Low-temperature studies of the scintillation of pure Cesium Iodide for cryogenic scintillator detectors

Michael Clark
Philippe Di Stefano

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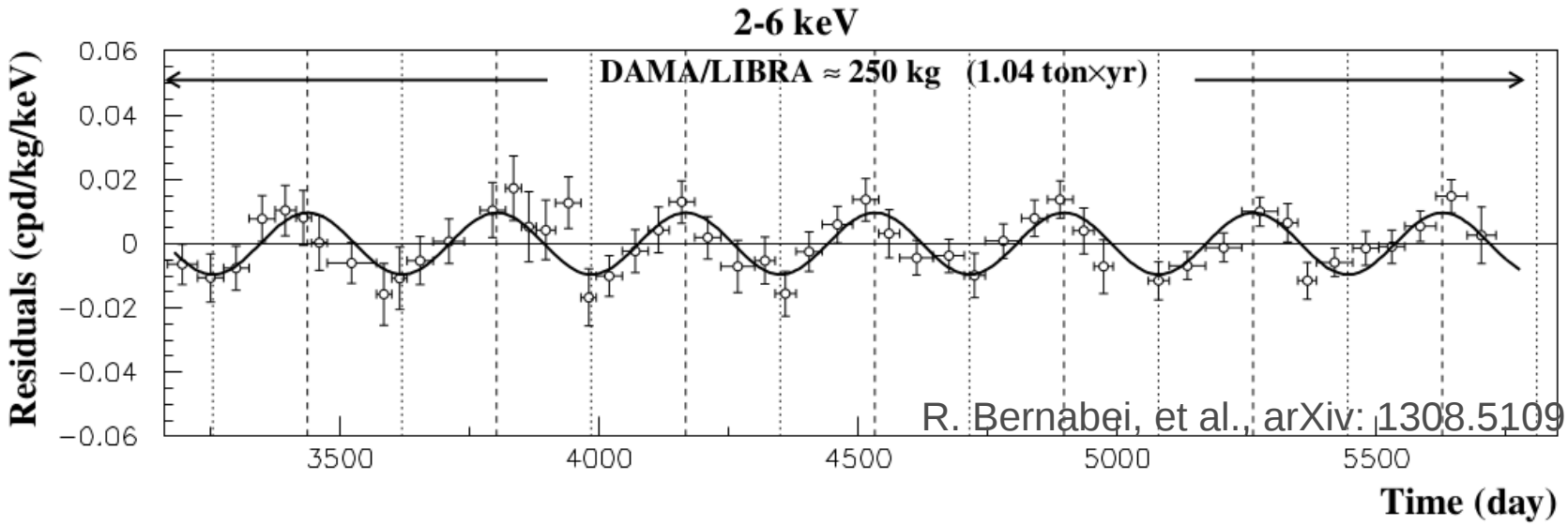
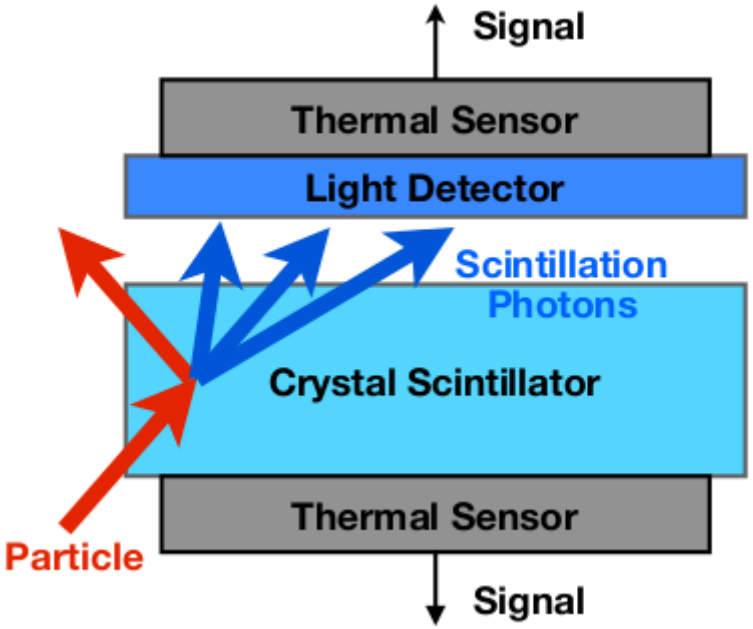
DAMA/LIBRA Dark Matter Claim

- Dark Matter search using room temp. radiopure NaI(Tl) scintillating crystals in Gran Sasso Lab
- Scintillation-only detector, no event-by-event background discrimination
- Detect modulation signal consistent (phase, period) with WIMP halo model, but phase space inconsistent with other experiments

