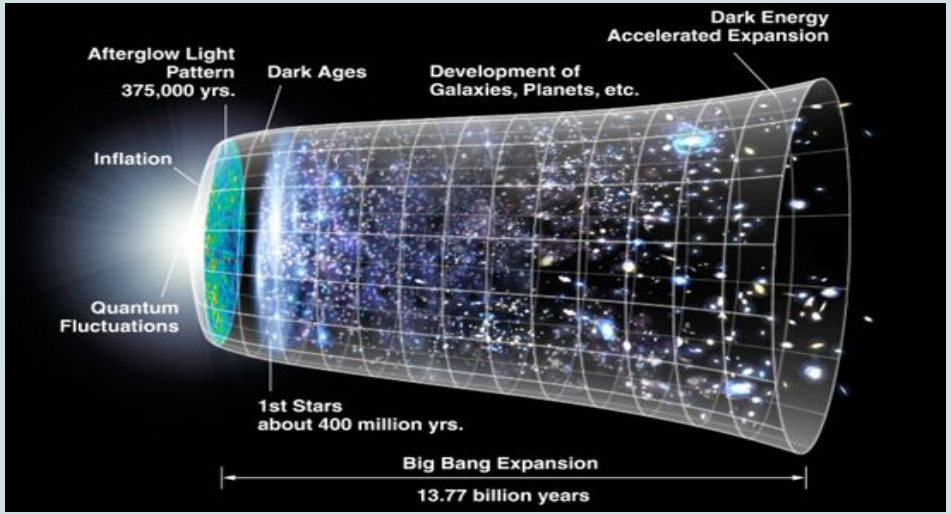
Matter-Antimatter Asymmetry

By Sofia Hueffer, Mia Popperwell,
Cori Zang, Vidhisha Chadda

What is antimatter ?

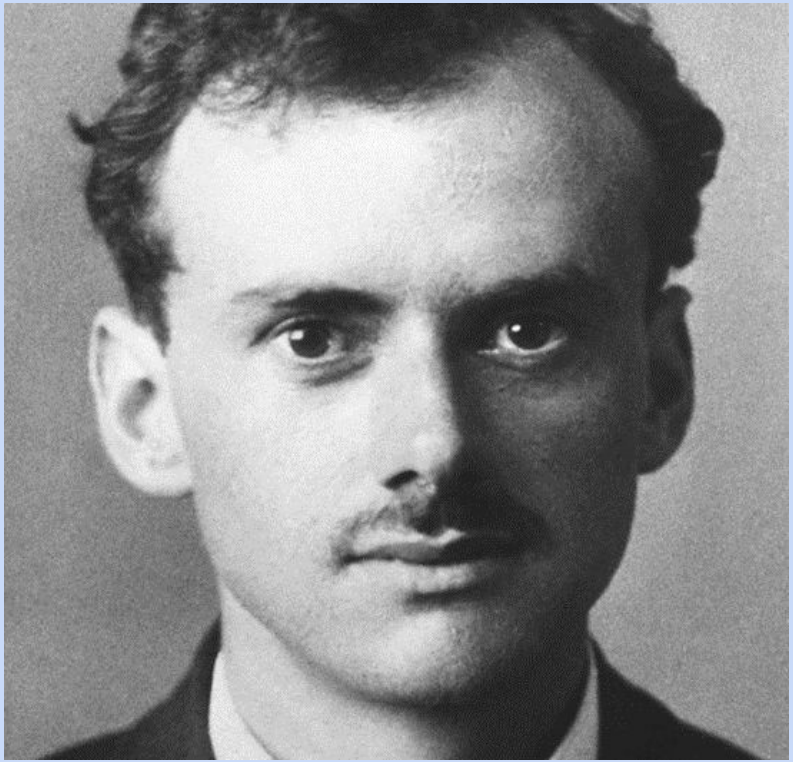
- The big bang created matter and antimatter, however, the composition of the universe has changed a lot since then.
- Antimatter is a substance which is the very opposite of matter.
- Every particle has an antimatter counterpart, including neutrinos whose counterparts are called antineutrinos. [1]



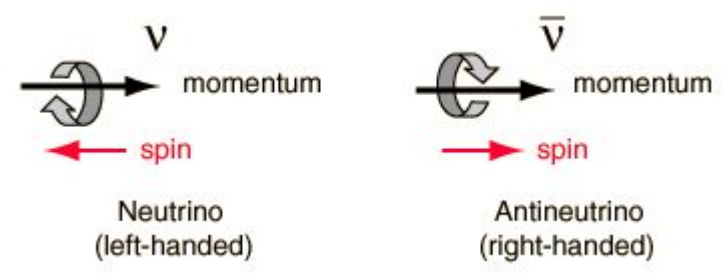
This image shows the big bang taking place

