Creating an ultra-thin parallel plate ionization chamber for Flash dosimetry

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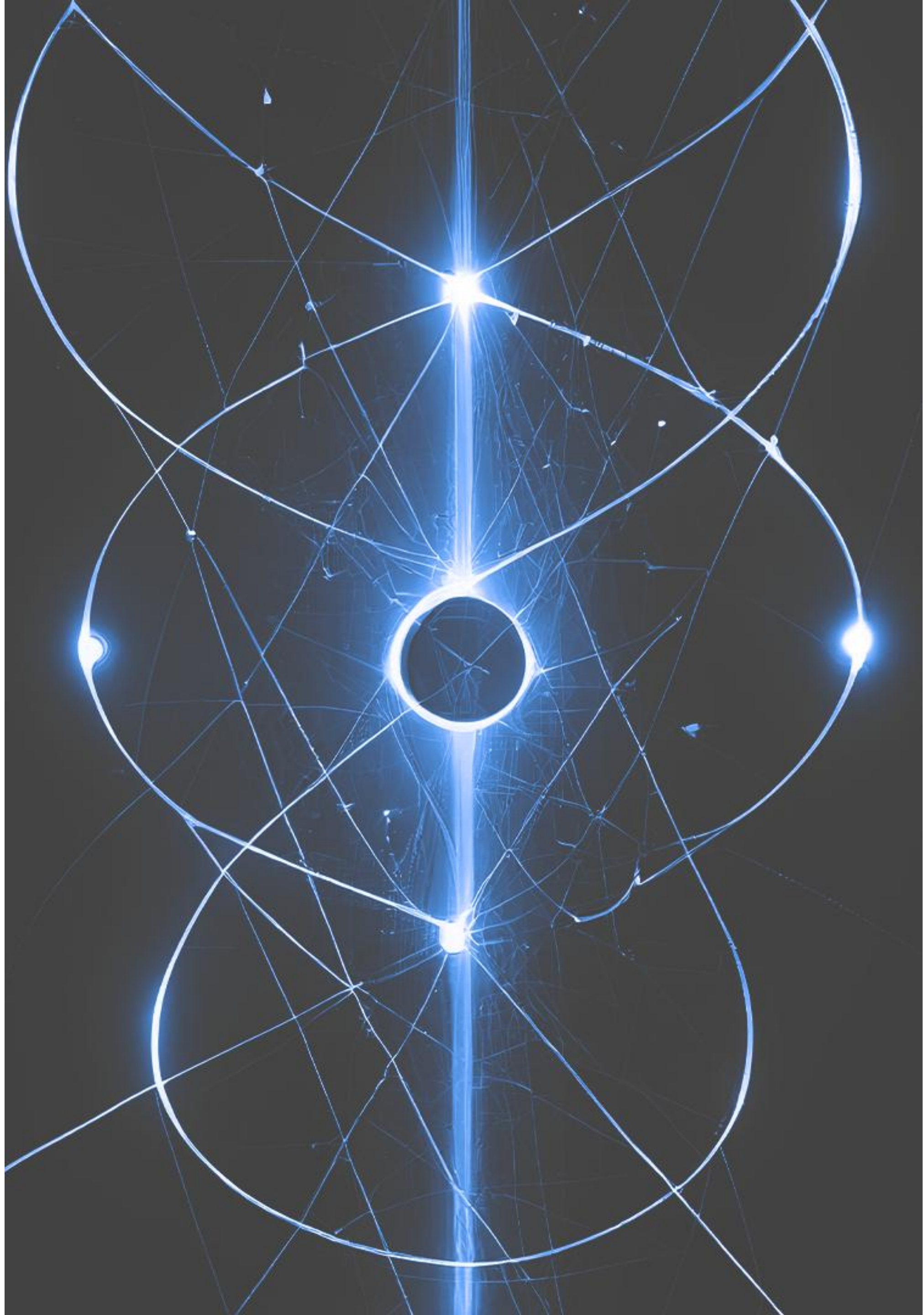

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Thank you!

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Progress in **ultra-high dose rate (UHDR) dosimetry** is currently blocked because we lack **a dosimetry protocol specific to UHDR beams**, which prevents **consistent dose reporting across institutions and between modalities**.

Brief introduction to Flash irradiation

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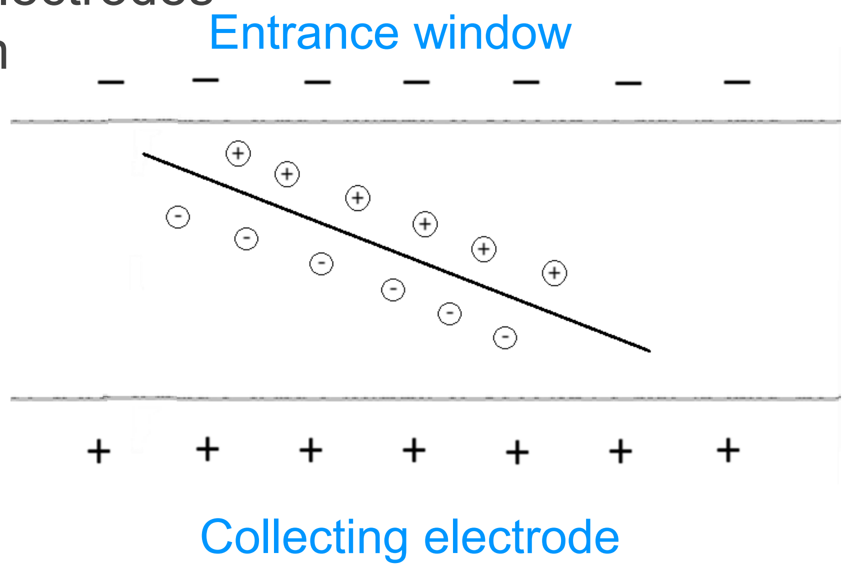
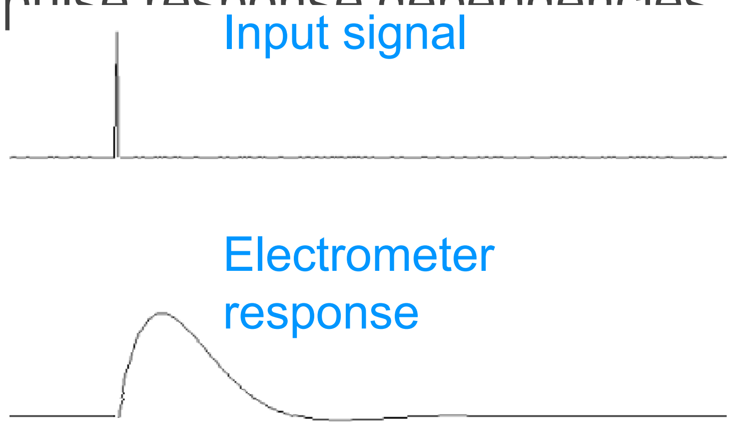
- Ultra-high dose rate “Flash” irradiation provides equivalent tumor control with decreased normal tissue complications compared with conventional dose rates
  - Favaudon et al., “Ultrahigh dose-rate FLASH irradiation increases the differential response between normal and tumor tissue in mice.” *Sci Transl Med.* 2014; 6(245)
- This generated a lot of excitement in radiotherapy!
  - Can we push the doses higher to get improved tumor control without increasing normal tissue toxicities?
  - What is the dose rate threshold required to achieve the Flash effect?
- We **NEED** to know the dose. Accurately.
  - As with SRS, there’s not much room for error.
- Existing ionization chambers show significant recombination/saturation effects in these high dose rates
- Other detectors used for UHDR dose calibrations are often labor intensive:
  - Radiochromic film, alanine, TLDs, OSLDs, calorimeters…
- Ion chambers are still the detector of choice for Medical Physicists.
  - Active, simple to use, and can be calibrated at an ADCL
- **The challenge**: Create an ion chamber that has minimal saturation and can be calibrated

Challenge of dosimetry

Why don't existing ion chambers work?

