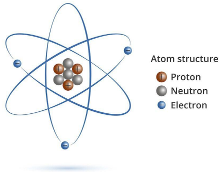
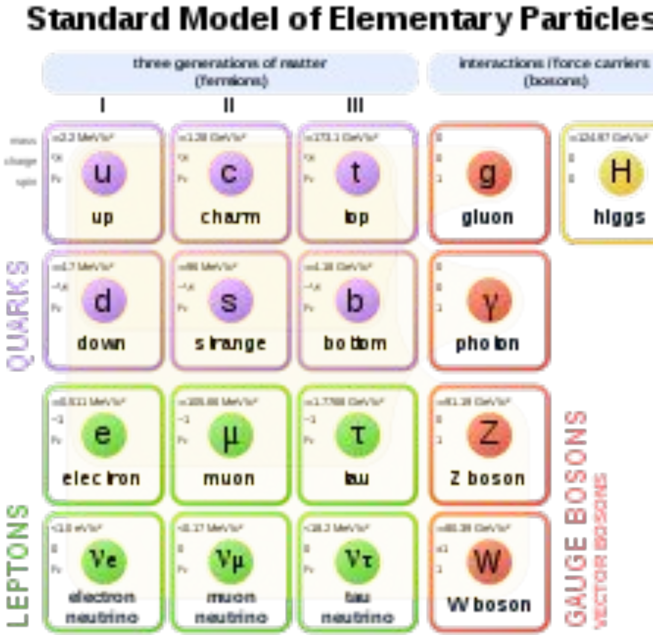
Audrey and Gab

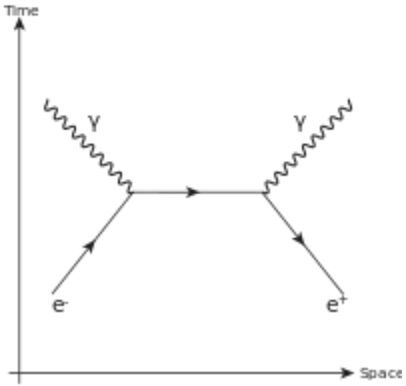
Basics of Particle Physics

- Atom
- Protons/neutrons=baryons made of quarks
- proton= 2 up, 1 down quark
- neutron= 1 up, 2 down quark
- Elementary particles= 6 quarks and 6 leptons
- Fermions= quarks + leptons
- Quarks= up, down, charm, strange, top, bottom
- Leptons= electron, electron neutrino, muon, muon neutrino, tau, tau neutrino
- e, m, and τ have an electric charge and a “sizeable mass”,
- neutrinos are electrically neutral and have very little mass.





Basics pt. 2



- Baryon= made of odd # of quarks, thus classified as fermions
- Non baryonic matter (dark matter?) vs. baryonic (Max)
- Gluons= "glue" quarks together, forms hadrons like protons/neutrons
- GOD PARTICLE= SM includes field need to "break" electroweak symmetry and give particles their correct mass, called higgs field, prove higgs field exists= prove SM correct
- Higgs boson= massive boson w/ 0 spin, no electric charge, no colour charge
- Can particle collisions on earth cause black holes??- NO, well maybe
- Physics suggests it would take more than 3 times current energy of LHC to create black hole
- Hawking radiation (Max)- small black hole, would shrink by evaporation faster than get matter, die within <1 second

Antimatter

- Antiparticle= has same mass, but opposite electric charge
- MUTUAL ANNIHILATION (not as bad as it sounds)- both particles collide and give rise to stuff like photon (gamma rays), neutrinos, etc SUPER unstable, want to annihilate w paired particle bc antiparticle is extremely unstable, so why do we exist??
- Universe should have destroyed itself (wants to be neutral according to SM) but did not- baryon asymmetry, 1 extra matter particle for every billion matter/antimatter pairs
- Way more matter than antimatter, but still antimatter exists/can be produced- Positrons occur in bananas due to radioactive decay of potassium (PET scan)
- A gram of antimatter could produce an explosion the size of a nuclear bomb- only nanograms produced currently;

