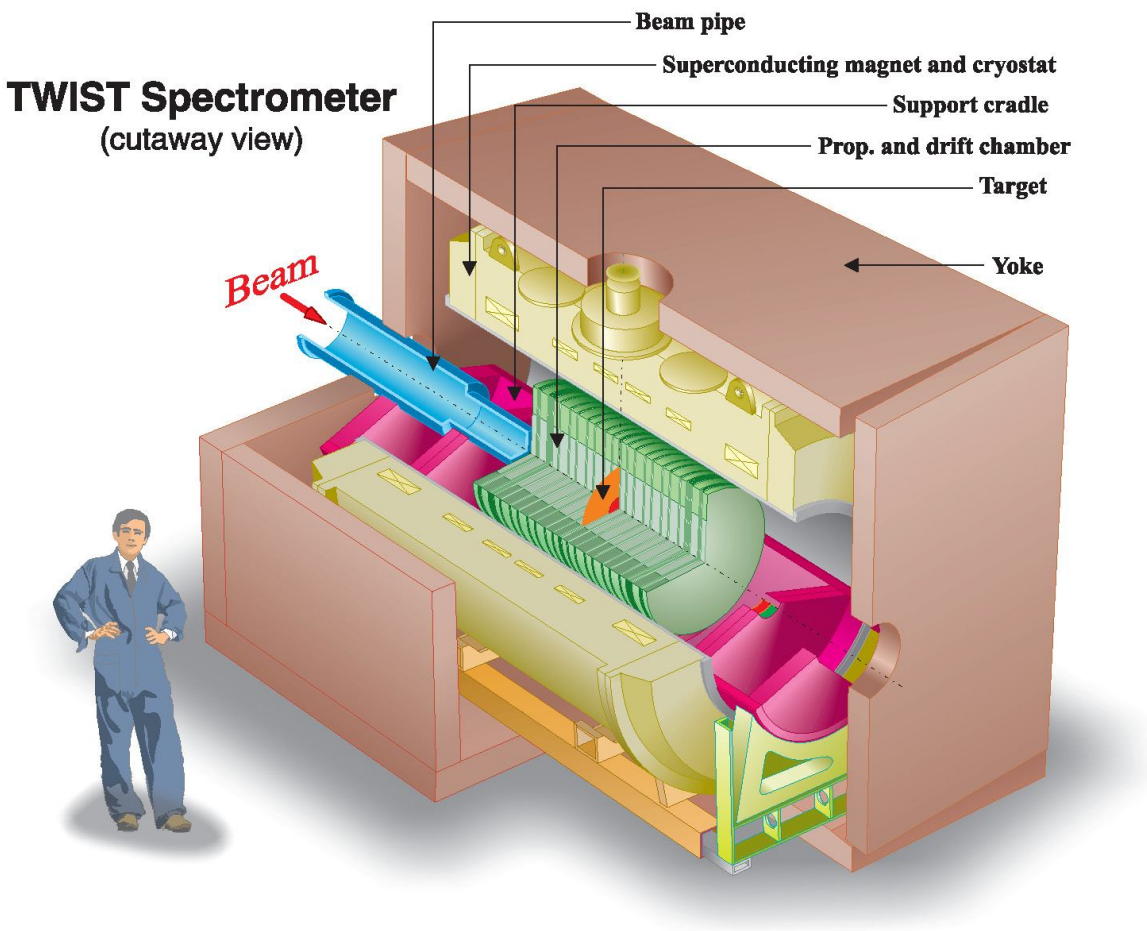
TWIST Results

CIPANP 2009, San Diego

James Bueno, University of British Columbia
on behalf of the TWIST collaboration

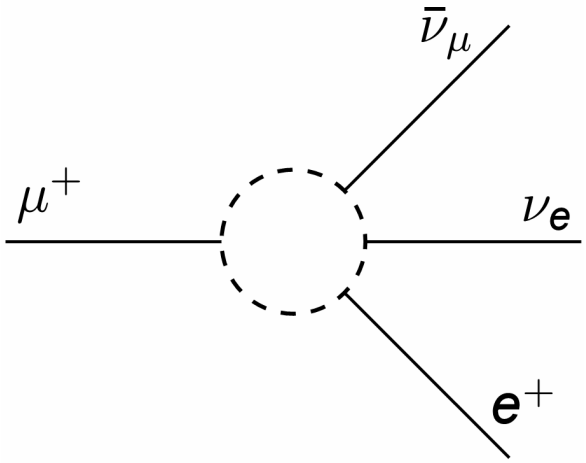
The TWIST experiment



Nucl. Instr. and Meth. A548 (2005) 306-335

- **T**riumf **W**eak **I**nteraction **S**ymmetry **T**est.
- Highly polarized μ^+ stopped in centre of symmetric detector.
- e^+ tracked in uniform magnetic field.
- Measures muon decay parameters by comparison to a detailed GEANT3 simulation.
- New data acquired in 2006/2007. Analysis is ongoing.

Muon decay



General 4-fermion interaction:

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

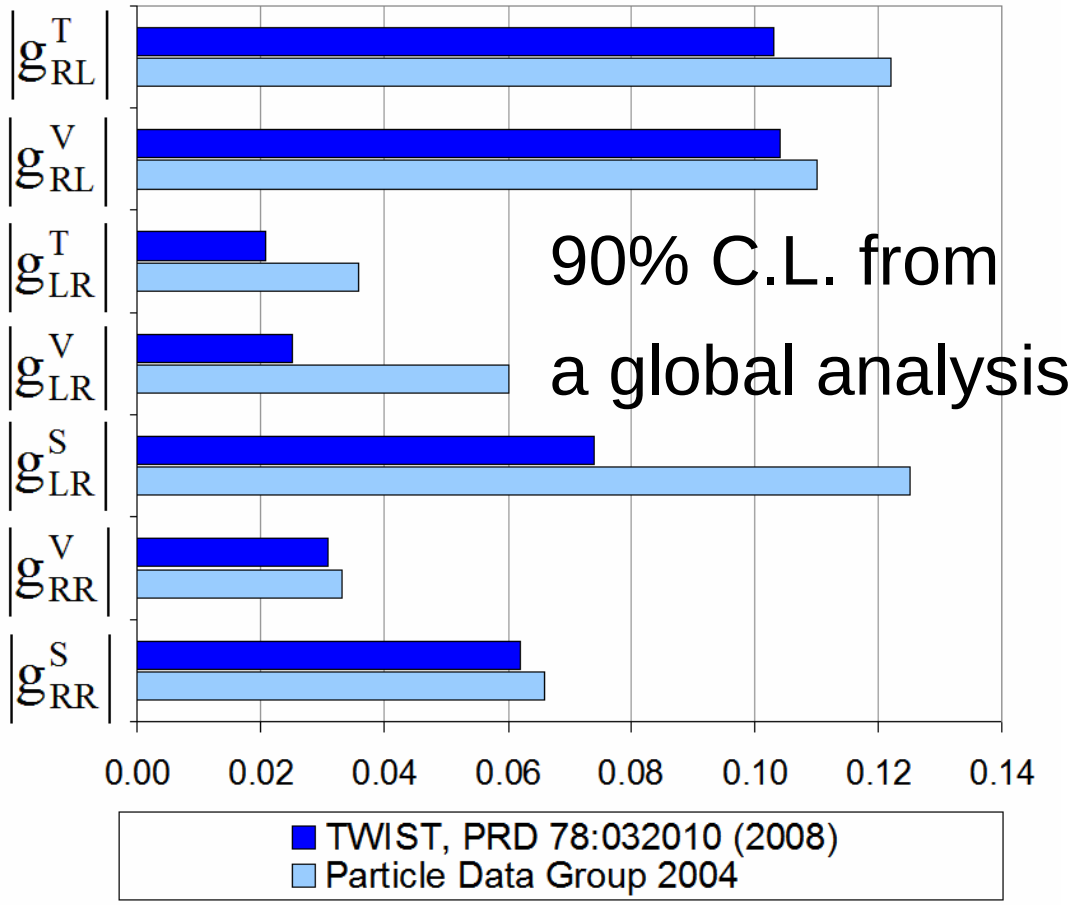
$$\epsilon, \mu = R, L$$

Standard Model ("V-A"):

$g^{V}_{LL} = 1$, all others zero

Experimentally:

$\left| g^{V}_{LL} \right| > 0.96$ @ 90% C.L.

