BubXe: a liquid xenon bubble chamber for Dark Matter detection
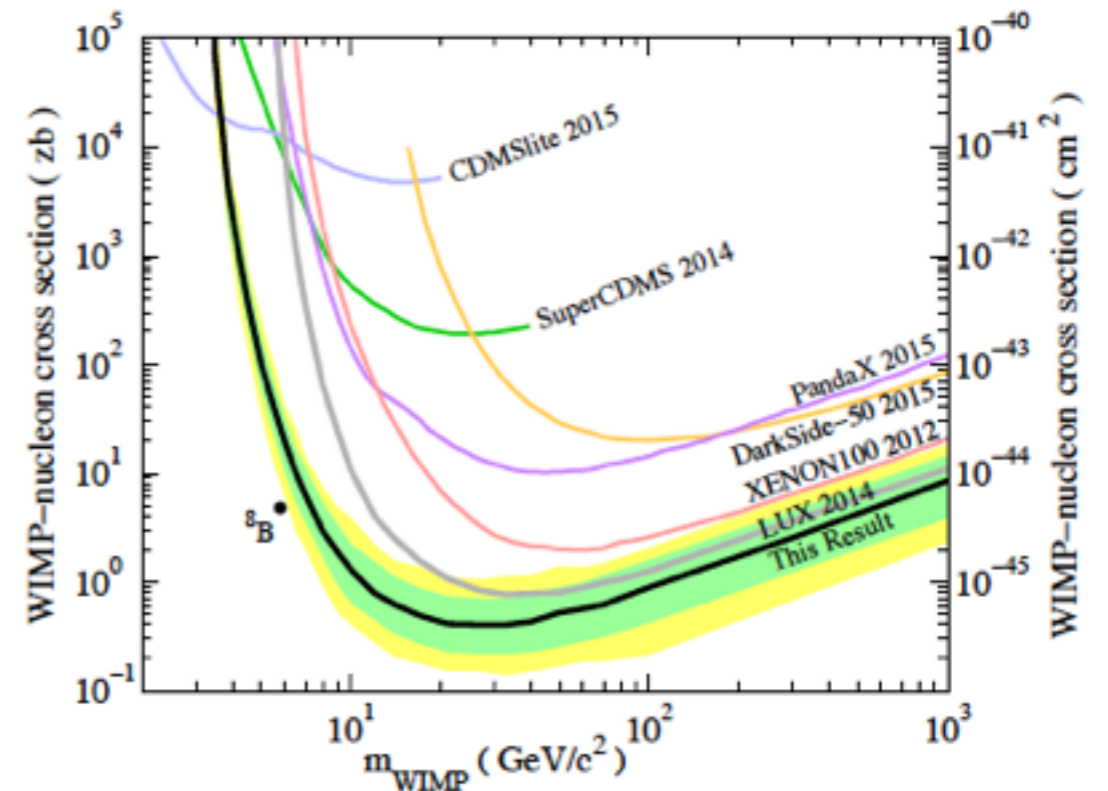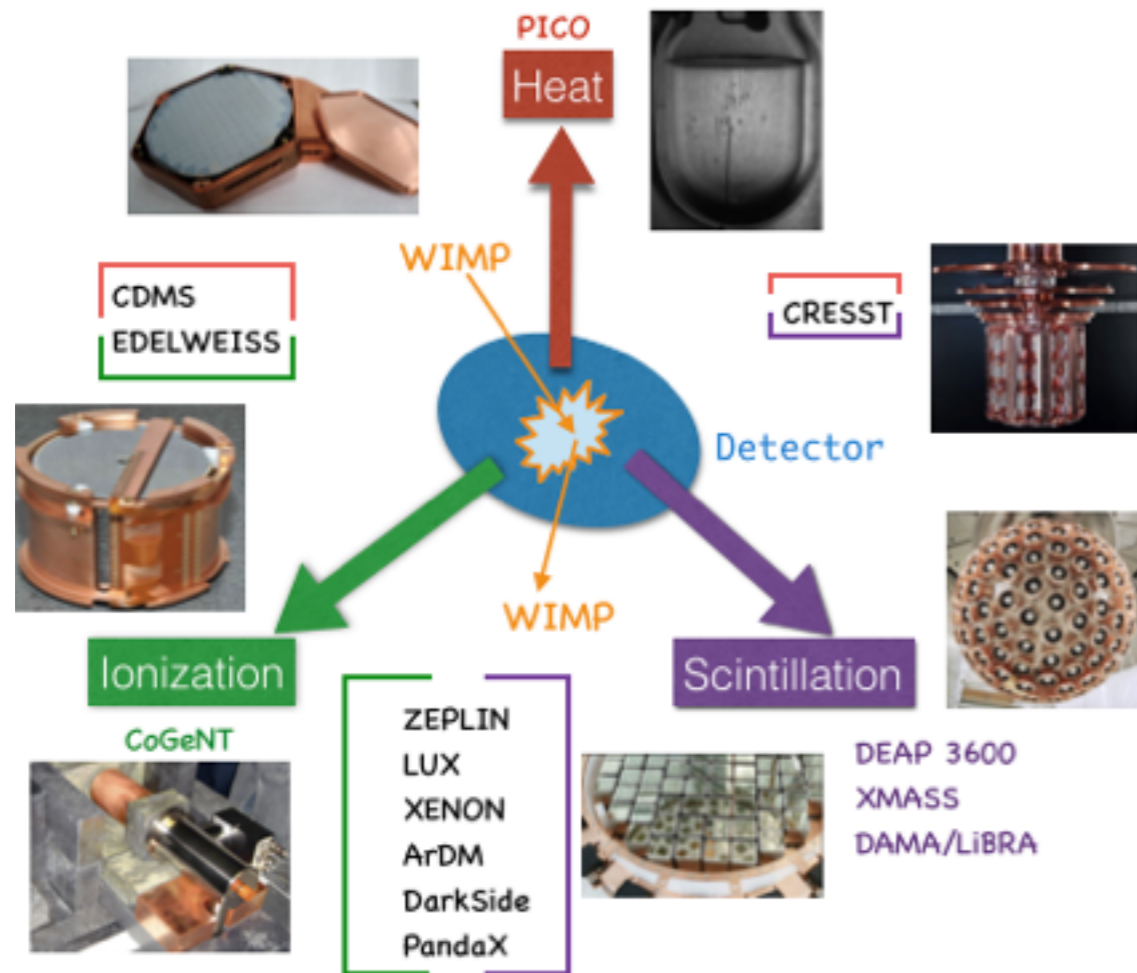
Jeremy Mock,
on behalf of Cecilia Levy and Matthew Szydagis

SUNY Albany

UNIVERSITY
AT ALBANY
State University of New York

Direct DM Search Today

3 detection channels (light, charge, heat): **2 used at most**
3 main experimental techniques (cryogenic crystals, liquid nobles, superheated bubble chambers)
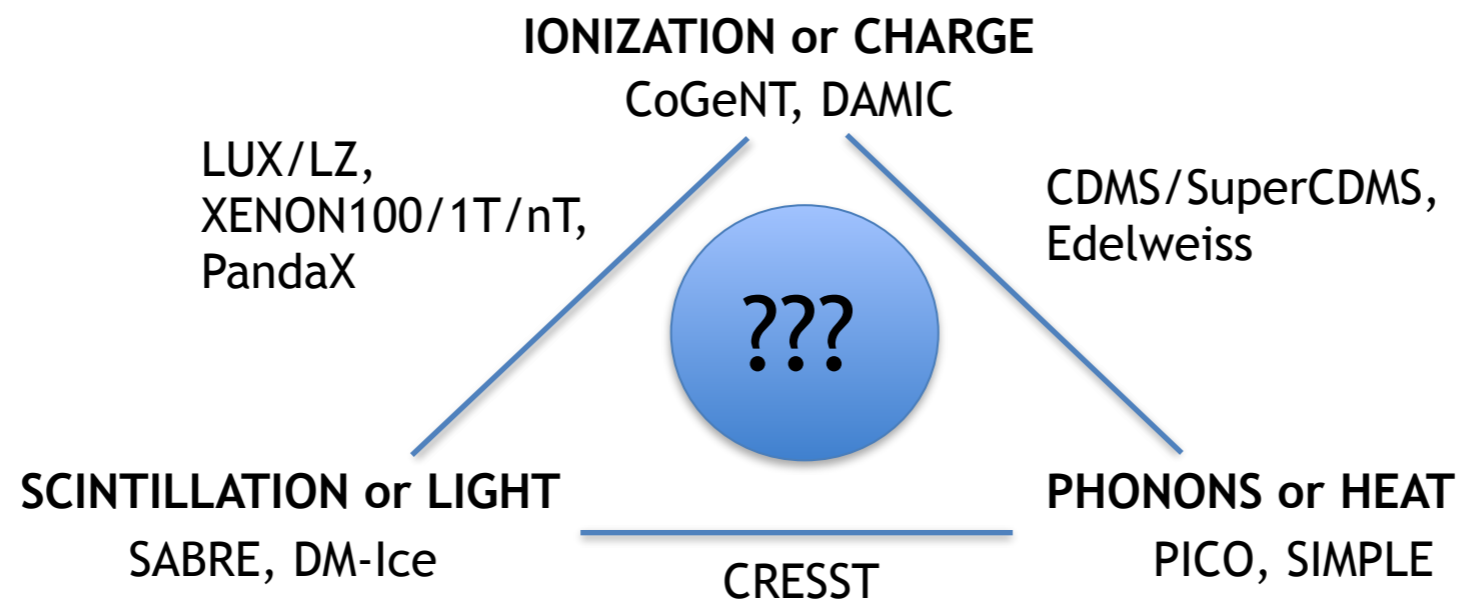

