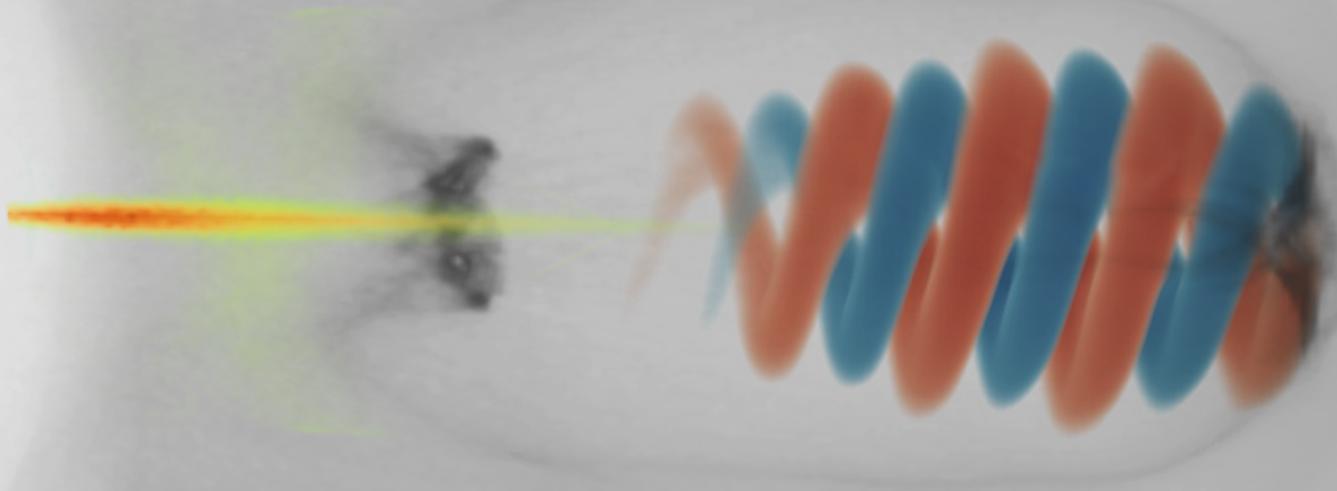




PLASMA INJECTORS FOR POLARIZED BEAM SOURCES

An overview of the state-of-the-art for polarized electrons

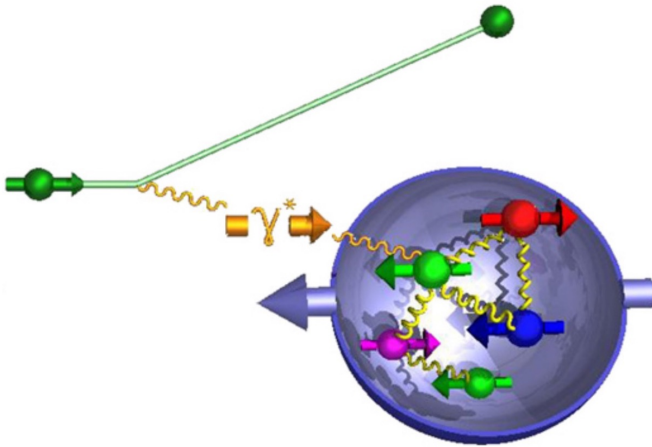
15.09.26 | LARS REICHWEIN, ALEXANDER PUKHOV & MARKUS BÜSCHER

CONTENT

- ▶ **Why polarized beams?**
- ▶ **State-of-the-art for plasma-based polarized beams**
- ▶ **Hydrogen halides as sources of polarized electrons**
- ▶ **Pinching injection**
- ▶ **State-selected plasma photocathode**

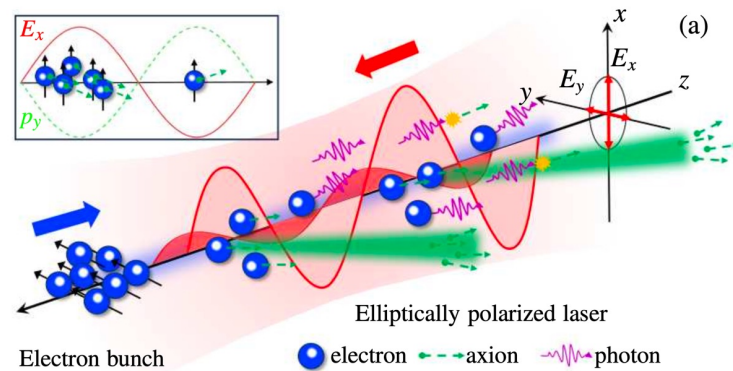
WHY POLARIZED BEAMS?

Deep-inelastic scattering



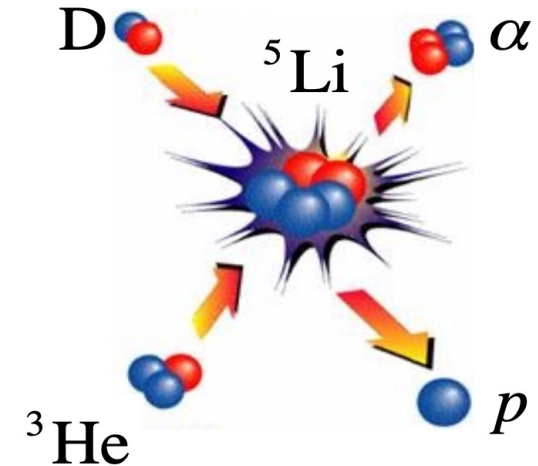
M Burkardt, *ROPP* **73**, 016201 (2010)

The search for axions



JD Chen, *PRD* **114**, L011906 (2026)

Nuclear fusion



RM Kulsrud, *PRL* **49**, 1248 (1982)