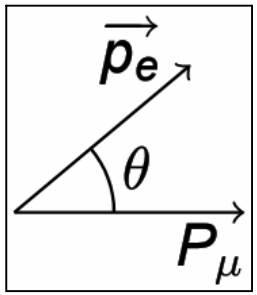


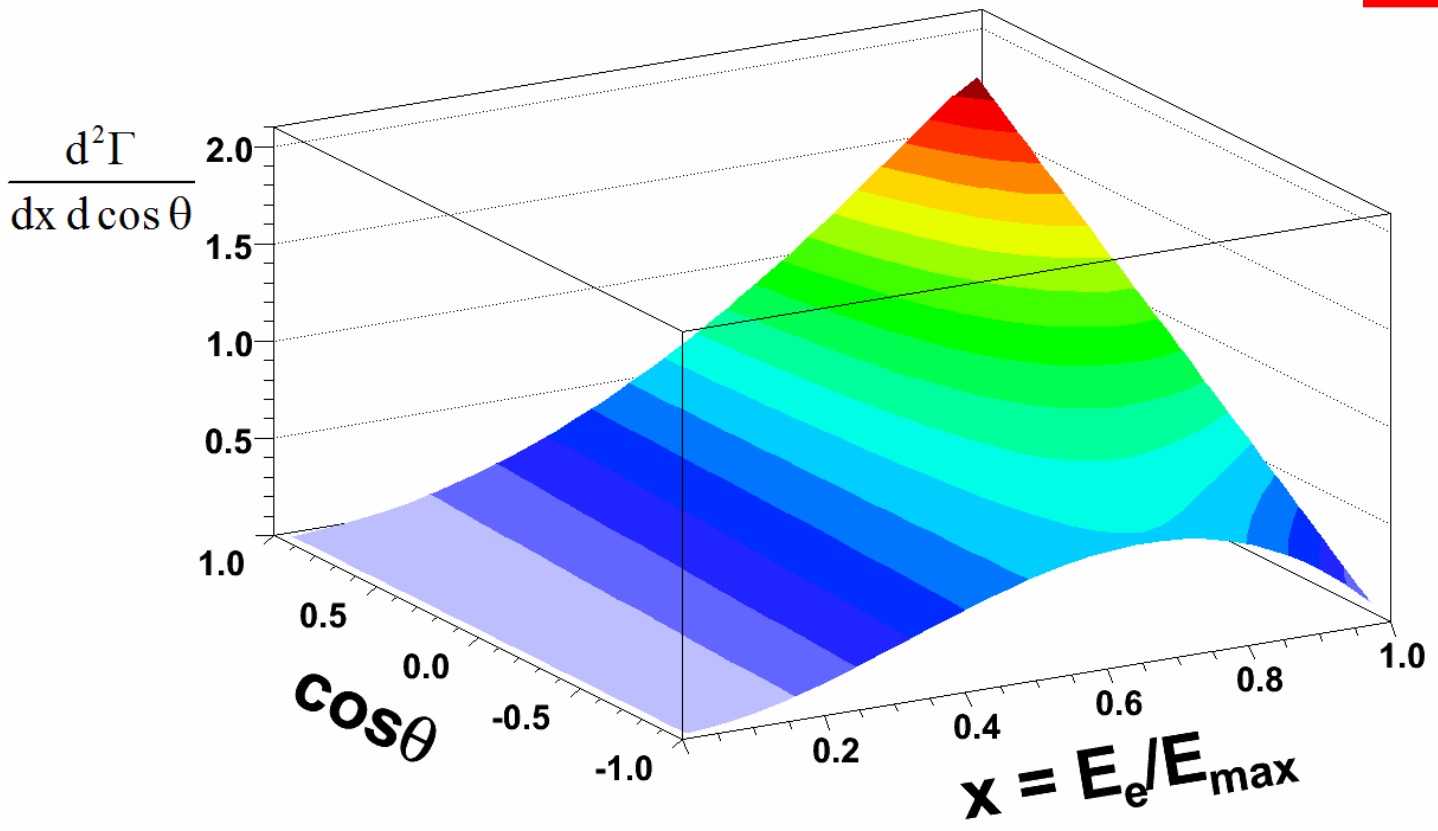
Decay spectrum

When e^+ polarization not detected, spectrum is described by four muon decay parameters (bilinear combinations of $g^{\gamma}_{\varepsilon\mu}$'s)

$$\frac{d^2\Gamma}{dx\ d\cos\theta} = \frac{1}{4} m_\mu W_{\mu e}^4 G_F^2 \sqrt{x^2 - x_0^2}\cdot$$

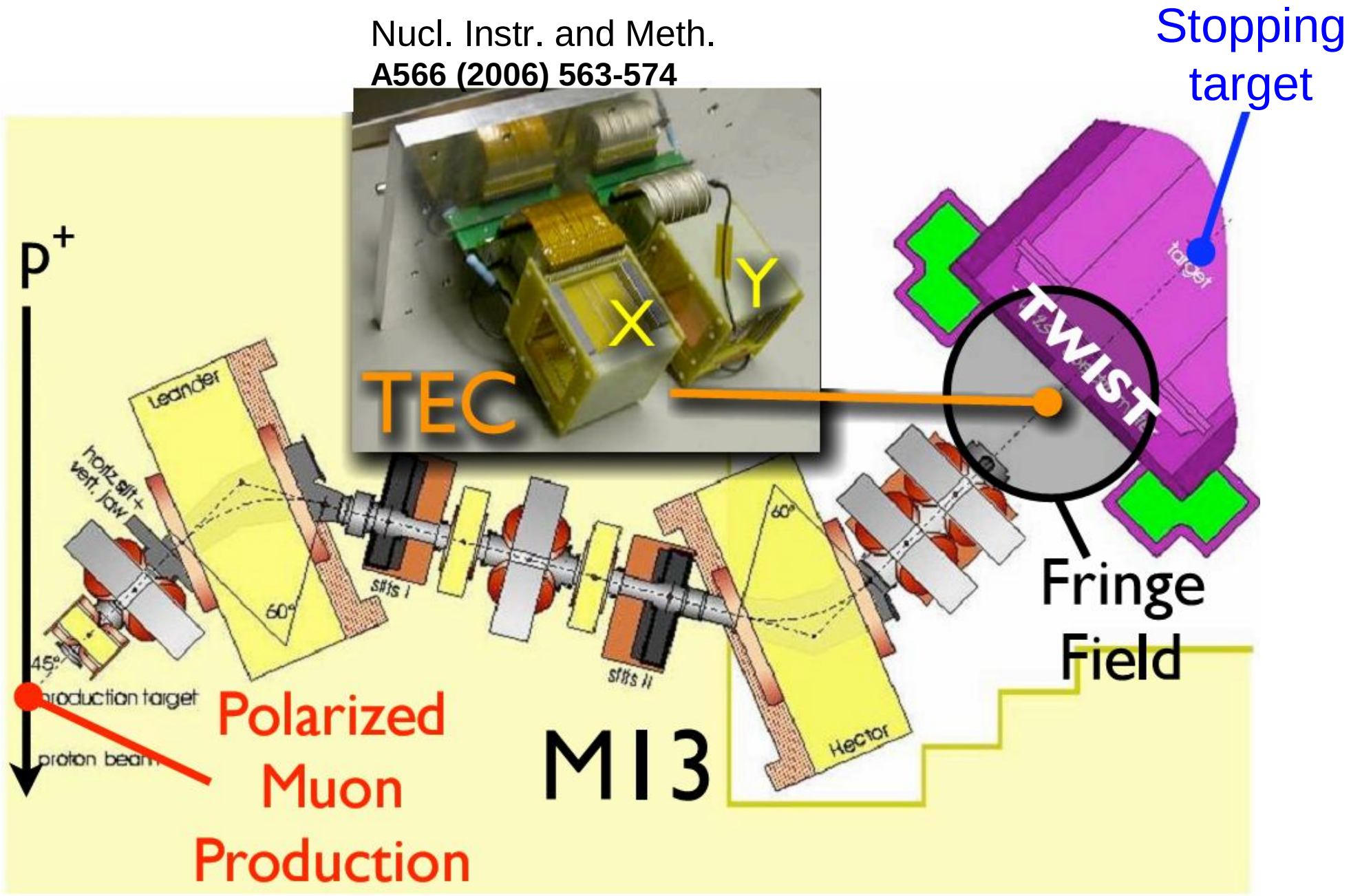
$$\{\mathcal{F}_{IS}(x,\rho,\eta) + \mathcal{P}_\mu \cos\theta \cdot \mathcal{F}_{AS}(x,\xi,\delta)\} + R.C.$$



