

The Final Measurement of the Muon Decay Parameters from the *TWIST* Experiment

Ryan Bayes

For the **TRIUMF Weak Interaction Symmetry Test** Collaboration

School of Physics and Astronomy
University of Glasgow

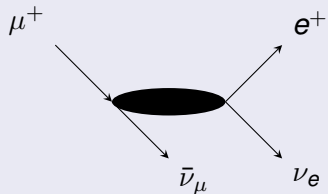
April 6, 2011

Muon Decay as a Probe for the Weak Interaction

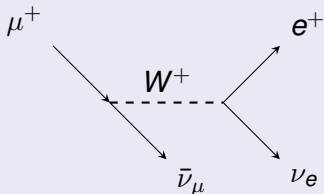
- General Lorentz invariant, derivative-free, interaction¹

$$\mathcal{M} = \frac{4G_F}{\sqrt{2}} \sum_{\substack{\gamma=S,V,T \\ \epsilon,\mu=R,L}} g_{\epsilon\mu}^{\gamma} \langle \bar{e}_{\epsilon} | \Gamma^{\gamma} | (\nu_e)_n \rangle \langle (\bar{\nu}_{\mu})_m | \Gamma_{\gamma} | \mu_{\mu} \rangle.$$

General Case


 \Rightarrow

Standard Model (V-A): $g_{LL}^V = 1$



¹W. Fetscher, H.J. Gerber, and K.F. Johnson, *Phys. Lett.* **B173 (1986) 102**

Decay Spectrum Parametrization

- Given in energy and angle as ²

$$\frac{\partial^2 \Gamma}{\partial x \partial \cos \theta} = \frac{m_\mu}{4\pi^3} W_{e\mu}^4 G_F^2 (F(x) - |P_\mu| \cos \theta G(x)) + R.C., \quad x = \frac{E_e}{W_{e\mu}}$$

In the Standard Model

$$\begin{aligned} \rho &= 0.75 \\ \eta &= 0 \\ \delta &= 0.75 \\ P_\mu^\pi \xi &= 1 \end{aligned}$$

