Progress toward a continuous molecular beam source for the ACME eEDM experiment

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Abstract: A slow high-flux beam of thorium monoxide (ThO) is an essential component of the ACME collaboration experiment to measure the electric dipole moment of the electron. The experiment currently employs a buffer gas cooled pulsed beam source of $\sim 10^{13}$ molecules sr^{-1} s^{-1} at 170 m/s in a single rovibrational level. We present progress toward the realization of a continuous source of ThO via a high-temperature reaction between Th and ThO_2. This source offers many potential advantages over the current pulsed ablation source, including higher fractional, peak, and time-averaged yields.

For More Information:

Hutzler et al., "A cryogenic beam of refractory, chemically reactive molecules with expansion cooling," *PCCP*, vol. 13, pp. 18976-18985, June, 2011.

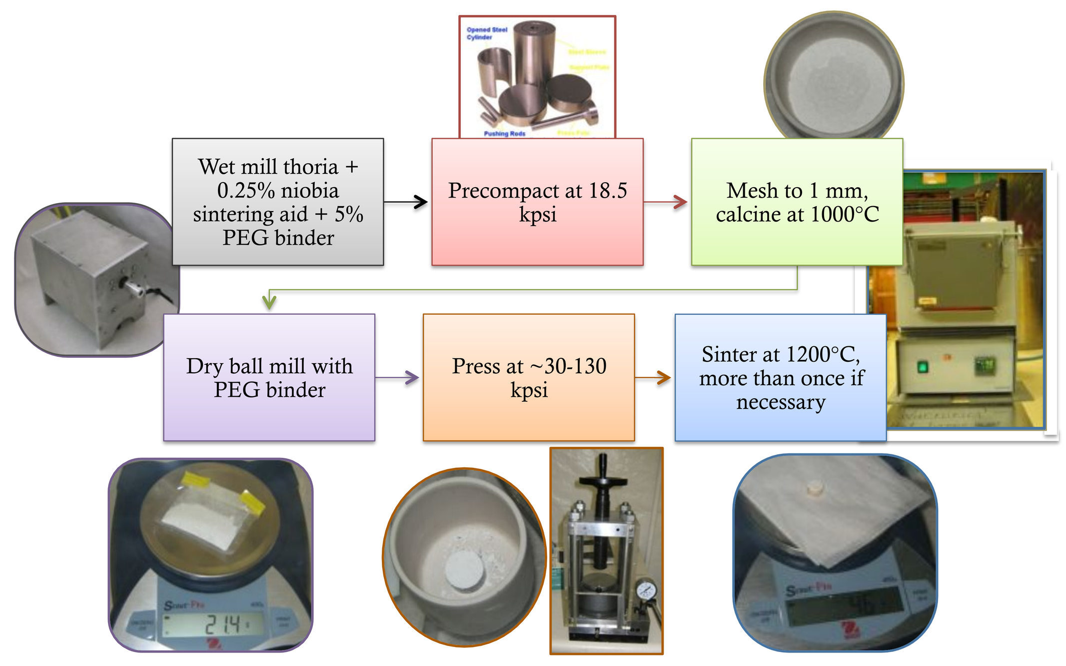
Hutzler et al., "An intense, cold, and slow source for atoms and molecules," *Chemical Reviews*, 112 (9), 4803-4827 2012.

