Neutron detection by laser-induced fluorescence in LHe

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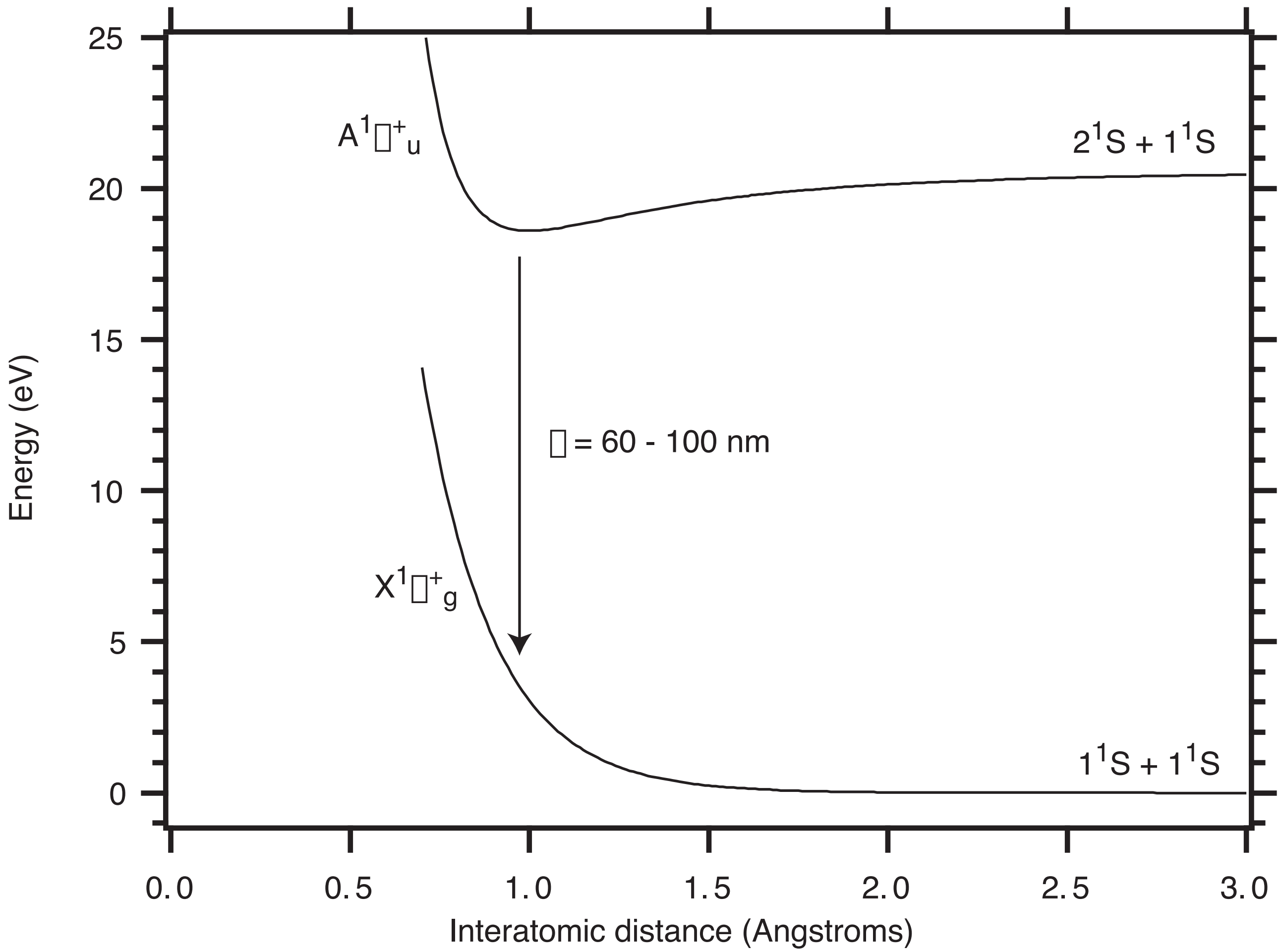
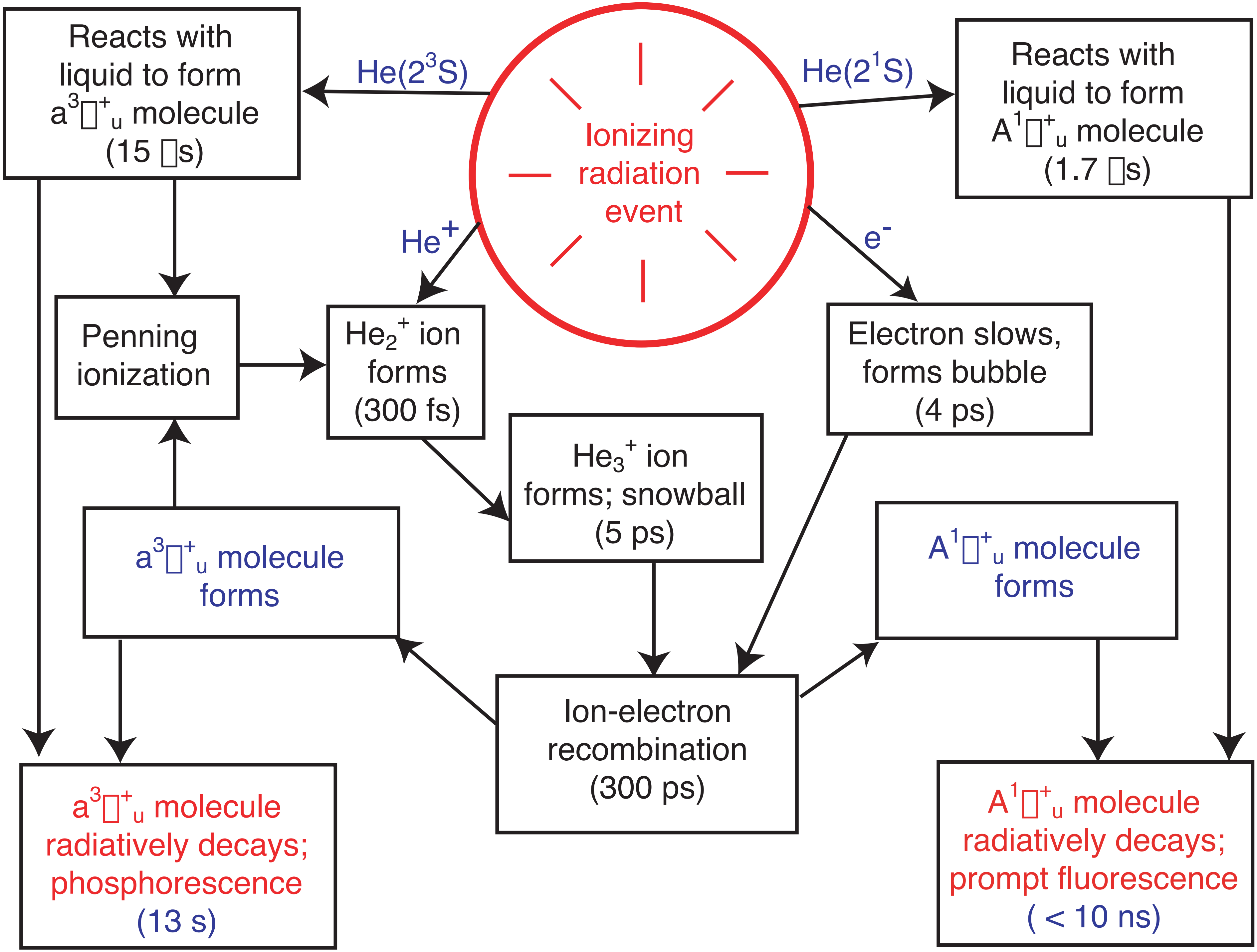
12/2/04



