TWIST – the TRIUMF Weak Interaction Symmetry Test

A precision study of the μ^+ decay spectrum

- Designed to achieve ~ 0.01% in the ***shape*** of the μ 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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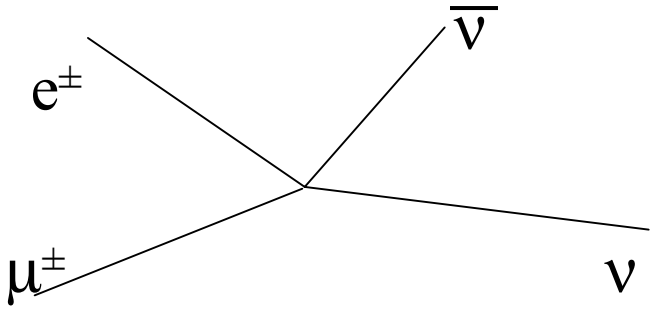
TWIST Motivation – testing the Standard Model

… Most general interaction does not presuppose the W

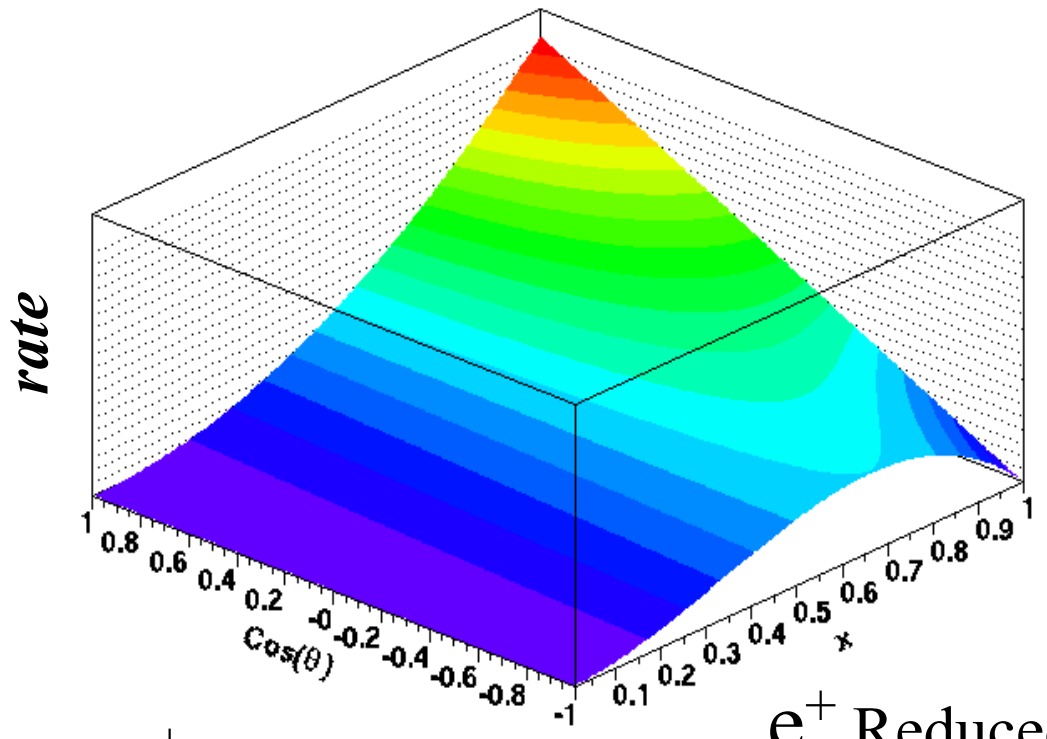


$$rate \sim \left| \sum_{\substack{\gamma = S,V,T \\ i,j = R,L}} g_{ij}^{\gamma} \left\langle \overline{\psi}_{ei} \left| \Gamma^{\gamma} \right| \psi_{\nu_e} \right\rangle \left\langle \overline{\psi}_{\nu_\mu} \left| \Gamma_{\gamma} \right| \psi_{\mu\, j} \right\rangle \right|^2$$

- ***S,V,T*** **= scalar, vector or tensor interactions**
- ***R, L*** **= right and left handed leptons (*e*, μ, or τ)**

Expanded in terms what have become known as the Michel parameters

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



e^+ angle (Cosine)

e^+ Reduced Energy

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

Modified by radiative corrections.