PLASMA-BASED POLARIZED BEAMS

The current state-of-the-art

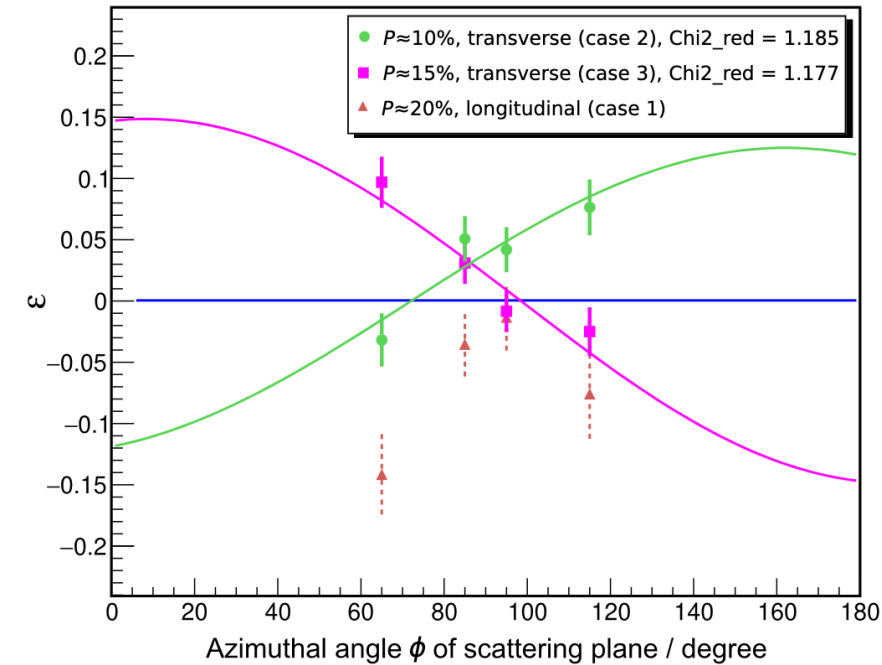
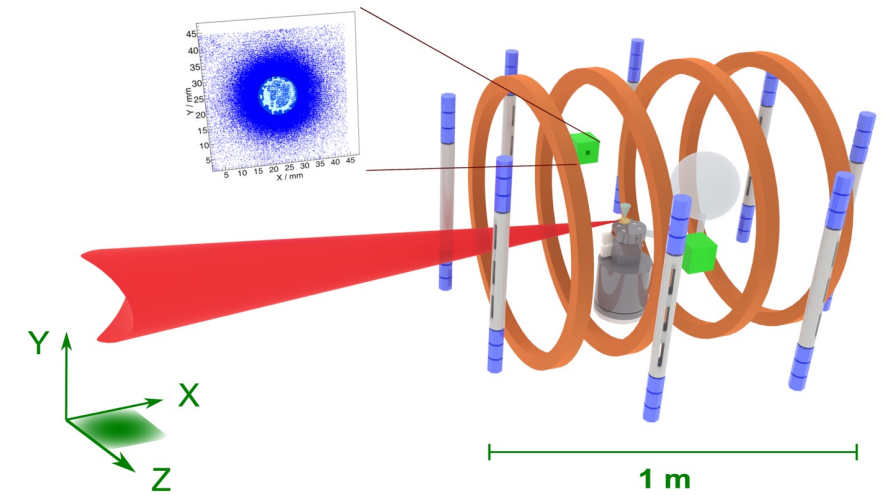
Ion beams

- First exp. proof-of-principle with nuclear-polarized ^3He conducted at GSI Darmstadt
- Further campaigns planned in the near future (both ^3He and p)

C Zheng, *HPLSE* **14**, e48 (2026)

Polarized electrons

- Currently, no experimental results
- Abundant theoretical work predominantly on pre-polarized targets
- Exp. realization of pol. electron source planned at SIOM



A GENERAL REVIEW OF THE TOPIC

L Reichwein, Z Gong, C Zheng, LL Ji, A Pukhov & M Büscher,
Rep. Prog. Phys. 88, 117001 (2025)

Covers current state-of-the art for plasma-based,
polarized particle sources

- Targetry and Polarimetry
- Pol. electrons
- Pol. positrons
- Pol. ions
- Pol. gamma quanta

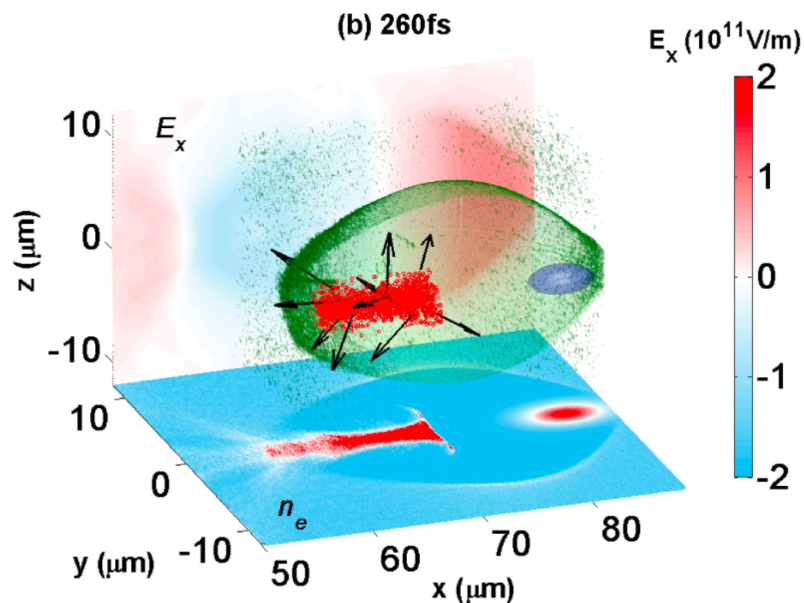
→ Let's talk about electrons!



SOURCES FOR POLARIZED ELECTRON BEAMS

We are left with two options ...

