# Laser-driven polarized deuterium source

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# Acknowledgments


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# Motivation

- Polarized deuterons are in the science programs for both US electron-ion collider (EIC) concepts

- Currently no operational polarized deuteron beam sources in the US
  - Recent atomic beam polarized ion source (ABPIS) development for NICA
  - Optically pumped polarized ion source (OPPIS)-type polarized source for deuterons at KEK in late 90s/early 00s

- ABPIS-type source can provide polarized deuterium beam to future EIC, but is there room for improvement?

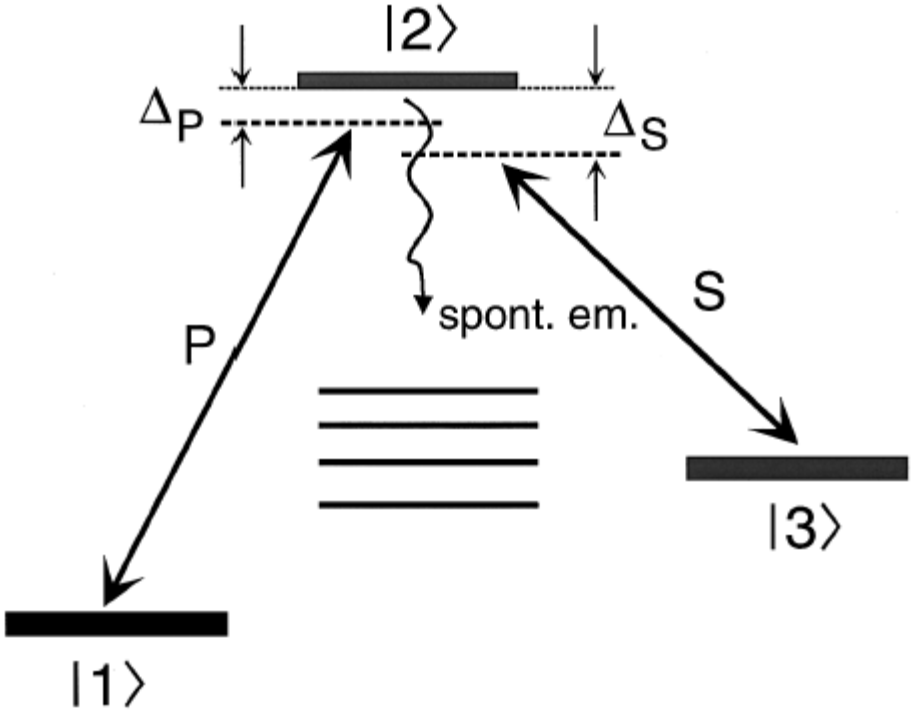
# Polarization timescale

- ABPIS uses Stern-Gerlach separation and RF transition units to form polarized atomic beam
  - Intrabeam scattering limits the max density
  - Polarized beam formation on the millisecond timescale – $10^{12}$ $cm^{-3}$
- Laser pulses on the order of the deuterium hyperfine-beating time (~ nanoseconds) can polarize deuterium atoms much more quickly
  - Has been demonstrated: D. Sofikitis, et al., doi: 10.1103/PhysRevLett.121.083001
- Polarized beam formation orders of magnitude faster → polarized beam density orders of magnitude greater
  - $10^{12}$ $cm^{-3}$ → $10^{18}$ $cm^{-3}$

# Method

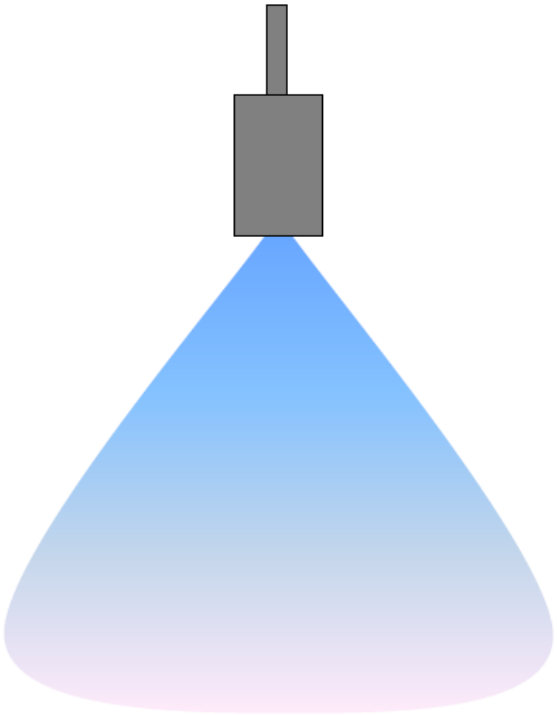
- STImulated Raman Adiabatic Passage (STIRAP): process by which population transfer between two quantum states is facilitated by at least two coherent light pulses
  - Two states each couple to an excited state; population transfer from one state to the other without populating the excited state