How we discovered/Standard Model

- 4 fundamental forces- weak/strong nuclear force, gravity, EM force
- Strong force= gluon, EM force= photon, Weak force= W and Z bosons, gravity= graviton??
- SM includes all forces but gravity and their carrier particles, explains how they forces act on all matter

THEORY OF EVERYTHING

- Right now, general relativity (gravity, large scale high mass) and quantum mechanics (non-gravitational forces, small scale low mass)
- Both right! But both wrong- everything proved in each separately, but incompatible together on the the Planck scale (black holes, big bang)
- String theory= posits that in big bang, 4 fundamental forces were 1, every particle in the universe consists of strands that vibrate, great in theory but no tests have given evidence, lacks testable predictions
- THUS SM could be wrong!

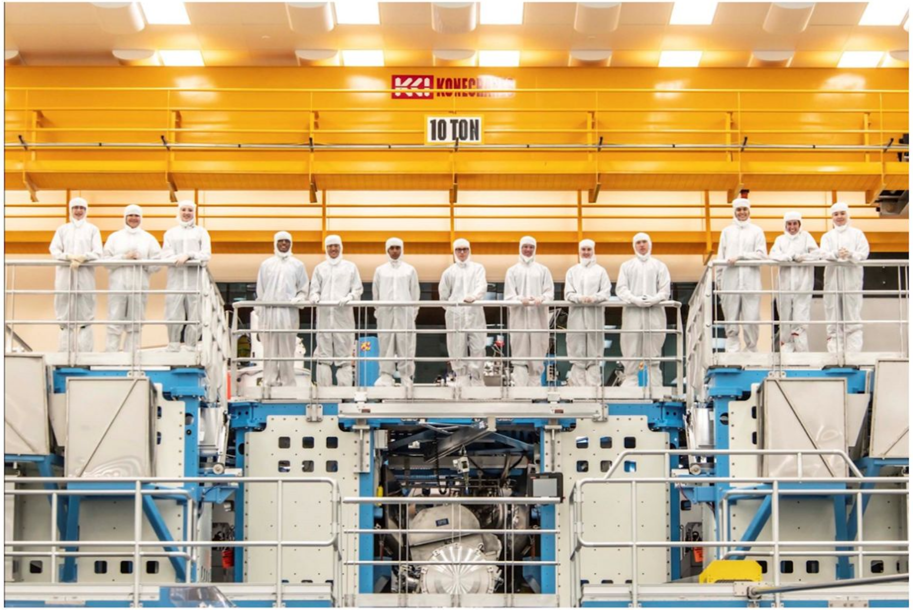
Nuclear Fusion and Fission

- Fusion is the process of making a single heavy nucleus from two lighter nuclei
    - Produced nucleus is lighter than the combined masses of the two original nuclei
    - Difference in mass is released in lots of energy (Famous E=mc2 equation)
    - Fusion reactions occur in stars, and are the source of their energy
    - Goal is to release more energy than required to initiate the reaction
- Fission is the process of splitting a single heavy nucleus into lighter nuclei
    - Can be spontaneous or induced
    - Usually binary, rarely ternary
    - Easy chain reactions as neutrons induce fission, but are also a product
    - Extremely radioactive products, high destructive potential

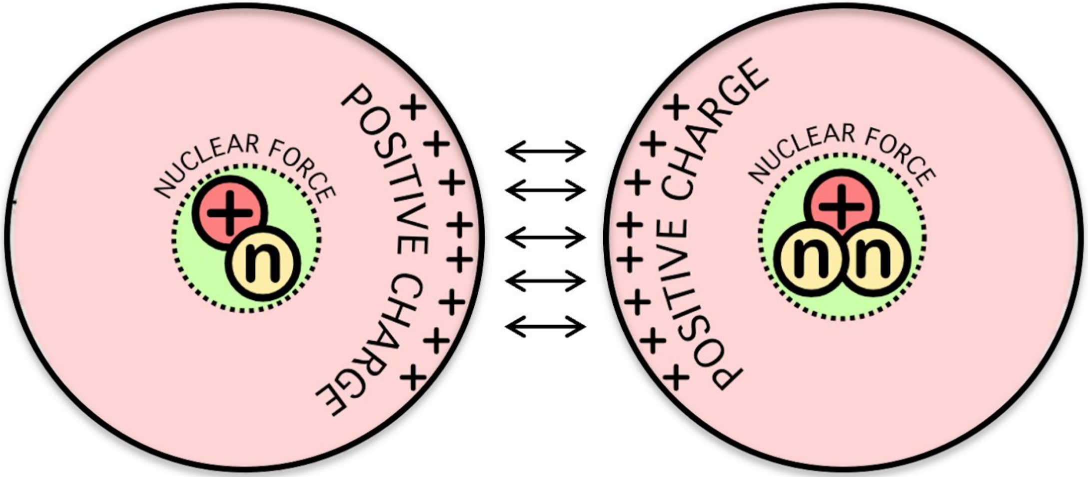
Fusion power is a clean, reliable energy source for the future

