A liquid xenon bubble chamber for Dark Matter detection

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on behalf of

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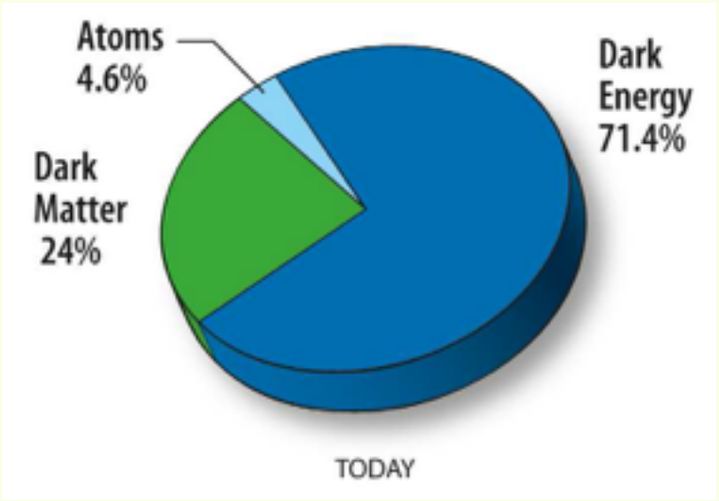
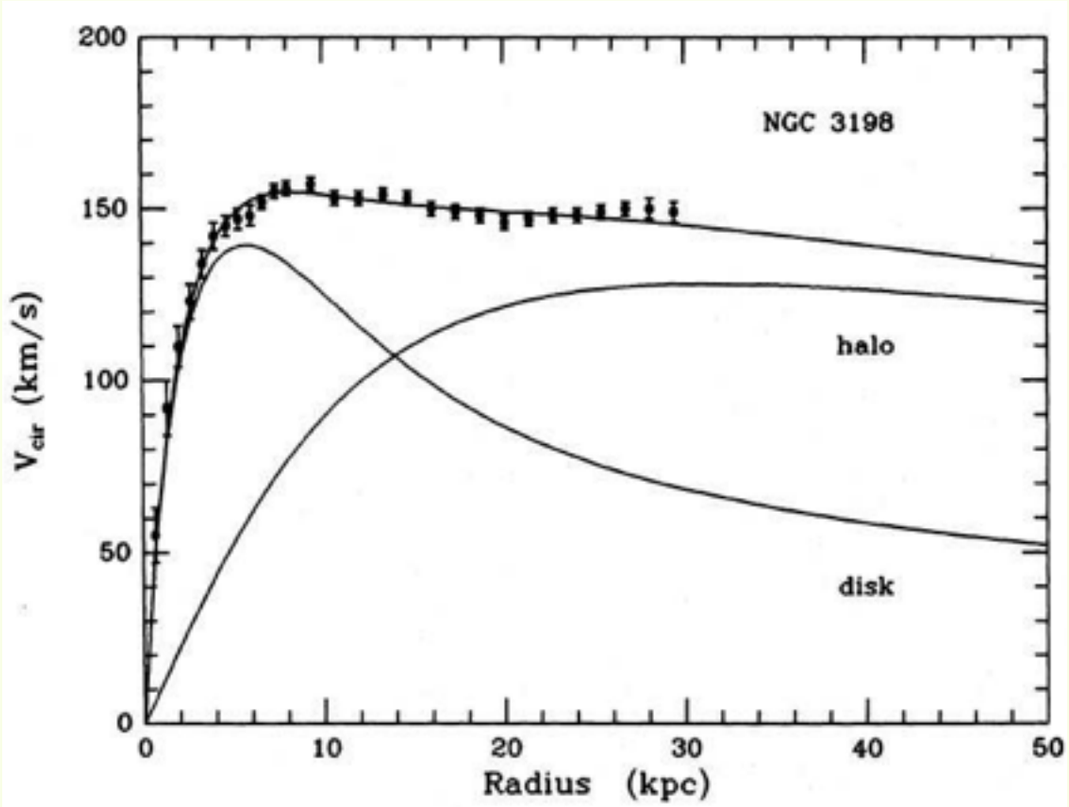
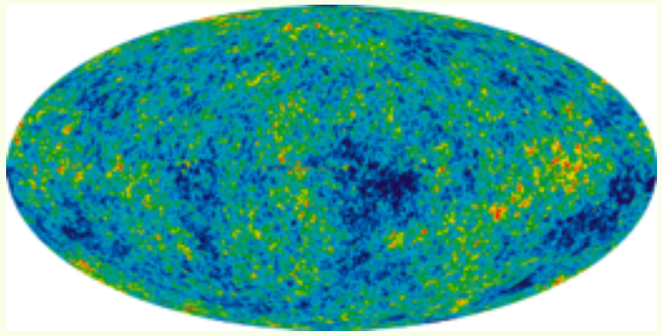
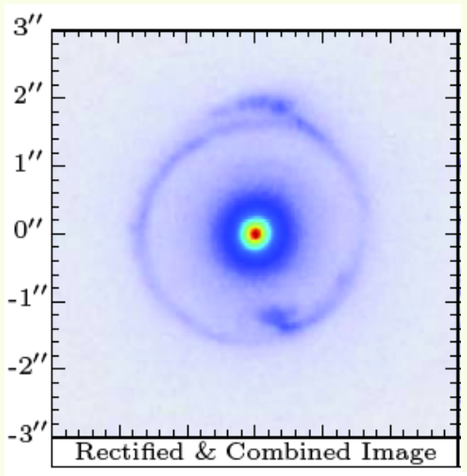
UNIVERSITY AT ALBANY
State University of New York

