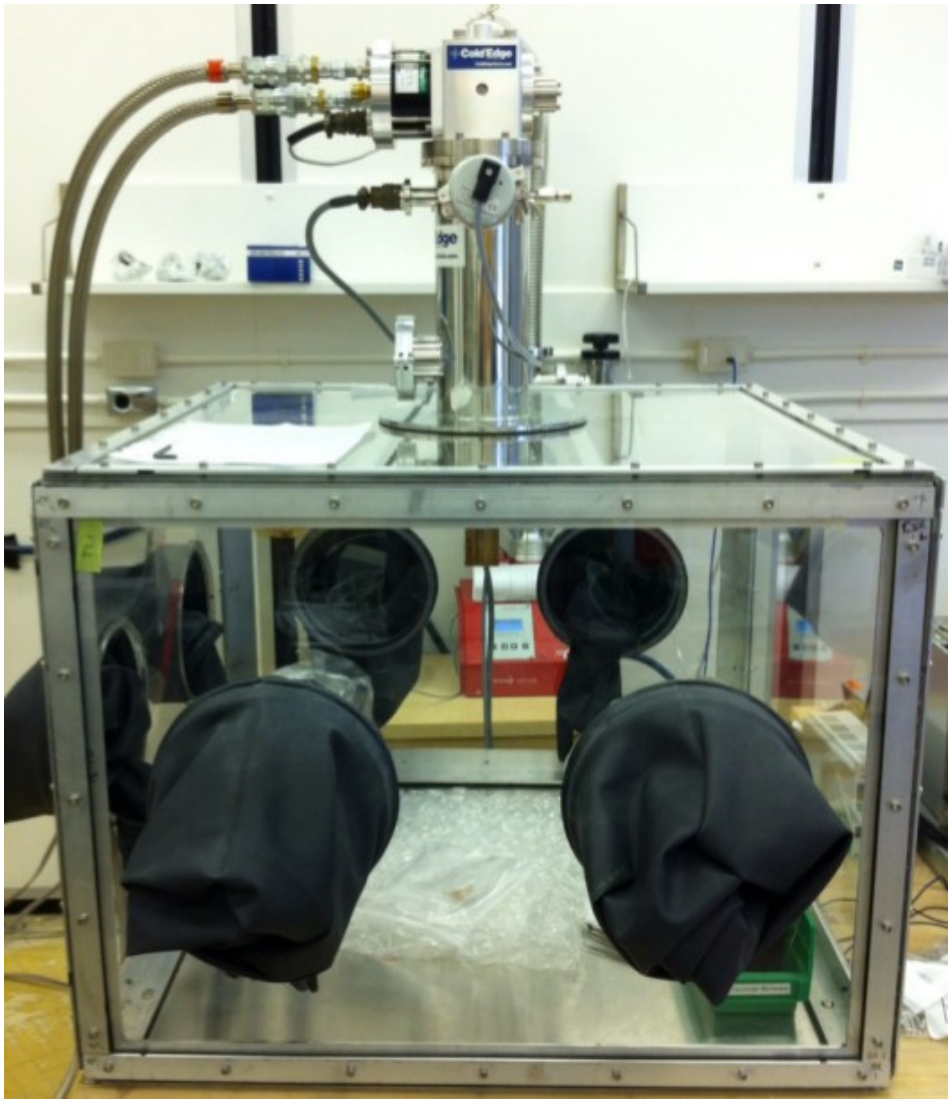
Sensitivity of Alkali Halide Cryogenic Scintillation-Phonon Detectors to WIMP Signals



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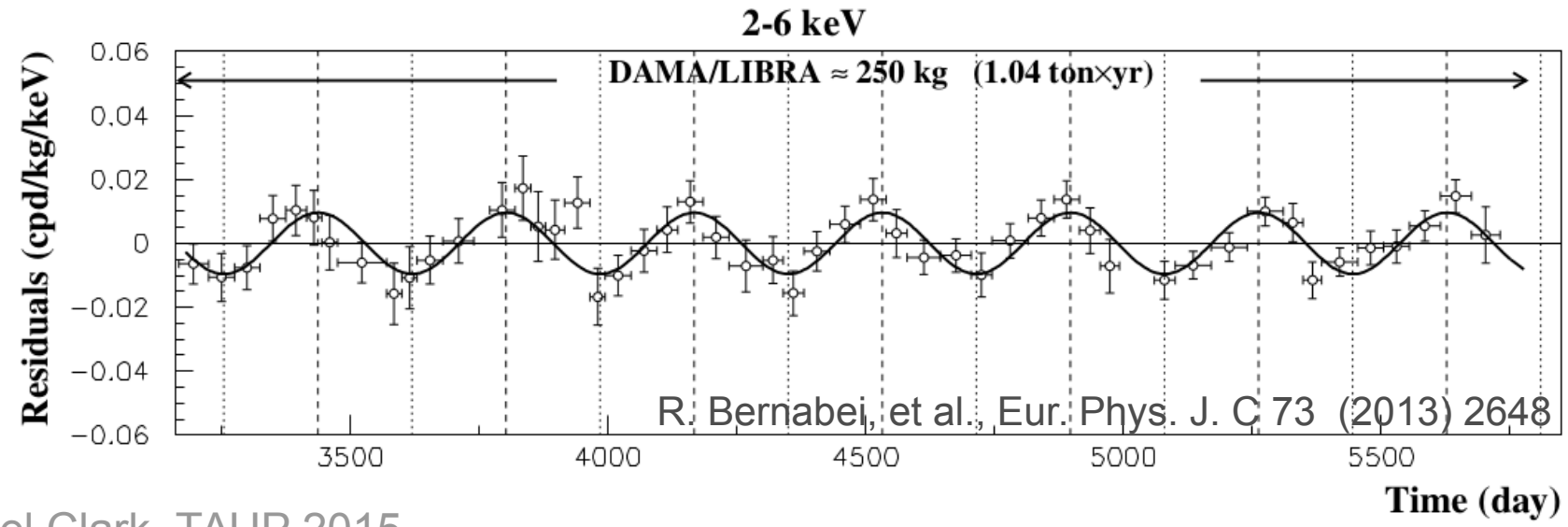
arXiv:1410.1573
Astropart. Phys. 67 (2015) 62-69
TAUP 2015

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 discrimination
- Detect modulation signal consistent (phase, period) with WIMP halo model, but phase space inconsistent with other experiments (different materials/detection strategies)

