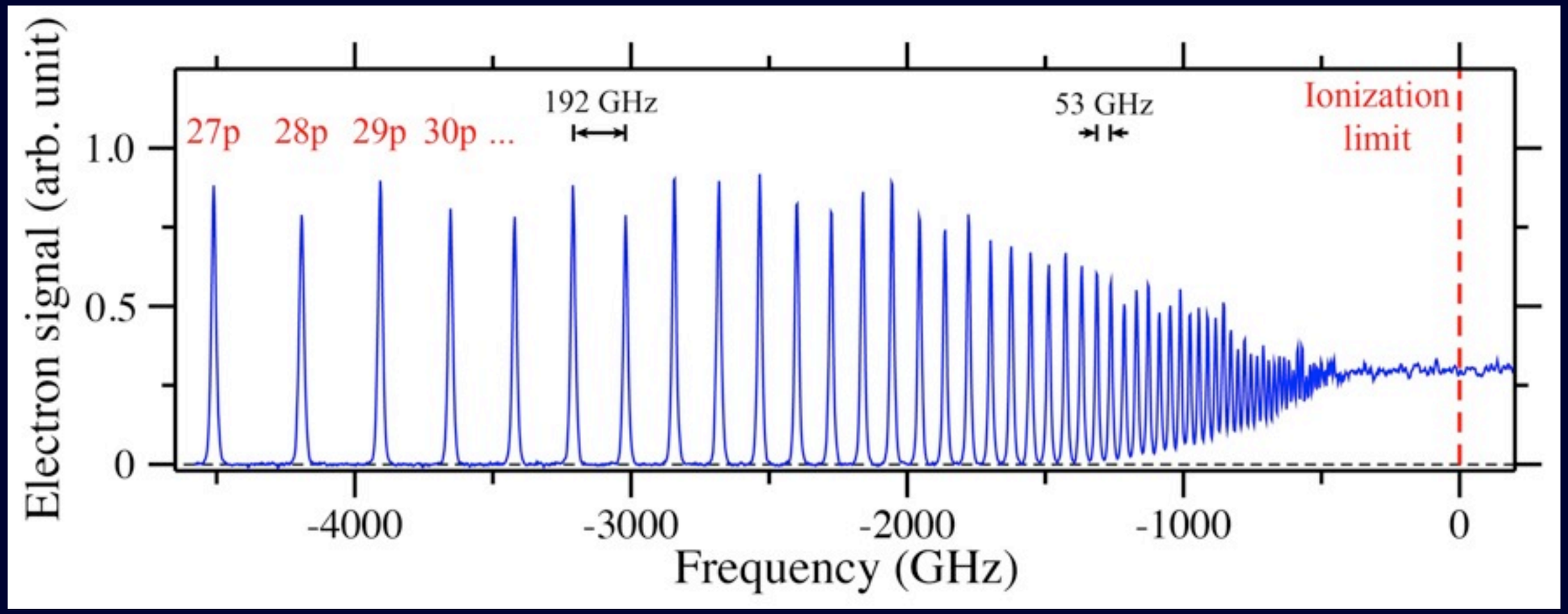
Rydberg atoms in surface-electrode traps

Stephen D. Hogan

Department of Physics and Astronomy
University College London

Rydberg states



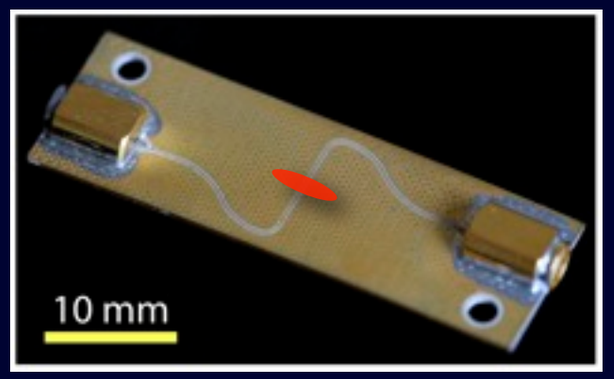
$$E_{n\ell} = E_{\mathrm{IP}} - \frac{Ry \cdot \mathrm{hc}}{(n-\delta_\ell)^2}$$

- Lifetimes $\propto n^3 - n^5$
- Maximum induced electric dipole moment $\propto n^2$

Motivation

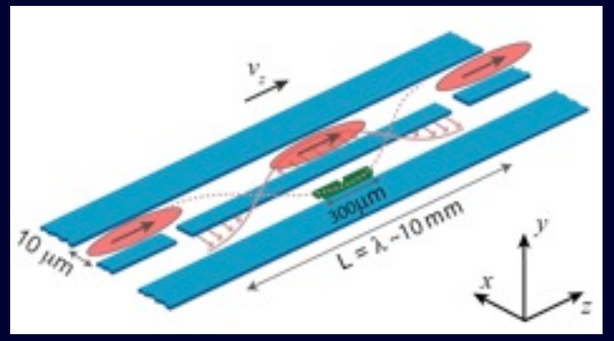
- Interactions of Rydberg atoms and molecules with surface

Hogan et al., *Phys. Rev. Lett.* **108**, 063004 (2012)



- Hybrid cavity-QED

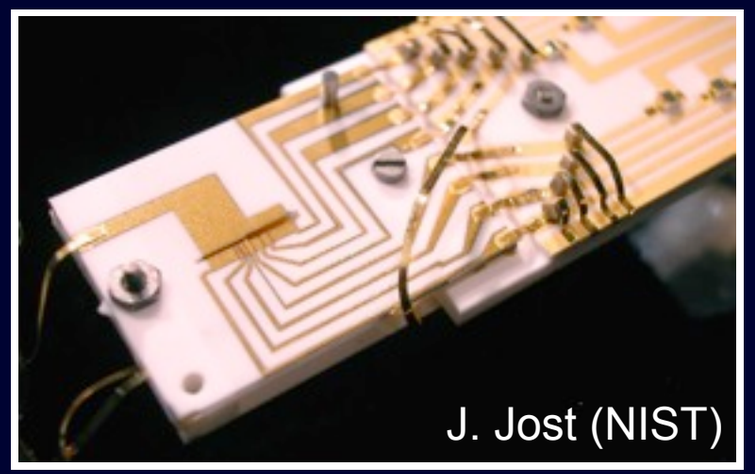
Wallraff et al., *Nature* **431**, 162 (2004)



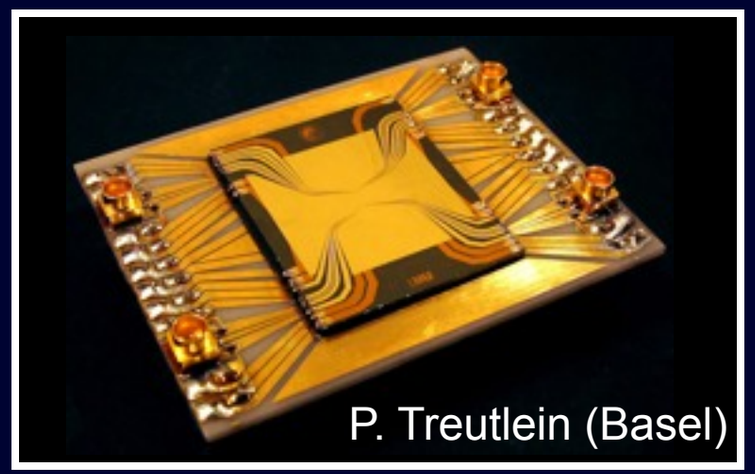
- Preparation of cold molecules
- Experiments with positronium and antihydrogen

Chip-based traps

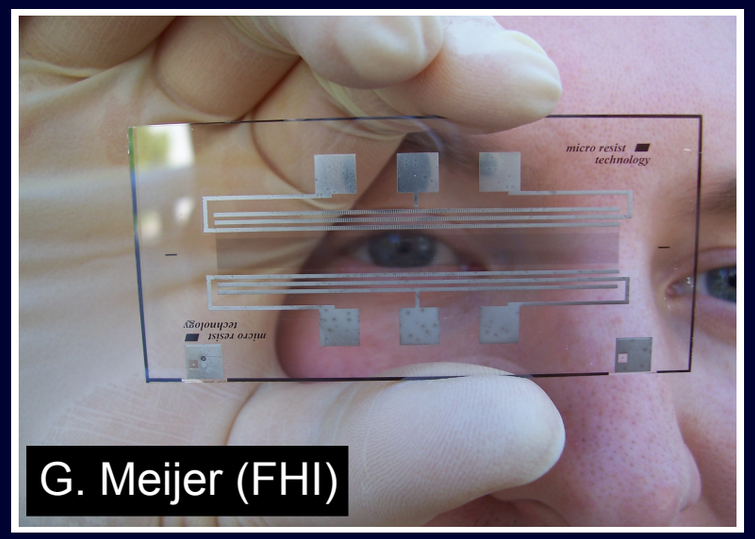
Ions



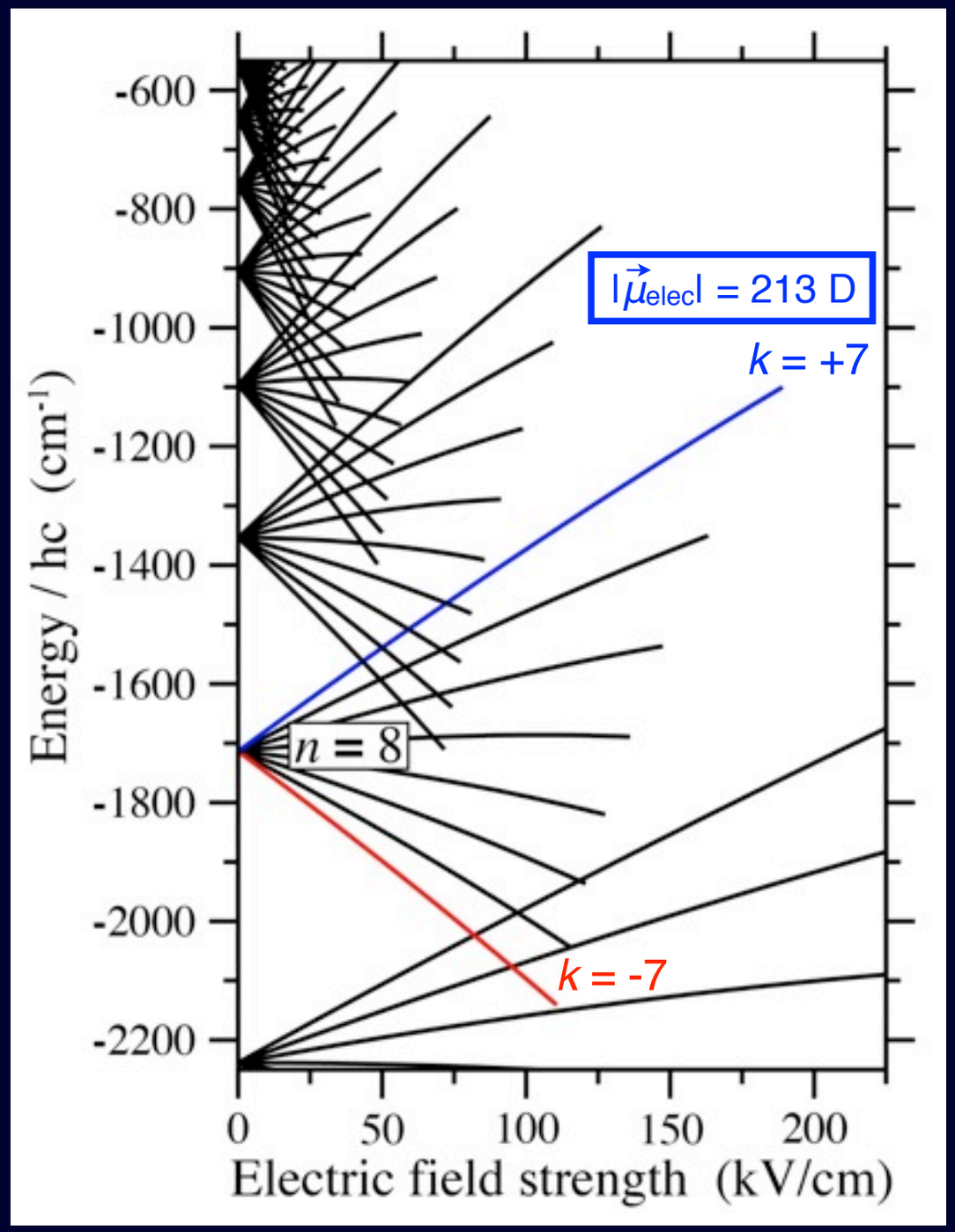
Ground state atoms



Polar molecules



Stark effect in the H atom



Stark Energy:

$$W_{\text{Stark}} = -\vec{\mu}_{\text{elec}} \cdot \vec{F}$$

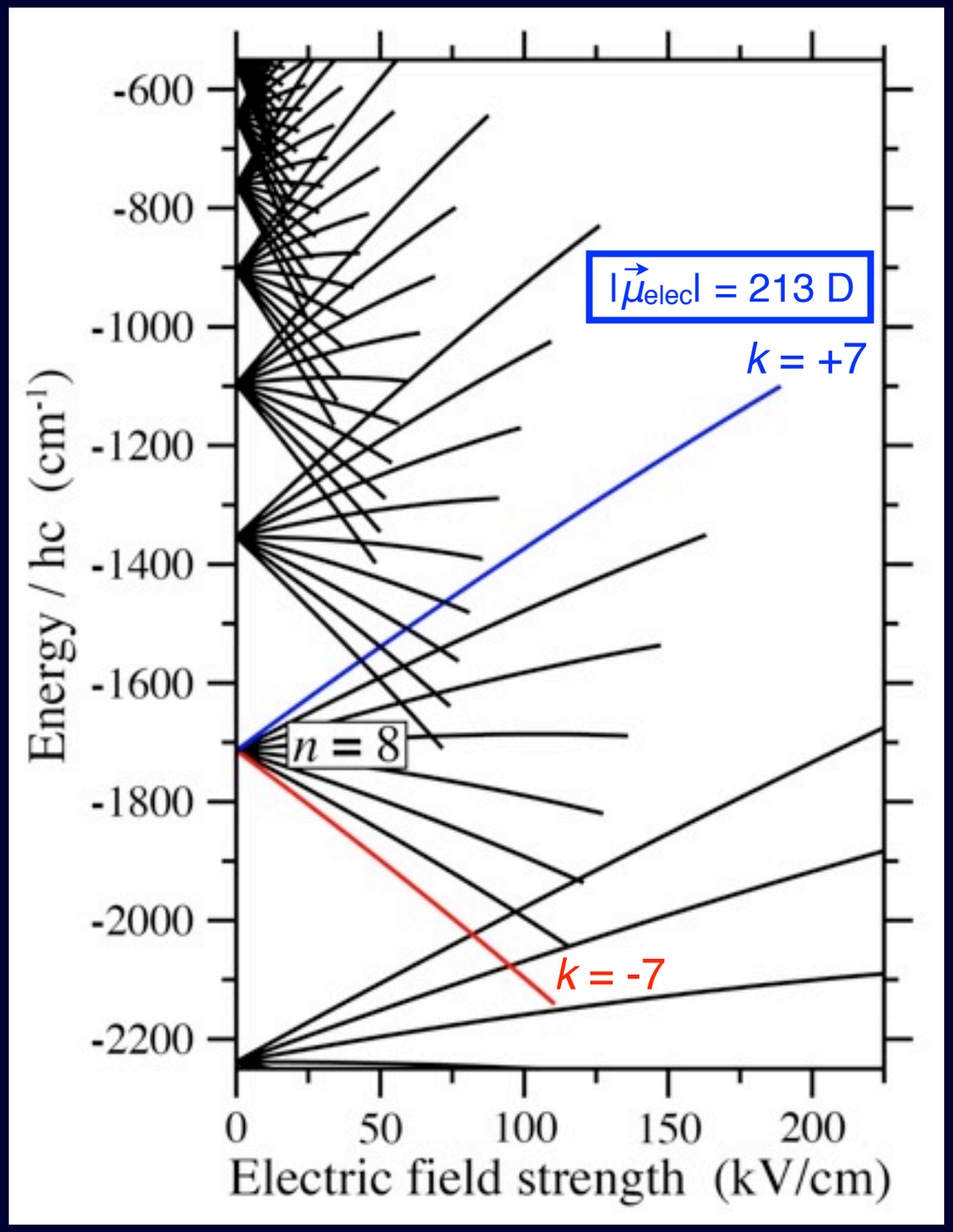
$$= \frac{3}{2} nk\, e a_0\, F_z$$

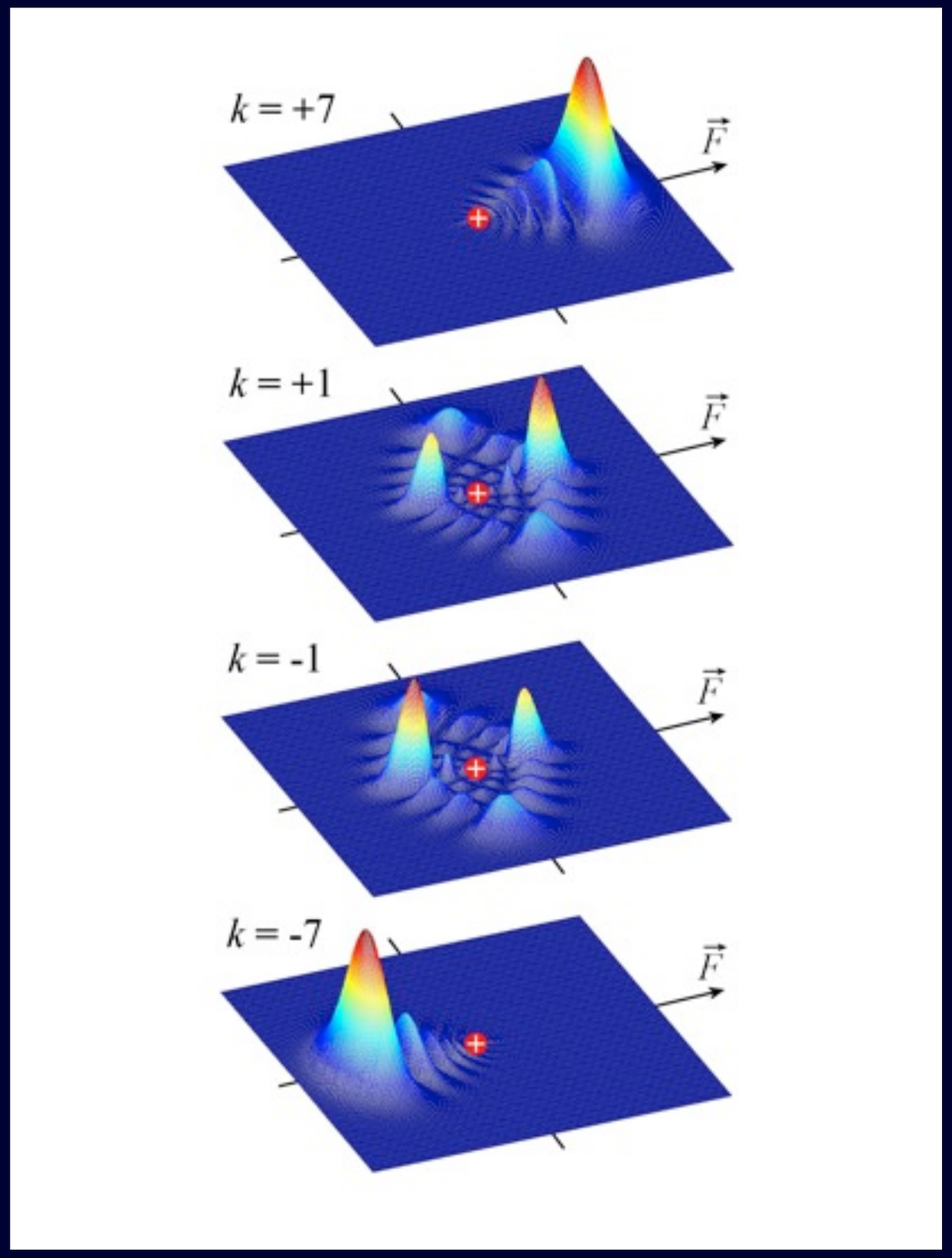
Force:

$$\vec{f} = -\nabla W_{\text{Stark}}$$

Wing, *Phys. Rev. Lett.* **45**, 631 (1980)
Breeden and Metcalf, *Phys. Rev. Lett.* **47**, 1726 (1981)

Stark effect in the H atom

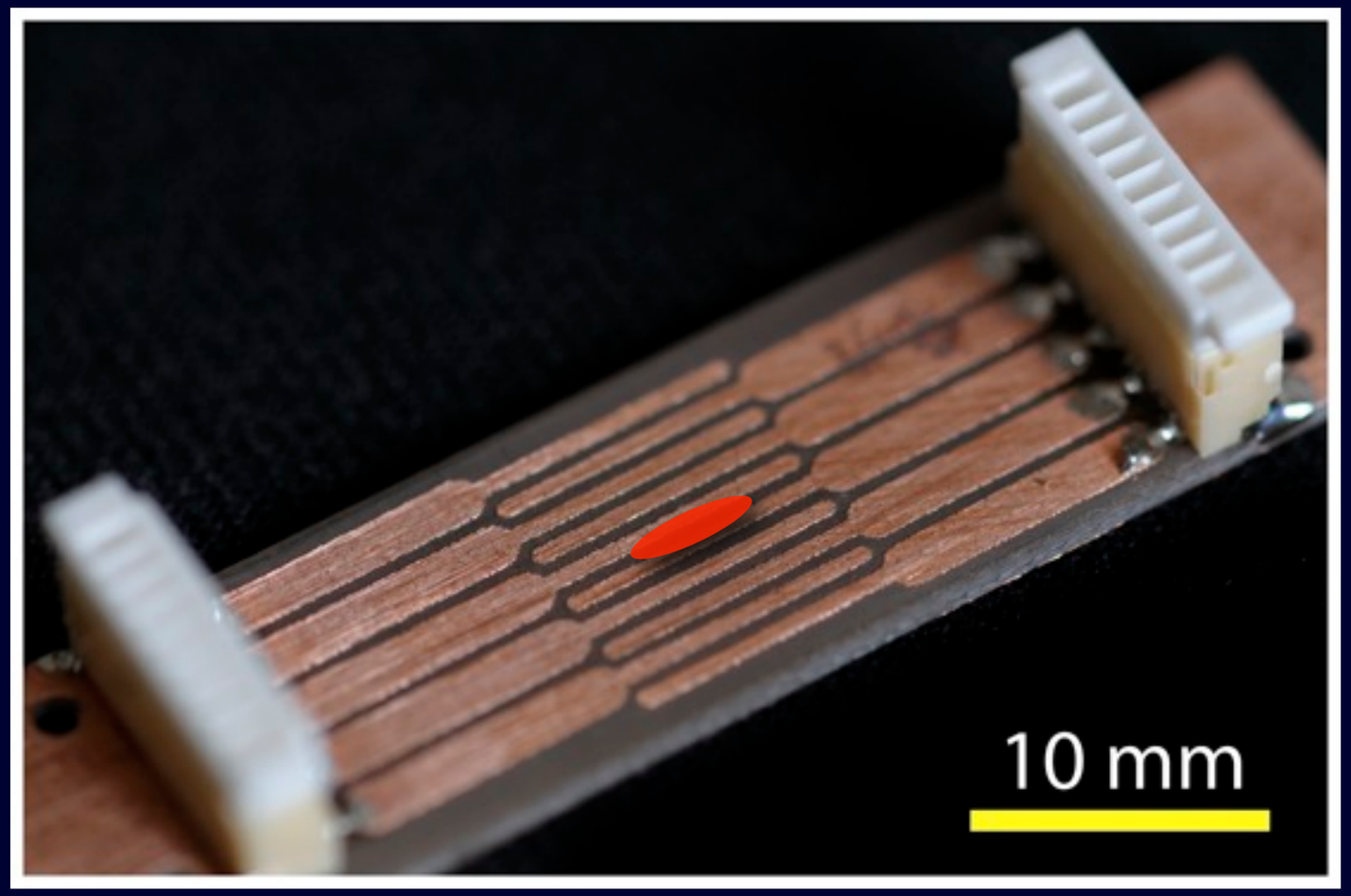




Gallagher, *Rydberg Atoms*, Cambridge (1994)

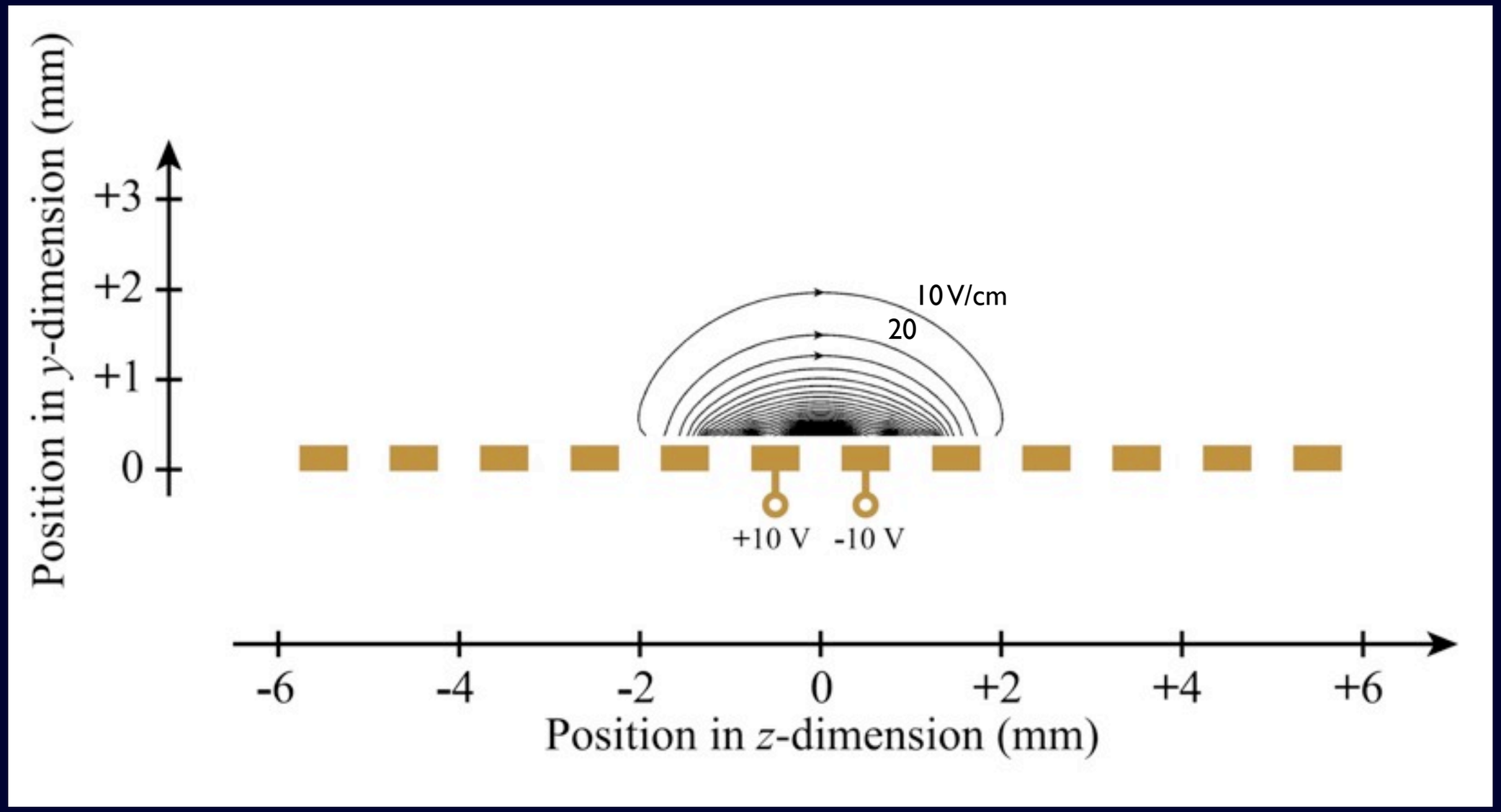
Rydberg-Stark deceleration

- Surface-electrode decelerator



Hogan et al., *Phys. Rev. Lett.* **108**, 063008 (2012)

Surface-electrode traps



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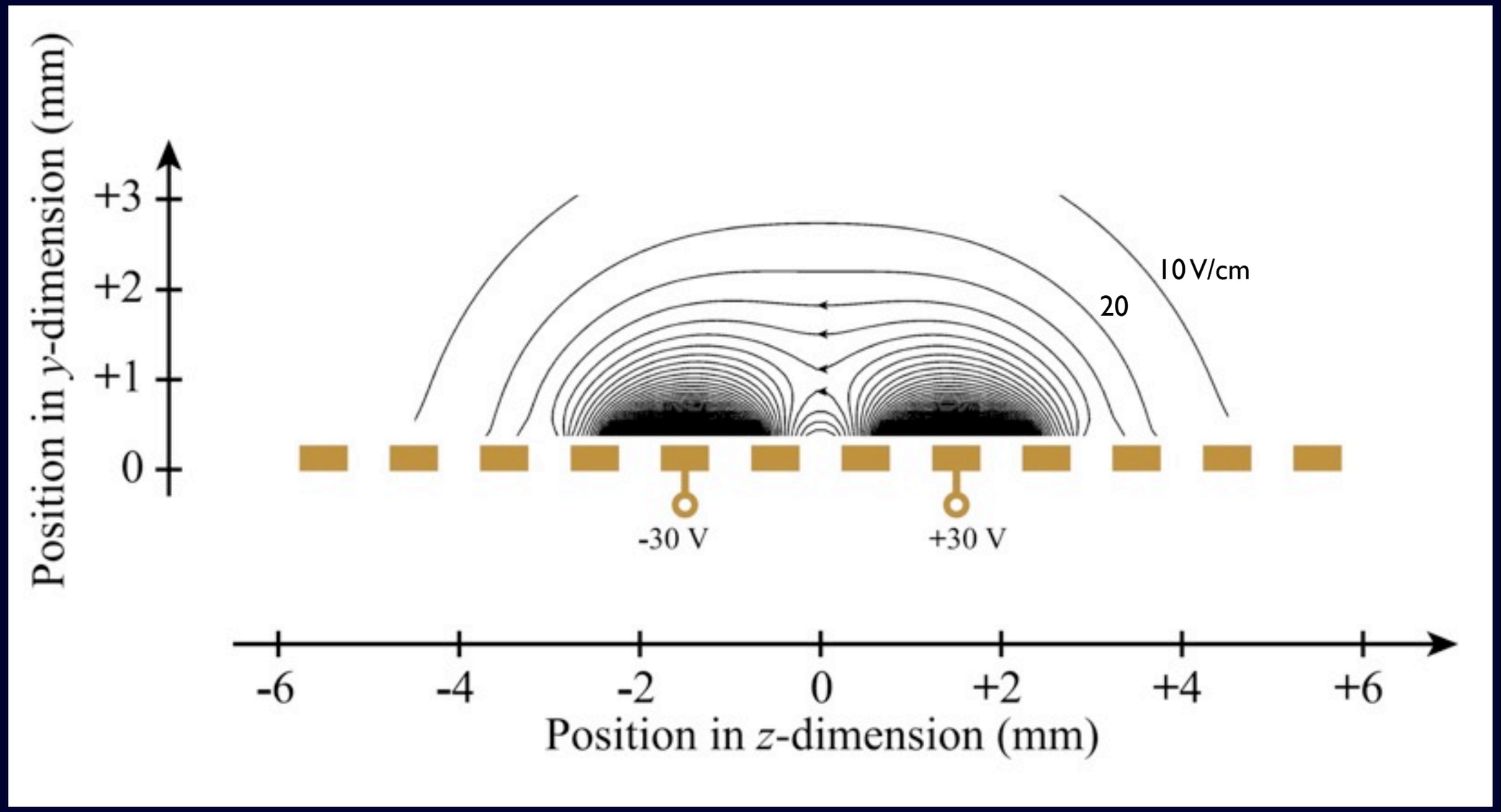

