Búsqueda de materia oscura con los experimentos PICO y DEAP en SNOLAB

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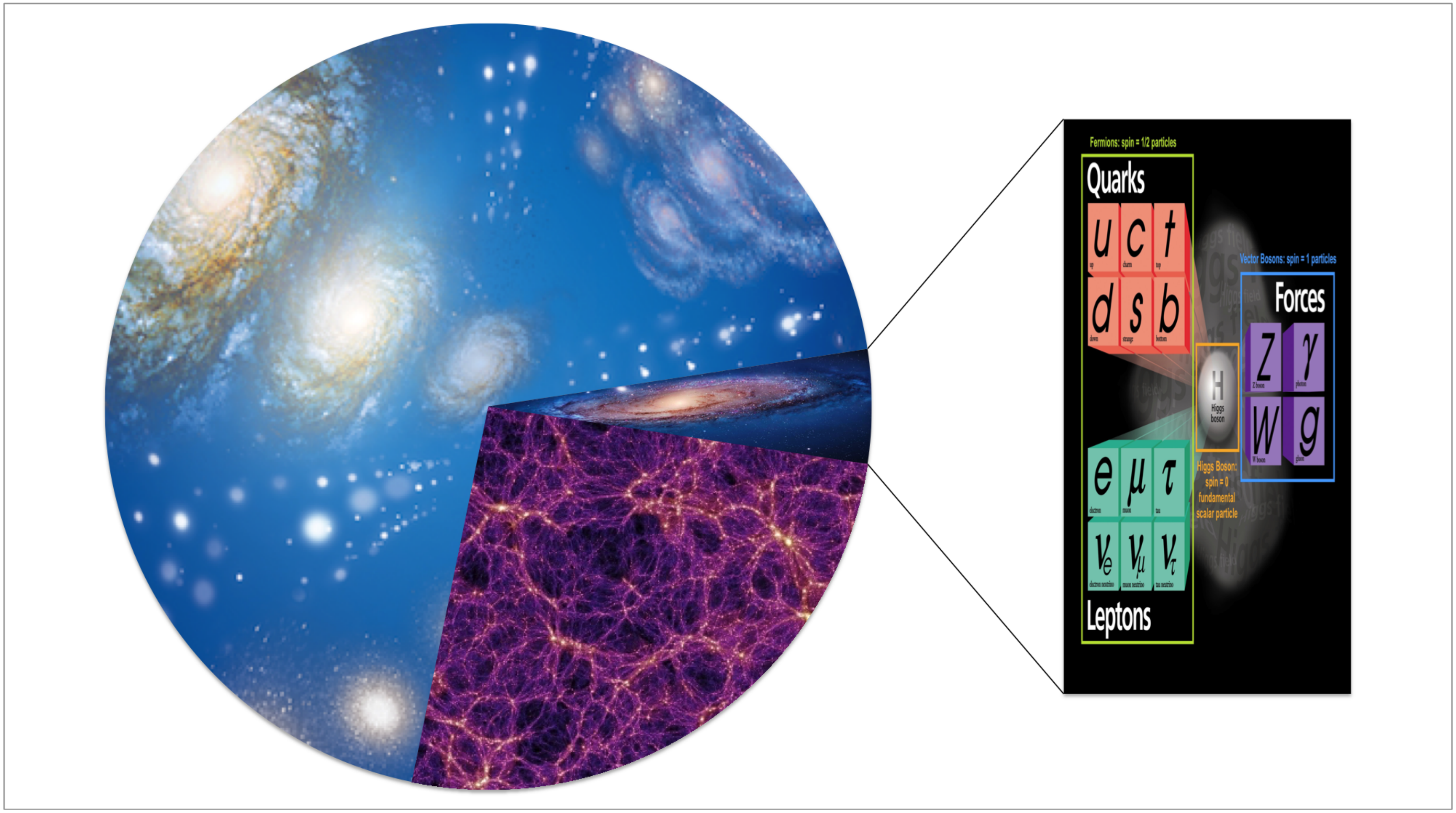
Outline

- **Dark Matter**
- **SNOLAB underground facility**
- **PICO bubble chambers**
- **Results from PICO-2L and PICO-60**
- **DEAP-3600 commissioning and current status**
- **Final remarks**

Pie chart of the Universe

What is the dark matter that makes up about one quarter of the contents of the universe?
(85% of the matter in the Universe)

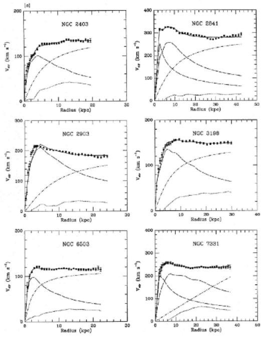


Our Universe today: ΛCDM
from an impressive number of observations

An impressive and overwhelming number of observations on all scales!

Rotation curves of galaxies

Scale ~ 10^{21-22}m

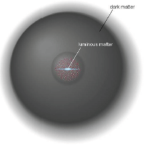


From Newtonian dynamics:

$$F = \frac{mv^2}{r} = G\frac{mM}{r^2}$$
$$v(r) \propto r^{-1/2}$$

For constant v:

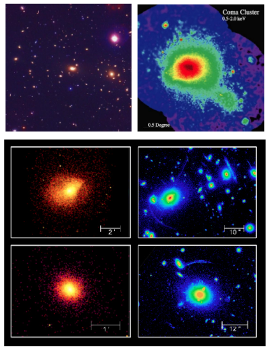
$$M(r) \propto r$$
$$\rho(r) \propto r^{-2}$$



Fritz Zwicky (1933)

Galaxy clusters: x rays

Scale ~ 10^{22}m



X rays radiated by the intracluster medium (hot gas)

temperature and distribution of gas
↓
average speed of gas molecules
↓
mass

Cluster masses obtained by x-ray measurements agree well with the galactic velocity method

Galaxy clusters: gravitational lensing

Scale ~ 10^{22}m

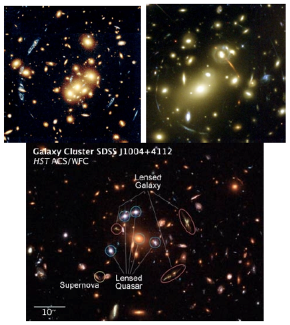
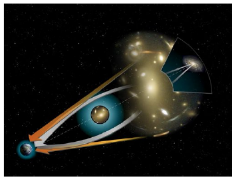


Image distortion by gravitational potential

strong/weak

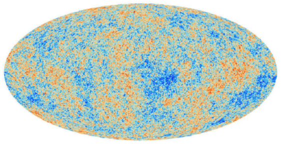
sensitive to total mass

Rotational curves and x-ray measurements agree with gravitational lensing



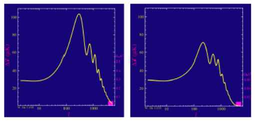
Cosmic Microwave Background

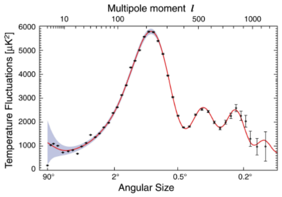
CMB angular power spectrum depends on several parameters, including Ω_b, Ω_c, Ω_Λ



$\Omega_{tot} = 1.080^{+0.093}_{-0.071}$

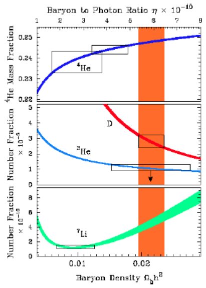
- $\Omega_b = 0.0449 \pm 0.0028$ (0.049)
- $\Omega_c = 0.222 \pm 0.026$ (0.268)
- $\Omega_\Lambda = 0.734 \pm 0.029$ (0.683)

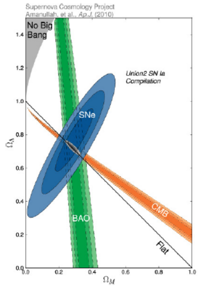




Precision cosmology

Abundance of primordial elements combined with predictions from Big Bang Nucleosynthesis



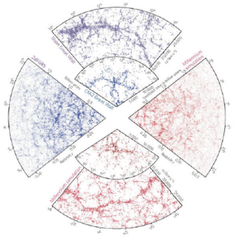


Λ_{CDM} (Lambda Cold Dark Matter)
Standard model of cosmology

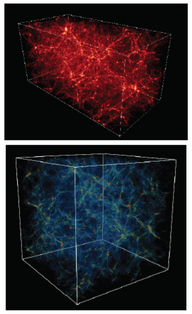
Structure formation

Simulations of structure formation

Structure growth depends on the amount and type of dark matter

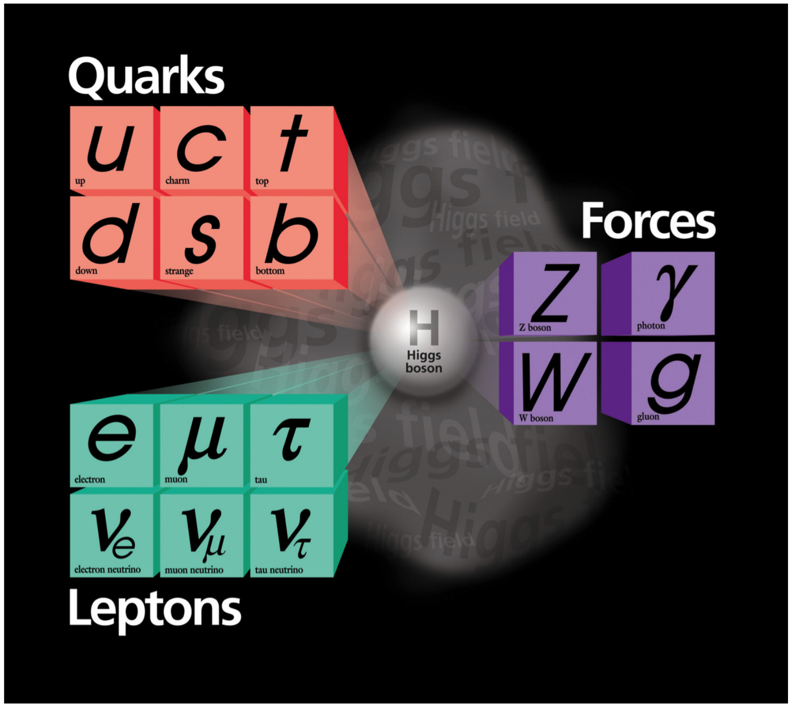


All viable models are dominated by cold dark matter



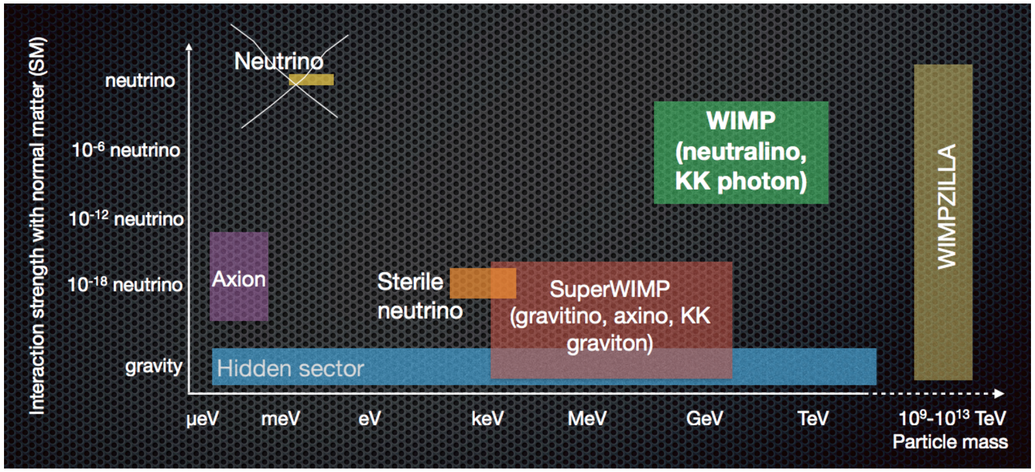
What do we know about dark matter?

- Gravitationally interacting
- Stable or long-lived
- Cold or warm
  not hot (relativistic)
- Non-baryonic
- Electrically neutral
- No Color
- Feebly interacting



Physics beyond
the Standard Model

Mass and cross section range
span many orders of magnitude



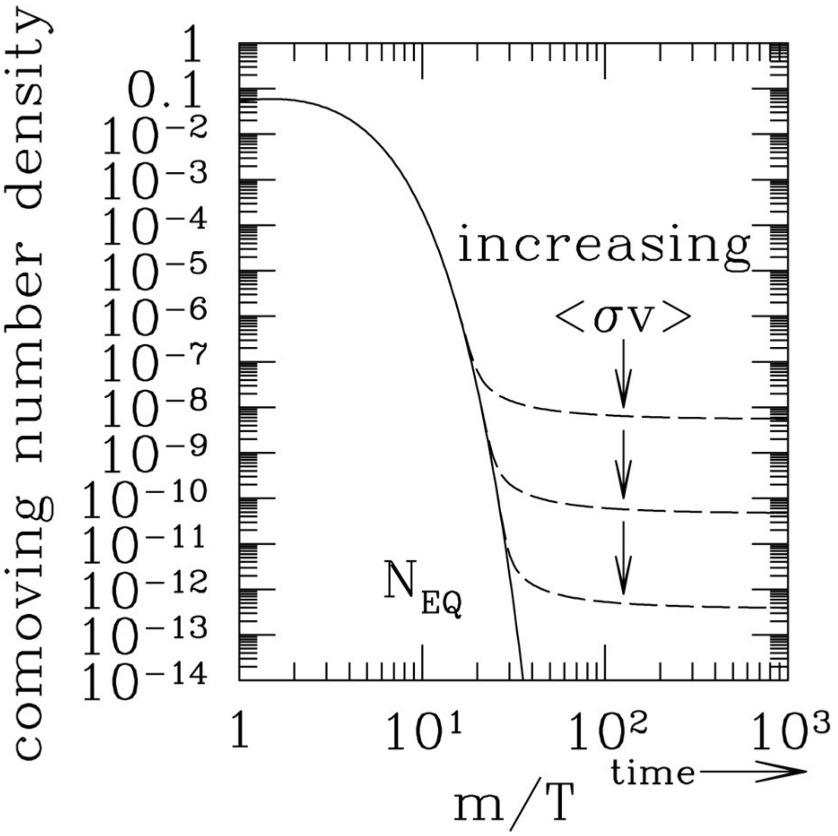
WIMP

- Most discussed candidate:
  Weakly Interacting
  Massive Particle

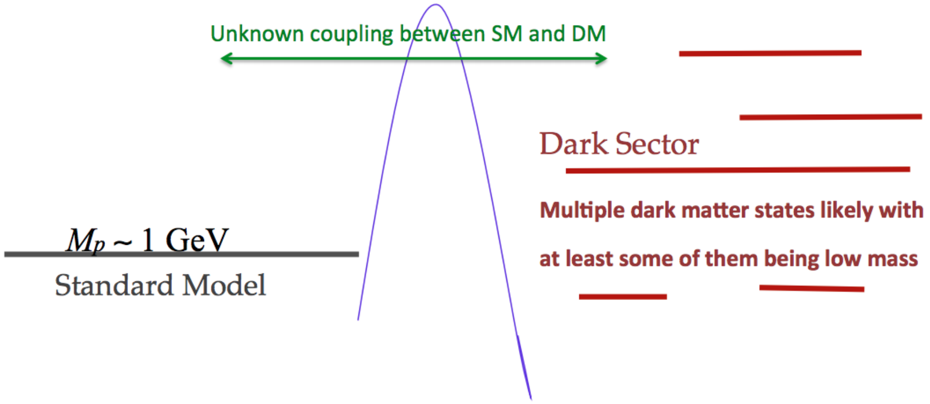
- Produced during Big Bang, in thermal equilibrium in the early Universe

- Decouples from ordinary matter as the Universe expands and cools

- Still around today with densities of about a few per liter



Dark sector could be
as complicated as the SM
Searches not limited by
expectations from SUSY models


Unknown coupling between SM and DM

$M_p \sim 1$ GeV

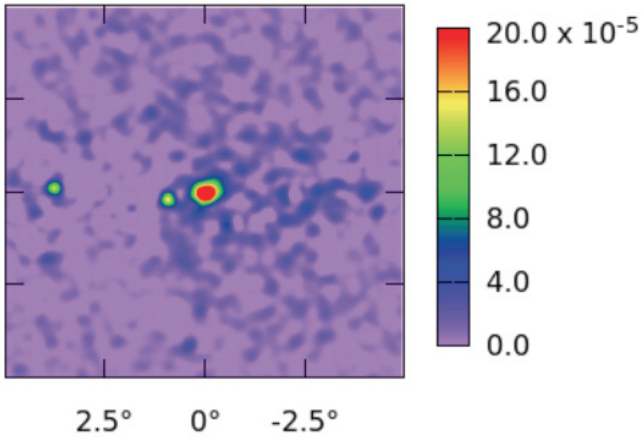
Standard Model

Dark Sector

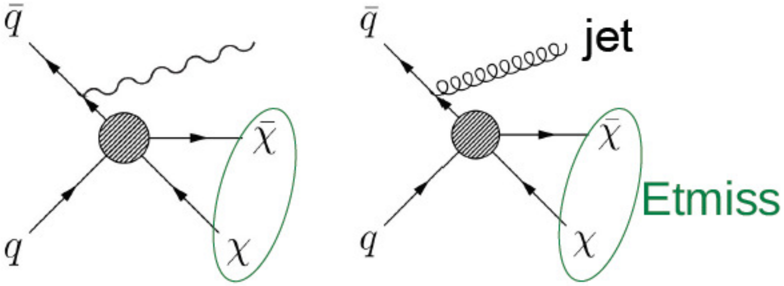
Multiple dark matter states likely with at least some of them being low mass

Detection methods

- **Astrophysics / Cosmology:**
  measurement of gravitational effects
- **Indirect detection:**
  from annihilation or decay (AMS, HAWC)



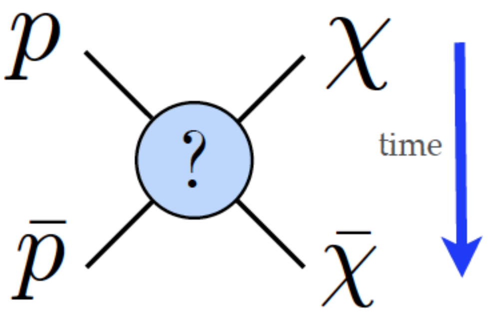
- **Accelerator-based creation and measurement (LHC)**



- **Direct detection: WIMP scattering**

Direct detection

WIMPs can scatter elastically with nuclei and the recoil can be detected



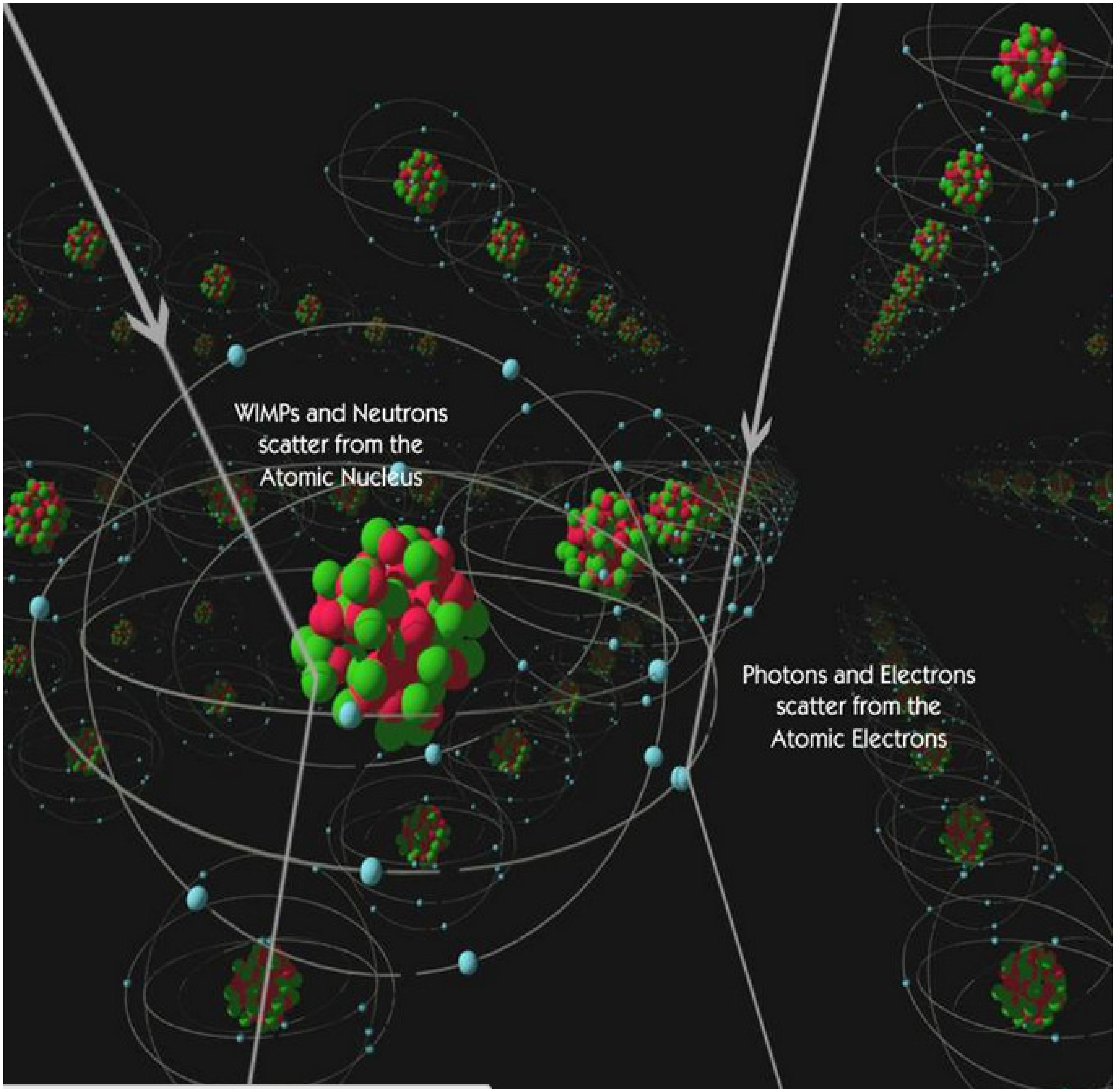
- **Calculate rate based on assumptions about the dark matter distribution and interaction**
- **Historically two interactions are considered (by DM experimentalists)**
  - **Spin independent (SI) - couples to all nucleons (enhancement for large nuclei)**
  - **Spin dependent (SD) - couples to the spin of the nucleus (unpaired spin of one nucleon)**

