

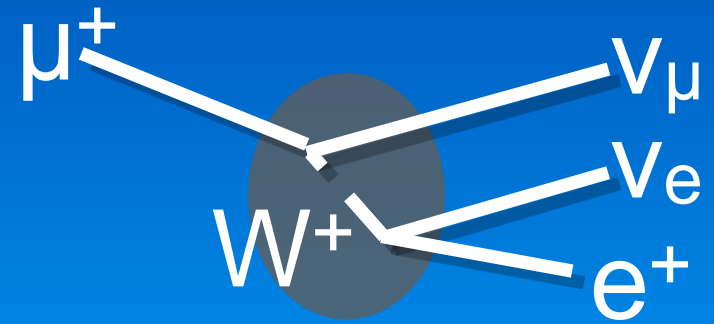
# *TWIST*: Precision Measurement of the Muon Decay Parameters

- Muon Decay and the Weak Interaction
- *TWIST* experiment
- New Results and Final analysis
- Physics Implications

Richard Mischke  
TRIUMF  
for the *TWIST* Collaboration

# Muon Decay

## Weak Matrix Element



$$M = \frac{4G_F}{\sqrt{2}} \sum_{\substack{\epsilon=L,R \\ m=L,R \\ \kappa=S,V,T}} g_{\epsilon m}^\kappa \langle \psi_{e_\epsilon} | \Gamma^\kappa | \psi_{\nu_e} \rangle \langle \psi_{\nu_\mu} | \Gamma_\kappa | \psi_{\mu_m} \rangle$$

In Standard Model (“V-A”):

$$g_{LL}^V = 1$$

$$g_{\epsilon m}^\kappa = 0 \text{ otherwise}$$

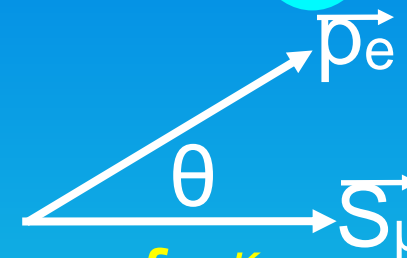
$g_{\epsilon m}^\kappa$  constrained by muon decay, inverse decay, etc.