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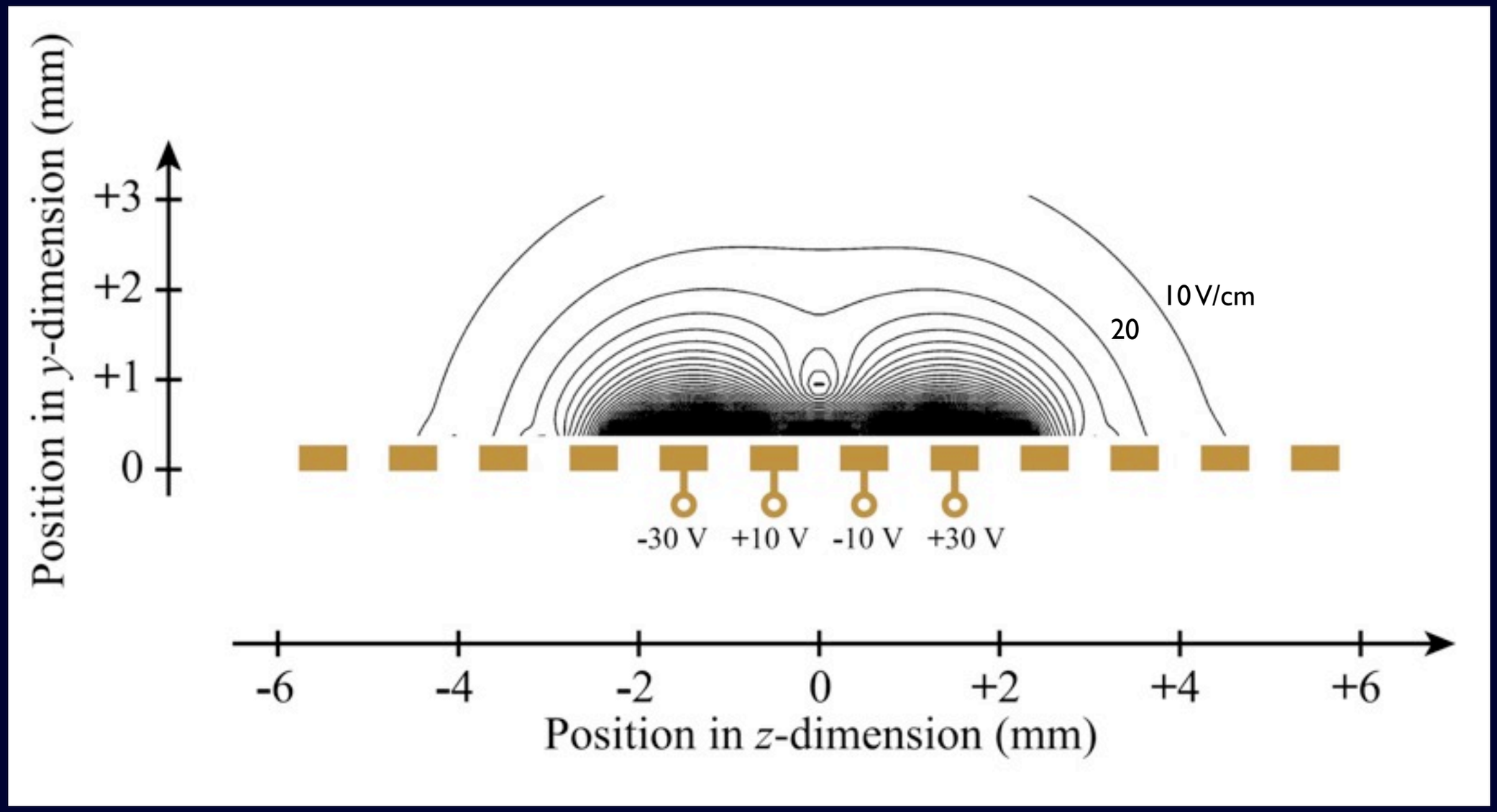
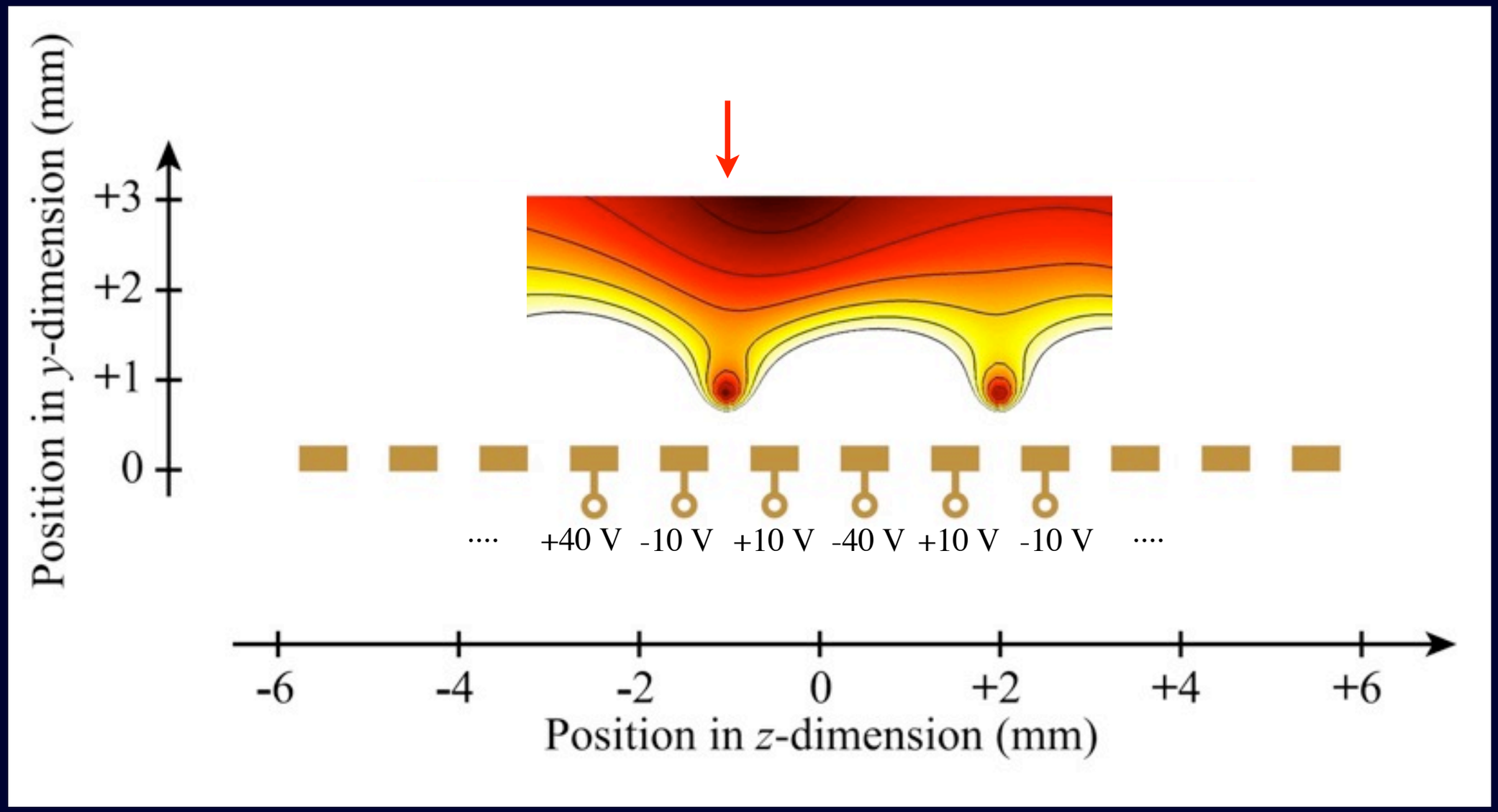


Surface-electrode decelerator



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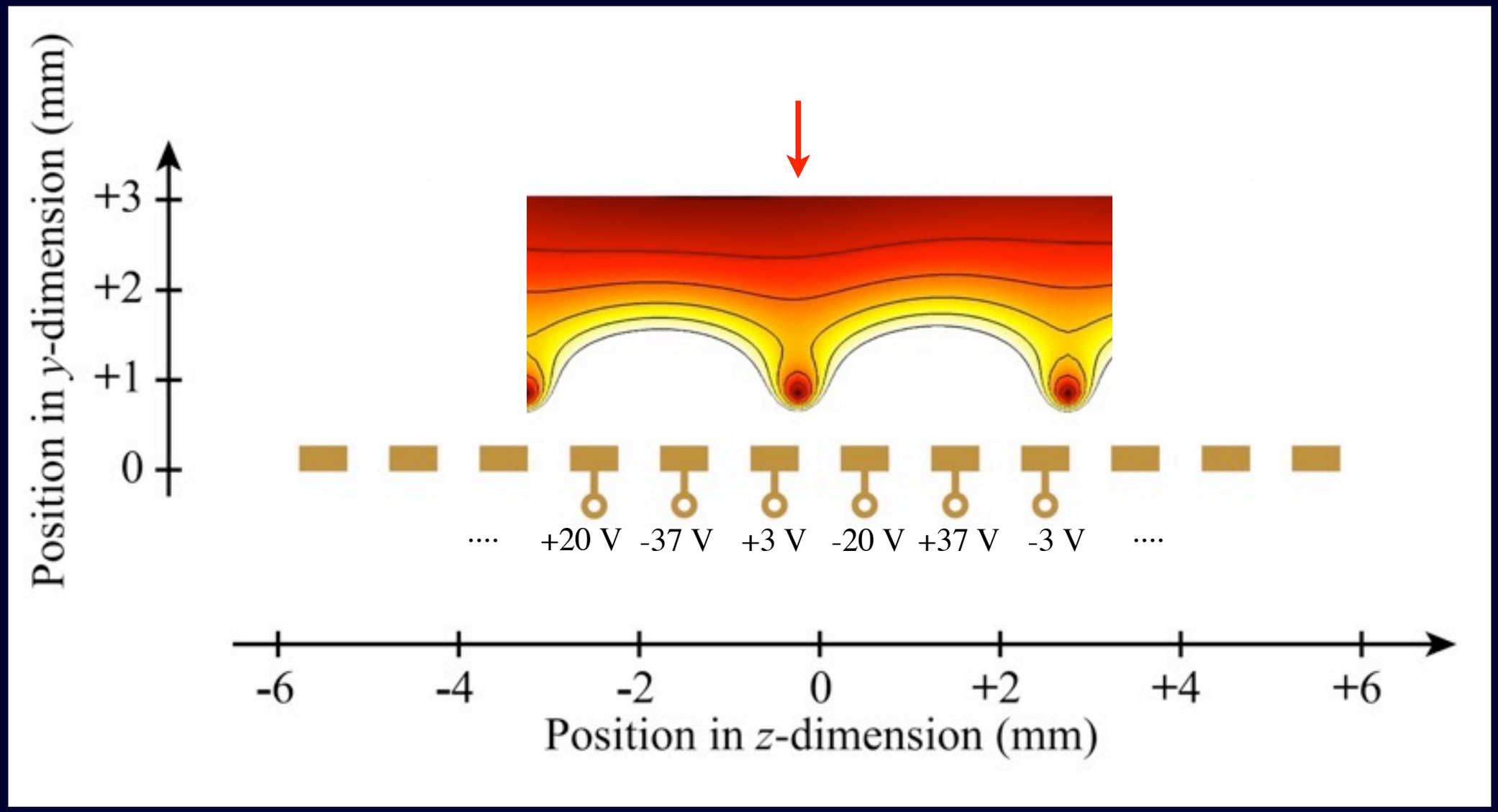

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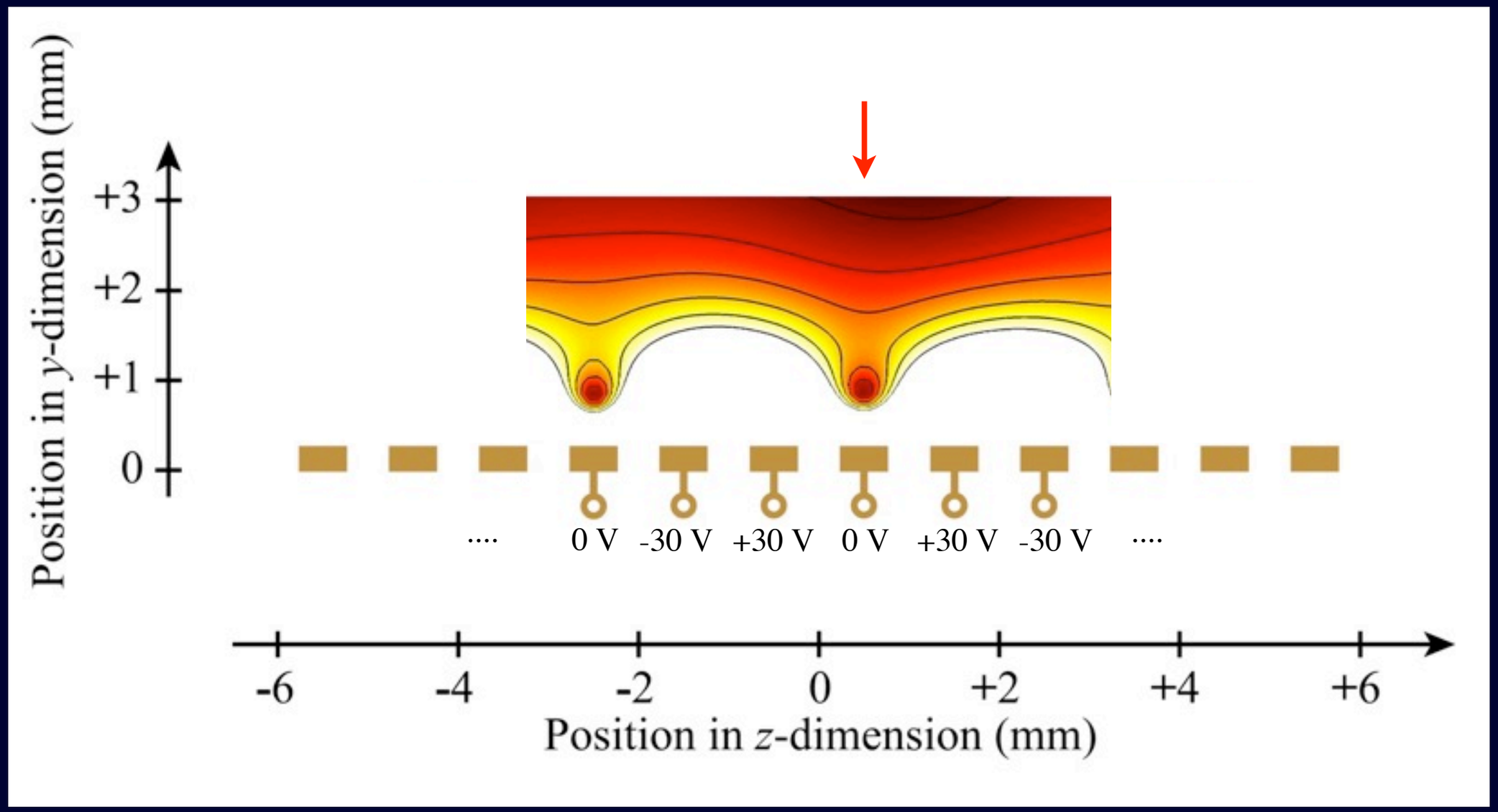

