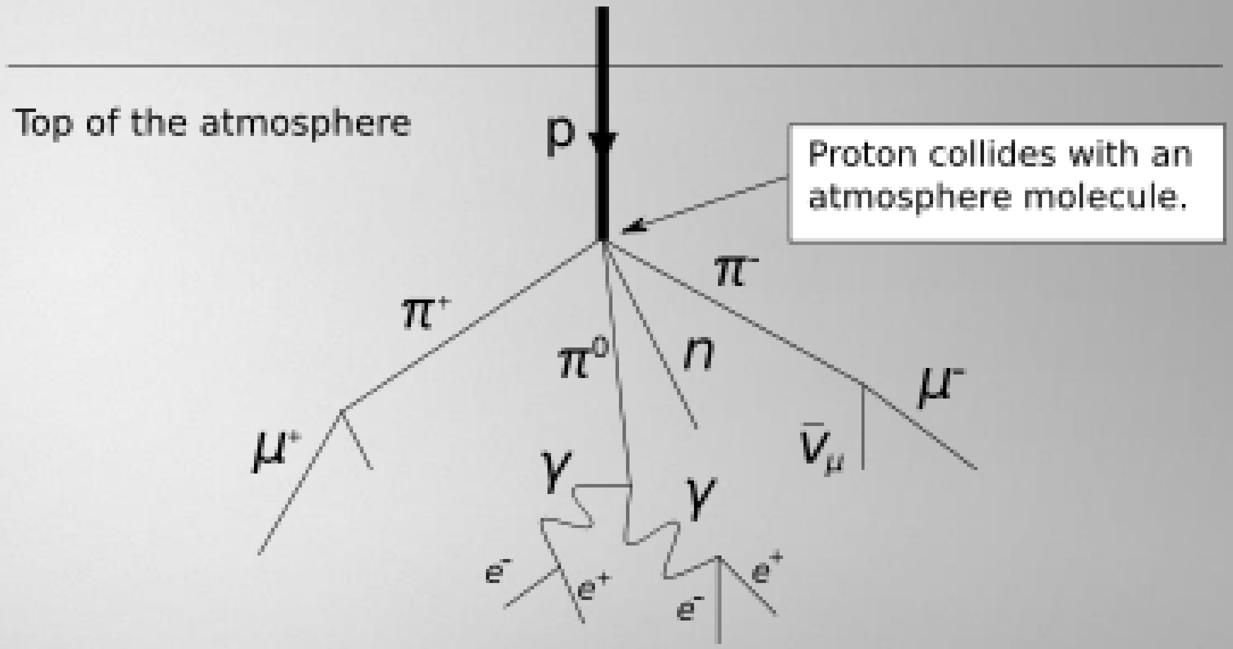
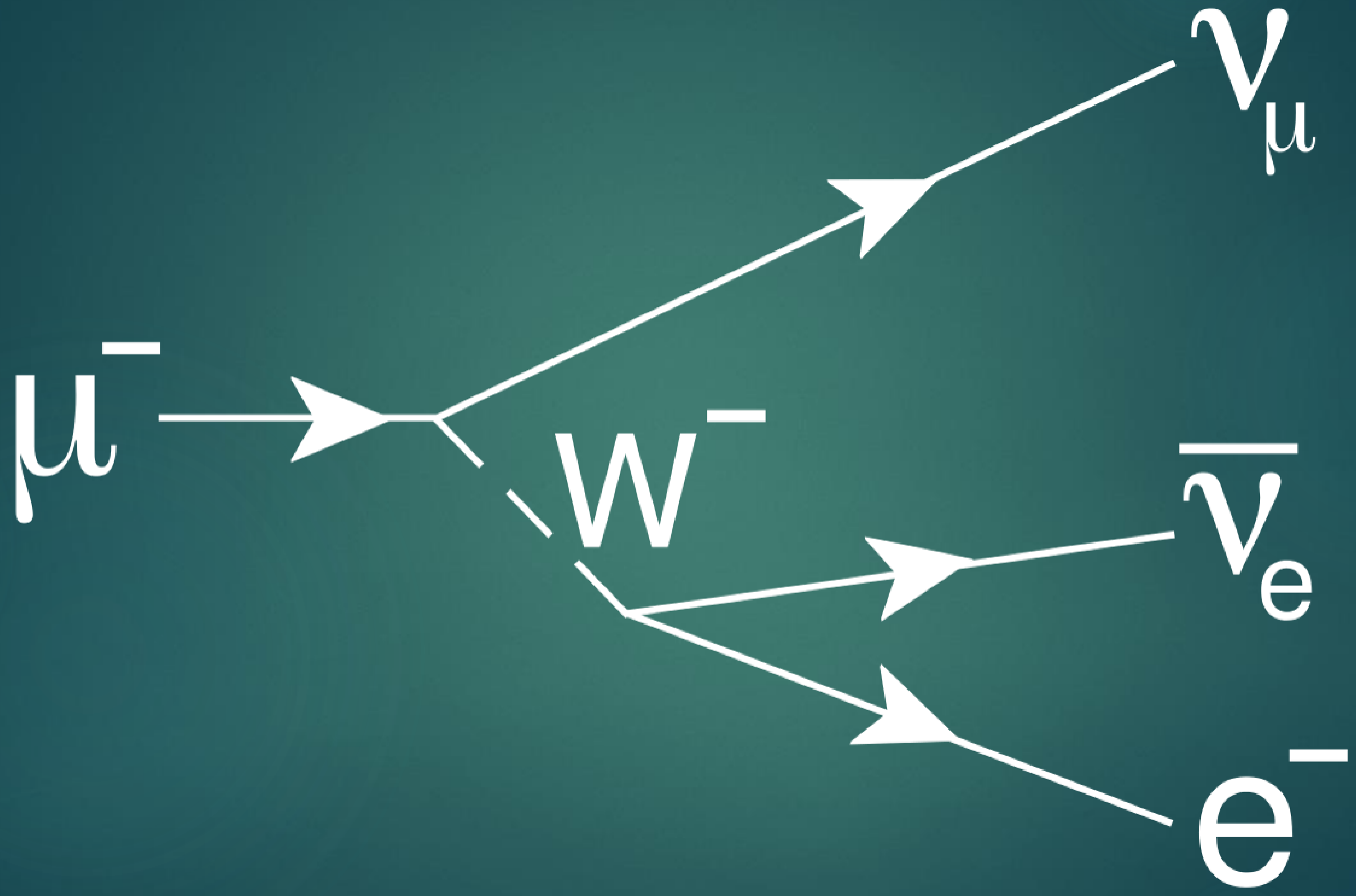
Alleyn’s Year 12 Muon Research