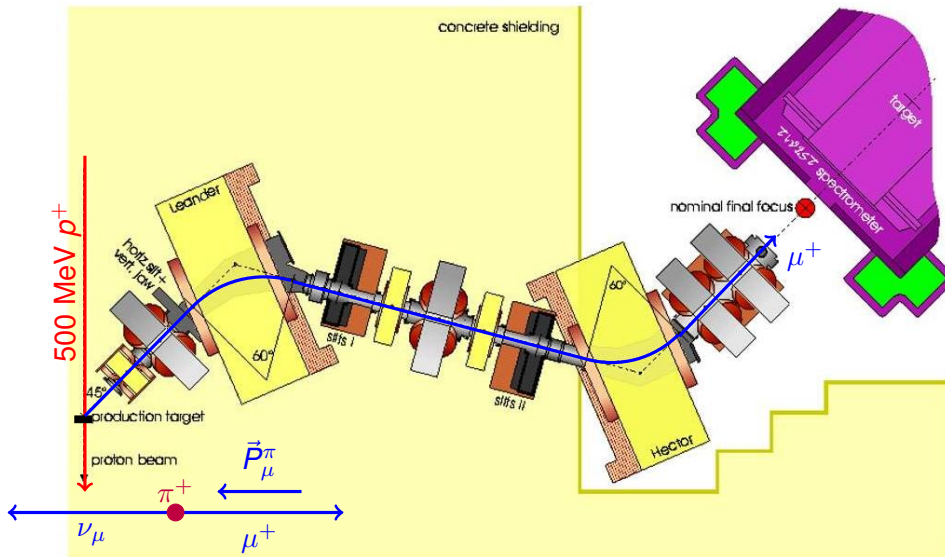
- deviations represent new physics

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

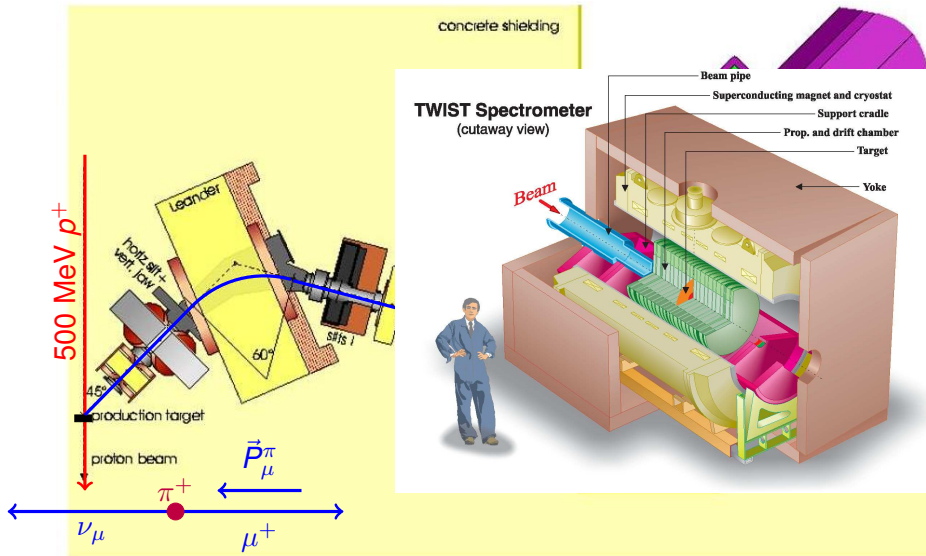
$$G(x) = \frac{1}{3} \xi (x^2 - x_0^2) \left(1 - x + \frac{2}{3} \delta \left(4x^2 - 3x + \left(\sqrt{1 - \cos^2 \theta} \sqrt{x_0^2 - 1} \right) \right) \right)$$

²K. Nakamura et al. (Particle Data Group), J. Phys. G **37**, 075021 (2010)

