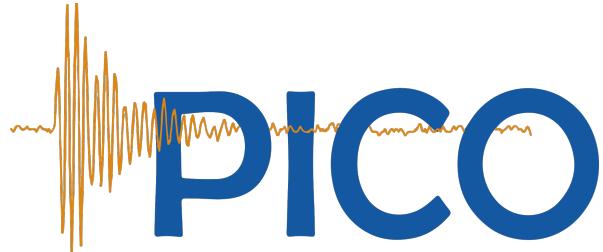


# Updated Dark Matter Search Results from the PICO-60 Bubble Chamber



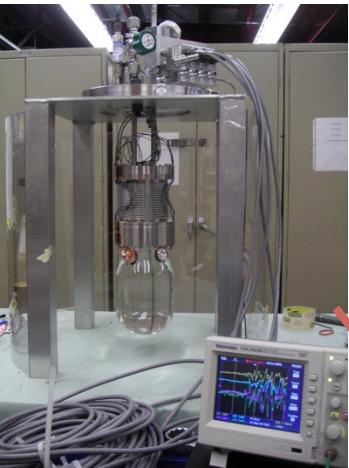
Russell Neilson, Drexel University

IDM2018, Brown University

July 24, 2018

# PICO overview

-2012  
COUPP



PICASSO



2013-17  
PICO-2L



PICO-60

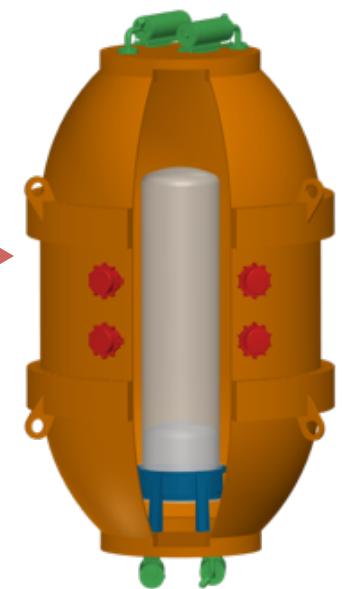


2018-

PICO-40L

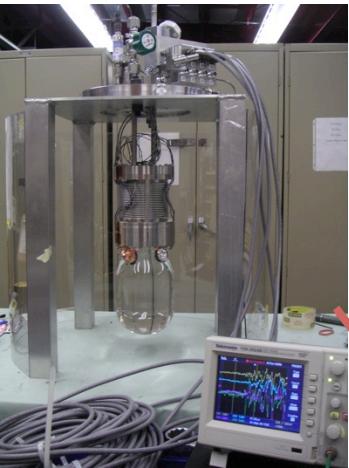


PICO-500



# PICO overview

-2012  
COUPP



PICASSO



IDM2018 Brown University

2013-17  
PICO-2L



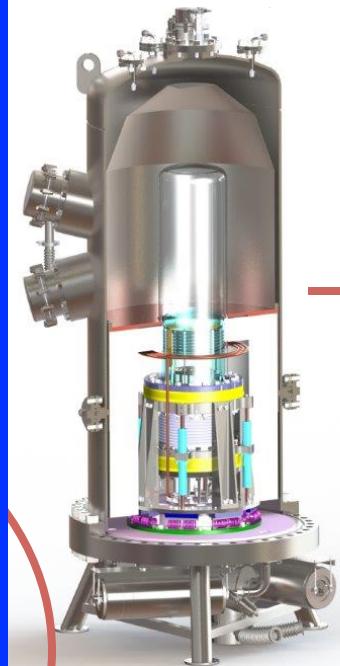
PICO



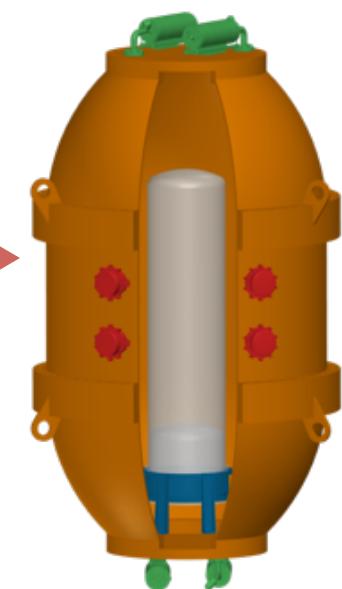
PICO-60

2018-

PICO-40L



PICO-500



This talk

See Carsten Krauss's talk



# PICO

**Northeastern**  
ILLINOIS UNIVERSITY

O. Harris



ČESKÉ  
VYSOKÉ  
UČENÍ  
TECHNICKÉ  
V PRAZE

**KICP**

Kavli Institute  
for Cosmological Physics  
at The University of Chicago

J.I. Collar



I. Lawson



UNIVERSITAT  
POLITÈCNICA  
DE VALÈNCIA

M. Ardid, M. Bou-Cabo, I. Felis



M. Bressler, R. Neilson



P.S. Cooper, M. Crisler,  
W.H. Lippincott, A. Sonnenschein



B. Broerman, G. Cao, K. Clark,  
G. Giroux, C. Hardy, C. Moore,  
A. Noble

**Queens**  
UNIVERSITY



UNIVERSITY OF  
ALBERTA

C. Coutu, S. Fallows,  
C. Krauss, M.-C. Piro



NORTHWESTERN  
UNIVERSITY

D. Baxter, C.E. Dahl, M. Jin,  
J. Zhang



Pacific Northwest  
NATIONAL LABORATORY

I. Arnquist, C. Cowles, C.M.  
Jackson, B. Loer, K. Wierman



Laurentian University  
Université Laurentienne

J. Farine, A. Le Blanc, C. Licciardi,  
O. Scallon, U. Wichoski

Université  
de Montréal

S. Chen, M. Laurin,  
J.-P. Martin, A. Plante,  
A.E. Robinson, N. Starinski,  
F. Tardif, D. Tiwari, V. Zacek,  
C. Wen Chao,



INDIANA UNIVERSITY  
SOUTH BEND

E. Behnke, I. Levine, T. Nania



M. Das, S. Sahoo,  
S. Seth



PennState

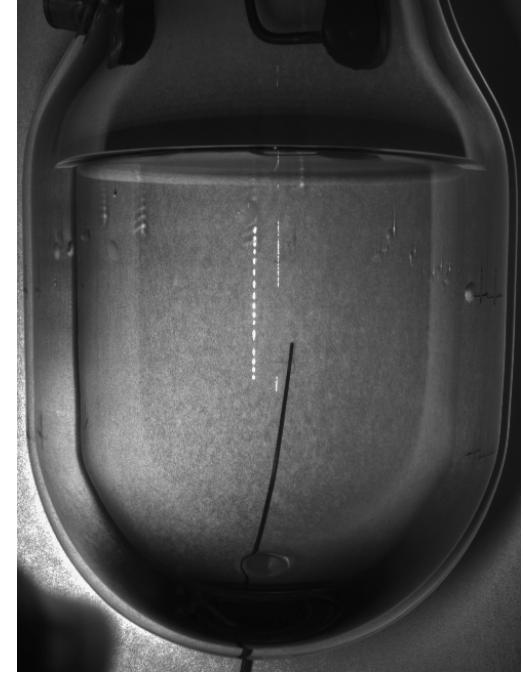
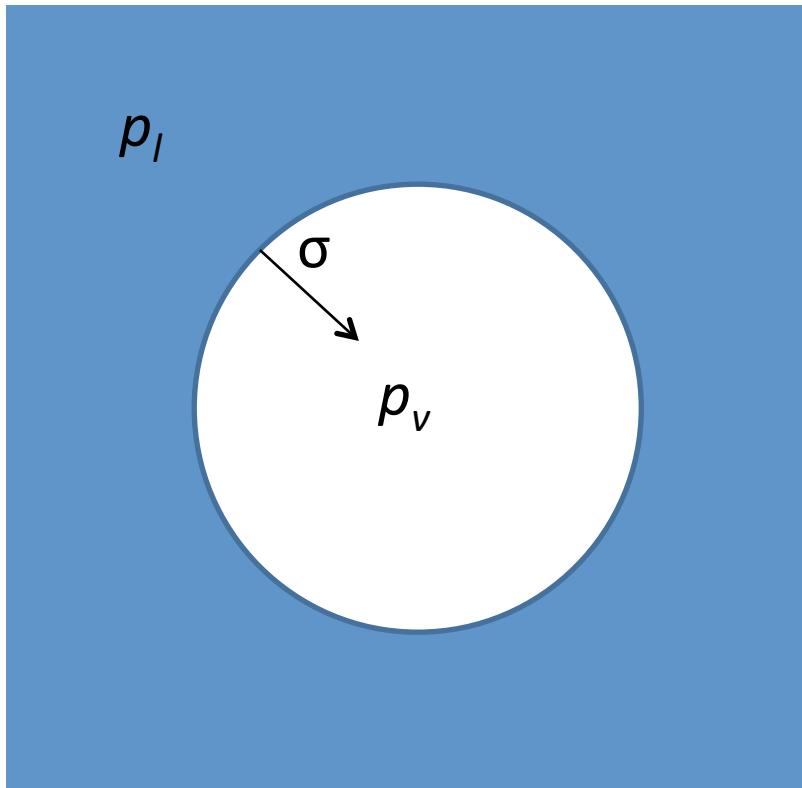
D. Maurya, S. Priya,  
Y. Yan



