Introduction to Bubble Chamber: Ops Training

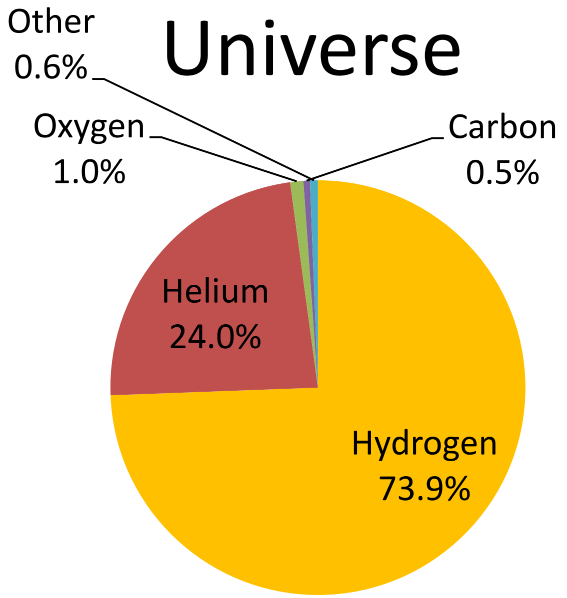
May 9, 2018

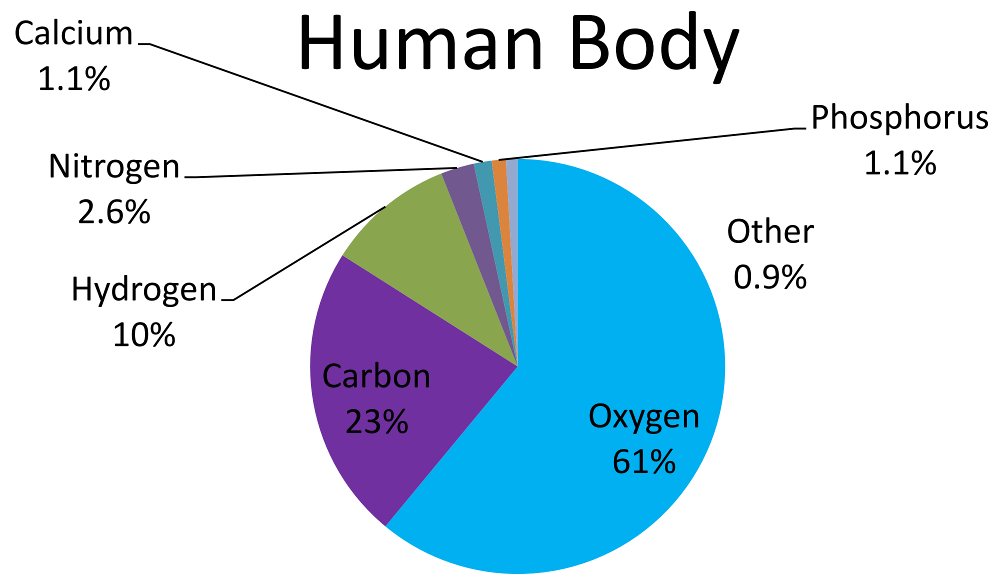
https://wiki.jlab.org/ciswiki/index.php/Bubble_Chamber

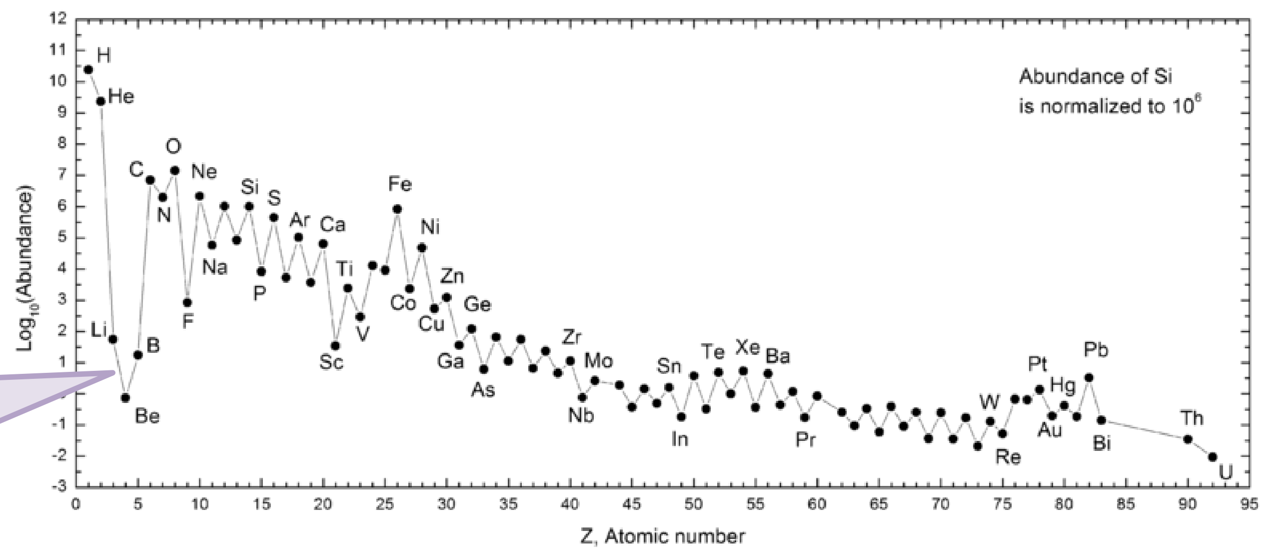
Outline

- Nucleosynthesis and $^{12}C(\alpha,\gamma)^{16}O$ Reaction
- Time Reversal Reaction: $^{16}O(\gamma,\alpha)^{12}C$
- Bubble Chamber
- Engineering Run – May 2018
- Measure $^{19}F(\gamma,\alpha)^{15}N$
- Electron Beam Requirements
- Bubble Chamber Test Plans
- Bubble Chamber Safety

