**TWIST – the TRIUMF Weak Interaction Symmetry Test**

* Motivation
* Overview of the experiment
* Accomplishments to date
* Upcoming schedule
* Introduction to the systematics

... The most general interaction, which does not presuppose the $W$

$$\text{rate} \sim \left| \sum_{\gamma=V,T} \frac{g^\gamma_{ij}}{\mathcal{M}_{ij}} \left( \langle \langle \frac{\Gamma^\gamma_j}{\langle V^\gamma_i \rangle} \rangle \langle \langle \frac{\Gamma^\gamma_{ij}}{\langle V^\gamma_{ij} \rangle} \rangle \right)^2 \right|$$

- scalar
- vector
- tensor

Actual knowledge of couplings:

| $|g^S_{\mu\mu}|<0.066$ | $|g^V_{\mu\mu}|<0.033$ | $|g^T_{\mu\mu}|=0$ |
|---------------------|---------------------|---------------------|
| $|g^S_{LR}|<0.125$ | $|g^V_{LR}|<0.060$ | $|g^T_{LR}|<0.036$ |
| $|g^S_{RL}|<0.424$ | $|g^V_{RL}|<0.110$ | $|g^T_{RL}|<0.122$ |
| $|g^S_{LL}|<0.55$ | $g^V_{LL}>0.96$ | $g^T_{LL}=0$ |

Interactions of right-handed and left-handed leptons.
The general interaction can be expanded in terms of the Michel parameters:

\[
\text{rate} \propto x^2 \left[ 3 - 3x + \frac{2}{3} \rho (4x - 3) + 3\eta \gamma_0 \frac{1-x}{x} + \beta \mu \xi \cos(\theta) \left( 1 - x + \frac{2}{3} \delta (4x - 3) \right) \right]
\]

The above decay distribution is modified by radiative corrections, required to second order.

Decay distribution

These are being calculated by Andrzej Czarnecki and Andrei Arbusov, at the University of Alberta.

Consider Left/Right Symmetric extensions to the Standard Model

Parity violation at low energy presumably due to \( \frac{m_{W_R}}{m_{W_L}} \gg 1 \)

Expect a non zero \( g_{RR} \) and \( g_{LR} \)

\[
g_{RR} = g_{RL} = \zeta \ll 1 \quad g_{LR} = \left( \frac{m_L}{m_R} \right)^2
\]

Where \( \zeta \) is the \( (W_R - W_L) \) mixing angle

If tensor and scalar couplings are excluded (as unnecessary) from these extensions, then:

\[
\rho = \frac{3}{4} \left| g_{LL} \right|^2 - 2 \left| g_{LR} \right|^2 \quad \zeta \delta = \frac{3}{4} \left[ \left( g_{LL} \right)^2 - 2 \left( g_{LR} \right)^2 + \left| g_{RR} \right|^2 \right]
\]

\[
\xi = \left| g_{LL} \right|^2 - 2 \left( \left| g_{RR} \right|^2 + \left| g_{LR} \right|^2 \right) \quad \eta = 0
\]
For Left/Right Symmetric extensions

For \( g_{LR}^V = g_{RL}^V = \zeta << 1 \quad \text{and} \quad g_{RR}^V = \left( \frac{m_L}{m_R} \right)^2 \)

\[
\begin{align*}
\rho &= \frac{3}{4} (1 - 2\zeta^2) \\
\xi &= 1 - 2 \left( \frac{m_L}{m_R} \right)^4 - 2\zeta^2 \\
\delta &= \frac{3}{4} \\
\eta &= 0
\end{align*}
\]

\( \rho \) is sensitive to the Left/Right mixing
\( \xi \) to the mixing and to the \( W_R \) mass
\( \delta \) and \( \eta \) are unchanged by Left/Right extensions

A measurement of \( \rho \) and \( \xi \) determines the \( W_R \) mass and its mixing

Testing SUSY

* R-parity violating SUSY leads to the following deviations in the parameters at tree level

\[
\begin{align*}
\Delta \rho &= \frac{3\epsilon^2}{16} \\
\Delta \eta &= \frac{\epsilon}{2} \\
\Delta \delta &= 0 \\
\Delta \xi &= -\frac{\epsilon^2}{4}
\end{align*}
\]

where
\[
\epsilon = \frac{\lambda_{311} \lambda_{322}}{4\sqrt{2}\alpha_F m^2}
\]

