A Single Fluid Bubble Chamber for Measuring Nuclear Reaction Rates of Astrophysical Importance

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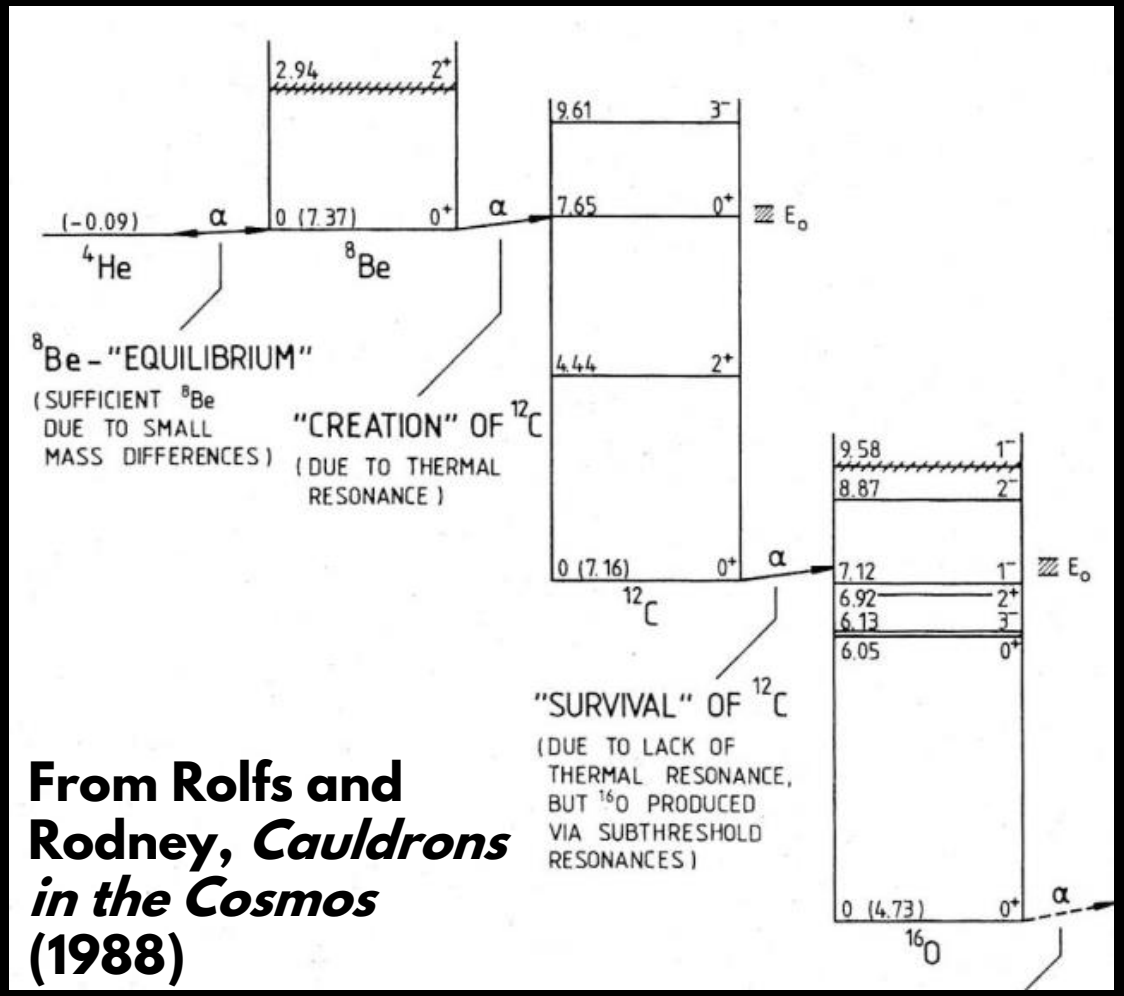
Nucleosynthesis of Oxygen 16



