Triumf Weak Interaction Symmetry Test

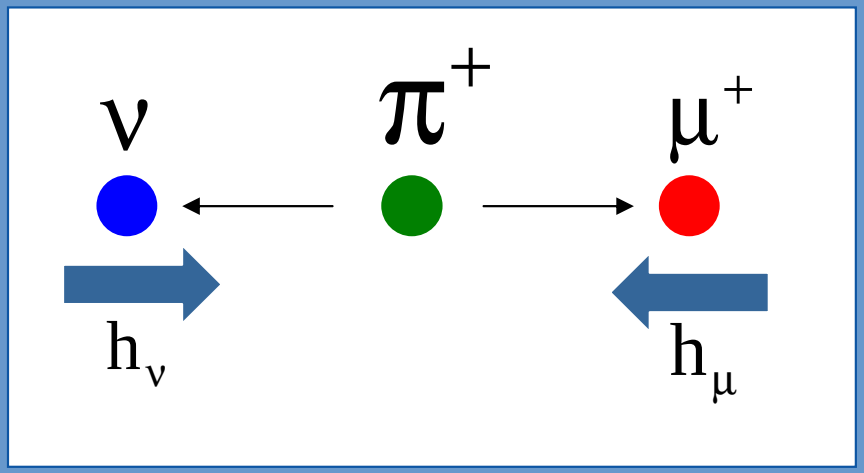
The final TWIST measurement of $P_\mu \xi$

James Bueno, TRIUMF / University of British Columbia

Outline

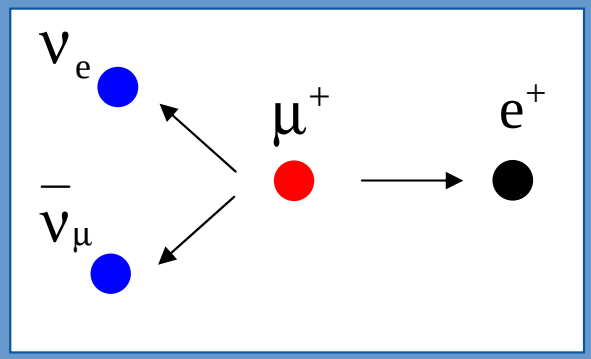
- Muon decay: physics relevant to $P_\mu \xi$
- Previous measurements and possibilities of new physics.
- Depolarisation in TWIST
  - solenoid fringe field
  - muon stopping target

Standard Model and $P_\mu \xi$



SM predicts

$$P_\mu = 1 \, , \, \xi = 1$$



$$\frac{d^2\Gamma}{dx \cdot d\cos\theta} = \left[\frac{m_\mu}{4\pi^3} W_{e\mu}^4 G_F^2 \sqrt{x^2 - x_0^2} \left(F_{IS}(x) + P_\mu \cos\theta \cdot F_{AS}(x) \right) + RC \right]$$

$$F_{AS}(x) \propto \tfrac{1}{3} \xi \sqrt{x^2 - x_0^2} \left[1 - x + \tfrac{2}{3} \delta \left(4x - 3 + \left(\sqrt{1 - x_0^2} - 1 \right) \right) \right]$$

c.f. Anthony's talk

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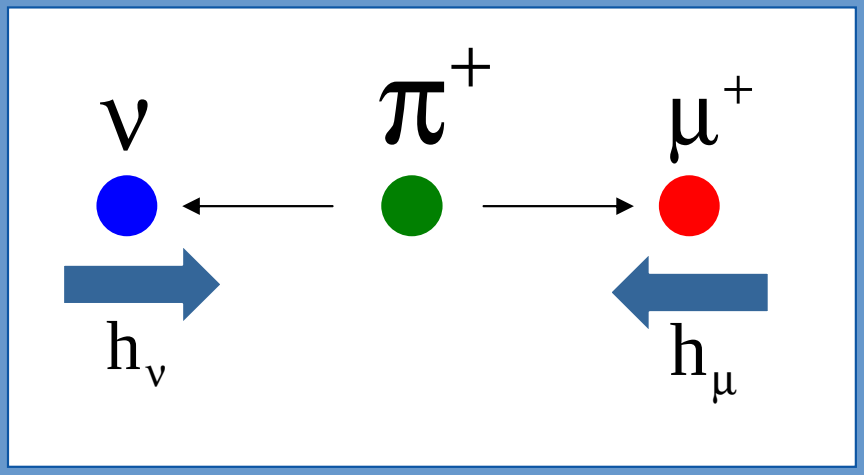

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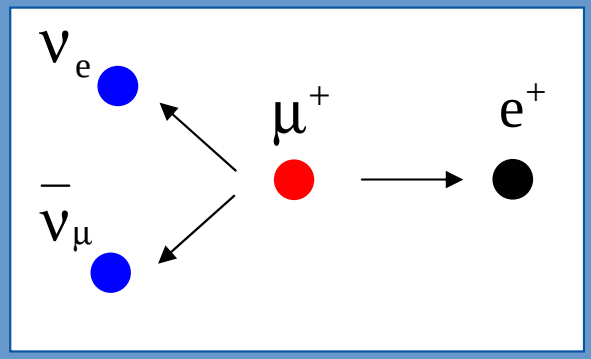

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The differential decay rate contains the product $P_\mu \xi$

New physics

muon handedness

SM predicts LH muon decays to LH positron.

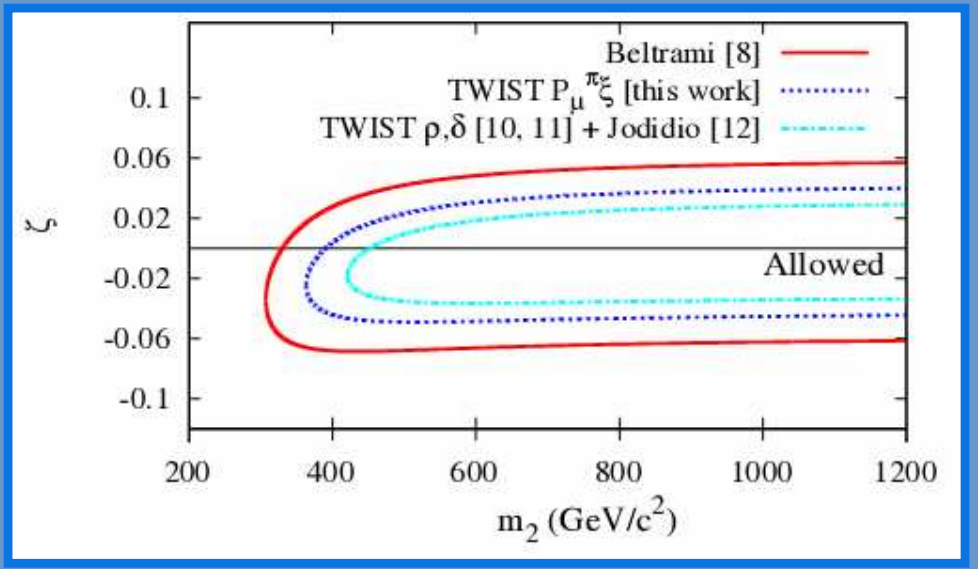
Probability of RH muon decay to a LH or RH positron is

