

# Approaching the Final Results of the *TWIST* Experiment

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For the *TWIST* Collaboration

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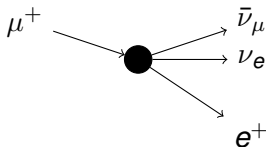
June 9, 2009

# Muon Decay: A Constraint on the Weak Interaction

- General Lorentz invariant, derivative-free, interaction<sup>1</sup>

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

- Standard Model (V - A) interaction:  $g_{LL}^V = 1$
- all other contributions are zero

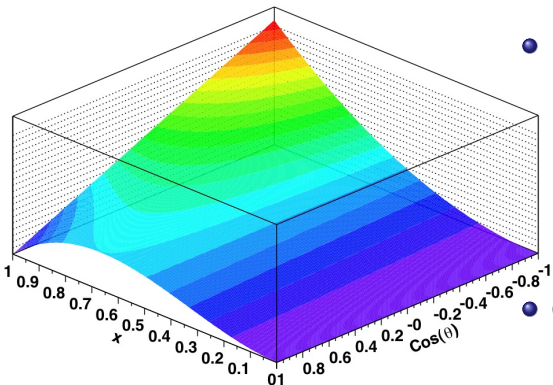


<sup>1</sup>W. Fetscher, H.J. Gerber, and K.F. Johnson, *Phys. Lett.* **B173 (1986) 102**

# Positron Spectrum of Muon Decay

- Given in momentum and angle as

$$\frac{\partial^2 \Gamma}{\partial x \partial \cos \theta} = F(x; \rho, \eta) - |P_\mu| \cos \theta G(x; \xi, \delta) + R.C., \quad x = \frac{E_e}{E_{max}}$$



- In the Standard Model

$$\rho = 0.75$$

$$\eta = 0$$

$$\delta = 0.75$$

$$P_\mu^\pi \xi = 1$$

- deviations represent new physics

# Tests for New Physics

## Right Handed Decays

- Probability given by

$$\begin{aligned}
 Q_R^\mu &= \frac{1}{4} (|g_{LR}^S|^2 + |g_{RR}^S|^2) + \\
 &\quad |g_{LR}^V|^2 + |g_{RR}^V|^2 + 3|g_{LR}^T|^2 \\
 &= \frac{1}{2} \left( 1 + \frac{\xi}{3} - \frac{16\xi\delta}{9} \right)
 \end{aligned}$$

