Guiding and manipulating Rydberg positronium with inhomogeneous electric fields

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UCL positronium spectroscopy group + UCL Rydberg atoms and manipulation group

David Cassidy

Alberto Alonso

Ben Cooper*

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Thomas Wall*

Stephen Hogan

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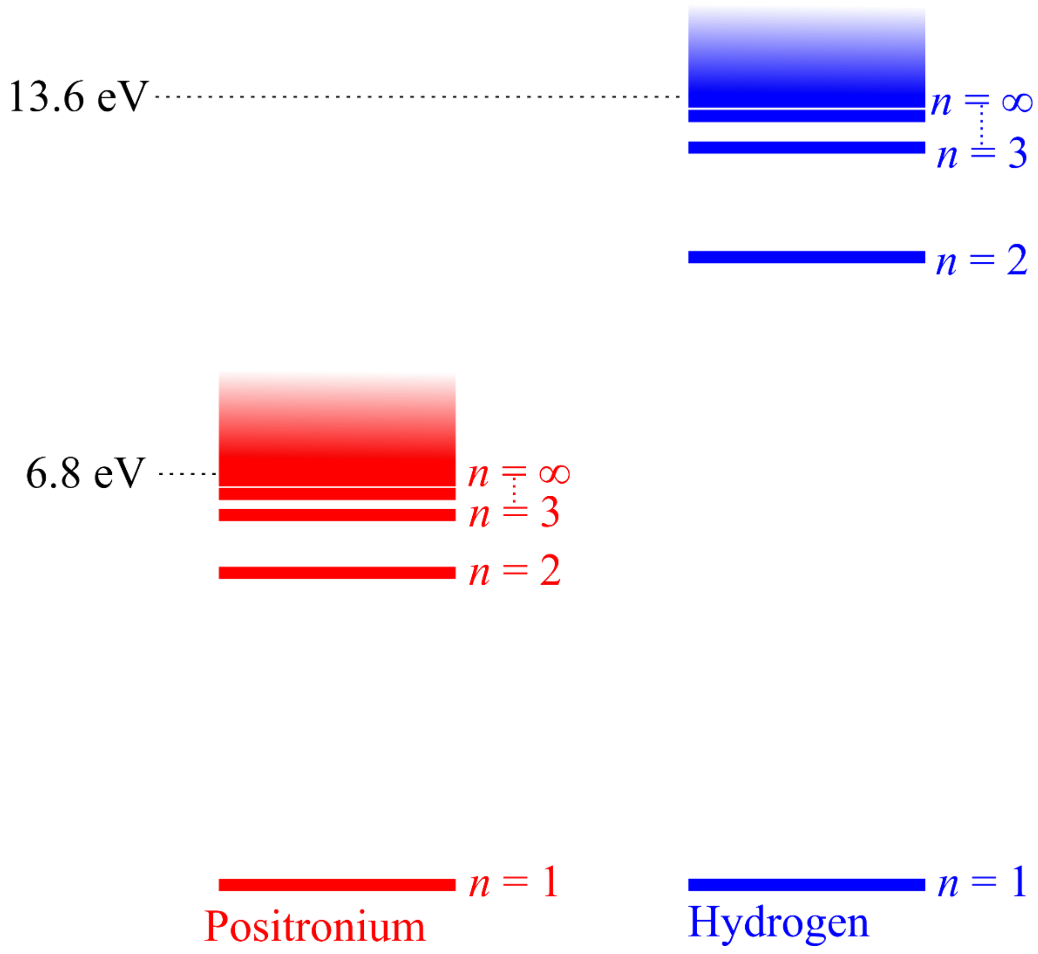
Motivation

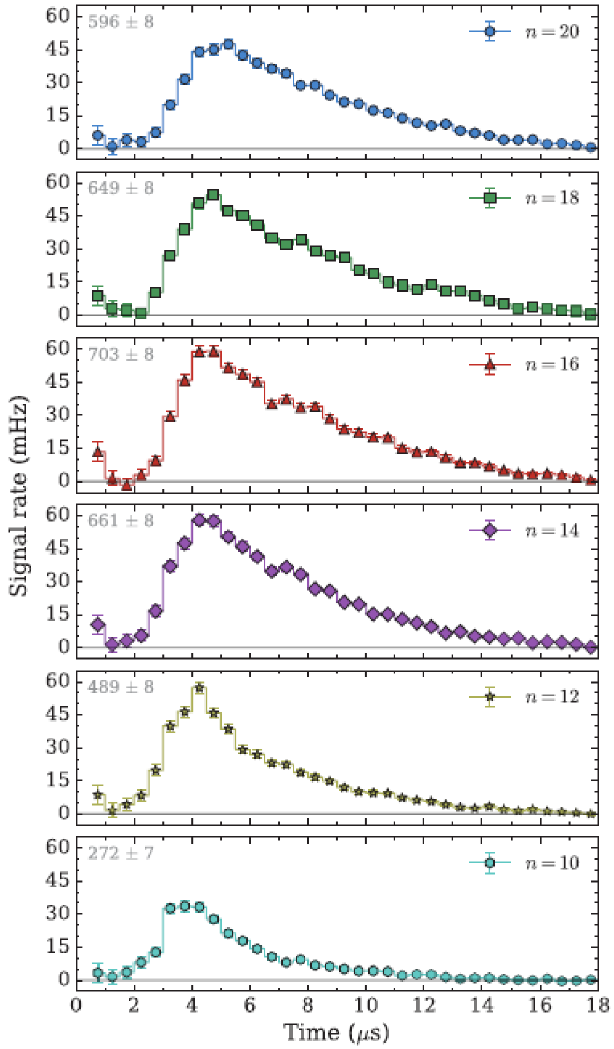
- High precision spectroscopy experiments (Rydberg constant, fine structure etc…)
- Time-of-flight measurements
- Scattering and formation of e^+ bound states formation
- Beam deflection for possible gravity measurements

Rydberg positronium



- $n = 1$ positronium has short lifetime (142 ns)
- High-n (Rydberg) excited states of positronium are dominated by fluorescence to $n = 1$, not self-annihilation
- Rydberg states have lifetimes of many 10's of microseconds or even milliseconds! (because states are ℓ-mixed)
- Large electric dipole moments (~1300D for $n = 14$ [k=+12]).

Rydberg positronium



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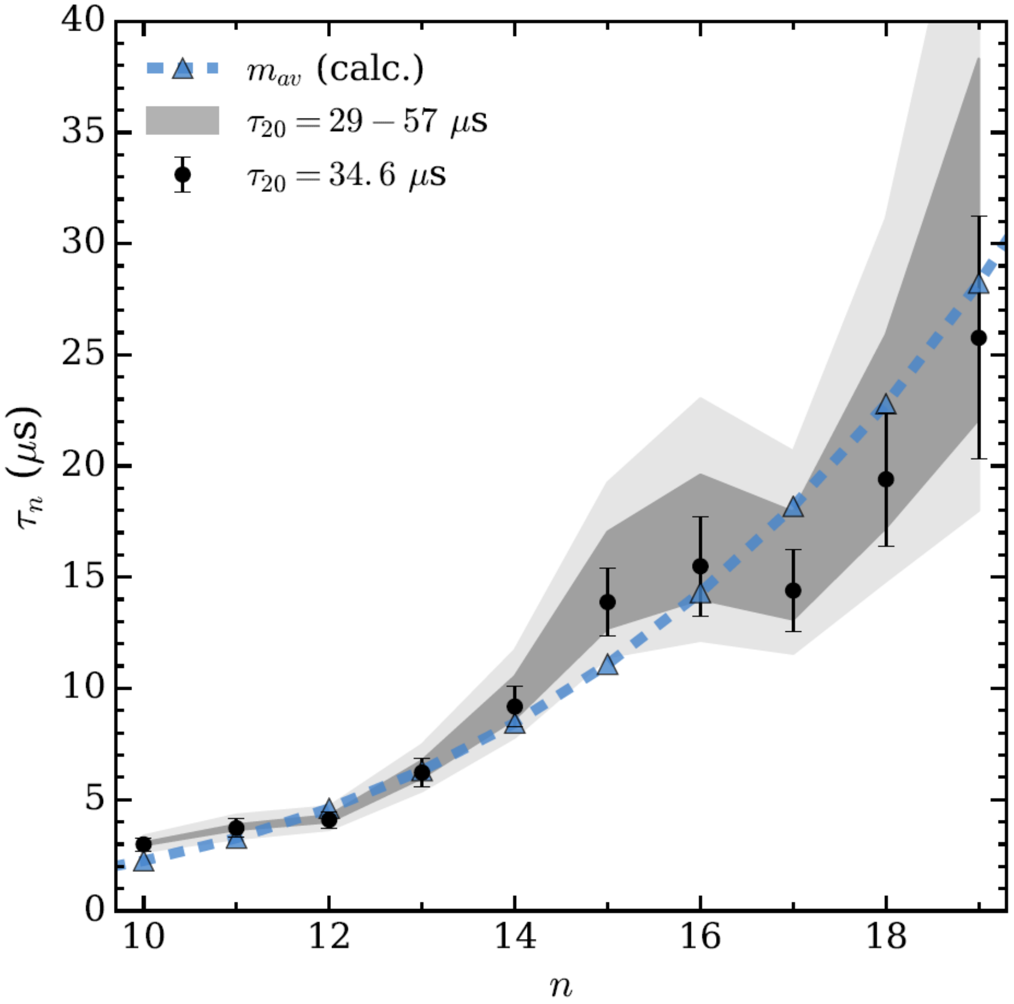
A. Deller et al. *Phys. Rev. A* **93**, 062513 (2016)

Rydberg positronium



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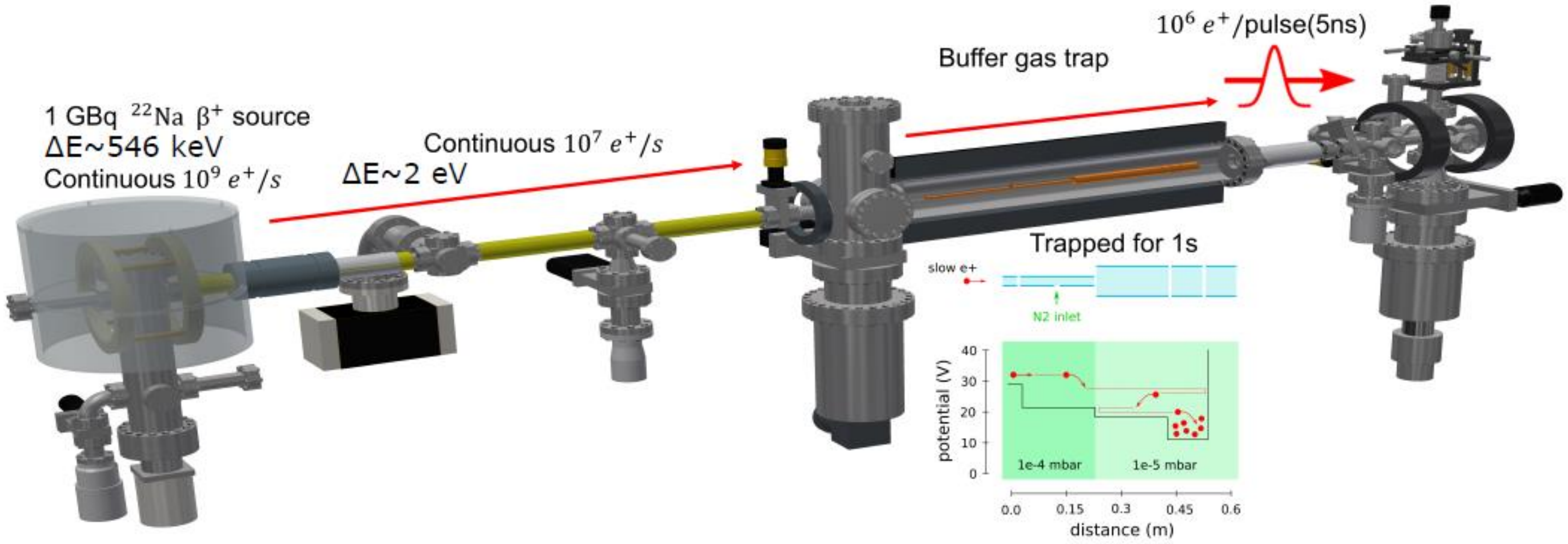
A. Deller et al. *Phys. Rev. A* **93**, 062513 (2016)

Production of positronium

e^+ pulsed beam



- β^+ from ^{22}Na source, moderated with solid neon (~1% efficient)
- Surko-type buffer gas (N_2) trap filled for 1s, applied rotating E field, e^+'s compressed and trapped (~10% efficient)
- Pulses of e^+ produced with 5ns timewidths

B. S. Cooper, A. M. Alonso, A. Deller, T. E. Wall, and D. B. Cassidy.
Rev. Sci. Instrum. **86**, 103101 (2015)

Positronium produced out of porous silica target

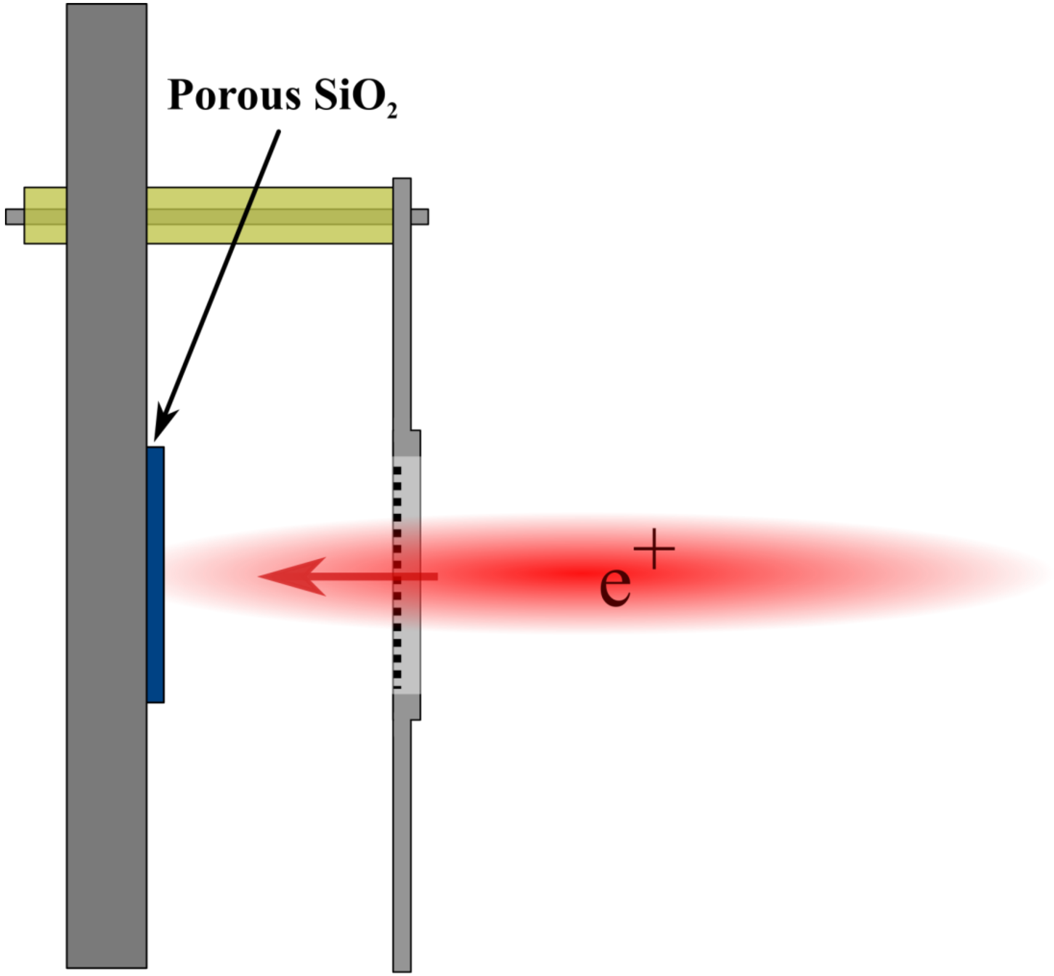
- Positrons implanted into silica target

- Electrons are captured in the bulk

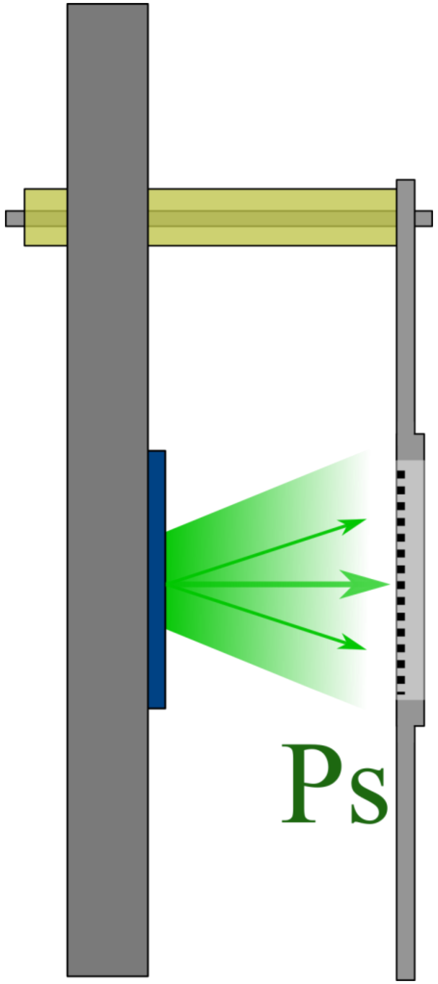
- Ps diffuses into pores, inelastic collisions with the walls lead to cool down (~30% efficient) and near thermalisation ($\mathrm{T} \sim 300\mathrm{K}$)

D. B. Cassidy, P. Crivelli, T. H. Hisakado, L. Liszkay, V. E. Meligne, P. Perez, H. W. K. Tom, and A. P. Mills, Jr. *Phys. Rev. A* **81** 012715 (2010)

Positronium production



Positronium production



Rydberg Positronium

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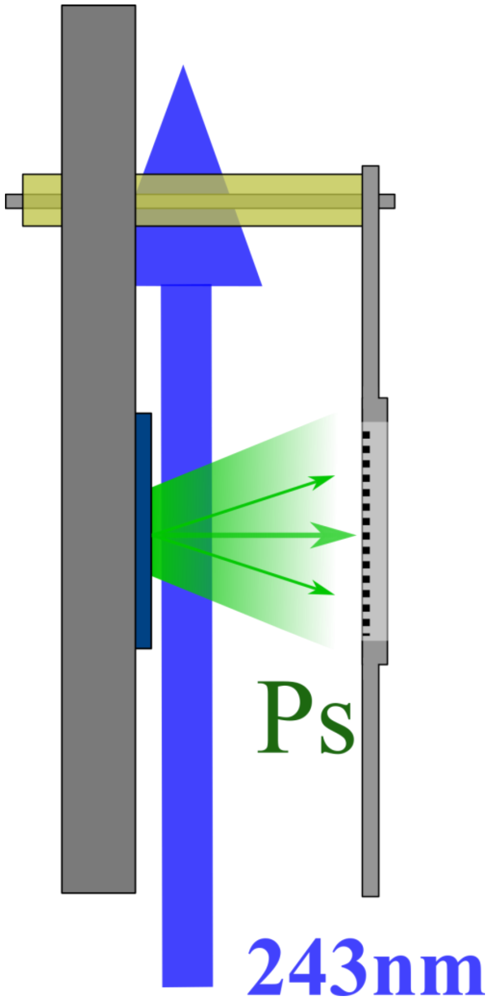

