Upgrading the ACME Electron Electric Dipole Moment (e⁻EDM) Search with a Molecular Lens

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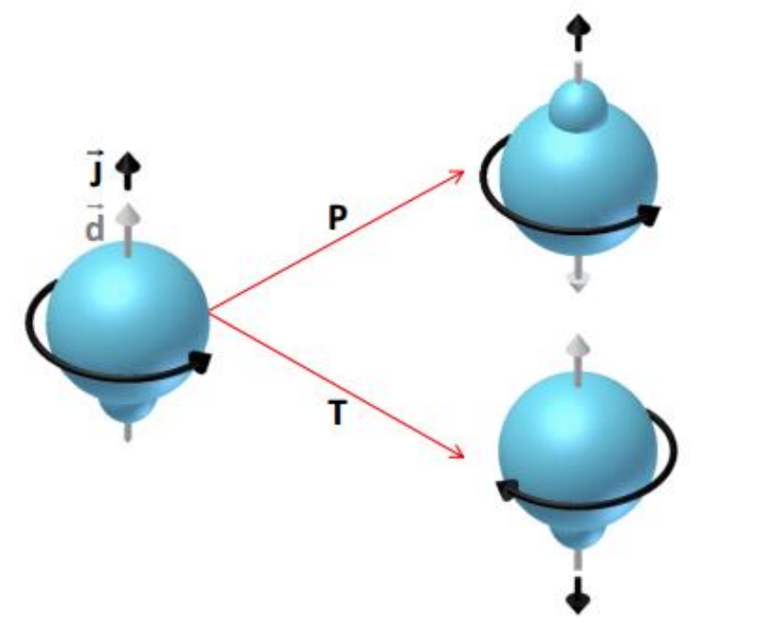
Zoom Meeting, **CLICK HERE**:
https://us02web.zoom.us/j/86326280273?pwd=OXNEWnVEcU4ralBKSm5VZzRNdlUzUT09

Meeting ID: 863 2628 0273; Password: 1JaxQS

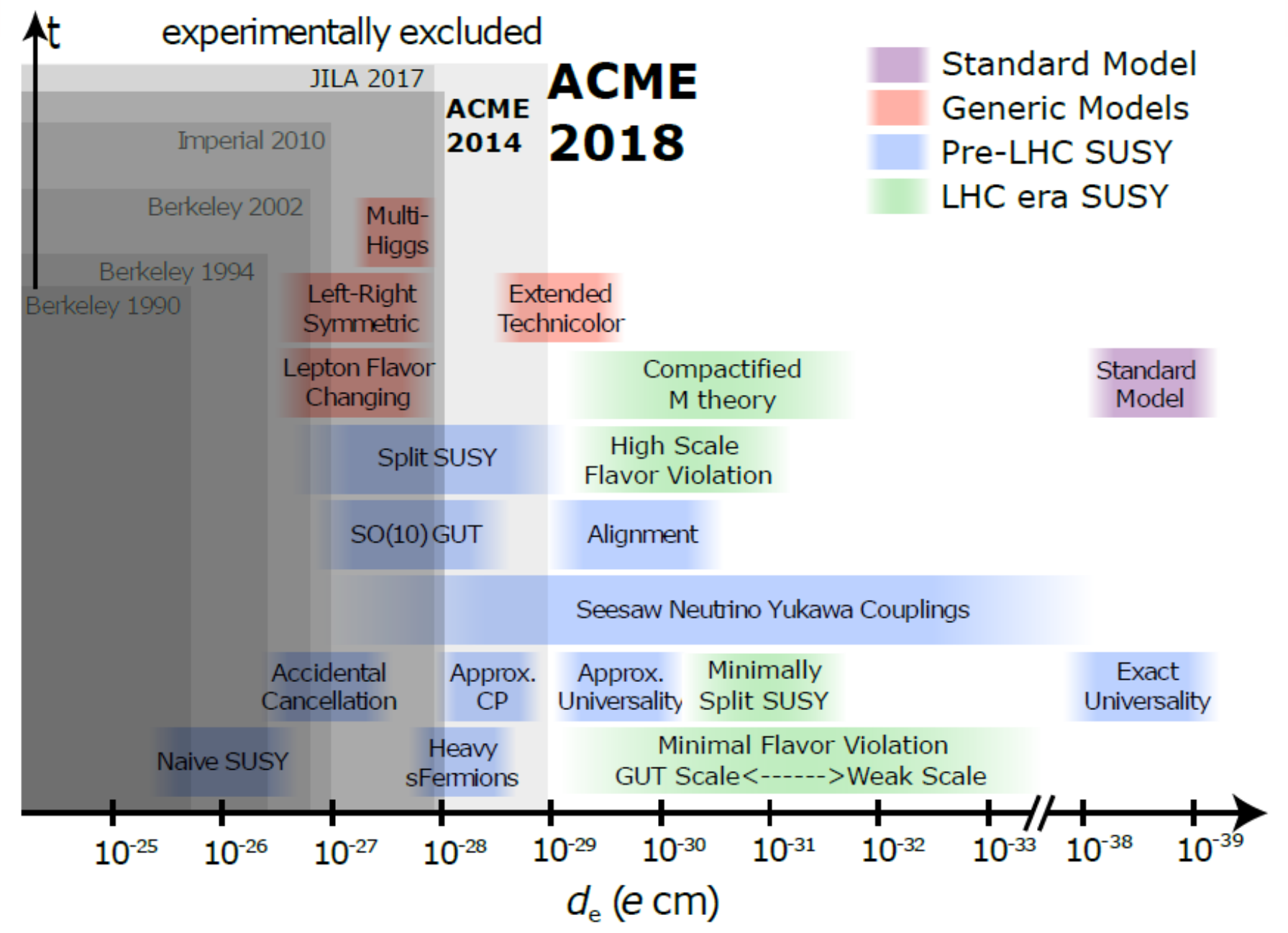
Motivation

$$H_d = -\vec{d}_e \cdot \vec{\mathcal{E}}$$



A permanent electric dipole of a fundamental particle violates both T- and P-symmetry

$$\delta d_e = \frac{1}{2T\mathcal{E}_{eff}\sqrt{N}}$$



Many theories beyond the Standard Model predict *T*-violation and associated EDMs at current experimental precision

eEDM sensitivity of ACME II is at ~4x10^{-30} e•cm.