25
20
15
10
5
0
Energy (eV)
A^1□^+_u
$2^1S + 1^1S$
□ = 60 - 100 nm
X^1□^+_g
$1^1S + 1^1S$
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Interatomic distance (Angstroms)


Ionizing radiation event
He(23S)
He(21S)
He+
e-
Reacts with liquid to form a3□+u molecule (15 □s)
Reacts with liquid to form A1□+u molecule (1.7 □s)
Penning ionization
He2+ ion forms (300 fs)
Electron slows, forms bubble (4 ps)
He3+ ion forms; snowball (5 ps)
a3□+u molecule forms
A1□+u molecule forms
Ion-electron recombination (300 ps)
a3□+u molecule radiatively decays; phosphorescence (13 s)
A1□+u molecule radiatively decays; prompt fluorescence (< 10 ns)

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Radiative decay of the metastable $He_2(a\,^3\Sigma_u^+)$ molecule in liquid helium

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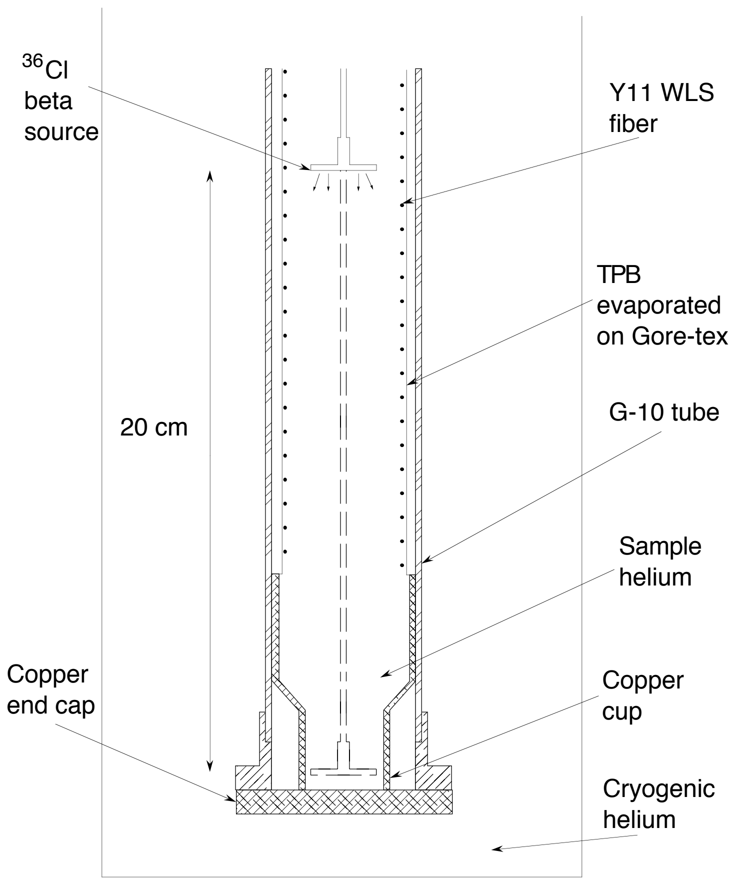