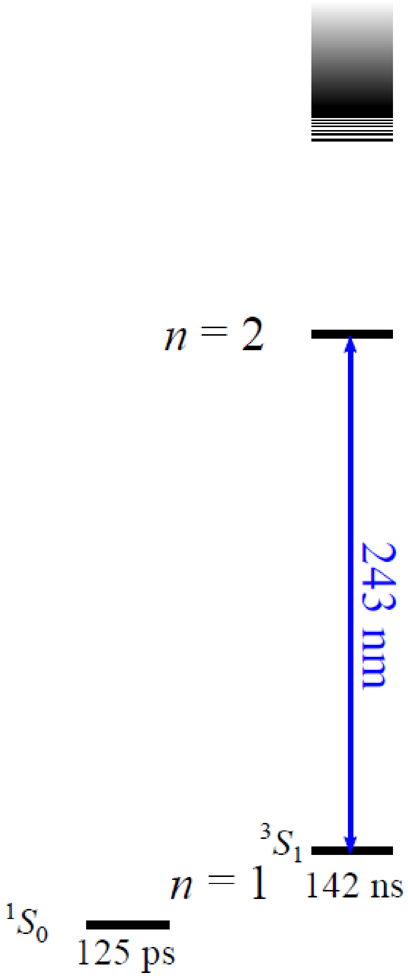

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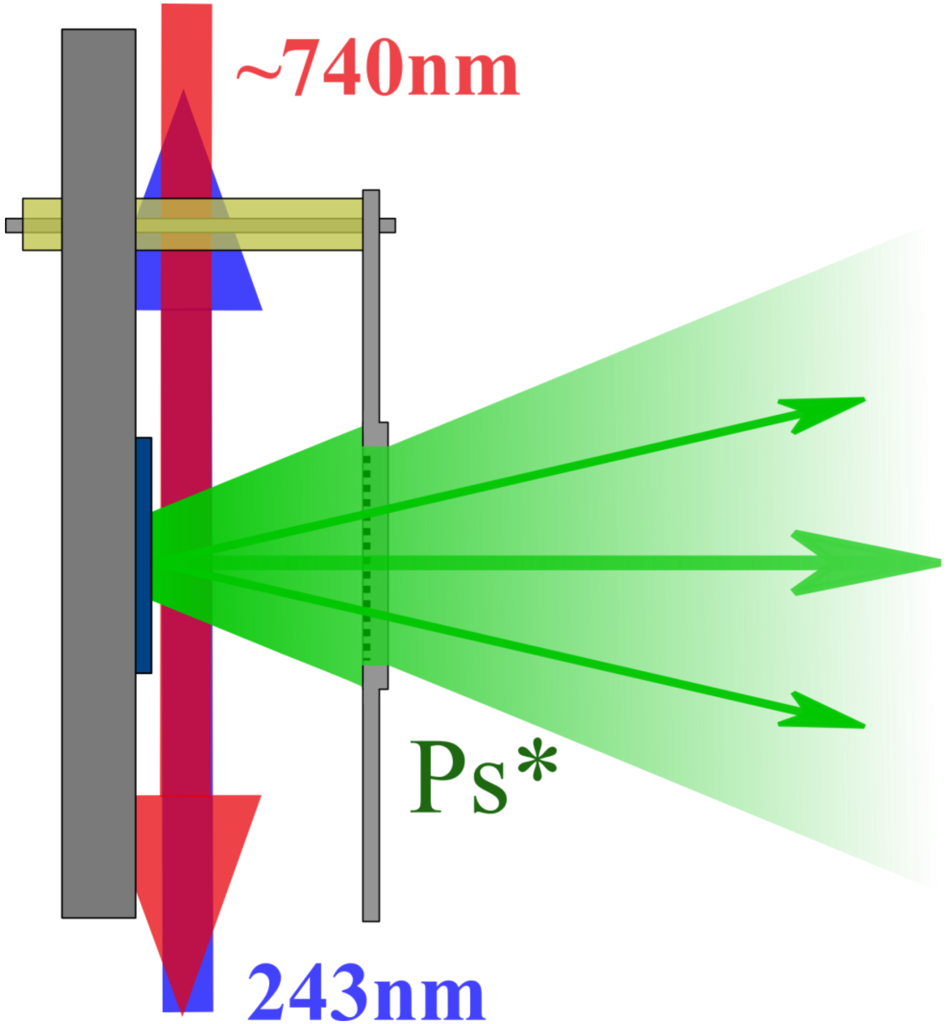

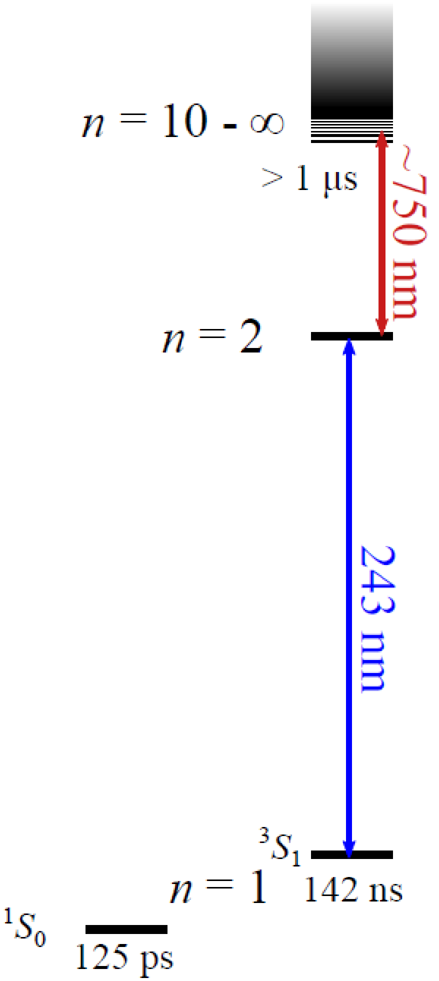

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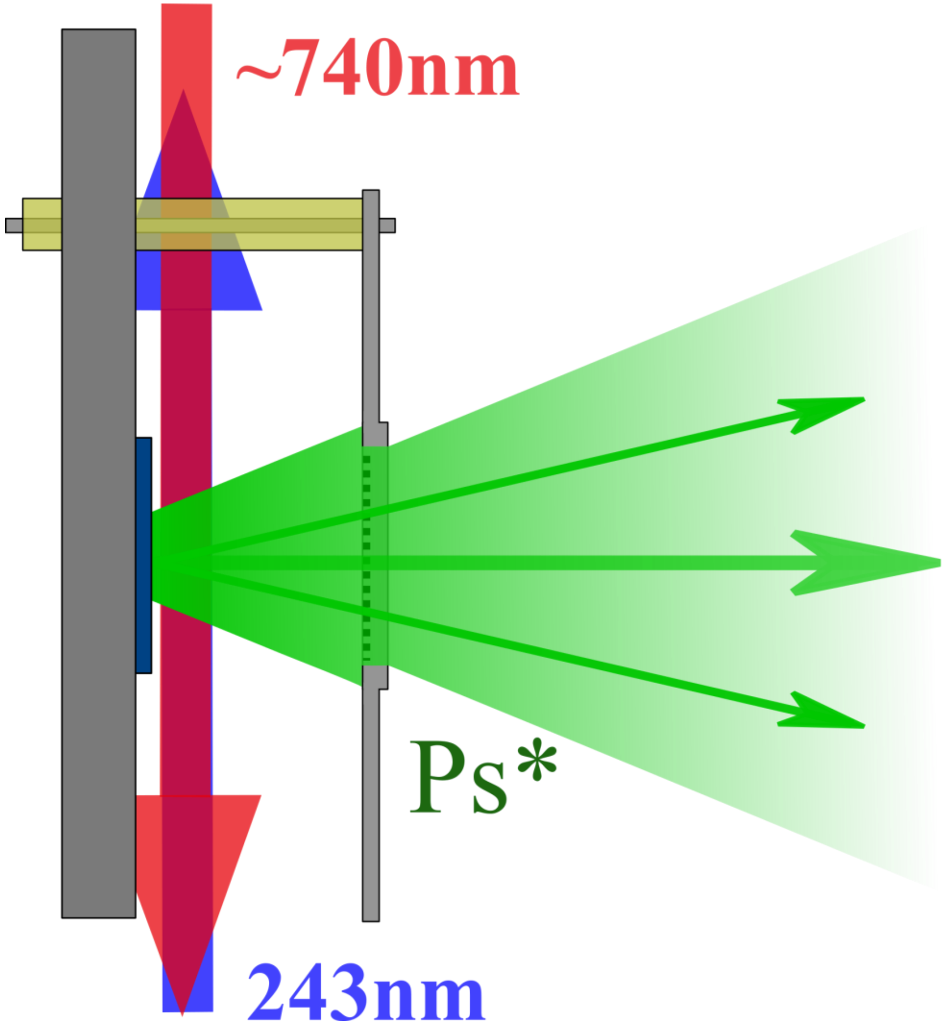

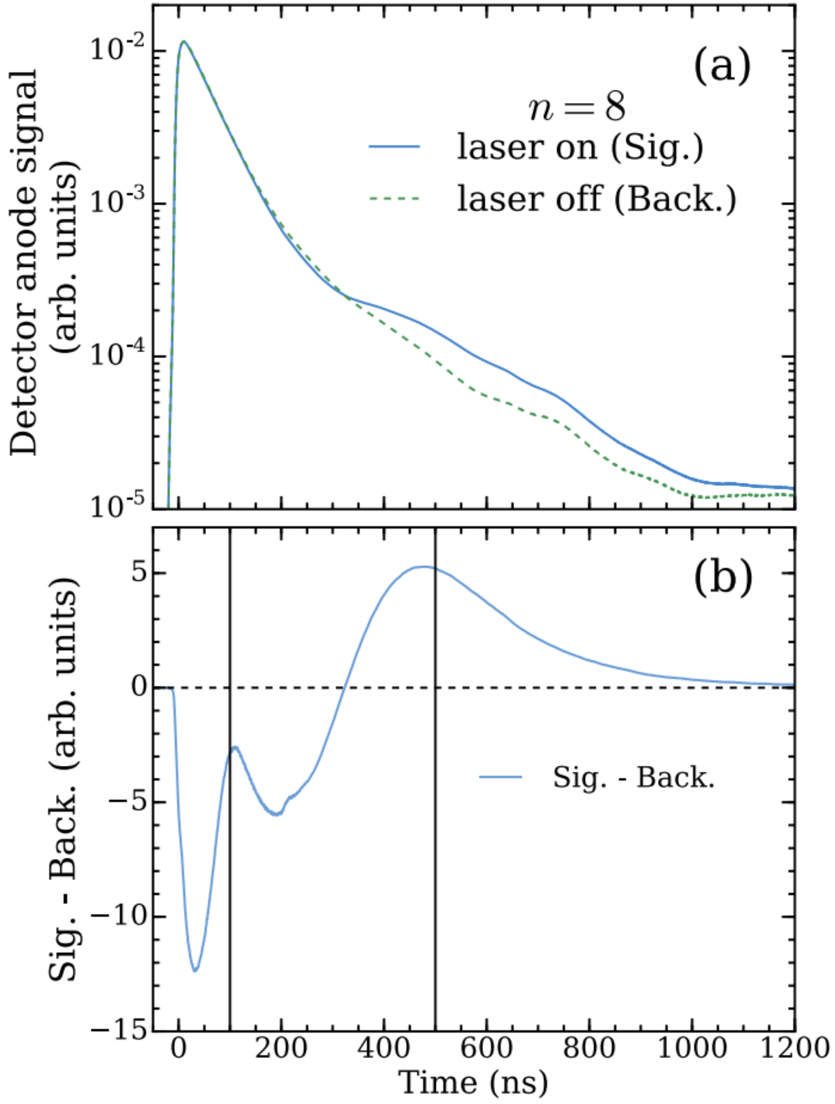

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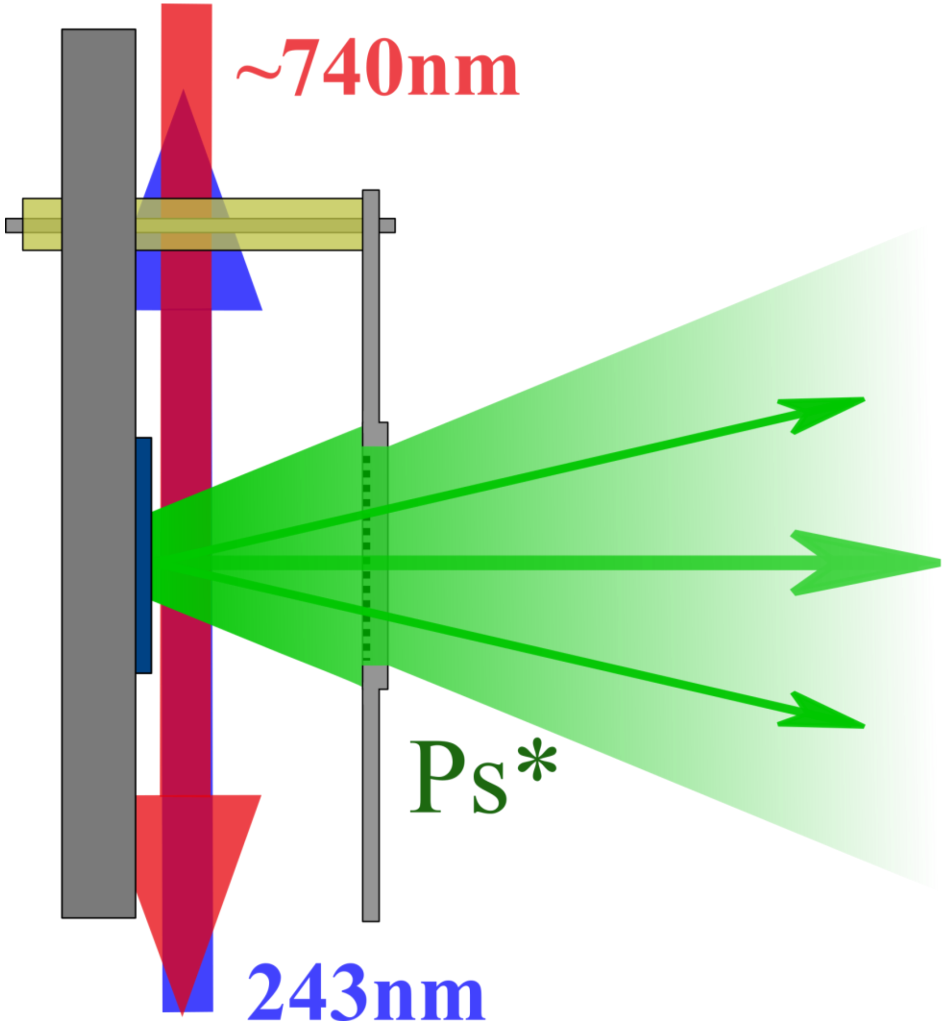

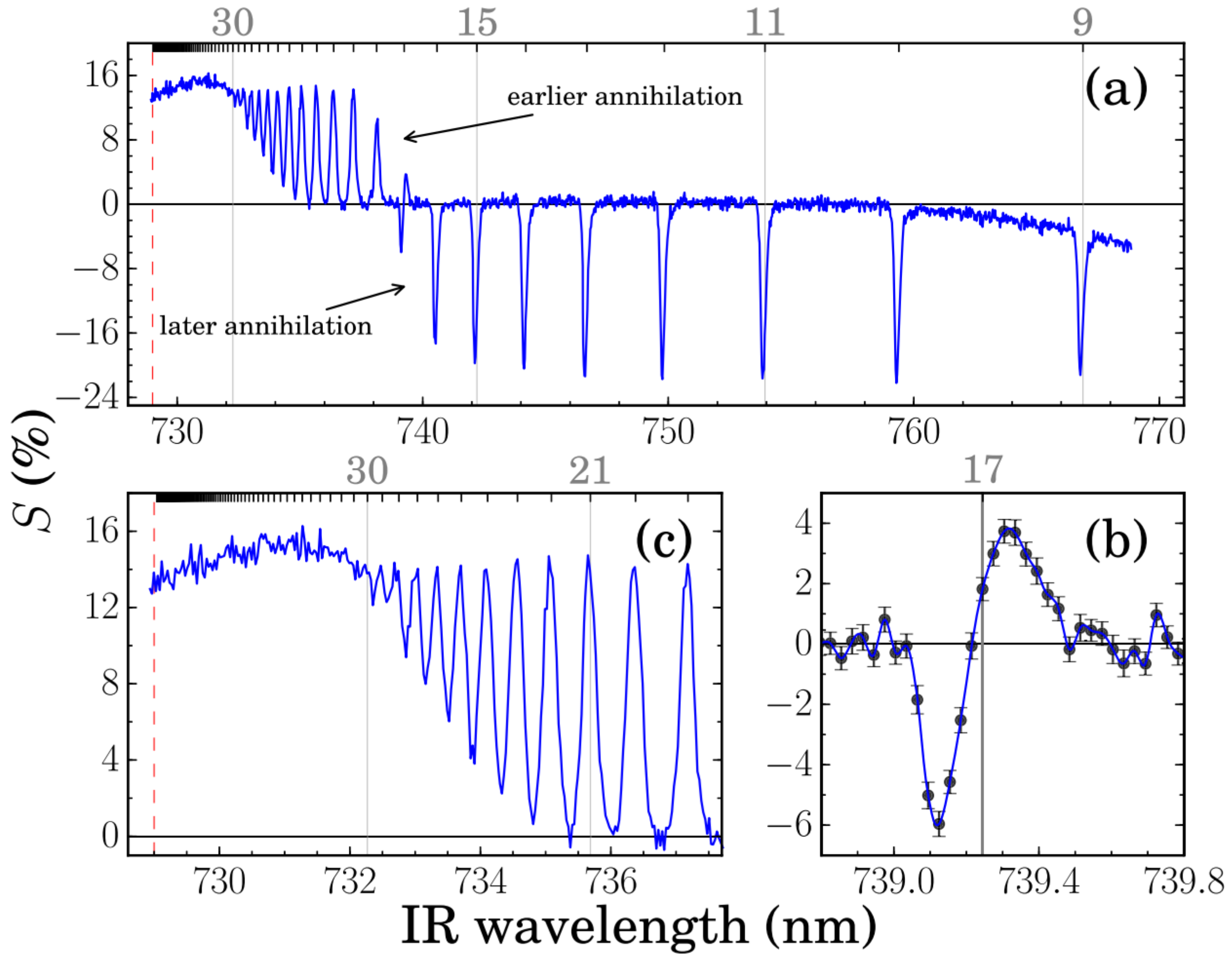

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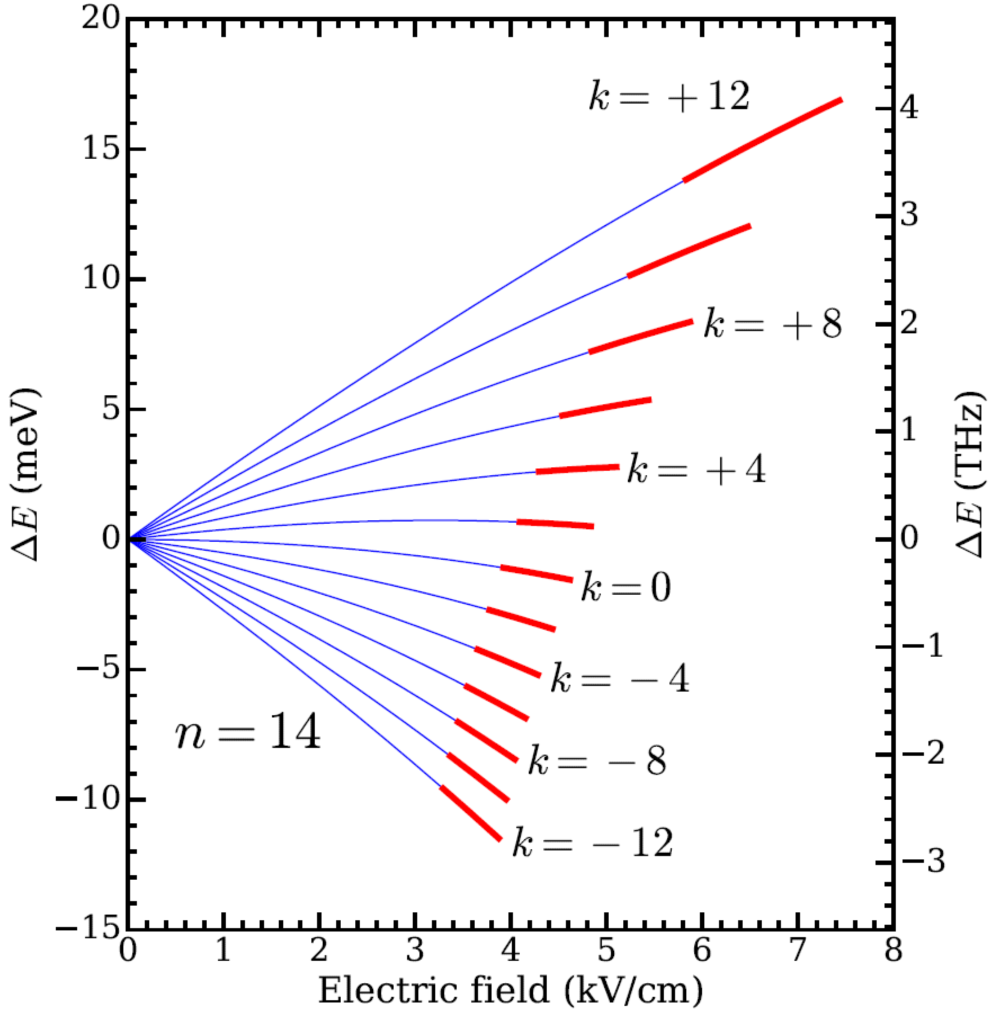


