In the electro-weak Standard model, three input parameters are:

- $\alpha / \alpha \sim 0.045$ ppm
- $G_F / G_F \sim 9$ ppm
- $M_Z / M_Z \sim 22$ ppm

Motivation:

- $\tau_\mu$, the muon lifetime, is defined by $G_F$.
- $G_F$ is one of the input parameters in the Standard Model.
- The error on $M_Z$ will be comparable to $G_F$.
- Precise test of the Standard Model.
Definition of the muon lifetime

\[ \tau^{-1} = \frac{G_F^2 m_\mu^5}{192\pi^3} \left[ 1 + \frac{3}{5} \frac{m_\mu^2}{m_W^2} \right] [1 + \Delta q] \]

\[ F(x) = 1 - 8x - 8x^3 - x^4 - 12x^2 \ln(x) \]

\[ \alpha^{-1}(m_\mu) = \alpha^{-1} - \frac{2}{3\pi} \ln\left( \frac{m_\mu}{m_e} \right) + \frac{1}{6\pi} \]

\[ \Delta q = C_1 \frac{\alpha(m_\mu)}{\pi} + C_2 \frac{\alpha^2(m_\mu)}{\pi^2} \]

\[ C_1 = \frac{25}{8} - \frac{\pi^2}{2} \]

\[ C_2 = \frac{156815}{5184} - \frac{1036}{27}\zeta(2) - \frac{895}{36}\zeta(3) + \frac{67}{8}\zeta(4) + 53\zeta(2) \ln(2) \]

Decay mode

\[ \mu^+ \rightarrow \bar{\nu}_\mu \nu_e^+ \nu_e \quad (~100\%) \]

\[ \mu^+ \rightarrow \bar{\nu}_\mu \nu_e^+ \nu_e \gamma \]

\[ \mu^+ \rightarrow \bar{\nu}_\mu \nu_e^+ \nu_e e^+ e^- \quad (~3.4 \times 10^4) \]
Historical Background

- **Experiment**
  - 1984 TRIUMF (Giovanetti et al.)
    - < 27 ppm
- **Theory**
  - 1999 T. van. Ritbergen et al.
    - < 1 ppm
    - Second order radiative collection
Present Experiment at RIKEN

- High event rate ex. at the RAL
  \[ 200 \times 50 \text{ Hz} = 10^4 \text{ events/sec} \]

- Count loss by the pile-up is a serious problem.

- Fine segmented detector

- Offline correction

To decrease the count loss
I. Higher event rate

- Strong pulsed beam at RIKEN-RAL (50 Hz, 10^6/sec surface μ +)
- Use MWPC for segmented detector (192 segmentations)

II. Target selection

- Very short spin relaxation time

III. Very accurate and multi-stop clock

- Synchronize GPS and Latching Memory every 100 nsec
- Monitor same signal with multi-stop TDC (500 psec bin)
Spin relaxation in Holmium

- Spin asymmetry was measured
- Zero, Transverse and Longitudinal field were applied (independent of the magnetic field)
- Rapid and exponential relaxation $T_1 \approx 500 \text{nsec}$

Graph showing $\frac{F-B}{F+B}$ vs. Time (ns) for Holmium with $B_T = 20 \text{ G}$, $B_T = 0 \text{ G}$, and $B_L = 100 \text{ G}$.
• Very Accurate Clock (<10^-12) Synchronized GPS and LM (10 MHz)

• Examine MWPC hit pattern Multi-hit TDC (500 psec)

• DAQ system 4 CAMACs in parallel (3 Mb/sec)

• Scintillators calibration purpose

• Data Acquisition System

- Scintillator
  - AMP & Discriminator
    - GPS 10 MHz
  - LM 0μ - 64μsec 100 nsec/bin
  - TDC 3M/sec/sec
  - PC
    - LeCroy 3377
      - long range TDC 0μ - 32μsec 500 psec/bin
      - DDS 3 12G
      - record
• Examine event structure (MWPC) event selection
  Determine the relationship between signal and background

• Time calibration
  LM analysis (Mainly used)
  Determine dead-time in the off-line analysis (d=200)

• Estimate count loss by pile-up event
  Establish the correction method

• Fitting
  Estimate systematic error

• Analysis

• Conclusion
• Examine event structure (MWPC) and event selection
  • Examine Multiplicity, Cluster size, Beam current

• Time calibration
  • LM analysis (Mainly used)
    • Determine dead-time in the off-line analysis (d=200)

• Estimate count loss by pile-up event
  • Establish the correction method

• Fitting

• Estimate systematic error
Count loss correction

I. Restore "distribution before count-loss (Poisson)"

- Observed mean value
- Mean value given by Poisson distribution

II. Calculate the correction

III. Add the correction to a observed time spectrum during the dead-time by "event by event" method
Conversion the Mean value

