μ g-2

Result of the 1999 data run.

G. Bunce

First presented at BNL
Feb 8, 2001
by Bill Morse

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8 Feb 2001

E821

W. Morse
Feb. 8, 2001

Precise Measurement of the Anomalous Magnetic Moment of the Muon

Results of Analysis of 1999 Run
(±1.3ppm)

1. Theory

2. Principle of the measurement
less than usual as we have given BNL Lectures, colloquia, and seminars on the principles.

3. Analysis
more than usual, maybe too much.

4. Systematic errors

5. Results

Particle with spin S:

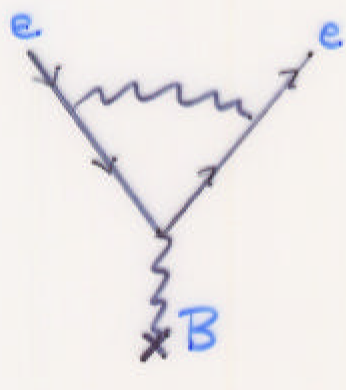
$$\vec{\mu}_m = g \frac{e\hbar}{2mc} \vec{S}$$

1930s: Dirac $g=2$ for point particle, spin $\frac{\hbar}{2}$.

Proton $g = 2.8 \times 2$
$= 5.6$

1940s: Electron $g = 2.002$!

Point particle $a_e = \frac{g_e - 2}{2} = \frac{\alpha}{2\pi} + \cdots$



$$a_e^{\text{new physics}} \sim \frac{m_e^2}{\Lambda^2}$$

	m	cτ
e	0.5MeV	∞
μ	105MeV	660m
τ	1784MeV	0.1mm

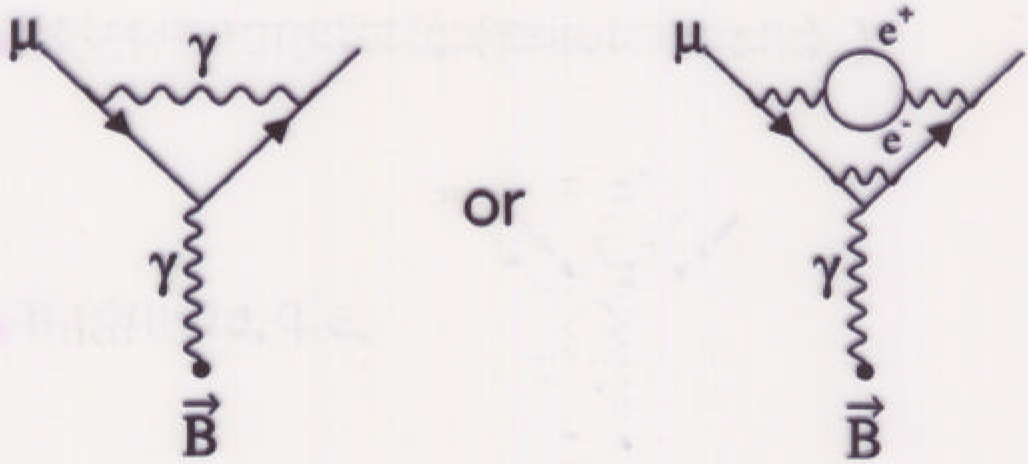
g – Factor

$$g = \frac{\text{magnetic moment}\left[\frac{e\hbar}{mc}\right]}{\text{angular momentum}[\hbar]}$$

$g = 2$

but . . .

... higher orders



lead to anomalous magnetic moment:

$$a = \frac{g-2}{2}$$

$(a \approx 10^{-3})$

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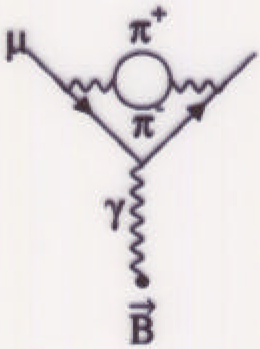
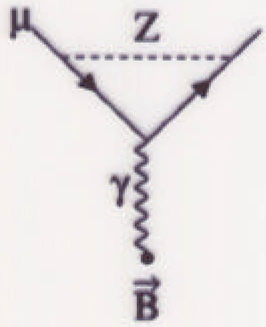
Standard Model Contributions

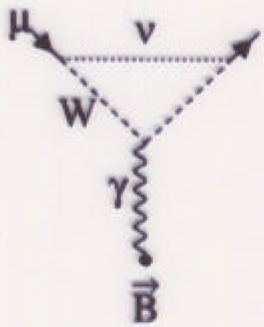
- electromagnetic (previous slide)
- hadronic, i.e.



