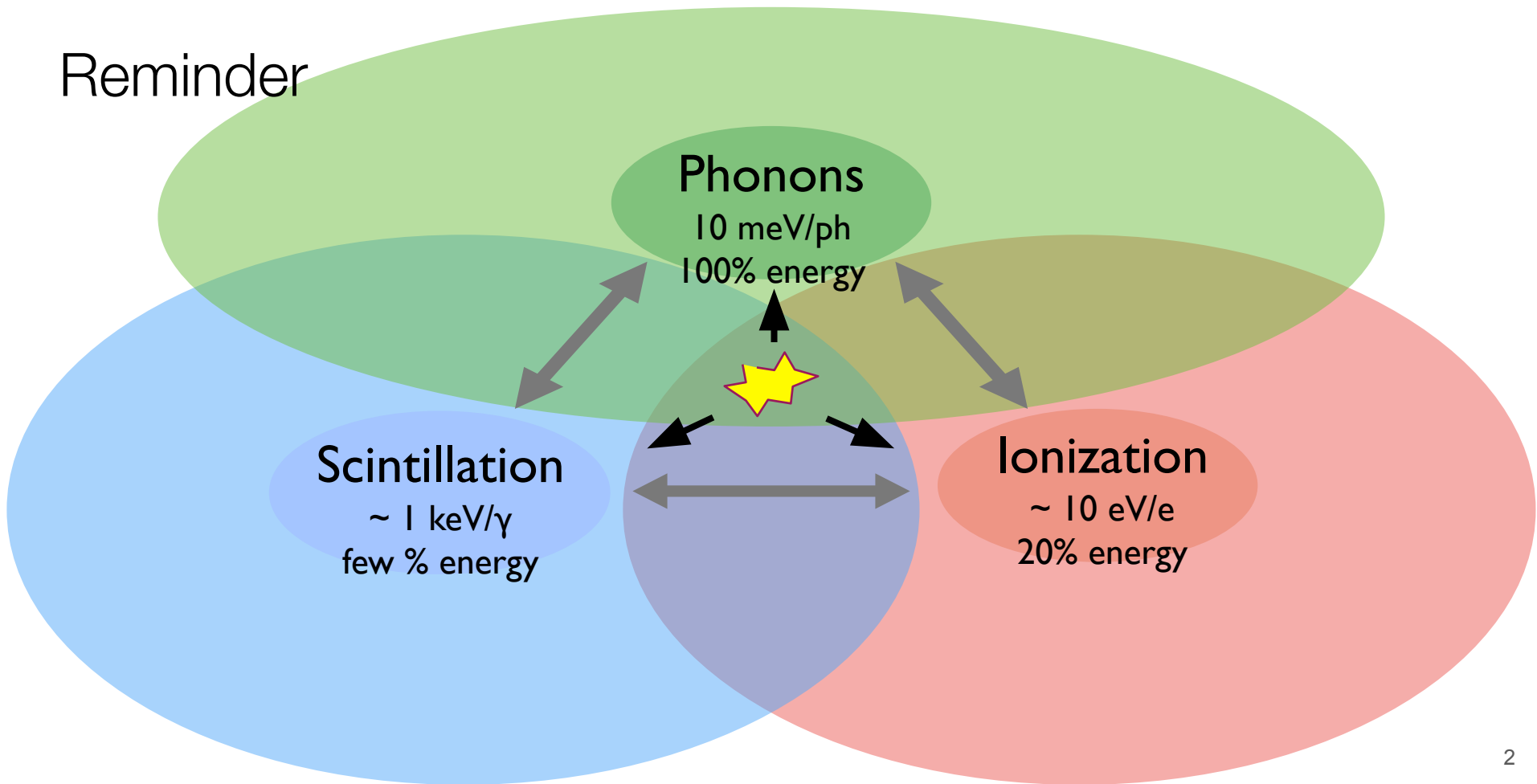


Other Rare Event Detectors

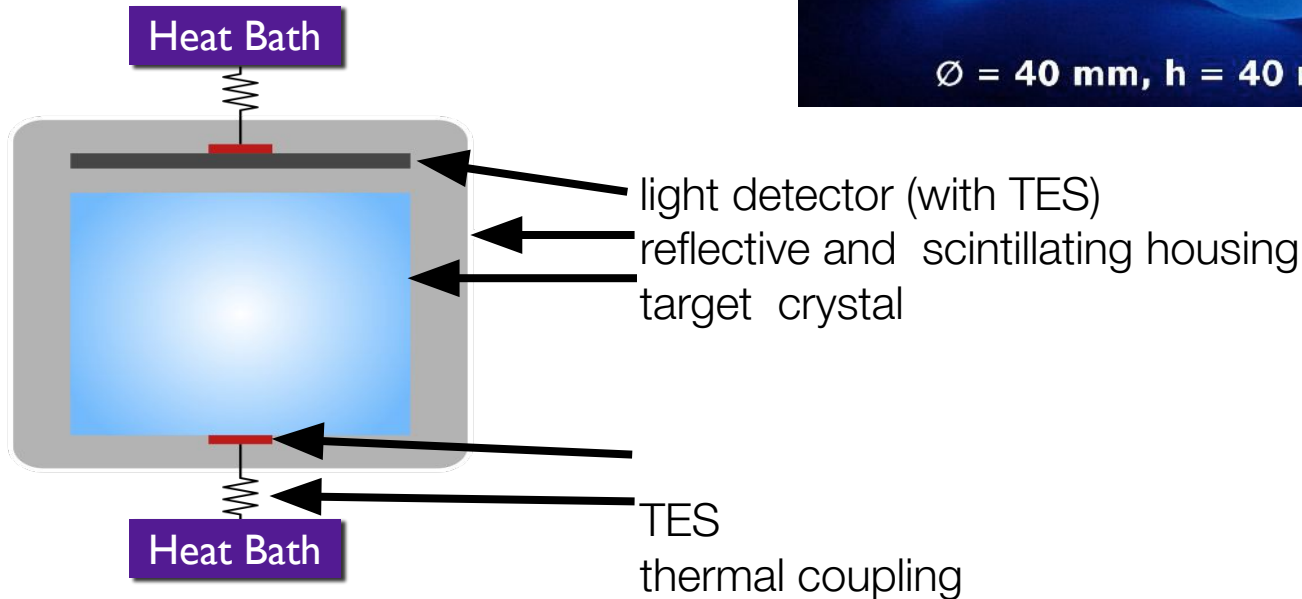
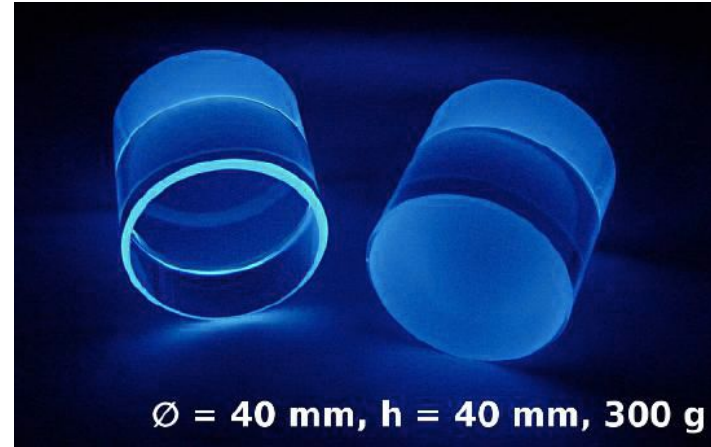
-- Other than SuperCDMS...

Reminder



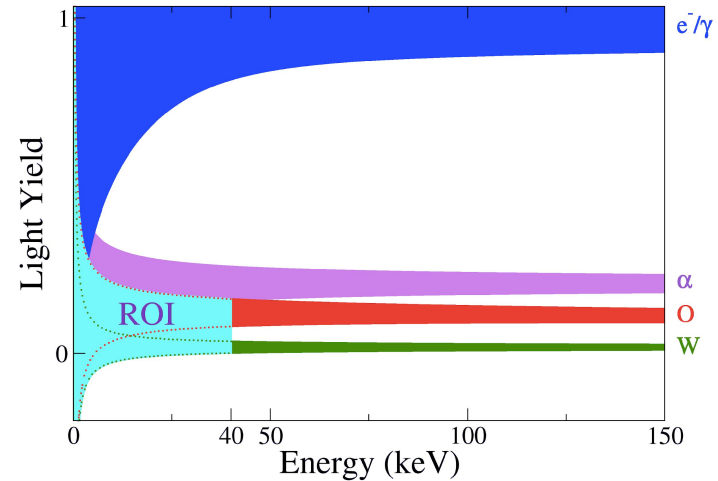
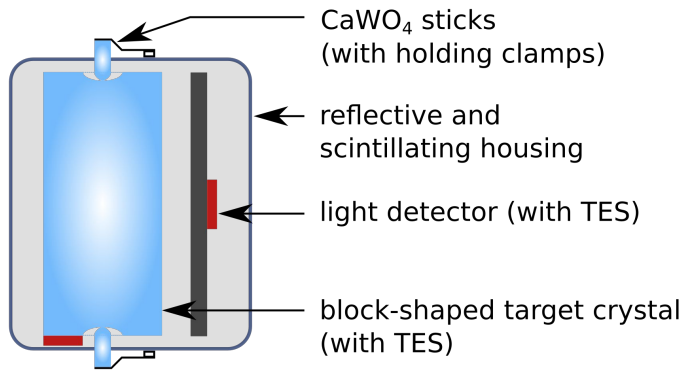
CRESST

- CRESST: phonon + light
- Thermal TES sensors



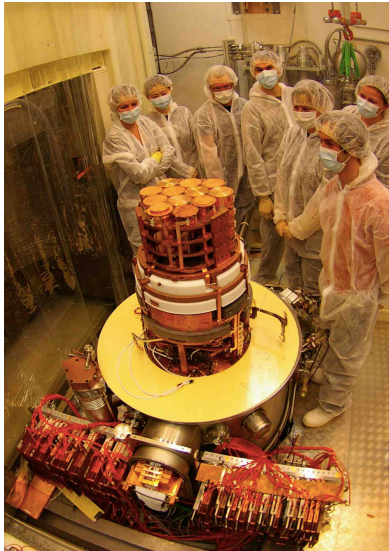
CRESST

- CRESST III detectors focused on low-mass WIMPs
- Design Goal: Threshold of 100 eV. How? Smaller Crystals!
- Going from 250g in CRESST II to 24g in CRESST III

