# E-989 g-2 experiment -

## Study of systematic errors affecting the electron spectrum
## &
## Straw Detectors

Fermilab

The purpose of g-2 experiment is to misure the muon anomalous magnetic momentum to ±0.14 ppm precision

$$\overline{\mu_{\mu}} = g_{\mu}\left(\frac{q}{2m}\right)\overline{s}$$

Dirac teory → $g_{\mu}$ = 2 is expected for a structureless, spin-1/2 particle of mass m and charge q = ± e

↓

Anomalous magnetic momentum

$$a_{\mu} = \left(\frac{g_{\mu}-2}{2}\right)$$

# *Radiative corrections*

Leading RC → lowest-order QED process involving the exchange of a virtual photon

$$a_\mu = \alpha / 2\pi = 1.16 \cdot 10^{-3}$$

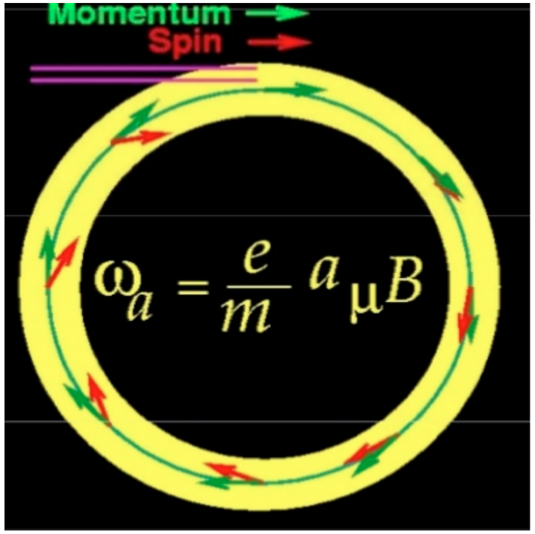
Complete standard model value of $a_\mu$

QED    Weak    Hadronic

0.5 ppm precision

# *E821 Experimental tecnique*

Muons moving in the horizontal plane of a magnetic storage ring, have an anomalous precession spin frequency:




$$\bar{\omega}_a = \omega_s - \omega_c = -a_\mu \frac{q\bar{B}}{m}$$

Spin precession frequency

$$\omega_s = -\frac{g\,q\,\bar{B}}{2\mathrm{m}} - (1-\gamma)\frac{q\,\bar{B}}{m\,\gamma}$$

Cyclotron frequency

$$\omega_c = -\frac{q\,\bar{B}}{m\,\gamma}$$

# *E821 Experimental tecnique-I*

Because electric quadrupoles are used to provide vertical focusing in the storage ring, their electric field is seen in the muon rest frame as a motional magnetic field that can affect the spin precession frequency:

$$\bar{\omega}_a = -\frac{q}{m}\left[a_\mu \bar{B} - \left(a_\mu - \frac{1}{\gamma^e - 1}\right)\frac{\bar{B}\, x\, \bar{E}}{c}\right]$$

→ = 0 if $\gamma$ = 29.3

Magic momentum $p_\mu$ = 3.094 Gev /c

# *E821 Experimental tecnique-II*

$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

Because of parity violation in the weak decay of the muon, a correlation exists between the muon spin and decay positron direction. Positrons of low energy are emitted preferentially along the muon spin direction and those of high energy are more likely emitted opposite to the spin.

We can measure the muon anomaly from the time distribution of positrons of a certain energy

# *E821 Experimental tecnique-III*

The integrated decay electron distribution in the lab frame is:

$$N(t) = \frac{N}{\gamma \tau_\mu} e^{\frac{-t}{\gamma \tau_\mu}} \left[ 1 + A \cos(\omega_a t + \phi) \right]$$

Normalization coefficient

Time dilated muon lifetime

Asymmetry

Phase

For a threshold enegy $E_{th}$ = 1.8 GeV, the asymmetry is A ≈ 0.4 and the average figure-of-merit is maximized, so the statistical uncertainty on $\omega_a$ is minimized.

Because I want to study the systematic errors, I chose this configuration.

# ROOT simulation-I

$$esp = \frac{N}{\gamma \tau_\mu} \cdot e^{\frac{-t}{\gamma \tau_\mu}} \cdot [1 + A \cdot \cos(\omega \cdot t + \phi)]$$

Guess: $A = 0.4$

$\gamma \cdot \tau_\mu = 64.4\ \mu s$

$\omega_a = 4.37\ \mu s$

$\Phi = 1.5$ rad

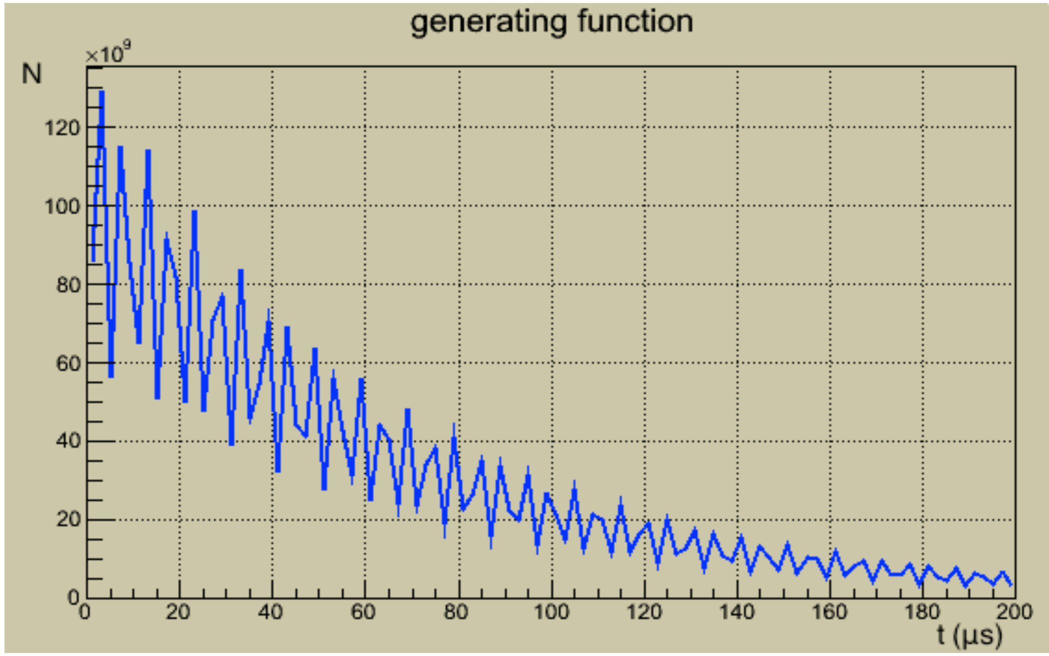
N chosen so that the histogram was filled by $10^{12}$ points