- weak, i.e.



or



$$a^{\mathrm{SM}} = a^{\mathrm{em}} + a^{\mathrm{had}} + a^{\mathrm{weak}}$$

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Standard Model Theory [1]

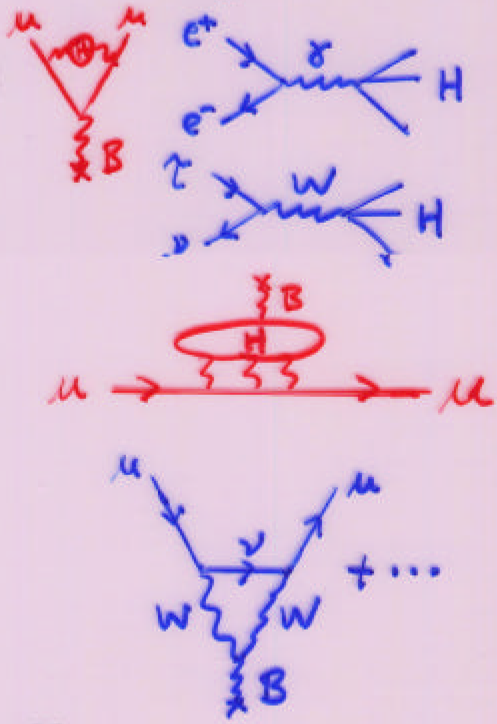
$a_\mu(\text{QED}) = 116584706\ (3) \times 10^{-11}$ $\frac{\alpha}{2\pi} + \cdots$

$a_\mu(\text{Had}_a) = 6924\ (62)$

$a_\mu(\text{Had}_b) = -100\ (6)$

$a_\mu(\text{Had}_{ll}) = -85\ (25)$

$a_\mu(\text{EW}) = 151\ (4)$



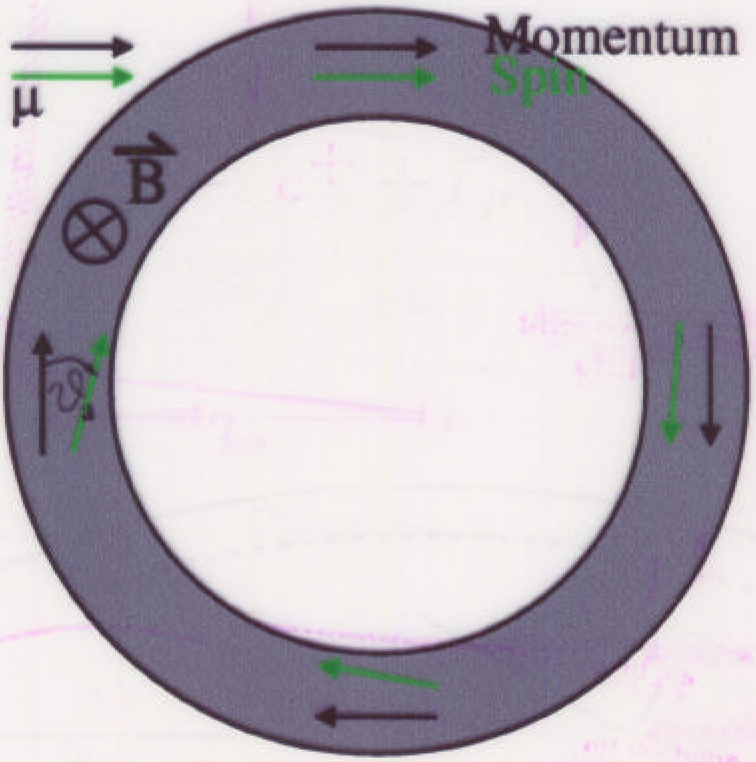
$\text{Total} = 116591596\ (67) \times 10^{-11}$

(0.6ppm)

1. A. Czarnecki, W. Marciano/Nuclear Physics B (Proc. Suppl.) 76 (1999) 245-252.

Method

Store polarized muons in a homogenous magnetic field and measure difference frequency between spin and momentum precession