$$Q_R^{\mu} = \frac{1}{2}\left[1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta\right]$$

left-right symmetric models

$$W_L = W_1 \cos\zeta + W_2 \sin\zeta$$

$$W_R = -W_1 \sin\zeta + W_2 \cos\zeta$$



$$1 - P_\mu \xi \approx 4\left[\zeta^2 + \zeta\left(\frac{m_1}{m_2}\right)^2 + \left(\frac{m_1}{m_2}\right)^4\right]$$

Previous measurements of $P_\mu\xi$

Direct measurements:

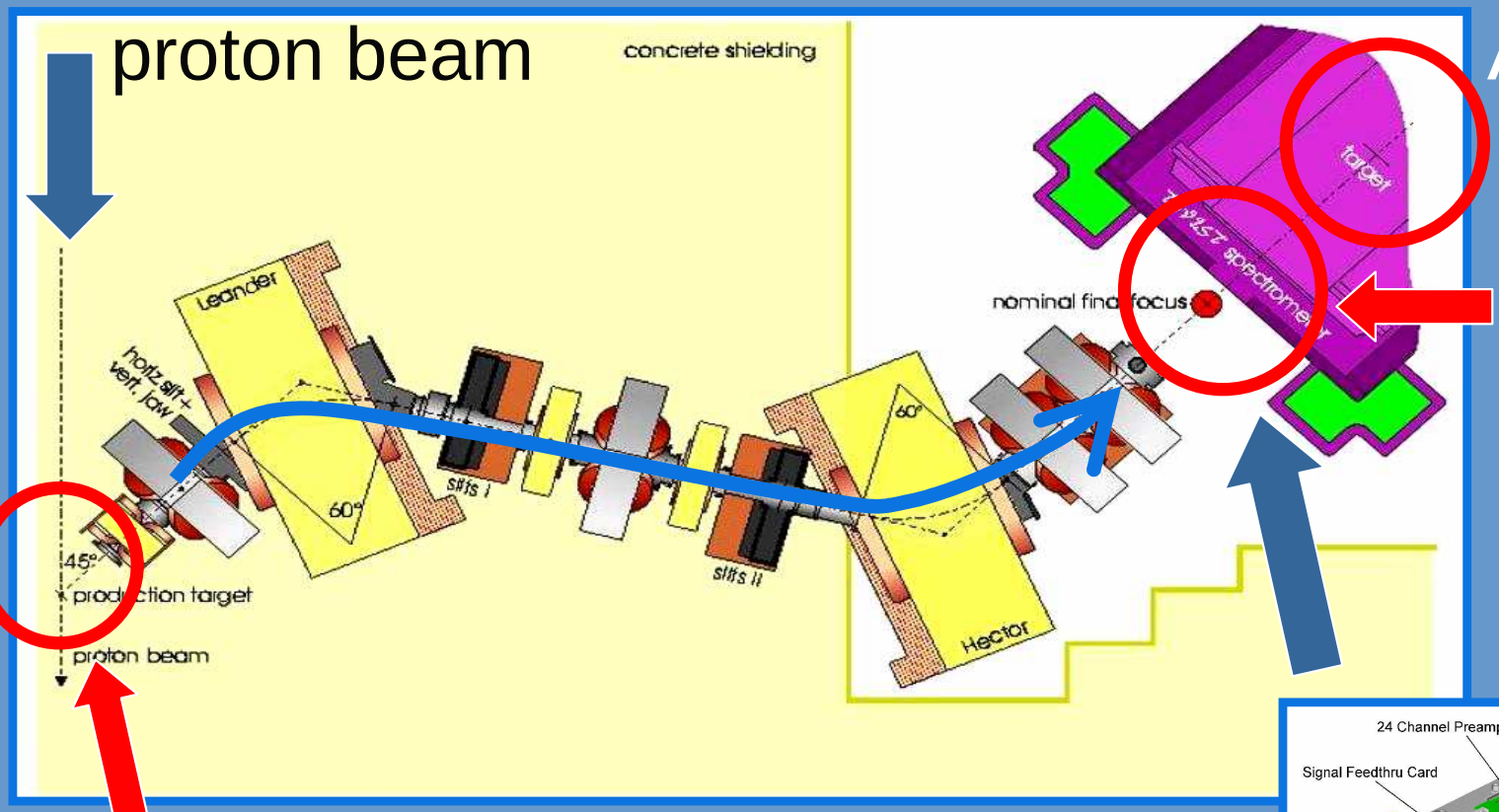
Beltrami et al. [1987]	1.0027 ± **0.0079 (stat)** ± 0.0030 (syst)
Jamieson et al. [2004] (TWIST)	1.0003 ± 0.0006 (stat) ± **0.0038 (syst)**

Indirect measurements:

Jodidio et al. & TWIST	$0.9960 < P_\mu\xi < 1.0040$ (90%)

2006/7 analysis: aim for total systematic uncertainty < **0.0010**.

