Direct Measurement of $P_{\mu}\xi$ at TWIST

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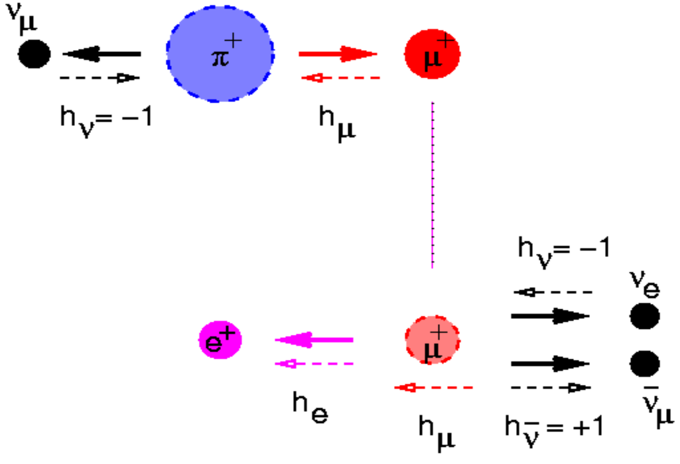
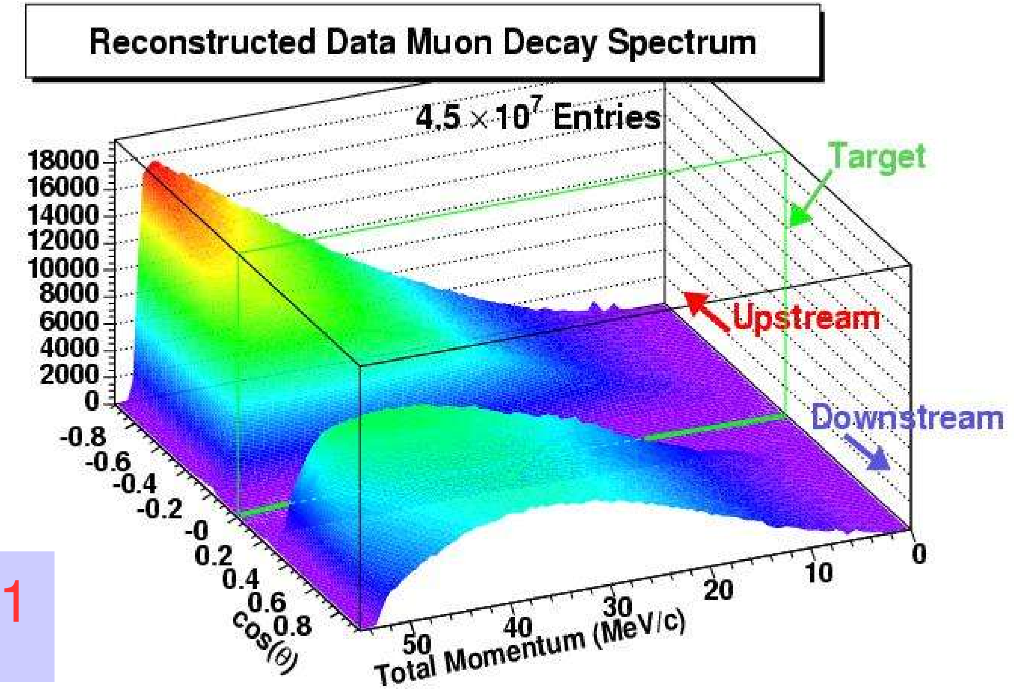
What is $P_\mu\xi$?

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

$$\frac{d^2\Gamma}{dx\,d\cos\theta} \propto \mathcal{F}_{IS}(x,\rho,\eta) \pm \mathcal{P}_\mu \xi \cos\theta \mathcal{F}_{AS}(x,\delta)$$