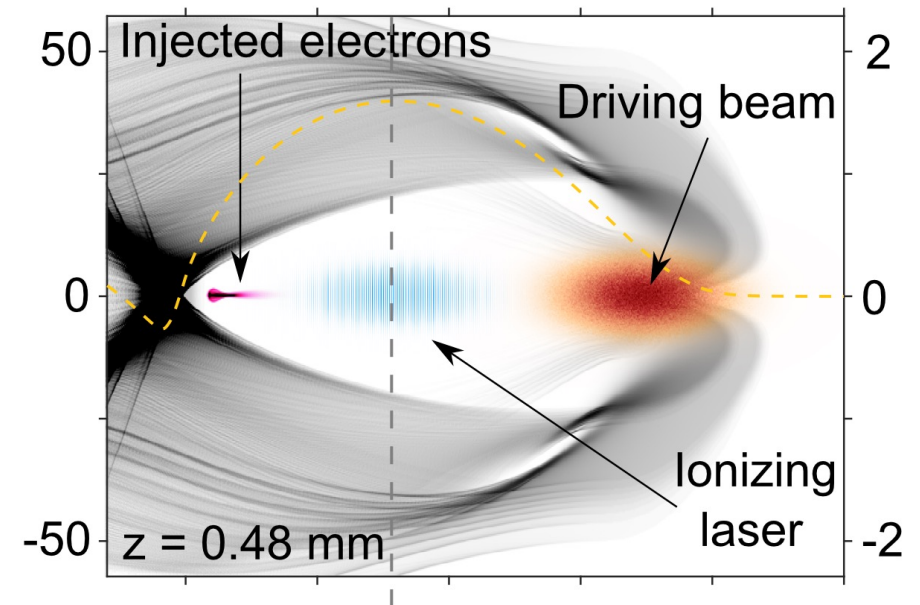
pre-polarized targets



Y Wu, *PRE* **100**, 043202 (2019)
Y Wu, *NJP* **21**, 073052 (2019)

...

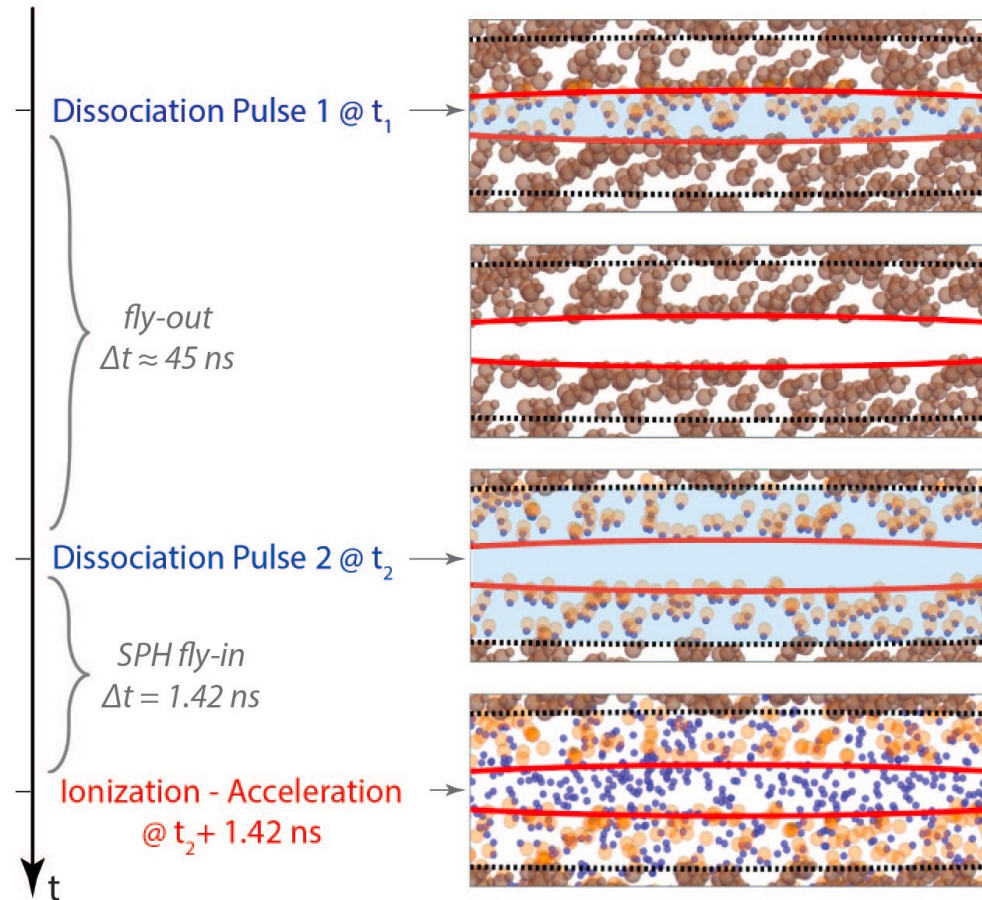
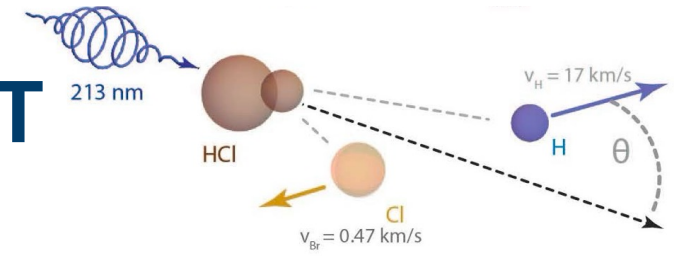
in-situ mechanisms (UCLA)



Z Nie, *PRL* **126**, 269901 (2021)
Z Nie, *PRR* **4**, 033015 (2022)