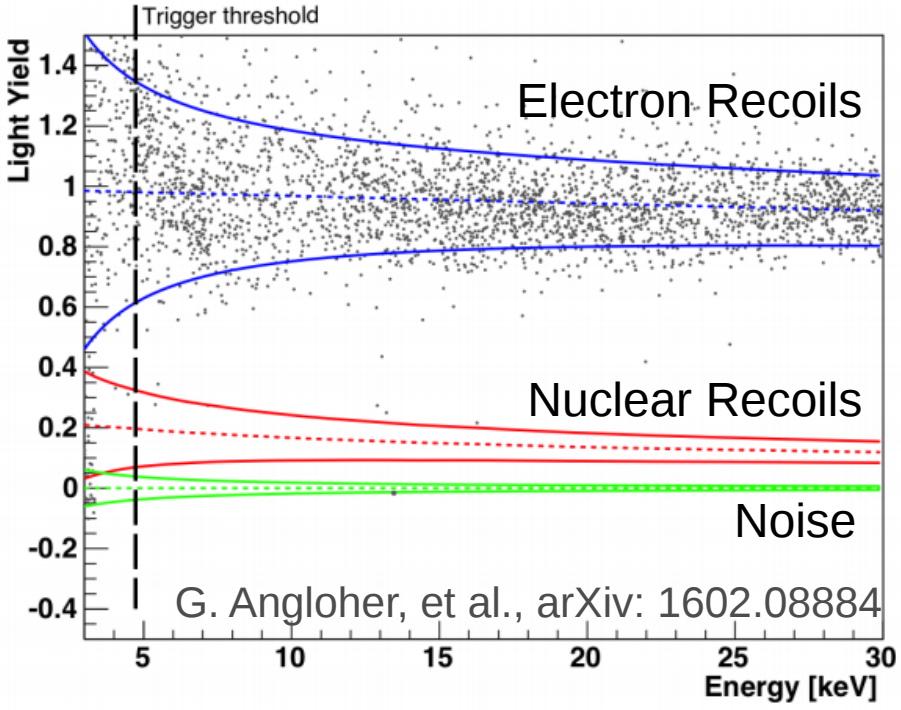


Cryogenic Alkali Halide Detector



- Some tests done with CsI at low temperature by COSINUS collaboration ->

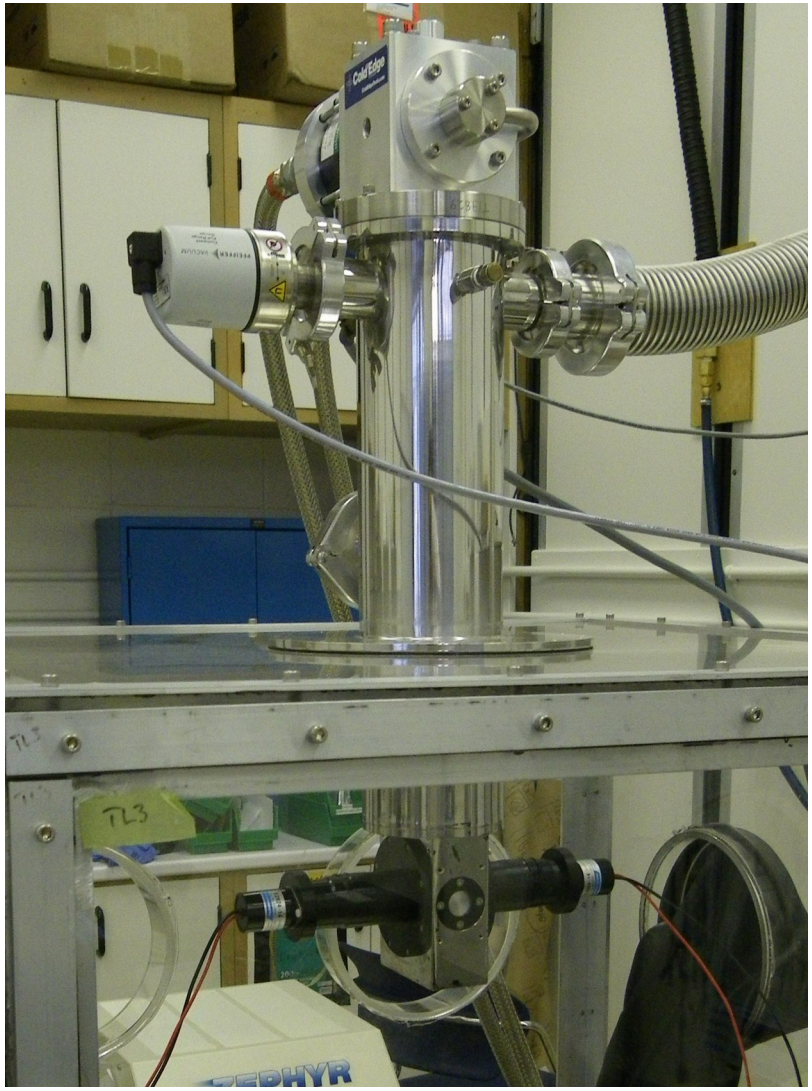
- NaI detector + background discrimination = check DAMA result in model independent way

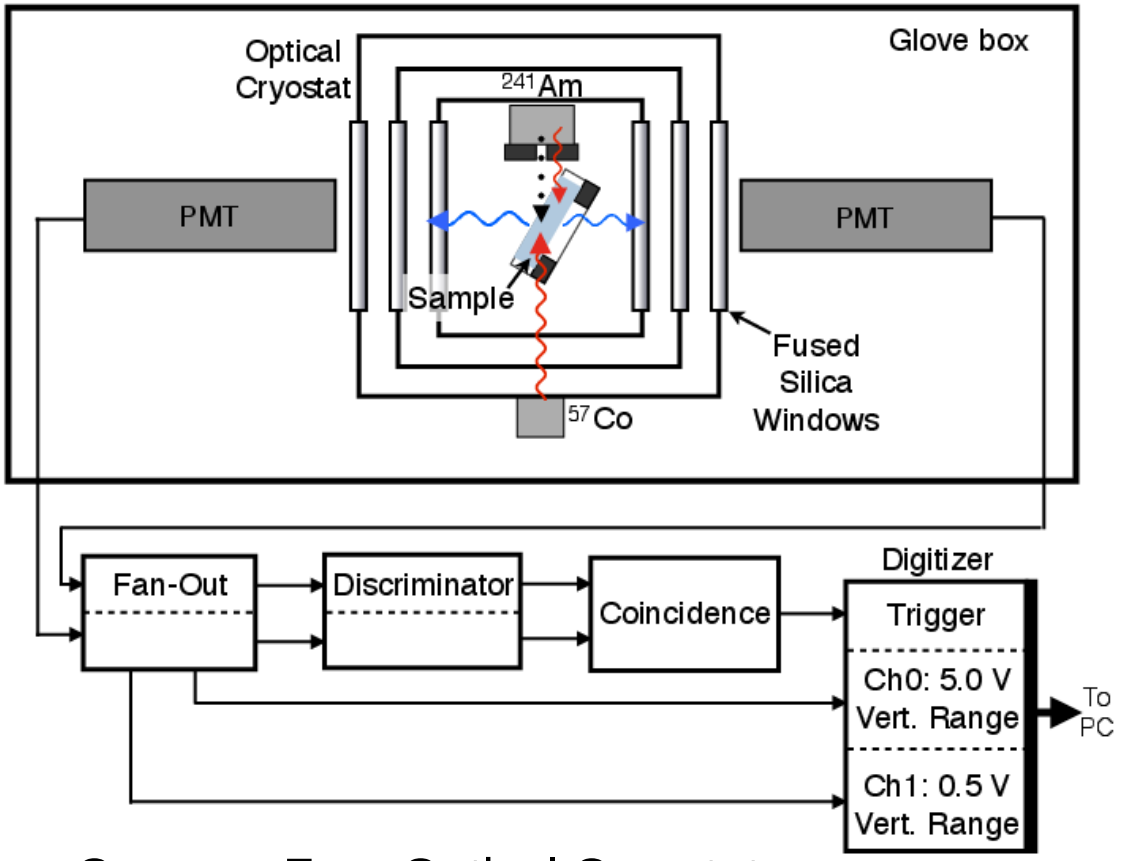


CsI Scintillation

- Lots of interest in CsI scintillation detectors
  - COSINUS Experiment (NaI/CsI cryogenic scintillation) arXiv:1610.03876; arXiv:1602.08884
  - COSINE Experiment (NaI/CsI scintillation) IDM2016 Proceedings
  - COHERENT Experiment (CsI[Na] scintillation) arXiv:1509.08702
  - Measurement of alpha light yield of pure CsI to <10K (Mikhailik et al.) arXiv:1411.6246
  - Sensitivity of alkali halide cryogenic detectors to WIMP signals (Queen's) arXiv:1410.1573