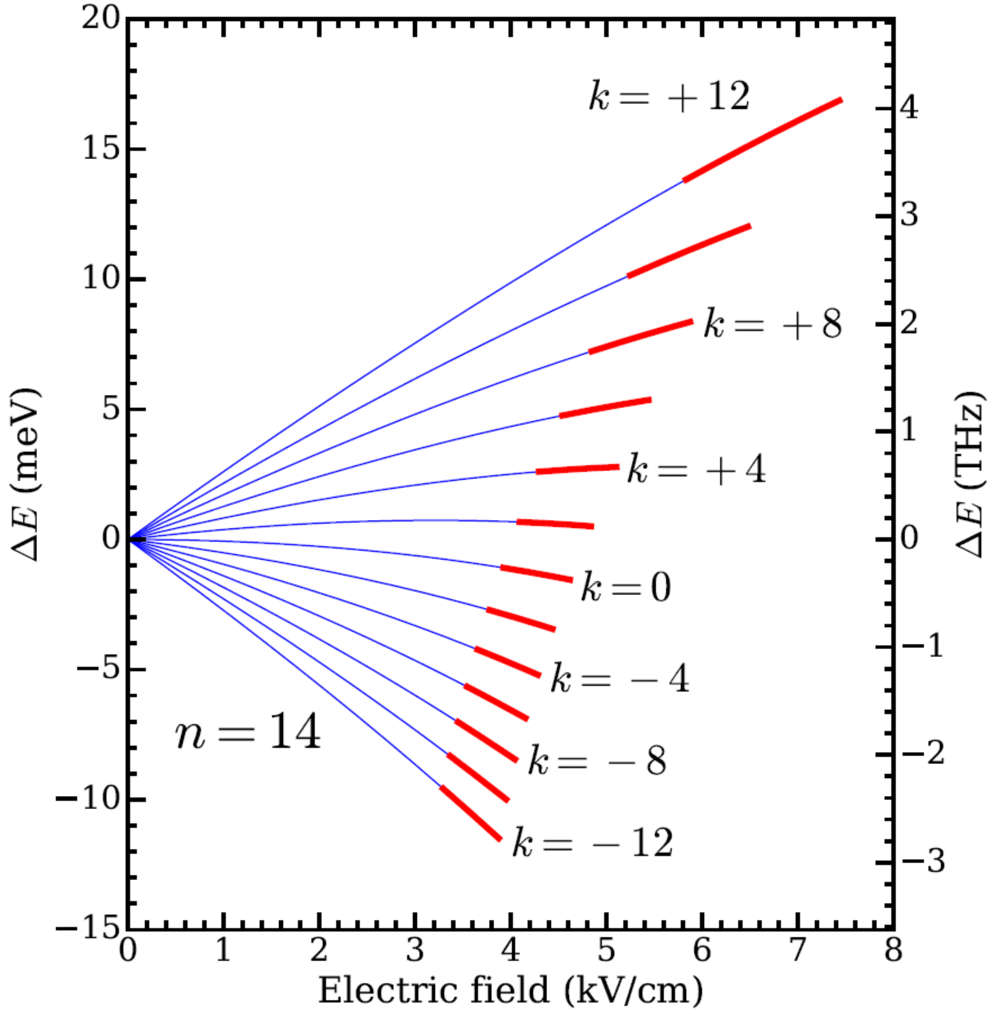
- $\Delta E = \frac{3}{2} n k e a_{\mathrm{Ps}} F_z$ (to first order)

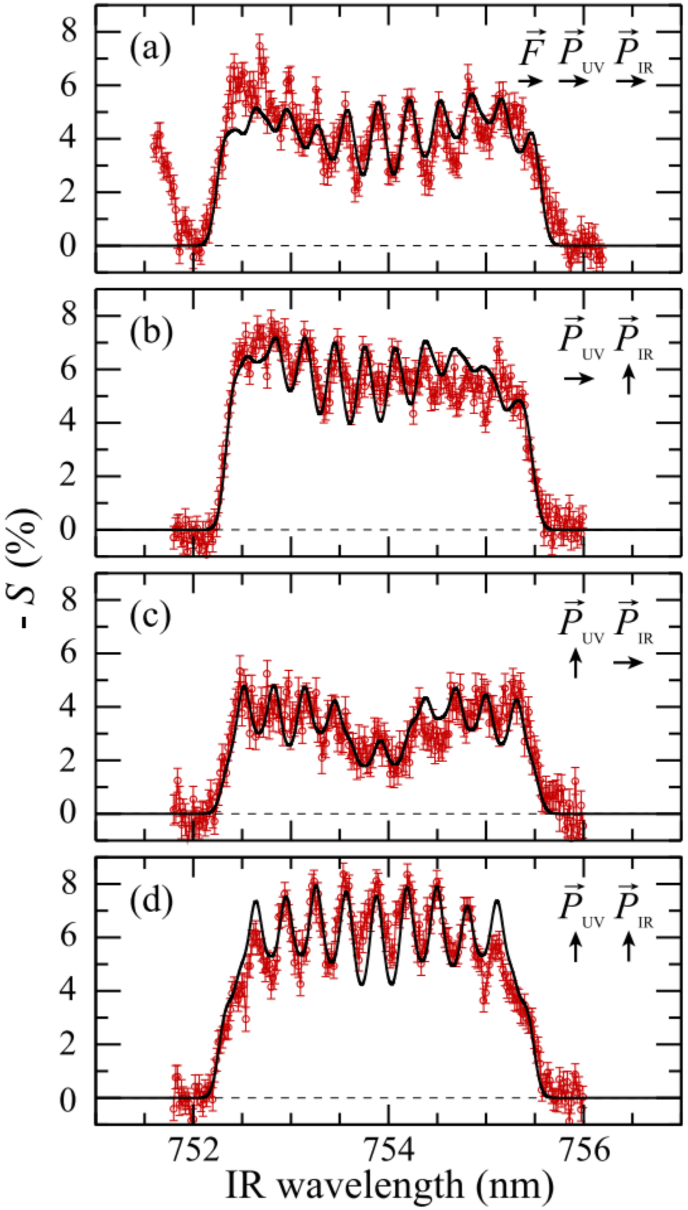
- $\Delta E = -\vec{\mu}_{elect} \cdot \vec{F}$

- $\vec{\mu}_{elect} \sim -\frac{3}{2} n k e a_{\mathrm{Ps}}$,
  for $n = 14$, $k = 12$, $\vec{\mu}_{elect}$ ~ 1300 D

S. D. Hogan, *Phys. Rev. A.* **87**, 063423 (2013)

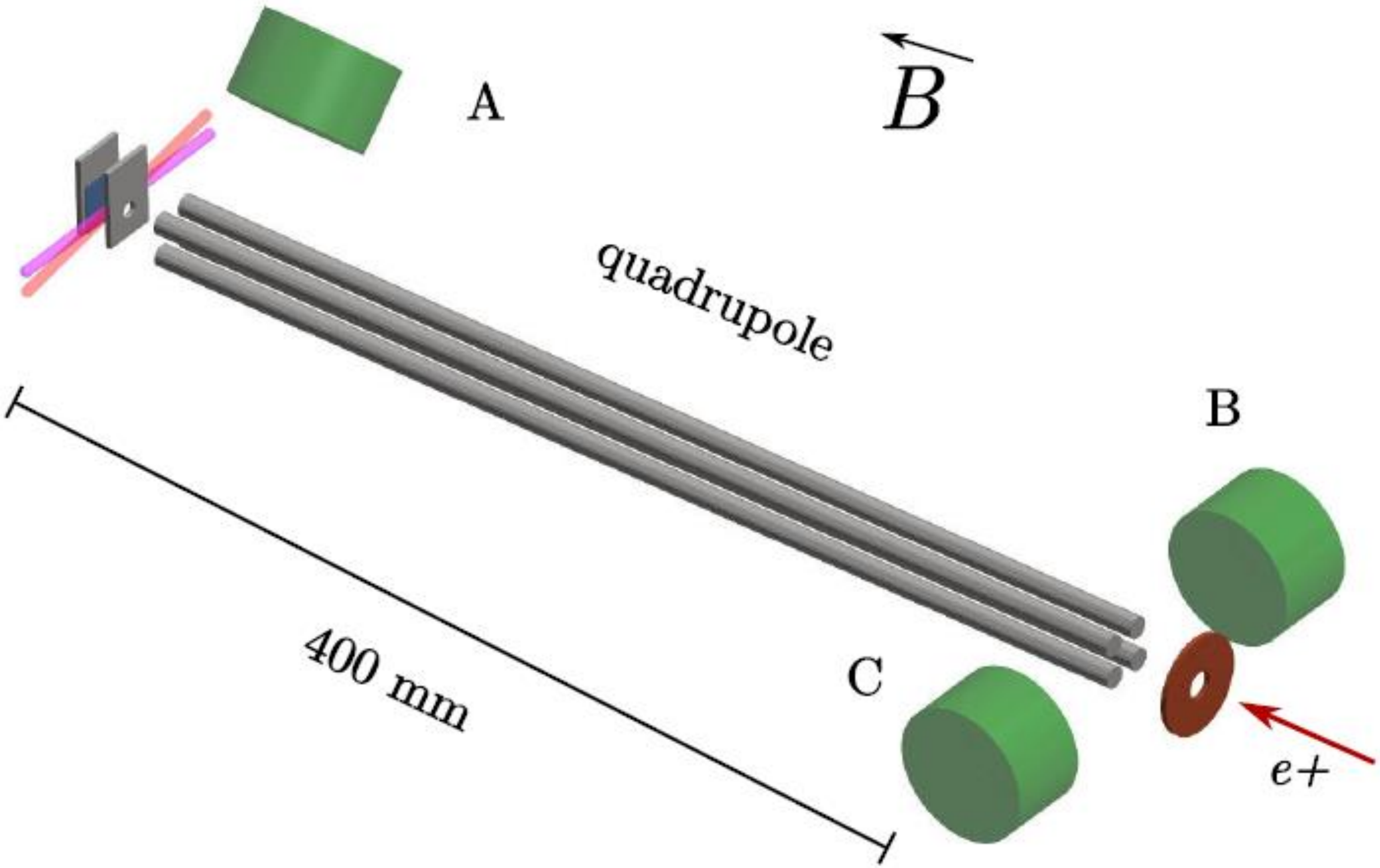
Rydberg Positronium





T. E. Wall et al. *Phys. Rev. Lett*. **114**, 173001 (2015)

Rydberg Positronium



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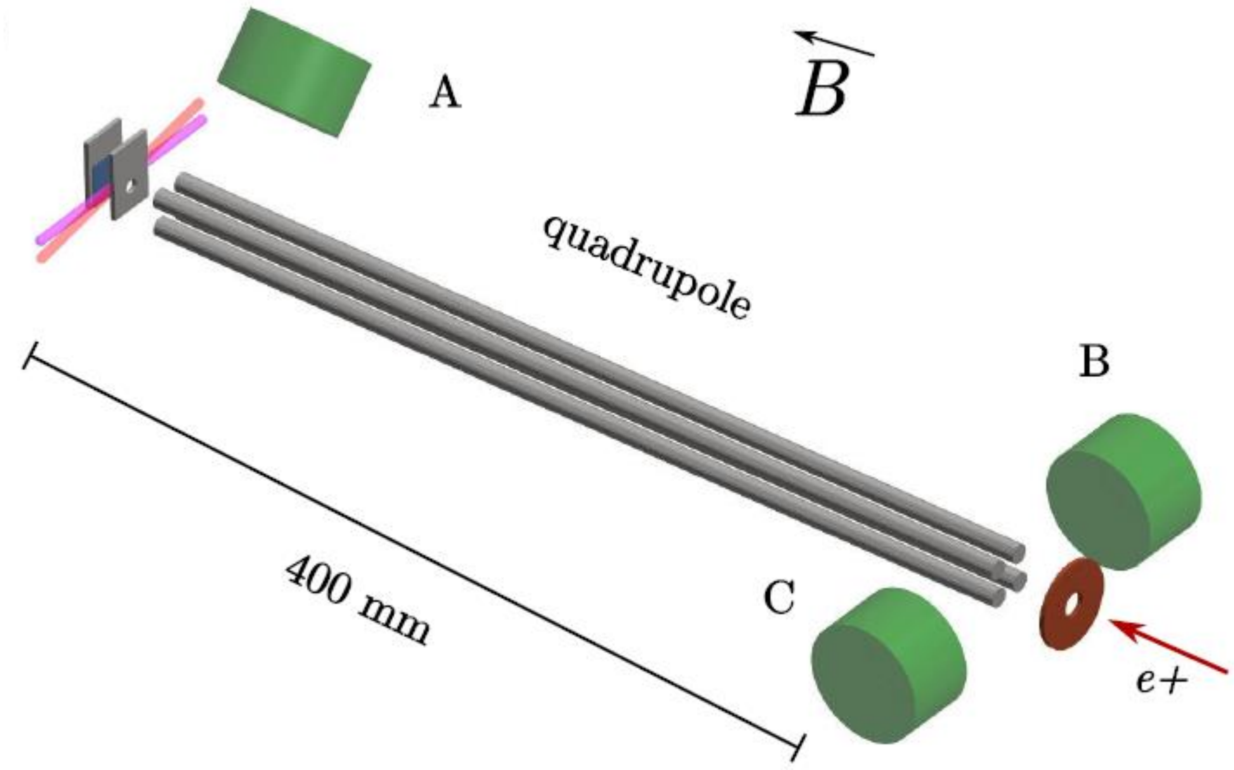

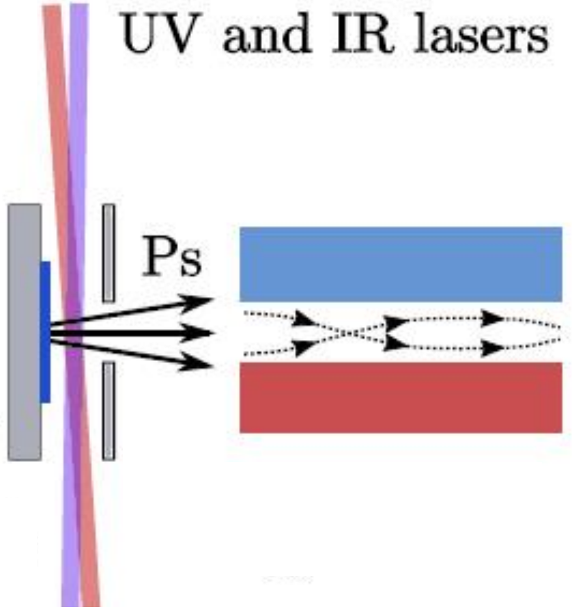

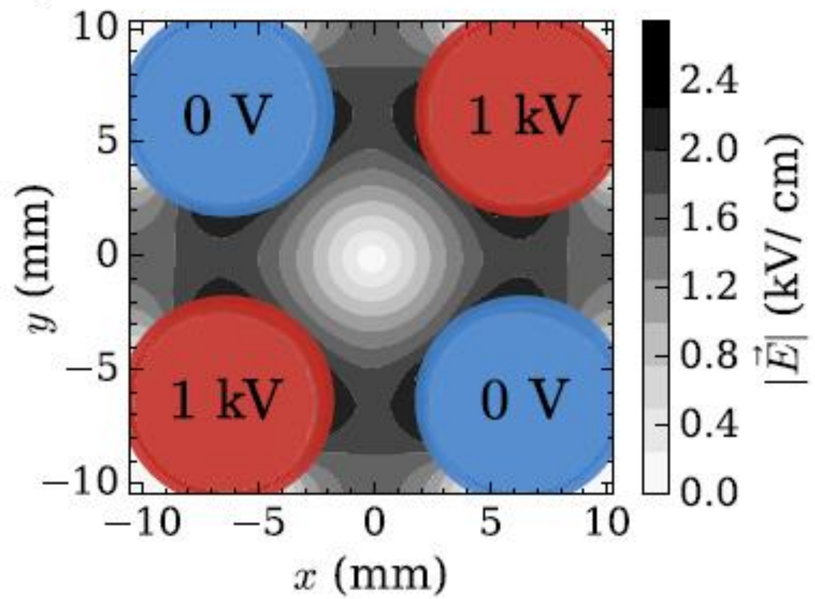

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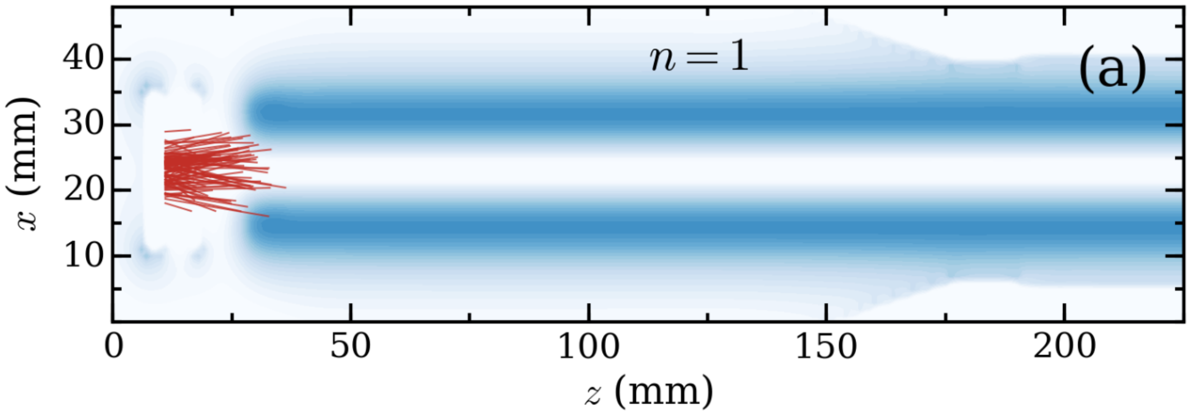

