Nuclear Astrophysics with γ-ray beams and a bubble chamber

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

Collaboration

List of people

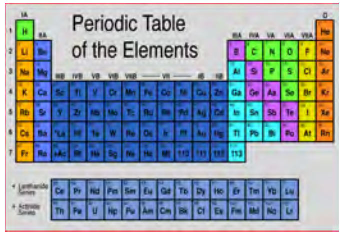
Jefferson Lab

Argonne NATIONAL LABORATORY

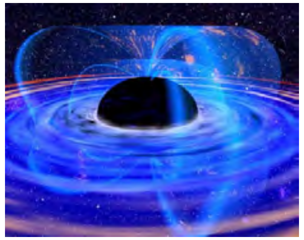
UIC UNIVERSITY OF ILLINOIS AT CHICAGO

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

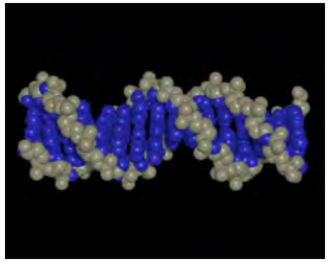
Key reaction for nucleosynthesis in massive stars, progenitors of Type Ia Supernovae, White Dwarf ages.



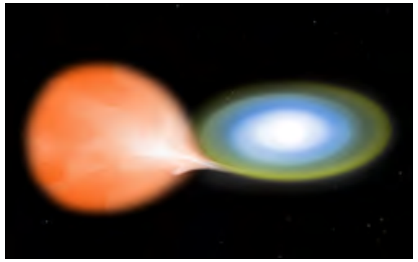
Affects the synthesis of most of the elements of the periodic table



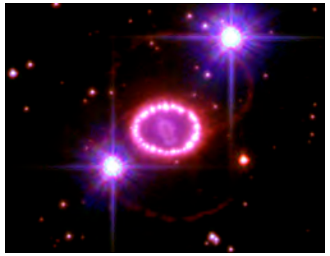
Determines whether for a given initial mass, a star will become a black hole or a neutron star



Sets the C to O ratio in the universe

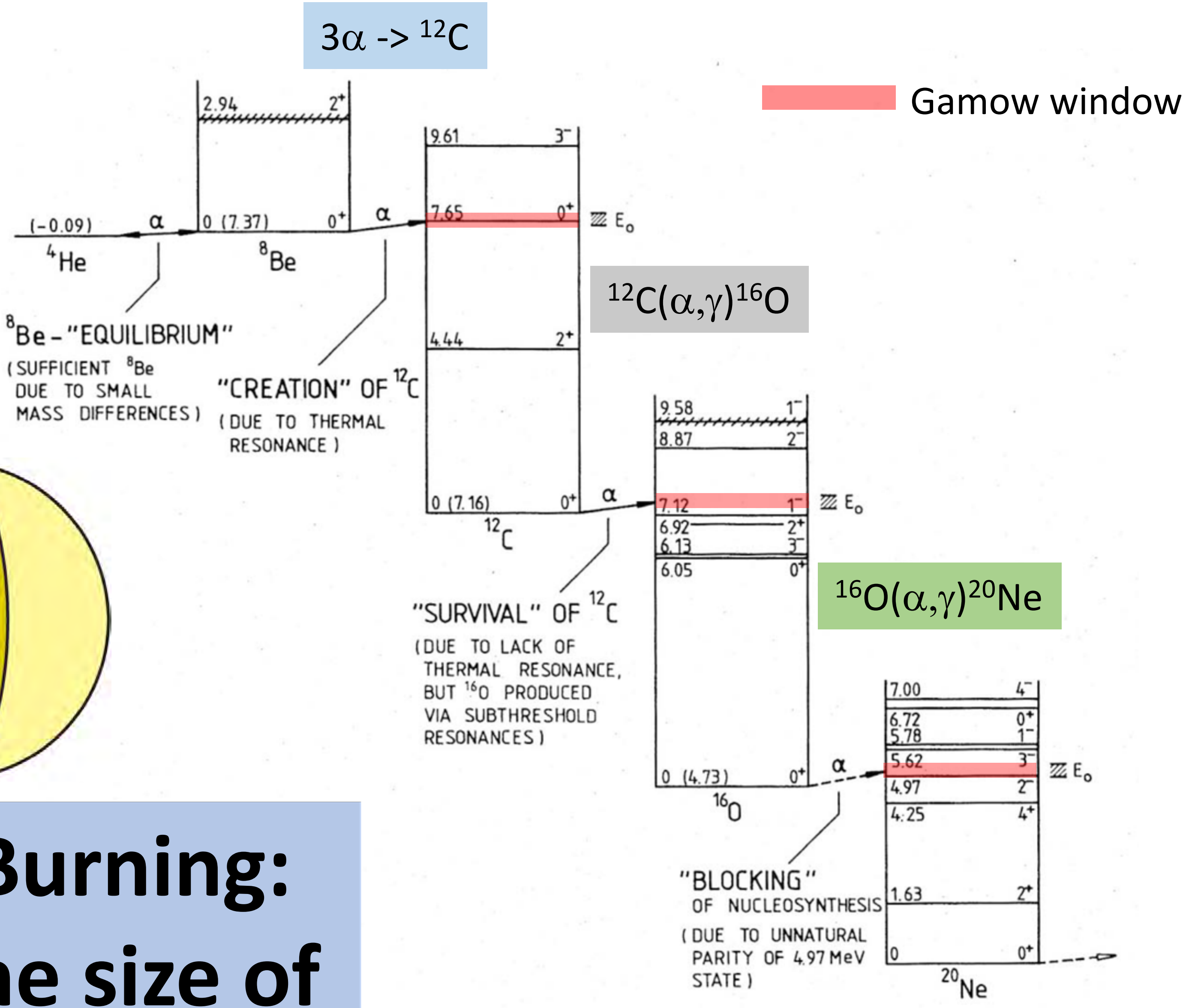


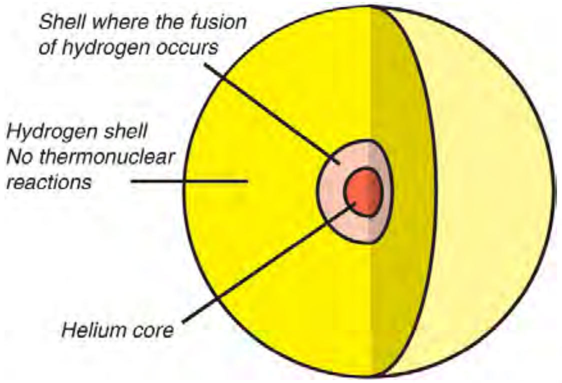
The variation of the C/O ratio in the progenitor might be a cause of the variation of SNIa brightness



Determines the minimum mass a star requires to become a core collapse supernova

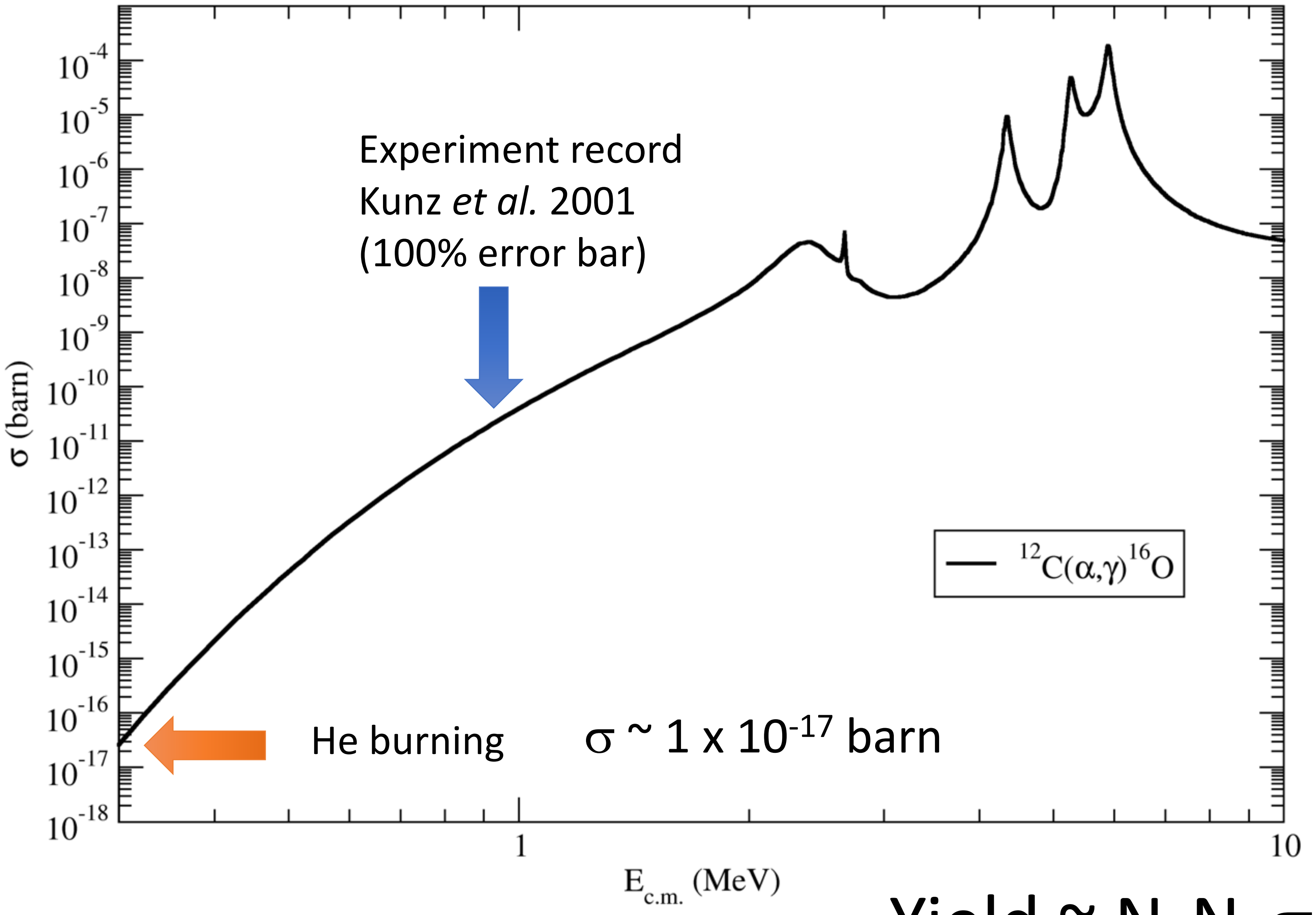
Affects the constraints on the age of stellar populations from White Dwarfs



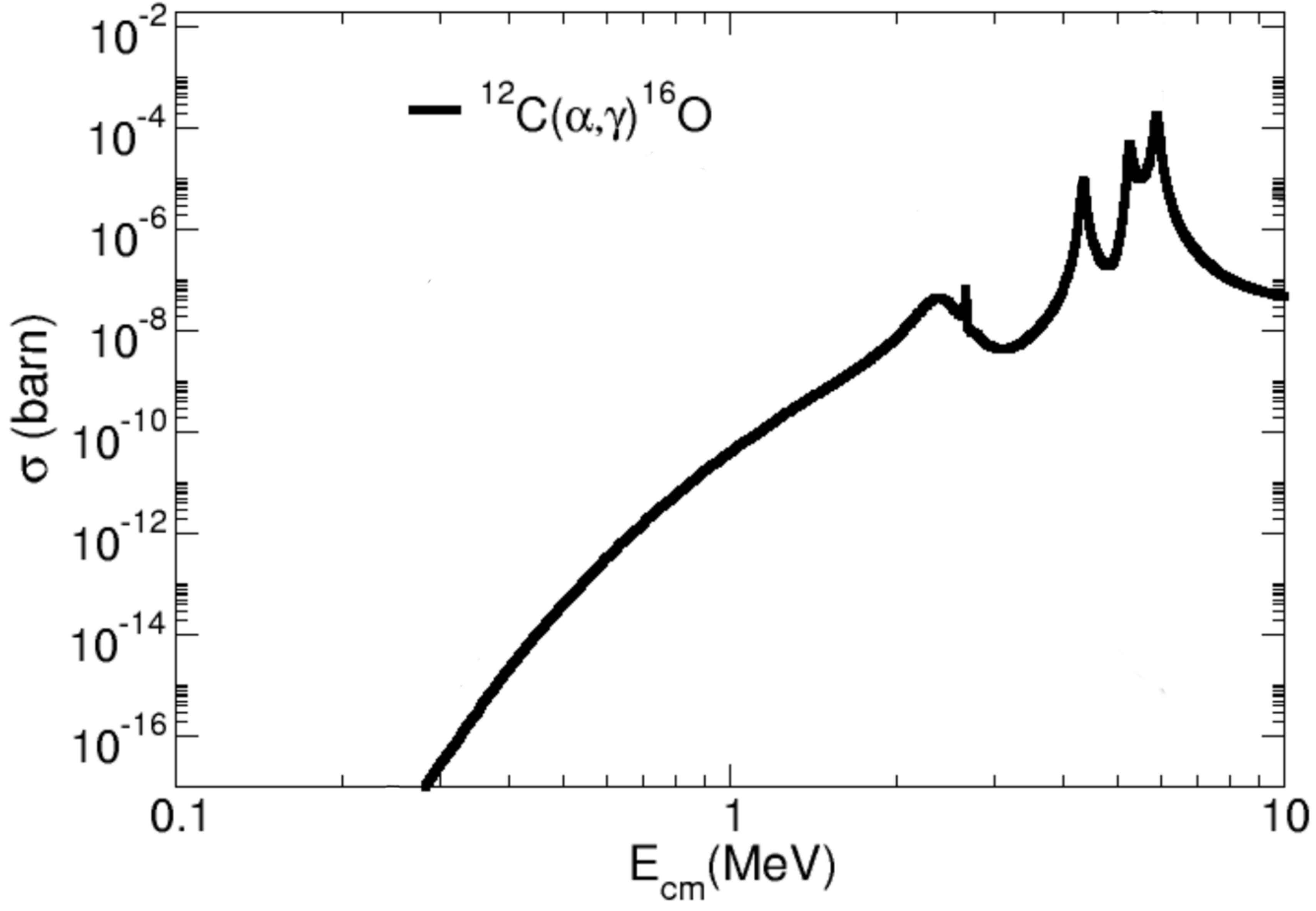


Helium Burning: Defines the size of the stellar core.