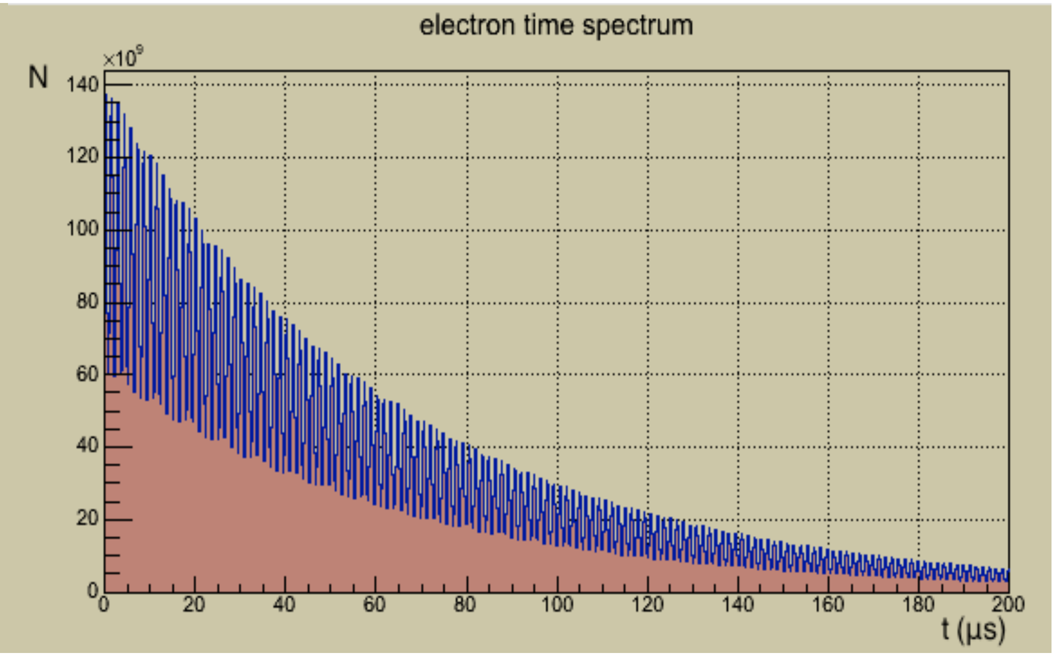
IDEAL CASE

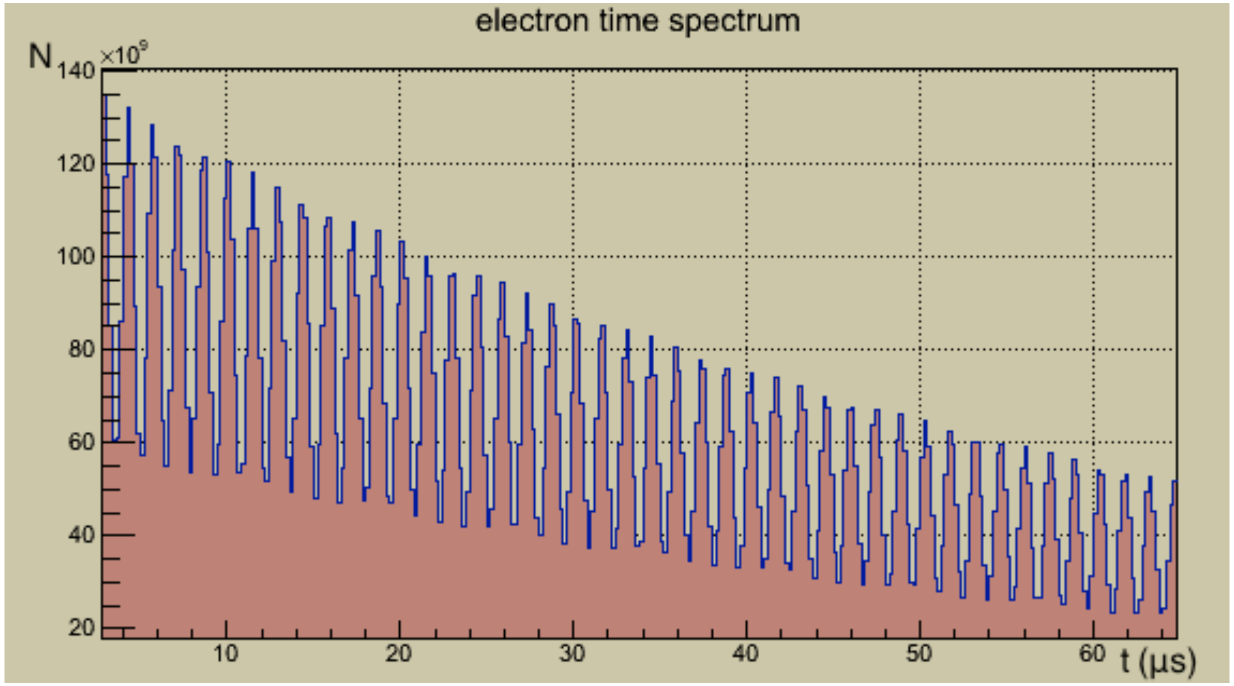
↓

Statistical errors negligible

# An example of electron decay time distribution histogram



# *ROOT simulation-II*

Systematic errors can be represented, at the first order, setting the asimmetry as a linear function of time in the generating function:

$$A = c_1 \left( 1 + c_2 t \right)$$

Generating function

All parameters, except A, are setted to their values at $E_{th}$ = 1.8 GeV

$$esp = \frac{N}{\gamma \tau_\mu} \cdot e^{\frac{-t}{\gamma \tau_\mu}} \cdot \left[ 1 + c_1 \left( 1 + c_2 \cdot t \right) \cdot \cos\left( \omega \cdot t + \phi \right) \right]$$

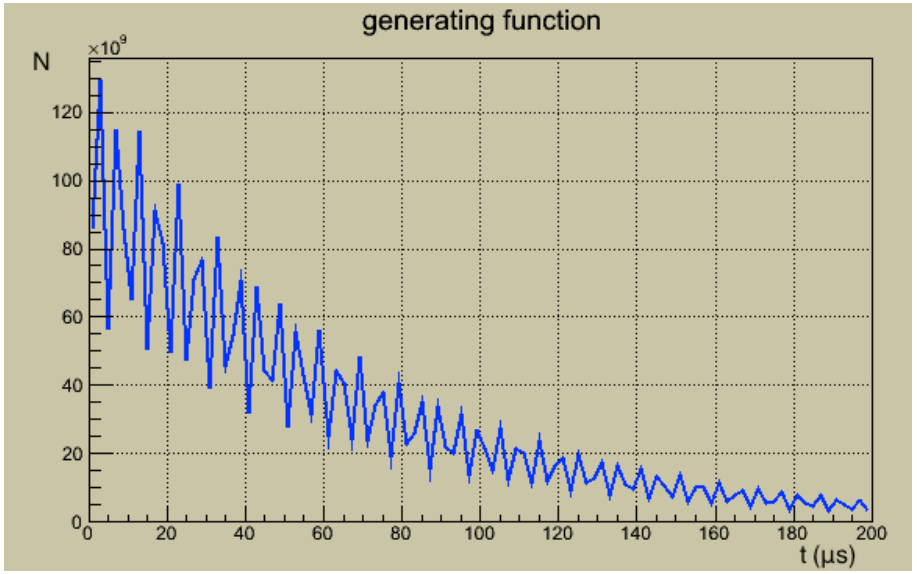
$$esp1 = \frac{N}{\gamma \tau_\mu} \cdot e^{\frac{-t}{\gamma \tau_\mu}} \cdot \left[ 1 + A \cdot \cos\left( \omega \cdot t + \phi \right) \right]$$

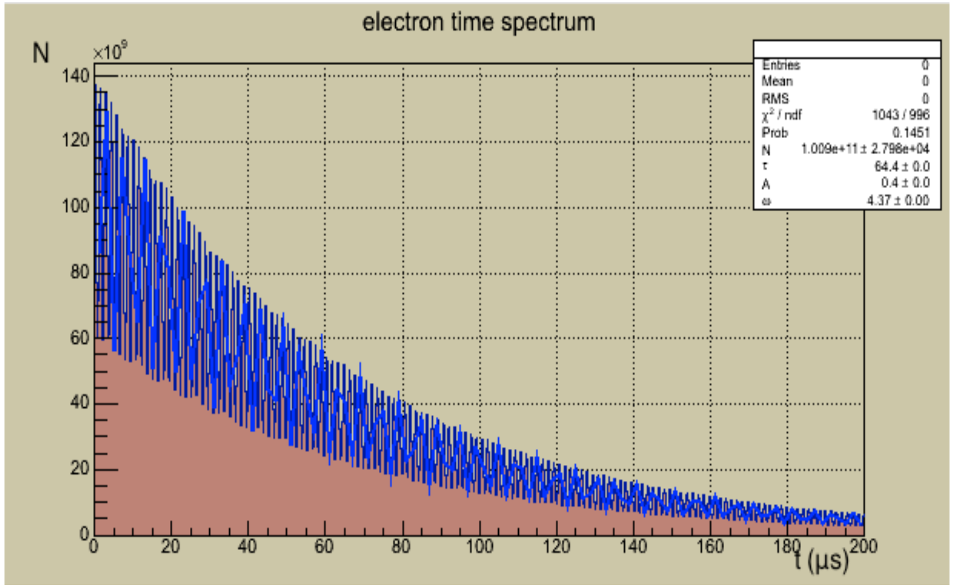
Fit function

Free parameters in the fit

# *ROOT simulation-III*

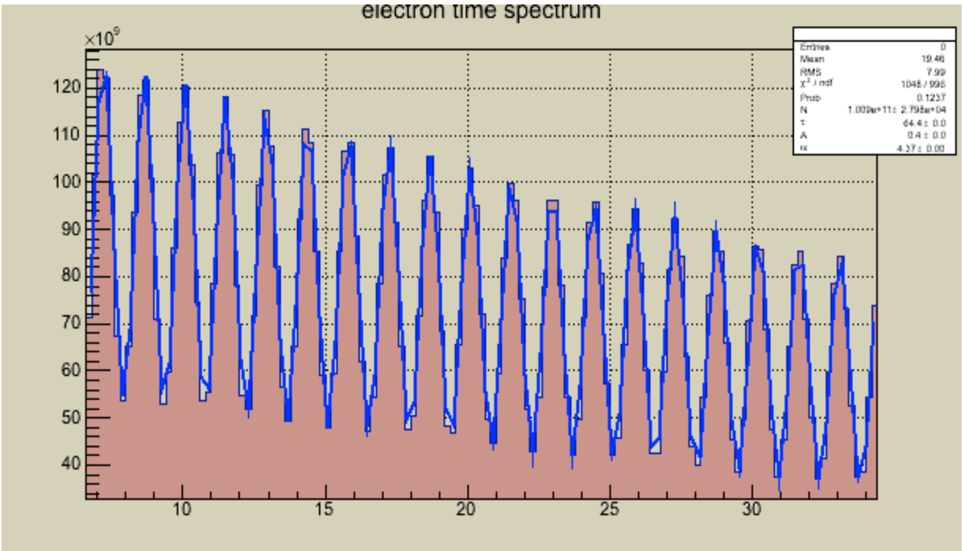
To verify the goodness of the implemented code and the guesses over the fit function and the generating function, we start setting $A = c_1$



