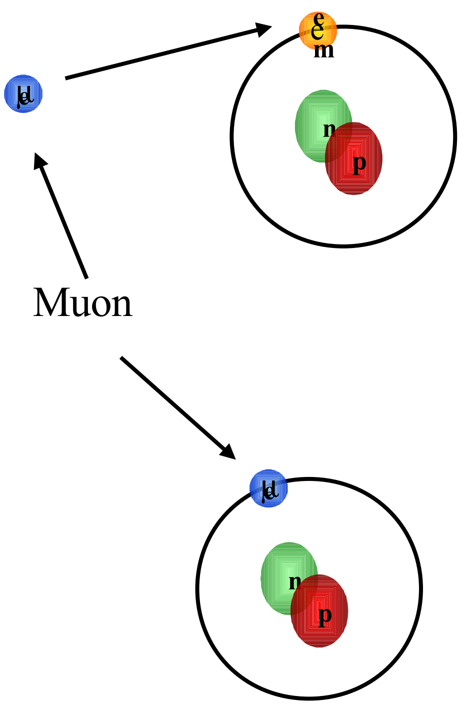
Introduction

Muon: An elementary particle similar to an electron.
Differences from an electron

- its mass ~ 207 times the mass of the electron (called an "heavy electron")
- its lifetime. Decays in ~ 2 ms into an electron as:

$$\mu^- \rightarrow e^- + \nu_e + \nu_\mu$$

Muonic atom
Muon is captured by an atom/molecule and binds to these just as an electron and forms a **muonic atom/molecule** respectively.
In the MuSun experiment, the muon is captured in deuterium gas.

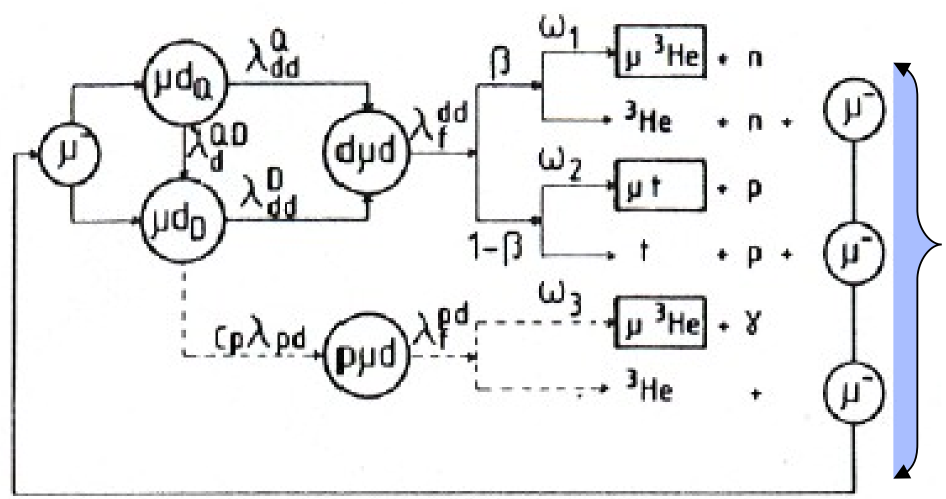


Muonic deuterium

Muon Chemistry in deuterium

- $(\mu d)1s$ atom is a mixture of Doublet(1/2) + Quartet spin (3/2) states
- Irreversible quartet to doublet transition at a rate λ_d^{QD} >> muon decay rate (λ_c) (that is why deuterium is used)
- μd atoms form $d\mu d$ molecules at rates λ_{dd}^{Q} or λ_{dd}^{D}
- $d\mu d$ undergo fusion with branching ratios

$$d\mu d \longrightarrow n + He + \mu^- \ (40\%)$$
$$d\mu d \longrightarrow t + p + \mu^- \ (60\%)$$



94% re-enter cycle

Experimental Goal and Motivation

- To measure the rate at which a muon is captured by liquid deuterium to a precision better than 1.5% .