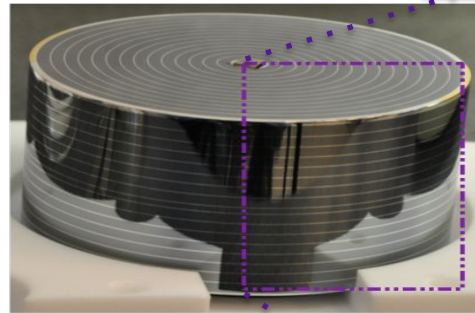


EDELWEISS

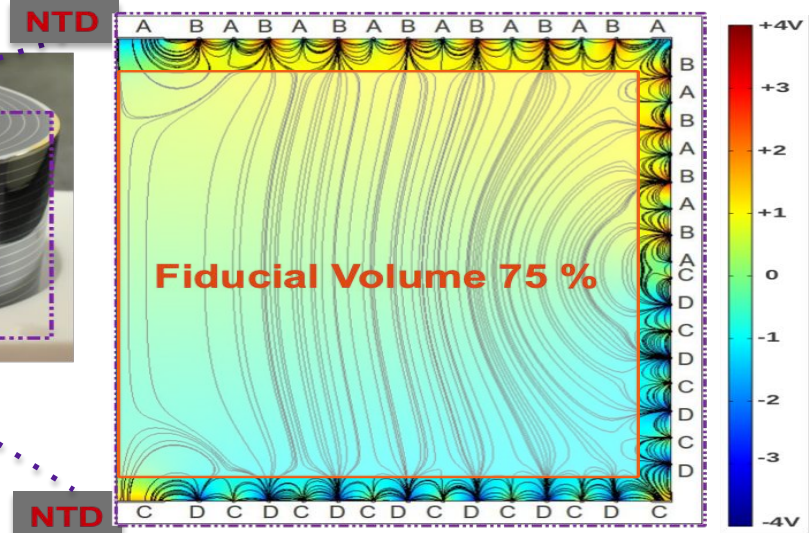
- EDELWEISS: phonon + charge
- 36 x 800 g detectors
- “Fully Inter-Digitized” charge sensors -- instrumented on the sidewalls
- NTD as heat sensor -- thermal detector



Height : 4cm



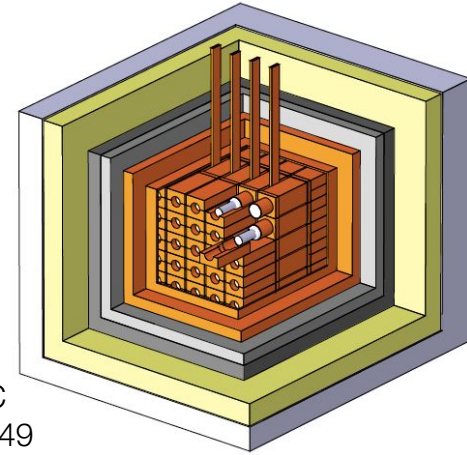
Width : 7cm



DAMA/LIBRA Experiment

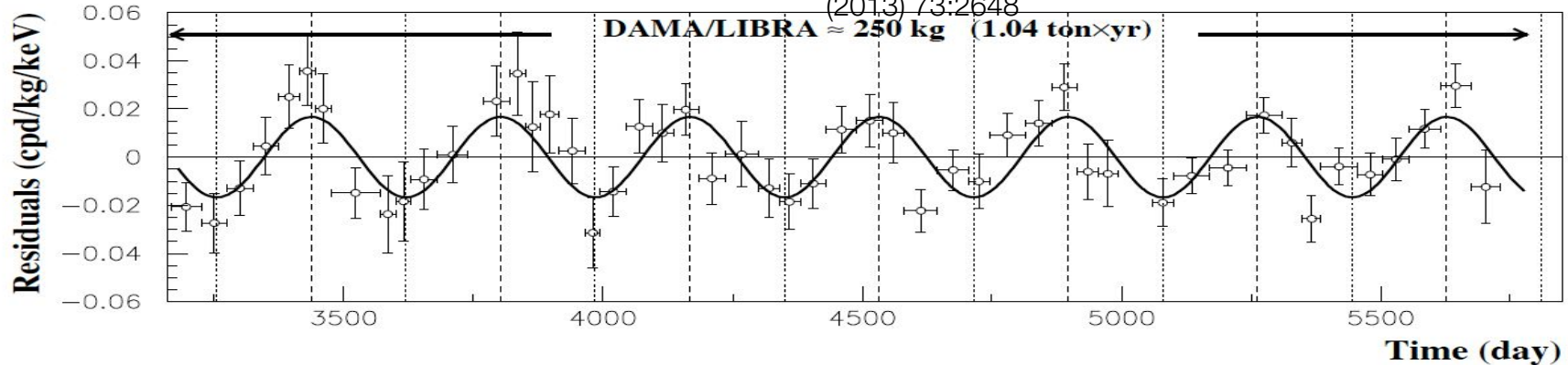
Have we already detected dark matter?

- Using an array of 25 radiopure NaI(Tl) crystals, DAMA/NaI reported an annual modulation in event rate consistent with dark matter, observed over 7 annual cycles.



Eur. Phys. J. C
(2010) 67: 39–49

2-4 keV Eur. Phys. J. C
(2013) 73:2648



Checking DAMA with NaI Detectors

Northern Hemisphere	Gran Sasso DAMA/LIBRA 250 kg running	Boulby DM-Ice North 37 kg R&D 250 kg planned	Canfranc ANAIS 37 kg R&D 250 kg planned	Y2L KIMS 45 kg R&D 200 kg planned	Gran Sasso SABRE R&D	Kamioka PICO-LON KamLAND- PICO R&D
Southern Hemisphere		South Pole DM-Ice 17 kg running 250 kg planned			Stawell SABRE Lab completion 2017	rock ice

Ultra-pure crystal development underway by DM-Ice, KIMS, ANAIS, SABRE, and PICO-LON collaborations

South Pole offers:

- Ultra-clean and ultra-stable environment
- Seasonal variation unambiguously different from dark matter modulation
- IceCube offers muon monitoring and veto as well as experience
- NSF-run South Pole Station for logistical support

Note: Annual Modulation is also being looked for with other detector technologies!

DM-ICE 17

Location: South Pole, Antarctica

Depth: 2457 m (2200 m.w.e)

Deployment: Dec. 2010

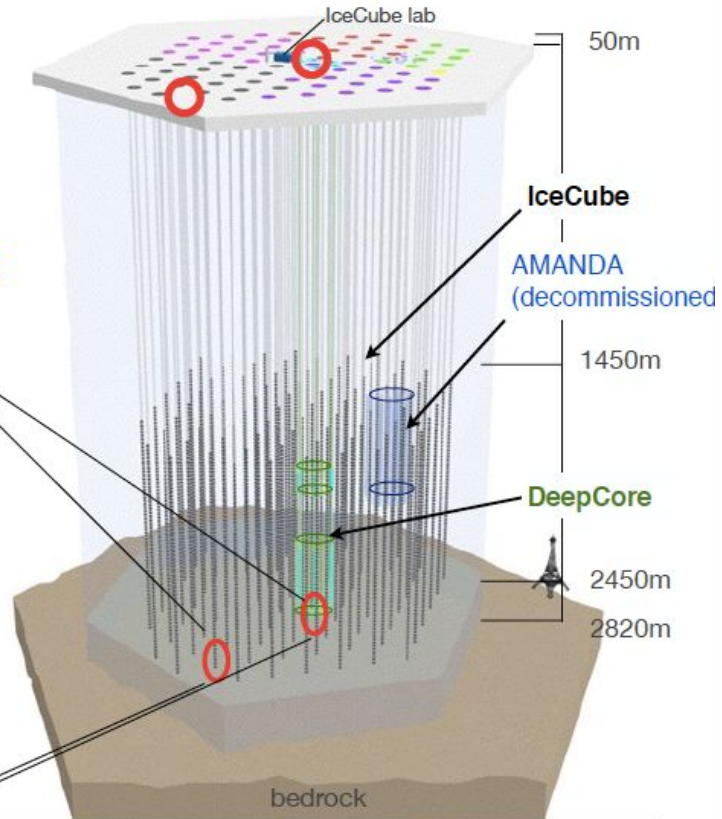
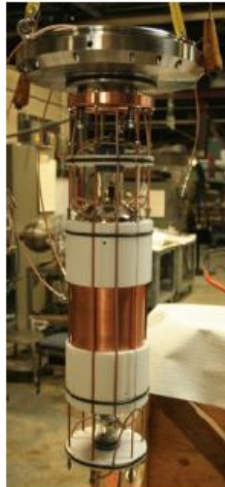
Science Run: Jun. 2011 – Jan. 2015