Spin-independent

Spin-dependent

$$\sigma_0 = \underbrace{\frac{4\mu^2}{\pi}\left[f_p N_p + f_n N_n\right]^2}_{\text{Spin-independent}} + \underbrace{\frac{32 G_F^2 \mu^2}{\pi}\frac{J+1}{J}\left[a_p\langle S_p\rangle + a_n\langle S_n\rangle\right]^2}_{\text{Spin-dependent}}$$

Direct detection



Rate calculation

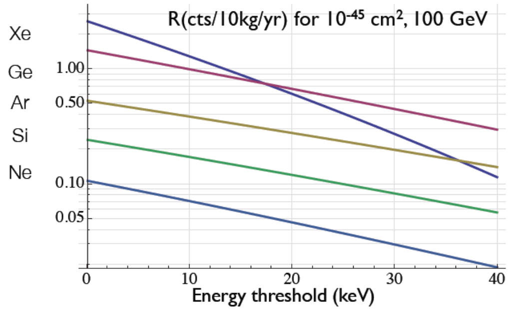
The differential cross section (for spin-independent interactions) in events/kg/keV mass per unit recoil energy is:

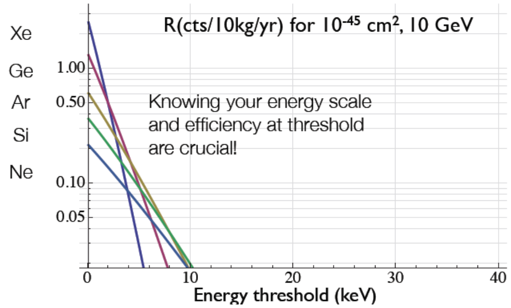
$$\frac{dR}{dQ} = \frac{\rho_0}{m_\chi} \times \frac{\sigma_0 A^2}{2\mu_p^2} \times F^2(Q) \times \int_{v_m} \frac{f(v)}{v} dv \tag{1}$$

- Dark matter density component, from local and galactic observations with historically a factor of 2 uncertainty
- The unknown particle physics component σ_0 (where μ_p is the reduced mass of the proton)
- The nuclear part, approximately given by $F^2(Q) = e^{-Q/Q_0}$ (where $Q_0 = \frac{80}{A^{5/3}}$ MeV)
- The velocity distribution of dark matter in the galaxy of order 30% uncertainty (not-statistical) and $v_m = \sqrt{Q m_N / 2 m_r^2}$

The recipe for direct detection of dark matter

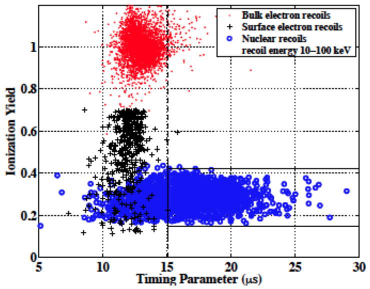
- **Detect tiny energy deposits, energy of recoils is tens of keV**
  $\frac{1}{2}m_N v_N^2 = \frac{1}{2}(100GeV)(10^{-6}) = 50keV$

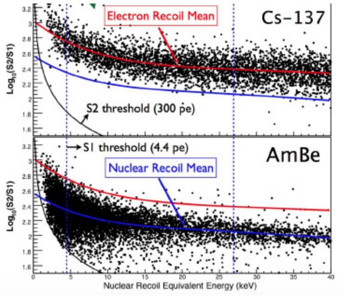


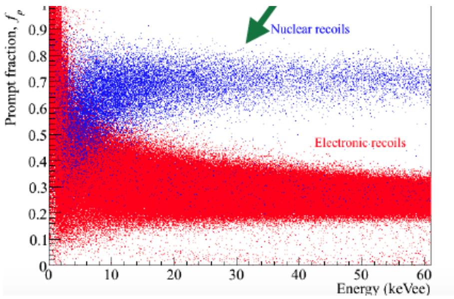


Knowing your energy scale and efficiency at threshold are crucial!

- **Background suppression:**
  - Deep sites to reduce cosmic ray flux
  - Passive/active shielding
  - Careful choice and preparation of material
- **Background discrimination (electronic recoils vs nuclear recoils)**







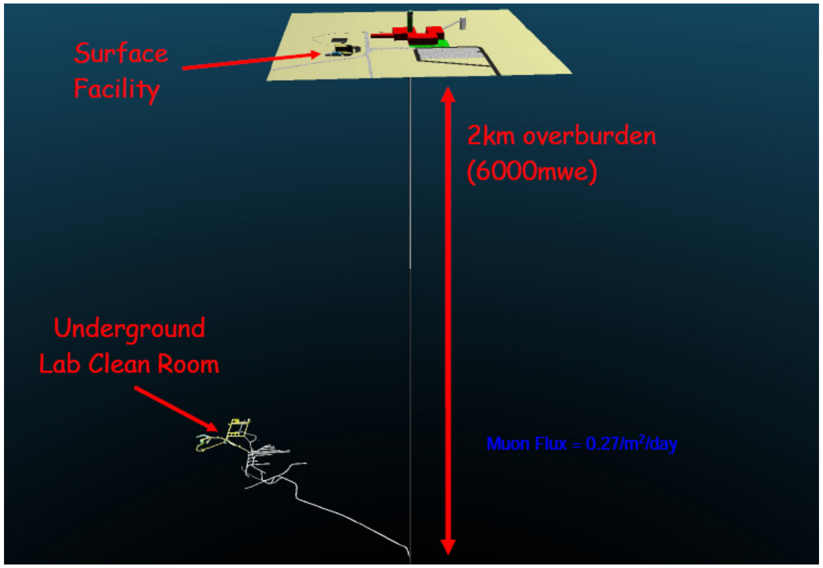
- **Large target mass, scalability to ton-scale targets**

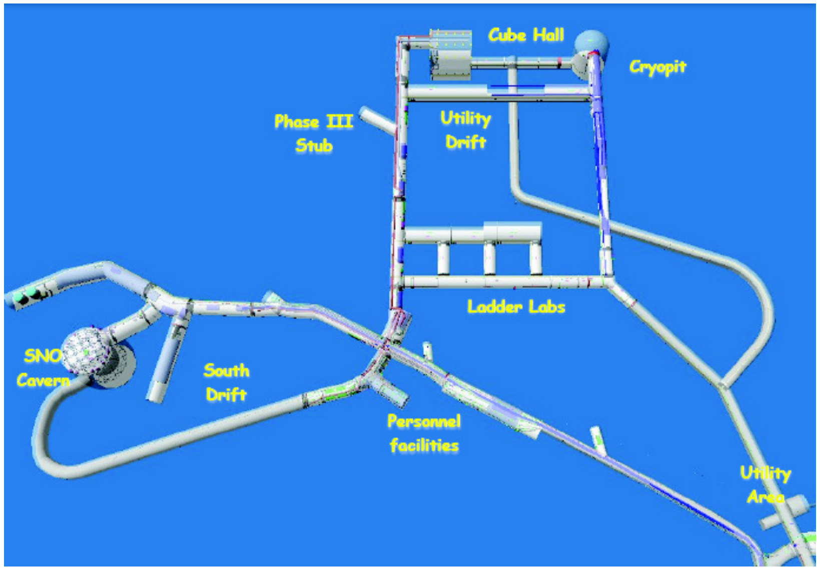
Sudbury Neutrino Observatory Laboratory

SNOLAB

deepest and cleanest large-space international facility in the world

- 2 km underground near Sudbury, Ontario
- ultra-low radioactivity background environment Class 2000
- Physics programme focused on neutrino physics and direct dark matter searches





PICO: search for dark matter with superheated liquids

PICO Collaboration

PICO

SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

I. Lawson

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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

NORTHWESTERN UNIVERSITY

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

SAHA INSTITUTE OF NUCLEAR PHYSICS
CALCUTTA

P. Bhattacharjee.
M. Das, S. Seth

CZECH TECHNICAL UNIVERSITY IN PRAGUE

R. Filgas, I. Stekl

KICP
Kavli Institute for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO

J.I. Collar,
A.E. Robinson

INDIANA UNIVERSITY SOUTH BEND

E. Behnke, H. Borsodi, O. Harris,
A. LeClair, I. Levine, E. Mann,
J. Wells

Drexel UNIVERSITY

R. Neilson

Université de Montréal

F. Debris, M. Fines-Neuschild,
F. Girard, C.M. Jackson,
M. Lafrenière, M. Laurin,
J.-P. Martin, A. Plante,
N. Starinski, V. Zacek

Fermilab

S.J. Brice, D. Broemmelsiek,
P.S. Cooper, M. Crisler,
W.H. Lippincott, E. Ramberg,
M.K. Ruschman, A. Sonnenschein

VirginiaTech

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IF Instituto de Física

E. Vázquez-Jáuregui

Queen's UNIVERSITY

C. Amole, M. Besnier,
G. Caria, G. Giroux,
A. Kamaha, A. Noble

Pacific Northwest NATIONAL LABORATORY

D.M. Asner, J. Hall

UNIVERSITY OF ALBERTA

S. Fallows, C. Krauss,
P. Mitra

UNIVERSITY OF TORONTO

K. Clark

LaurentianUniversity
UniversitéLaurentienne

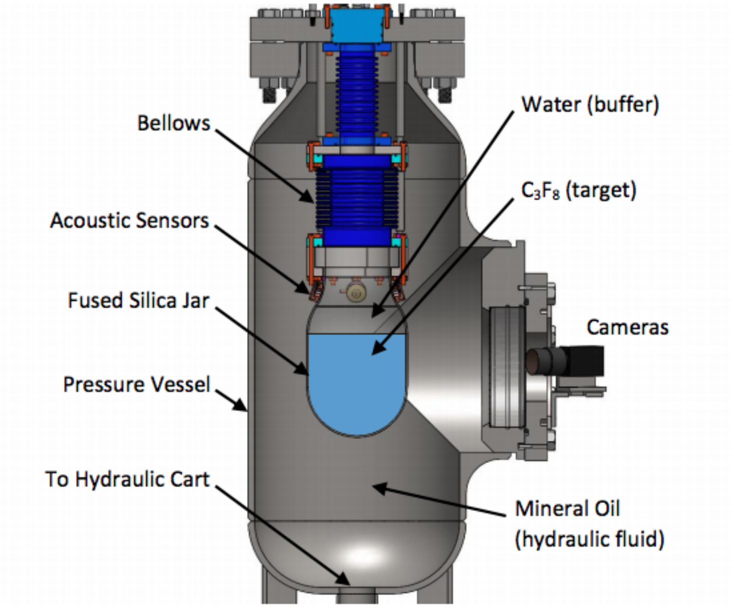
J. Farine, A. Le Blanc,
R. Podviyanuk, O. Scallon,
U. Wichoski

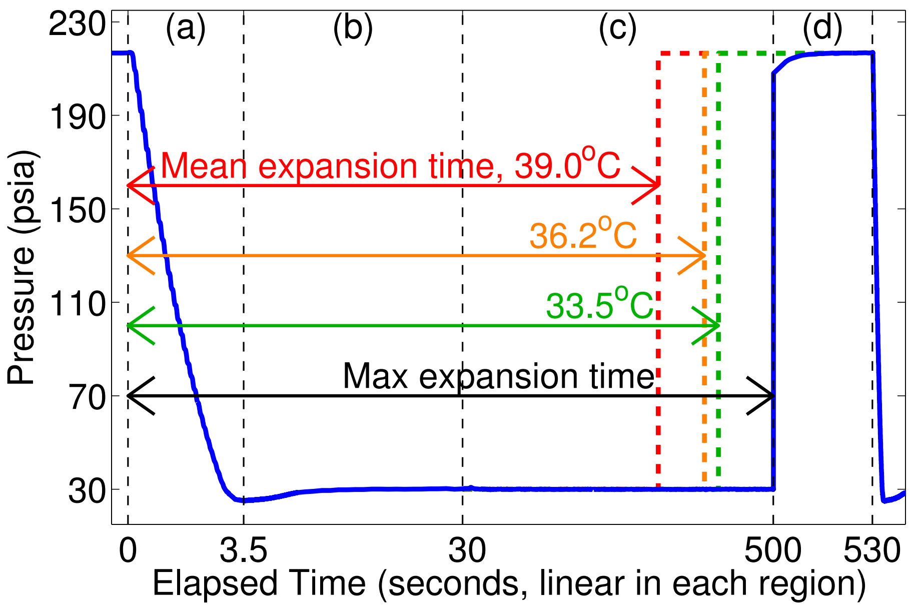
PICO bubble chambers

- **Target material: superheated CF_3I, C_3F_8, C_4F_10 spin-dependent/independent**

  Could make a dark matter bubble chamber with any liquid!

- **Particles interacting evaporate a small amount of material: bubble nucleation**
- **Cameras record bubbles**
- **Piezo sensors detect sound**
- **Recompression after each event**



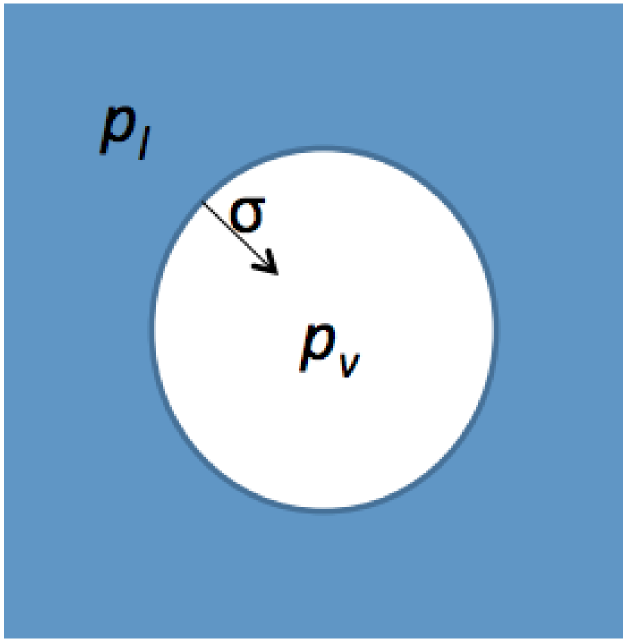


PICO bubble chambers

- In a superheated fluid, energy deposition greater than E_{th} in a radius less than r_c will result in a bubble large enough to overcome surface tension (Seitz "Hot-Spike" Model)
- Low E or dE/dx result in smaller bubbles that immediately collapse
- Classical Thermodynamics:

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

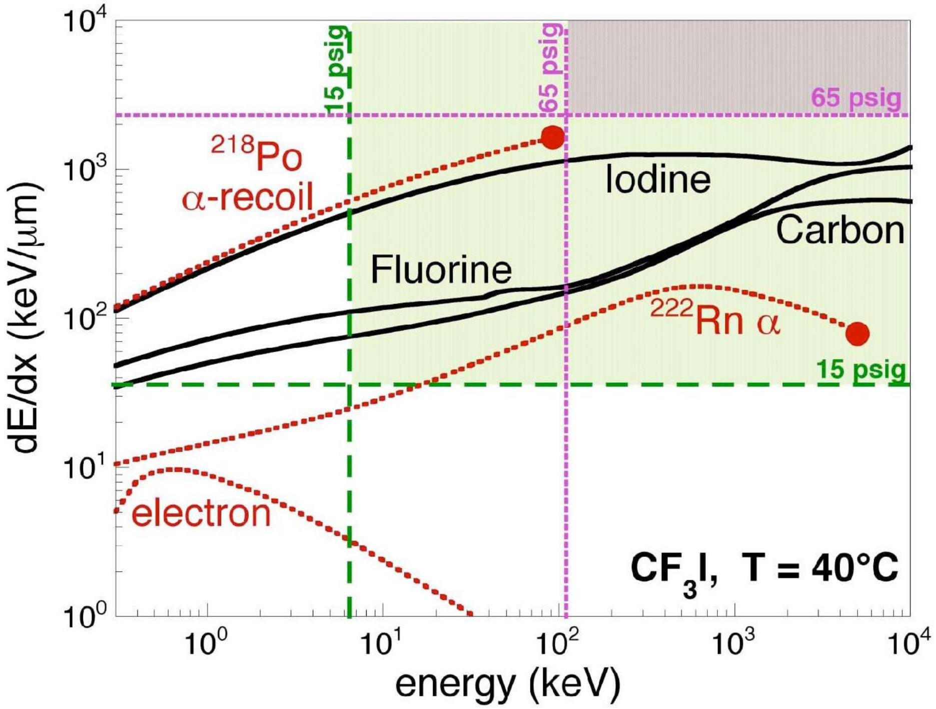
$$E_{th} = 4\pi \underbrace{r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right)}_{\text{Surface energy}} + \underbrace{\frac{4}{3}\pi r_c^3 \rho_v h}_{\text{Latent heat}}$$



Bubble nucleation

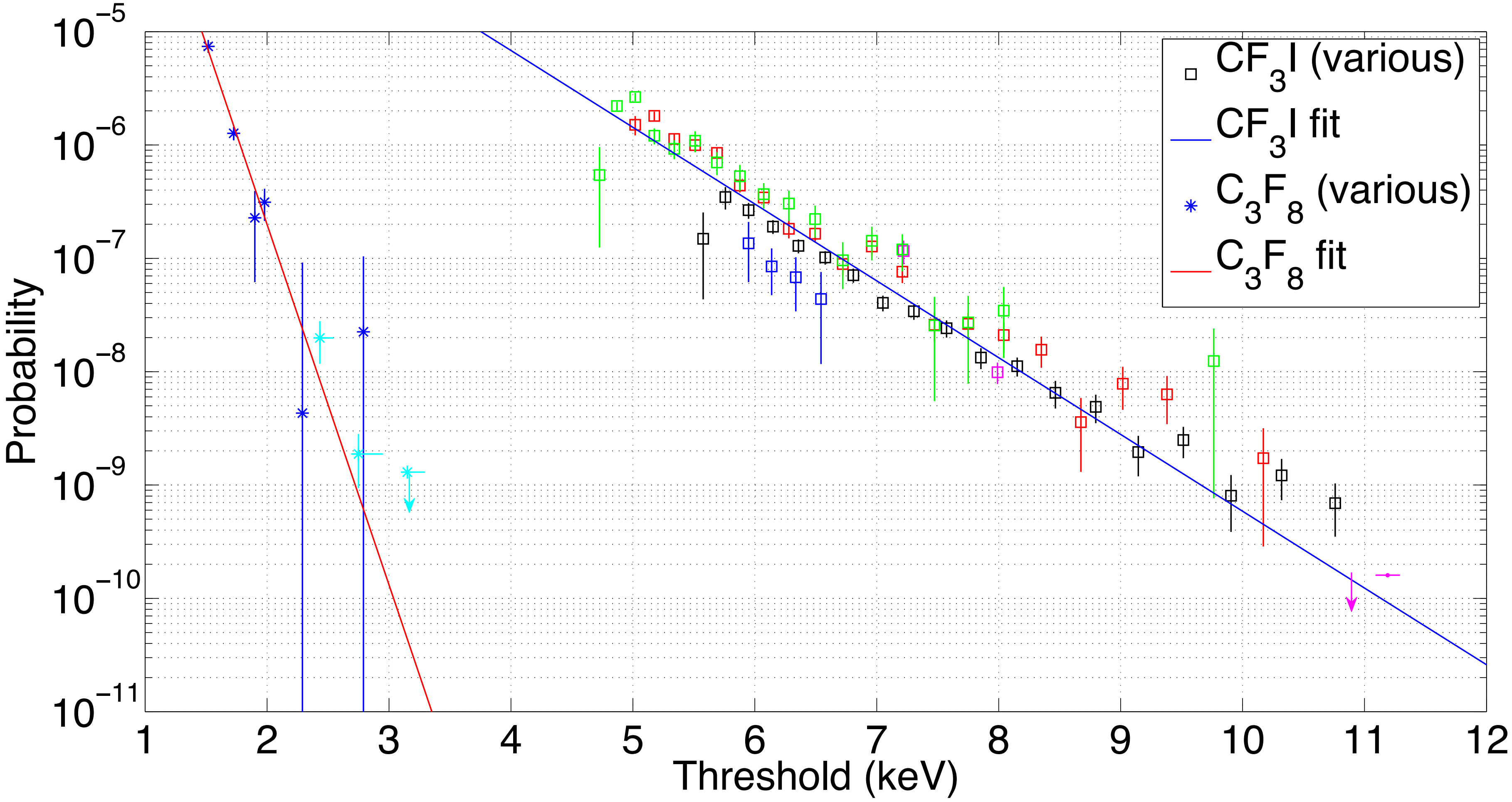
Dependence of bubble nucleation on the total deposited energy and dE/dx