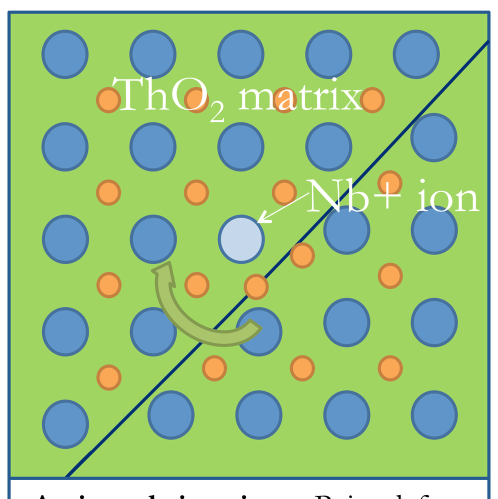
And Please Visit

ElectronEDM.info

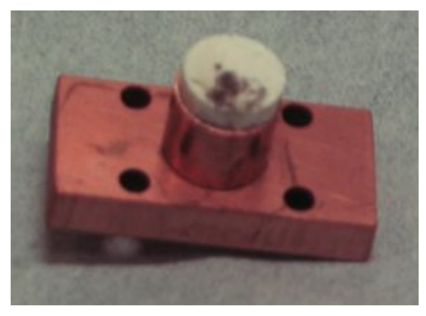
Generation I Beam Source

ThO is introduced into the cryogenic buffer gas cell by laser ablation of ThO_2, the stable solid oxide of thorium. ThO_2 is a highly refractory ceramic with a melting point of 3400˚C, so we use a technique for low-temperature sintering of thoria based on a recipe from Oak Ridge National Lab.





Activated sintering – Point defects facilitate diffusion of ions across grain boundaries



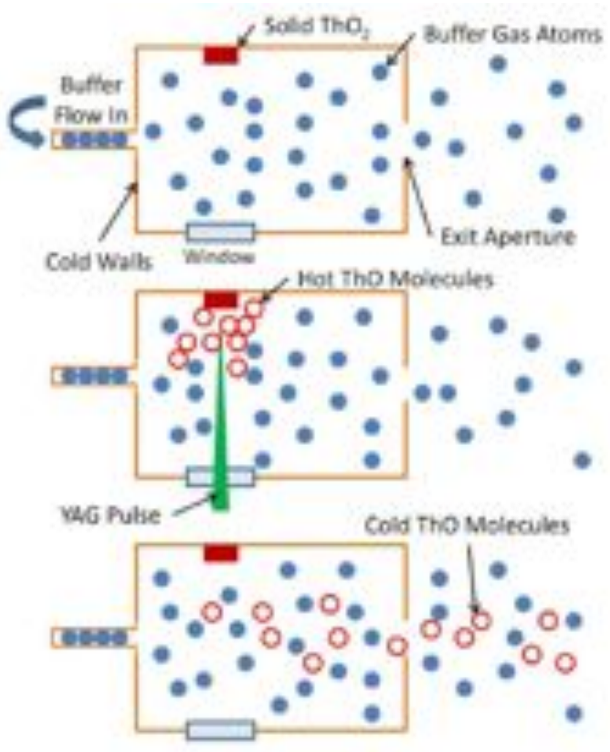
Finished Target Stats:
- Tough ceramic 65-85% of theoretical density
- Single ablation spot lasts for $\sim 10^{4\text{-}5}$ shots (50 mJ pulses)
- 5 gram target lasts for $>10^{7\text{-}8}$ shots (~5 months at typical duty cycle).

Buffer Gas Beam: A General Cold Molecule Source

For ACME experiment, molecule beam should be:

