Photon Polarization and Photon-Atom Entanglement in Atomic Yb

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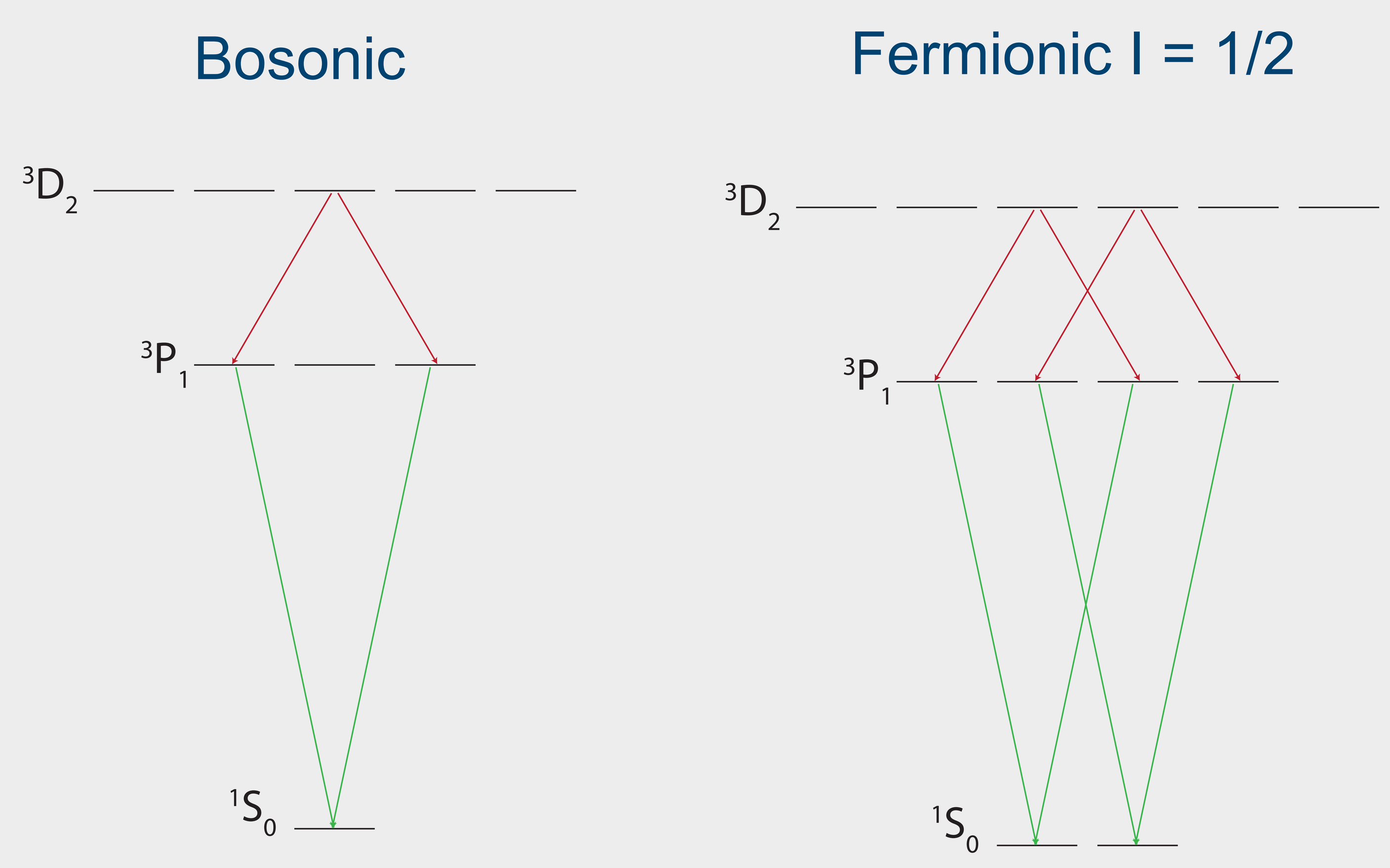
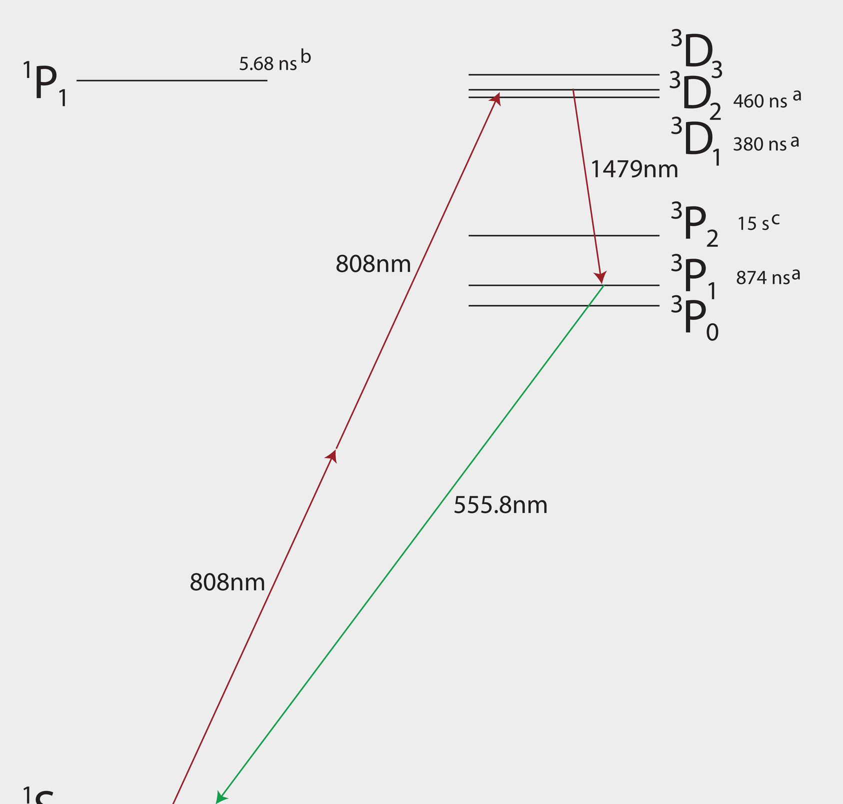
70 $^1S_0$
Yb
Ytterbium
173.04
$[Xe]4f^{14}6s^2$