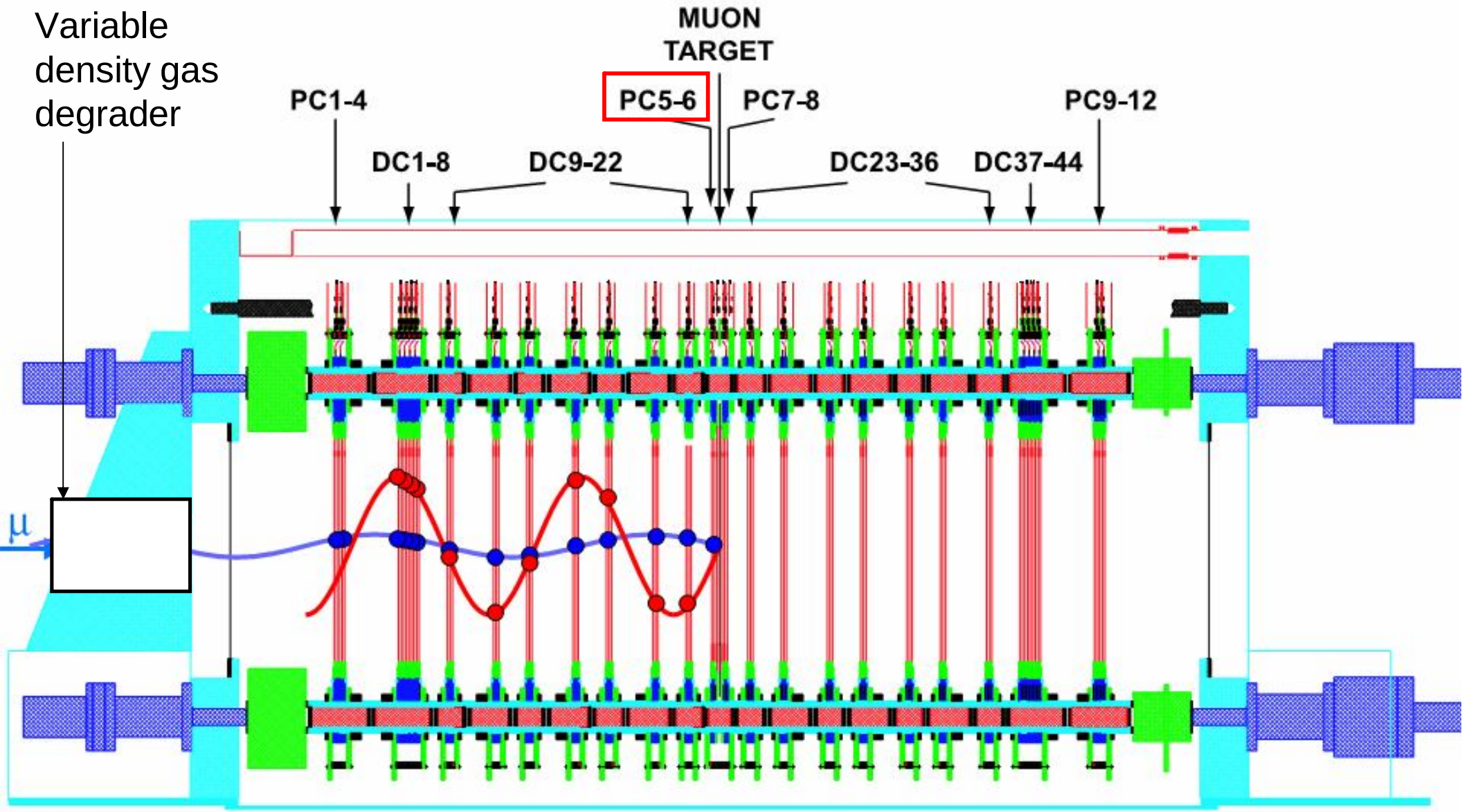


TWIST experiment: muon delivery

Nucl. Instr. and Meth.
A566 (2006) 563-574



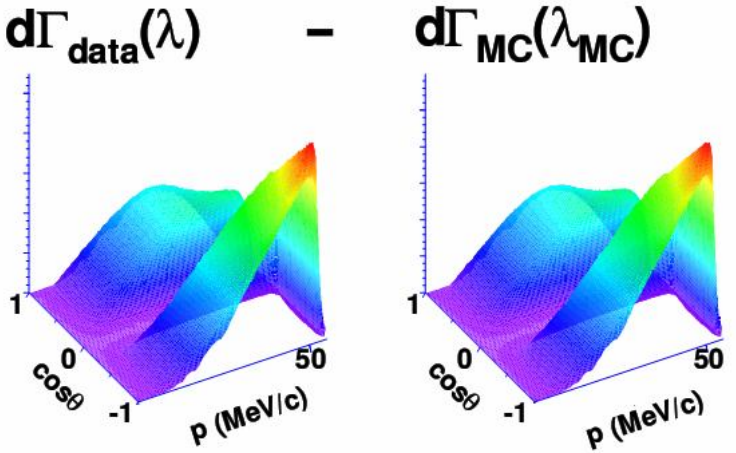
TWIST experiment: spectrometer



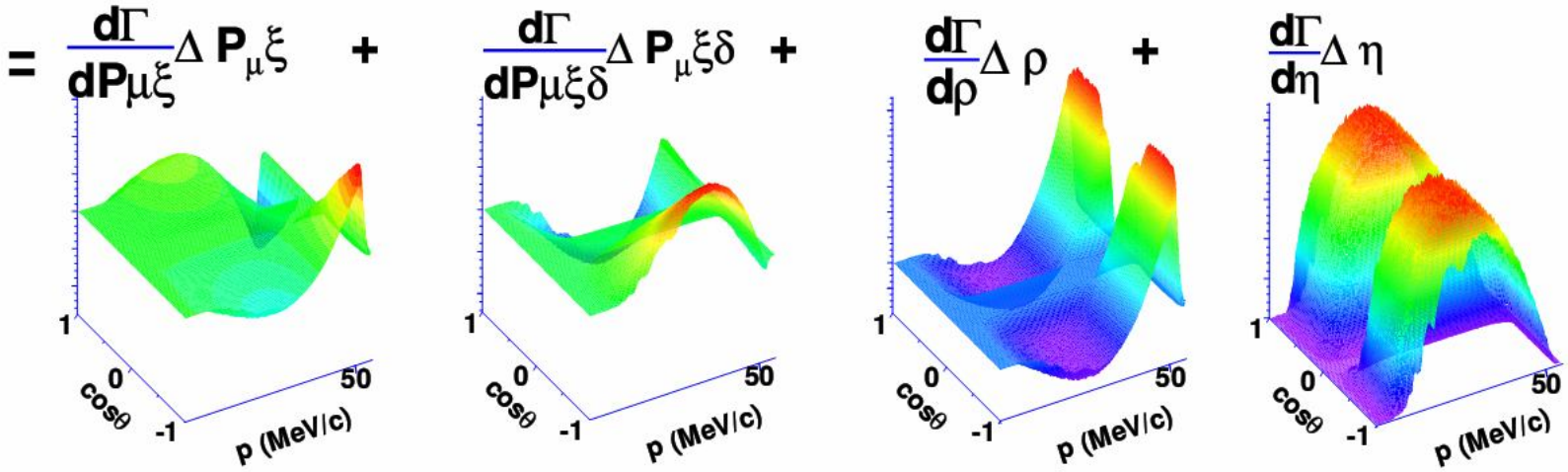
Nucl. Instr. and Meth. A548 (2005) 306-335

TWIST experiment: analysis

- Data compared to GEANT3 simulation with hidden decay parameters.

