Thoughts on a tonne-scale liquid noble bubble chamber

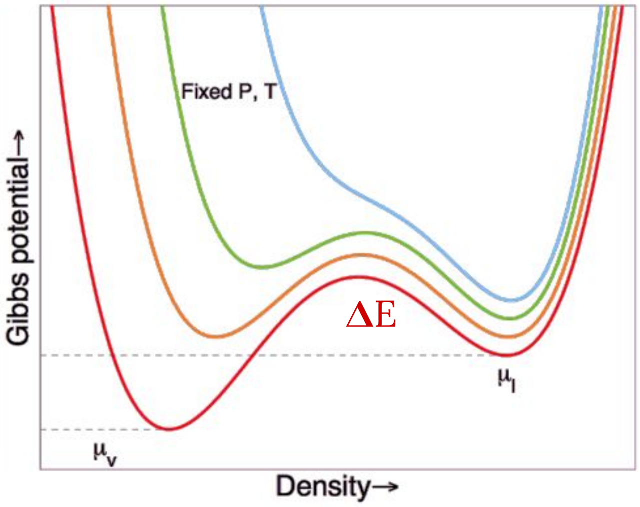
B. Broerman
for the SBC collaboration

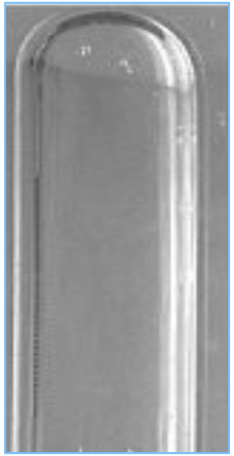
Queen's University

Arthur B. McDonald Canadian Astroparticle Physics Research Institute

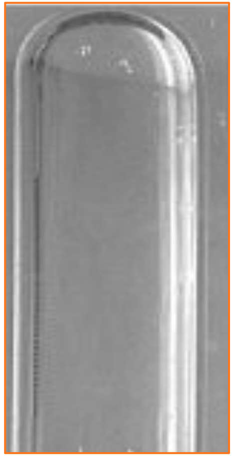
Bubble chambers, generally

- In superheated target fluids, particle interactions can create a bubble.

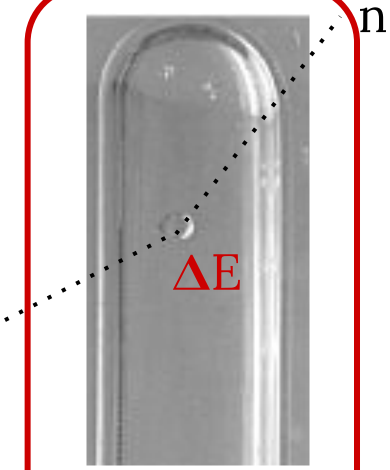




Not superheated (boring)