- **Nuclear fusion produces no radioactive waste or greenhouse gasses. The only waste product is helium**

- **A cubic kilometer of seawater would provide enough fusion materials to produce an amount of energy equal to all the world's oil reserves**

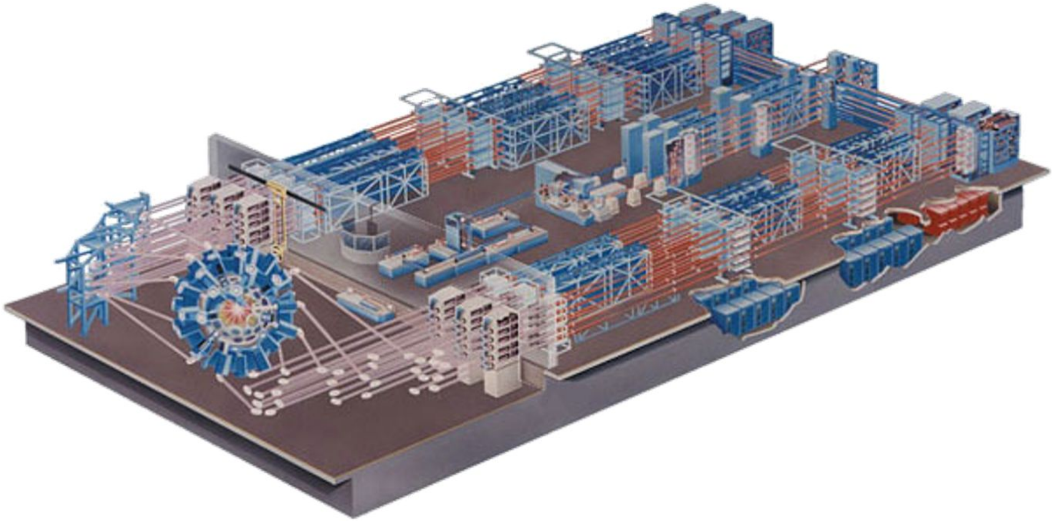


Nuclear fusion occurs when there is enough energy to overcome the electrostatic repulsive force between atoms



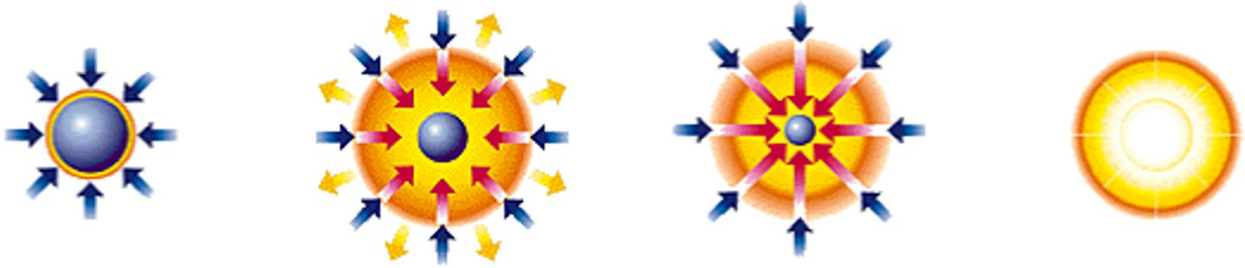
If two nuclei are forced close enough to each other, the strong nuclear force will take effect and bind the two light nuclei into a single, heavy nucleus