The first order contribution to \( \eta \) could signal SUSY
The Michel Parameter $\rho$

$$\rho = \frac{3}{4} | g_{LL} |^2 - \frac{3}{4} | g_{LR} |^2 + | g_{RL} |^2 + 2 | g_{LL} \cdot g_{LR} + g_{RL} \cdot g_{LL} \cdot e^{-i \theta} + g_{LR} \cdot g_{RL} |^2$$

$\rho$ is the shape parameter for the energy spectrum, independent of the muon polarization

$$\frac{d\Gamma}{dx} = \sqrt{x^2 - x_0^2}$$

$$\left\{ s - x^2 + \frac{2}{9} \rho \left( 4x^2 - 3x - x_0^2 \right) + \eta x_0 (1-x) \right\}$$

Spectral sensitivity to $\rho$

The Michel Parameter $\eta$ - Direct evidence for right-handed currents, correction to $G_F$

$$\eta = \frac{1}{2} \Re \left[ g_{LL} \cdot g_{LR} + g_{RL} \cdot g_{LL} + g_{LR} \cdot g_{RL} + g_{LR} \cdot g_{RL} \cdot e^{-i \theta} + g_{LR} \cdot g_{RL} \cdot e^{i \theta} \right]$$

A right-handed scalar interaction, $g_{RR} \neq 0$ would result in $\eta \neq 0$ in first order.

Further, $\eta \neq 0$ is direct evidence for right-handed couplings.

$$\Gamma = \frac{G_F^2 m_\mu^3}{192 \pi^3} \left( 1 + 4\eta \frac{m_e}{m_\mu} - 8 \left( \frac{m_e}{m_\mu} \right)^2 \right) \frac{1}{4} \Gamma_w f_t$$

The uncertainty in the Fermi coupling $G_F$ as derived from lepton decay is dominated by the uncertainty in $\eta$.
The Michel Parameter $\delta$

$$\delta = \frac{3}{4} g_{\mu L}^2 - \frac{3}{4} \left[ g_{\mu L}^2 + \frac{1}{2} g_{LR}^2 + 4 |g_{RL}|^2 + 2 |g_{RR}|^2 \right]$$

$$\left( \delta - \frac{3}{4} \right) = \frac{3}{4} \left[ 1 - 2 x_0 - \left( \sqrt{1 - x_0^2} - 1 \right) \right]$$

Where $x_0$ is the energy at which the decay distribution is independent of angle - independent of the actual value of the muon polarization.

Left/right symmetric extensions to the Standard Model do not alter $\delta$

---

The Michel Parameter $\xi$ - Sensitive to the $W_r$ mass in Left/Right symmetric models

$$\xi = g_{\mu L}^2 - \left[ \frac{1}{2} |g_{\mu R}|^2 + \frac{1}{2} |g_{LR}|^2 + 4 |g_{RL}|^2 - 2 |g_{RR}|^2 \right]$$

$$\left[ 1 - P_{\mu \xi} \right] = \xi^2 + \left( \frac{m_L}{m_R} \right)^4$$

In Left/right symmetric extensions to the Standard Model
The Experiment

* Highly polarized muons enter the spectrometer one at a time
* Data sets of $10^9$ muon decay events are obtained in roughly one week
* The experiment is systematics limited. The high data rate is essential for systematics studies

---

Essential aspects:

* Geometry
  * The chambers are built to high precision
  * Wires are placed to within about three microns of their nominal position
  * Average deviation in wire position much less than three microns

Note: talks by Yuri Davydov on Quality Control and by Roman Tacik on systematics
Essential aspects:

* Efficiency
  * A high degree of redundancy is built into the track reconstruction
  * Cell efficiency is greater than ~ 99.5%
* Note: talks by Yuri Davydov on chamber performance, Maher Quraan on tracking, and by Blair Jamieson on the tracking efficiency in the useful portion of the spectrum

Essential aspects:

* Magnet
  * Field uniformity and map
  * Opera calculations are consistent with measurements
  * Iron seems softer than anticipated – field is a bit flatter than design
* Note: talk by John Macdonald on magnet commissioning and field mapping

Field at 2T is flat to ~ 1½ /1000
Essential aspects:

* Muon beam
  * Surface muon flux and backgrounds
    * Surface muons are characterized by the time structure evidenced by the 26ns mean pion lifetime – TRIUMF time structure of ~1½ pion lifetimes is excellent