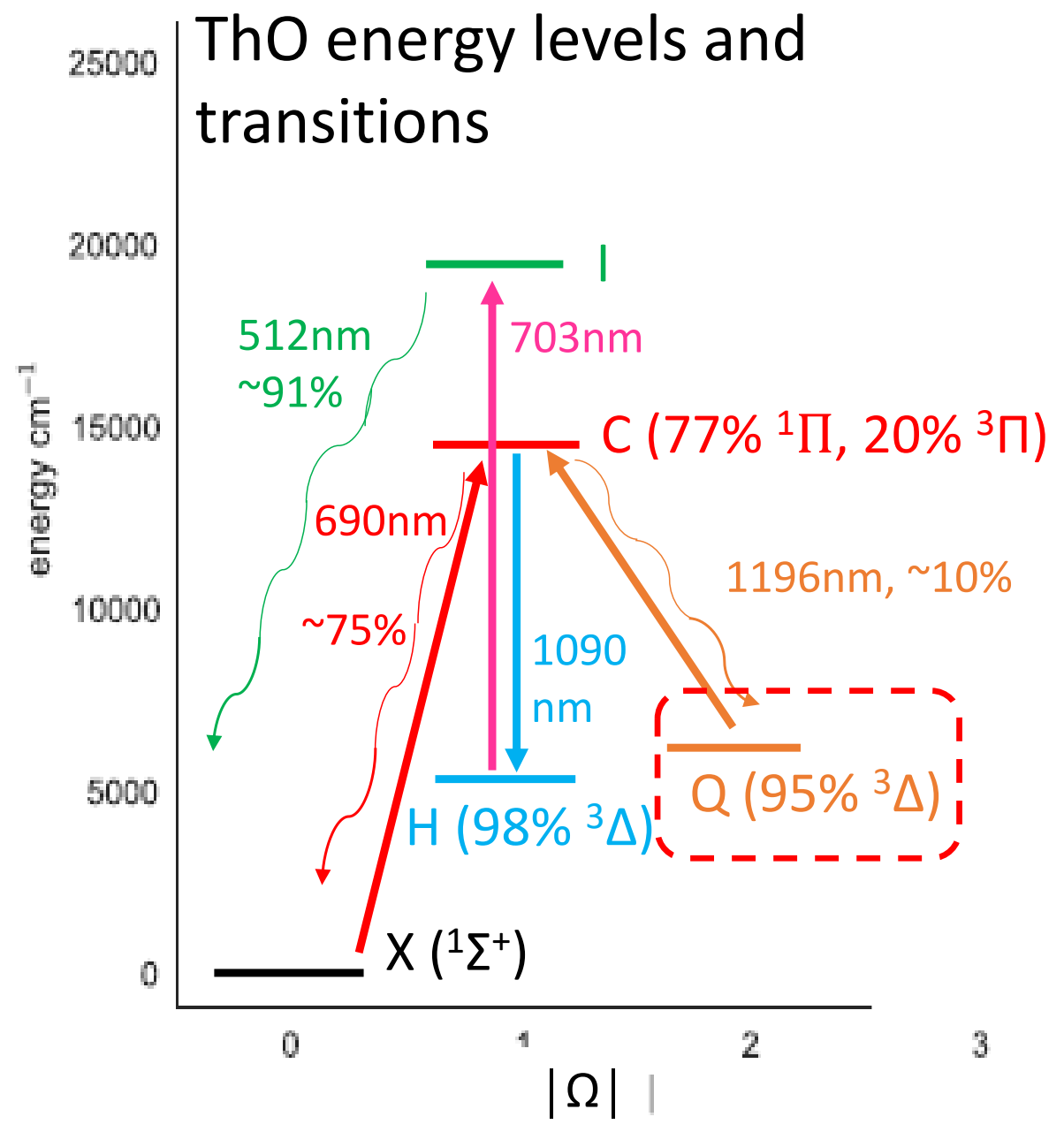
We optimize the sensitivity by maximizing the detected molecule number

Property of Q ($^3\Delta_2$) state of ThO

More details see:
X Wu *et al* 2020 *New J. Phys.* **22** 023013

— Use Q state to increase molecule flux & suppress systematics

ThO energy levels and transitions



Q state:

- Paramagnetic, $g_Q \approx g_L \Lambda + g_S \Sigma = 2$, compared to $g_H = 4.4\times10^{-3}$ & $g_X < 10^{-3}$ allows **magnetic lensing** & **co-magnetometer**
- Long lived (measured lifetime >62 ms, 90% c.l.)
- Linear Stark shift due to Ω-doublet (<<100kHz) , efficient **electrostatic lensing**

