# Deducing the Size of "Breakdown-Inducing-Tips"

Salvador Barranco Cárceles, Andreas Kyritsakis,
Veronika Zadin, and Ian Underwood

MeVArc, Tahoe City, 2024

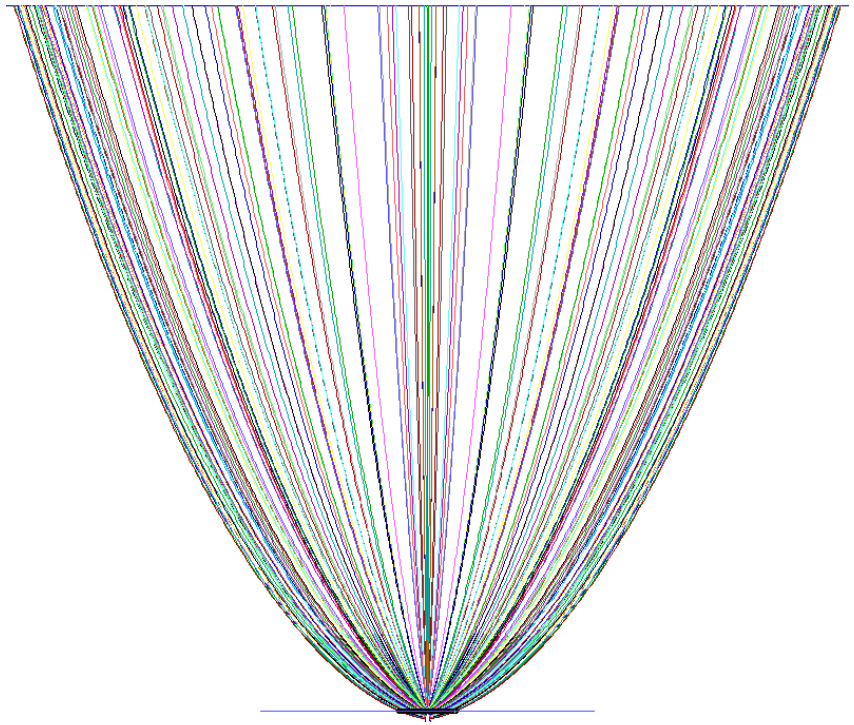
# Why Does VBD Occur?

Nano-Protrusions

Plasmons

Dislocations

# The Fingerprint



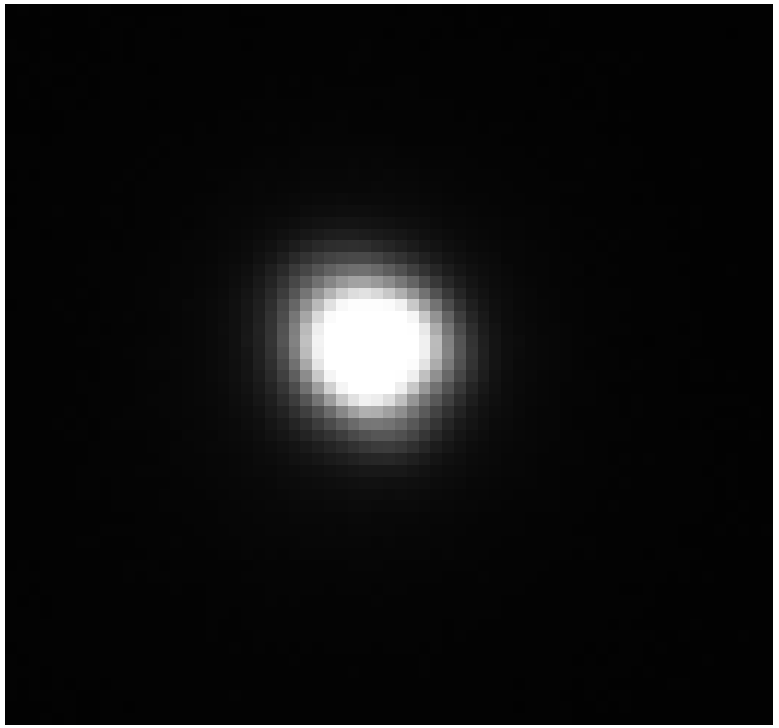


Image by Adaptix Ltd.

T. Utsumi, Journal of Applied Physics 38, 1967

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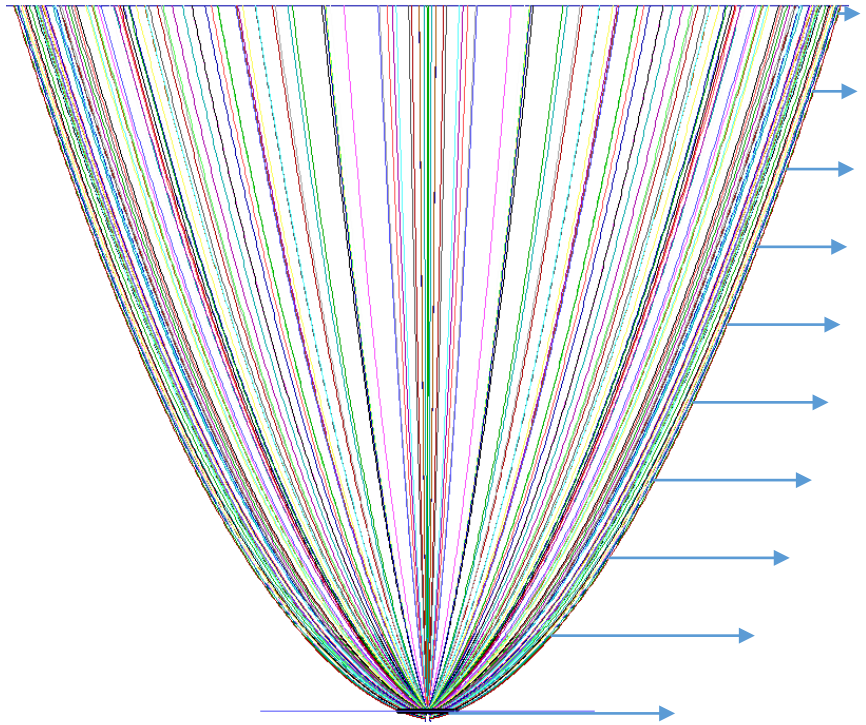

Field transversal component – $E_r$

T. Utsumi, Journal of Applied Physics 38, 1967

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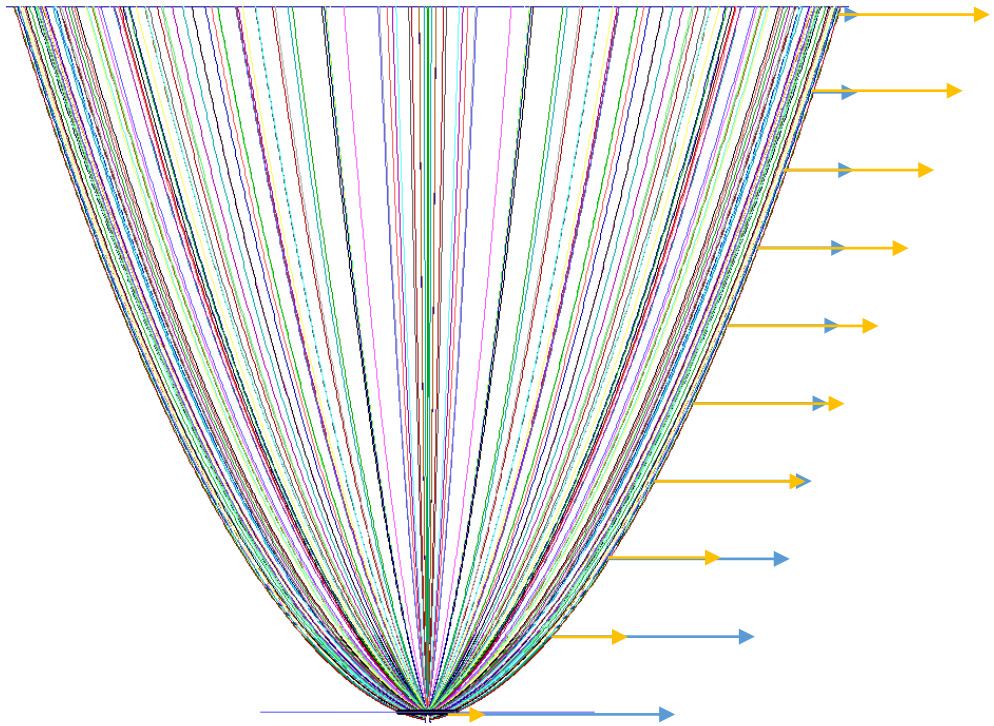

