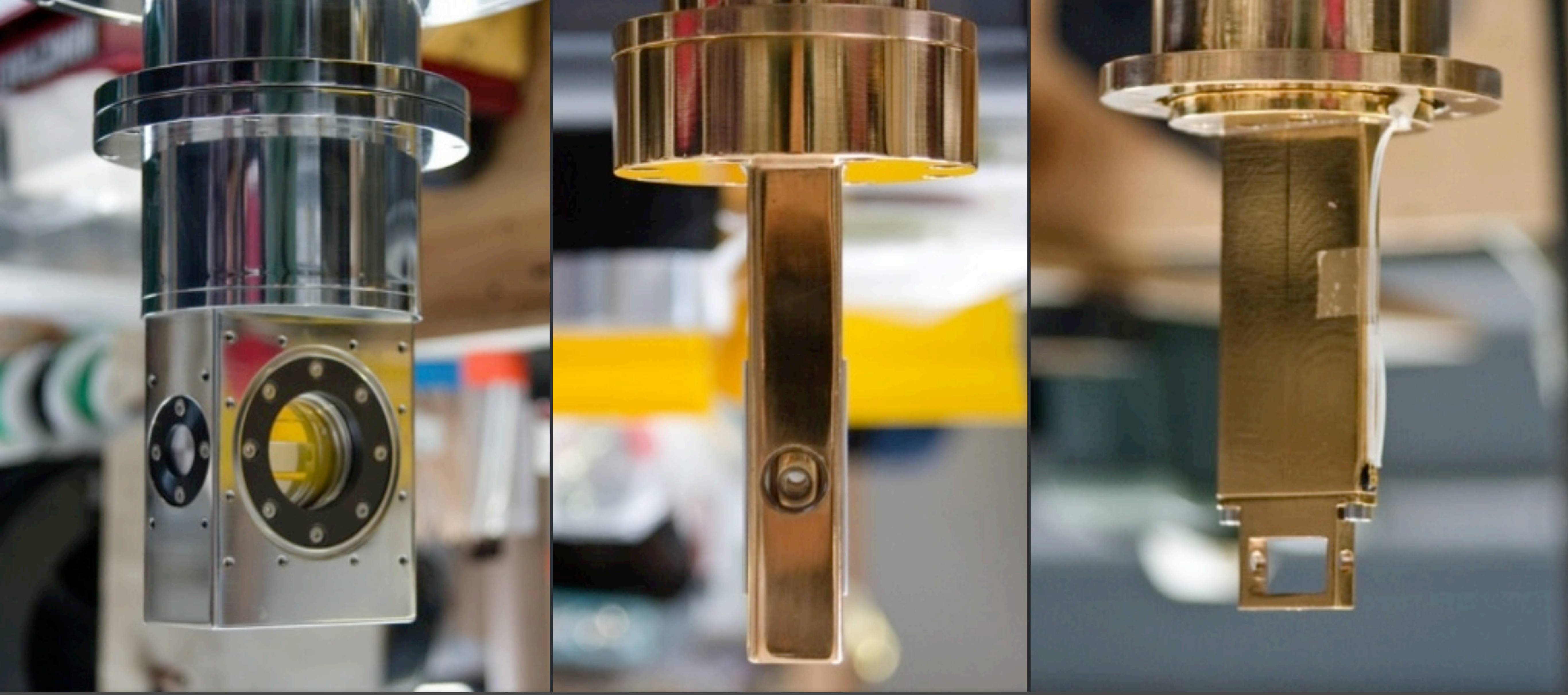

Cryogenic Scintillators for Rare Event Searches

WNPPC 2012

NSERC Canada (Grant SAPIN 386432), CFI-LOF and ORF-SIF (Project 24536)

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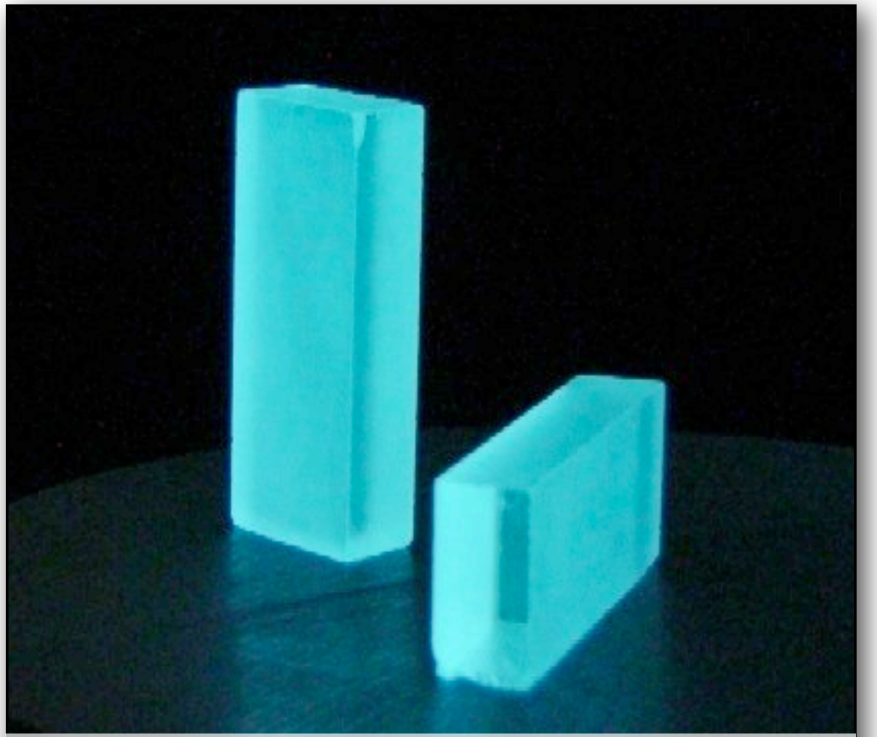
On behalf of C. Behan, M. Clavel, P. Di Stefano, F. Duquerroix, S. Hills, C. Martinez, E. Mony, W. Rau and M.-A. Verdier
Queen’s University

Scintillators & Rare Event Searches

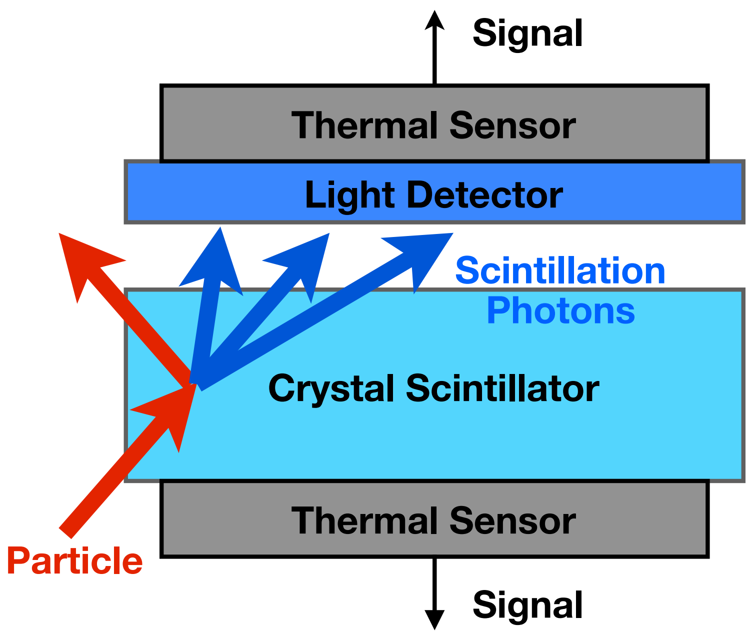
- Crystal scintillators
  - Widely used to detect ionizing radiation
  - High scintillation efficiency
- Rare event searches
  - Neutrinoless double beta-decay (i.e. ZnSe, $CdWO_4$)
  - Long-lived radioisotopes (α-decay of ^{209}Bi *)
  - Direct detection of dark matter (CRESST, ROSEBUD)



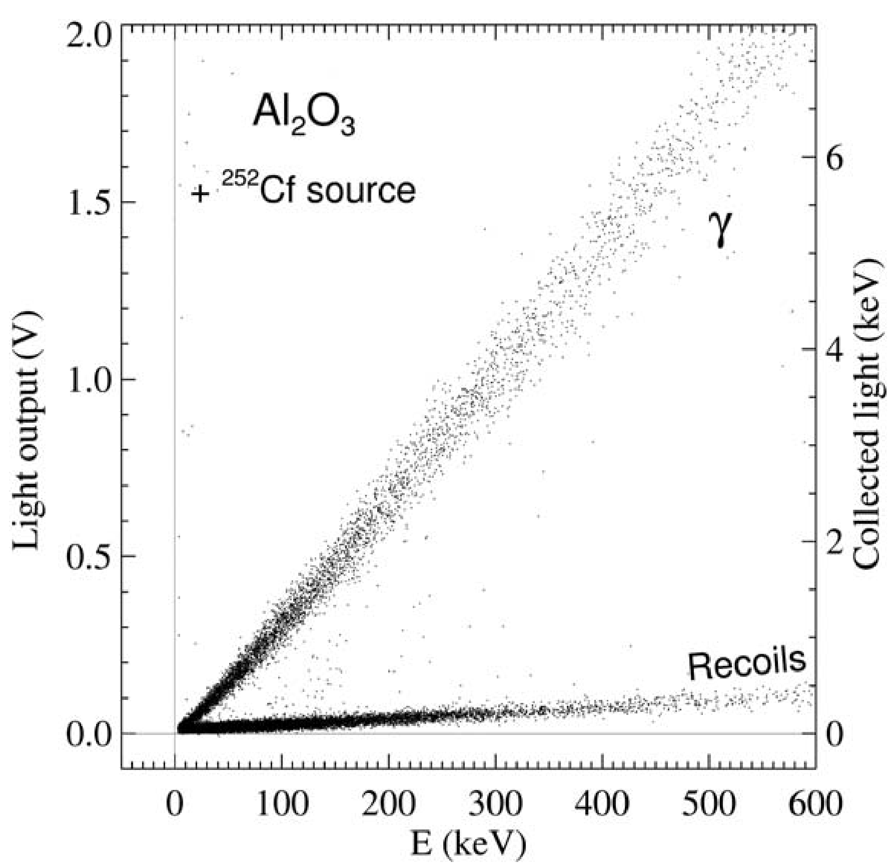
Bismuth germanate (BGO), scintillating under x-ray excitation. (http://carlwillis.wordpress.com)