Reaction involved : $\mu^- + d \rightarrow \nu + n + n$ Rate Λ_d from $\mu d(\uparrow\downarrow)$ atom

- Impact understanding of fundamental reactions of astrophysical interest, like
  - Solar pp fusion

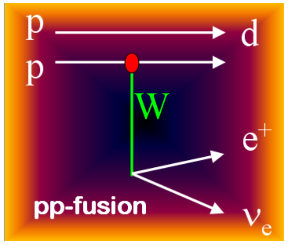
    $p + p \dashrightarrow d + e^+ + \nu_e$

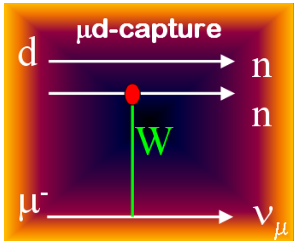
  - Sudbury Neutrino Observatory observed

    $\nu + d$ reactions

  Since these reactions are similar to the muon decay reaction:

  $$\mu^- + d \rightarrow n + n + \nu_\mu$$





- Close relation to neutrino/astrophysics

  ← model-independent connection μ+d to pp fusion and ν+d reaction via EFT (Effective field theory)

Use Basic MuCap Technique

- Lifetime method
  10^{10} $\mu\to e\nu\nu$ decays
  measure $\tau_{\mu-}$ to 10ppm,

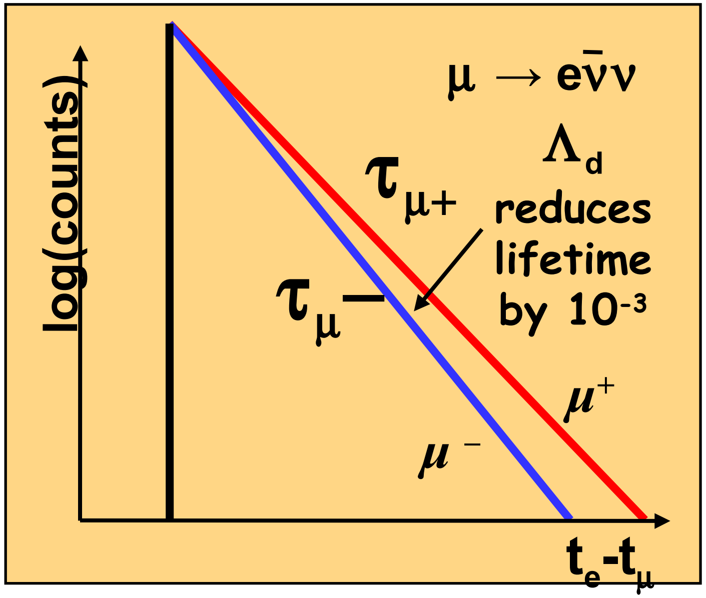
  $\Lambda_d = 1/\tau_{\mu-} - 1/\tau_{\mu+}$ to 1%

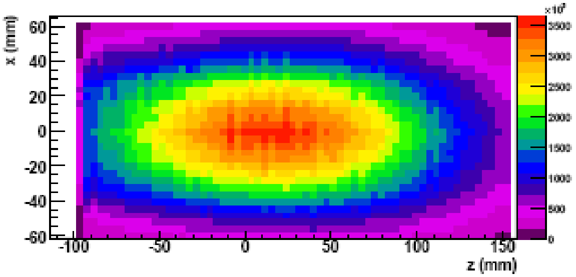
- Unambiguous interpretation at optimized target conditions

- Ultra-pure gas system and purity monitoring at 1 ppb level

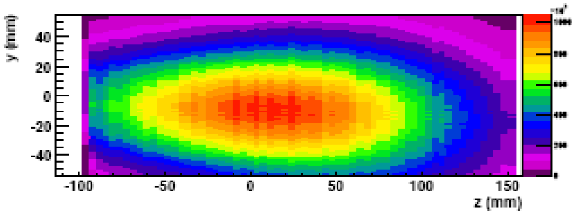
- Clean μ stop definition in active target (TPC)

- 3 times higher rate with Muon-On-Request (MuLan Experiment)





MuCap TPC top



TPC side

Experiment Overview

Goal of the experiment:

Precise determination of the μd doublet capture rate (< 1.5%).