Relative Abundance of Elements by Weight



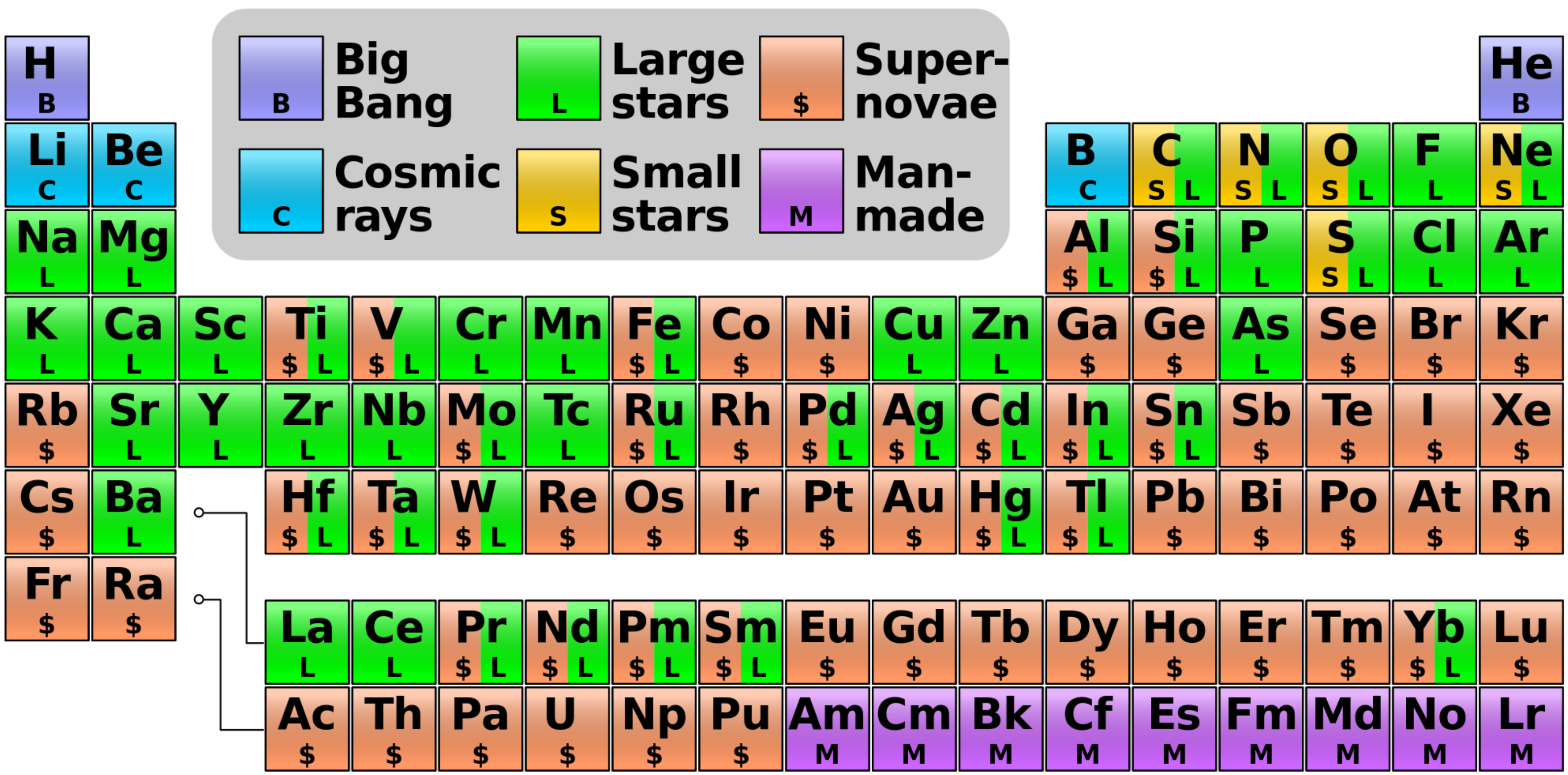




This region is bypassed by 3α process

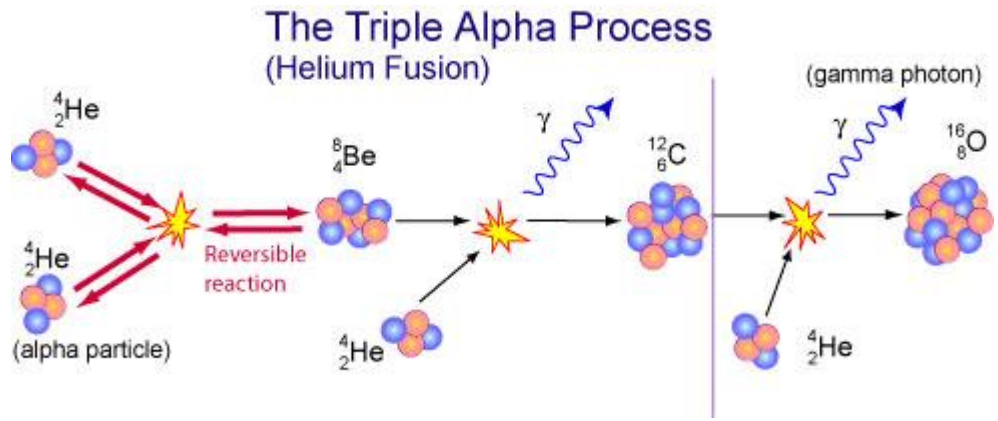
NUCLEOSYNTHESIS

- **Big Bang Nucleosynthesis:** quark–gluon plasma → p, n, He
- **Stellar Nucleosynthesis:** H burning, He burning, NCO cycle
- **Supernovae Nucleosynthesis:** Si burning
- **Cosmic Ray Spallation**

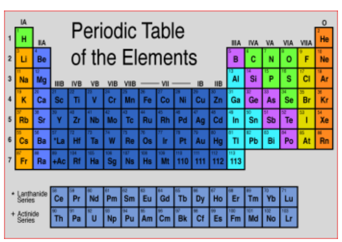


NUCLEOSYNTHESIS AND $^{12}C(\alpha,\gamma)^{16}O$

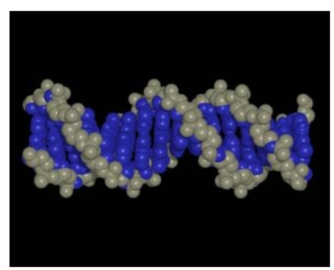
Stellar Helium burning



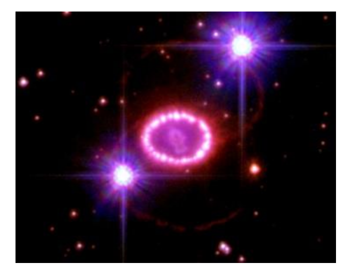
➢ The *holy grail* of nuclear astrophysics:



Affects synthesis of most of elements in periodic table



Sets $N(^{12}C)/N(^{16}O)$ ($\approx$0.4) ratio in universe



Determines minimum mass star requires to become supernova

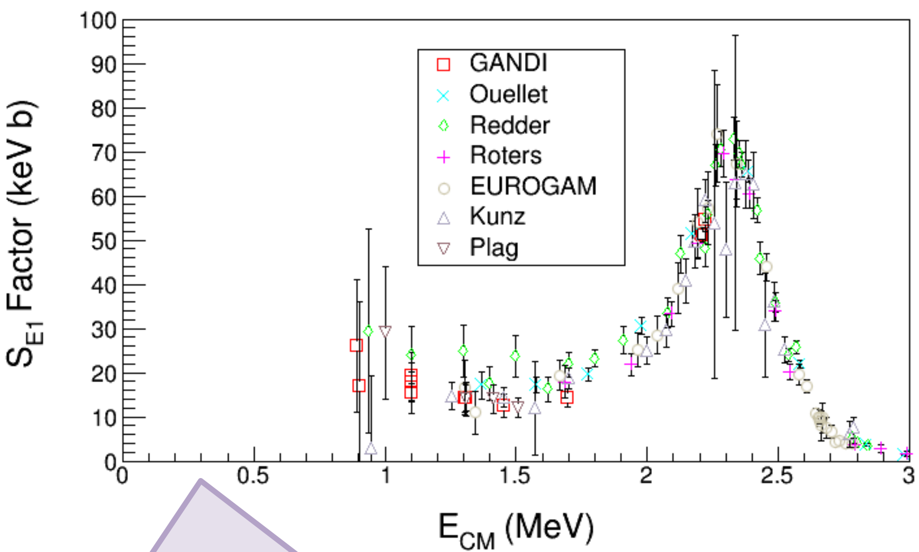
HEROIC EFFORTS IN SEARCH OF $^{12}C(\alpha,\gamma)^{16}O$