Now several calculations

to **2nd order** exist

See Arbuzov JHEP0303:063,2003 {hep-ph/0206036}

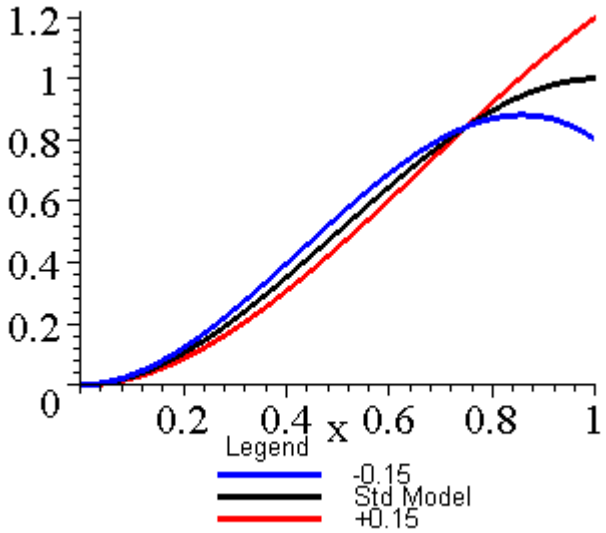
The Michel Parameter - ρ

The parameter ρ largely determines the shape of the positron energy spectrum

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

$$+ \frac{3}{4}\left[\mathrm{Re}\left(g_{LR}^{S} g_{LR}^{T*}\right) + \mathrm{Re}\left(g_{LR}^{S*} g_{LR}^{T}\right) + \mathrm{Re}\left(g_{RL}^{S} g_{RL}^{T*}\right) + \mathrm{Re}\left(g_{RL}^{S*} g_{RL}^{T}\right)\right]$$

-positive definite terms
→ fewer required experiments
-can conspire so ρ = ¾
→ measure parameters simultaneously

