Solid-state Cryogenic Scintillators for Particle Detectors

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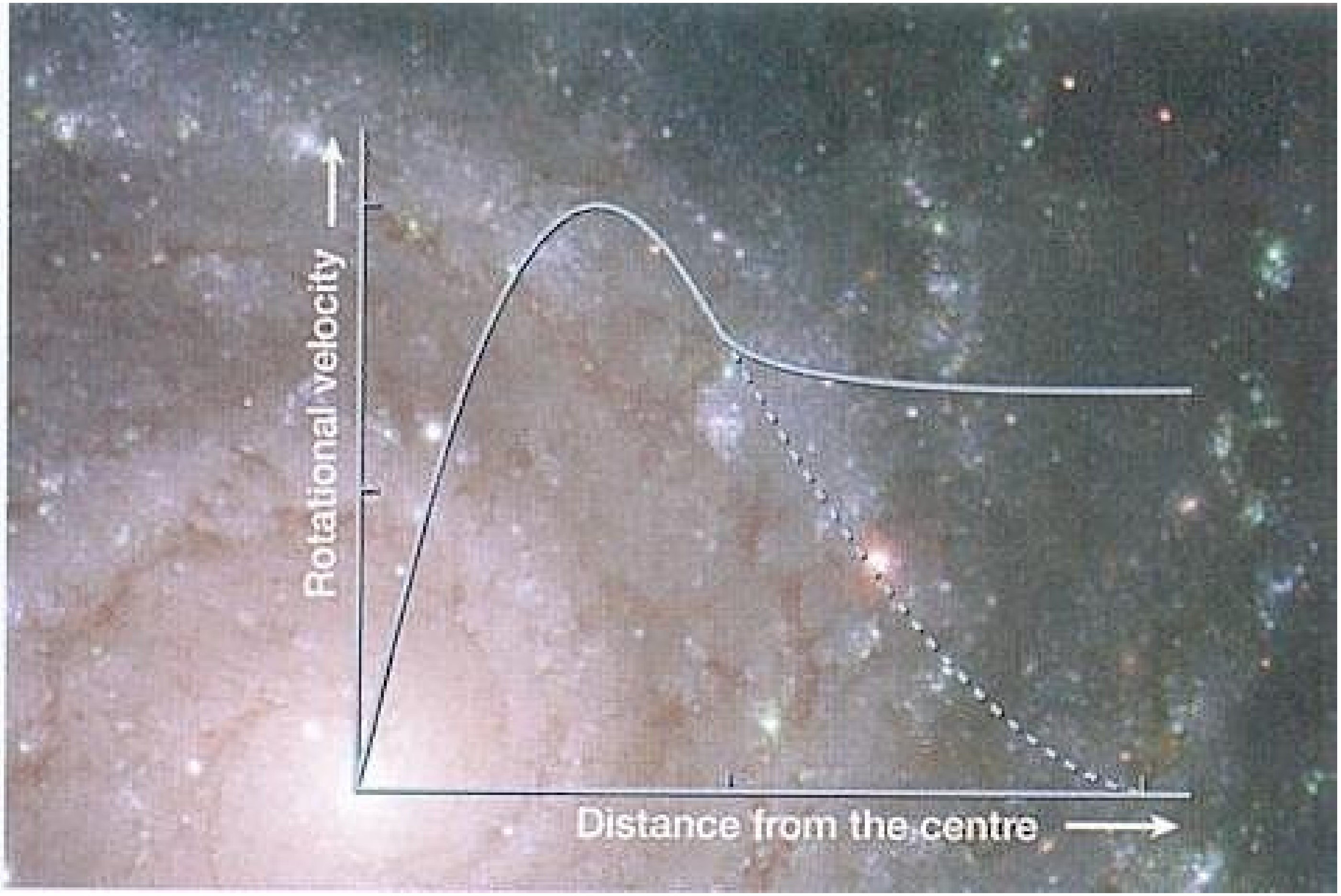
The Dark Matter Problem

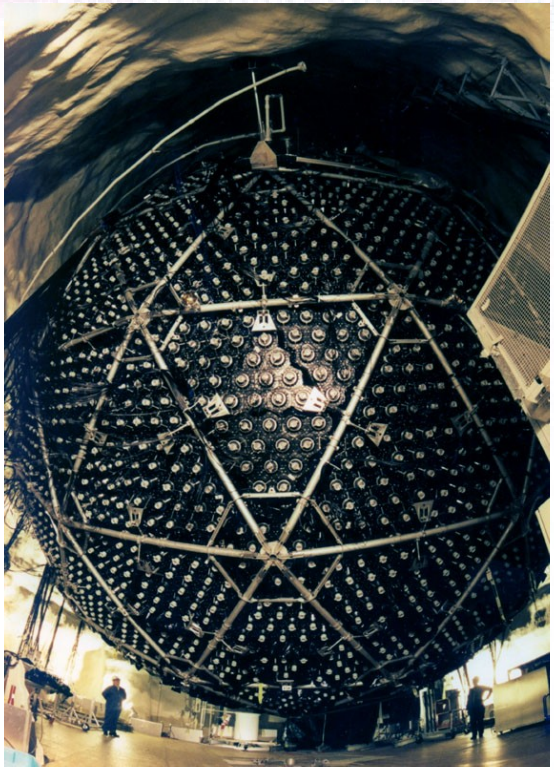


- Thought to contribute most of the mass in the universe.
- Possibly in the form of WIMPs – Weakly Interacting Massive Particles (that are very hard to detect).

WIMP Detection Experiments

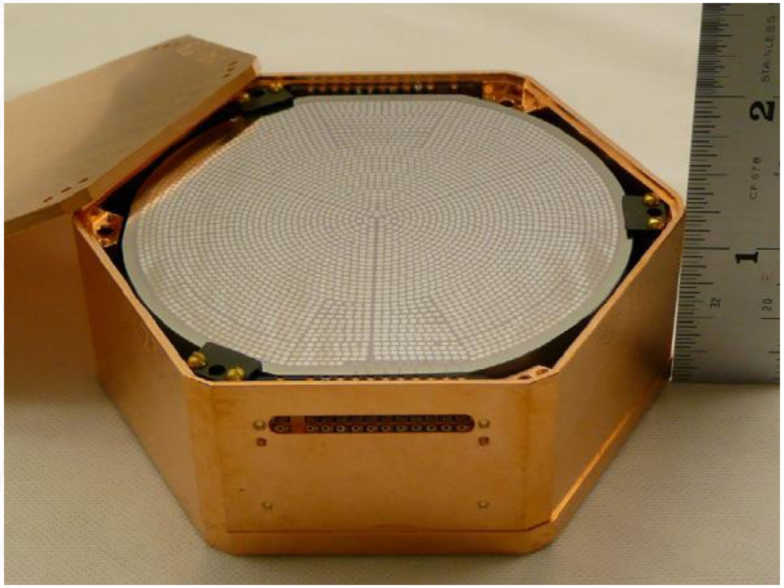
- SuperCDMS currently in Soudan, MN.
- Planning to move to Sudbury, ON in near future.

