Gain Suppression Studies on IMB-CNM LGAD Detectors

November 12th 2025

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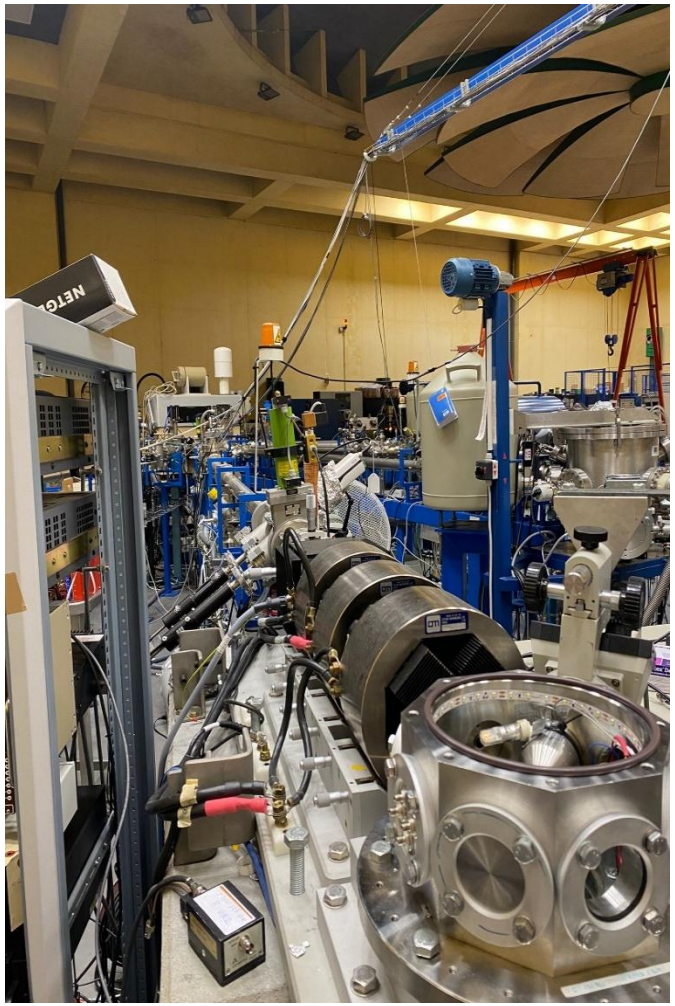
Gain Suppression Phenomena in LGADs

- Gain suppression is observed for **high ionization charge densities**
  - ➢ The effect is typically stronger for ions than for photons due to their denser charge deposition.
- Reduced gain suppression at non-normal incidence*
  - ➢ For incidence angles different from 0º, the projected ionization profile **spreads the charge along the gain layer**, **mitigating the suppression effect**.
- Bragg peak entering the active volume*
  - ➢ When the ion Bragg peak lies within the active region, the local charge density becomes extremely high, leading to **plasma effects** and a **stronger gain suppression**.

* With the IBIC technique at the CNA Microprobe Line, these two phenomenona were observed separately in https://doi.org/10.3390/s22031080 but, *how do they combine*?

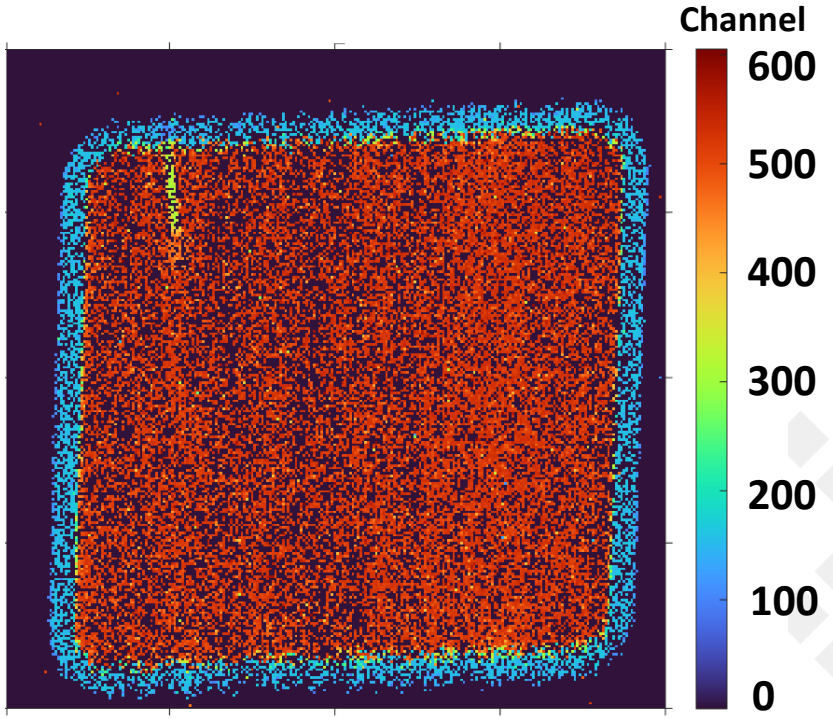
IBIC Technique with the Microprobe Line at CNA