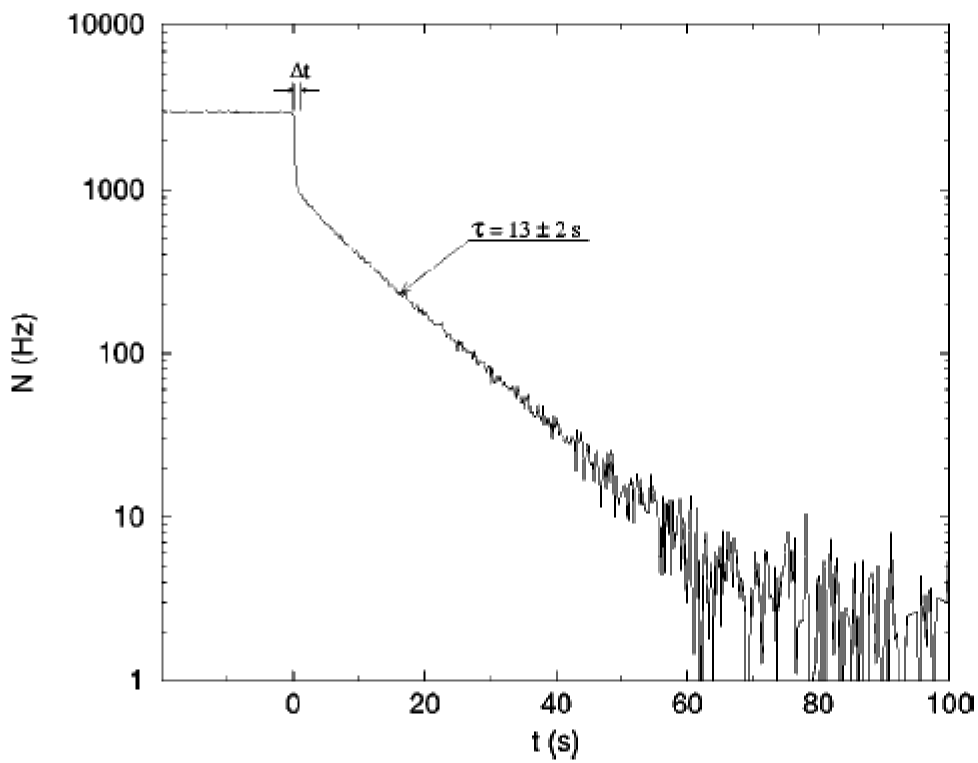
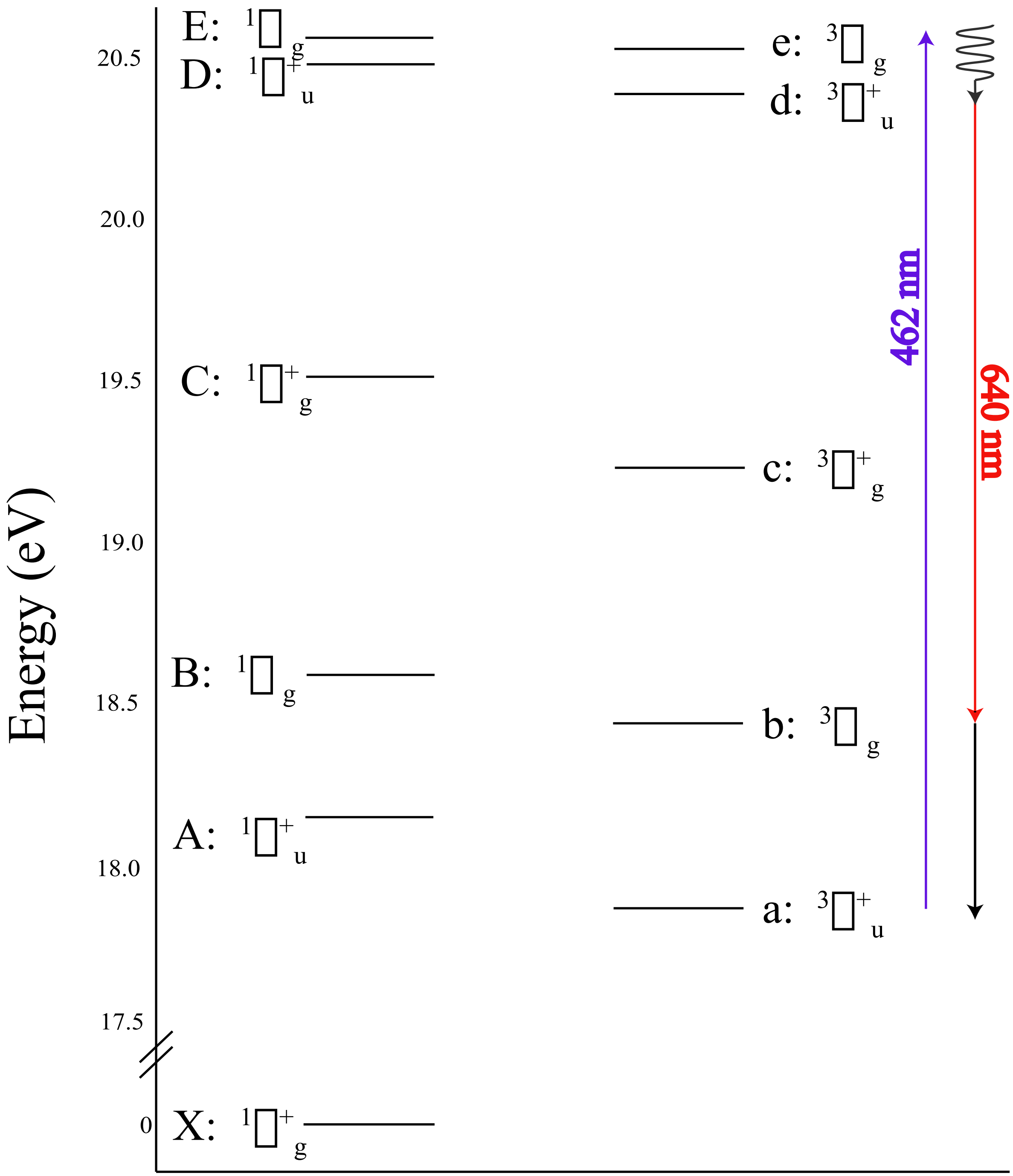