## Left - Right Symmetric Models

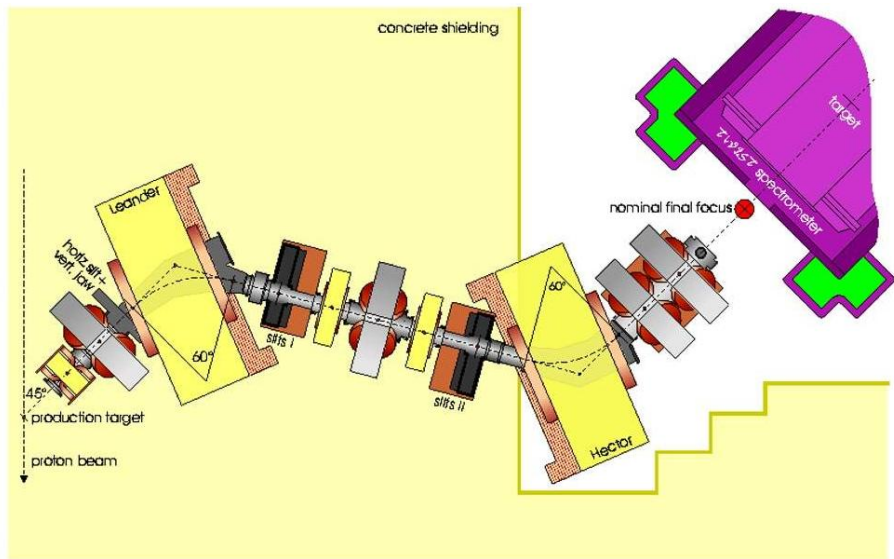
where

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

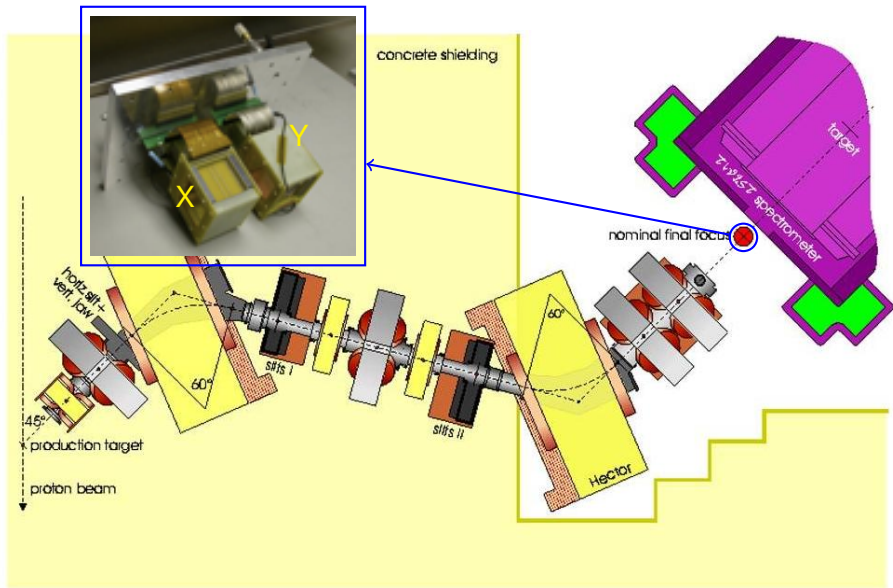
$$W_R = e^{i\omega} (-\sin \zeta W_1 + \cos \zeta W_2)$$

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

# TWIST experiment



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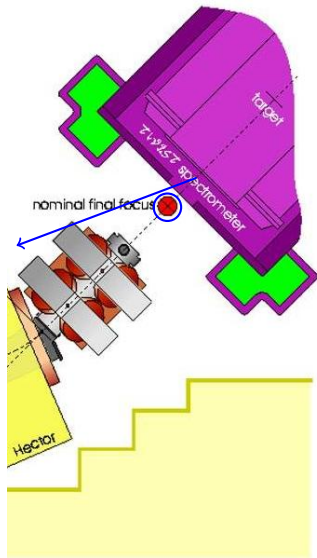
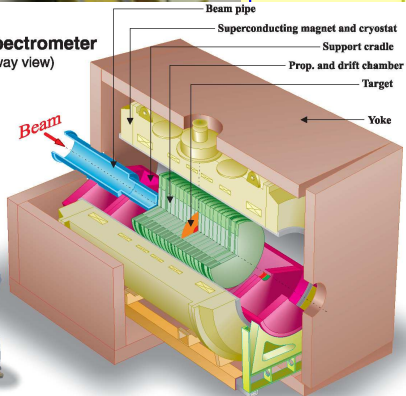


