Measurement of the muon decay parameters with the TRIUMF Weak Interaction Symmetry Test (TWIST) Experiment

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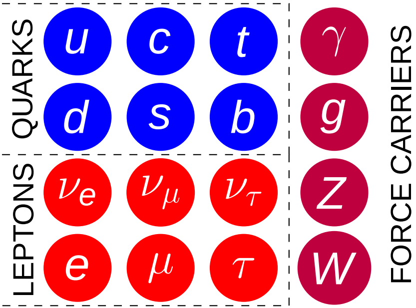
Canada-America-Mexico Graduate Student Physics Conference,9 August 2007

University of Victoria

TRIUMF

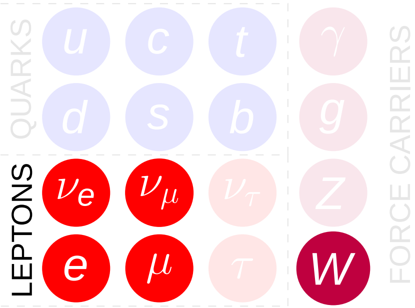


The muon decay is very interesting

- Only weak interaction involved
- Muons are easy to produce
- One decay mode dominant ($\approx$ 100%)

$$\mu^+ \rightarrow e^+ \, \nu_e \, \bar{\nu}_\mu$$

The Physics Motivation



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4-fermion formalism

To study the muon decay we describe it by using a very general formalism.
The interaction is described as a derivative-free, Lorentz-invariant and lepton-number conserving matrix:

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

- $g^T_{RR} \equiv g^T_{LL} \equiv 0$
- A common phase doesn't matter

Standard Model, V-A interaction

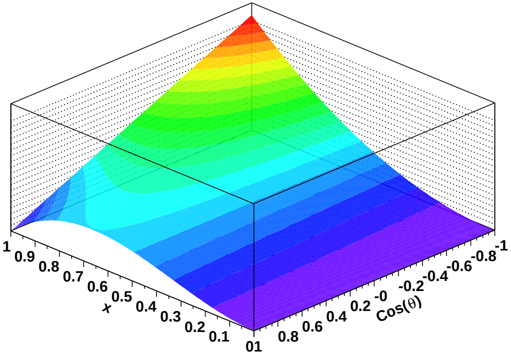
g^V_{LL} is the only non zero coupling

$\Longrightarrow$ 19 real and independent parameters

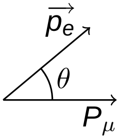
The Michel parametrization

The differential decay rate can be written using the Michel parametrization:

$$\frac{d^2\Gamma}{dx\,d\cos\theta} = \frac{m_\mu}{4\pi^3} W_{e\mu}^4 G_F^2 \sqrt{x^2 - x_0^2}\left(F_{IS}(x) + P_\mu \cos\theta F_{AS}(x)\right) + \mathrm{RC}.$$



$$x = \frac{E_e}{W_{e\mu}}$$



The Michel parametrization

The isotropic and anisotropic parts of the Michel parameters are:

$$F_{IS}(x) = x(1-x) + \frac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x)$$

$$F_{AS}(x) = \frac{1}{3}\xi\sqrt{x^2 - x_0^2}\left[1 - x + \frac{2}{3}\delta\left(4x - 3 + \left(\sqrt{1 - x_0^2} - 1\right)\right)\right]$$

Standard Model predictions

$$\rho = \frac{3}{4}, \qquad \eta = 0, \qquad P_\mu \xi = 1, \qquad \delta = \frac{3}{4}$$