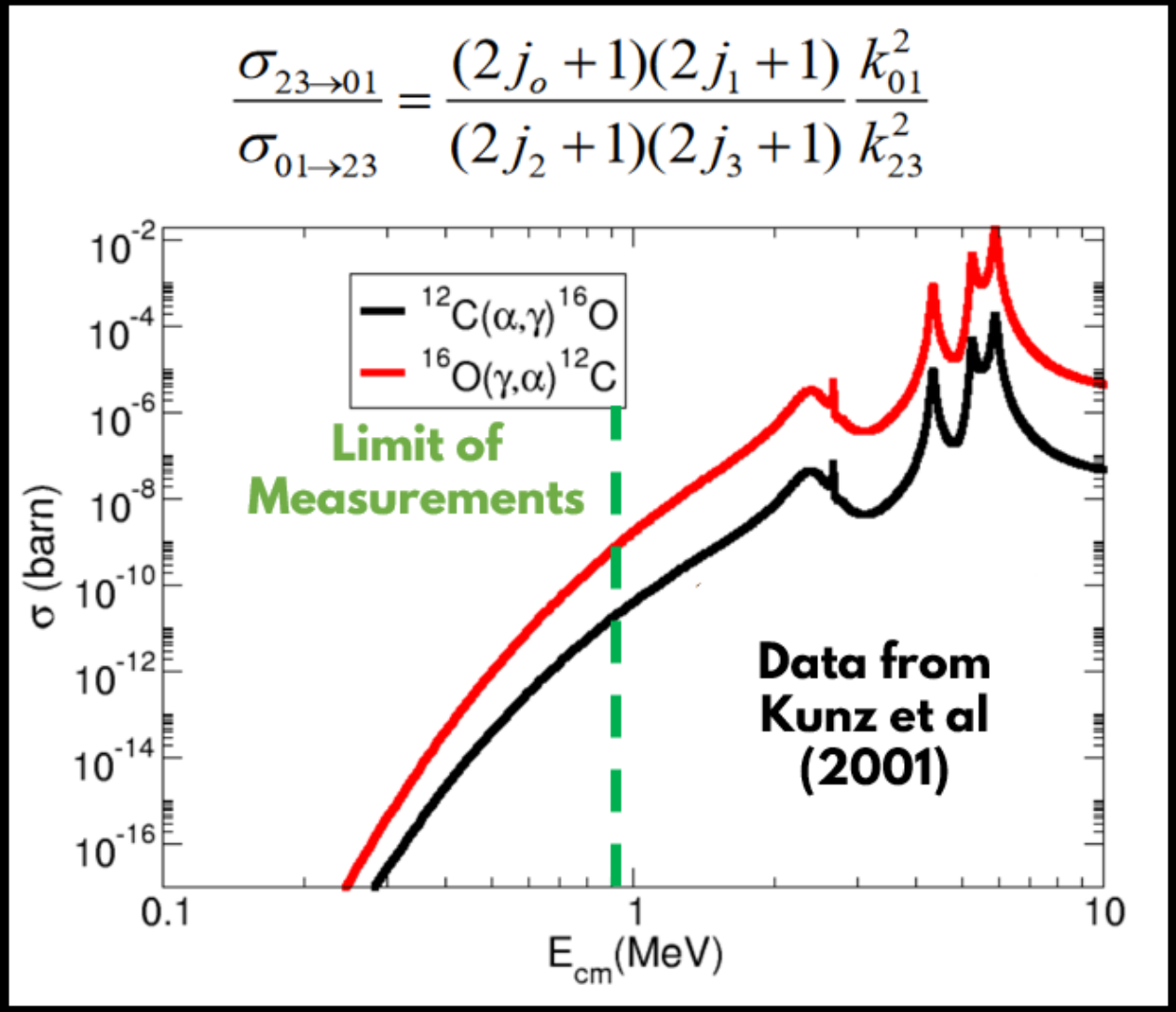
From Rolfs and Rodney, *Cauldrons in the Cosmos* (1988)

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

- Determines ratio of oxygen and carbon in the universe
- Determines lifetimes and evolution of large stars
- Necessary for accurate supernova modeling
- Difficulty in measurement from sub-threshold resonances
- Small cross section near stellar core energies

