

TRIUMF Muon Decay Asymmetry Measurement

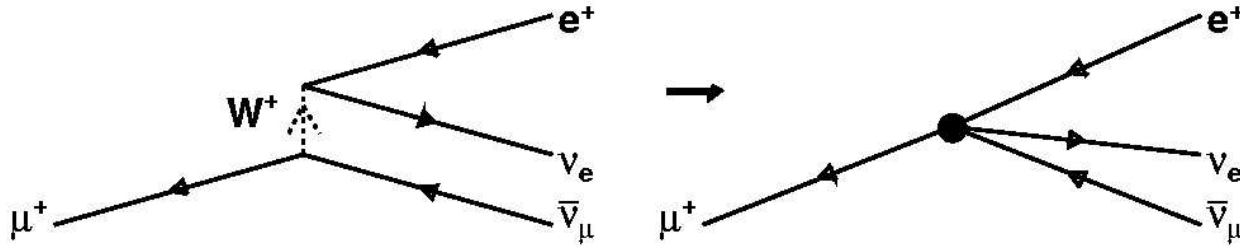
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for the *TWIST* Collaboration
APS/JPS Meeting, Sept 19, 2005, Maui, HI

OUTLINE

- Physics of μ decay asymmetry
- Brief review of previous measurements
- Systematic error estimates
- Data Sets and Consistency Checks
- Summary and Outlook

Muon Decay $\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$



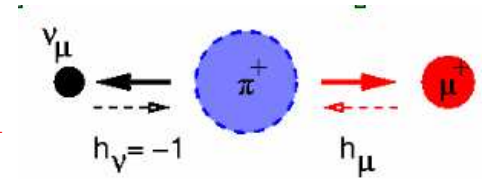
General derivative free interaction matrix element:

$$M = 4 \frac{G_F}{\sqrt{2}} \sum_{\substack{\gamma=S,V,T \\ \epsilon,\mu=R,L}} g_{\epsilon\mu}^\gamma \langle \bar{e}_\epsilon | \Gamma^\gamma | \nu_e \rangle \langle \bar{\nu}_\mu | \Gamma_\gamma | \mu_\mu \rangle \quad (1)$$

- $g_{\epsilon\mu}^\gamma$ are the decay coupling constants
- $\gamma = S, V, T$ are the scalar, vector, and tensor interactions
- $\epsilon, \mu = L, R$ are the chirality of the electron or muon
- SM: all zero coupling constants, except $g_{LL}^V = 1$

Physics of μ decay asymmetry

- P_μ is the polarization of the muon, ξ is the asymmetry in angle of the decay positrons from normal μ decay
- Standard Model (V-A) predicts $\xi = 1$ and $P_\mu = -1$

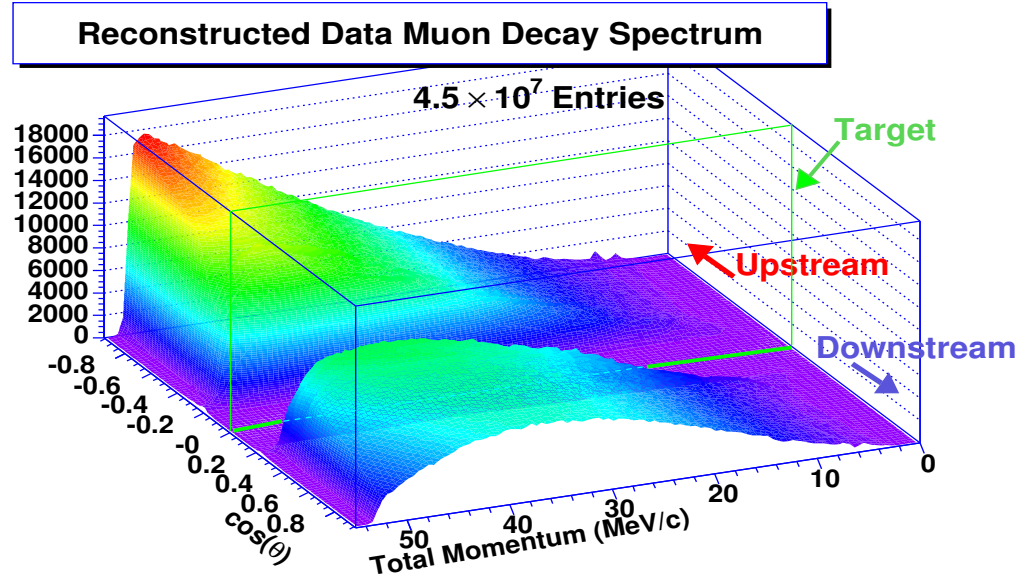


$$\frac{d^2\Gamma}{dx d\cos\theta} \propto F_{IS}(x, \rho, \eta) + P_\mu \xi \cos\theta F_{AS}(x, \delta) \quad (2)$$

$$x = E_e/W_{e\mu}$$

$$W_{e\mu} = \frac{m_\mu^2 + m_e^2}{2m_\mu}$$

$$x_0 = \frac{m_e}{W_{e\mu}}$$



Measurements and Motivation for $P_\mu\xi$

- Direct Measurements:

- $P_\mu\xi = 1.0027 \pm 0.0079 \pm 0.0030$ (Beltrami et al, PL **B194** 1987)
- $P_\mu\xi\delta/\rho > 0.99682$, 90% conf. level (Jodidio et al, PR **D34**, PR **D37** 1986)

- Indirect Measurement (*TWIST* ρ/δ PRL **94**, 101805 + PRD **71**, 071101(R) (2005)):

$$0.9960 < P_\mu\xi \leq \xi < 1.0040 \text{ at 90\% conf. level}$$

- ξ and δ limit probability of right-handed muon decaying into any handed positron:

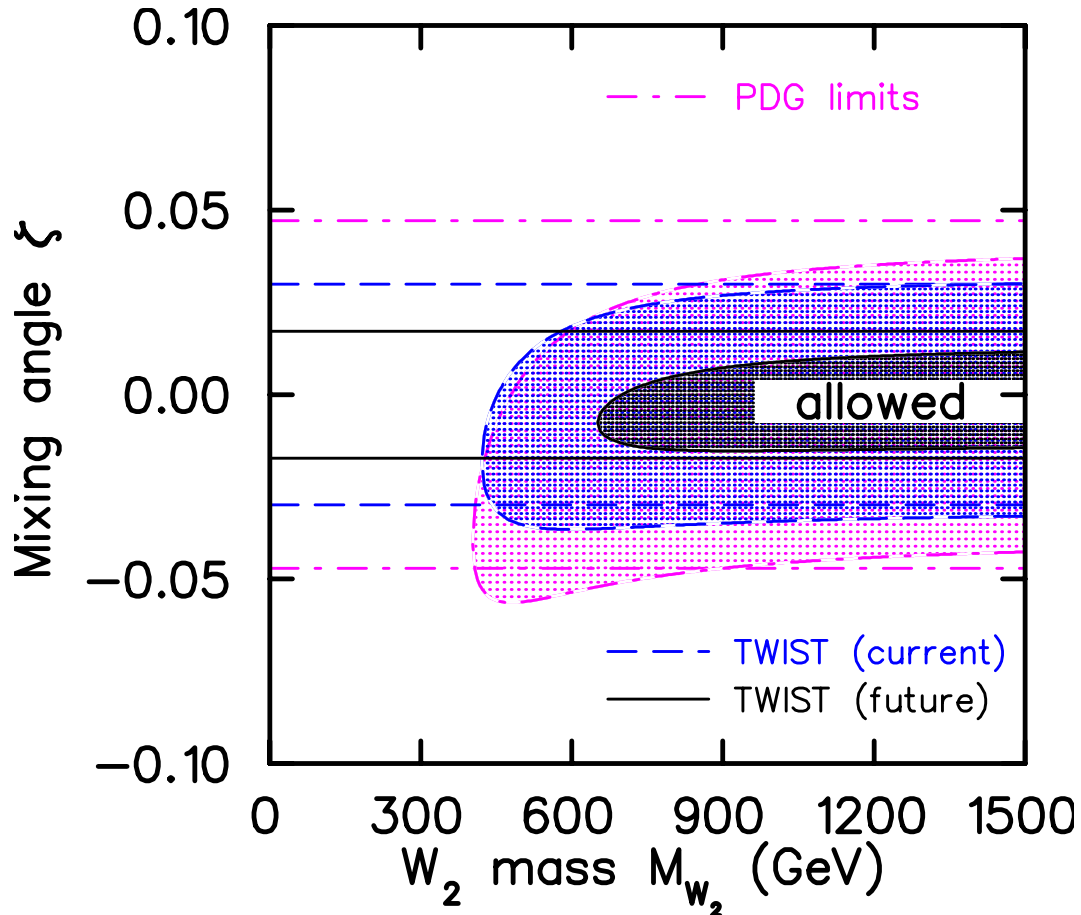
$$Q_R^\mu = \frac{1}{2}\left(1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta\right) \quad (3)$$

- In Left-Right Symmetric Models, $P_\mu\xi$ sets limit on W_L/W_R mass ($\epsilon = \left(\frac{g_R M_1}{g_L M_2}\right)^2$) and LR mixing parameter ($\zeta_g = \frac{g_R}{g_L}\zeta$): (Herczeg, PR **D34**)