* P. de Marcillac, et al., Nature (2003)

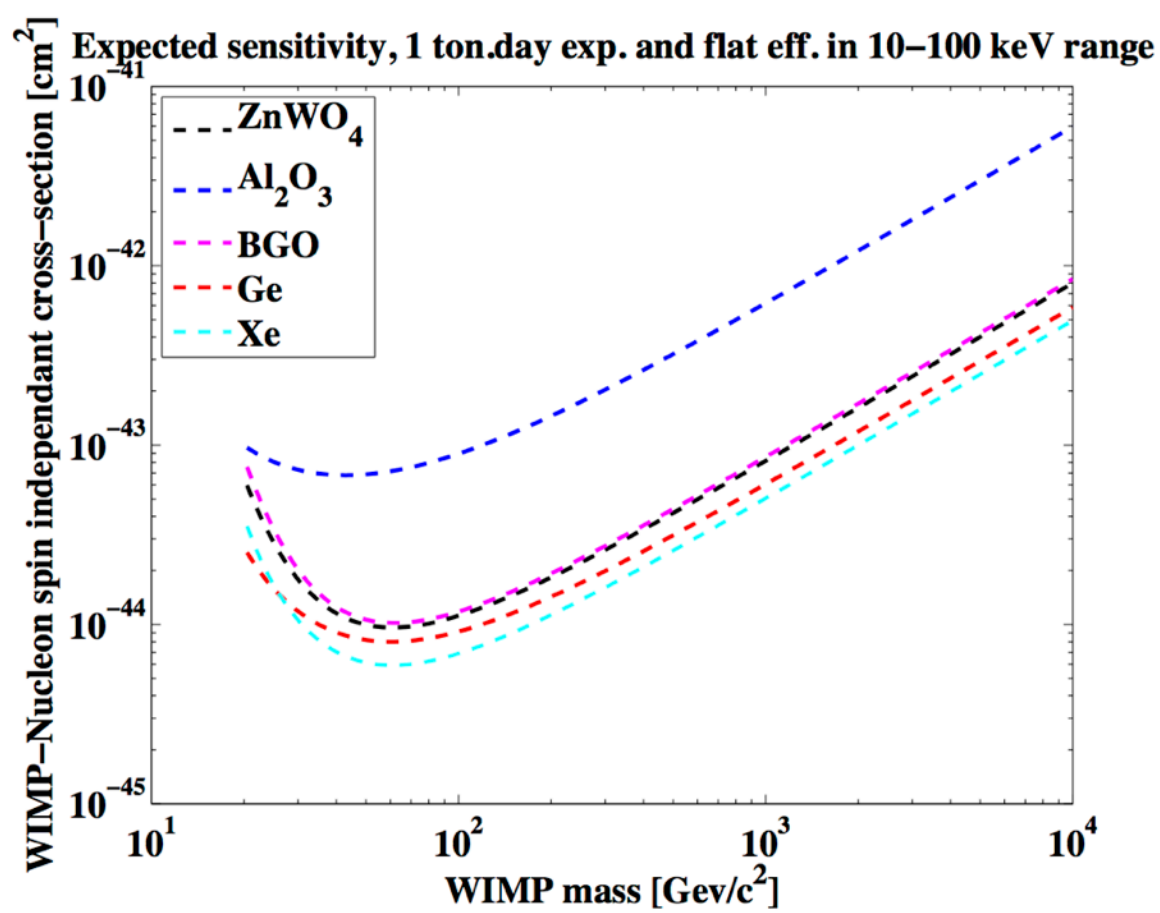
Cryogenic Detectors



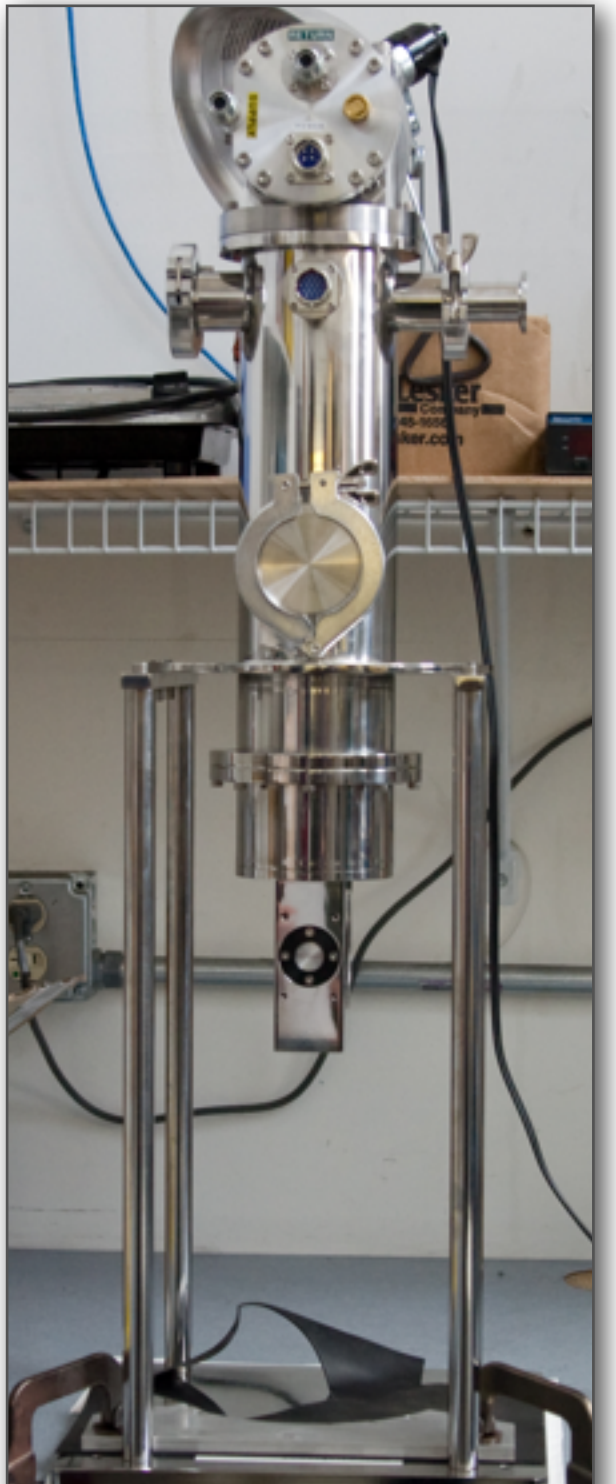
- Scintillation-Phonon Detectors: Light + phonon signals give background rejection
- Many more options for target nuclei than with ionization-phonon detectors (Ge, Si)
- More targets → can confirm WIMP signal
- Lighter targets → understand neutron background