Uptime: > 99%

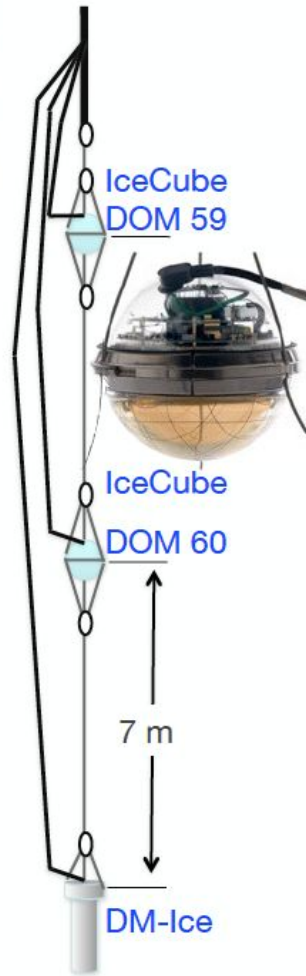
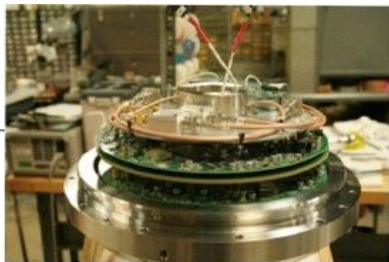
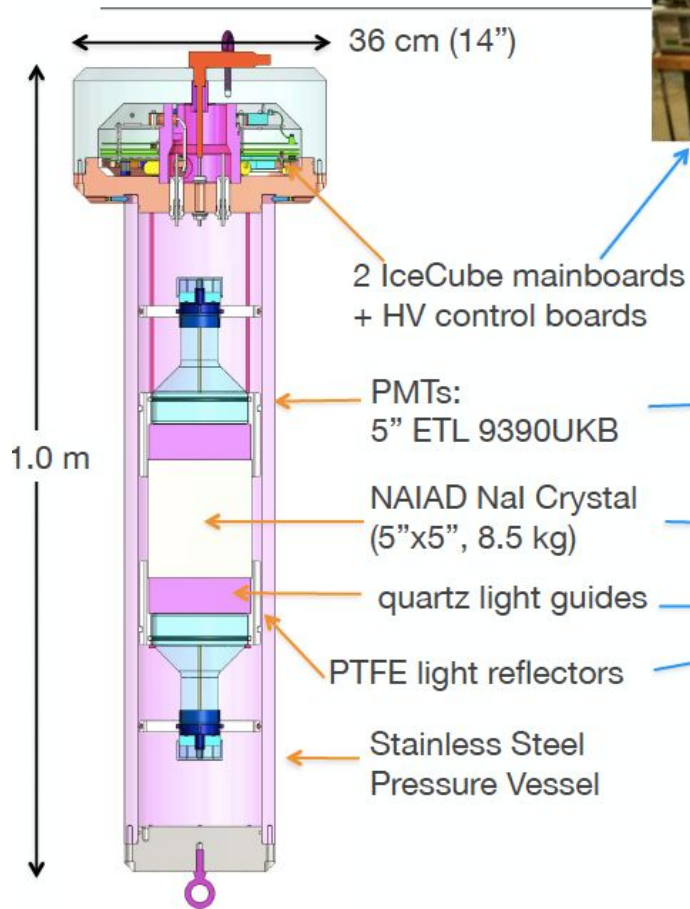
Exposure: 60.8 kg-yr

Target: NaI(Tl)

Mass: 2 x 8.5 kg

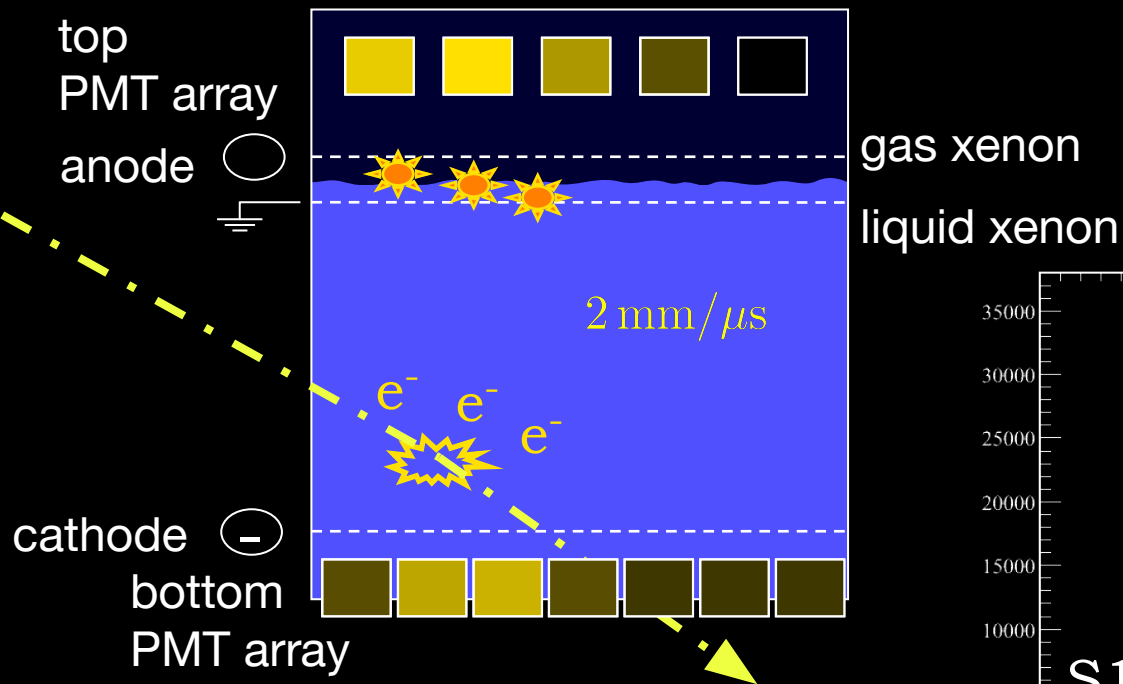


DM-Ice-17 Detector

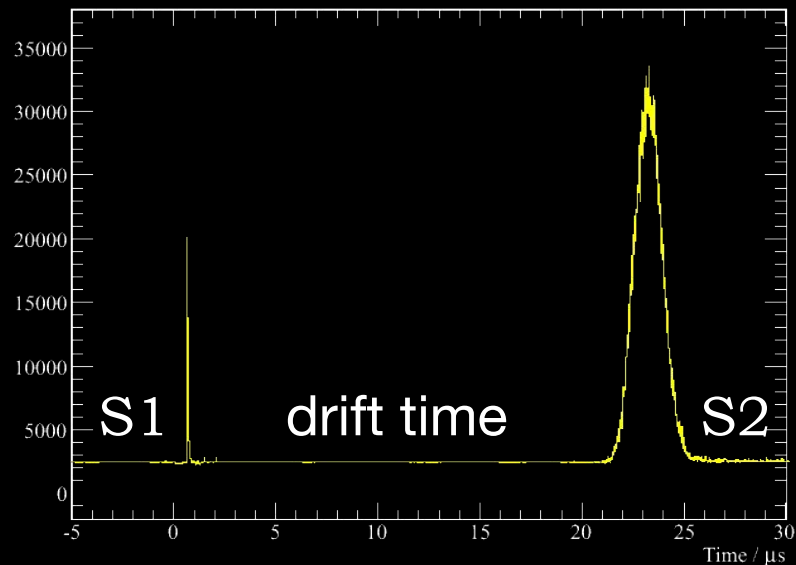


Noble Liquid Time Projection Chambers

<https://xenonexperiment.org/time-projection-chamber/>



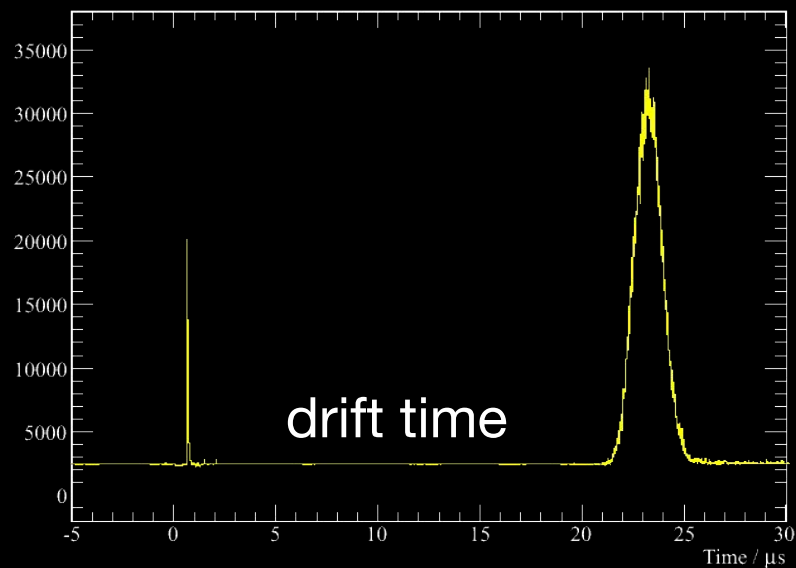
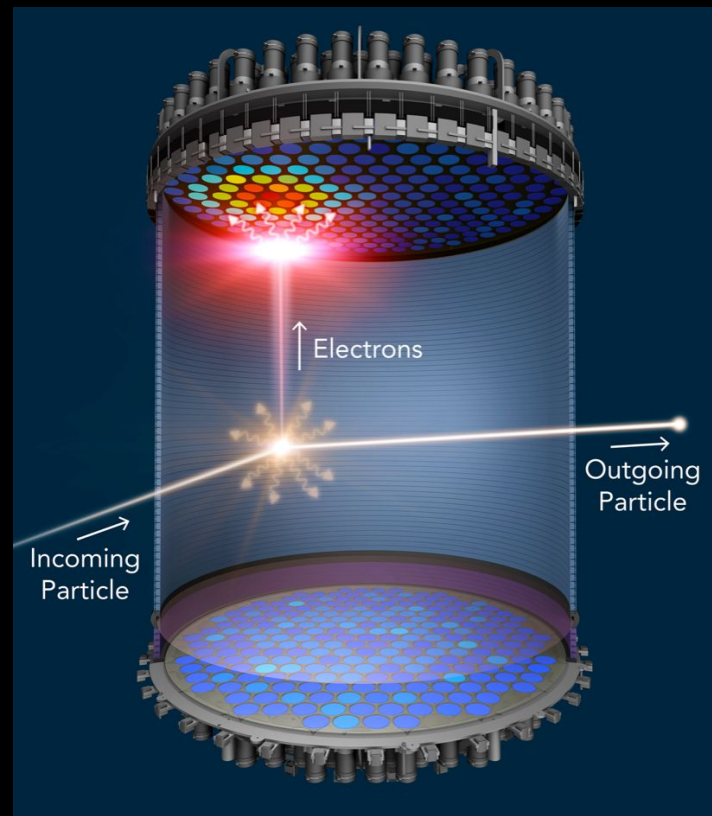
- Obtain vertex position from S2 hit pattern and drift time
- Ratio of S2/S1 provides nuclear/electron recoil discrimination



