Construction of a Drift Chamber for SeaQuest
and
Test of Performance and Optimization

SeaQuest 実験に用いる大型ドリフトチェンバーの製作と
飛跡再構成による性能評価および最適化

修士論文発表会
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1. Introduction
1. Introduction

- The proton consists of valence quarks, sea quarks, and gluons.
- The flavor symmetry of the sea quarks had been assumed.

\[
\bar{d}(x) = \bar{u}(x), \quad x = \frac{\text{parton momentum}}{\text{proton momentum}}
\]

- In 1991, NMC experiment showed that the assumption is not correct.
  - It means that the \( \bar{u} \) and \( \bar{d} \) are asymmetric.

E866 experiment measured \( \bar{d}/\bar{u} \) in the proton.
- The blue points show the result of E866
- Flavor asymmetry was measured at lower \( x \).
- Around \( x = 0.3 \), E866 suggested \( \bar{d}(x)/\bar{u}(x) < 1 \).
  - No theory predicts such a phenomenon.
    → If it’s really \( \bar{d}(x)/\bar{u}(x) < 1 \), it’s a new physics!
- However, the statistic error at \( x \sim 0.3 \) is very large.
- No one has measured the asymmetry at large \( x \) region.
  → More precise measurement in a wider range of \( x \) is important!
2. SeaQuest experiment
2. SeaQuest experiment

- SeaQuest experiment studies the structure of the proton, especially the sea quarks in the proton.
- 120 GeV proton beam at Fermilab is used.
  - The Main Injector in the figure supplies us with 120 GeV proton beam.
- The participants are Japan (Tokyo Tech., KEK, RIKEN, Univ. of Yamagata), U.S.A., and Taiwan.
  - SeaQuest experiment will measure $\bar{d}/\bar{u}$ in the region $0.1 < x < 0.45$ by Drell-Yan process.
  - The number of events will be 50 times larger than that of E866 experiment.
Drell-Yan process

Drell-Yan process is the process in which the quark and anti-quark in the hadrons annihilate and produce a muon-pair through the virtual photon.

Drell-Yan process is suited to measure anti-quarks in the proton
- an anti-quark in the proton is always involved in this process
- the kinematics of this process is simple

The cross section for the Drell-Yan process is

\[
\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9M^2} \sum_i e_i^2 \left[ q_i(x_1)\bar{q}_i(x_2) + \bar{q}_i(x_1)q_i(x_2) \right]
\]

The second term can be ignored because of the acceptance of the detector.

From the cross section ratio, we obtain

\[
\frac{\sigma^{pd}}{2\sigma^{pp}} \sim \frac{1}{2} \left[ 1 + \frac{d}{u} \right]
\]

SeaQuest measures the cross section for proton-proton and proton-deuteron Drell-Yan process.
SeaQuest spectrometer
The momenta of muons are measured by SeaQuest spectrometer.

\[ q\bar{q} \rightarrow \gamma^* \rightarrow \mu^+\mu^- \]

- Targets are proton and deuteron.
- Magnet is used for momentum determination of the muons.
- We have four tracking “Stations”.
  Station is a set of the detectors, namely hodoscopes and tracking chambers.
  St. 3 consists of two parts: St. 3+ covers the upper half of the St. 3.
  St. 3− covers the lower half of the St. 3.
  - I worked for construction of the new St. 3− drift chamber.
St. 3 Drift Chambers

The St. 3 drift chambers have six planes.

- They are named U, U', X, X', V, and V'.
- U and U' planes are tilted by $-14^\circ$ and V and V' planes are tilted by $14^\circ$ from the vertical direction.

The cell structure of the drift chamber is shown in the figure above.

- A cell consists of one sense wire and eight cathode wires.
- The size of the cell is $2 \text{ cm} \times 2 \text{ cm}$. 
3. My works during the master course on drift chambers

My works in my master course were

1) construction of new St. 3 drift chamber,
2) identifying the crosstalk signals of St. 3± chambers developing a method to handle the crosstalk
3) check the single-plane efficiency and single-plane position resolution of the drift chambers

Today, I will report on 2) and 3).
4. Chamber Performance I
- A Method to Handle the Crosstalk Signals -
Crosstalk is the phenomenon in which a signal on a wire is propagated to other wires. The crosstalk signals create extra hits on the chamber.