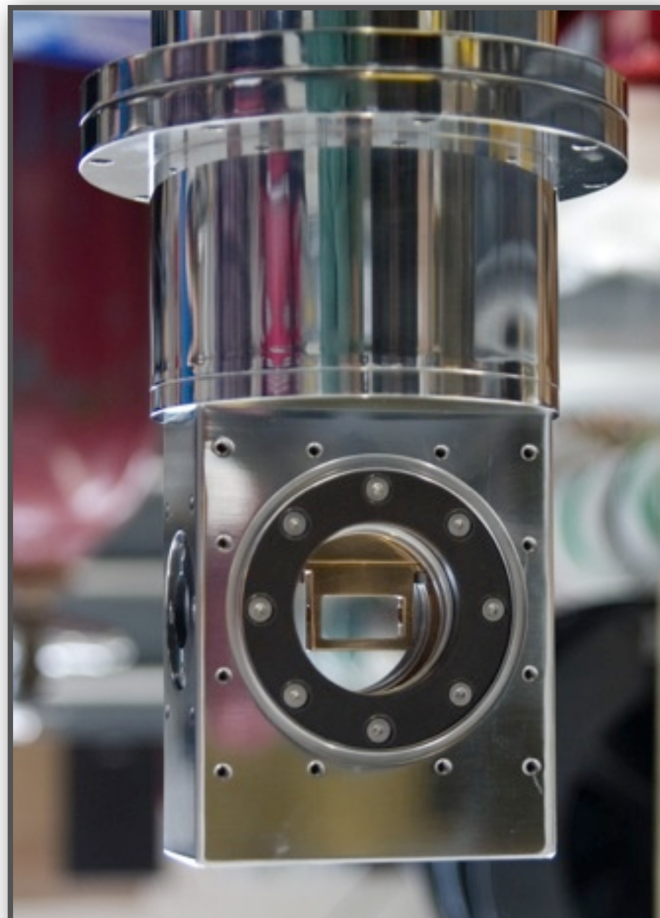


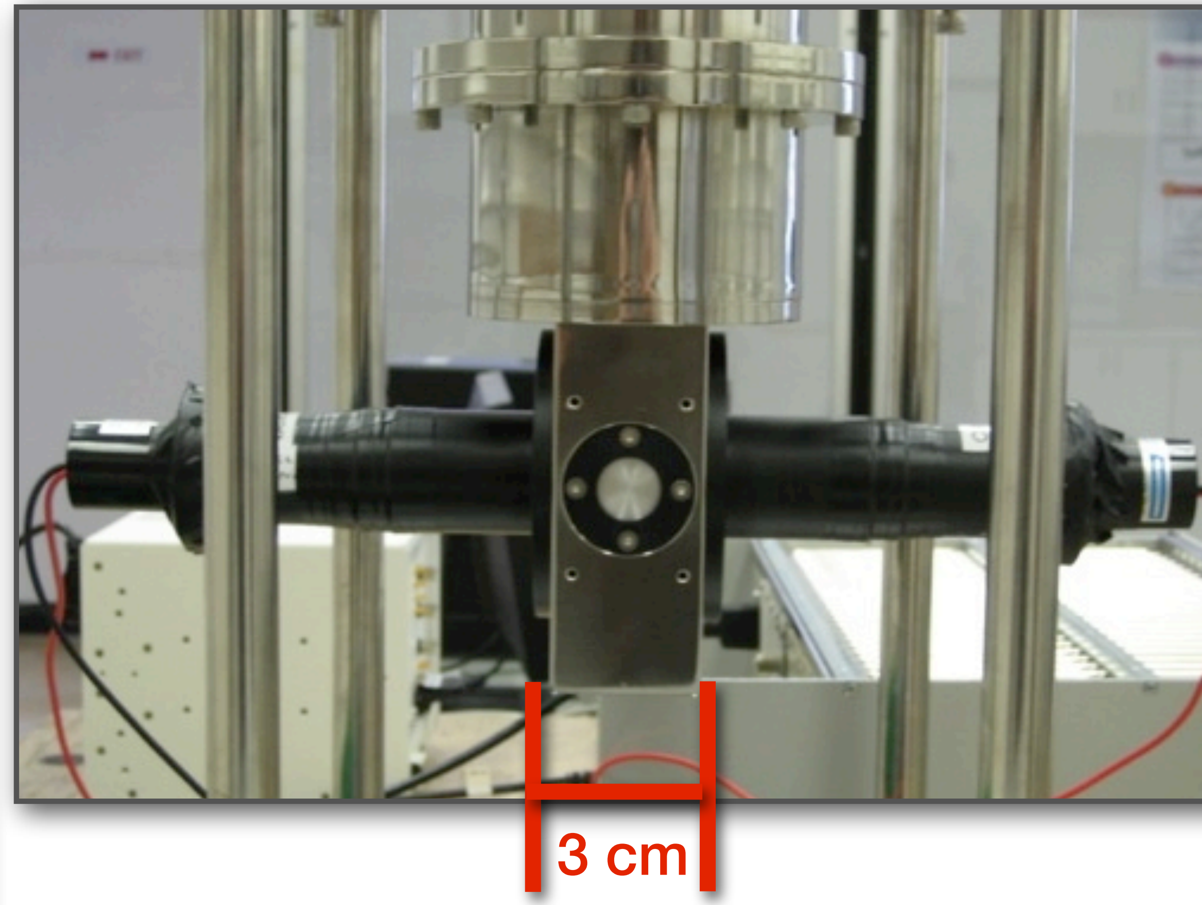
Coron, *et al.*, NIM A 520 (2004)



Optical Cryostat at Queen's



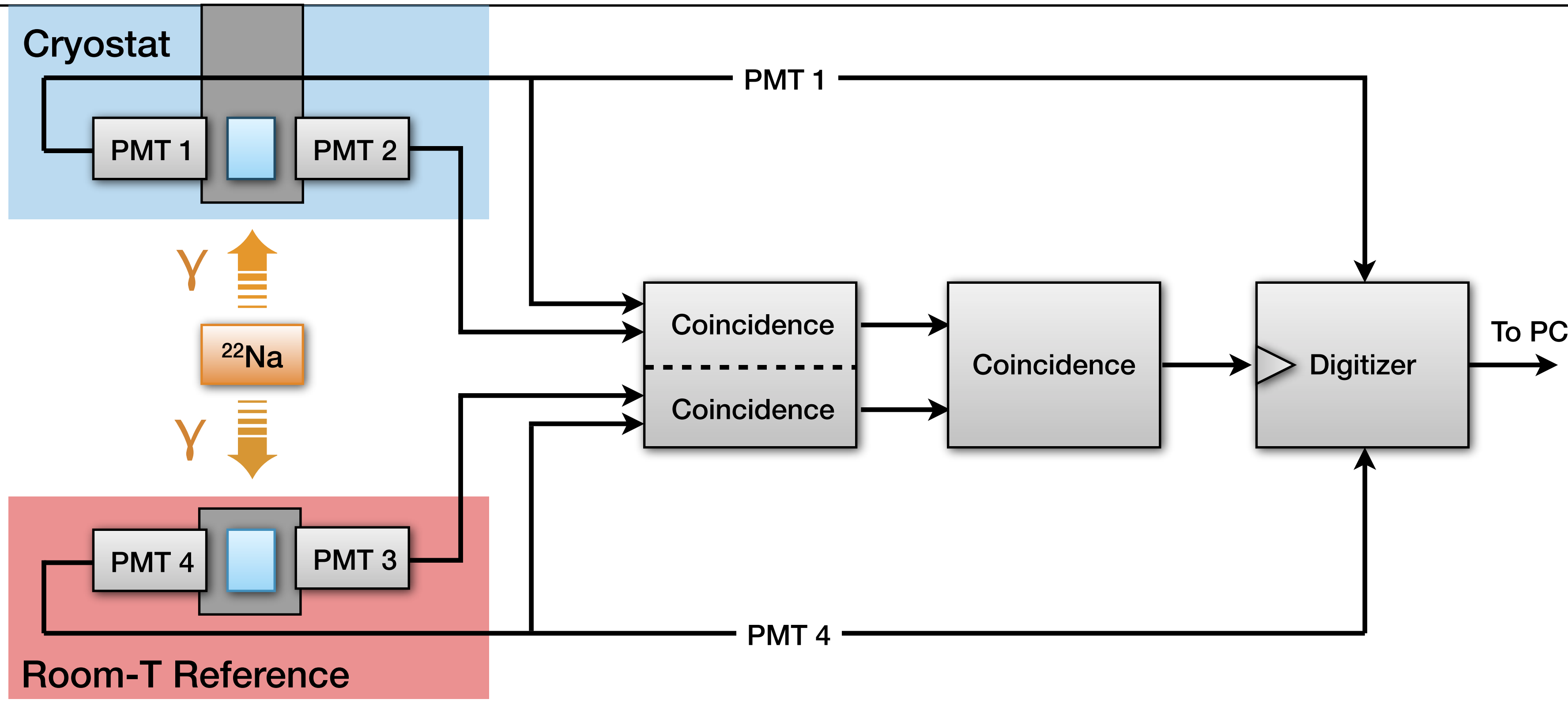


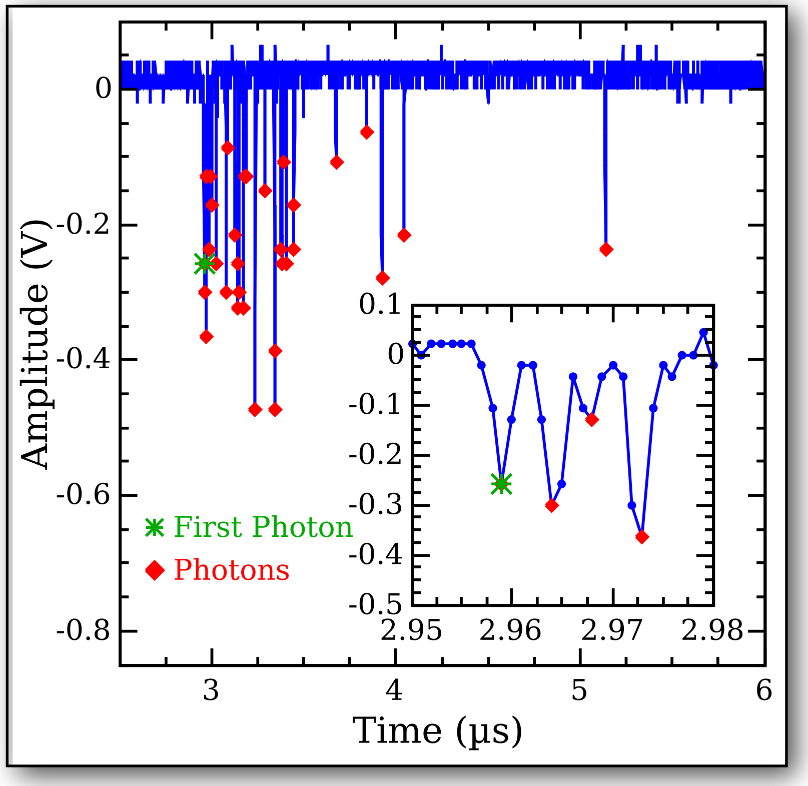


- Cryogen free
- Compact, 2-PMT see-through geometry (40% solid angle)
- 5x10x20 mm^3 samples (max)
- Uniquely designed for γ measurements

