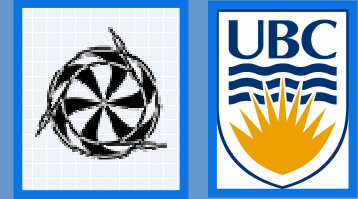


# Triumf Weak Interaction Symmetry Test



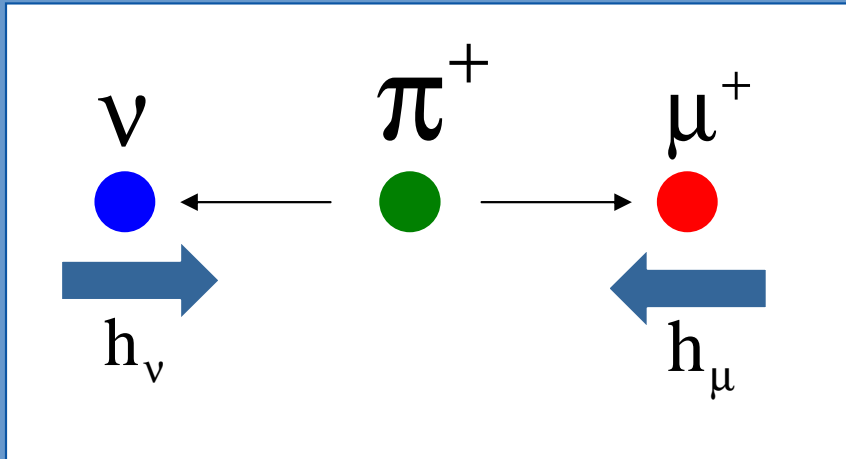
## The final TWIST measurement of $P_{\mu}^{\xi}$

James Bueno, TRIUMF / University of British Columbia

# Outline

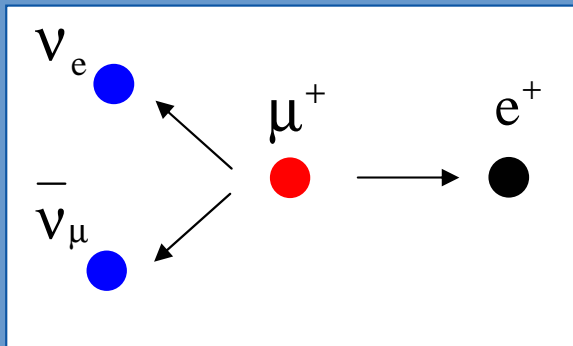
- Muon decay: physics relevant to  $P_{\mu}^{\xi}$
- Previous measurements and possibilities of new physics.
- Depolarisation in TWIST
  - solenoid fringe field
  - muon stopping target

# Standard Model and $P_\mu \xi$



SM predicts

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

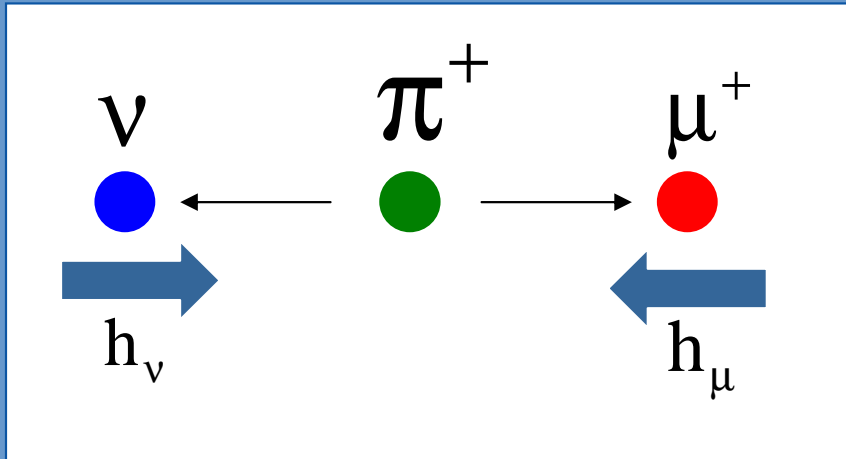


$$\frac{d^2\Gamma}{dx \cdot d\cos\theta} = \left[ \frac{m_\mu}{4\pi^3} W_{e\mu}^4 G_F^2 \sqrt{x^2 - x_0^2} (F_{IS}(x) + P_\mu \cos\theta \cdot F_{AS}(x)) + RC \right]$$

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

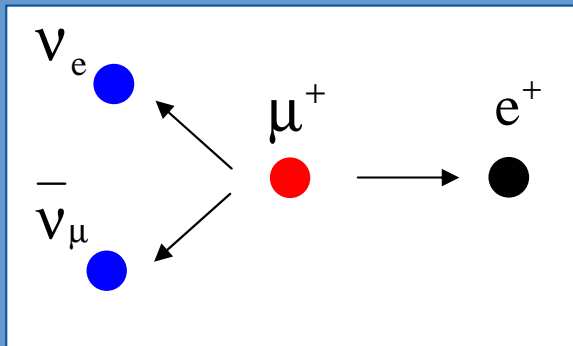
c.f. Anthony's talk

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

c.f. Anthony's talk

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

# New physics

muon handedness

SM predicts LH muon decays to LH positron.

