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Secondary standard dosimetry: Understanding the ionization chambers for the future ultra-high dose rate applications

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Disclosure

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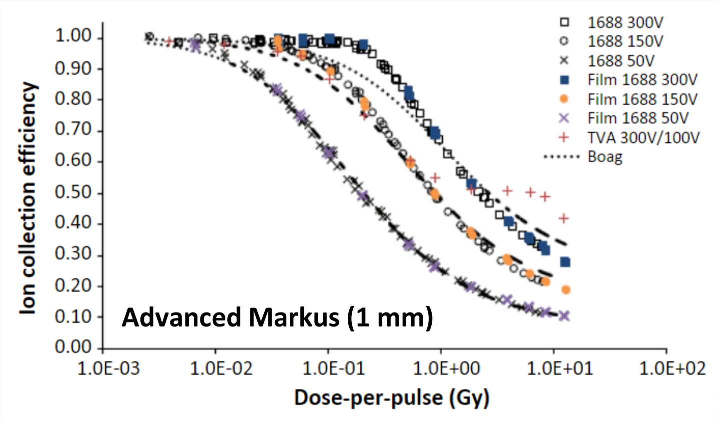
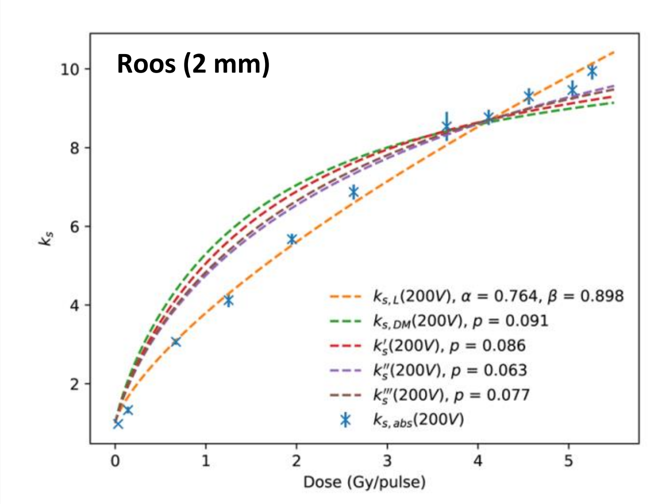
Air vented parallel plate ionization chambers in ultra high pulse dose rate

- Conventional parallel plate ionization chambers are compromised by high ion recombination losses up to 83 % for a 2 mm electrode distance chamber at 5 Gy per pulse and 350 V bias voltage.



Petersson et al Med. Phys. **44**, 1157-1167 (2017)



M. McManus et al Sci Rep ***10,*** *9089 (2020)*

- Boag-like analytical ion recombination corrections factors do not reproduce the actual chamber response.

Charge carrier transport equations

Ionization chamber can be described by the following set of one-dimensional equivalent equations, similar approach used by M. Gotz *et al Phys. Med. Biol.* **62** 8634 (2017) :

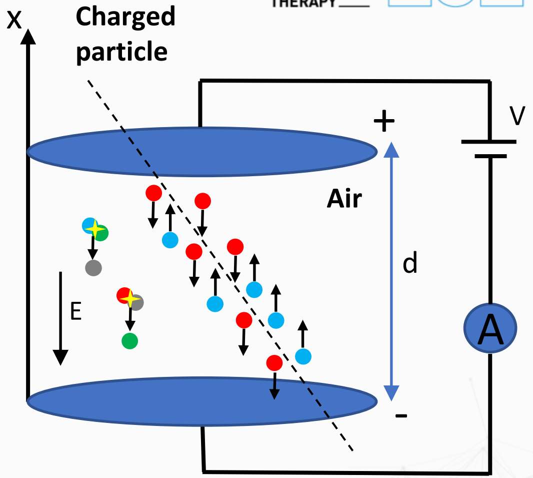
$$\frac{\partial}{\partial t}n_+(x,t) = R(x,t) - \alpha n_+(x,t)n_-(x,t) - \frac{\partial}{\partial x}[E(x,t)\mu_+ n_+(x,t)]$$

