Nuclear Astrophysics with γ-ray beams and a bubble chamber

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

Collaboration

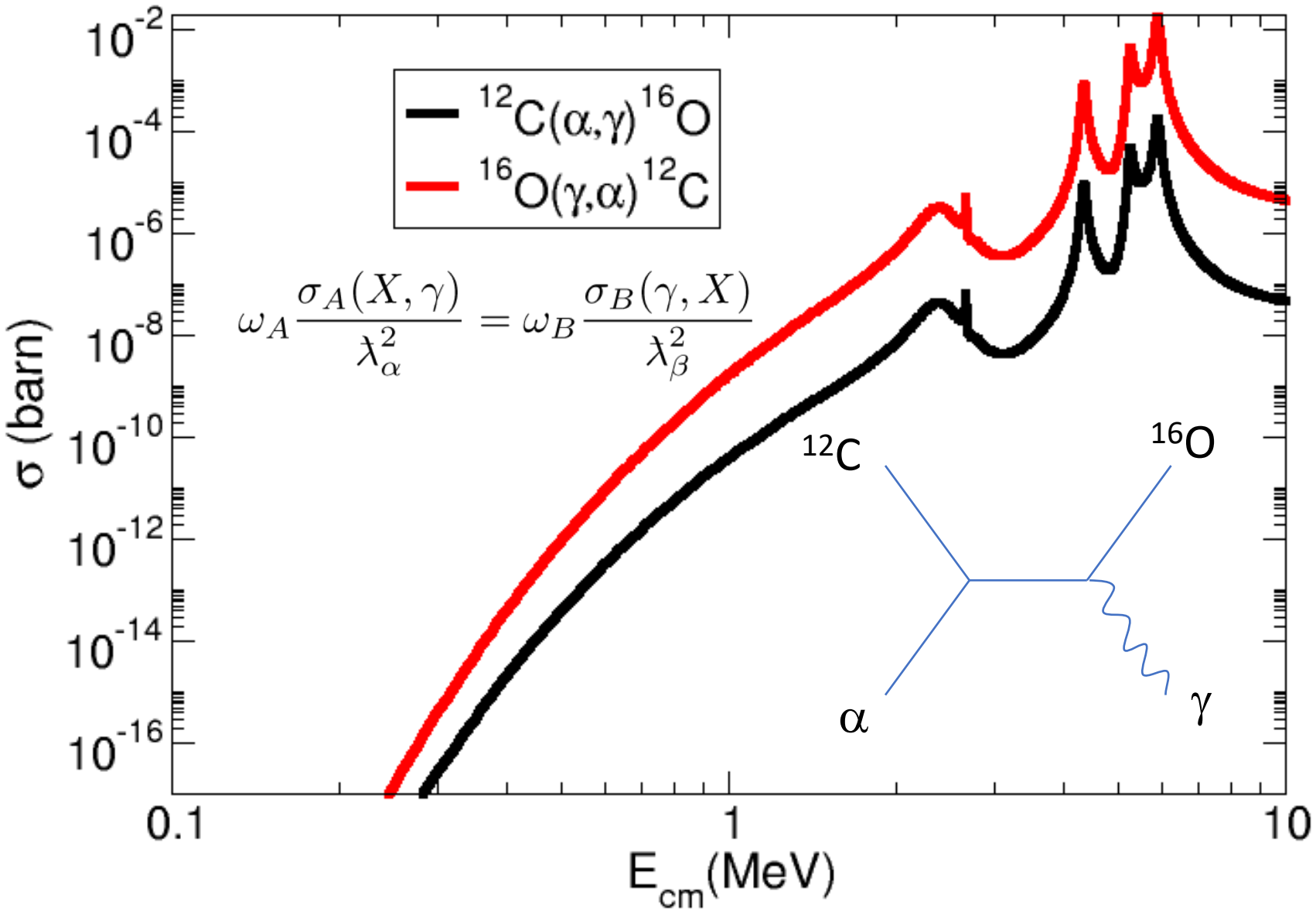
Riad Suleiman
Whitney Armstrong
Kevin Bailey
Jay Benesch
Brad DiGiovine
Arne Freyberger
Joe Grames
Alicia Hofler
Roy Holt
David Meekins
Daniel Moser
David Neto **(PhD thesis)**
Tom O'Connor
Matt Poelker
Ernst Rehm
Seamus Riordan
Rashi Talwar
Claudio Ugalde

Jefferson Lab

Argonne NATIONAL LABORATORY

UIC UNIVERSITY OF ILLINOIS AT CHICAGO

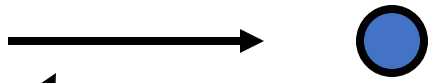
Time reversal symmetry: x100 gain in cross section



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

beam target signal

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



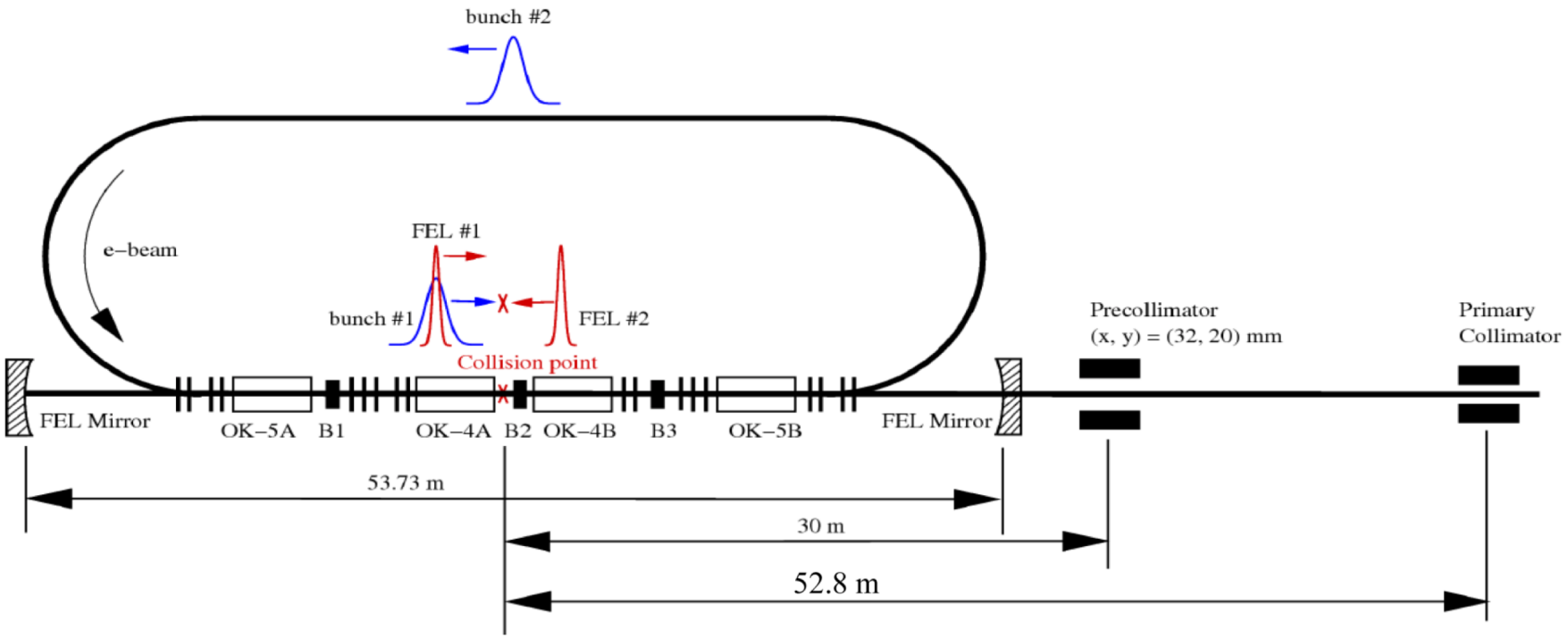
Bremsstrahlung from JLab ~ 10^9 γ/s (top 250 keV)

Oxygen bubble chamber

- 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})