E. Vázquez-Jáuregui

# Bubble formation

Proto-bubble in superheated liquid



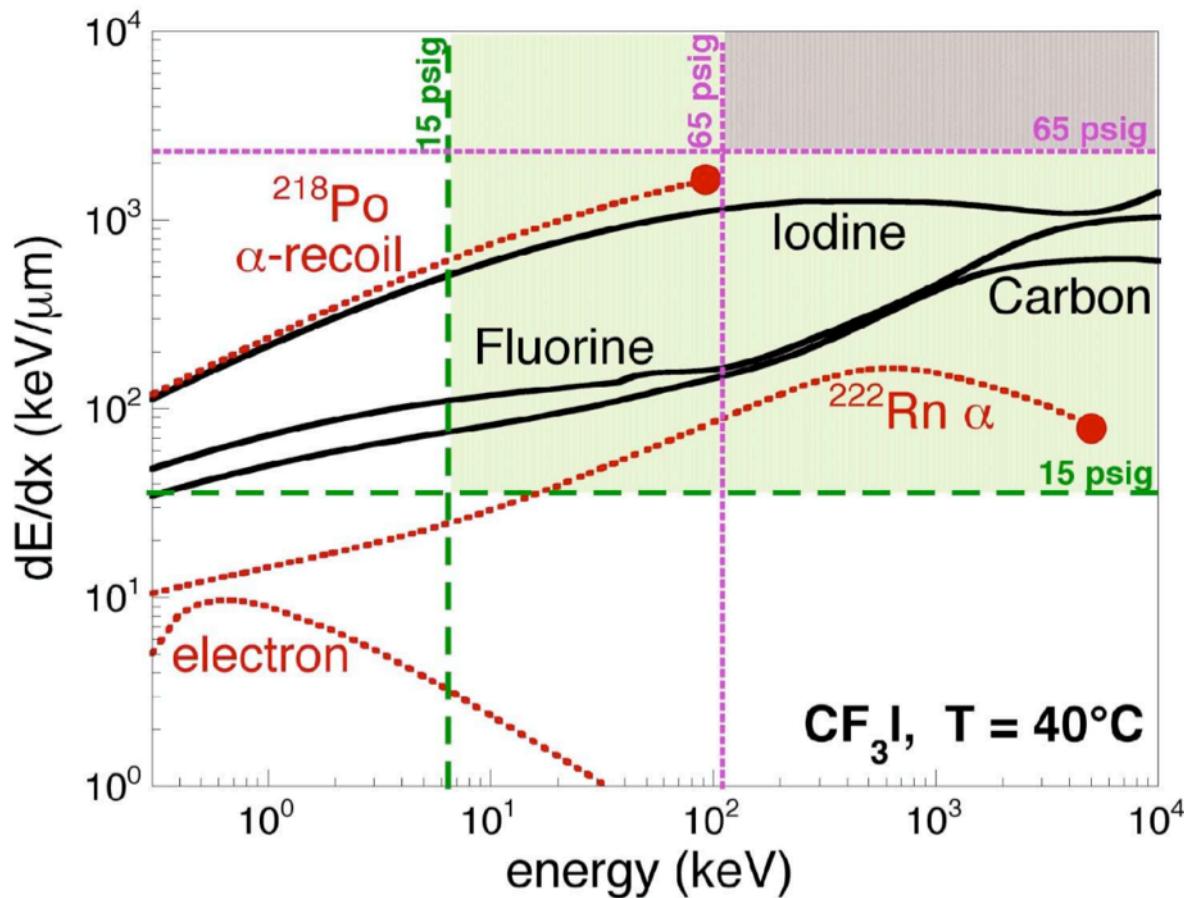
$$p_v - p_l = \frac{2\sigma}{r_c}$$

$$E_{th} = \boxed{4\pi r_c^2 \left( \sigma - T \frac{\partial \sigma}{\partial T} \right)} + \frac{4}{3}\pi r_c^3 \rho_v h$$

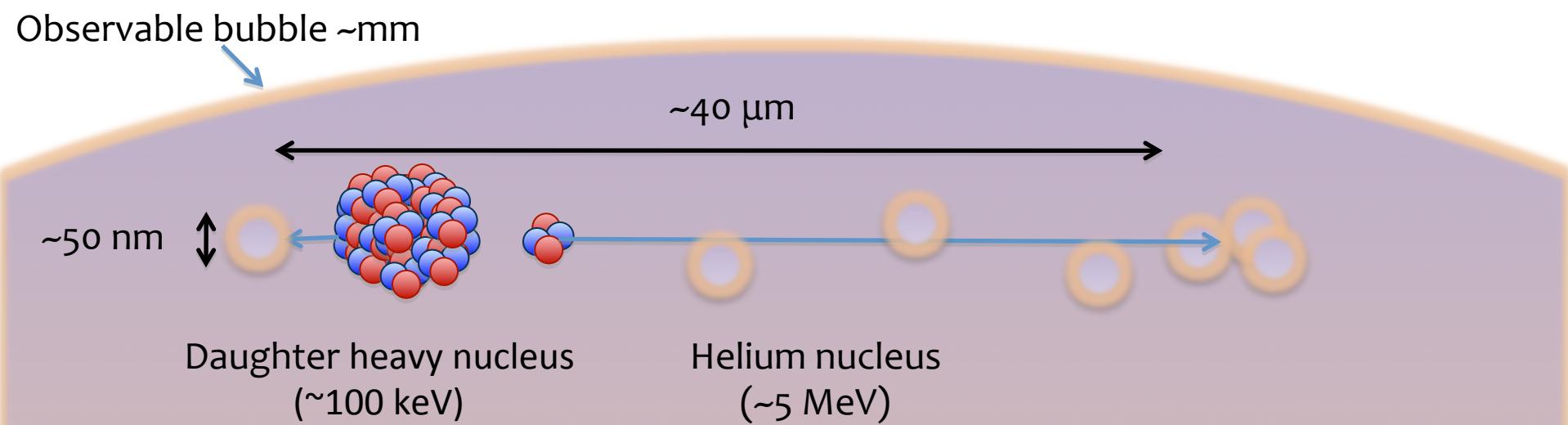
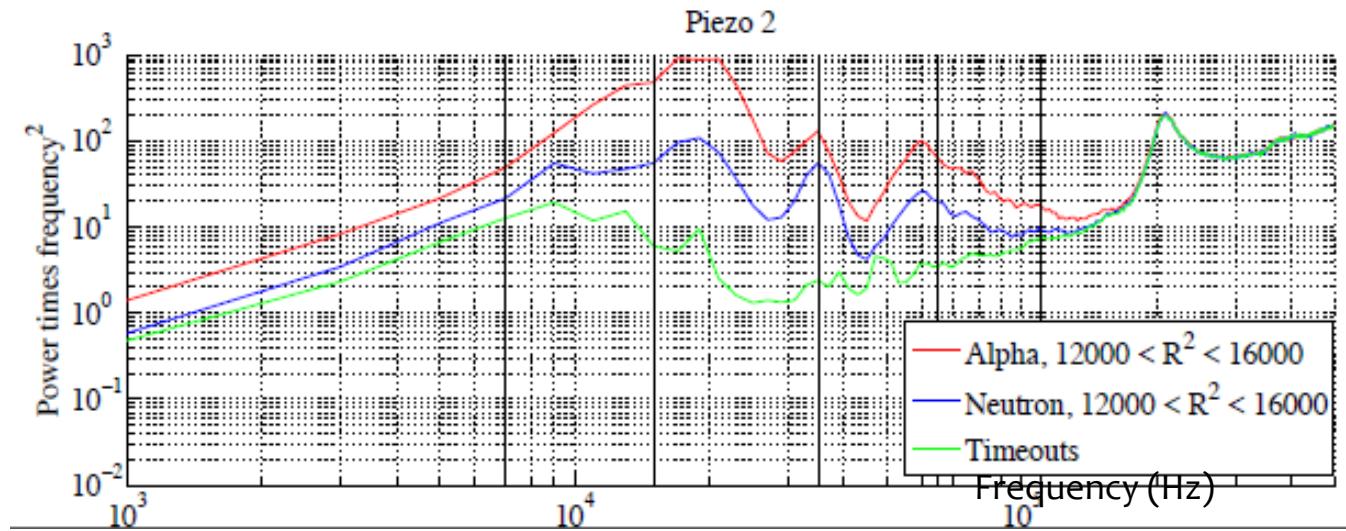
Surface energy

