Laser-Induced Fluorescence of He_2 Molecules in Superfluid Helium

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The signal in the neutron EDM experiment is the result of neutron absorption on ^{3}He:

$n + {}^3\text{He} \longrightarrow p + {}^3\text{H} + 764$ keV

The ionization and excitation of helium atoms results in the rapid formation of Helium molecules, which radiatively decay, emitting EUV scintillation light. This scintillation chiefly occurson three different times scales, corresponding to three different physical processes:

1) Prompt scintillation (time < 20 ns)

- Radiative decay of singlet helium molecules

2) Afterpulsing (varies in intensity as roughly 1/time)

- Results from destructive interaction of triplet molecules with each other (Penning ionization). Products of this can result in singlet molecule formation, which then radiatively decay. This component is more intense for neutron absorption events than for gammas.

3) Phosphorescence (exponential decay with 13 second lifetime)

- Triplet molecules radiatively decay (unless they hit a wall first)
- This component is less intense for neutrons than for gammas

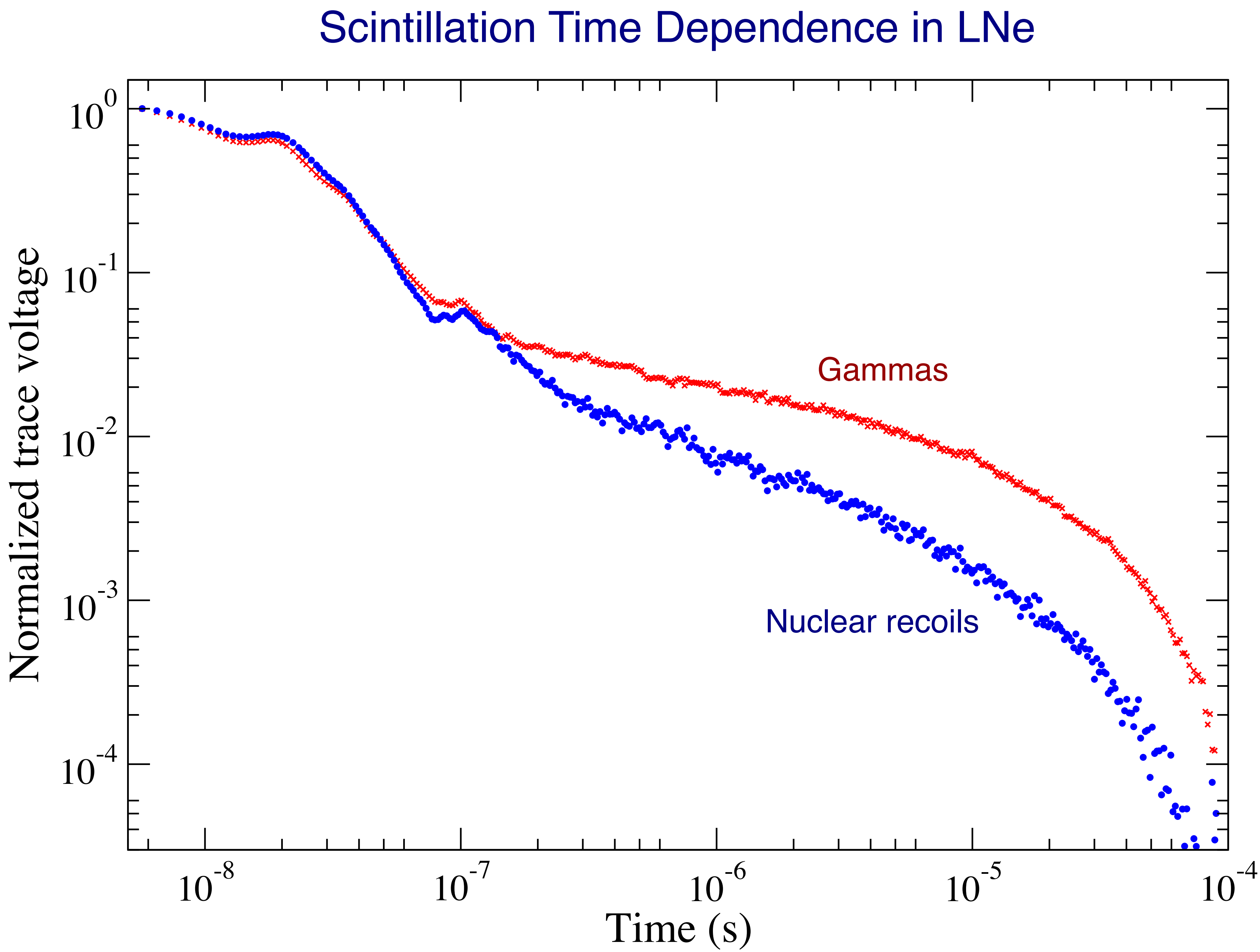
Why try to detect the triplet molecules?