Nuclear Microprobe line

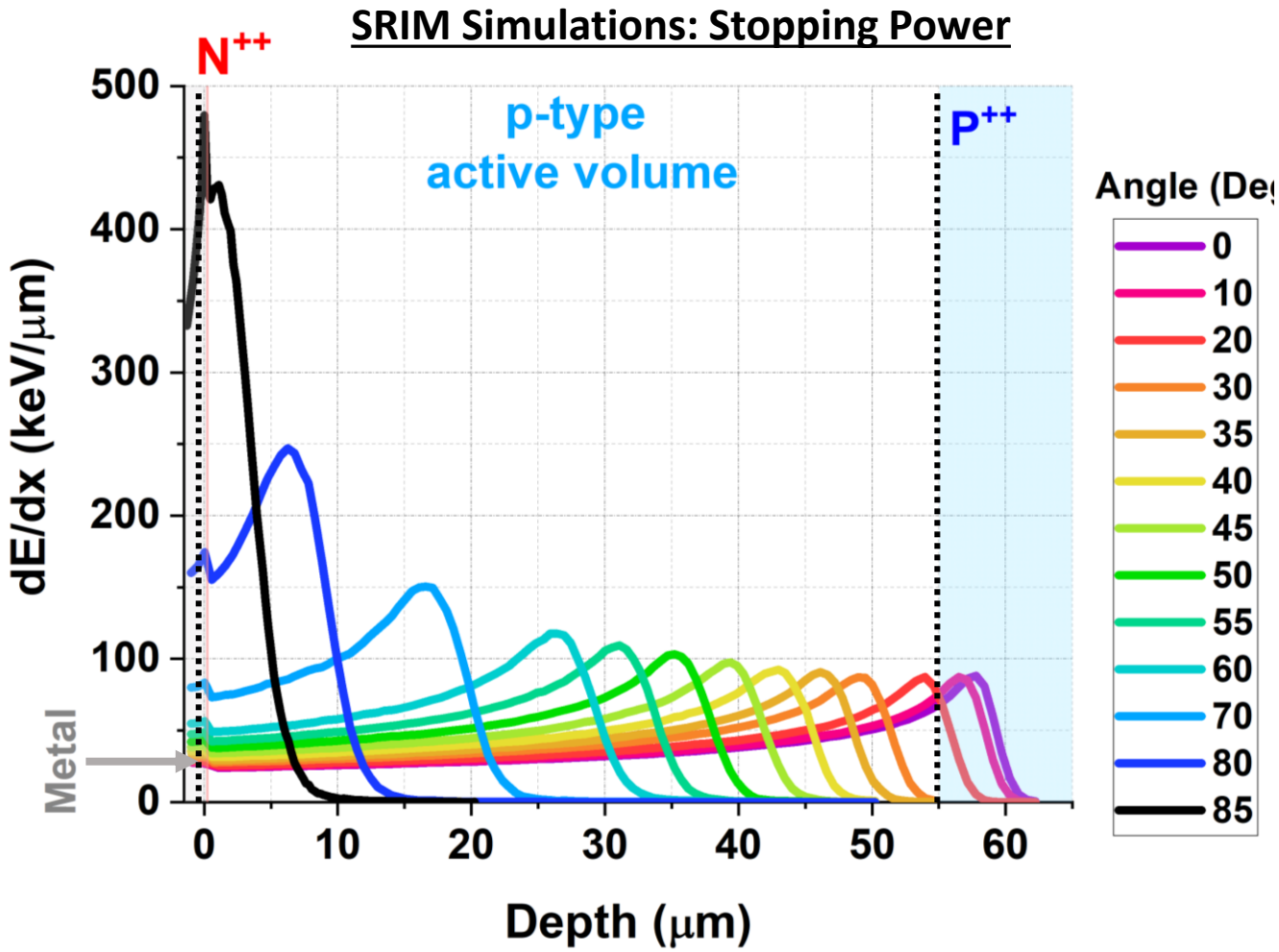
Tandem room

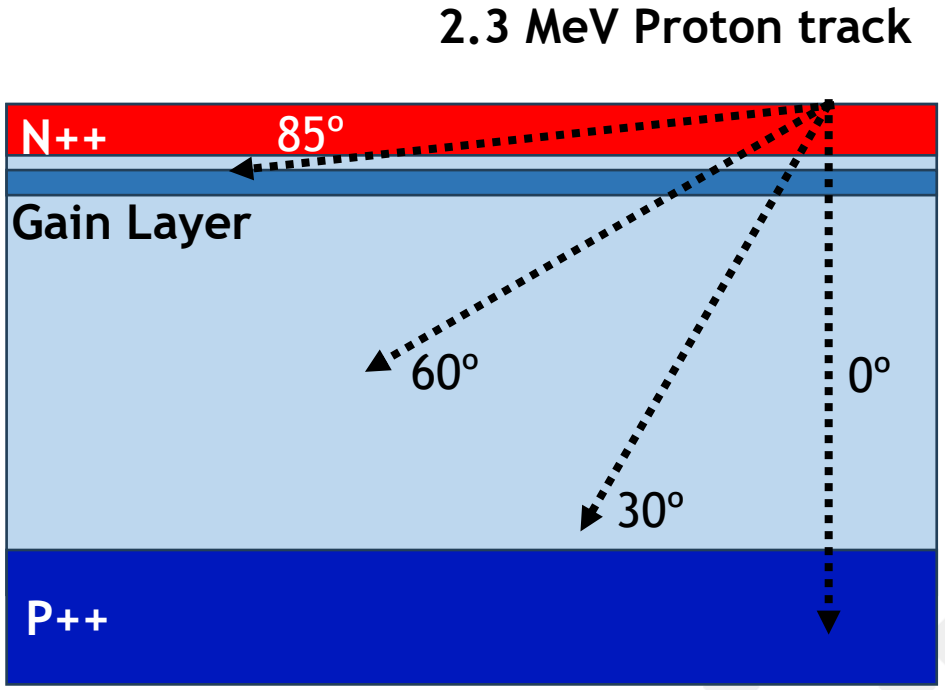
- **Low particle rate** (≈ 100 Hz) to avoid sensor damage.
- Tuning of particle energy within the MeV range (**2.3 MeV protons** used in this work).
- **Goniometer** to evaluate the dependence of the LGAD response on the incidence angle.



SRIM Simulations: 2.3 MeV proton track in silicon

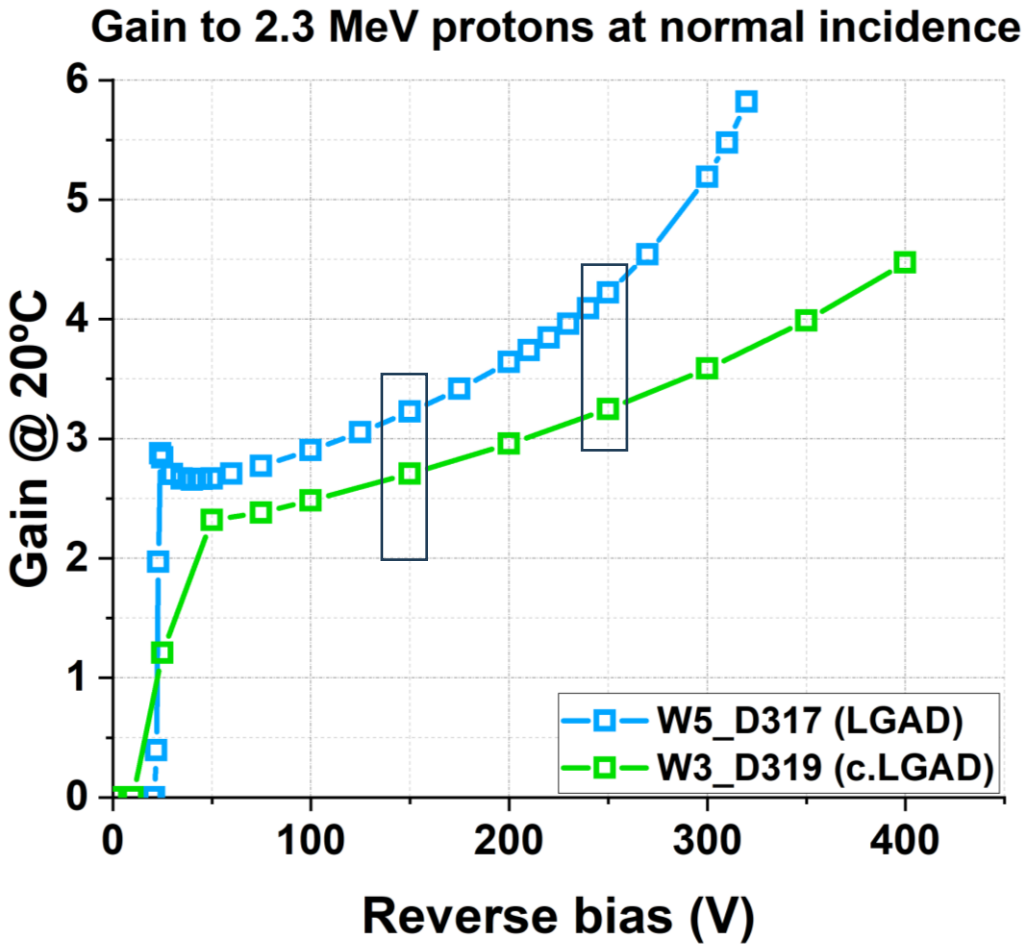
- The proton track, and hence its ionization density and its projection onto the gain layer, can be modified when varying the incidence angle.