FIG. 2. Count rate N of detected $He_2(a\,^3\Sigma_u^+)$ decays versus time. A ^{36}Cl β source is placed in the center of the detection region and then removed in a time $\Delta t<1$ s. This measurement was performed at a temperature of 1.8 K and resulted in a measured decay rate τ of 13 ± 2 s.

Energy levels of He_2



How many scattered photons per neutron absorption event?

750 keV per event, 5% of energy goes into triplets -> 2000 triplets/event.

Assume laser power of 10 mW/cm^2

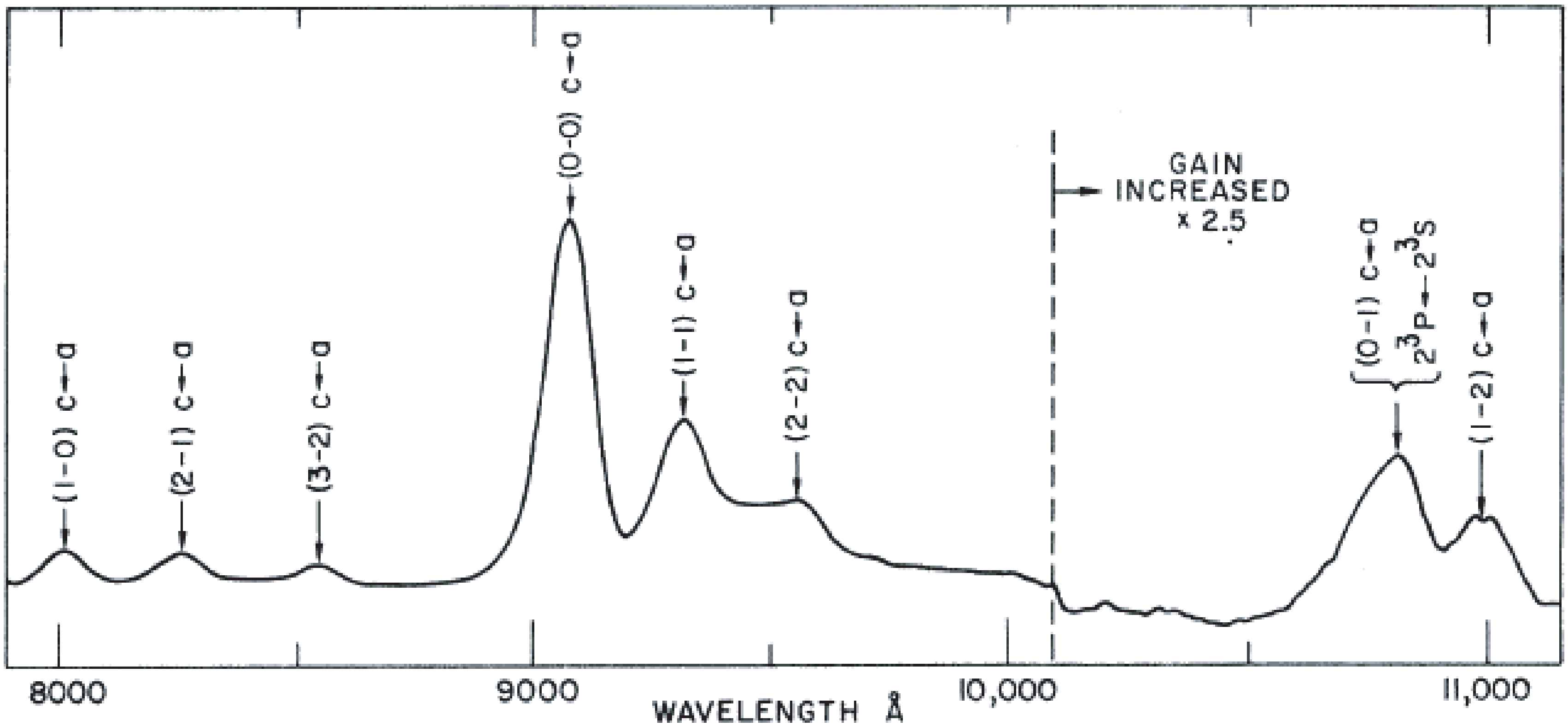
$\sigma = 2.4 \times 10^{-15}$ cm^2 (El'tsov et al, JETP 81, 909 (1995))