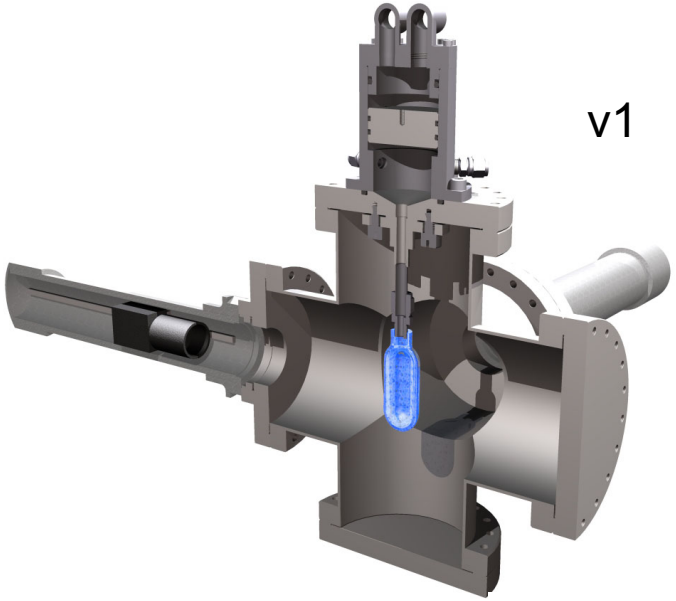
2010-2013 experiments at HIγS

HIγS Photon Beam

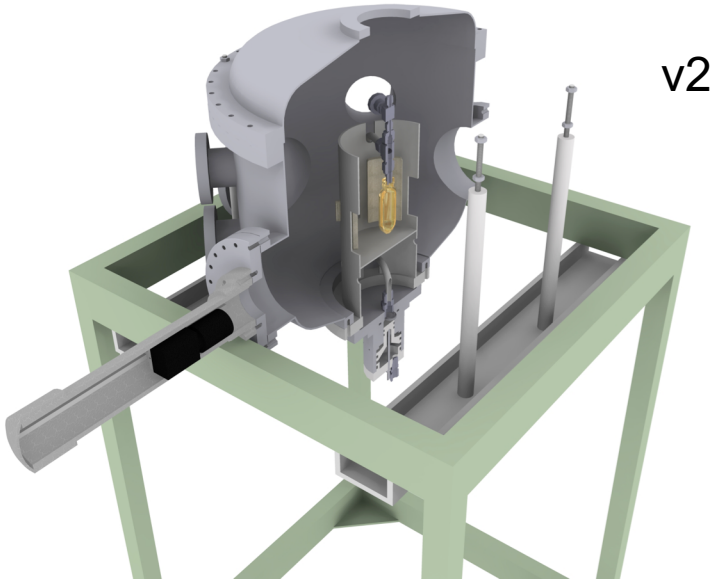


Liquids tested

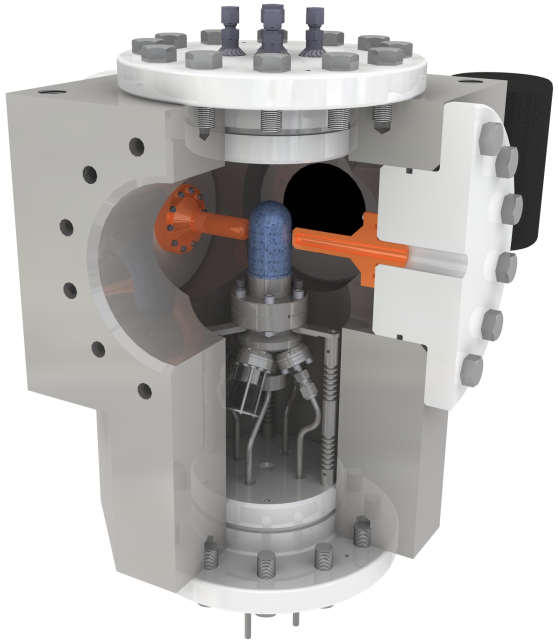
- CH_2FCF_3
- C_4F_{10}
- H_2O
- N_2O
- CO_2