Rolfs and Rodney, 1988

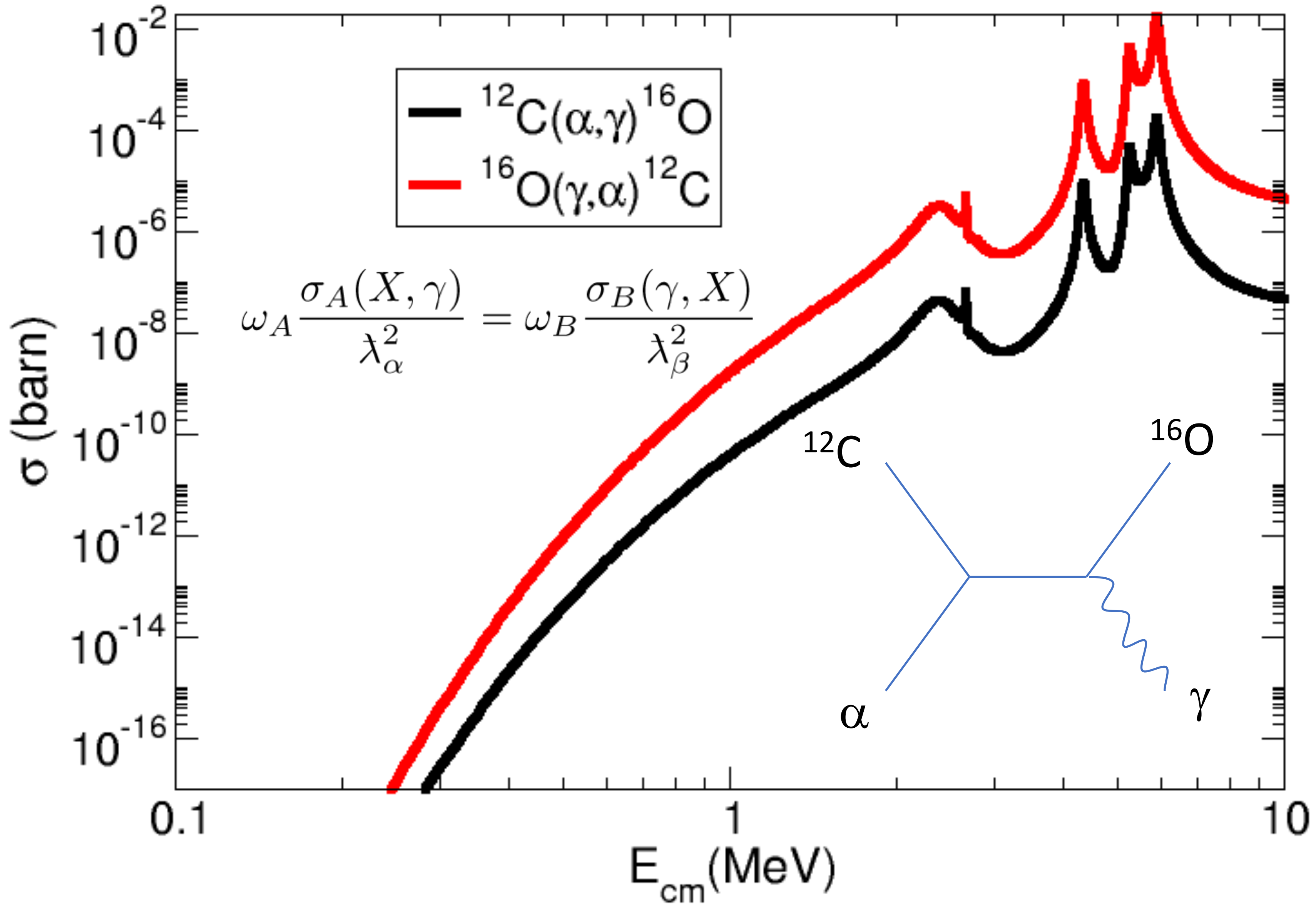


$$\text{Yield} \sim N_1 N_2 \sigma g$$



$^{12}C(\alpha,\gamma)^{16}O$
σ (barn)
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
0.1
1
10
E_{cm}(MeV)

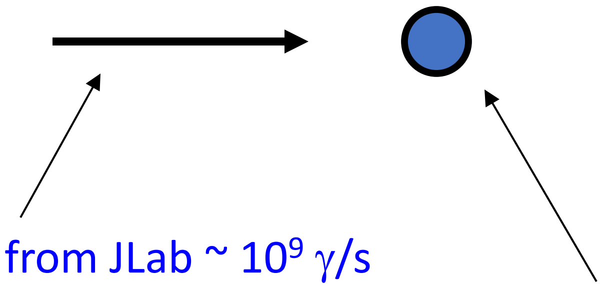
Time reversal symmetry: x100 gain in cross section



Our approach:
Inverse reaction + Bubble chamber + γ ray beam

beam | target | signal

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



- Extra gain (x100) by measuring time inverse reaction
- The target density up to x10^6 higher than conventional targets.
- Superheated water will nucleate from α and ^{12}C recoils
- The detector is insensitive to γ-rays (at least 1 part in 10^{11})

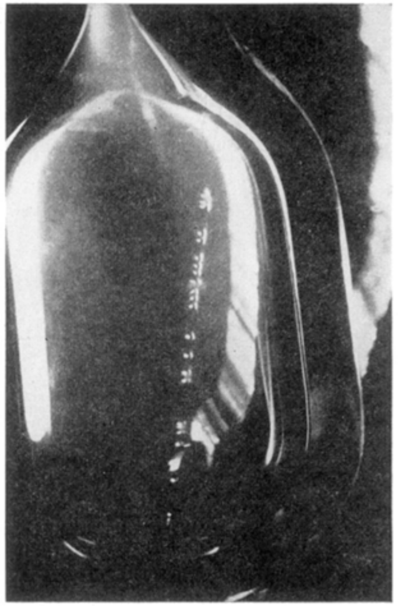
Liquid target (internal detection)
The bubble chamber

Donald A. Glaser
Nobel Prize in Physics, 1960

Phys. Rev. **87,** 665 (1952).

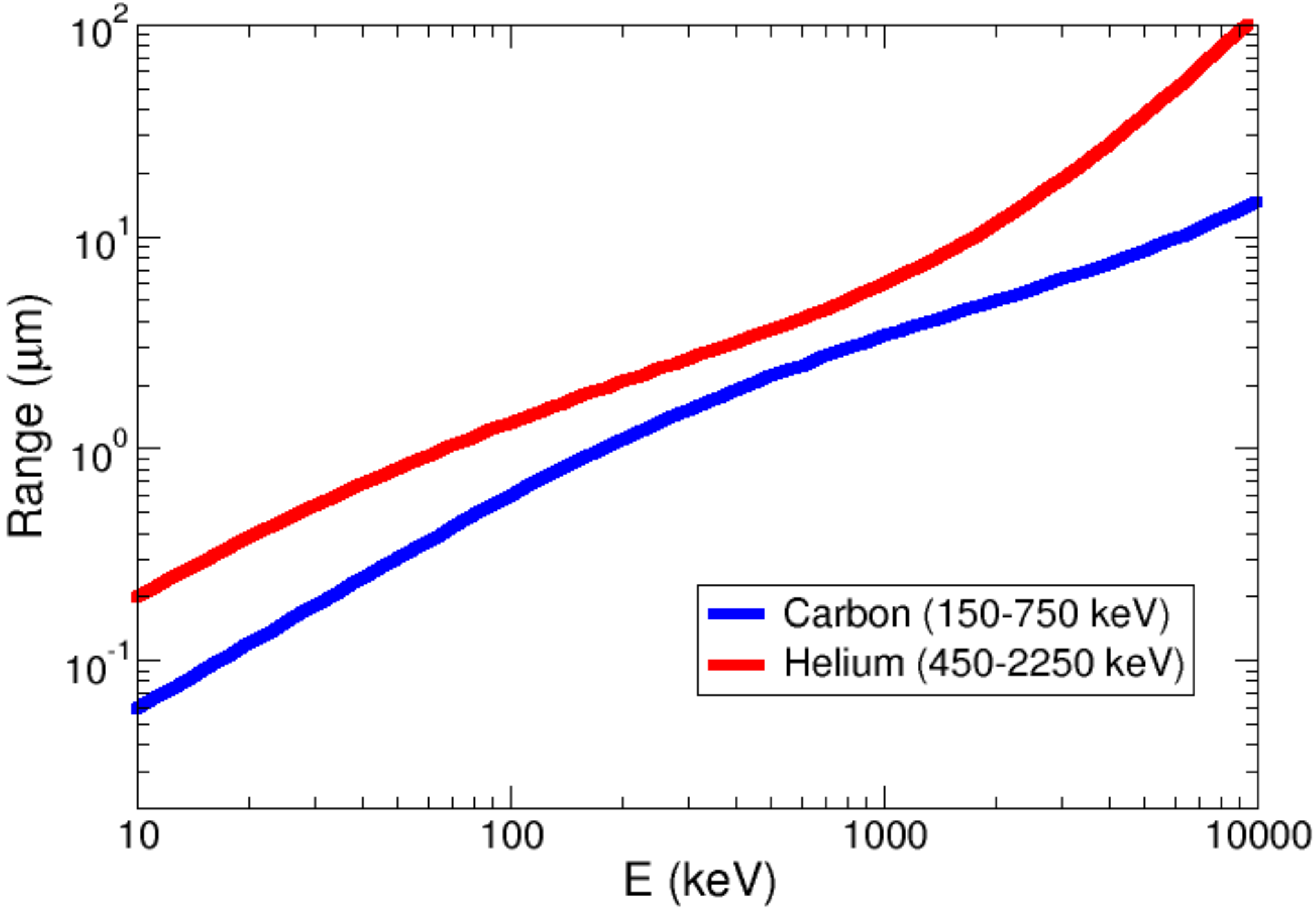
Some Effects of Ionizing Radiation on the Formation of Bubbles in Liquids*

DONALD A. GLASER
University of Michigan, Ann Arbor, Michigan
(Received June 12, 1952)

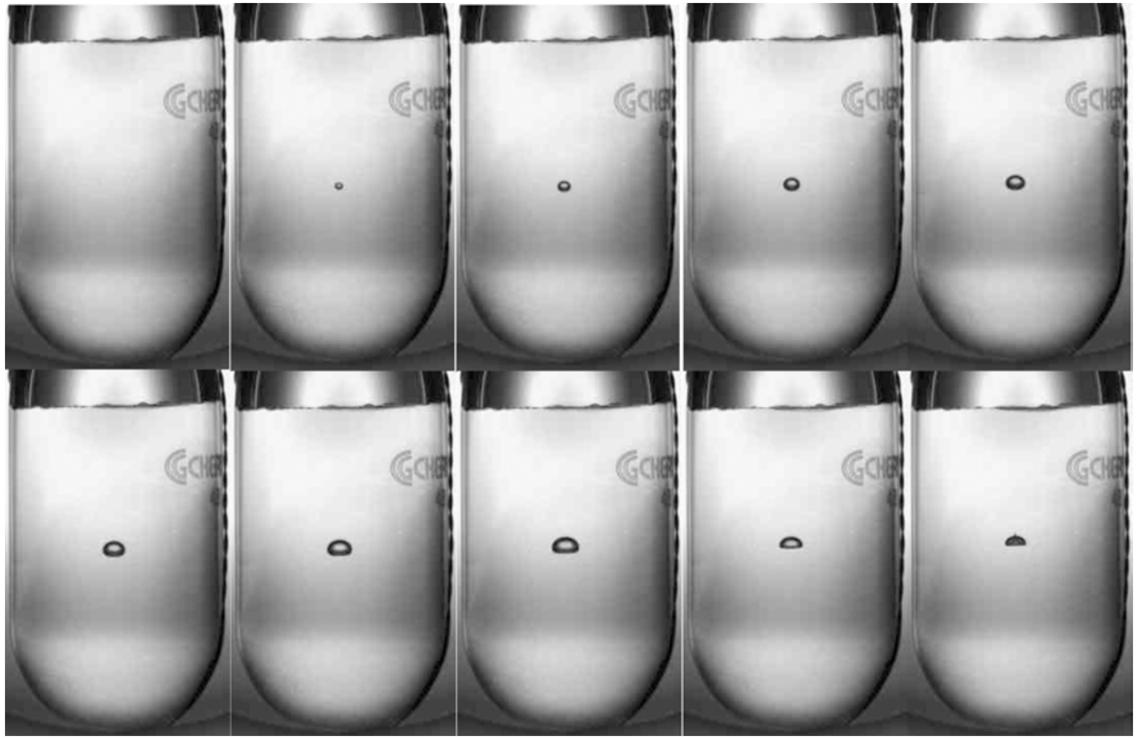


Ingredients:
- Superheated liquid
- Ionizing radiation

Ranges in water



Bubble growth and quenching. $^{19}F(\gamma,\alpha)^{15}N$ in R134a



$\Delta t = 10$ ms

Theory of Operation

1➔2

Active liquid is pressurized

2➔3

Active liquid is heated

3➔4

Pressure is reduced creating a superheated liquid

4

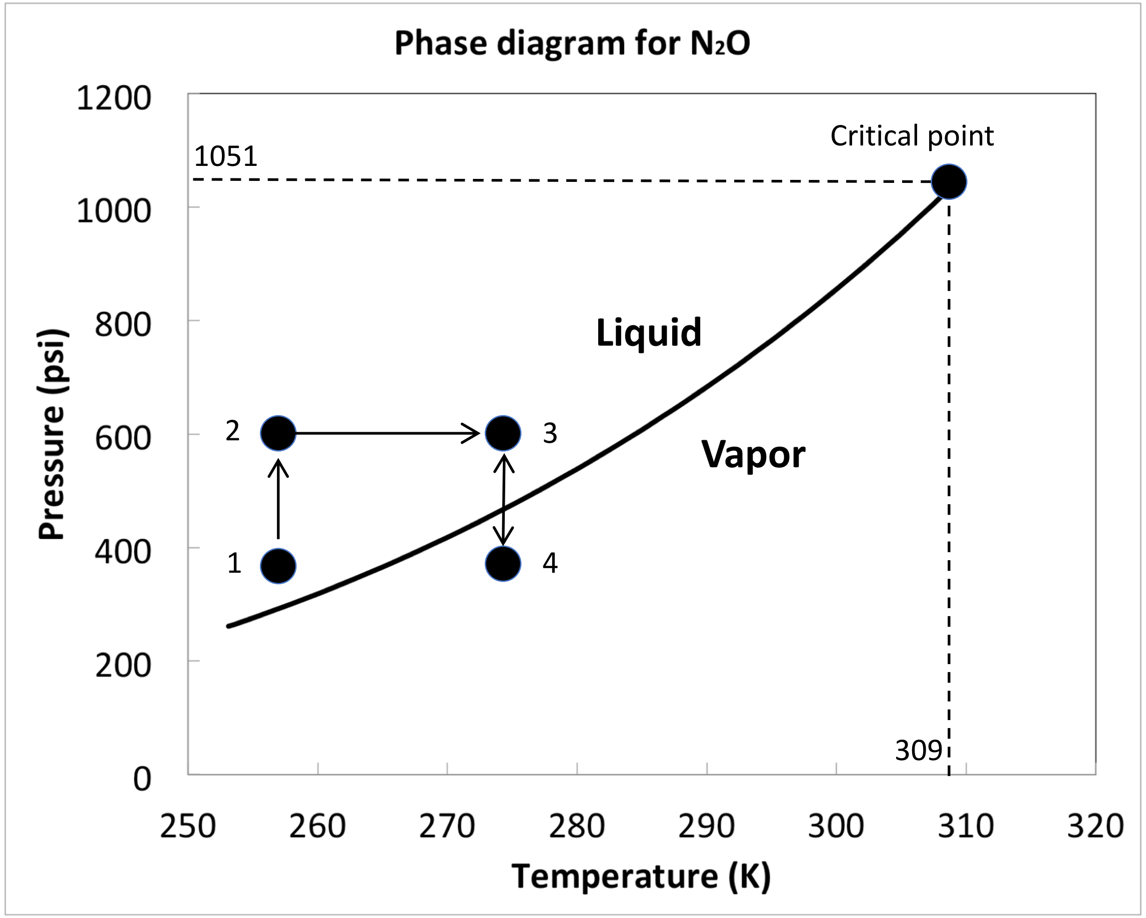
Nuclear reactions induce bubble nucleation