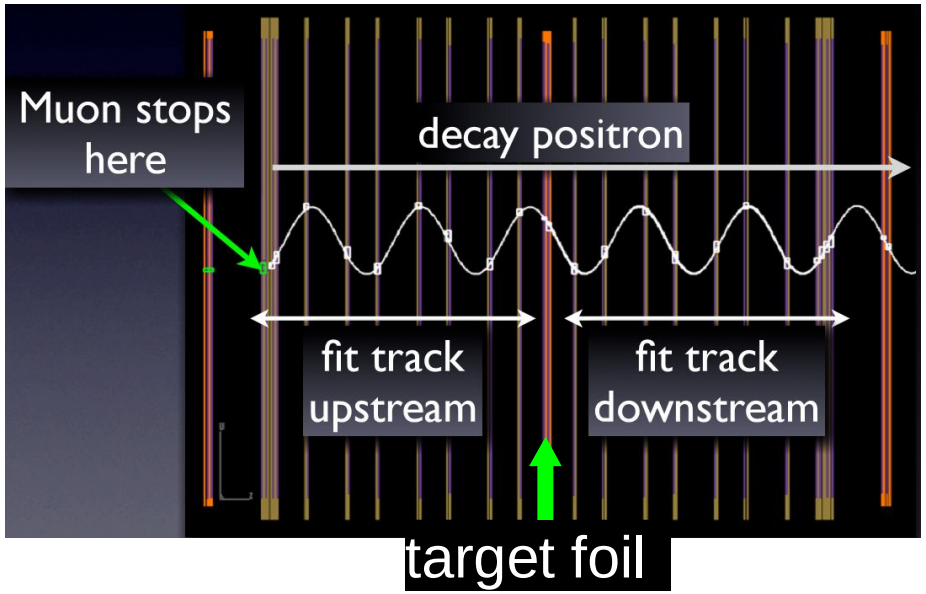


- Spectrum is linear in $P_\mu\xi$, $P_\mu\xi\delta$, ρ, η
- Differences from hidden parameters are measured.

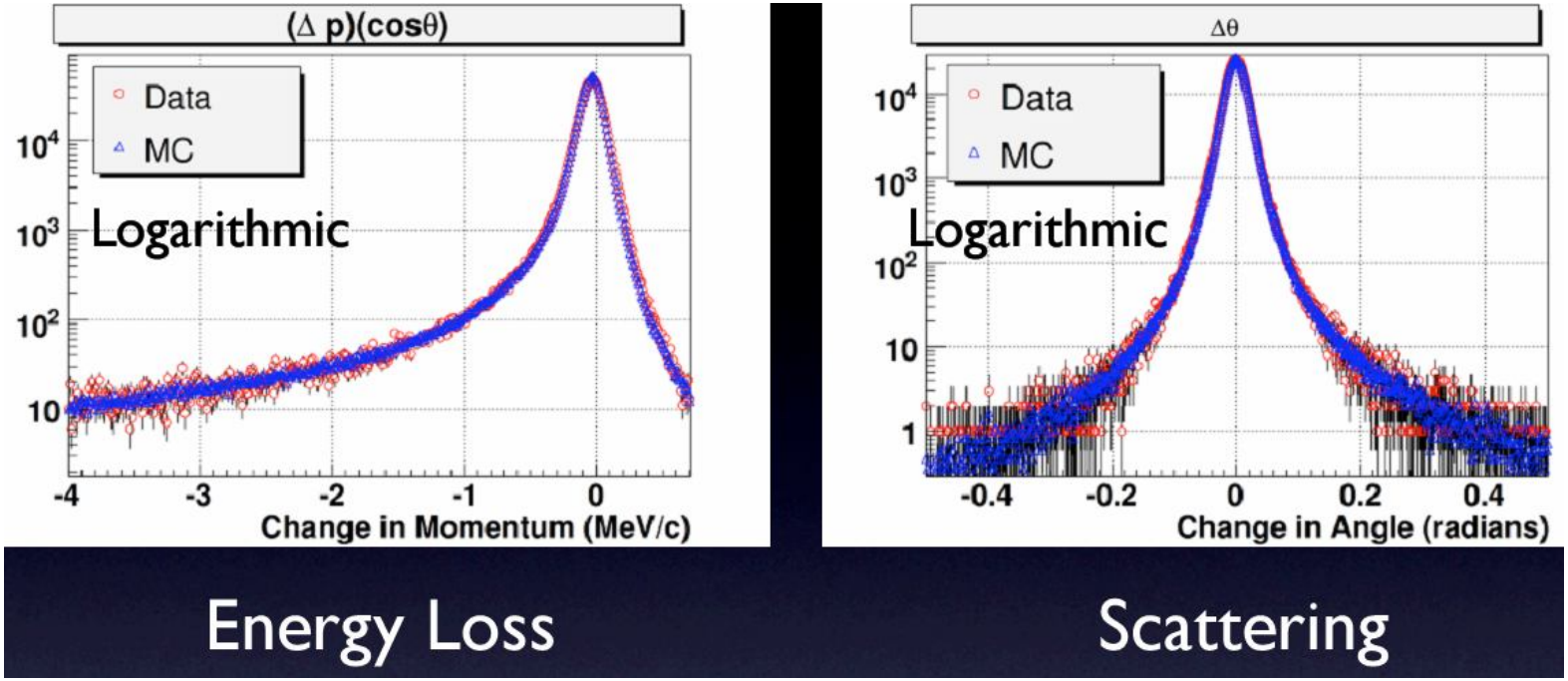


- Hidden parameters are revealed after systematic uncertainties evaluated.

Validation of GEANT3 simulation

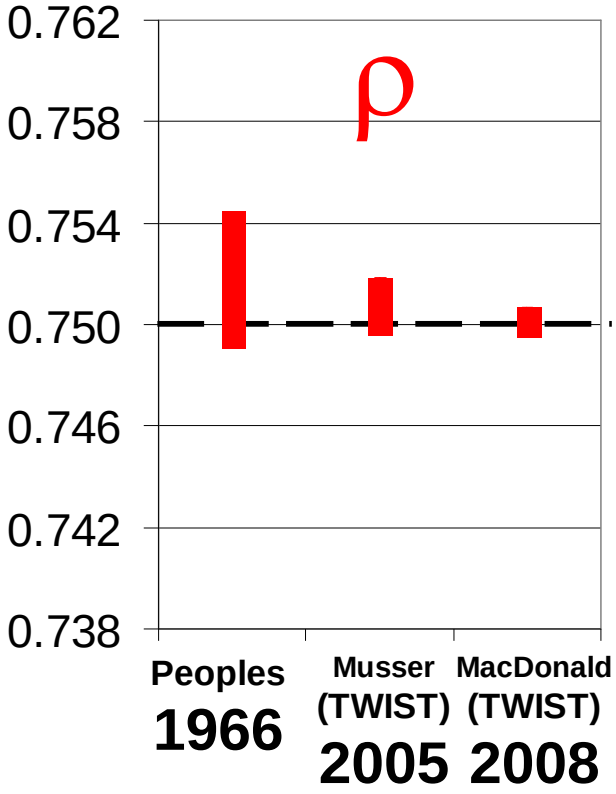


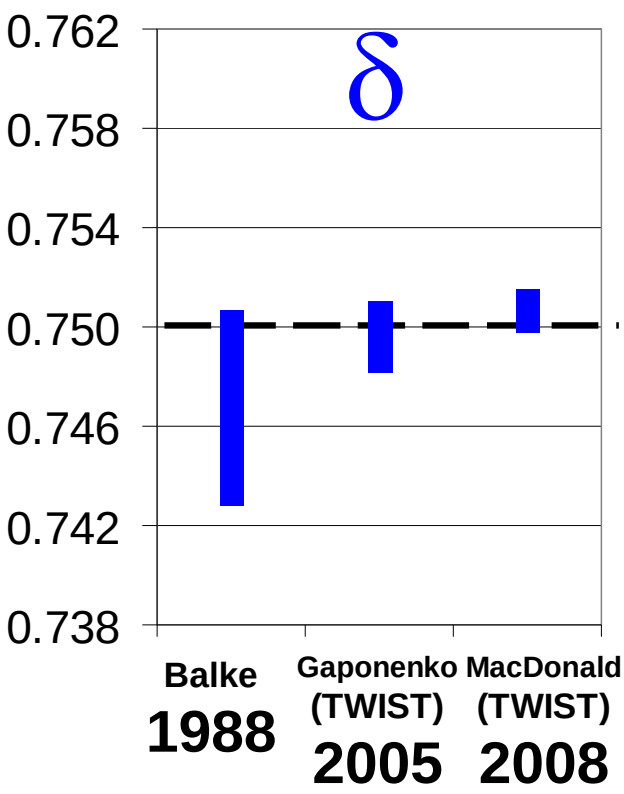
- e^+ reconstructed in each half of the detector.
- Energy loss and scattering angle are compared between data and simulation.

