Distribution of Ions in Laser-Driven Fusion Reactions

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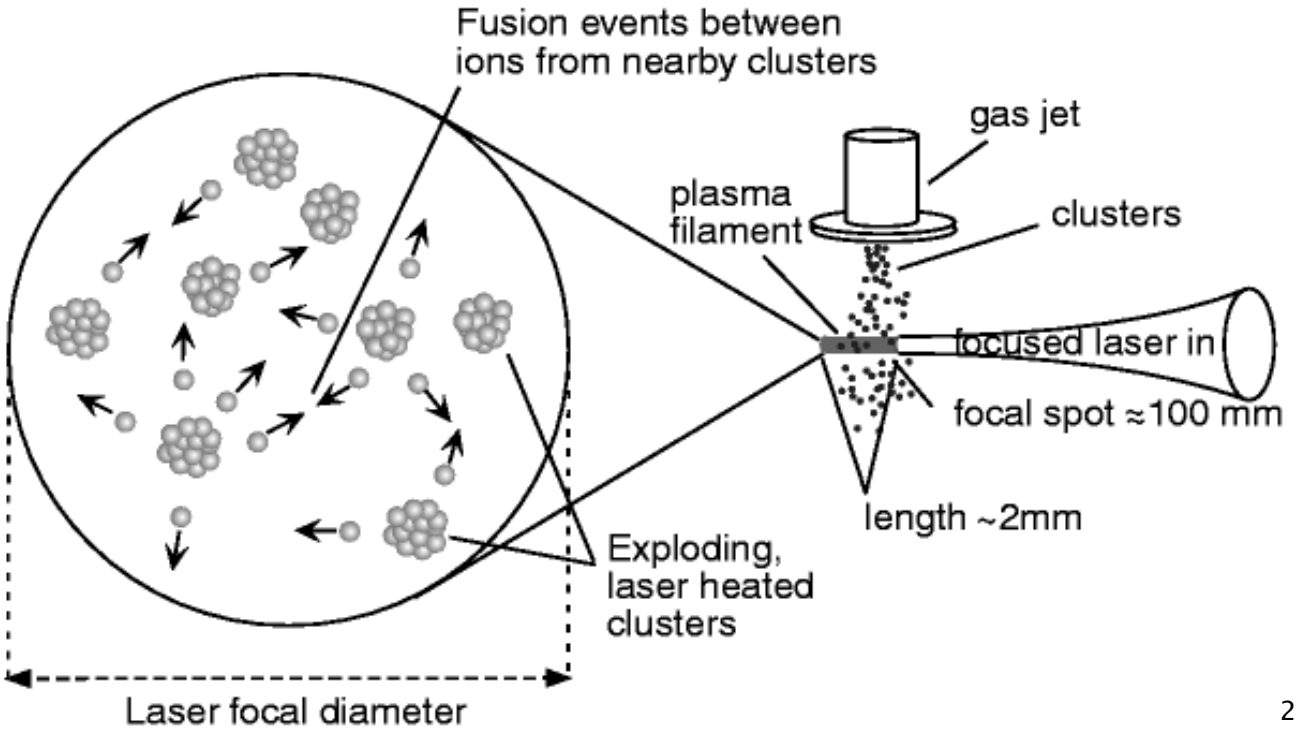
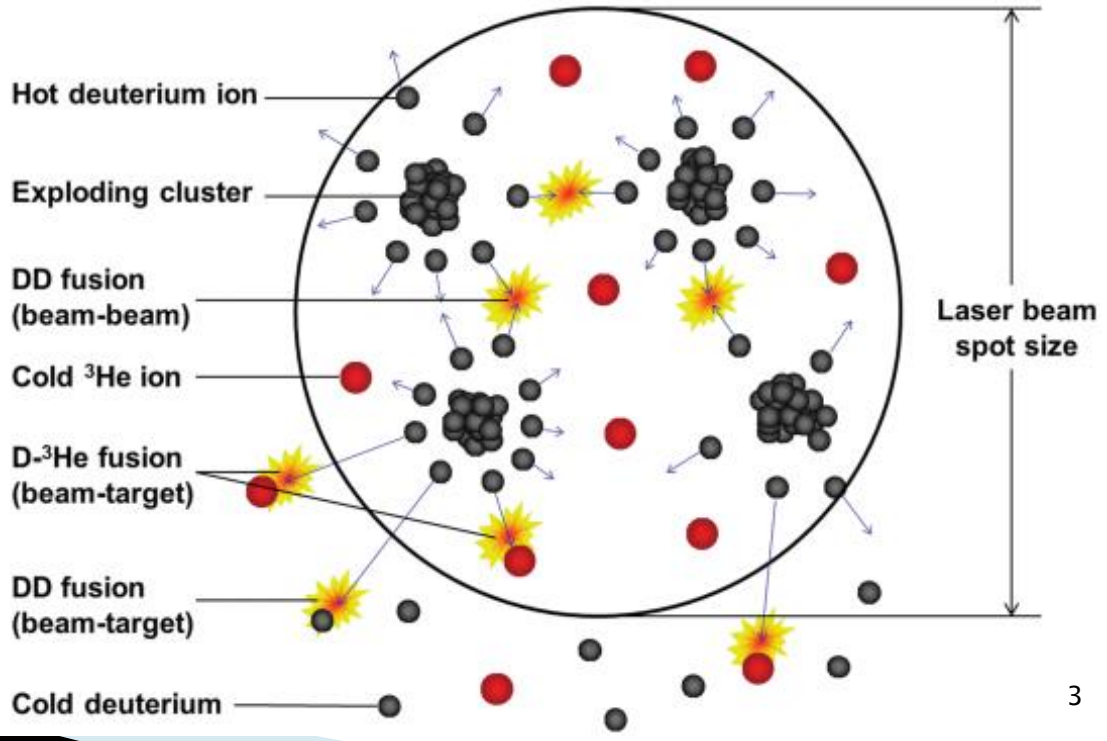
The Experiment