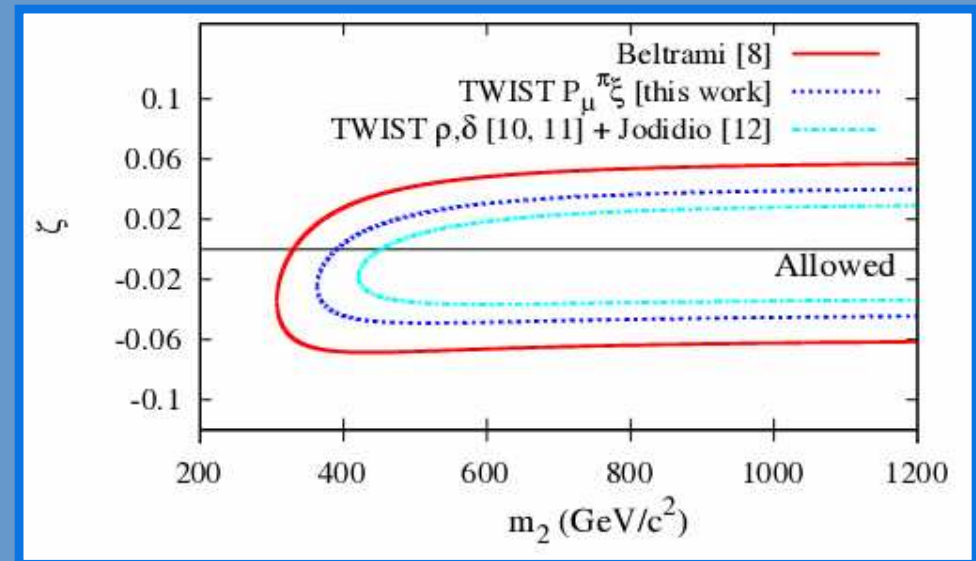
Probability of RH muon decay to a LH or RH positron is

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

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]  $1.0027 \pm \underline{0.0079 \text{ (stat)}} \pm 0.0030 \text{ (syst)}$

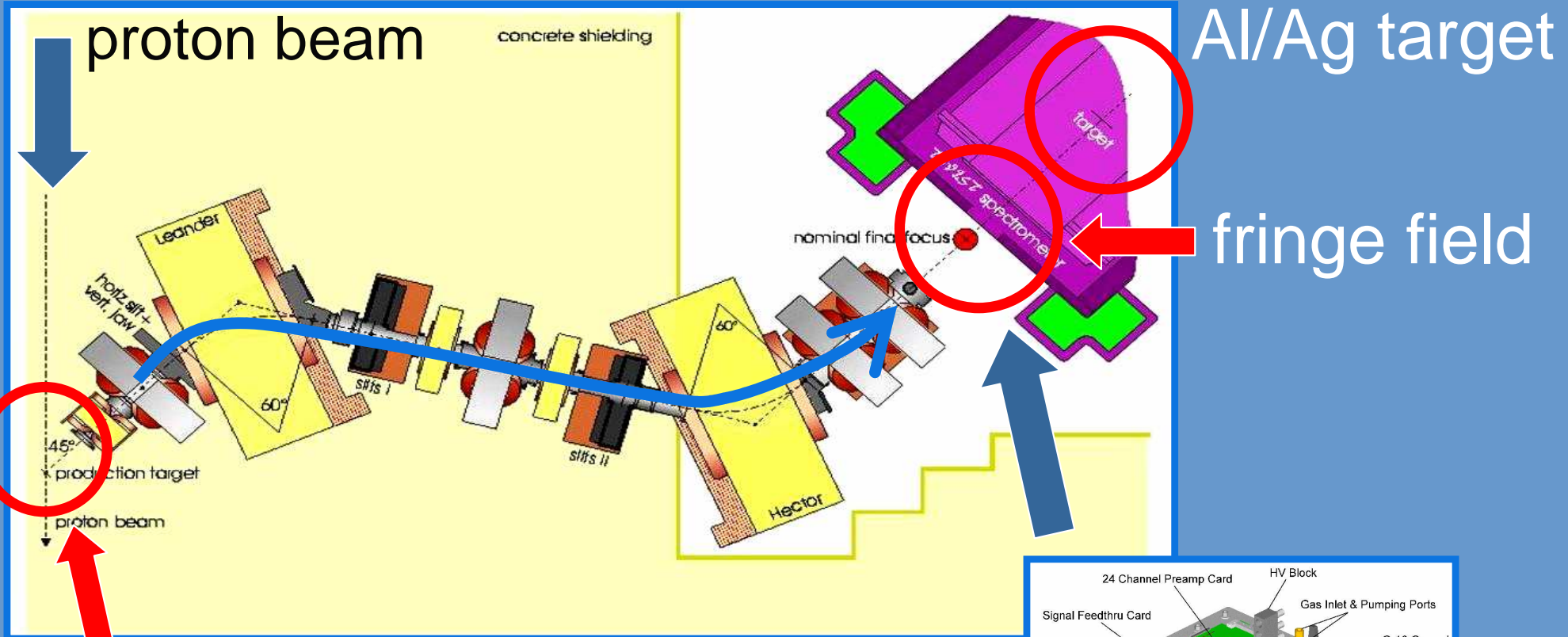
Jamieson et al. [2004]  
(TWIST)  $1.0003 \pm 0.0006 \text{ (stat)} \pm \underline{0.0038 \text{ (syst)}}$

Indirect measurements:

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

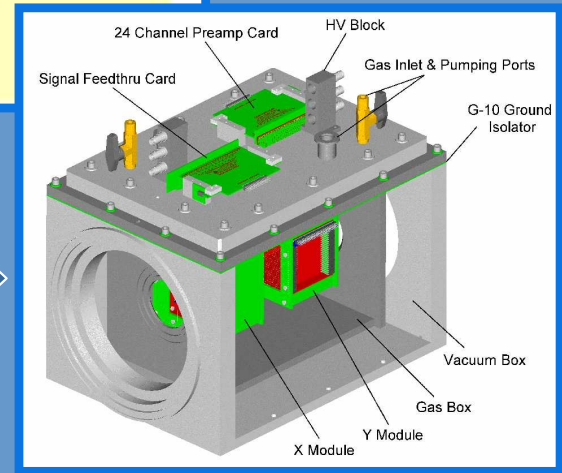
2006/7 analysis: aim for total  
systematic uncertainty < 0.0010.

