

# *TWIST* – the TRIUMF Weak Interaction Symmetry Test

A precision study of the  $\mu^+$  decay spectrum

- ❖ Designed to achieve  $\sim 0.01\%$  in the *shape* of the  $\mu$  decay spectrum
- ❖ Several data sets of  $10^9$  events each
- ❖ A precision test of the weak interaction in the Standard Model

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# Outline

- ❖ Motivation
- ❖ Overview of the experiment
- ❖ Analysis status
- ❖ Timeline

# The *TWIST* Collaboration

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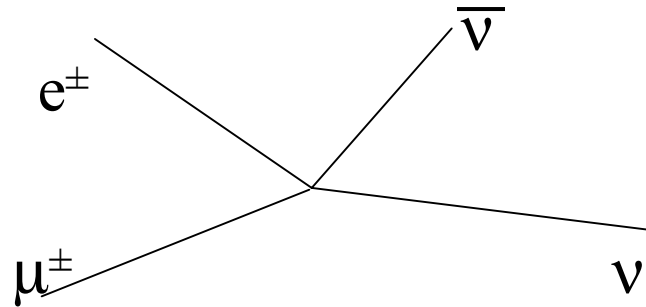
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† † also LANL

# ***TWIST*** Motivation – testing the Standard Model

... Most general interaction does not presuppose the W

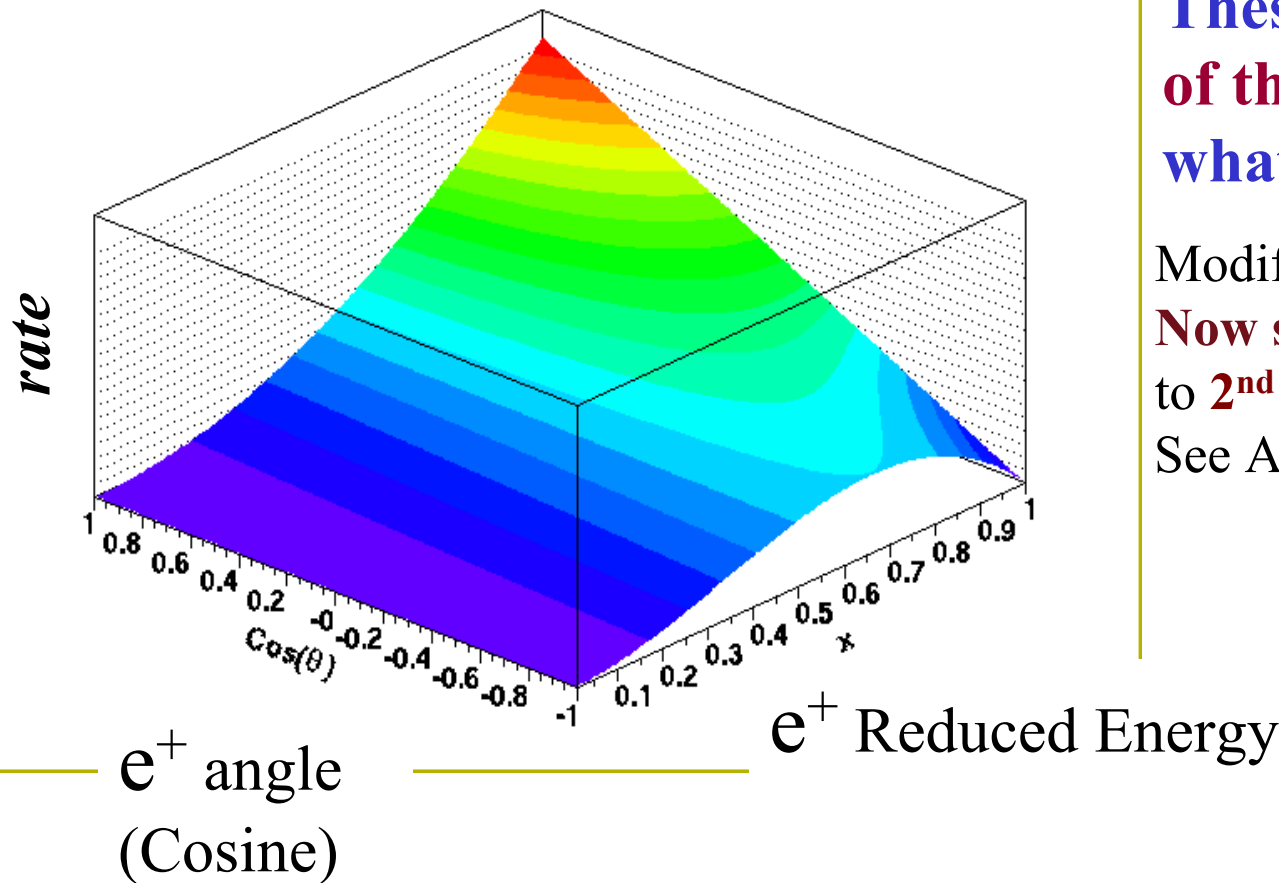


$$rate \sim \left| \sum_{\substack{\gamma=S,V,T \\ i,j=R,L}} g_{ij}^\gamma \langle \bar{\psi}_{ei} | \Gamma^\gamma | \psi_{\nu_e} \rangle \langle \bar{\psi}_{\nu_\mu} | \Gamma_\gamma | \psi_{\mu j} \rangle \right|^2$$

