Status of the TWIST Measurement of the Muon Decay Asymmetry

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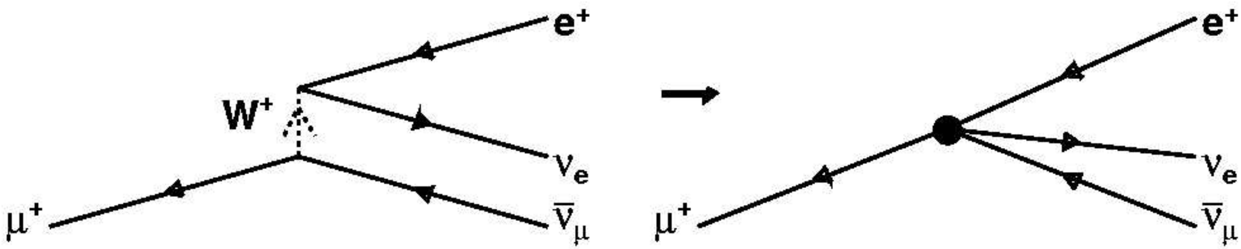
OVERVIEW

- Physics of μ decay asymmetry
- Brief review of past measurements
- Systematic error estimates
- Data Sets and Consistency
- Conclusions

Muon Decay $\mu^+ \to e^+ \bar{\nu}_\mu \nu_e$



General derivative free interaction matrix element:

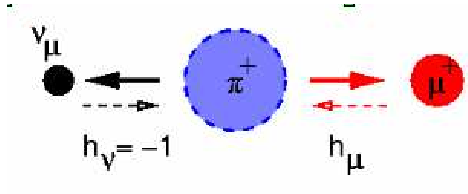
$$M = 4\frac{G_F}{\sqrt{2}} \sum_{\substack{\gamma=S,V,T \\ \epsilon,\mu=R,L}} g^\gamma_{\epsilon\mu} < \bar{e}_\epsilon|\Gamma^\gamma|\nu_e >< \bar{\nu}_\mu|\Gamma_\gamma|\mu_\mu > \tag{1}$$

- $g^\gamma_{\epsilon\mu}$ are decay coupling constants
- $\gamma = S, V, T$ are scalar, vector, and tensor interactions
- $\epsilon, \mu = L, R$ are chirality of the electron, muon
- SM: all zero coupling, except $g^V_{LL} = 1$

Physics of μ decay asymmetry

- 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 $\text{P}_\mu = -1$

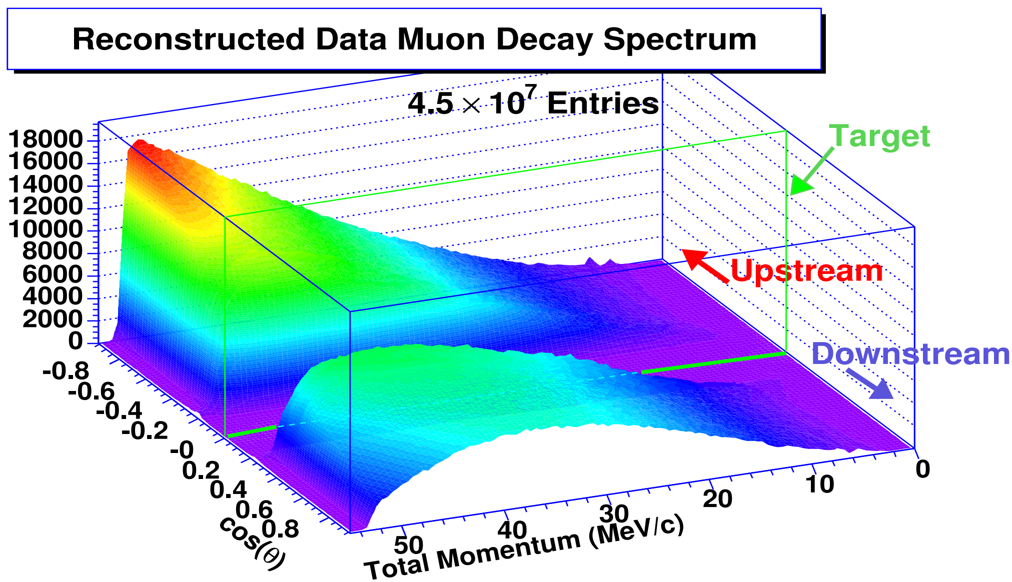


$$\frac{d^2\Gamma}{dx\, d\cos\theta} \propto F_{IS}(x, \rho, \eta) + P_\mu \xi \cos\theta F'_{AS}(x, \delta) \qquad (2)$$

