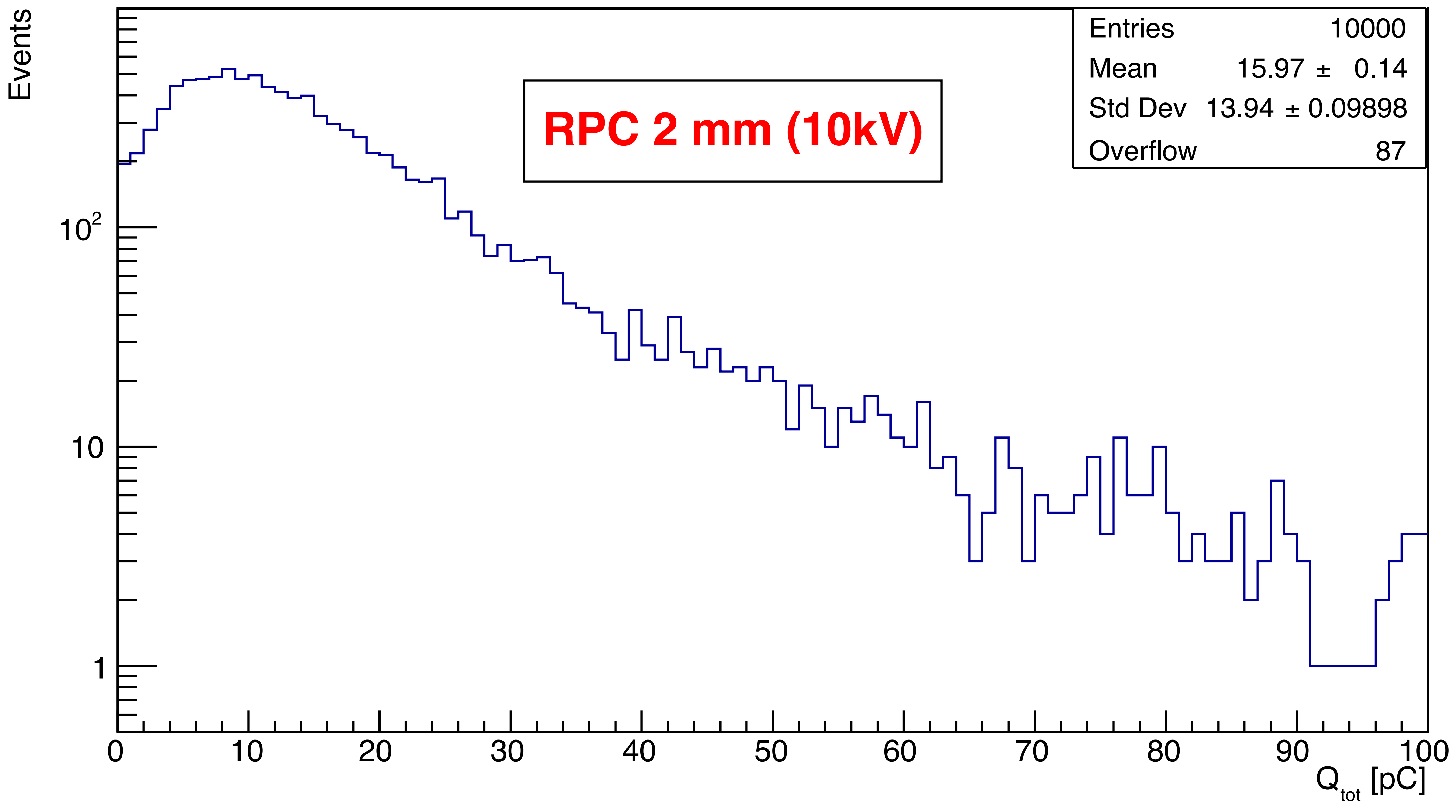
Full simulation: RPC 2mm

Putting all the ingredients together: For a particle crossing the gas gap

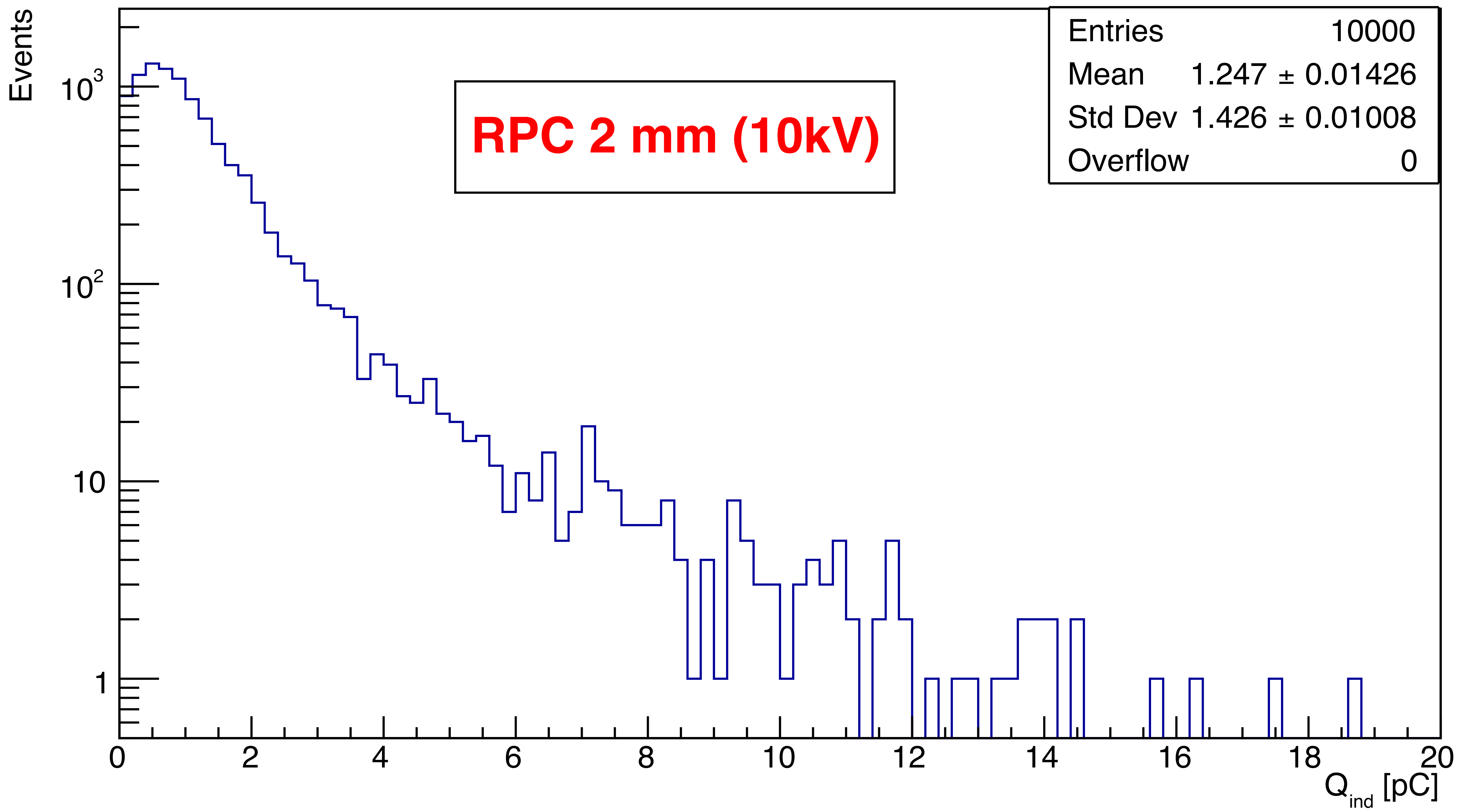
- Generate number of primary clusters $<N_p> = 7.3\ mm^{-1}$ for STD gas mix
- Generate number of secondary electrons for each primary cluster according to distribution in slide 8
- For each electron evaluate Q_{Tot} and $Q_{Induced}$ .. and sum.

