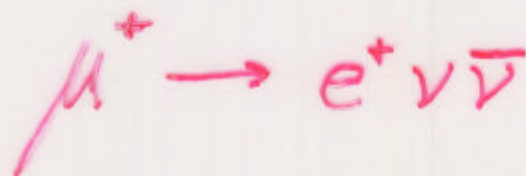
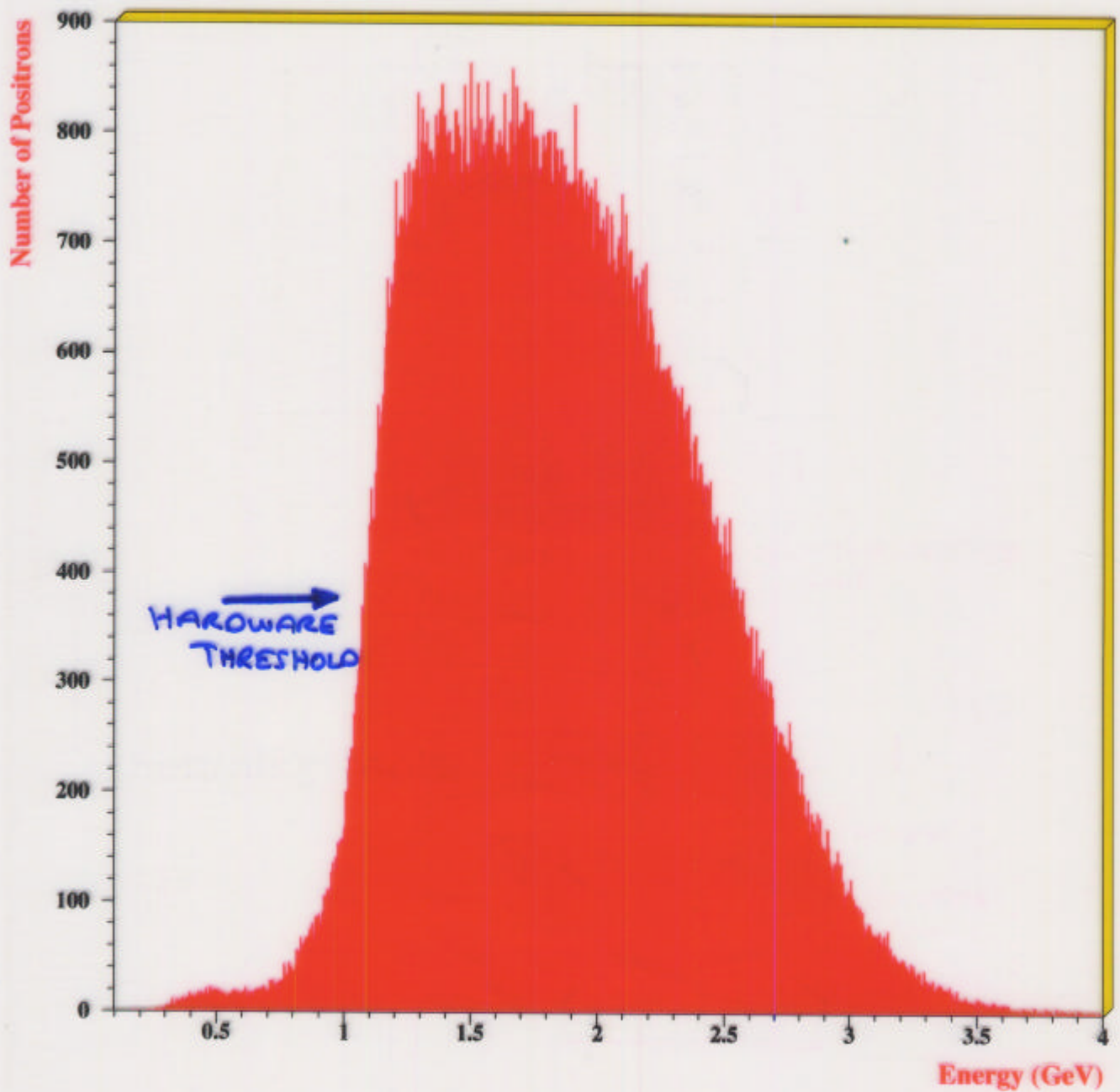
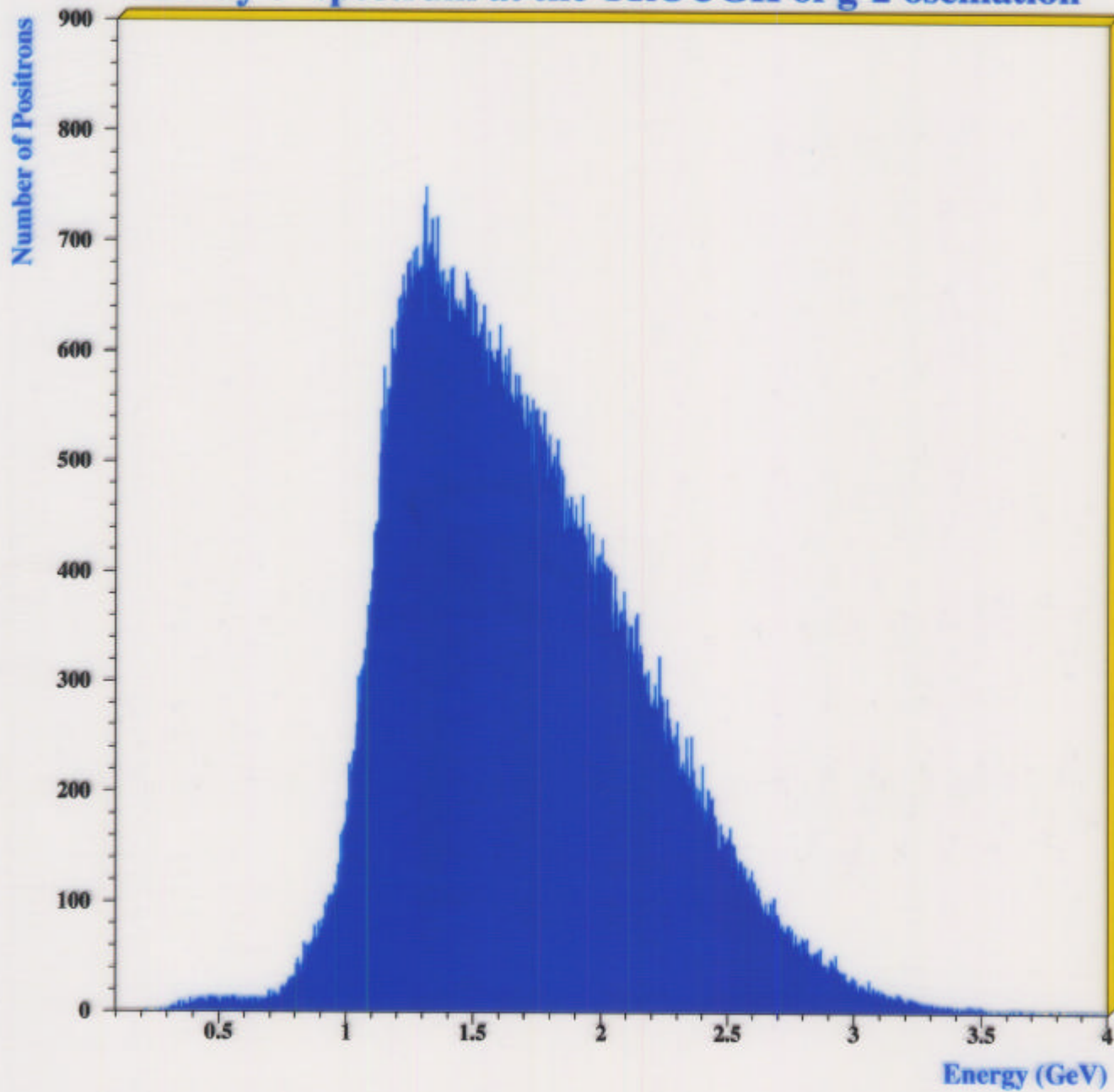


Decay e^+ spectrum at the PEAK of g-2 oscillation

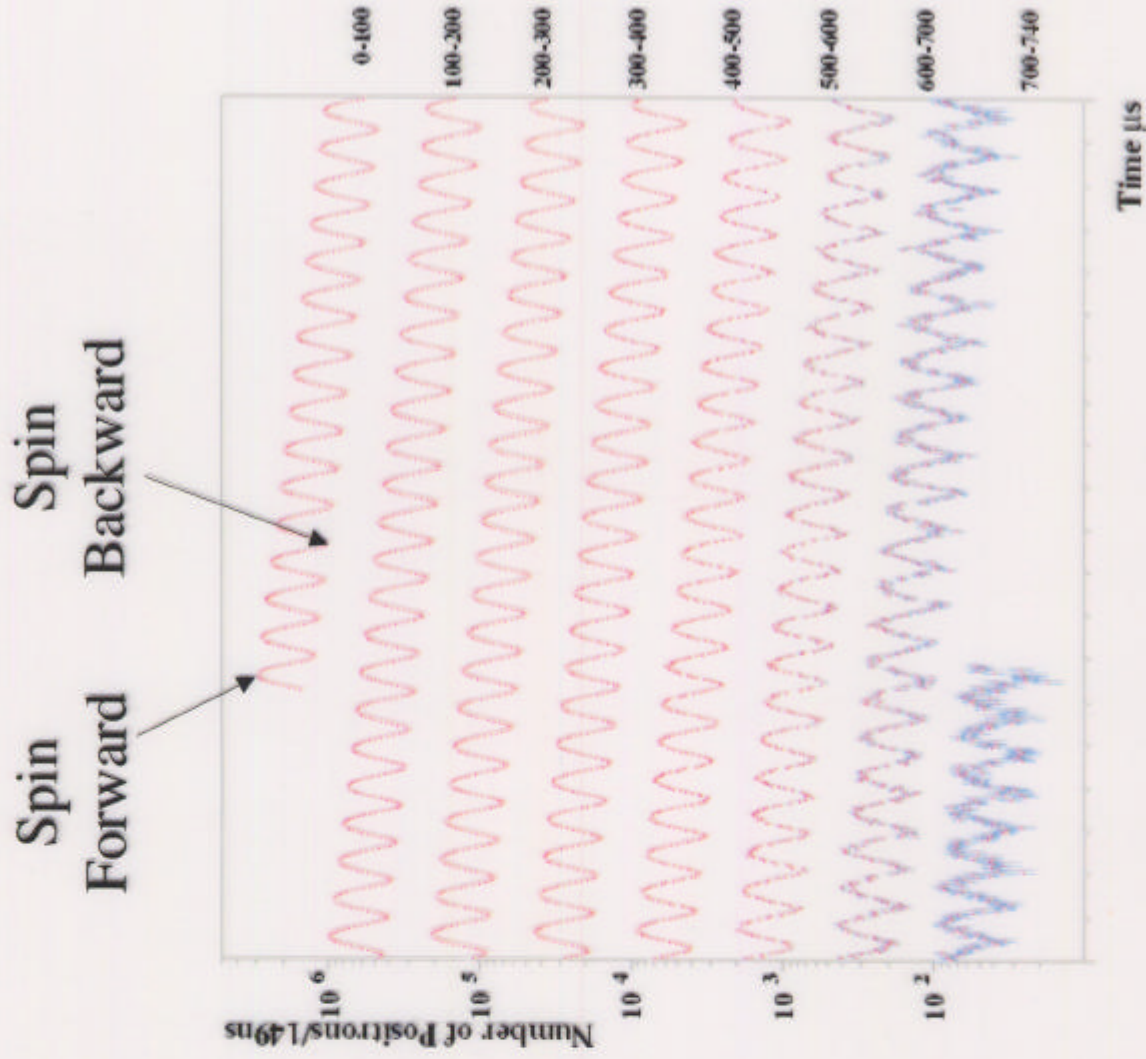


Decay e^+ spectrum at the TROUGH of $g-2$ oscillation



The $g-2$ Oscillation

~1 Billion Positrons



Determining a_μ

Separate and Independent Muon and B Analyses

Four analyses (Boston Univ, BNL-based, Univ. Illinois, Univ. Minnesota) determine R:

$$R = (f_0 - f_a + \text{offset}_a)/f_0$$

Two analyses determine B, actually proton NMR frequency:

$$\Delta B/B_0 = (f_p - f_0 + \text{offset}_b)/f_0$$

Final answer is:

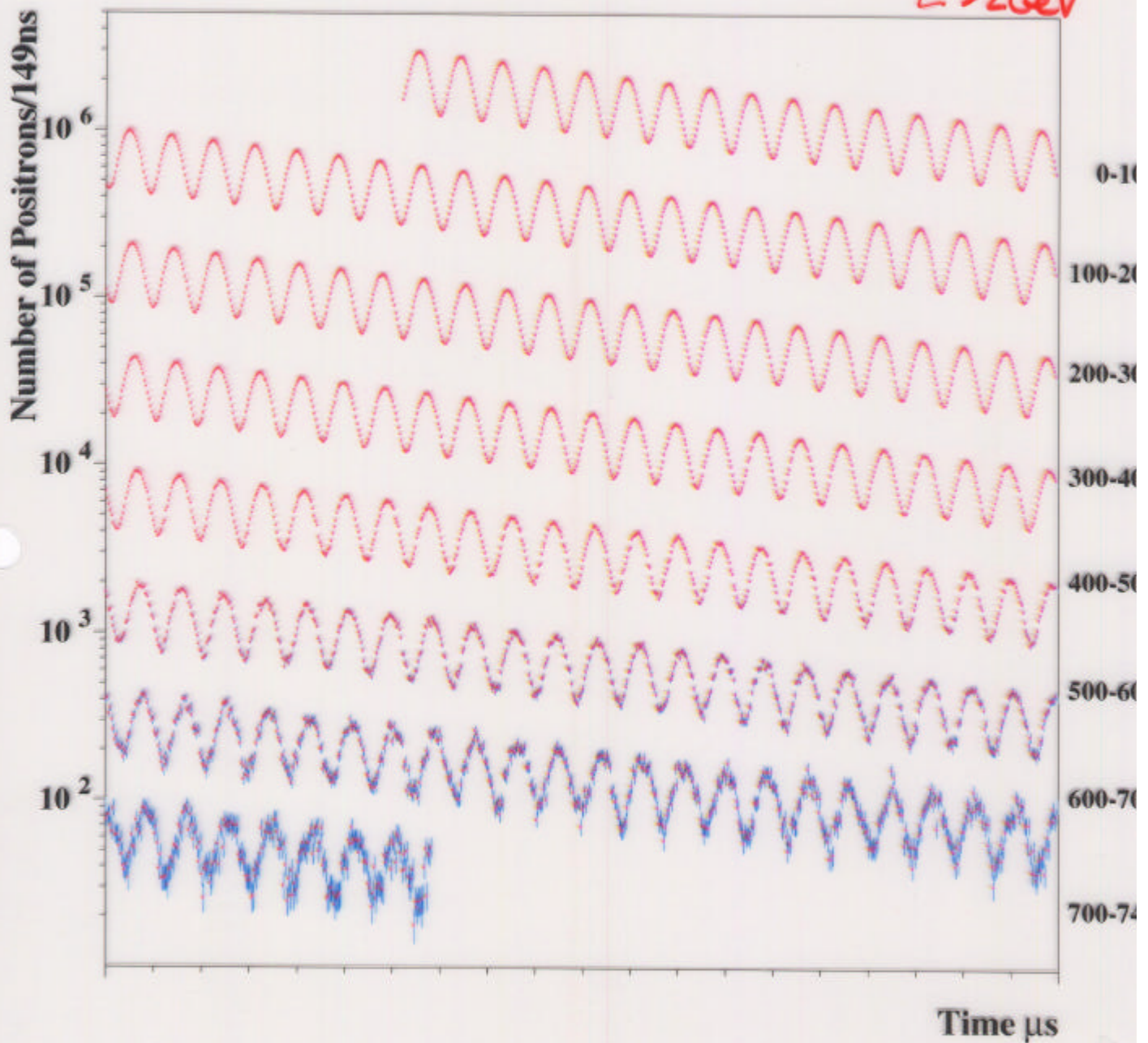
$$a_\mu = \frac{f_a/f_p}{\mu_\mu/\mu_p - f_a/f_p}$$

$$\mu_\mu/\mu_p = 3.18334539(10) \text{ (World Average)}$$

Open the "box" only after both analyses are final.
(Remove offsets)

$$\frac{dN}{dt} = N_0 e^{-t/\tau} (1 + A \cos(\omega t + \phi))$$

$E > 2\text{GeV}$



Challenge to obtain acceptable χ^2/dof with 10^9 events in one histogram!

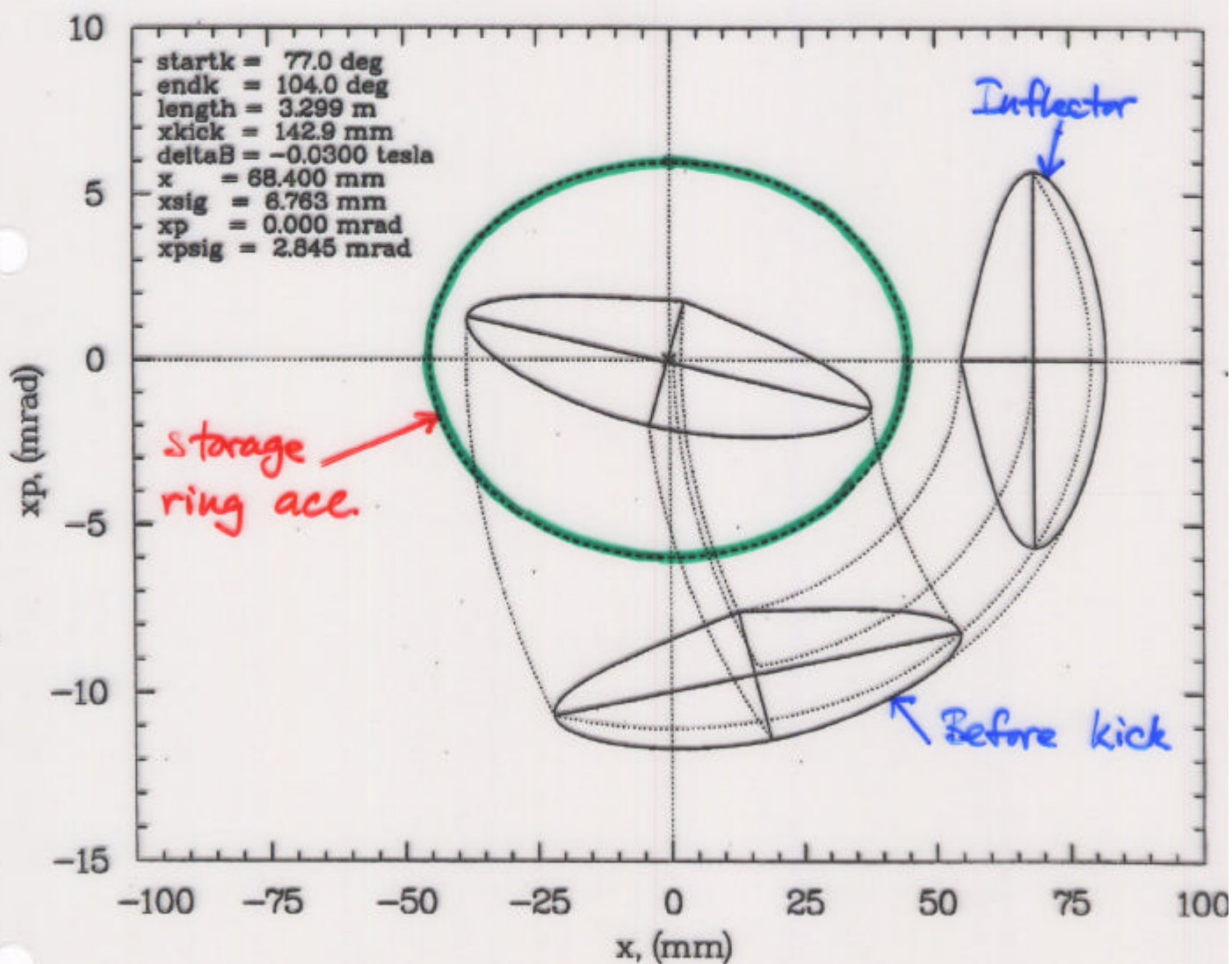
~ 4000 bins

Betatron Oscillations

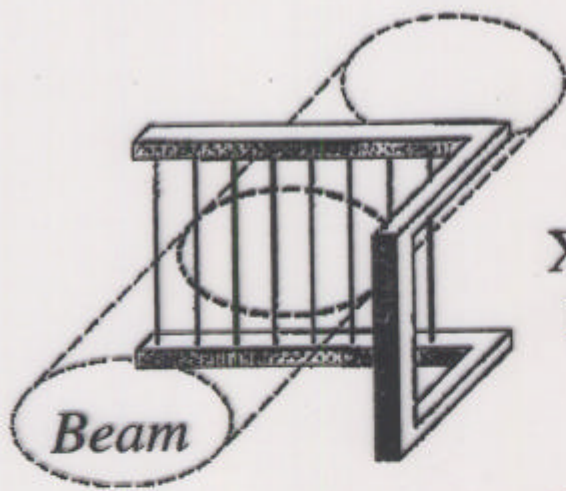
$$x = x_e + A \cos\left(\frac{\nu_x s}{R} + \phi\right)$$

$$x' = \frac{A \nu_x}{R} \sin\left(\frac{\nu_x s}{R} + \phi\right) \quad \nu_x = \sqrt{1-n}$$