- **$S, V, T$  = scalar, vector or tensor interactions**
- **$R, L$  = right and left handed leptons ( $e, \mu, \text{ or } \tau$ )**

# Expanded in terms what have become known as the Michel parameters

$$rate \sim x^2 \left[ 3 - 3x + \frac{2}{3} \rho(4x - 3) + 3\eta x_o \frac{1-x}{x} + P_\mu \xi \cos(\theta) \left( 1 - x + \frac{2}{3} \delta(4x - 3) \right) \right]$$



**These shape parameters  
of the spectrum are  
what TWIST is studying!**

Modified by radiative corrections.

**Now several calculations  
to 2<sup>nd</sup> order exist**

See Arbuzov JHEP0303:063,2003

{hep-ph/0206036}

# The Michel Parameter - $\rho$

The parameter  $\rho$  largely determines the shape of the positron energy spectrum

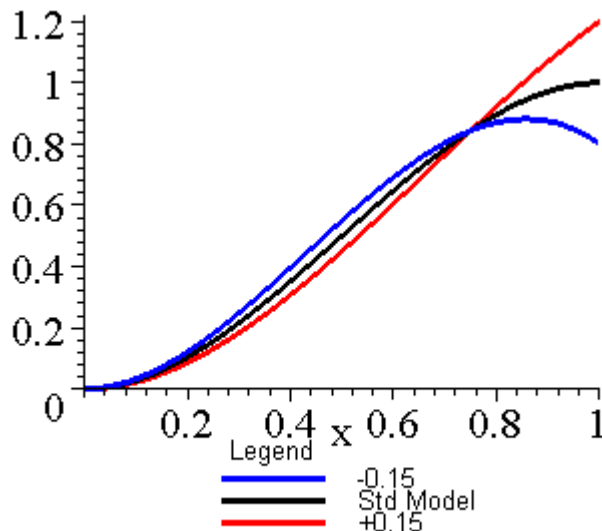
$$\rho - \frac{3}{4} \equiv \frac{3}{4} \left[ -|g_{LR}^V|^2 - |g_{RL}^V|^2 - 2(|g_{LR}^T|^2 + |g_{RL}^T|^2) \right] \\ + \frac{3}{4} \left[ \text{Re}(g_{LR}^S g_{LR}^{T*}) + \text{Re}(g_{LR}^{S*} g_{LR}^T) + \text{Re}(g_{RL}^S g_{RL}^{T*}) + \text{Re}(g_{RL}^{S*} g_{RL}^T) \right]$$

