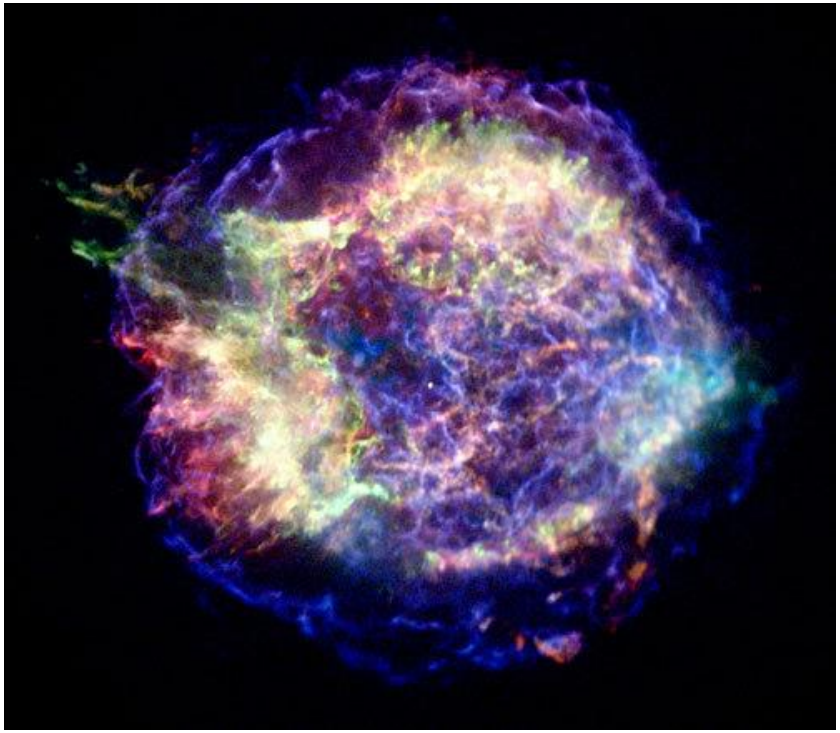
Supernova Neutrino Detection with LBNE far Detector



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Contents

- LBNE experimental setup
- Using LBNE for Supernova physics
- Making a background model

LBNE

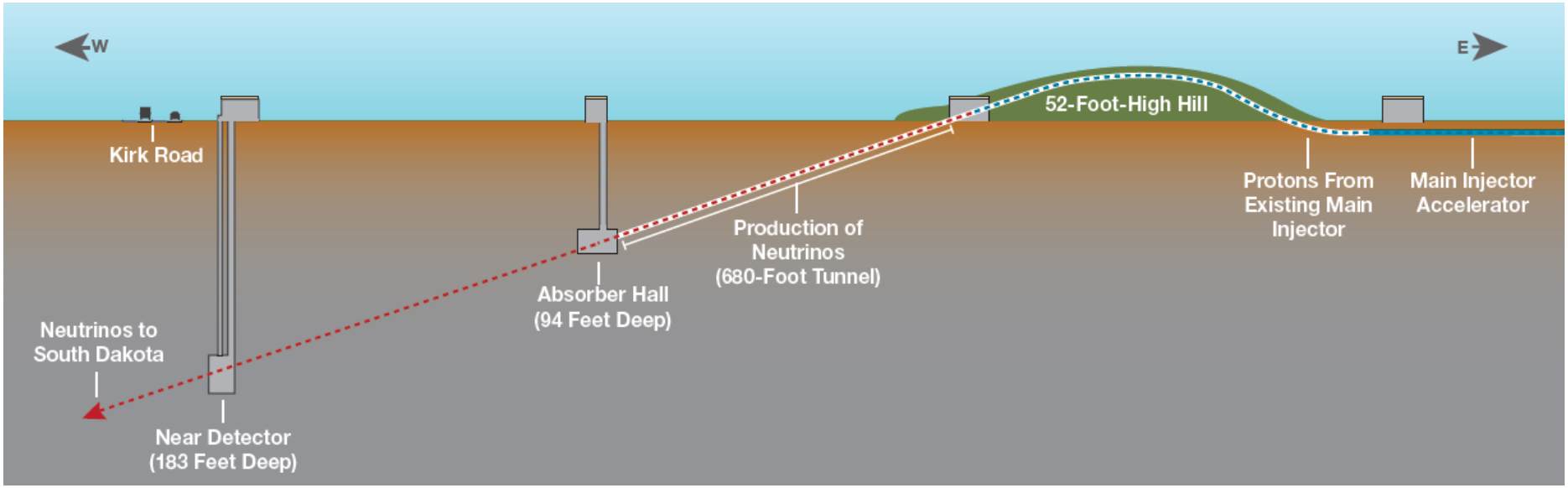
- Long baseline neutrino experiment
- Neutrino oscillation experiment
- What is a neutrino oscillation?
  - Three flavor of eigenstates of the neutrino
    - Electron: ν_e
    - Muon: ν_μ
    - Tauon: ν_τ
  - Transitions from one flavor eigenstate to another
- What is long baseline?
  - Distance between source of neutrinos and detector