# TWIST experiment



concrete shielding

## TWIST Spectrometer (cutaway view)

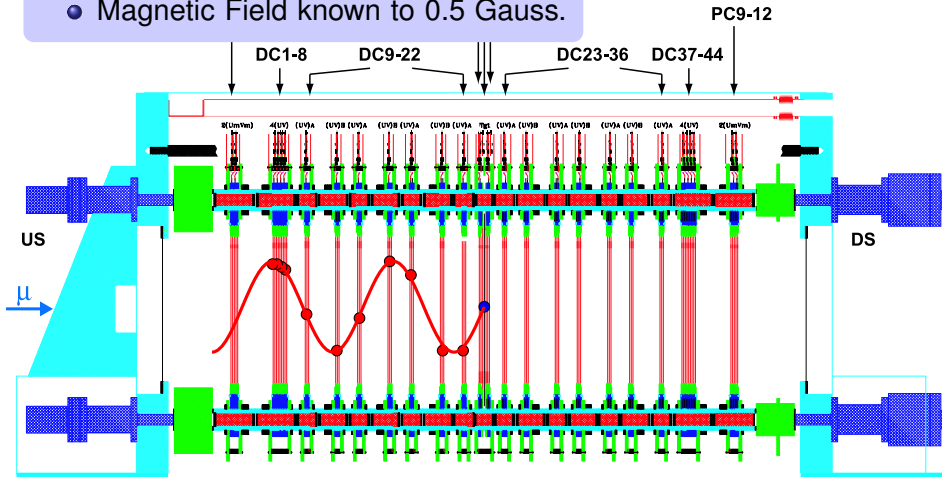






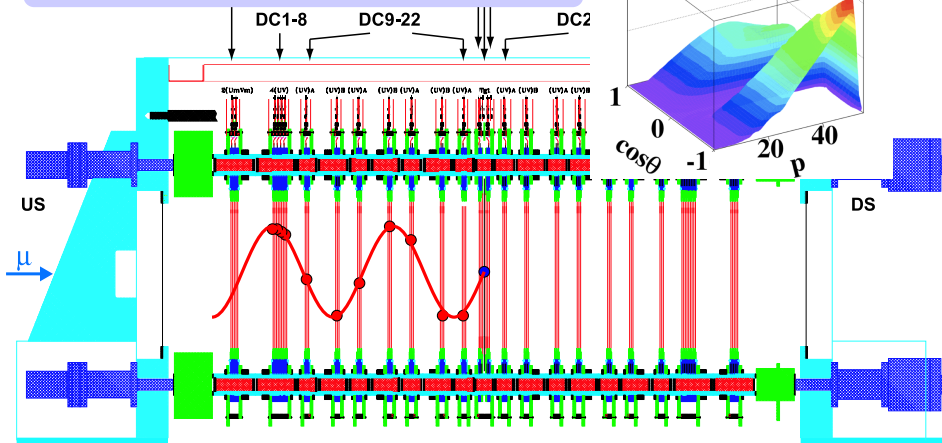
# TWIST spectrometer

- Dimensions known to parts in  $10^5$ .
- Magnetic Field known to 0.5 Gauss.



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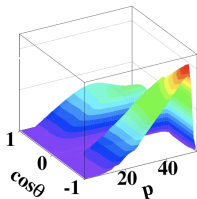
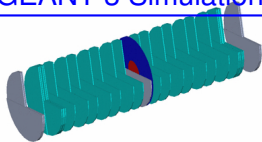