1) More signal:

Past experience (on neutron trapping experiment) would imply that every photoelectron is valuable for digging out of activation and luminescence backgrounds.

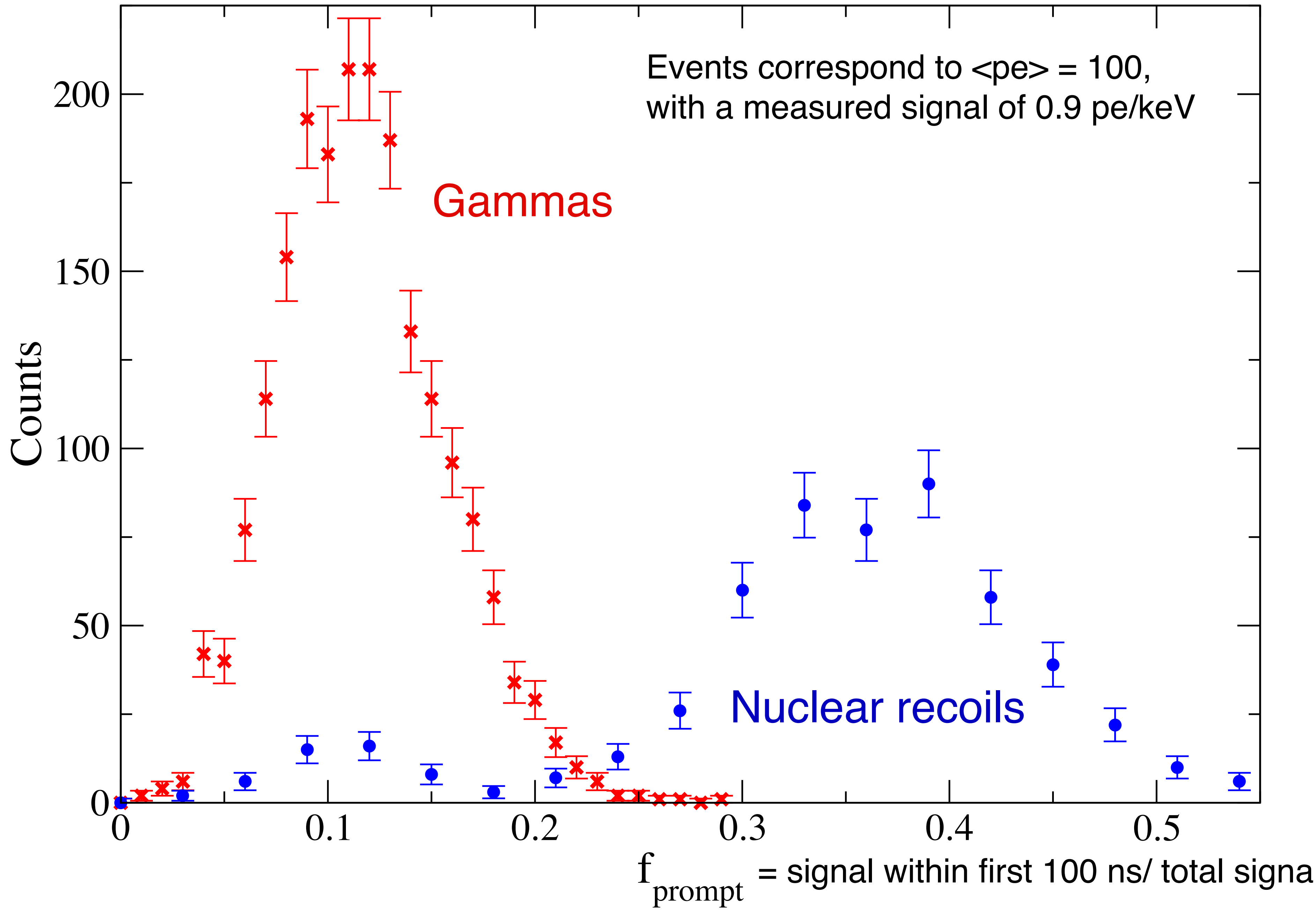
2) Complementary information for gamma rejection:

In liquid neon and liquid argon, the ratio of singlet molecules to triplet molecules is a strong indicator of the ionization density and can be used to discriminate between gammas and heavy ionizers. This is probably because for heavy ionizing particles, many of the triplet molecules are lost through destructive triplet-triplet interactions (Penning ionization). It is likely that this would work in liquid helium as well.