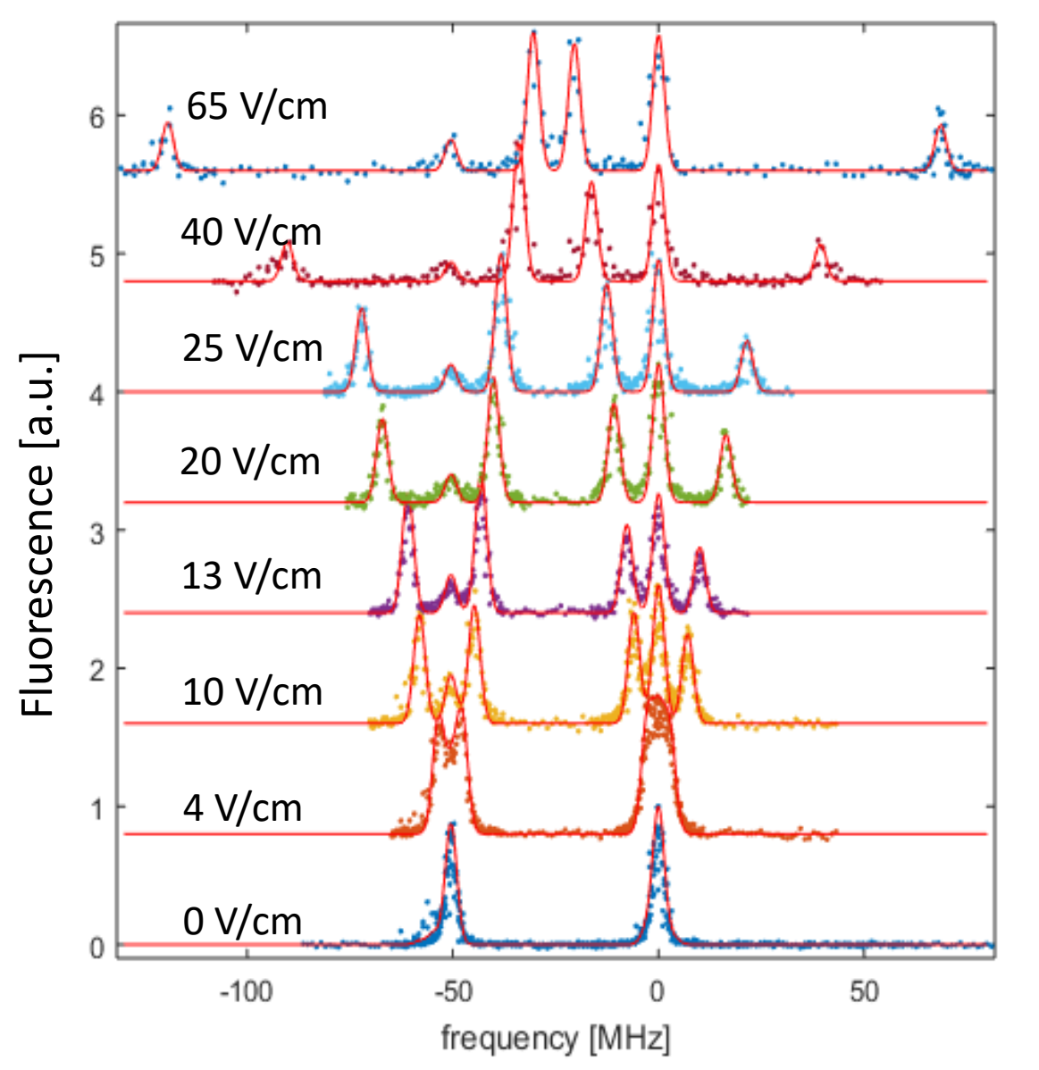
H state: for EDM measurement

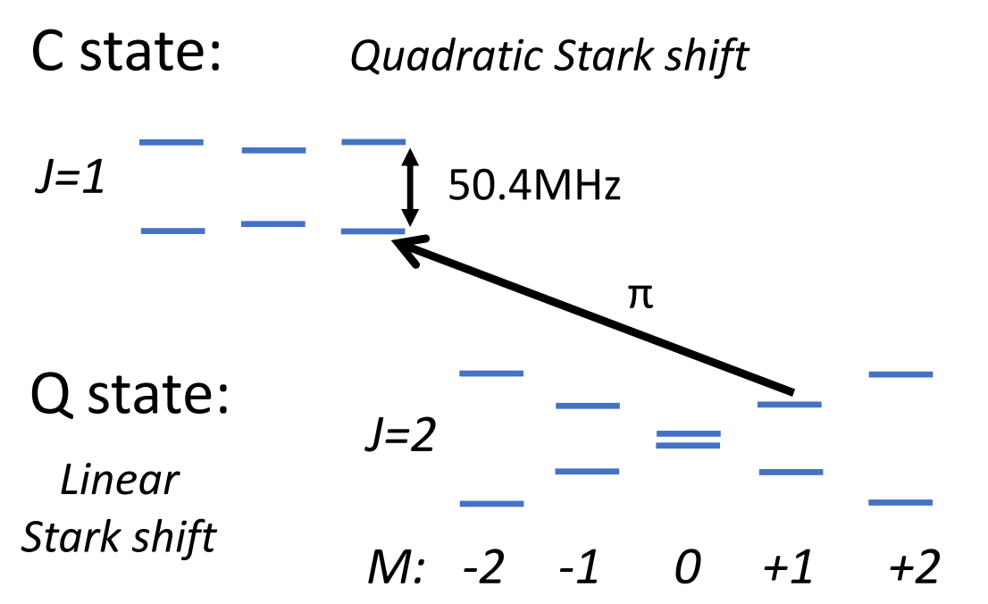
X-C-H STIRAP: EDM state preparation

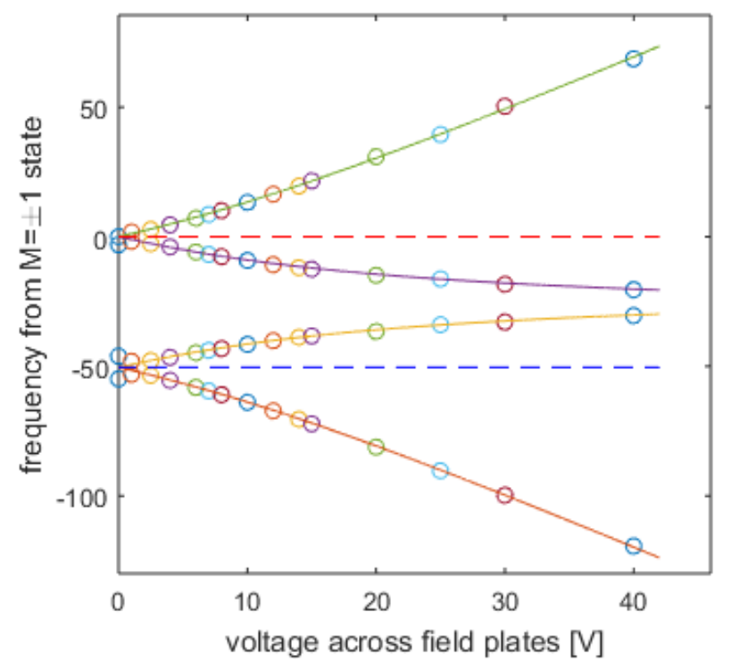
I state: read out via 512nm LIF detection

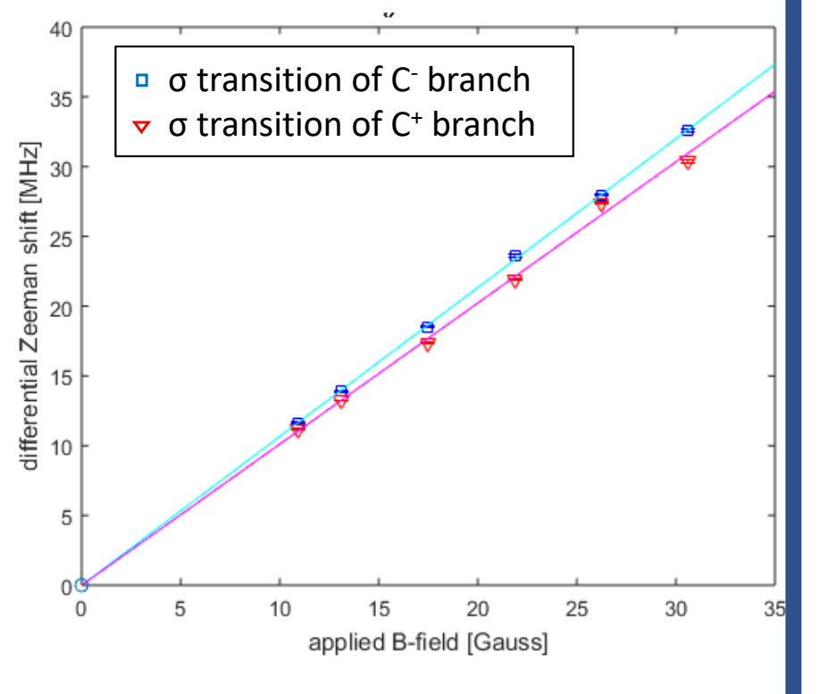
Characterization of Q—C transition

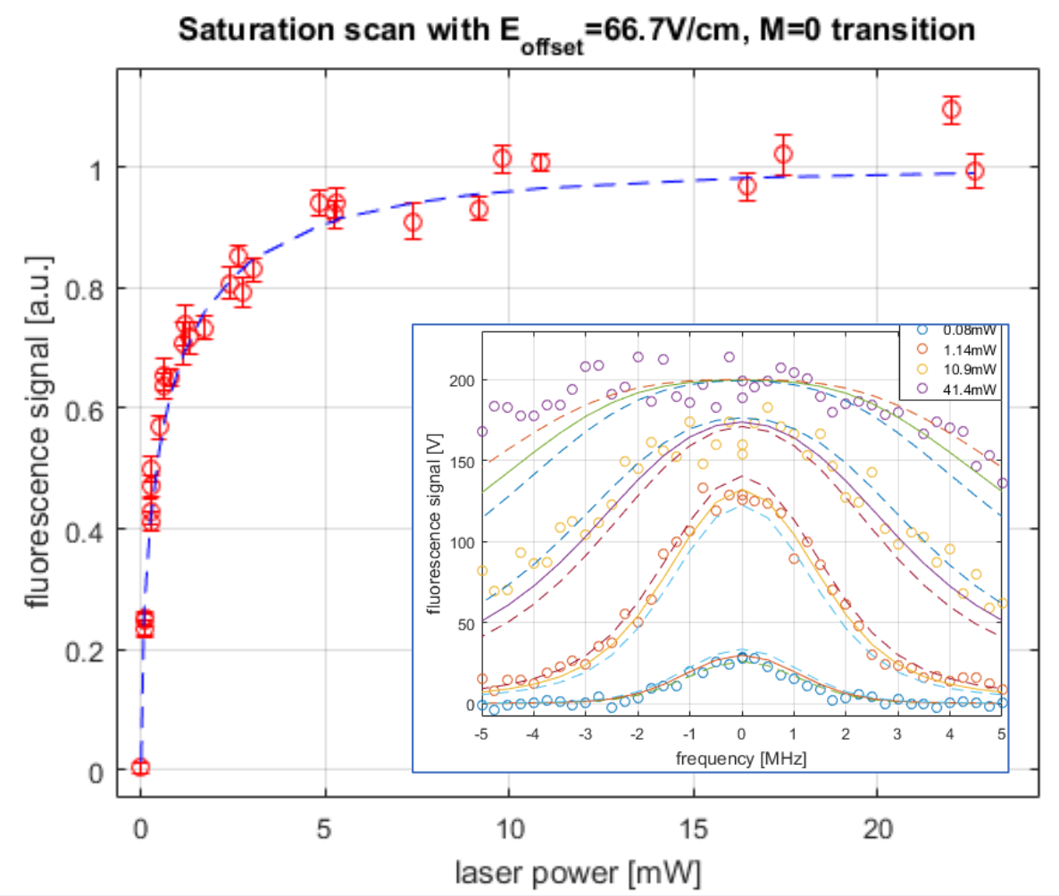
Differential Stark shift of Q—C transition