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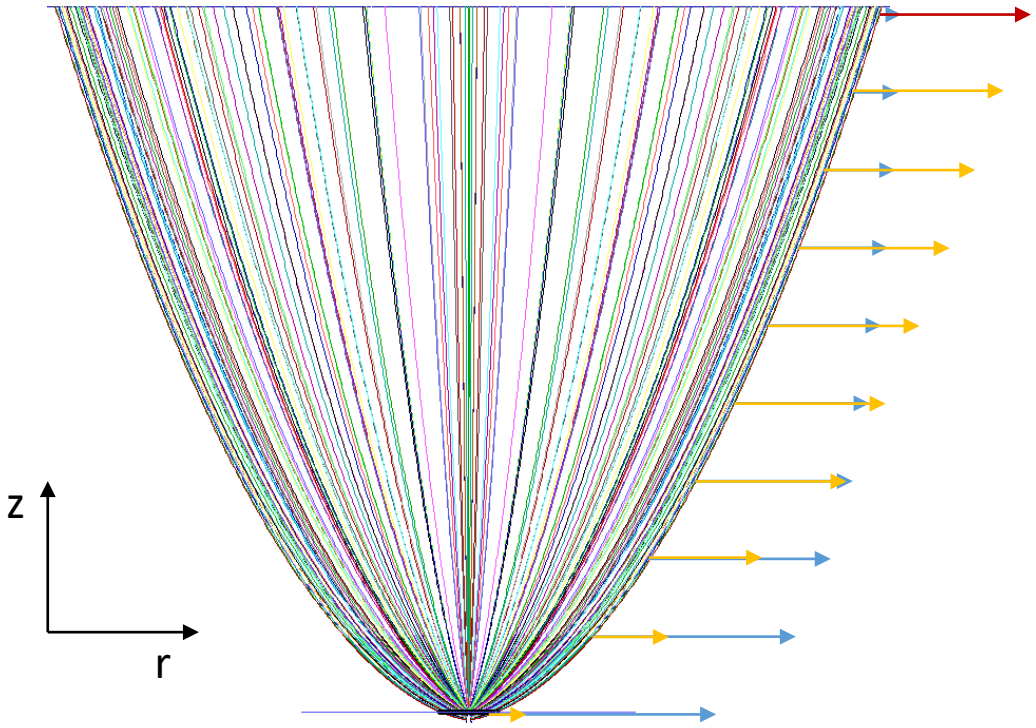


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$$z = c \cdot r^2$$

$$\varepsilon_{t\_terminal} = \int_{trajectory} E_r \cdot r \, dr$$

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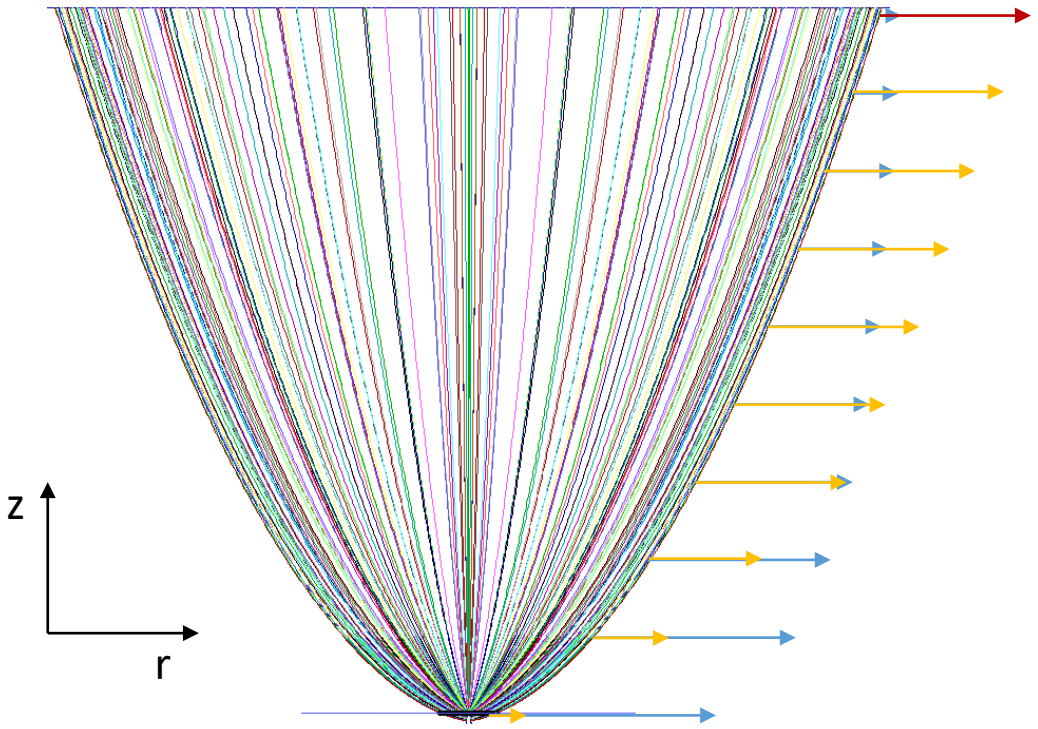


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$$\eta = \frac{\varepsilon_{t\_terminal}}{h \cdot E_{macro}}$$

$$h = \frac{r^2}{4 \cdot \eta \cdot z}$$

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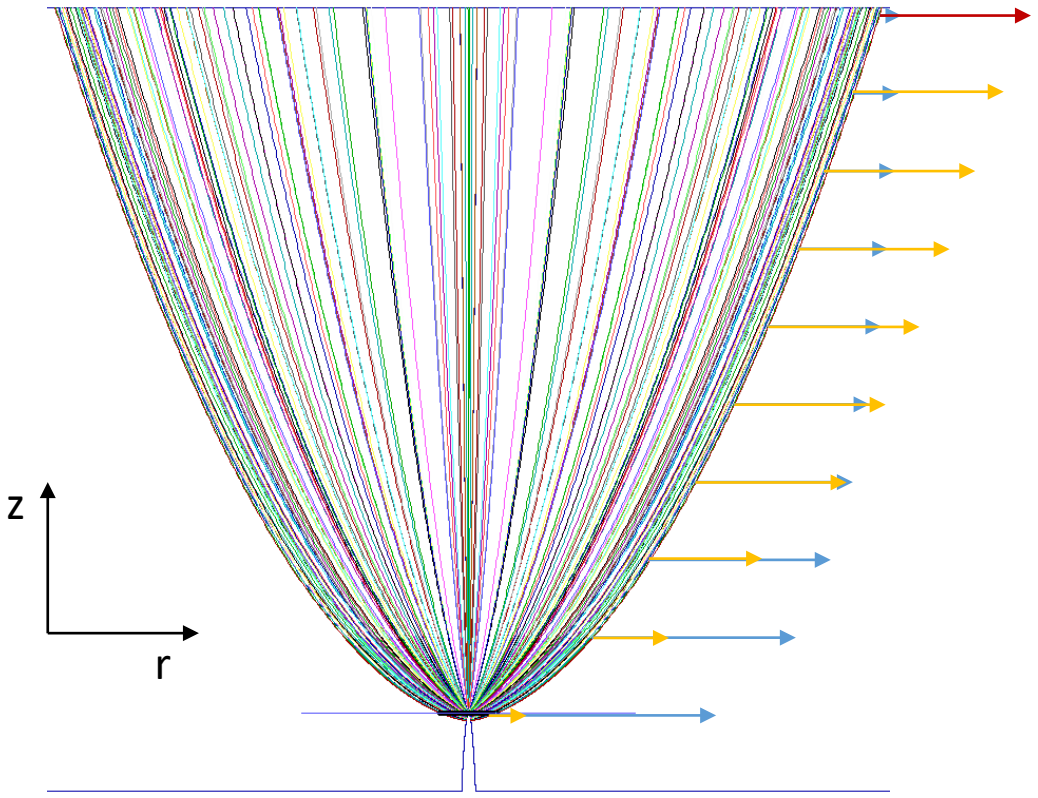
# The Fingerprint of a Protrusion




Field transversal component – $E_r$

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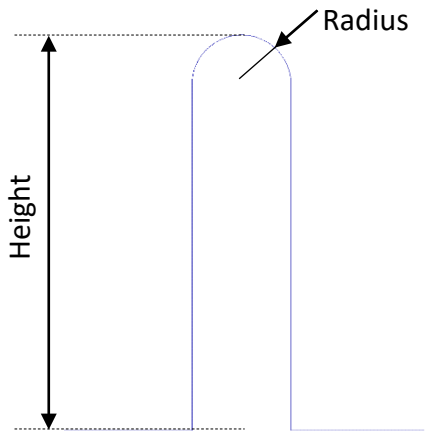
$$\eta = \frac{\varepsilon_{t\_terminal}}{h \cdot E_{macro}} \in [0.25 - 0.5]$$

$$h = \frac{r^2}{4 \cdot \eta \cdot z} > 10 \, \mu m$$

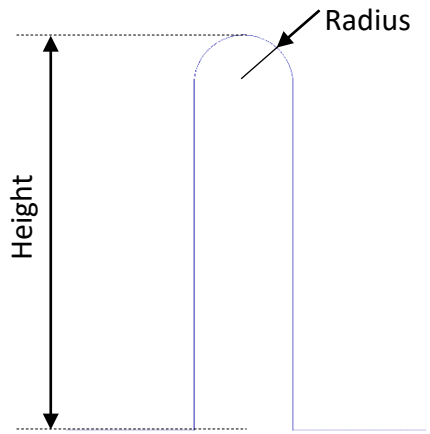
T. Utsumi, Journal of Applied Physics 38, 1967