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

$W_{e\mu} = \frac{m_\mu^2 + m_e^2}{2 m_\mu}$

$x_0 = \frac{m_e}{W_{e\mu}}$



Measurements and Motivation for $P_\mu\xi$

- Direct Measurements:
  - $P_\mu\xi = 1.0027 \pm 0.0079 \pm 0.0030$ (Beltrami et. al., PL**B194** 1987)
  - $P_\mu\xi\delta/\rho > 0.99682$, 90% conf. level (Jodidio et.al., PR **D34**, PR **D37** 1986)

- Indirect Measurement ($\mathcal{TWIST}$ ρ/δ PRL **94**, 101805 + PRD **71**, 071101(R) (2005)):
  $0.9960 < P_\mu\xi <= \xi < 1.0040$ at 90% conf. level

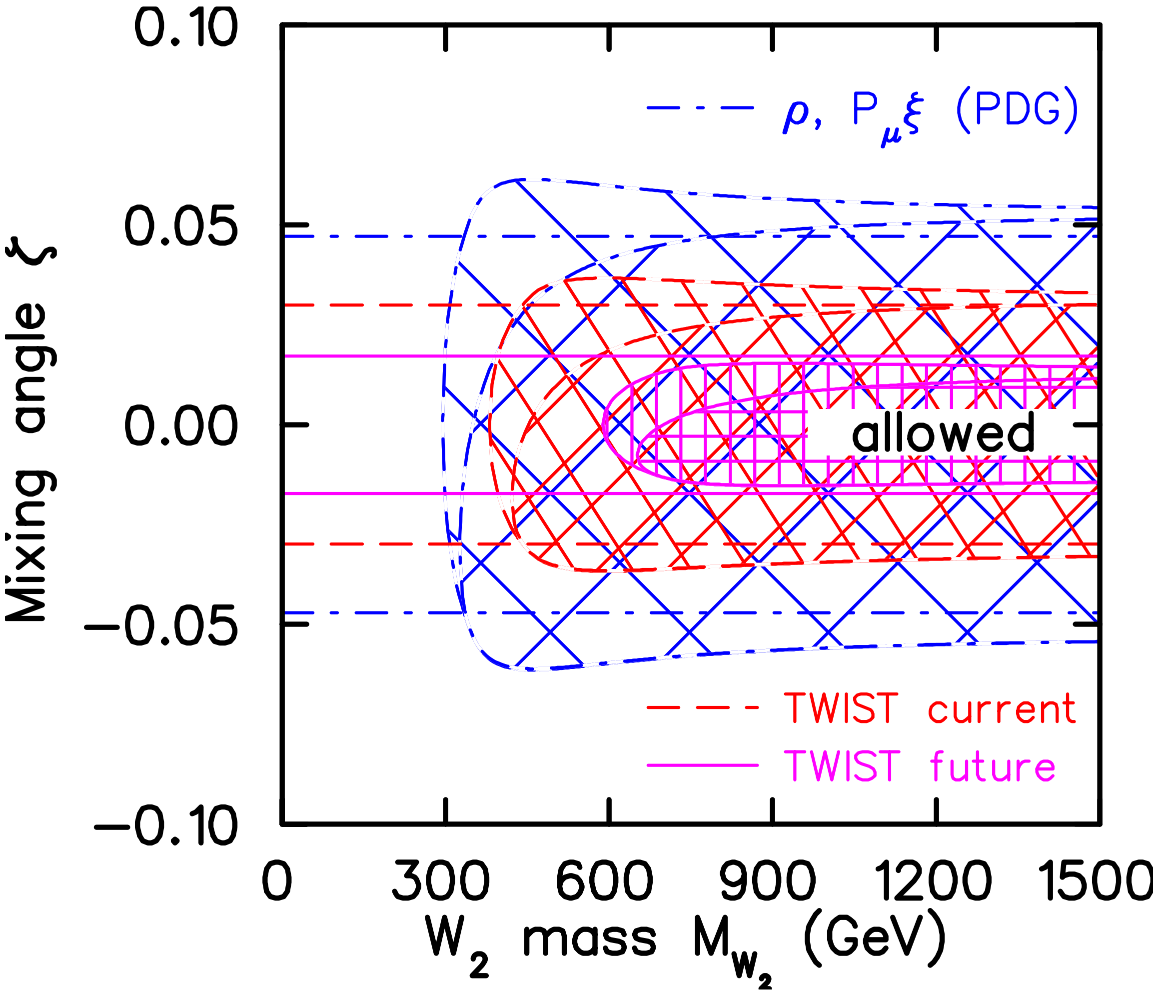
- ξ and δ limit probability of right-handed muon decaying into any handed positron:

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

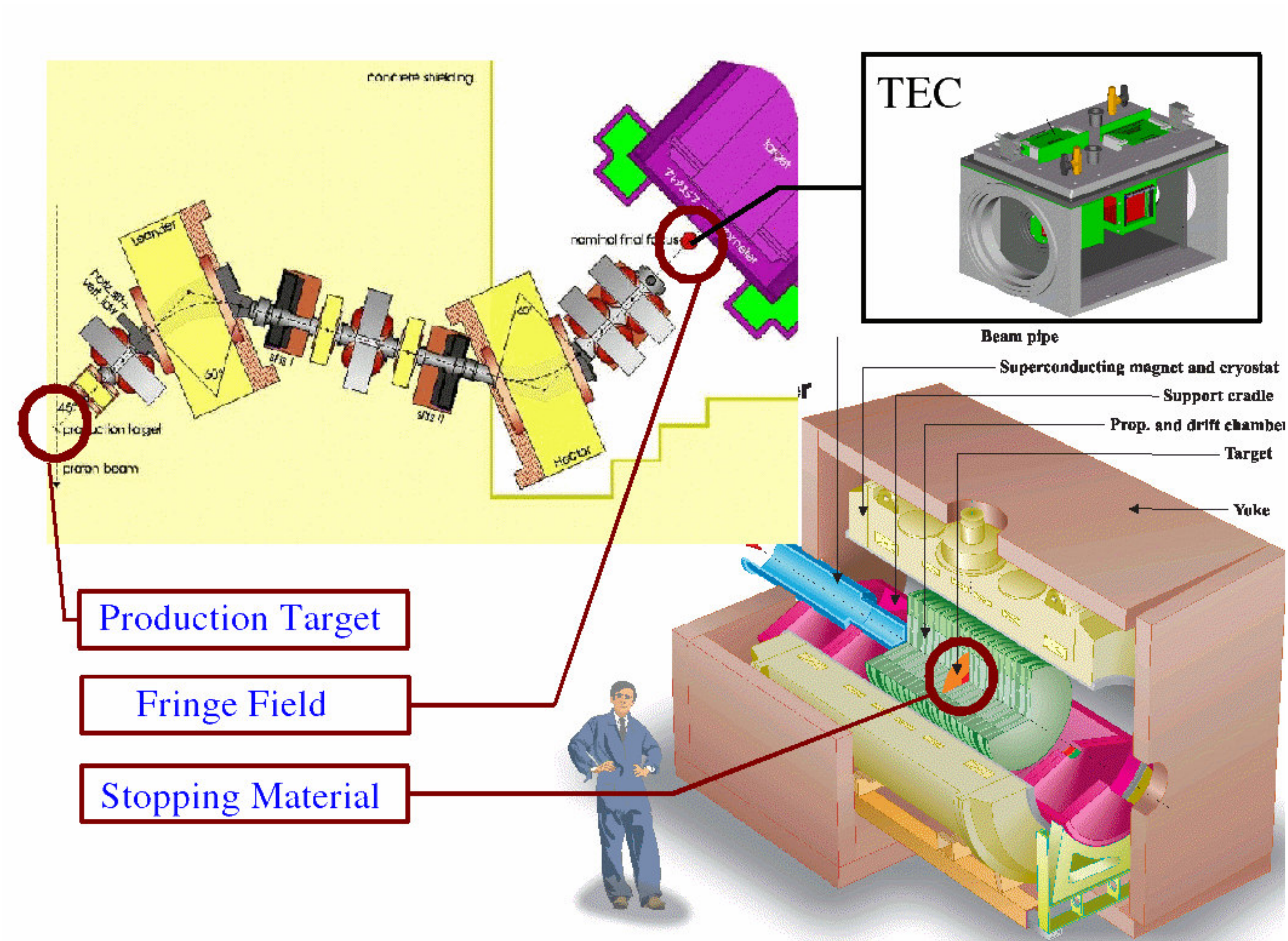
- In Left-right symmetric models, $P_\mu\xi$ sets limit on W_L/W_R mass (ϵ) and LR mixing parameter (ζ):

$$P_\mu\xi = 1 - 2\epsilon^2 - 2\zeta^2 - 2\epsilon^2(\frac{V_{ud}^R}{V_{ud}^L})^2 - \epsilon\zeta\frac{V_{ud}^R}{V_{ud}^L} \tag{4}$$