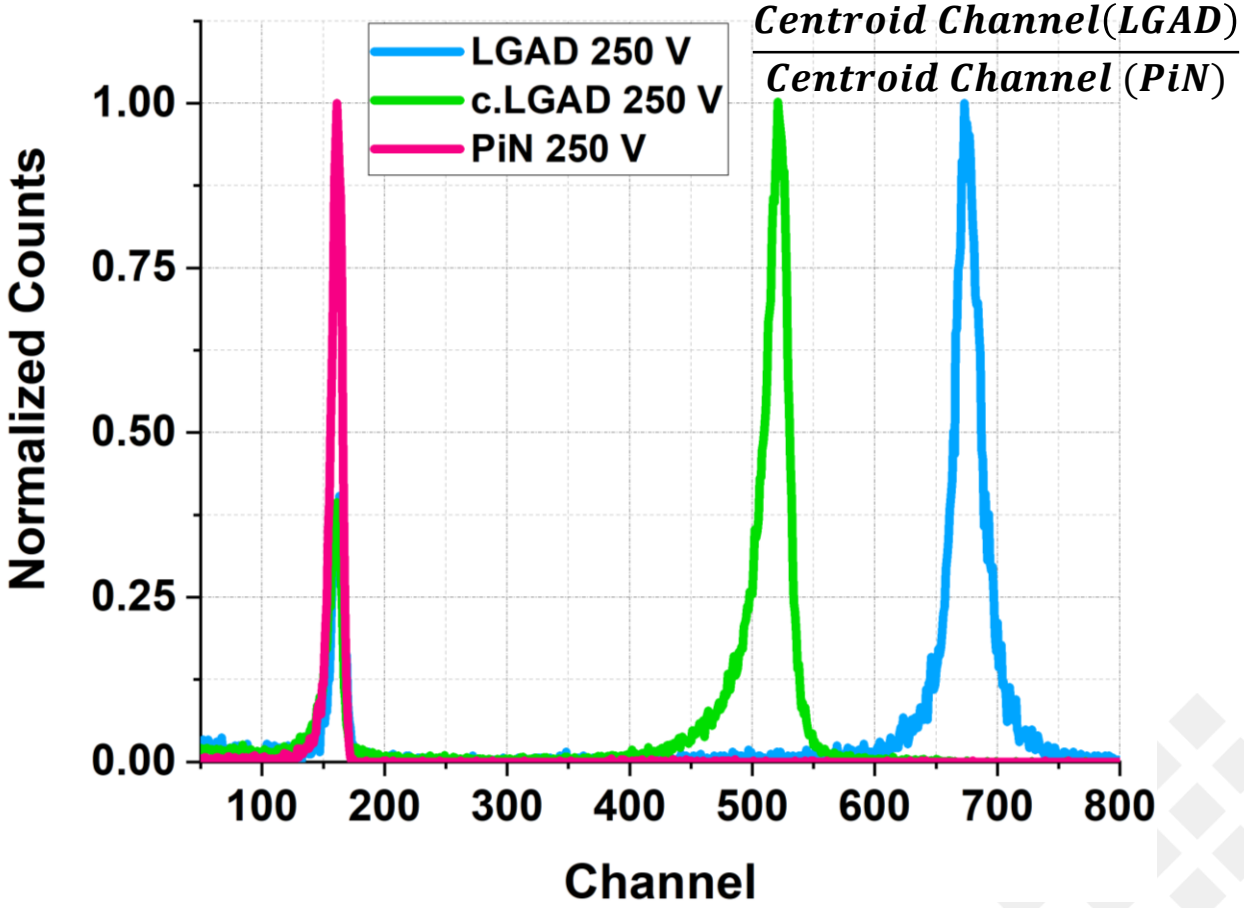


The Studied IMB-CNM Detectors

- Two LGADs with different gain layer layouts from the latest IMB-CNM run* were studied.
- The incidence angle variation was studied at 150 and 250 V, at room temperature (20 °C).



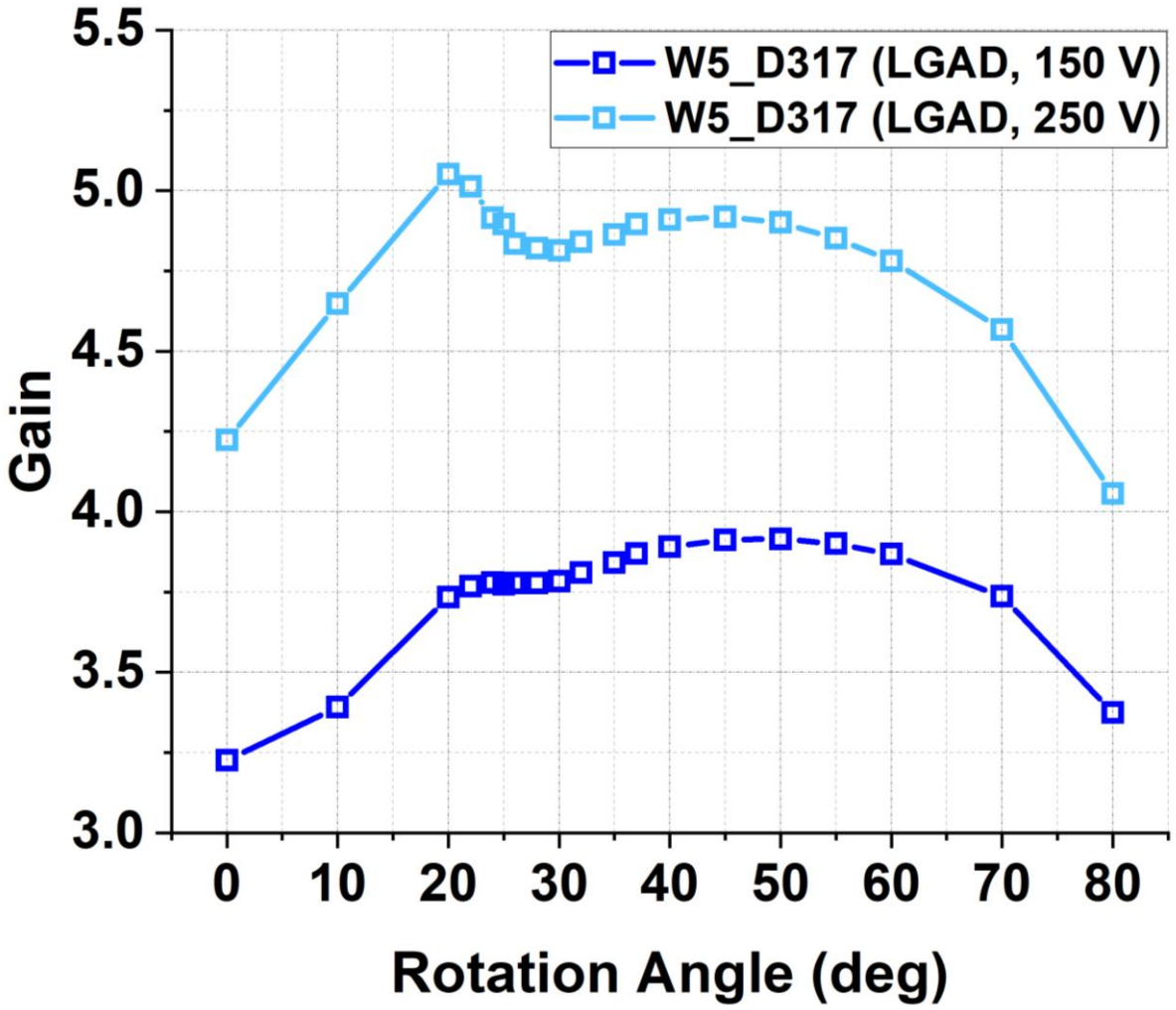
$$Gain = \frac{Centroid\ Channel(LGAD)}{Centroid\ Channel\ (PiN)}$$

