The TWIST experiment at TRIUMF (a status report)

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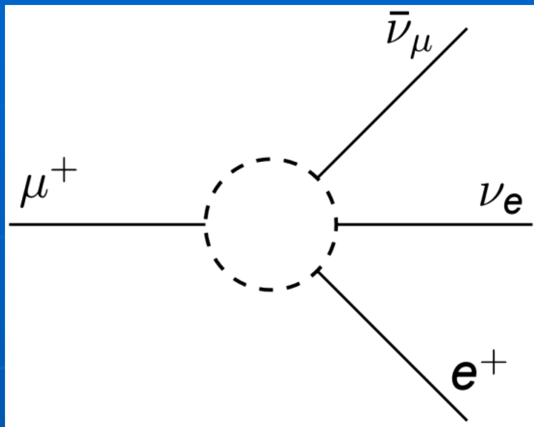
Muon Decay

- Purely leptonic weak process
- Most precisely studied weak process
- Theoretically known up to second order radiative corrections (A.Czarnecki, U of Alberta)
- Large Experimental effort :

  Lifetime (PSI,RAL),
  Michel parameters (TRIUMF,PSI),
  Magnetic moment (g-2 @BNL), New g-2
  Rare decays (PSI,J-PARC,FNAL?)

Muon decay



General 4-fermion interaction:

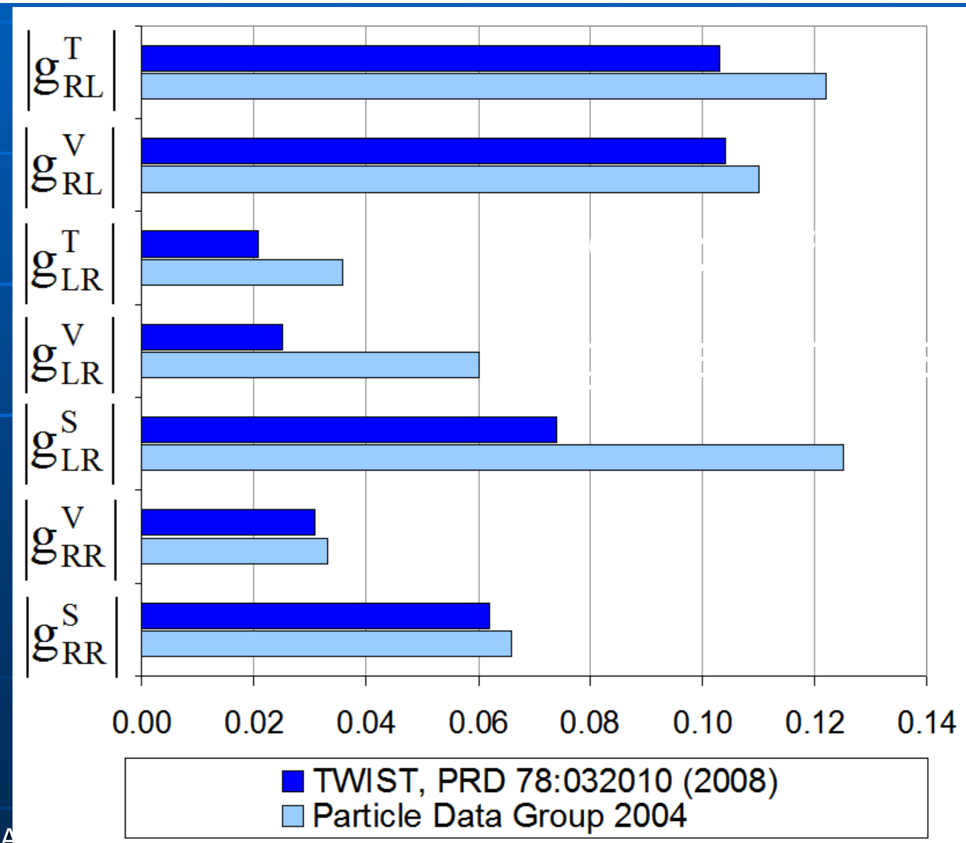
$$M = 4\frac{G_F}{\sqrt{2}} \sum_{\substack{\gamma = S,V,T \\ \epsilon,\mu = R,L}} g^\gamma_{\epsilon\mu} < \bar{e}_\epsilon|\Gamma^\gamma|\nu_e >< \bar{\nu}_\mu|\Gamma_\gamma|\mu_\mu >$$