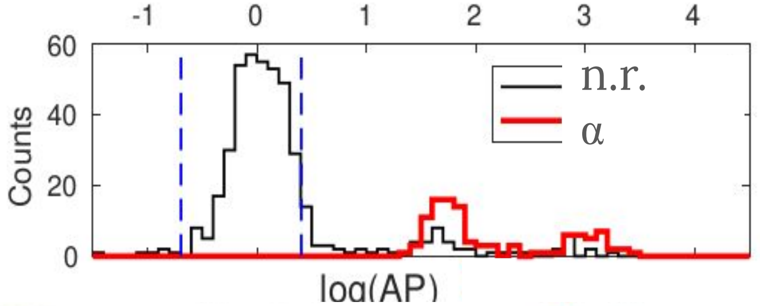
P ↓, Metastable superheated

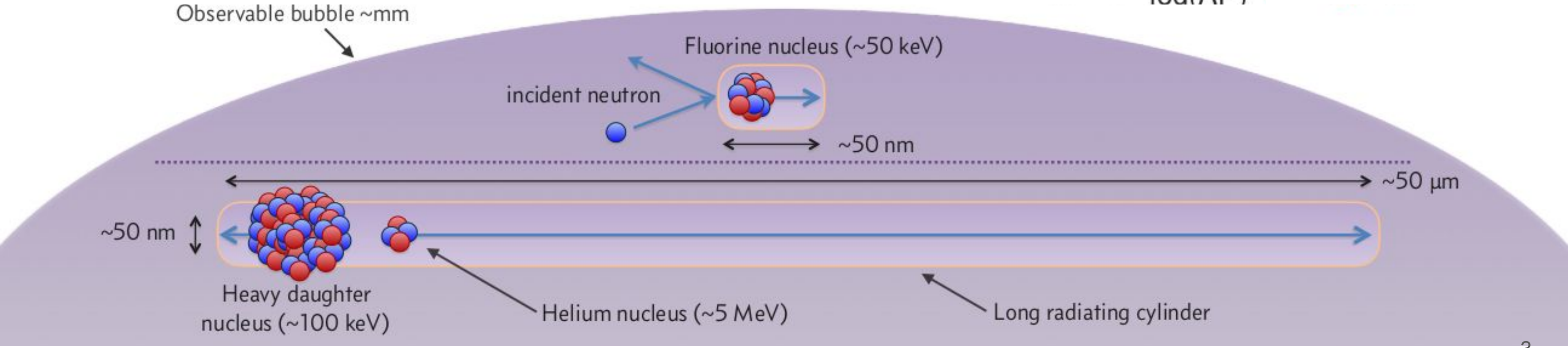


If ΔE deposited, local phase change

Bubble chambers for DM searches

- Efficient nucleation at low n.r. thresholds
- Highly β/γ insensitive
- n.r./α discrimination:



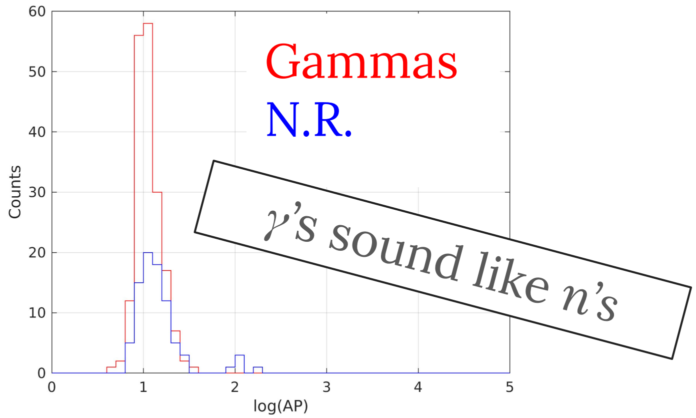


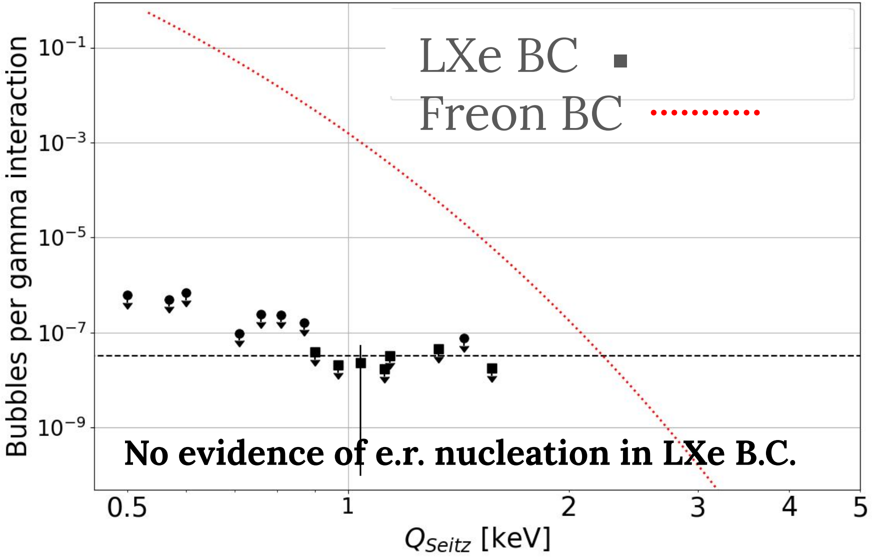
A liquid-noble bubble chamber

Adds in:

- Energy reconstruction

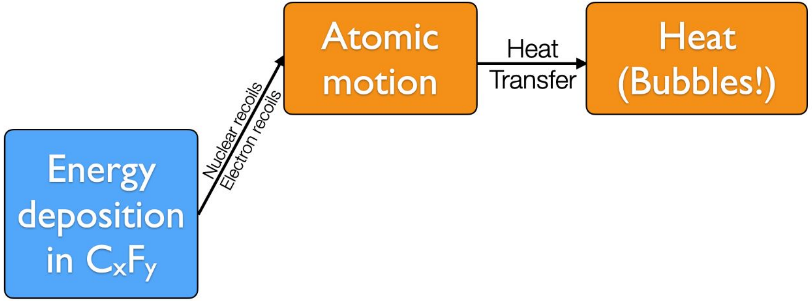
- Higher β/γ rejection than Freons
    - Lower threshold w/o e.r. backgrounds increases sensitivity to lower DM masses