$$\frac{\partial}{\partial t}n_-(x,t) = \gamma(E)n_e(x,t) - \alpha n_+(x,t)n_-(x,t) + \frac{\partial}{\partial x}[E(x,t)\mu_- n_-(x,t)]$$

$$\frac{\partial}{\partial t}n_e(x,t) = R(x,t) - \gamma(E)n_e(x,t) + \frac{\partial}{\partial x}[E(x,t)\mu_e(E)n_e(x,t)]$$

$$\frac{\partial}{\partial t}E(x,t) = \frac{e}{\epsilon}\,[n_+(x,t) - n_-\,(x,t) - n_e(x,t)] \qquad \int_0^d E(x,t)dx = V$$

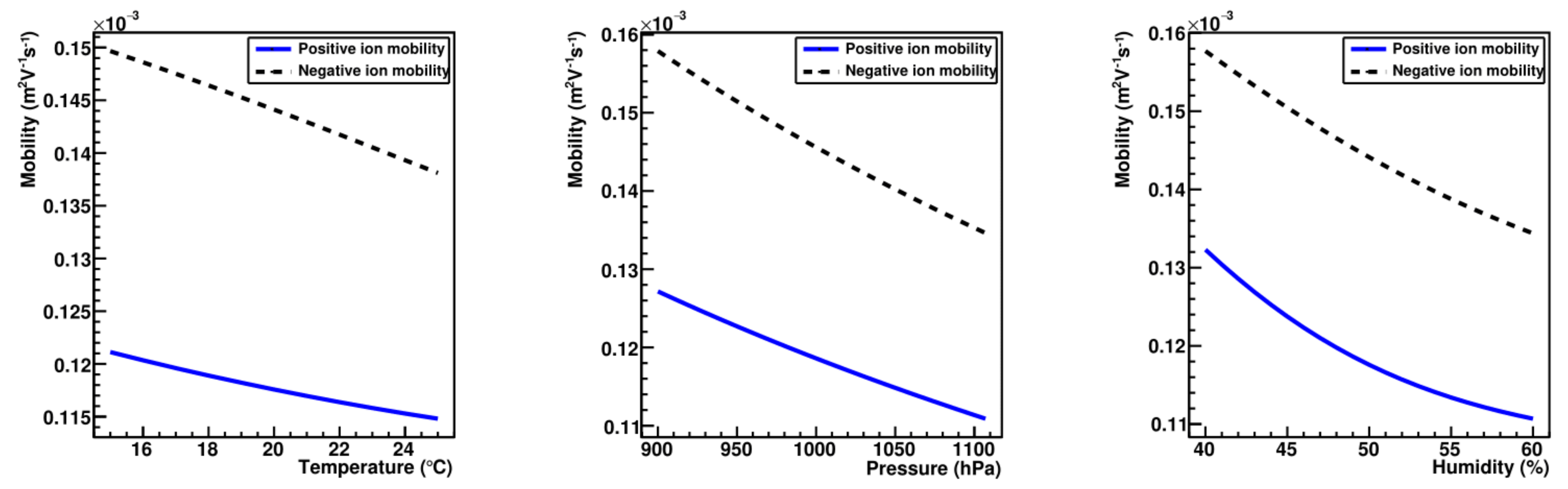
$$I = qvE_w \approx q\mu\frac{E}{d}$$



- 🟥 Positive charged ion
- 🟦 Electron
- ● Negative charged ion
- 🟩 Neutral molecule