4➔3

High speed camera detects bubble and repressurizes

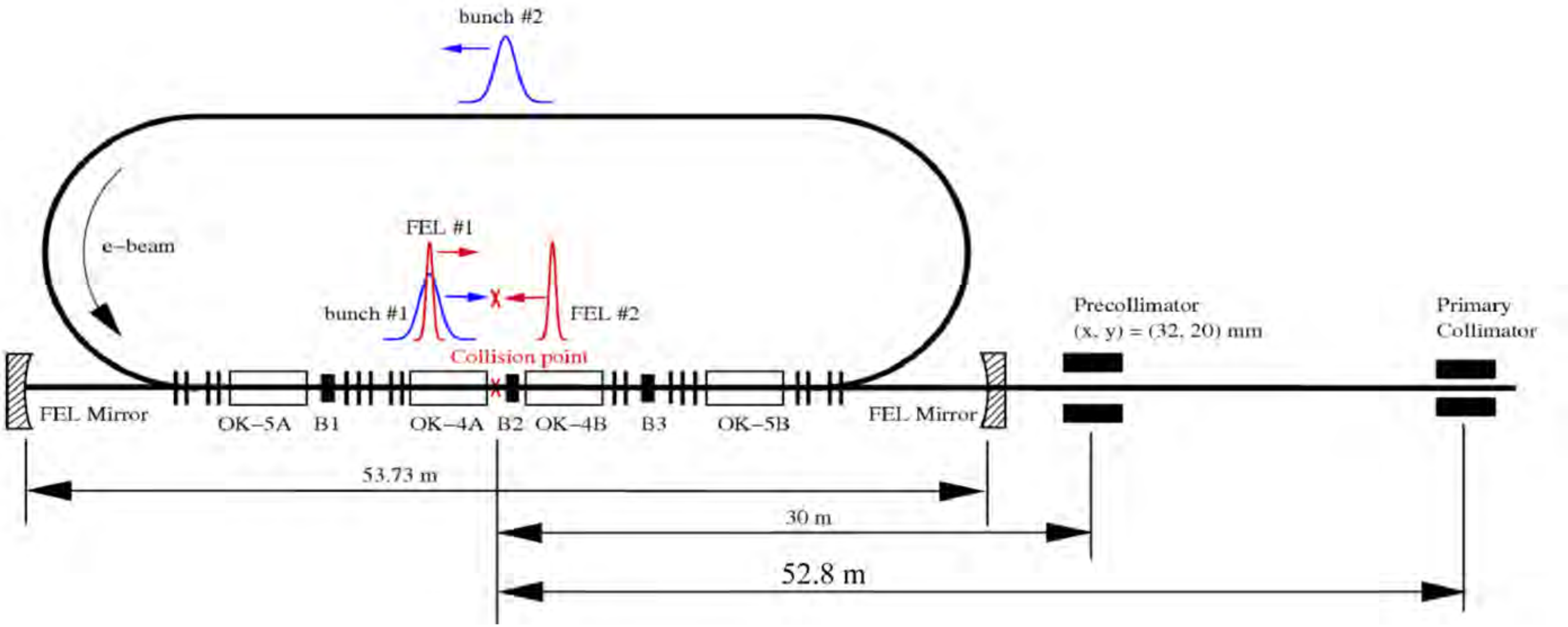
3➔4➔3

System ready for another cycle



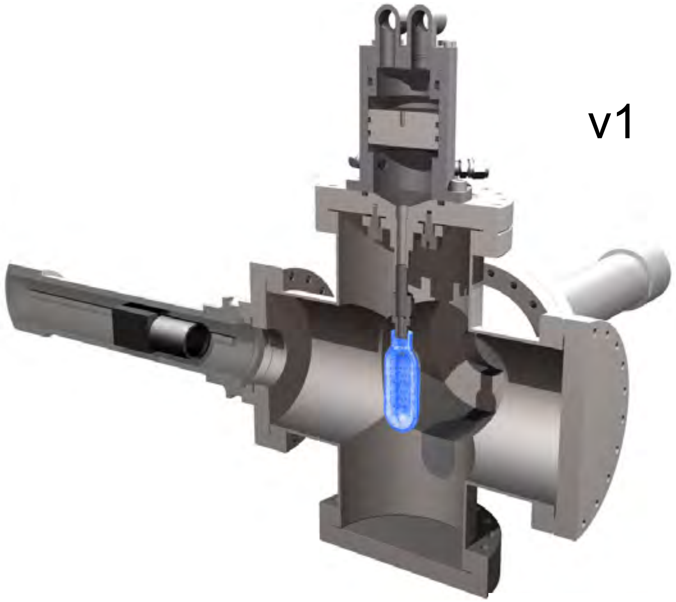
2010-2013 experiments at HIγS

HIγS Photon Beam

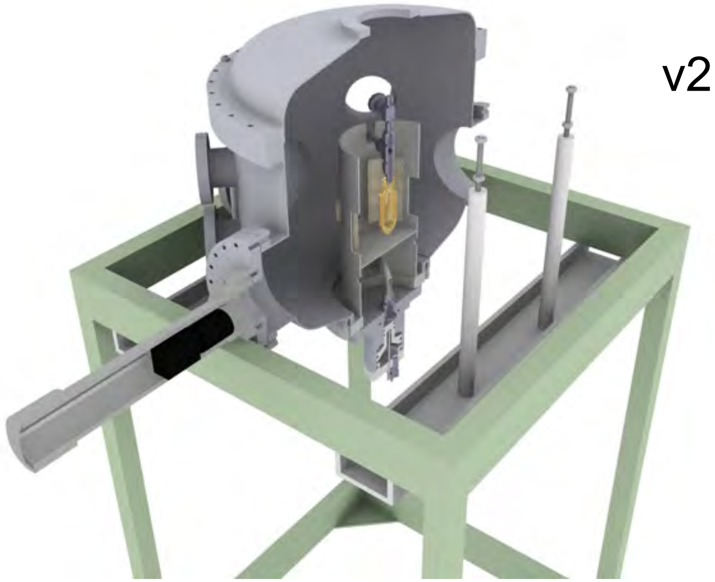


Liquids tested

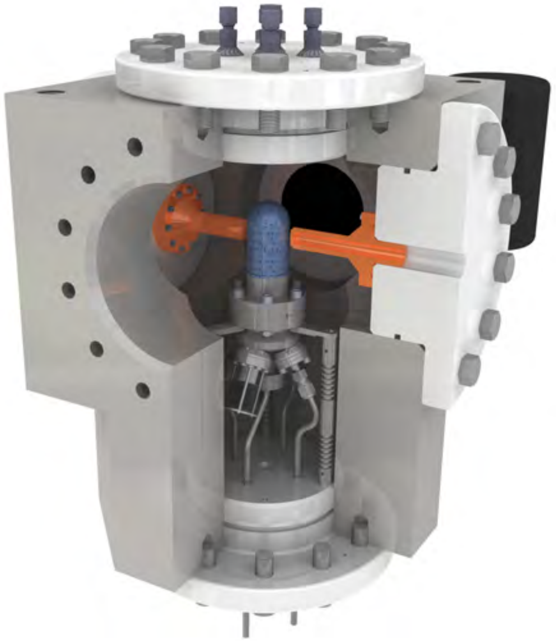
- CH_2FCF_3
- C_4F_{10}
- H_2O
- N_2O
- CO_2



