Muon Decay Parameters from TWIST: Results and Limiting Systematic Uncertainties

Precision Measurements, Fundamental Symmetries, and Tests of the Standard Model

APS April Meeting

2 May 2011

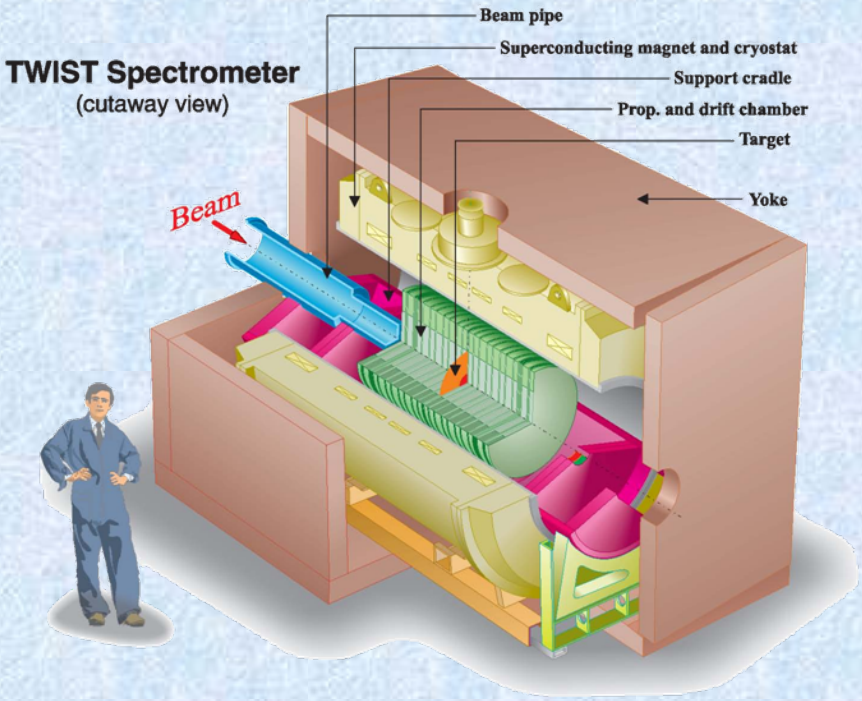
R.E. Mischke, TRIUMF

on behalf of the *TWIST* collaboration

The *TWIST* Experiment

$$\mu^+ \rightarrow e^+ \nu \bar{\nu}$$

- Uses highly polarized μ^+ beam.
- Time expansion chambers (TECs) to measure muon beam.
- Stops μ^+ in a symmetric detector.
- Tracks e^+ through uniform, well-known solenoidal field.

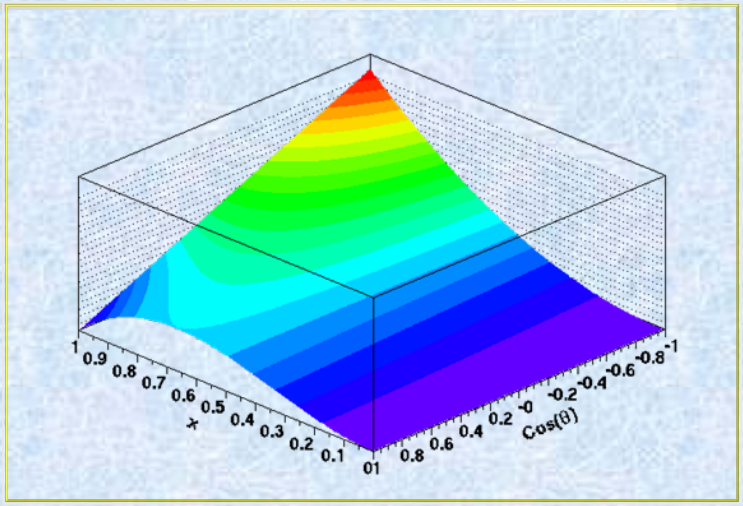


TEC: **J. Hu et al., Nucl. Instr. and Meth. A566 563, (2006)**

detector: **R. Henderson et al., Nucl. Instr. and Meth. A548 306, (2005)**

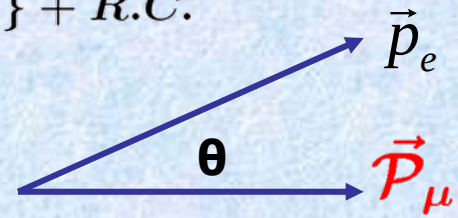
Decay parameter description

- Spectrum of e^+ in momentum and angle.
- Extract decay parameters by comparison to detailed GEANT3 simulation.