Carrier Transport Parameters : Ion average mobility

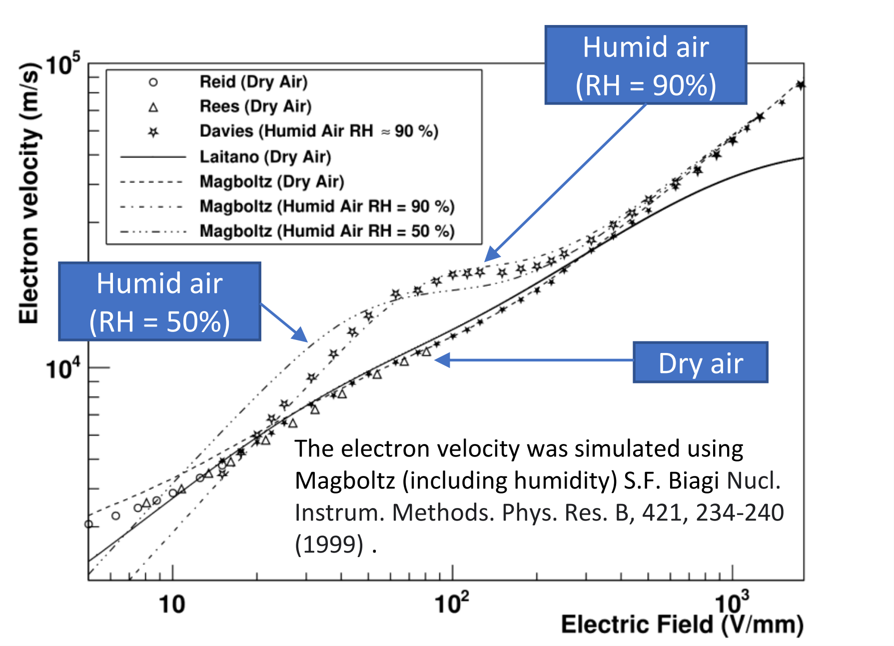
Standard conditions (P = 1013.25 hPa, T = 20 ºC, H = 50 %)



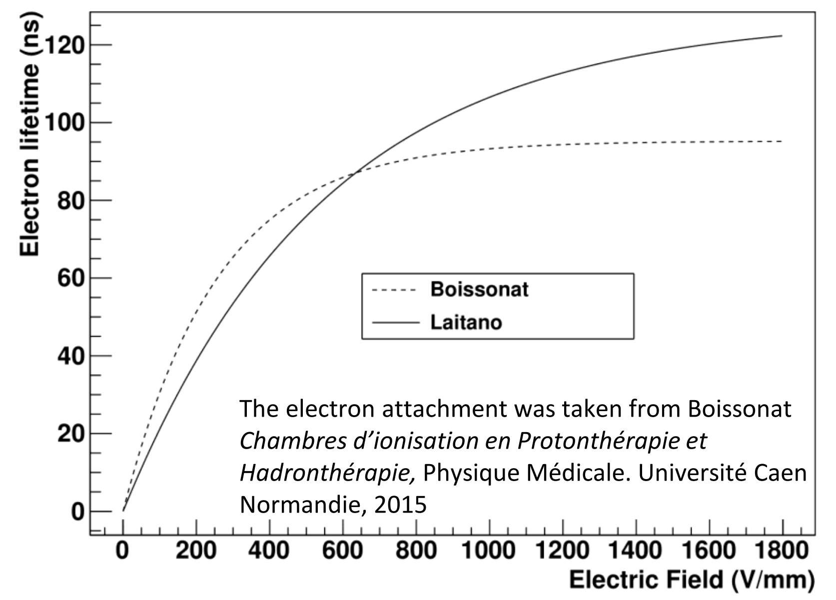
We have taken ion mobility parametrization from B. Zhang *et al* IEEE Trans. Dielectr. Electr. Insul., **26**, 1403-1410 (2019).

Carrier Transport Parameters : Electron Velocity and Lifetime

Standard conditions (P = 1013.25 hPa, T = 20 ºC)



The electron velocity was simulated using Magboltz (including humidity) S.F. Biagi Nucl. Instrum. Methods. Phys. Res. B, 421, 234-240 (1999) .