Latent heat

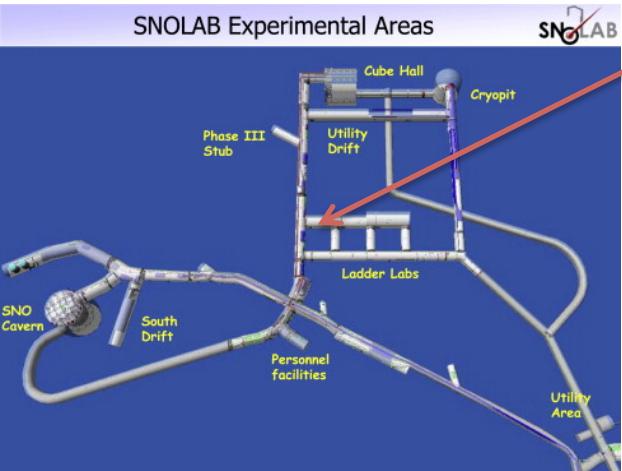
# Nuclear recoil detectors



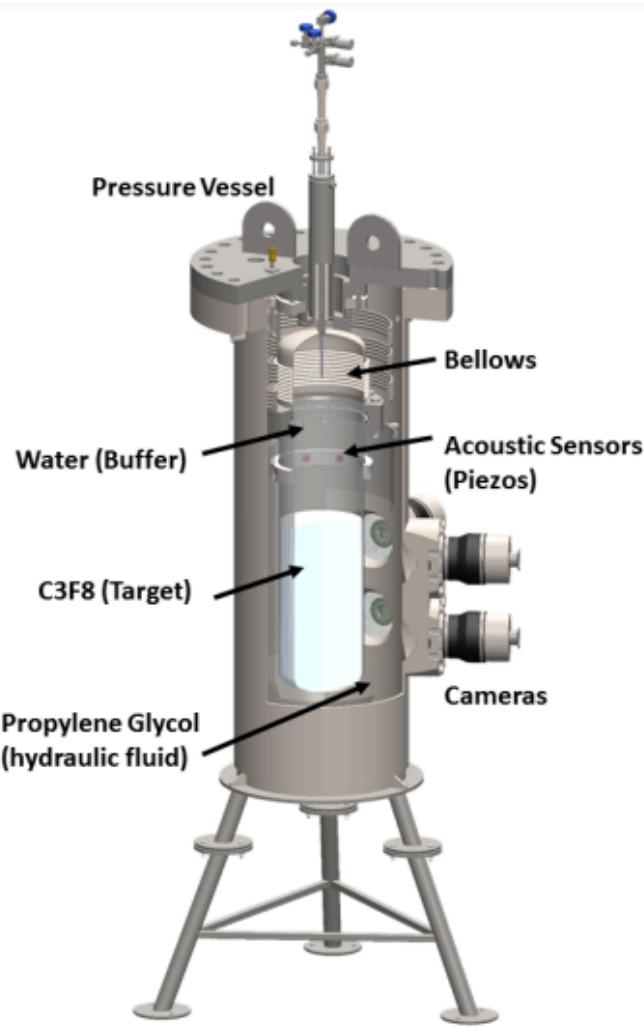
# PICO acoustics



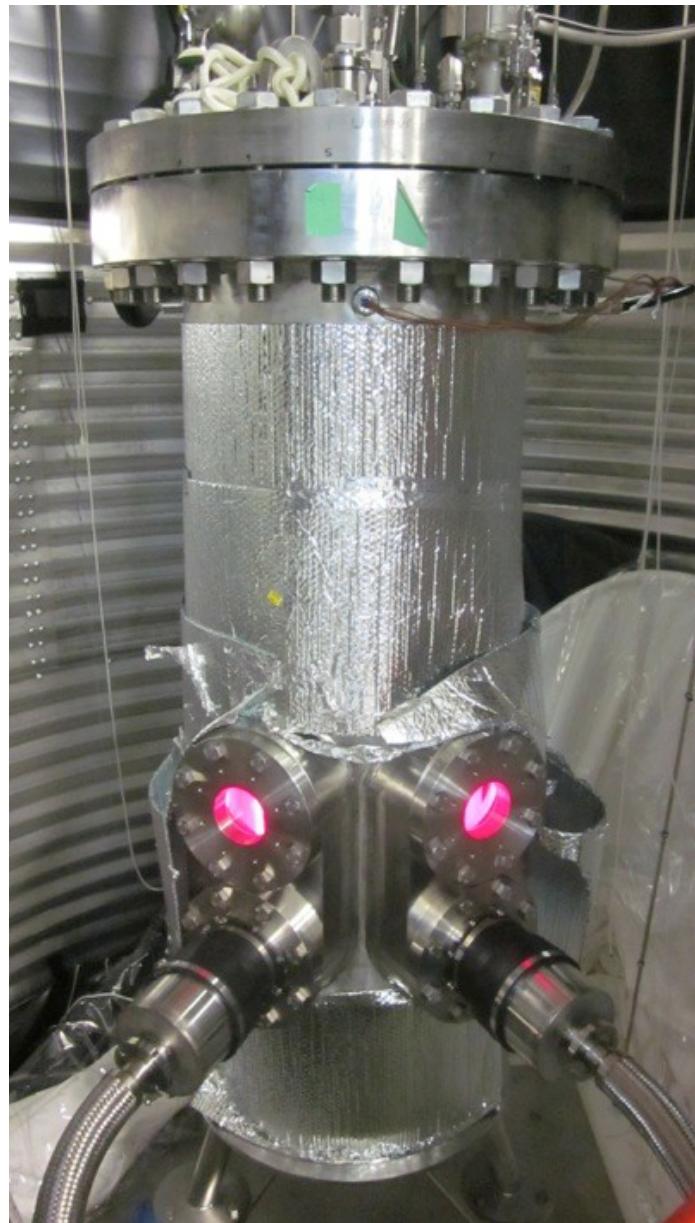
# PICO-60



# PICO-60

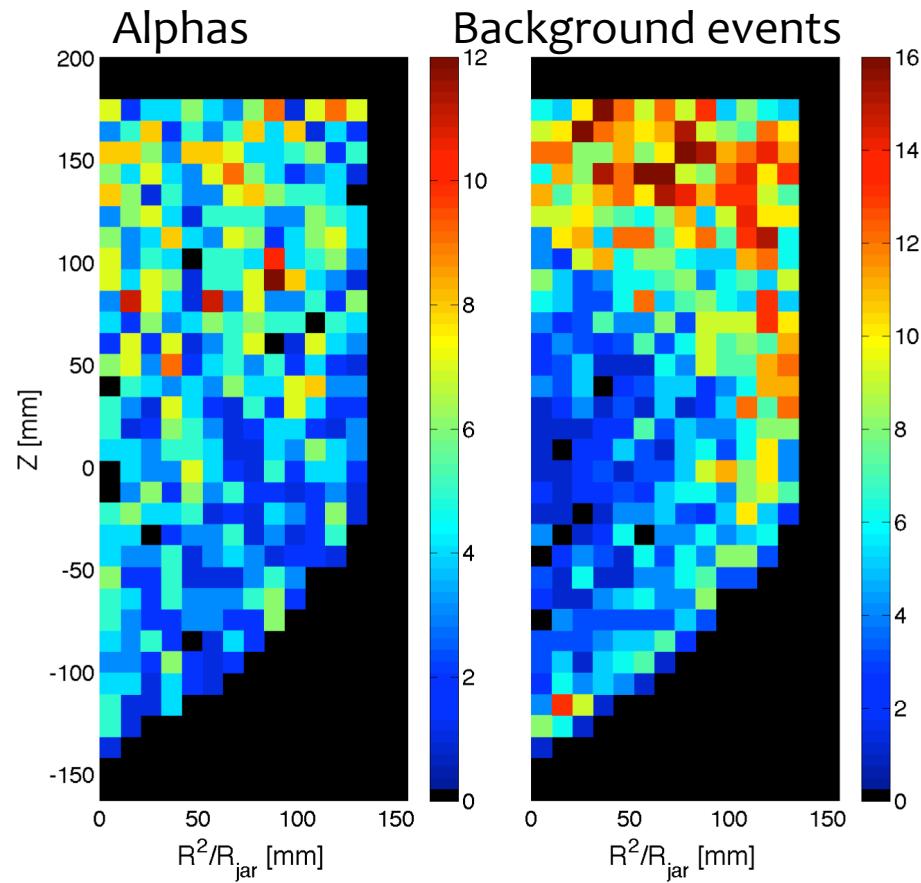


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# PICO-60 CF<sub>3</sub>I

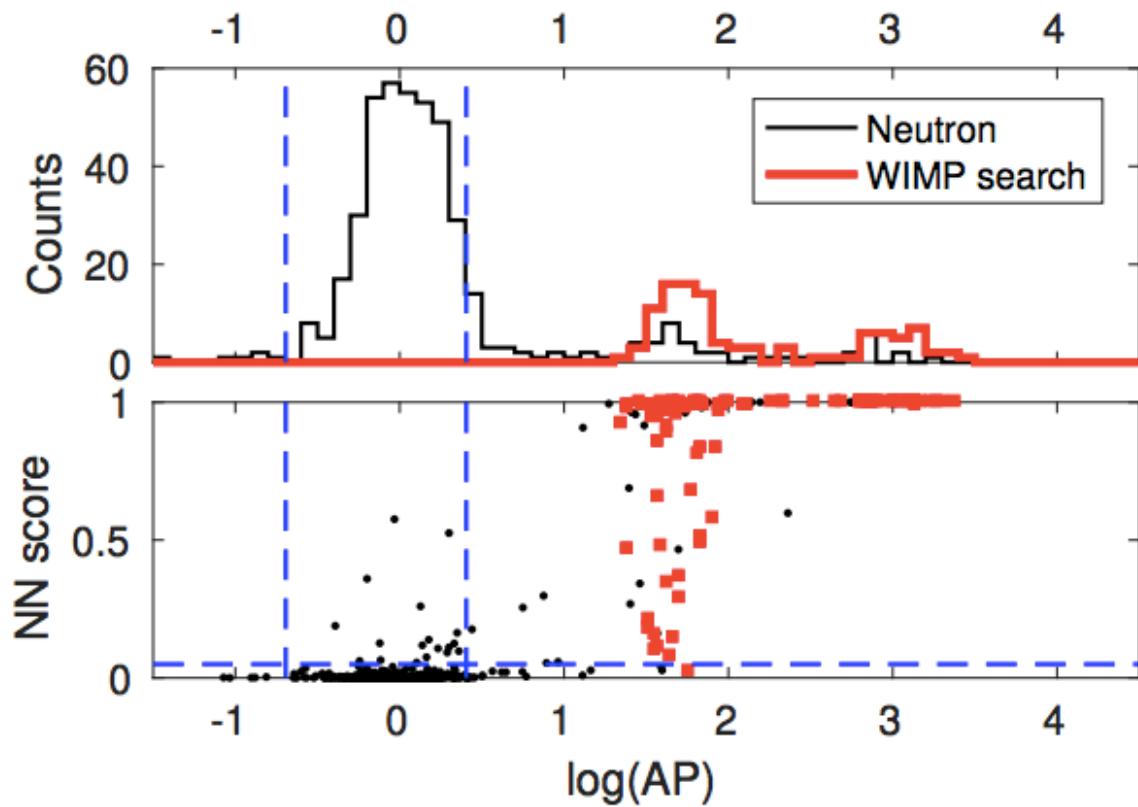
- First PICO-60 run 2013-14 with CF<sub>3</sub>I target.
- Substantial background, but able to be removed with fiducial, acoustic and timing cuts.
- Now believe background results from water mixing facilitated by particulate contamination.