v1

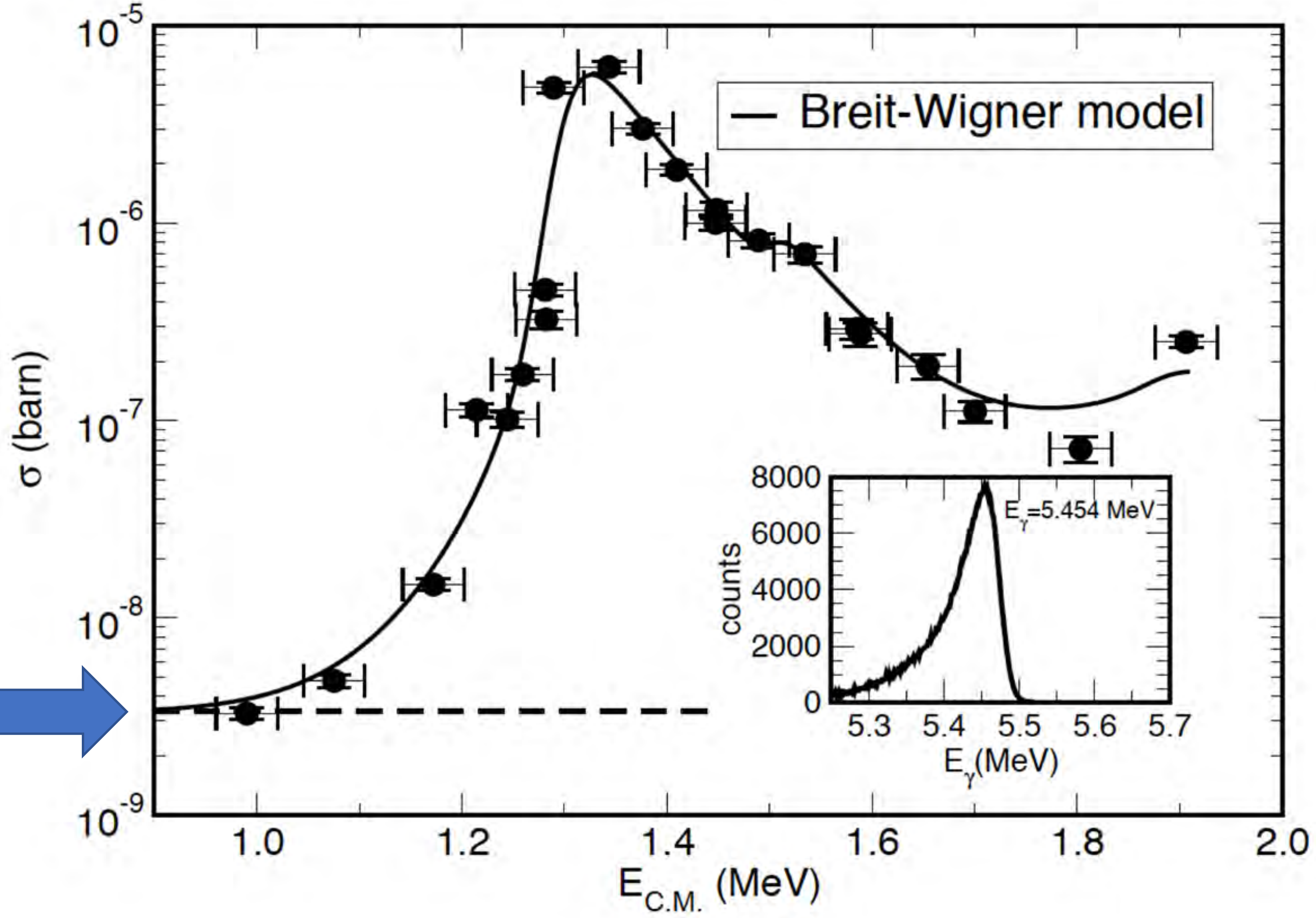


v2



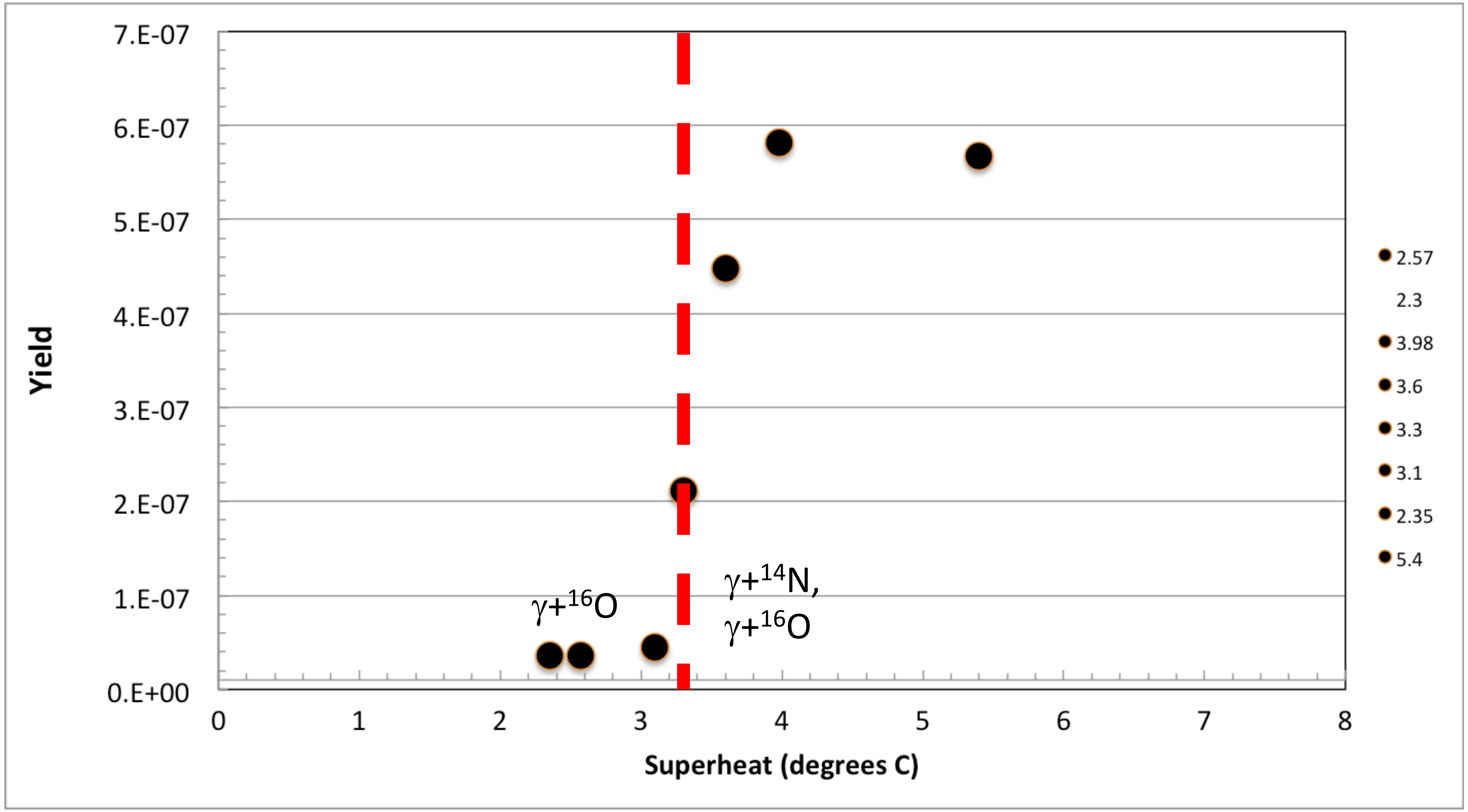
v3

$^{19}F(\gamma,\alpha)^{15}N$



Bremsstrahlung

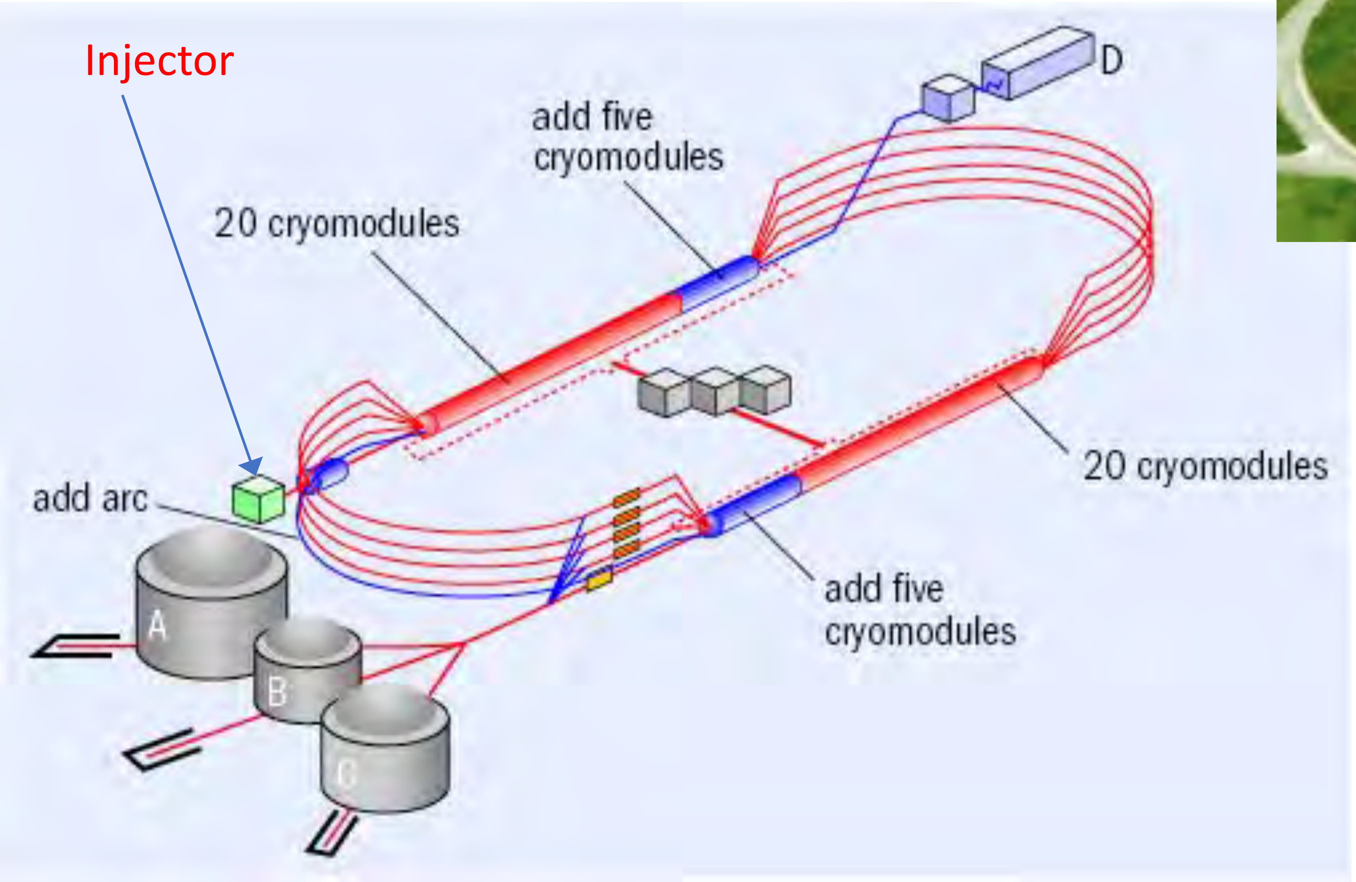
N_2O efficiency curve, HIγS April 2013. $E\gamma$ = 9.7MeV