M.-A. Verdier et al., Rev. Sci. Instrum. 80 (2009)

Data Acquisition

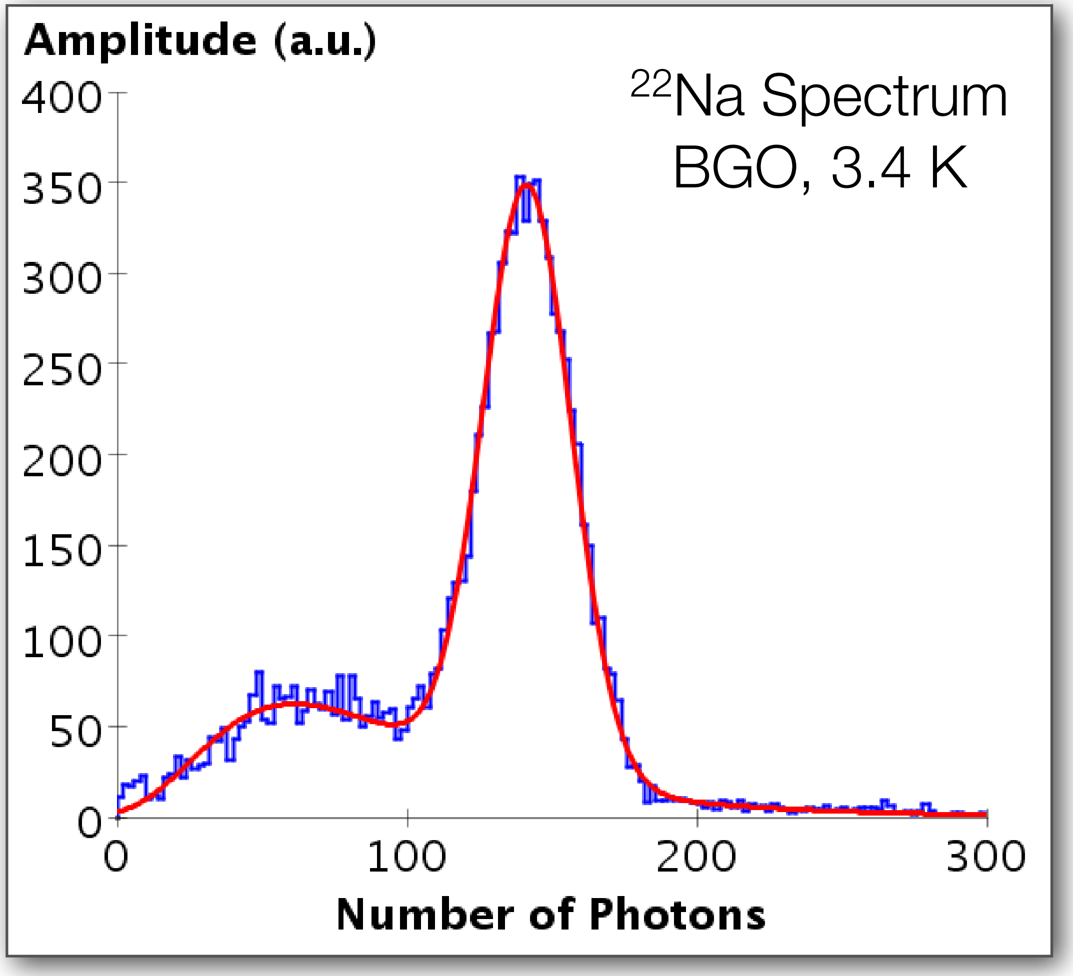


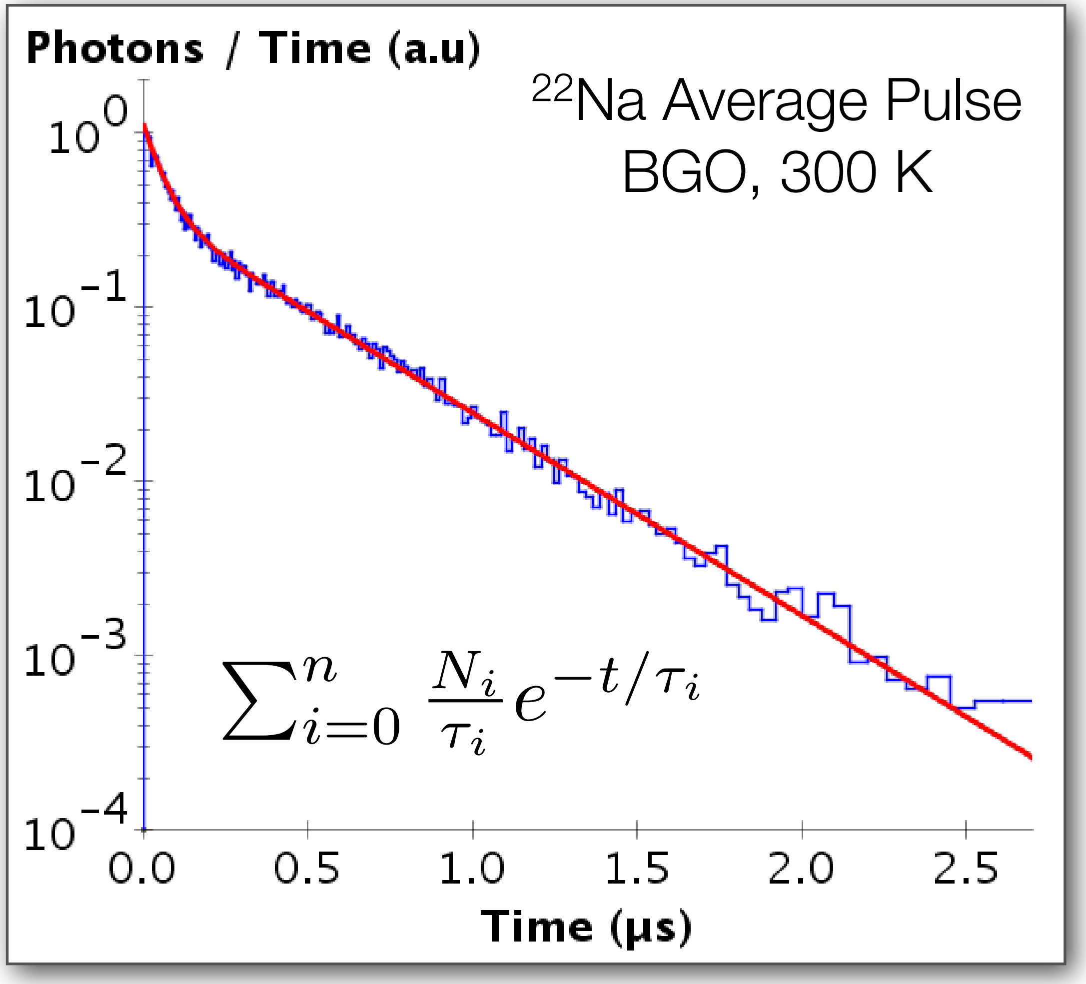


- Based on Multiple Photon Counting Coincidence (MPCC) technique [H. Kraus, *et al.*, NIM A (2005)]
- Room-T reference crystal (fast) can be used for timing
- Measures individual photons

Data Analysis

- For each run with a given crystal at temperature T, we want:
  - **Photon Spectrum** (num. of photons/event) → Light Yield → LY(T)
  - **Average Pulse Shape** (sum of good events) → Decay Constants → $\tau_i(T)$
- Perform cuts to remove bad events





Scintillation Studies at Queen's

BGO + γ

- Bismuth germanate ($Bi_4Ge_3O_{12}$)
- Already studied under α-excitation down to 6 K *
- Not previously studied under γ's at cryogenic temperatures
- Some interest for future dark matter detectors (ROSEBUD)