LBNE Goals

- Primary Goals:
  - Measure parameters that characterize three flavor neutrino oscillations
  - $\sin^2(2\Theta_{13})$, $\sin^2(2\Theta_{23})$
  - Study leptonic CP violation: δ_{CP}
  - Determine relative neutrino masses
  - Δm_{13}^2, Δm_{23}^2 normal or inverted
- Secondary Goals:
  - Proton decay
  - Supernova Neutrinos
- Constructed by 2022
- Take data for 2 decades

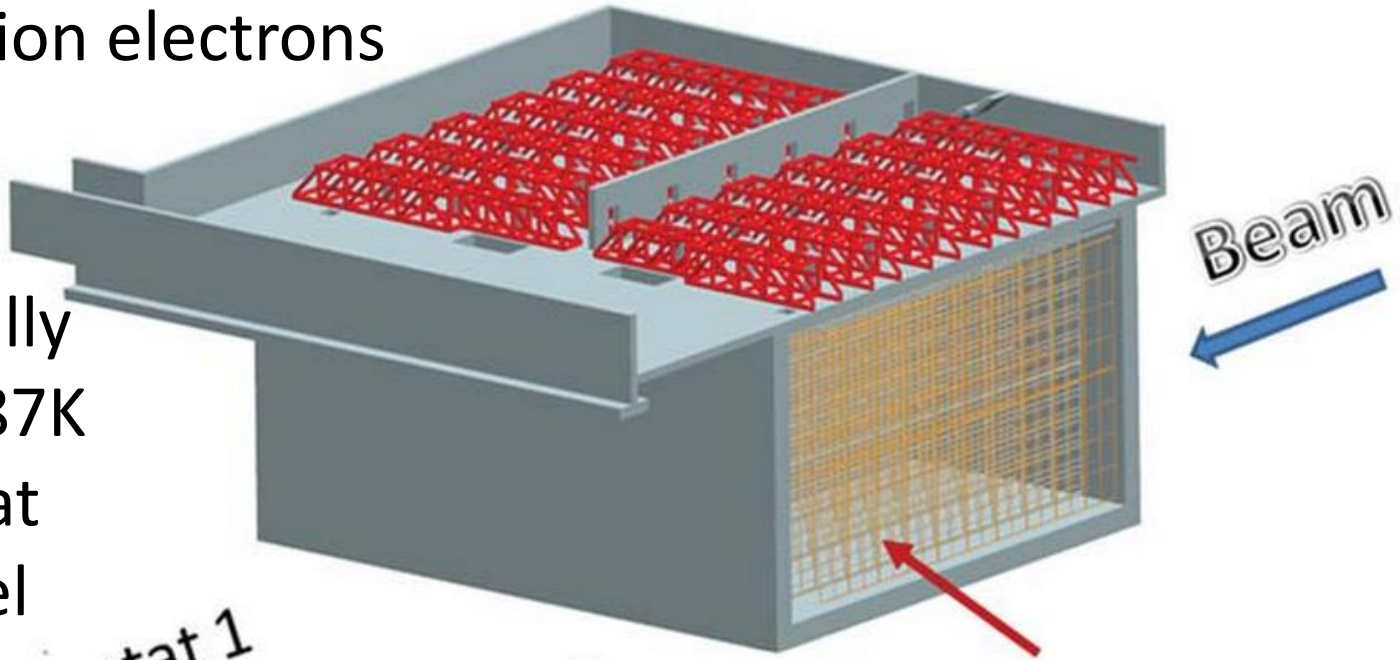
Experimental Setup

- Neutrino beam (Fermilab to SURF)
  - From Main injector proton accelerator
  - Mostly muon neutrinos
  - ~120GeV
  - Highest intensity neutrino beam
- Near and far detector
  - Near detector characterizes the initial muon neutrino beam
  - Far detector is located ~1300km