- The characteristics of the crosstalk signals are
  - the crosstalk signals appear in the wires next to the true hit wire
  - the time differences between neighboring wires are constant.

- The crosstalk is a common problem of wire chamber.
- In the data of 2012, there are crosstalk signals on St. 3+ and St. 3−.
  - If there are many extra hits, the track reconstruction becomes difficult.
  - I checked the probability that the crosstalk appears.
  - I developed a method to handle the crosstalk signals.
The method to evaluate the probability that the crosstalk appears

1. I plotted the distribution of the difference between the time of a hit and the time of the neighboring hit.

2. The red points in the figure seems to include the crosstalk signals. I fitted the black points of histogram (background) with the exp function.

3. The blue curve shows the background. The difference between the red points and blue curve is the number of crosstalk.

4. The probability that the crosstalk appears is

\[ \frac{N_{\text{crosstalk}}}{6 \times N_{\text{muon}}} \]

The factor “6” is due to the fact that the figure includes all the six planes of the chamber.

5. The probability that the crosstalk appears: the results are

- St. 3+: 4.9 ± 1.0%
- St. 3−: 3.3 ± 0.7%
I developed a method to handle the crosstalk

In this page, I use the word “group”. “Group” is a set of contiguous wire hits.

In order to handle the crosstalk, I used the hit pattern. Hit pattern is shown in the figure.
If the time differences of hits in the group are a common value as shown in the figure, the group includes crosstalk signals.

In this figure,
- the earliest hit is the true hit, and
- other hits are crosstalks.

→ I selected the earliest hit as the true hit.
5. Chamber performance II
- Efficiency and Position Resolution -
5. Chamber Performance II

The efficiency and the position resolution are basic properties of the drift chambers. I checked the

- single-plane efficiency and
- single-plane position resolution.

In order to obtain these, I used the reconstructed tracks determined by all the planes of St. 1, 2, 3+ drift chambers.
Efficiency

I checked one plane of the St. 3+ drift chamber (named as D3+X).

- The definition of the efficiency is $\frac{N_{\text{det}}}{N_{\text{track}}}$

  $N_{\text{det}}$ : number of tracks detected by D3+X
  $N_{\text{track}}$ : number of tracks penetrating the St. 3+ drift chamber

- In order to determine the efficiency, I checked if the wire which is the nearest to the reconstructed track has a hit or not.

In this analysis, the track is reconstructed without using D3+X itself.
The details for obtaining the efficiency is shown in this page.

1. **Track without D3+X.**
2. **Select the clean events.**
   “Clean” means
   - the number of tracks penetrating D3+ is only one, and
   - there are no extra hits on other planes.
3. **Check the hits on D3+X.**

<table>
<thead>
<tr>
<th>Check if D3+X has a hit or not.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Check if the distance between the track and the closest hit wire to the track is small enough.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
</tbody>
</table>

   → Inefficient

   The analysis on D3+X’ is also done using the same method.**

**Results:**

<table>
<thead>
<tr>
<th>Plane</th>
<th>$N_{\text{track}}$</th>
<th>$N_{\text{det}}$</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>D3+X</td>
<td>2212</td>
<td>2140</td>
<td>96.7 ± 0.4%</td>
</tr>
<tr>
<td>D3+X’</td>
<td>2237</td>
<td>2159</td>
<td>96.5 ± 0.4%</td>
</tr>
</tbody>
</table>
Position Resolution

I checked the single-plane position resolution of each plane of St. 2 and 3+ drift chambers. In this analysis, the track is reconstructed using all the planes of St. 1, 2, and 3+.

- I used the $R - T$ curve in order to measure the position resolution.
  - $R - T$ curve shows the relation between the distance and the drift time.
    - The plus sign in the figure shows that the track passes on the left side of the wire.
    - The minus sign shows that the track passes on the right side of the wire.
  - The uncertainty of the $R - T$ curve is the position resolution.

A cell of drift chamber

- 2 cm
- track
- wire
- distance
- cell
I projected the $R - T$ curve to the horizontal axis in each time bin (10 ns).