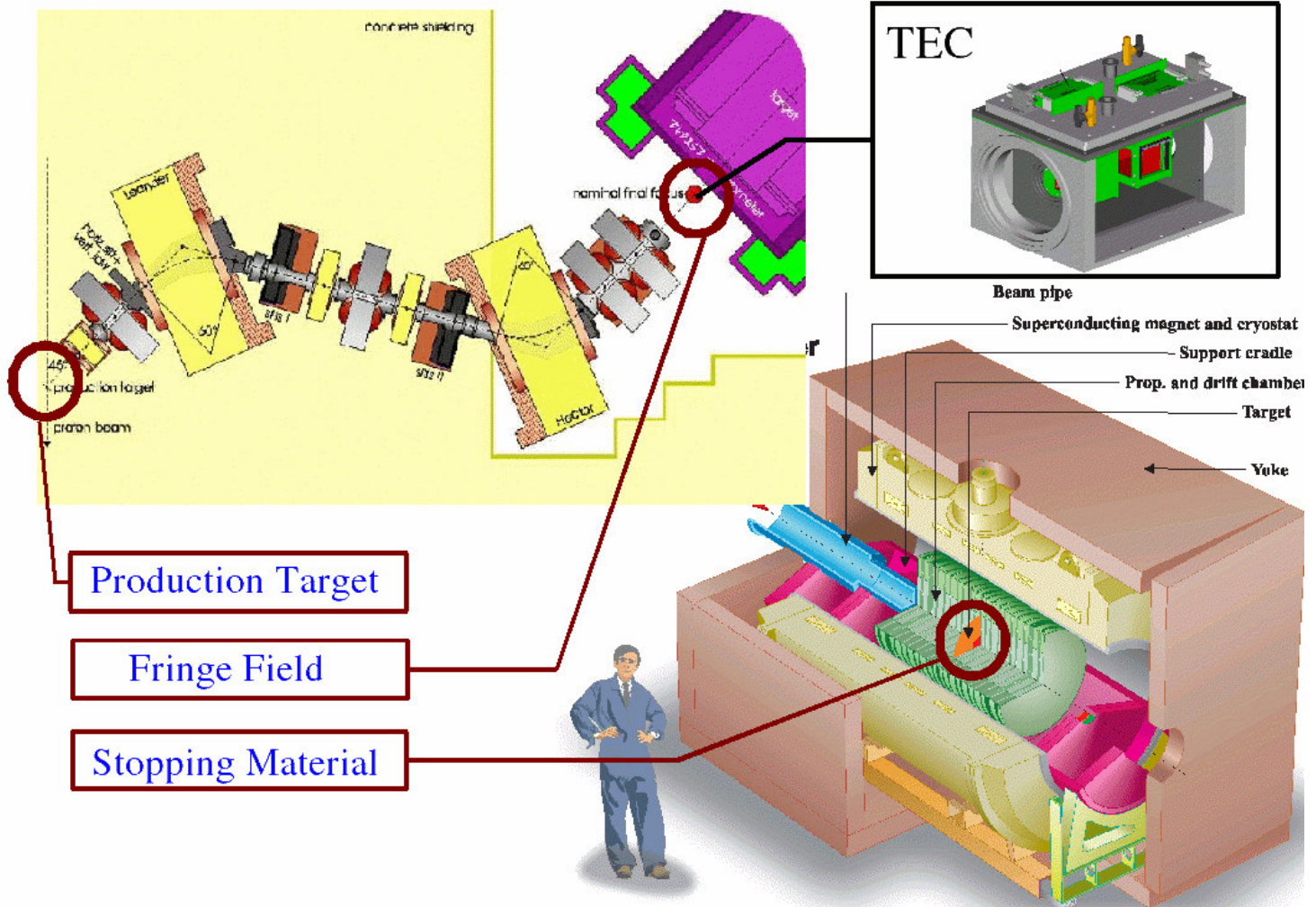
$$P_\mu\xi \approx 1 - 2\epsilon^2 - 4\zeta_g^2 - 2\epsilon^2\left(\frac{\cos\theta_1^R}{\cos\theta_2^L}\right)^2 - 4\epsilon\zeta_g\frac{\cos\theta_1^R}{\cos\theta_2^L} \quad (4)$$