Scintillation Time Dependence in LNe
Normalized trace voltage
Time (s)
Gammas
Nuclear recoils
10^0
10^-1
10^-2
10^-3
10^-4
10^-8
10^-7
10^-6
10^-5
10^-4

Pulse shape discrimination in LNe



Laser-based detection scheme

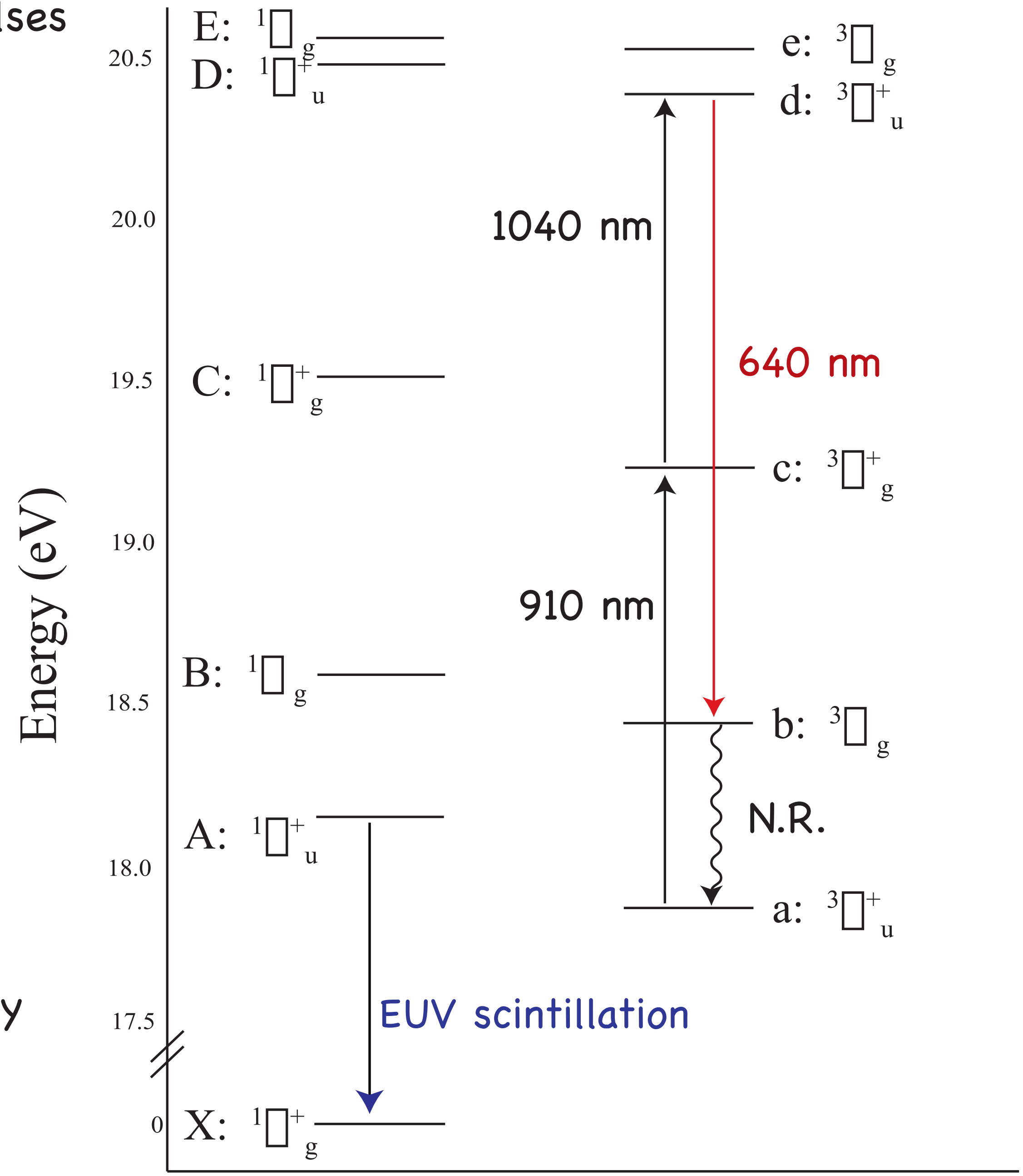
Detection of the scintillation light from A--->X decay would trigger IR laser pulses at 910 nm and 1040 nm.