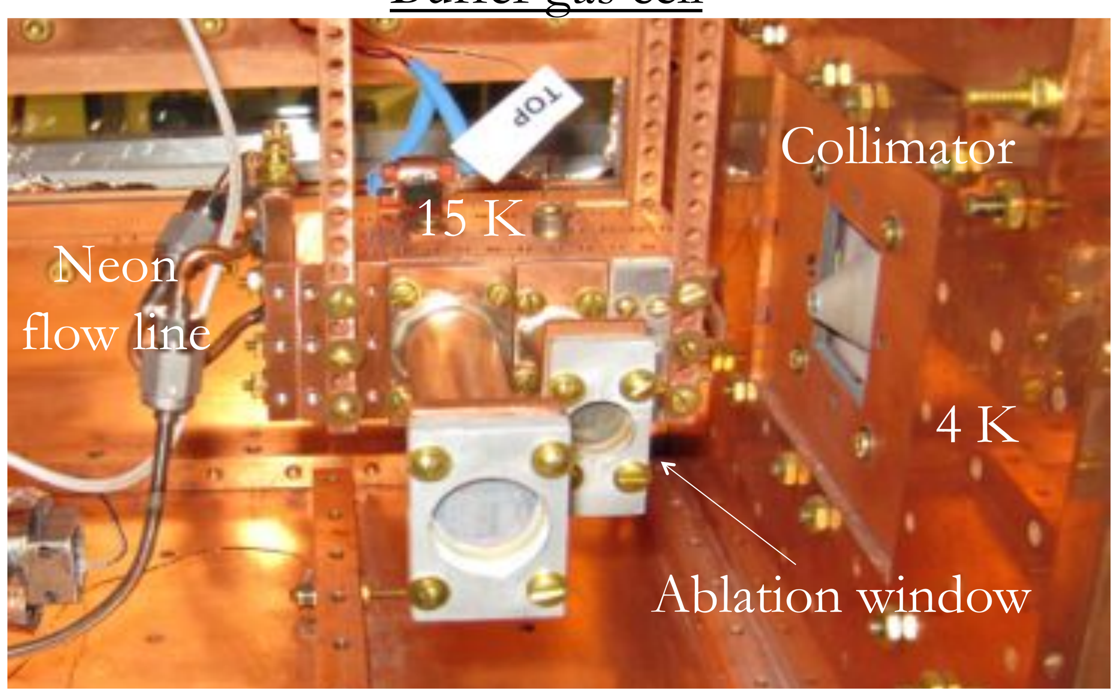
- **Slow** – reduces requirements for experiment length scale
  - Achieved: ~170 m/s
- **Cold** – improves per-quantum state fluxes
  - Achieved: ~3 K
- **Intense** – improves count rate for precision measurement
  - Achieved: $\sim 10^{13}$ s^{-1} sr^{-1}

Solution: Use a buffer gas beam



ThO Beam Intensity $= 3 \times 10^{13}$ sr^{-1} s^{-1} **per quantum state**

Buffer gas cell



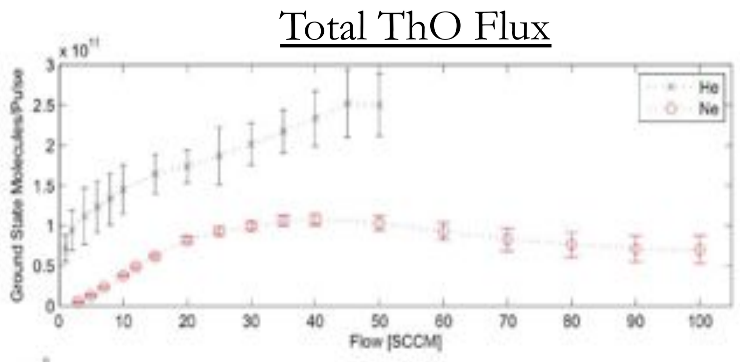
7 cm

Beams of reactive polar molecules

Species	Beam type	Intensity [s^{-1} sr^{-1}]	Velocity [m/s]
ThO	Buffer gas	3×10^{13}	170
ThO	Effusive	1×10^{11}	540
SrF	Buffer gas	1.7×10^{12}	140
SrF	Effusive	5×10^{11}	650
YbF*	Supersonic	$\sim 5 \times 10^{10}$	290
BaF	Supersonic	1.3×10^{10}	500
CaH	Buffer gas	5×10^{9}	40

Source: Hutzler et al., *Chemical Reviews*, 112 (9), 4803-4827 2012., *Hinds, private communication