# Decay (“Michel”) Spectrum

*Michel, Kinoshita & Sirlin*

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

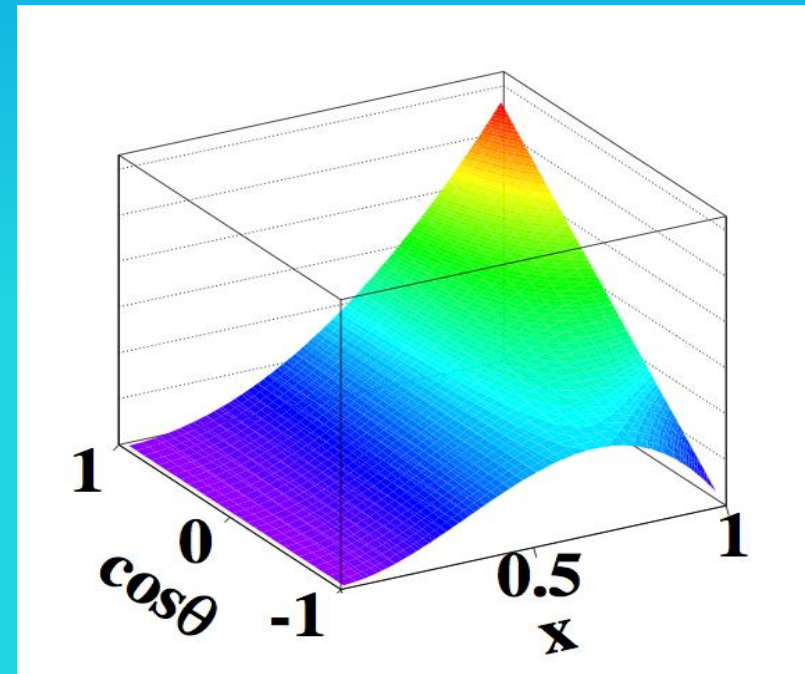
$$x = \frac{E}{E_{\max}}$$



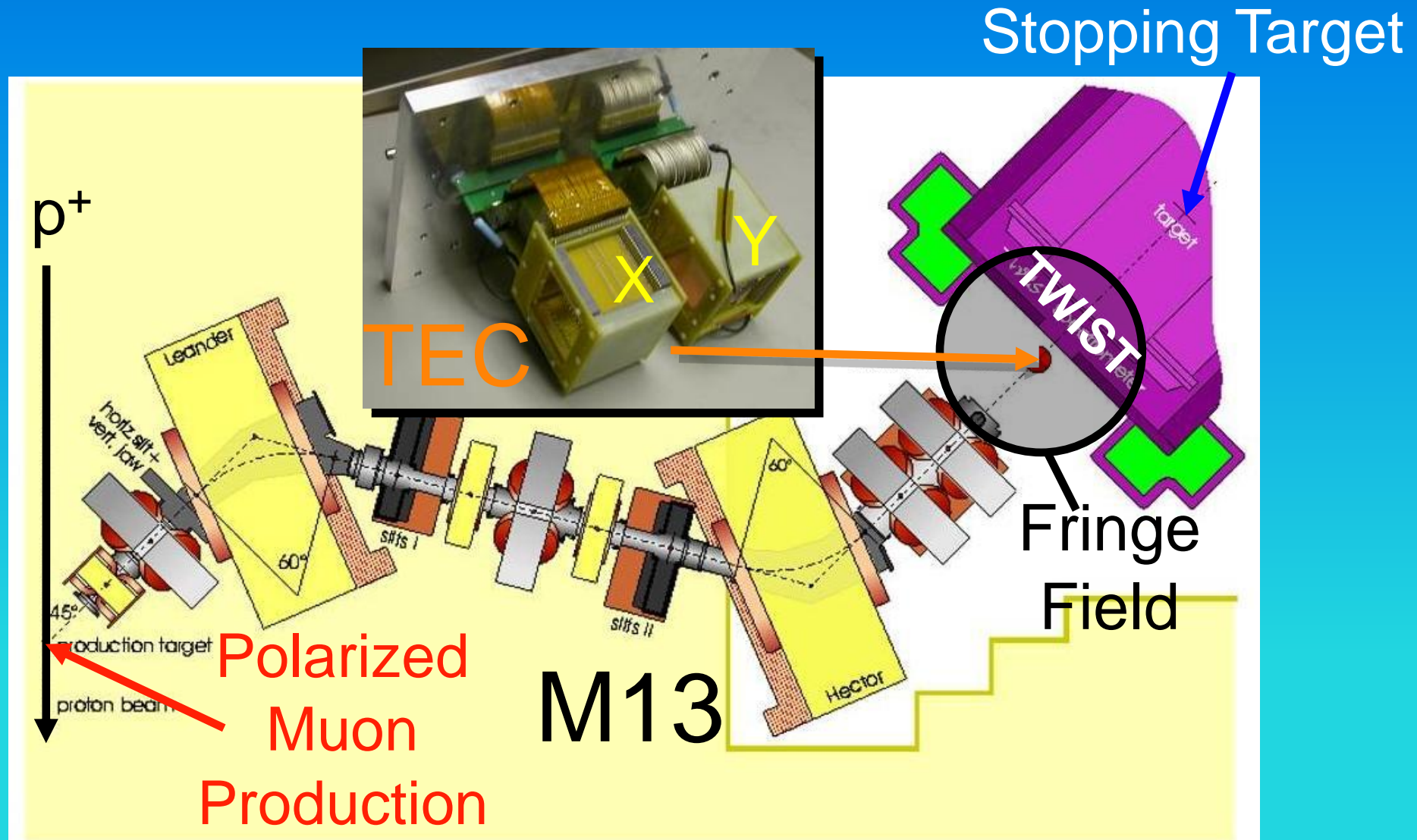
$\rho, \eta, \delta, \xi$  are bilinear combinations of  $g^k_{em}$

	Old results	SM
$\rho$	$0.7518 \pm 0.0026$	0.75
$\eta$	$-0.007 \pm 0.013$	0
$P_\mu \xi$	$1.0027 \pm 0.0085$	1
$\delta$	$0.7486 \pm 0.0038$	0.75