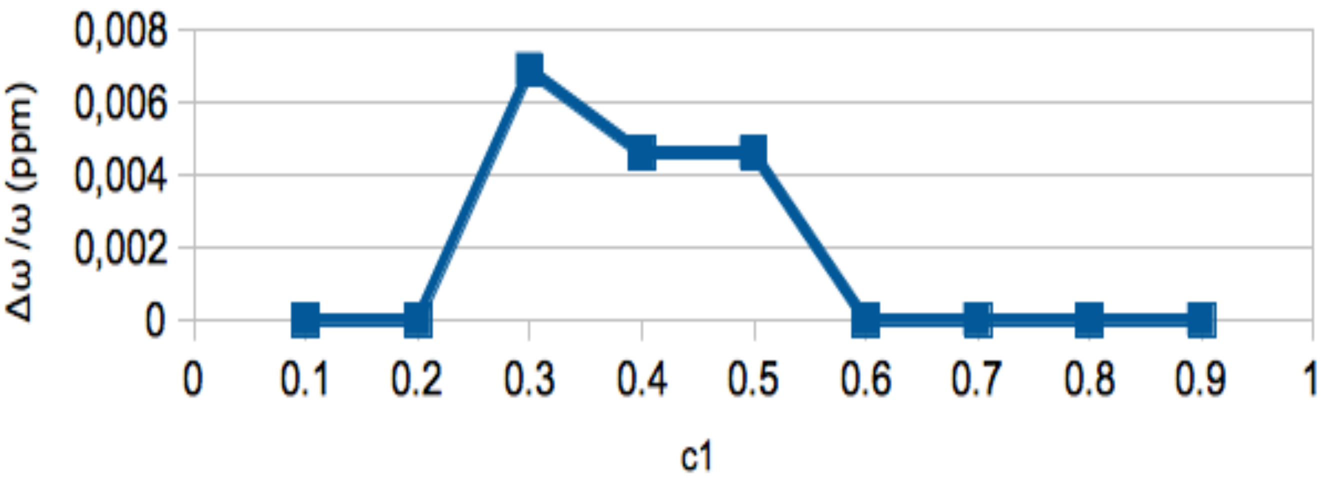




$c_1 = 0.4$

$c_2 = 0$



# ROOT simulation-III

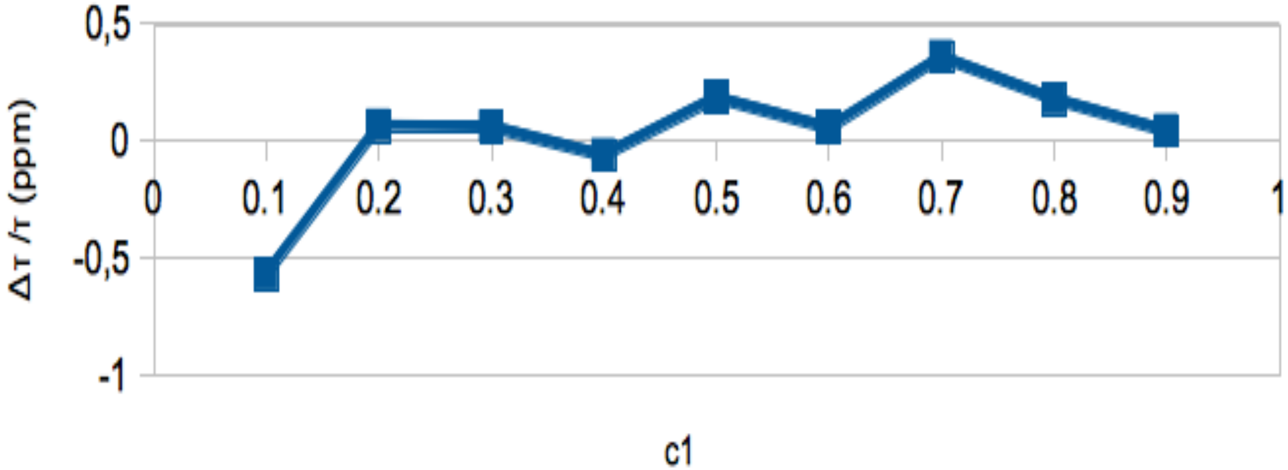



$0.1 \leq c_1 \leq 0.9$

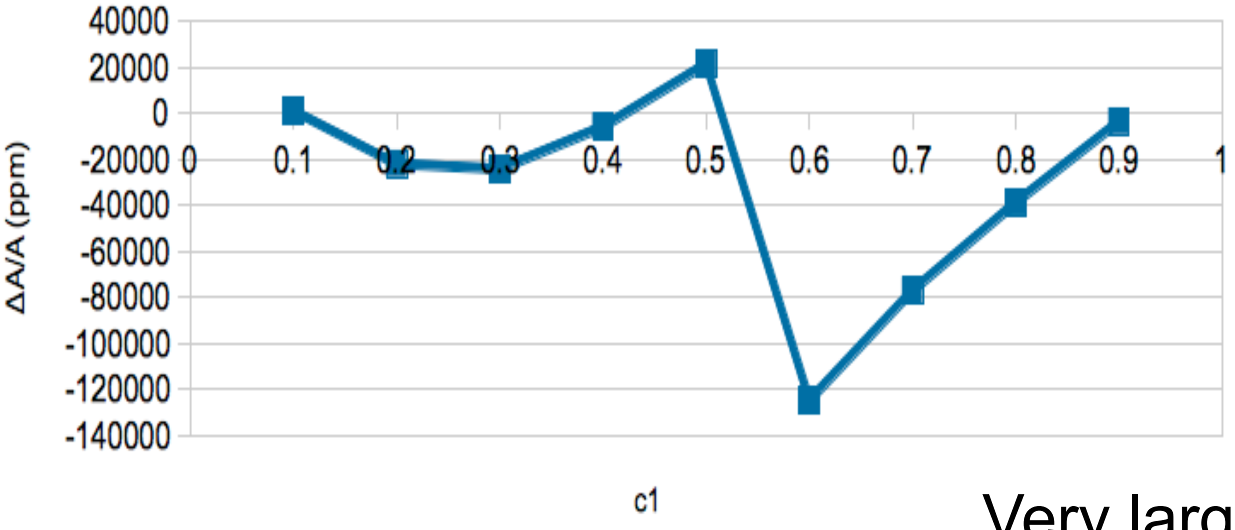
$c_2 = 0$

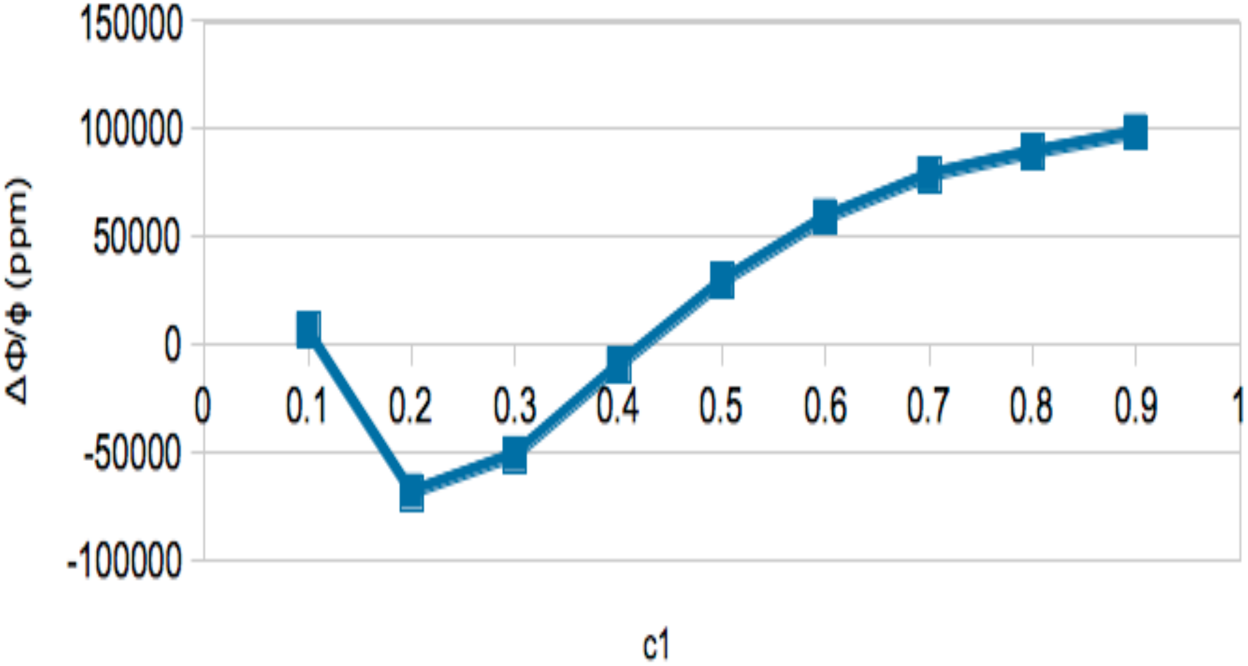
Maximum variation $10^{-3}$ ppm

Maximum variation 1 ppm



# ROOT simulation-IV




Very large values for ΔA/A and ΔΦ/Φ

There is a problem!

# *ROOT simulation-V*

Is the code or the fit function choice the problem?