Phase-space plot for muons with $X_0 = 0.0$ mm



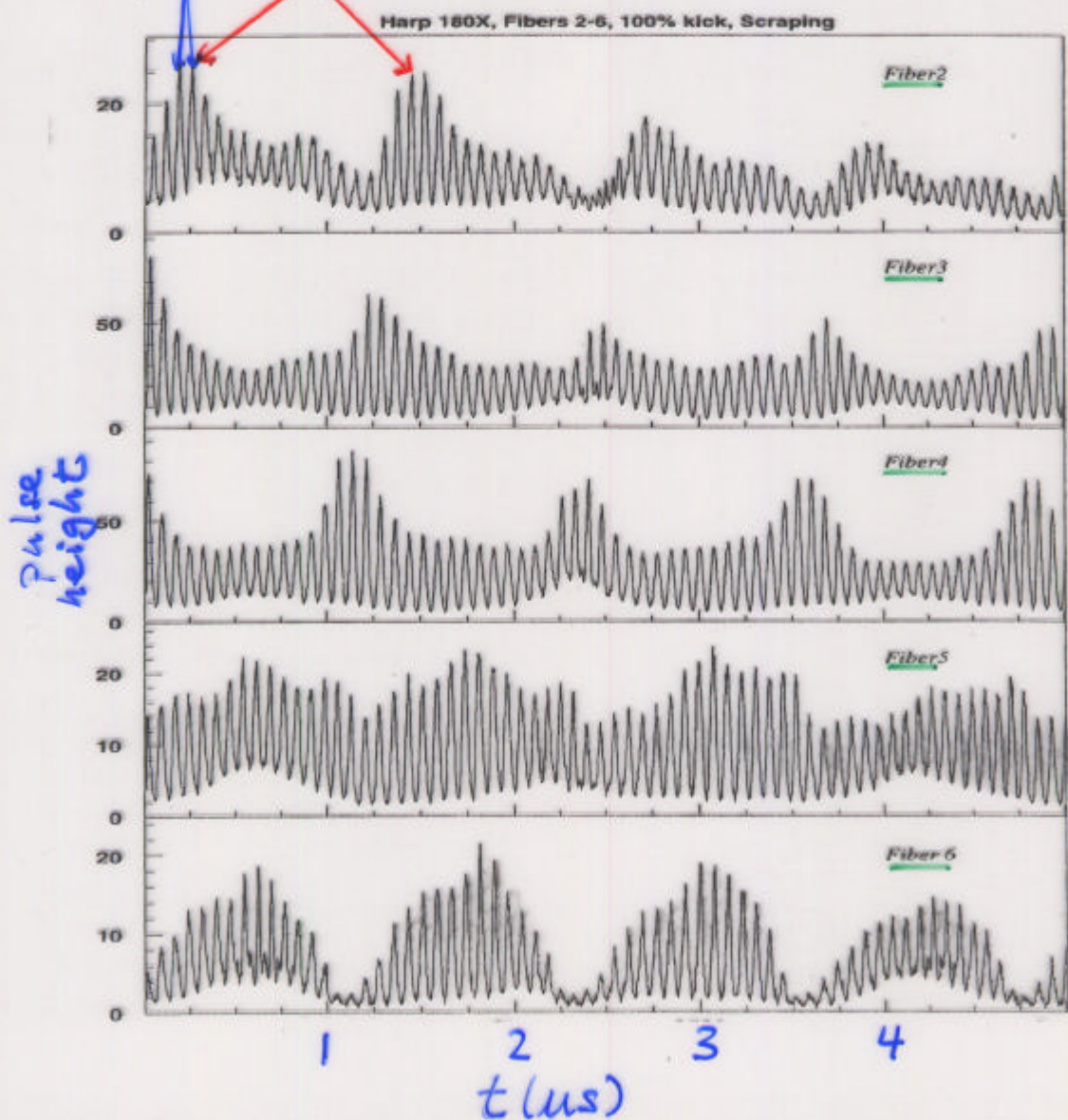
Scintillating Fiber Beam Monitor



X-profile
Monitor

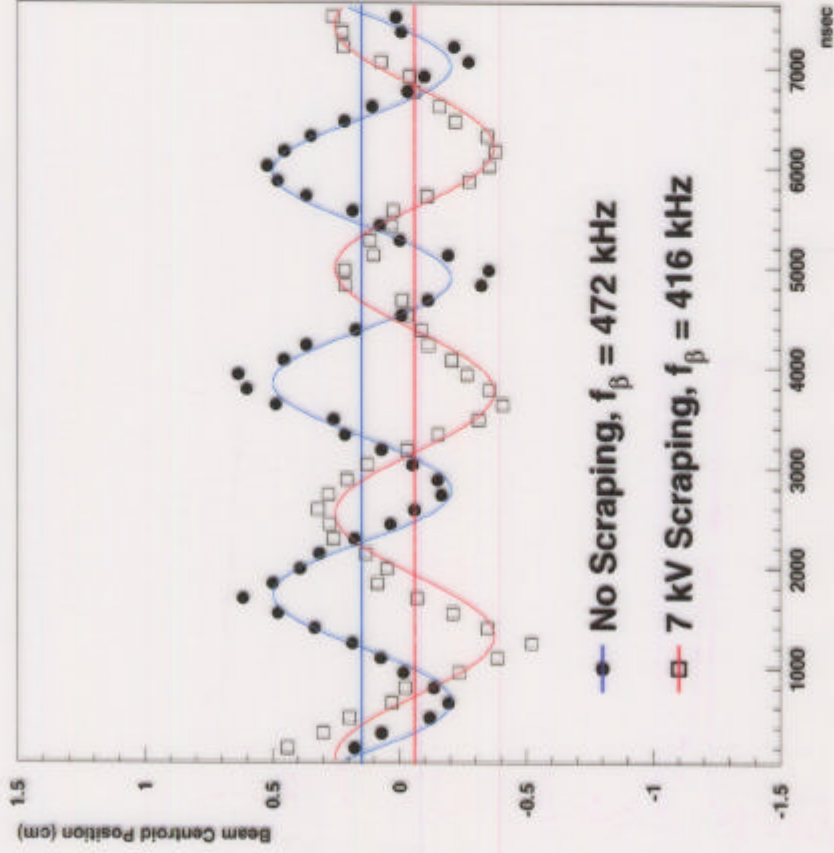
0.5mm thick fi
13mm spacing

$$\omega_c \quad \omega_{c20} = \omega_c (1 - \sqrt{1-n})$$

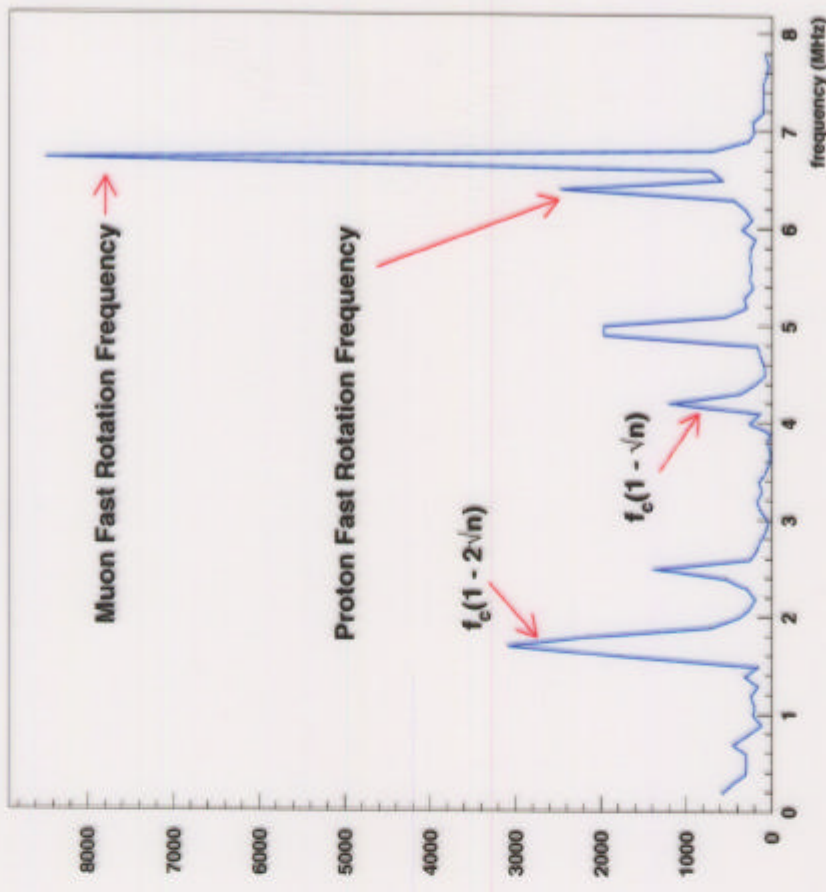


Measurement of Beam Dynamics and Composition

Turn-by-turn Evolution of Radial Beam Centroid

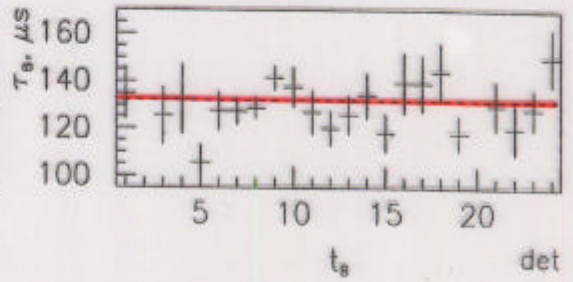
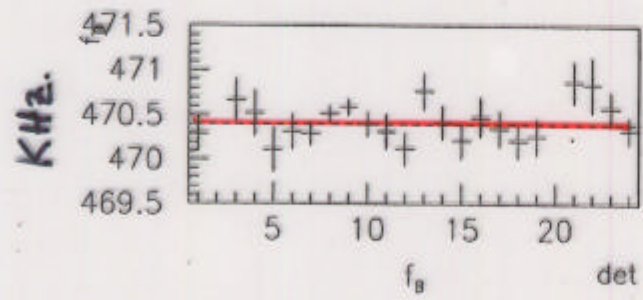
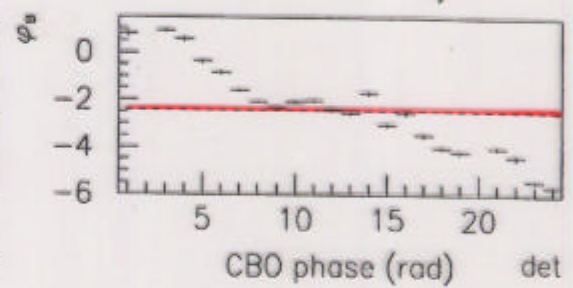
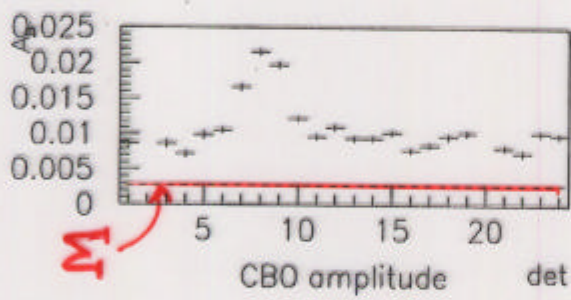
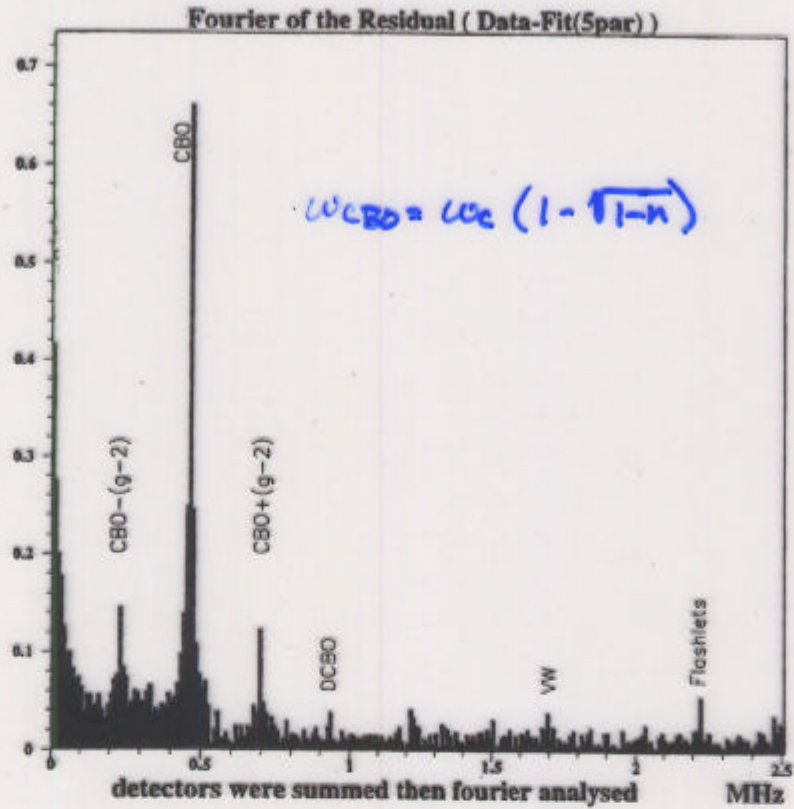