Left-Right Symmetric Model Limits

- Pseudomanifest Left-Right Symmetry

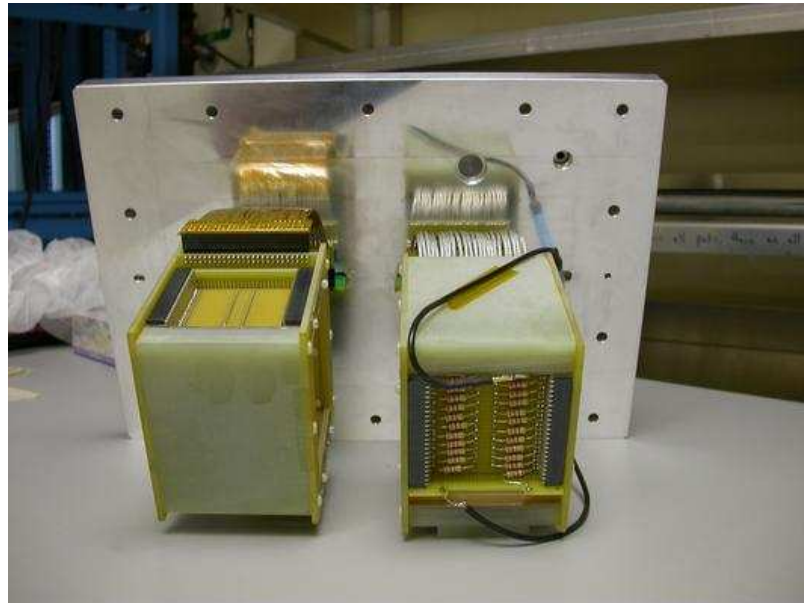


Locations of Muon Depolarization

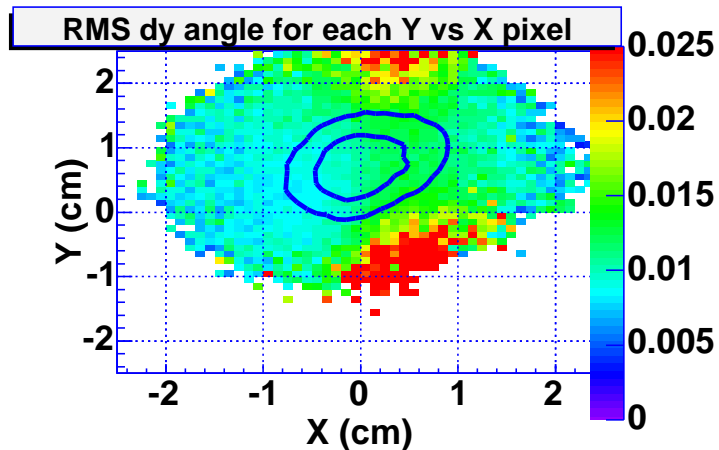
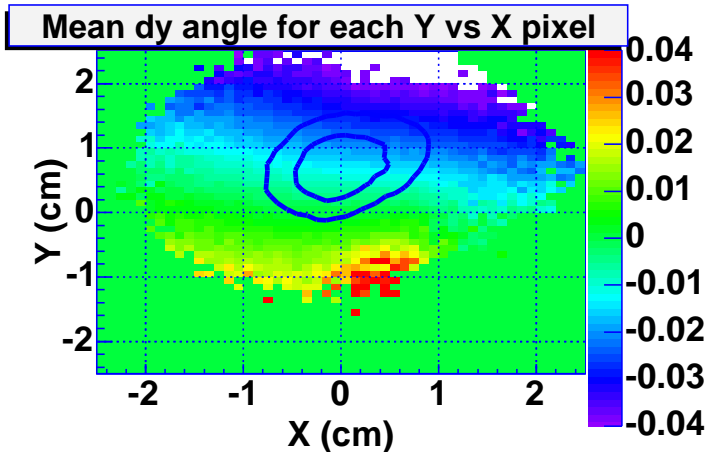
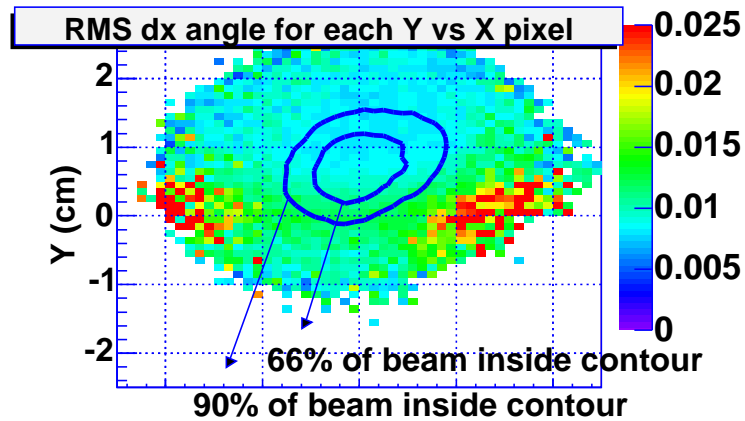
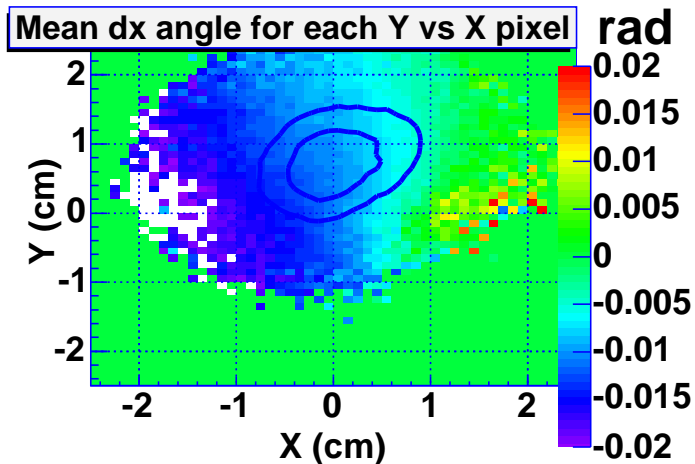