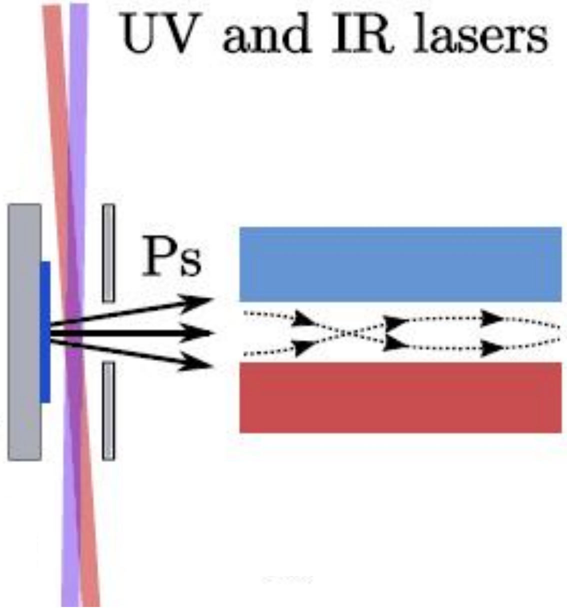

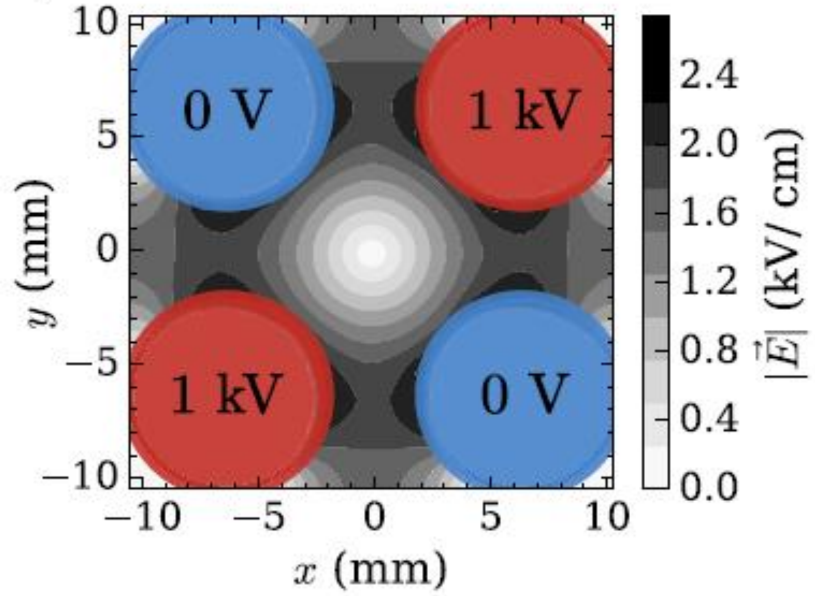

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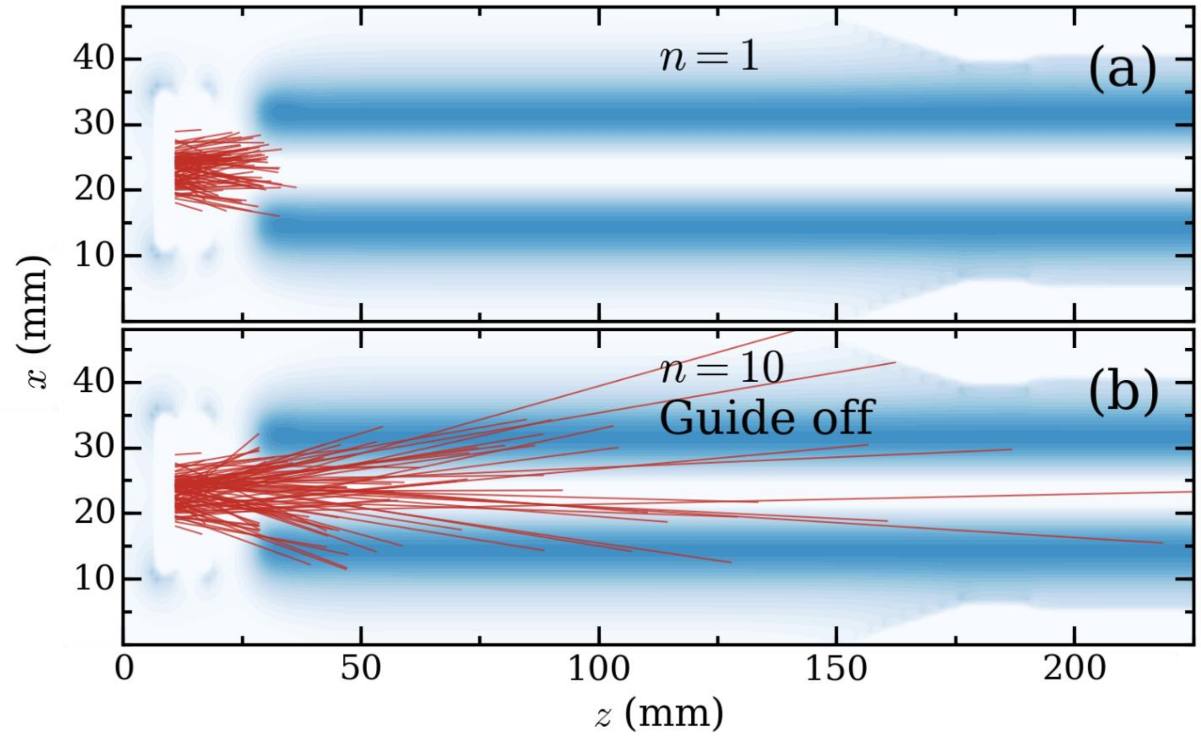

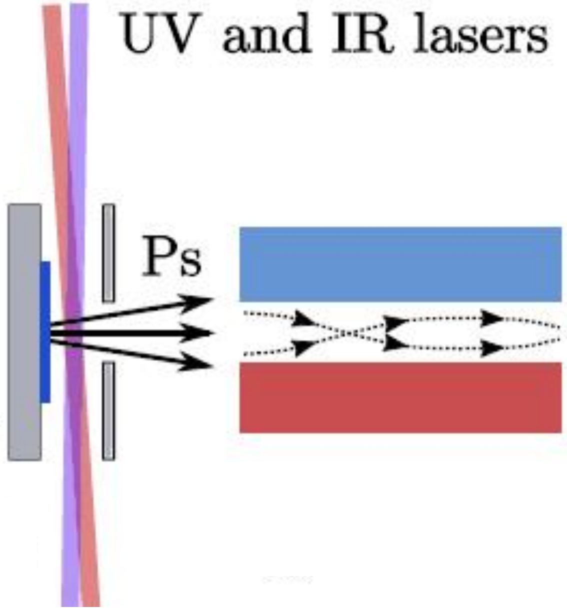

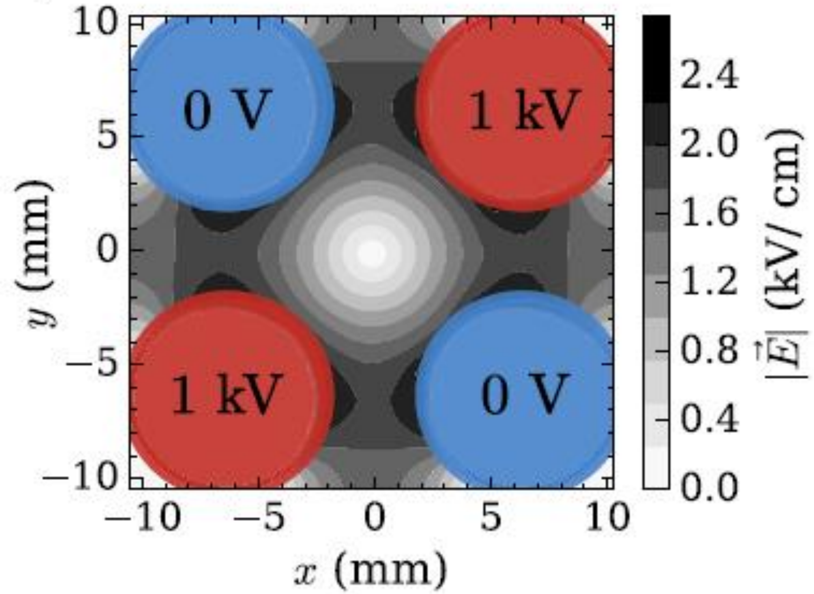

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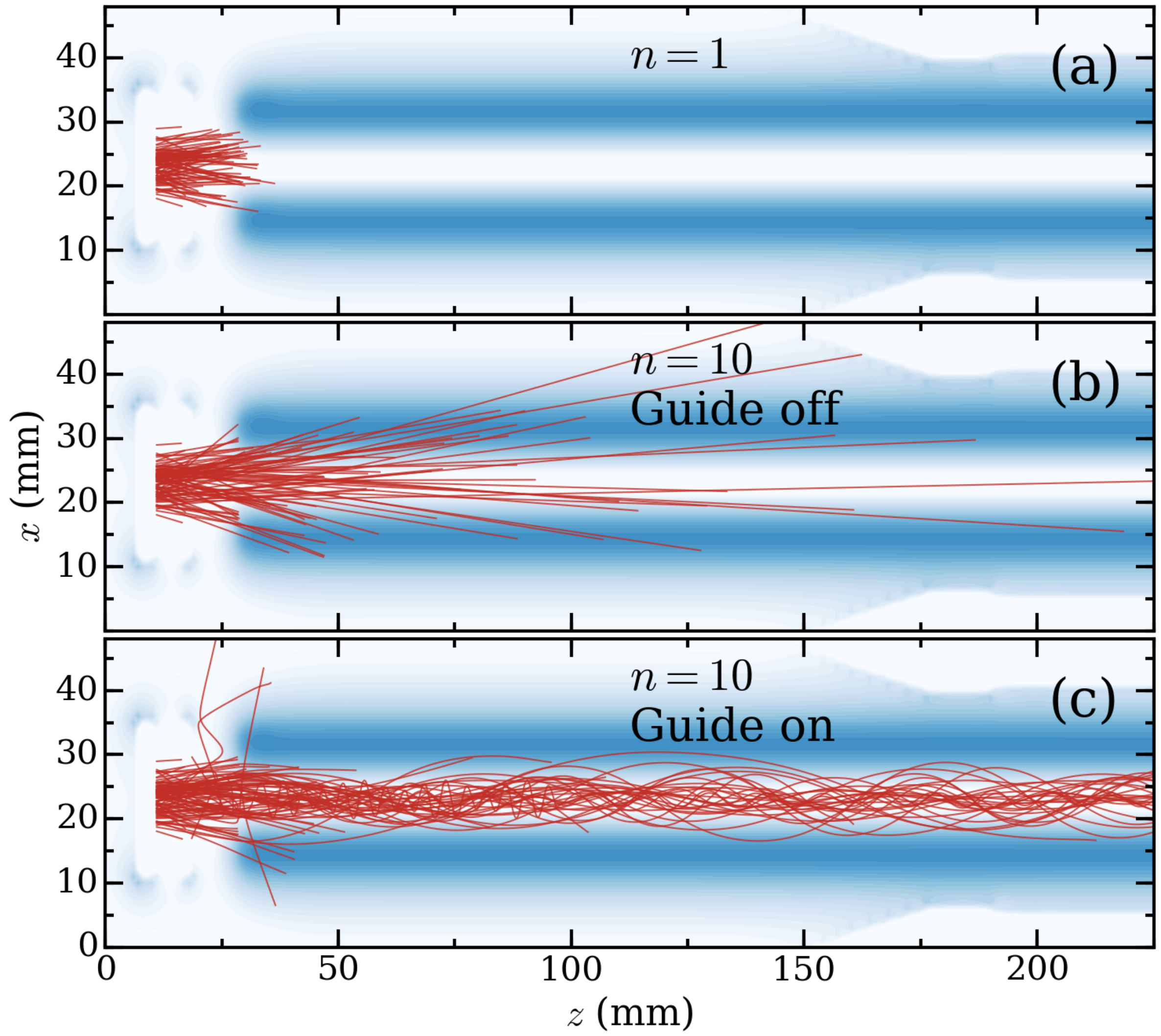
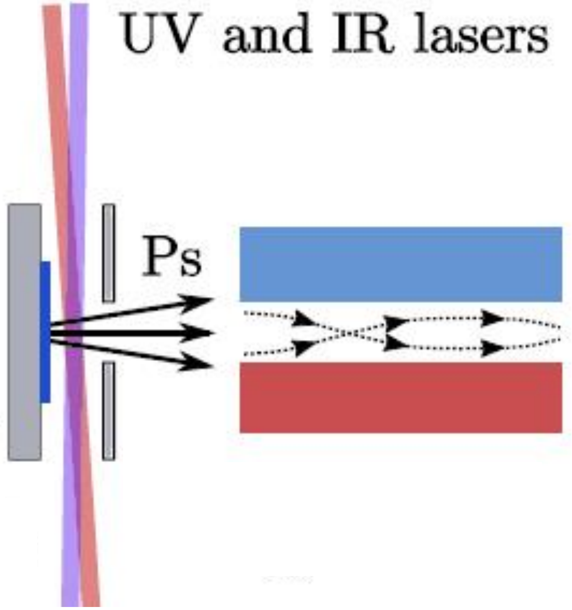
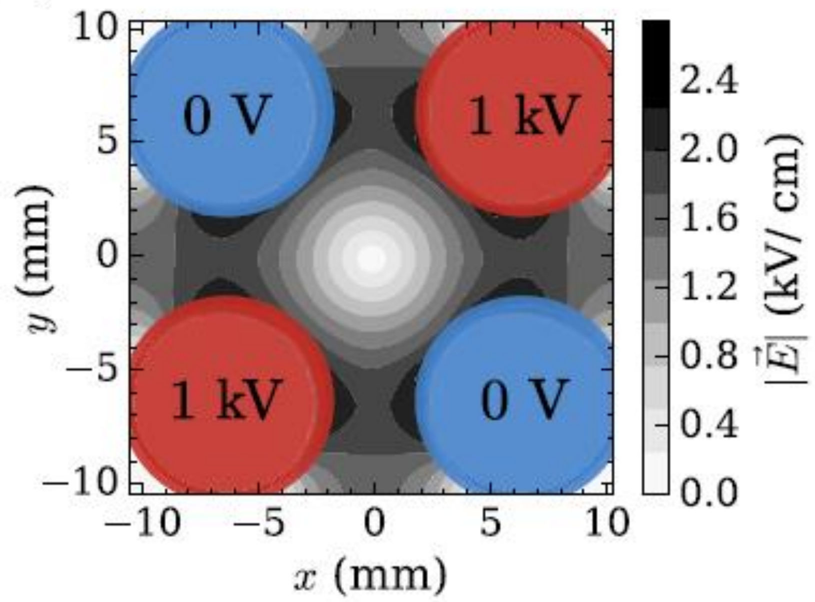
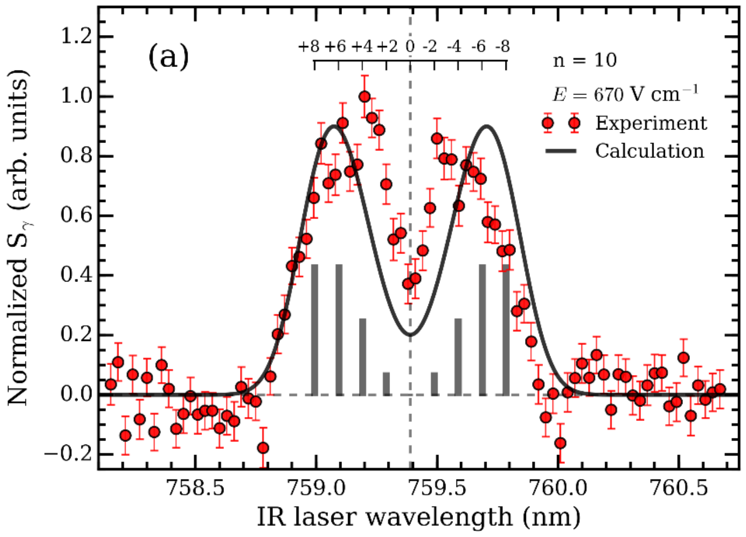
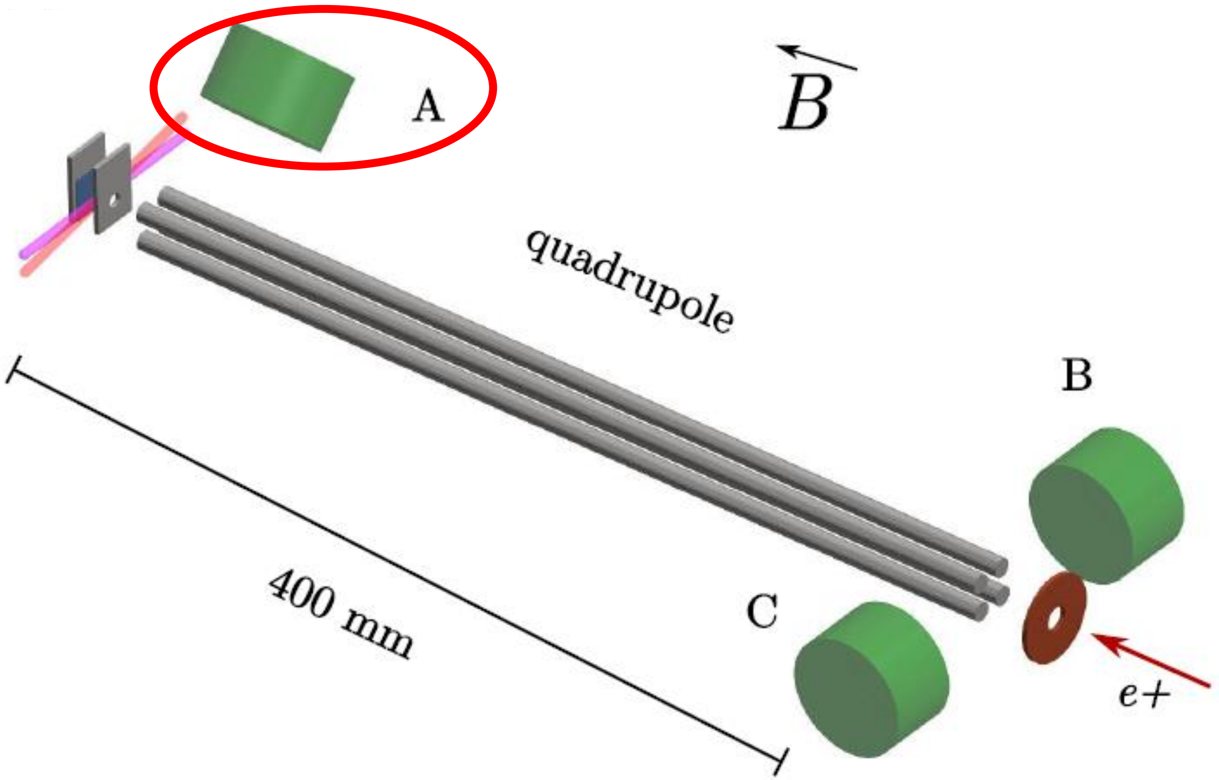






Ps manipulation





A. Deller et al. *Phys. Rev. L*ett. **117** 073202 (2016)

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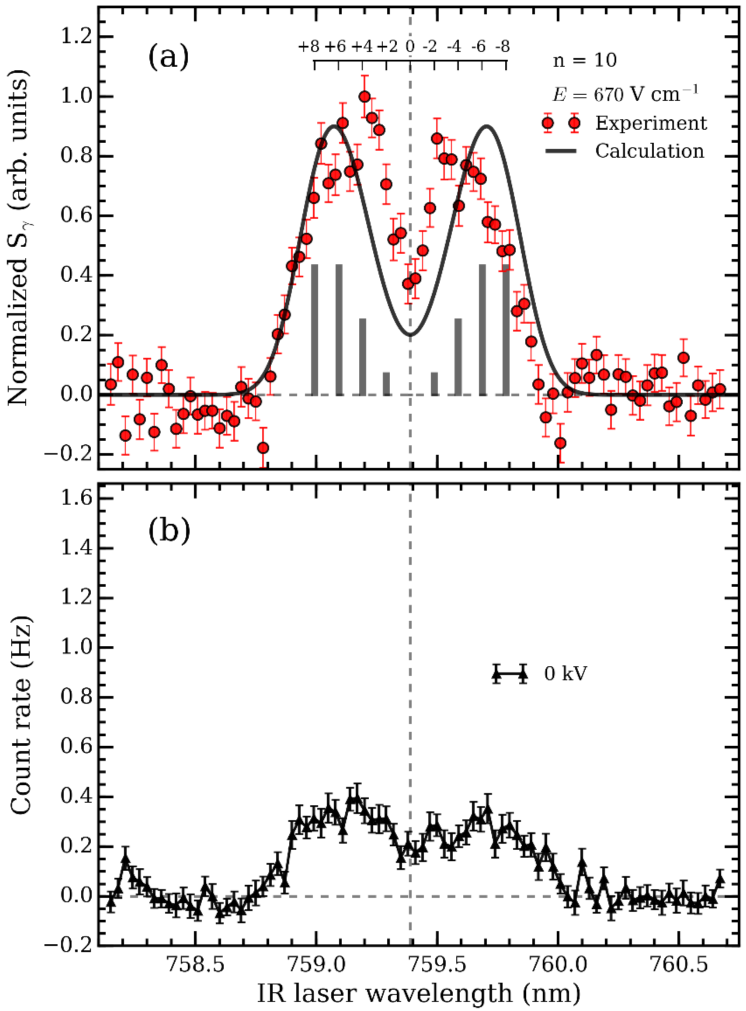