*TWIST* results: new  $\rho, \delta,$  and  $P_\mu \xi$



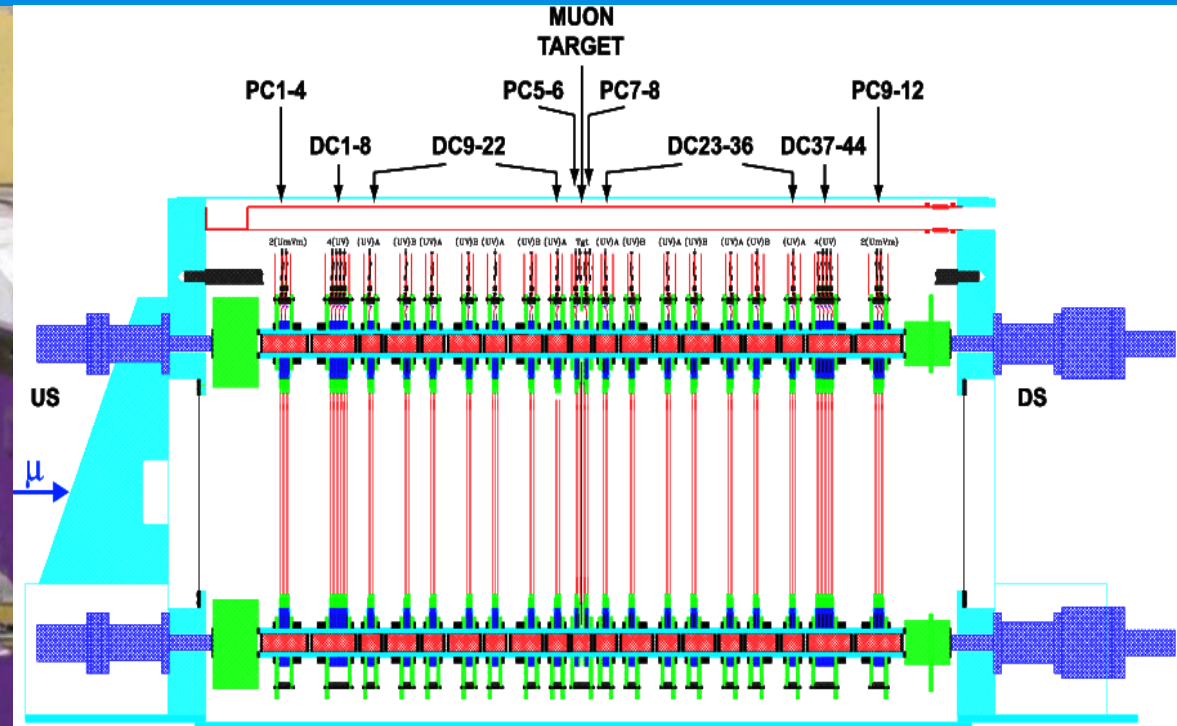
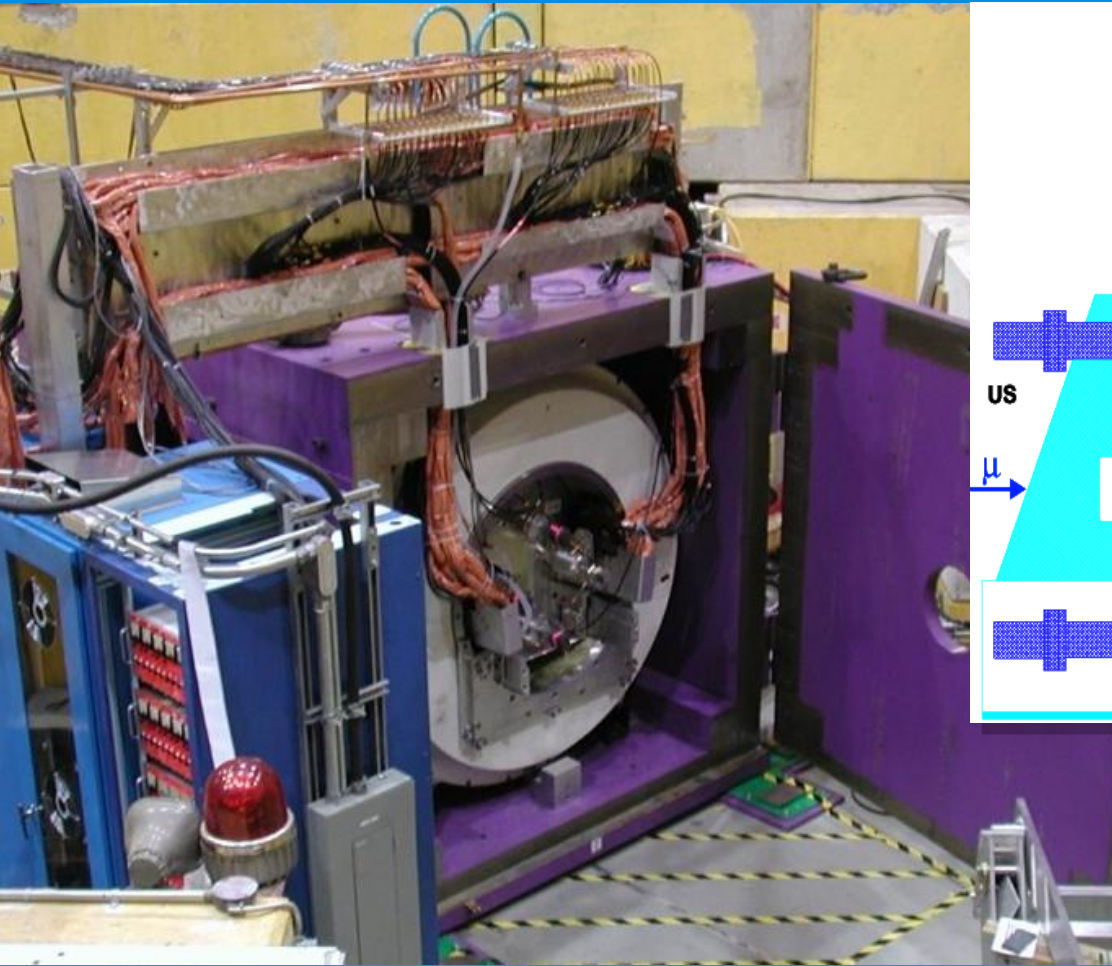
# Muon Production and Transport