Note: talk by Glen Marshall

TWIST Progress in one year

Beam studies 11/2000

Bare floor
August 2000

High momentum, field off 8/2001

Full system commissioning November/December 2001
TWIST Milestones

* Chambers
  * ½ stack commissioned on the bench in July
  * ½ stack commissioned in the beam in August
  * Full stack commissioned with surface muon beam in the magnet in at full 2T field in November/December 2001
  * Spare chambers are in production (20%)

* Electronics
  * Postamp production is complete
  * Preamp production for the full stack is complete
    * spares are in production

TWIST Milestones... continued

* Magnet
  * Rebuilt and commissioned to full field

* Tracking software
  * Straight tracking
  * Efficiencies
  * helical tracking
    * Studying reconstruction errors at 1-10 parts per 10^4 level

* MC Software
  * As built geometry fully implemented, digitization allows analysis studies
Modern software interfaces enhance efficiency and control of the experiment.
Where do we stand?

* The experiment is commissioned
  * Hardware and software function as expected
    * Three planes had hardware faults upon startup, and a fourth failed during the run
  * Alignment, efficiency, and tracking codes are working
* Data quality is high
  * Cross talk is low, and readily rejected
  * Resolution meets expectation
  * Hot and Dead wires are not a problem
  * Backgrounds are reasonable
* Anticipate first physics run in May 2002

The Collaboration

Center of Mass in Canada

* TWIST Comprises 27 faculty and research scientists:
  * 19 Canadian Faculty and Research Scientists
  * 5 American Faculty
  * 3 Russian Research Scientists
* Four graduate students
  * Three Canadian graduate students
  * One American graduate student
* Five Research Associates (FTE)
  * 4.5 Canadian Research Associates (three on project funds)
  * One American Research Associates at half time
* A large complement of excellent professional staff
The Collaboration...

* Students
  * 24 undergraduate students to date, three more in January 2002 (26 Canadian, one from France)
    * Plus additional student volunteers, and students working on for-credit projects
  * Two MSc completions (both students Canadian)
  * Four PhD students (three Canadian, one from the US)
* Three NSERC project funded Research Associates
  * Plus roughly two more FTE Research Associates

TWIST - Personnel

TRIUMF
- Willy Andersson
- Curtis Ballard
- Yuri Davydyov
- Jaap Doornbos
- Wayne Faszer
- Dave Gill
- Peter Gumplinger
- Richard Helmer
- Robert Henderson
- John Macdonald
- Glen Marshall
- Art Olin
- David Ottewell
- Robert Openshaw
- Jean-Michel Poulissou
- Renee Poulissou
- Grant Sheffer
- Hans-Christian Walter
- Dennis Wright

Alberta
- Andrei Gaponenko
- Peter Green
- Peter Kitching
- Rob MacDonald
- Maher Quraan
- Nathan Redding
- John Schaapman
- Jan Soukup
- Glen Stinson
- British Columbia
- Blair Jamieson
- Doug Maas
- Mike Hasinoff
- Northern British Columbia
- Else Kortmann
- Tracy Porcelli
- Montreal
- Pierre Depommier

Regina
- Ted Mathie
- Roman Tacik

Saskatchewan
- Bill Chiu
- Texas A&M
- Carl Gagliardi
- John Hardy
- Jim Musser
- Robert Tribble
- Maxim Vasiliev

Valparaiso
- Don Koeltz
- Robert Manweiler
- Paul Nord

Shinel Stanislaus
KIAC (Russia)
- Arkadi Khroushinsky
- Vladimir Selivanov
- Vladimir Terokhov

TWIST - Personnel

Presently at SLAC

Students
- Professional Staff
Upcoming schedule
* $10^7$ muon decay events are in hand
  * “practice” analysis during January–March 2002
* Field mapping: January – March 2002
* First physics beam: May 2002
* Beamline and depolarization studies: 2002/2003

Brief list of systematics
* Positron Energy Calibration: Andrei Gaponenko
* Intrinsic DC resolution: Maher Quraan
* Tracking efficiency: Blair Jamieson
* Random errors and average errors in wire positions
  Field mapping errors: Roman Tacik
* Spectrometer Response Function: Carl Gagliardi
* Alignment errors: Donald Koetke
* Muon Beam: Glen Marshall
* Muon depolarization: Dave Gill