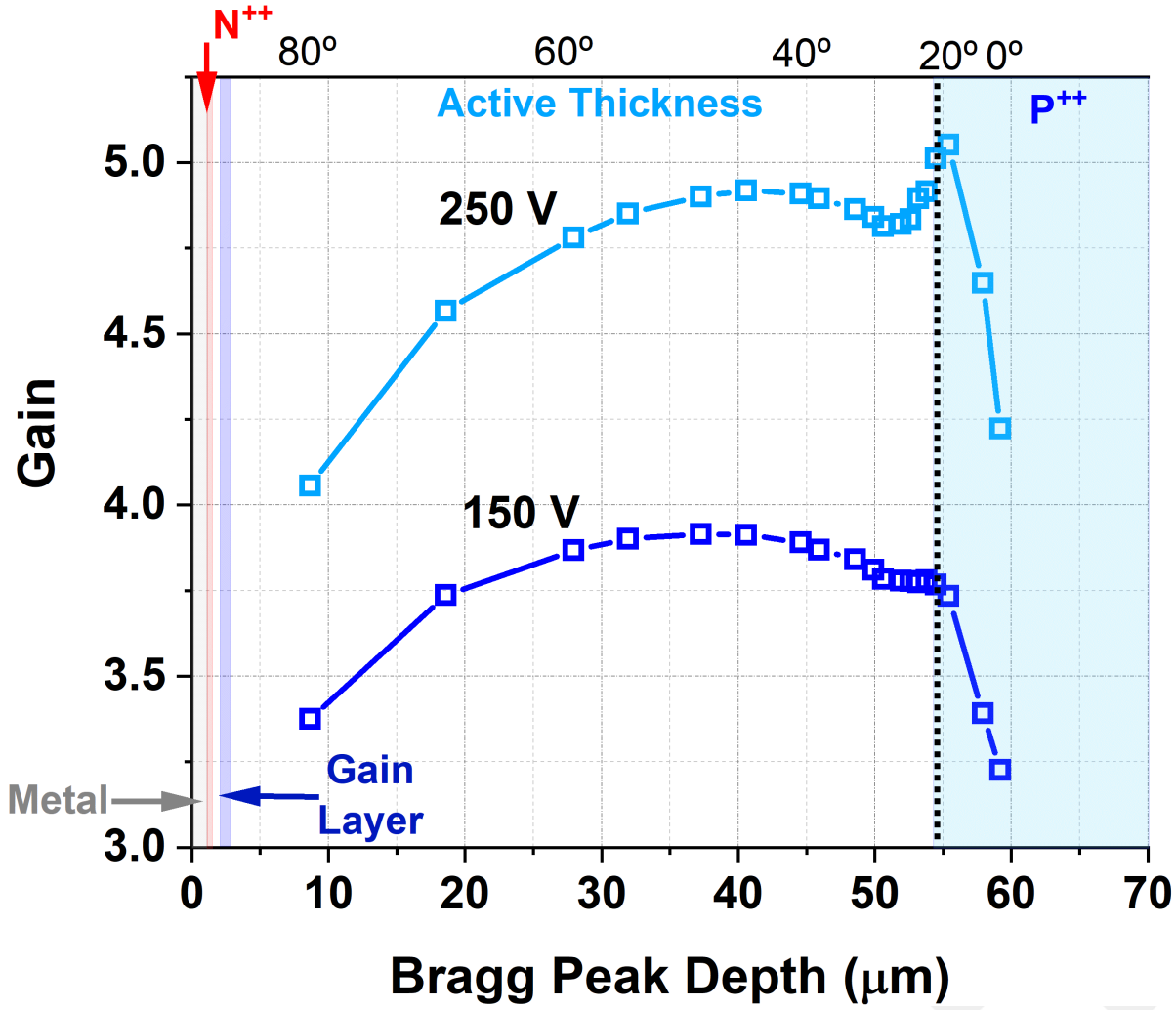


*See Florent Dougados' talk and paper https://doi.org/10.3390/s25175571 for details on fabrication features and electrical characterization of this run.

Gain dependence on incidence angle

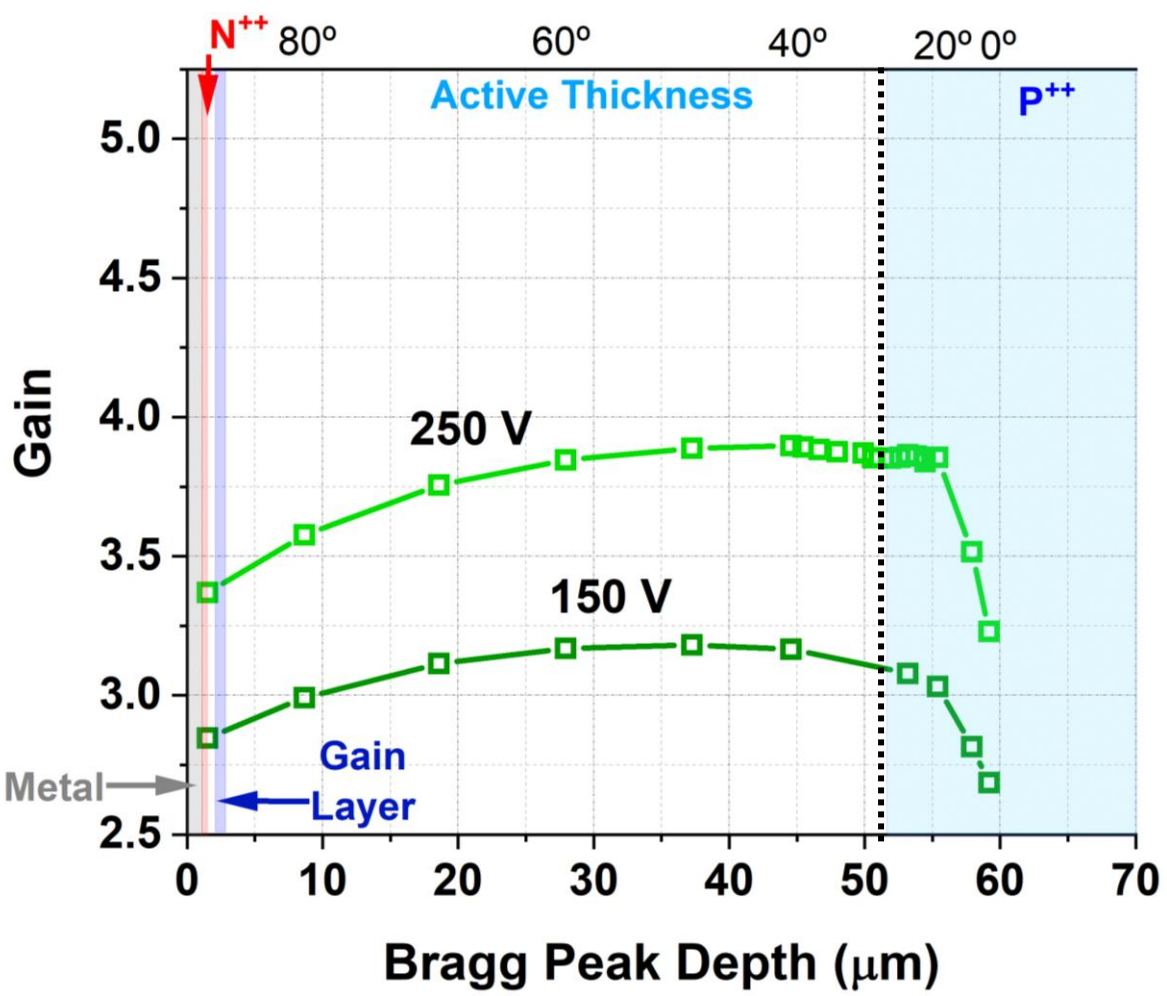
- The gain vs incidence angle data can be transformed into Gain vs Bragg Peak depth with SRIM simulations

