# Scintillation yield from electronic and nuclear recoils in superfluid $^4$He

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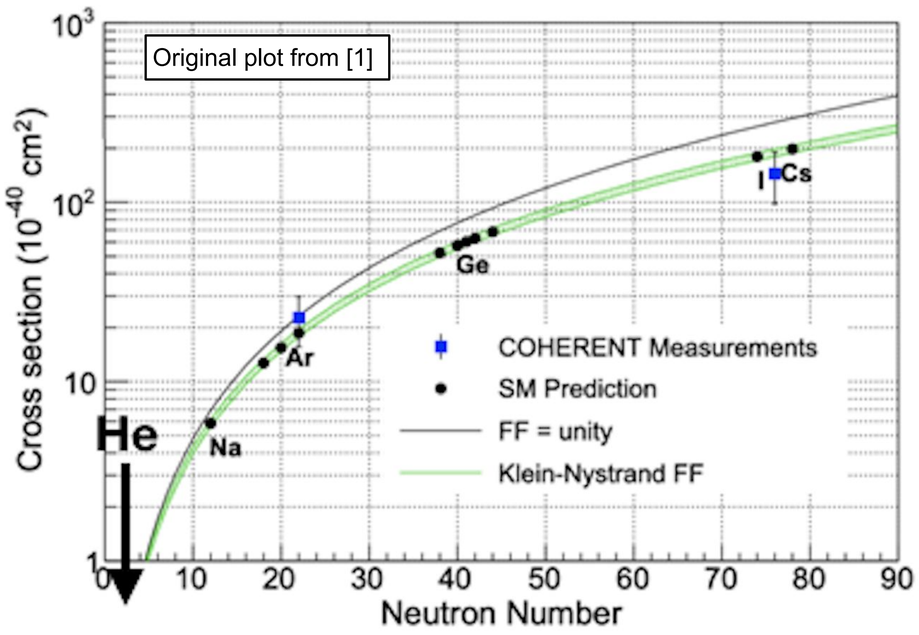
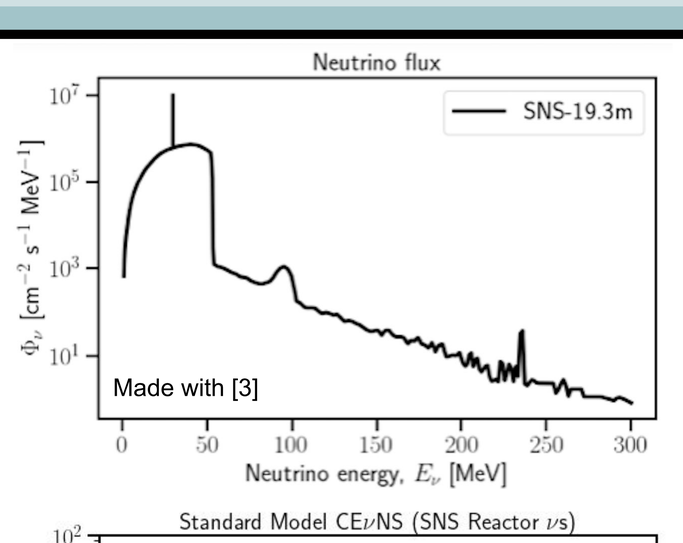
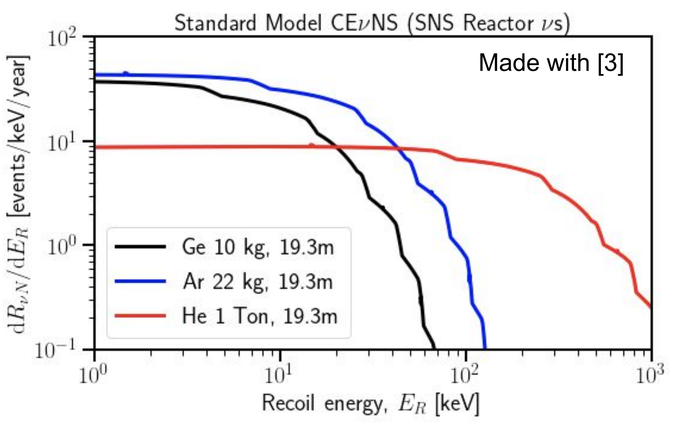
## Helium as a CEvNS target



