Status of the $\mathcal{TWIST}$ Measurement of the Muon Decay Parameter $P_{\mu\xi}$

Blair Jamieson
Ph.D. Candidate

University of British Columbia
for the $\mathcal{TWIST}$ Collaboration

WRNPPC'05
February 18-20, 2005

Overview

- What is $P_\mu \xi$?
- Physics motivation for $P_\mu \xi$
- Data Sets and Consistency
- Systematic Errors
  - Fringe field depolarization
  - Material dependent depolarization
- Conclusion

What is $P_\mu\xi$?

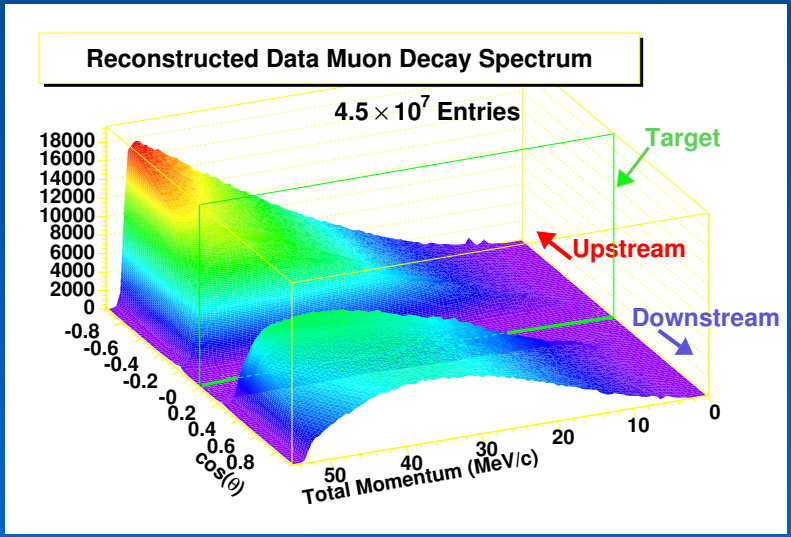
- P_μ is the polarization of the muon, ξ is asymmetry in angle of decay positrons from normal μ decay
- Standard Model (V-A) predicts $\xi = 1$ and $P_\mu = -1$

$$\frac{d^2\Gamma}{dx\,d\cos\theta} \propto x^2 - x^3 + \frac{2}{9}\rho(4x^3 - 3x^2) + \eta x_0(x - x^2) + \frac{1}{3}P_\mu\xi\cos\theta(x^2 - x^3 + \frac{2}{3}\delta(4x^3 - 3x^2)) \quad (1)$$