- Muon decay parameters ρ (Michel), η, $\mathbf{P}_\mu\xi$, δ: muon differential decay rate *vs.* energy and angle:

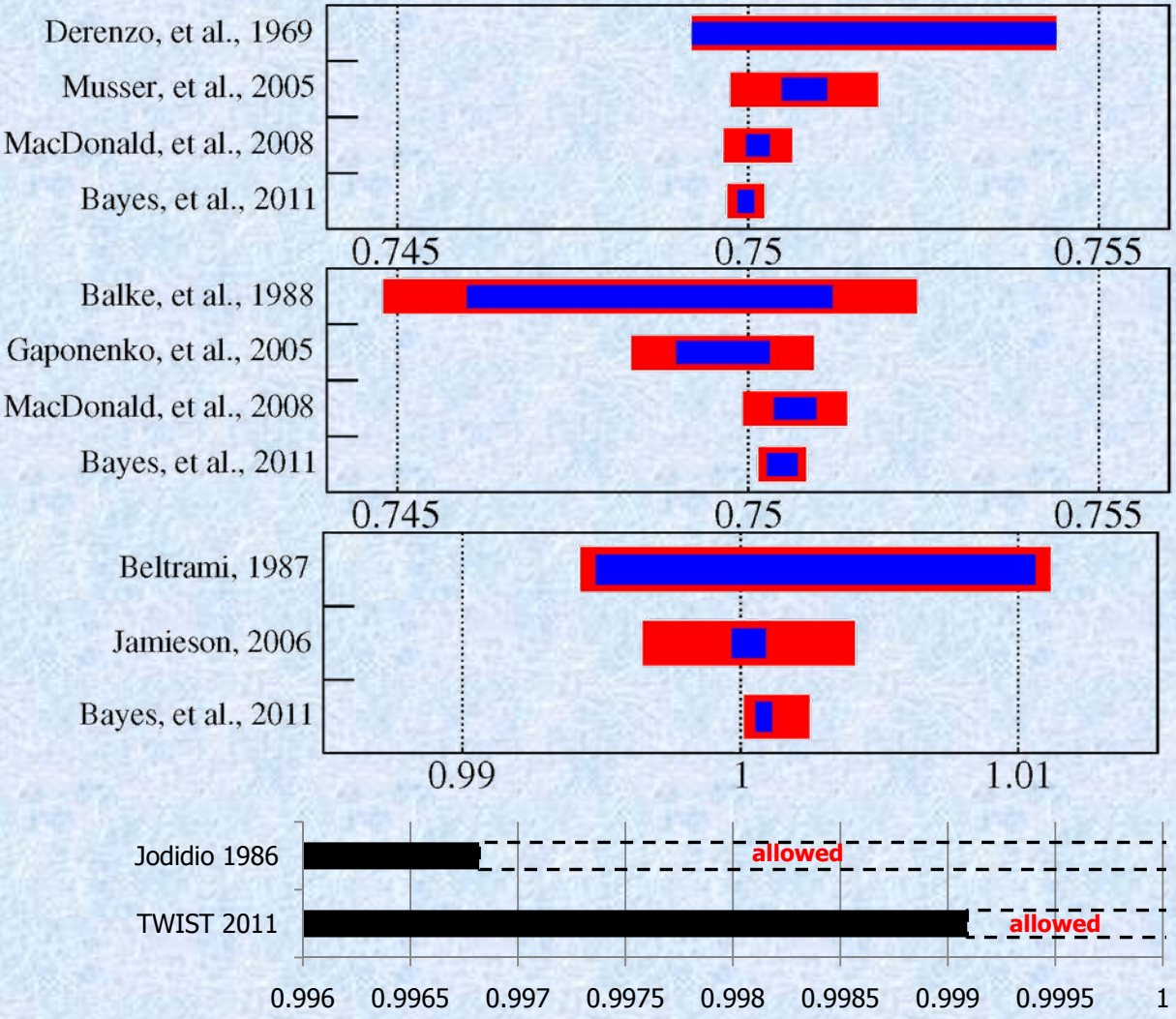
$$\frac{d^2\Gamma}{dx\ d\cos\theta} = \frac{1}{2\pi^3} m_\mu W_{\mu e}^4 G_F^2 \sqrt{x^2 - x_0^2}\cdot$$
$$\{\mathcal{F}_{IS}(x,\rho,\eta) \pm \mathcal{P}_\mu \cos\theta \cdot \mathcal{F}_{AS}(x,\xi,\delta)\} + R.C.$$



L. Michel, Proc. Phys. Soc. A63, 514 (1950)
C. Bouchiat and L. Michel, Phys. Rev. 106, 170 (1957).
T. Kinoshita and A. Sirlin, Phys. Rev. 107, 593 (1957).
T. Kinoshita and A. Sirlin, Phys. Rev. 108, 844 (1957).