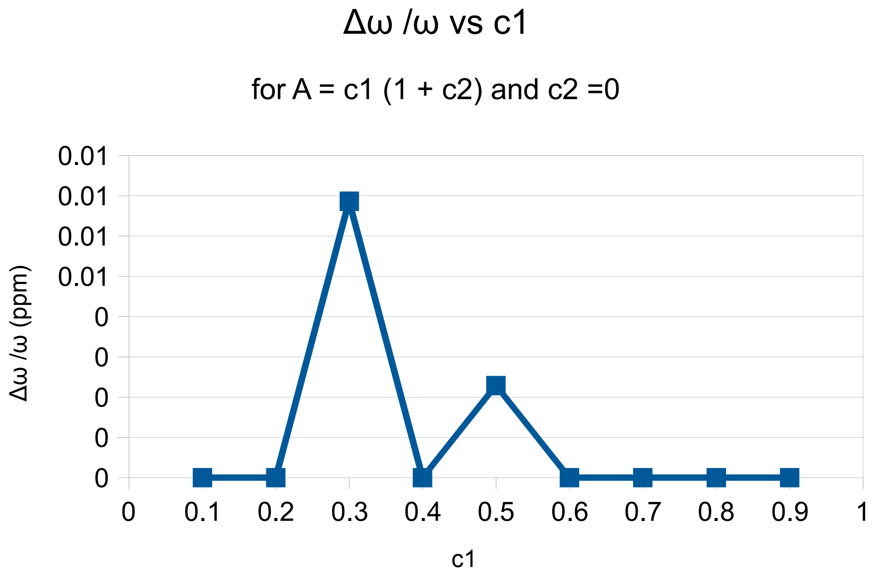
To understand this, I have removed parameters in the fit function one at a time and found out it was the phase

Using a fit function and a generating function without the phase also the asimmetry variations are negligible

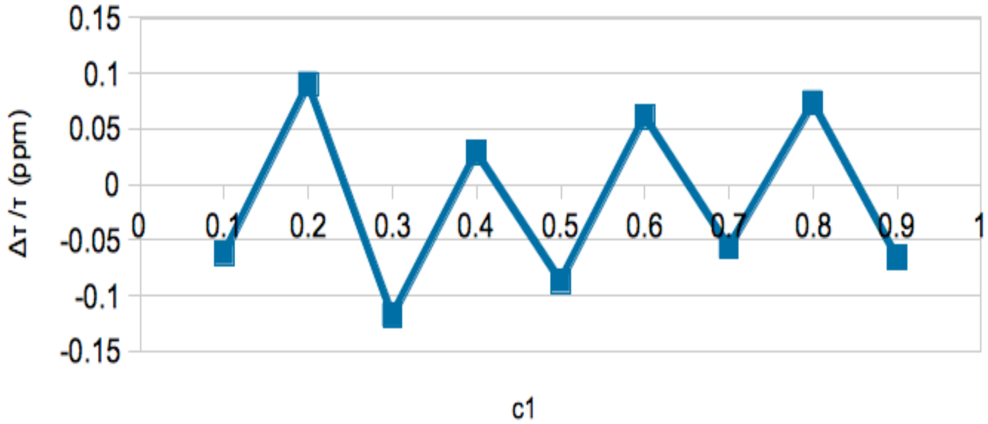
↓

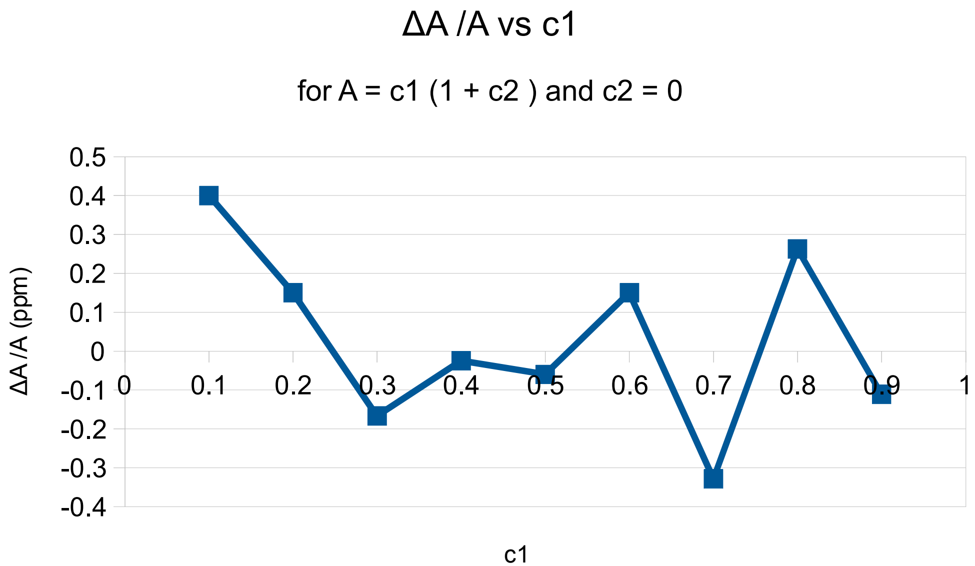
The problem is the phase!

# *ROOT simulation-VI*




## Getting rid of the phase



# *Conclusions-I*

- We found that we could not perform the fit with Φ as a free parameter
- When we add a linear offset to the generated A, we get expected offsets in the measured value of A and we found that this is so
- The extracted value of omega seems to be insensitive to a linear offset in A

# *Straw Chambers*

Straw chambers are basically proportional chambers constructed with a single anode wire centered in an aluminized mylar tube forming the grounded cathode. The cathode is filled with gas at 1÷4 atmospheres.

This mylar tube is serveral mils thick wrapped with two strips glued toghether in a barber pole strip fashion

Those we used are 1m longe and 5.1 mm wide and filled with Ar-CO2 .

# *Straw Chambers-I*

The advantages of a straw chambers when compared to the similar multiwire chambers are:

- The straw detector is inexpensive, robust and relatively simple to construct

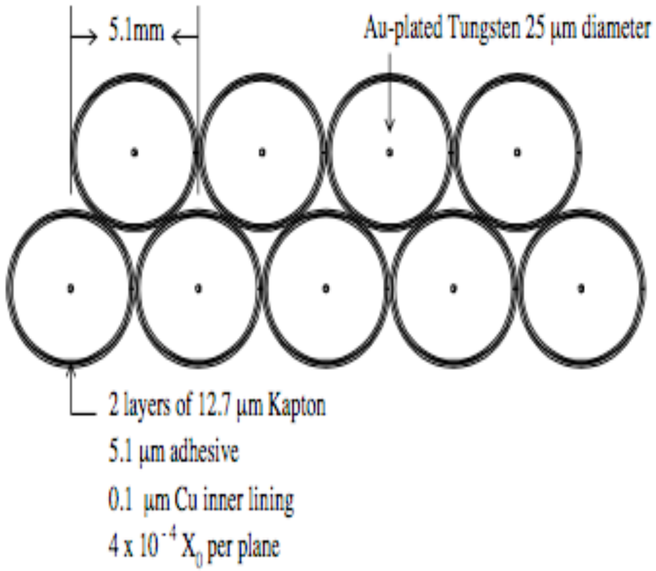
- The damage and possible down time caused by wire breakage is minimal since the broken wire is isolated in the tube cell and will only need to be disconnected

- The effects of signal cross talk are minimized as the straw cathode provides a complete ground shield between nearby wires

- The problems of electrostatic alignment distortions are minimal when the anode is kept reasonably centered in the straw.