LXe TPCs lead the field

All experiments lose some information in one way or another.

What if…

… you could build a DM detector that has zero loss of information?
$\longrightarrow$ active on all 3 detections channels

IONIZATION or CHARGE
CoGeNT, DAMIC

LUX/LZ,
XENON100/1T/nT,
PandaX

CDMS/SuperCDMS,
Edelweiss

???

SCINTILLATION or LIGHT
SABRE, DM-Ice

**PHONONS or HEAT**
PICO, SIMPLE

CRESST

Challenge questions:

• What adaptions can we make to current detectors/technology? Meaning, can we do anything new/interesting without having to start from scratch?

• Are there ideas from competing experiments that could be merged together to make a better one?
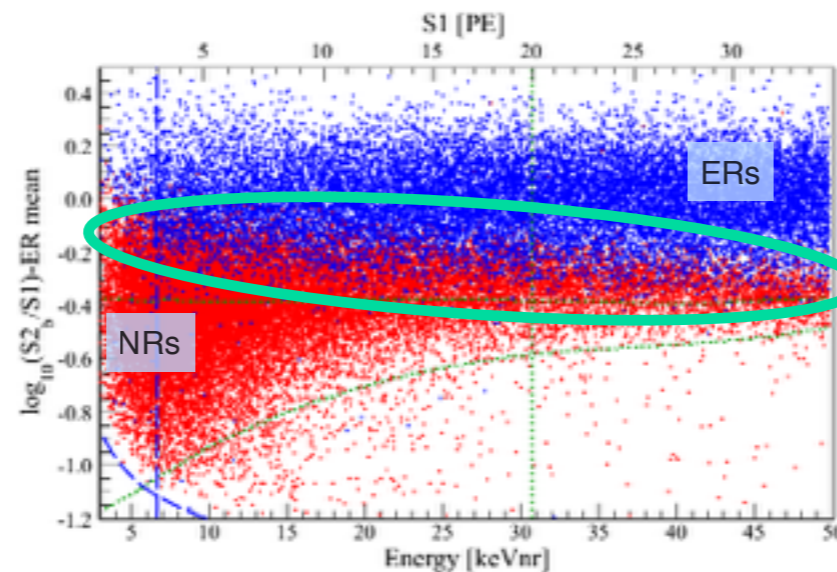
The Making Of a New DM Detector

DM detection relies on distinguishing between ER and NR
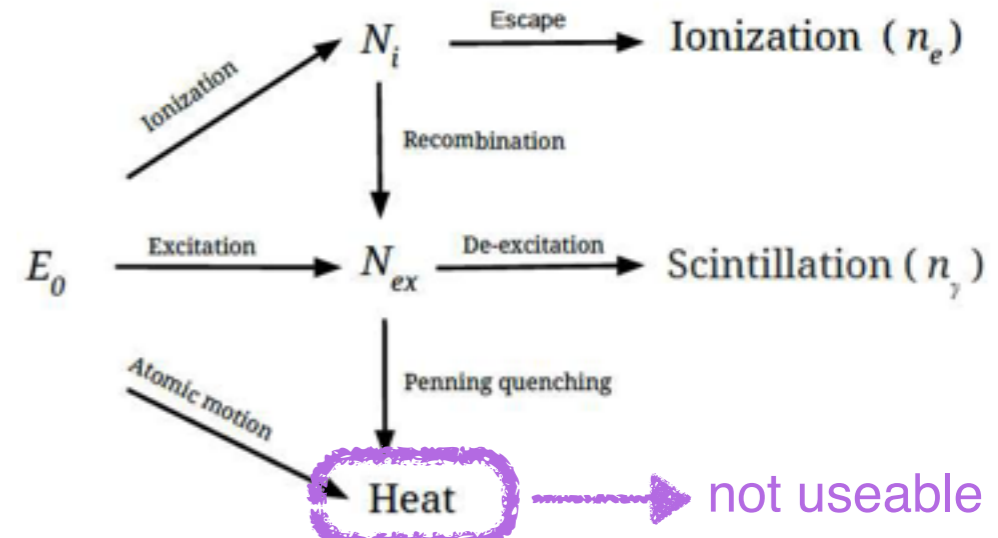$\longrightarrow$ low misidentification probability

$\longrightarrow$ energy information

LXe detectors:
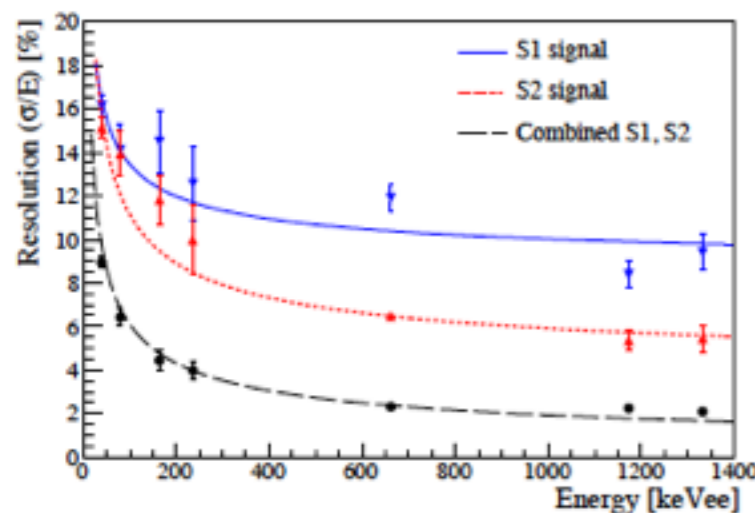
good energy information
$\longrightarrow$ 2 - 18% energy resolution

not that good misidentification probability (2 in 10^3)
$\longrightarrow$ ~50% NR efficiency

not useable

especially bad since NRs lose most of their energy to heat

Is there a way to combine LXe technology with something else to make it better?
$\longrightarrow$ needs to gain heat information

$\longrightarrow$ needs to gain lower misidentification probability

Scintillating Xenon Bubble Chamber

A bubble chamber:
- has heat information
- has great misidentification probability
- has no energy information
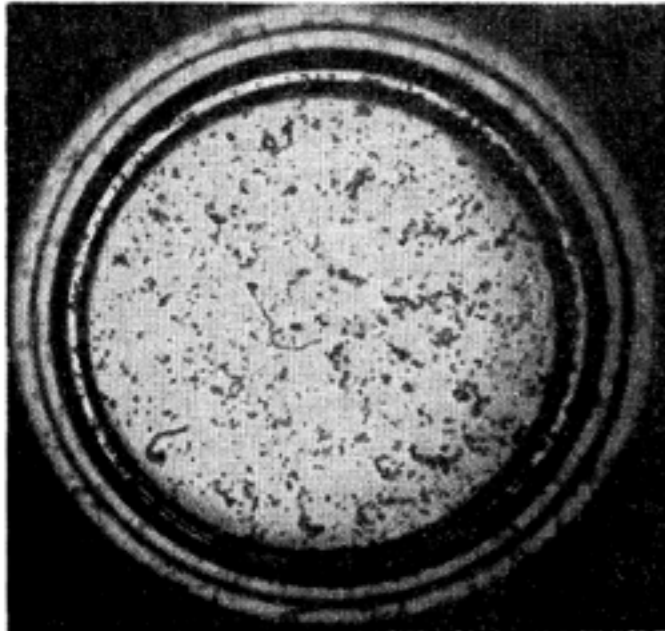
} the perfect complement to a LXe detector