# Calculating η



# Calculating η

| | radius (nm) | height (nm) | macro field (V/m) | max field (V/m) | beta |
|---|---|---|---|---|---|
| **pillar_1** | 0.221 | 30 | 5.00E+07 | 5.01E+09 | 100.20 |
| **pillar_2** | 0.71 | 100 | 5.00E+07 | 5.01E+09 | 100.12 |
| **pillar_3** | 1.08 | 150 | 5.00E+07 | 4.99E+09 | 99.84 |
| **pillar_4** | 2.18 | 300 | 5.00E+07 | 5.00E+09 | 99.98 |
| **pillar_5** | 3.65 | 500 | 5.00E+07 | 5.00E+09 | 100.02 |
| **pillar_6** | 7.3 | 1000 | 5.00E+07 | 5.02E+09 | 100.46 |



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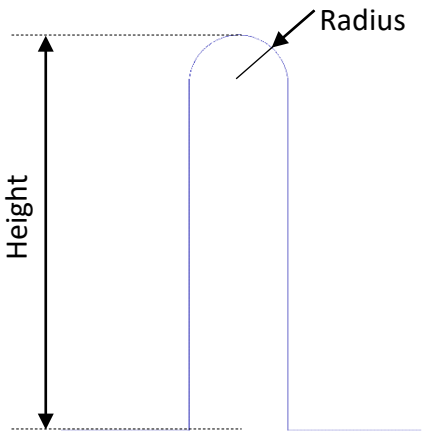


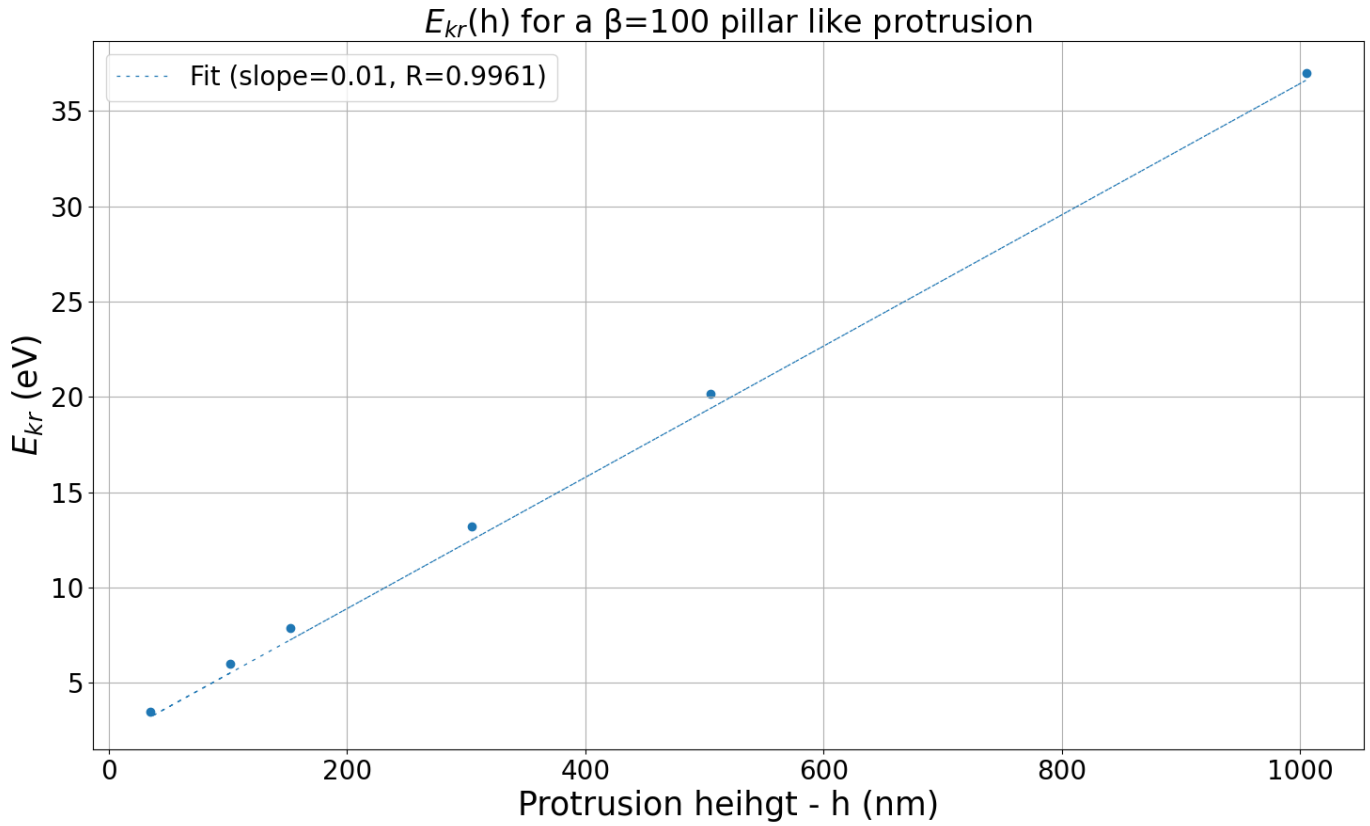

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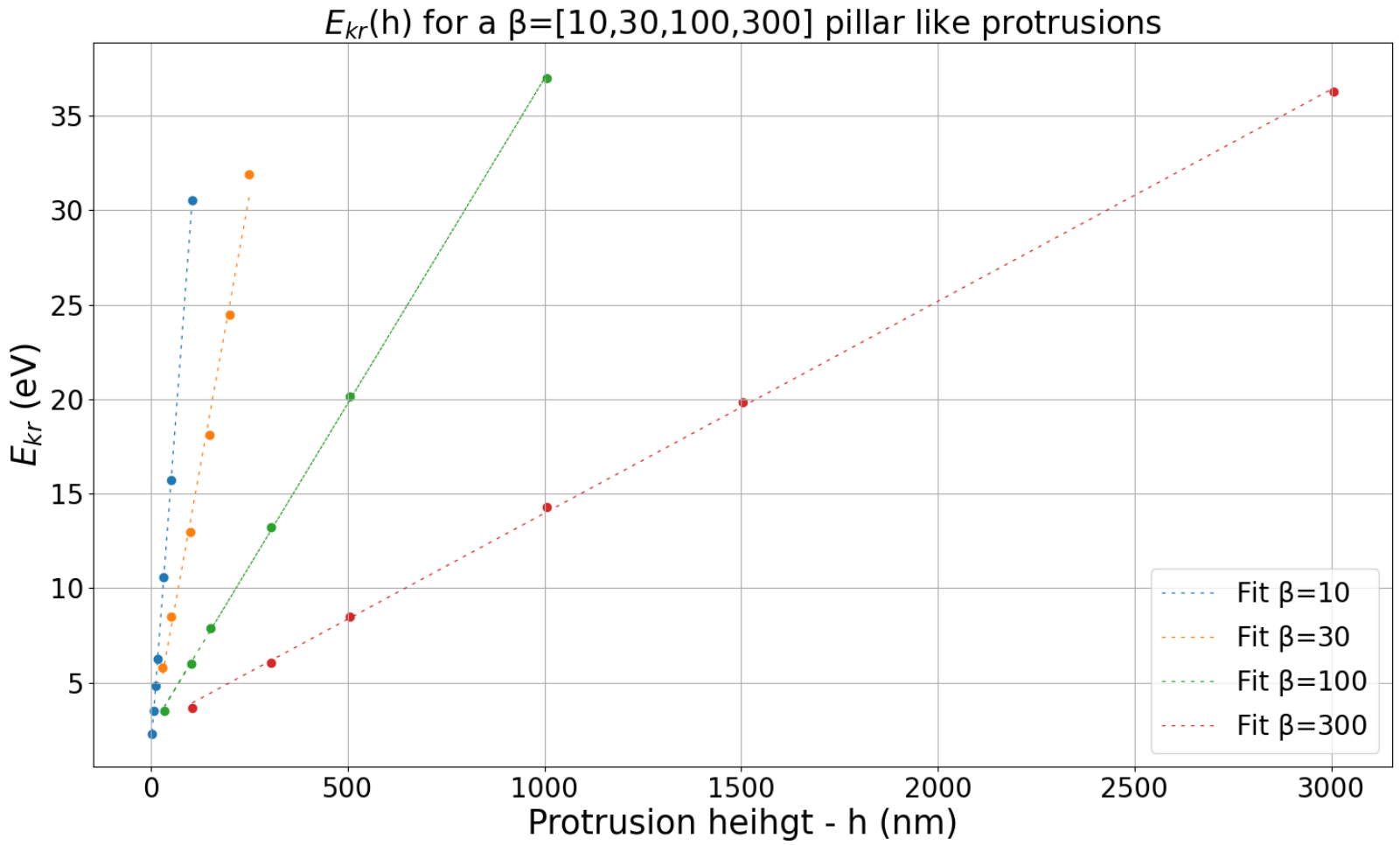