Standard Model ("V-A"):

$g^{V}_{LL} = 1$, all others zero

Experimentally:

$\left|g^{V}_{LL}\right| > 0.96$ @ 90% C.L.



e^{+} spectrum in x, $\cos\theta_e$

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

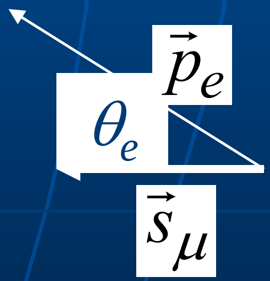
Spectral shape in x, $\cos\theta_e$ is characterized in terms of four parameters -- ρ, η, ξ, δ

P_μ is the muon polarization

$$E_e^{\max} \equiv \frac{m_\mu^2 + m_e^2}{2m_\mu}$$

$$x_o \equiv \frac{m_e}{E_e^{\max}}$$

$$x \equiv \frac{E_e}{E_e^{\max}}$$



(L. Michel, A. Sirlin)

Muon decay parameters in terms of Non SM weak couplings

$$\rho = \frac{3}{4} - \frac{3}{4}[|g^V_{RL}|^2 + |g^V_{LR}|^2 + 2|g^T_{RL}|^2 + 2|g^T_{LR}|^2$$
$$+Re(g^S_{RL}g^{T*}_{RL} + g^S_{LR}g^{T*}_{LR})],$$

$$\eta = \frac{1}{2}Re[g^V_{RR}g^{S*}_{LL} + g^V_{LL}g^{S*}_{RR} + g^V_{RL}(g^{S*}_{LR} + 6g^{T*}_{LR}) + g^V_{LR}(g^{S*}_{RL} + 6g^{T*}_{RL})],$$

$$\xi = 1 - \frac{1}{2}|g^S_{LR}|^2 - \frac{1}{2}|g^S_{RR}|^2 - 4|g^V_{RL}|^2 + 2|g^V_{LR}|^2 - 2|g^V_{RR}|^2$$
$$+2|g^T_{LR}|^2 - 8|g^T_{RL}|^2 + 4Re(g^S_{LR}g^{T*}_{LR} - g^S_{RL}g^{T*}_{RL}),$$

$$\xi\delta = \frac{3}{4} - \frac{3}{8}|g^S_{RR}|^2 - \frac{3}{8}|g^S_{LR}|^2 - \frac{3}{2}|g^V_{RR}|^2 - \frac{3}{4}|g^V_{RL}|^2 - \frac{3}{4}|g^V_{LR}|^2$$
$$-\frac{3}{2}|g^T_{RL}|^2 - 3|g^T_{LR}|^2 + \frac{3}{4}Re(g^S_{LR}g^{T*}_{LR} - g^S_{RL}g^{T*}_{RL}).$$

status prior to TWIST--

	SM		PDG	Year
ρ	$3/4$	$=$	0.7518 ± 0.0026	1969
δ	$3/4$	$=$	$0.7486 \pm 0.0026 \pm 0.0028$	1988
ξ	1.0	$=$	1.0027 ± 0.0026	1987
η	0.0	$=$	-0.007 ± 0.013	1985
$P_\mu \frac{\xi\delta}{\rho}$	1.0	$>$	$0.99682, \ \mathrm{CL} = 90\%$	1986