TEC: NIM A566 (2006), 563

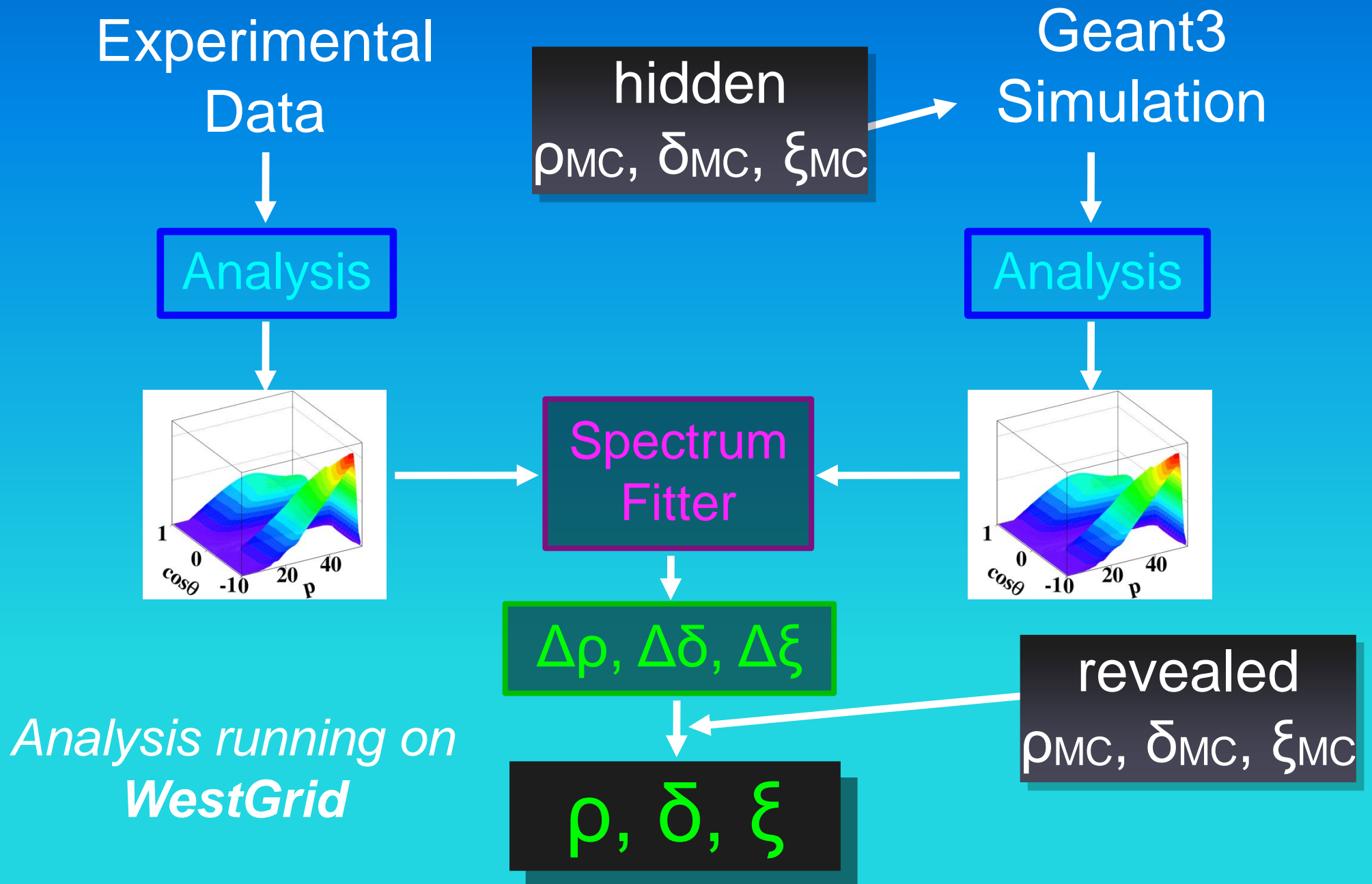
# The *TWIST* Experiment

TRIUMF Weak Interaction Symmetry Test



Low mass, symmetric,  
high-precision construction