**-positive definite terms**

**→ fewer required experiments**

**-can conspire so  $\rho = 3/4$**

**→ measure parameters simultaneously**

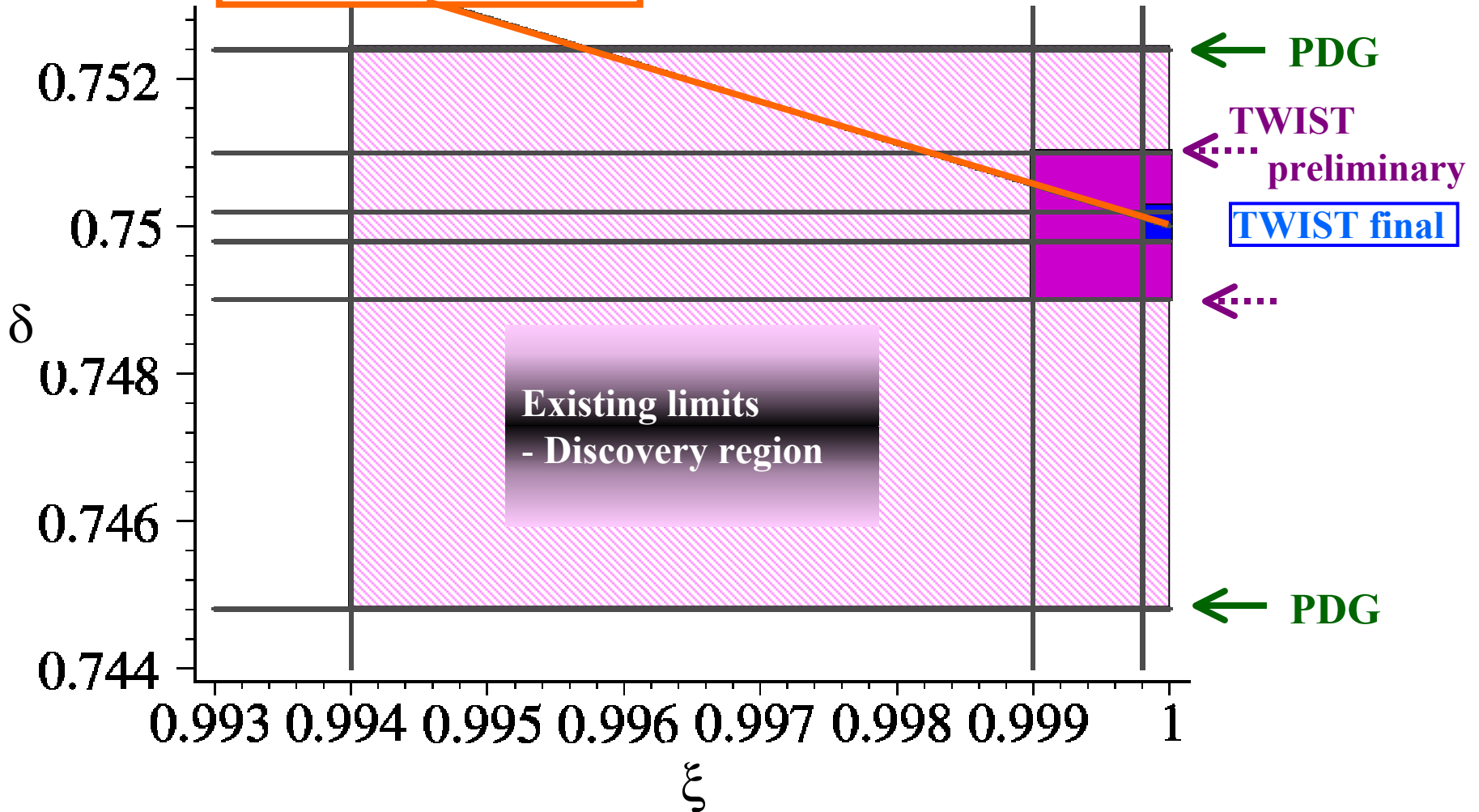


The effect of large deviations in  $\rho$  on the shape of the energy spectrum. The effect shown is roughly **500** times the TWIST sensitivity

# Anticipated TWIST sensitivity to R-H currents in muon decay

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

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



# Left/Right **Symmetric Extensions** of the Standard Model

Two weak bosons with mass eigenstates  $M_1$  and  $M_2$

$$M_{W_L} = M_1 \cos(\zeta) - M_2 \sin(\zeta)$$

$$M_{W_R} = e^{i\omega} (M_1 \cos(\zeta) + M_2 \sin(\zeta))$$

Parity violation at low energy is presumably due to

$$\frac{m_{W_R}}{m_{W_L}} \gg 1$$

In general, the models may include a CP violating phase ( $\omega$ ), and a left/right mixing parameter  $\zeta$



# For Left/Right Symmetric extensions

For  $g_{LR}^V = g_{RL}^V \approx \zeta \ll 1$        $g_{RR}^V \approx \left(\frac{m_L}{m_R}\right)^2$