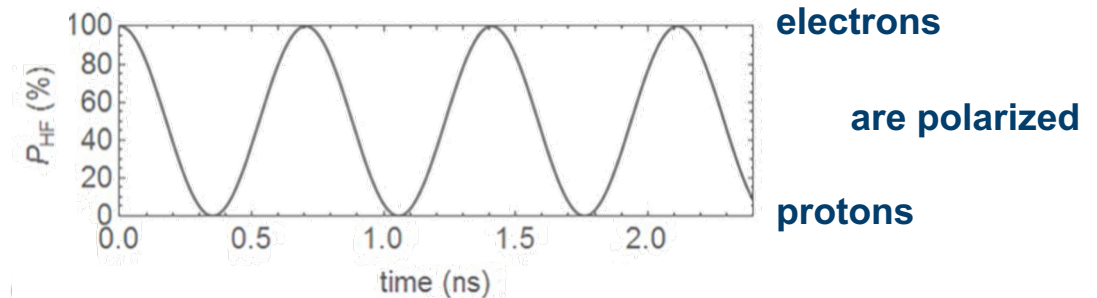
A POLARIZED PROTON/ELECTRON TARGET

Method based on photodissociation of HCl , HBr or HI molecules



- UV laser to dissociate all molecules within focus
- SPH atom polarization oscillates due to hyperfine interaction
- Subsequent dissociation steps are relevant for generation of polarized **electrons**

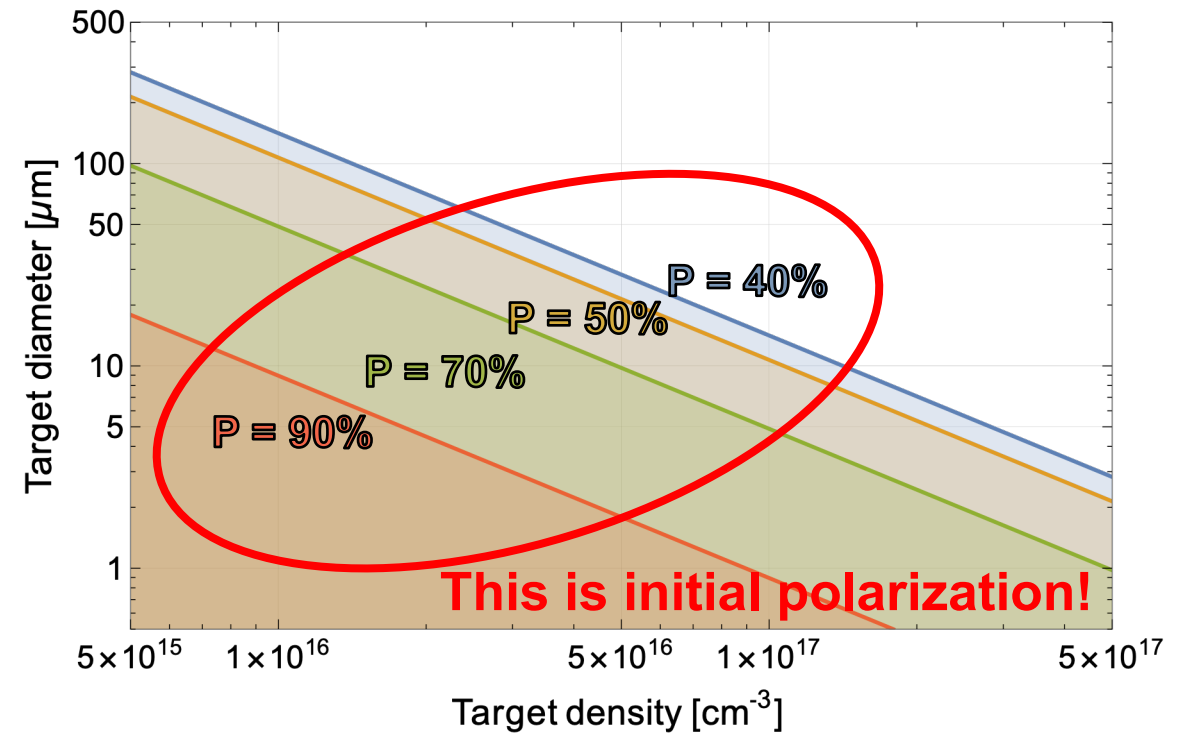
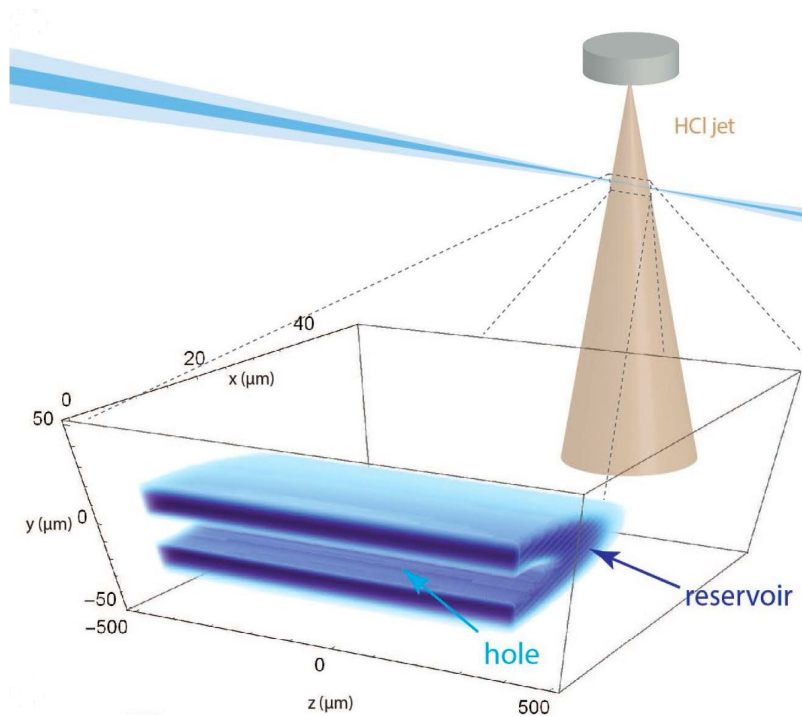
→ proton target „easier“ to realize



D Sofikitis, *PRA* **111**, 053119 (2025)