- Previous cross section measurements:
  I. Helium ions on carbon target: $^{12}C(\alpha,\gamma)^{16}O$
  II. Carbon ions on helium gas: $^{4}He(^{12}C,\gamma)^{16}O$ or $^{4}He(^{12}C,^{16}O)\gamma$

- Define *S-Factor* to remove both 1/E dependence of nuclear cross sections and Coulomb barrier transmission probability:

$$S \equiv E_{CM}\sigma(\alpha,\gamma)e^{2\pi\eta}$$

Author	S_{tot}(300) (keV b)
Hammer (2005)	162±39
Kunz (2001)	165±50



R-matrix Extrapolation to stellar helium burning at E = 300 keV

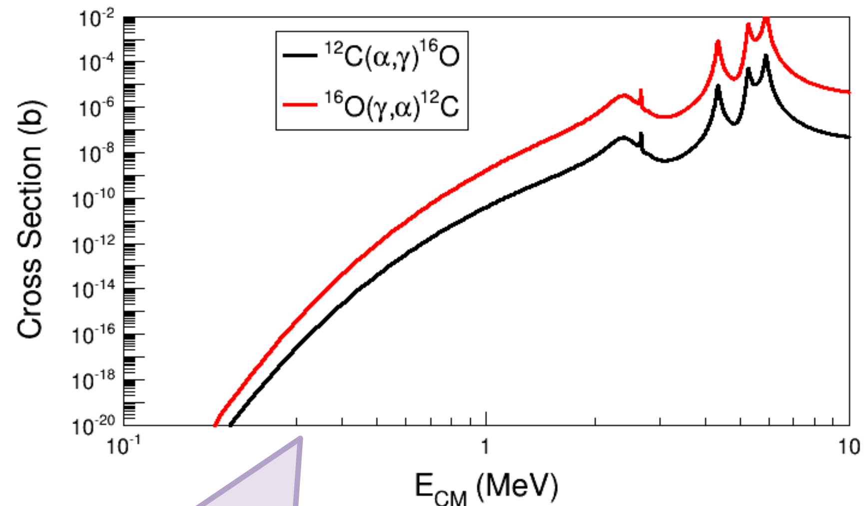
New Approach: Reversal Reaction + Bubble Chamber

beam | target | signal

$$\gamma + {}^{16}\mathrm{O} \rightarrow {}^{12}\mathrm{C} + \alpha$$

$$Q = +7.162\ \mathrm{MeV}$$

$$E_{\gamma} \cong E_{CM} + Q$$



Stellar helium burning at
E = 300 keV, T=200 10^6 K

- Extra gain (factor of 100) by measuring time reversal reaction
- Bremsstrahlung at JLab $\sim 10^9$ γ/s (top 250 keV)
- Target density up to 10^4 higher than conventional targets. Number of ^{16}O nuclei = $3.5 \times 10^{22}/cm^2$ (3.0 cm cell)
- Electromagnetic debris (electrons and gammas, or positrons) do NOT trigger nucleation (detector is insensitive to γ-rays by at least 1 part in 10^{11})

THE BUBBLE CHAMBER

1 Cell is cooled then filled with room temperature gas

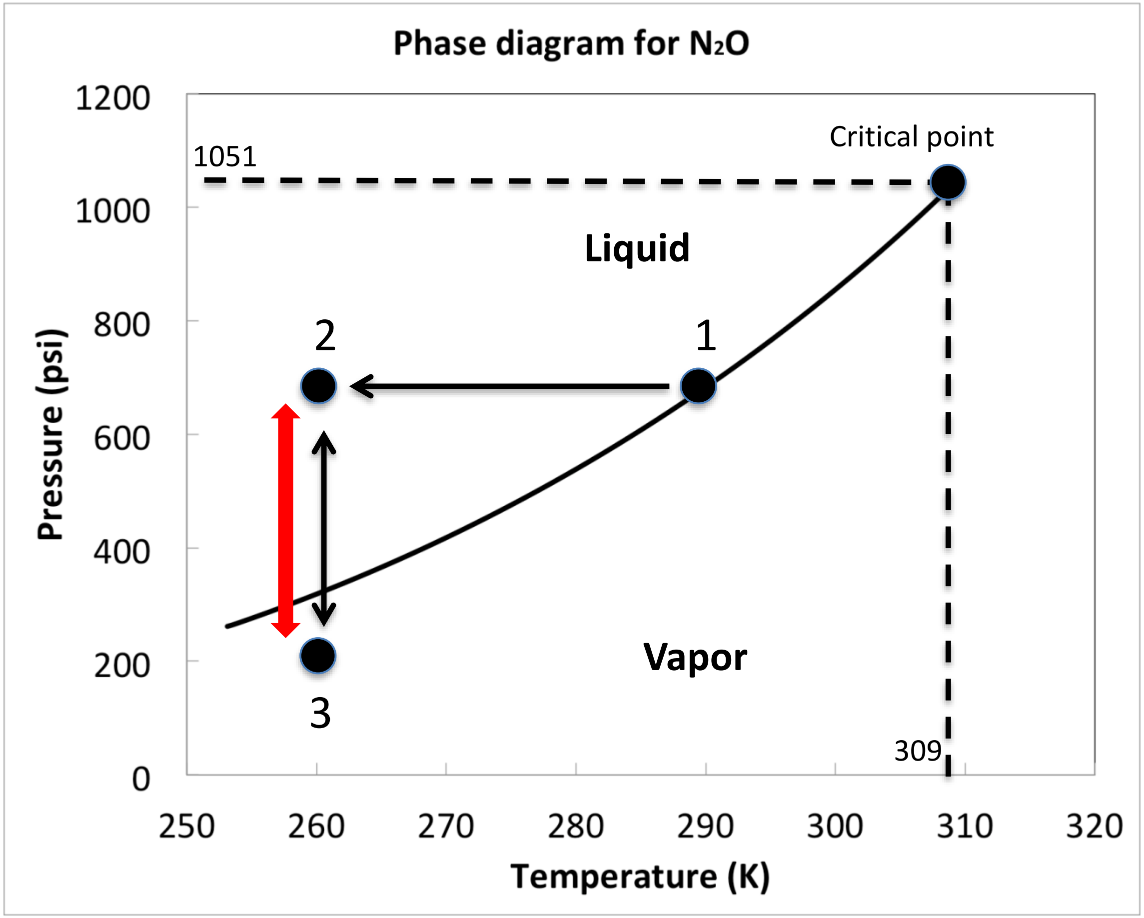
2 Gas is cooled and condenses into liquid

3 Once cell is completely filled with liquid, pressure is reduced creating a superheated liquid

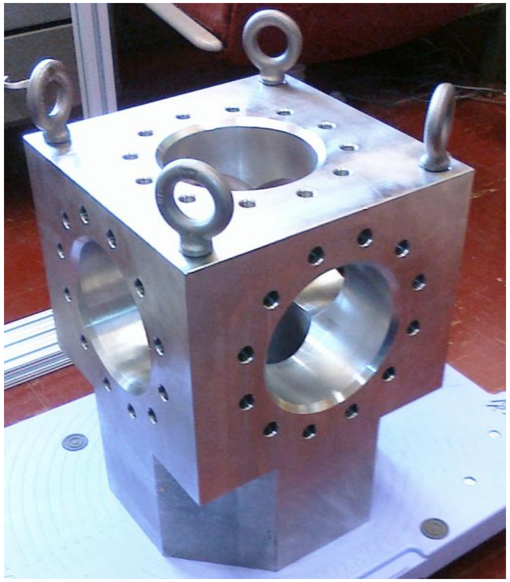
3 Nuclear reactions induce bubble nucleation