Fast Fourier Transform of Single Fiber Trace



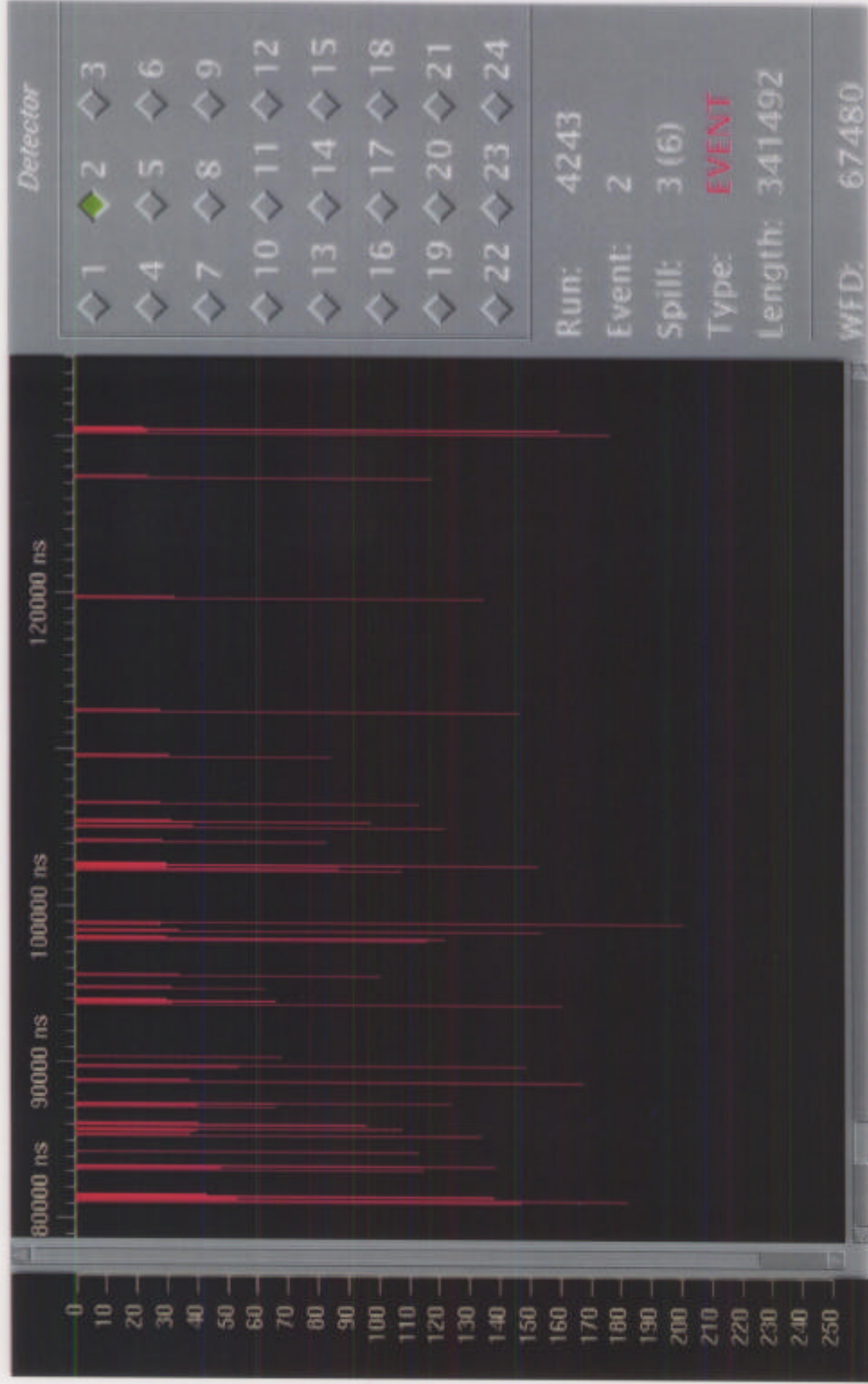
n-value of storage ring changes from 0.136 to 0.120 during 7 kV quadrupole scraping

Measurement of fast rotation frequency, betatron frequency, and evidence of stored protons



$$F_{cbo}(t) = 1 + A_{cbo} \exp\left[-\left(\frac{t}{\tau_{cbo}}\right)^2\right] \cos[\omega_{cbo}t + \phi_{cbo}]$$

Muon Injection



Positron Signal



digitized with 400 MHz

Double Pulse

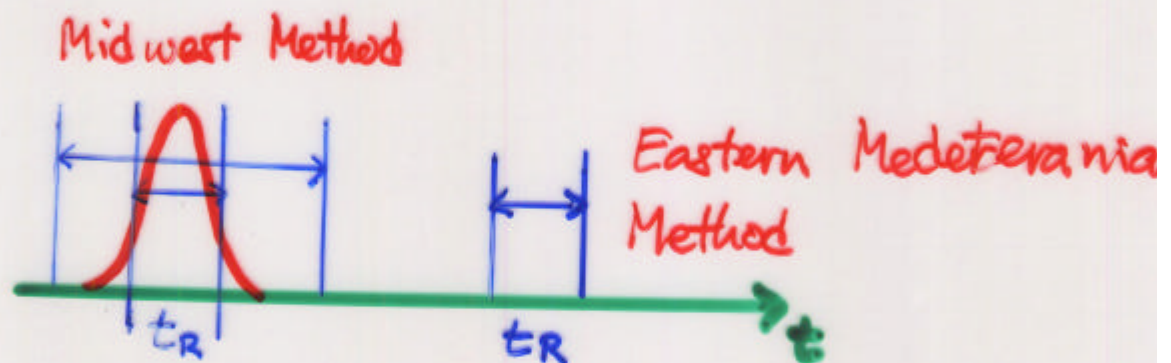


Pileup Subtraction

$$N_{pu} = e^{-2t/\tau} [N_2 + A_p \cos(\omega_a t + \phi_p) + A_{2p} \cos(2\omega_a t + \phi_{2p})] \times FF(t)$$

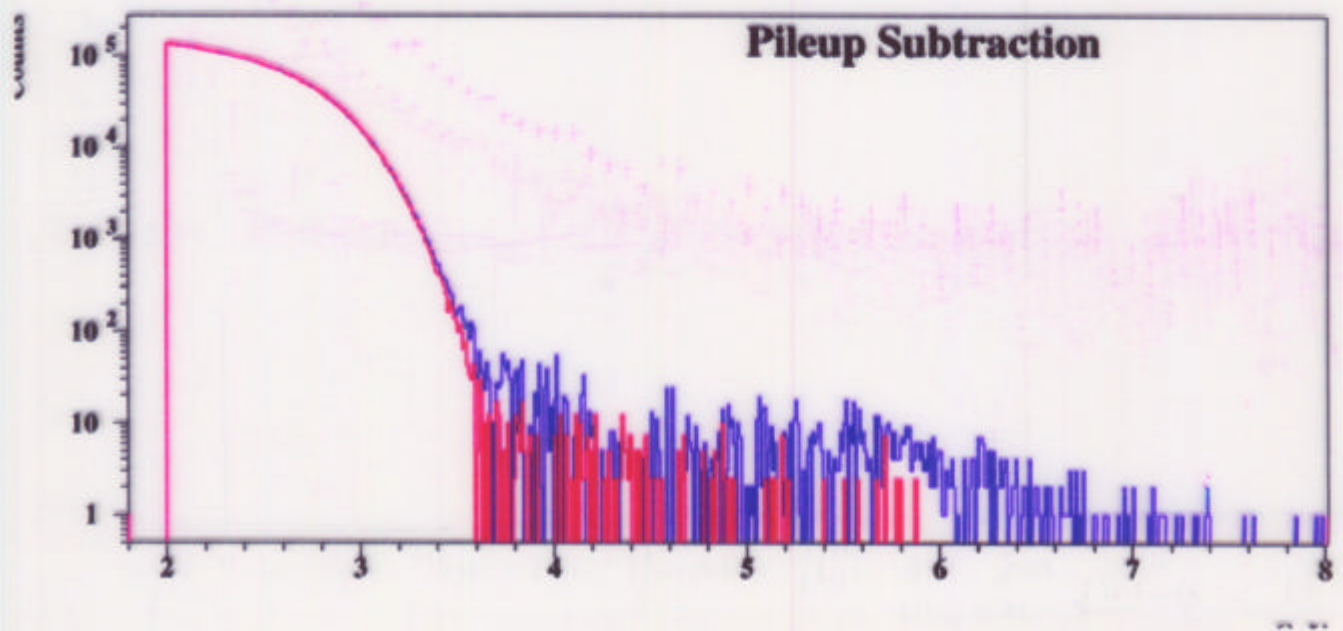
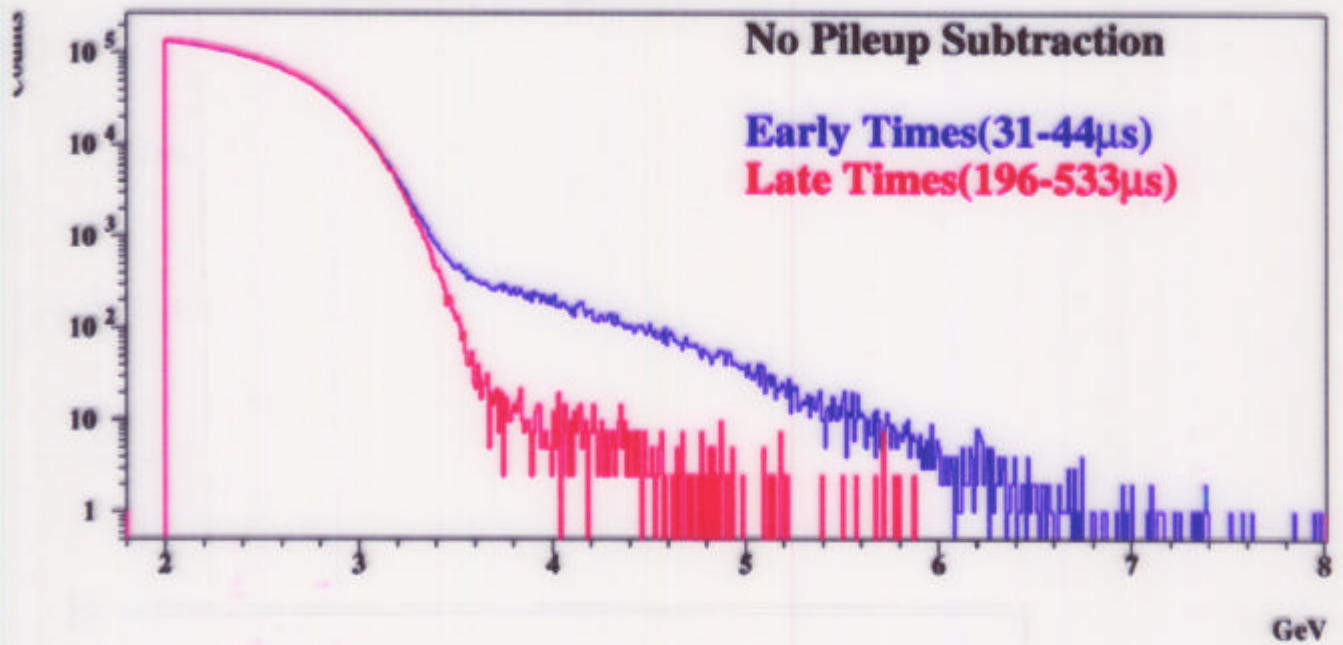
Pileup is proportional to rate squared.