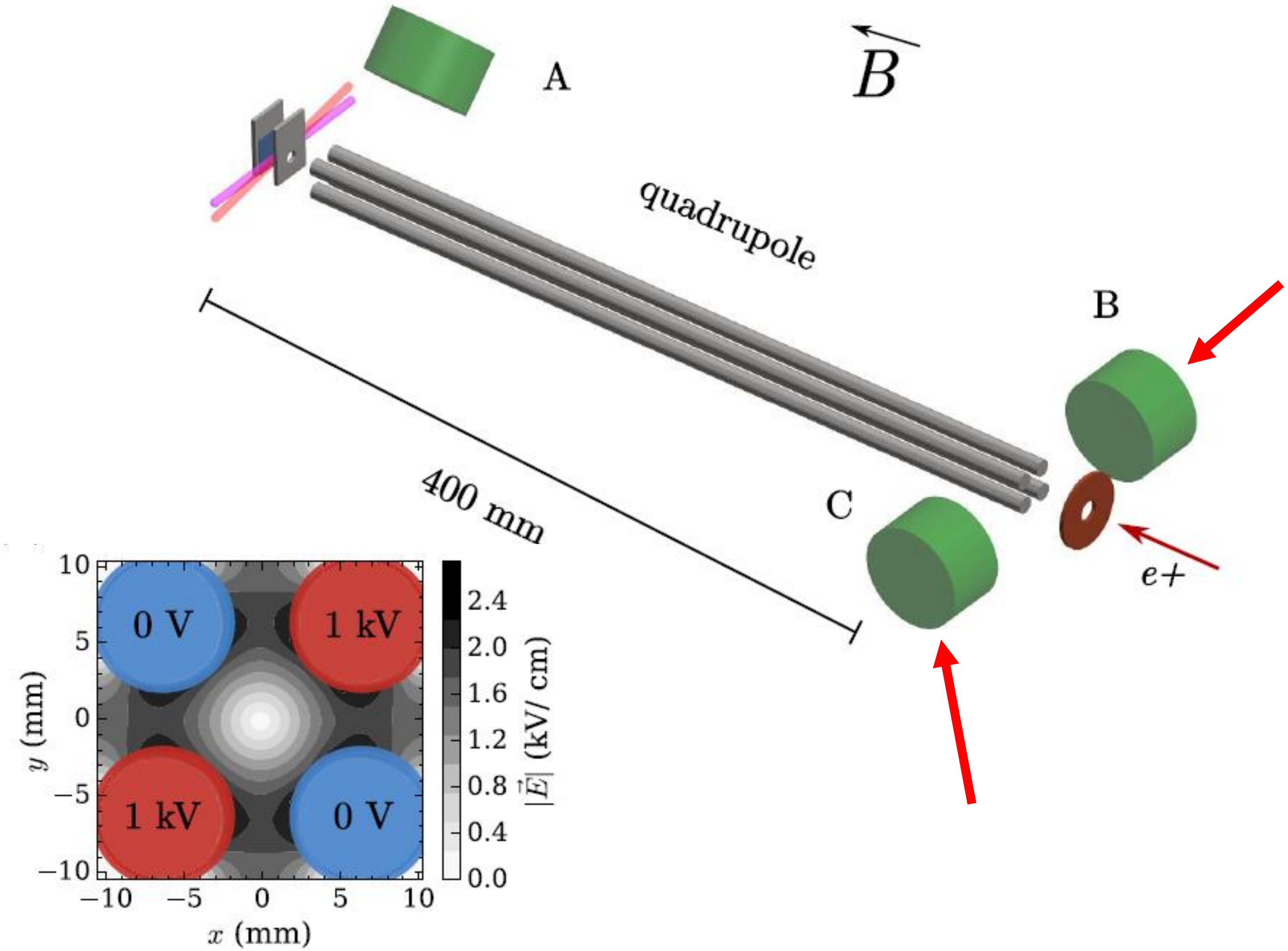

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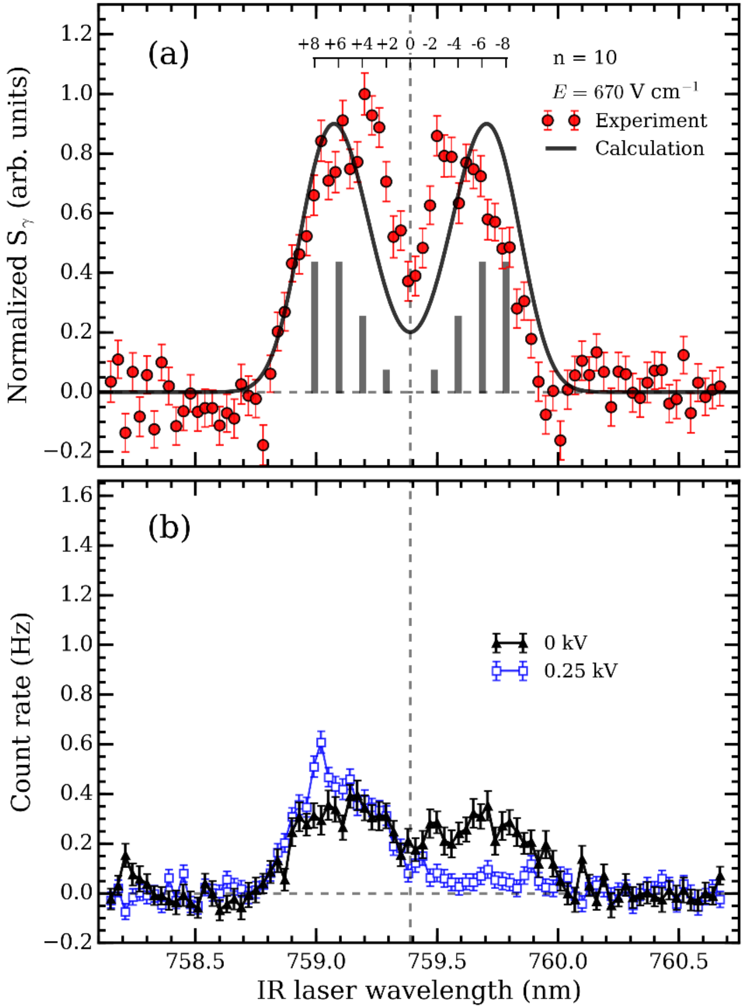

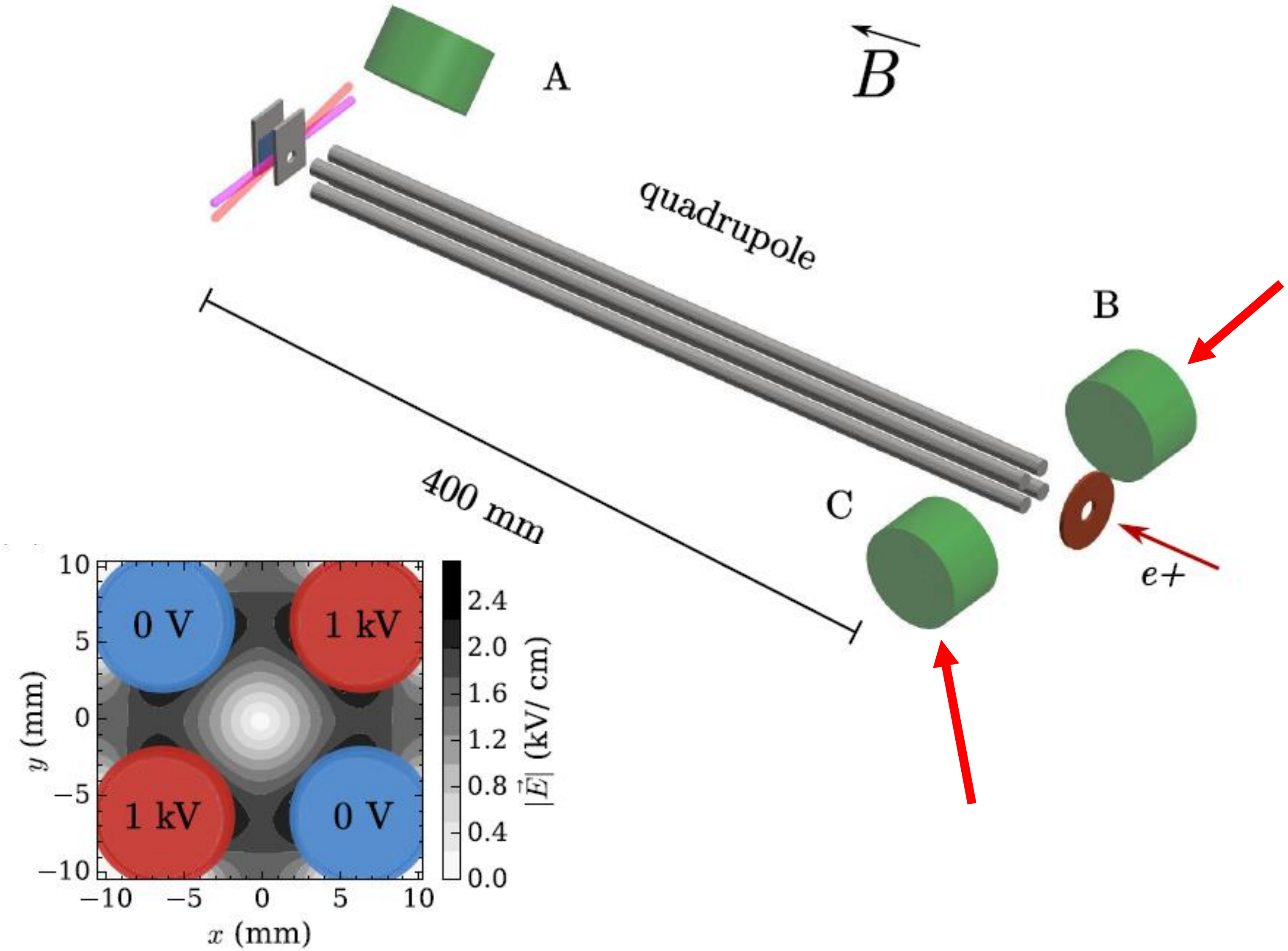

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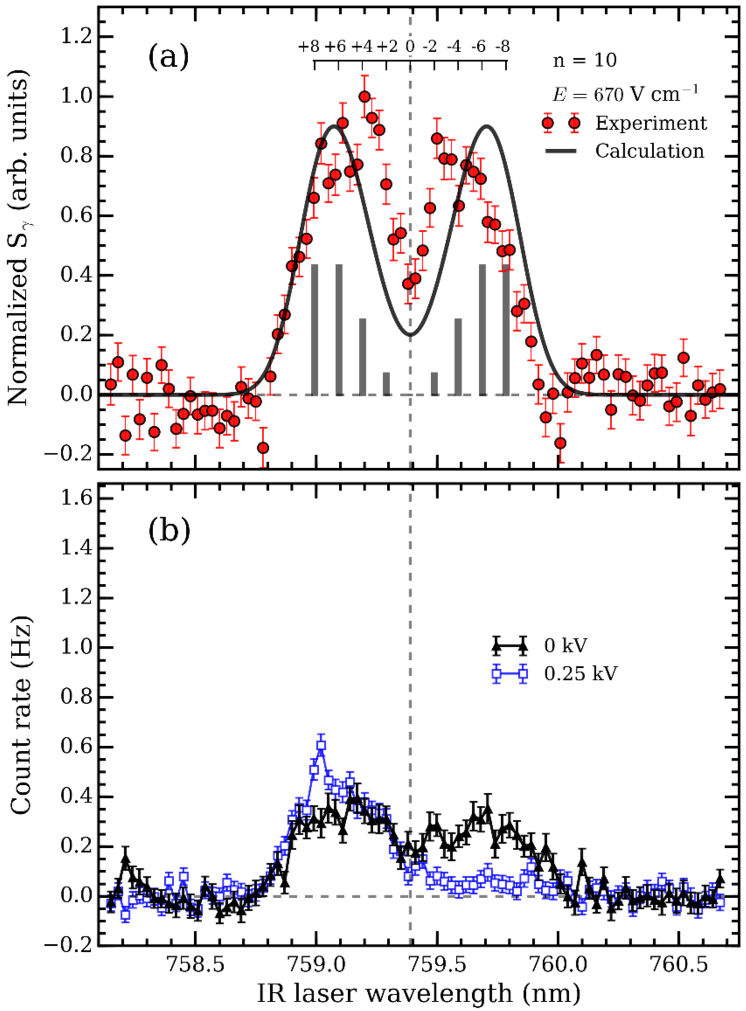

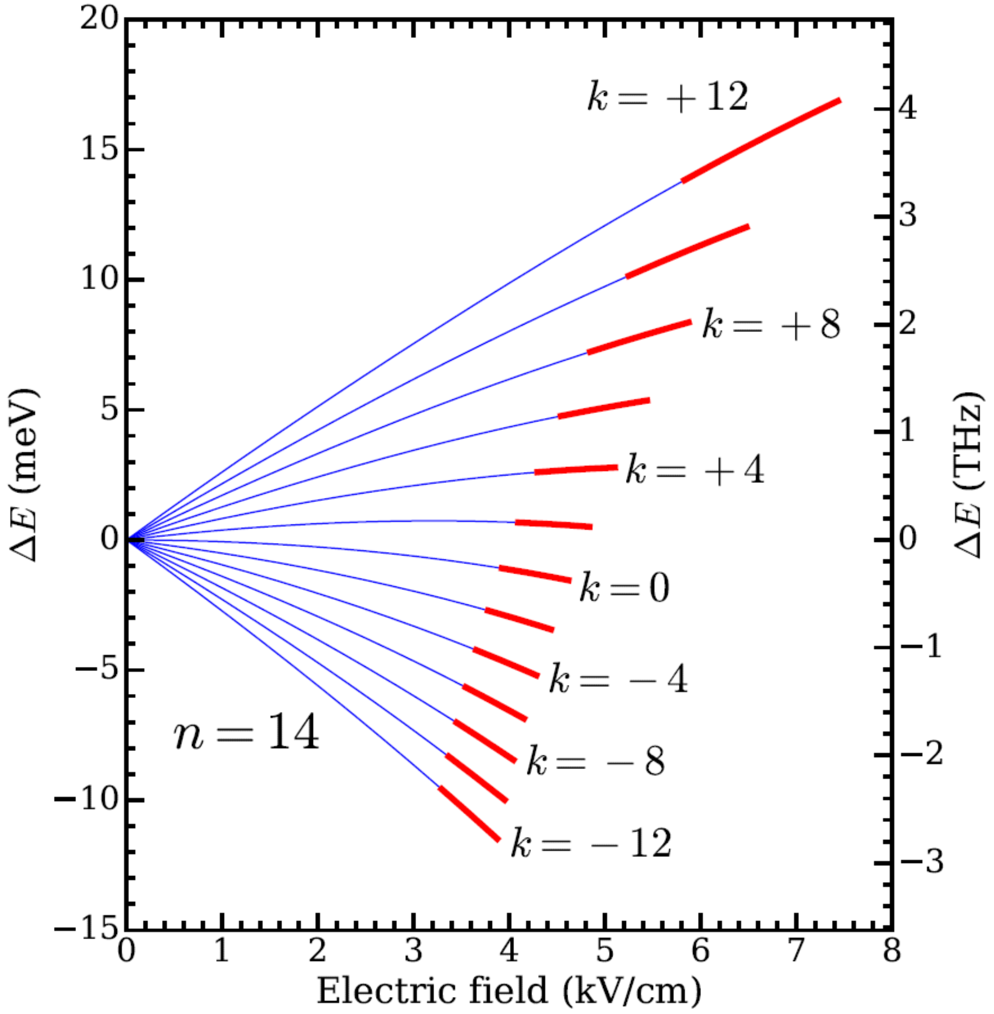

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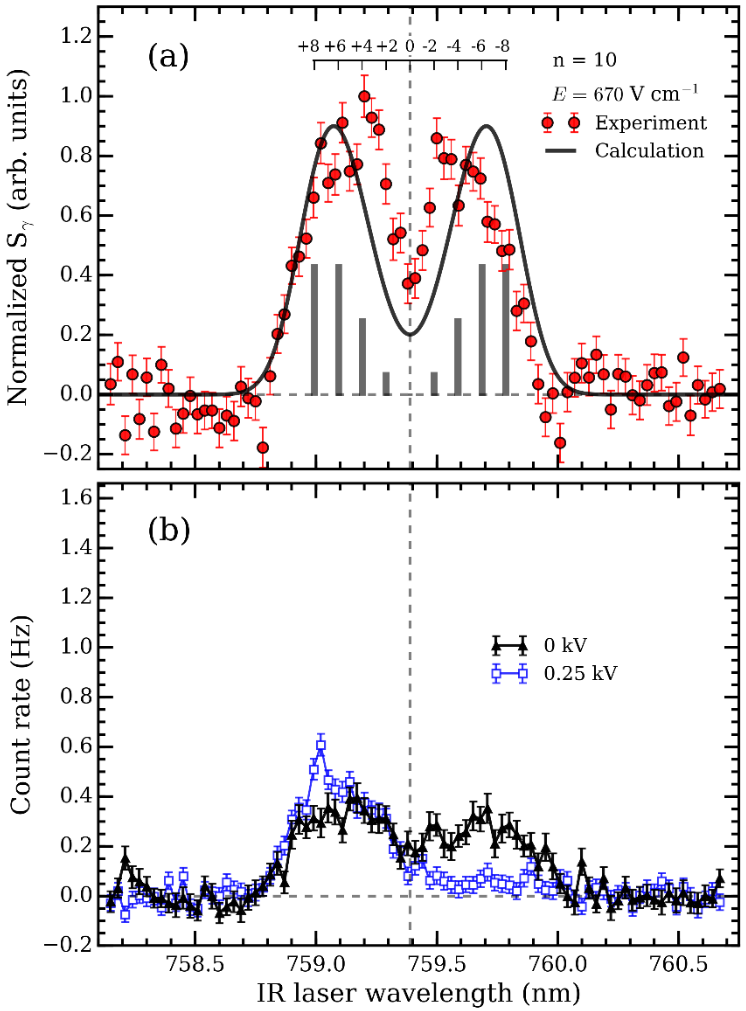

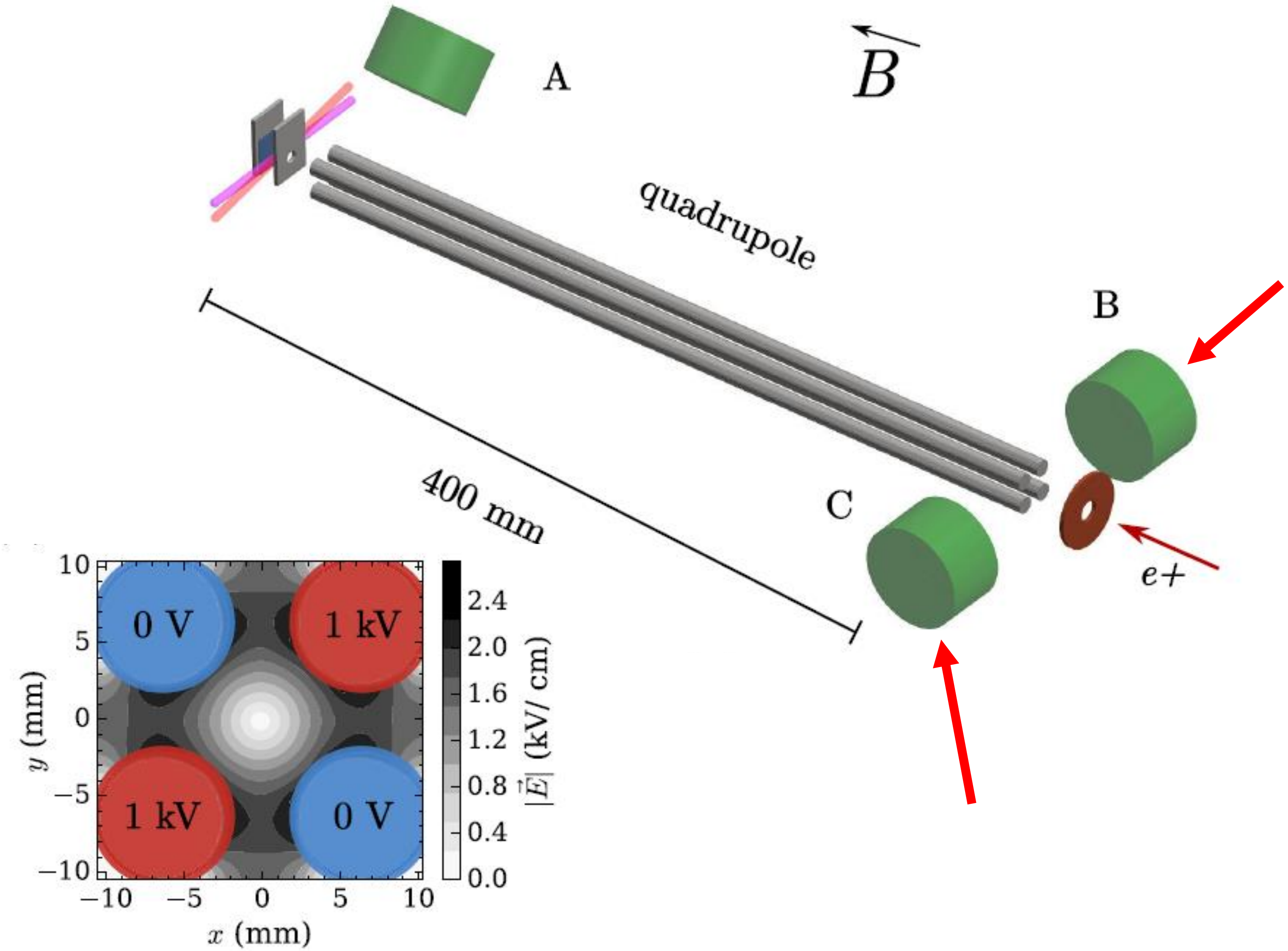

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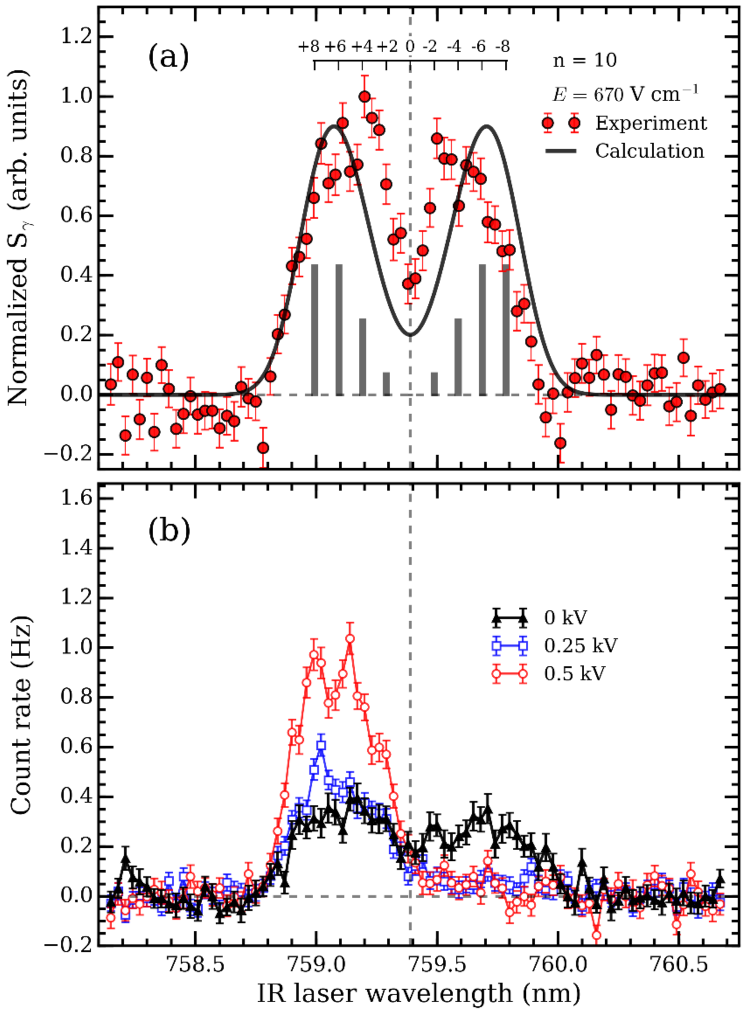