- Region of bubble nucleation at 15 psig
- Backgrounds:
  electrons, ^{218}Po, ^{222}Rn
- Signal processes of
  Iodine, Fluorine and Carbon nuclear recoils



insensitive to
electrons and gammas

Backgrounds in PICO: γ rejection



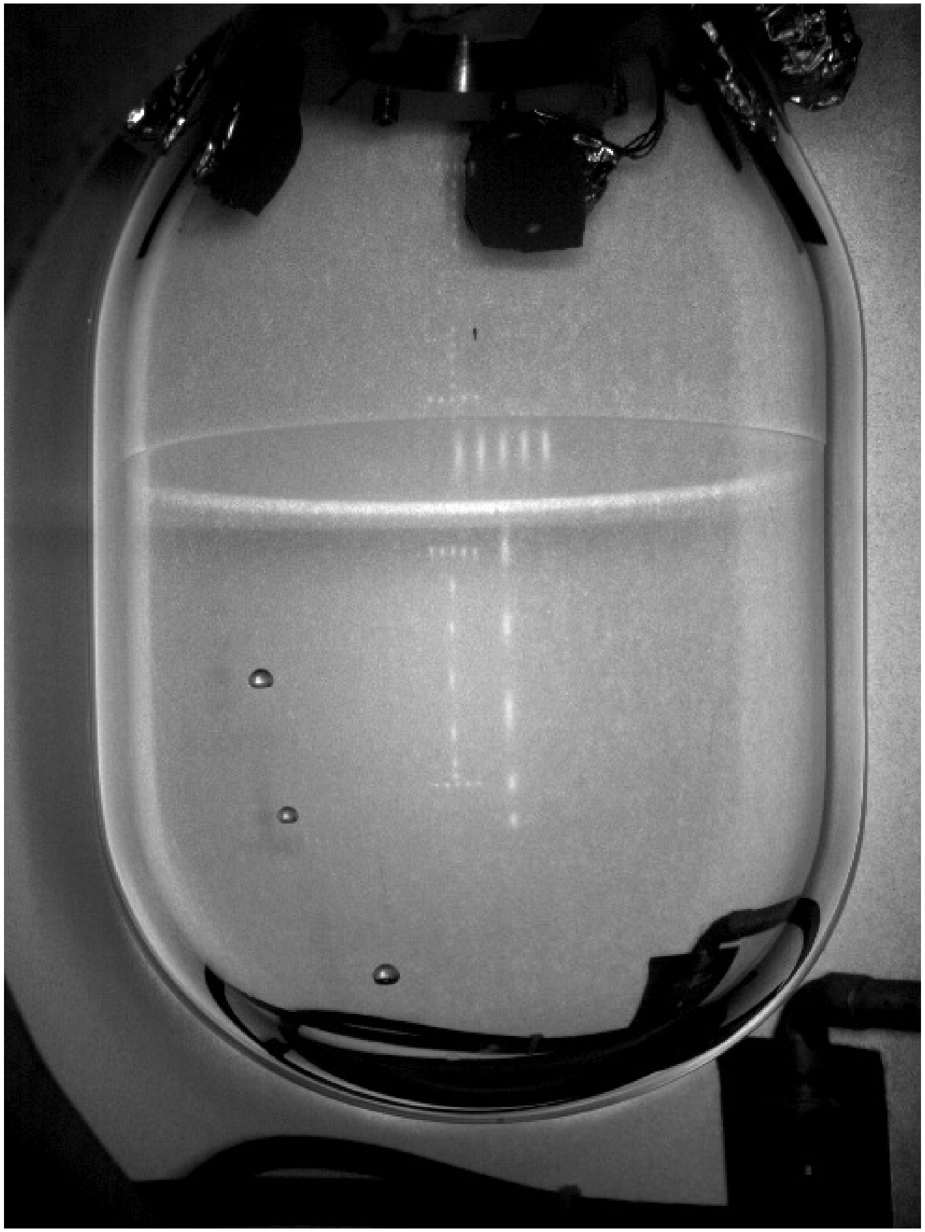
Bubble nucleation probability from gamma interactions in C_3F_8 and CF_3I

PICO bubble chambers

- **Alpha decays:**
  Nuclear recoil and
  40 μm alpha track
  1 bubble

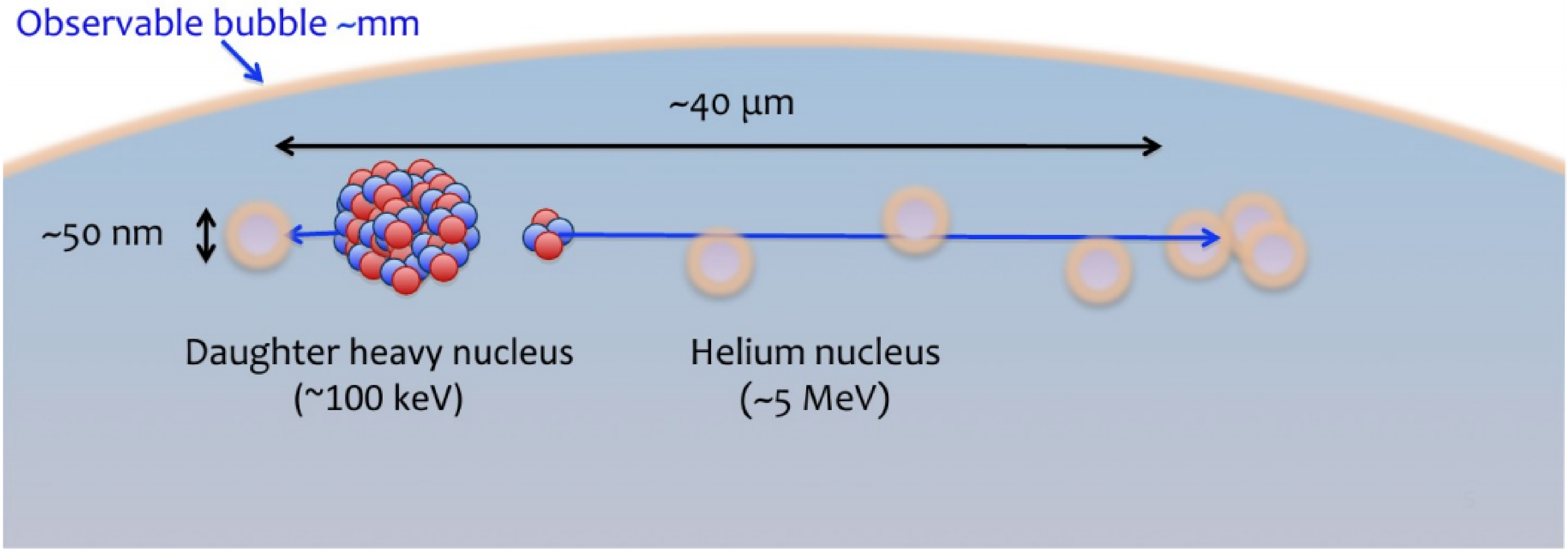
- **Neutrons:**
  Nuclear recoils
  mean free path ∼20 cm
  3:1 single-multiple ratio
  in COUPP4

- **WIMPs:**
  Nuclear recoil
  mean free path $> 10^{12}$ cm
  1 bubble



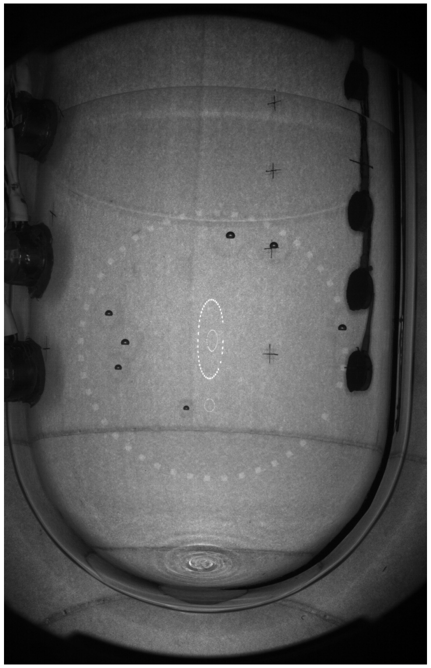
PICO bubble chambers

- **Alphas are $\sim$ 4 times louder than nuclear recoil bubbles**
- **$>$ 99.4% discrimination against alpha events demonstrated**
- **Discovered by the PICASSO collaboration**



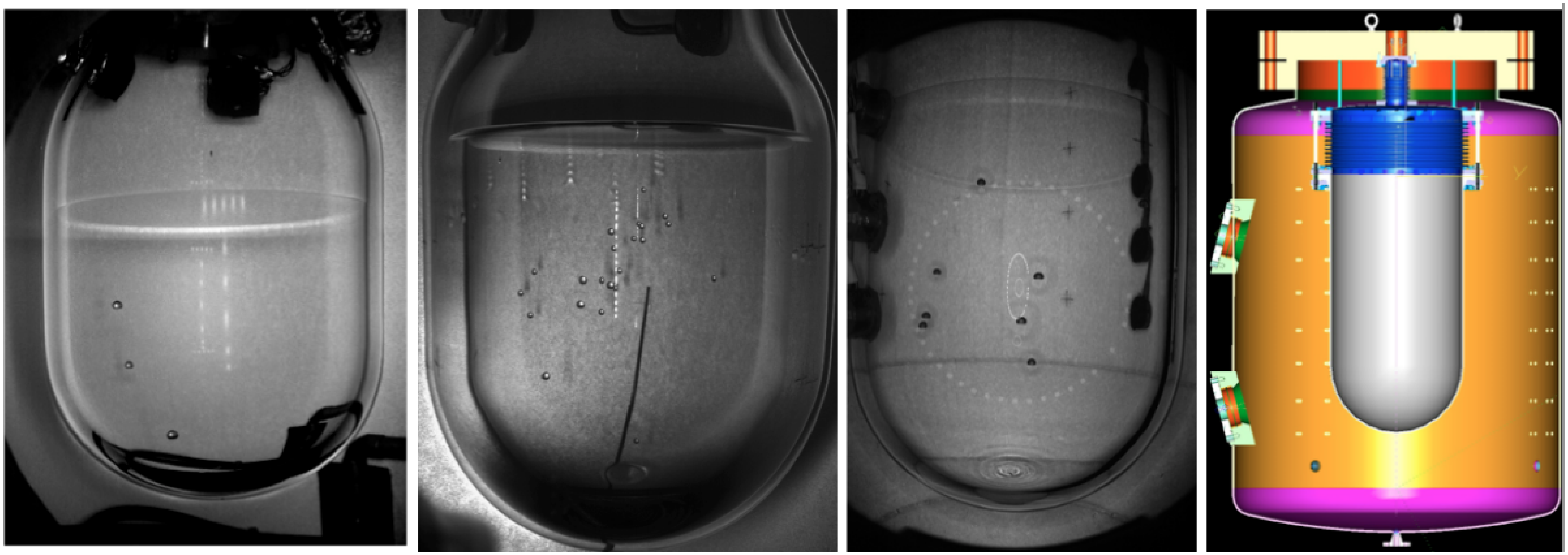
PICO detectors features

- **Energy: threshold detector**
- **Background suppression:**
  - **UG at SNOLAB**
  - **Water shielding**
  - **Clean materials**
- **Background discrimination:**
  - **Neutrons:**
    multiples bubbles
    Nuclear recoil, $l \sim 20$ cm
  - **α: acoustic parameter**
    Nuclear recoil, 40 μm track
- **Large target mass:**
  COUPP4 to COUPP60
  PICO-2L to PICO-60

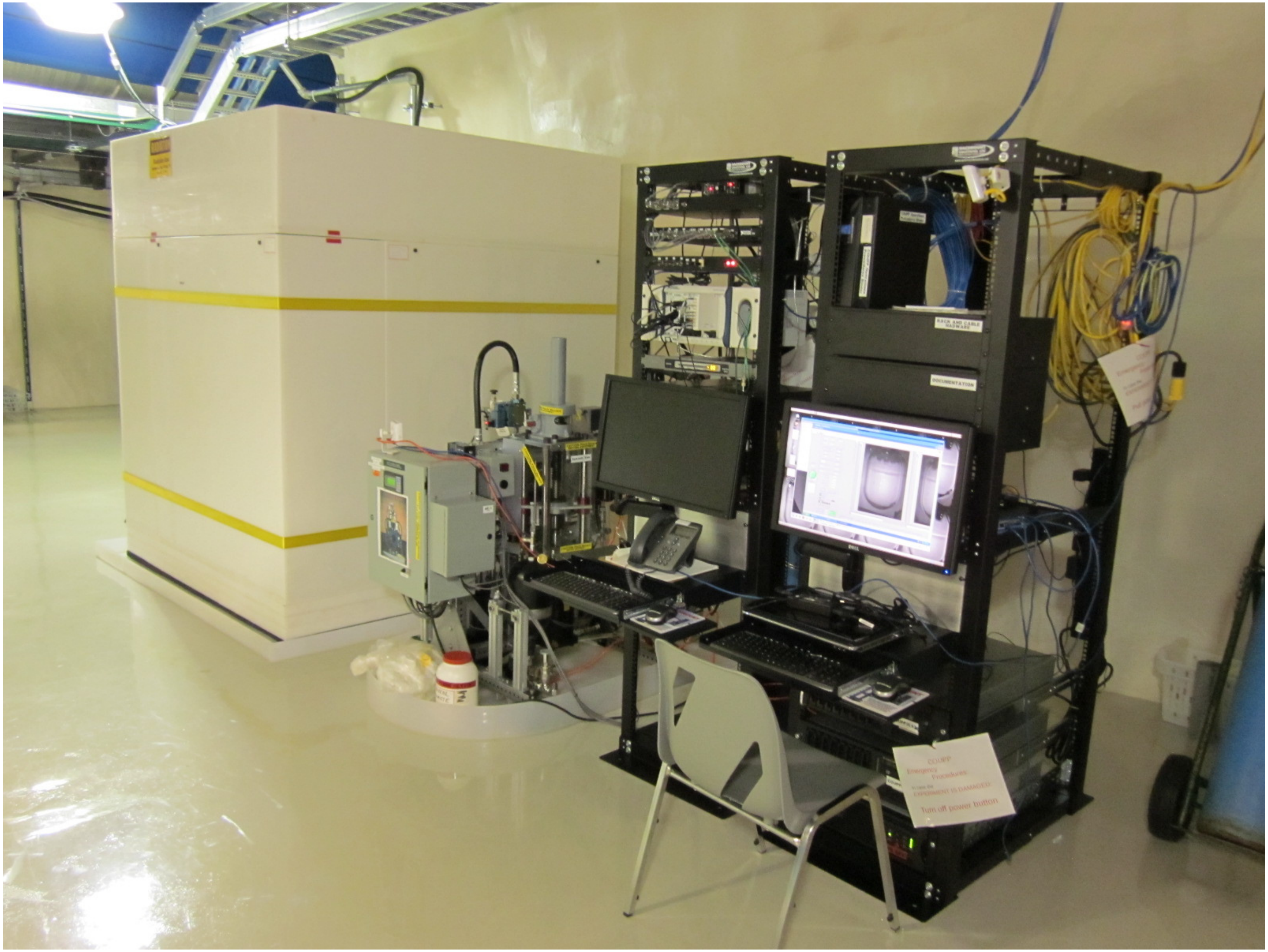


PICO bubble chambers

- **COUPP4: a 2-liter CF3I chamber run at SNOLAB in 2010 and 2012**
- **COUPP60: up to 40 liter CF3I chamber run at SNOLAB 2013-2014**
- **PICO-2L: a 2-liter C3F8 chamber run at SNOLAB 2013-2014 and 2015**
- **PICO-250L: future ton-scale experiment**

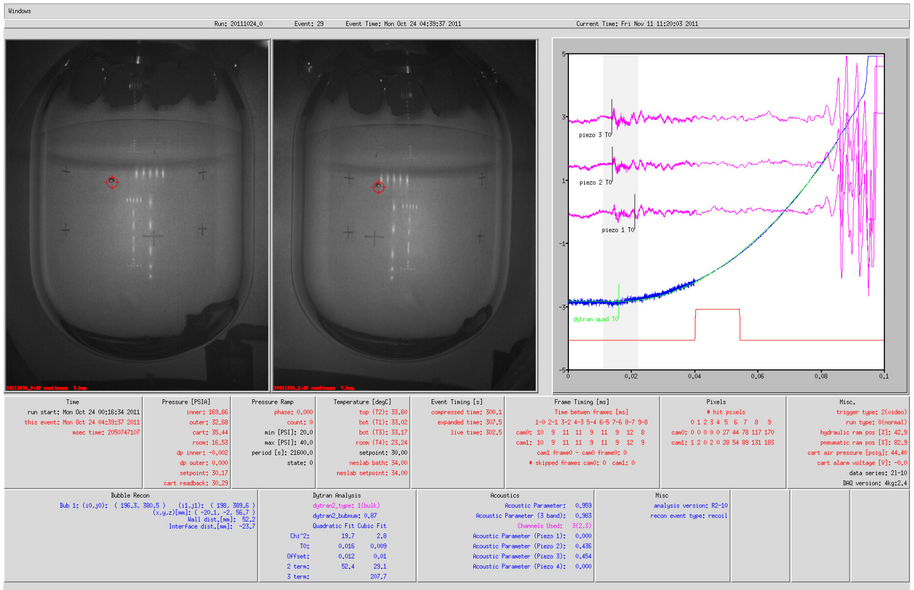


COUPP4



PICO: data analysis

- Examination of images: algorithm searching for clusters among pixels that changed between consecutive frames
- Examination of pressure rise: fit to the rate of pressure rise by a quadratic time dependence for bubbles in the bulk
- Examination of the acoustic signal



Run: 20111024_0 Event: 29 Event Time: Mon Oct 24 04:39:37 2011 Current Time: Fri Nov 11 11:20:03 2011

Time
run start: Mon Oct 24 00:16:34 2011
this event: Mon Oct 24 04:39:37 2011
msec time: 2050747107

Pressure [PSIA]
inner: 169.66
outer: 32.68
cart: 35.44
room: 16.53
dp inner: -0.002
dp outer: 0.000
setpoint: 30.17
cart readback: 30.29

Pressure Ramp
phase: 0.000
count: 0
min [PSI]: 20.0
max [PSI]: 40.0
period [s]: 21600.0
state: 0

Temperature [degC]
top (T2): 33.60
bot (T1): 33.02
bot (T3): 33.17
room (T4): 23.24
setpoint: 30.00
neslab bath: 34.00
neslab setpoint: 34.00

Event Timing [s]
compressed time: 300.1
expanded time: 307.5
live time: 302.5

Frame Timing [ms]
Time betwen frames [ms]

	1-0	2-1	3-2	4-3	5-4	6-5	7-6	8-7	9-8
cam0:	10	9	11	11	9	11	9	12	8
cam1:	10	9	11	11	9	11	9	12	9

cam1 frame0 - cam0 frame0: 0
skipped frames cam0: 0 cam1: 0

Pixels
hit pixels

	0	1	2	3	4	5	6	7	8	9
cam0:	0	0	0	0	0	27	44	78	117	170
cam1:	1	2	0	2	0	28	54	89	131	183

Misc.
trigger type: 2(video)
run type: 0(normal)
hydraulic ram pos [%]: 42.9
pneumatic ram pos [%]: 82.9
cart air pressure [psig]: 44.40
cart alarm voltage [V]: -0.0
data series: 21-10
DAQ version: 4kg:2.4

Bubble Recon
Bub 1: (i0,j0): (196.3, 380.5) (i1,j1): (198, 389.6)
(x,y,z)[mm]: (-20.1, -2, 56.7)
Wall dist.[mm]: 52.2
Interface dist.[mm]: -23.7

Dytran Analysis
dytran2_type: 1(bulk)
dytran2_bubnum: 0.87

	Quadratic Fit	Cubic Fit
Chi^2:	19.7	2.8
T0:	0.016	0.009
Offset:	0.012	0.01
2 term:	52.4	29.1
3 term:		207.7

Acoustics
Acoustic Parameter: 0.959
Acoustic Parameter (3 band): 0.983
Channels Used: 3(2,3)
Acoustic Parameter (Piezo 1): 0.000
Acoustic Parameter (Piezo 2): 0.436
Acoustic Parameter (Piezo 3): 0.454
Acoustic Parameter (Piezo 4): 0.000

Misc
analysis version: R2-10
recon event type: recoil

hand-scanned to
resolve disagreement

overall efficiency for all data quality and fiducial volume cuts is $\sim 80\%$

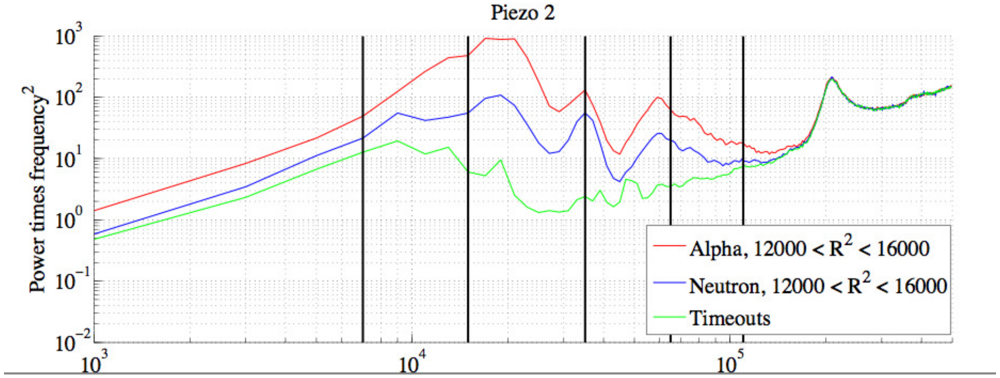
COUPP4 at SNOLAB

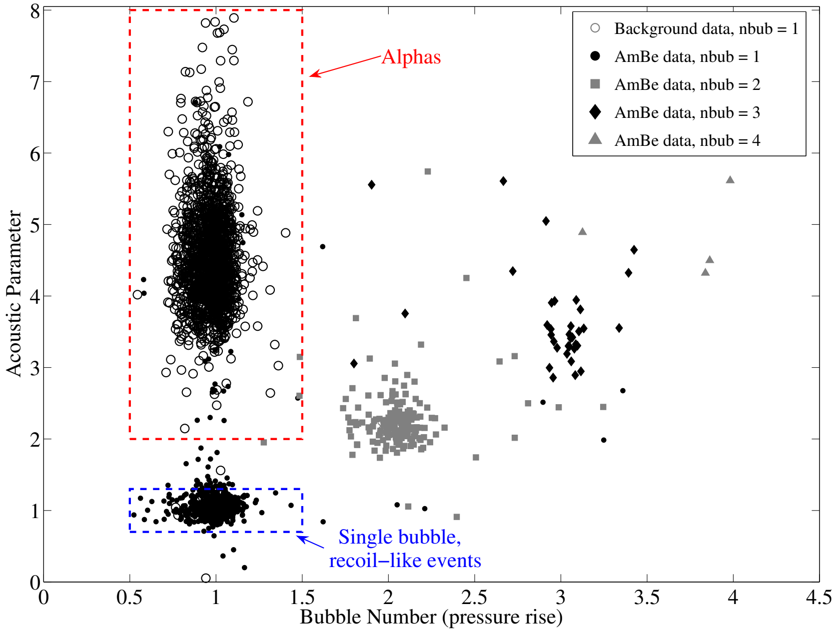
Acoustic transducer signals digitized with a 2.5 MHz sampling rate and recorded for 40 ms for each event

