Nuclear Astrophysics with γ-ray beams

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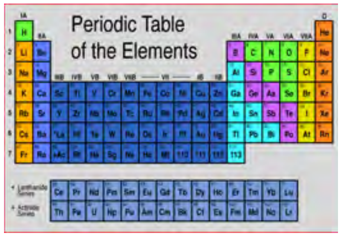
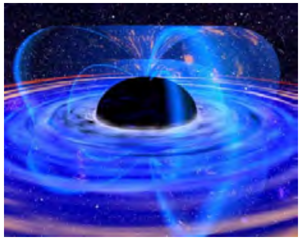
$^{12}C(\alpha,\gamma)^{16}O$ Reaction

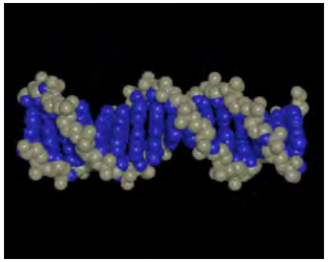
Key reaction for nucleosynthesis in massive stars, progenitors of Type Ia Supernovae, White Dwarf ages.



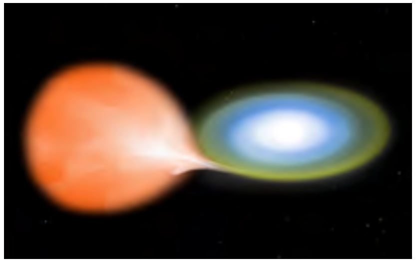
Affects the synthesis of most of the elements of the periodic table



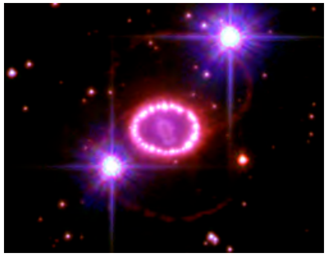
Determines whether for a given initial mass, a star will become a black hole or a neutron star



Sets the C to O ratio in the universe

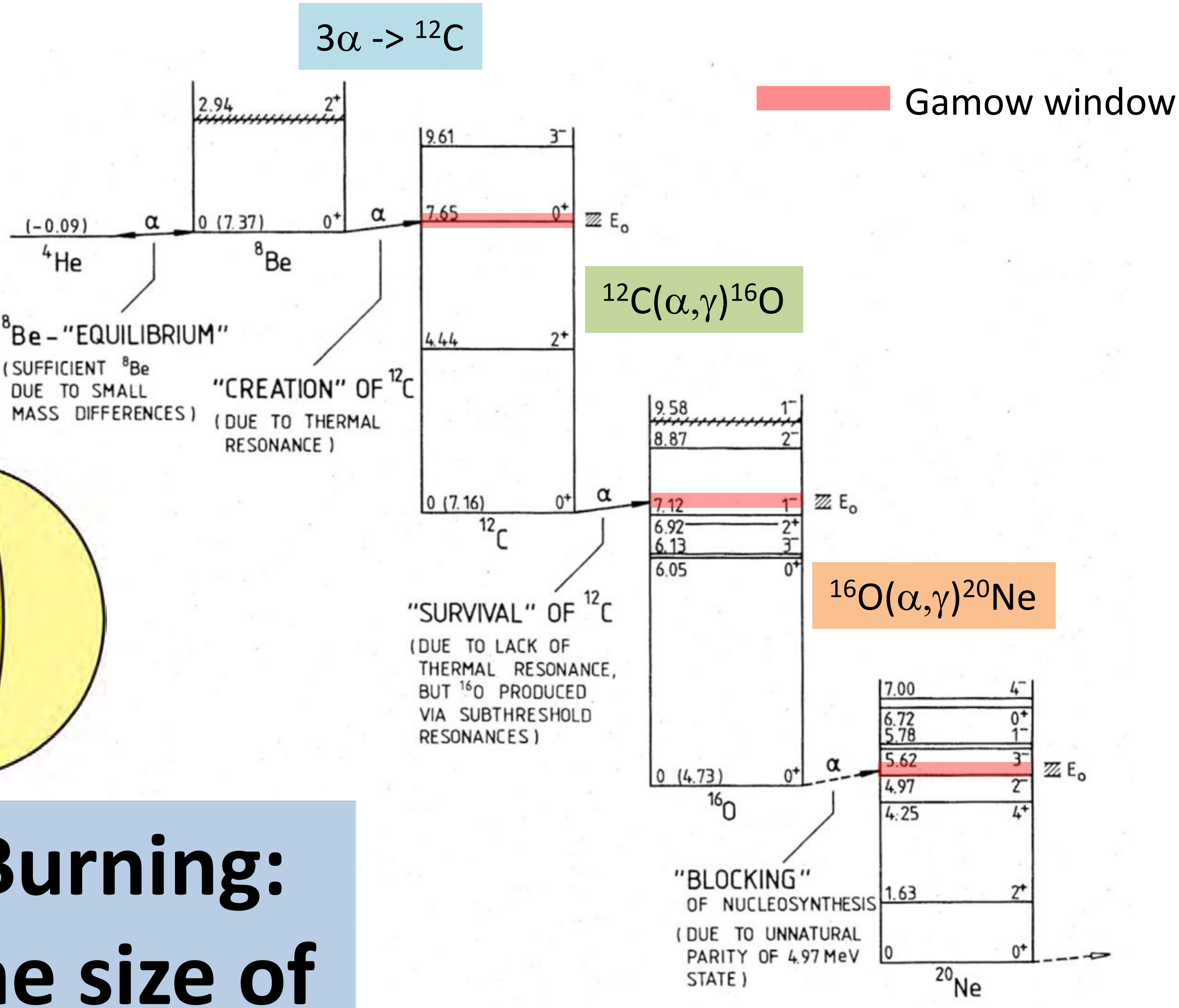


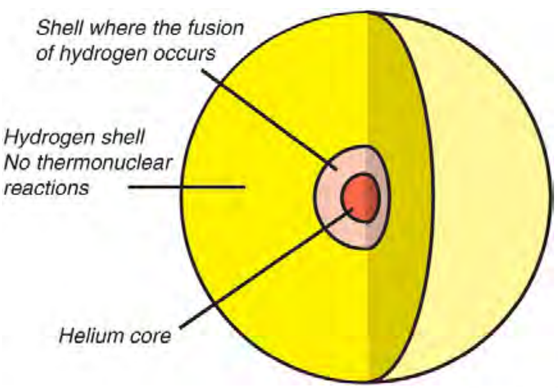
The variation of the C/O ratio in the progenitor might be a cause of the variation of SNIa brightness