- STIRAP process has been explored in the context of preparation of polarized molecular targets, among other applications
- Narrow bandwidth IR allows for partial resolution of hyperfine splittings



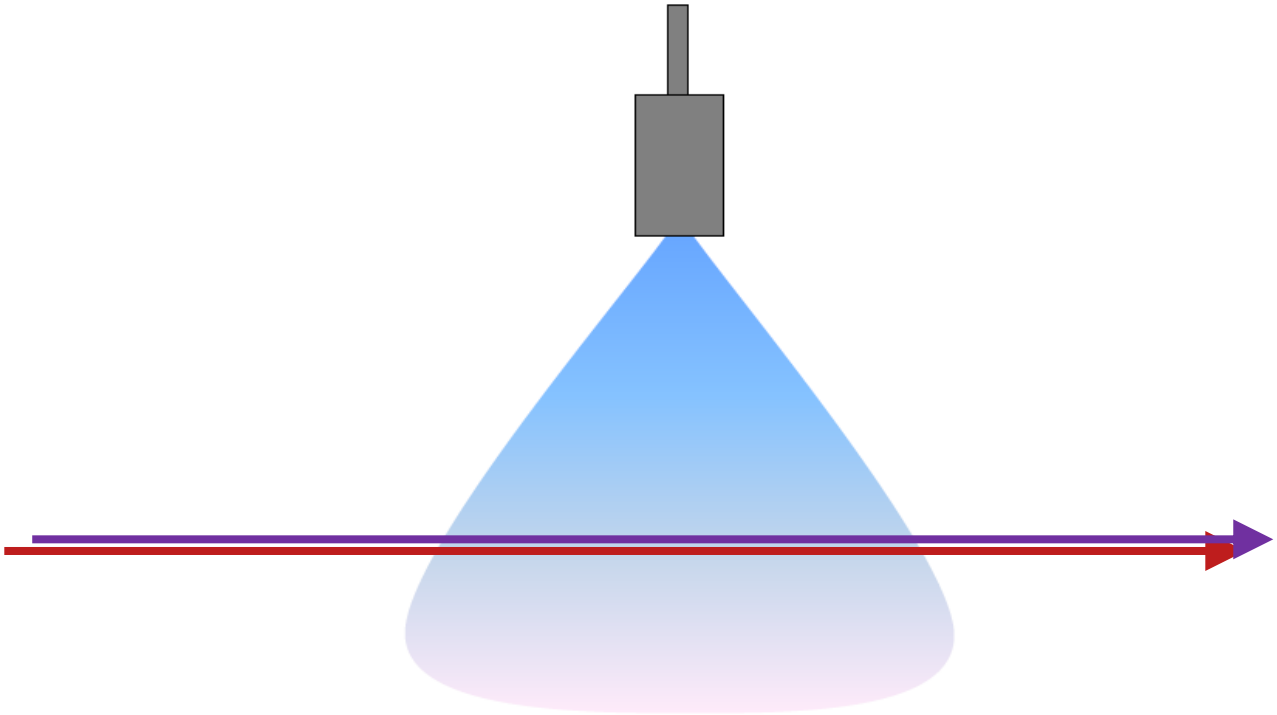

[doi: 10.1103/RevModPhys.70.1003]

# IR STIRAP for polarized deuterium production – 1



- Cooling of DCl gas via supersonic expansion through a nozzle
- Cooling drives DCl molecules into ground state with J(orbital) = 0, S(D) = 1/2, S(Cl) = 3/2
- Molecular beam speed 1000 m/s possible