<10^{-10} chance of misidentification

plot from PICO

NR threshold

IONIZATION or CHARGE
CoGeNT, DAMIC

LUX/LZ,
XENON100/1T/nT,
PandaX

CDMS/SuperCDMS,
Edelweiss

Xe bubble chamber

SCINTILLATION or LIGHT
SABRE, DM-Ice

PHONONS or HEAT
PICO, SIMPLE

CRESST
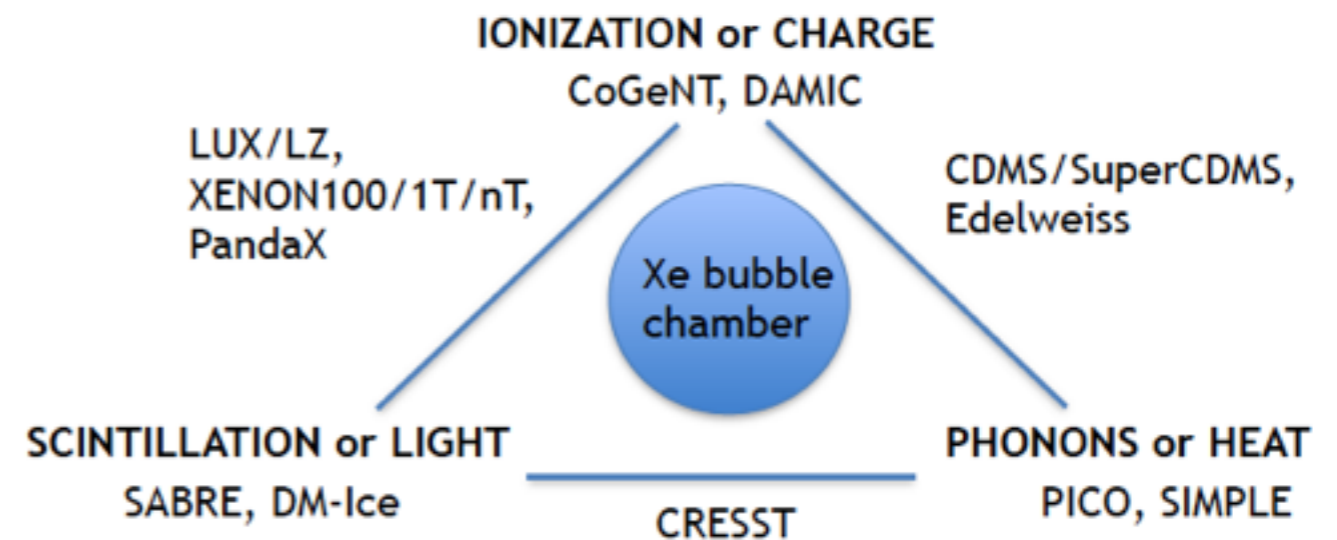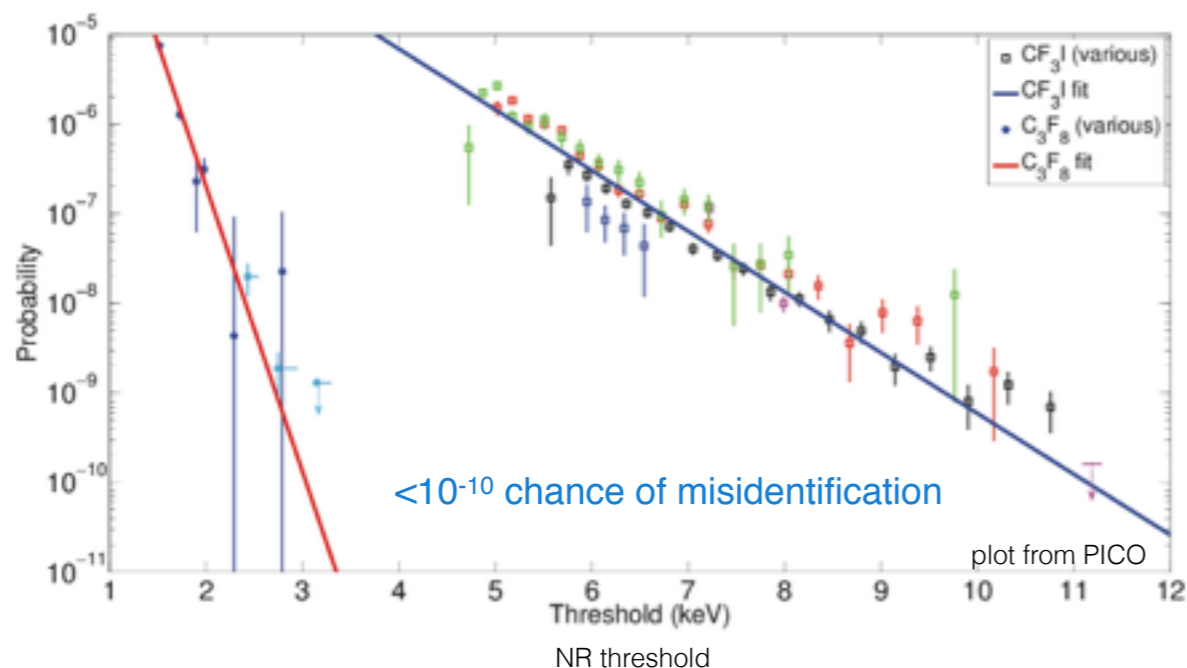
LXe detector + bubble chamber = LXe bubble chamber

⟶ has energy information

⟶ has great misidentification probability

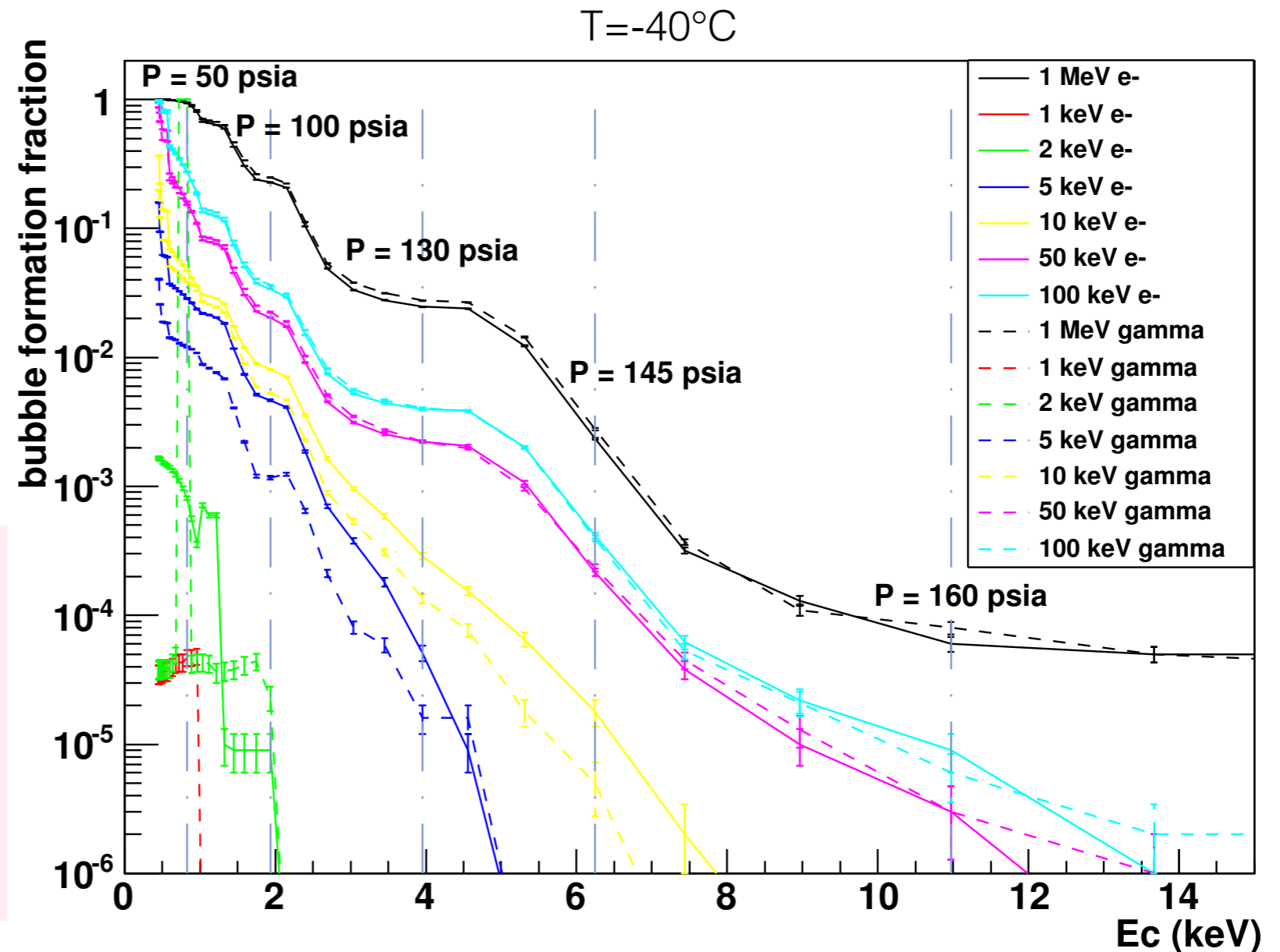⟶ active on all 3 channels at a time!