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

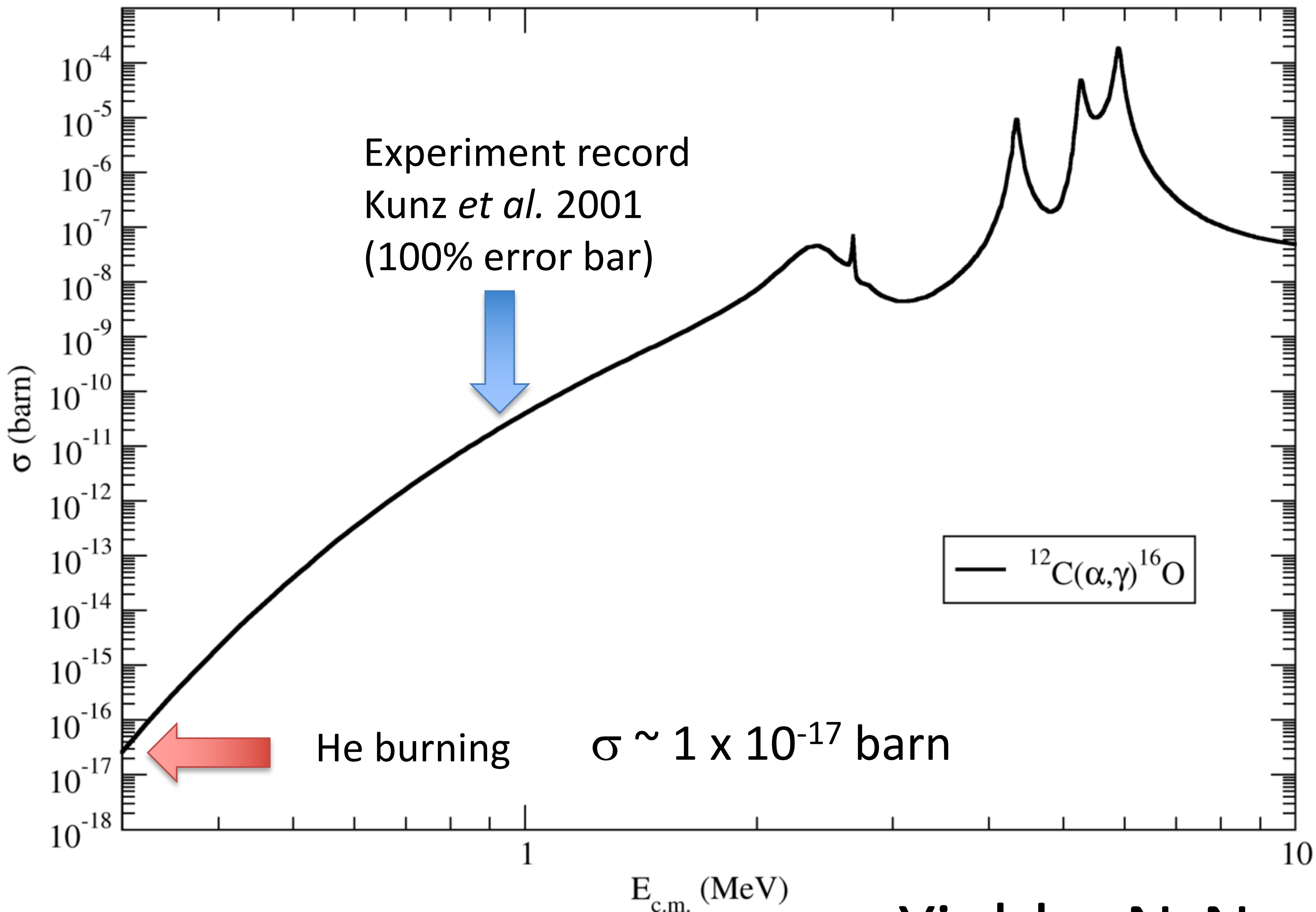
Affects the constraints on the age of stellar populations from White Dwarfs



