Status of the $\mathcal{TWIST}$ Measurement of $\mathbf{P}_{\mu}\xi$ and Systematics

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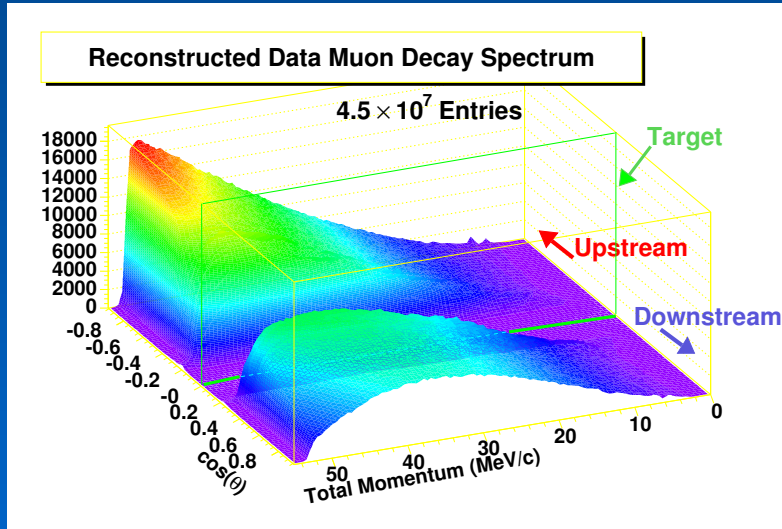for the $\mathcal{TWIST}$ Collaboration

Overview

- What is $P_\mu\xi$?

- Some Physics motivation for $P_\mu\xi$

- Muon polarization and rough limits

- $\mathcal{TWIST}$ measurements of $P_\mu\xi$

- Summary of systematic effects on $P_\mu\xi$

- Speculation on main challenges for improved precision

What is $P_\mu\xi$?

- P_μ is the polarization of the muon, ξ is asymmetry in angle of decay positrons from normal μ decay

- Standard Model (V-A) predicts $\xi = 1$ and $P_\mu = 1$

$$\frac{d^2\Gamma}{dx\,d\cos\theta} \propto x^2 - x^3 + \tfrac{2}{9}\rho(4x^3 - 3x^2) + \eta x_0(x - x^2) + \tfrac{1}{3}P_\mu\xi\cos\theta(x^2 - x^3 + \tfrac{2}{3}\delta(4x^3 - 3x^2))$$

(1)

$x = E_e/W_{e\mu}$
$W_{e\mu} = \frac{m_\mu^2 + m_e^2}{2m_\mu}$
$x_0 = \frac{m_e}{W_{e\mu}}$