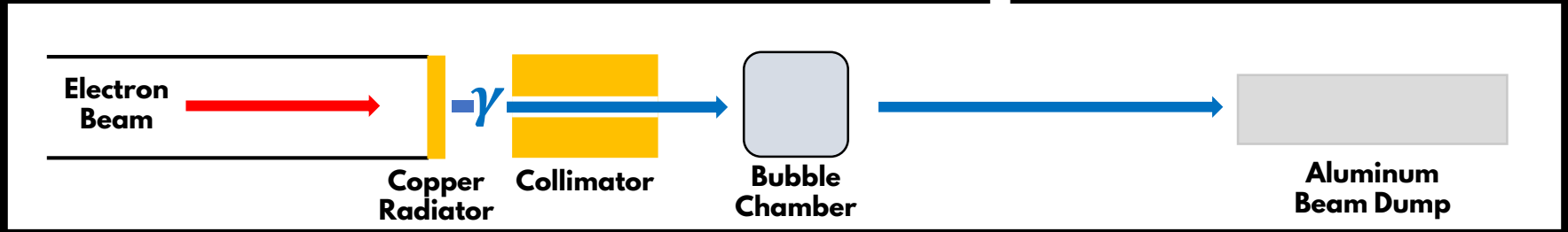
Time Reversed Process

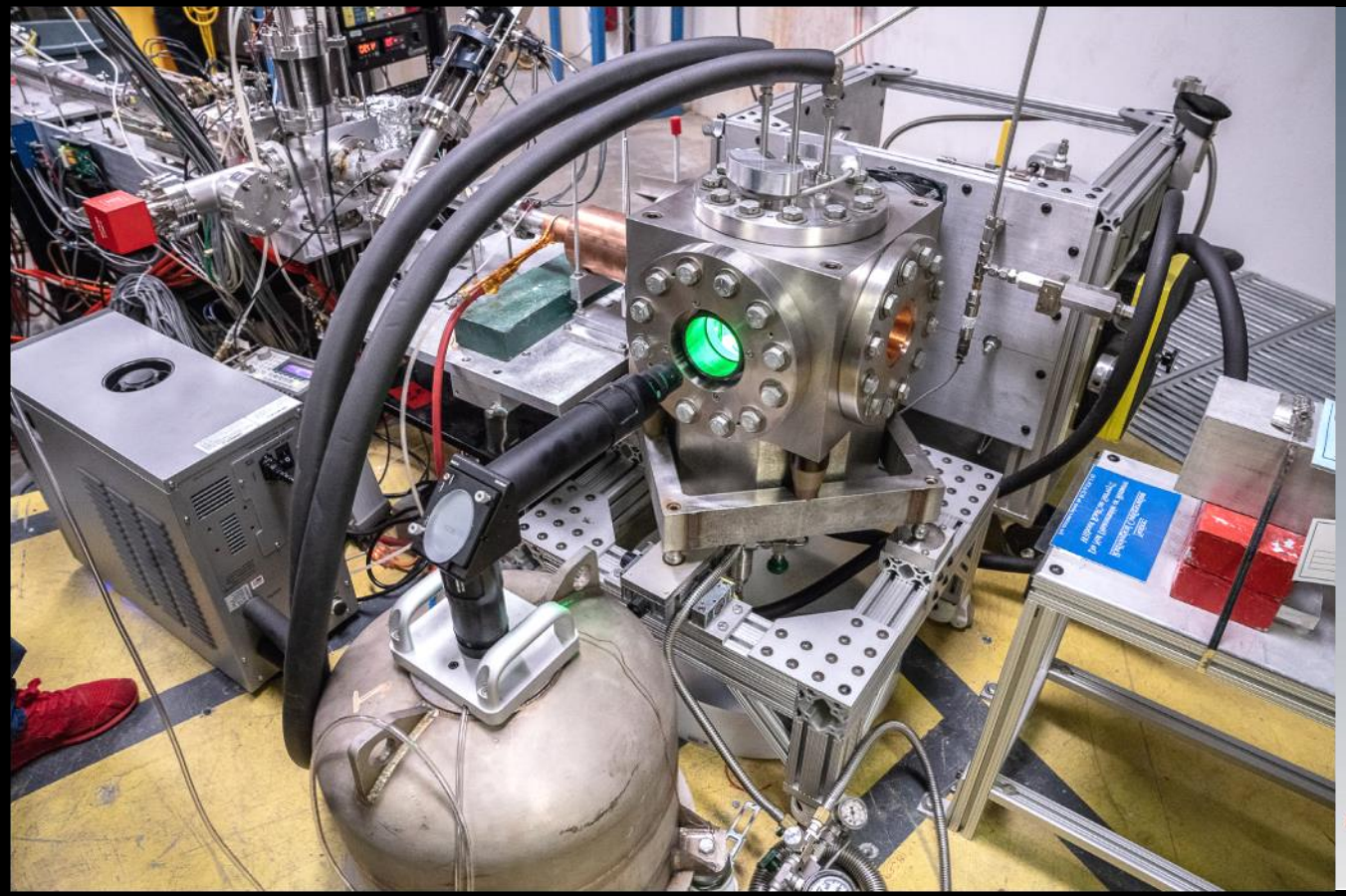
$$\frac{\sigma_{23\to01}}{\sigma_{01\to23}} = \frac{(2j_o+1)(2j_1+1)}{(2j_2+1)(2j_3+1)}\frac{k_{01}^2}{k_{23}^2}$$