$x = E_e/W_{e\mu}$

$W_{e\mu} = \frac{m_\mu^2 + m_e^2}{2m_\mu}$

$x_0 = \frac{m_e}{W_{e\mu}}$



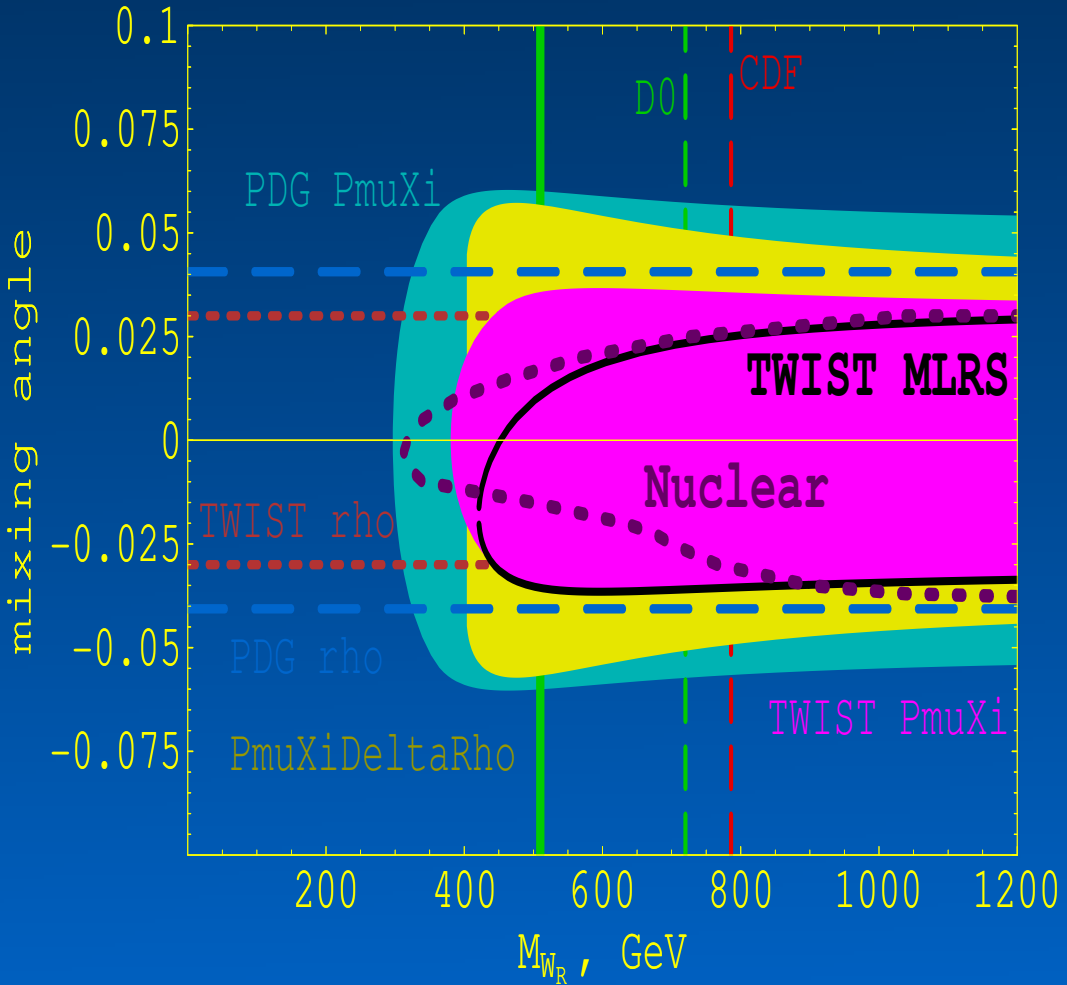
Physics and Motivation for $P_\mu\xi$

- Best Direct Measurements:
  - $P_\mu\xi = 1.0027 \pm 0.0079 \pm 0.0030$ (Beltrami et. al., PL **B194** 326)
  - $P_\mu\xi\delta/\rho > 0.99682$, 90% conf. level (Jodidio et.al., PR **D34** 1967, PR **D37** 237)
- ξ and δ together give limit on probability of right-handed muon decaying into any handed positron:

$$Q_R^\mu = \frac{1}{2}(1 + \frac{1}{3}\xi - \frac{16}{9}\xi\delta) \tag{2}$$

- In Left-right symmetric model, $P_\mu\xi$ sets limit on W_R mass (ϵ) and left/right mixing parameter (ζ):

$$P_\mu\xi = 1 - 2\epsilon^2 - 2\zeta^2 - 2\epsilon^2(\frac{V_{ud}^R}{V_{ud}^L})^2 - \epsilon\zeta\frac{V_{ud}^R}{V_{ud}^L} \tag{3}$$