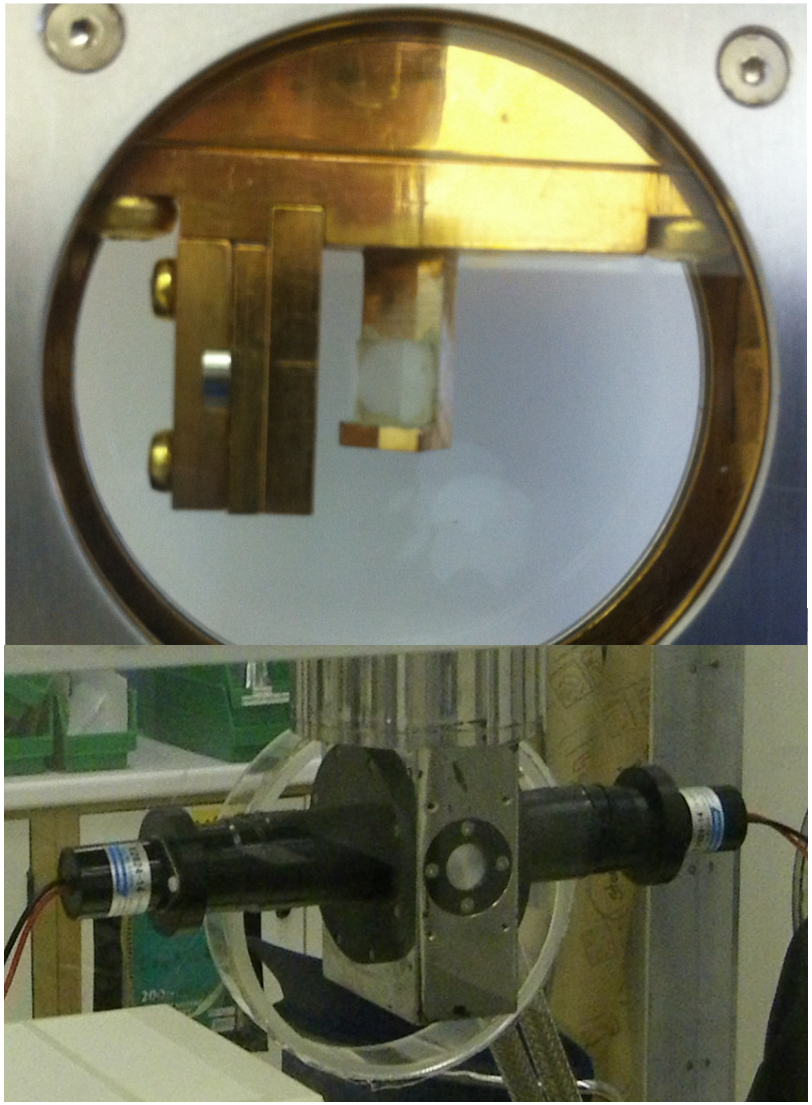
Optical Cryostat at Queen's

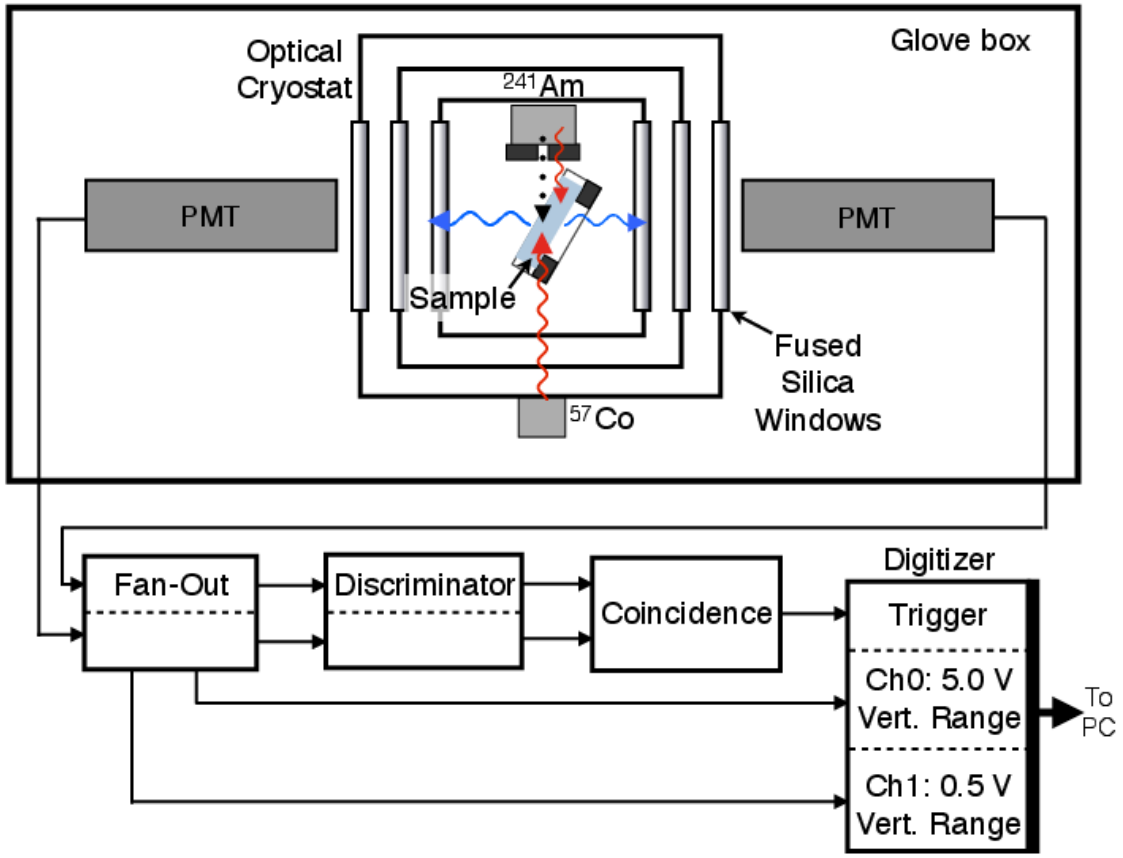




- Cryogen-Free Optical Cryostat
- Base Temp: 3.4 K
- 2 PMT geometry for light yield + trigger