# Analysis chain



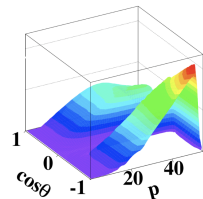
GEANT 3 Simulation

$$\rho_h, P_\mu^\pi, \xi, \delta_h \rightarrow$$

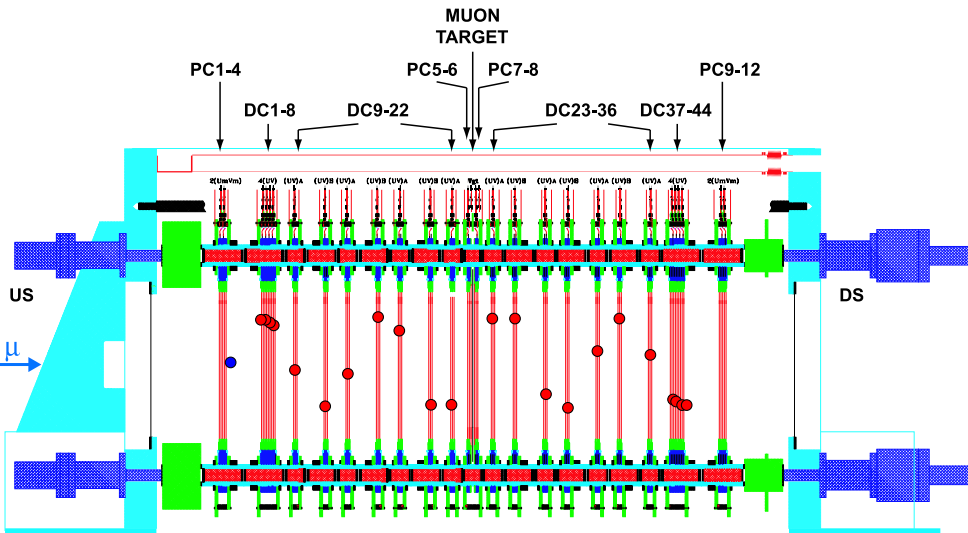


Spectrum Fit

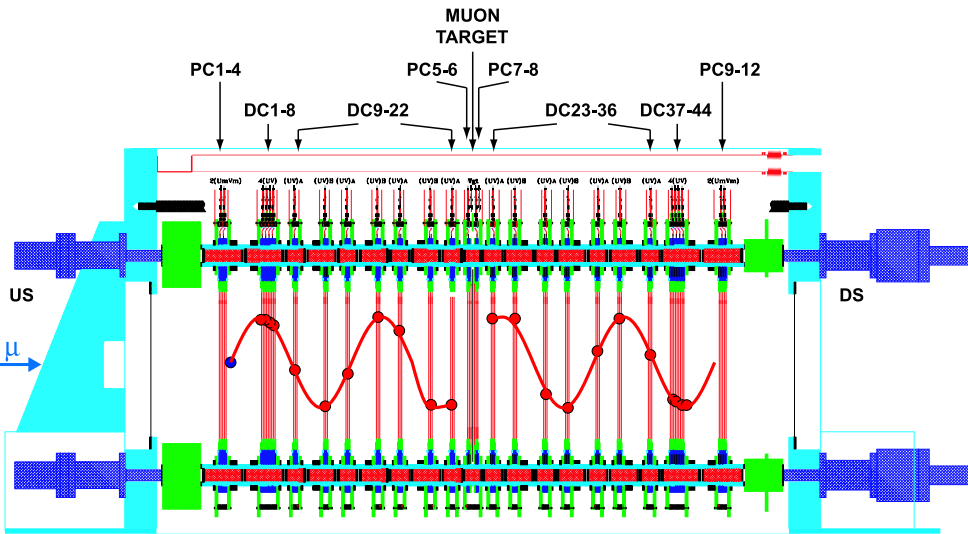
$$\Delta\rho, \Delta P_\mu^\pi, \Delta\xi, \Delta\delta$$



# Monte Carlo Validation: Upstream Stops



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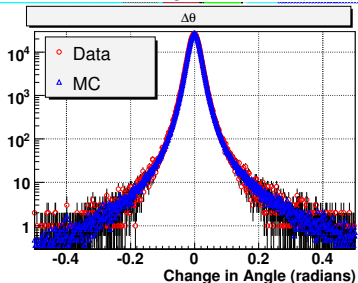
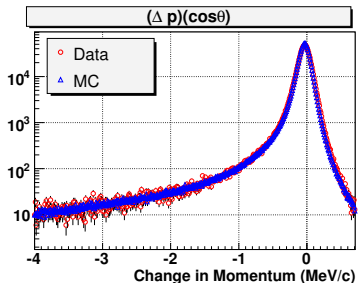
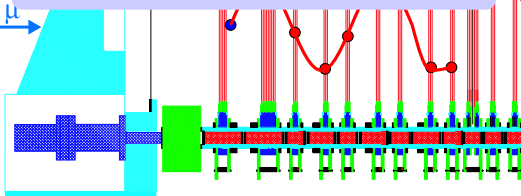
# Monte Carlo Validation: Upstream Stops

- Compare momentum loss and scattering in data and Monte Carlo

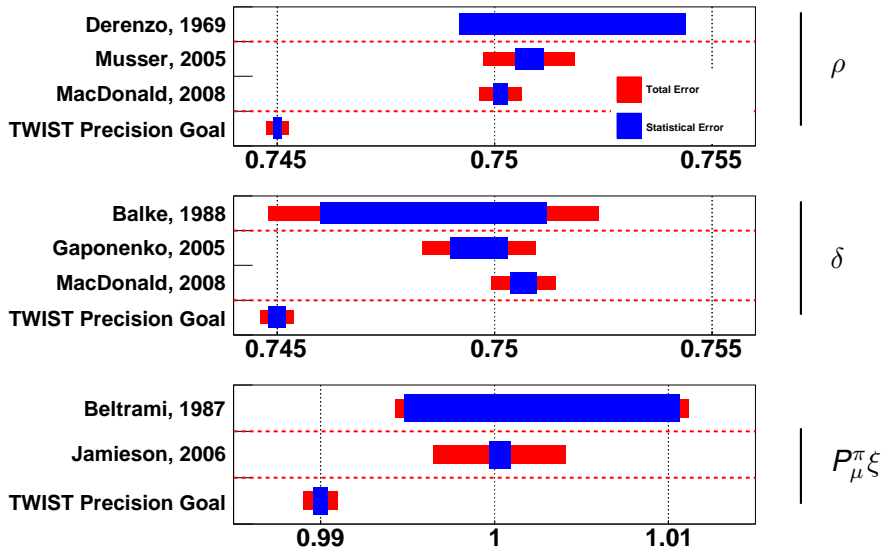
$$\Delta p|_{M.P.}^{data} \approx 1 \text{ keV/c}$$

