# Progress on the final TWIST measurement of $P_\mu \xi$

James Bueno, University of British Columbia and TRIUMF

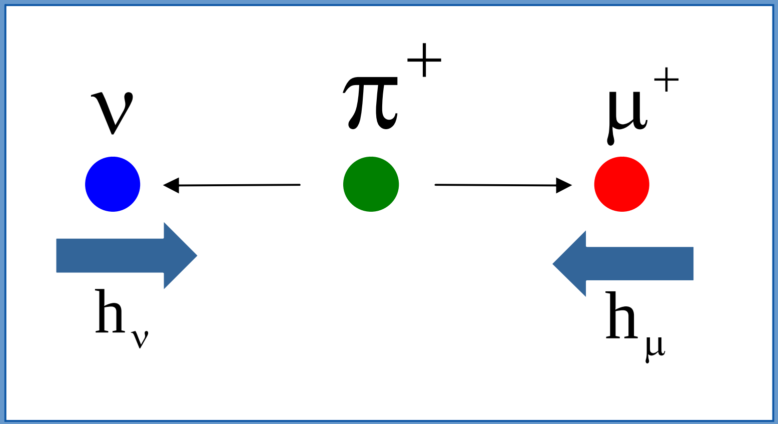
on behalf of the
Triumf Weak Interaction Symmetry Test

# Outline



- Muon production and decay
- Previous measurements of $P_\mu \xi$
- Sources of depolarisation, and their simulation.
  - Depolarisation in fringe field of solenoid.
  - Depolarisation in the muon stopping target.

# Muon production and $P_\mu \xi$

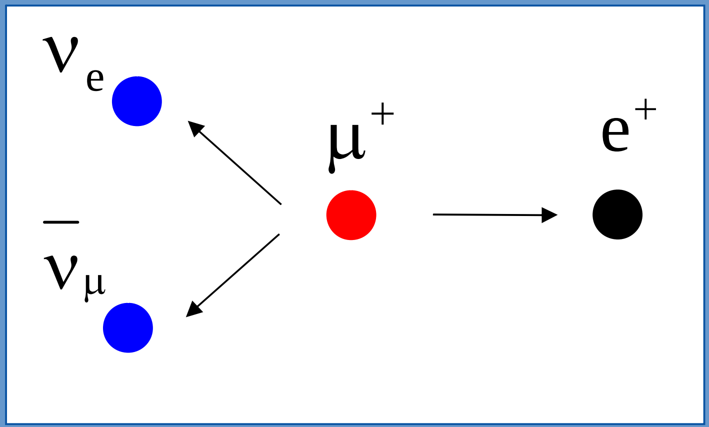



Muons from stationary pion decay are perfectly polarised
(for massless neutrinos)

TWIST only accepts a narrow momentum range
→ muon beam is highly polarised

# Muon decay and $P_\mu \xi$






TWIST measures $e^+$ energy (x) and angle (θ) relative to muon spin.

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

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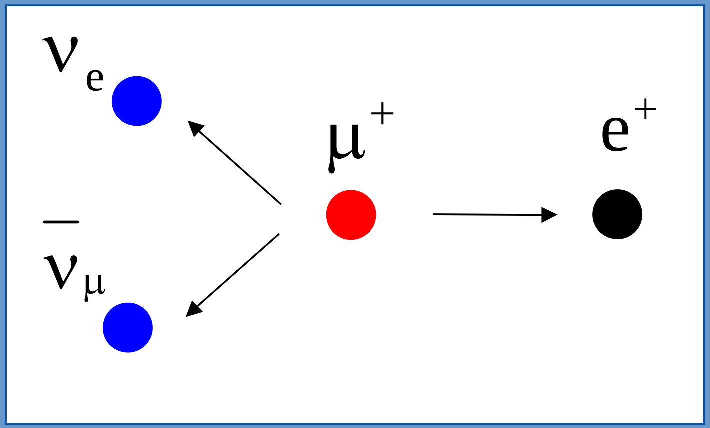


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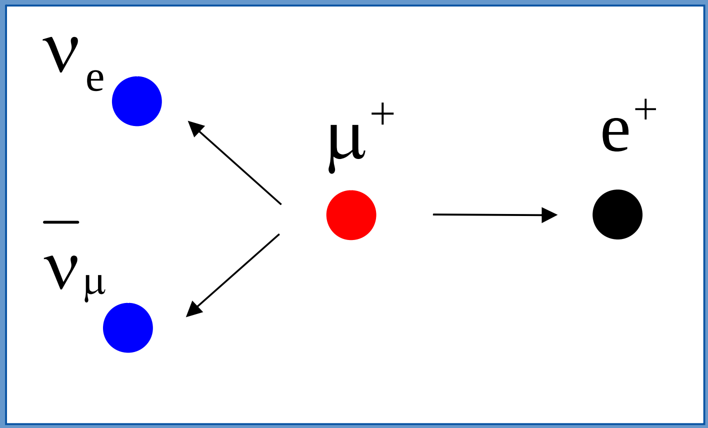


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$$\frac{d^2\Gamma}{dx\; d\cos\theta} \propto F_{IS}(x,\rho,\eta) + F_{AS}(x,\delta)\, P_\mu \xi \cos\theta$$

$P_\mu \xi$ appears as an inseparable product

determines forward-backward asymmetry

# Physics motivation



muon handedness

SM predicts LH muon decays to LH positron.

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

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

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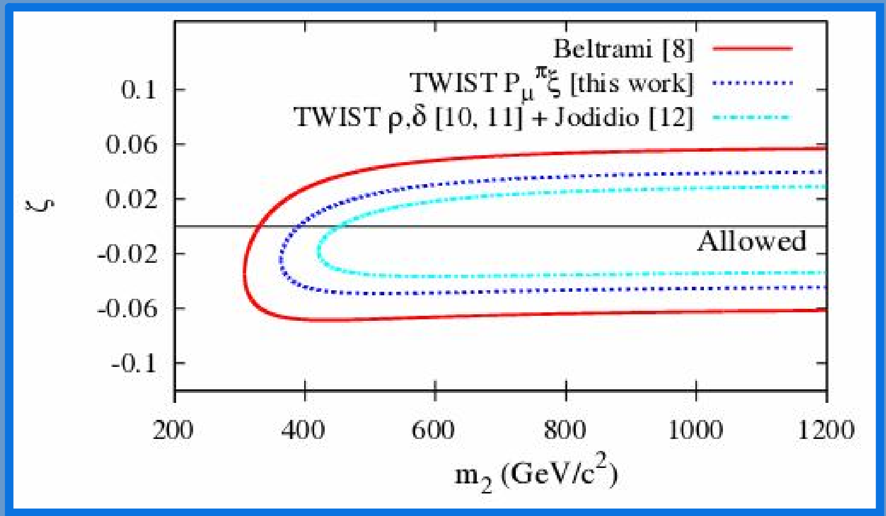
## left-right symmetric models

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




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

# Previous measurements of $P_\mu \xi$



Standard model, $P_\mu = 1, \;\; \xi = 1$

| | |
|---|---|
| 1987, Beltrami et al. (PSI) | 1.0027 ± **0.0079 (stat.)**<br>± 0.0030 (syst.) |
| 2006, Jamieson et al.<br>(TWIST, TRIUMF) | 1.0003 ± 0.0006 (stat.)<br>± **0.0038 (syst.)** |
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| *2009, final result from TWIST (goal)* | *± 0.0003 (stat.)* *± **0.0010 (syst.)*** |

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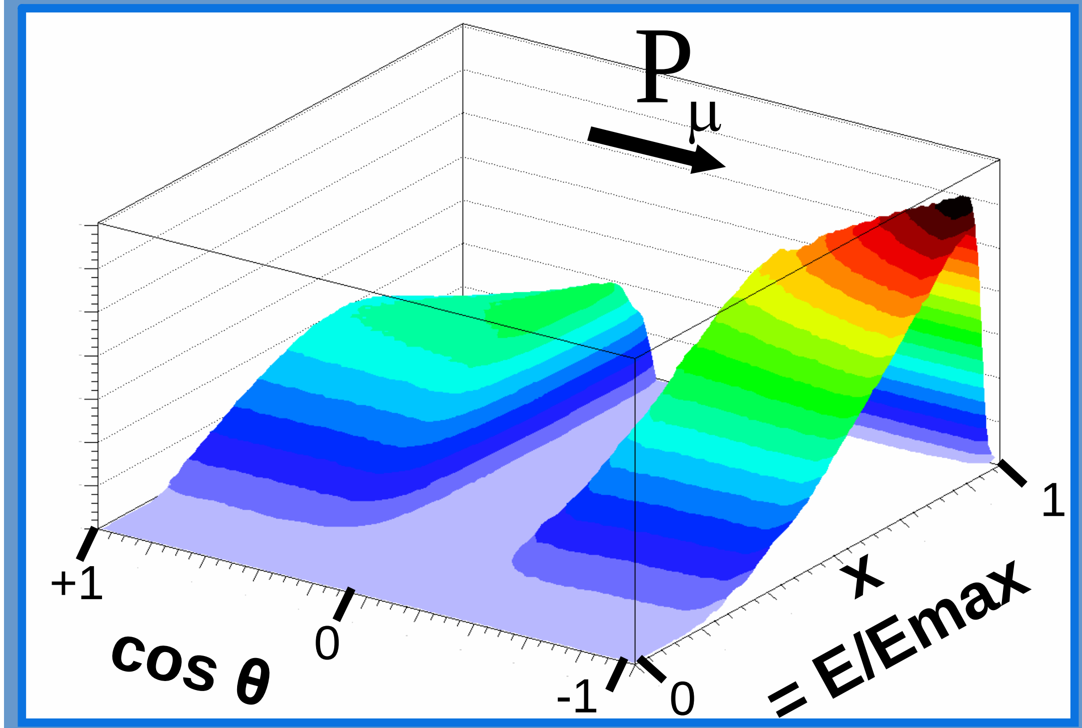
Previous TWIST direct measurement limited by uncertainties in simulating $P_\mu$