Optical Cryostat at Queen's



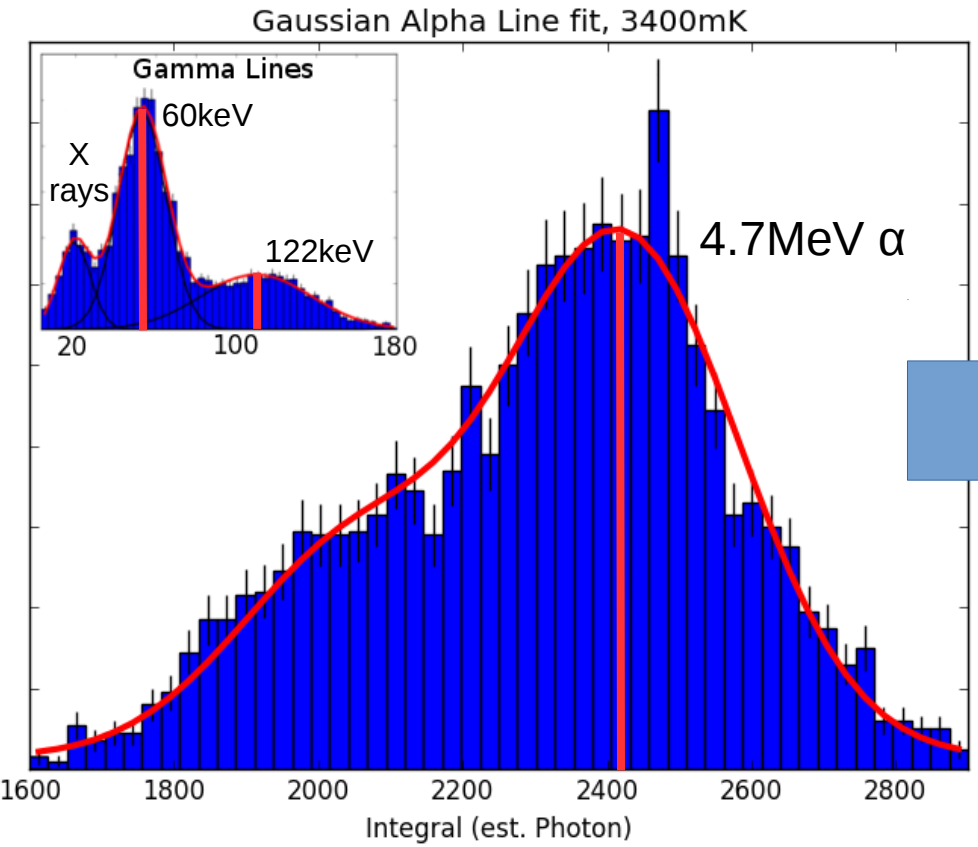


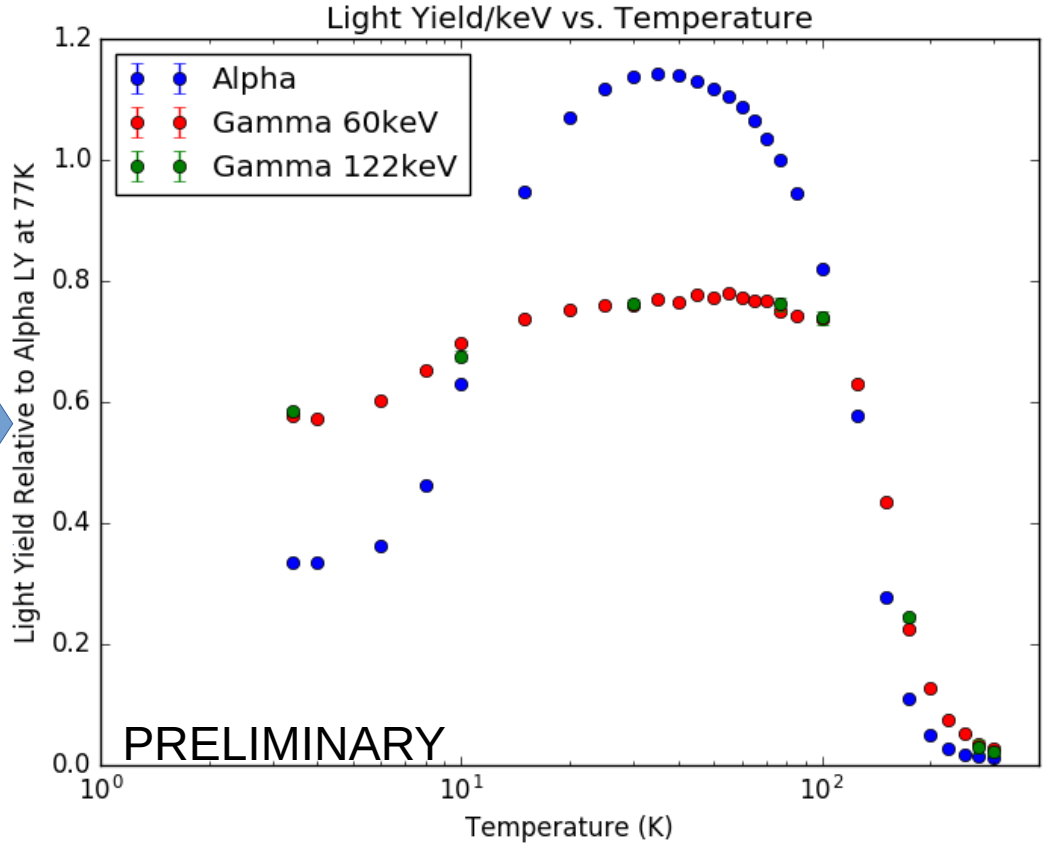
- For more information see:

  P.C.F. Di Stefano et al., NIM A 700 (2013)

Light Yield Determination

- Trigger on particle interactions and record PMT charge in set time window for many events
- Calculate light yield/keV of incident particle at temperatures down to 3.4K using location of peaks
- Alpha LY increases by factor 100 from 300K-40K, factor 30 from 300K-3.4K
- Gamma LY increases by factor 25 from 300K-40K, factor 20 from 300K-3.4K