The electron attachment was taken from Boissonat *Chambres d'ionisation en Protonthérapie et Hadronthérapie,* Physique Médicale. Université Caen Normandie, 2015

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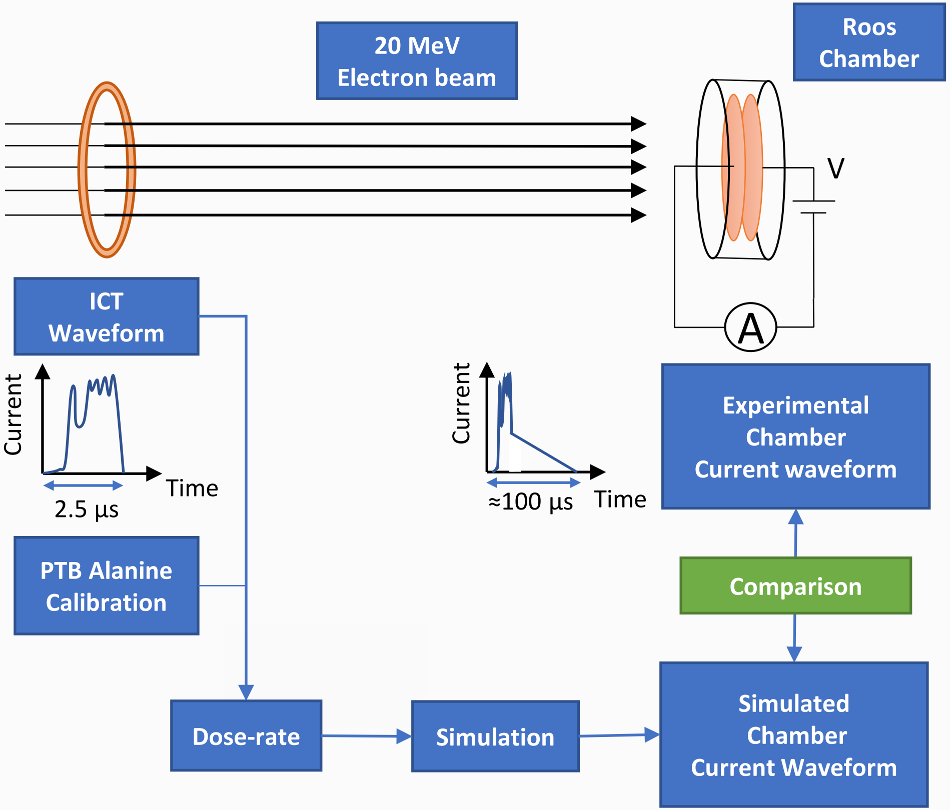
Simulation vs Measurements at PTB MELAF