- Cryo-cooled gas mixture of D_2+^{3}He was released from the gas jet
- 90-180J pulse from the Texas Pettawatt Laser irradiated the D_2 clusters
- Coulomb explosion
- Hot plasma
- Fusions

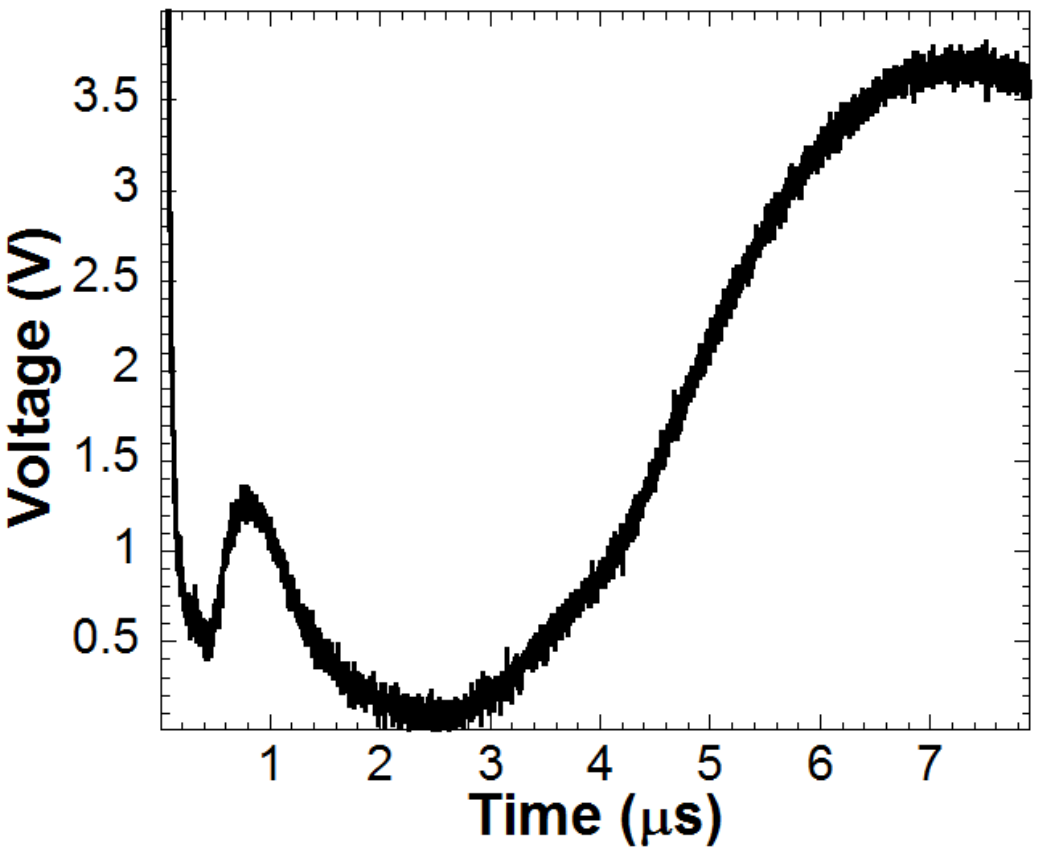


The Experiment

- Hot deuterium ions in plasma can undergo three reactions:
  - D(d,t)p produce 3 MeV protons
