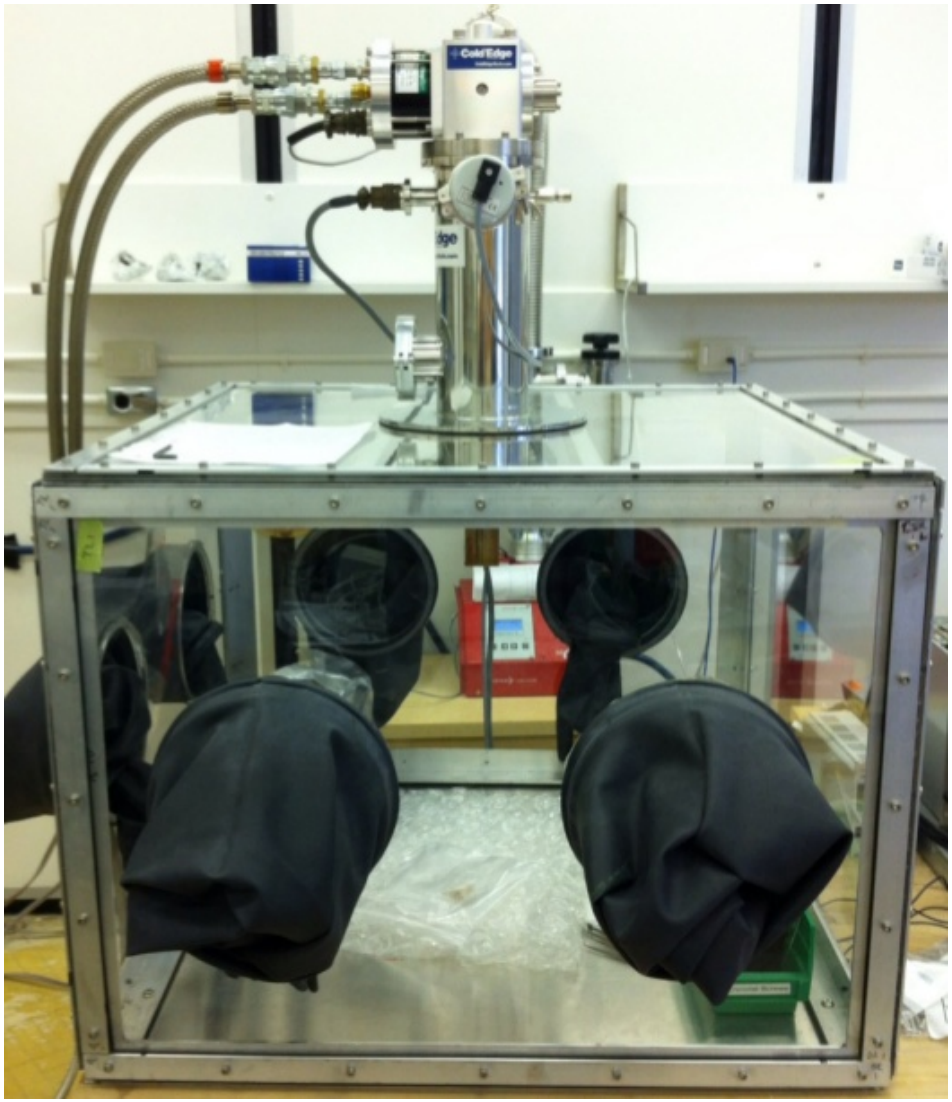
Sensitivity of Alkali Halide Cryogenic Scintillation-Phonon Detectors to WIMP Signals



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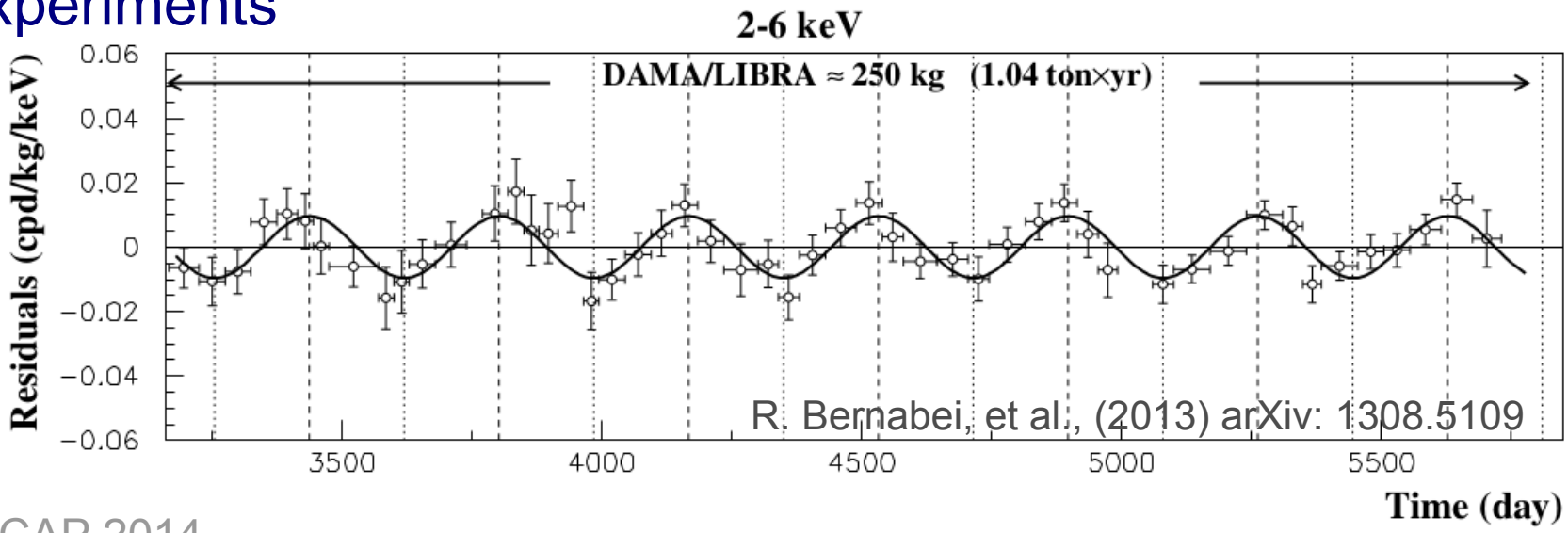
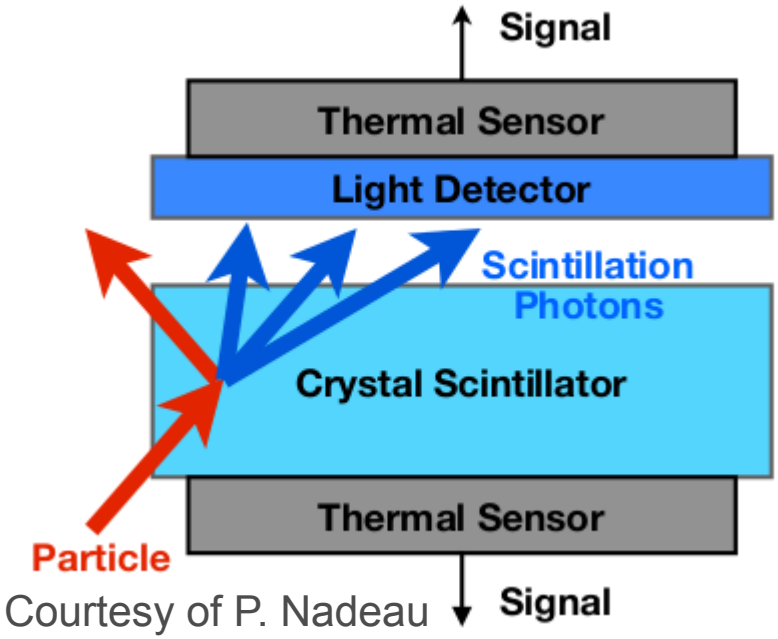
June 20, 2014
CAP Congress 2014
Laurentian University