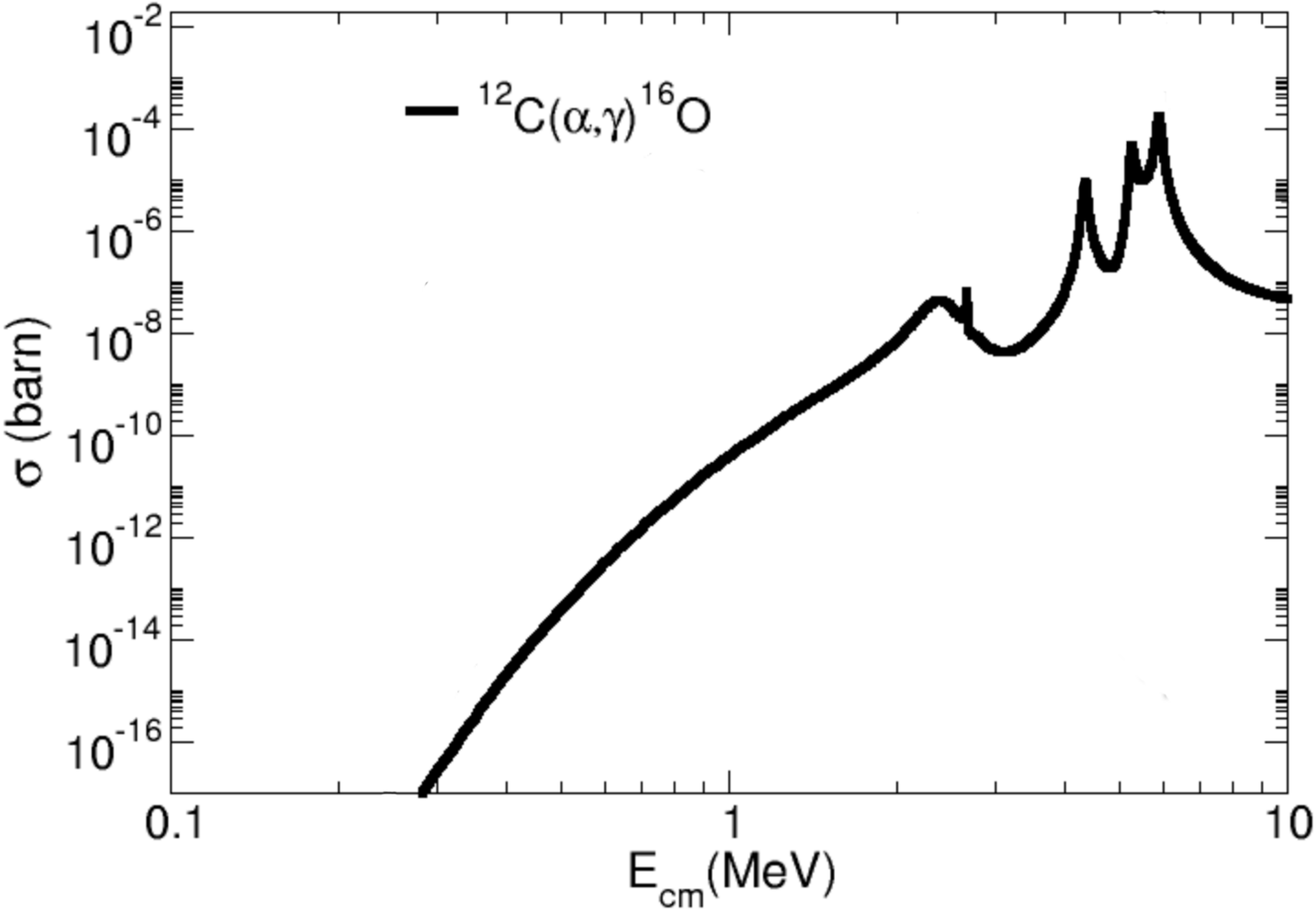


Helium Burning: Defines the size of the stellar core.

Rolfs and Rodney, 1988

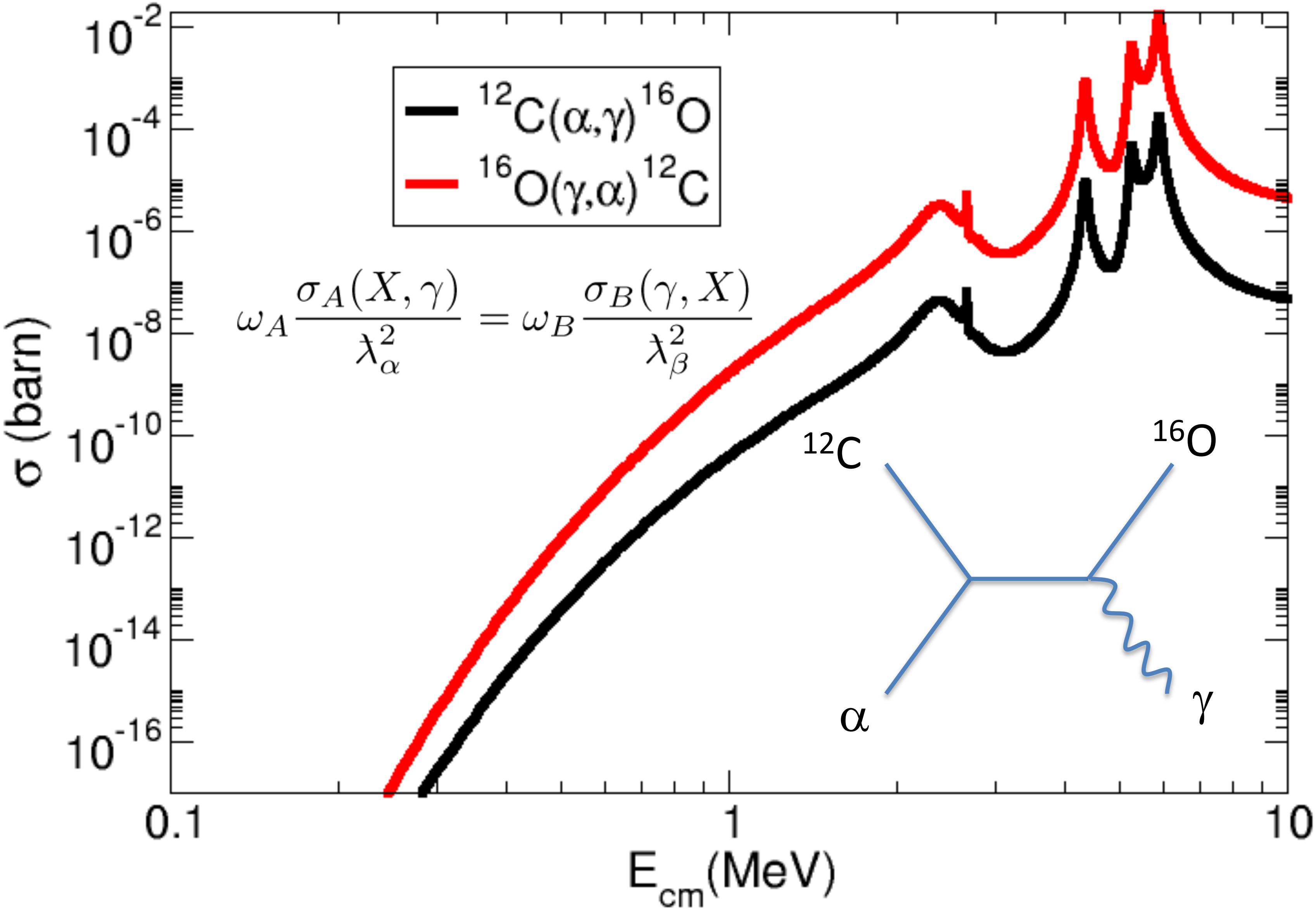


Yield ~ $N_1 N_2 \sigma g$



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

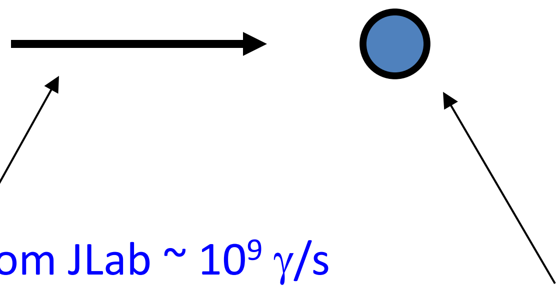


Our approach:
Inverse reaction + Bubble chamber + γ ray beam

beam | target | signal

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

- 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})