  - D(d, ^{3}He)n produce 2.45 MeV neutrons
  - D(^{3}He,p) ^{4}He produce 14.7 MeV protons
- Studied last two



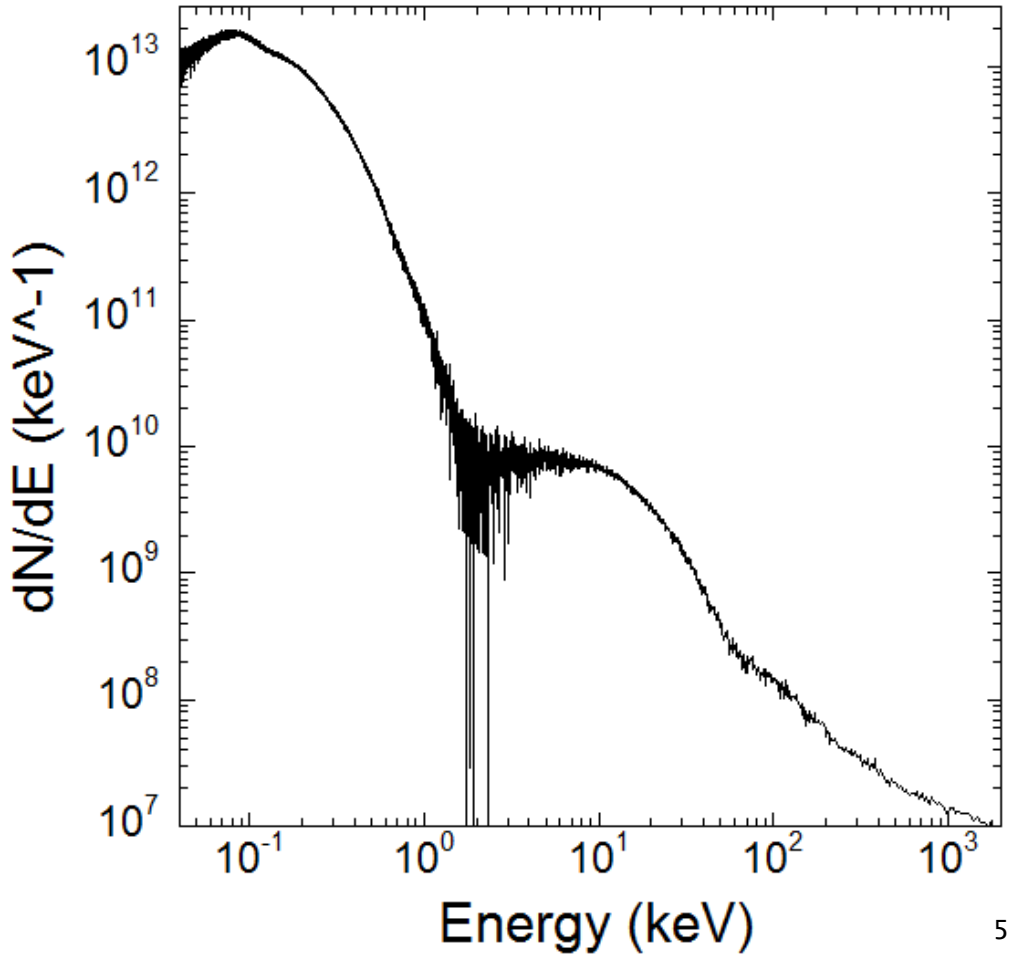
Time Space



- Faraday cup measures current
- Initial spike caused by x-rays due to electromagnetic field
- Transform current of ions to energy for analysis