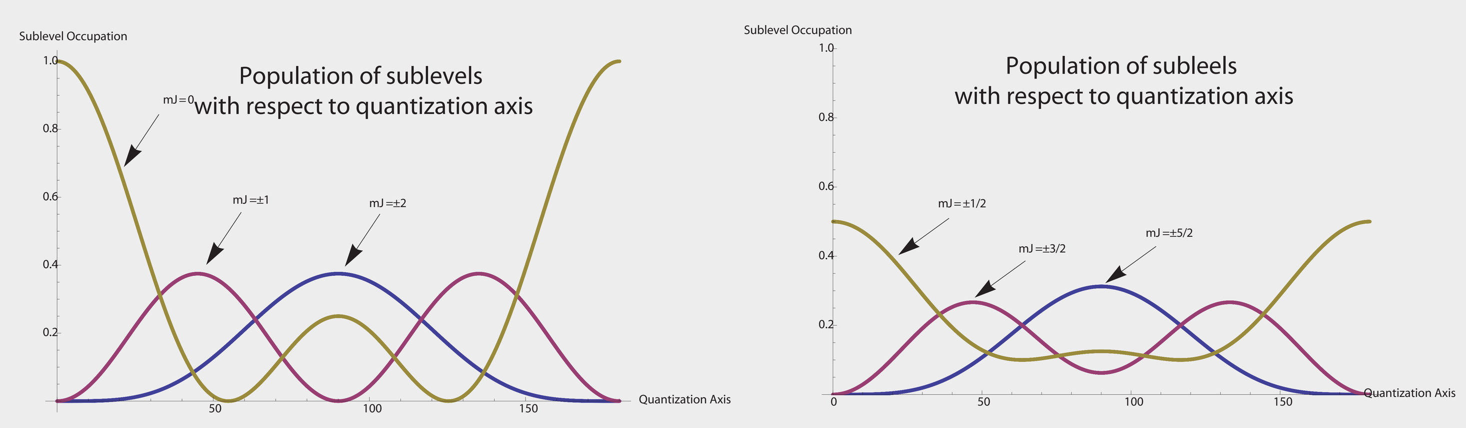
Atomic Yb Structure

The basic structure of Yb allows for the generation of entangled states of either two photon polarizations or photon polarization with atomic spin.