$$\rho \approx \frac{3}{4}(1 - 2\zeta^2)$$

$\rho$  is sensitive to the  
Left/Right mixing

$$\xi \approx 1 - 2\left(\frac{m_L}{m_R}\right)^4 - 2\zeta^2$$

$\xi$  to the mixing and to  
the  $W_R$  mass

$$\approx \frac{4}{3}\rho - 2\left(\frac{m_L}{m_R}\right)^4$$

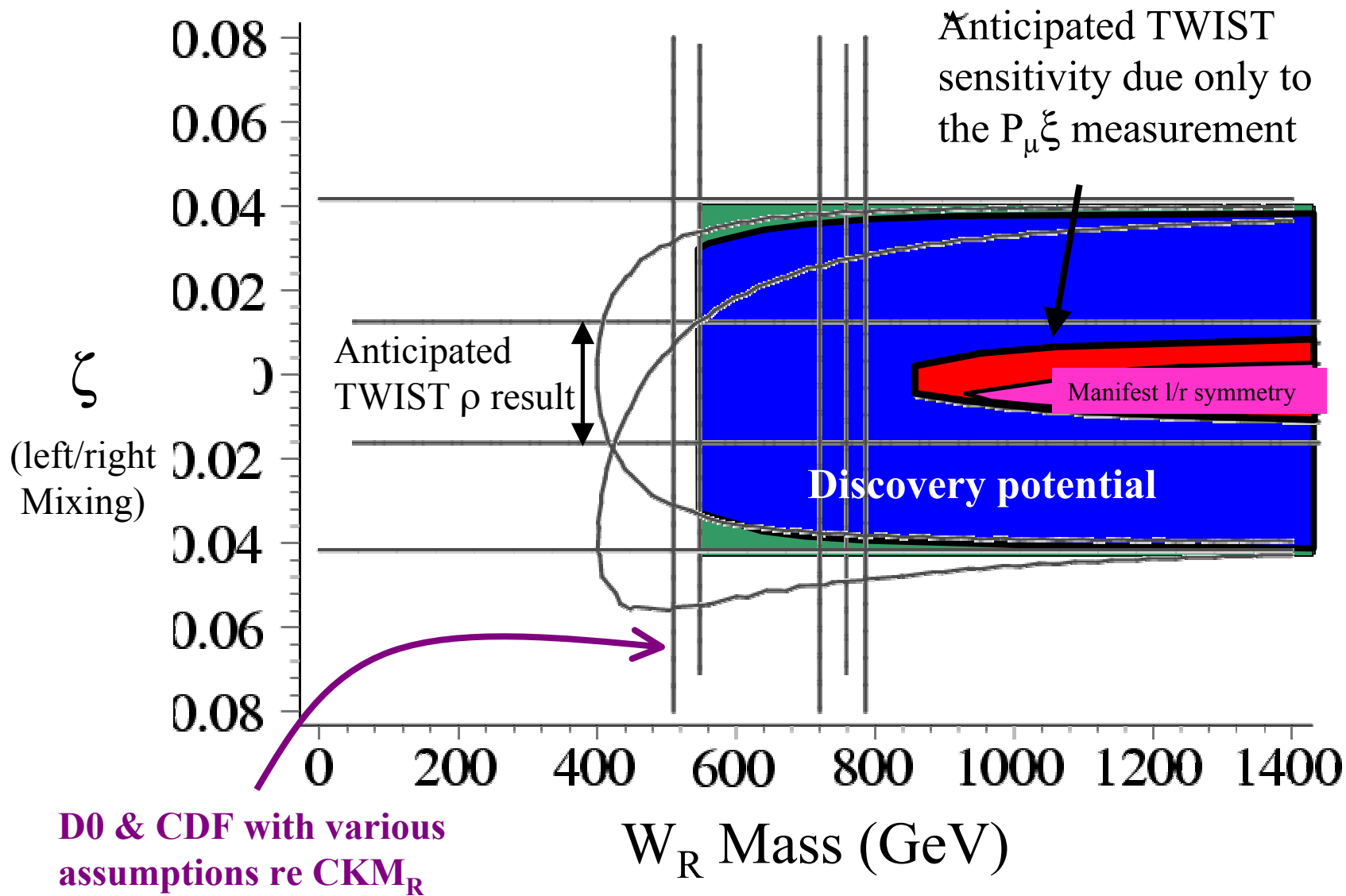
$\delta$  and  $\eta$  are unchanged  
by Left/Right  
extensions with  
manifest symmetry

$$\delta \approx \frac{3}{4}$$

$$\eta \approx 0$$

A measurement of  $\rho$  and  $\xi$  determines the  
 $W_R$  mass and its mixing

# Left/Right Mixing constraints – Anticipated TWIST Sensitivity



# Complementary

$\beta$  decay

$$\left(\frac{g_R}{g_L}\right)^4 \left(\frac{V_{ud}^R}{V_{ud}^L}\right)^2 \left(\frac{M_L}{M_R}\right)^4$$

$p$   $\bar{p}$  collider

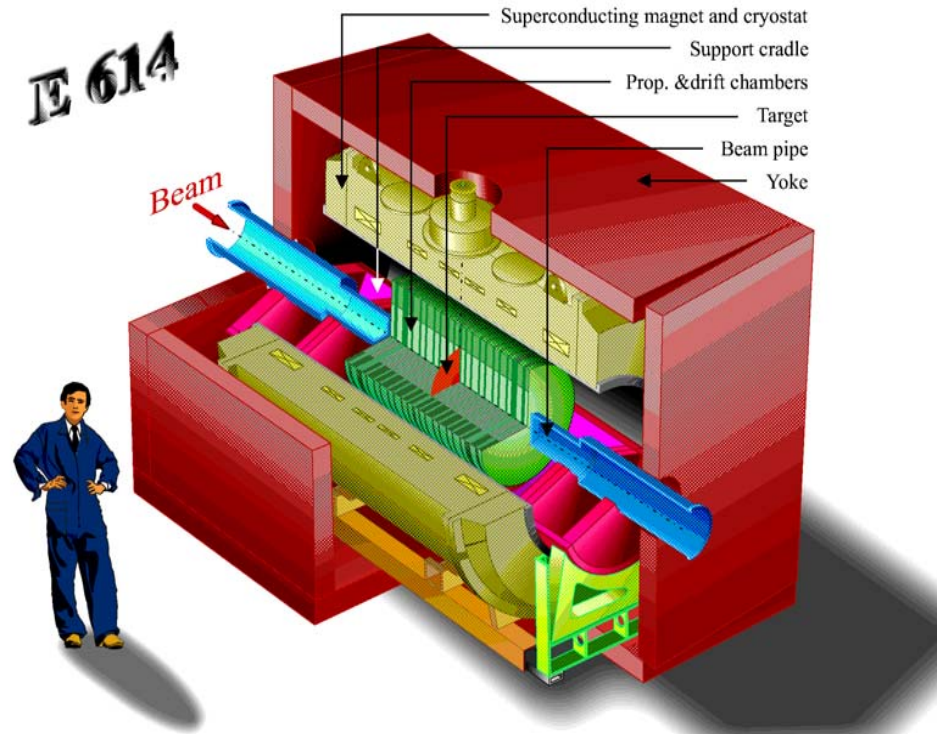
$$\left(\frac{g_R}{g_L}\right)^2 \left(\frac{V_{ud}^R}{V_{ud}^L}\right)^2 \textit{function} \left(\frac{M_L}{M_R}\right)$$