$$\Delta \theta|_{M.P.} \approx 0.4 \text{ mrad}$$

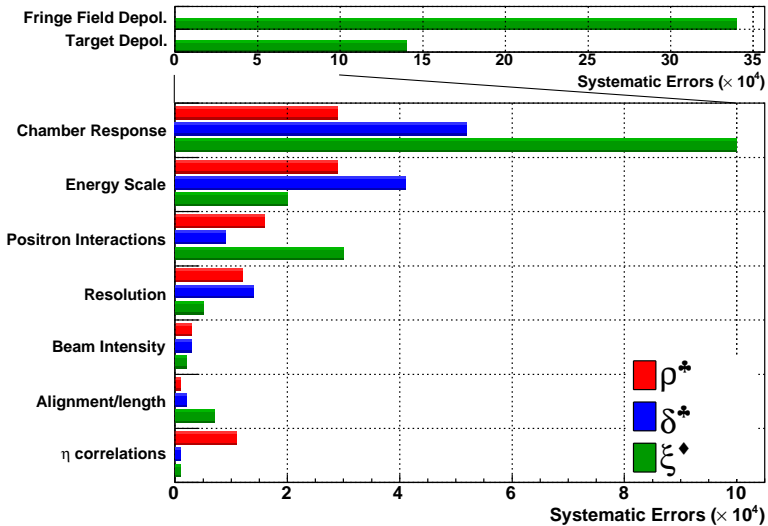
- Study discrete momentum loss processes (ie bremsstrahlung production)



## Decay Parameter State of the Art



# Systematics Summary



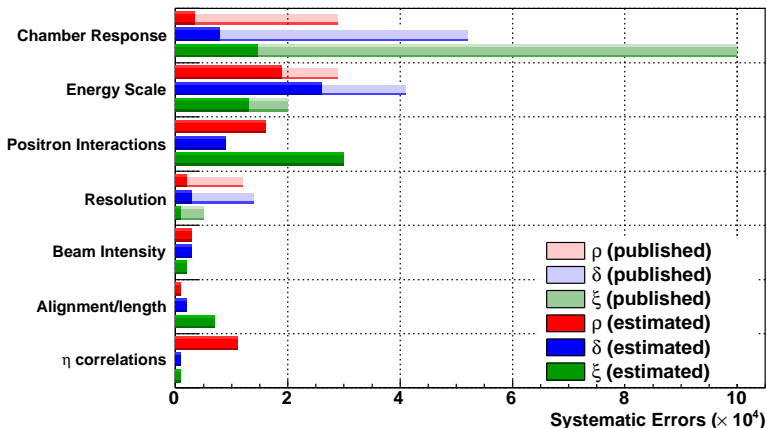
● Published: ( $\clubsuit$ ) PRD 78, 032010 (2008) and ( $\blacklozenge$ ) PRD 74, 072007 (2006)



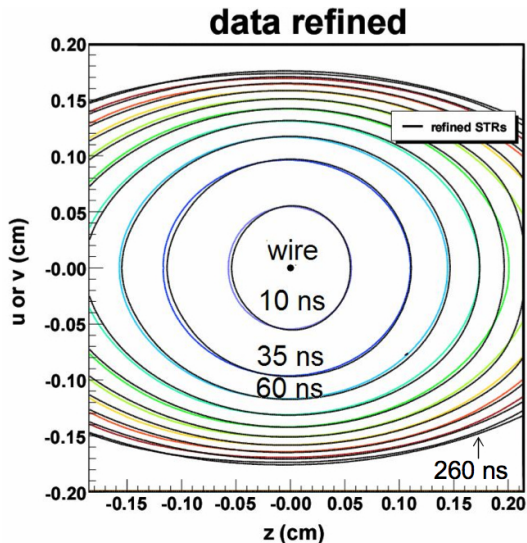
# Improvements

## Improvements in Statistical Uncertainties

- Experiment collected  $8 \times 10^9$  events during 2006 and 2007
  - physics data set nearly 6 times larger than previous