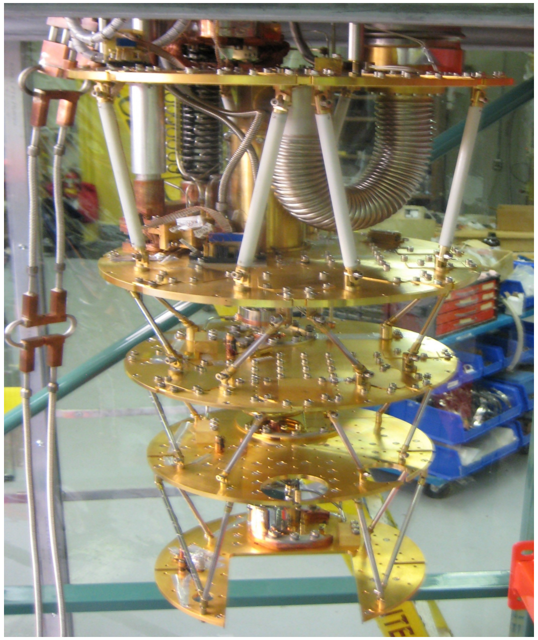
SNOLAB



- Famous for the Sudbury Neutrino Observatory.
- Ultra-low cosmic ray background.
- 2km underground in the Vale/Inco Creighton mine.
- Deepest cleanroom in the world.
- Home to > 5 particle physics experiments.

Cryogenic Dark Matter Search





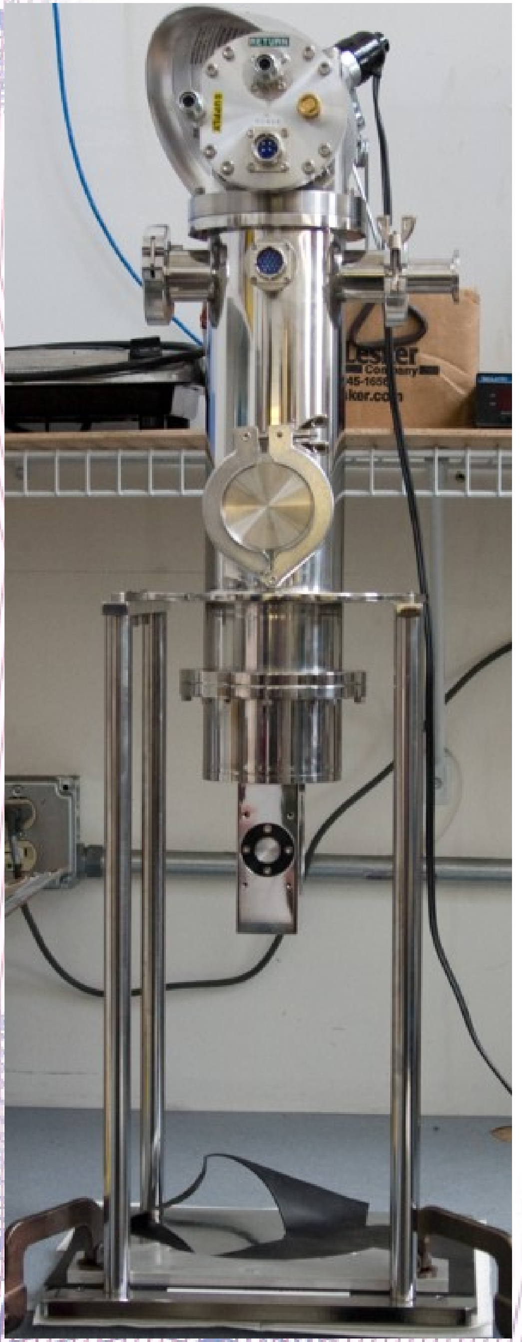
- Germanium target nucleus at mK temperatures.
- Phonon (heat) signal causes superconducting to normal-conducting transition in thin film.
- Ionization signal detected by semiconductor.
- Ratio discriminates between electron recoil (background) and nuclear recoil (WIMP).

Scintillators

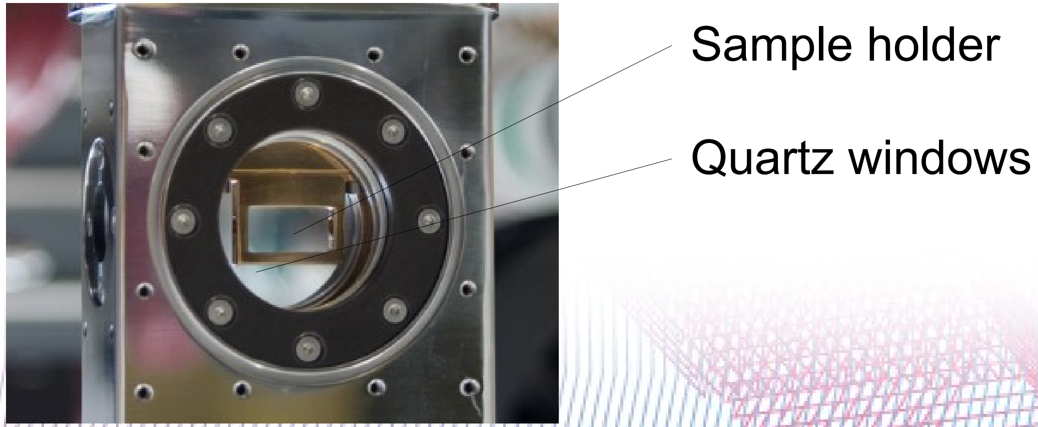
- Ionization-phonon devices are currently the most sensitive dark matter detectors but have a restricted range of targets.
- Understanding backgrounds and confirming a signal will require more target nuclei → investigate cryogenic scintillation-phonon detectors.
- A scintillator emits light when a particle interacts in it (WIMP, gamma, neutron, etc).
- The number of photons "light-yield" is roughly proportional to energy but the proportionality constant depends on temperature.