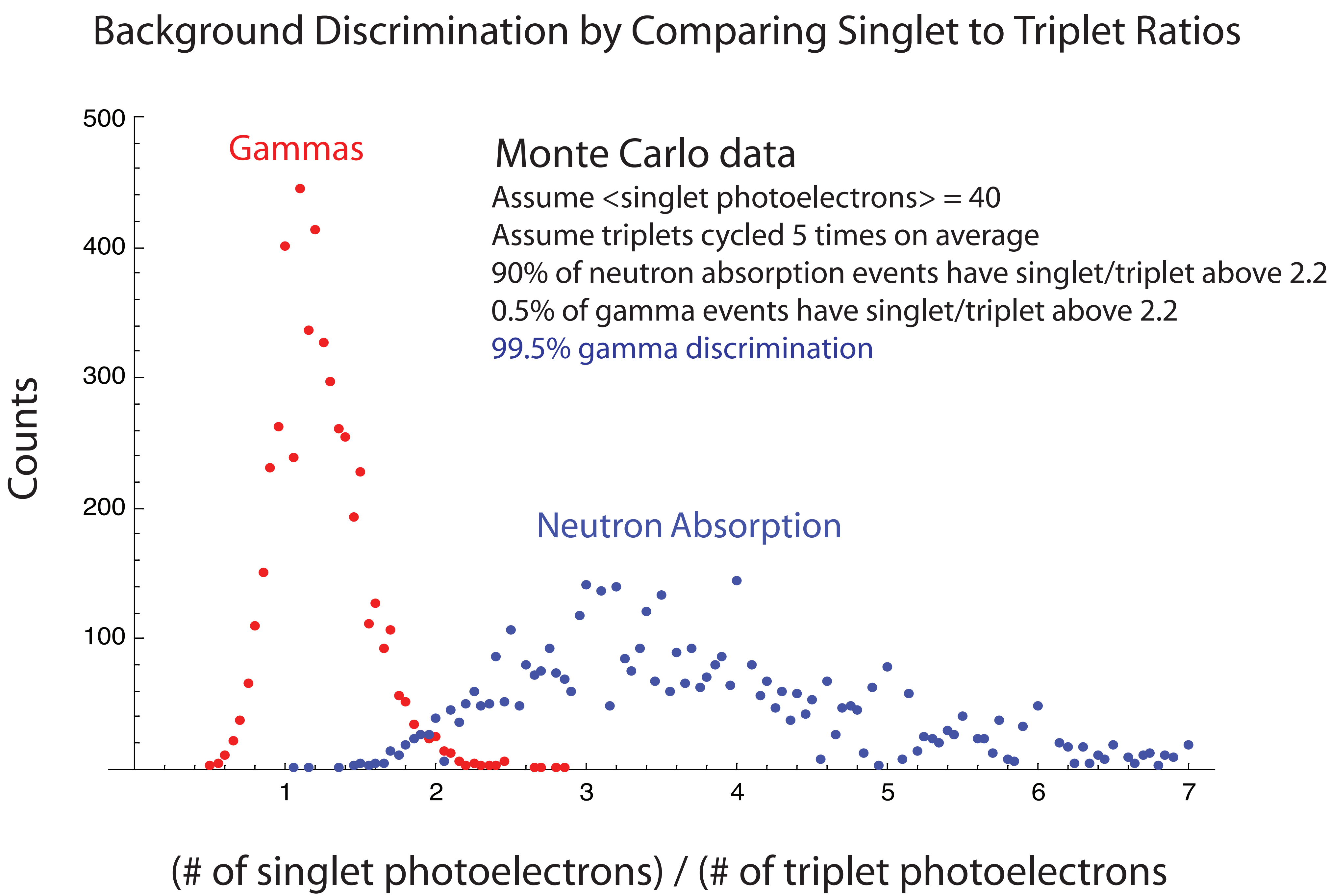
This will drive the triplet molecules from a--->c and then c--->d.
The molecules will then decay from d--->b with a 90% branching ratio, emitting a 640 nm photon.

The b state will then decay non-radiatively back to the a state.
The molecules can be pumped multiple times, emitting many red photons.