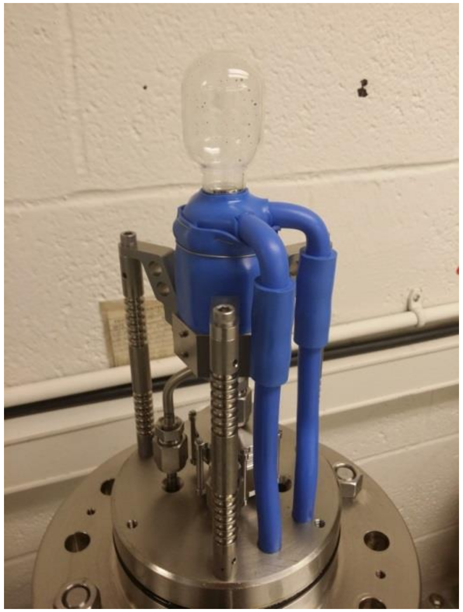
2 High speed camera detects bubble and repressurizes

3 System depressurizes and ready for another cycle



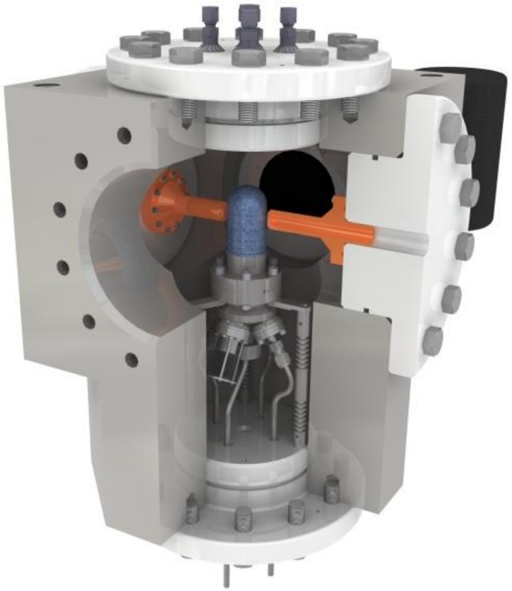
BUBBLE CHAMBER

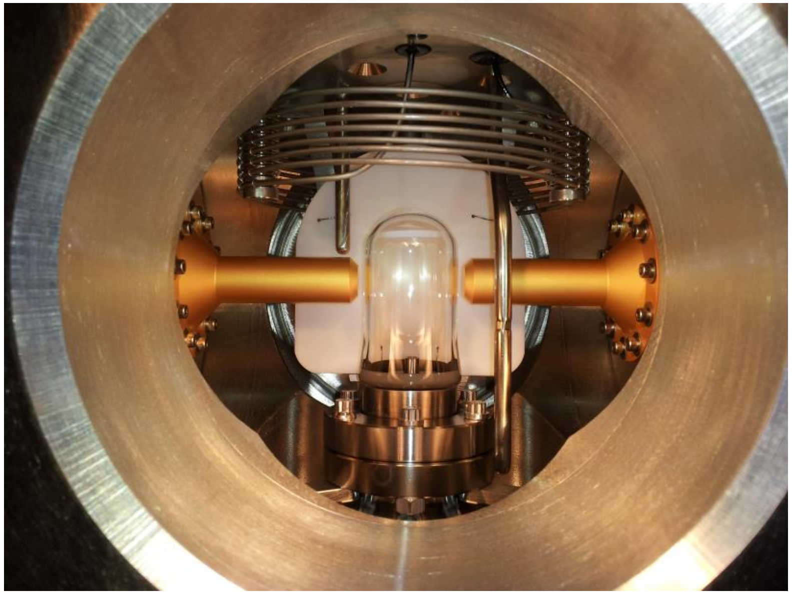




T = -10˚C

P = 50 atm





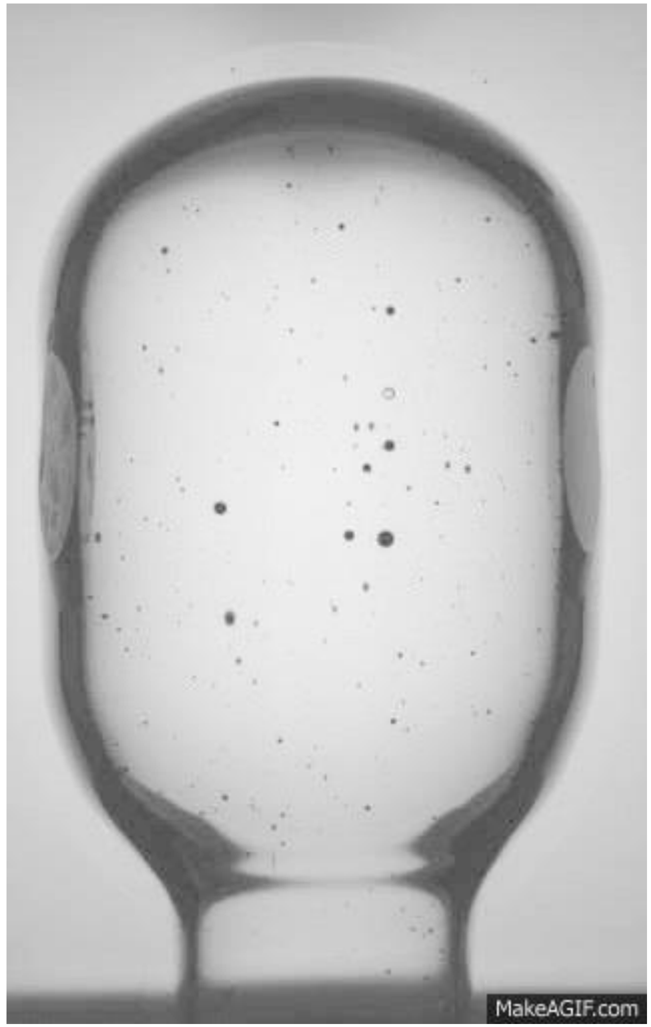
USER INTERFACE

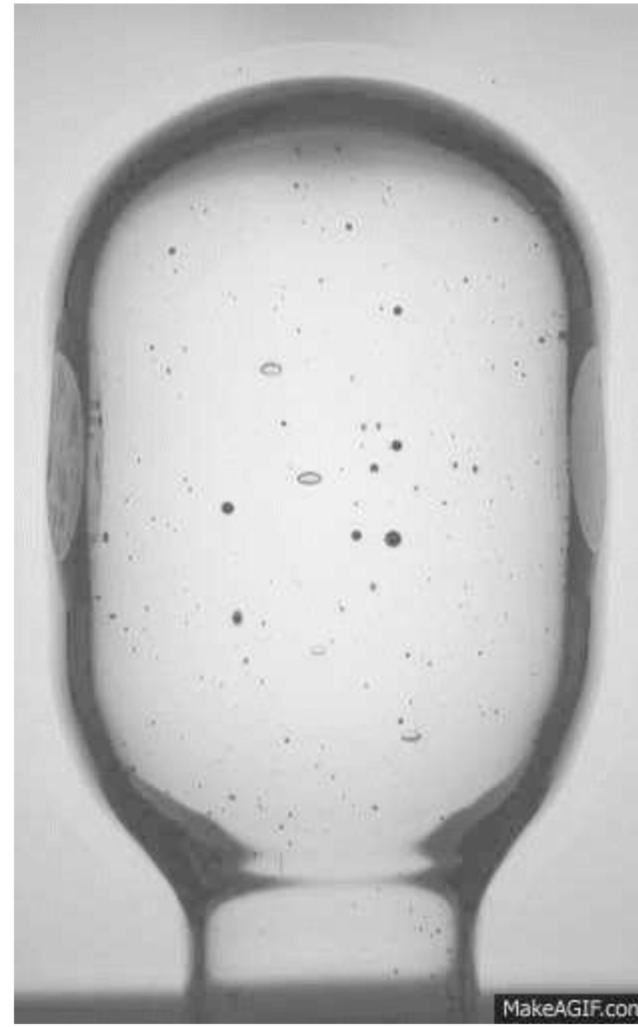
BUBBLE GROWTH AND QUENCHING

3.0 cm

100 Hz Digital
Camera Δt = 10 ms

N_2O Chamber with PuC neutron source





ENGINEERING RUN – MAY 2018

I. Measure $^{19}F(\gamma,\alpha)^{15}N$ (Q = +4.013 MeV)

