TRIUMF Weak Interaction Symmetry Test

Towards Higher Precision Measurements of the Muon Decay Parameters by *TWIST*

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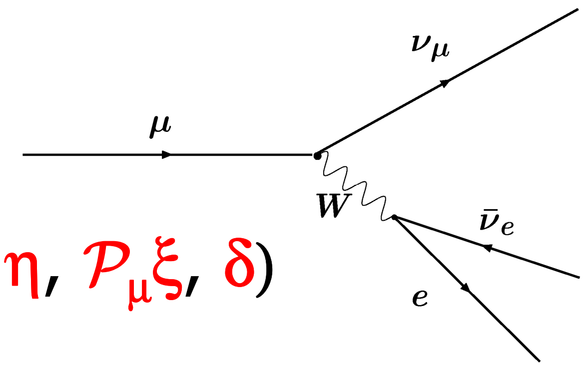
Normal Muon Decay

- Muon differential decay rate *vs.* energy and angle
  (Michel parameter description: ρ, η, $\mathcal{P}_\mu\xi$, δ)



$$\frac{d^2\Gamma}{dx\ d\cos\theta} = \frac{1}{4} m_\mu W_{\mu e}^4 G_F^2 \sqrt{x^2 - x_0^2}\ \{\mathcal{F}_{IS}(x,\rho,\eta) + \mathcal{P}_\mu \cos\theta \cdot \mathcal{F}_{AS}(x,\xi,\delta)\} + R.C.$$

where

$$\mathcal{F}_{IS}(x,\rho,\eta) = x(1-x) + \frac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x)$$

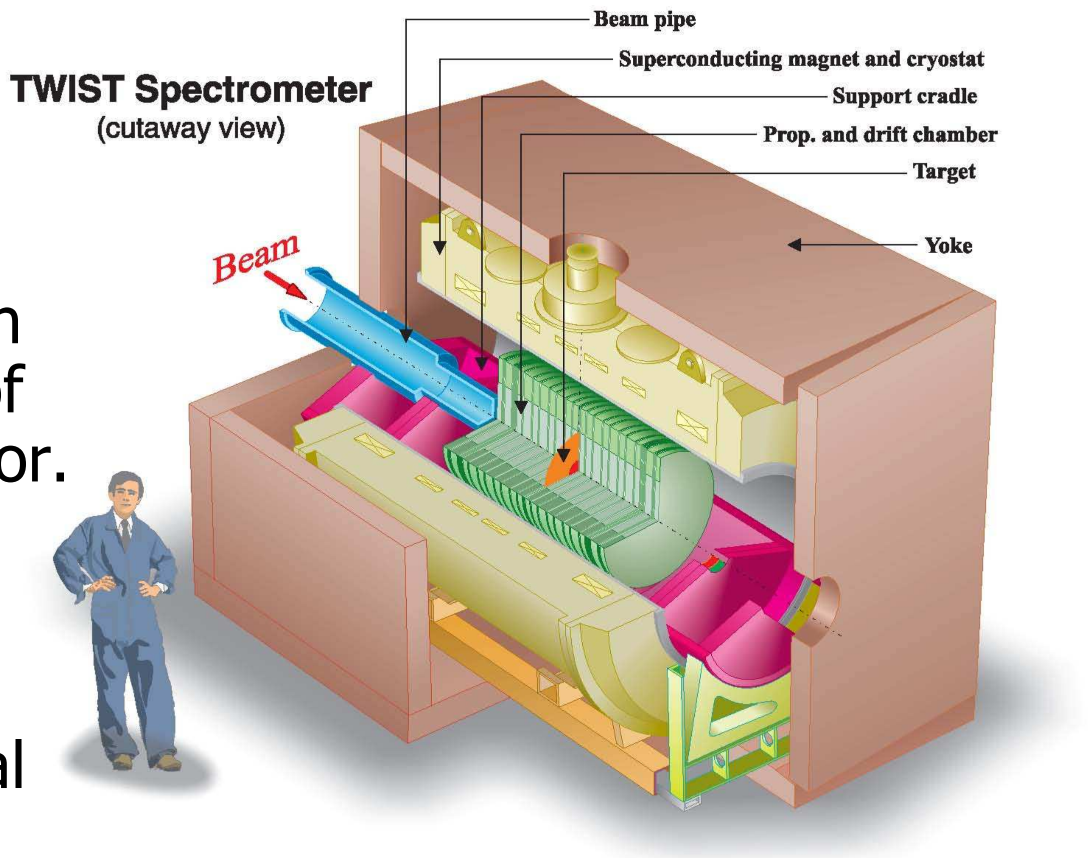
$$\mathcal{F}_{AS}(x,\xi,\delta) = \frac{1}{3}\xi\sqrt{x^2 - x_0^2}\left[1 - x + \frac{2}{3}\delta\left\{4x - 3 + \left(\sqrt{1 - x_0^2} - 1\right)\right\}\right]$$