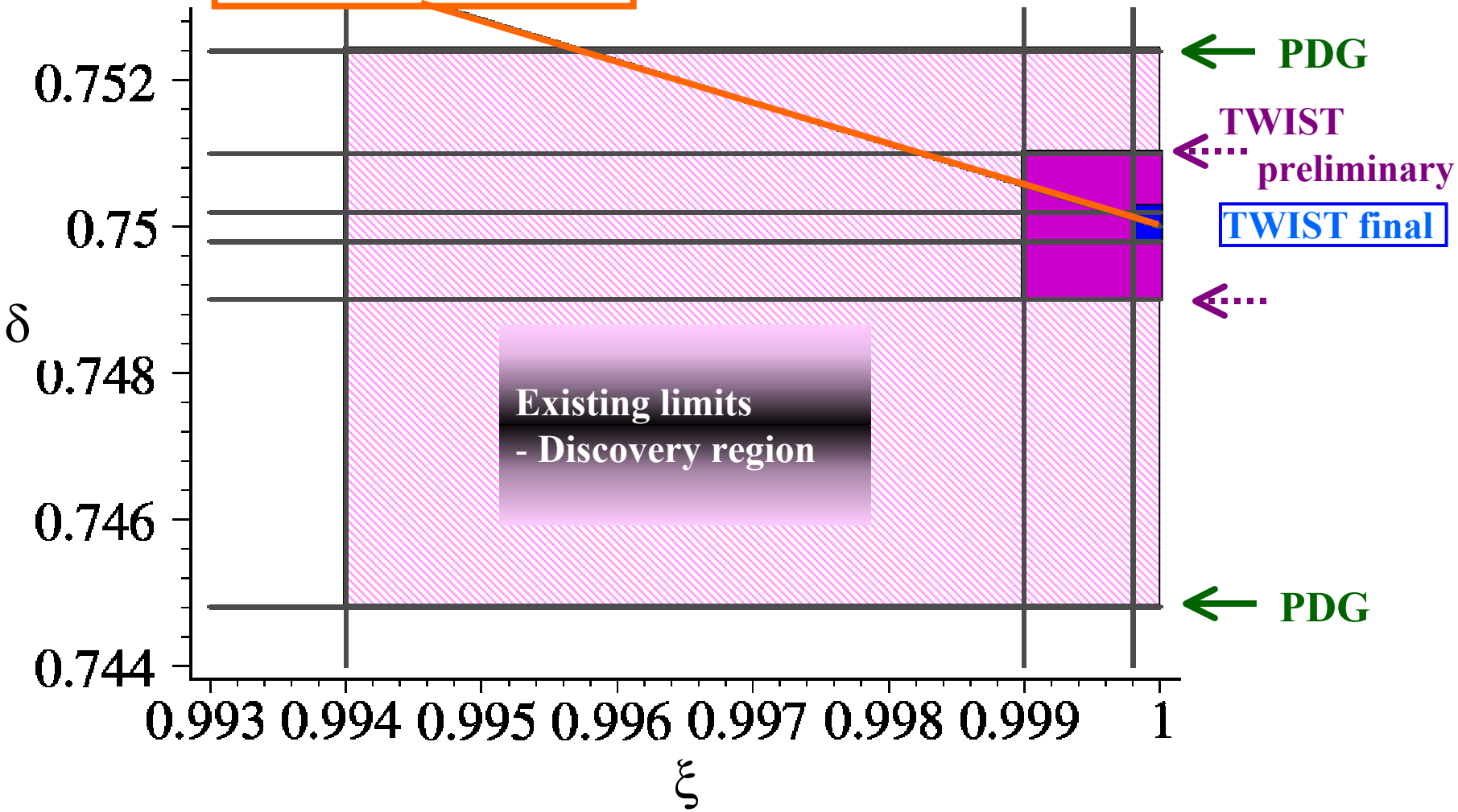


The effect of large deviations in ρ on the shape of the energy spectrum. The effect shown is roughly **500** times the TWIST sensitivity

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

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

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

Parity violation at low energy is presumably due to

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

In general, the models may include a CP violating phase (ω), and a left/right mixing parameter ζ

For Left/Right Symmetric extensions

For $g^V_{LR} = g^V_{RL} \approx \zeta << 1$ $\qquad g^V_{RR} \approx \left(m_L / m_R \right)^2$