Decay parameter results

R. Bayes *et al.*, Phys. Rev. Lett. 106, 041804 (2011).



ρ = 0.74977 ± 0.00012 (stat)
± 0.00023 (syst)

δ = 0.75049 ± 0.00021 (stat)
± 0.00027 (syst)

$P_\mu\xi$ = 1.00084 ± 0.00029 (stat)
+0.00165
-0.00063 (syst)

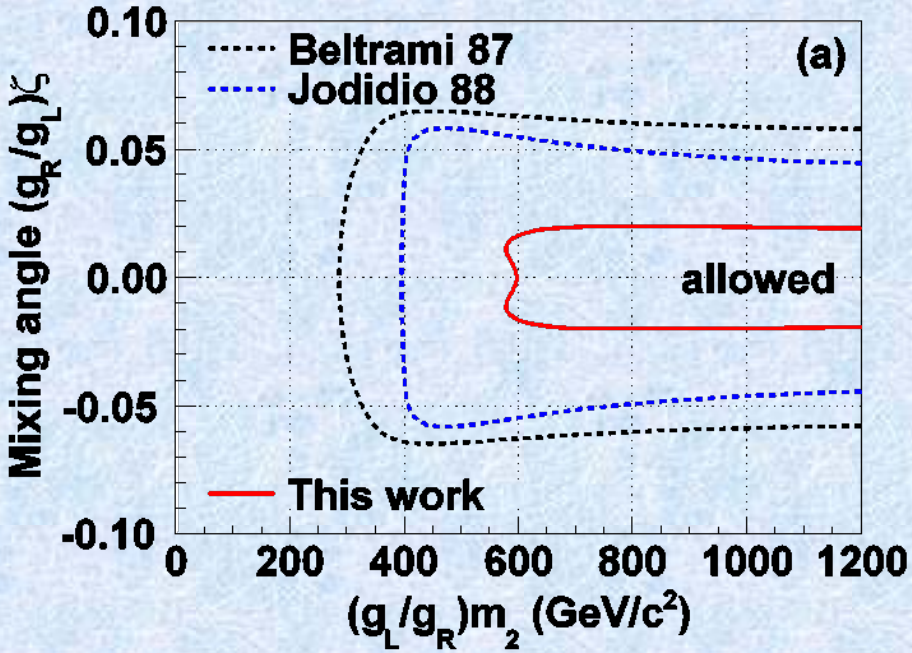
$P_\mu\xi\delta/\rho > 0.99909$ (90%CL)
from global analysis

Left-Right Symmetric model

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

$$t = \frac{g_R^2 m_1^2}{g_L^2 m_2^2}, \qquad t_\theta = t\frac{|V_{ud}^R|}{|V_{ud}^L|} \simeq t\frac{\cos\theta_R}{\cos\theta_{Cab}}, \qquad \zeta_g^2 = \frac{g_R^2}{g_L^2}\zeta^2$$

$$1 - \frac{\mathcal{P}_\mu^\pi \xi\delta}{\rho} \simeq 2t^2\left(1 + \frac{\cos^2\theta^R}{\cos^2\theta_{Cab}}\right) + 2\zeta_g^2 + 4\zeta_g t\frac{\cos\theta^R}{\cos\theta_{Cab}}\cos(\alpha+\omega)$$