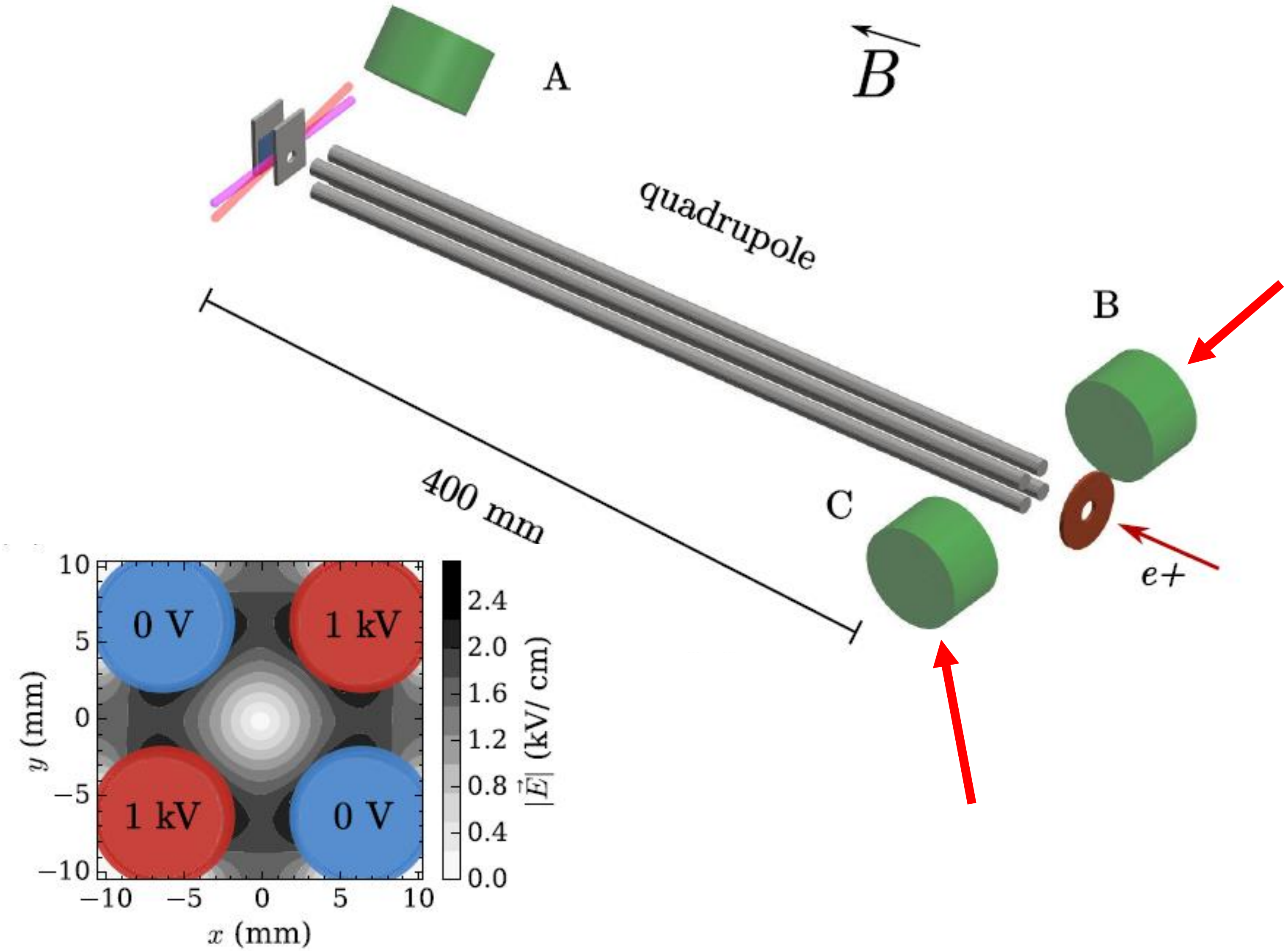

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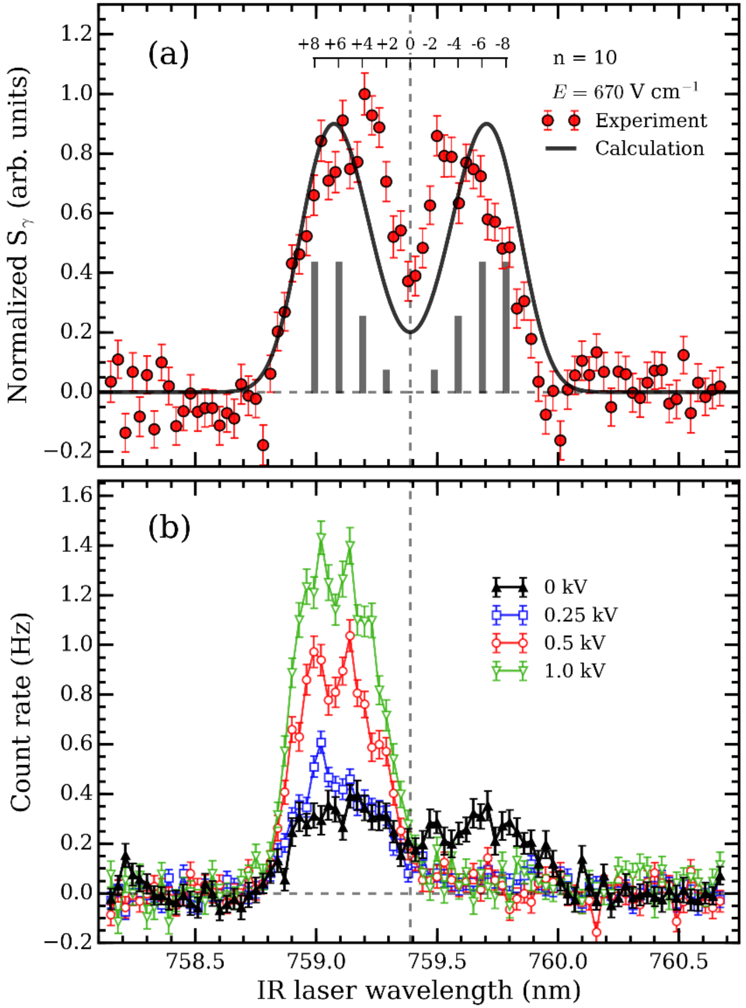

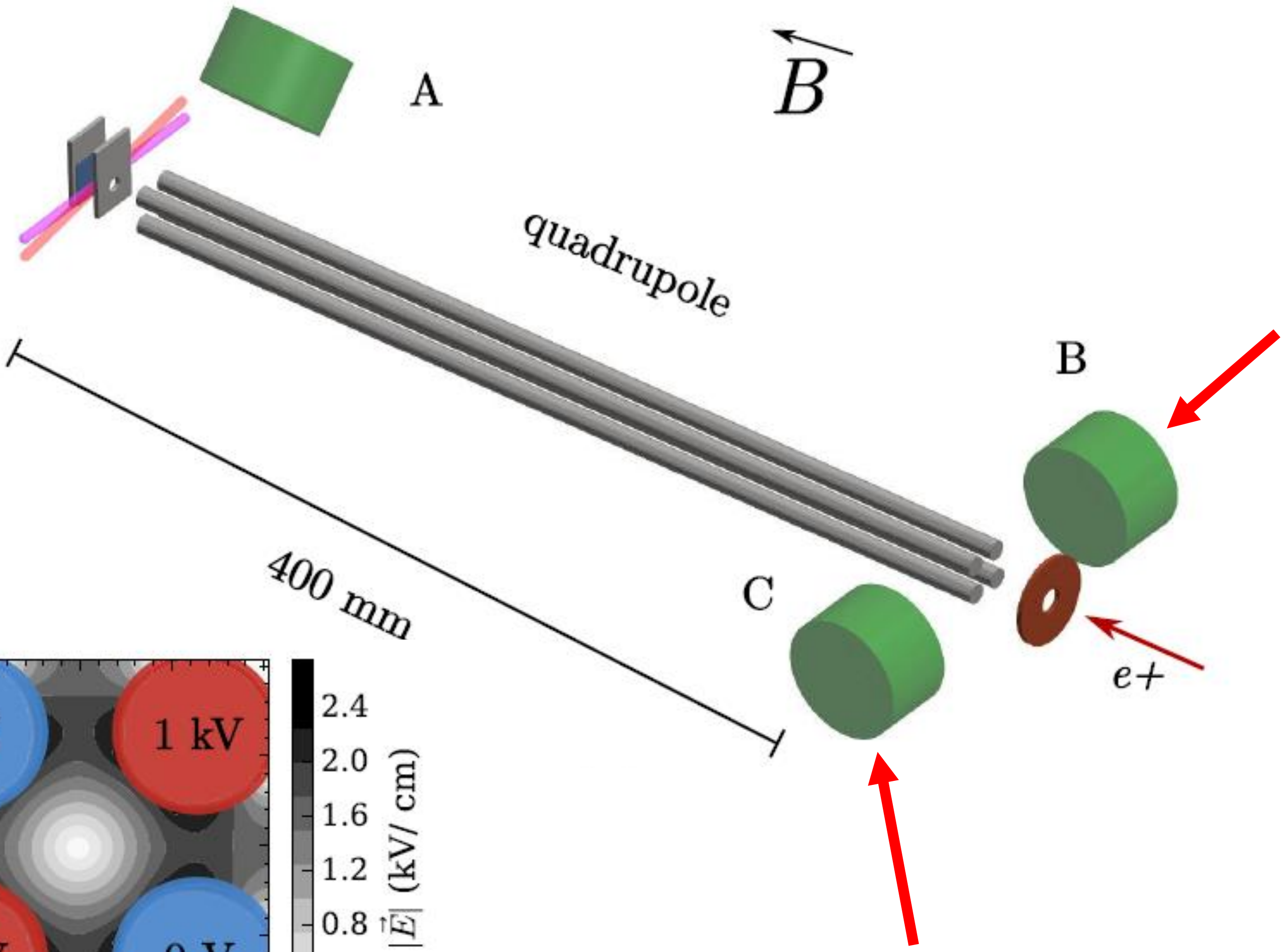

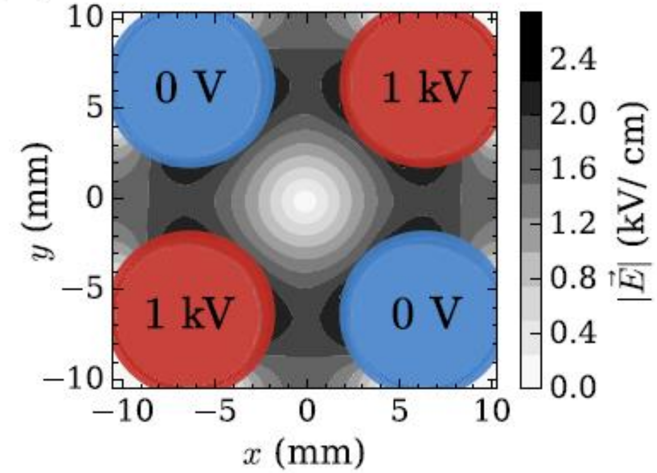

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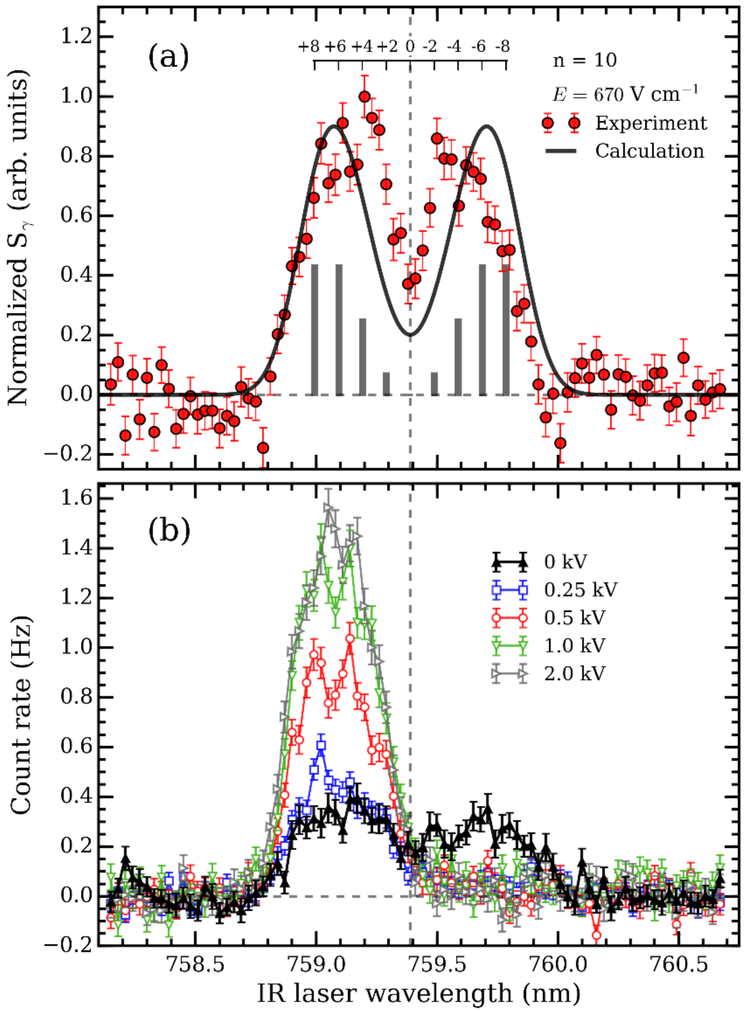