Time Space to Energy Space

- $\frac{dN}{dt} \rightarrow \frac{dN}{dE}$
- $\frac{dN}{dE} = \frac{dVs^2}{qeRmv^3}\ keV^{-1}$
  - $v = \frac{ds}{dt}$



Log-normal fit

- Cluster size follow log-normal distribution
  - With relationship to E, log-normal distribution can also describe energy distribution [1-2]

$$n_C(M) = \frac{M_0}{M\sqrt{2\pi\sigma^2}} e^{-\frac{(lnM-\mu)^2}{2\sigma^2}}$$

  - M_0 is the normalization constant
  - μ and σ are the mean and standard deviation of the distribution of the natural logarithm of the cluster size

Purpose

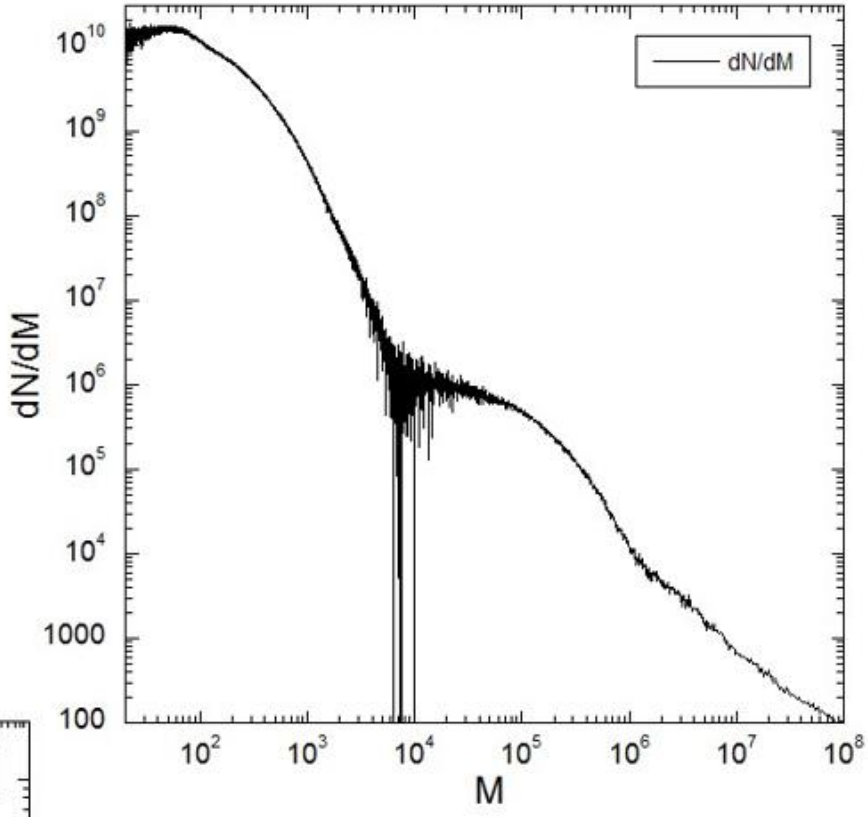
- To test if the experimentally measured distribution follows log-normal distribution
  - If yes, the energy distribution of the hot deuterium ions is so chaotic that it appears thermalized
  - The chaos is caused by
    - many-body interactions over long distances
    - different charges of the particles involved
    - different masses of the particles involved