20 MeV Electron beam

Roos Chamber

ICT Waveform

PTB Alanine Calibration

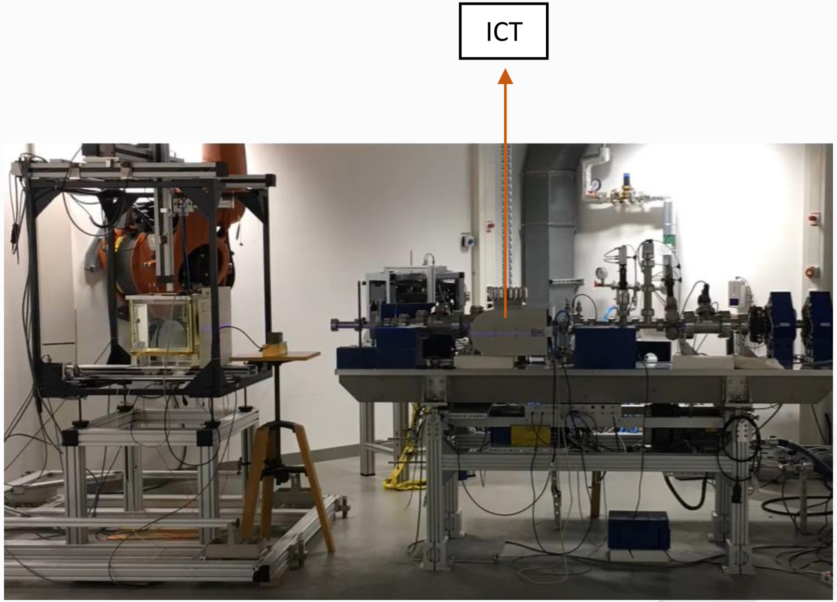
Experimental Chamber Current waveform

Comparison

Simulated Chamber Current Waveform

Dose-rate

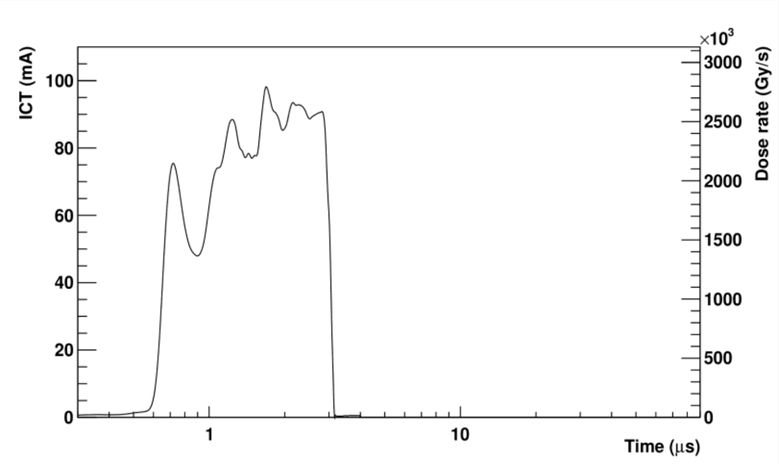
Simulation



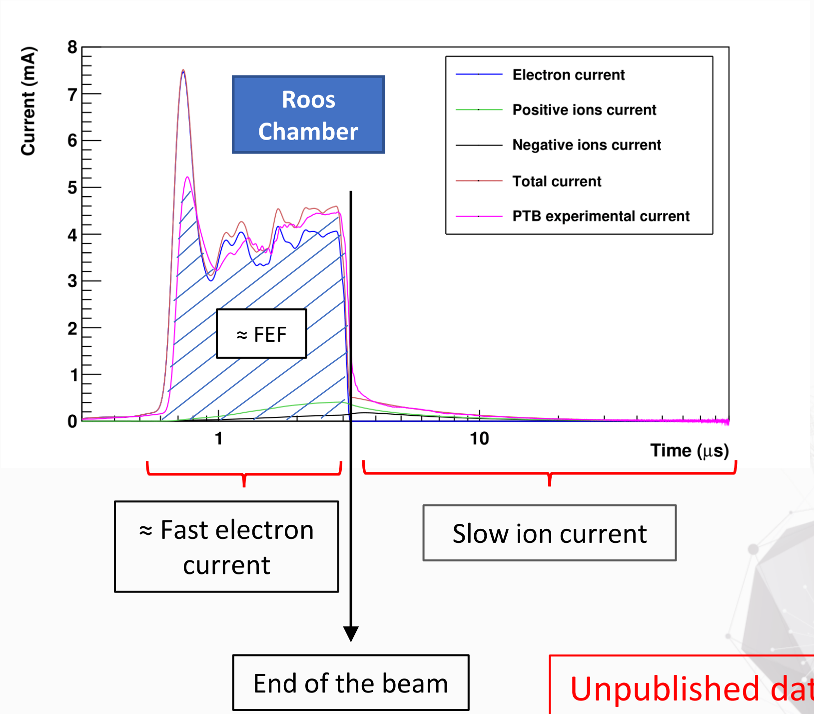
A. Bourgouin et al *Towards primary and secondary standards for dosimetry in Flash radiotherapy*

Results: Instantaneous Induced Current

ICT current



Ionization chamber induced current



≈ Fast electron current

Slow ion current

End of the beam

Pulse repetition frequency: 5 Hz
Nominal beam energy: 20 MeV
Pulse duration: 2.5 μs
Dose per pulse: 5.74 Gy
Nominal bias voltage: +400 V