However, statistically we can subtract pileup:

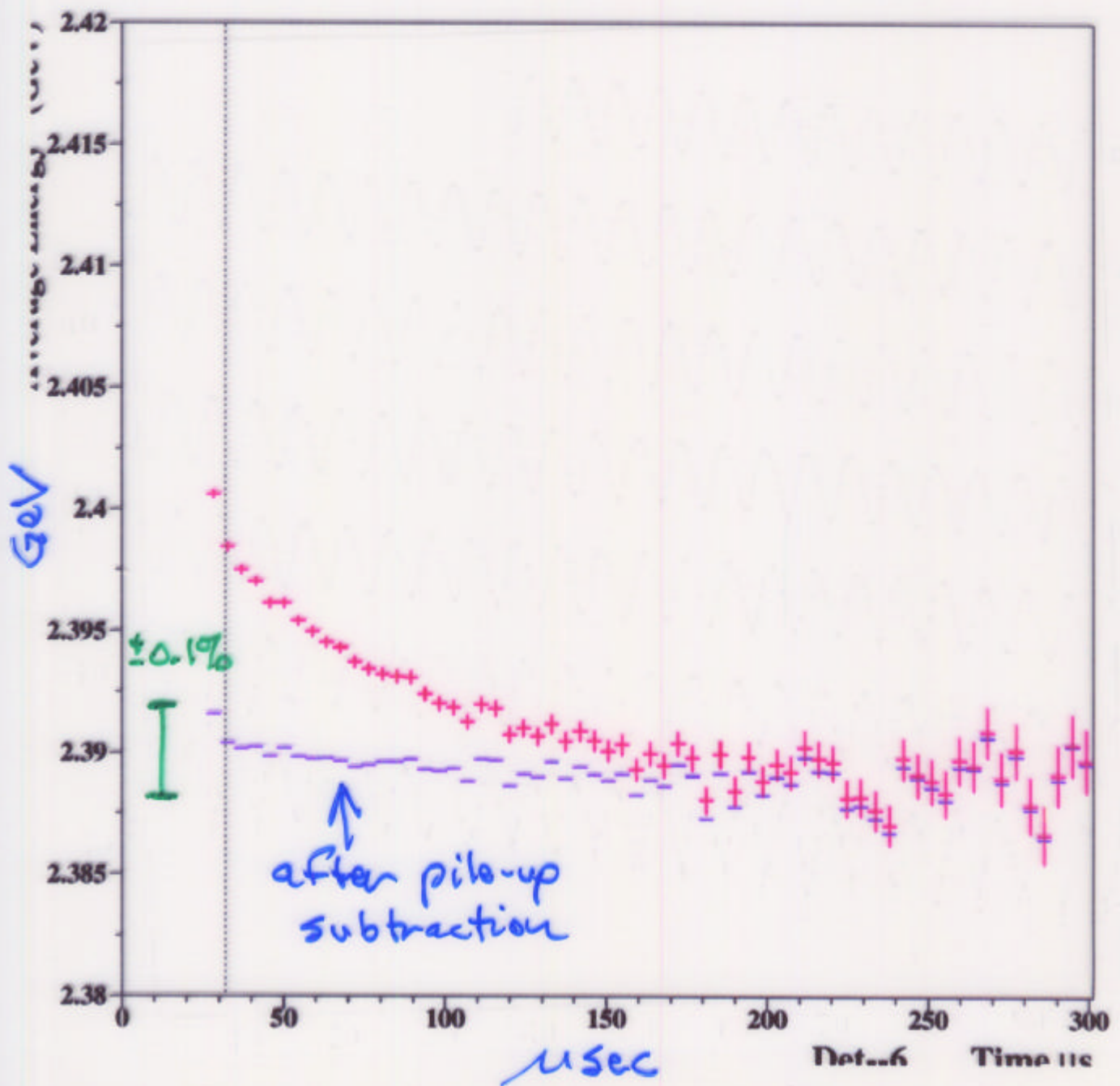


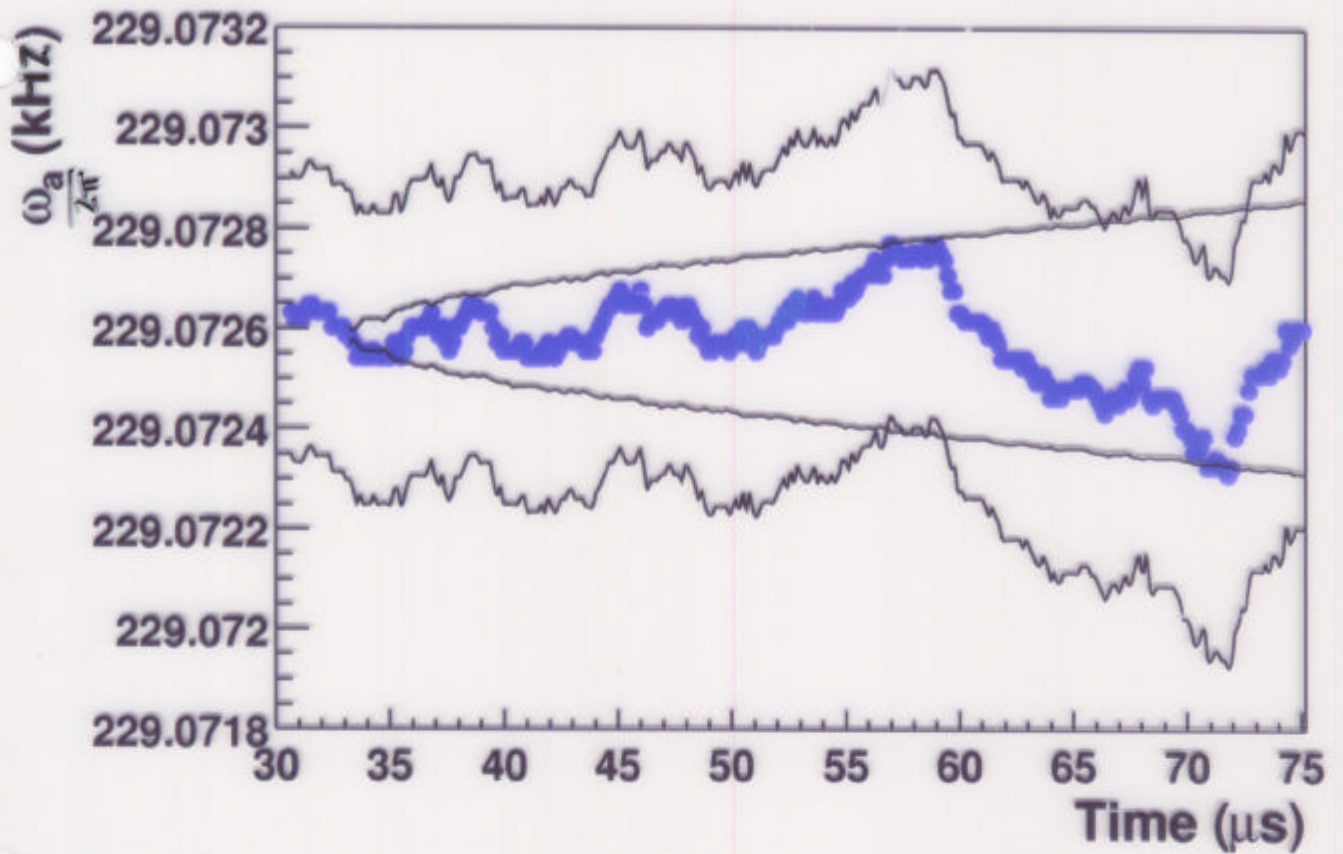
Pileup level is about 1% at earliest time of fits.