  - Looking for electron neutrinos through charged current interactions
  - All neutrino flavors through elastic scattering



Far Detector

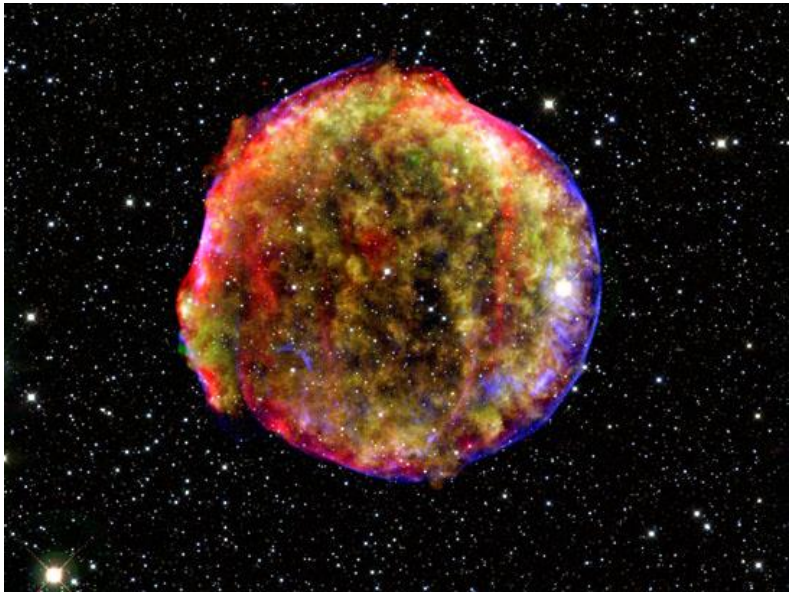
- Liquid Argon TPC (LArTPC)
- Two vessels 60ftx60ftx100ft
- Alternating anode, cathode wire plans read out ionization electrons

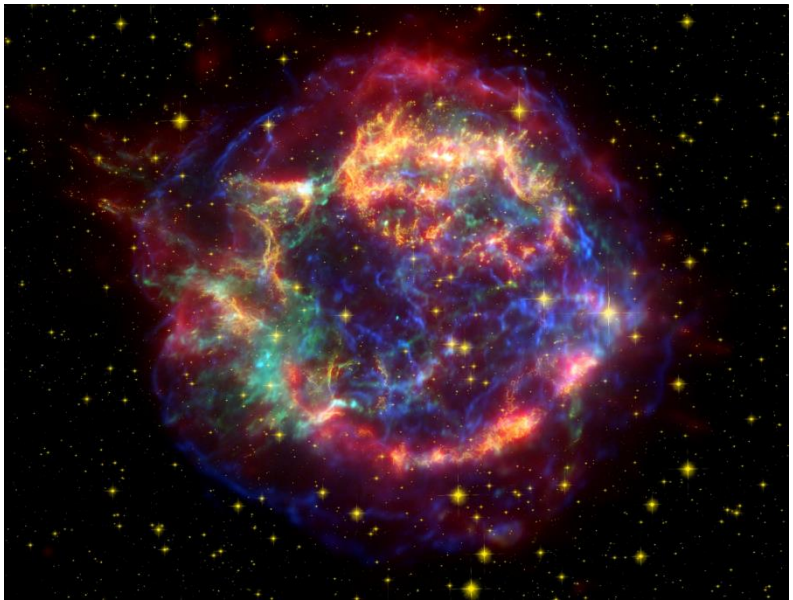


- Cryogenically cooled to 87K
- Hopefully at 4850ft level

Supernova Burst Physics

- 2-3 per century in Milky Way
- 40% chance during LBNE run time
- SN1987A
  - 19 neutrino events observed
- LBNE detectors would likely register between 1000 and 10000 neutrinos
- High event rate makes observation of second by second evolution possible