Depolarisation in TWIST

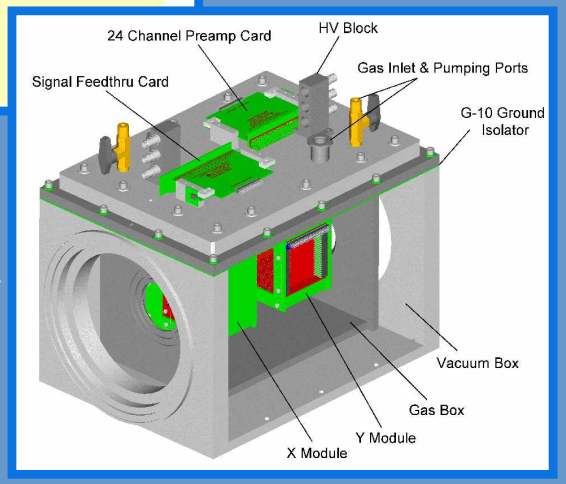


Al/Ag target

fringe field

graphite
proton target

removable
beam monitor



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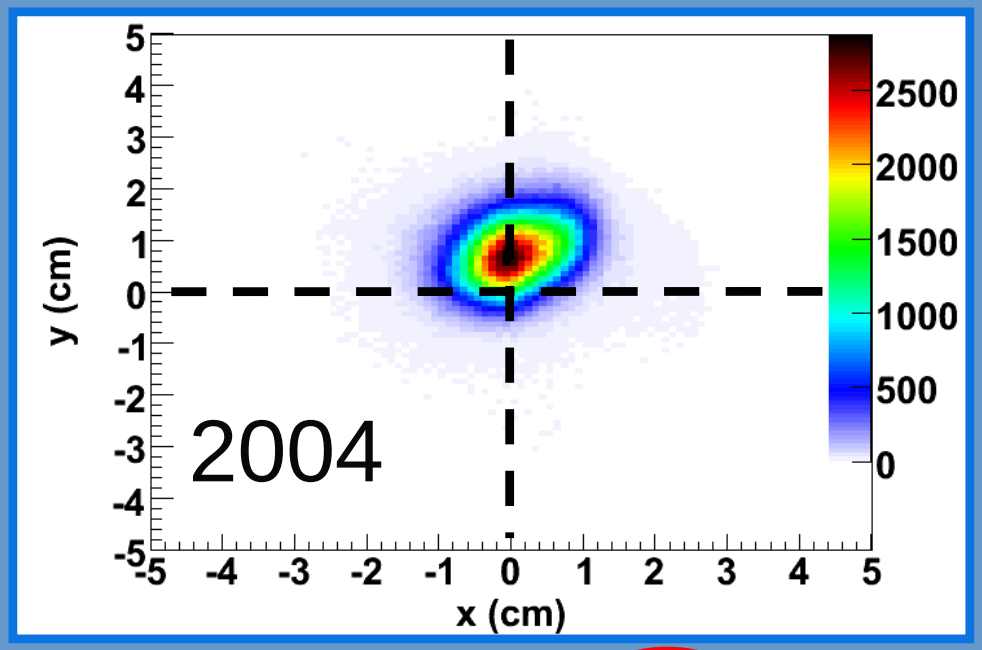

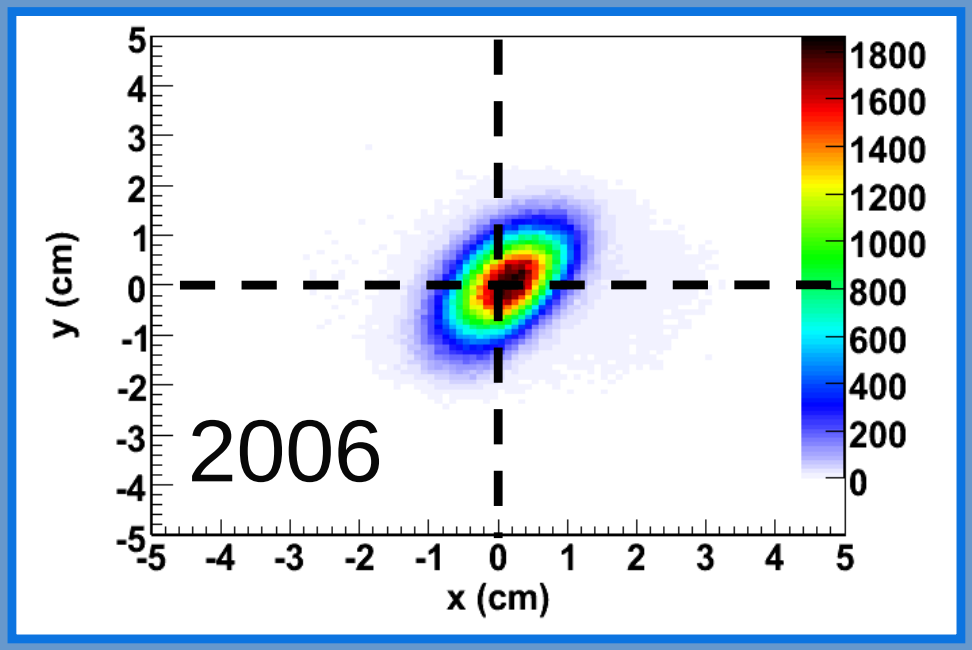

$\langle x \rangle, \langle y \rangle = (0.05, 0.74)$ cm
$\langle \theta_x \rangle, \langle \theta_y \rangle = (-6.7, -11.2)$ mrad

$\langle x \rangle, \langle y \rangle = (0.13, 0.02)$ cm
$\langle \theta_x \rangle, \langle \theta_y \rangle = (-4.9, -1.0)$ mrad

also:3 sets taken in 2006 with deliberate mis-steering to validate simulation of P_μ

Depolarisation in fringe field

2004: uncertainty of 0.0031 in $P_\mu \xi$

B2 (mT)	$\bar{x}$ (cm)	$\bar{\theta}_x$ (mrad)	$\bar{y}$ (cm)	$\bar{\theta}_y$ (mrad)	P_μ^{sim}
94.4	0.07	−5.9	0.97	7.0	0.9929
94.4	0.06	−6.7	0.73	−11.2	0.9941
94.9	0.85	−1.1	0.87	−5.0	0.9955
94.9	0.94	−1.5	0.64	−19.2	0.9922

beam angle changed between monitoring runs

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For 2006/7:

- Monitor beam at beginning and end of every set.
- Monitor proton beamline and beam on production target.
- Entire sets with beam monitor ‘in’ to look for changes.