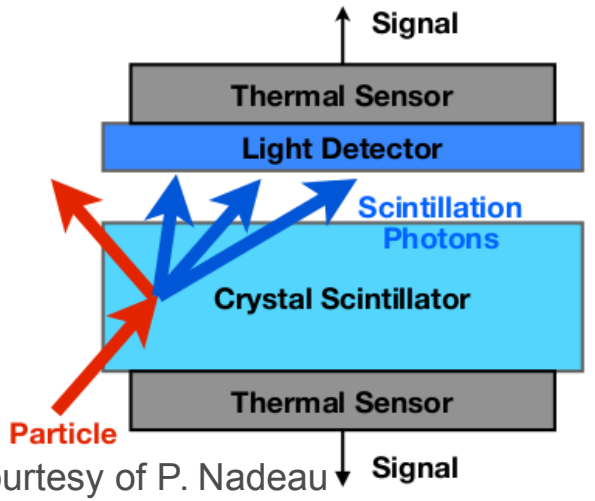


Cryogenic Alkali Halide Detector

- Scintillation-only NaI detectors to test DAMA

Wed. DM A

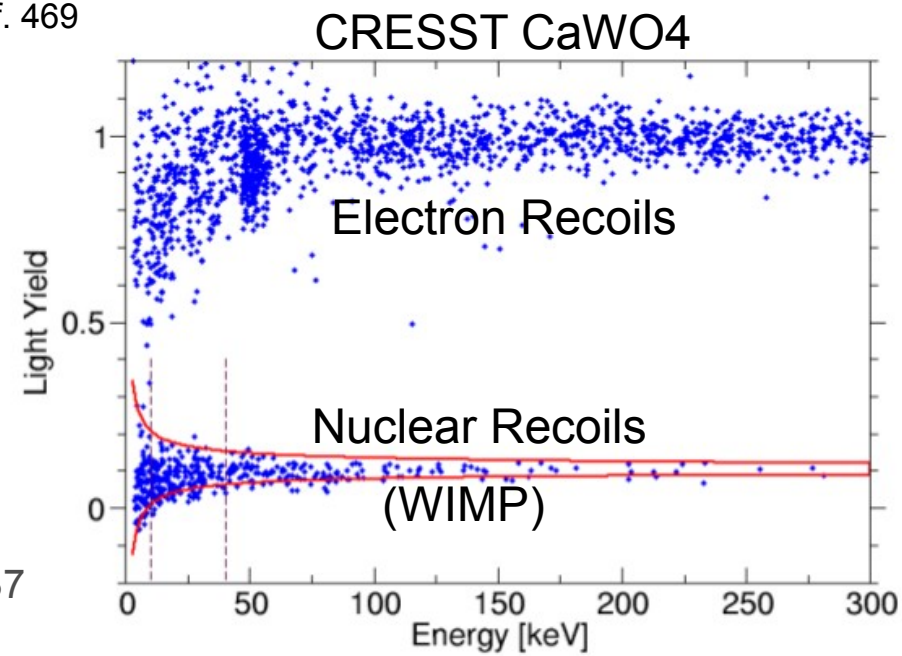
- DM-Ice — DM-Ice, Phys. Rev. D 90 (2014) 092005
- ANAIS — J.Amare et al., arXiv:1501.00104
- KIMS — K. Kim et al., Astropart. Phys. 62 (2015) 249
- SABRE — E. Shields et al., Phys. Procedia 61 (2015) 169
- PICO-LON — K. Fushimi et al., J. Phys. Conf. 469 (2013) 1



Courtesy of P. Nadeau

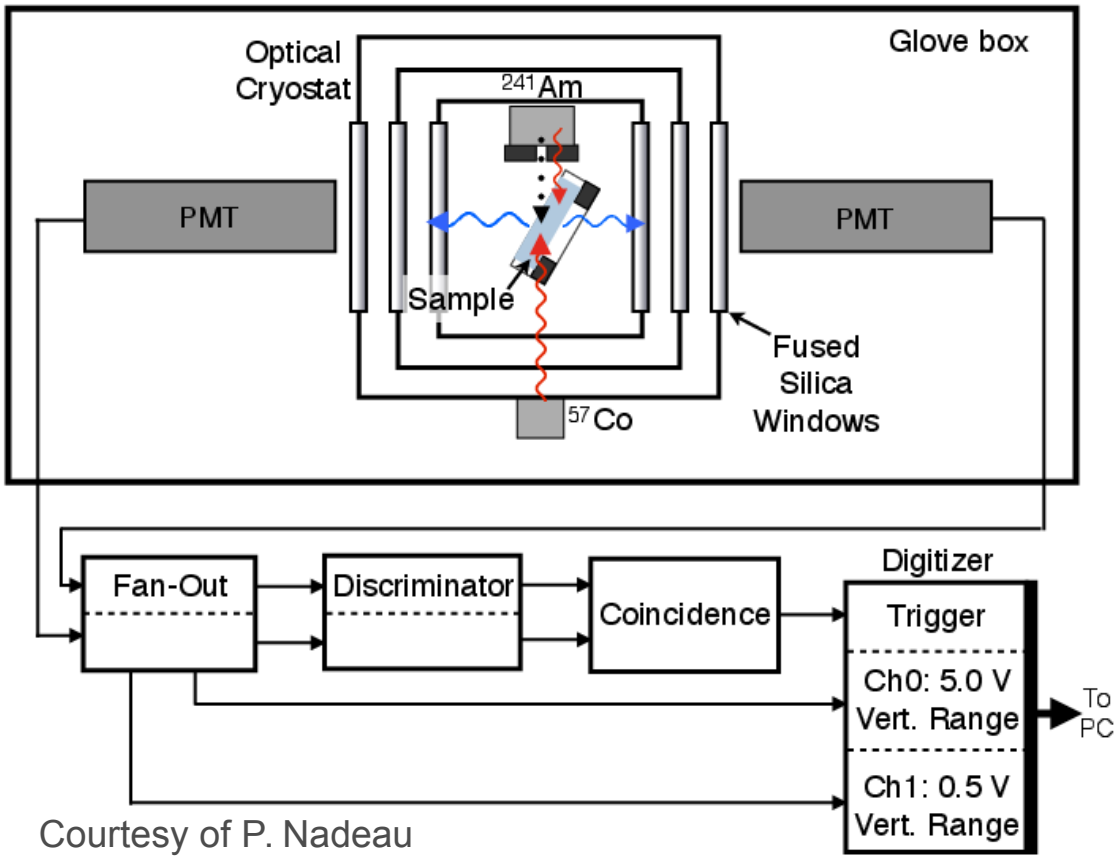
- NaI detector + background discrimination = check DAMA result in model independent way
- Cryogenic Scintillators can provide such discimination

