SEARCH FOR DARK MATTER PARTICLE WITH THE PICO-40L C3F8 BUBBLE CHAMBER

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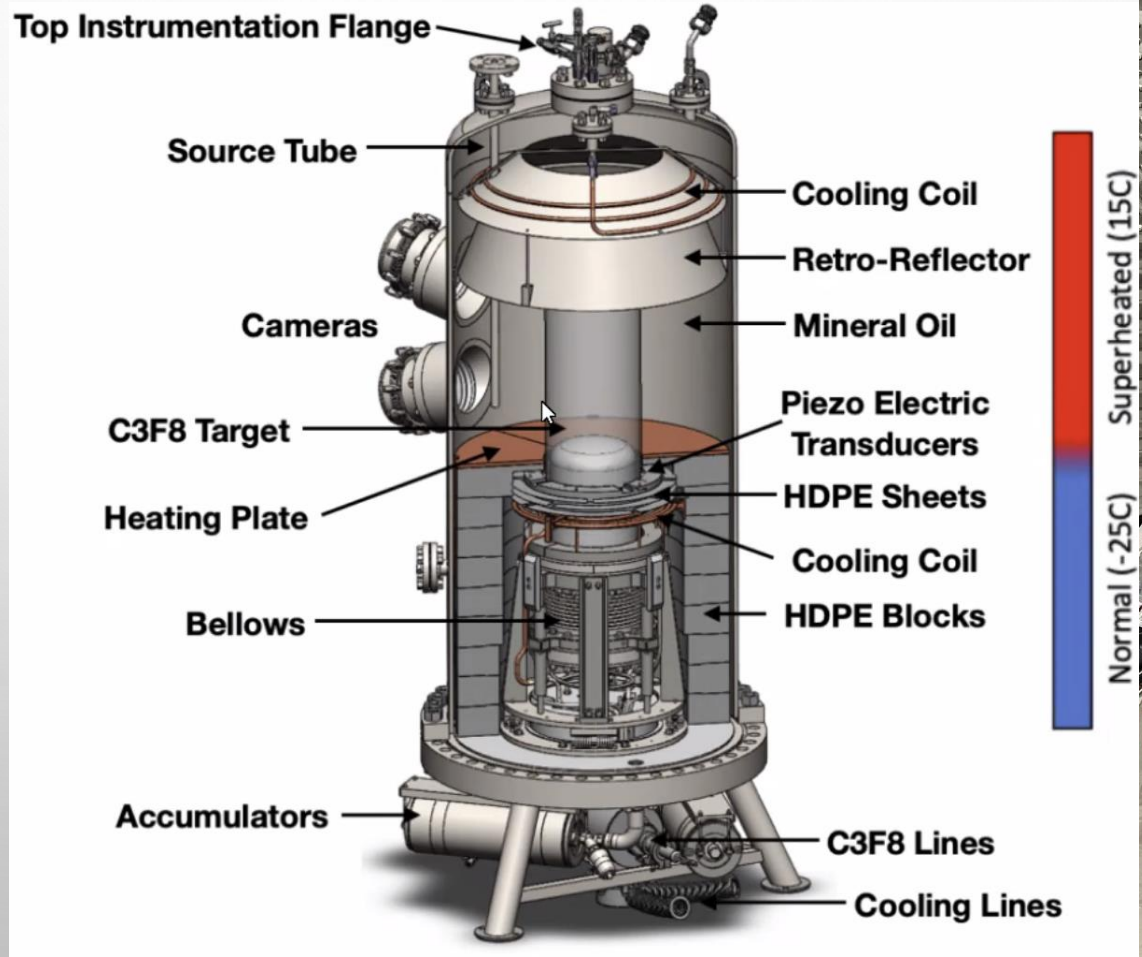
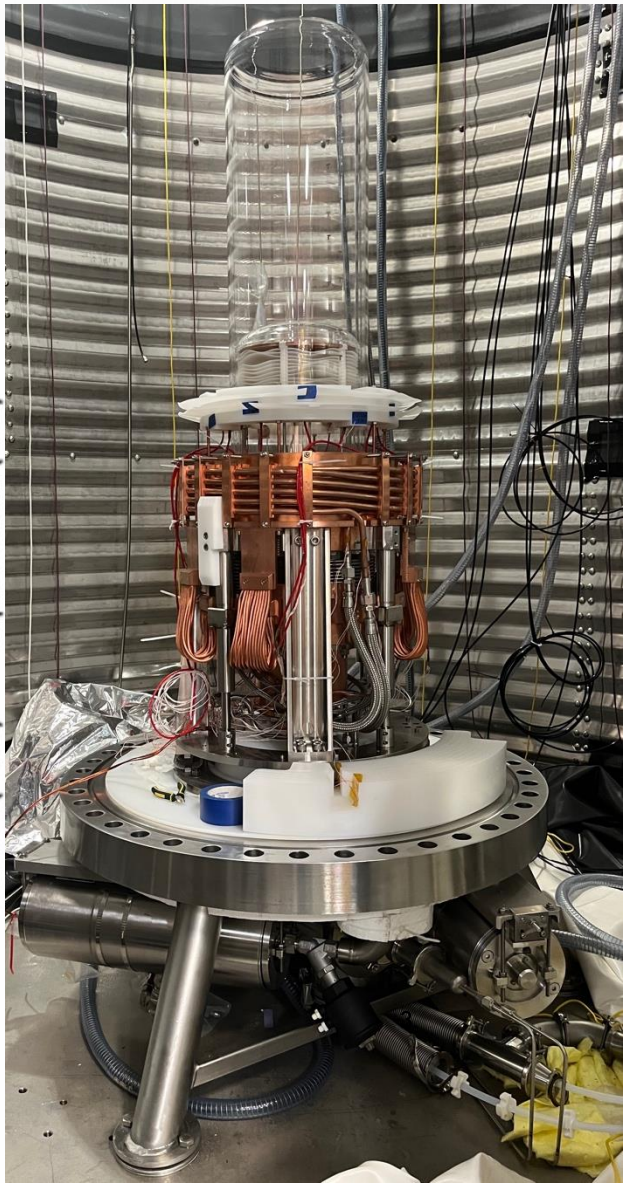
OUTLINE

- INTRODUCTION
  - WHAT IS THE PICO-40L BUBBLE CHAMBER?
- IMPACTED ASPECTS
  - DETECTION PRINCIPLE: CYCLE
  - FAST PRESSURE TRANSDUCER : DYTRAN → FIDUCIALIZATION
  - HYPOTHESIS ON THE ORIGIN OF THE HIGH NUMBER OF WALL EVENTS: SURFACE ROUGHNESS
  - ADVANTAGES
  - GEOMETRY → THERMAL CONCEPT
  - COMMISSIONING
  - SENSITIVITY
- CONCLUSION : VALIDATION FOR THE NEXT-TONNE SCALE BUBBLE CHAMBER PICO-500

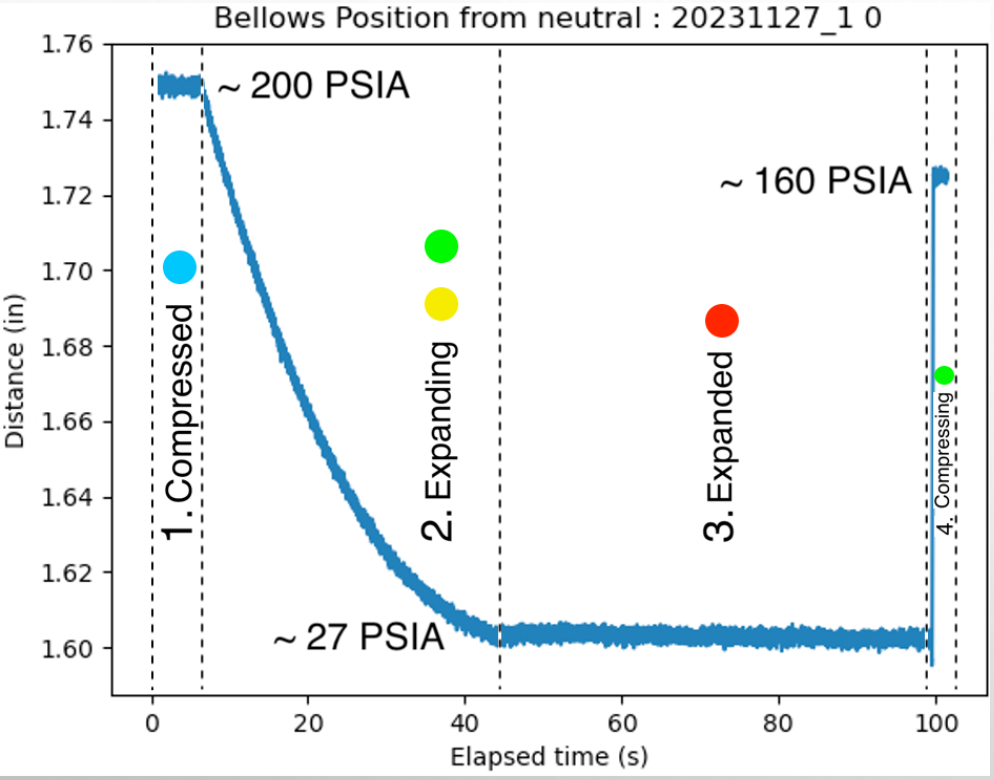
PICO-40L BUBBLE CHAMBER

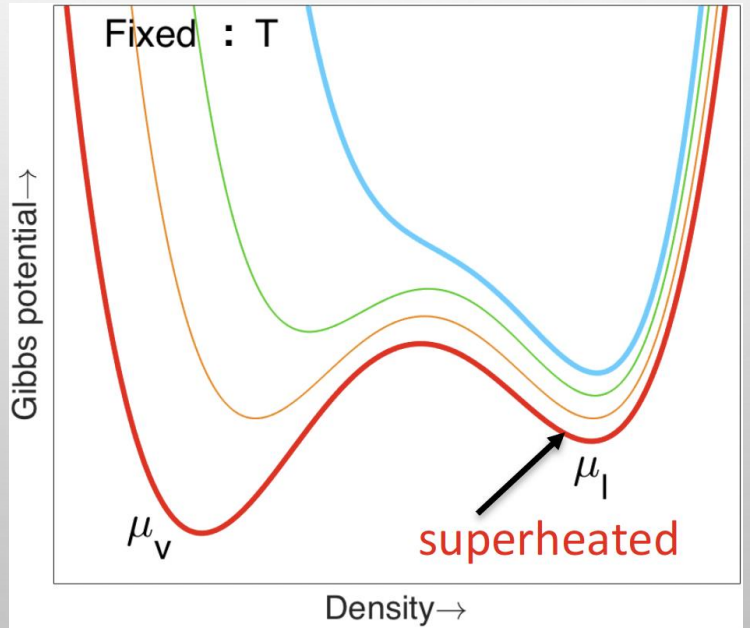
- C3F8 → METASTABLE (SUPERHEATED STATE)
- ENERGY DEPOSITION BEYOND THE THRESHOLD → BUBBLE(S)
- CAMERAS OBSERVE THE BUBBLES & EMITS THE FIRST TRIGGER
- PRESSURE CONTROL (TRANSDUCER / ACCUMULATORS)