TWIST measured ρ, ξ, δ in two steps --
10^{-3} in 2004; ~2×10^{-4} in 2006/7

Requirements for High precision Michel Parameter measurement

- High (Known) muon polarization

must account for depolarisation in muon transport, injection, stopping

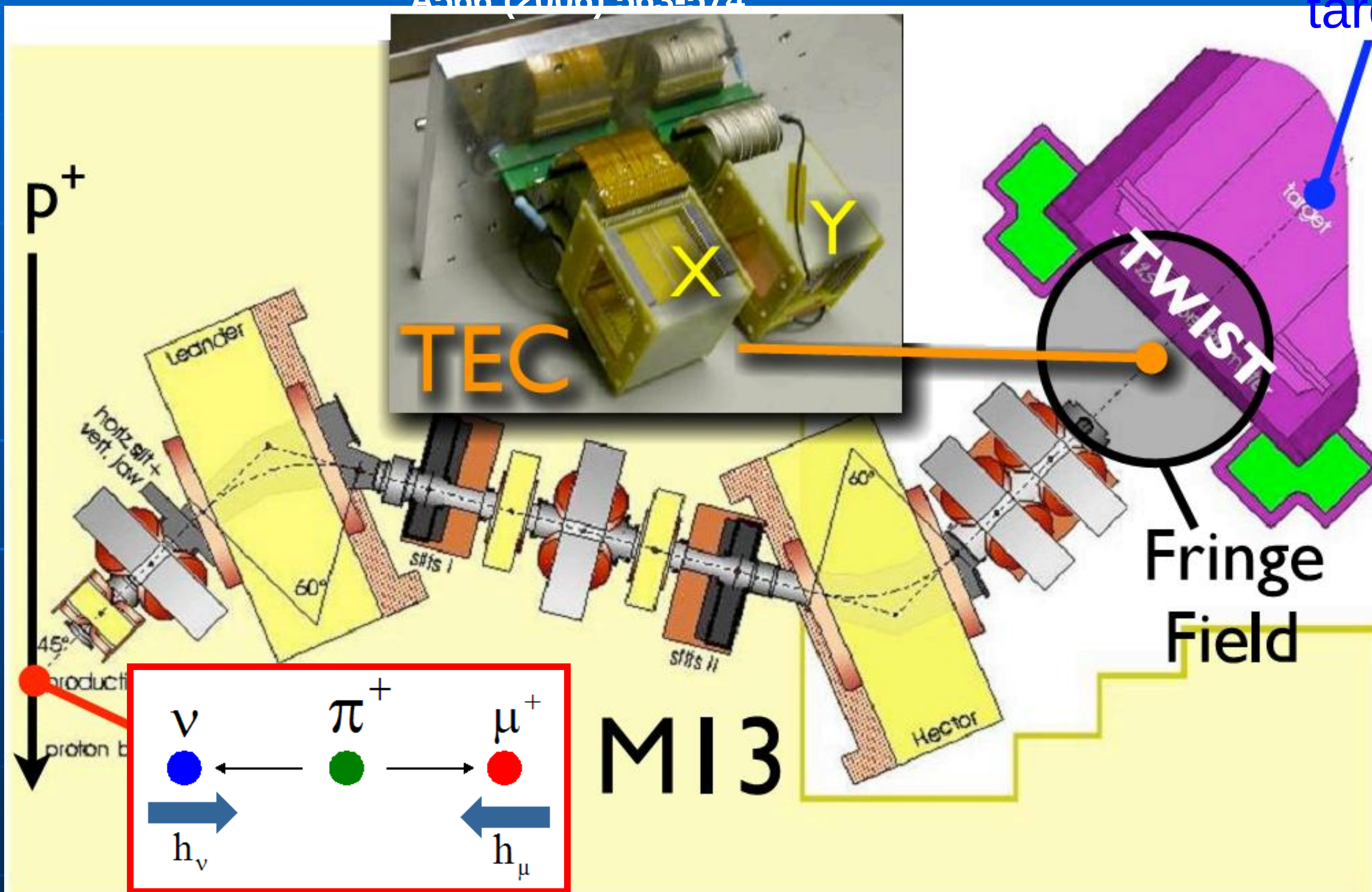
- Excellent energy resolution
- Uniform and known acceptance
- Uniform tracking efficiency
- Repeatability of measurement under varying conditions.