- High recombination effects
  - Dense ionization tracks = high initial recombination AND high volume recombination
  - Self-shielding of ions reduces the pull of the electrodes
  - Larger plate separation increases the problem
- Electrometer limitations
  - Saturation due to high instantaneous current
  - Impulse response dependencies





Types of Flash beams

Particles, pulses, and PRFs

- Proton
  - Increase pulse repetition frequency to obtain high dose rate
    - “Quasi continuous” beam
  - May have fine structure (micro pulses) within larger groups (macro pulses)
- Electron
  - Extremely high dose per pulse, few pulses
  - High instantaneous dose rates
- Photon
  - Pre-clinical systems, quasi continuous?

Electrons provide the biggest challenge for ion chambers.

Designing a new chamber

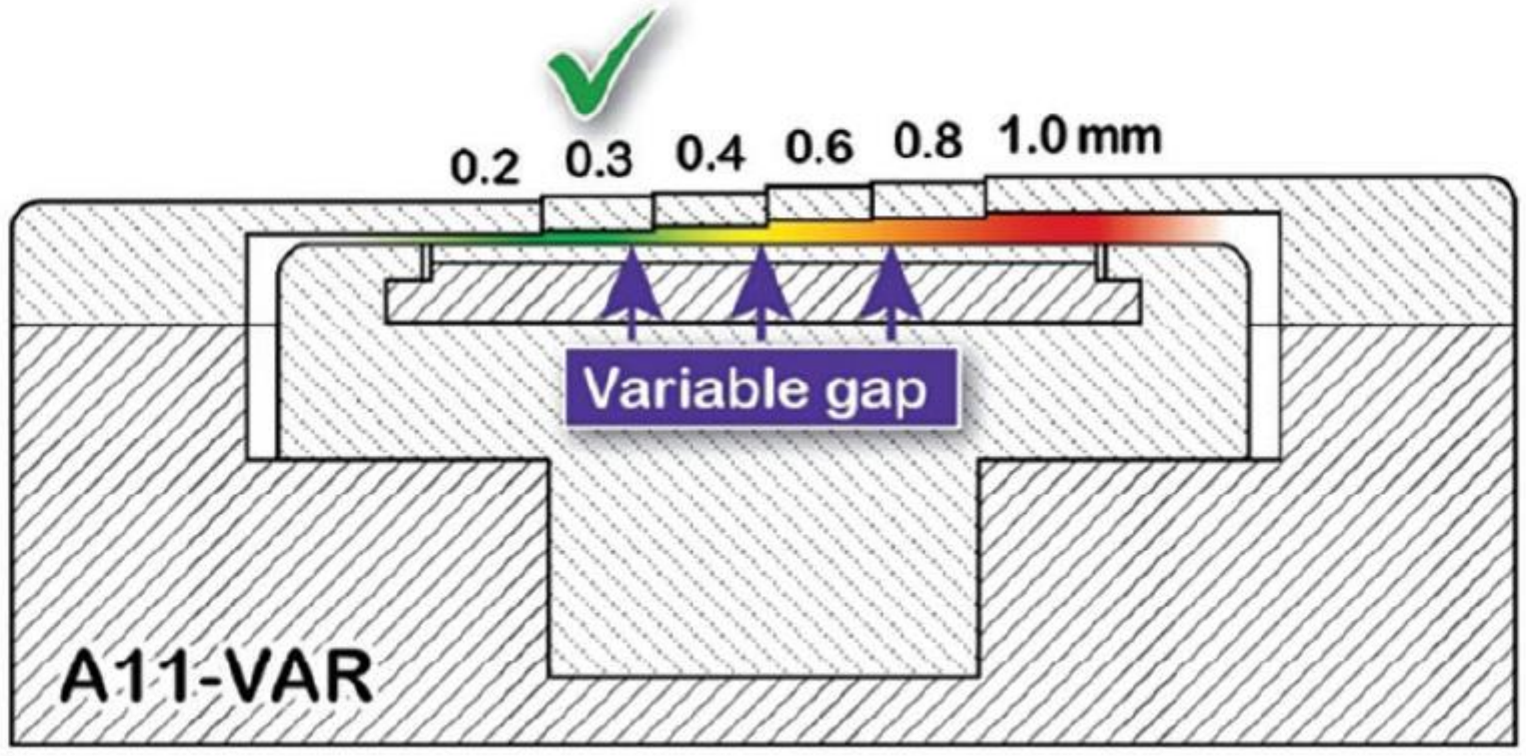
Ideals and expectations

- Prior publications for ultra thin parallel plate chambers
  - Reduced recombination
  - 1D MATLAB calculations confirmed published hypothesis, at least in the simple model
- Construction challenges
  - Parallel smooth surfaces
  - Accurate plate separation
  - Material selection
    - No high Z materials
    - High dose resistance
- Design decisions
  - Chamber volume (i.e. electrode diameter)
    - Large enough signal for ADCL calibration (Co-60)
    - Small enough to avoid electrometer saturation (as much as possible)
  - Can we make it waterproof?

Prototype chamber design

Liu, et al., *Development of novel ionization chambers for reference dosimetry in electron flash radiotherapy.* Med Phys. 2024; 1-15. https://doi.org/10.1002/mp.17425

First challenge: create a single chamber with variable (and precise!) configurations.



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Electric field strength

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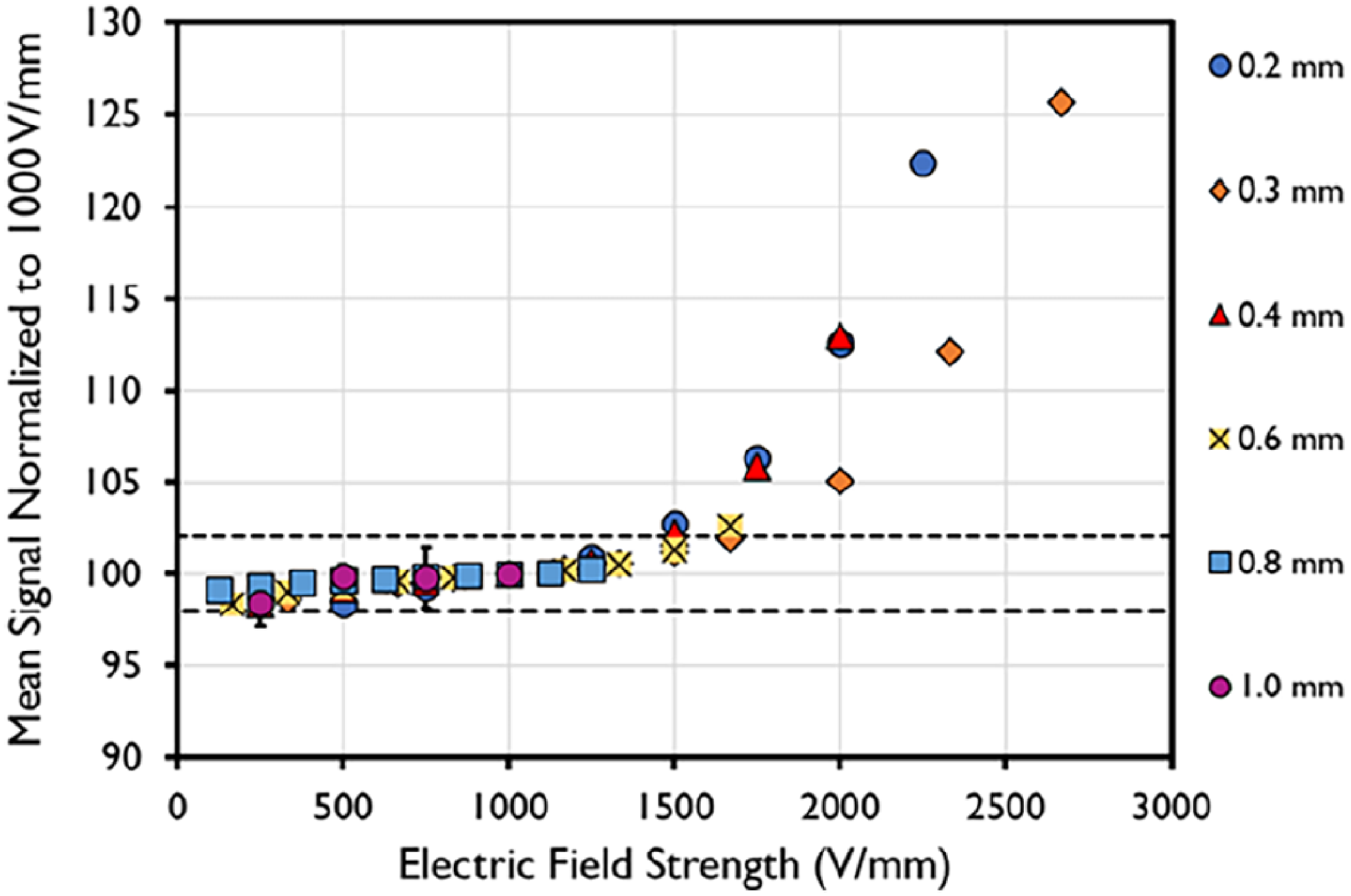