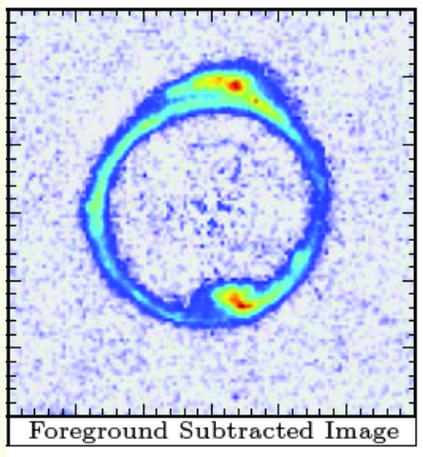
Dark Matter

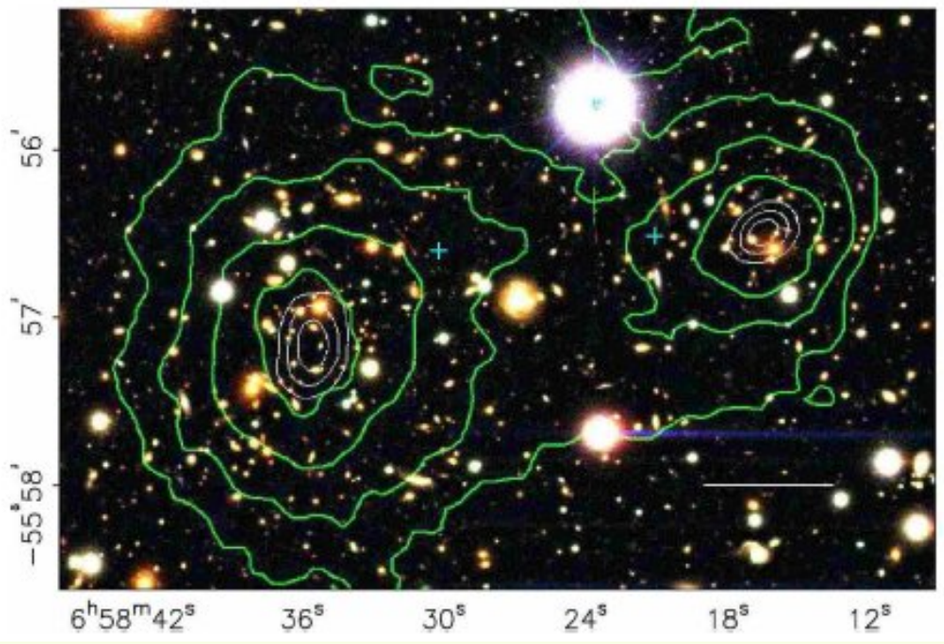

Atoms
4.6%
Dark
Matter
24%
Dark
Energy
71.4%
TODAY

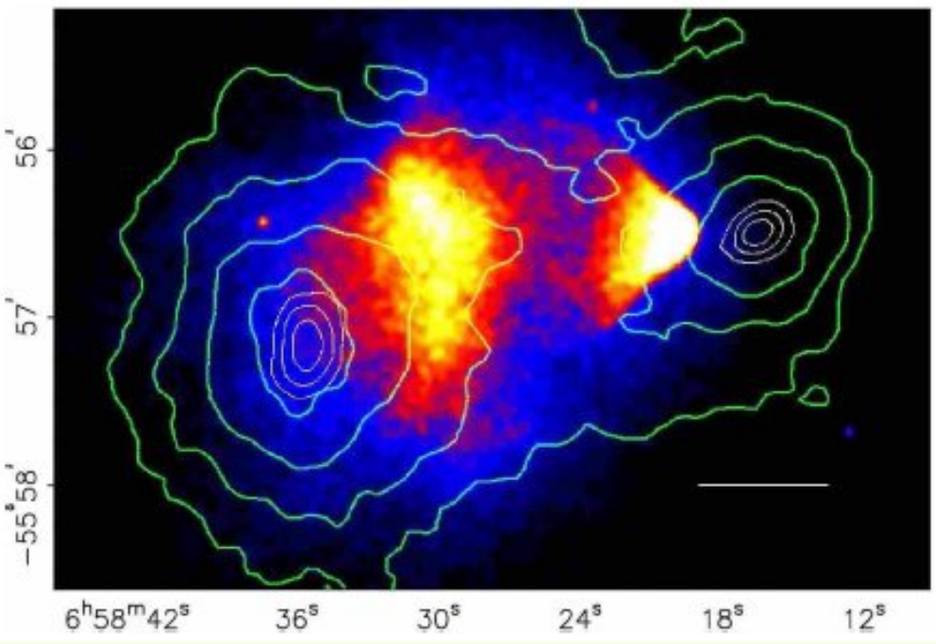

NGC 3198
halo
disk
V_{cir} (km/s)
Radius (kpc)
0
50
100
150
200
0
10
20
30
40
50




3″
2″
1″
0″
-1″
-2″
-3″
Rectified & Combined Image

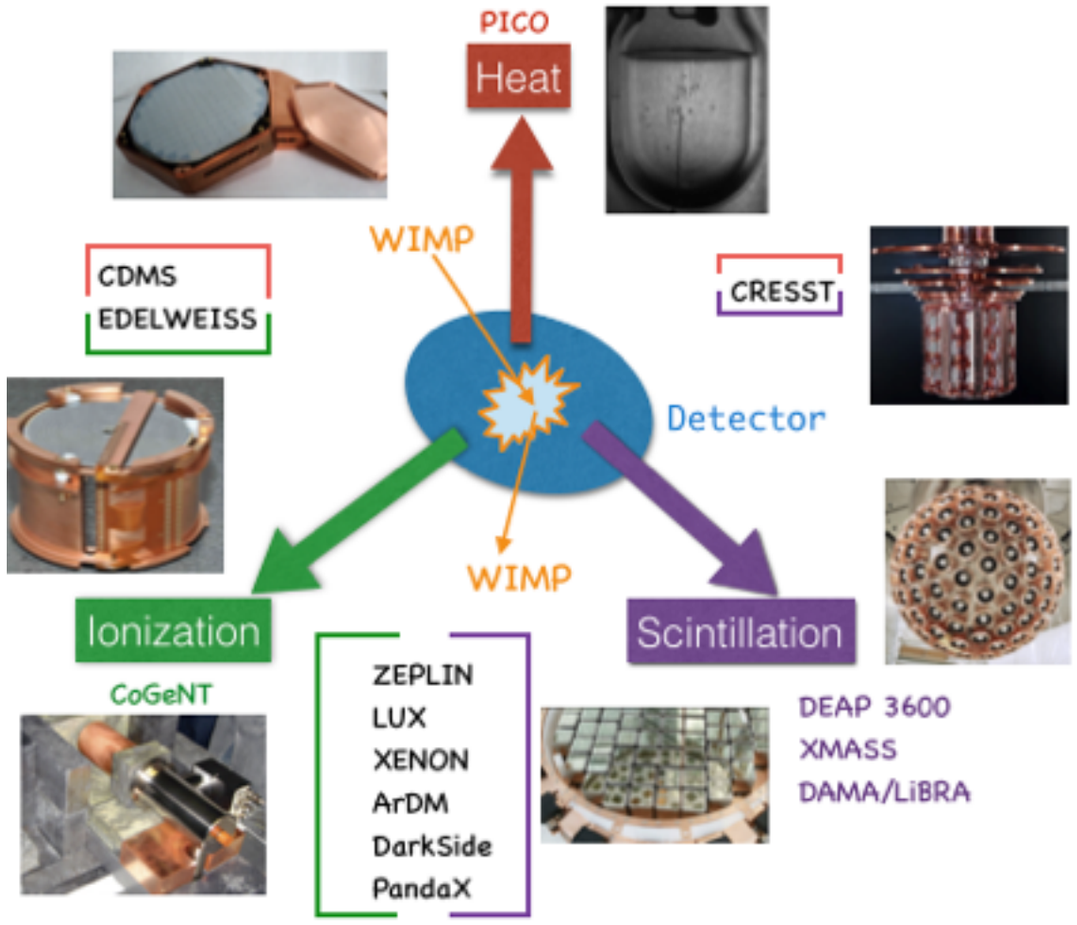

Foreground Subtracted Image

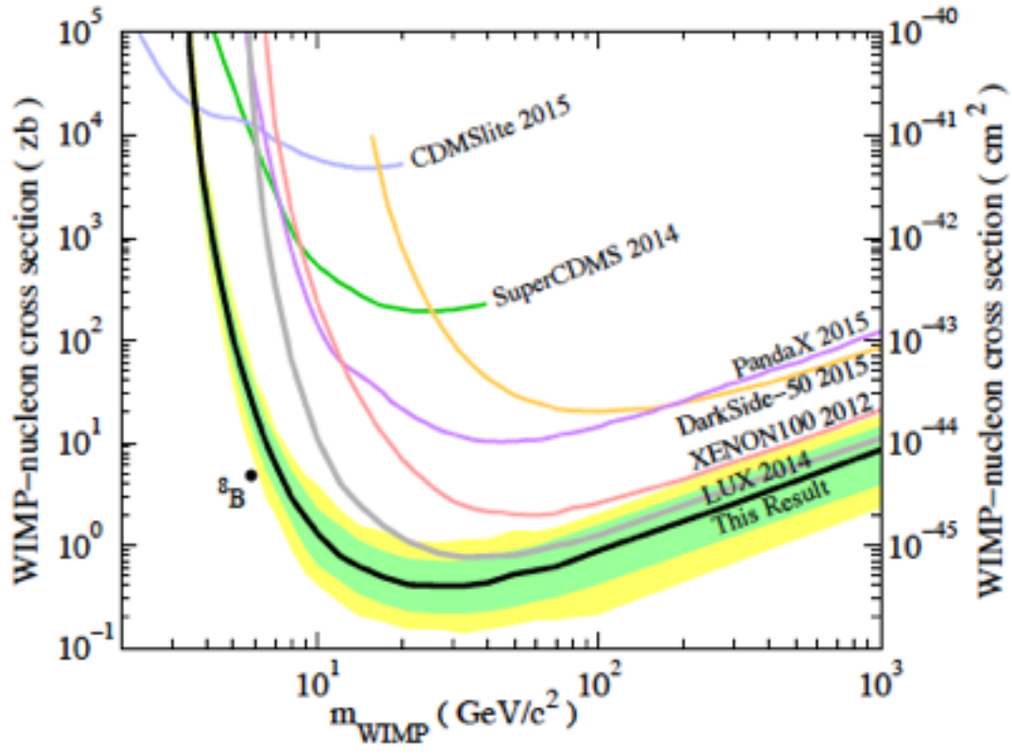

56′
57′
−55°58′
6h58m42s
36s
30s
24s
18s
12s


56′
57′
−55°58′
6h58m42s
36s
30s
24s
18s
12s

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)



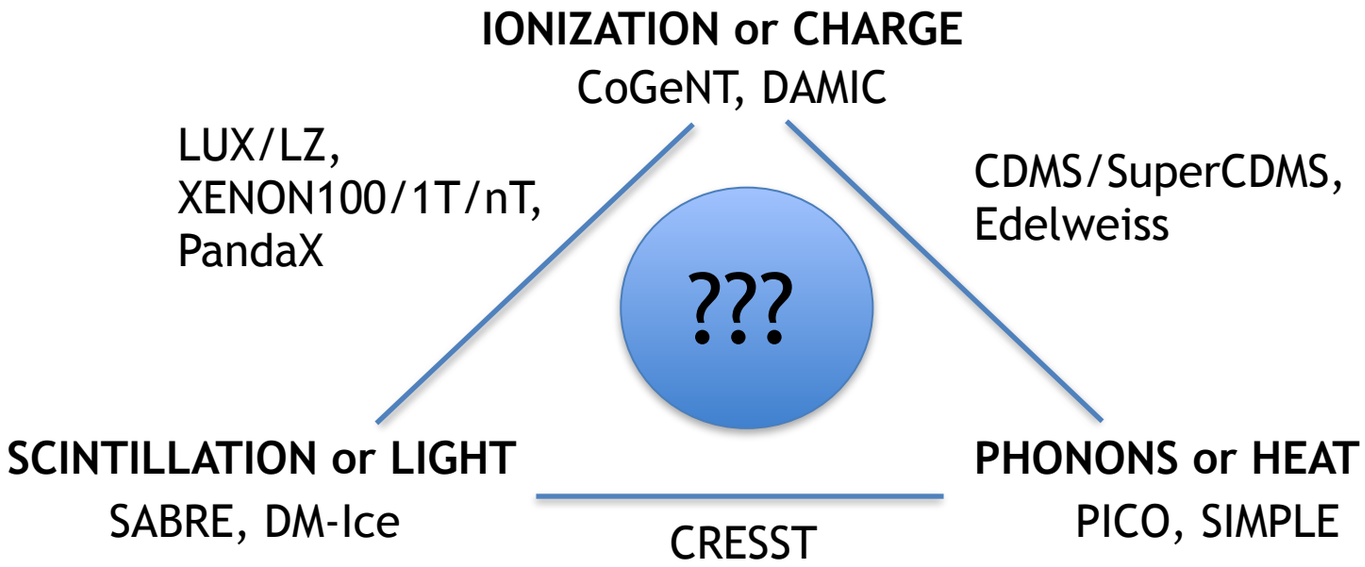


LXe TPCs lead the field

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



… what if it could be done by adapting/merging current detectors/technology ?