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

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

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

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

$$\eta \approx 0$$

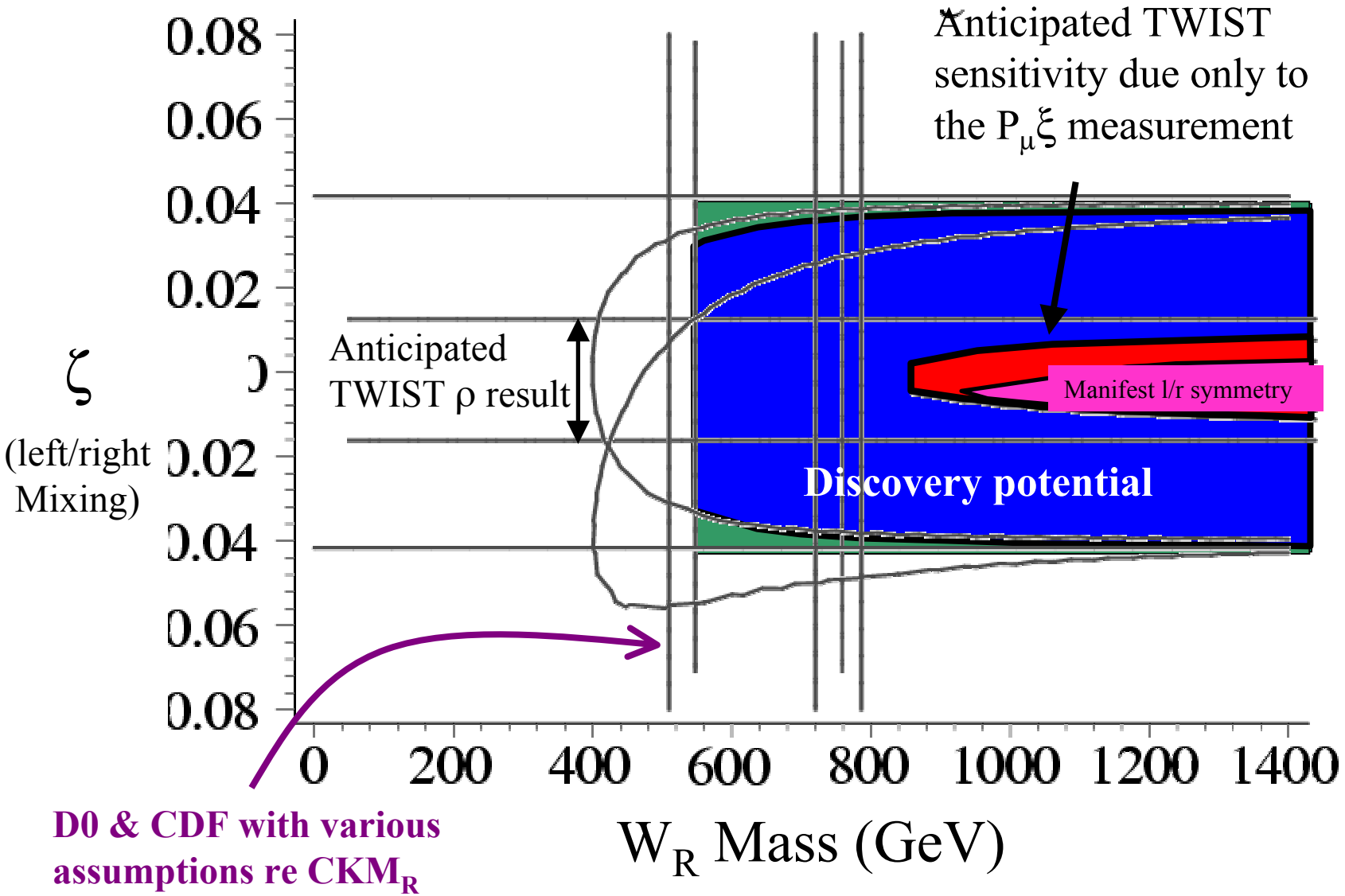
ρ is sensitive to the Left/Right mixing

ξ to the mixing and to the W_R mass

δ and η are unchanged by Left/Right extensions with manifest symmetry

A measurement of ρ and ξ determines the W_R mass and its mixing

Left/Right Mixing constraints – Anticipated TWIST Sensitivity



D0 & CDF with various assumptions re CKM_R