# Depolarisation in TWIST

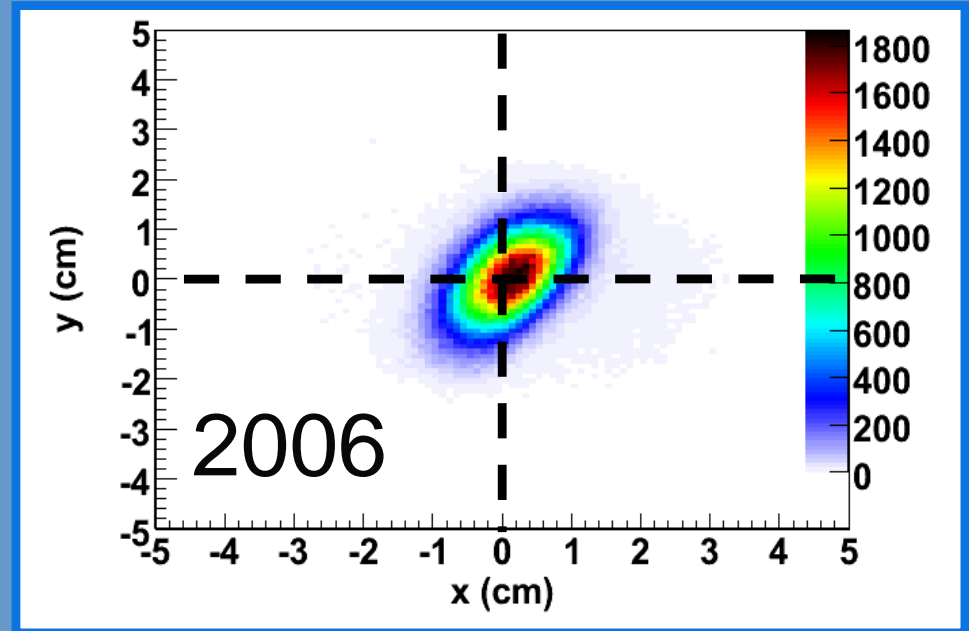
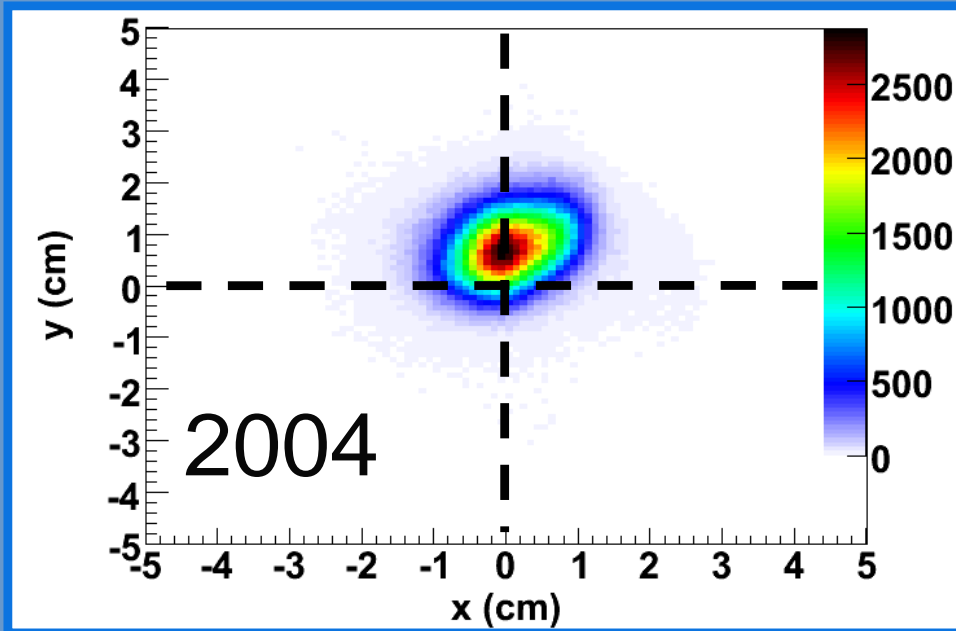


graphite proton target

removable beam monitor



# Depolarisation in fringe field



$$\langle x \rangle, \langle y \rangle = (0.05, 0.74) \text{ cm}$$

$$\langle \theta_x \rangle, \langle \theta_y \rangle = (-6.7, -11.2) \text{ mrad}$$

$$\langle x \rangle, \langle y \rangle = (0.13, 0.02) \text{ cm}$$

$$\langle \theta_x \rangle, \langle \theta_y \rangle = (-4.9, -1.0) \text{ mrad}$$

also: 3 sets taken in 2006 with deliberate mis-steering  
to validate simulation of  $P_\mu$



# 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)	$P_{\mu}^{\text{sim}}$
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  
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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.

# Depolarisation in fringe field

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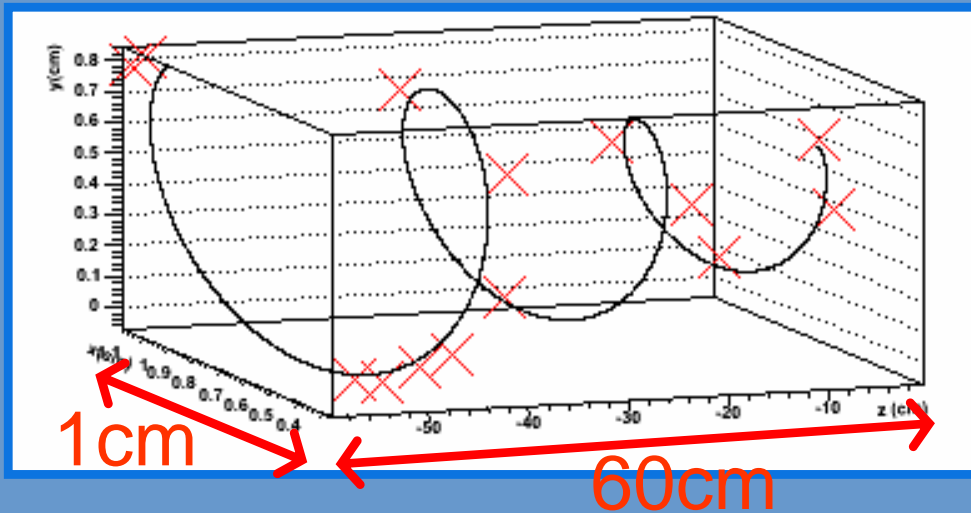
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For 2006/7:

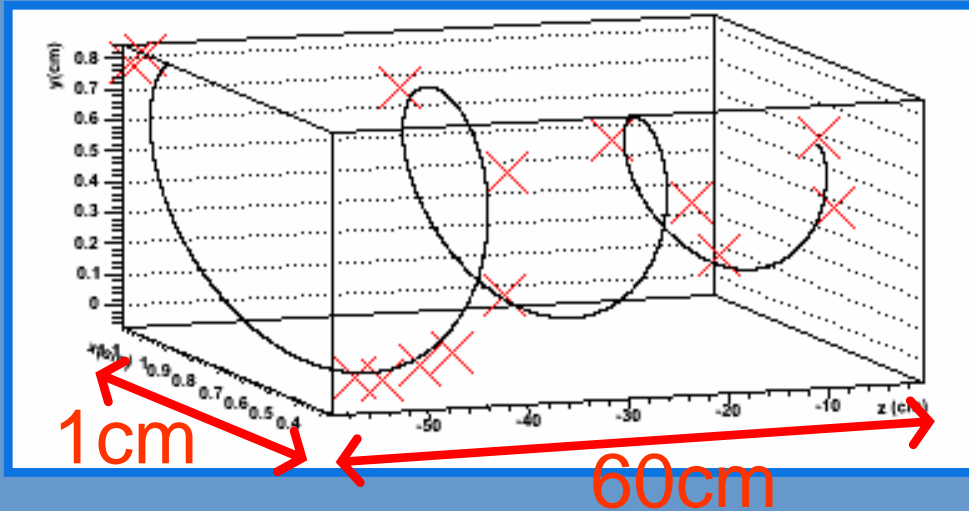
- Monitor beam at beginning and end of every set.
- Monitor proton beamline and beam on production target.
- Entire sets with beam monitor 'in' to look for changes.
- Efficiency of beam monitor closely monitored.
- Improved beam monitor to detector alignment and beam monitor calibration.

# Beam stability

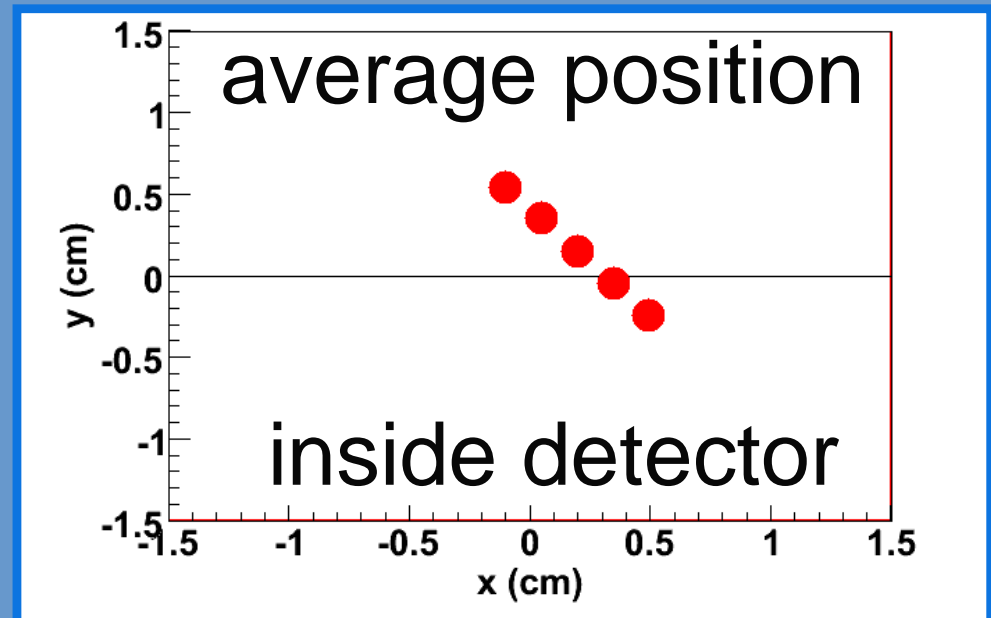
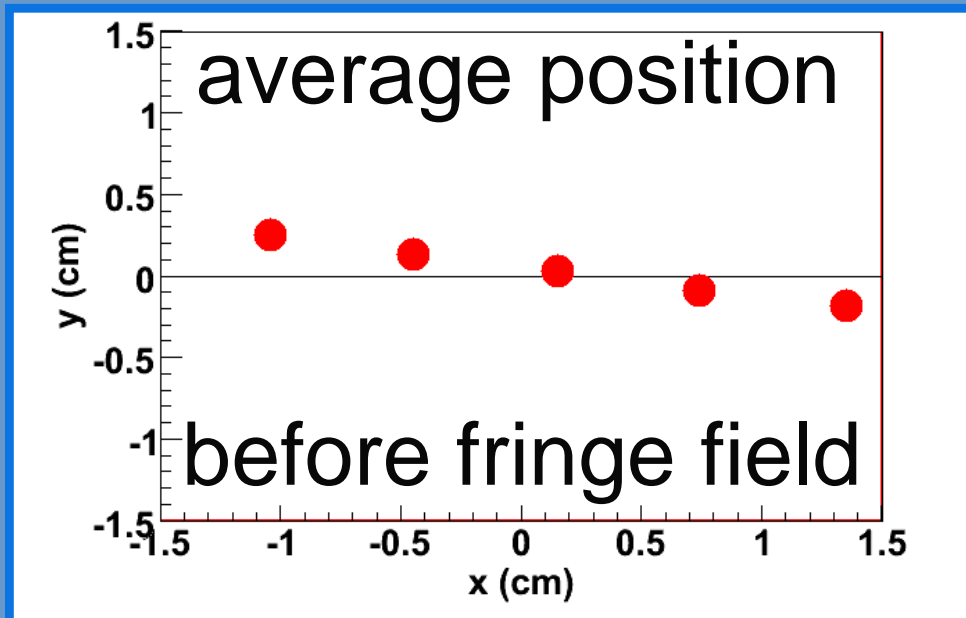