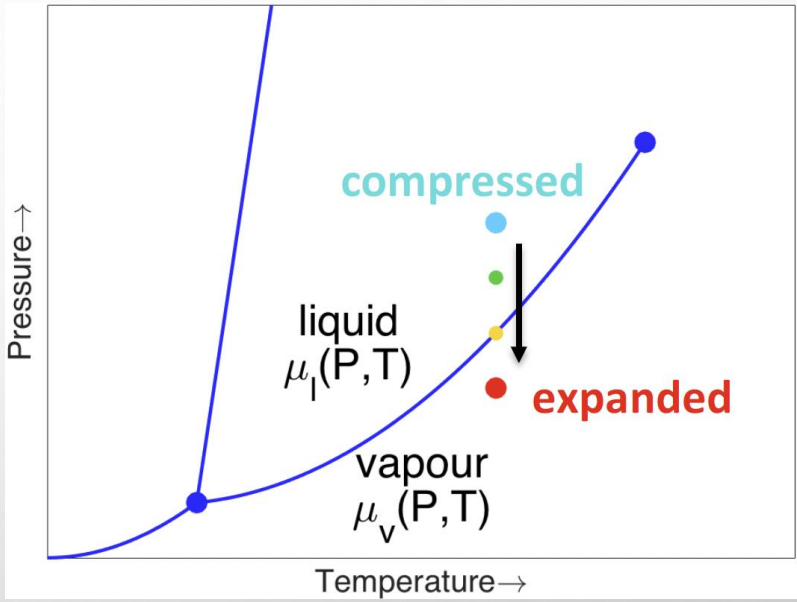




PICO-40L BUBBLE CHAMBER : DETECTION PRINCIPLE







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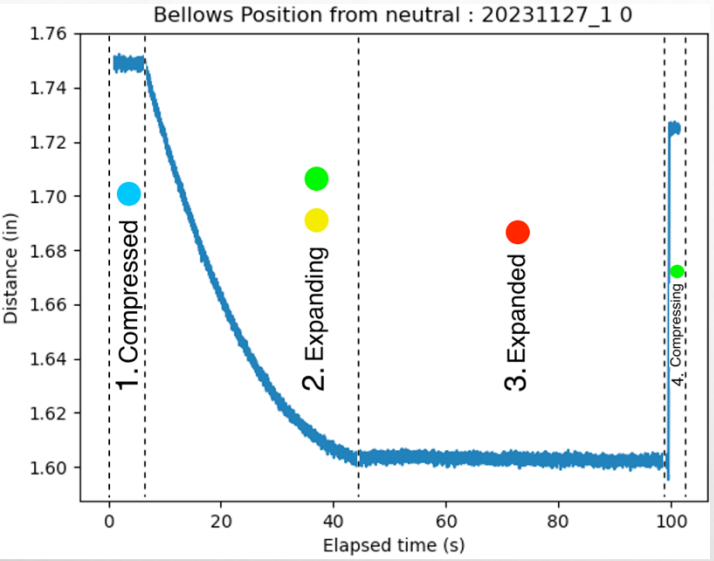
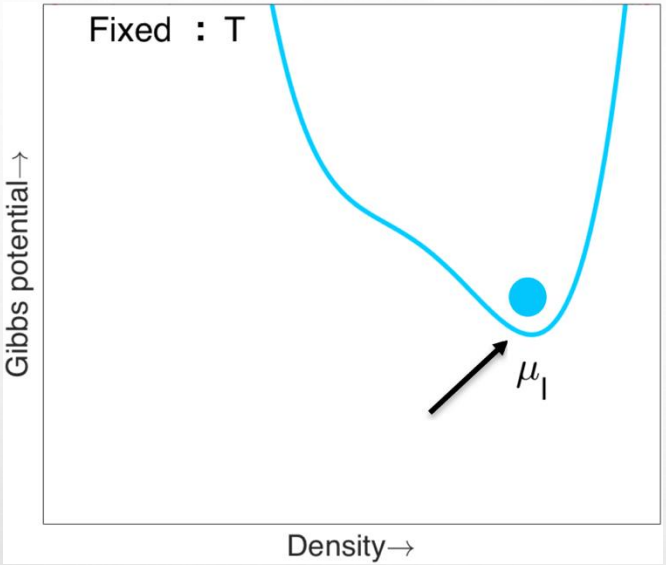
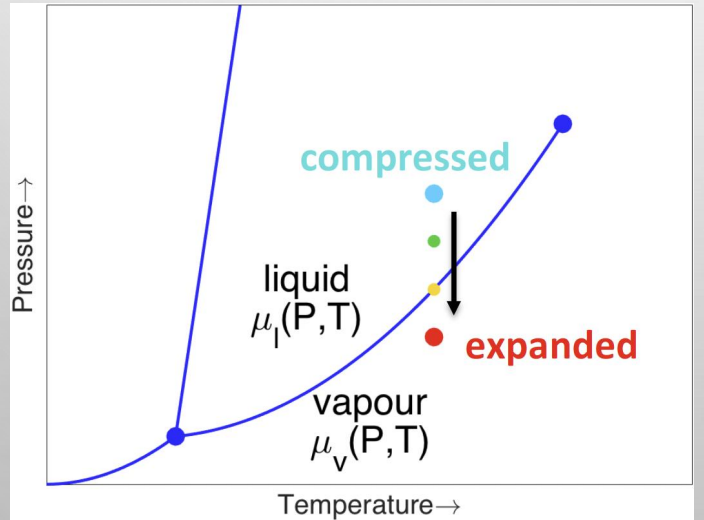
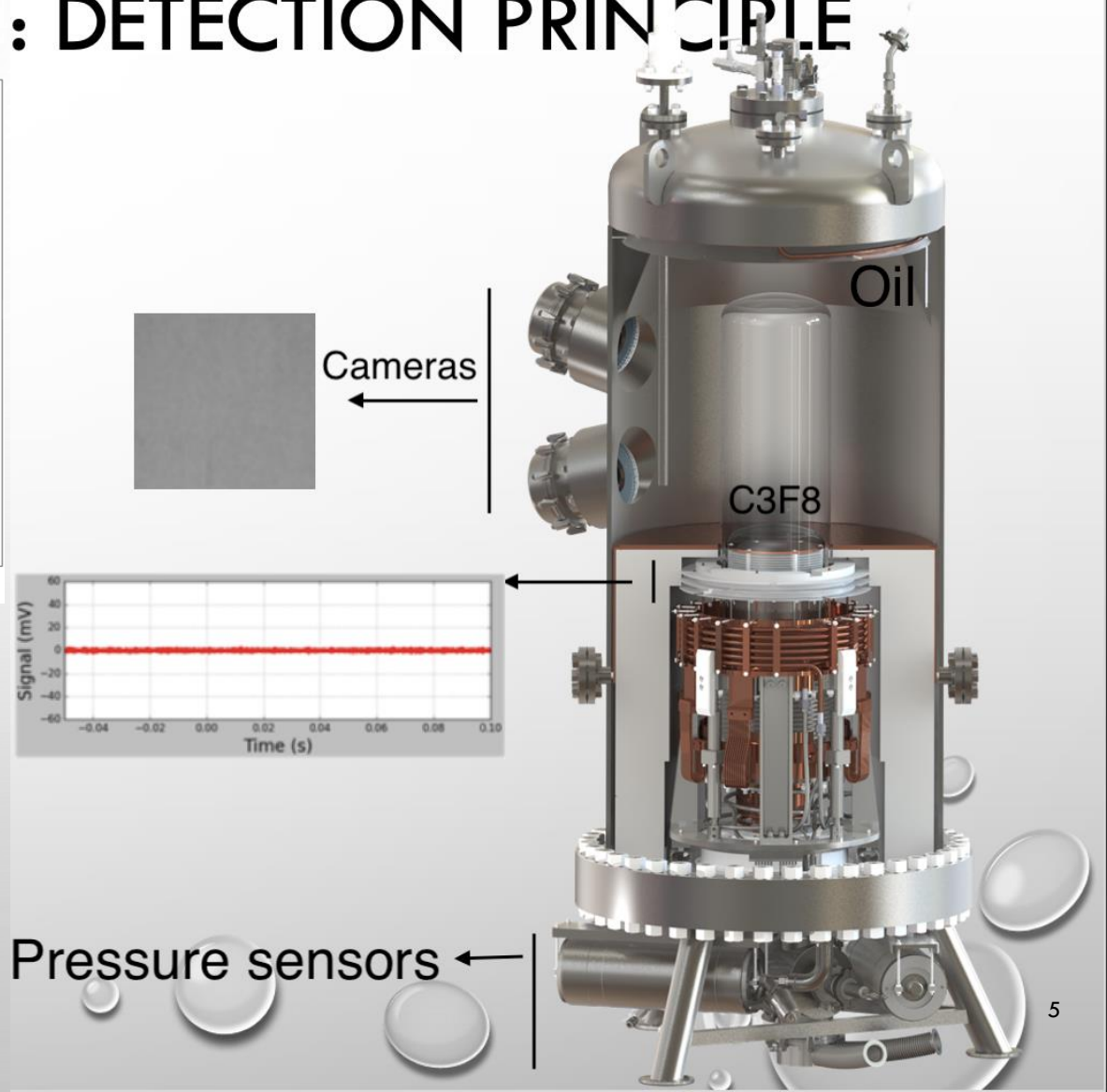




Compressed state

- remove all bubbles





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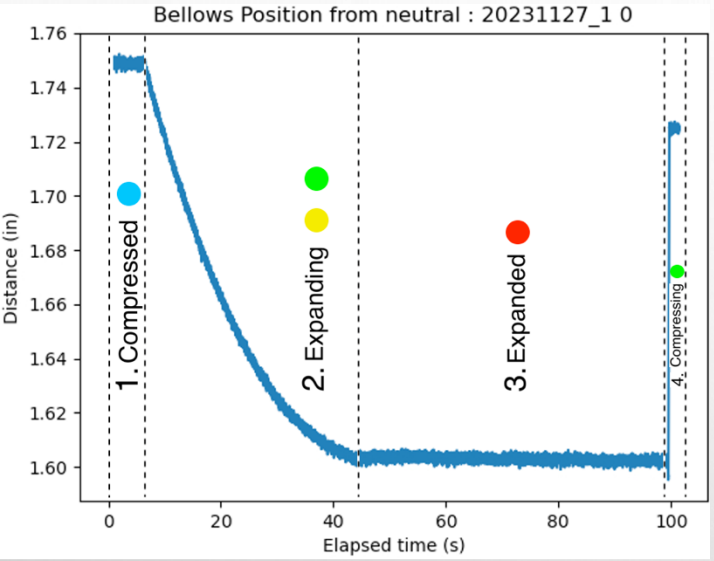
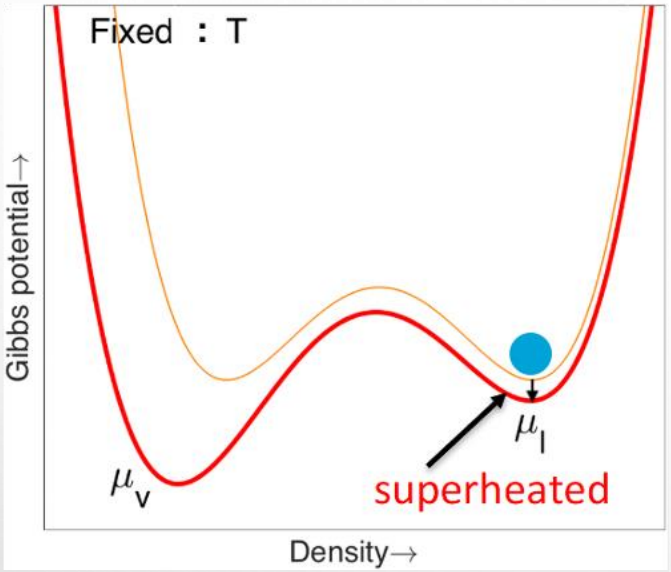
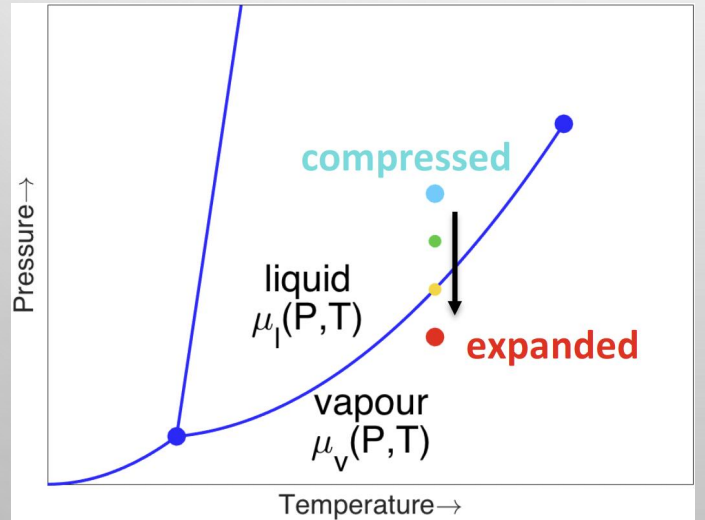
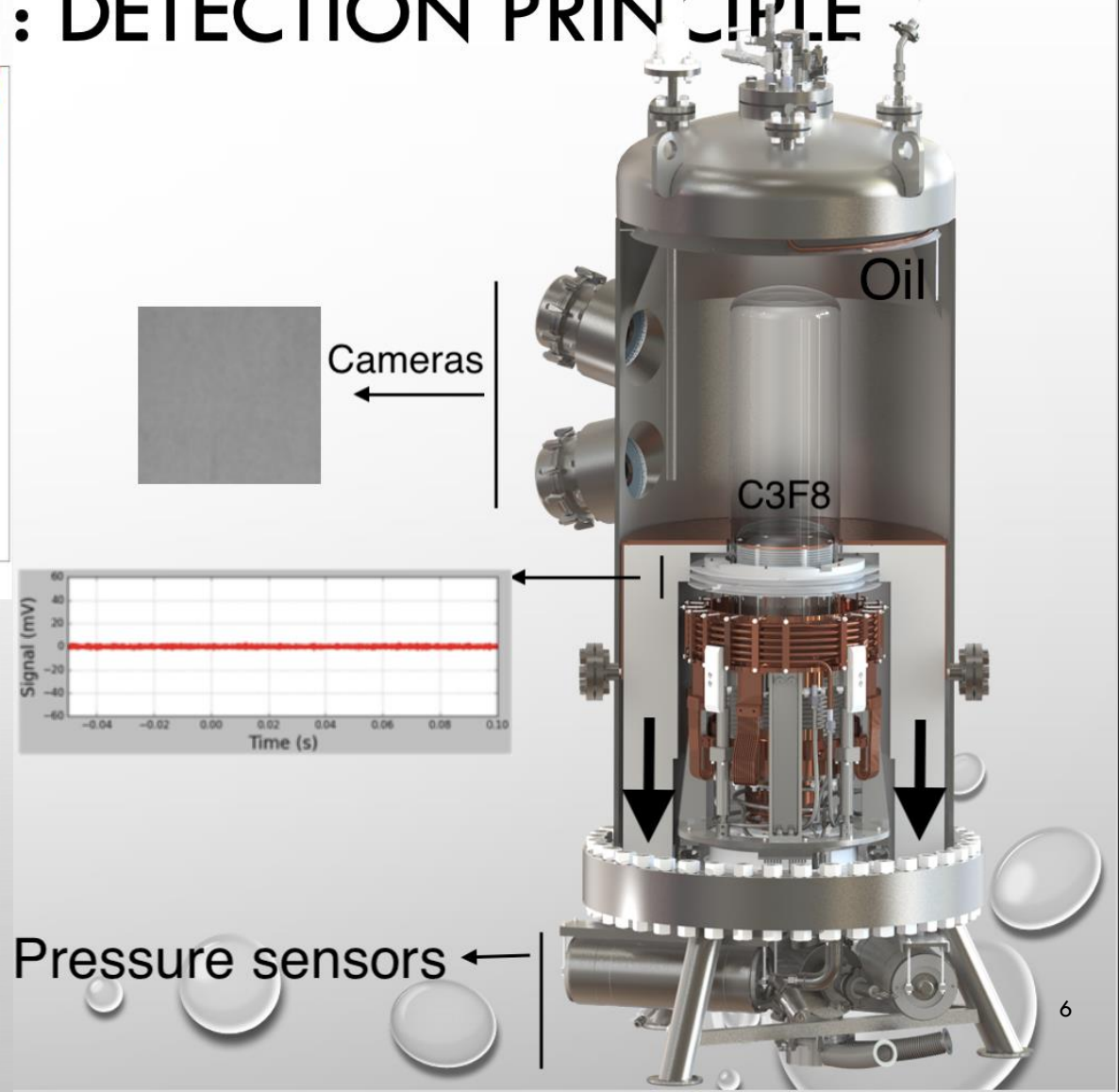