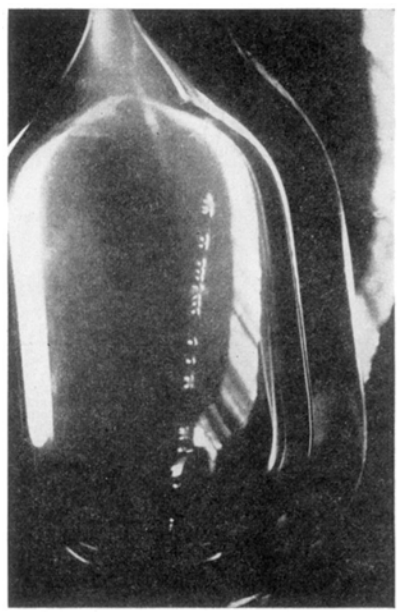
Liquid target (internal detection)
The bubble chamber

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*

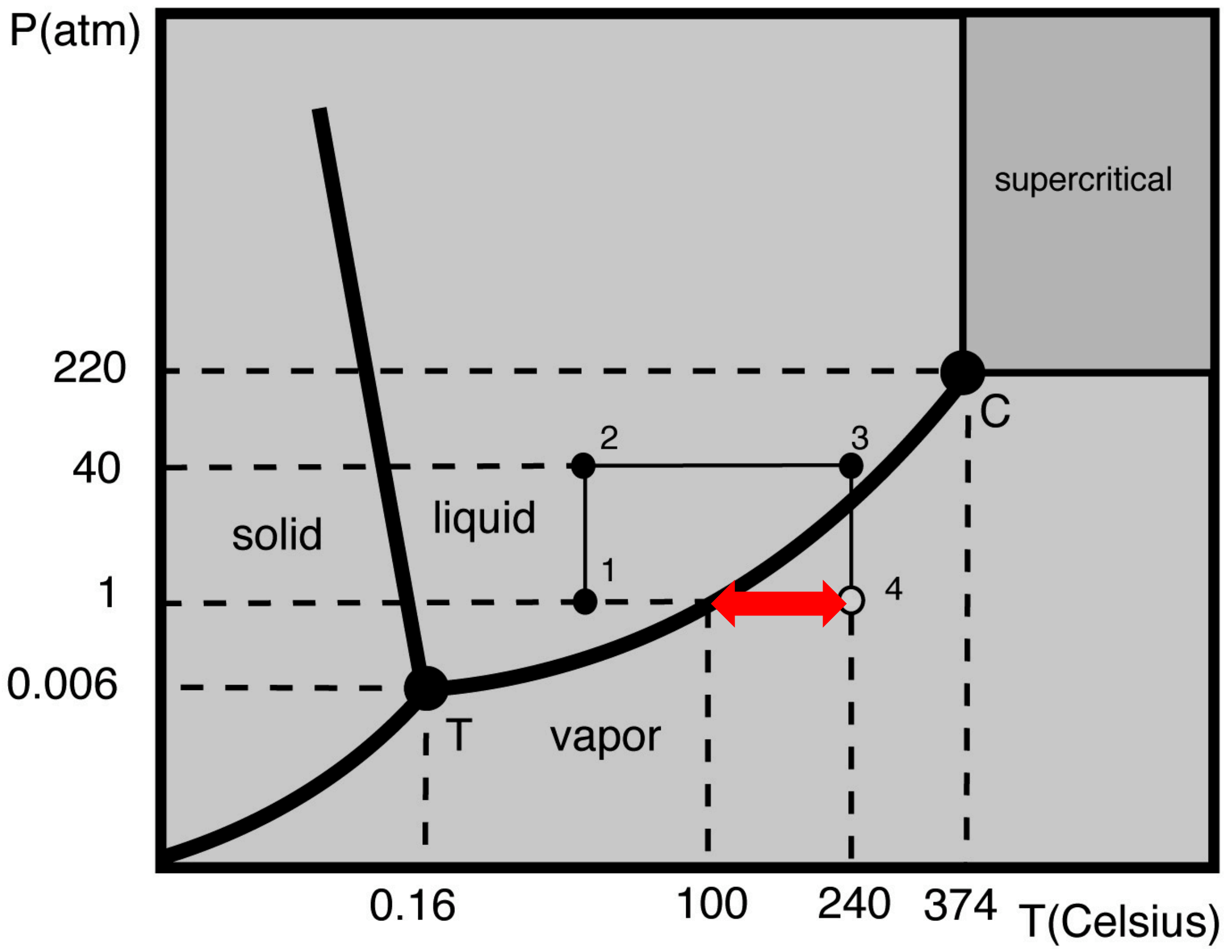
DONALD A. GLASER
University of Michigan, Ann Arbor, Michigan
(Received June 12, 1952)