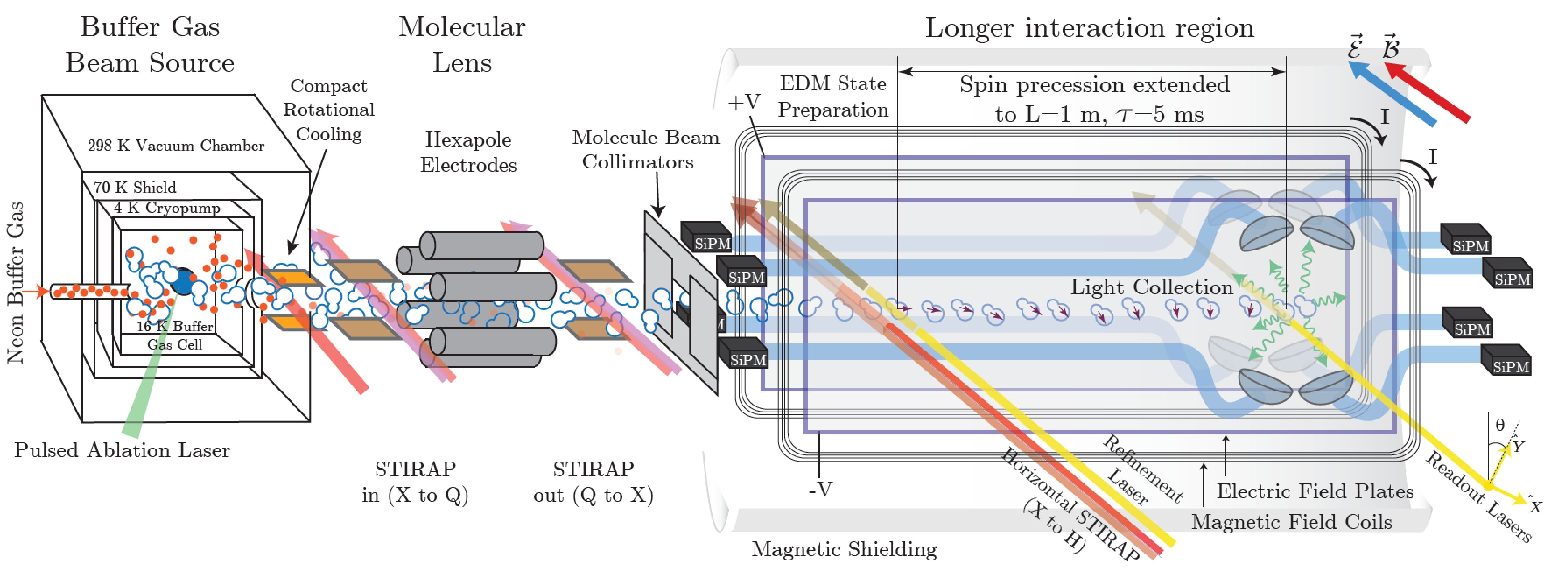
Large electric & magnetic dipole

- Extracted molecule frame dipole:
  D_Q=4.07D (Q state),
  D_C=2.60D (C state)
- From Zeeman shift measurement:
  $G_Q=2.06\mu_B$,
  $G_C=1.22\mu_B$

Strong transition dipole to C state

- Power saturation scan of Q—C transition:
  D_{Q-C} = 1.0±.12 D

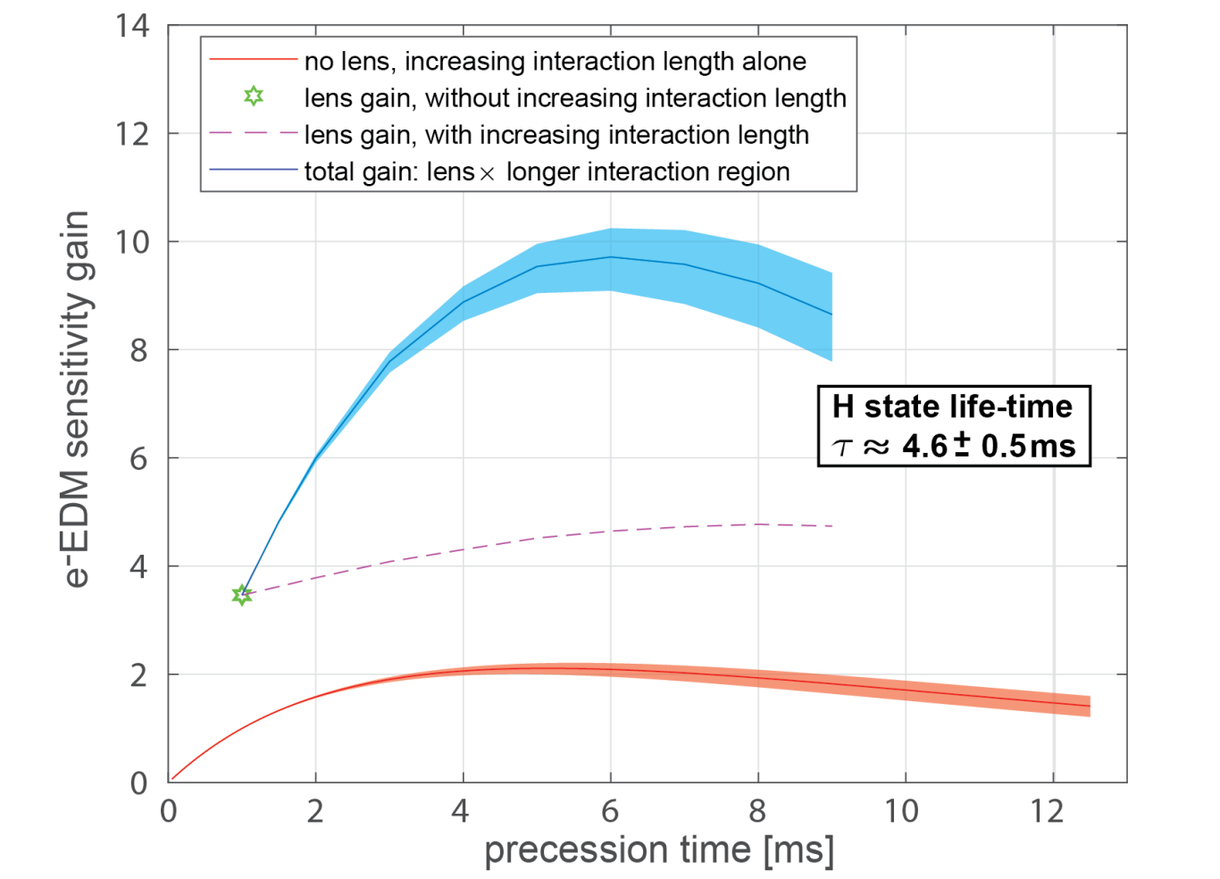
Advanced ACME overview



Proposed sensitivity improvement

Improvement	Signal Gain	EDM Sensitivity Gain
Increased Precession Time	0.20	2.3
Electrostatic Lens	20.5	4.5
SiPM Detector Upgrade	2.3	1.5
Timing Jitter Noise Reduction	1	1.7
Total	**9.4**	**26.4**