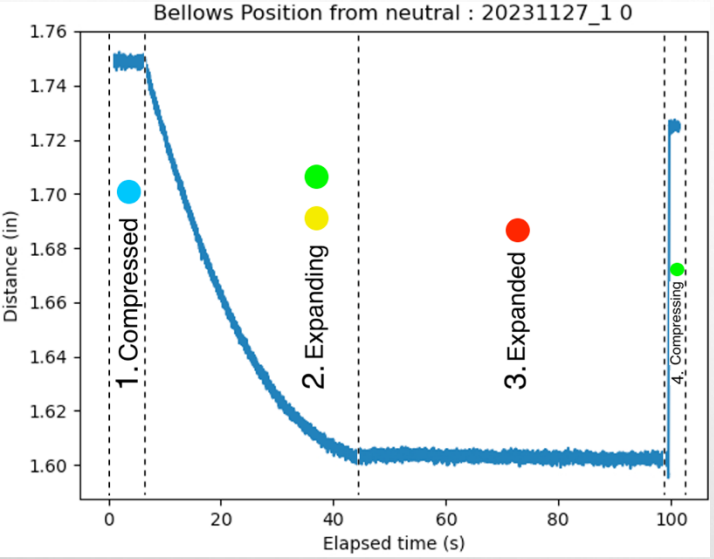
Expanded state

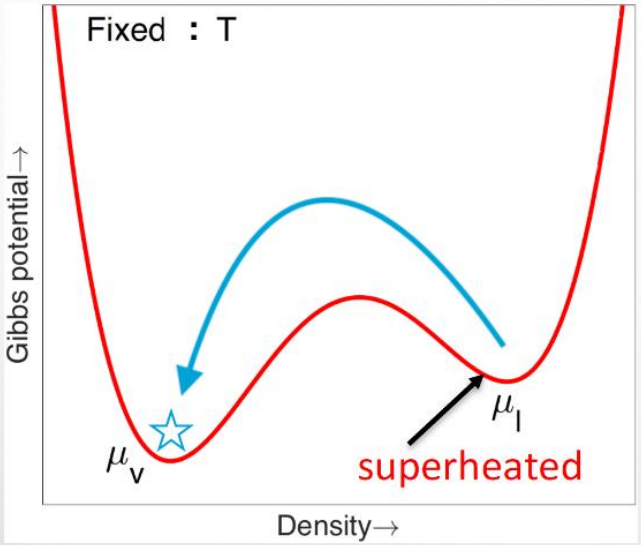
- Lower the pressure

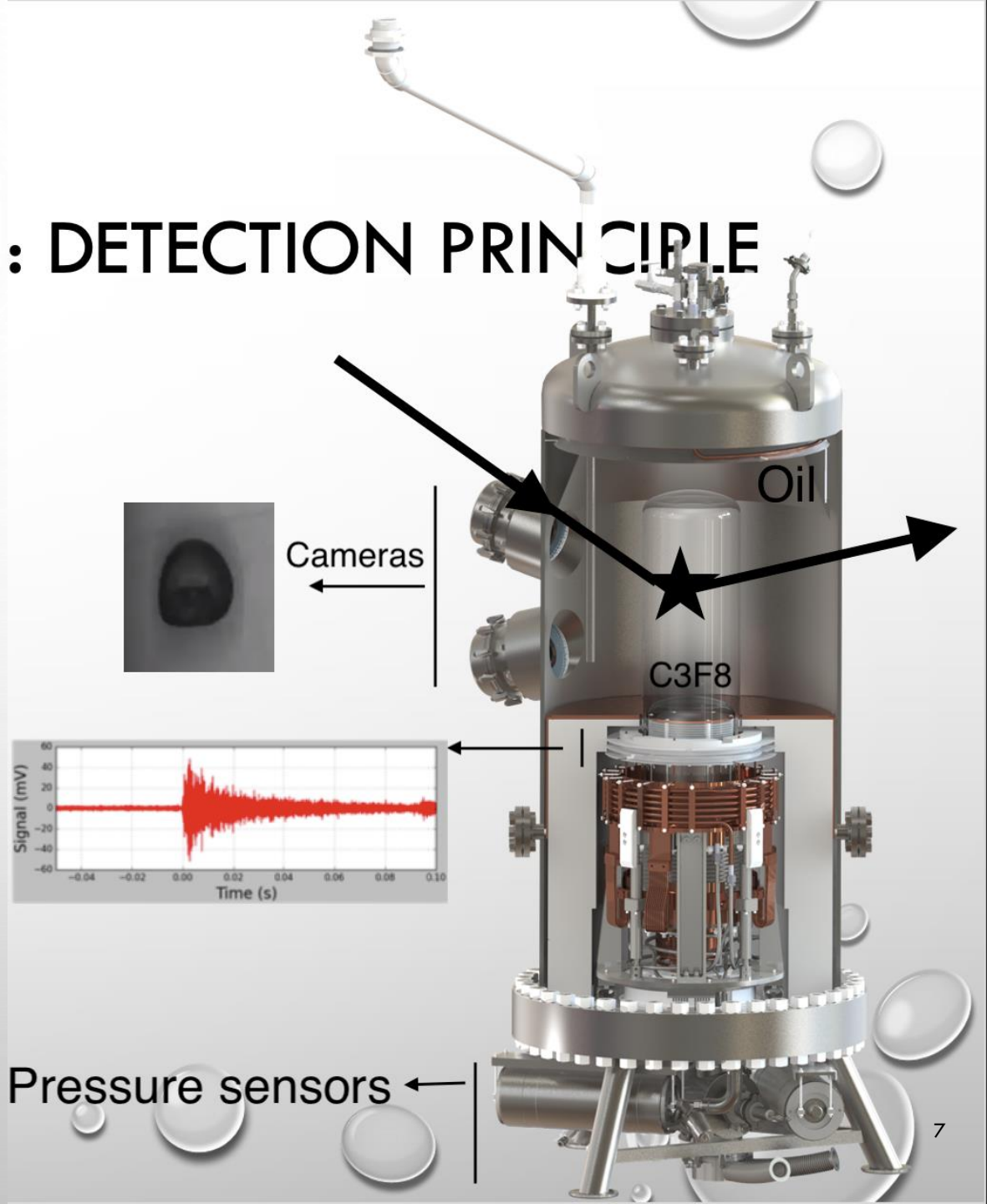




PICO-40L BUBBLE CHAMBER : DETECTION PRINCIPLE

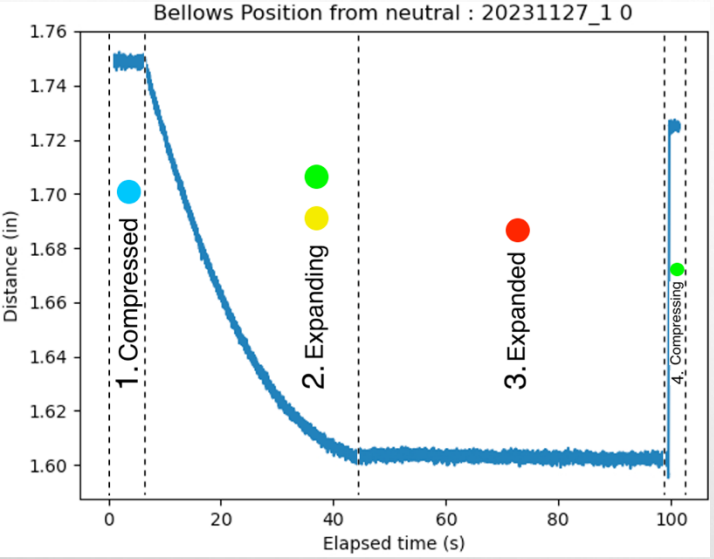


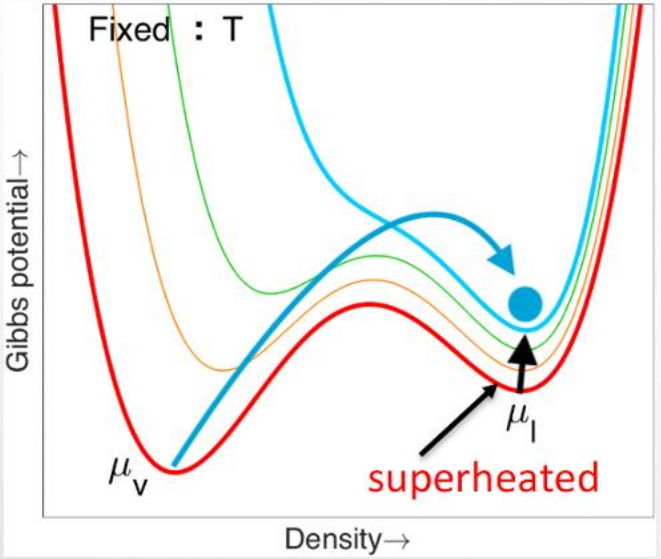


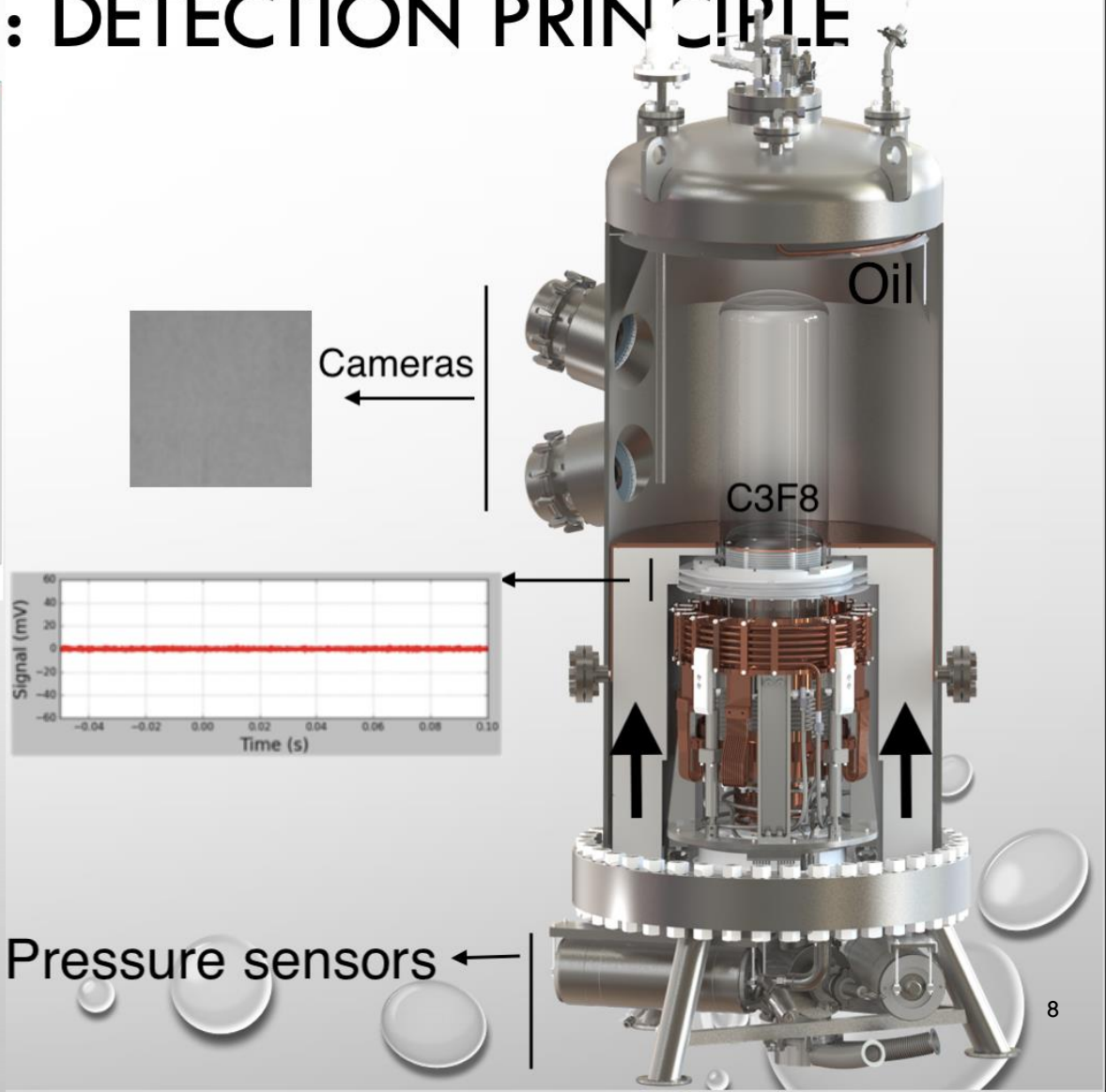


The deposition of energy within the critical radius and beyond the threshold will allow the liquid to overcome the energy barrier and form a bubble.

PICO-40L BUBBLE CHAMBER : DETECTION PRINCIPLE