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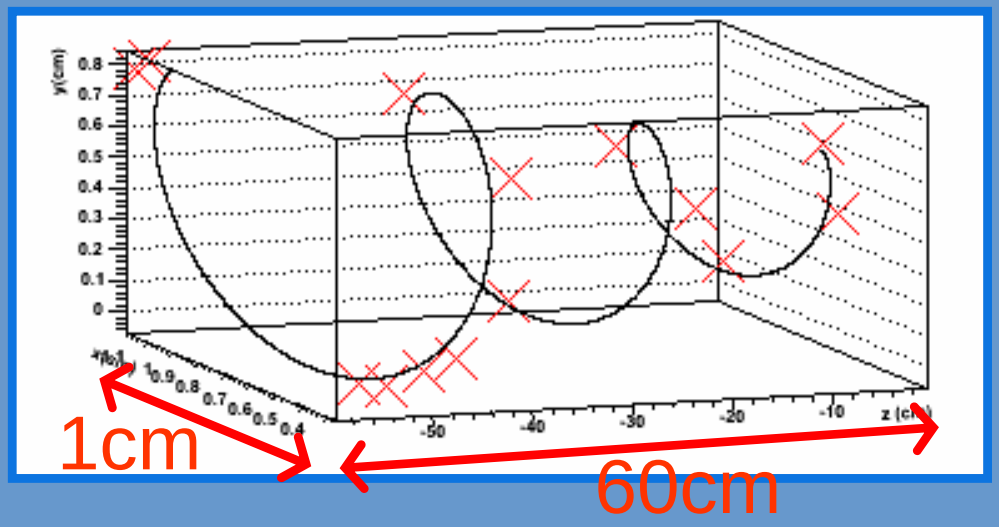
For 2006/7:

- Monitor beam at beginning and end of every set.
- Monitor proton beamline and beam on production target.
- Entire sets with beam monitor ‘in’ to look for changes.
- Efficiency of beam monitor closely monitored.
- Improved beam monitor to detector alignment and beam monitor calibration.

Beam stability



discovered that internal muon beam is sensitive to angle changes <2mrad position changes <2mm

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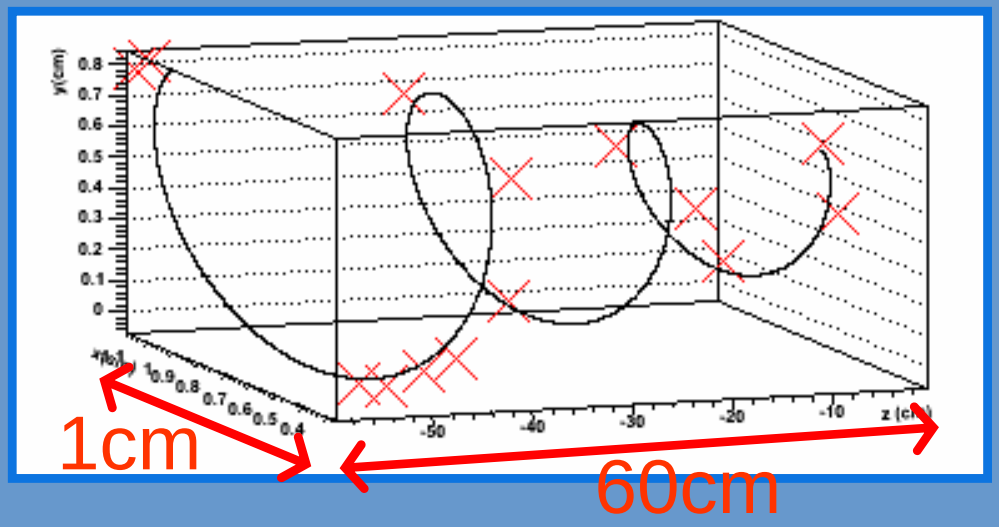

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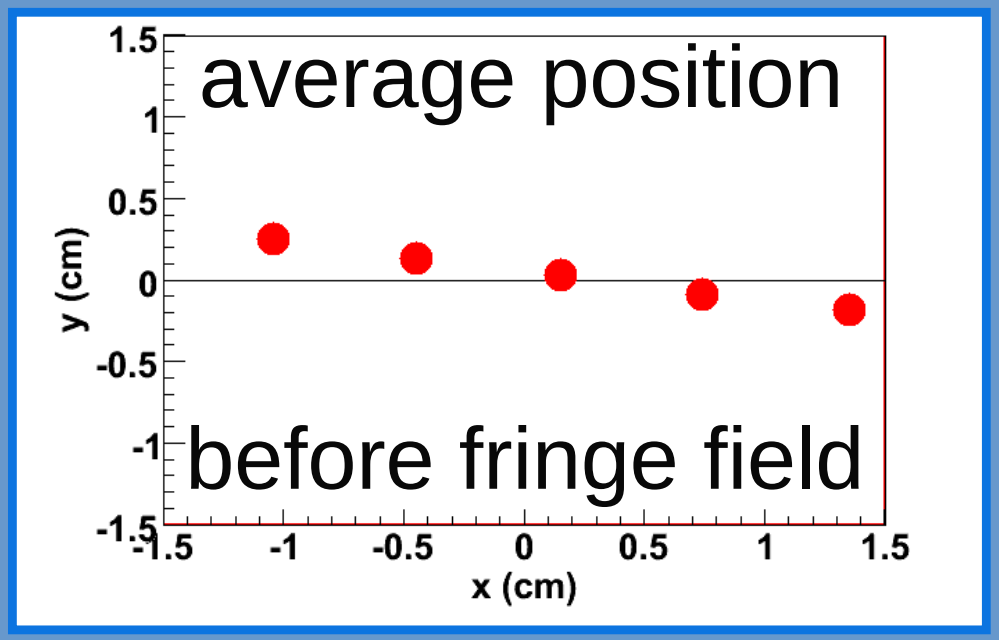
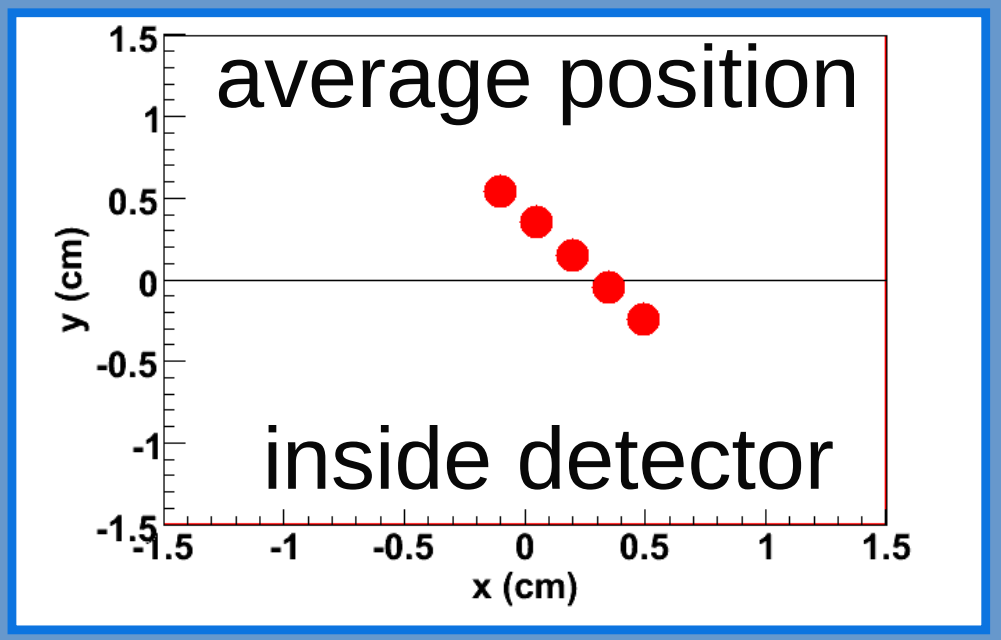




