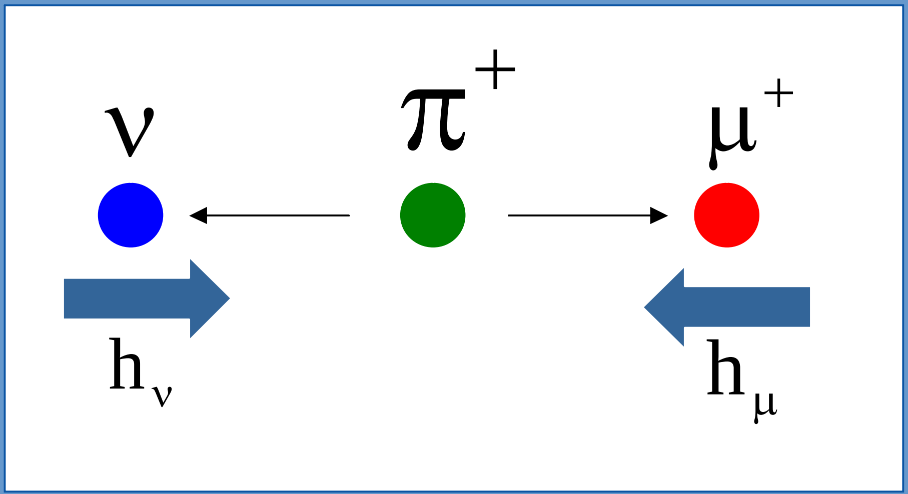
Muon decay asymmetry and the Standard Model

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

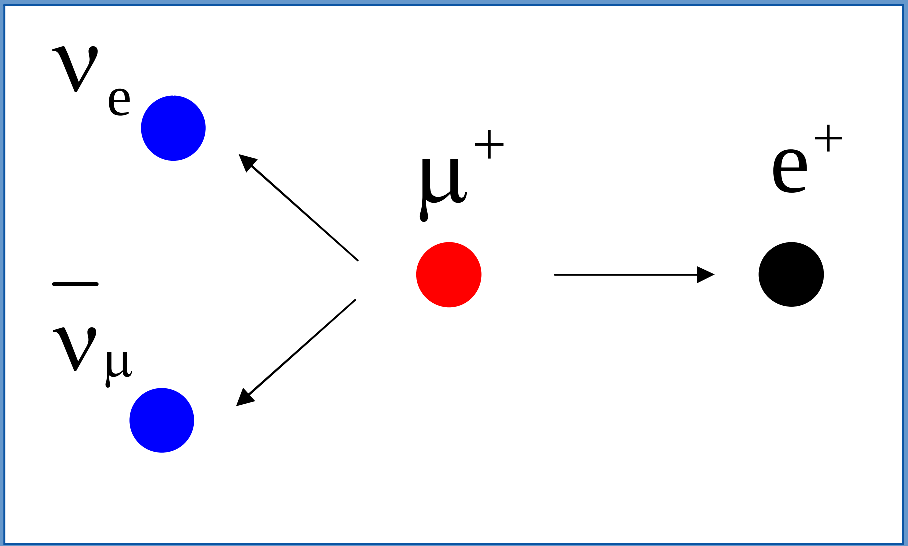
Outline

- Theory
  - Muon decay and $P_\mu\xi$
  - Existing $P_\mu\xi$ measurements
  - Left-right symmetric models
- TWIST experiment
  - Precision goals
  - Depolarisation uncertainties
    - Magnetic field
    - Stopping target

Muon production and decay



- Muons from pion decay are 100% spin polarised.