# TWIST measurement of $P_\mu \xi$



Michel spectrum

from real data



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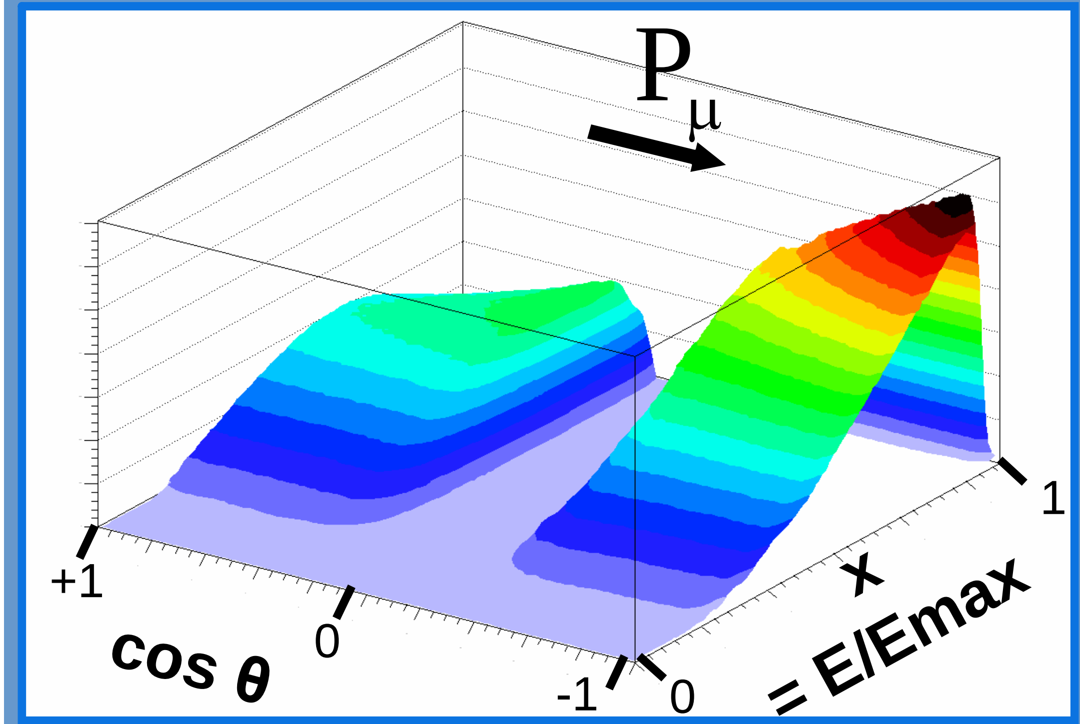
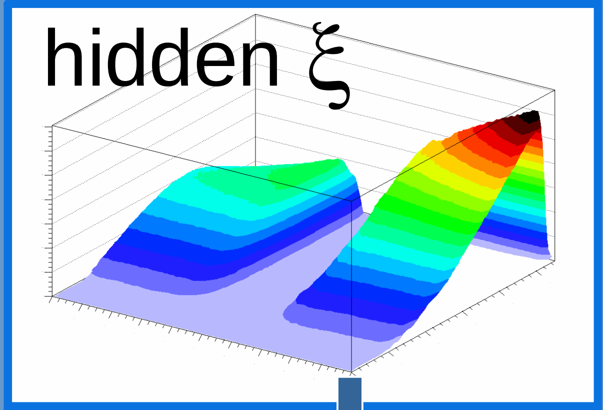



Spectrum from GEANT simulation

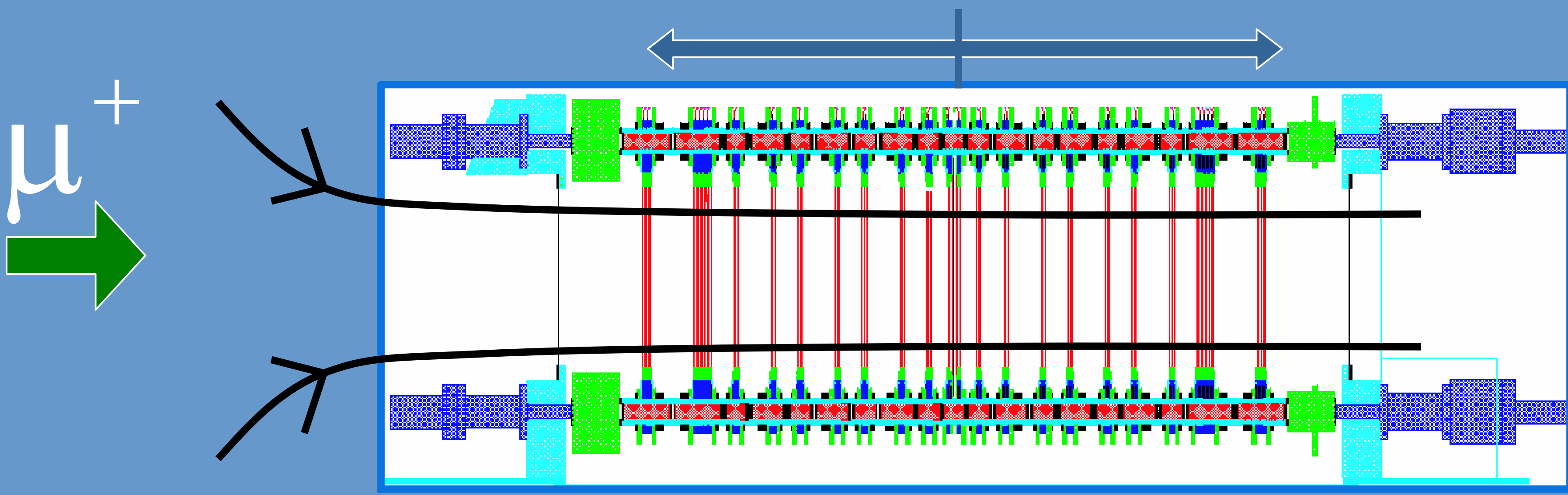



**<u>difference</u>** in $P_\mu \xi$ is measured

Spectra from decay (depolarised) μ are compared
→ depolarisation in simulation must match data

# Sources of depolarisation

symmetric tracking volume



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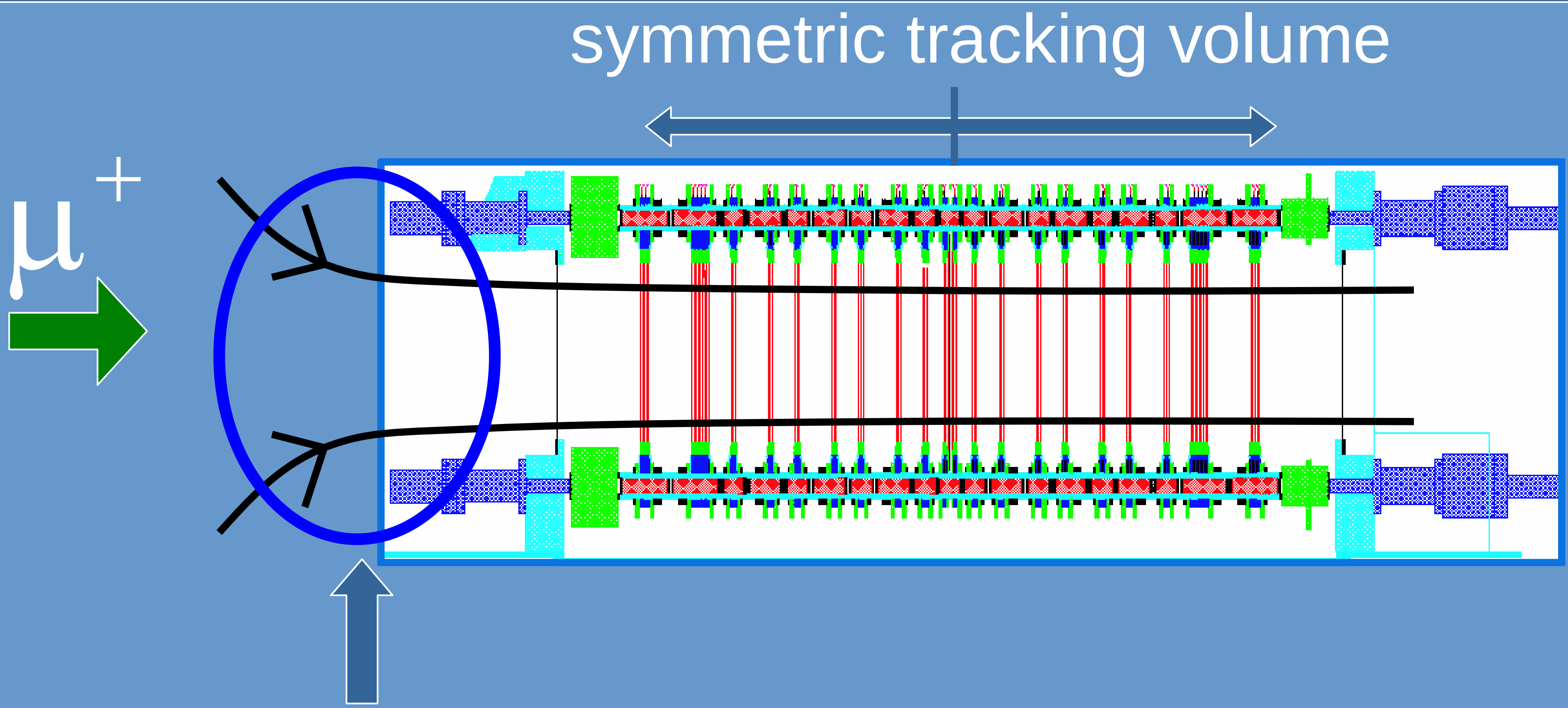
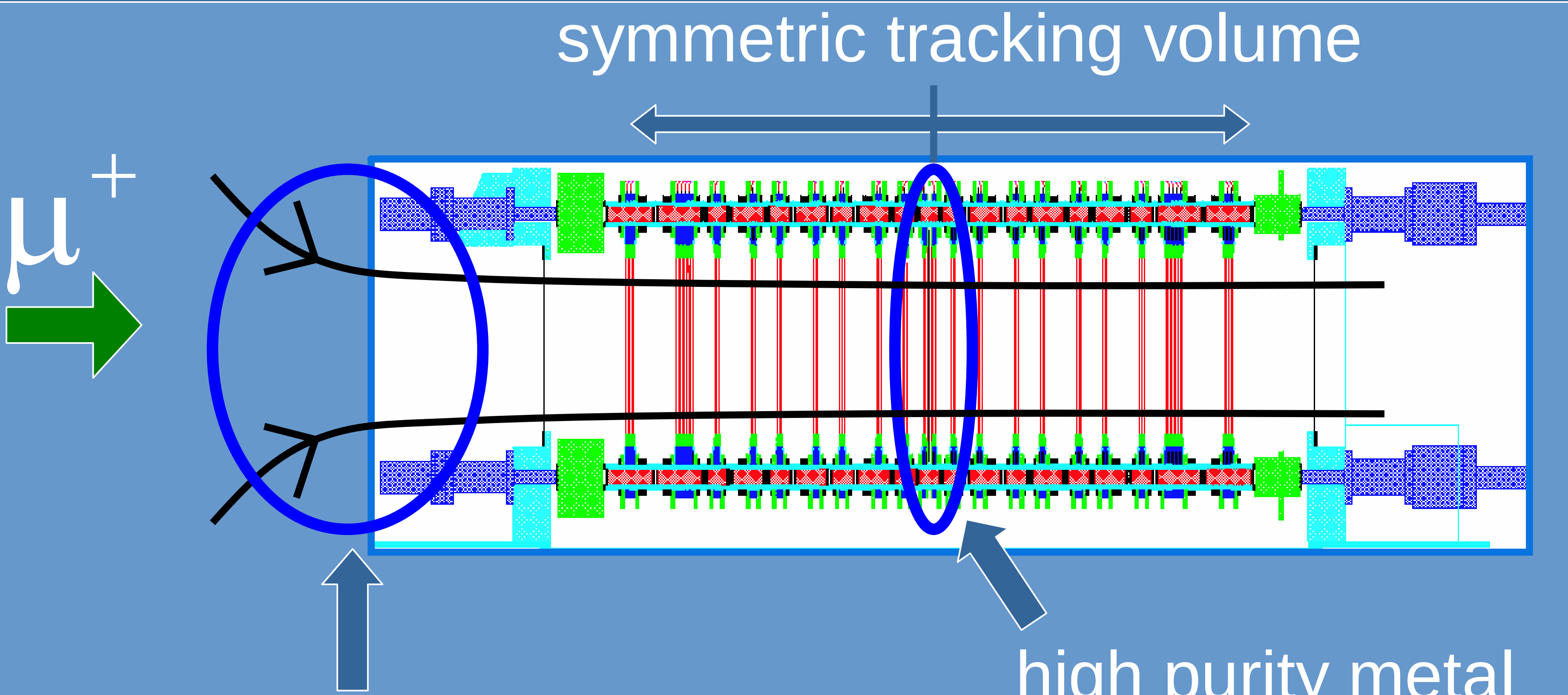