The nuclear recoil acceptance of the AP cut is ∼ 95%

3 ways of counting:

- **Images: cameras**
- **Pressure rise: transducer**
- **Acoustic parameter: piezos**

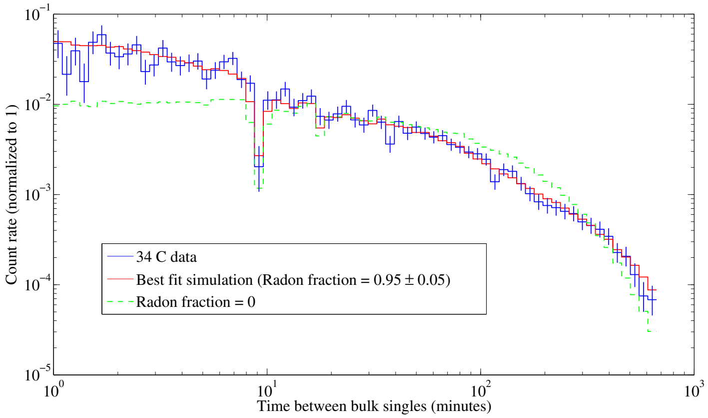


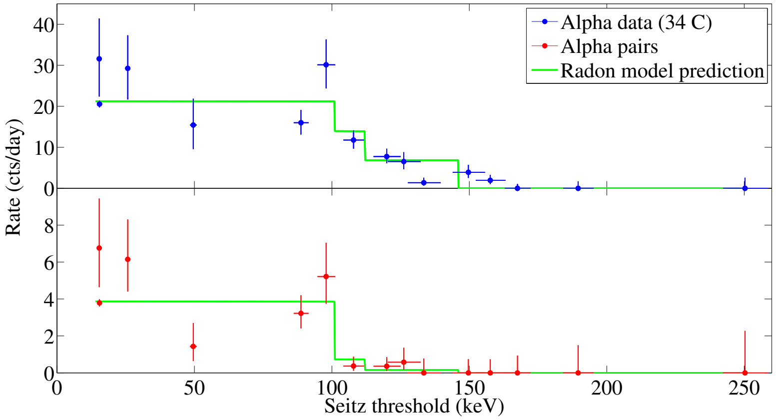


COUPP4 at SNOLAB: calibrations

Radon fraction = 0.95 ± 0.05

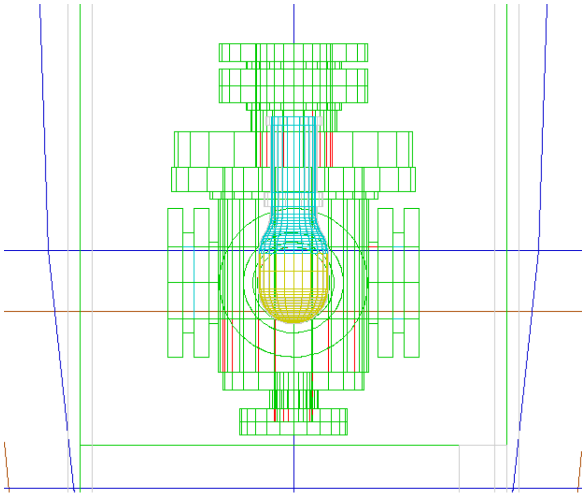
^{222}Rn (101 keV),
^{218}Po (112 keV),
^{214}Po (146 keV)

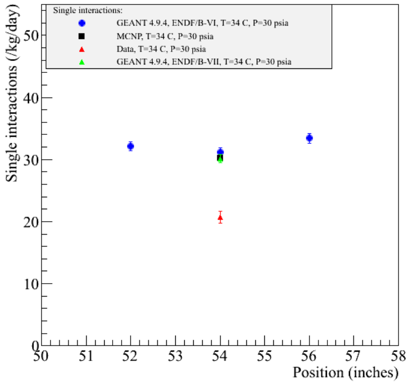


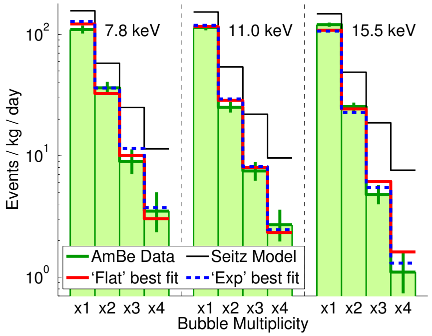


GEANT and MCNP simulations

- Bubble rate is 50% higher

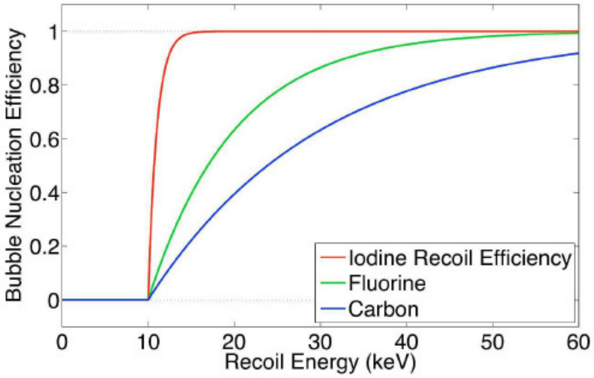




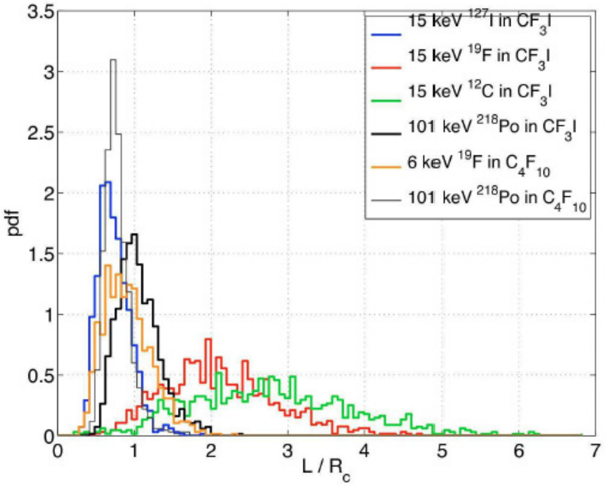


COUPP4 at SNOLAB: calibrations

- **Lower efficiency for ^{19}F and ^{12}C recoils**
- **Seitz model for ^{127}I recoils**



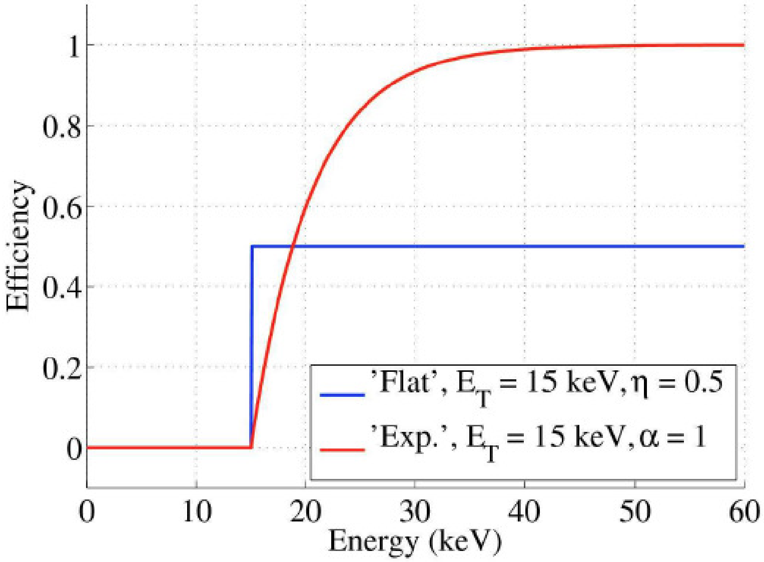
SRIM → TRIM calculation



Seitz model:

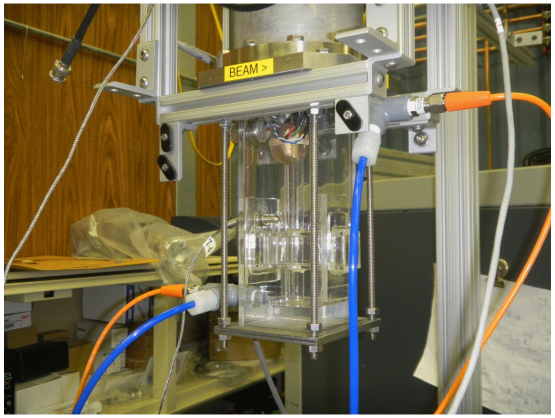
- **6 keV ^{19}F recoils, C_4F_{10} (PICASSO)**
- **101 keV ^{218}Po recoils, C_4F_{10} (PICASSO)**
- **101 keV ^{218}Po recoils, CF_3I**

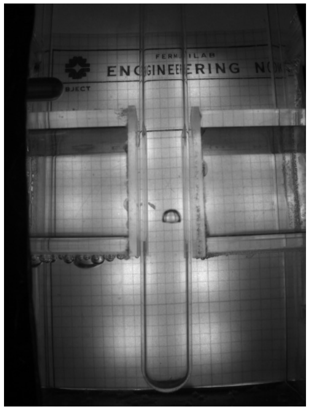
Understand efficiency for 15 keV recoils in CF_3I

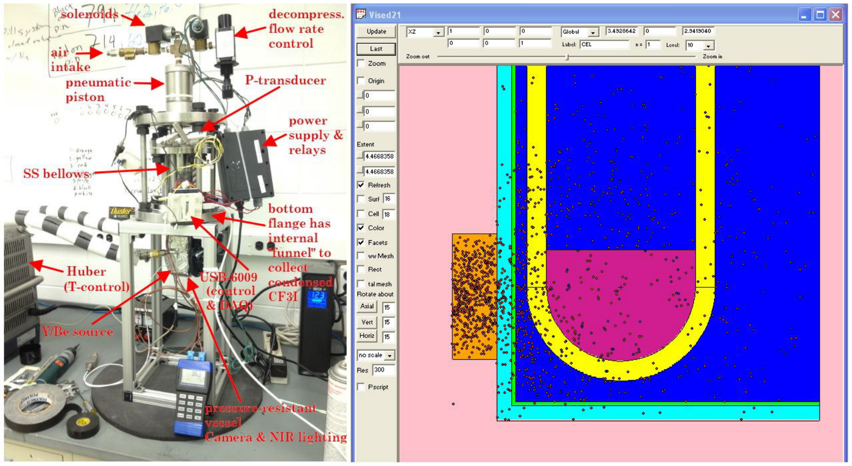


Calibrations

- γ and neutron calibrations
  - AmBe and ^{252}Cf
  - ^{60}Co and ^{133}Ba
  - Neutron beam at Montreal
- COUPP Iodine Recoil Threshold Experiment
  - Low energy Iodine recoils
  - π beam and silicon trackers
- ^{88}Y/Be calibration chamber
  - Understand response to low energy recoils
  - Monochromatic low energy neutrons



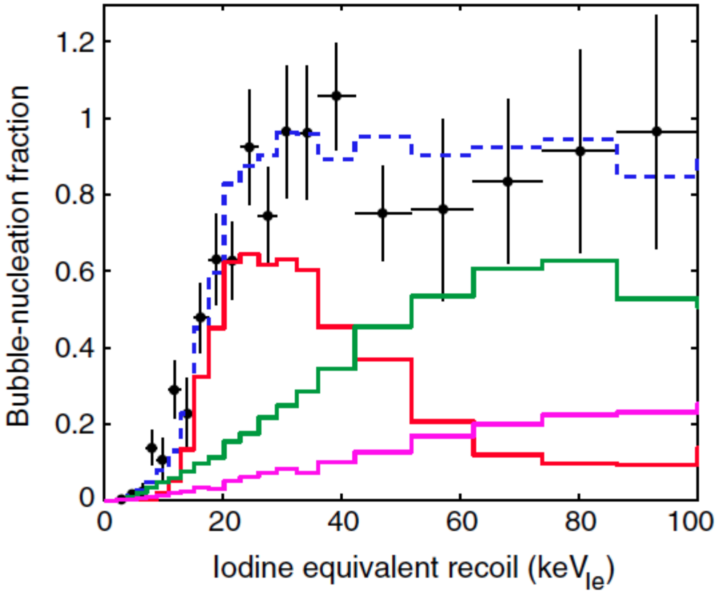


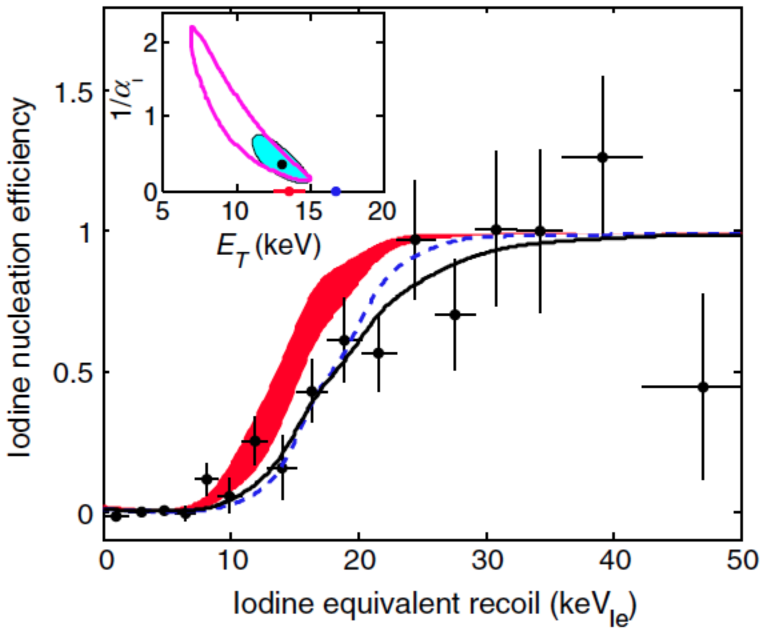


CIRTE

COUPP Iodine Recoil Threshold Experiment

Elastic scattering of pions to study iodine recoils directly





red for iodine, green for fluorine, and pink for carbon and inelastics

red region: step function model with the threshold varied within the uncertainty on the Seitz theory prediction,
$E_T = (13.6 \pm 0.6)$ **keV** $\pm 6\%$
dashed blue curve: best fit step function with $E_T = 16.8$ **keV**

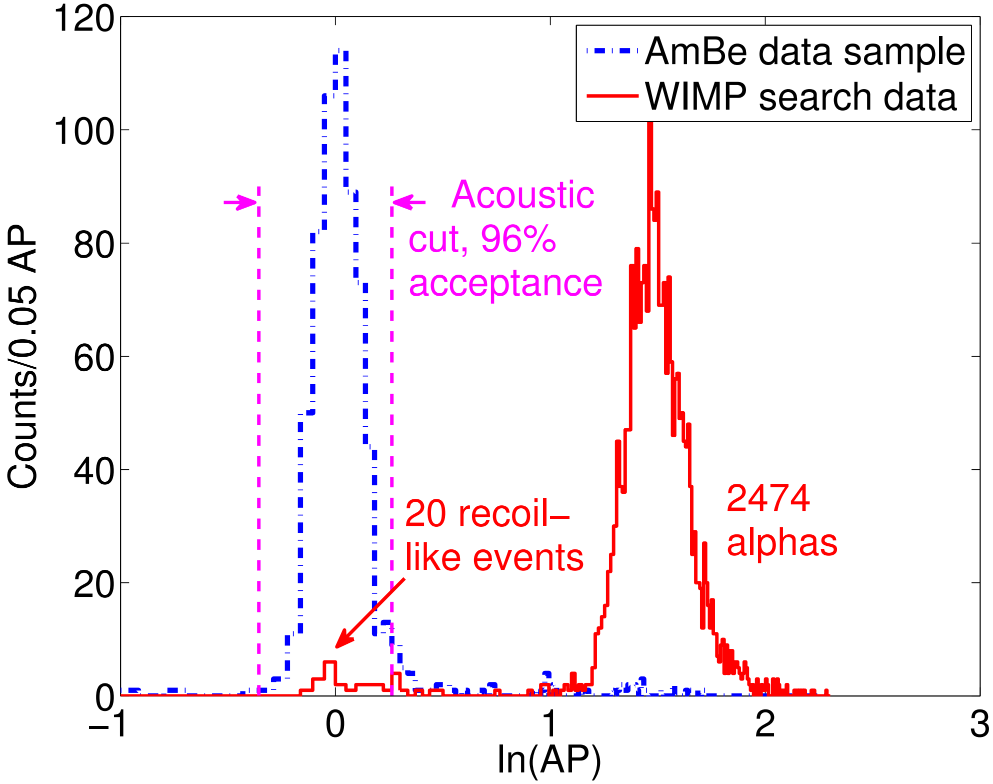
COUPP4 at SNOLAB: results

456 kg-days, 2474 alphas
1733 alphas (15 keV data)

5.3 alpha decays/ kg-day
95% from radon

$> 98.9\%$ α rejection
$> 99.3\%$ (15 keV data)

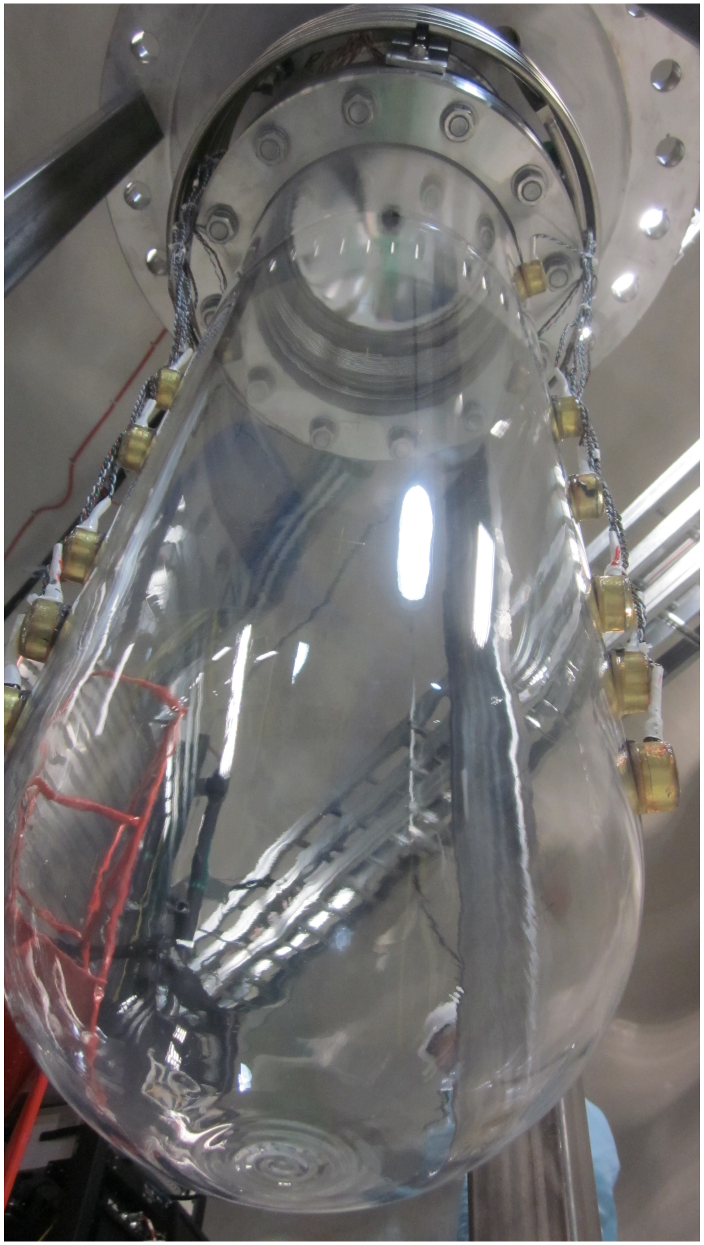
- **6 events at 8 keV**
- **6 events at 10 keV (2 triples)**
- **8 events at 15 keV (1 double)**



20 WIMP candidates

(Neutrons from rock: < 1/year)

COUPP60



COUPP60

COUPP60 physics run

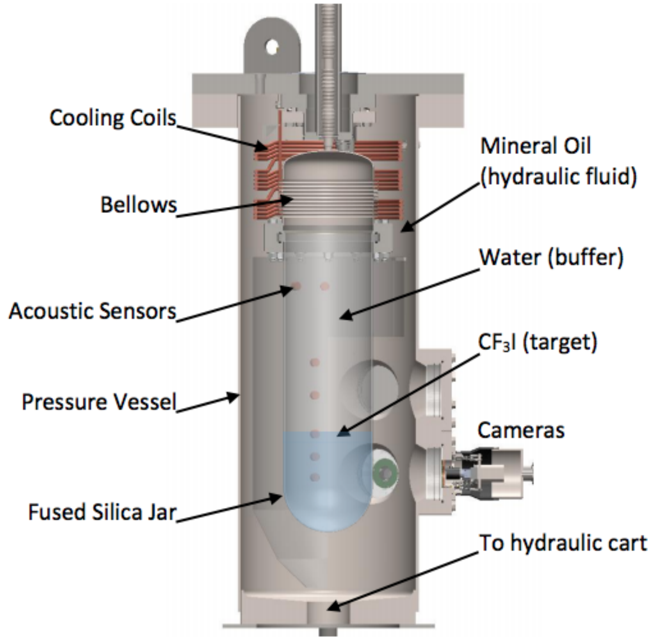
Physics run: June 2013-May 2014

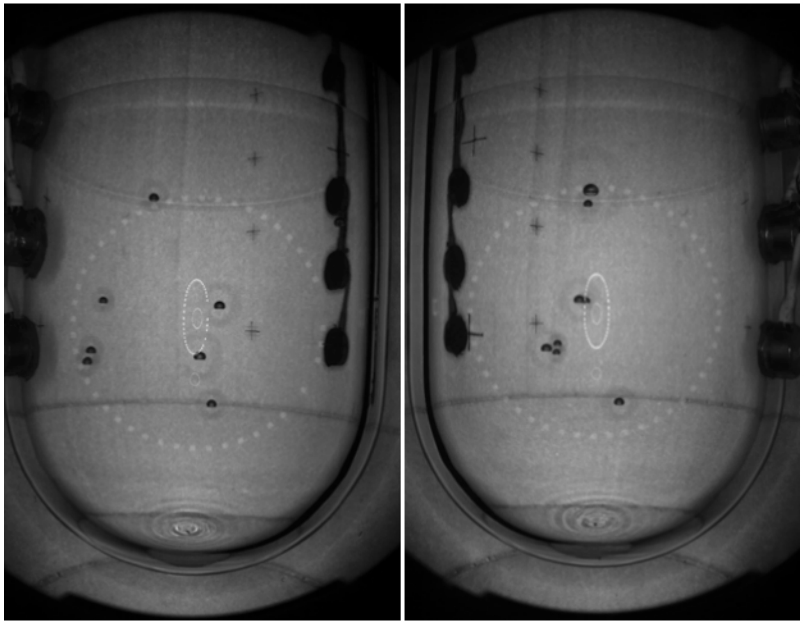
- Filled with 36.8 kg of CF_3I
- Collected >3000 kg-days of dark matter search data
- between 10 and 20 keV threshold