C. Amole et al., Phys. Rev. D 93, 052014 (2016)

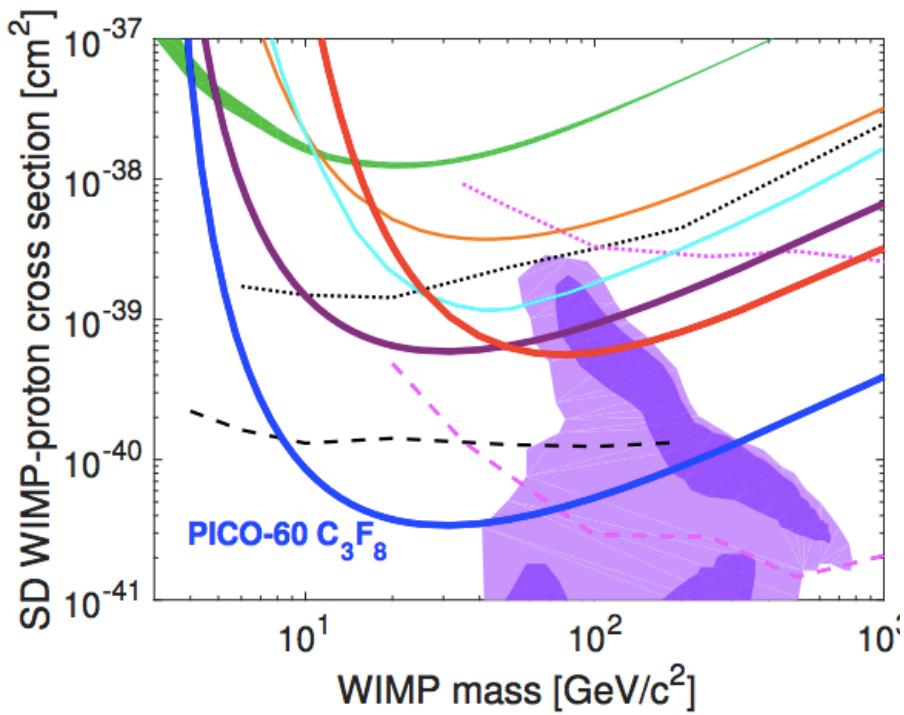
# PICO-60 $\text{C}_3\text{F}_8$ 3.29keV run

- 52 kg  $\text{C}_3\text{F}_8$ , 30 live-days Nov 2016 – Jan 2017.
- 1167 kg-days blind exposure.
- Zero WIMP candidates.
- Three multiple bubble events observed, signature of neutron background.

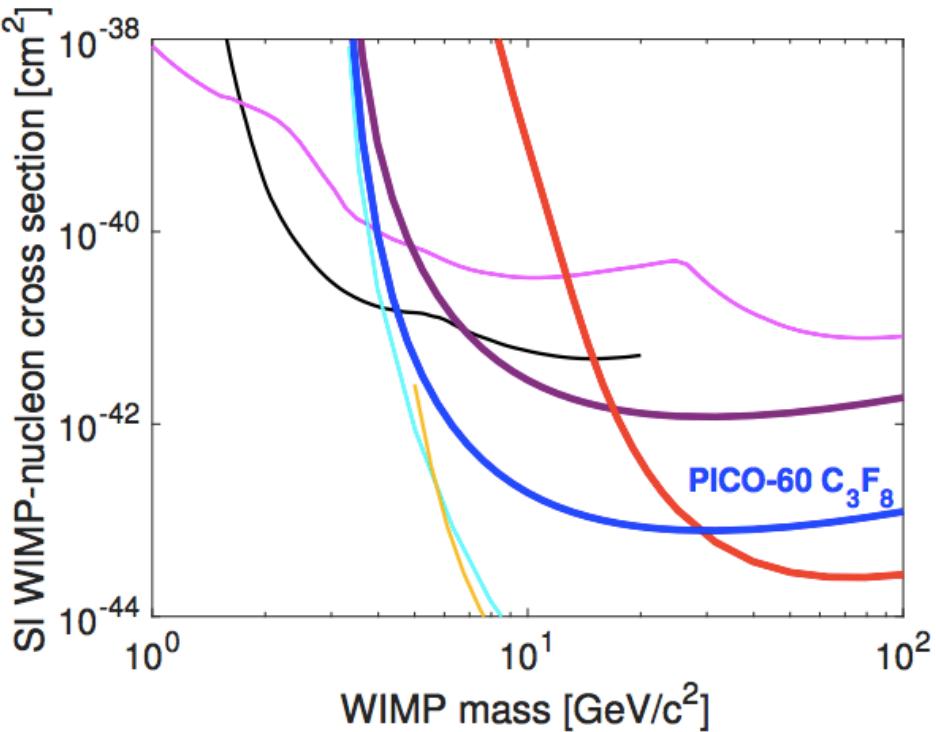


C. Amole et al., Phys. Rev. Lett. 118, 251301 (2017)

# PICO-60 (previous) limits



PICO-60 CF3I	PandaX-II
PICO-2L	IceCube
PICASSO	SuperK
SIMPLE	



PICO-60 CF3I	PandaX-II
PICO-2L	CRESST-II
LUX	CDMS-lite

C. Amole et al., Phys. Rev. Lett. 118, 251301 (2017)

# PICO-60 low-threshold (and de-commissioning)

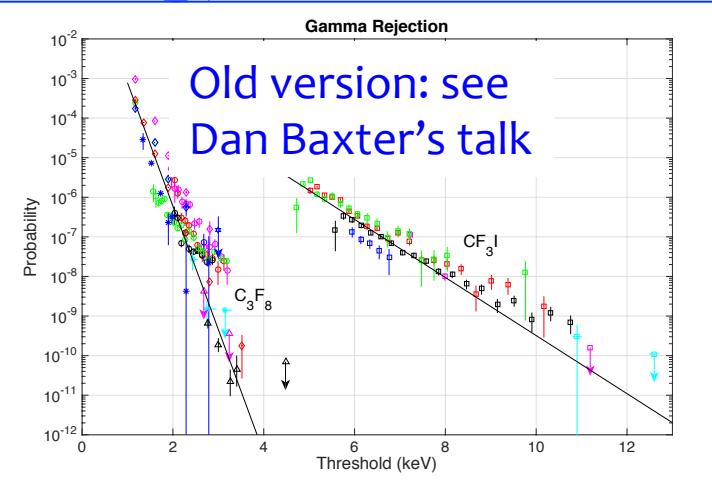
Need to make space for PICO-40L, but first dial down the threshold and see what happens.

T (°C)	P (psia)	Seitz threshold, $E_T$ (keV)	Livetime (d)	Exposure (kg-d)
19.9	25.5	$1.20 \pm 0.1(\text{exp}) \pm 0.1(\text{th})$	0.21	8.2
19.9	34.3	$1.58 \pm 0.1(\text{exp}) \pm 0.1(\text{th})$	1.29	50.3
15.9	21.7	$1.81 \pm 0.1(\text{exp}) \pm 0.2(\text{th})$	7.04	310.81
15.9	30.5	$2.45 \pm 0.1(\text{exp}) \pm 0.2(\text{th})$	29.95	1404.22
13.9	30.2	$3.29 \pm 0.1(\text{exp}) \pm 0.2(\text{th})$	29.96	1167

# PICO-60 low-threshold (and de-commissioning)

Need to make space for PICO-40L, but first dial down the threshold and see what happens.

No WIMP search below 2keV because:



T (°C)	P (psia)	Seitz threshold, $E_T$ (keV)	Livetime (d)	Exposure (kg-d)
19.9	25.5	$1.20 \pm 0.1(\text{exp}) \pm 0.1(\text{th})$	0.21	8.2
19.9	34.3	$1.58 \pm 0.1(\text{exp}) \pm 0.1(\text{th})$	1.29	50.3
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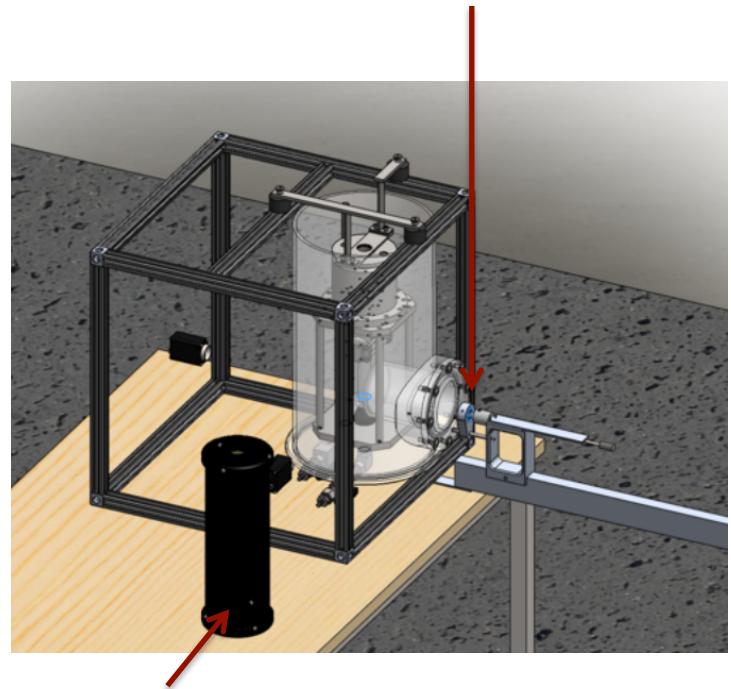
Combined WIMP-search dataset