Left-Right Symmetric Model Limits



Locations of Muon Depolarization



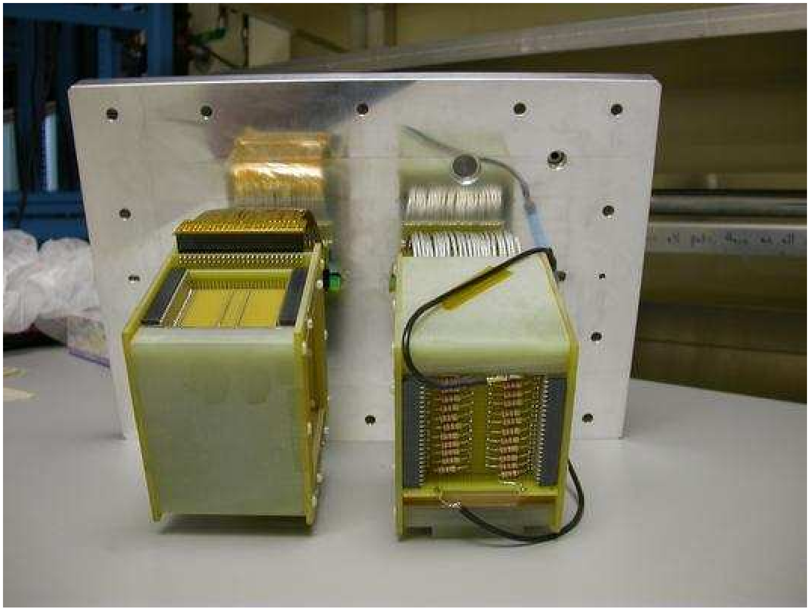
Short Systematic Error Estimate List $\times 10^{-3}$

- Muon beam and polarization $\approx \pm 2.00$
  - Fringe field depolarization $\approx \pm 1$ to ± 2
  - Depolarization in prod. target -1.17
- Chamber response ± 0.69
  - Dead zone ± 0.54
- Spectrometer alignment ± 0.40
  - B field to detector axis ± 0.39
- Momentum calibration ± 0.27
- Positron interactions ± 0.11
  - Hard interactions ± 0.10