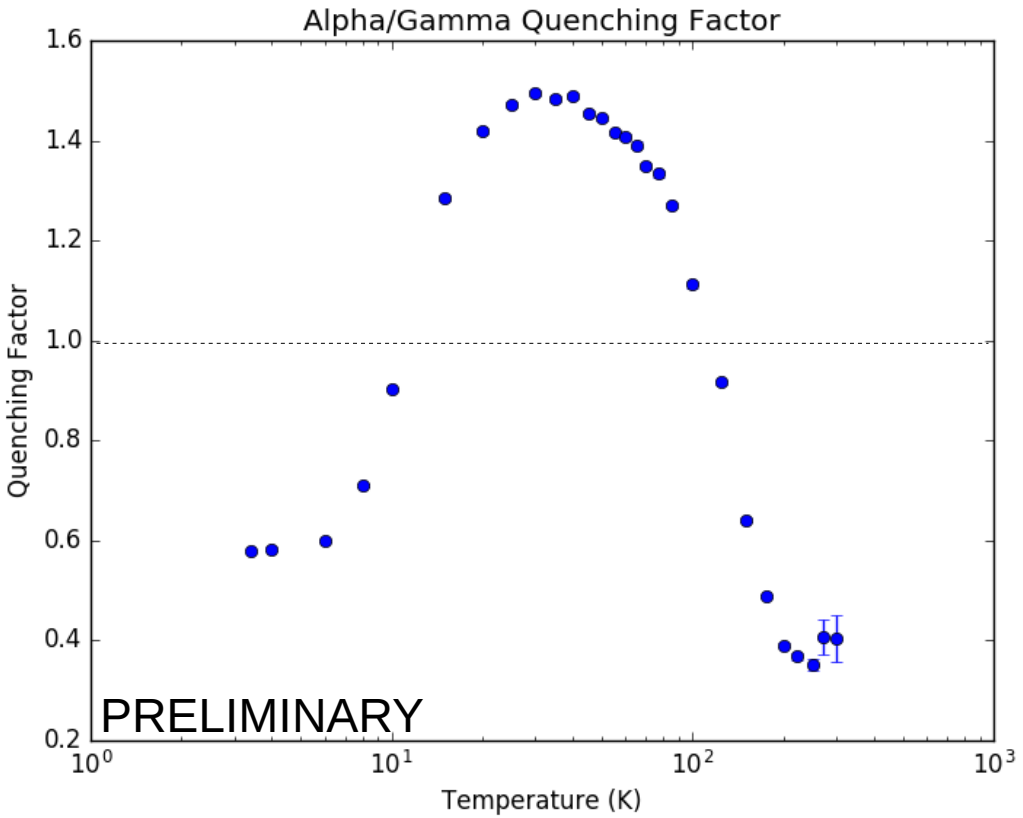


Alpha peak structure due to uneven crystal surface

Alpha/Gamma Quenching Factor

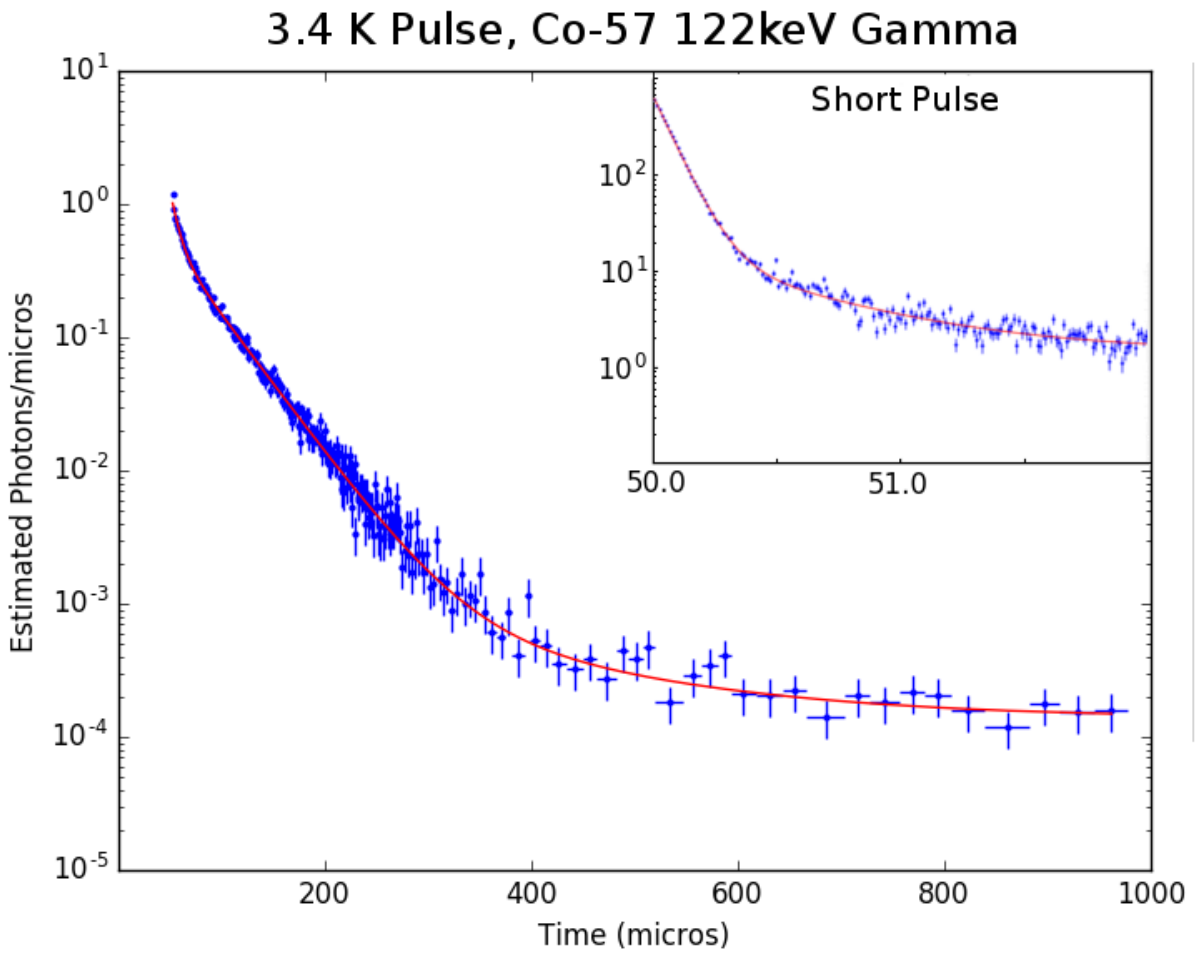
- Ratio of light/energy of alpha events to gamma events
- Calculated using different energy between alpha/gamma, so linearity could be a factor as temperature decreases
- Expected to be low, but we observe a alpha/gamma quenching factor greater than one from 10-100K!

$$QF_{\alpha/\gamma} = \frac{LY_{\alpha}(300\mathrm{K})/4700\mathrm{keV}}{LY_{\gamma}(300\mathrm{K})/60\mathrm{keV}}$$