Scattering rate is then 400 photons s^{-1} molecule^{-1}

So we have (2000 molecules)(400 photons s^{-1} molecule^{-1}) = 8×10^5 photons s^{-1}

Absorption spectrum of electron-excited liquid helium

J. C. Hill et al, Phys. Rev. Lett. 26, 1213 (1971).



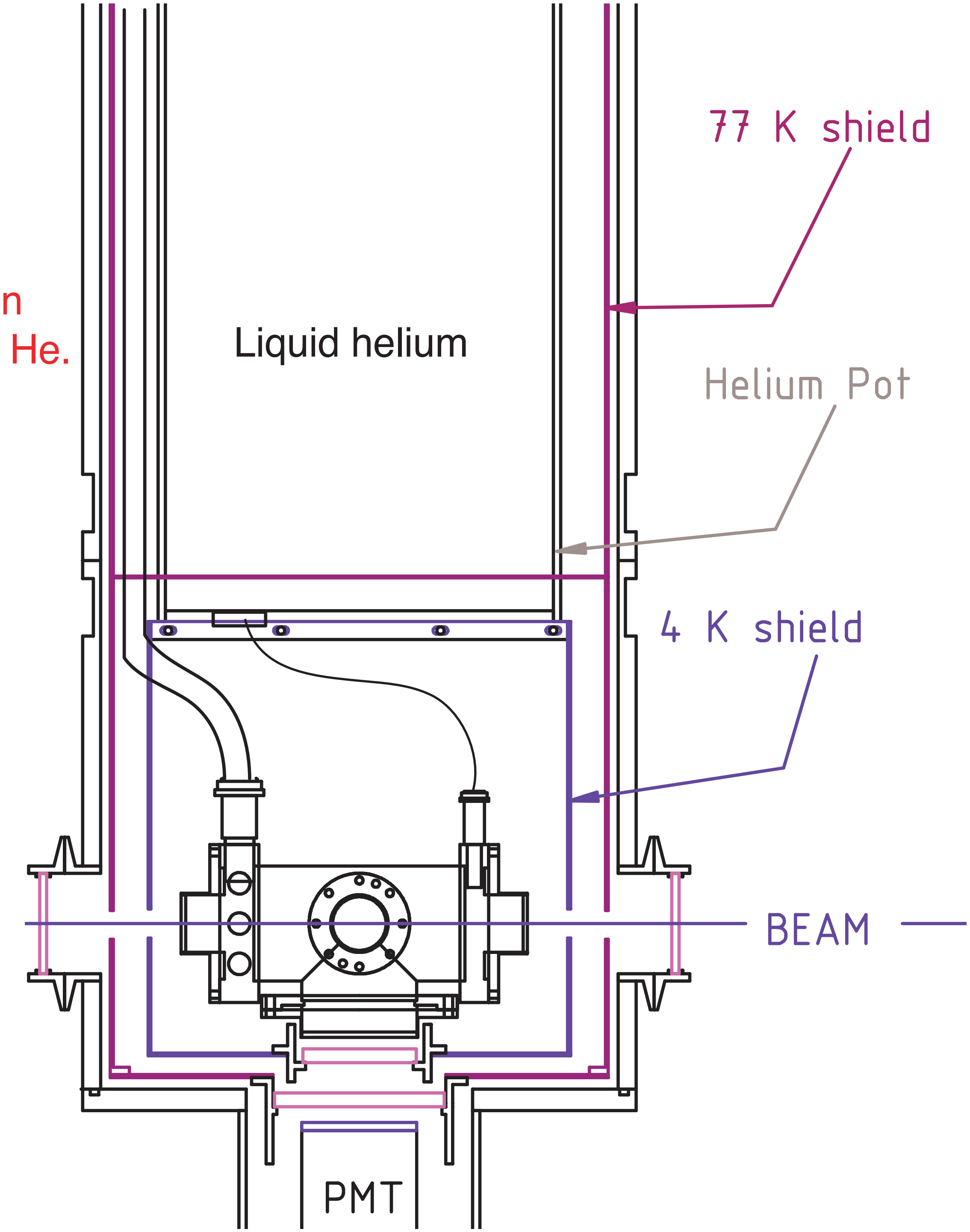
Strong absorption at 910 nm: c-a transition, 0-0 vibrational
Other vibrational transitions available, including 1-0 at 1070 nm for repumping
(otherwise vibrational relaxation lifetime is 140 ms)