Standard Model: $\xi = 1$, $P_\mu = -1$

Motivation

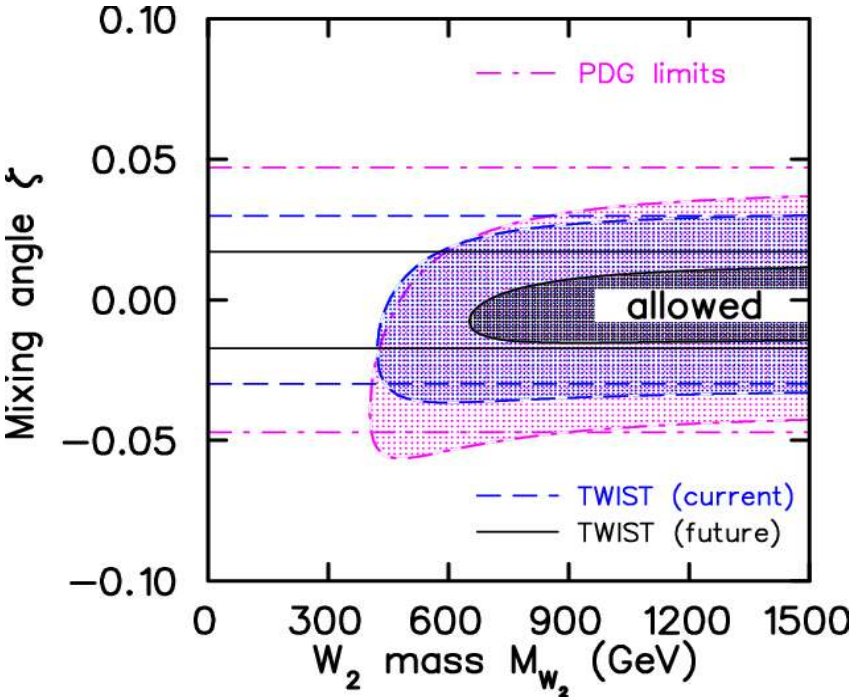
- ξ and δ limit the probability of a right-handed muon decaying into any handed positron:

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

– $P_\mu\xi$ sets limit on mass and mixing parameter in Left-Right Symmetric Models:

$$1 - \mathcal{P}_\mu\xi = 4\{\zeta^2 + \frac{M_1^4}{M_2^4} + \zeta\frac{M_1^2}{M_2^2}\}$$

$$\frac{3}{4} - \rho = \frac{3}{2}\zeta^2$$



Status of $P_\mu\xi$ Measurement

- Direct measurements:
  - $P_\mu\xi = 1.0027 \pm 0.0079 \pm 0.0030$

    Beltrami et al, PL B194 (1987)