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Results: Instantaneous Induced Current

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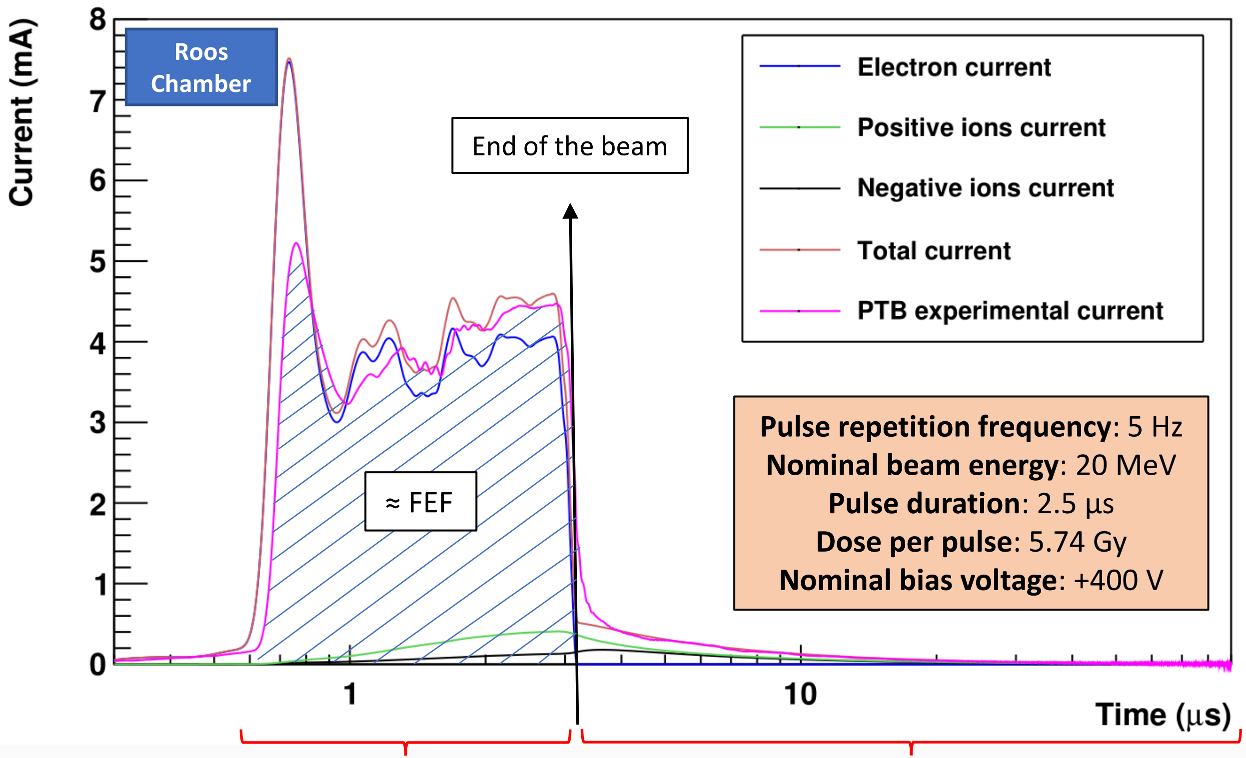

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Dose per pulse: 5.74 Gy
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Slow ion current