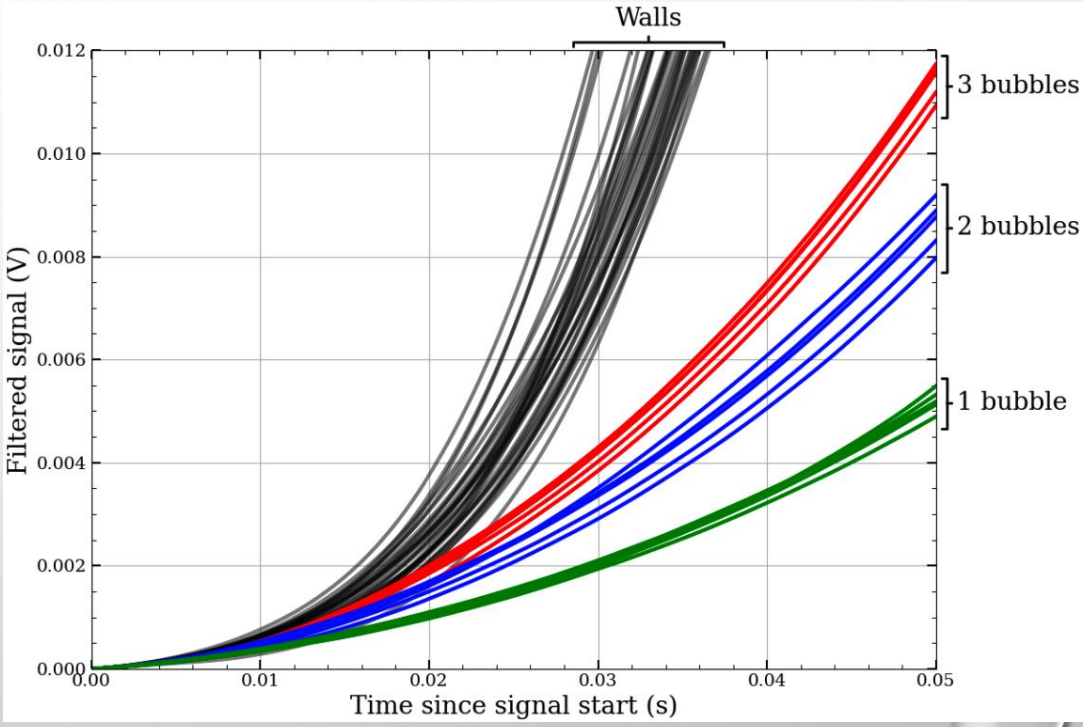


Compressing state

- remove all visible bubbles

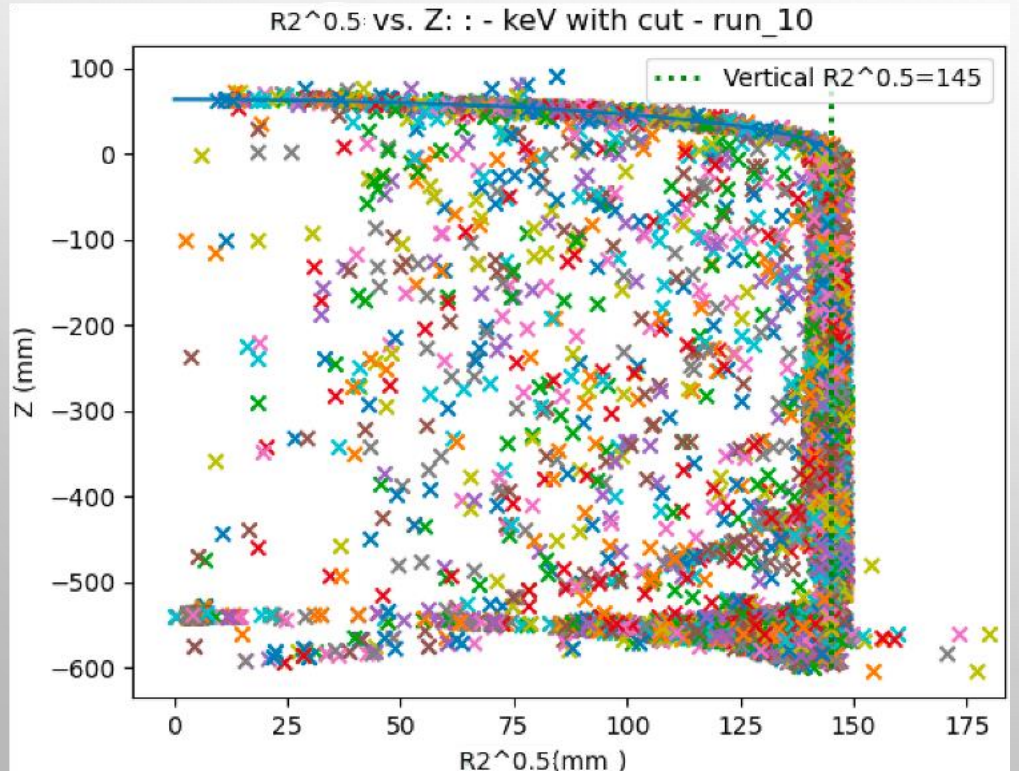
PICO-40L BUBBLE CHAMBER

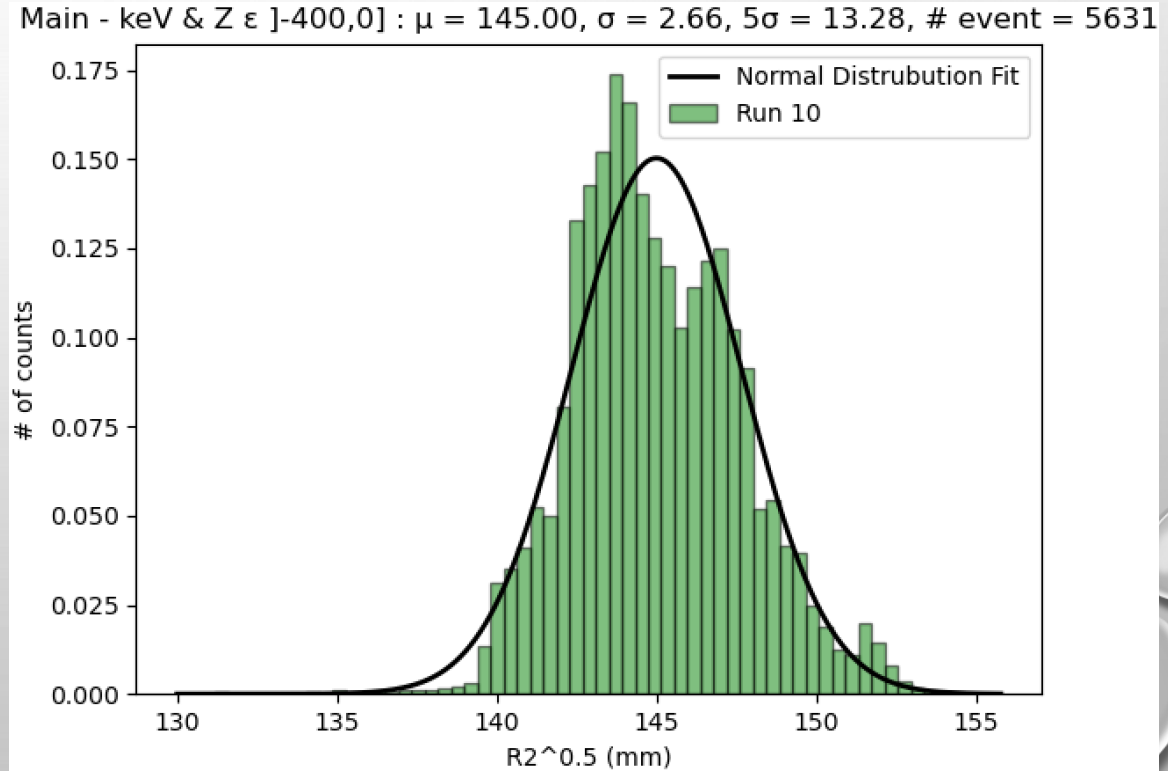
- PRIMARY TRIGGER : IMAGE OF A BUBBLE
  - CALCULATE DIFFERENCE OF SUCCESSIVE FRAME
  - ACQUIRED AT 200-340 HZ (FOR PICO-60)
  - IMAGE RECONSTRUCTION : 2 MM SPATIAL RESOLUTION
- SECONDARY TRIGGER : PRESSURE (BELLOWS EVENTS)
  - FAST PRESSURE TRANSDUCER DYTRAN
  - EVENT TYPE : BULK OR WALLS
  - MULTIPLICITY: COUNTING BUBBLES