Coron et al., Astropart. Phys. 47 (2013) 31-37

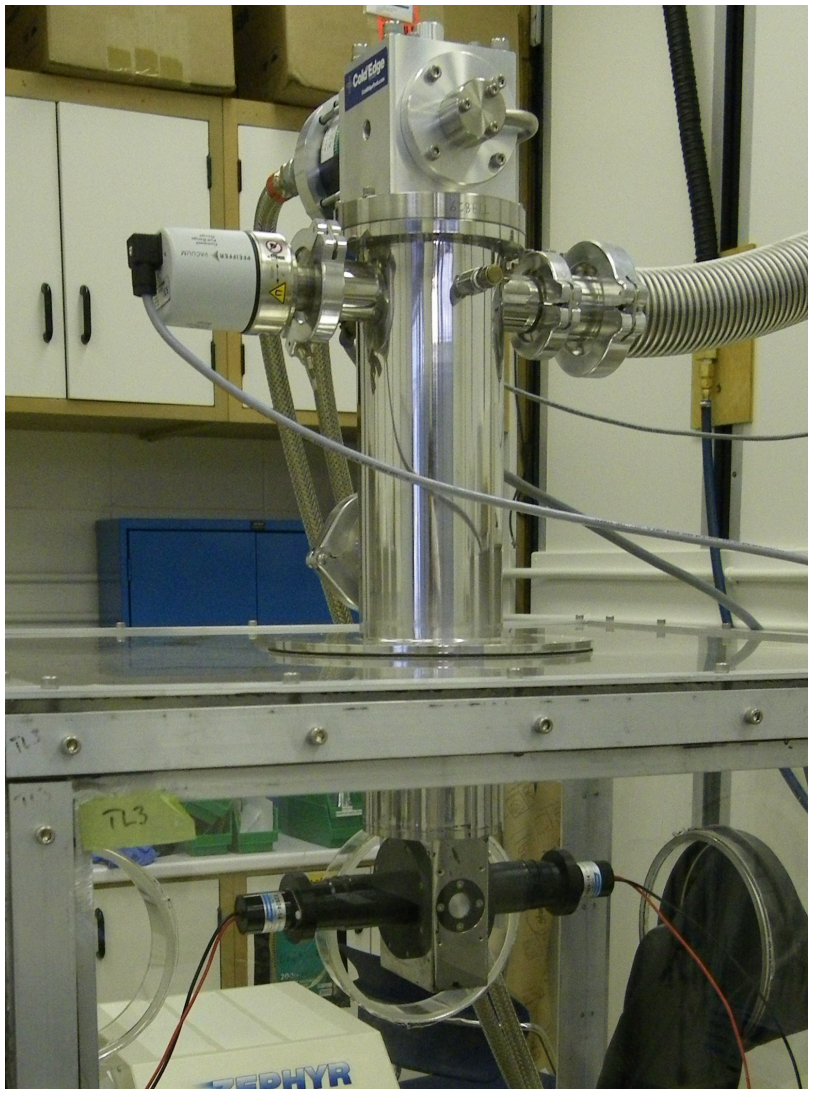


G. Angloher et al., Eur. Phys. J. C 72 (2012) 1971

Optical Cryostat



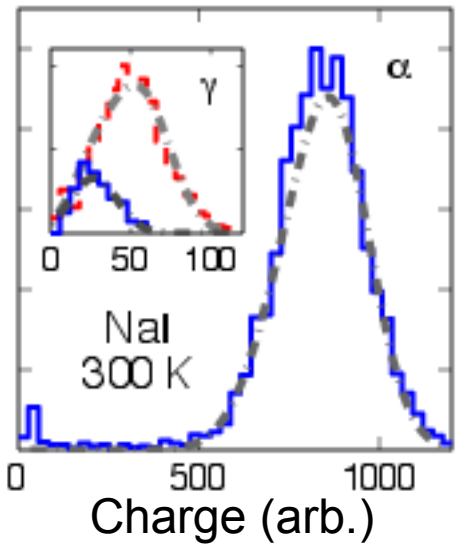
Courtesy of P. Nadeau



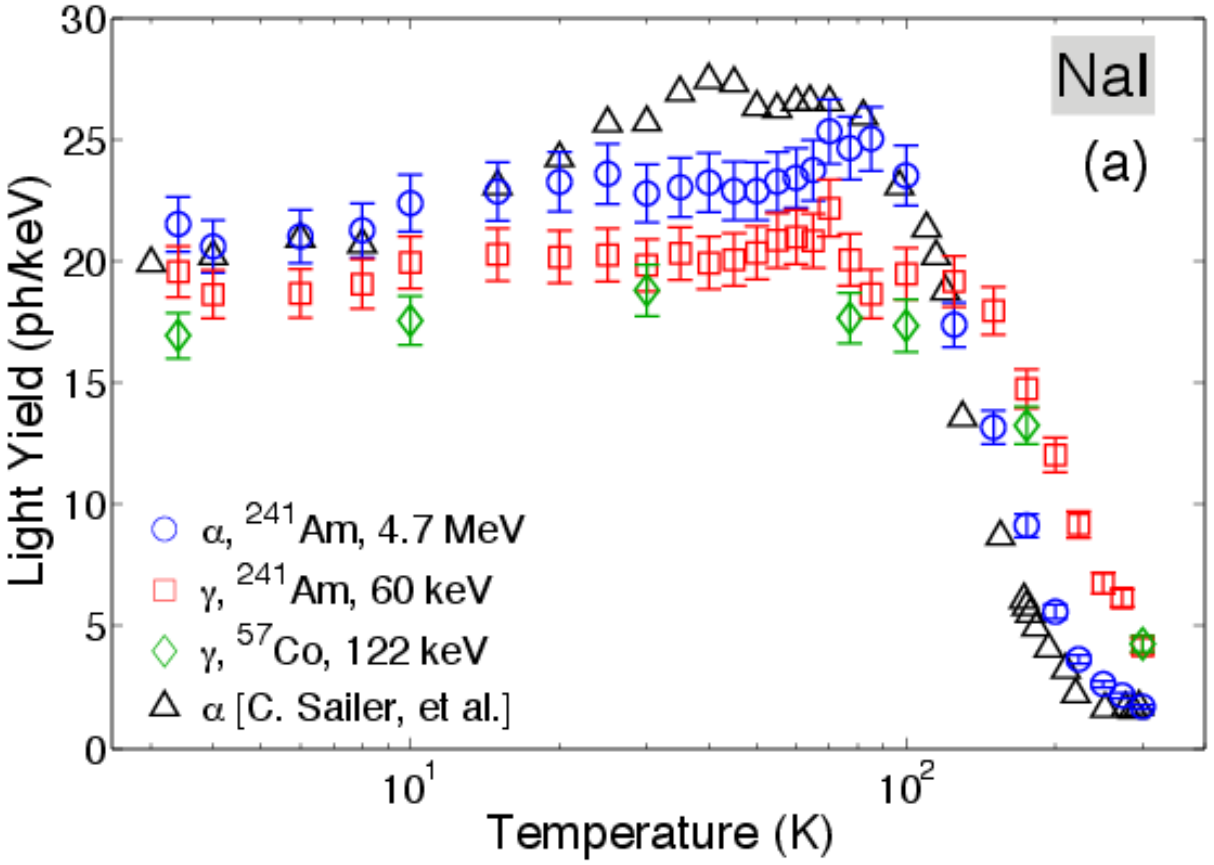
P.C.F. Di Stefano et al., NIM A 700 (2013)

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

Light Yield Measurements



Courtesy of P. Nadeau



Use lit. value of 300K gamma light yield to determine abs. Yield in photons/keV (corrected for 60keV Am-241 gamma)