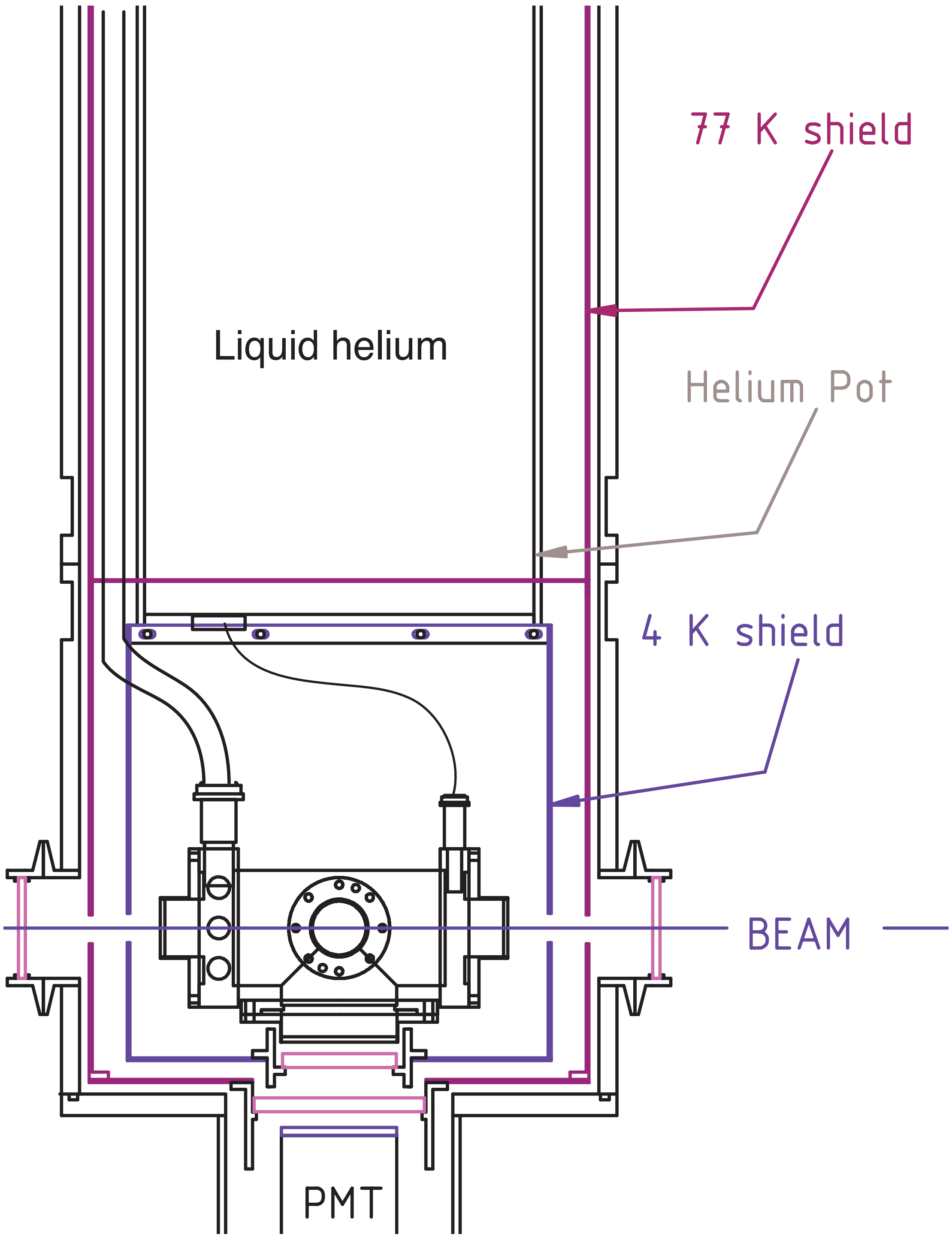
The 640 nm light can be detected with the same photomultipliers used to detect the prompt scintillation light.

By comparing the ratio of prompt light to laser-induced fluorescence, gamma ray backgrounds may be reduced.





Background Discrimination by Comparing Singlet to Triplet Ratios
Gammas
Monte Carlo data
Assume <singlet photoelectrons> = 40
Assume triplets cycled 5 times on average
90% of neutron absorption events have singlet/triplet above 2.2
0.5% of gamma events have singlet/triplet above 2.2
99.5% gamma discrimination
Neutron Absorption
Counts
500
400
300
200
100
1
2
3
4
5
6
7
(# of singlet photoelectrons) / (# of triplet photoelectrons