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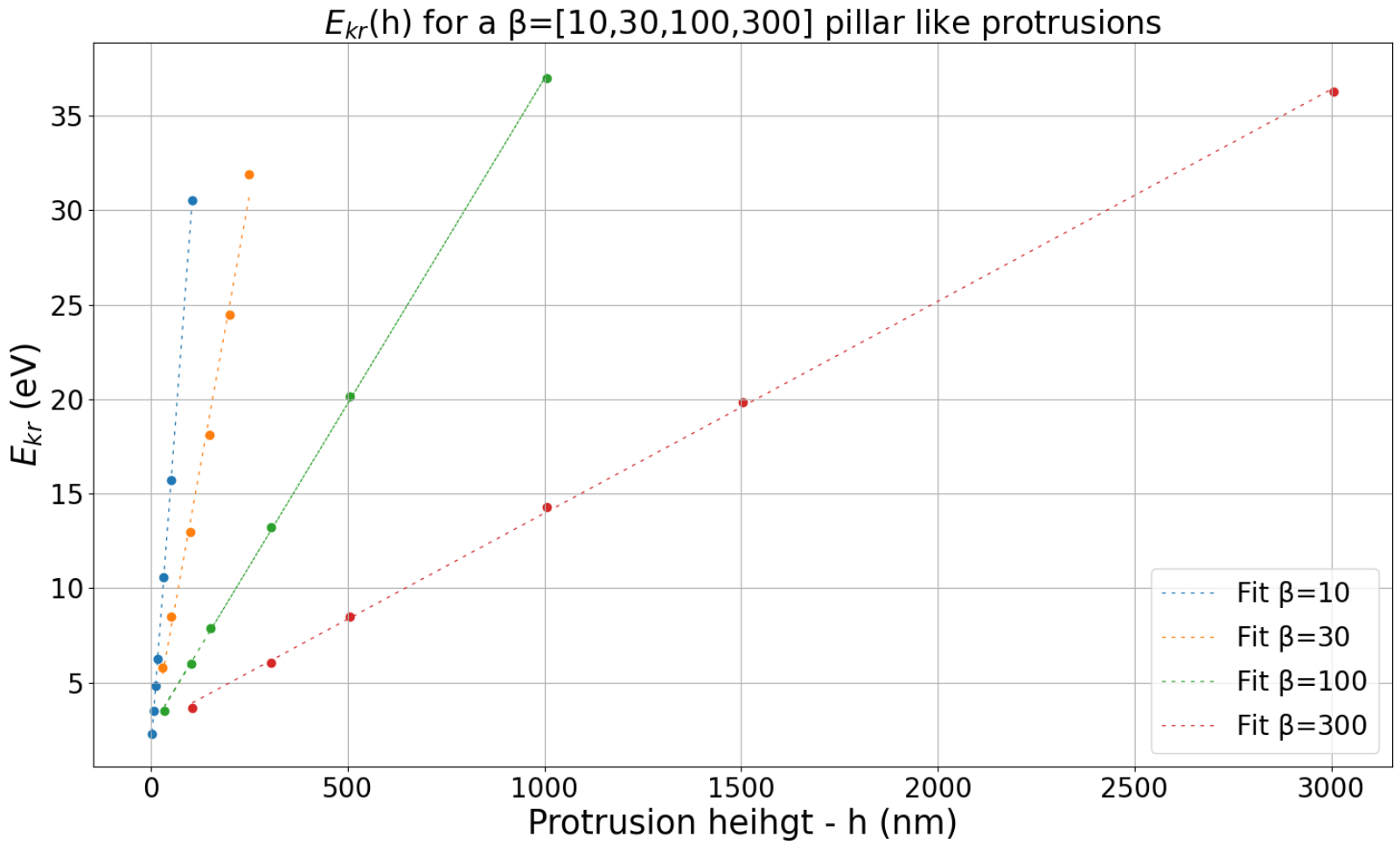


$$\eta = \frac{m_{\beta_n}}{E_{macro,\beta_n}}$$

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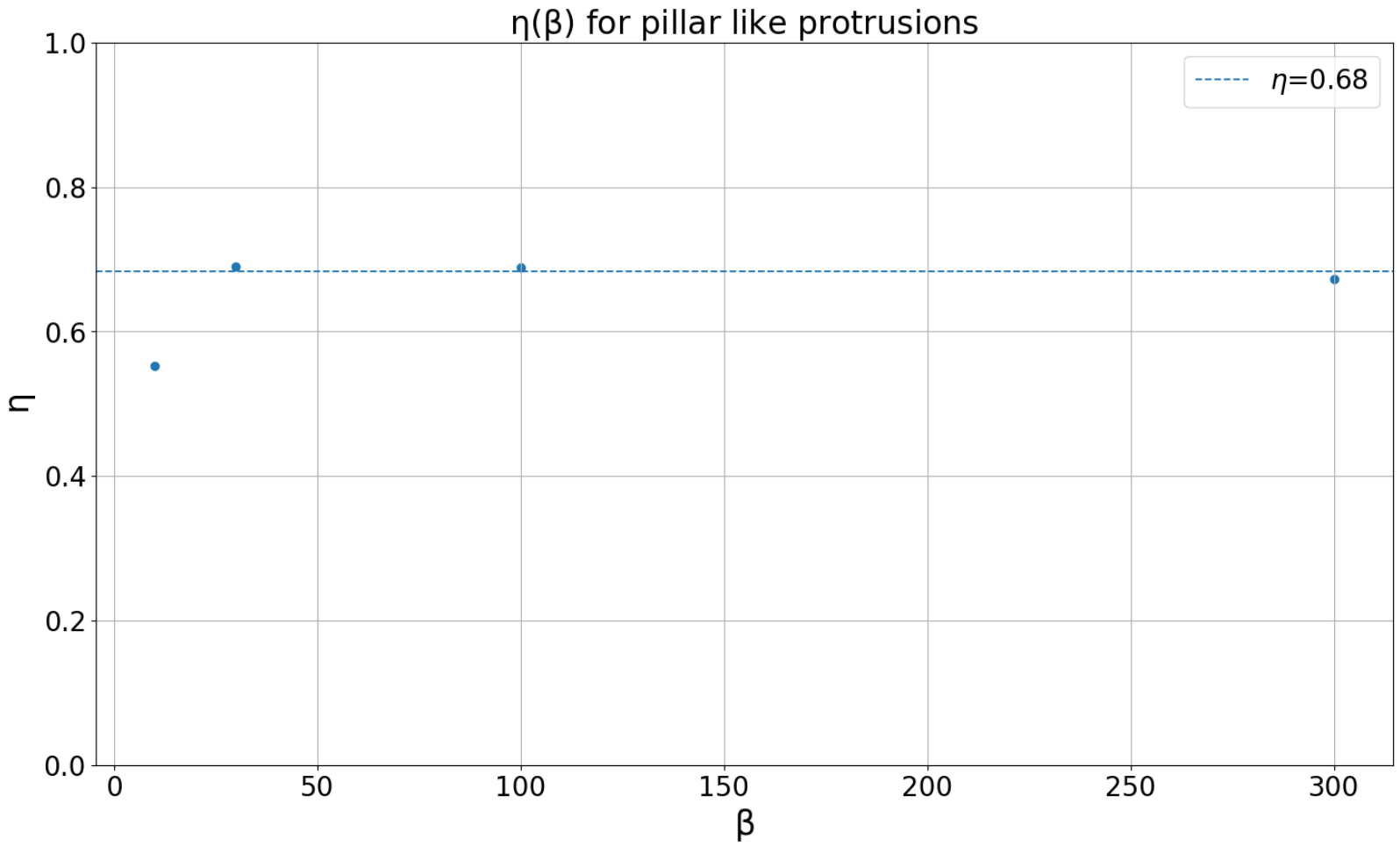