v1

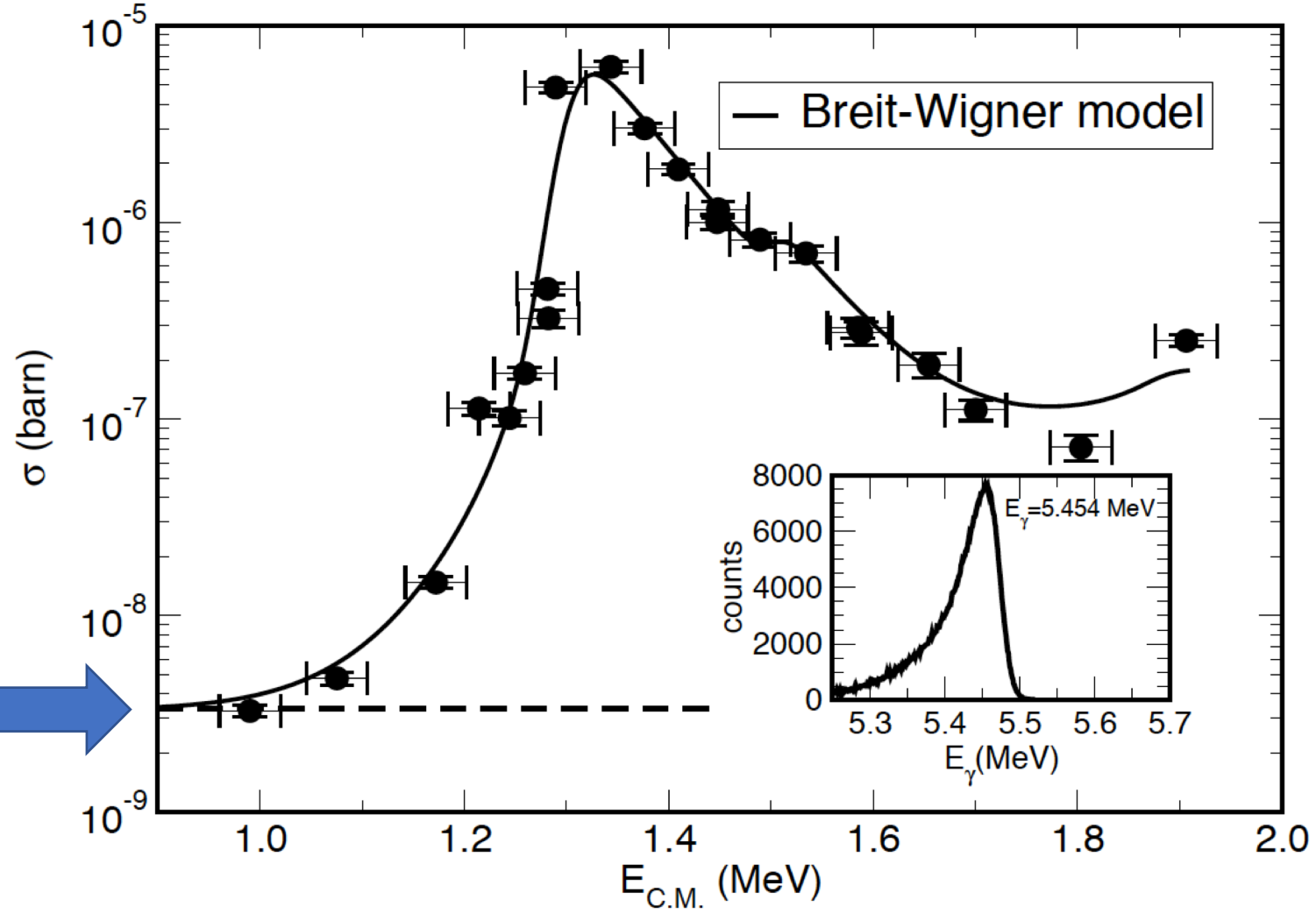


v2



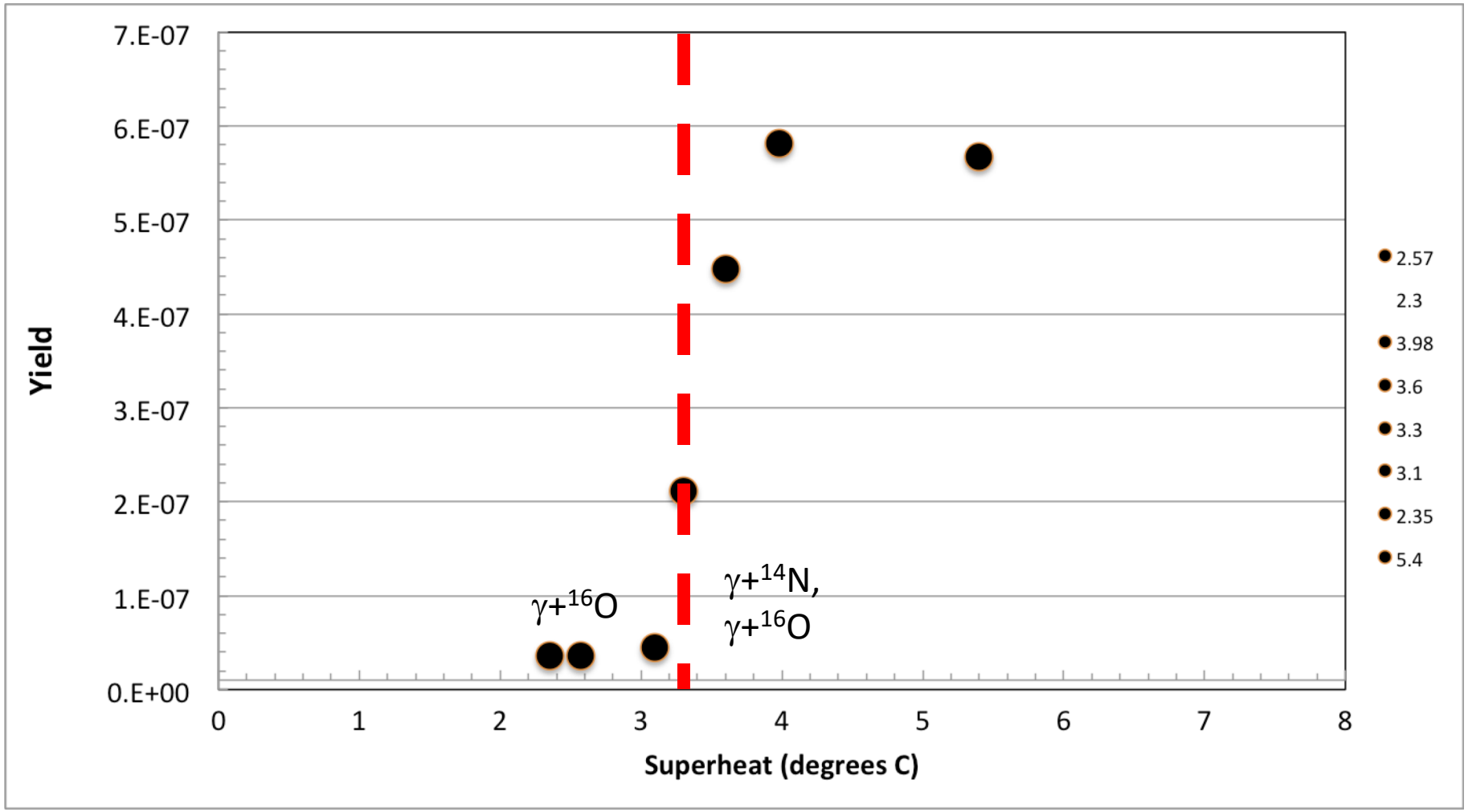
v3

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



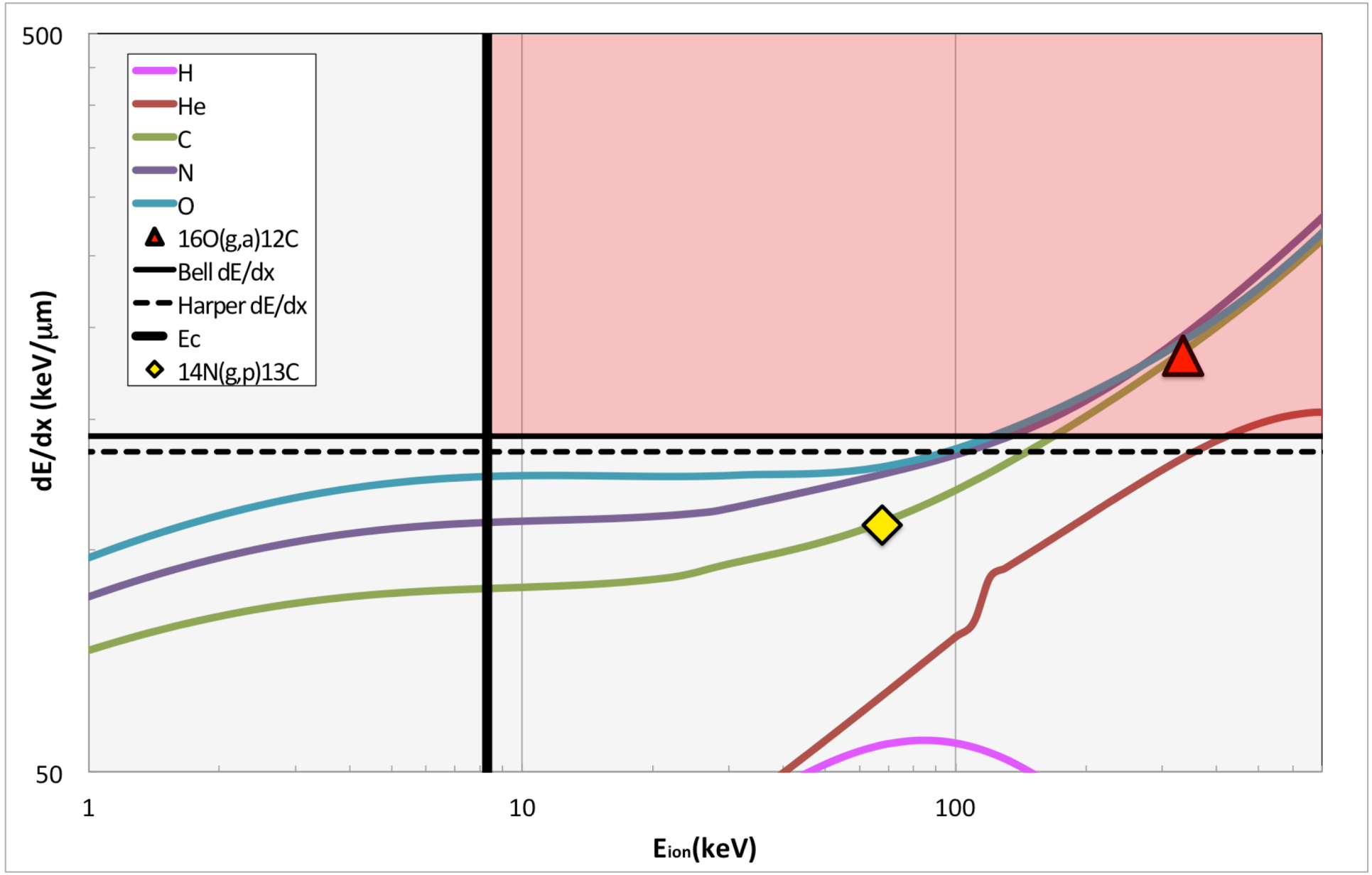
Bremsstrahlung

N_2O efficiency curve, HIγS April 2013. Eγ = 9.7MeV

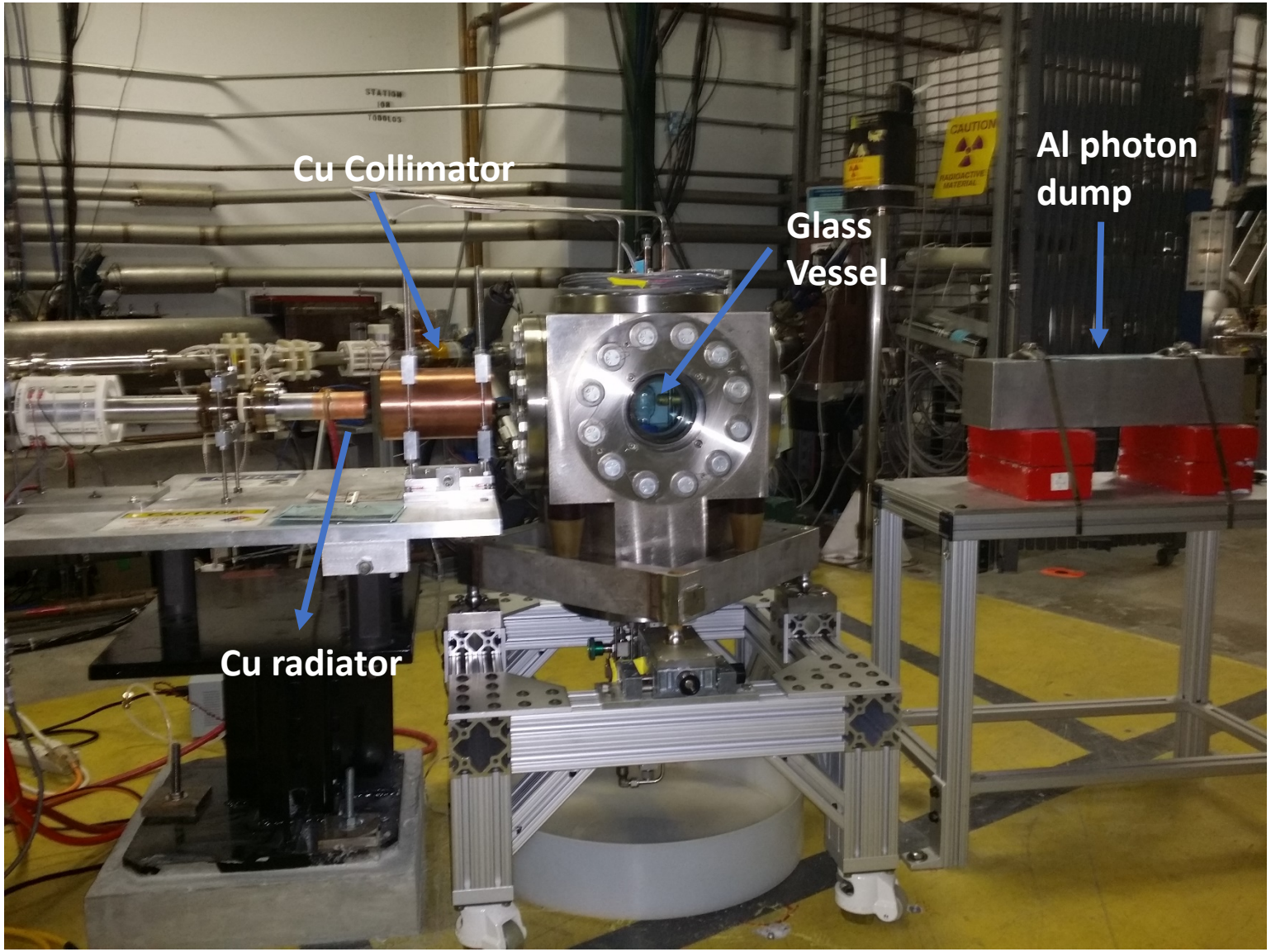