PICO-40L BUBBLE CHAMBER

- FAST PRESSURE TRANSDUCER : DYTRAN
  - FIDUCIALIZATION : WALL EVENTS = BACKGROUND





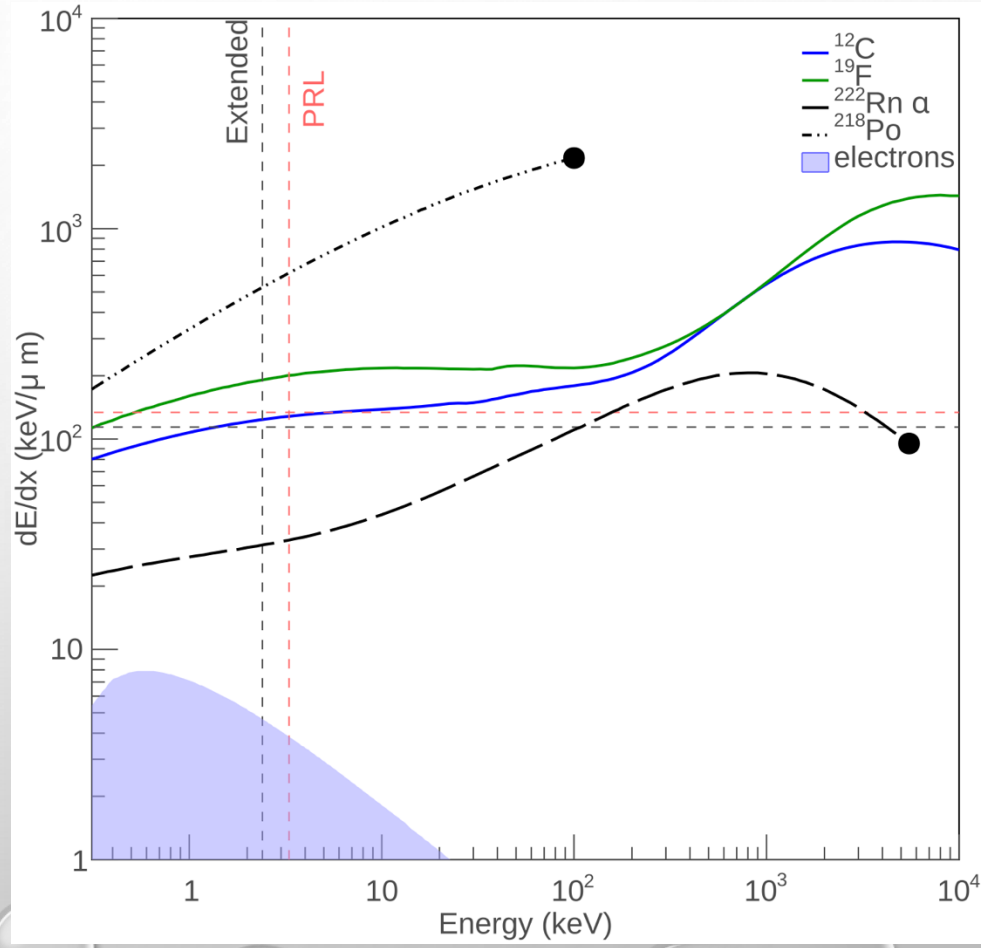
PICO-40L BUBBLE CHAMBER : LIMITATION

- BACKGROUND NOISE LEVEL ON WALLS
  - 437 EVENTS / DAY
  - AFFECT THE TOTAL LIFETIME

- HYPOTHESIS
  - THE SURFACE ROUGHNESS IS APPROXIMATELY 32 MICROINCHES
  - ANY IMPERFECTION CAN ACT AS A NUCLEATION SITE
  - THE GIBBS ENERGY REQUIRED TO PERFORM THE PHASE CHANGE IS REDUCED
  - SOLUTION : SURFACE POLISHING

PICO-40L BUBBLE CHAMBER : ADVANTAGE

- INSENSITIVE TO ELECTRON RECOIL (BLUE REGION)
  - PROTOBUBBLE COLLAPSES ALMOST IMMEDIATELY
  - T AND P ARE CAREFULLY CHOSEN
  - → SENSITIVE TO ALPHA, NEUTRON AND ~ WIMP
- RADIATION THAT INTERACTS WITH AN ELECTRON
  - THEIR ENERGY DEPOSITION IS LESS LOCALIZED THAN NUCLEAR RECOILS
- STOPPING POWER & RECOIL ENERGY TO NUCLEATE A BUBBLE
  - C3F8 AT 30 PSIA: 2.4 (EXTENDED, 16 ^{0}C) AND 3.3 (PRL, 14 ^{0}C) KEV THRESHOLD ENERGY



PICO-40L BUBBLE CHAMBER : ADVANTAGE

- GAMMA REJECTION
  - TYPE OF ELECTRON RECOIL EVENTS
  - DOES NOT DEPOSIT ENOUGH ENERGY LOCALLY
  - UNLIKELY SIGNAL PRODUCTION : NUCLEATION PROBABILITY $< 10^{-7}$; (PICO-60)
  - THE AP SIGNAL IS SIMILAR TO THAT OF THE NEUTRON

- ORIGIN
  - RADIOACTIVE DECAY
  - COSMIC RAY PARTICLES

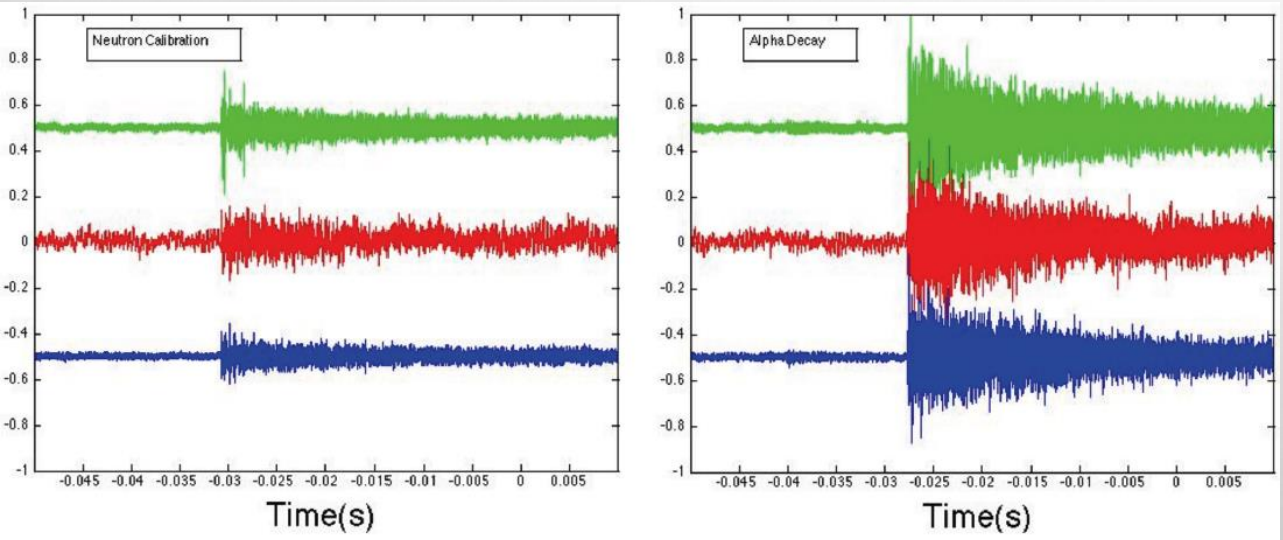
PICO-40L BUBBLE CHAMBER : ADVANTAGE

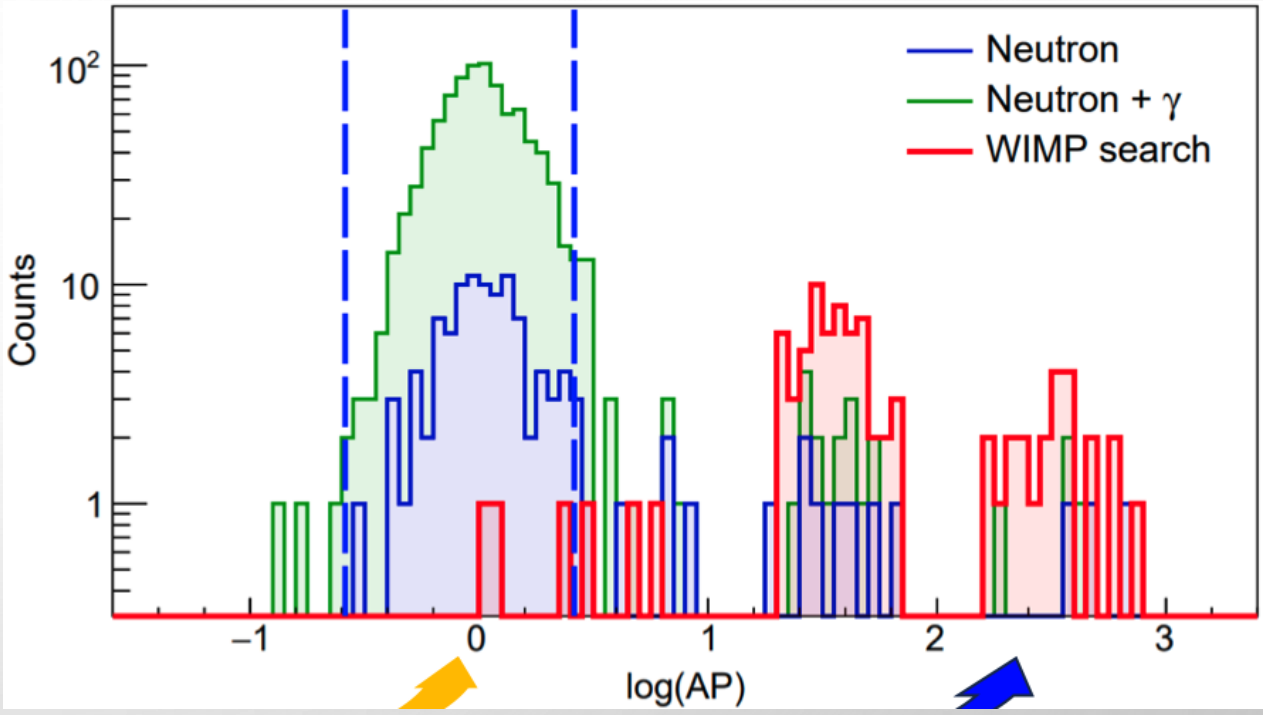
- ALPHA
  - ACOUSTIC SHOCKWAVE DISCRIMINATOR AGAINST **ALPHA** DECAYS
  - ENERGY DEPOSITION WITHIN THE CRITICAL RADIUS → MULTIPLE PROBUBBLES → LOUDER SOUNDS
  - PRODUCE SINGLE BUBBLE → HIGH STOPPING POWER
  - FROM THE PIEZOELECTRIC ACOUSTIC TRANSDUCERS → ACOUSTIC PARAMETER (AP)

- ORIGIN
  - ^{238}U AND ^{232}TH PRODUCE THEIR DAUGHTERS AND GASEOUS RADON (^{222}RN & ^{220}RN)
  - **^{222}RN** DECAY TO ^{218}PO : 1ST ALPHA (5.6 MEV) -- **^{218}PO** DECAY TO ^{214}PB : 2ND ALPHA (6.11 MEV)
  - EMANATION AND DIFFUSION THROUGH MATERIALS
  - ROCK AT SNOLAB : RN CONCENTRATION IS HIGH (150 BQ/M^3)

PICO-40L BUBBLE CHAMBER : ADVANTAGE

- ALPHA DISCRIMINATION : LOG(AP)
  - ALPHA SOUND IS LOUDER : AMPLITUDE





(https://arxiv.org/abs/1902.04031)

- BACKGROUND BUDGET FOR NEUTRON
  - < 1 SINGLE BUBBLE EVENT/YEAR

PICO-40L BUBBLE CHAMBER : ADVANTAGE

- NEUTRON
  - DM INTERACTS IN THE DETECTOR AS FAST A NEUTRON
  - DEPOSIT ENERGY ON A SINGLE NUCLEUS AT A TIME → CALIBRATION
  - CAN SCATTER MULTIPLE TIMES → MULTIPLE BUBBLES ; (1:3 SINGLE/MULTIPLE)
  - WATER SHIELDING TO MINIMIZE EXPOSURE TO ENVIRONMENTAL NEUTRONS