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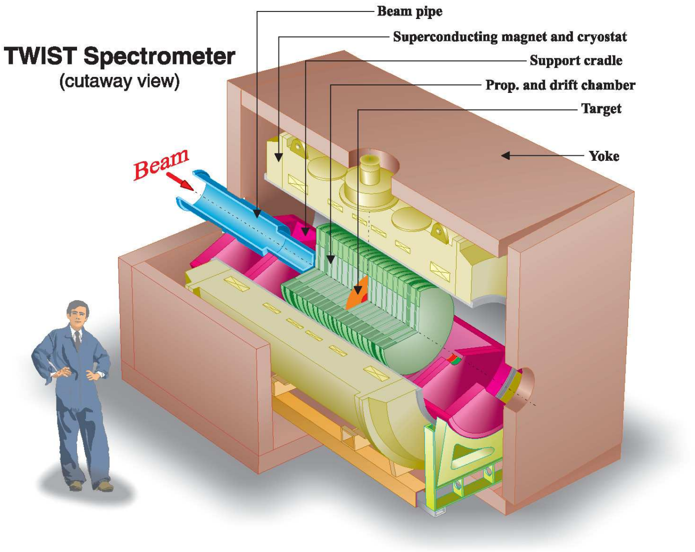
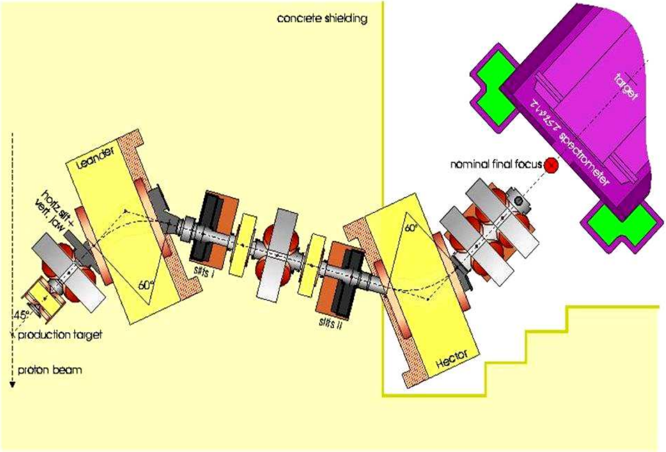
The TWIST spectrometer



The spectrometer in the M13 beamline



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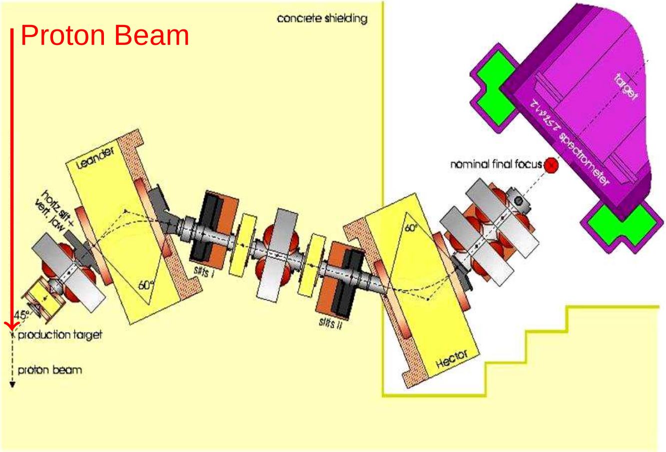

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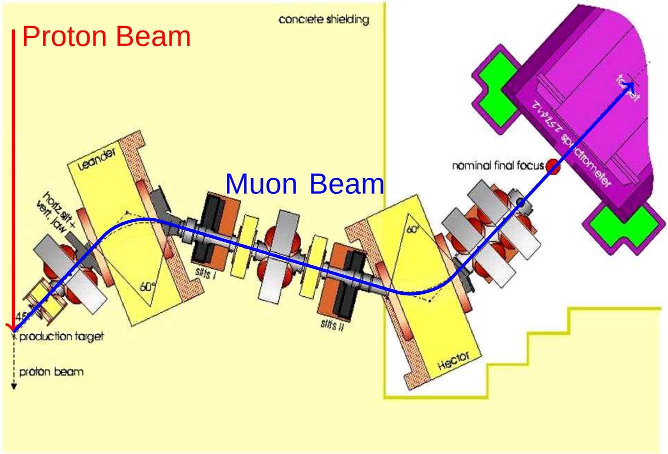

