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INFN
Istituto Nazionale di Fisica Nucleare

A Standalone Simulation Framework for the Physical Modeling of Resistive Plate Chambers (RPCs) and Resistive Cylindrical Chambers (RCCs)

D. Piccolo (LNF INFN) for the TANGO_RD project

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- ***LNF:*** D. Piccolo, S. Bianco, A. Paoloni, S. Meola, A. Rocchi, G. Saviano*, C. Vendittozzi*, S. Colafranceschi**
- ***Bari:*** A. Pastore, M. Abbrescia, M. De Serio

* University of materials engineering La Sapienza (RM) ** also James Madison University (JMU)

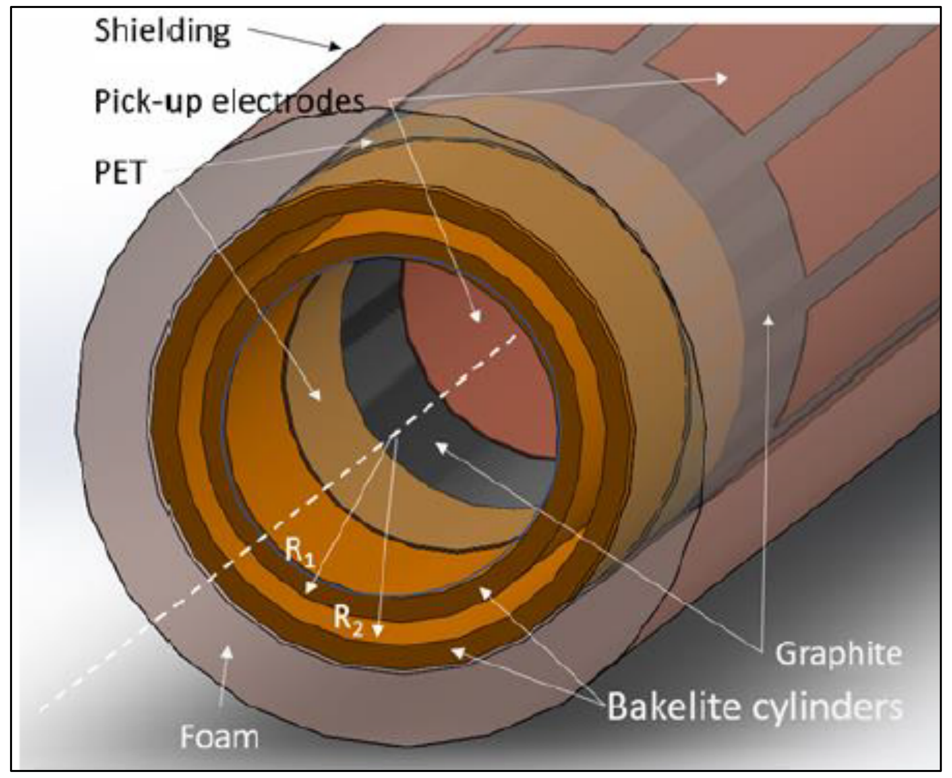
Resistive Cylindrical Chamber: RCC

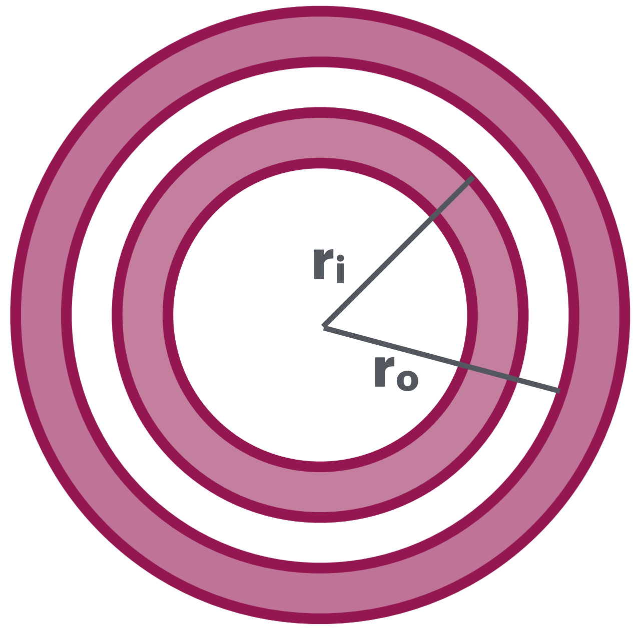
The RCC detector is a new gaseous detector introduced by **R. Cardarelli** in 2021:

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

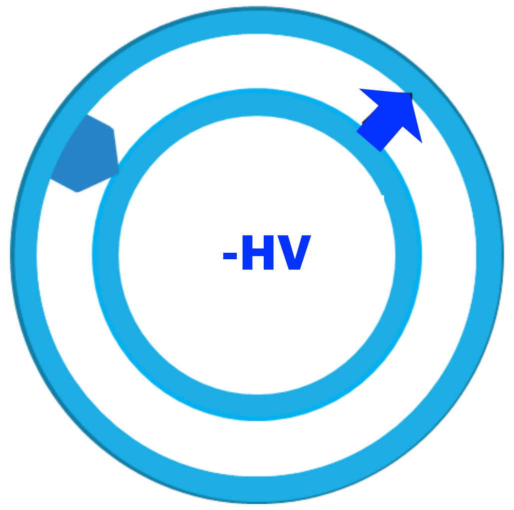
https://doi.org/10.1016/j.nima.2023.168822





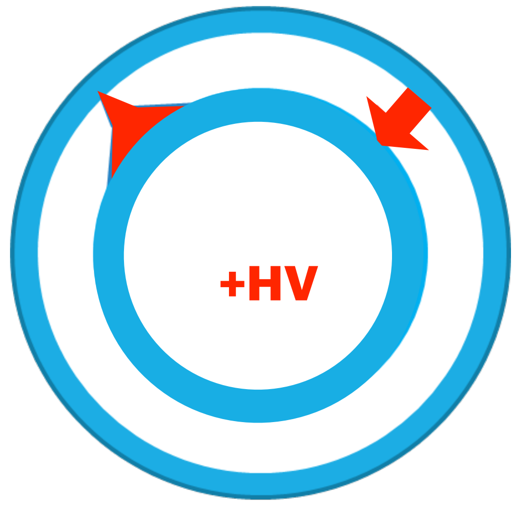
$$E(r) = \frac{V}{r \cdot ln\frac{r_o}{r_i}}$$

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



Multiplication followed by drift

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



Drift followed by multiplication

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]

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TANGO_RD: New INFN project started in 2026 to characterize RCC detectors: *see talk on Thursday*

BUT

Still Lack of simulation program for the new geometry

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RPCs simulation

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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.

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

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 (similar to Lippmann-Riegler approach);
- **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

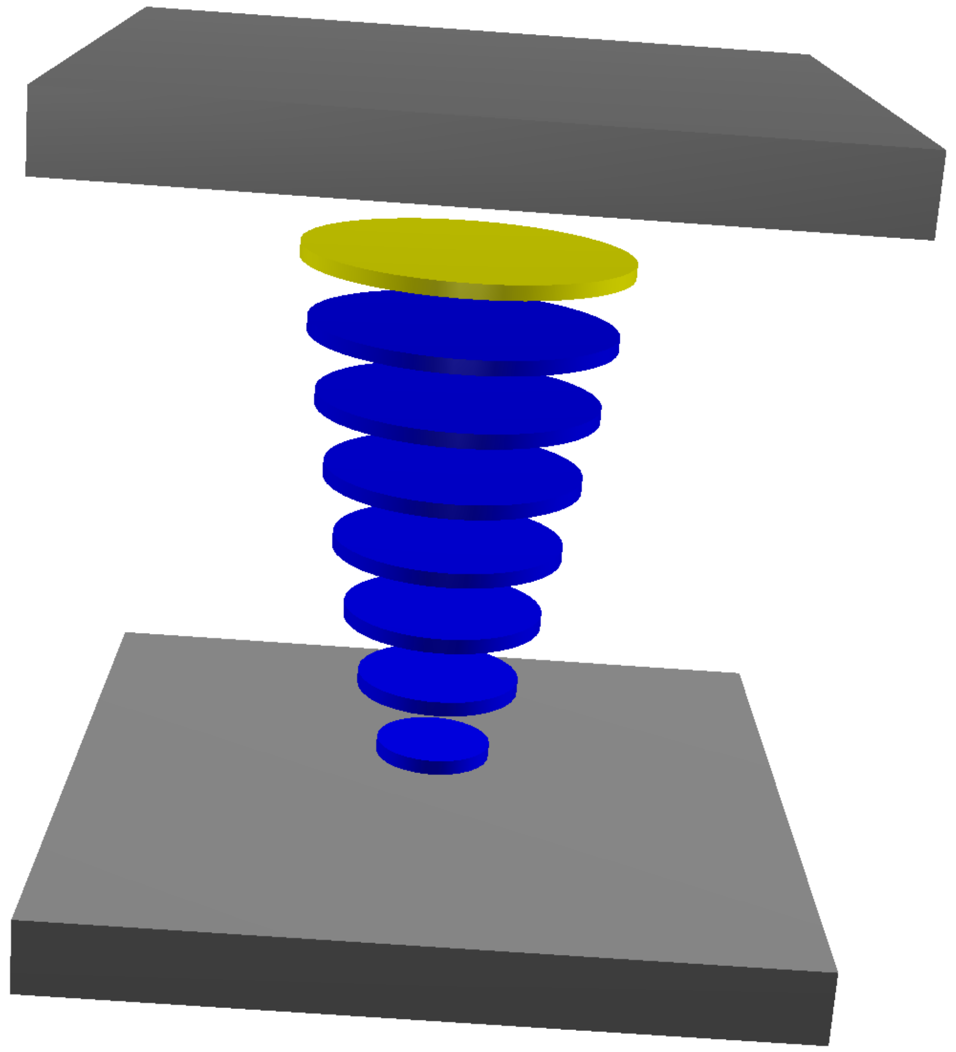
The gas gap is divided in n steps (100-1000) and for each step the electric field is considered constant: On each step evaluate n(x).

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

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

Where D_T is Transverse diffusion coefficient, and λ is an external parameter to be tuned (=2 for this talk)

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)



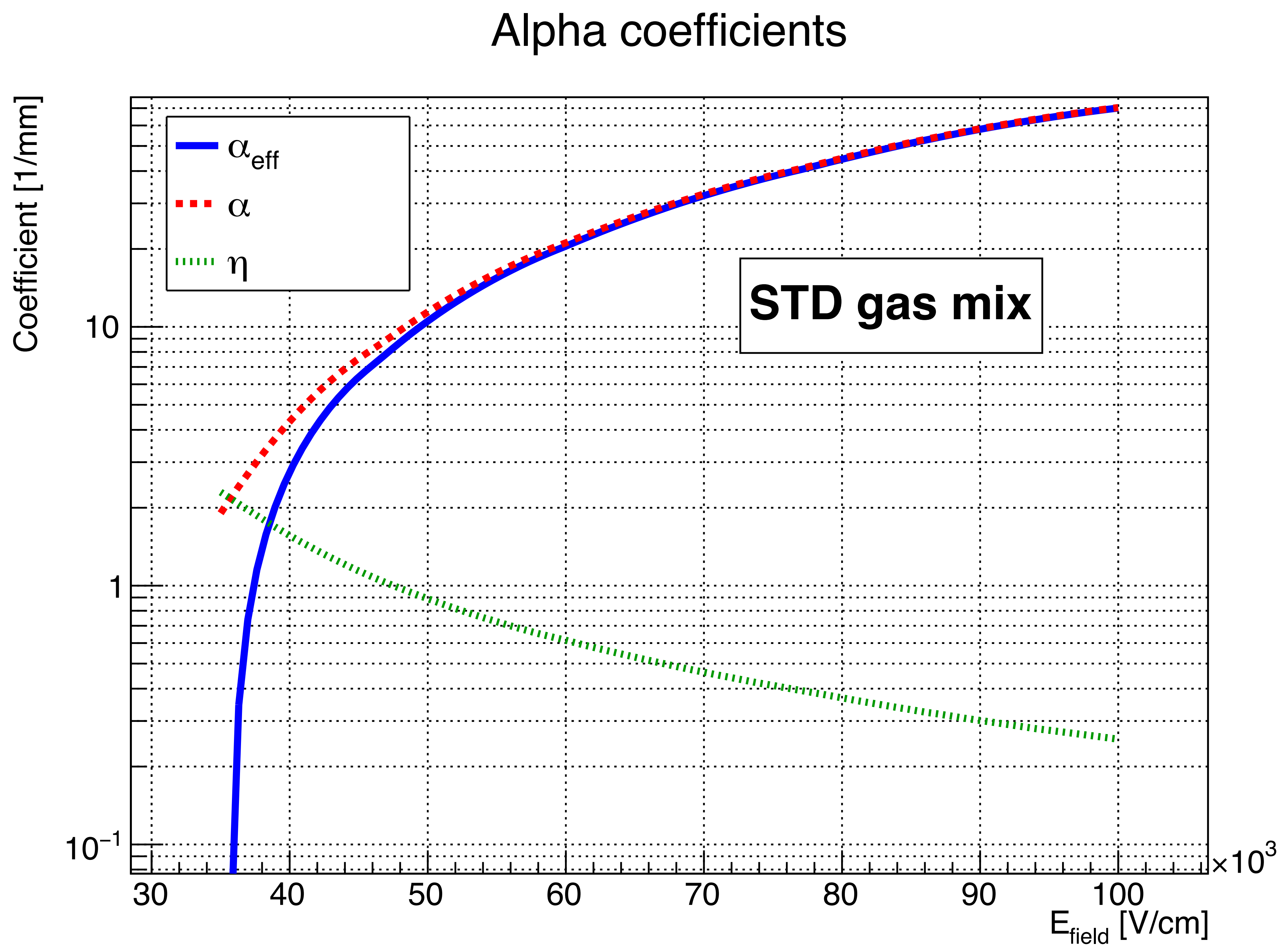
$$E(s) = \frac{\sigma}{2\epsilon_0}\left(1 - \frac{s}{\sqrt{s^2 + a^2}}\right),$$

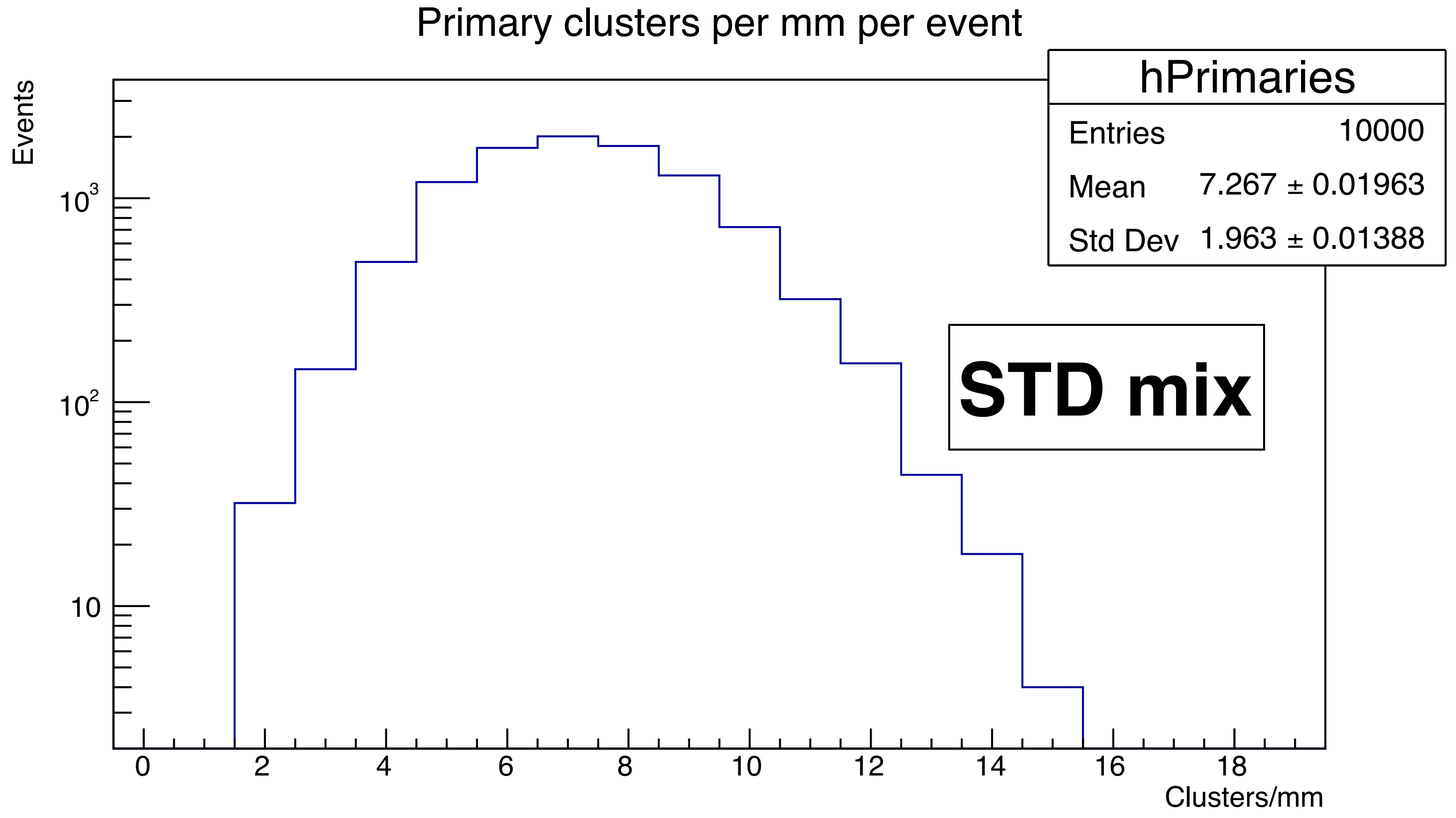
Electric field evaluated on the axis due to a uniformly charged disk at distance s

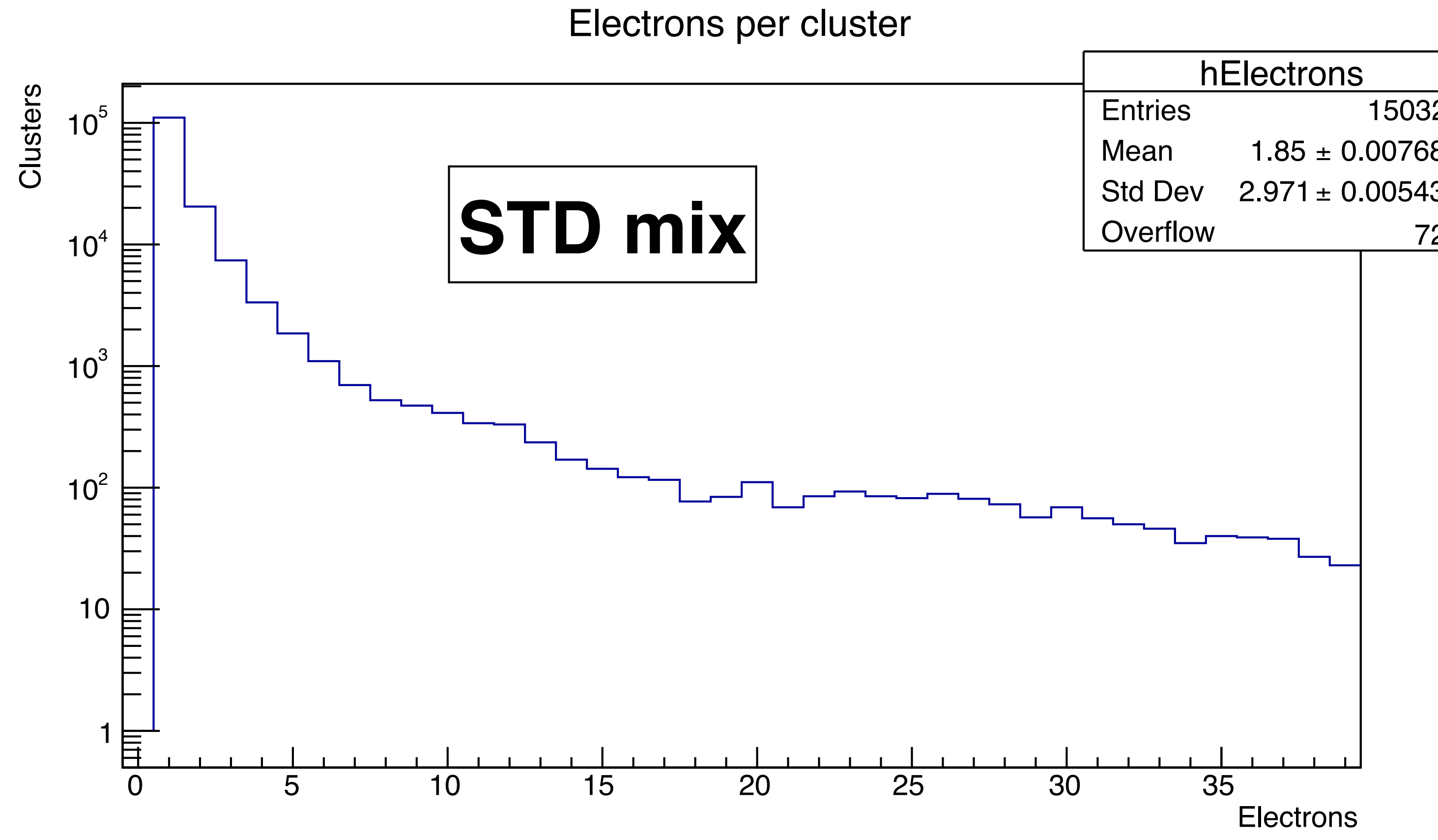
Present main limitations: All avalanches are independent, simplified space charge model

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.







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

Caveat: rescaling of a factor $\delta = 1.43$ 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.]

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Avalanche evolution for RPC (2 mm)