$$Q_{\text{tot}}^{(\text{event})} = \sum_{c=1}^{N_c} \sum_{k=1}^{n_e^{(c)}} Q_{\text{tot}}^{(c,k)}, \qquad Q_{\text{ind}}^{(\text{event})} = \sum_{c=1}^{N_c} \sum_{k=1}^{n_e^{(c)}} Q_{\text{ind}}^{(c,k)},$$

Total charge (all events)



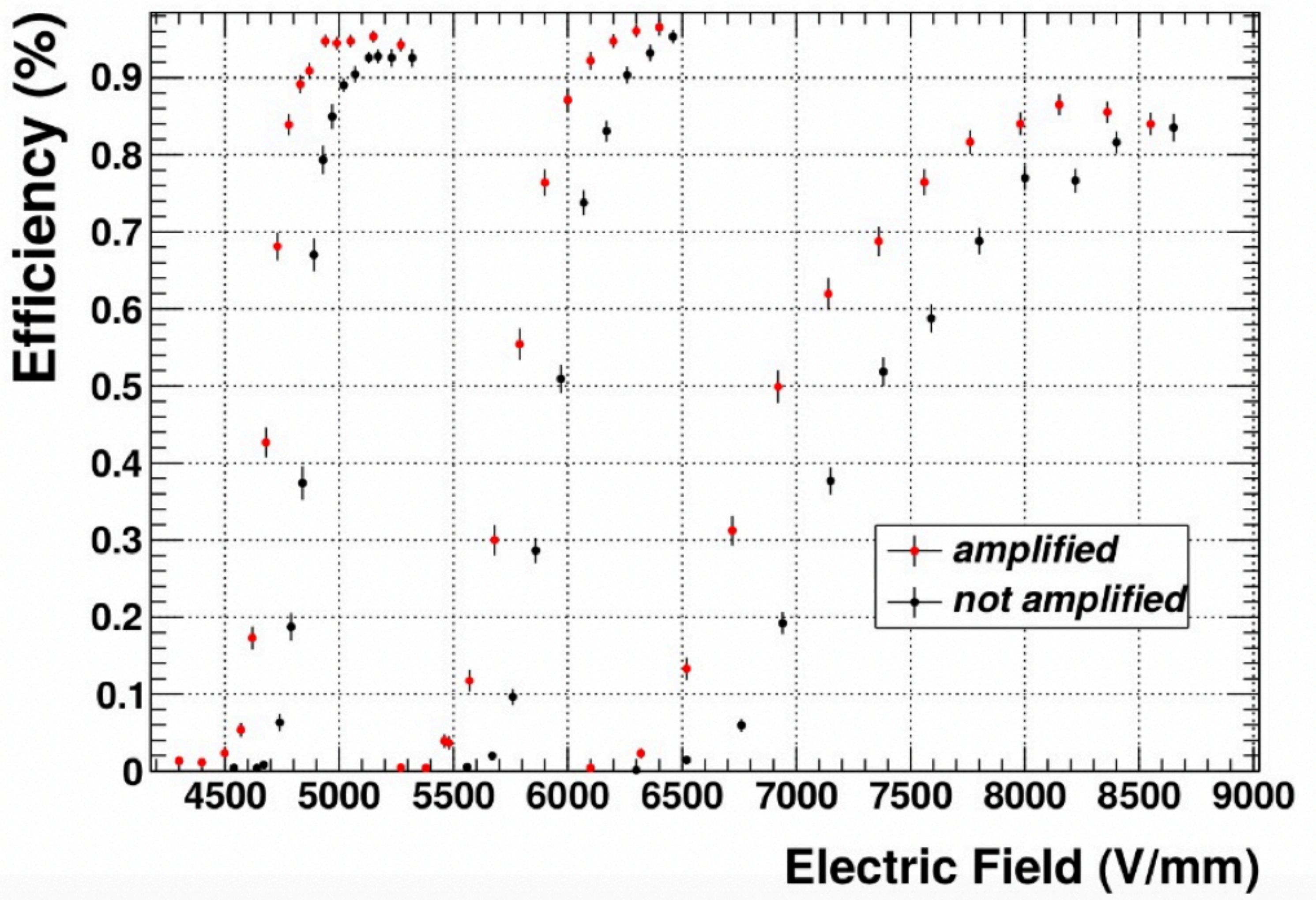
Induced charge (all events)