P. Herczeg, Phys. Rev. D 34, 3449 (1986)

generalized or non-manifest LRS

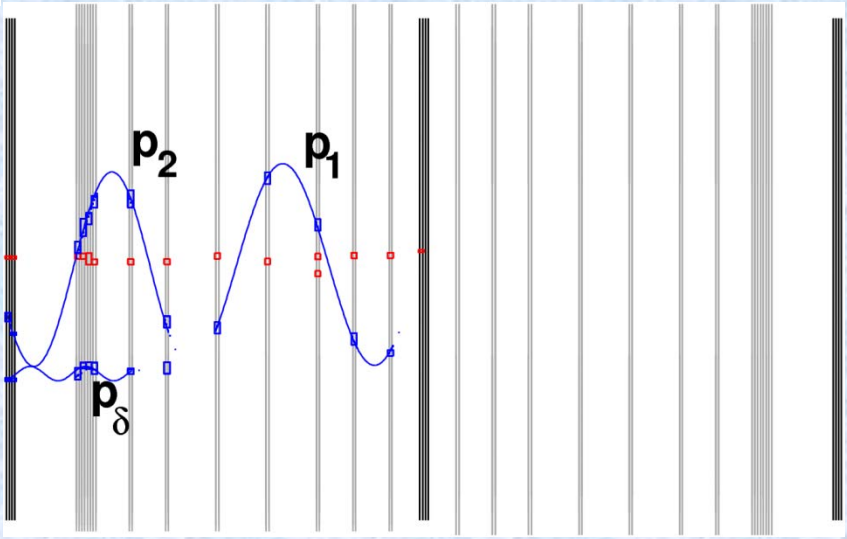
$(g_L/g_R)m_2 > 578$ GeV/c^2

$-0.020 < (g_R/g_L)\,\zeta < +0.020$

Limiting Systematic Uncertainties

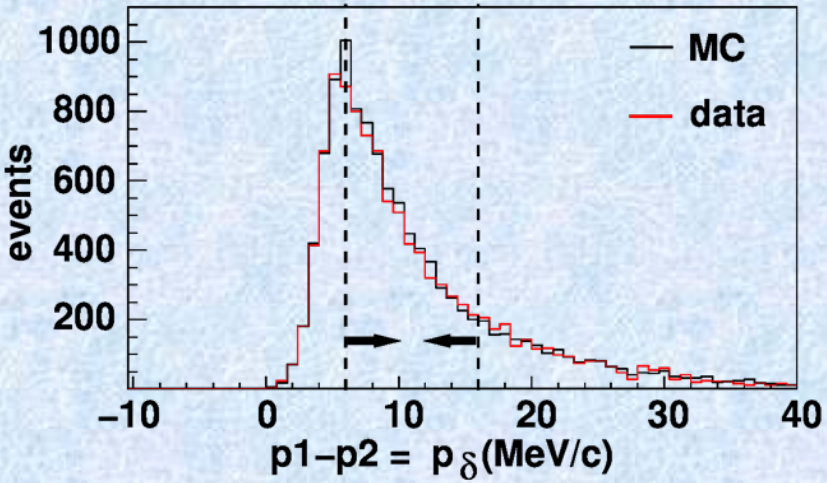
- Successes
  - discrete positron interactions
  - selecting stops in target
- Surprises
  - momentum calibration
  - stopping position in target
- Specifically for $P_\mu \xi$
  - depolarization in fringe field
  - depolarization in stopping target

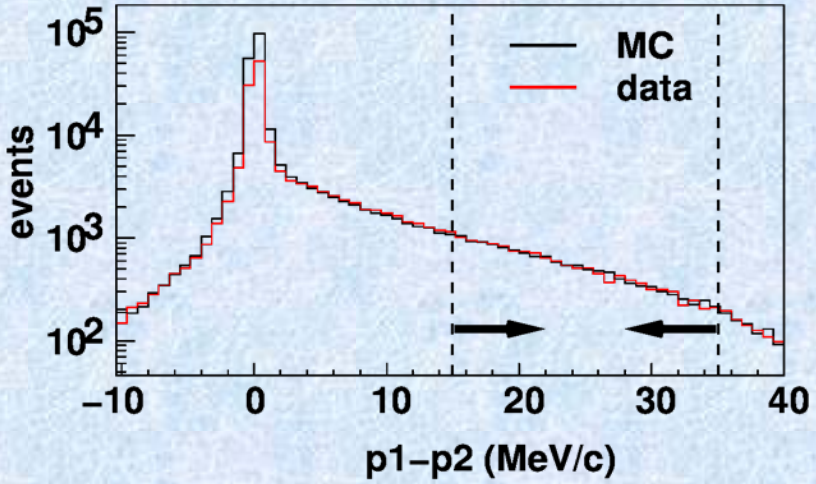
Positron interactions



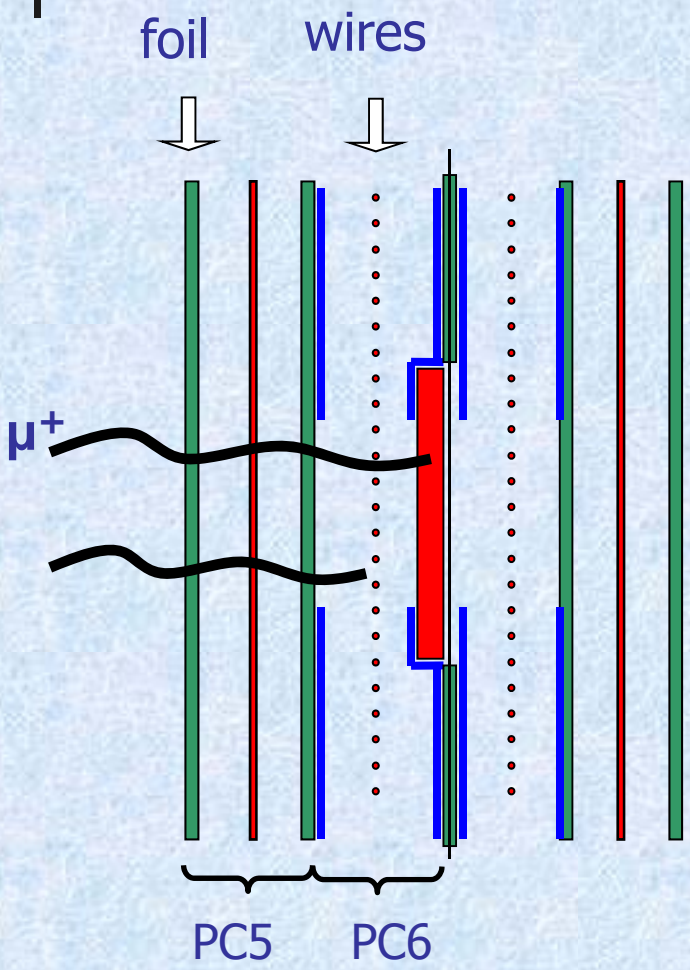
"Broken tracks" analysis:
$2e^+$, 1 e^- ≡ δ-electron
2 e^+ ≡ Bremsstrahlung