Experimental solutions

- M13 beam ,small dp/p selection.
- High field solenoidal magnet (2T)
- Special injection optics and tracking TEC
- High purity metal targets (Al, Ag)
- Low mass, High precision detector
- Large solid angle and uniform acceptance
- High performance tracking software
- Detailed,as built geant 3 simulation

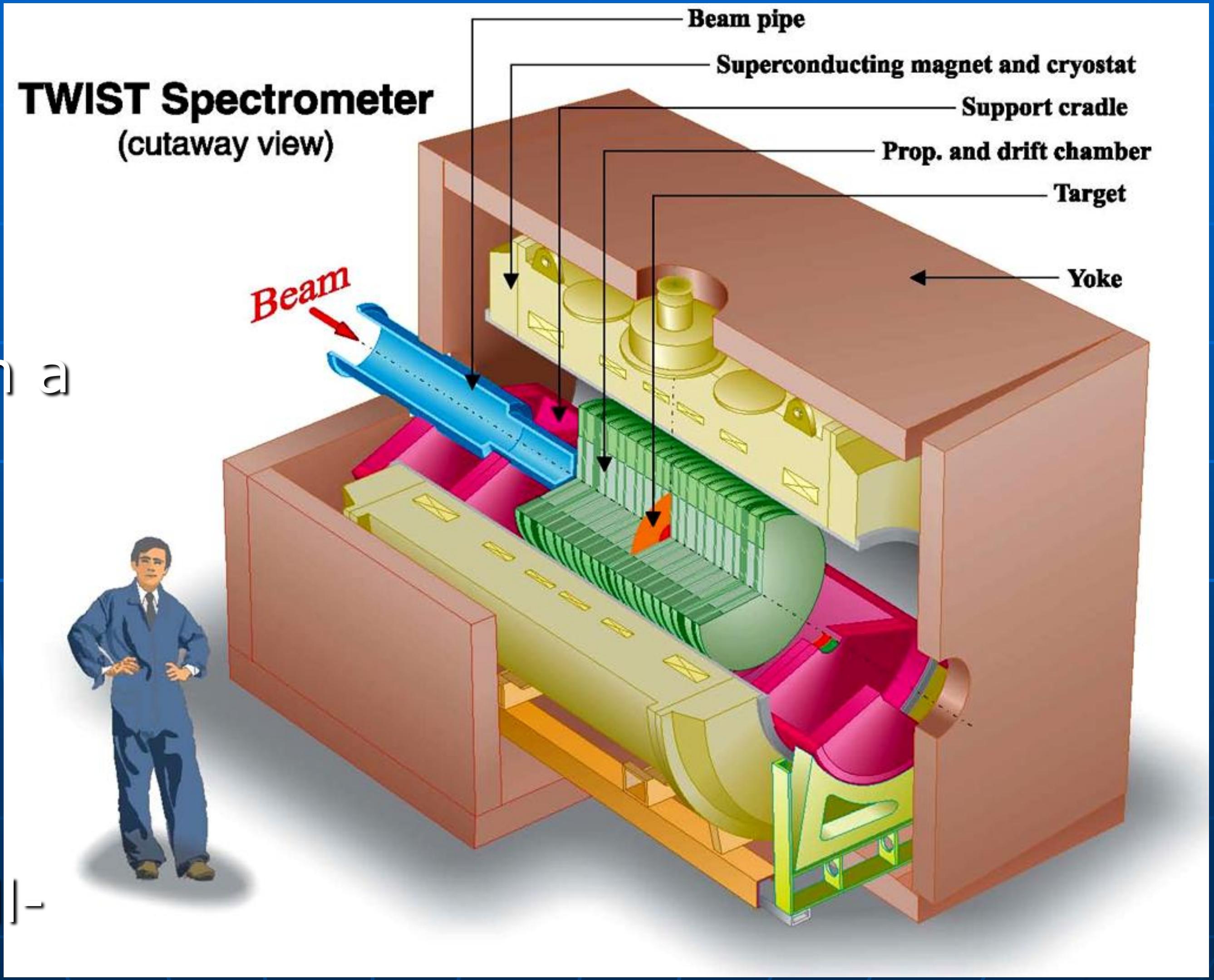
TWIST experiment: muon delivery

Nucl. Instr. and Meth.
A566 (2006) 563-574



The TWIST Spectrometer

- Use highly polarized μ^+ beam.
- Stop them in a very symmetric detector.
- Decay e^+ are tracked through uniform, well-known field.