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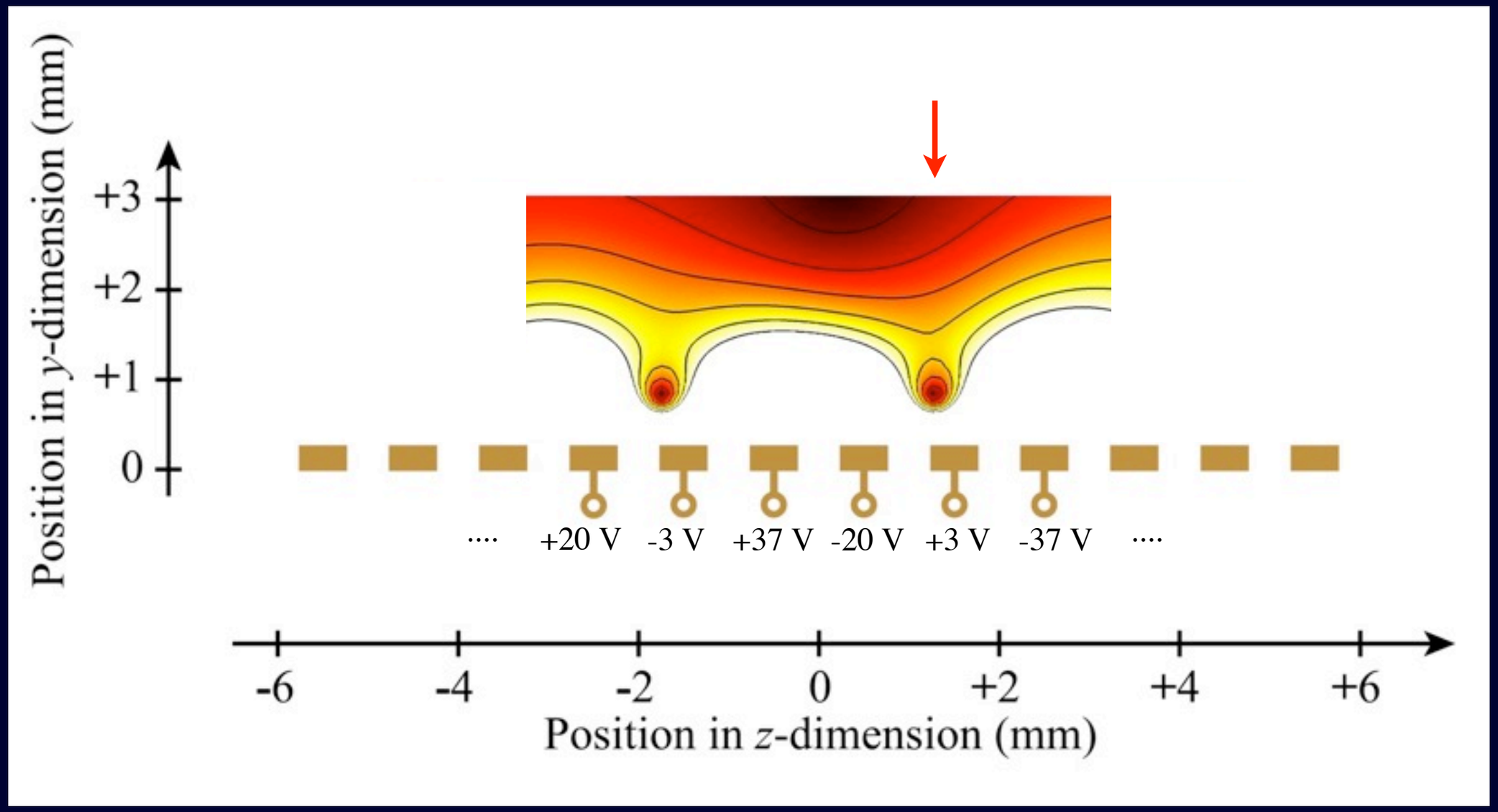

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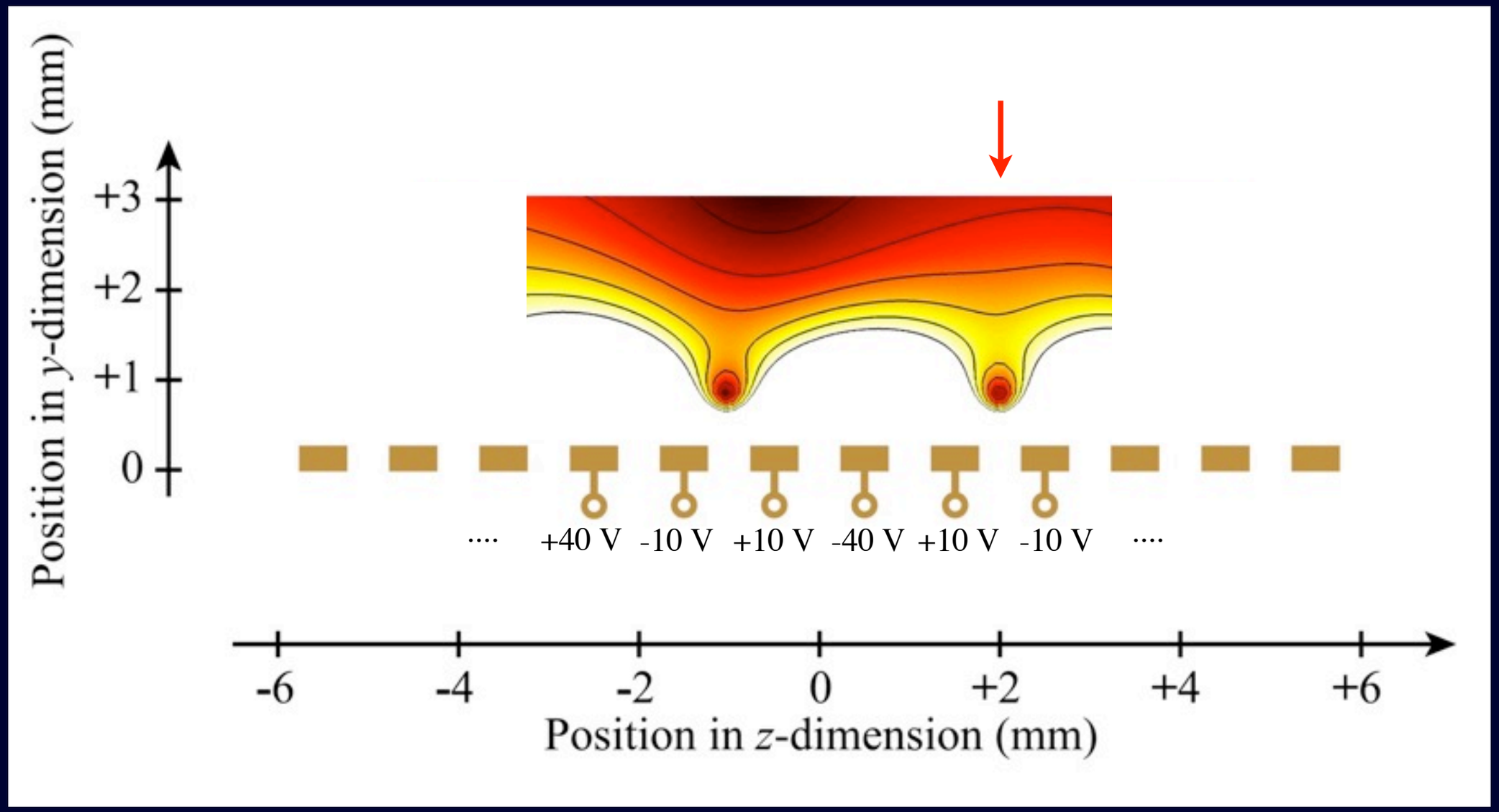
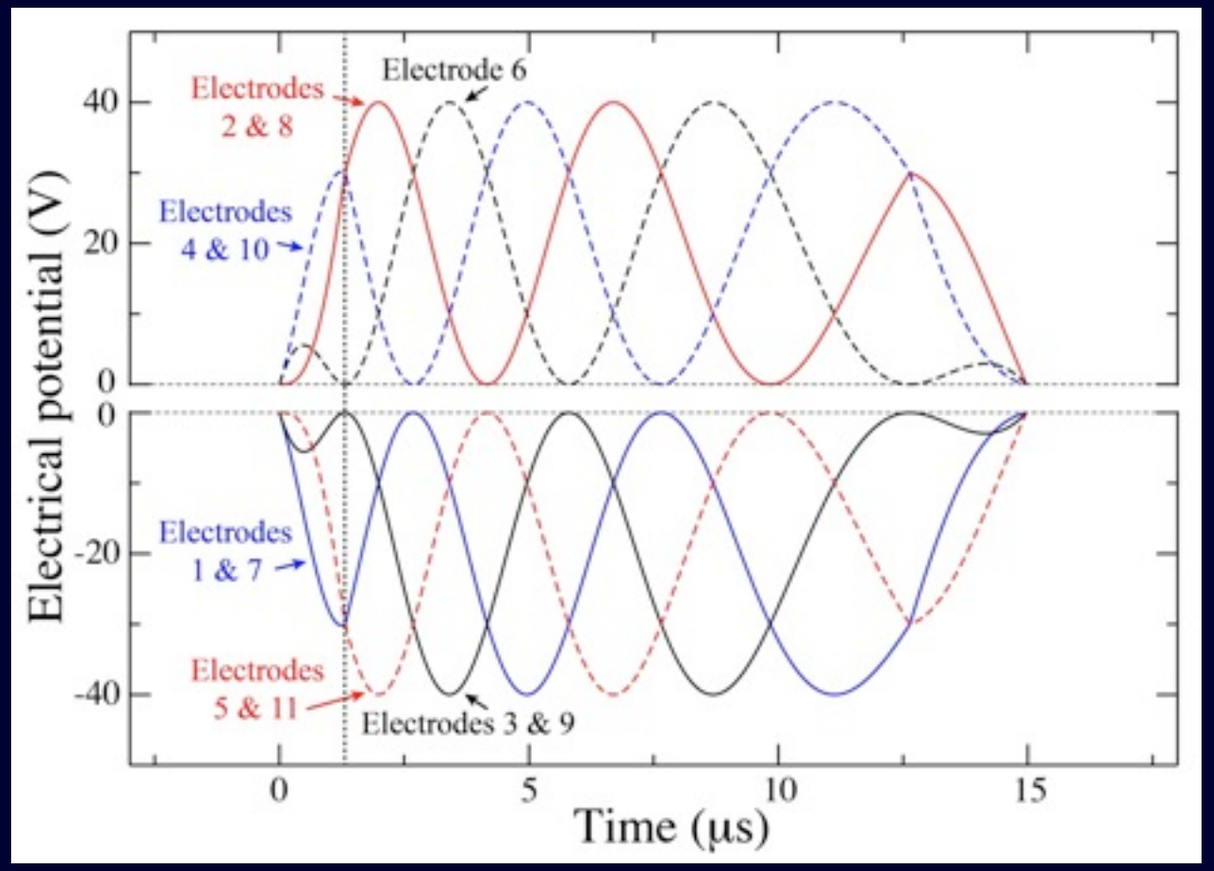


Surface-electrode decelerator

- Decelerator operation

$$V_i = (-1)^i V_0 [1 + \cos(\omega t + \varphi_i)]$$

$$v_z = 3 d_z \omega / 2\pi$$



Initial velocity: 760 m/s

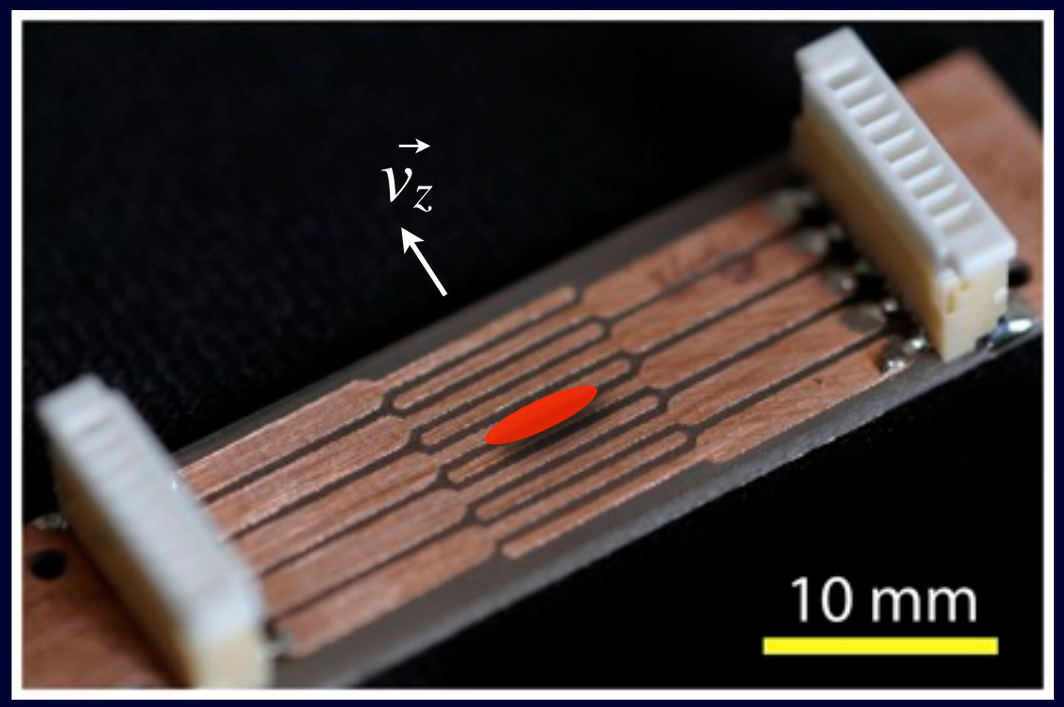
Final velocity: 300 m/s

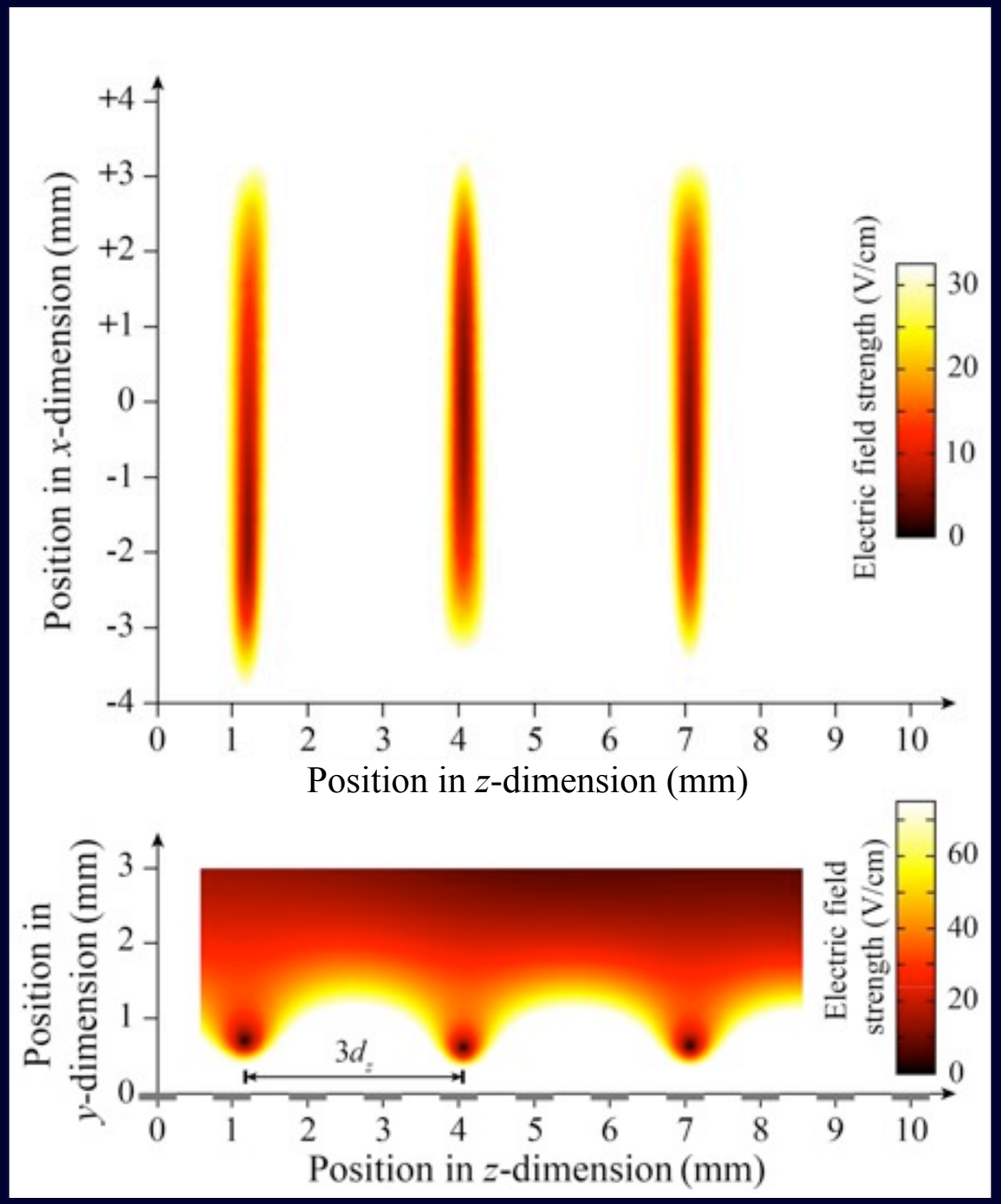
Meek et al., *Phys. Rev. Lett.* **108**, 053003 (2008)
Meek et al., *Science* **324**, 1699 (2009)