Total ThO Flux



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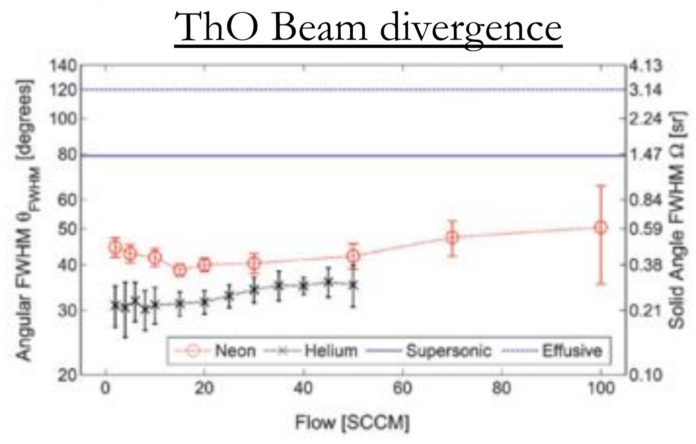
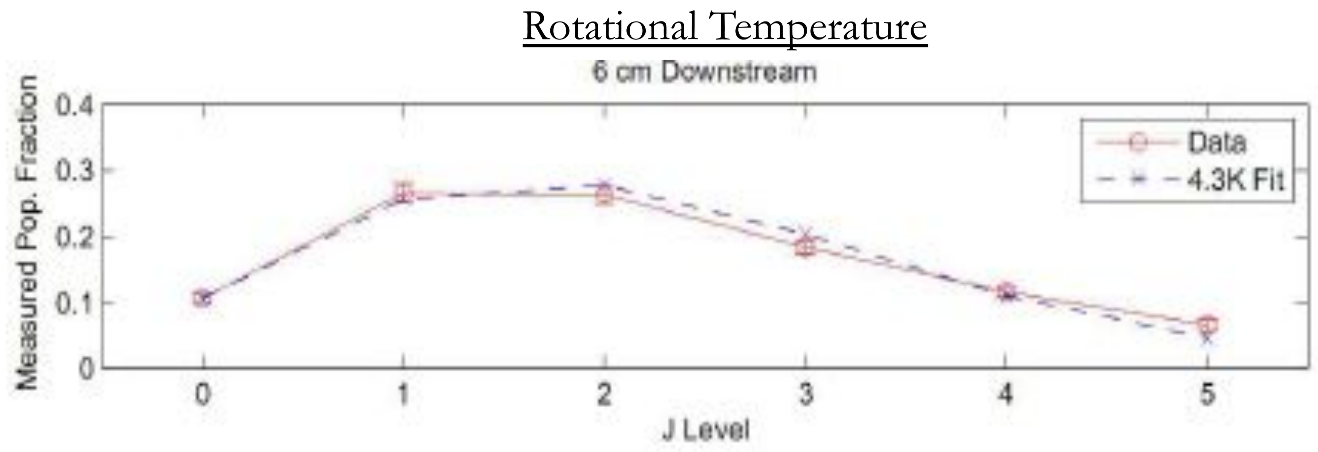
ThO Beam divergence



= Beam Intensity

Rotational Temperature



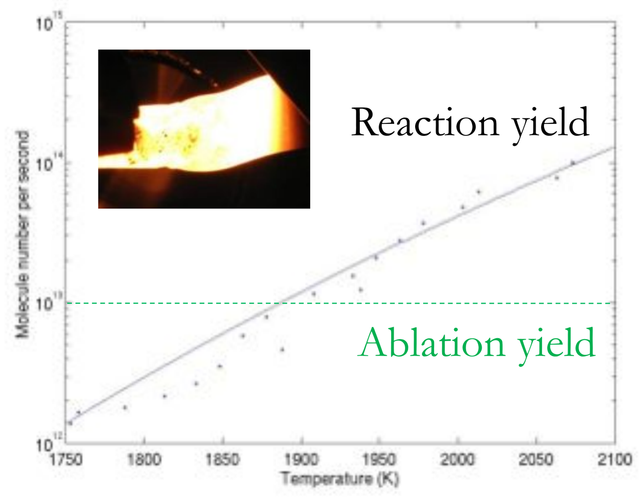
Generation II: Thermochemical Source

- Use high temperature reaction

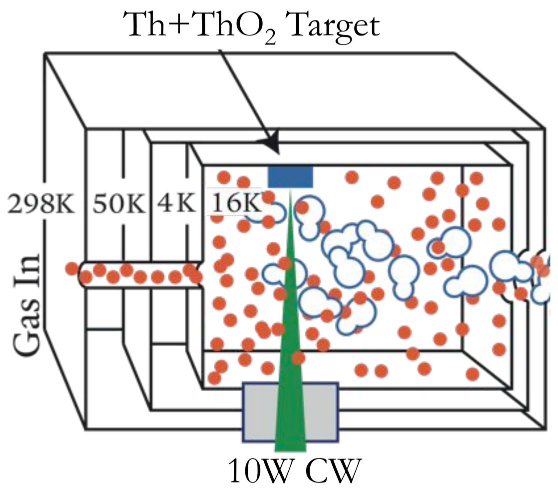
$$Th(s)+ThO_2(s) \leftrightarrow 2ThO(g)$$