Slide courtesy of Rafael Lang

Noble Liquid Time Projection Chambers

- Obtain vertex position from S2 hit pattern and drift time
- Ratio of S2/S1 provides nuclear/electron recoil discrimination



Signal Production in Noble Liquids

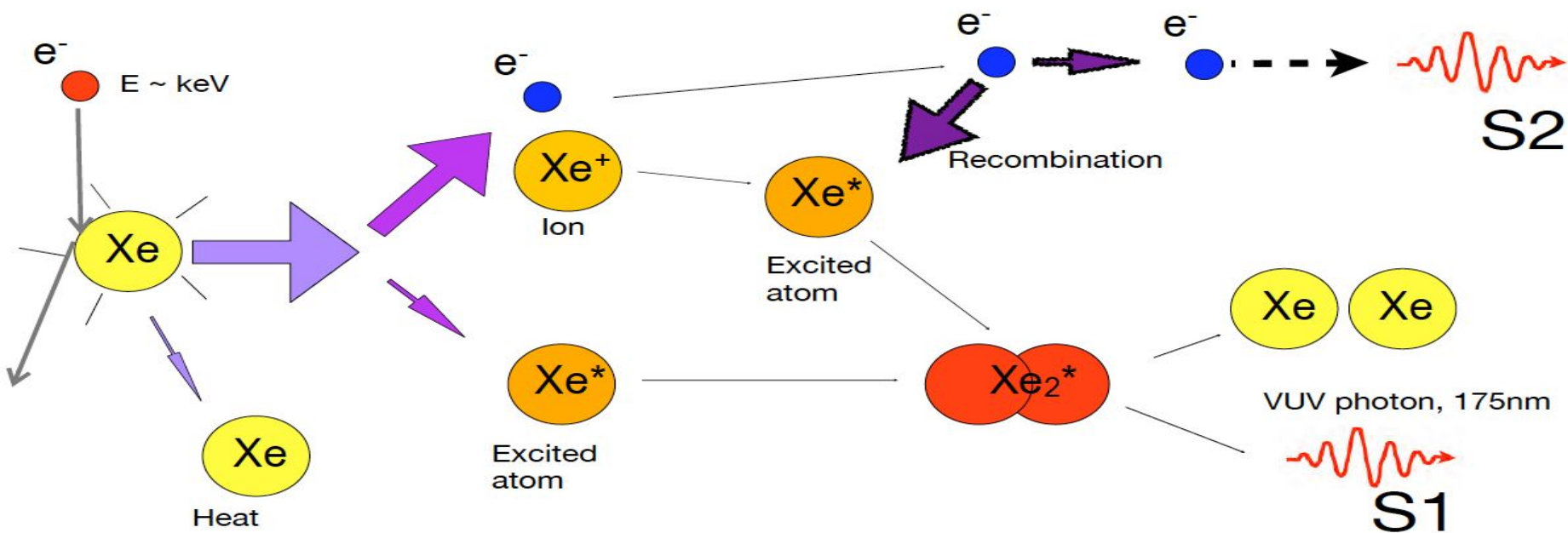


Figure: Gibson/Shutt

Electron Recoils
Low field, low energy

Signal Production in Noble Liquids

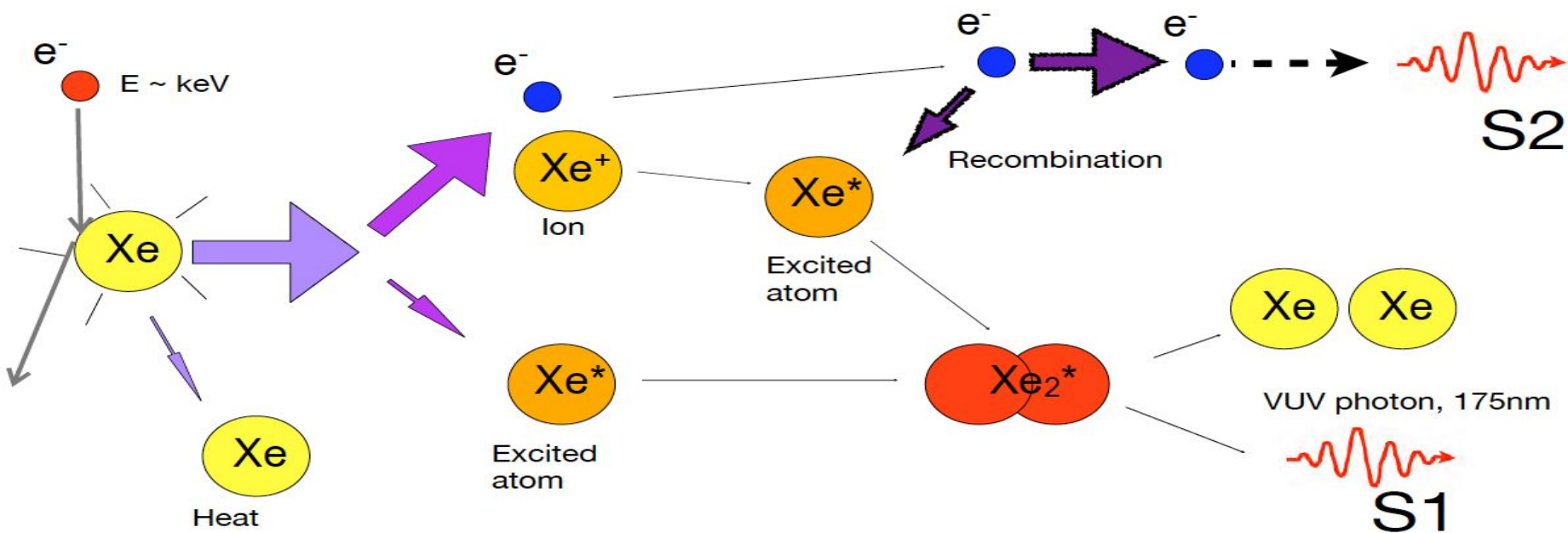


Figure: Gibson/Shutt

Electron Recoils
High field, high energy

Signal Production in Noble Liquids

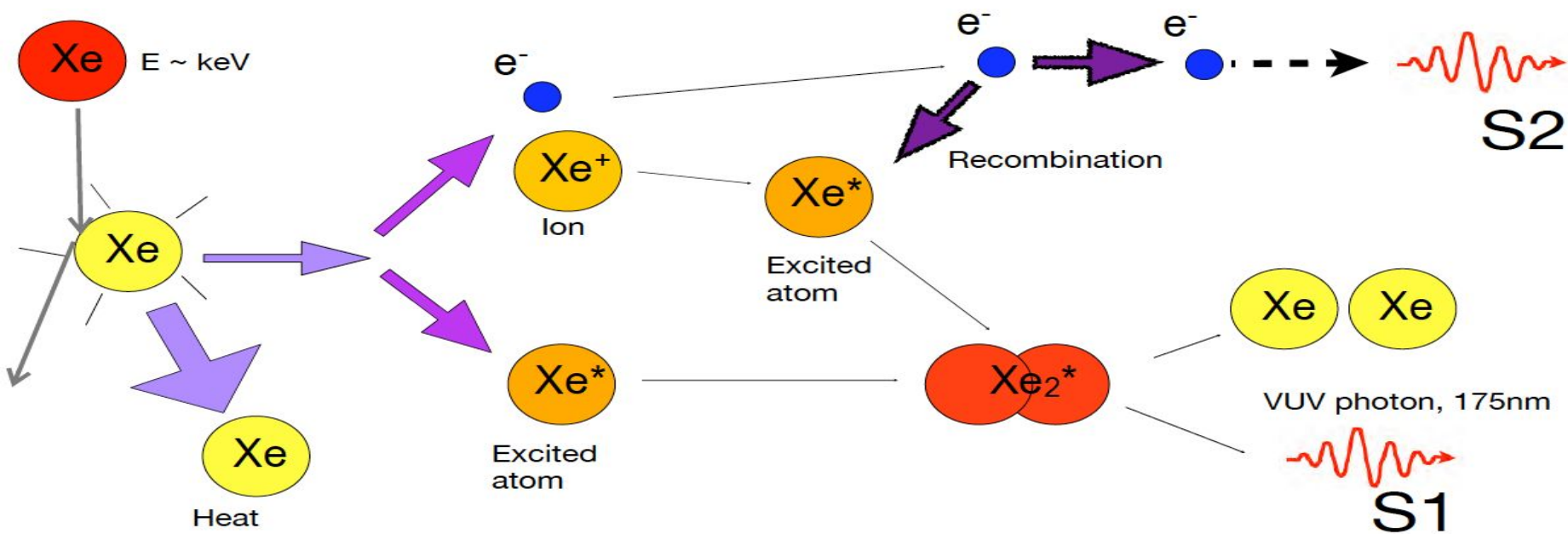
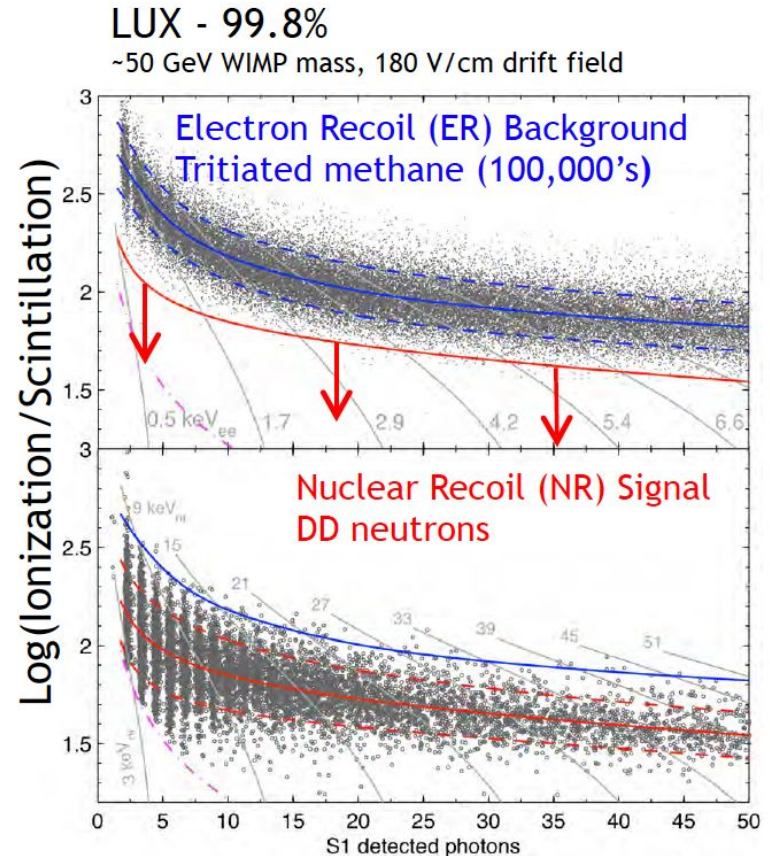