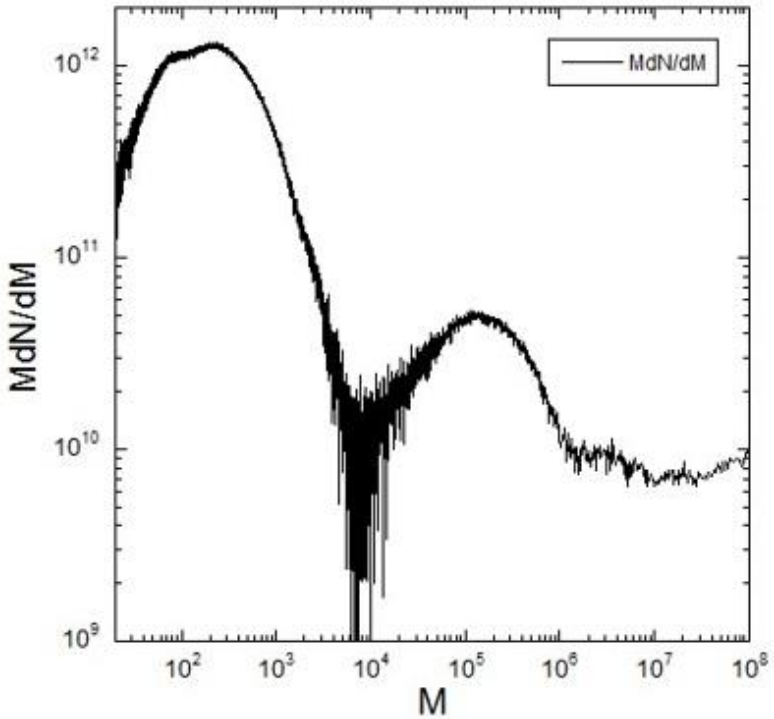
M space

- Relationship between cluster size (M) and Coulomb energy

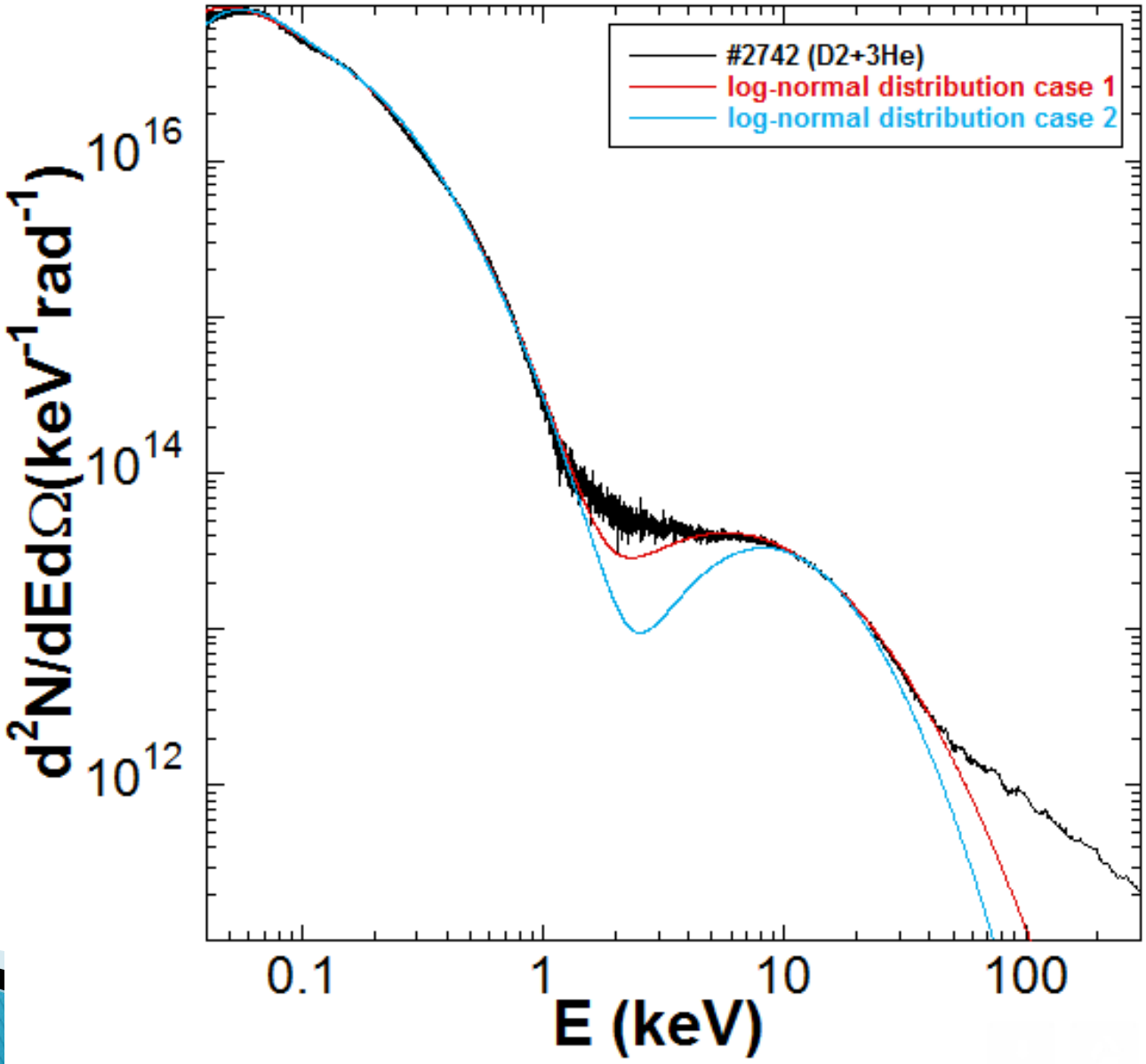
$$\frac{V_C}{M} = 5.1 * 10^{-3} M^{\frac{2}{3}} = E_d$$