Supernova Burst Physics

- Time evolution of supernova:
  - Collapse of iron core
  - Accretion phase
  - Cooling stage
- Exotic features:
  - Transitions to quark matter
  - Black hole
- Neutrino oscillation physics in supernova:
  - Flavor states are coupled (coherent scattering off each other)
  - Different oscillation patterns for normal and inverted mass hierarchies
  - Signal has high sensitivity to values of Θ_{13}
- Neutrinos emerge quickly after core collapse:
  - Supernova alert
  - Catch supernova in early light turn on stages

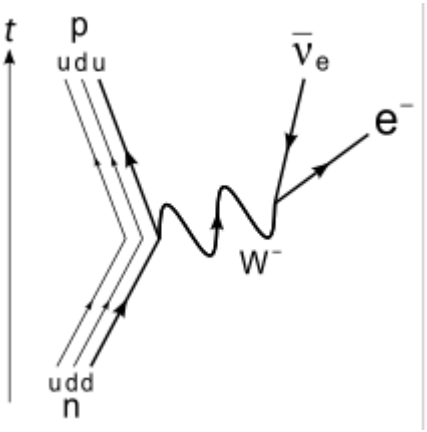
Cosmogenic Activation Background

Isotope	Q [MeV]	Ex [MeV]	Half Life [s]	Decay	% Decay Cross Section
21Na	3.5476	0	22.49	Beta+	100
22Na	2.8423	0	8.2135E+07	Beta+	100
23Na	-	-	-	-	-
24Na	-	0.4712074	0.02018	IT	99.95
24Na	5.551545	0	5.40E+04	Beta-	100
24Na	5.5136	0.47207	2.020E-02	Beta-	0.05
25Na	3.8350	0	59.1	Beta-	100
26Na	9.312	0	1.077	Beta-	100
28Na	14.030	0	0.0305	Beta-	100
23Mg	4.0561	0	11.317	EC	100
24Mg	-	-	-	-	-
25Mg	-	-	-	-	-
26Mg	-	-	-	-	-
27Mg	2.6106	0	5.67E+02	Beta-	100
28Mg	1.8318	0	7.53E+04	Beta-	100
29Mg	7.613	0	1.30	Beta-	100
26Al	4.00414	0	2.26E+13	EC	100
26Al	4.00414	0.228305	6.3452	Ec	100
27Al	-	-	-	-	-
28Al	4.6418	0	134.48	Beta-	100
29Al	3.679712	0	394	Beta-	100
30Al	8.561	0	3.62	Beta-	100
31Al	7.994	0	0.644	Beta-	100
27Si	4.81236	0	4.16	EC	100
28Si	-	-	-	-	-
29Si	-	-	-	-	-
30Si	-	-	-	-	-
31Si	1.49150	0	9441.6	Beta-	100
32Si	0.2272	0	4.83E+09	Beta-	100
33Si	5.845	0	6.11	Beta-	100
34Si	4.592	0	2.77	Beta-	100
35Si	2.117	0	0.78	Beta-n	<5.30
35Si	10.500	0	0.78	Beta-	100
36Si	4.469	0	0.45	Beta-n	<10.00
36Si	7.833	0	0.45	Beta-	100

- Cosmic rays
- Interact with ^{40}Ar inellastically
- Result is new radioactive nuclei, undergoes beta decay