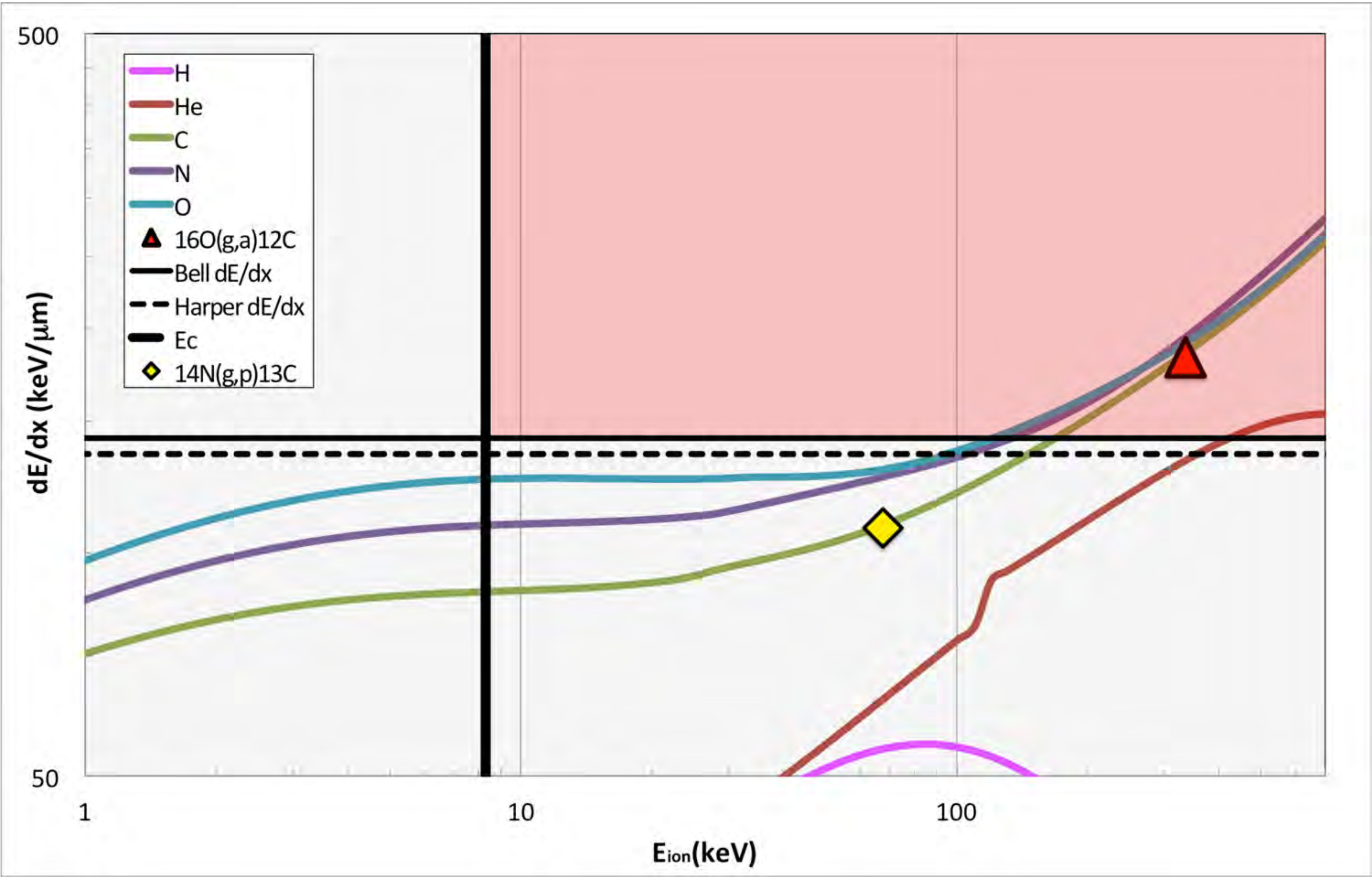
Ingredients:
- Superheated liquid
- Ionizing radiation