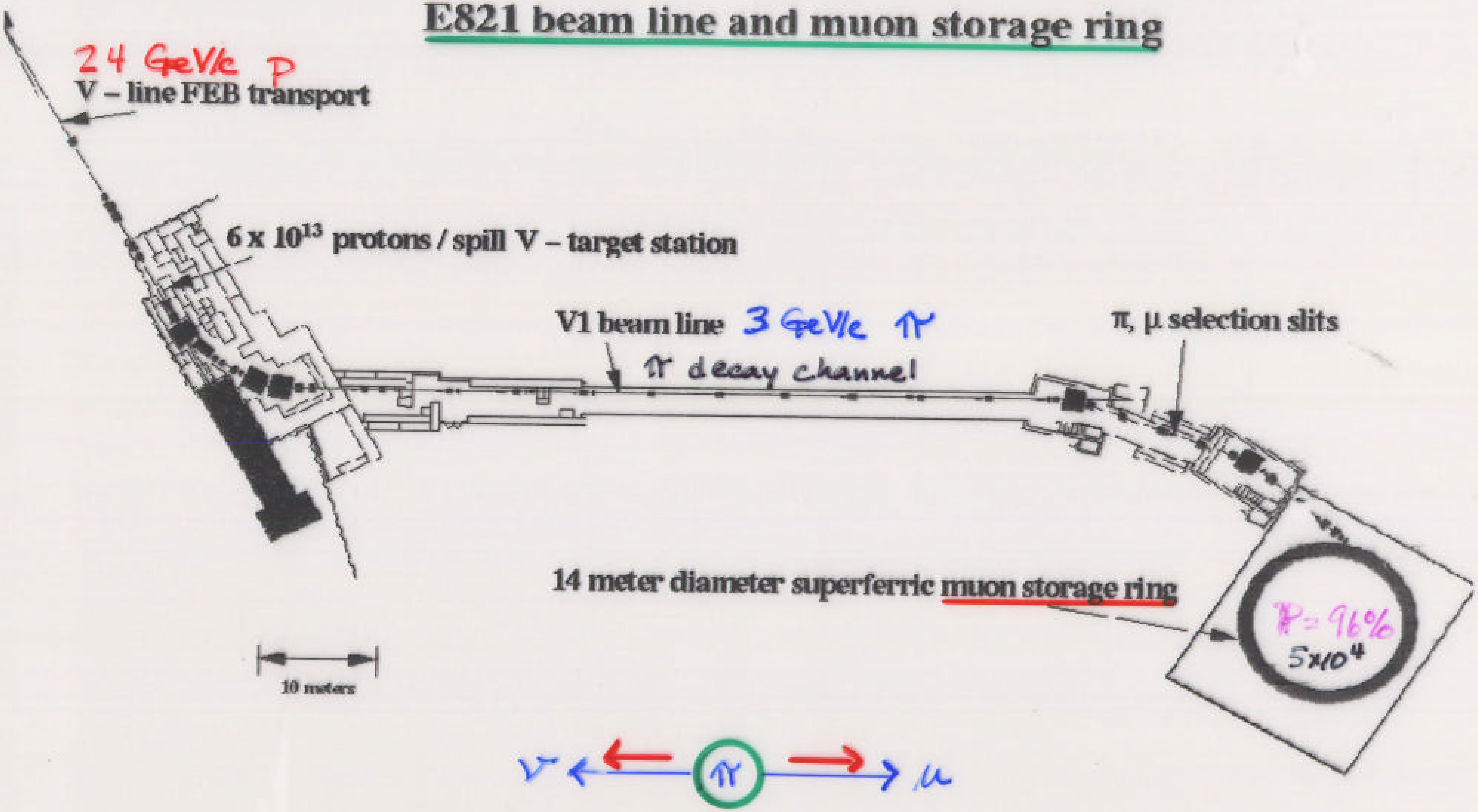


measure

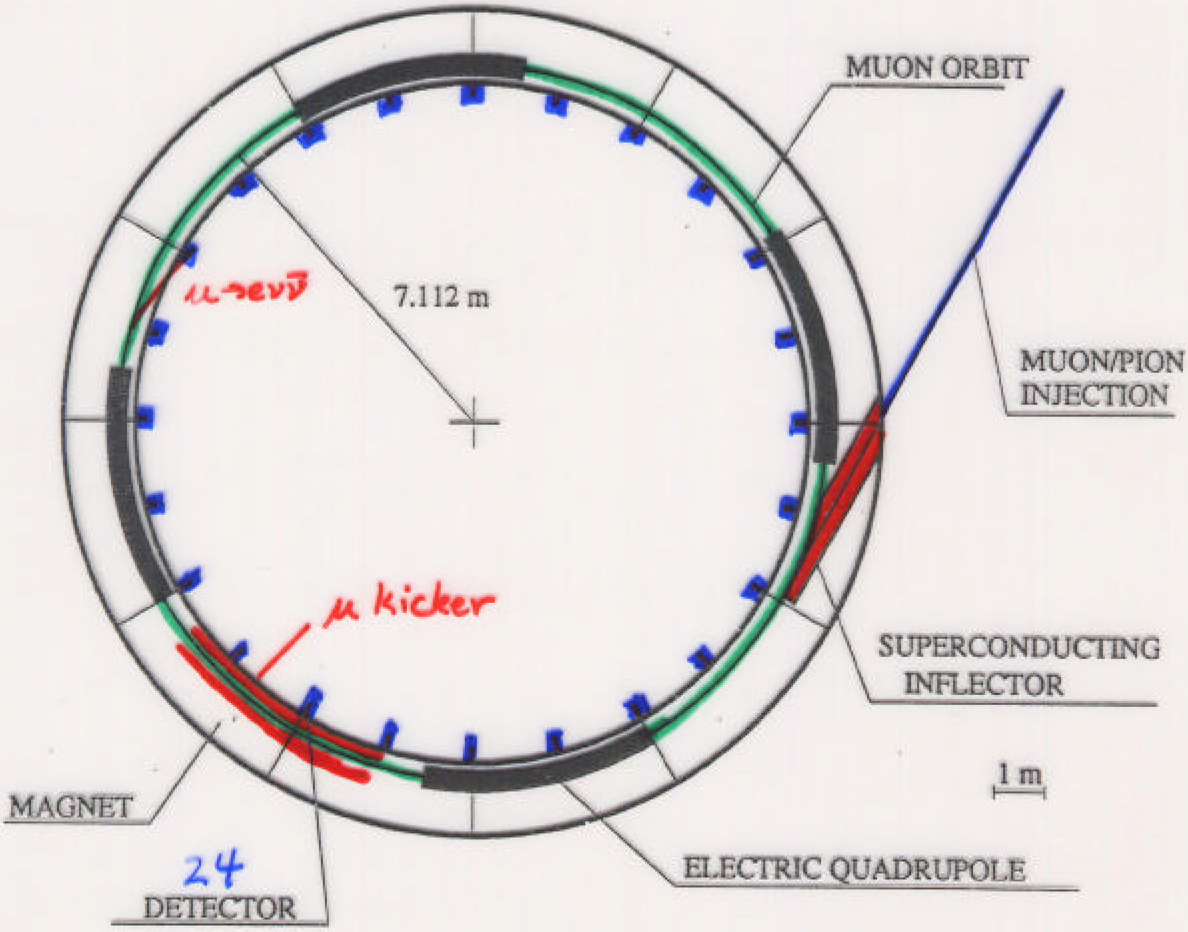
$$\vec{\omega}_a = \frac{d\vec{\vartheta}_a}{dt} = \frac{e}{m_\mu c} a_\mu \vec{B}$$