Our goal is to characterize the evolution of light yield and time constants as a function of temperature.

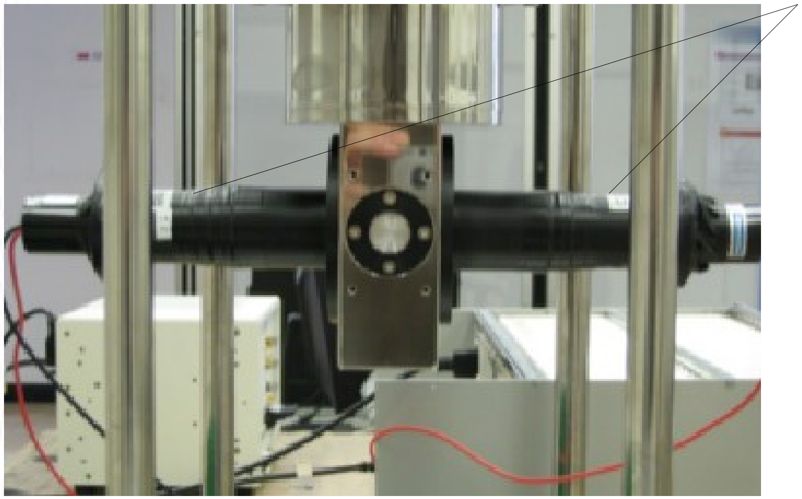
The Experiment



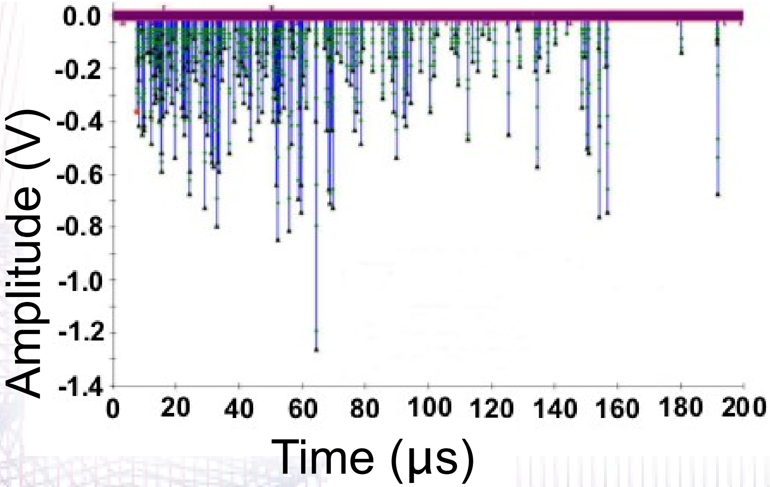
- Gifford McMahon cryostat with 3.4K base temperature.
- Optically accessible.
- Temperature can be adjusted with Joule heating.



The Experiment

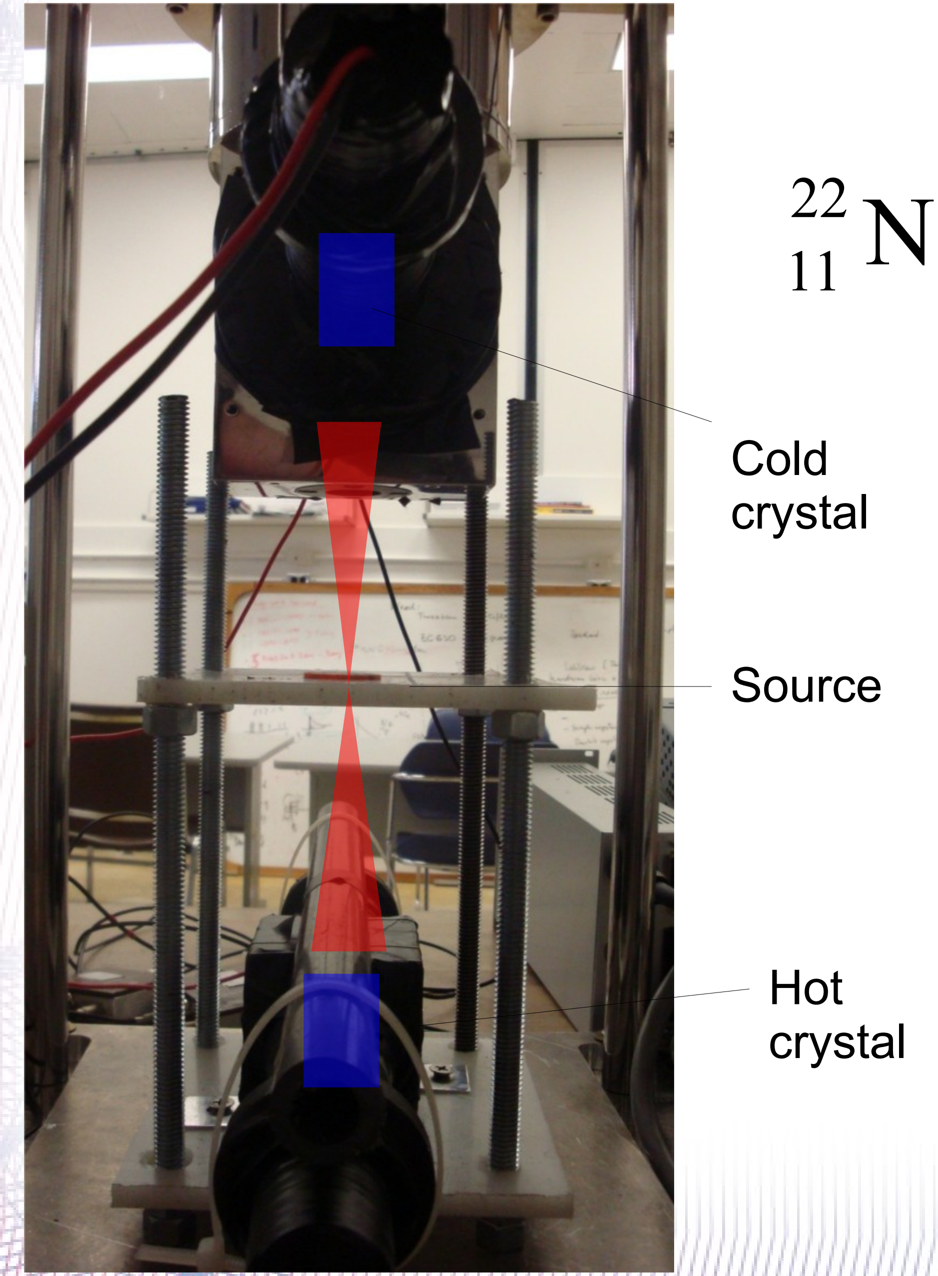

PMTs

BGO Scintillation Event at 20K



- Scintillation light is collected by photomultiplier tubes.
- For a scintillation, photons may arrive exponentially in time.
- The crystal is excited by events from a radioactive source that arrive randomly in time.