Liu et al., https://doi.org/10.1002/mp.17425

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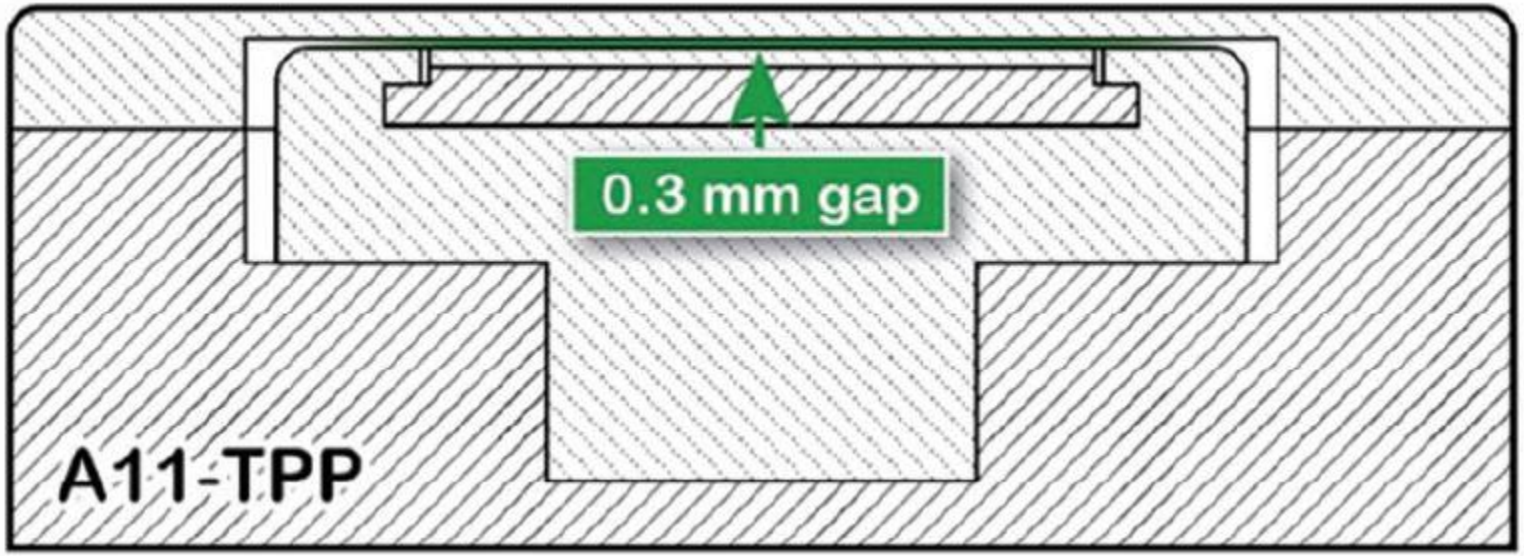
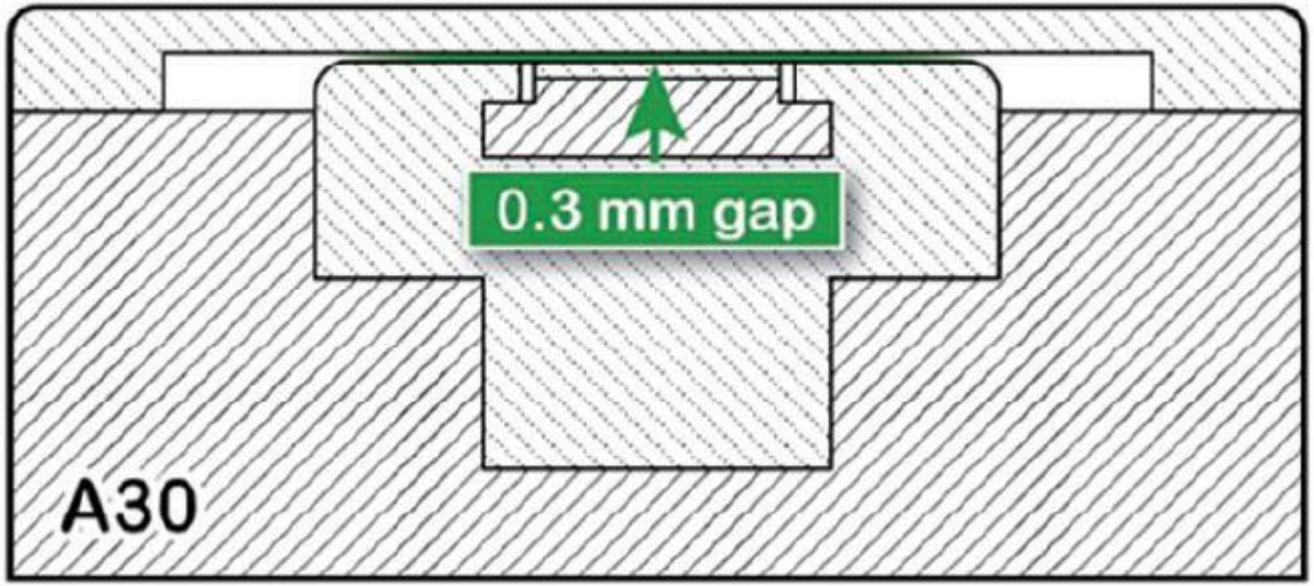
Next prototypes