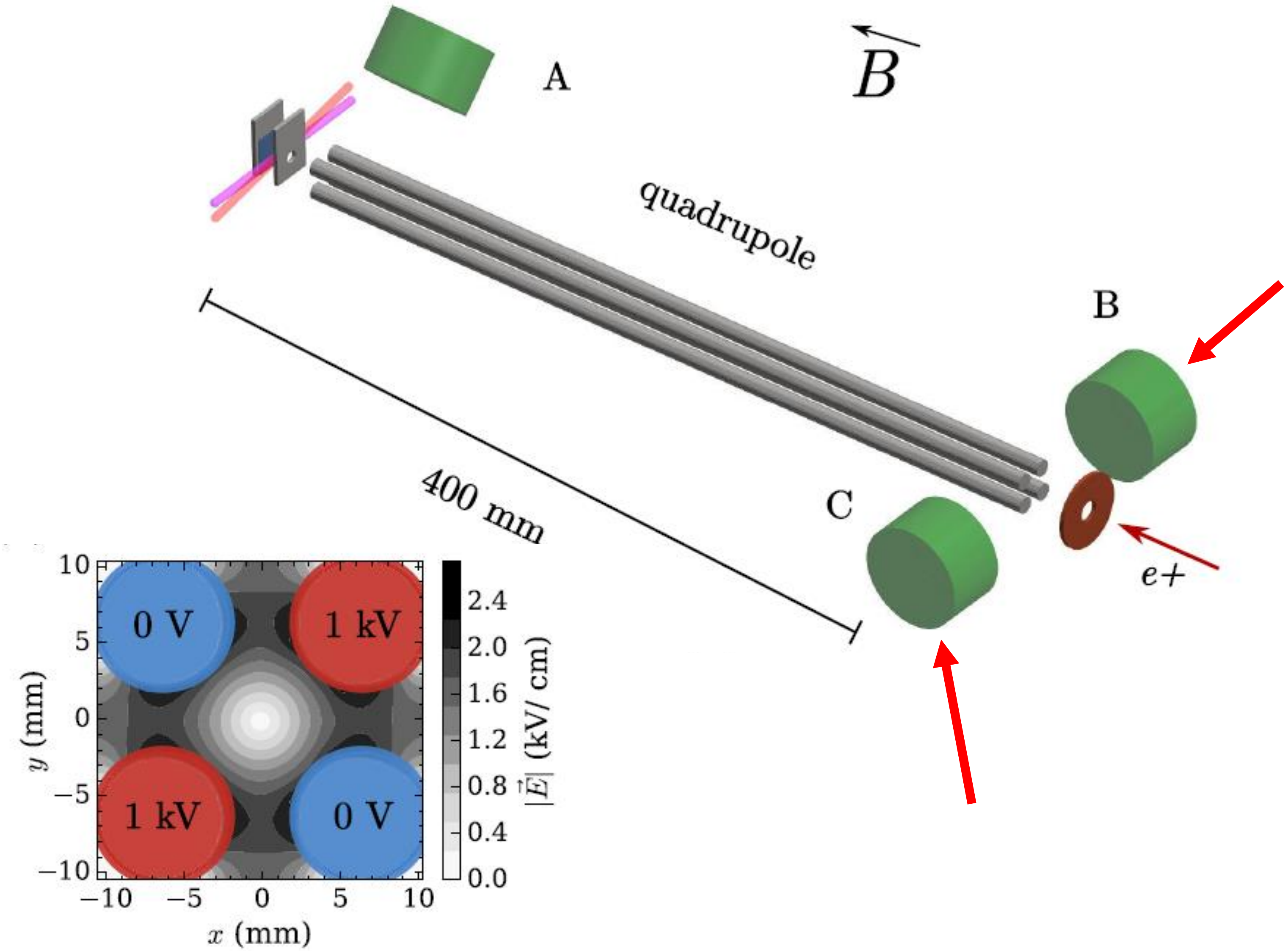

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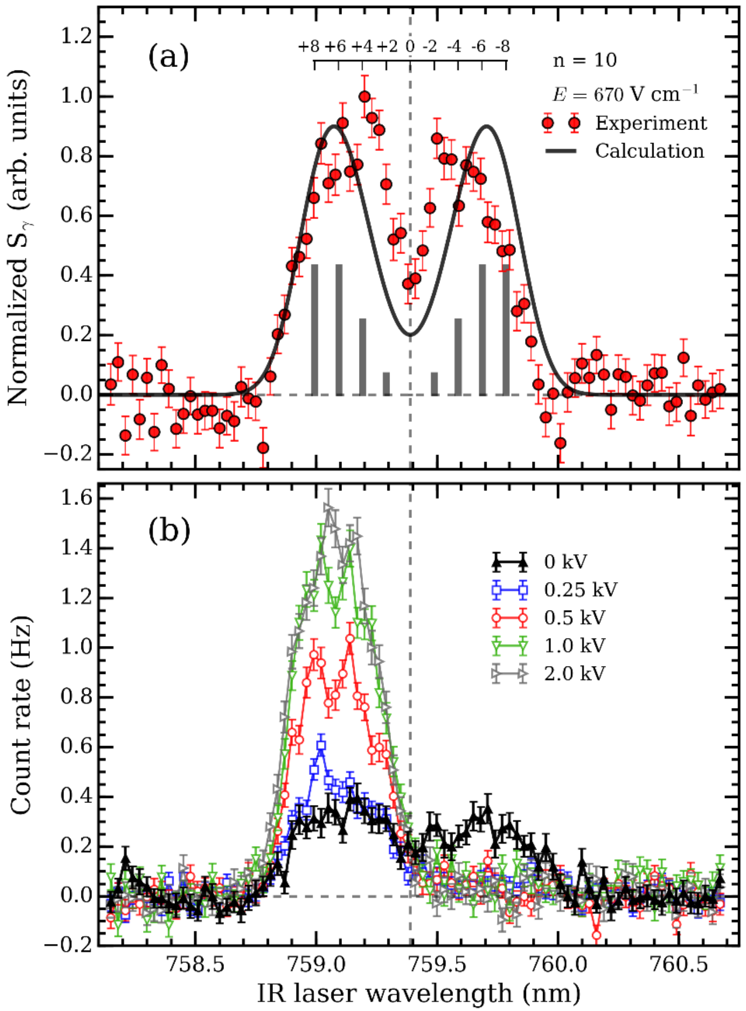
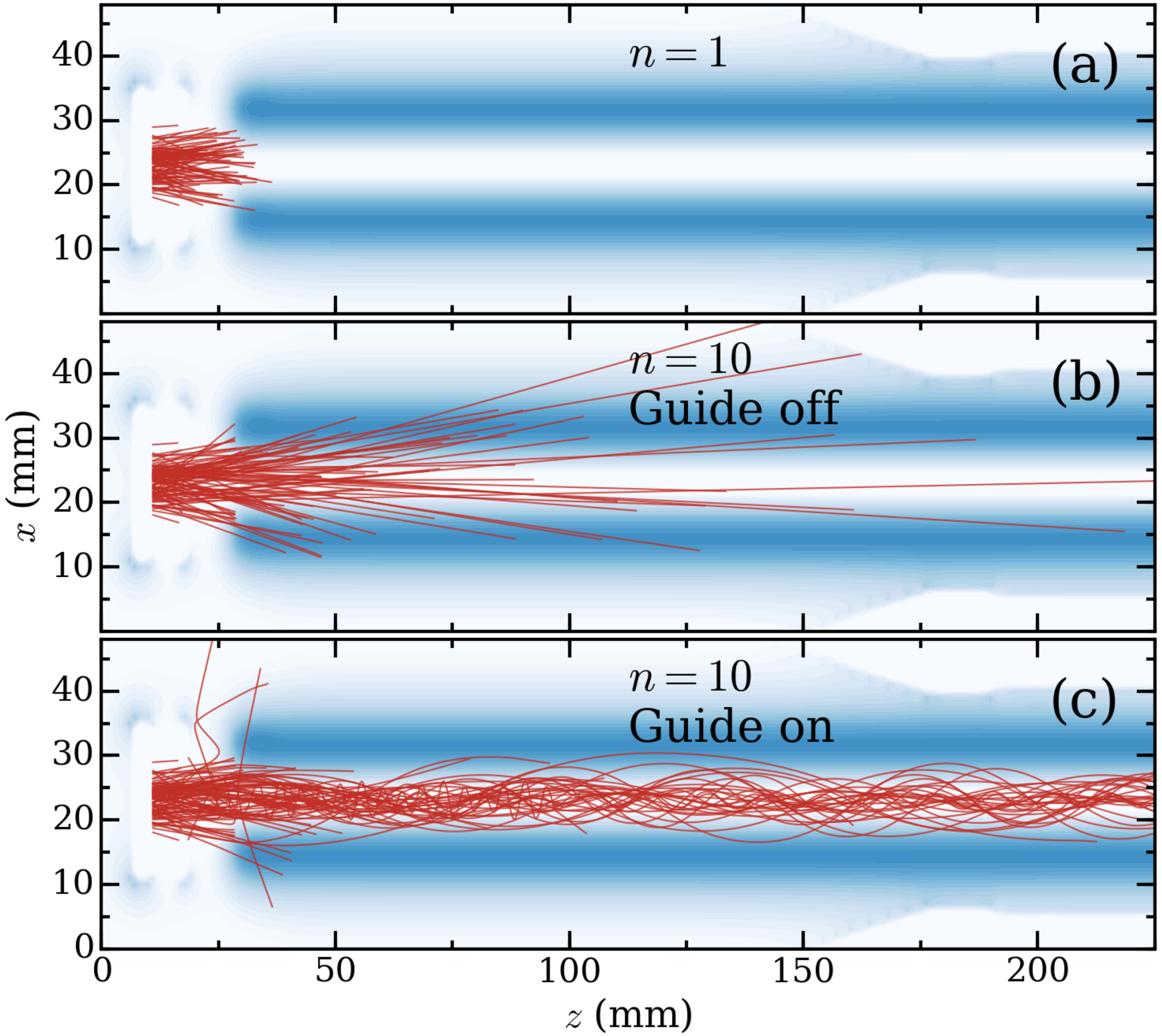
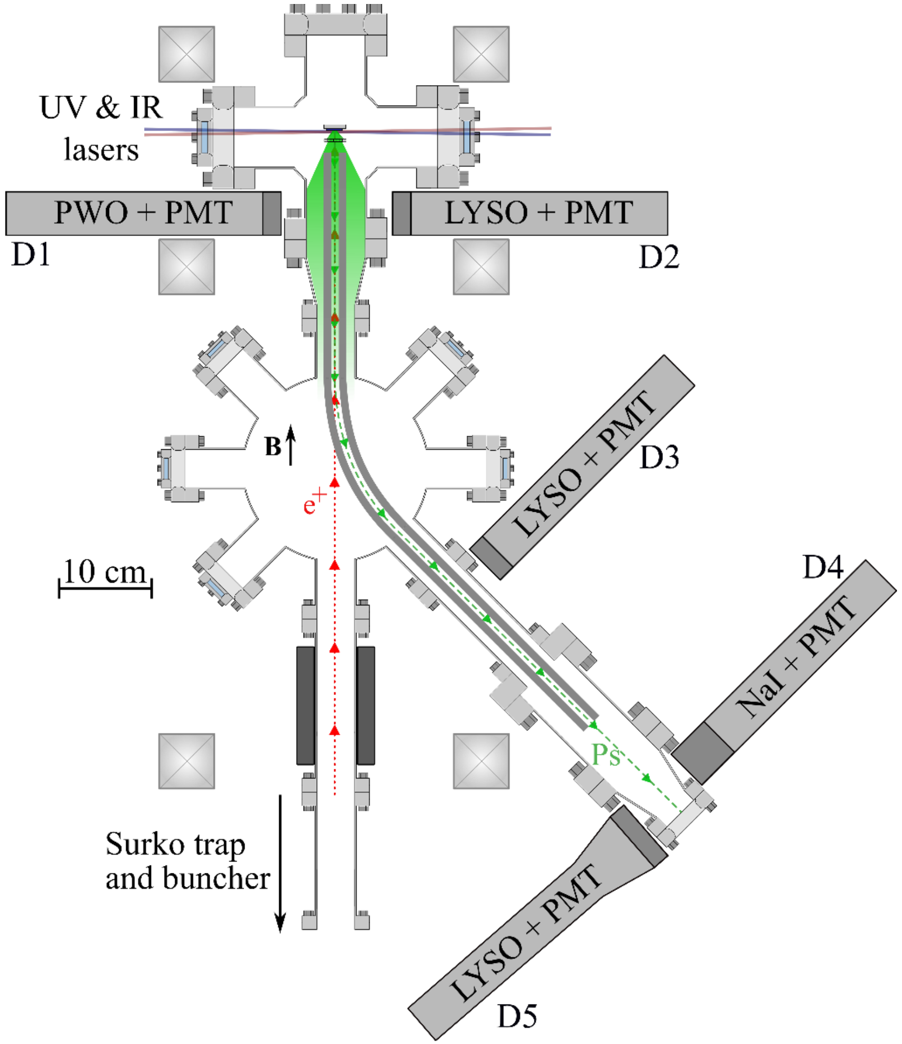


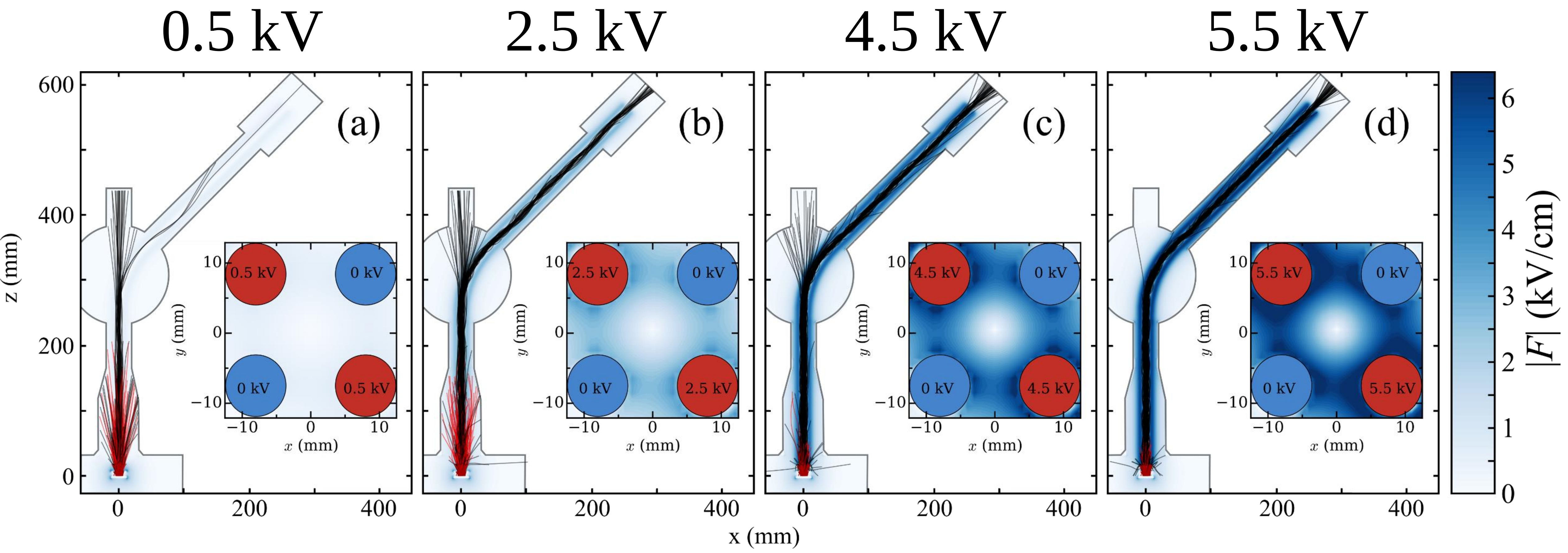


A. Deller et al. *Phys. Rev. L*ett. **117** 073202 (2016)

Curved guide



Curved guide



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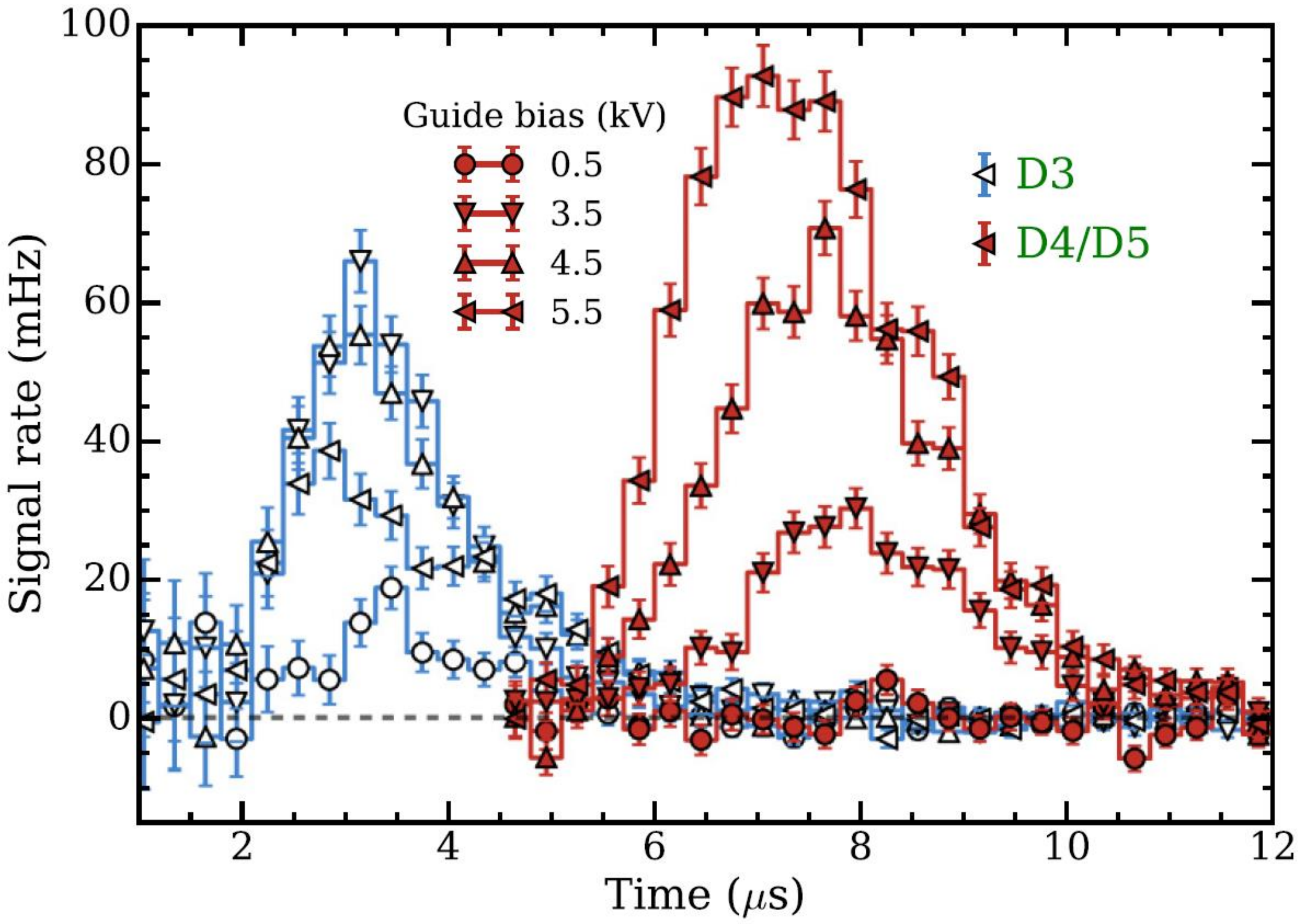
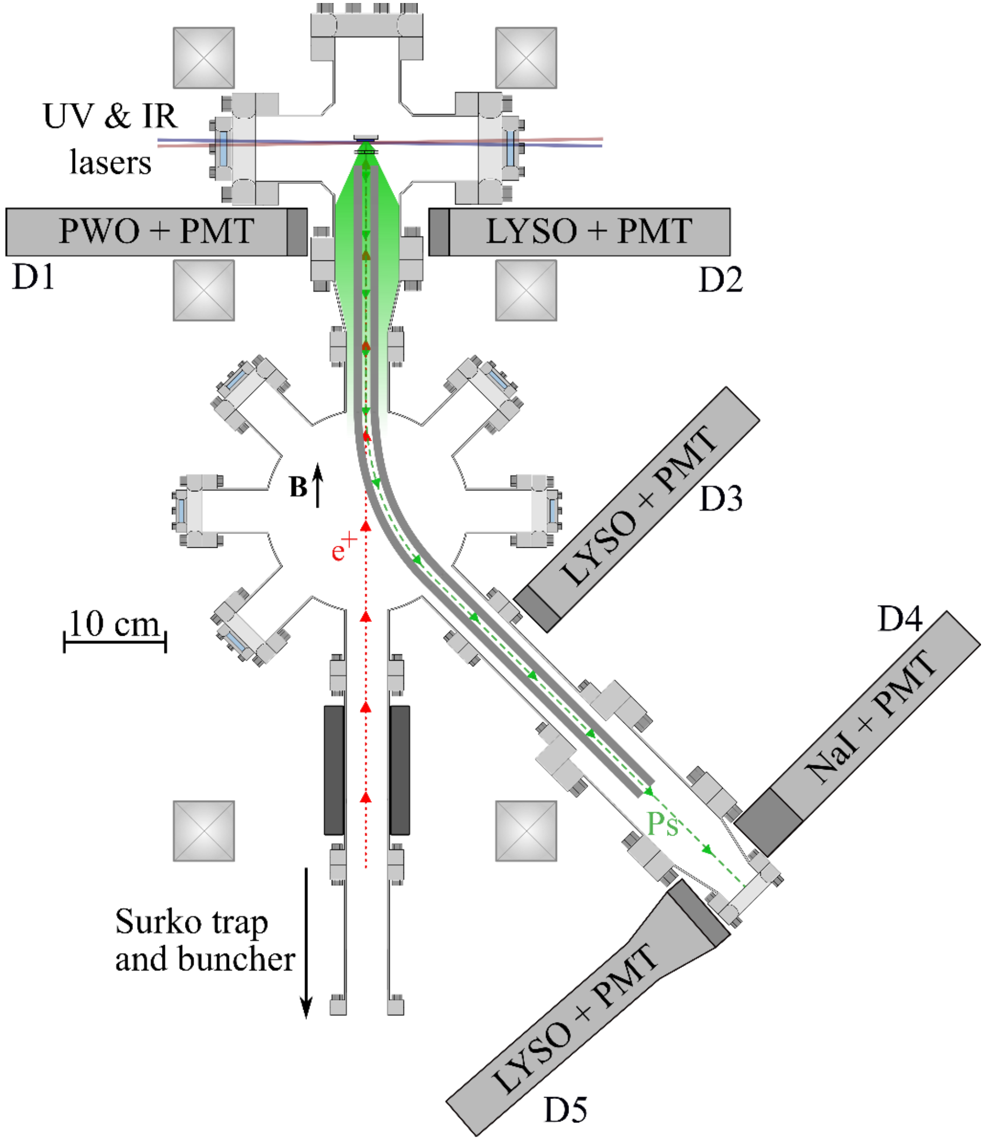
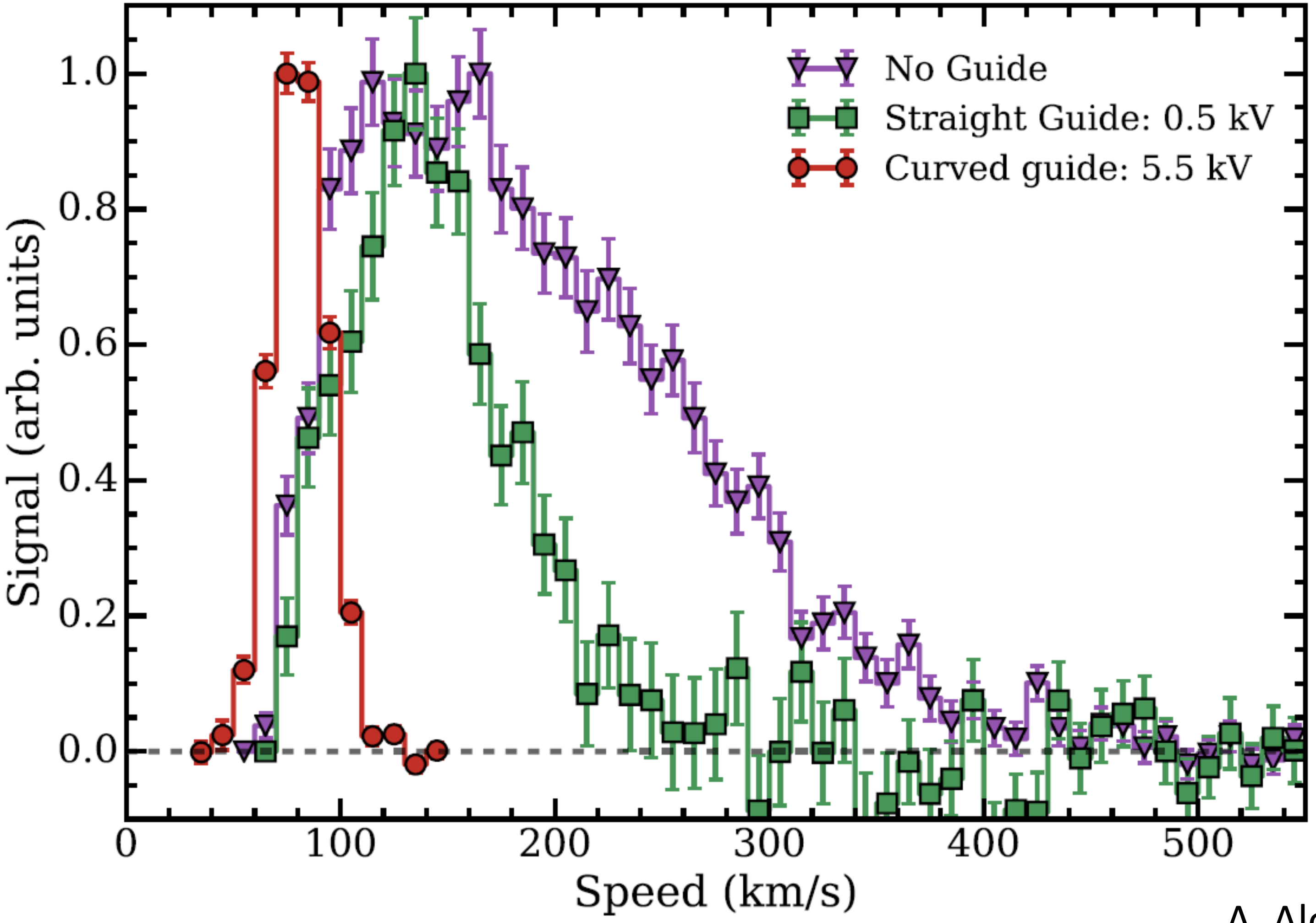