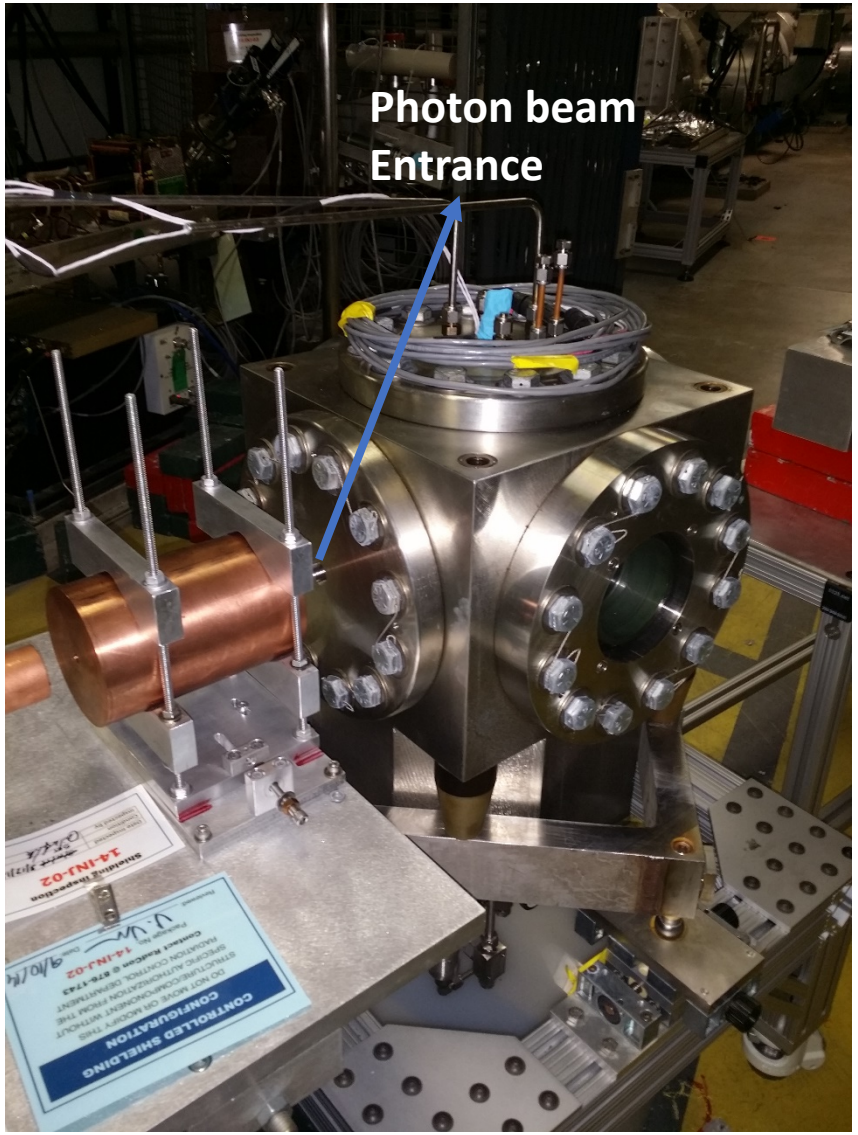
September 2015 experiments at JLab

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

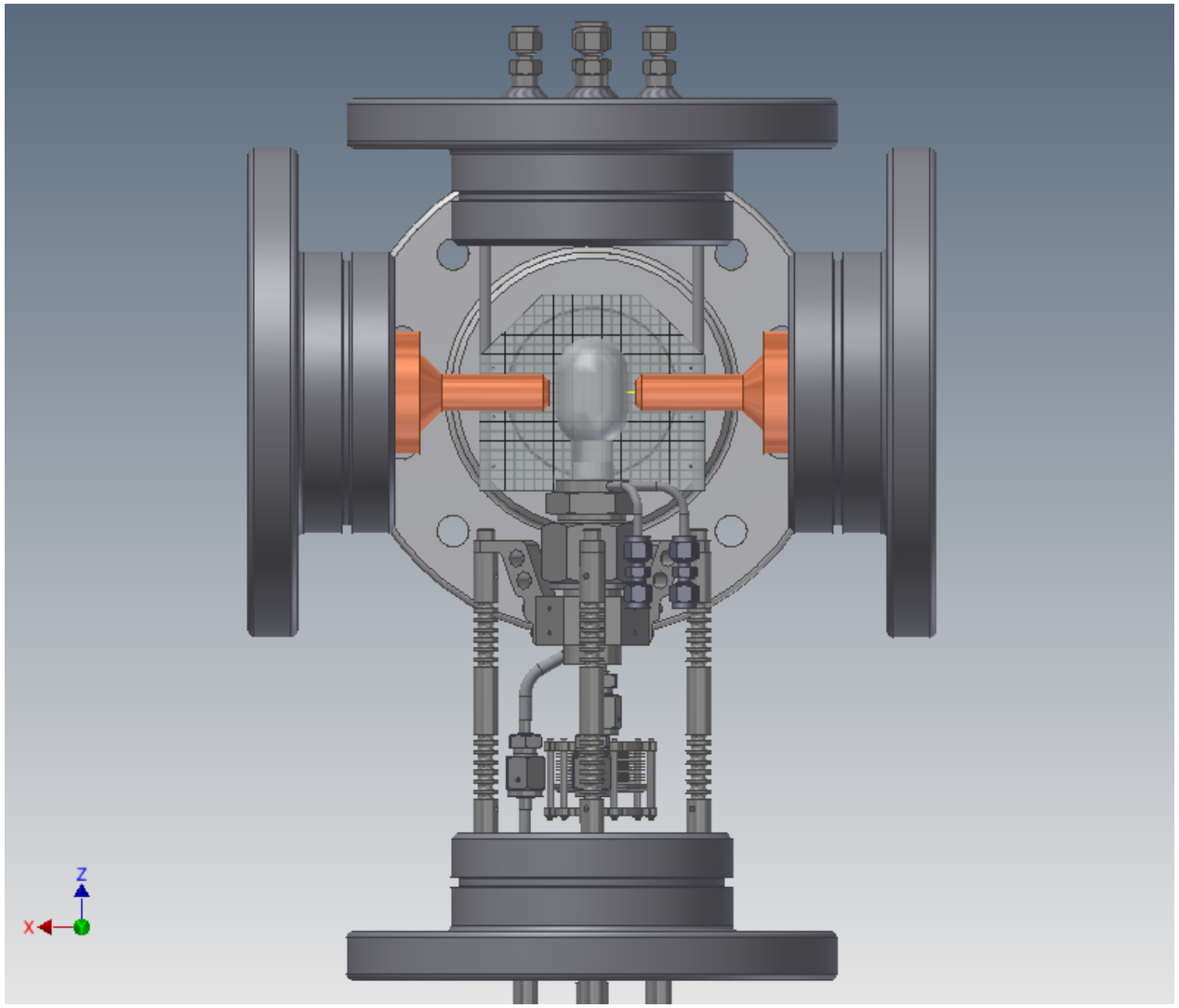


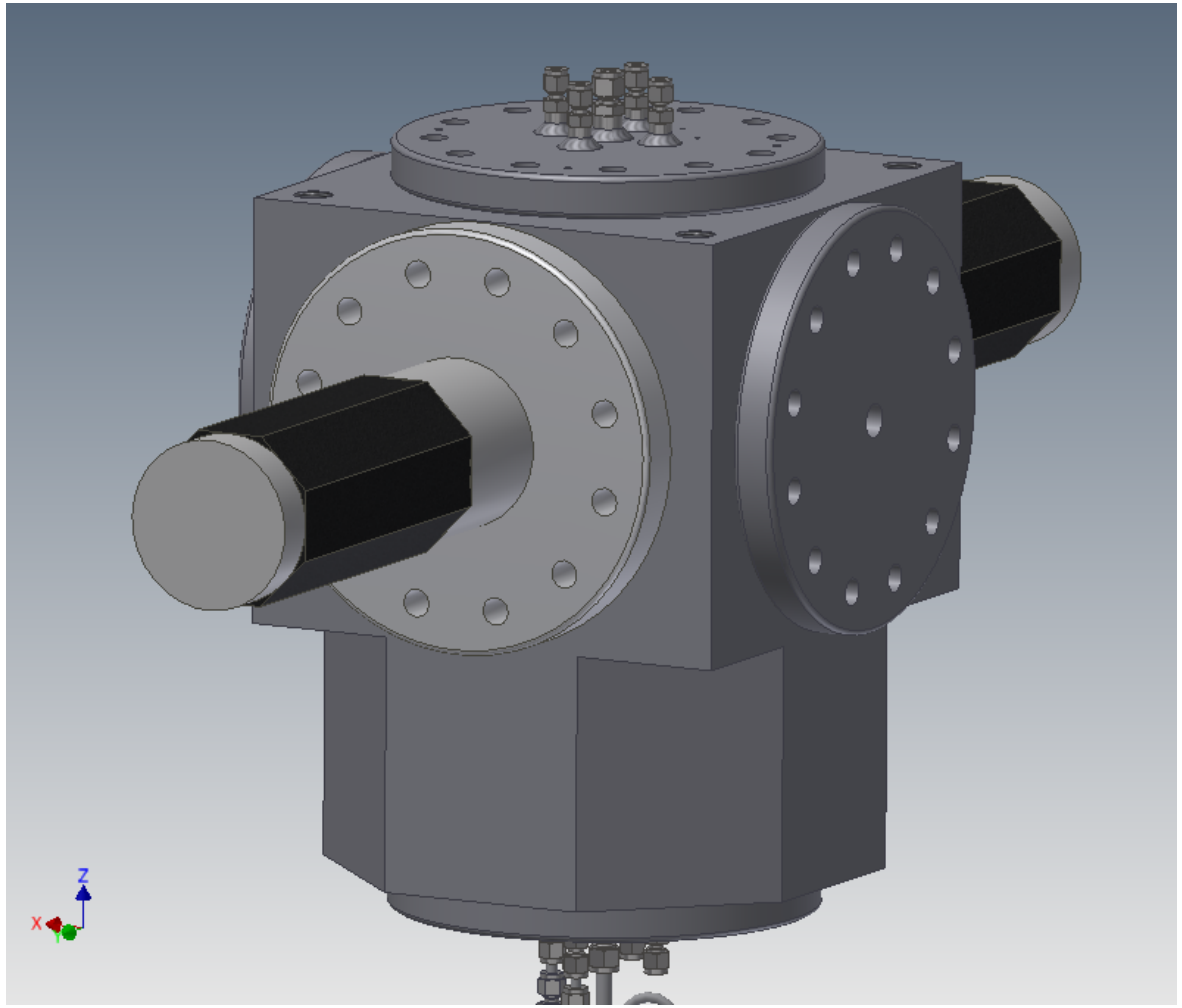
Experimental Set-Up for the N_2O Bubble Chamber