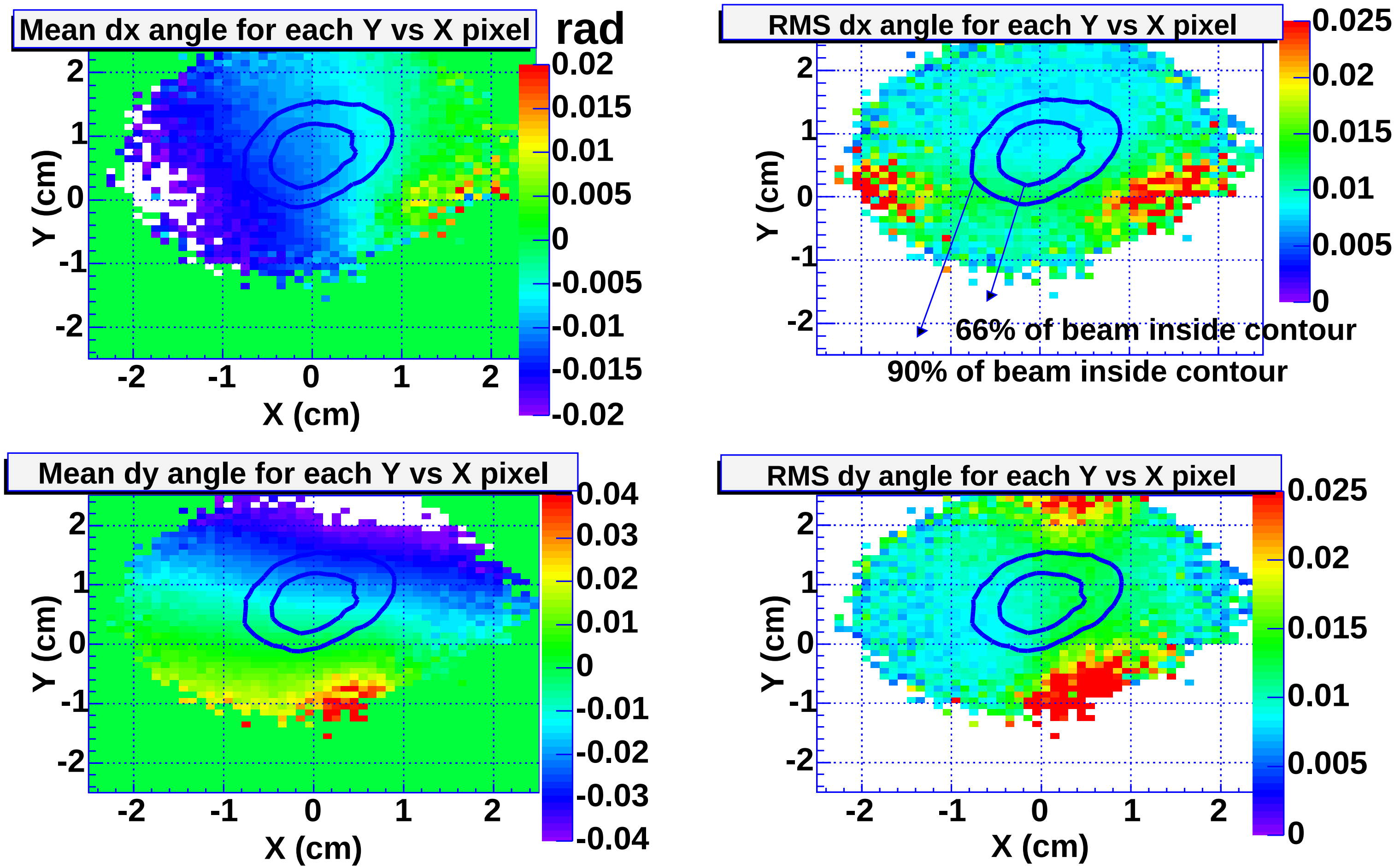
Total systematic error $\approx \pm 2.3$

Fringe field depolarization

- Muons depolarized in solenoid magnet fringe field
- Estimate by knowing:
  - muon beam size + divergence (from TEC)
  - magnetic field map
- Transport Spins in Monte-Carlo



Time Expansion Chamber - Muon Beam



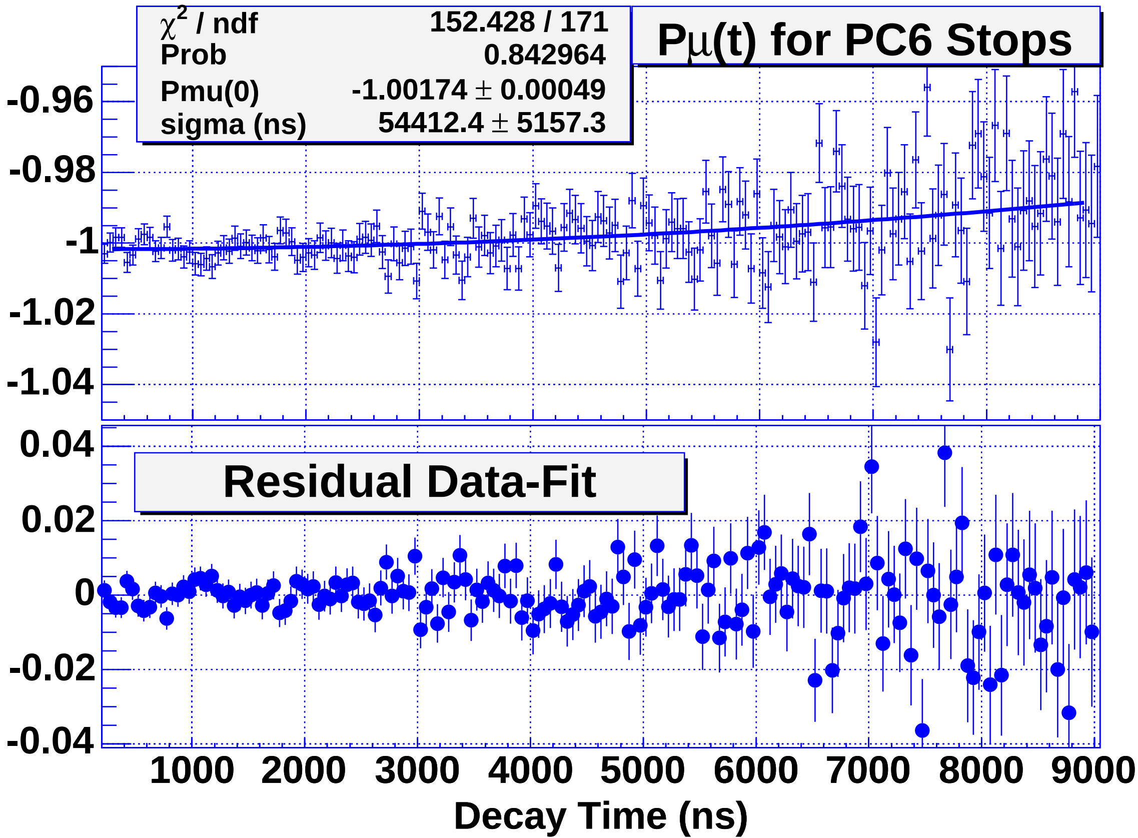
Data Set Summary for $\mathcal{TWIST}$ $P_\mu \xi$