# “Blind” Analysis

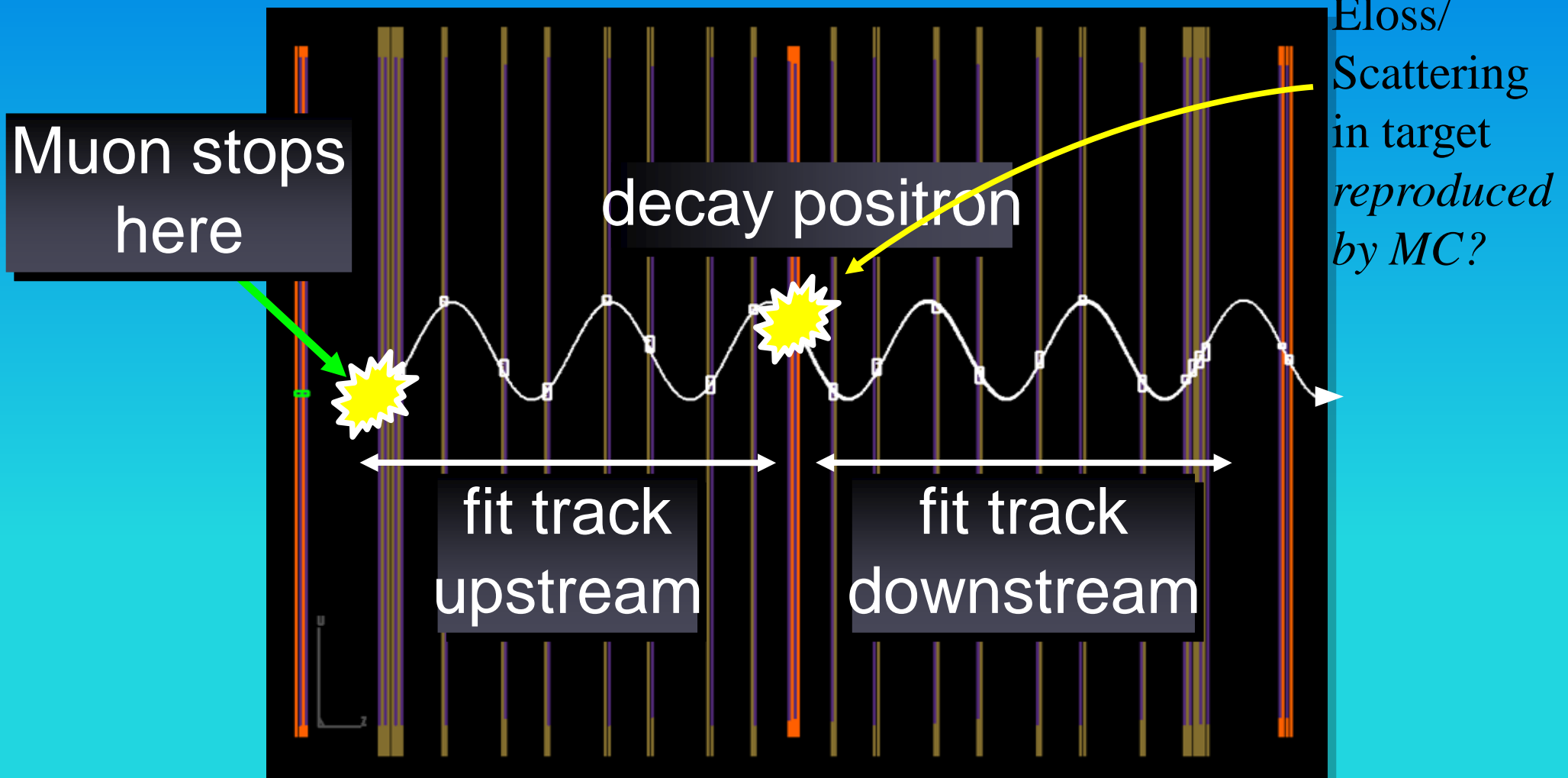


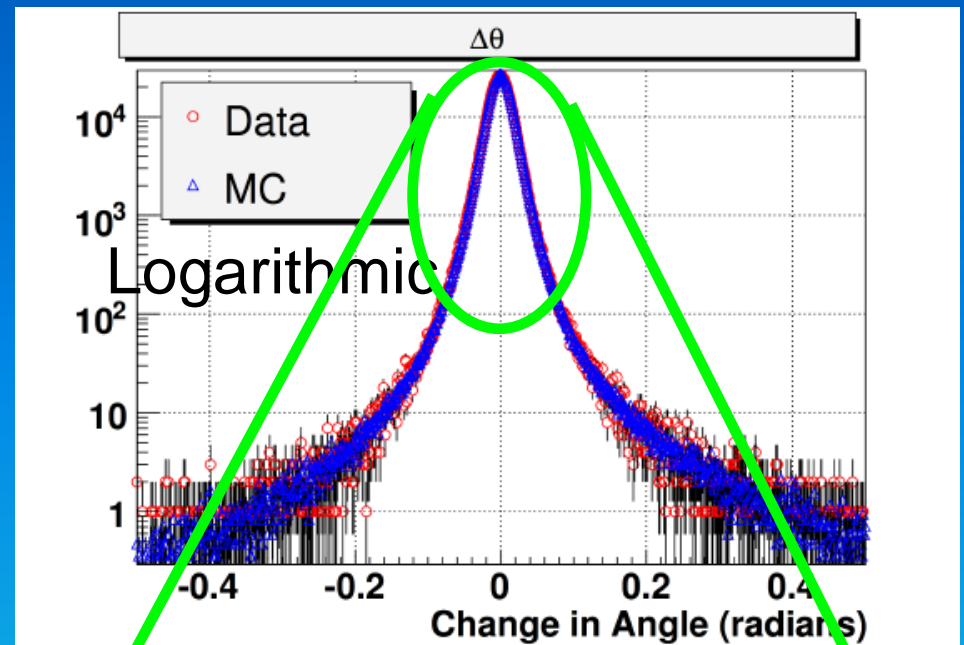
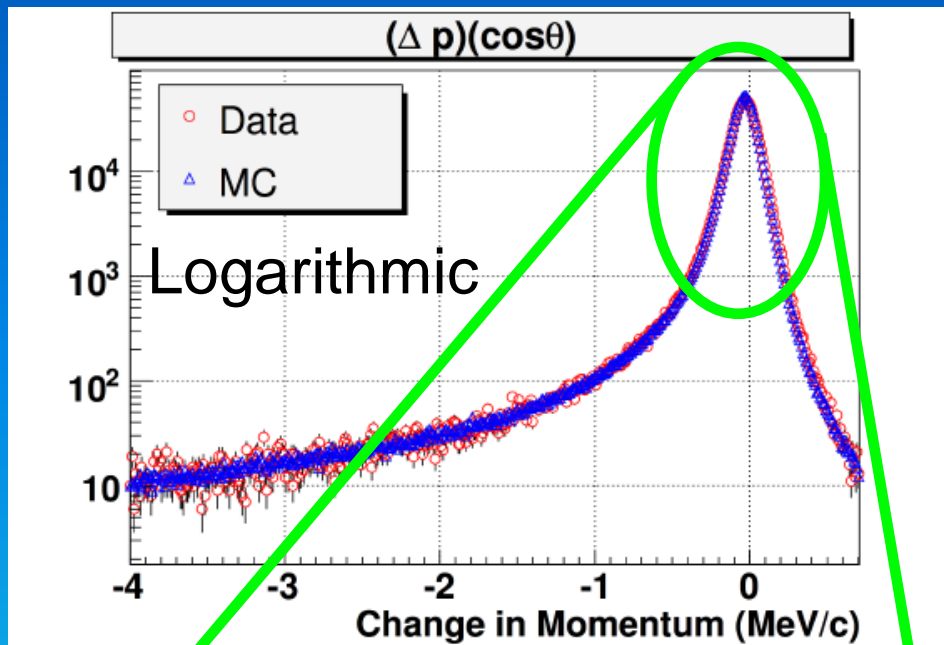
# Verifying the Simulation

