Muon Decay Parameters From TWIST

Art Olin, TRIUMF/UVic for the TWIST Collaboration

Outline
- Muon decay physics
- TWIST Experiment
- Systematics
- Results
The energy and angle distributions of positrons following polarized muon decay obey:

\[
\frac{d^2 \Gamma}{x^2 dx d(\cos \theta)} \propto (3 - 3x) + \frac{2}{3} \rho(4x - 3) + 3\eta \frac{x^0}{x}(1 - x) + P_{\mu} \xi \cos \theta \left[ (1 - x) + \frac{2}{3} \delta(4x - 3) \right]
\]

where \( x = \frac{E_e}{E_{e,\text{max}}} \)

- Lorentz invariant, local weak interaction.
- SM postulates maximally parity violating V-A: \( \rho = \delta = 3/4; \xi = 1; \eta = 0. \)
- Mediated by W boson.
- Empirically based – tested in present work.
Muon decay matrix element

- Most general Lorentz-invariant, local, lepton-number conserving muon decay matrix element:

\[
M = \frac{4G_F}{\sqrt{2}} \sum_{\gamma=S,V,T} g_{\epsilon\mu}^{\gamma} \langle \overline{e}_\epsilon \mid \Gamma_\gamma \mid (\nu_e)_n \rangle \langle (\nu_\mu)_m \mid \Gamma_\gamma \mid \mu_\mu \rangle
\]

- The muon decay parameters are bi-linear combinations of the \( g_{\epsilon\mu}^{\gamma} \).
- In the Standard Model, \( g_{ll}^{V} = 1 \), all others are zero.
- Pre-TWIST global fit results (all 90% c.l.):

| \( |g_{RR}^{S}| \) | \( |g_{RR}^{V}| \) | \( |g_{RR}^{T}| \) |
|---|---|---|
| < 0.066 | < 0.033 | \( \equiv 0 \) |
| \( |g_{LR}^{S}| \) | \( |g_{LR}^{V}| \) | \( |g_{LR}^{T}| \) |
| < 0.125 | < 0.060 | < 0.036 |
| \( |g_{RL}^{S}| \) | \( |g_{RL}^{V}| \) | \( |g_{RL}^{T}| \) |
| < 0.424 | < 0.110 | < 0.122 |
| \( |g_{LL}^{S}| \) | \( |g_{LL}^{V}| \) | \( |g_{LL}^{T}| \) |
| < 0.550 | > 0.960 | \( \equiv 0 \) |
Goal of TWIST

- Search for new physics that can be revealed by order-of-magnitude improvements in our knowledge of $\rho$, $\delta$, and $P_\mu \xi$

Two examples

- Model-independent limit on muon handedness

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

- Left-right symmetric model: $SU(2)_L \times SU(2)_R \times U(1)$

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

$$\frac{3}{4} - \rho = \frac{3}{2} \xi^2$$
$$1 - P_\mu \xi = 4 \left( \xi^2 + \xi \left( \frac{M_1}{M_2} \right)^2 + \left( \frac{M_1}{M_2} \right)^4 \right)$$
The **TWIST** Experiment

**TRIUMF Weak Interaction Symmetry Test**
Muon production and transport

500 MeV proton beam

Muons and pions produced in the target are transported through the TECs (Telescopes) and into the fringe field region where they decay.
Positron tracking

Variable density gas degrader

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Muon Decay Spectrum Acceptance
Spectrum Fit Procedure

- Decay spectrum linear in $\rho, P_\mu \xi, P_\mu \xi \delta$.
- Derivative spectra are simulated.
- Offset added to parameters to blind them.
- Consistency is tested and systematics determined before unblinding.
- Spectrum edge is fit in angle slices to the simulation. A momentum-calibrated spectrum is regenerated and fit.

$$N(\text{Data}) = N(\text{MC}) + \frac{\partial N}{\partial \rho} \Delta \rho$$

$$+ \frac{\partial N}{\partial P_\mu \xi \delta} \Delta P_\mu \xi \delta + \frac{\partial N}{\partial P_\mu \xi} \Delta P_\mu \xi$$
Spectrum fit quality

- All data sets: $11 \times 10^9$ events, $0.55 \times 10^9$ in $(p, \cos \mu)$ fiducial
- Simulation sets: 2.7 times data statistics