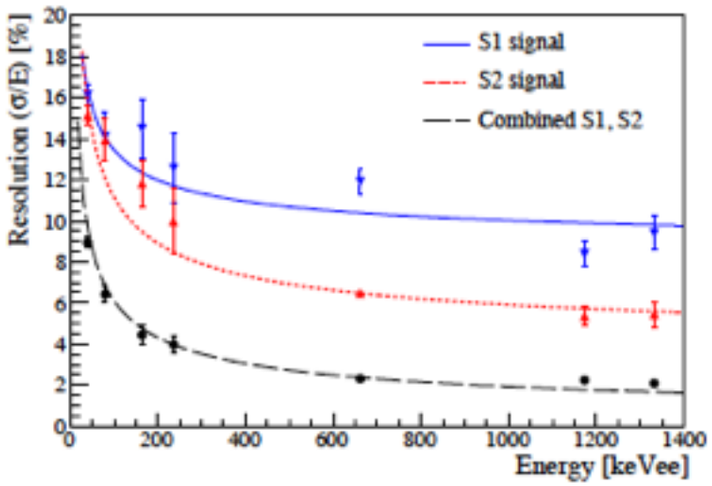
The Making Of a New DM Detector

DM detection relies on distinguishing between ER and NR

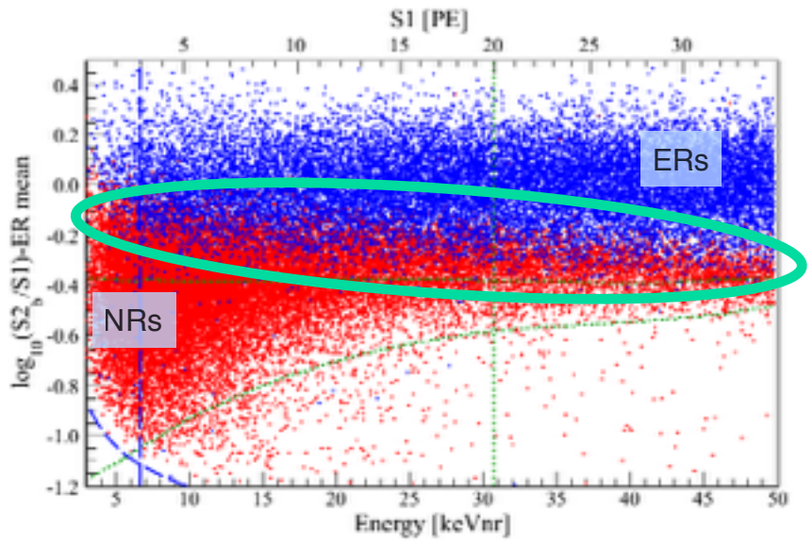
⟶ low misidentification probability

⟶ energy information

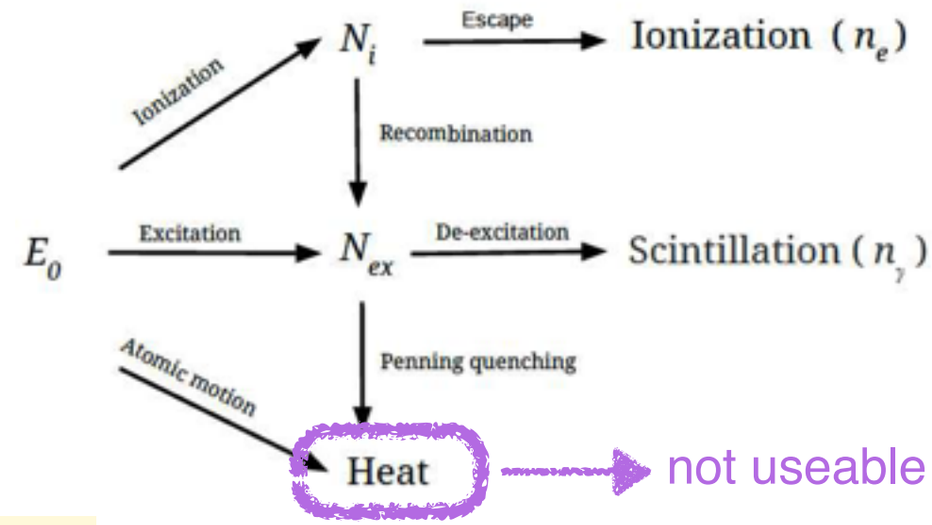
LXe detectors:



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

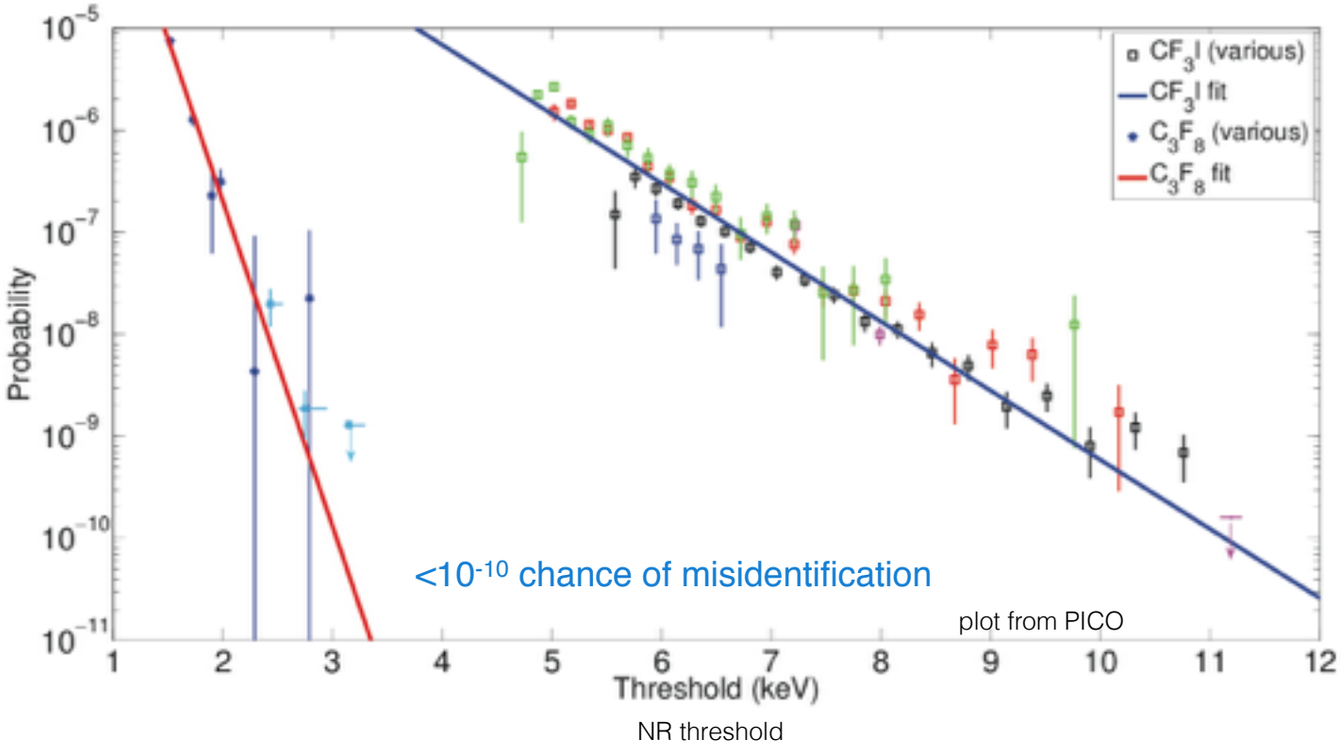
⟶ needs to gain lower misidentification probability

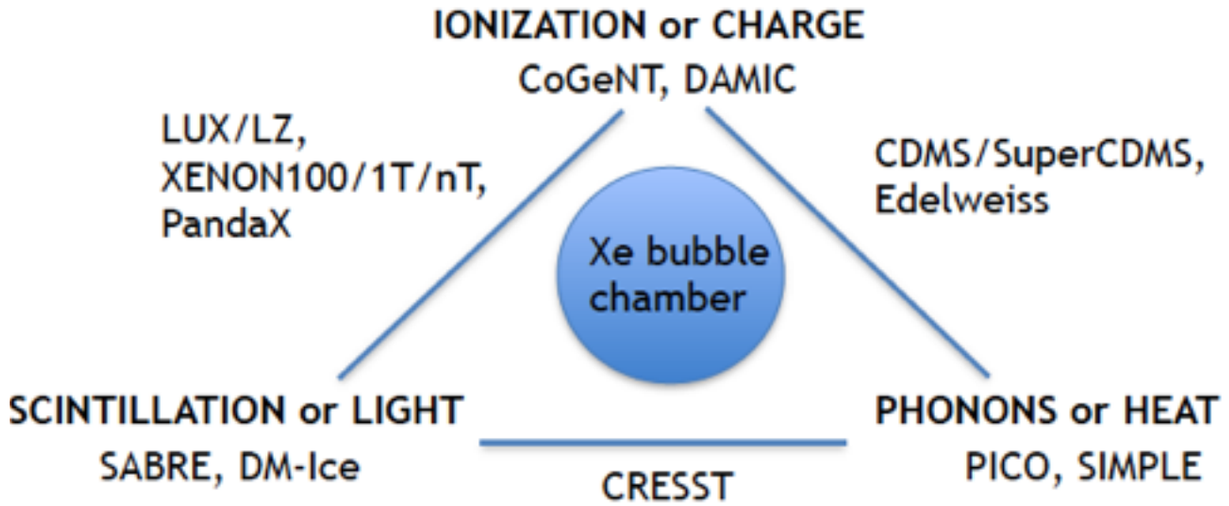
Scintillating Xenon Bubble Chamber

A bubble chamber:

- has heat information
- has great misidentification probability
- has no energy information

} **the perfect complement to a LXe detector**





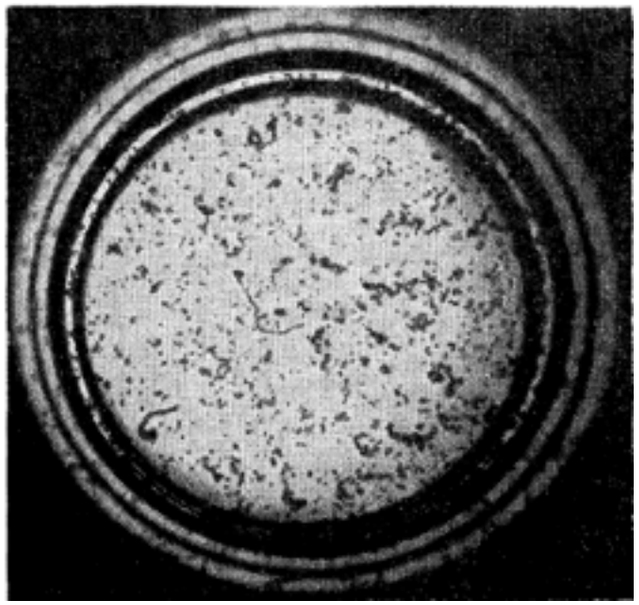
LXe detector + bubble chamber = LXe bubble chamber