Superfluid helium system under construction at Yale

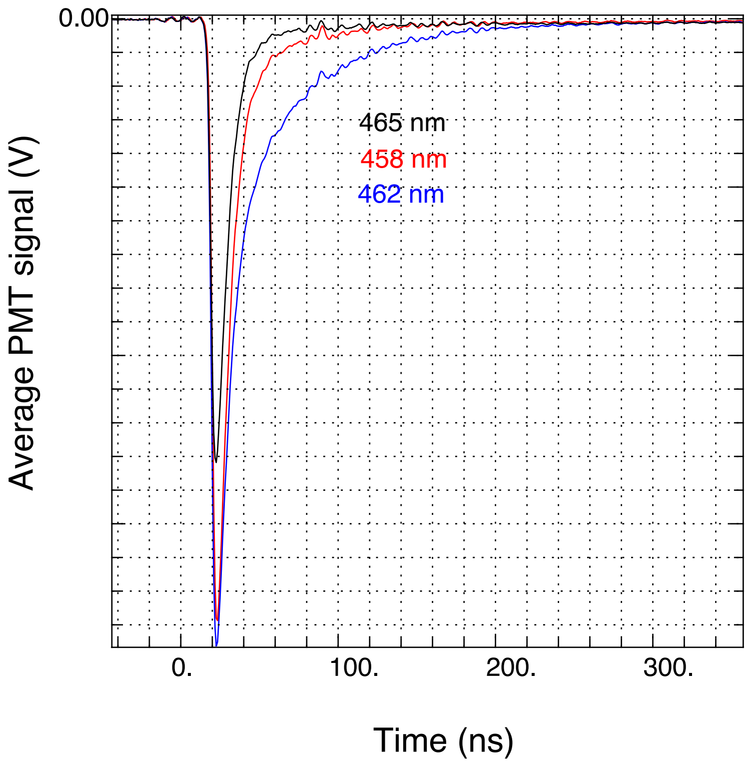
Goals:

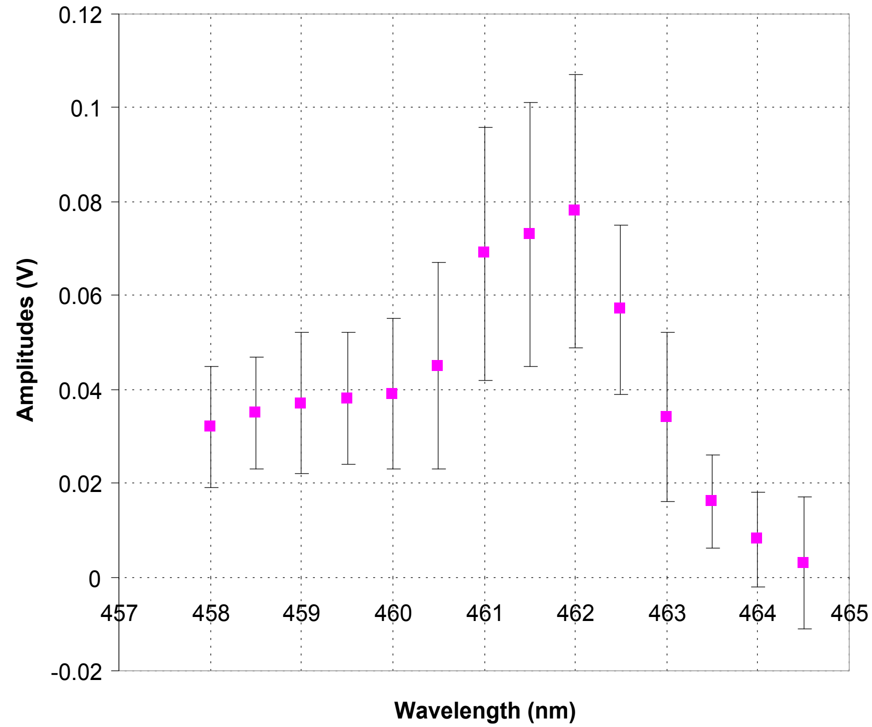
1) Demonstrate LIF-based detection of triplet molecules in superfluid He.

2) Investigate sensitivity to ionizing radiation events.