Reconstructed Data Muon Decay Spectrum

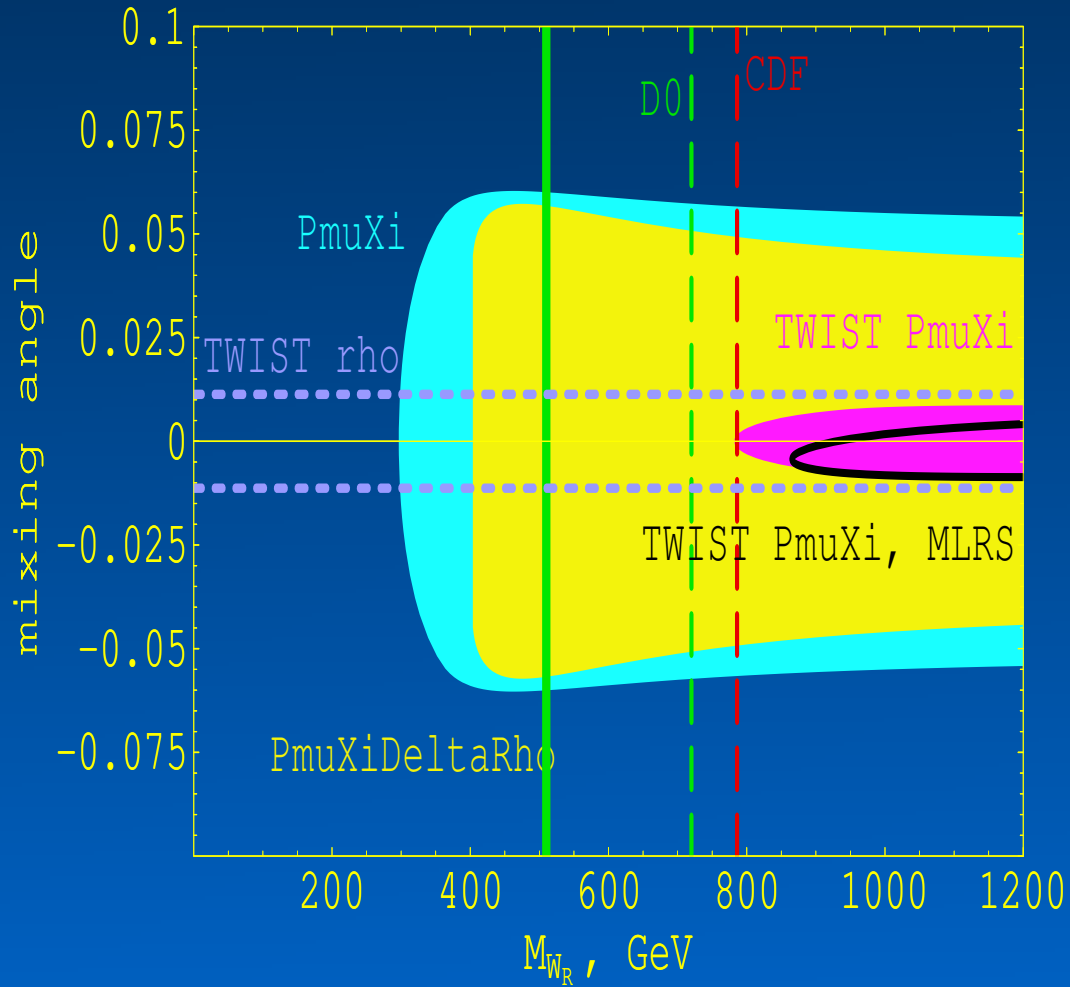# Physics and Motivation for $P_\mu\xi$

- Best Measurements:

    - $P_\mu\xi = 1.0027 \pm 0.0079 \pm 0.0030$ (Beltrami et. al., PL **B194** 326)
    - $P_\mu\xi\delta/\rho > 0.99682$, 90% conf. level (Jodidio et.al., PR **D34** 1967, PR **D37** 237)

- ξ and δ together give limit on probability of right-handed muon decaying into any handed positron:

$$Q_R^\mu = \frac{1}{2}(1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta) \tag{2}$$

- In Left-right symmetric model, $P_\mu\xi$ sets limit on W_R mass (ϵ) and left/right mixing parameter (ζ):