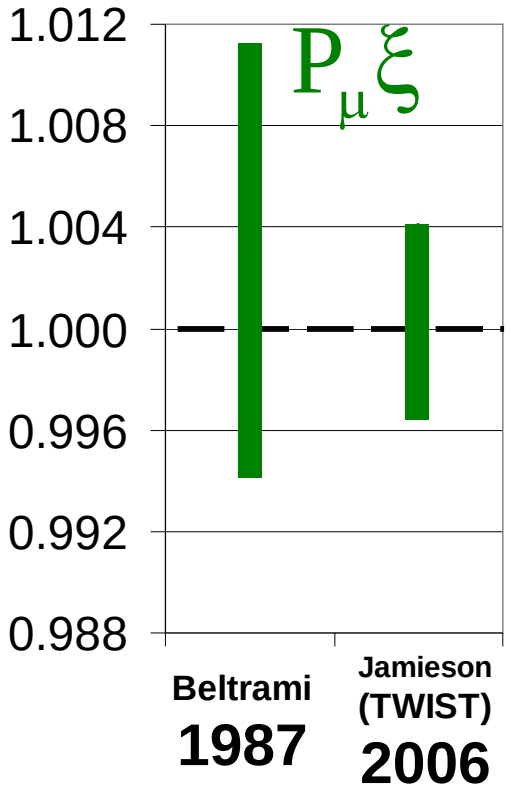


No tuning of physics processes in GEANT3 was needed.

Measurements







$$\rho = 0.75014 \pm 0.00017\,(\text{stat.}) \pm 0.00046\,(\text{syst.}) \pm 0.00011\,(\eta)$$

$$\delta = 0.75068 \pm 0.00030\,(\text{stat.}) \pm 0.00067\,(\text{syst.})$$

$$P_\mu \xi = 1.0003 \pm 0.0006\,(\text{stat.}) \pm 0.0038\,(\text{syst.})$$

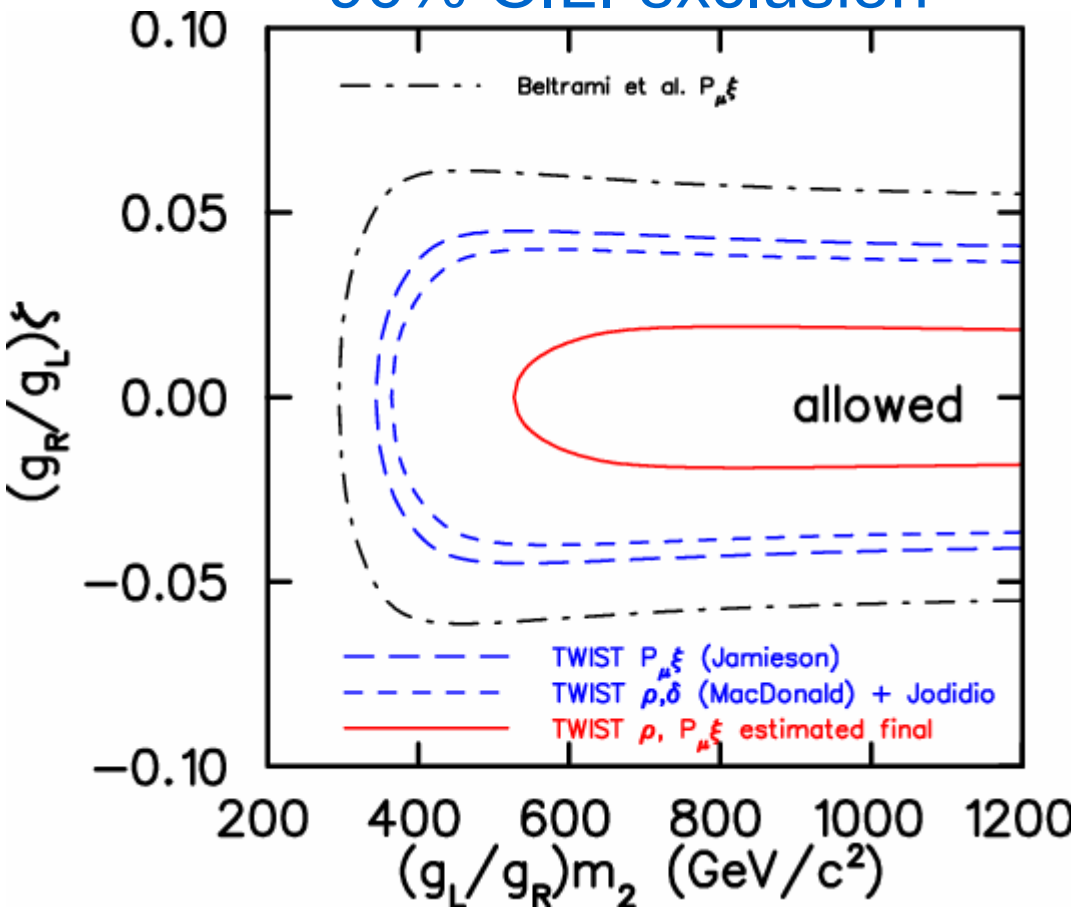
$P_\mu \xi \delta / \rho > 0.9975$ at 90% C.L. Phys. Rev. D 34, 1967 - 1990 (1986)

Left-right symmetric models

P. Herczeg, Phys. Rev. D 34, 3449 - 3456 (1986)

Parity conservation restored at higher energies by introducing a right-handed W.

90% C.L. exclusion



Weak interaction eigenstates (W_L, W_R) in terms of mass eigenstates (W_1,W_2) and mixing angle (ζ):

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

(Direct searches exclude $m_2 > 1$ TeV at 95% C.L., assuming $g_L = g_R$)

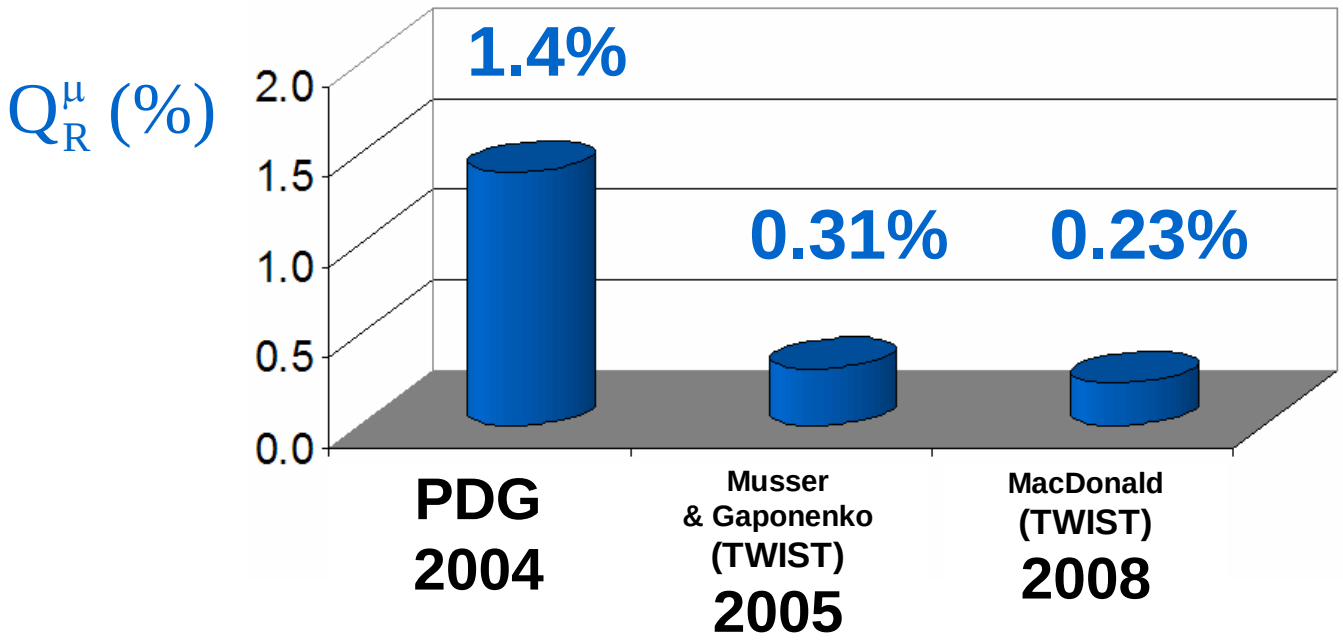
Phys. Rev. Lett. 100, 031804 (2008)