Double-Coincidence



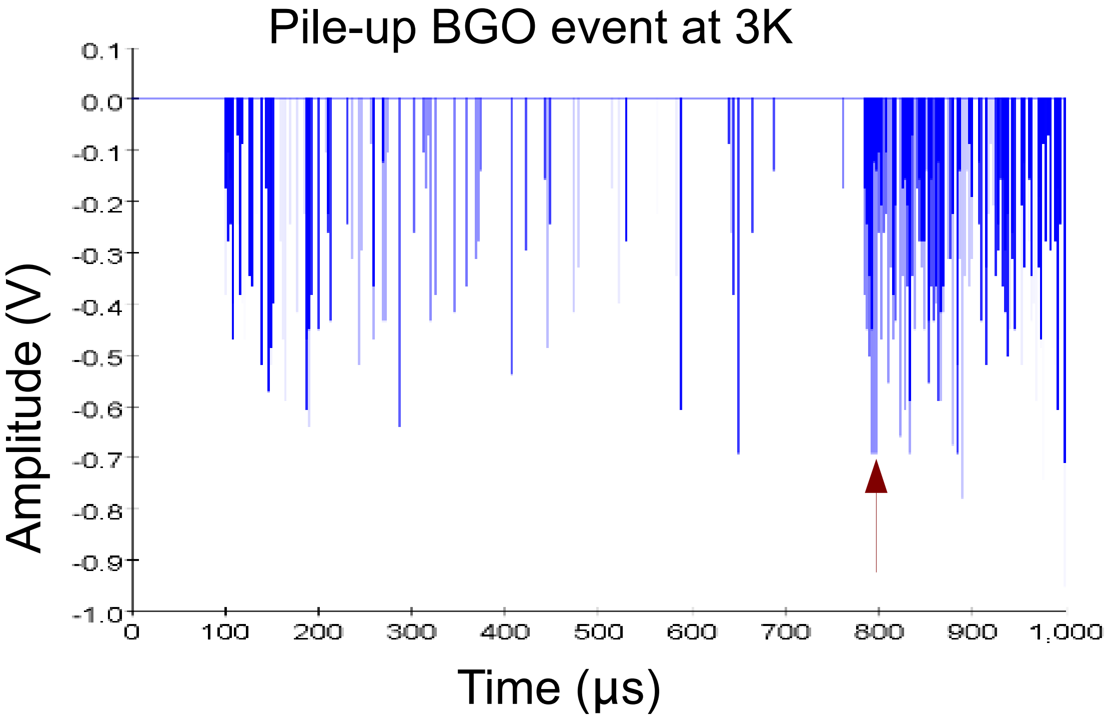
$$^{22}_{11}\mathrm{Na} \rightarrow {}^{22}_{10}\mathrm{Ne} + e^{+} + \nu + \gamma$$

- Two 5mm x 10mm x 20mm $Bi_4Ge_3O_{12}$ equidistant from the source.
- Positron gives us back-to-back 511keV gammas in addition to the 1.2MeV.

Definition of an Event

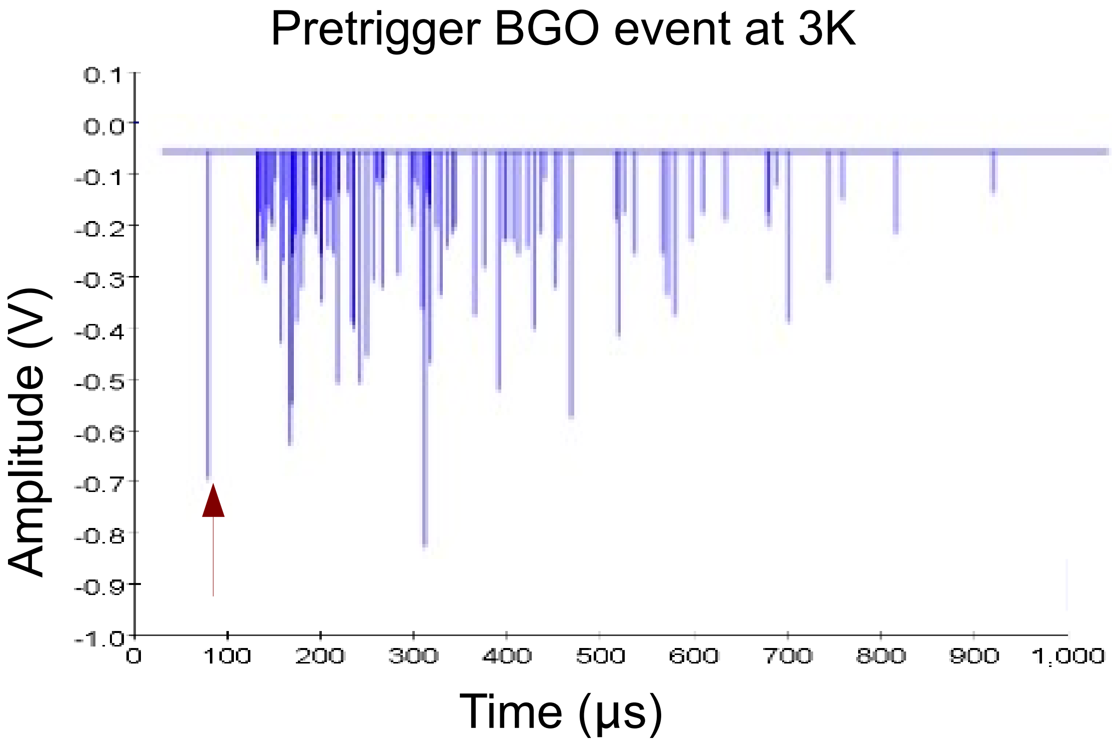
- Step 1: PMT 1 sees a photon from the hot crystal at t_1.
- Step 2: PMT 2 sees a photon from the hot crystal at t_2 - less than 30ns later.
- We now have a coincidence at t_2.
- Step 3: PMT 3 sees a photon from the cold crystal at t_3.
- Step 4: PMT 4 sees a photon from the cold crystal at t_4 – less than 900ns later.
- We now have a coincidence at t_4.
- If t_4 came less than 900ns after t_2 we have a double coincidence or an “event”.
- Data is collected starting at t_4 (with a 10% pretrigger).
- The time t_1 is recorded as the start of the scintillation.