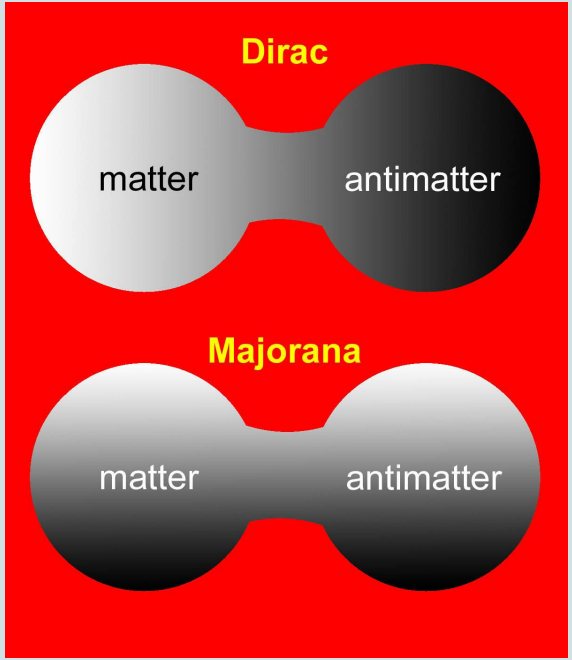
How research into antimatter begun and why is it important

- The modern theory of antimatter began in 1928 due to a paper by Paul Dirac.
- Matter and antimatter symmetry is a very key field to research into in physics today. [2]



Neutrinos and Antineutrinos





Electron neutrinos:

- Mass - 0
- Charge - 0
- Spin - ½ anticlockwise

Electron antineutrinos:

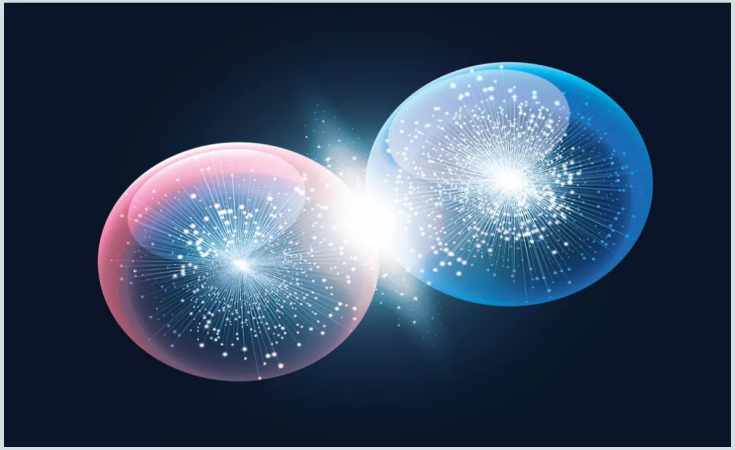
- Mass - 0
- Charge - 0
- Spin - ½ clockwise

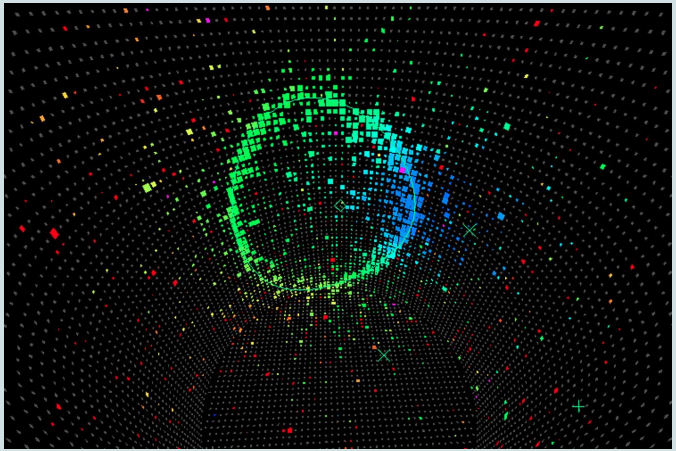
[3] [4]