Specialized data, reproduced in simulation

→ independent of Michel parameters

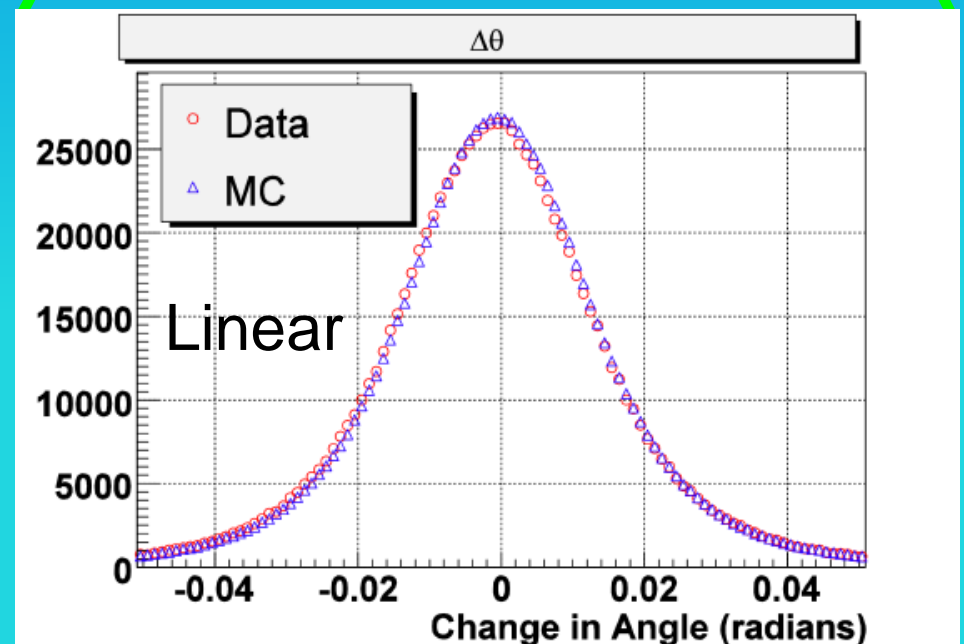
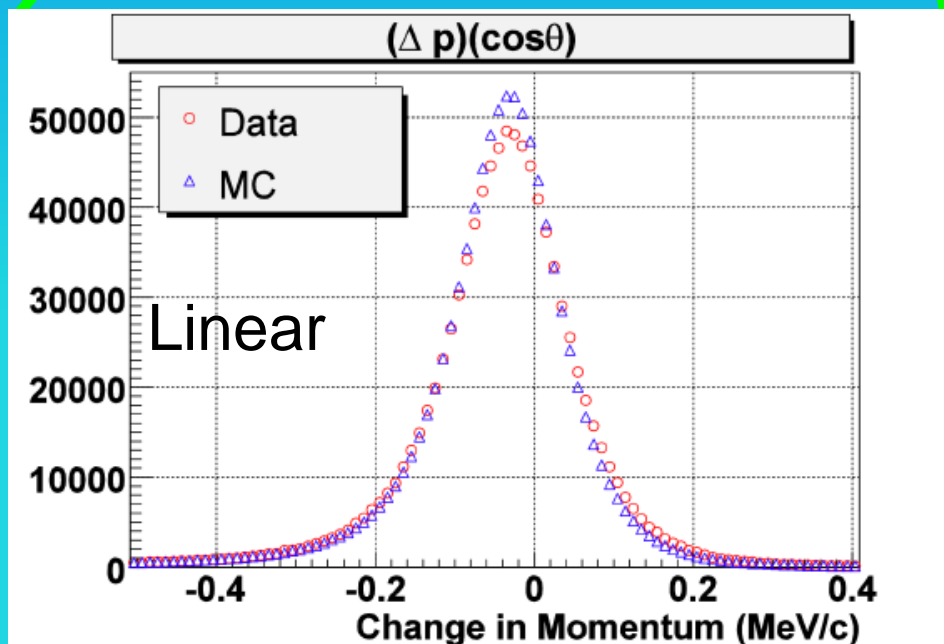
For example: “upstream stops”:





Energy Loss

Scattering





# Determining Systematics

exaggerated  
MC or Data

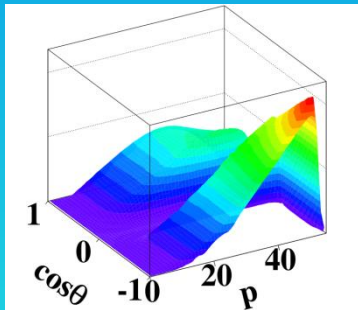
- Bremsstrahlung
- Chamber geometry
- ...