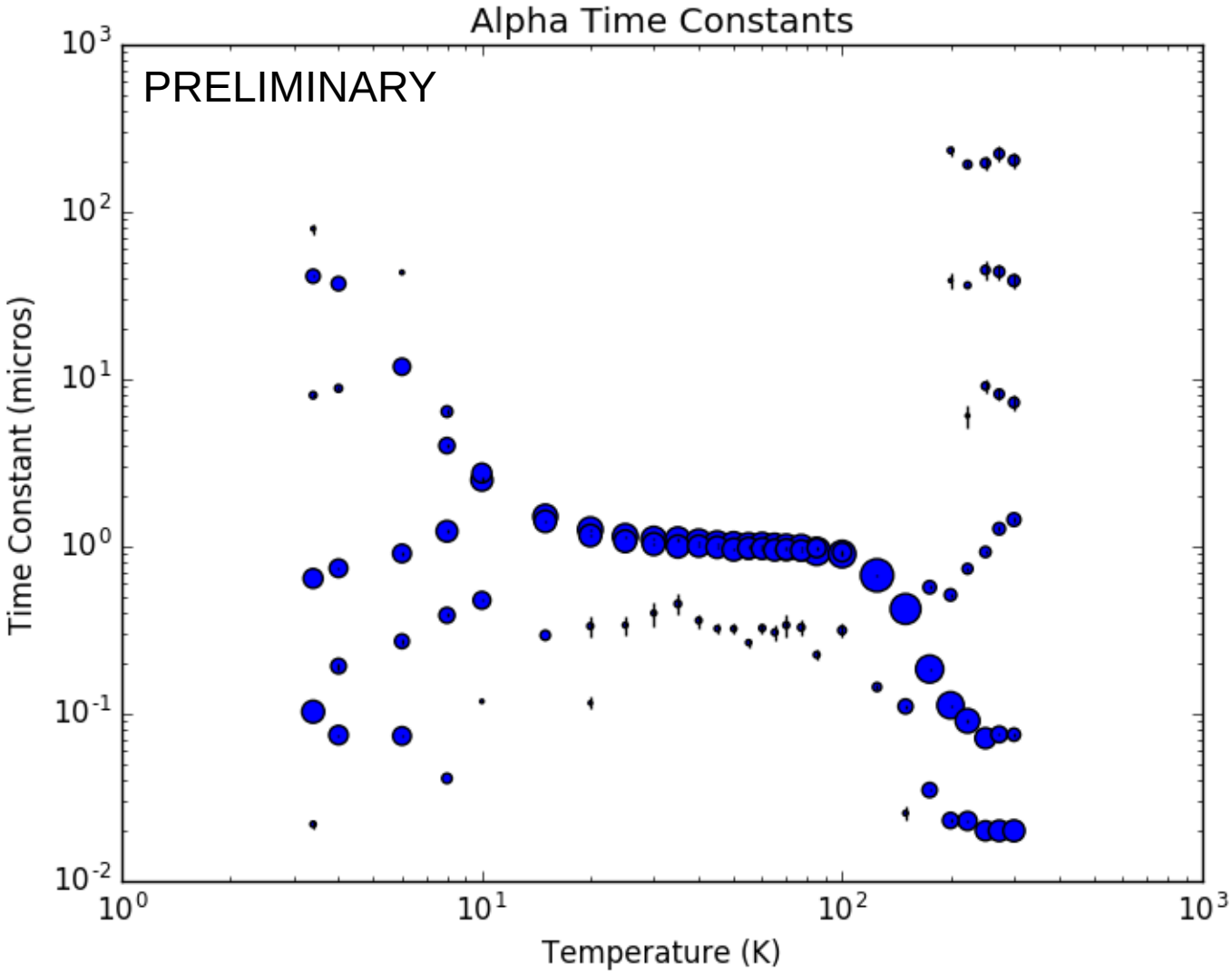


Time Constants

- Fit pulse to a total of six exponential decays
- Expect time constants to increase as temperature decreases due to reduction in vibrational modes
- Determine contribution of each exponential to total light yield by integral to find relevant components
- Due to coincidence trigger, not sensitive to initial < 10 ns of pulse

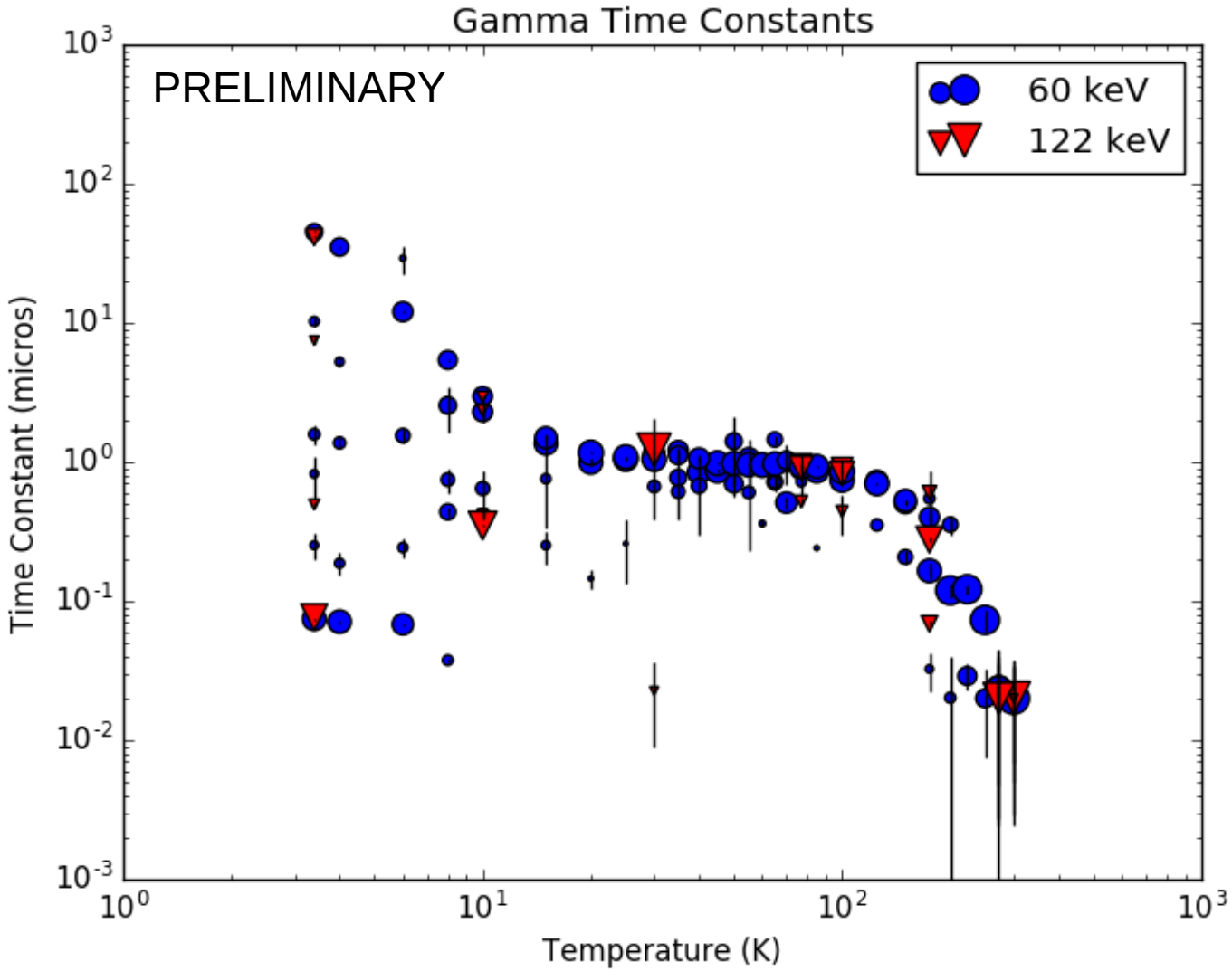


Alpha Time Constants



Point size proportional to contribution of that time constant to total light yield at that temperature