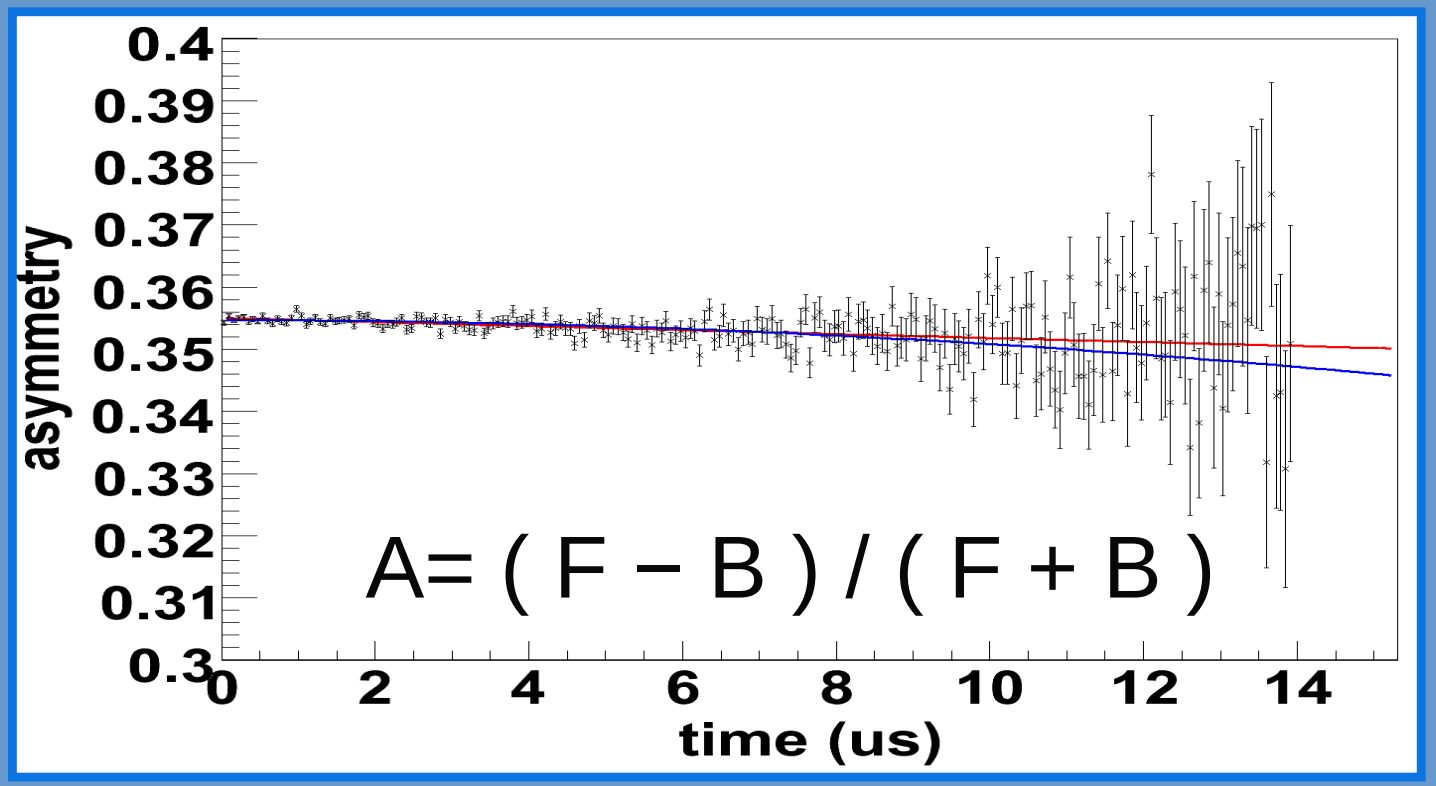
Depolarisation at stopping target

2004: uncertainty of 0.0012 in $P_\mu \xi$

$P_\mu(t) = P_\mu(0) \cdot \exp(-at)$ **(red)**

$P_\mu(t) = P_\mu(0) \cdot \exp(-bt^2)$ **(blue)**

MuSR needed



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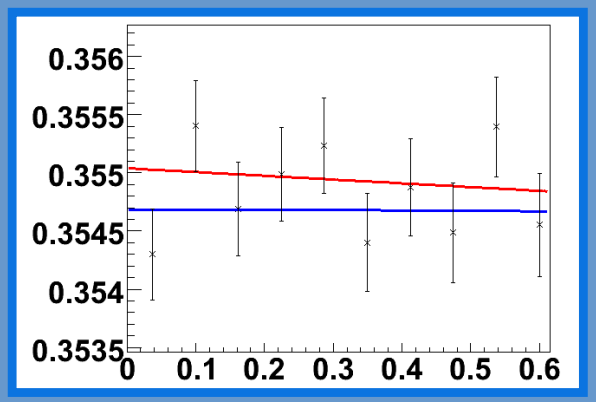