⟶ has energy information

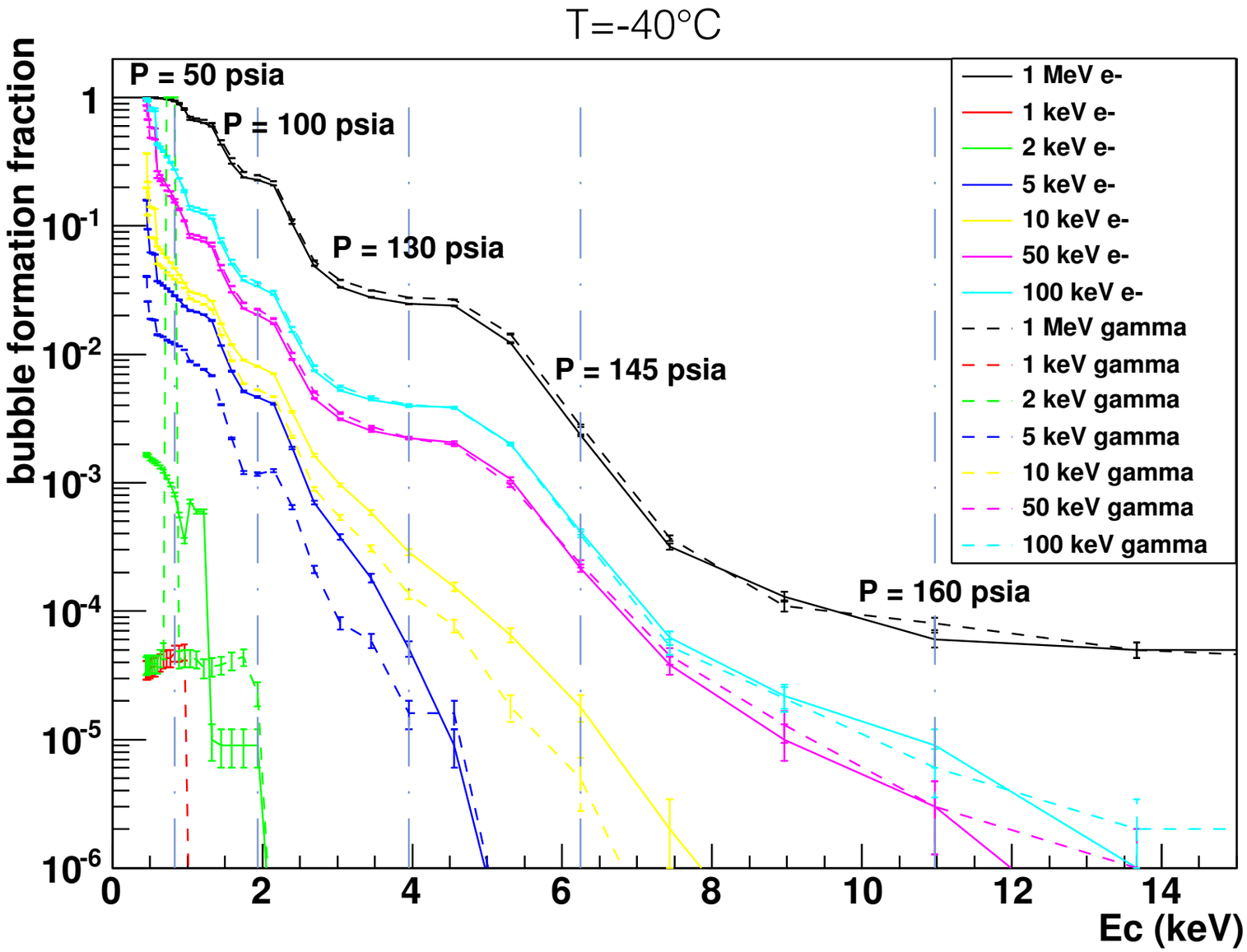
⟶ has great misidentification probability

⟶ 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



First simulation results:

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

Levy et al arXiv:1601.05131 (JINST 2016)

→ **Looks very promising!**

Other Advantages of a LXe Bubble Chamber

What will the backgrounds be?

⟶ the only background left is NR
- can be shielded against
- careful choice of material

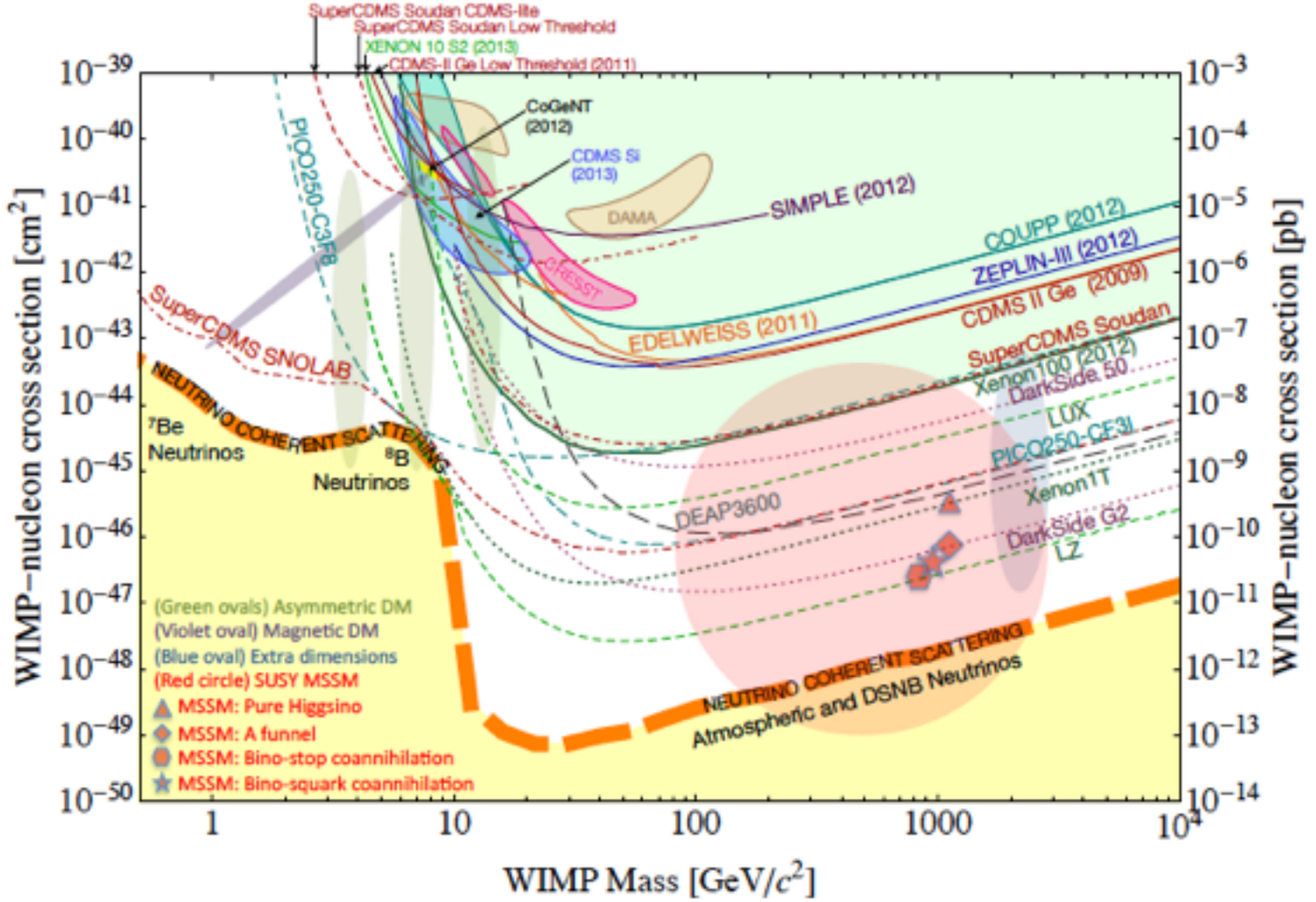
⟶ to be fair, (α,n) reactions still a problem

Sub-keV threshold detector = 100% NR efficiency above threshold

⟶ no more need for 40-50% fiducialization

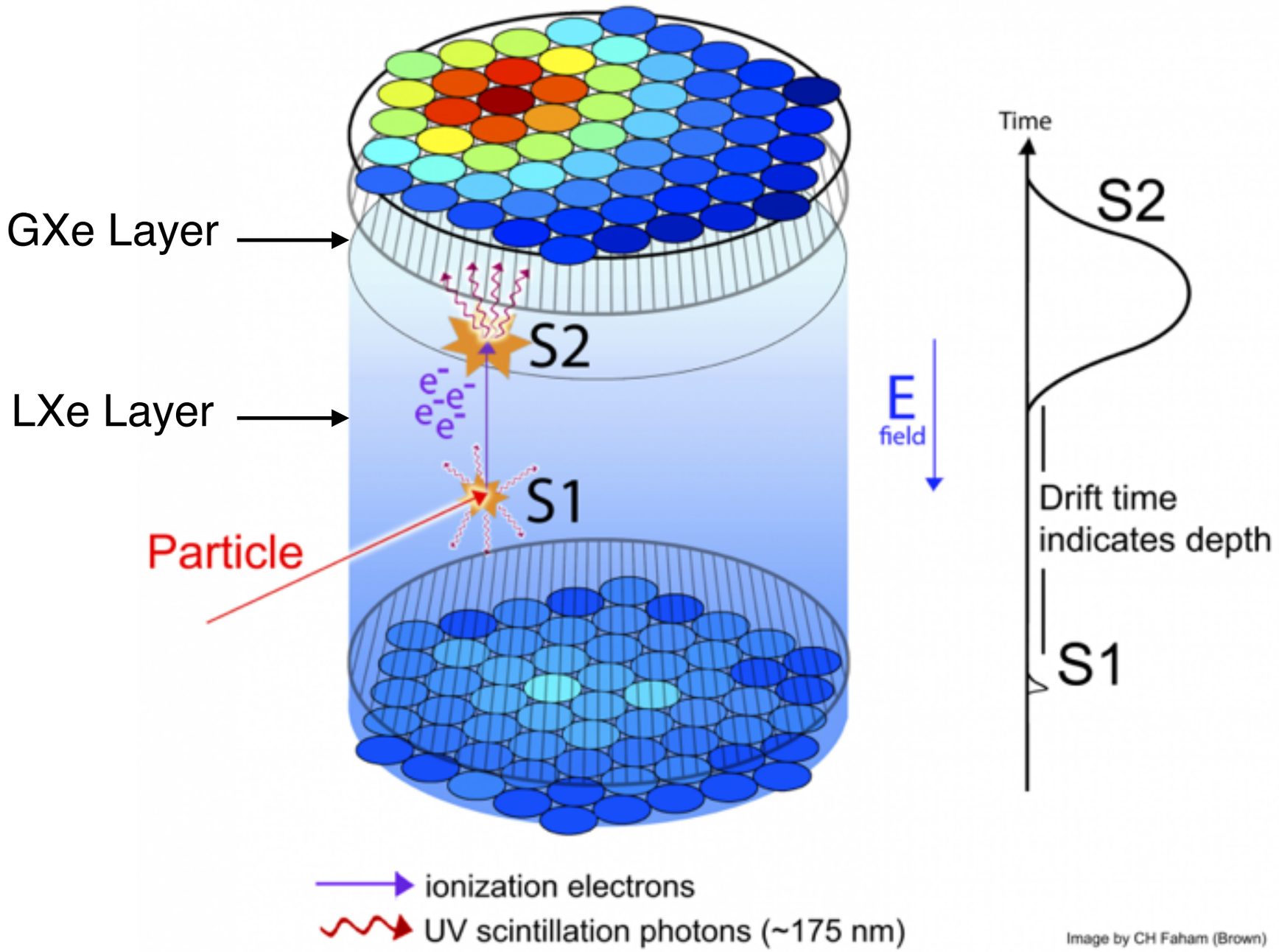
Can we broaden the kinds of physics these experiments are sensitive to?