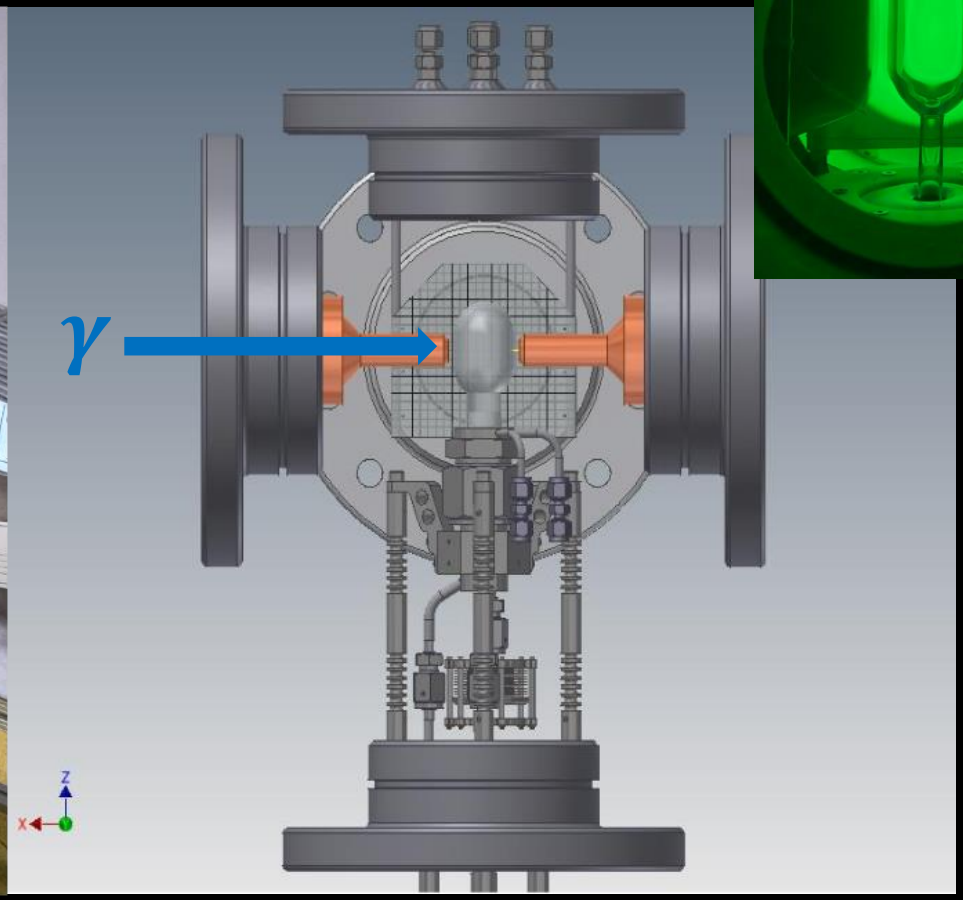


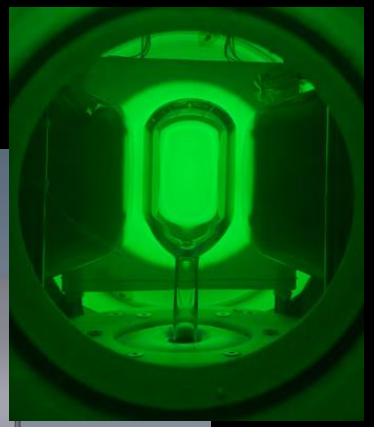
- (γ, α) cross section nearly two orders of magnitude larger than (α, γ)
- Requires a detector insensitive to gamma rays
- Bubble chamber is insensitive to gamma rays, bubble nucleation results from nuclear reactions
- We use bubble chamber techniques originally developed for dark matter searches

Bubble Chamber Experiment



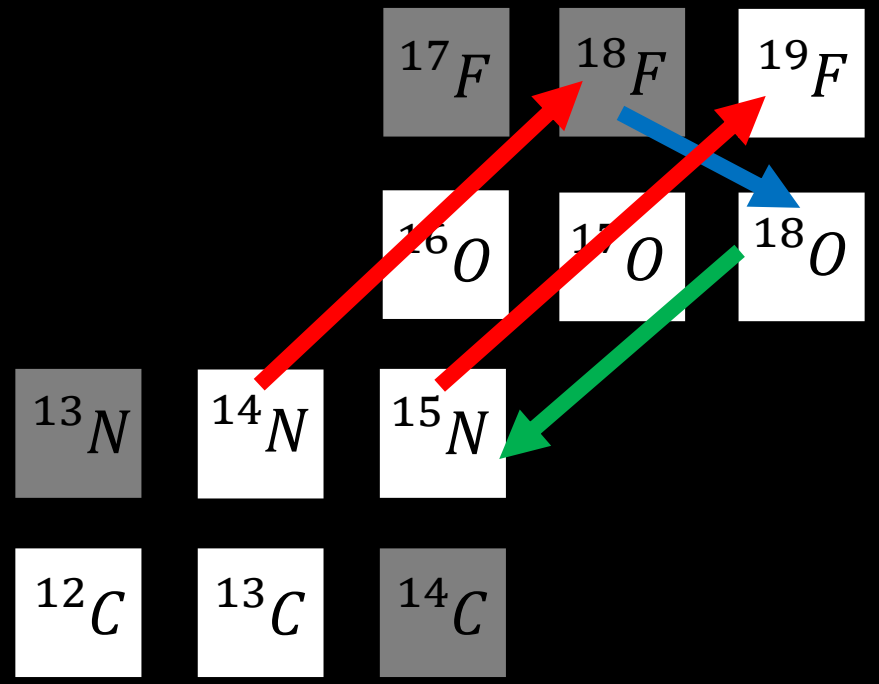






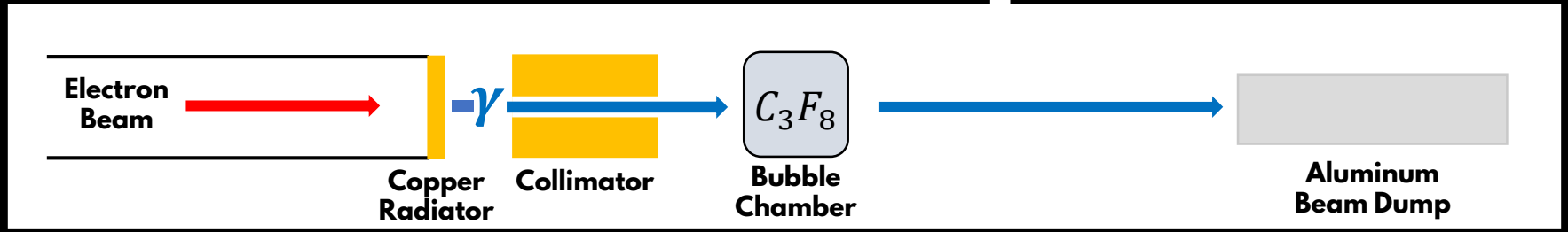
The $^{19}F(\gamma,\alpha)^{15}N$ Reaction