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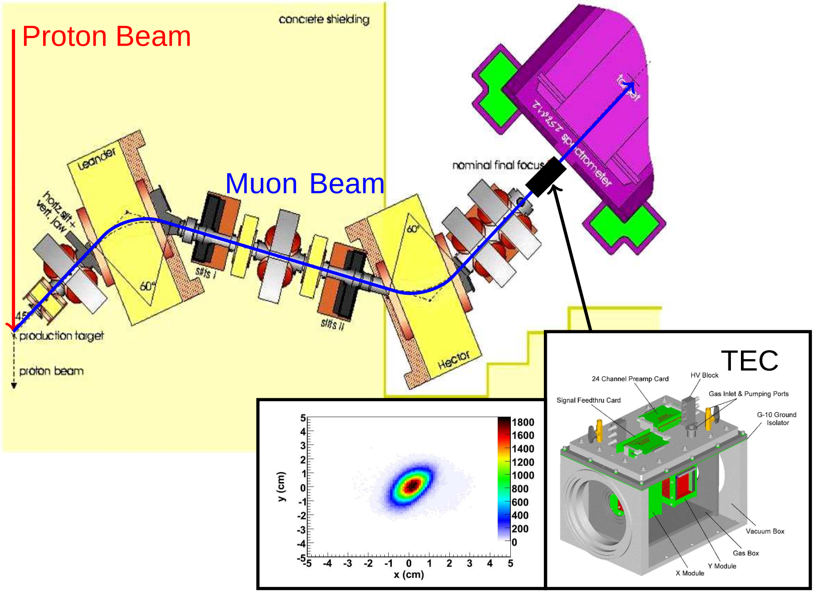
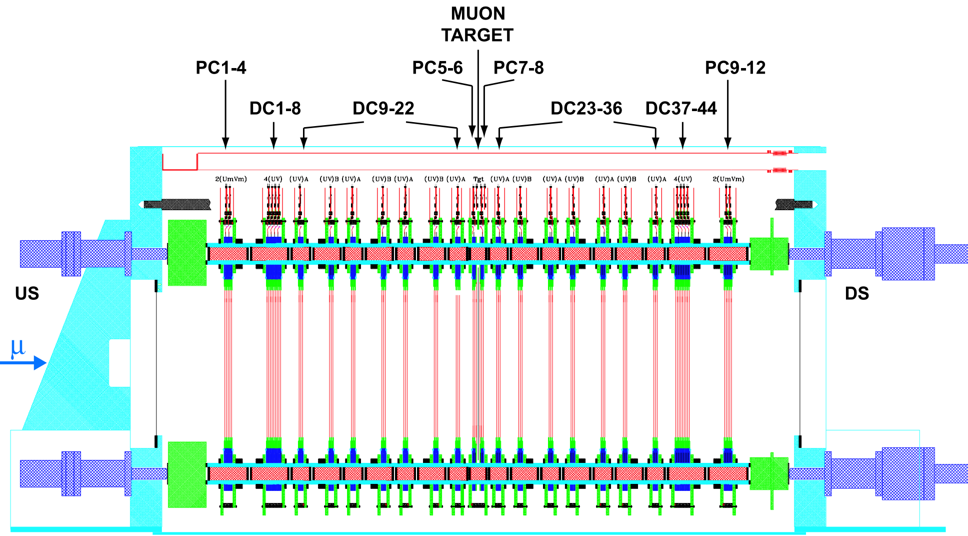