Cutting out Events



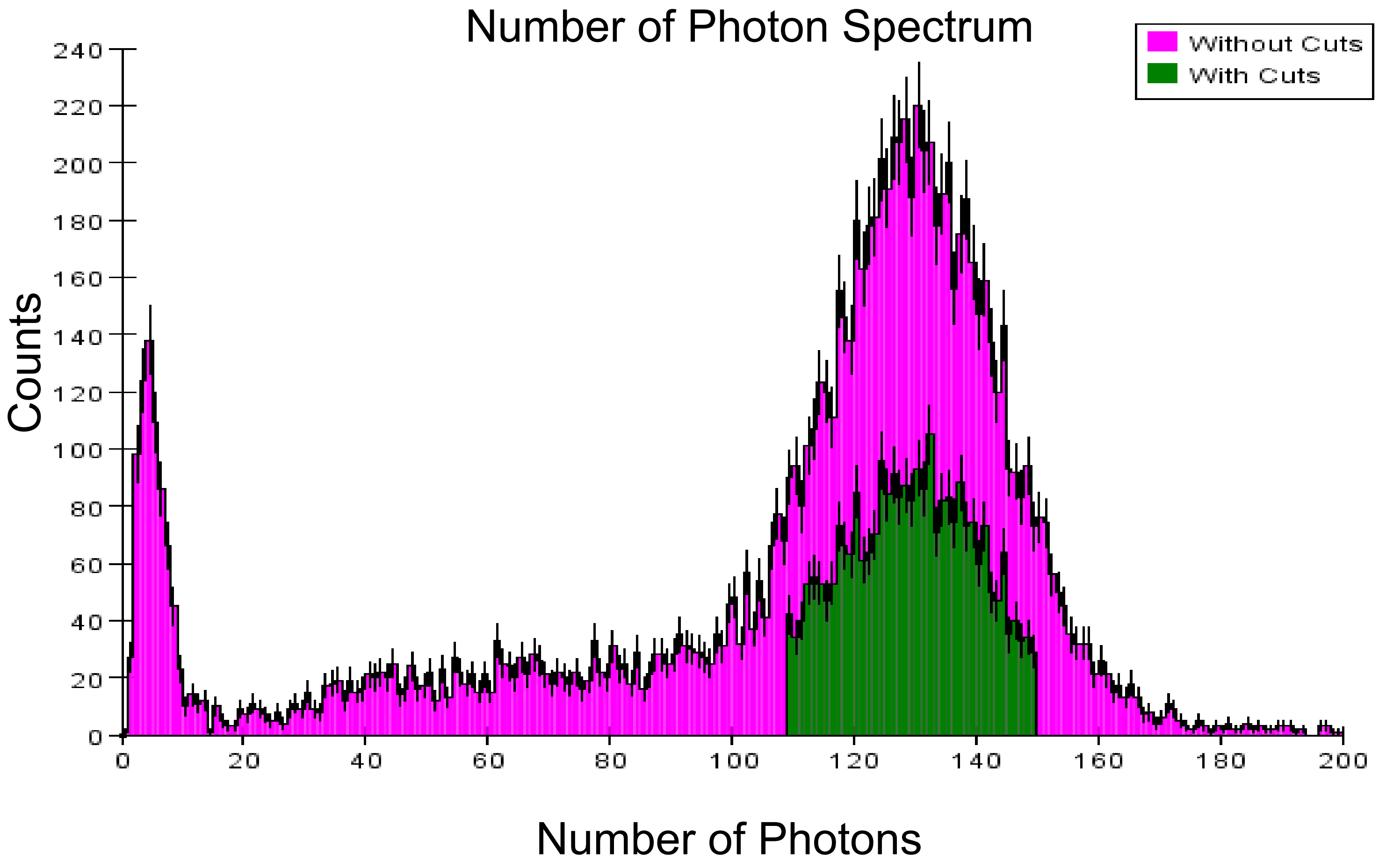
- A run may have pile-up (more than one scintillation in a recorded event).
  - Cut events where the mean arrival time of photons relative to the start is too high.