- Reaction begins taking place at ~2000K [1]
- **Advantages over ablation:**
  - (Potential) higher peak and time-averaged yields
  - Higher duty cycle
  - Greater experimental timing control
  - Fewer unwanted byproducts

[1] Darnell, McCollum. Atomics International, (1961).

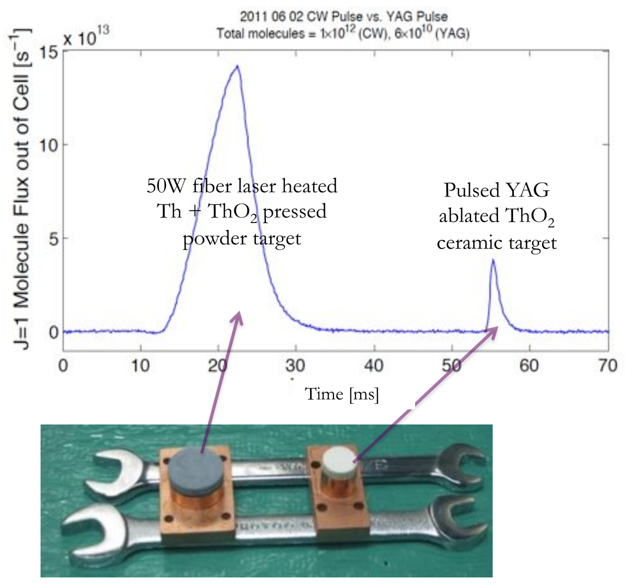


Our estimated yields compare favorably with ablation yields above 2000 K.



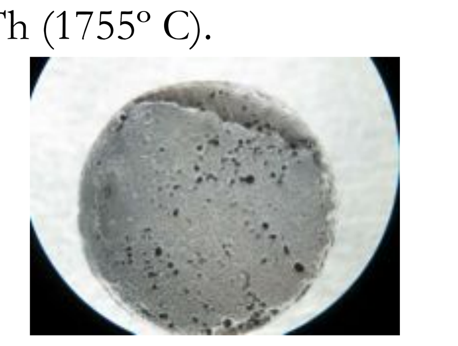
A new buffer gas loading technique

CW laser (10W) heating of thermochemical source in cyrogenic buffer gas cell



We have seen evidence that thermochemical source results in higher peak and time-averaged ThO yields

ThO_2 has been shown to dissolve in molten Th metal, so we plan to sinter Th $+ThO_2$ targets slightly below the melting point of Th (1755° C).