This requires: (i) Maximum doublet population and (ii) background from μ^3He minimized.

Technique for < 1.5% Measurement:

Muons are stopped in an active, ultra pure deuterium gas target (of high density and high pressure 0.5 MPa to accelerate hyperfine transition from quartet to doublet) consisting of a cryogenic ionization chamber operated as time projection chamber (TPC or cryo-TPC).

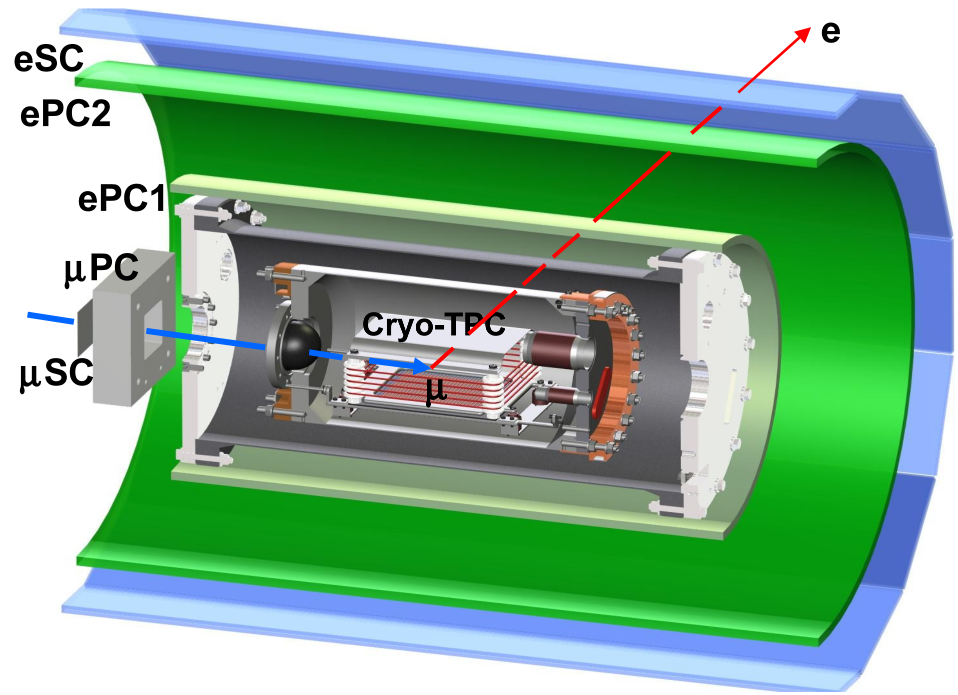
Low temperature (25 – 35 K) causes smaller rate of λ_d leads to less quartet population (via recycling)

eSC: Electron Scintillator

ePC: Electron Projection Chamber

μPC: Muon Projection Chamber

μSC: Muon Scintillator



Cryo-TPC Design

Cathode: Top of chamber at a high voltage. Designed obtain a homogeneous field.
Grid: Mounted on 4 ceramic insulators. Distance from anode pad plane varies from 0.5 mm to 1.5 mm. Acts as an electrical screen for the positive charges.
Anode: A pad is in the form of meshes which helps to detect delayed protons, neutrons, He etc.

Muons colliding with deuterium gas create positive ions and electrons. The anode traps these electrons to detect delayed protons, neutrons, He etc.

Target in an aluminum shell which transmits decay electrons, and yet endures pressure in the chamber

Cryo-TPC special