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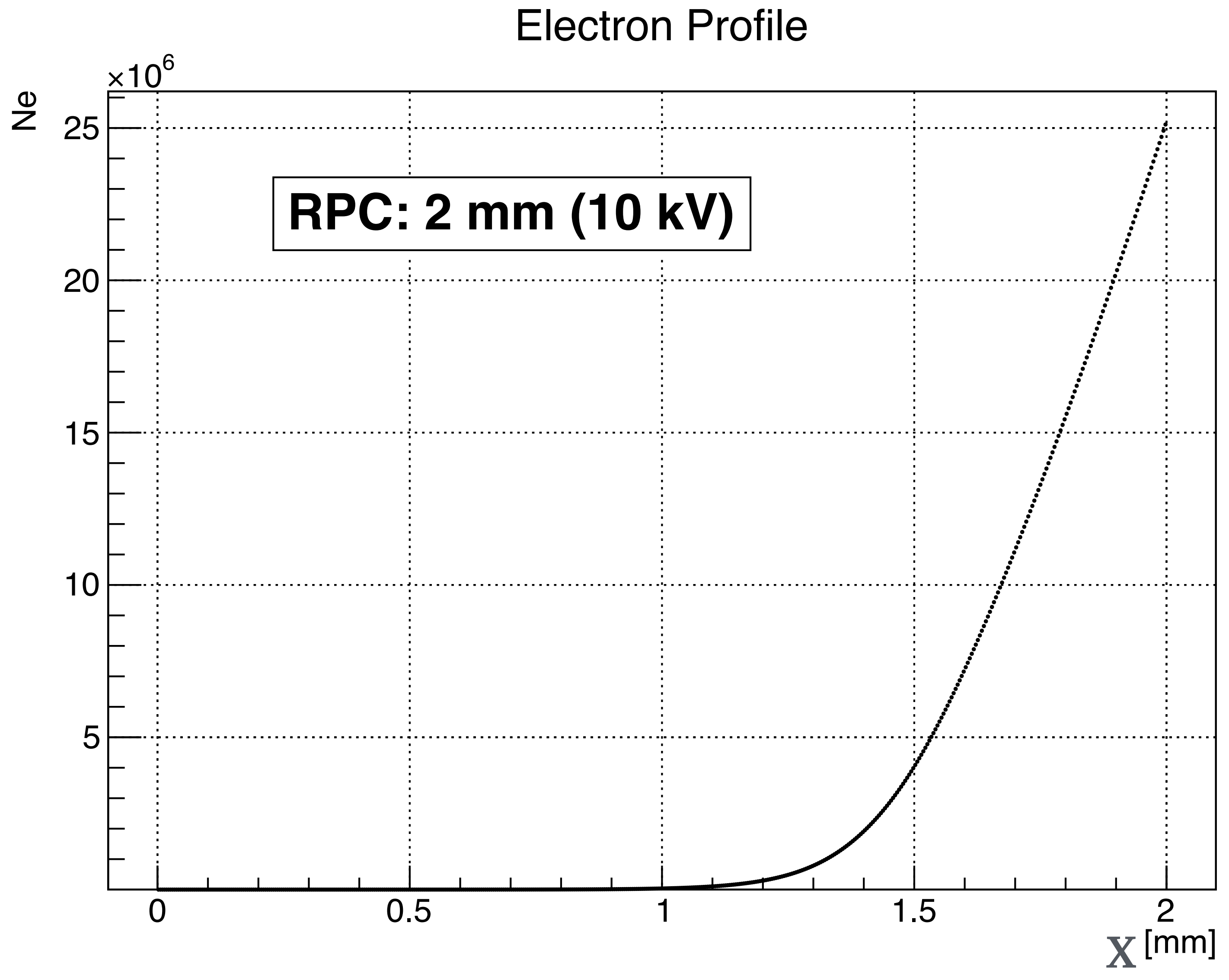
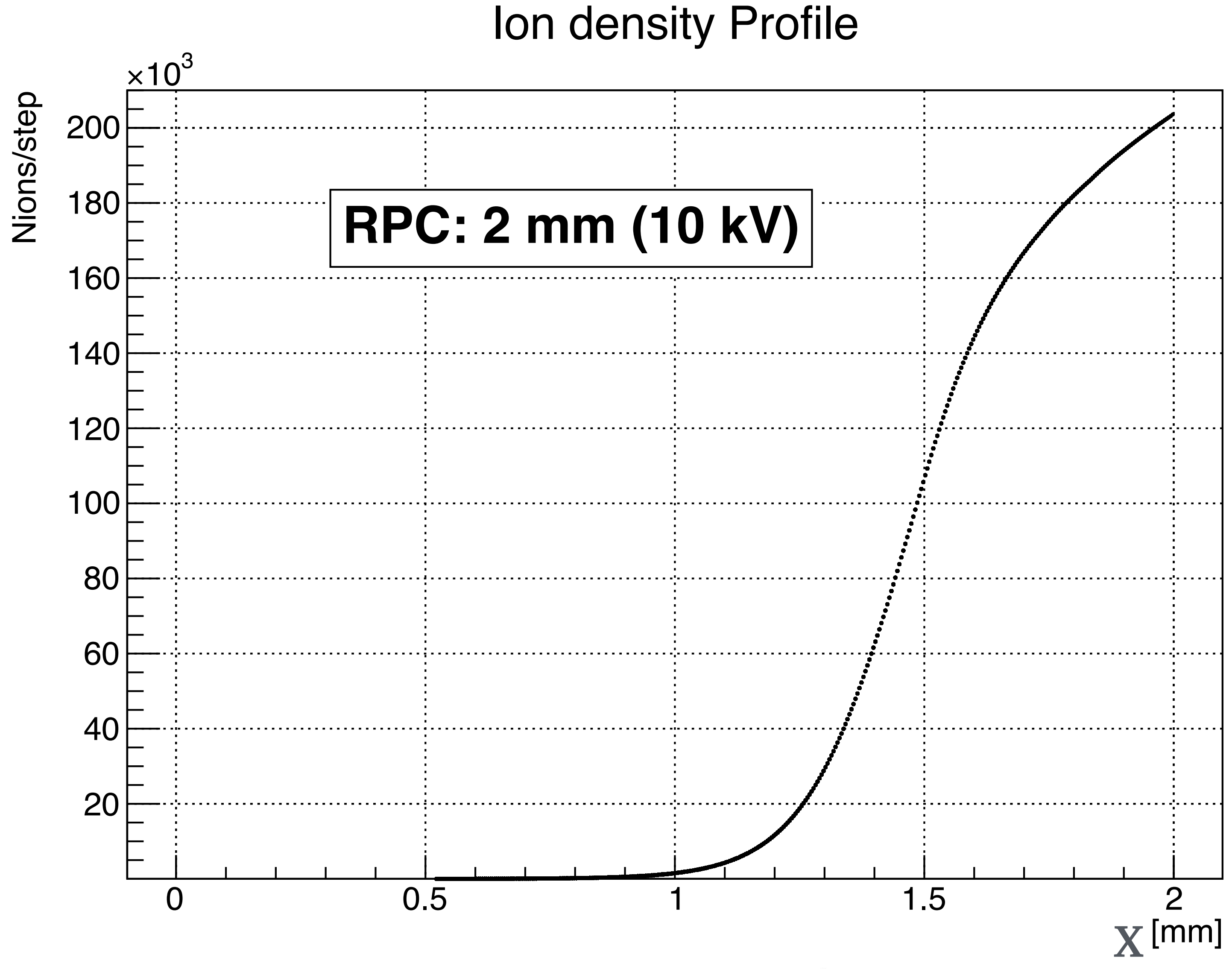
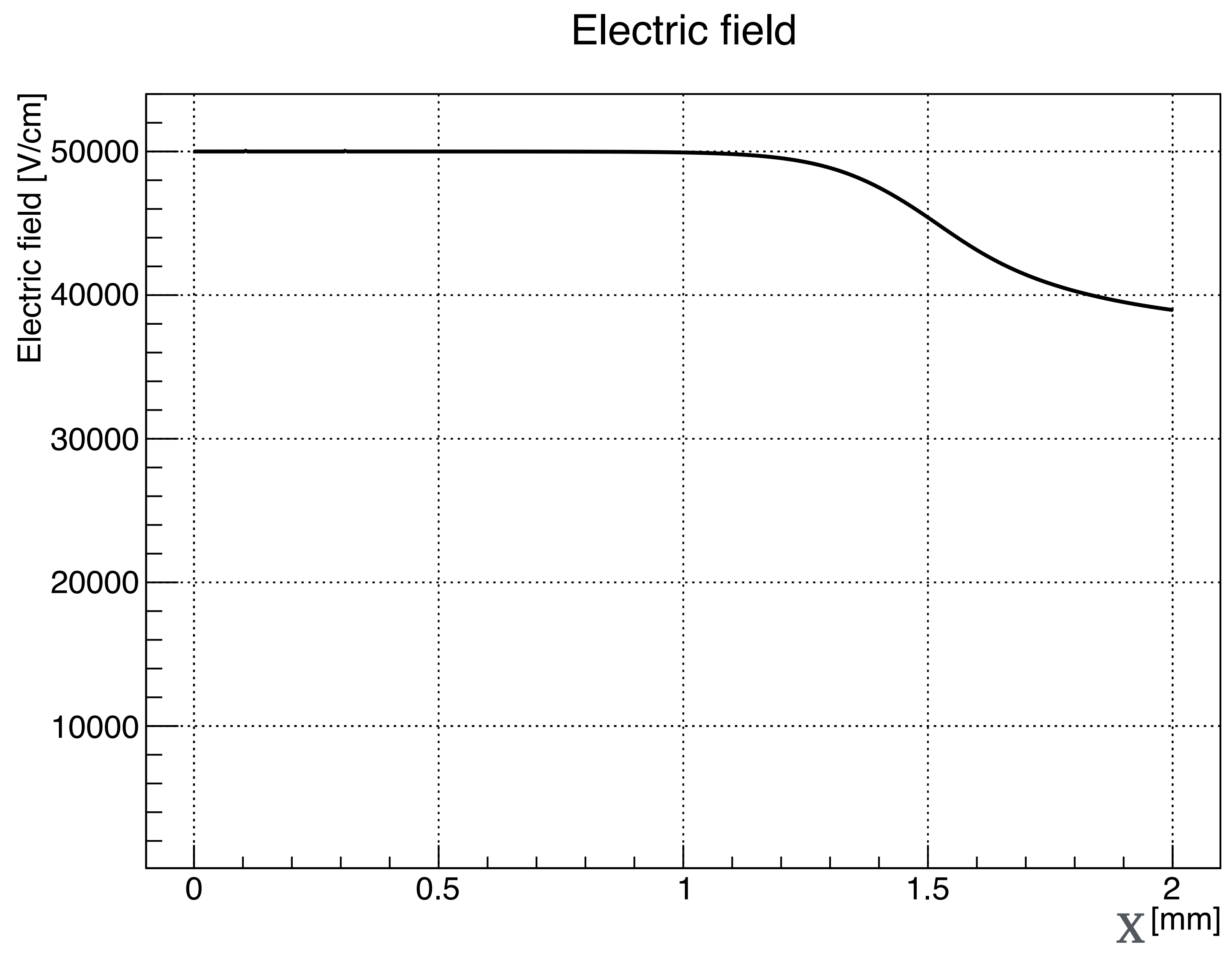
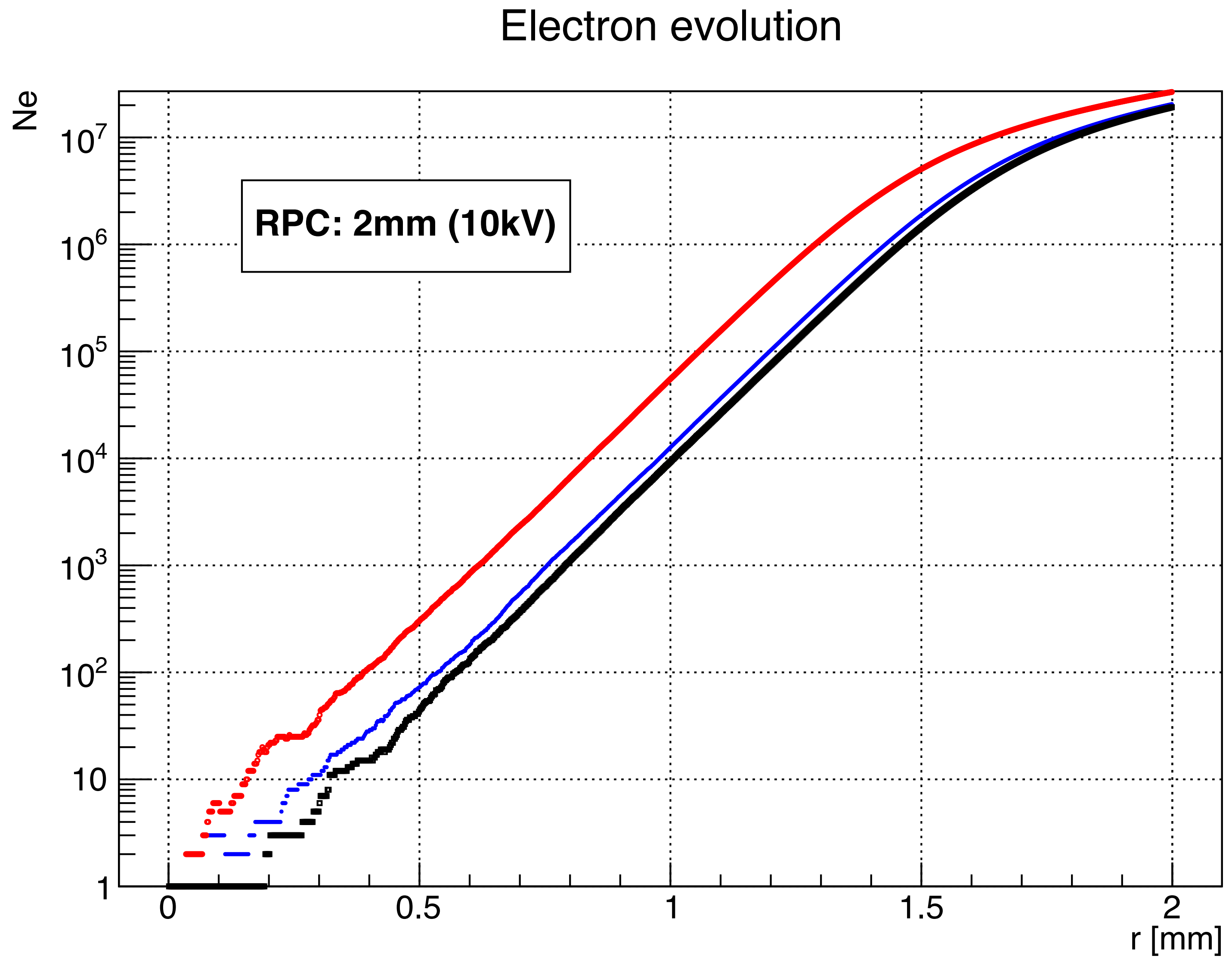
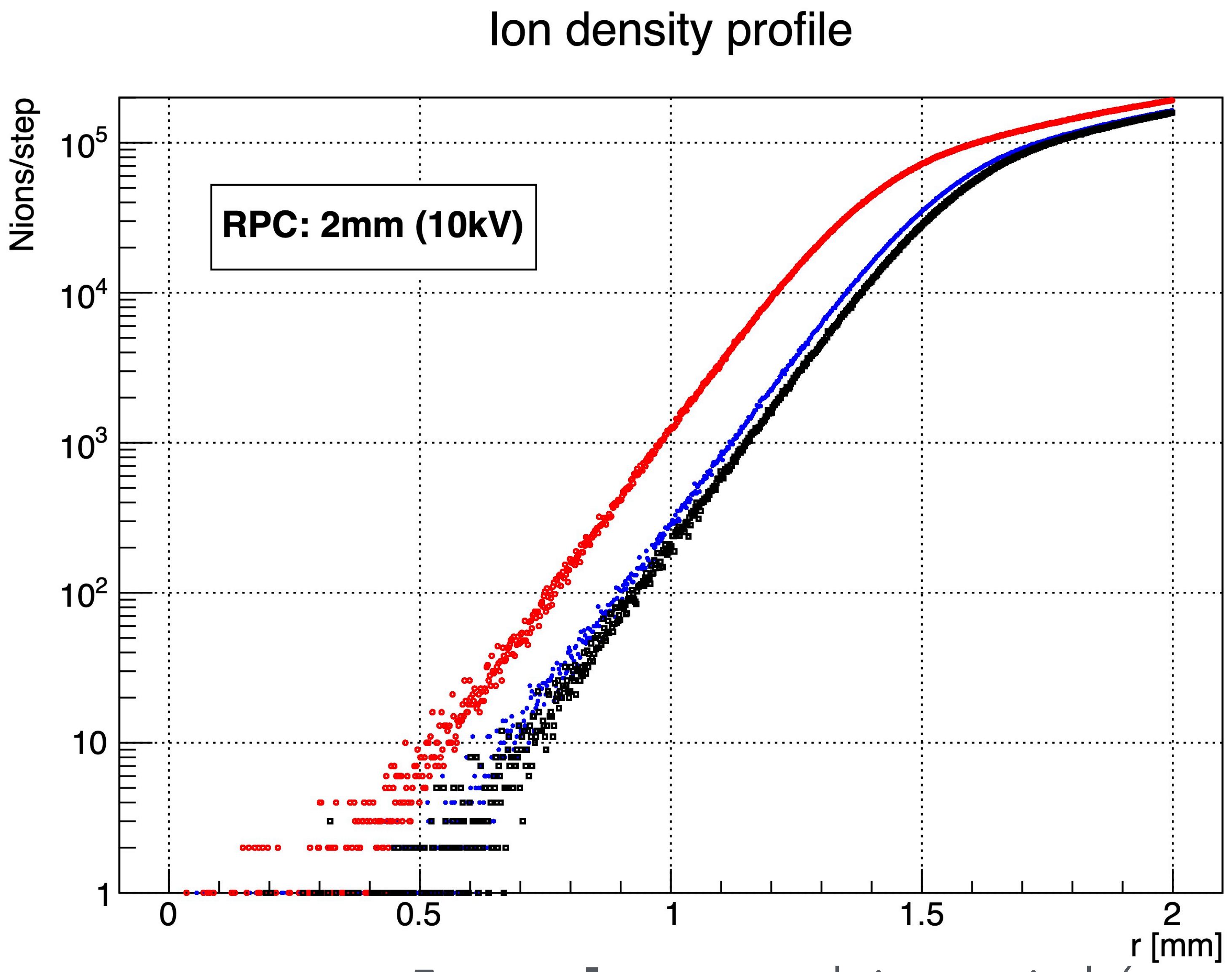
Example of avalanche evolution starting from the cathode for an RPC 2 mm gas gap @ 10 kV

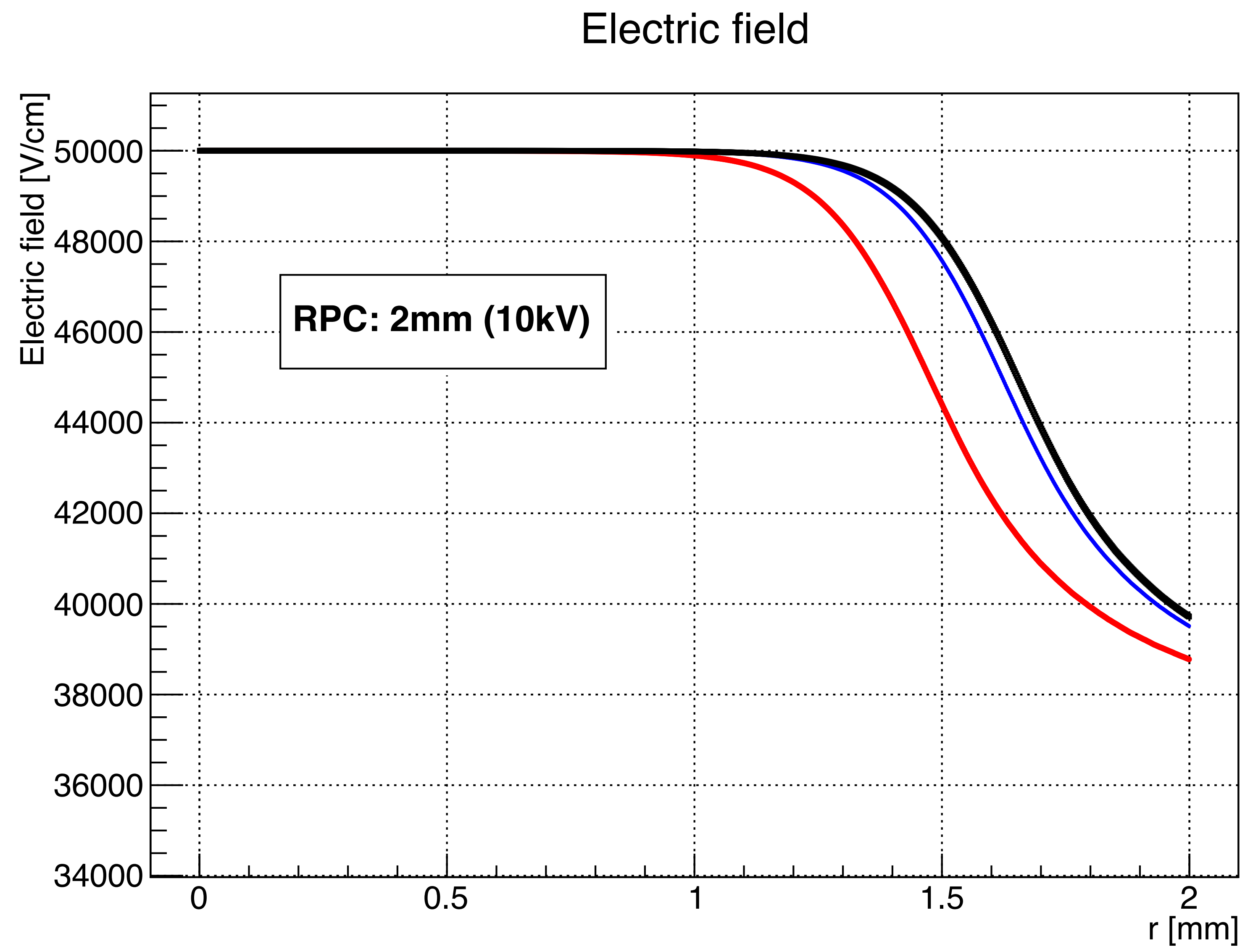










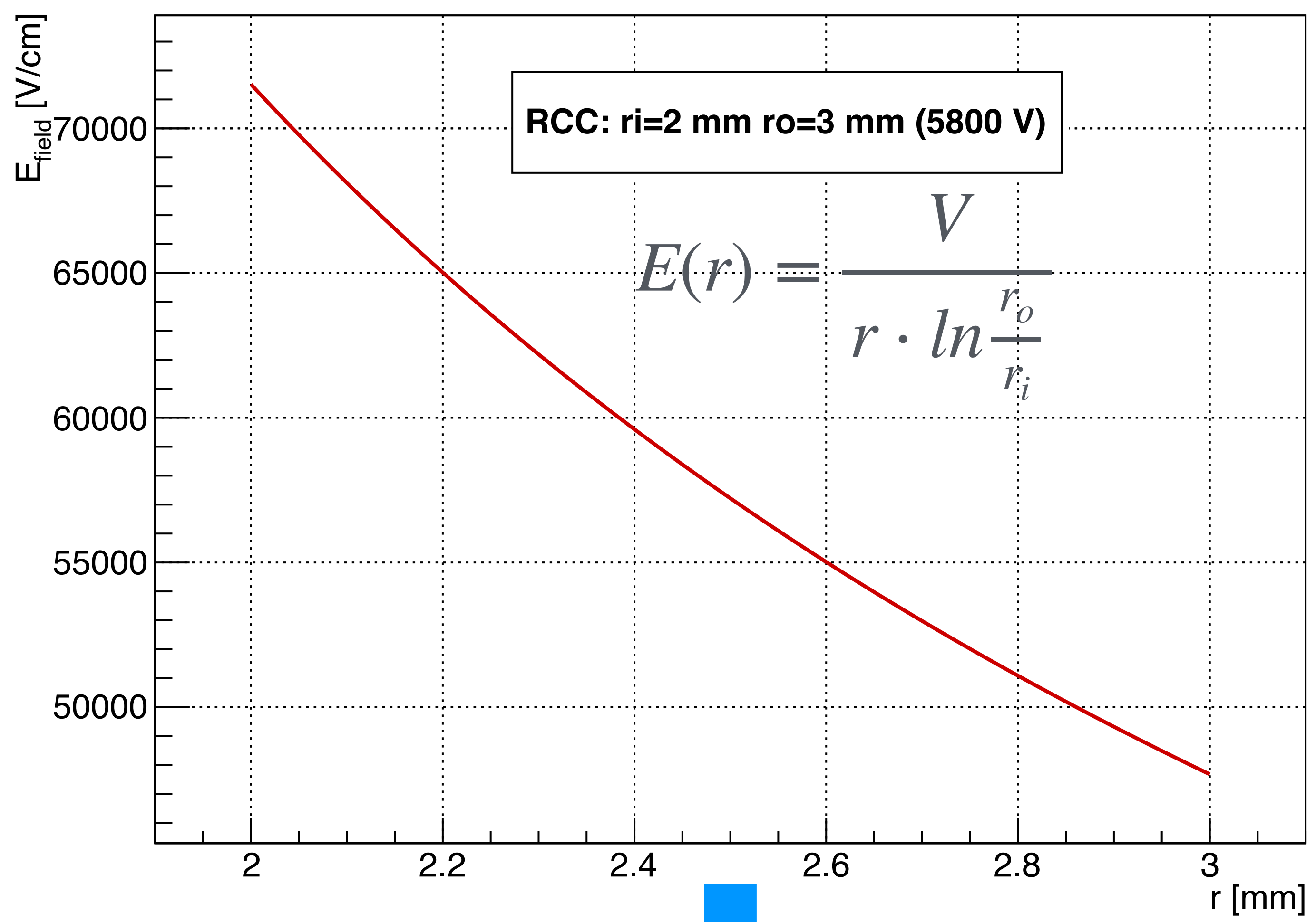


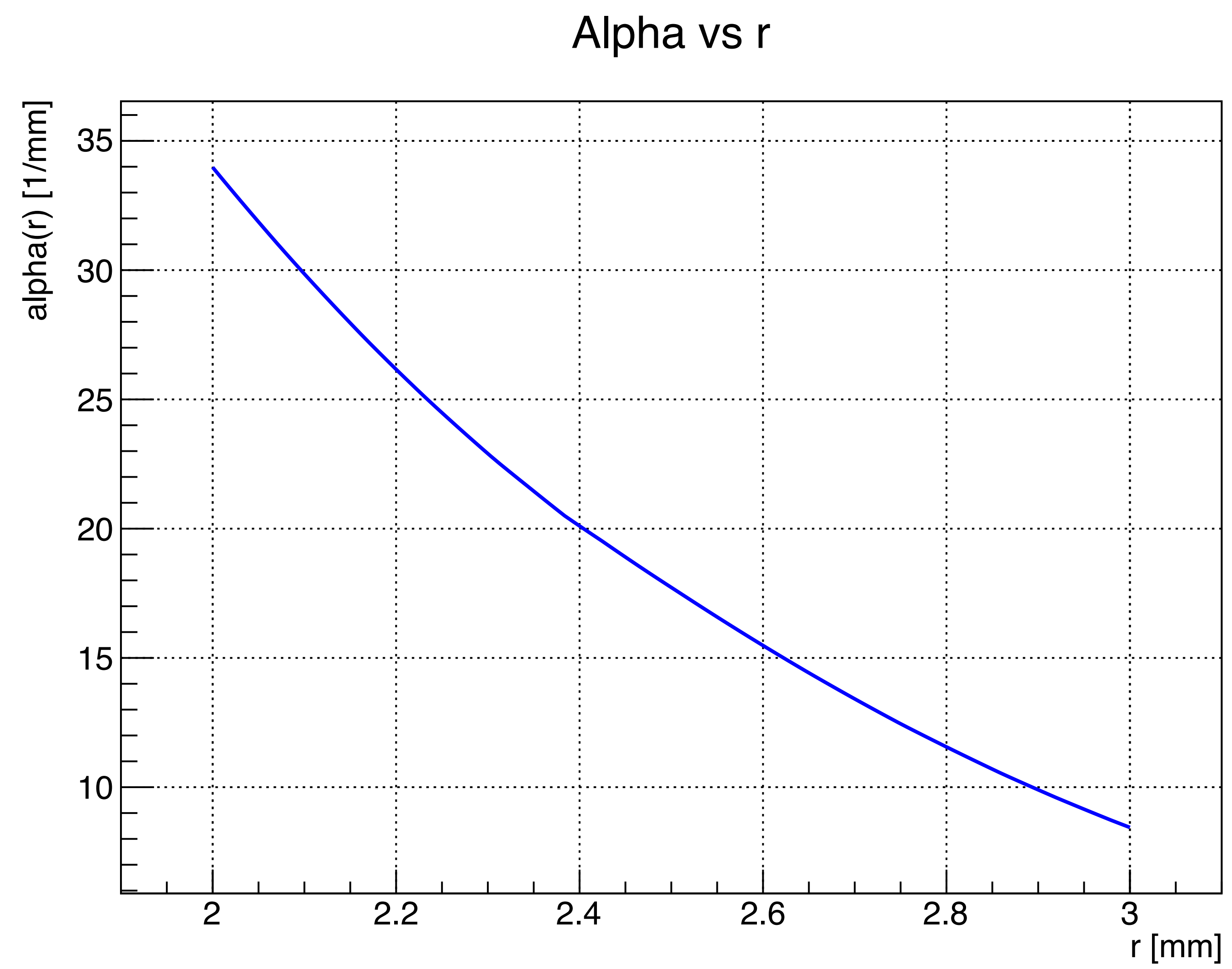
Avalanche multiplication statistics: poisson **Attachment:** binomial (up to 1000 electrons), then gaussian

Avalanche evolution for RCC (No SC)

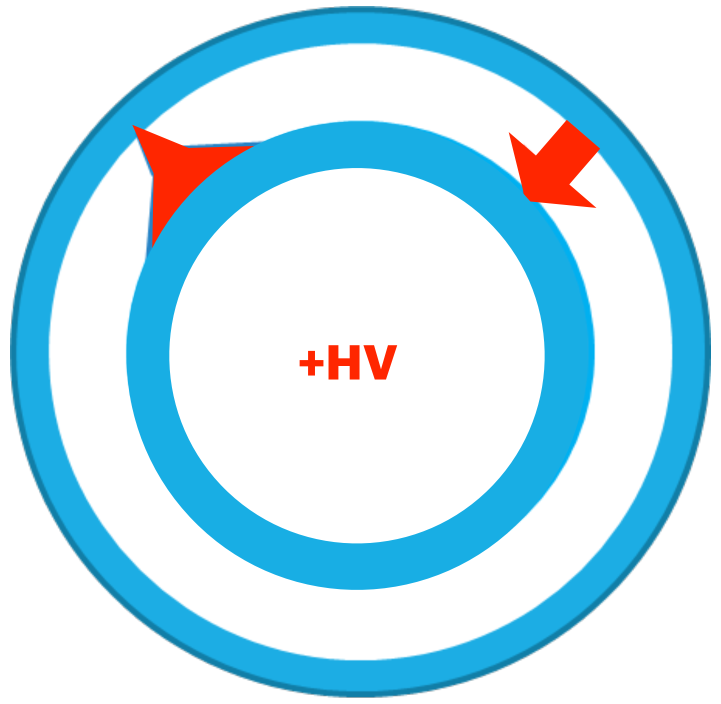
RCC example: r_i = 2 mm r_o = 3 mm V= 5800 V