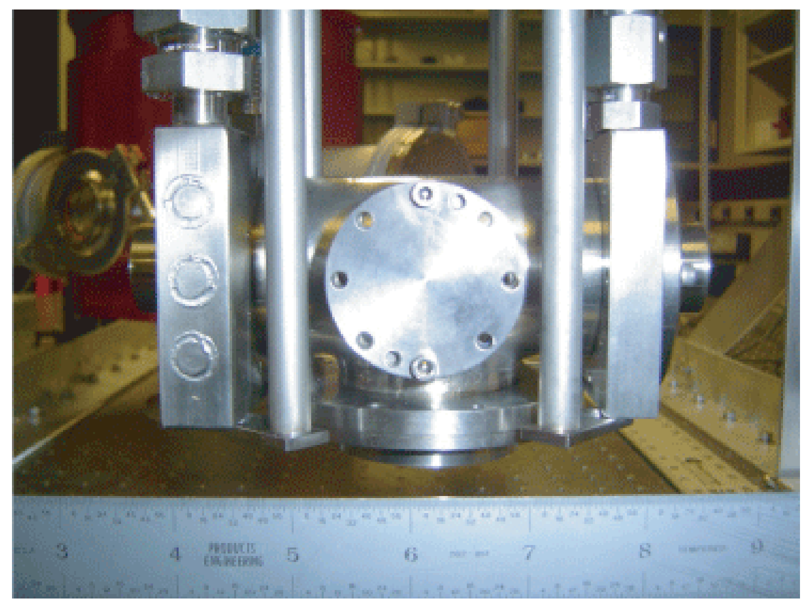


Beta source produces density of 10^7 He_2 molecules per cc

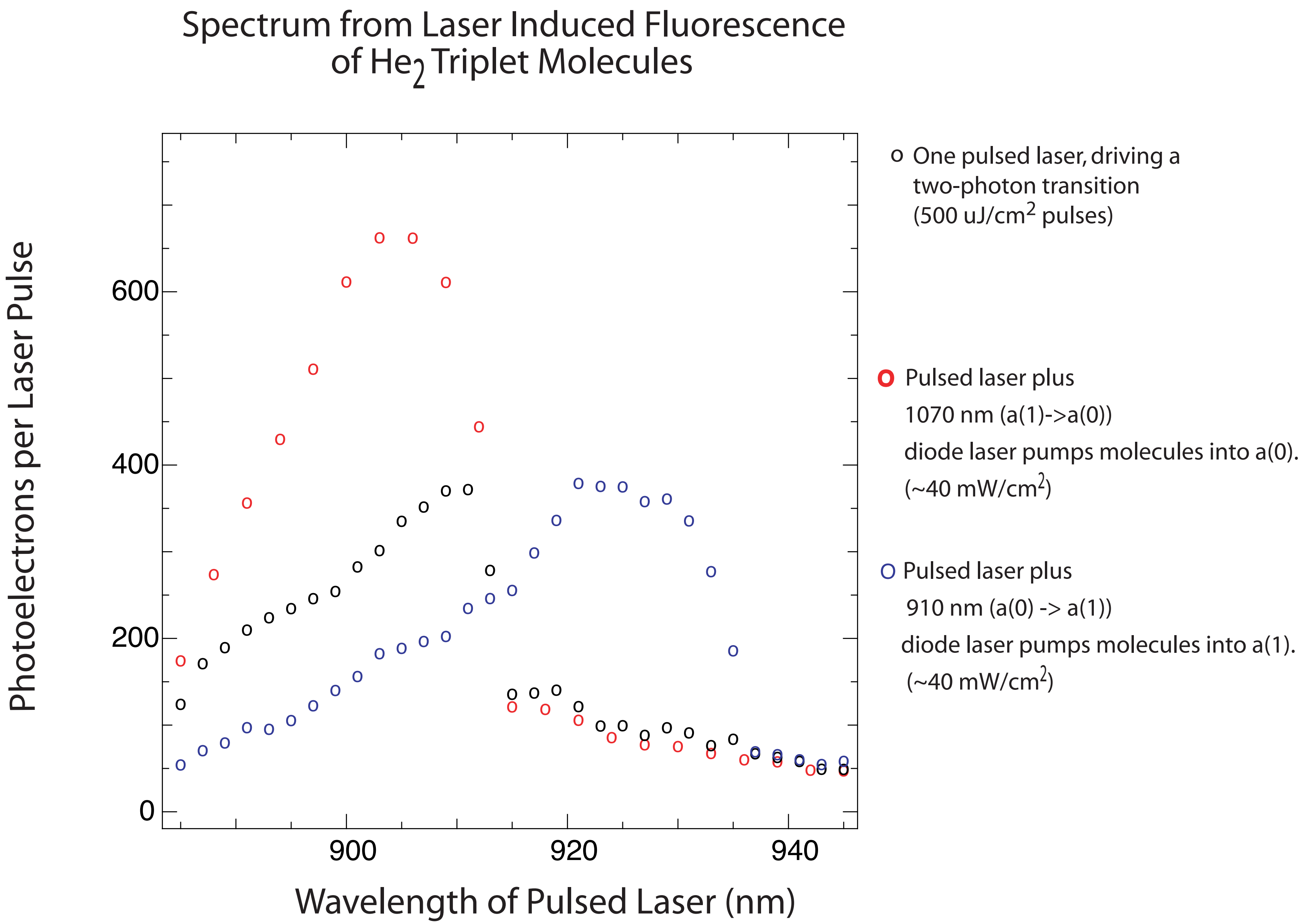
Infra-red laser beams pass through superfluid helium