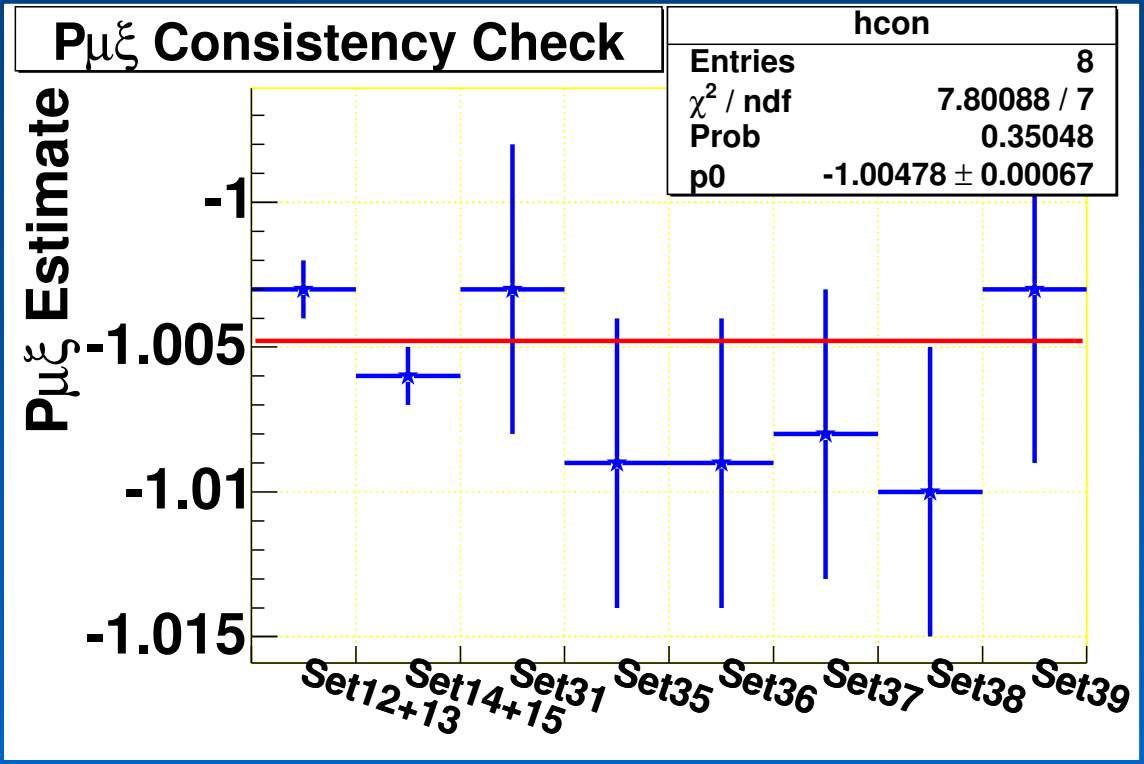

0.1
0.075
0.05
0.025
0
-0.025
-0.05
-0.075
mixing angle
200
400
600
800
1000
1200
M_{W_R}, GeV
D0
CDF
PDG PmuXi
TWIST MLRS
Nuclear
TWIST rho
PDG rho
PmuXiDeltaRho
TWIST PmuXi

Data Set Summary for $TWIST$ $P_\mu\xi$

Set #	# 2GByte Runs	Description
12	211	28.9 MeV/c
13	115	28.9 MeV/c
14	176	2003 Nominal
15	217	2003 Nominal
30	60	B2=949G, z cent, M1 Trigger
31	265	B2=949G, z cent, M Trigger
32	120	B2=944G, PC5 Stops
33	91	Far Upstream Stops
34	11	Far Downstream Stops
35	368	B2=944G, z cent, start z reg
36	390	B2=944G, z at 3 / 4
37	281	High Rate (B2=944G, z at 3/4)
38	303	Aperture in (B2=944G, z at 3/4)
39	211	B2=944, z at 3 / 4
Total	2819(5.6TB)	2272 Nominal Runs

Data Set Consistency

Consistency check with no detector response,
and no radiative corrections



Systematics List (page 1) $all \times 10^{-3}$

- Positron interactions ± 0.65
  - Energy smearing (± 0.19)
  - Multiple scattering (-0.16 ± 0.07)
  - Hard interactions (± 0.60)
  - Material in detector (± 0.07)
  - Material outside detector (± 0.03)
- Spectrometer alignment $\pm 0.48 \rightarrow \pm 0.16$
  - Translations (± 0.02)
  - Rotations (0.1 ± 0.01)
  - z (± 0.09)
  - B field to detector axis (± 0.46) $\rightarrow$ better calibration $/5$?