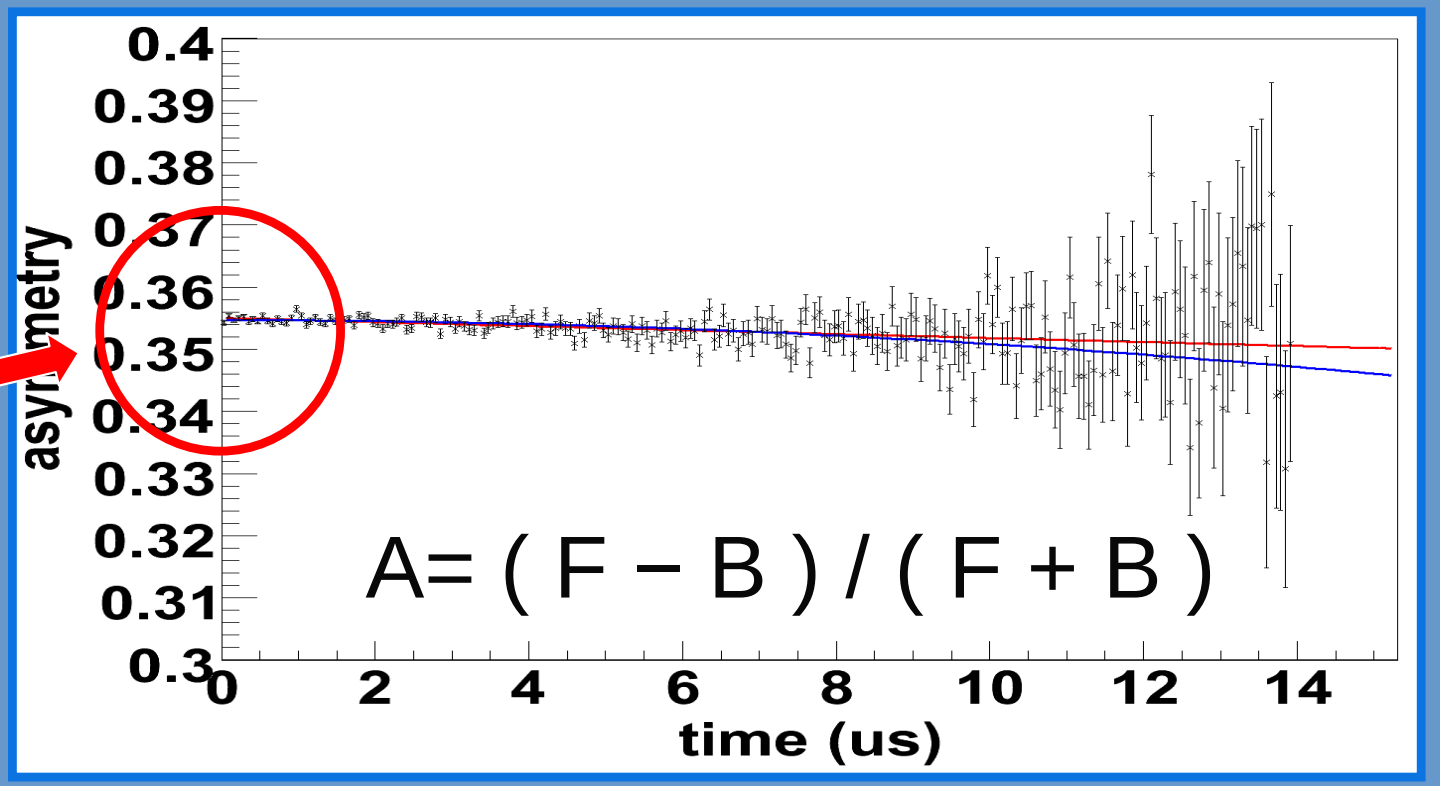

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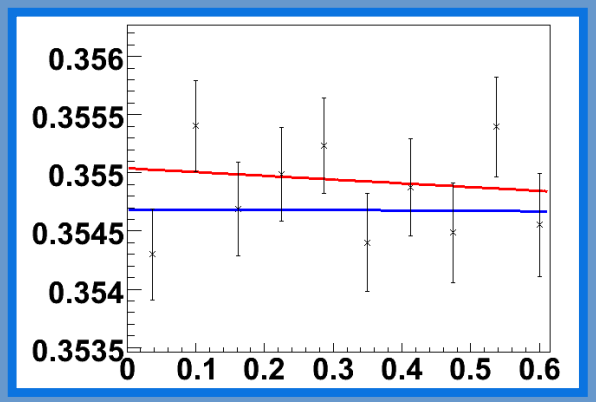