Fringe field depolarization

- Muons depolarized in fringe field of the solenoid
- Estimate by knowing:
 - muon beam size + divergence (from TEC)
 - magnetic field map
- Transport Spins in Monte-Carlo



Time Expansion Chamber - Muon Beam



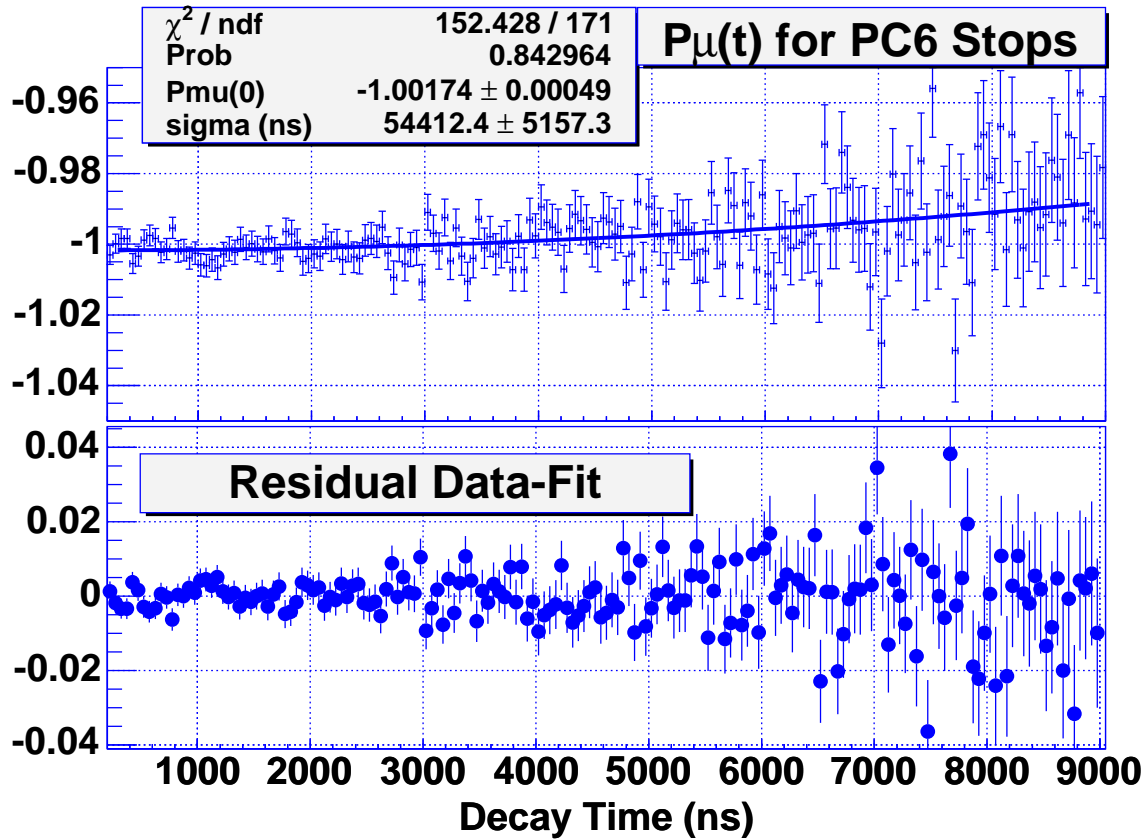
Data Set Summary for *TWIST* $P_{\mu\xi}$

Set #	# Runs (2 GB)	Description
12	211	28.9 MeV/c
13	115	28.9 MeV/c
14	176	2003 Nominal
15	217	2003 Nominal
30	60	B2=949G, z cent, M1 Trigger
31	265	B2=949G, z cent, M Trigger
32	120	B2=944G, PC5 Stops
33	91	Far Upstream Stops
34	11	Far Downstream Stops
35	368	2004 Nominal Stop centered
36	390	2004 Stop at 3/4
37	281	High Rate
38	303	Aperture In
39	211	2004 Stop at 3/4
Total	2819 (5.6 TB)	2272 Nominal Runs