What are Muons?

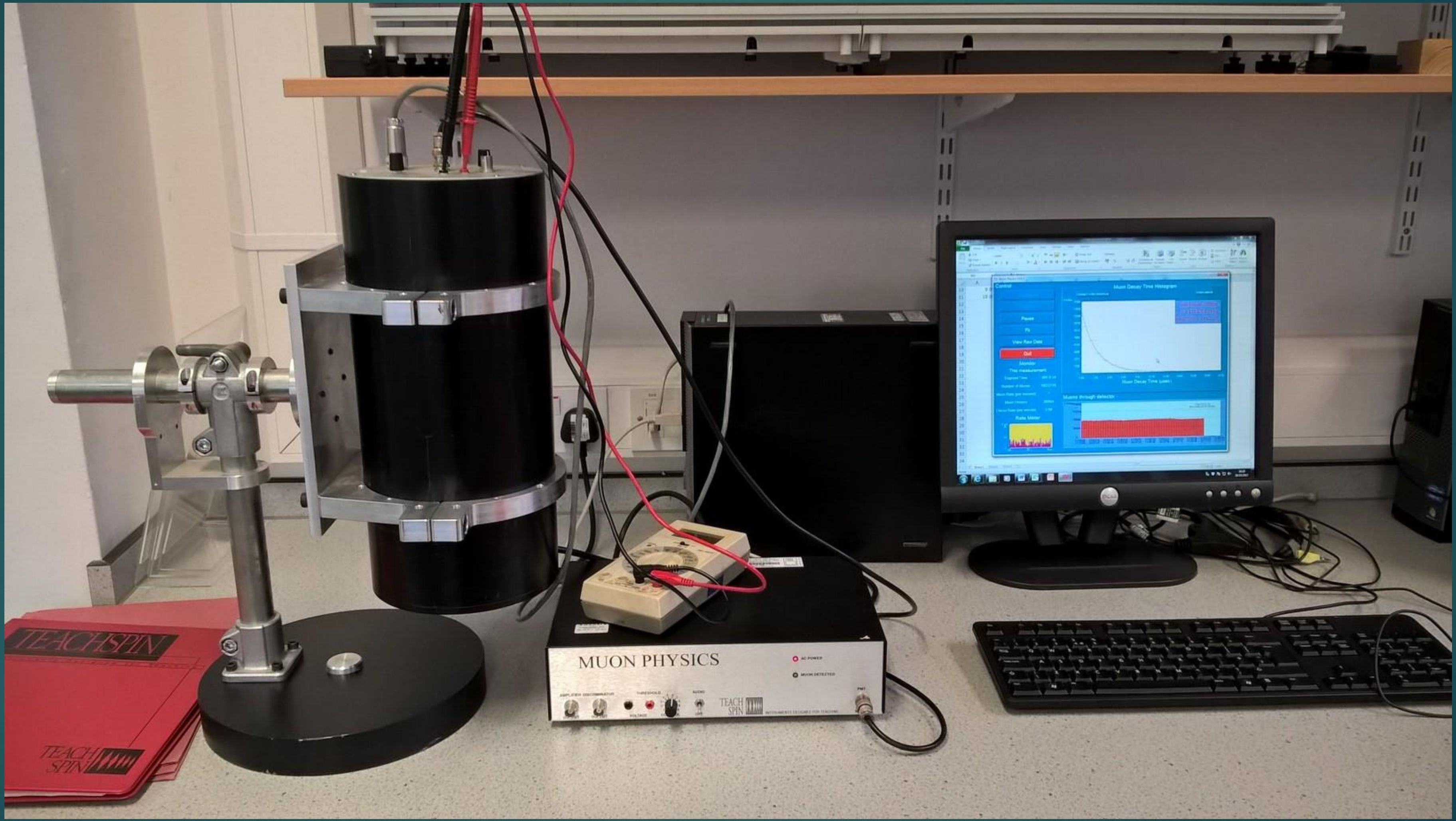
- Heavier version of electrons.
- Unstable and decay quickly.
- Produced from cosmic ray interactions with the atmosphere.
- We can only detect then because of special relativity.