# Low energy neutron calibrations



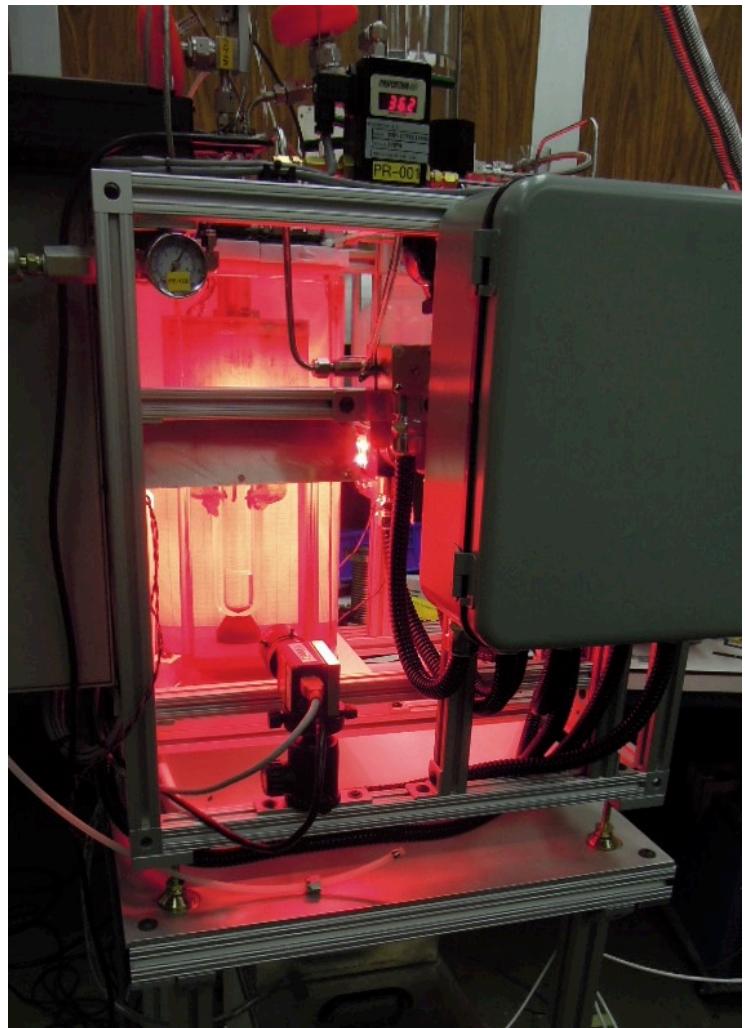
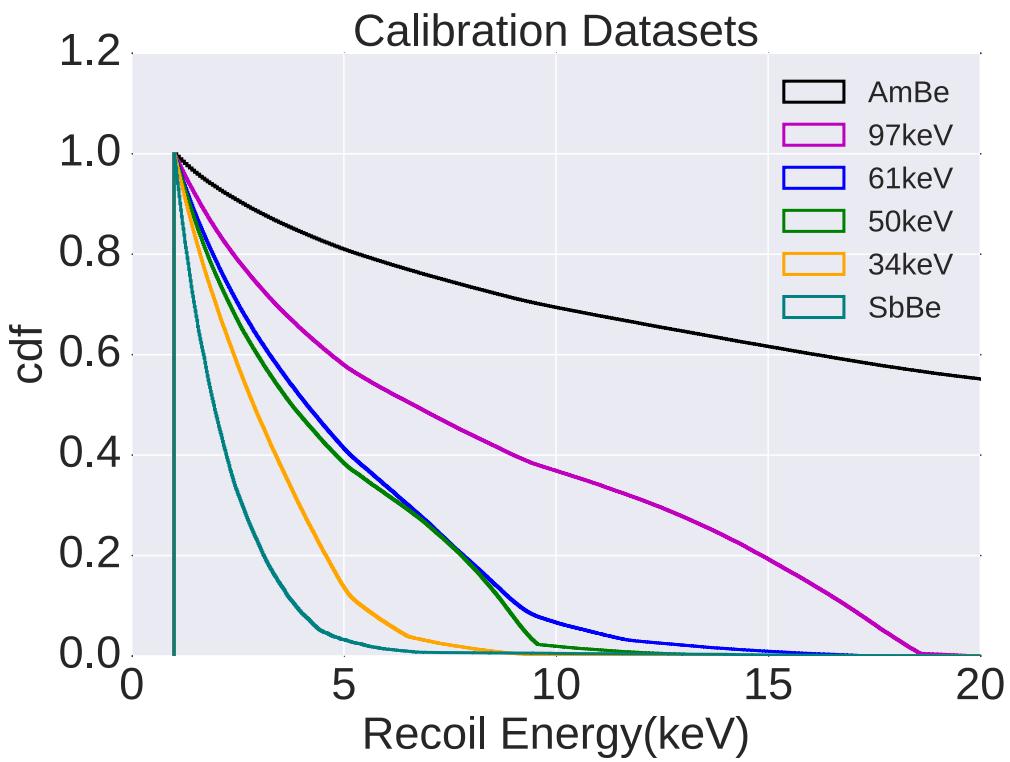
Tandem Van der Graaff at  
Université de Montréal  
Resonances in  $^{51}\text{V}(\text{p},\text{n})^{51}\text{Cr}$

$^{124}\text{SbBe}$  photoneutron source  
1,691keV gamma gives 24keV  
neutrons



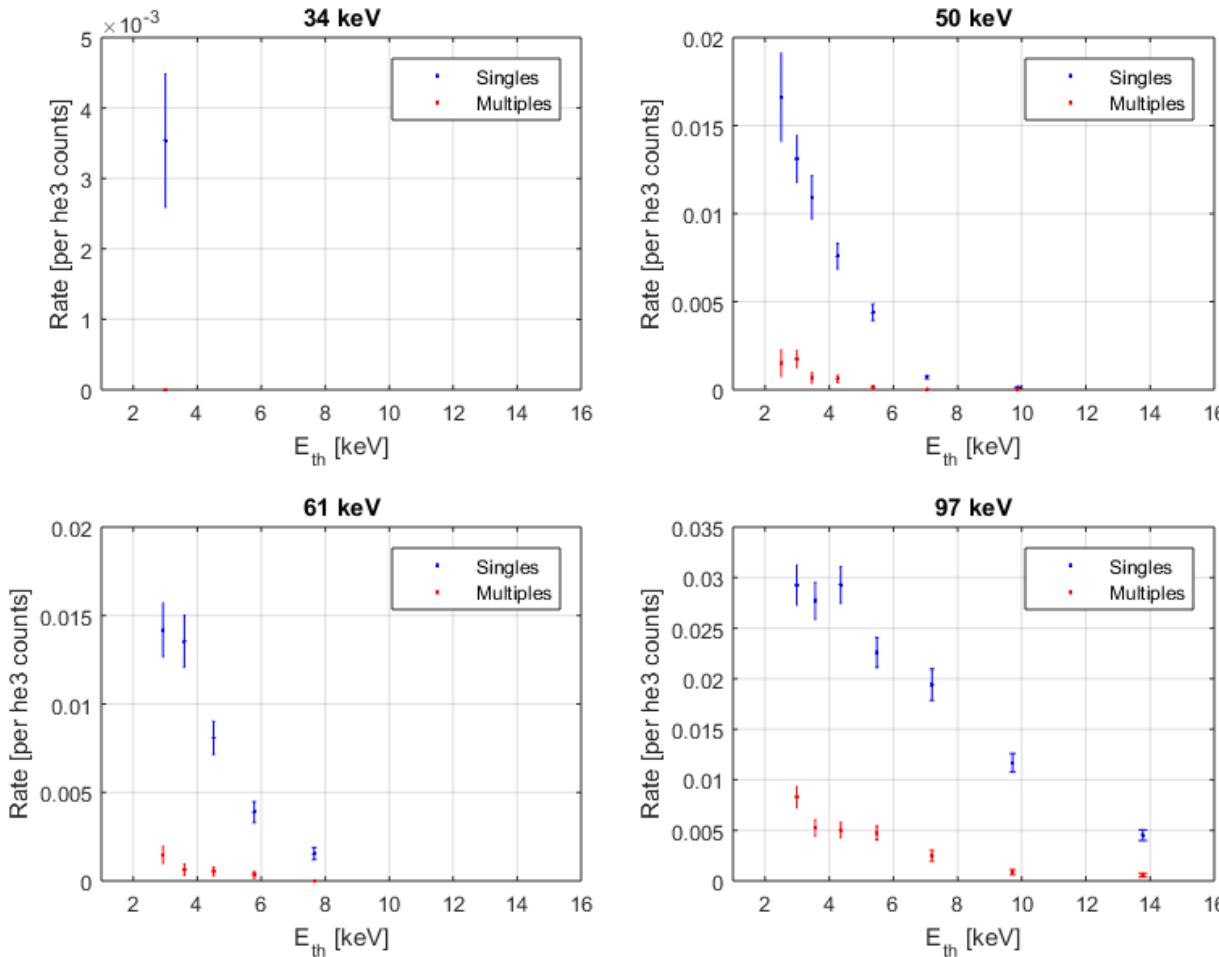
$^3\text{He}$  counter for neutron  
flux monitoring