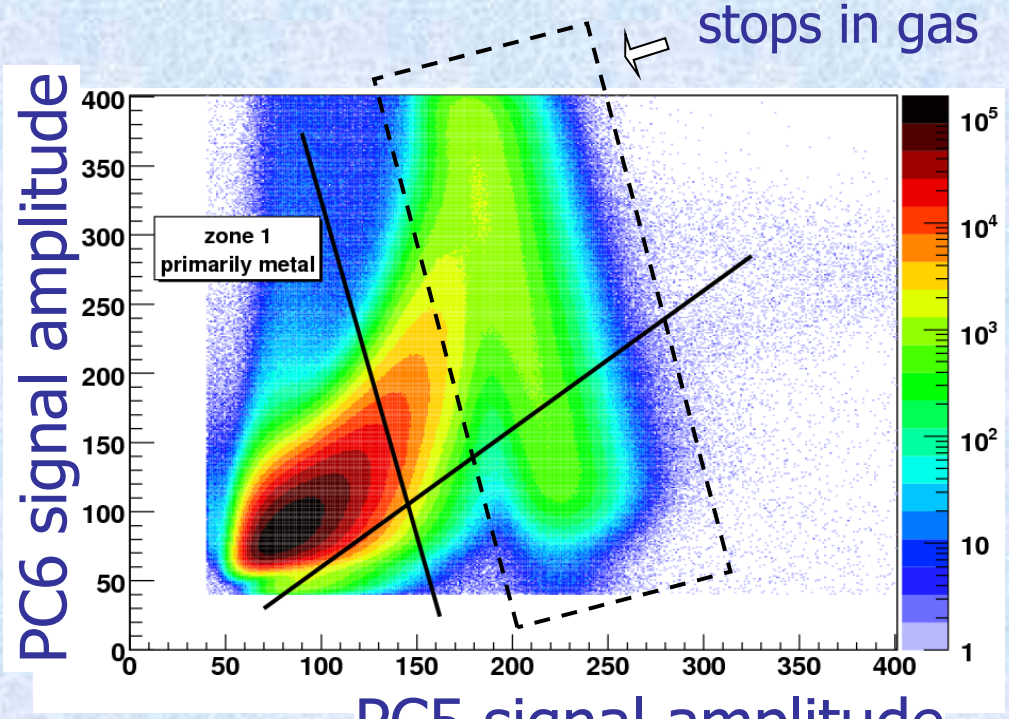
Agreement of data and sim:
δ -electrons < 1%
Bremsstrahlung differs by 2.4%