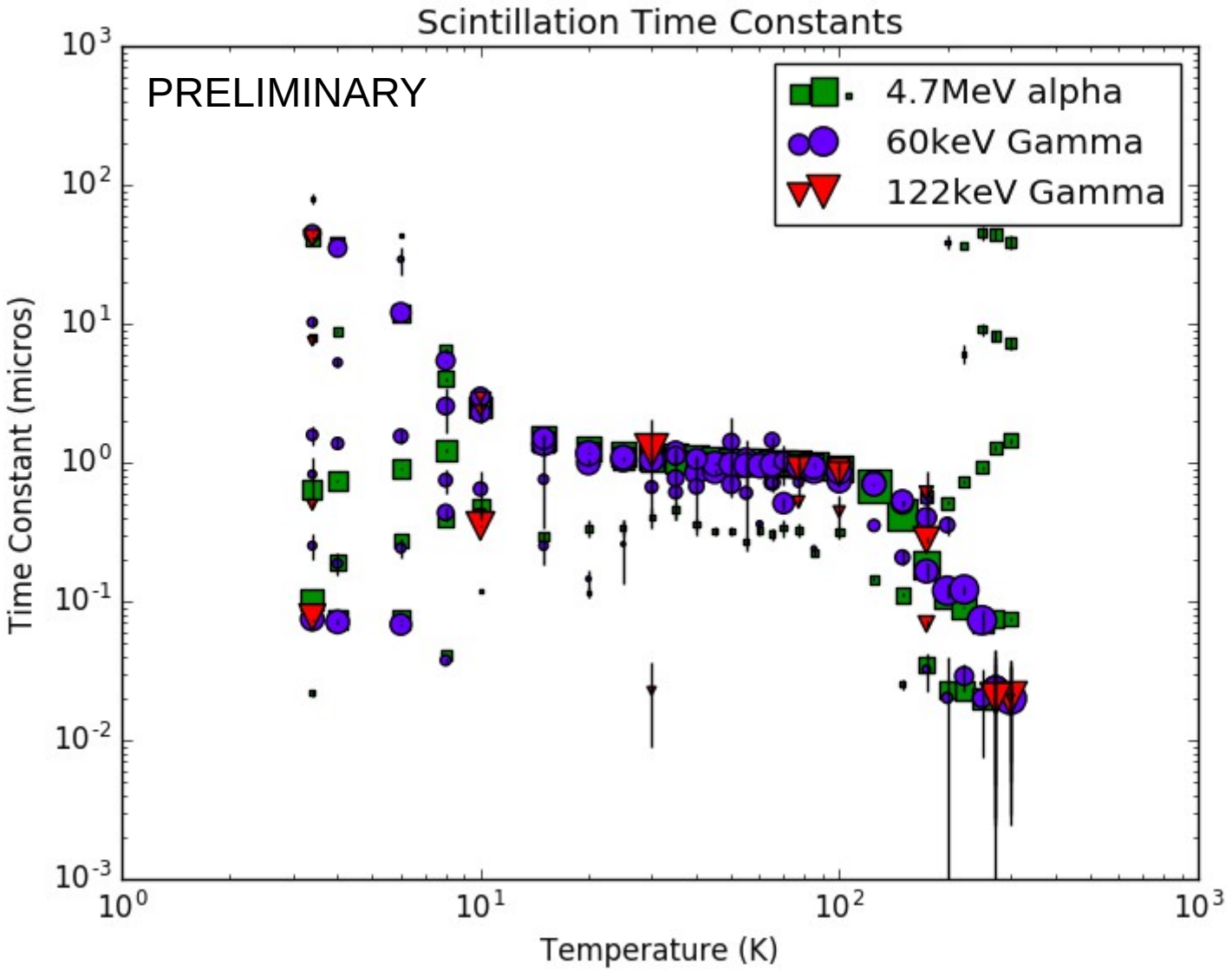
Gamma Time Constants



Components with contribution lower than 1% removed from plot to reduce clutter

All Time Constants

- Both alpha and gamma interactions appear to produce the same major scintillation time constant
- Comparison still needs to be done with previous work of other collaborations



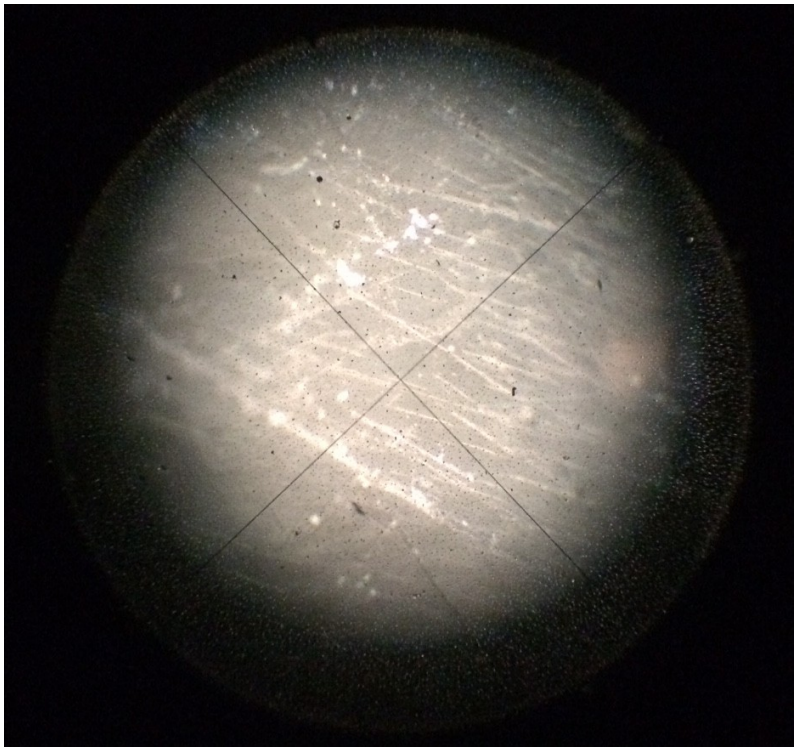
Conclusion

- Lots of interest in CsI for rare event searches
- Measured light yield,scintillation time constants, and alpha/gamma quenching factor of CsI for temperatures from 3.4K – 300K
- Promising light yield values at low as well as intermediate temperatures for rare event searches
- Measured alpha/gamma quenching factor > 1 for temperatures from 10-100K

BACKUP SLIDES

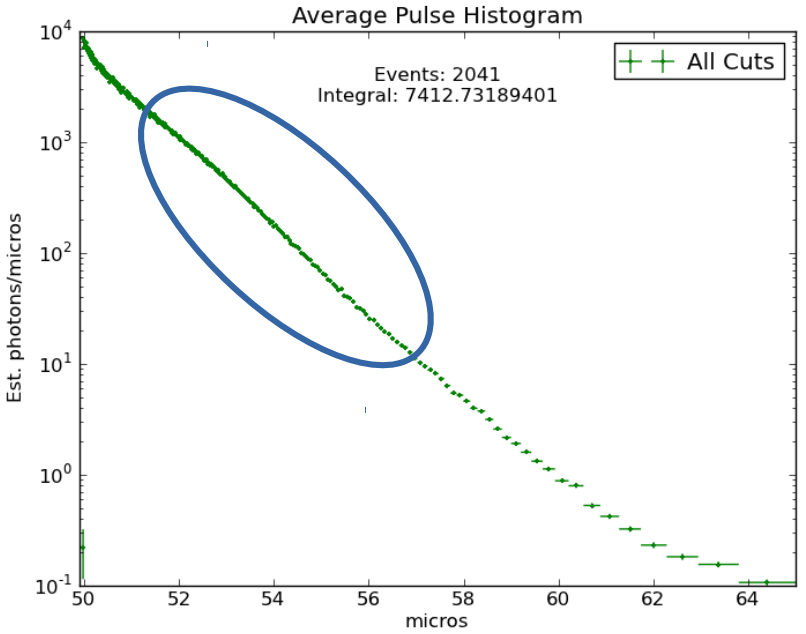
Alpha Peak Shape

- See an asymmetry in the alpha peak
- Attributed to alphas hitting uneven surface features, depositing energy or releasing light differently