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

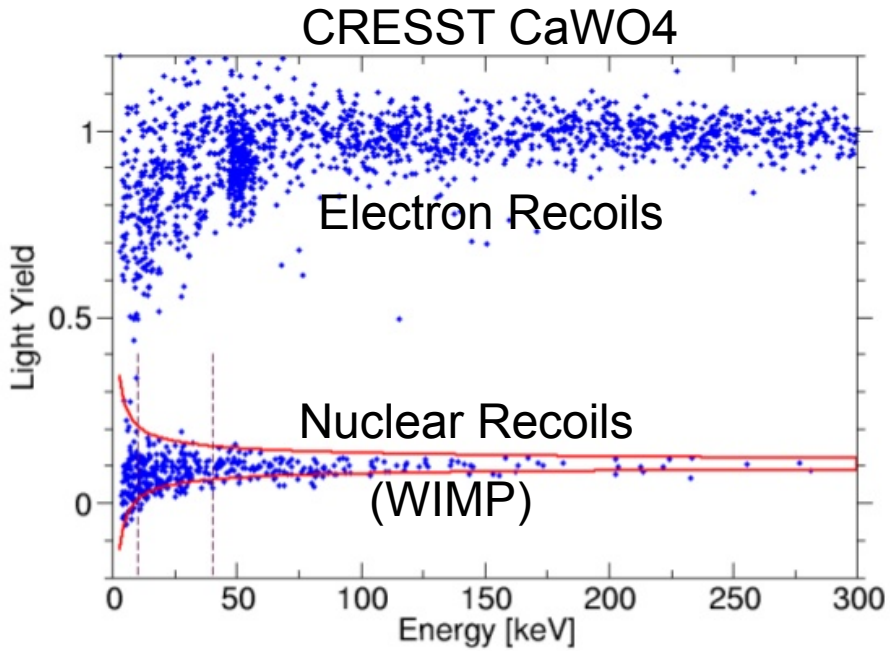


Courtesy of P. Nadeau

- At Queen's: Measure optical properties of AH crystals at low temperatures

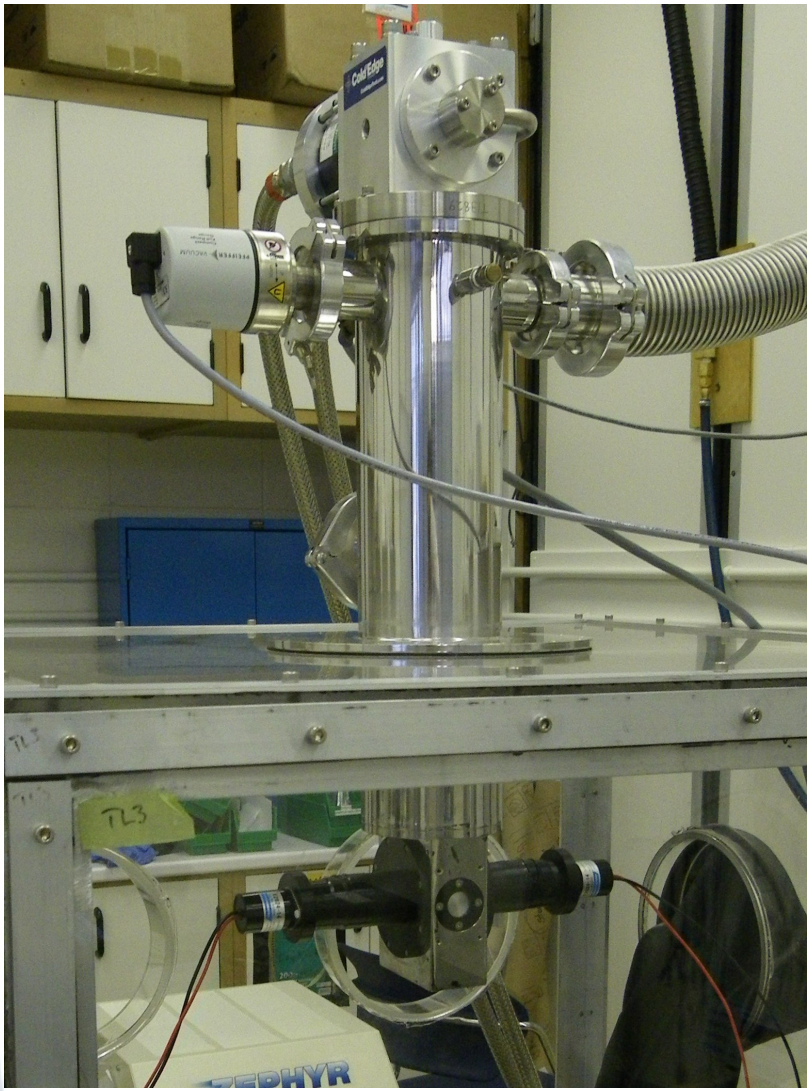
- NaI detector + background discrimination = check DAMA result in model independent way

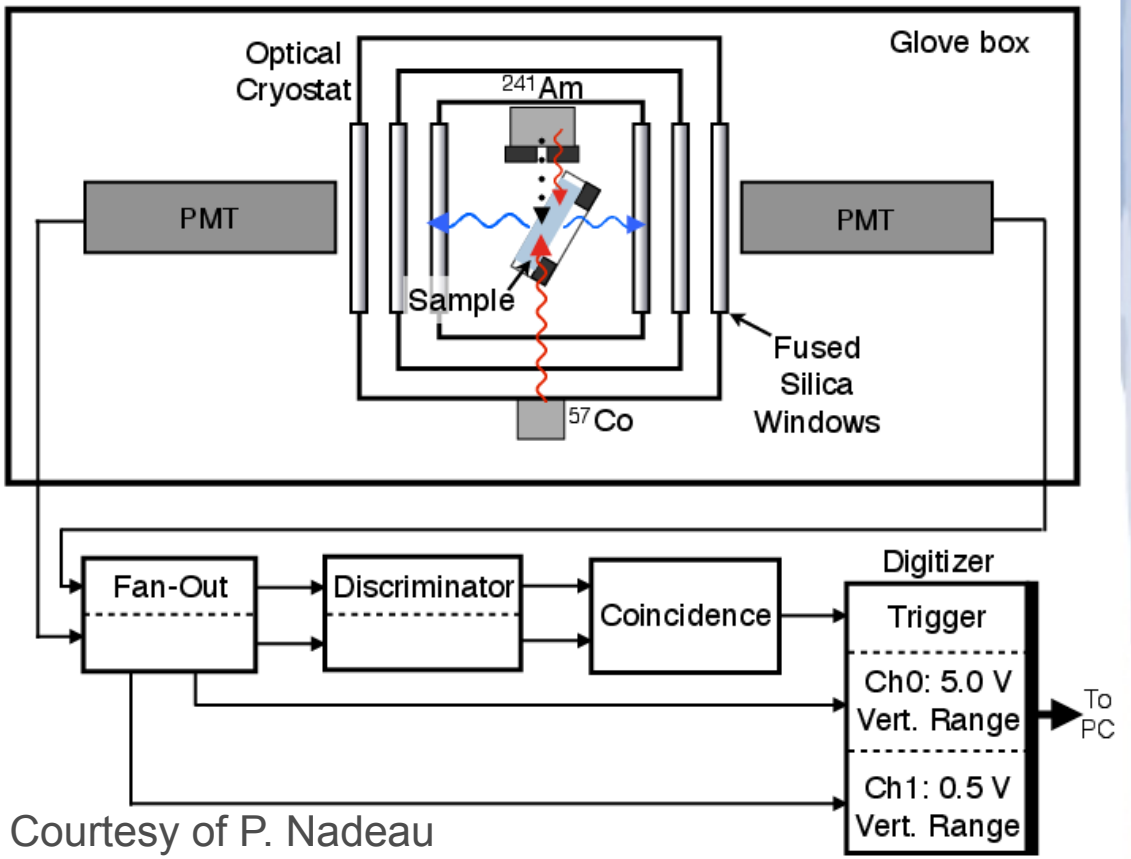
UK DM Collab.,Phys.Lett.B, 616 (2005) 17-24
Coron et al., Astropart. Phys. 47 (2013) 31-37