Superheating of liquids

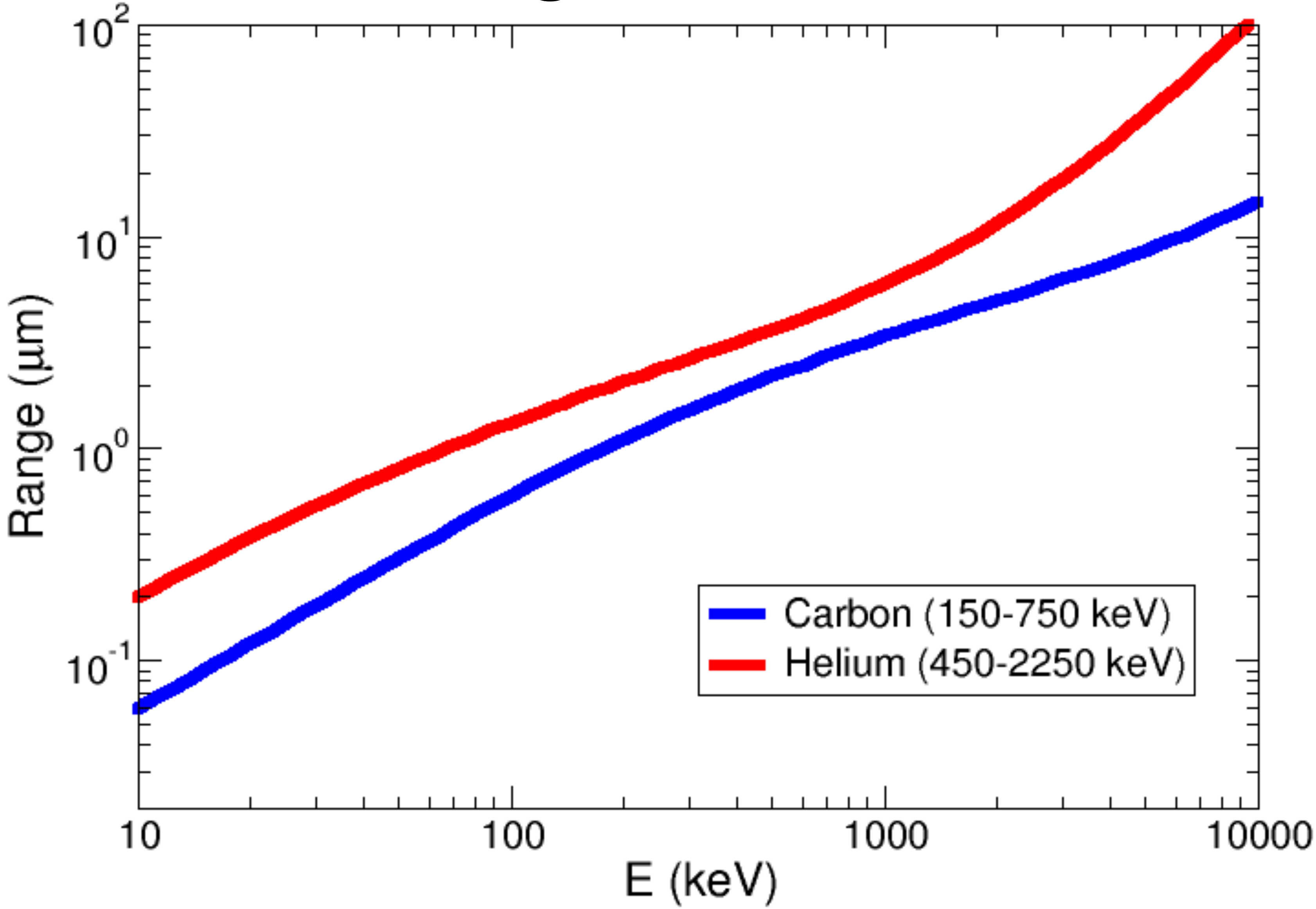
Water



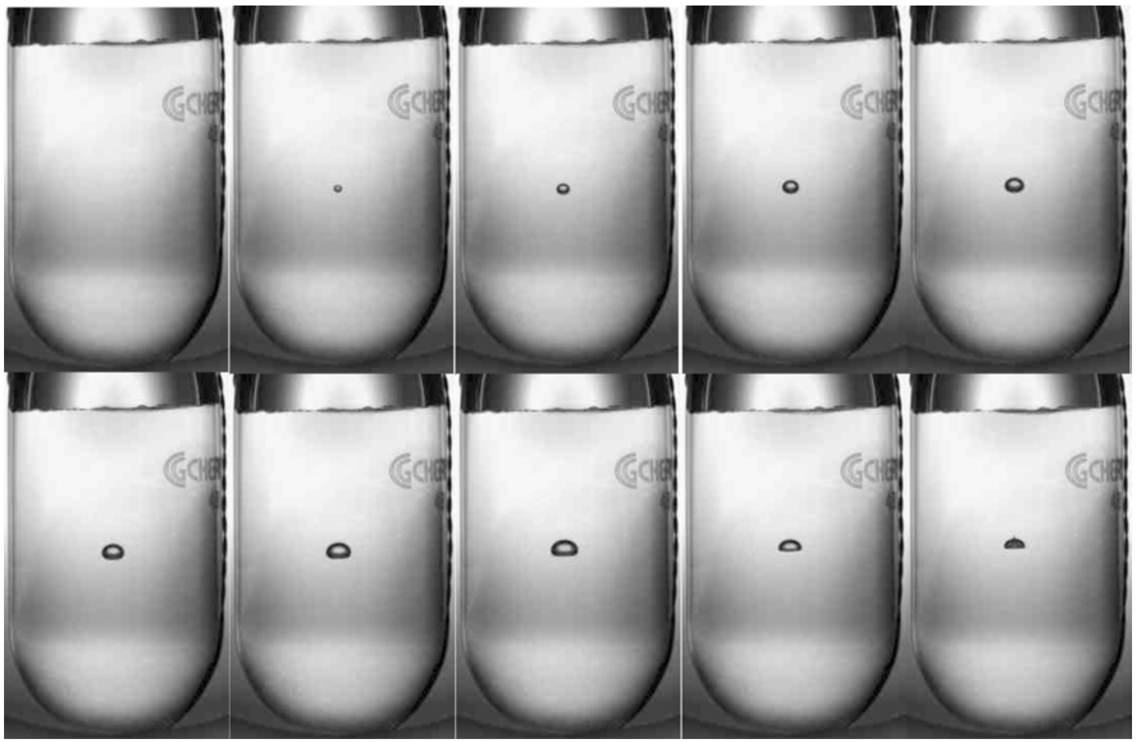
N_2O thresholds, Superheat = 3.3 ^{O}C, $E\gamma$=8.5 MeV



Ranges in water



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



Δt = 10 ms

Bremsstrahlung beams

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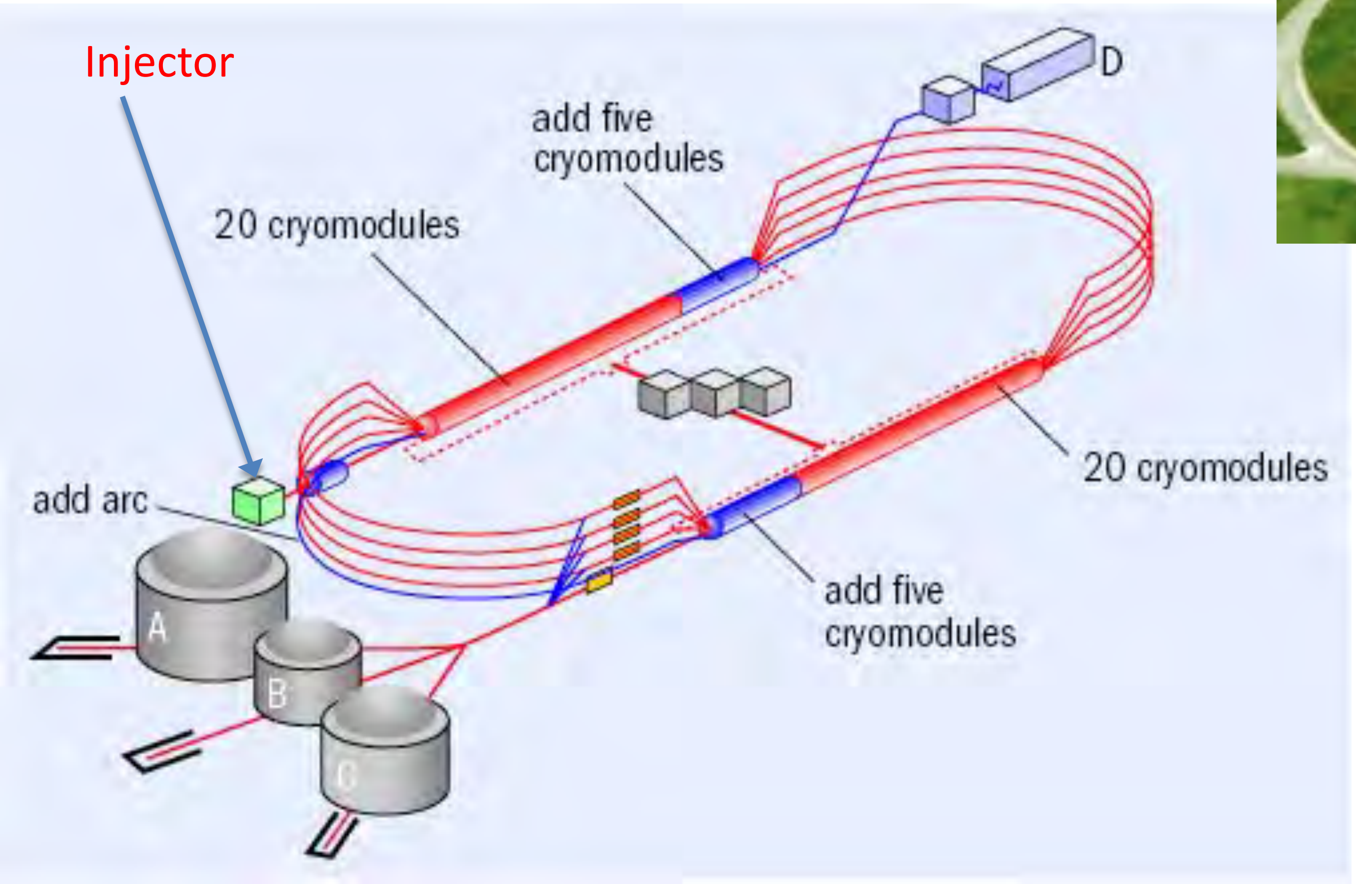


