Gas Cherenkov Muon Detector

Max Weiner
Adviser: Alysia Marino
University of Colorado Boulder
Predicting a Muon Distribution with a Gas Cherenkov Detector

- The goal of my project is to extrapolate, or constrain, the muon beam distribution by observing the subsequent signal from a gas Cherenkov detector over several yaws and pressures. (Look at output signal and reconstruct muon distribution in momentum and direction.) This in turn will help constrain the associated neutrino distribution.
- We currently utilize a detector located in muon alcove 2 of the NuMI beam line for our analysis.
Muon Alcoves
Gas Cherenkov Detector
Detector in Alcove 2

- Located in Alcove 2 and filled with argon gas.
- Yaw controlled by actuator (angle varies from -6.064° to 4.695°).
- Varying the pressure changes number of photons radiated per muon.
- Roughly at same height as beam line.
Predicting Muon Distribution

- We need a way to predict and compare a signal given some muon distribution in momentum and incident angle...
- We do this by using our yaw scans as “fingerprints”: a given muon distribution will produce a unique signal over various detector configurations.
Yaw Scans at Various Pressures

- We can compare our real signal with Monte Carlo simulations. Alter muon distribution until signals agree.
  
  - Simulation
  
  - Real Data

![Graphs showing data fit to MC simulation at 16 psi and 150 psi](Image)
Slow Way

- One way to do this is feed our Geant4 Cherenkov code different muon distributions over corresponding pressures and yaws until signals match.
- Altering muon distributions would be a pain.
- We have ~1 million muons to simulate over seven pressures and about ten detector angles, that is 70 simulations for each muon input...
Better Way

- Create a “Yield Matrix” which assigns any given muon a number of photon detections (signal) based on muon momentum & incident angle, as well as detector angle & pressure:

\[ YM(p, \theta, P, Y) \]

where \( p \) is muon momentum, \( \theta \) is muon incident angle from beam center, \( P \) is detector pressure, and \( Y \) is detector angle in yaw from beam center. We build this using a TGraph2D.
Neutrino Distribution

Muon Distribution

Yield Matrix

Predict a signal for each pressure

Run over all pressures

Run each pressure over all yaw angles

Agree?
Begin with neutrino distribution from flugg file and convert to muons via conservation of momentum and energy.

\[ \pi^+ \rightarrow \mu^+ + \nu_\mu \]

My detector sits here, some muons do make it through!
Building Yield Matrix

- We selected discrete values of $p$, $\theta$, $P$, and $Y$:
  - $p = \{1, 2, 4, 8, 12, 18\}$ GeV
  - $\theta = \{0.1, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5\}$ degrees (from beam center)
  - $P = \{8, 16, 32, 60, 100, 150, 200\}$ psi
  - $Y = \{0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5\}$ degrees (from beam center)
- This comes to 4,620 files which count photon “Hits”. Each file assigns a muon with an associated detector configuration a number of hits.
- Each run had 100k muons and if we decide we are low on statistics we can increase this number.
Yield Matrix

- We turn this information into a TGraph2D plotted in $p$-$\theta$ space. From this we can assign any given muon a number of hits (detected photons). Most muons are not discrete values, but we are able to interpolate.

![Graph showing hits vs. momentum and angle](image-url)
Distribution Function

- We have our Yield Matrix, now all we need are some muons! We decided to create a function in $p$ & $\theta$ of alcove 2 muons. With an educated guess utilizing work from the previous student working on this project we started with:

$$N_\mu(p, \theta) = \left( a(p)\theta + b(p)\theta^2 + c(p)\theta^3 + d(p)\theta^4 \right) \times 2.2^{-\theta/\sigma(p)}$$

and fitted for this function over several momentum regimes (including parameters which are a function of momentum).
~1 million muons from flugg file to best match a realistic distribution
$a(p) = Ap + Bp^3$
$b(p) = Ap^2 + Bp^3$
\[ c(p) = Ap^2 + Bp^3 \]
\[ d(p) = Ap^2 + Bp^3 \]
$\sigma(p) = \frac{a}{p^b} + c$
Full Distribution Function

- After fitting all momentum parameters we came up with the function:

\[
\]
Parameter values from Fit:

\[
\begin{align*}
[0] & = 5790 \pm 50 \\
[1] & = 125 \pm 7 \\
[2] & = 1000 \pm 40 \\
[3] & = -479 \pm 20 \\
[4] & = 3600 \pm 20 \\
[5] & = 460 \pm 10 \\
[6] & = -121 \pm 1 \\
[7] & = -136 \pm 2
\end{align*}
\]
TF2 Fitted to TGraph2DErrors ('Black Data Points')
Comparing Function with TGraph

- The following plots attempt to quantify how well the function matches the TGraph by analyzing their discrepancy:

\[ \text{Discrepancy} = \frac{|\text{Function} - \text{TGraph}|}{\text{TGraph}} \]
% Discrepancy ($N_\mu >100$)

*For bins with greater than 100 events -- illustrates that largest disagreements occur at “edges” where there are fewer events.
What’s Next

- First we will see if our Yield Matrix accurately reproduces a signal compared to what the Cherenkov code generates. We do this by feeding each method the exact same distribution and comparing the subsequent signals.
- From here we will look at real data we have taken from yaw and pressure scans in the past. The challenge here is how to compare the real signal (which is a voltage) with the simulated signal (detected photons).
Questions?