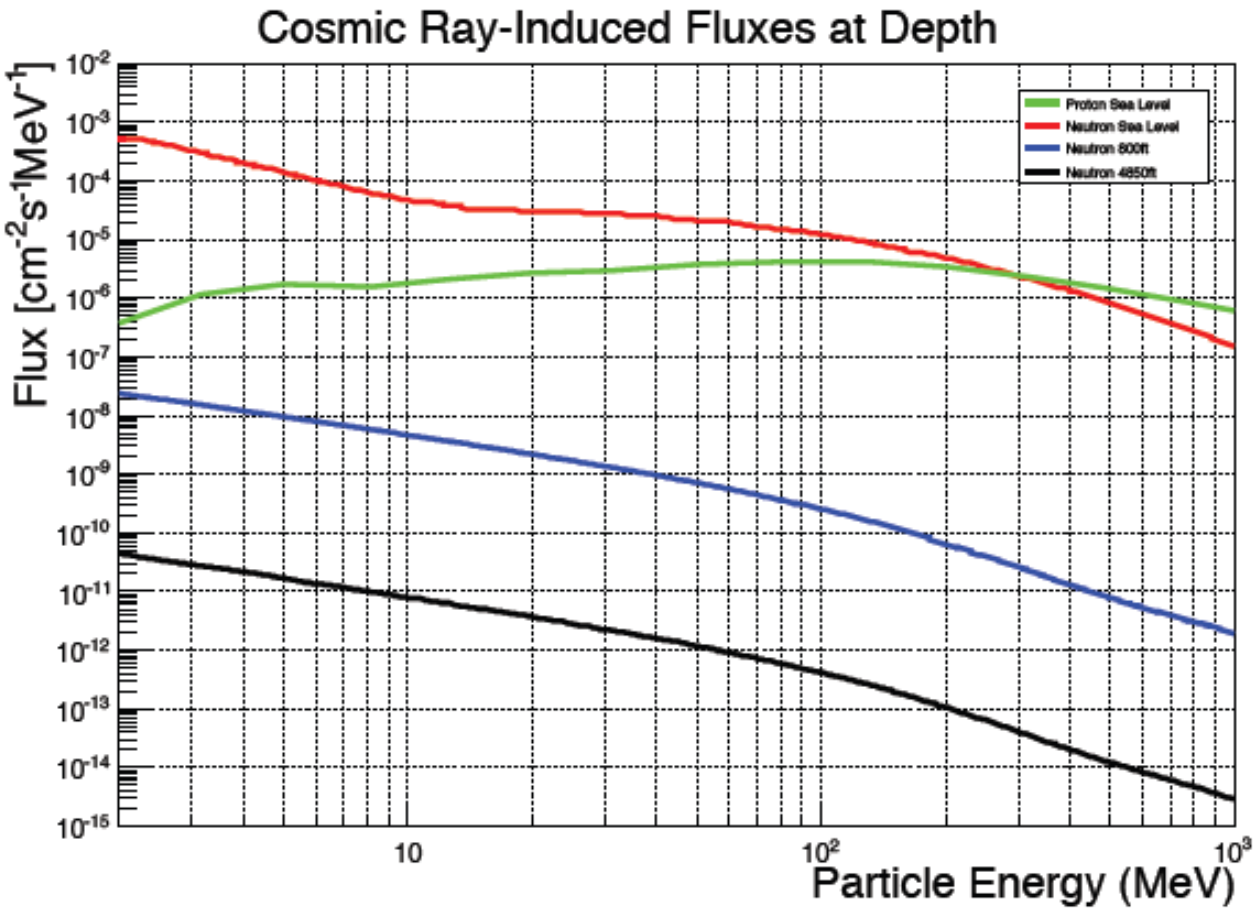
$$ {}^{A}_{Z}N \rightarrow {}^{A}_{Z-1}N' + e^{+} + \nu_e $$