The Experiment

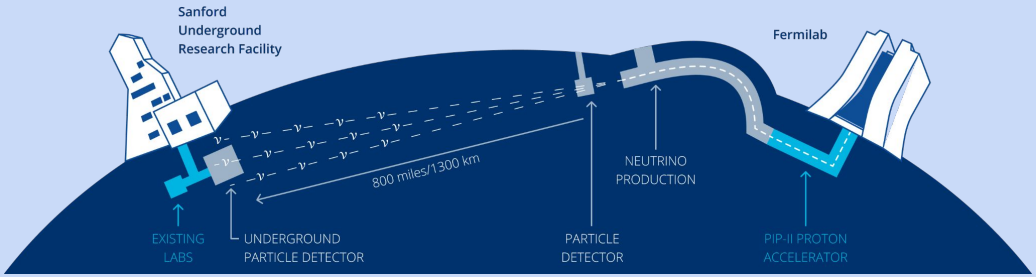
- Two experiments:
  - Neutrino interaction with matter
  - Antineutrino interaction with matter [5]
- The interaction with neutrinos should produce negatively charged electrons
- The interaction with antineutrinos should produce positively charged positrons.
- Experiment at large scale over long time

Hypothesised Results





- Results may show imbalance of product which is incompatible with Standard Model
- Possible explanation of matter and antimatter asymmetry
- Other results may provide insight to other phenomena

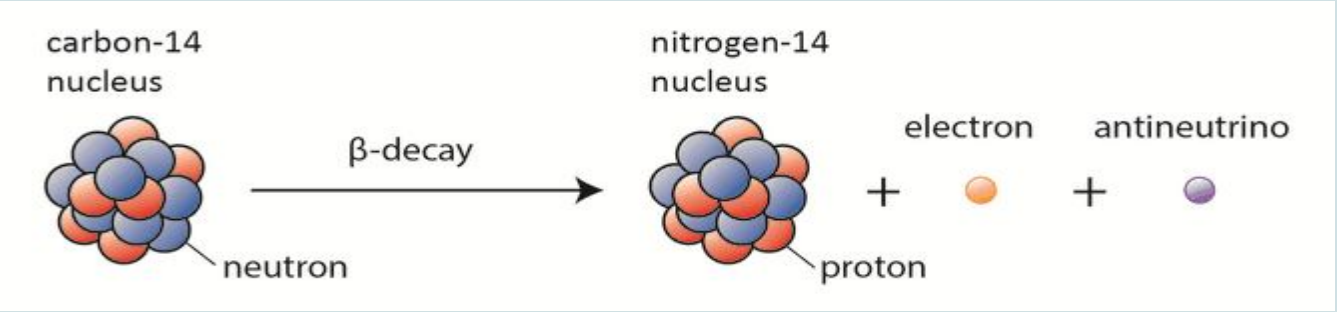


CREATING A NEUTRINO BEAM

To create a beam of neutrinos we can use the same method as Fermilab at DUNE (Deep Underground Neutrino Experiment).

(1) Accelerate protons into a graphite target, the collisions with the graphite nuclei will produce neutrons and positive/negative pions.
(2) Using magnets (called horns), attract the positive pions and focus them into a beam.
(3) The positive pions will then decay into muons and neutrinos.
(4) Use a block of concrete/steel to slow and absorb the muons, leaving a beam of neutrinos! [6]