TOWARDS REALISTIC PRE-POLARIZED TARGETS

Limited degree of pre-polarization depending on regime

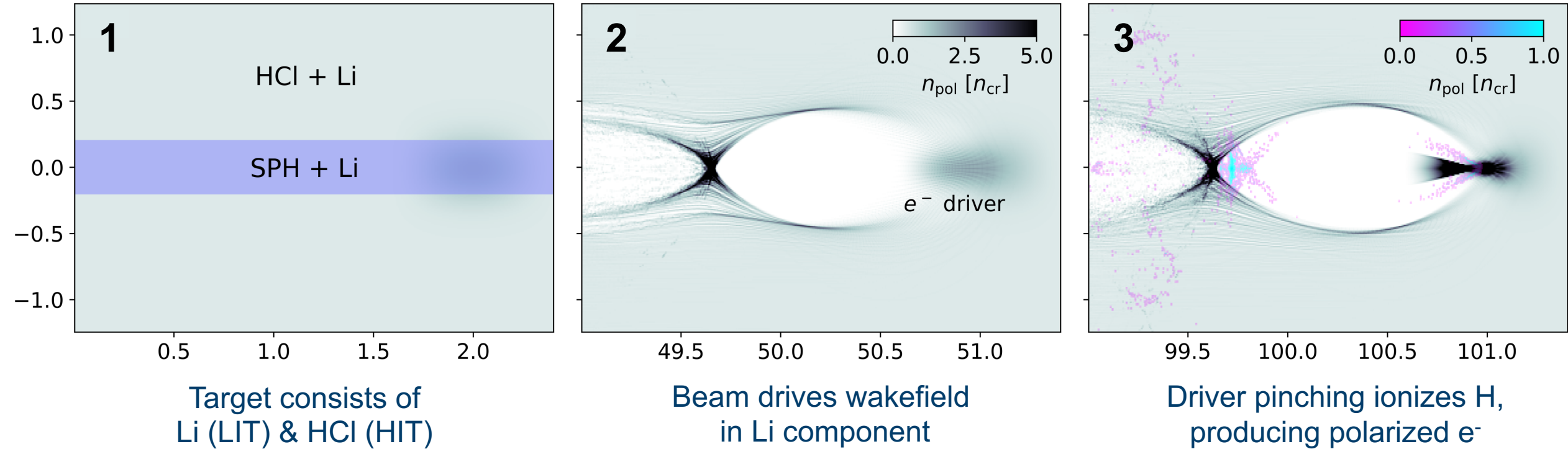


D Sofikitis, *PRA* **111**, 053119 (2025)

CIRCUMVENTING TARGET LIMITATIONS

CIRCUMVENTING TARGET LIMITATIONS (I)

Pinching injection for polarized electron beams



L Reichwein, *arXiv:2604.22369* (2026)

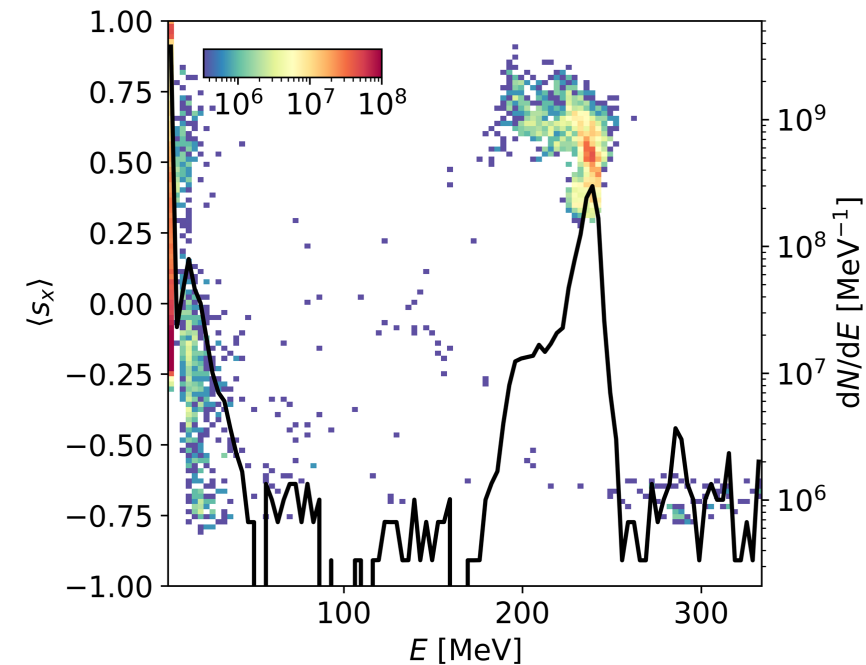
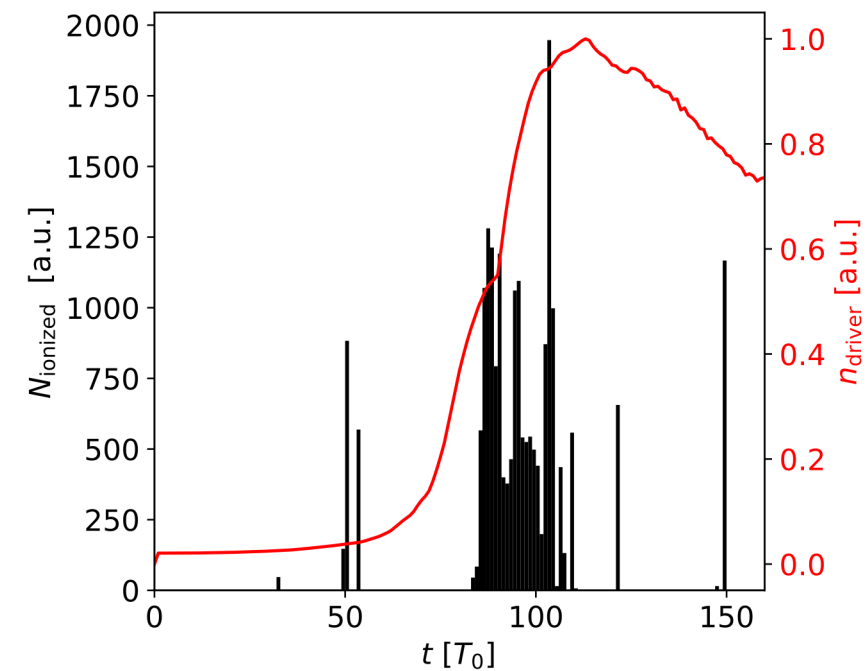
PINCHING INJECTION

Results & Discussion

- Injection of pol. electrons initiated by driver pinching
 - Injection of non-polarized electrons negligible
- 0.187 nC with $P \sim 51\%$ for 10 GeV driver
 - Injection continues as pinching progresses
 - Polarization remains stable at later stages

Ideally, we would still want higher polarization and easier alignment with the pre-polarized electrons ...