Lifetime data
a) Bowers, Phys. Rev. A 53, 3103 - 3109 (1996) - EXP
b) K.B. Blagoev and V.A. Komarovskii, At. DNucl. D Tables 56, 1 (1994) - EXP
c) Porsev, Phys. Rev. A 60, 2781 - 2785 (1999) - THEORY

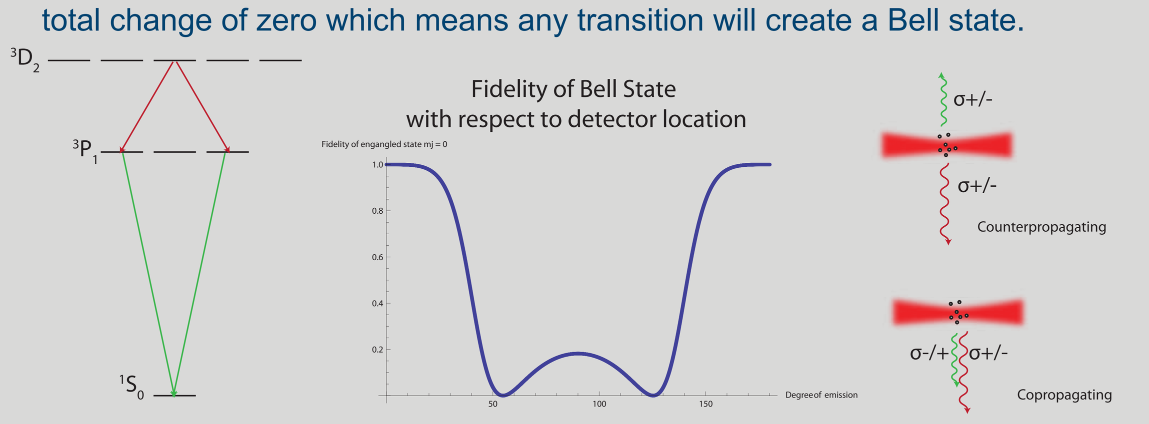


Photon Polarization Entanglement

The polarization of two photons can be entangled in Bosonic or Fermionic Yb. This is done deterministically in the case where the photons are co- or counter-propagating along the quantization axis for a known initial state population.

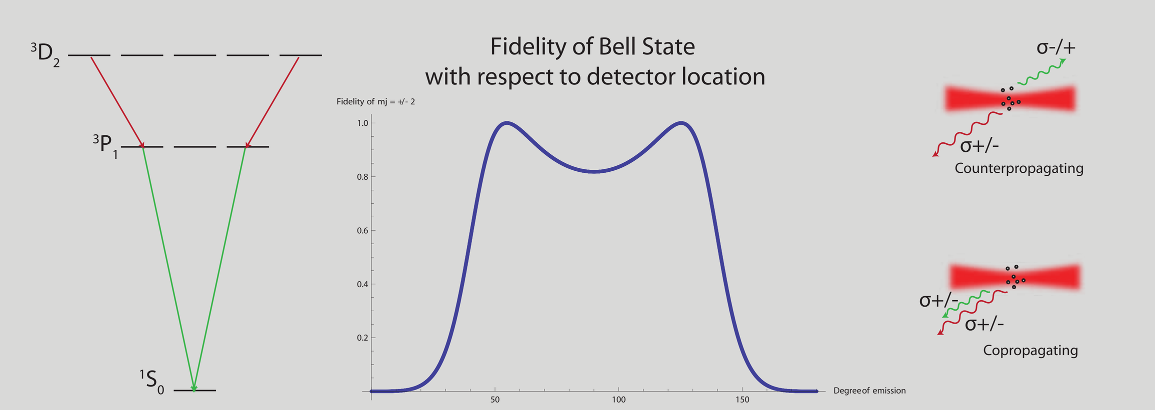
$$|\Psi^+> \;=\; |LR> + |RL>$$

Photons initially in the mJ = 0 sublevel of the excited state will end up in the mJ=0 sublevel of the ground state. Photons along the quantization axis change the angular momentum of the atom, but they are constrained to a total change of zero which means any transition will create a Bell state.



$$|\Phi^+> \;=\; |LL> + |RR>$$

Photons in the mJ = +/-2 sublevels of the excited state will alsoend up in the mJ=0 sublevel of the ground state after two photon decays. In this case they must have a total change of +/-2 and will again create a Bell state.