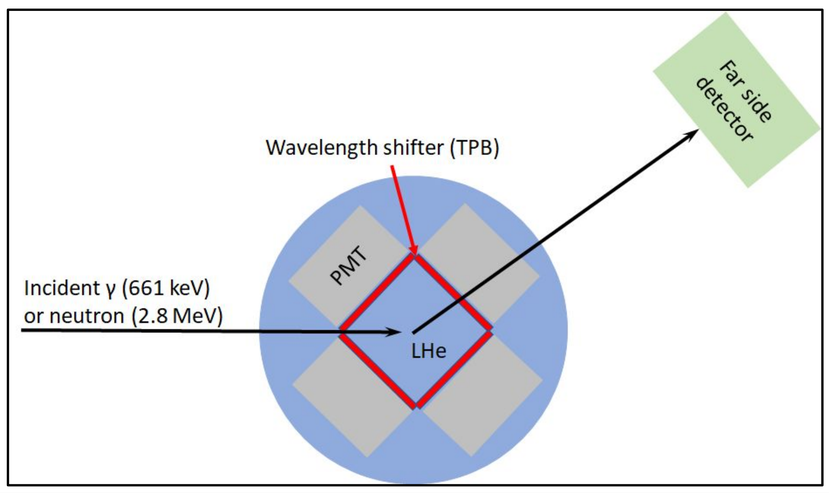

- Helium is a scalable scintillator that has demonstrated capabilities of detecting particle interactions
  - We are currently pursuing R&D of using superfluid helium has a dark matter detector [2]
- In the context of CEvNS, helium is interesting for verifying the scaling of the cross section with $N^2$
  - Expect typical signals of 100s of keV
  - Would probably require a ton-scale helium mass, SNS example plotted to the right
  - Comparison of integrated rates per year, neglecting detection efficiencies:
    - 10 kg Ge: 490 evts
    - 22 kg Ar: 1100 evts
    - 1 t He: 2600 evts
- Pulse shape discrimination of electron and nuclear recoils should be possible
  - See measurements presented on this poster, already at energies relevant for CEvNS

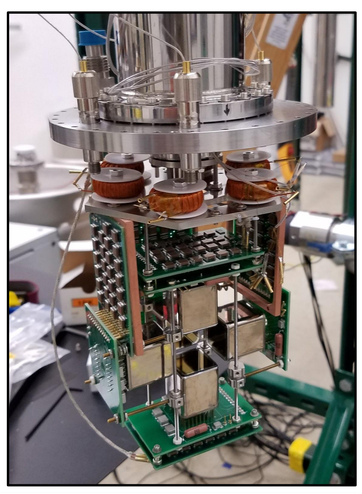



## The experimental apparatus

- We measured 1.75 K superfluid helium scintillation by creating a 1 in$^3$ target cube monitored by 6 immersed PMTs
  - Helium scintillation is ~80 nm, wavelength shifter around target cube shifts to ~420 nm
- We used monoenergetic sources to induce electron recoils (ERs) and nuclear recoils (NRs) in the detector
  - ERs were observed with 661 keV $^{137}$Cs decay gammas
  - NRs were observed with 2.8 MeV DD generator neutrons
- The scattering angle was tagged by a far side detector, which fixed the recoil energy
- Achieved 0.4 photoelectrons / keVnr detected on average in liquid helium target