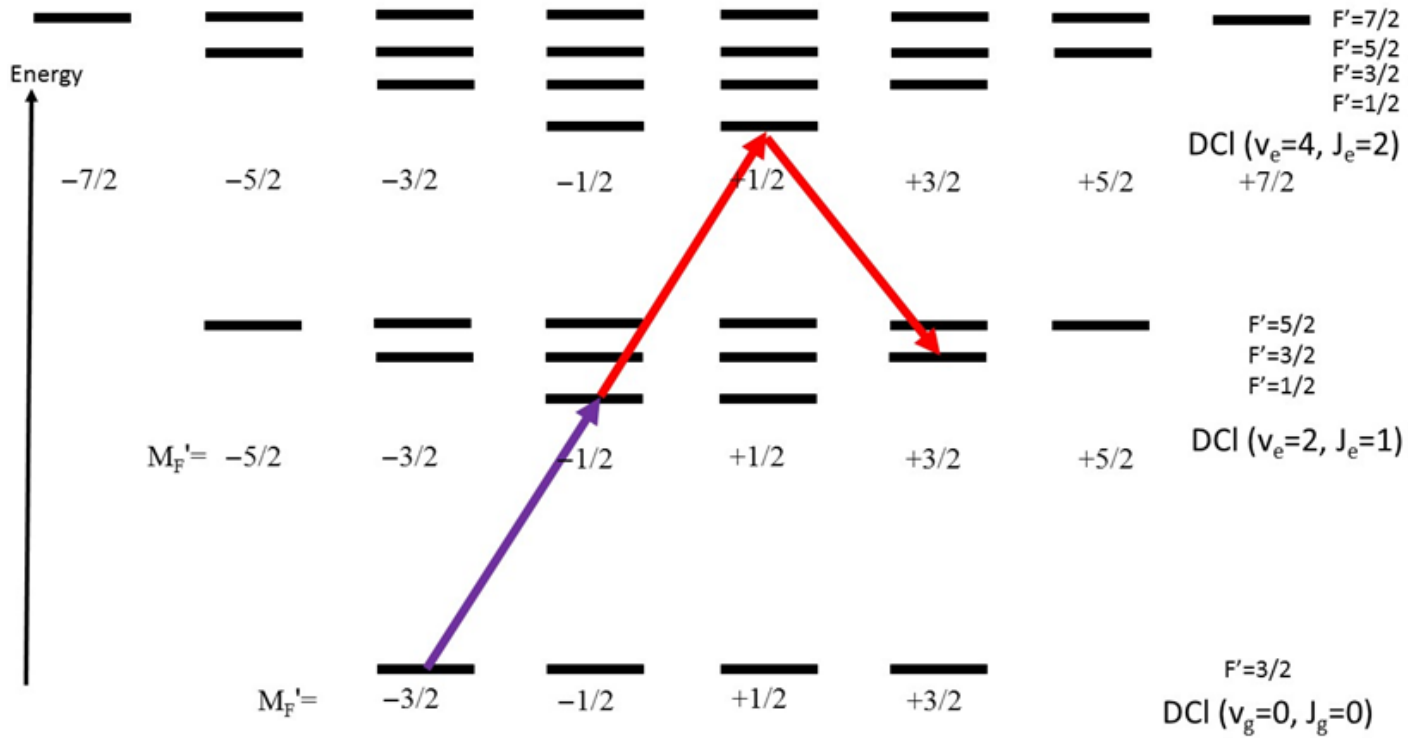
# IR STIRAP for polarized deuterium production – 2



- DCl molecular beam excited to rovibrational state using circularly-polarized IR laser lines

# IR STIRAP for polarized deuterium production – 2

- DCl molecular beam excited to rovibrational state using circularly-polarized IR laser lines
  - Laser direction perpendicular to gas propagation direction
  - Three transitions; two lasers required + acousto-optic modulators