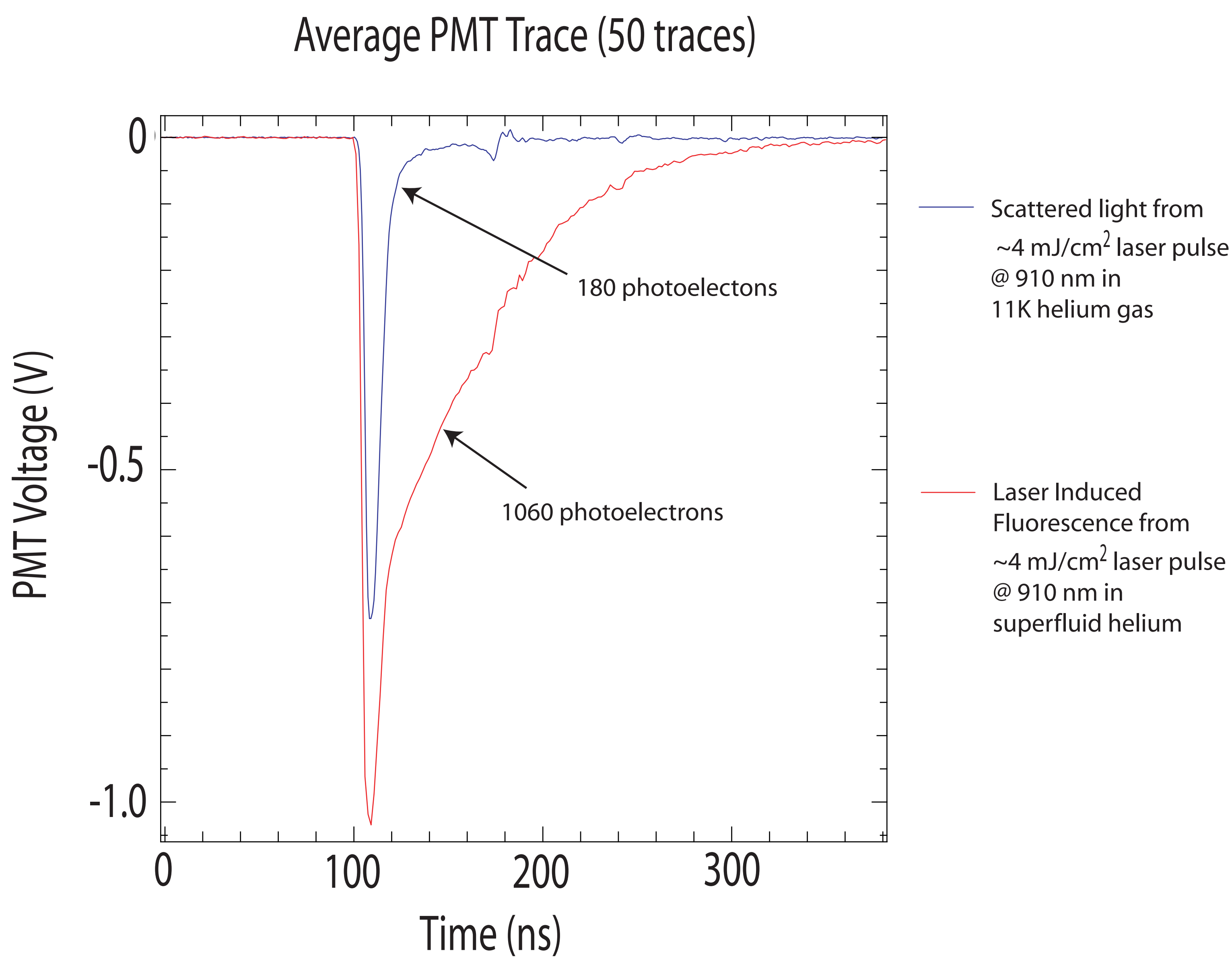
640 nm fluorescence signal detected by PMT