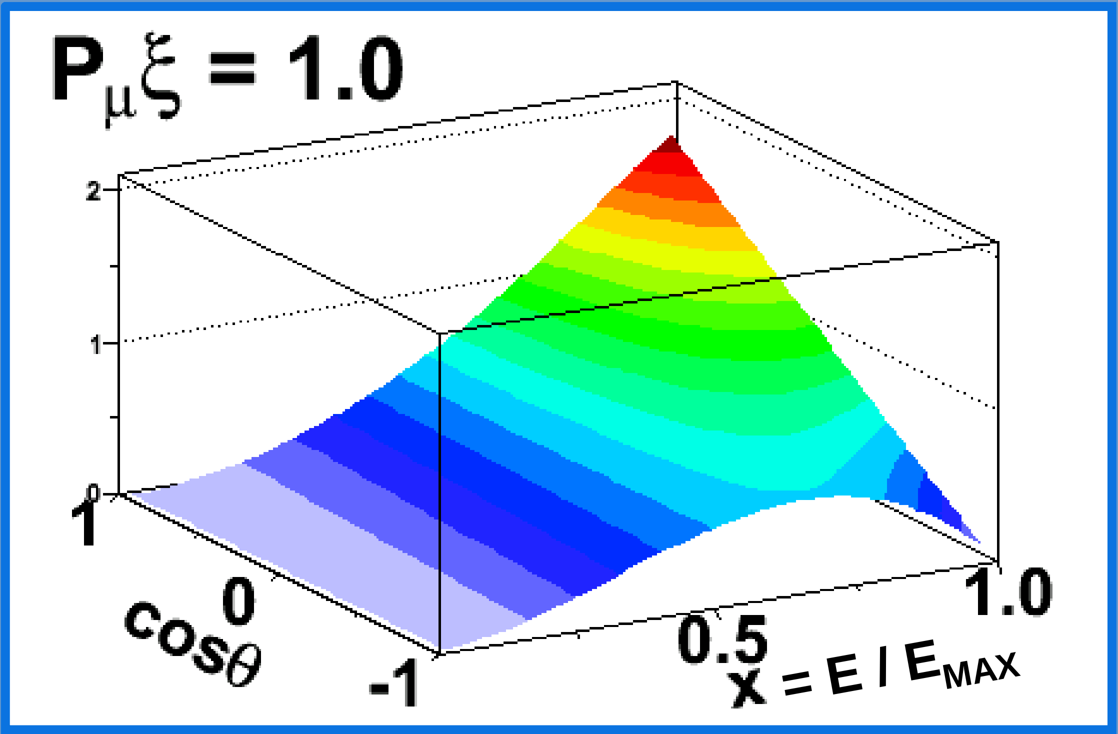
- Muon decay only involves leptons.
- e^+ preferentially emitted in direction of μ^+ spin.

Positron spectrum

(see PDG review "Muon Decay Parameters")

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

Integral asymmetry



Standard Model

$P_\mu = \xi = 1$

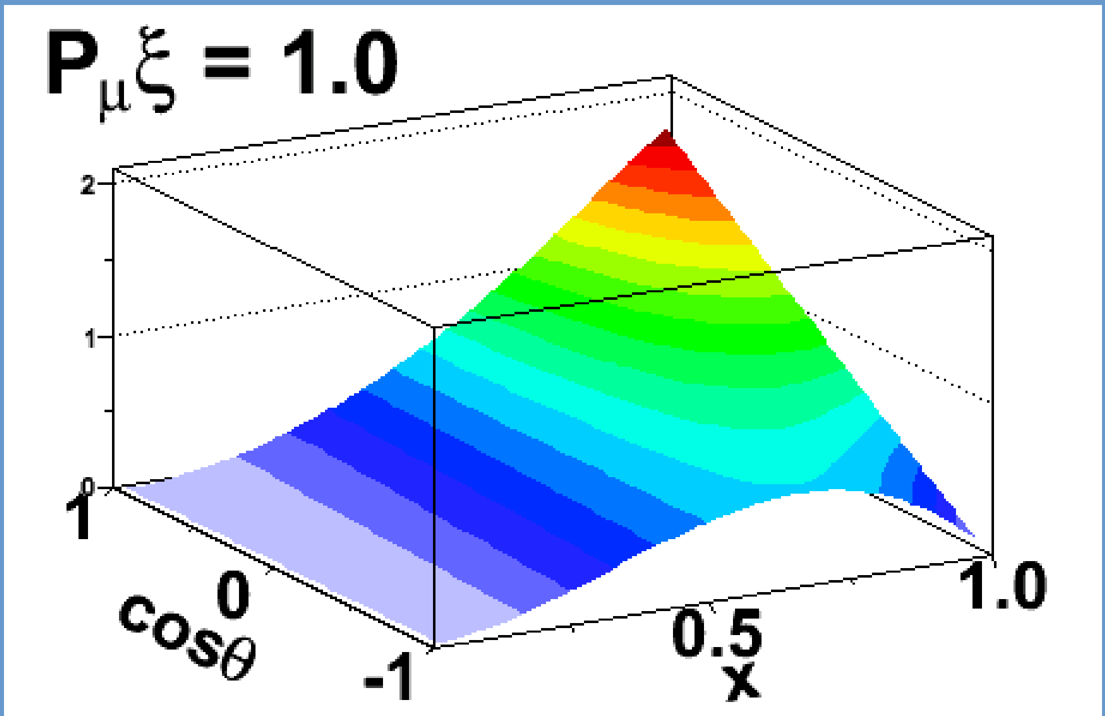
("V-A")

Positron spectrum

(see PDG review "Muon Decay Parameters")