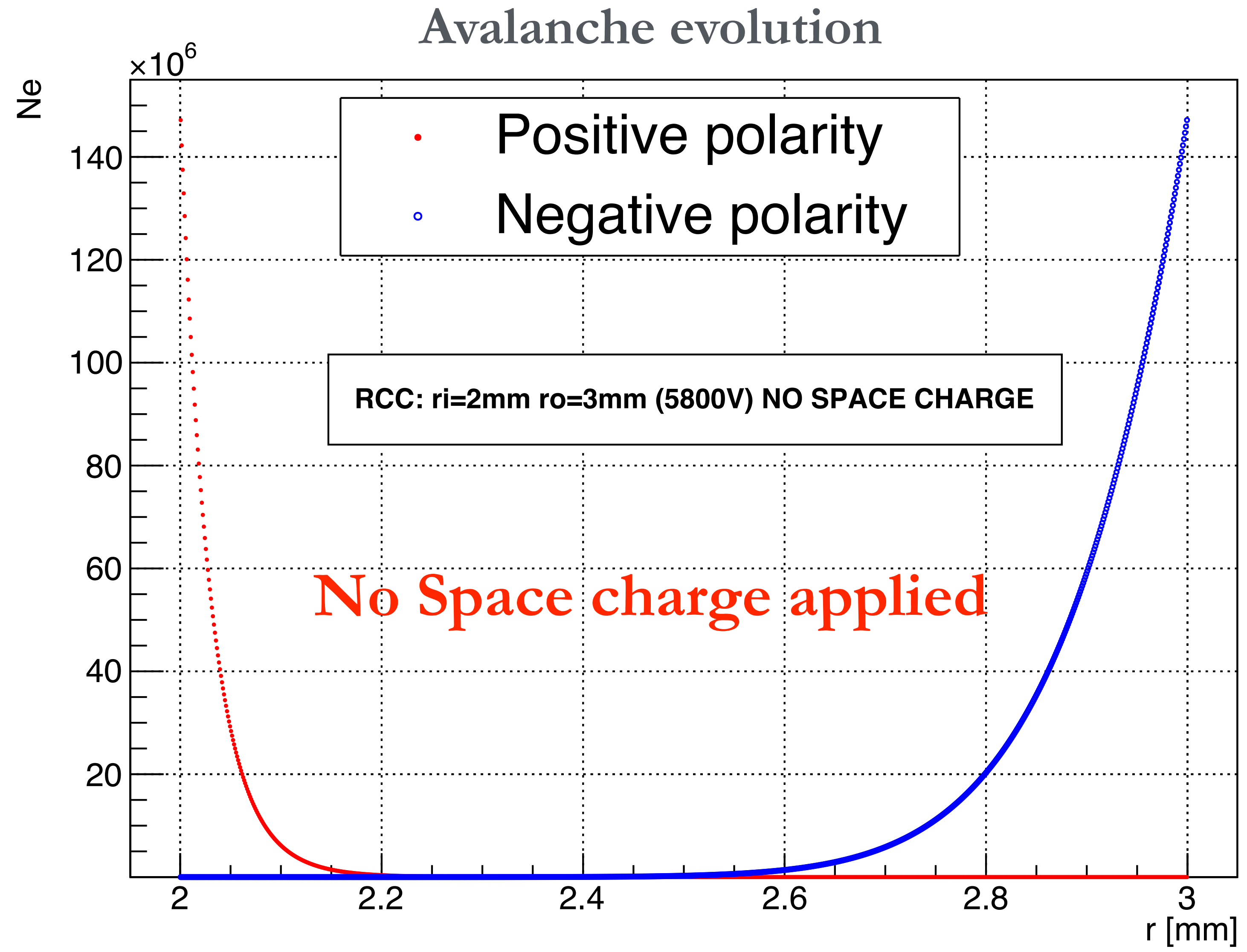
Electric field vs r

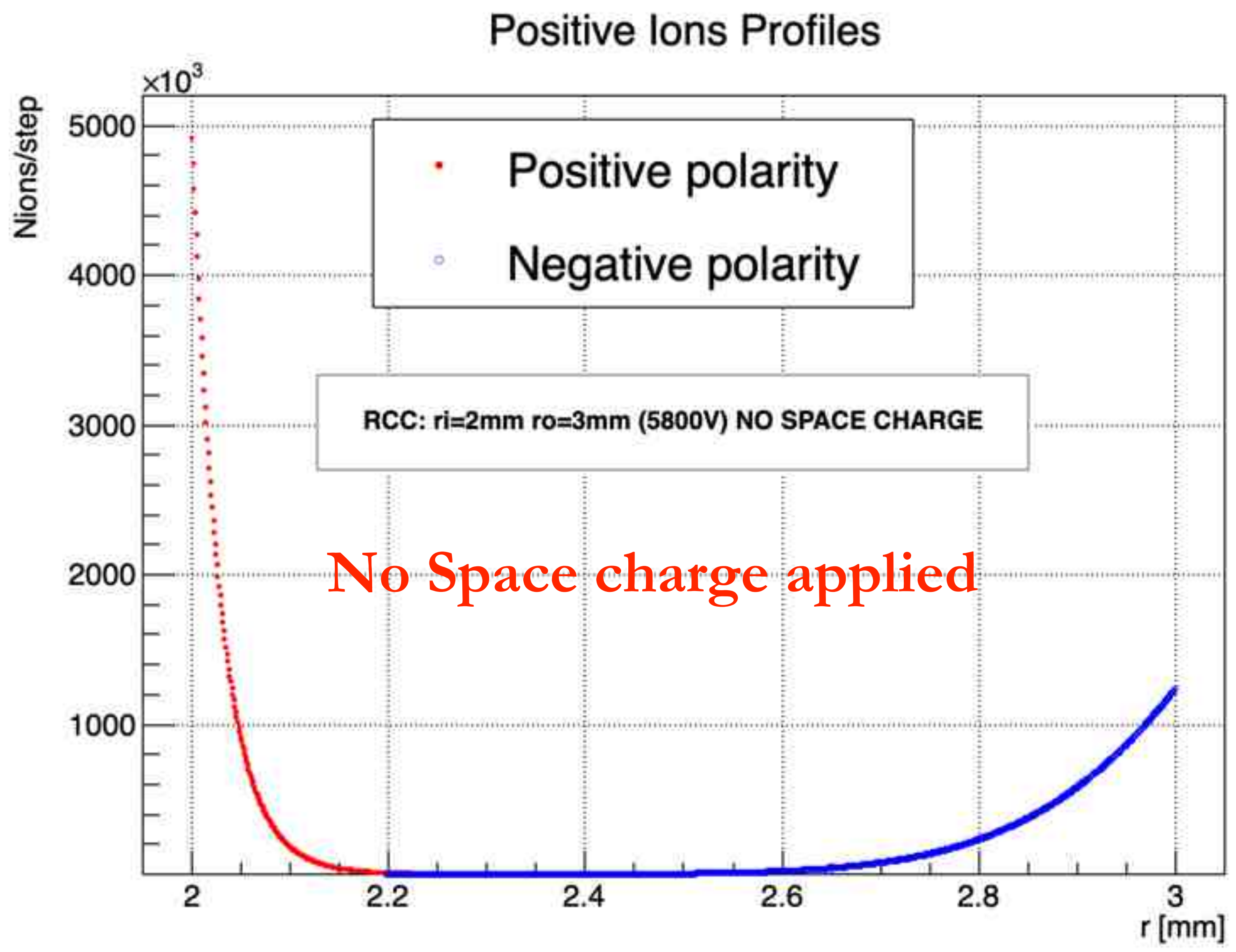




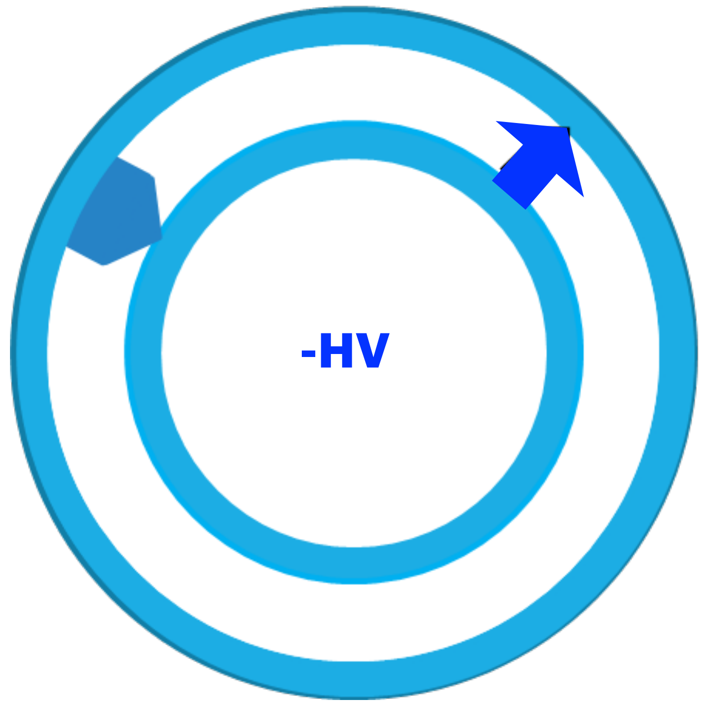
Positive polarity: avalanche from outer electrode (r=3mm) to inner (r=2mm)





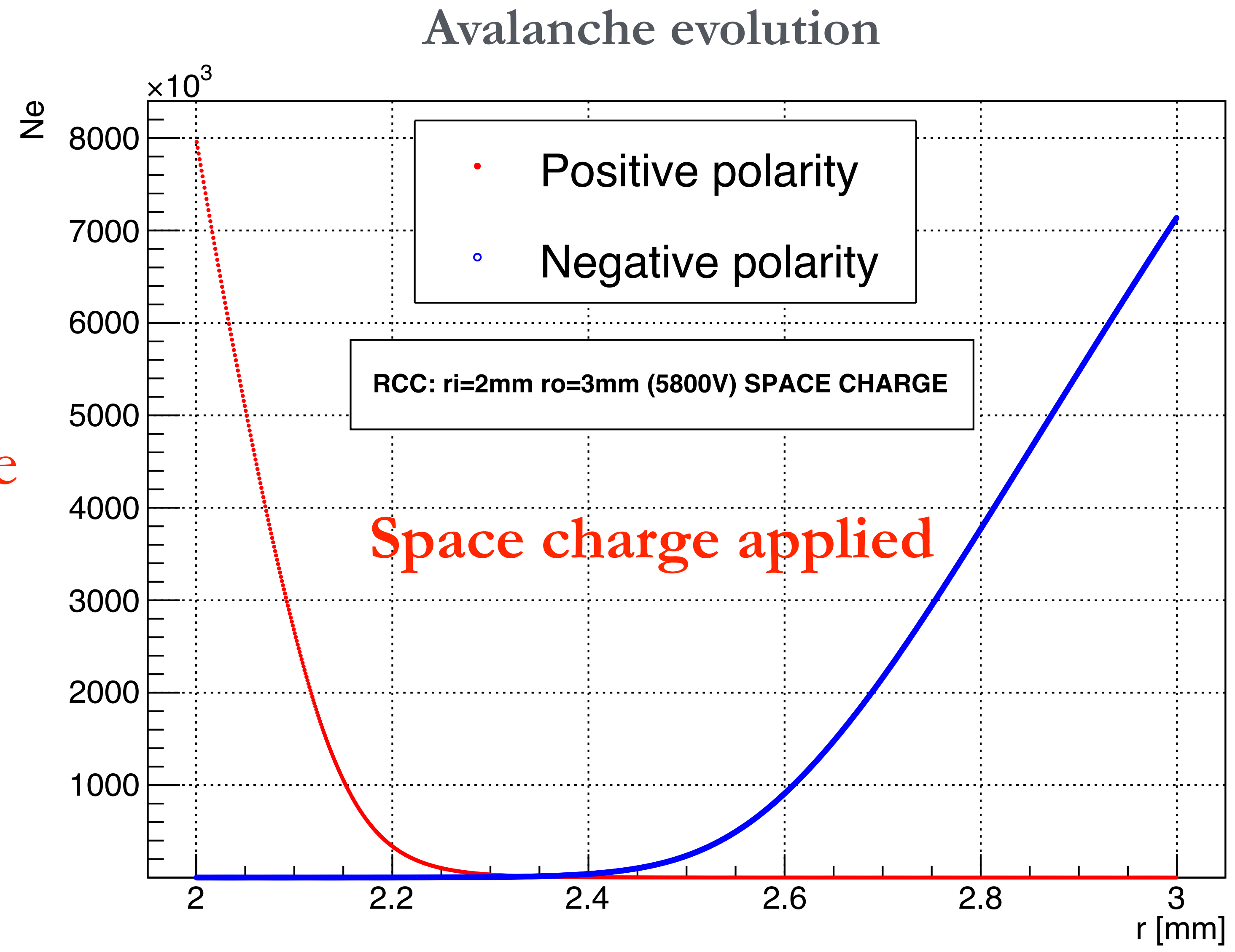


Negative polarity: avalanche from inner electrode (r=2mm) to outer (r=3mm)



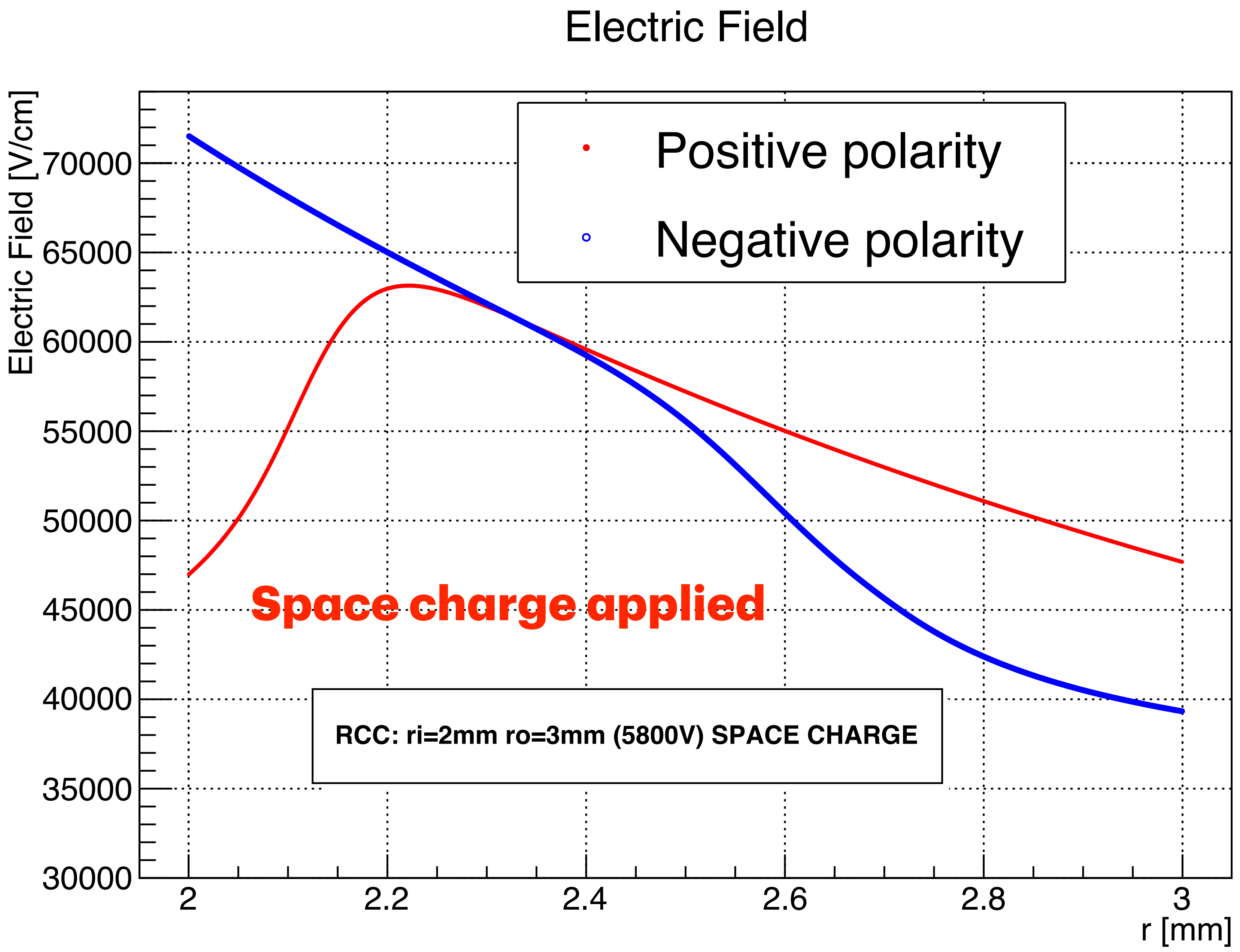
Avalanche evolution for RCC (SC)

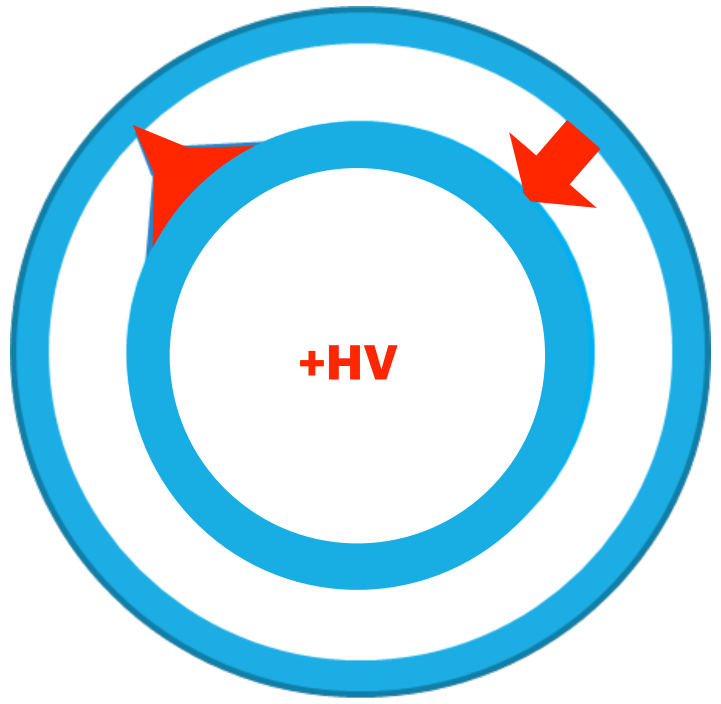
RCC example: $r_i = 2$ mm $r_o = 3$ mm

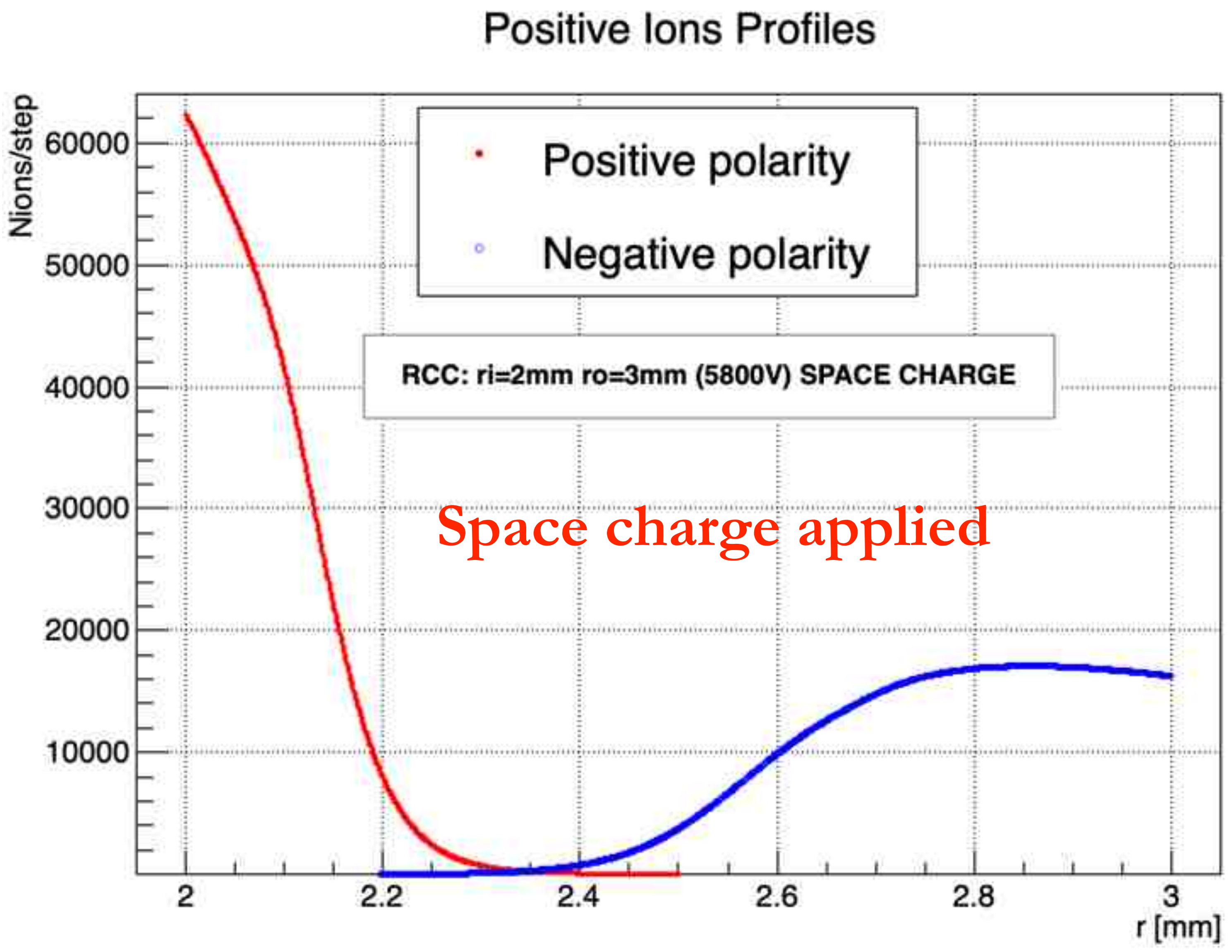


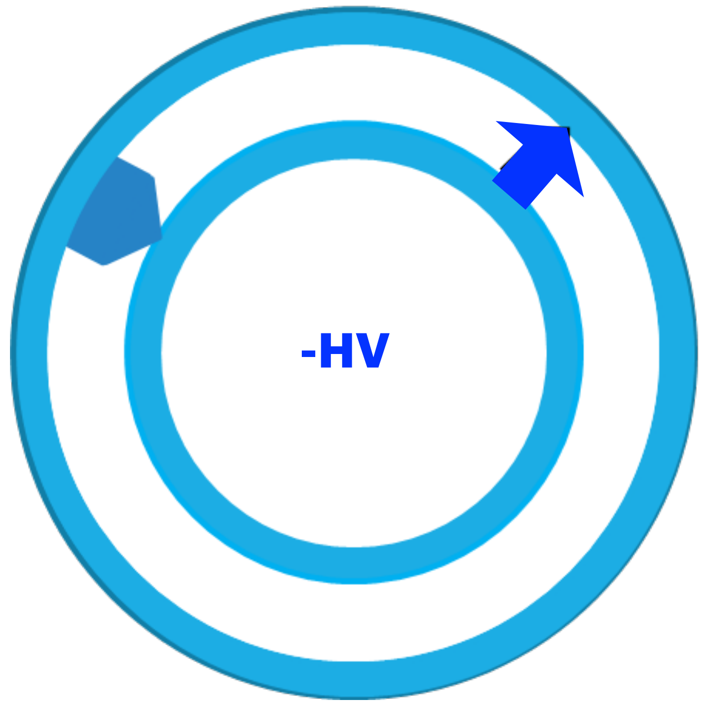
Positive polarity: avalanche from outer electrode (r=3mm) to inner (r=2mm)