20 mm collecting electrode diameter
0.093 cm^3 volume



5.4 mm collecting electrode diameter
0.0075 cm^3 volume

Liu et al., https://doi.org/10.1002/mp.17425

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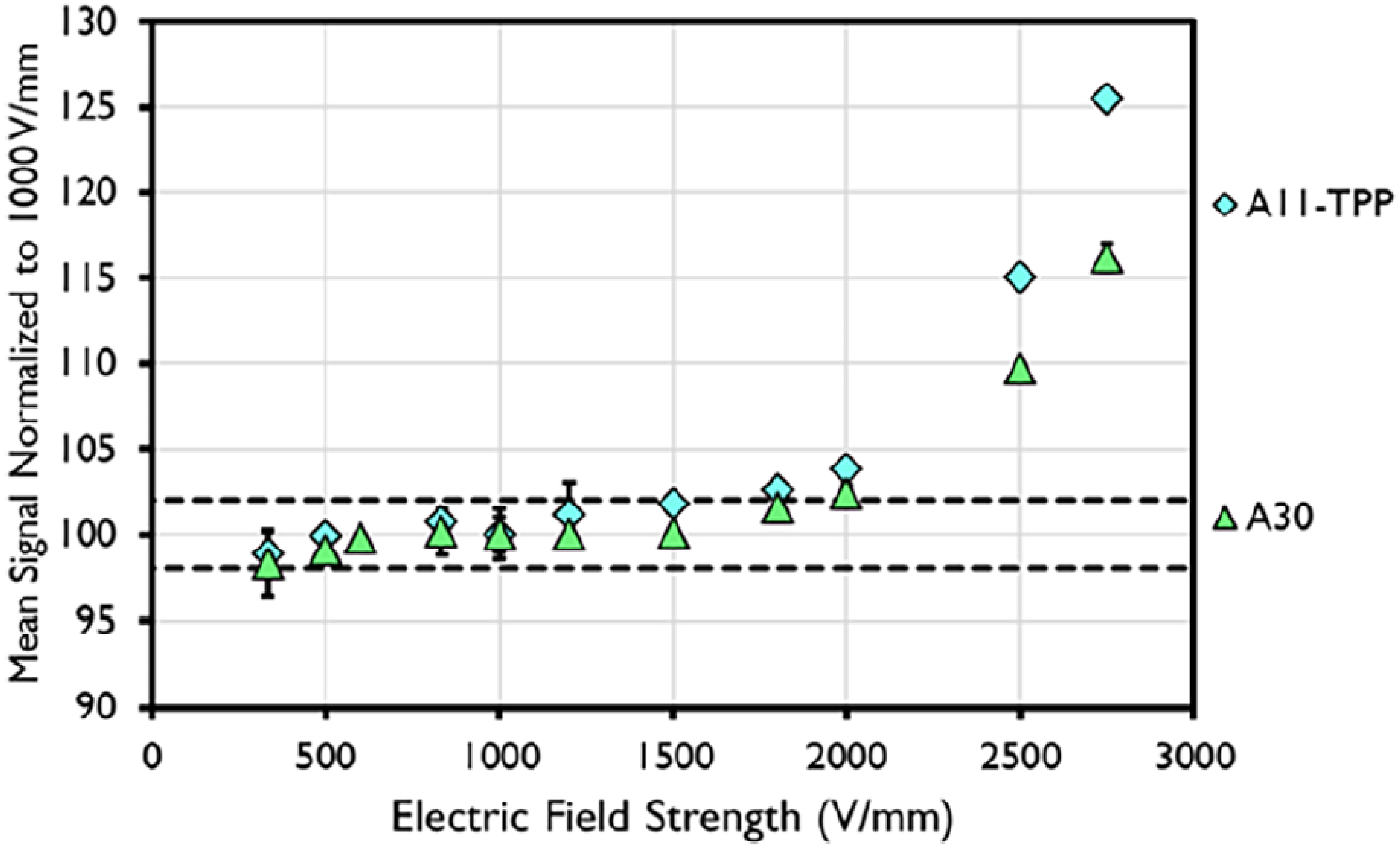
Electric field strength (again)



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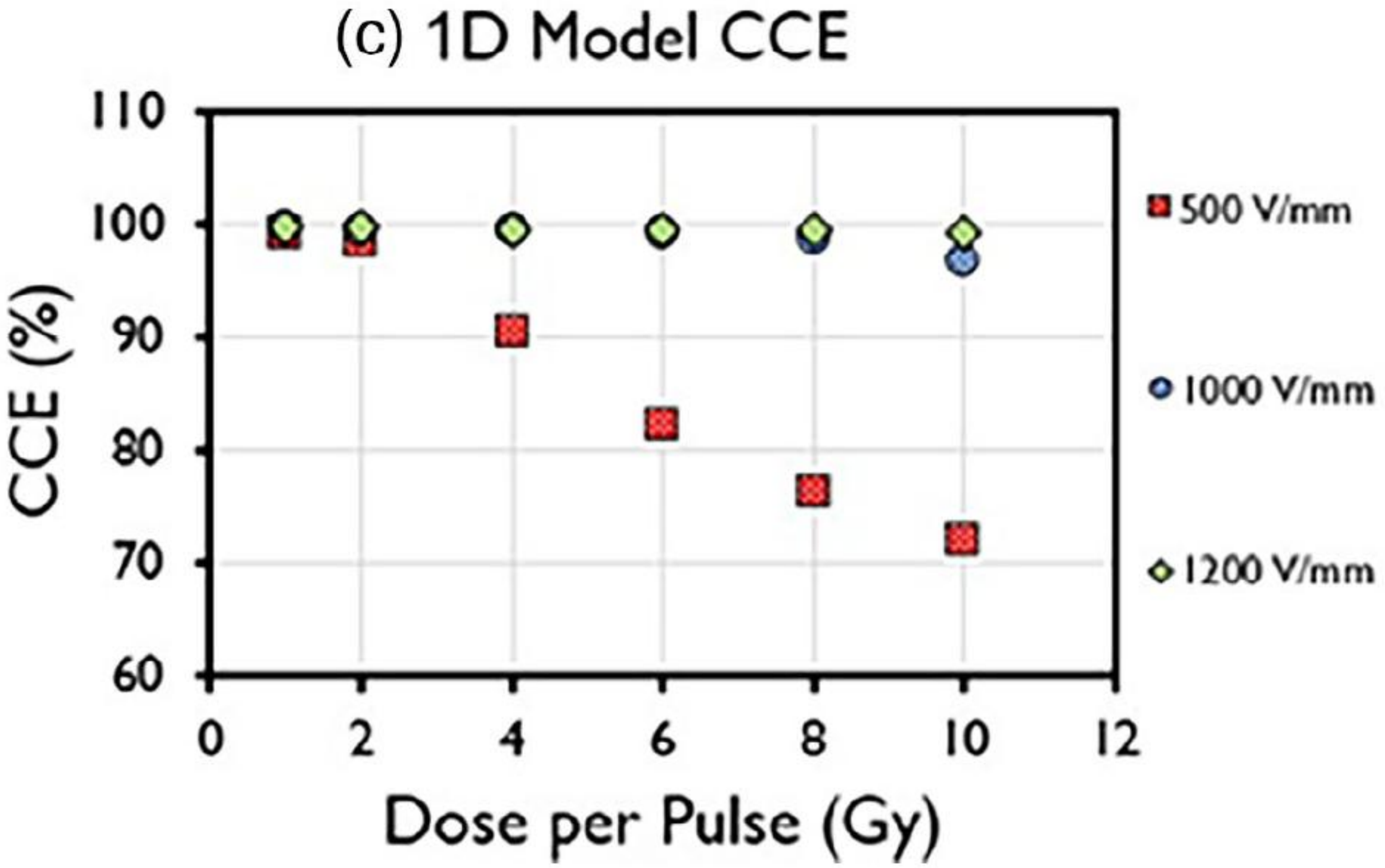
Modeled Charge Collection Efficiency



