High Yield Muon Catalyzed Fusion

Erica Garcia Badaracco
New Perspectives 2023
27 June 2023

Advisors: Carol J. Johnstone¹, Kevin Lynch¹, Ara Knaian²
¹Fermi National Accelerator Laboratory
²NK Labs, LLC

Acknowledgements: This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics. This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Community College Internships Program (CCI).
Thermonuclear Fusion

Need for PLASMA -> temperatures >50 million degrees (several times hotter than the center of the sun).

Our Sun

Isotopes of Hydrogen

Fusion Outcome

Deuterium

Tritium

Helium

Neutron
Muon-Catalyzed Fusion

- Mixture of Deuterium-Tritium
- Muon replaces electron
- Overcome Coulomb barrier
- Fusion!
- Emission of $\alpha$ particle + neutron + $\mu$

Muon-Catalyzed Fusion Process

Goal -> Increase Fusion per Muon!
Method -> Decrease time between fusions & sticking factor.

Atomic size of Hydrogen vs. Muonic Hydrogen

Isotopes of Hydrogen
Target operating point for commercial fusion

(Assumes superconducting accelerator, Brayton cycle balance-of-plant, exothermic tritium breeding, and revenue from heat sales.)
Temperature and Pressure Dependence

Fig. 12. (a) Normalized cycling rates as a function of temperature for the gaseous D/T mixture at $C_I \approx 33\%$ and different densities $\varphi = 0.88–0.91 (~\square) , 0.62–0.64 (~\blacktriangleleft) , 0.49–0.52 (~\blacktriangle) , 0.39–0.45 (~\blacksquare) , 0.19–0.24 (~\bullet) ~LHD$. (b) Normalized cycling rates as a function of density for the gaseous D/T mixture at $C_I \approx 33\%$ and different temperatures $T = 800 \, K , C_I = 0.34–0.36 (~\blacktriangleleft) ; T = 550 \, K , C_I = 0.33–0.36 (~\blacktriangle) ; T = 300 \, K , C_I = 0.31–0.36 (~\blacksquare) ; T = 158 \, K , C_I = 0.31 (~\bullet)$. The curves are obtained with optimum parameters.
Theory and Experiment Disagree Quantitatively

\[ Q = 22.4 \text{MeV} \times \frac{N_{\text{fusions}}/\mu}{E_\mu} \]

New Areas of Temperature and Pressure

Explore Temperatures from 7 to 1500 K

New Areas of Temperature & Pressure that will be Explored

Explore density of up to 3 LHD

Diamond Anvil Cell - Used to Achieve High Pressures

Pressure = \frac{\text{Force}}{\text{Area}}
Experimental Setup
Experimental Setup at PSI in 2022

piE1 muon beamline - around 50,000 μ⁻/s - Villigen, Switzerland
Results

Hydrogen (18K, 1 LHD)  Deuterium (22K, 1 LHD)
Fermilab Muon Beam

400 MeV proton LINAC → Tungsten Target \( \pi^- \) decay → \( \mu^- \)