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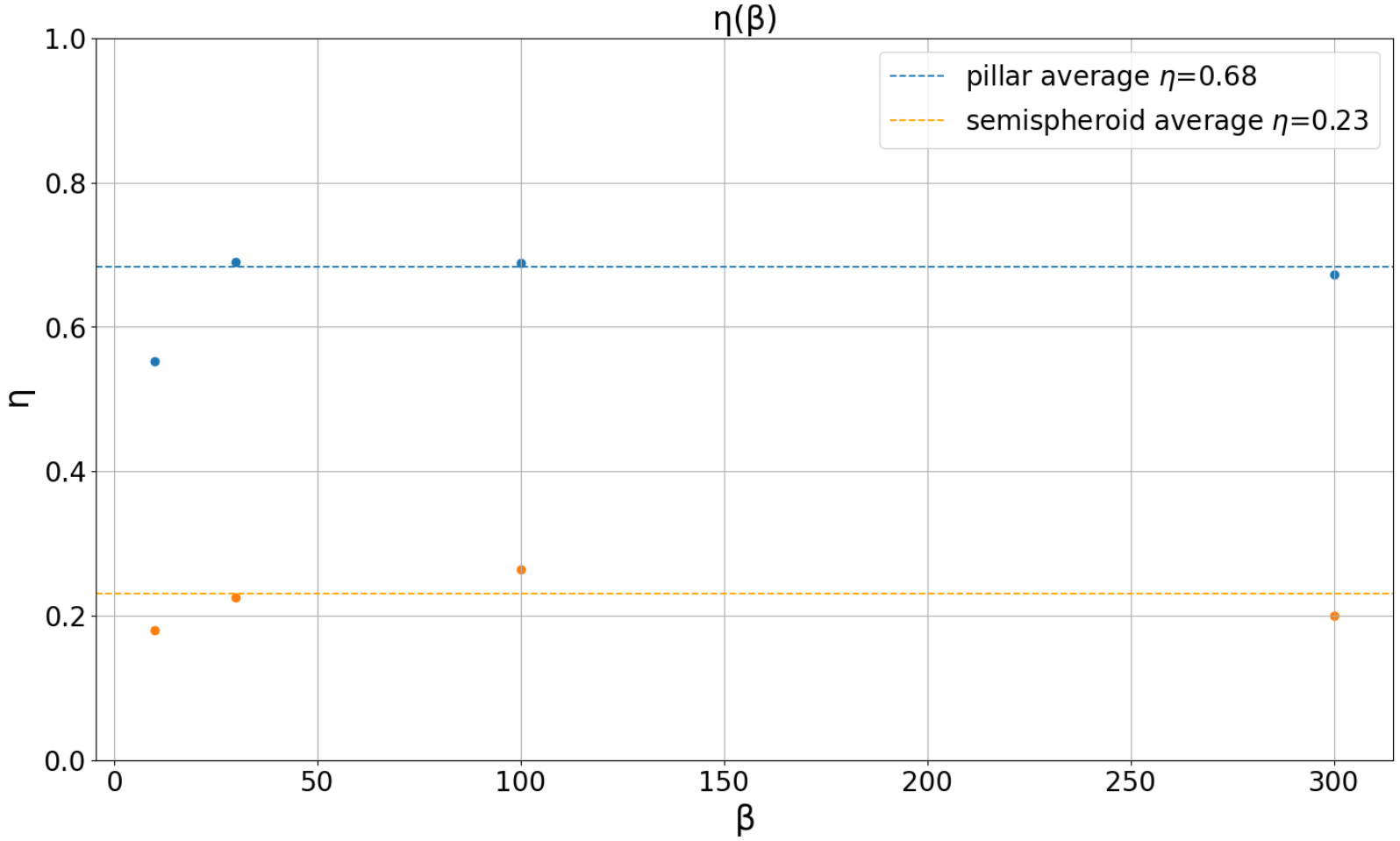

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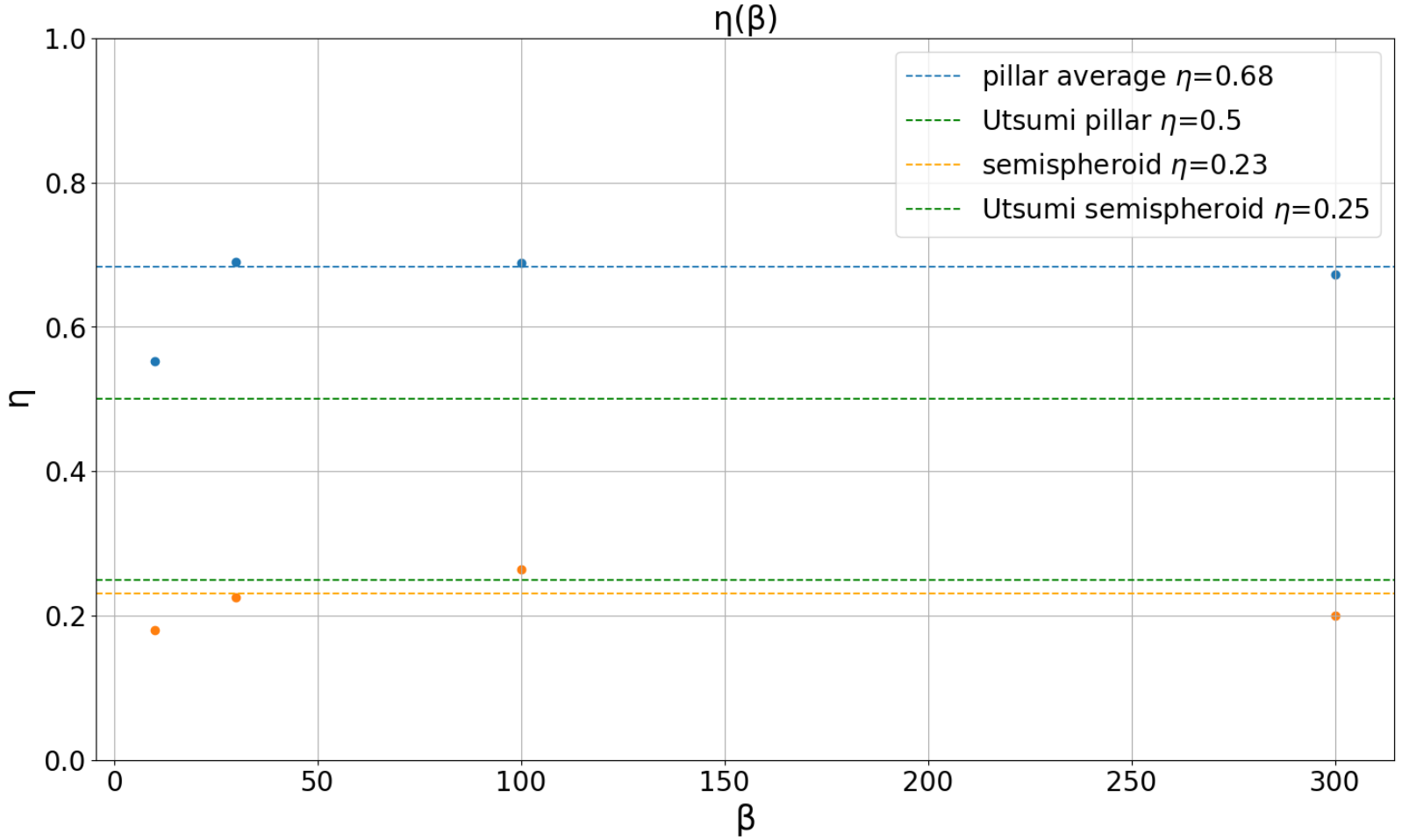
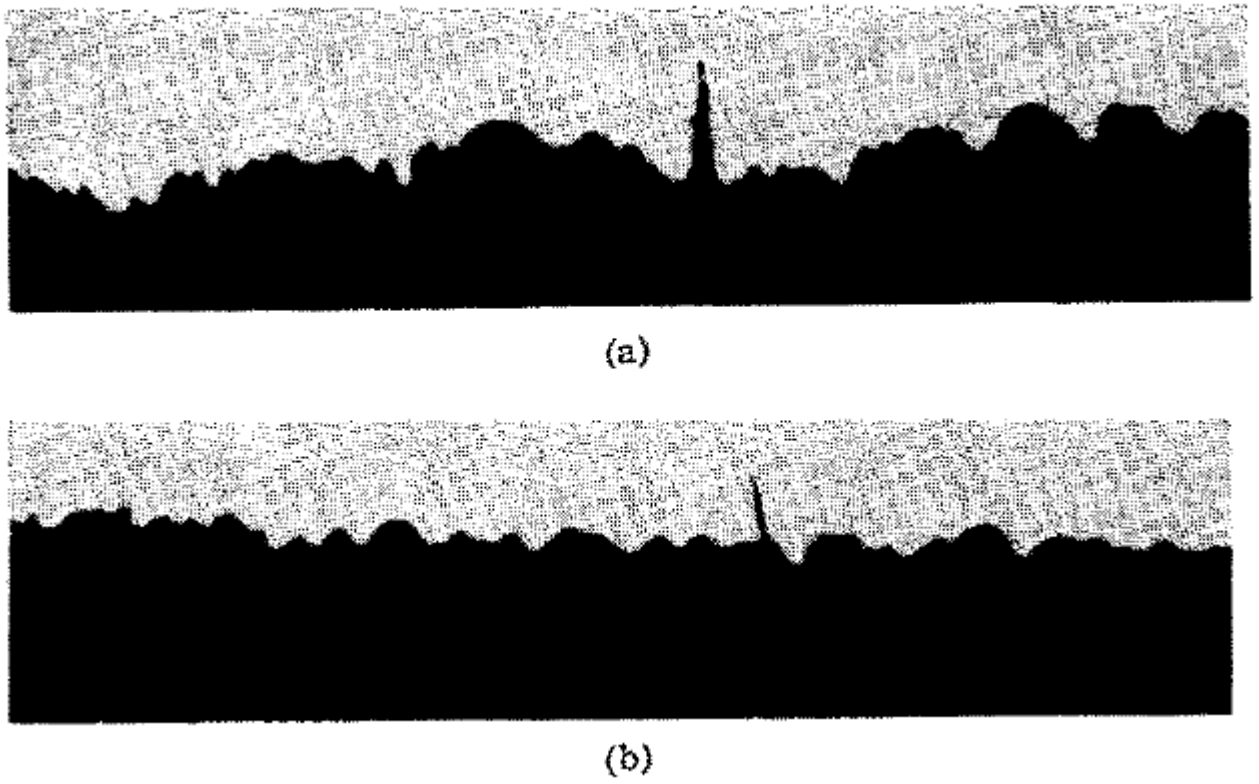