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



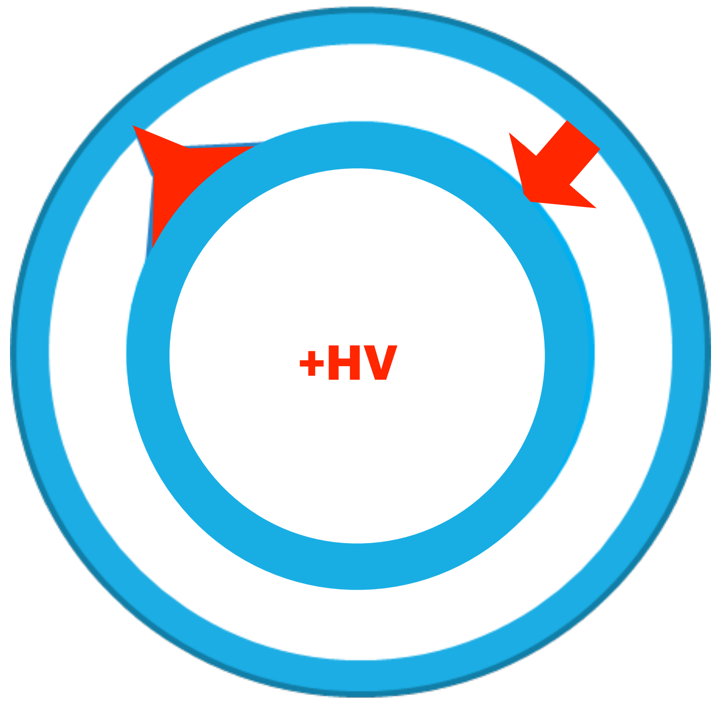


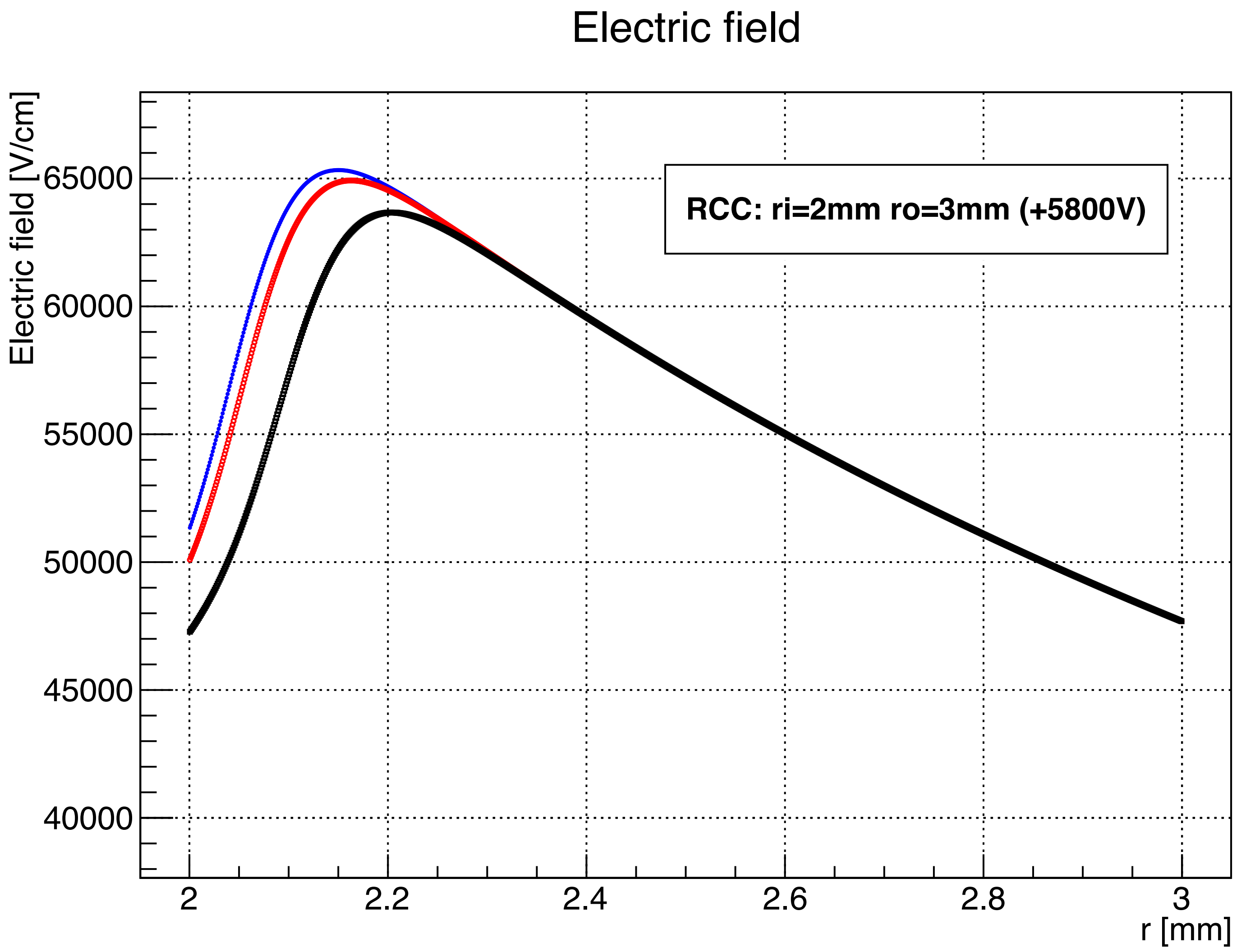


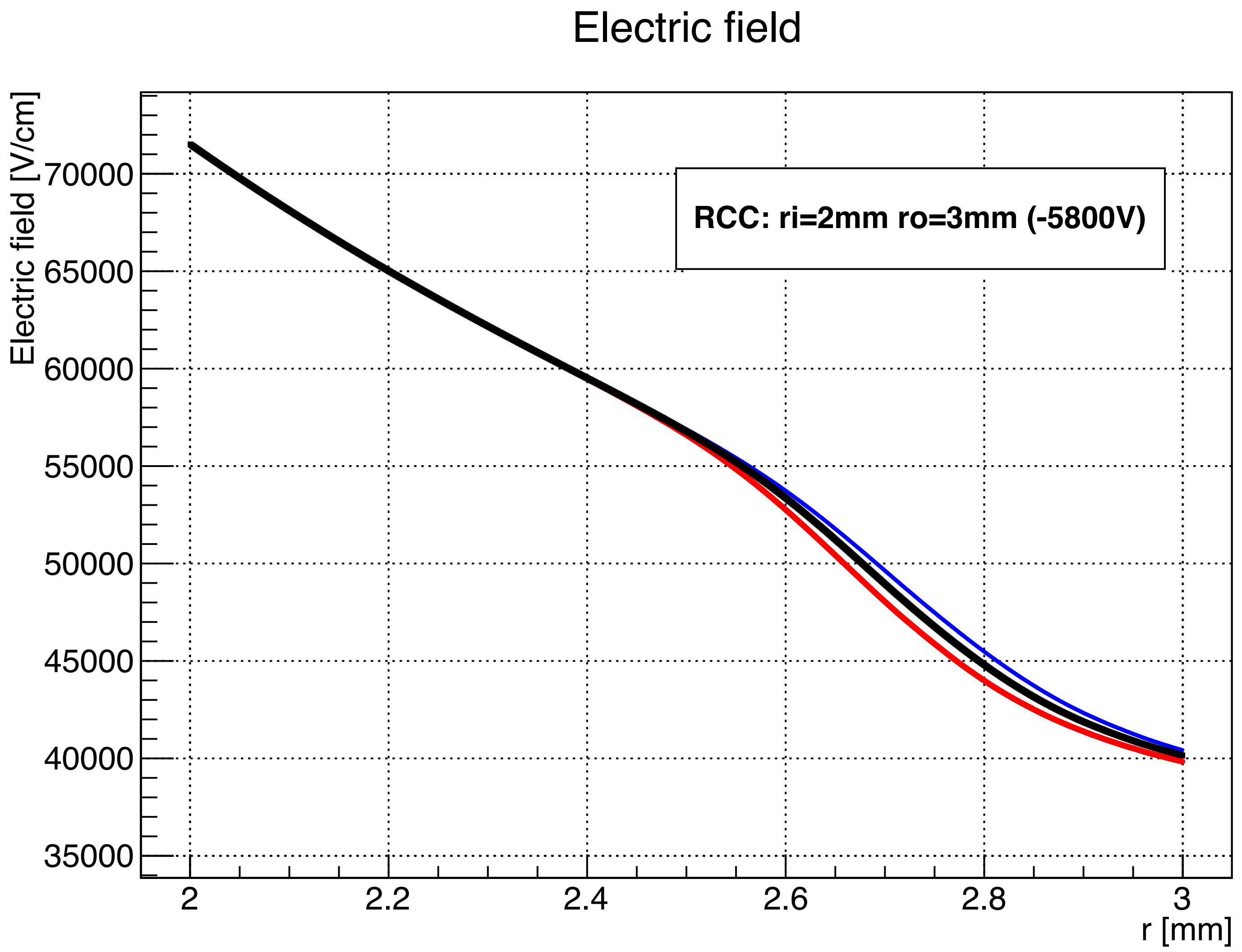


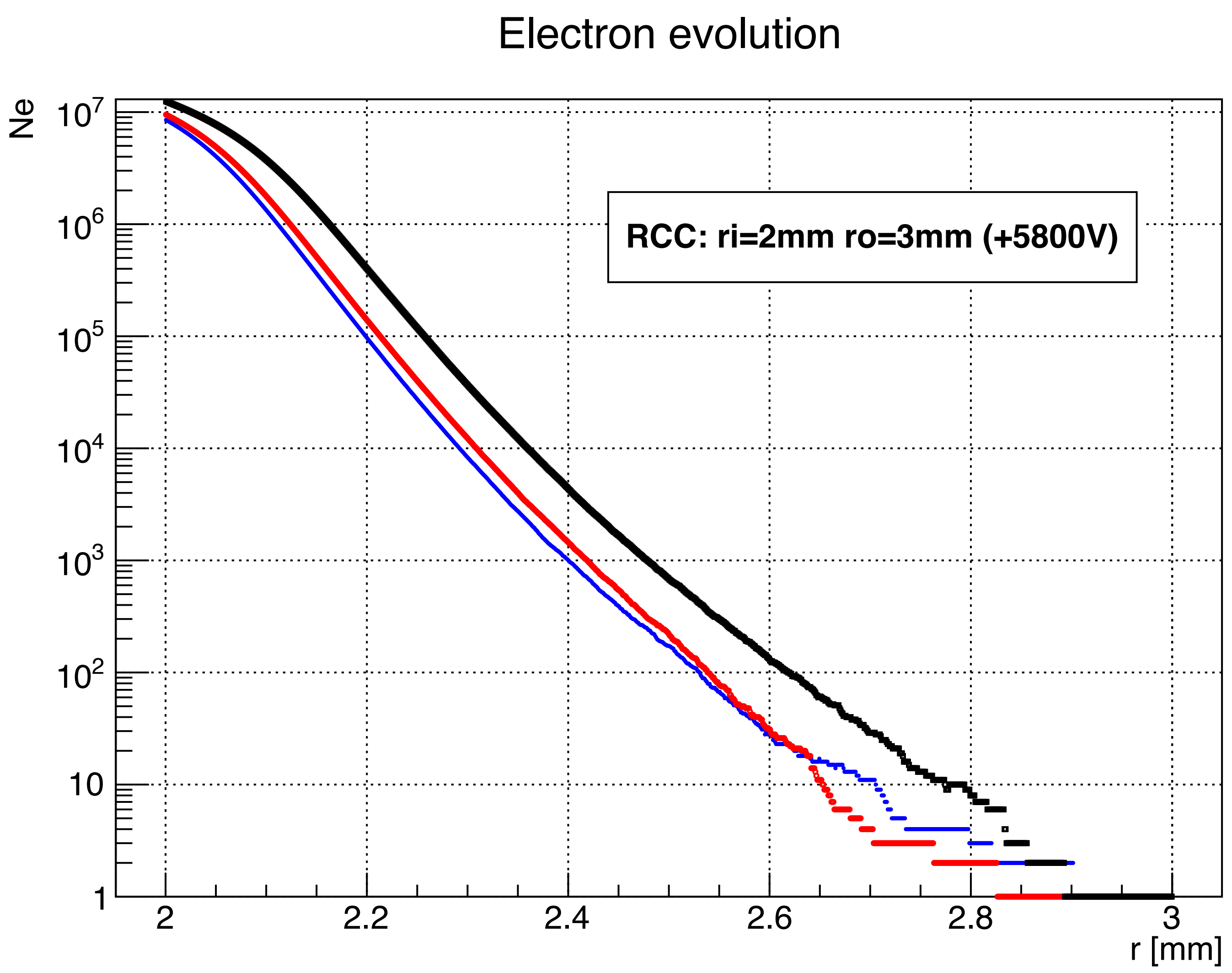
Statistical effects:
Avalanche evolution for RCC (SC)

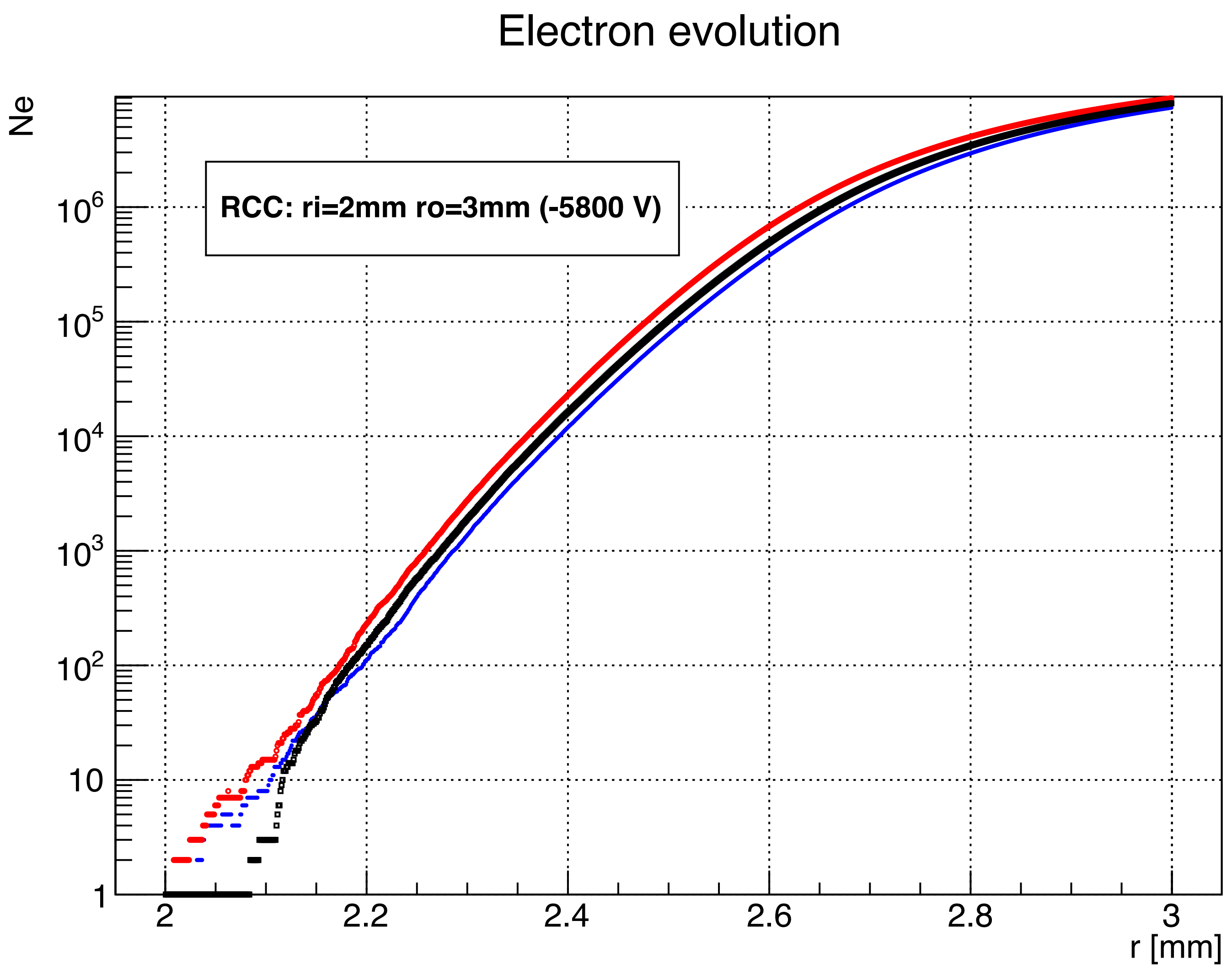
RCC example: $r_i = 2$ mm $r_o = 3$ mm

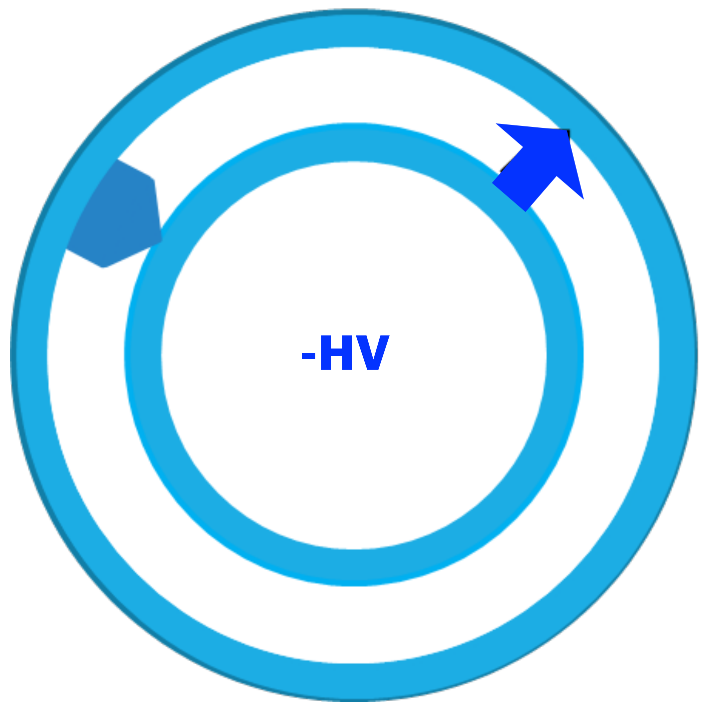












Induced charge

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

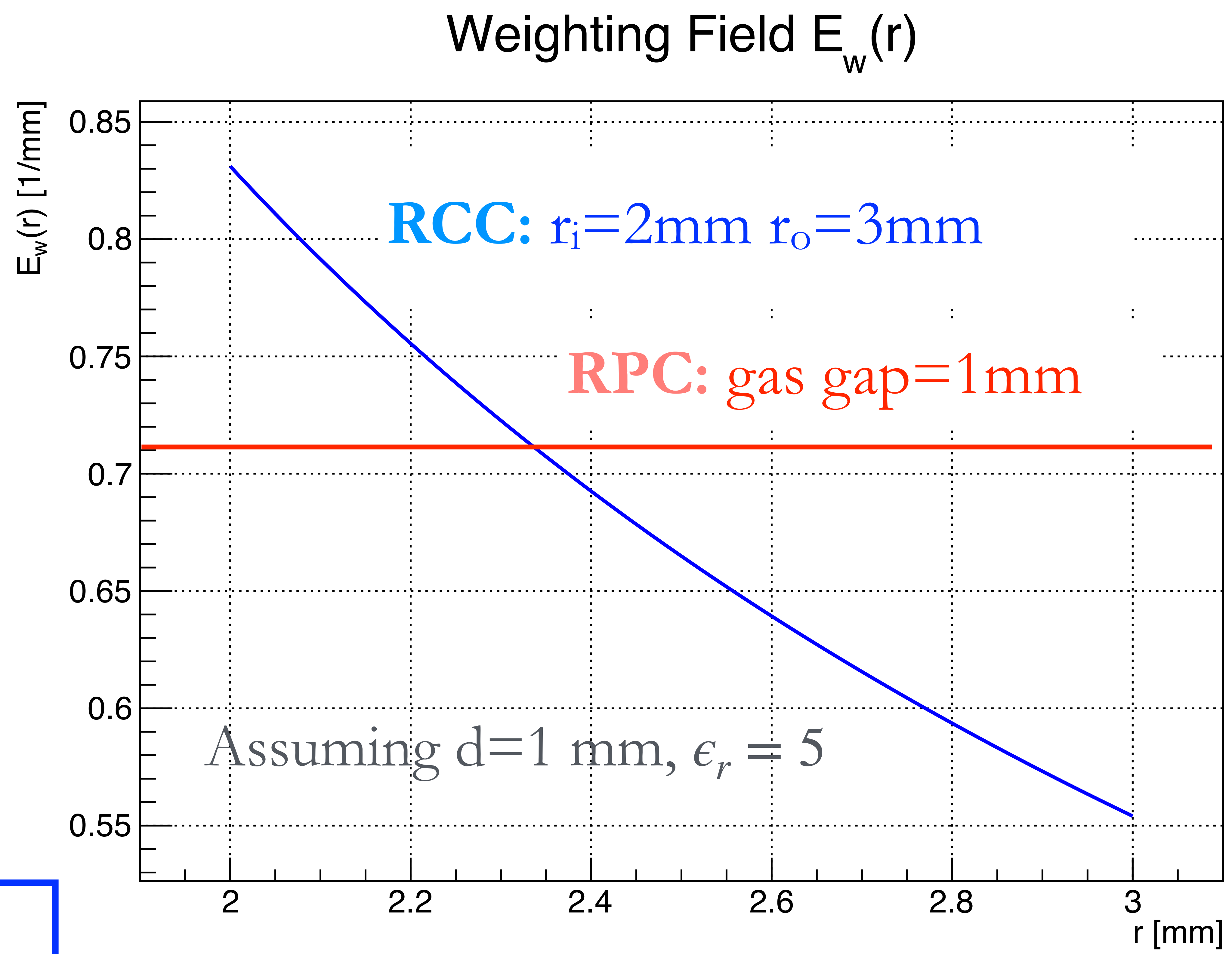
Planar Geometry: RPC

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

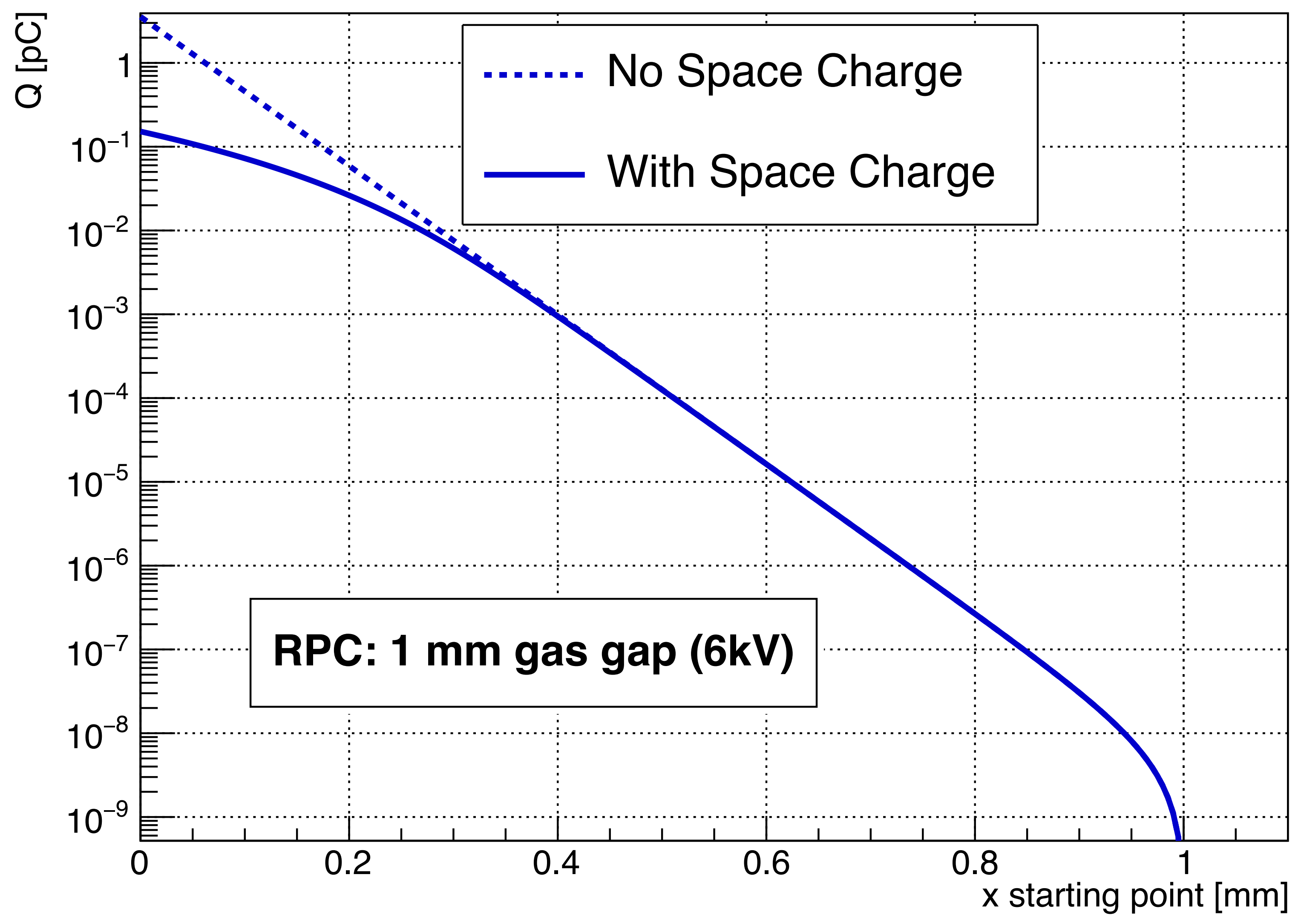
Electrode thickness d - Gas gap g

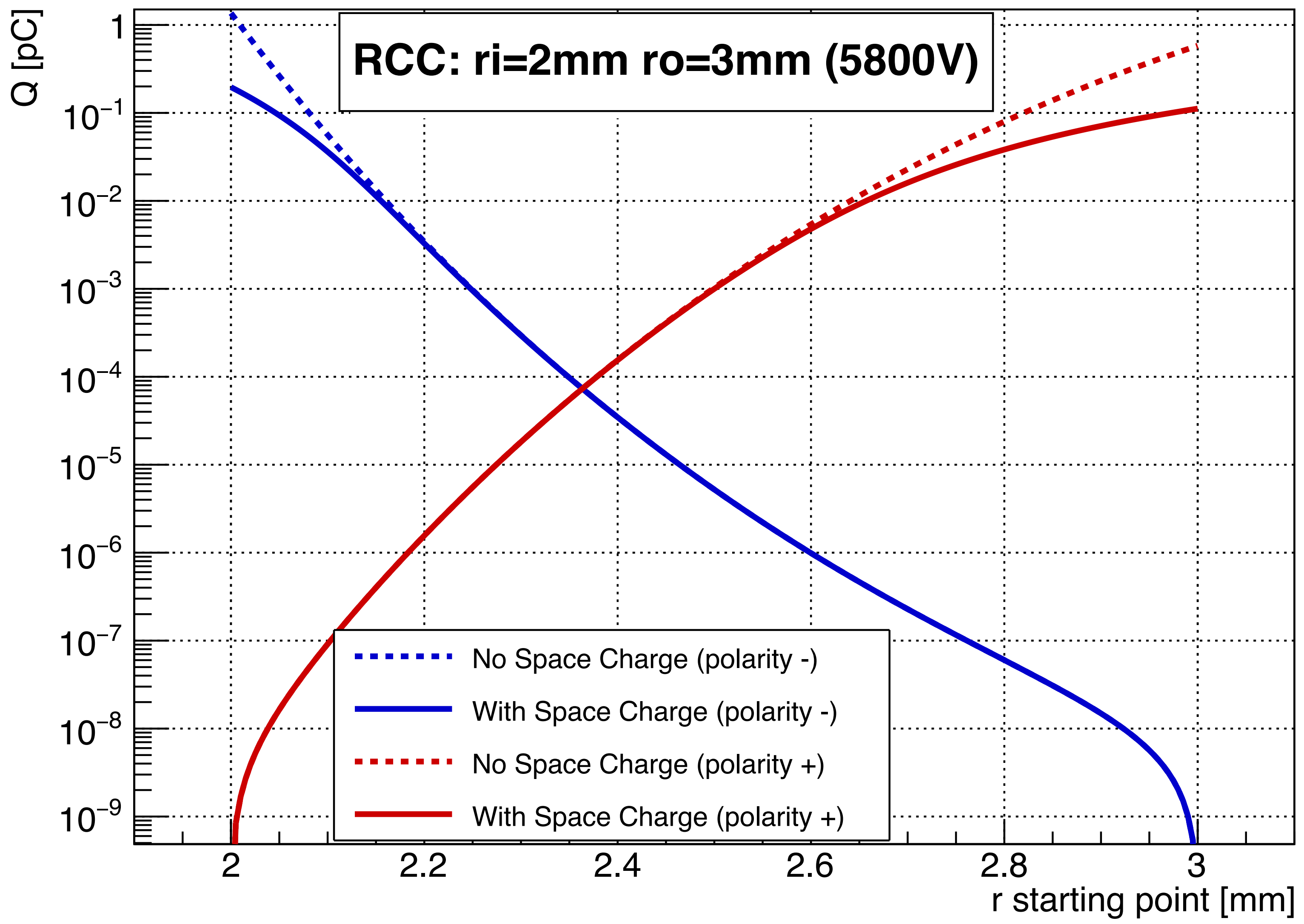
Cylindrical Geometry: RCC

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



Induced charge vs avalanche starting point

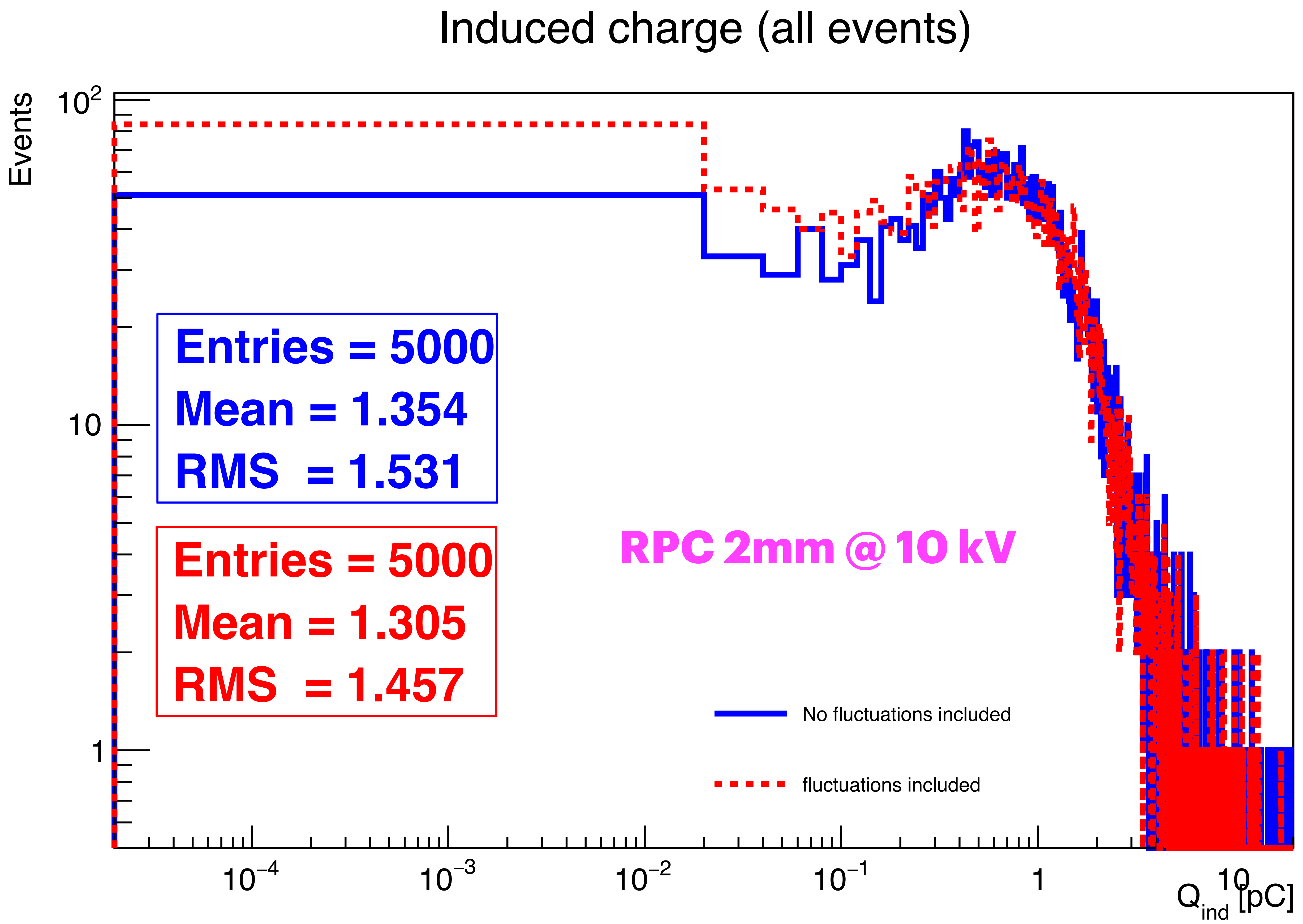




Full simulation: RPC 2mm

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

- Generate number of primary clusters $\langle N_p \rangle = 7.3\ \mathrm{mm}^{-1}$ for STD gas mix
- Generate number of secondary electrons for each primary cluster according to distribution in slide 5
- For each electron evaluate Q_{Tot} and $Q_{Induced}$ .. and sum.