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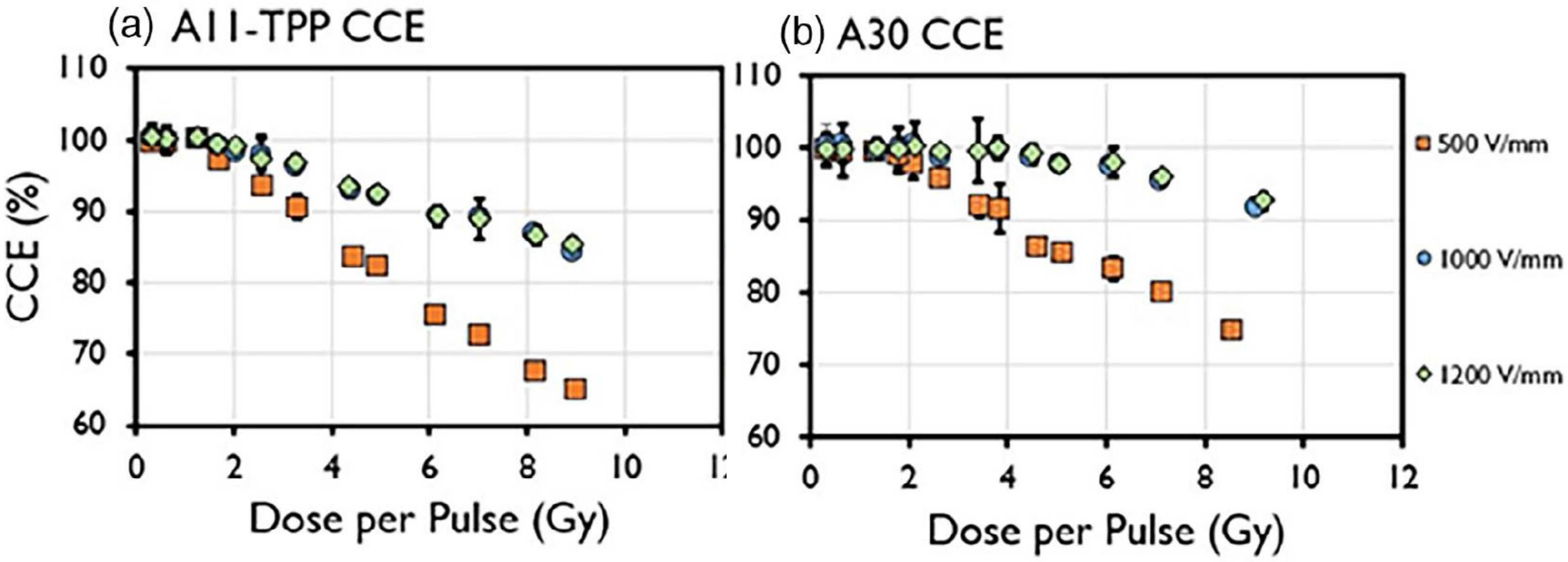
Measured Charge Collection Efficiency



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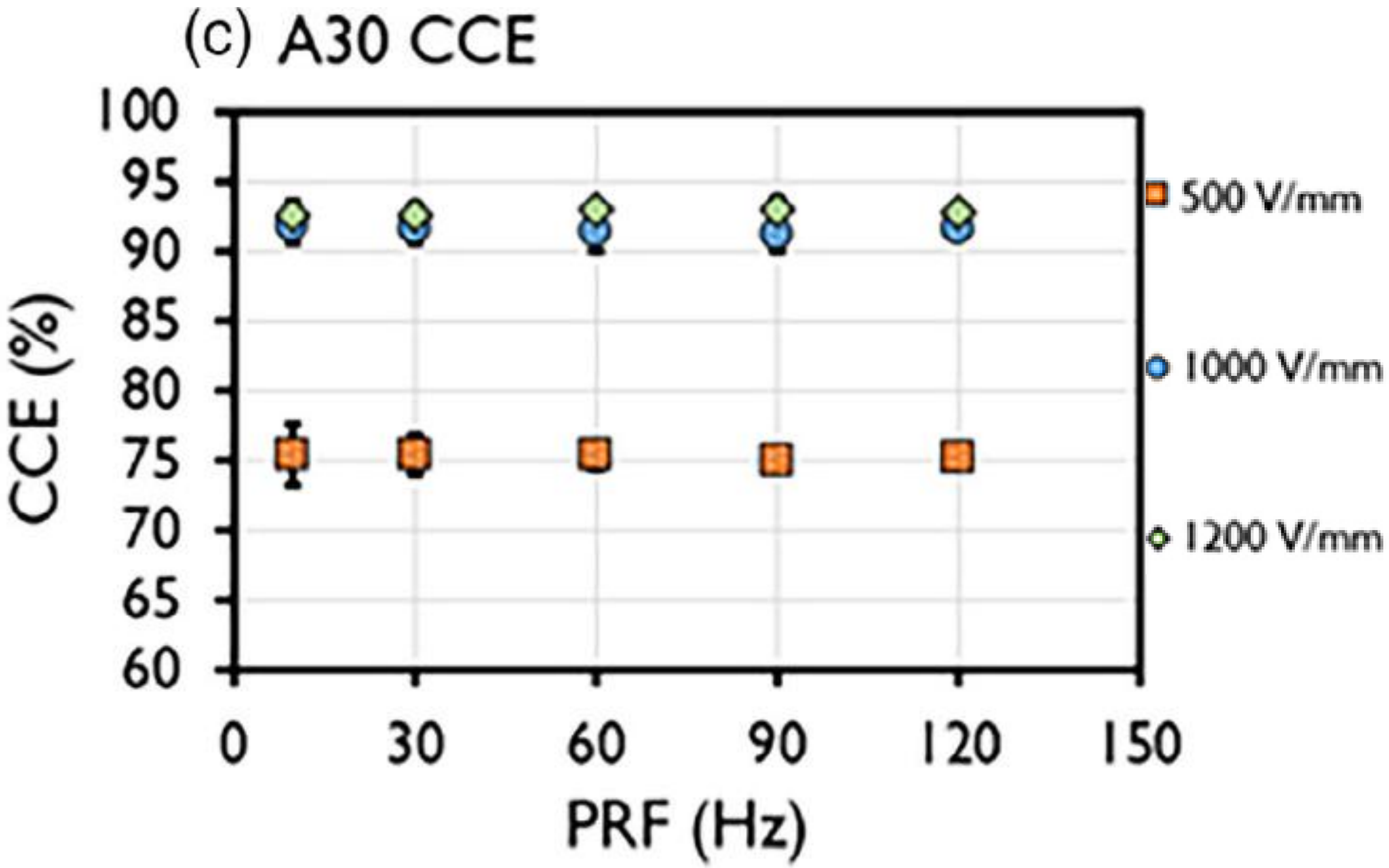
Pulse Repetition Frequency