September 2015 experiments at JLab

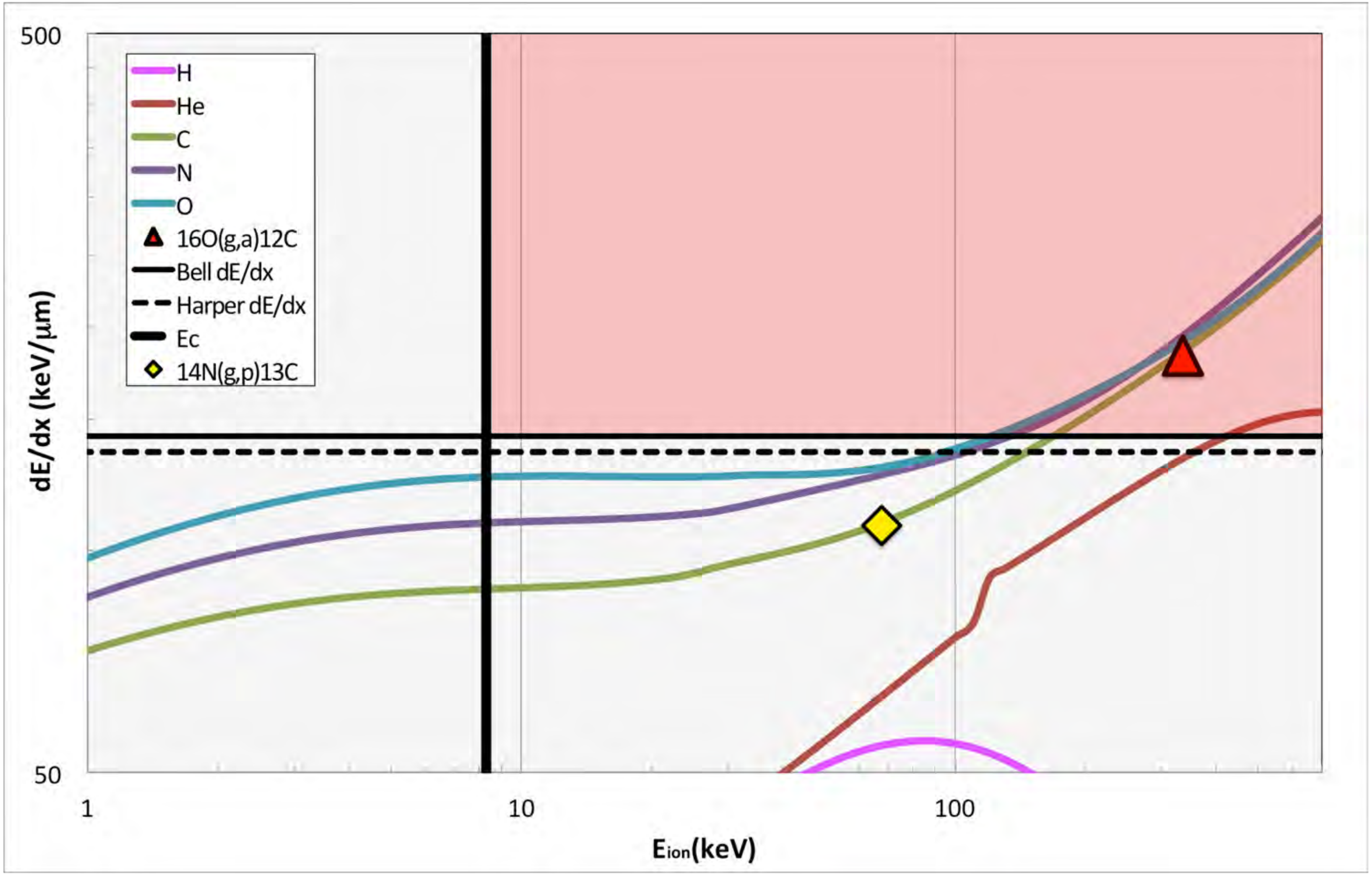
Bremsstrahlung beams

Jefferson Lab

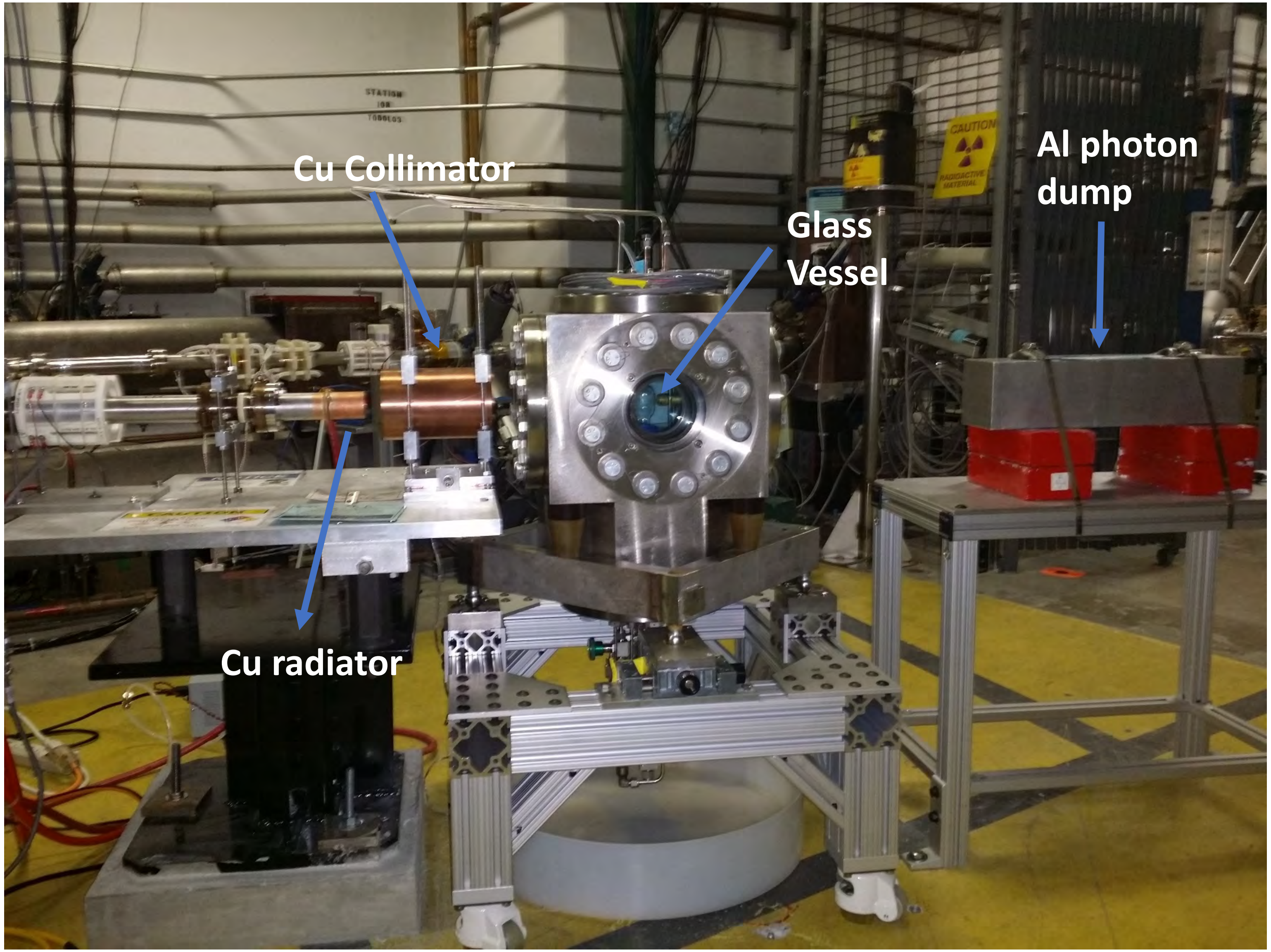


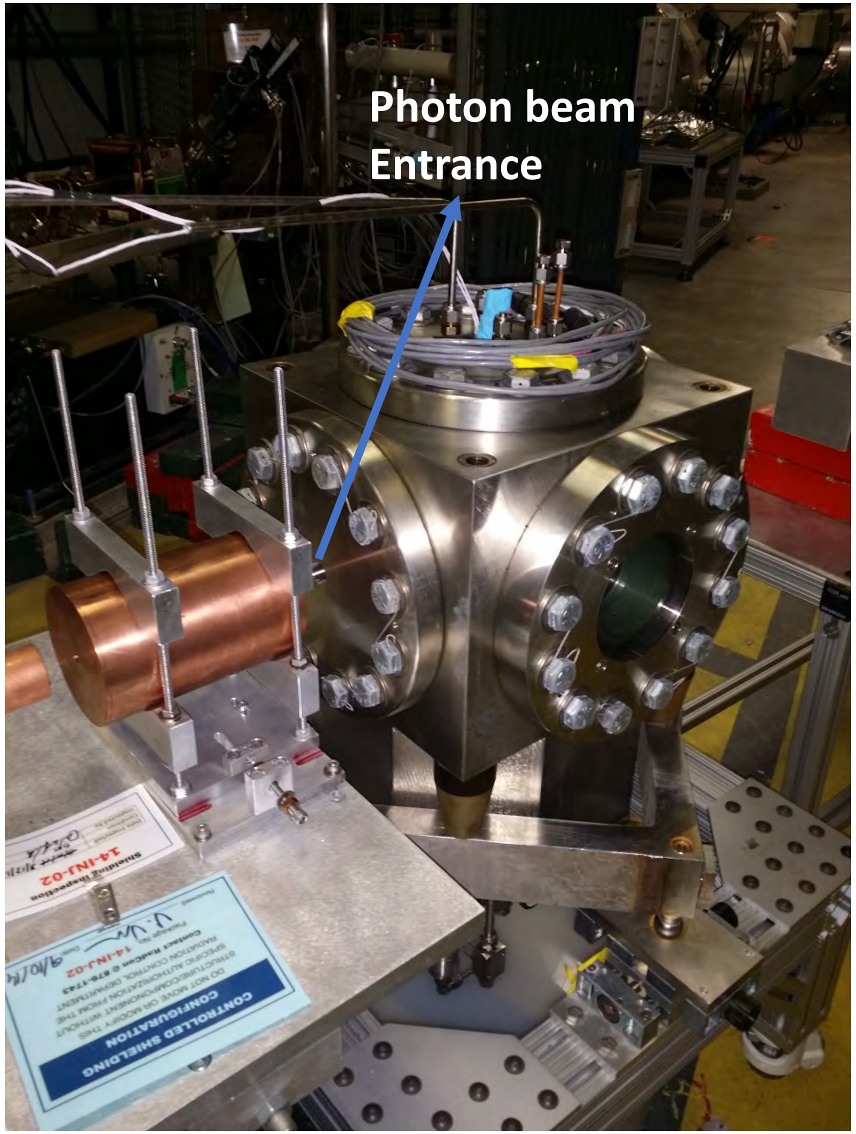
CEBAF 12 GeV

N_2O thresholds, Superheat = 3.3 ^{O}C, $E\gamma$=8.5 MeV

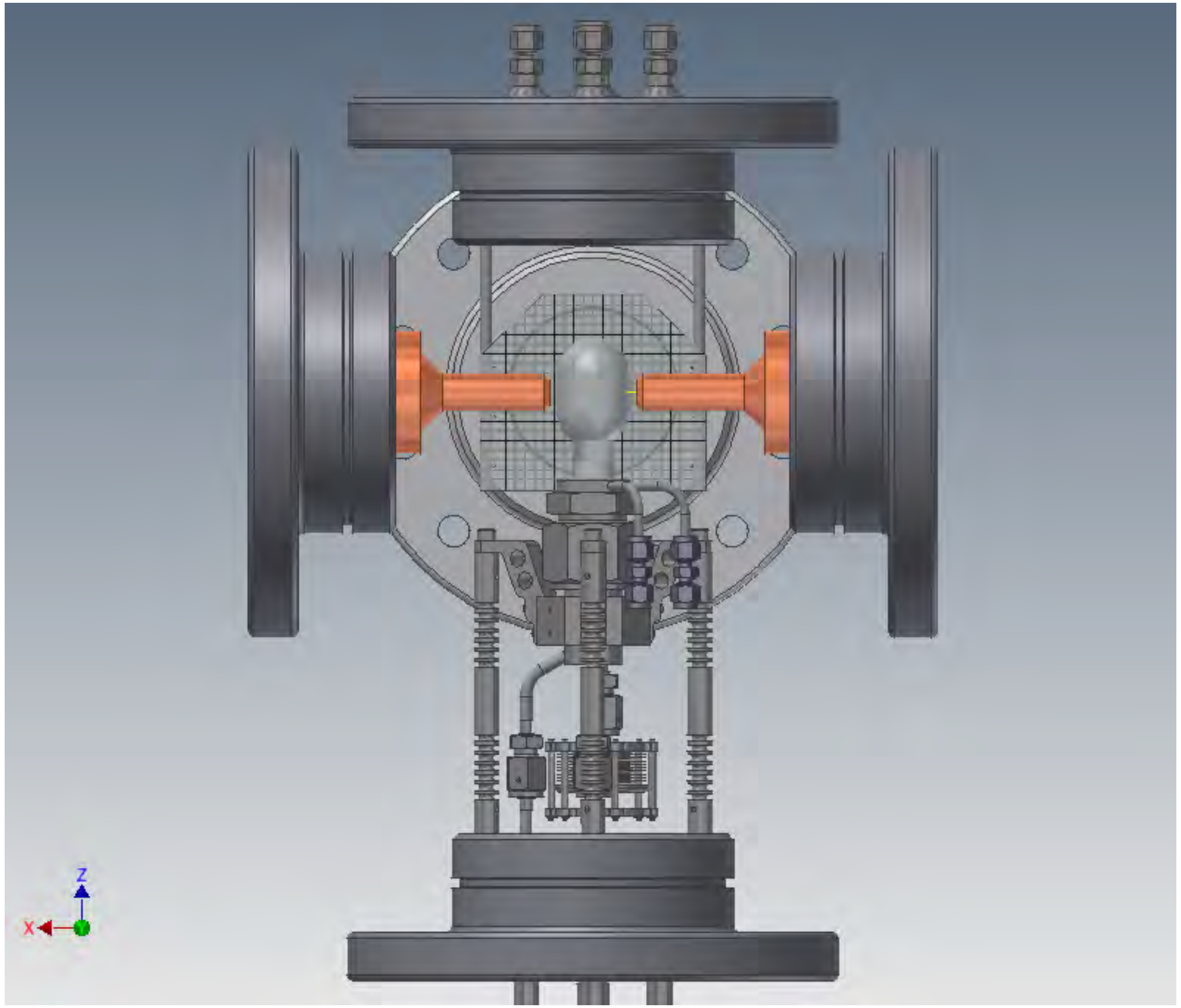


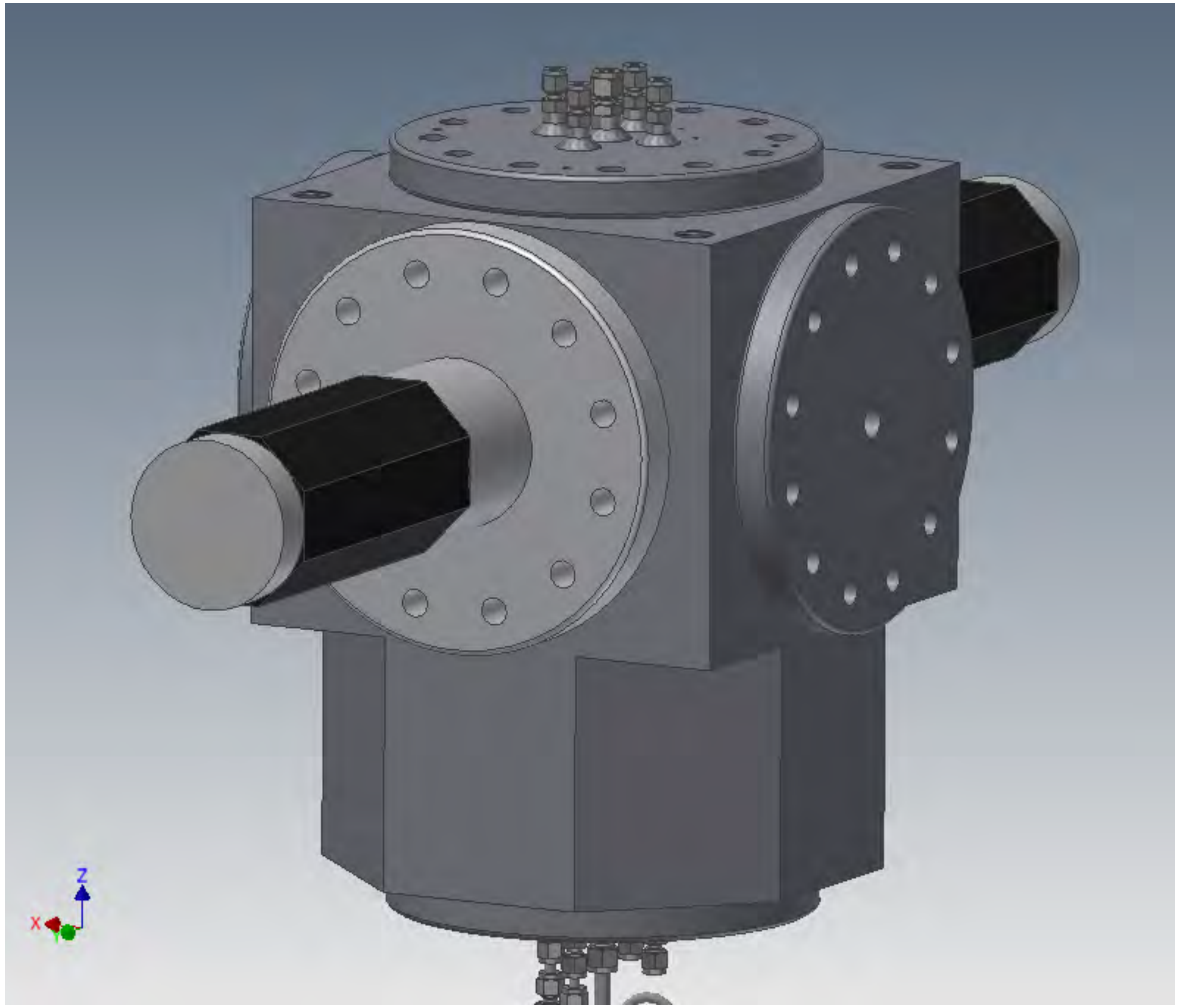
Experimental Set-Up for the N_2O Bubble Chamber





Mechanical Design of the Bubble Chamber





Fluids in the Glass Vessel

Active Fluid :

- Molecular content of target ions should be maximized
- Transparent liquid is a convenient choice for using optical imaging techniques to detect the bubble events

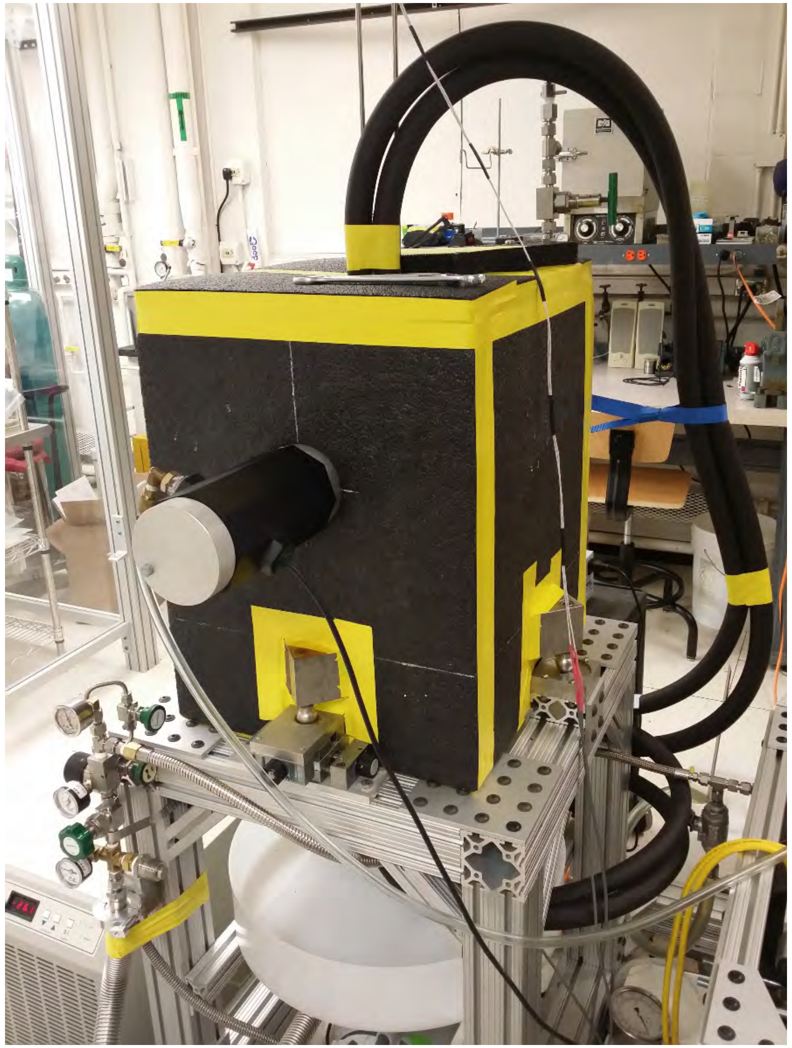
Buffer Fluid :

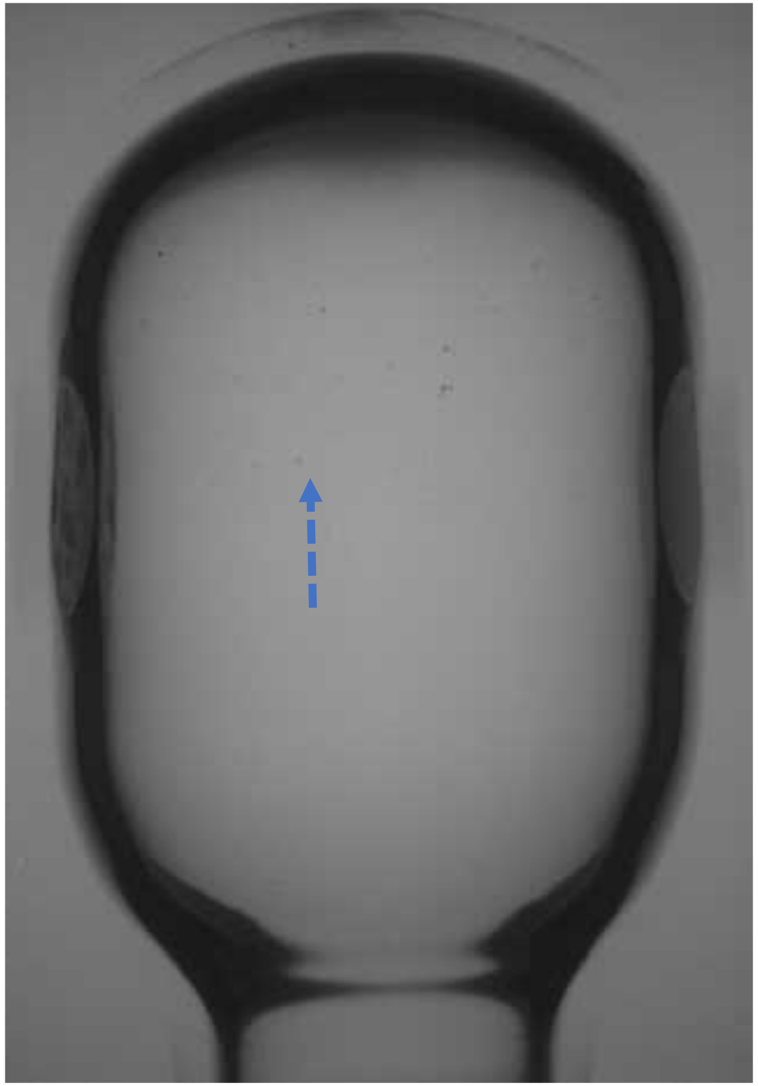
- It must be immiscible with active fluid to form a meniscus
- Solubility between active fluid and buffer fluid must be very low
- It should not become superheated in the pressure/temperature range chosen for the experiment

The active fluid should be kept clean and must only come in contact with smooth surfaces. Therefore it is only allowed to come in contact with the glass pressure vessel or the buffer fluid which provides a smooth interface for the transmission of pressure changes from the hydraulic system.