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

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

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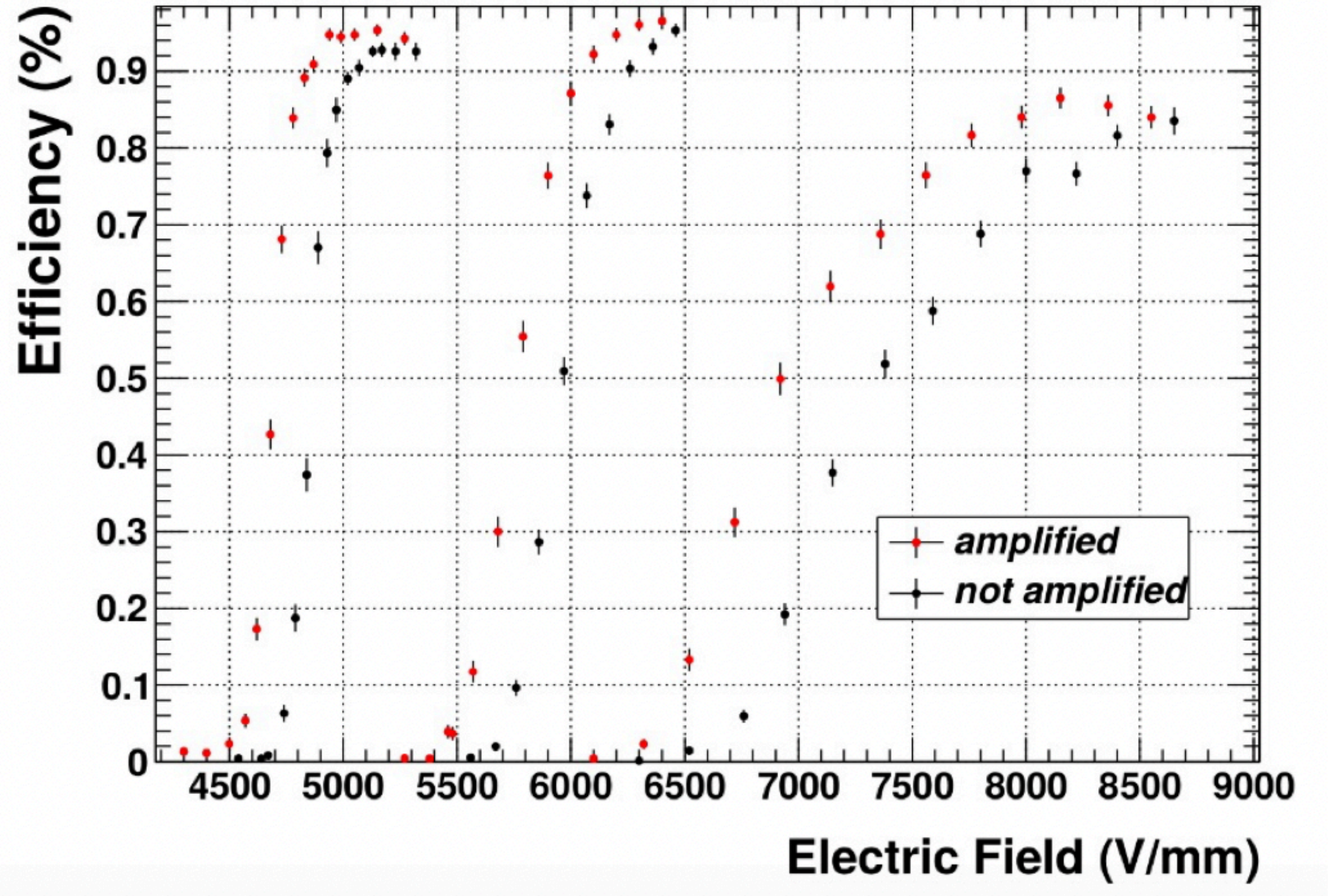
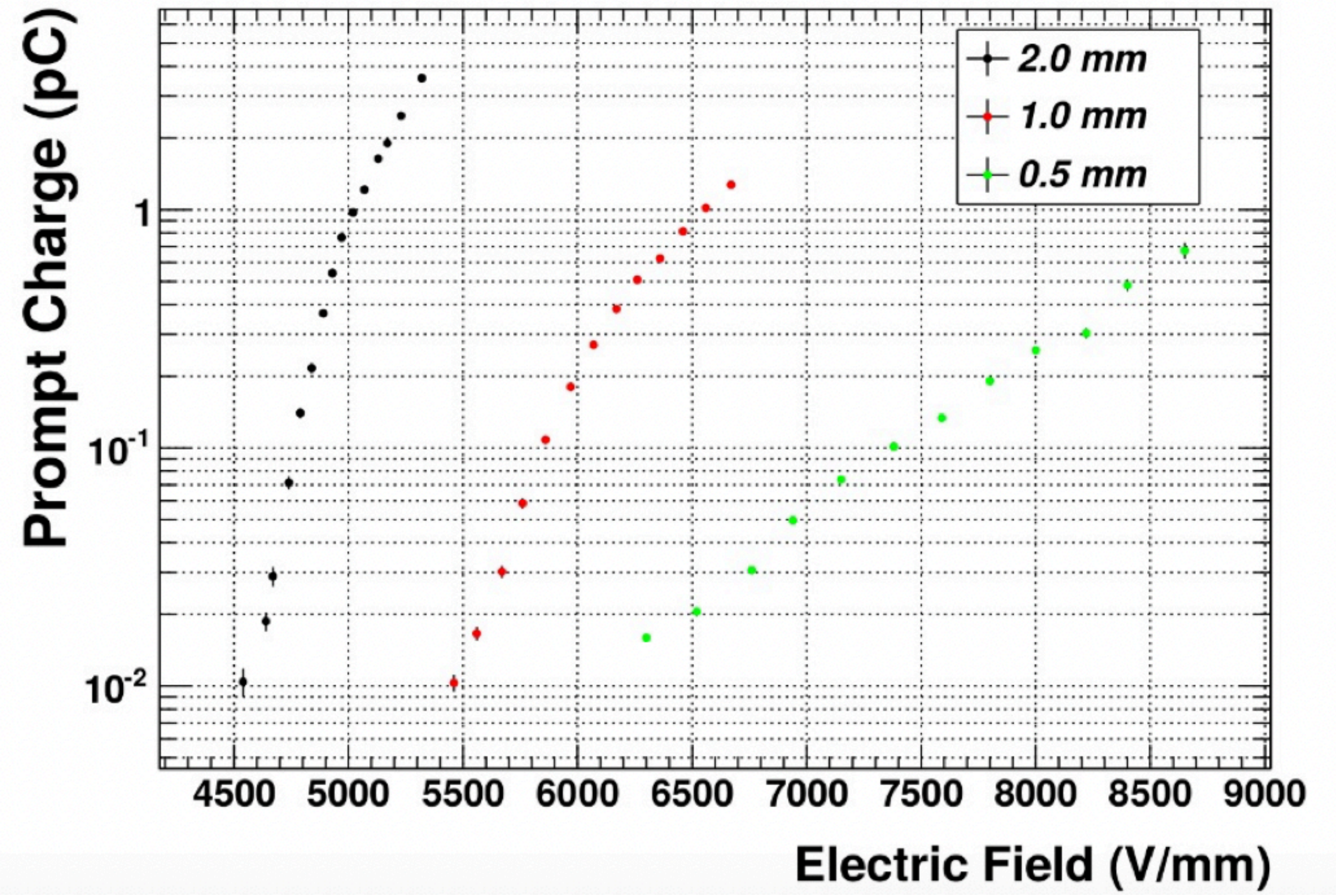
Comparison with experimental data: RPC

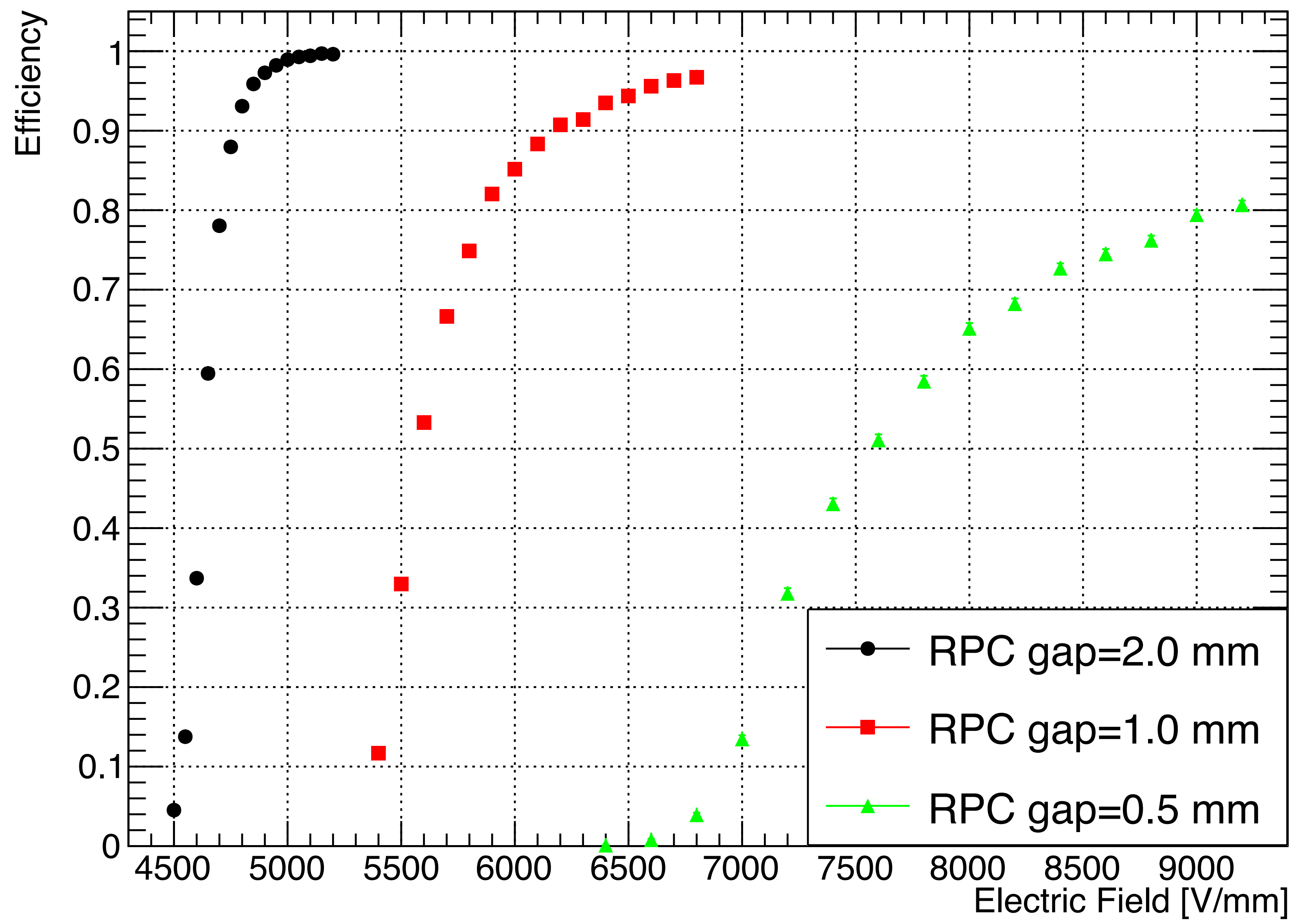
R. Santonico, B. Liberti, et al. “Improving rate capability of rpcs.” arXiv:1606.03448, 2016.

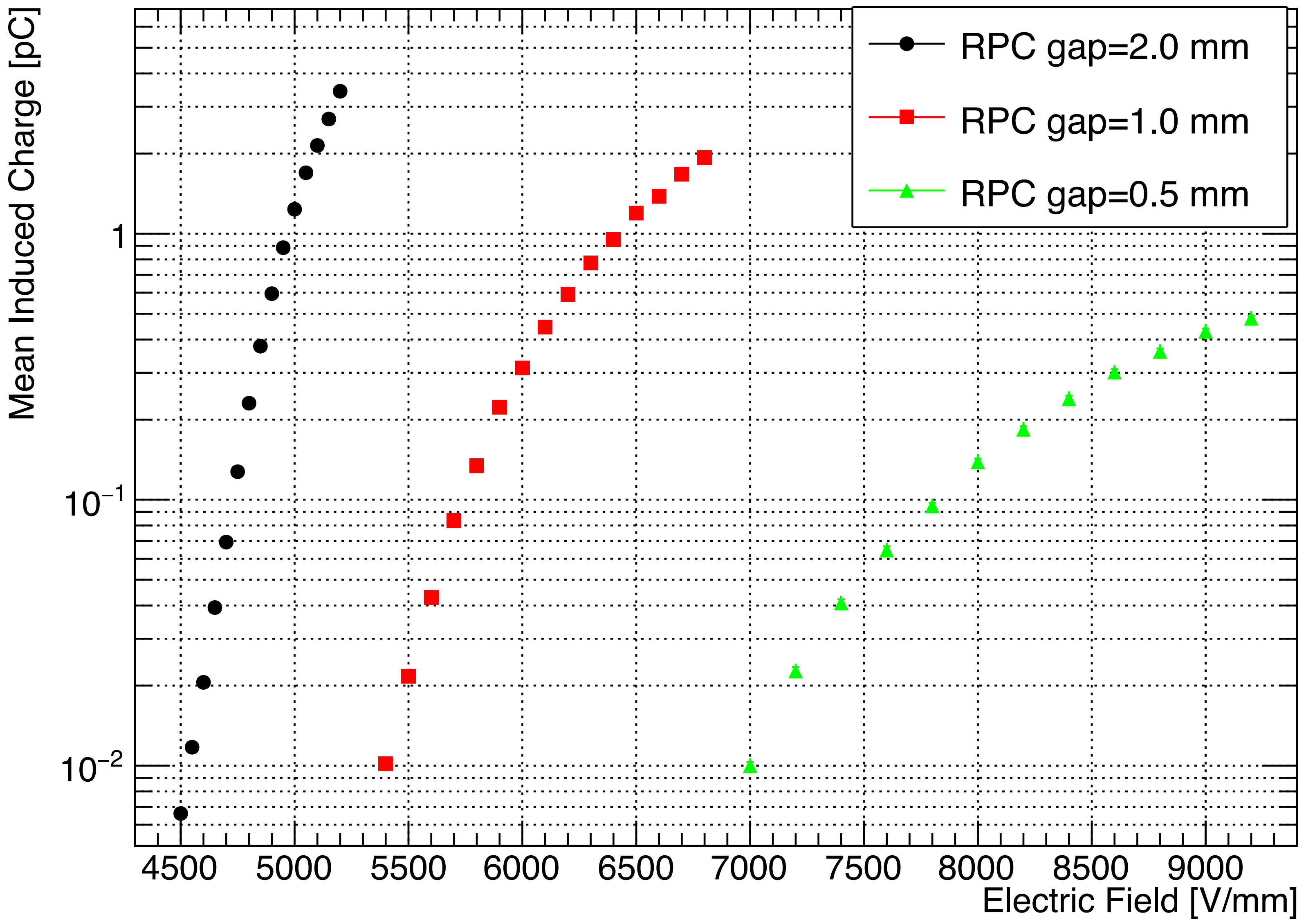
Experimental data





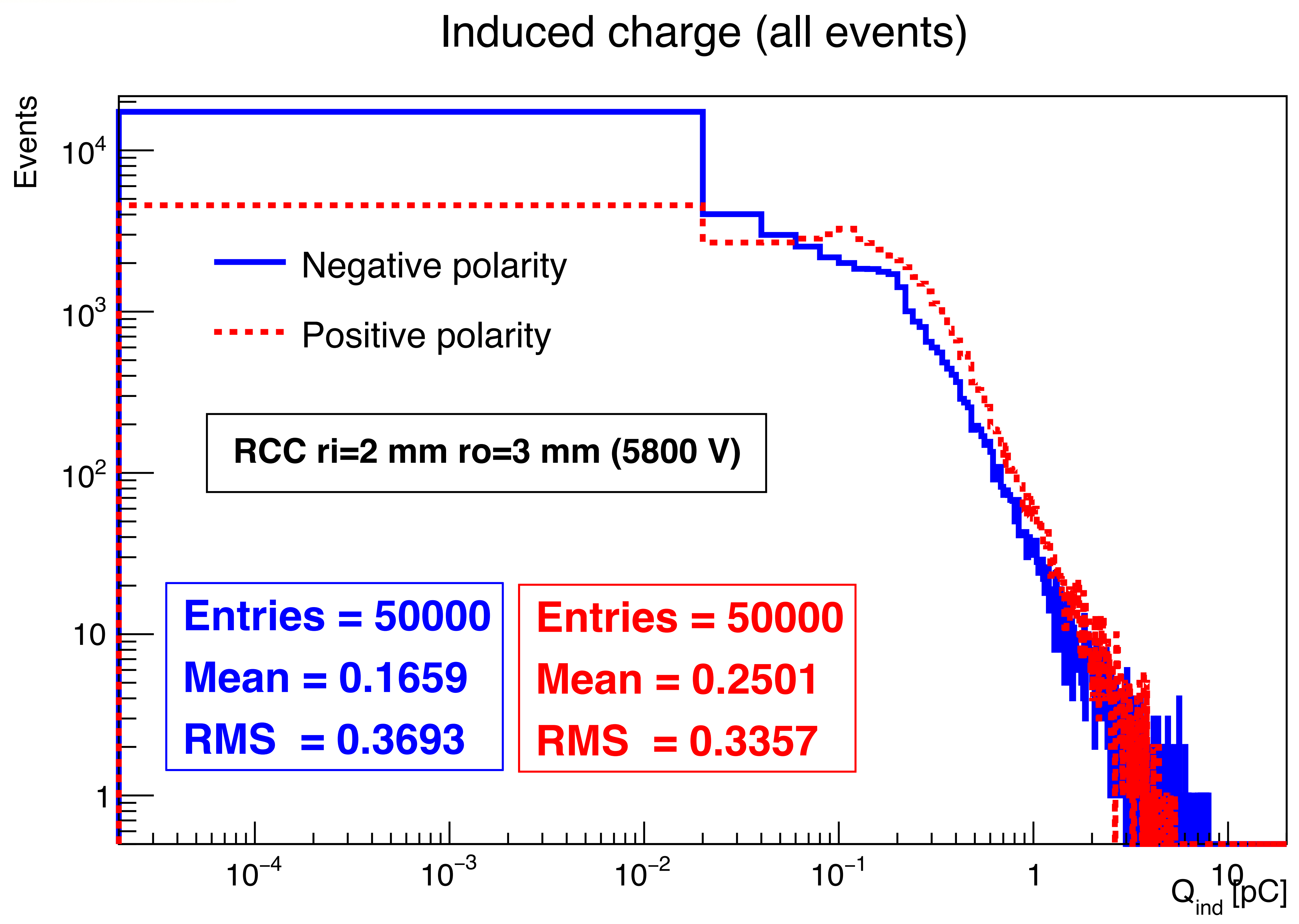
Simulation

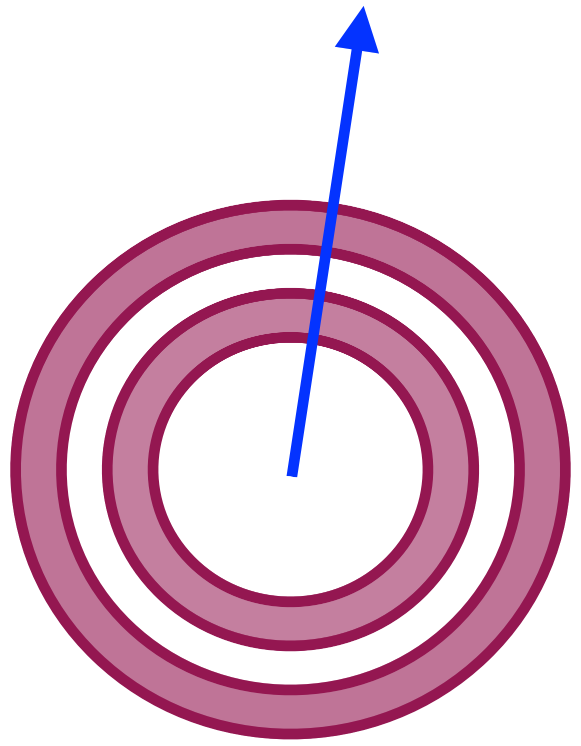




Electronic threshold for amplified signal: **20 fC**

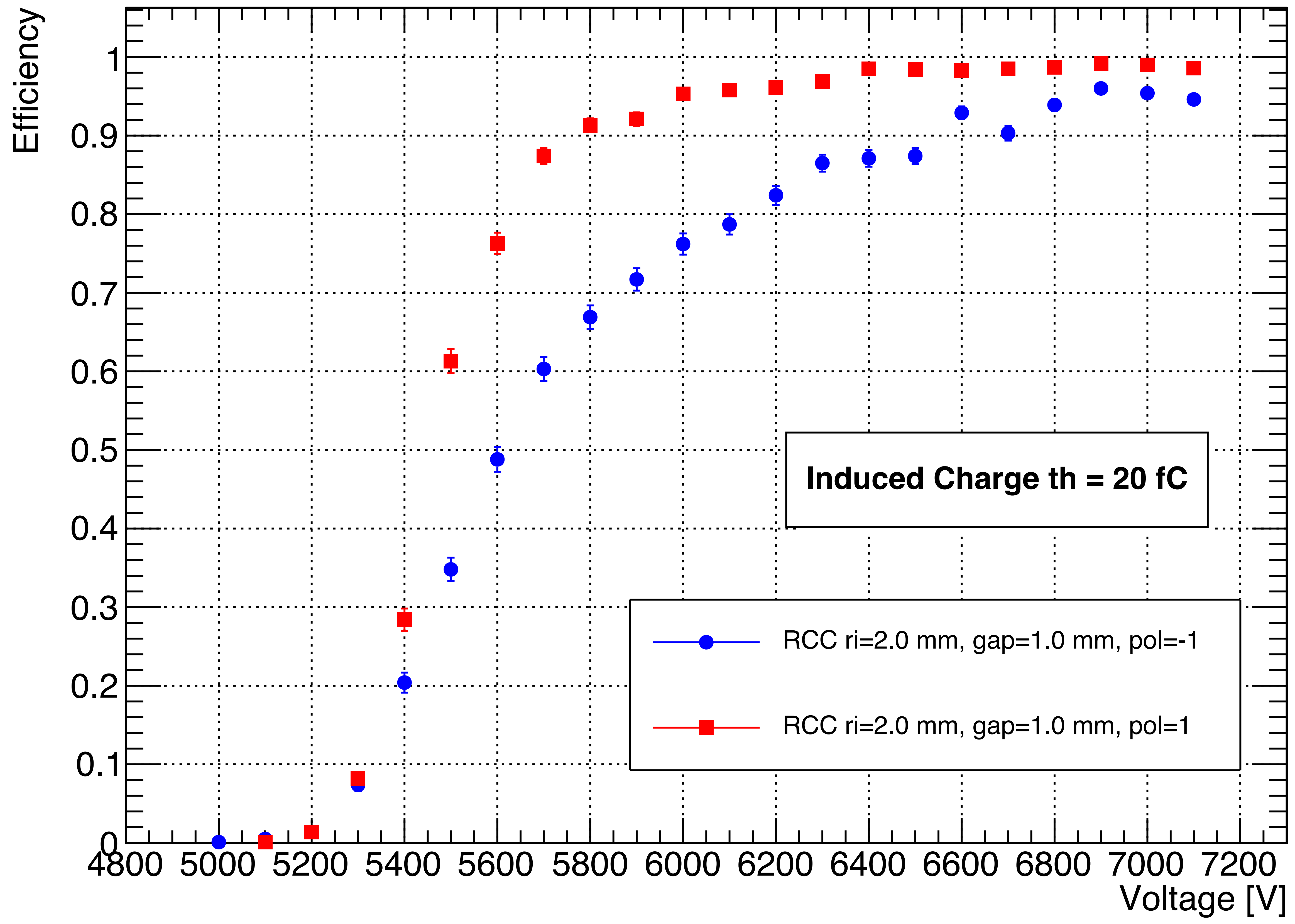
Full simulation: RCC 3-2 mm





Results shown for tracks starting from center

Polarity dependence reproduced by simulation

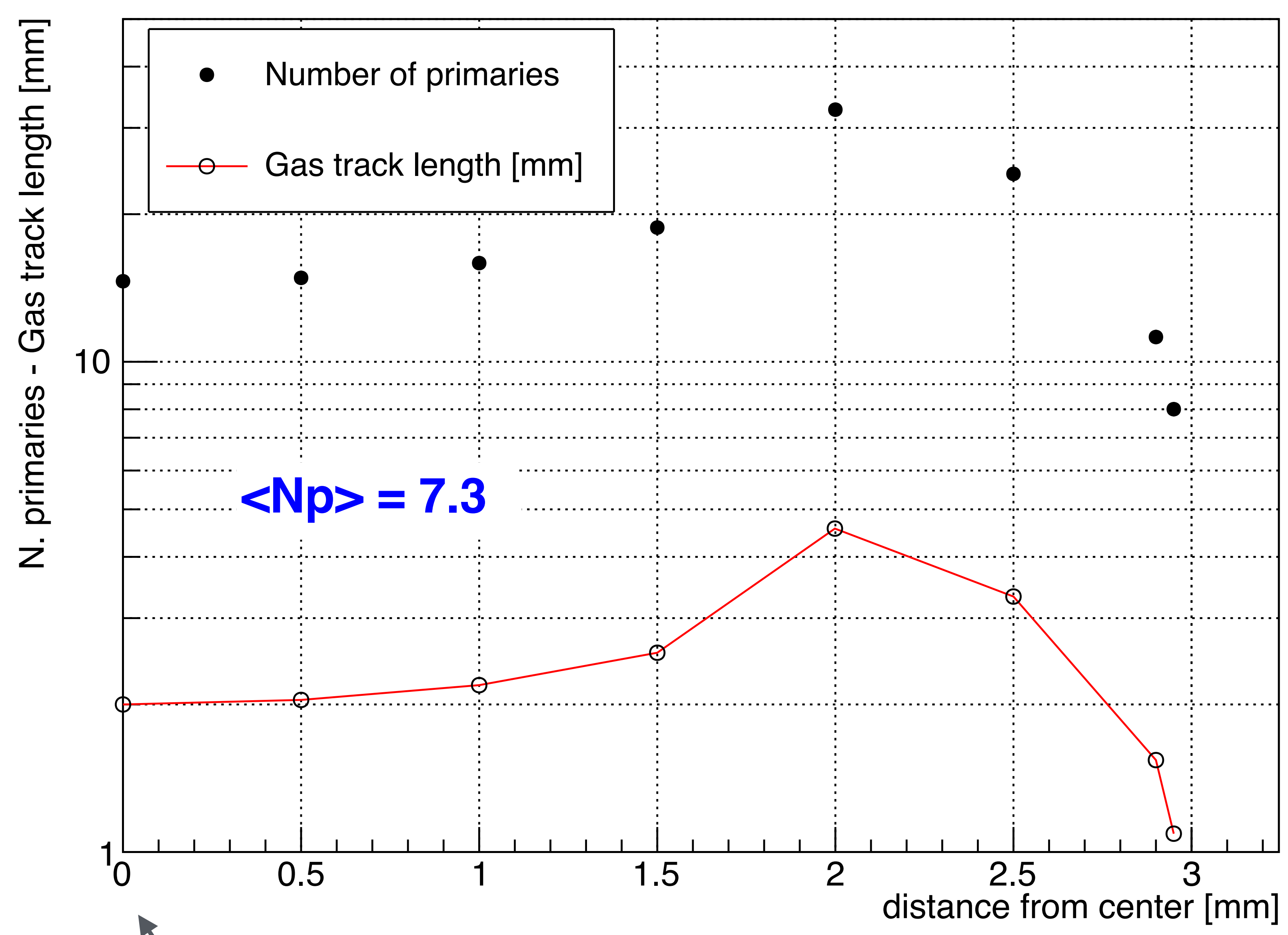


For a complete comparison to experimental data the code has to be extended for 3D simulation