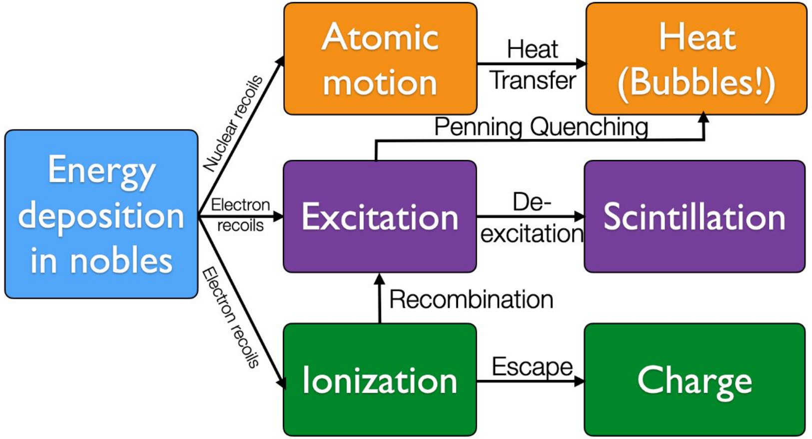


Why liquid-nobles work

Freon-based target fluid



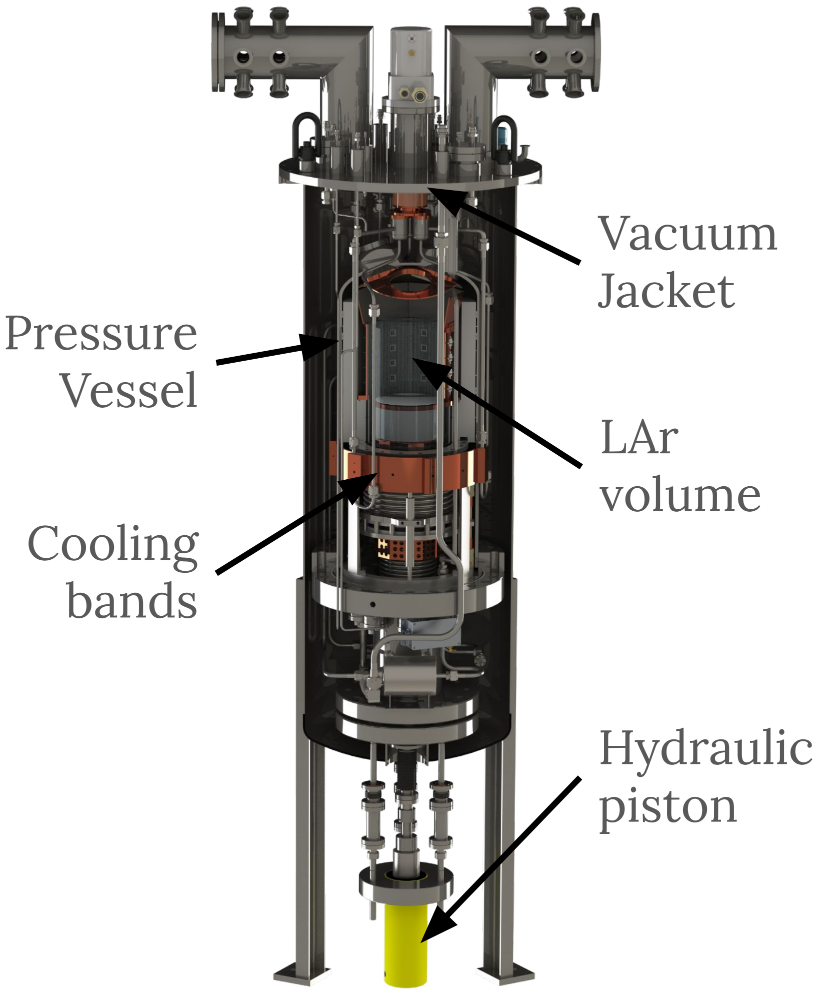
Liquid-noble target fluid



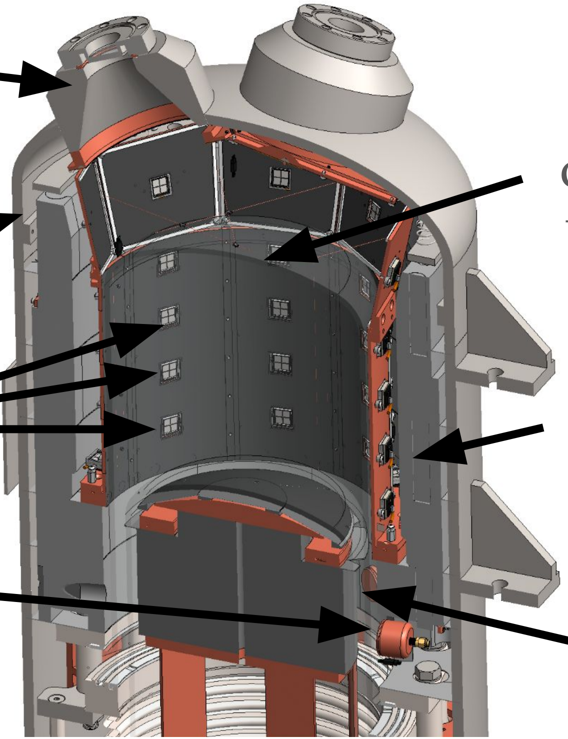
Main point: Liquid nobles remain β/γ blind in GeV-scale ROI
$\rightarrow$ **sensitive to only nuclear recoils**

The **S**cintillating **B**ubble **C**hamber program, currently

- 10 kg LAr, doped with Xe
- Phased development
  - SBC-LAr10 at FNAL: engineering and calibration
  - SBC-SNOLAB: low-background dark matter search
- Targeting 100 eV n.r. threshold



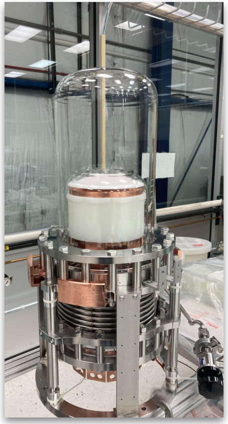
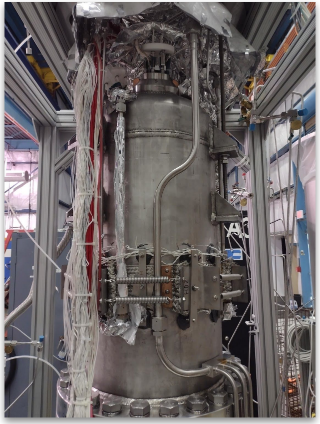
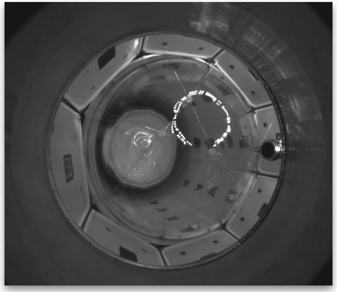
SBC’s 10 kg detector design



Design Goals	
Target Volume	10 L (10 kg LAr @ 130 K)
Nucleation Threshold	100 eV (30 psi , 130 K)
Thermodynamic Regulation	±0.5 K, ±0.1 bar, (± 5 eV Seitz threshold)
Scintillation Detection	~2% collection, 1 photon/ 5 keV n.r.
Bubble Imaging	100 fps, mm resolution
Acoustic Reconstruction	Time-of-nucleation to ± 25 μs

Beyond 10 kg-yr exposure

SBC at FNAL: final assembly/ commissioning this summer

SNOLAB: TDR completed, beginning surface assembly this summer

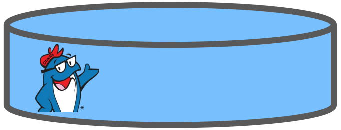
To achieve tonne-yr exposures, 1 tonne superheated volume?