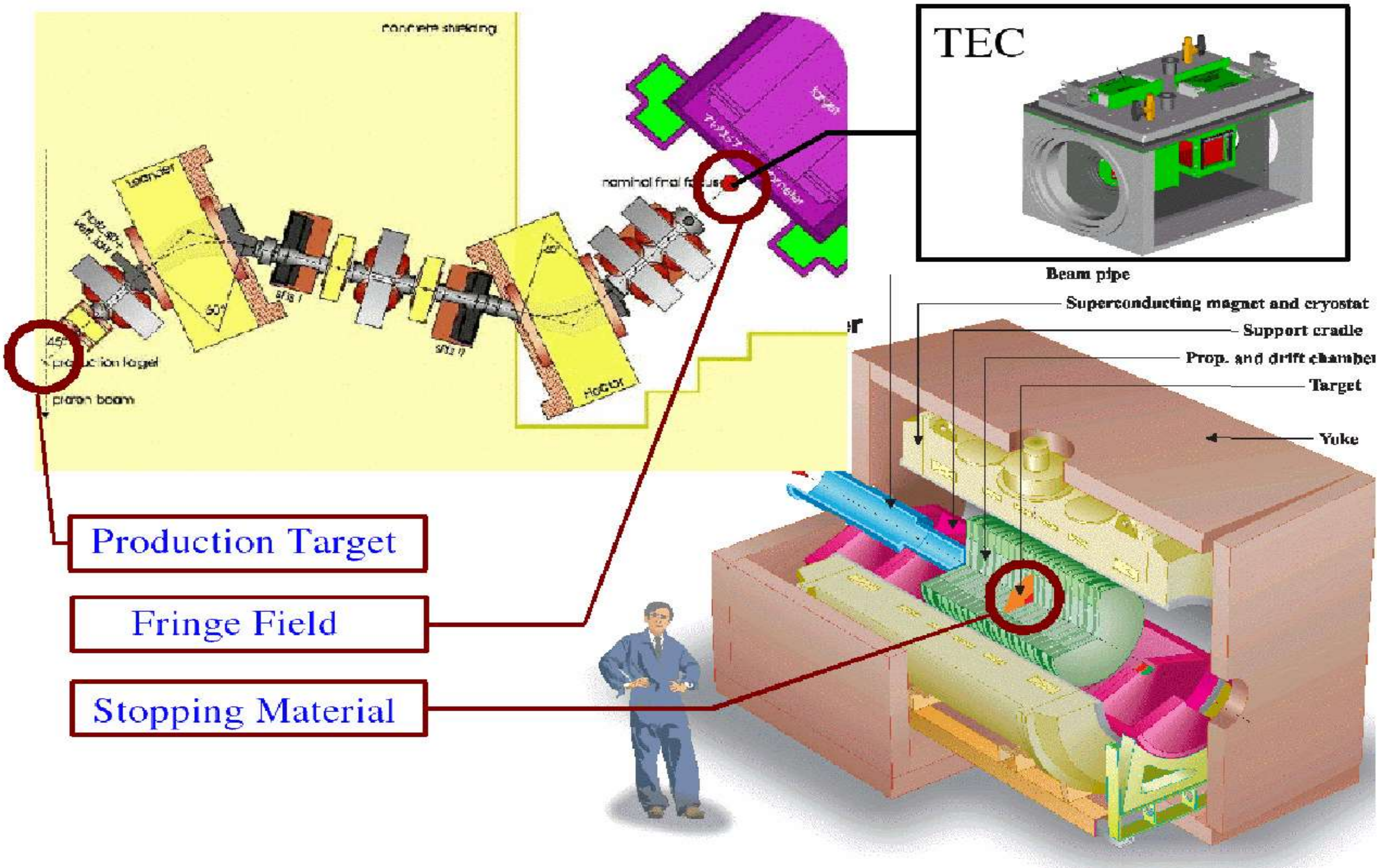
  - $P_\mu\xi\delta/\rho > 0.99682$ (90% *c.l.*)

    Jodidio et al, PR D34, PR D37 (1986)

- Indirect measurement:
  - $0.9960 < P_\mu\xi < \xi < 1.0040$ (90% *c.l.*)

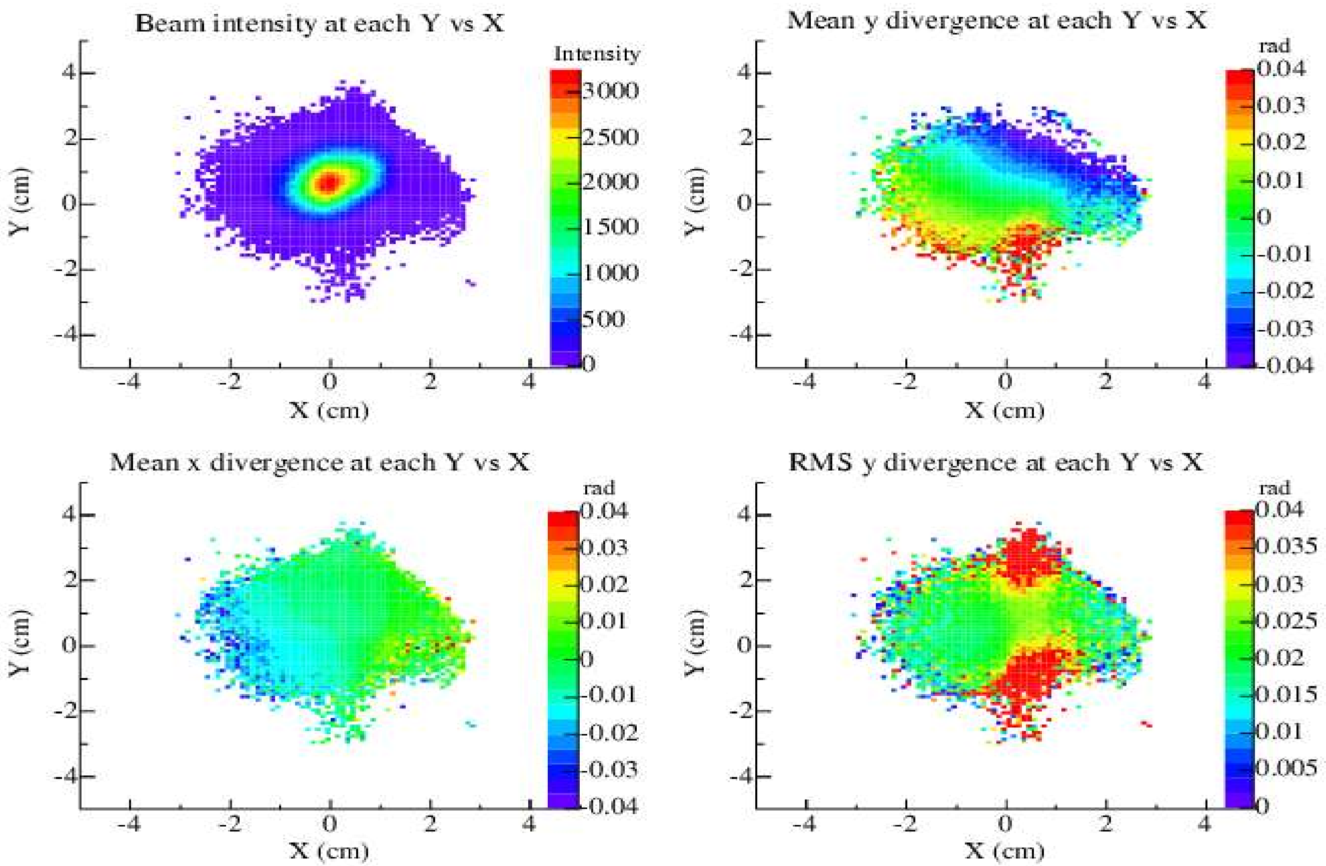
    TWIST, PRL 94, 101805 + PRD 71, 071101(R)