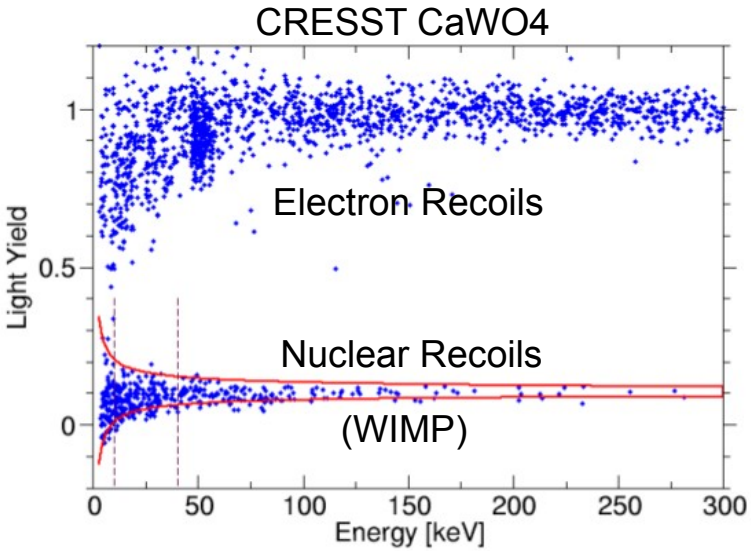
Light Yield Summary

		NaI	CsI	NaI(Tl)
60 keV Gamma LY at 300K (photons/keV)		4.16 [1]	3.23 [2]	44.8 [3]
LY (3.4K) (ph/keV)	Gamma	19.5 ± 1.0	58.9 ± 5.6	40.6 ± 0.8
	Alpha	21.5 ± 1.1	31.6 ± 3.0	24.2 ± 0.3

[1] M.Moszinski et al., IEEE Trans. Nucl. Sci. 50 (2003)
[2] C.Amsler et al., NIM A 480 (2002)
[3] I.Holl et al., IEEE Trans. Nucl. Sci. 35 (1988)

Simulating WIMP Sensitivity

- Use backgrounds reported by DAMA (NaI, NaI(Tl)) and KIMS (CsI) as theoretical backgrounds[a], assume electron recoils
- Generate event energies using background PDF
- Assume thresholds/resolutions for light and phonon channels
- Determine expected discrimination power using nuclear recoil region

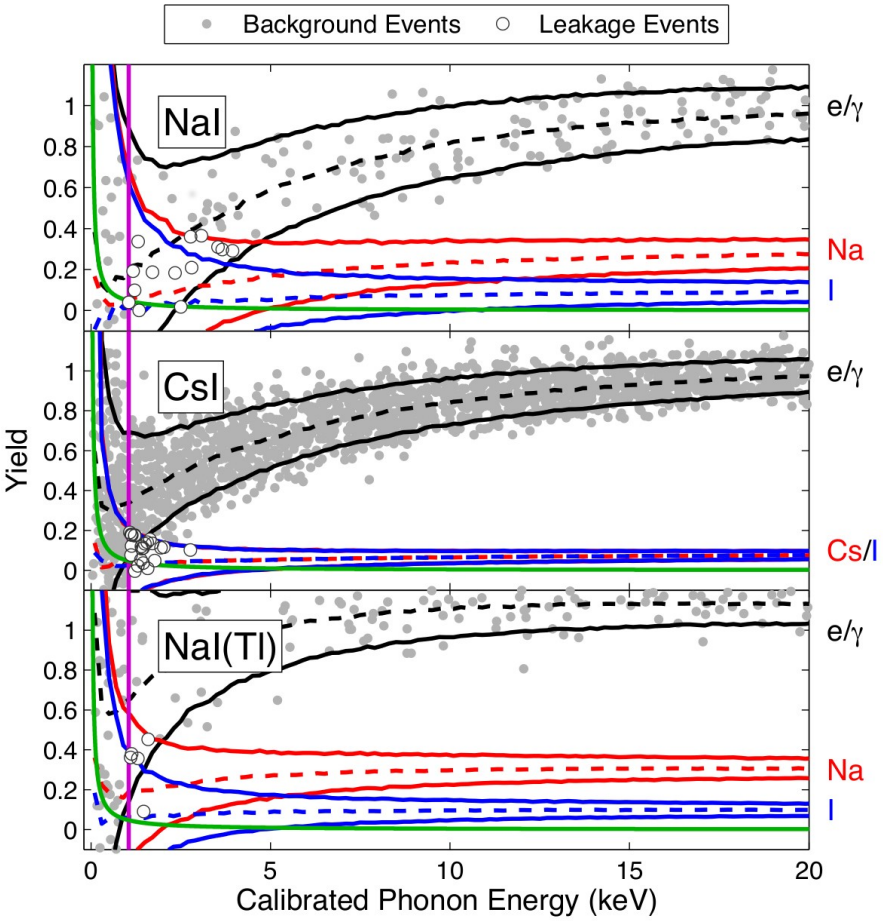


G. Angloher et al., (2011) arXiv:1109.0702

a) R. Bernabei, et al., NIM A 592 (2008) 297-318
KIMS Collab., Phys.Lett.B633 (2006) 201-208