Energy Spectra

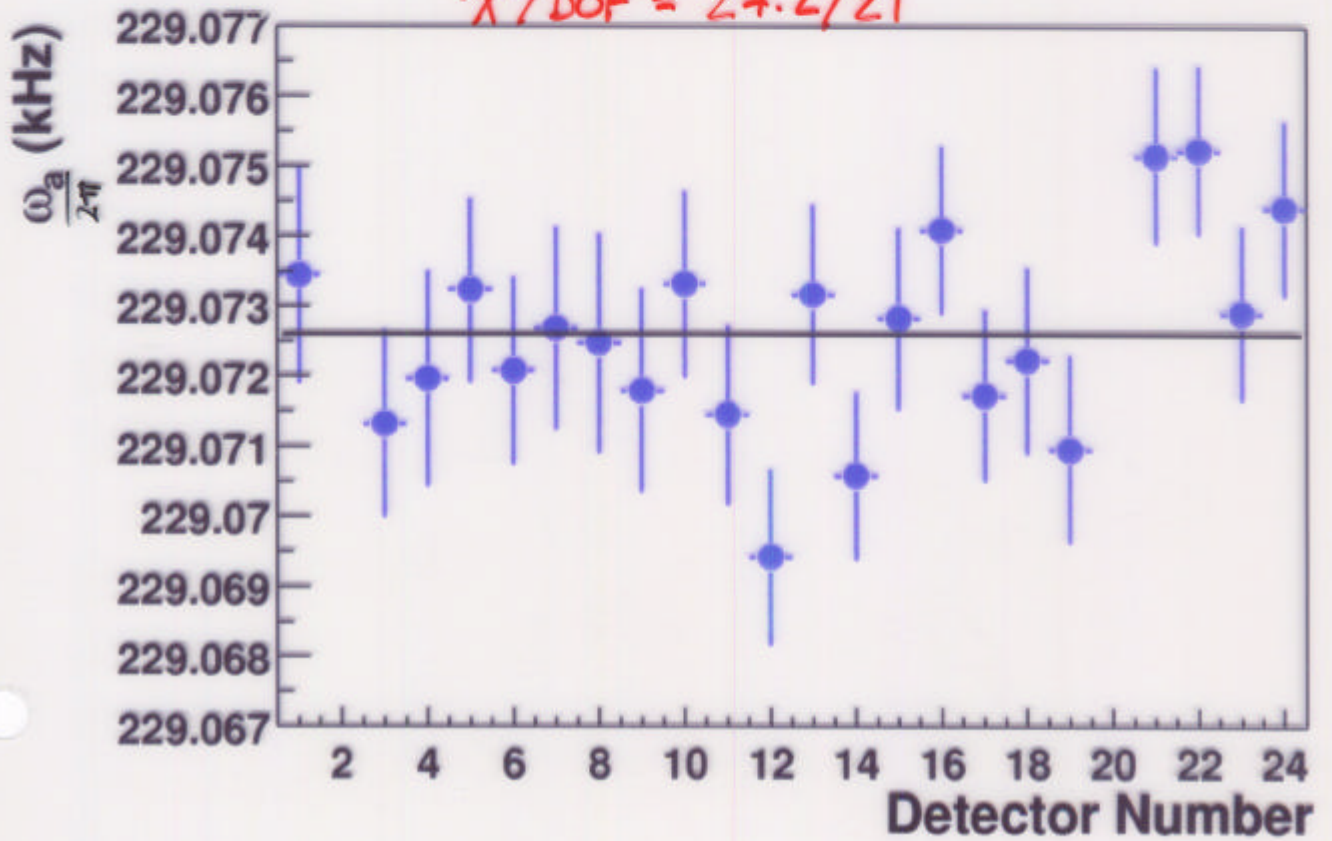


Average Energy seen in Detector 6 vs. time after injection

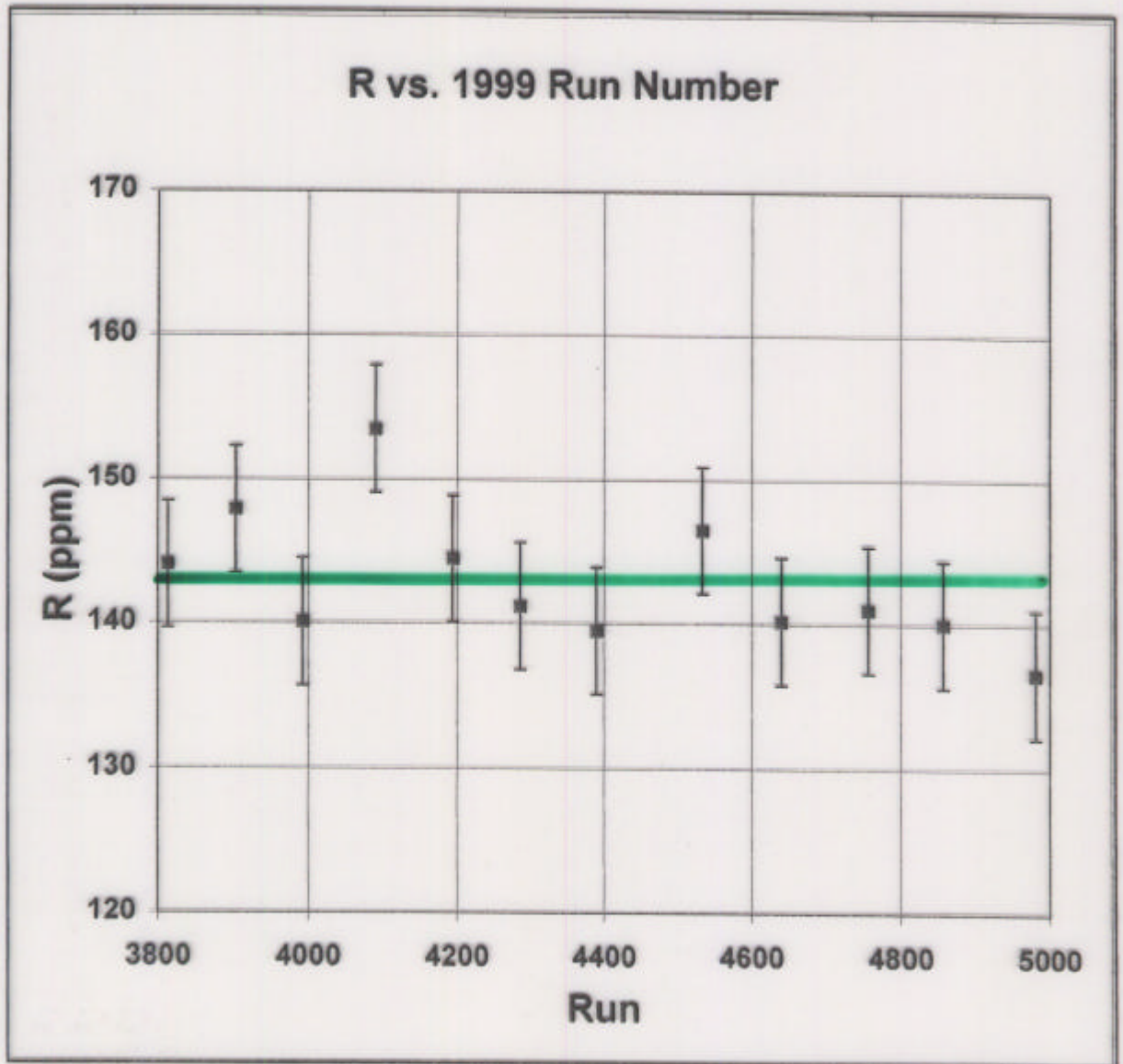




$\chi^2/\text{DOF} = 27.2/21$

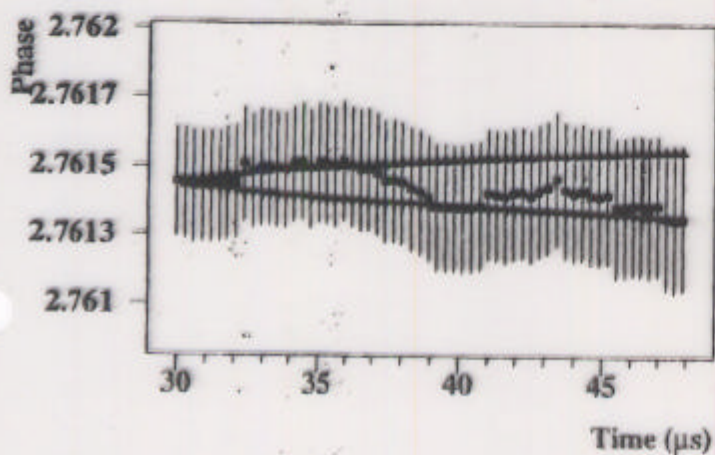
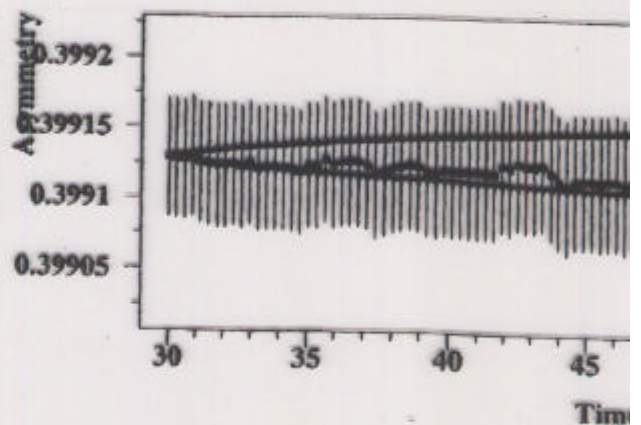
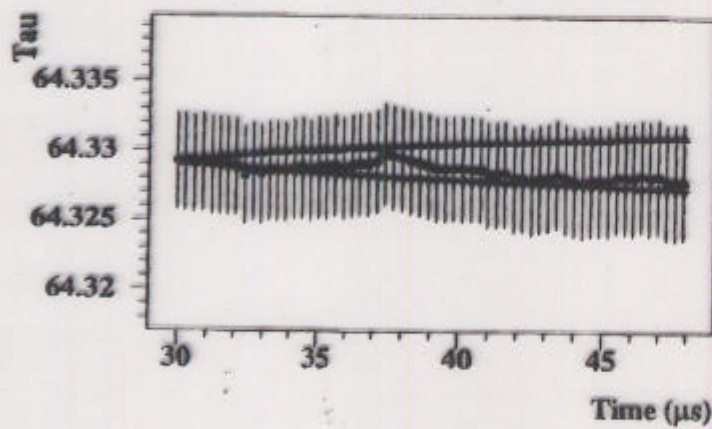
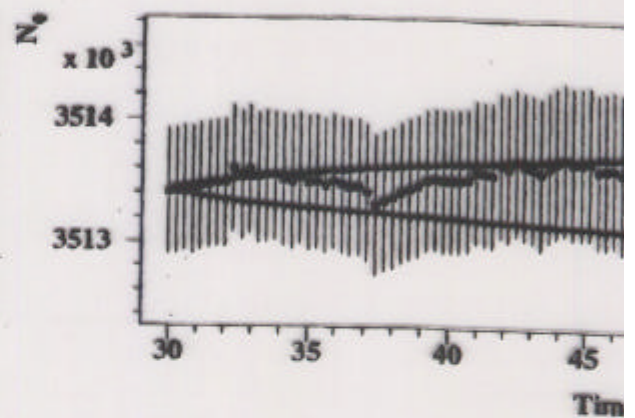
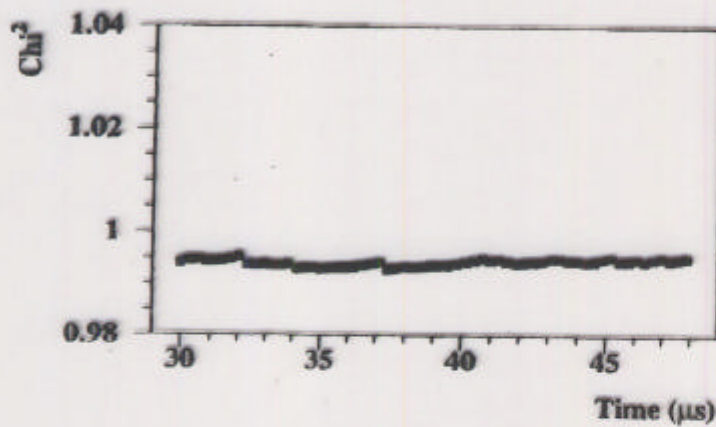


$$\chi^2/\text{dof} = \underline{12.3/11}$$



Parameter Stability

Pileup Subtracted



Independent Analyses Results

Institution	Production	Fit Start time	Para. Fit	χ^2/DOF	(R \pm statistical error) ppm
B.U.	I	32 μ s	13	1.012 \pm 0.023	143.25 \pm 1.2
BNL-based	I	32 μ s	10	1.005 \pm 0.023	143.08 \pm 1.2
Illinois	II	25-56 μ s	9	1.016 \pm 0.005	143.30 \pm 1.2
Minn	II	34 μ s*	3	0.986 \pm 0.025	143.37 \pm 1.2

* average start time.

13 fit parameters: CBO, lost muons, pileup (ϕ_p from study)

10 fit parameters: CBO, lost muons (Eastern pileup subtraction)

9 fit parameters: CBO (lost muon counter used for τ_{LM} ,
Midwest pileup subtraction)

3 parameter fit: $A \cos(\omega_a t + \phi) + \tau_a^2/16\tau^2$ to data:

$$\frac{N_1(t+\tau_a/2) + N_2(t-\tau_a/2) - N_3(t) - N_4(t)}{N_1(t+\tau_a/2) + N_2(t-\tau_a/2) + N_3(t) + N_4(t)}$$

Latest detector gated on at 28 μ s (near inflector - flash)

Method 3 has lowest statistical error; however higher levels of CBO, etc. Higher χ^2/DOF is understood.

All numbers agree within standard statistical tests.