$\frac{g_\mu - 2}{2}$

E821 beam line and muon storage ring



BNL MUON G–2 EXPERIMENT



$$a = \frac{g-2}{2}$$

$$\omega_c = \frac{eB}{mc\gamma}$$

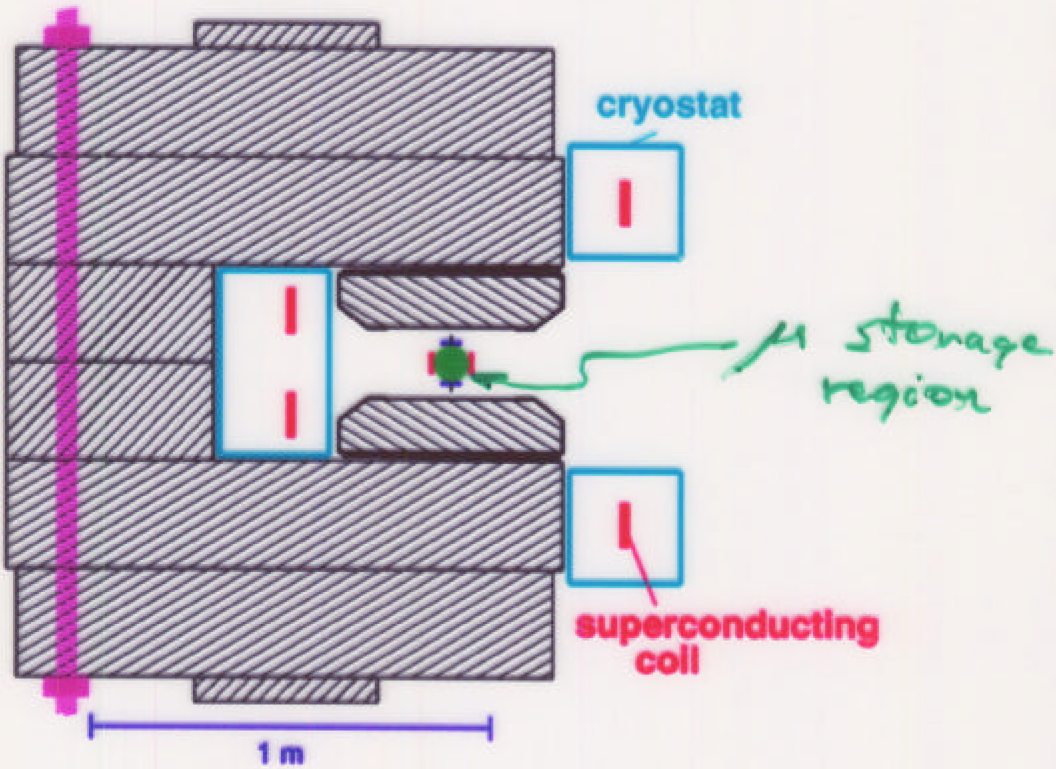
$$\omega_s = \frac{eB}{mc\gamma} + \frac{e}{mc}aB$$

$$\omega_a = \omega_s - \omega_c = \frac{e}{mc}aB$$

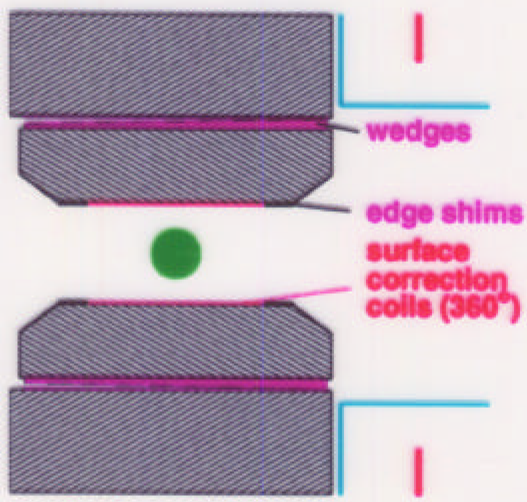
$$\omega_a = \frac{e}{mc}\left[aB - (a - \frac{1}{\gamma^2 - 1})(\vec{\beta} \times \vec{E})\right]$$

at $\gamma = 29.3, p = 3.09\,\frac{GeV}{c}, \omega_a$ is independent of E

The E821 Ring Magnet



shimming tools:



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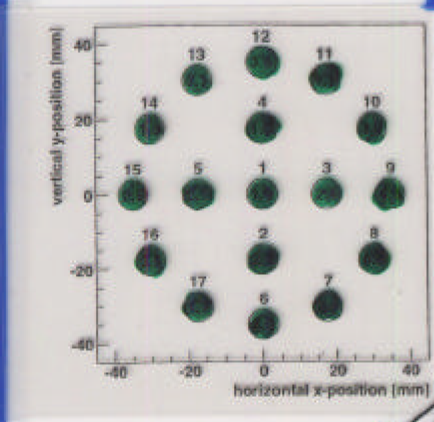
- world's largest superconducting magnet
- g-2 magnet gap = 18 cm
- circumference ≈ 44 m
- field uniform to ± 1 ppm