II. Use C_3F_8 (Octafluoropropane – refrigerant gas)

III. Only one stable natural isotope (^{19}F)

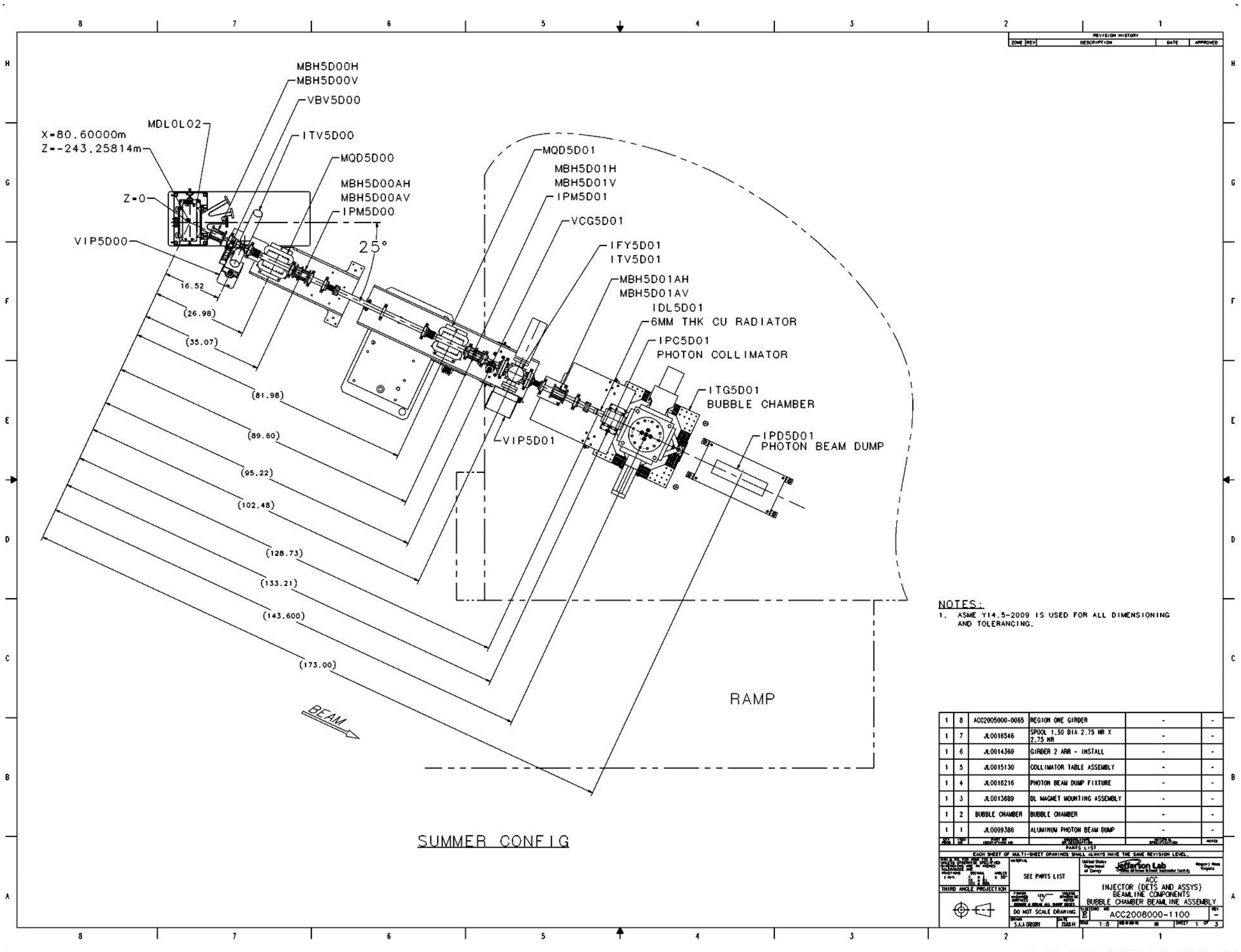
IV. Low electron beam kinetic energy (4.6 – 5.2 MeV) – below threshold of any background reaction

Electron Beam Requirements

I. Beam Properties at Radiator:

Beam Kinetic Energy, (MeV)	4.8 – 5.3
Beam Current (μA)	0.01 – 50
Absolute Beam Energy Uncertainty	<0.1%
Relative Beam Energy Uncertainty	<0.02%
Energy Resolution (Spread), σ_T/T	<0.06%
Beam Size, $\sigma_{x,y}$ (mm)	1
Polarization	None