$P_\mu$ depends on trajectory

# Sources of depolarisation

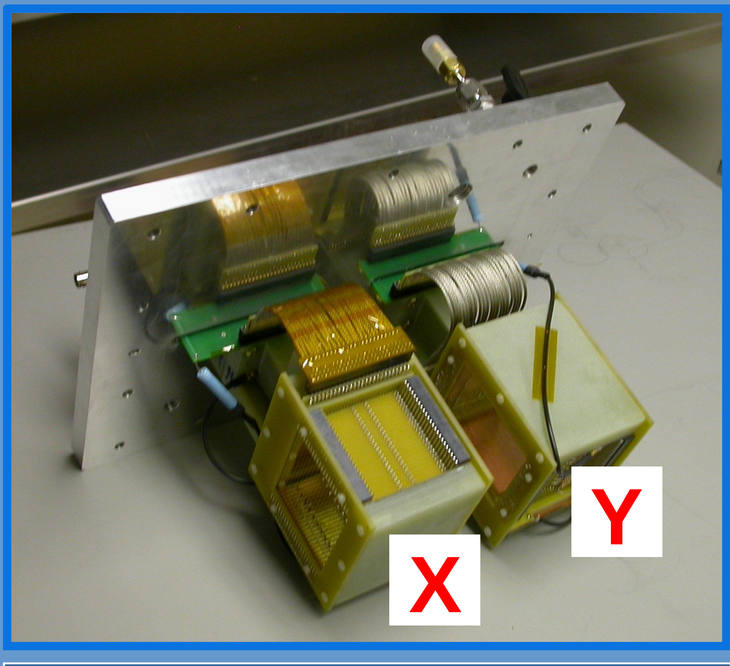




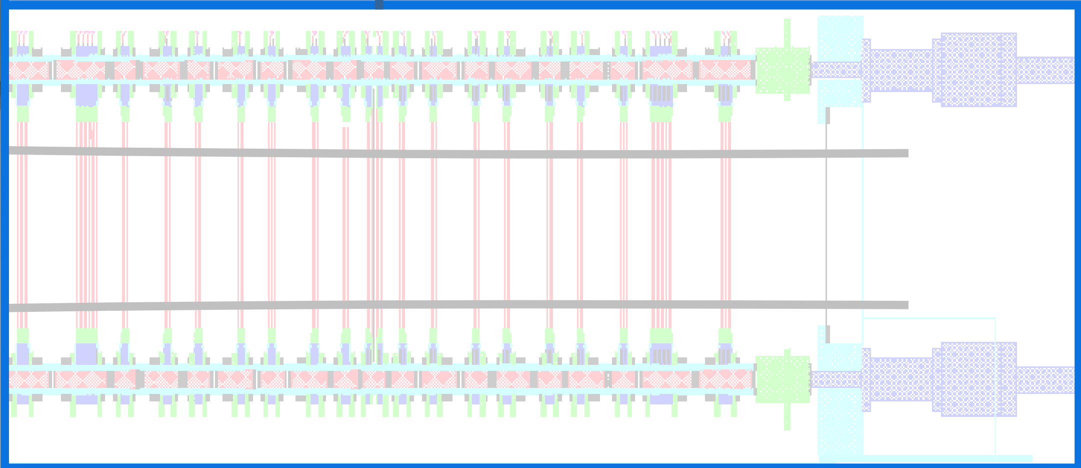

$P_\mu$ depends on trajectory

$P_\mu$ depends on time

# Simulating the depolarisation



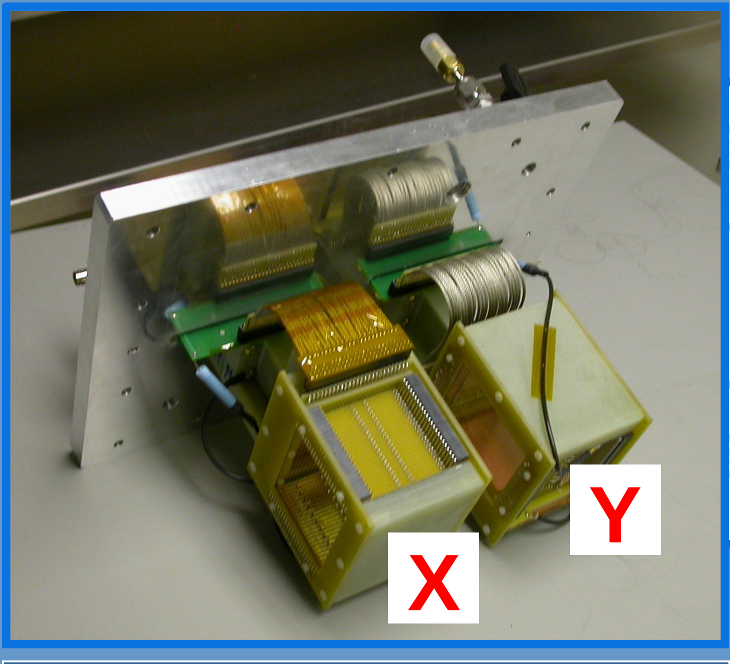

symmetric tracking volume

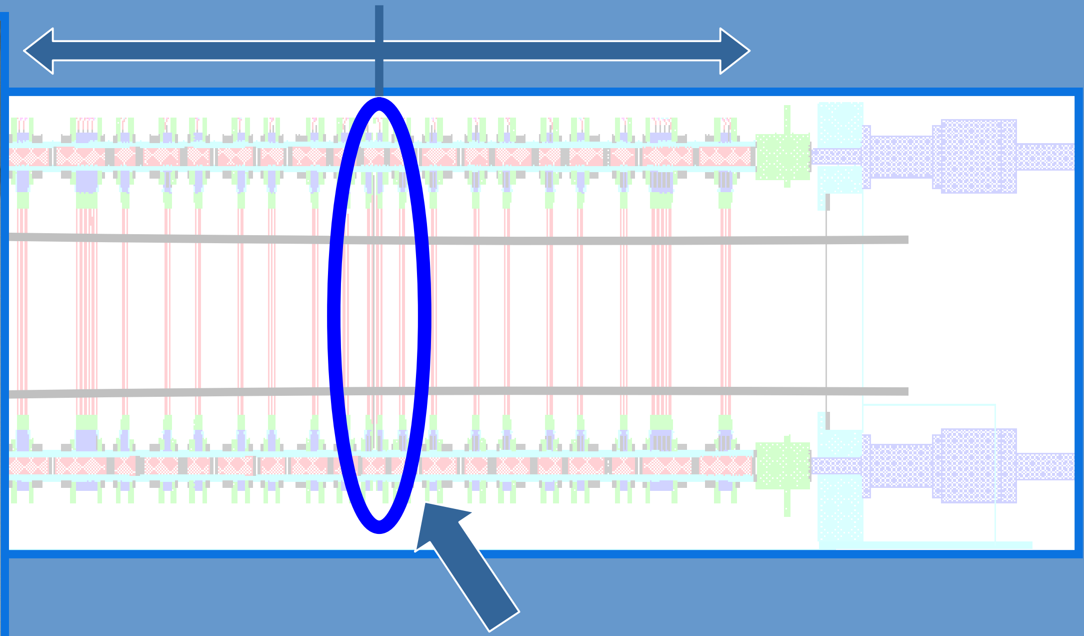


Beam is measured by time expansion chambers BEFORE the fringe field

# Simulating the depolarisation

symmetric tracking volume



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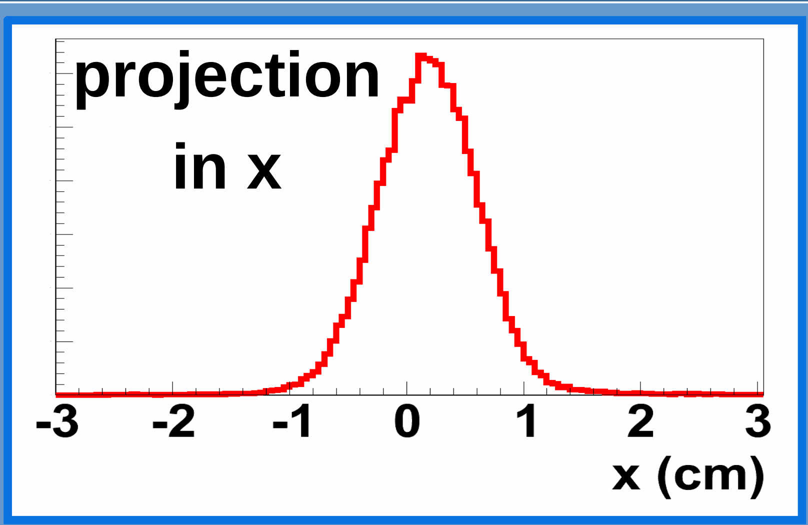
Time dependence of $e^+$ forward-backward asymmetry gives $P_\mu(t)$ in target

# Simulating muon trajectories



1. Measure each **muon's** position and angle with time expansion chambers.



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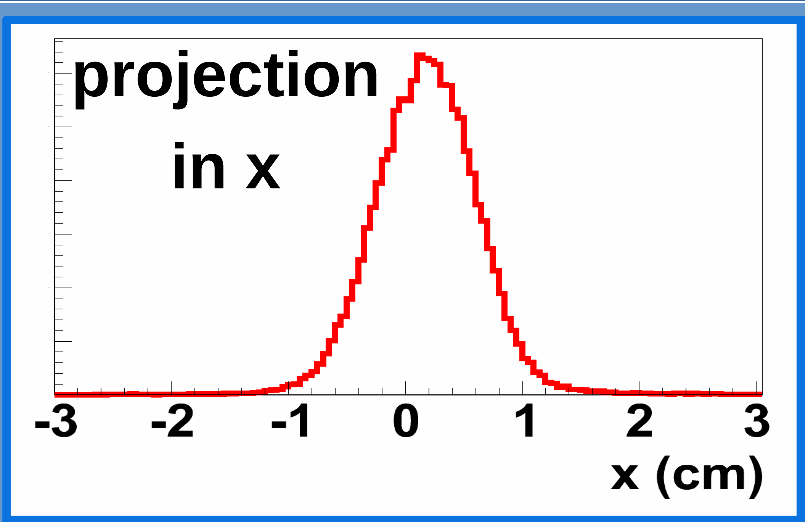


2. Correct angles for multiple scattering.

3. Simulate muons with GEANT and track spin to predict $P_\mu$ at target.

Uncertainties due to beam instability, initial position & angle of beam, position & shape of B-field.