CREATING AN ANTINEUTRINO BEAM



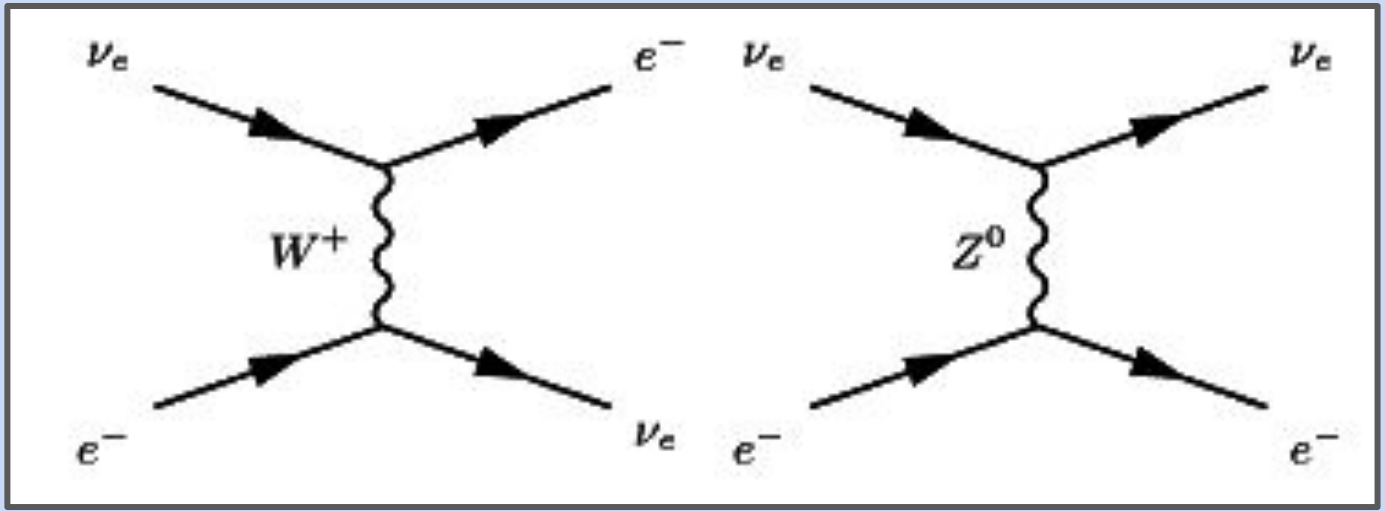
Electron antineutrinos are commonly produced in beta-minus decay.

But for this experiment we will use a similar method for the production of an antineutrino beam, as described in the previous slide.

The only difference is we use the magnets to focus a beam of negative pions, which by the same method can be used to produce a beam of antineutrinos. [7]

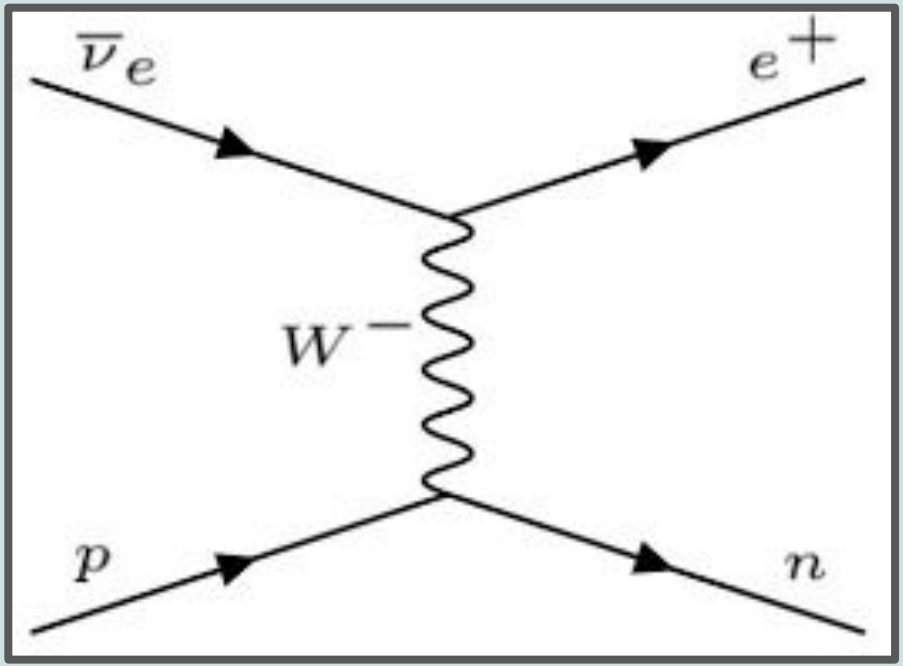
The Neutrino Interaction

As neutrinos do not have charge the only way in they can react with matter is via gravity (but their mass is VERY small) or the weak force.



Neutrinos can interact via the neutral current (Z bosons) or charged current (W bosons) weak interactions to produce electrons. This is known as Neutrino-Electron scattering. But this interaction is extremely infrequent, therefore the experiment will require large volumes of neutrinos of a large period of time. [8]

The Antineutrino Interaction



The interaction we are looking for from the antineutrino beam is known as inverse beta decay.