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Fringe field, solenoid entrance

Position

Angle

2 m

Art Olin: PANIC2011 TRIUMF Weak Interaction Symmetry Test
Fringe field, solenoid entrance

Position

Angle

$P^\mu$

$z$ (cm)

$y$ (cm)

$x$ (cm)

$\theta_y$ (rad)

$y$ (cm)

$-0.10$ $-0.05$ $0.00$ $0.05$ $0.10$

$2$ m

YOKE
Measured average muon positions

The average muon beam trajectory inside the detector is sensitive to the muon transverse momentum:
- Identify changes in muon beam properties between TEC measurements.

Comparisons between nominal and mis-steered beams:
- Observed muon beam trajectories within the detector.
- Difference in the decay asymmetry in data vs that predicted by the simulation.

Resulting uncertainties are asymmetric.
- Direct determination of the effective distance vs time relation.
- Accounts for small plane-to-plane fabrication differences.
- Improved momentum resolution (near the endpoint)
  - Was ~ 69 keV/sin(θ) in simulation and ~ 74 keV/sin(θ) in data.
  - Now ~ 58 keV/sin(θ) in both.

Bremsstrahlung

- Leading systematic for $\rho$ and $\delta$.
- Separately determined from upstream stops and broken decay tracks.
- Larger in Ag target.
- Both consistent with GEANT3 simulation at 2.5% level.

*Art Olin: PANIC2011 TRIUMF Weak Interaction Symmetry Test*
Consistency of data sets

14 data sets for $\rho$ and $\delta$, $\chi^2$ of 14.0 and 17.7 respectively
9 data sets used for $P_\mu \xi$, $\chi^2 = 9.7$
statistical uncertainties only, after corrections

Key:
68 – $z_{\text{stop}}$ shifted
70 – $B = 1.96$ T
71 – $B = 2.04$ T
72 – TEC in
74 – Nominal
75 – Nominal
76 – Mis-steered
83 – External material
84 – Nominal
86 – Mis-steered
87 – Nominal
91 – Low momentum
92 – Low momentum
93 – Low momentum
Decay parameter results

\[ \rho = 0.74977 \pm 0.00012 \text{ (stat)} \pm 0.00023 \text{ (syst)} \]
(<1σ from SM, -1.4x10^{-4} from blind)

\[ \delta = 0.75049 \pm 0.00021 \text{ (stat)} \pm 0.00027 \text{ (syst)} \]
(+1.4σ from SM, -2.3x10^{-4} from blind)

\[ P_{\pi\mu\xi} = 1.00084 \pm 0.00029 \text{ (stat)} \]
(+1.2σ from SM, same as blind)

\[ P_{\mu\xi}^{\pi\delta/\rho} > 0.99909 \text{ (90%CL)} \]
from global analysis

J. Bueno et al., Phys. Rev. D (August)
Decay parameter results

\[ \rho = 0.74977 \pm 0.00012 \text{ (stat)} \pm 0.00023 \text{ (syst)} \]

\[ \delta = 0.75049 \pm 0.00021 \text{ (stat)} \pm 0.00027 \text{ (syst)} \]

\[ \rho^\pi_\mu \xi = 1.00084 \pm 0.00029 \text{ (stat)} \pm 0.00165 \text{ (syst)} \]

\[ P^\pi_\mu \xi \delta/\rho > 0.99909 \text{ (90\% CL)} \]

+0.00165

-0.00063

\[ +1.2\sigma \text{ from SM, same as blind} \]

\[ -2.3 \times 10^{-4} \text{ from blind} \]

Implies a negative decay rate!
Triggered a full analysis review.
Identified sensitivity to stop position, target-dependent systematics.
Final results are slightly modified.

Final results are slightly modified.