Systematics List (page 2) $all \times 10^{-3}$

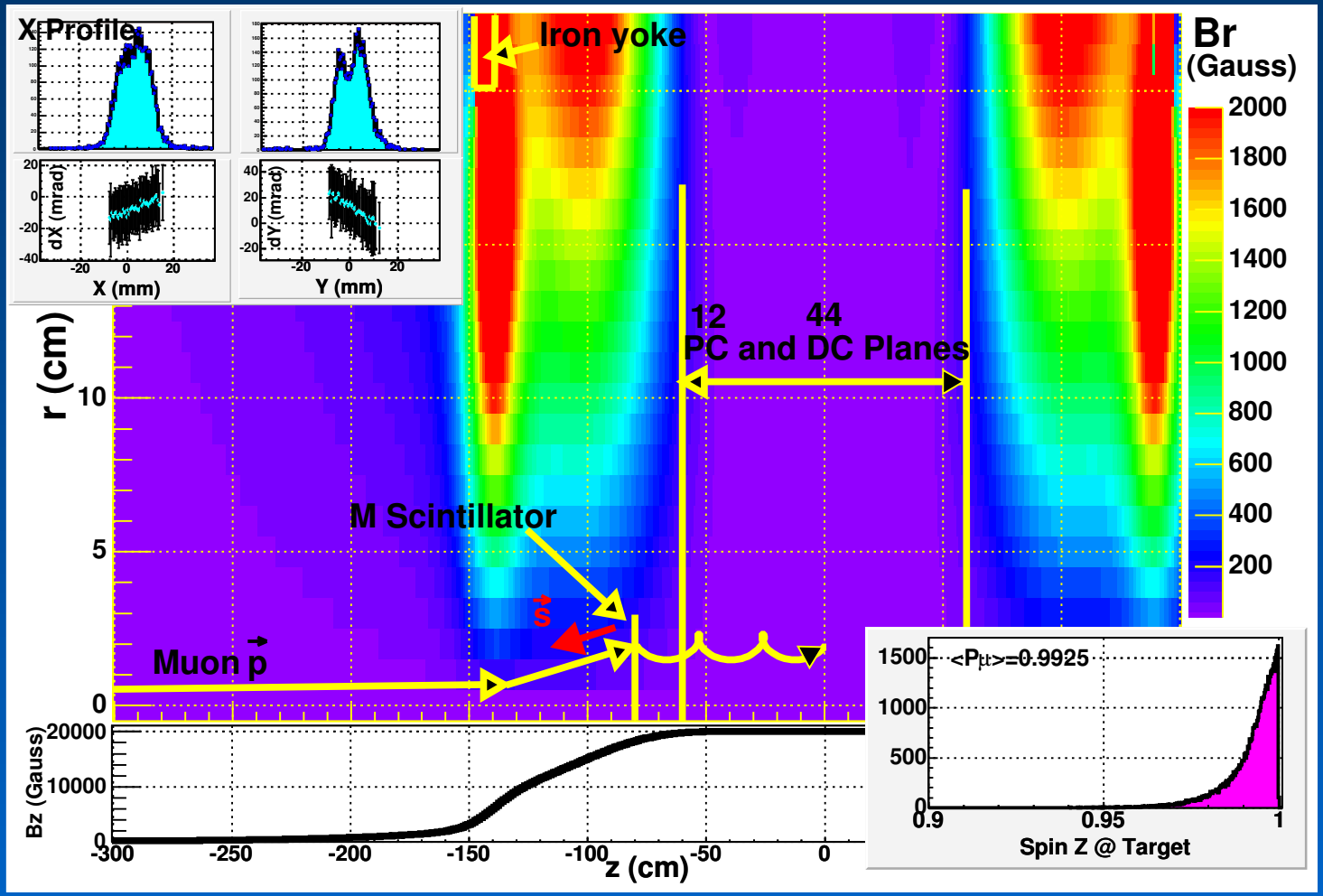
- Chamber response $\pm 1.09 \rightarrow \pm 0.45$
  - DC efficiency (± 0.02)
  - PC efficiency (± 0.01)
  - Dead zone (± 0.26)
  - Long drift times (± 0.17)
  - HV variations (± 0.03)
  - Temperature and pressure (0.24 ± 0.14)
  - Foil bulges (0.89 ± 0.56) $\rightarrow$ better controlled now $/5$?
  - Crosstalk (± 0.04)
  - t0 variations (0.49 ± 0.09) $\rightarrow$ more frequent calibration now $/4$?
- Momentum calibration ± 0.34
  - Endpoint fits (± 0.27)
  - Magnetic field reproduction (-0.20 ± 0.09)

Systematics List (page 3) $all \times 10^{-3}$

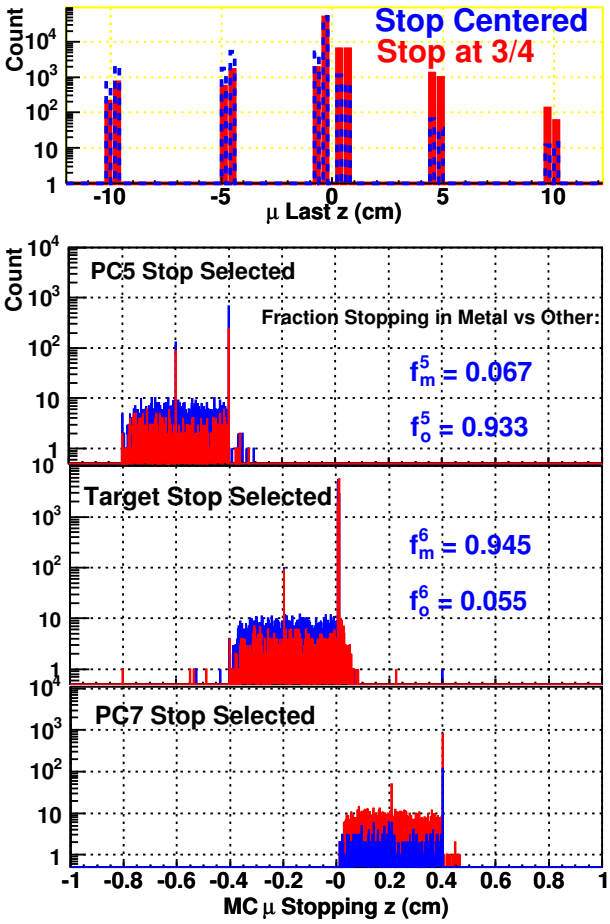
- Muon beam and polarization $\pm 0.60 \rightarrow \pm 0.45$
  - depolarization in prod. target (-0.04 ± 0.02)
  - cloud muon contamination (± 0.12)
  - fringe field depolarization $(-7.5 \pm 0.5) \rightarrow -3.0 \pm 0.3$ with aperture
  - proton beam stability (-0.3 ± 0.07)
  - material dependent depolarization (-2.5 ± 0.1)