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

Integral asymmetry

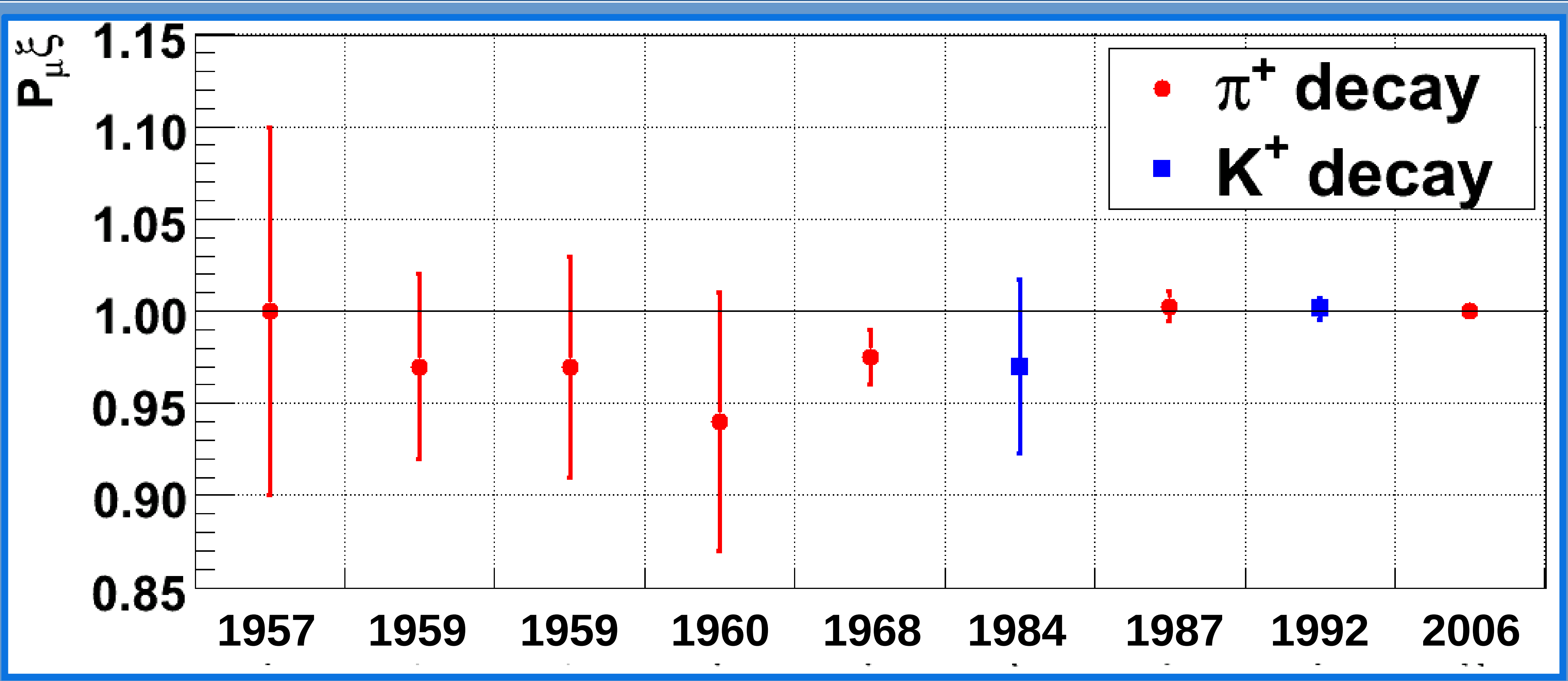