$ZnWO_4$ + γ & α

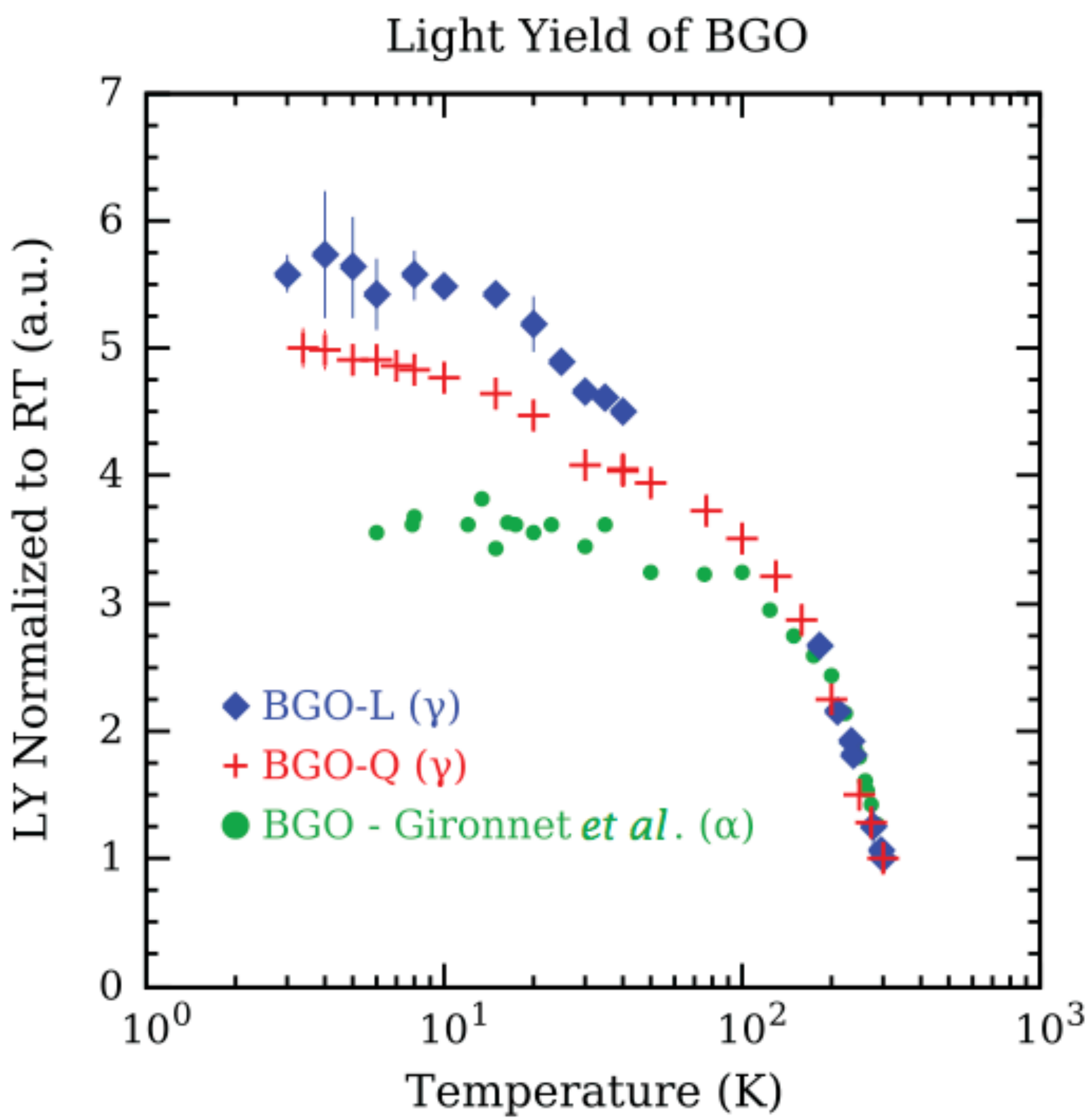
- Previously studied down to 7 K **
  - LY(T): ^{241}Am α's
  - τ(T): ^{60}Co γ's
- Interest from CRESST in using $ZnWO_4$ as future dark matter detectors

*J. Gironnet, *et al.*, NIM A 594 (2008)

**H. Kraus, *et al.*, NIM A 600 (2009)

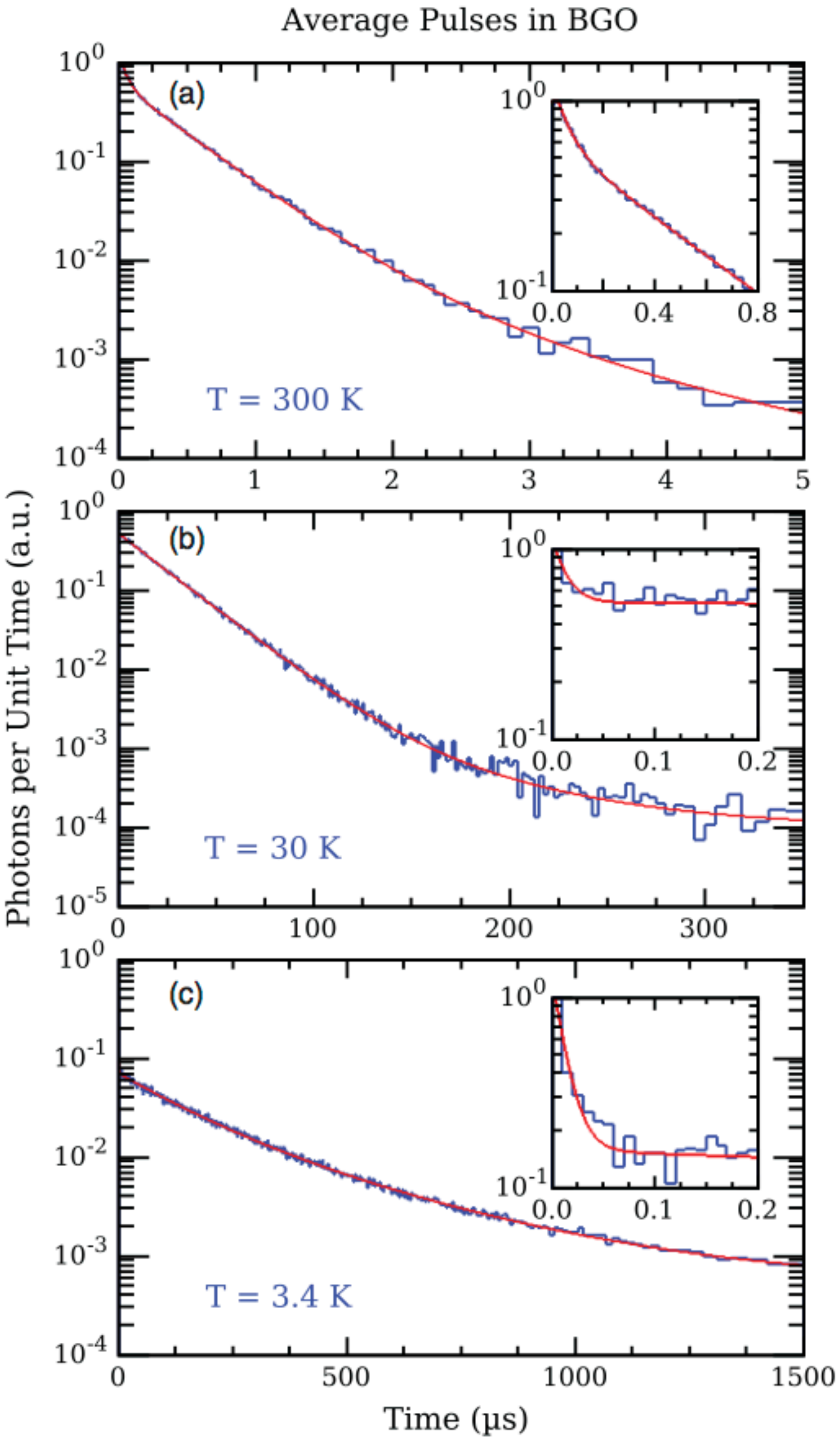
Study of BGO + γ | *Light Yield*

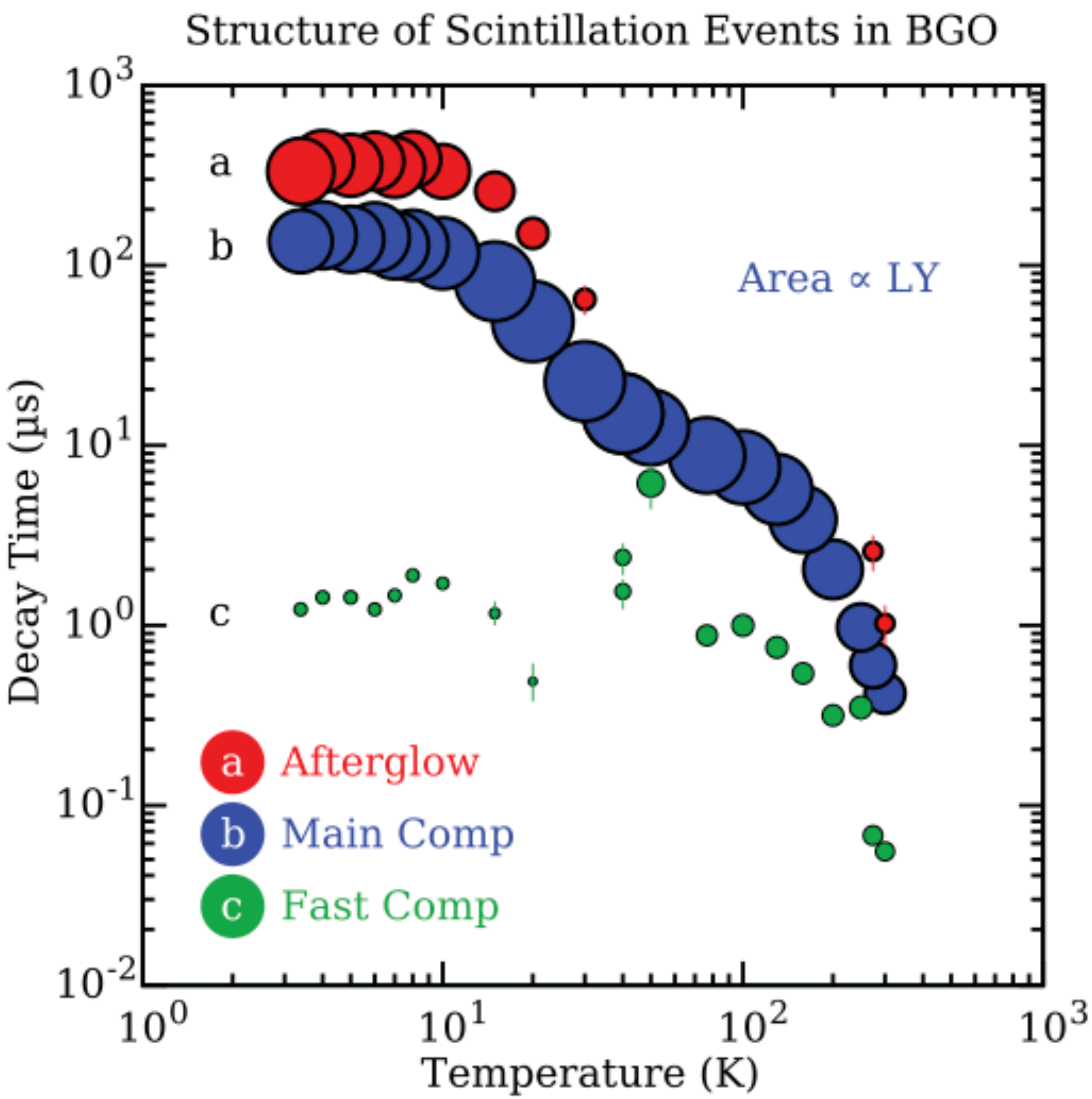
- Studied 2 BGO crystals in 2 similar cryostats with ^{22}Na γ source
- Compared to BGO + α (^{241}Am)
- Differences may be sample specific or from properties of particles