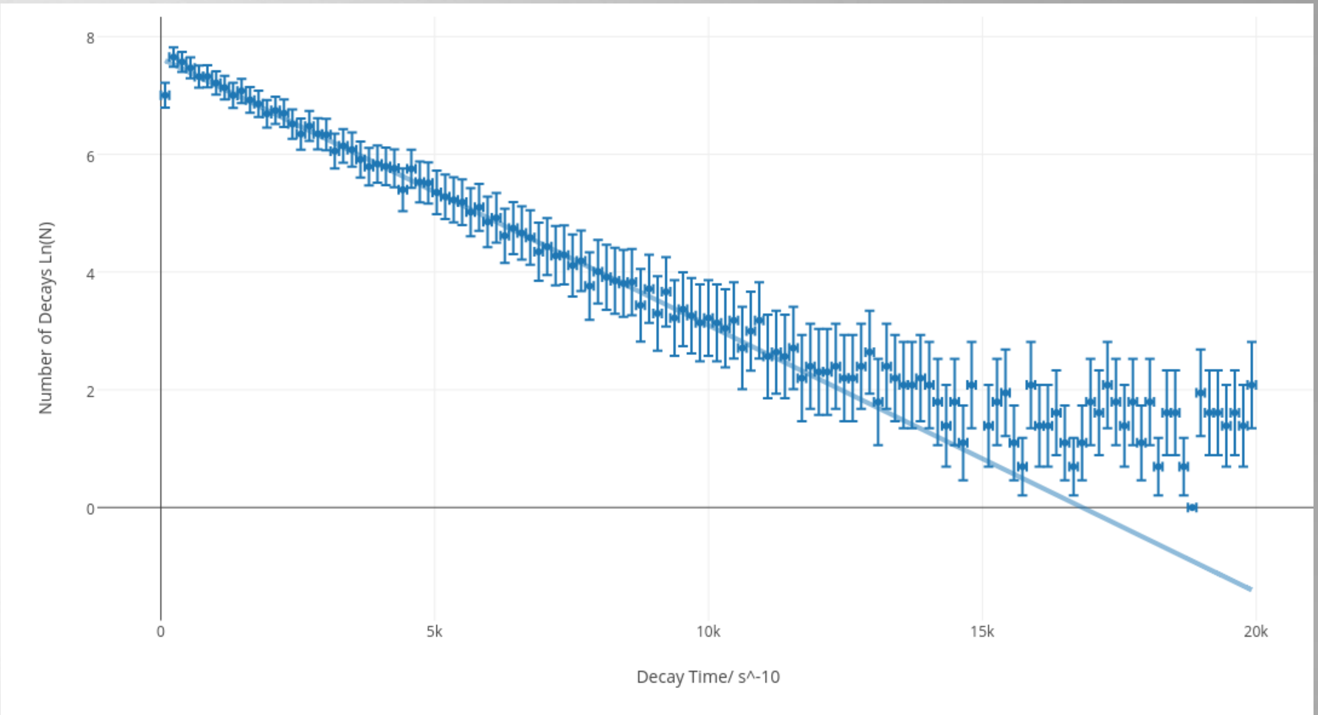
ν_μ
μ^-
W^-
$\bar{\nu}_e$
e^-

The Detector



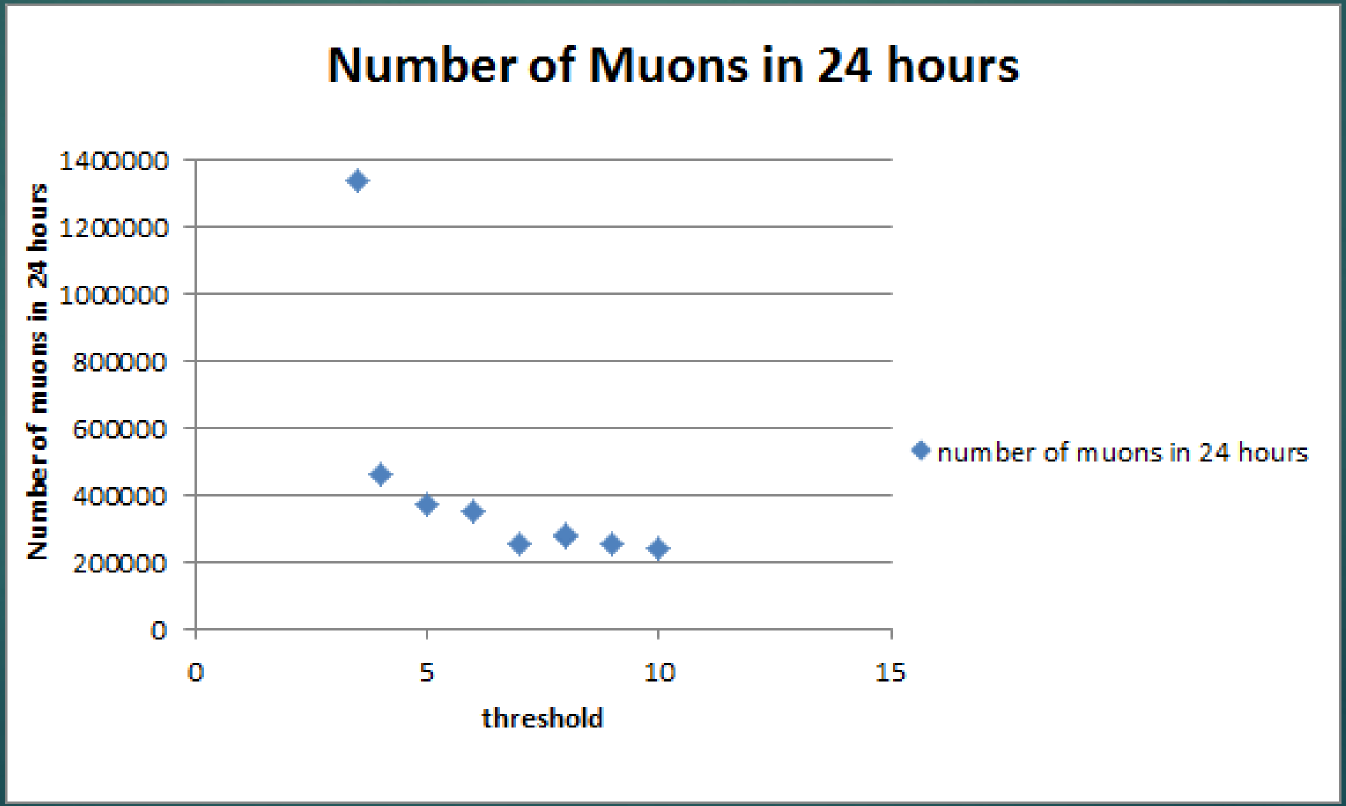
How We Detected Them

- A muon detector is used
- Adjustable voltage and threshold



Thresholds

- The threshold can be changed to determine which data the muon detector keeps
- A higher threshold keeps less data than a lower one



How the threshold affects the data taken

- The known value of the lifetime of a muon is about 2200 ns
- Thresholds 5 and above give the correct value for the muon lifetime
- Threshold 4: 2010 ± 40 ns
- Threshold 3.5: 934 ± 5 ns