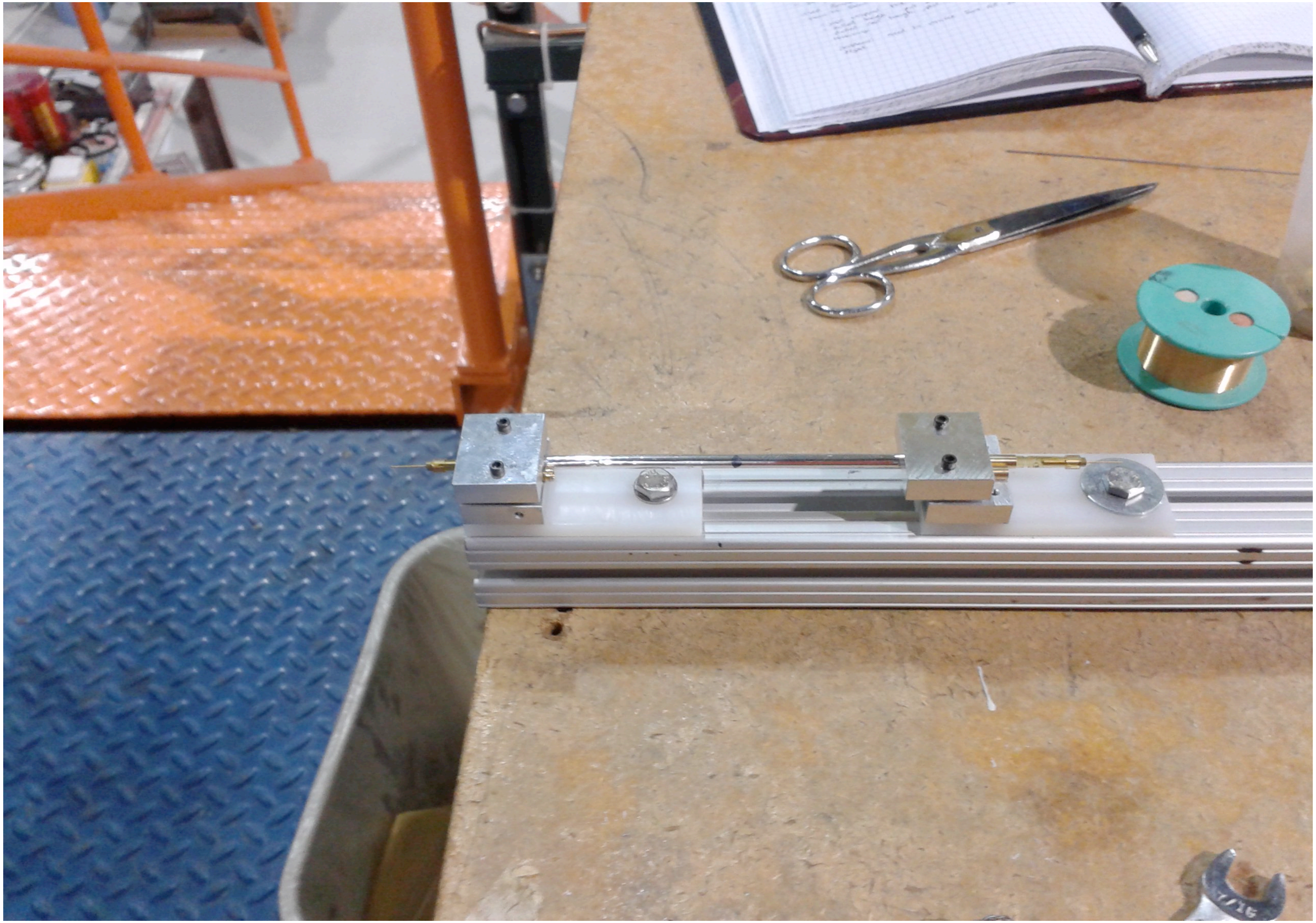
# *Straw Chambers-II*

There are three main components to performing the g-2 measurement: measurement of the precession frequency, measurement of the magnetic field and measurement of the spacial distribution of muons within the field.
The muon spacial distribution can be mapped by measuring the position trajectories and extrapolating back to the point where the trajectory is tangent to the muon orbit. This is do using straw detectors.

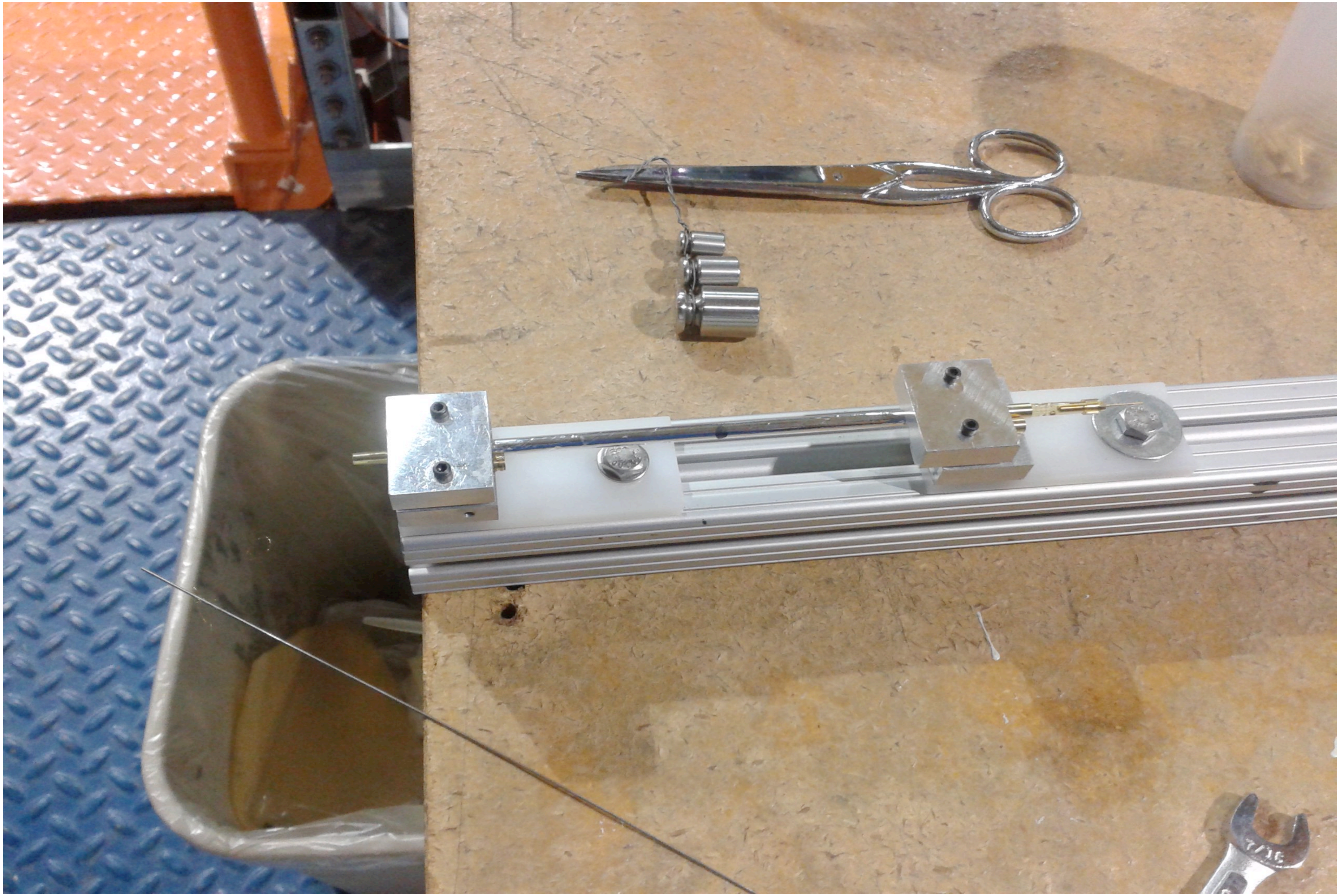



The prototype system consist of 20 straws arranged ad in figure, split equally between vertical and horizontal configuration.
The decay point of the muon is required to be knew within 3 mm in both the radial and vertical position, this led to a requirement of better than 100 μm position resolution per straw.

# Straw Prototype Construction



# *Straw Prototype Construction*



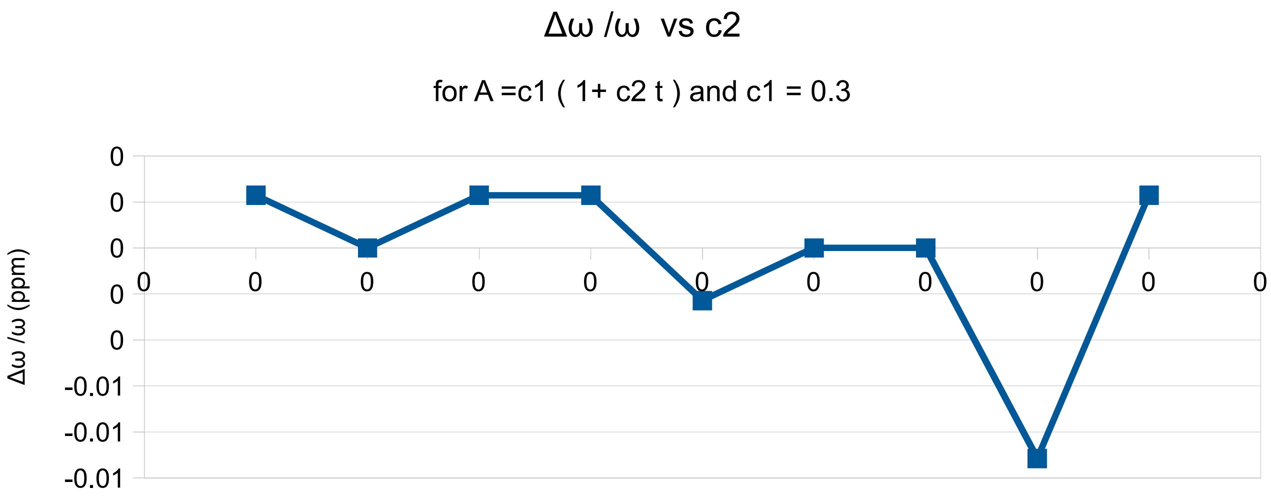
# ROOT simulation-VII

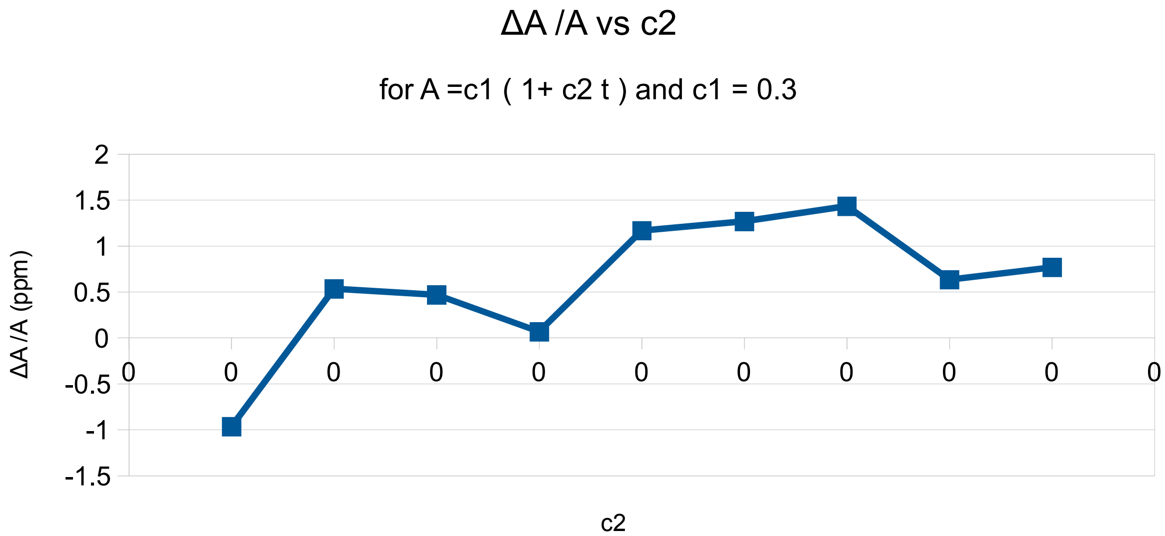
Step 2: $c_2 \neq 0$

| $c_1$ | $c_2$ | $\tau$ | A | $\omega$ | $X^2$/dof |
|---|---|---|---|---|---|
| 0.3 | 2.000E-009 | 64.3999944 | 0.2999999 | 4.37 | 0.95 |
| | 2.00E-008 | 64.3999952 | 0.30000036 | 4.36999998 | 0.96746386 |
| | 2.00E-007 | 64.3999951 | 0.30000268 | 4.36999999 | 1.09702811 |
| | 2.00E-006 | 64.3999629 | 0.30002255 | 4.37000001 | 8.63818273 |
| | 2.00E-005 | 64.3999304 | 0.30022562 | 4.37000002 | 739.460843 |