Experimental results



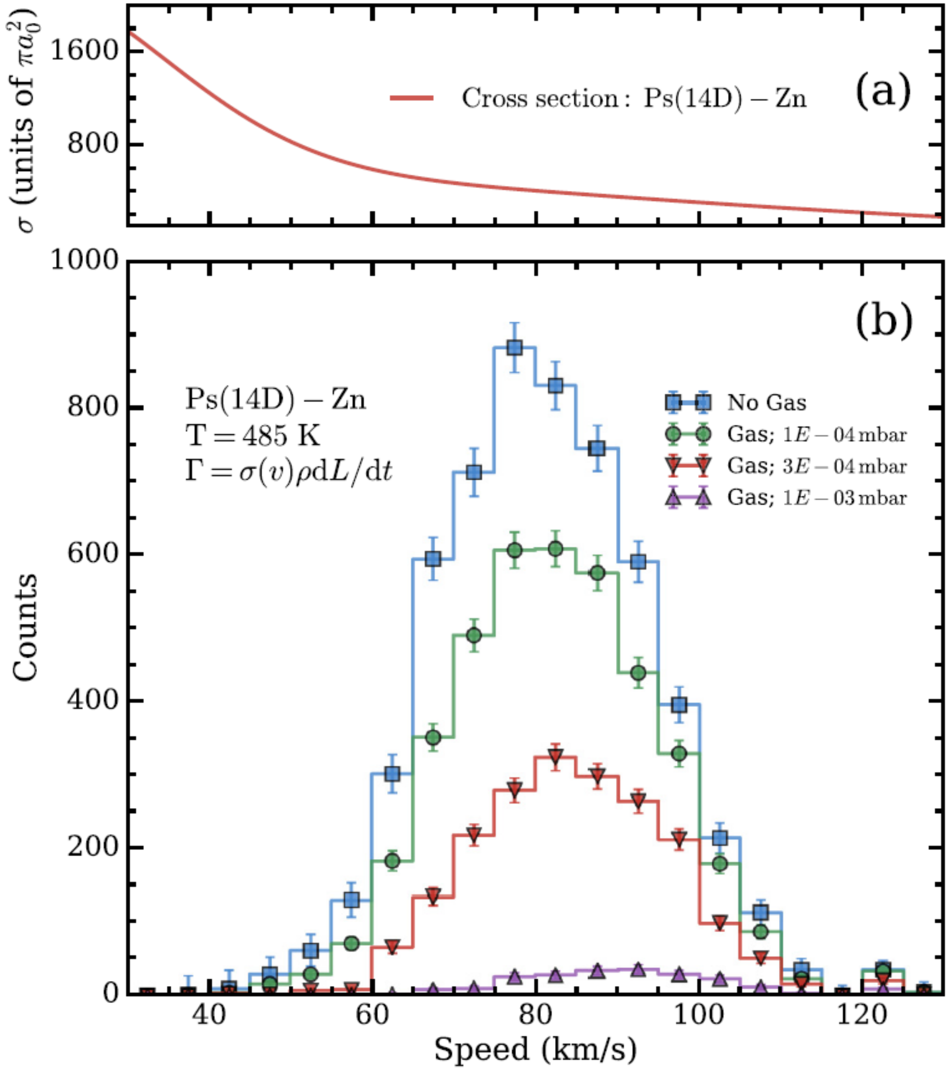
- No guiding has large distribution of speeds (purple)
- Guiding with no curve narrows the distribution slightly (green)
- Curved guiding provides control over velocity selection (red)

A. Alonso et al. *Phys. Rev. A* **95**, 053409 (2017)

Future Work

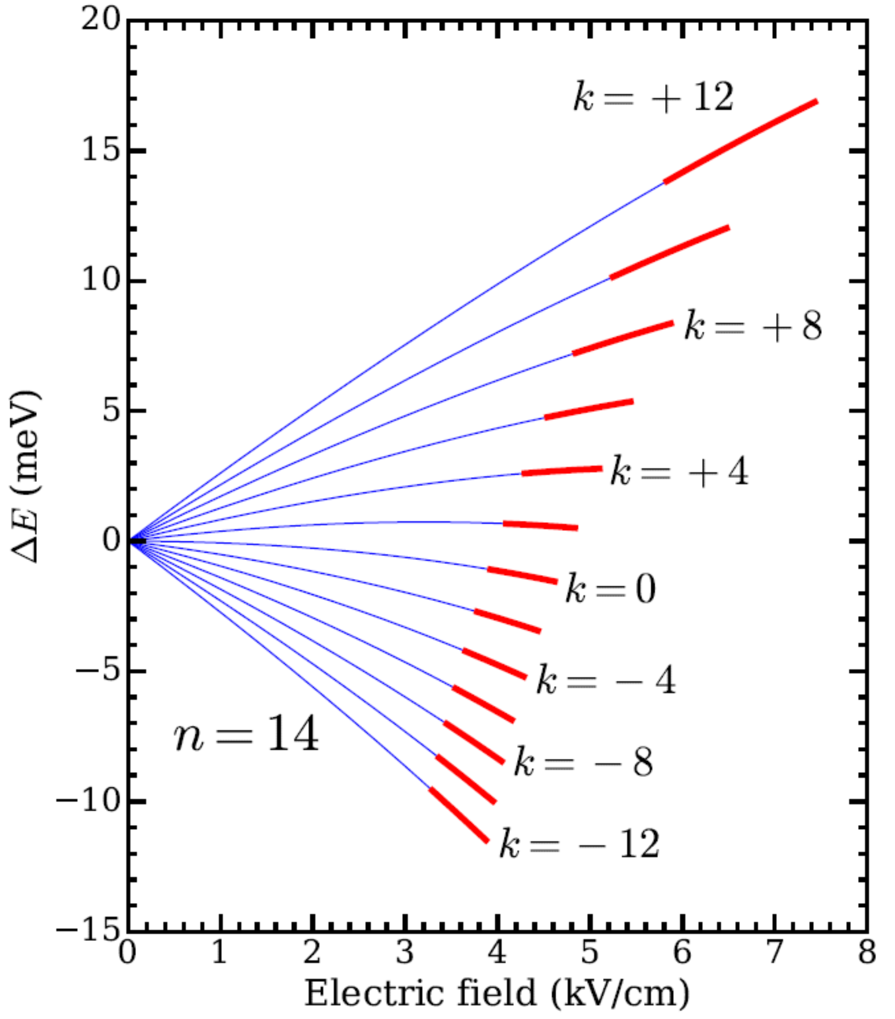
e^+ – atom bound states

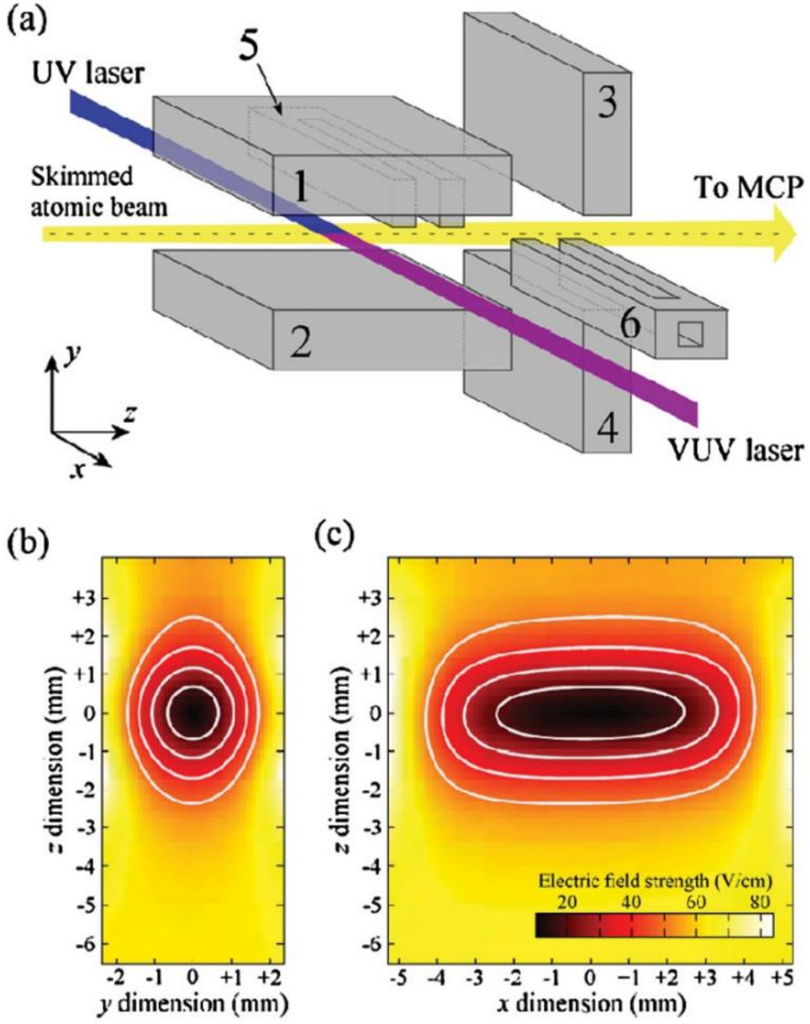
- Rydberg Ps cross sections scale as n^4!
- Monte Carlo simulations using cross sections from A. R. Swann
- Previously unobserved e^+-atom bound states should be possible to measure using Rydberg positronium



A. R. Swann *et al.* *Phys. Rev. A* **93** 052712 (2016)

Positronium Deceleration and trapping





S. D. Hogan and F. Merkt *Phys. Rev. L*ett. **100**, 043001 (2008)

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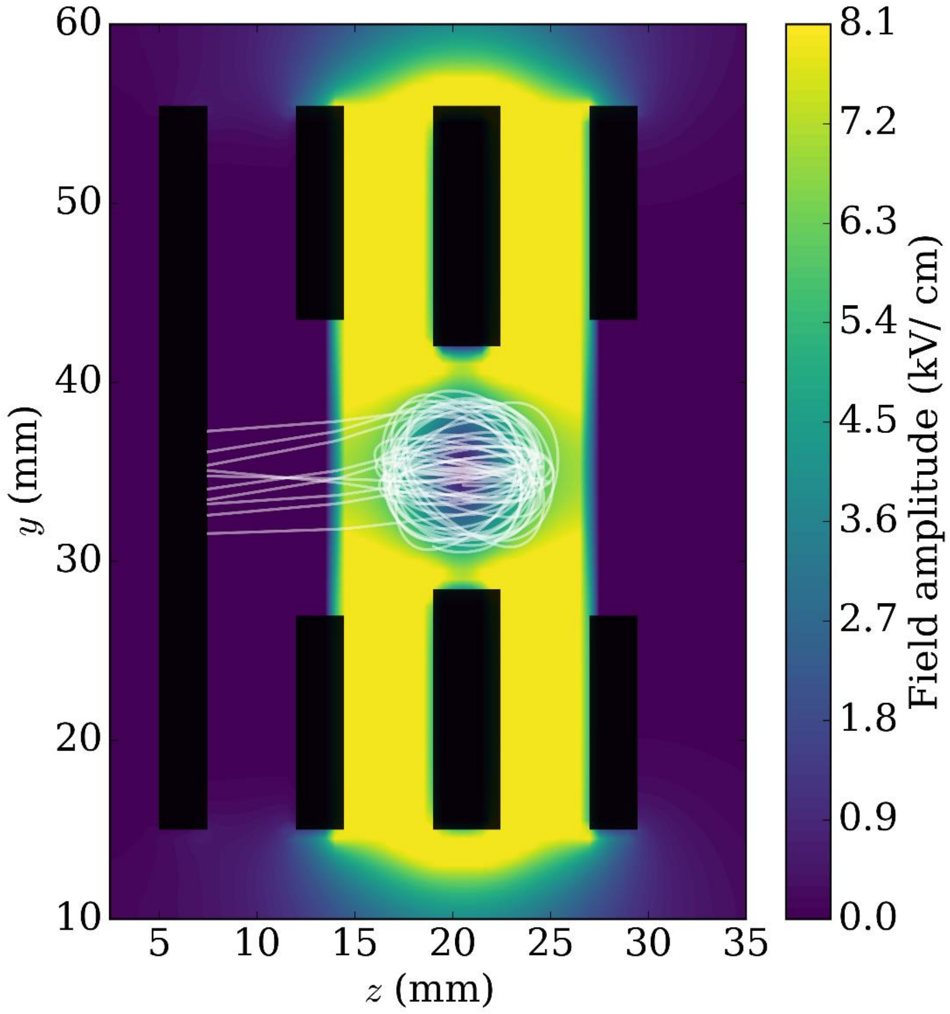
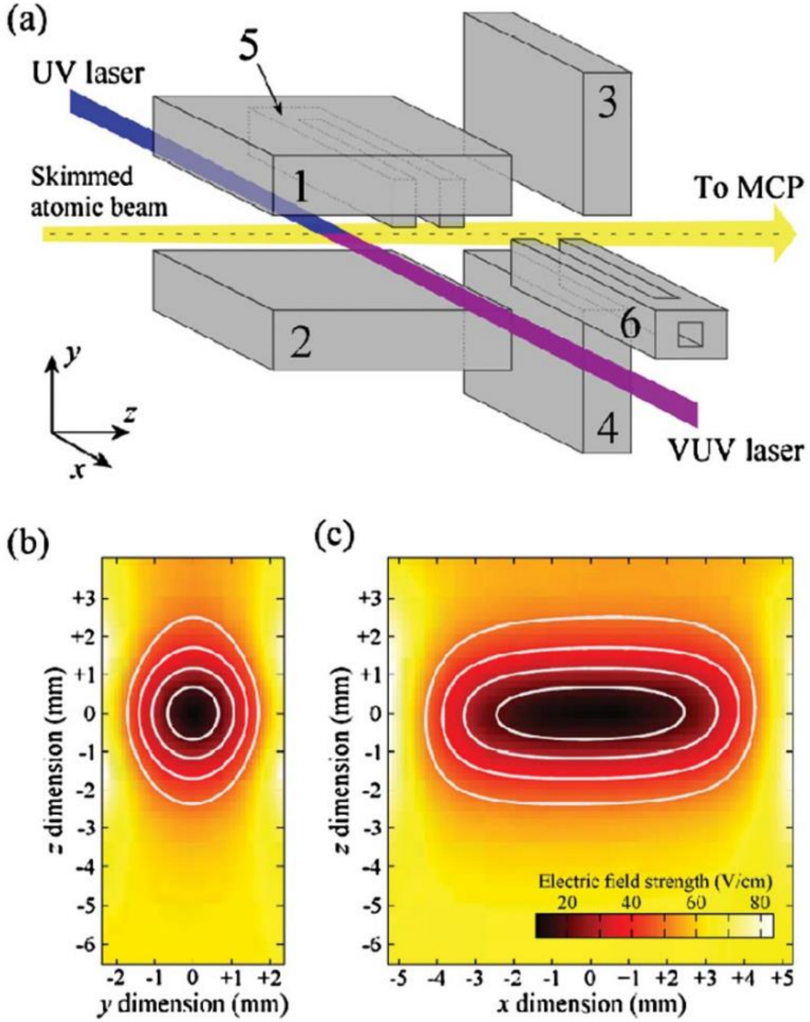




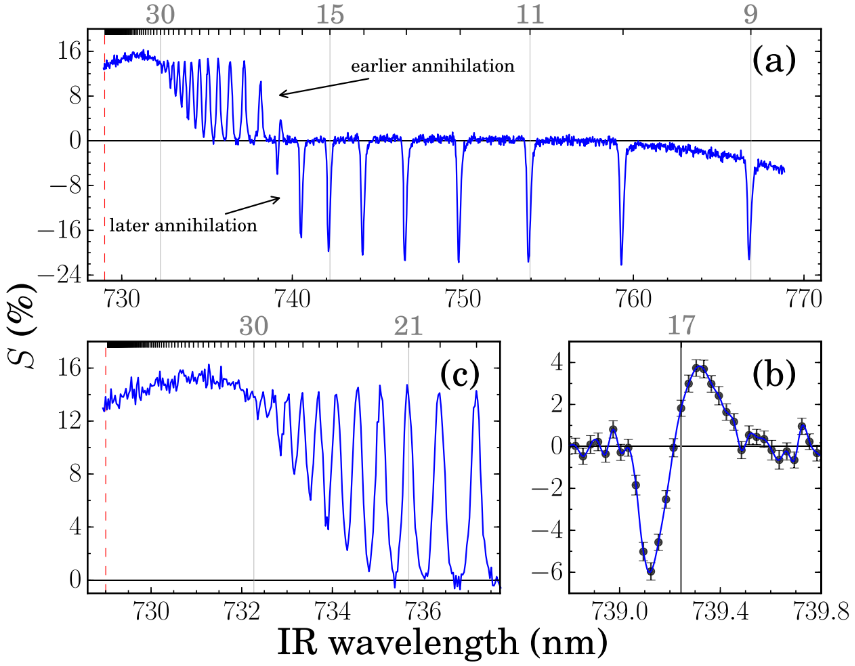
S. D. Hogan and F. Merkt *Phys. Rev. L*ett. **100**, 043001 (2008)

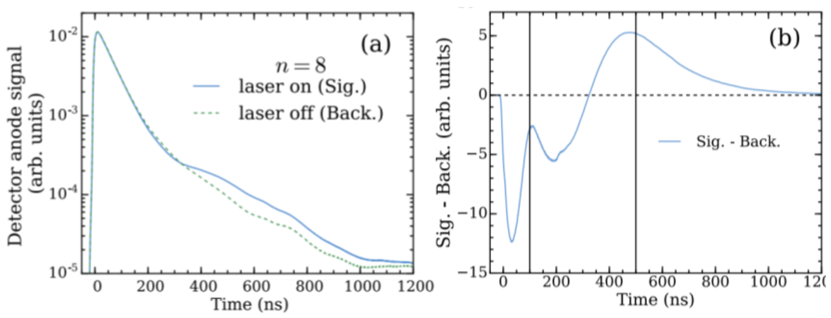
Questions?

A. Alonso

UCL

Rydberg Ps production





Rydberg Ps guiding and long lifetimes