Figure: Gibson/Shutt

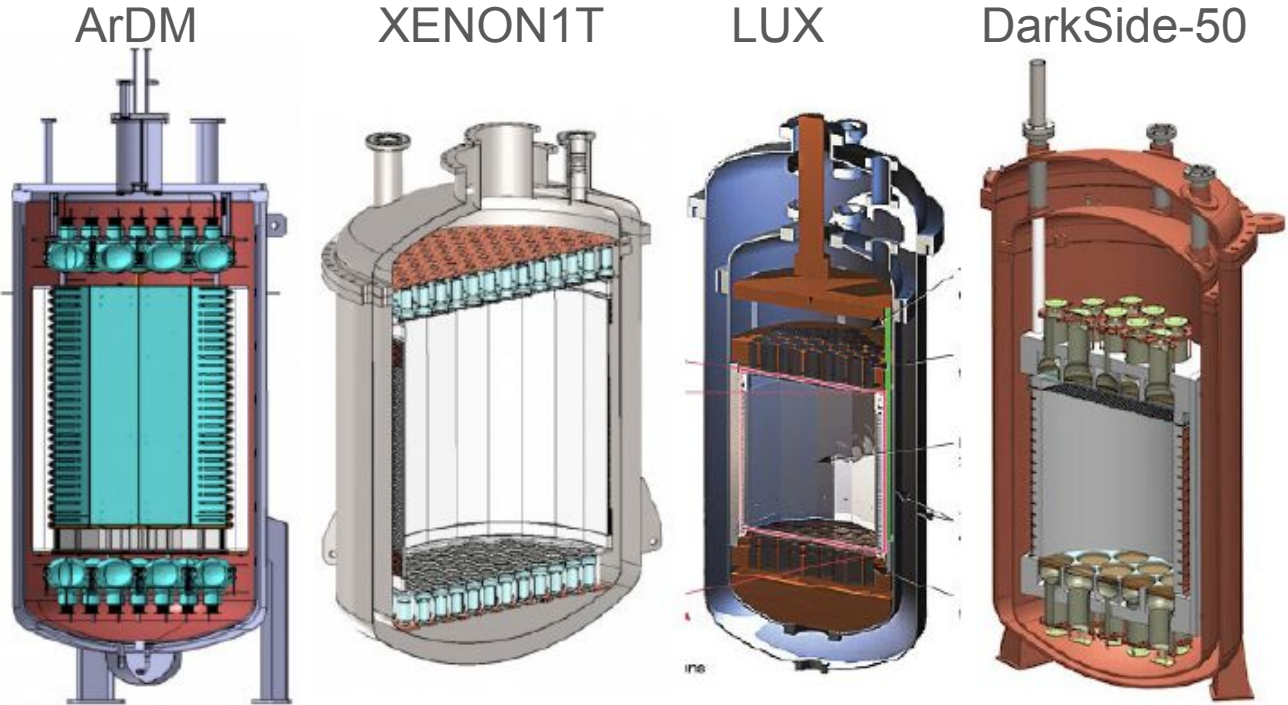
Nuclear Recoils

Signal Production in Noble Liquids

- Electron Recoils and Nuclear Recoils are Separated in $\text{Log}(S2/S1)$ vs $S1$ plane
- Look for WIMPs below the mean of the nuclear recoil distribution (the red line in the plot)



Noble Liquid Time Projection Chambers



NOT TO SCALE!

Current Two-Phase XeTPCs for WIMP Search

XENONnT@LNGS

LZ@SURF

PandaX-4T@JinPing

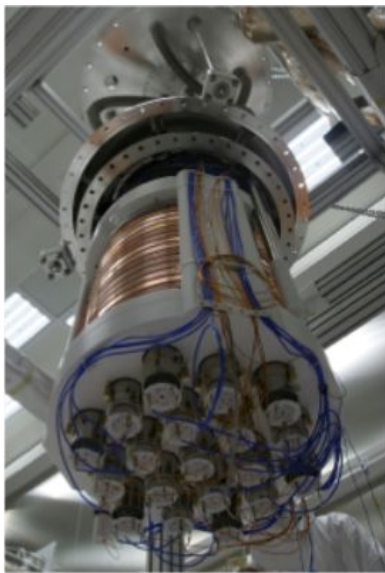
<https://indico.cern.ch/event/1188759/contributions/5044010/>



	XENONnT	LZ	PandaX-4T
Total (sensitive) mass	8.5 (5.9) tonnes	10 (7) tonnes	5.6 (3.7) tonnes
3-inch PMTs	494	494	368
Drift Field	23 V/cm	193 V/cm	93 V/cm

The DarkSide Program: Liquid Argon TPC

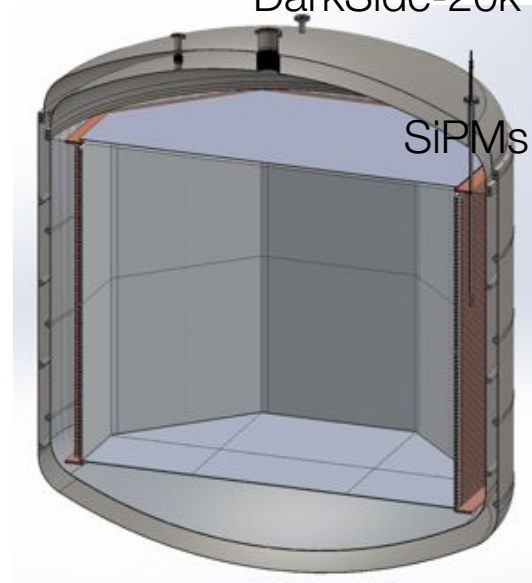
DarkSide-50



- 46 kg active Ar, 36.9 kg Fiducial
- Active neutron veto (borated liquid scintillator)
- Using underground Ar obtained 1400x less ^{39}Ar events than atmospheric Ar

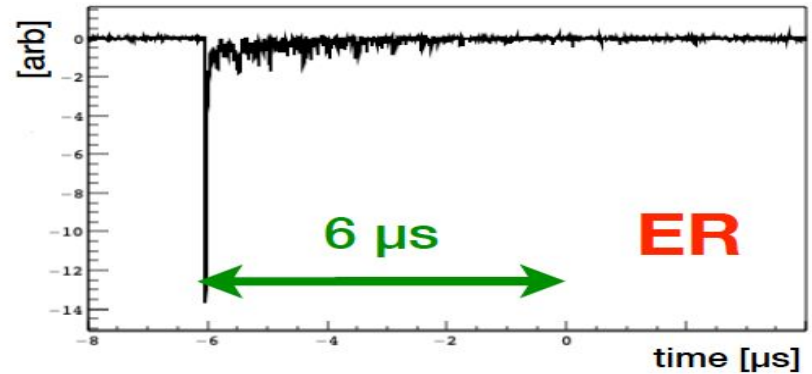
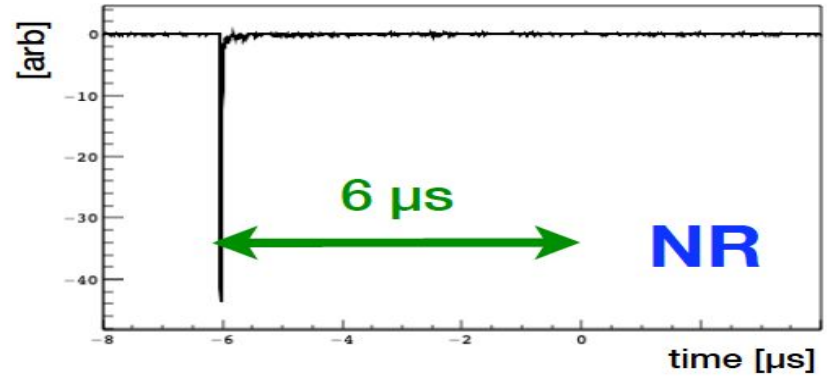
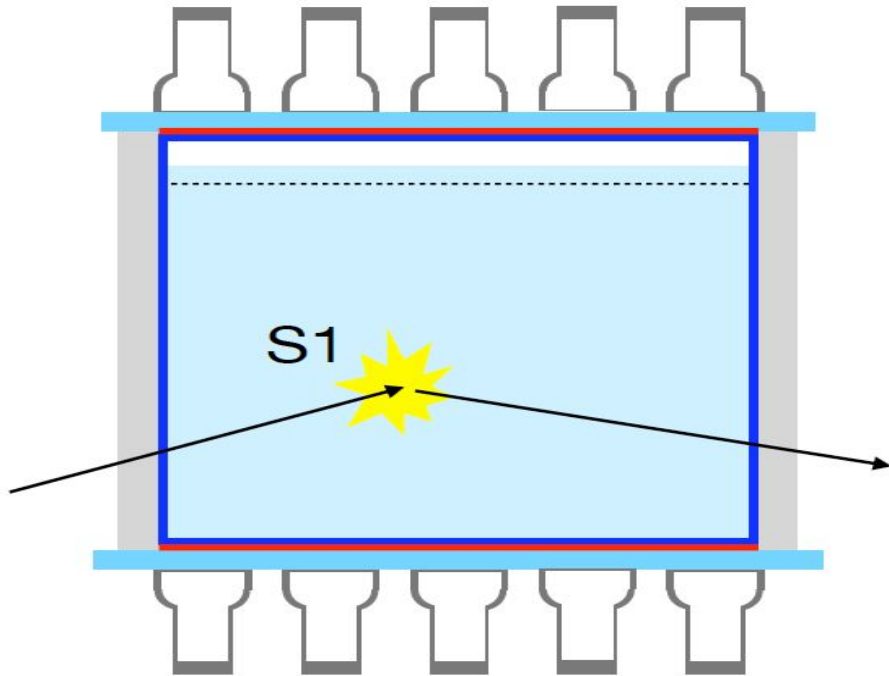