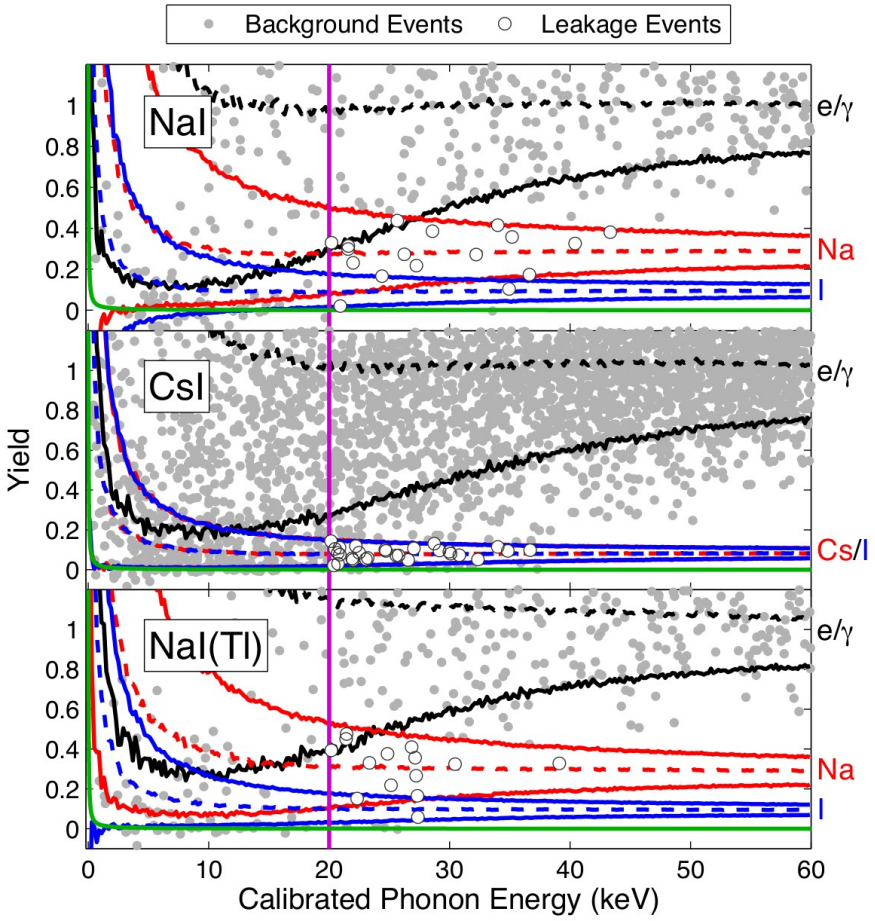
Expected WIMP Sensitivity

Current CRESST CaWO4 Resolution

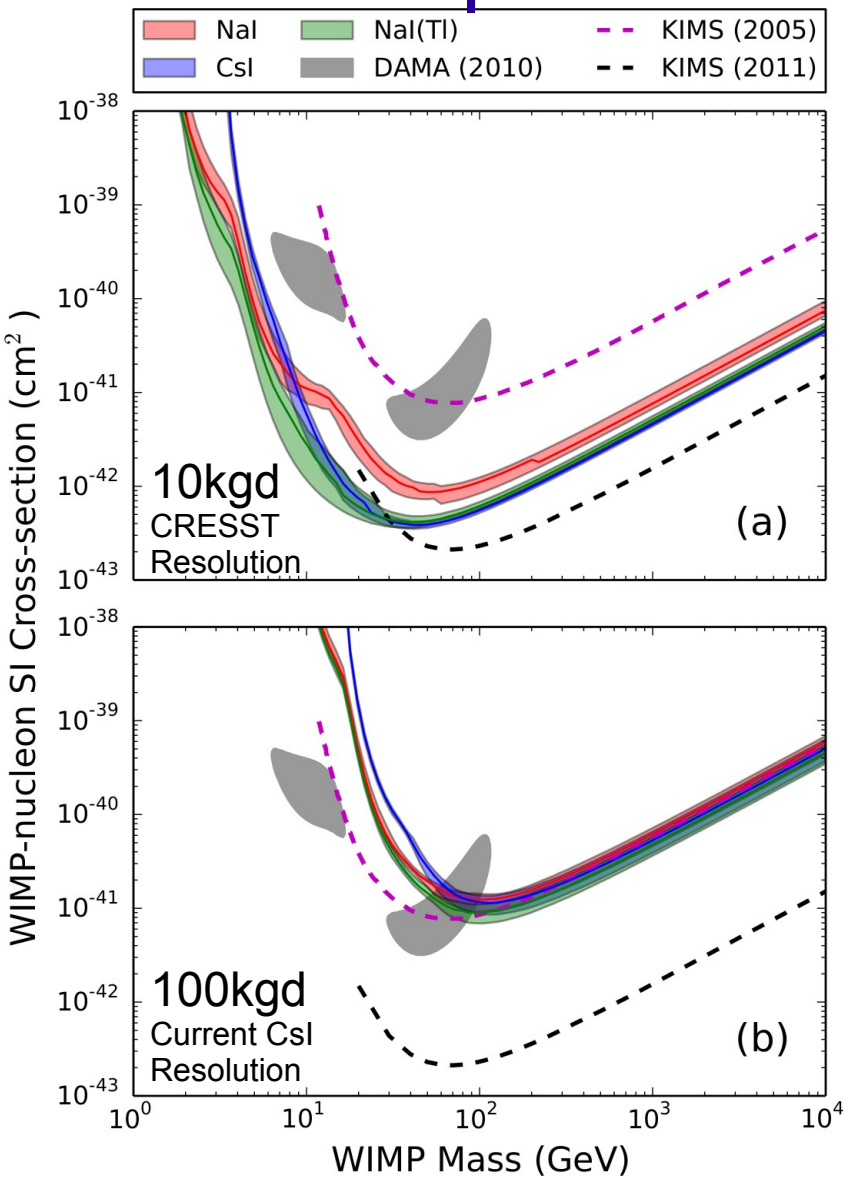


Measured CsI Phonon Resolution

K.Schaffner et al., J Low T Phys 167 (2012)



Expected WIMP Sensitivity



- Optimum interval limit calculation using events in signal region
  S.Yellin, (2007) arXiv:0709.2701
- Could exclude/verify DAMA result after 10 kgd if background rejection + resolution achieved
- Without improvements in phonon performance, difficult to check DAMA claim

Modulation Signal Sensitivity

- How sensitive would this detector be to a modulation signal?
- Generate time events using Background + Signal Monte Carlo (params from DAMA)

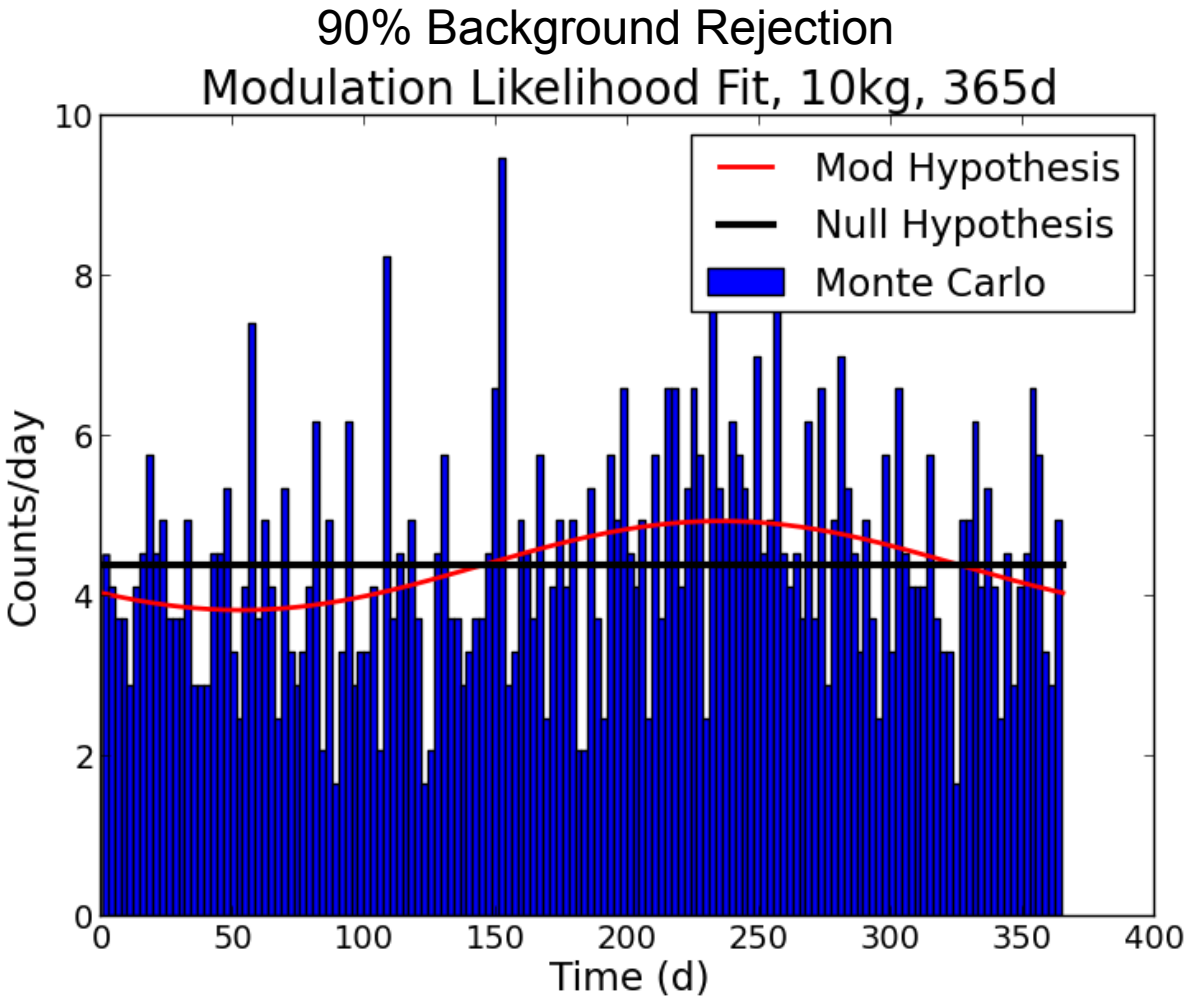
E Range	Amplitude	Period	Phase
2-6 keVee	0.045 cpd/kg	365 days	144 days after Jan.1