Fluorescence in Gaseous Helium at 7K





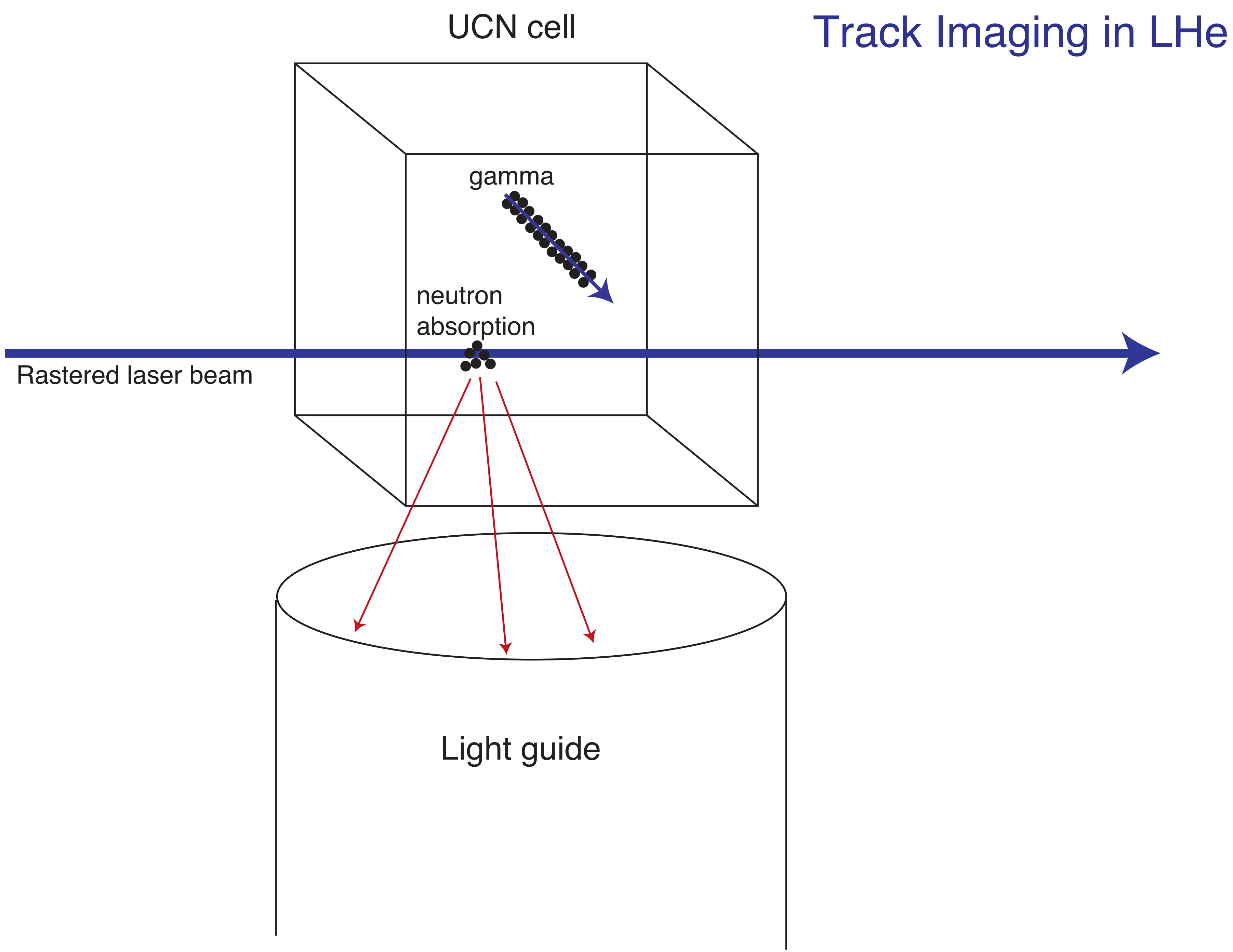
Possible advantages:

1) Amplification of small neutron absorption signal
2) No need for wavelength shifter - eliminate in favor of better ^{3}He or neutron storage?
3) Image track or measure singlet/triplet ratio to discriminate gammas

Disadvantage:

Signal is slow

- Drive triplet-singlet transition to shorten lifetime? (But then less signal)
- How quickly do triplets quench on the walls?
- Use AC field to lower difference in n and ^{3}He precession rates?



UCN cell
Track Imaging in LHe
gamma
neutron
absorption
Rastered laser beam
Light guide

Other applications for laser-induced fluorescence in LHe:

1) Spin-dependent WIMP search with ^{3}He

Liquid ^{3}He could be a great detection medium for searching for WIMP particles scattering by a spin-dependent interaction. The difficulty lies in the fact that a massive WIMP would only deposit a small amount of energy (O(keV)) into the helium. But if individual molecules could be detected using LIF, then this could allow a sensitive experiment, with good position resolution to eliminate x-ray backgrounds.

2) Low energy solar neutrinos

Superfluid helium is a promising medium for neutrino detection because of its extraordinary cleanliness (low in radioactive impurities, no intrinsic radioactivity). But gamma rays scattering from electrons looks just like neutrino-electron scattering. Could use LIF to achieve very good position resolution, allowing rejection of multiple scattering (neutrinos won't multiply scatter; gammas will)

3) Neutrino magnetic moment

If neutrinos have magnetic moments, then neutrino-electron scattering is enhanced at low recoil energy. Detection of individual helium molecules by LIF would allow an energy threshold much lower than is presently achievable. This could allow a much more sensitive search for the neutrino magnetic moment.