# Beam stability (1 of 2)



During data acquisition, we needed a stable muon beam for weeks on end.

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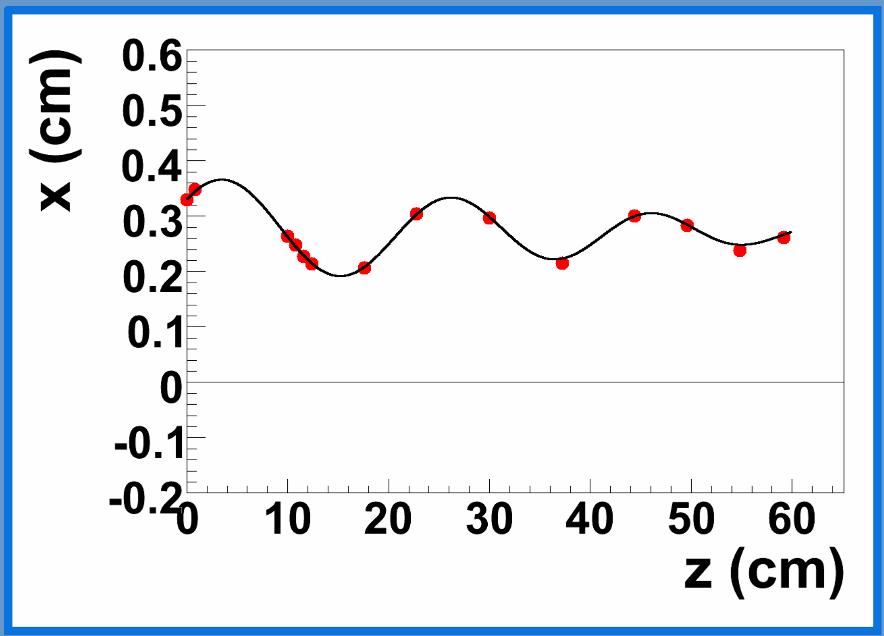
During data acquisition, we needed a stable muon beam for weeks on end.

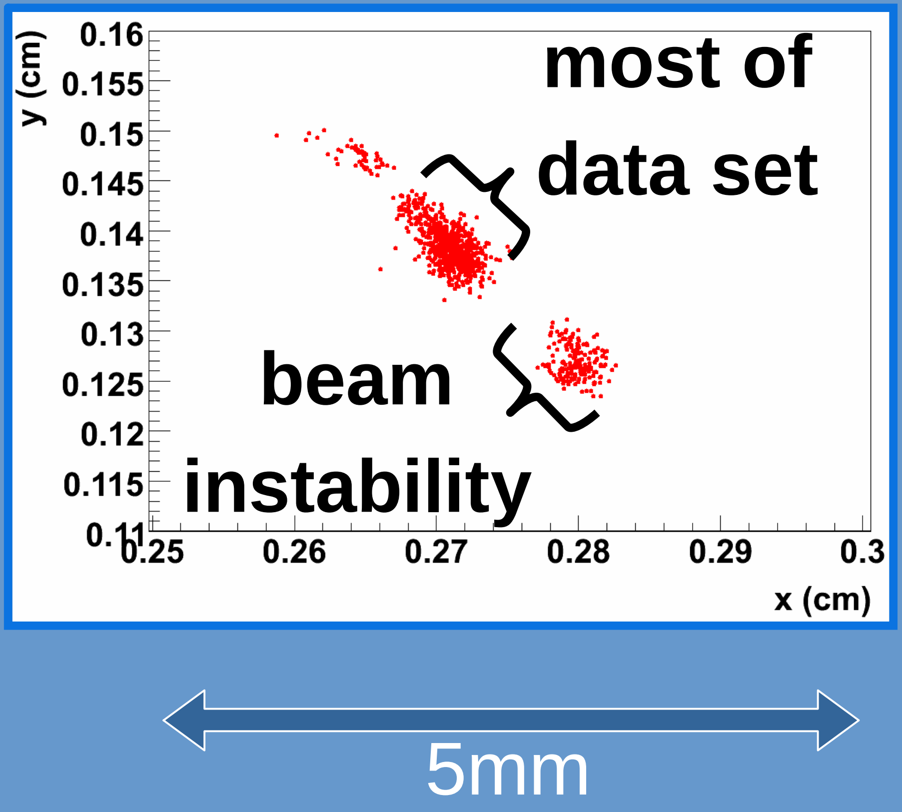
And a method of detecting beam instabilities without the time expansion chambers in place.
(too much multiple scattering)

# Beam stability (2 of 2)

For 2006/7, internal beamspots are fit to a helix.



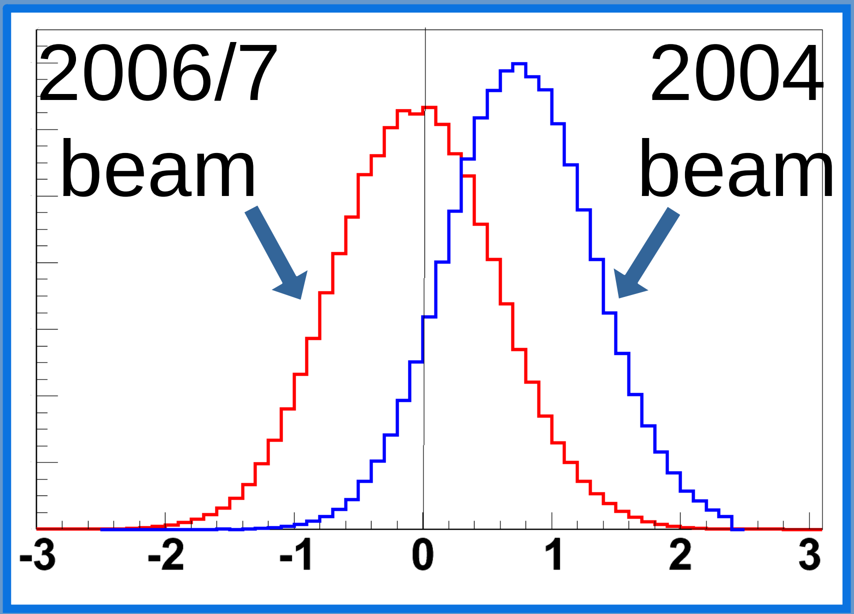

Helix fit parameters indicate position and momentum.



# Misalignment uncertainties



For 2006/2007 data, the beam was steered onto the solenoid axis.

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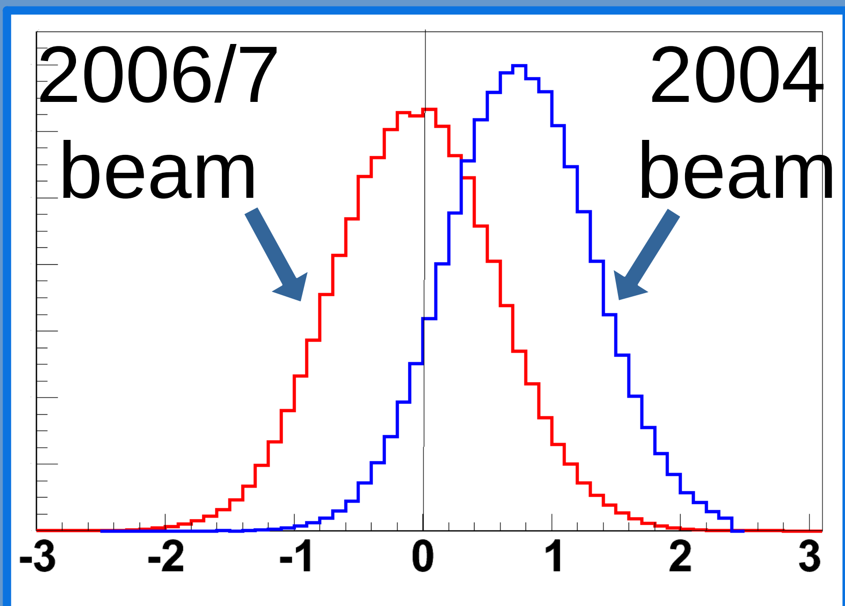


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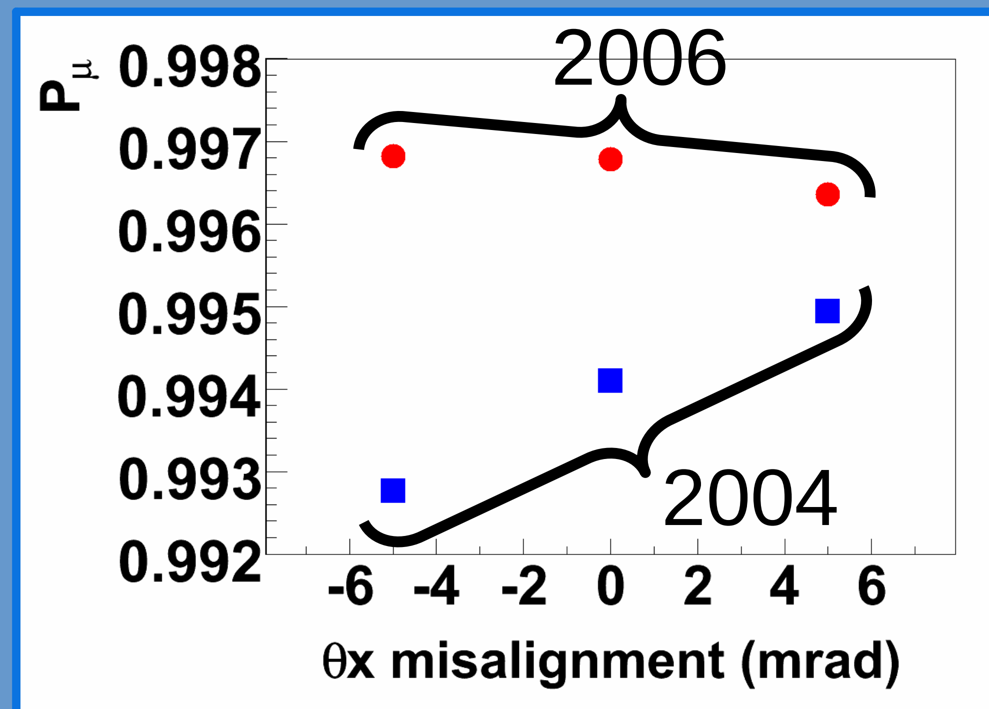
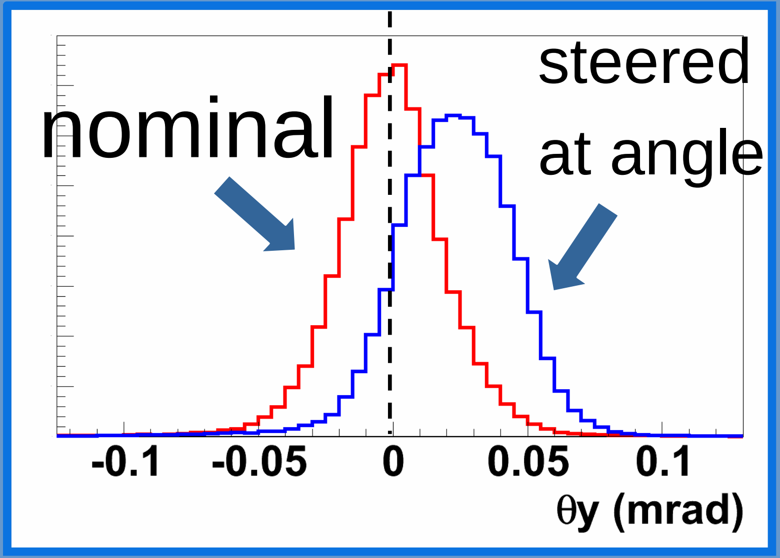