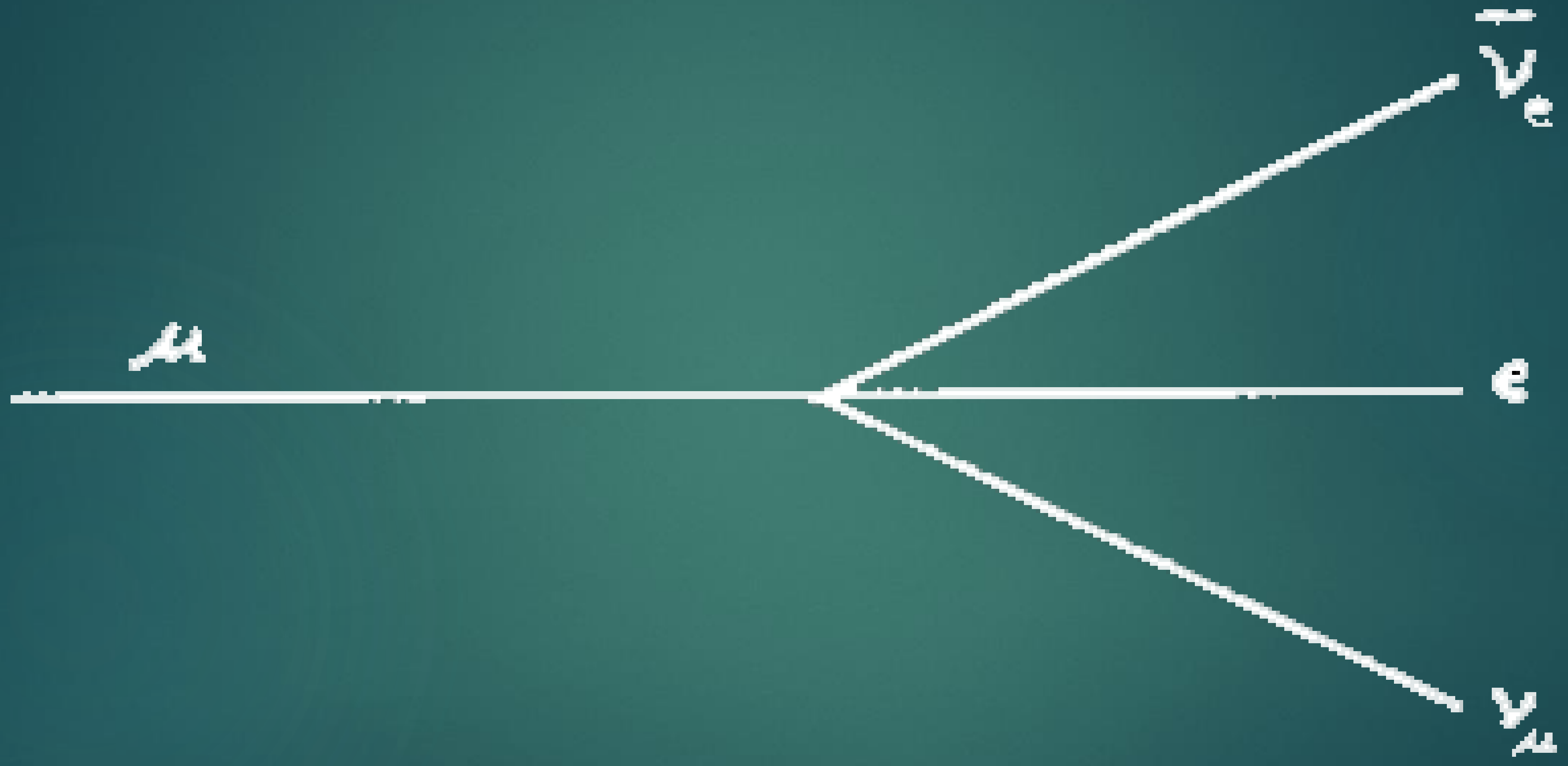
Our Value for the Average Lifetime

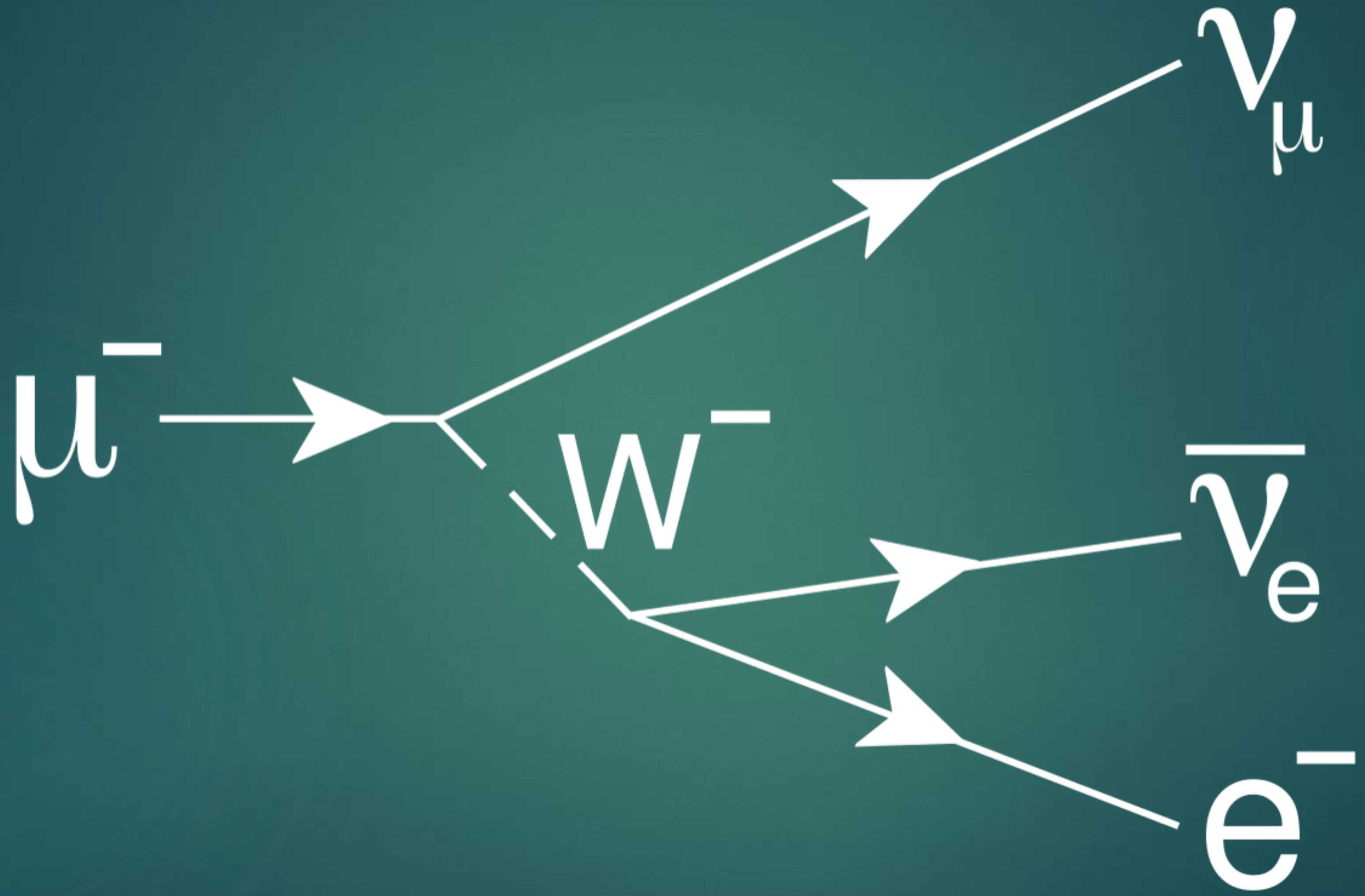
- Muon decay equation: $y = Ae^{-\lambda t}$ where y is number of decays, A and e are constants; t is the decay time and λ is the decay constant which is equal to 1/lifetime.
- Converting to logs, for a gave us a linear fit.
- Our mean lifetime: **2.20 ± 0.04 μs**
- **Published value: 2.1969811 ± 0.0000022 μs** [1]
- Percentage difference: **0.09 %**
- Published value within error bounds, so our value is consistent.