M.-A. Verdier, *et al.*, Phys. Rev. B 84 (2011) J. Gironnet, *et al.*, NIM A 594 (2008)

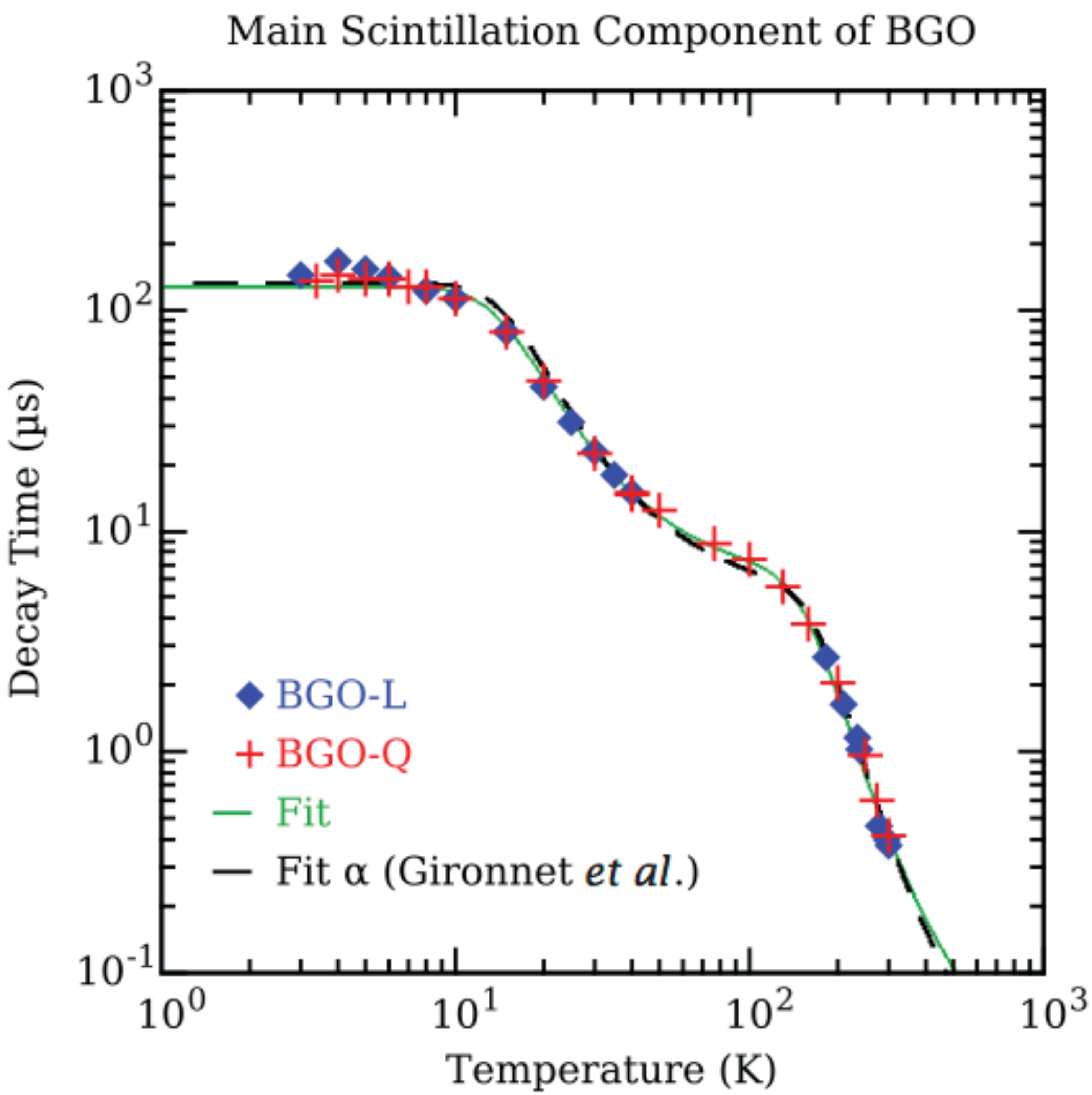
Study of BGO + γ | *Decay Times*



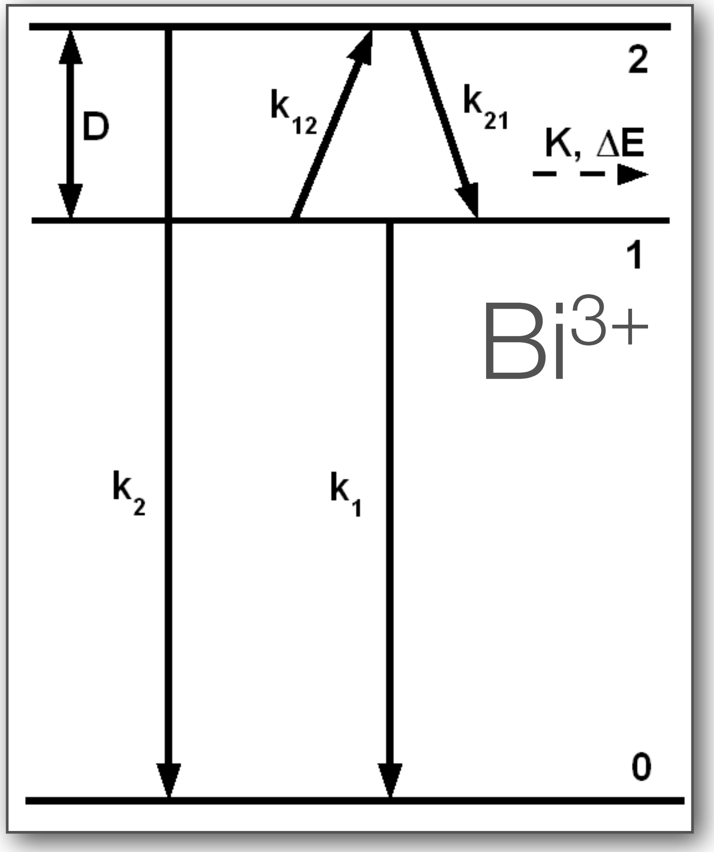


M.-A. Verdier, *et al.*, Phys. Rev. B 84 (2011)