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

Optical Cryostat

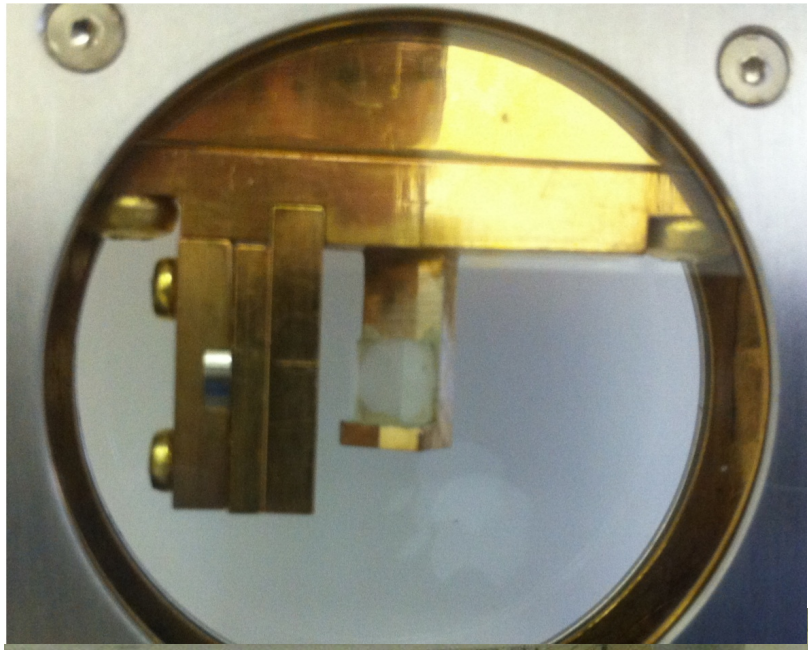


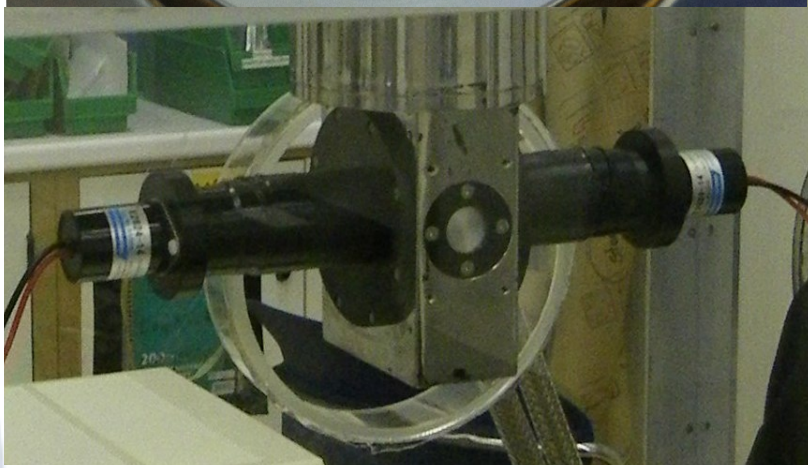


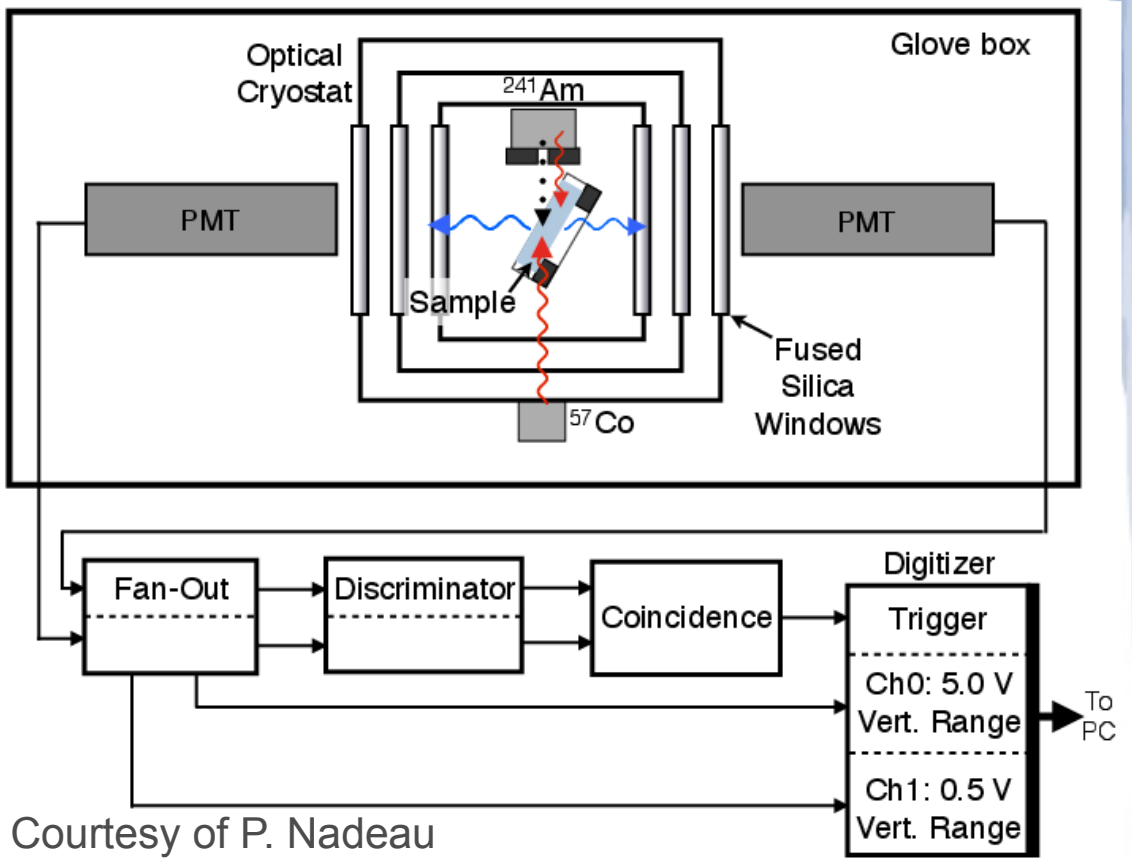
Courtesy of P. Nadeau

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

Optical Cryostat





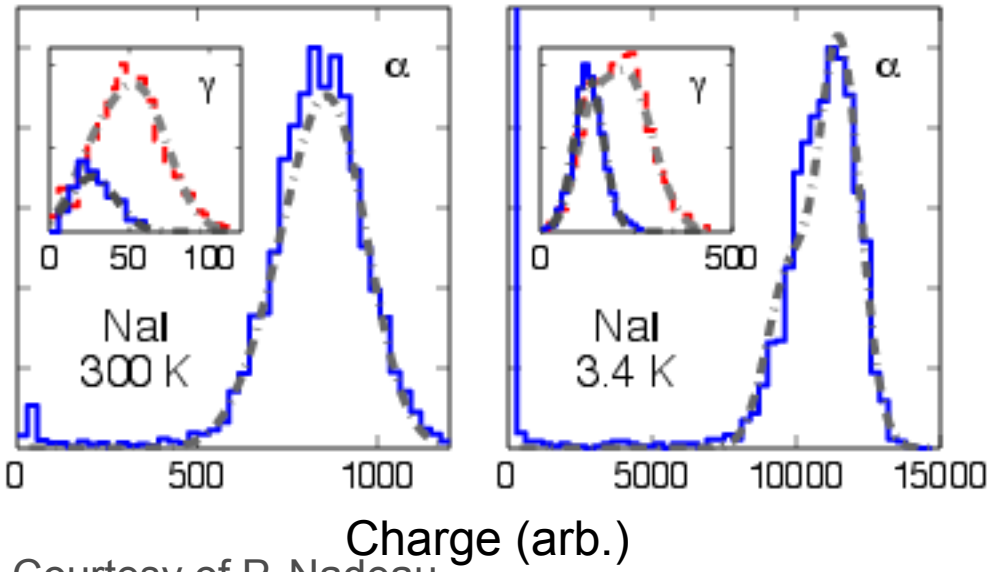


Courtesy of P. Nadeau

- For more information see:

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

Light Yield Measurements



Courtesy of P. Nadeau

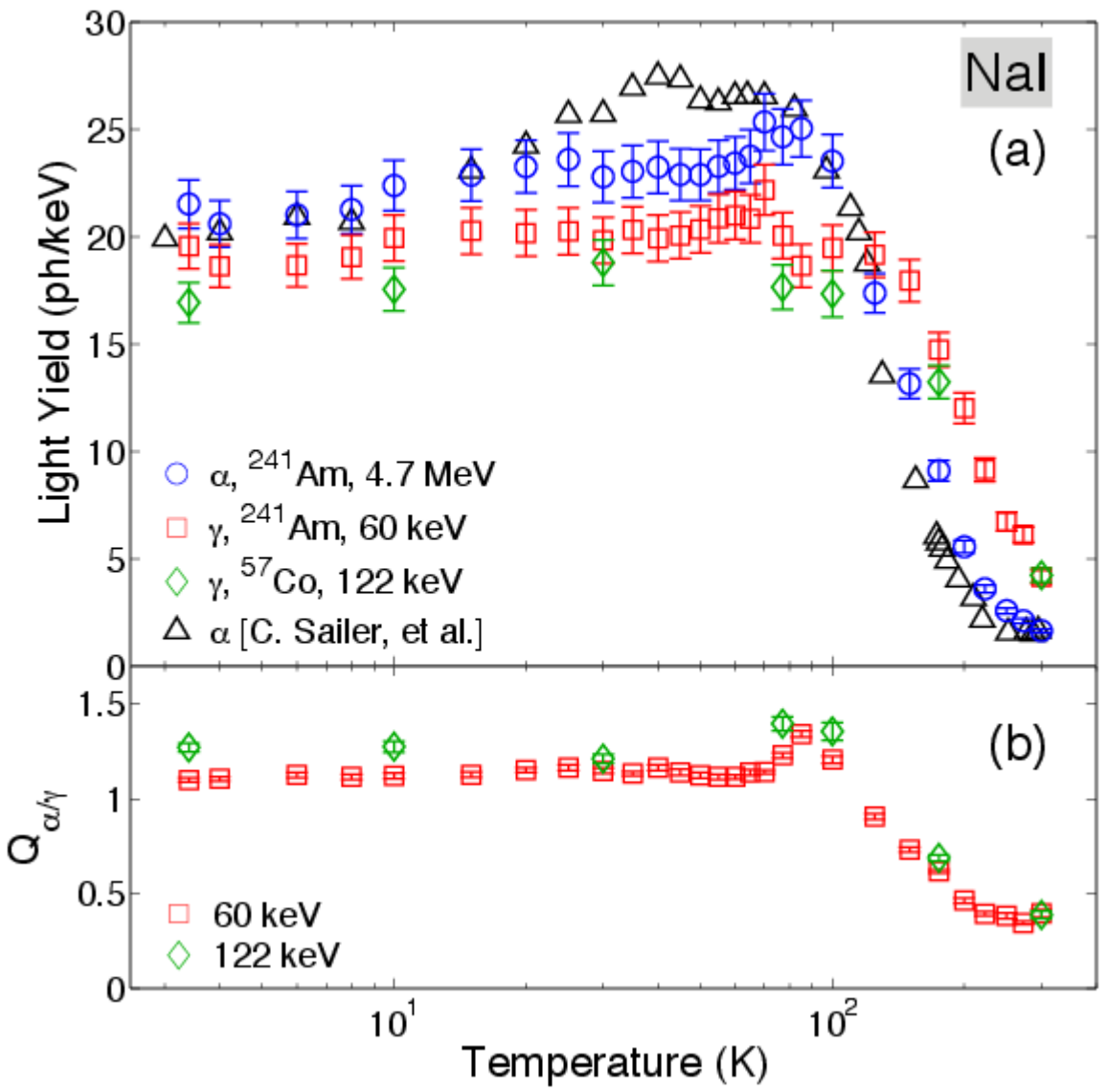
- Goal: to determine how much light is produced in alkali halide crystals at low temperatures

- Trigger on particle interactions and record PMT charge in set time window for many events
- Calculate light yield at temperatures down to 3.4K using location of peaks
- Use lit. value of 300K gamma light yield to determine abs. Yield in photons/keV (corrected for 60keV Am-241 gamma)

Light Yield Results Example

- Example: NaI
- Lit. value 4 phot/keV at 300K for gammas
- Large increase in light yield from room Temp
- Alpha yield in agreement with other observations

  C.Sailer et al., Eur. Phys. J C 72 (2012) 1-4
- CsI, NaI(Tl)



Courtesy of P. Nadeau

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)

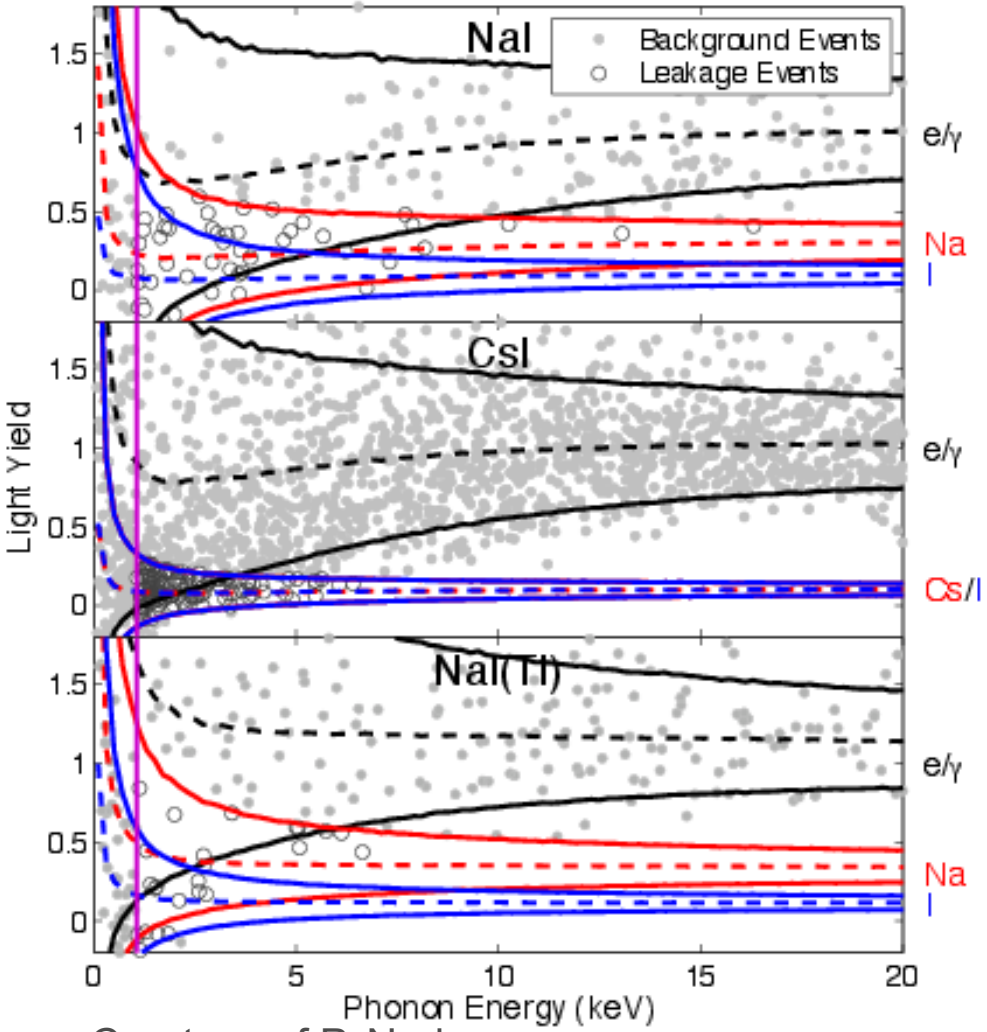
Simulating WIMP Sensitivity

- Can we use these crystals to test the DAMA result?
- Use backgrounds reported by DAMA (NaI, NaI(Tl)) and KIMS (CsI) as theoretical backgrounds[a], assume electron recoils
- Simulate backgrounds using Monte Carlo
- Assume thresholds/resolutions for light and phonon channels
- Determine expected discrimination power
- Use optimum interval method to calculate limit on cross section, mass

S.Yellin, (2007) arXiv:0709.2701

a R. Bernabei, et al., (2008) arXiv: 0804.2738
KIMS Collab., Phys.Lett.B633 (2006) 201-208