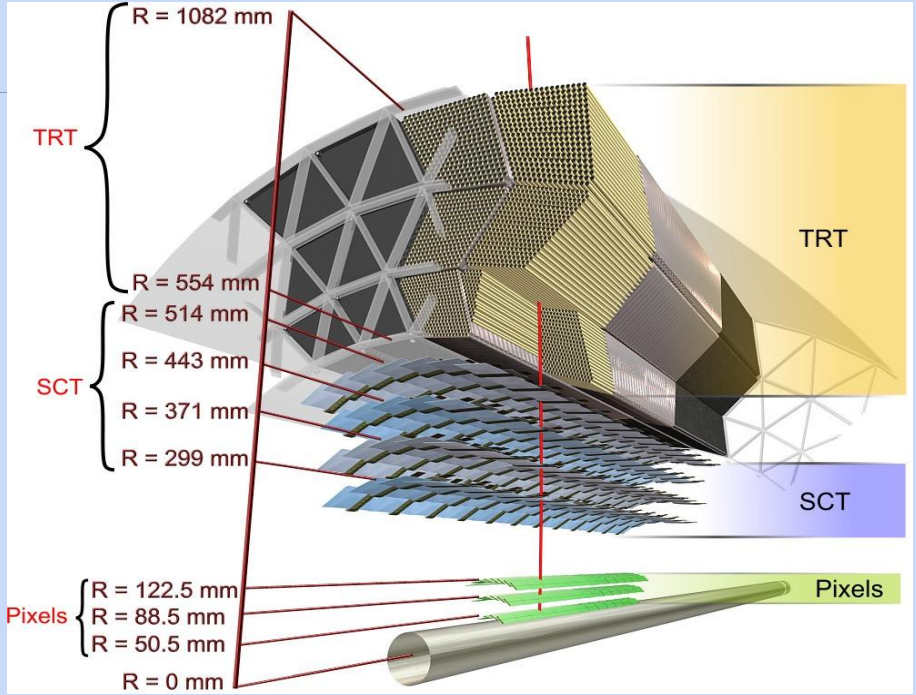
In this interaction the antineutrino scatters off of a proton creating a positron and a neutron.

The positron of which will be detected. [9]

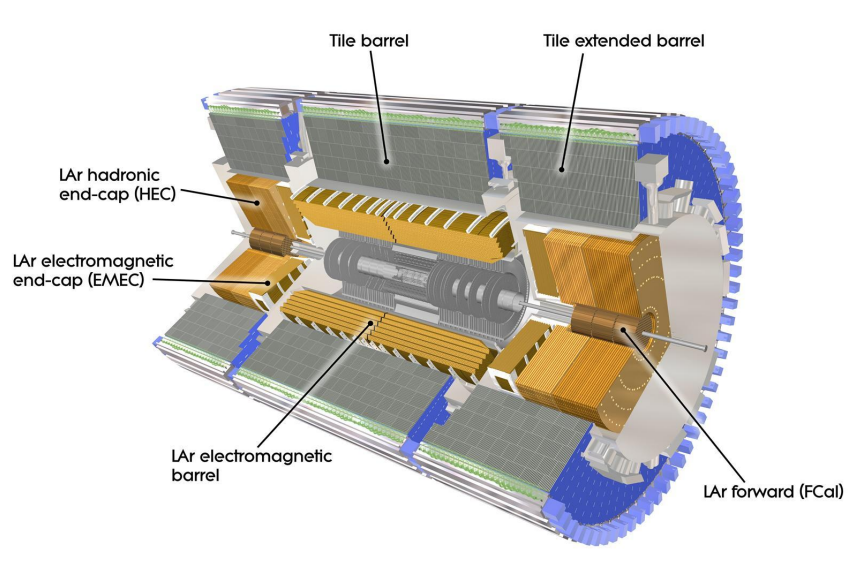
The inner detector

Component:
1. Pixel detector
2. Silicon strip detector
3. Transition radiation tracker