Analysis Method

- Extract energy and angle distributions for data:
  - apply (unbiased) cuts on muon variables.
  - reject fast decays and backgrounds.
  - calibrate e^+ energy to kinematic end point at 52.8 MeV.
- Fit to identically derived distributions from simulation:
  - GEANT3 geometry contains virtually all detector components.
  - simulate detector response in detail (clusters of ionization).
  - realistic, measured beam profile and divergence.
  - extra muon and beam positron contamination included.
  - output into digitized format, identical to real data.
  - fit to hidden variables with blind analysis method.
  - Validation by special data sets (upstream stops)

Determination of the difference between data and MC data

Geant data are produced with Hidden decay parameters

Twist data are collected

Event Analysis

- Event classification (31 types)
- Helix fit to events within fiducial volume
- Extract e^+ momentum and angle *spectrum* in bins of x and $\cos\theta_e$

Geant data *spectrum*

Fit

Twist data *spectrum*

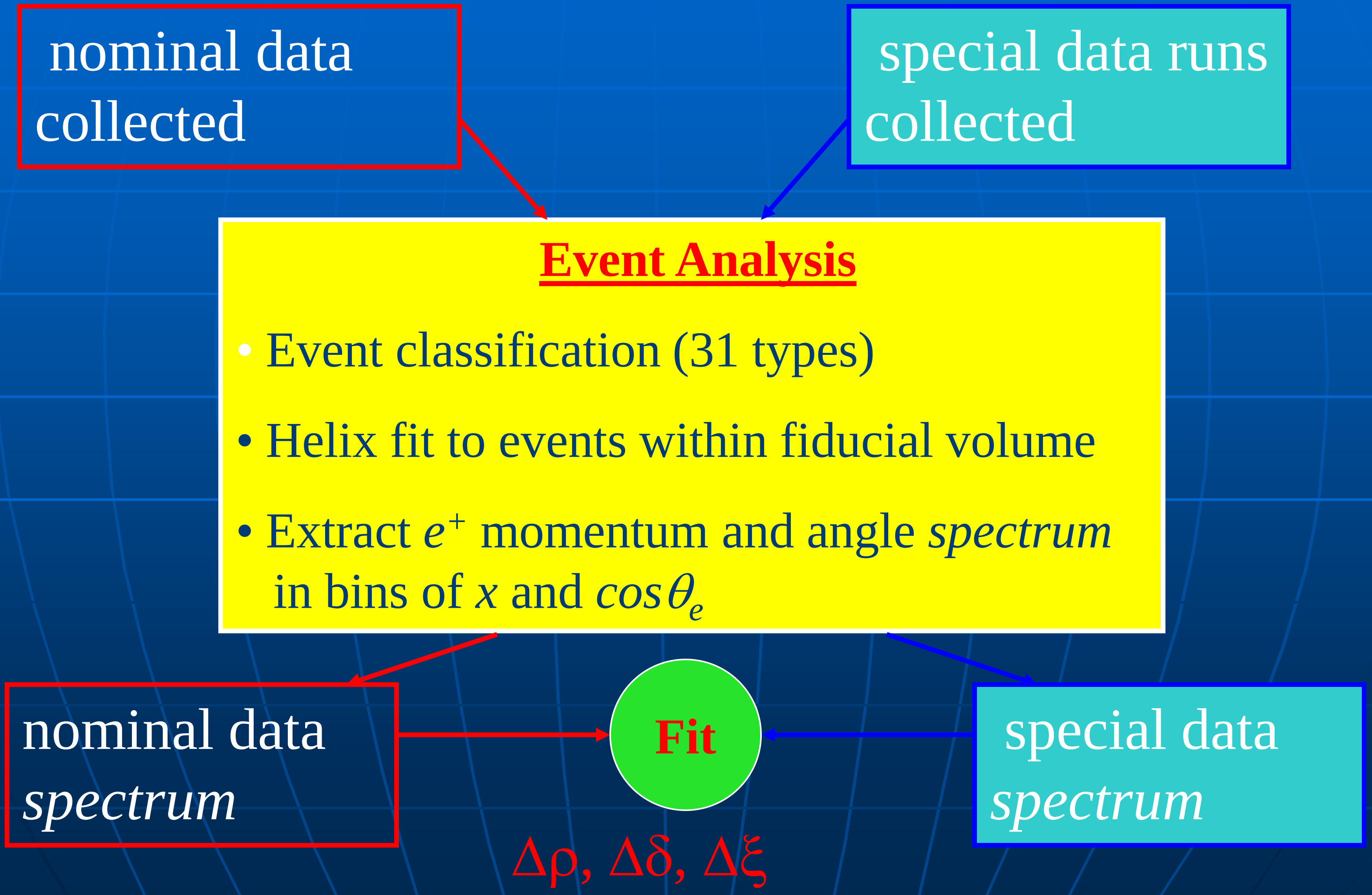
$\Delta\rho$, $\Delta\delta$, $\Delta\xi$