Zero multiple bubbles, no neutrons
Limit on neutron rate is factor 3 below observed rate in COUPP4

- Population of events that sound like nuclear recoils but are clearly not WIMPs

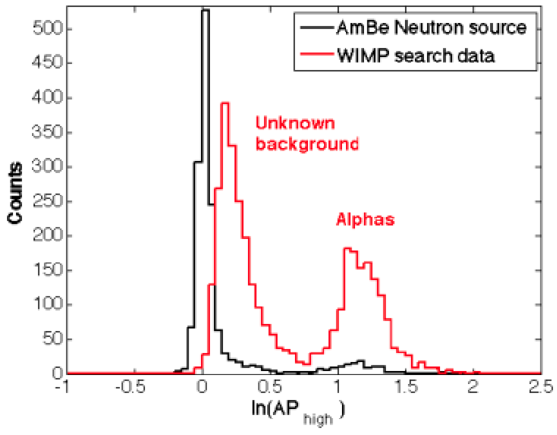
several events (statistics): able to study them in detail

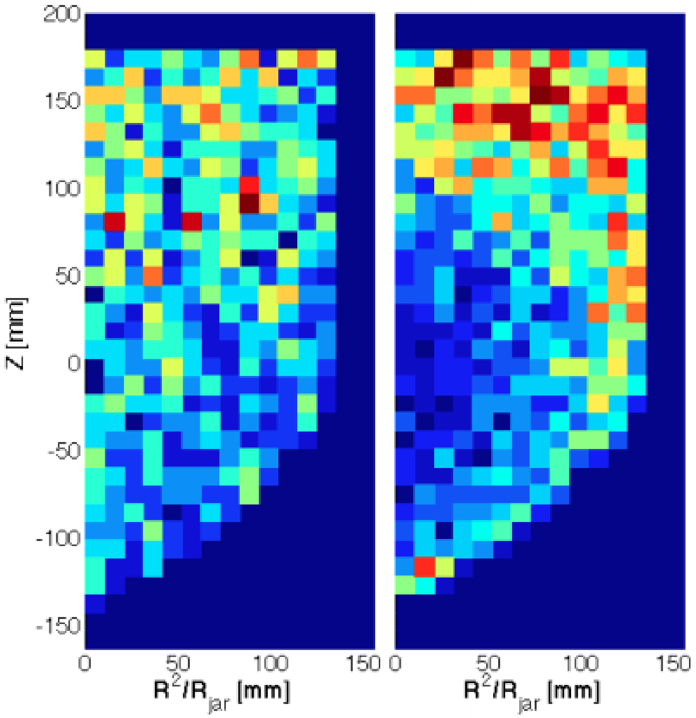


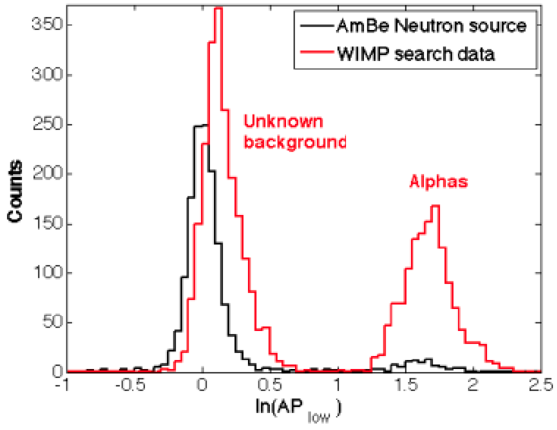


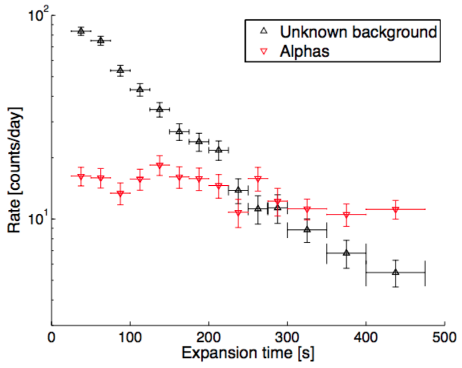
COUPP60 physics run

Seitz Threshold [keV]	Livetime (d)	
	<=33.4 psi	>33.4 psi
7.0– 8.2	1.2	0.0
8.2– 9.6	2.9	0.0
9.6–11.5	17.7	0.0
11.5–13.0	24.1	0.8
13.0–14.5	28.3	0.9
14.5–17.0	14.6	2.6
17.0–20.0	4.0	7.9
>20.0	6.6*	43.5
Total	92.8	55.7



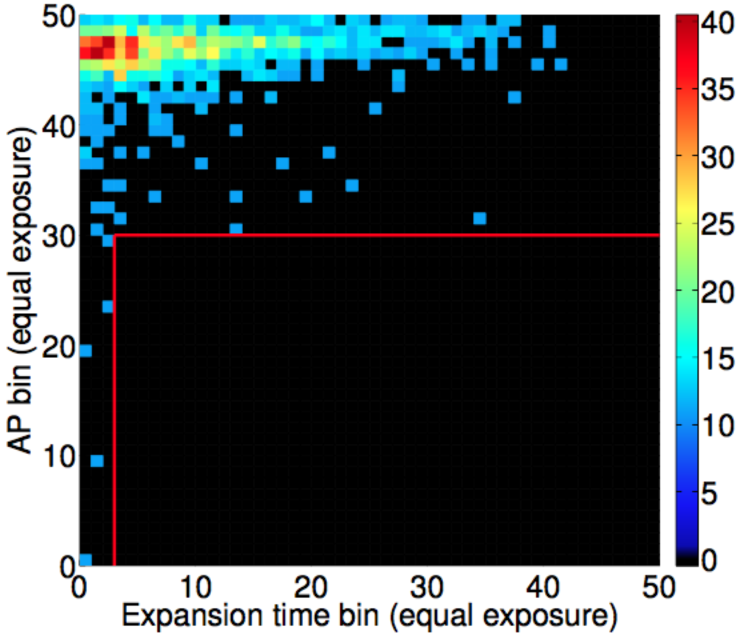


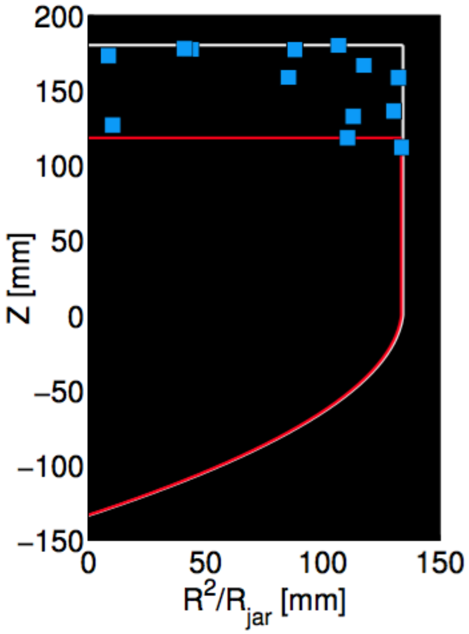




COUPP60 event selection

- Use spatial coordinate, expansion time, and acoustic parameter to define consistency cut
- Generic method of using a KS-test on these distributions to define a cut where the distributions are consistent at p=0.003
- Using method similar to optimum interval method (penalty of 1.8)
- Keeps 48% exposure, 0 candidates



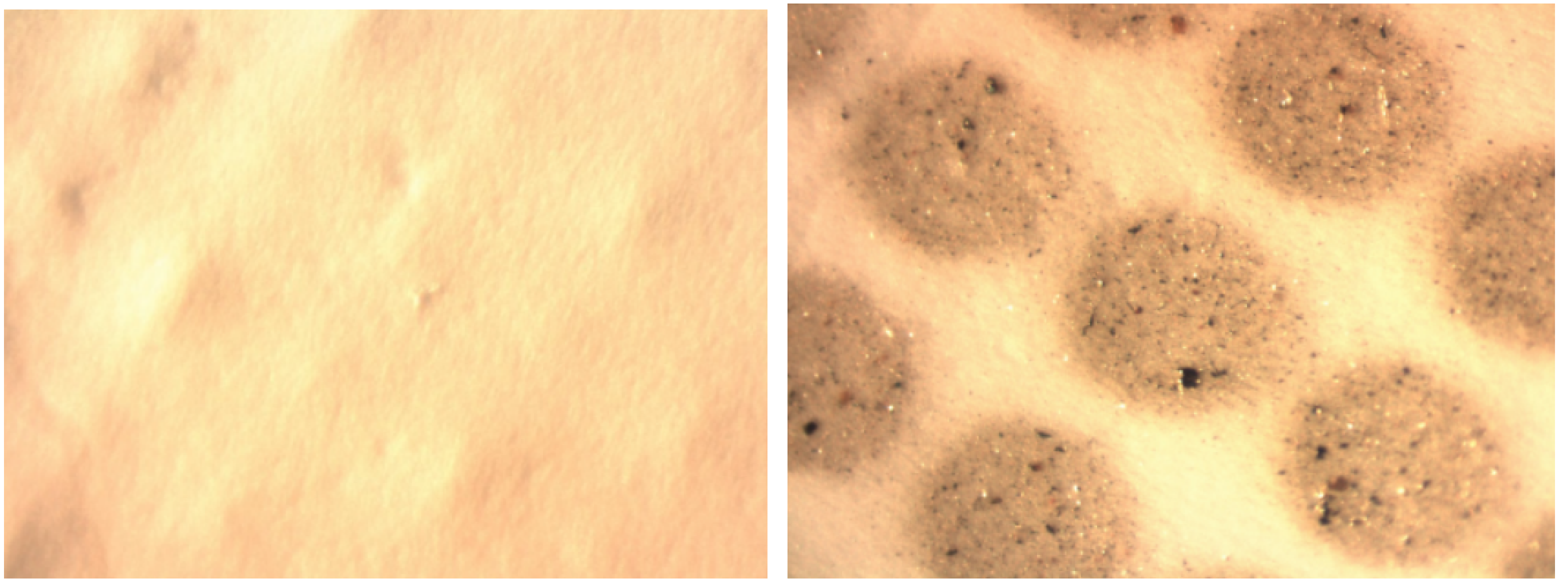


Backgrounds in PICO

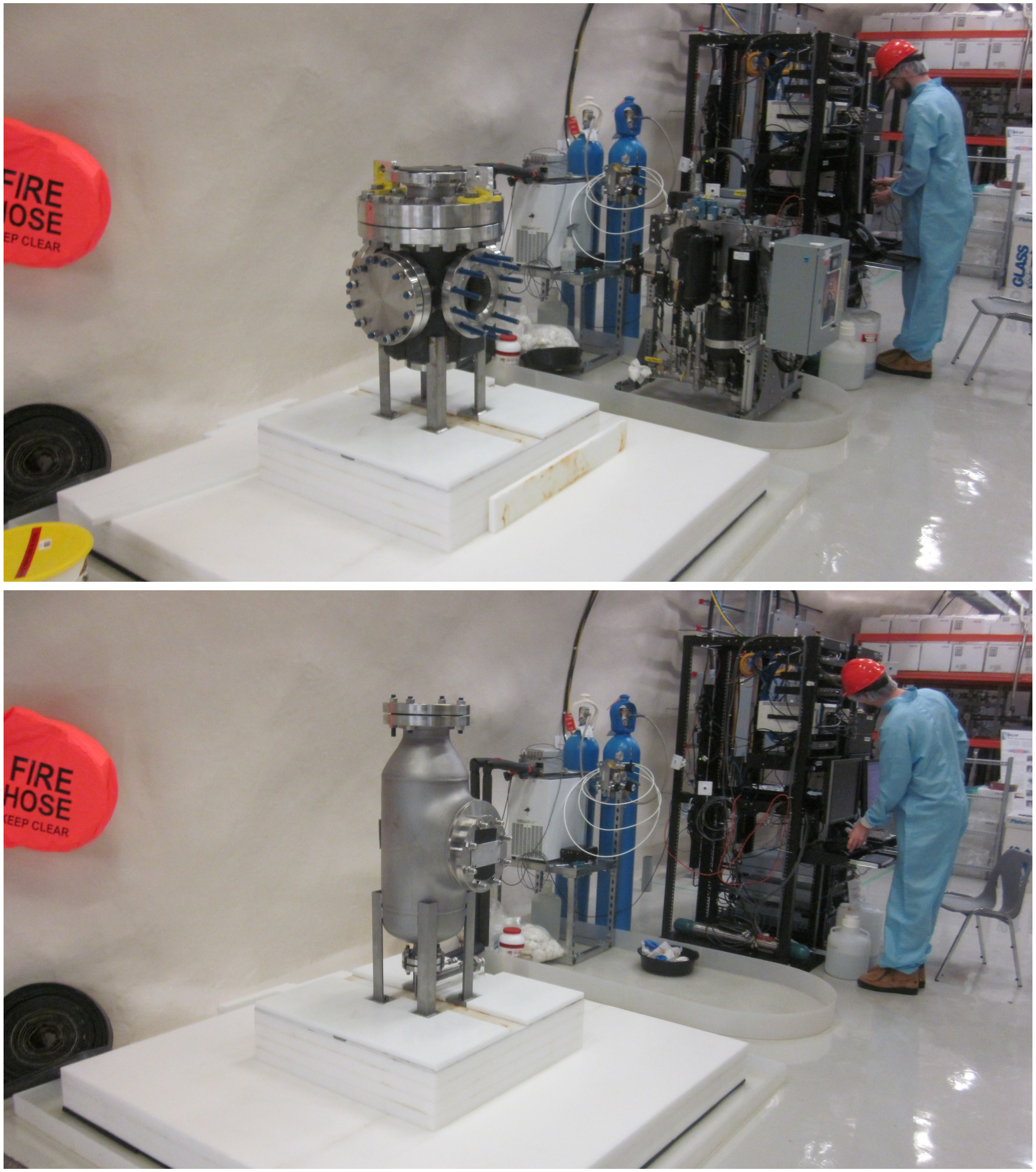
Two working hypothesis for source of backgrounds in PICO bubble chambers

- **Particulates (dust, stainless steel, silica):**
  ICP-MS assay and better cleaning protocols,
  optical and electron microscopy

- **Water droplets:**
  switching buffer fluid to Linear Alkyl Benzene

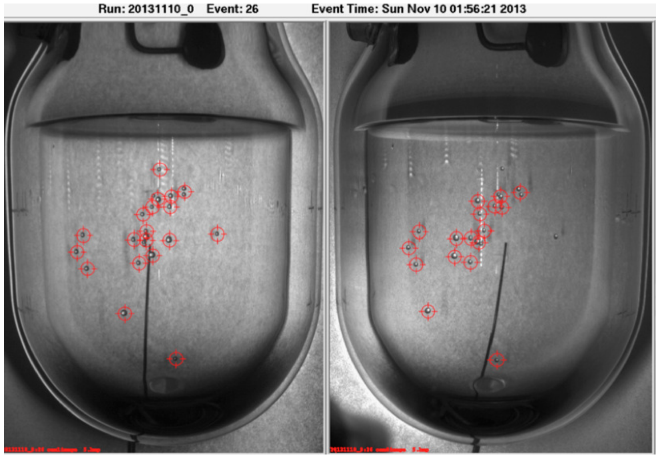


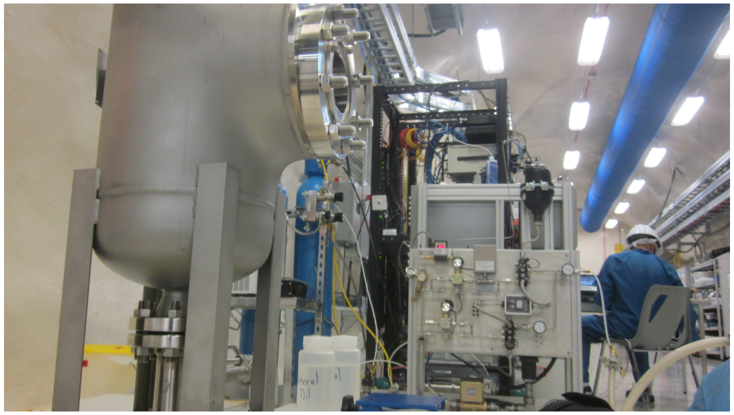
From COUPP4 to PICO-2L

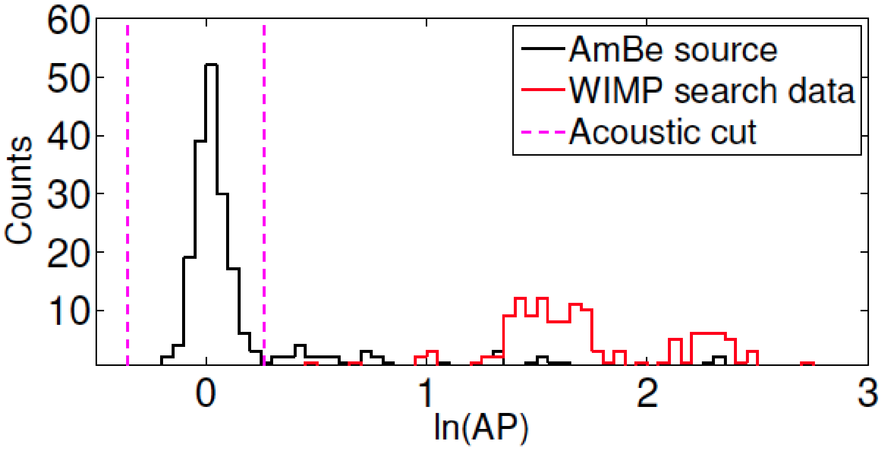


PICO-2L

- C_3F_8 as target material
- spin-dependent sensitivity: world leading limit
- Low energy threshold, as low as 3 keV
- Test recent claims of evidence for light WIMPs







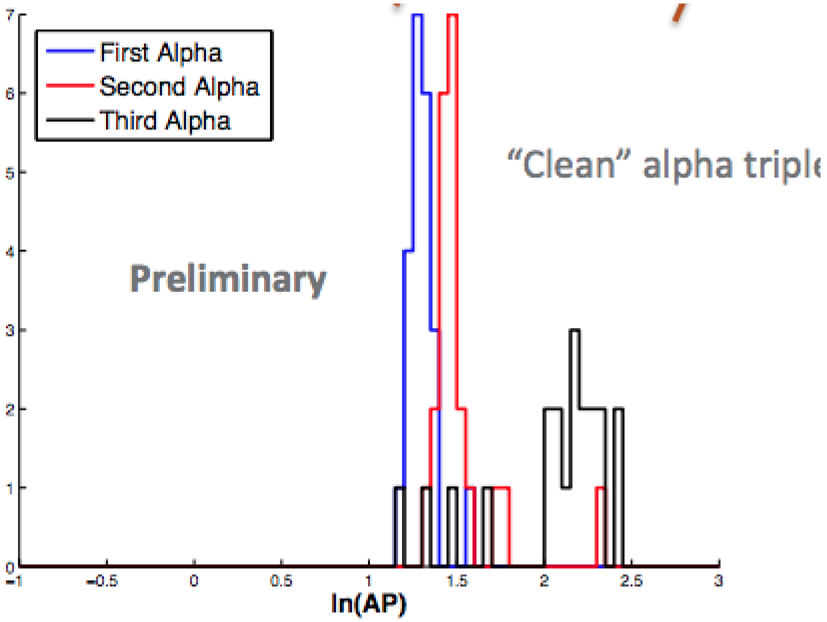
(alpha calorimetry observed for the first time)

Results from run I published on June!