Art Olin: PANIC2011 TRIUMF Weak Interaction Symmetry Test
Implications for the Weak Couplings

- The final TWIST results have been included in a new muon decay global analysis together with all previous muon decay parameter measurements.
- Find significantly tighter 90% c.l. upper limits on the coupling of right-handed muons to right- or left-handed electrons:
  - $|g_{RR}^S| < 0.031$  
  - $|g_{RR}^V| < 0.015$  
  - $|g_{LR}^S| < 0.041$  
  - $|g_{LR}^V| < 0.018$  
  - $|g_{LR}^T| < 0.012$

- New limit on right-handed muon couplings: $Q_{\mu}^R < 5.8 \times 10^{-4}$ (90% c.l.)
  - Factor of ~2 smaller than pre-TWIST values
  - Factor of ~3 smaller than pre-TWIST values

- Uncertainty for $\eta$ reduced by 1/3 compared to 2005 global analysis
  - $\eta = -0.0033 \pm 0.0046$
    - Important for the determination of $G_F$
Left-Right Symmetric limit comparison

- **“manifest” LRS, 90%CL**
  - TWIST 2011

- **generalized or non-manifest LRS, 90%CL**
  - TWIST 2011

Other $W'$ direct search mass limits:
- ATLAS: $>1.49$ TeV/$c^2$, 95%CL (LLWI11)
- CMS: $>1.58$ TeV/$c^2$, 95%CL (LLWI11)
- CMS: $>1.36$ TeV/$c^2$, 95%CL (2011)
- CDF: $>1.12$ TeV/$c^2$, 95%CL (2011)
- D0: $>1.0$ TeV/$c^2$, 95%CL (2008)

Other limits on mixing angle $\zeta$:
- Hardy and Towner: $<0.0005$ (MLRS), $<0.04$ (generalized)
- K decay: $<0.004$ (MLRS)
Inclusive Limits on $\mu \rightarrow e X^0$

- Limits when $X^0$ is undetectable.
- First search for two-body decays with possible asymmetries.
- Order of magnitude improvement for massive isotropic decays.
- Peak structures at the endpoint are produced by small momentum scale mismatches, so this sets the systematic limit.
- Jodidio more sensitive to isotropic signal but completely insensitive to asymmetric decay.
- Limits on 3-body $X^0$ decays are obtained from decay parameter values.

<table>
<thead>
<tr>
<th>Decay Anisotropy</th>
<th>Massless $B$ 90% CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A = -1$</td>
<td>$52 \times 10^{-6}$</td>
</tr>
<tr>
<td>$A = 0$</td>
<td>$20 \times 10^{-6}$</td>
</tr>
<tr>
<td>$A = +1$</td>
<td>$10 \times 10^{-6}$</td>
</tr>
<tr>
<td>Jodidio $A=0$</td>
<td>$2.6 \times 10^{-6}$</td>
</tr>
</tbody>
</table>
Muon decay spectrum shape places limits on heavy neutrino mass and mixing in a mass region inaccessible with $\pi$ or $K$ decays.


**Summary and Outlook**

- **TWIST** has significantly improved the measurements of $\rho$, $\delta$, and $P_{\mu}^{\pi} \xi$. These results are in agreement with the Standard Model.
- The value of $P_{\mu}^{\pi} \xi \delta / \rho > 1$ disagrees even with the general weak interaction. We have reexamined all of our key assumptions and repeated the analysis, leading only to small changes.
- Constraints on the weak couplings and LRS models are significantly improved.
- New inclusive bounds on $\mu \rightarrow e X^0$.
- $\mu \cdot \text{Al}$ decay spectrum — not presented.
TWIST Collaboration

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**Graduated student**
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Supported by NSERC, DOE, RMF, Westgrid
Extras
Early $\mu$ Decay Measurements

The Absorption of Charged Particles from the 2.2-$\mu$sec. Meson Decay

E. P. Hincks and B. Pontecorvo
National Research Council of Canada, Chalk River Laboratory,
Chalk River, Ontario, Canada
July 26, 1948

T

HE energy spectrum of the charged particles (commonly assumed to be electrons) emitted in the 2.2-$\mu$sec. meson decay is still unknown. Conversi and Piccioni in 1944 deduced from the relative numbers of decay electrons escaping from iron plates 0.6 cm and 5 cm thick that less than 0.03 count per hour can be due to radiation from 25-Mev electrons in our arrangement. Consequently, it may be seen from Table I that at least a substantial fraction of the electrons must have a range greater than 15 g/cm$^2$ of carbon. Therefore, we conclude that there are decay electrons having energies greater than 25 Mev and therefore that the 2-particle decay process (Eq. (1)), with a unique energy of about 25 Mev for the decay electron, is incompatible with our results.