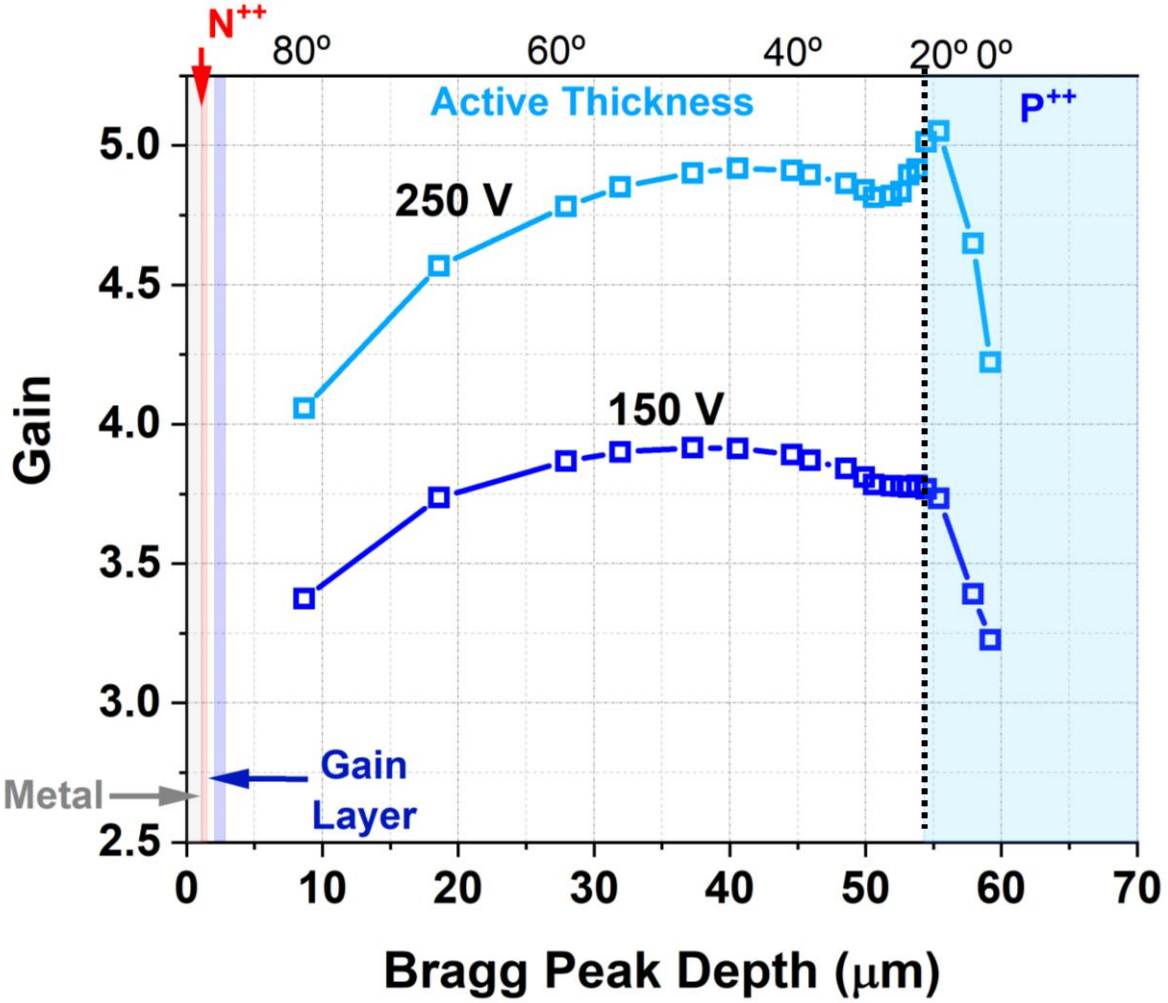




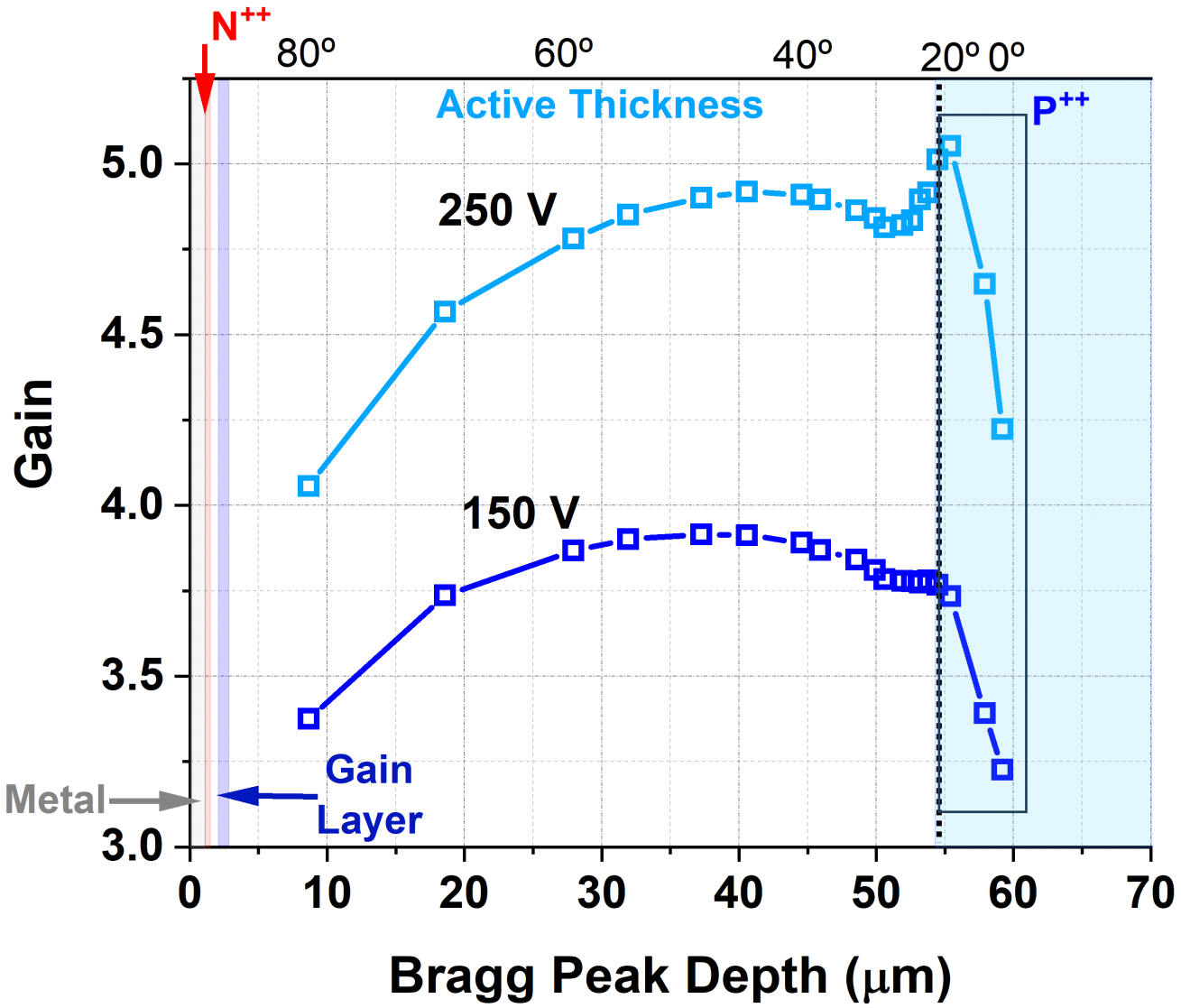
Gain dependence on Bragg Peak depth

Overall, **LGAD** shows a higher gain tan **c.LGAD** (expected). Also, **two competing phenomena** are observed: Charge spread along gain layer (mitigation of gain suppression) and plasma effects (enhancement of gain suppression)