# Low energy neutron calibrations



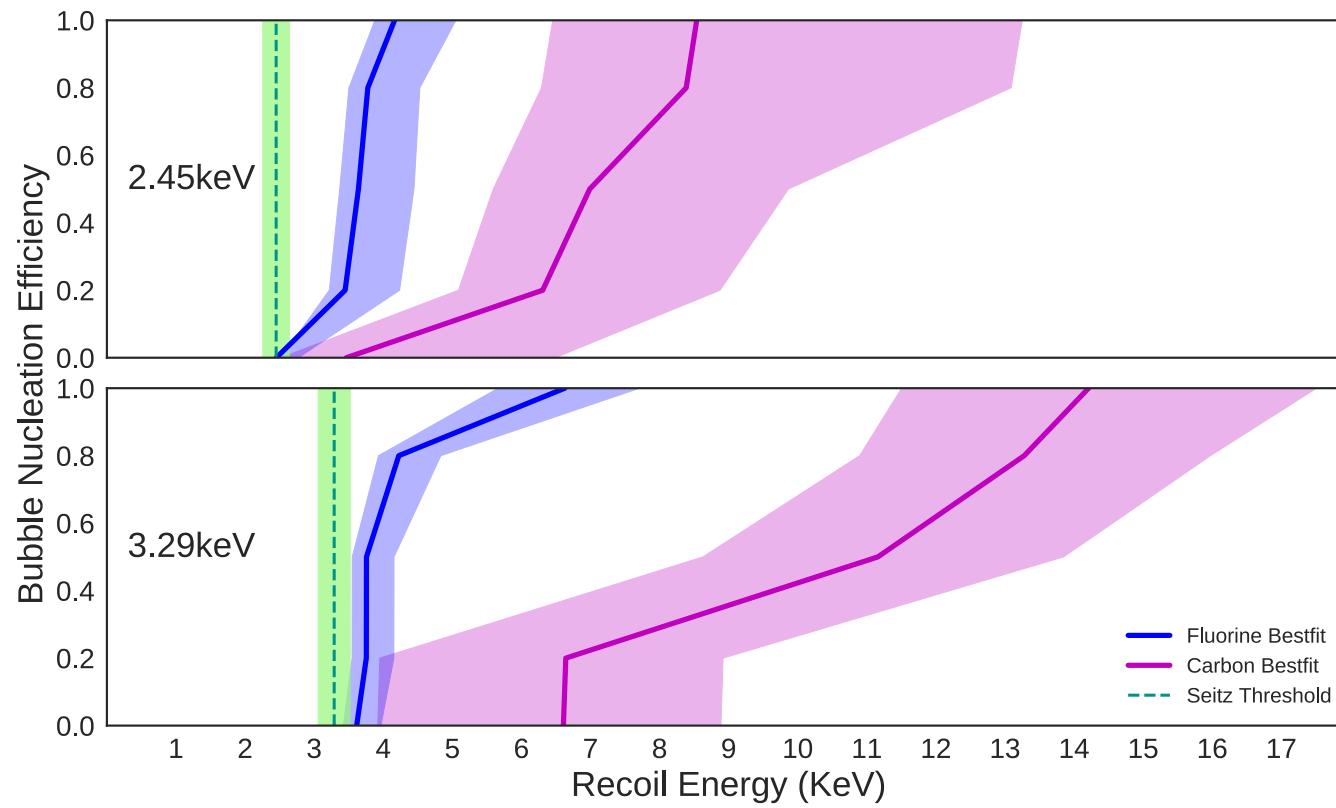
PICO-0.1

# Neutron beam data

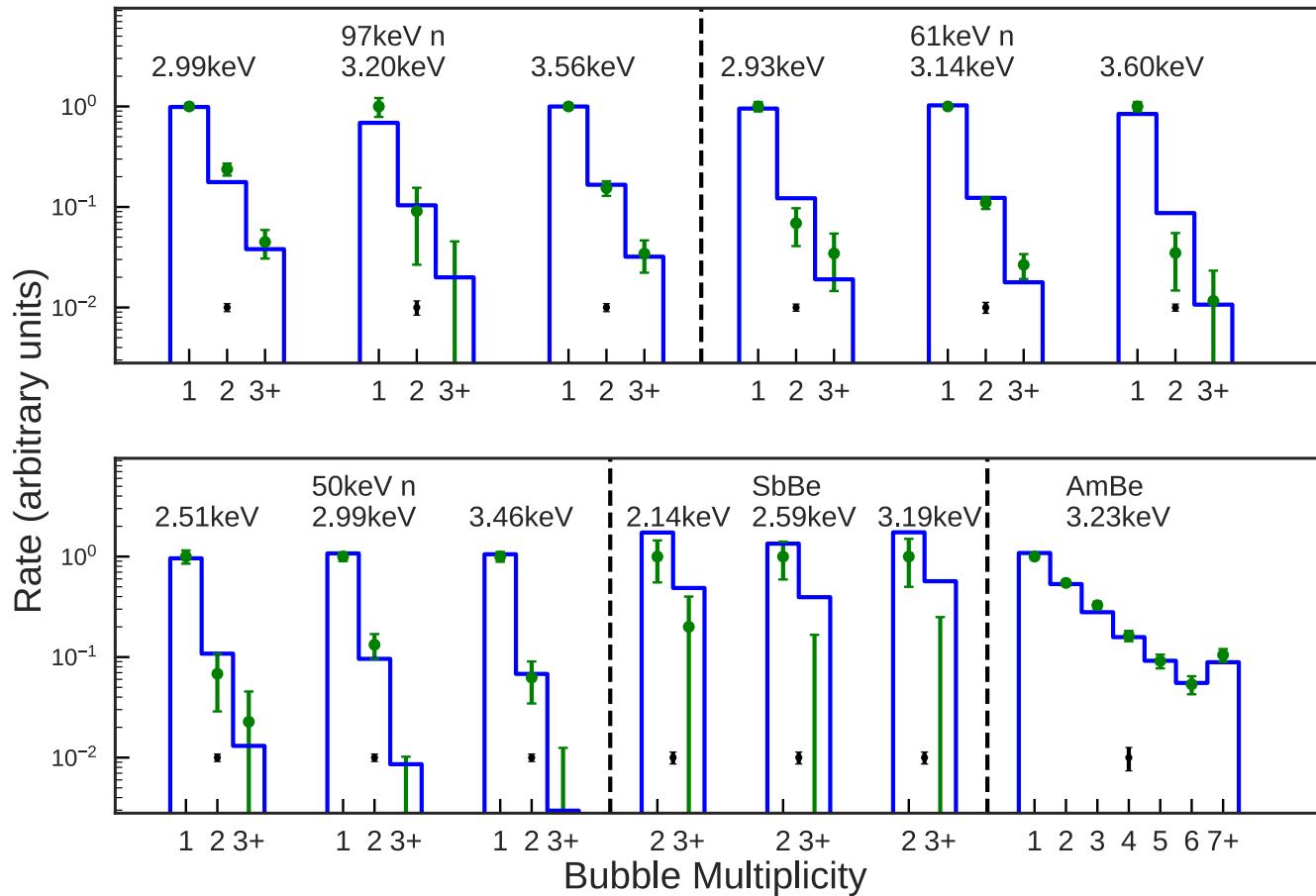


Fit all neutron data with systematic uncertainties for each dataset to piecewise efficiency curves with Markov Chain Monte Carlo.