We observe, however, that a maximum energy of about 50 Mev for the decay electrons would be consistent with the data of Table I.

On the Range of the Electrons in Meson Decay

J. Steinberger*
The Institute for Nuclear Study, University of Chicago, Chicago, Illinois
(Received January 10, 1949)

An experiment has been carried out both at Chicago and on Mt. Evans, Colorado, to determine the absorption of the electrons emitted in the decay of cosmic-ray mesons. Approximately 8000 counts have been obtained, using a hydrocarbon as the absorbing material. These data are used to deduce some features of the energy spectrum of the decay electrons. The resolution of the apparatus is calculated, taking the geometry, scattering, and radiation into account. The results indicate that the spectrum is either continuous, from 0 to about 55 Mev with an average energy ~32 Mev or consists of three or more discrete energies. No variation of the lifetime with the thickness of the absorber is observed. The experiment, therefore, offers some evidence in favor of the hypothesis that the $\mu$-meson disintegrates into 3 light particles.

Fig. 9. The decay electron spectrum in this figure has been calculated to give as good a fit as possible with the data, at the same time excluding energies greater than 55 Mev. The limits of error of this spectrum are unknown, but large.
Uncertainties in $\rho$ and $\delta$

<table>
<thead>
<tr>
<th>COMMON</th>
<th>Uncertainty in $\rho$ ($\times 10^{-4}$)</th>
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</thead>
<tbody>
<tr>
<td>Momentum calibration ($\pm 1.2$)</td>
<td>(±1.2)</td>
</tr>
<tr>
<td>Chamber response ($\pm 1.0$)</td>
<td>(±1.8)</td>
</tr>
<tr>
<td>Radiative corrections, $\eta$ ($\pm 1.3$)</td>
<td>(±0.6)</td>
</tr>
<tr>
<td>Resolution ($\pm 0.6$)</td>
<td>(±0.6)</td>
</tr>
<tr>
<td>Positron interactions ($\pm 0.5$)</td>
<td>(±0.2)</td>
</tr>
<tr>
<td>Others ($\pm 0.3$)</td>
<td>(±0.2)</td>
</tr>
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<table>
<thead>
<tr>
<th>Ag TARGET</th>
<th>Uncertainty in $\rho$ ($\times 10^{-4}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bremsstrahlung rate ($\pm 1.8$)</td>
<td>(±1.6)</td>
</tr>
<tr>
<td>Ag thickness/stop position ($\pm 3.8$)</td>
<td>(±6.4)</td>
</tr>
<tr>
<td>Statistical ($\pm 1.2$)</td>
<td>(±2.1)</td>
</tr>
</tbody>
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<td>(±2.4)</td>
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</table>

<table>
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<tr>
<th>Total</th>
<th>Uncertainty in $\rho$ ($\times 10^{-4}$)</th>
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<tbody>
<tr>
<td>Weighted total systematic ($\pm 2.3$)</td>
<td>(±2.7)</td>
</tr>
<tr>
<td>Weighted total statistical ($\pm 1.2$)</td>
<td>(±2.1)</td>
</tr>
<tr>
<td>TOTAL ($\pm 2.6$)</td>
<td>(±3.4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Uncertainty in $\delta$ ($\times 10^{-4}$)</th>
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</thead>
<tbody>
<tr>
<td>(±1.2)</td>
</tr>
<tr>
<td>(±1.8)</td>
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<tr>
<td>(±0.6)</td>
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<tr>
<td>(±0.7)</td>
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<td>(±3.4)</td>
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</table>
### $P_{\mu \xi}$ uncertainties