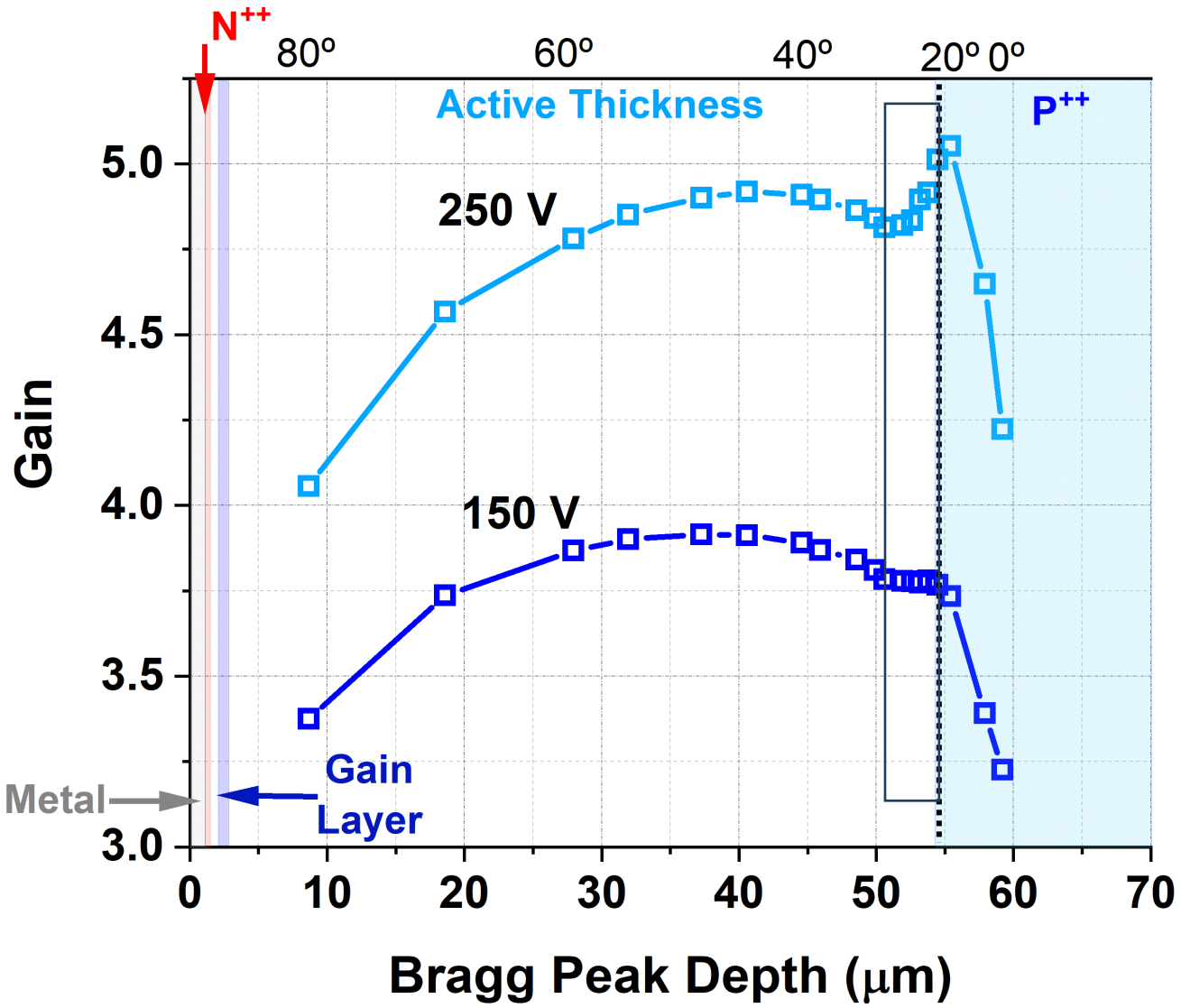


Gain dependence on Bragg Peak depth



- 0-20º → **Bragg Peak falls witin P++**
  Charge spread across gain layer dominates: **Gain increases**

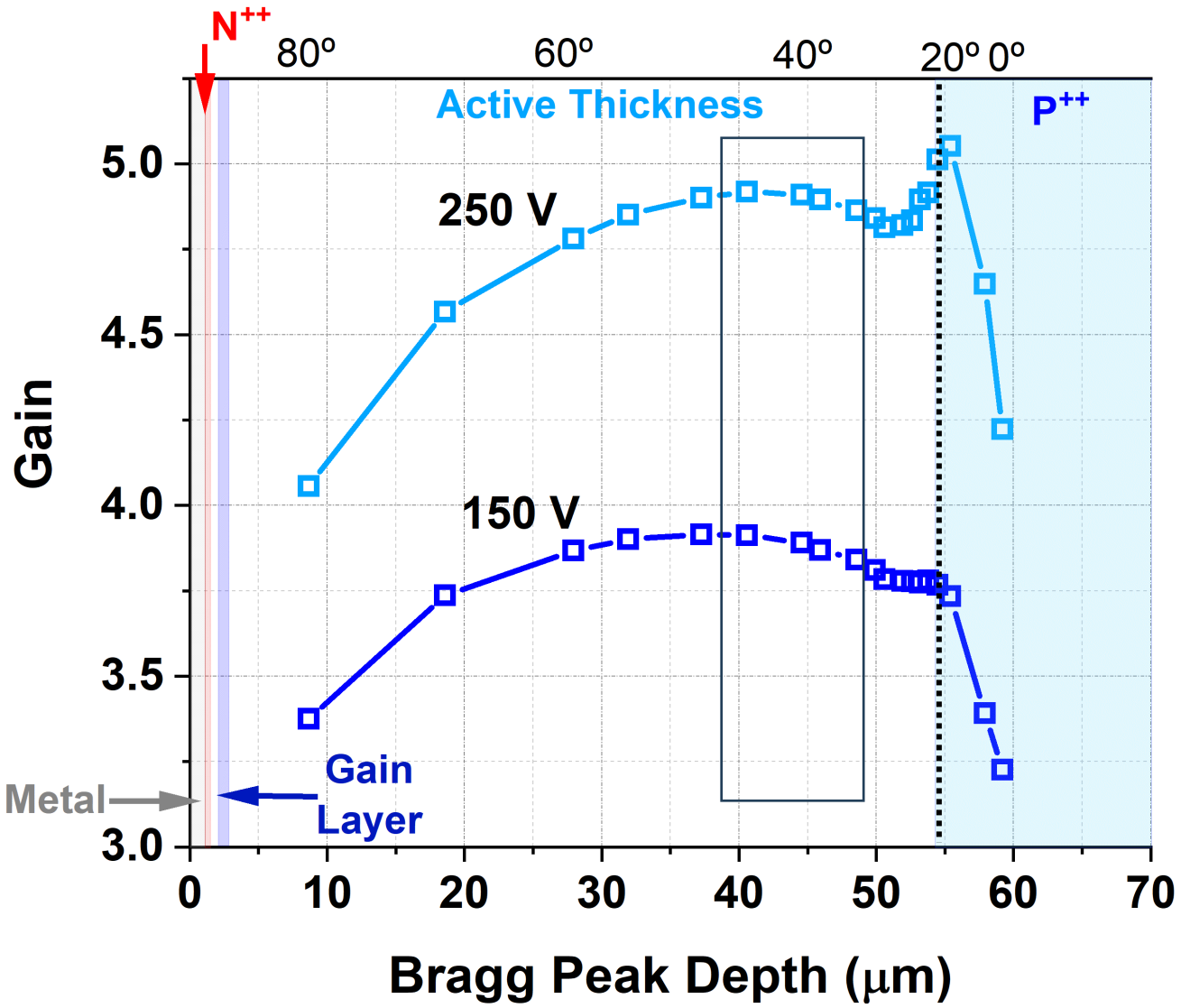
Gain dependence on Bragg Peak depth



- 0-20º → Bragg Peak falls witin P++, Charge spread across gain layer dominates: Gain increases
- 20-30º → **Bragg Peak enters active volumen**, plasma effects show up: **Gain decreases or stays still**