Right-handed muons

Probability of right handed muon decay,

$$\begin{aligned} Q_R^\mu &= Q_{RR} + Q_{LR} \\ &= \frac{1}{4}\left|g_{LR}^S\right|^2 + \frac{1}{4}\left|g_{RR}^S\right|^2 + \left|g_{LR}^V\right|^2 + \left|g_{RR}^V\right|^2 + 3\left|g_{LR}^T\right|^2, \\ &= \frac{1}{2}\left(1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta\right). \end{aligned}$$

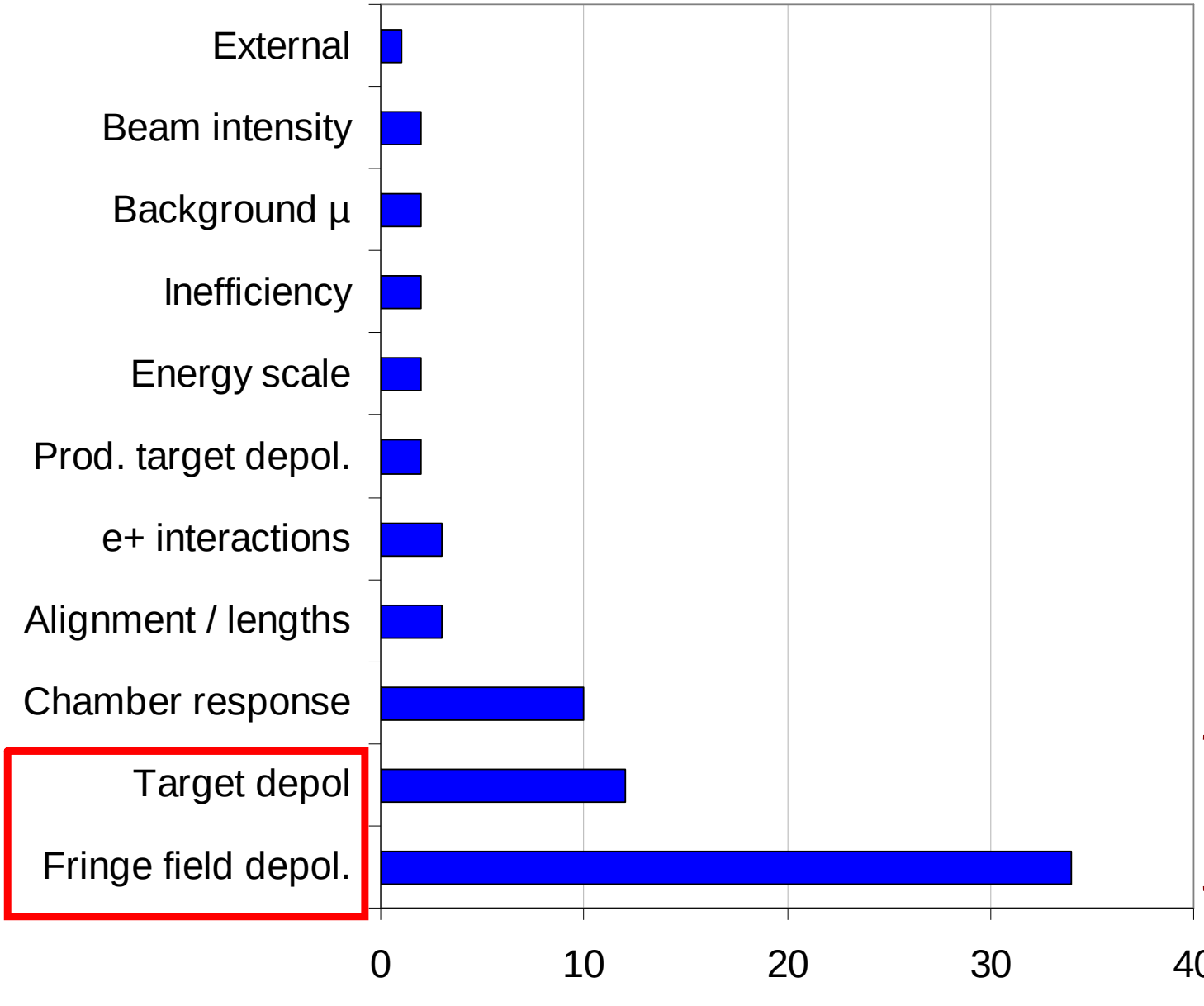
90% C.L. from global analysis



Final TWIST result could reduce limit to <0.15%

Systematic uncertainties for $P_\mu \xi$

Published: Phys. Rev. D 74, 072007 (2006)

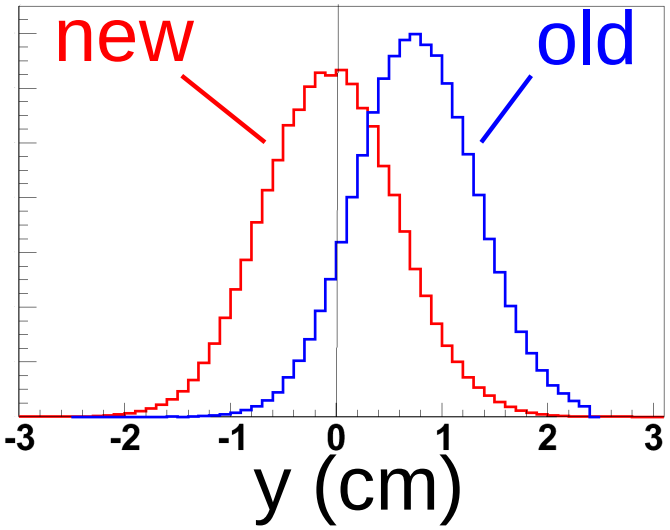


Final goal:
10×10^{-4}

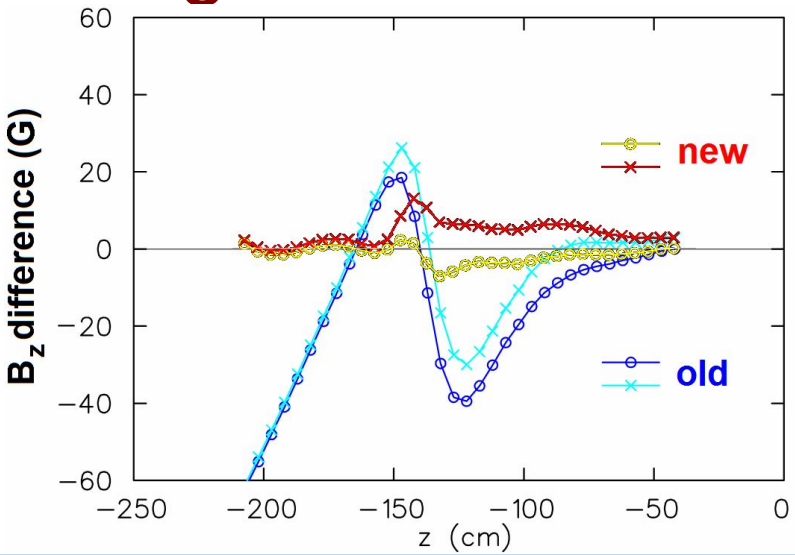
Polarization uncertainties dominate $P_\mu \xi$

Reducing the fringe field uncertainty

Beam steered on-axis



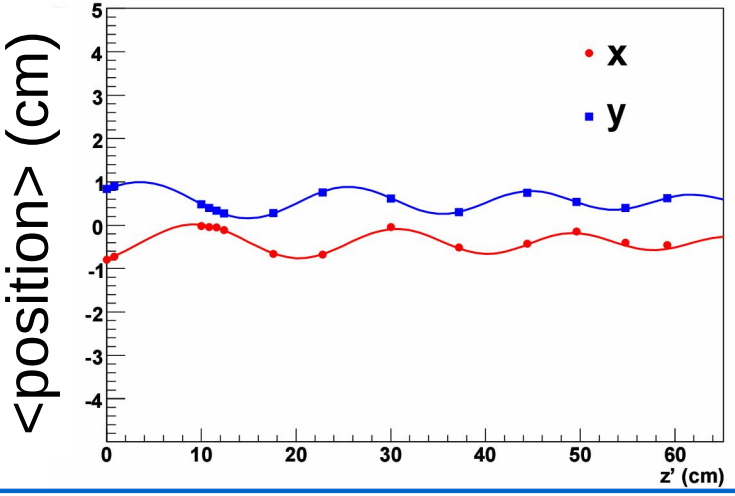
Fringe field corrected



Frequency of beam measurements increased

- Beginning and end of every data set (~1 week)
- TECs found to be reproducible to < 0.2 cm, < 3 mrad.
- TEC engineering also improved.