Sub-keV threshold detector =
- probe parameter space above neutrino floor at low masses
- sensitive to coherent neutrino scattering : at -40.C and low pressures ~0.5 keVnr



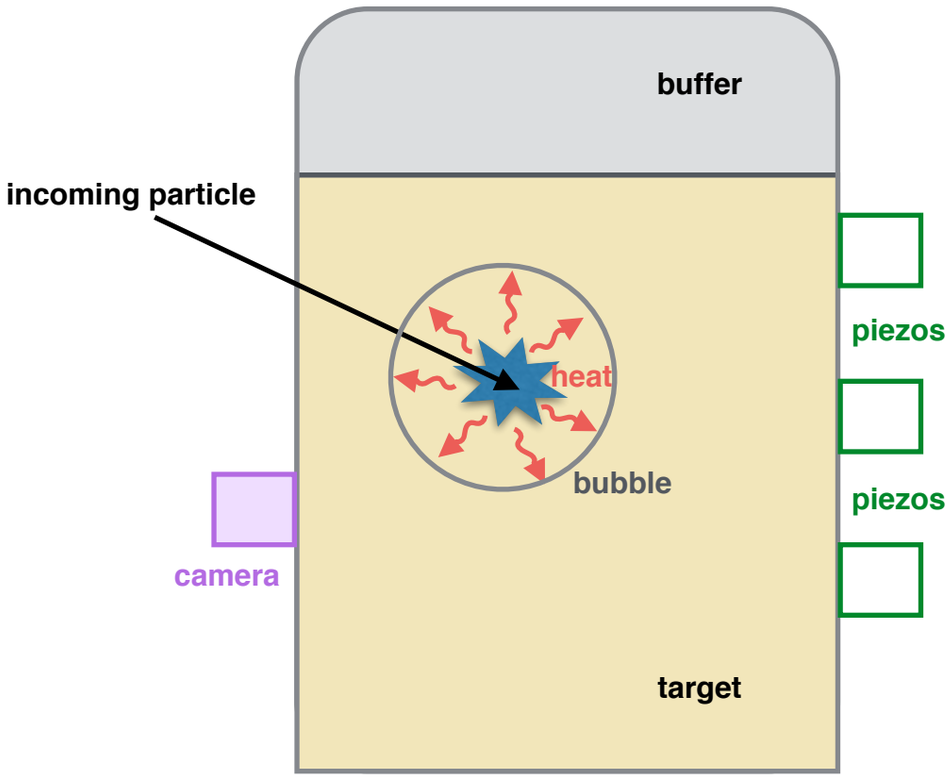
How it works: LXe TPC

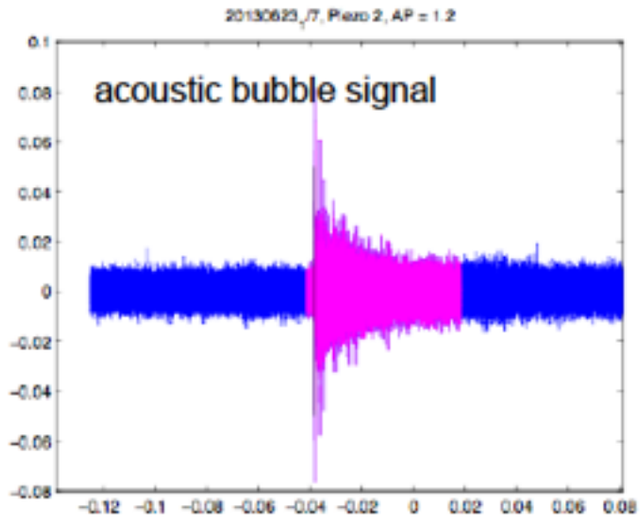
Double phase time projection chamber (TPC)

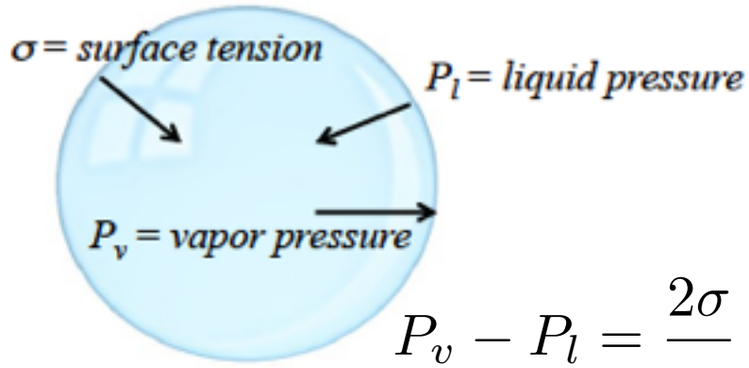


Use 2 detection channels: **ionization + scintillation**

How it works: Bubble Chamber

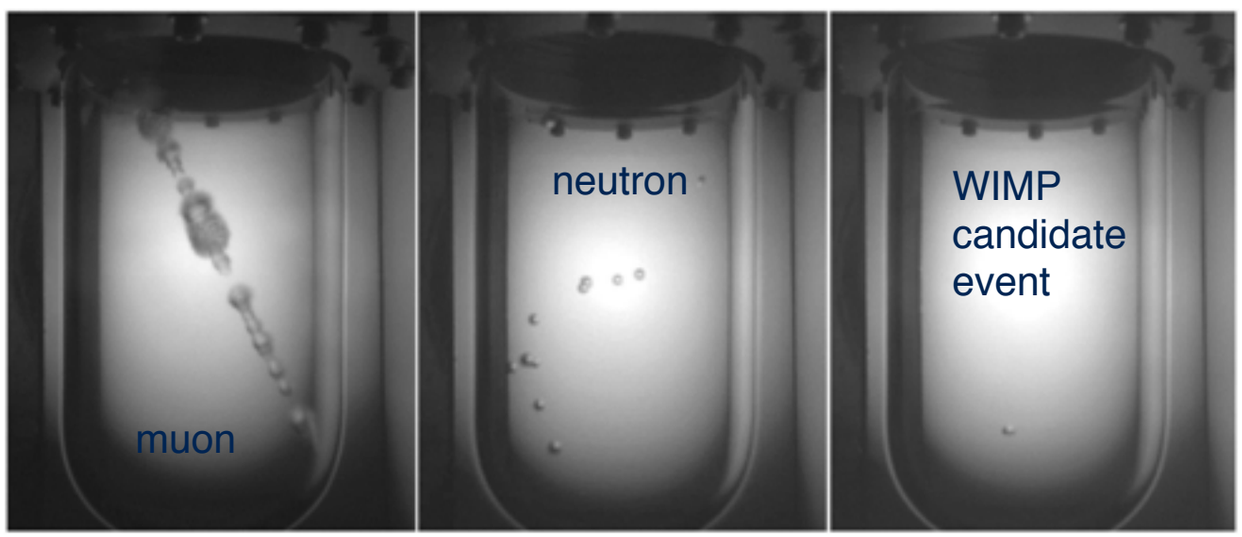






$$P_v - P_l = \frac{2\sigma}{r_c}$$

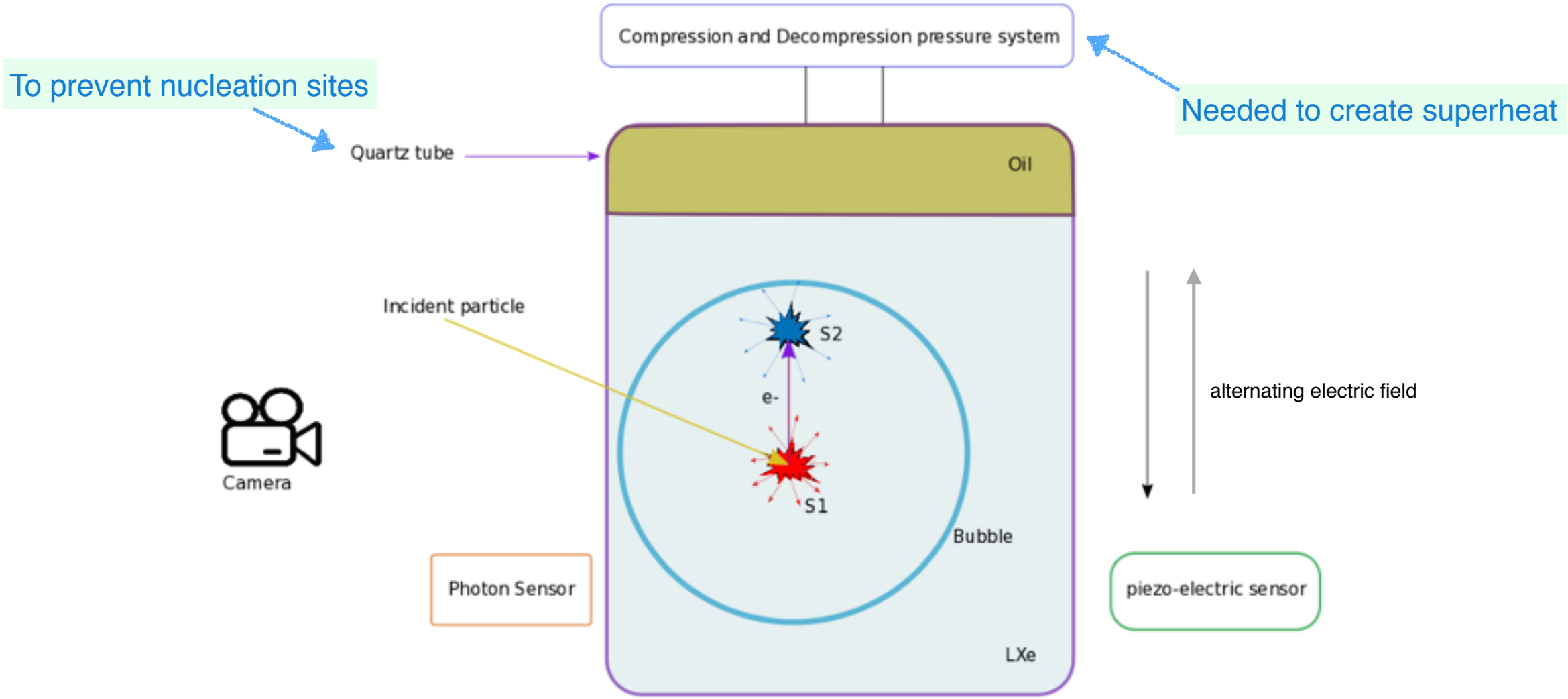
- Chamber filled with a **superheated fluid** (above boiling temperature but in a liquid state)
- **Bubble formation** if heat deposition > E_{th} within r_c (recoil path length)