PRL 114(2015), 231302

PICO-2L

- No multiple bubble events in the low background data
- Two distinct alpha peaks, clearly separated from nuclear recoils
- Timing of events in high AP peaks consistent with radon chain alphas, and indicate that the higher energy 214Po alphas are significantly louder
  (a new effect not seen in CF3I)



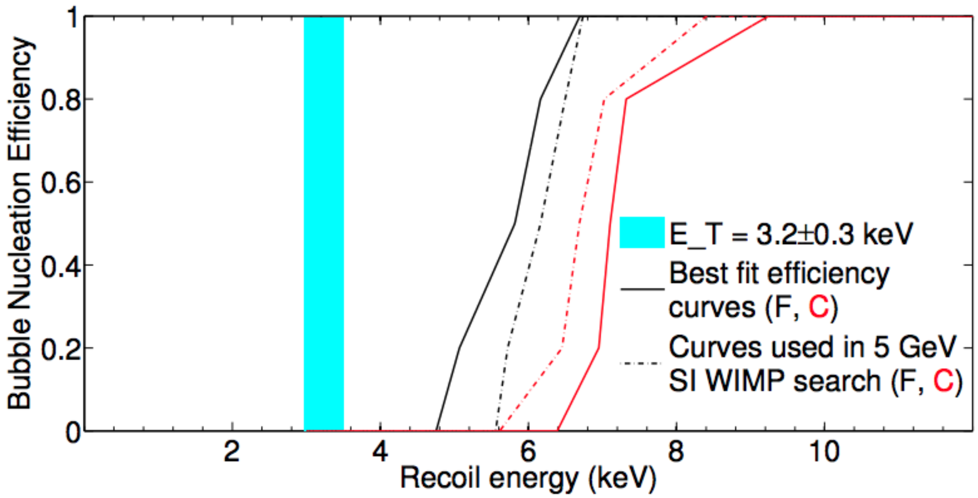
^{222}Rn
α(5.6 MeV)

^{218}Po
α(6.1 MeV)

^{214}Po
α(7.9 MeV)

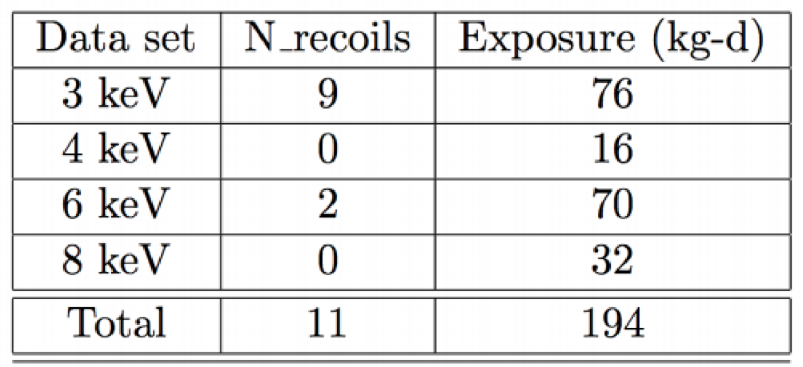
3 minutes

55 minutes

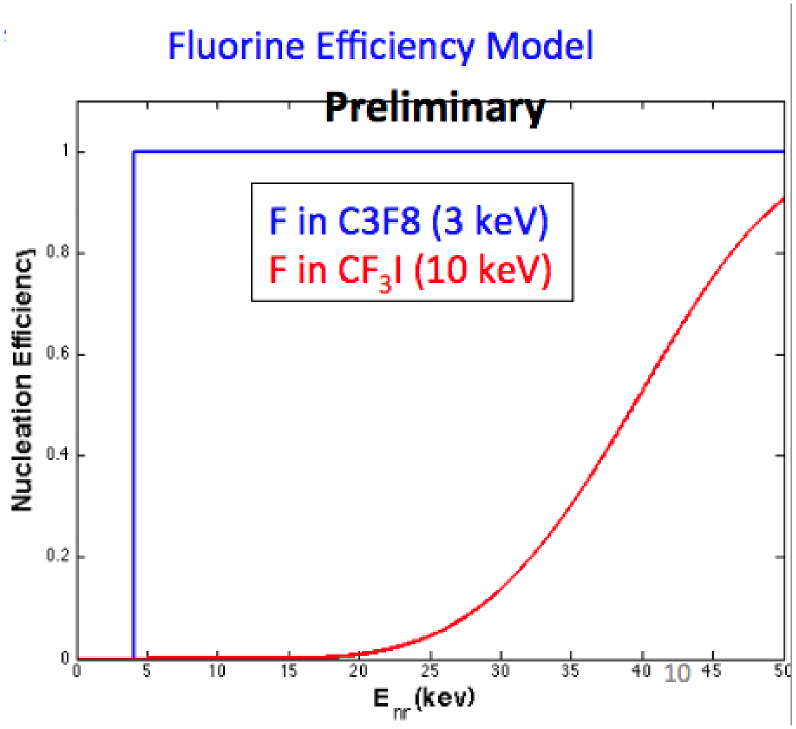


PICO-2L

- **11 total WIMP candidate events**
- **194 kg-days of data (3-8 keV thresholds)**
- **Expected background: ∼ 1 event**

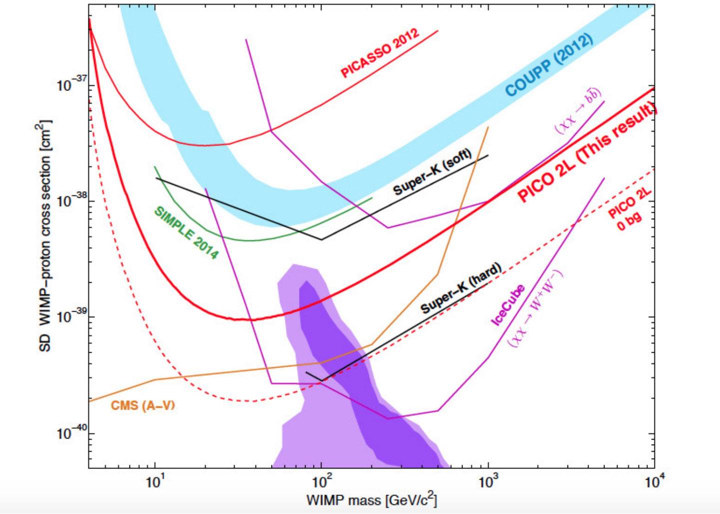


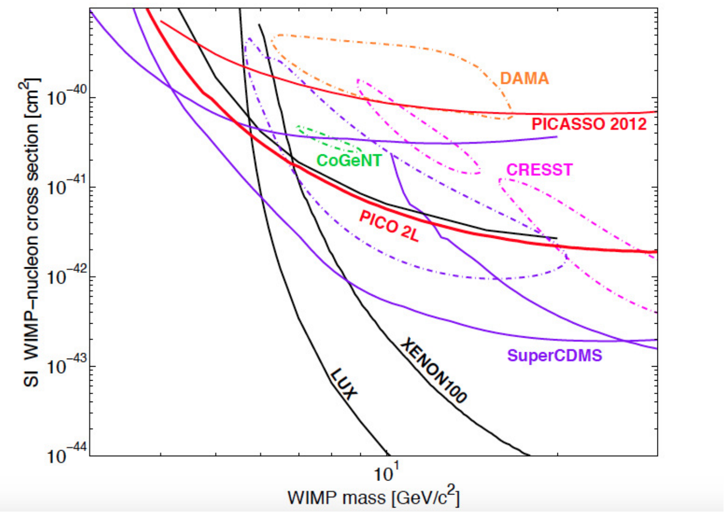
Data set	N_recoils	Exposure (kg-d)
3 keV	9	76
4 keV	0	16
6 keV	2	70
8 keV	0	32
Total	11	194



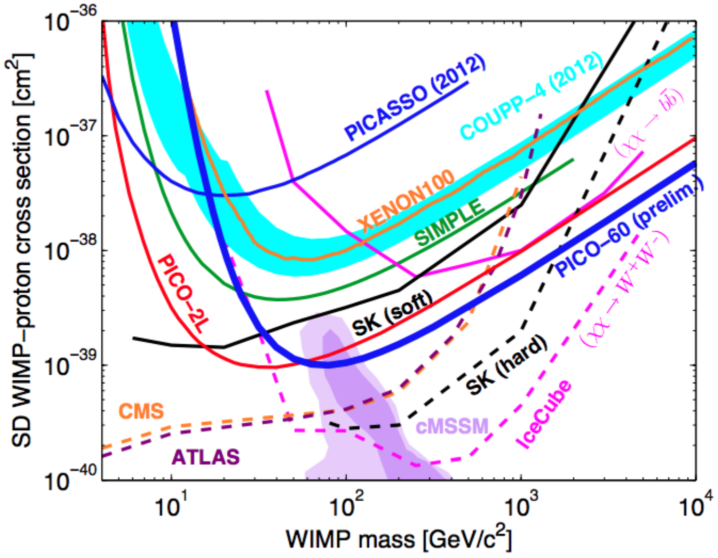
- **Candidate events have timing correlations inconsistent with WIMPs or neutrons**
- **Post-run PICO-2L samples show evidence of particulate contamination.**
  Analysis of samples ongoing
- **In addition to in-situ AmBe calibrations we are calibrating the nuclear recoil response of C3F8 with low-energy neutron sources on test chambers (Montrel, NU, UofC)**

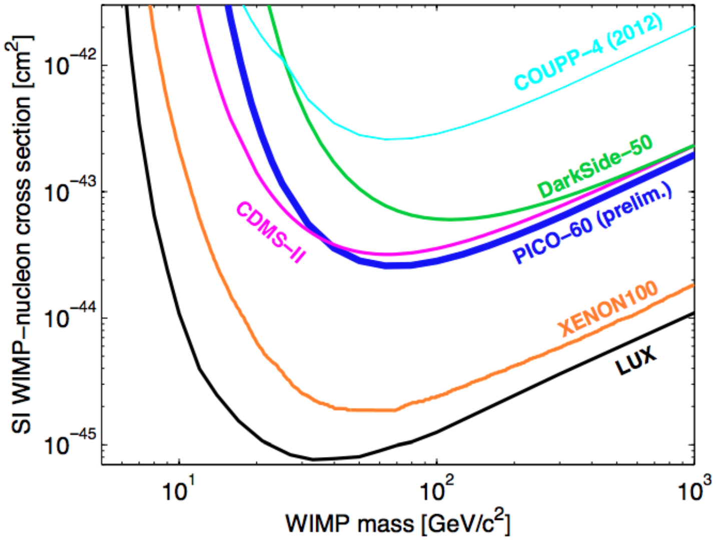
Results and preliminary results





PICO-2L is world leading experiment for SD WIMP-proton scattering, first time supersymmetric parameter space has been probed by direct detection in the SD-proton channel





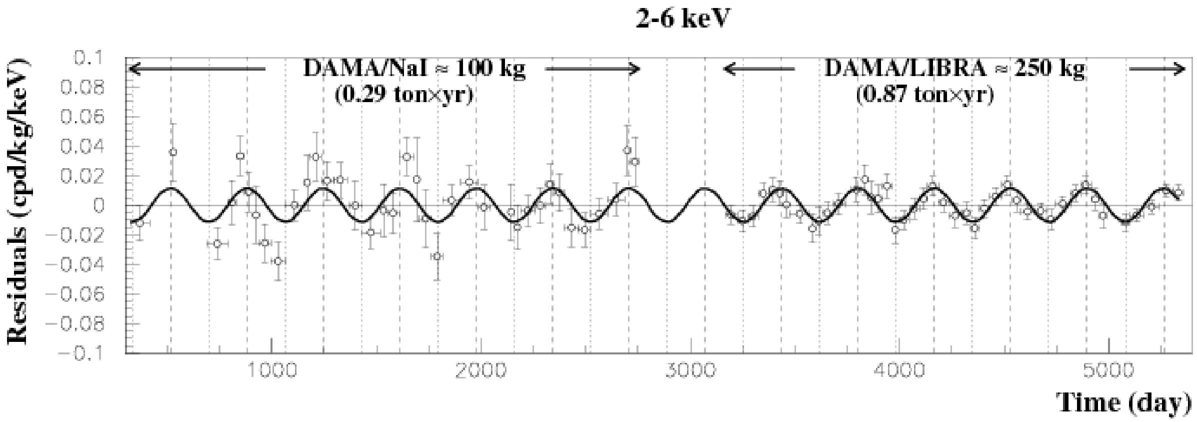
Implications to DAMA-LIBRA signal

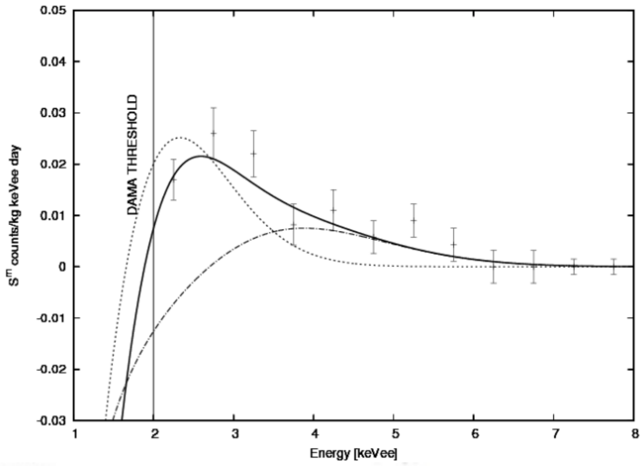
- **Using DAMA spectrum between 2 and 6 keV**

- **Applying DAMA iodine quenching factor (0.09) results in expectation of 49 recoils above 22 keV**

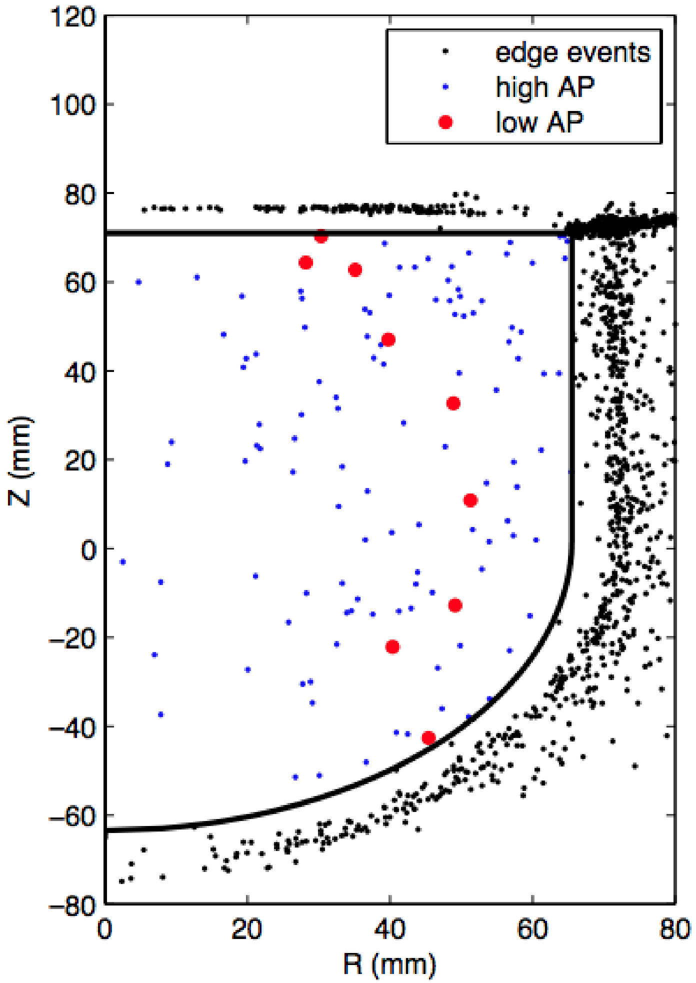
- **PICO-60 observes <4.1 events at 90% C.L.**

- **Background estimate:**
  singles $= 4.27 \pm 1.06$ per yr, multiples $= 3.85 \pm 0.94$ per yr



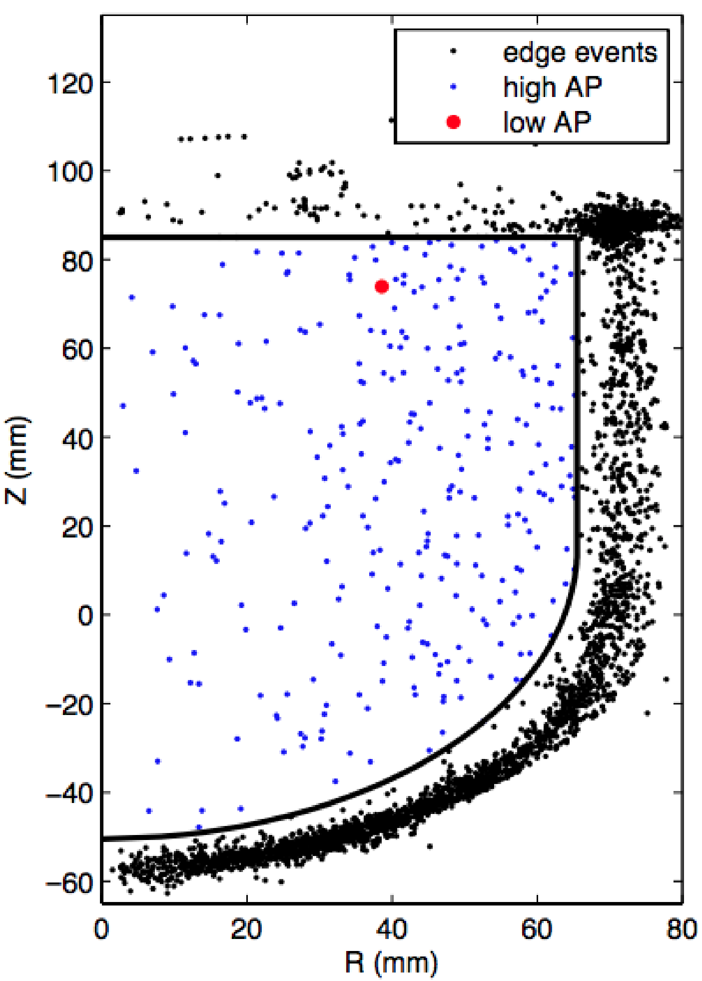


New PICO-2L run



Run-1 3.2keV data

- 32 live days
- Est. neutron bkgd $0.9^{+0.2}_{-0.7}$ events

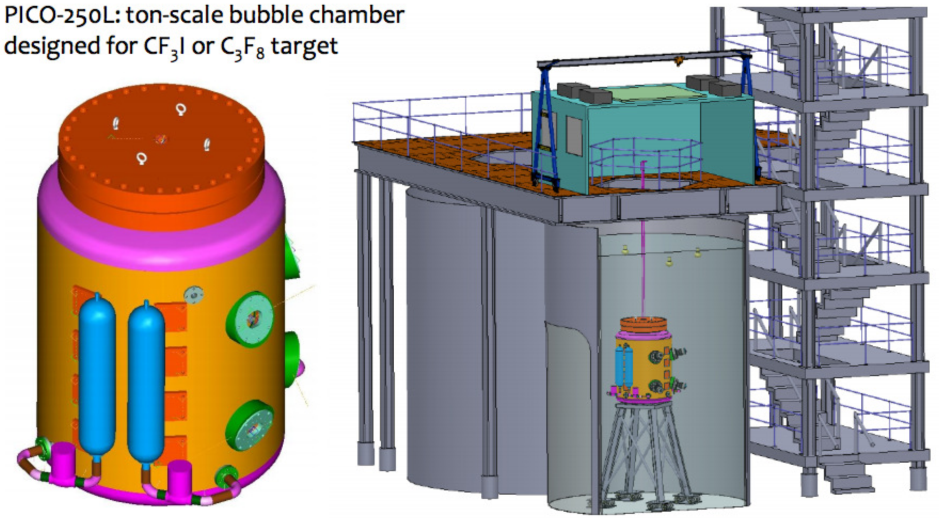


Run-2 3.2keV prelim. data

- ~51 live days and counting
- Est. neutron bkgd $1.5^{+0.3}_{-1.1}$ events

PICO-250L

- $> 10^{10}$ γ/β insensitivity
- $> 99.3\%$ acoustic α discrimination
- Multi-target capability
  SD- and SI-coupling
  High- and low-mass WIMPs
- Easily scalable,
  inexpensive to replicate

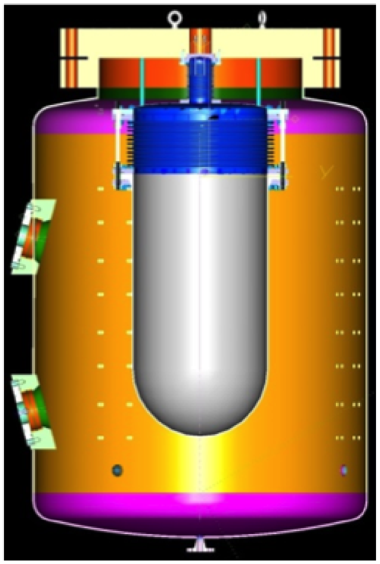


PICO-250L: ton-scale bubble chamber designed for CF_3I or C_3F_8 target

Data taking by 2017-2018

Working to deploy new detector:
Right Side Up chamber

Solve background issues



A few comments on backgrounds in dark matter detectors

- **Radioactivity of surroundings**
- **Radioactivity of detector and shield materials**
- **Cosmic rays and secondary reactions**

Some comparisons:

- **How much radioactivity (in Bq) is in your body? where from?**
- **What is the most radioactive food we eat?**
- **How many radon atoms escape per m^2 of ground, per second?**