$$P_\mu\xi = 1 - 2\epsilon^2 - 2\zeta^2 - 2\epsilon^2(\frac{V_{ud}^R}{V_{ud}^L})^2 - \epsilon\zeta\frac{V_{ud}^R}{V_{ud}^L} \tag{3}$$
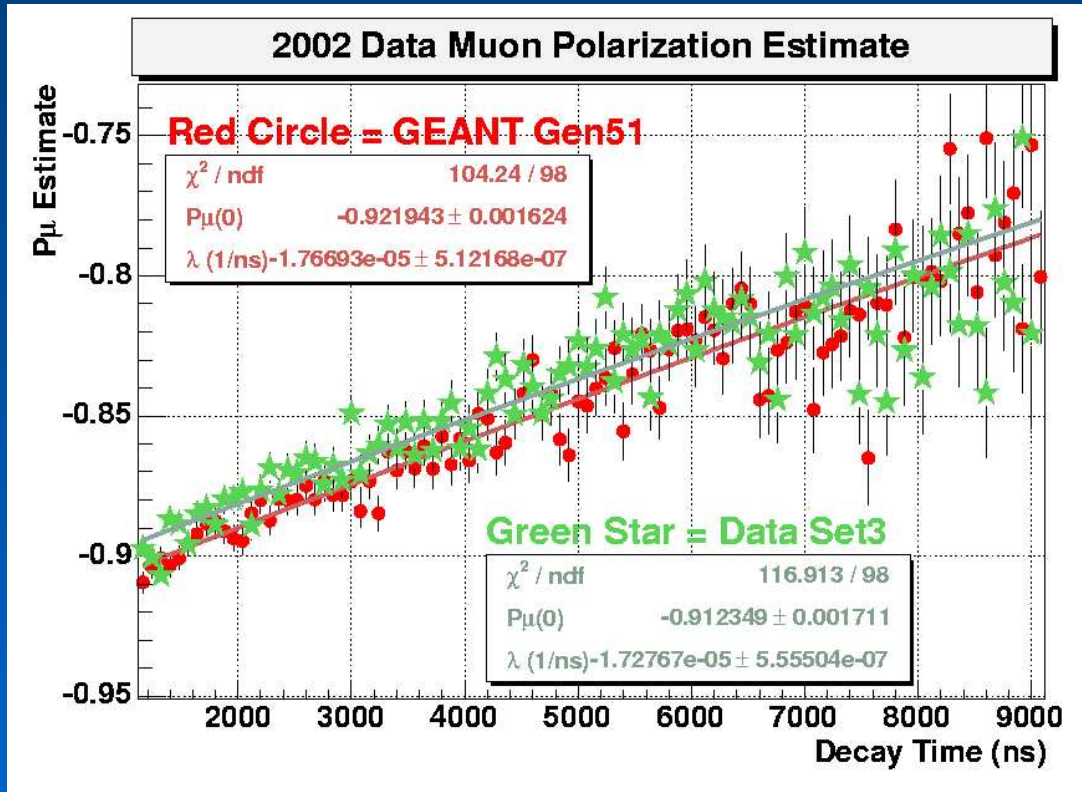
Muon Polarization and Limits

- Estimate to 1% level by fit to slope (m) and intercept (b) of reconstructed $\cos\theta$ distribution

- Compare to asymmetry estimated by integrating Tree level Michel distribution from $p < x < q$ yields:

$$P_\mu^{estimated} = \frac{m}{b} \frac{2(q^3 - p^3) - q^4 + p^4}{3(q^4 - p^4) - 2(q^3 - p^3)} \tag{4}$$