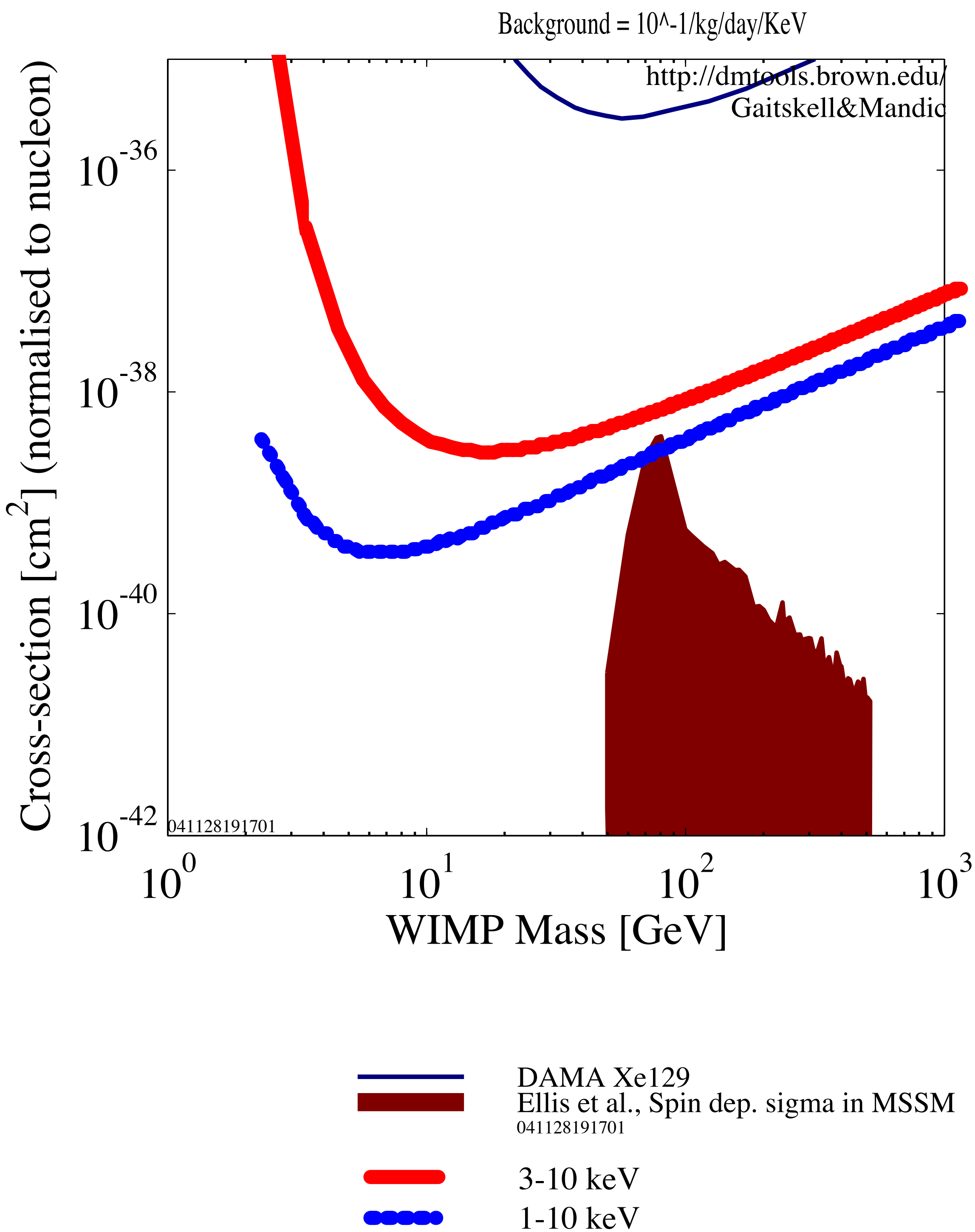
4) Imaging of superfluid turbulence

If excitations in superfluid helium can be imaged in real time, then this could allow a "superfluid wind tunnel", in which the movement of the superfluid is determined by the movement of the excitations. The system can be characterized by extremely high Reynolds numbers, with a transition to turbulent flow at low velocities.

Predicted limits on WIMP scattering cross-section

Assumes:

1 year exposure,
1 kg ^3He cell,
background of 0.1/kg/day/keV



Conclusions

1) Detection of triplet molecules in liquid helium by laser-induced fluorescence may be useful for the neutron EDM experiment.
   - Amplification of neutron signal?
   - No wavelength shifter needed?
   - Better gamma rejection?

2) Study of general technique is just beginning at Yale.

3) Have detected molecules, but sensitivity is currently limited by laser power (100 μW)

4) Much greater sensitivity may be possible with more laser power

5) Other applications may include: WIMP detection, solar neutrinos, neutrino magnetic moment, imaging superfluid turbulence, ...