Mechanical Design of the Bubble Chamber





Fluids in the Glass Vessel

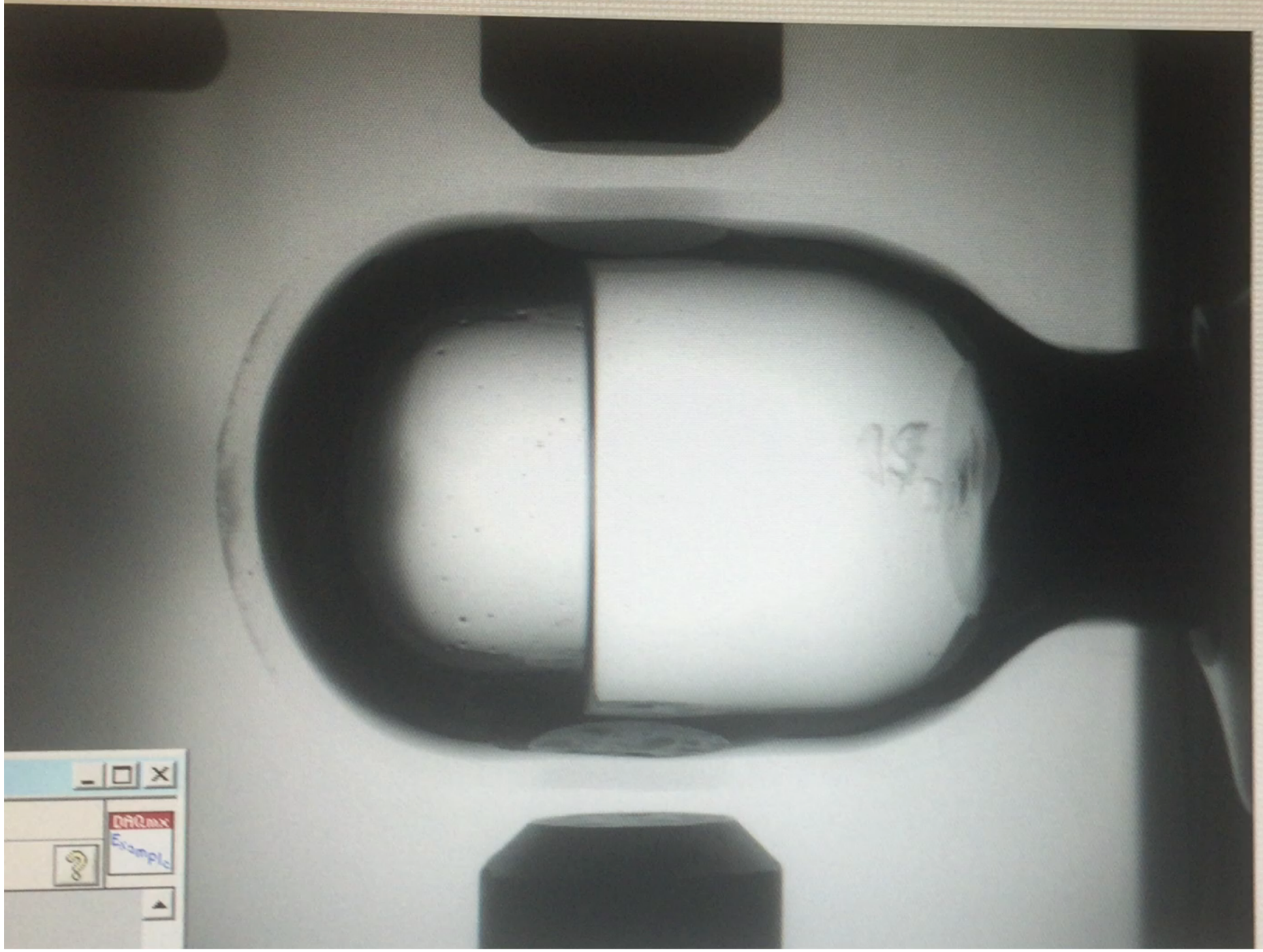
Active Fluid :

- 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.



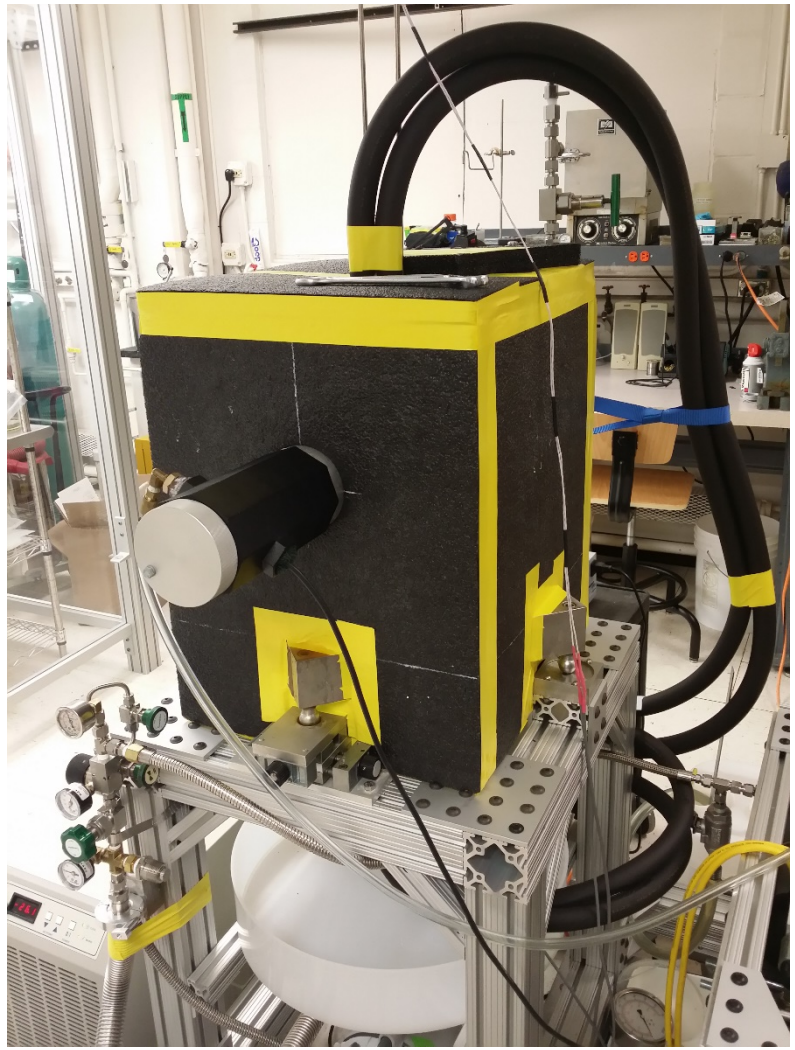
Back

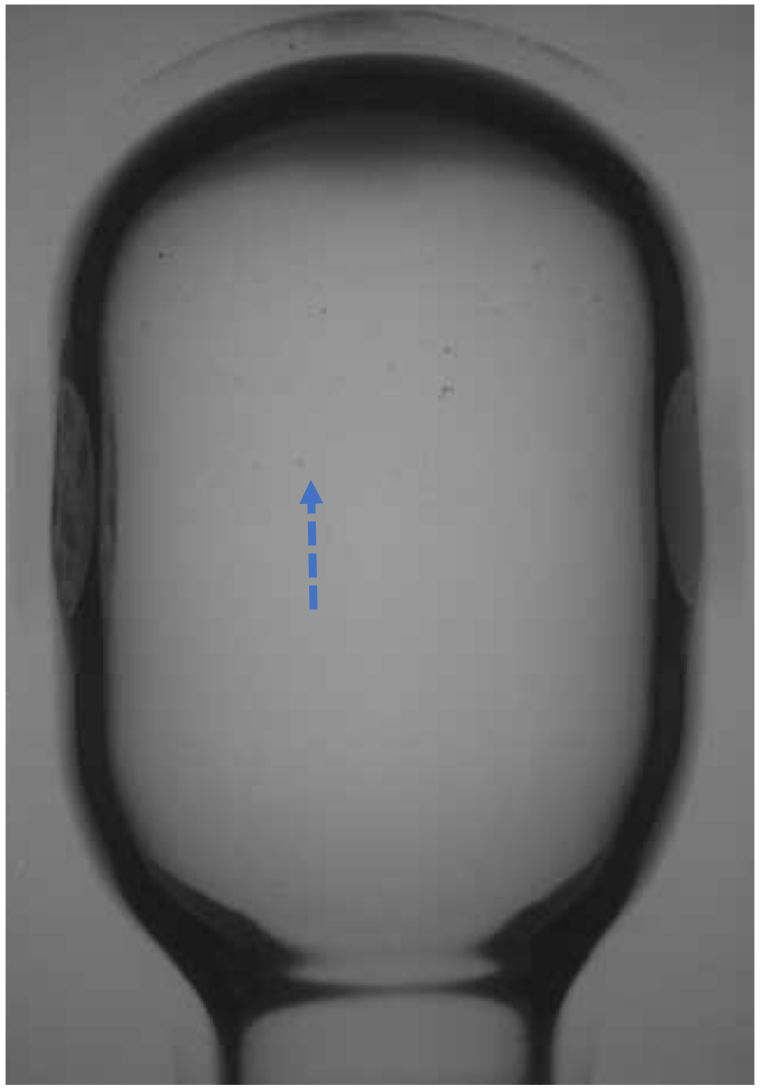
NI-IMAQdx Basics

What do you want to do?