- SOURCE
  - SPONTANEOUS FISSION : 238U DECAY BUT BRANCHING RATIO IS SMALL
  - (ALPHA,N) → INTERACTION OF ALPHA WITH THE FLUID : (CAPTURE AND EMISSION)
  - MUON-INDUCED NEUTRONS
  - GAMMA RADIATION

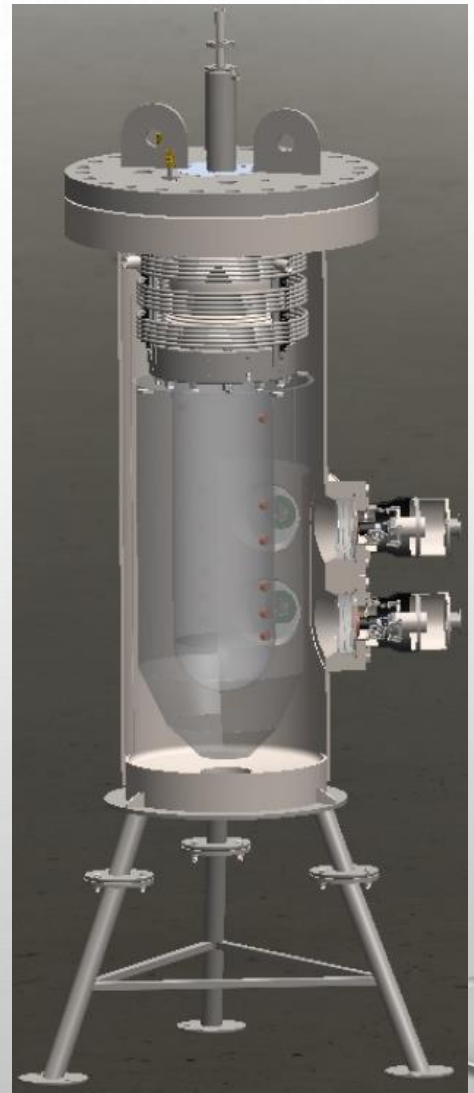
PICO-40L BUBBLE CHAMBER : GEOMETRY

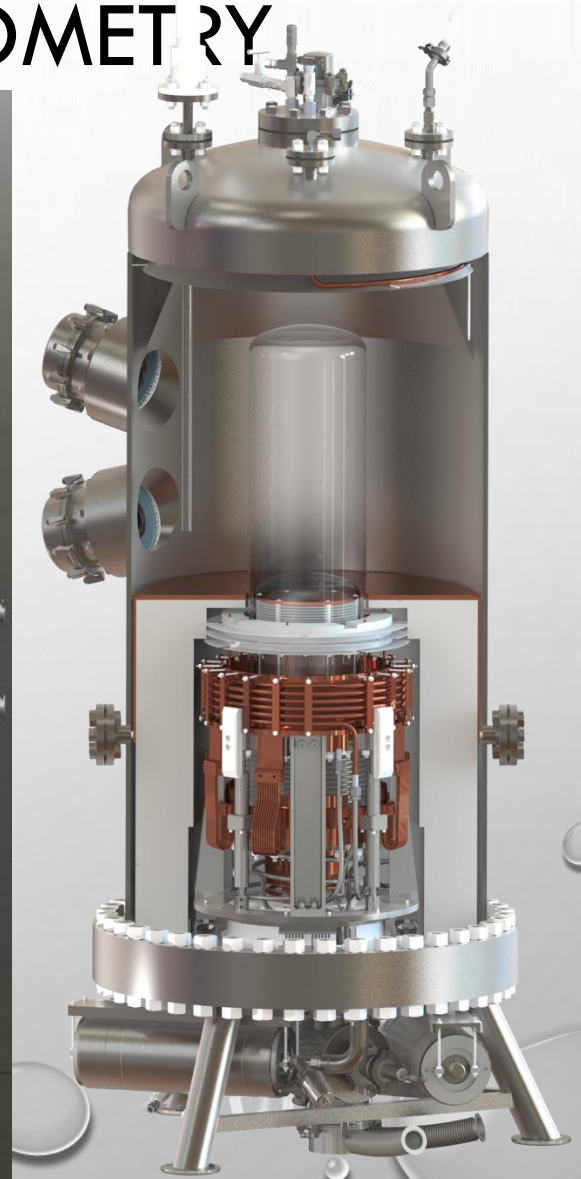
PICO-60

- EXCESS EVENTS AT BUFFER-C3F8 INTERFACE
- DEBRIS AT THE BOTTOM

PICO-40L

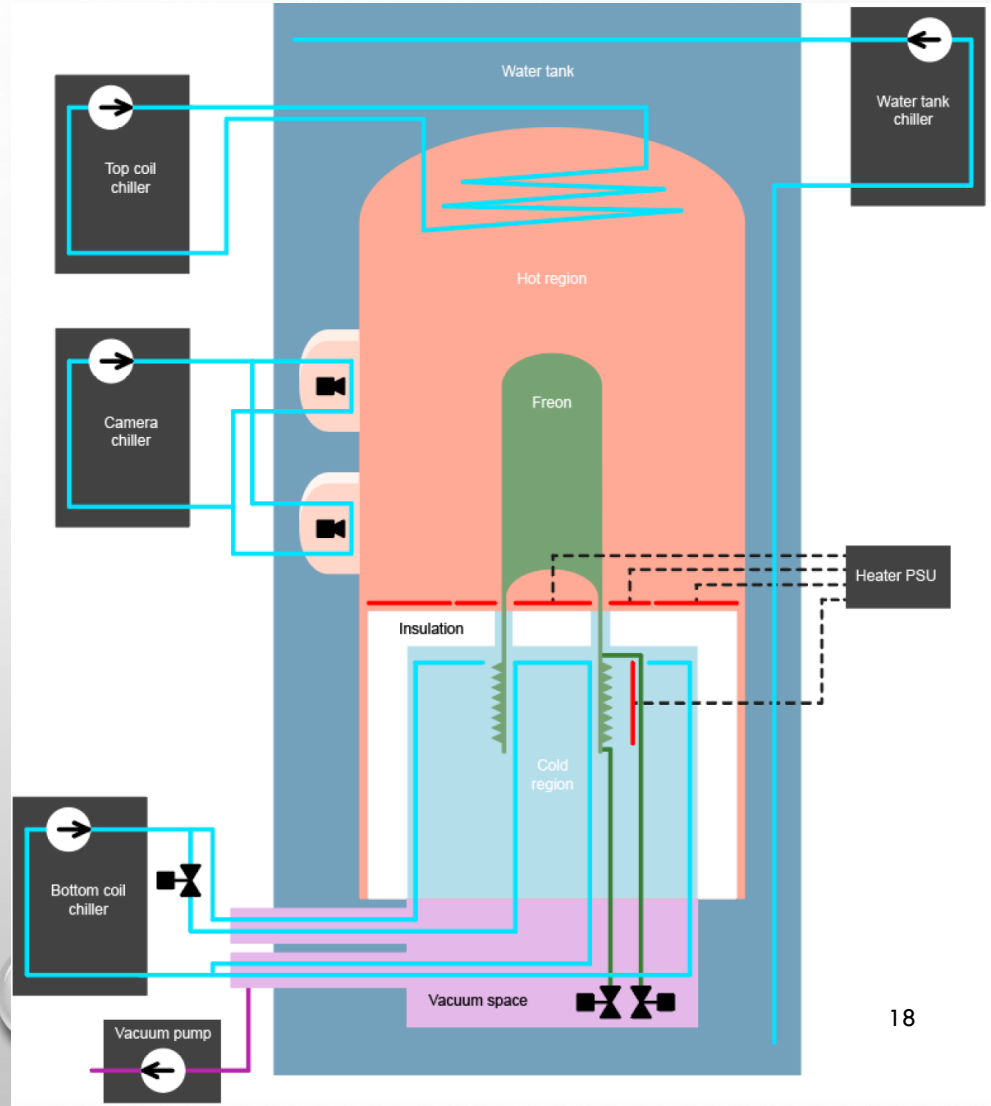
- NO BUFFER LIQUID, C3F8 IN CONTACT WITH THE BELLOWS
- RIGHT SIDE UP GEOMETRY
- NEED TWO REGIONS : COLD (COIL/BELLOWS) & WARM (WATER BATH/C3F8)
- NEED FOR A GOOD UNDERSTANDING OF T OF THE TRANSITION REGION





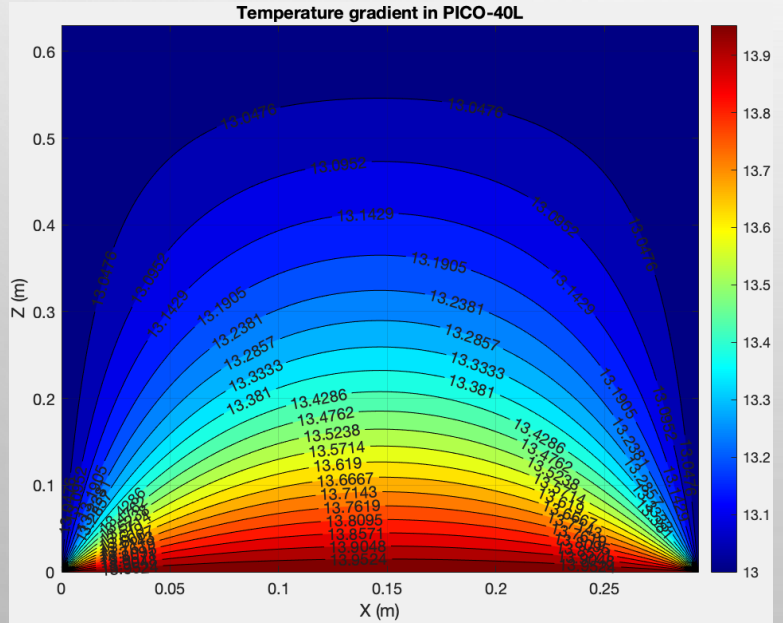
PICO-40L BUBBLE CHAMBER : THERMAL CONCEPT

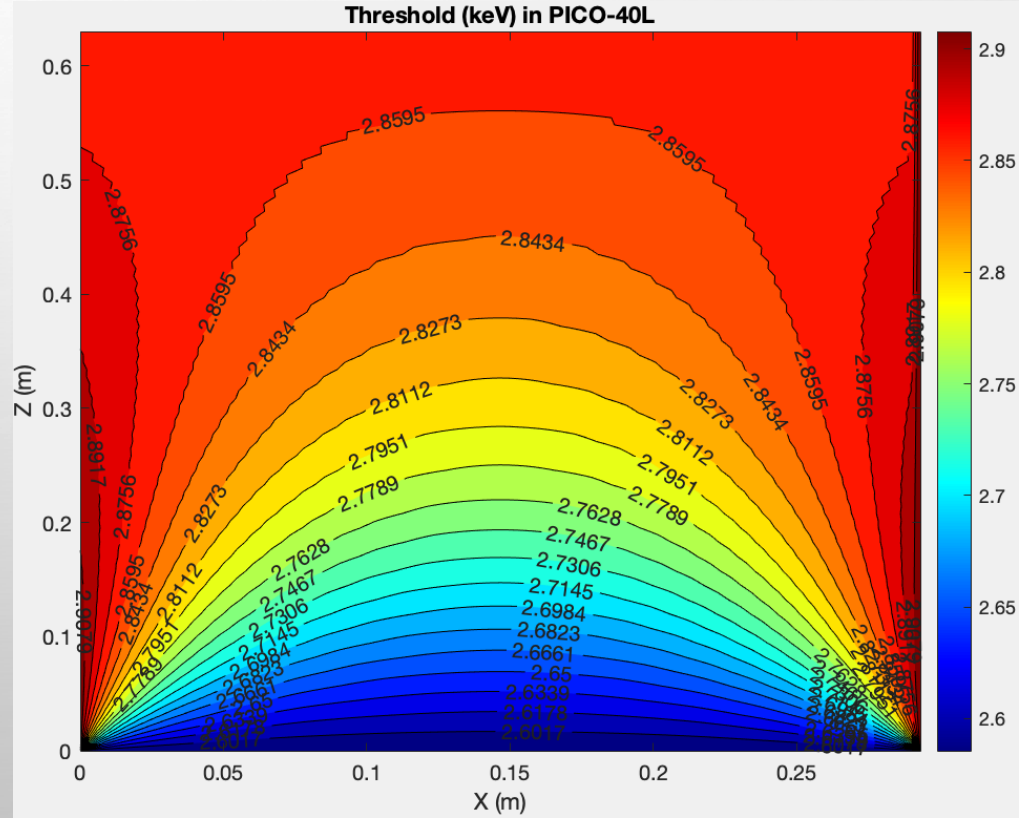
- LIMIT NUCLEATION IN THE BELLOWS REGIONS
  - NOT IN SUPERHEATED STATE → T AT AROUND ~ – 25 C
- TRANSITION ZONE → ISOLATE, REGULATE AND STABILIZE
  - HDPE SHEETS (PRESSURE VESSEL): CONVECTION, HEAT EXCHANGE
  - TOP COIL : T OF THE OIL THAT GOES UP
  - HEATER PLATE