Back
NI-IMAQdx Basics
What do you want to do?
Connect my camera
Configure my device
Set my remote image options

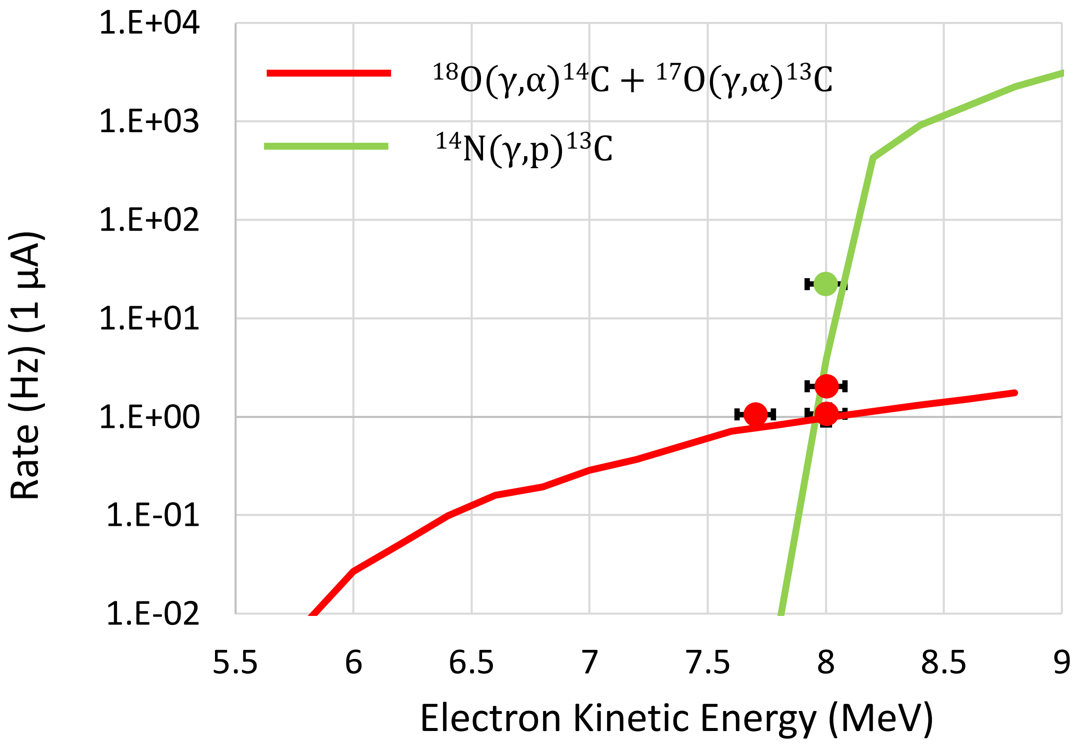
Bubble Formation and Data Acquisition

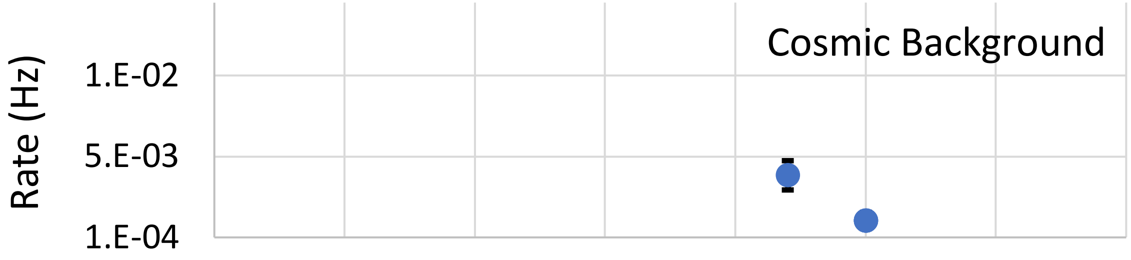




First Half of the Experiment

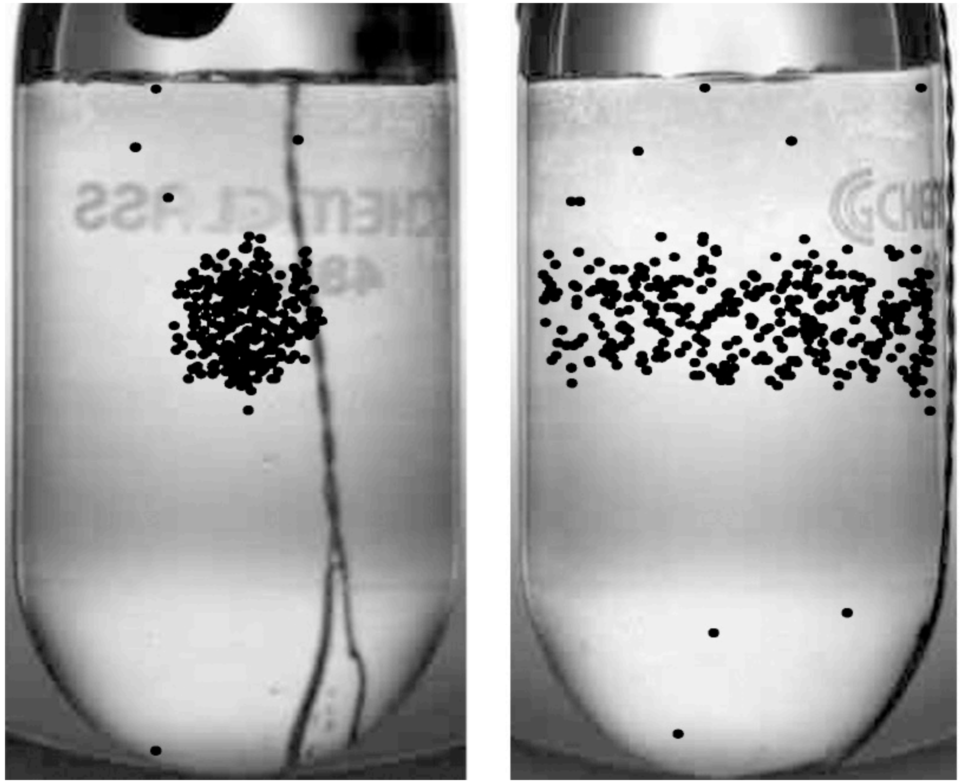
Energy Measured (MeV)	Superheat Pressure (psi)	Superheat Temperature (°C)	Beam Current (μA)
7.7	325	-8	0.4
8	325	-8	0.4
8	325	-8	0.04
8	310	-8	0.035