DarkSide-20k



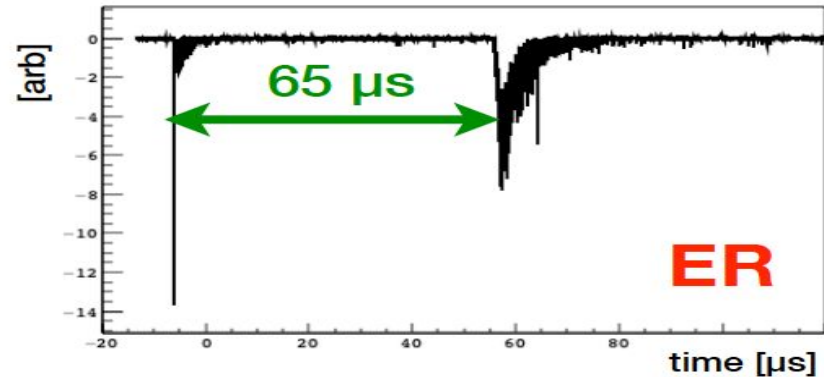
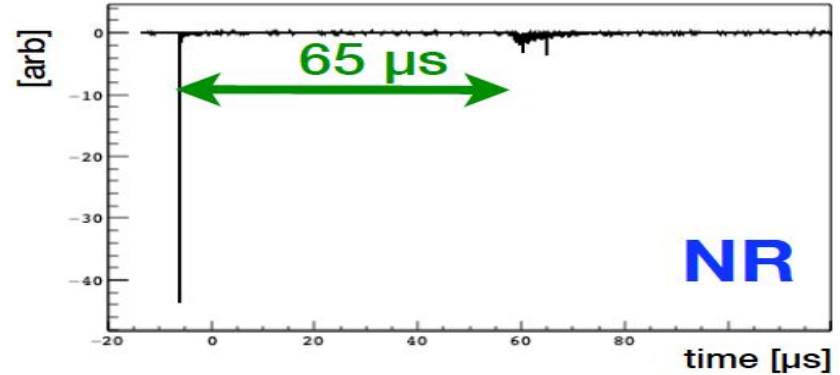
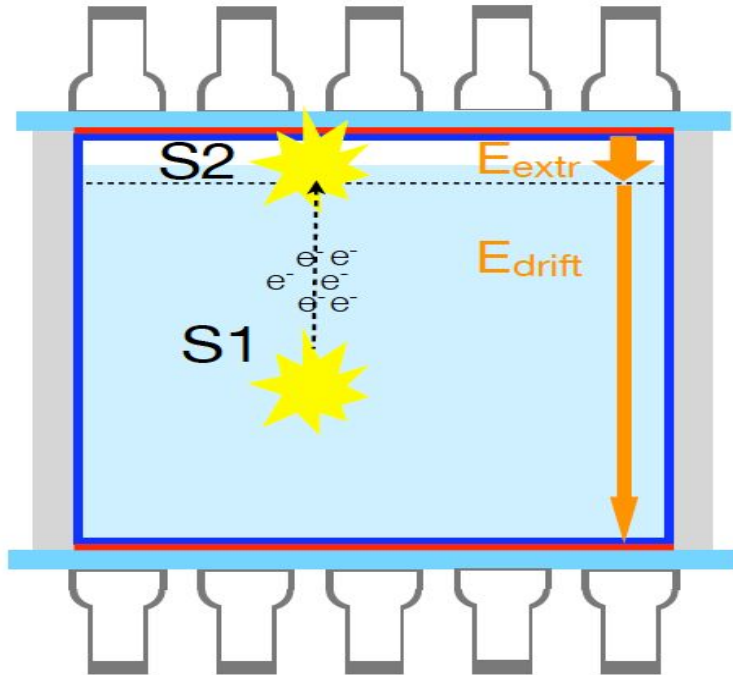
- 23 Ton Ar, 20 Ton fiducial
- 100 Ton-yr background-free exposure
- Gd-loaded Water Cherenkov active veto
- Timeline: TBD

Dual Phase Liquid Argon TPC



PSD parameter: **F90** = fraction of light in first 90 ns

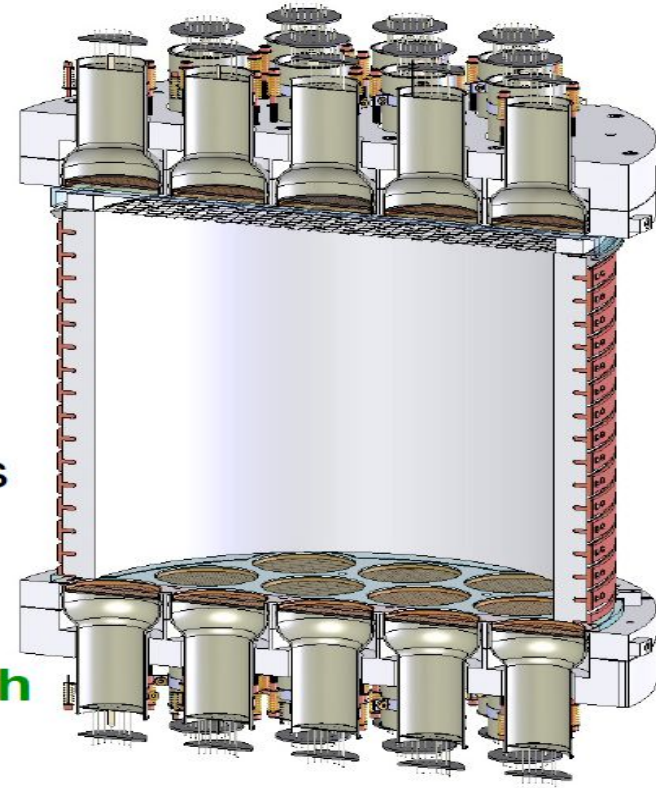
Dual Phase Liquid Argon TPC



S2 allows for **3D position reconstruction** and additional discrimination power

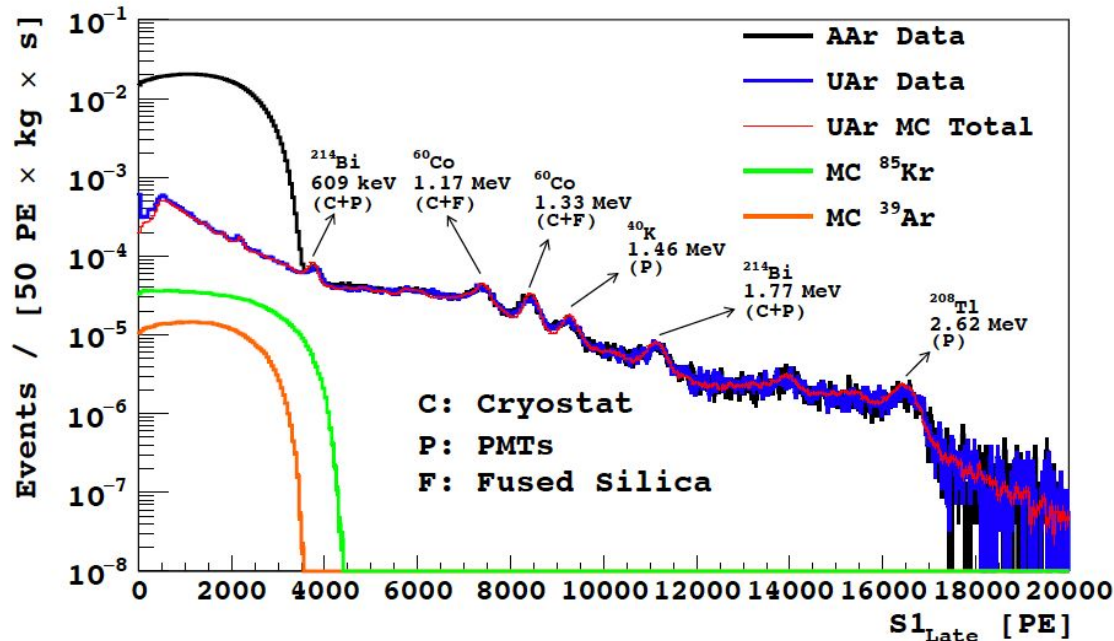
Dual Phase Liquid Argon TPC

- **46 kg active** volume
- 36 cm diameter, 36 cm height
- 38 3" PMTs
- **Cold pre-amps**
- High **reflectivity** Teflon walls
- Fused silica anode and cathode windows
 - Coated with **transparent conductor** (Indium Tin Oxide)
- All inner surfaces coated with **wavelength shifter** (Tetraphenyl Butadiene)
- 0.2 kV/cm drift, 2.8 kV/cm extraction