Typical event



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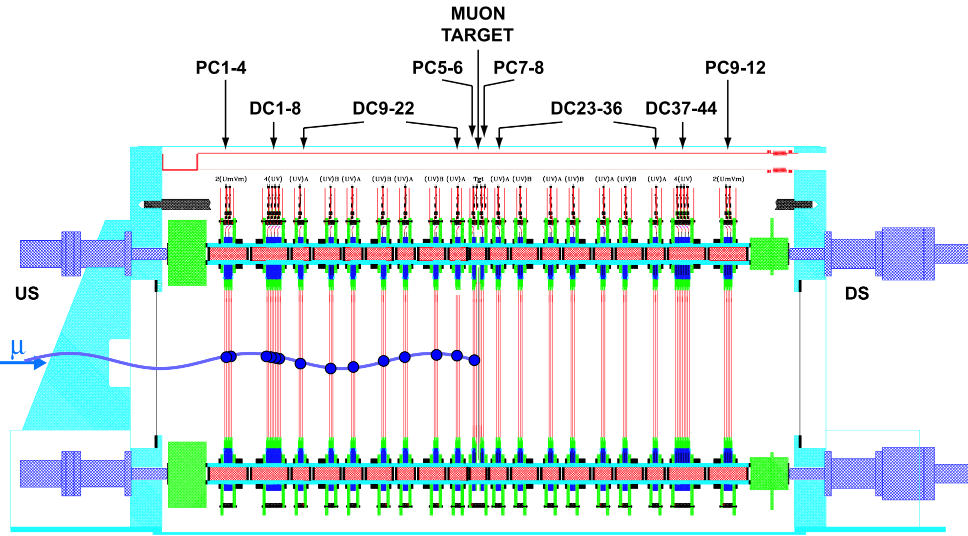
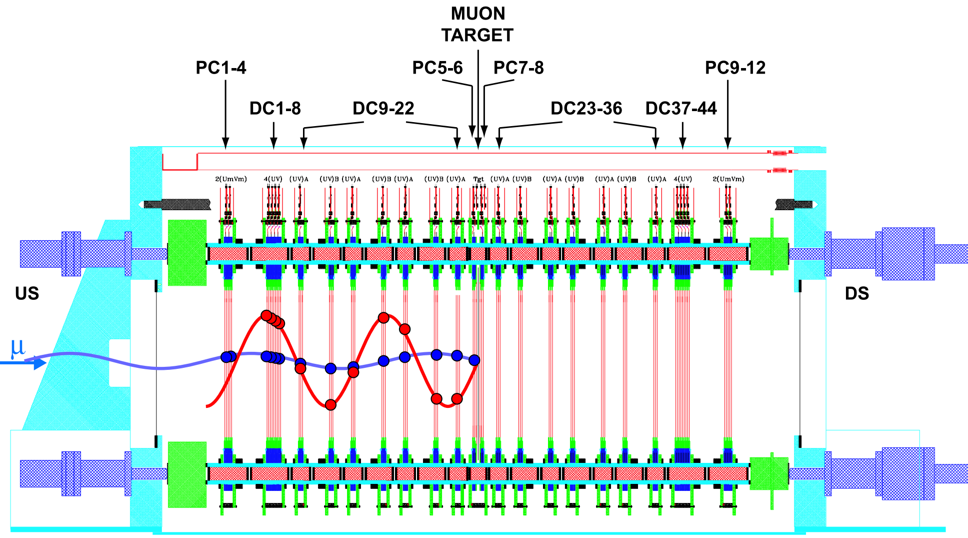
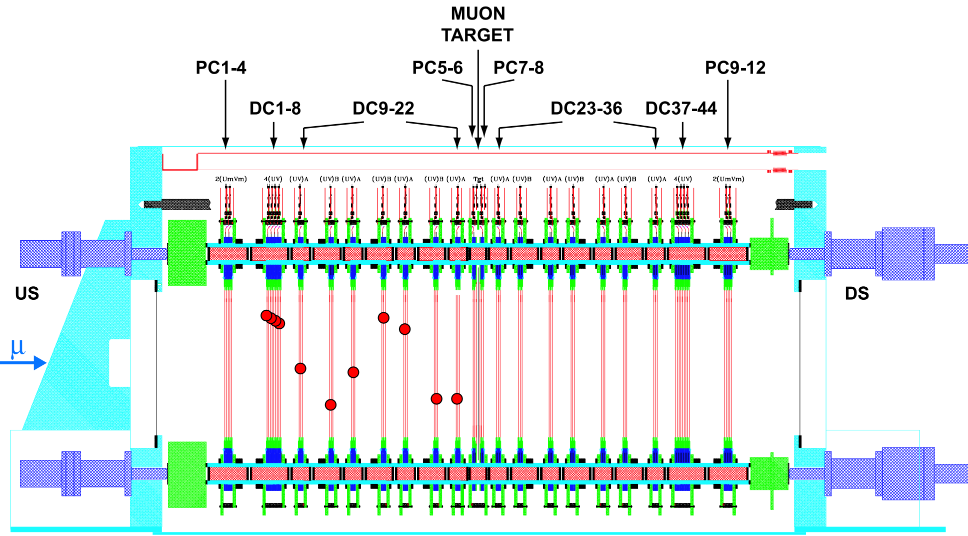