Standard model

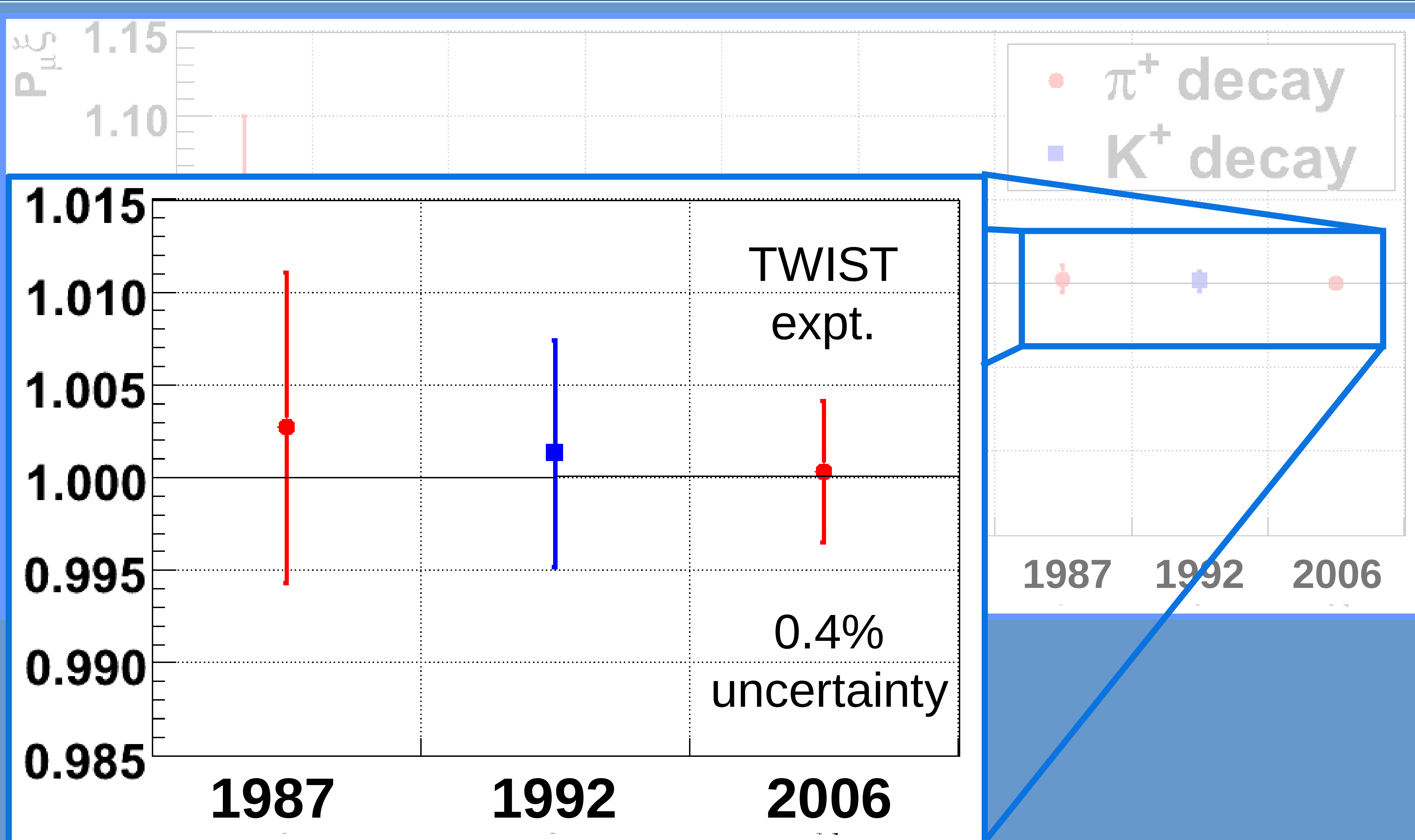
$P_\mu = \xi = 1$

("V-A")