TWIST Experiment

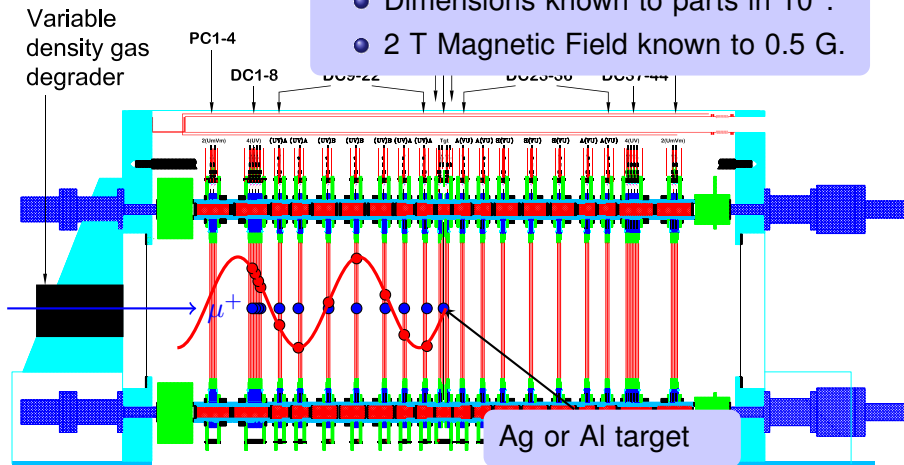


TWIST Experiment

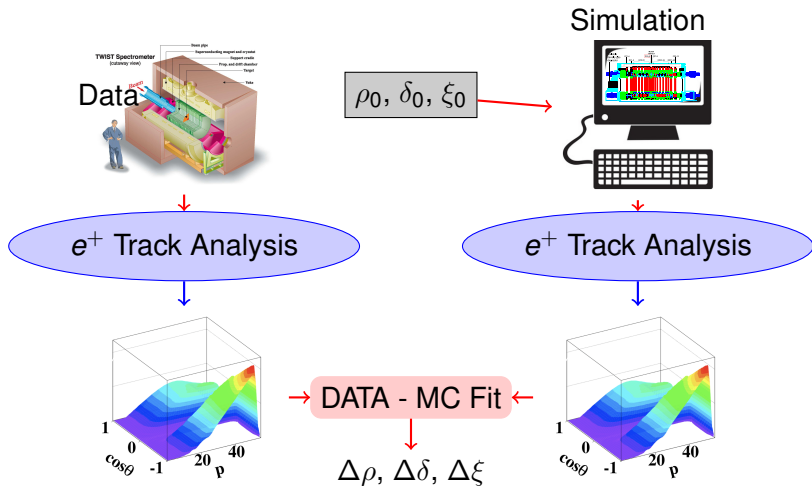


TWIST Spectrometer

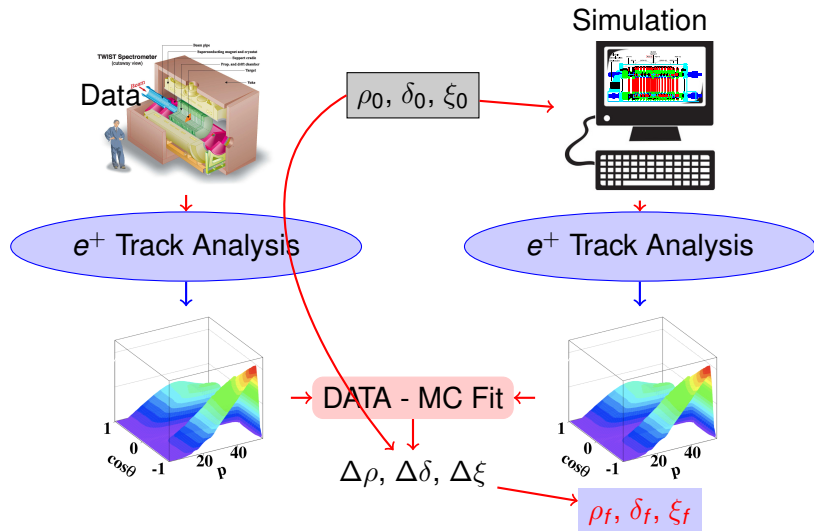
- Dimensions known to parts in 10^5 .
- 2 T Magnetic Field known to 0.5 G.



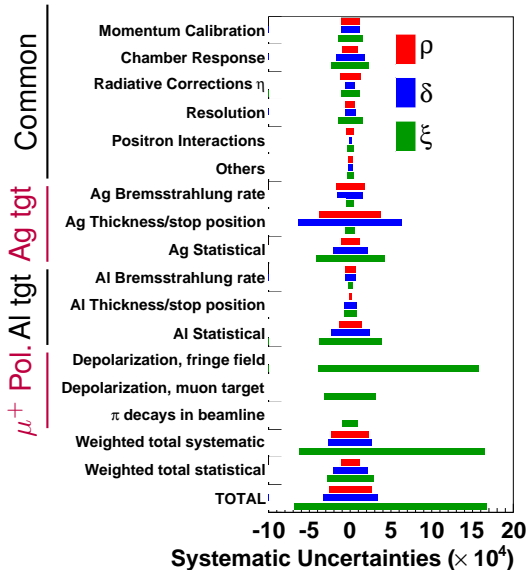
TWIST Analysis Overview



TWIST Analysis Overview



Systematics Summary



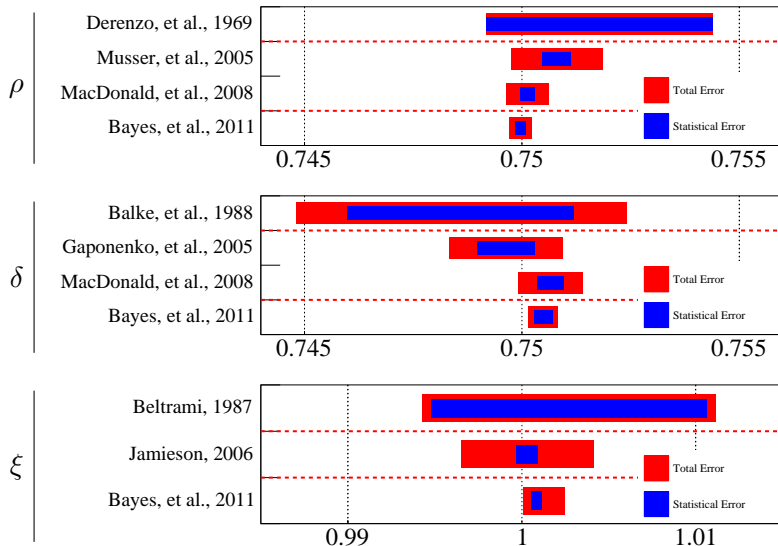
Systematics categorized as

- Common
- Silver target only
- Aluminium target only
- P_{μ}^{π} specific

Measured Results

	Units of $\times 10^{-4}$		
	Ave. Diff.	Stat.	Sys
ρ	95.1	± 1.2	± 2.3
δ	51.3	± 2.1	± 2.7
ξ	80.3	± 2.9	+16.5 -6.3

Decay Parameters



Revision Due to $P_{\mu}^{\pi} \xi \delta / \rho$

Endpoint Anisotropy

$$P_{\mu}^{\pi} \xi \delta / \rho = 1.00179_{-0.00063}^{+0.00156}$$

> 0.99909 (90% C.L.)