- MdN/dM to make peaks clearer





Sample fit


#2742 (D2+3He)
log-normal distribution case 1
log-normal distribution case 2
$d^2N/dEd\Omega(keV^{-1}rad^{-1})$
10^{16}
10^{14}
10^{12}
0.1
1
10
100
E (keV)

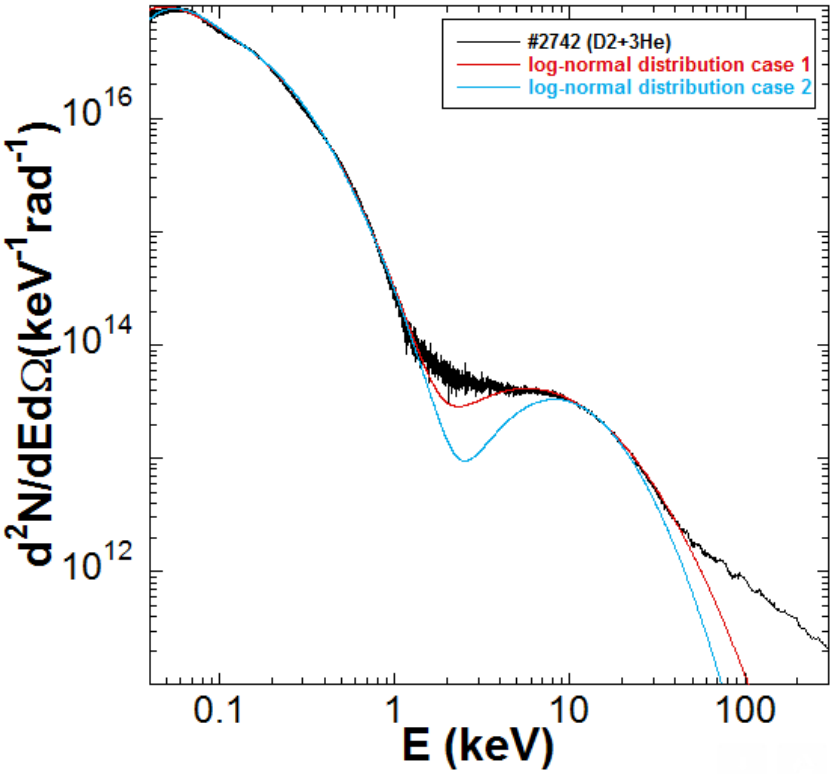
Cross Section – σ(E)