Before Count-loss (Poisson distribution)

Mean value

Simulation

After Count-loss (not Poisson)

Observed distribution

Poison distribution (before and after count-loss) - simulation

Number of Spill

Registered event number (count/spill/ch)

Sum = 1000000000 mean = 1.8307 disp = 1.56689

Sum = 1000000000 mean = 2.0000 disp = 2.0001
- Follow Poisson distribution
- Limit positrons less than \( \frac{counts}{spill/channel} \)
- Calculate the expected event number registered in the dead-time
- Integrate this function over \([t:t+b]\)

**Count-loss Correction Calculation**

\[
N_{observed} = \frac{m}{\tau} \exp(-mDe^{-\frac{t}{\tau}}) \exp\left(-\frac{t}{\tau}\right)
\]

\[
N_{loss} = \frac{m}{\tau} \left(1 - \exp(-mDe^{-\frac{t}{\tau}})\right) \exp\left(-\frac{t}{\tau}\right)
\]

\[
m_d = mDe^{-t/\tau} = \sqrt{\frac{t + d}{t}} \int_t^{t+d} e^{-t/\tau} dt
\]
\{(\text{observed spectrum}) \times (\text{correction})\} \div (\text{in loss spectrum})

\begin{center}
\text{correction}
\end{center}

\[ m = 2 \]
• Valid if consistent lifetime values are obtained in any time region within the statistical error
• tried m<2 (consistent in any mean value)
• Consistent correction after 1 µs for m=2
• Apply this method to a real data set

![Fit to the corrected data (Simulation)](image-url)
Difference between "Correction" and "Fitting"

- Event rate fluctuation is taken into account in the long time (event by event method)

- Count-loss correction is flexible to the dead-time determined by the offline analysis (now d = 200 nsec)

- Less parameter fitting (3 parameters)

Merits for the count loss correction

- Correction parameters, mean value and dead-time (d) should be taken precisely into the correction scheme.

- Consistency check by iterating the lifetime value because of using a known lifetime value (known precision) in the correction
- Event rate
- Cosmic ray and neutron from the beam-line
- Constant

\[ \sim 10^4 \]
Fitting Procedure

- 3 parameters fitting (Less parameters)
- Using Minuit

Fitting Function

\[ N(t) = Ae^{-\frac{t}{\tau}} + B \]

- \( A \): Amplitude
- \( B \): Background
- \( \tau \): Lifetime
Fitting (\([t : 22000 \text{ nsec}]\))

- Determine the amplitude to distribute the lifetime at the constant level.
- Should check all data in the analysis.
Fitting Result (Preliminary)

- 1 set has half-day data
- Fitting region $2\mu s - 'Q'Q$ µs

---

- [Data Points]
- $2.0 \cdot 10^8$
- $1.5 \cdot 10^8$
- $1.0 \cdot 10^8$
- $5.0 \cdot 10^7$
- $0$

![Graph Image]

- \[ \mu \]
- \[ 22 \mu \]
mu-e decay Time Spectrum (raw)

Decay Positron [count]

total: $N = 2.7 \times 10^9$
Fitting results (Preliminary)

- Not all data set
- Fitting region $2 \mu s - 2'Q \mu s$
- Data $2.5 \times 10^9$ in the fitting region $1.18 \times 10^9$

**mu-e decay Time Spectrum**

- $N = 1.18 \times 10^9$
- $\mu - 2 \mu$
- $N$ in the fitting region

![Graph showing mu-e decay time spectrum with fitting region and data points.](image)
• Systematic error

<table>
<thead>
<tr>
<th>Systematic Error</th>
<th>Expected Count Loss Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 ppm Bin size (100 nsec LM)</td>
<td></td>
</tr>
<tr>
<td>&lt; 10 ppm MWPC multiplicity cut</td>
<td></td>
</tr>
<tr>
<td>&lt; 1 ppm Muon stopping</td>
<td></td>
</tr>
<tr>
<td>&lt; 10 ppm Background (Charged particles)</td>
<td></td>
</tr>
<tr>
<td>&lt; 1 ppm GPS Clock (Synchronized Latching Memory)</td>
<td></td>
</tr>
</tbody>
</table>

All data = Analysis efficiency

< 30% MWPC multi-hit effect

~ 65% Fitting region limit

~ 75% – 80% Event selection

• Statistical error

< 10^{11}

\[ \text{Data} \sim 10^{10} \]
Data analysis is now in the last stage.

Count loss correction method was developed.

We determined the lifetime by fitting LM data (preliminary).

Statistics by the analysis efficiency is the key point to determine the statistical error.

Iteration should be done to obtain the self-consistent lifetime value (now doing).

Systematic error should be determined.

Summary