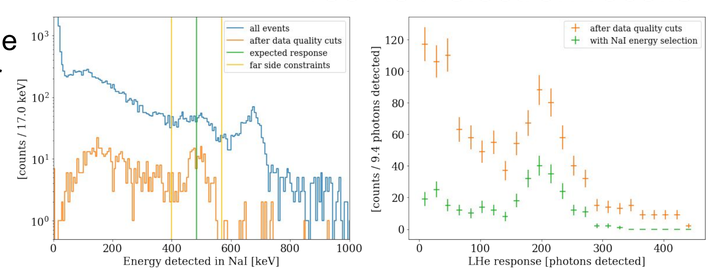


## Data selection cuts

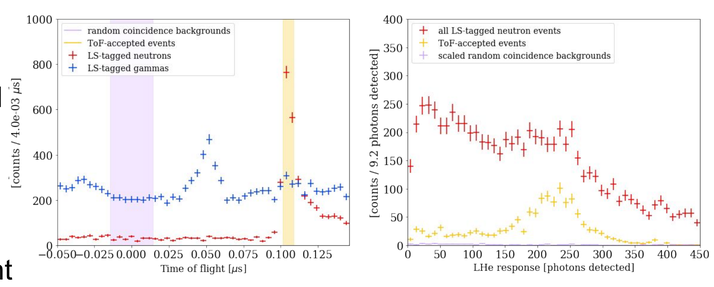
- ER data was reduced with timing cuts and by using the energy deposited in the far side NaI detector
  - Gammas which only scatter once in the helium have a well-defined energy

185 keV electron recoils



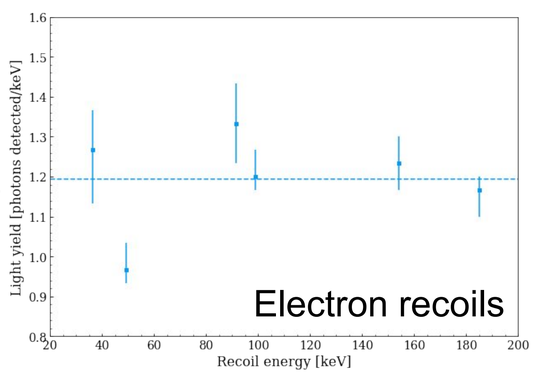

- NR data was reduced by using pulse shape discrimination in the BC-501A scintillator to eliminate backgrounds and with timing cuts
  - Neutrons which only scatter once in the helium have a well-defined time of flight

561 keV nuclear recoils

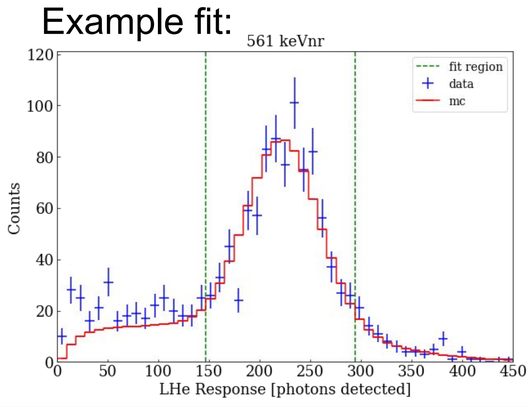


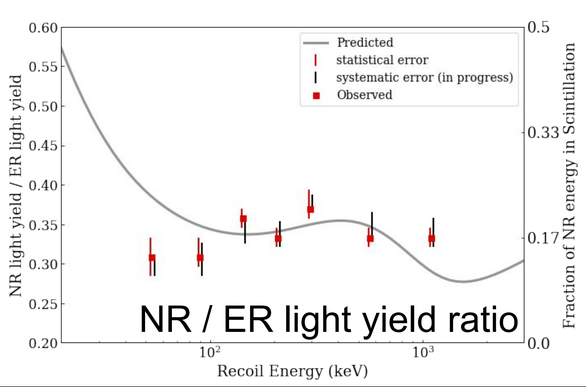

## Prompt scintillation yield

- For each scattering angle, we fit simulations to the data with floating light yield and energy resolution parameters
  - The fit region was defined iteratively based on an initial fit of the parameters
  - Fit via $\chi^2$ minimization
- We expect the ER light yield to be roughly uniform in energy, so we take the mean of our measured values
  - The ratio of NR / ER eliminates geometric effects in the measurement
  - The predicted curve comes from the model described in [2].