The final answer is the weighted average of 1-4:

$$R_{av} = 143.17 \text{ ppm}; \text{ Stat error} = \pm 1.24 \text{ ppm}$$

99 Systematic Errors

Source of errors	Size [ppm]
<u>Pileup</u>	0.13
AGS background	0.10
<u>Lost muons</u>	0.10
Timing shifts	0.10
<u>E field and vertical betatron oscillation</u>	0.08
Binning and fitting procedure	0.07
<u>Coherent betatron oscillation</u>	0.05
Beam debunching/randomization	0.04
<u>Gain changes</u>	0.02
<u>Total systematic error on ω_a</u>	<u>0.3</u>

Spin resonances < 0.01 ppm

Source of errors	Size [ppm]
Absolute calibration of standard probe	0.05
Calibration of trolley probes	0.20
<u>Trolley measurements of B_0</u>	0.10
<u>Interpolation with fixed probes</u>	0.15
<u>Inflector fringe field</u>	0.20
<u>Uncertainty from muon distribution</u>	0.12
Others †	0.15
<u>Total systematic error on ω_p</u>	<u>0.4</u>

† higher multipoles, trolley temperature and its power supply voltage response, and eddy currents from the kicker.

Important Contributions from Japan*

Design of 14m diameter coils: (KEK)

H. Hirabayashi, A. Yamamoto

Topaz-type superconductor (~4 km): K

Iron yoke specifications; ultra-low carbon pole steel: (KEK)

K. Endo

Scintillating fiber monitors inside storage ring:

Y. Mizumachi (KEK)

M. Iwasaki, M. Kawamura (Tokyo I T)

Superconducting inflector:

A. Yamamoto (KEK)

Tokai, Nippon Steel Co.

☞ M. Tanaka ☞ ☞ Dr. S. Itoh ☞

* under U.S.-Japan agreement in IHEP

Precise measurement of the positive muon anomalous magnetic moment

H.N. Brown², G. Bunce², R.M. Carey¹, P. Cushman⁹, G.T. Danby², P.T. Debevec⁷,
M. Deile¹¹, H. Deng¹¹, W. Deninger⁷, S.K. Dhawan¹¹, V.P. Druzhinin³, L. Duong⁹,
E. Efsthadiadis¹, F.J.M. Farley¹¹, G.V. Fedotovitch³, S. Giron⁹, F. Gray⁷, D. Grigoriev³,
M. Grosse-Perdekamp¹¹, A. Grossmann⁶, M.F. Hare¹, D.W. Hertzog⁷, V.W. Hughes¹¹,
M. Iwasaki¹⁰, K. Jungmann⁶, D. Kawall¹¹, M. Kawamura¹⁰, B.I. Khazin³, J. Kindem⁹,
F. Krienen¹, I. Kronkvist⁹, R. Larsen², Y.Y. Lee², I. Logashenko^{1,3}, R. McNabb⁹,
W. Meng², J. Mi², J.P. Miller¹, W.M. Morse², D. Nikas², C.J.G. Onderwater⁷, Y. Orlov⁴,
C.S. Özben², J.M. Paley¹, C. Polly⁷, J. Pretz¹¹, R. Prigl², G. zu Putlitz⁶, S.I. Redin¹¹,
O. Rind¹, B.L. Roberts¹, N. Ryskulov³, S. Sedykh⁷, Y.K. Semertzidis², Yu.M. Shatunov³,
E.P. Sichtermann¹¹, E. Solodov³, M. Sossong⁷, A. Steinmetz¹¹, L.R. Sulak¹,
C. Timmermans⁹, A. Trofimov¹, D. Urner⁷, P. von Walter⁶, D. Warburton², D. Winn⁵,
A. Yamamoto⁸, D. Zimmerman⁹

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⁴*Newman Laboratory, Cornell University, Ithaca, NY 14853, USA*

⁵*Fairfield University, Fairfield, CT 06430, USA*

⁶*Physikalisches Institut der Universität Heidelberg, 69120 Heidelberg, Germany*

⁷*Department of Physics, University of Illinois at Urbana-Champaign, IL 61801, USA*

⁸*KEK, High Energy Accelerator Research Organization, Tsukuba, Ibaraki 305-0801, Japan*

⁹*Department of Physics, University of Minnesota, Minneapolis, MN 55455, USA*

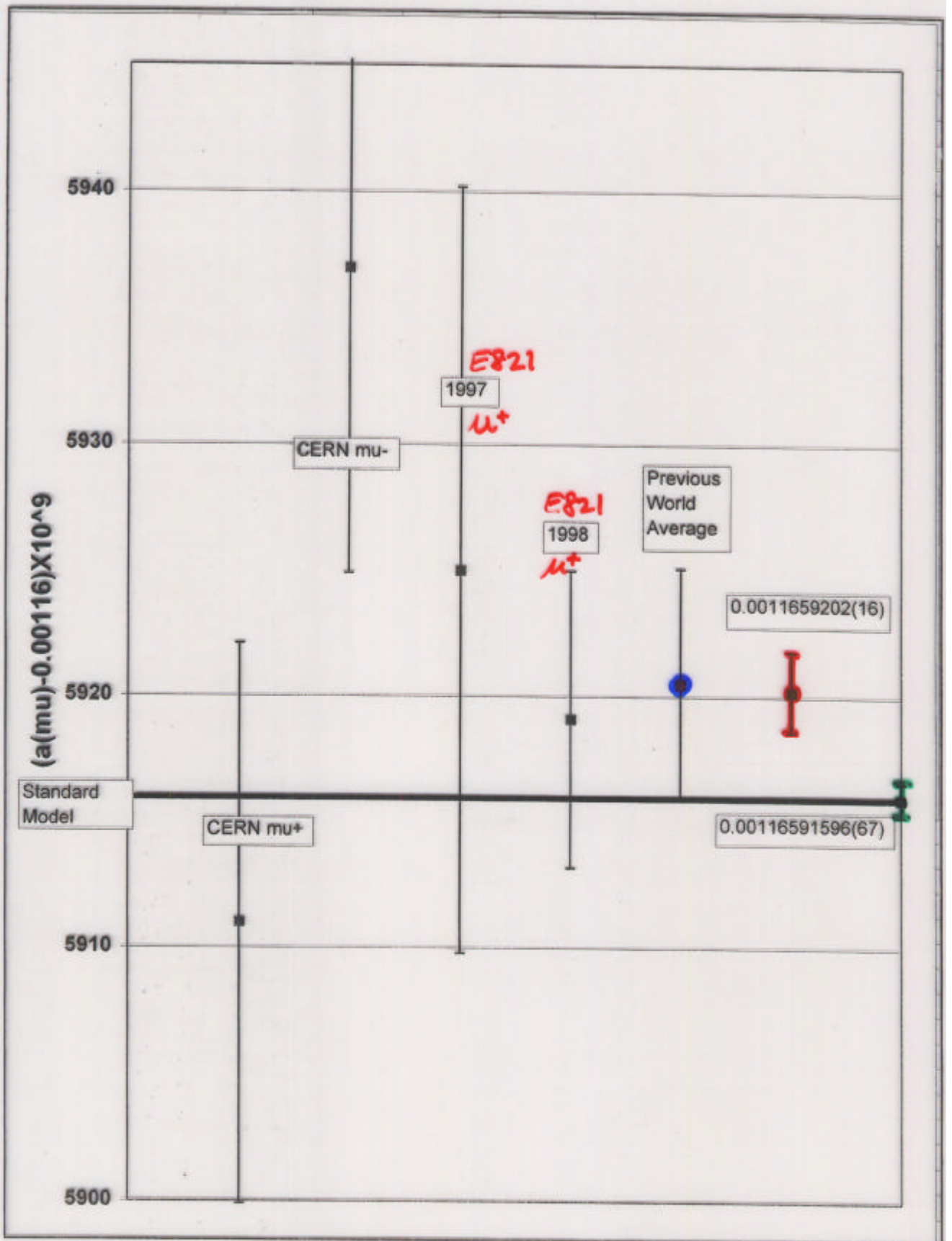
¹⁰*Tokyo Institute of Technology, Tokyo, Japan*