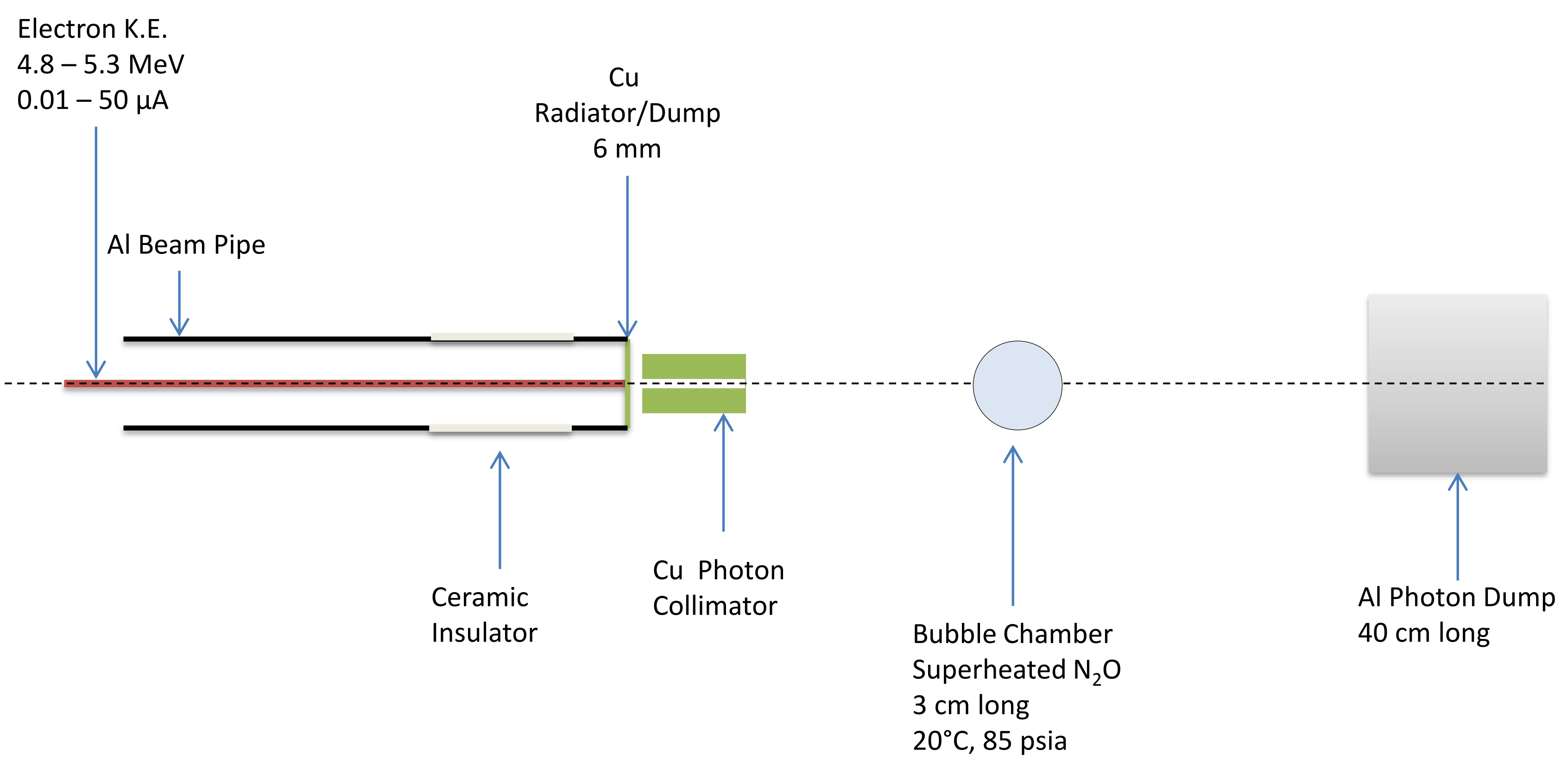
TEST BEAMLINE

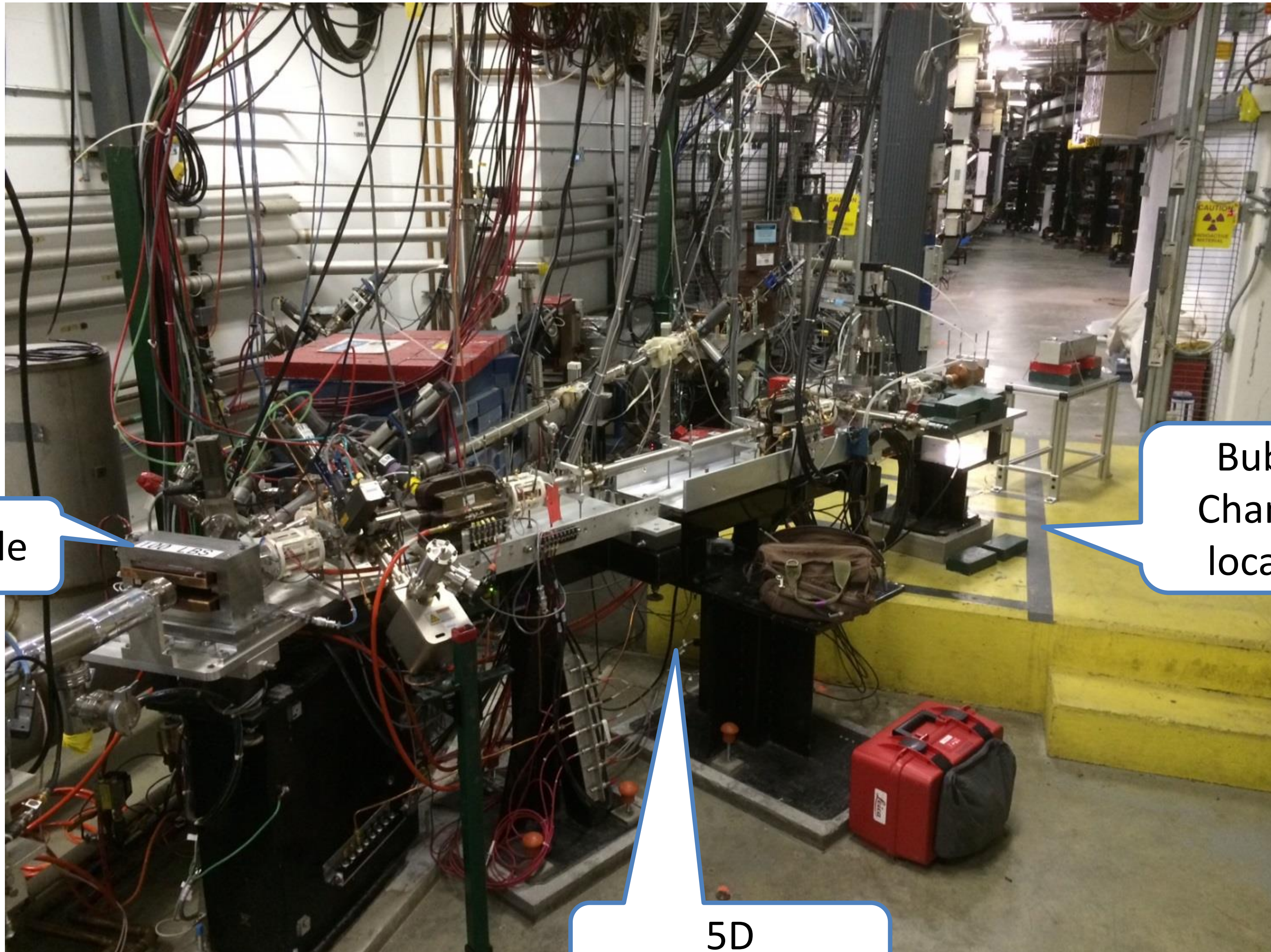


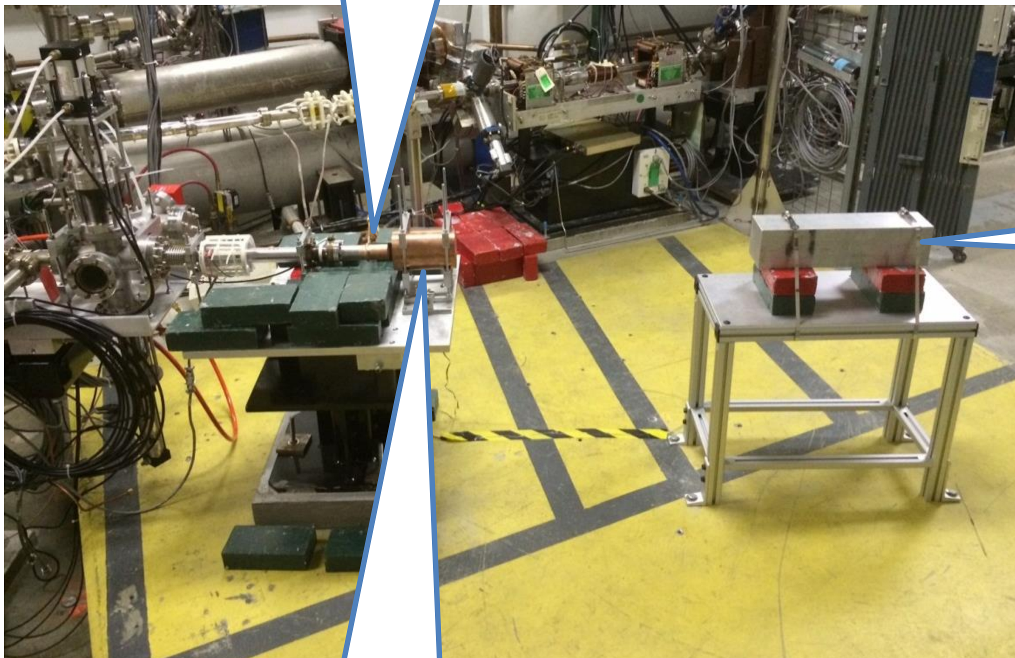
SCHEMATICS OF TEST BEAMLINE

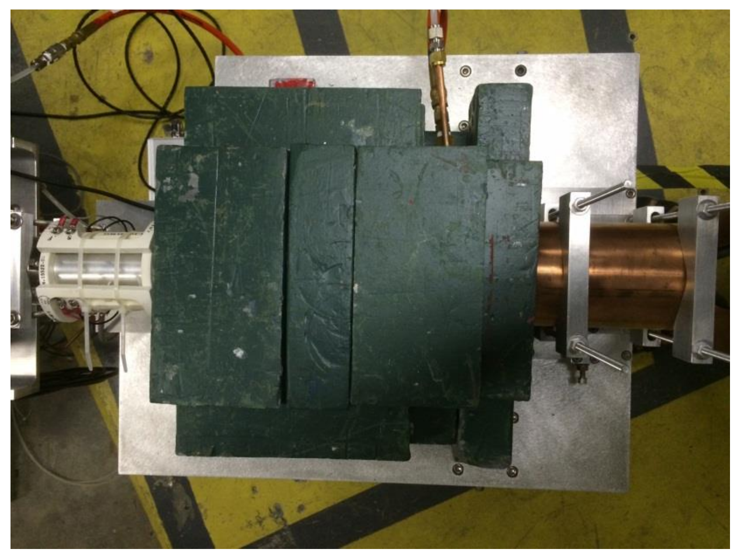