PICO-40L BUBBLE CHAMBER : THERMAL CONCEPT

- QUESTION THAT NEED TO BE ADDRESS THROUGH SIMULATION: MATLAB & COMSOL
  - T → THRESHOLDS AND NEUTRON EFFICIENCY
  - ERROR BAR ON THRESHOLD
  - T OF RTD VS SIMULATION : Z HEAT MAP





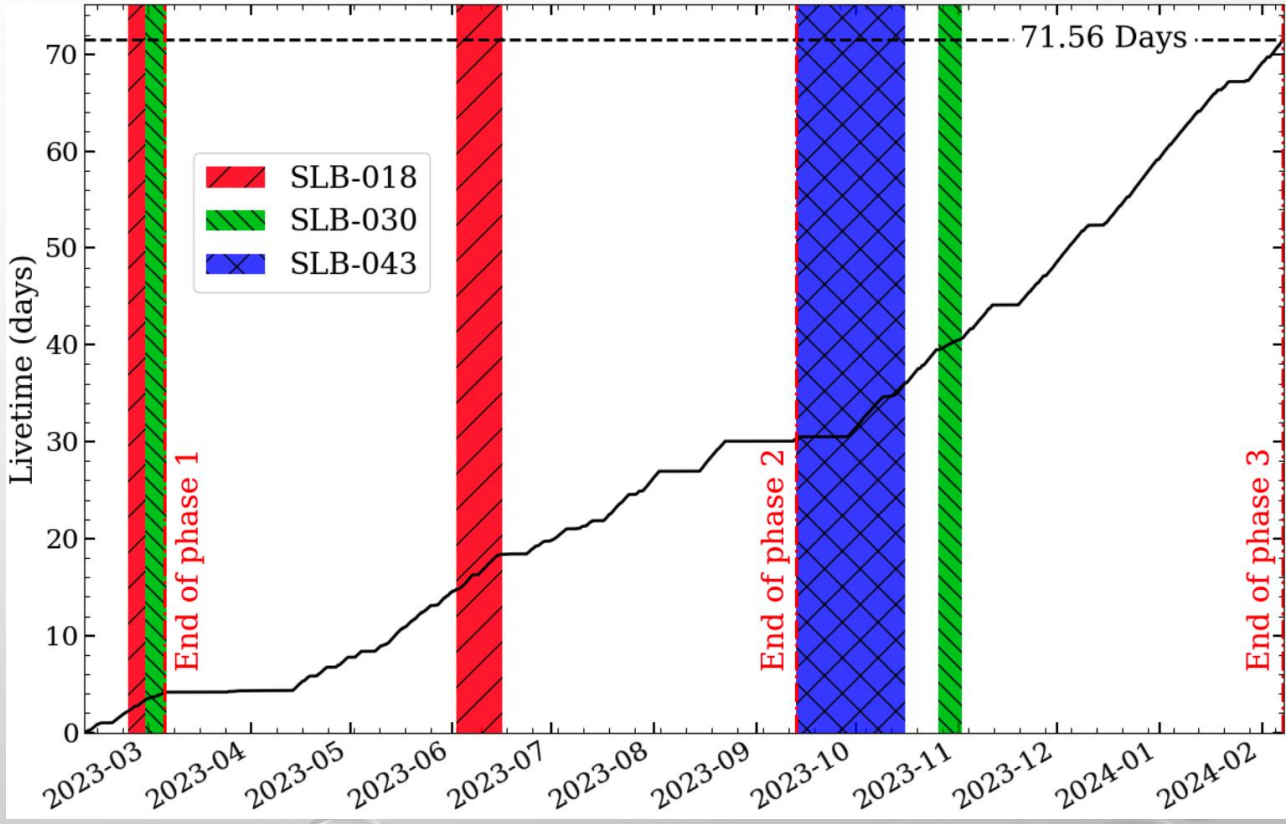
PICO-40L BUBBLE CHAMBER : COMMISSIONING

LIFETIME

- COUNTING AFTER ~ 25 S STABILITY

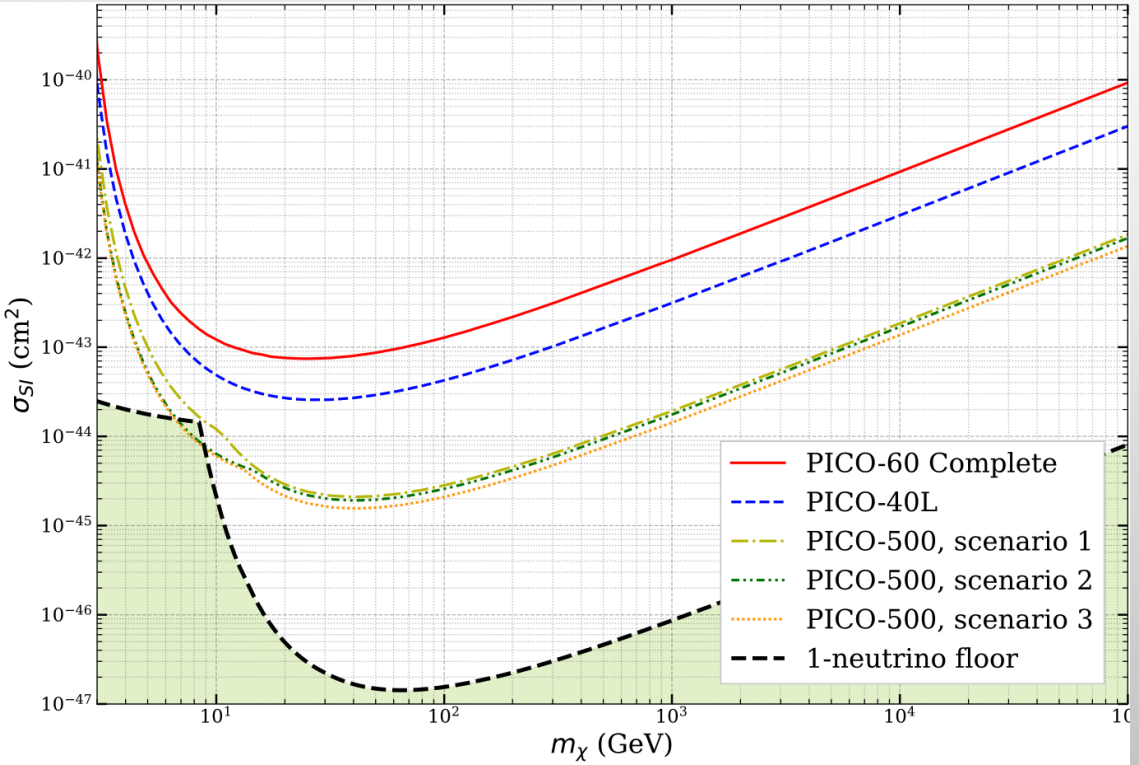
- NEUTRON CALIBRATION WITH CF-252 : SLB-018
- NEUTRON CALIBRATION WITH CF-252 : SLB-030
- GAMMA CALIBRATION WITH CO-60 : SLB-030

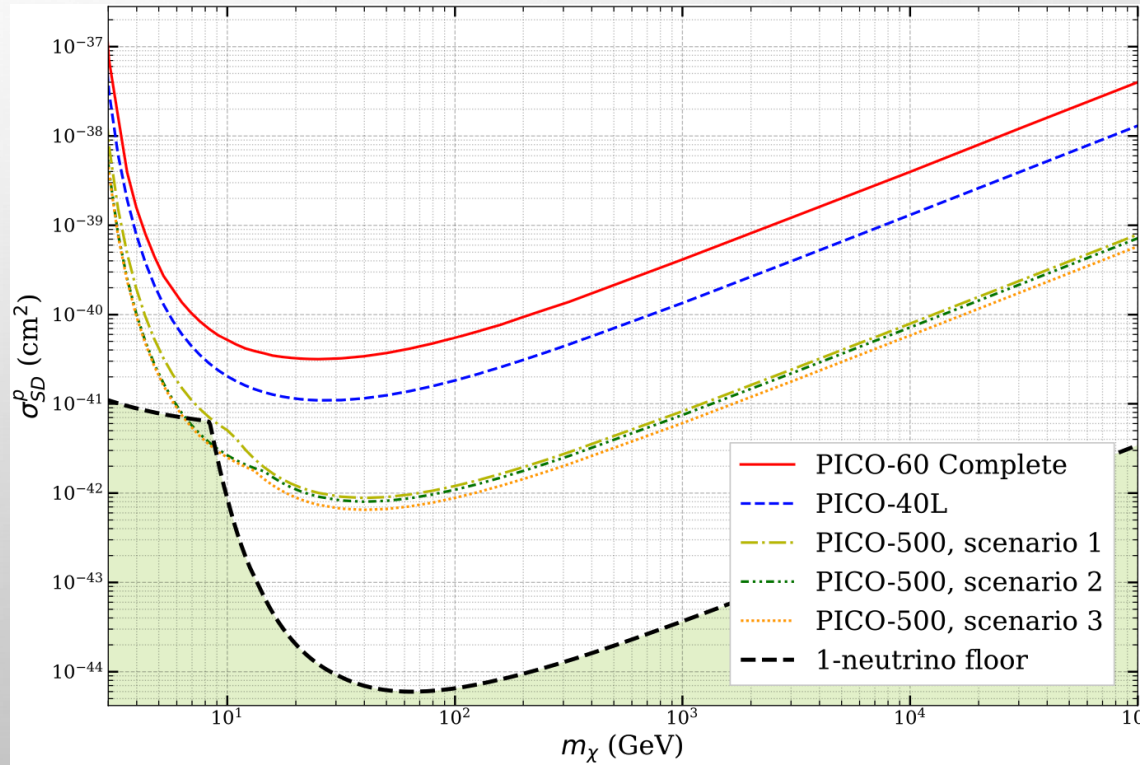
- 45.33 KG * 71.56 DAYS = 3244 KG*DAYS



PICO-40L BUBBLE CHAMBER : SENSITIVITY

- PICO-40L IMPROVED THE SENSITIVITY BY A FACTOR OF 5
- LESS BACKGROUND : LARGER PRESSURE VESSEL & RSU GEOMETRY





PICO-40L BUBBLE CHAMBER : SUMMARY

- ORDER OF MAGNITUDE MORE SENSITIVE THAN PICO-60
- BLINDED PHYSICS RUN IS ABOUT TO TAKE PLACE
  - ACOUSTIC SIGNAL ARE BLINDED : UNBIASED CUT ON **AP**
- VALIDATE THE RIGHT SIDE UP GEOMETRY FOR THE TONE SCALE PICO-500