- For $0.3 < x < 1$. the factor is 1/0.3597
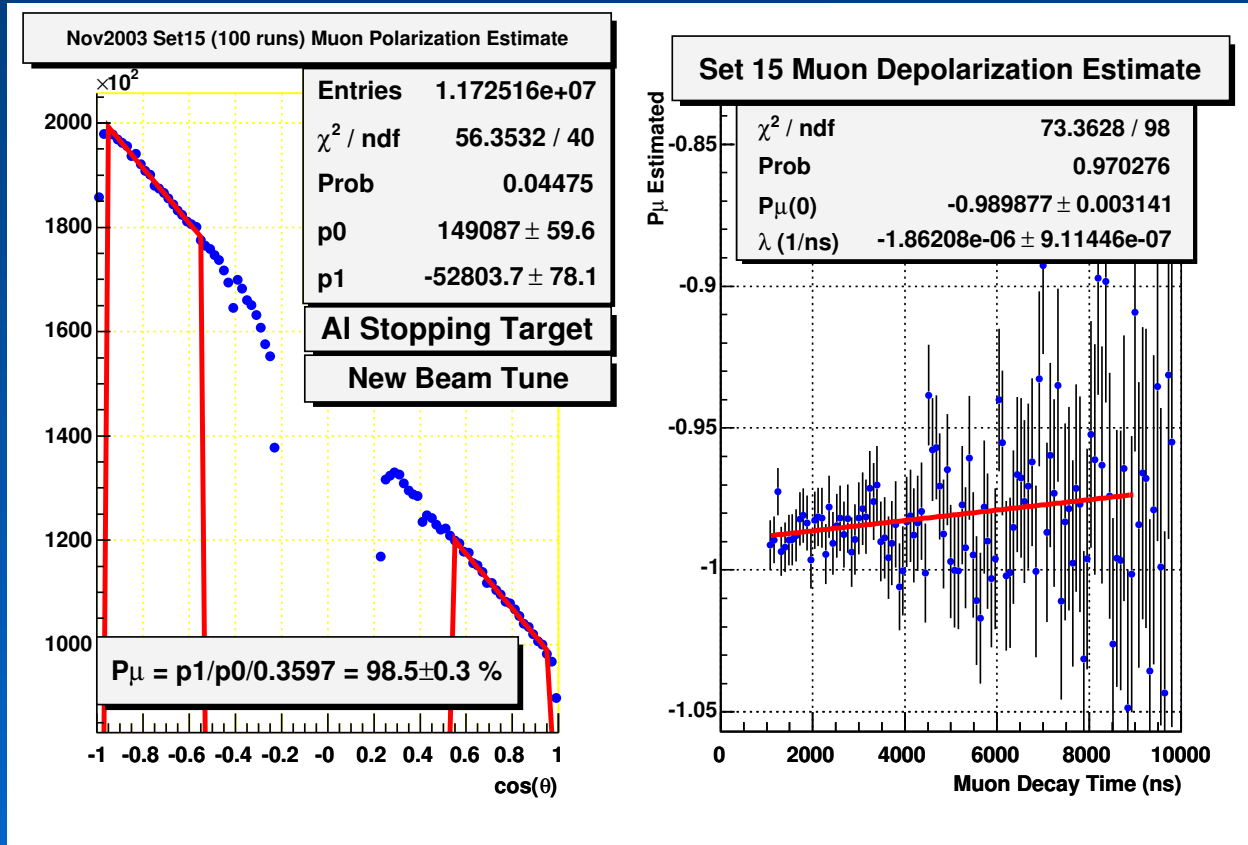
- Assumption is that ξ is close to 1

Nov2002 Data Muon Polarization

- Mylar stopping target, Be production target, beam tune

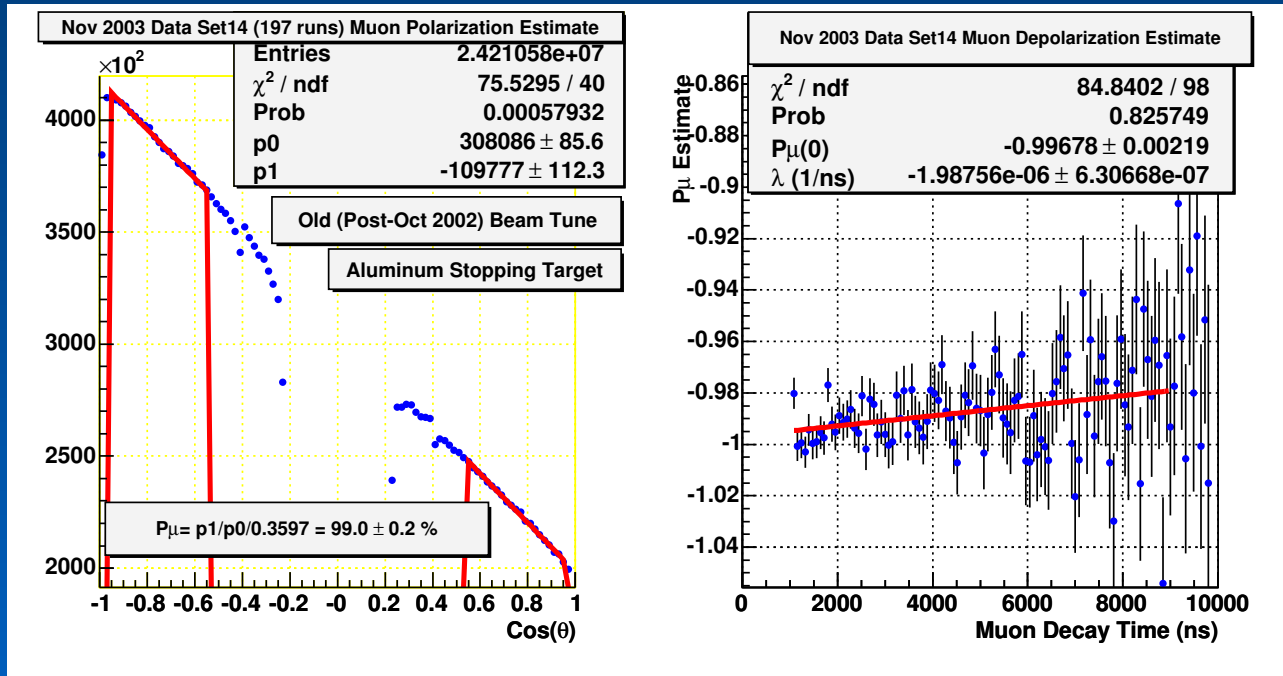- $P\mu(0) = 92.0 \pm 0.2\%$, $\lambda = (-1.72 \pm 0.06) \times 10^{-5} 1/ns$