$$ {}^{A}_{Z}N \rightarrow {}^{A}_{Z+1}N' + e^{-} + \bar{\nu}_e $$



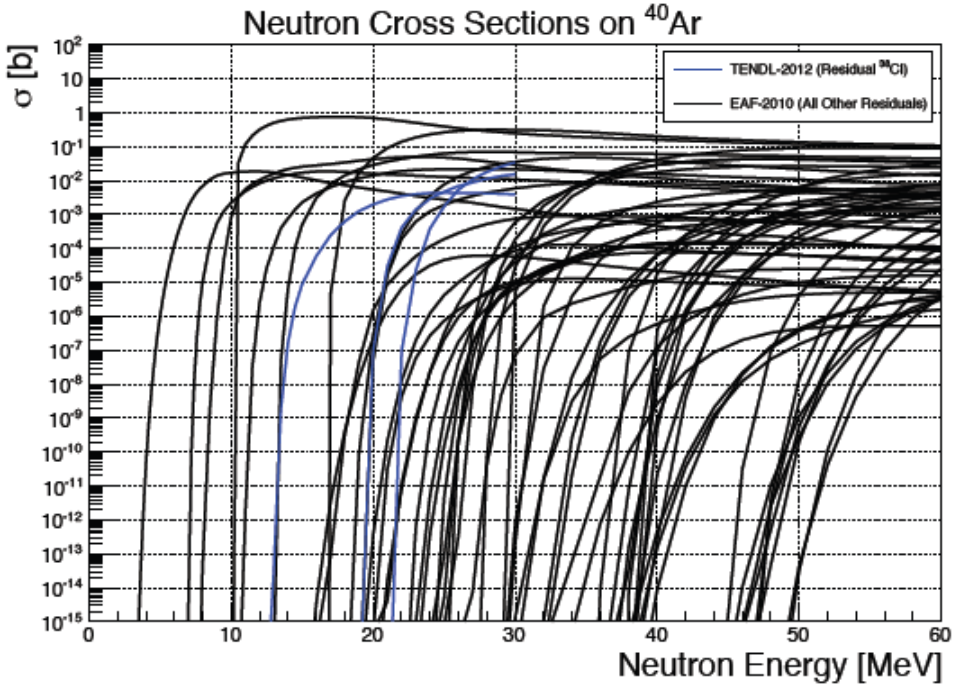
- Supernova neutrinos in range 5-50MeV (same range)