Complementary

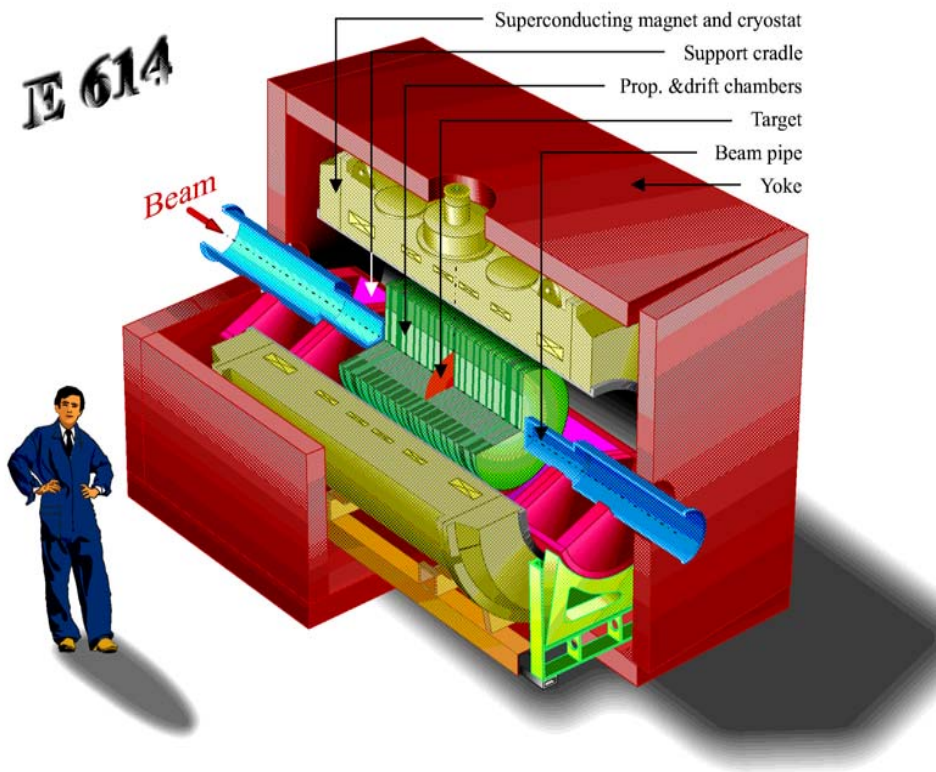
β decay $\left(\frac{g_R}{g_L}\right)^4 \left(\frac{V_{ud}^R}{V_{ud}^L}\right)^2 \left(\frac{M_L}{M_R}\right)^4$

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

μ 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

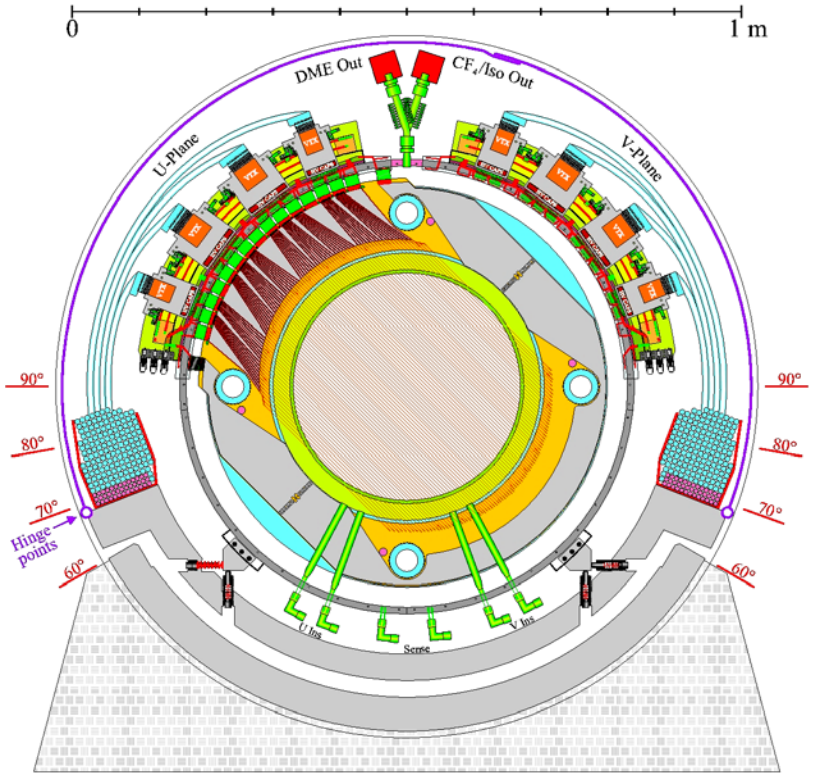
- Highly polarized muons enter the spectrometer one at a time
- Unbiased trigger on muon entering system
- Data sets of **10^9** muon decay events in roughly two weeks (modern computing)
- The experiment is **systematics limited**. The high data rate is a must for systematics studies