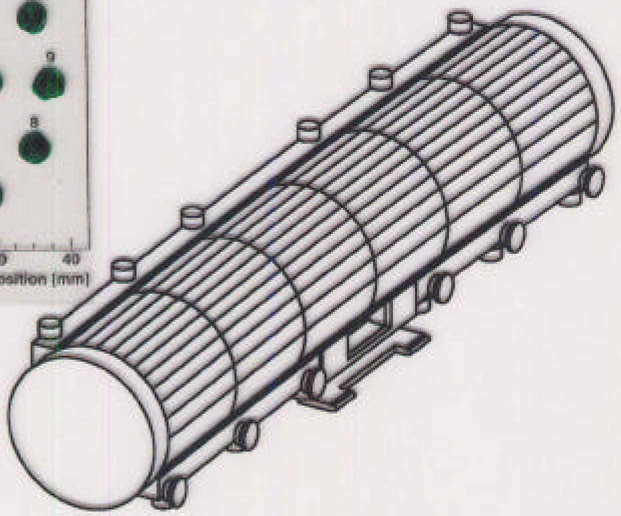
diam. (human hair) ≈ 50 μm

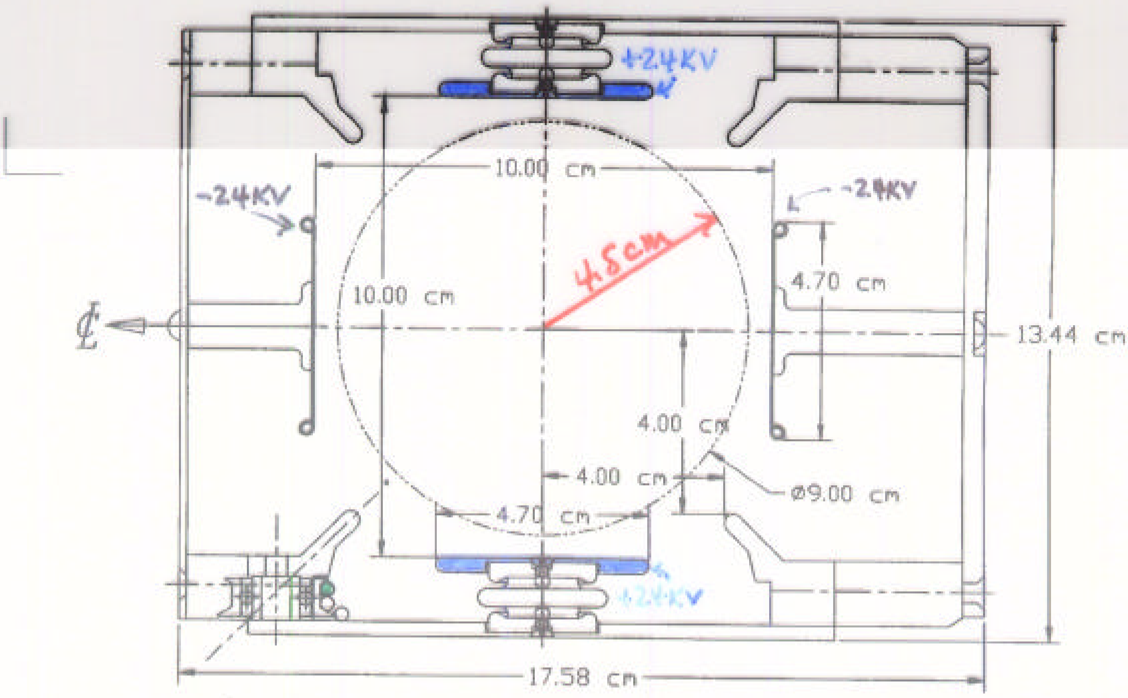
$$\frac{d\,(\text{hair})}{d\,(\text{gap})} = \frac{50 \times 10^{-6}}{2 \times 10^{-1}} = 250 \text{ ppm}$$