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

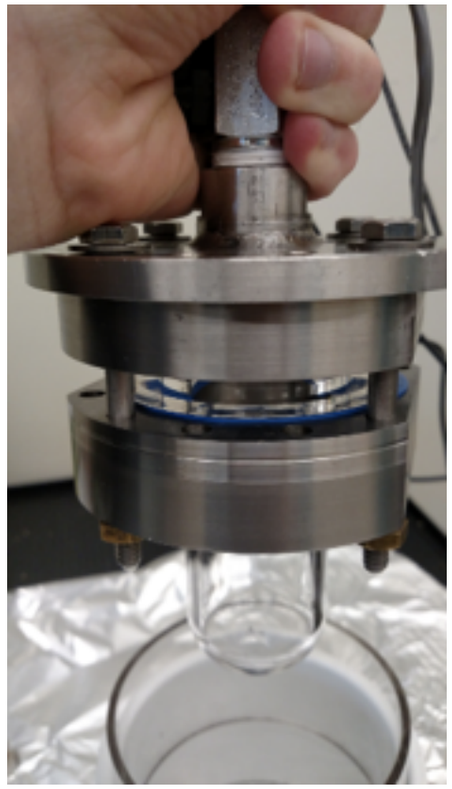


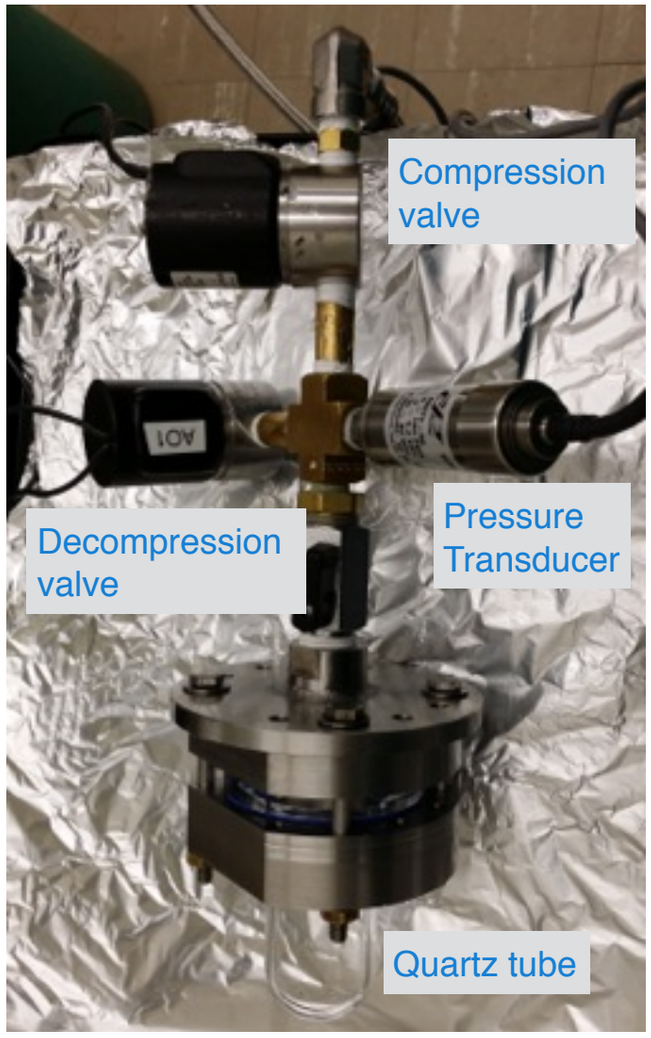
No loss of information

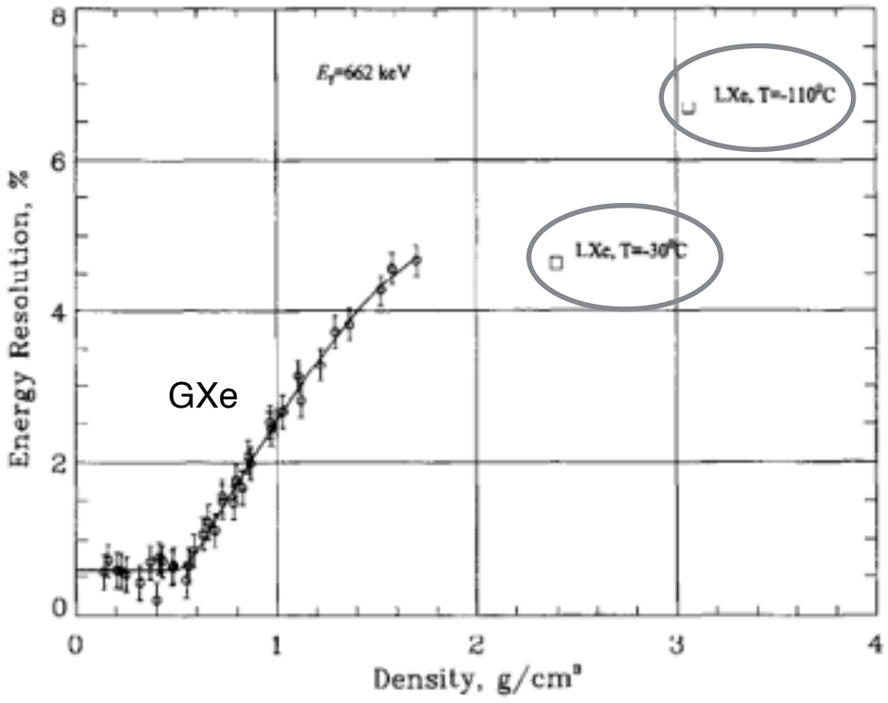
Introducing BubXe

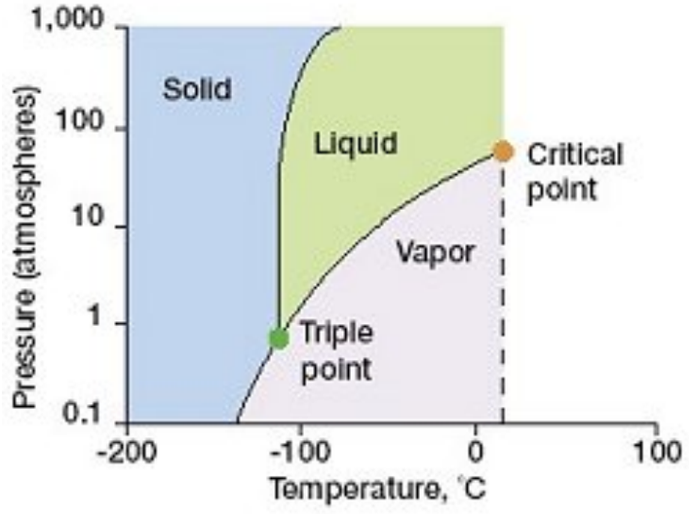
A prototype LXe Bubble Chamber at SUNY Albany

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







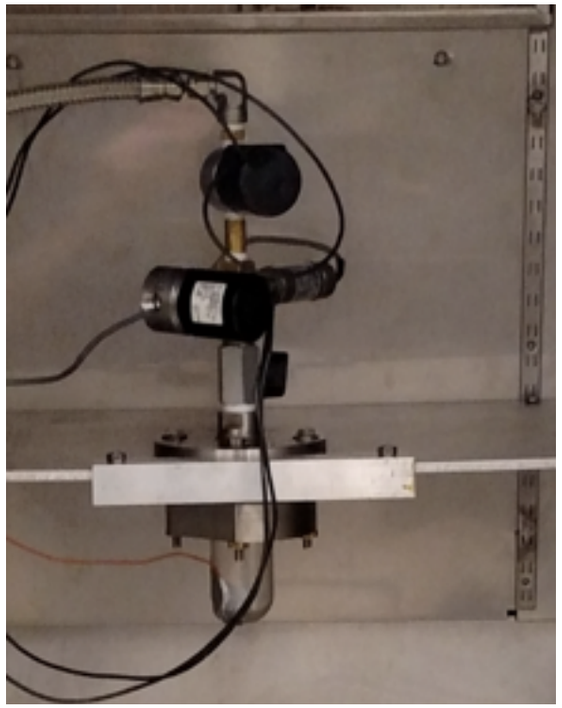


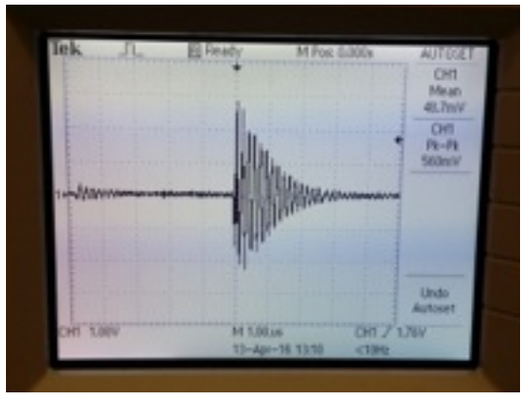
- Variable temperature/pressure operation
- **Fine tuning may increase energy resolution**