Experimental Setup



Muon Beam Characterization: Time Expansion Chamber

- 2 modules measure μ beam positions & divergences in X & Y directions.
- uncertainty in tracking: Δx = 270.0 μm, $\Delta\theta$ = 3.0 mrad
- uncertainty in TEC position: Δx = 2 mm, $\Delta\theta$ = 5.0 mrad



Evaluation of Systematic Uncertainties

Methodology

- Take data set or generate Monte Carlo runs under a condition that exaggerates possible sources of systematic error.
- Measure the effect on (ρ, η, ξ, $\xi\delta$) by fitting two correlated data sets.
- Scale the effect by exaggeration factor.

Example

- Drift chamber time zero (t_0) might change during the data taking. What is the uncertainty in $P_\mu\xi$ due to the t_0 variation?
  - analyze a data set with t_0 before the data collection (t_0^{begin}).
  - analyze the same data with $t_0^{begin} + 10\text{x}(t_0^{end} - t_0^{begin})$ (10x exaggeration).
  - fit to each other: $\Delta P_\mu\xi = 8.9 \times 10^{-3}$
  - divide the shift by exaggeration factor.

Summary of Systematic Uncertainties

- Muon Beam & Polarization		3.69
fringe field	3.40	
stopping target	1.40	
production target	0.21	
- Chamber Response		0.98
t0 variations	0.89	
foil bulges	0.22	
cell asymmetry	0.22	
up-down efficiency	0.19	
density	0.17	
- Spectrometer Alignment		0.31
rotations	0.22	
z position	0.22	
B field to axis	0.03	

- Positron Interactions		0.30
hard interactions	0.29	
multiple scattering	0.08	
outside material	0.02	
- Momentum Calibration		0.19
endpoint fits	0.16	
B field uniformity	0.09	
- Radiative Corrections		0.10

Total Systematic Uncertainty:

3.80×10^{-3}

Why is the Contribution from Fringe Field Big?

- Beam measurement by the TEC is not precise
  - TEC efficiency is low, which causes a big uncertainty in the angle measurement and a bias in the position measurement.
  - TEC calibration is not prefect.
  - TEC alignment to the drift chamber is not monitored.