# Systematics Improvement: Chamber Response



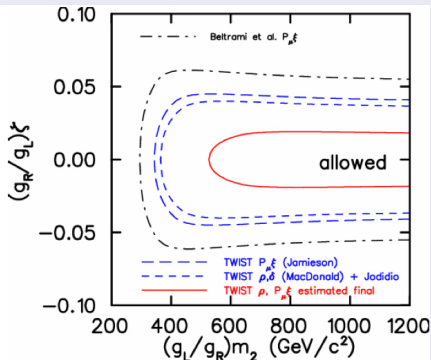
- Chamber space time relationships corrected to minimize  $e^+$  track fit time residuals
- Corrects for plane to plane construction differences
- Procedure repeated for data and Monte Carlo

# Limits on New Physics

## Right Handed Muon Decays

- $Q_R^\mu < 0.014$ : 90% limit before 2004
- $Q_R^\mu < 0.0024$ : 90% limit from current results

## Improved Limits on Left-Right-Symmetric Models



# Summary

## Consistency with the Standard Model

$$\rho = 0.75014 \pm 0.00017(\text{stat}) \pm 0.00046(\text{sys}) \pm 0.00011(\eta)$$

$$\delta = 0.75068 \pm 0.00030(\text{stat}) \pm 0.00067(\text{sys})$$

$$P_{\mu}^{\pi\xi} = 1.0003 \pm 0.0006(\text{stat}) \pm 0.0038(\text{sys})$$

- Published results improve precision on  $\rho$  and  $\delta$  by a factor of 5.
- Improved precision on  $P_{\mu}^{\pi\xi}$  by a factor of 2 .
- Precision goal of an order of magnitude improvement over pre TWIST results coming in early 2010.

# The *TWIST* Collaboration

## TRIUMF

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## Texas A&M

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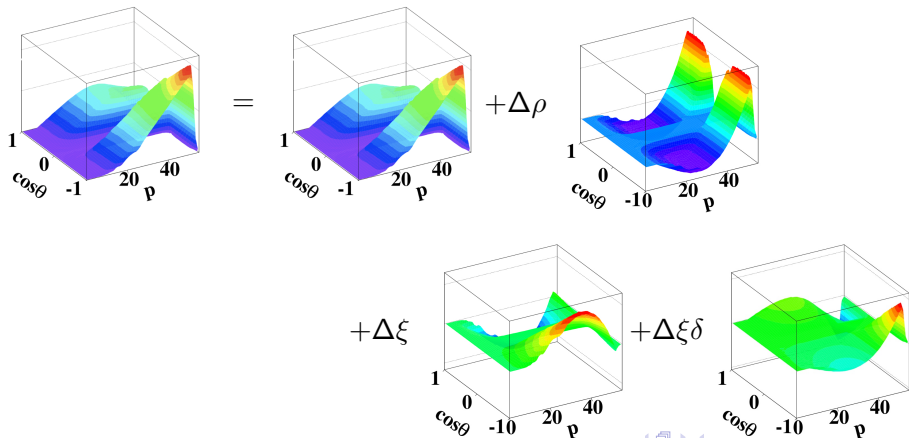
Don Koetke  
 Shirvel Stanislaus

★ graduate student  
 ⊛ graduated  
 ♣ also UVic

- Funding Support from NSERC and US DOE
- Additional support from TRIUMF, Russian Science Ministry, and NRC
- Computing resources provided by WestGrid

## Spectrum Fits

$$\left. \frac{\partial^2 \Gamma}{\partial x \partial \cos \theta} \right|_{fit} = \left. \frac{\partial^2 \Gamma}{\partial x \partial \cos \theta} \right|_{base} + \Delta \rho \frac{\partial}{\partial \rho} \left. \frac{\partial^2 \Gamma}{\partial x \partial \cos \theta} \right|_{base} + \dots$$



# Coupling Constants

- 90% confidence interval limits on the weak coupling constants.