- Connect my camera
- Configure my device
- Set my remote image options

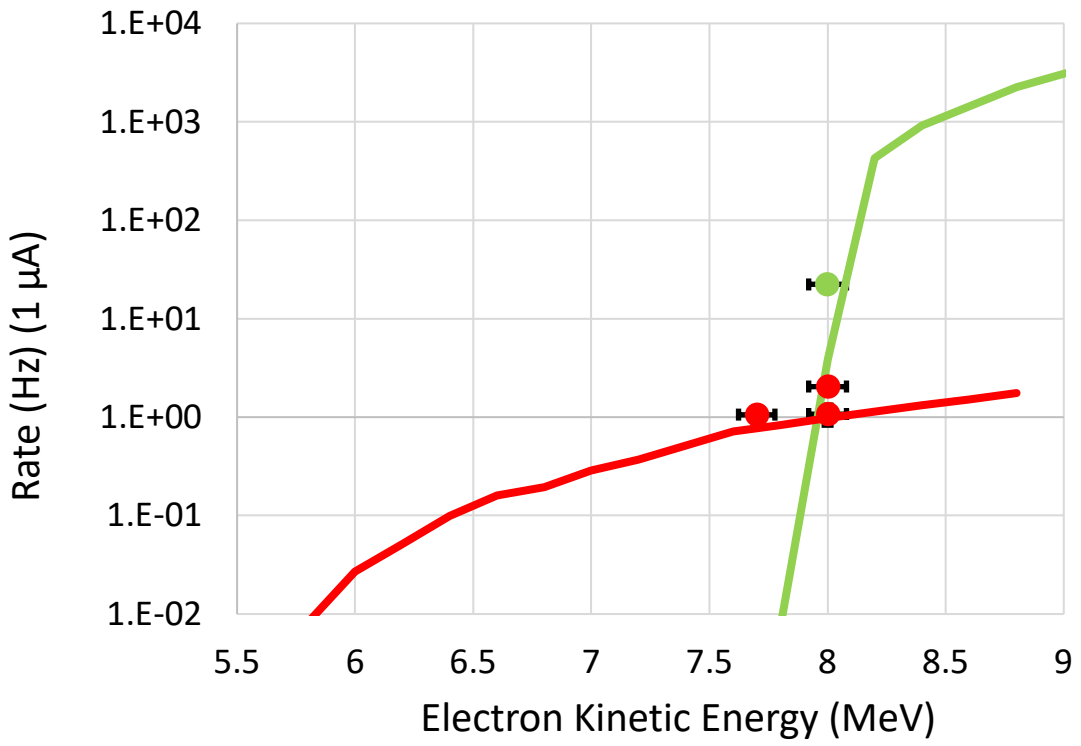
Bubble Formation and Data Acquisition

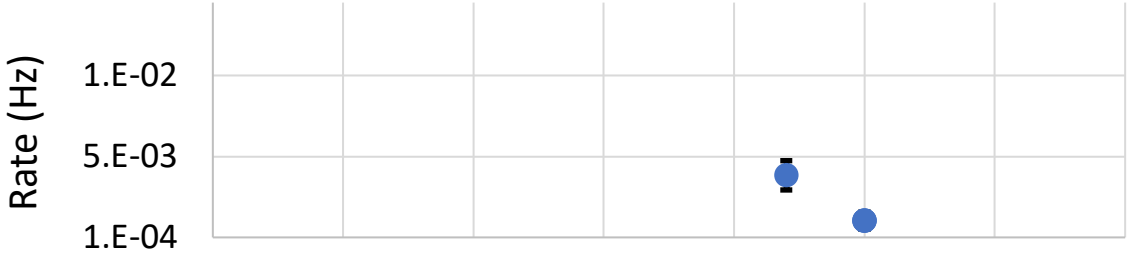




First Half of the Experiment

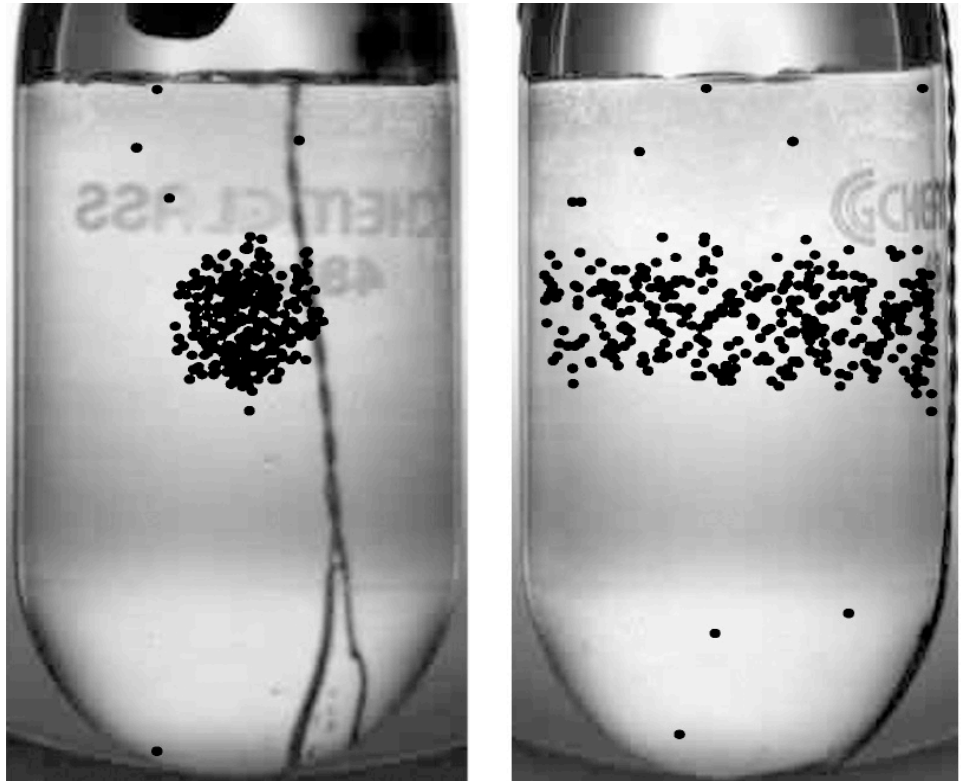
Energy Measured (MeV)	Superheat Pressure (psi)	Superheat Temperature (°C)	Beam Current (µA)
7.7	325	-8	0.4
8	325	-8	0.4
8	325	-8	0.04
8	310	-8	0.035