Collection Rates

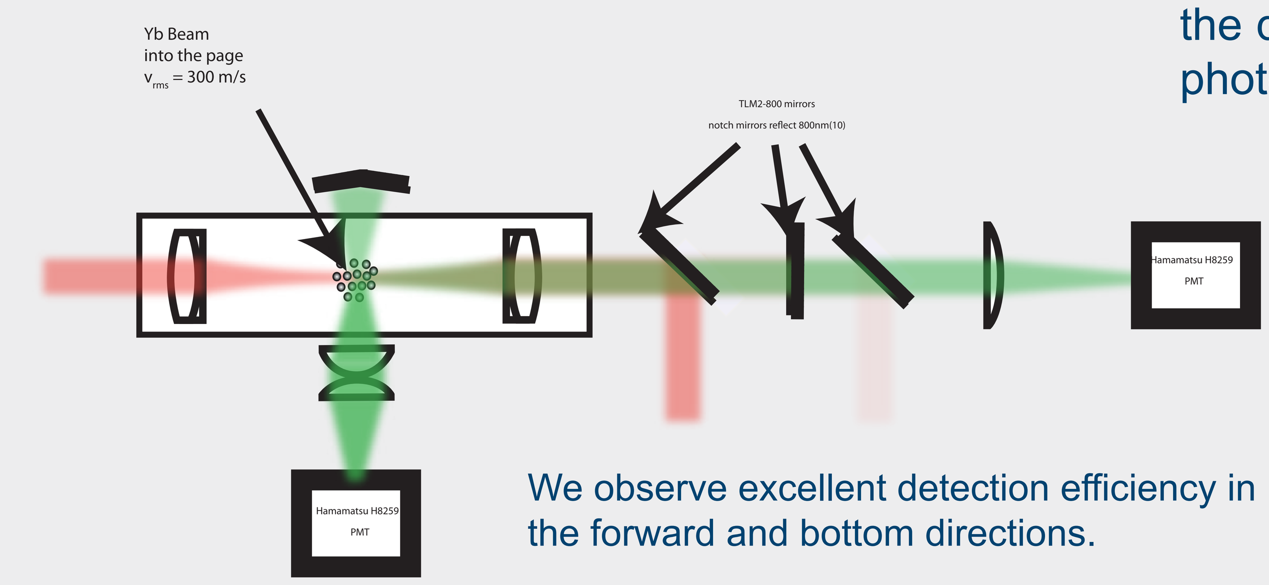
While the structure of Yb is ideal for generating correlated photon pairs, to guarantee the excited state is only populated in the mJ=0 sublevel limits where we can place detectors. For the $|\Psi^+>$ Bell state, only 1% of radiated photon pairs are radiated in an angular region with acceptable fidelity. For the $|\Phi^+>$ Bell state, 14% of photon pairs are radiated in an angular region with acceptable fidelity.

References

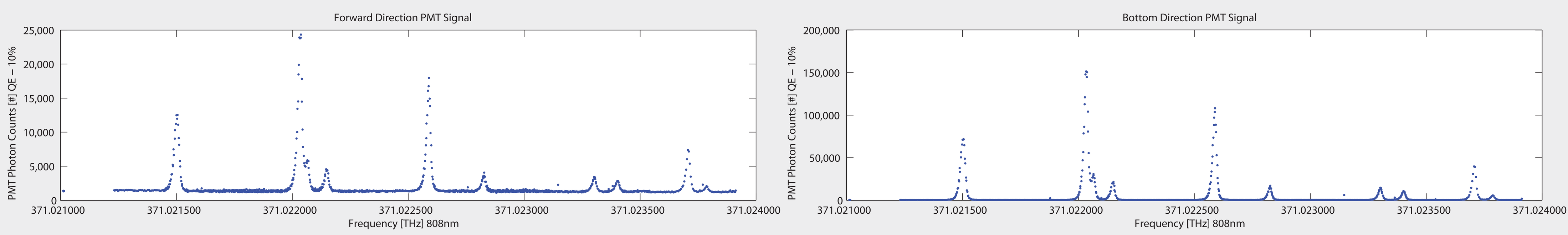
[1] Edamatsu, "Entangled Photons: Generation, Observation, and Characterization" Japanese Journal of Applied Physics 46, 7175 (2007)
[2] Blinov, BB; Moehring, DL; Duan, LM; Monroe, C. (2004) "Observation of entanglement between a single trapped atom and a single photon." Nature 428(6979): 153-157
[3]F. E. Becerra, R. T. Willis, S. L. Rolston, and L. A. Orozco, "Nondegenerate four-wave mixing in rubidium vapor: the diamond configuration," Phys. Rev. A 78, 013834 (2008).
[4]R. T. Willis, F. E. Becerra, L. A. Orozco, and S. L. Rolston, "Four-wave mixing in the diamond configuration in an atomic vapor," Phys. Rev. A 79, 033814 (2009)
[5]E. S. Fry, "Two-Photon Correlations in Atomic Transitions,"Phys. Rev. A 8, 1219 (1973)