Typical event

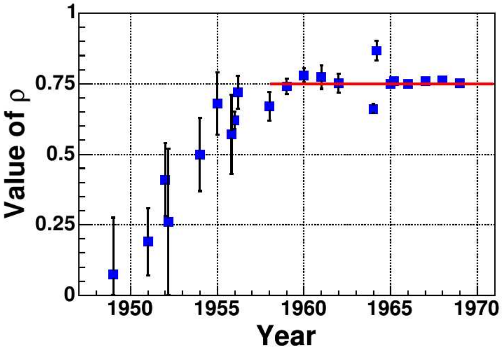


Typical event

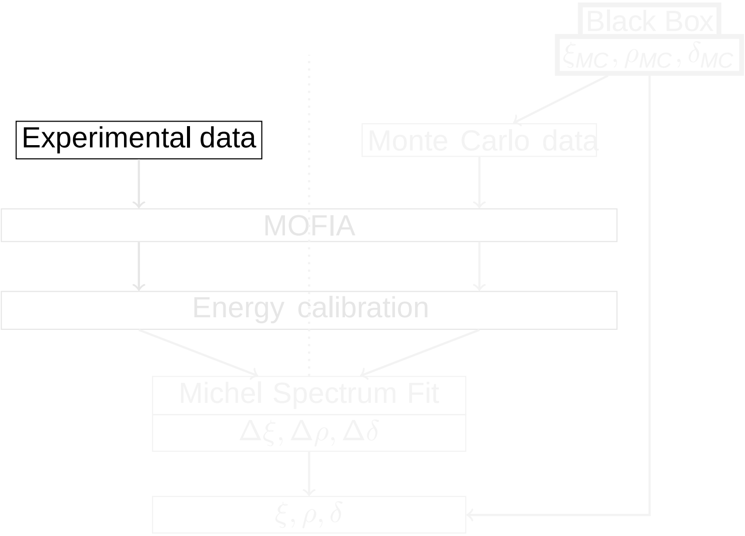


The TWIST analysis is blind to avoid any human bias:

- Choices of data samples
- Looking for errors if disagreement with expectations
- Systematic error evaluation influenced by final result



The software analysis



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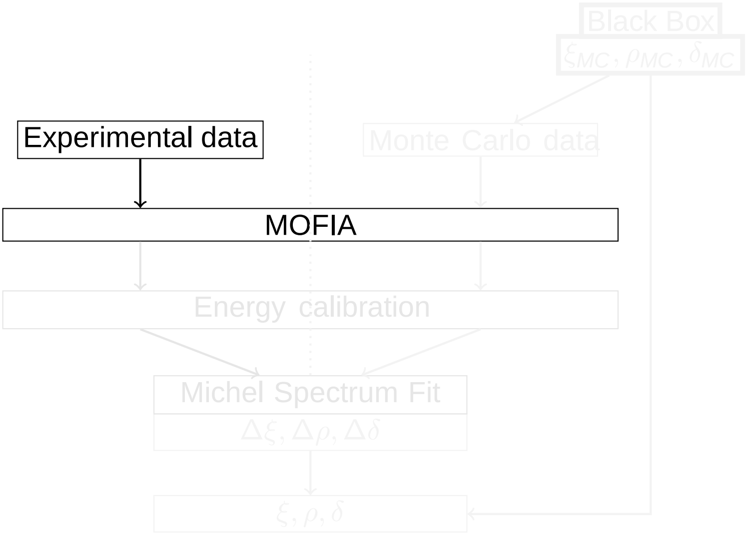