The OMEGA 60-beam laser at the Laboratory for Laser Energetics



- **The OMEGA 60-beam laser focuses up to 40,000 joules of energy onto a target that measures less than 1 millimeter in diameter in approximately one billionth of a second**

Inertial Confinement Fusion (ICF) is one of the largest fields of research at LLE

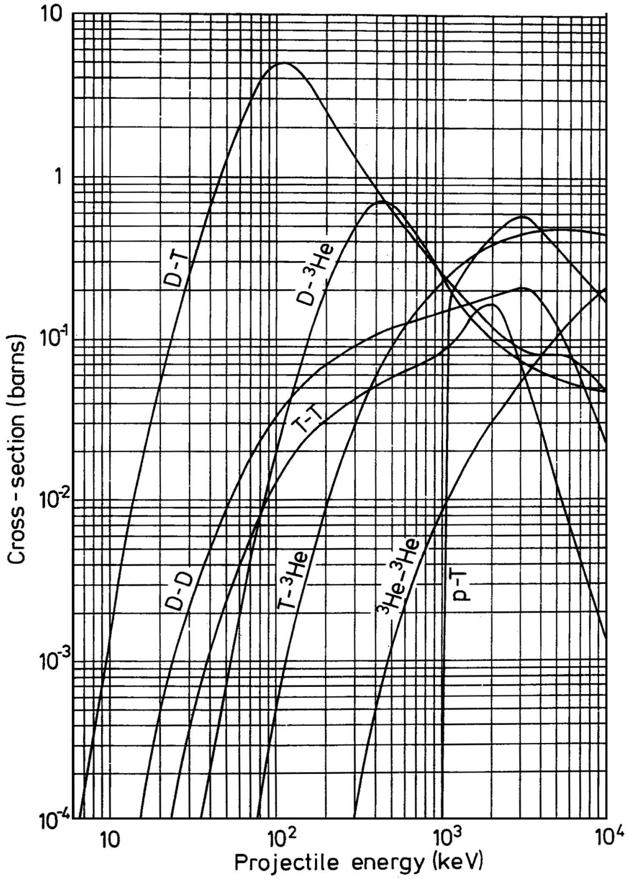


1) Atmosphere formation: Laser beams rapidly heat the surface of the fusion target forming a surrounding plasma envelope.	2) Compression: Fuel is compressed by the rocket-like blowoff of the hot surface material.	3) Ignition: During the final part of the laser pulse, the fuel core reaches 20 times the density of lead and ignites at 100,000,000 degrees Celsius.	4) Burn: Thermonuclear burn spreads rapidly through the compressed fuel, yielding many times the input energy.

Laser energy Blowoff Inward transported thermal energy

Nuclear Cross Sections

- Used to describe the probability of a specific nuclear reaction occuring
- Related to the characteristic area of nuclei
- Peaks represent the most efficient reactions
- Note that x-axis is in keV