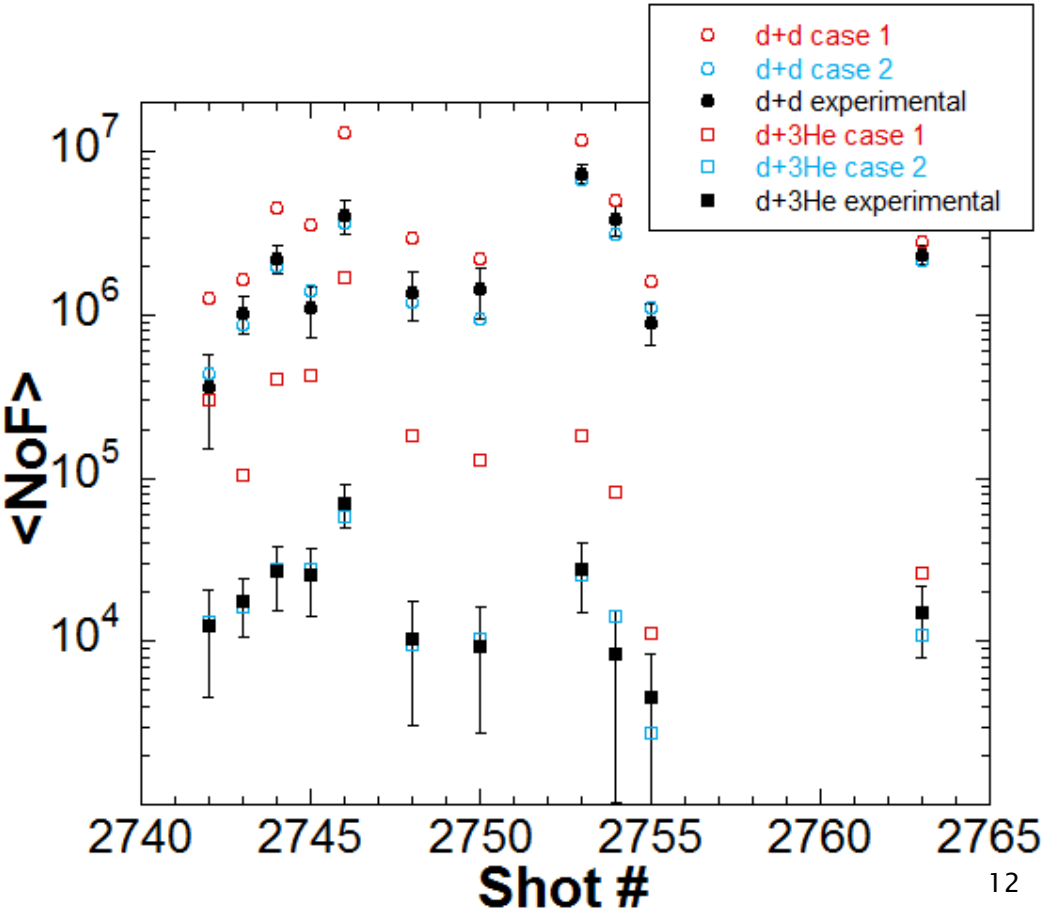
- $\sigma(E) = \frac{S(E)}{E} * e^{-\sqrt{\frac{b}{E}}}$
  - $\sqrt{b} = 31.42 * z1 * z2 * \sqrt{\mu} = 31.42\ keV^{\frac{1}{2}}$
- Use well known astrophysical factor for each reaction
- Use energy at the center of mass of each contribution
  - $E_{CM\ hc} = \frac{1}{2} E_{CM\ hh}$
  - $E_{CM\ d+3He} = \frac{3}{5} E_{CM\ hh}$

Estimating Fusions

- Use fit in energy space and cross section for hot-hot reaction
- $< NoF > = N_1 \rho_2 < \sigma v \tau >$
  - $\tau = \frac{d}{<v>}$
  - $< NoF > = N_1 \rho_2 d < \sigma >$
  - $< \sigma > = \int \frac{dN}{dE} \sigma(E) dE$

Results


#2742 (D2+3He)
log-normal distribution case 1
log-normal distribution case 2
d²N/dEdΩ(keV⁻¹rad⁻¹)
10¹⁶
10¹⁴
10¹²
0.1
1
10
100
E (keV)


d+d case 1
d+d case 2
d+d experimental
d+3He case 1
d+3He case 2
d+3He experimental
<NoF>
10⁷
10⁶
10⁵
10⁴
2740
2745
2750
2755
2760
2765
Shot #

Conclusion

- Log-normal distribution does not model the energy distribution of the deuterium ions
- Hard to differentiate signal from noise
  - Take difference of the two fits and subtract from the signal
- Fit the data with one log-normal instead of two?

Acknowledgements

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Works Consulted

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