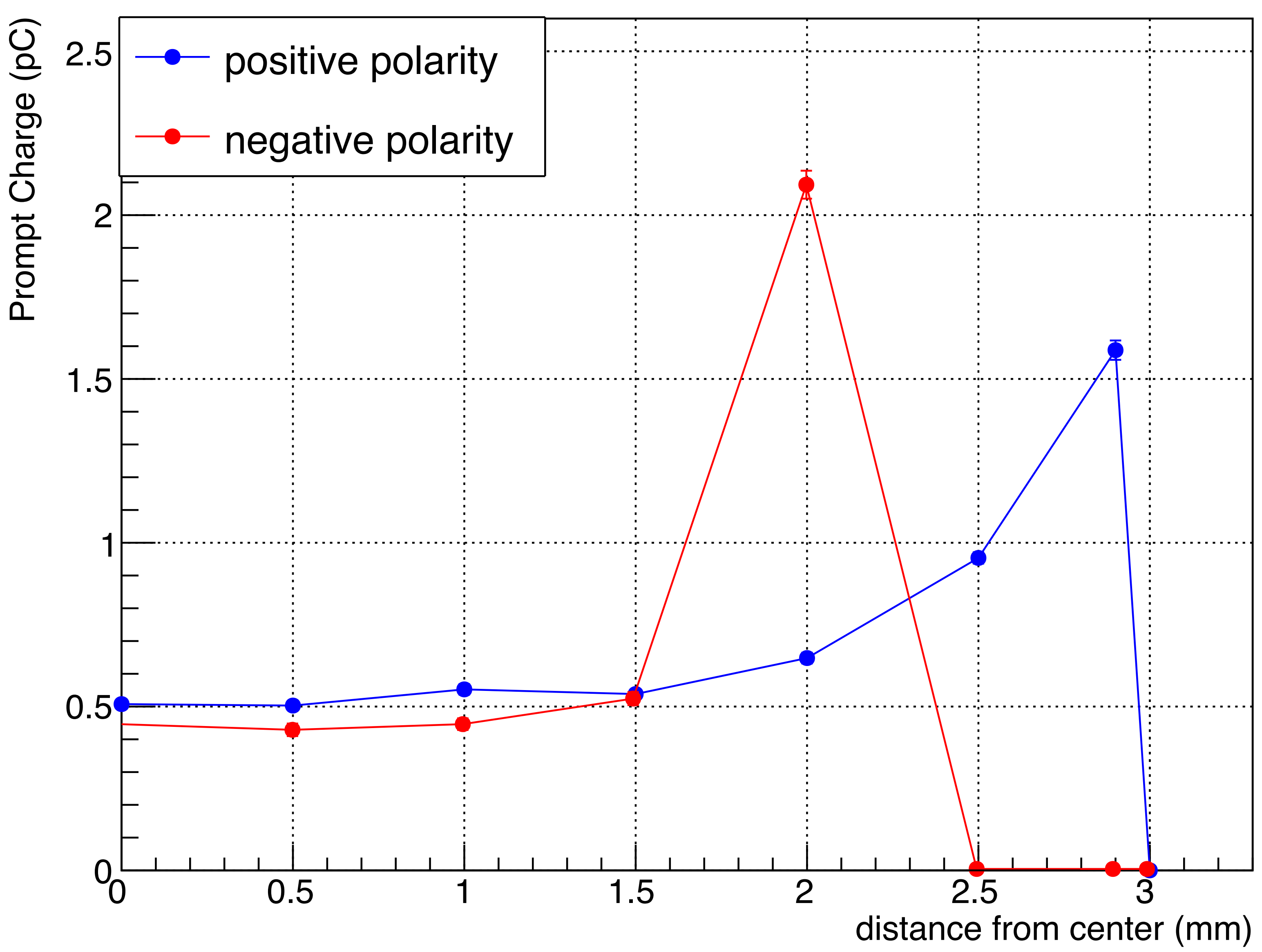
3D simulation RCC 2_3

5800 V. fth=20 fC

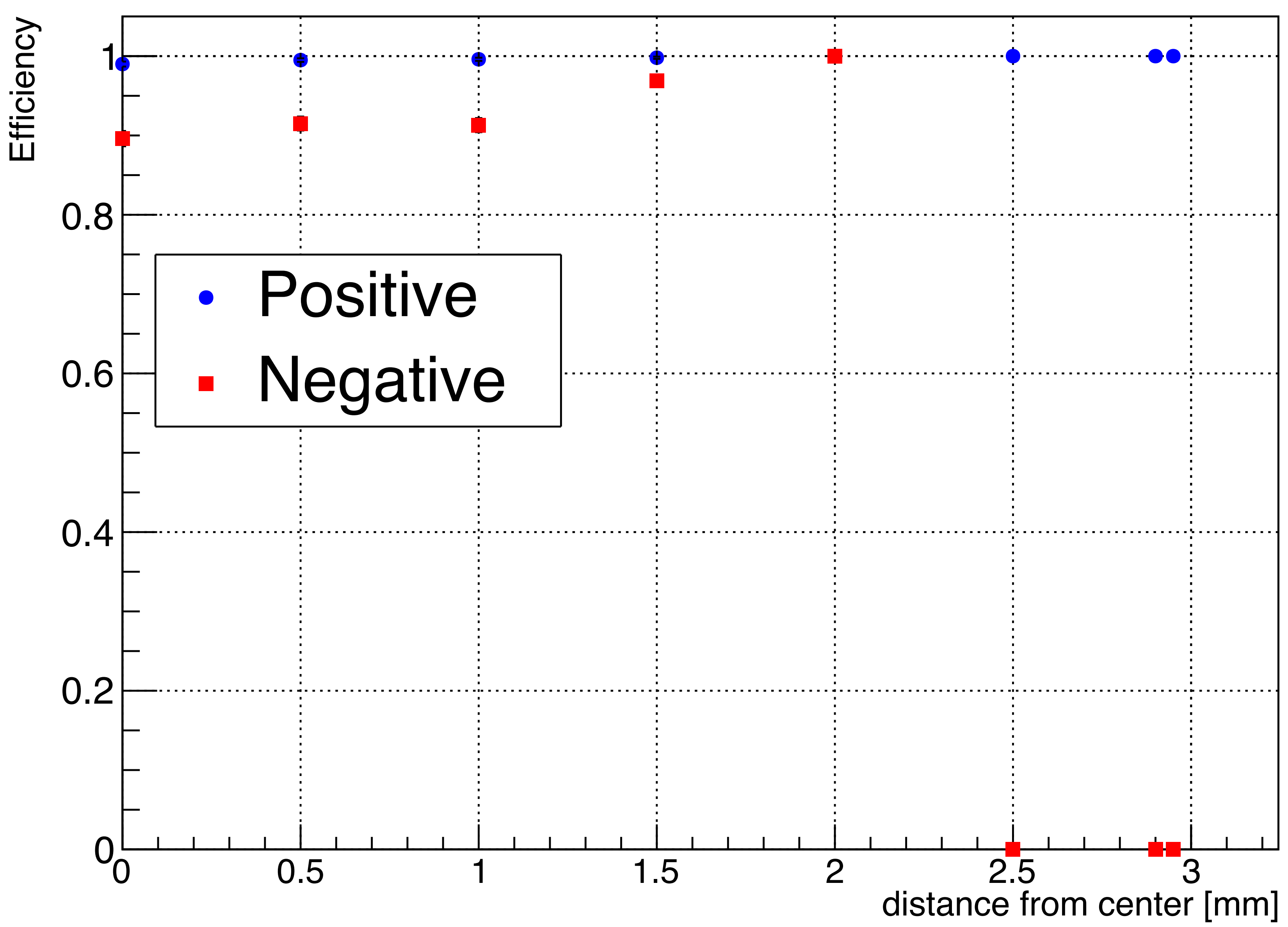
Number of primaries and Gas length

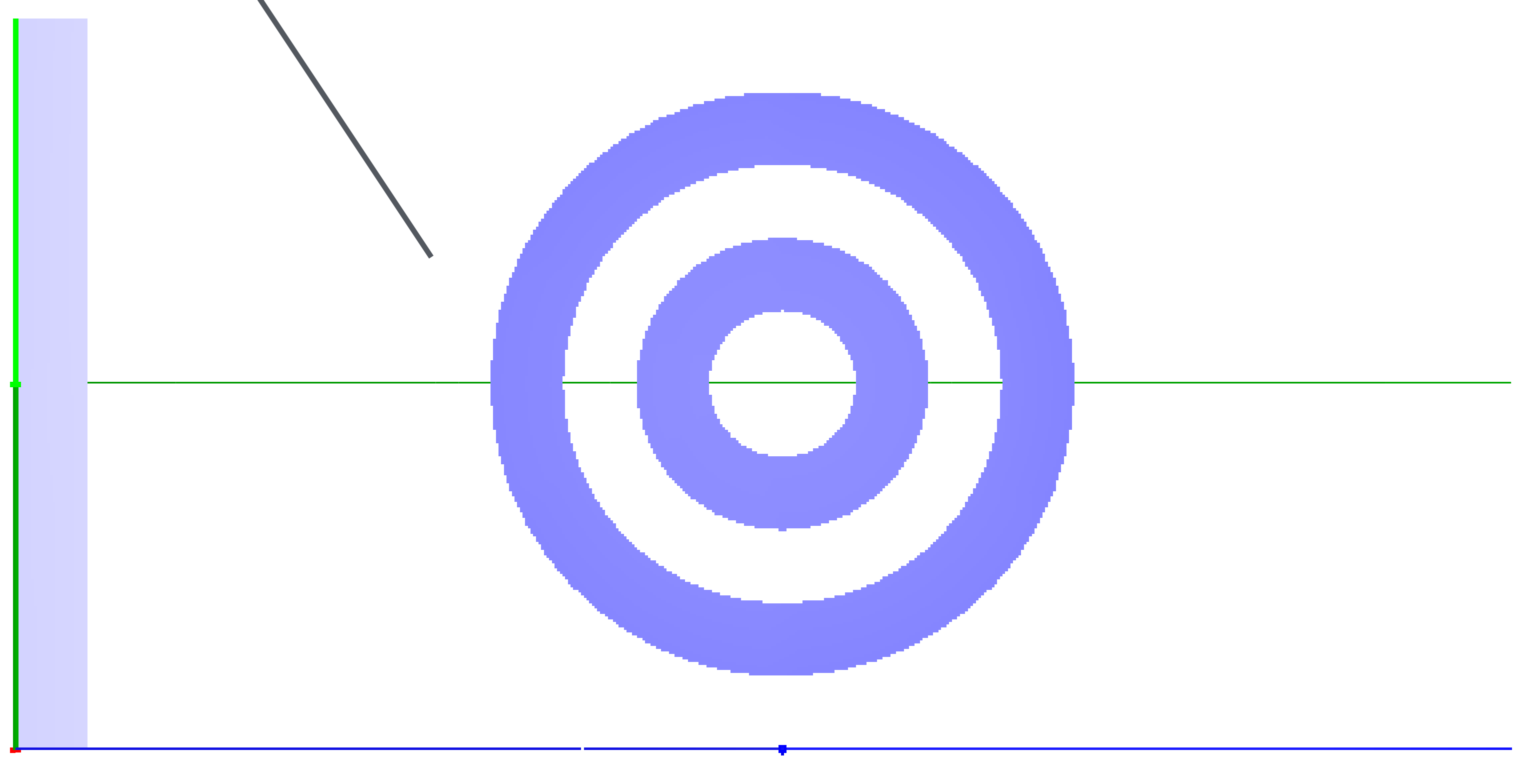


Induced charge



Efficiency





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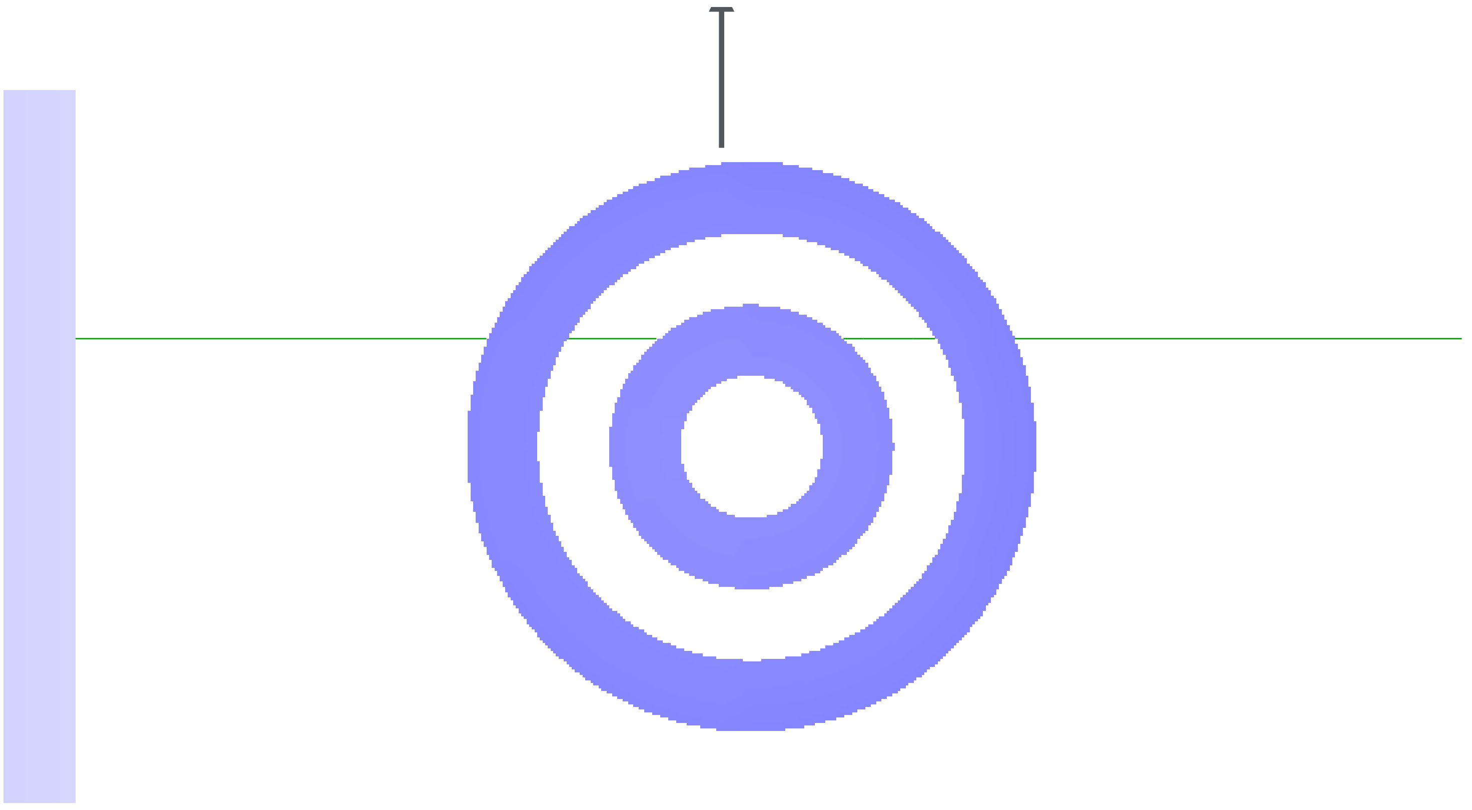
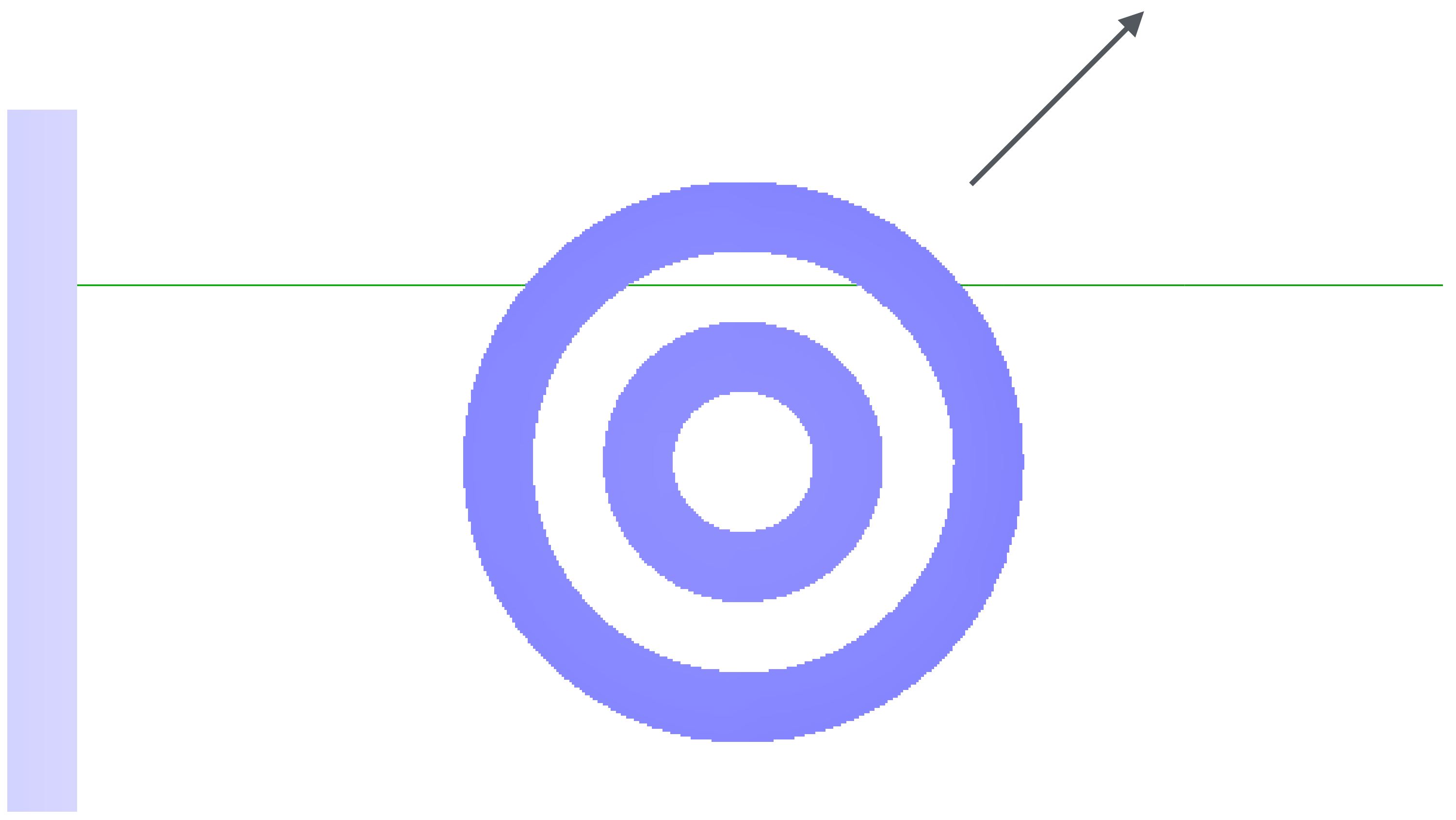


1.5 mm



2.5 mm

Resistive Cylindrical Chamber: RCC

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

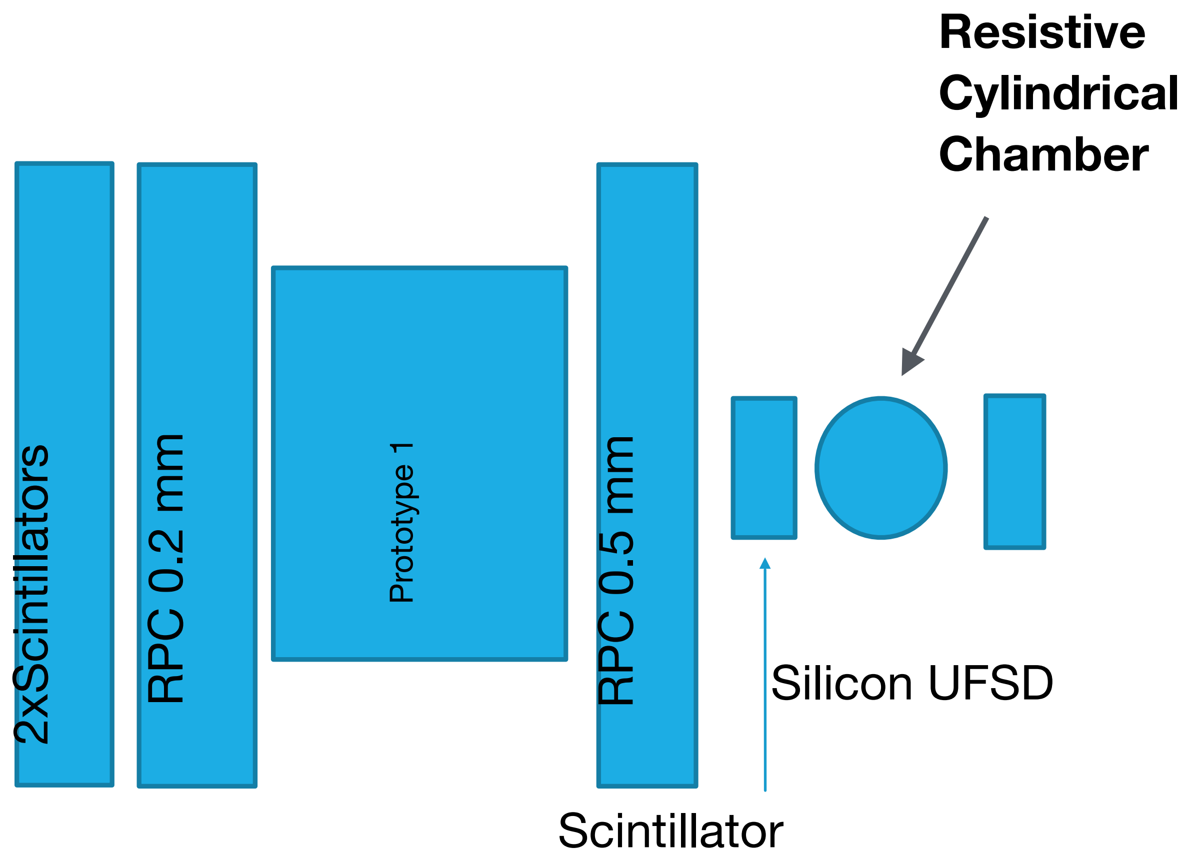
[**R. Cardarelli, A. Rocchi et al, The Resistive Cylindrical Chamber**. NIM Section A. Volume 1058,2024,168822-ISSN 0168-9002]

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

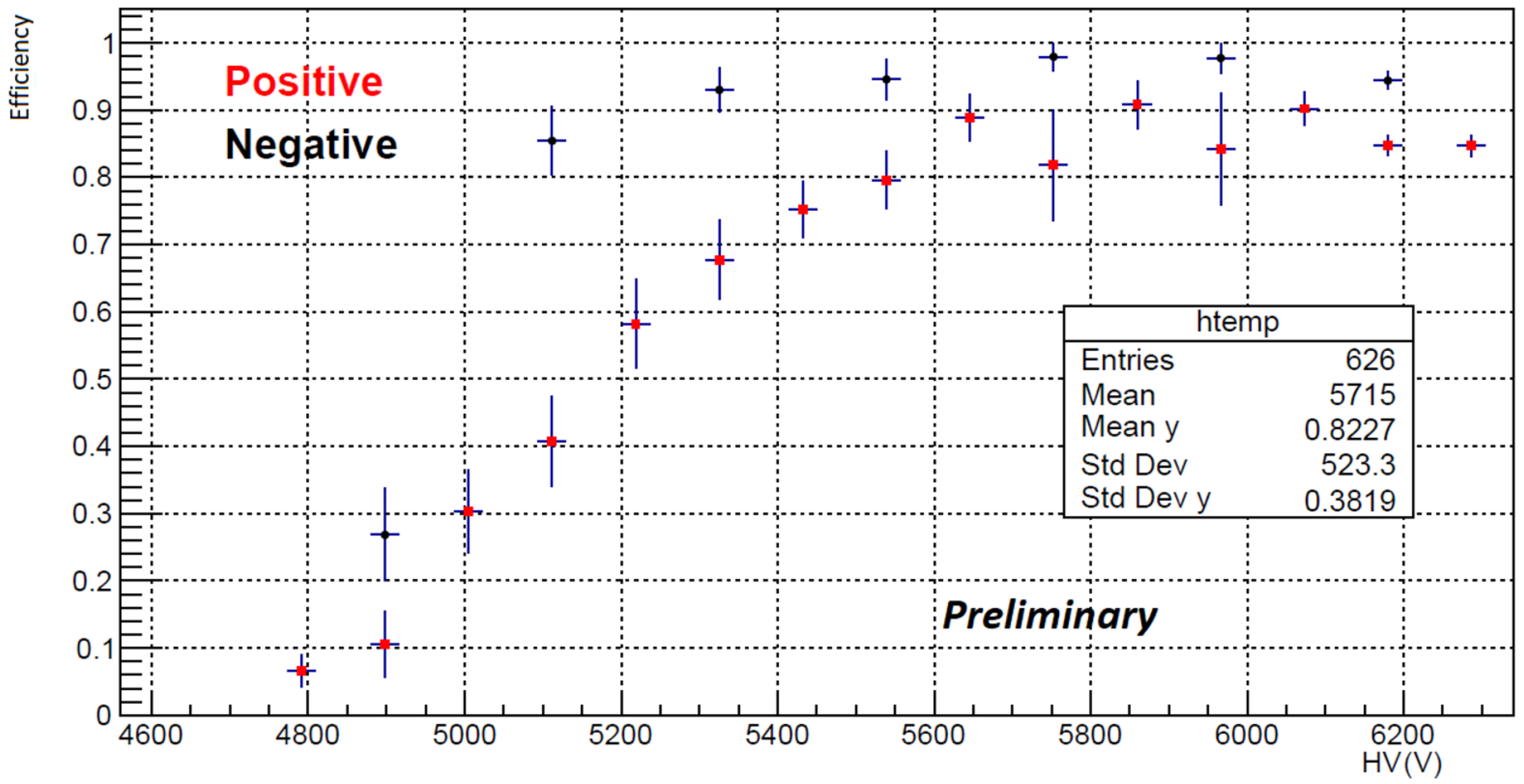
Experimentally characterized: [**A. Rocchi et al**, “**Efficiency and time resolution of a thin gap Resistive Cylindrical Chamber**.” Contribution to RPC2024 Conference