Set #	# Runs (2 GB)	Description
12	211	28.9 MeV/c
13	115	28.9 MeV/c
14	176	2003 Nominal
15	217	2003 Nominal
30	60	B2=949G, z cent, M1 Trigger
31	265	B2=949G, z cent, M Trigger
32	120	B2=944G, PC5 Stops
33	91	Far Upstream Stops
34	11	Far Downstream Stops
35	368	2004 Nominal Stop centered
36	390	2004 Stop at 3/4
37	281	High Rate
38	303	Aperture In
39	211	2004 Stop at 3/4
Total	2819 (5.6 TB)	2272 Nominal Runs

Material Dependent Depolarization

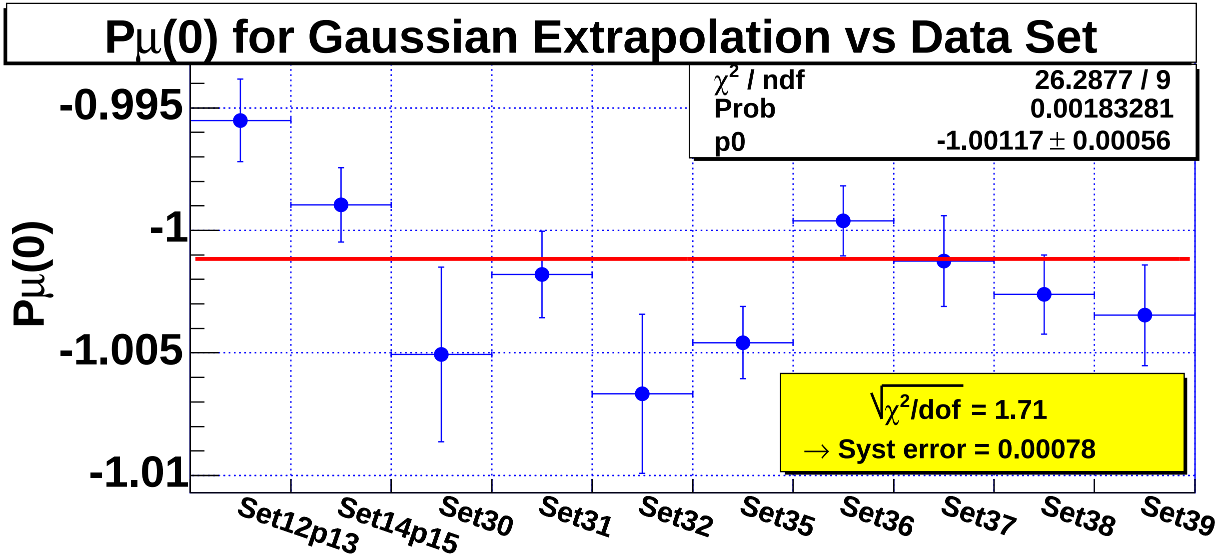
Sum of all 2003+2004 data asymmetry vs decay time fit to half-gaussian (still blind):

$$P_\mu(t) = P_\mu(0)e^{\frac{-t^2}{2\sigma^2}} \tag{5}$$



Data Set Consistency

- Consistency check with unknown offset (still blind)



Conclusions

- Direct measurement of $P_\mu\xi$ by end of this summer
- Result will reduce error in PDG value by a factor of about $3\times$
- Largest systematic error will be due to fringe field depolarization
- Remaining tasks include:
  - generation and analysis of MC to match 2004 data
  - finalize systematic error estimates

Results made possible by NSERC funding, and
by the use of Westgrid Computing Resources.