Average μ^+ trajectory used to monitor stability



Reducing target depolarization syst.

Theory review

In 2 Tesla longitudinal field, with high purity (>99.999%) metal targets, form is

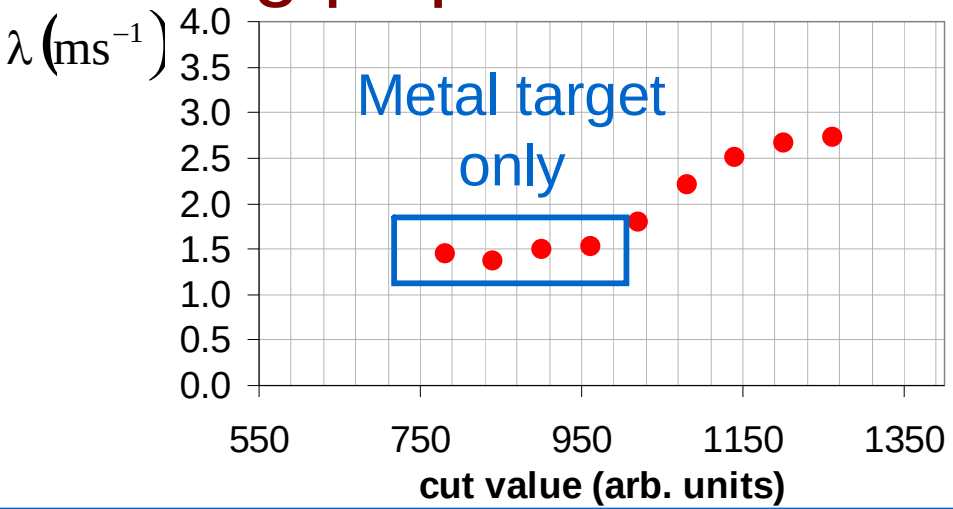
$$P_\mu(t) = P_\mu(0)\exp(-\lambda t)$$

(as long as μ^+ stop in target)

Increased statistics

	$\lambda\,(\mathrm{ms}^{-1})$	
	Previous	Now
Aluminum	1.6 ± 0.3	1.17 ± 0.06
Silver	-	0.72 ± 0.06

Selected μ^+ in metal using μ^+ pulse width



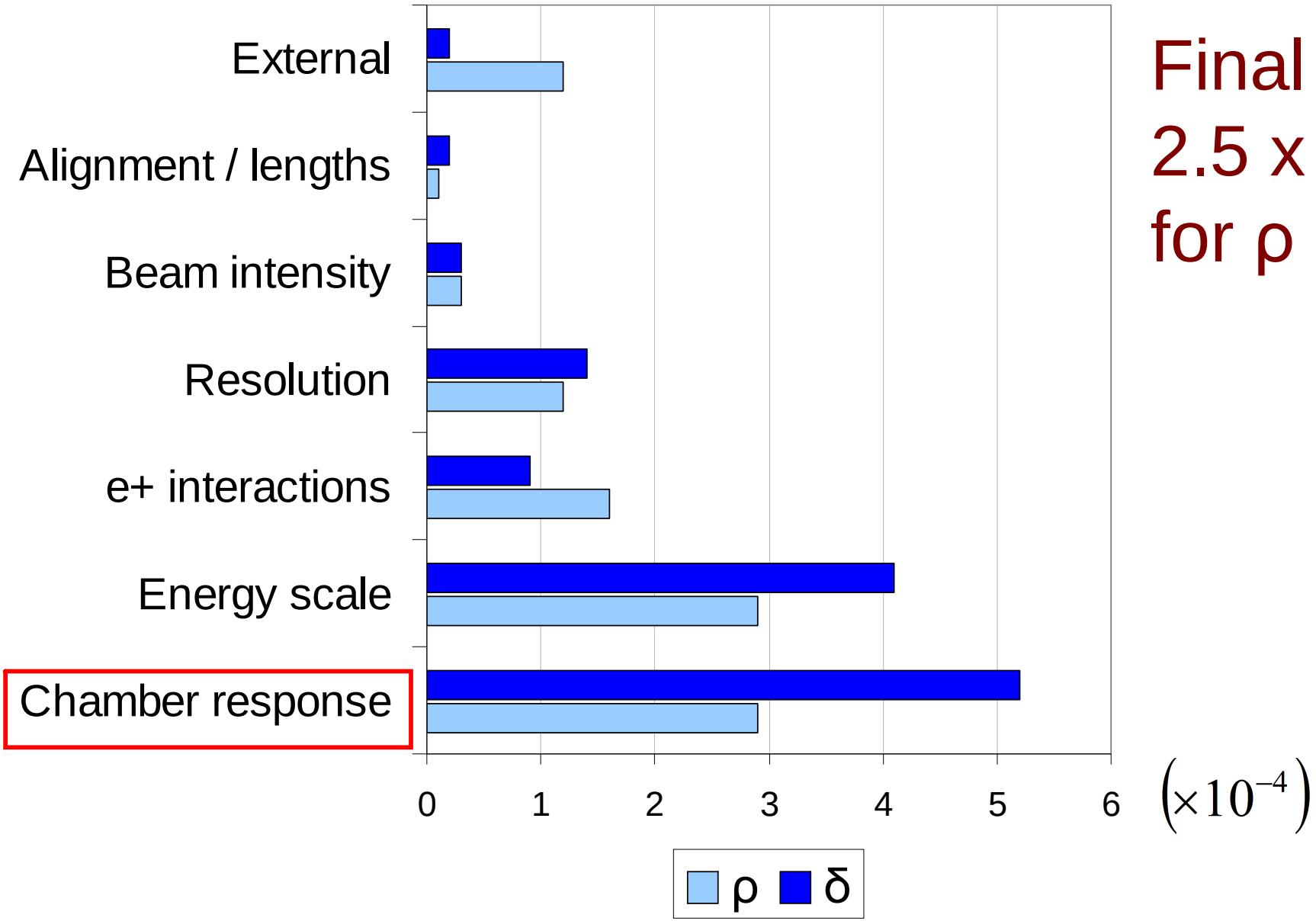
Subsidiary μ^+SR

- Found no "fast depolarization" down to 5 ns.
- Found consistent relaxation rates:

$$\lambda_{\mathrm{Al}} = (1.32 \pm 0.22(\mathrm{stat.}) \pm 0.28(\mathrm{syst.}))\,\mathrm{ms}^{-1},$$
$$\lambda_{\mathrm{Ag}} = (0.86 \pm 0.24(\mathrm{stat.}) \pm 0.21(\mathrm{syst.}))\,\mathrm{ms}^{-1},$$

Systematic uncertainties (without depol.)