R. Bernabei, et al., (2013) arXiv: 1308.5109

- Compare flat BG + modulation hypothesis to flat BG only (null) hypothesis using Likelihood ratio test
- Fixed period, fit for modulation amplitude, phase, and BG level

Modulation Signal Sensitivity

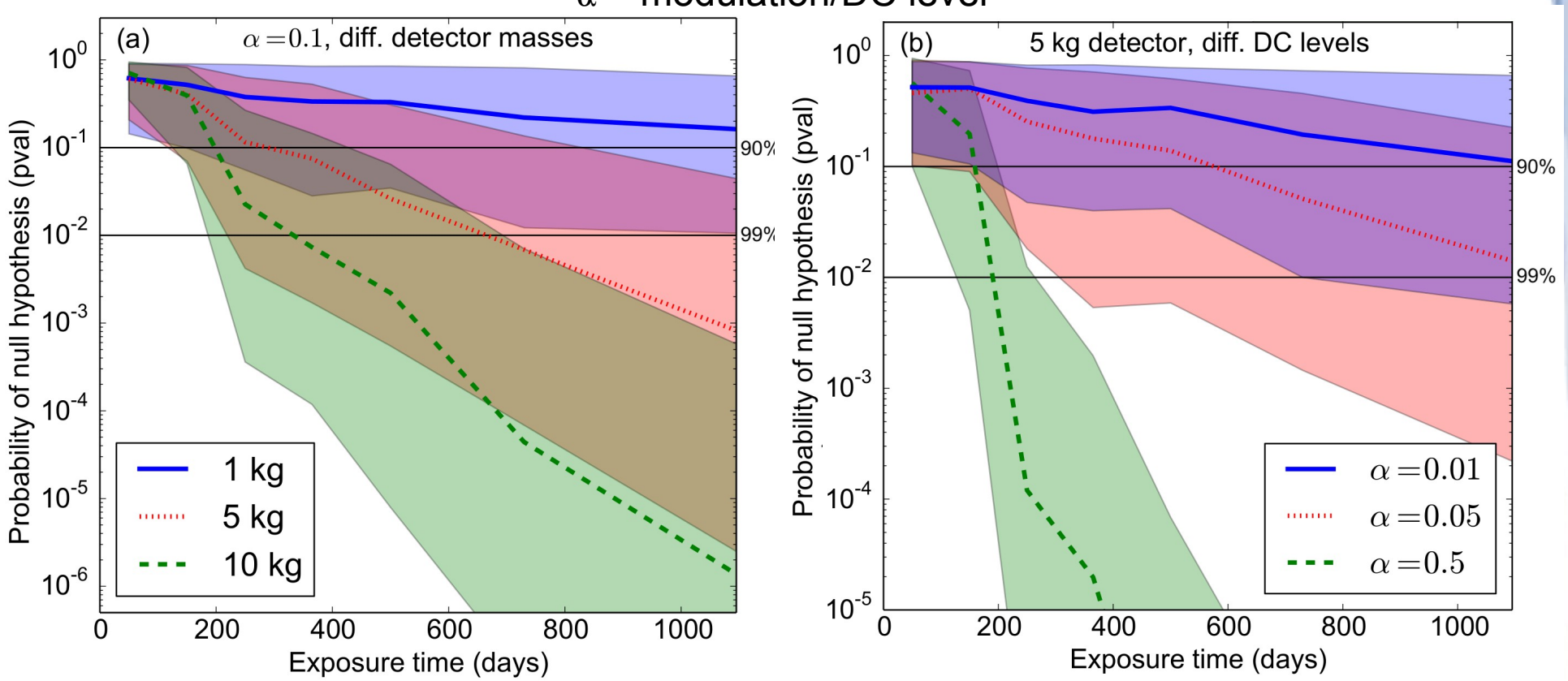
- Example of likelihood fit to MC modulation data using PyMINUIT
- Perform many experiments, calculate LR for different times, detector mass, DC level
- Convert LR to p-value of modulation



Likelihood Ratio Results

Modulation Amplitude: 0.045 cpd/kg

α = modulation/DC level



- Could achieve 90% confidence in 2 years with 5 kg detector and 90% BG discrimination assuming minimal DC signal
- α = 0.01 would be result if DC level the same as for DAMA (4 cpd/kg in 2-6 keVee range)