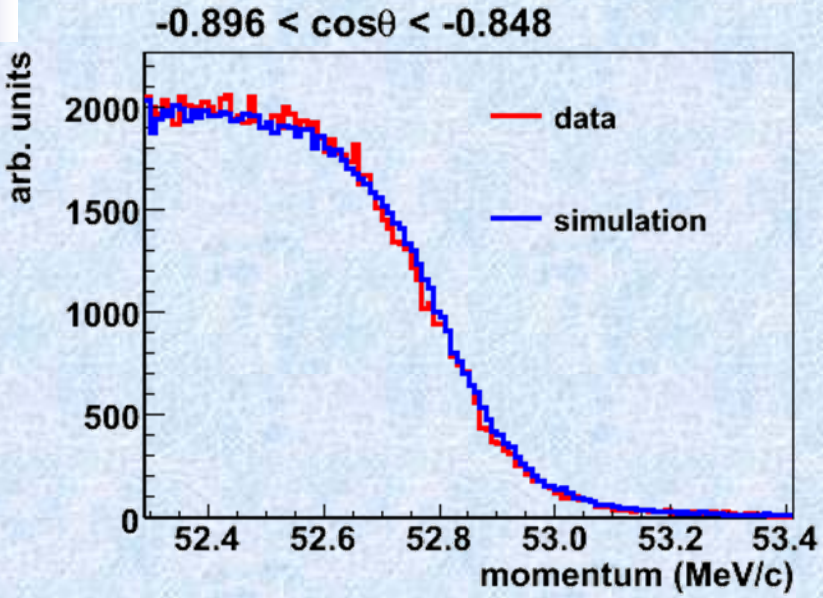
Reject stops in chamber gas

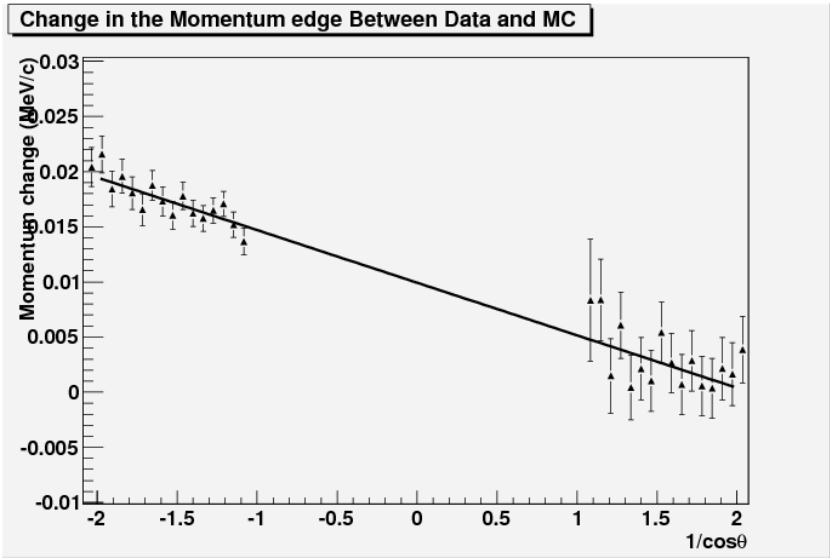




Place cut on 2-d distribution so that <0.5% of "stops in gas" contaminate "stops in target" region (zone 1).

Momentum calibration

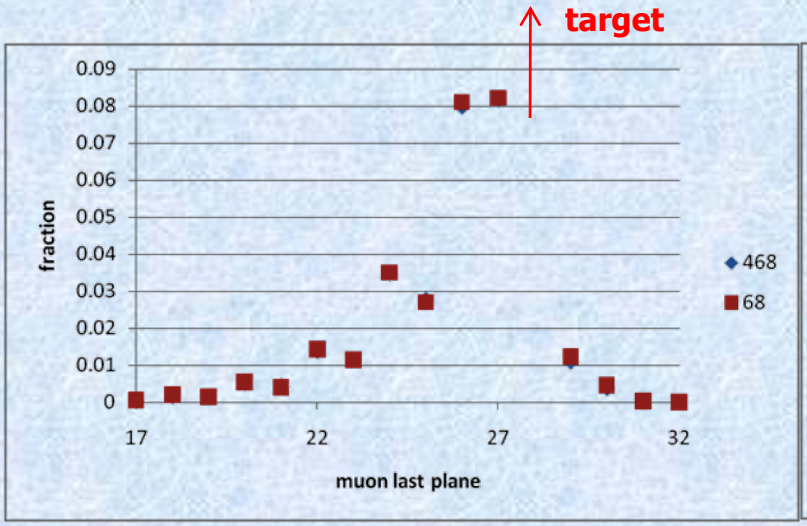


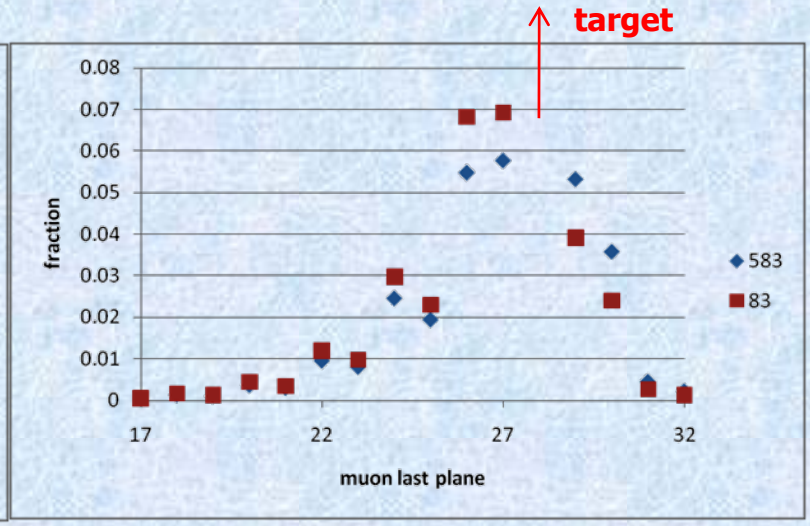


- Use kinematic edge at 52.8 MeV/c: energy loss and planar geometry lead to cosθ dependence.
- Data and sim compared for each angular bin. Offset of ~10 keV/c. Slope due to difference in stopping position.
- Calibration at edge provides no guidance on how to propagate the difference to lower momenta in the spectrum.