and

$$W_{\mu e} = \frac{m_\mu^2 + m_e^2}{2m_\mu},\ x = \frac{E_e}{W_{\mu e}},\ x_0 = \frac{m_e}{W_{\mu e}}.$$

The *TWIST* Experiment

- Highly polarized surface μ^+ beam.
- μ^+ stopped in thin target at center of symmetric detector.
- Decay e^+ are tracked through uniform solenoidal magnetic field.



Data sets and analysis

- Data taken in Fall 2002:
  - 6×10^9 muon decay events in 16 data sets of about 2-3 days each.
  - Five (ρ) or four (δ) sets were analyzed and fit to extract results.
  - Remaining sets were for systematic tests.
- Monte Carlo simulation based on GEANT3
  - Decay spectrum includes 2^{nd} order radiative corrections and more
  - Hidden offsets to Michel parameters to keep analysis blind
- Data and MC events analyzed with same code
  - Analysis used WestGrid at UBC (1008 Intel 3 GHz processors)
  - $\sim$31,000 CPU days to analyze data and simulations

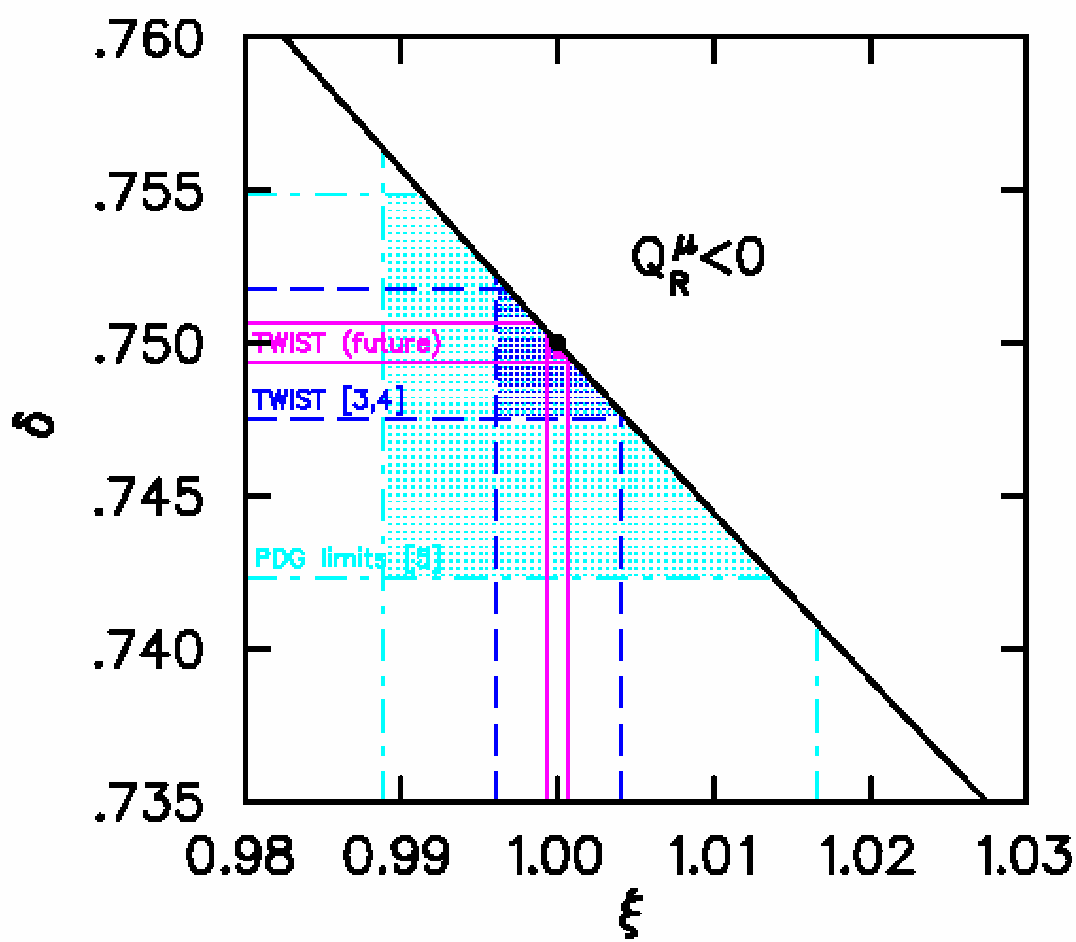
Results for ρ and δ

- ρ **= 0.75080 $\pm$ 0.00032(stat) $\pm$ 0.00097(syst) $\pm$ 0.00023(η)**
  - 2.5 times better than PDG value.
  - Uncertainty scaled to account for χ^2/dof = 7.5/4 for different data sets.
  - hep-ex/0409063; Physical Review Letters 94, 101805 (2005)
- δ **= 0.74964 $\pm$ 0.00066(stat) $\pm$ 0.00112(syst)**
  - 2.9 times better than PDG value.
  - hep-ex/0410045; Physical Review D 71, 071101(R) (2005)
- Using the above values of ρ and δ, with $\mathcal{P}_\mu(\xi\delta/\rho) > 0.99682$ (PDG) and $Q^R_\mu \geq 0$, we get

  $0.9960 < \mathcal{P}_\mu\xi \leq \xi < 1.0040$
  - improves upon $\mathcal{P}_\mu\xi = 1.0027 \pm 0.0079 \pm 0.0030$.