$$\eta \in [0.2 - 0.7]$$

$$h > 1\ \mu m$$

# Theory Validation




R. P. Little and W. T. Whitney, Journal of Applied Physics 34, 1963

Protrusion in pre-breakdown site

Distance between electrodes – d = 380 µm

Applied potential – V = 7000 V

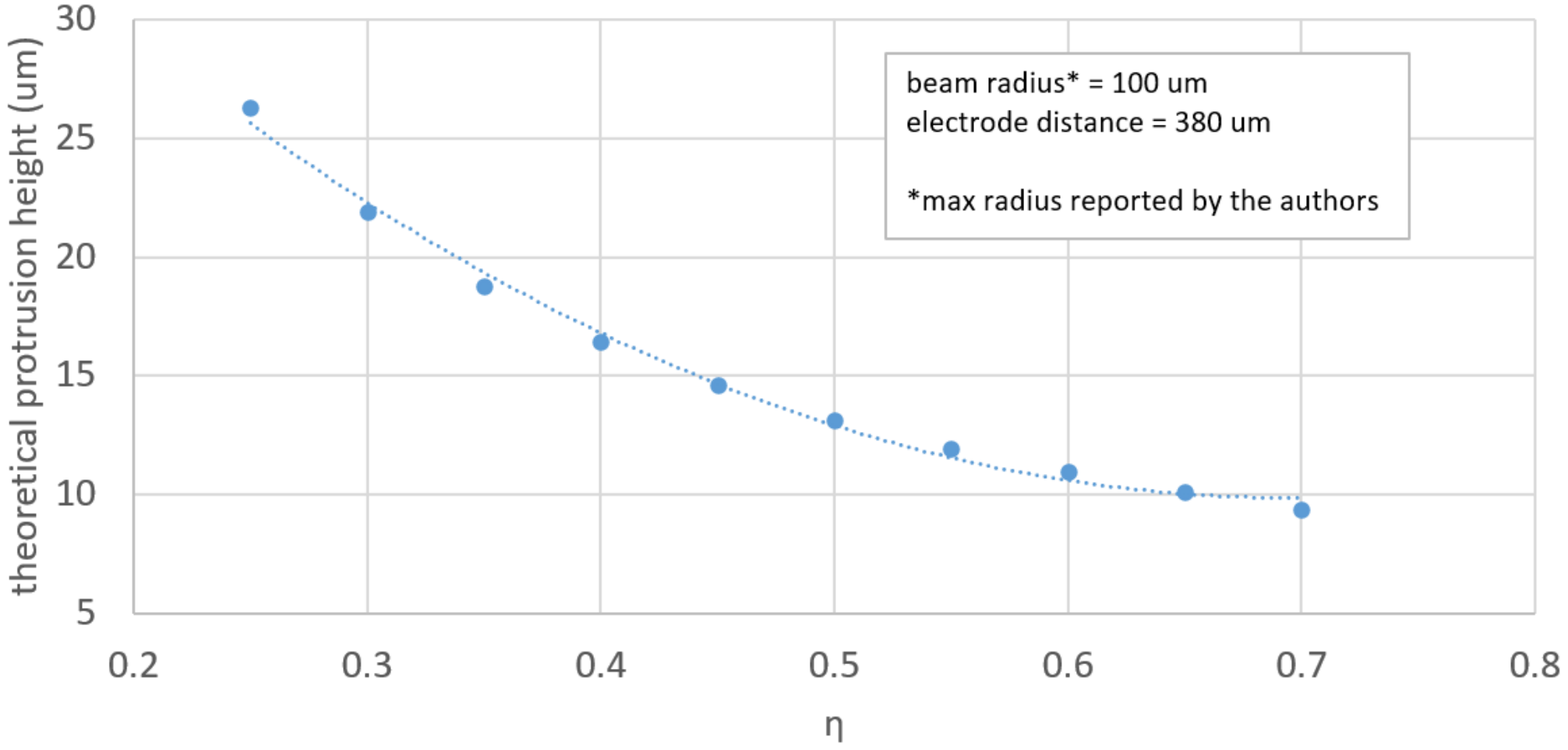
Measured current – J ~10 nA

Spot radius in phosphor screen – r < 100 µm

Protrusion height – h = 2 µm

Protrusion base – b = 0.2 µm

# Theory Validation – Height & Beam Radius



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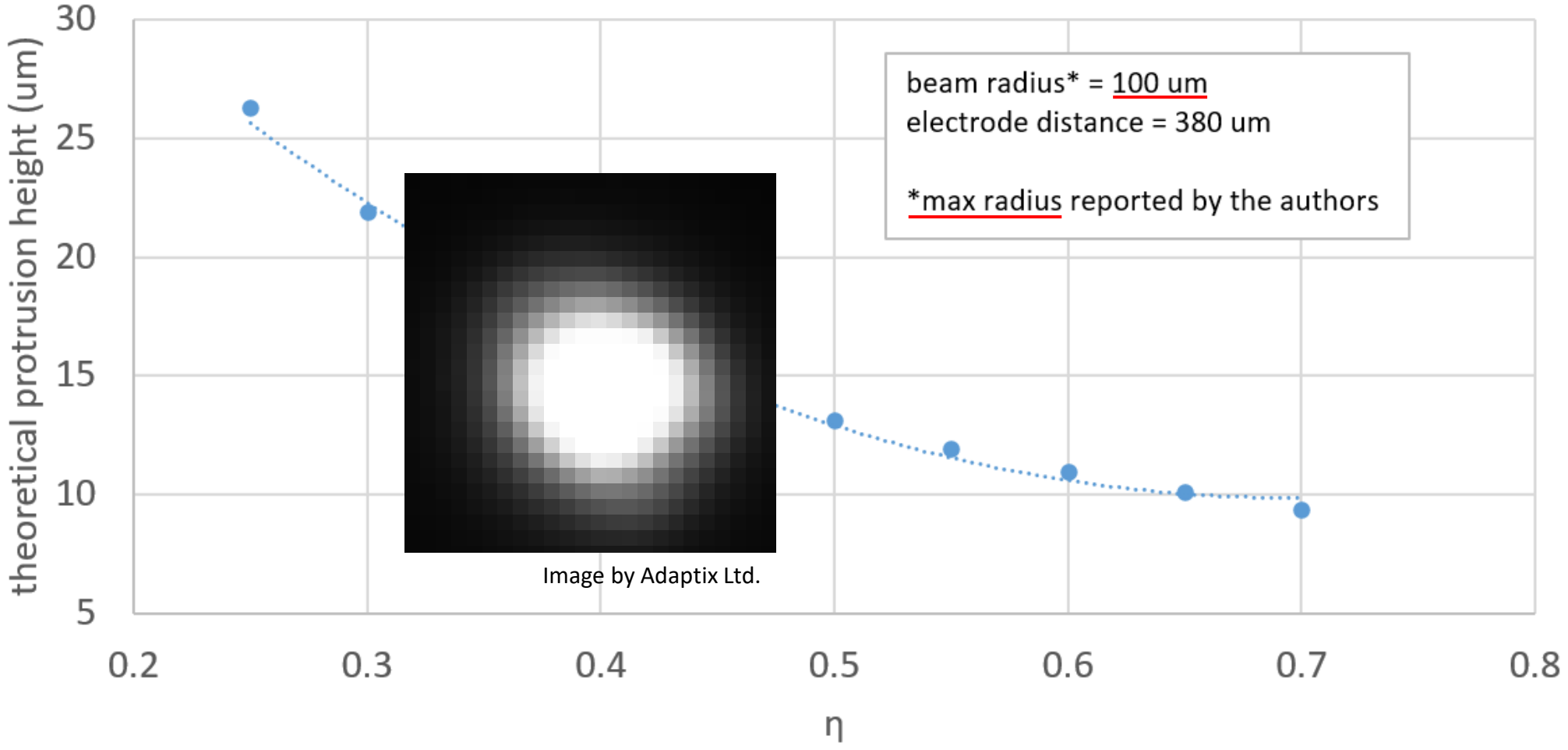