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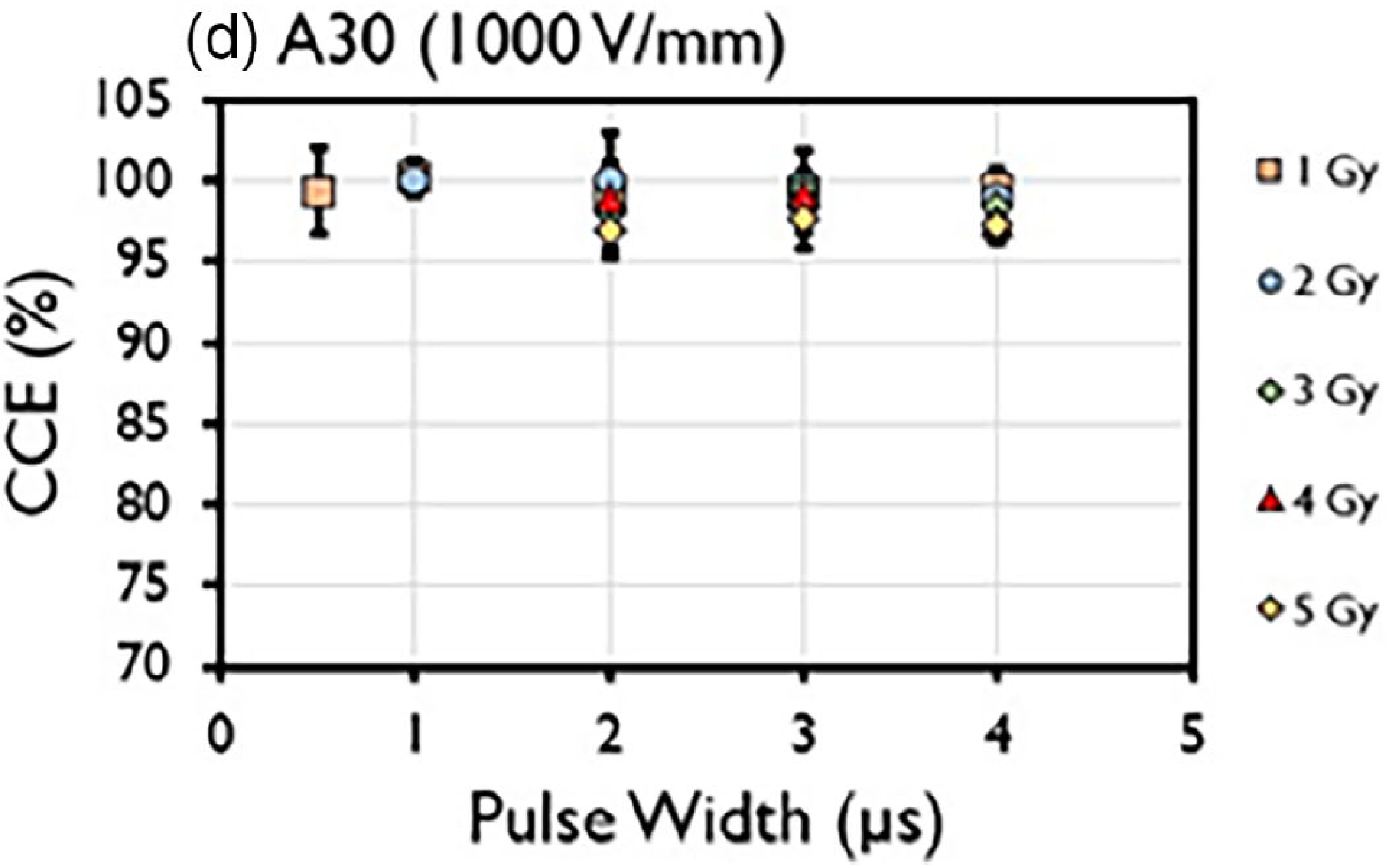
Pulse width



Liu et al., https://doi.org/10.1002/mp.17425

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Dose lifetime evaluation

- Initial prototype design
  - 300 kGy delivered over a period of months
  - Leakage values showed no dose degradation

- Due to a slight misunderstanding, an additional
  300 kGy was delivered in a single session.

- Material that was damaged by the heat and radiation has been replaced with an alternate plastic (that <u>did</u> survive the single high dose intact).

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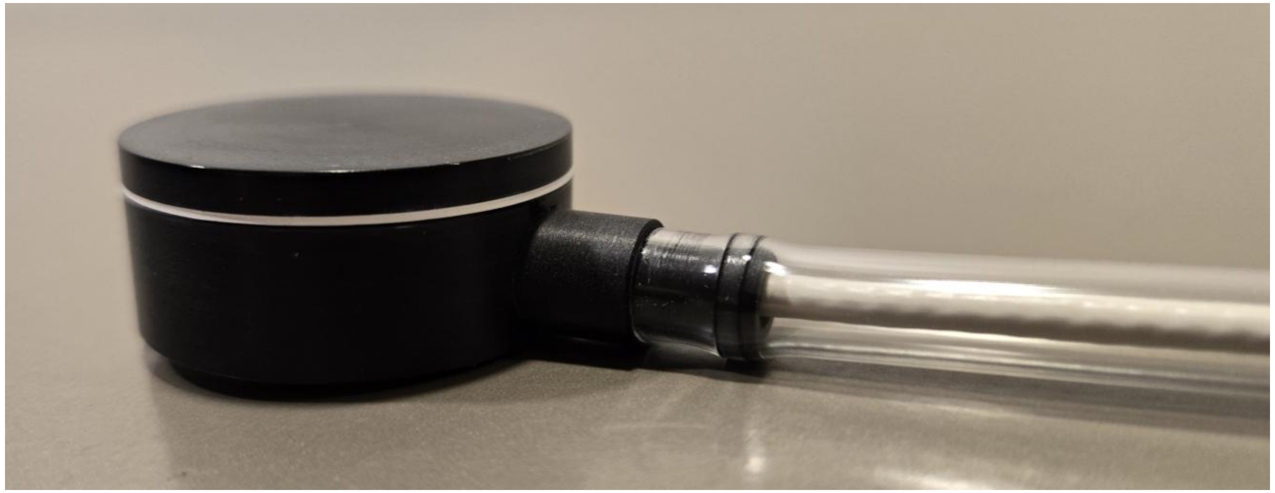
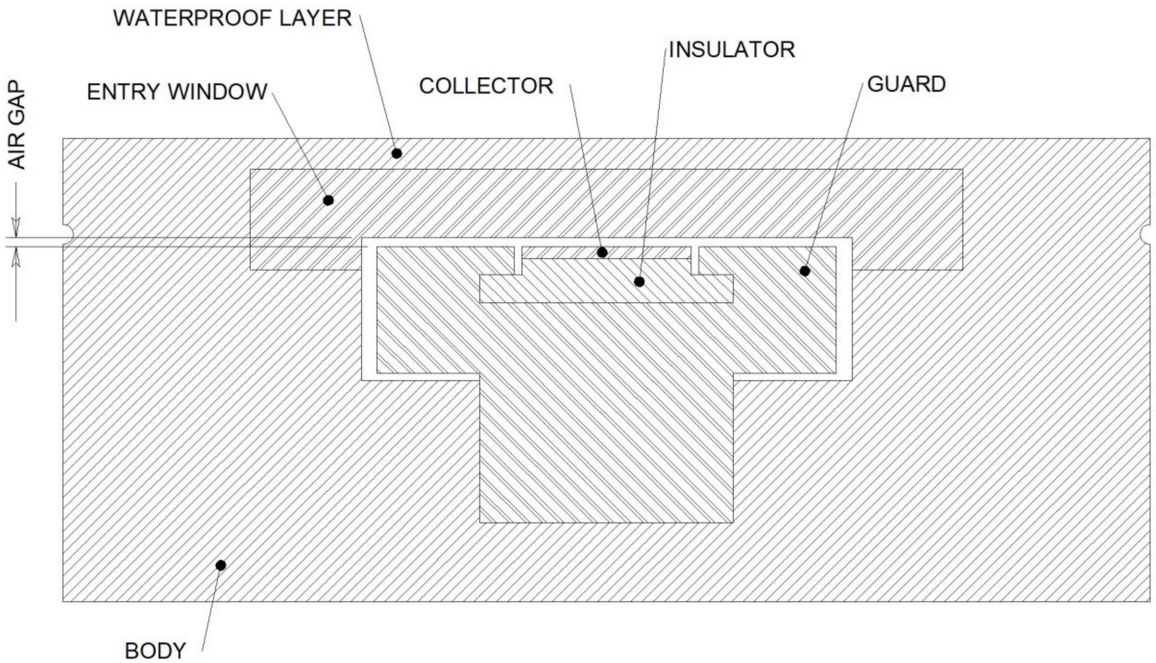
Updated chamber design