Nov2003 Data Muon Polarization

$P_\mu \xi \approx 100 \pm 1\%$, can proceed with analysis of systematics. What changed since Nov 2002 running? Aluminum stopping target, improved beam tune

Nov2003 Data Post-Oct 2002 Beam Tune

Results show that most of change in polarization was due to change of stopping Target.

Data to MC $\Delta P_\mu \xi$

- Four parameter blind Michel spectrum fits using derivatives from reconstructed GEANT

- Endpoint energy calibration applied before spectrum fit

- MC Base set had $P_\mu(0) = 0.935$ and $2 \times \frac{1}{\lambda} = 0.000116s$ to match data

- 10^7 data events in fiducial volume for about 300 data runs of 8×10^5 events

- 1.5×10^7 MC events in fiducial volume for about 1500 MC runs of 10^5 events

- Fiducial volume:

  - $19.8 MeV/c < TotalMomentum < 50.4 MeV/c$
  - $0.54 < |\cos\theta| < 0.82$
  - Muon Decay Time $> 1050 ns$

- Current statistical error is 3×10^{-3}

MC To Nov2002 Data Description	in x-costh	chi2/dof	conlev	$\Delta\xi(10^{-3})$
Nov2002 1.96T	11,548,000	1542/1424	0.02	-14.5±3.0
Nov2002 SetB	11,856,100	1450/1424	0.31	-3.3±3.0
Nov2002 SetA	10,516,800	1393/1424	0.72	-8.9±3.0
Nov2002 SetA, STR=1850V	10,520,800	1435/1424	0.41	-8.6±3.0
Nov2002 SetA, STR=270K	10,594,300	1459/1424	0.25	-8.3±3.0
Nov2002 SetA, move foil 200μm	10,559,500	1406/1424	0.63	-8.9±3.0
Nov2002 SetA, Ntuple EvType Cut	10,545,100	1399/1424	0.68	-8.8±3.0
Nov2002 SetA, plane random pos.	10,548,600	1397/1424	0.69	-5.8±3.0
Nov2002 SetA, t0 change	10,620,200	1447/1424	0.33	-6.3±3.0
Nov2002 SetA, STR=1750V	10,499,400	1452/1424	0.30	-8.4±3.0
Nov2002 SetA, 900ns Window	10,559,800	1395/1424	0.70	-9.0±3.1
Nov2002 SetA, WC helixfit	10,456,000	1715/1424	1e-7	-7.3±3.1
Nov2002 Slightly US Stop	6,948,670	1484/1424	0.13	-15.0±3.5
Nov2002 DC=1850V	12,630,900	1551/1424	0.01	-13.7±2.9
Nov2002 DC=1850V,STR=1950V	12,630,900	1551/1424	0.01	-13.7±2.9
Nov2002 DS 1/4" Al	4,956,040	1429/1424	0.46	-13.9±3.9
Nov2002 DS 5.9mm Lucite	8,029,130	1392/1424	0.72	-11.1±3.3
Nov2002 5kHz Rate	11,497,700	1466/1424	0.21	-16.3±3.0