- Fluorine has only one stable isotope, simplifying analysis
- Reaction involved in synthesis of fluorine in AGB, and potentially Wolf-Rayet, stars
- Use C_3F_8 as target fluid, has been used in dark matter experiments (chemical and physical properties well known)
- Previously have done C_4F_{10} in buffer fluid chamber at HIγS
  - Ugalde et al., *Phys. Lett. B* 719 (2013)
  - DiGiovine et al., *Nucl. Inst. Meth. A* 781 (2015)



$^{14}N(\alpha,\gamma)^{18}F\ (\beta\upsilon)^{18}O\ (p,\alpha)^{15}N(\alpha,\gamma)^{19}F$

Bubble Chamber Experiment

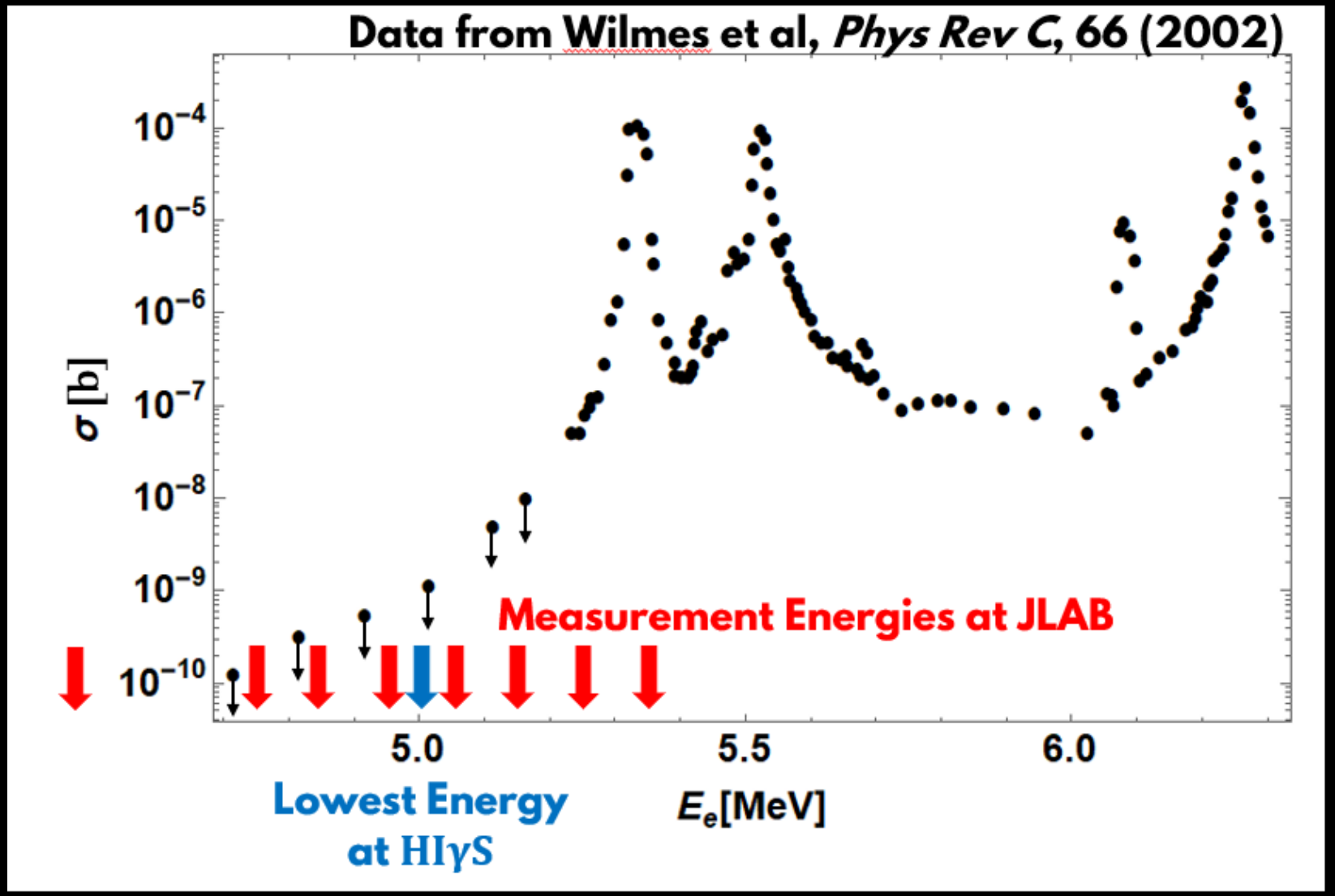


Advantages of Bubble Chamber

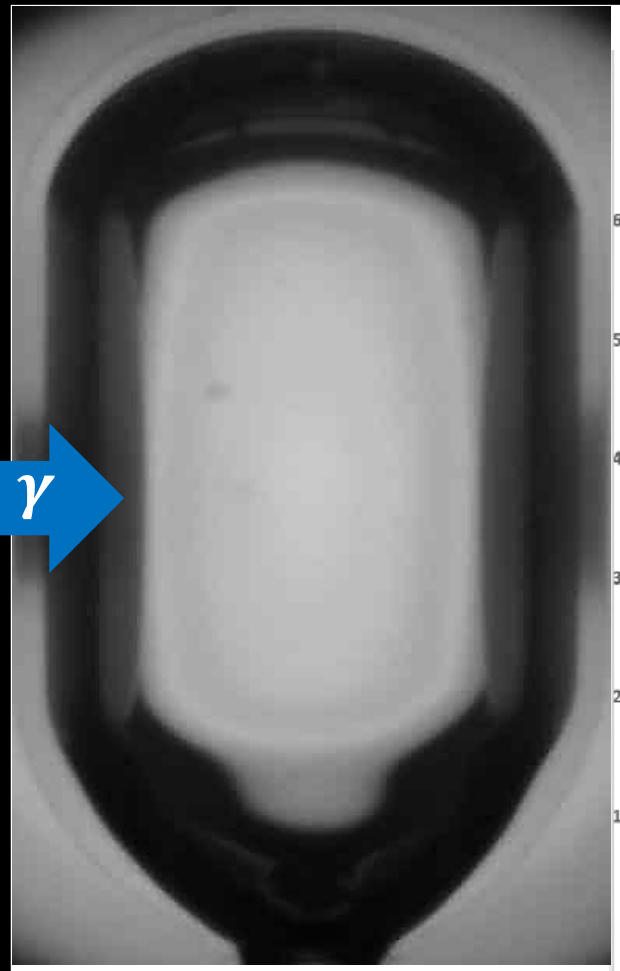
- Insensitive to Gamma Rays
- Temperature and Pressure can be adjusted to reduce nucleation from unwanted signals (sensitive to heavy ions)
- Higher target density verses gas or thin film targets (a factor of 10^5 thicker)