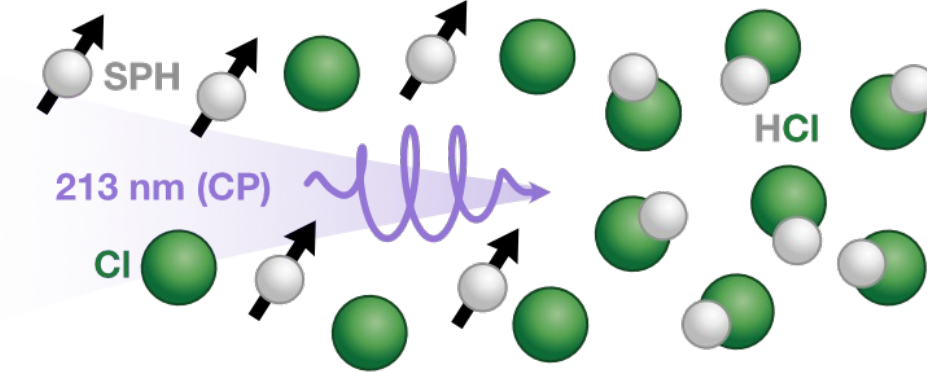
L Reichwein, [arXiv:2604.22369](https://arxiv.org/abs/2604.22369) (2026)



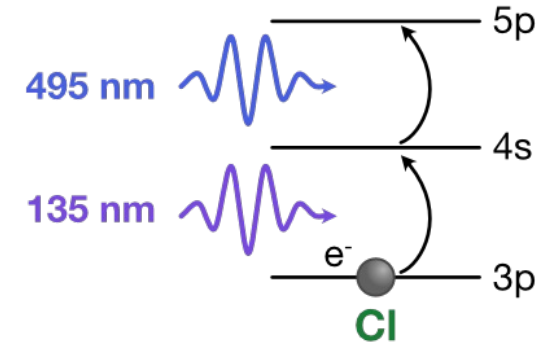
CIRCUMVENTING TARGET LIMITATIONS (II)