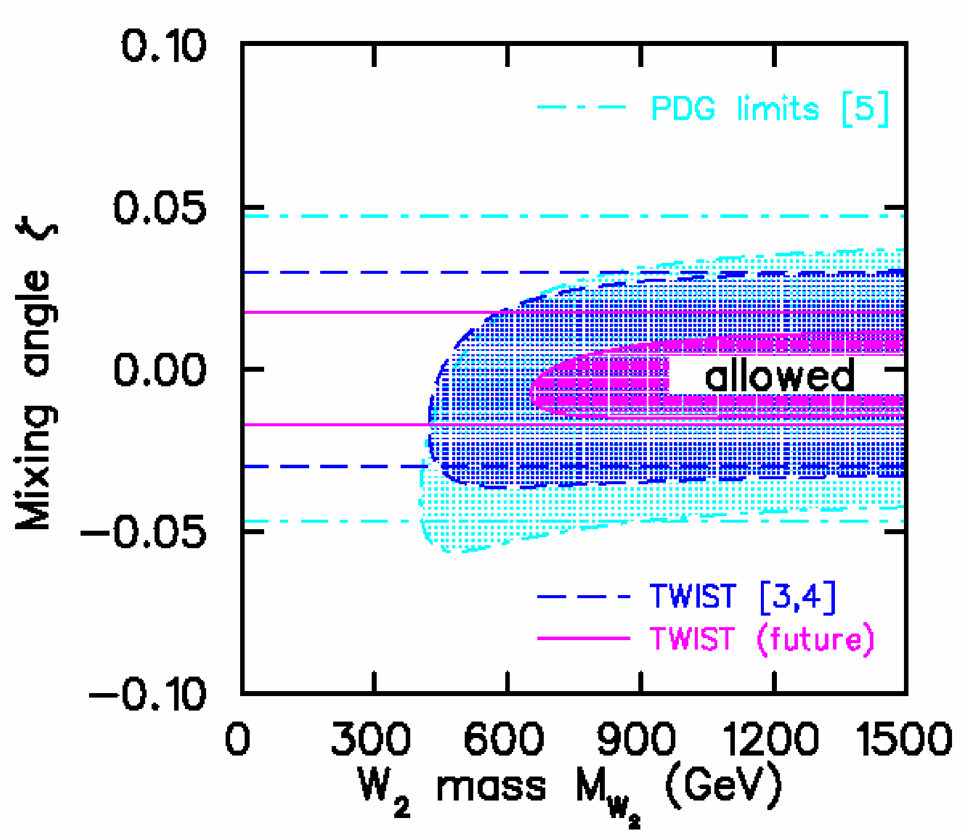
Model Independent Muon Handedness

$$Q_R^\mu = \frac{1}{2}[1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta]$$



Implications for L-R symmetric model

$$\frac{3}{4} - \rho = \frac{3}{2}\zeta^2, \qquad 1 - \mathcal{P}_\mu \xi = 4\{\zeta^2 + \frac{M_L^4}{M_R^4} + \zeta \frac{M_L^2}{M_R^2}\}$$



Exclusion plot for L-R symmetric model mixing angle and right-coupling partner boson W_R mass.

Summary of systematic uncertainties

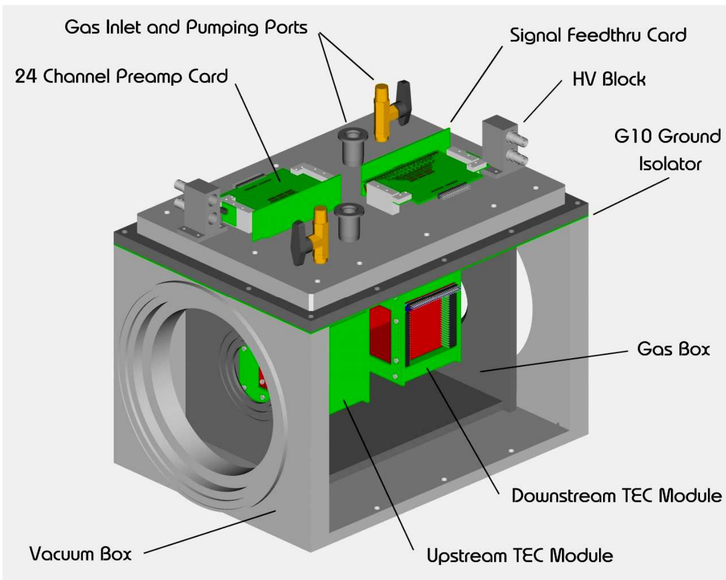
Systematic effect	Uncertainty in ρ ($\times 10^3$)
Chamber response (ave)	0.51
Stopping target thickness	0.49
Positron interactions	0.46
Spectrometer alignment	0.22
Momentum calibration (ave)	0.20
Theoretical radiative correction	0.20
Track selection algorithm	0.11
Muon beam stability (ave)	0.04