$^1S_0 \rightarrow {^3D_2}$ Two Photon Transition

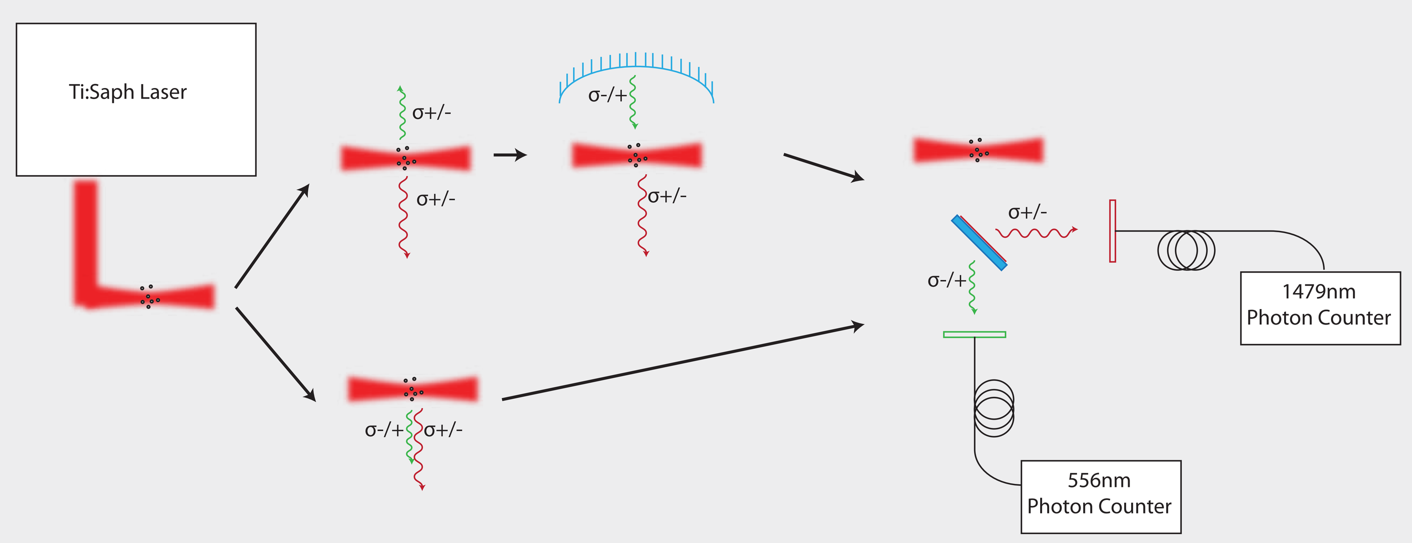
The single level gournd state of Bosonic Yb and the degenerate ground state of Fermionic Yb allows for the deterministic generation of polarization correlated photons and photon-atom entanglement.



We observe excellent detection efficiency in the forward and bottom directions.



Isotopes	MHz Offset
173 1/2	2390
171 5/2	2234
173 3/2	1625
170	1431
173 5/2	474
172	0
173 7/2	887
174	1111
171 3/2	1054
176	2159
173 9/2	2189