A) Soup can:

1-m-⌀ × 1.4 m

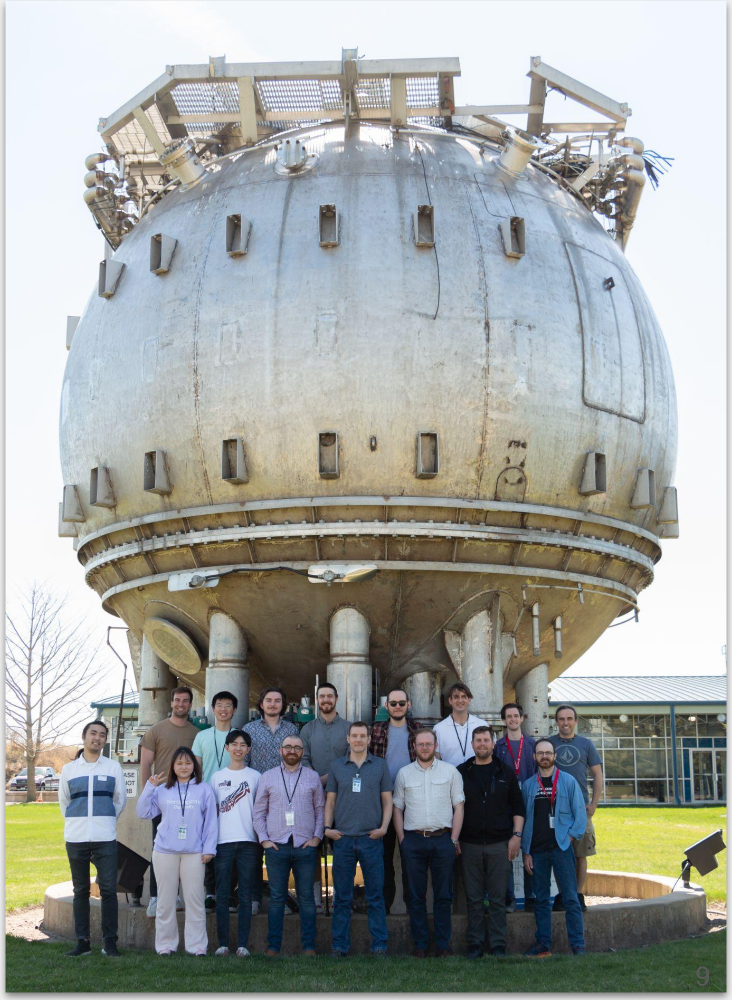
B) Tuna can:

1.6-m-⌀ × 0.5 m



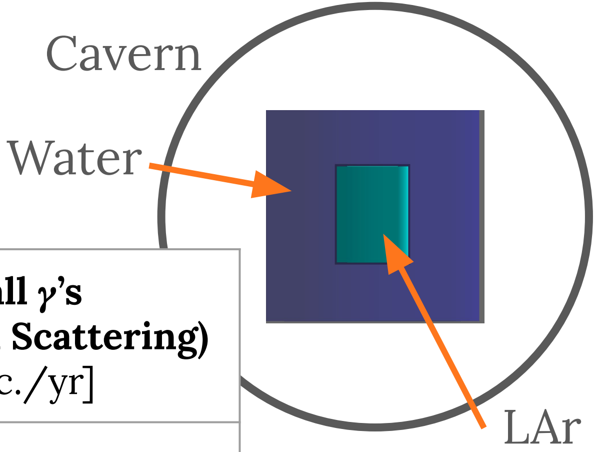
Big can be done

Gargamelle
18 t of $CBrF_3$



15’ (F)NAL chamber
7 t of H_2
with $\subseteq$ the SBC collaboration

External shielding requirements



Water Shielding Dimensions (⌀ & h)	**Wall Neutrons** [nuc./yr]	**Muon-Induced Neutrons** [nuc./yr]	**Wall γ's (Thomson Scattering)** [nuc./yr]
Unshielded	$(7 \pm 3) \times 10^5$	35 ± 4	$(1.2 \pm 0.2) \times 10^5$
3 m	< 1	12 ± 2	1980 ± 400
6 m	< 1	3 ± 1	1.3 ± 0.3
9 m	Negligible	Negligible	Negligible

Single scatters with energy deposit > 100 eV (no scintillation veto).