- The figure on the right is an example (at 125 ns).

There are two peaks in the figure on the right. I used double gaussian to fit the histogram.

$$a \times \exp \left( -\frac{(x - m)^2}{2\sigma^2} \right) + b \times \exp \left( -\frac{(-x - m)^2}{2\sigma^2} \right) + c$$

- $\sigma$ shows the position resolution.
Results of Position Resolution

Results of D2

Results of D3

However, these results are not yet “pure” resolutions.

- The tracking error needs to be taken into account.
- It is in progress.
6. Summary

- SeaQuest experiment studies the structure of the proton at Fermilab.
  - It measures $\bar{d}/\bar{u}$ by Drell-Yan process.
  - SeaQuest uses the magnetic spectrometer for detecting the muons.

- My works during the master course were
  - construction of a new drift chamber
  - identifying the crosstalk signals of St. 3± chamber
    - The probability that the crosstalk appears is 4.9±1.0% for St. 3+ and 3.3±0.7% for St. 3−.
    - I developed a method to handle the crosstalk signals by selecting the earliest signal.
  - test of the single-plane efficiency and single-plane position resolution
    - The single-plane efficiency of St. 3+ drift chamber is 96.7±0.4%.
    - The single-plane position resolutions of St. 2 & St. 3+ drift chambers are obtained as a function of drift time.
Backup
Because of the acceptance of SeaQuest spectrometer, $x_{\text{beam}} \gg x_{\text{target}}$ events are chosen.

$$\frac{d^2 \sigma}{dx_1 dx_2} = \frac{4\pi \alpha^2}{9M^2} \sum_i e_i^2 [q_i(x_1)\bar{q}_i(x_2) + \bar{q}_i(x_1)q_i(x_2)]$$
Time difference on St. 3+ drift chamber.
The mean values of the peaks are 10 ns and 30 ns.
σ of the peaks are 3.5 ns.
→ If the time difference is 10 or 30±3 × 3.5 ns, it’s a “common value”.

Time difference on St. 3− drift chamber.
The mean value of the peak is 23 ns.
σ of the peaks are 3.5 ns.
→ If the time difference is 23±3 × 3.5 ns, it’s a “common value”.

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If the distance is less than $1 \times \sqrt{2} \times \cos(\pi/4 - \theta) + 0.2$ cm, it is “efficient”.

1 ... half of cell size
$\sqrt{2} \cos(\pi/4 - \theta)$ ... distance between the track and the wire if the track passes on the corner of the cell
0.2 ... roughly $3 \times$ resolution
Correction of the resolution

The observed errors by track reconstructed with all planes are smaller than the true resolution.

Because the track is pulled by the hit.

I think the correction factor can be calculate from the least square method.

\[
\frac{\partial x_t^i}{\partial x_k^i} = \frac{1}{X_i} \left[ \left( (N_{\text{plane}} - 1)z_k - \sum_{j \neq i} z_j \right) z_i + \left( \sum_{j \neq i} z_j^2 - z_k \sum_{j \neq i} z_j \right) \right]
\]

\[
X_i = (N_{\text{plane}} - 1) \sum_{k \neq i} z_k^2 - \left( \sum_{k \neq i} z_k \right)^2
\]

\[
X_a = N_{\text{plane}} \sum_k z_k^2 - \left( \sum_k z_k \right)^2
\]

\[
\downarrow
\]

\[
C_i = \sqrt{\left( \frac{X_i}{X_a} \right)^2 \left[ \sum_{k \neq i} \left( \frac{\partial x_t^i}{\partial x_k^i} \right)^2 + 1 \right]}
\]
The gas in the chamber ionizes.
The movement of the ions induces the charge on the wires.
The wire pair becomes like a condenser.
The “condenser” moves to the side of the chamber.
The signal on the field wire is reflected.
The signal on the sense wire is read-out.
The reflected signal induces the signal on the neighboring sense wires (capacitive coupling).
The same thing is occur on the opposite side.
The signal on the neighboring sense wire is detected.

The time difference depends on the wire length.

→ The time difference on the same chamber is the same.