<table>
<thead>
<tr>
<th>Uncertainties</th>
<th>$P_{\mu \xi} \times 10^{-4}$</th>
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</thead>
<tbody>
<tr>
<td>Depolarization in fringe field</td>
<td>+15.8, -4.0</td>
</tr>
<tr>
<td>Depolarization in stopping material</td>
<td>3.2</td>
</tr>
<tr>
<td>Background muons</td>
<td>1.0</td>
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<tr>
<td>Depolarization in production target</td>
<td>0.3</td>
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<tr>
<td>Chamber response</td>
<td>2.3</td>
</tr>
<tr>
<td>Resolution</td>
<td>1.5</td>
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<tr>
<td>Momentum calibration</td>
<td>1.5</td>
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<tr>
<td>External uncertainties</td>
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<tr>
<td>Positron interactions</td>
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<td>Beam stability</td>
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<td>Spectrometer alignment</td>
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<tr>
<td>Systematics in quadrature</td>
<td>+16.5, -6.2</td>
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<tr>
<td>Statistical uncertainty</td>
<td>3.5</td>
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<tr>
<td>Total uncertainty</td>
<td>+16.9, -7.2</td>
</tr>
</tbody>
</table>
Depolarization in target material

- Estimate of relaxation is included in simulation; small correction is made to polarization parameter.
- $\mu$SR experiment establishes no fast relaxation.
- Statistical uncertainty in $\lambda$ is included in decay parameter systematic uncertainty.

$P_\mu(t) = P_\mu(0) \exp(-\lambda t)$

Previous TWIST (E1111) $\mu$SR TWIST New TWIST (E1111) $\mu$SR New TWIST

Aluminum Silver
Ensuring muons stop in the metal target

- Muons that stop in gas can depolarize through muonium formation
- Use muon energy depositions near the stopping target to reject those that stop in gas
Energy calibration procedure matches the position of data and simulation edges

**Ag**
- Data Resolution: $59.5 \pm 0.2$ keV/c
- MC Resolution: $59.5 \pm 0.2$ keV/c
- Response func diff: $1.2$ keV/c

**Al**
- Data Resolution: $58.5 \pm 0.2$ keV/c
- MC Resolution: $58.4 \pm 0.2$ keV/c
- Response func diff: $2.0$ keV/c

*2004 analysis*
- Data Resolution: $65$ keV/c
- MC resolution: $60$ keV/c
Reconstruction Inefficiency

(a) Difference between inefficiencies from data and Monte Carlo averaged with respect to angles over the fiducial region.

(b) Difference between inefficiencies from data and Monte Carlo averaged with respect to momenta over the fiducial region.
Weak eigenstates in terms of mass eigenstates and mixing angle:

\[ W_L = W_1 \cos \zeta + W_2 \sin \zeta, \quad W_R = e^{i\omega}(-W_1 \sin \zeta + W_2 \cos \zeta) \]

Assume possible differences in left and right couplings and CKM character.

Use notation:

\[ t = \frac{g_R^2 m_1^2}{g_L^2 m_2^2}, \quad t_\theta = t \frac{|V_{ud}^R|}{|V_{ud}^L|}, \quad \zeta_g^2 = \frac{g_R^2}{g_L^2} \zeta^2 \]

Then, for muon decay, the Michel parameters are modified:

\[ \rho = \frac{3}{4} (1 - 2\zeta_g^2), \quad \xi = 1 - 2 (t^2 \zeta_g^2) \]

\[ P_{\mu} \xi = 1 - 2t_\theta^2 - 2\zeta_g^2 - 4t_\theta \zeta_g \cos(\alpha + \omega) \]

- “manifest” LRS assumes \( g_R = g_L, \quad V_R = V_L, \quad \omega = 0 \) (no CP violation).
- “pseudo-manifest” LRS allows CP violation, but \( V_R = (V_L)^* \) and \( g_R = g_L \).
- LRS “non-manifest” or generalized LRS makes no such assumptions.

Many experiments must make assumptions about LRS models!
Right-Left Symmetric Models
- Spontaneous breaking of parity

R-Parity Violating Supersymmetric Models

Lepton Flavour Violating 2-body decays $\mu \Rightarrow e X^0$
- Strong limits exist when $X^0$ or it's products are detectable
- $\mu$ decay limits interesting when $X^0$ is not detectable.
Estimating field component effects

Estimate of error

Opera field

f, scale factor applied to $B_x$ and $B_y$
The Michel parameters are bilinear combinations of the coupling constants:

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

\[ + \Re \left( g_{RL}^S g_{RL}^{T*} + g_{LR}^S g_{LR}^{T*} \right) \]

\[ \eta = \frac{1}{2} \Re \left[ g_{RR}^V g_{LL}^{S*} + g_{LL}^V g_{RR}^{S*} + g_{RL}^V (g_{LR}^{S*} + 6g_{LR}^{T*}) + g_{LR}^V (g_{RL}^{S*} + 6g_{RL}^{T*}) \right] \]

\[ \xi = 1 - \frac{1}{2} \left| g_{LR}^S \right|^2 - \frac{1}{2} \left| g_{RR}^S \right|^2 - 4 \left| g_{RL}^V \right|^2 + 2 \left| g_{LR}^V \right|^2 - 2 \left| g_{RR}^V \right|^2 \]

\[ + 2 \left| g_{LR}^T \right|^2 - 8 \left| g_{RL}^T \right|^2 + 4 \Re \left( g_{RL}^S g_{LR}^{T*} - g_{RL}^T g_{LR}^{S*} \right) \]

\[ \xi \delta = \frac{3}{4} - \frac{3}{8} \left| g_{RR}^S \right|^2 - \frac{3}{8} \left| g_{LR}^S \right|^2 - \frac{3}{2} \left| g_{RR}^V \right|^2 - \frac{3}{4} \left| g_{RL}^V \right|^2 - \frac{3}{4} \left| g_{LR}^V \right|^2 \]

\[ - \frac{3}{2} \left| g_{RL}^T \right|^2 - 3 \left| g_{LR}^T \right|^2 + \frac{3}{4} \Re \left( g_{LR}^S g_{LR}^{T*} - g_{RL}^S g_{RL}^{T*} \right) \]
## Limits on LRS parameters

| Observable                  | $m_2$ (GeV/c$^2$) | $|\zeta|$ | +            | -            |
|-----------------------------|------------------|--------|-------------|-------------|
| $m(K_L - K_S)$              | >1600            |        | reach       | (P)MLRS     |
| Direct $W_R$ searches       | >1000 (D0)       |        | clear signal| (P)MLRS     |
|                            | >652 (CDF)       |        |             | decay model |
| CMM unitarity               |                  | <10$^{-3}$ | sensitivity | (P)MLRS     |
| $\beta$ decay              | >310             | <0.040 | both parameters | (P)MLRS   |
| $\mu$ decay (TWIST)        | >420             | <0.022 | model independenc | light $\nu_R$ |

\[ |\zeta| < 0.022 \]

\[ |\zeta| > 420 \]

\[ |\zeta| > 400 \]
Selecting muons in metal target

Place cut on 2-d distribution so that <0.5% of “stops in gas” contaminate “stops in target” region (zone 1).
Electron spectrum from ^1_{-}\text{Al}

- One week of data with $\mu^{-}$ beam
- Precise measure of muonic aluminum ($\mu^{-}$-Al) decay in orbit (DIO)
  - changes phase space, initial KE
  - competes with nuclear muon capture
- Comparison with calculation
  - consistency above 53 MeV, but limited to $p<75$ MeV
  - (below $\mu e$ conversion signal)
  - mismatch near peak and excess events at lower energies
  - higher order corrections required?

A. Grossheim et al.,
Radiative corrections

Arbuzov et al., JHEP03:063(2003).

Included in TWIST simulation
Full O(\(\alpha\)) radiative corrections with exact electron mass dependence.
Leading and next-to-leading large log terms of O(\(\alpha^2\)).
Corrections for soft pairs, virtual pairs, and an ad-hoc exponentiation.
Uncertainty is non-log O(\(\alpha^2\)) term recently calculated.

Art Olin: PANIC2011 TRIUMF Weak Interaction Symmetry Test
Decay parameter results

\[ \rho = 0.74977 \pm 0.00012 \text{ (stat)} \pm 0.00023 \text{ (syst)} \]

(<1σ from SM, -1.4x10^{-4} from blind)

\[ \delta = 0.75049 \pm 0.00021 \text{ (stat)} \pm 0.00027 \text{ (syst)} \]

(+1.4σ from SM, -2.3x10^{-4} from blind)

\[ P_{\pi \mu \xi} = 1.00084 \pm 0.00029 \text{ (stat)} \pm 0.00063 \text{ (syst)} \]

(+1.2σ from SM, same as blind)

\[ P_{\mu \xi \delta/\rho} > 0.99909 \text{ (90\% CL)} \]

(from global analysis)