Laser light filtered out to allow sensitive molecule detection

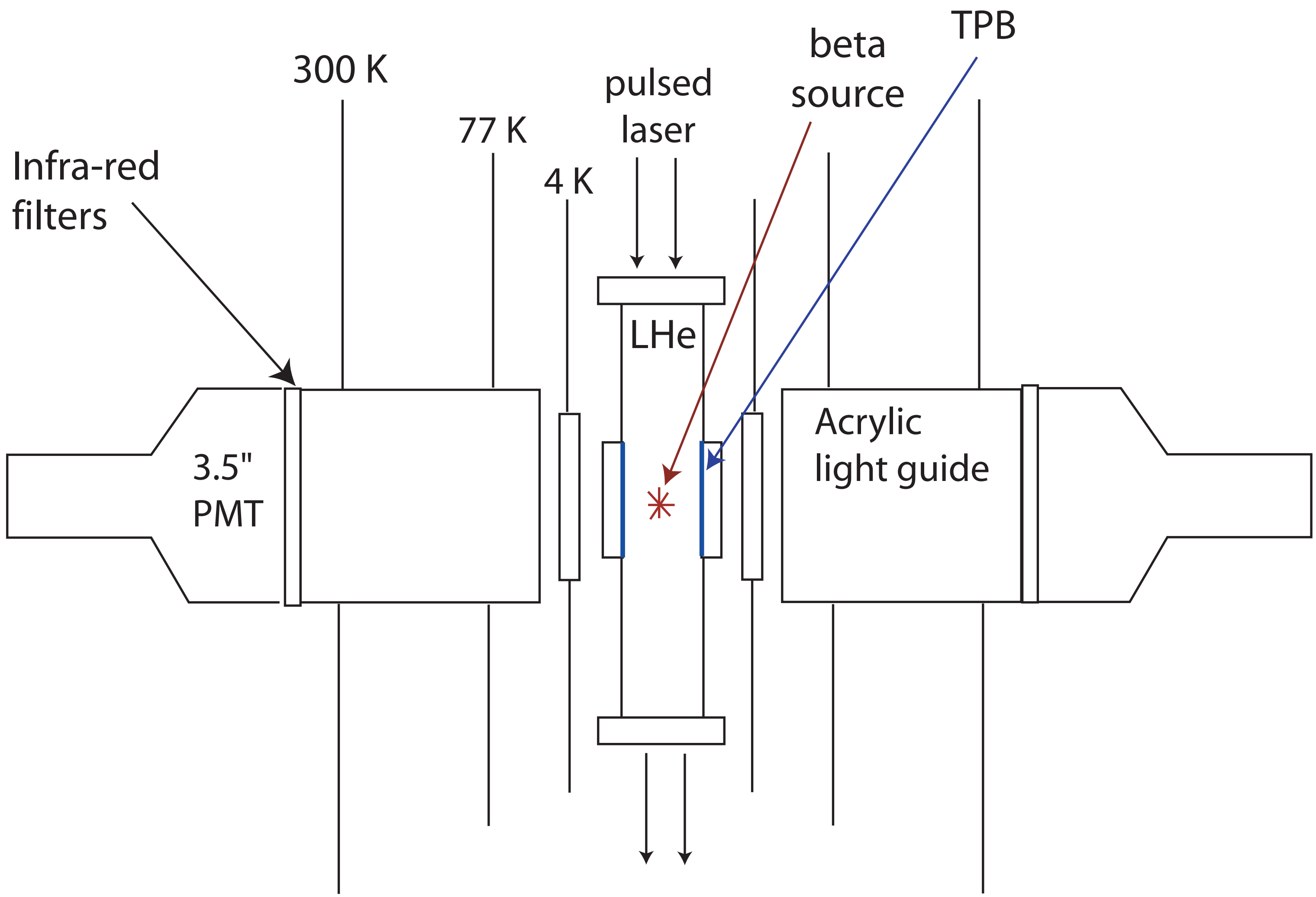


First detection of He_2 molecules using laser-induced fluorescence, August 2006 at Yale.
This detection only used one pulsed laser (instead of 2 as in original scheme)
Vibrational state can be manipulated using CW diode lasers, changing the spectrum shape.
Upcoming tests will use 2 simultaneous laser pulses of different wavelength (like 910 + 1040)




Average PMT Trace (50 traces)
PMT Voltage (V)
0
-0.5
-1.0
0
100
200
300
Time (ns)
180 photoelectons
1060 photoelectrons
Scattered light from
~4 mJ/cm2 laser pulse
@ 910 nm in
11K helium gas
Laser Induced
Fluorescence from
~4 mJ/cm2 laser pulse
@ 910 nm in
superfluid helium

Proposed apparatus for detecting both prompt scintillation and laser-induced fluorescence from individual events



Top-down view of apparatus
Central cell filled with He-4 at 300 mK
Lasers triggered by prompt scintillation, 10% light collection.
Both prompt scintillation and laser-induced fluorescence measured for individual events
Expect 380 prompt photoelectrons for a 1 MeV beta, 40 photoelectrons per laser pulse

Budget request:

Closed-cycle He-3 refrigerator:	$140k
PMTs (red-sensitive, 3.5" diameter):	$4k
Dewar modifications:	$12k
Optical cell:	$4k
	$160k

Existing equipment in the McKinsey group:

Pulsed, tunable OPO infra-red lasers:	$72k
Optics, wavelength filters :	$10k
4-channel 1GHz digital scope:	$20k
Temperature control electronics:	$4k
PMT power supplies:	$4k
	$110k

Summary

Laser-induced fluorescence would allow detection of triplet helium molecules, a signal that is not used in the "baseline" n-EDM design

In LNe and LAr, it has been shown that measurement of the singlet/triplet ratio allows excellent discrimination against gamma rays.

In LHe, this sort of discrimination should be possible through event-by-event detection of both the singlet EUV fluorescence and the triplet laser-induced fluorescence.

At Yale, recent measurements of laser-induced fluorescence have confirmed a large signal from triplet helium molecules in 1.7 K LHe.

Event-by-event discrimination could be tested with a $160k investment, primarily in a He-3 refrigerator that would allow measurements at low LHe temperatures. Necessary lasers are available at Yale.