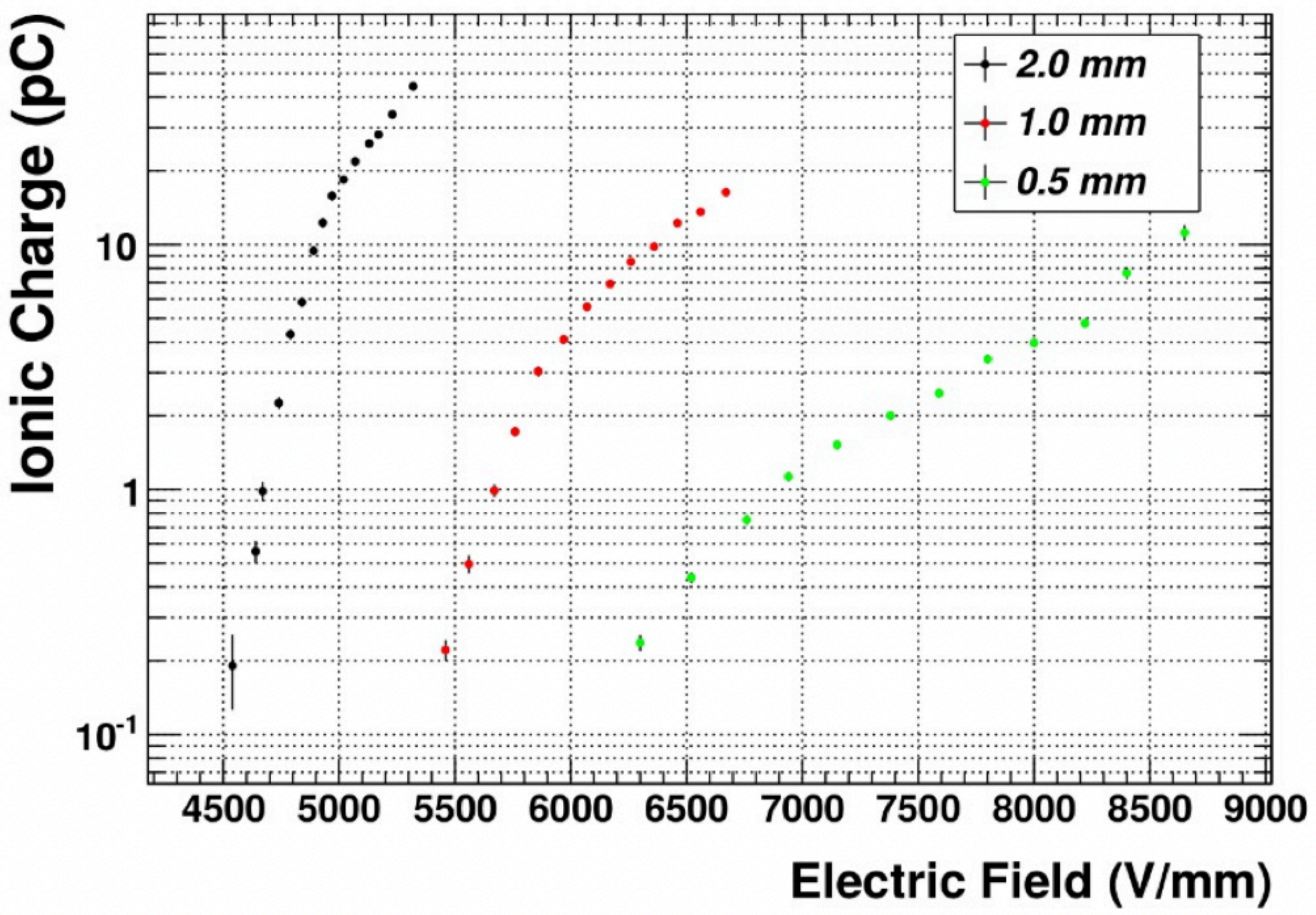


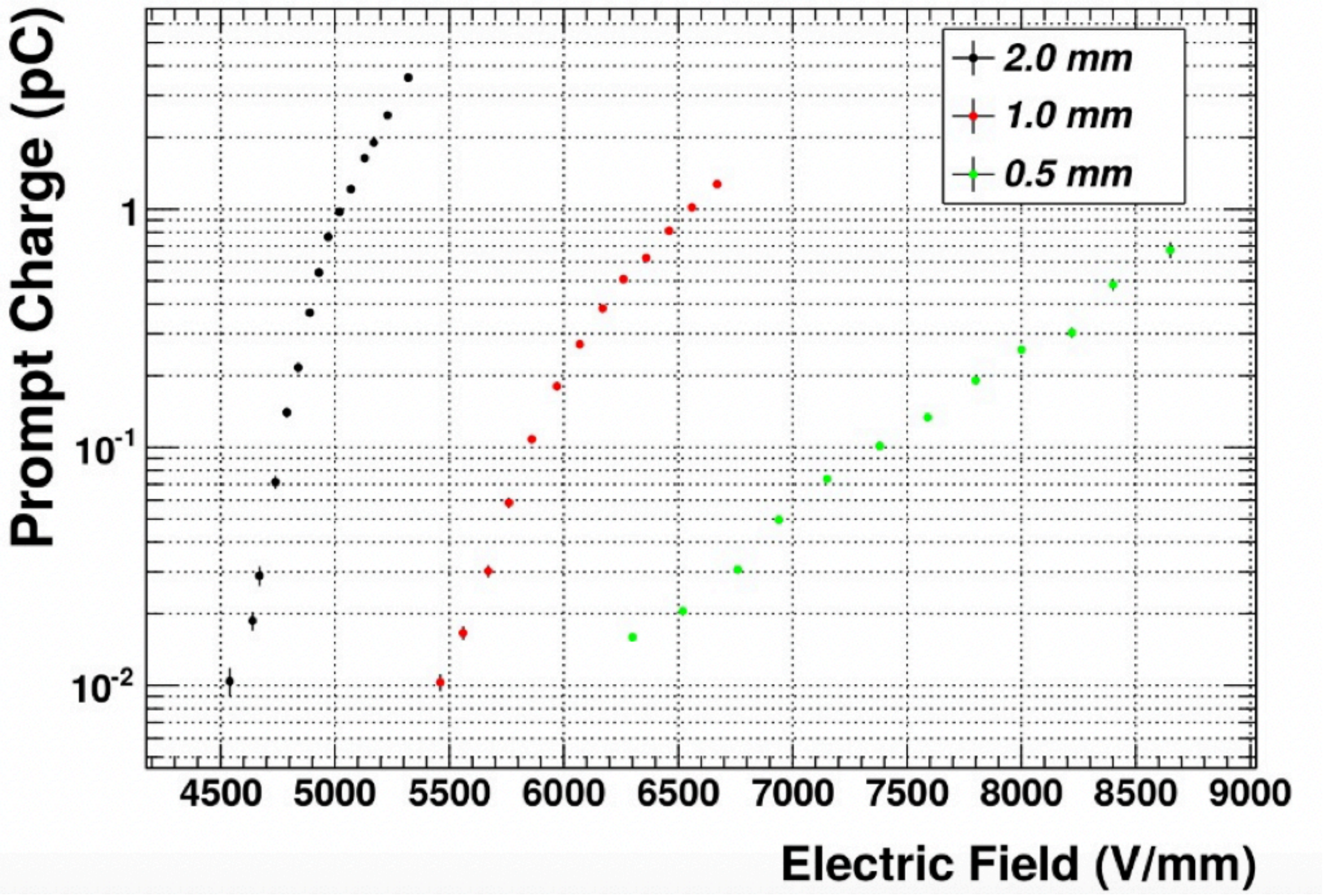
Comparison with experimental data: RPC

R. Santonico, B. Liberti, et al. "Improving rate capability of rpcs." arXiv:1606.03448, 2016.

Experimental data

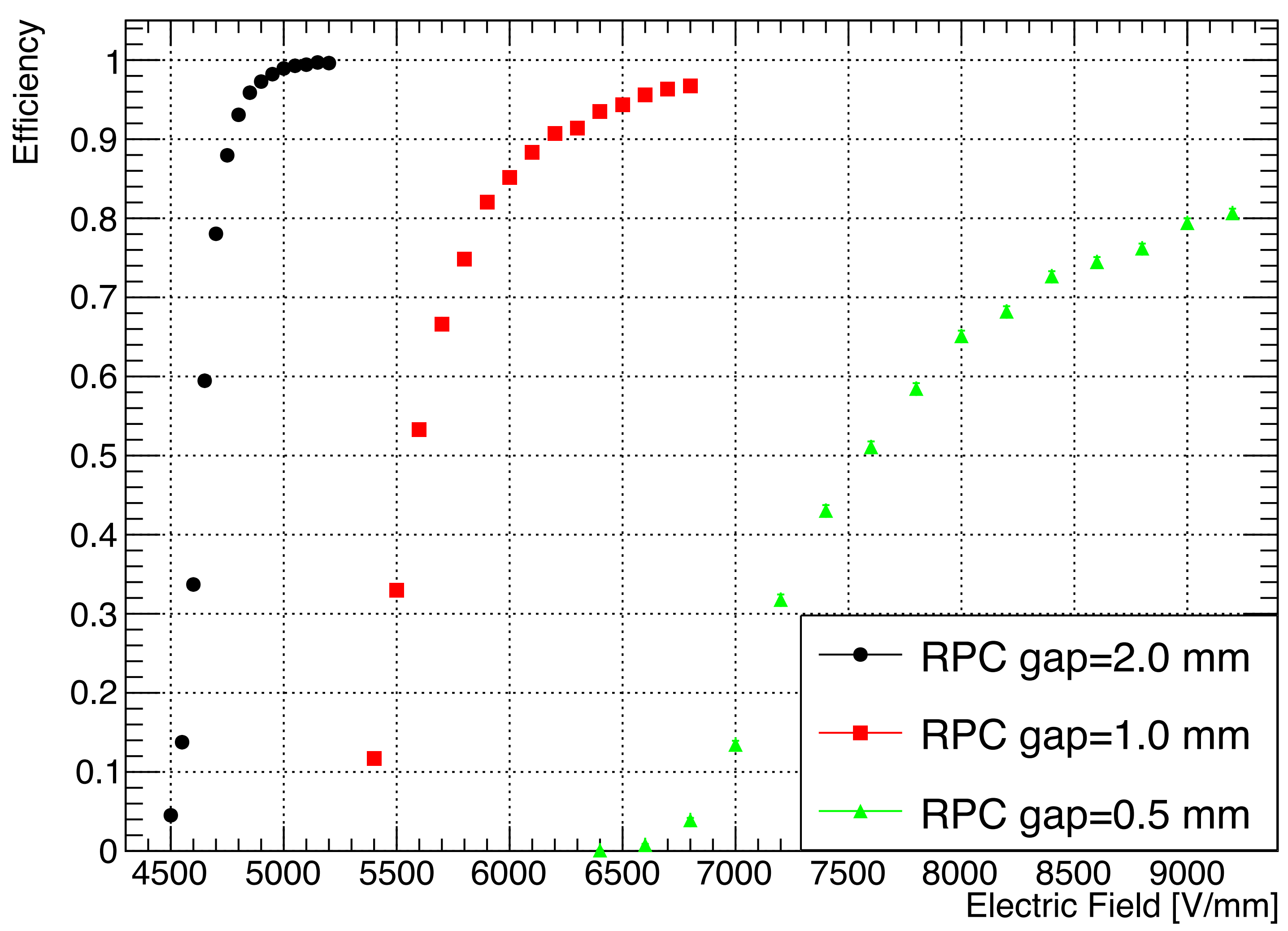


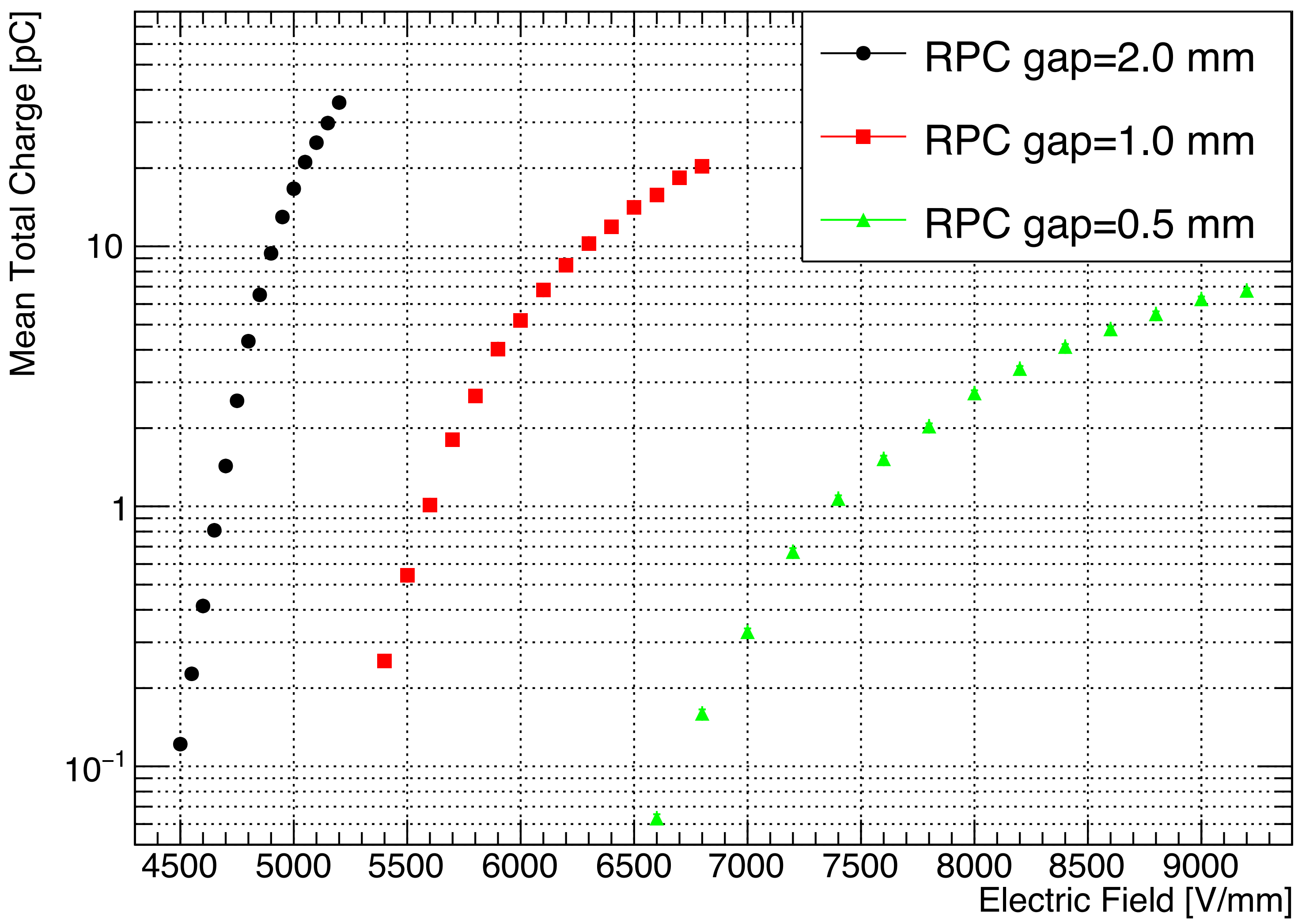