Expected WIMP Sensitivity



Courtesy of P. Nadeau

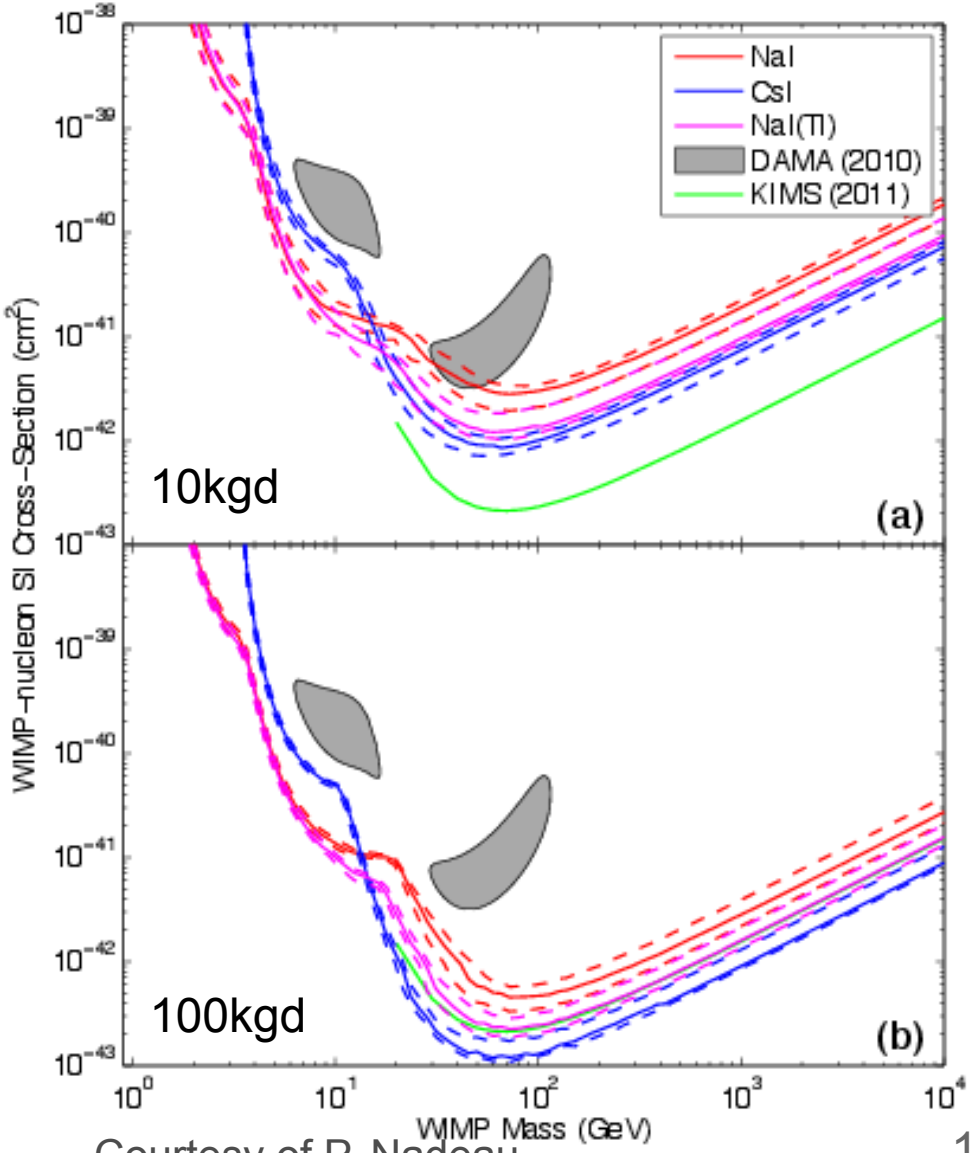
- Using measurements from CRESST of CsI phonon resolution

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

- 10keV std. dev. at 122keV phonon res.
- 10eV light resolution + Poisson photon statistics
- 10 kgd exposure
- Signal region is red/blue bands

Expected WIMP Sensitivity

- Optimum interval limit calculation using events in signal region
- Could exclude/verify DAMA result after 10 kgd if background rejection achieved
- Comparable to KIMS after 100 kgd



Courtesy of P. Nadeau

Modulation Signal Sensitivity

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

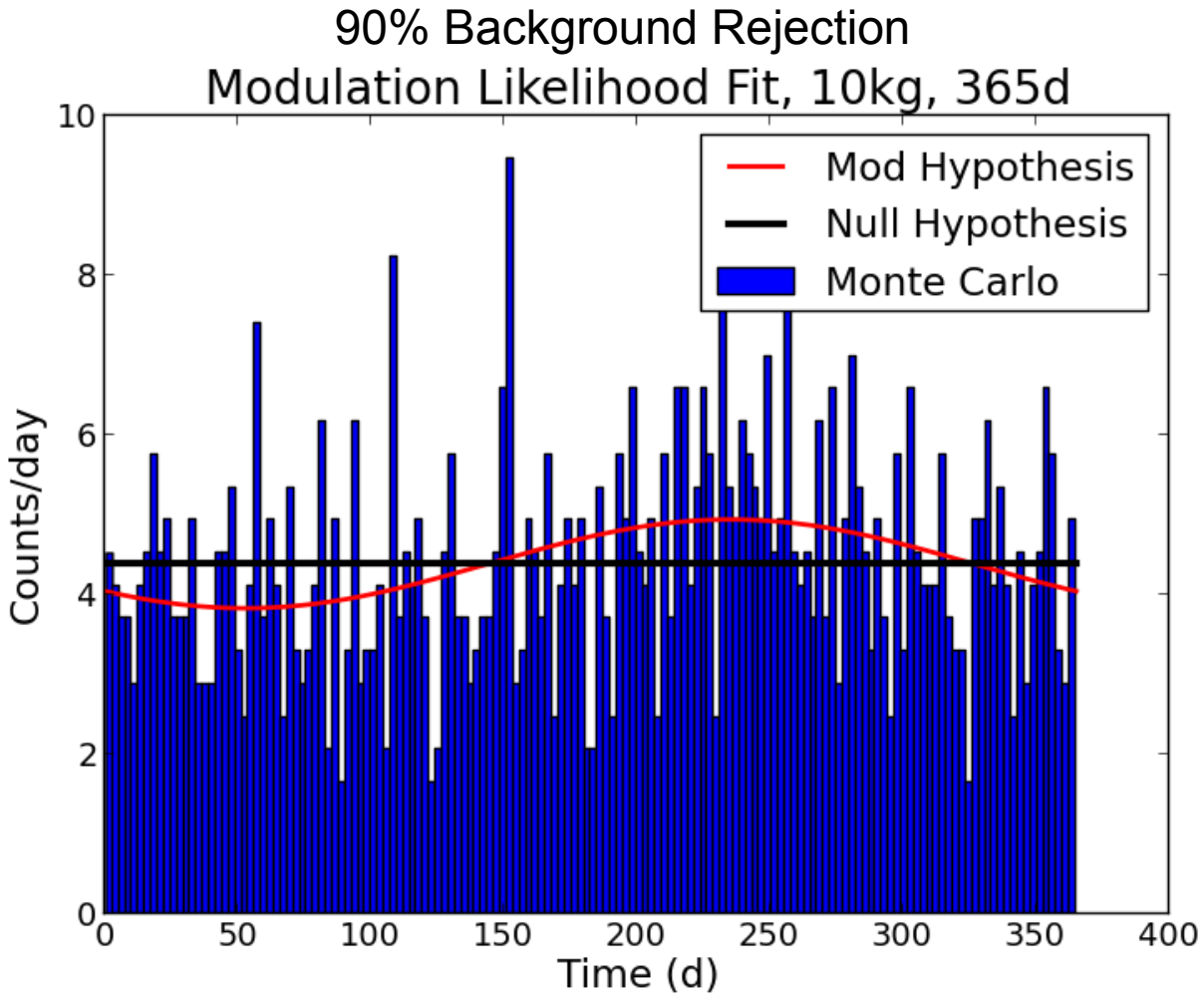
Range	Amplitude	Period	Phase
2-6 keVee	0.045 cpd/kg	365 days	144 days after Jan.1