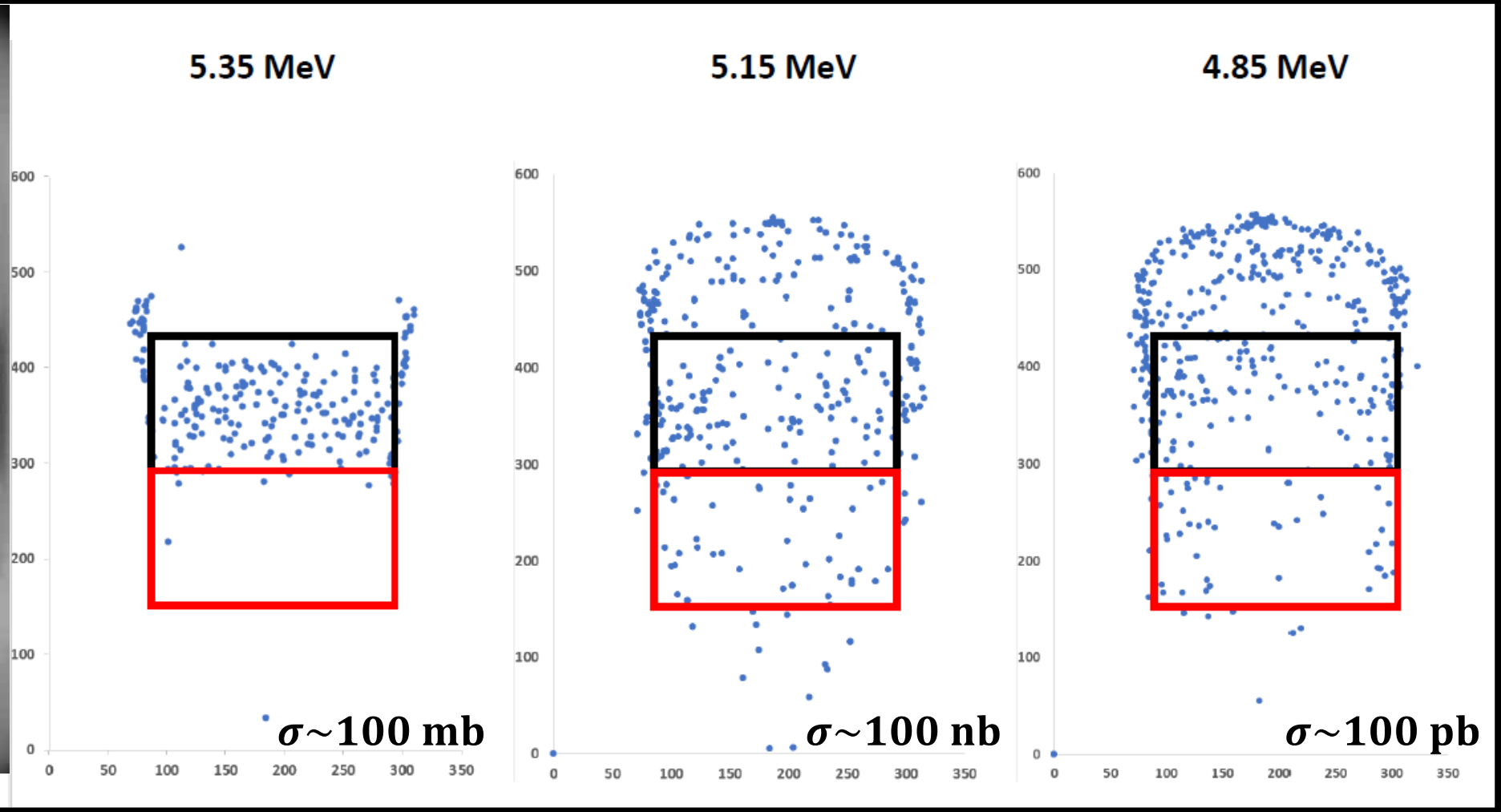
Measurements

Electron Energy [MeV]	Integrated Time [hrs]
4.00	1.8
4.75	15.5
4.85	10.9
4.95	8.5
5.05	5.9
5.15	12.2
5.25	8.3
5.35	3.1

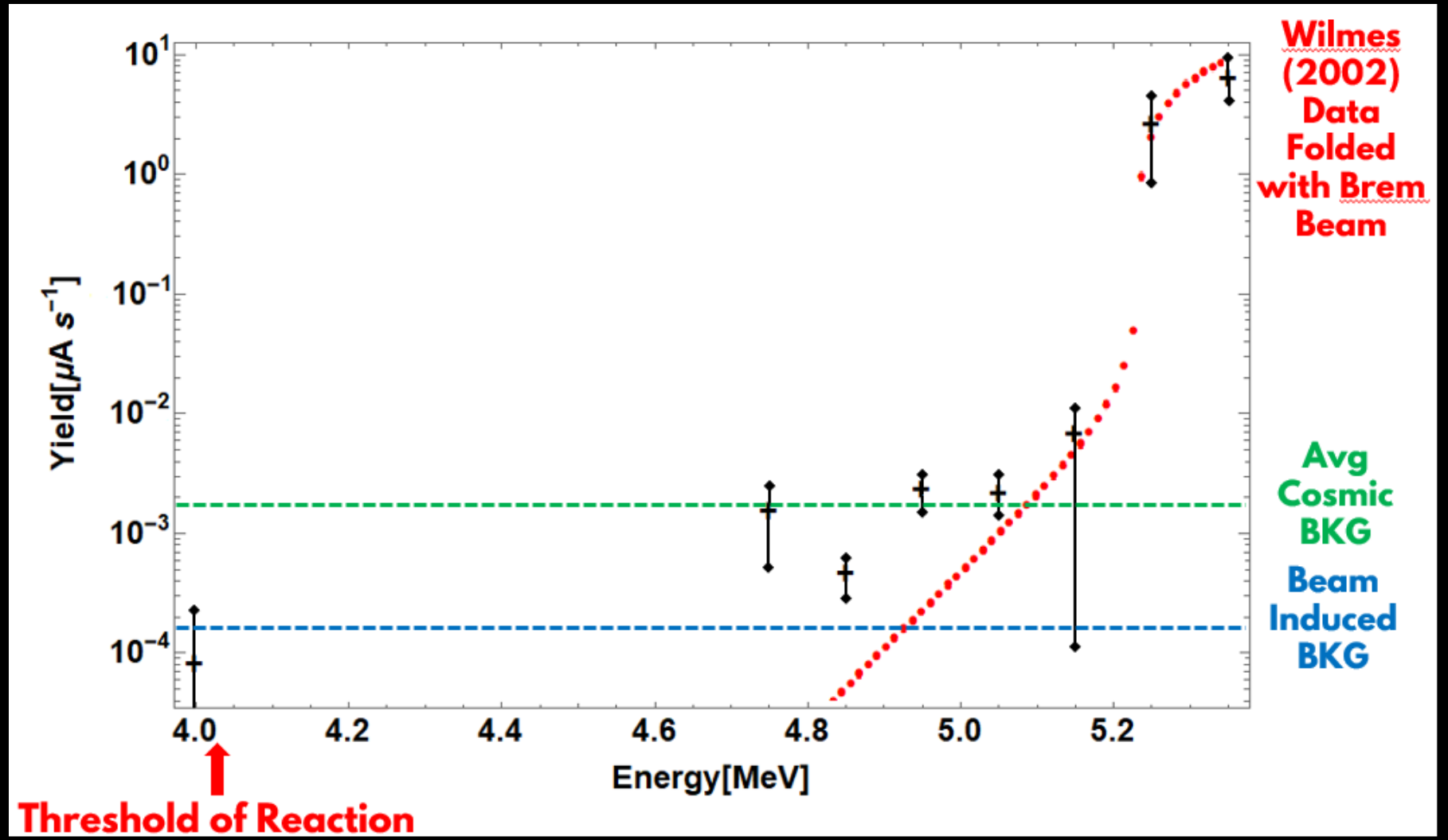


Fiducial Region and Background





Preliminary Results: Yield



Conclusions

- Able to measure down to ~80 pb (factor of 40 better than previous measurements at HIγS)
- Still determining systematic uncertainties
- More analysis to be done, but looks promising