$\mu$  decay

$$\left(\frac{g_R}{g_L}\right)^4 \left[ 1 + \left(\frac{V_{ud}^R}{V_{ud}^L}\right)^2 \right] \left(\frac{M_L}{M_R}\right)^4$$

# The Experiment

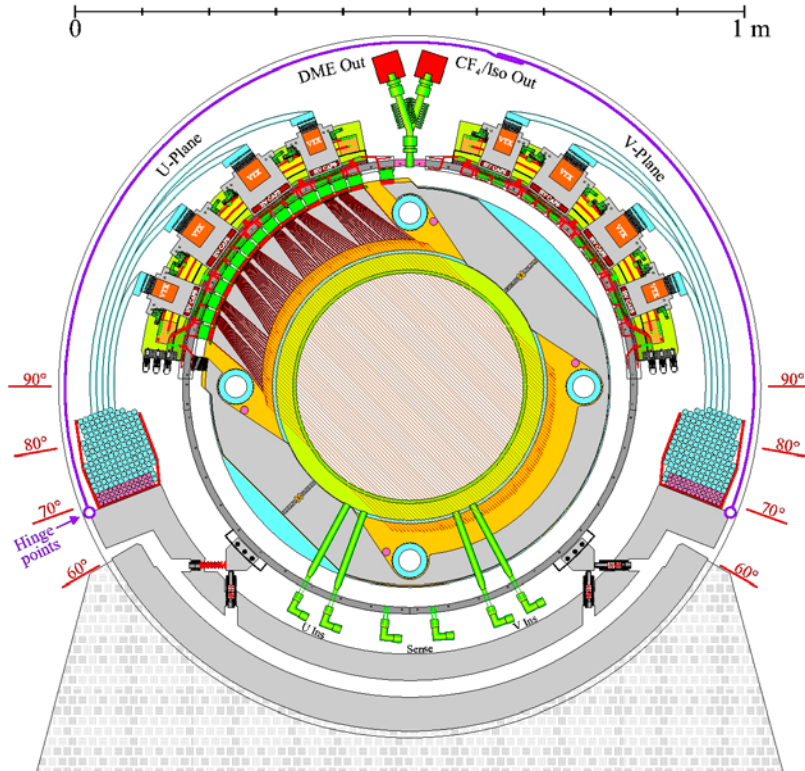
- ❖ Highly polarized muons enter the spectrometer one at a time
- ❖ Unbiased trigger on muon entering system
- ❖ Data sets of  $10^9$  muon decay events in roughly two weeks (modern computing)
- ❖ The experiment is **systematics limited**. The high data rate is a must for systematics studies



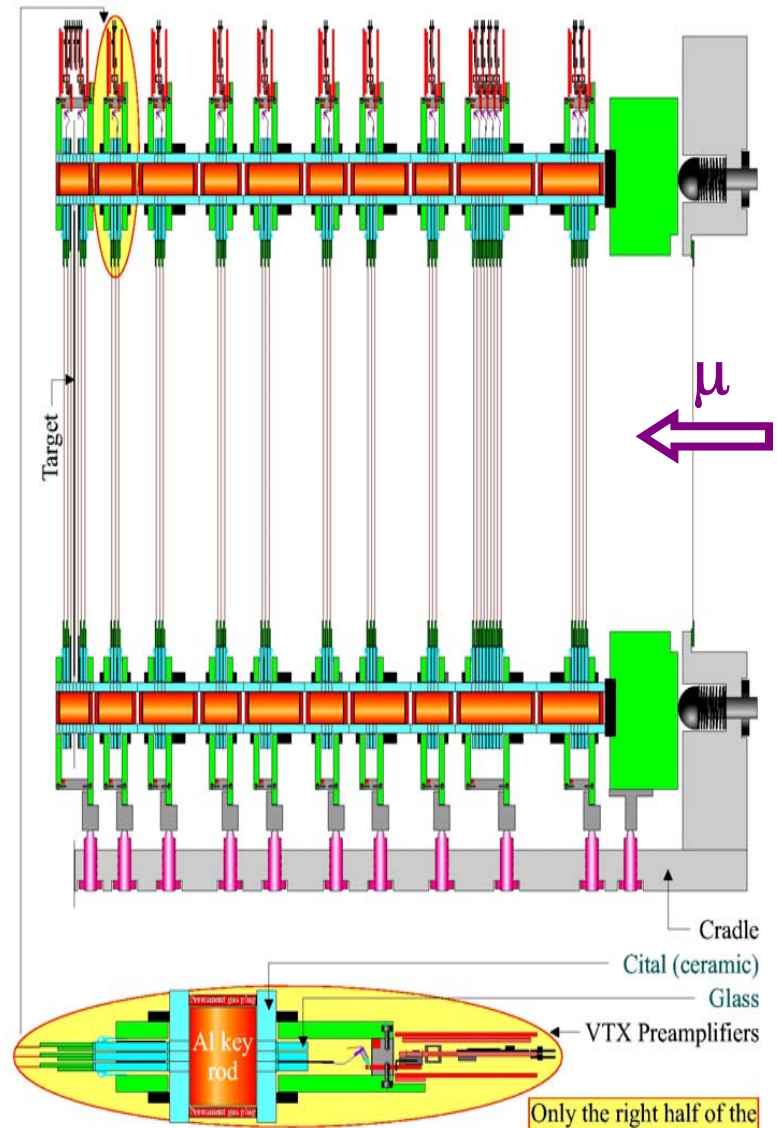
The large acceptance makes possible measurements of Michel parameters under differing conditions – therefore improving the reliability of the result.