Material Dependent Depolarization

Sum of all 2003+2004 data asymmetry vs decay time fit to half-gaussian (still blind):

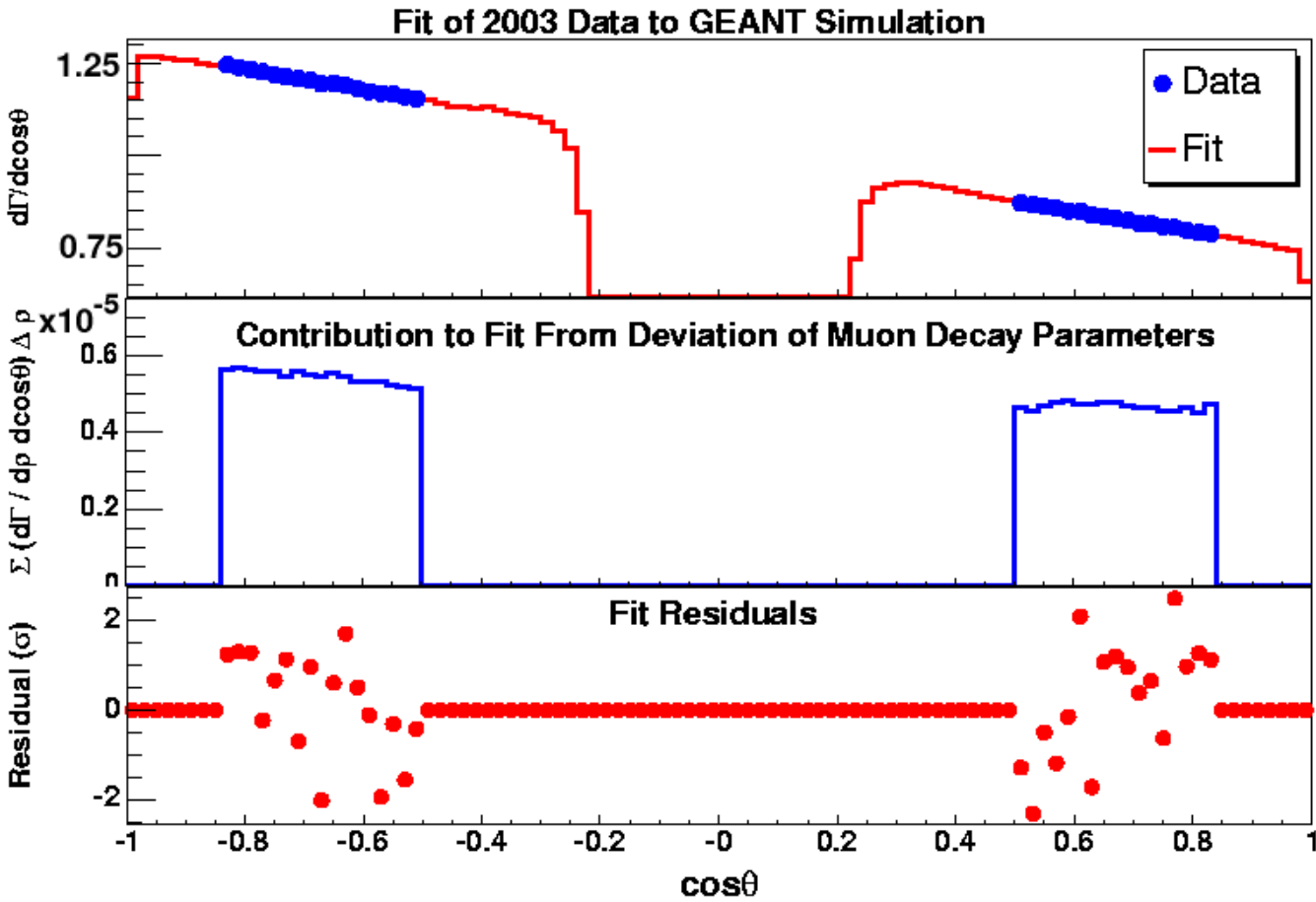
$$P_{\mu}(t) = P_{\mu}(0)e^{\frac{-t^2}{2\sigma^2}} \quad (5)$$