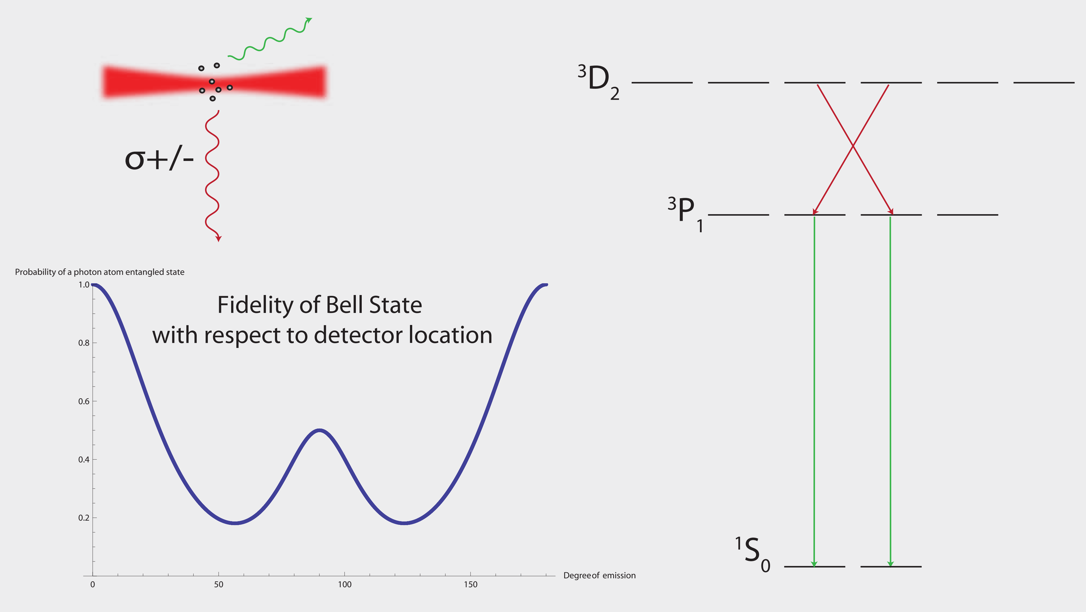


Our experimental setup drives the $^1S_0 \rightarrow {^3D_2}$ transition, which can be detected through a 1479nm and a 556nm photon. The alignment of these photons with respect to the quantization axis determines the entanglement of the photons.

Photon Polarization and Atomic Spin Entanglement

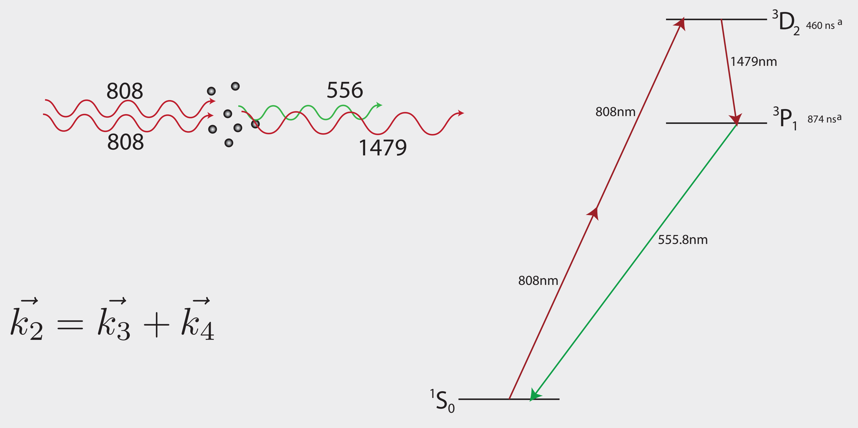
The polarization of two photons can be entangled in Fermionic Yb 171, I = 1/2. This is done deterministically in the case where one photon propagates along the quantization axis, and the other propagates perpendicular to the quantization axis.

$$|\Psi^+> \;=\; |L\uparrow> + |R\downarrow>$$



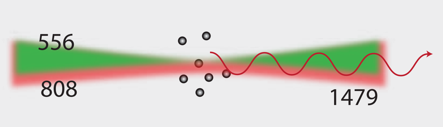
Four Wave Mixing in Yb Vapor

We propose to generate correlated photon pairs from thermal Yb atoms. Four photon processes must satisfy phase matching conditions. Given this condition we can determine the direction of emitted photons.



$$\vec{k_1} + \vec{k_2} = \vec{k_3} + \vec{k_4}$$

Our first step in this process will be to apply co-propagating 808nm and 556nm beams. This will produce 1479nm photons in the direction of laser light propagation.



$$\vec{k}_{808} + \vec{k}_{808} = \vec{k}_{556} + \vec{k}_{1479}$$