Total systematic error $= \pm 1.52 \rightarrow \pm 0.98$

Fringe field depolarization



Material dependent depolarization



Michel spectrum fit to estimate:

$P\mu^5$ for Stop in PC5

$P\mu^6$ for Stop in Target

In terms of μ polarization in material:

$$P\mu^5 = f_m^5 P\mu^m + f_o^5 P\mu^o$$

$$P\mu^6 = f_m^6 P\mu^m + f_o^6 P\mu^o$$

A PC5 to Target Stop distribution fit, with $P\mu^m$=1 gives:

$$P\mu^5 - P\mu^6 = f_m^5 - f_m^6 + (f_o^5 - f_o^6) P\mu^o$$

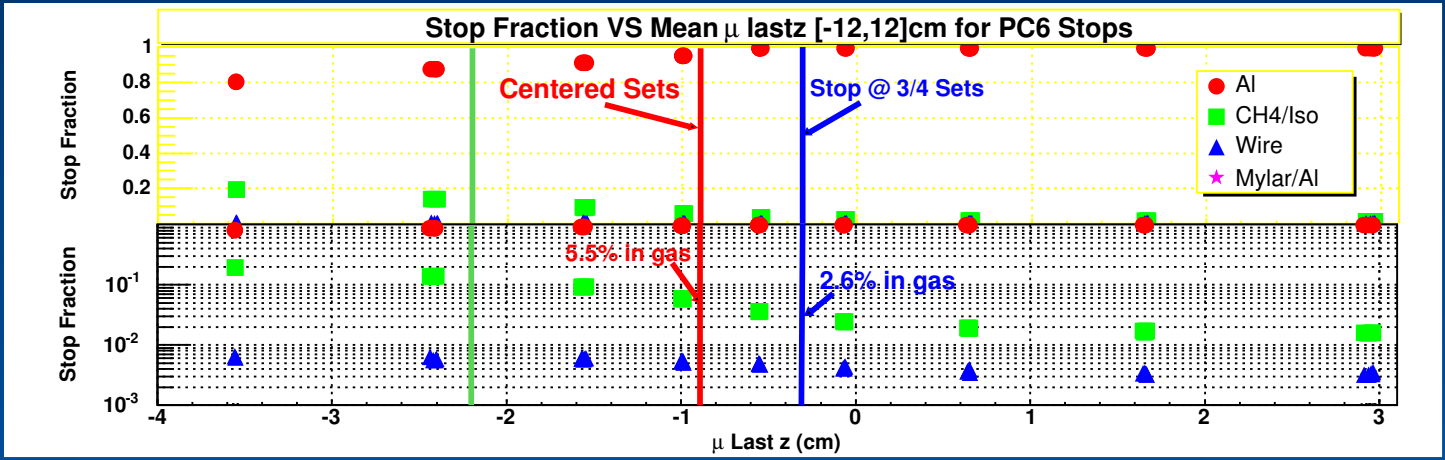
$$P\mu^o = -\frac{(f_m^5 - f_m^6) + (P\mu^5 - P\mu^6)}{(f_o^5 - f_o^6)}$$

Fit for Set 14:

$$P\mu^5 - P\mu^6 = -0.0595 \pm 0.0051$$

$$P\mu^o = 0.932 \pm 0.006$$

Material dependent depolarization



Initial estimate of depolarization in gas measured to be 0.068 ± 0.006.
Expect to reduce error to ± 0.002, then correction and systematic are:

- Centered $\approx 0.055 * (0.068 \pm 0.002) = 0.0037 \pm 0.0001$
- At $3/4 \approx 0.026 * (0.068 \pm 0.002) = 0.0018 \pm 0.0001$

Conclusion

- First $\mathcal{TWIST}$ measurement of $P_\mu \xi$ result this summer
- Expect to have errors better than $\pm 0.0008(stat) \pm 0.0010(syst)$
- An improvement of almost an order of magnitude of value in PDG