Existing results for $P_\mu \xi$

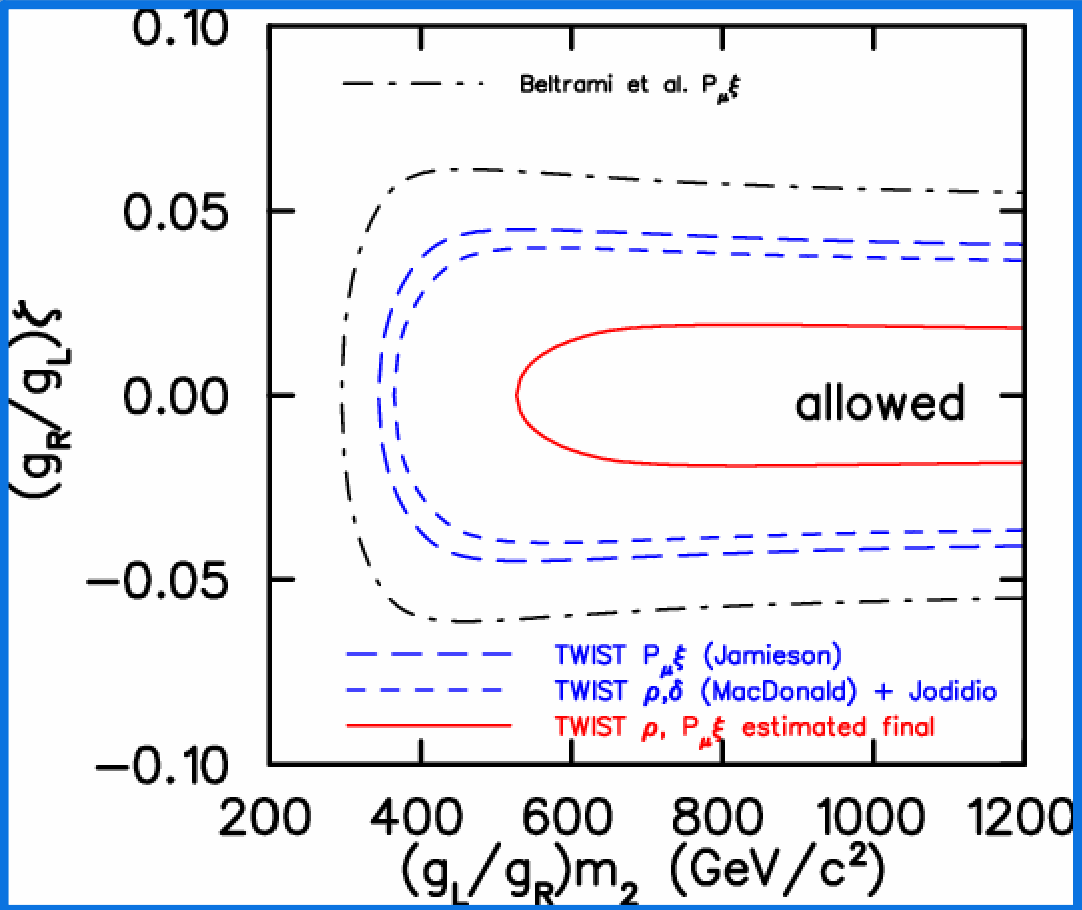


Existing results for $P_\mu \xi$



Left-right symmetric models

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

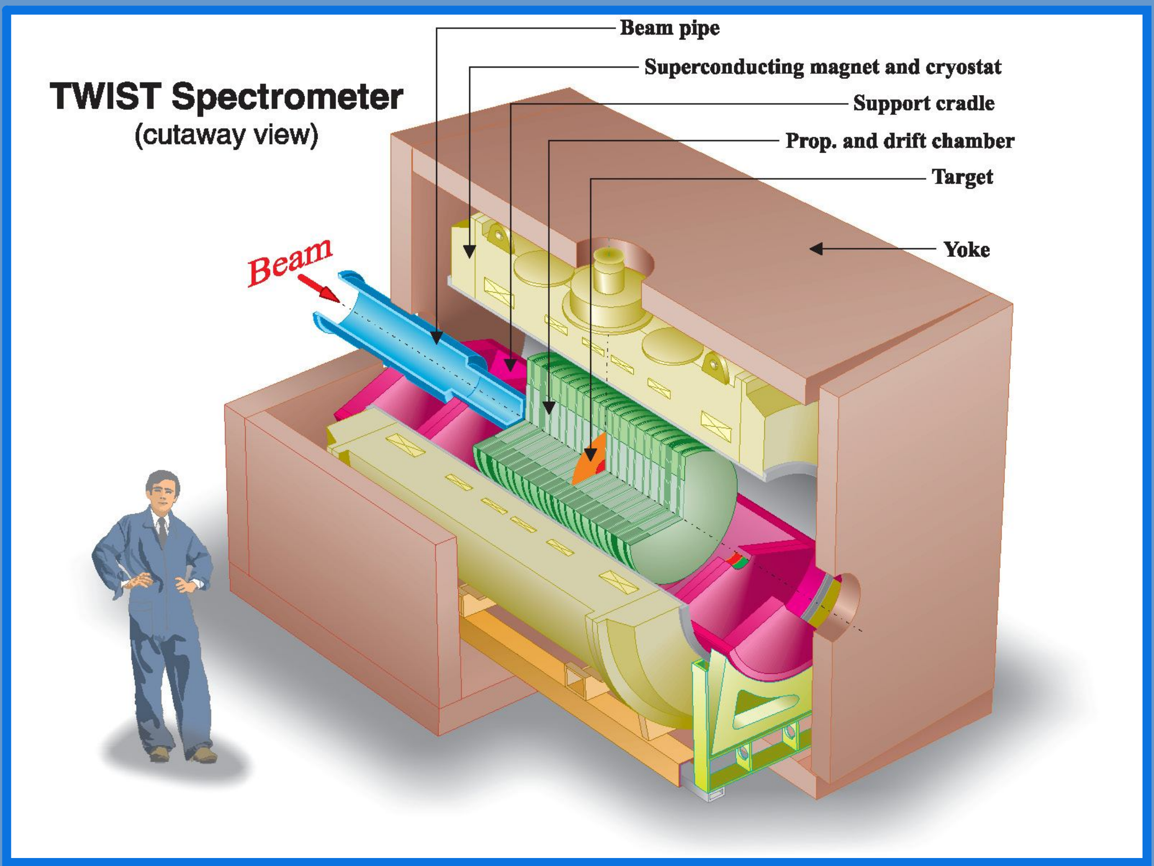


Weak interaction eigenstates (W_L, W_R) in terms of mass eigenstates (W_1,W_2) and mixing angle (ζ):