# Chambers & half detector

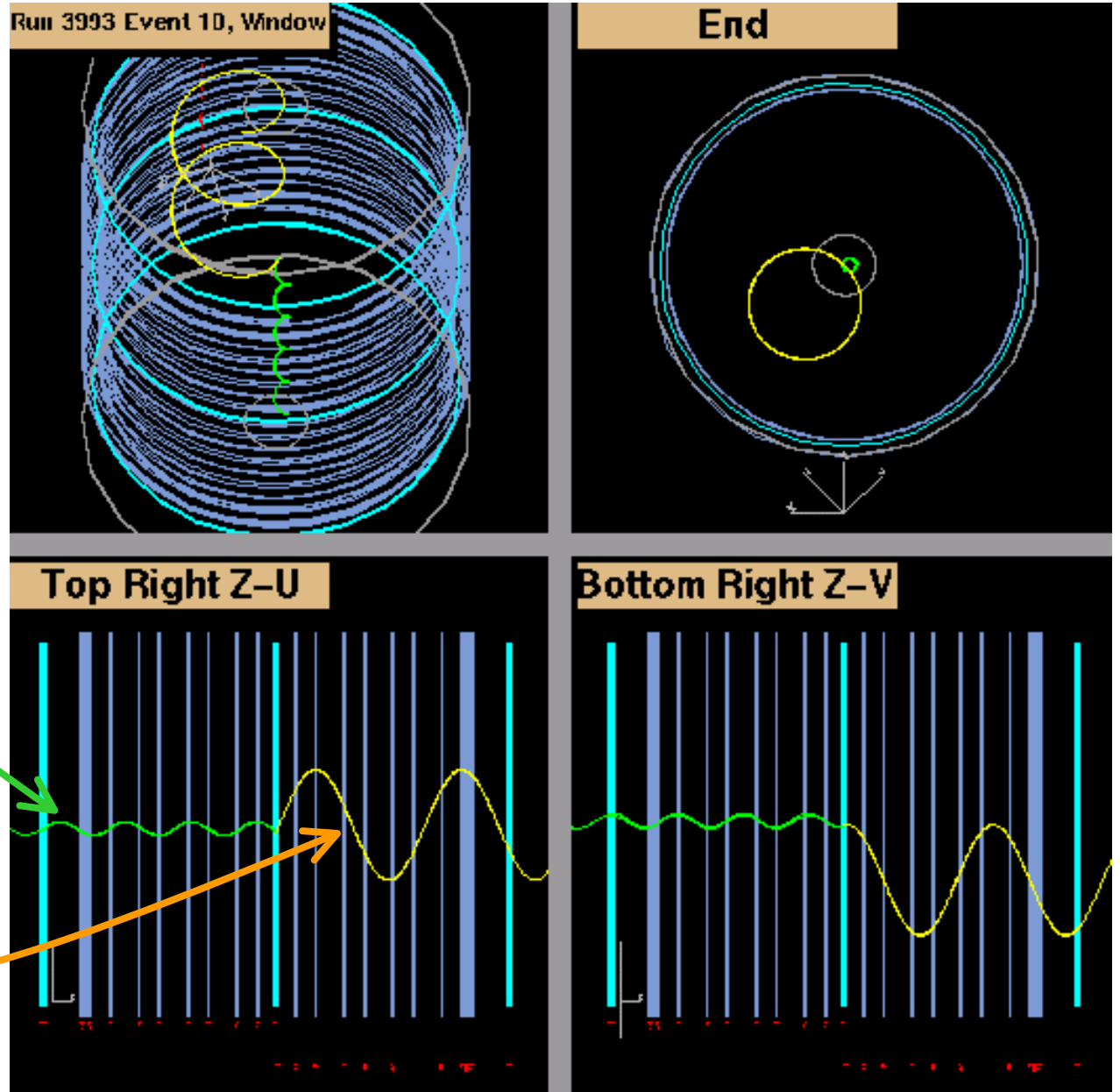
Planar drift chambers sample positron track



Use 44 drift planes,  
and 12 PC planes



# Typical decay event



# Analysis Concept

**Fit real data to Monte Carlo generated data**

- many effects of reconstruction cancel
- MC must reproduce the detector response well