¹¹*Department of Physics, Yale University, New Haven, CT 06511, USA*

E821

Jan. 12, 2001 Removed Offsets → Am

Muon Anomaly CERN and BNL



Conclusions

$$99 \text{ run: } a_{\mu} = 116\,592\,02 (16) \times 10^{-10}$$

$$\text{SM}^{\mathbf{1}} \quad a_{\mu} = 116\,591\,59.6 (6.7) \times 10^{-10}$$

$$\text{Difference: } (42 \pm 16) \times 10^{-10}$$

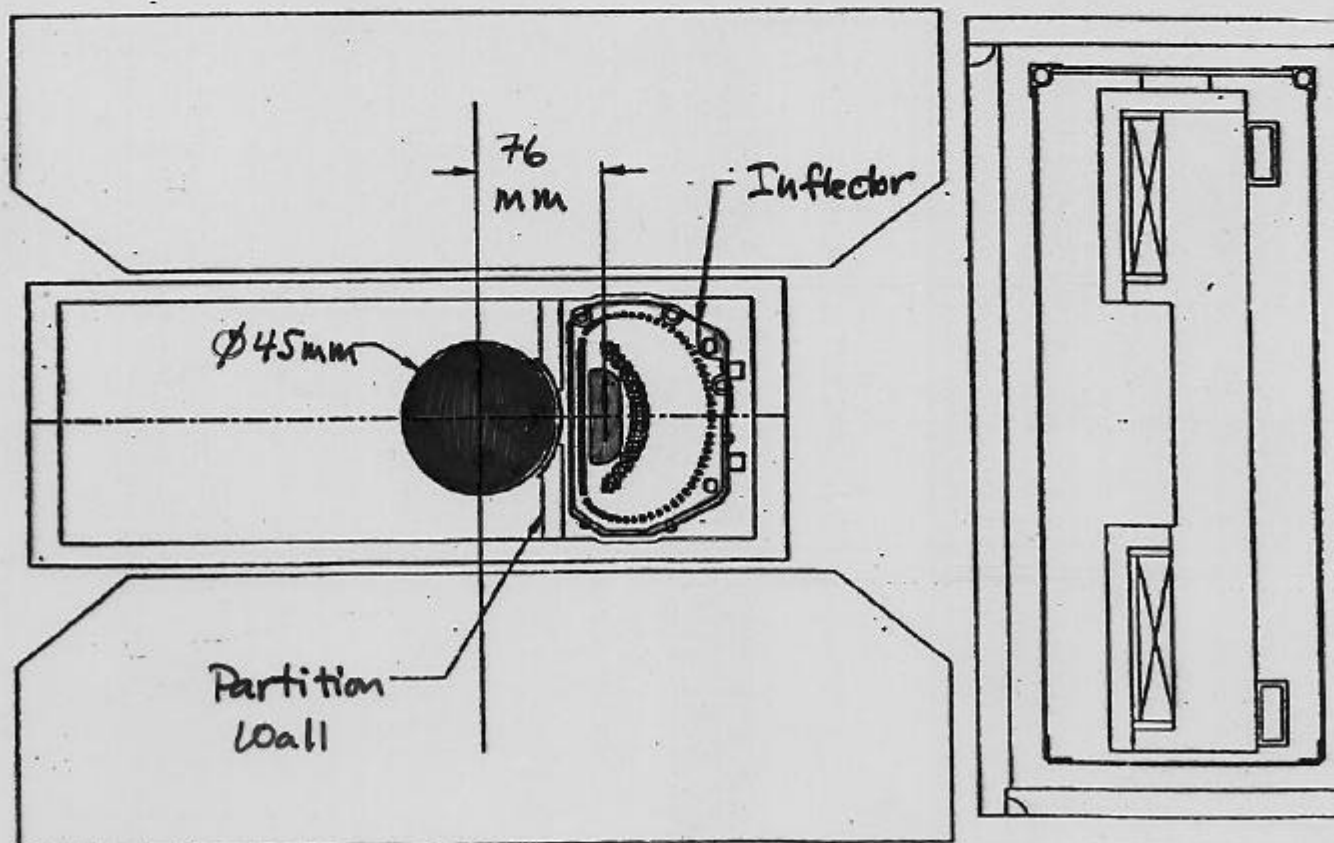
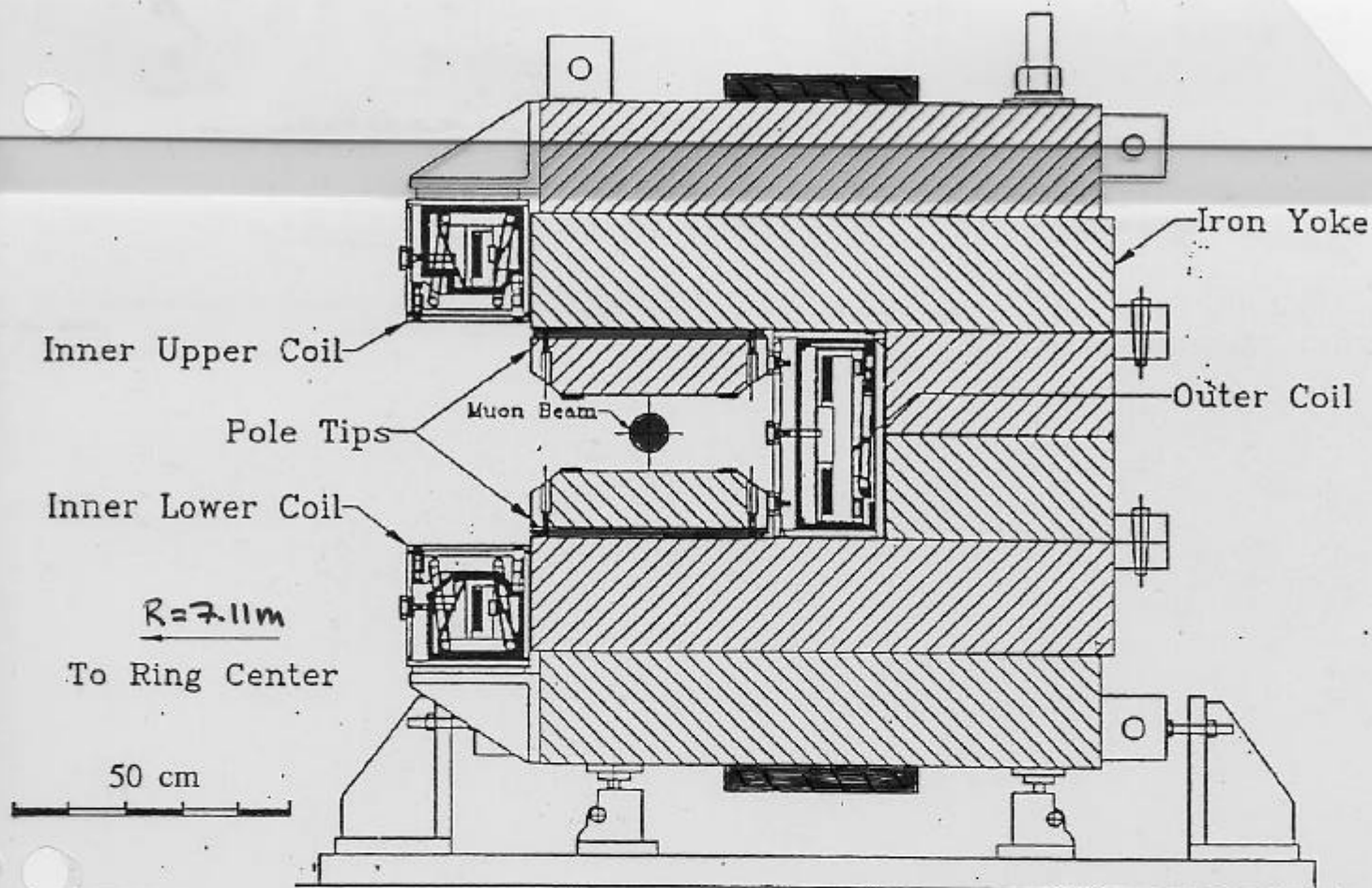
$$\underline{(3.6 \pm 1.3) \text{ ppm or } 2.6 \sigma}$$

Coming attractions: now analyzing
2000 run μ^+ data, with result probably
late 2001 or early 2002. ($\sim 4 \times \mu \rightarrow e \nu \bar{\nu}$)

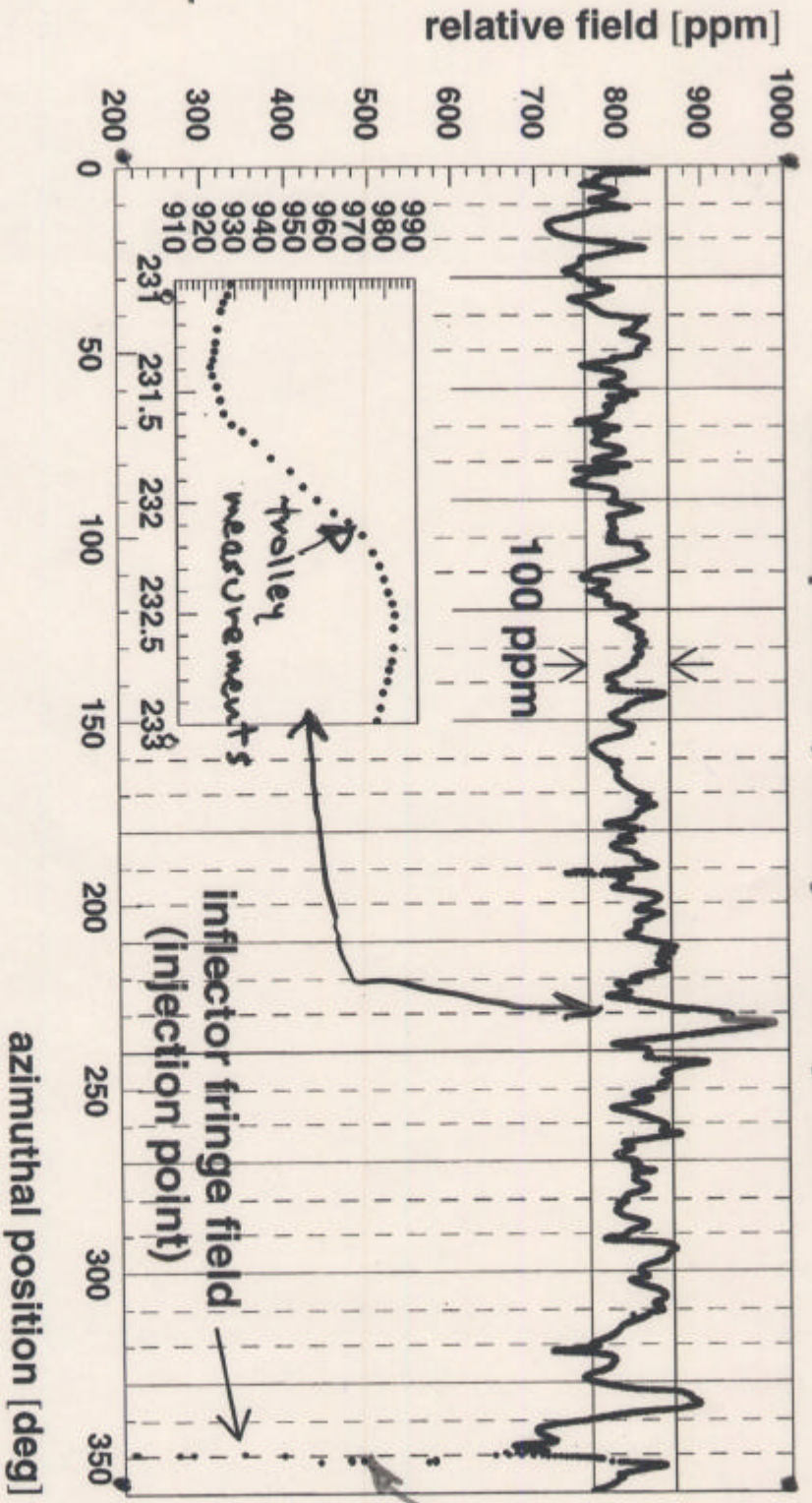
Feb.-Apr. 2001 run with μ^- .

1. A. Czarnecki and W. Marciano
Nucl. Phys. B(Proc. Suppl.) 76 (1999) 245.

STORAGE RING CROSS SECTION



fieldmap 2-5-99, trolley center probe

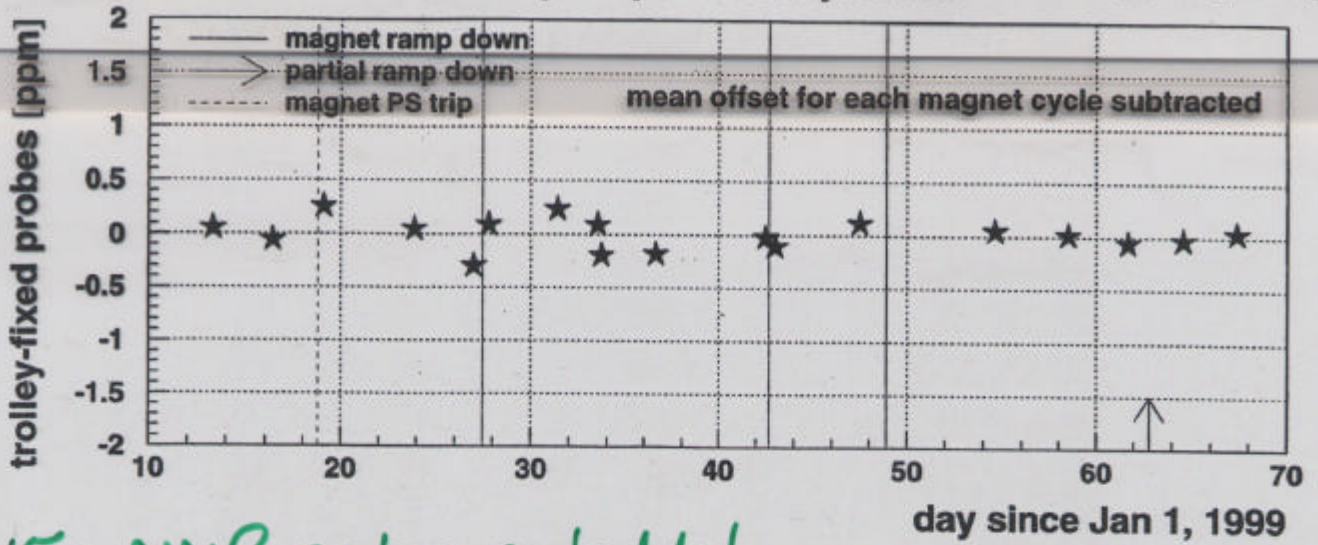


CERN g-2 $\left(\frac{\Delta B}{B}\right)_{\text{CERN}} \approx 1 \text{ ppm}$

351° - 349° ($\sim 359^\circ$ of range - non-injector) $\pm 0.10 \text{ ppm}$
 350° ($\sim 1^\circ$ of range - inflector) $\pm 0.20 \text{ ppm}$

trolley maps - fixed probes

$$\sigma = \pm 0.15 \text{ ppm}$$



150 NMR probes embedded in vacuum chamber walls