Moving Forward

- Near Term Upgrades
  - Upgrading to a new controller (higher resolution cameras)
  - Reduce Wall Events
    - Replace Borosilicate cell with Quartz cell
    - Change to a fluorocarbon oil
  - Stereoscopic optics
- Long Term
  - Acoustic sensors (alpha/neutron discrimination)

Collaboration

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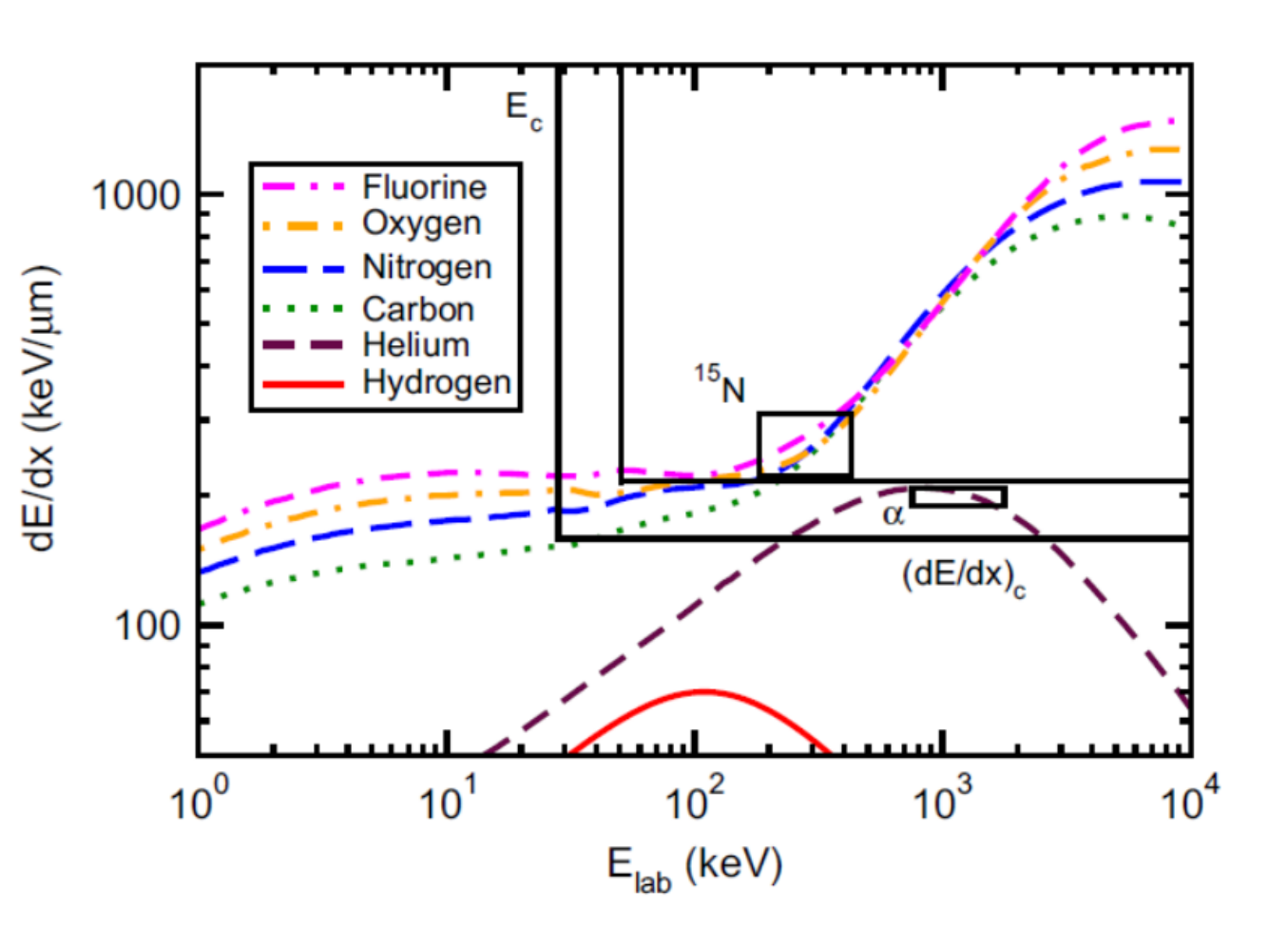
DE-AC05-06OR23177 (JLAB)

Extra Slide I: Stopping Power Curve



For more detail on figure see
DiGiovine et al., *Nucl. Inst. Meth. A* 781 (2015)

- **Critical Radius**

$$R_c = \frac{2\sigma_s}{P_v - P_l}$$

- **Stopping power threshold and critical energy**

$$\left(\frac{dE}{dx}\right)_c = \frac{E_c}{aR_c}$$

$$E_c = -\frac{4}{3}\pi R_c^3 \Delta P + \frac{4}{3}\pi R_c^3 \rho_v H_{lv} \cdots$$

$$\cdots + 4\pi R_c^2 \left(\sigma_s - T\frac{d\sigma_s}{dT}\right)$$

Extra Slide II: Energy Levels