**TWIST detector thin so effects small**

**Useful for systematics search/study**

- systematics comparisons can be done directly
- fit data to data or MC to MC**

**Hide values of  $\rho$ ,  $\delta$ ,  $\xi$  and  $\eta$  used in MC generation**

- can be done in straightforward way
- avoids human bias in analysis of systematics

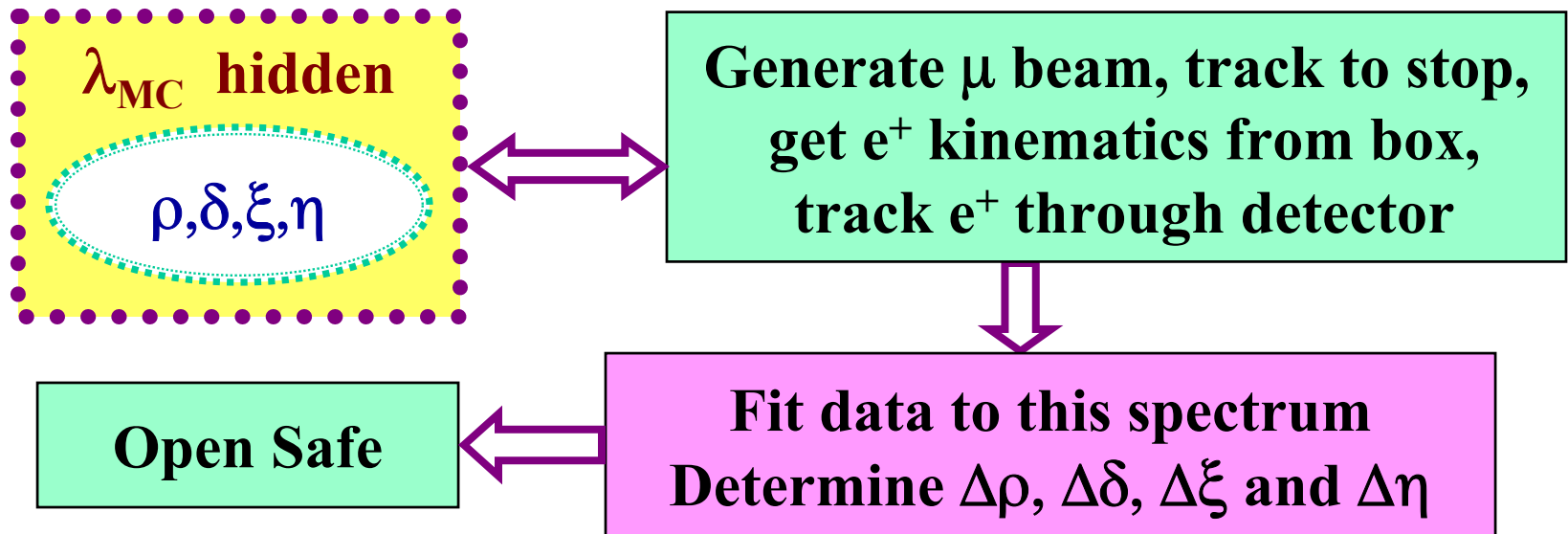
# Technology WestGrid: 1000\*3GHz

Spectrum is linear in  $\rho$ ,  $\eta$ ,  $\xi$  and  $\xi\delta$  so fit

$$N_i(\lambda_{data}) = N_i(\lambda_{MC}) + \frac{\partial N_i}{\partial \lambda} (\lambda_{data} - \lambda_{MC})$$