How do we know it will work?

First xenon bubble chamber (Glaser, 1956): bubbles due to gammas in LXe after adding additive to quench scintillation

T=-40°C

bubble formation fraction (y-axis)

P = 50 psia
P = 100 psia
P = 130 psia
P = 145 psia
P = 160 psia

Legend:
- 1 MeV e-
- 1 keV e-
- 2 keV e-
- 5 keV e-
- 10 keV e-
- 50 keV e-
- 100 keV e-
- 1 MeV gamma
- 1 keV gamma
- 2 keV gamma
- 5 keV gamma
- 10 keV gamma
- 50 keV gamma
- 100 keV gamma

E_c (keV)

Levy et al arXiv:1601.05131 (JINST 2016)

First simulation results:

- 1 in a million misidentification probability
- a factor 4000 better than LXe detectors!

⟶ **Looks very promising!**

Other Advantages of a LXe Bubble Chamber

Challenge questions:
- What are the limiting backgrounds? How much can shielding help? What about (internal) radioactive backgrounds? Surface events? Comptons? Which technologies suffer from which backgrounds?

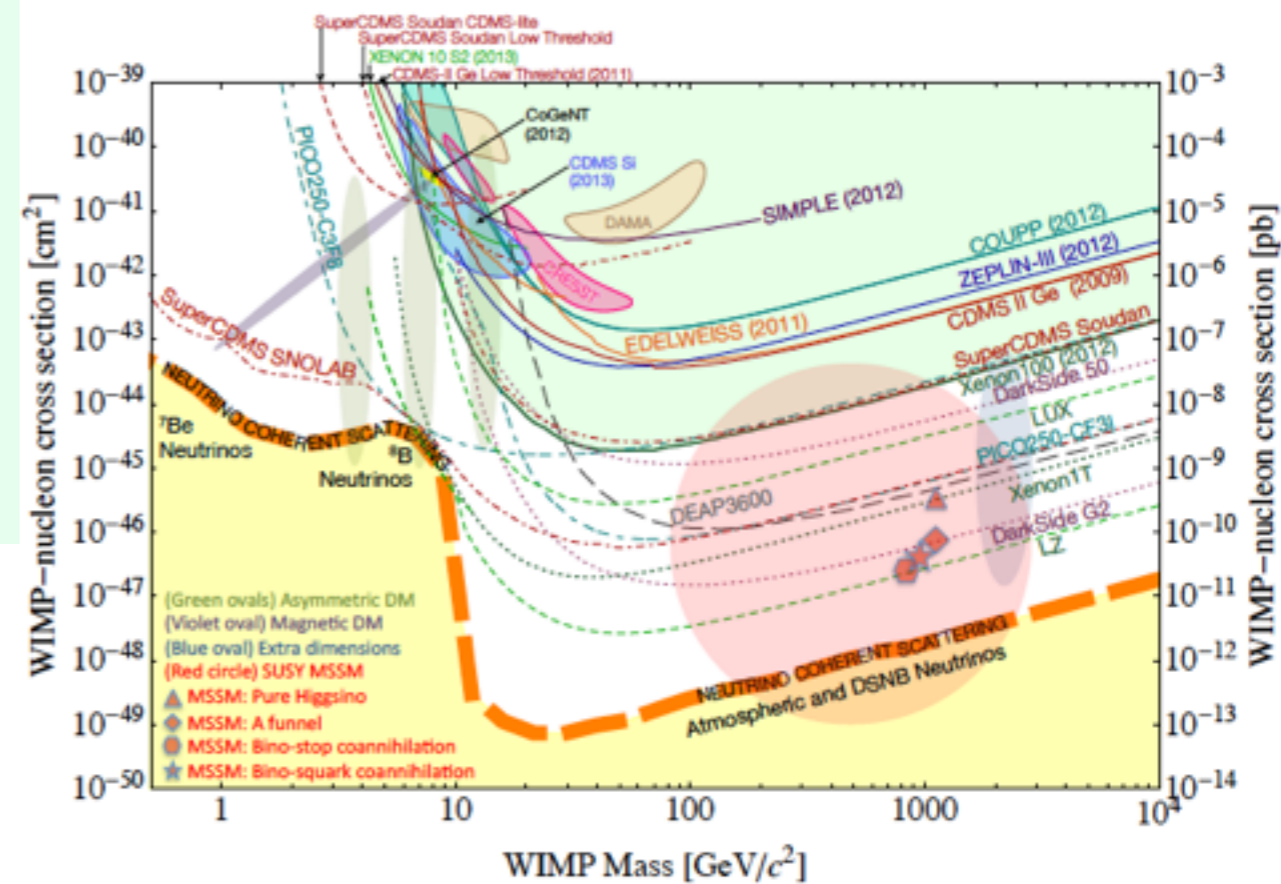- How can we broaden the kinds of physics these experiments are sensitive to?