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

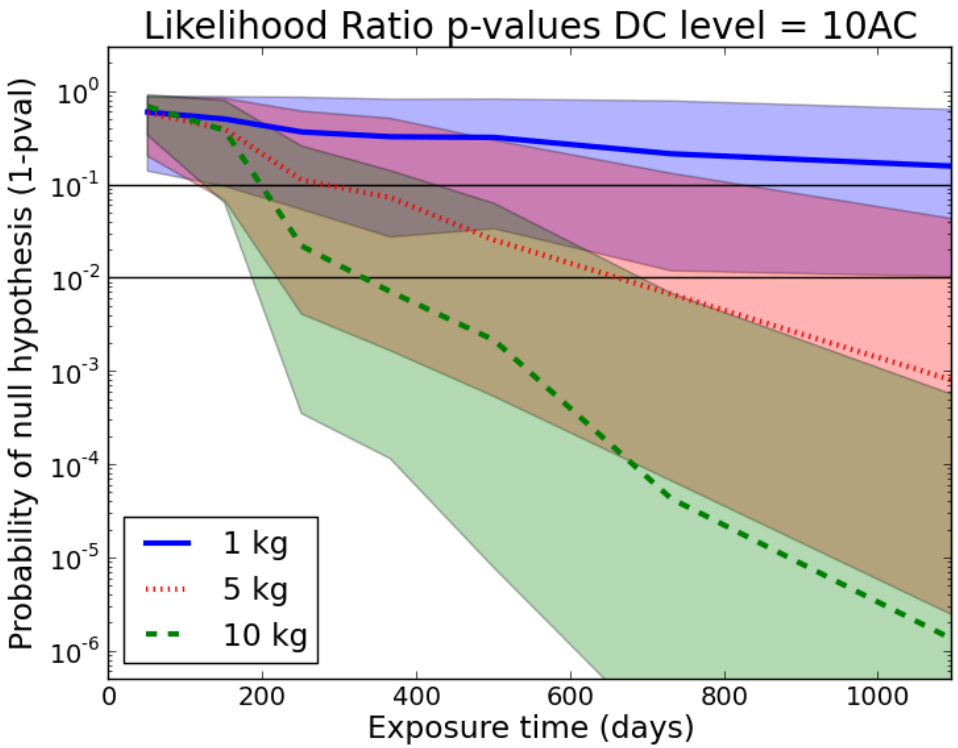
- Compare flat BG + modulation signal hypothesis to flat BG only (null) hypothesis using likelihood ratio test
- Background level used as free parameter because of discrimination

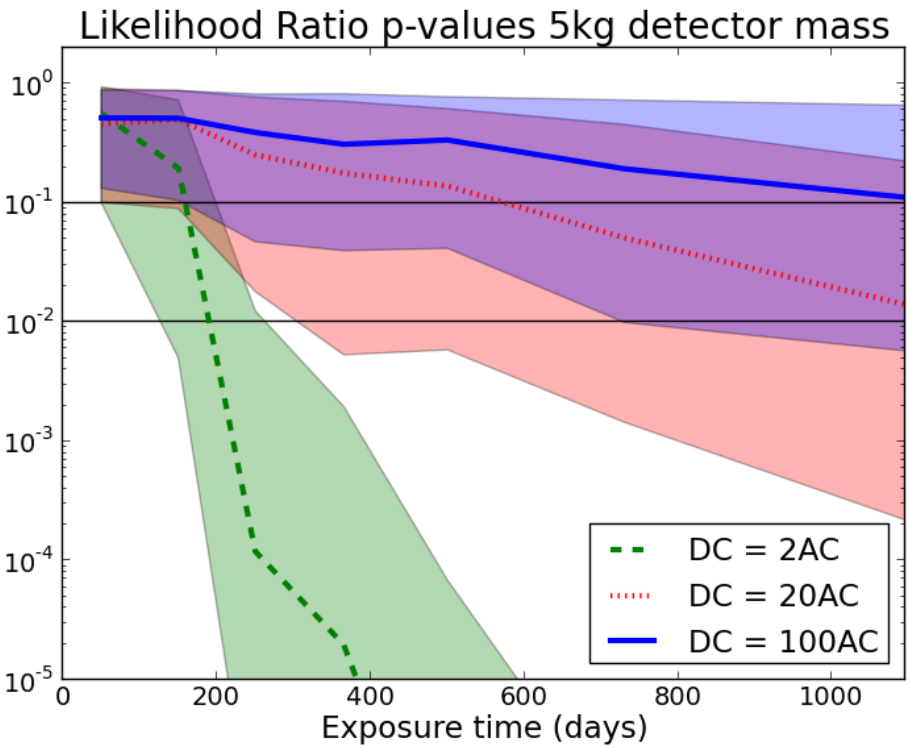
Modulation Signal Sensitivity

- Example of likelihood fit to MC modulation data using PyMINUIT
- Perform many experiments, calculate LR for different times, detector mass, background



Likelihood Ratio Results





- Could achieve 90% confidence in 2 years with 5 kg detector and 90% BG discrim.
- DC = 100AC would be result if background the same as DAMA

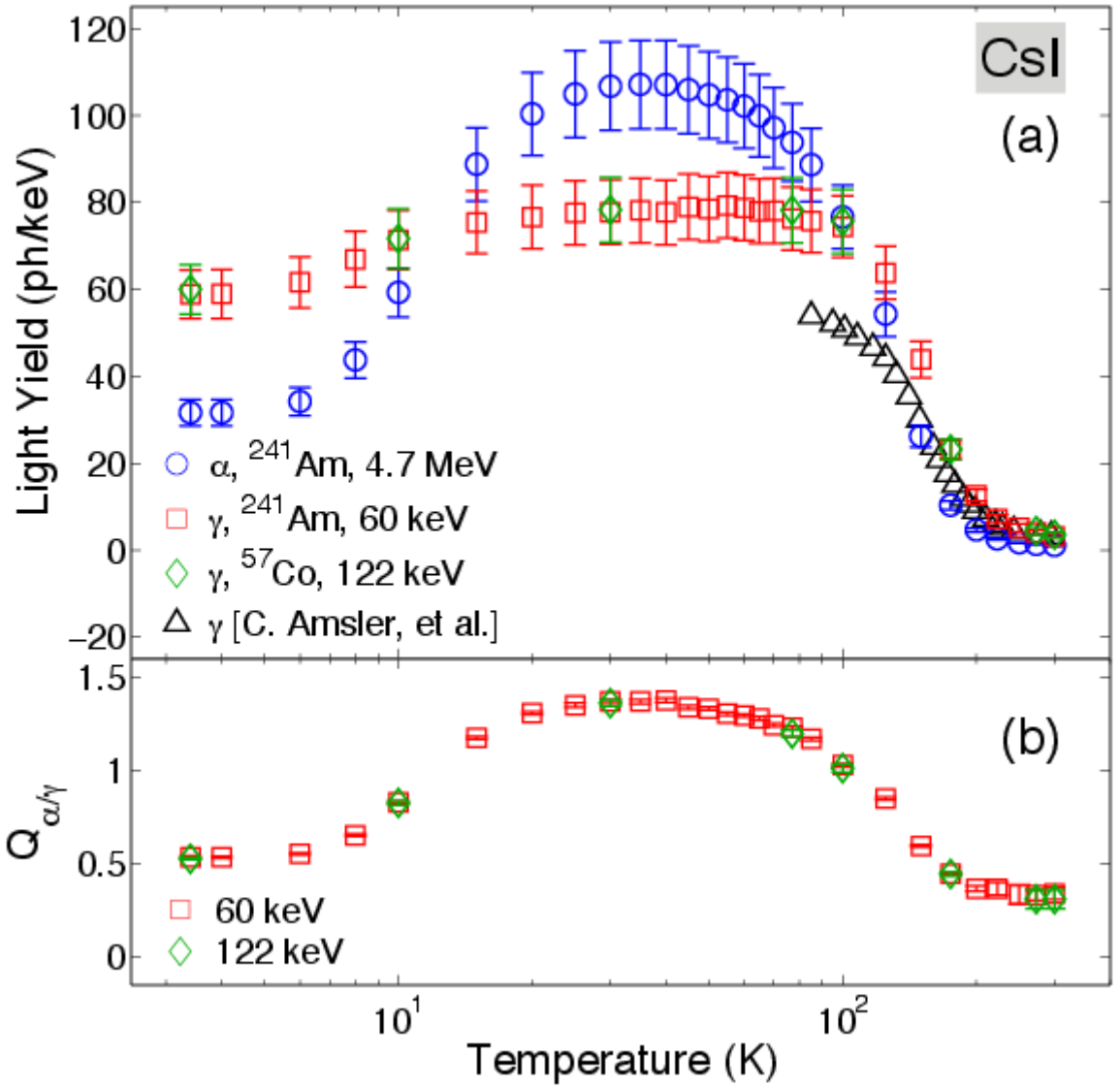
Conclusions

- Measured Alkali Halide light yield curves at cryogenic temperatures
- Used light yield information to determine expected sensitivity to spin-independent WIMP signals and annual modulation signal using Monte Carlo simulation
- Could test DAMA with only 10 kgd exposure
- Many experimental challenges to overcome (hygroscopic crystals, phonon resolution, backgrounds)
- Pulse shape analysis could add additional background discrimination methods (NAIAD)