Surface-electrode decelerator

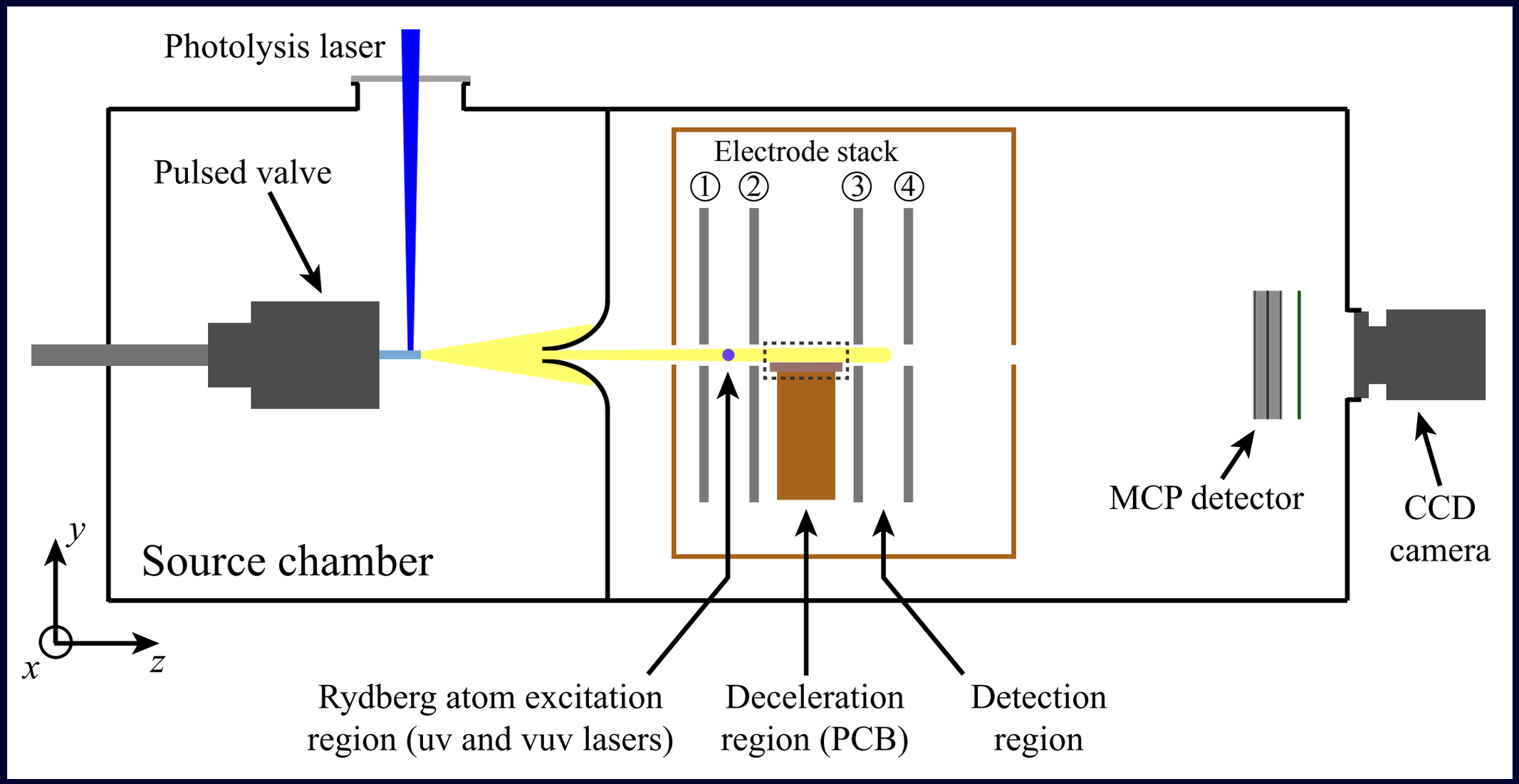
Decelerator structure

- Potentials: $V_{pp} \sim 30$ V
- Trap depth: $T \sim 2$ K ($n = 30$)





Experiment

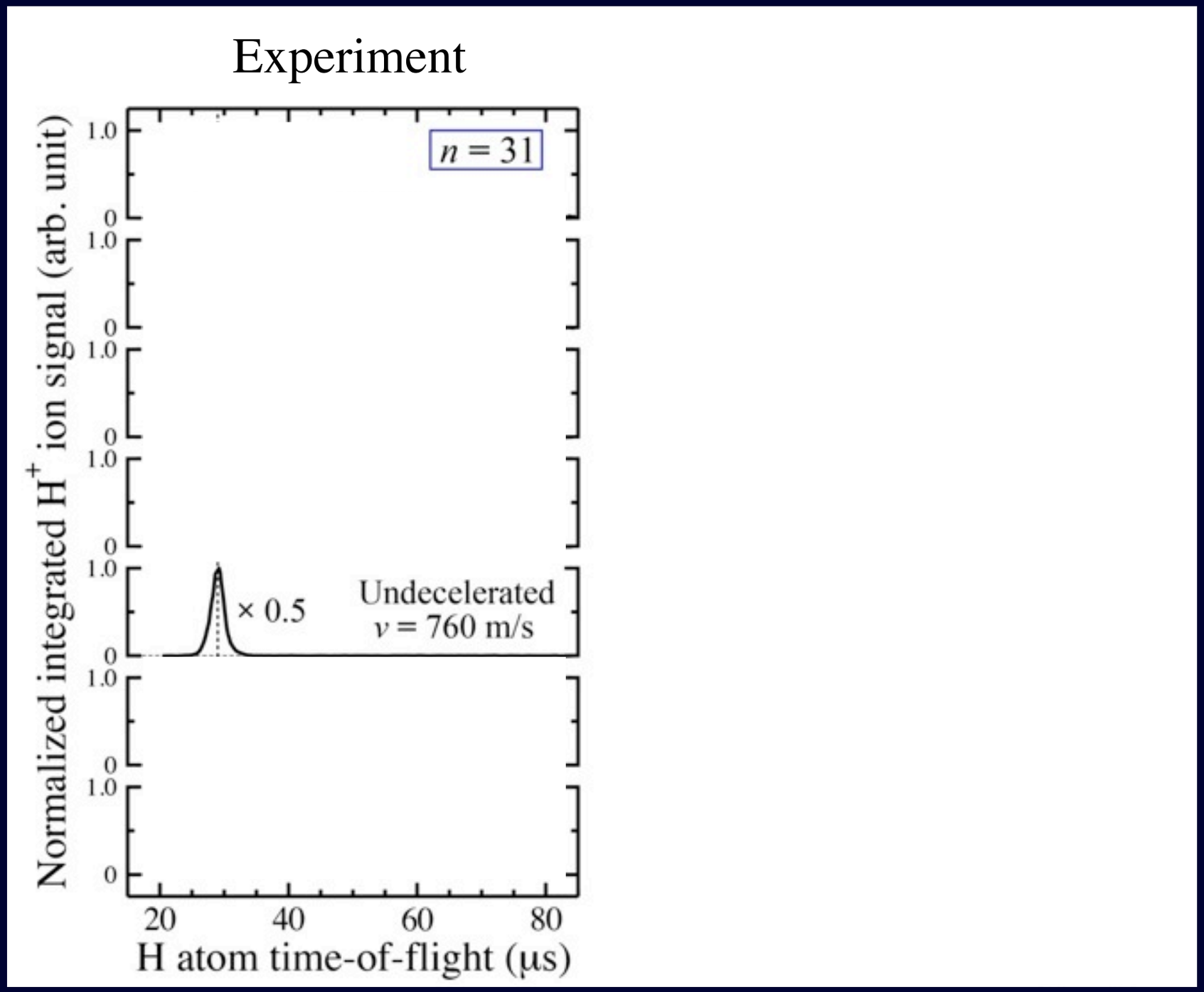


H atom production: $NH_3 + h\nu \rightarrow NH_2 + H$

Photoexcitation: $1^2S \rightarrow 2^2P \rightarrow ns/nd$

Acceleration/deceleration

- Acceleration/deceleration of H atoms ($a_z \sim \pm 10^8$ m/s^2)



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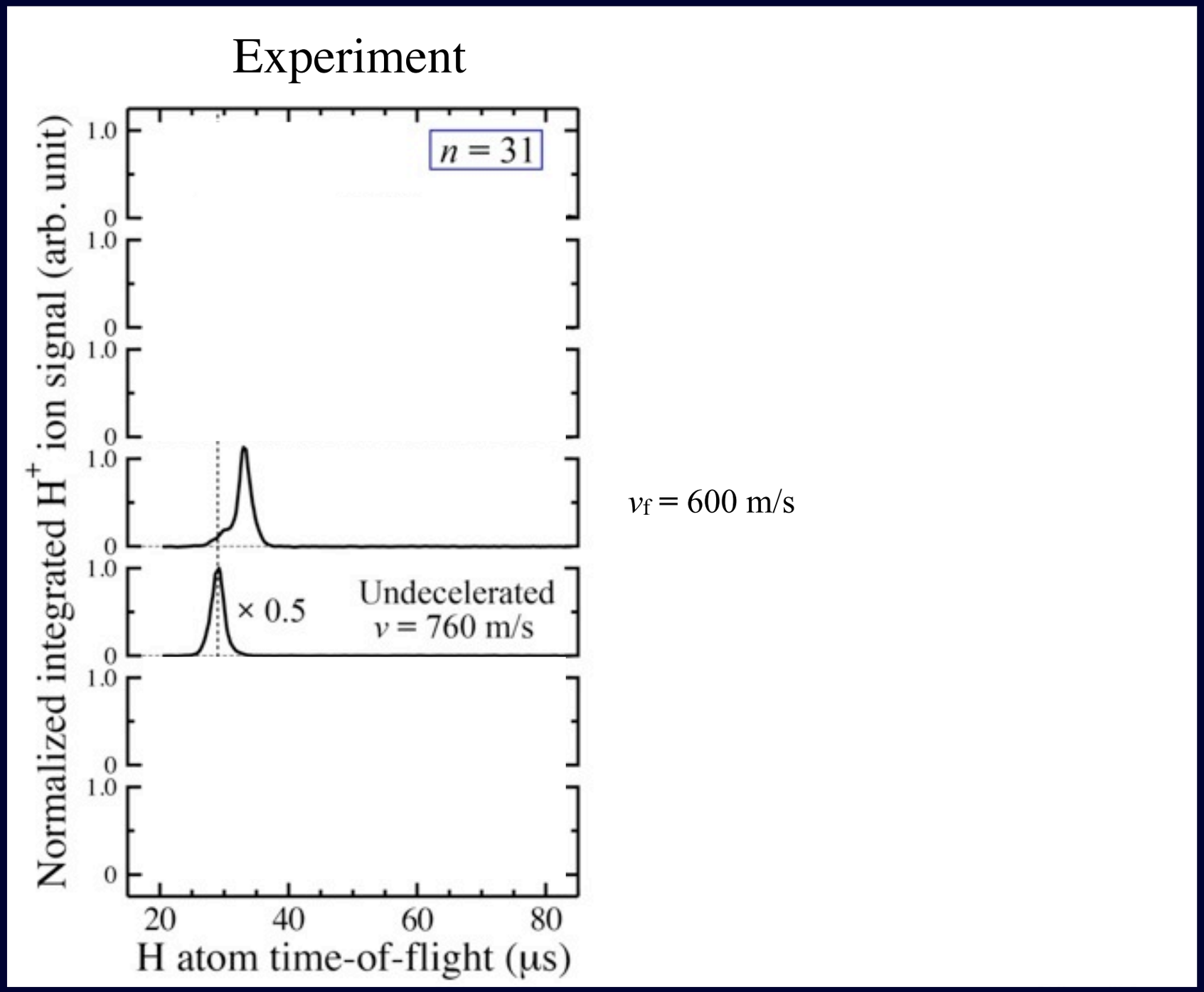

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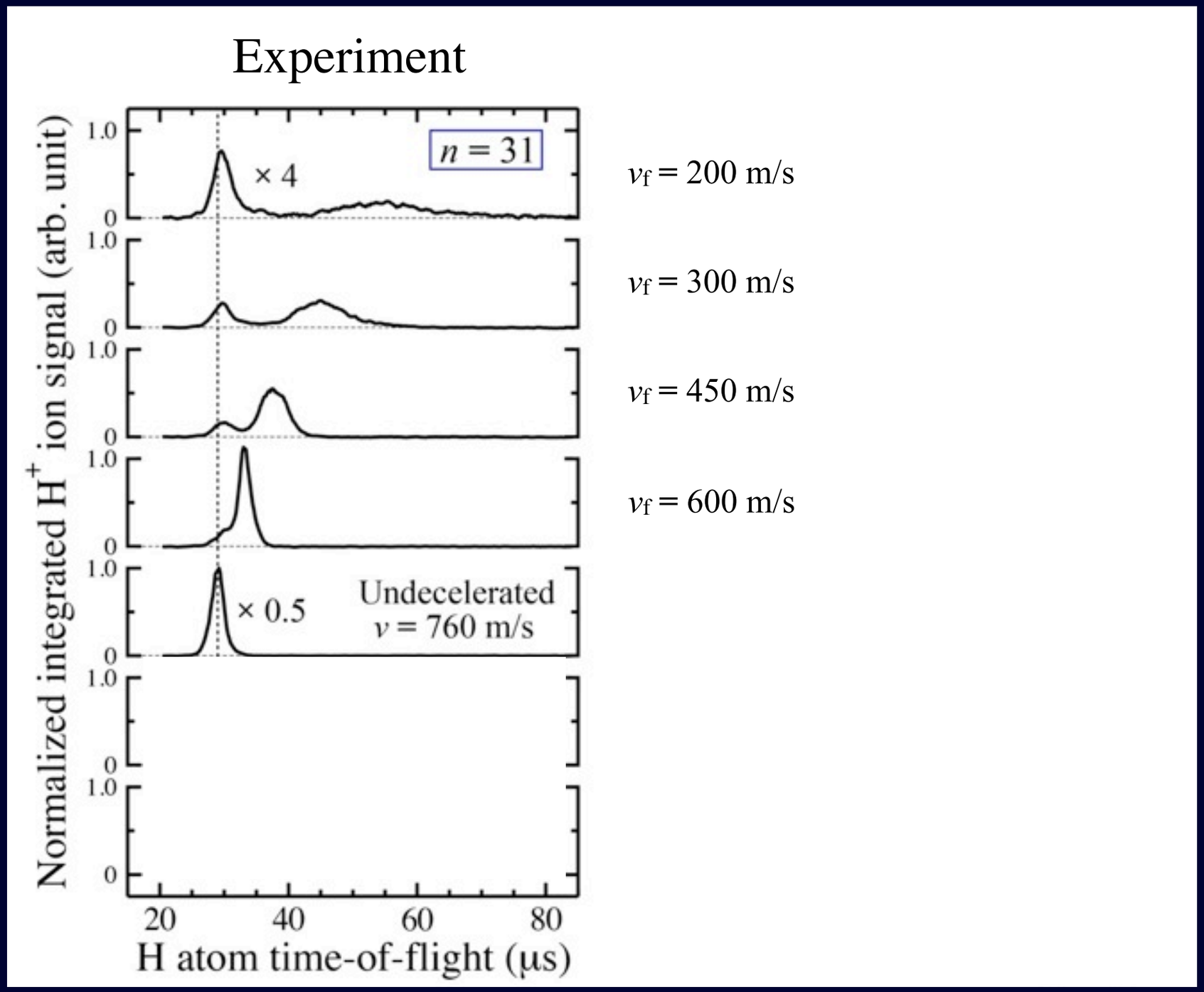