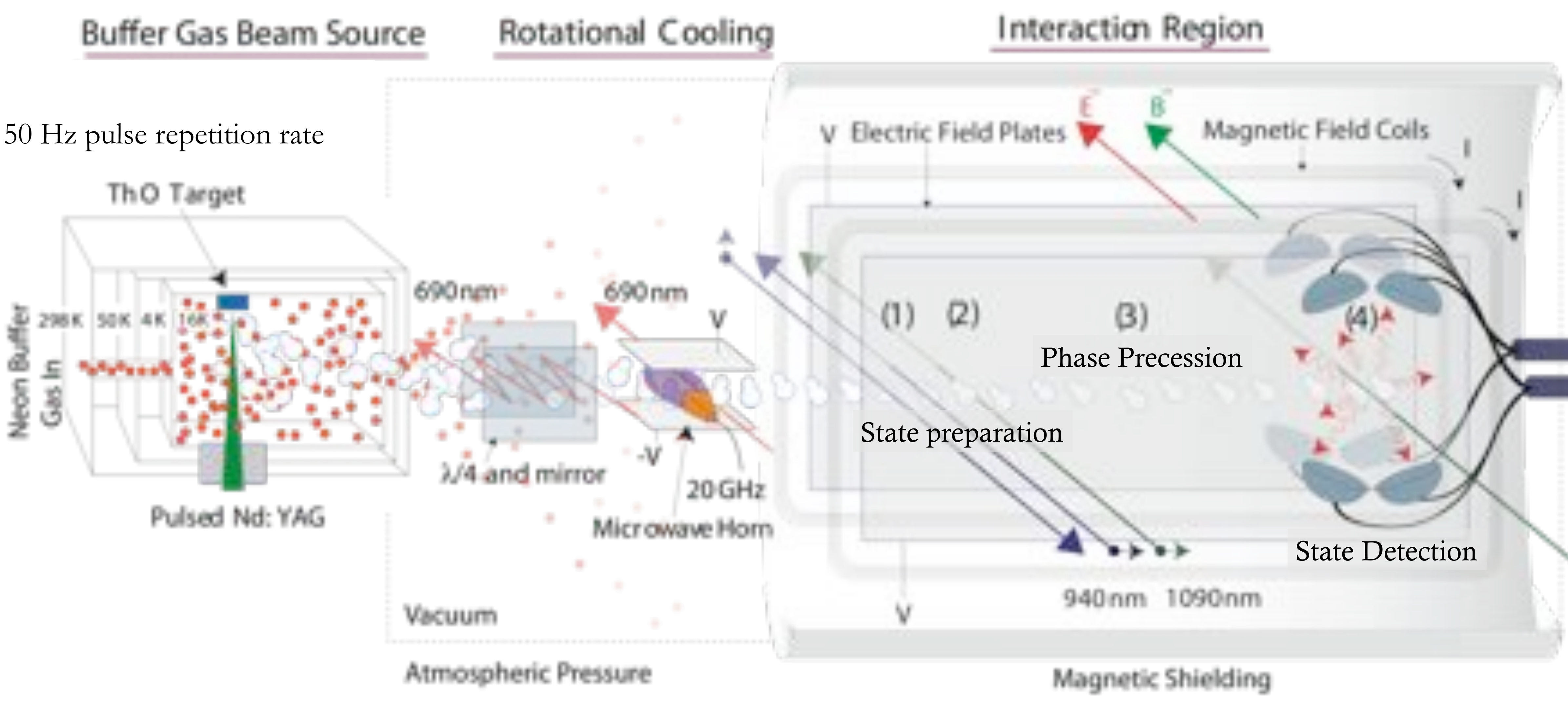
Current Status:

In the process of characterizing and optimizing new beam source.

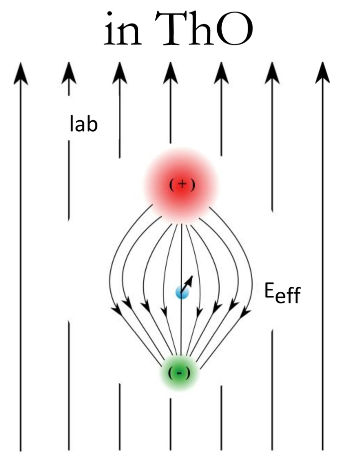
ACME eEDM Experiment Preview

See posters 25 and 28 for more information!

50 Hz pulse repetition rate



Electron EDM interacting with fields in ThO



- A nonzero electron EDM would be the first empirical evidence of CP violation that cannot be explained by the Standard Model.
- The electron EDM precesses around the internal electric field of ThO. ACME performs a Ramsey fringe experiment to read out the precession angle.
- The experimental sensitivity scales as:

$$\delta d_e = \frac{1/\tau_c}{2\,\mathcal{E}_{mol}\sqrt{NT}}$$

where τ_c is the precession time, E_{mol} is the internal electric field of the molecule and dN/dt is the number flux of molecules.

New beam source offers potential for significant improvements.