A plasma photocathode using state-selected hydrogen halide photofragments

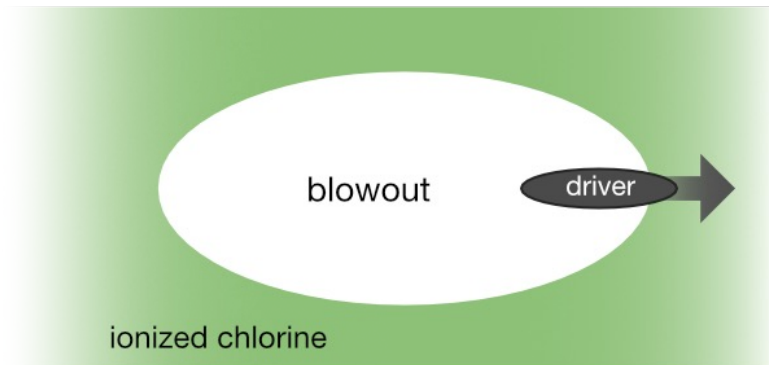
(a) photo dissociation



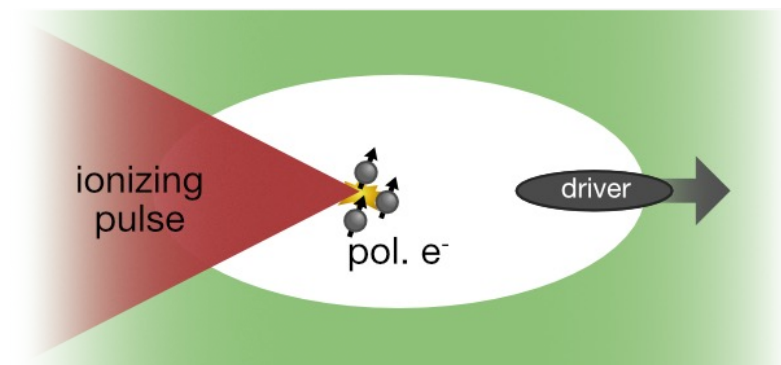
(b) chlorine excitation



(c) wakefield formation



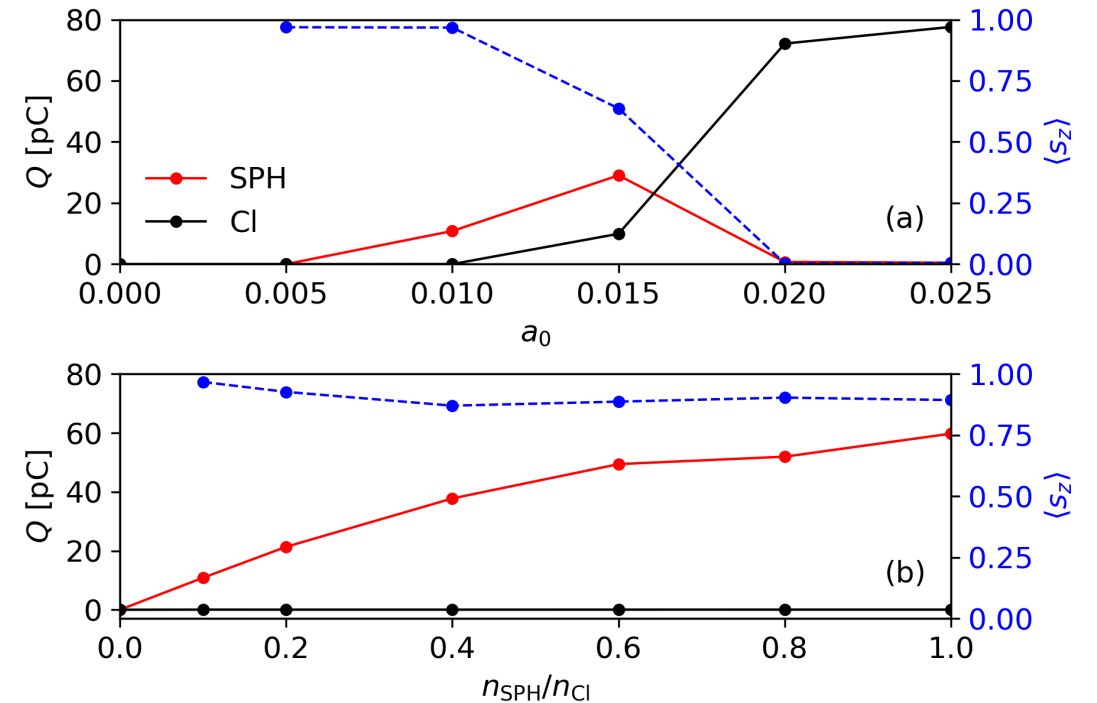
(d) hydrogen ionization



L Reichwein, *arXiv:2608.04932* (2026)

EXCITED PHOTOCATHODE – RESULTS

- We obtain 10.8 pC with $P \sim 97\%$
 - $\sqrt{\epsilon_x \epsilon_y} = 57 \text{ nm}$
 - Only $\sim 0.04 \text{ pC}$ unpol. Cl electrons in witness region
- Charge/polarization can be tuned with ionizing laser and n_H/n_{Cl} density ratio
 - e.g. 60 pC with $P \sim 90\%$
- Competitive with conventional photoguns in terms of polarization



L Reichwein, [arXiv:2608.04932](https://arxiv.org/abs/2608.04932) (2026)

CONCLUSION & OUTLOOK

- Work on electrons theoretical, but plans for experimental realization exist
 - LL Ji & M Büscher @SIOM
- Pre-polarized targets (e.g. HCl) generally have restrictive parameters
- In-situ methods rely on ionization of specific orbitals (e.g. $4f^{14}$ of Yb)
- State-selected plasma photocathode provides $P \geq 90\%$ for tens of pC

L Reichwein, *arXiv:2604.22369* (2026)



L Reichwein, *ROPP* 88,
117001 (2025)

THANK YOU FOR YOUR ATTENTION!

And thanks to all our collaborators ...



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HHU Düsseldorf

Oliver Mathiak



SIOM

Liangliang Ji, Xiaofeng Li



University of Ioannina/Crete

T Peter Rakitzis, Dimitris Sofikitis



ITP CAS

Zheng Gong



NUDT

Tong-Pu Yu



Peking University

Xiaofei Shen

BACKUP SLIDES

WHAT DETERMINES SPIN DYNAMICS IN PLASMA?

Spin precession according to the T-BMT equation

- **Hom. fields:** initially polarized particle ensembles precess in unison
- **Inhom. fields:** precession changed locally, lose polarization

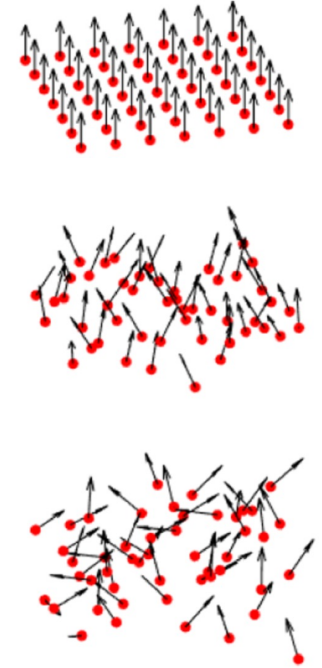
$$\frac{d\mathbf{s}}{dt} = -\mathbf{\Omega} \times \mathbf{s}$$

with precession frequency

$$\mathbf{\Omega} = \frac{qe}{mc} \left[\Omega_B \mathbf{B} - \Omega_V \left(\frac{\mathbf{v}}{c} \cdot \mathbf{B} \right) \frac{\mathbf{v}}{c} - \Omega_E \frac{\mathbf{v}}{c} \times \mathbf{E} \right],$$

$$\Omega_B = a + \frac{1}{\gamma}, \quad \Omega_V = \frac{a\gamma}{\gamma+1}, \quad \Omega_E = a + \frac{1}{1+\gamma}$$

J Thomas, *PRAB* **23**, 064401 (2020)



Anomalous magnetic moment

$$a = (g - 2)/2$$

$$a_p \approx 1.8$$

IN-SITU MECHANISM (UCLA)

A plasma photocathode approach

Case 1: mixture of Li & Xe

- Beam-driven wakefield in Li
- CP laser pulse to strong-field ionize $5p^6$ electrons of Xe
- pC-level beam with 31% polarization