Function:
Reconstruction of the trajectories of charged particles



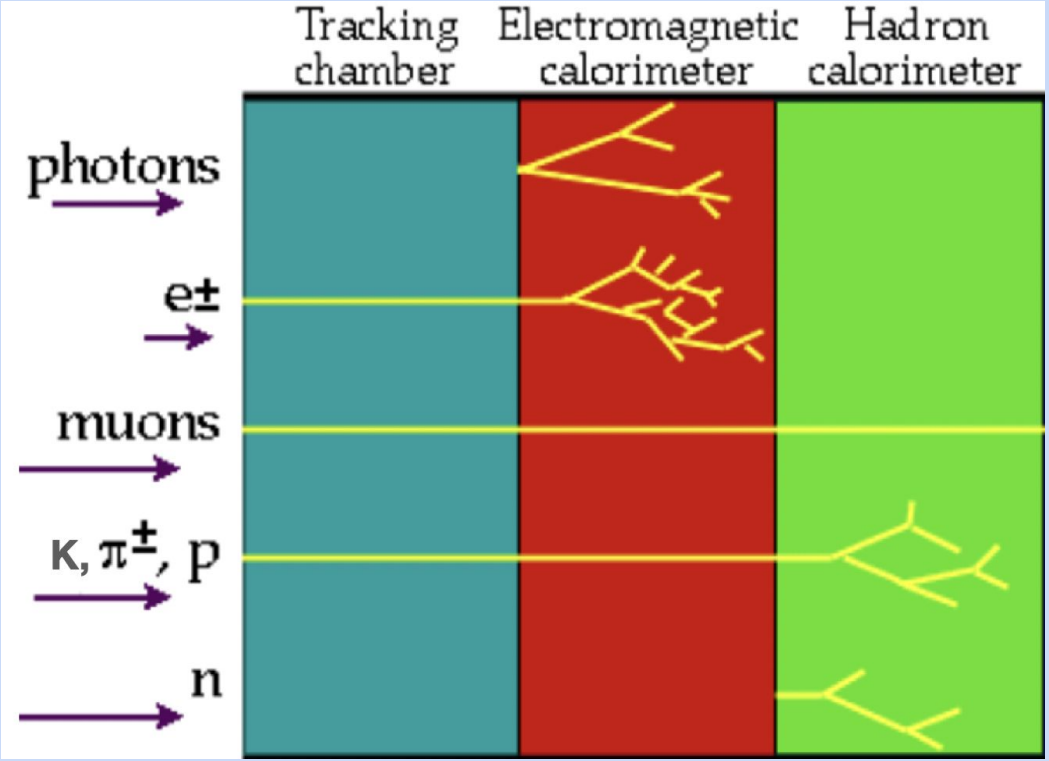
The Calorimeters



1. Electromagnetic calorimeter
2. Hadron calorimeter

The calorimeters are designed to capture the difference in behavior of electrons and hadrons in the calorimeters, namely that electrons deposit their energy in a narrow shower contained inside the EM calorimeter, whereas hadrons showers are more diffuse and penetrate into the hadronic calorimeter. [10]

Identification of electrons/positrons



Thank you for listening!

Does anyone have any questions?

References

[1] Christine Sutton, (2021), antimatter, Encyclopedia Britannica [online] Last accessed 25 August 2022: https://www.britannica.com/science/antimatter

[2] Suresh Emre (2020), On the transformation of neutrino into electron [online] Last accessed 25 August 2022: https://sureshemre.wordpress.com/2020/03/28/on-the-transformation-of-neutrino-into-electron/

[3] Justin Evans (2017), Are the Neutrino and Antineutrino the Same Particle? [online] Last accessed 25 August 2022: https://www.realclearscience.com/articles/2017/11/25/are_the_neutrino_and_antineutrino_the_same_particle_110469.html

[4] SuperNEMO (2022), Why is the Universe Made of Matter? [online] Last accessed 25 August 2022: https://www2.ph.ed.ac.uk/~cpatrick/research/supernemo.html

[5] F. Vannucci (2017), Interactions of neutrinos with matter, Progress in Particle and Nuclear Physics, vol 95, pp 1-47, https://doi.org/10.1016/j.ppnp.2017.03.003.

[6] DUNE (2020), An International Experiment for Neutrino Science [online] Last accessed 25 August 2022: https://www.dunescience.org/

[7] Fermilab (2022), How to make a neutrino beam [online] Last accessed 25 August 2022: https://lbnf-dune.fnal.gov/how-it-works/neutrino-beam/

[8] Lei Ma (2021), Interaction With Matter [online] Last accessed 25 August 2022: https://docs.neutrino.xyz/matter/index.html#:~:text=Neutrinos%20do%20interact%20with%20matter,and%20neutral%20current%20weak%20interaction.&text=For%20neutral%20current%2C%20all%20the,proportional%20to%20identity%20as%20potential

[9] Nuclear Power (2022), Electron Capture – Inverse Beta Decay [online] Last accessed 25 August 2022: https://www.nuclear-power.com/nuclear-power/reactor-physics/atomic-nuclear-physics/radioactive-decay/electron-capture-inverse-beta-decay/

[10] Kurt Brendlinger (2016), Physics with Electrons in the ATLAS Detector [online] Last accessed 25 August 2022: https://cds.cern.ch/record/2228644/files/CERN-THESIS-2016-144.pdf