Lowering ^{39}Ar background using Underground Ar

^{39}Ar reduction factor: 1400



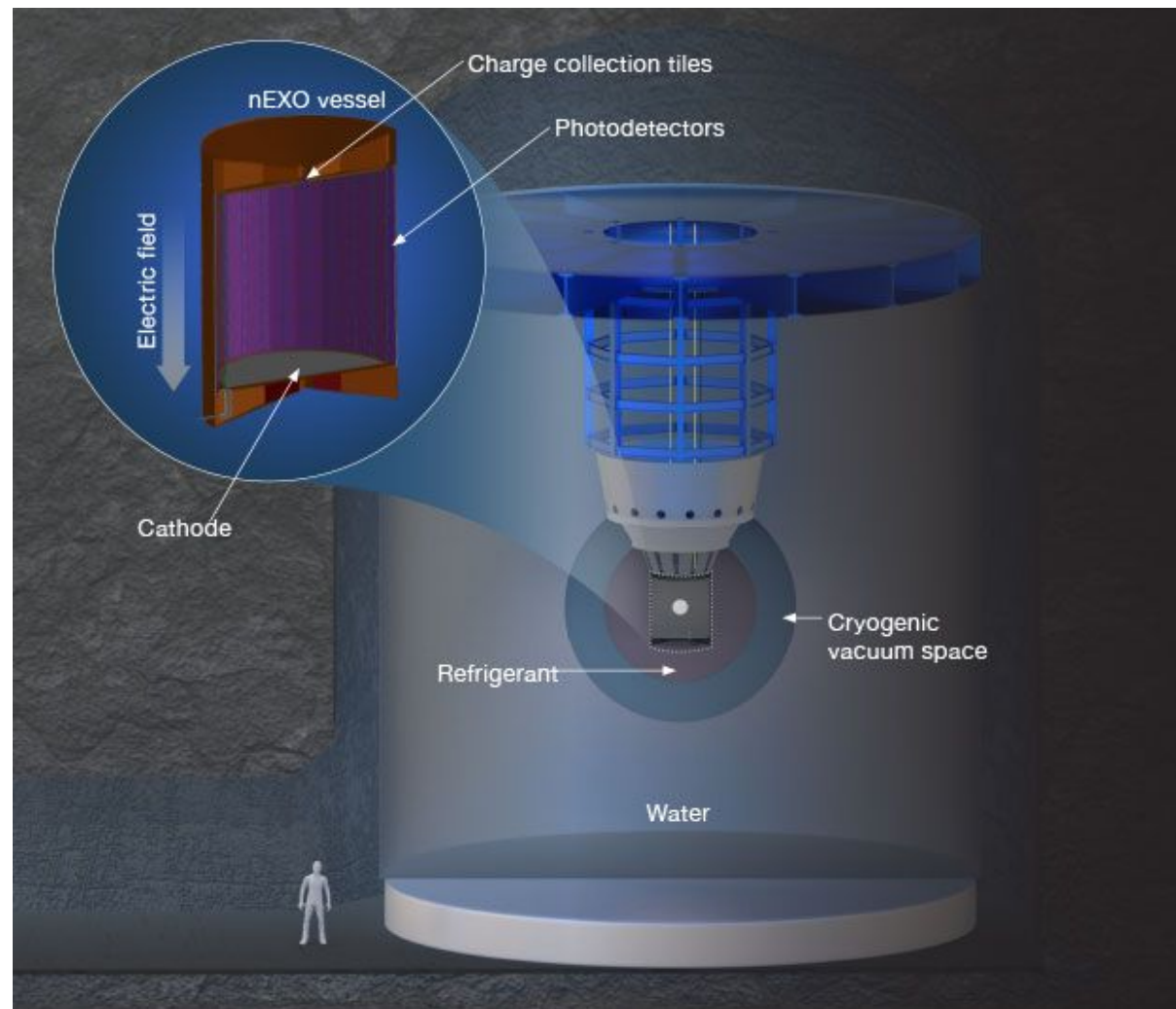
Fitted ^{85}Kr activity in UAr: 2.05 ± 0.13 mBq/kg

Fitted ^{39}Ar activity in UAr: 0.73 ± 0.11 mBq/kg

^{39}Ar activity in AAr: 1000 mBq/kg

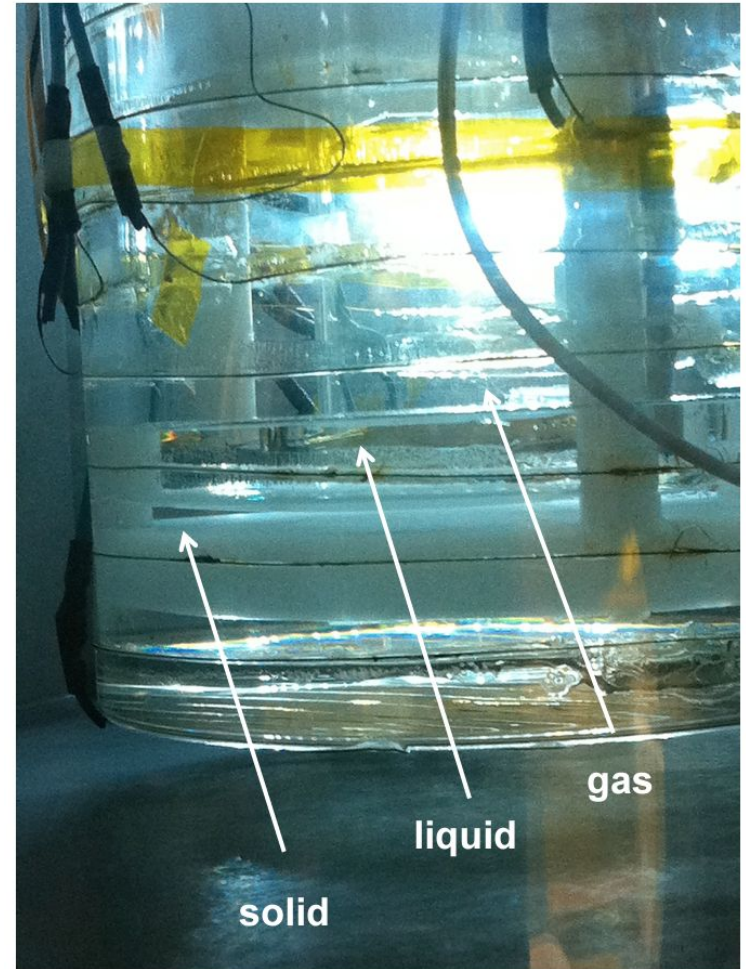
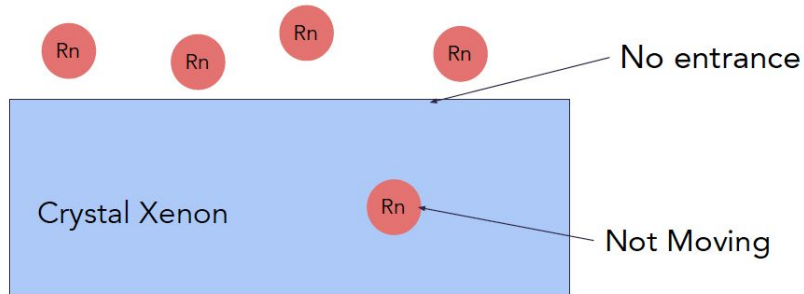
Single phase TPC

- nEXO
- LXe
- Single phase TPC easier to build
- Measure charge directly on electrode
 - No amplification like S2
- Maybe will go to SNOLAB soon?

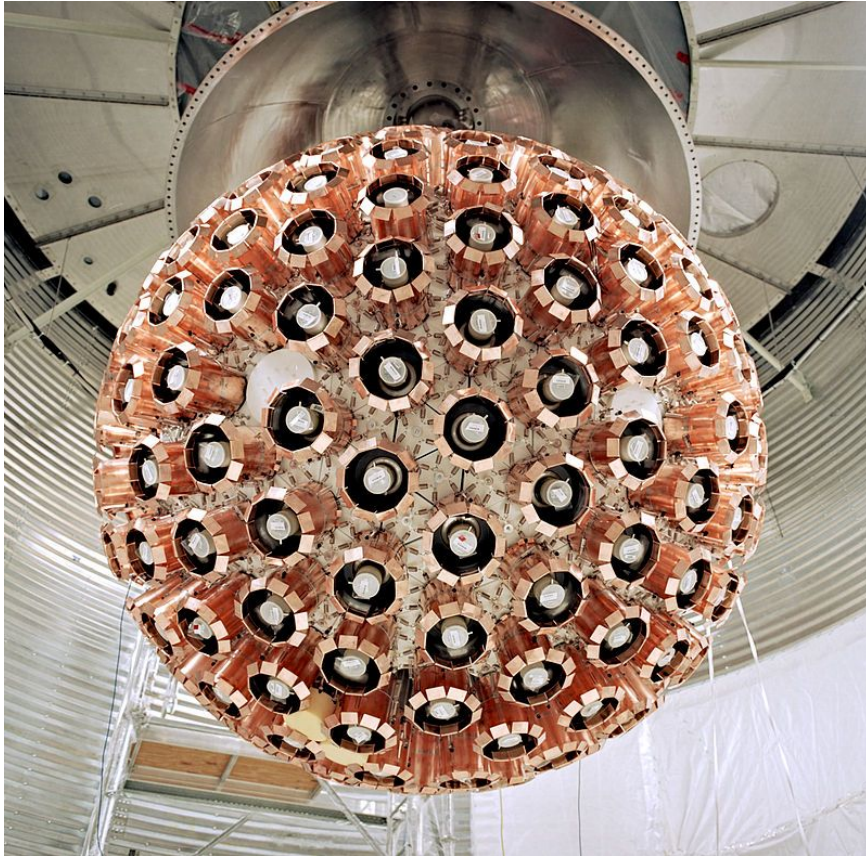


Freeze it up?