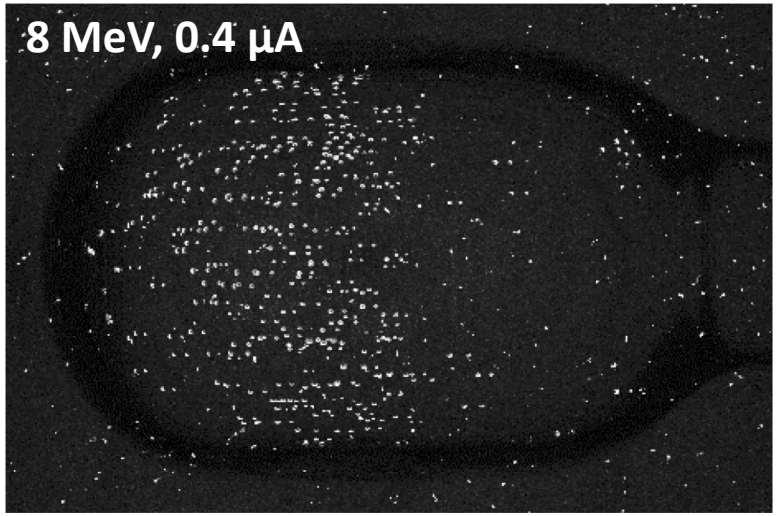


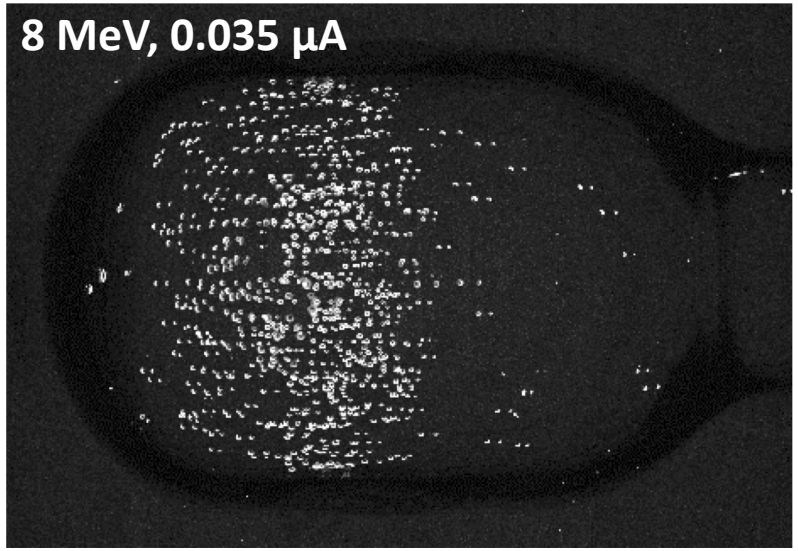
Bubble Distribution

HIγS Data

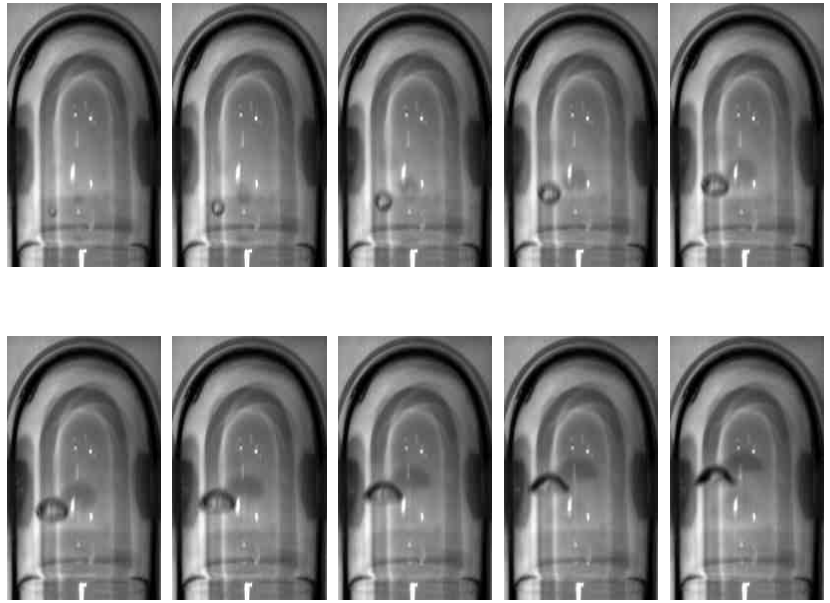


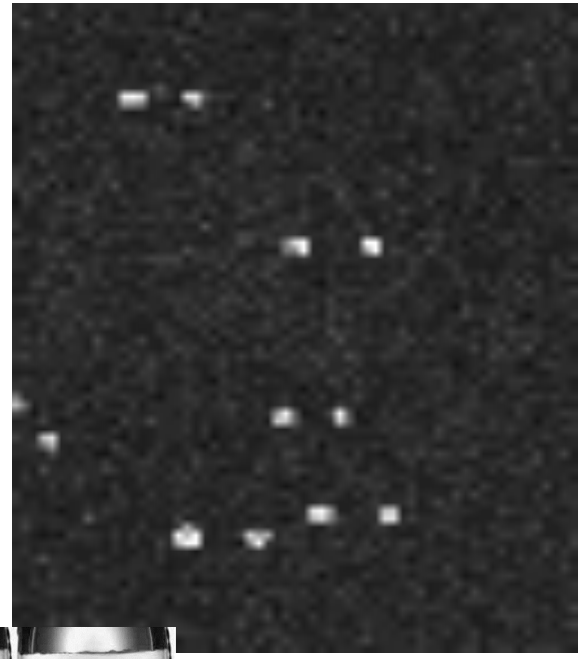
JLab Data





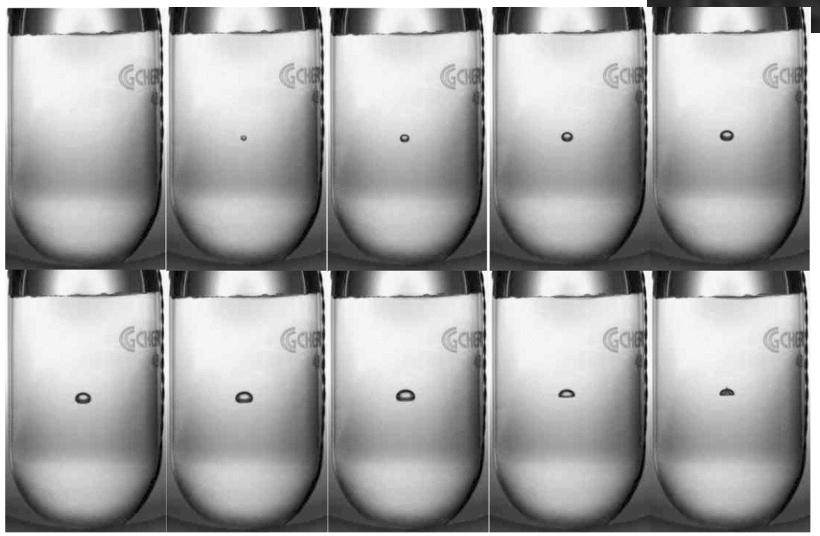
Bubble Size





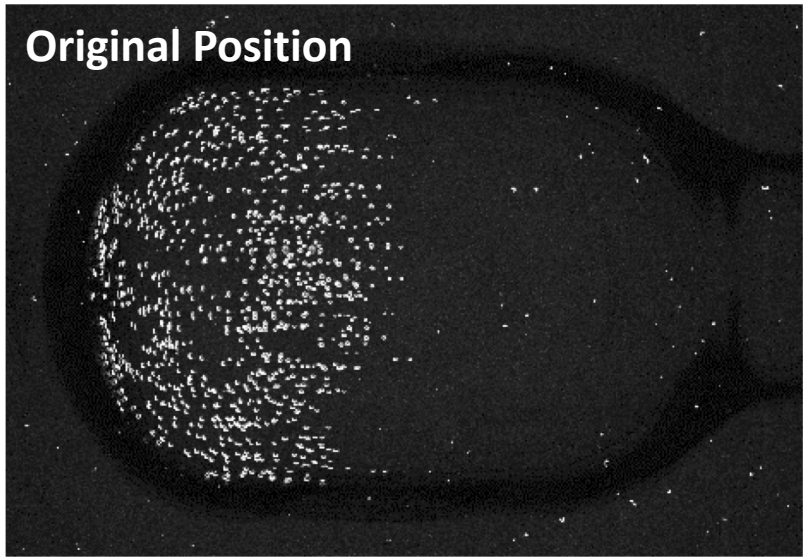
N_2O bubble

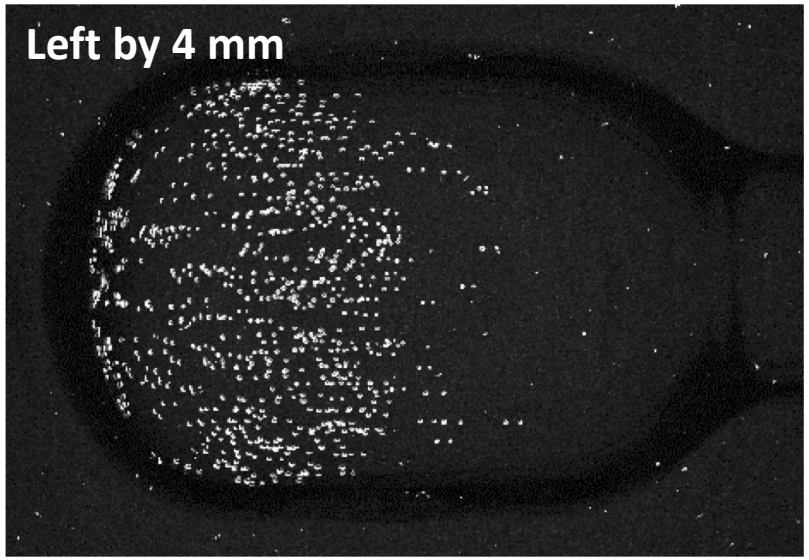
H_2O bubble

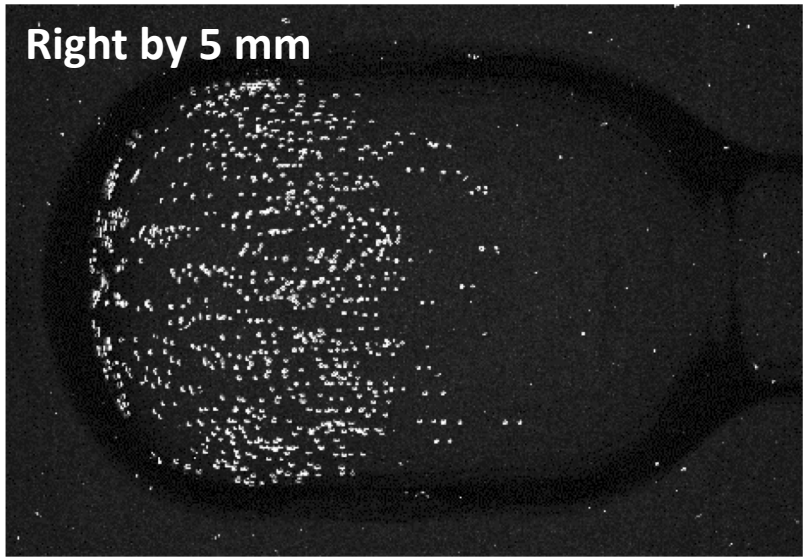


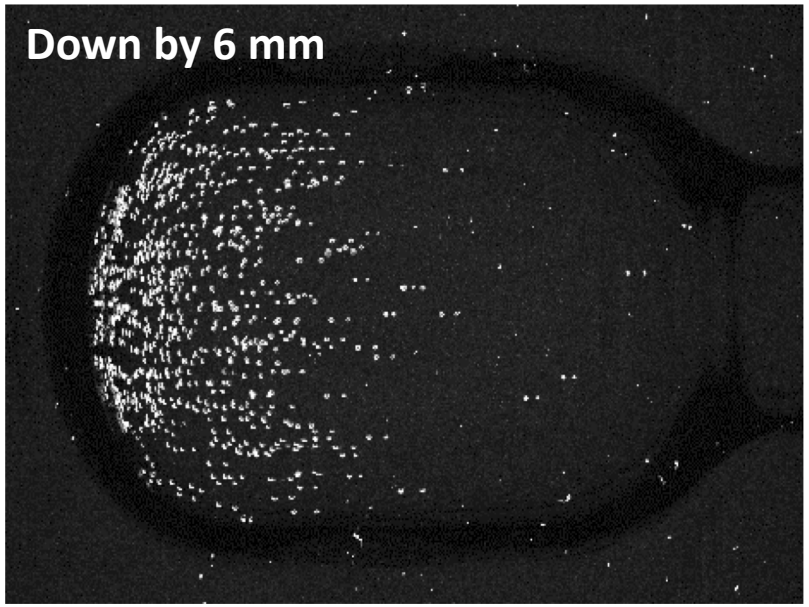
C_4F_{10} bubble

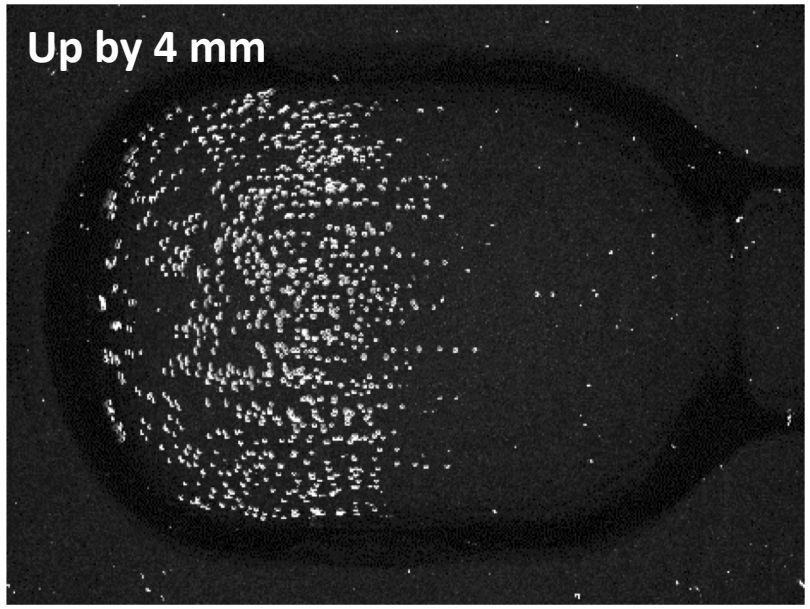
Beam Position Test





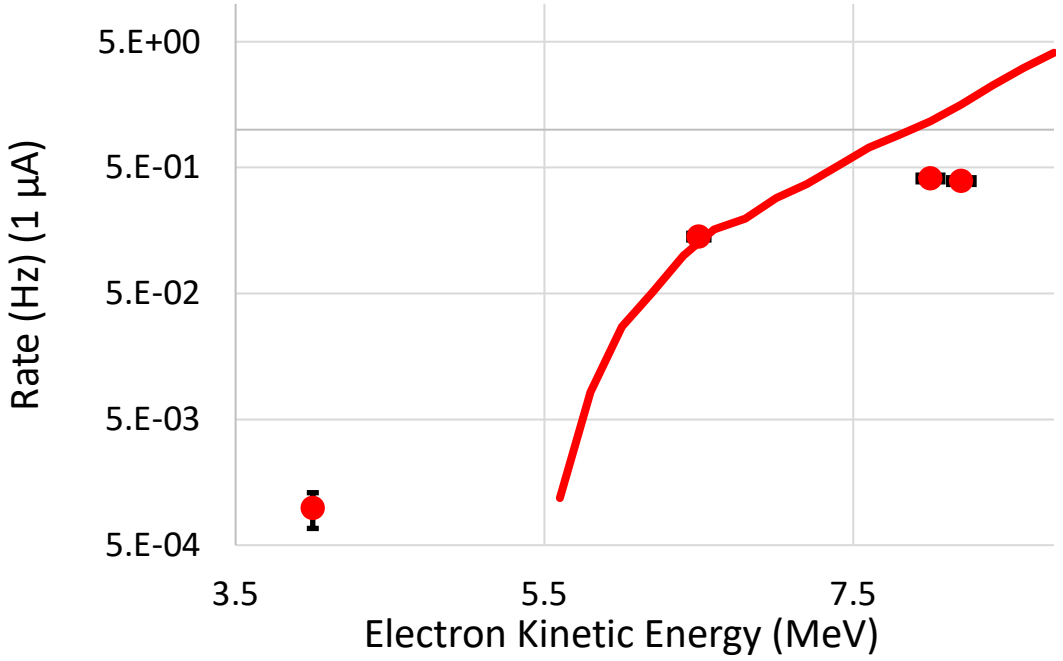


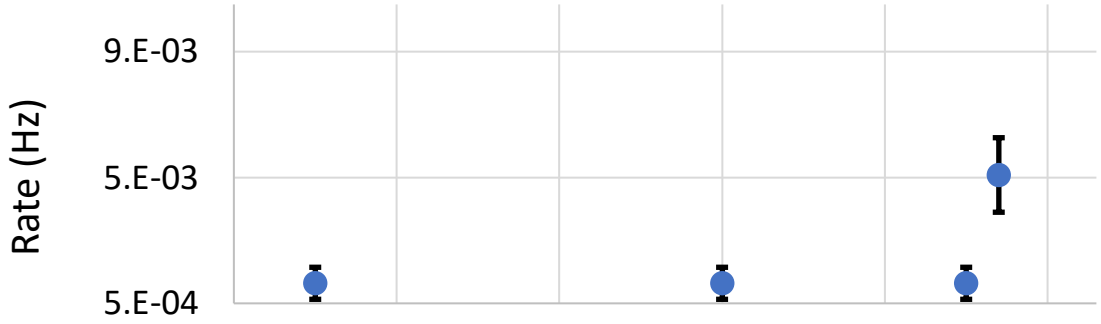




Second Half of The Experiment

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





Experimental aspects that had to be improved

- Did not reduce beam current below 35 nA
- At high beam currents (10 μA), we observed camera scintillation events
- During the last few days, beam induced background became very high throughout the volume of the bubble chamber.