- Copper radiator: 6 mm

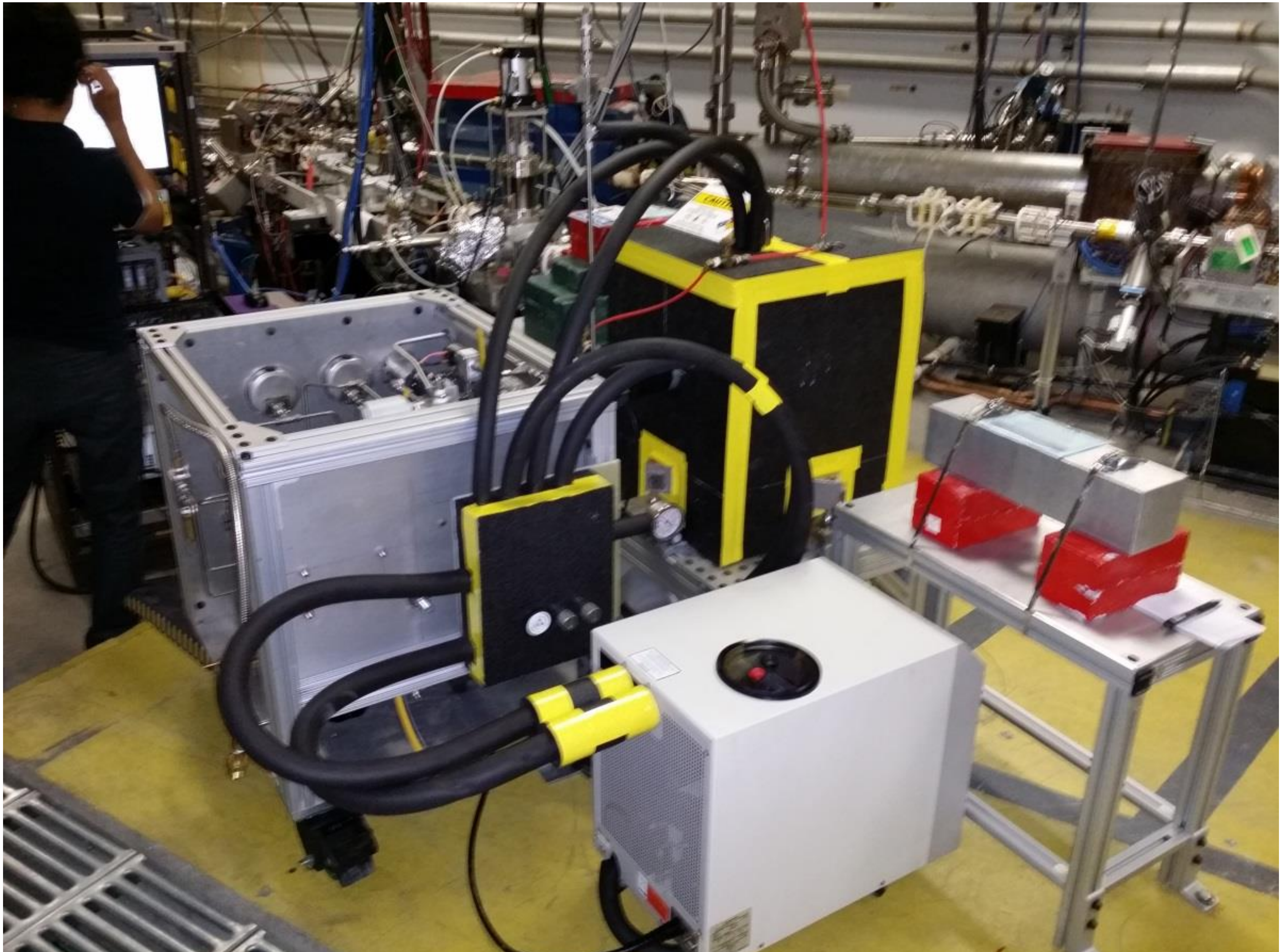
- Pure Copper and Aluminum (high neutron threshold):
  I. $^{63}C(\gamma,n)$ threshold = 10.86 MeV
  II. $^{27}Al(\gamma,n)$ threshold = 13.06 MeV