NMR

Beam Tube Trolley







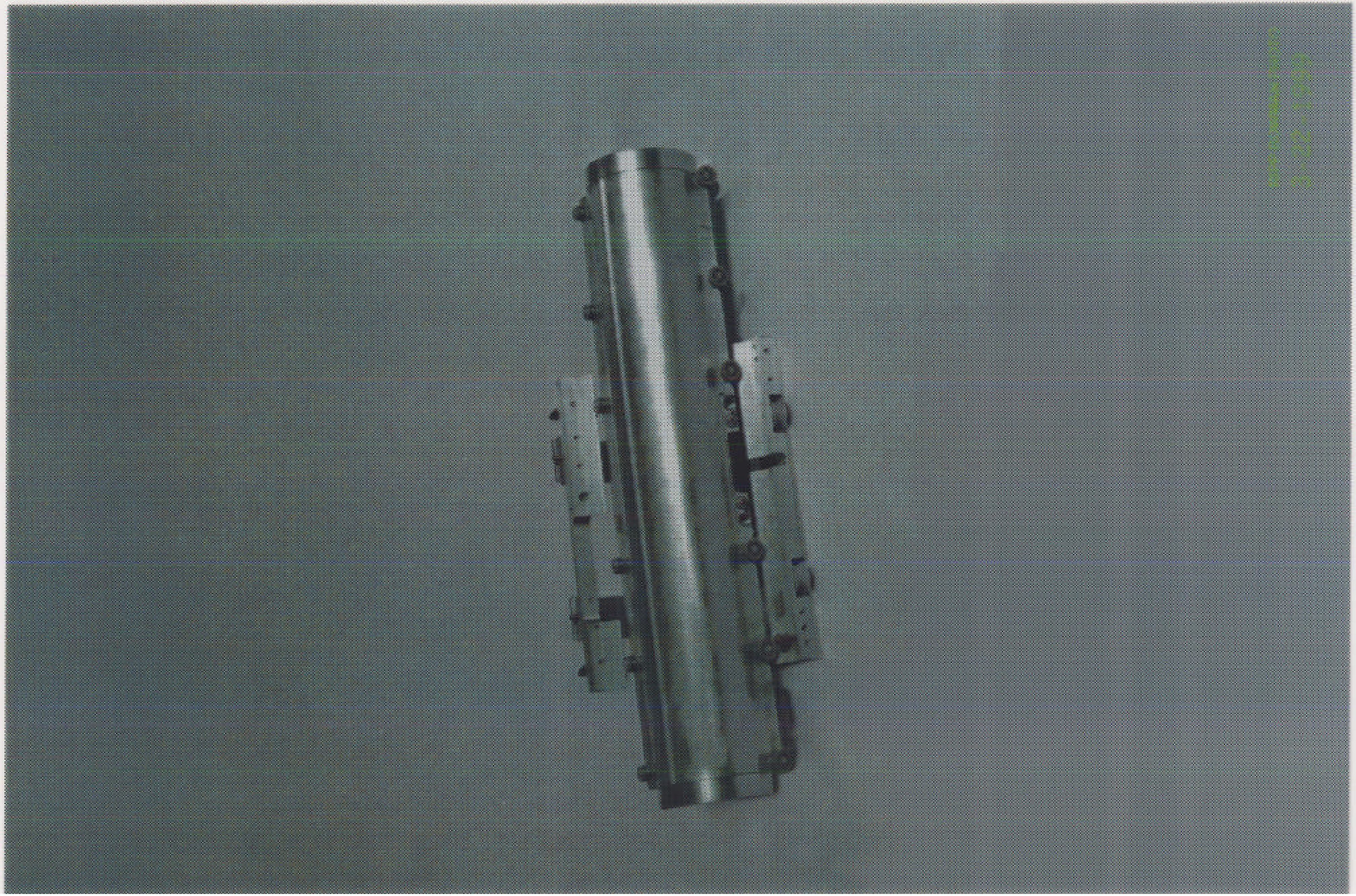
$$n = \frac{R}{cB_0}\frac{\partial E}{\partial r} = 0.139$$