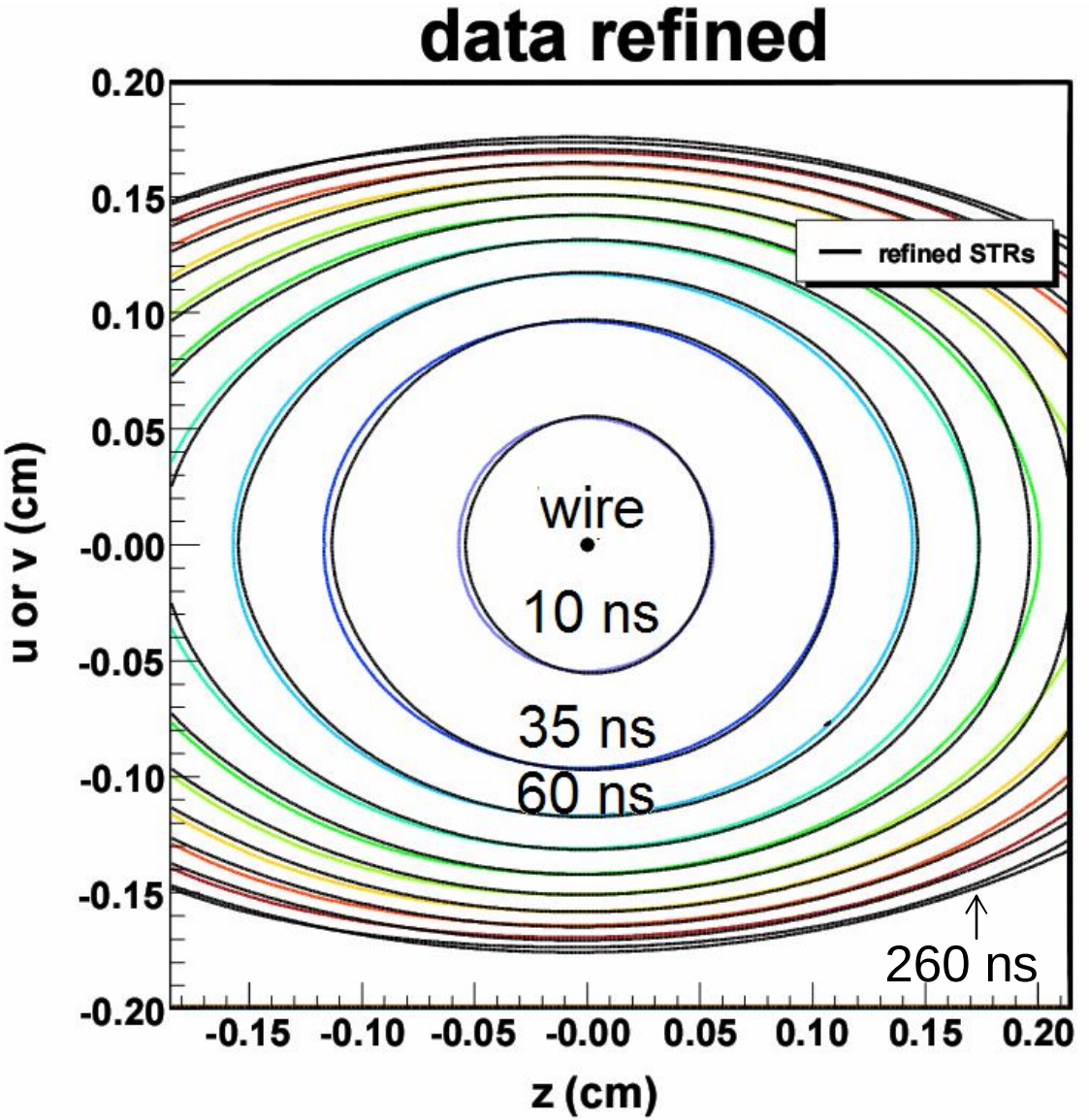
Published: Phys. Rev. D 78, 032010 (2008)



Final goal:
2.5×10^{-4}
for ρ and δ

Chamber response

Dominant systematic uncertainty for recent ρ, δ results.



- Space-time relationship from a simulation is now refined to minimize track fit residuals.
- Corrects for plane-to-plane construction differences, tracking bias.
- Changes are small but significant.
- No longer a dominant uncertainty.

Summary: final results expected early 2010

	Published		
	Statistics	Systematics	Improvement
ρ	1.7	4.4	**factor 5**
δ	3.0	6.7	**factor 5**
Pμ ξ	6.0	38.0	**factor 2**

⇦ over pre-TWIST

	Final (estimated)		
	Statistics	Systematics	Improvement
ρ	1.0	2.4	**factor 11**
δ	1.9	2.4	**factor 12**
Pμ ξ	2.4	10.0	**factor 8**

⇦ Still some challenges to overcome.

Units: 10^{-4}

The TWIST collaboration (http://twist.triumf.ca)

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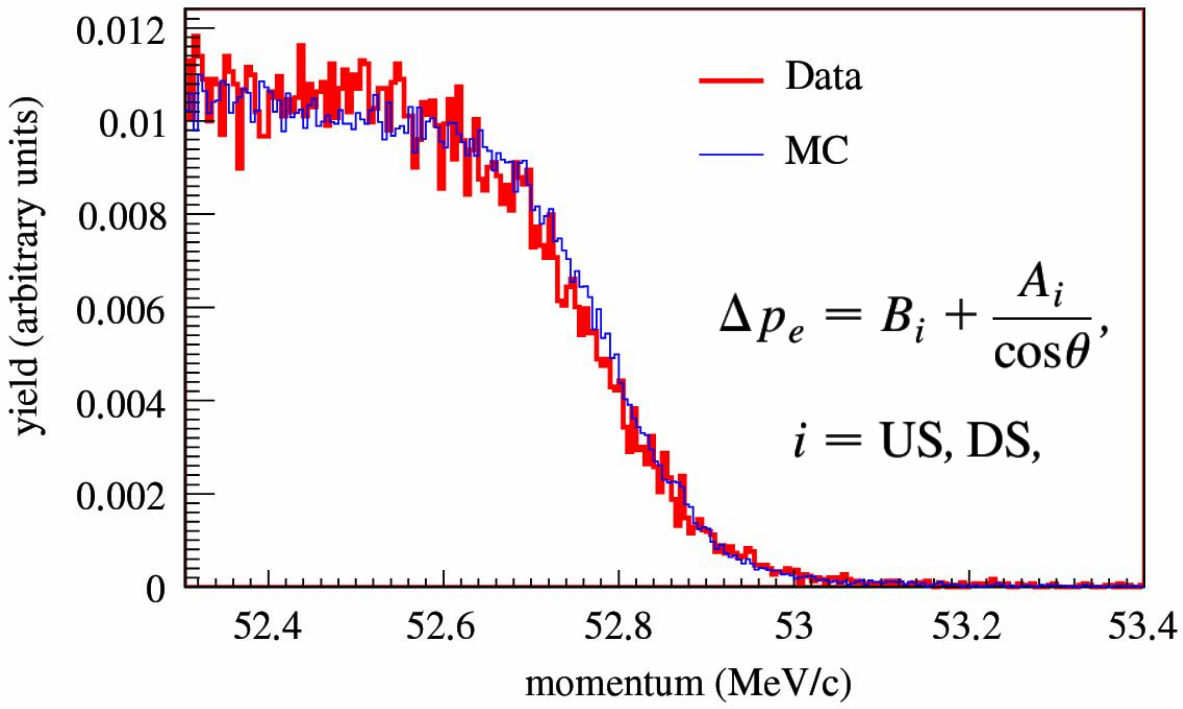
Supported by NSERC, the National Research Council of Canada, the Russian Ministry of Science, and the US department of energy. Computing resources provided by WestGrid.

Backup slide: energy scale



Spectrum endpoints for data and simulation differ by ~10 keV/c due to different stopping distributions, target thickness, magnetic field map scale.

Statistical part:

- Will be reduced since data sets are now 3x larger.

Systematic part:

- Difference must be propagated to rest of spectrum.
- Shift vs. scale are extremes.

Backup slide: global analysis

Global analysis

To extract the couplings $g^{\gamma}_{\epsilon\mu}$ from muon decay, one needs 11 (not all independent) parameters:

- the four muon decay parameters ρ, η, $P_\mu\xi$ and δ
- the measurement of $P_\mu\xi\delta/\rho$
- the parameters ξ' and ξ'' from the longitudinal polarisation of the outgoing electrons
- the parameters η'', α, β, α' and β' from the transverse polarisation of the outgoing electrons
- the parameter $\bar{\eta}$ from the radiative muon decay

Gagliardi and al. (Phys. Rev. D 72, 073002) performed a global fit analysis extracting the coupling constants from the most recent results.