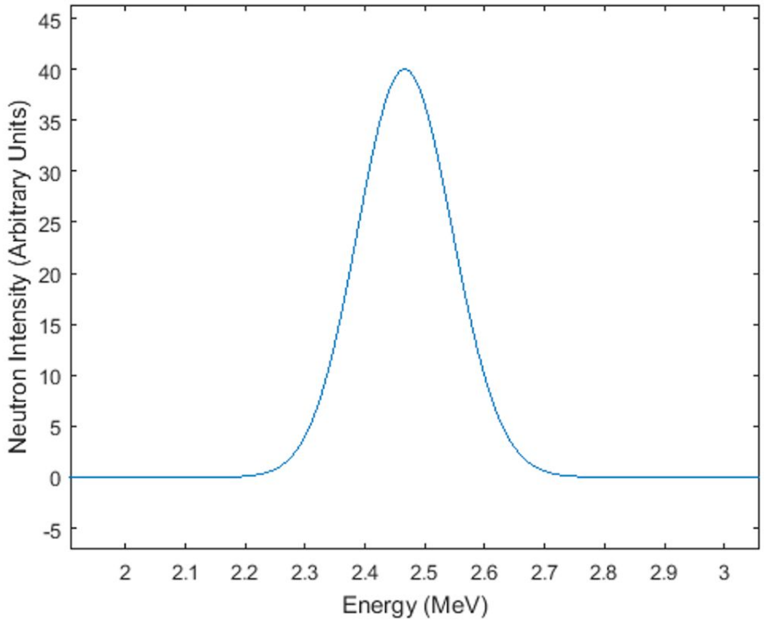


Using Mass-Energy

- Conservation of mass as you learn in high school isn't accurate
- Conservation of mass-energy is used in practice, as mass and energy are treated as interconvertible manifestations of the same thing
- Given a Deuterium-Deuterium fusion reaction producing Helium 3 and a neutron, how much energy is released?
- 2.014 amu + 2.014 amu => 3.016 amu + 1.008 amu
- 1 amu converts to about 931.5 MeV, so how many MeV are produced here?

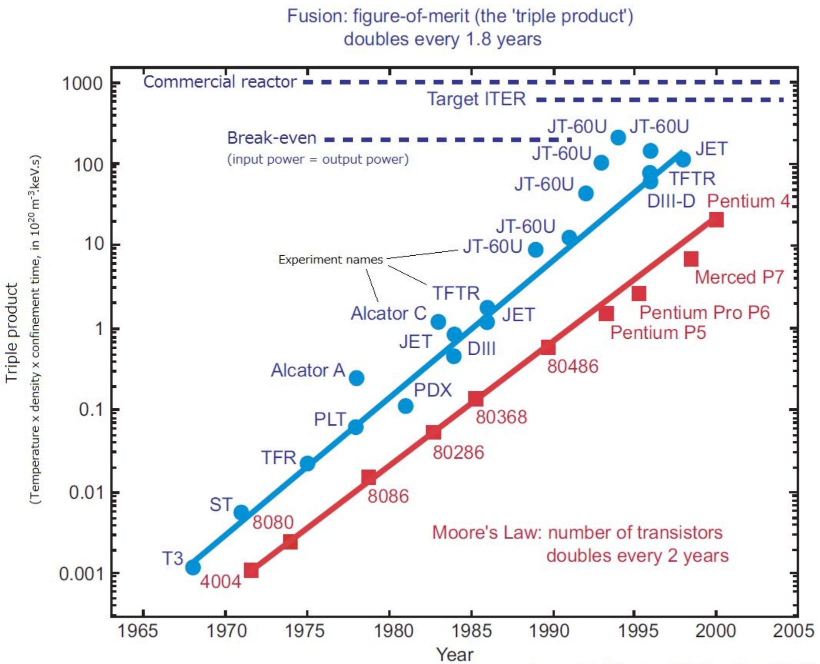
Inertial confinement fusion implosions generate thermonuclear reactions

$$^{2}_{1}\mathrm{H} + ^{2}_{1}\mathrm{H} \rightarrow ^{3}_{2}\mathrm{He} + 2.45\ \mathrm{MeV\ neutron}$$



Efficiency is King

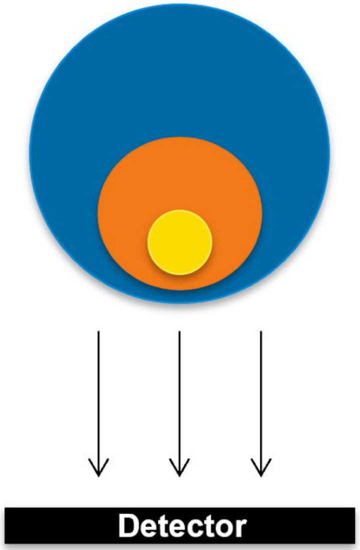
- Essentially the only obstacle to fusion as an energy source
- Incomplete conversion of applied energy to kinetic energy of fuel
- Unwanted conversion to thermal energy
- Asymmetry yields bad containment

