BubXe: a liquid xenon bubble chamber for Dark Matter detection

Jeremy Mock,
on behalf of Cecilia Levy and Matthew Szydagis

SUNY Albany
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? ➔ active on all 3 detections channels

IONIZATION or CHARGE
CoGeNT, DAMIC
LUX/LZ, XENON100/1T/nT, PandaX

???

SCINTILLATION or LIGHT
SABRE, DM-Ice

???

CDMS/SuperCDMS, Edelweiss

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
- low misidentification probability
- energy information

LXe detectors:

- good energy information
  - → 2 - 18% energy resolution
- not that good misidentification probability (2 in $10^3$)
  - → ~50% NR efficiency

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?
- needs to gain heat information
- needs to gain lower misidentification probability
Scintillating Xenon Bubble Chamber

A bubble chamber:
- has heat information
- has great misidentification probability
- has no energy information

\[
\text{LXe detector + bubble chamber = LXe bubble chamber}
\]

\[\rightarrow\text{has energy information}\]
\[\rightarrow\text{has great misidentification probability}\]
\[\rightarrow\text{active on all 3 channels at a time!}\]
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

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, ($\alpha$,n) reactions still a problem
How it works: LXe TPC

Double phase time projection chamber (TPC)

Use 2 detection channels: ionization + scintillation
How it works: Bubble Chamber

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

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

alternating electric field

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

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

Started small…

成功的泄漏和压缩循环测试
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
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 → 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 Čerenkov test expected this summer
- 1st xenon test expected by the end of the year
What would constitute a game-changing experiment — even if you’re not at all sure how to do it?
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 detection 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 adaptations can we make to current detectors/technology? Meaning, can we do anything new/interesting without having to start from scratch?