Study of BGO + γ | *Main Decay Time Model*



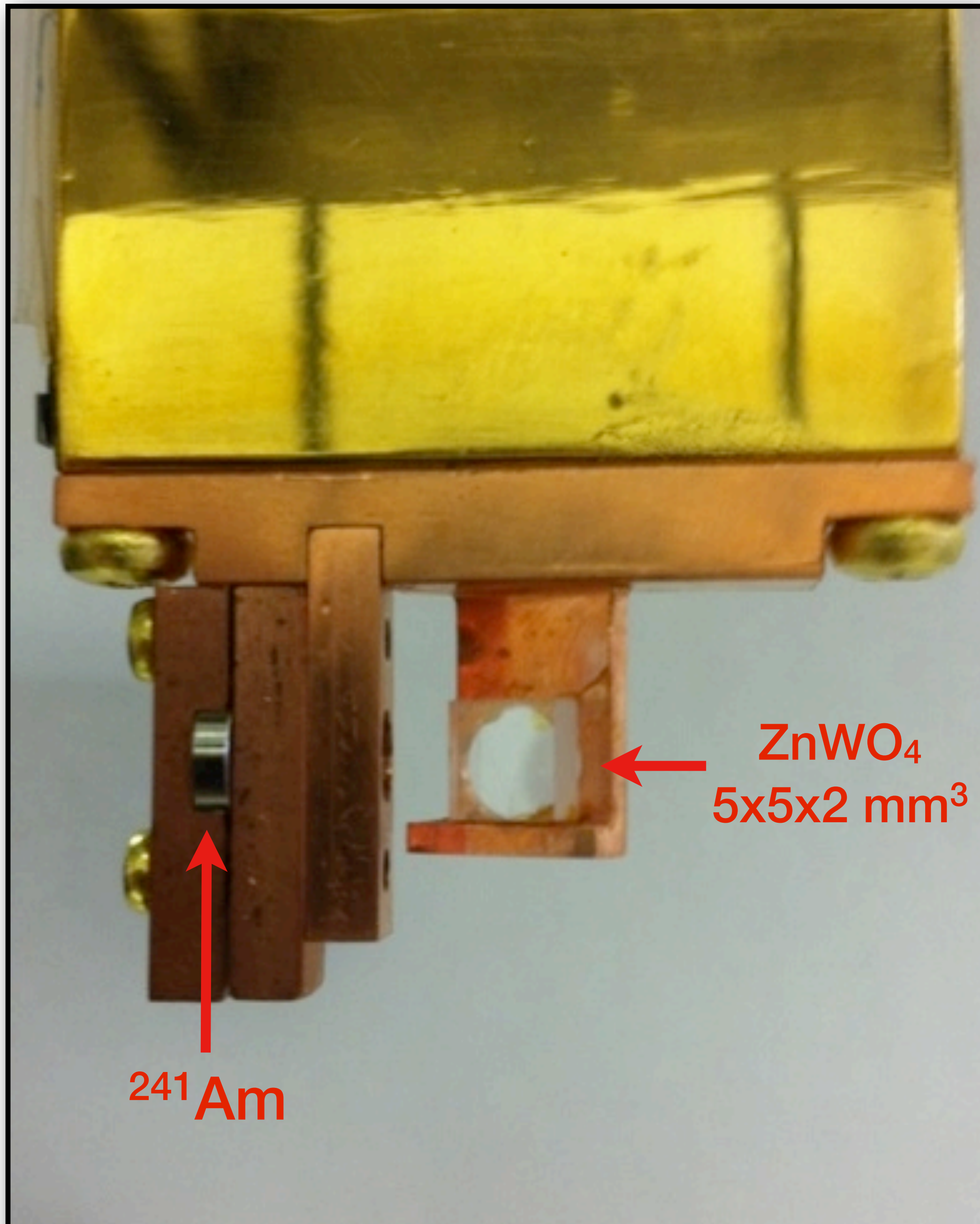
M.-A. Verdier, *et al.*, Phys. Rev. B 84 (2011)

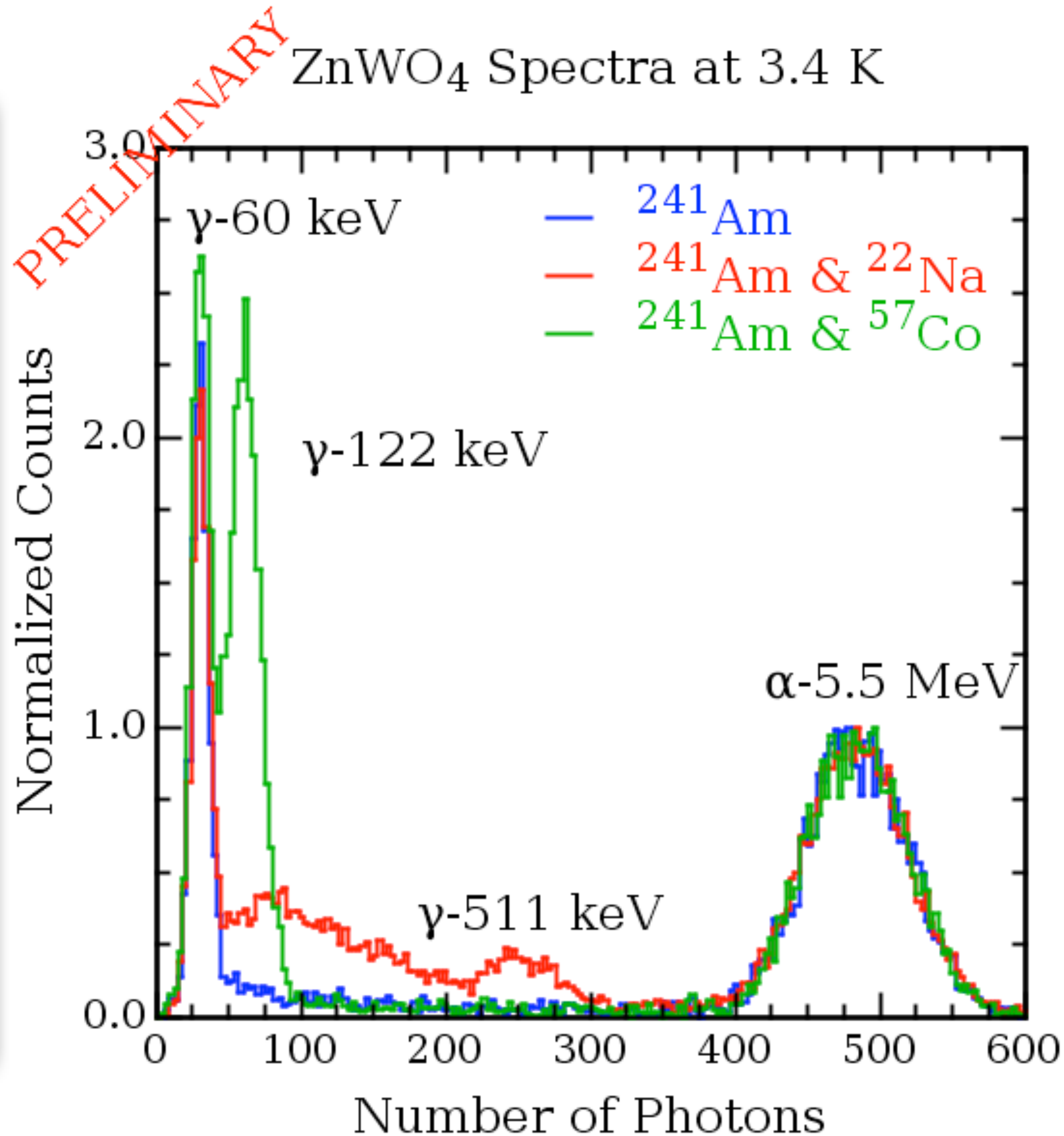


$$\frac{1}{\tau} = \frac{k_1 + k_2 e^{-D/k_b T}}{1 + e^{-D/k_b T}} + K e^{-\Delta E/k_b T}$$

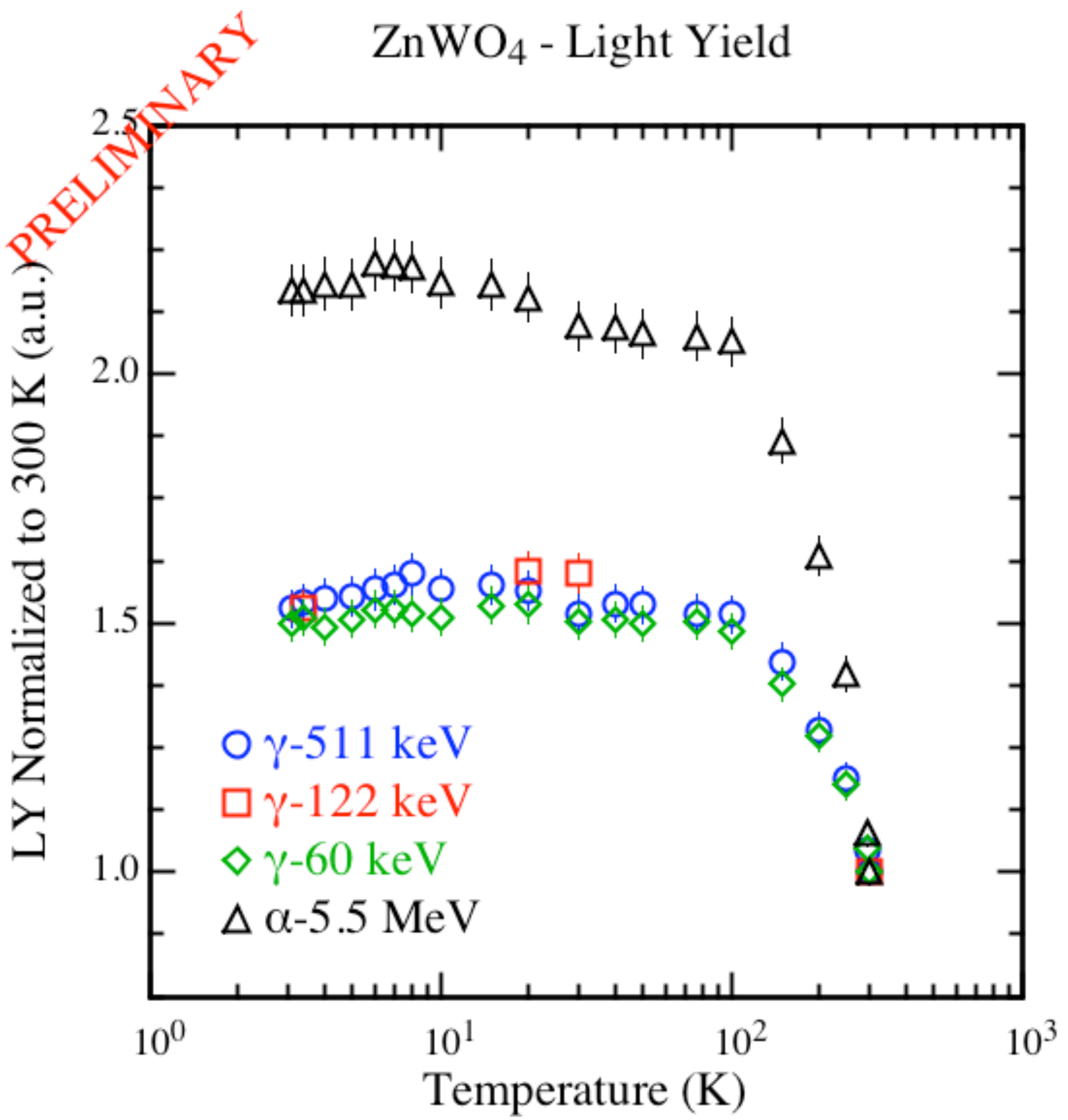
J. Gironnet, *et al.*, NIM A 594 (2008)