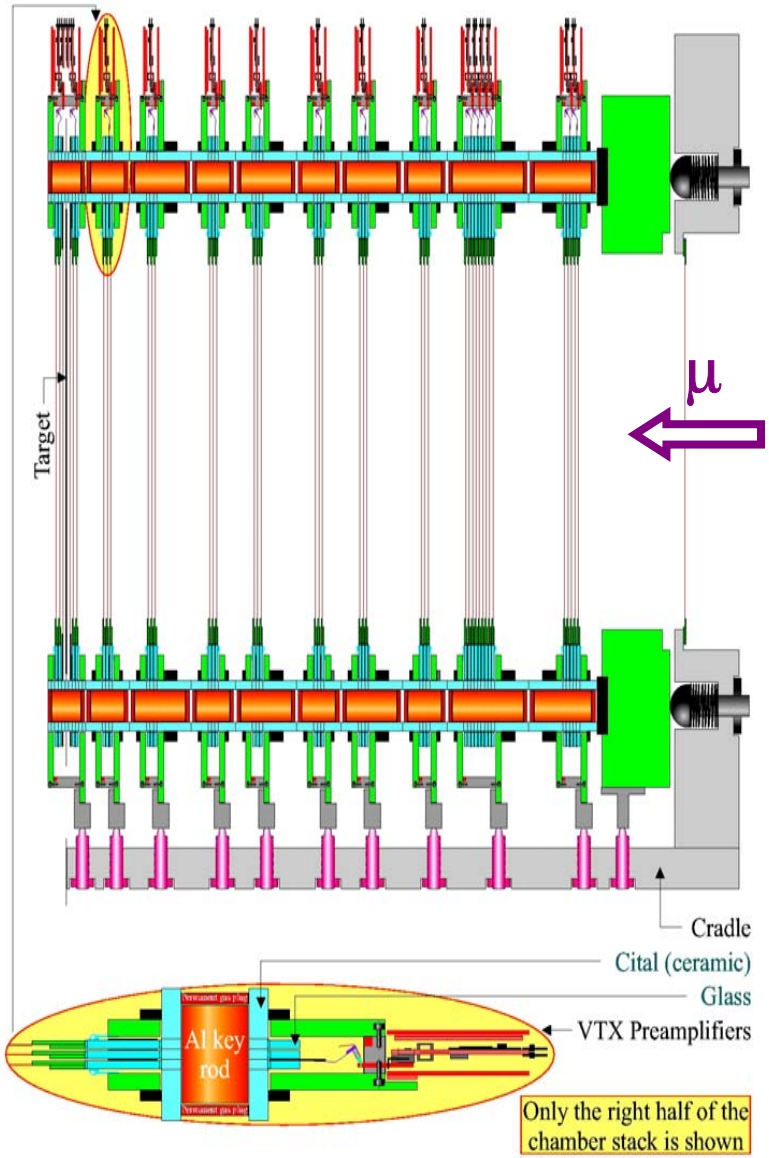
The large acceptance makes possible measurements of Michel parameters under differing conditions – therefore improving the reliability of the result.