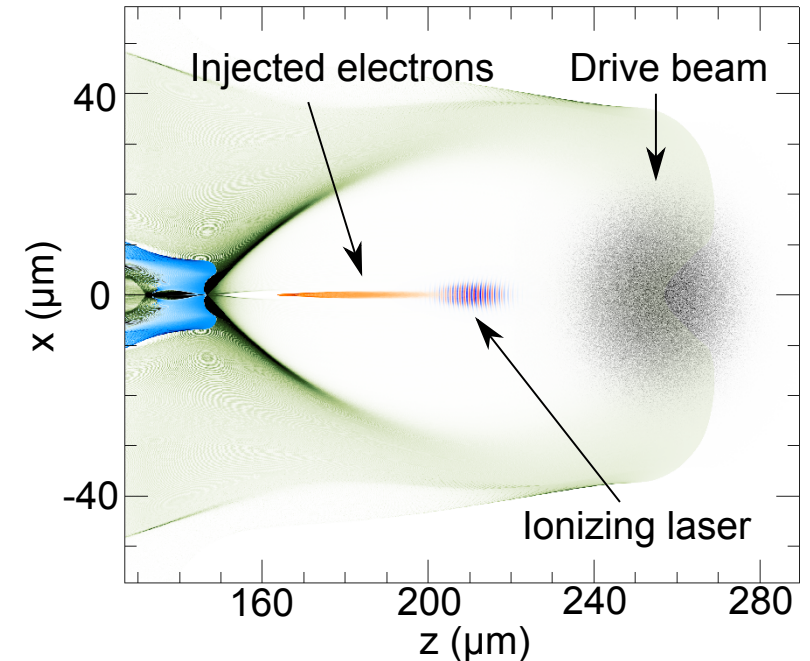
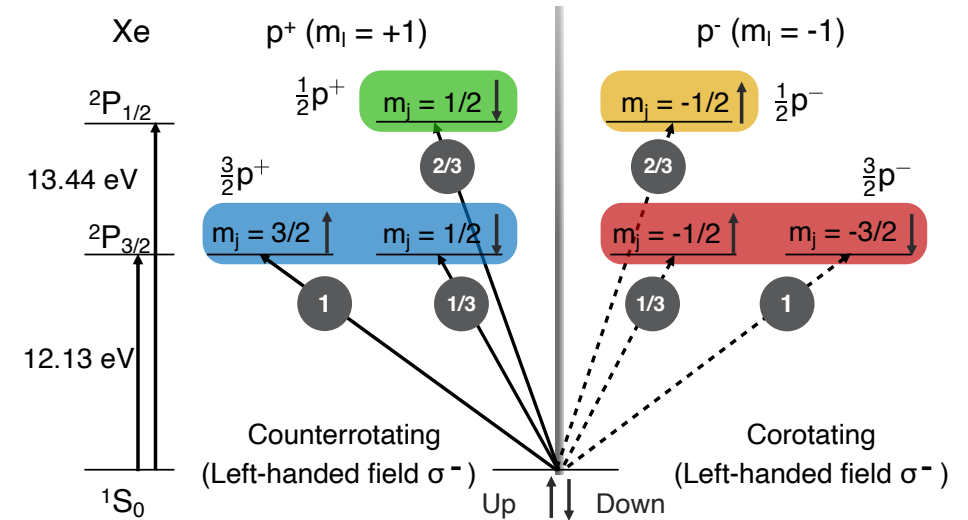
Case 2: single-species

- Ionize $4f^{14}$ orbital of Ytterbium
- Improved polarization, $P \sim 56\%$

Z Nie, *PRL* **126**, 269901 (2021)

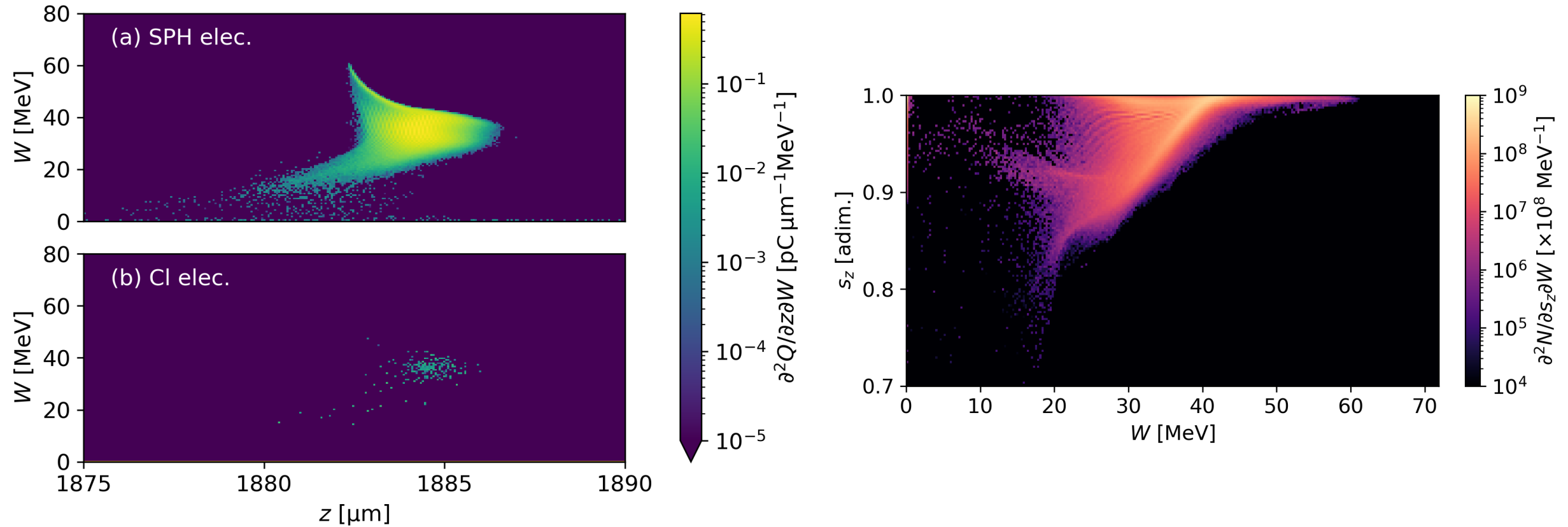
Z Nie, *PRR* **4**, 033015 (2022)

I Barth, *PRA* **88**, 013401 (2013)



EXCITED PHOTOCATHODE

Phase space & spin



L Reichwein, [arXiv:2608.04932](https://arxiv.org/abs/2608.04932) (2026)