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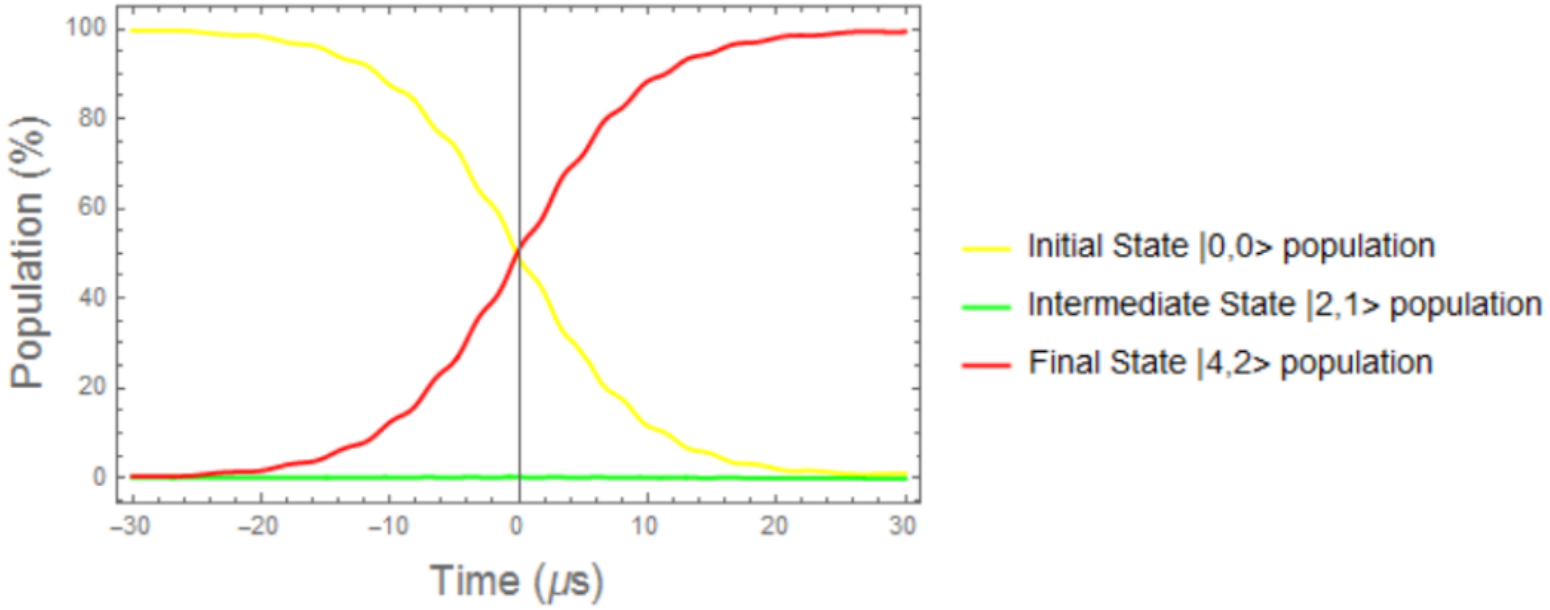
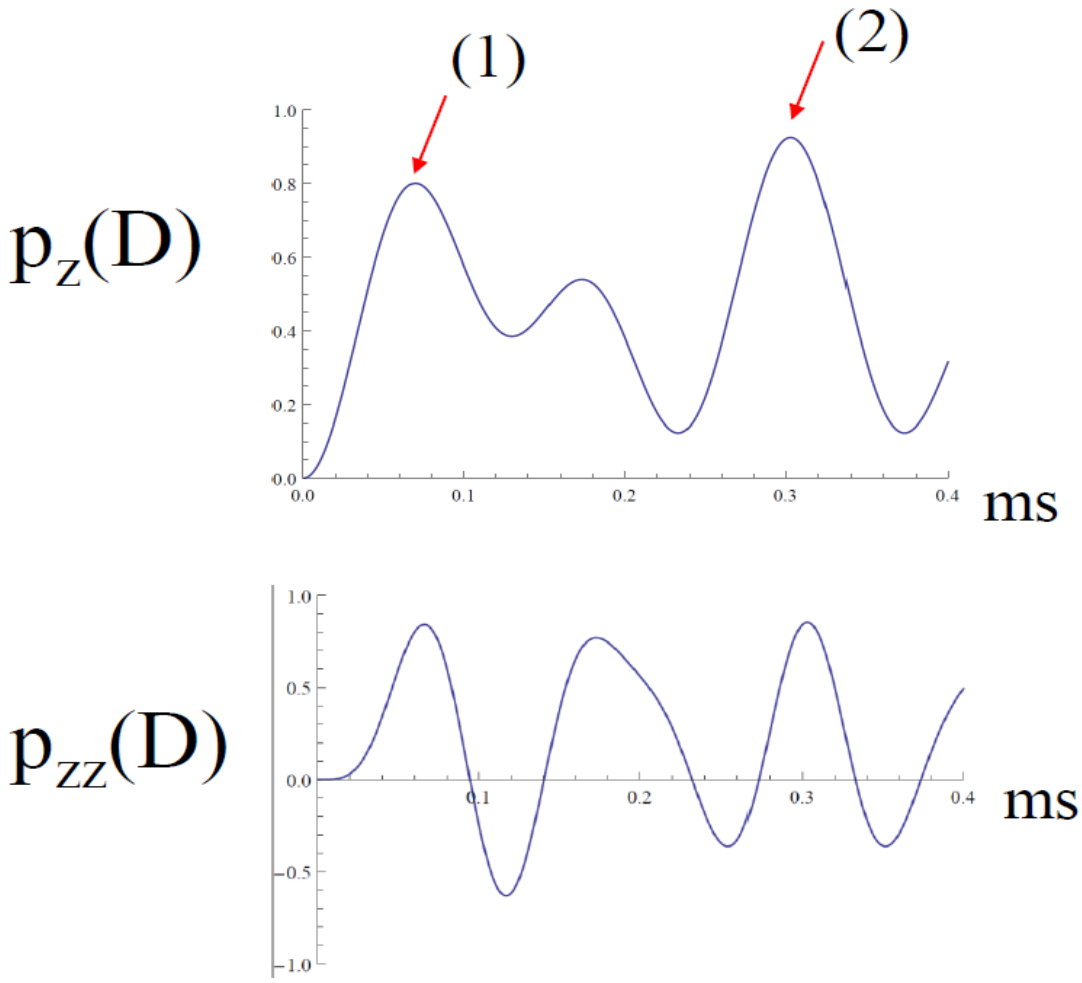
# IR STIRAP for polarized deuterium production – 2