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

P_μ and ξ are sensitive to mass ratio and ζ

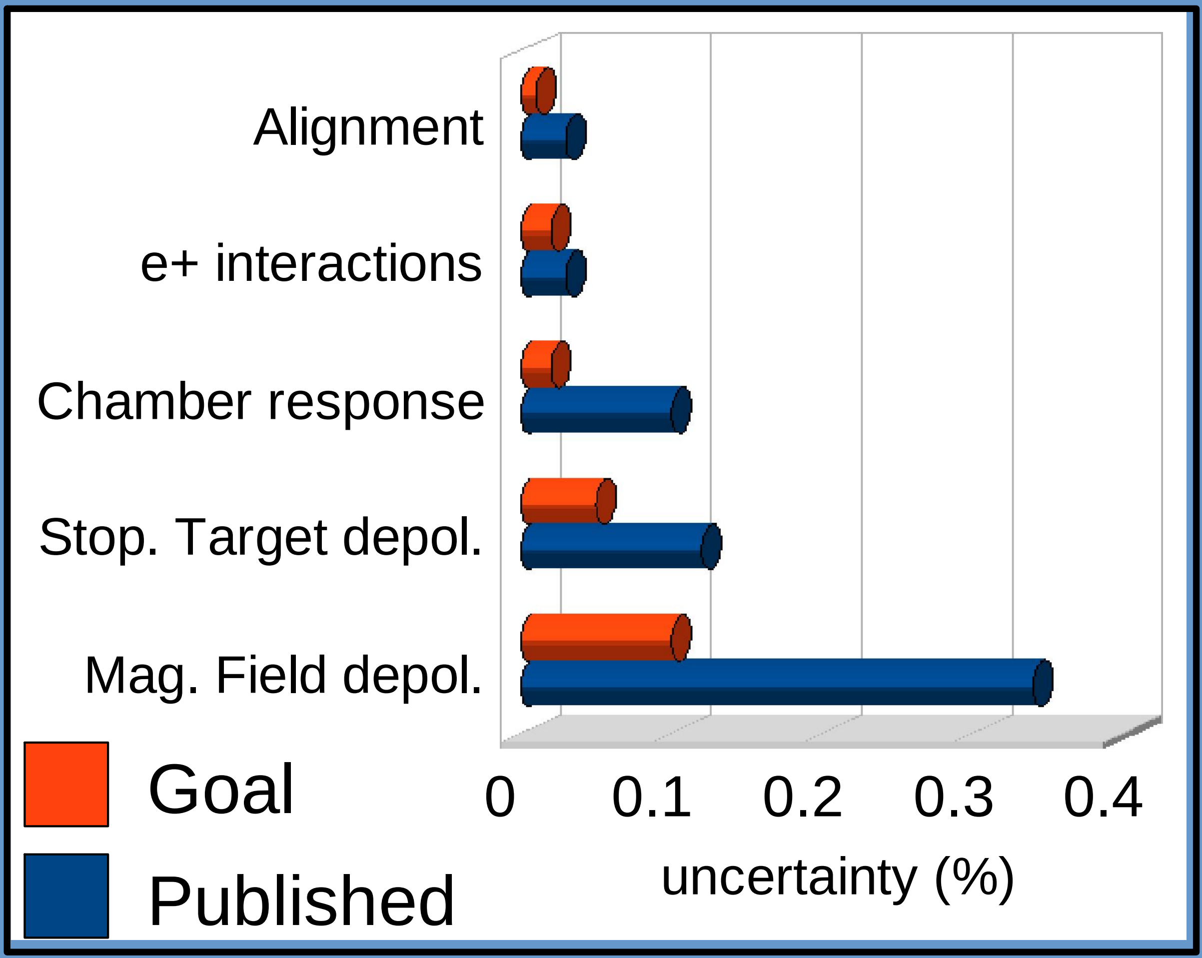
Triumf Weak Interaction Symmetry Test (TWIST)



- Highly polarized μ^+ stopped in centre of symmetric detector.
- e^+ tracked in highly uniform magnetic field.
- New data acquired in 2006/2007. Analysis is ongoing.