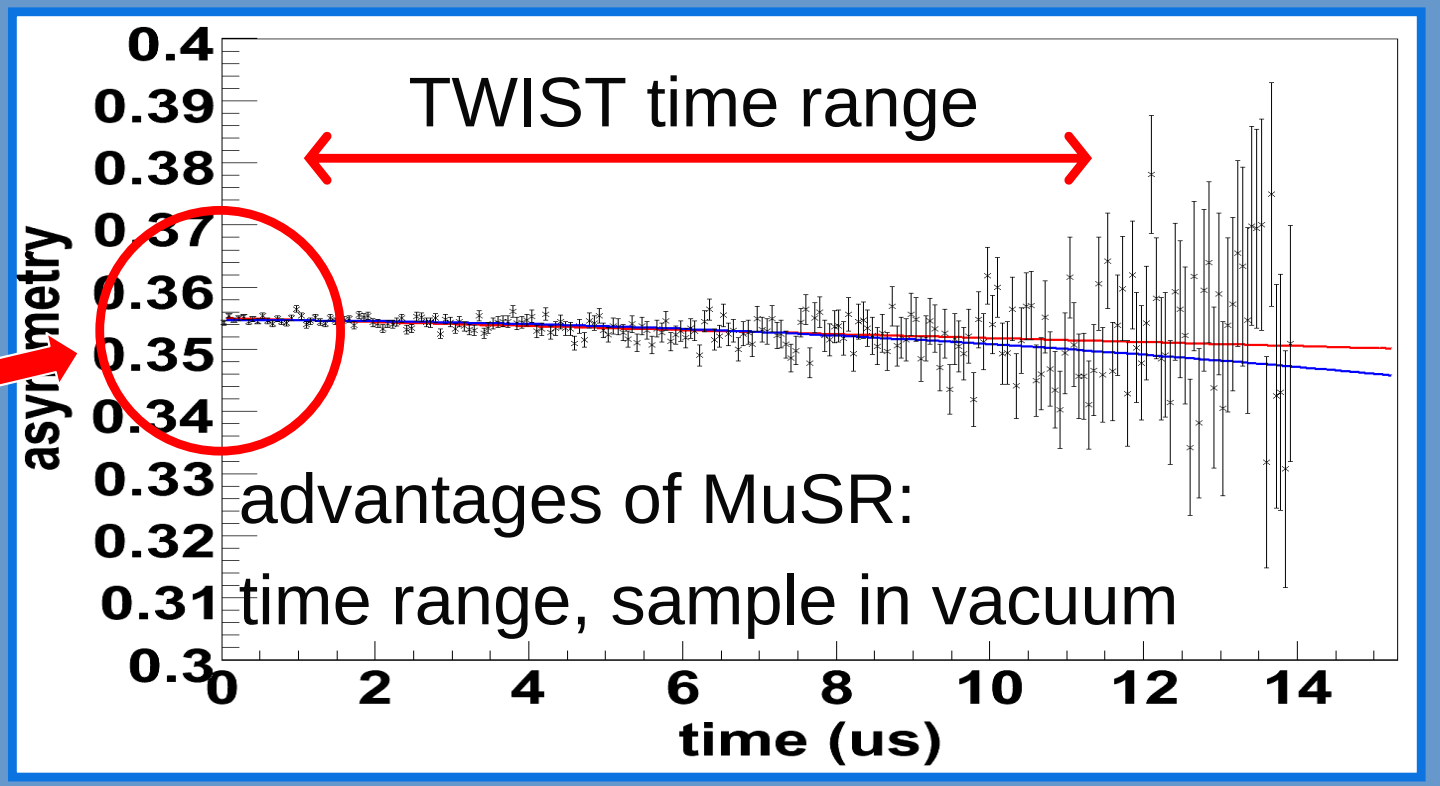

Summary for $P_\mu\xi$

- Aim to improve uncertainty on pre-TWIST measurement of $P_\mu\xi$ by an order of magnitude.
- Beam steered on axis to reduce depolarisation.
- Many improvements in beam monitor.
- Internal muon beam information gives stability information.
- MuSR experiment reduces uncertainty on stopping target depolarisation.
- Expect final results in 2008/9.

Questions and comments

TRIUMF

Ryan Bayes*†
Yuri Davydov
Wayne Faszer
Makoto Fujiwara
David Gill
Alex Grossheim
Peter Gumplinger
Anthony Hillairet*†
Robert Henderson
Jingliang Hu
Glen Marshall
Dick Mischke
Mina Nozar
Konstantin Olchanski
Art Olin†
Robert Openshaw
Jean-Michel Poutissou
Renée Poutissou
Grant Sheffer
Bill Shin‡‡

Regina

Ted Mathie
Roman Tacik

Montréal

Pierre Depommier

Valparaiso

Don Koetke
Shirvel Stanislaus

Kurchatov Institute

Vladimir Selivanov

Alberta

Andrei Gaponenko**
Peter Kitching
Robert MacDonald*
Maher Quraan

British Columbia

James Bueno*
Mike Hasinoff
Blair Jamieson**

Texas A&M

Carl Gagliardi
Jim Musser**
Bob Tribble

* graduate student, ** graduated
† also UVic, ‡‡ also Saskatchewan

TWIST is supported in part by the Natural Sciences and Engineering Research Council and the National Research Council of Canada, the Russian Ministry of Science, and the U.S. Department of Energy.

Computing resources for the analysis are provided by Westgrid.

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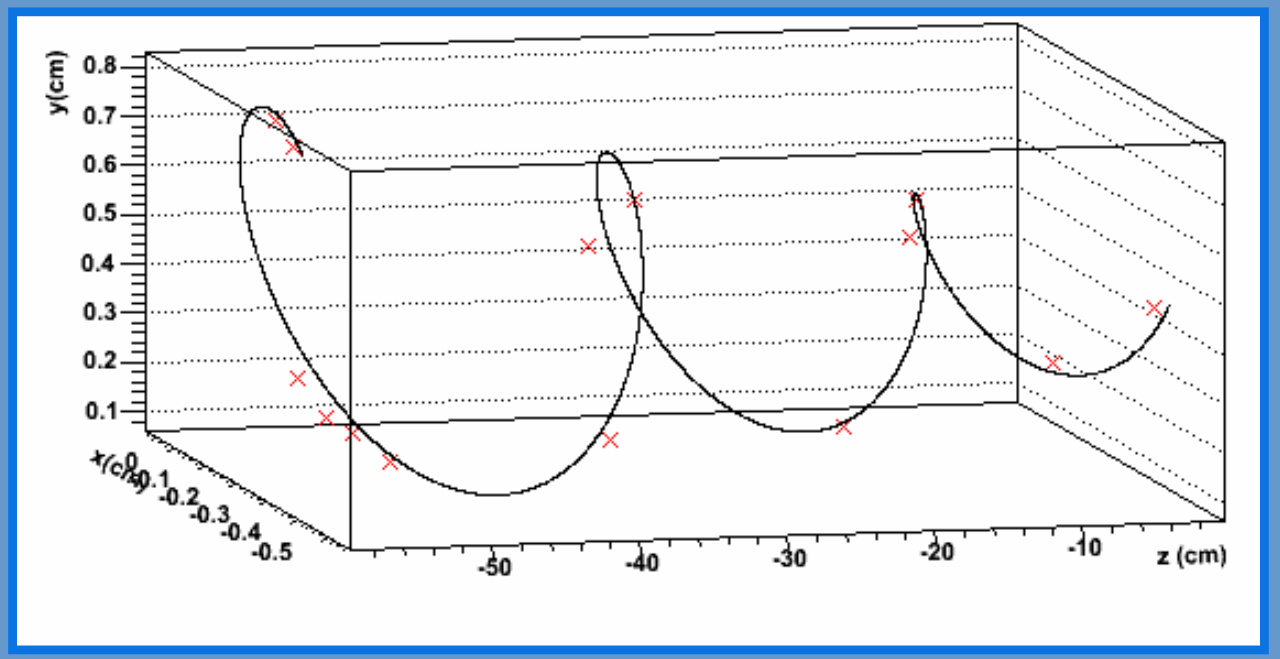
Fitting the average beam

$$\begin{pmatrix} x \\ y \end{pmatrix} = (A - A_\rho \cdot z') \begin{pmatrix} \sin f(z) \\ \cos f(z) \end{pmatrix} + \begin{pmatrix} \Delta_x \\ \Delta_y \end{pmatrix}$$

$$f(z) = \frac{2\pi}{\lambda - \lambda_\rho \cdot z'} \cdot z' + \phi$$

$$z' = z + \text{position of PC1,2 (-59.59 cm)}$$

Helix works!