Sub-keV threshold detector :
- 100% NR efficiency above threshold
  - ⟶ no more need for 40-50% fiducialization
- probe parameter space above neutrino floor at low masses
- sensitive to coherent neutrino scattering
  - ⟶ at -40.C and low pressures ~0.5 keVnr
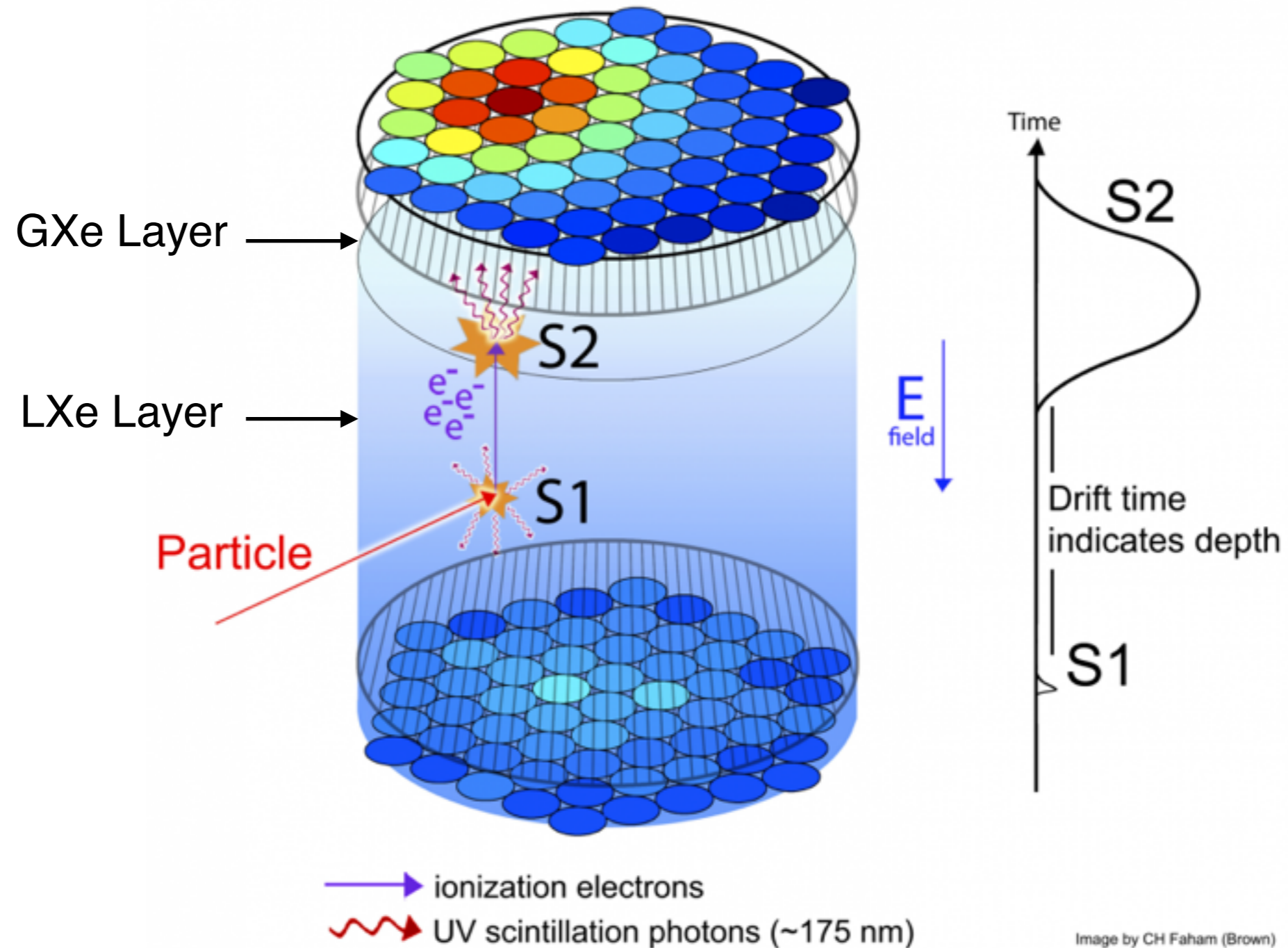
⟶ the only background left is NR
- can be shielded against
- careful choice of material
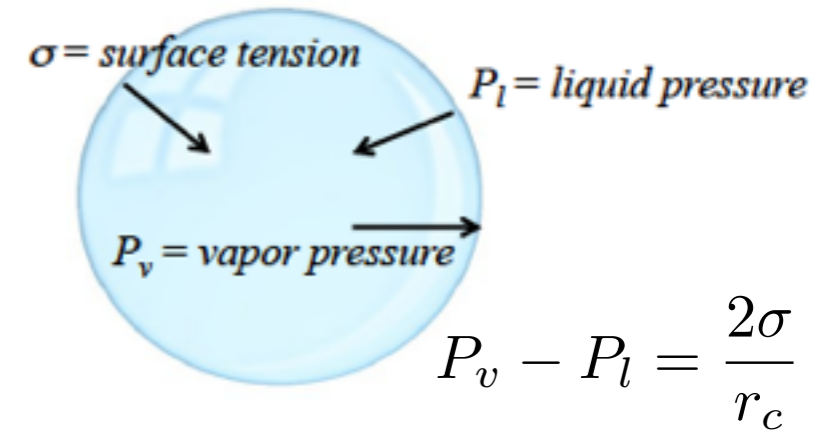
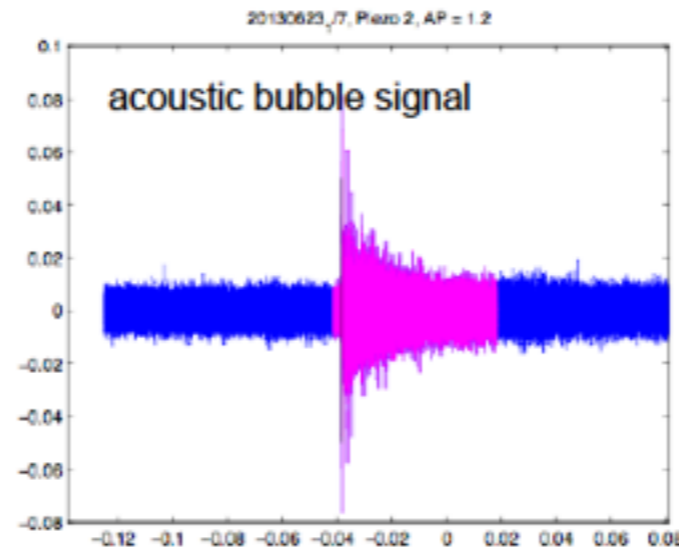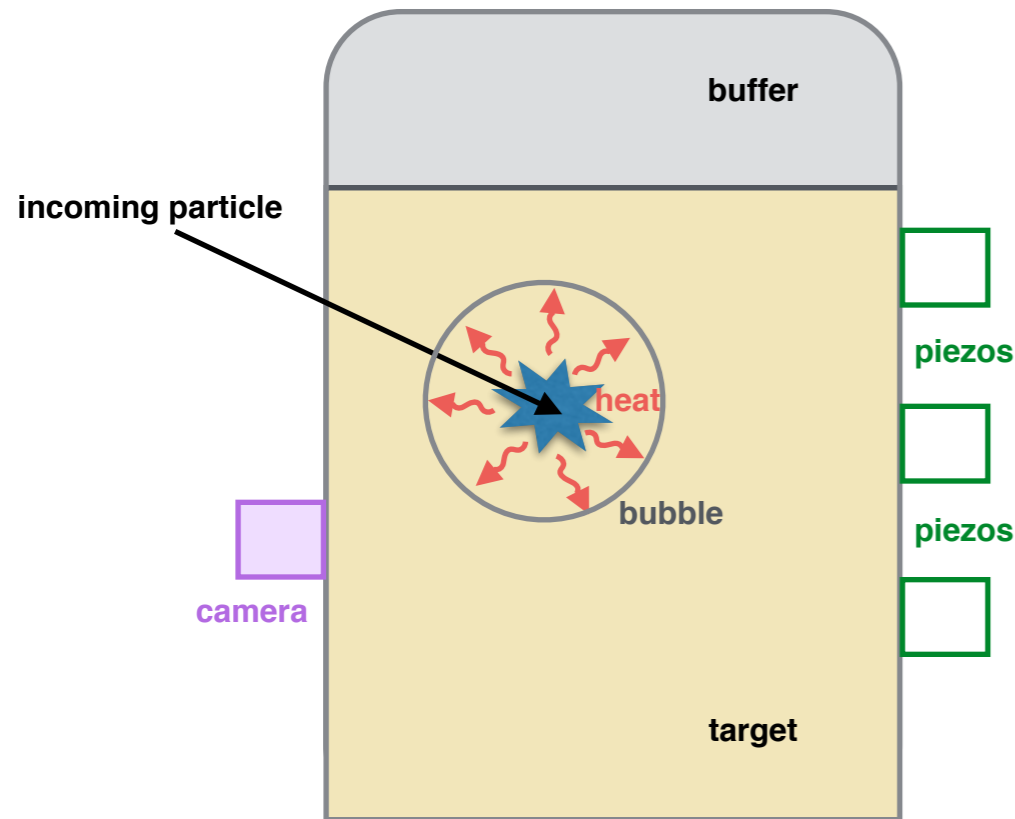⟶ to be fair, (α,n) reactions still a problem

How it works: LXe TPC

GXe Layer

LXe Layer

Particle

e^- e^- e^- e^-

S2

S1

E field

Time

S2

Drift time indicates depth

S1

→ ionization electrons

∿⤳ UV scintillation photons (~175 nm)

Image by CH Faham (Brown)