Evaluation of Systematic Uncertainties

- **TWIST** relies on a fit to a Geant 3 simulation:
  - Simulation must be validated.
  - Reconstruction systematics eliminated if simulation is perfect.

- General method:
  - exaggerate a condition (in data or MC) that may cause error.
  - measure effect by fitting, using correlated sets where practical.
  - scale results according to variance in a data set.

Evaluating Systematic Errors



Blind analysis

- The base MC set is generated using unknown, hidden values of decay parameters (α_{MC}).
- All systematic uncertainties as well as offsets $\Delta\alpha$ are confirmed prior to revealing hidden values.
- Open box to reveal hidden values of $\Delta\alpha$.
- Obtain final values of decay parameters.

Fitting the data distributions

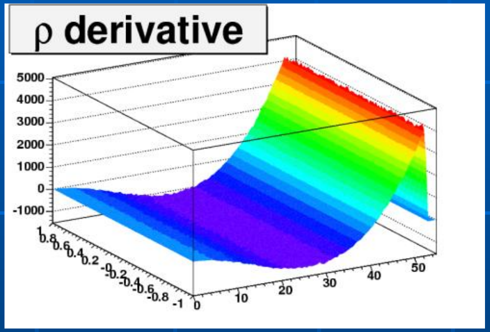
- Michel distribution is linear in ρ, η, ξ, and $\xi\delta$, so a fit to first order expansion is exact.

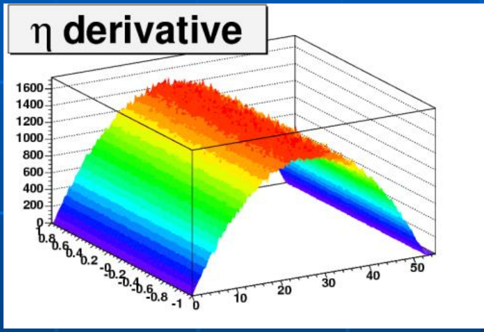
- Fit data (α_{data}) to sum of a base MC distribution (α_{MC}) plus MC-generated derivative distributions times fitting parameters ($\Delta\alpha$) representing deviations from base MC.

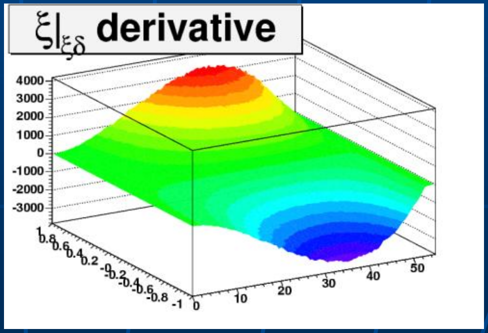
- Can also fit data to data and MC to MC for systematic tests.