Sensitivity gain vs. interaction length

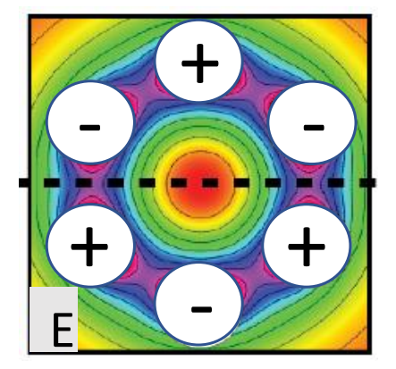


Increase useful molecule flux with beam focusing

- Molecules exiting the beam source have high divergence – solid angle subtended by EDM measurement region ~0.05% in ACME II, and worse for longer interaction region
- Lensing-state of ThO: X-C-Q STIRAP to a single M=2 or -2 level in Q (J=2) state

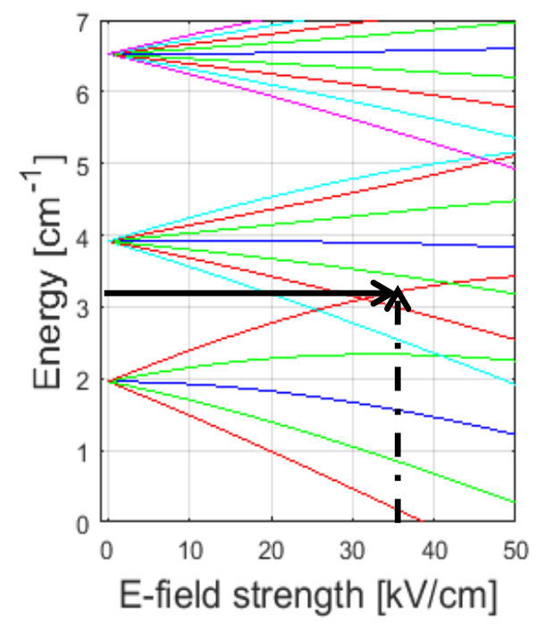
Electric hexapole lens

- Electrode voltage 22.5 kV, .75” radius: ≈1.8K trap-depth
- Control and minimize possible X-ray production
- Expect **factor of ~15 increase** in signal (molecular flux)