- STIRAP method is used to enable complete population transfer from the initial to final state, without exciting intermediate state
- Counterintuitive timing – laser to couple intermediate to final state fires before laser coupling ground to intermediate state
- Delayed excitation – overlap of IR pulses for adiabatic transfer
- For DCl transitions, 2 W laser power, 2 cm laser spot size



# IR STIRAP for polarized deuterium production – 3

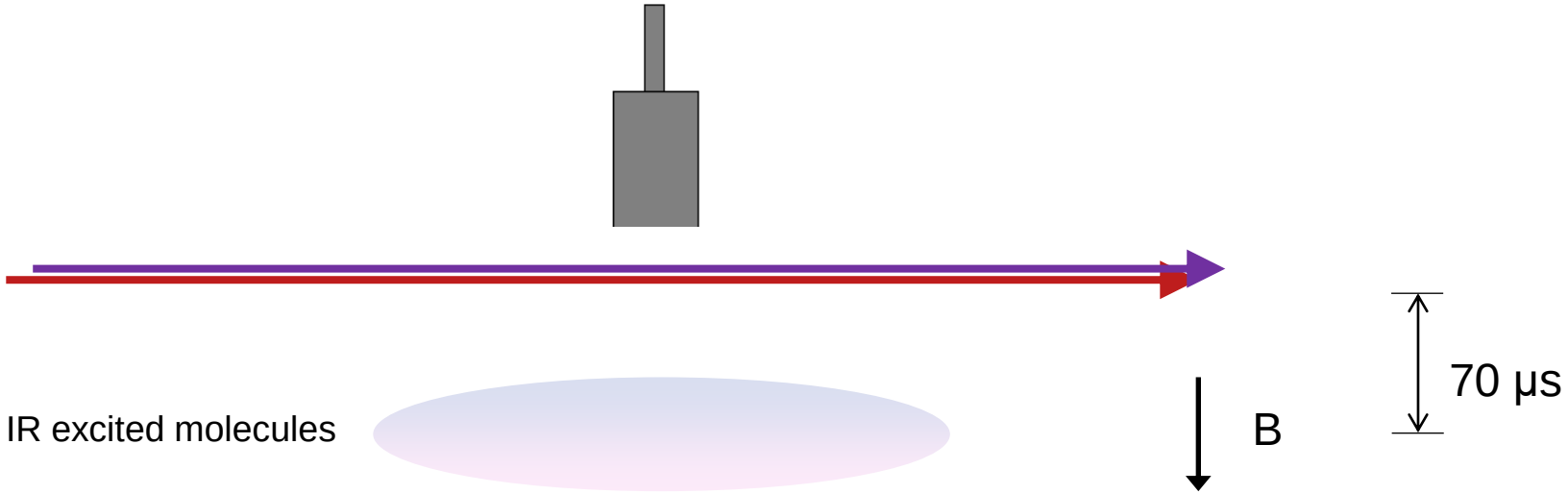
- Rotational polarization in DCl molecules couples to the unpolarized nuclear spin, undergoes hyperfine beating cycles