- To reject Radon...
- Can associate multiple decay daughters at the same location



Single-phase Noble Liquid Detectors



DEAP3600

- 3600 kg Ar, 1000 kg Fiducial
- 3 Ton-yr exposure
- Scintillator detector

Overview of DEAP-3600: Pulse Shape Discrimination



Nuclear Recoils

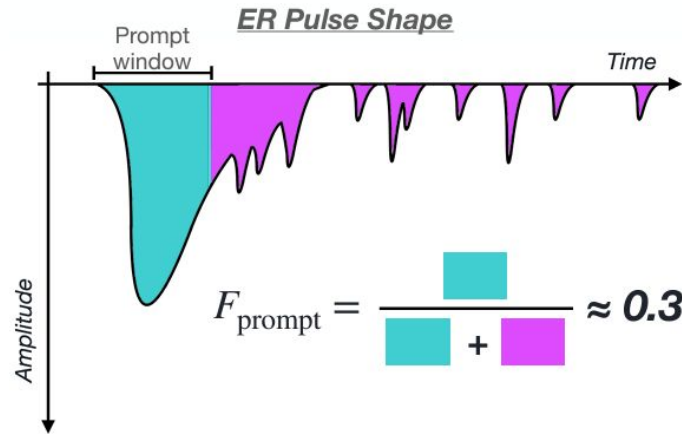
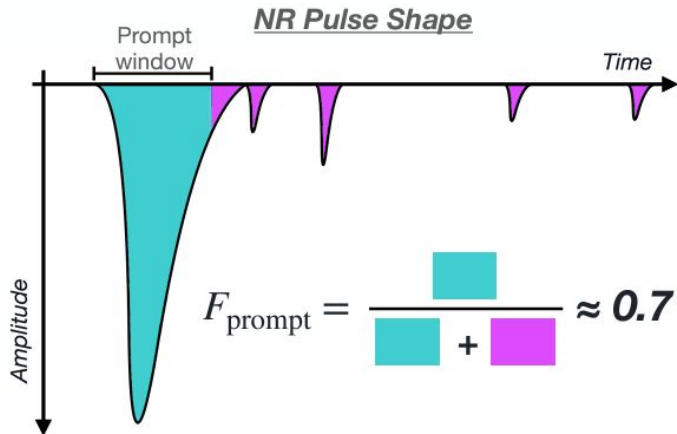
Scattering directly with argon nuclei; excimers mostly populate the **singlet state**, relax quickly. Induced by:

- Neutrons
- Alphas
- WIMPs

Electronic Recoils

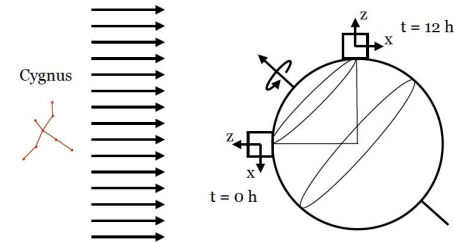
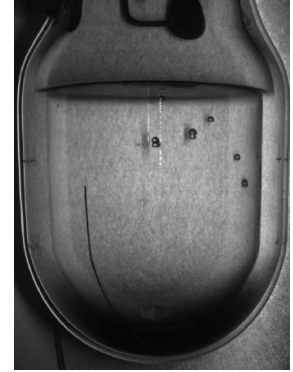
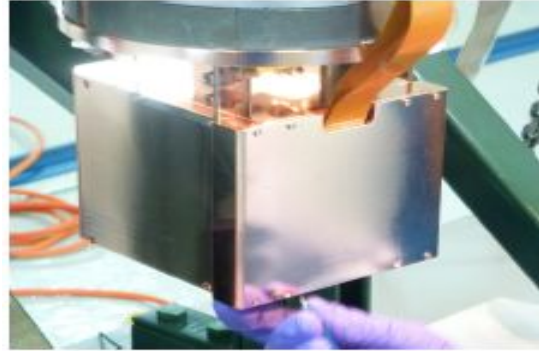
Scattering with argon atomic electrons, ionizing argon; excimers tend to populate **triplet state**, relax slowly. Induced by:

- Betas (especially ^{39}Ar at ~ 3 kHz)
- Gammas



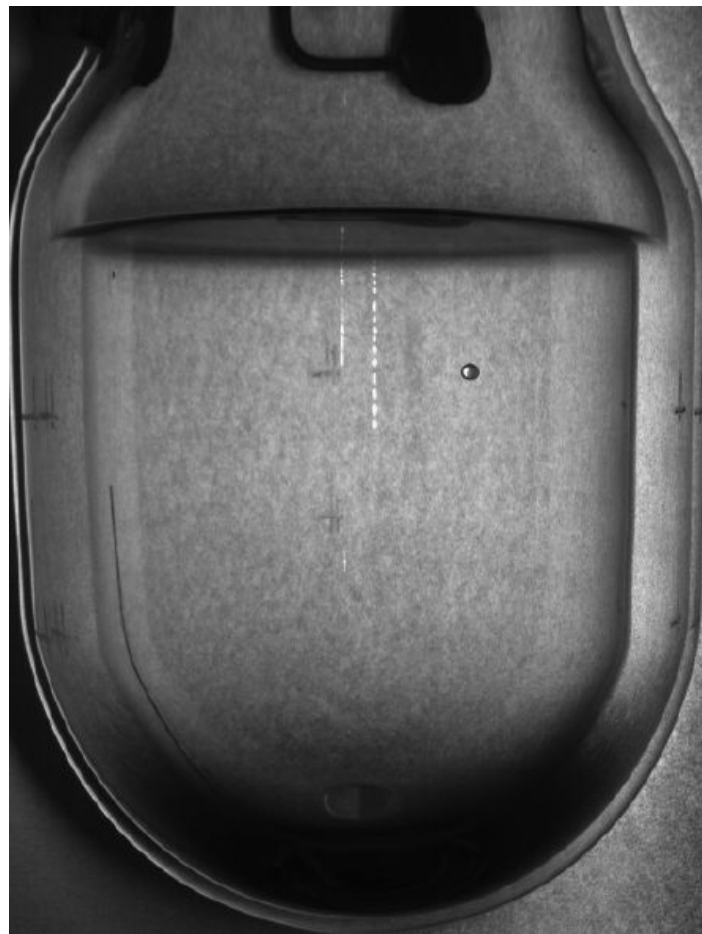
Other Nuclear Detection Technologies

- Silicon CCDs: DAMIC
- Bubble Chamber Experiments
 - PICO
 - Excellent SD Sensitivity
 - (currently running at SNOLAB)
 - Scintillating Bubble Chamber
- Directional Detection Experiments
 - DRIFT, DMTPC, NEWAGE, MIMAC

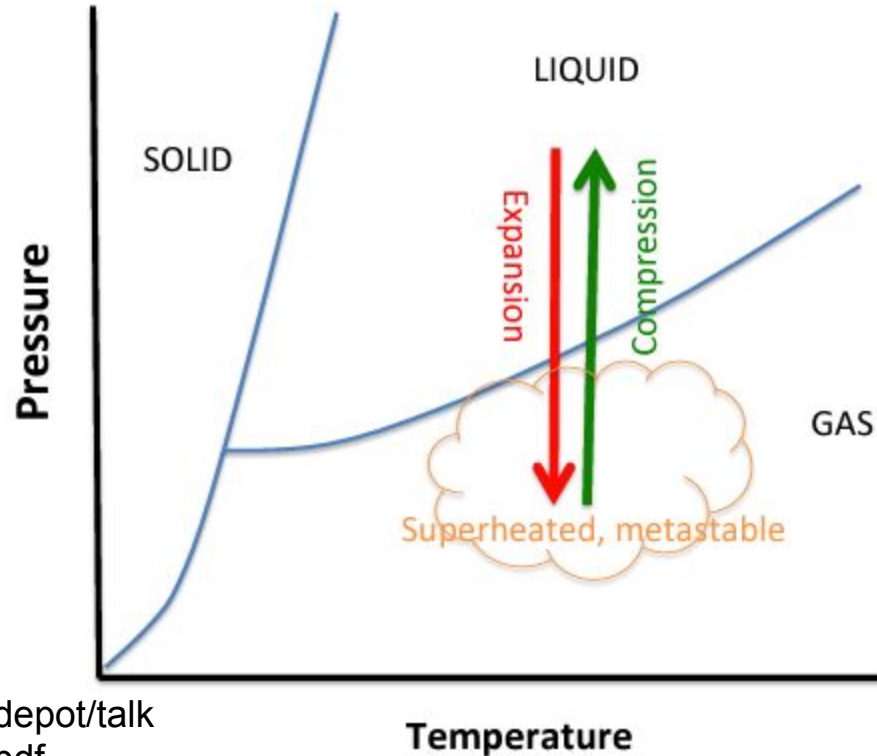


PICO Bubble Chamber

- Insensitive to gamma backgrounds due to dE/dx needed to nucleate a bubble.
- Slow detector, but OK for rare event searches
- Alpha discrimination by acoustic
 - Alpha popping is x4 louder



Bubble Chamber Expansion/ Compression Cycle



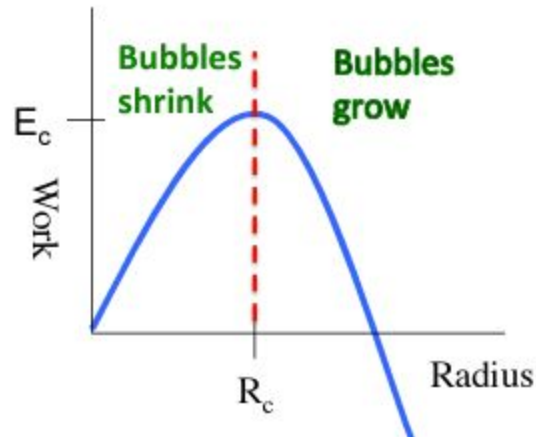
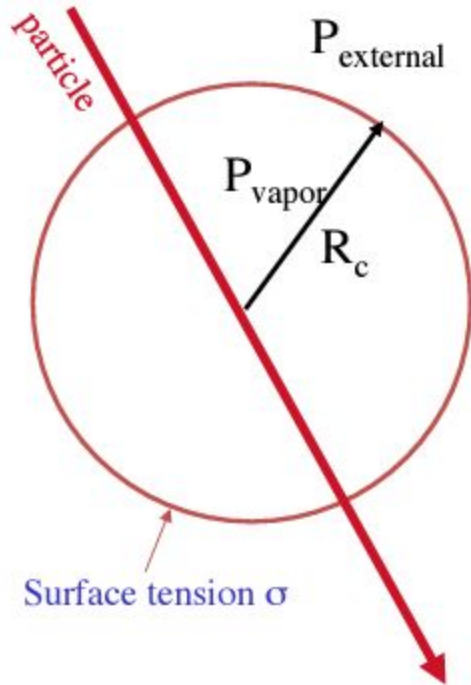
Bubble Nucleation by Radiation

(Seitz, "Thermal Spike Model", 1957)

- Pressure inside bubble is equilibrium vapor pressure.
- At critical radius R_c surface tension balances pressure.

$$R_c = \frac{2\sigma}{P_{\text{vapor}} - P_{\text{external}}}$$

- Bubbles bigger than the critical radius R_c will grow; smaller bubbles will shrink to zero.



Energy Barrier to Bubble Nucleation

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

Surface energy

Latent heat