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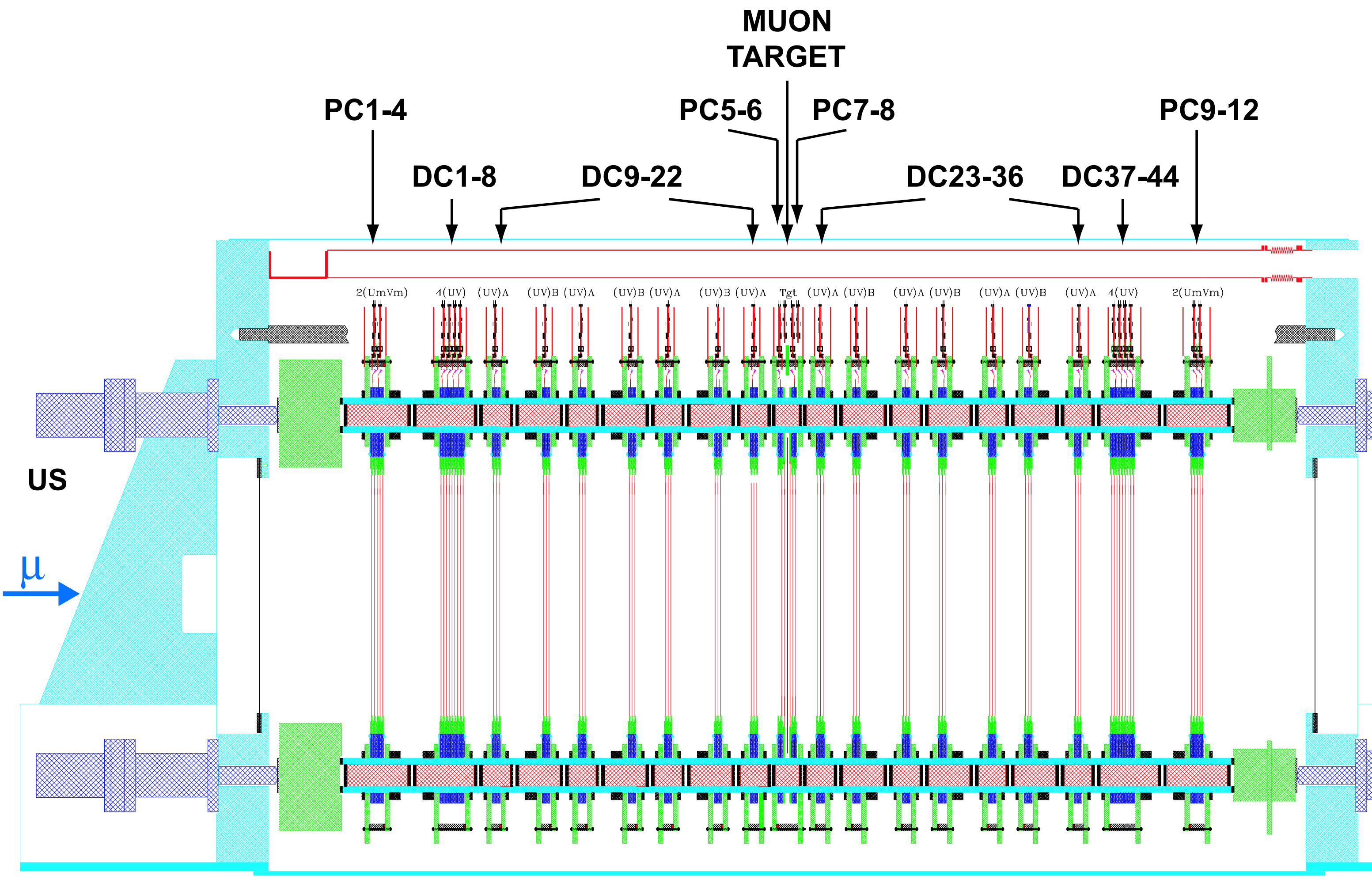
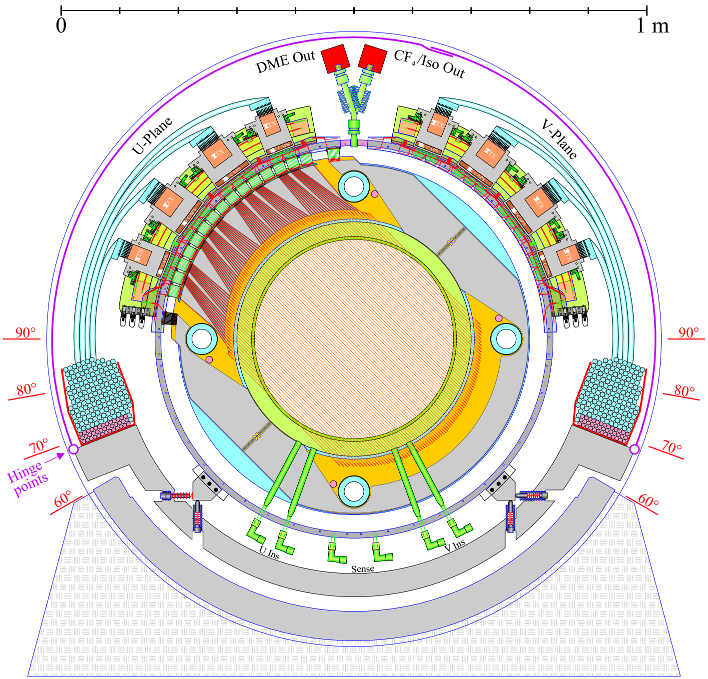
Detector Planes