In the high dose per pulse region ±2 % FEF reproduction

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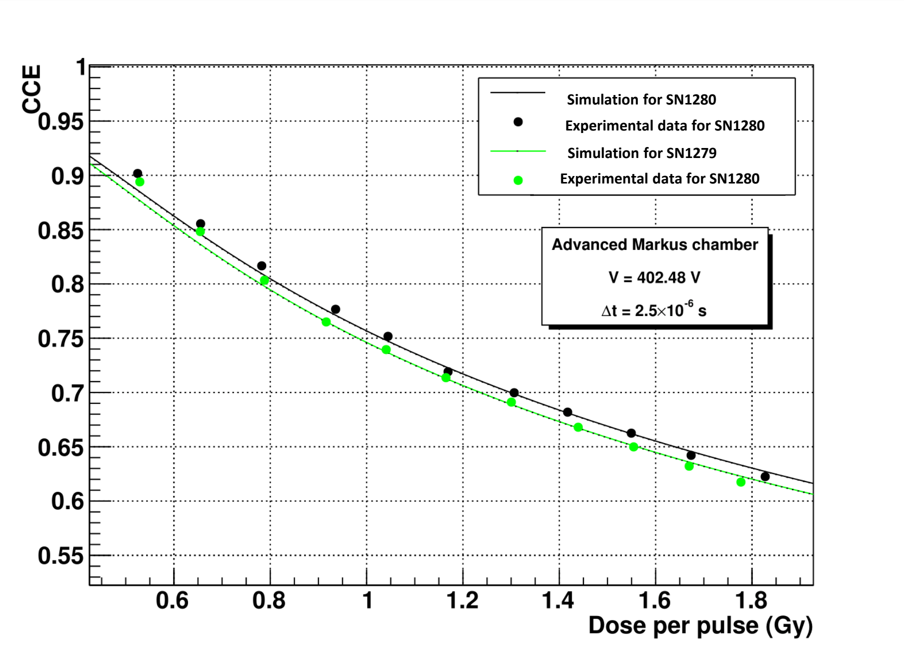
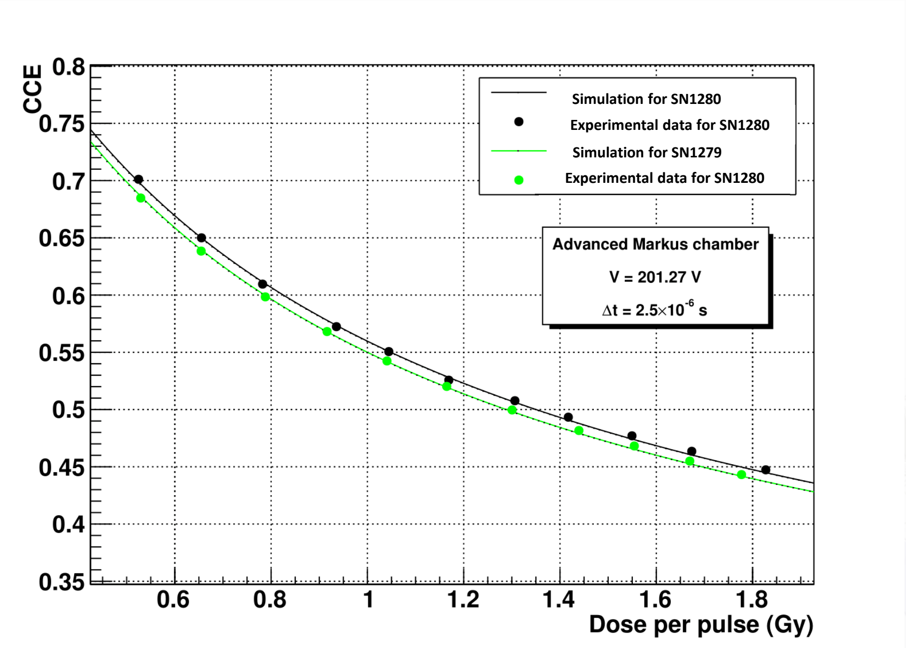
Results: Charge Collection Efficiency





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Conclusions

- Charge carrier transport numerical simulations show promising results to model the performance of ionization chambers in ultra-high dose rate.
- This approach can still be improved. Transport parameters, such as electron attachment, need to be further studied for a more precise simulation.
- Instantaneous induced current due to charge carriers transport across the chamber is a more demanding way of benchmarking those models.
- We have created a beta version distributable simulation software. Contact Faustino.gomez@usc.es, jose.martin@usc.es .