Systematics for TWIST $P_{\mu\xi}$

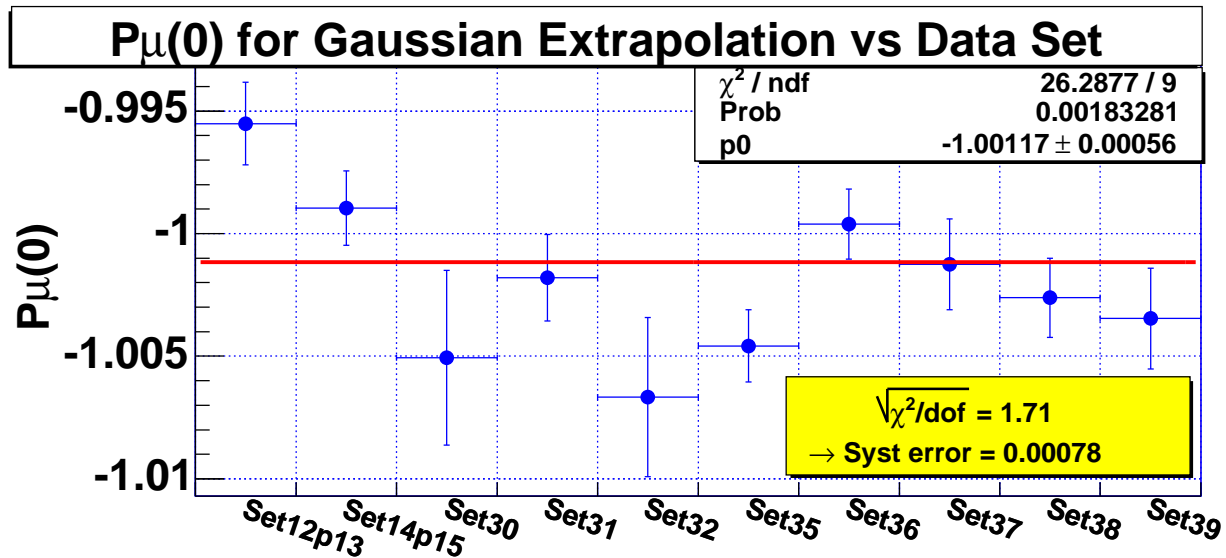
Systematic Effect	Uncertainty ($\times 10^3$)	Total
Muon Beam and Polarization		3.97
fringe field depolarization	3.58	
stopping target depolarization	1.70	
μ beam contamination/rate	0.18	
Chamber Response		0.98
t_0 variations	0.89	
foil bulges	0.22	
cell asymmetry	0.22	
up-down efficiency	0.19	
density	0.17	
Positron Interactions		0.36
hard interactions	0.30	
multiple scattering	0.16	
radiative corrections	0.10	
energy loss	0.01	
Spectrometer Alignment		0.31
rotations	0.22	
z position	0.22	
B field to axis	0.03	
Momentum Calibration		0.28
end point fits	0.27	
B field uniformity	0.09	
Total Systematic Uncertainty		4.1