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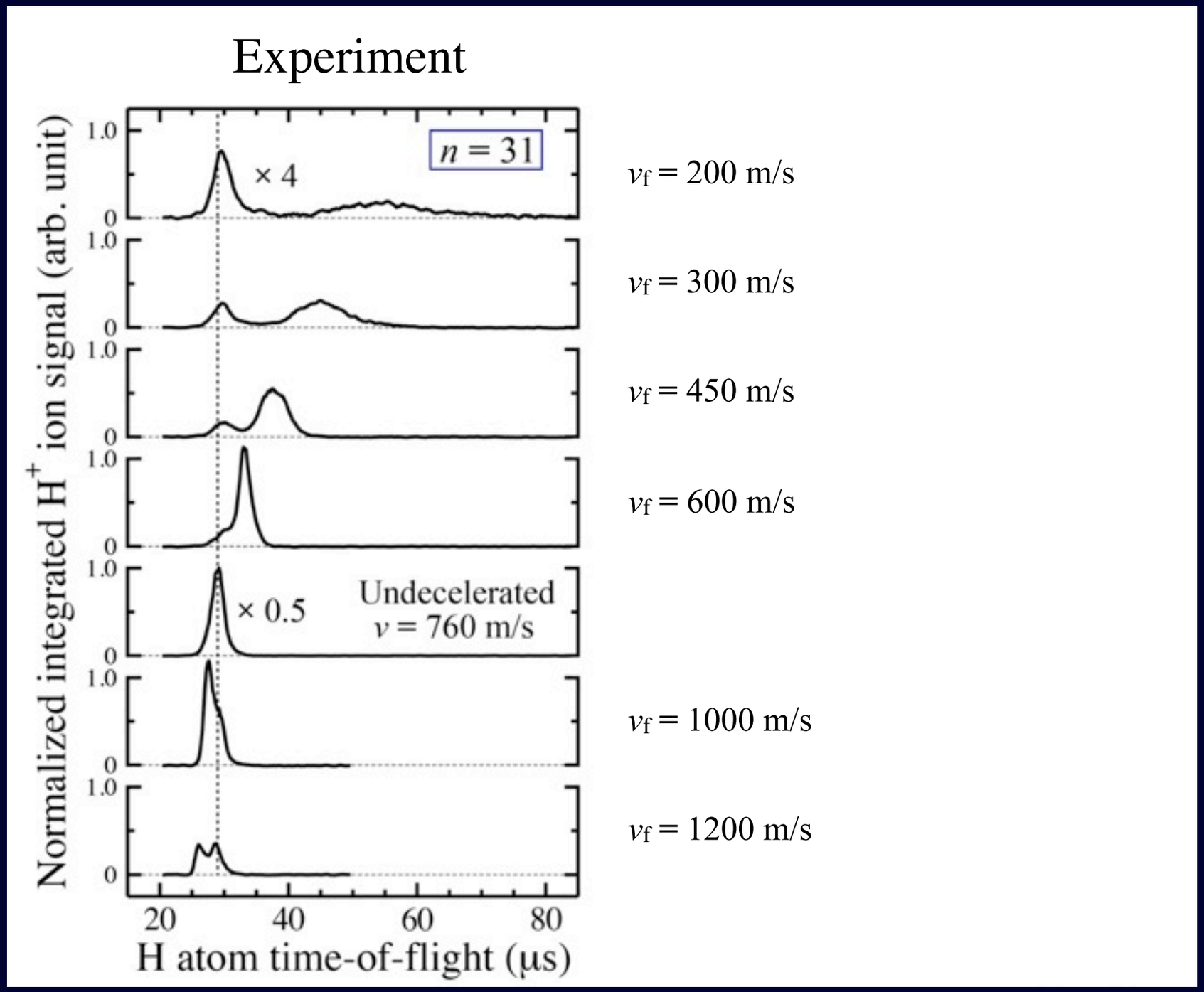

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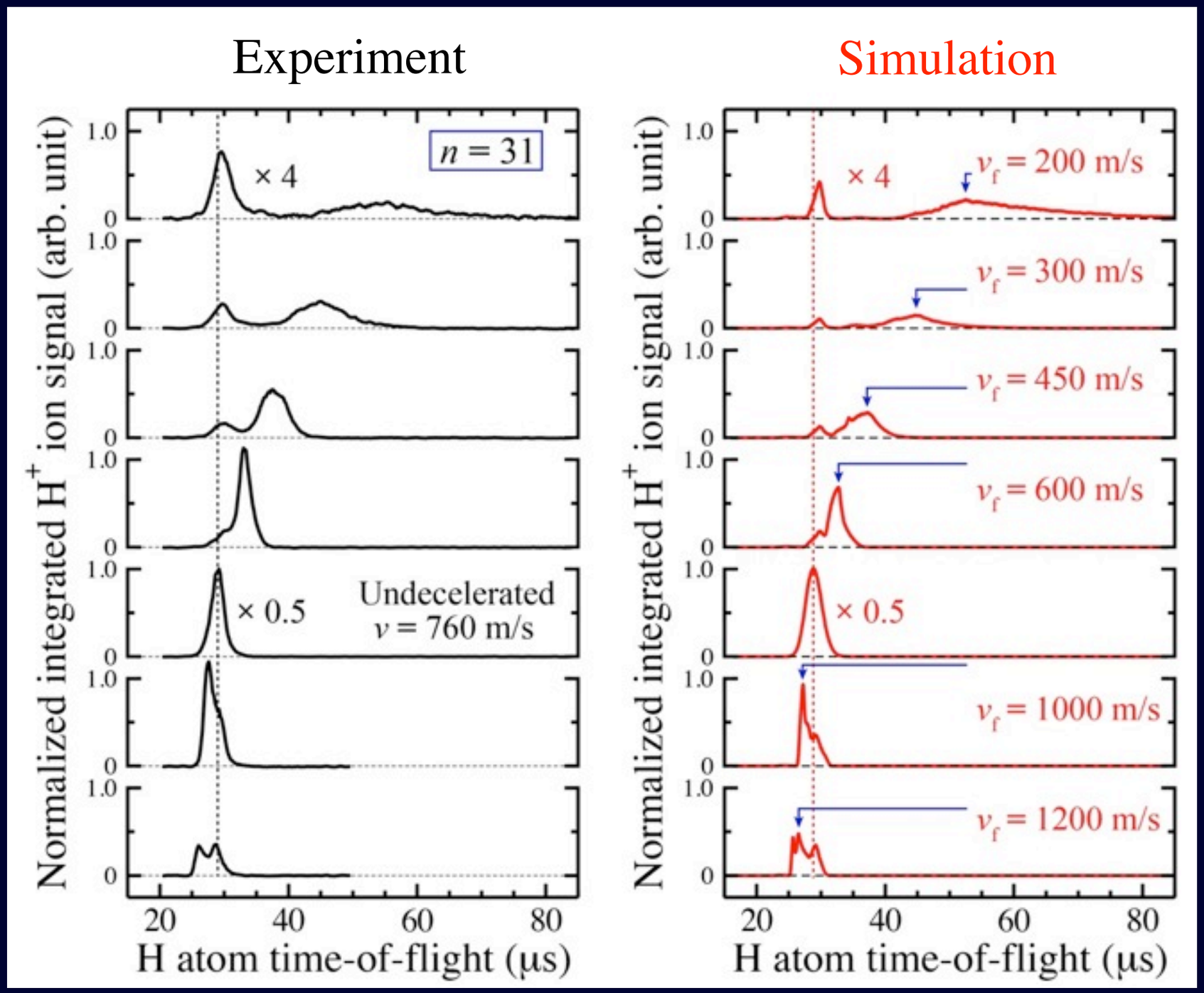
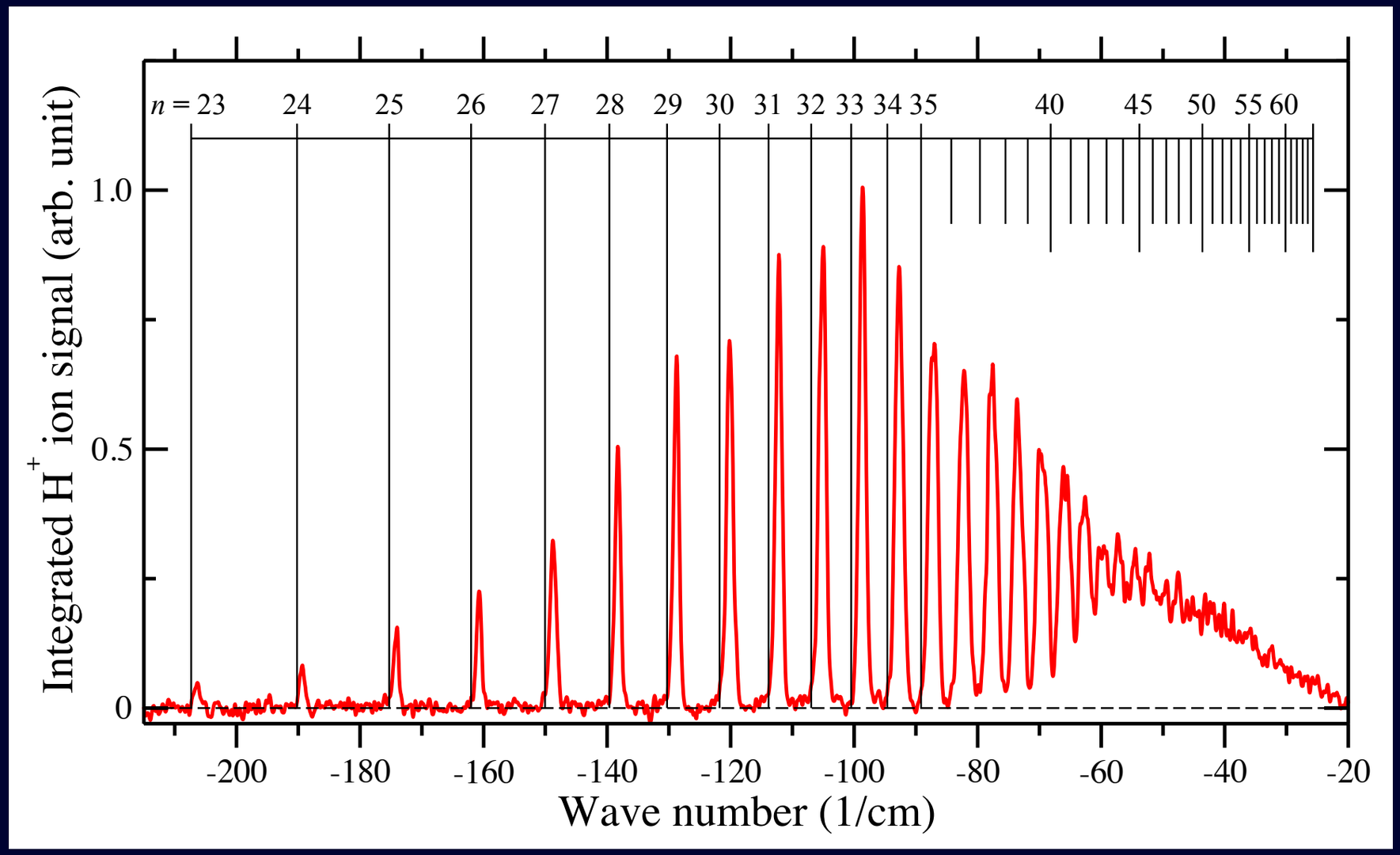


Rydberg-state acceptance

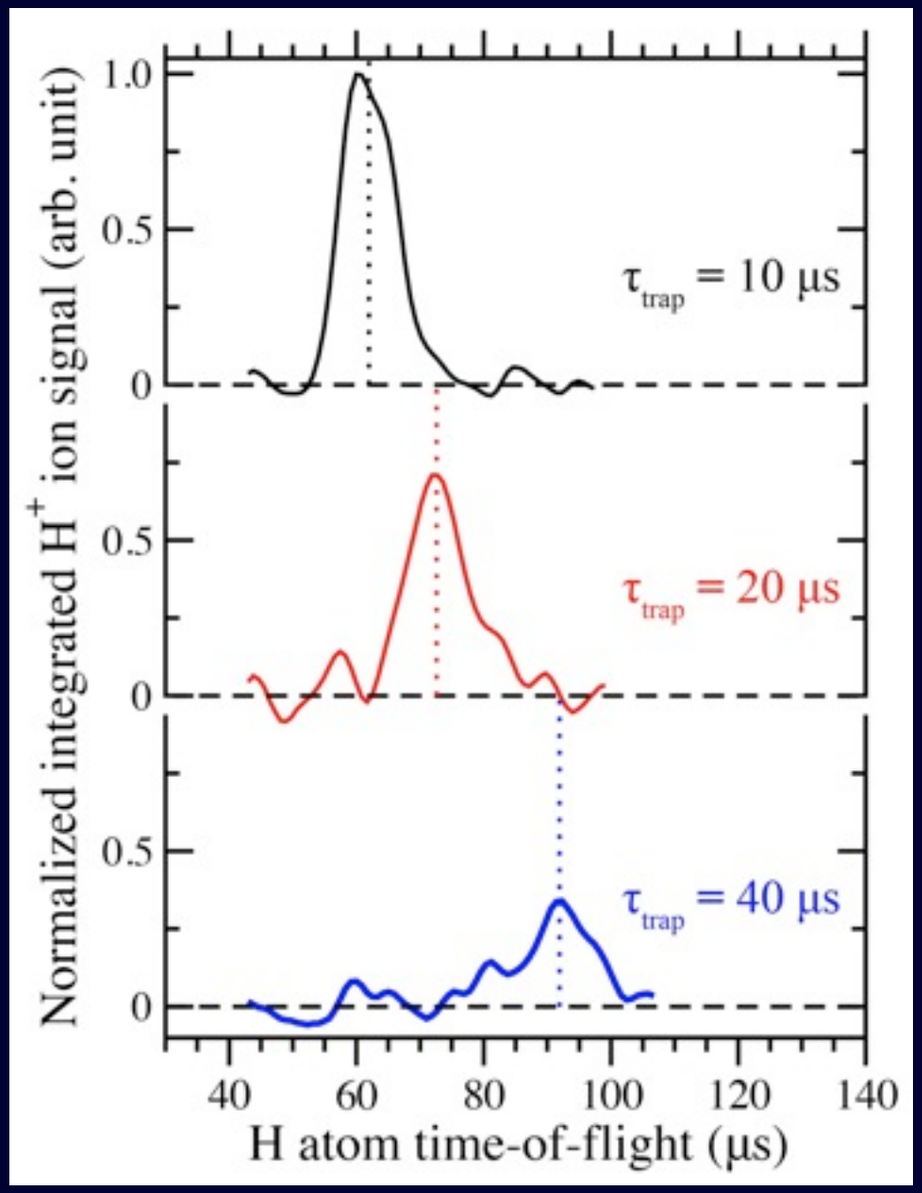
- Deceleration in low fields with large gradients
  - wide range of Rydberg states accepted



Hogan et al., *Phys. Rev. Lett.* **108**, 063008 (2012)