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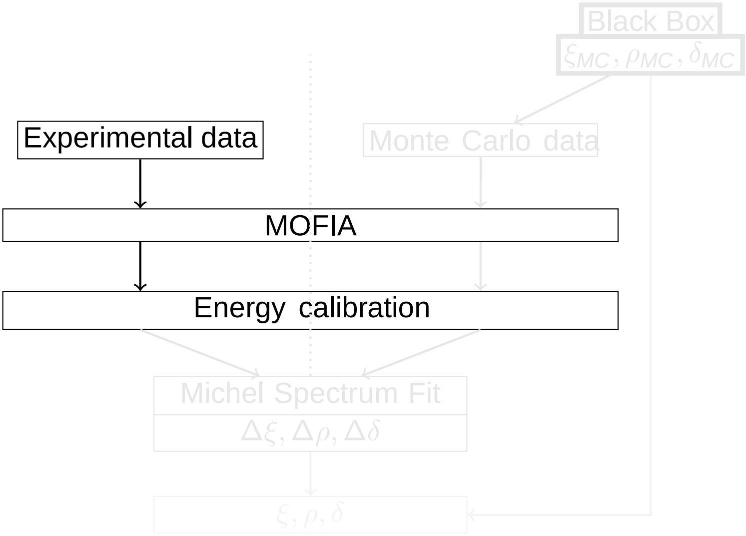
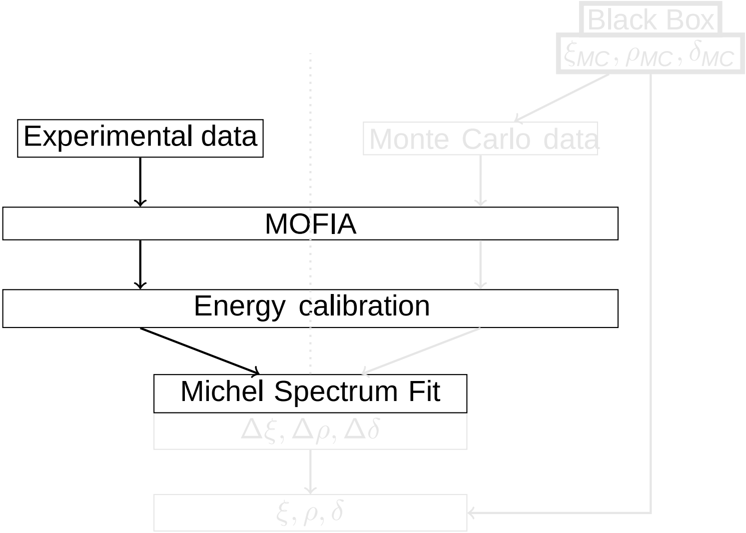
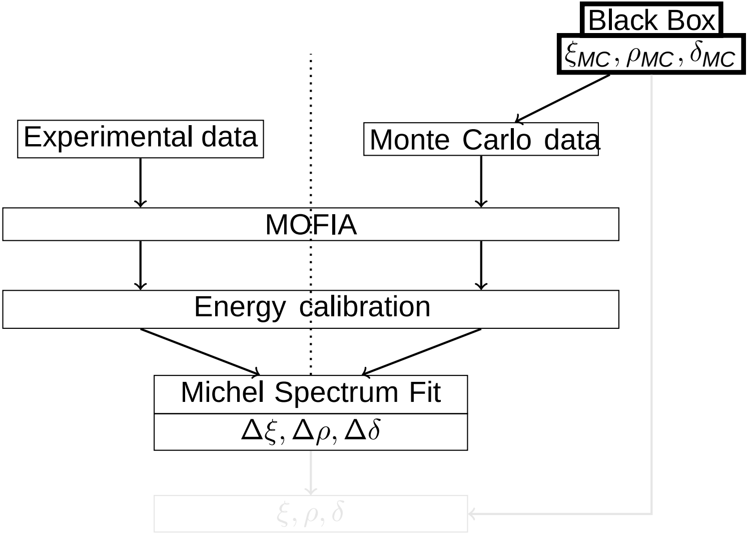



Black Box
$\xi_{MC}, \rho_{MC}, \delta_{MC}$
Experimental data
Monte Carlo data
MOFIA
Energy calibration
Michel Spectrum Fit
$\Delta\xi, \Delta\rho, \Delta\delta$
ξ, ρ, δ

The software analysis



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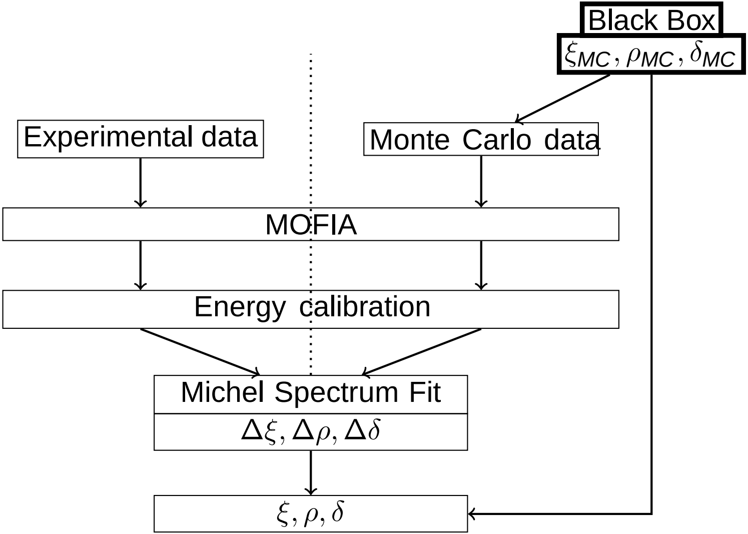
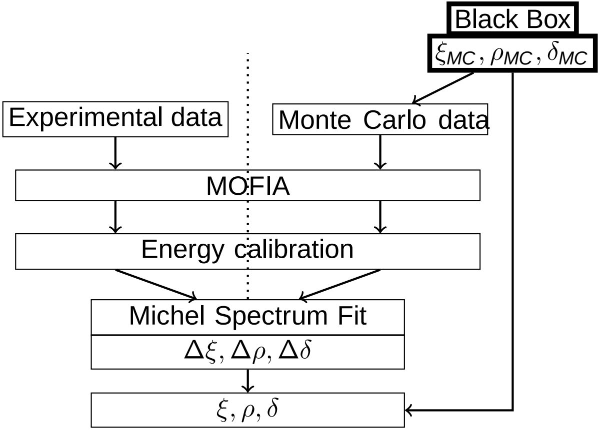