Use 2 detection channels: **ionization + scintillation**

How it works: Bubble Chamber

acoustic bubble signal

$\sigma = surface\ tension$
$P_l = liquid\ pressure$
$P_v = vapor\ pressure$

$$P_v - P_l = \frac{2\sigma}{r_c}$$

- Chamber filled with a **superheated fluid** (above boiling temperature but in a liquid state)
- **Bubble formation** if heat deposition > E_{th} within r_c (recoil path length)
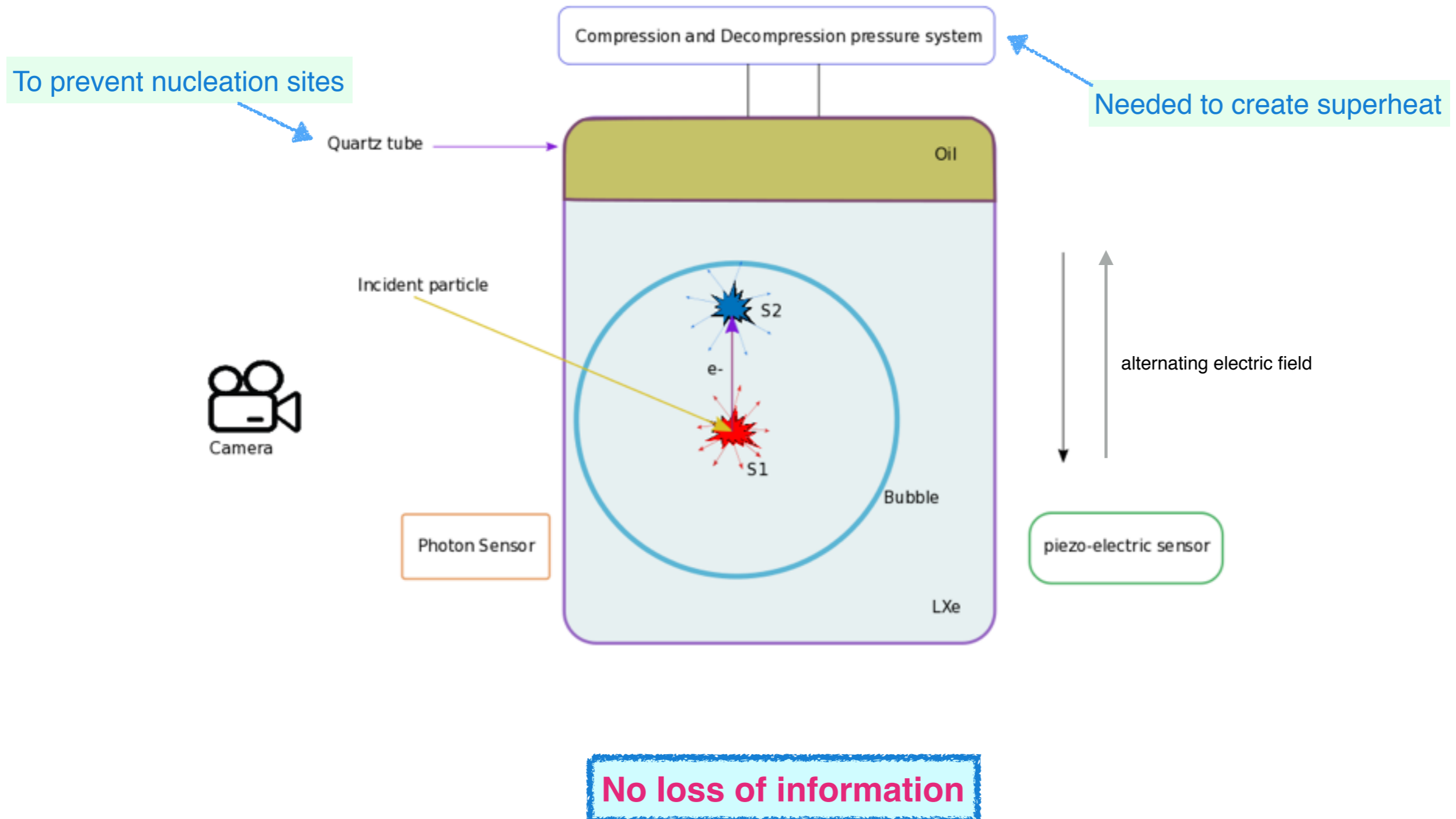

muon

neutron

WIMP candidate event
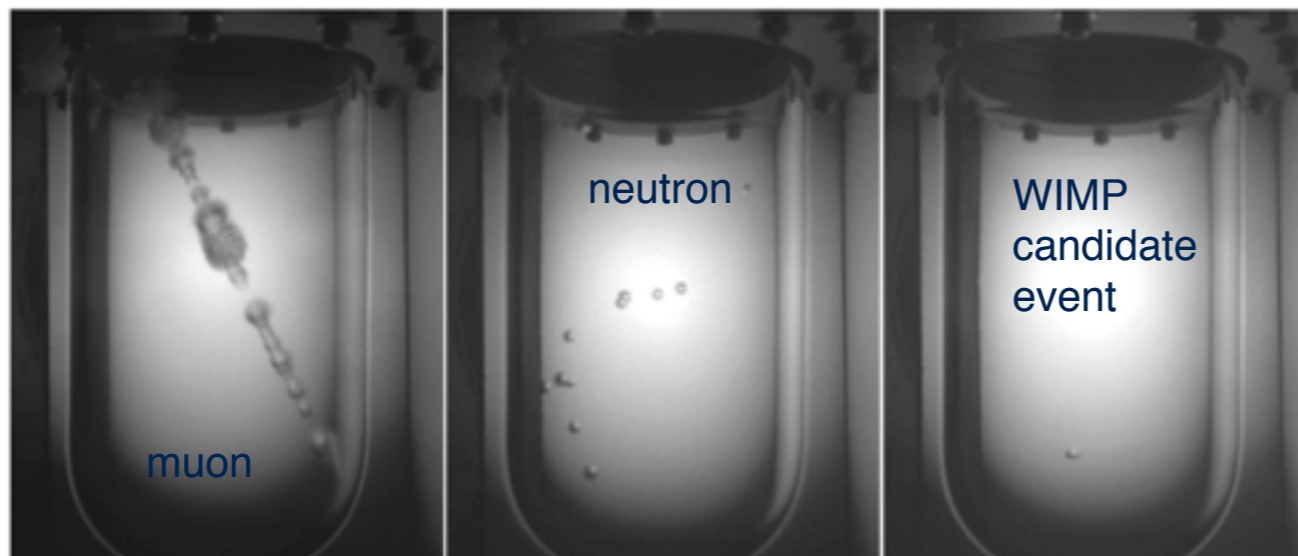
Challenge questions:

- What technologies are needed to probe below the 100's of keV scale?

- Are there particularly challenging regions of parameter space? How do we start reaching them?

Visible tracks in bubble chamber = possibility to use directionality for ultra-light (relativistic) WIMPs and/or dark photon / **dark sector mediators**

How it works: LXe Bubble Chamber

Energy resolution from LXe + discrimination power from BC

To prevent nucleation sites

Needed to create superheat

Compression and Decompression pressure system

Quartz tube

Oil

Incident particle

S2

e-

alternating electric field

Camera

S1

Bubble

Photon Sensor

piezo-electric sensor

LXe

No loss of information

Introducing BubXe

A prototype LXe Bubble Chamber at SUNY Albany

- Thick quartz vessel will contain ~50g of LXe
- Operated at -40°C, 220-300 psia

Compression valve

Decompression valve

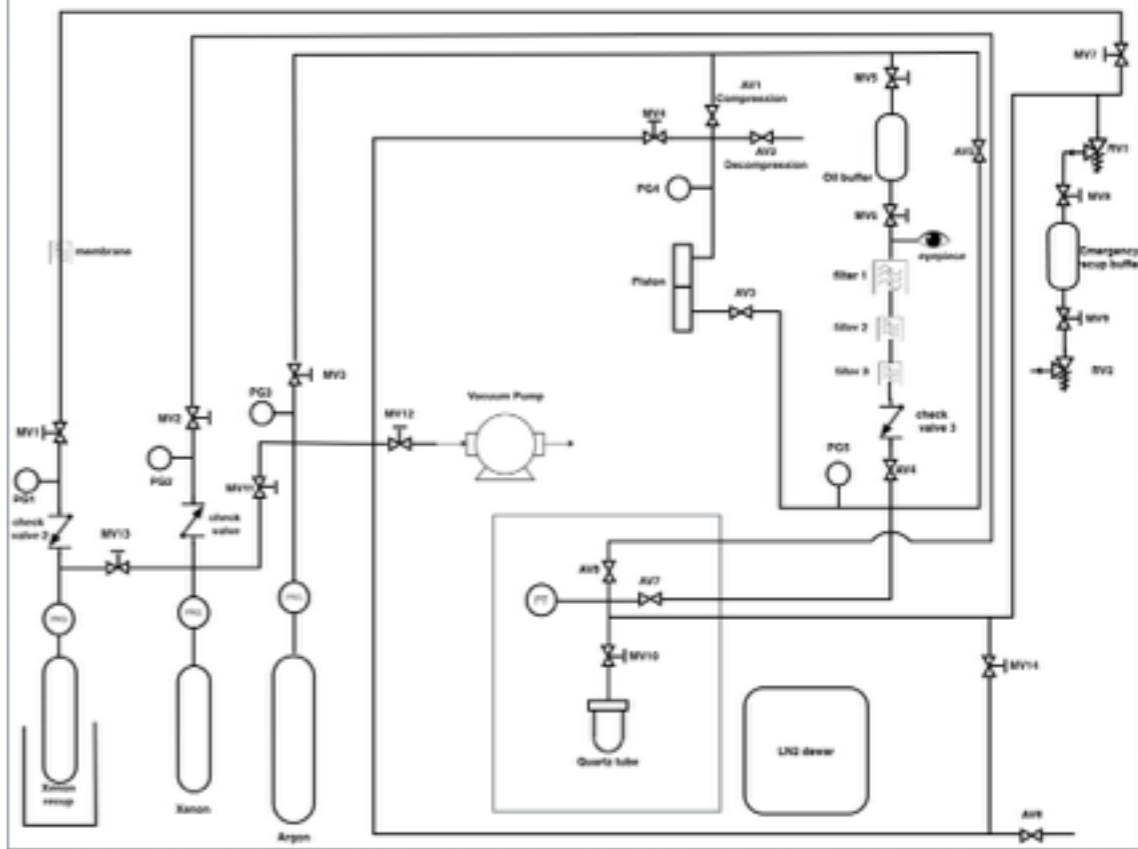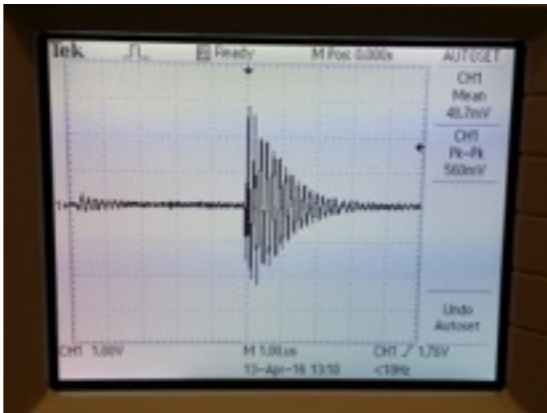Pressure Transducer