- Beam positon was not very well defined
- Mercury droplets on the glass vessel

May 2018 experiments JLab

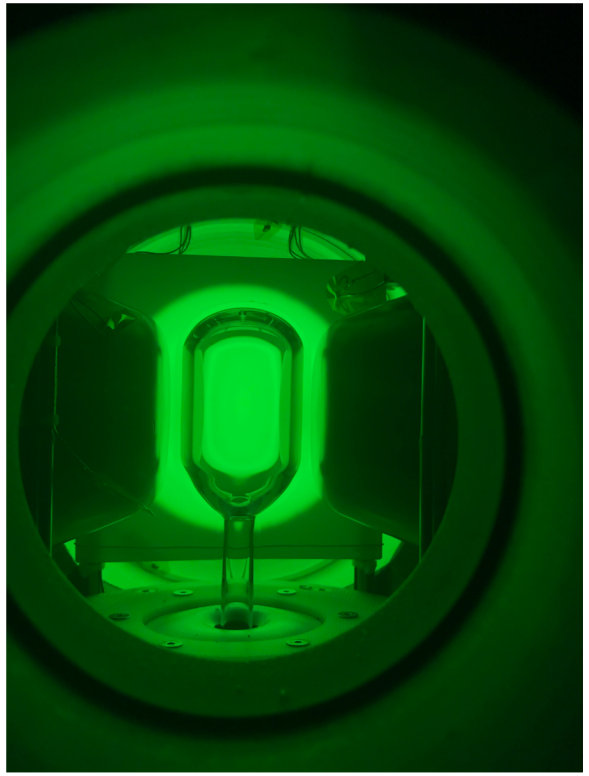
Improvements over previous generation bubble chamber

Switched from two-liquid bubble chamber to single fluid. This removed chemical interactions between superheated fluid and buffer fluid. Also removed accumulation of drops of buffer fluid (mercury) on glass wall.

Lead shielding of video camera from scattered γ-rays.

Improved system of beam collimators and determination of beam parameters (current, momentum, position).

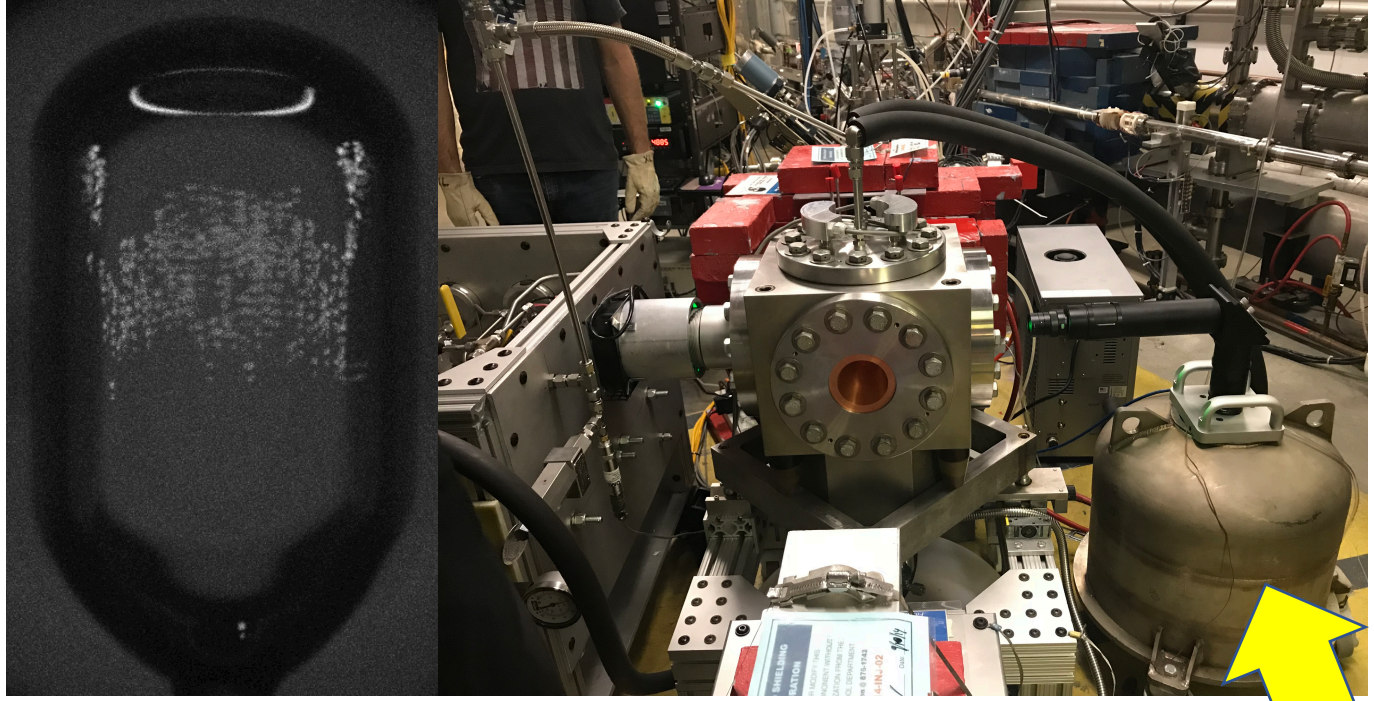
All were implemented successfully.



May 2018 Run
Jefferson Lab

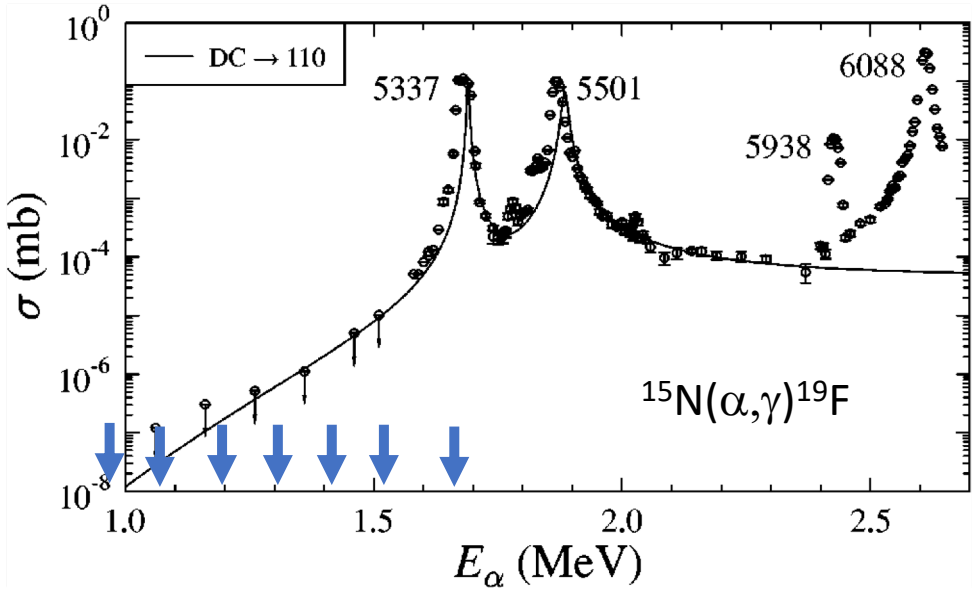
C_3F_8

p ~ 5.5 MeV/c



- Easier to work with than with N_2O (Temperature and Pressure)
- We have measured these cross sections for $^{19}F(\gamma,\alpha)^{15}N$ before. This would allow us to test cross section unfolding.

Wilmes et al. (2005)



Pb shielding of camera
Removed scintillation