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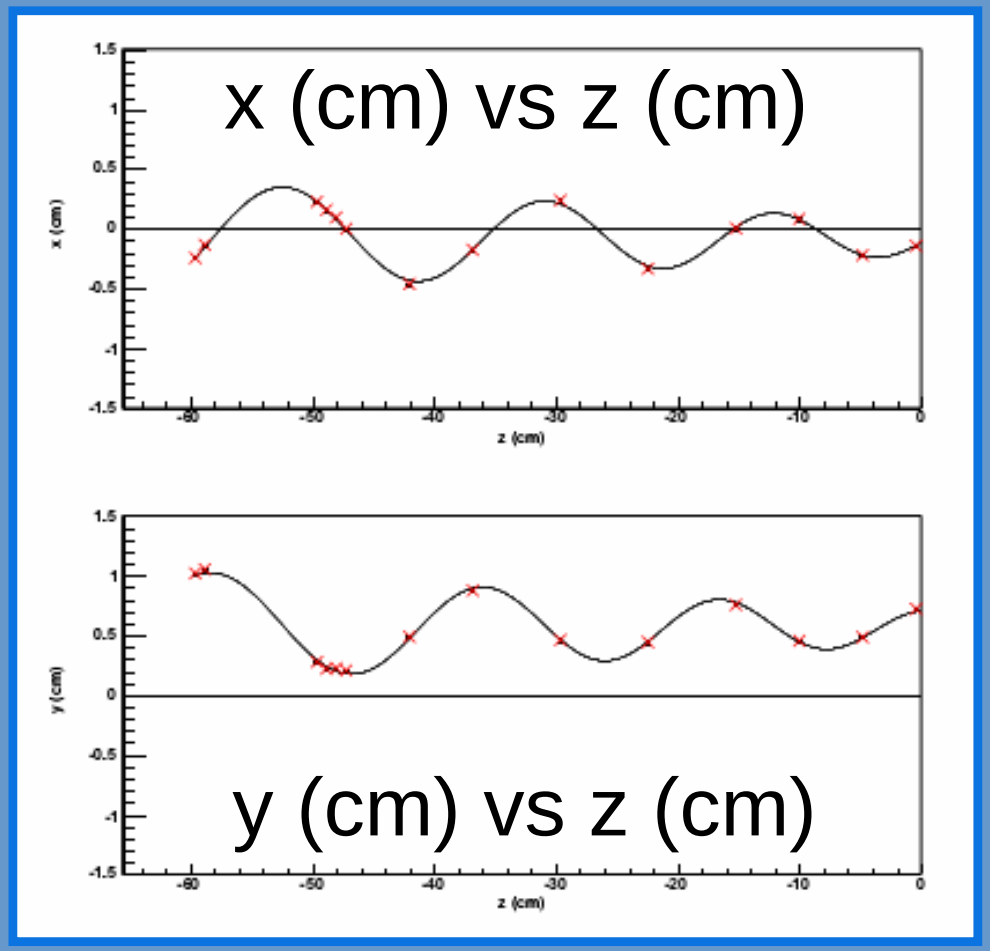
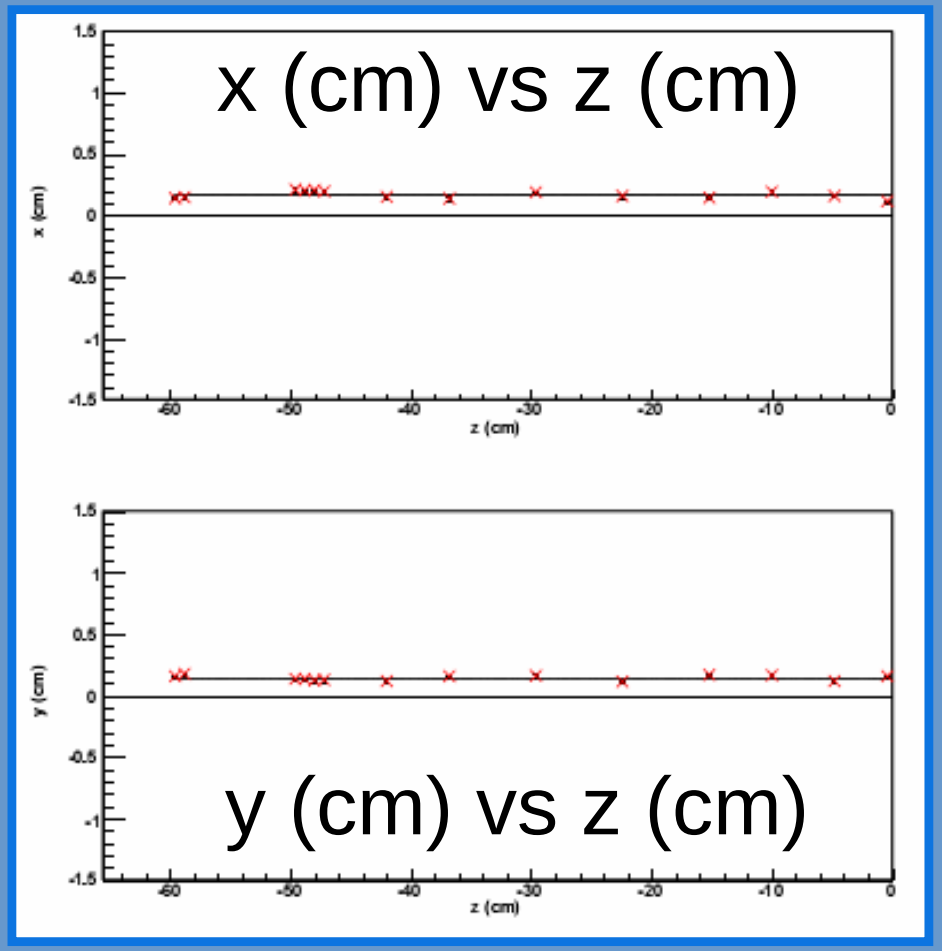
Example

(from the 2006 research proposal)



B2 changed



vertically steered beam

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Depolarisation theory

- No muonium as B field aligns conduction electron spins to shield formation.

- Relaxation could occur due to

  i) conduction electrons [Korringa, most likely]

  ii) nuclear moments of Al or Ag

  iii) paramagnetic impurities

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Exponential fits to Al and Ag

aluminium	λ (10^{-6}ns^{-1})
Jodidio	0.43 ± 0.34
2004 TWIST best fit	1.36 ± 0.12
Jess's fit	1.64 ± 0.17
James's preliminary fit	1.74 ± 0.20

silver	λ (10^{-6}ns^{-1})
Dick's fit	1.4 ± 0.2
James's fit	1.41 ± 0.26