Sensitivity to misalignments is now reduced

# Spin tracking in the B-field



To validate GEANT's spin tracking: two weeks of low $P_\mu$ data taken in 2006/7.



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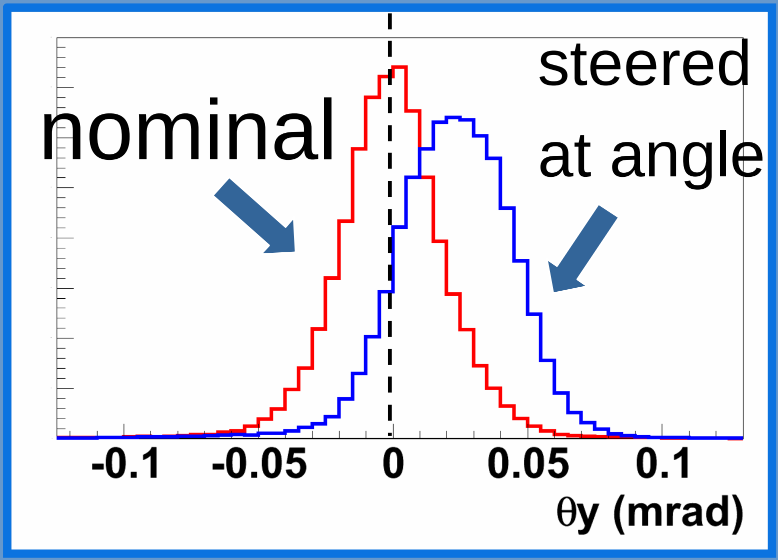


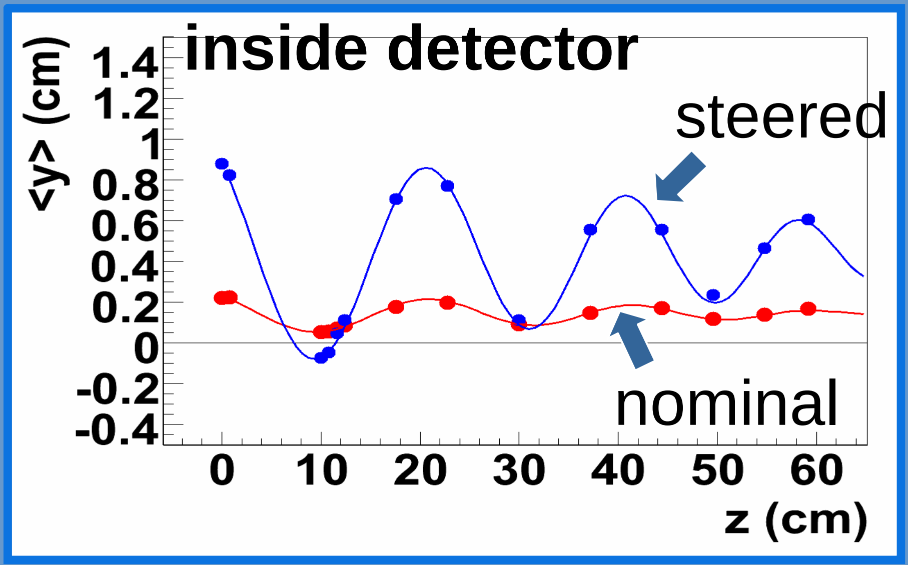

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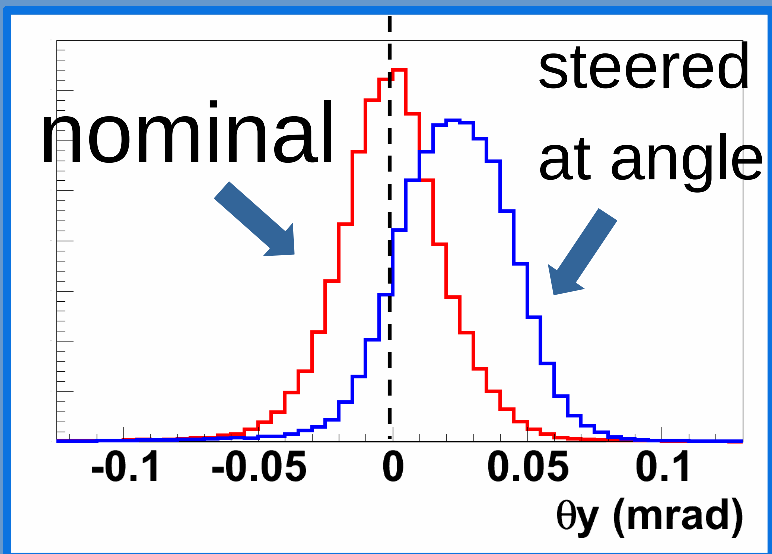


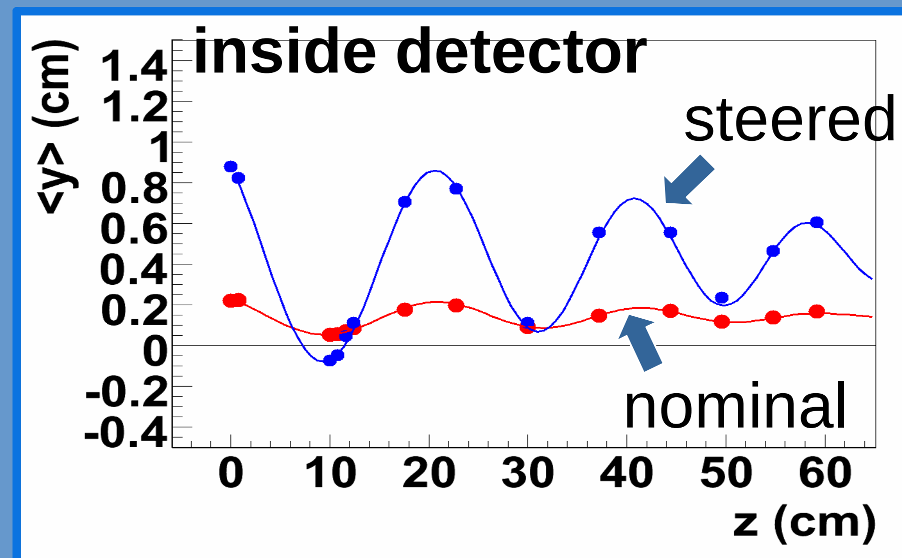


Validation (in progress now) will require:

$$\left(P_\mu^{nominal} - P_\mu^{steered}\right)_{DATA} = \left(P_\mu^{nominal} - P_\mu^{steered}\right)_{SIMULATION}$$

# Stopping target depolarisation



Ideally, the muons would not depolarise at the stopping target
(it’s 99.999% pure aluminium, or silver).

However, an individual muon spin can interact with local magnetic fields and reverse sign.

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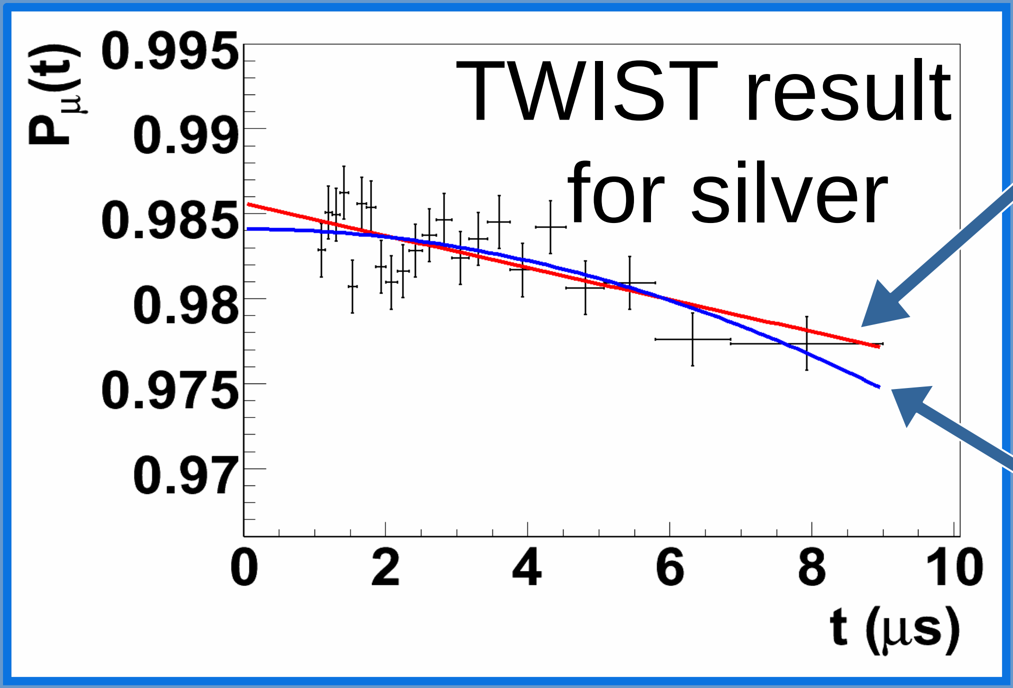