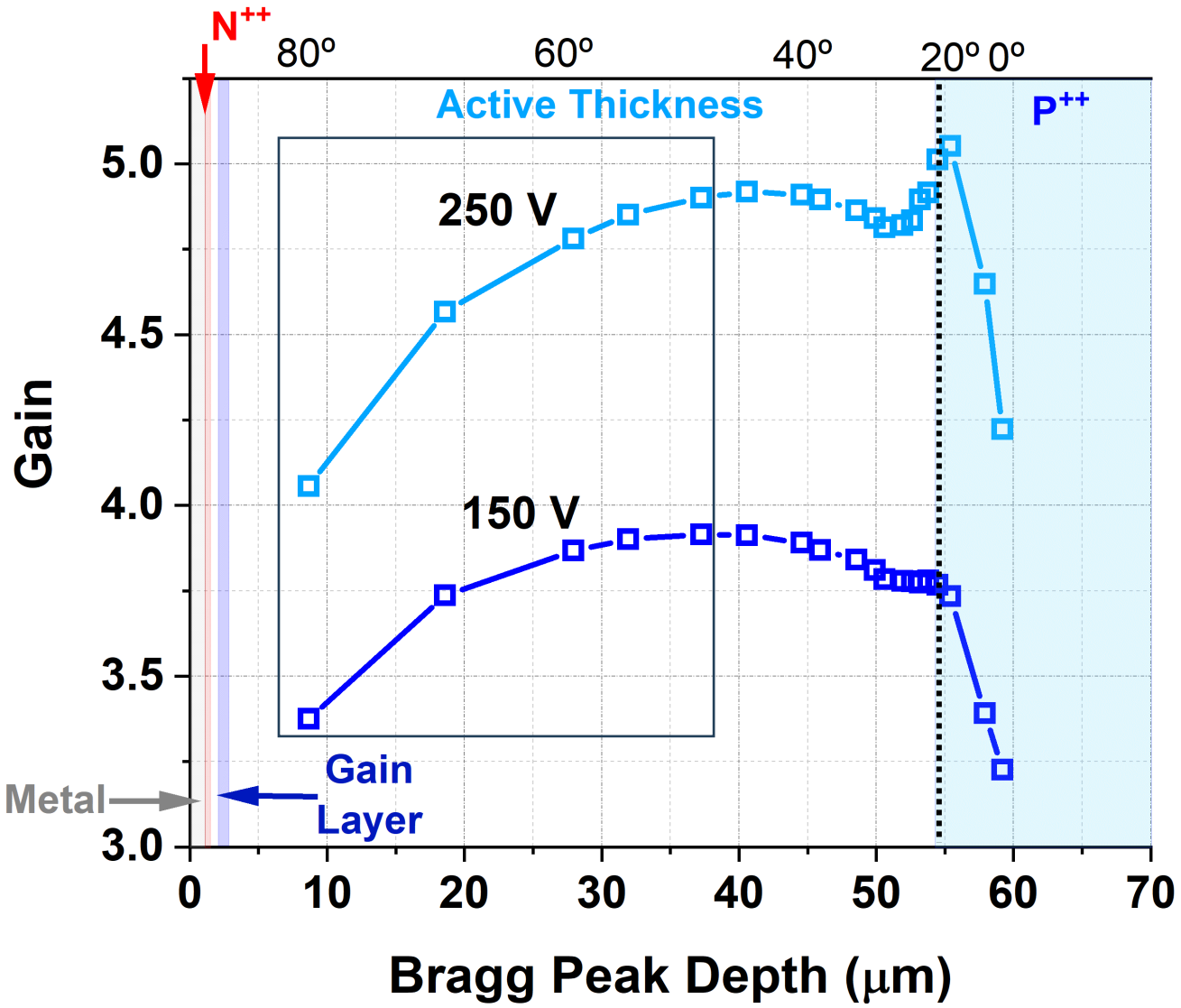
- The combination of these effects depends on the applied voltage, suggesting a **dependence of gain suppression on the very gain**.

Gain dependence on Bragg Peak depth



- 0-20º → Bragg Peak falls witin P++, Charge spread across gain layer dominates: Gain increases
- 20-30º → Bragg Peak enters active volumen, plasma effects show up: Gain decreases or stays still
- 30º-45º → Charge spread across gain layer dominates over plasma effects: Gain slightly increases