discovered that internal muon beam is sensitive to angle changes  $< 2\text{mrad}$   
position changes  $< 2\text{mm}$

# Beam stability



discovered that internal muon beam is sensitive to angle changes  $< 2 \text{ mrad}$   
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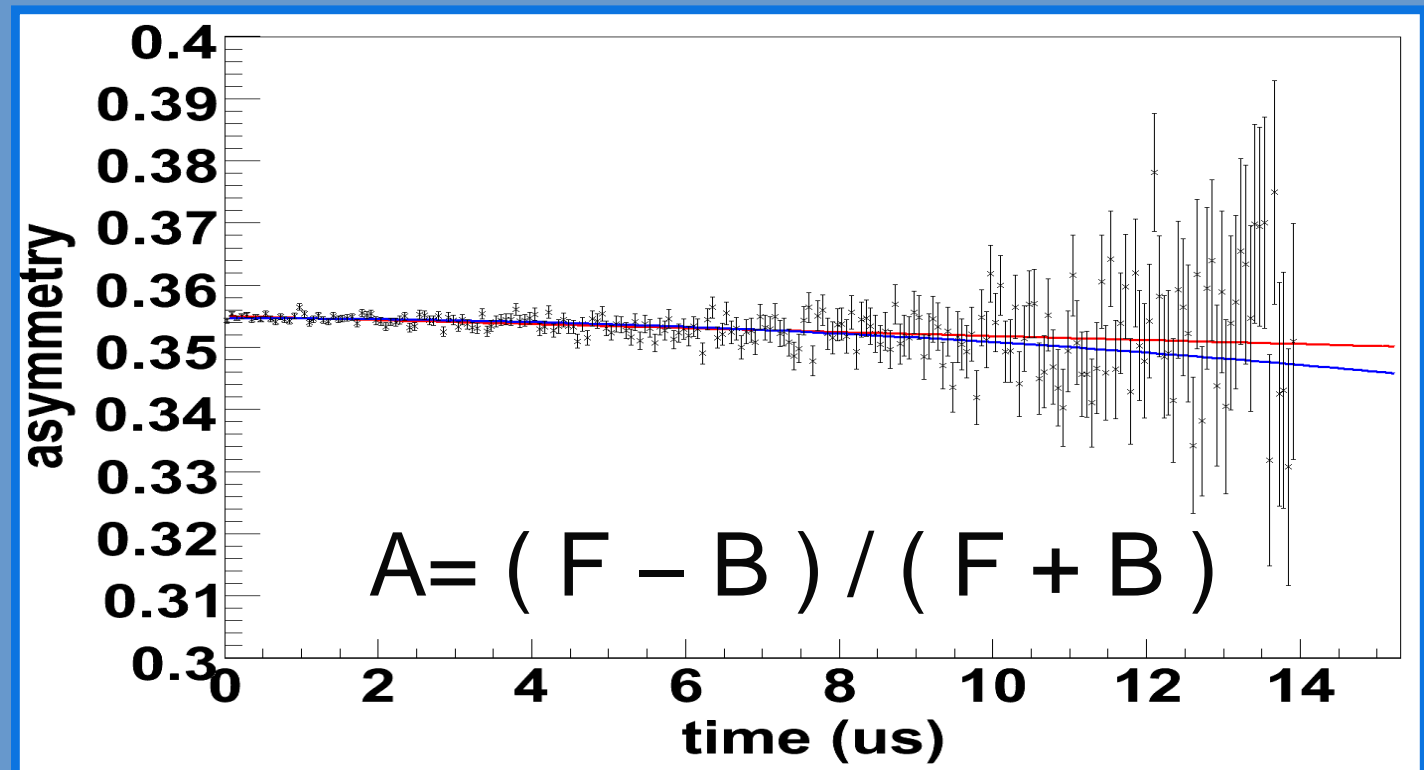
# Depolarisation at stopping target