Comparison of Data and MCarlo



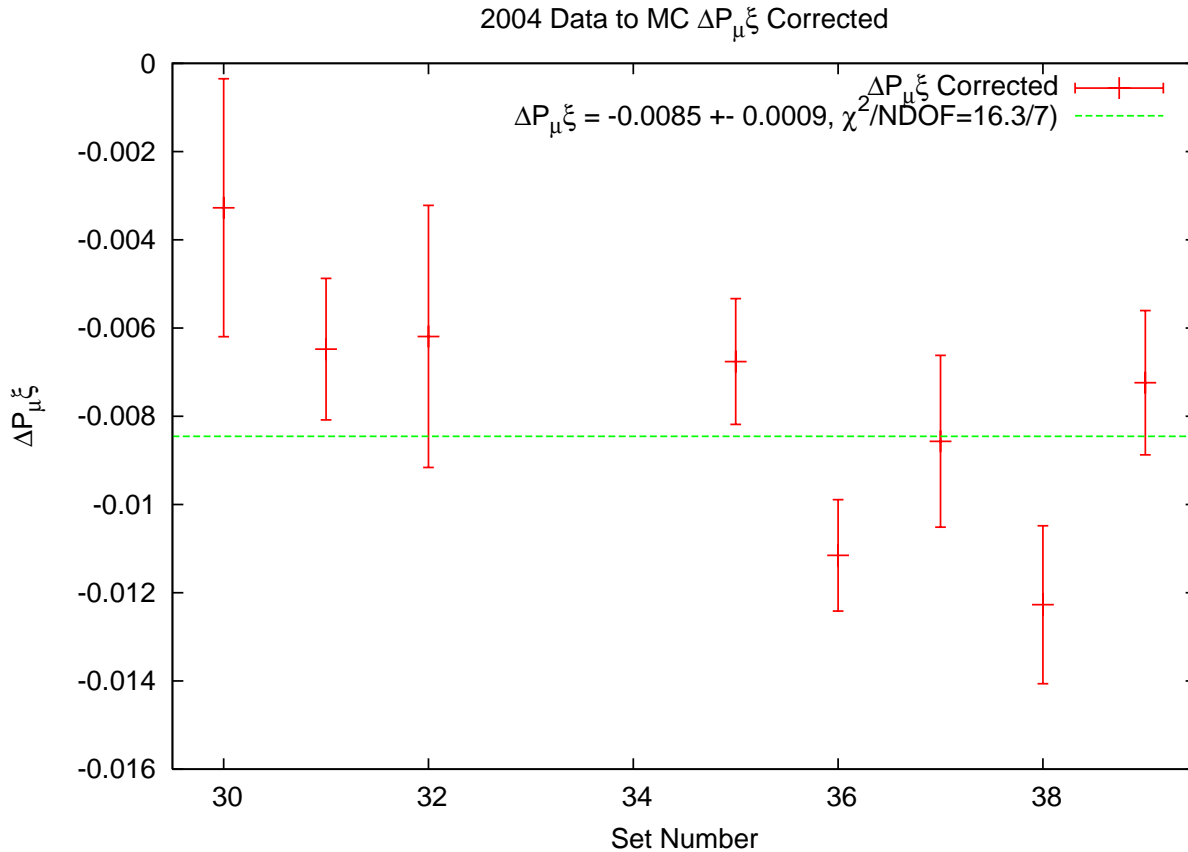
Data Set Consistency

- Consistency check with unknown offset (still blind)



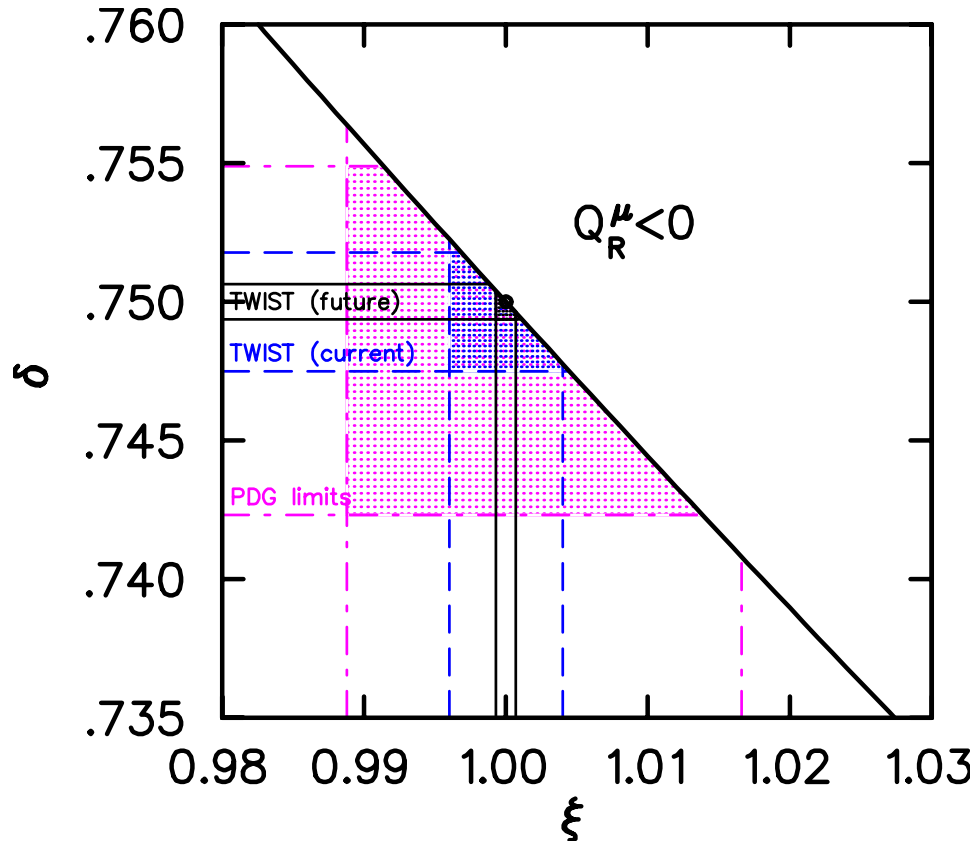
$P_{\mu\xi}$ Consistency

- Consistency check with unknown offset (still blind)



Model Independent Muon Handedness

$$Q_R^\mu = \frac{1}{2} \left(1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta \right)$$



Summary and Outlook

- Direct measurement of $P_{\mu\xi}$ should be available within 1 month
- Result will reduce error in PDG value by a factor of about 2. Current PDG value = $1.0027 \pm 0.0079 \pm 0.0030$. Our statistical error ≈ 0.001 .
- Largest systematic error is due to fringe field depolarization
- Remaining tasks include:
 - make the MC match the 2004 data
 - finalize the systematic error estimates
 - open the black box to obtain the final value for $P_{\mu\xi}$

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