[1] *J. Beringer et al. (Particle Data Group) (2012). "PDGLive Particle Summary 'Leptons (e, mu, tau, ... neutrinos ...)'" (PDF).*

Fermi Coupling Constant

- Fermi coupling constant is a measure of the relative strength of the weak nuclear force.
- Can be easily determined from mean muon lifetime, using this equation:
- $$\frac{G_f}{(\hbar c)^3} = \sqrt{\frac{\hbar \times 192\pi^3}{T_\mu \times (m_\mu c^2)^5}}$$
- Where T_μ is the average lifetime of a muon, m_μ is the mass of a muon and c, π and $\hbar$ are constants.
- $$\hbar = \frac{h}{2\pi}$$


μ
$\bar{\nu}_e$
e
ν_μ


μ^-
W^-
ν_μ
$\bar{\nu}_e$
e^-

Our Fermi Coupling Constant Value

- We got **($4.51 \pm 0.08) \times 10^{14}$ J^{-2}**
- Which converts to **($1.16 \pm 0.02) \times 10^{-5}$ GeV^{-2}**
- Published Value: **($1.166\,378\,7 \pm 0.000\,0006) \times 10^{-5}$ GeV^{-2}** [2]
- This gives a % difference of **0.7 %**
- Published value is within error bounds, so our value is consistent.

$$\frac{G_f}{(\hbar c)^3} = \sqrt{\frac{\hbar \times 192\pi^3}{T_\mu \times (m_\mu c^2)^5}}$$

[2] P.J. Mohr (*Particle Data Group*) *(2013).*

Higgs Vacuum Expectation Value

- Can be derived from:
- $v = (\sqrt{2}G_f)^{-1/2}$
- v: Vacuum expectation value.
- G_f: Fermi Coupling constant.

Our Vacuum Expectation Value

- Our value: **247 ± 4 GeV**
- Published Value: **246.22 GeV** [3]
- % difference: **0.3 %**
- Our value is consistent with the published value, as the error bounds overlap.
- Demonstrates spontaneous symmetry breaking of the Higgs field.
- Underlies the standard model, Higgs mechanism.
- Allows for Grand Unified Theories.

[3] Plehn, T.; Rauch, M. (2005). "Quartic Higgs coupling at hadron colliders". *Physical Review D*. **72**: 053008.

Shape of the Higgs Field