Backgrounds in dark matter detectors

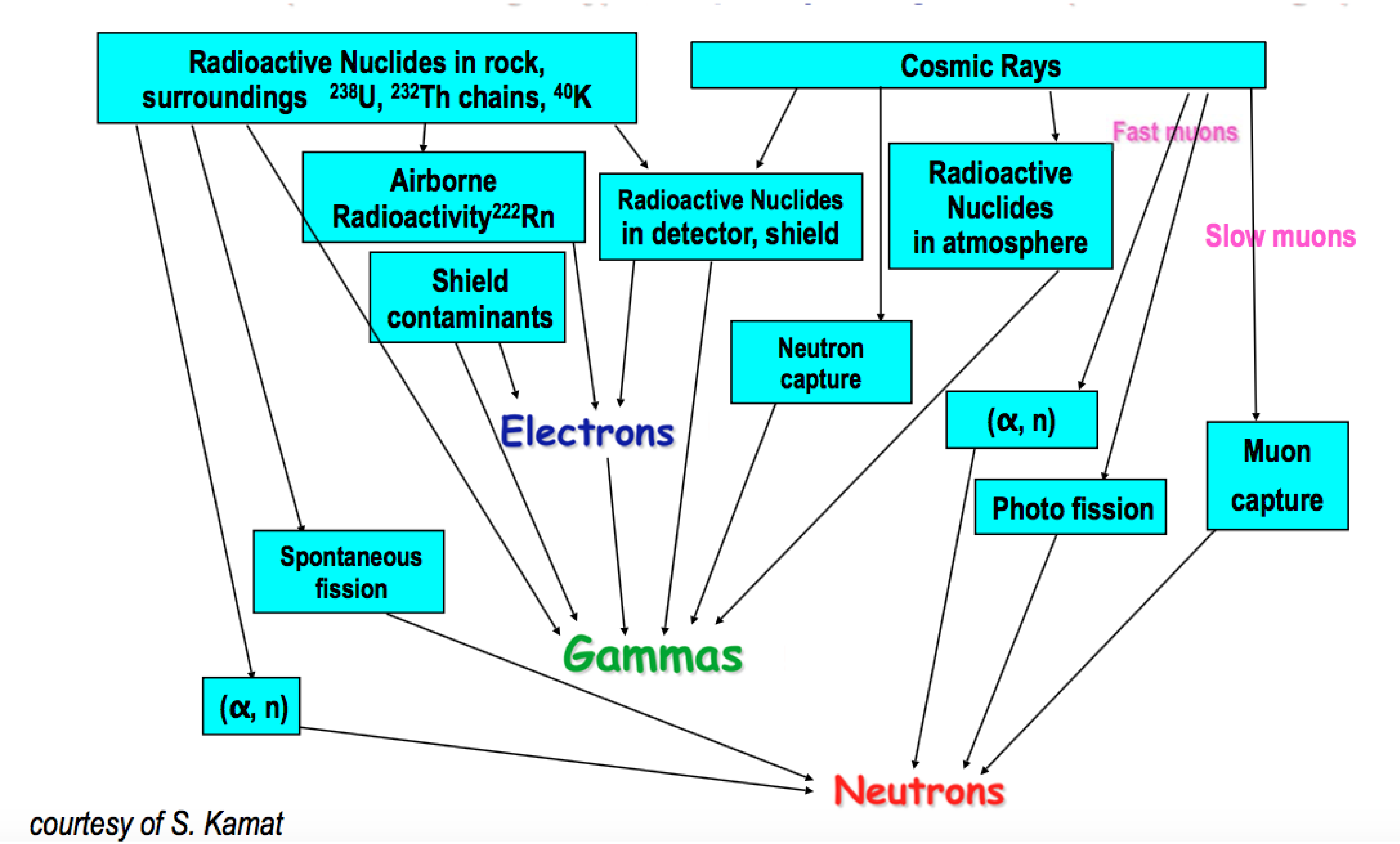
- **Radioactivity of surroundings**
- **Radioactivity of detector and shield materials**
- **Cosmic rays and secondary reactions**

Some comparisons:

- **How much radioactivity (in Bq) is in your body? where from?**
  4000 Bq from 14C, 4000 Bq from 40K (including about 8000 neutrinos)
- **What is the most radioactive food we eat?**
  Bananas and coffee (1000 Bq)
- **How many radon atoms escape per m^2 of ground, per second?**
  7000 atoms/m^2/s

WIMP scatters (<1 event/ton/year) swamped by backgrounds
($> 10^{11-12}$ events/ton/year)

Cosmic rays and natural radioactivity



courtesy of S. Kamat

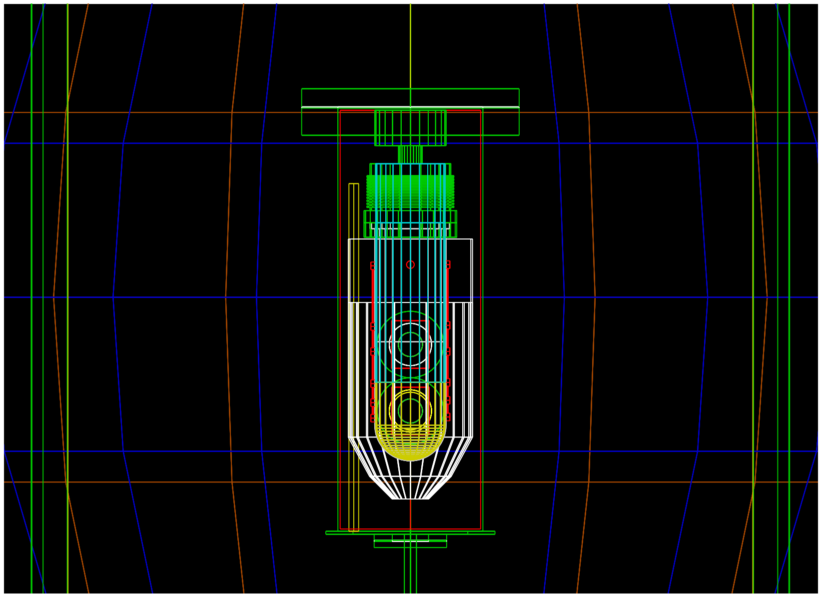
Backgrounds in dark matter detectors

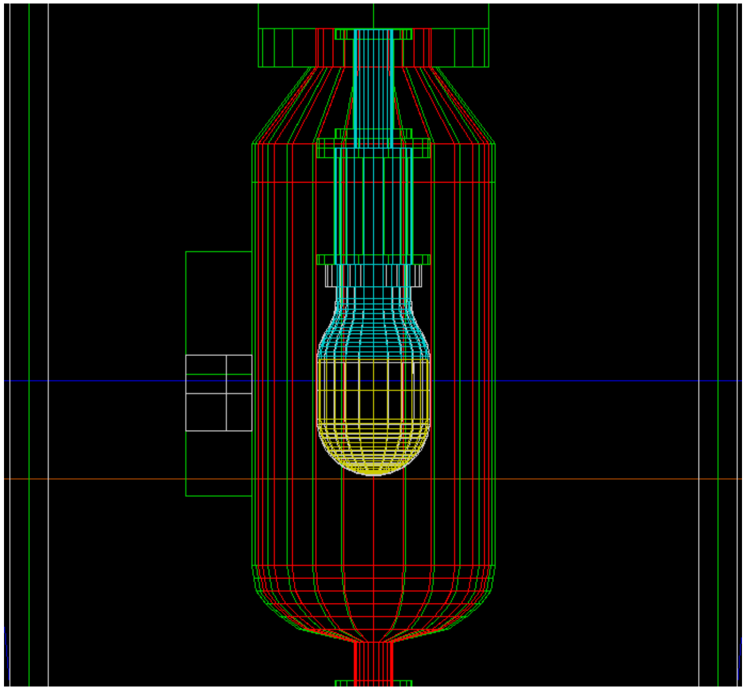
- External radioactivity from the walls and concrete
- Radon decays in air
- Internal radioactivity of materials target and shielding
- Cosmic rays
- Activation of detector and other materials during production and transportation on earth
- Worst? neutrons (MeV neutrons can mimic WIMPs)

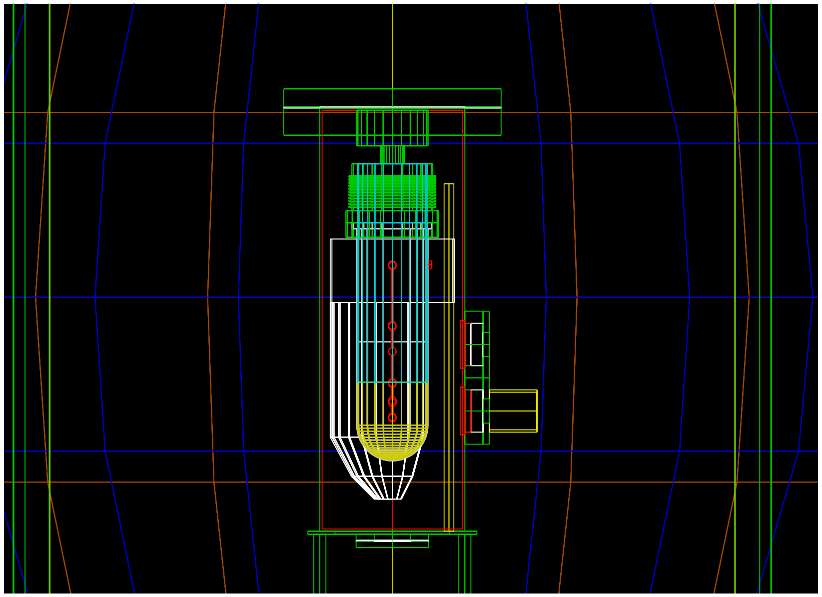
Three extremely important issues:
backgrounds, backgrounds and backgrounds

Crucial to correctly/precisely understand your detector
Model detectors with some standard tools:
SOURCES, MCNP, GEANT4, ...

Detectors in GEANT







PICO-60 and PICO-2L
GEANT4 models

DEAP-3600: search for dark matter with liquid Argon

DEAP3600 Collaboration

Queen's UNIVERSITY

Carleton UNIVERSITY

ROYAL HOLLOWAY UNIVERSITY OF LONDON

UNIVERSITY OF ALBERTA

iF Instituto de Física

Particle Physics
Rutherford Appleton Laboratory

TRIUMF

SNOLAB
MINING FOR KNOWLEDG
CREUSER POUR TROUVER... L'EXCELLENC

US University of Sussex

Science & Technology Facilities Council

Laurentian University
Université Laurentienne

DEAP

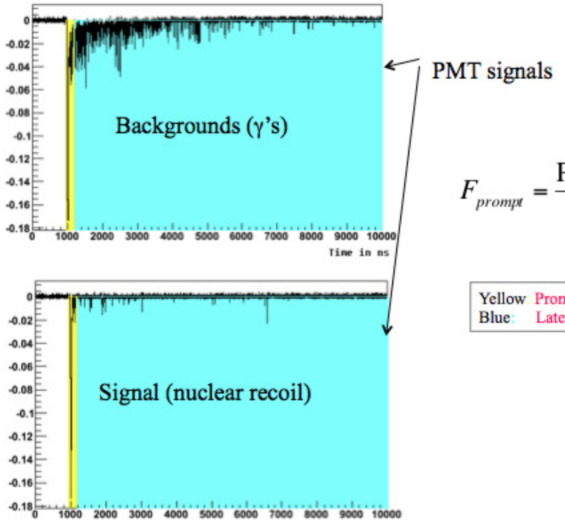
Dark Matter Experiment with Argon and Pulse-shape Discrimination:

- scattered nucleus detected via scintillation
- pulse shape discrimination for suppression of β/γ events
- LAr advantages:
  - is easily purified and high light yield
  - is well understood
  - has an easily accessible temperature $(85K)$
  - allows a very large detector mass with uniform response
- Detectors:
  - DEAP-1: prototype, 7 kg LAr, 2 PMTs
  - DEAP-3600: 3600 kg LAr, 255 8” PMTs

DEAP-1

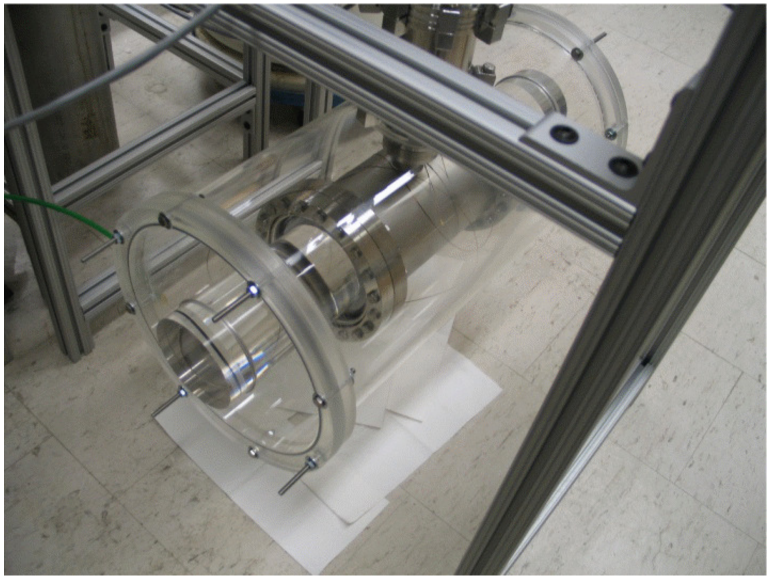
Demonstrate discrimination between electromagnetic events and nuclear recoils

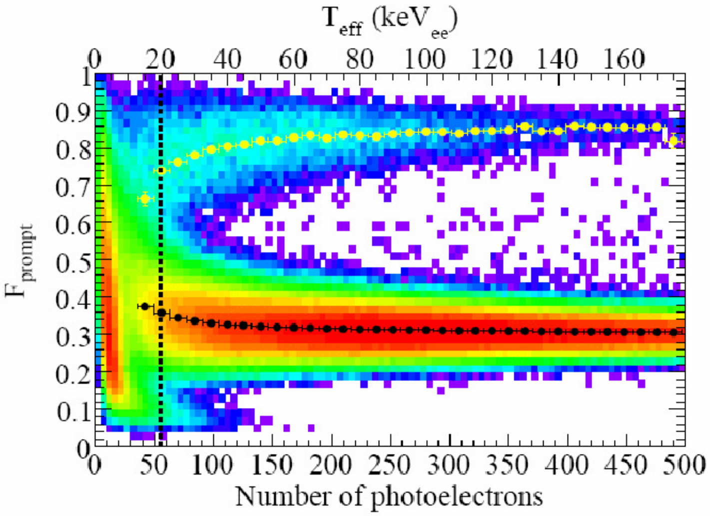
γ suppression better than: 3×10^{-8}

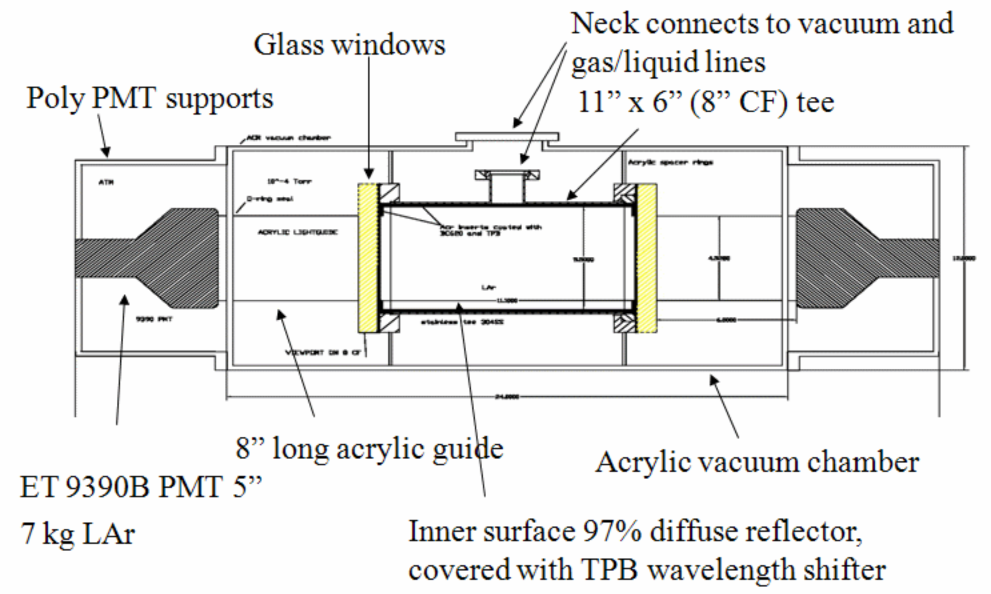


$$F_{prompt} = \frac{\text{PromptPE } (150ns)}{\text{TotalPE } (9\mu s)}$$

Yellow: Prompt light region
Blue: Late light region







Glass windows

Neck connects to vacuum and gas/liquid lines

11” x 6” (8” CF) tee

Poly PMT supports

8” long acrylic guide

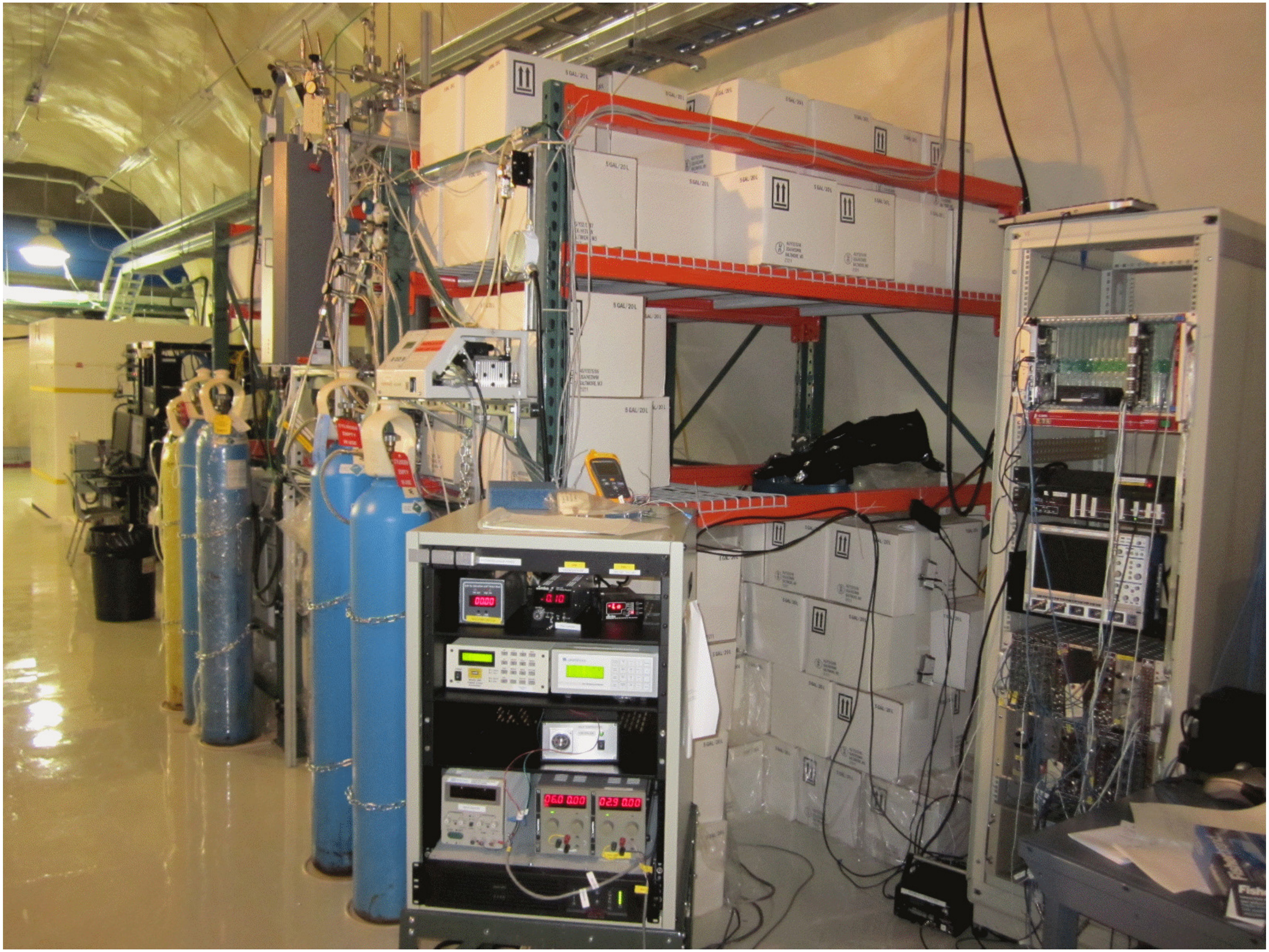
Acrylic vacuum chamber

ET 9390B PMT 5”

7 kg LAr

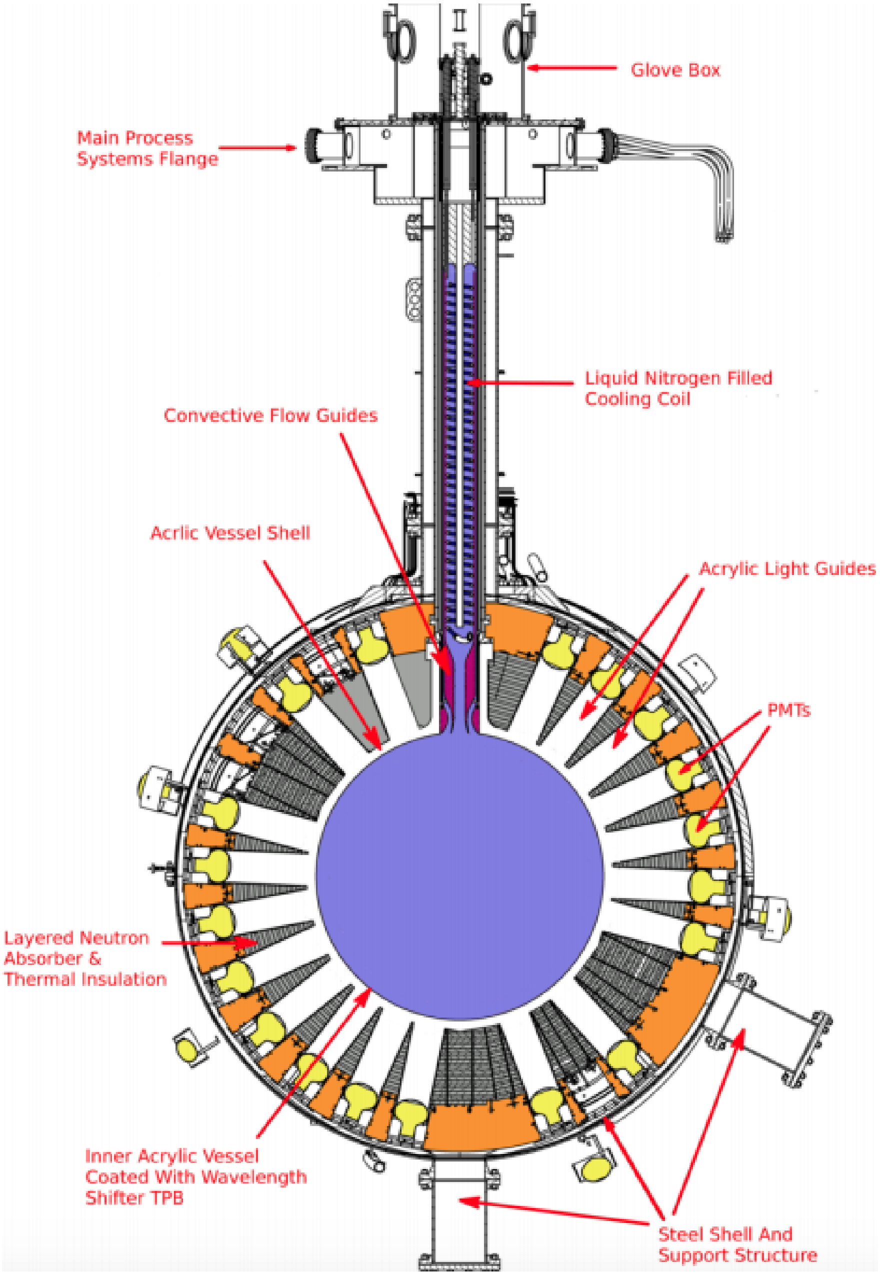
Inner surface 97% diffuse reflector, covered with TPB wavelength shifter