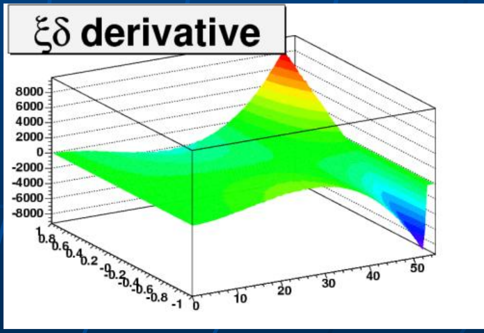
$$n_i(\alpha_{\mathrm{data}}) = n_i(\alpha_{\mathrm{MC}}) + \frac{\partial n_i}{\partial \alpha}\Delta\alpha,$$

$$\alpha = [\rho, \eta, \xi, \xi\delta]$$









TWIST Precision

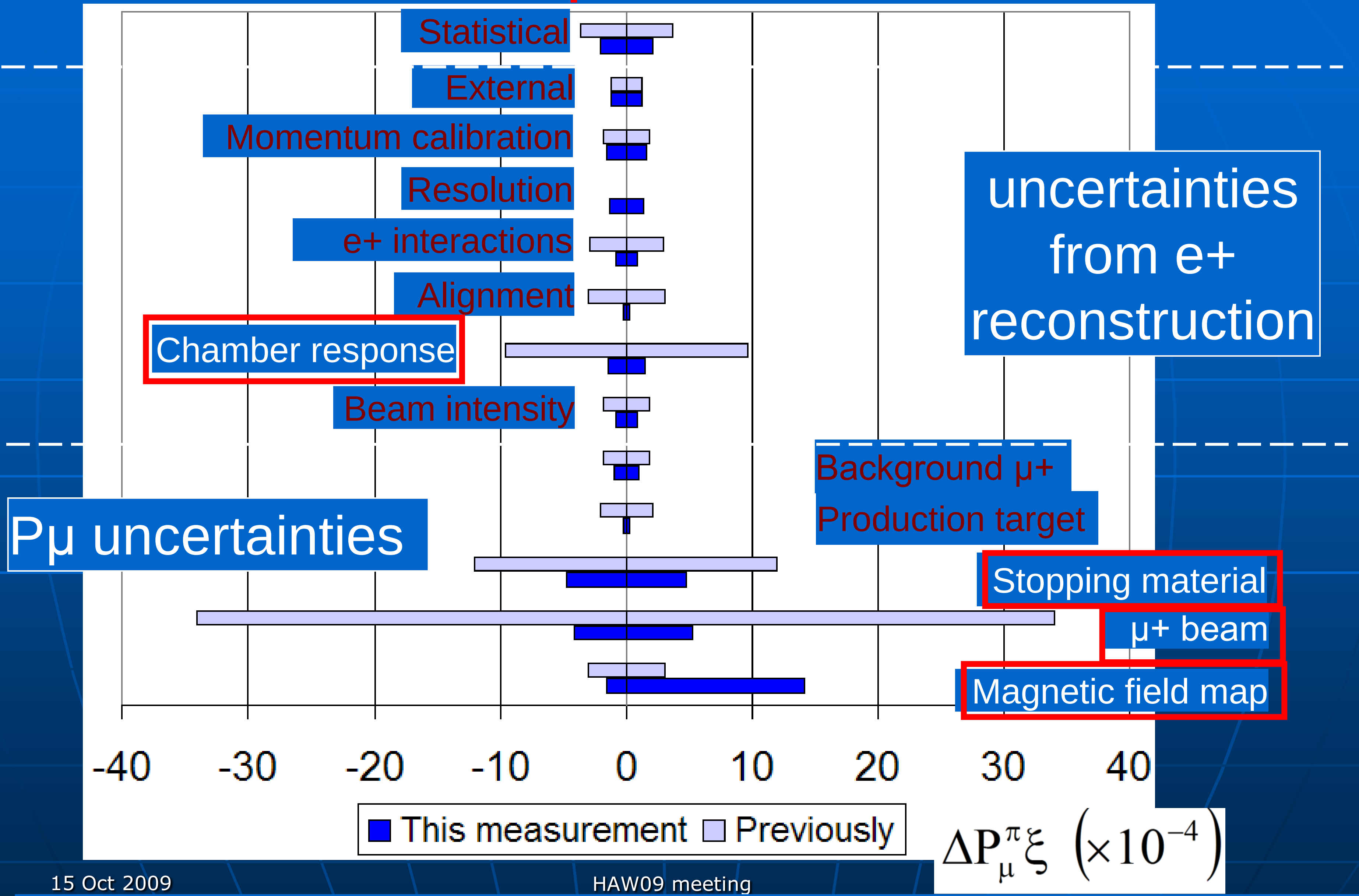
- Final stages of systematics verifications and consistency checks underway
- Hidden parameters of blind analysis should be revealed by end of 2009
- Original goal of order-of-magnitude improvements have been achieved