Conclusions

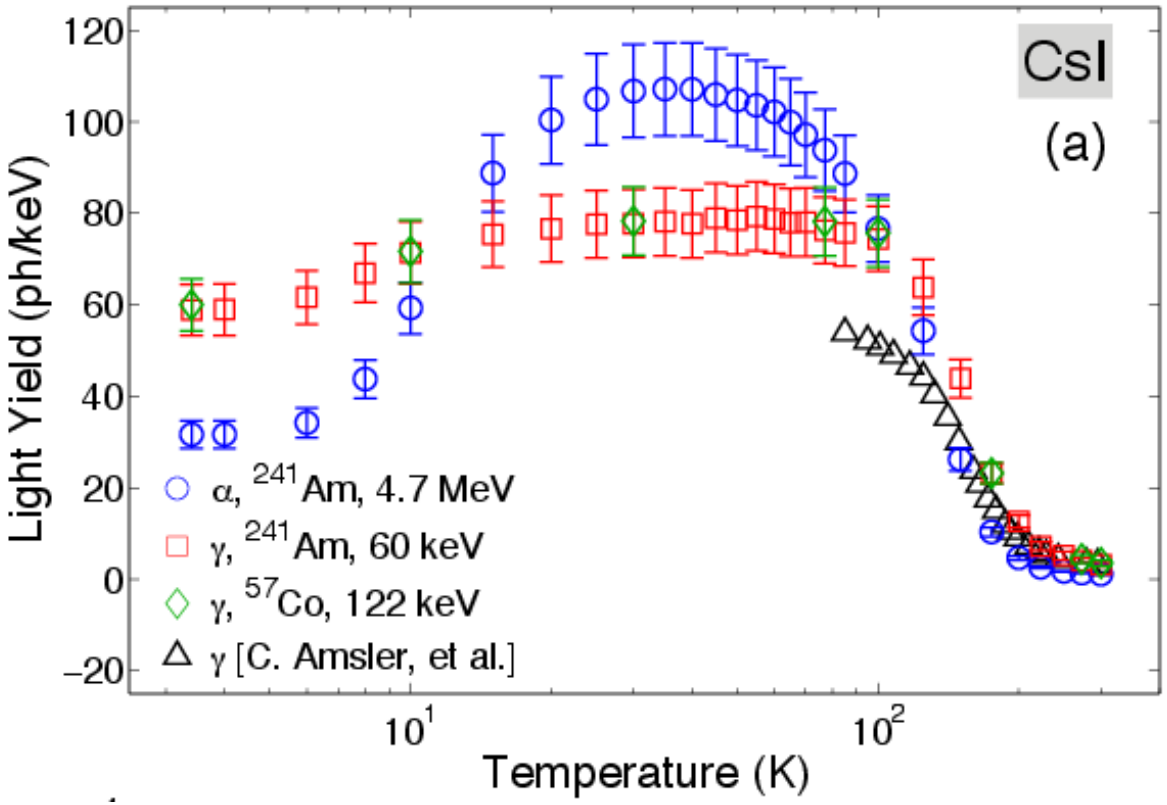
- Measured Alkali Halide light yield curves at cryogenic temperatures at Queen's University
- Used light yield information to determine expected sensitivity to spin-independent WIMP signals and annual modulation signal using Monte Carlo simulation
- Could check DAMA with only 10 kgd exposure with time independant analysis; 90% confidence in 2 years with modulation analysis
- Many experimental challenges to overcome (phonon resolution, hygroscopicity, backgrounds...); new ideas exist to improve threshold and facilitate fabrication

Pyle et al., arXiv:1503.01200

EXTRA SLIDES

CsI Light Yield Results

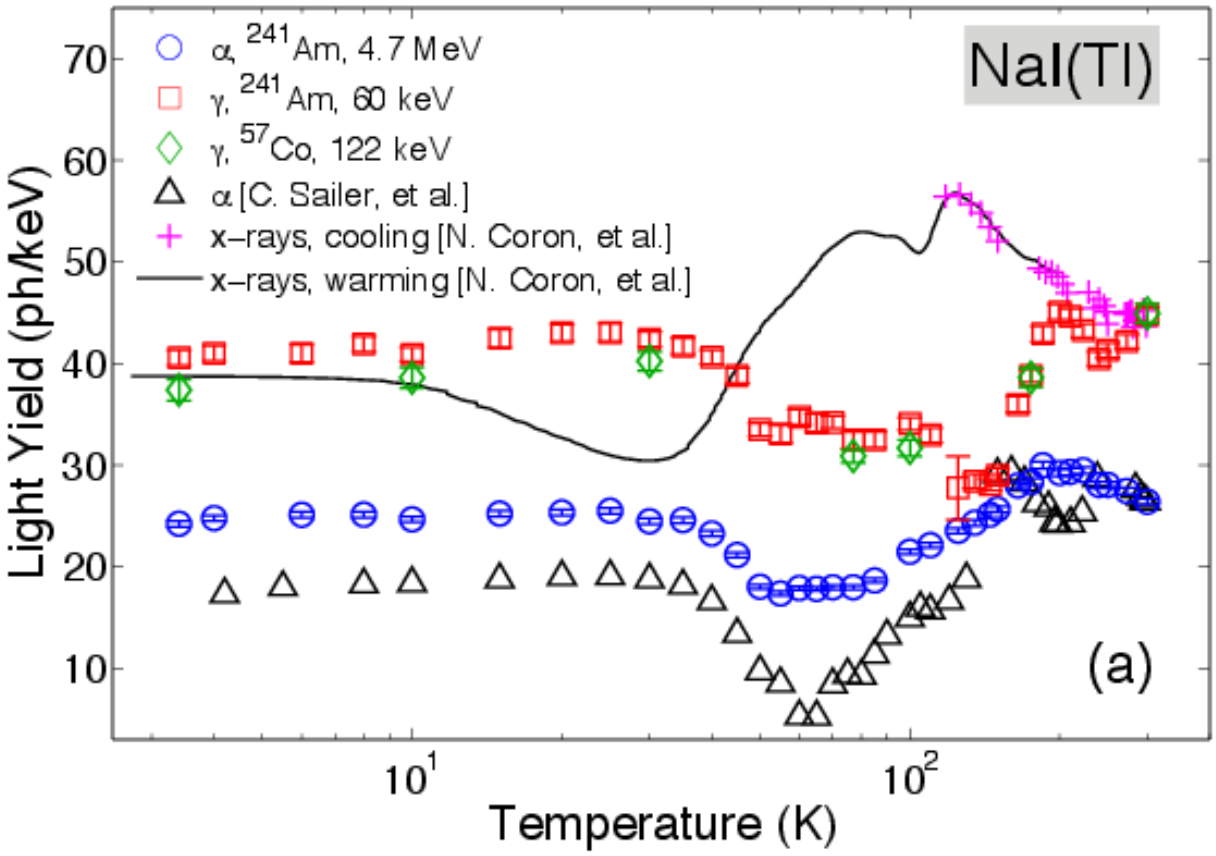
- Large Increase in light yield
- Agreement between gammas of different energy
- Achieves best limits out of our three crystals because of high light yield



C.Amsler et al., NIM A 480 (2002)

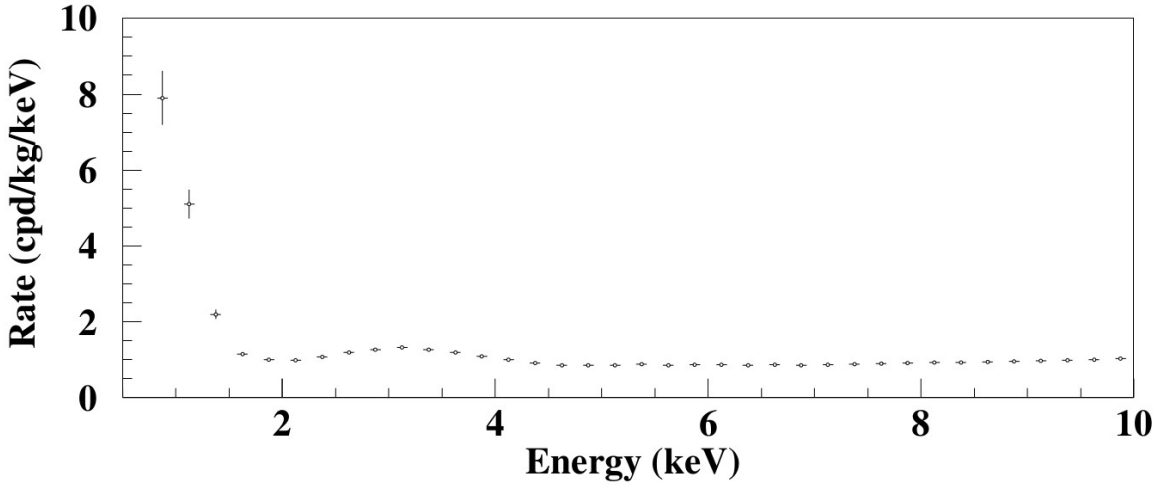
NaI(Tl) Light Yield Results

- Low temp. LY approx. Equal to RT yield.
- Many different particle interactions shown on this graph