Electrostatic trapping

- Trap atoms for time τ_{trap} above electrode array
  - after trapping re-accelerate toward detection region



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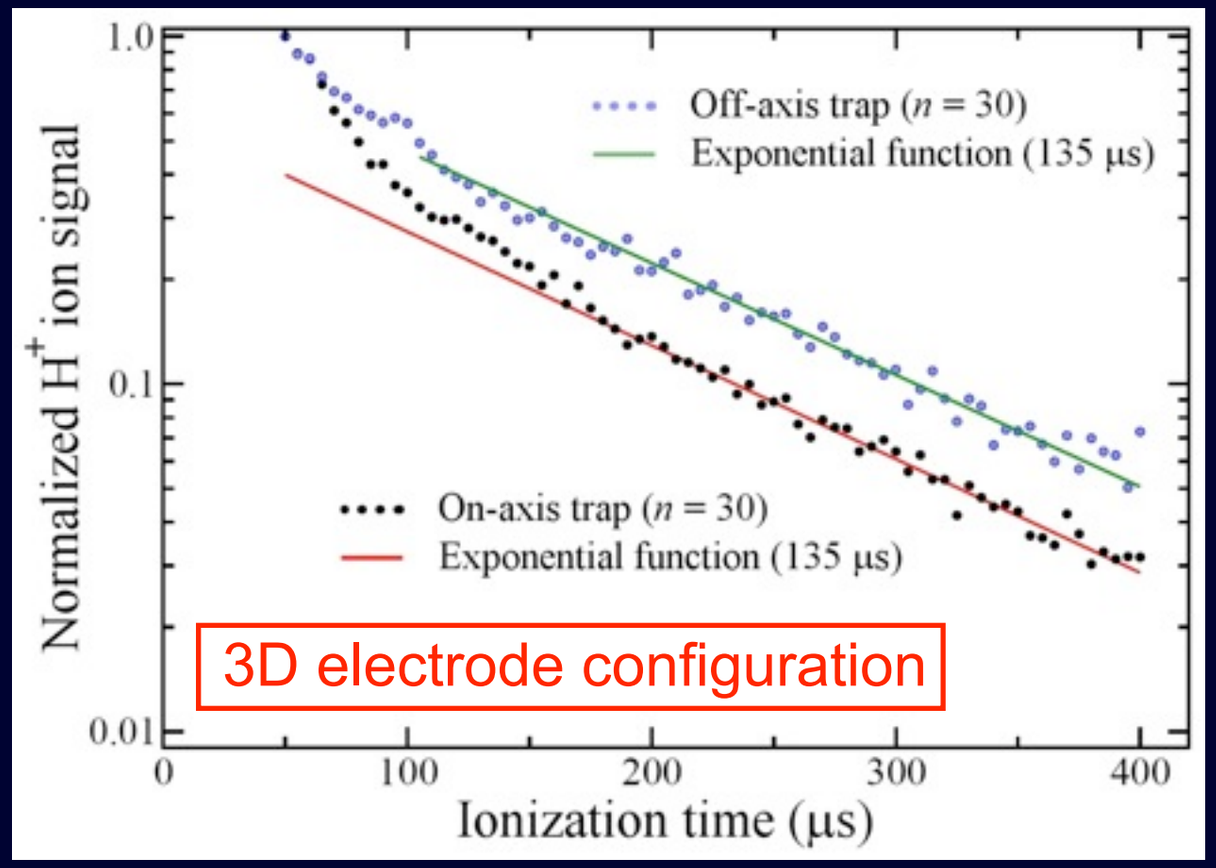
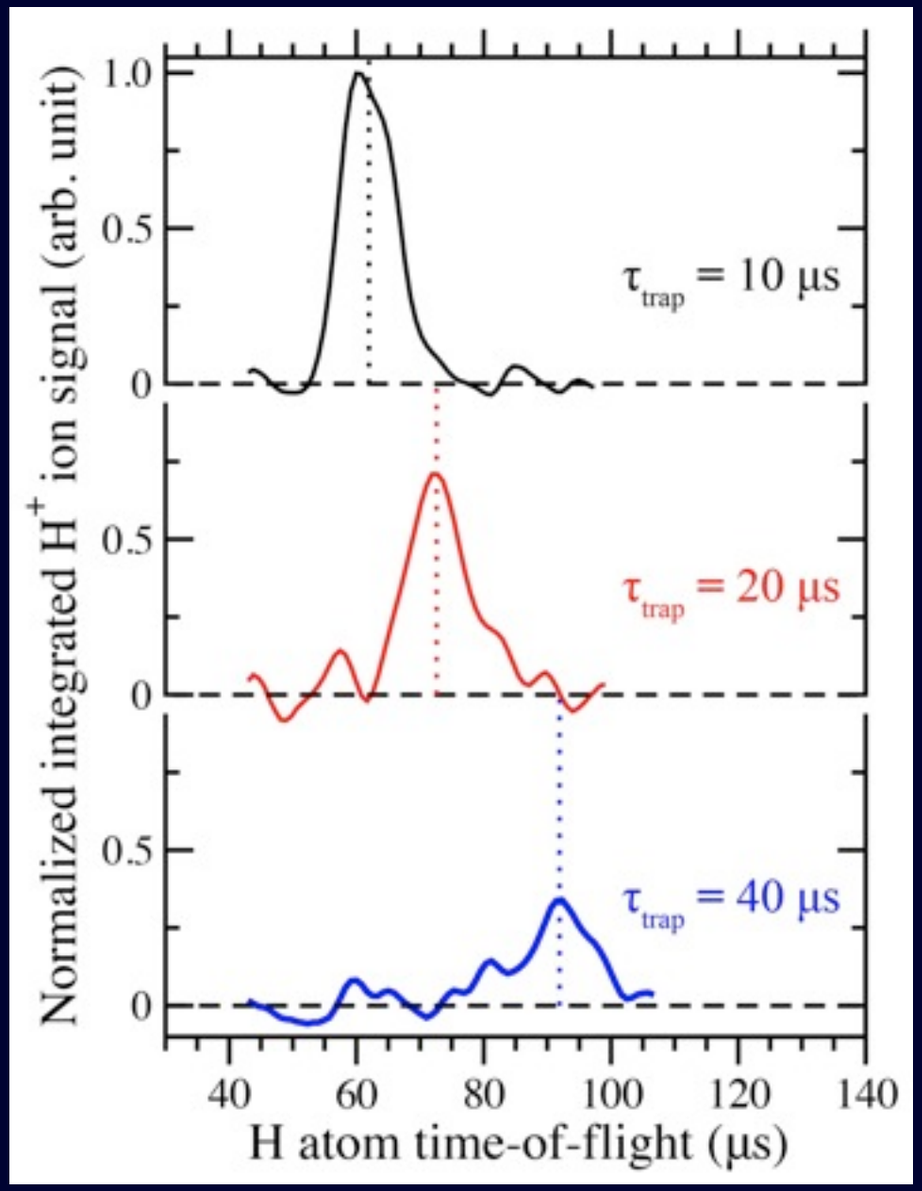
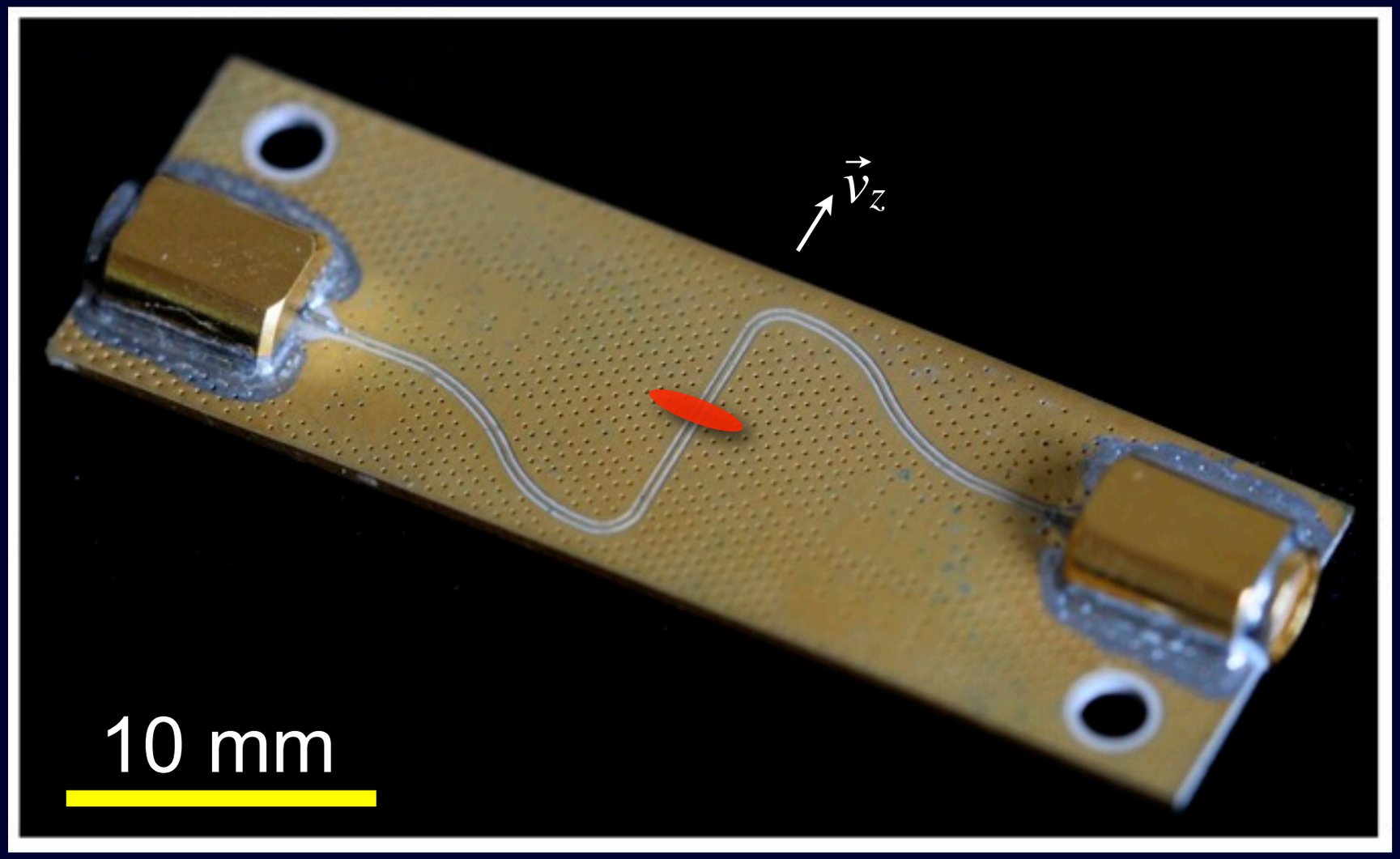


Decay time ~30 μs
- dominated by collisional losses

Seiler et al., *Phys. Rev. Lett.* **106**, 073003(2011)



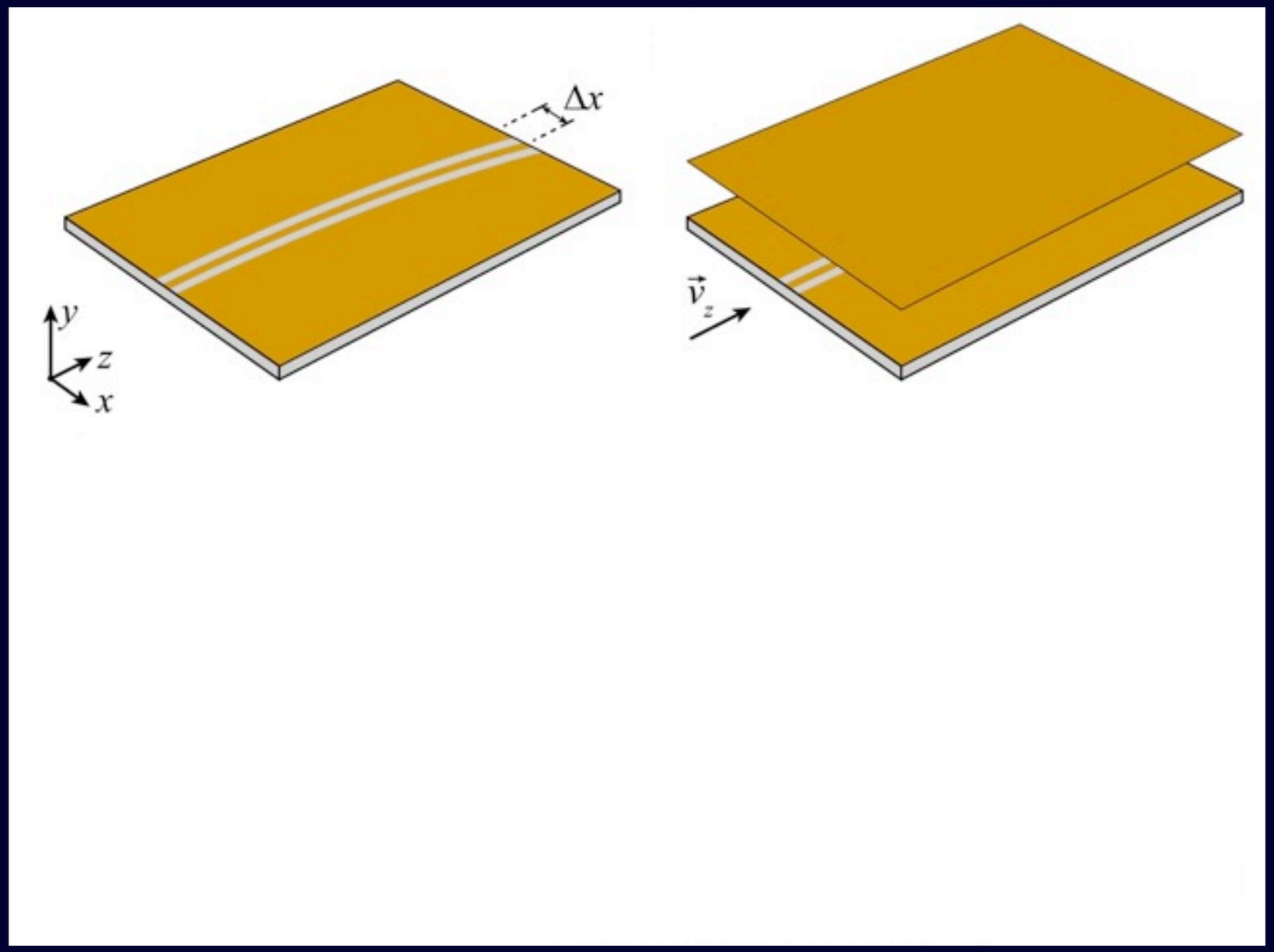
Coupling to microwave circuits



Hogan et al., *Phys. Rev. Lett.* **108**, 063004 (2012)