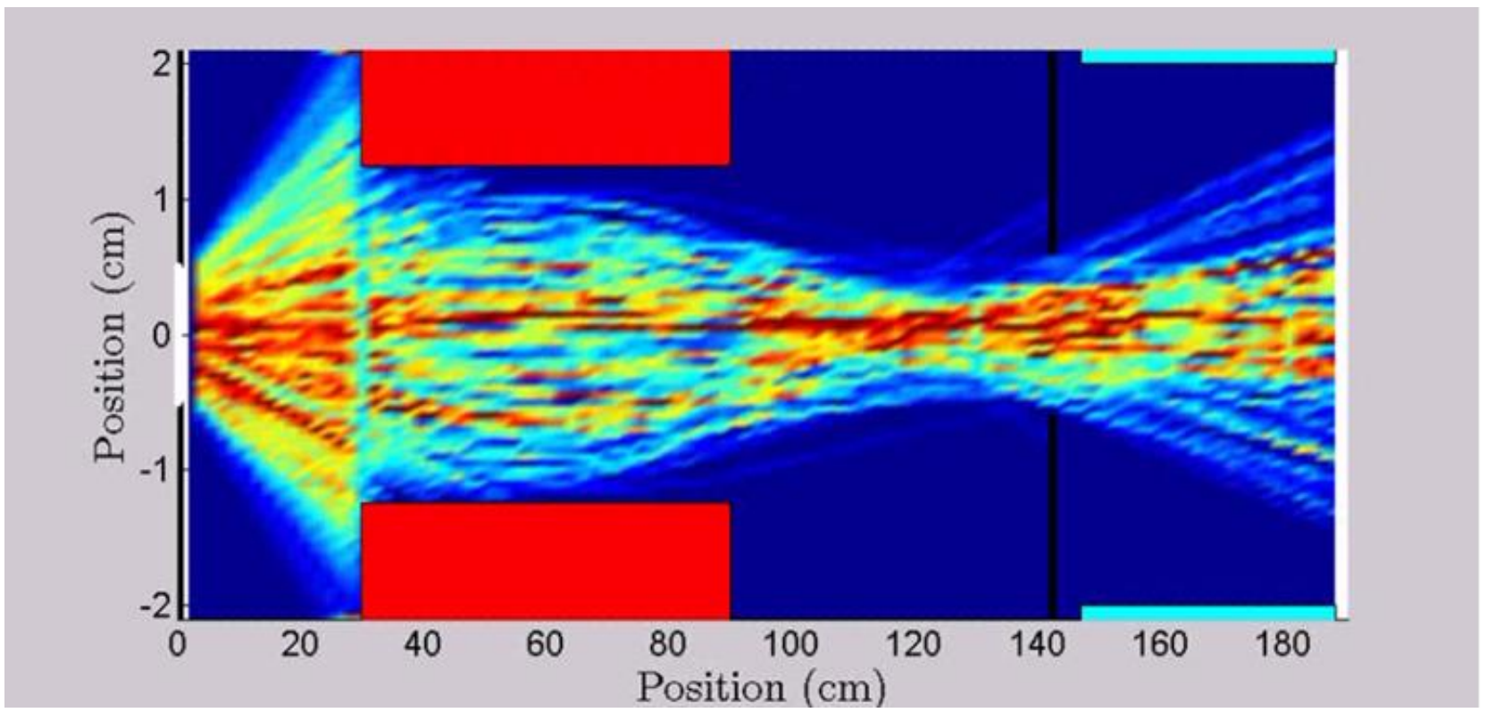
DC Stark shift of Q state

D_Q=4.1D from measurement



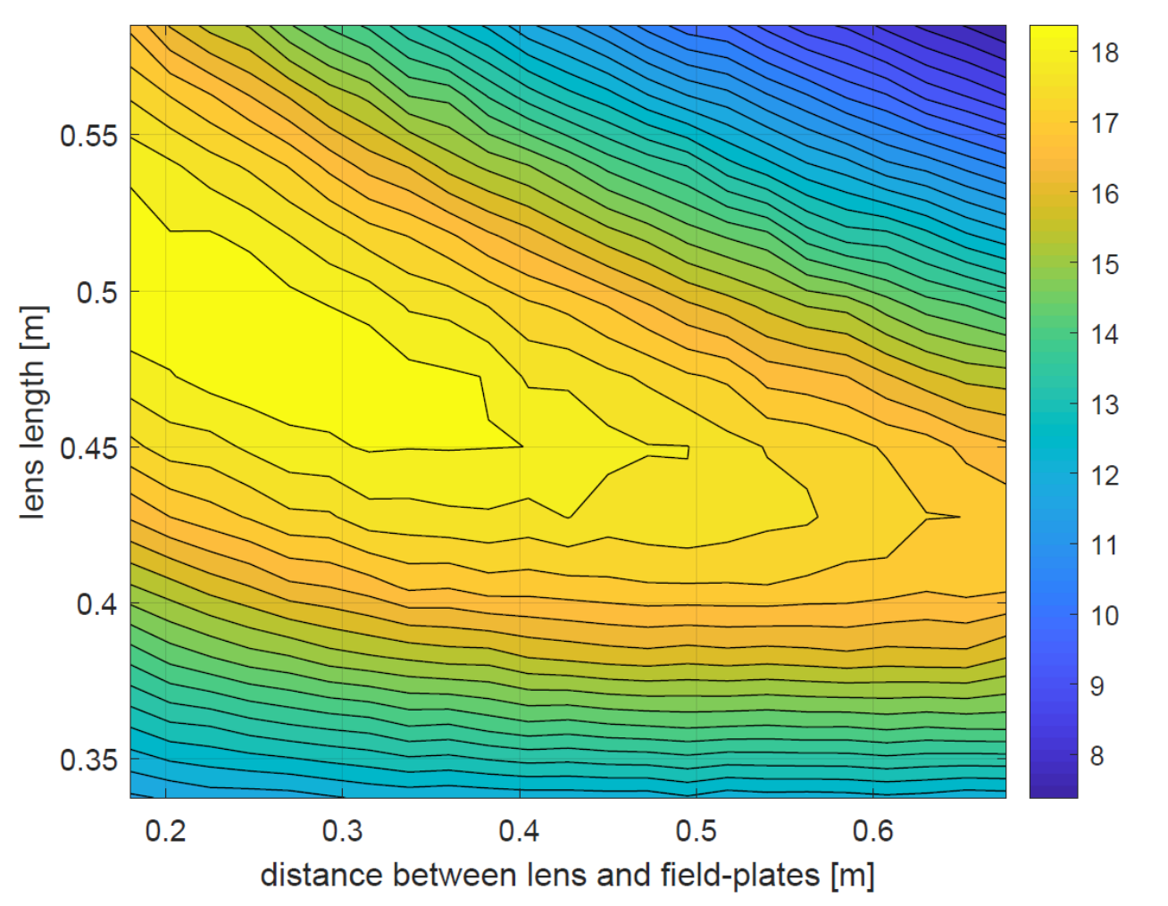
1.8 K trap-depth at 35.4kV/cm

Trajectory simulation for molecular lens design



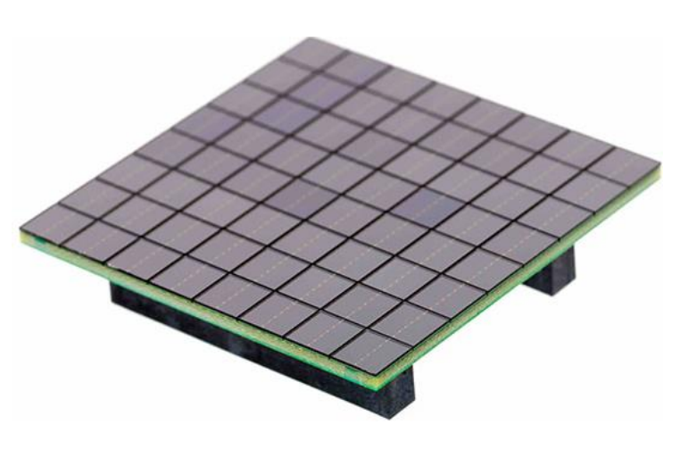
Simulation of molecule focusing with electrostatic lens. Red is lens, black is collimator

Molecular flux enhance for ACME II interaction length



Increase quantum efficiency

- Silicon photomultipliers (SiPMs) for more efficient fluorescence detection
- PMTS ~25% efficient. SiPMs ~ 50%, giving **factor ~2 increase** in signal
- **Challenge:** large dark current, large capacitance (slow), unstable gain
- **Solution:**
  - Custom high-gain, low-noise, high-bandwidth amplifiers
  - moderately low temperature (-20 C°) suppresses dark current sufficiently
  - with nonimaging optical concentrator (Winston cone)
  - dynamically adjust bias voltage and temperature for stable gain



large-area SiPM array

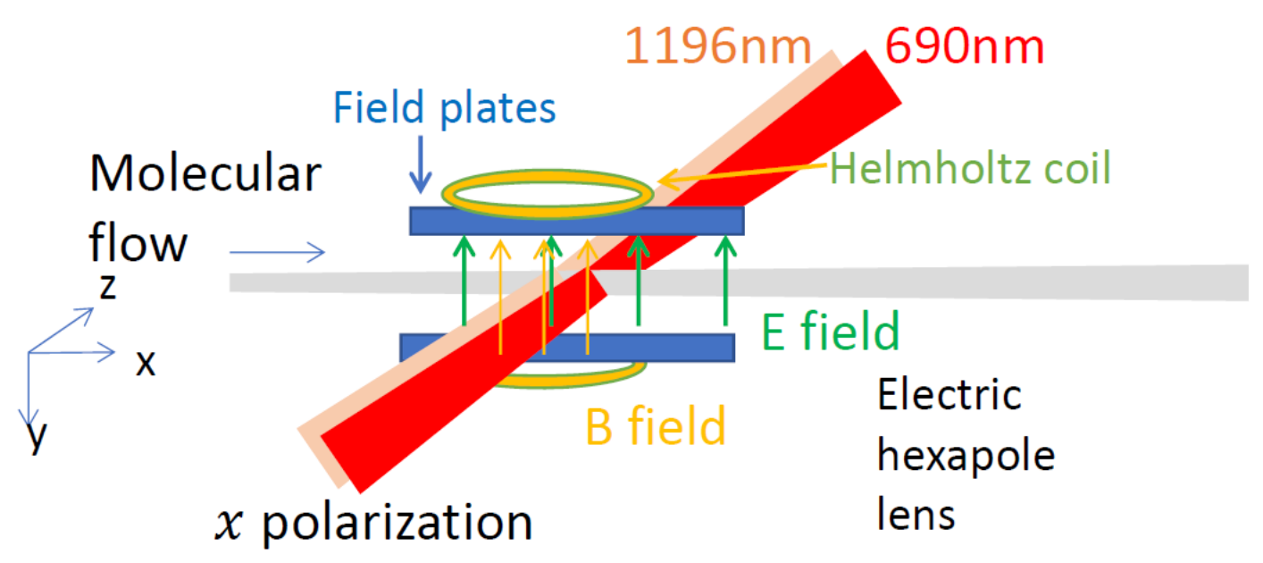
Demonstrate ‘double’ STIRAP between X and Q ($^3\Delta_2$) state of ThO