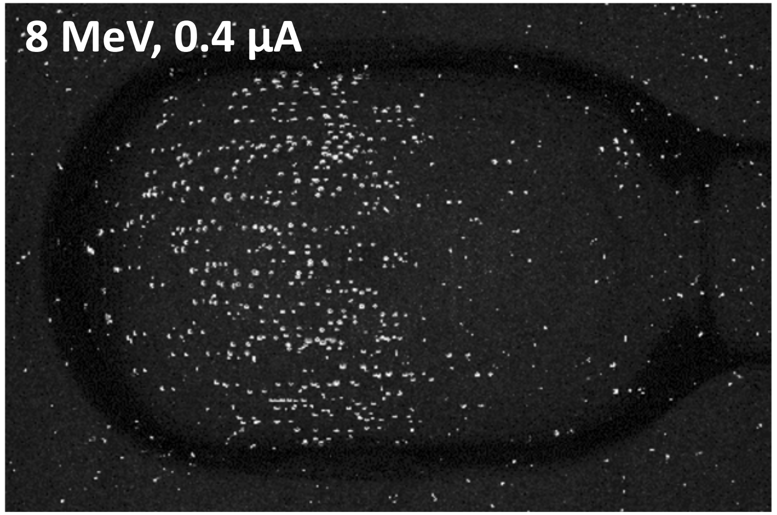


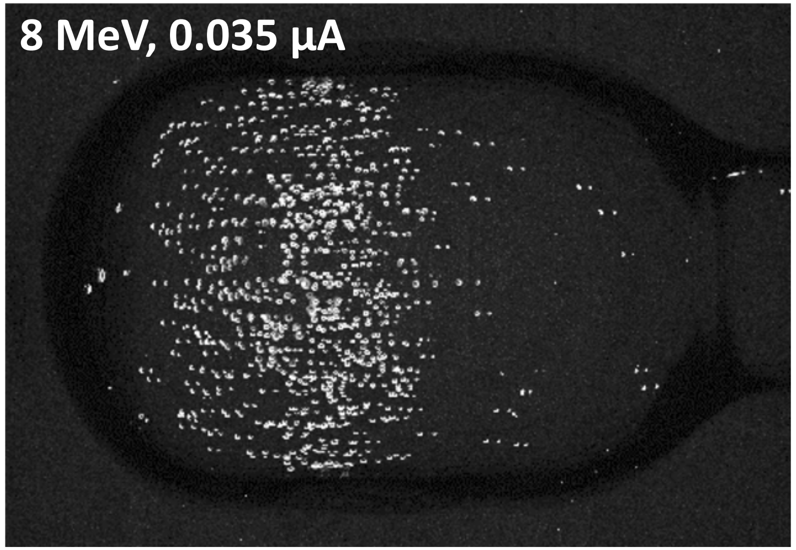
Bubble Distribution

HIγS Data

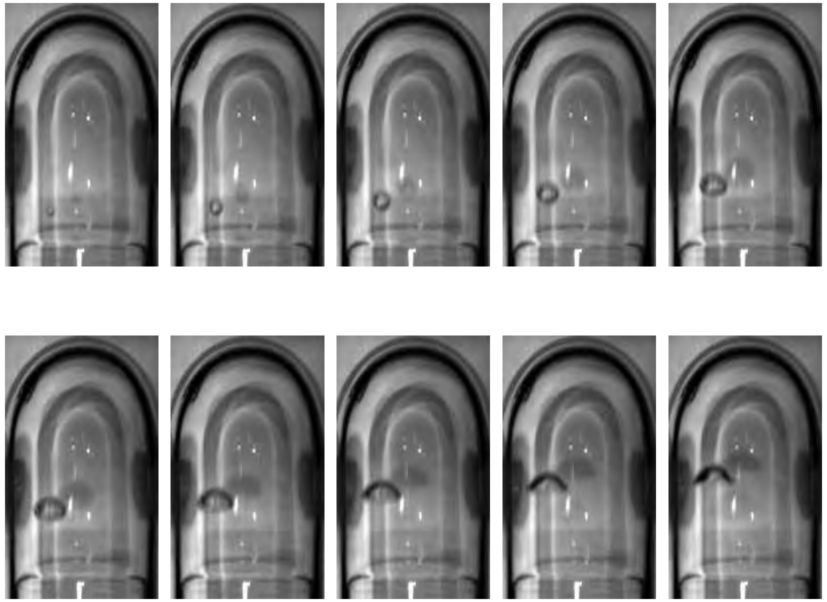


JLab Data

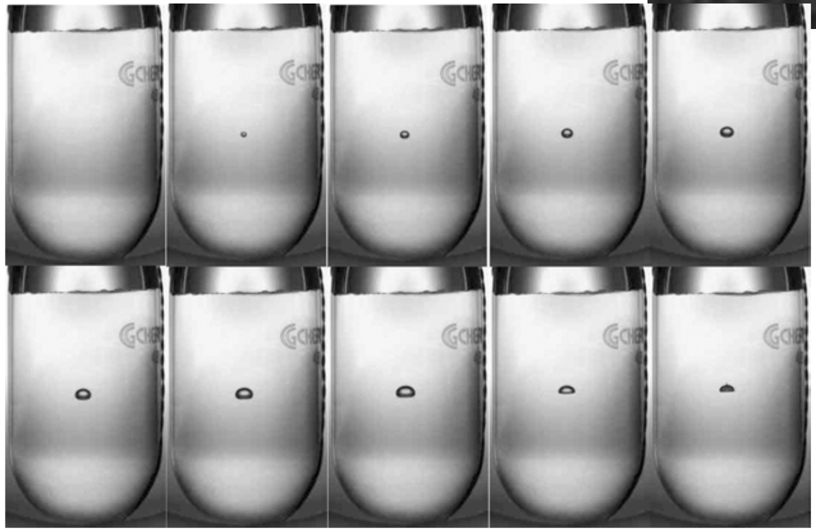




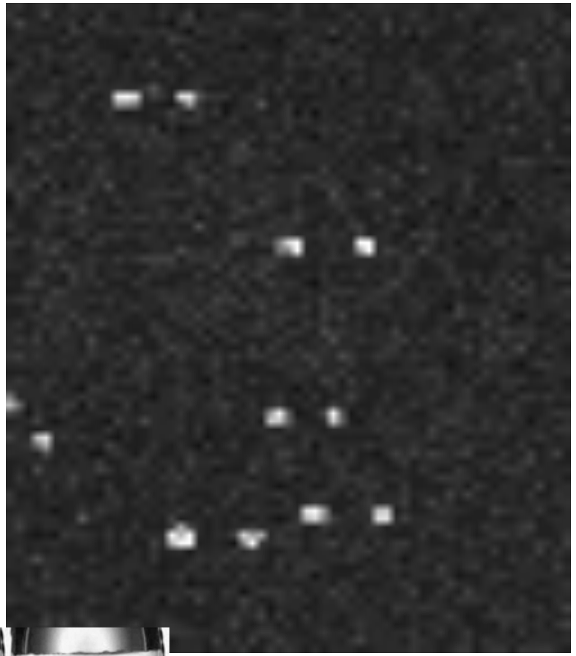
Bubble Size



H_2O bubble

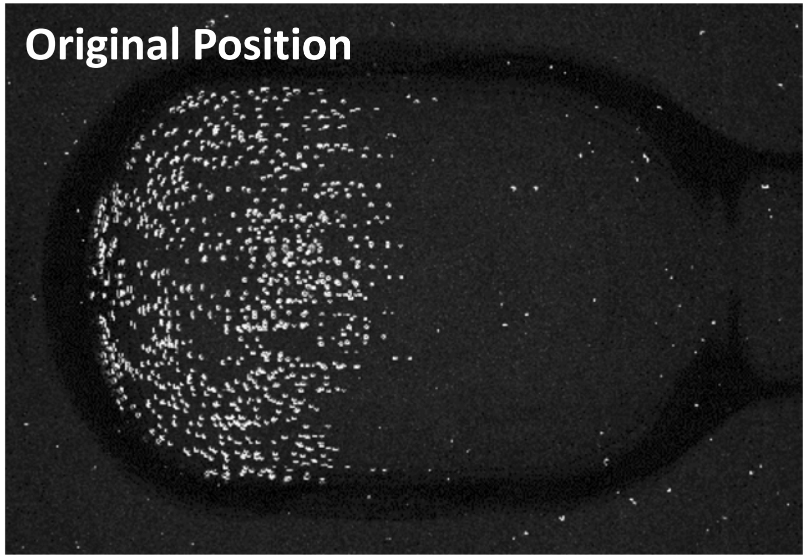


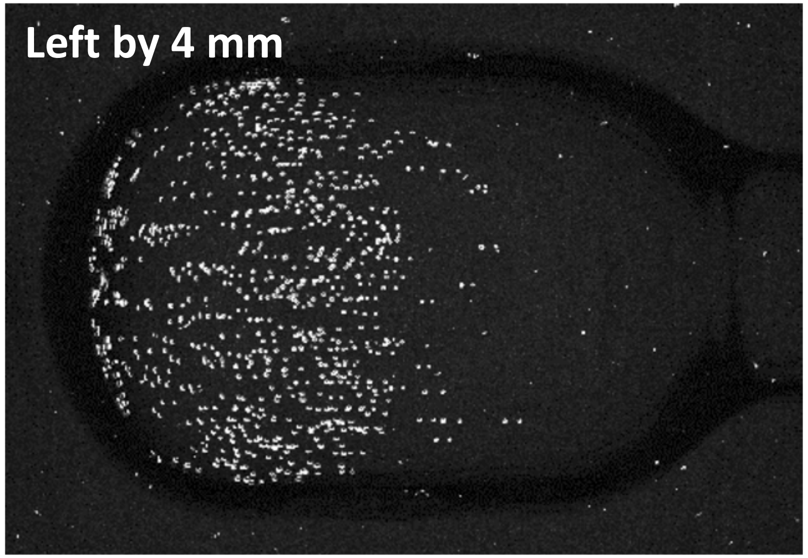
C_4F_{10} bubble

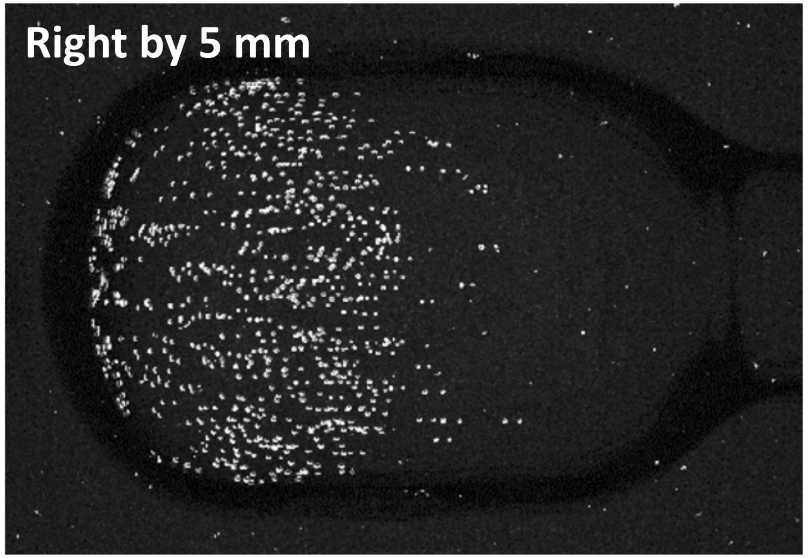


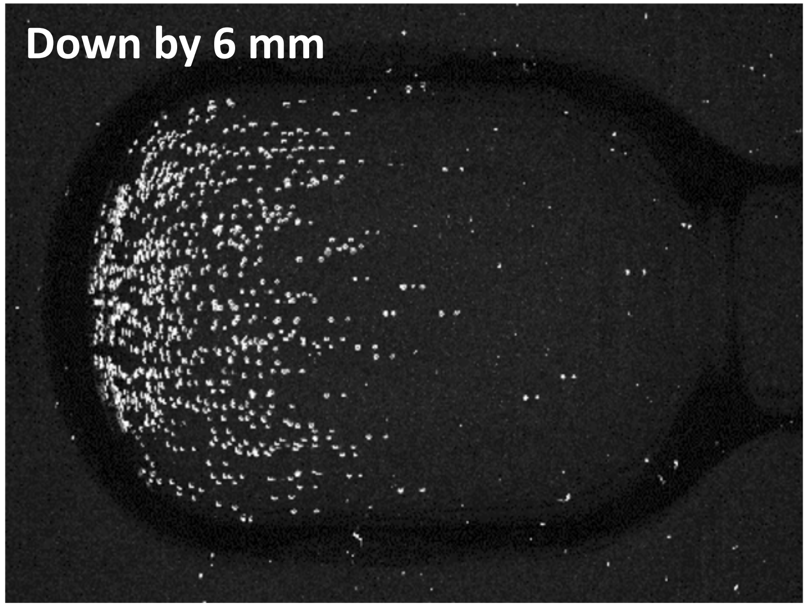
N_2O bubble

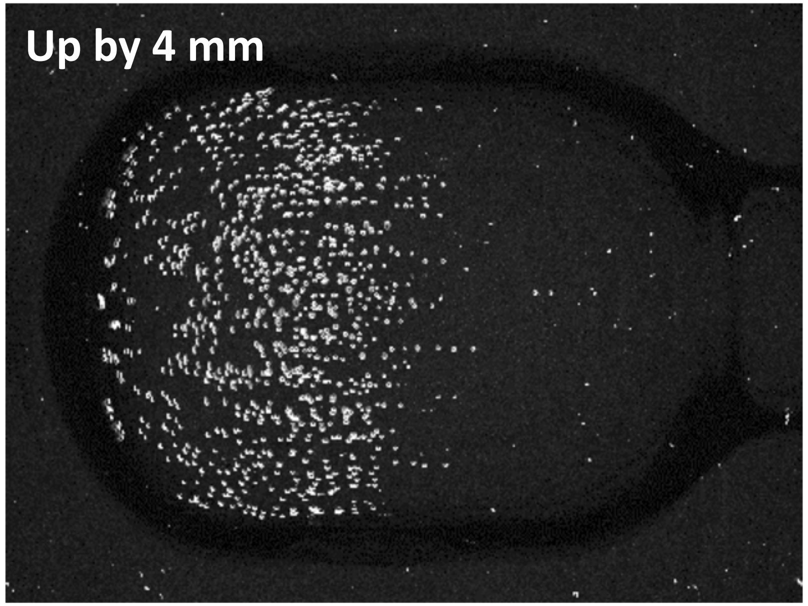
Beam Position Test





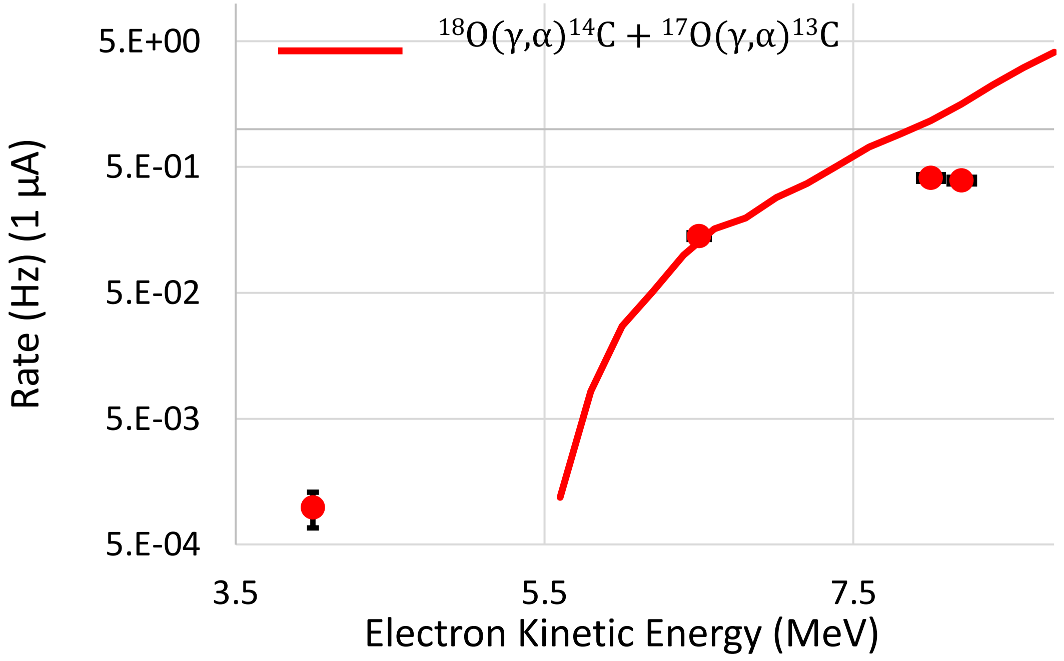






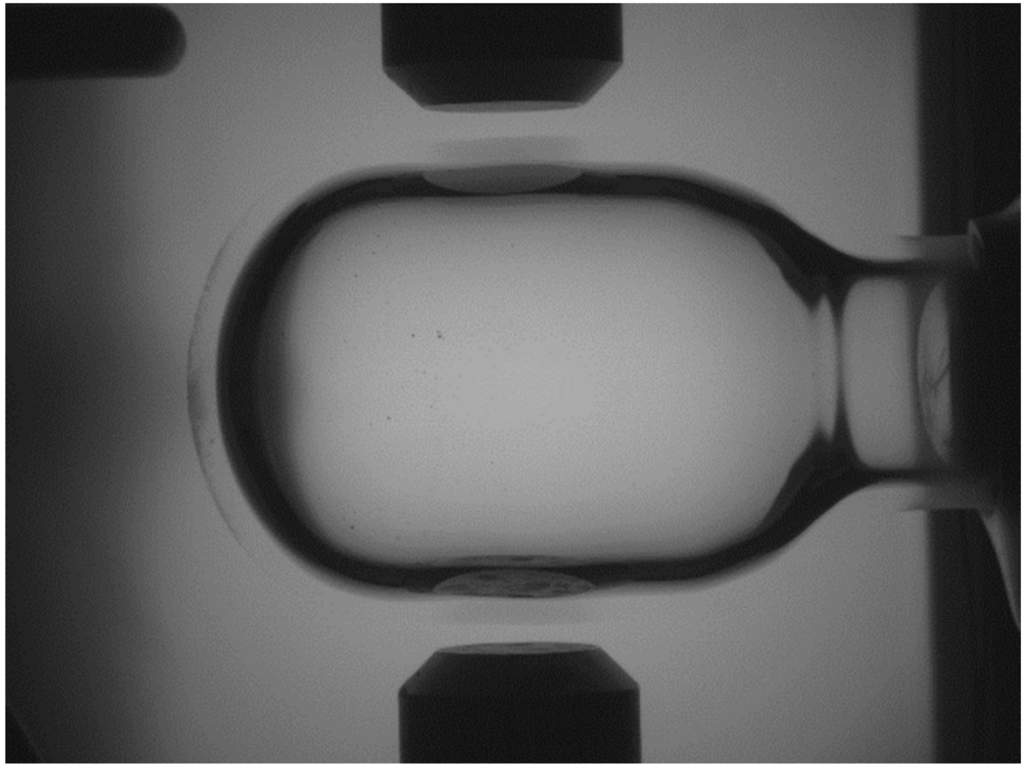
Second Half of The Experiment

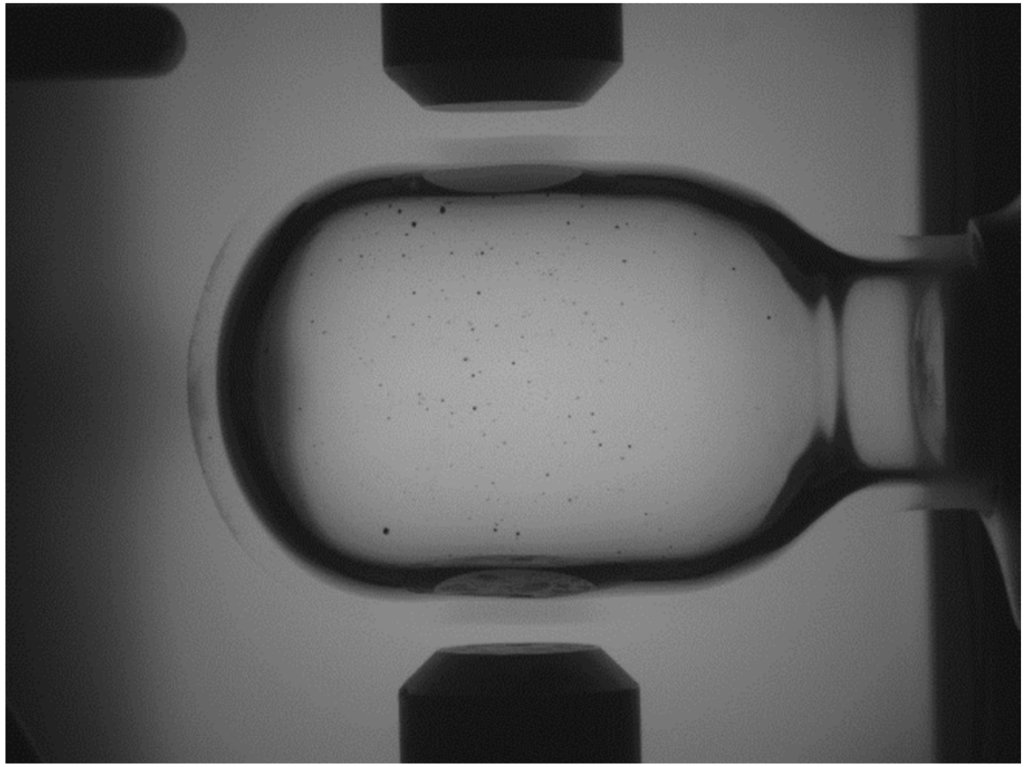
Energy Measured (MeV)	Superheat Pressure (psi)	Superheat Temperature (°C)	Beam Current (μA)
8	325	-8	0.4
8.2	325	-8	0.4
6.5	325	-8	1
4	325	-8	10