- Replaced the lower dose-tolerant non-conductive plastics with higher dose-tolerant plastic to improve dose lifetime
- Implemented a waterproof construction design
- Added alignment line
- Performed k_Q calculations and measurements
- Obtained $N_{D,W}$ calibrations from the UW ADCL
- Re-evaluated key performance features





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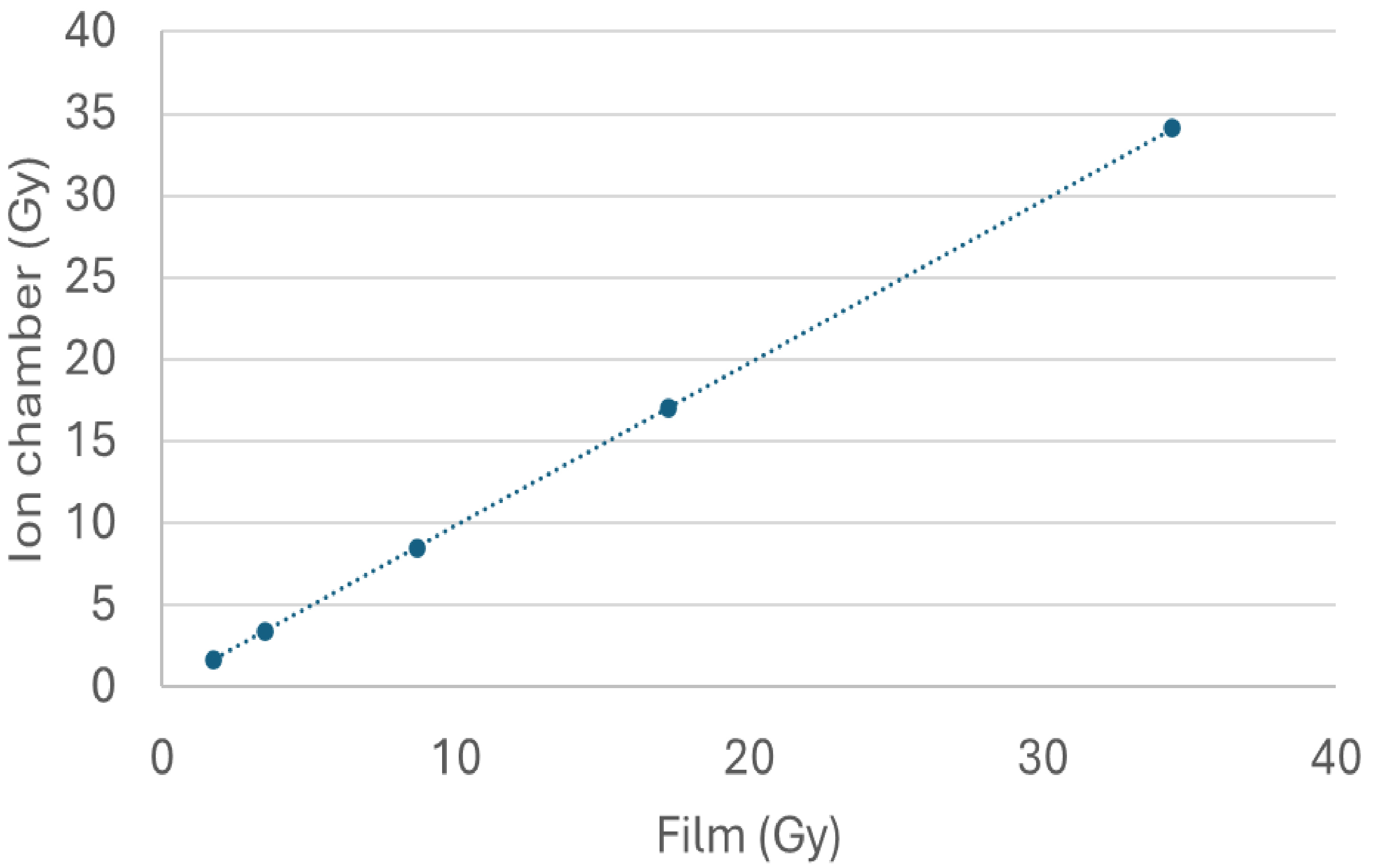
Dose response

- Linear response for doses from 1 to 34 Gy
- Dose to water calibration factor ($N_{D,W}$) was used to convert measured charge to dose
- 1-20 pulses delivered using 4 μs pulses with instantaneous dose rate of 4.3×10^5 Gy/s