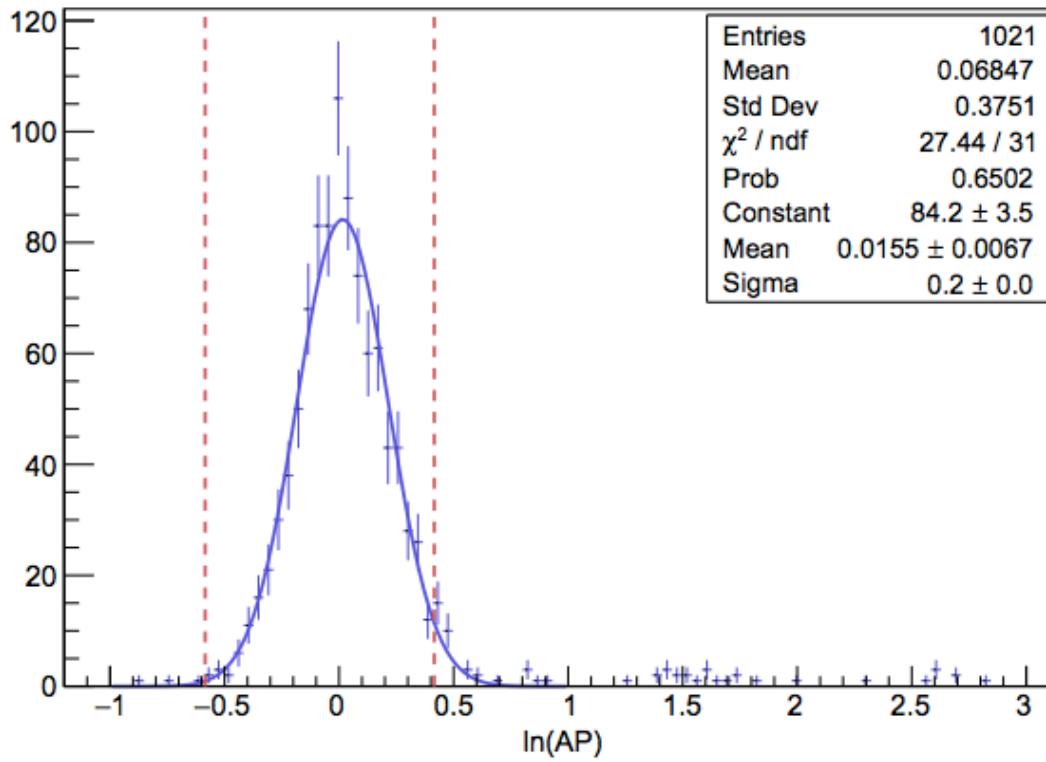
# Nucleation efficiency fitted curves



# Nucleation efficiency fit

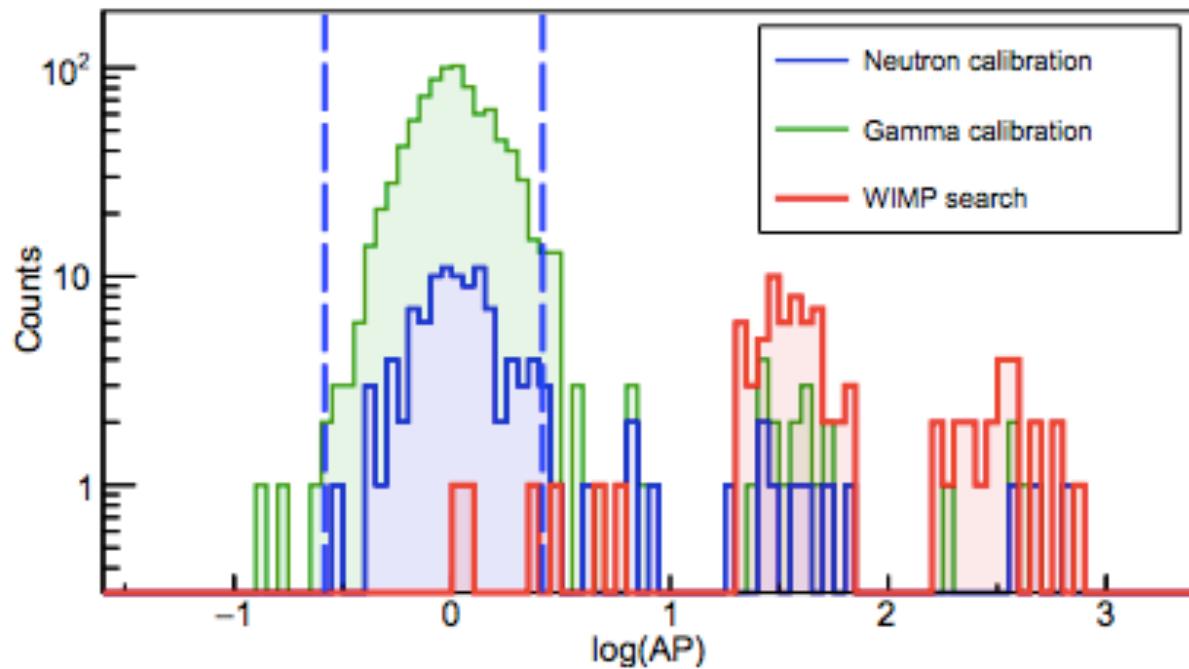


# Blind acoustics 2.45keV run



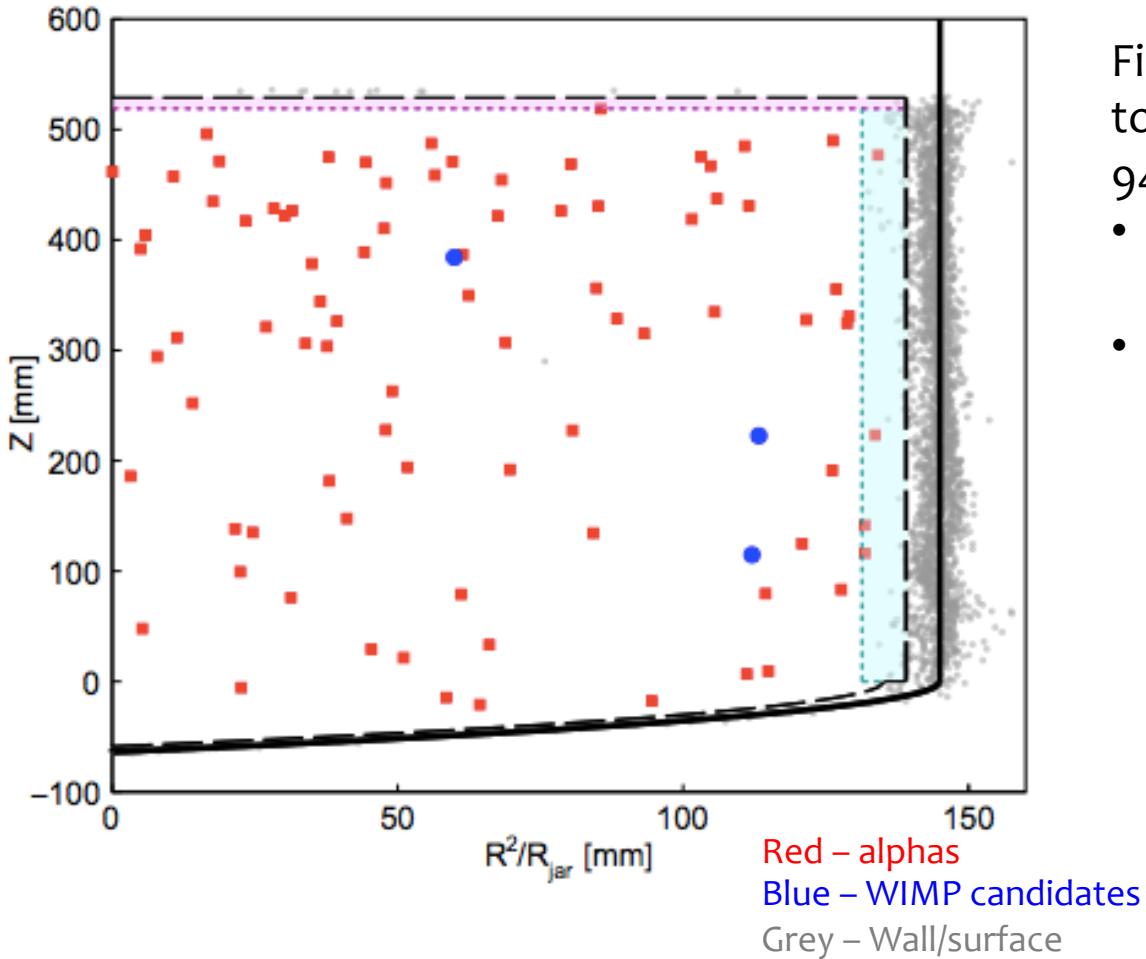
WIMP search cut defined based on combined neutron and gamma calibrations before unblinding WIMP search data

# Acoustic Parameter 2.45keV run



After unblinding: three WIMP candidates events.

# Spatial distribution 2.45keV run



Fiducial mass increased from to 45.7 to 48.8kg (from 88 to 94% of active mass).

- Improved optical reconstruction.
- Fiducial cut moved closer to walls with additional data quality cuts added.
  - Bubble track angle cut in cyan region.
  - Camera timing agreement cut in magenta region.

# Combined PICO-60 C<sub>3</sub>F<sub>8</sub> results

	2.45keV	3.29keV	Total
Exposure (kg-d)	1404.2	1167.0	2571.2
<b>WIMP candidates</b>	<b>3</b>	<b>0</b>	<b>3</b>
Multiple bubble events*	2	3	5

Background prediction			
Neutron background from multiples**	0.8	0.5	1.3
Neutron background from simulation	0.38	0.25	0.63
Gamma background	0.13	0.03	0.16
<sup>8</sup> B CEVNS background	0.10	0.06	0.16

Rough (2-sigma) agreement between observation and background simulation, but we choose not to make use of the background prediction in setting exclusion limits.

\*Multiples exposure is larger than WIMP search exposure due to fewer cuts.

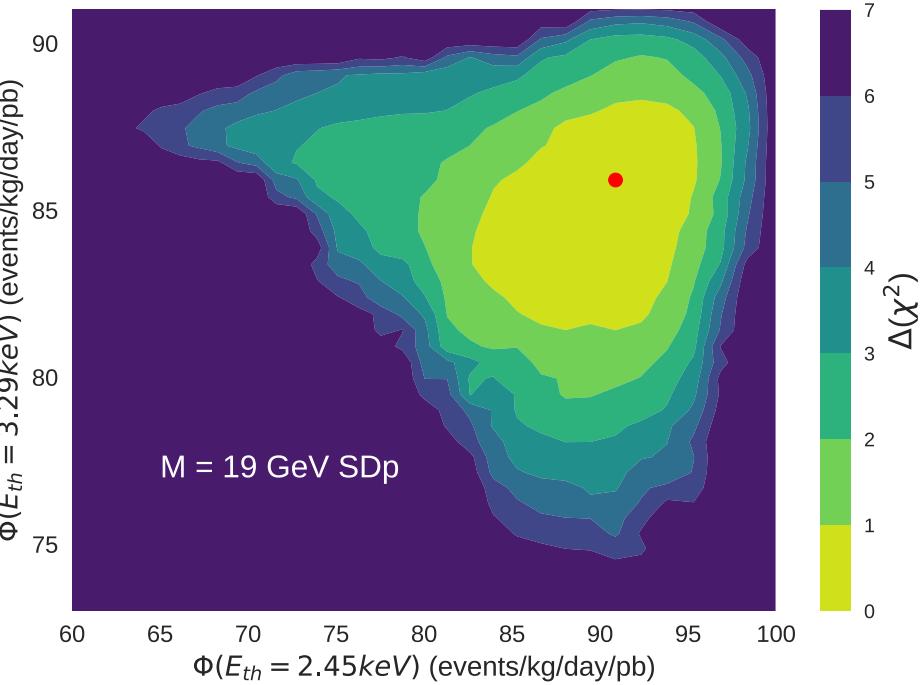
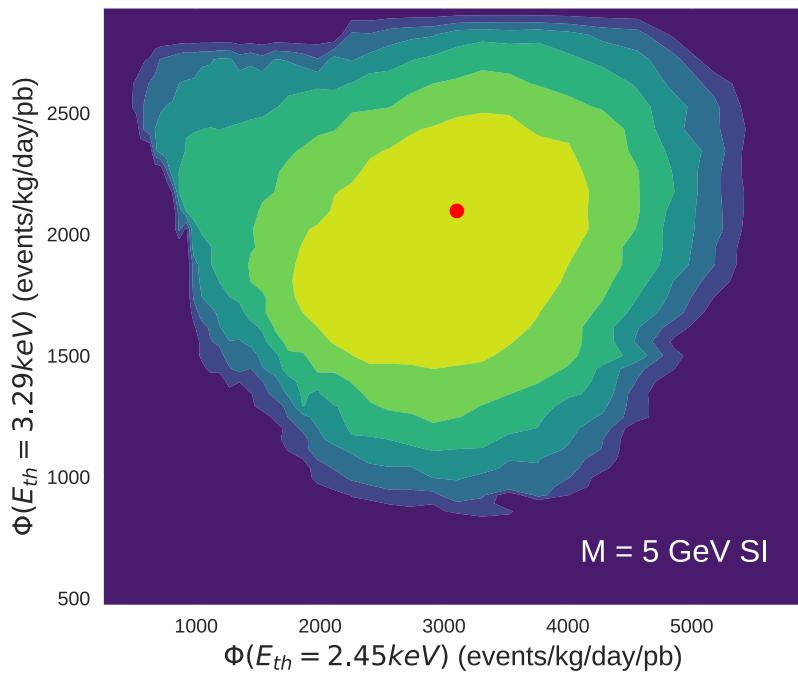
\*\*Expect 3.8 multiples per single bubble from neutron backgrounds.