- $P_{\mu}^{\pi} \xi \delta / \rho$ changed in Ag and Al targets by 3.9σ

- $P_{\mu}^{\pi} \xi \delta / \rho > 1$ by 2.9σ
- Prompted review of systematics after black box opening

Changes in the Revised analysis

- Motivated categorization of systematics
- Corrected parameter weighting
- Identified systematics from mean stopping position

Change between blind and revised results

	Units of $\times 10^4$	
	Value	σ_{total}
ρ	-1.4	-0.3
δ	-2.3	+0.1
$P_{\mu}^{\pi} \xi$	0	-0.2

Left - Right Symmetric Models

Mixing $V - A$ and $V + A$ currents^a

$$W_L = \cos \zeta W_1 + \sin \zeta W_2$$

$$W_R = e^{i\omega} (-\sin \zeta W_1 + \cos \zeta W_2)$$

- $W_{R(L)}$ mediate $V + A(V - A)$ currents
- ζ is the mixing angle between W_1 and W_2
- ω CP violating phase

^aP. Herczeg, **PRD** 34,3449,(1986)

Decay Parameters in This Model

$$\rho \simeq \frac{3}{4} \left(1 - 2 \left(\frac{g_R}{g_L} \right)^2 \zeta^2 \right), \delta \equiv \frac{3}{4}, \xi \simeq 1 - 2 \left(\left(\frac{g_R m_1}{g_L m_2} \right)^4 + \left(\frac{g_R}{g_L} \right)^2 \zeta^2 \right)$$

$$\frac{P_{\mu}^{\pi} \xi \delta}{\rho} \simeq 2 \frac{g_R^4 m_1^4}{g_L^4 m_2^4} \left(1 + \frac{\cos^2 \theta_1^R}{\cos^2 \theta_1^L} \right) + 2 \frac{g_R^2}{g_L^2} \zeta^2 + 4 \frac{g_R^3 m_1^2 \cos \theta_1^R}{g_L^3 m_2^2 \cos \theta_1^L} \zeta \cos(\alpha + \omega)$$

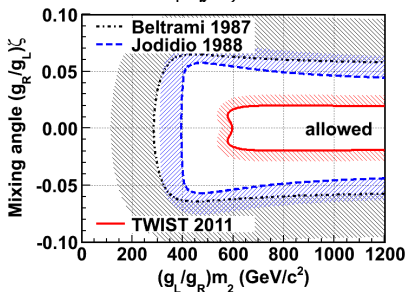
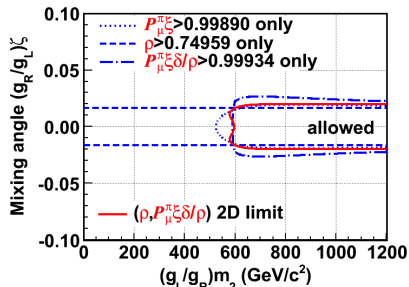
Left-Right Symmetric Models

90% Confidence limits

- $|\frac{g_R}{g_L}\zeta| < 0.02$
- $|\frac{g_R}{g_L}|m_2 > 578 \text{ GeV}/c$
- Set using a combination of 90% limits on ρ , and $P_\mu\xi\delta/\rho$

Generalized approach to model

- No assumption of model parameters
- W_2 Direct searches assume $g_R = g_L, \omega = 0$



Conclusions

- Order of magnitude improvement in precision of decay parameters has been completed by the TWIST experiment

$$\begin{aligned}
 \rho &= 0.74997 \pm 0.00012 \pm 0.00023 \\
 \delta &= 0.75049 \pm 0.00021 \pm 0.00027 \\
 P_{\mu\xi} &= 1.00084 \pm 0.00029^{+0.00165}_{-0.00063} \\
 P_{\mu\xi\delta/\rho} &= 1.00179^{+0.00156}_{-0.00071} \\
 &> 0.99909 \text{ (90\% C.L.)}
 \end{aligned}$$

- $P_{\mu\xi\delta/\rho} > 1$ has been investigated; no problem with analysis has been identified
- Left-Right mixing angle $|\frac{g_R}{g_L}\zeta| < 0.02$

Thank you

TRIUMF

Ryan Bayes *†
 Yuri Davydov
 Wayne Faszer
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 David Gill
 Alexander Grossheim
 Peter Gumplinger
 Anthony Hillairet *†
 Robert Henderson
 Jingliang Hu
 John A. Macdonald §
 Glen Marshall
 Dick Mischke
 Mina Nozar
 Konstantin Olchanski
 Art Olin †
 Robert Openshaw
 Jean-Michel Poutissou
 Renée Poutissou
 Grant Sheffer
 Bill Shin ††