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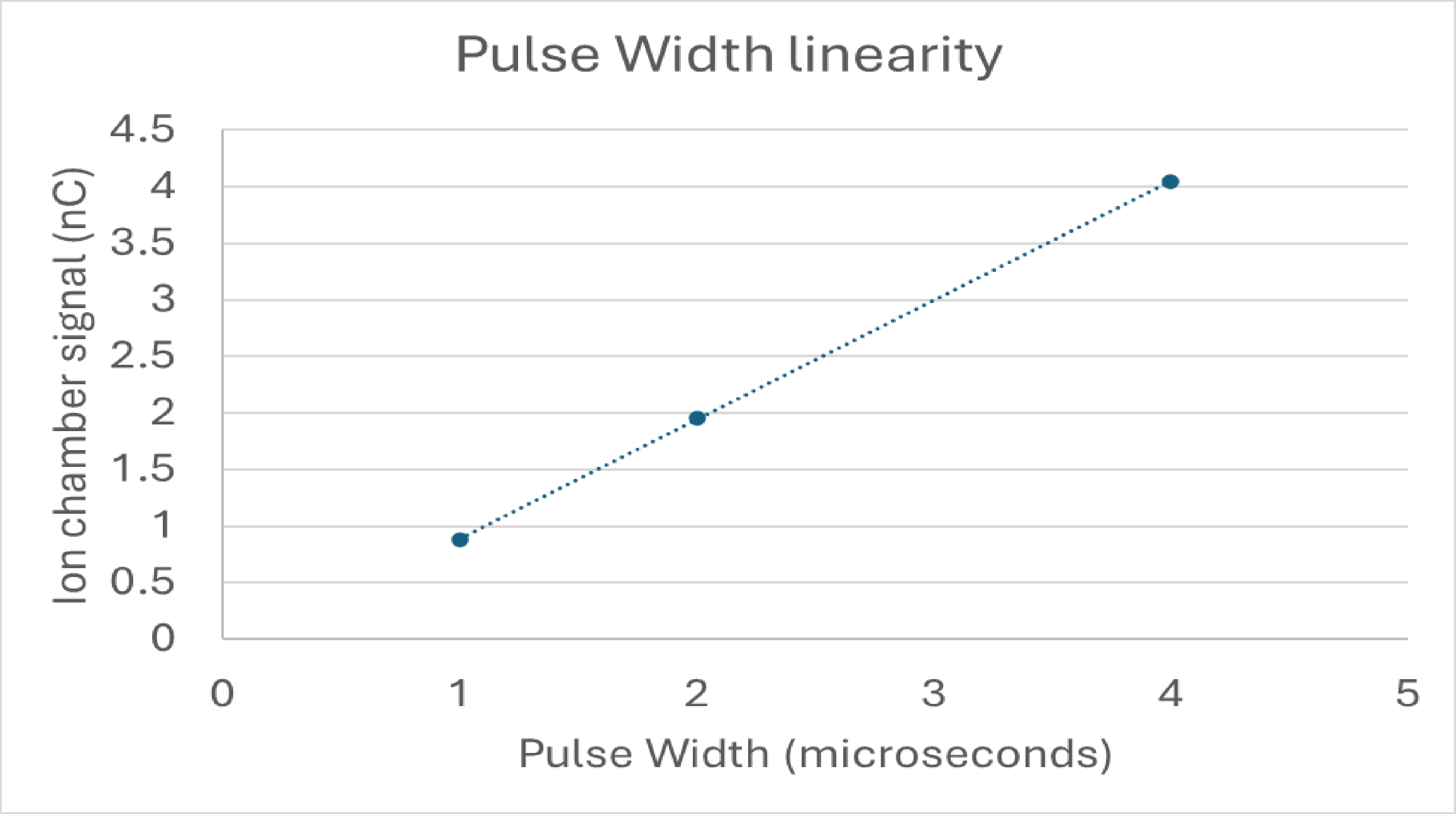
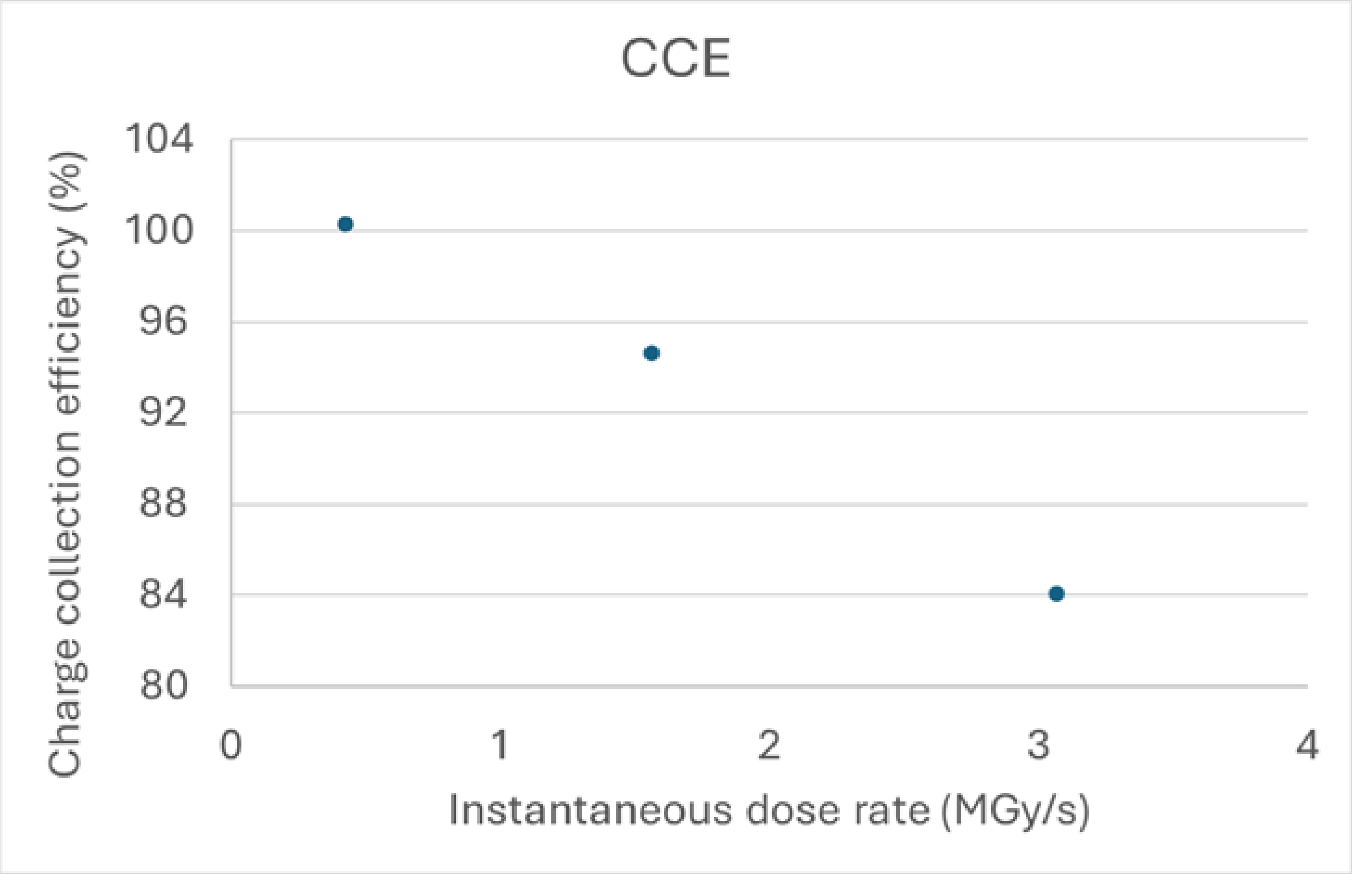
Pulse width linearity

- Linear response with pulse widths from 1 to 4 μs
- Instantaneous dose rate of 4.3×10^5 Gy/s



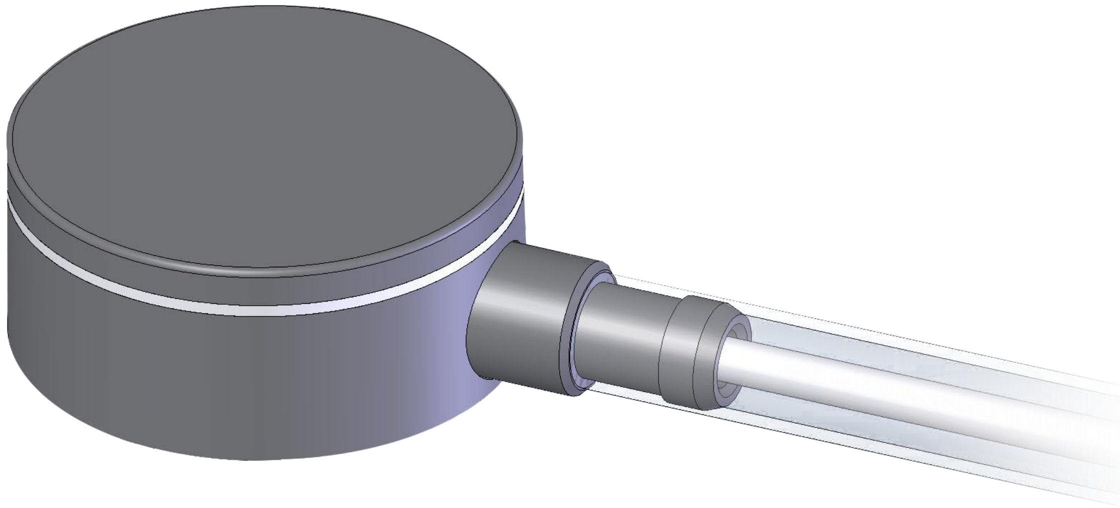
Charge collection efficiency

- Matched prior prototype performance, showing ~95% CCE at 6.2 Gy/pulse for 4 μs pulse width.
- CCE dropped to ~84% at 12.2 Gy/pulse
- Plotted here as a function of the instantaneous dose rate



Summary of the Exradin A30

- Parallel plate design with 0.3 mm plate separation
- Uses C552 conducting plastic
- Waterproof
- Capable of functioning in both traditional and Flash beams
    - NIST-traceable $N_{D,W}$ calibrations can be obtained from an ADCL
- High dose lifetime
- Manuscript in process with k_Q calculations and measurements



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