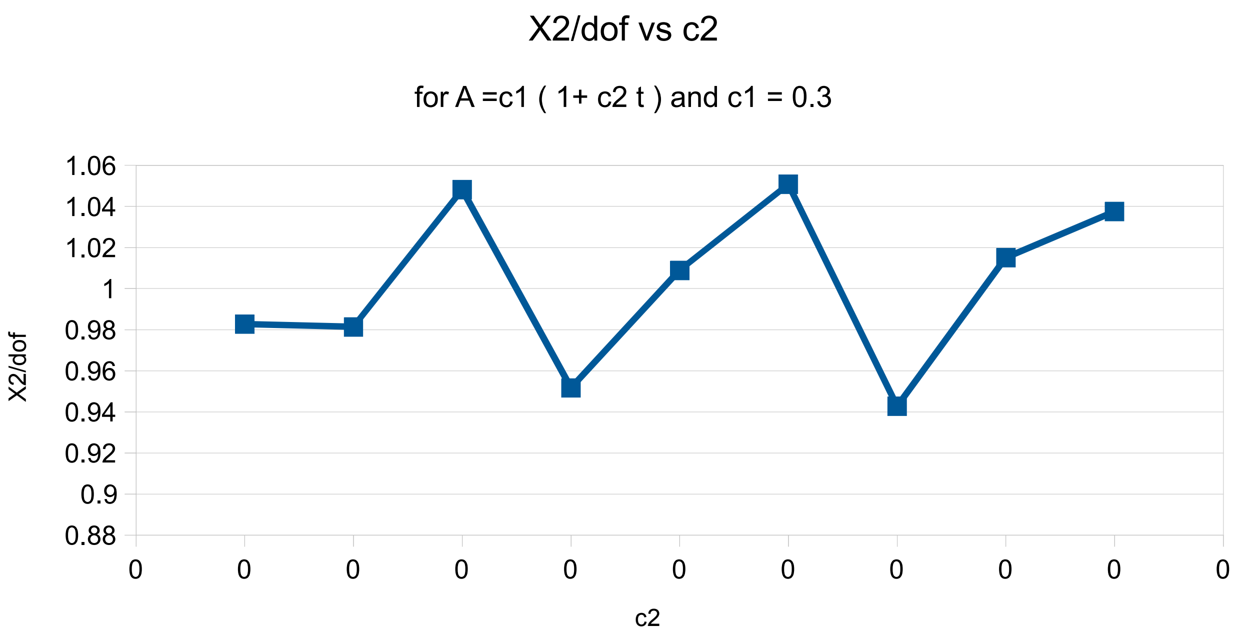
# ROOT simulation-VIII

$c_1 = 0.3$ $0.1 \cdot 10^{-9} \leq c_2 \leq 0.9 \cdot 10^{-9}$

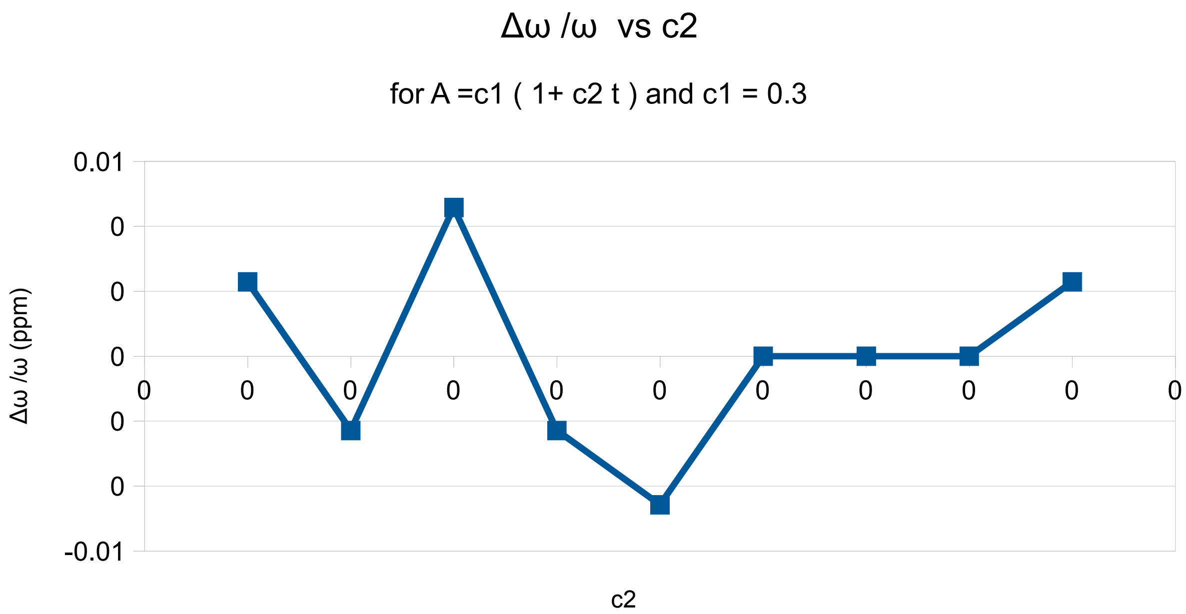


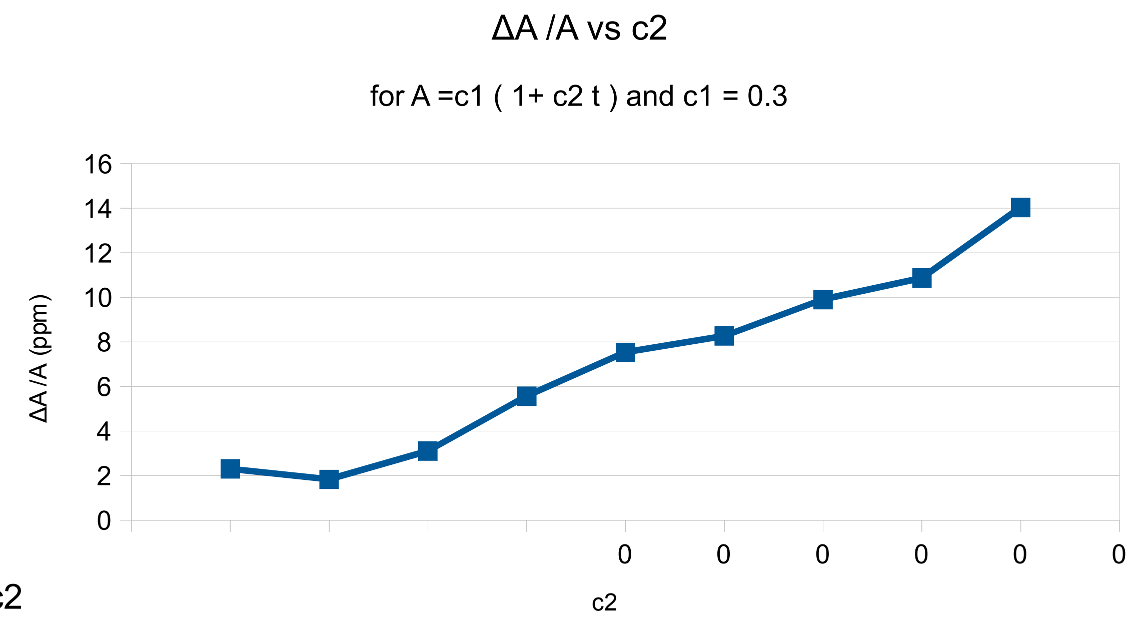
# ROOT simulation-IX

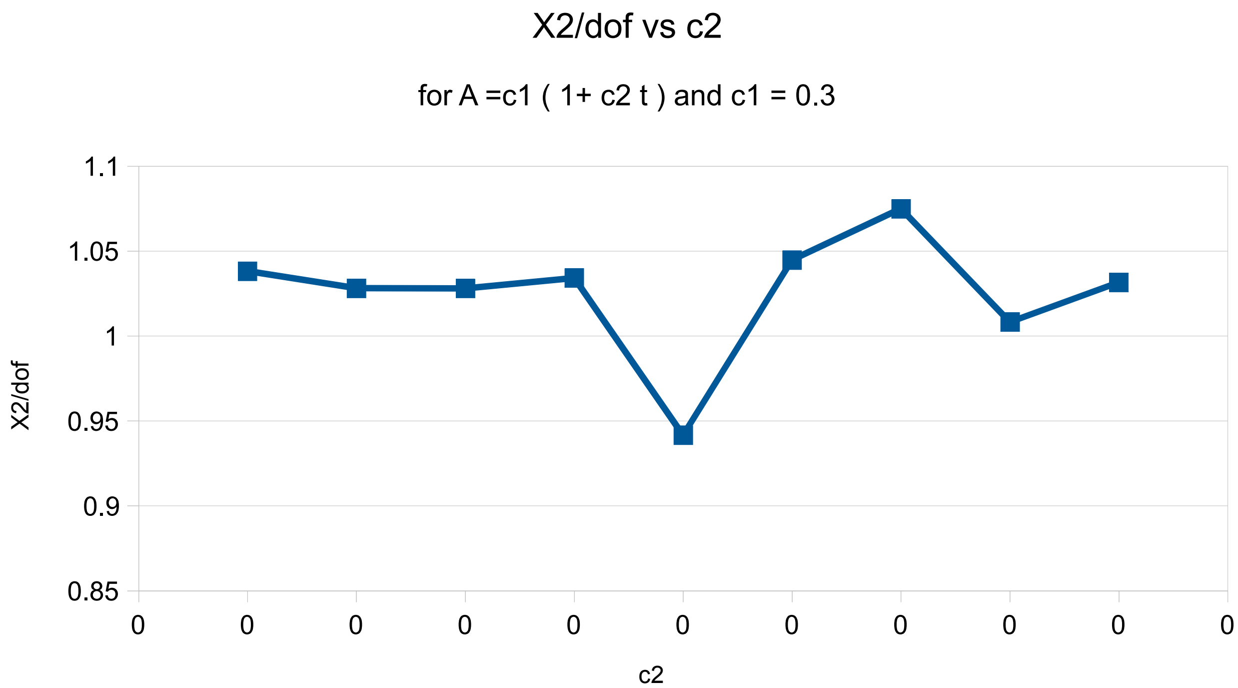



$c_1 = 0.3$ $\quad 0.1\cdot10^{-8} \leq c_2 \leq 0.9\cdot10^{-8}$

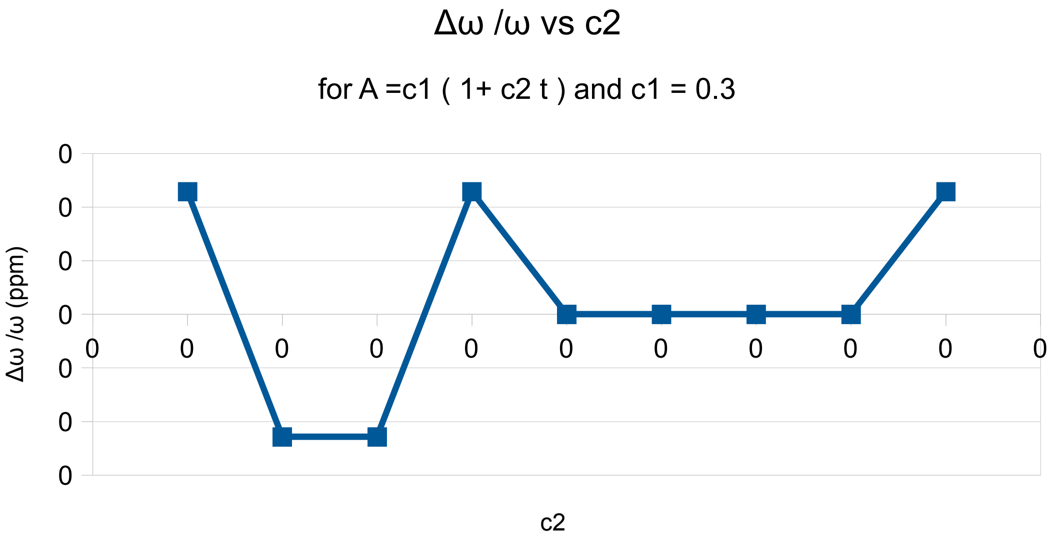


# ROOT simulation-X



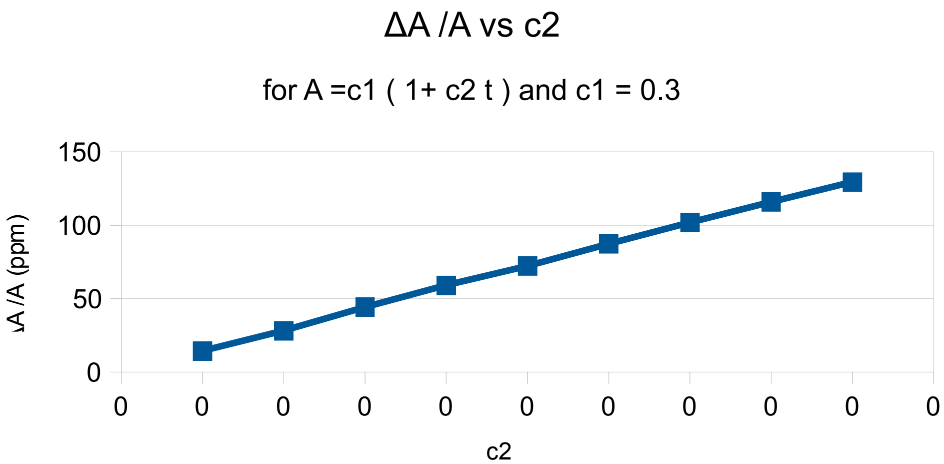



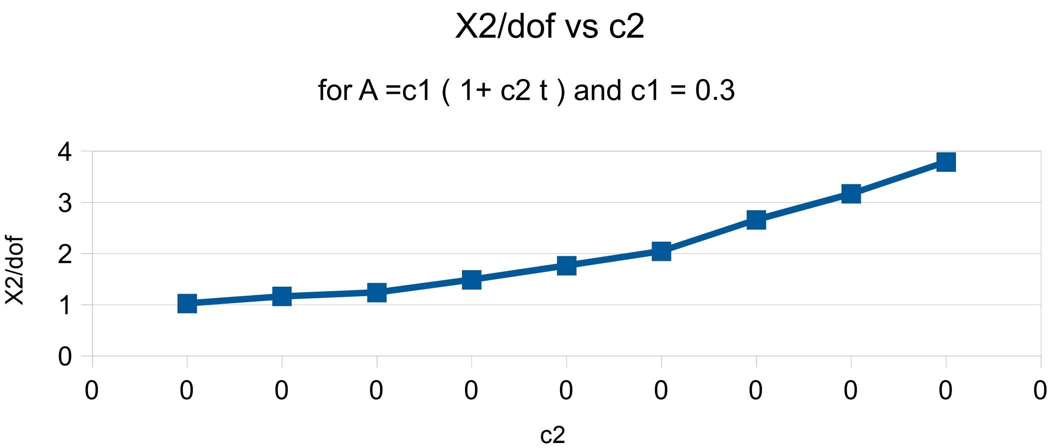