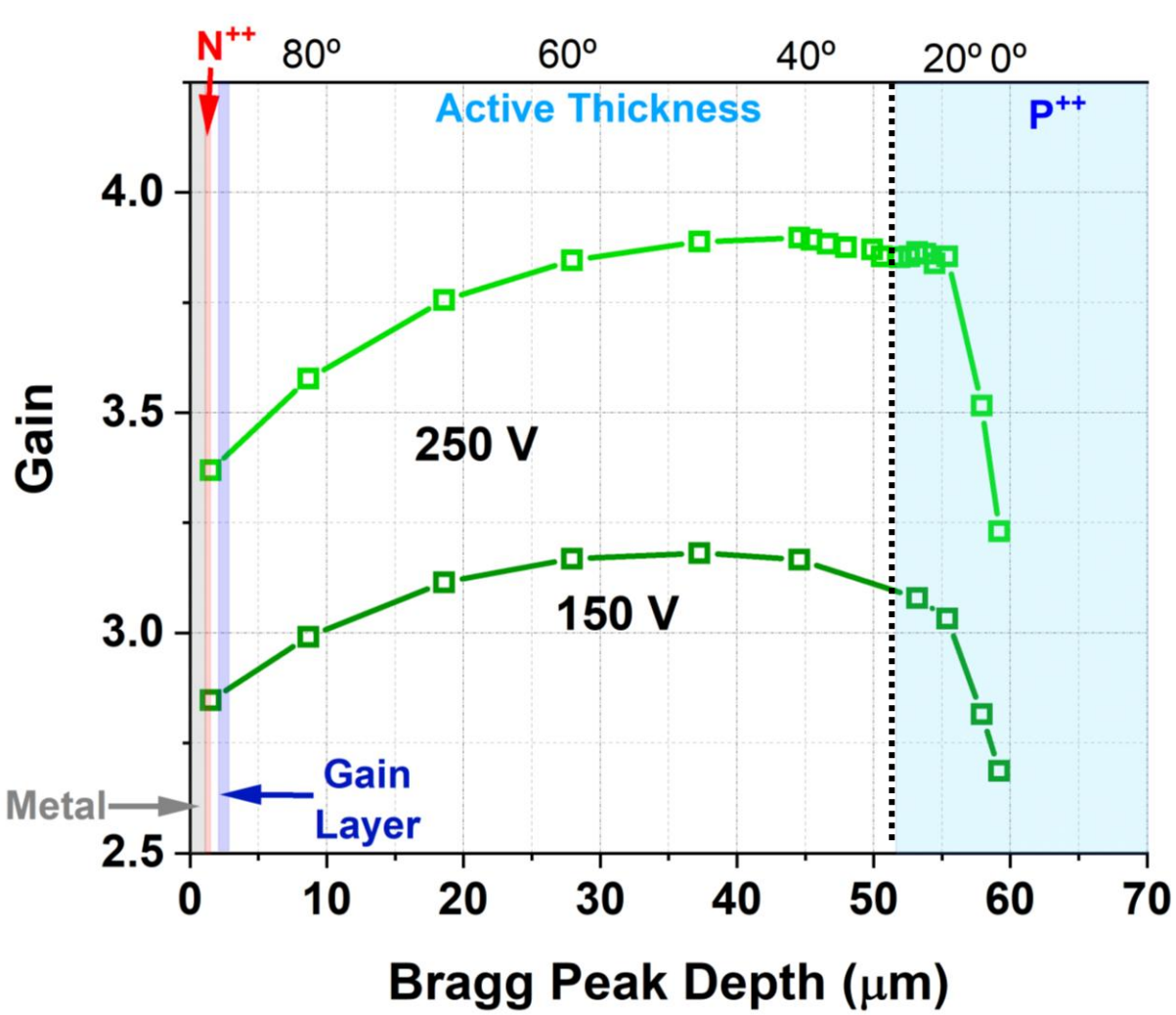
Gain dependence on Bragg Peak depth

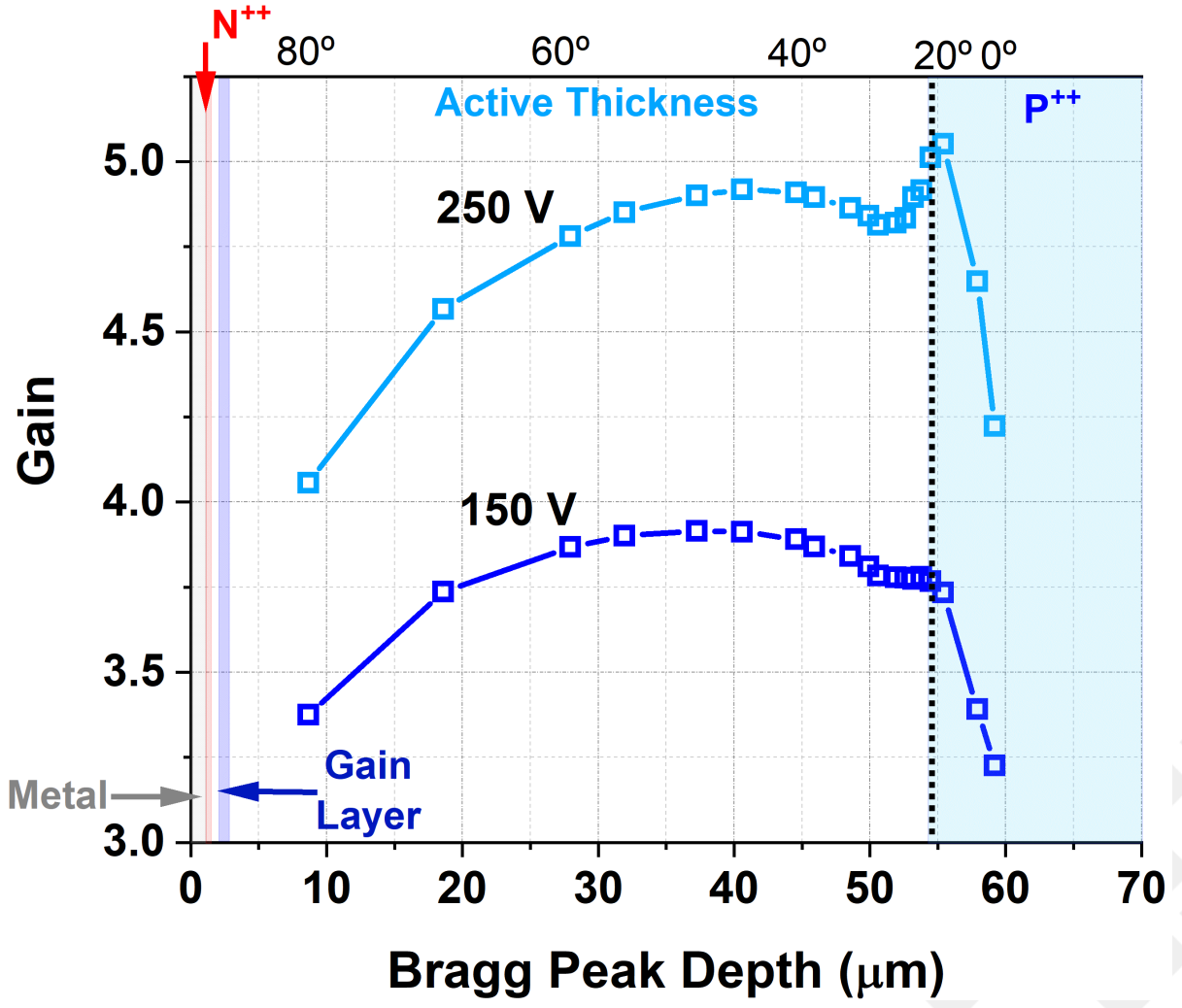


- 0-20º → Bragg Peak falls witin P++, Charge spread across gain layer dominates: Gain increases
- 20-30º → Bragg Peak enters active volumen, plasma effects show up: Gain decreases or stays still
- 30º-45º → Charge spread across gain layer dominates over plasma effects: Gain slightly increases
- 45-80º-85º → **Bragg peak gets closer to gain layer**, plasma effects dominate over charge spread: **Gain decreases**

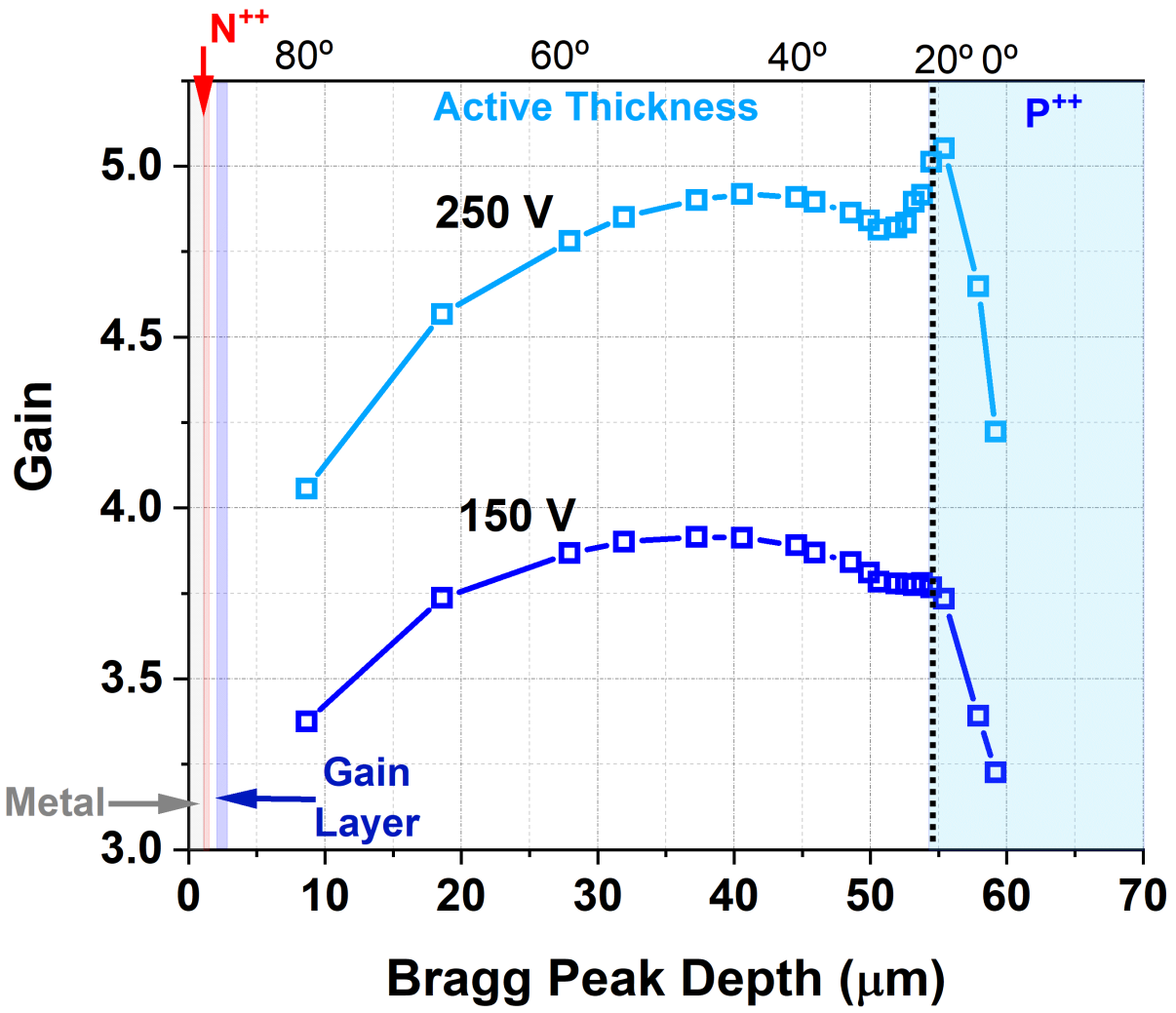
Gain dependence on Bragg Peak depth

- Seeing the big picture: for 2.3 MeV protons at incidence angles between 0º and 85º, the relative gain suppression varies by 10-20%.





Gain dependence on Bragg Peak depth



- Seeing the big picture: for 2.3 MeV protons at incidence angles between 0º and 85º, the studied devices show gains between ***3-5*** with a relative gain suppression between ***10-20%***.
- The results reported in https://doi.org/10.3390/s22031080, for 3 MeV protons at incidence angles between 0º and 85º, show gains between ***4-13*** (similar bias) and relative gain suppression between ***45-60%***
- **Could a lower gain** (3-5) **be preferable** to higher gains (10-20) in terms of gain stability with particle incidence angle?

Acknowledgments

This work was funded by the Spanish Ministry of Science, Innovation, and Universities (MICIU/AEI/10.13039/501100011033/) and by the European Union's ERDF program "A way of making Europe", under grant numbers CEX2023-001397-M, PID2023-148418NB-C42, PID2023-148418NB-C44, and PDC2023-145925-C32. This investigation was also partially financed by the project ref. ASTRO21/1.1/1, with financing from the European Union NextGenerationEU; the Ministry of Science, Innovation, and Universities; the Recovery, Transformation, and Resilience Plan; the Department of University, Research, and Innovation of the Junta de Andalucía; and the University of Sevilla.

Thanks for your attention!

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