Detector End View

Chamber plane for E 614

80 sense wires (20 m) + 2x3 guard wires at 4 mm distance. 22 pairs of drift chambers (each one U and V plane) with DME gas, 6 pairs of proportional chambers with CF_4 / Isobutane. ~5000 wires with VTX preamplifiers



Walter - 17. Nov. 1999 - E614_lamel - TRI241

Spectrum Fit Procedure

Extracting Michel parameters

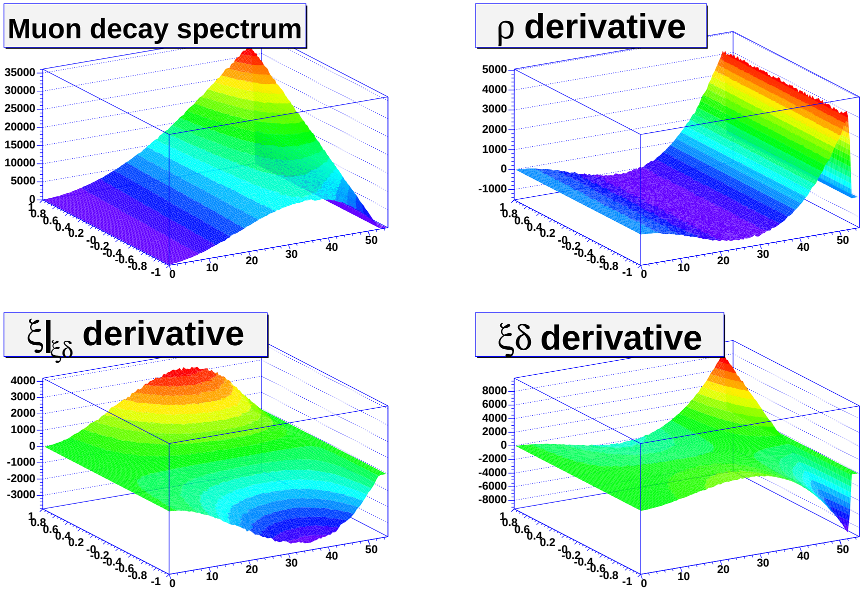
Need to take into account detector response. The technique:

$$\underbrace{n_i(\rho_{\mathrm{Data}})}_{\substack{\uparrow \\ \text{Data}}} = \underbrace{n_i(\rho_{\mathrm{MC}}) + \frac{\partial n_i}{\partial \rho}}_{\substack{\uparrow \\ \text{MC}}} \underbrace{(\rho_{\mathrm{Data}} - \rho_{\mathrm{MC}})}_{\substack{\uparrow \\ \text{Fit parameter}}}$$

(ρ stands for any spectrum parameter).

- Many effects of reconstruction cancel.
- Monte-Carlo must reproduce effects of the detector.
  - ▷ But spectrum distortions by the thin detector are small.

Spectrum Distributions



Contents