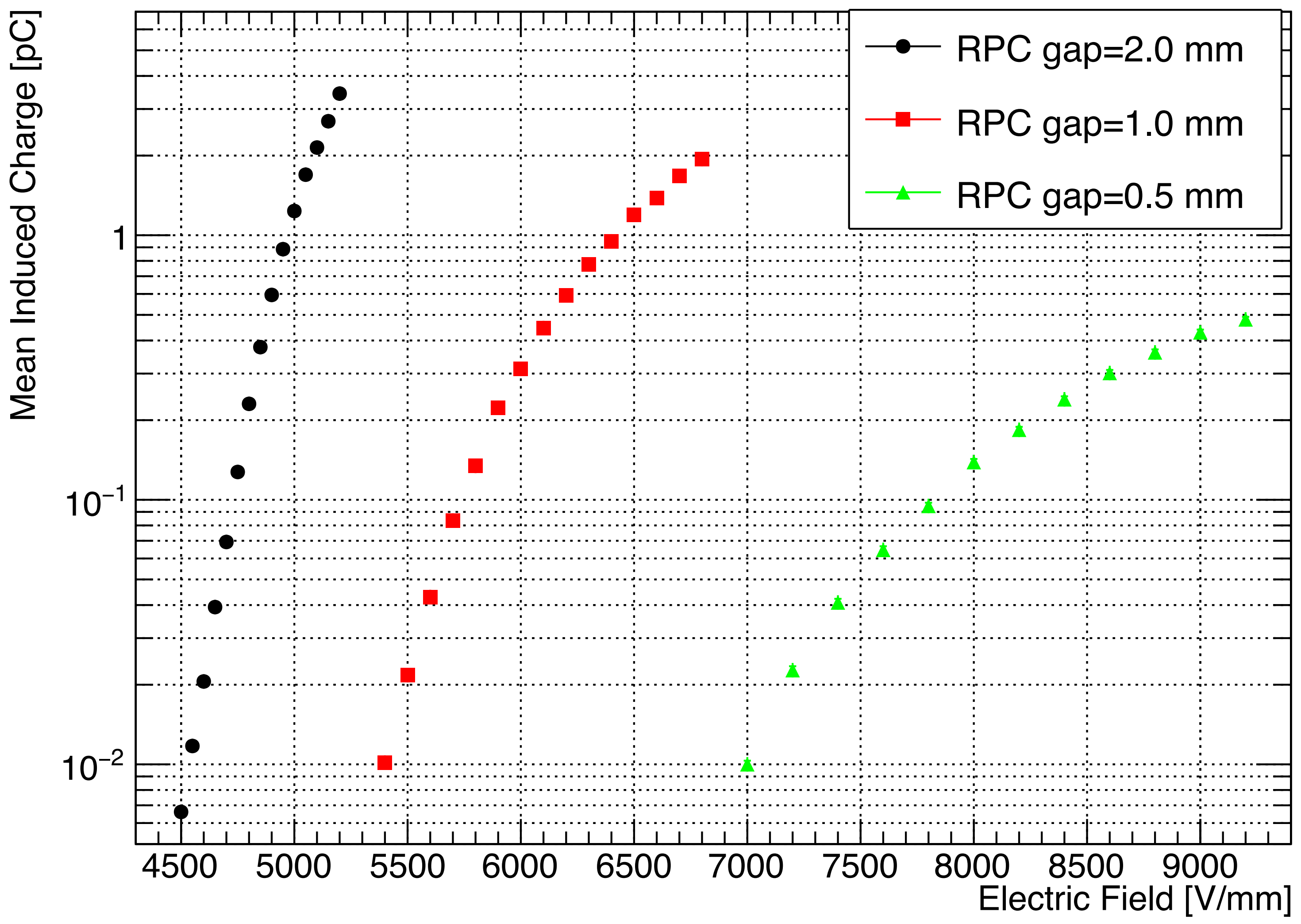


Electronic threshold for amplified signal: **20 fC**

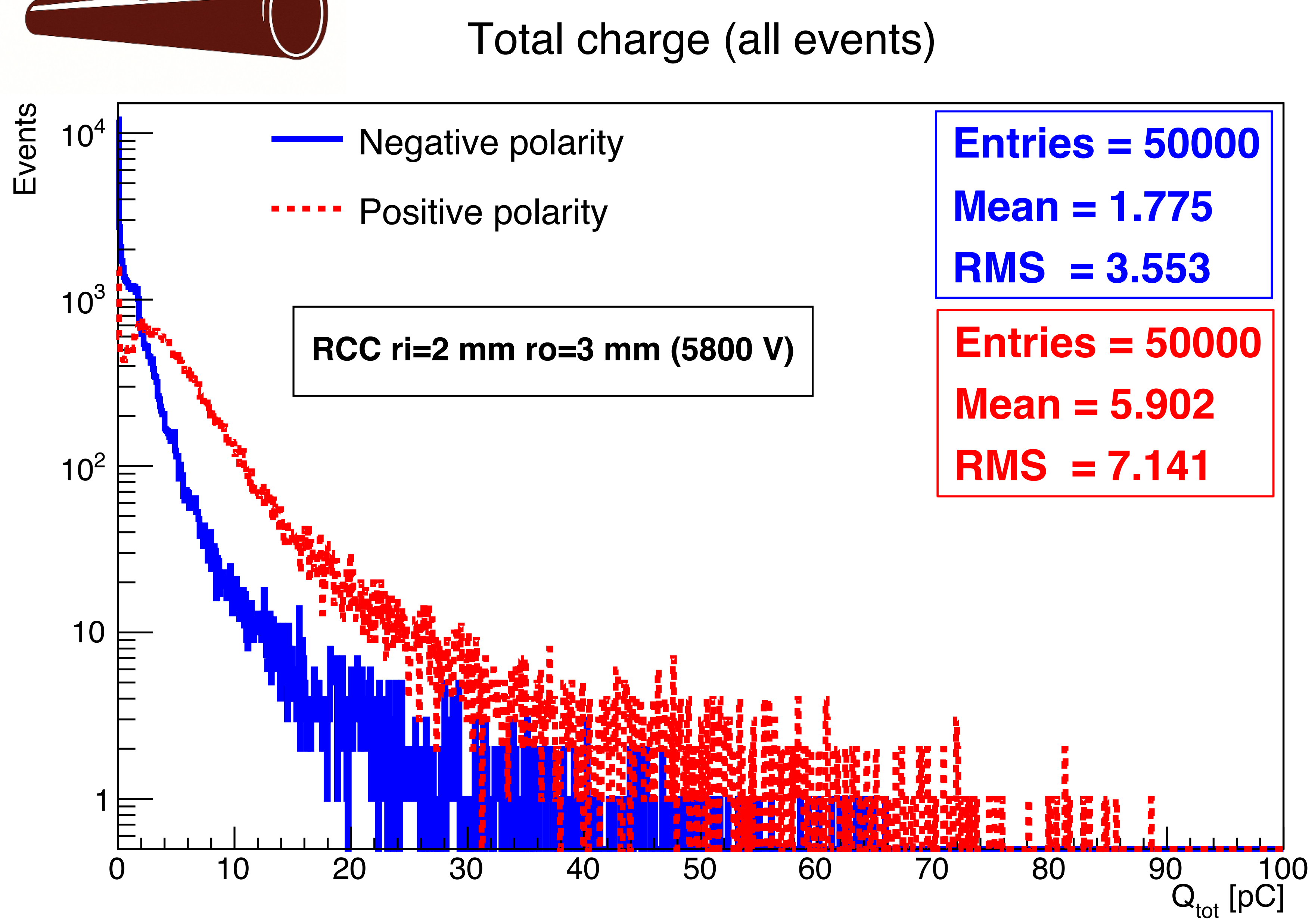
Simulation

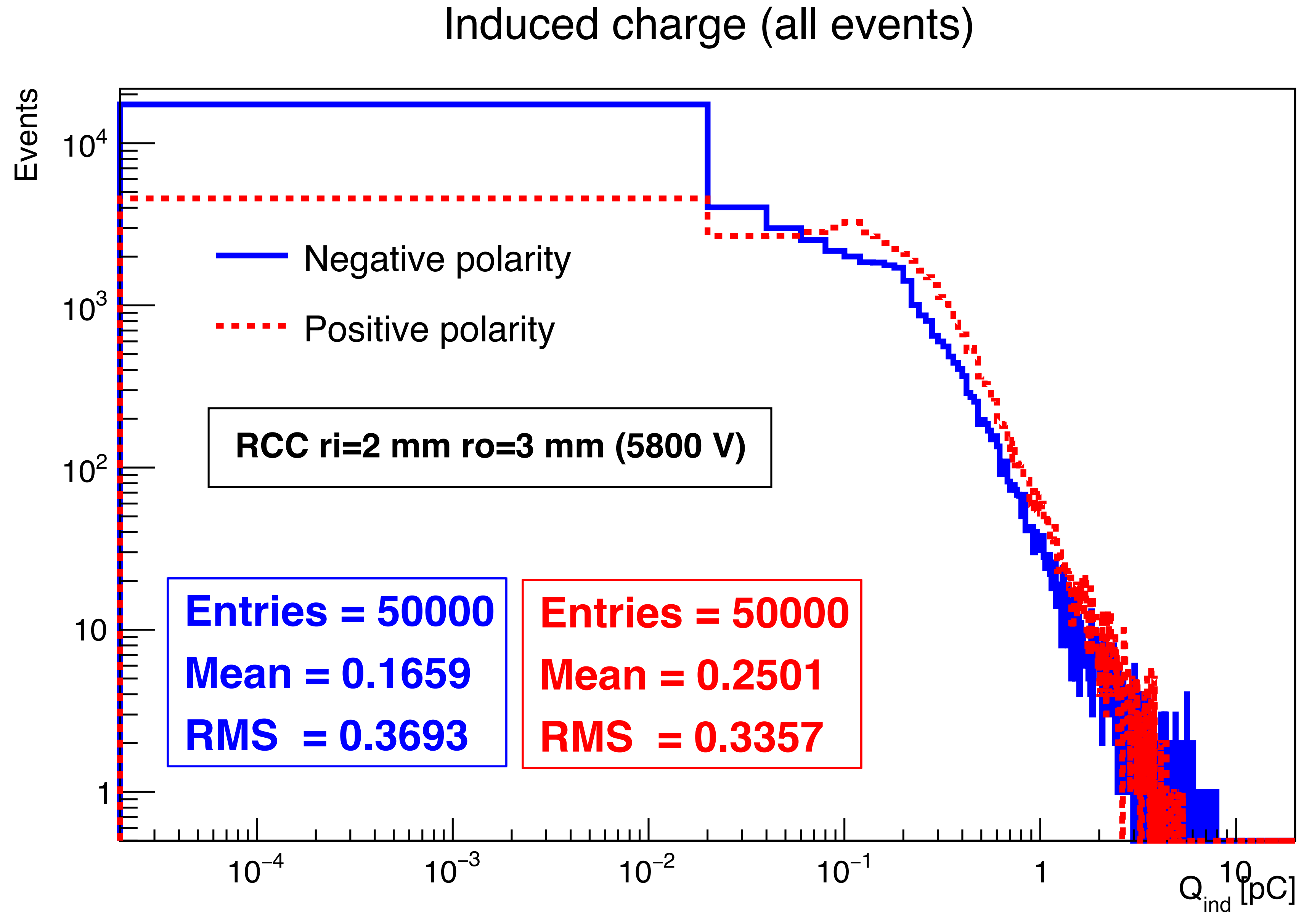




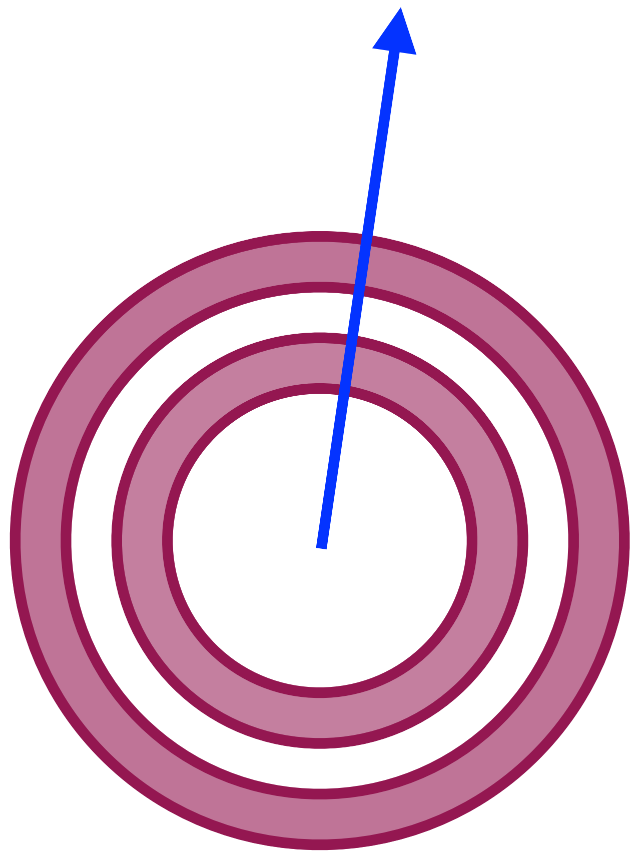


Full simulation: RCC 3-2 mm

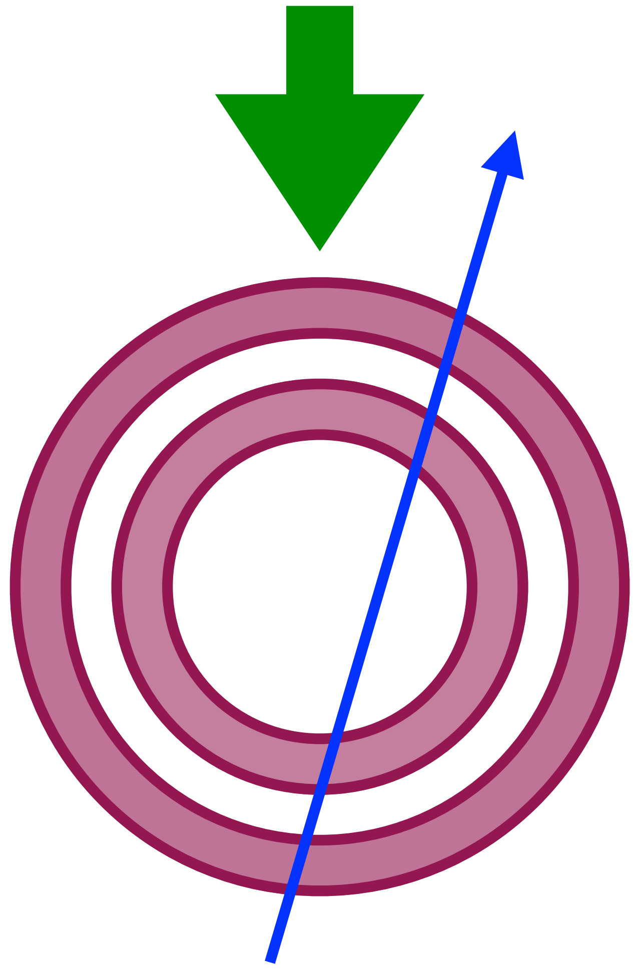




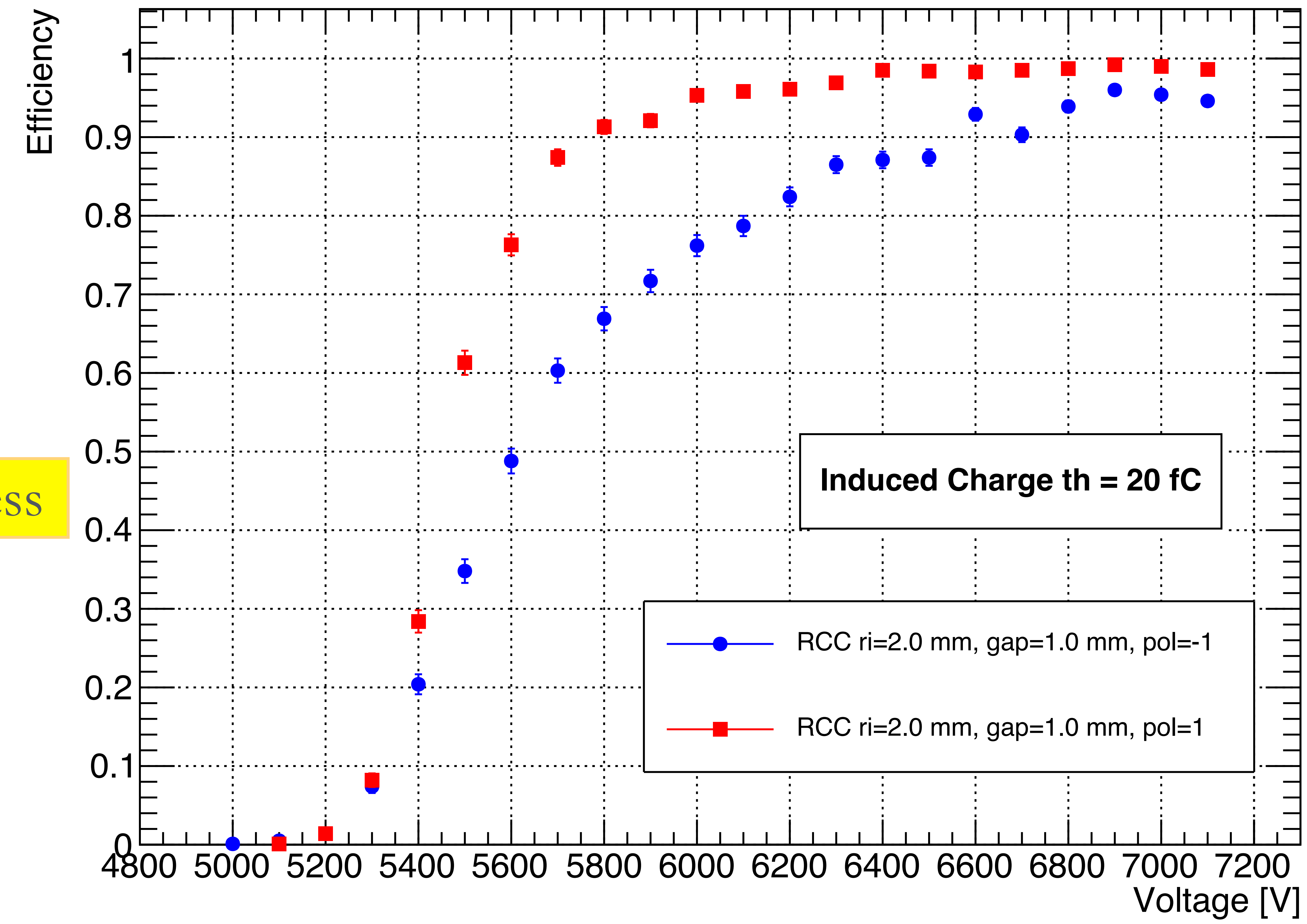
Results shown for tracks starting from center



Extension in progress



Polarity dependence reproduced by simulation



For a complete comparison to experimental data the code has to be extended for 3D simulation

Conclusions

- The **TANGO_RD** project is a new INFN project with the plan to fully characterize the RCC detector (with special emphasis to the exploration of ecological gas mixture and innovative electrode materials);

- One of the pillar of the project is the development of simulation tools to guide the RCC experimental line;

- A **standalone simulation program** is under development and preliminary results have been presented:

  - The tool is fast, flexible and although based on a simplified approach to the avalanche development, it **reproduces quite well the RPC performance.** (To be upgraded to take into account the inter-dependence among avalanches, and still to understand the issue related to α_{eff});

  - **First highlights on the characteristics of the RCC** device have been explored. The simulation reproduce the polarity dependence in the correct direction with respect to experimental results;

  - New features (Avalanche fluctuations, 3D model of tracks, .. and others) and comparison with experimental data in progress;

  - The tool will guide the experimental program of the TANGO_RD project.