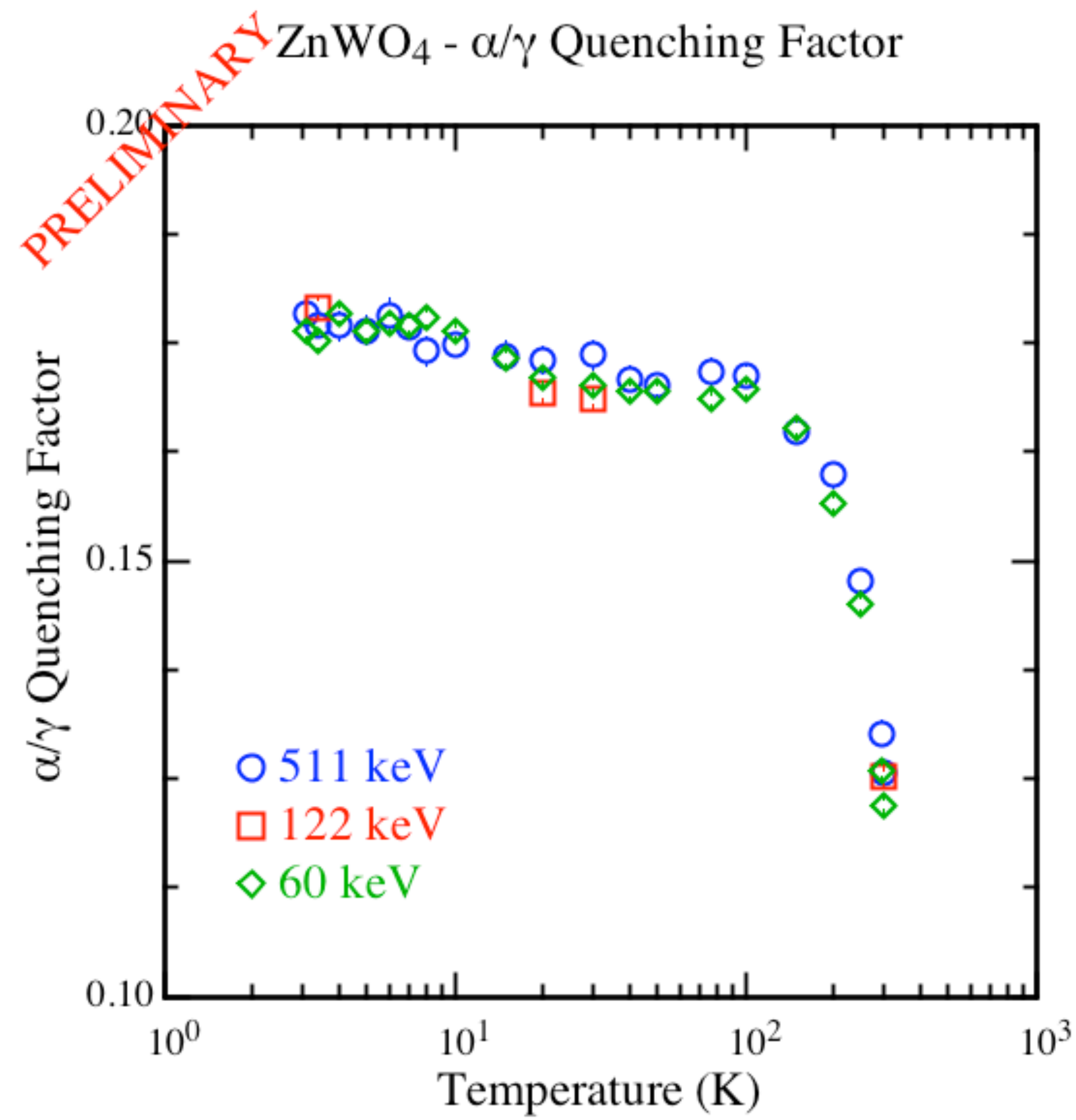
Study of $ZnWO_4$ + γ and α



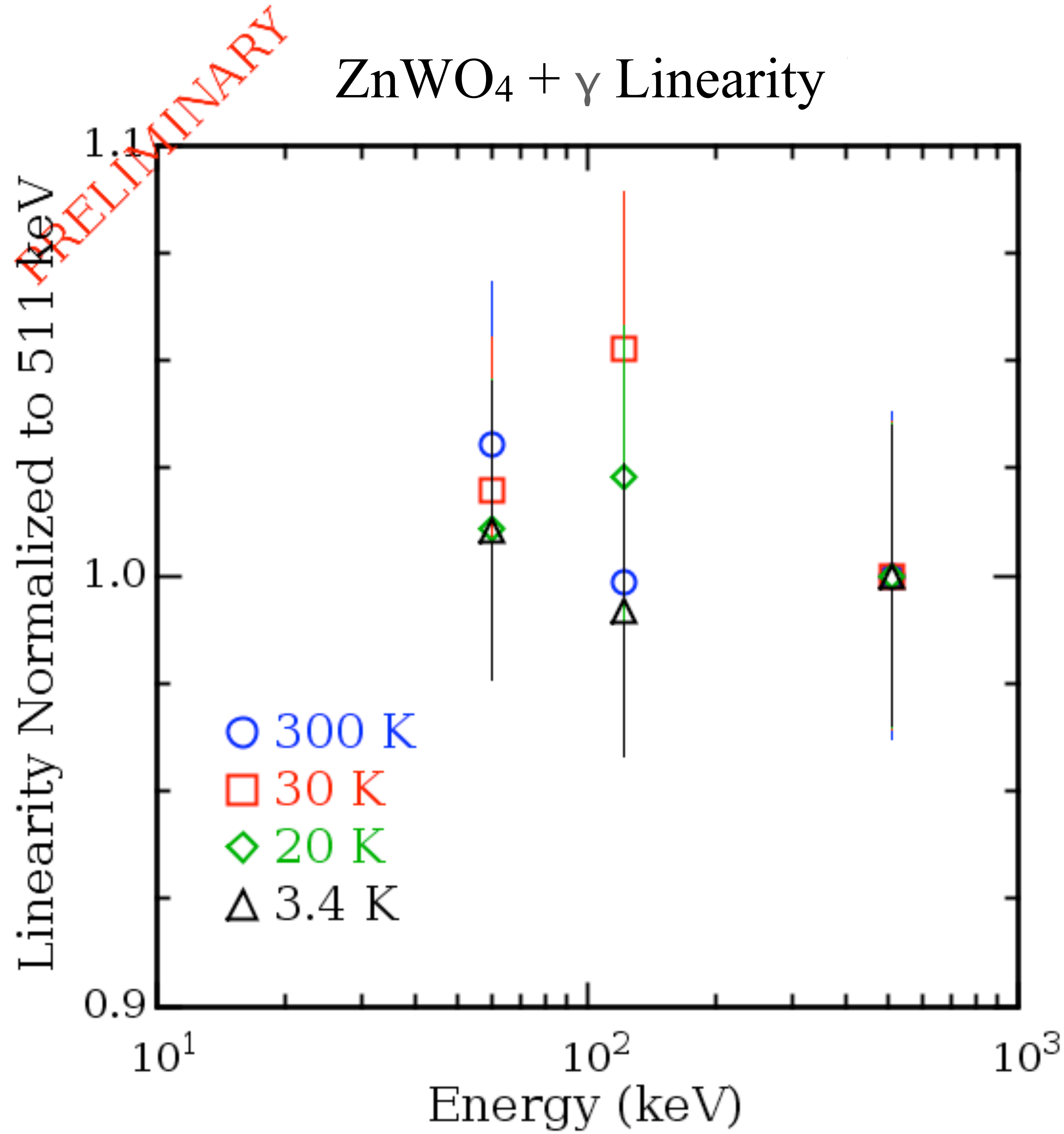


Study of $ZnWO_4$ + γ and α





Study of $ZnWO_4$ + γ and α



Summary and Outlook

- Our optical cryostat has uniquely excellent light collection, allowing measurement of photo-peaks at least down to 60 keV
- First measurement of BGO + γ from 3-300 K
  - Slow (300 μs at 3 K), but not a factor for rare event searches
- Early results from $ZnWO_4$ under γ- and α-excitation
  - α/γ quenching factor is temperature dependent
  - γ response linear over all temperatures
- **Outlook:**
  - Study more crystals: NaI, NaI(Tl), CsI, Al_2O_3
    - New glovebox for hygroscopic crystals
  - Sub-kelvin measurements in dilution fridge (T < 40 mK)