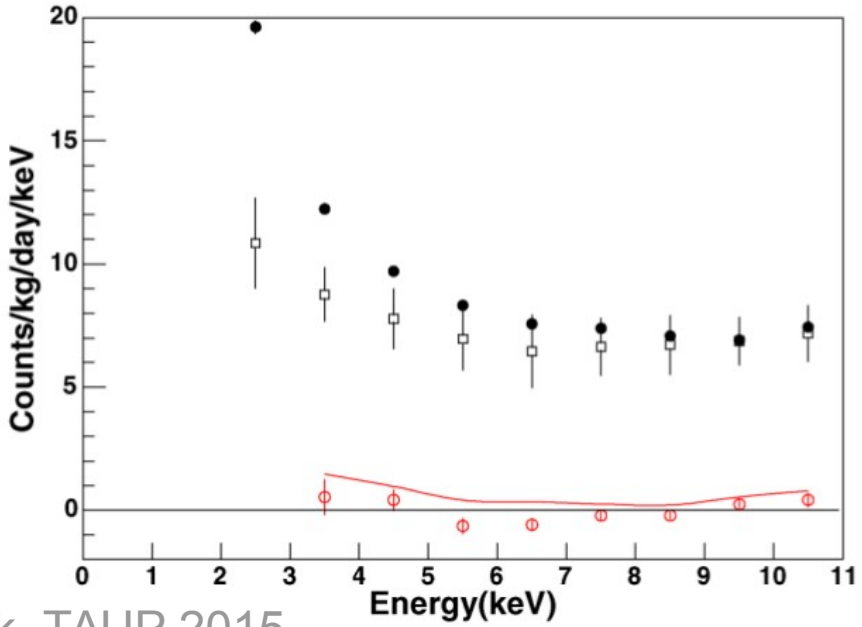


C.Sailer et al., Eur. Phys. J C 72 (2012) 1-4
Coron et al., Astropart. Phys. 47 (2013) 31-37

Background spectra



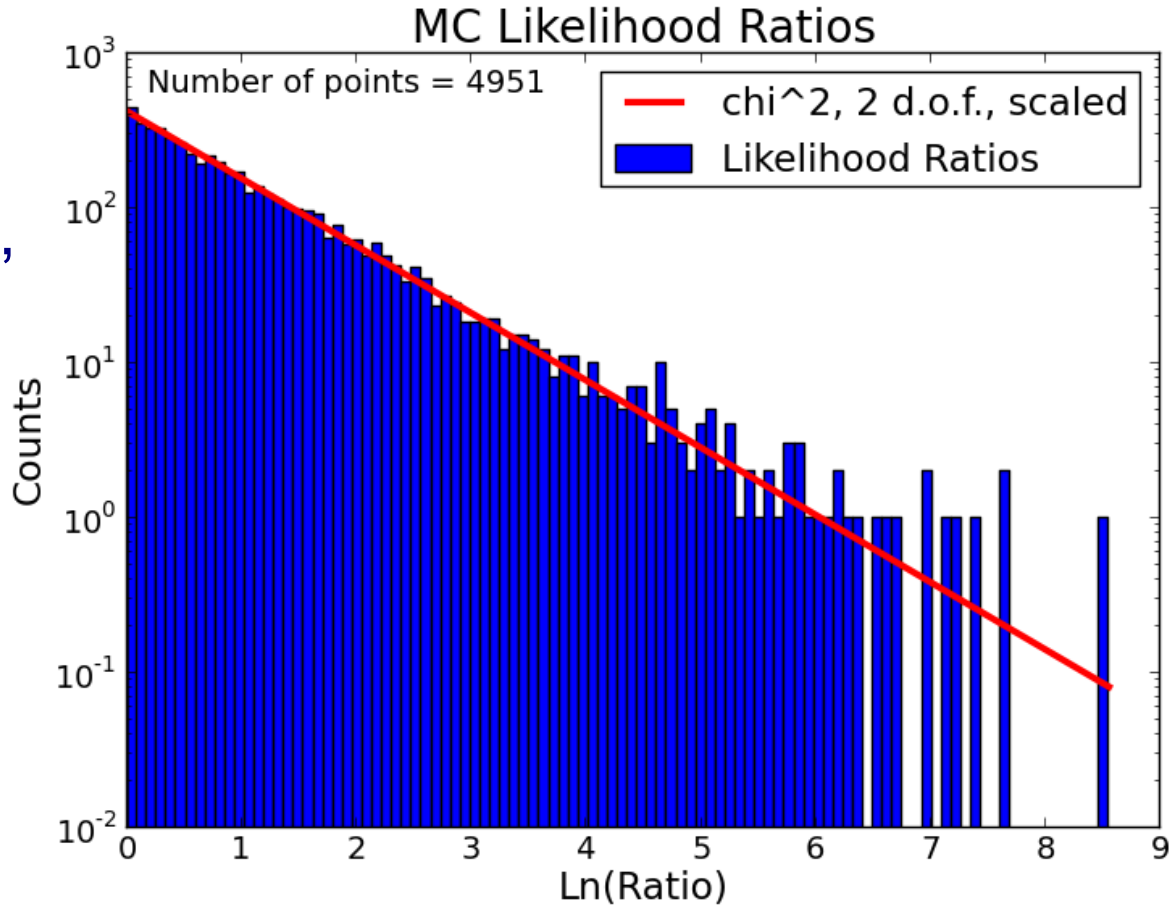
DAMA Spectrum
NaI, NaI(Tl)



KIMS Spectrum
CsI

Distribution of Likelihood Ratio

- For datasets drawn from a distribution with NO modulation (true null hypothesis), log(likelihood ratio) follows chi-squared distribution (Wilk's Theorem)



Total Rate vs. Modulation

- Modulation Amplitude: 0.045 cpd/kg in 2-6 keVee range
- If total rate does not exceed 0.045 cpd/kg in this range, the modulation can be ruled out
- For Example: 1000 kgd –> 45 counts
- Background ~4 cpd/kg -> 4000 counts: would require 99% bg rejection

PMT QE and low-T crystal spectra

- Peaked in UV for Alk. Halide sensitivity
- From Hamamatsu Data Sheets R7056