# ROOT simulation-XI



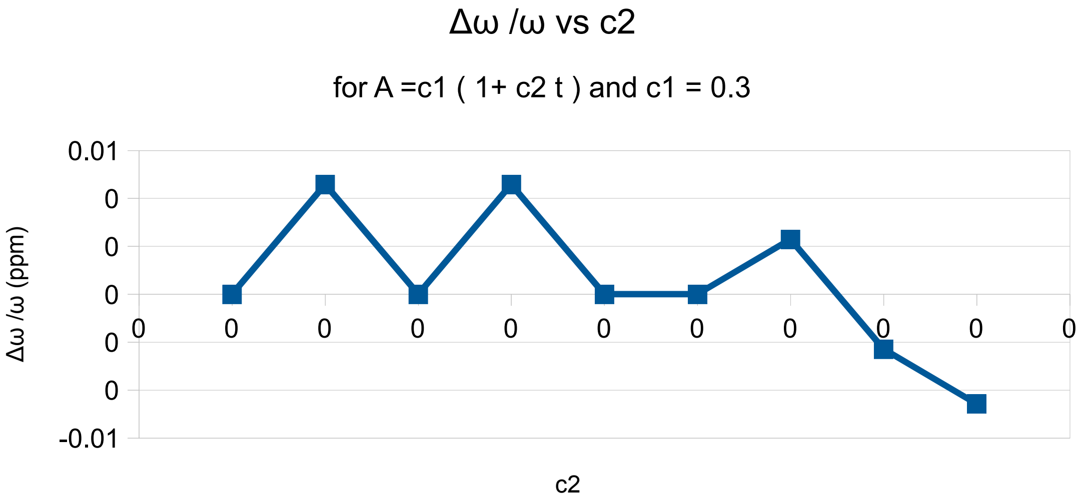

$c_1 = 0.3$

$0.1 \cdot 10^{-7} \leq c_2 \leq 0.9 \cdot 10^{-7}$



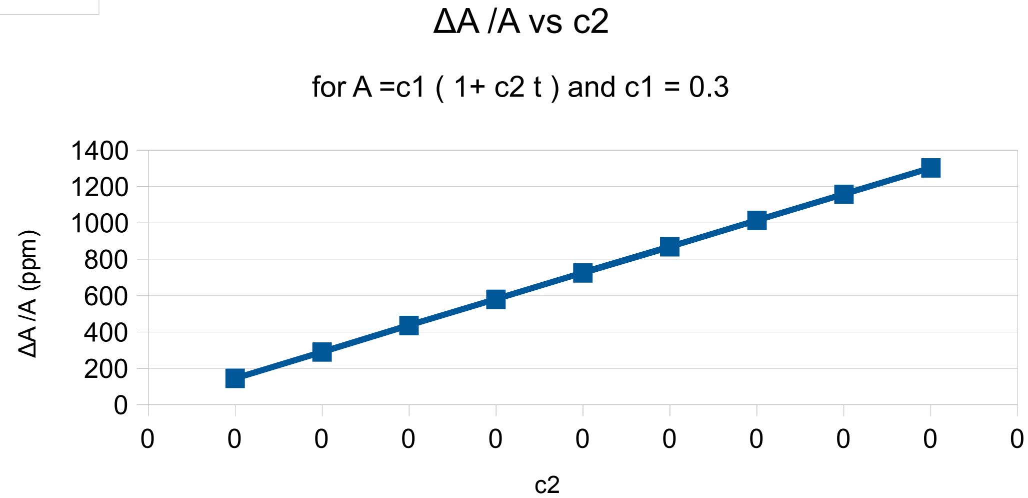



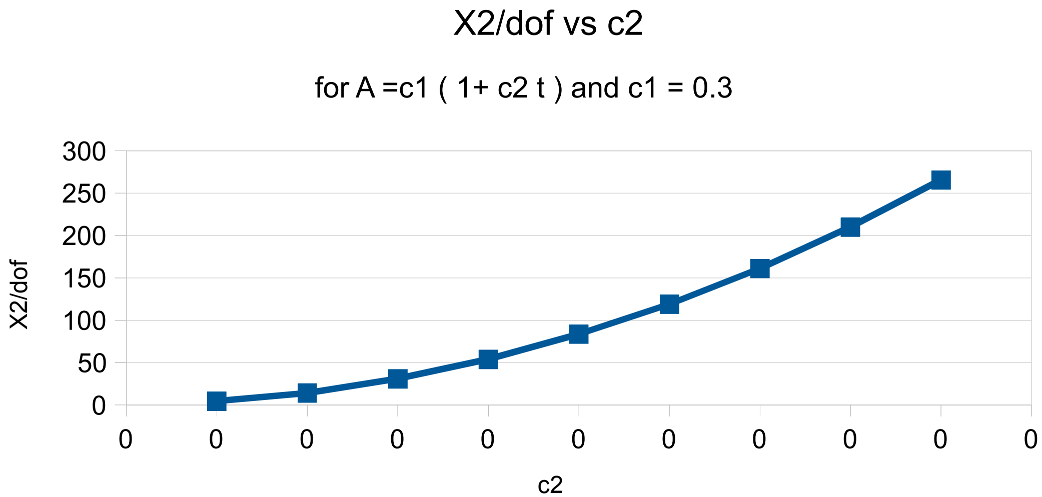
# ROOT simulation-XII



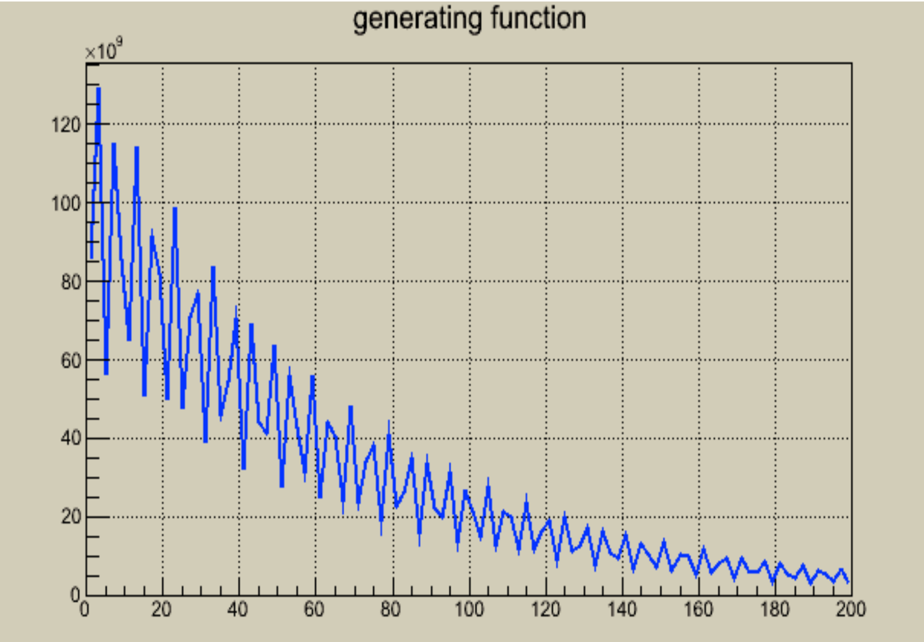

$c_1 = 0.3$

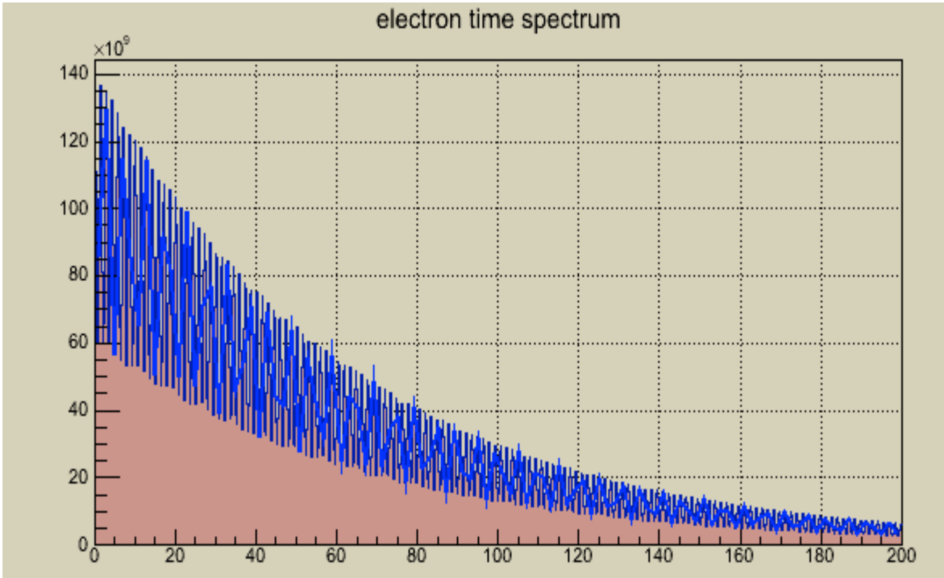
$0.1 \cdot 10^{-6} \leq c_2 \leq 0.9 \cdot 10^{-6}$

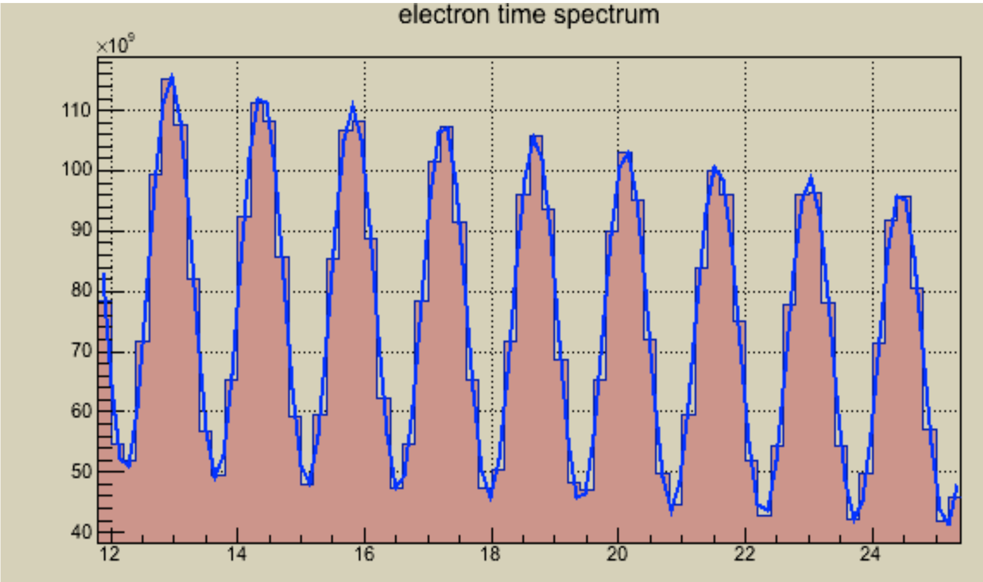


# ROOT simulation-XIII



# Conclusions-I

- We found that we could not perform the fit with Φ as a free parameter
- When we add a linear offset to the generated A, we get expected offsets in the measured value of A and we found that this is so
- The extracted value of omega seems to be insensitive to a linear offset in A
- The $\chi^2$ of the fit gets very bad very quickly (c2 > 5 x 10^-7)
  We are not sure how to translate this into a systematic error on omega.
  Might be more of a hard specification.