CEBAF 12 GeV

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

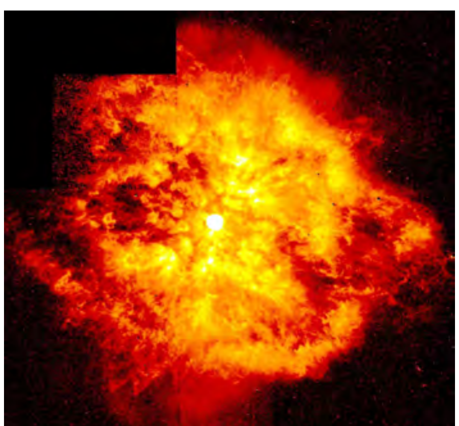
Fluorine nucleosynthesis

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

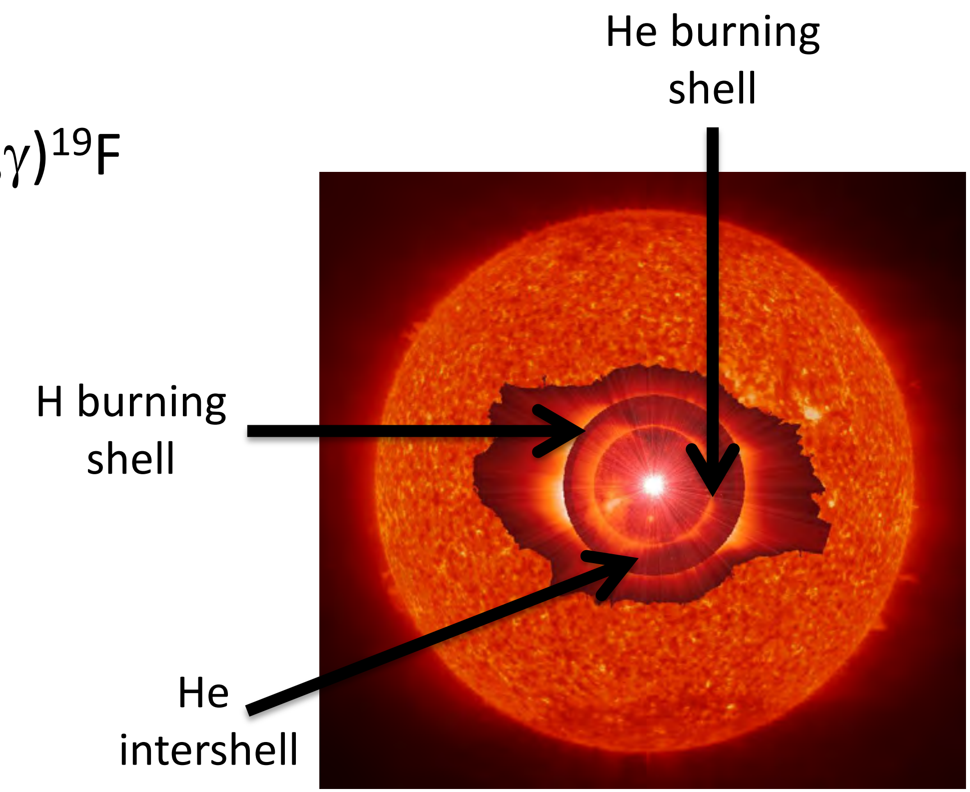
$^{15}N(\alpha,\gamma)^{19}F$ still uncertain at stellar temperatures