Cutting out Events



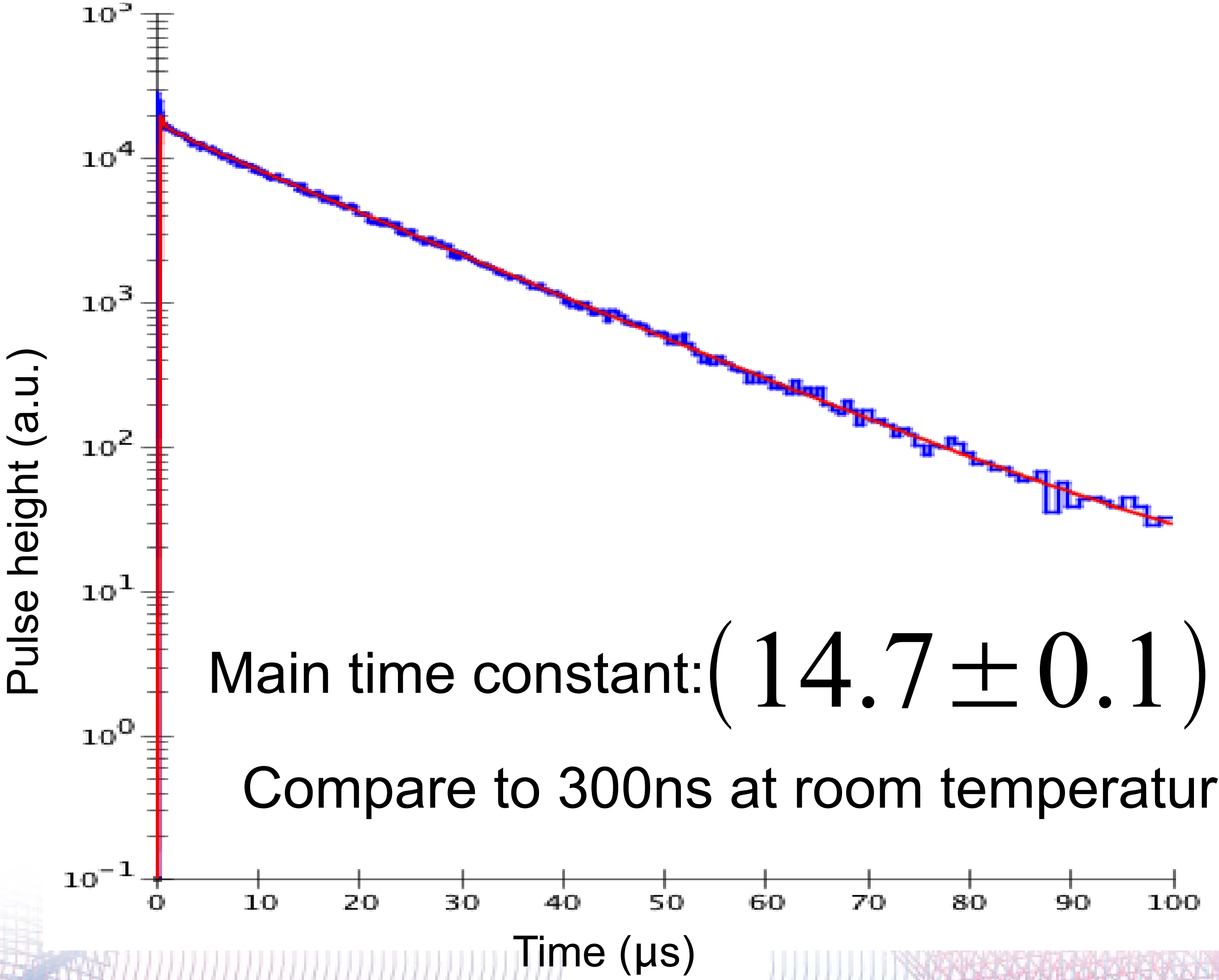
- The tail of a previous event can make an event appear to have started very early.
  - Cut events where the first photon arrived too early in the pretrigger region.

Cutting out Events



- Only keep events in the photopeak because it is a well-defined population (guards against pile-up from 1.2MeV photons, backscattering, etc).

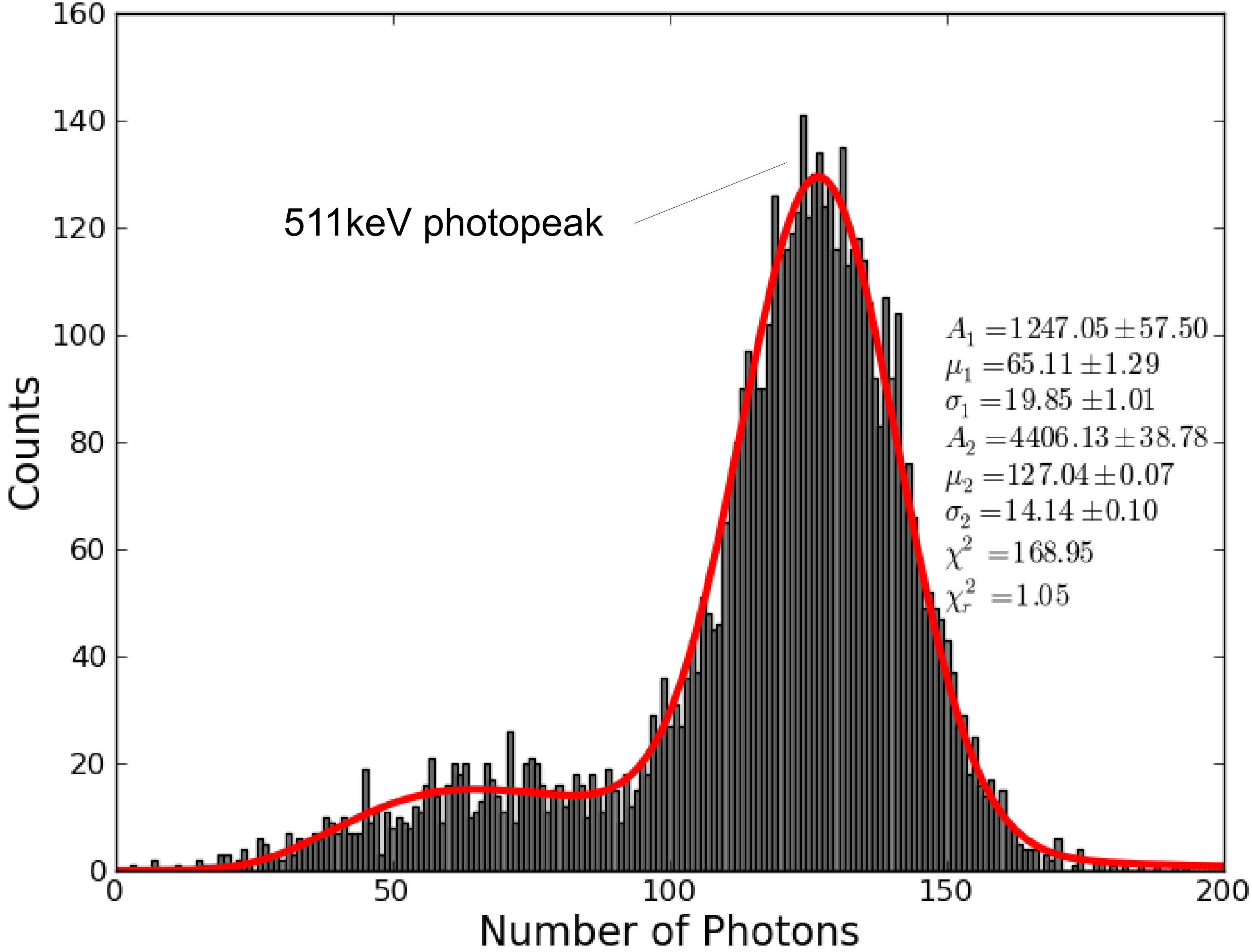
Typical Average Pulse Fit (40K)



Main time constant: $(14.7 \pm 0.1)\,\mu s$

Compare to 300ns at room temperature.