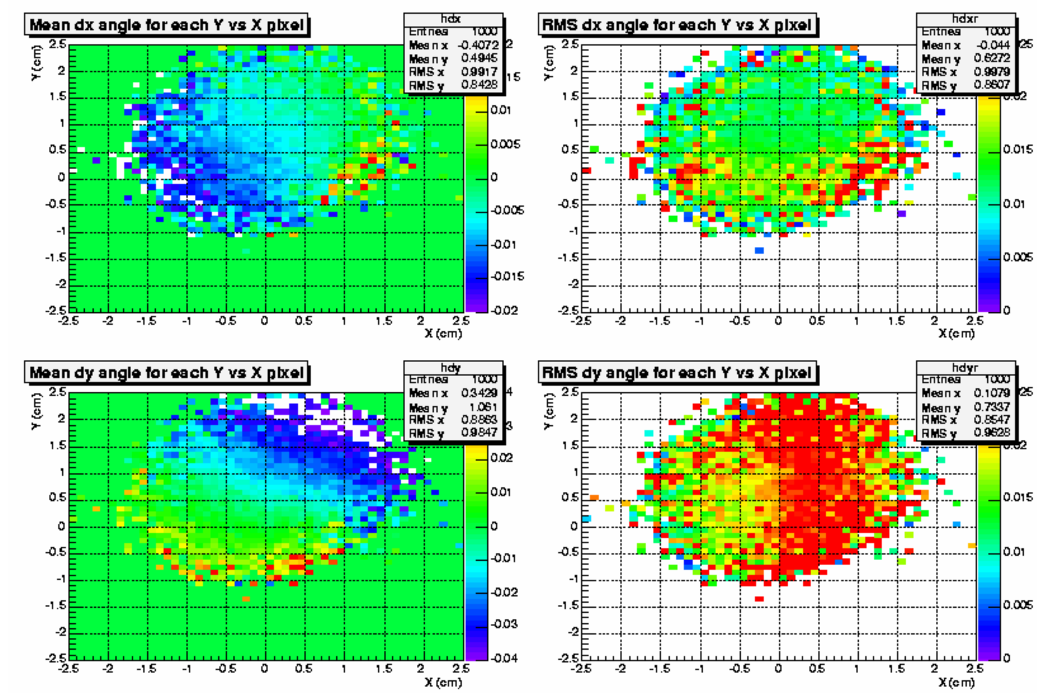
Systematics for ρ

Systematic effect	Uncertainty in δ ($\times 10^3$)
Spectrometer alignment	0.61
Chamber response (ave)	0.56
Positron interactions	0.55
Stopping target thickness	0.37
Momentum calibration (ave)	0.29
Muon beam stability (ave)	0.10
Theoretical radiative correction	0.10
Up and downstream efficiencies	0.04

Systematics for δ

The TEC





The TEC (time expansion chamber) is a transverse drift chamber operating at 0.08 bar, separated from beam vacuum by 6 μm Mylar windows. It has two modules, one for x and one for y.

The second phase for *TWIST*

- Data taken in 2004 with improved apparatus and procedures:
  - 71 μm high-purity aluminum target (reduced muon depolarization and target thickness uncertainty).
  - better monitoring and control of muon beam with TEC (reduced beam uncertainty for simulation).
  - improved control of chamber drift cell geometry (more stable chamber response).
  - better online diagnostics of detectors and beam.
  - feedback to gas degrader (control stopping location)
  - data for calibration of positron interactions ...
- First direct measurement of $\mathcal{P}_\mu \xi$ (next talk) and 2× better precision for ρ and δ (early 2006)

Projection of future results

Engineering studies to improve beam tune (summer 2005)

Production running beginning fall 2005; estimated requirement for statistics and systematics is

2.4×10^{10} events (160 days)

Simulation and analysis improvements:

Drift chamber details, Dead zone, Cell geometry, …

Final goals for uncertainties ($\times 10^3$):

parameter	stat	sys	total
ρ	0.10	0.24	0.26
δ	0.22	0.32	0.39
$P_\mu \xi$	0.30	0.30	0.43

Summary

- *TWIST* has produced its first physics results.
- Has also successfully tested strategies and procedures for the next phase.
- Current analysis is for the first direct measurement of $\mathcal{P}_\mu\xi$, improving it by up to a factor of 5. It will also lead to gains in precision for ρ and δ.
- In 2006-2008, *TWIST* will produce its final results, the goal is an overall reduction of uncertainty by at least an order of magnitude (twice that for $\mathcal{P}_\mu\xi$).

TWIST Participants

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