PICO

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
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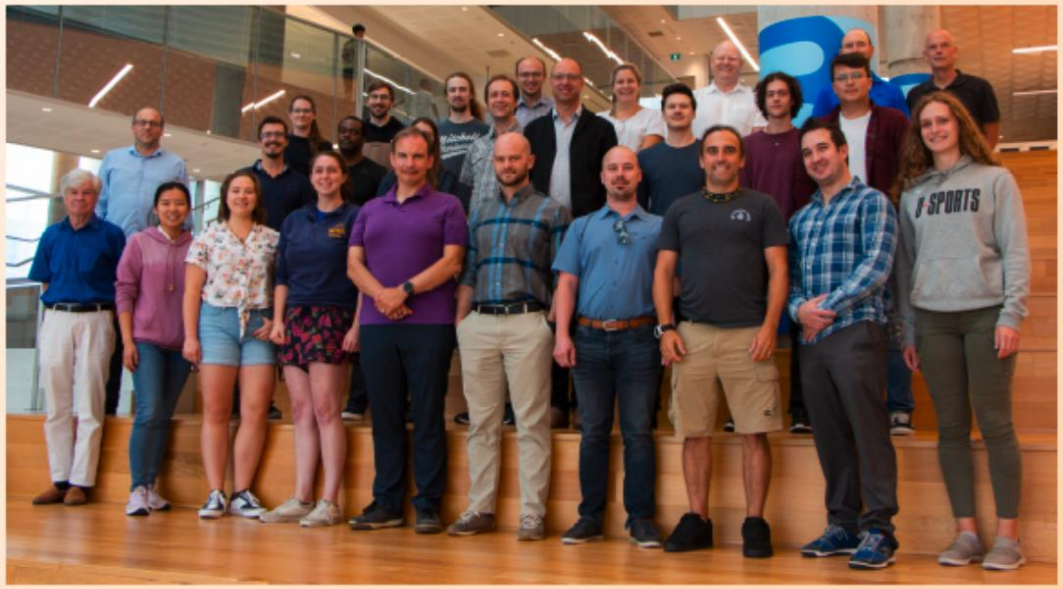

KICP
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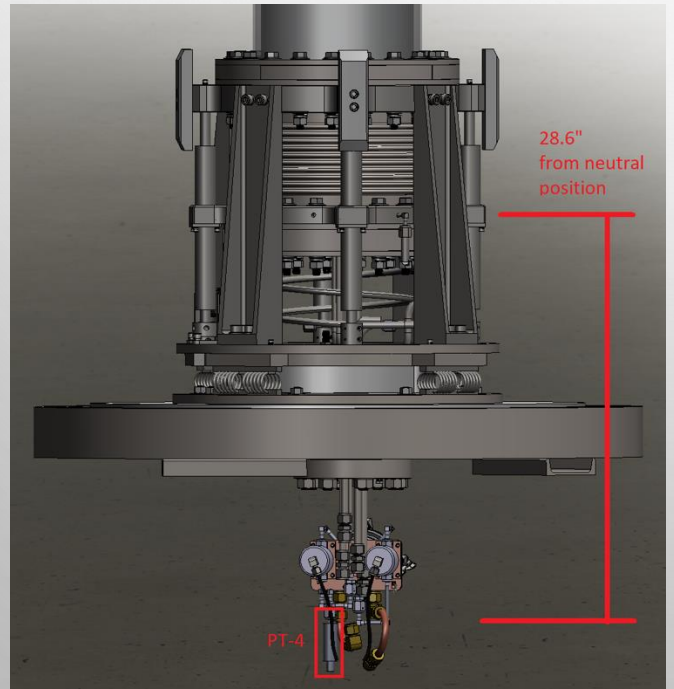
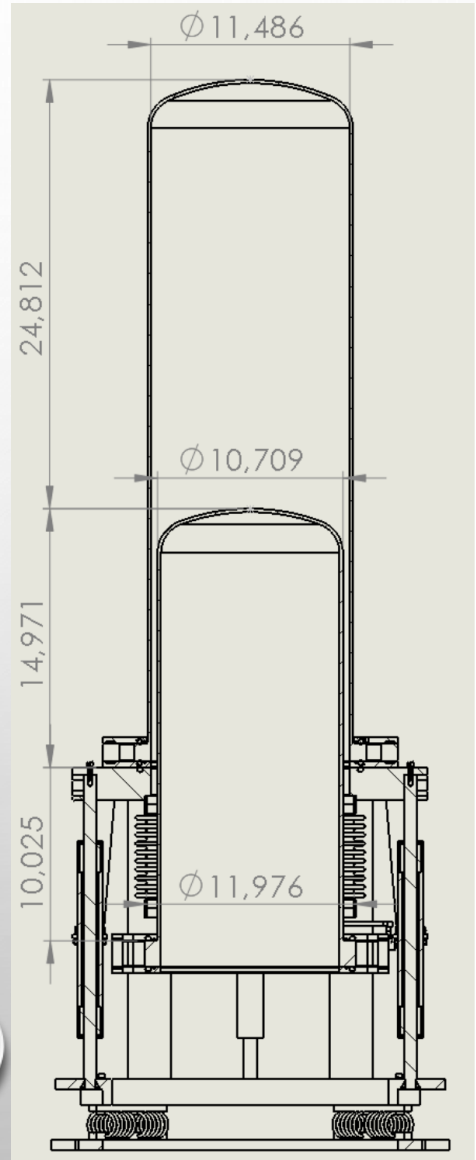
ANNEX: SYSTEM

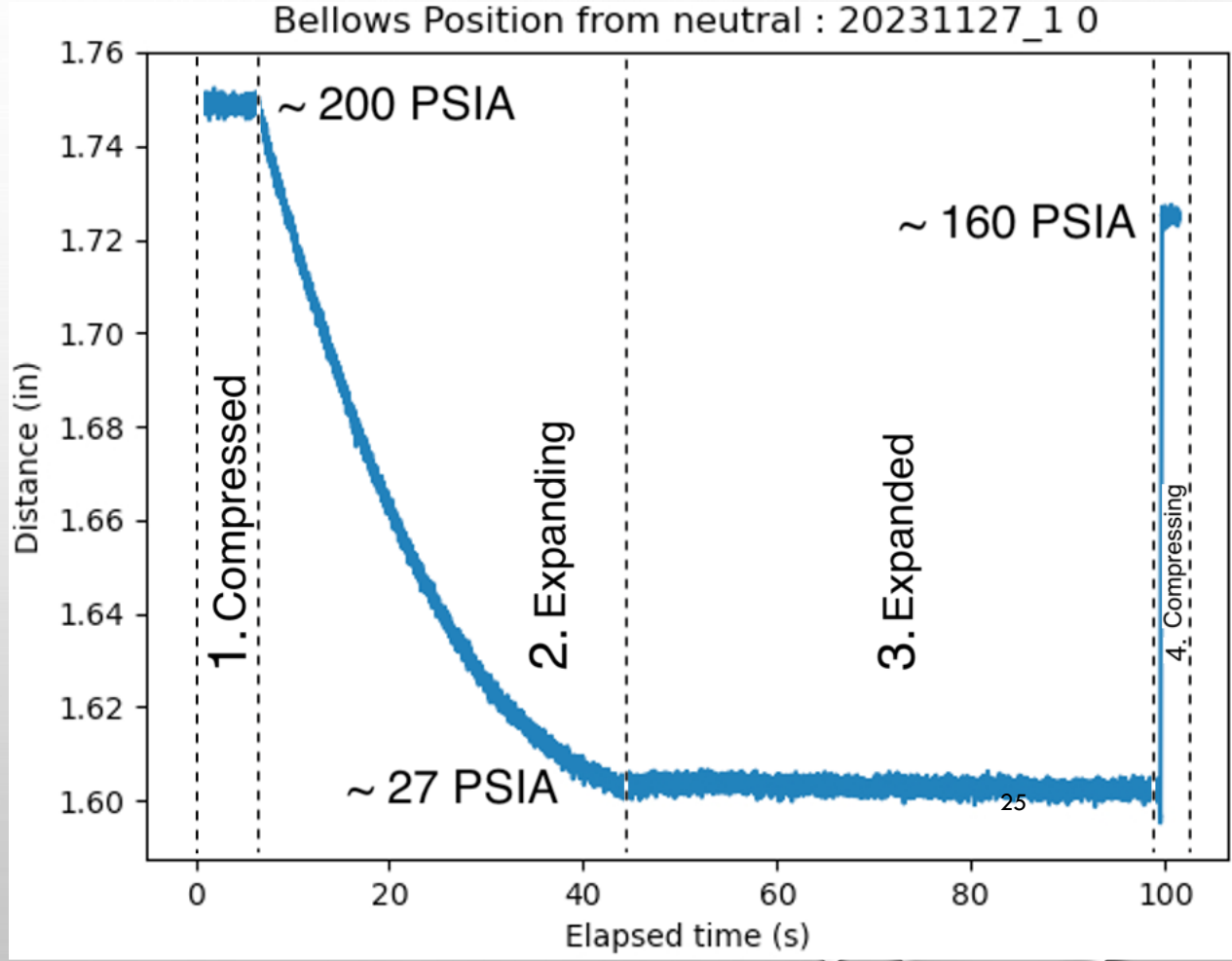
- DIMENSION (IN INCH): PICO-40L





ANNEXE : DETECTION PRINCIPLE

- 1ST START WITH COMPRESSED STATE (~ 200 PSIA)
  - SAFE MODE & REMOVE ANY BUBBLE (90 S)
- 2ND EXPANDING STATE (~ 200 – 27 PSIA)
  - LOWER PRESSURE -> METASTABLE STATE (~ 30 S)
- 3RD EXPANDED STATE (~ 27 PSIA)
  - REACH METASTABLE SUPERHEATED STATE
  - (LAST UNTIL A TRIGGER OCCURS)
- 4TH RECOMPRESSION (160 PSIA)
  - REMOVE VISIBLE BUBBLE (5 S)



ANNEX : SEITZ MMODEL

- CONDITIONS FOR NUCLEATION (Q_S > = W_MIN)
  - W_MIN = 4 PI /3 * SIGMA * R_C^2
  - E_R > Q_S
  - ENERGY MUST BE DEPOSITED WITHIN R_C ~ 25 NM AT 30 PSIA AND 13 C

$$r_c \approx \frac{2\sigma}{P_v - P_l}\frac{\rho_l}{\rho_l - \rho_v}$$

- Q_S
  - CONTAIN THREE PRINCIPAL TERMS
  - W_C : COMBAT THE PRESSURE OF THE LIQUID TO ALLOW THE PROTOBUBBLE TO EXPAND
  - W_V : TO EVAPORATE THE LIQUID AND TRANSFORM IT INTO GAS
  - W_S : ENERGY TO FORM THE SURFACE OF THE CRITICAL SPHERE
  - W_IRR : IRREVERSIBLE PROCESSES SUCH AS ACOUSTIC WAVE EMISSION (ABOUT 2%)

$$\begin{aligned} E_c &= W_c + W_v + W_s + W_{irr} \\ &= \frac{4\pi}{3} r_c^3 (P_l - P_b) + \frac{4\pi}{3} r_c^3 \rho_b (h_b(T) - h_l(T)) + 4\pi r_c^2 (\sigma - T\frac{\partial \sigma}{\partial T}) + W_{irr} \end{aligned}$$

ANNEX

- INFORMATION ON THE SOURCES USED FOR CALIBRATION

Source name	Source (type)	Activity (kBq)	Date of Measurement	Activity on 2023/10/28 (kBq)
SLB-018	^{252}Cf (n)	0.370	1999/01/05	5.5×10^{-4}
SLB-030	^{252}Cf (n)	1.6	2010/11/01	5.3×10^{-2}
SLB-043	^{60}Co (γ)	3.8×10^{3}	2018/11/22	2.0×10^{3}

ANNEX : THERMAL EQUATION

TRANSIENT

- $\frac{1}{r}\frac{\partial T(r,z,t)}{\partial r} + \frac{\partial^2 T(r,z,t)}{\partial r^2} + \frac{\partial^2 T(r,z,t)}{\partial z^2} - \frac{\rho C_p v_r}{k}\frac{\partial T(r,z,t)}{\partial r} - \frac{\rho C_p v_z}{k}\frac{\partial T(r,z,t)}{\partial z} + \frac{\dot{g}}{k} = \frac{\rho C_p}{k}\frac{\partial T(r,z,t)}{\partial t}$

- WHERE $v_r \; and \; v_z$ ARE GIVEN BY THE BOUSSINESQ APPROXIMATION OF THE NAVIER-STOKES EQUATIONS;
  - WHERE, C_p IS THE HEAT CAPACITY
  - ρ THE DENSITY
  - k THE THERMAL CONDUCTIVITY
  - $\dot{g}$ HEAT GENERATION TERM
  - v_r AND v_z ARE THE VELOCITY COMPONENTS
  - T THE TEMPERATURE

- IGNORED TERMS
  - FRICTION $\mu\phi$, ~ DILATATION $\beta T \frac{\partial p(r,z,t)}{\partial t}$ AND COMPRESSIBILITY FLUID $\beta T v \cdot \nabla p$