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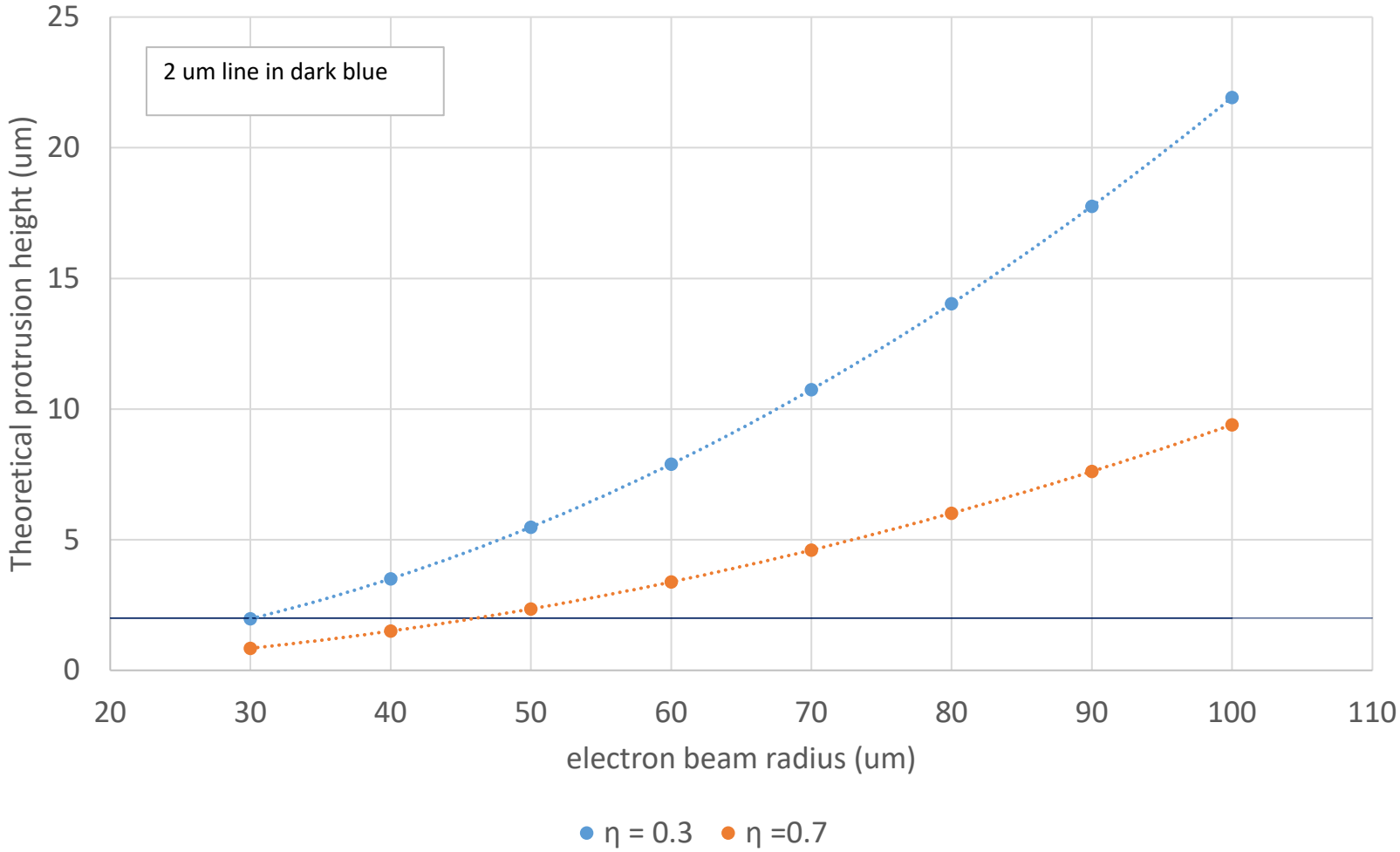

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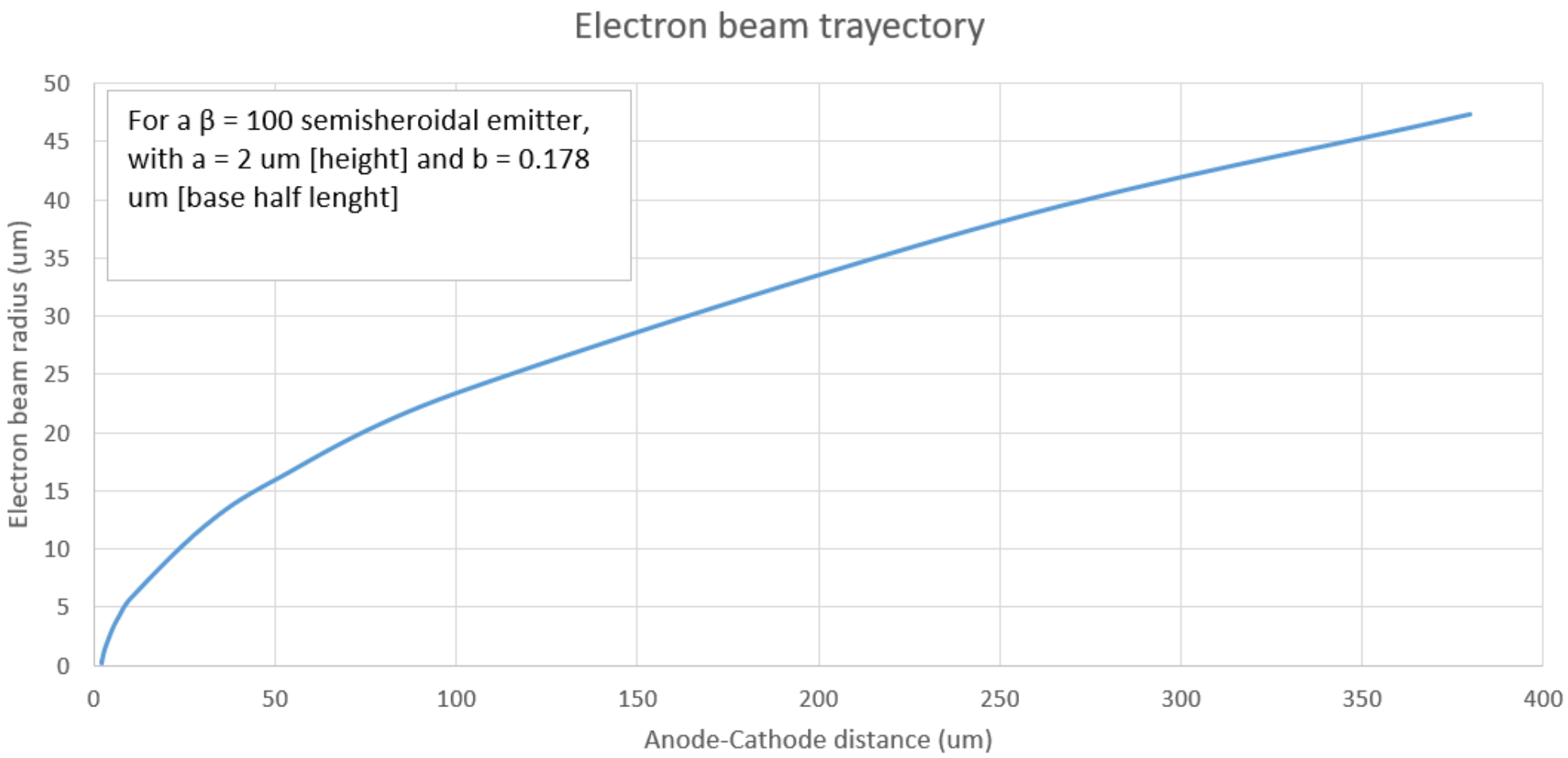

# Theory Validation – Emission Characteristics

| h (um) | b (um) | h/b | d (um) | Work function (eV) | potential (V) | macro field (V/m) | max field (V/m) | β | Experimentally measured current (nA) |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.1789 | 11.18 | 380 | 4.5 | 7000 | 1.84E+07 | 1.85E+09 | 100.39 | 10 |

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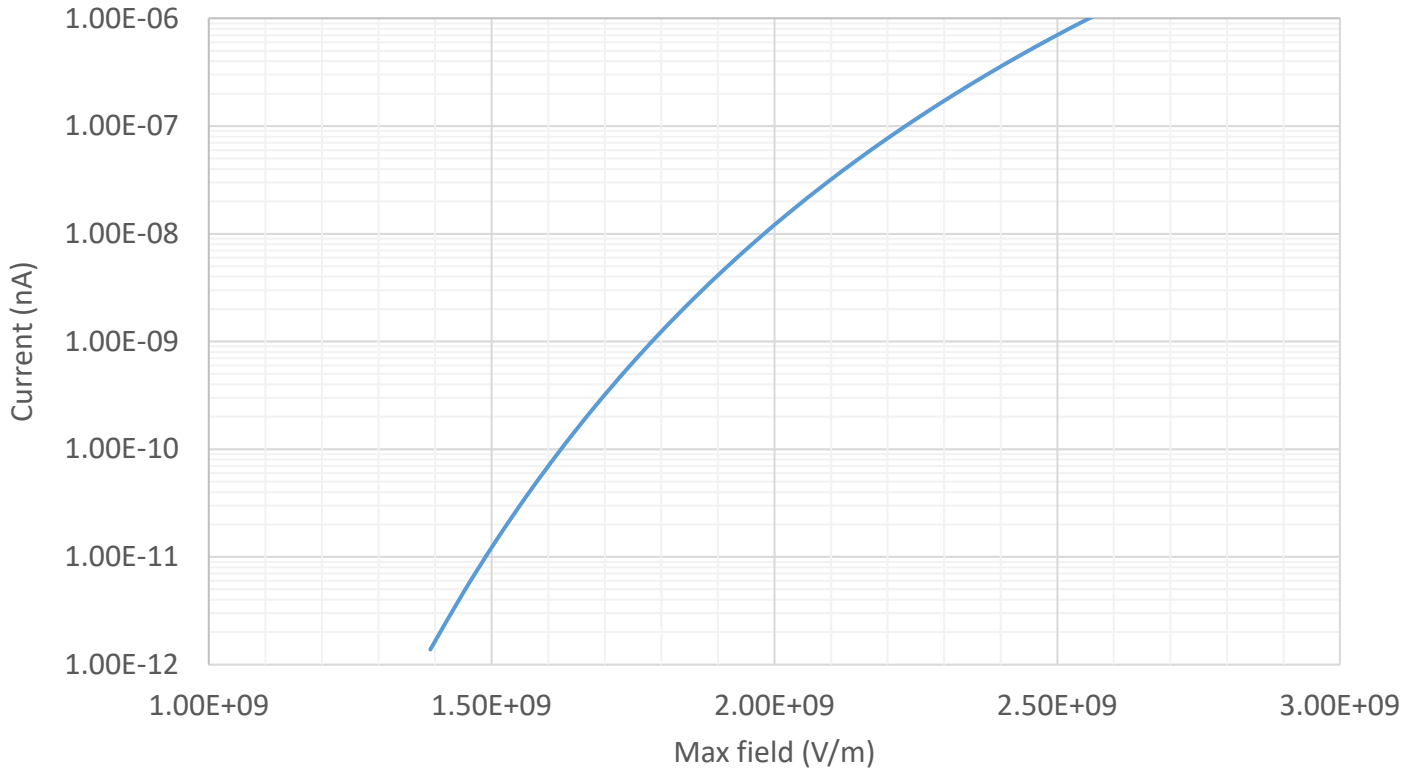