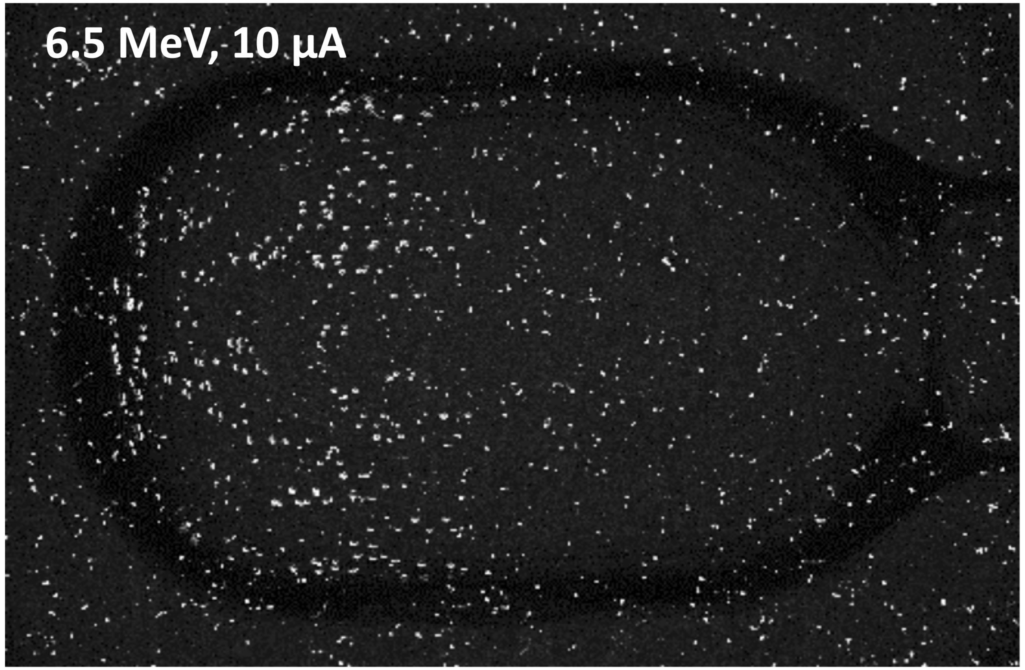
Problems Encountered during the Experiment

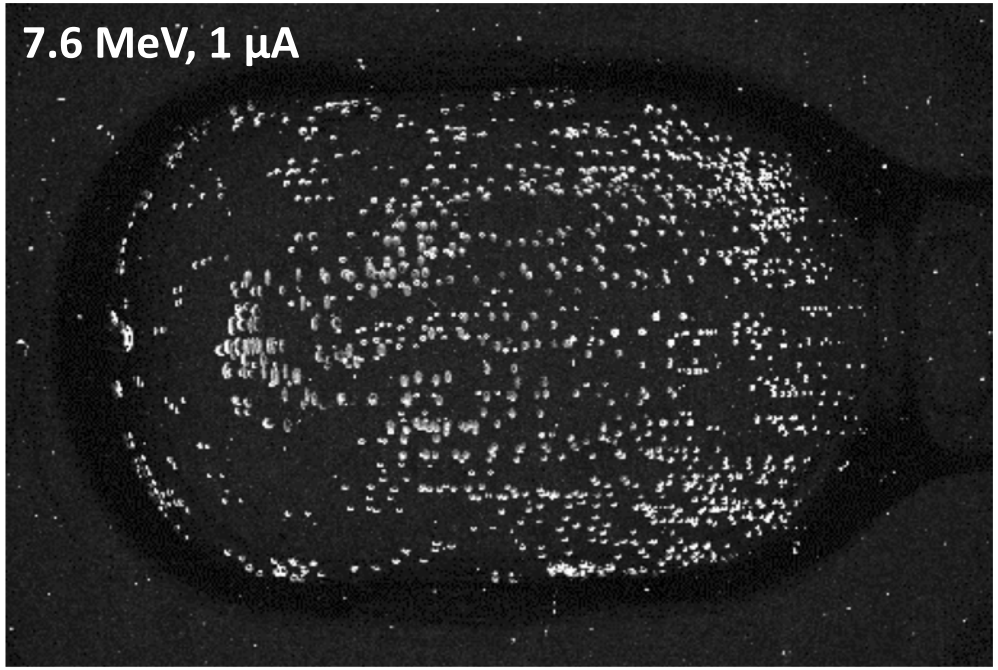
- Beam positon was not very well defined
- Mercury droplets on the glass vessel





- Could not reduce beam current below 35 nA
- At high beam currents (10 uA), we observed lot of camera scintillation events
- During the last few days, beam induced background became very high throughout the volume of the bubble chamber.





May 2018 experiments JLab

Commissioning: $^{19}F(\gamma,\alpha)^{15}N$

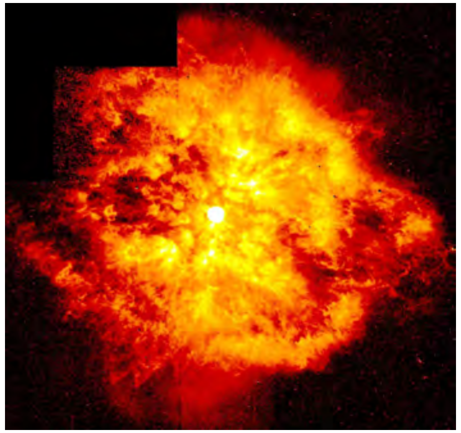
Fluorine nucleosynthesis

Possible scenarios:
a) Neutrino spallation in core collapse SN
b) He intershell in AGB stars
c) Core He burning in Wolf-Rayet stars

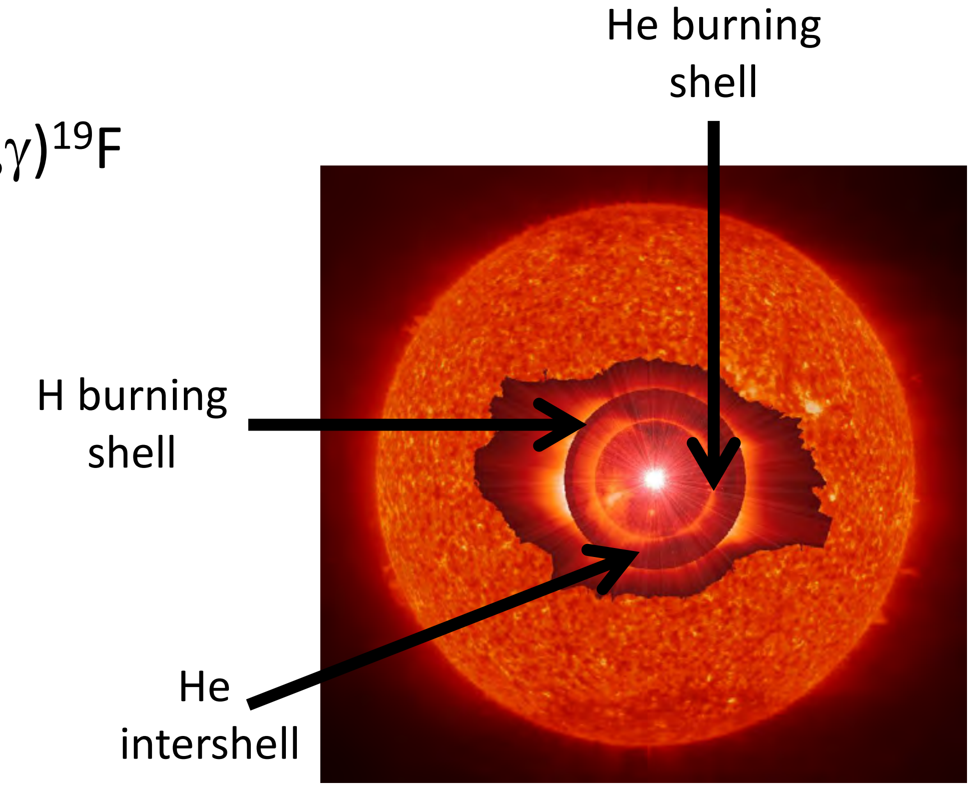
$^{15}N(\alpha,\gamma)^{19}F$ still uncertain at stellar temperatures

For AGB and WR scenarios,
$^{14}N(\alpha,\gamma)^{18}F(\beta\nu)^{18}O(p,\alpha)^{15}N(\alpha,\gamma)^{19}F$

Wolf-Rayet star



WR124, HST

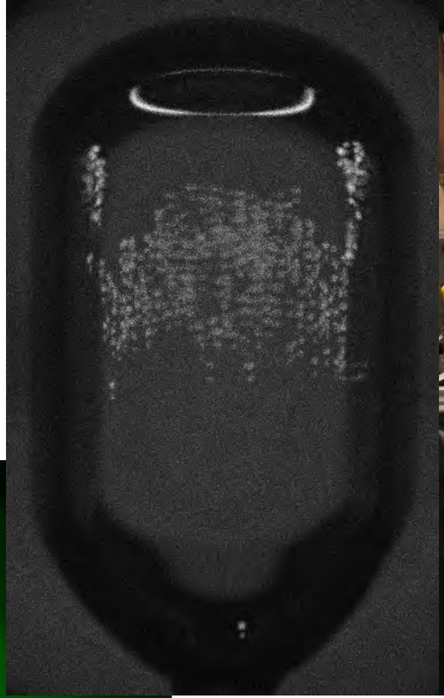


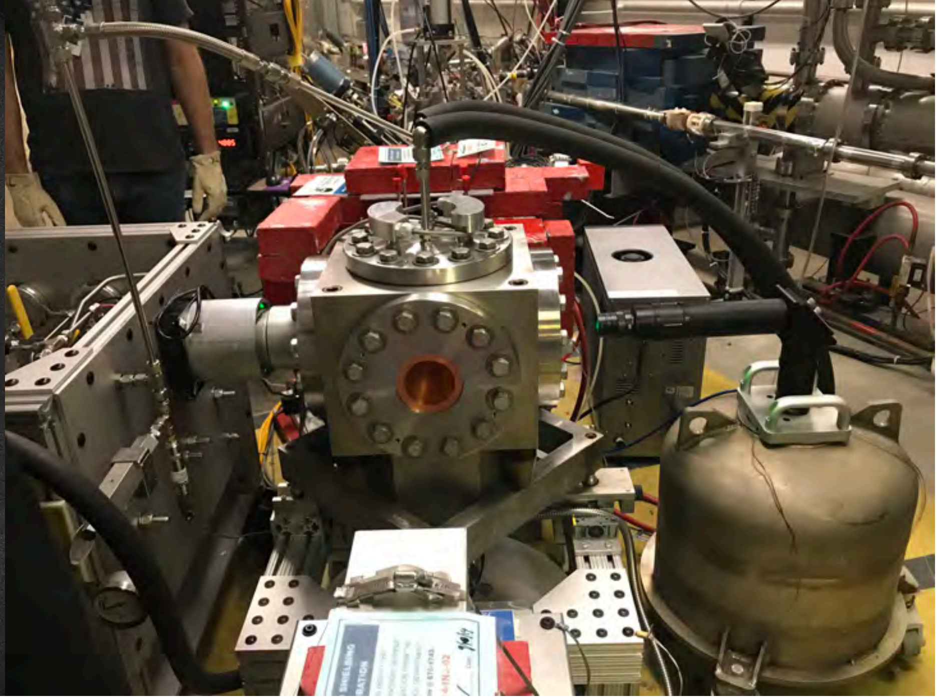
Asymptotic Giant Branch star

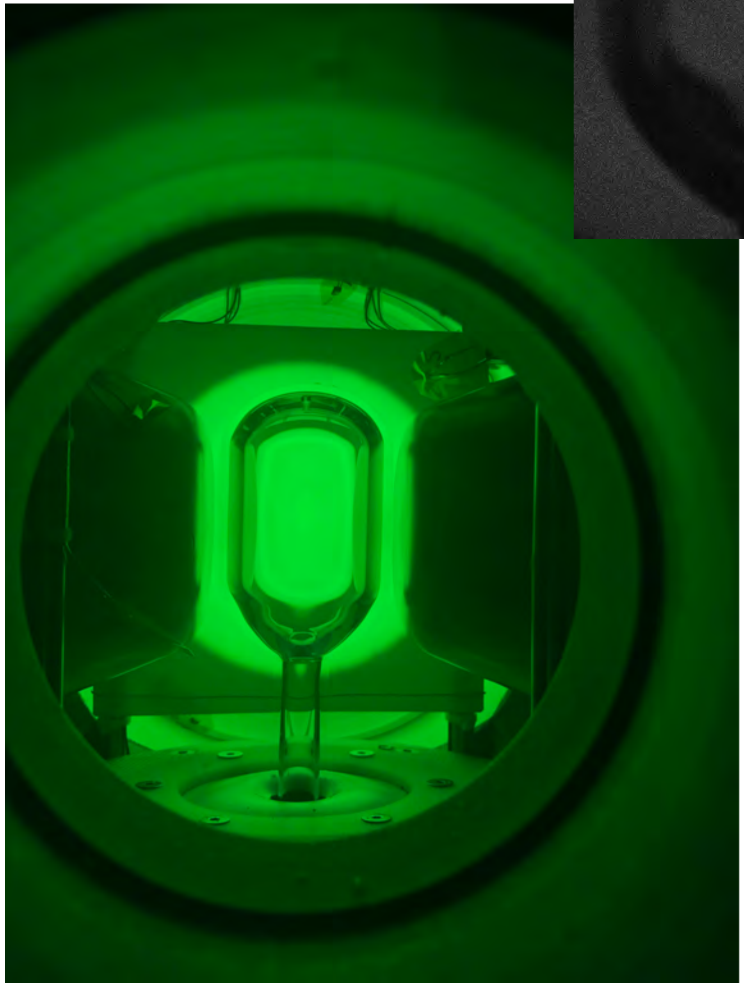
May 2018 Run
Jefferson Lab

C_3F_8

p ~ 5.5 MeV/c







Wilmes et al. (2005)