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

$$P_\mu(t) = P_\mu(0) \cdot \exp(-at) \quad (\text{red})$$

$$P_\mu(t) = P_\mu(0) \cdot \exp(-bt^2) \quad (\text{blue})$$

MuSR  
needed



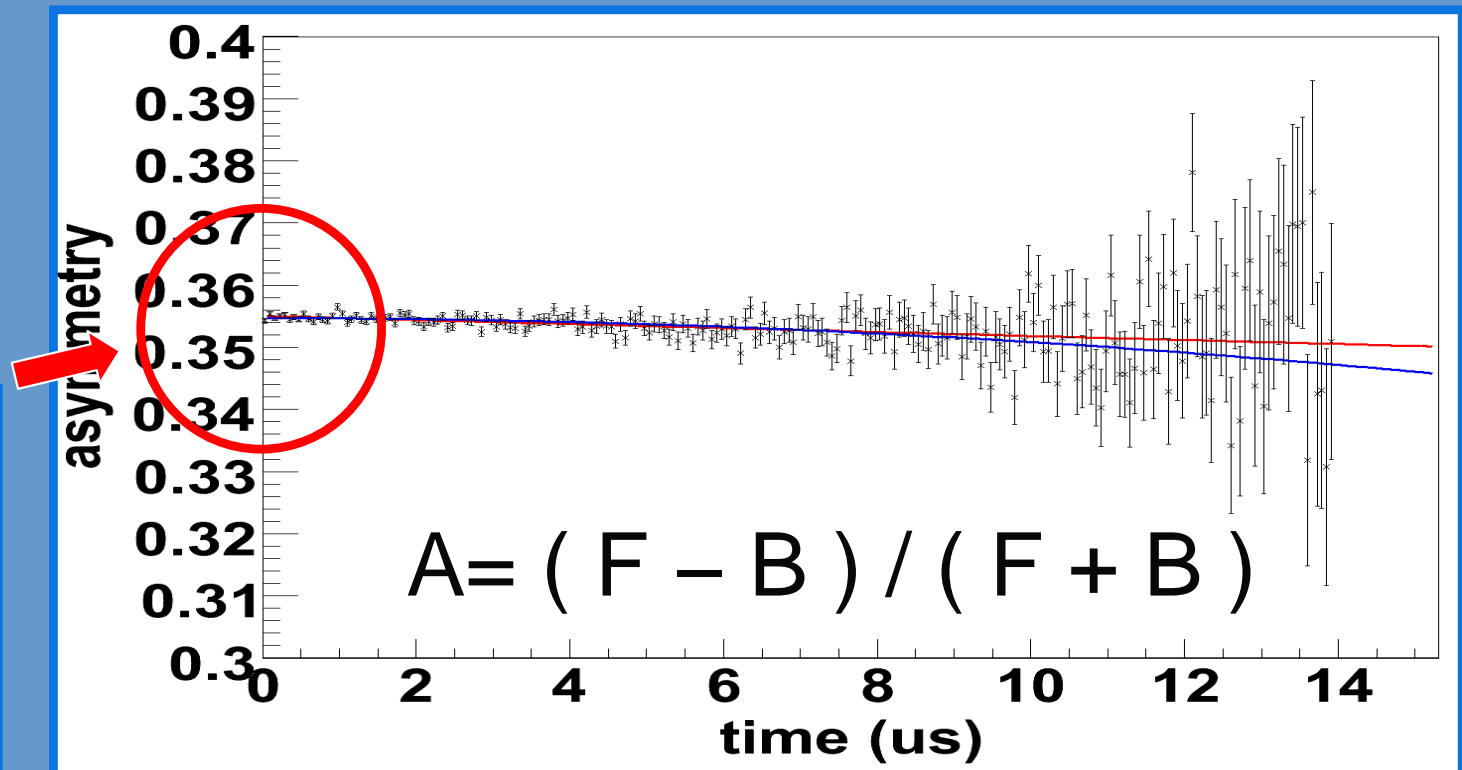
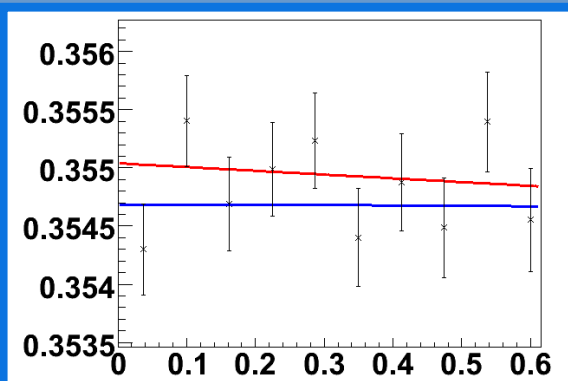
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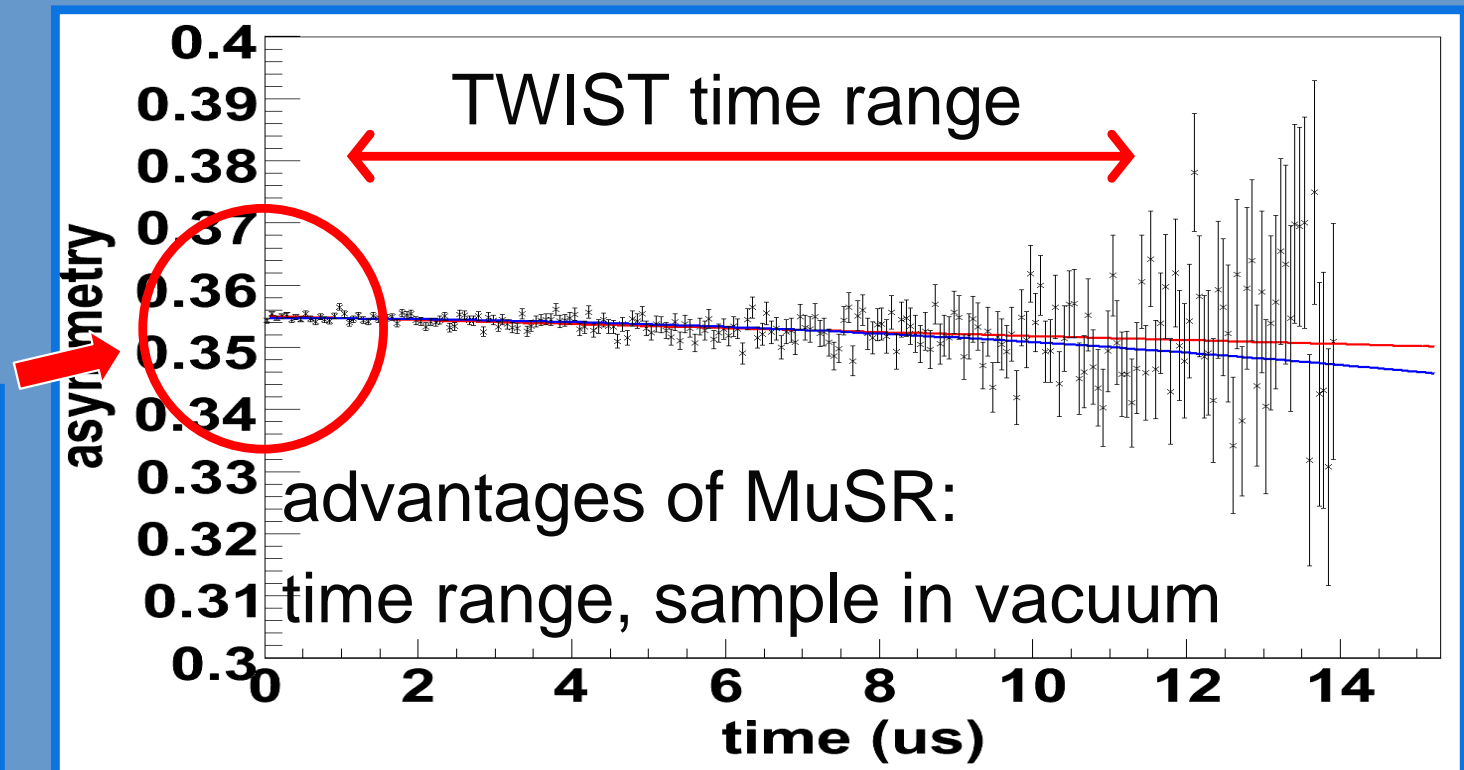
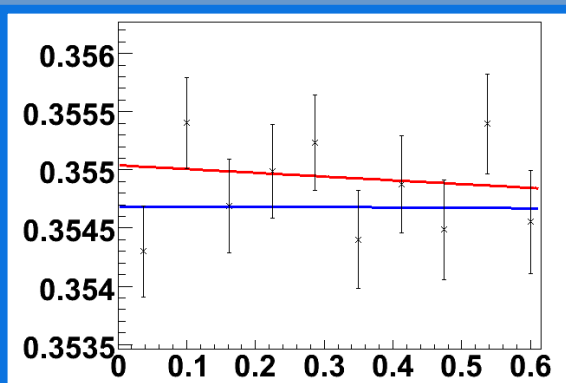
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MuSR  
needed