The software analysis



- Detector response included in MC
- Reconstruction biases reduced because $\Delta\xi, \Delta\rho, \Delta\delta$ are small
- Most systematics are from the difference between the MC simulation and the reality

The TWIST Results

Published results

$$\rho = 0.75080 \pm 0.00044\ \text{(stat)} \pm 0.00093\ \text{(sys)} \pm 0.00023\ (\eta)$$

$$\delta = 0.74964 \pm 0.00066\ \text{(stat)} \pm 0.00112\ \text{(sys)}$$

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

- 2002 data $\Longrightarrow \rho$ and δ
- Improvements:
  - TEC construction and installation
  - DC chambers rearranged
- 2004 data $\Longrightarrow P_\mu$

The Final Measurement Goal

Data taken in 2006 and 2007 for the last measurement of the three parameters.
Final results publication planned for 2009

Table of the uncertainties $\times 10^{-4}$

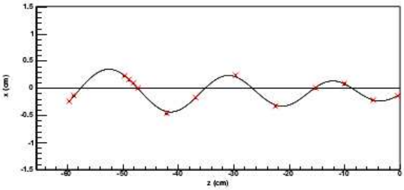
	Published		Final Goal	
	Statistics	Systematics	Statistics	Systematics
ρ	4.4	9.3	1.3	2.4
δ	6.6	11.2	2.3	2.2
$P_\mu \xi$	6.0	38	2.8	7.5

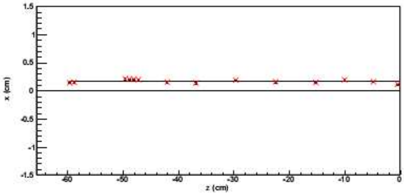
Improvements: Muon Beam Monitoring

- The individual muon tracks cannot be reconstructed
- The muon beam spots at each plane are used instead

Improvements

- Muon beam stability monitored
- Reduced $p_T \rightarrow$ lower depolarisation

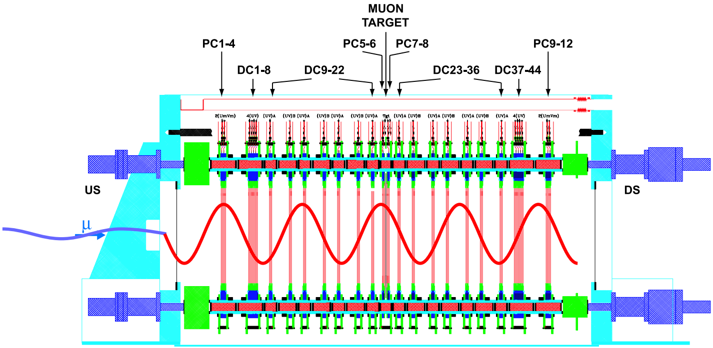




Improvements: Better upstream stops data

The upstream stops data gives us informations on the physics and the response of the detector

- Test of the detector asymmetry
- Measure of the positron interaction with the target
- ...