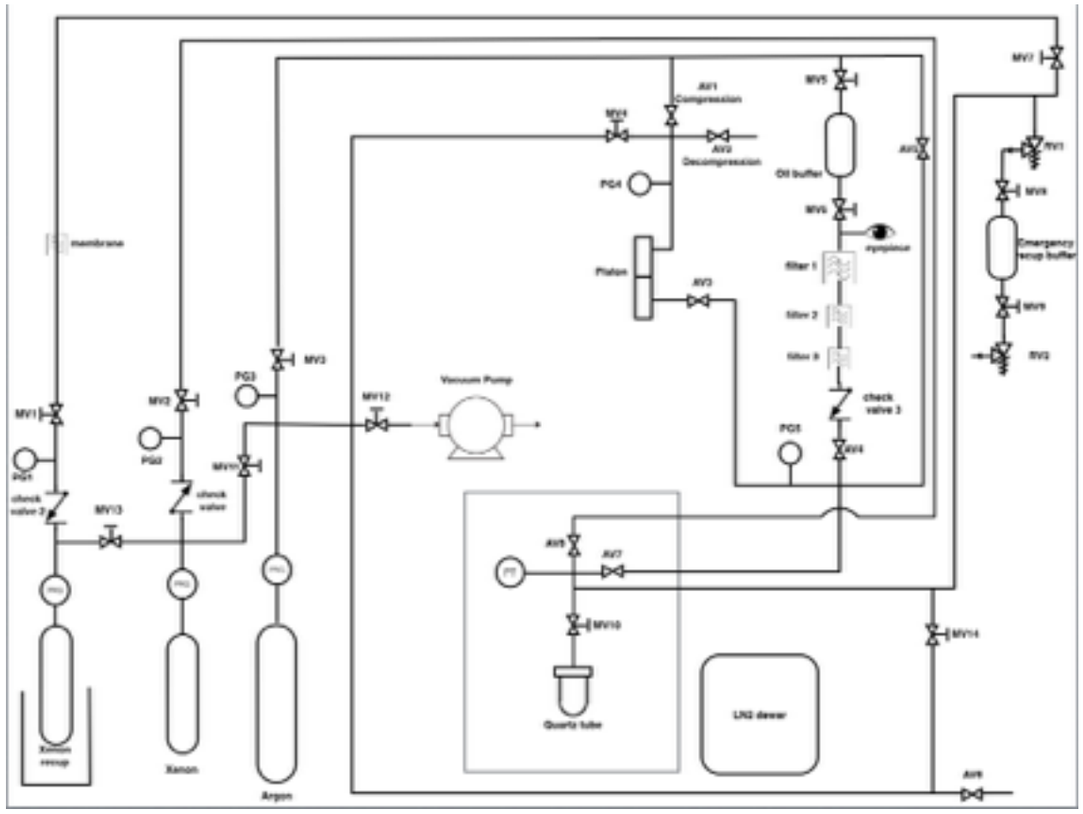
Started small…
⟶ Successful **leak and compression cycles** tests

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

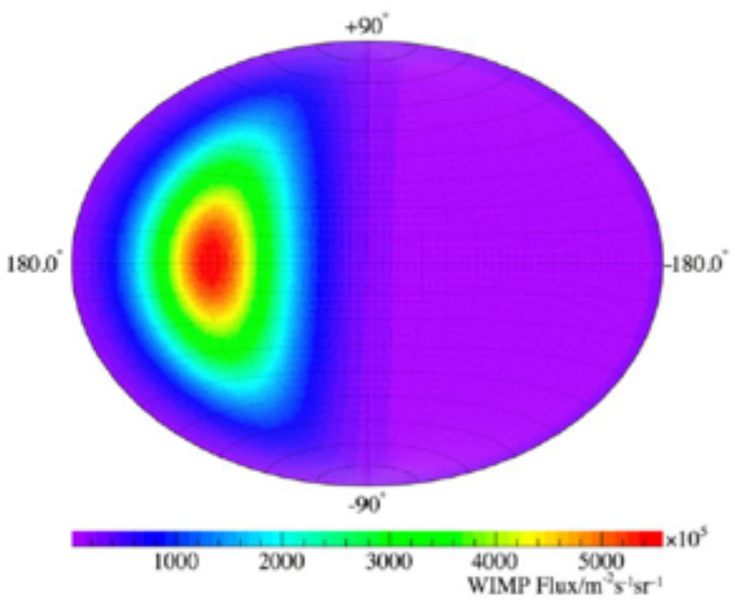
⟶ Water Cerenkov Bubble chamber should be operational this summer

Directional Dark Matter

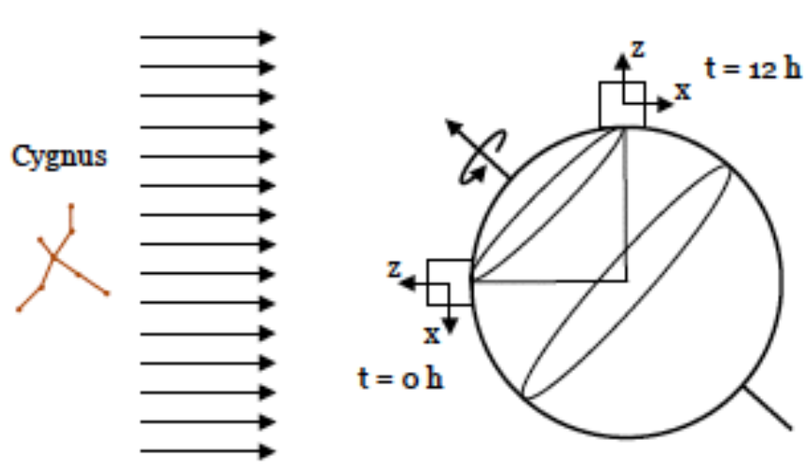
Neutrino floor is a hard stop for current (and planned) DM detectors

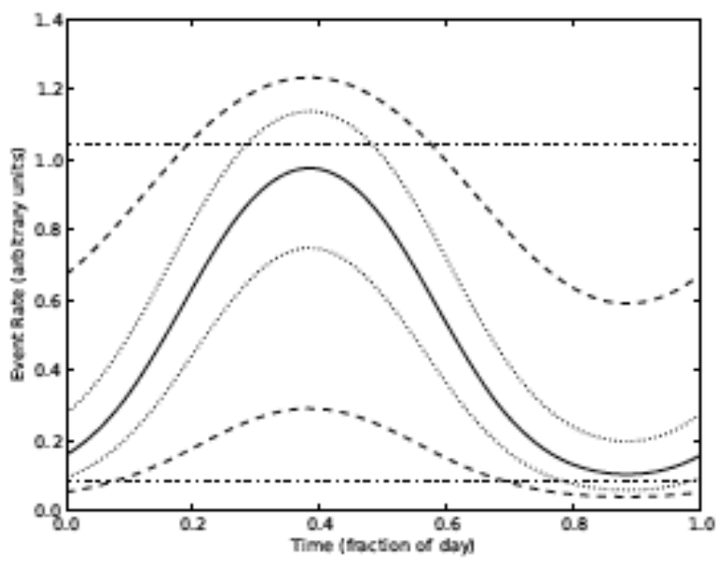
Directionality: only known way to get through the neutrino floor
⟶ looks at the direction of the incoming particle
⟶ has already been proposed to detect DM
⟶ interesting idea but never really developed

DM comes from the direction of the Cygnus constellation (direction of solar motion)



Ahlen et al. arXiv:0911.0323 (2009)