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

Test at CERN

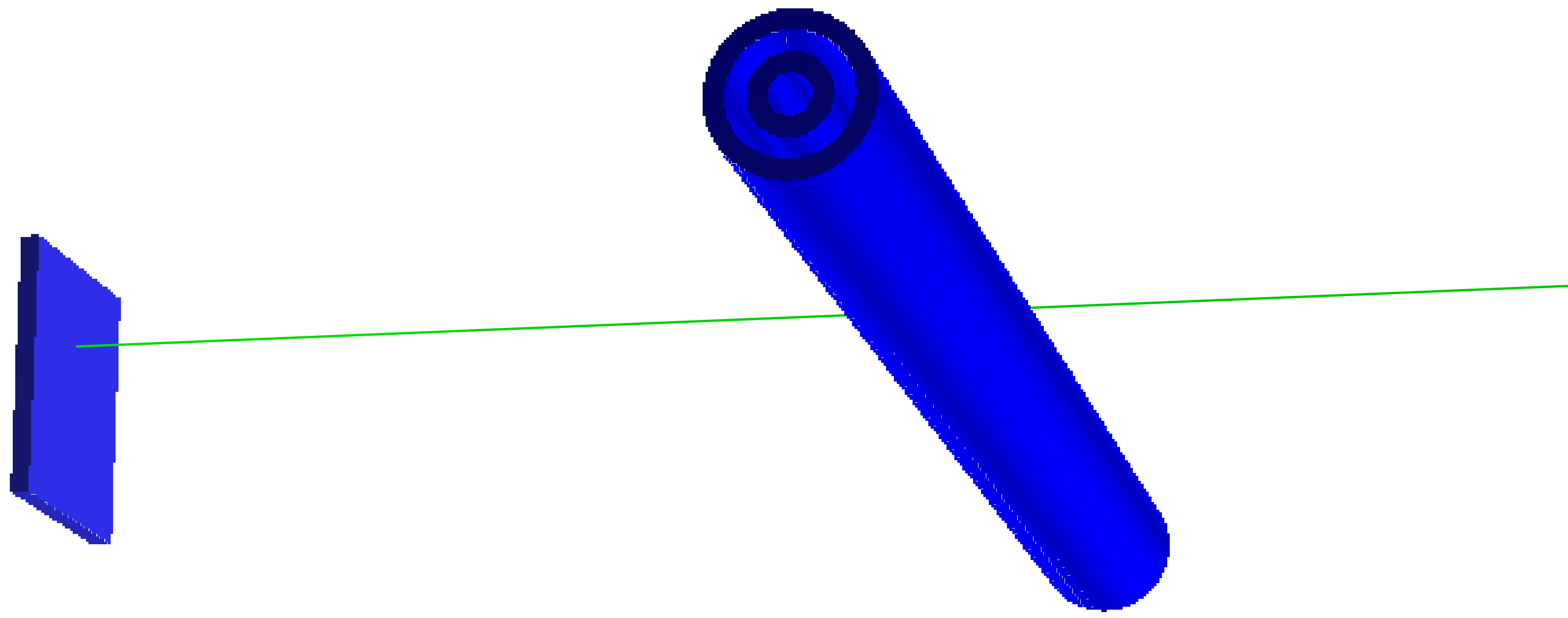


First experimental results from A. Rocchi



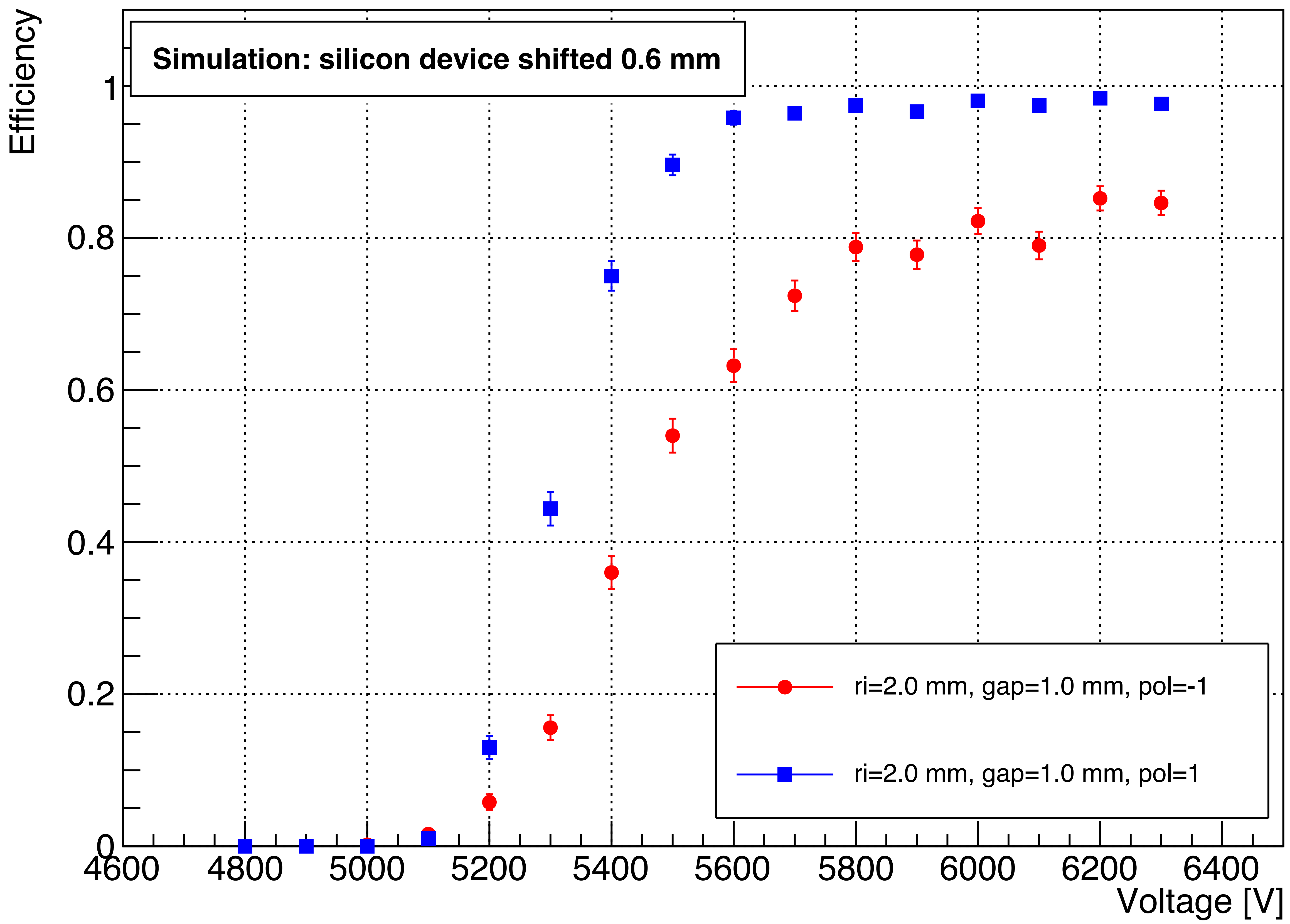
Hybrid RCC r_i=2 mm r_o=3 mm

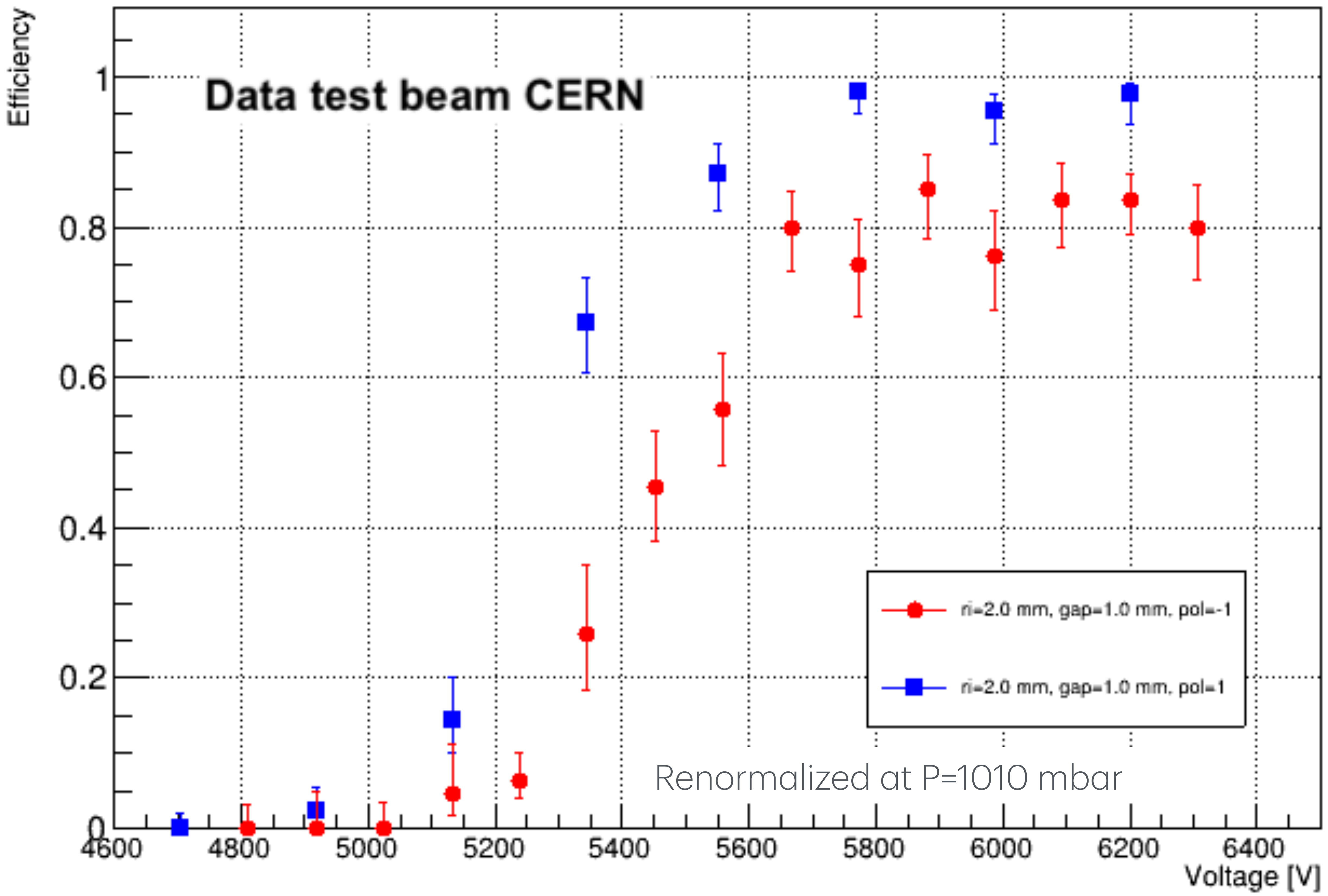
3D extension of the simulation



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

Comparison with experimental data

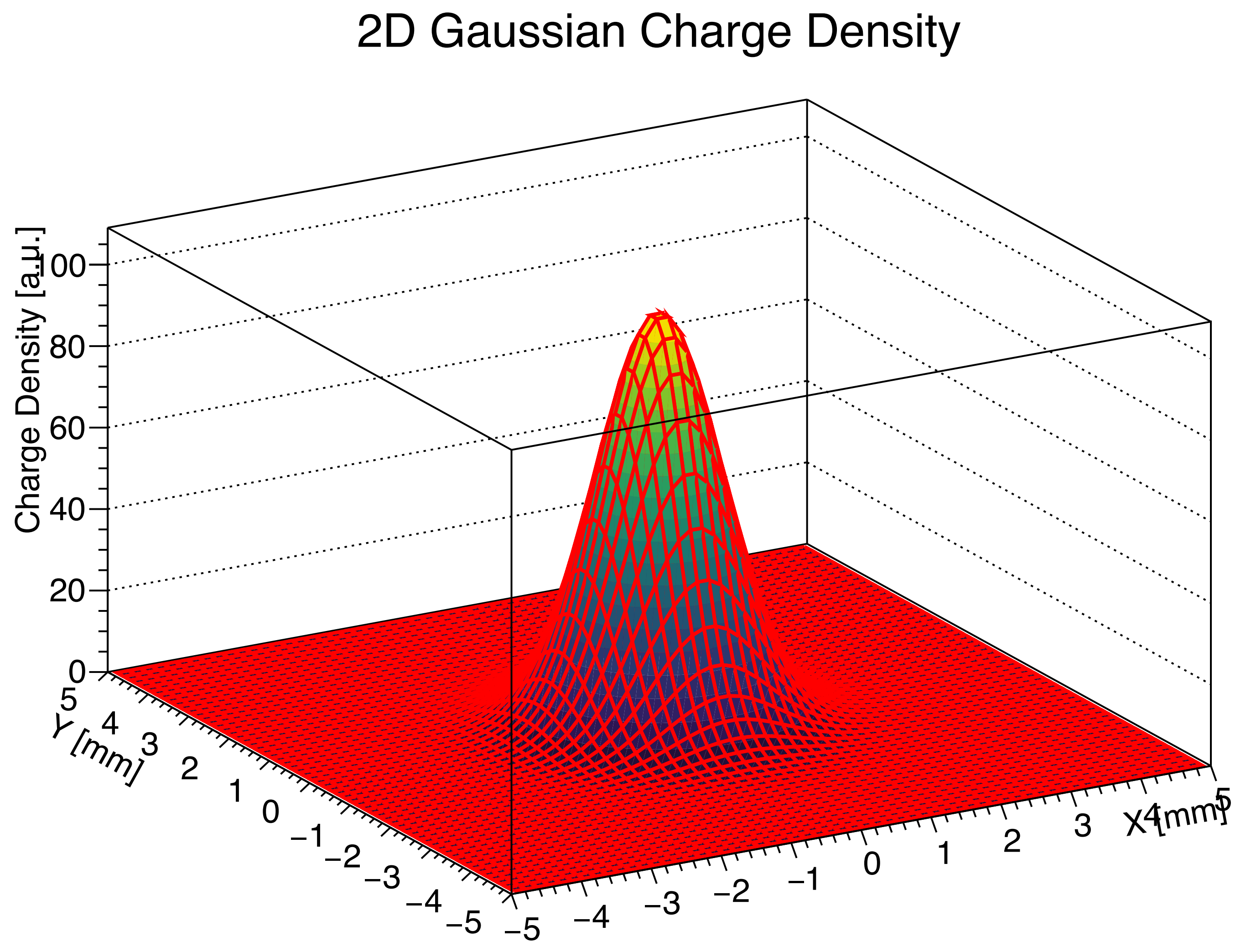




Electronic threshold set at 40 fC

Work in progress

Extension of the model to handle several avalanches at the same time.



Gaussian 2D distribution for space charge:

Electric field on the axis

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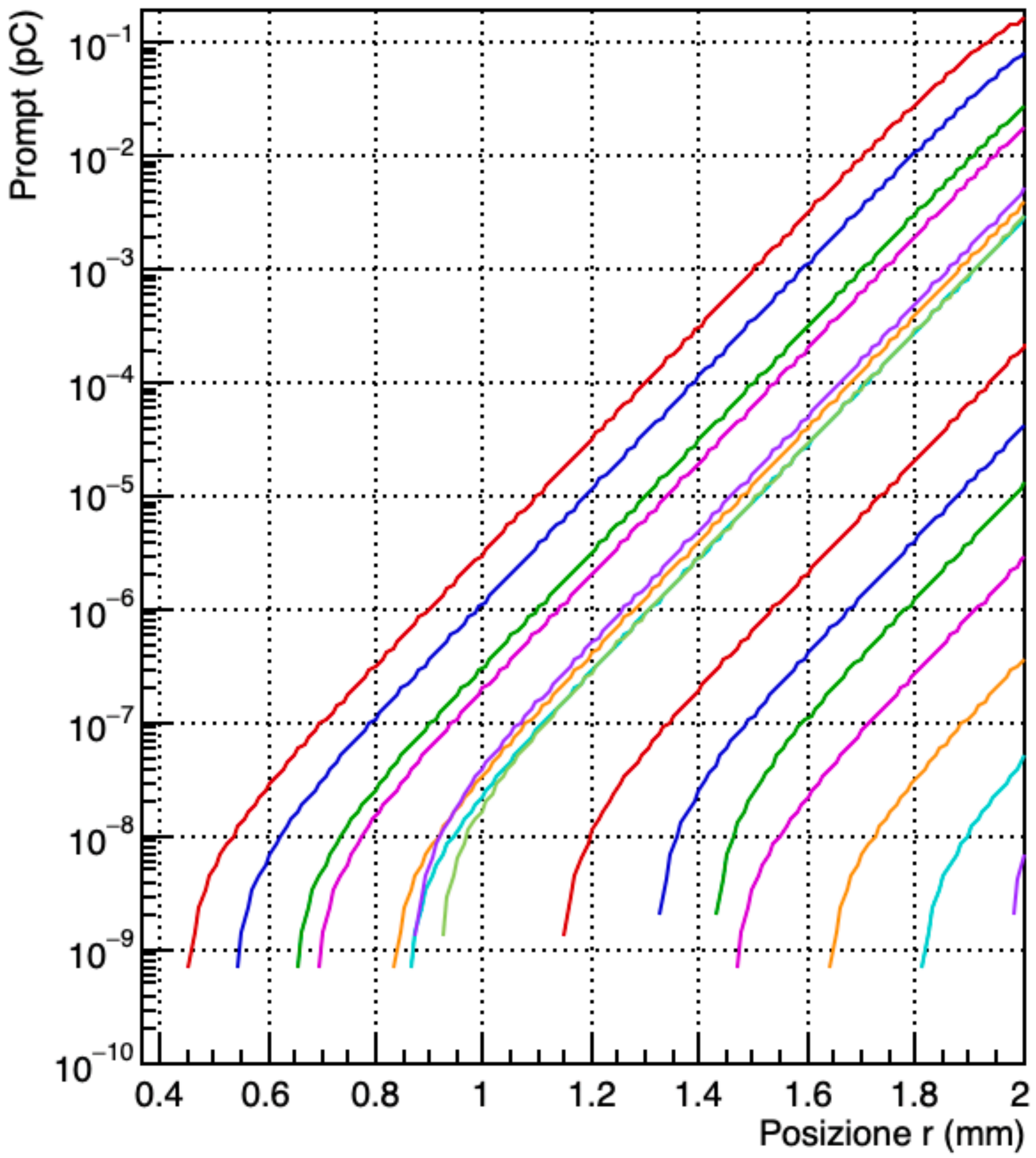
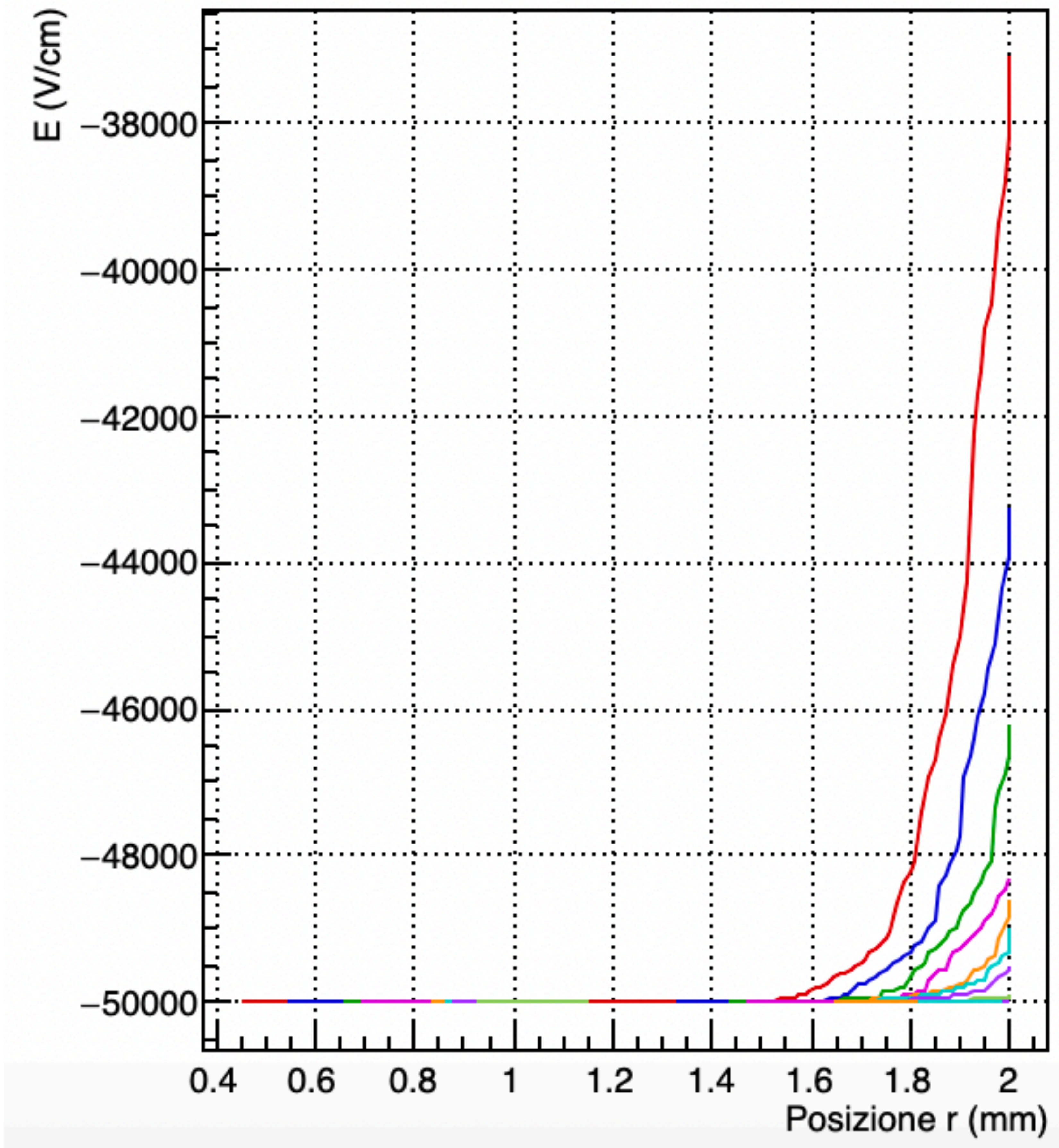
Fine tuning in progress



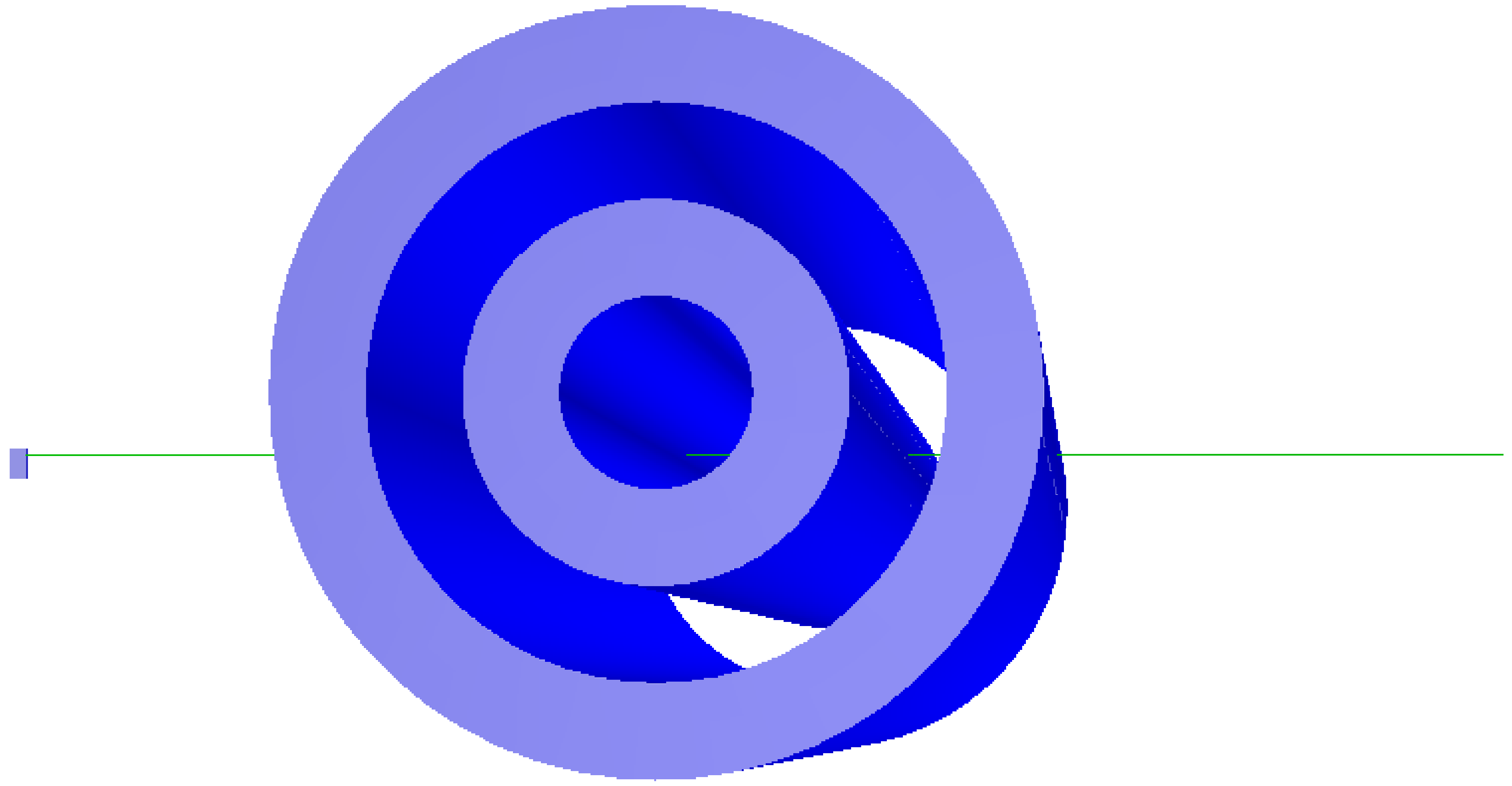
Preliminary

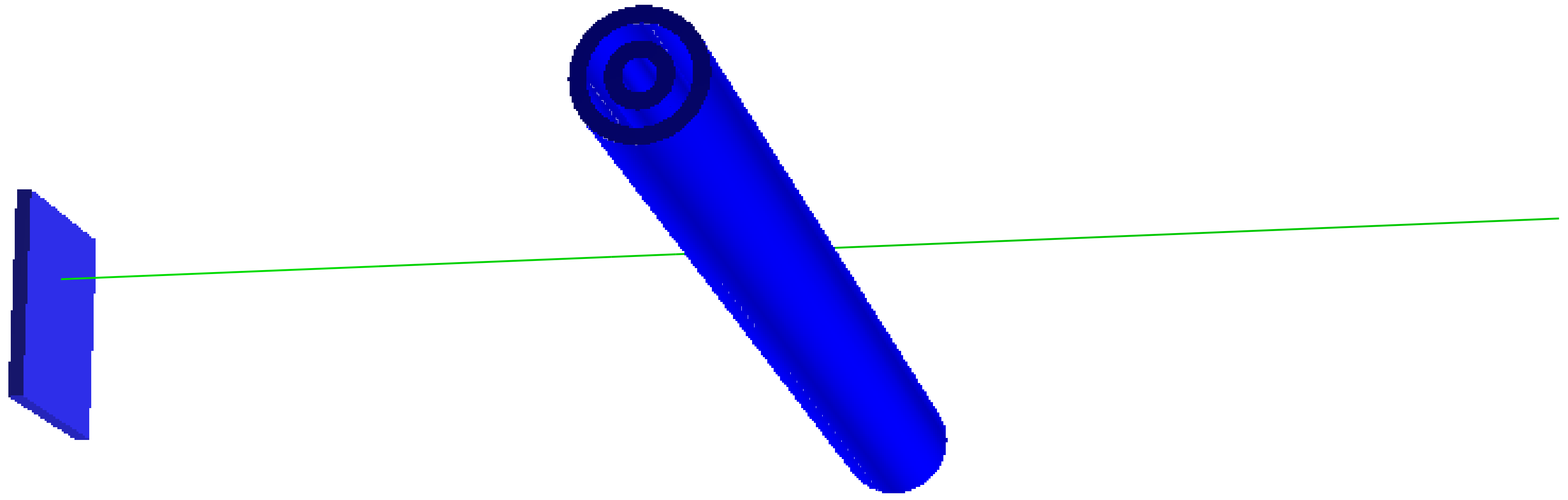


Conclusions

- 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;**
  - **First highlights on the characteristics of the RCC** device have been explored. The simulation reproduce the polarity dependence and efficiencies vs HV in the correct direction with respect to experimental results;
  - M. Abbrescia, D. Piccolo *et al.* **A standalone simulation program for resistive cylindrical chamber (RCC).** Eur. Phys. J. C 86, 351 (2026). https://doi.org/10.1140/epjc/s10052-026-15576-5
  - The tool will guide the experimental program of the TANGO_RD project.
    - **We look forward to compare more RCC results**
  - Dynamic contributions among different avalanches implemented:
    - Fine tuning in progress to improve space charge contributions in a proper way