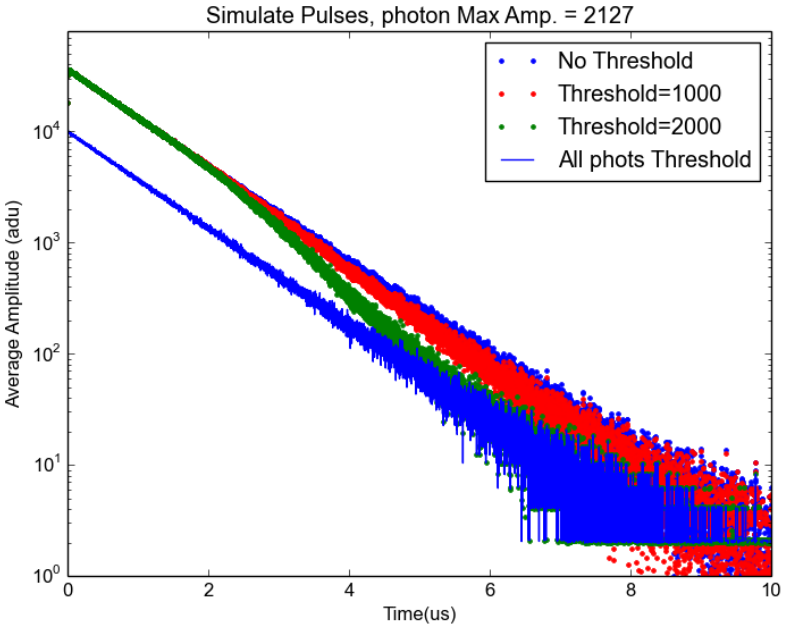


Microscope photo taken of crystal surface after data was collected

Threshold Effect on Pulse Shape



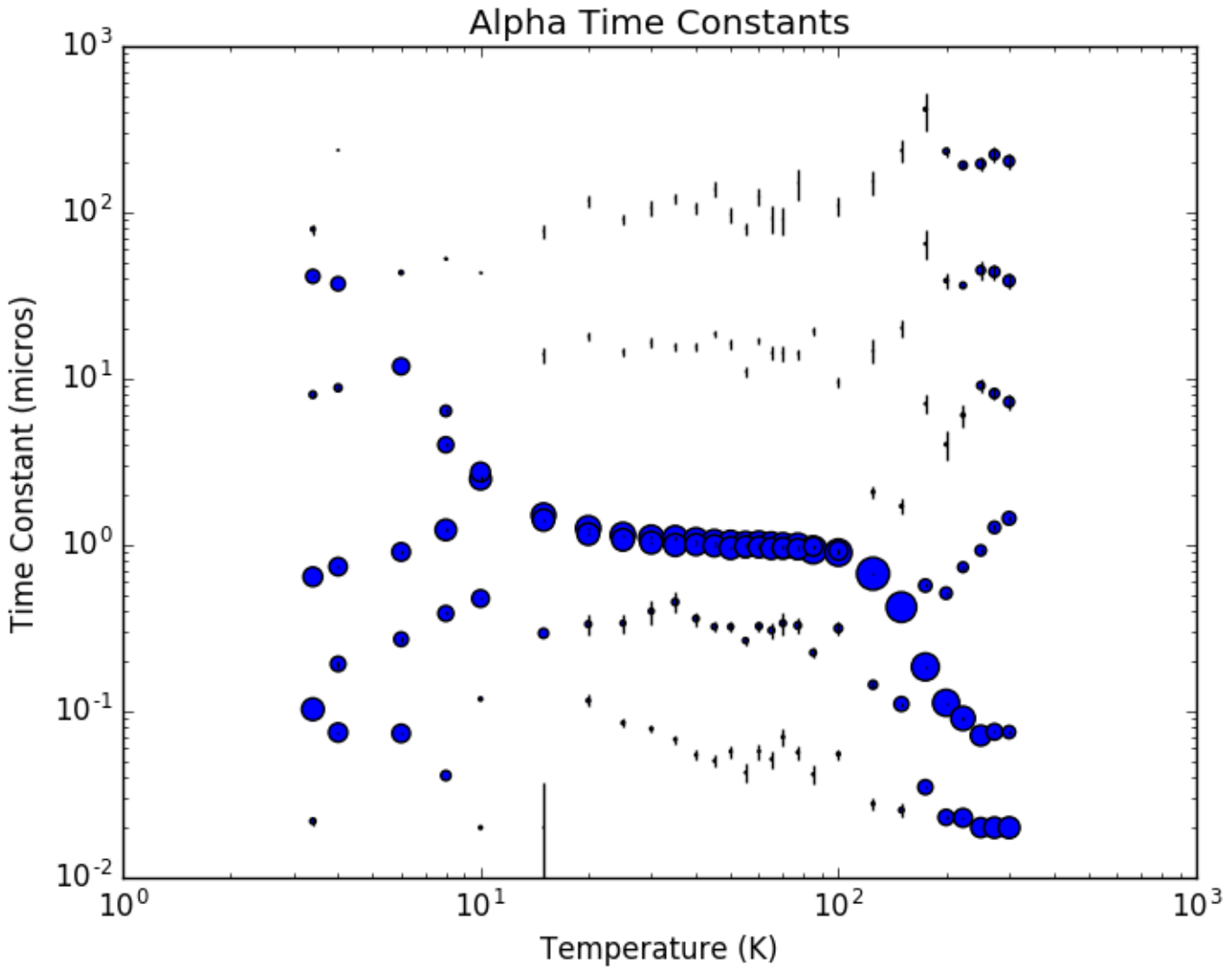
Real pulse shape with strange feature circled



Simulated Pulse to determine threshold effect

- Observed an unexpected feature in the pulse (left), determined through simulation (right) that it was most likely due to our analysis threshold
- Solution: Fit above (50-52 micros) and below the feature (56-1000 micros), time constant should be the same before and after

All fitted time constants Alpha Pulse Shapes



All fitted time constants Gamma Pulse Shapes