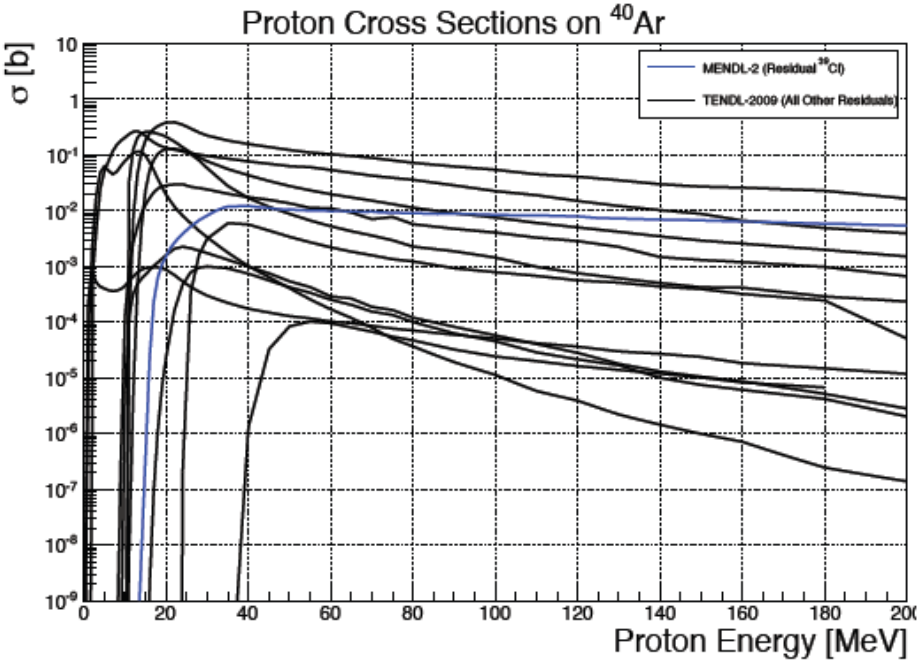
Cosmic Ray Flux



- Protons and neutrons at surface
- Neutrons underground

Cross Section for Interaction



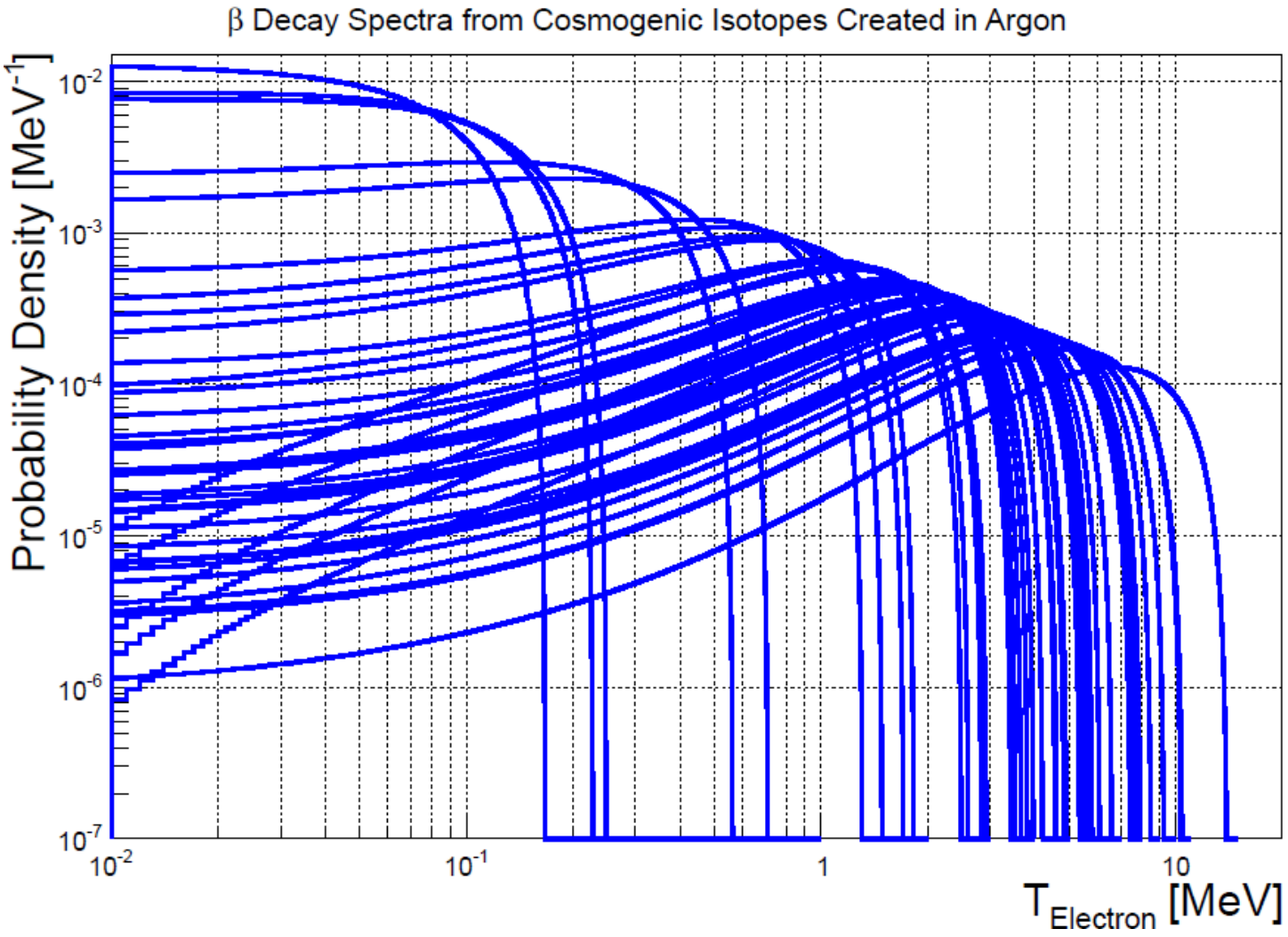


- The probability of the particle interacting with a ^{40}Ar nuclei

$$r_n = \sum_{CR} \sigma_n \varphi_{CR}$$

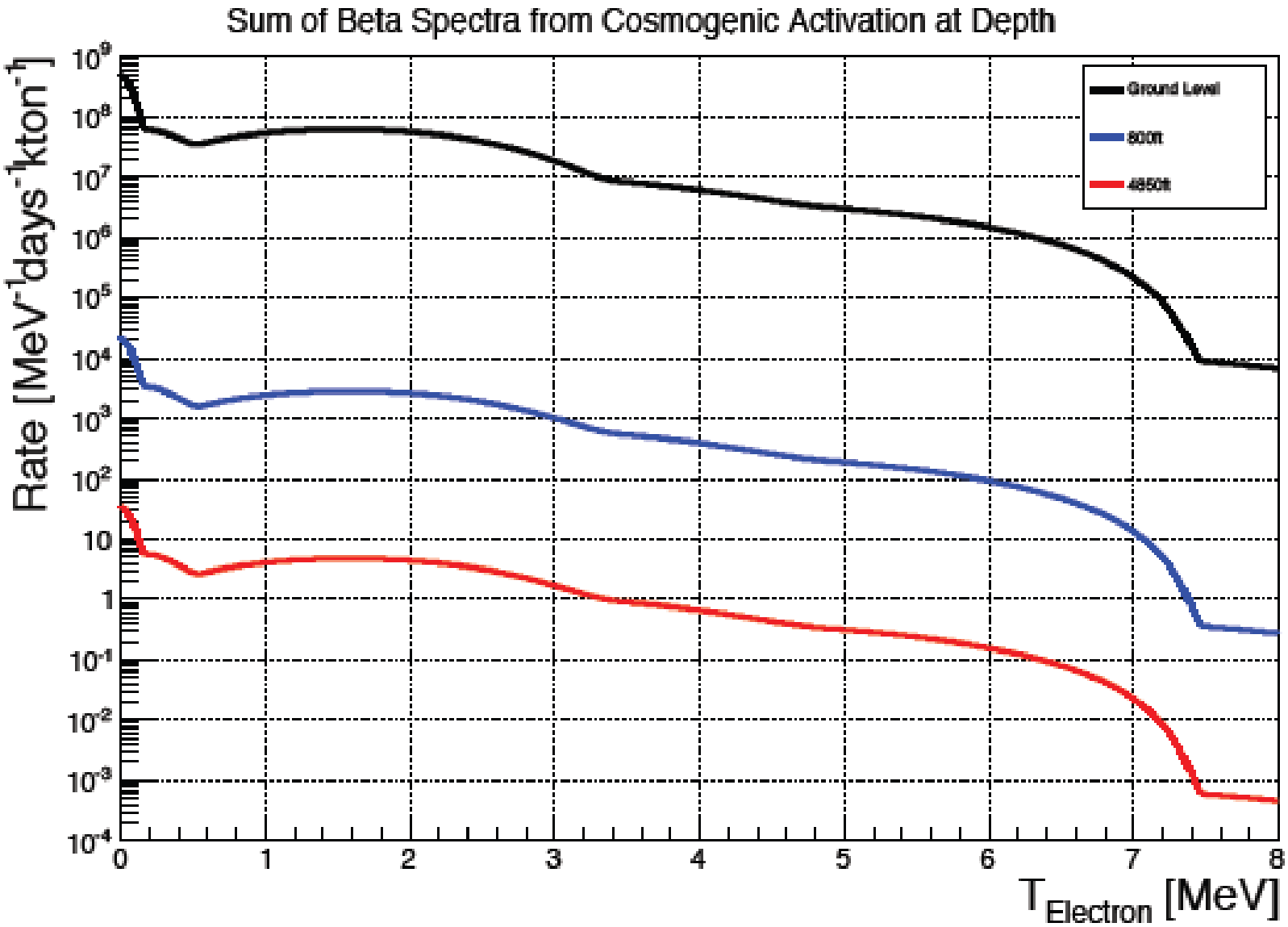
- Rate of creating each radionuclei

Beta Spectra



- Fermi function
  - Statistical distribution of energy between electron and neutrino
  - Coulomb correction

Background


Sum of Beta Spectra from Cosmogenic Activation at Depth
Rate [MeV^{-1}days^{-1}kton^{-1}]
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
1
2
3
4
5
6
7
8
$T_{Electron}$ [MeV]
Ground Level
800ft
4850ft

Conclusion

- There is a lot to learn if a supernova event occurs while LBNE is running
- So far:
  - Created a preliminary background estimate
- Currently:
  - Waiting to get more experimental data to expand the background estimate
- Why this is important:
  - LBNE is the only detector of its kind currently funded for construction
  - There is a lot of physics you can get out of observing a supernova
  - This is awesome