Muon Stopping Distribution

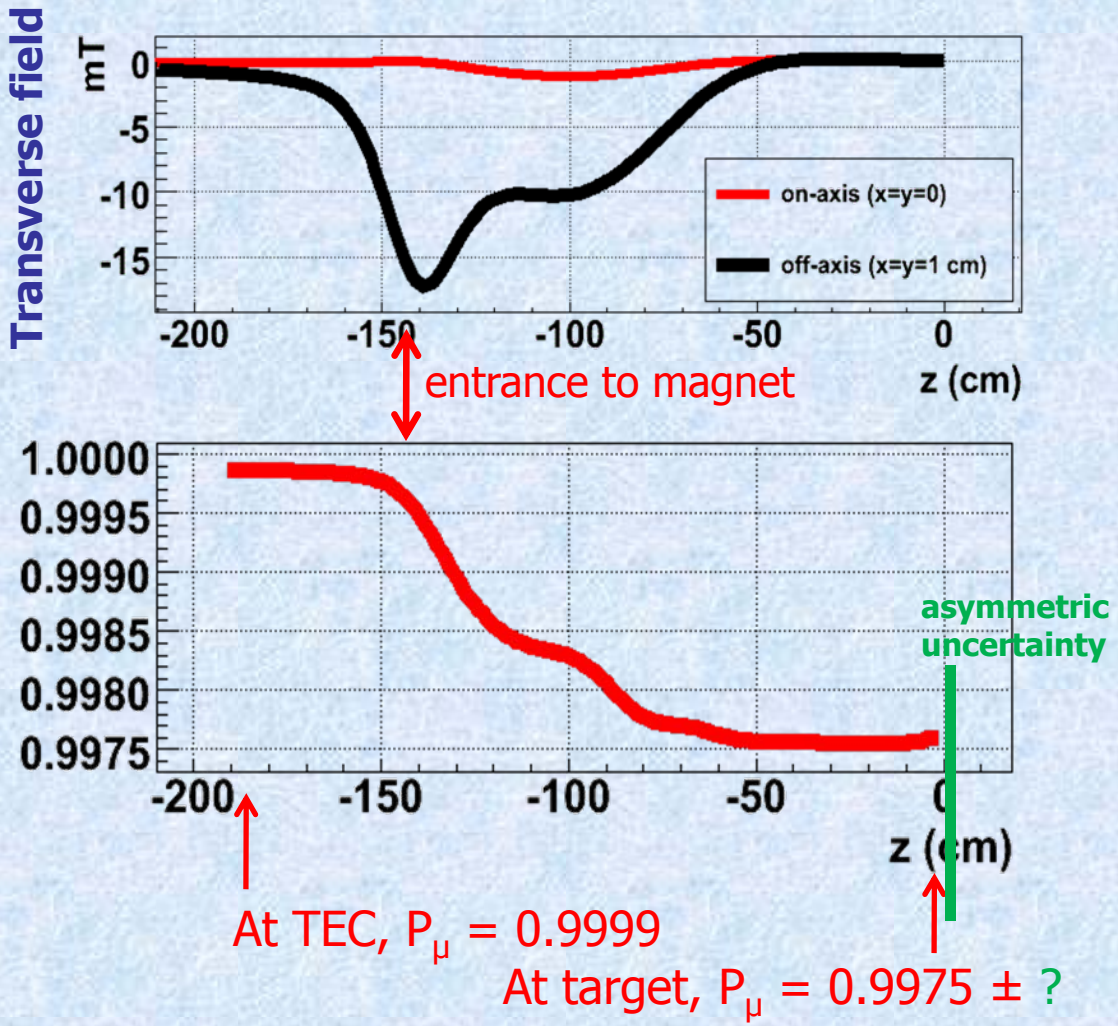
- Energy calibration should remove the effect of any mismatch
  - sensitivity of 1 keV, but unknown "zero"
- Very thin stopping targets: 30 μm for Ag and 70 μm for Al
  - 80% of muons stop in target
  - mismatch between data and simulation of up to 2 μm
- Use tails of stopping distribution outside of target
  - match of data and simulation for all planes defines zero
- Calibrate and determine sensitivity to fit parameters with sim.