MC or Data

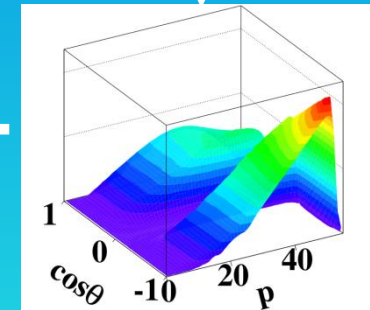
- Magnetic field
- Chamber alignment
- ...

Exaggerated Analysis

Analysis



Spectrum  
Fitter



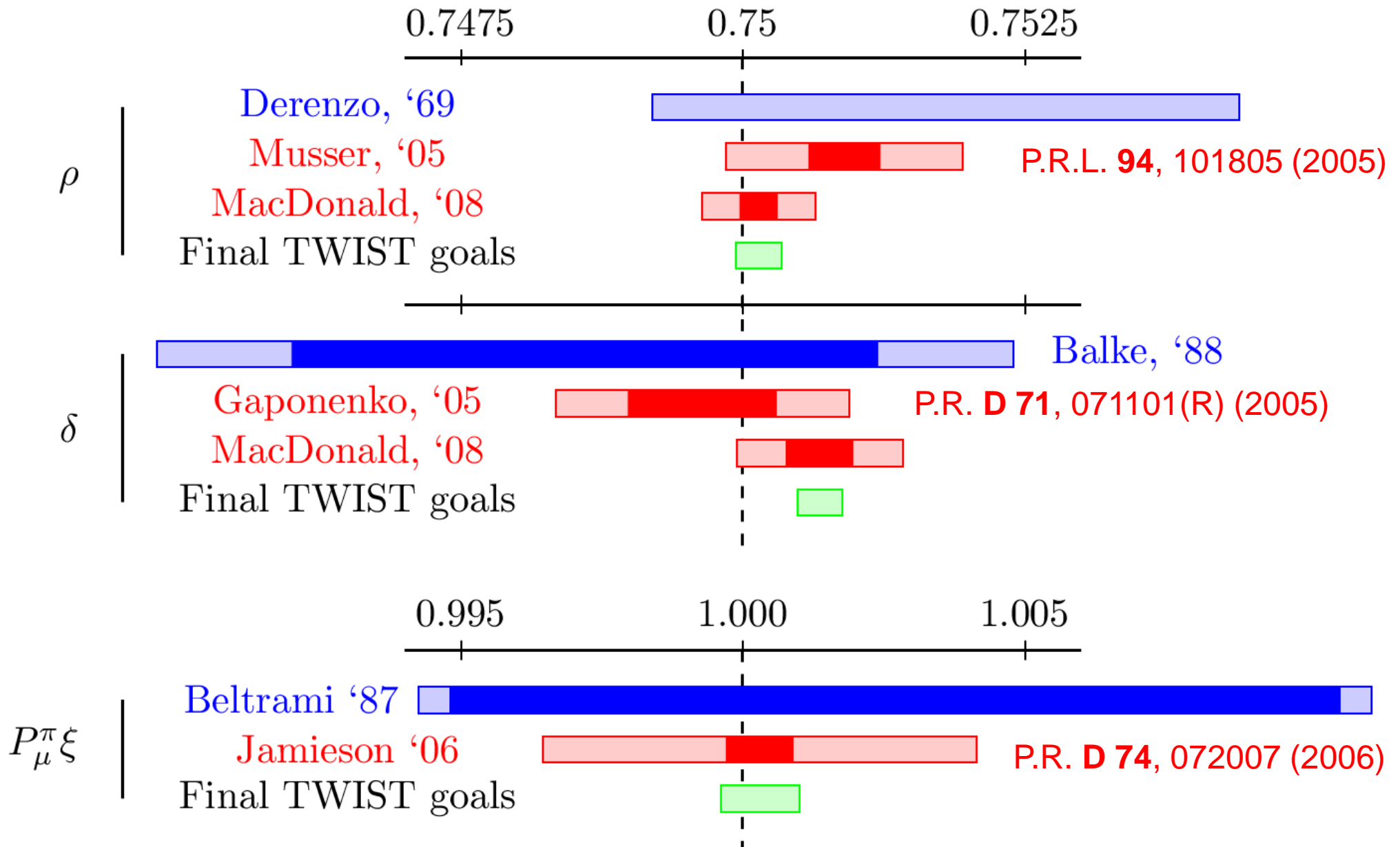
$\Delta\rho, \Delta\delta, \Delta\xi$

$$\text{Systematic Uncertainty} = \frac{(\Delta\rho, \Delta\delta, \Delta\xi)}{\text{Exaggeration}}$$