$$P_\mu(t) = P_\mu(0) \cdot \exp(-at)$$

theoretically preferred

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

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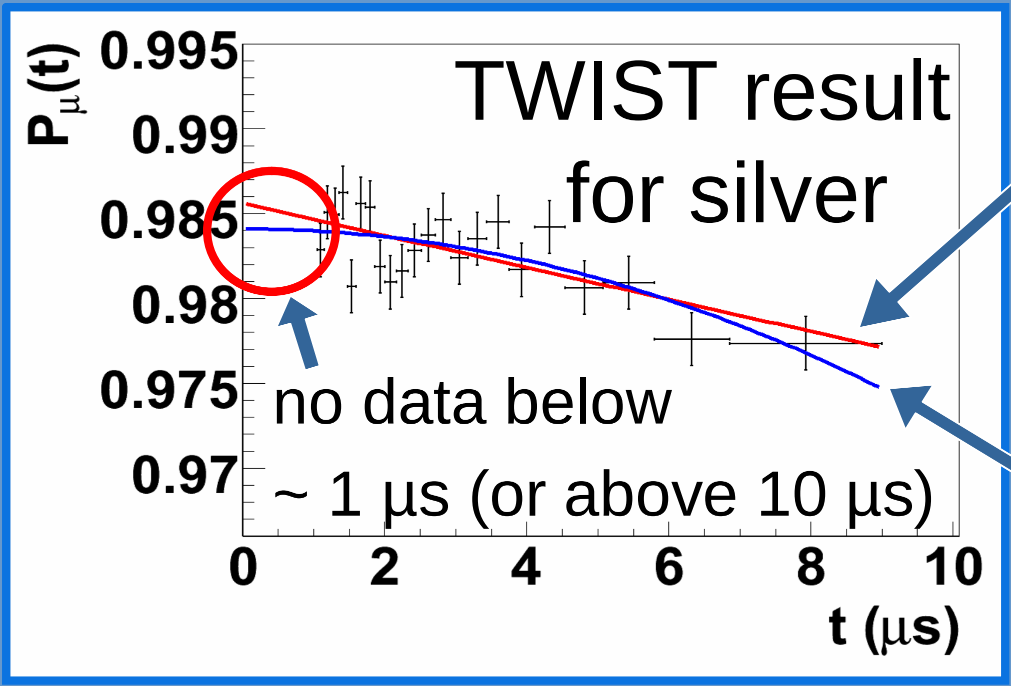


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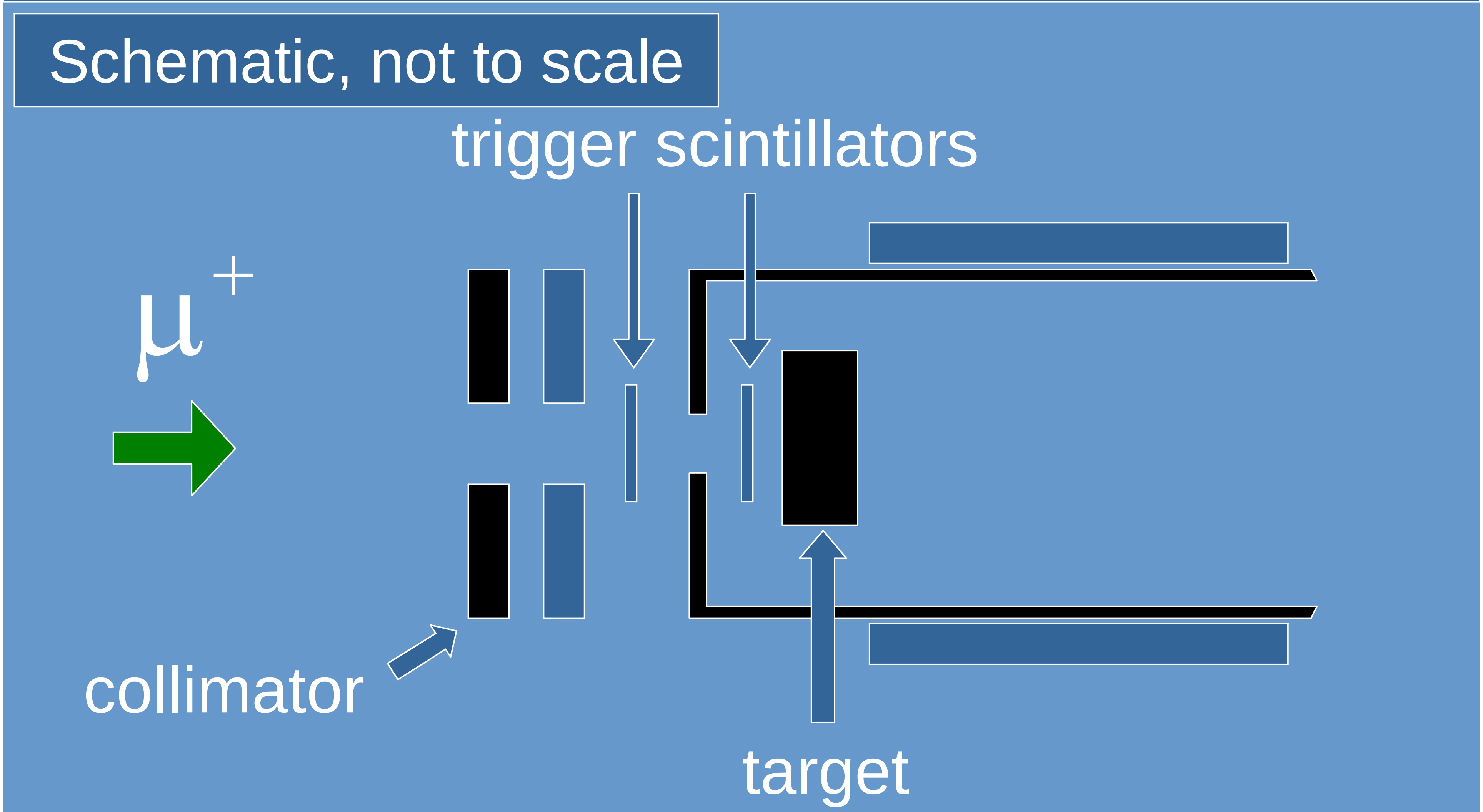
A subsidiary experiment would be helpful…

# Subsidiary muSR experiment





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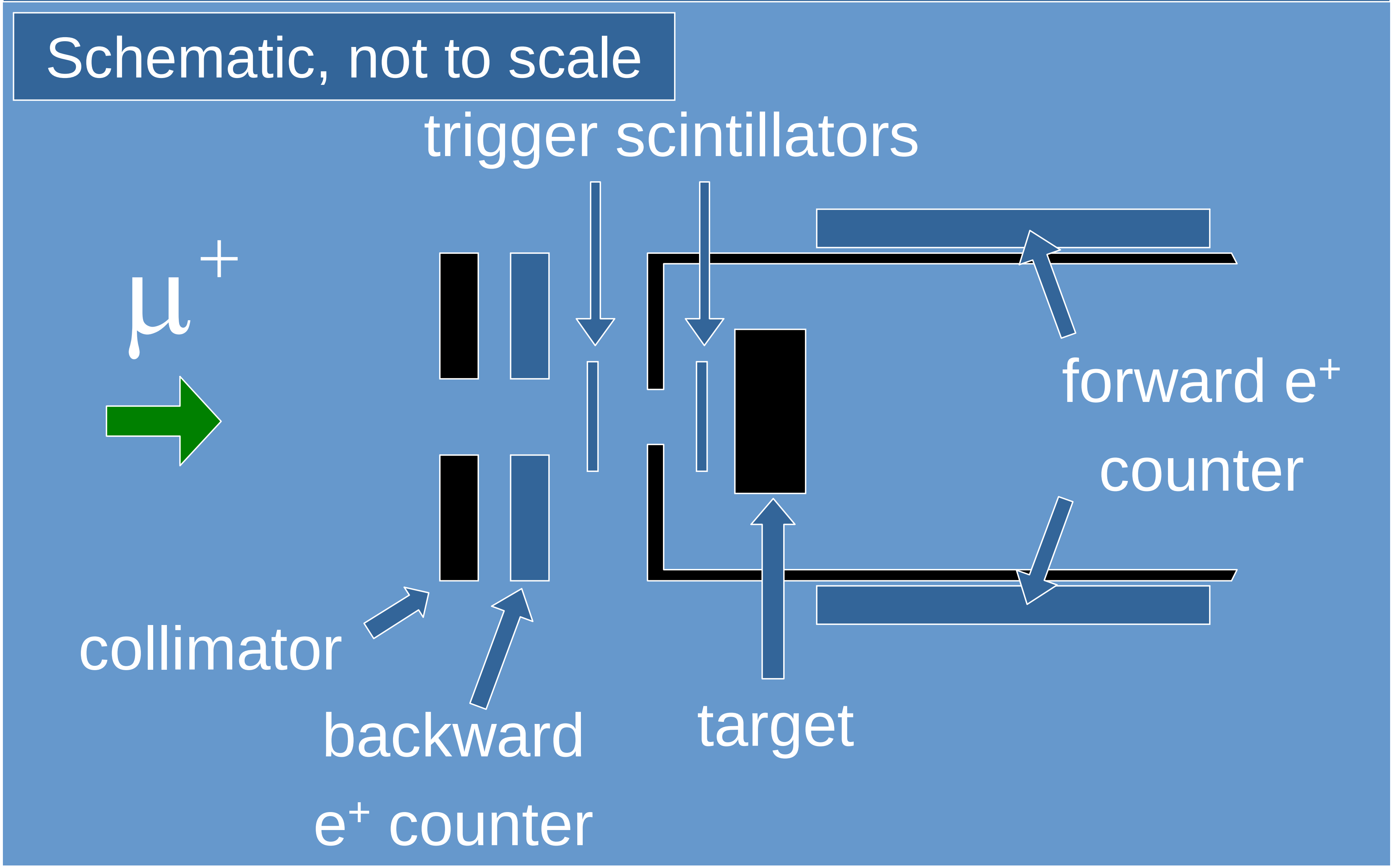