Chambers & half detector

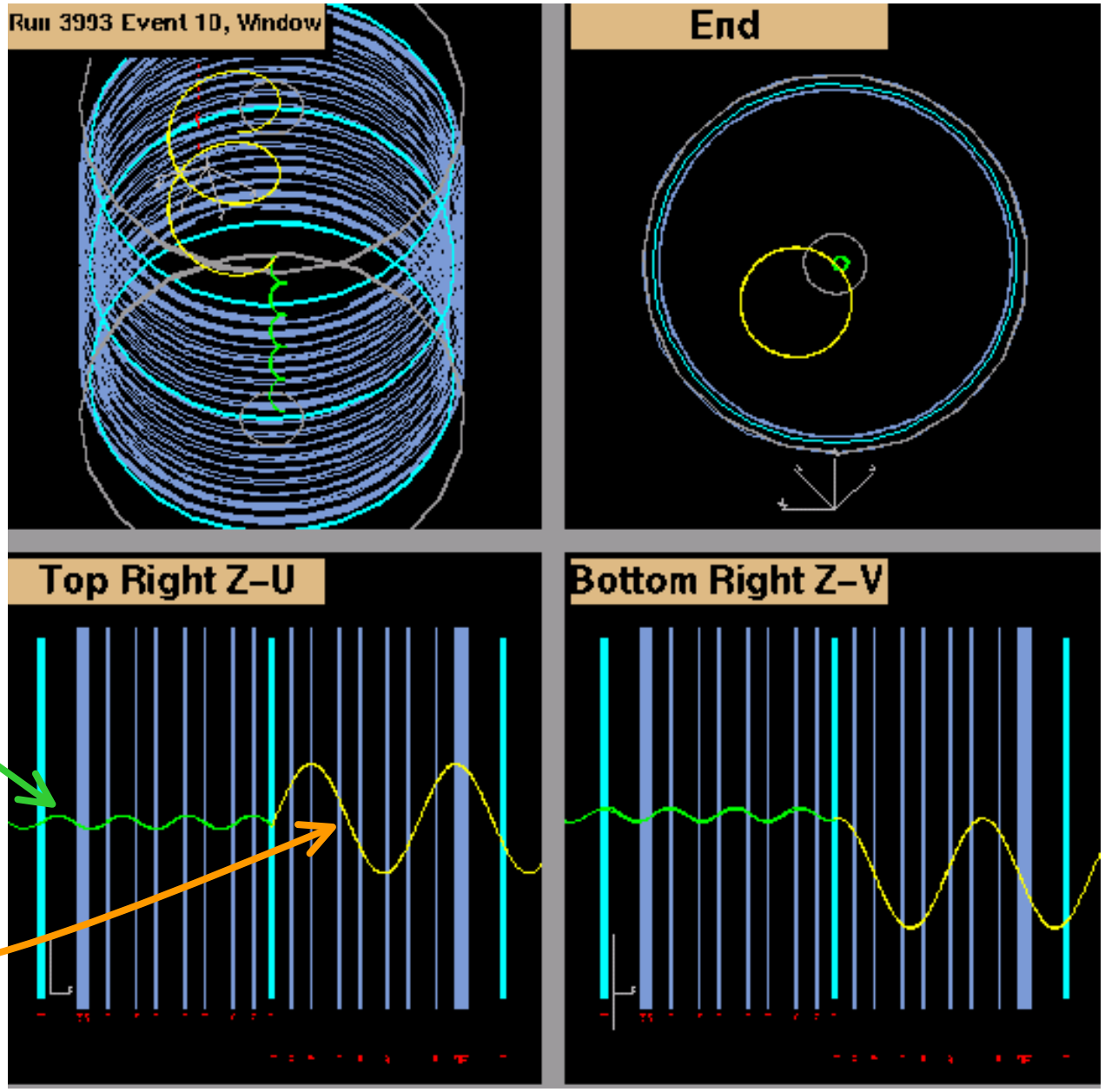
Planar drift chambers sample positron track



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 ρ, δ, ξ and η 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 ρ, η, ξ and ξδ 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*