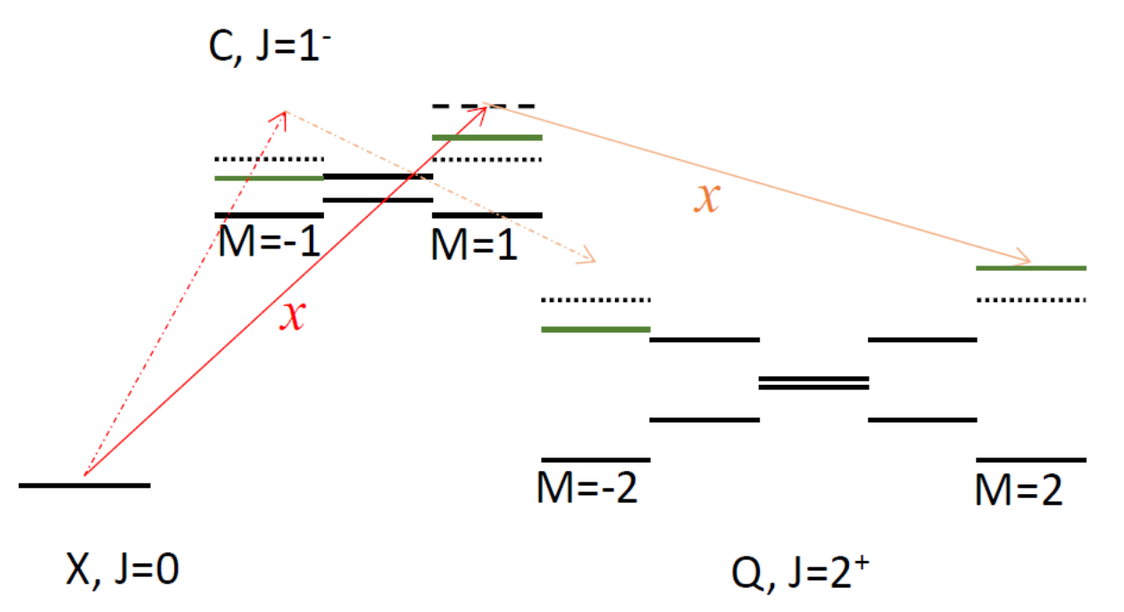
Scheme to prepare single M level in Q

More details see: X Wu *et al* 2020 *New J. Phys.* **22** 023013

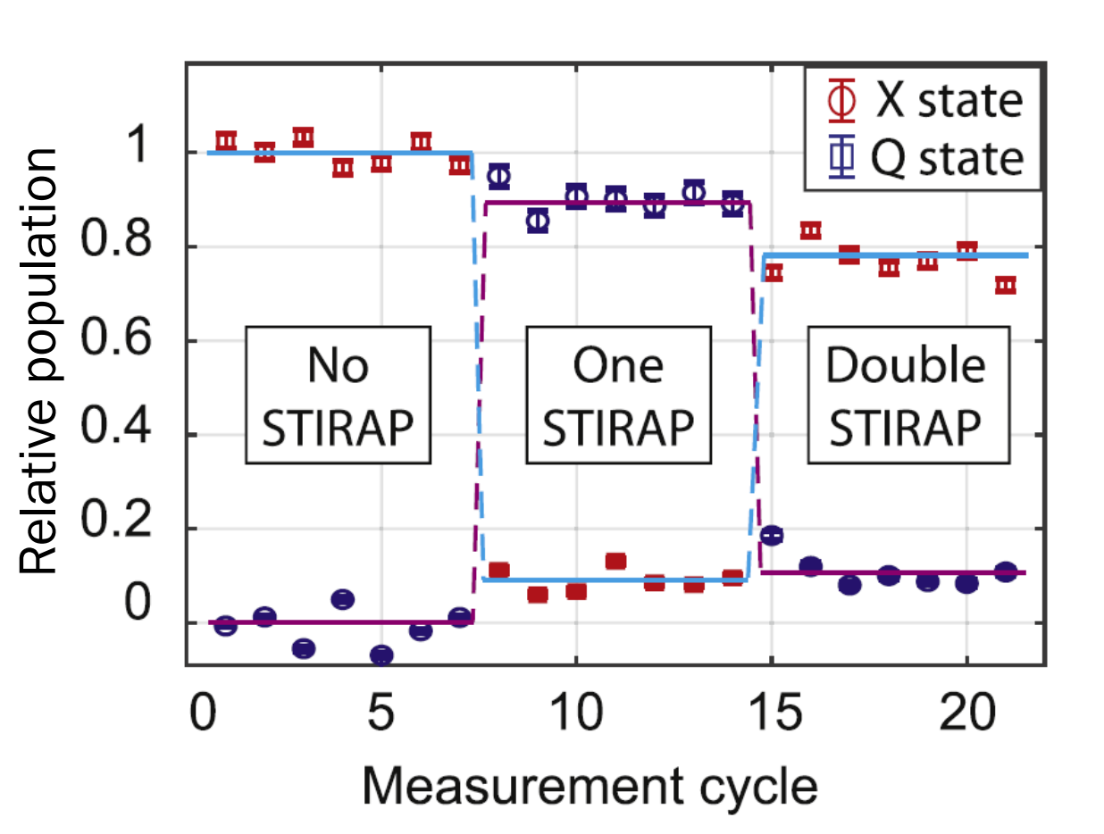
Main challenges:

- In a molecular beam: extended spatial and velocity distribution
- For molecular lens to work effectively, need to cover Δv_{tran} = ± 10m/s, i.e. FWHM 2-photon linewidth of 8MHz
- Complex ambient E and B field environment
- Need efficient STIRAP both before and after the Lens!