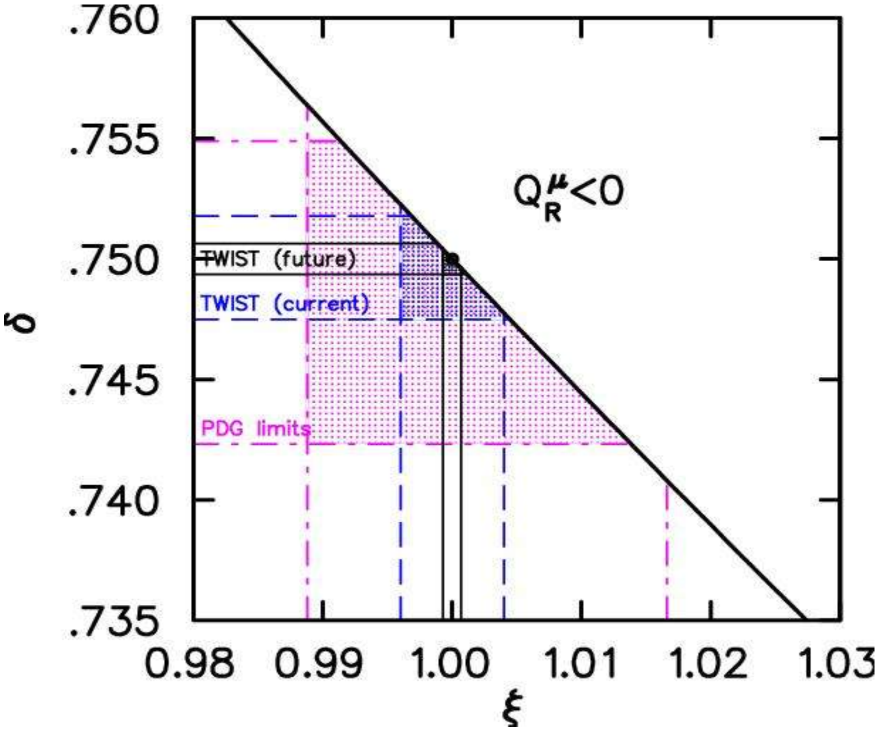
- Beam characterization runs are not consistent
  - runs with "same settings" see a large difference in θ_y.

Run	B2(G)	$\overline{x}$(cm)	$\overline{y}$(cm)	$\overline{\theta_x}$(mrad)	$\overline{\theta_y}$(mrad)	P_μ^{MC}
18820	949	0.85	-1.1	0.87	-5.0	0.9955
18825	944	0.07	-5.9	0.97	7.0	0.9929
20565	949	0.94	-1.5	0.64	-19.2	0.9922
20558	944	0.06	-6.7	0.73	-11.2	0.9941

Result and Its Implication

$P_\mu \xi$ = 1.0003 ± 0.0006 (stat) ± 0.0038 (syst)

- Consistent with the Standard Model prediction of 1. Reduces the uncertainty by about a factor of two on the current PDG value = 1.0027 ± 0.0079 ± 0.0030.
- Set new limits on muon handedness: $Q_R^\mu = \frac{1}{2}(1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta)$



Summary and Outlook

- TWIST has completed its first direct measurement of $P_\mu\xi$ with 2004 data. The result reduces the uncertainty by a factor of ~2 on the PDG value.
- Largest systematic error is due to fringe field depolarization. Main reason is understood now. Improvements to the detector and beam line systems were made in 2005 data.
  - better calibration procedure
  - TEC alignment was carefully monitored and well determined
- Anticipation to improve $P_\mu\xi$ measurement by another factor of 2 in the future should be reasonable .