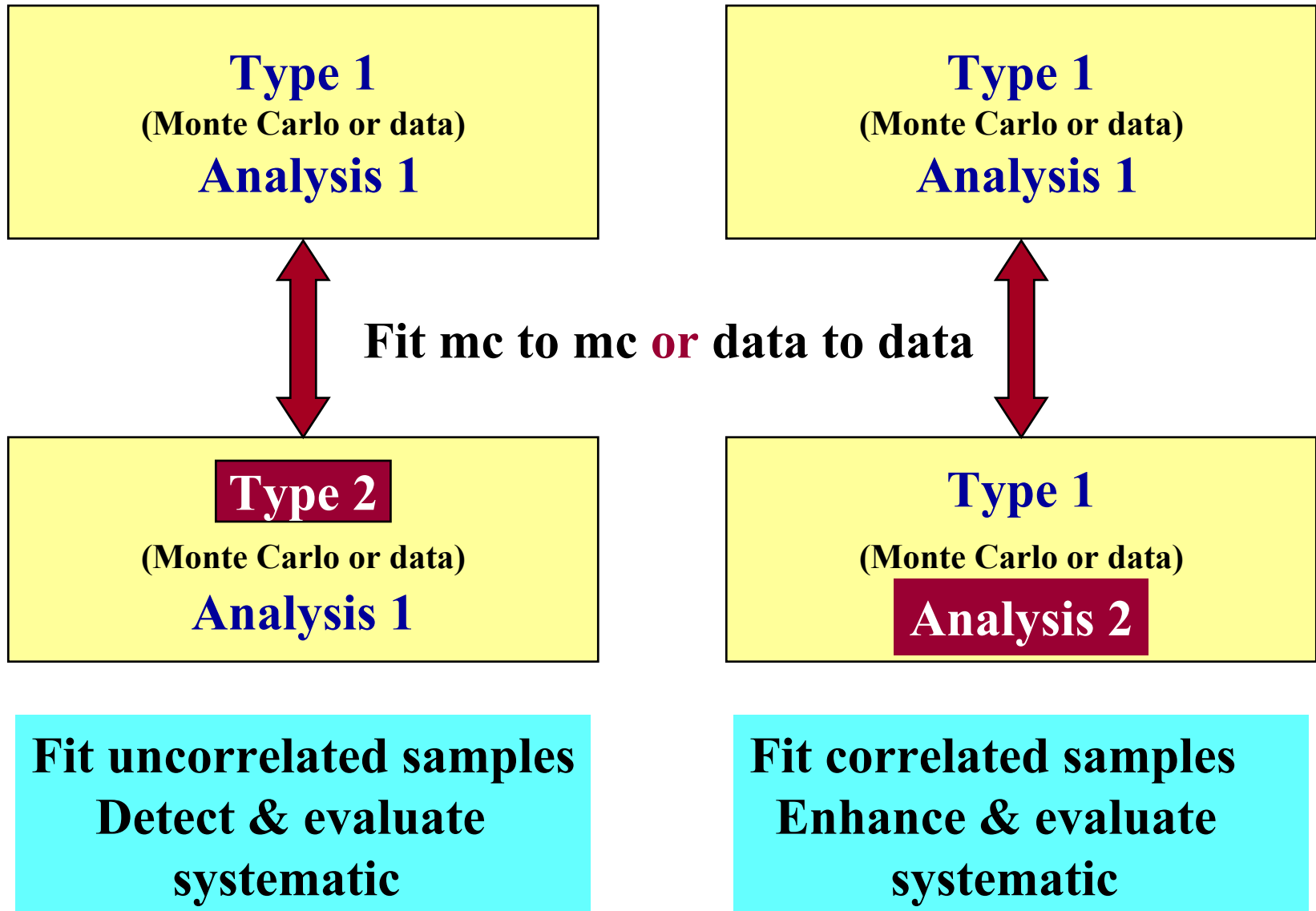
where  $\lambda_{data} - \lambda_{MC} = \Delta\lambda$  is the fit parameter

$N_i$  - number in momentum/angle bin  $i$





# Use in systematics studies



# Systematics study status

## Sample from correlated data to data fits

|                    | $10^{-3}$            | $\rho$      | $\delta$    | $\xi$       | $\eta$     |
|--------------------|----------------------|-------------|-------------|-------------|------------|
| <b>Alignment</b>   | <b>Translation</b>   | <b>0.10</b> | <b>0.08</b> | <b>0.13</b> | <b>5.8</b> |
|                    | <b>Rotation</b>      | <b>0.07</b> | <b>0.05</b> | <b>0.28</b> | <b>3.9</b> |
| <b>Chamber</b>     | <b>HV</b>            | <b>0.05</b> | <b>0.03</b> | <b>0.06</b> | <b>2.6</b> |
|                    | <b>Cell Geometry</b> | <b>0.28</b> | <b>0.21</b> | <b>0.36</b> | <b>16.</b> |
|                    | <b>Gas Density</b>   | <b>0.15</b> | <b>0.11</b> | <b>0.20</b> | <b>8.5</b> |
| <b>Calibration</b> | <b>Trigger time</b>  | <b>0.13</b> | <b>0.09</b> | <b>0.16</b> | <b>7.0</b> |

**Long list at this level – No showstopper found**

**session J11**

$\rho$  – (Musser)

$\delta$  – (Gaponenko)

# Timeline

- ❖  $6 \times 10^9$  muon decay events are in hand
  - ❖ complete  $10^{-3}$  analysis **this summer!**
  - ❖ publish determination of  $\rho$  and  $\delta$
- ❖ 2004 data run
  - ❖ data on  $P_\mu \xi$  at  $10^{-3}$  (and  $\eta$ ?) this summer/fall
- ❖ at least 3 PhD's granted by 2005
- ❖ Final parts in  $10^{-4}$  data & publications: 2005/2006
- ❖ **Need More Graduate Students Now**

# Summary

- ❖ The TWIST experiment is near end of phase 1
  - ❖ Anticipate preliminary measurements at  $\sim 0.1\%$  of:
    - ❖  $\rho$  and  $\delta$  (this summer)
    - ❖  $P_\mu \xi$  (Data during the summer/fall of 2004)
    - ❖ Final precision on  $\rho$  and  $\delta$  and  $P_\mu \xi$  at  $\sim \pm 0.02\%$
- ❖ TWIST is exploring significant new space where evidence may be found to challenge the standard model
- ❖ For left/right symmetric models, TWIST has a mass reach which is comparable to - and which **complements**  $\beta$  decay experiments and direct searches at the Tevatron