# 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

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Computing resources for the analysis are provided by Westgrid.

\* graduate student, \*\* graduated

† also UVic, ‡‡ also Saskatchewan

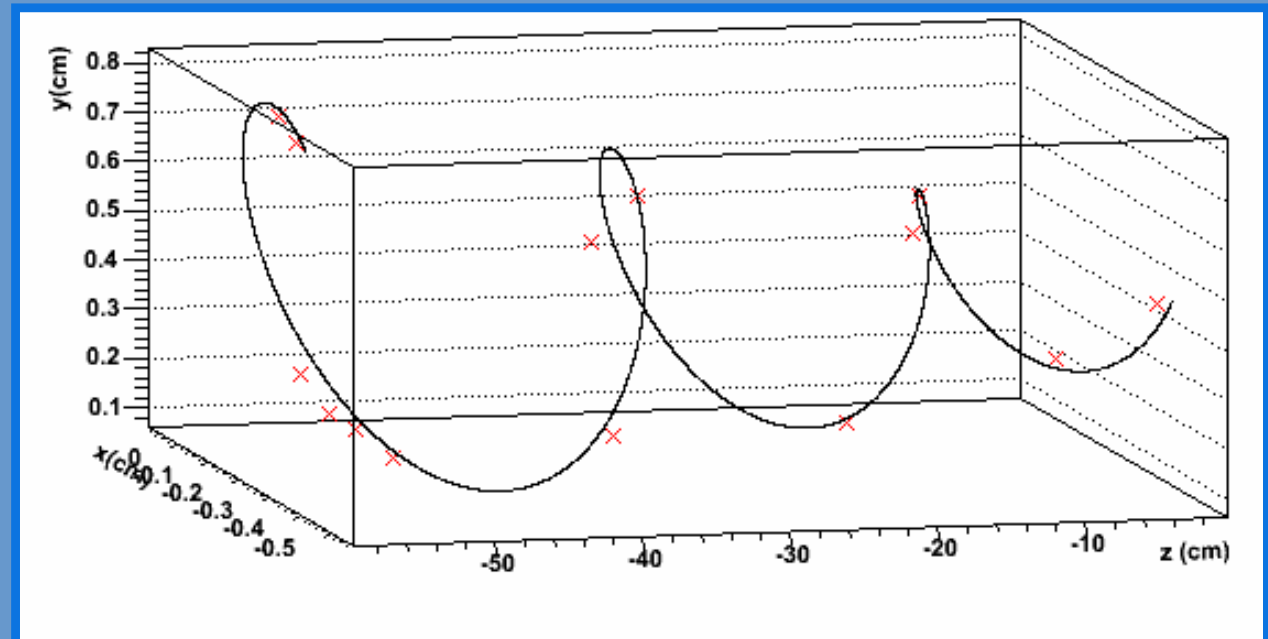
# Fitting the average beam

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

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

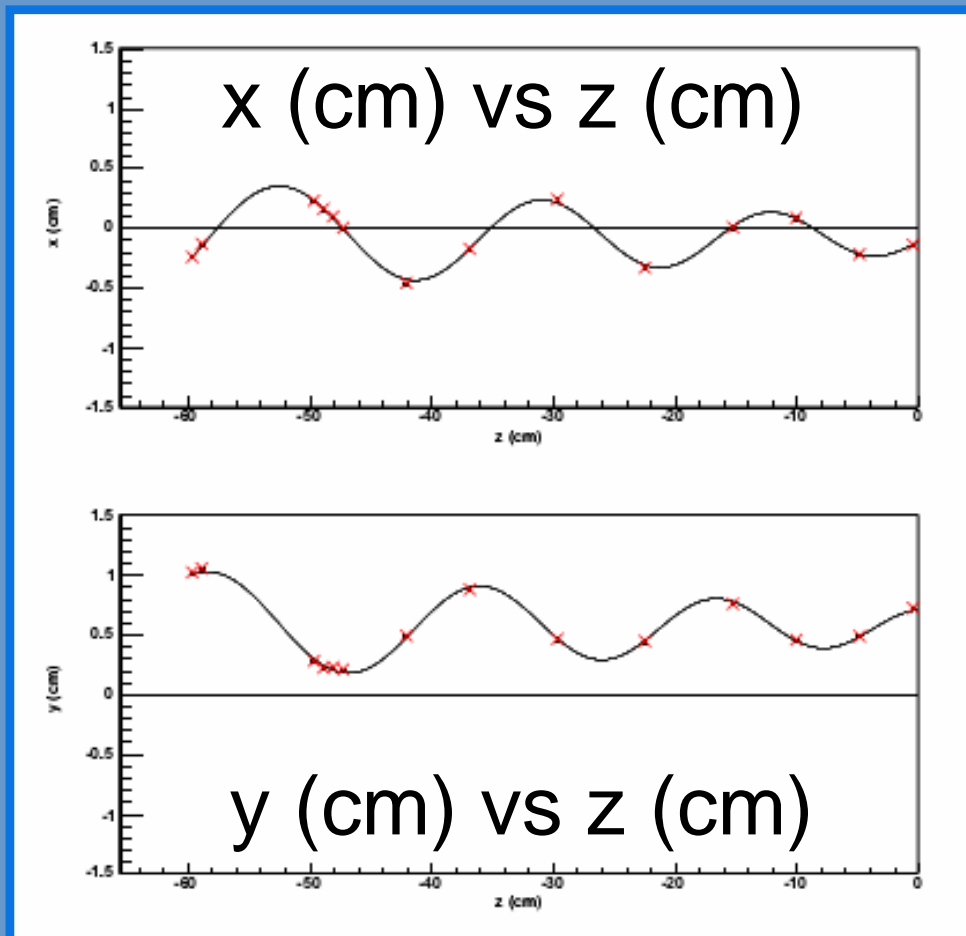
$$z' = z + \text{position of PC1,2 (-59.59 cm)}$$

Helix works!