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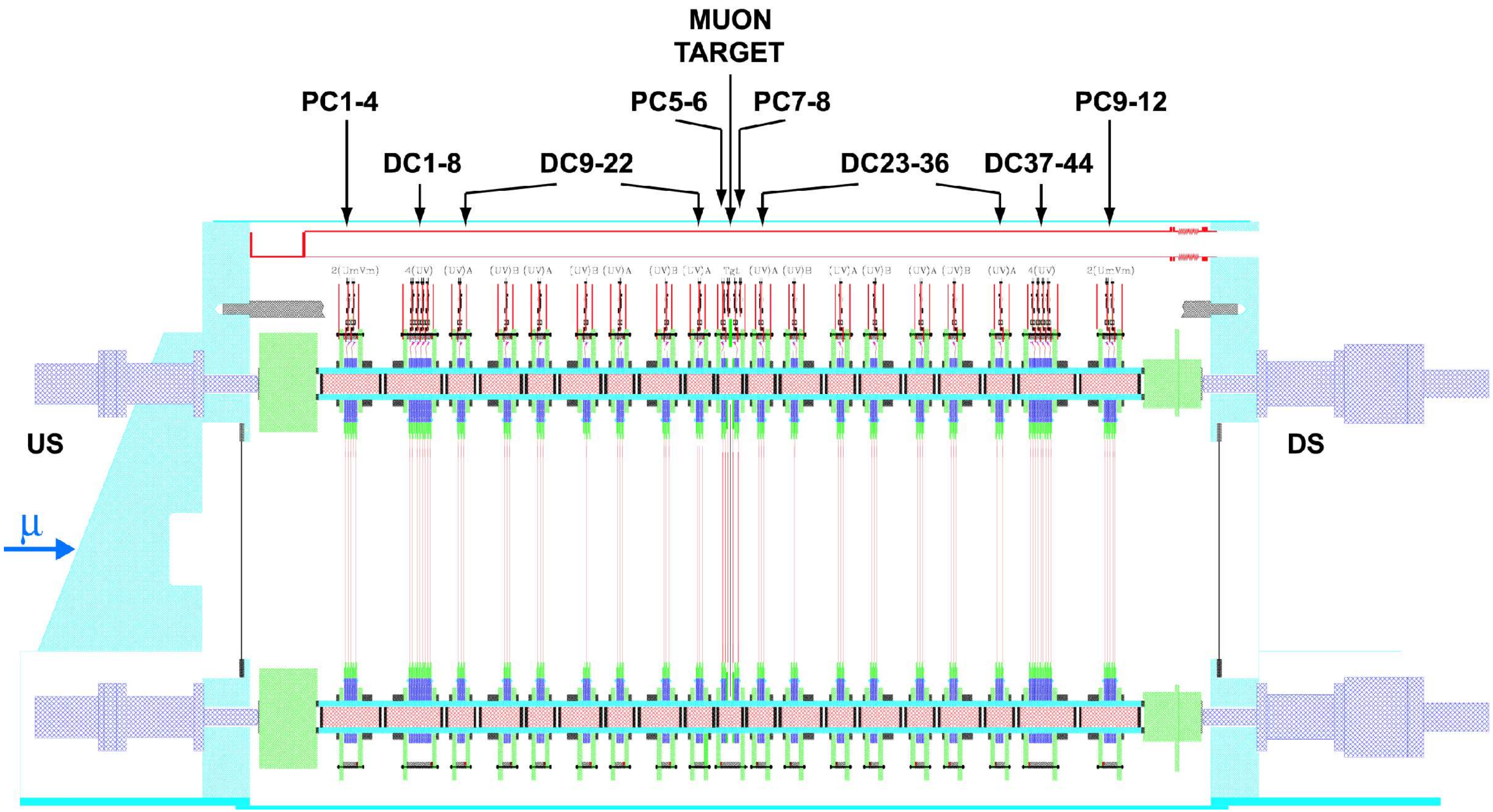
Extra Slides