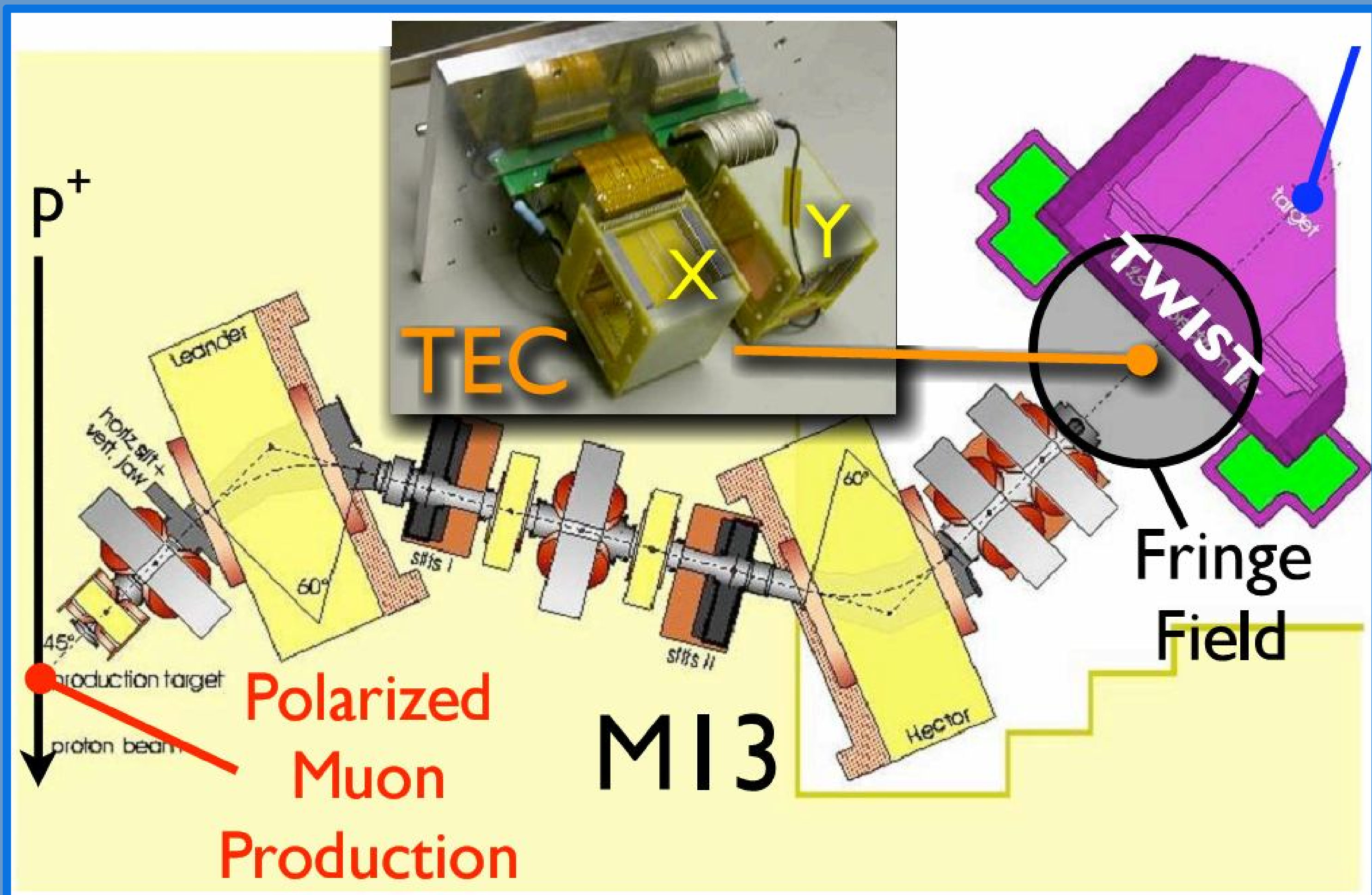
Precision goals for $P_\mu\xi$

Uncertainties >0.03% for published TWIST $P_\mu\xi$ result:



} Depolarisation uncertainties are dominant.

Depolarisation

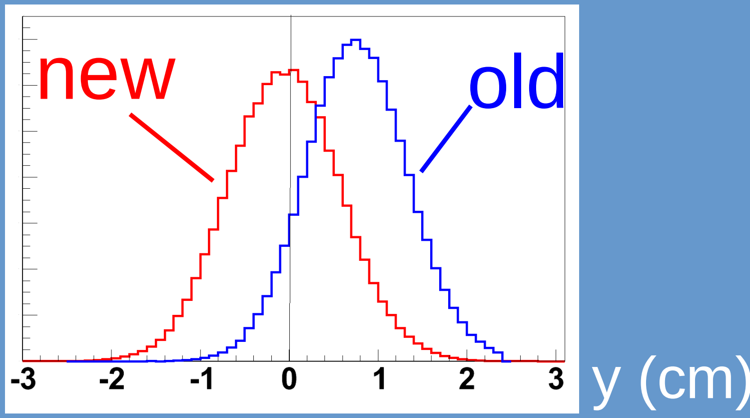


Stopping target (P_μ depends on time)

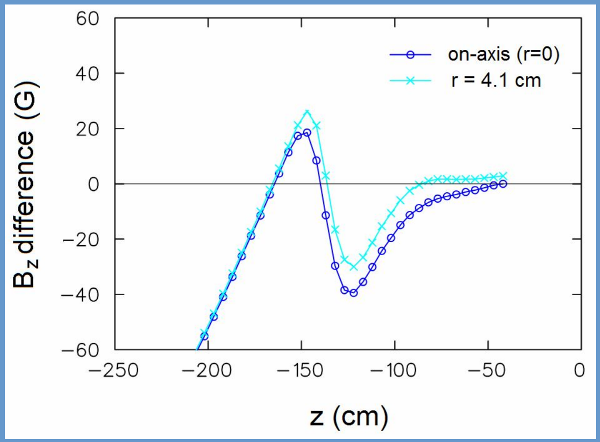
P_μ depends on trajectory when entering fringe field.