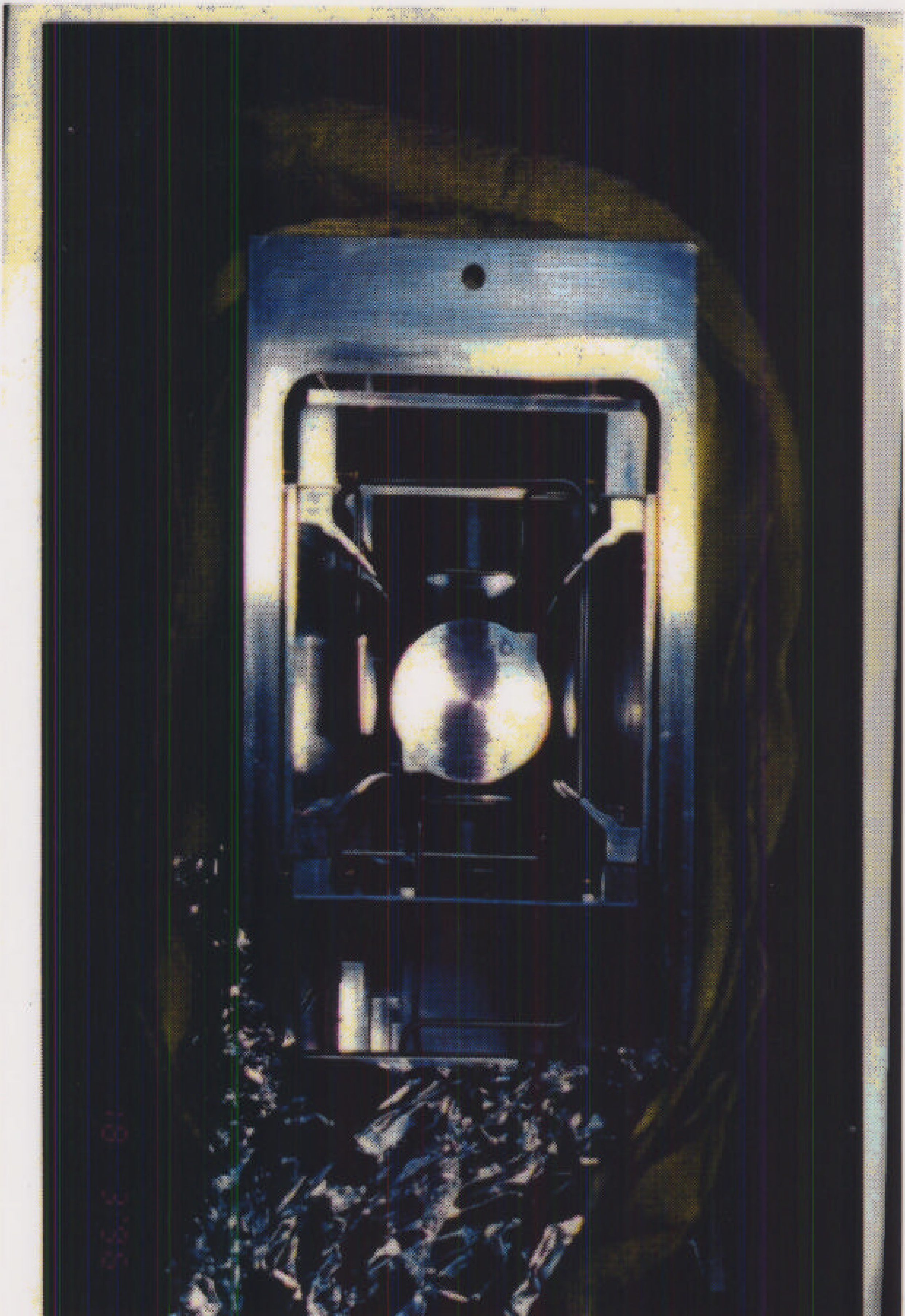
$\theta_V^{max} = 2.3\,mr$

$\theta_R^{max} = 5.6\,mr$

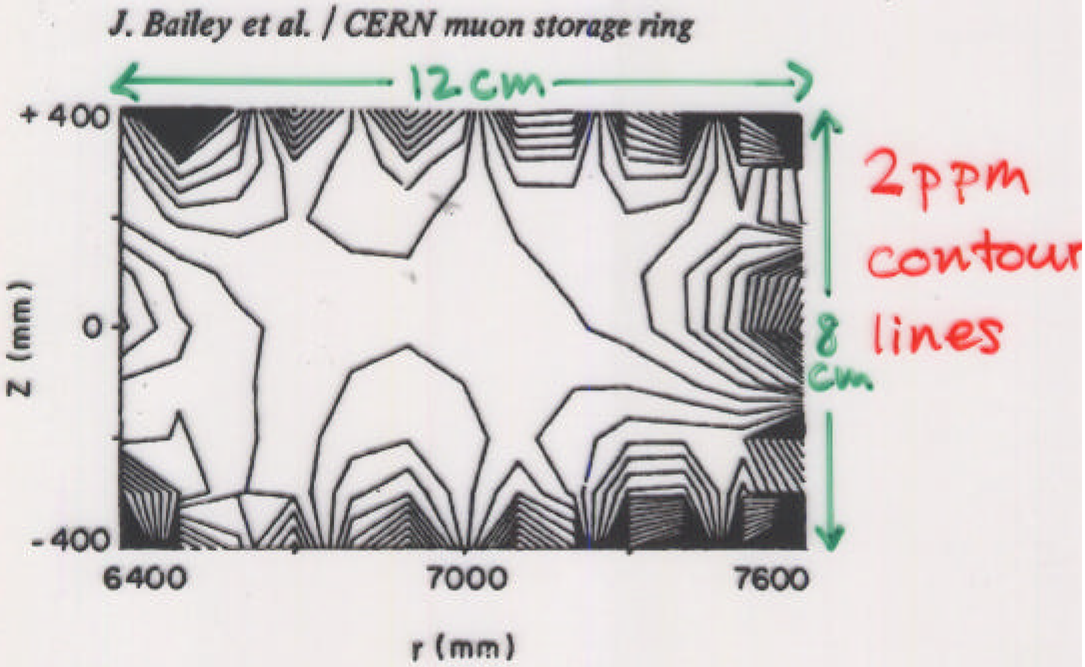
$\frac{dp}{p} = \pm 0.5\%$

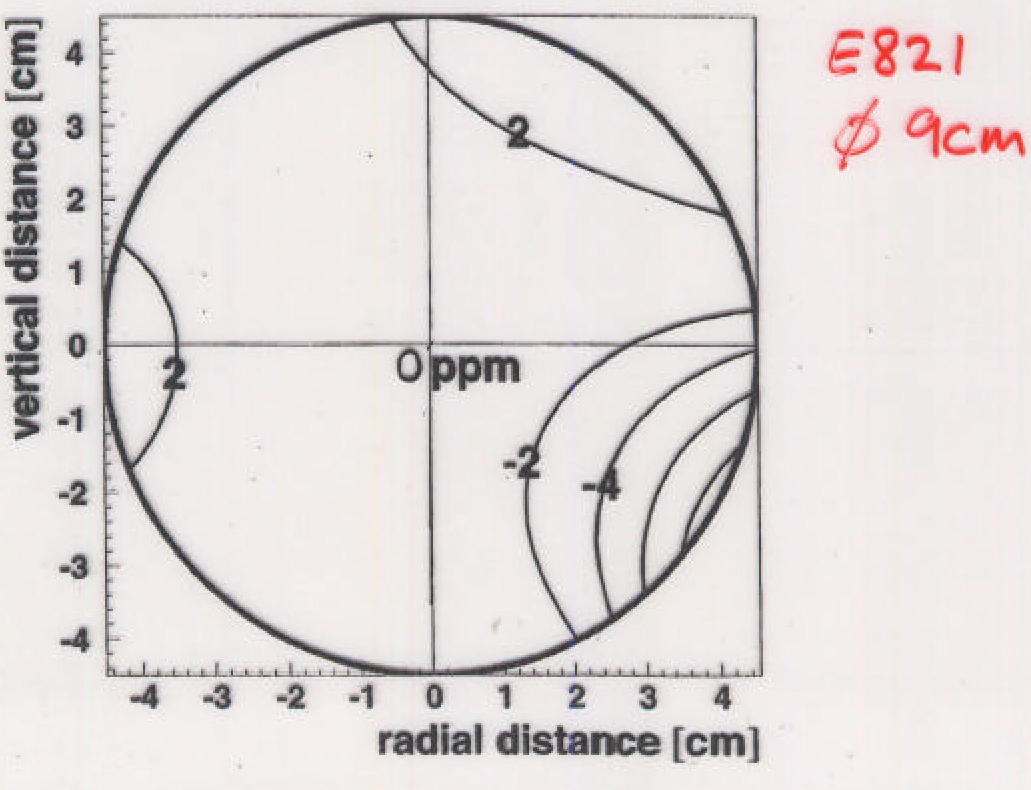
FILE # proj4.psd





Magnetic Field Uniformity and <B>





<B> = Field Averaged Over the Muon Distribution

Muon and B Normal Multipole Analysis

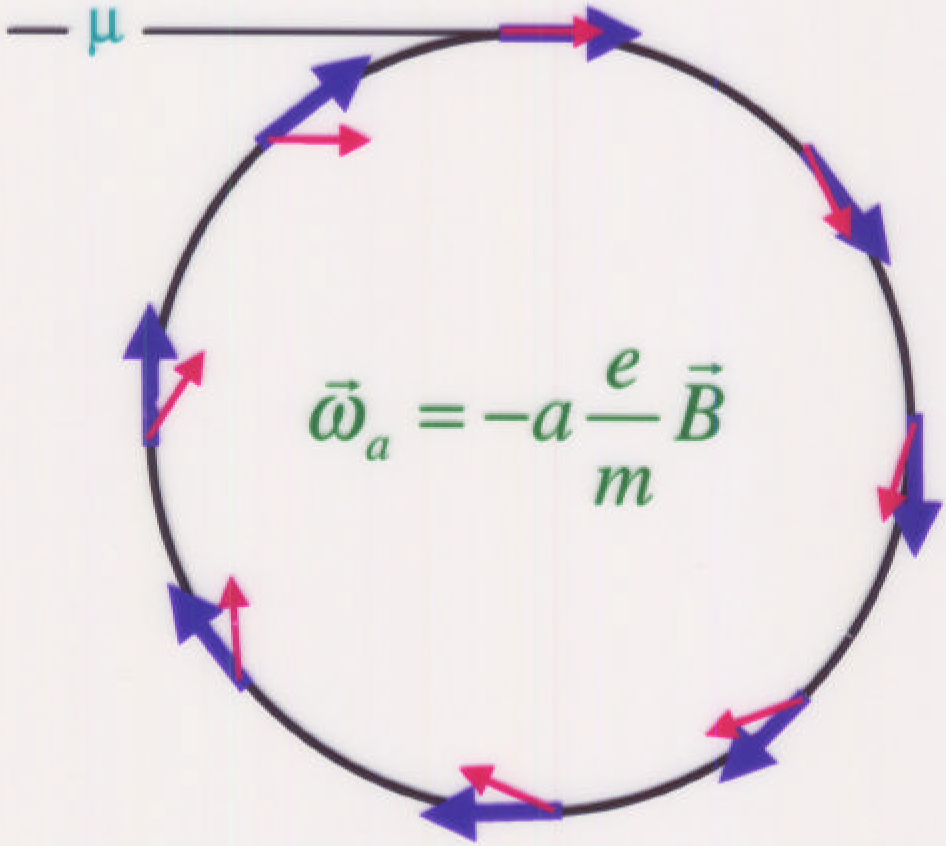
1999 E821	M(x,y)	B(x,y)	d <B>
Quadrupole	±1mm/45mm	-2.23 ppm	0.05 ppm
Sextupole	0.020	-1.15 ppm	0.02 ppm
Octupole	-0.003	-1.33 ppm	0.004ppm
Decupole	-0.005	0.92 ppm	0.005ppm

Total: 0.08ppm (normal), 0.09ppm (skew)

Beam dynamics calculations using tracking codes find $\langle B \rangle = B(x_0,y_0) \pm 0.07$ppm.

Tracking $d\langle B \rangle = \pm 0.12$ppm.

Spin Precession in g-2 Ring



$$\vec{\omega}_a = -a\frac{e}{m}\vec{B}$$