The TWIST Collaboration

TRIUMF

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Mike Hasinoff
Blair Jamieson◇

Texas A&M

Carl Gagliardi
Jim Musser◇
Bob Tribble

Kurchatov Institute

Vladimir Selivanov

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† Graduate student

EXTRA SLIDES

Model-Independent search for right-handed interactions

$$Q_{RR} = \frac{1}{4}|g^S_{RR}|^2 + |g^V_{RR}|^2$$
$$Q_{LR} = \frac{1}{4}|g^S_{LR}|^2 + |g^V_{LR}|^2 + 3|g^T_{LR}|^2$$

- Right-handed interaction contribution in the muon decay :

$$Q^\mu_R = Q_{RR} + Q_{LR}$$

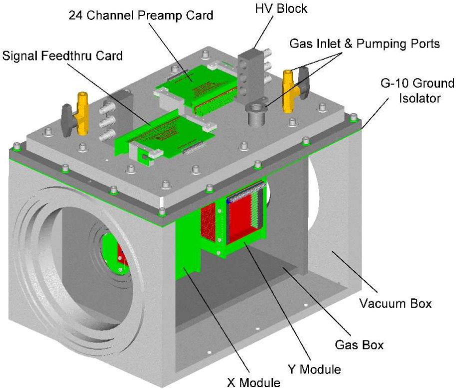
- Also defined as :

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

Standard Model, V-A interaction

$$Q^\mu_R = 0$$

The Time Expansion Chamber (TEC)

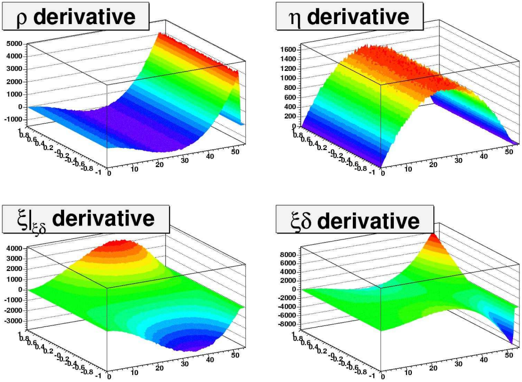


The TEC:

- is low mass
- operates in the beamline vaccum
- is removed during data taking

Michel Parameters Derivatives

$$\underbrace{\frac{d^2\Gamma}{dx\,d(\cos\theta)}\bigg|_{\rho_{MC},\delta_{MC},\xi_{MC}}}_{\text{MC spectrum}} + \underbrace{\sum_{\alpha=\rho,\xi,\xi\delta} \frac{\partial}{\partial\alpha}\left[\frac{d^2\Gamma}{dx\,d(\cos\theta)}\right]\Delta\alpha}_{\text{Derivatives fitted}}$$



Systematics in the previous measurement

TABLE II. Contributions to the systematic uncertainty in ρ. Average values are given for those denoted (av), which are considered set dependent when performing the weighted average of the data sets.

Effect	Uncertainty
Chamber response (av)	$\pm 0.000\,51$
Stopping target thickness	$\pm 0.000\,49$
Positron interactions	$\pm 0.000\,46$
Spectrometer alignment	$\pm 0.000\,22$
Momentum calibration (av)	$\pm 0.000\,20$
Theoretical radiative corrections [12]	$\pm 0.000\,20$
Track selection algorithm	$\pm 0.000\,11$
Muon beam stability (av)	$\pm 0.000\,04$
Total in quadrature	$\pm 0.000\,93$
Scaled total	$\pm 0.000\,97$

TABLE II. Contributions to the systematic uncertainty for δ. Average values are denoted by (ave), which are considered set-dependent when performing the weighted average of data sets.

Effect	Uncertainty
Spectrometer alignment	$\pm 0.00\,061$
Chamber response(ave)	$\pm 0.00\,056$
Positron interactions	$\pm 0.00\,055$
Stopping target thickness	$\pm 0.00\,037$
Momentum calibration(ave)	$\pm 0.00\,029$
Muon beam stability(ave)	$\pm 0.00\,010$
Theoretical radiative corrections[9]	$\pm 0.00\,010$
Upstream/downstream efficiencies	$\pm 0.00\,004$

TABLE III. Contributions to the systematic uncertainty for $P_\mu^\pi \xi$.

Effect	Uncertainty
Depolarization in fringe field (ave)	0.0034
Depolarization in stopping material (ave)	0.0012
Chamber response (ave)	0.0010
Spectrometer alignment	0.0003
Positron interactions (ave)	0.0003
Depolarization in production target	0.0002
Momentum calibration	0.0002
Upstream-downstream efficiency	0.0002
Background muon contamination (ave)	0.0002
Beam intensity (ave)	0.0002
Michel parameter η	0.0001
Theoretical radiative corrections	0.0001