TWIST People

TWIST Participants

TRIUMF	(TRIUMF cont.)	British Columbia	Kurchatov Institute
Ryan Bayes*†	Tracy Porcelli‡	Mike Hasinoff	Vladimir Selivanov
Yuri Davydov	Jean-Michel Poutissou	Blair Jamieson*	Vladimir Torokhov
Jaap Doornbos	Renée Poutissou		
Wayne Faszer	Grant Sheffer	Montréal	Texas A&M
Makoto Fujiwara	Bill Shin‡‡	Pierre Depommier	Carl Gagliardi
David Gill			Jim Musser*
Robert Henderson	Alberta	Regina	Bob Tribble
Jingliang Hu	Andrei Gaponenko*	Ted Mathie	Maxim Vasiliev
John A. Macdonald§	Peter Kitching	Roman Tacik	
Glen Marshall	Robert MacDonald*		Valparaiso
Dick Mischke	Maher Quraan		Don Koetke
Mina Nozar	Nate Rodning§		Paul Nord
Konstantin Olchanski	John Schaapman		Shirvel Stanislaus
Art Olin†	Glen Stinson		
Robert Openshaw			

Previous collaborators:

Peter Green, Arkadi Khruchinsky, Michael Kroupa, Farhana Sobratee, Sun-Chong Wang, Dennis Wright.

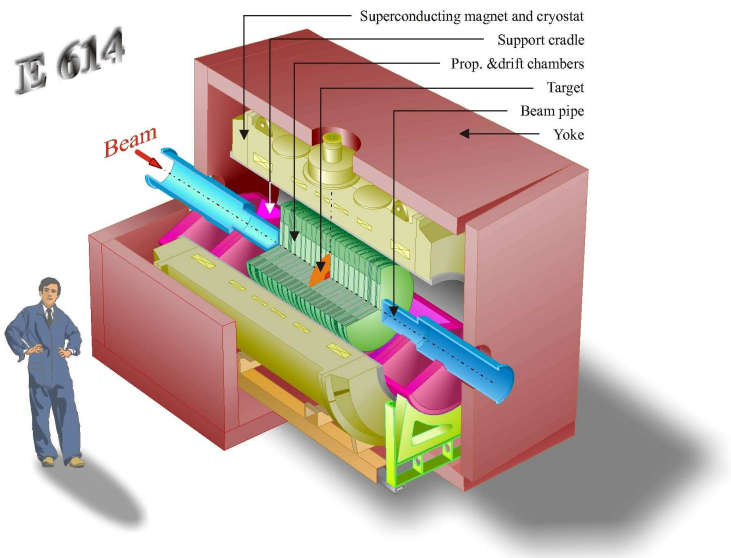
Professional and technical support:

Daniel Allen, Pierre Amaudruz, Willy Andersson, Curtis Ballard, Michael Barnes, Brian Evans, Marielle Goyette, Peter Gumplinger, Doug Maas, Jan Soukup, Len Wampler, and many undergraduate student research assistants.