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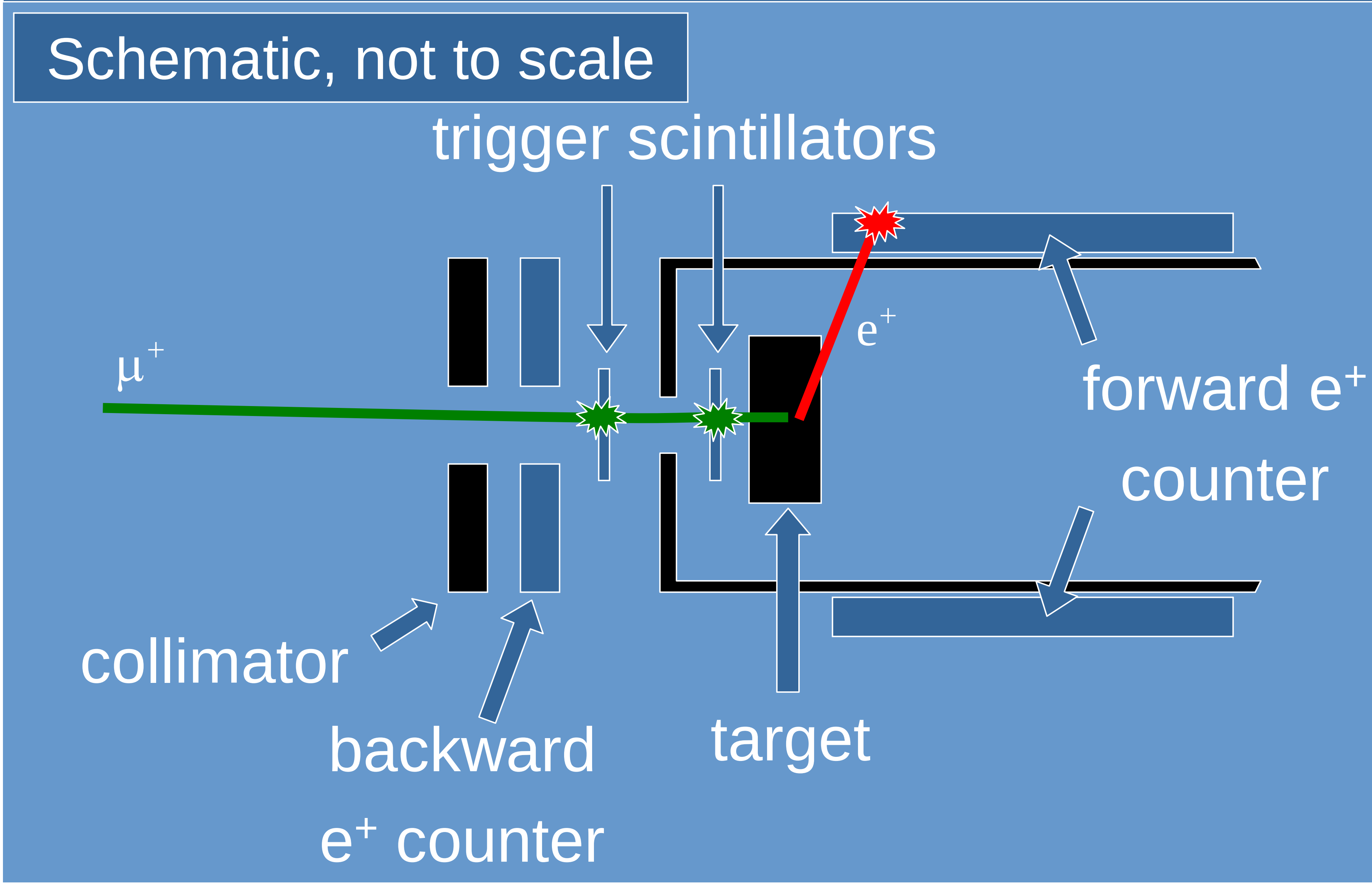

# Subsidiary muSR experiment



Advantages:

- Higher rate (~30kHz compared to ~3kHz)
- Larger time fiducial

  (~5 ns → 14 μs, compared to ~1 μs → ~9 μs).

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- Larger time fiducial
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Disadvantages:

- Background from beam positrons.
- A fraction of muons stop in the scintillator.

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Unfortunately, still no discrimination between

$P_\mu(t) = P_\mu(0) \cdot \exp(-at)$ and $P_\mu(t) = P_\mu(0) \cdot \exp(-bt^2)$

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| TWIST | 1.4 ± 0.1 | 1.1 ± 0.3 |
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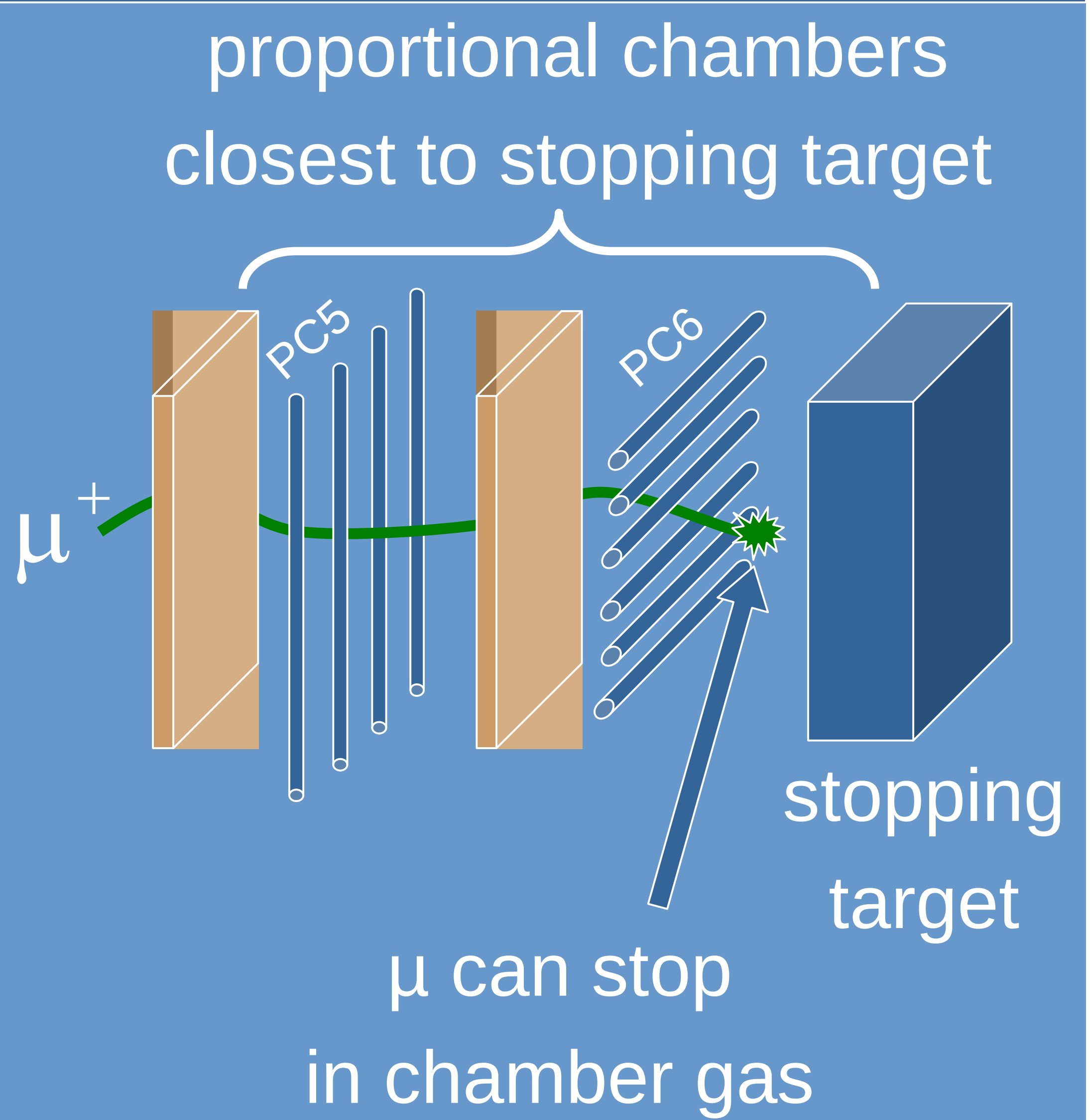
Experiment confirmed no fast depolarisation between ~5 ns and 1 µs, and results are consistent with TWIST.

# Using target PCs in TWIST

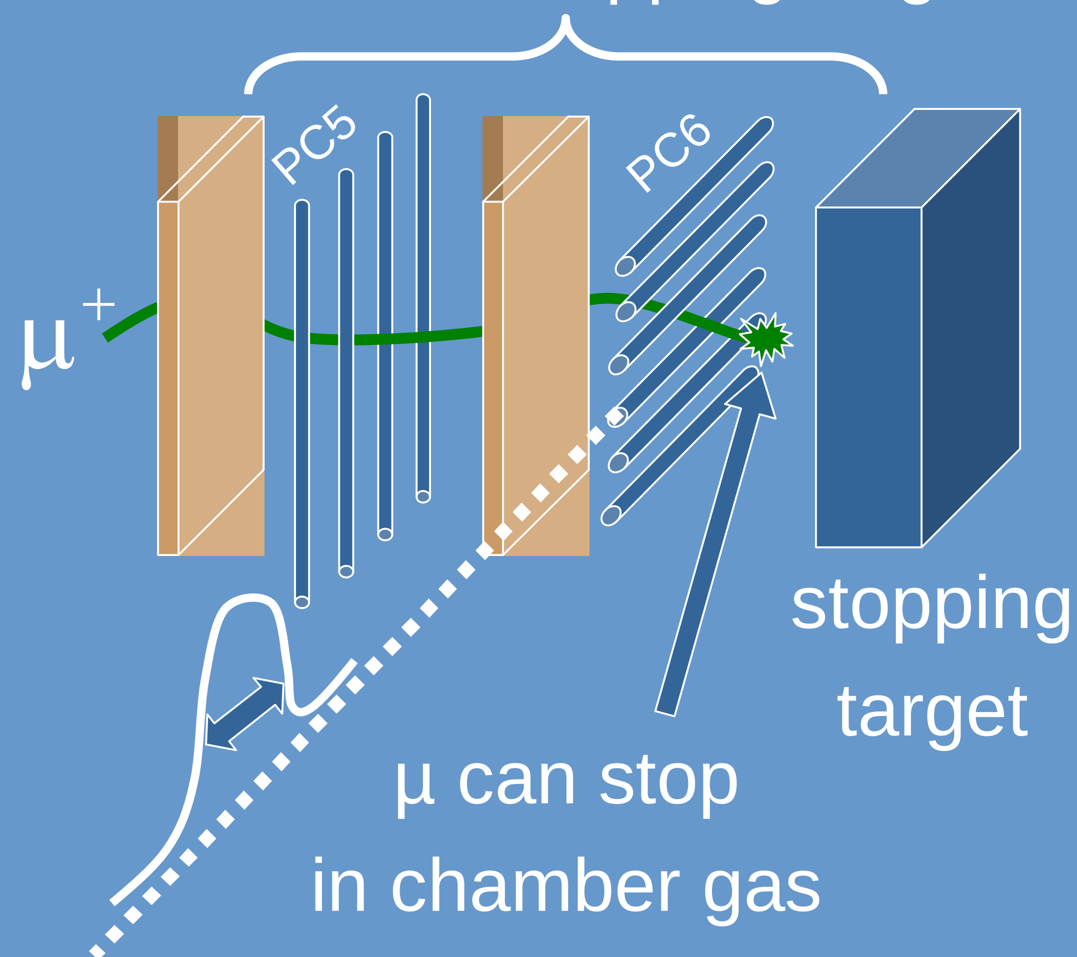




# Using target PCs in TWIST



proportional chambers closest to stopping target




pulse width in final PC greater for muons that stop here (more energy deposited)