- Spin-orbit coupling between molecular orbital J and halide atom (Cl) much stronger than between J and deuterium atom

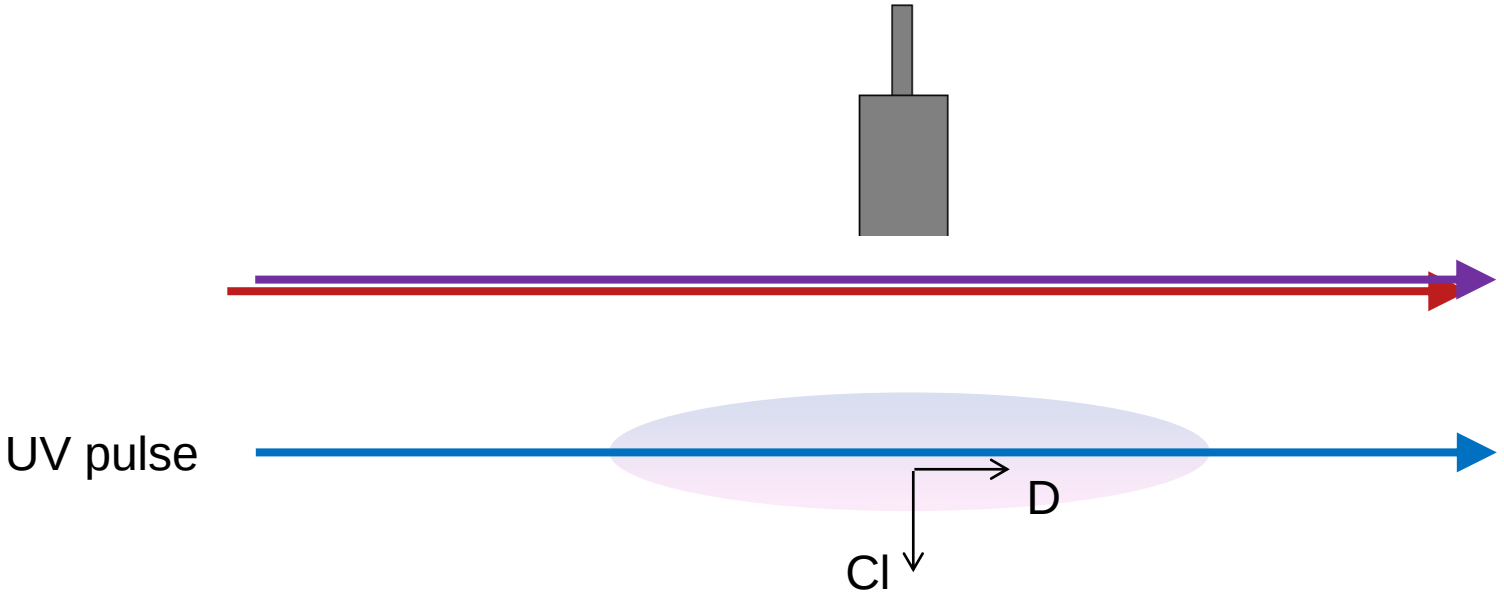
- J/Cl and J/D hyperfine beatings are very different and well resolved