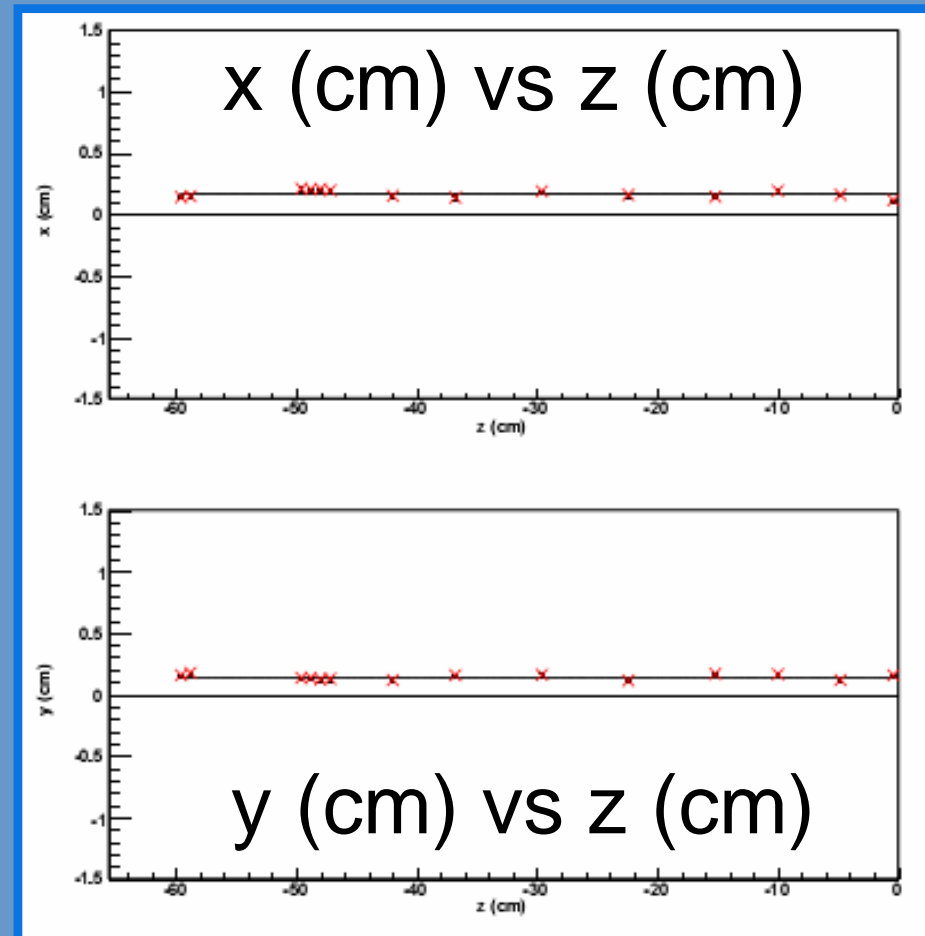


# Example

(from the 2006 research proposal)



B2 changed



vertically steered beam

# 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

# Exponential fits to Al and Ag

<b>aluminium</b>	<b><math>\lambda</math> (<math>10^{-6}\text{ns}^{-1}</math>)</b>
Jodidio	$0.43 \pm 0.34$
2004 TWIST best fit	$1.36 \pm 0.12$
Jess's fit	$1.64 \pm 0.17$
James's preliminary fit	$1.74 \pm 0.20$

<b>silver</b>	<b><math>\lambda</math> (<math>10^{-6}\text{ns}^{-1}</math>)</b>
Dick's fit	$1.4 \pm 0.2$
James's fit	$1.41 \pm 0.26$