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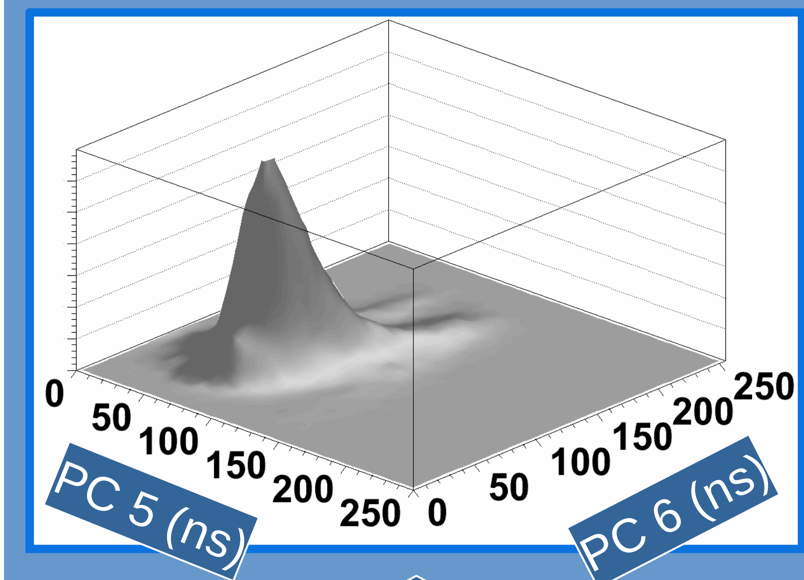


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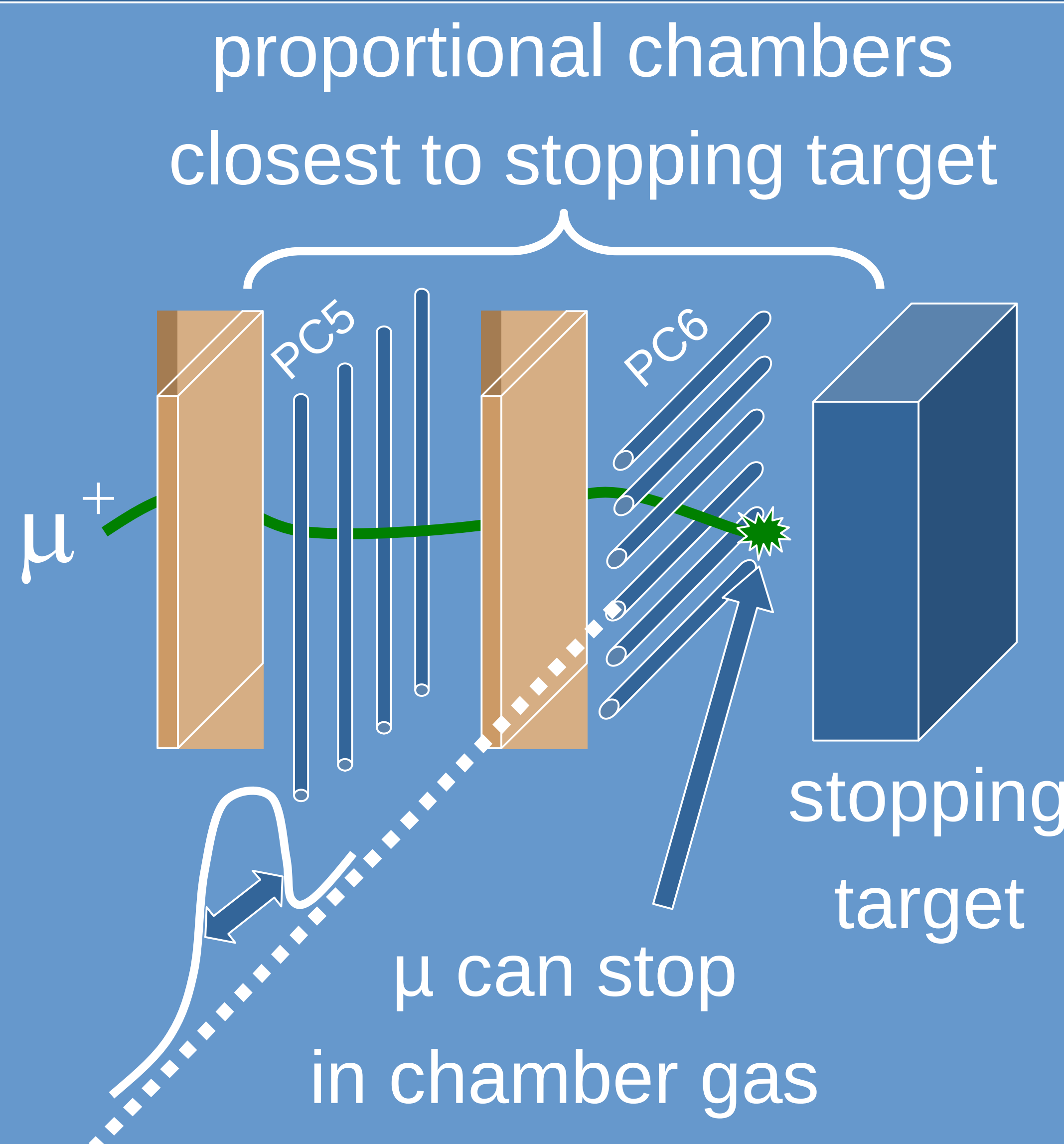
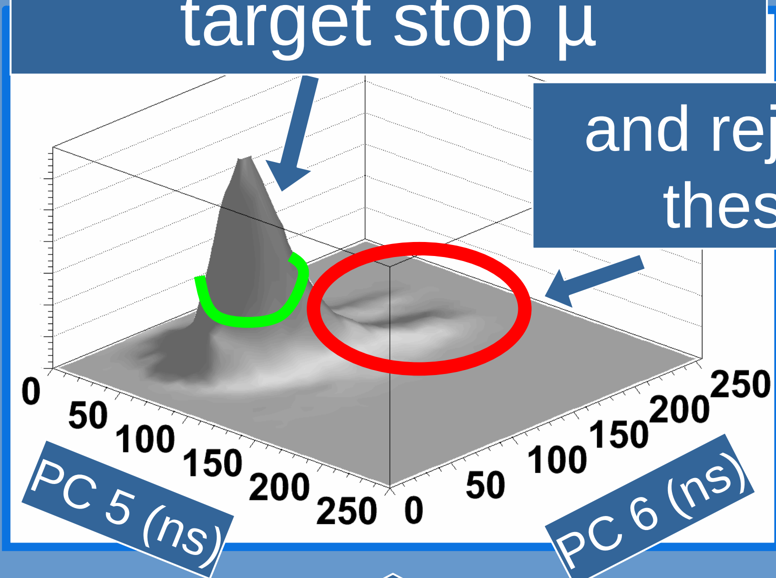


# Using target PCs in TWIST



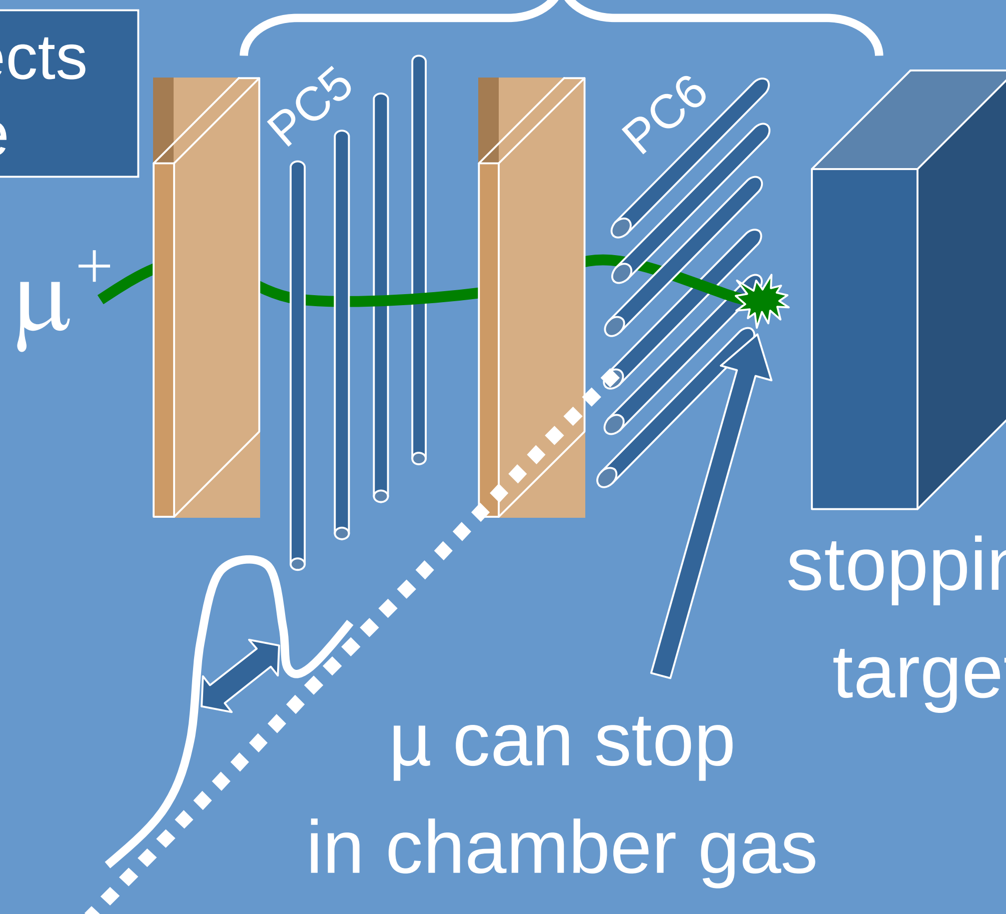
deep cut selects target stop μ




and rejects these

pulse width in final PC greater for muons that stop here (more energy deposited)

proportional chambers closest to stopping target




stopping target

μ can stop in chamber gas

# Summary

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- Validation of the spin tracking is well underway.
- Improvements in data acquisition in 2006/7 will reduce $P_\mu$ uncertainties.
- Subsidiary muSR experiment has confirmed no fast depolarisation exists (this could not be measured by TWIST).
- Time dependent depolarisation uncertainties can be minimised by selecting genuine target stops.

# The TWIST collaboration




**TRIUMF**

Ryan Bayes*†
Yuri Davydov
Wayne Faszer
Makoto Fujiwara
David Gill
Alexander 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

**Kurchatov Institute**

Vladimir Selivanov

**Montréal**

Pierre Depommier

**Valparaiso**

Don Koetke
Shirvel Stanislaus

**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



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