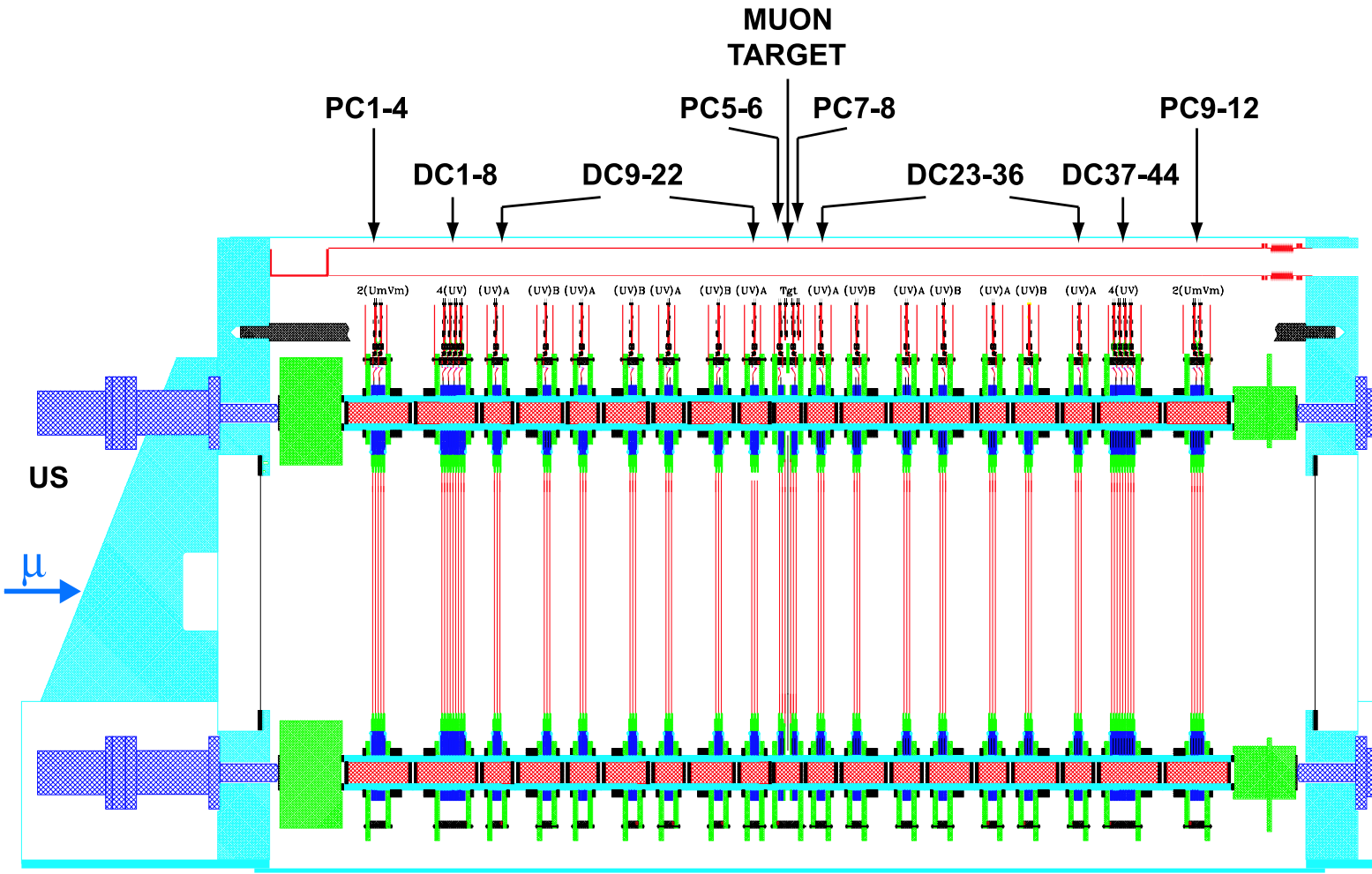
*graduate student	†also UVic	‡‡also Saskatchewan
§deceased	‡also UNBC	