EXTRA SLIDES

CsI Light Yield Results

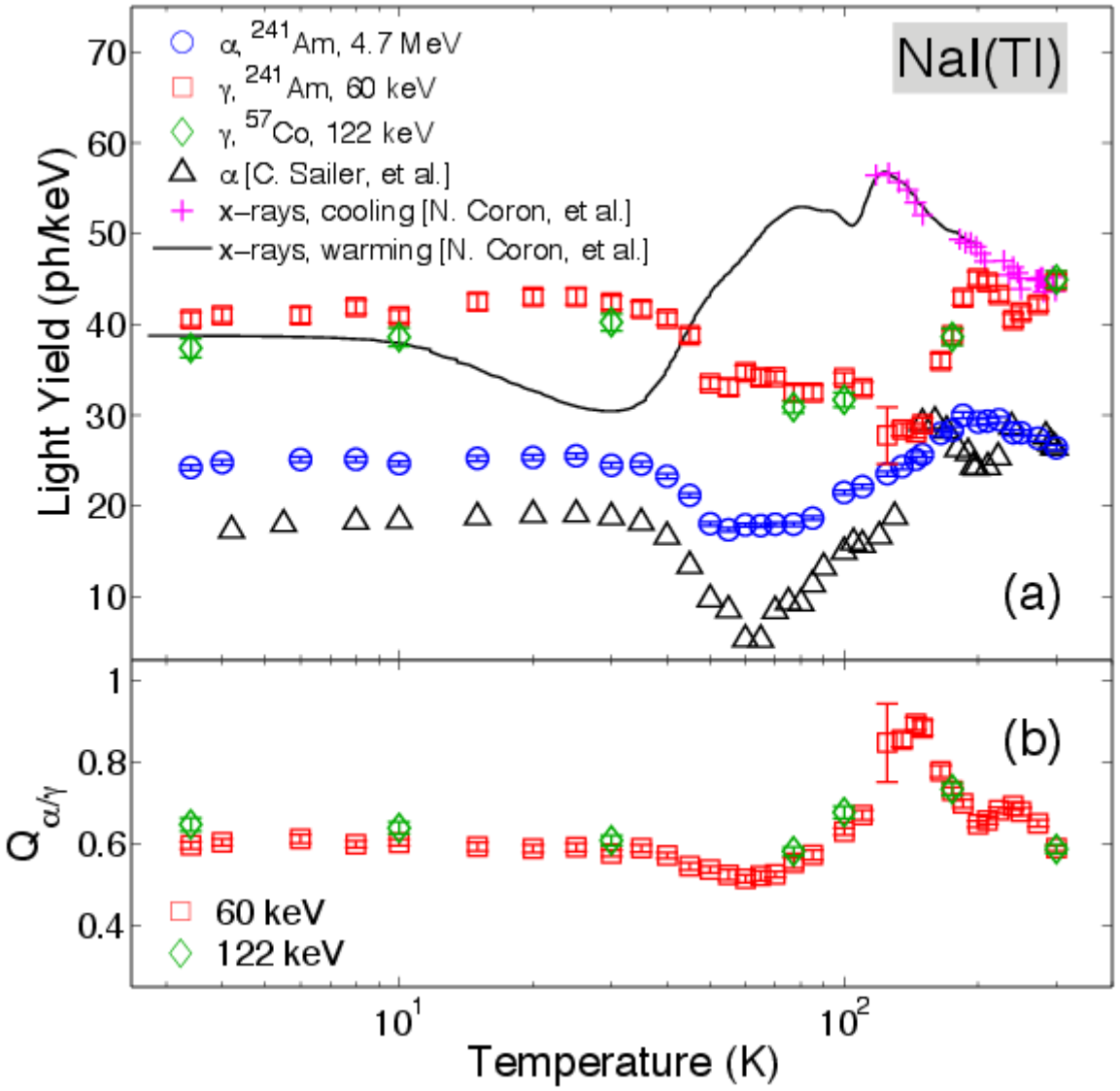
- Large Increase in light yield
- Nice agreement between gammas of different energy
- Achieves best limits out of our three crystals because of high light yield



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

NaI(Tl) Light Yield Results

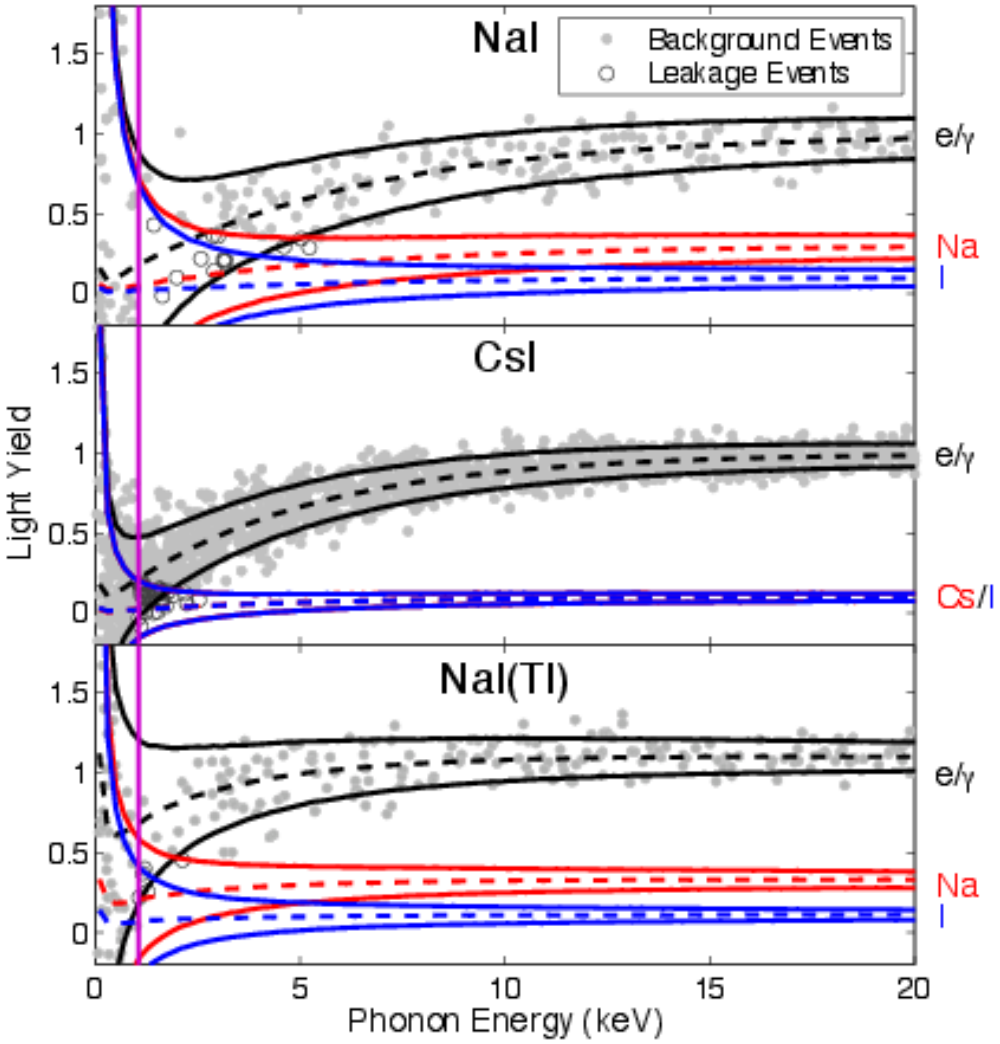
- Low temp. LY approx. Equal to RT yield.
- Many different particle interactions on this graph