Quartz tube
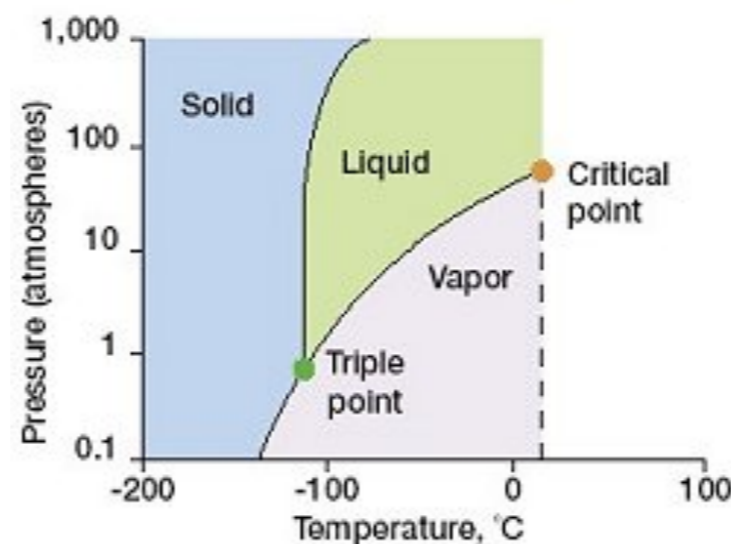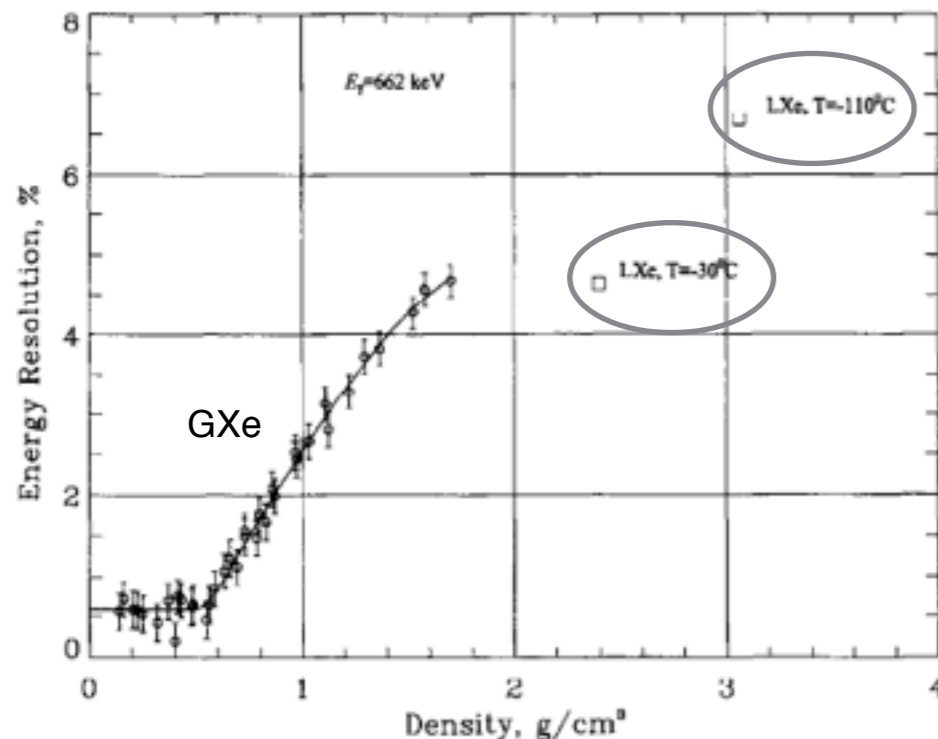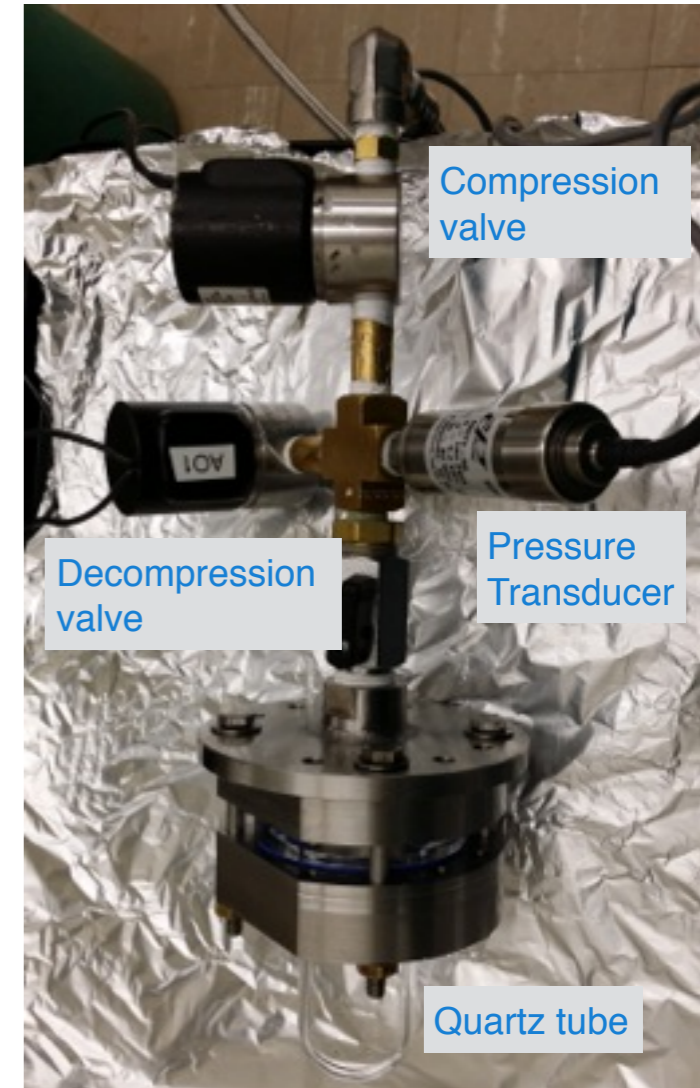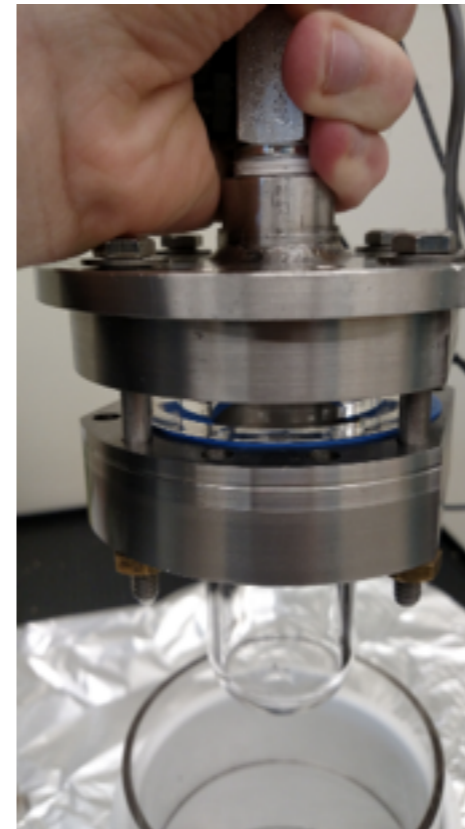
- Variable temperature/pressure operation
- **Fine tuning may increase energy resolution**