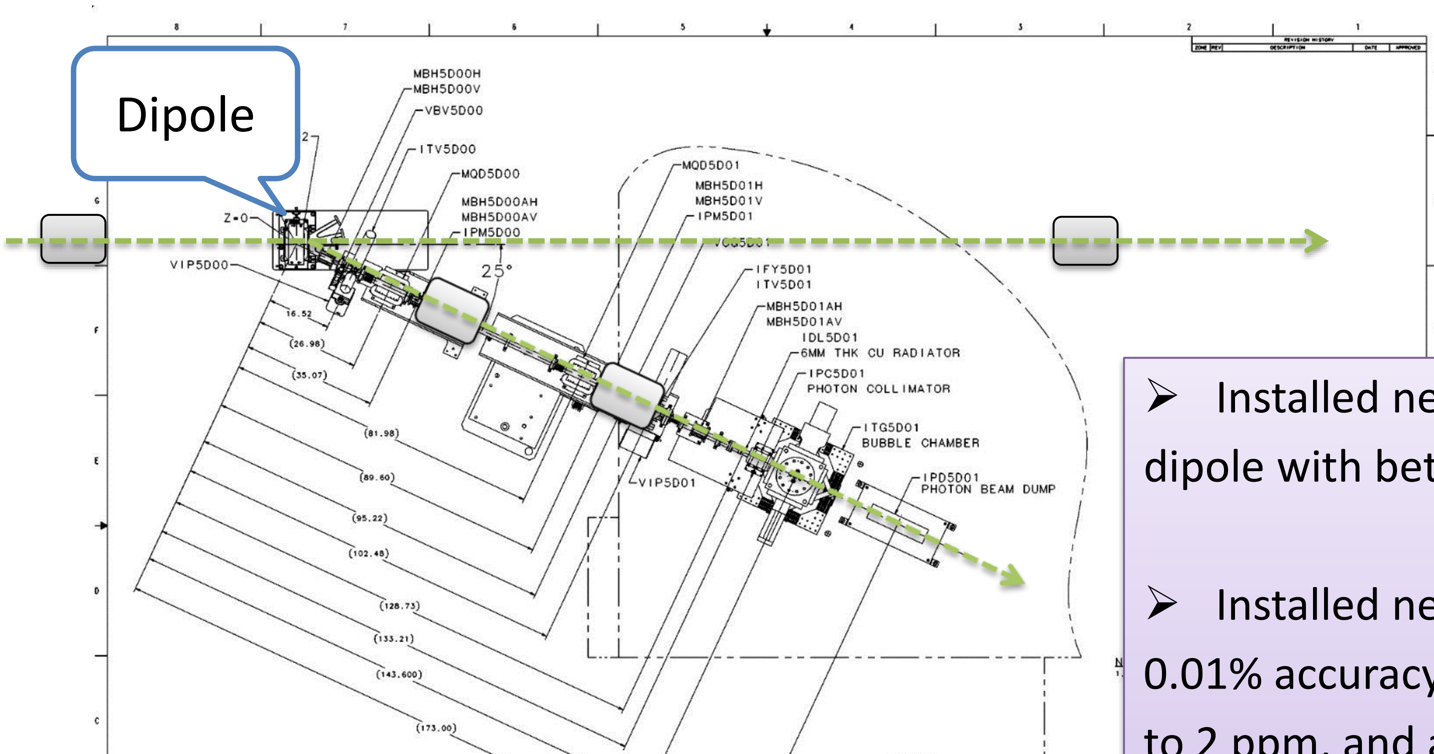

Dipole
Bubble Chamber location
5D Spectrometer


Cu Electron Radiator/Dump
Al Photon Dump
Cu Photon Collimator





MEASURING ABSOLUTE BEAM ENERGY



Beam Position Monitor (BPM)

Electron Beam Momentum

$$p = \frac{\int B dl}{\theta}$$

- Installed new higher field dipole with better uniformity
- Installed new Hall probe: 0.01% accuracy, resolution to 2 ppm, and a temperature stability of 10 ppm/°C
- Shielded Earth's and other stray magnetic fields

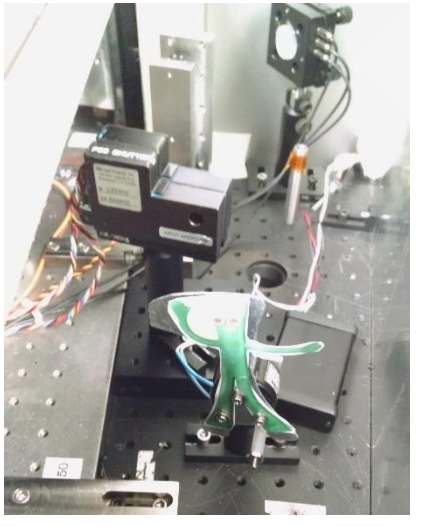
BUBBLE CHAMBER TEST PLANS

1. Run from MCC fish bowl

2. Use neutron source – test bubble chamber systems operation

3. Measure cosmic background

4. With beam (24/7, May 10 – 18)



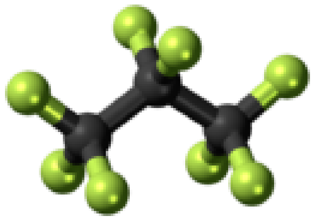
   I. Check CCD camera with beam-on

   II. Test bubble chamber laser shutter (***gumby shutter***) – Stop beam once a bubble is detected for 5 seconds to allow for time to quench bubble

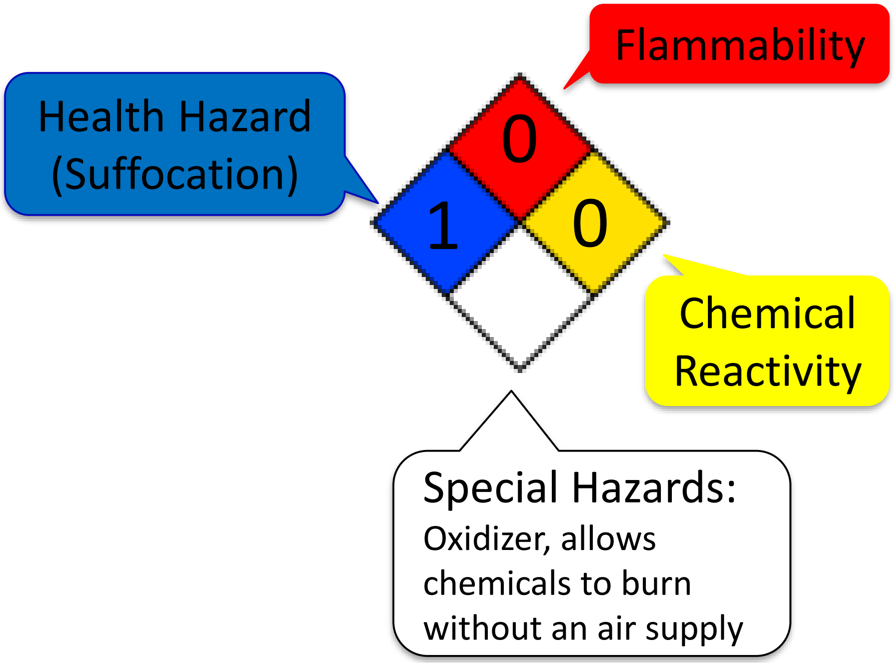
   III. Collect bubbles at few beam energies – expect a bubble every 10 sec at 5.3 MeV and every 10 minutes at 4.8 MeV

BUBBLE CHAMBER SAFETY REVIEWS

- Superheated liquid: C_3F_8 (Octafluoropropane – refrigerant gas)
  I. Fluorocarbon non-flammable greenhouse gas



- High pressure system:
  I. Design Authority: Dave Meekins
  II. Temperature = 20˚C
  III. Operational Pressure = 85 psia
  IV. Quenching Pressure = 350 psia



- Temporary Operational Safety Procedures (**TOSP**) is approved