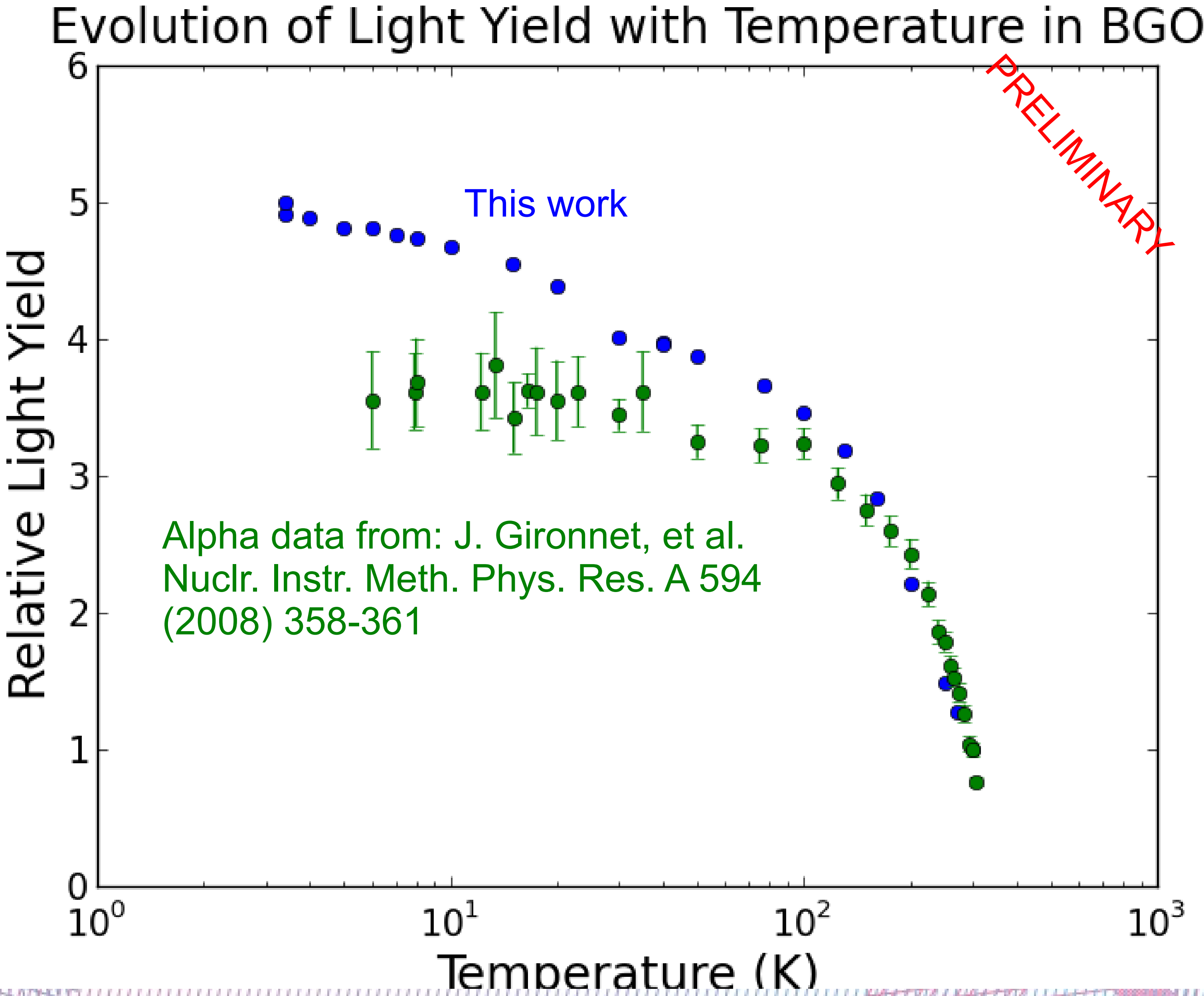
Typical Spectrum Fit (5K)



Method

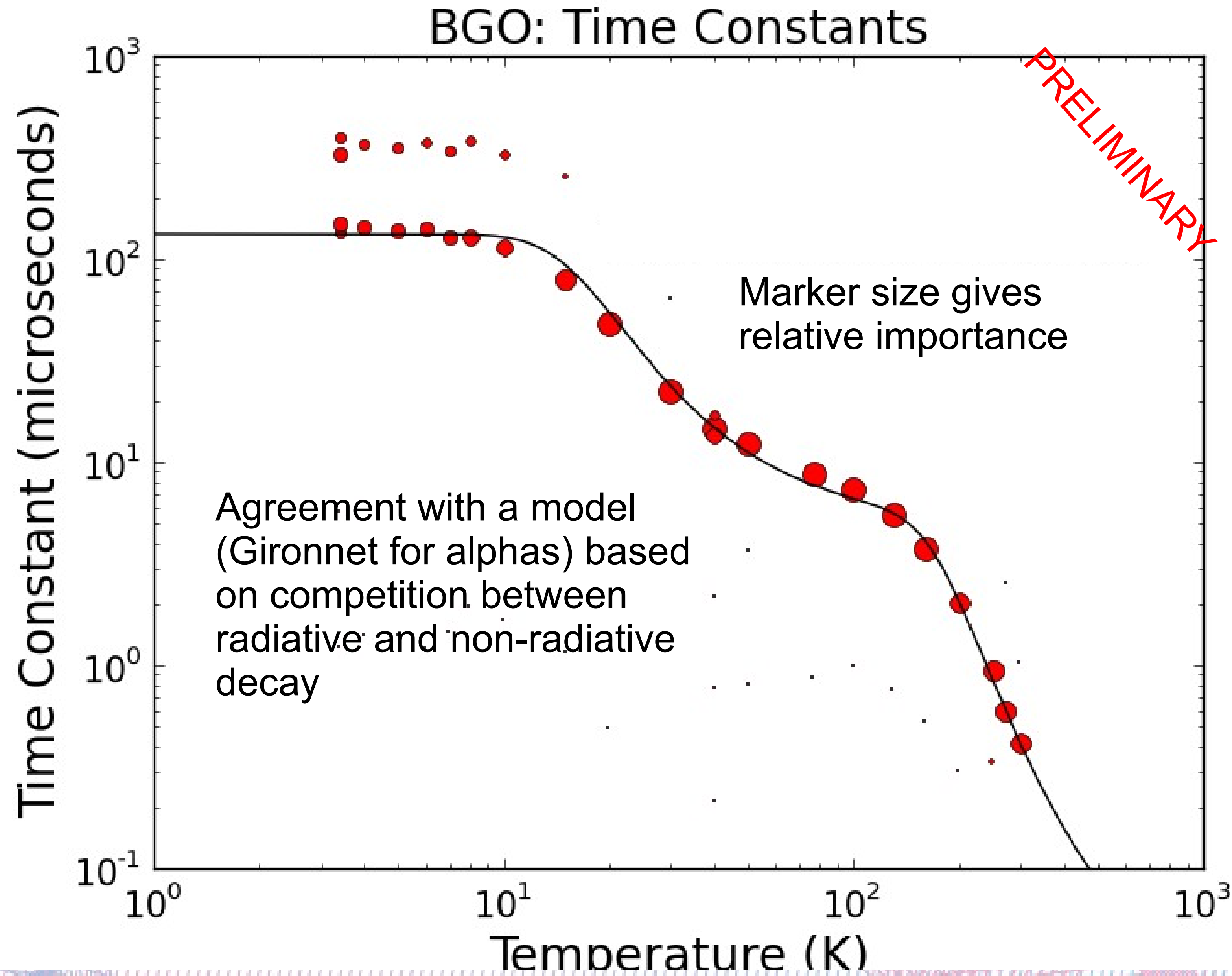
- Set the sample temperature.
- Wait for it to stabilize.
- Read in 10,000 events (~12 hours).
- Perform initial reduction (done on HPCVL grid).
- Perform reanalysis (cuts).
- Possibly change the acquisition window.
- Repeat.