DEAP-1

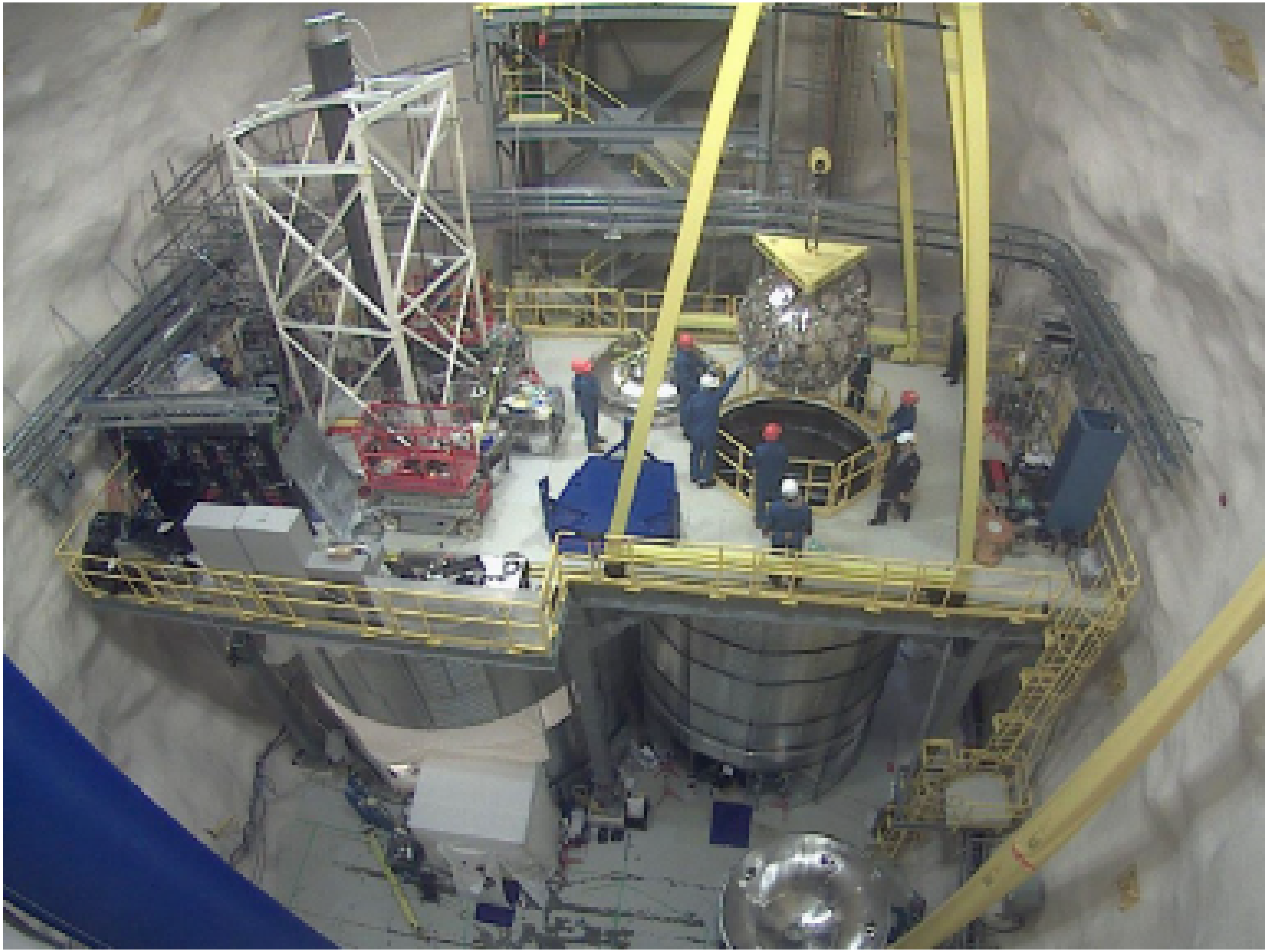


DEAP-3600

- 3600 kg argon
  (1000 kg fiducial)
  in ultra-clean AV
- Vessel is “resurfaced” in-situ
  to remove Rn daughters
- TPB wavelength shifter
  deposition
- 255 Hamamatsu R5912
  HQE 8” PMTs
  (75% coverage)
- 50 cm light guides
  PE shielding for neutron
  moderation
- 8 m water shield
  in Cube Hall

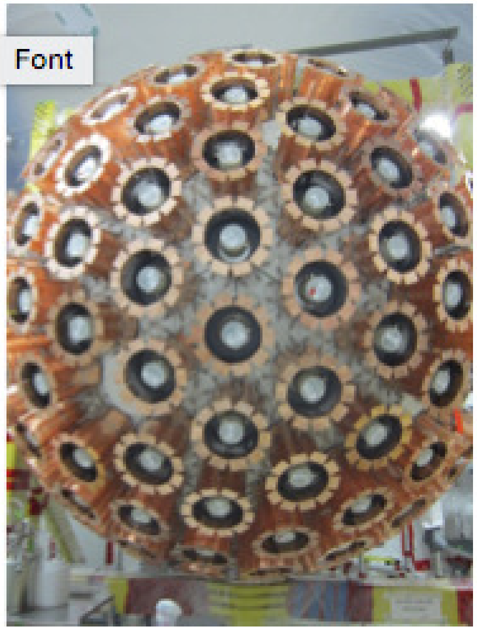


DEAP-3600

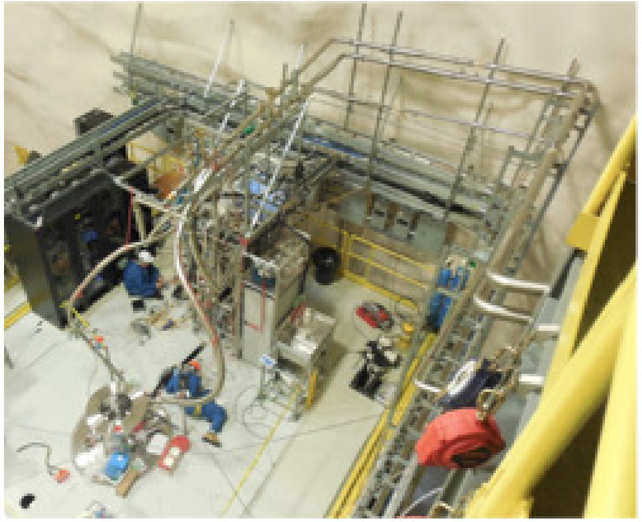


DEAP progress

Status of DEAP-3600 Installation at SNOLAB



Completed inner detector



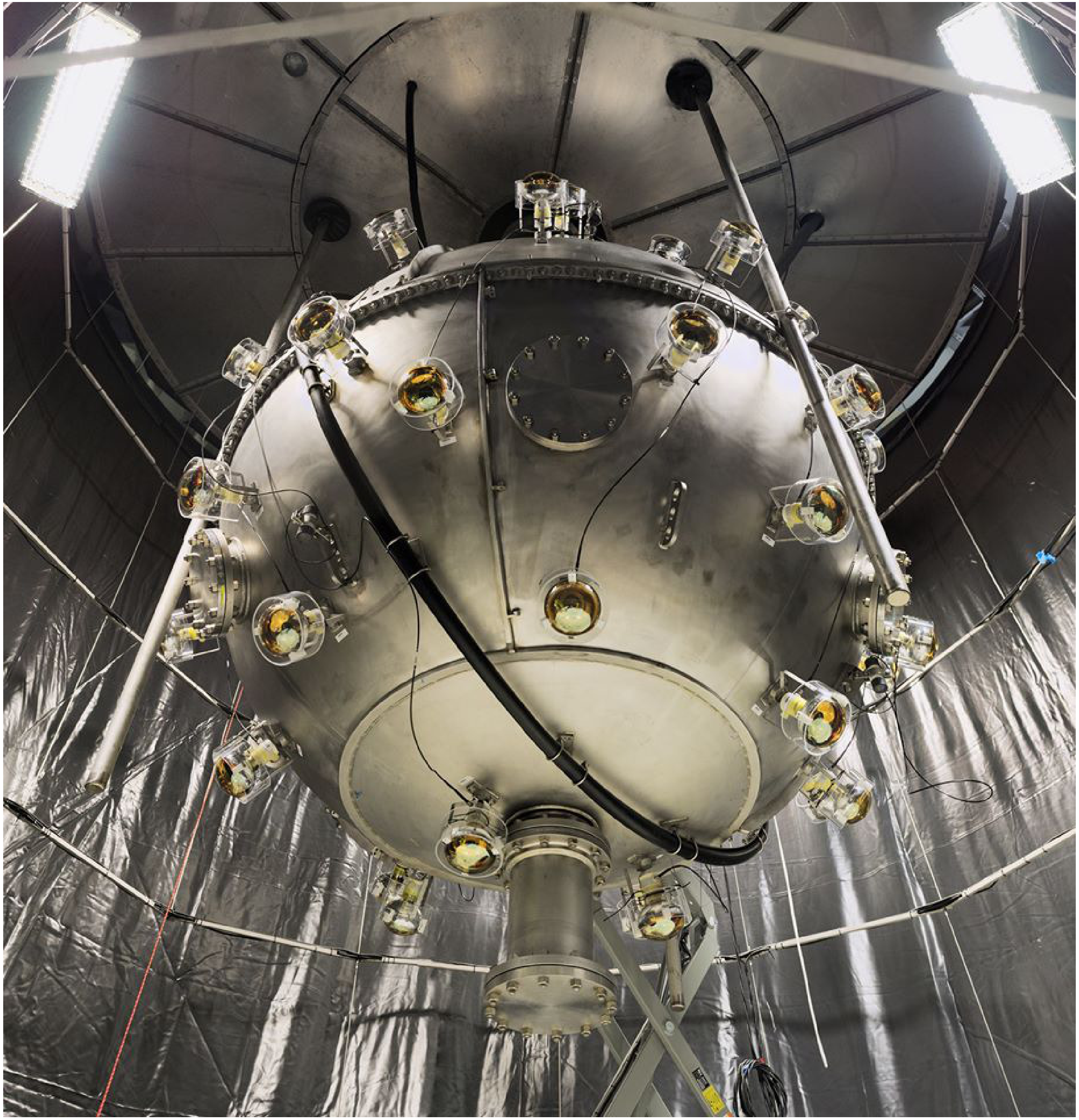
Cryosystem, electronics

Detector ready for Final Lift onto Neck

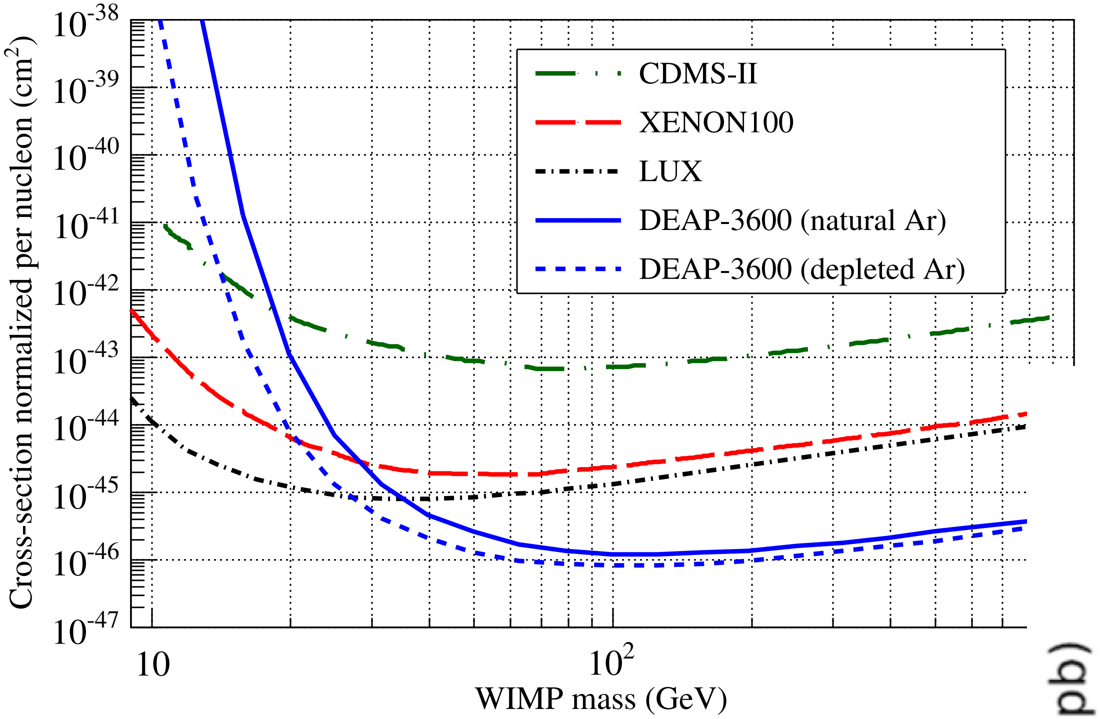
Steel Shell in shield tank

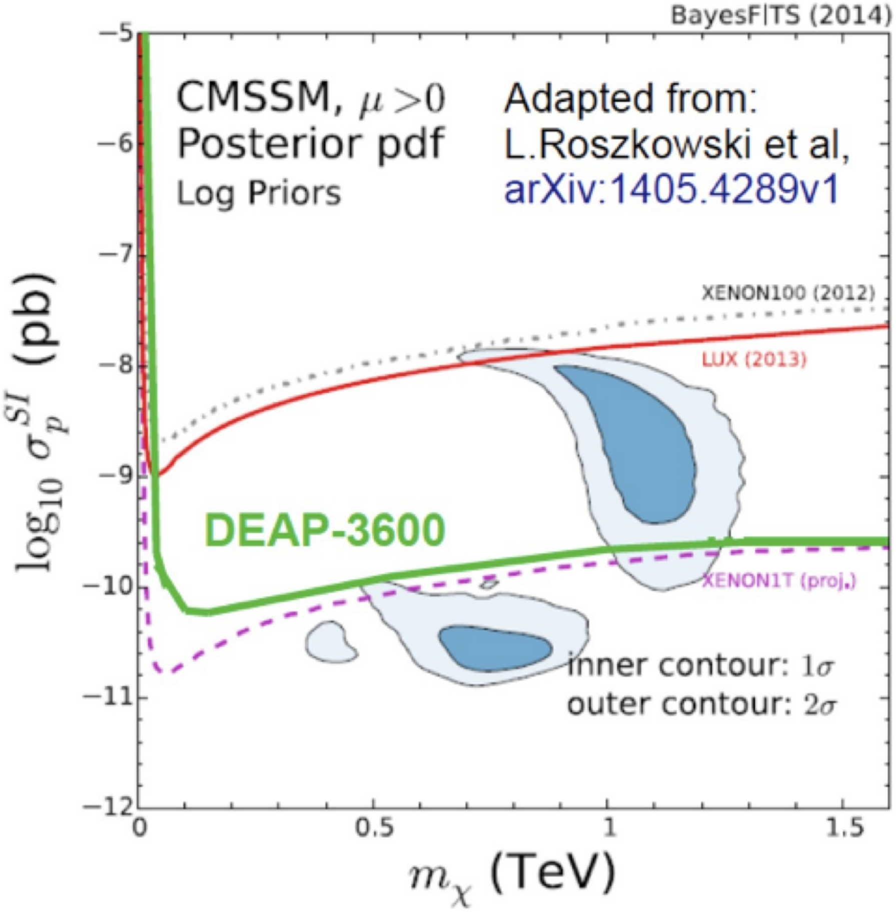
View down detector neck

DEAP-3600 almost ready!



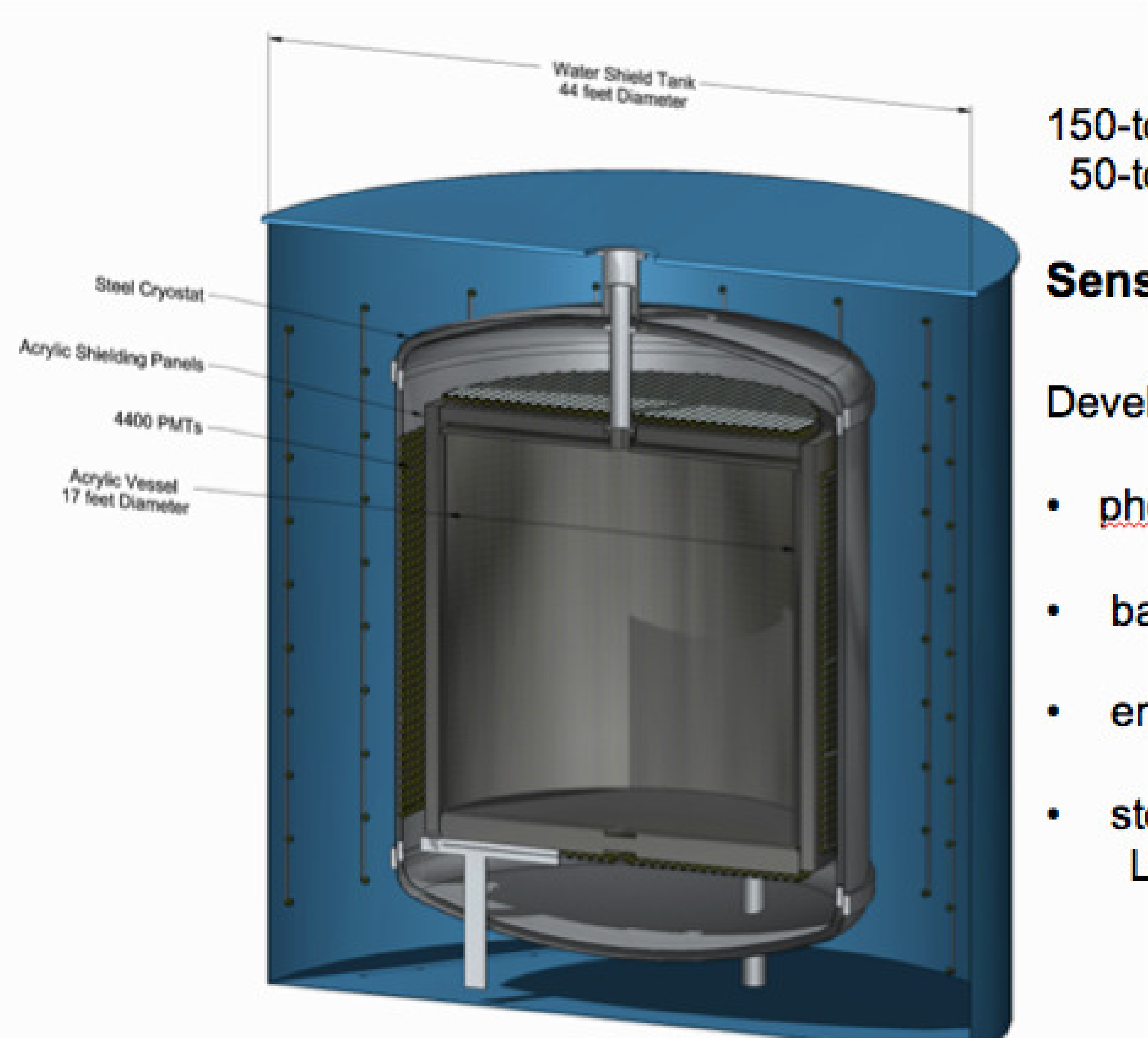
DEAP-3600 sensitivity





Future: DEAP-50T

DEAP-50T: 50-tonnes (fiducial) of liquid argon



150-tonnes DAr in AV
50-tonne fiducial

Sensitivity 10^{-48} cm^2

Development Proposal:

- photodetector characterization
- background reduction
- engineering design and safety
- storage and screening of Low-Radioactivity Argon

Conclusions

- **PICO bubble chambers are producing world leading direct detection limits using flourine targets**
- **PICO-2L has a new world-best spin dependent WIMP-proton limit**
- **PICO-60 results are inconsistent with hypothesis that DAMA modulation is due to iodine recoils and is an independent iodine experiment**
  - **PICO-2L is running again with better cleaning protocols and temperature control**
  - **PICO-60 is being upgraded for a C3F8 run this fall with better temperature control, muon tagging, and particulate control**
- **DEAP-3600 commissioning under way**
- **First data from DEAP-3600 coming this fall**
- **Potential to become the best detector for spin independent WIMP-proton couplings (WIMP masses around 100 GeV)**

IFUNAM actively participating in PICO and DEAP

SNO+ Collaboration

SNOLAB
TRIUMF
UNIVERSITY OF ALBERTA
QUEENS UNIVERSITY
LAURENTIAN UNIVERSITY

ARMSTRONG STATE UNIVERSITY
BROOKHAVEN NATIONAL LAB
UNIVERSITY OF CALIFORNIA
BERKELEY
UNIVERSITY OF CHICAGO
UNIVERSITY OF PENNSYLVANIA
UNIVERSITY OF WASHINGTON
UC DAVIS

OXFORD UNIVERSITY
QUEEN MARY,
UNIVERSITY OF LONDON
UNIVERSITY OF LIVERPOOL
UNIVERSITY OF SUSSEX
UNIVERSITY OF LANCASTER

TU DRESDEN

LIP COIMBRA
LIP LISBOA

UNAM

SNO+ Physics Goals

- **Double beta decay with Tellurium**
- **Low energy solar neutrinos**
- **Geo-neutrinos**
- **Reactor neutrino oscillations**
- **Supernova neutrinos**
- **Nucleon decay**
- **Other exotic searches: axions**

The top priority is a sensitive search for neutrinoless double-beta decay ($0\nu\beta\beta$) in ^{130}Te