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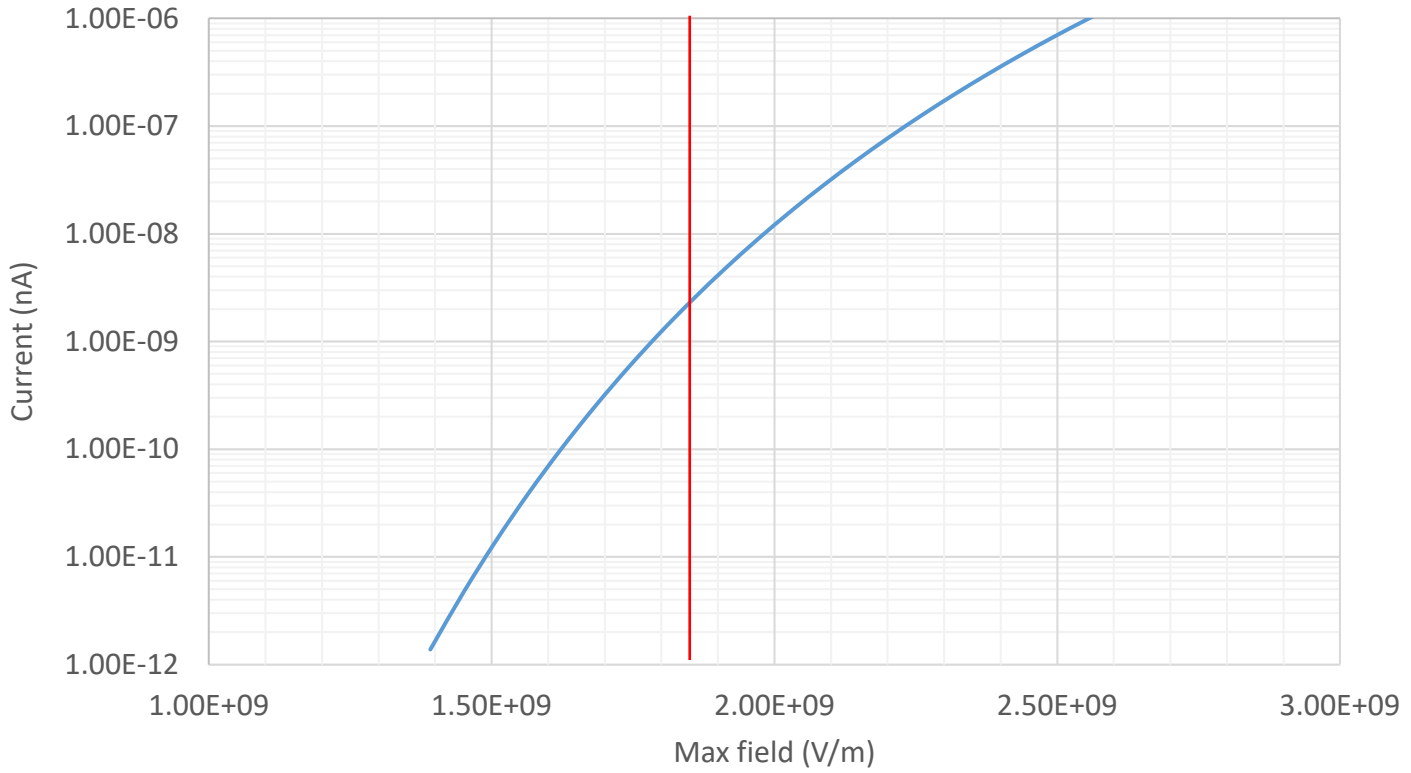

# Theory Fits Experiments

✓Protrusion dimensions and aspect ratio

✓ Electron beam spread

✓ Field emitted current

# Where Are They?

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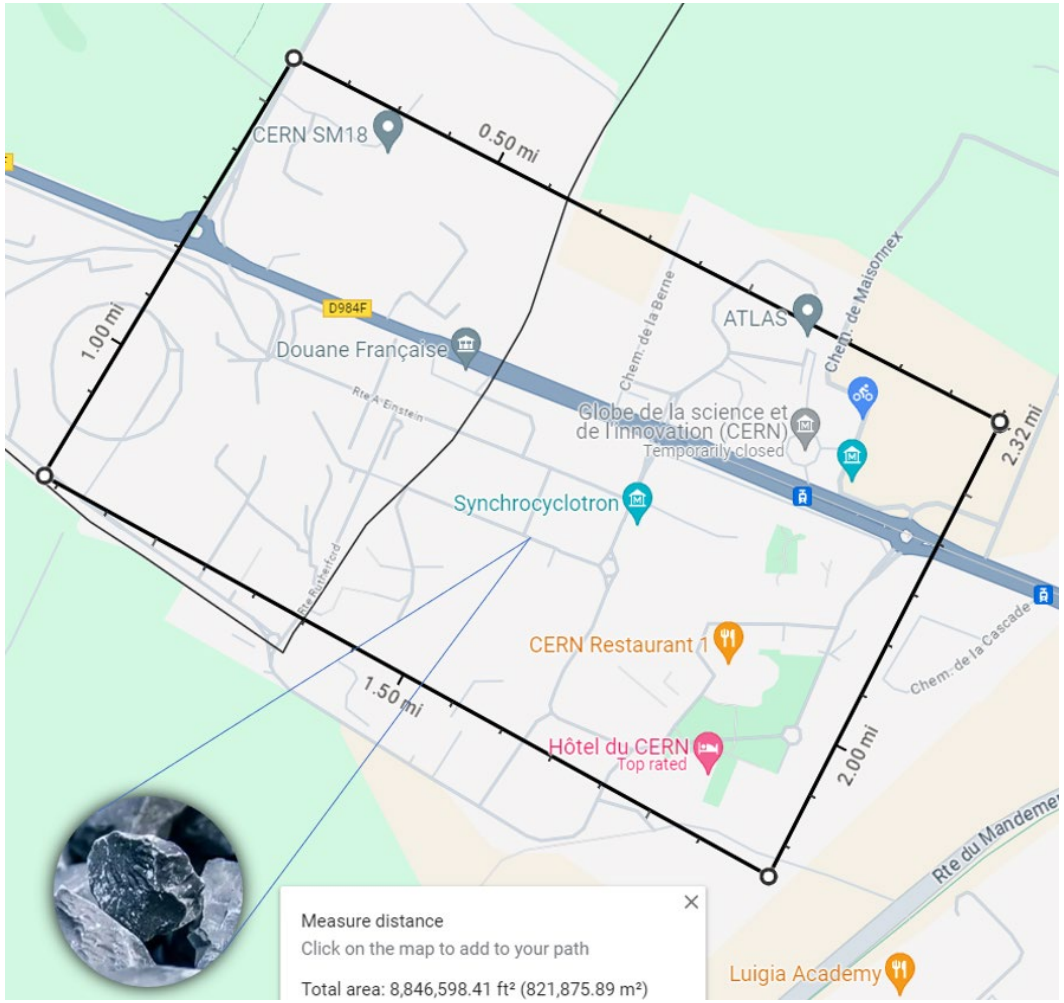
Protrusion cross section ≈ $2 \cdot 10^{-13}$ $m^2$
Cathode area ≈ $6 \cdot 10^{-4}$ $m^2$

Size difference: 9 orders of magnitude!



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# Conclusions

- Theory and experimental observations in agreement
- The η method can be applied to determine the size of protrusions
- We can't generalise for modern VBD systems, but this is a solid foundation
- If we want to see pre-breakdown protrusions:
  Phosphor screen and shadow SEM experiments

DALL-E

# THANK YOU


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