Light Yields vs T



Alpha data from: J. Gironnet, et al.
Nuclr. Instr. Meth. Phys. Res. A 594
(2008) 358-361

Time Constants vs T



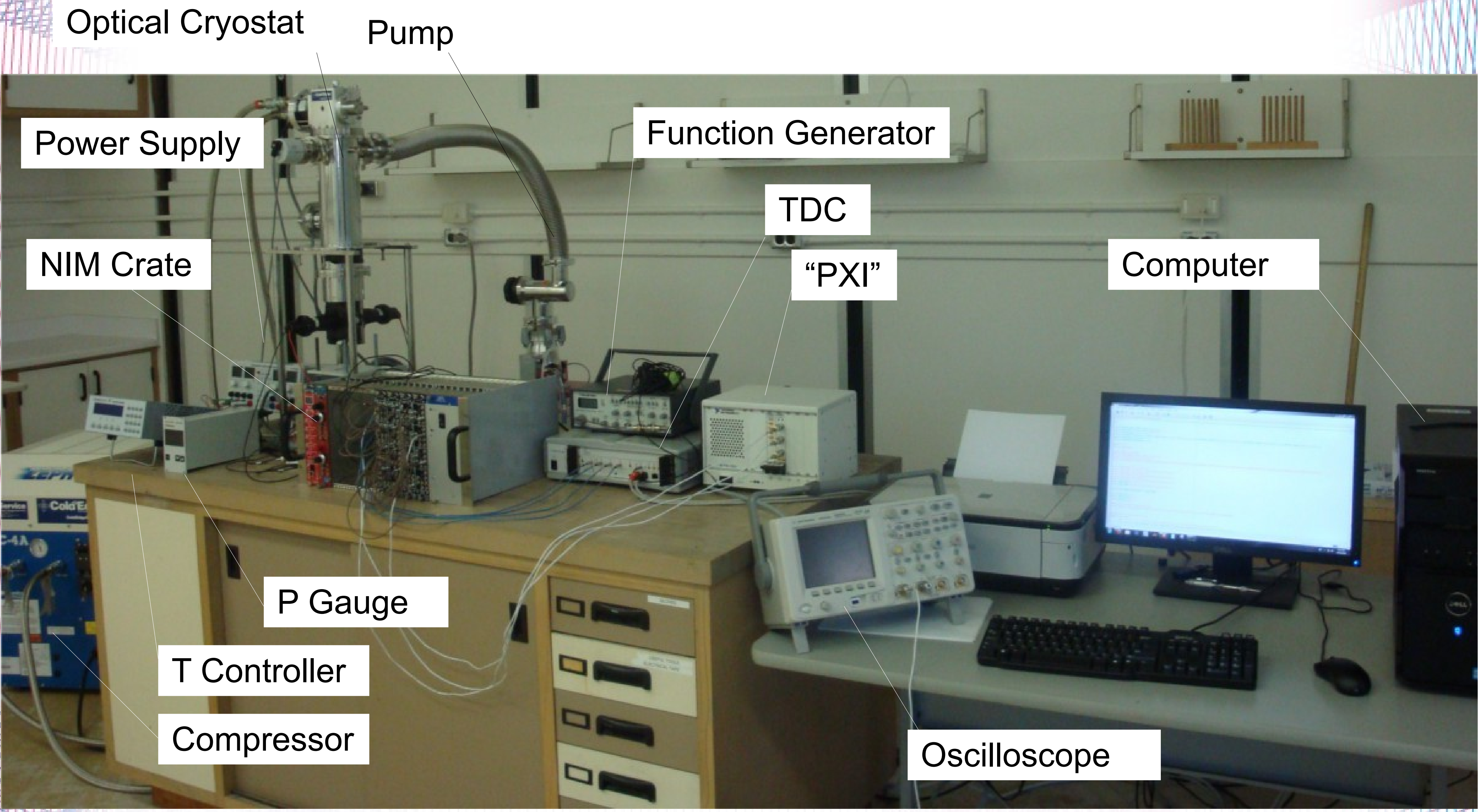
Marker size gives relative importance

Agreement with a model (Gironnet for alphas) based on competition between radiative and non-radiative decay

Conclusions

- Detecting dark matter is still an open problem.
- Low temperature scintillators can help solve it.
- Queen's has a test facility for characterizing them which has demonstrated success with BGO from 300K to 3.4K.
- Light yield for BGO increases by a factor of 5 for gammas – significantly more than with alphas (still being studied).
- Pulse lengthens by a factor of 1000 (like alphas).
- Positions available at SuperCDMS Queen's and SNOLAB! http://www.sno.phy.queensu.ca distefan@queensu.ca

The Lab


Optical Cryostat
Pump
Power Supply
Function Generator
TDC
NIM Crate
"PXI"
Computer
P Gauge
T Controller
Compressor
Oscilloscope

Thanks for listening!