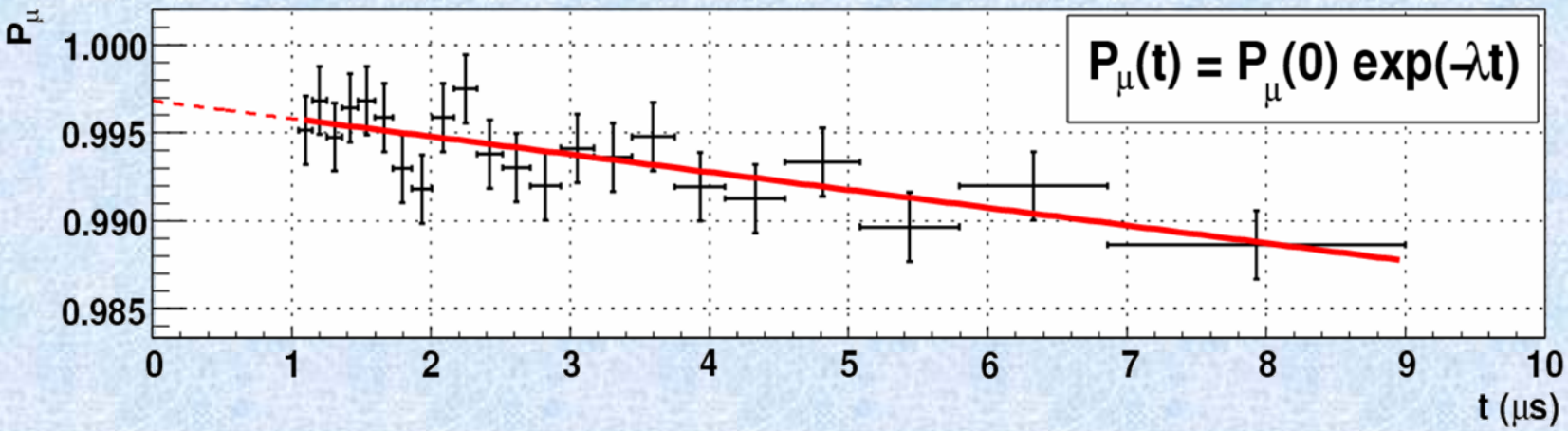


Depolarization in fringe field

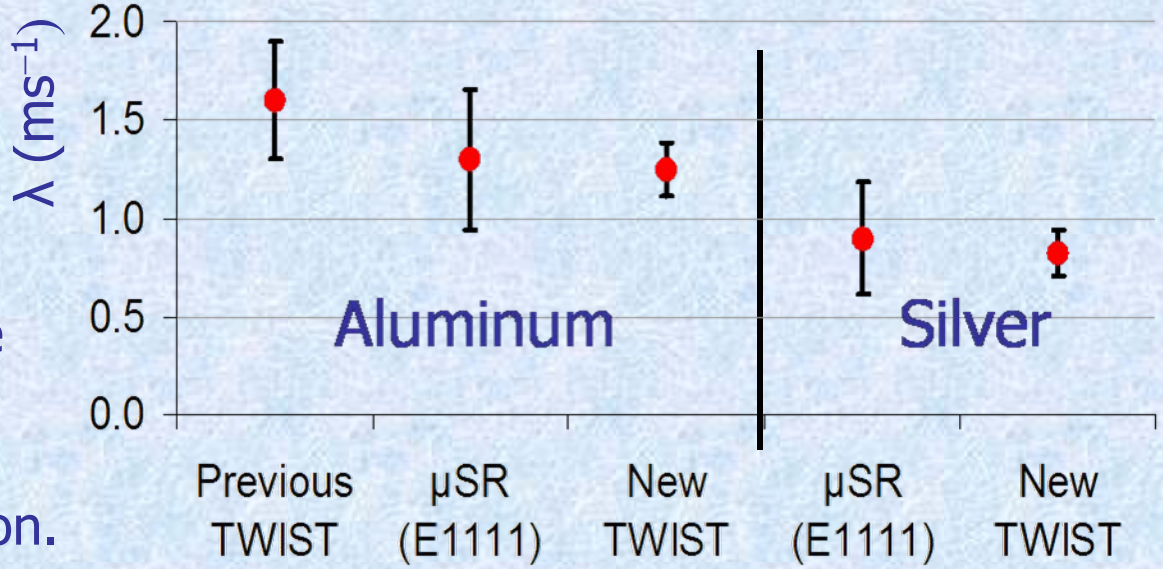
- Dominant uncertainty for measurement of $P_\mu \xi$
- Contributions from
  - position of beam
  - transverse components of fringe field
- Studied with mis-steered beams



Depolarization in target material



- Small, but significant and observable depolarization.
- Extrapolation to zero time required.
- Separate μSR experiment established no fast relaxation.



J. Bueno *et al.*, Phys. Rev. B (accepted for publication).