MC to MC $\Delta P_\mu \xi$

- Four parameter blind Michel spectrum fits to nominal reconstructed GEANT set

- 2×10^7 events in fiducial volume for GEANT spectrum fit

- Fiducial volume:

  - $19.8 MeV/c < Total Momentum < 50.4 MeV/c$
  - $0.54 < |\cos\theta| < 0.82$
  - Muon Decay Time $> 1050 ns$

MC to MC Fit Description	in x-costh	chi2/dof	conlev	$\Delta\xi(10^{-3})$
Different Pat. Rec. I	18,892,000	197/1424	1	-3.5±2.6
Different Pat. Rec. II	18,810,800	183/1424	1	-6.1±2.6
STR=1850V	18,837,100	253/1424	1	1.0±2.6
STR=270K	19,304,100	303/1424	1	1.6±2.6
STR=mv foil 200μm	19,227,900	130/1424	1	0.5±2.6
Large PC+DC deadzone	10,366,000	482/1424	1	4.5±3.1
Changed TMAXFD	18,751,700	1431/1424	0.44	1.9±2.6
Heavy Wires	18,744,400	1524/1424	0.03	5.2±2.6
DS 1/4" Al	16,054,900	1438/1424	0.39	3.5±2.7
Deltas off	4,896,200	1398/1424	0.68	-3.7±4.1
100% CO2	2,193,450	1402/1424	0.65	11.7±5.7
5% CO2	4,087,000	1409/1424	0.61	0.9±4.4
UniformB=2.04T	9,999,290	1507/1424	0.06	2.8±3.1
UniformB=1.96T	9,858,210	1403/1424	0.65	-3.3±3.1
Pre-Oct 2002 Tune	17,803,200	1405/1424	0.63	6.3±2.6

Data to Data $\Delta P_\mu \xi$

- Four parameter blind Michel spectrum fits using derivatives from reconstructed GEANT

- Derivatives are from MC with $100\% P_\mu$

- Fit to Nov2002 SetB

- 10^7 events in fiducial volume for about 300 data runs

- Fiducial volume:

  - $19.8 MeV/c < Total Momentum < 50.4 MeV/c$
  - $0.54 < |\cos\theta| < 0.82$
  - Muon Decay Time $> 1050ns$

Data to Data Description	in x-costh	chi2/dof	conlev	$\Delta\xi(10^{-3})$
SetA	10,516,800	1451/1424	0.30	-5.4±3.2
SetA, STR=1850V	10,520,800	1488/1424	0.12	-5.4±3.2
SetA, STR=1750V	10,499,400	1487/1424	0.12	-5.1±3.2
SetA, STR=270K	10,594,300	1497/1424	0.09	-5.0±3.2
SetA, mv foil 200 μm	10,559,500	1464/1424	0.23	-5.6±3.2
SetA, Ntuple EvType Cut	10,545,100	1455/1424	0.28	-5.5±3.2
SetA, all plane rand. pos.	10,548,600	1493/1424	0.10	-2.4±3.2
SetA, t0 change	10,620,200	1448/1424	0.32	-3.0±3.2
SetA, 900ns Window	10,559,800	1450/1424	0.31	-5.7±3.2
Slightly US Stop	6,948,670	1426/1424	0.48	-11.8±3.6
DS 1/4" Al	4,956,040	1530/1424	0.03	-10.4±4.1
DS 5.9mm Lucite	8,029,130	1416/1424	0.56	-7.8±3.5
5kHz Rate	11,497,700	1427/1424	0.47	-13.0±3.1
Cloud Muon Data	3,363,030	1601/1424	0.0007	-1346.5±5.3

Remaining Challenges for $P_\mu\xi$ Measurement

- Muon beam understanding (TEC)

- Control of muon stops needed? (CO_2 change)

- Better agreement of effect of material asymmetry in detector between MC and data

- Determine weight factors to multiply each of the systematic effects

Contents