	Published ($\times 10^4$)		Improvement factor	Final, *estimated* ($\times 10^4$)		Improvement factor
	Statistical	Systematic	vs pre-*TWIST*	Statistical	Systematic	vs pre-*TWIST*
ρ	1.7	4.4	×5	1.0	2.4	×11
δ	3.0	6.7	×5	1.9	2.4	×12
$\mathcal{P}_\mu \xi$	6.0	38	×2	3.5	+15.9 -.6.6	×7

Systematic uncertainties for 2004 data: ρ and δ

Systematic uncertainties	ρ (×10⁴)		δ (×10⁴)	
	2002	2004	2002	2004
Chamber response (ave)	5.1	2.9	6.1	5.2
Stopping target thickness	4.9	<0.1	3.7	<0.1
Positron interactions	4.6	1.6	5.5	0.9
Spectrometer alignment	2.2	0.3	6.1	0.3
Momentum calibration (ave)	2.0	2.9	2.9	4.1
Theoretical radiative correction	2.0	<0.1	1.0	<0.1
Other	1.2	1.1	1.1	0.4
Total in quadrature	9.2	4.6	11.3	6.7

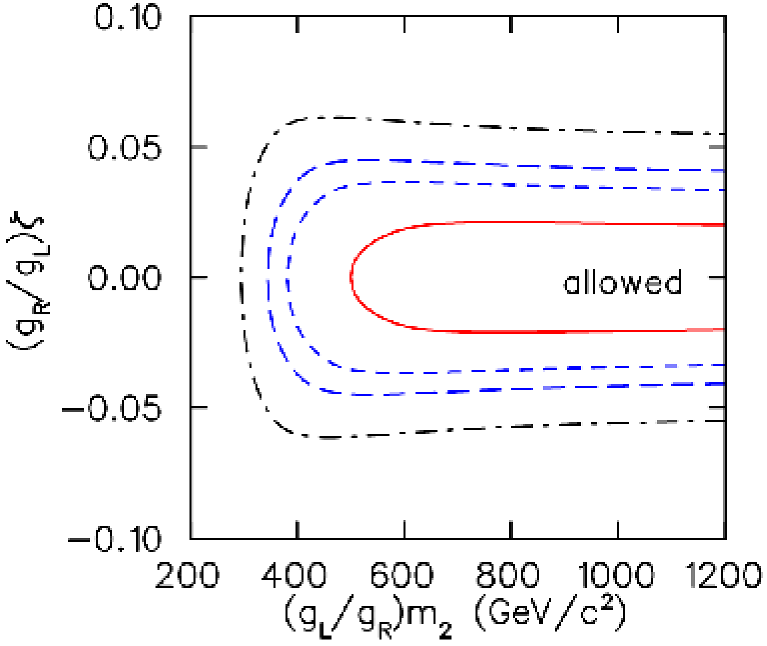
Summary of $P_\mu \xi$ final uncertainties



Opening the BOX

- TBA….. soon

TWIST impact on Left-Right model



New limits on non-manifest (generalised) left-right symmetric models.

This measurement

(for $\mathcal{P}_\mu\xi = 1$)

Recent TWIST ρ, δ

Previous TWIST $\mathcal{P}_\mu\xi$

Pre-TWIST

Conclusions

- TWIST will meet its objectives of an order of magnitude improvements in the precision of the determination of the Michel parameters.
- So far no inconsistencies with the Standard Model
- New constraints on physics beyond the SM are provided

TWIST Participants

TRIUMF

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