# Systematic Uncertainties

units of $10^{-4}$	$\rho$	$\delta$	$P_{\mu\xi}$
Chamber response	2.9	5.2	10
Positron interactions	1.6	0.9	3
Alignment	0.3	0.3	3
Momentum calibration	2.9	4.1	2
Radiative corrections	<0.1	<0.1	1
Other	1.1	0.4	4
Fringe field depol	--	--	34
Stopping tgt depol	--	--	12
<b>Total</b>	<b>4.6</b>	<b>6.7</b>	<b>38</b>

# Summary of results



TWIST goal: reduce uncertainties by factor of 10

# Improvements for the final data and analysis

Stopping target	both Al and Ag
Beam tuning	reduced depolarization
Positron interactions	better&more calibration data
Chamber response	space-time relations determined from data
Momentum calibration	new calibration techniques, uncertainty is statistical
Increased Statistics	both data and simulation

# Global Analysis of Muon Data

$$M = \frac{4G_F}{\sqrt{2}} \sum_{\substack{\epsilon=L,R \\ m=L,R \\ \kappa=S,V,T}} g_{\epsilon m}^{\kappa} \langle \psi_{e\epsilon} | \Gamma^{\kappa} | \psi_{\nu_e} \rangle \langle \psi_{\nu_\mu} | \Gamma_{\kappa} | \psi_{\mu m} \rangle$$

	pre- <i>TWIST</i>	Gagliardi et. al.*	MacDonald '08
$ g_{LR}^S $	$< 0.125$	$< 0.088$	<b><math>&lt; 0.076</math></b>
$ g_{LR}^V $	$< 0.066$	$< 0.036$	<b><math>&lt; 0.027</math></b>
$ g_{LR}^T $	$< 0.036$	$< 0.025$	<b><math>&lt; 0.022</math></b>

90% Confidence Limits

\**Phys. Rev. D* 72, 073002 (2005)

# Limits on Right-Handed Muon Decay

$$Q_R^\mu = \frac{1}{4} |g_{LR}^S|^2 + \frac{1}{4} |g_{RR}^S|^2 + |g_{LR}^V|^2 + |g_{RR}^V|^2 + 3 |g_{LR}^T|^2$$

Pre-*TWIST*:  $Q_R^\mu < 0.014$

Gagliardi:  $Q_R^\mu < 0.003$

Current:  $Q_R^\mu < 0.0024$

# Left-Right Symmetry

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

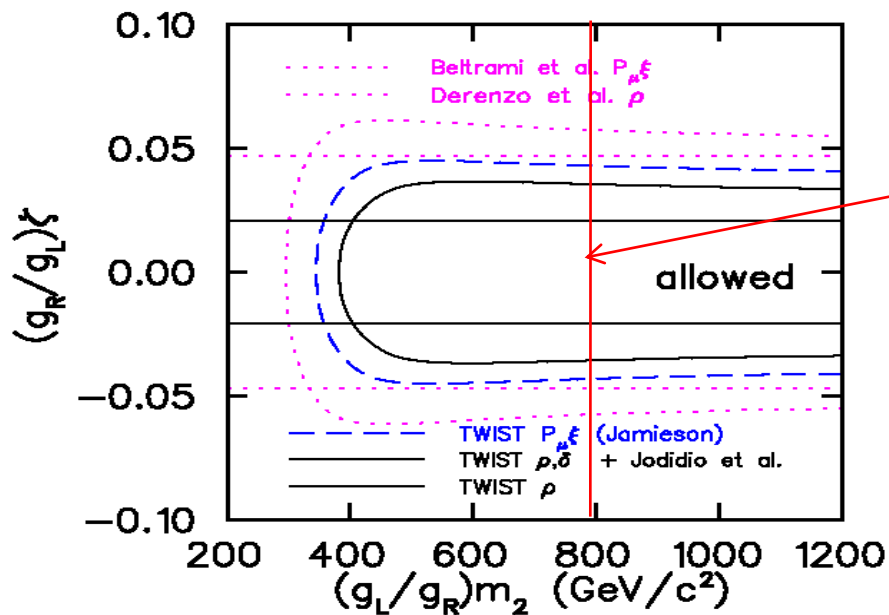
$$W_R = e^{i\omega} (-W_1 \sin \zeta + W_2 \cos \zeta)$$

$$\zeta_g = \left| \frac{g_R}{g_L} \zeta \right| = \sqrt{\frac{1}{2} \left( 1 - \frac{4}{3} \rho \right)}$$

Pre-TWIST:  $|\zeta_g| < 0.066$

TWIST Published:  $|\zeta_g| < 0.028$

Current:  $|\zeta_g| < 0.022$



Approximate direct mass limit from D0 and CDF (model dependent)

# Summary

*TWIST* has measured full  $\mu^+$  decay spectrum to extract Michel parameters

- Latest results with **no evidence for *new physics*, but new limits**
- $\rho = 0.75014 \pm 0.00017(\text{stat}) \pm 0.00046(\text{sys}) \pm 0.00011(\eta)$
- $\delta = 0.75068 \pm 0.00030(\text{stat}) \pm 0.00067(\text{sys})$

(R.P. MacDonald, et al., Phys. Rev. D, Aug. 2008)

- Final analysis underway
  - more statistics (for physics and calibration)
  - all leading systematics addressed
- Original goal of reducing uncertainties by a factor of 10 in reach



# The *TWIST* Collaboration

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\* deceased



<http://twist.triumf.ca>

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