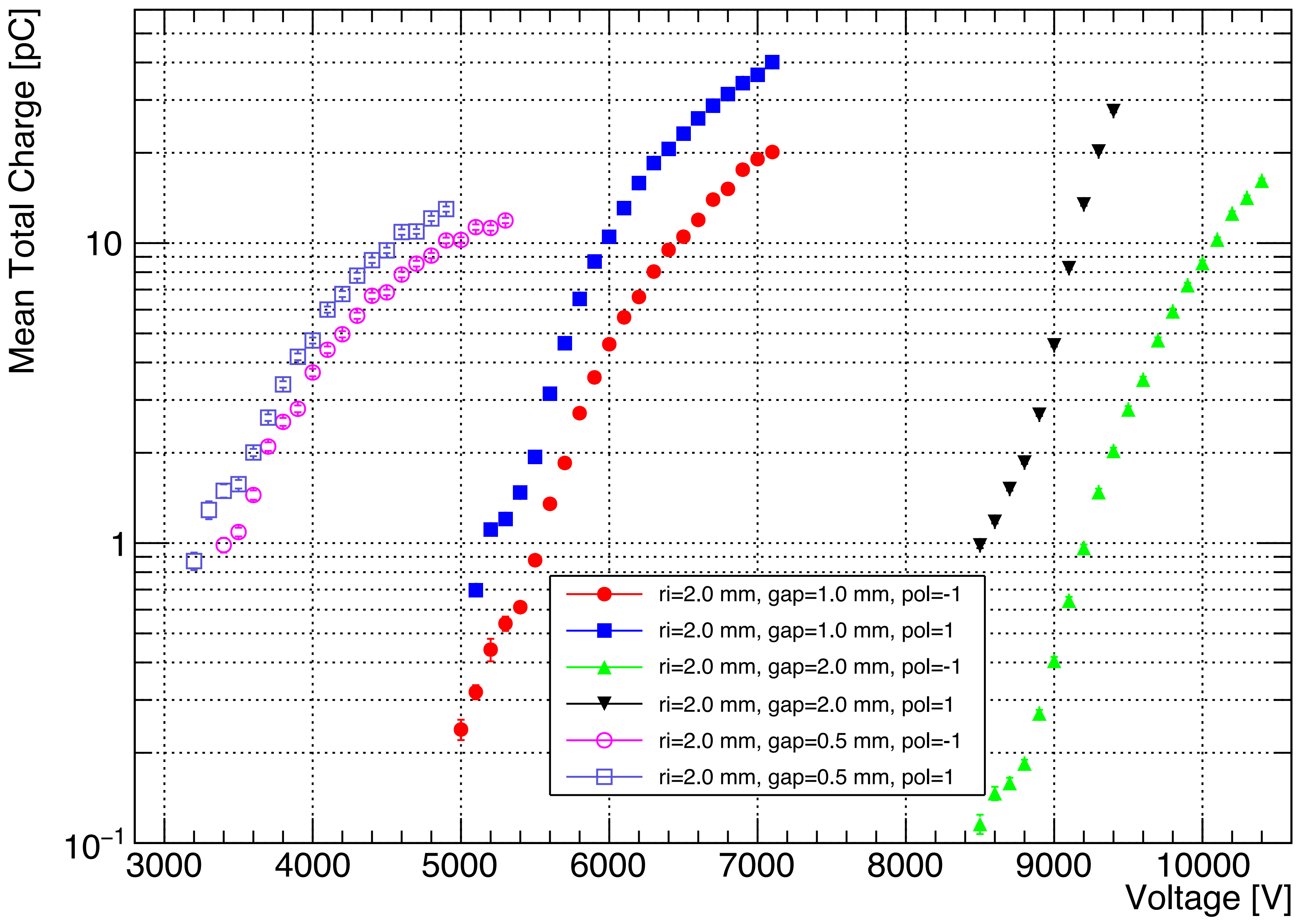
3D simulation

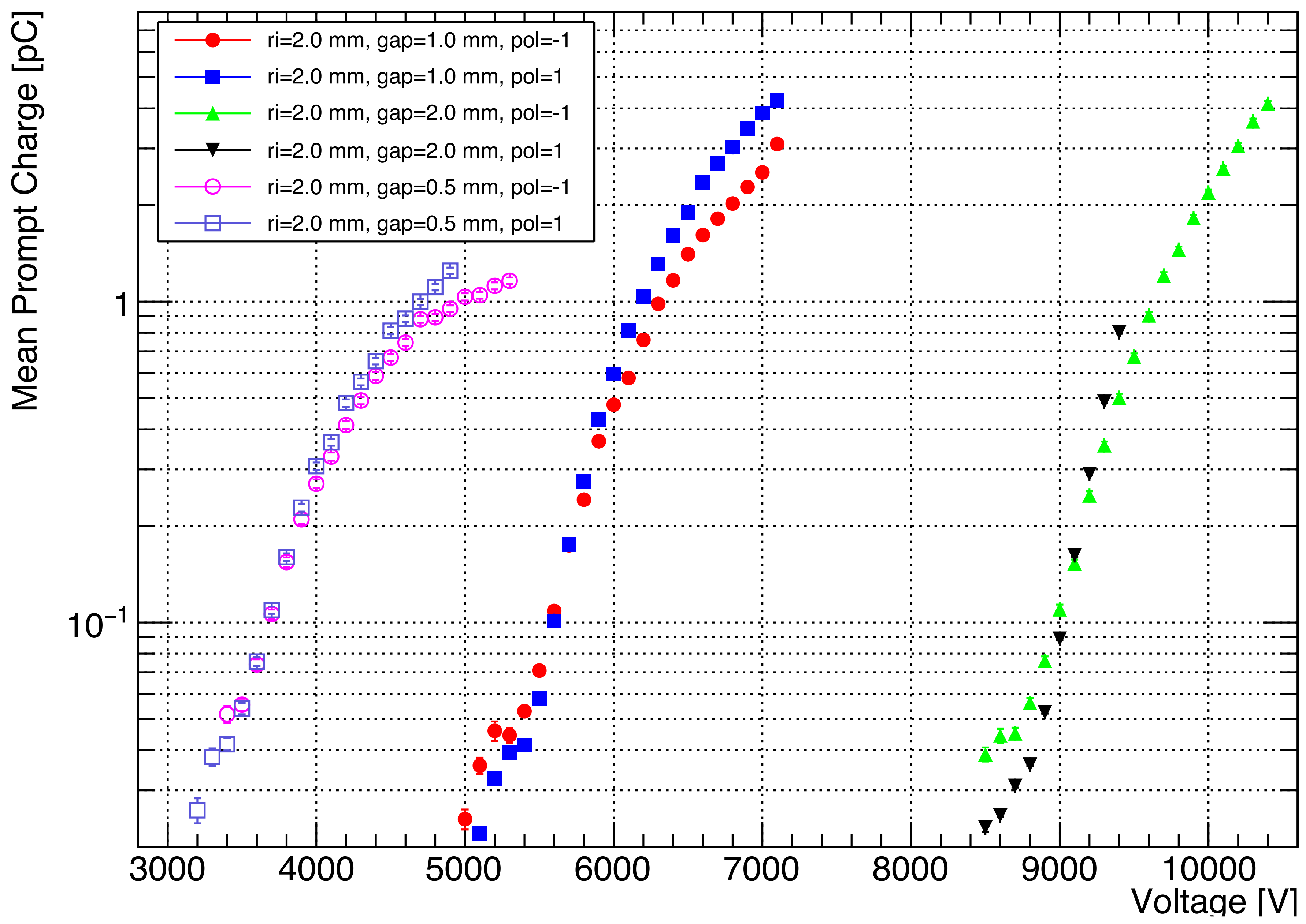


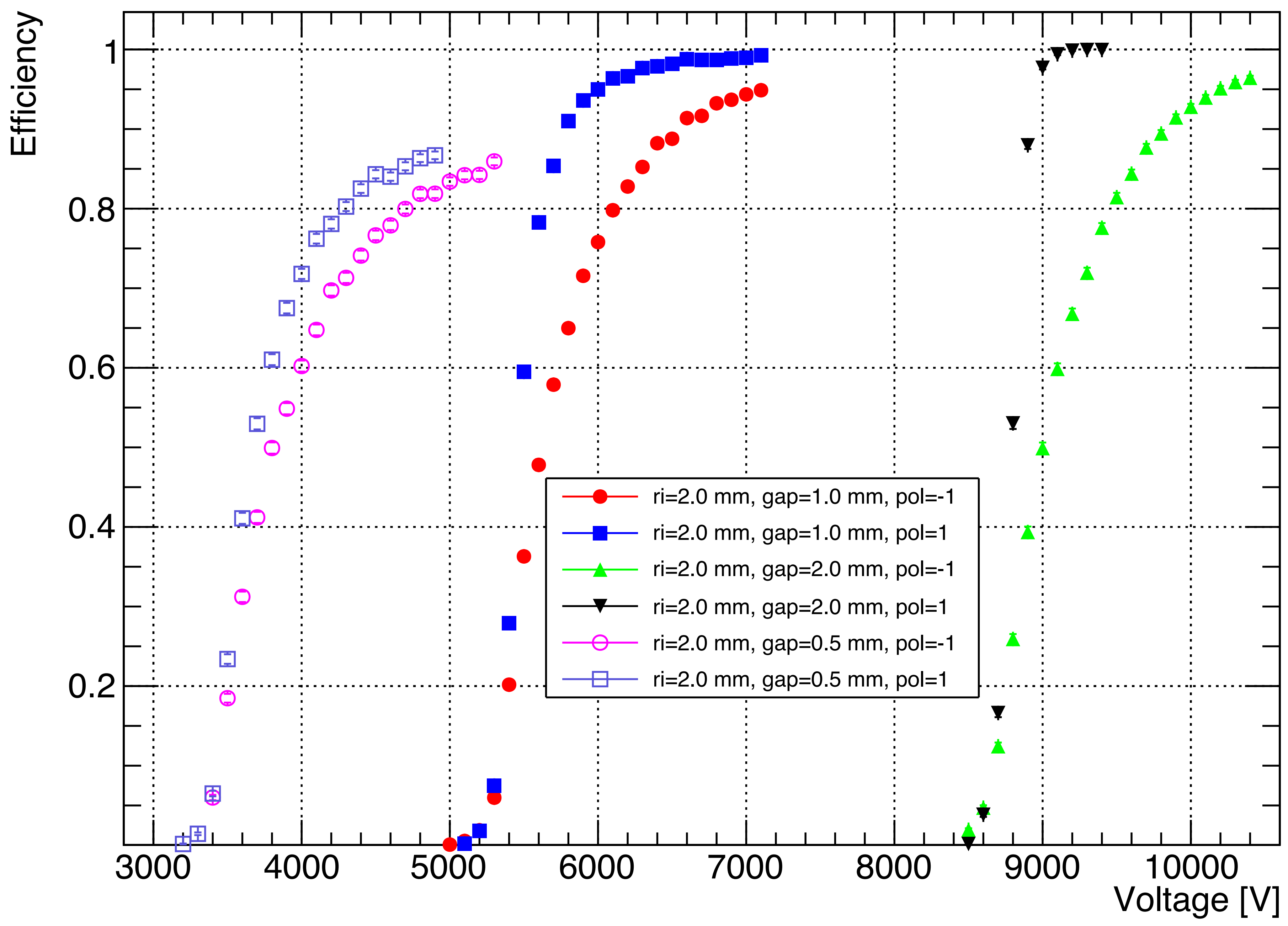


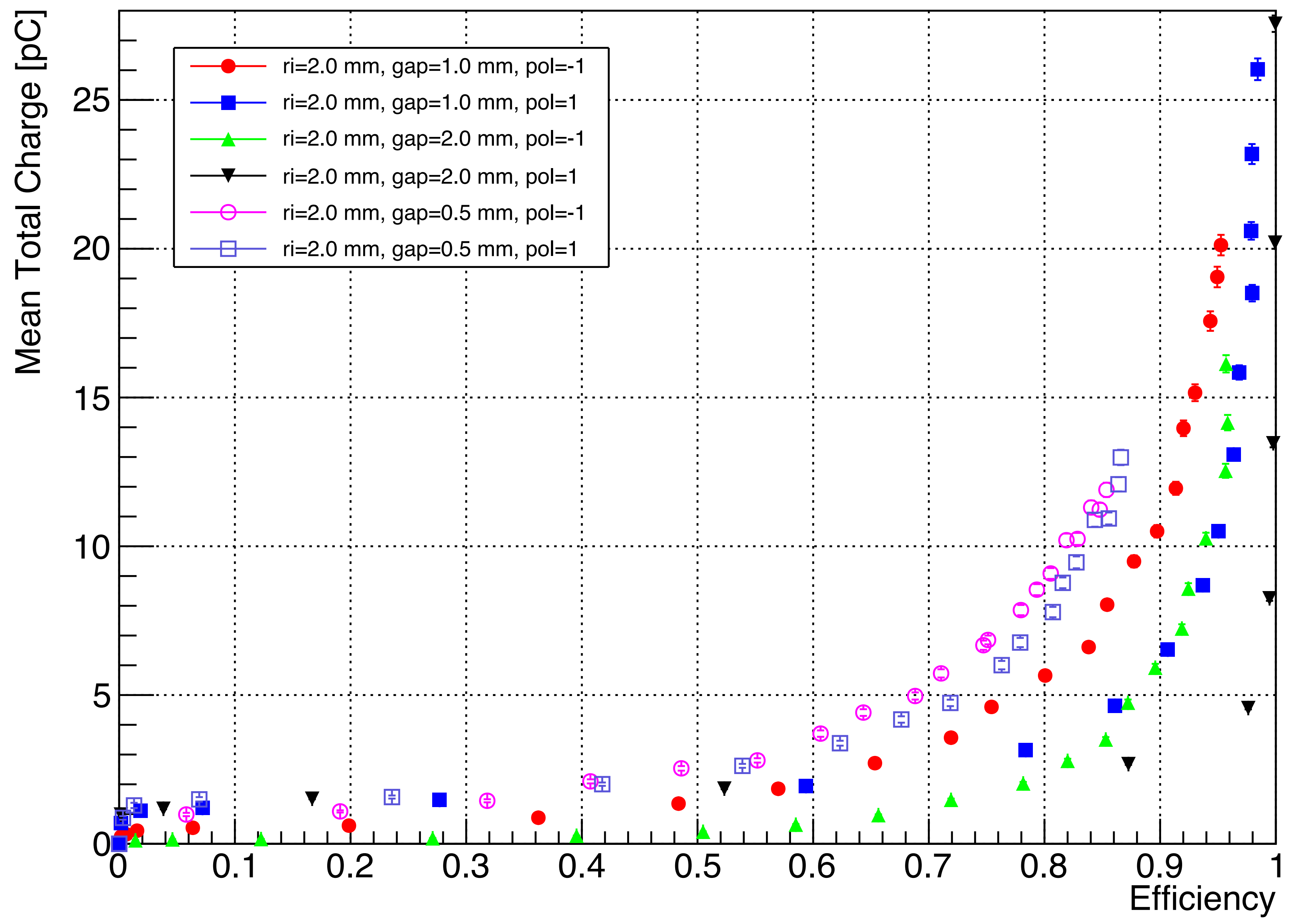
TANGO_RD

Gap dependence (ri=2mm)



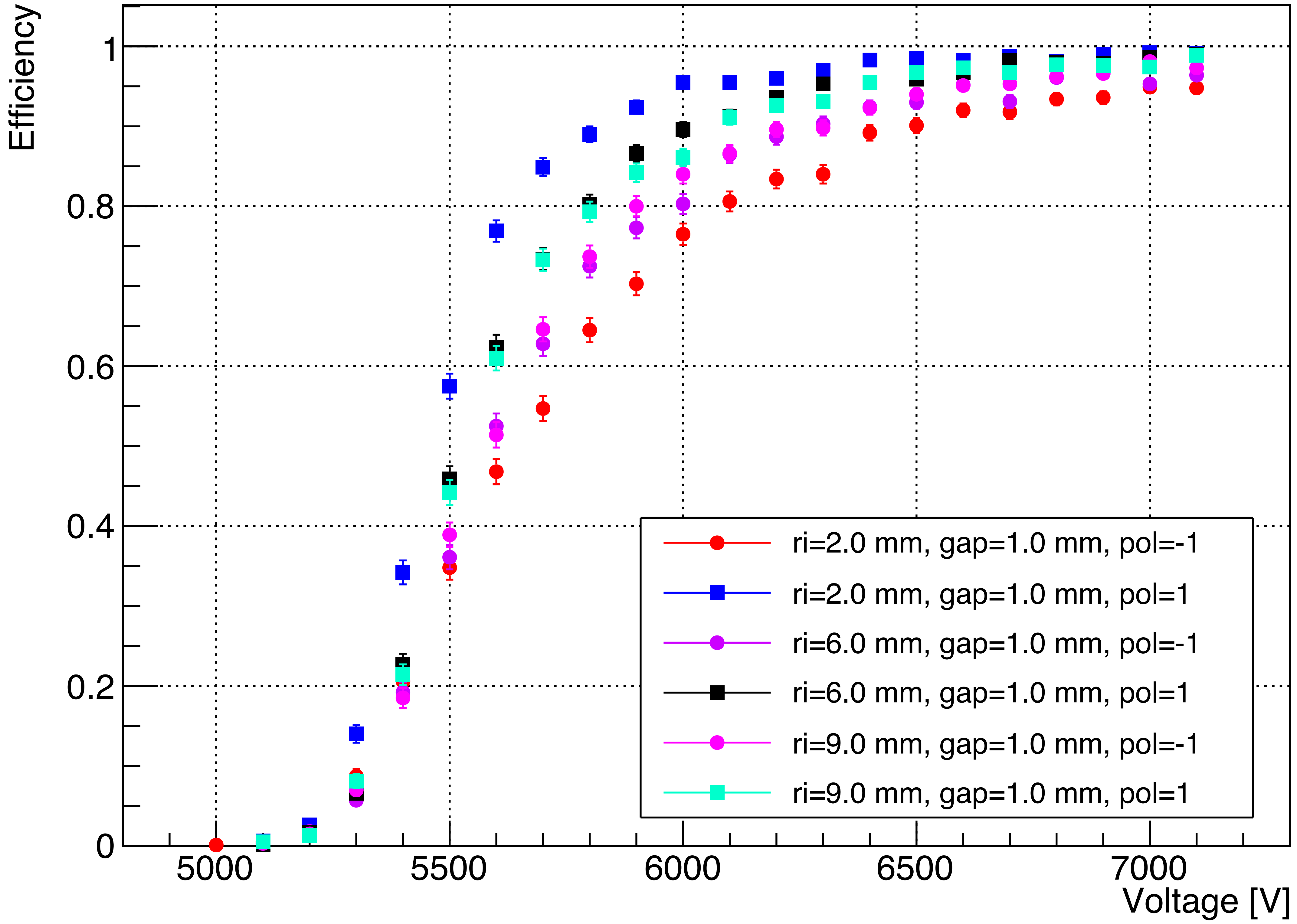


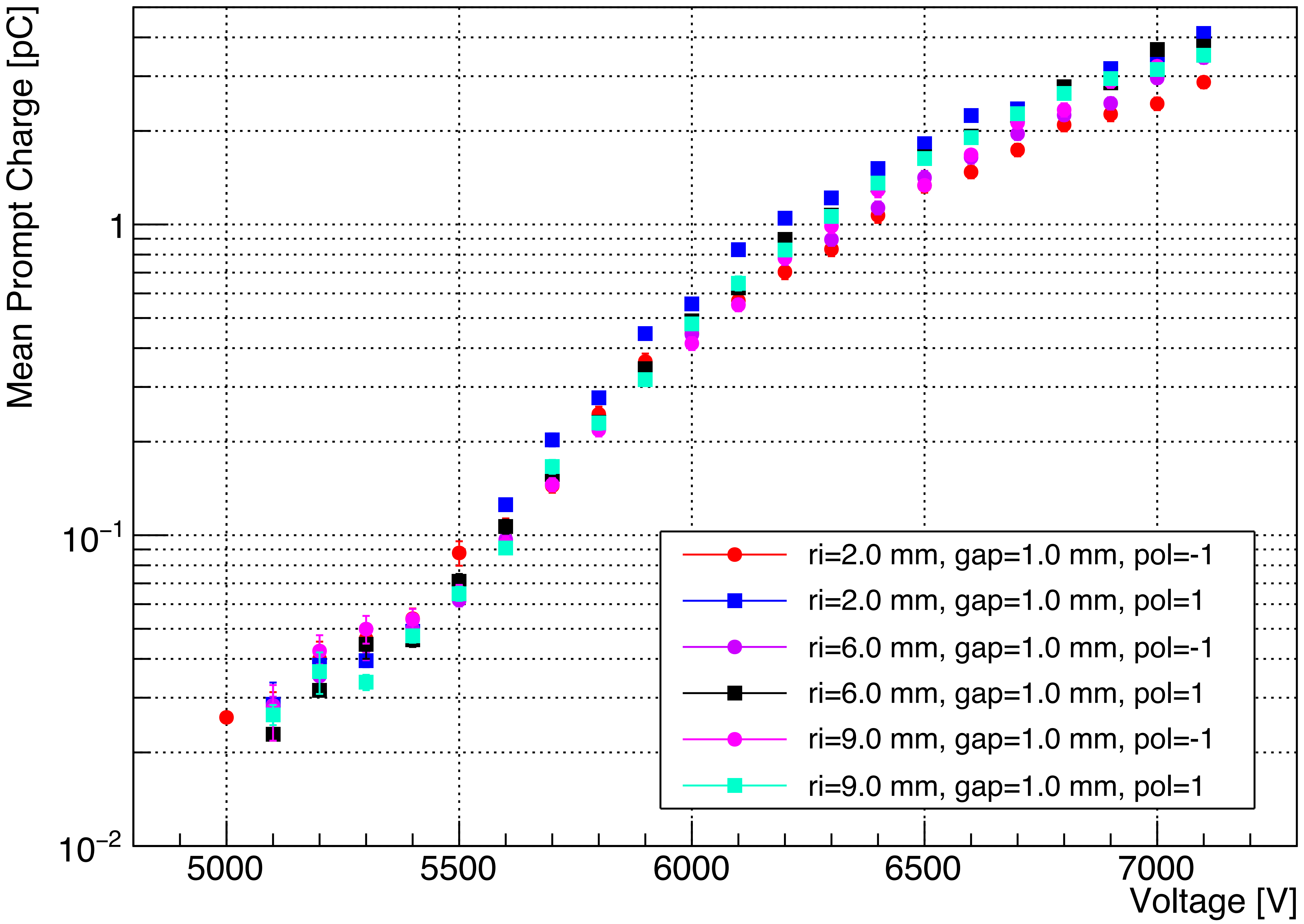




A tool to guide experimental studies

Radius dependence (Gap 1 mm)





Work in progress

TANGO_RD

INFN
Istituto Nazionale di Fisica Nucleare

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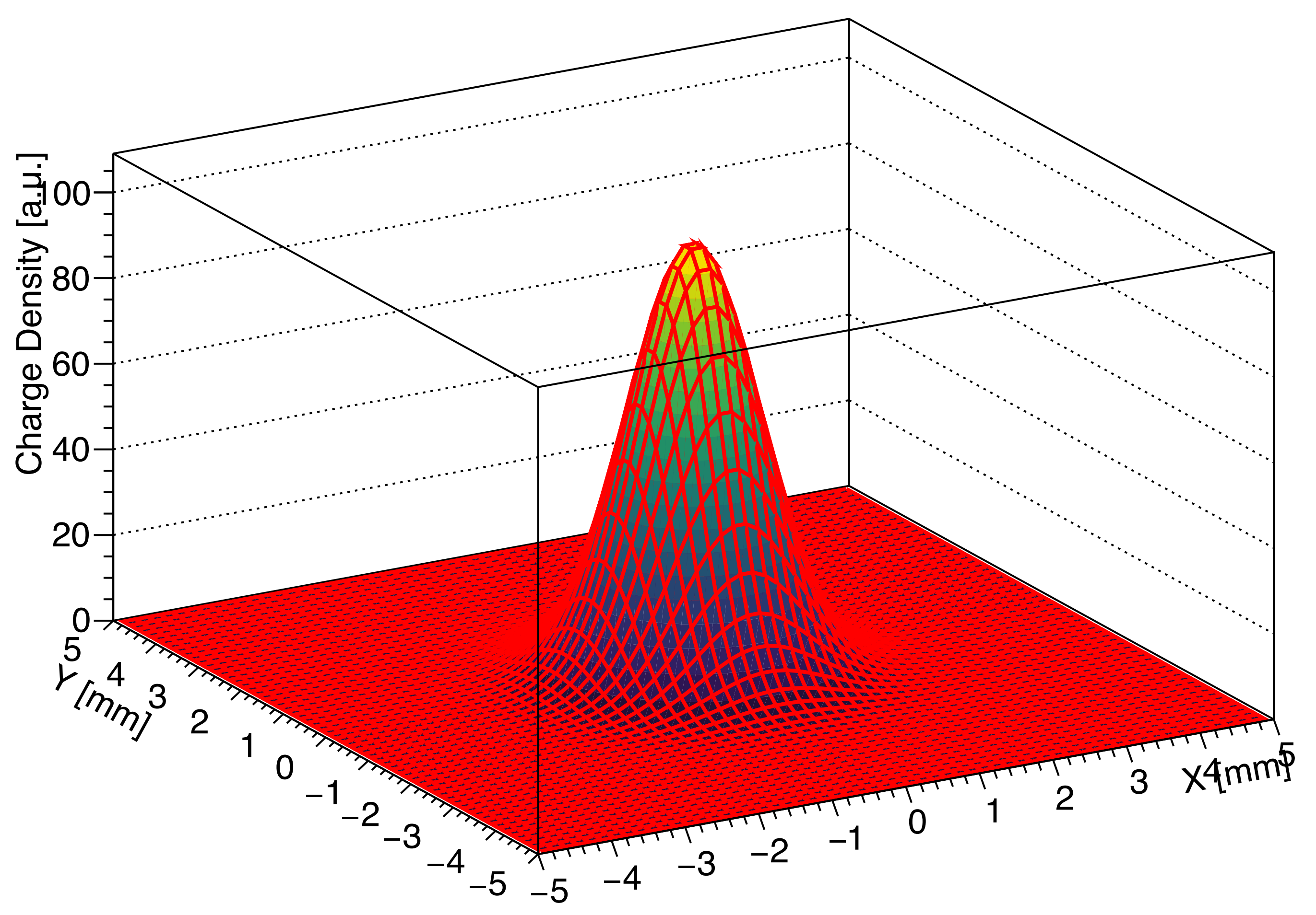

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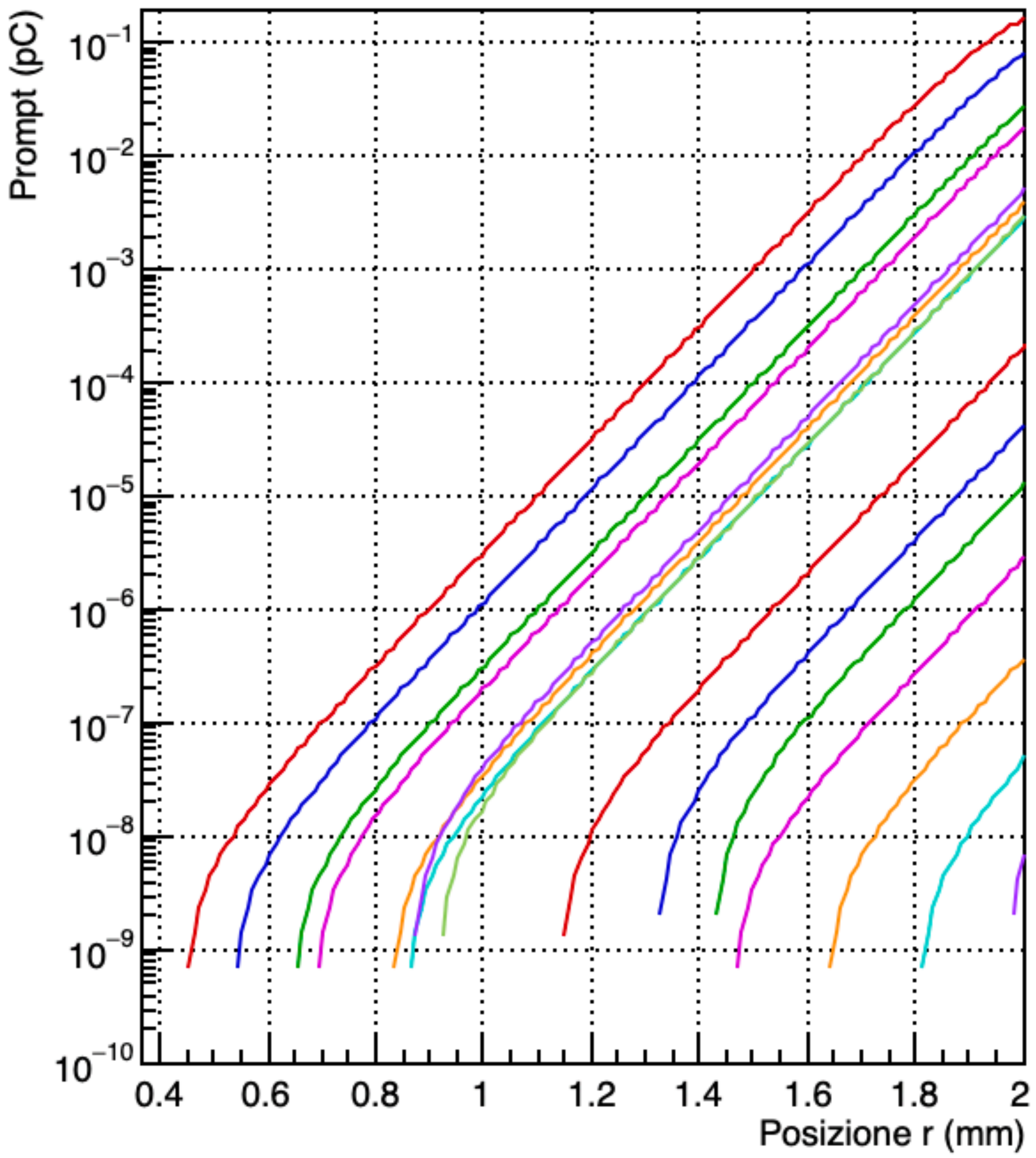
$$\zeta = \frac{|s|}{\sqrt{2}\,a}$$

$$\mathrm{erfc}(x) = 1 - \mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}\int_x^\infty e^{-t^2}\,dt$$

Fine tuning in progress



Preliminary