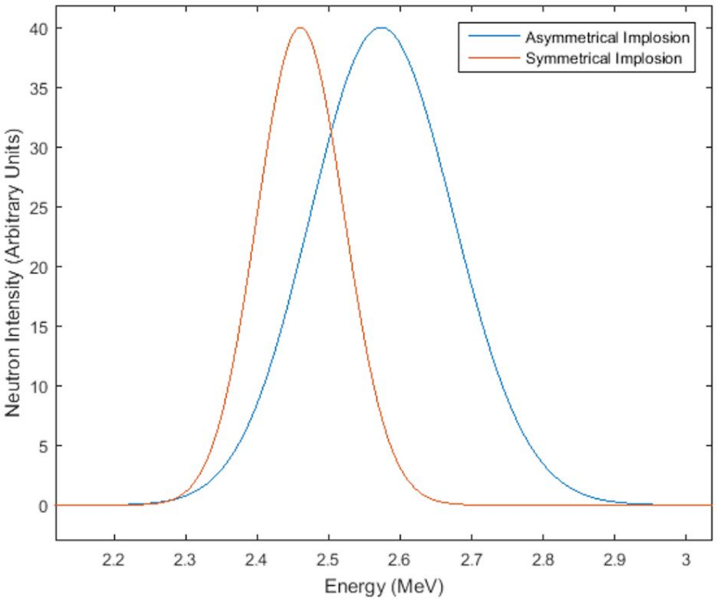


Source: A.J. Webster, 2003 Phys. Educ. 38 135

Variations in the fuel assembly at peak compression will result in underperformance of the target

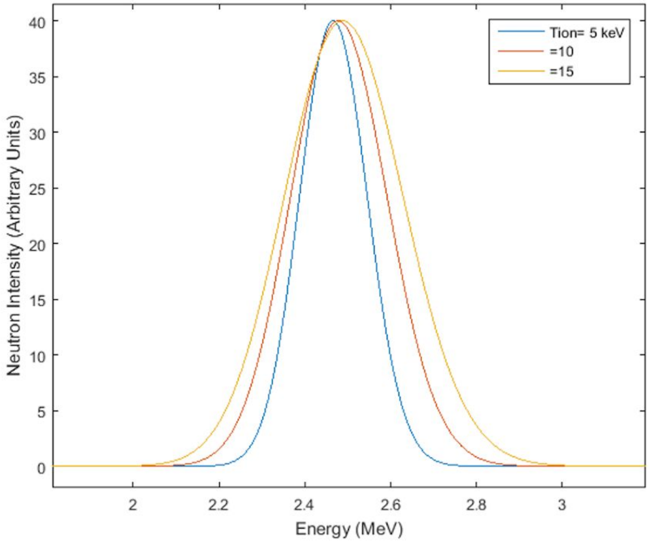
- By inducing asymmetries in the laser-target system, the effect of offsets can be evaluated and used to diagnose and correct asymmetries and power imbalances