Reducing fringe field systematic

Beam steered on-axis



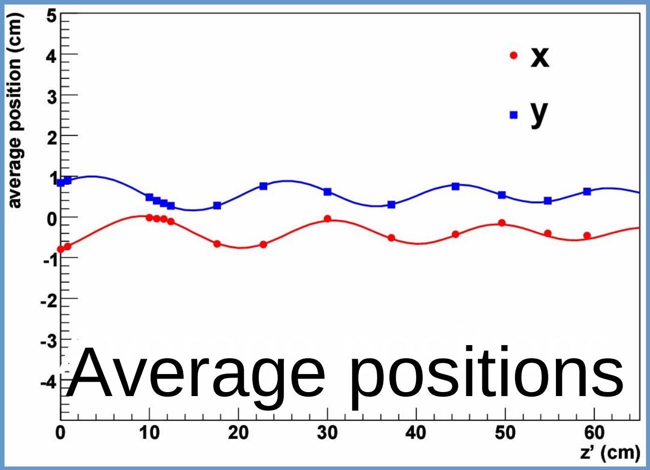
Fringe field corrected



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.

Internal muon beam used to monitor stability



Reducing target depol. systematic

Theory review

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

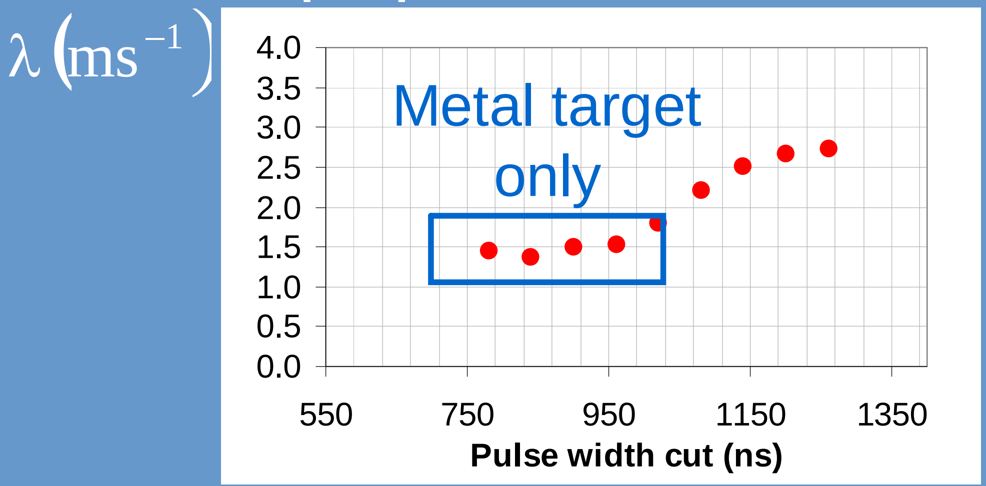
$$P_{\mu}(t) = P_{\mu}(0)\exp(-\lambda t)$$

(as long as μ^+ stop in target)

A lot more TWIST data

	$\lambda\,(ms^{-1})$	
	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:

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

Conclusions

- Final results for $P_\mu\xi$ due in 2010.
- Improvements made in muon beam steering and measurement, magnetic field map and time dependent relaxation.
- Goal is a total $P_\mu\xi$ uncertainty of 0.1%, likely to be limited by reproducibility of beam measurement.

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
Konstantin Olchanski
Art Olin†
Robert Openshaw
Jean-Michel Poutissou
Renée Poutissou
Grant Sheffer
Bill Shin‡‡

Alberta
Andrei Gaponenko*
Robert MacDonald*

British Columbia
James Bueno*
Mike Hasinoff

Texas A&M
Carl Gagliardi
Bob Tribble

Regina
Ted Mathie
Roman Tacik

Kurchatov Institute
Vladimir Selivanov

Montréal
Pierre Depommier

Valparaiso
Don Koetke
Shirvel Stanislaus

* = graduate student
† = also UVIC
‡‡ = also Saskatchewan

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Subsidiary muSR experiment

Schematic, not to scale