Surface-based electrostatic guides

- Based on geometry of co-planar waveguide



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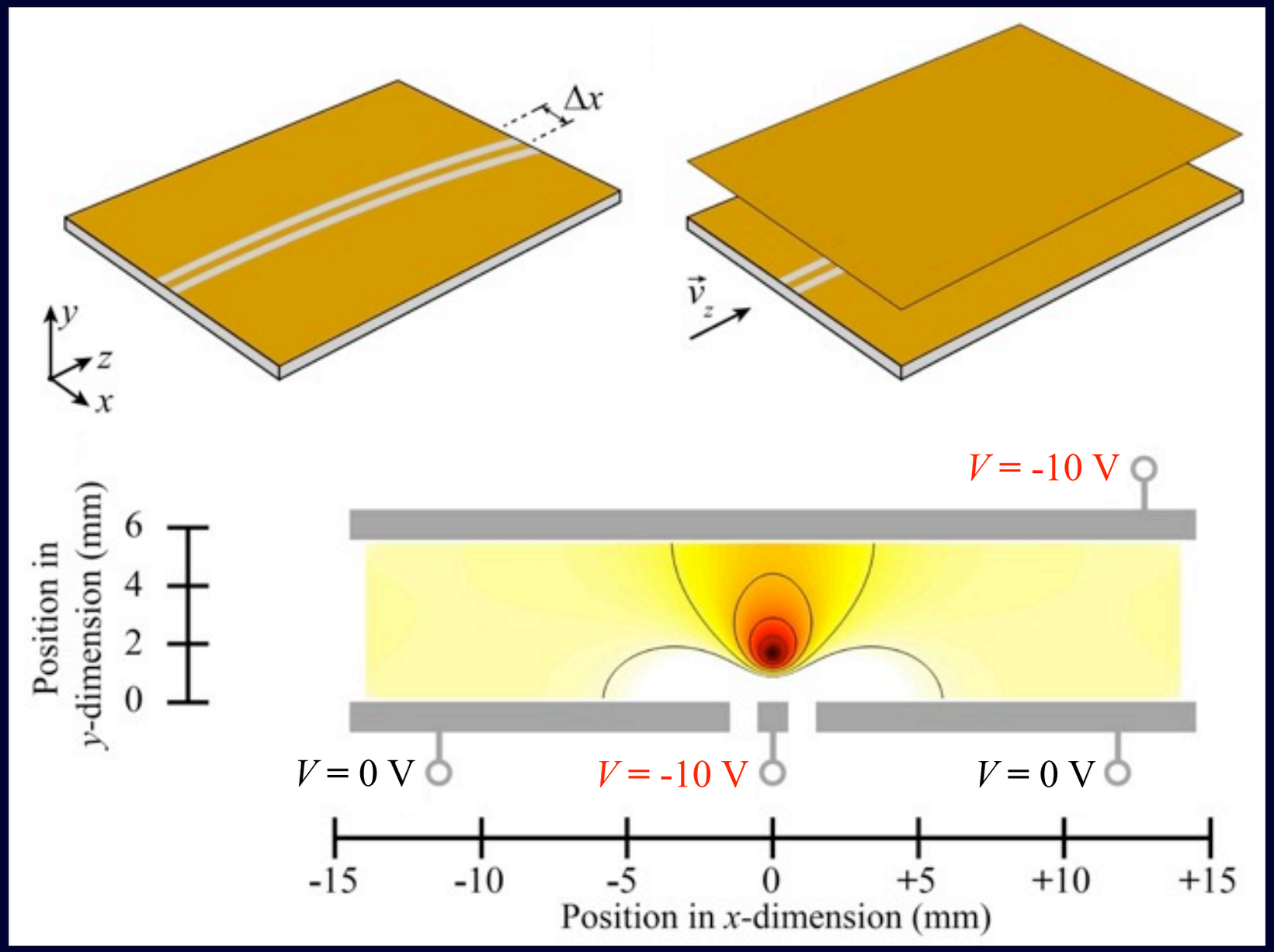

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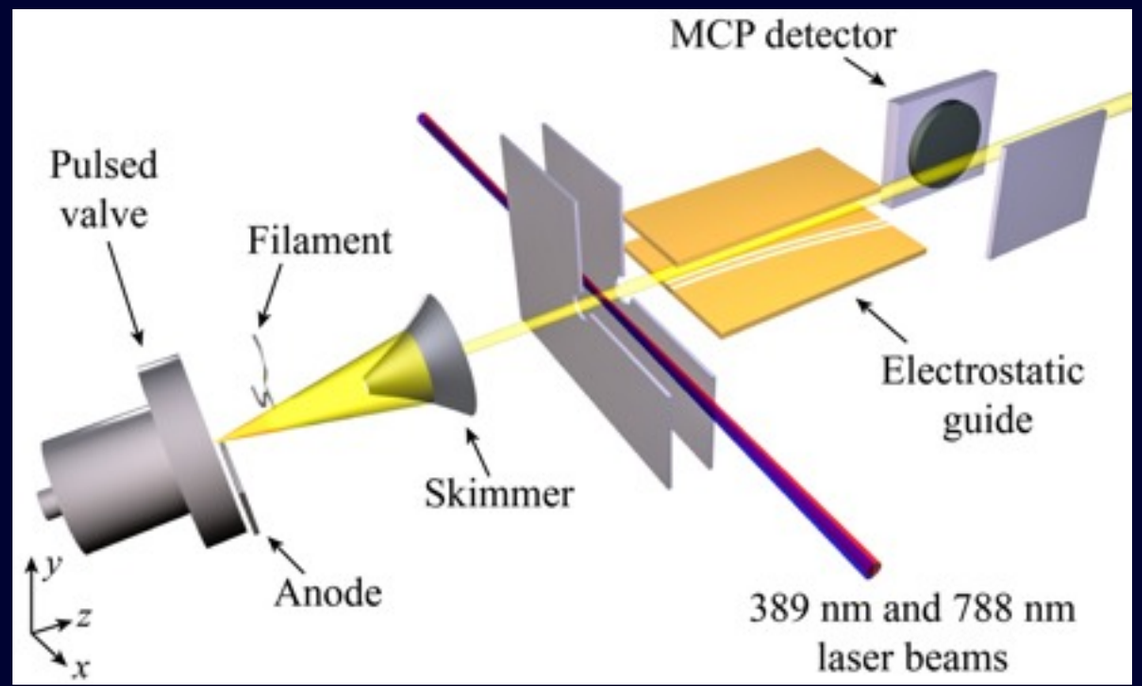
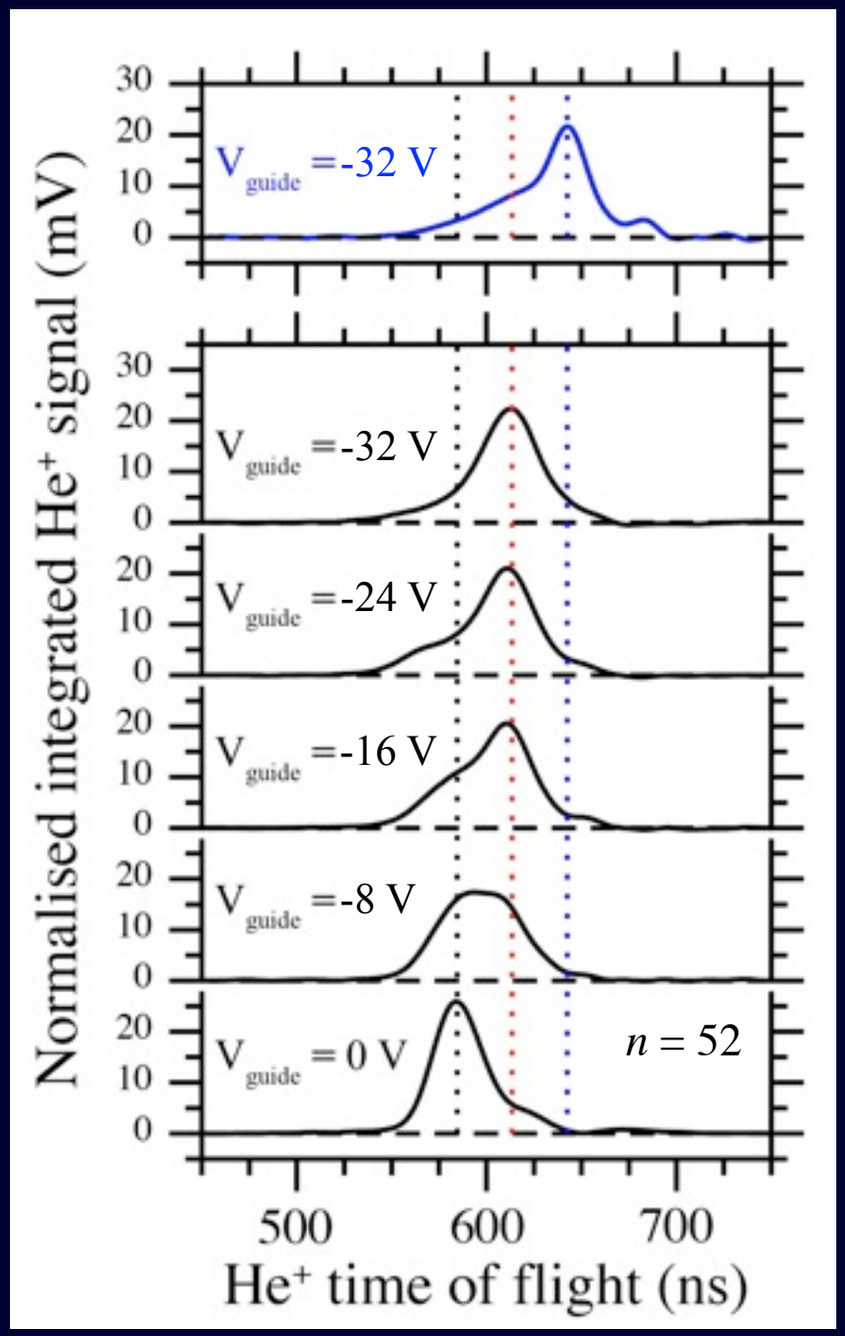
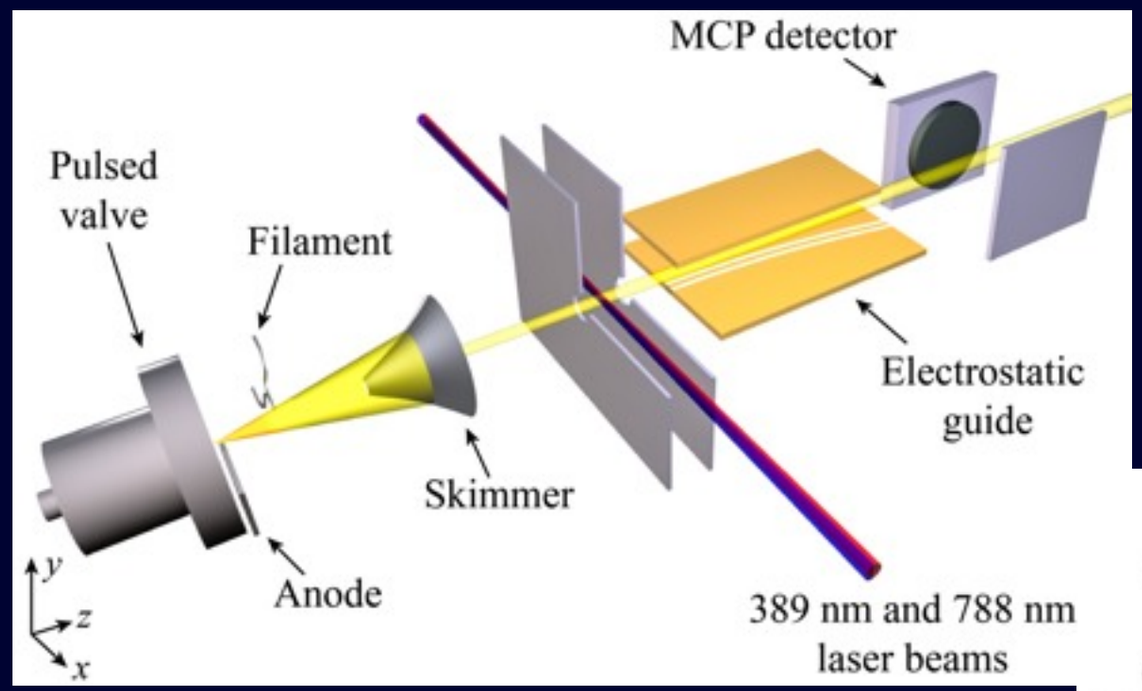




- Metastable helium beam

Surface-based electrostatic guides



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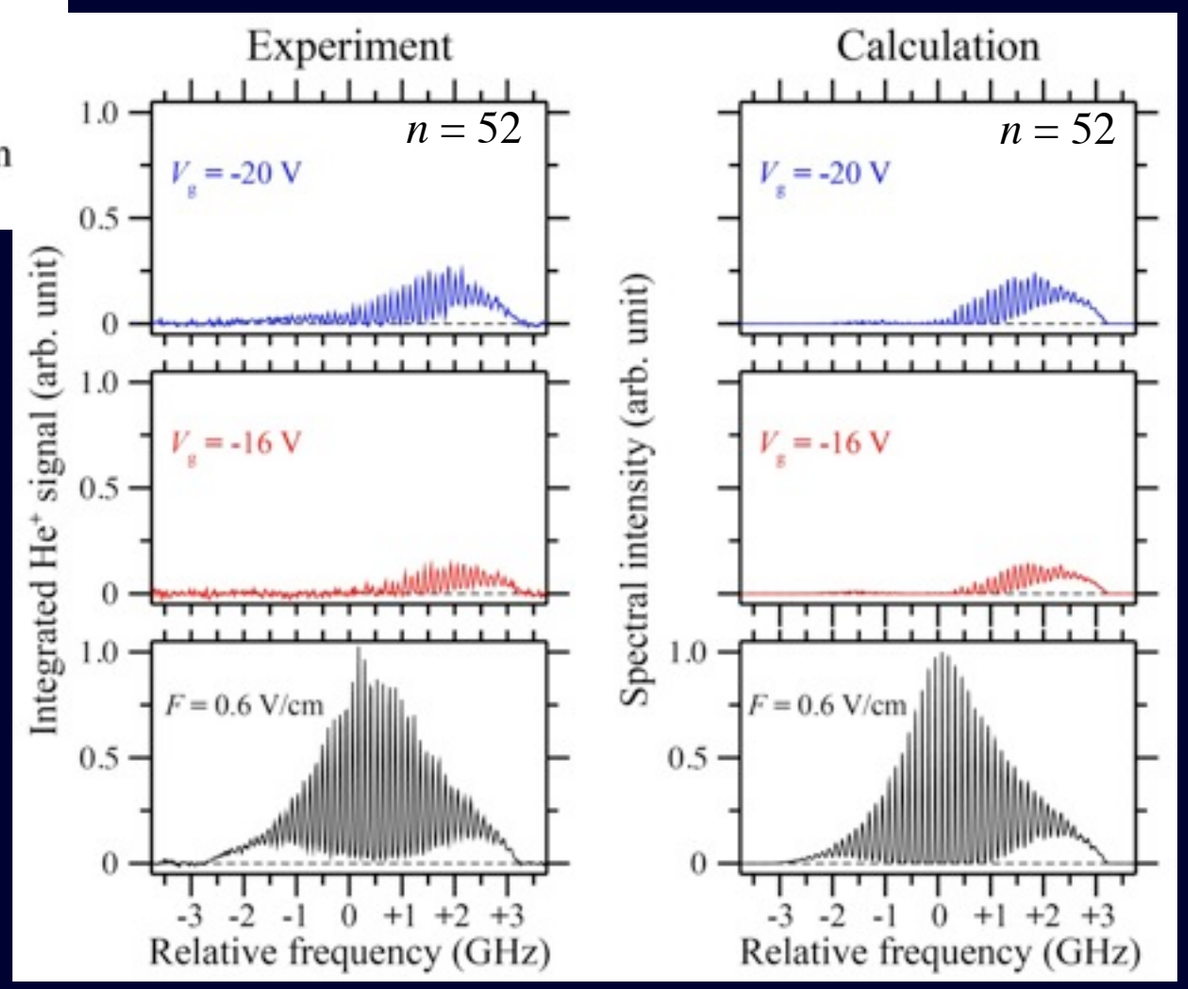
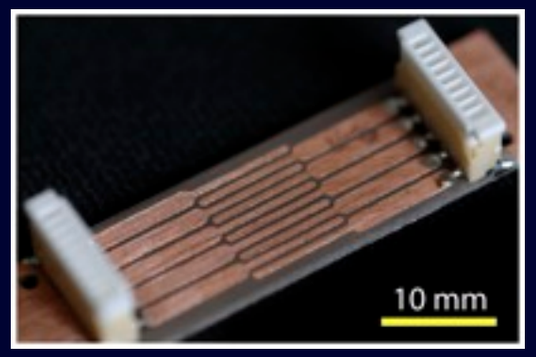


Summary

- Surface-based decelerators and traps for atoms in Rydberg states

H. Sassmannshausen, P. Allmendinger, H. Schmutz, J. Agner and F. Merkt (ETH Zurich)



- Surface-based electrostatic guides

P. Lancuba (UCL)