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

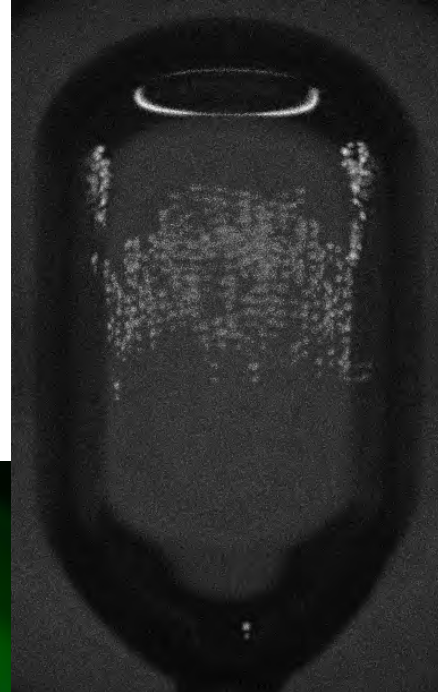


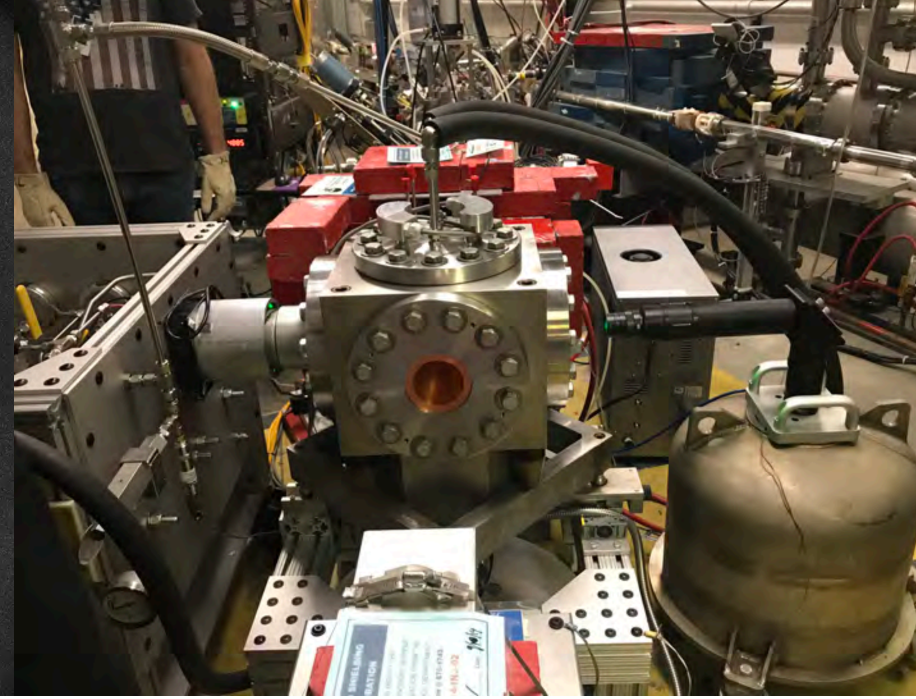
Asymptotic Giant Branch star

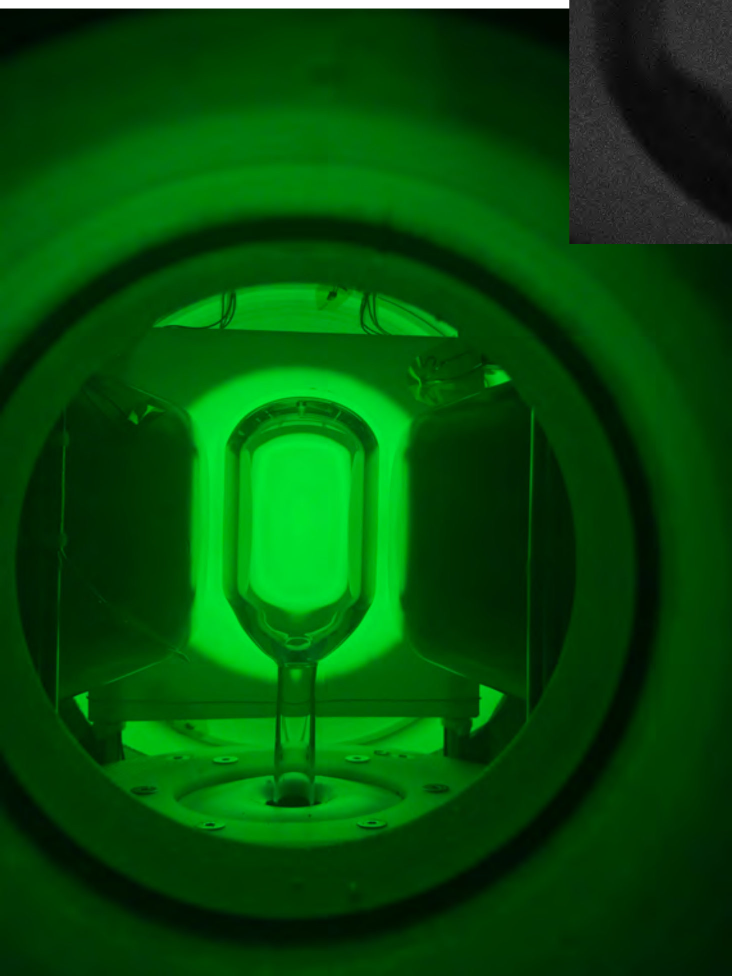
May 2018 Run
Jefferson Lab

C_3F_8

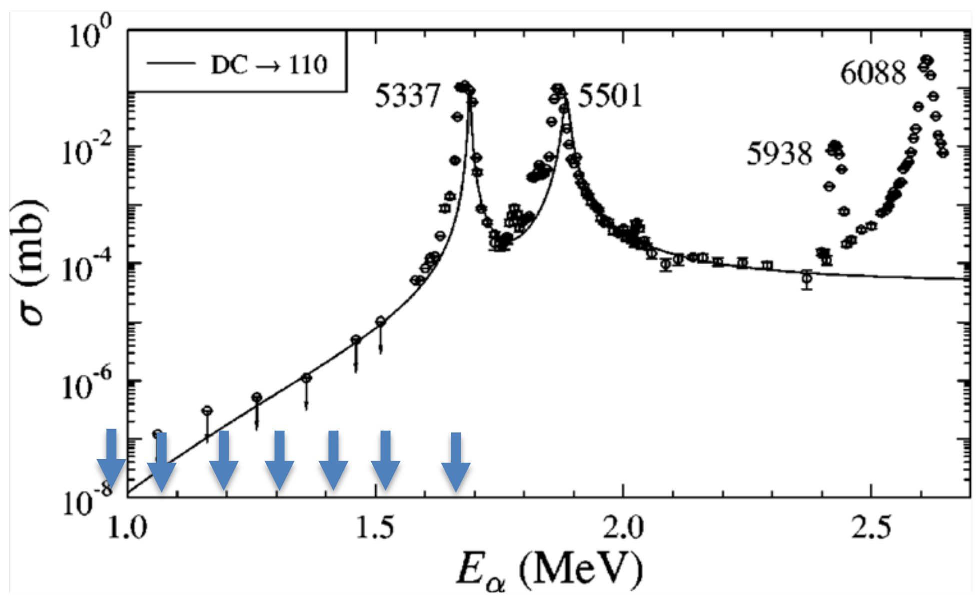
p ~ 5.5 MeV/c







Wilmes et al. (2005)



Conclusions

Provided a proof of principle of operation of the bubble chamber as a low rate counter for use with γ-ray beams.

Ideal for nuclear astrophysics applications.

Bremsstrahlung radiation from the injector

Main challenges:

- **Maximize beam intensity**
- **Minimize electron beam energy spread**
- **Minimize photo neutrons reaching bubble chamber**

- **Need excellent characterization of γ-ray beam properties**