U. Alberta

Andrei Gaponenko **
 Robert MacDonald **
 Maher Quraan
 Nate Rodning §

U. British Columbia

James Bueno *
 Mike Hasinoff
 Blair Jamieson **

U. Montréal

Pierre Depommier

U. Regina

Ted Mathie
 Roman Tacik

Kurchatov Institute

Vladimir Selivanov

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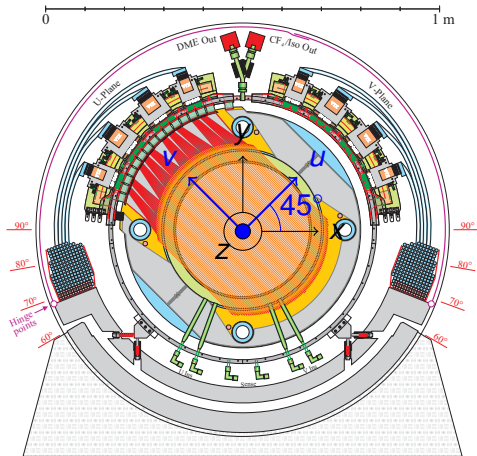
Carl Gagliardi
 Jim Musser **
 Bob Tribble

Valparaiso U.

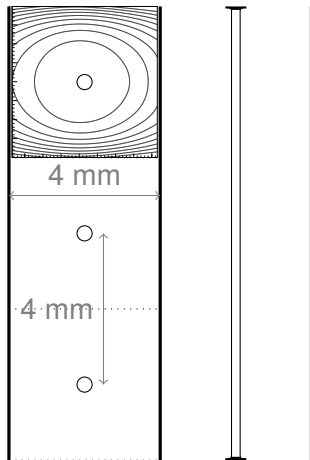
Don Koetke
 Shirvel Stanislaus

* Recently graduated
 ** Graduated
 † also U. Vic
 †† also U. Saskatchewan
 § deceased

Drift Chambers

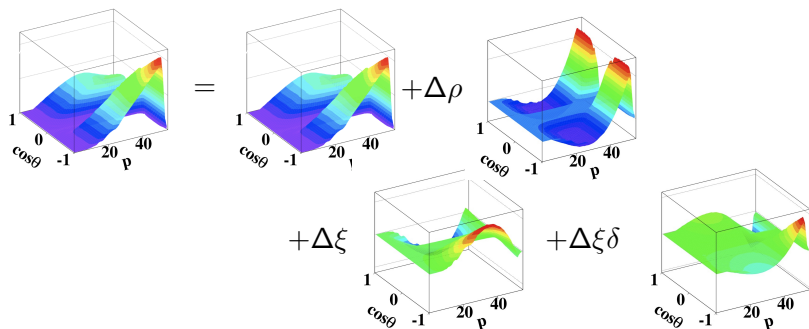


U - Plane V - Plane



Spectrum Fits

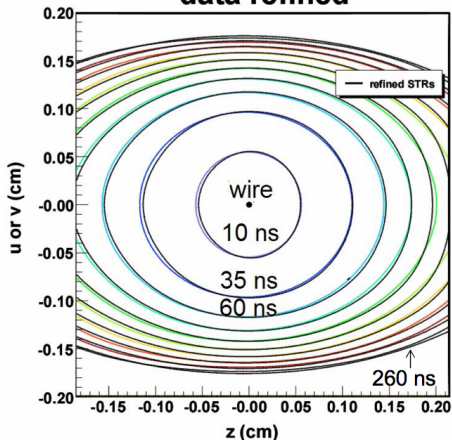
- Sum of simulated spectra used as fitting function



- Parameters minimized using a χ^2 statistic.

Systematics Improvement

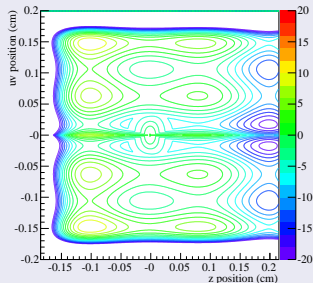
data refined



- Chamber space time relationships corrected to minimize e^+ track fit time residuals
- Corrects for plane to plane construction differences
- Procedure repeated for data and Monte Carlo

Systematic Effect

Exaggerated - Standard STR



- Exaggerated time residuals between data and MC
- Factor of 10 effect

$\Delta\rho$	-0.31 ± 0.17
$\Delta\delta$	-1.03 ± 0.29
$\Delta\xi$	0.88 ± 0.36