# IR STIRAP for polarized deuterium production – 4



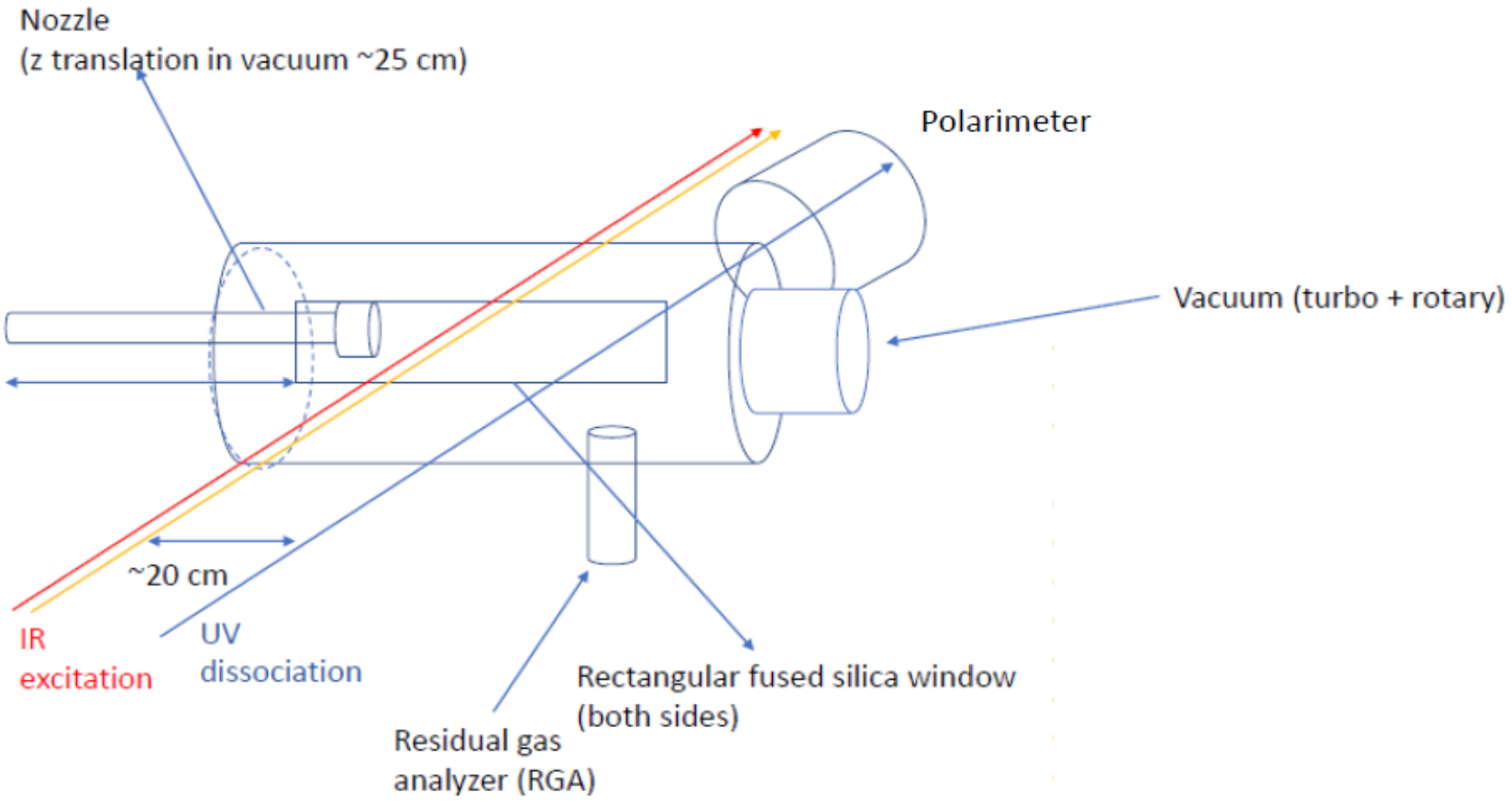

- Polarization reaches maxima at certain times
- Time of flight of polarized molecules can be used to terminate the hyperfine beating of the polarization with a magnetic field when polarization is at a max
  - ~80% $p_z$ 70 μs after polarization
- Second, higher field (any orientation) needed to prevent hyperfine beating of electronic and nuclear polarizations in subsequent photodissociation step

# IR STIRAP for polarized deuterium production – 5




- Photodissociate polarized DCl into D and Cl atoms
  - Polarized D atoms emitted perpendicular to molecular beam direction
- Polarized atom density depends on UV absorption, molecular beam density, # photons in UV pulse
- Neutral polarized D atoms for charge-exchange ionization

- Possible experimental setup



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# Summary

- US EIC concepts feature polarized deuteron physics, but there are currently no operational polarized deuterium beam sources in the US

- The recent availability of narrow bandwidth IR lasers makes possible new techniques for production of polarized atomic deuterium at higher densities than in conventional methods

- We describe a method for producing highly polarized deuterium atoms from DCl gas using IR STIRAP technique