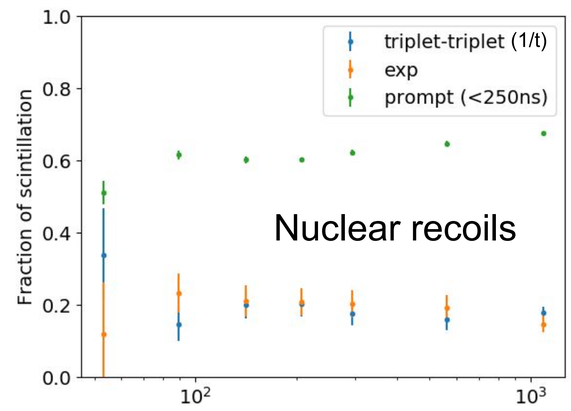

Example fit:



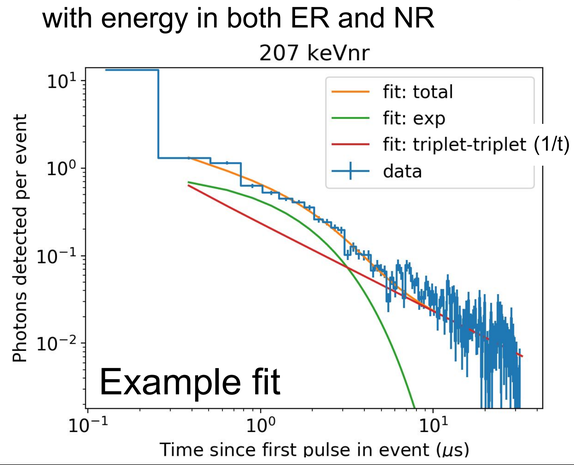



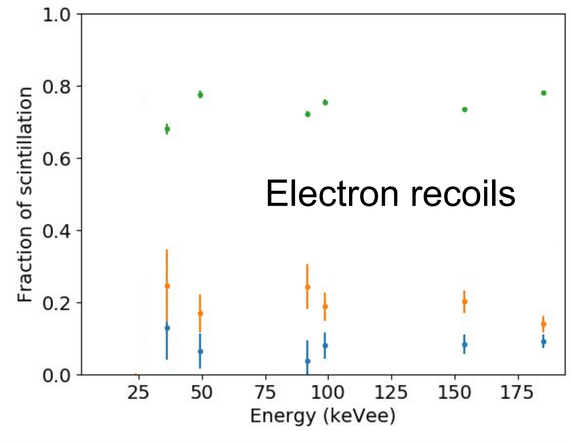

## Scintillation timing

- After prompt window (250 ns), fit temporal distribution of single electrons in events with 1/*t* and exponential components
  - Power-law component from triplet-triplet quenching
  - Exponential component not well-understood, but previously observed in [4]. Characteristic time is ~1 μs, but we see some evidence for energy dependence
  - Relative size of components different in ER and NR
  - Some variation in relative size of components with energy in both ER and NR




207 keVnr




## References:

1. D. Akimov *et al*. arXiv:2003.10630.
2. S. A. Hertel *et al*. Phys Rev D 100(9), 2019. arXiv:1810.06283.
3. B. J. Kavanagh, https://github.com/bradkav/CEvNS
4. D. N. McKinsey *et al*. Phys Rev A, 67(6), 2003.

Look out for Pratyush Patel's talk on Wednesday for more on future directions of this work!