λ_{MC} hidden

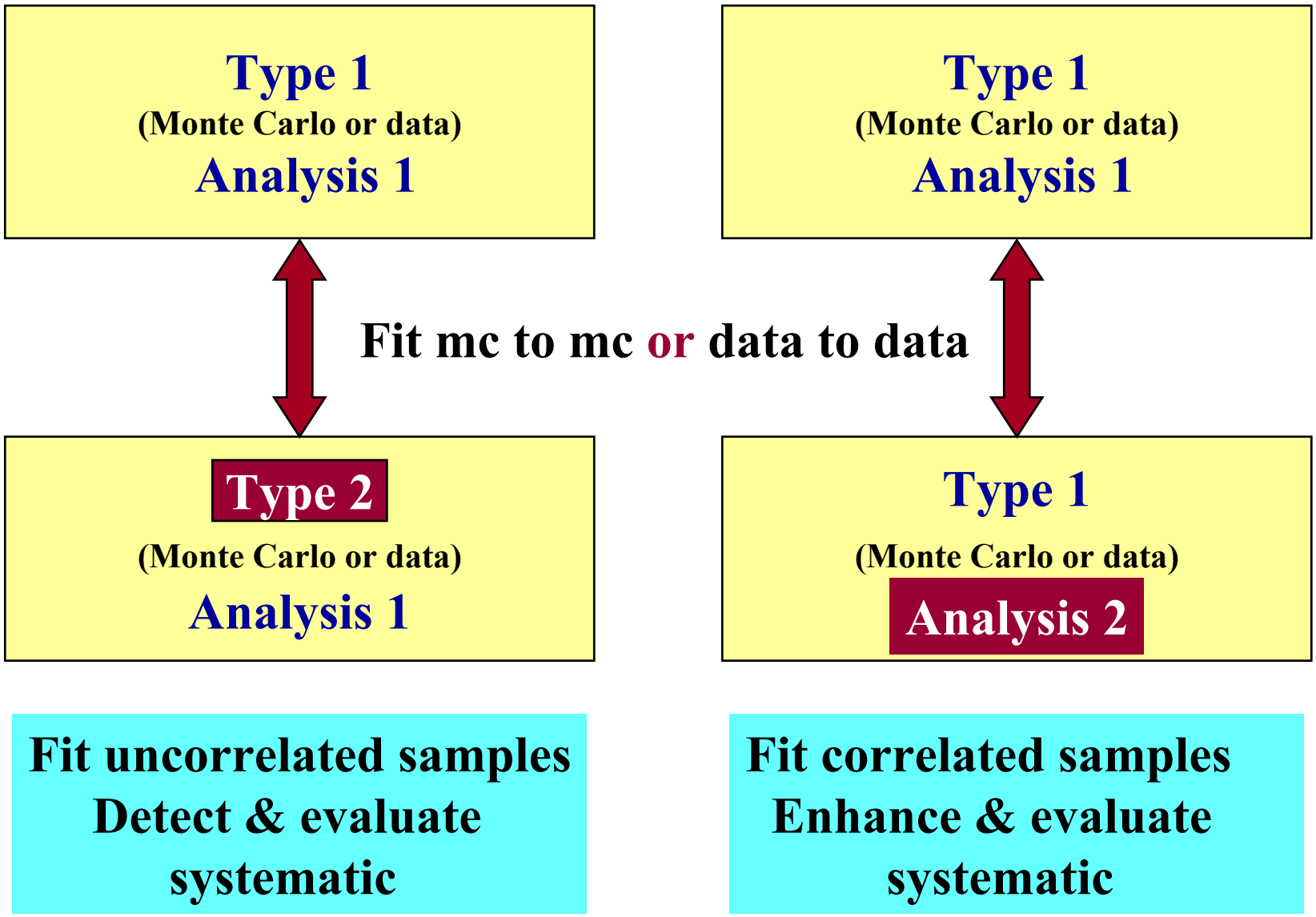
ρ,δ,ξ,η

Generate μ beam, track to stop, get e^+ kinematics from box, track e^+ through detector

Fit data to this spectrum Determine Δρ, Δδ, Δξ and Δη

Open Safe

Use in systematics studies



Systematics study status

Sample from correlated data to data fits

	10^{-3}	ρ	δ	ξ	η
Alignment	Translation	0.10	0.08	0.13	5.8
	Rotation	0.07	0.05	0.28	3.9
Chamber	HV	0.05	0.03	0.06	2.6
	Cell Geometry	0.28	0.21	0.36	16.
	Gas Density	0.15	0.11	0.20	8.5
Calibration	Trigger time	0.13	0.09	0.16	7.0

Long list at this level – No showstopper found

session J11
ρ – (Musser)
δ – (Gaponenko)

Timeline

- 6×10^9 muon decay events are in hand
  - complete $\mathbf{10^{-3}}$ analysis **this summer!**
  - publish determination of ρ and δ
- 2004 data run
  - data on $\mathbf{P}_\mu \xi$ at $\mathbf{10^{-3}}$ (and η?) 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 **~0.1%** of:
    - ρ and δ (this summer)
    - $P_\mu \xi$ (Data during the summer/fall of 2004)
    - Final precision on ρ and δ and $P_\mu \xi$ at ~ **±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** β decay experiments and direct searches at the Tevatron