Started small…
→ Successful **leak and compression cycles** tests

Introducing BubXe

Moving to bigger chamber for "real" tests, first water then LXe
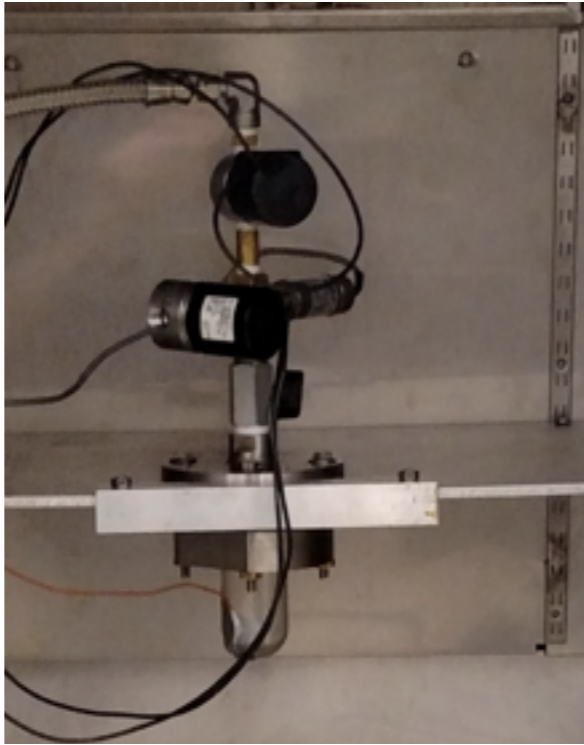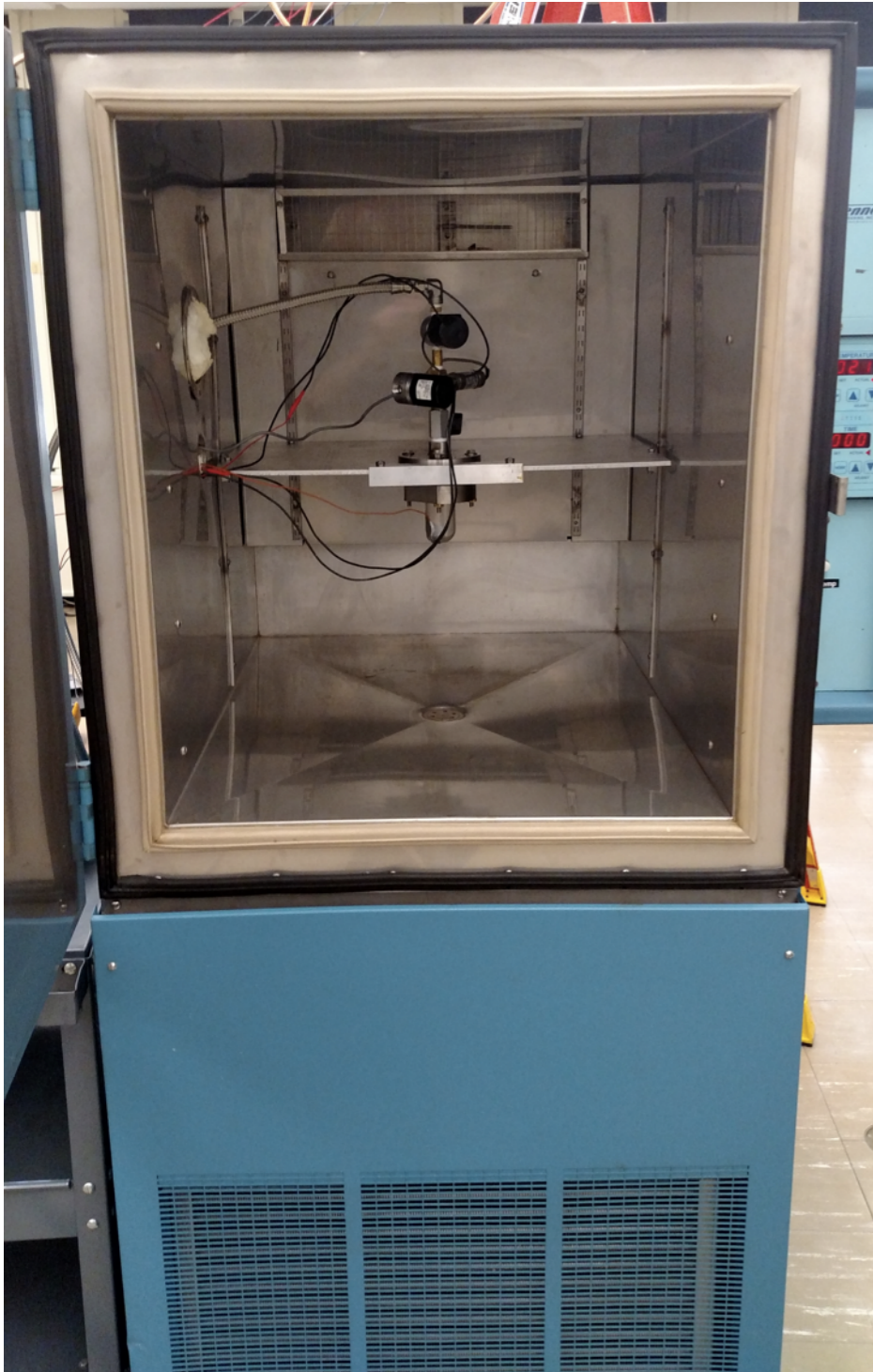
- Test signal from piezo
- Camera is good to go
- VUV MPPC test from Hamamatsu
- Rough DAQ in place
- PnID in place

⟶ Water Cerenkov Bubble chamber should be operational this summer

Conclusion 1

Liquid xenon bubble chamber is being developed at UAlbany

Many advantages:

- energy information + amazing discrimination in 1 detector
- 3 detection channels active including heat
- no loss of information $\longrightarrow$ especially useful at low energies
- ability to manage operating conditions (temperature and pressure)
- very easily tunable to different target material

- useful to have now for feedback on current experiments
- useful in case of discovery, more information will be needed
- useful in case of no discovery, a new more sensitive dark matter detector?

Status:

- basic setup in place
- equipment tested to extreme conditions
- everything checks out
- 1st water Cerenkov test expected this summer
- 1st xenon test expected by the end of the year

Conclusion 2 : Final Challenge Question

What would constitute a game-changing experiment — even if you're not at all sure how to do it?

Conclusion 2 : Final Challenge Question

What would constitute a game-changing experiment — even if you're not at all sure how to do it?

A liquid xenon bubble chamber of course!

Challenge questions

— Are there particularly well motivated parts of parameter space? What does it take to reach these targets?

— Are there particularly challenging regions of parameter space? How do we start reaching them?

— What does it take to make a convincing discovery?

— Are there "brick walls" to sensitivity that don't just plague one experiment but are inherent to a common approach?

— How can we broaden the kinds of physics these experiments are sensitive to?

— Are there ideas from competing experiments that could be merged together to make a better one?

— What would constitute a game-changing experiment — even if you're not at all sure how to do it?

— Which models can be probed by direct detect ion that cannot be probed by beam dumps, colliders, and indirect detection?

— What are the limiting backgrounds? How much can shielding help? What about (internal) radioactive backgrounds? Surface events? Comptons? Which technologies suffer from which backgrounds?

— Current generation DM-nuclear recoil searches usually rely on two signals to reject signal from backgrounds (e.g. scintillation + ionization in XENON100/LUX, phonons+ionization in SuperCDMS). Can we think of two distinguishing signals for DM-electron recoils?

— The annual modulation signal is larger for DM-electron scattering that for typical WIMP scattering. If one were to see a signal, what would it take to convince oneself that it is real? How can one verify it?

— What technologies are needed to probe below the 100's of keV scale?

— What adaptions can we make to current detectors/technology? Meaning, can we do anything new/interesting without having to start from scratch?