Internal radiopurity requirements (3 t PV)

- Activity targets for < 1 event from neutrons and < 1 event from Thomson scattering
- Upper limits on Timet Ti are not so far off from these desired limits
- Do expect 1 spontaneous nucleation event/tonne year at a 40 eV threshold

	Neutron	**Thomson Scattering**
Chain	**Activity** [mBq/kg]	**Activity** [mBq/kg]
^{232}Th : $(\alpha$,n)	< 0.01	< 0.01
$^{238}U_{Up}$: S.F.	< 0.02	-
$^{238}U_{low}$: $(\alpha$,n)	< 0.05	< 0.03
^{235}U : $(\alpha$,n)	< 0.07	< 65
^{210}Pb : $(\alpha$,n)	< 21	-
^{40}K	-	< 34

Surface rates

Area of R&D

To have 1 event/hour on the superheated, argon-wetted surface (radio-background + surface effects):

- Soup can: 6 m^2 , needs 4.7 nBq/cm^2
- Tuna can: 6.5 cm^2, needs 4.2 nBq/cm^2

Experiment	**Surface rates** [nBq/cm^2]
PICO 60	200
DEAP-3600	26
SBC 1t	~5

Big question: understanding surface event mechanism

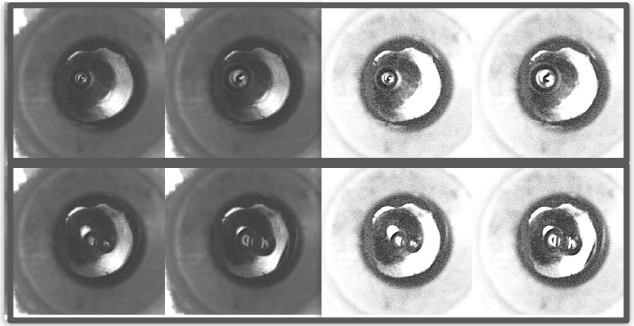
Materials other than quartz

Area of R&D

We are unable to make quartz vessels larger than 250L (fiducial)

- Metals (stainless steel)
  - Demonstrated in test chambers
  - Electropolished, Ra ≲ 10 nm (low surface nucleations)
  - Could act as PV & containment

- Plastics (acrylic, Lexan)
  - Demonstrated in test chambers & LEBC @ CERN/NAL



Stainless steel test chamber

LExan Bubble Chamber

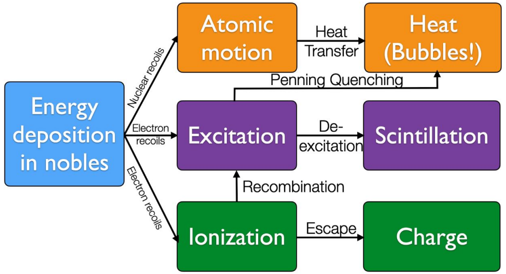
Acrylic test chamber

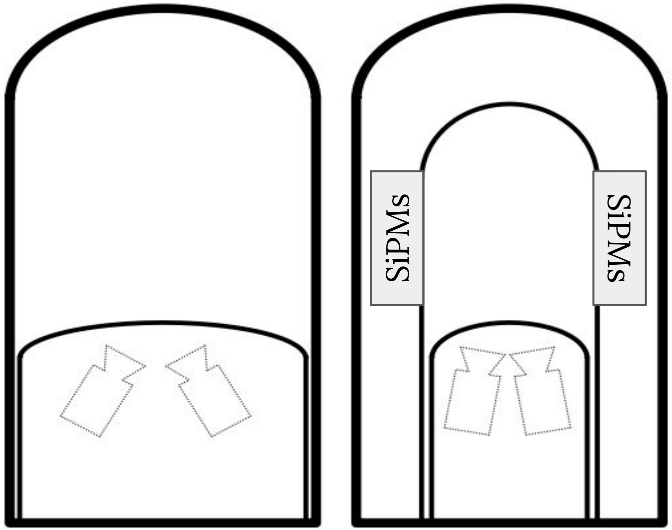
Scintillation: can we detect it, or do we need to?

- The scintillation mechanism works, whether we detect the γ's or not

- Having lots of SiPMs
  - Increases internal backgrounds
  - Pressure vessel becomes holey (need to get signals out)

- Something more clever?
  - Light collection within central piston
  - PEN/polymeric w.l.s. coatings on acrylic





Conclusion

- Liquid-nobles are well suited to GeV-scale DM searches
  - Sensitive only to n.r. scattering
  - Possible to swap with Xe, N2, CF4

- Commissioning at FNAL and preparing for SNOLAB this summer

- Tonne-yr exposure can reach Ar fog
  - Could do 500 kg × 2 yr, etc.
  - Will require some R&D effort