# Combined analysis

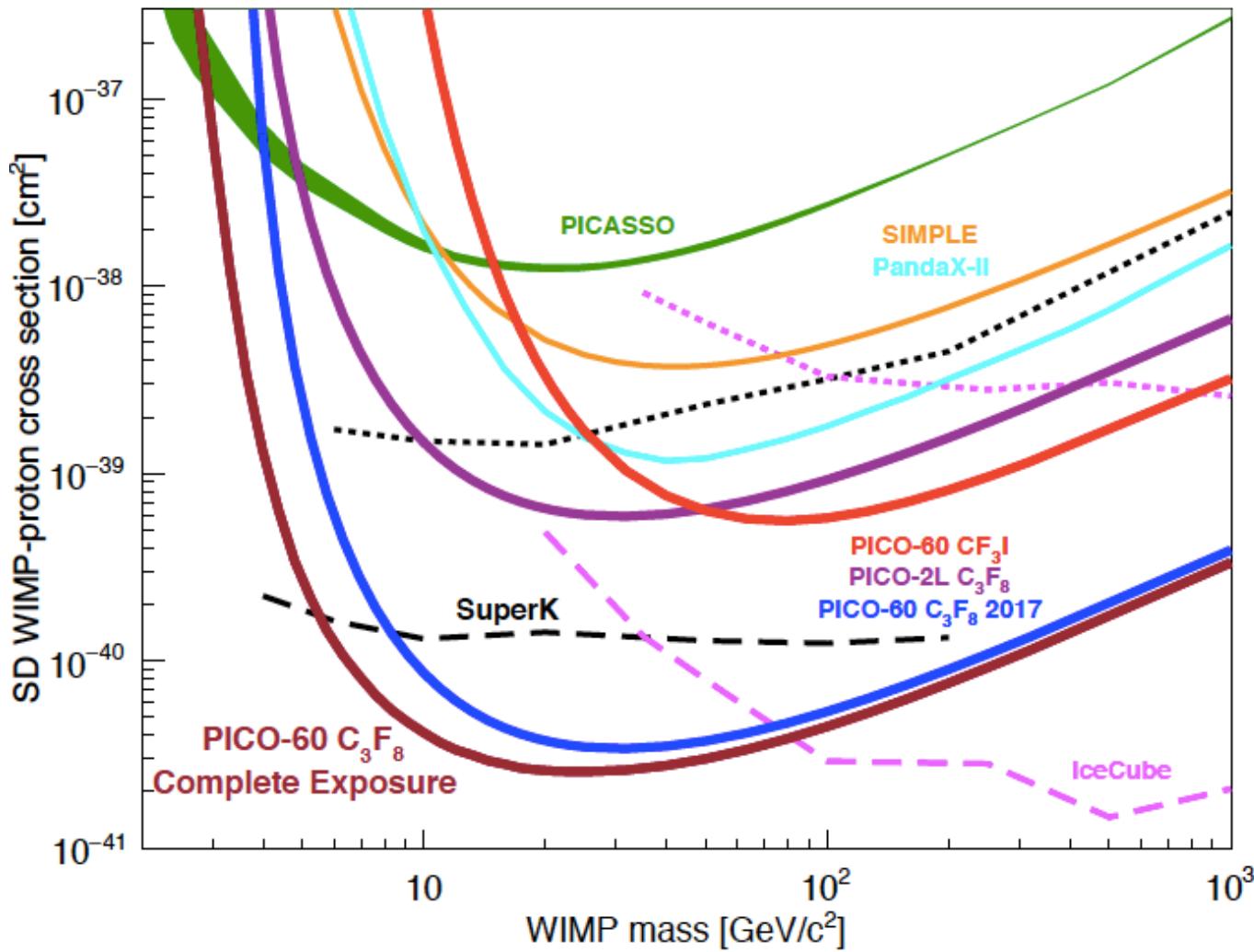
Use a 1D Profile Likelihood Ratio to calculate combined WIMP cross-section upper limits.

No constraint is placed on the background at each threshold (flat likelihood function).

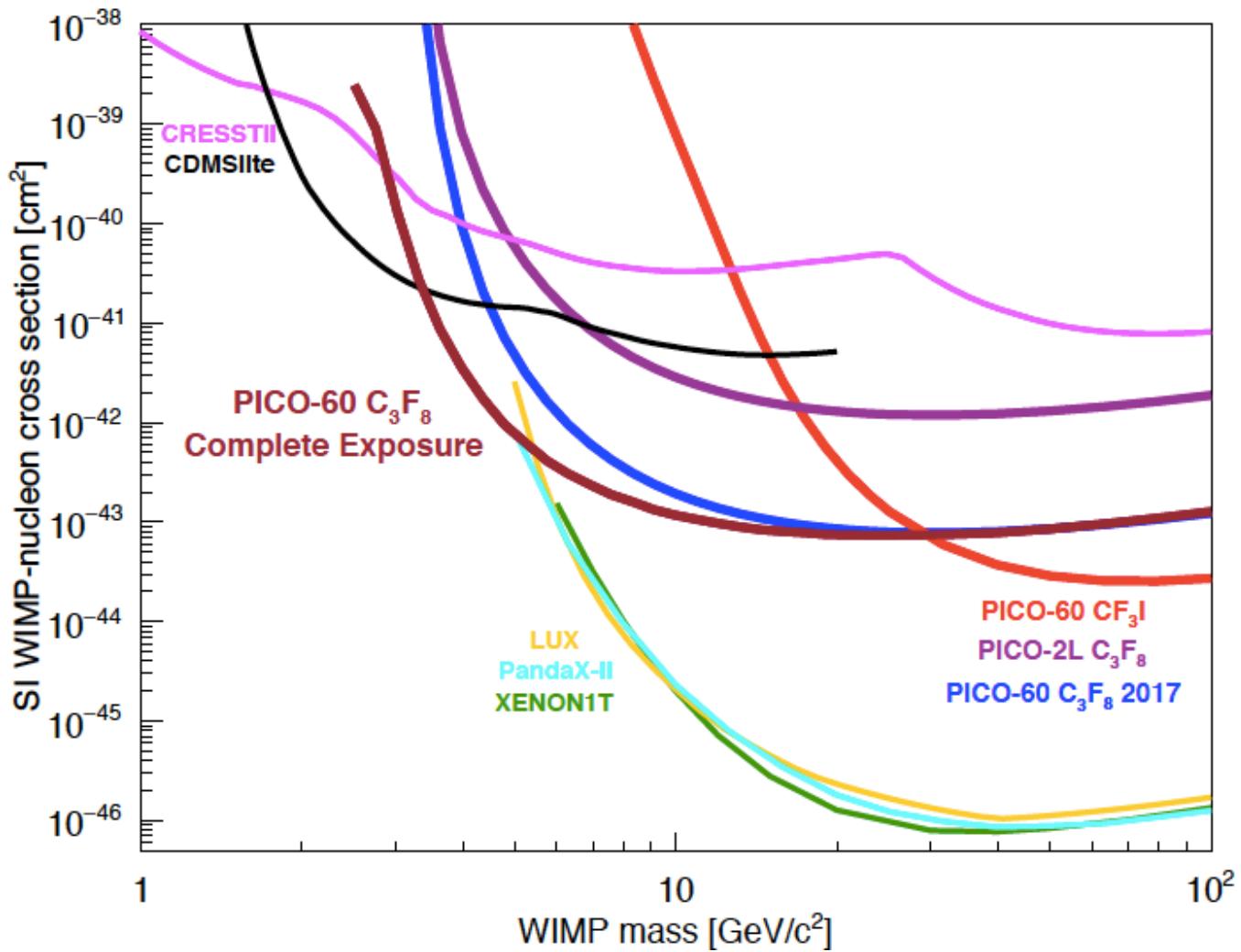
Nucleation efficiency uncertainty is converted into a 2D likelihood surface in WIMP detection efficiency  $\Phi$  in events per kg-day-pb.



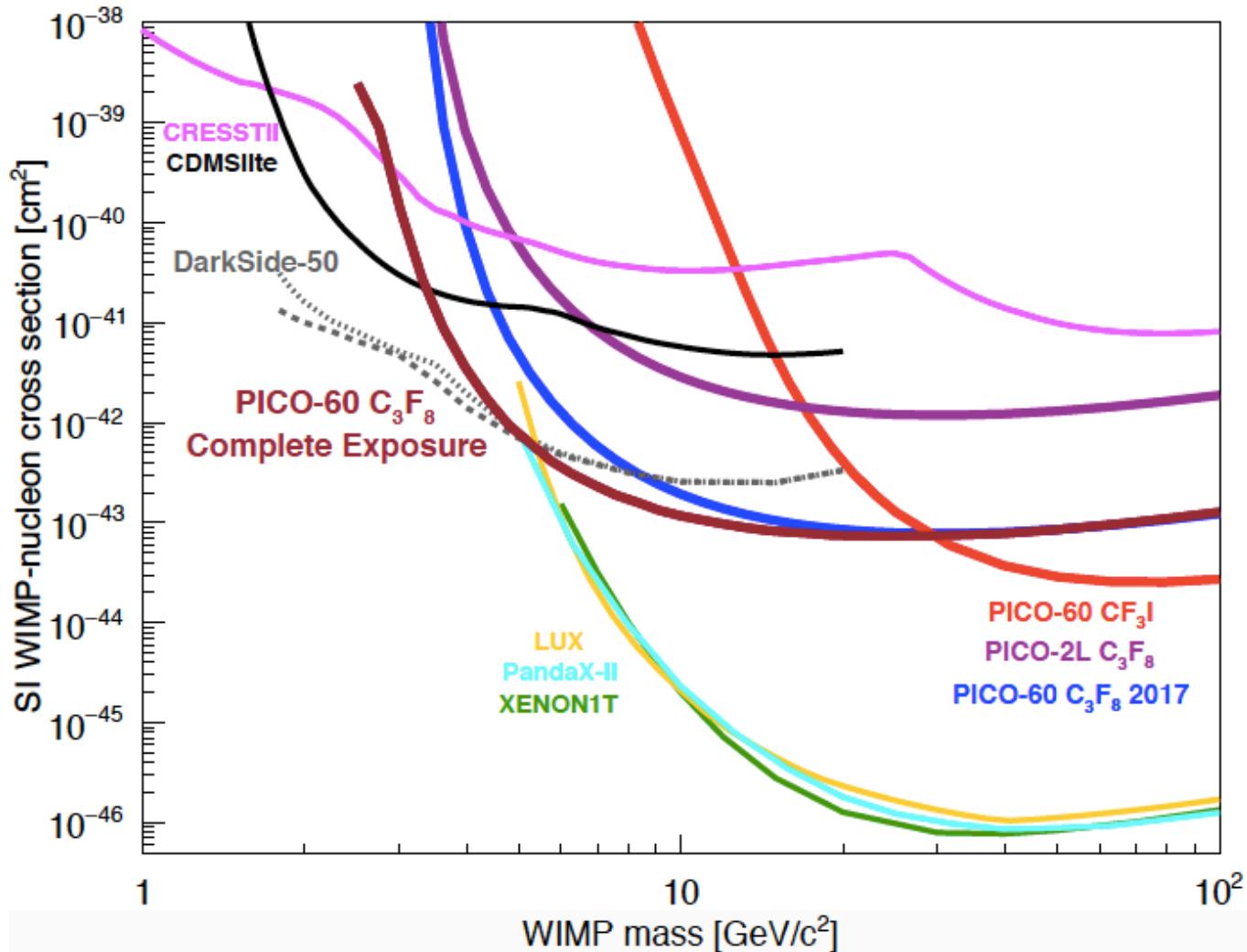
# SD limits



# SI limits



# SI limits



# Summary

- PICO-60 completed operations in June 2017 and is now decommissioned to make room for PICO-40L.
- Stable operation was achieved down to a threshold of 1.20keV.
- An additional WIMP search blind exposure was acquired at 2.45keV threshold.
- New low-energy neutron sources improve the nuclear recoil nucleation efficiency function.
- WIMP exclusion limits are extended down to lower masses than previously reported.