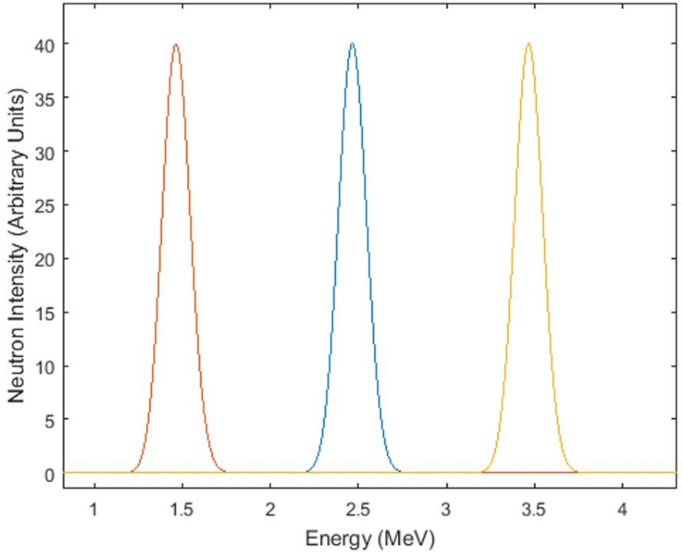




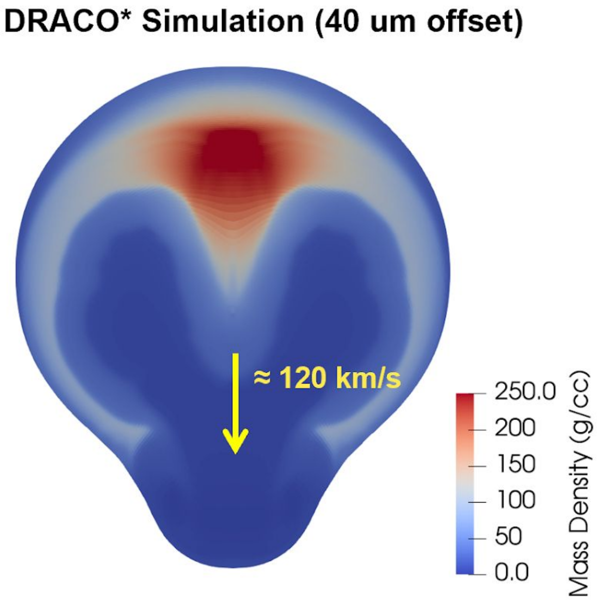
Neutron energy spectra can be used to infer characteristics of fusing plasma

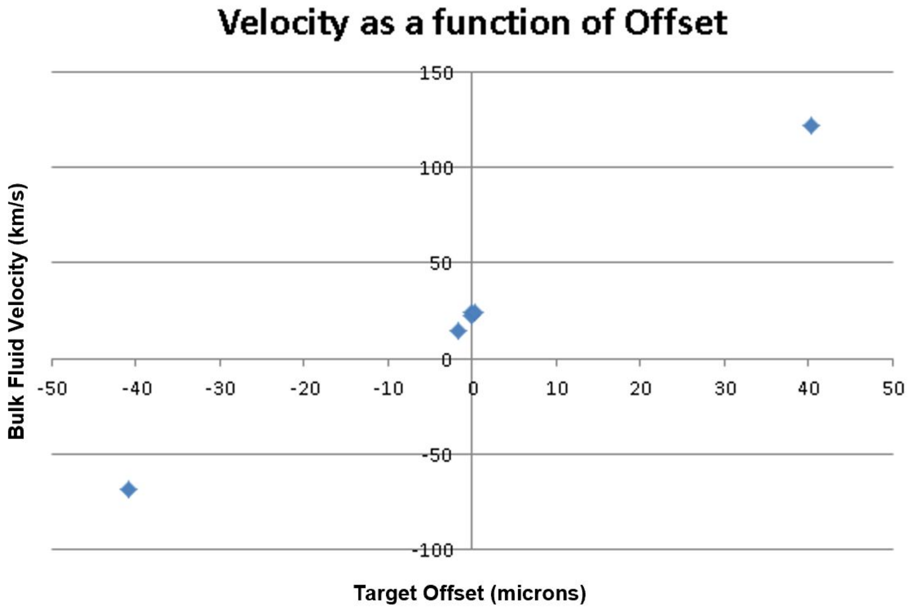
- The breadth of the spectrum indicates the ion temperature of the plasma
- The mean value of the spectrum can be used to interpret the bulk fluid velocity





Target offset-induced modes were visible in the recorded bulk fluid velocities





* D. Keller, T. J. B. Collins, J. A. Delettrez, P. W. McKenty, P. B. Radha, B. Whitney, and G. A. Moses, Bull. Am. Phys. Soc. 44,37 (1999)

**Weilacher, F., Radha, P. B., & Forrest, C. (2018). Three-dimensional modeling of the neutron spectrum to infer plasma conditions in cryogenic inertial confinement fusion implosions. Physics of Plasmas, 25(4)

HOW TO GET RESEARCH OPPORTUNITIES

- Find what you're passionate about and ASK!!
- Look through research groups, and email people doing cool stuff
- Once you're in college, approach professors directly
- If you're looking for experience, and people are hesitant to hire you, offer to work for free
- If you can't find a mentor, mentor yourself!
  - Tons of amazing publicly accessible science on the internet
  - Look up NASA's citizen science page! Train AI, identify new planets, examine satellite data