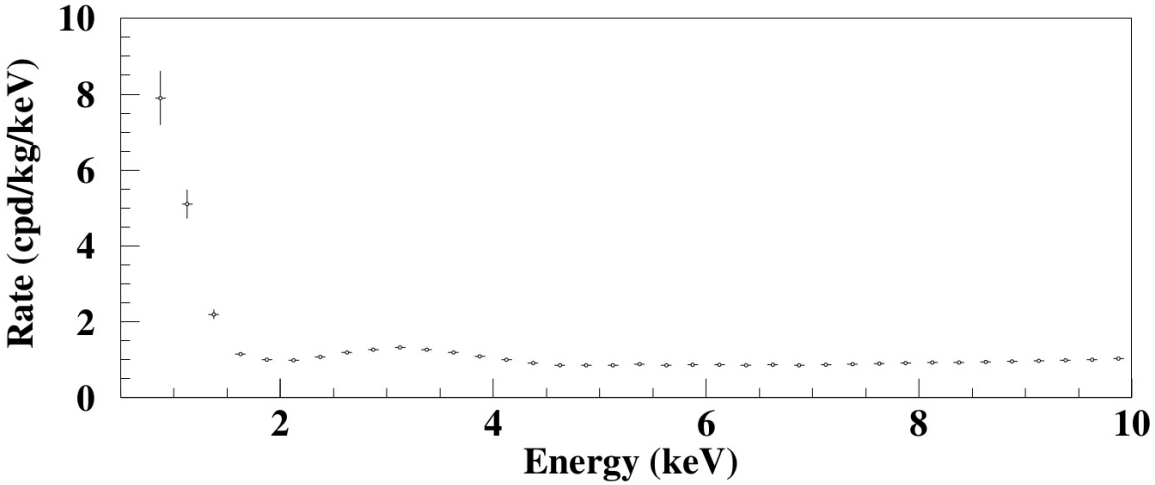
C.Sailer et al., Eur. Phys. J C 72 (2012) 1-4
Coron et al., Astropart. Phys. 47 (2013) 31-37

CRESST resolution Discrimination bands

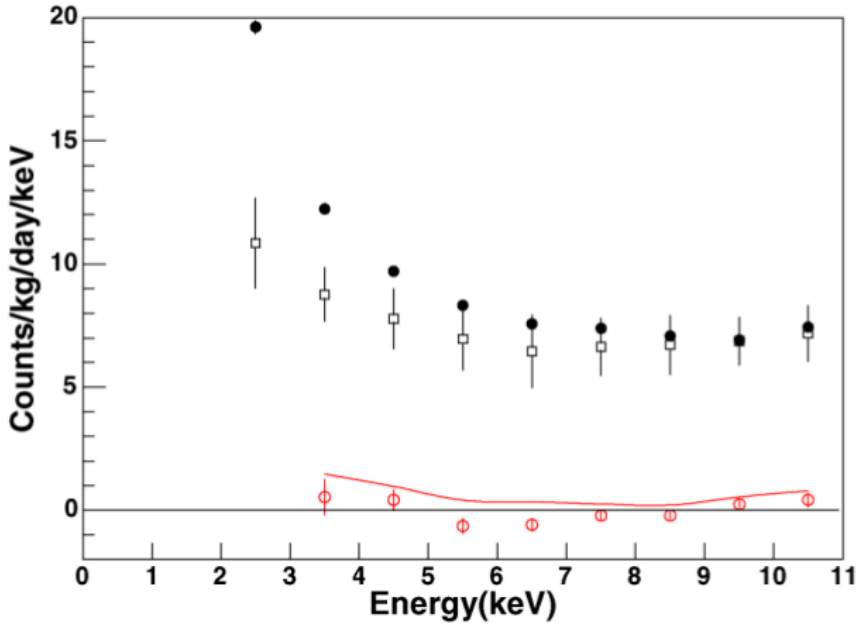
- Discrimination bands using CRESST resolutions
- 600 eV phonon resolution at 122 keV
- Quenching Factors: 0.3 for Na, 0.1 for Cs,I



Background spectra



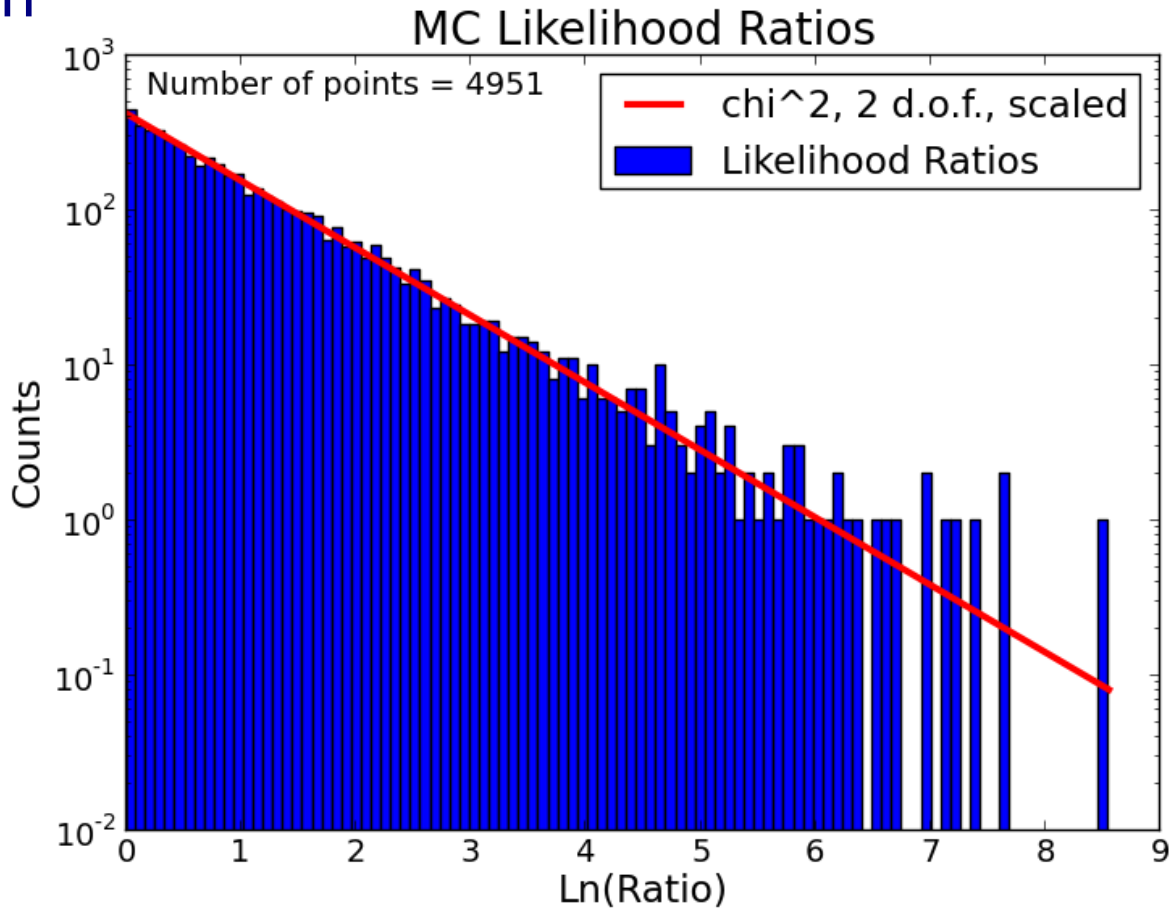
DAMA Spectrum
NaI, NaI(Tl)



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



PMT QE and low-T crystal spectra

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