THE SEARCH FOR FCNC
IN THE K0TO EXPERIMENT

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Some Definitions

- **Branching Ratio**: The fraction of particles that decay via one decay mode with respect to the total number of particles that decay.

- **Standard Model**: Theory of fundamental particles and how they interact using the electromagnetic, strong, and weak forces.

- **Feynman Diagram**: Pictorial representation of the behavior of subatomic particles.
What is K0TO Doing?

- The K0TO experiment is trying to accurately measure the branching ratio of $K_L \to \pi^0 \nu \bar{\nu}$.

- The Standard Model predicts the branching ratio of $K_L \to \pi^0 \nu \bar{\nu}$ to be about $2.8 \times 10^{-11}$, which means for about every $10^{12}$ Kaon decays, one Kaon will decay into a $\pi^0$, neutrino, and an antineutrino.

- If the branching ratio measured by K0TO is larger than the branching ratio predicted by the Standard Model, it could mean the discovery of a new process, called Flavor Changing Neutral Current (FCNC).
\( K^0 \rightarrow \pi^0 \nu \bar{\nu} \) Feynman Diagrams

The neutral Kaon, \( K_L \), is a meson composed of a \( d \) quark and an \( \bar{s} \) quark.

\[
K^0 \left\{ \begin{array}{c}
\bar{s} \\
\bar{u}, \bar{c}, \text{ or } \bar{t}
\end{array} \right\} W \left\{ 
\begin{array}{c}
d \\
\bar{d}
\end{array} \right\} \pi^0
\]

This decay is mediated by 2 vector bosons, the \( W \) and \( Z \), which makes this a second order weak decay. The branching ratio of this decay is about \( 2.8 \times 10^{-11} \).

\[
K^0 \left\{ \begin{array}{c}
\bar{s} \\
\bar{d}
\end{array} \right\} \pi^0
\]

From \( \bar{s} \) to \( \bar{d} \), the quark changes flavor, but keeps the same charge. This is mediated by some unknown, neutral particle (X) and is called Flavor Changing Neutral Current (FCNC).
Why Should You Care?

- The discovery of FCNC could either lead to more precise limits on the Standard Model or new physics!
The Accelerator

- The K0TO experiment is being hosted by the Japan Proton Accelerator Research Complex (J-PARC).
- J-PARC includes three main parts: 400-MeV normal-conducting Linac, 600-MeV superconducting Linac to increase the energy of the proton beam from 400 to 600 MeV, 3-GeV synchrotron ring, and a 50-GeV synchrotron ring.
Layout of J-PARC

Pacific Ocean

3 GeV Proton Synchrotron (1MW, 25Hz)

Neutrino Facility

Hadron Physics Facility

Materials and Life Science Facility

60 GeV Proton Synchrotron (15 μA)

Transmutation Experimental Facility

Linac

Detector for K0TO
Layout of J-PARC

Detector for KOTO
Detection Method

- Once a $\pi^0$ is produced from the $K_L$ decay, it decays into two photons.
- These photons are then detected by CsI crystals in the detector.
- CsI Crystals $\rightarrow$ Photomultiplier Tubes $\rightarrow$ Copper wires $\rightarrow$ ADC boards (Ethernet to fiber optic cable conversion) $\rightarrow$ (fiber to Ethernet conversion) Level 1 and level 2 Trigger Boards $\rightarrow$ Power PCs $\rightarrow$ AWESOME DATA! (hopefully...)
Start of the Kaon Beamline

Front Barrel begins (23m)
The Detector

Front Barrel begins (23m)
Construction of the Detector

- Piling up CsI crystals in the calorimeter.
Modeling $K_L$ Decay in Mathematica

- This Mathematica program models $K_L \rightarrow (\pi \mu)_{atom} \nu$.
- A $(\pi \mu)_{atom}$ occurs when a $\pi^+$ and a $\mu^-$ electrically bond together to form an atom.
- This decay is important because the $(\pi \mu)_{atom}$ decays into a $\pi^0$ and a $\nu$. The $\pi^0$ then decays into 2 photons creating a signal that is virtually the same as the decay that we want to detect, $K^0 \rightarrow \pi^0 \nu \bar{\nu}$.
An Example Problem

- My goal was to maximize the fraction of Kaons that decay in the K0TO detector by solving for the optimum initial energy that the $K_L$ beam should have.

$$N(l) = N_0 e^{-\frac{1}{l_0} l}$$

- I found that the maximum number of Kaons will decay in the detector, which is located between 26m and 29m from the start of the $K_L$ beam, if the initial beam energy is 998.3 MeV.

- I did this by solving for $l_0$ and then $\beta \gamma$ and plugging $\gamma$ into $E = \gamma mc^2$.

$$l_0 = \beta \gamma c \tau$$

- This energy is lower than what the actual $K_L$ beam energy will be, which is about 2 GeV.
Because of this initial beam energy difference, I solved for the fraction of Kaons that would decay in the 3m range in the detector.

\[ E = \gamma mc^2 \rightarrow \text{Solve for } \gamma \rightarrow \text{Plug into } l_0 = \beta \gamma c t \rightarrow \text{use } l_0 \text{ to solve for the fraction of Kaons that decay} \]

\[
N(l_1) - N(l_2) = N_0 \left( e^{-\frac{l_1}{l_0}} - e^{-\frac{l_2}{l_0}} \right)
\]

This fraction turns out to be 3.17%, which is higher than what was expected.
My task was to mount and power Fiber Optic Cables to Ethernet converters.

These converters are useful because Ethernet signal degrades over long distances, and the ADC boards are far enough away from the trigger boards to see a signal difference.
What I Learned This Summer

- A LOT!
  - 4-vectors
  - Basics of fundamental particles and their decays
  - Basics of electronics
  - Mathematica
  - Soldering
  - Machining

- What I have learned this summer has made me even more excited about my future in physics.
Acknowledgements

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- The research team: Monica Tecchio, Jon Ameel, Shumin Li, Craig Harabedian, Jia Xu

- References: https://sharepoint.umich.edu/lsa/physics/collaborations/k0to/default.aspx
Thanks for Listening!
Extra

- Requires ‘pencil beam’, 4 cm diameter
- L0 is characteristic decay length