Analysis Strategy

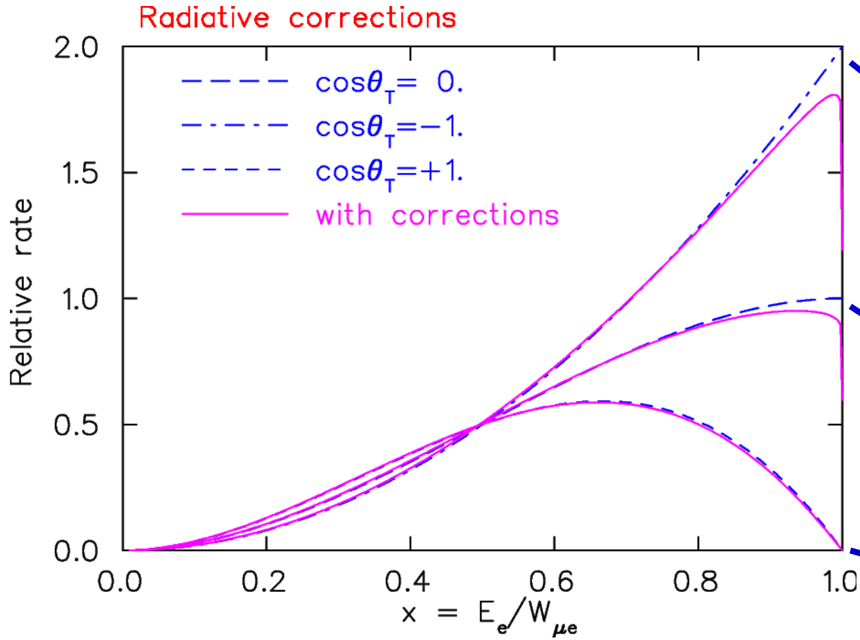
- Measure energy and angular distribution of decay positron
  - Reconstruct e^+ track with helix fit and take into account multiple scattering and field non-uniformity.
  - Calibrate e^+ energy to kinematic end point.
- Simulate detector acceptance with GEANT3
  - GEANT3 geometry contains virtually all detector components.
  - simulate detector response in detail (match TDC shape).
  - realistic, measured beam profile and divergence.
  - muon pileup and beam e^+ contamination.
- Extract Michel Parameters with blind analysis technique
  - Monte Carlo data are generated using unknown, hidden values of (ρ, η, ξ, $\xi\delta$).
  - Final result kept hidden until the analysis is completed and systematic uncertainties evaluated.

Detector Array



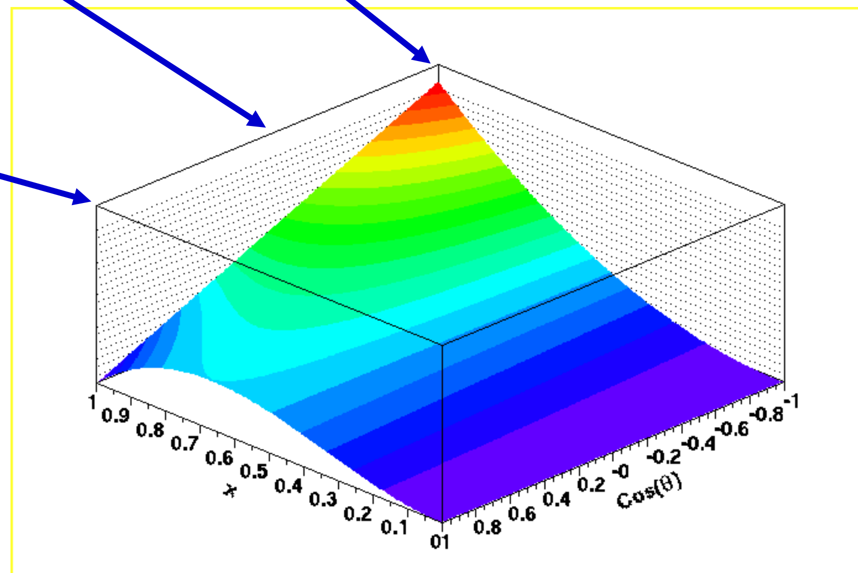
- 56 chambers (44 DC+12 PC planes) symmetrically placed around the target.
- All planes precisely aligned rotationally and translationally.
- Beam stopping position carefully controlled by variable CO_2/He gas degrader.