Detector Concept

Spectrometer Conceptual Drawing



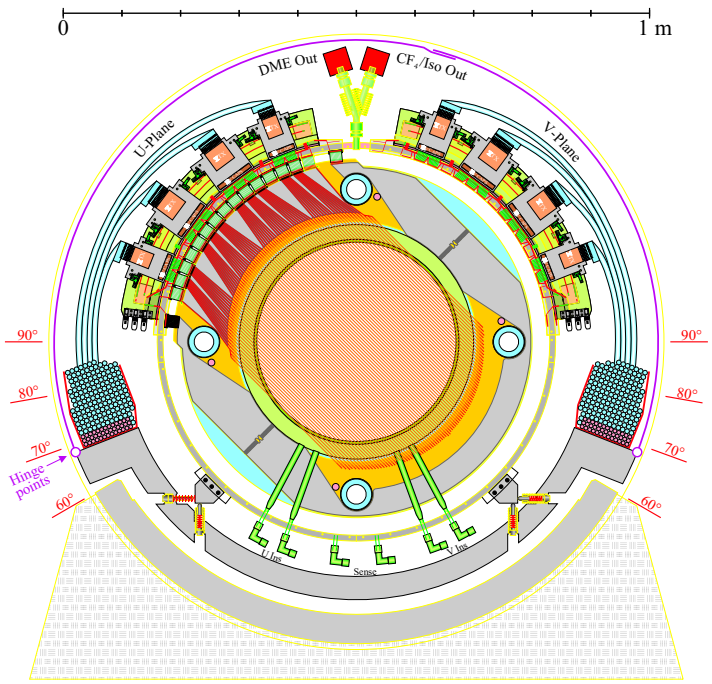
Detector Planes



Detector End View

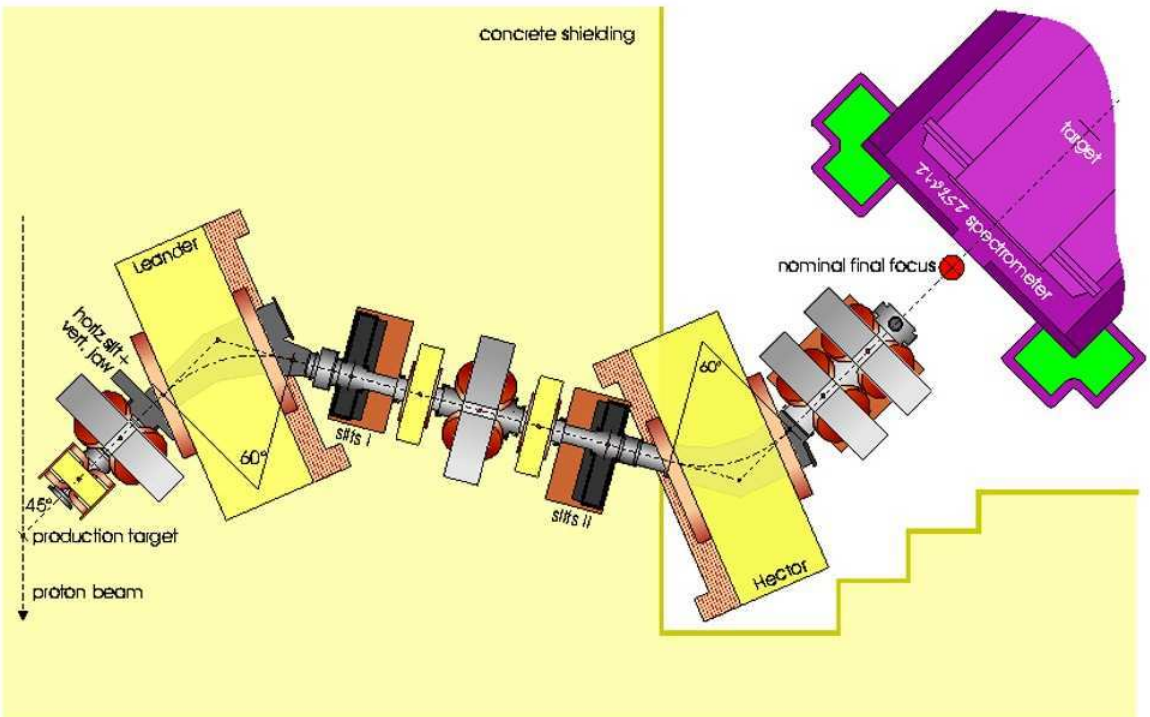
Chamber plane for E 614

80 sense wires (20 m) + 2x3 guard wires at 4 mm distance. 22 pairs of drift chambers (each one U and V plane) with DME gas, 6 pairs of proportional chambers with CF_4 / Isobutane. ~5000 wires with VTX preamplifiers



Beamline

M13 beamline delivers surface ($P_\mu \approx -1$) or cloud ($P_\mu \approx +0.3$) muons.



Spectrum Fit Procedure

Extracting Michel parameters

Need to take into account detector response. The technique:

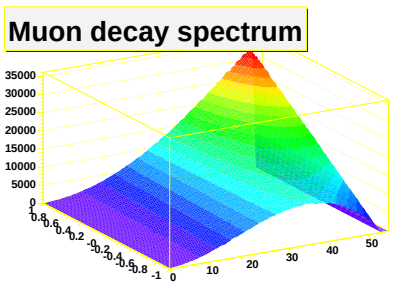
$$\underbrace{n_i(\rho_{\text{Data}})}_{\uparrow} = \underbrace{n_i(\rho_{\text{MC}}) + \frac{\partial n_i}{\partial \rho}}_{\uparrow} \underbrace{(\rho_{\text{Data}} - \rho_{\text{MC}})}_{\uparrow}$$

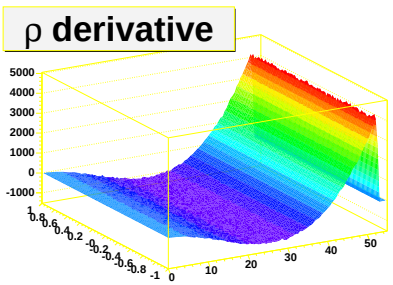
Data MC Fit parameter

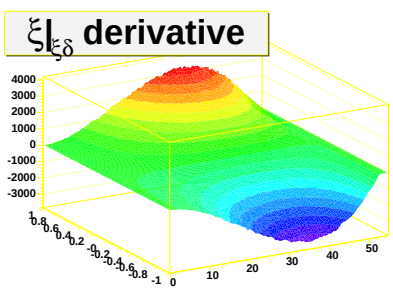
(ρ stands for any spectrum parameter).

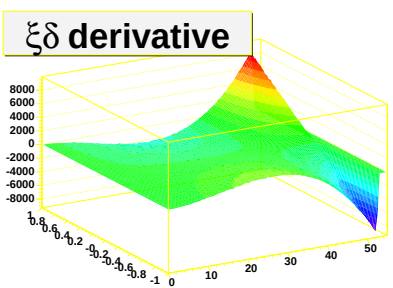
- Many effects of reconstruction cancel.
- Monte-Carlo must reproduce effects of the detector.
  - ▷ But spectrum distortions by the thin detector are small.

Spectrum Distributions









Contents