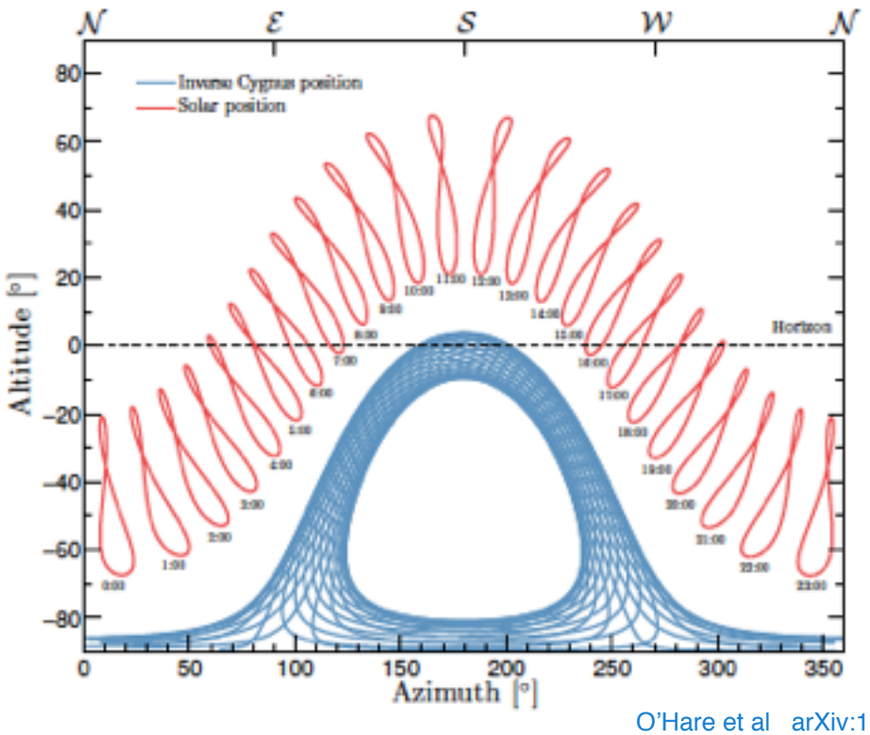


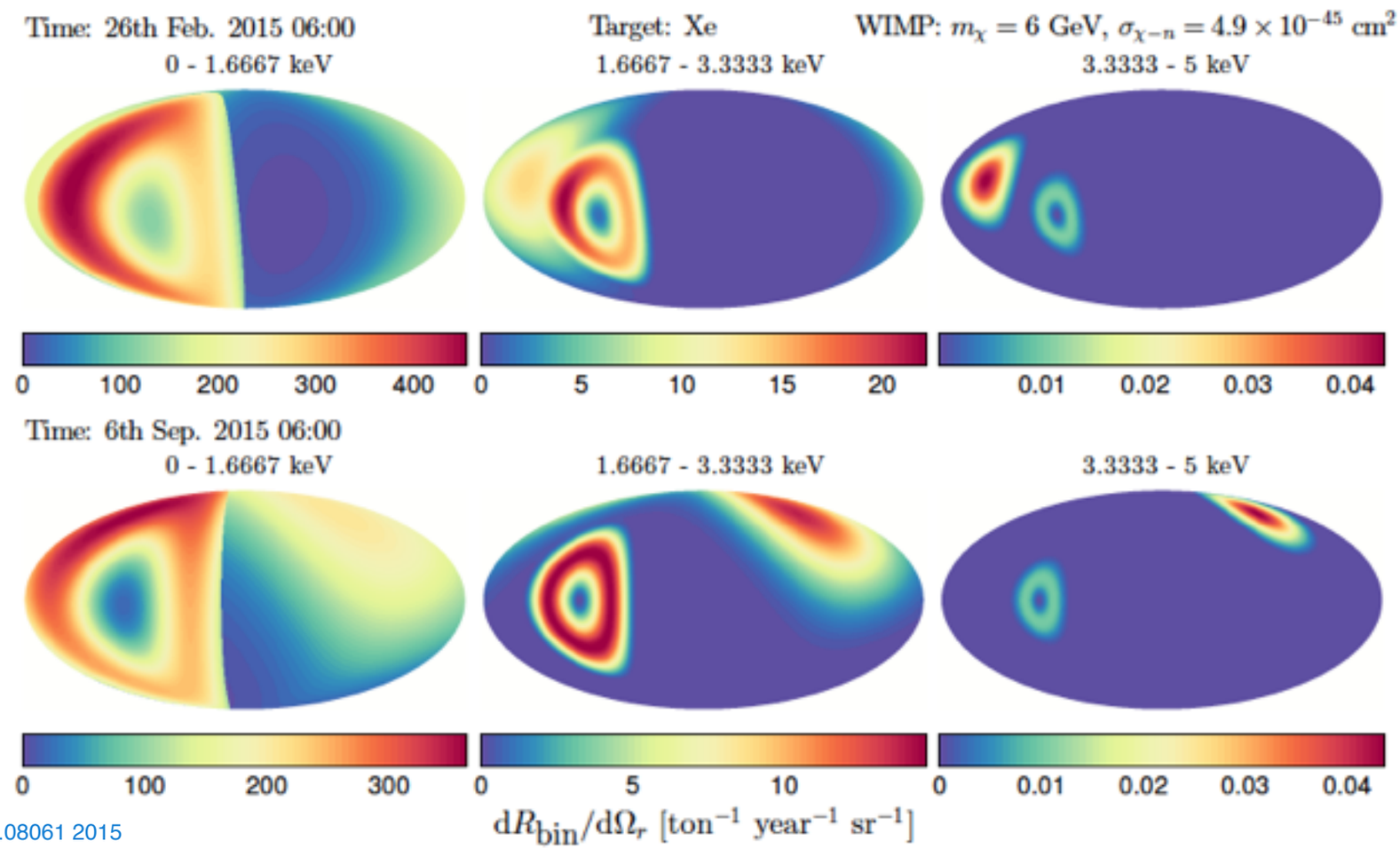
Solar neutrinos come from the Sun

⟶ Can we identify particles based on their incoming direction?

Differentiating between WIMPs and Neutrinos

The sun's position never coincides with Cygnus





O'Hare et al arXiv:1505.08061 2015

- ✦ Yes, one **can differentiate** between WIMPs and neutrinos (in theory)
- ✦ No, no-one has ever done that in practice (**no detector has the potential to do that**)

- ✧ Unfortunately directionality **only useable in gas detectors** (length of electron tracks)
- ✧ But ton-scale gas detectors will require large, expensive readout systems.

But BubXe is a gas detector, and also a liquid one ⟶ **how to test for directionality?**

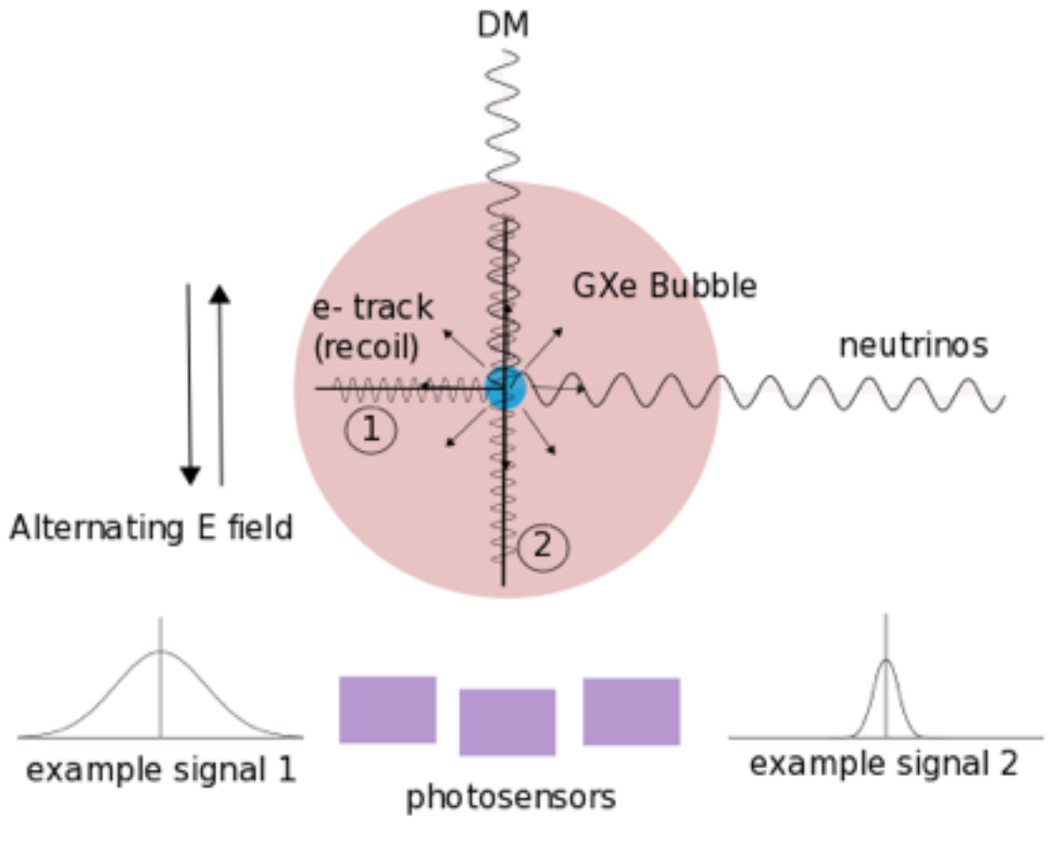
Directionality with BubXe

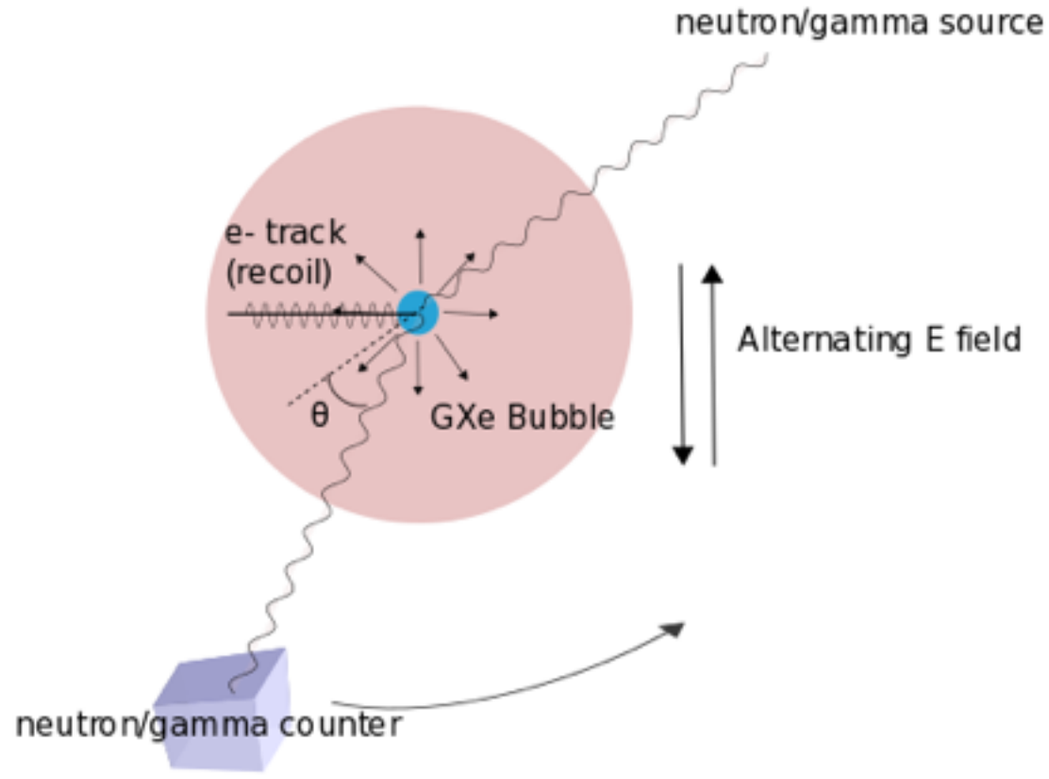
Requires long electron track in the bubble: ok with alternating electric field

⟶ look at scintillation pattern, shape, timing etc…

⟶ try to find a way to discriminate between WIMPs and neutrinos

* Requires a very precise calibration system to measure NRs
* Coincidentally, the same calibration system can be used for ERs discrimination
* Can also be used as global calibration system to directly measure recoil energy





First DM detector that could go beyond the neutrino floor…

Conclusion

Liquid xenon bubble chamber is being developed at UAlbany

- **Liquid detector that is also a gas detector whenever you want it to be!**
- **First detector design that can potentially go beyond the neutrino floor.**

Many more 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 Cerenkov test expected this summer
- 1st xenon test expected by the end of the year