Radiative Corrections



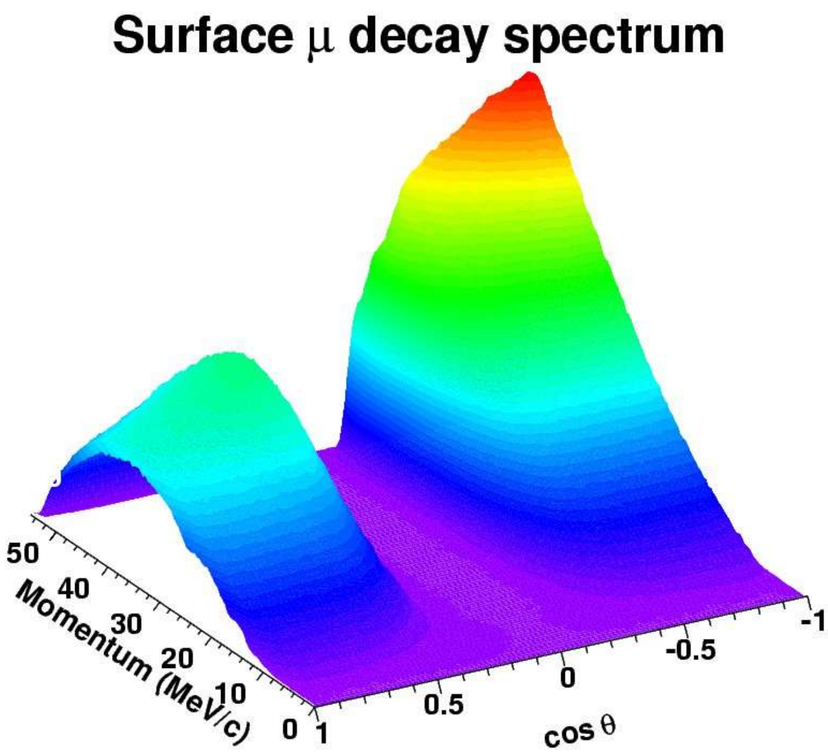
Arbuzov et al., Phys. Rev. D66 (2002) 93003.

Arbuzov et al., Phys. Rev. D65 (2002) 113006.

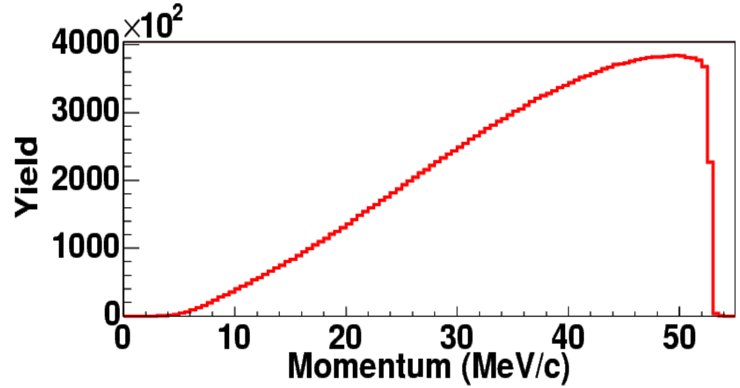


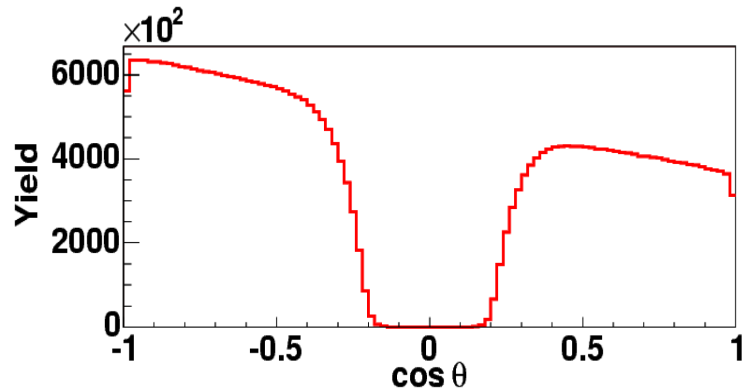
- Full O(α) radiative corrections with exact electron mass dependence.
- Leading and next-to-leading logarithmic terms of O(α^2).
- Leading logarithmic terms of O(α^3).
- Corrections for soft pairs, virtual pairs, and an ad-hoc exponentiation.

Data Distribution



Acceptance of **TWIST** spectrometer





Extract the Michel Parameters

- Michel distribution is linear in ρ, η, ξ, and $\xi\delta$, so a fit to first order expansion is exact.

$$n_i(\alpha_{\rm data}) = n_i(\alpha_{\rm MC}) + \frac{\partial n_i}{\partial \alpha}\Delta\alpha,$$
$$\alpha = [\rho, \eta, \xi, \xi\delta]$$

- Fit data (α_{data}) to sum of a base MC distribution (α_{MC}) plus MC-generated derivative distributions times fitting parameters ($\Delta\alpha$) representing deviations from base MC.

- Can also fit data to data and MC to MC for systematic tests.