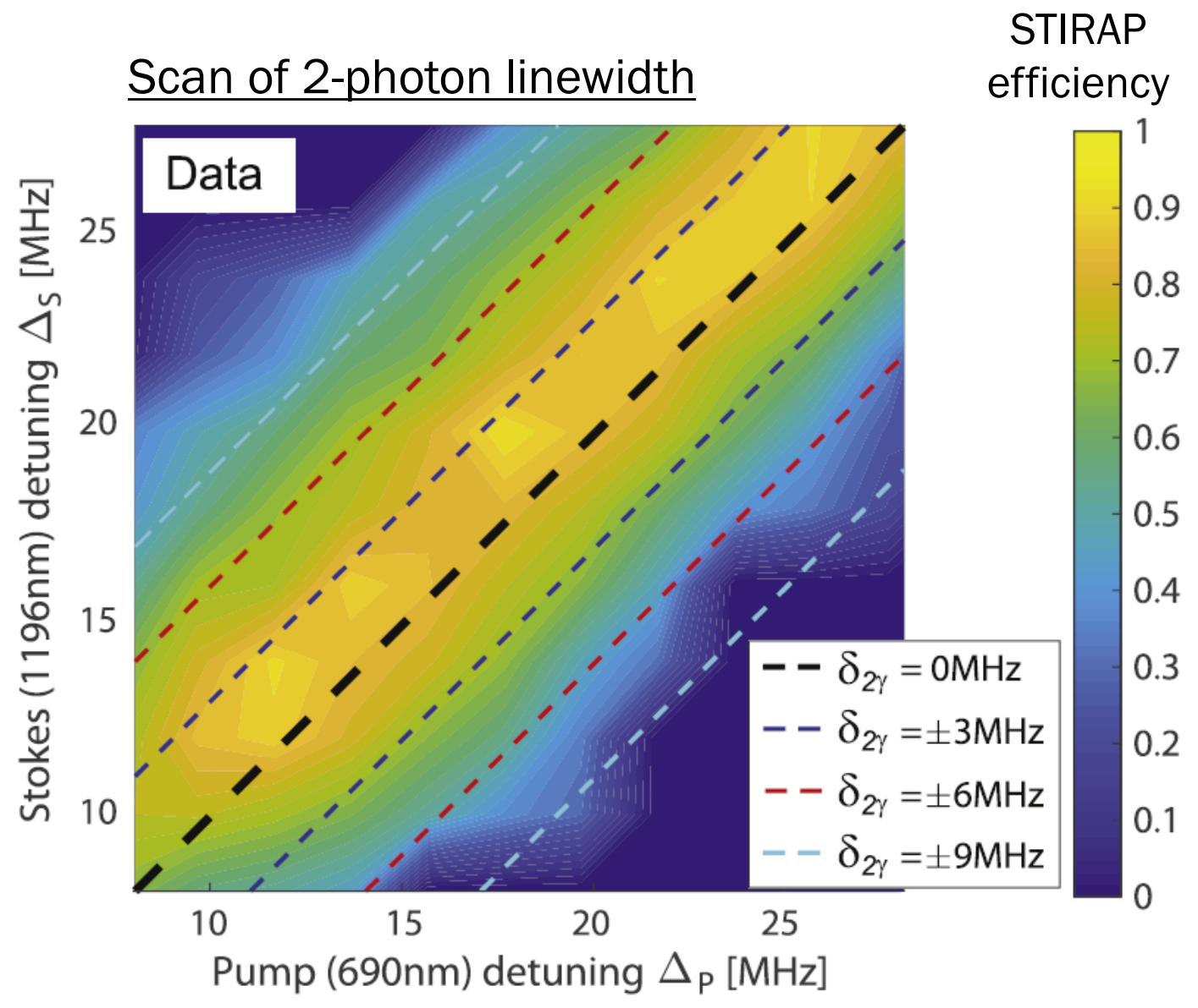




Demonstrate efficient two-way STIRAP

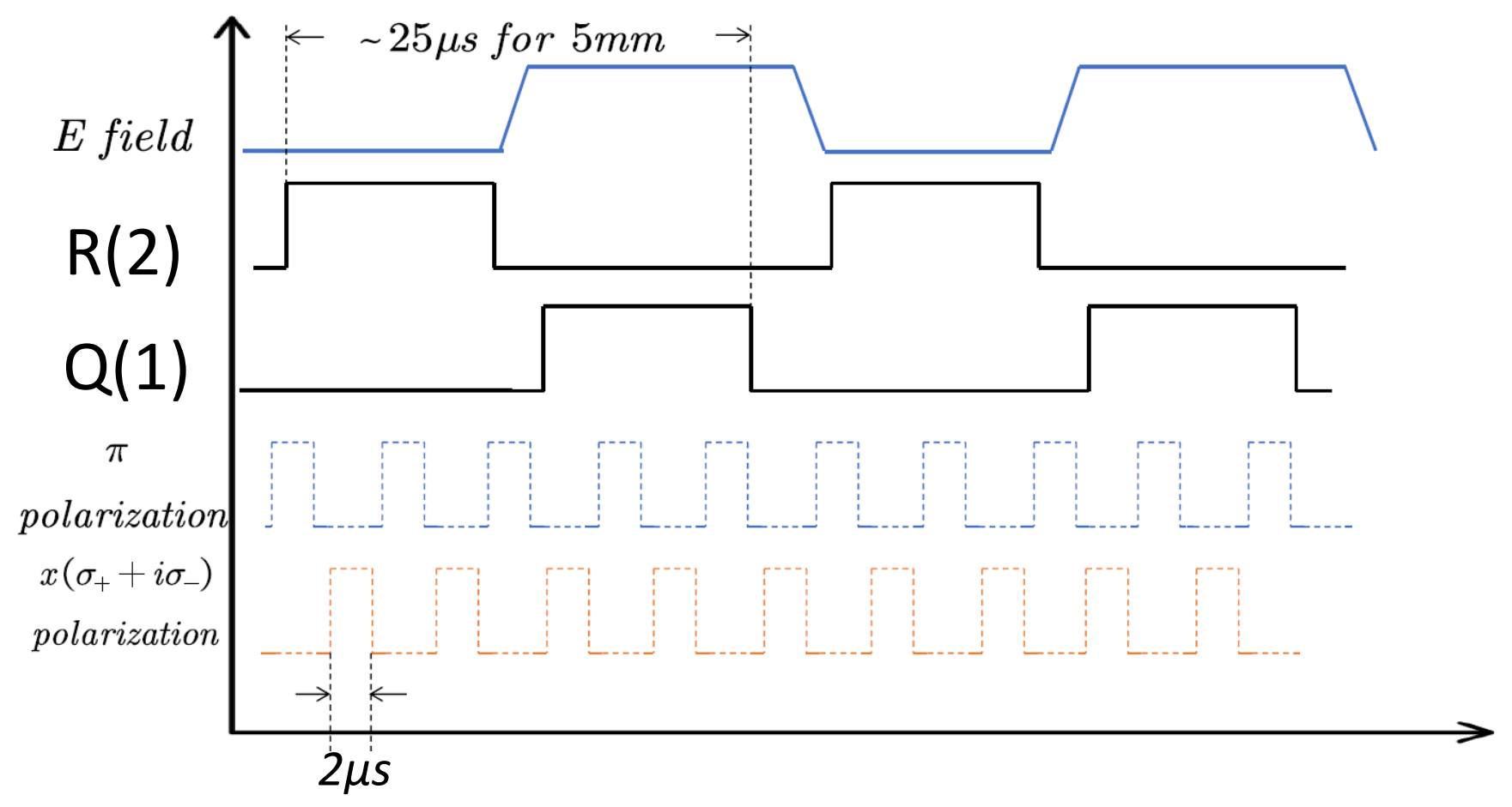


Scan of 2-photon linewidth



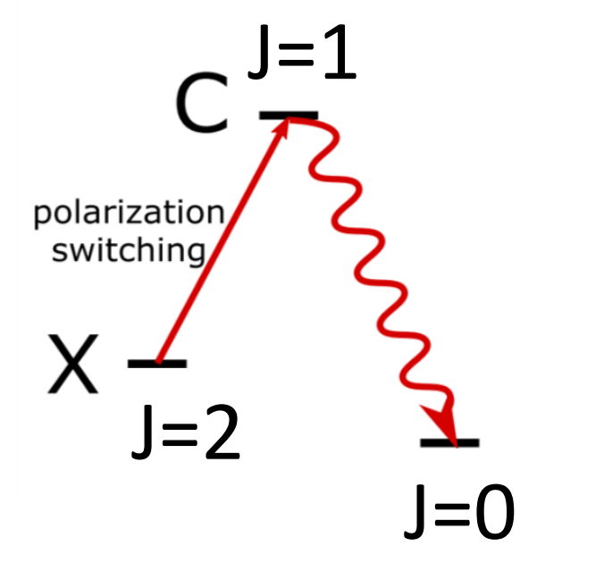
Compact rotational cooling stage

- Minimize the distance between source and Lens entrance, to increase the spatial acceptance into Molecular Lens



- Necessary to cover 15MHz FWHM Doppler distribution. Spectrally broadened by mixing 90 sidebands at 330kHz spacing (natural linewidth of C state).
- Single optical path for both rotational line, switch between frequencies, E field, and polarizations

E-field OFF



E-field ON