Recent results of the muon g-2 experiment at BNL and status of the 2000 analysis

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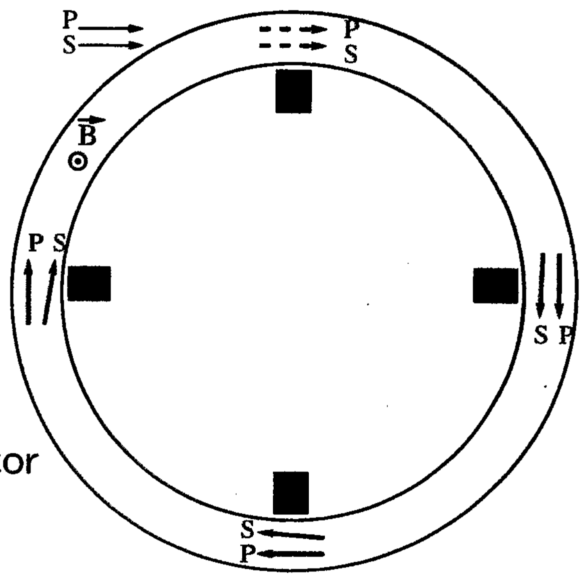
Outline

- Experimental Method
- Recall 1999 Analysis
- 2000 at a Glance
- 2001 at a Glance

Method

In the presence of the vertical field, **B**
for g=2

$$\omega_c = \frac{eB}{m_\mu c\gamma} = \frac{2\mu_B B}{\hbar\gamma} \qquad \omega_c = \omega_s$$



Due to anomaly on the magnetic moment,
Spin precess faster than the momentum

$$\omega_s = \frac{eB}{m_\mu c\gamma}(1 + a_\mu\gamma)$$

Spin precession relative to momentum vector

$$\omega_a = \omega_s - \omega_c = \frac{e}{m_\mu c} a_\mu B$$

Plus weak focusing electric field $\vec{E}$:

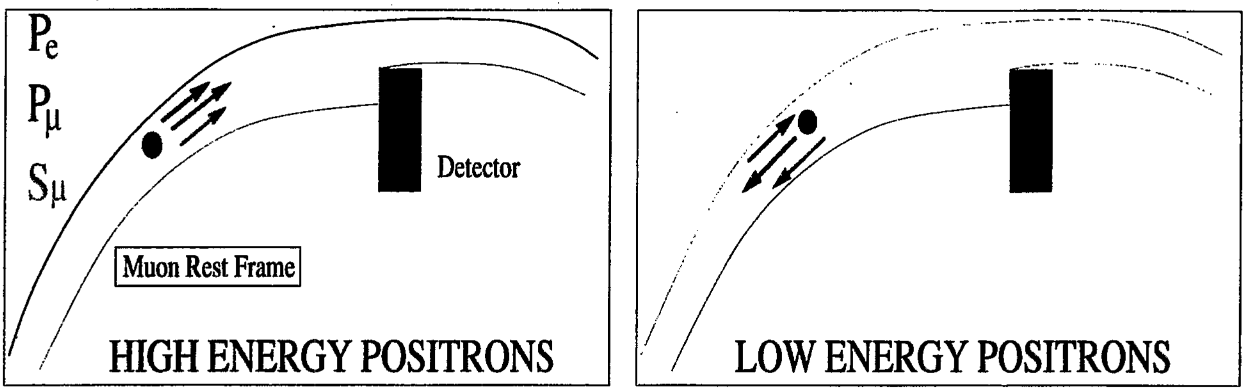
$$\vec{\omega}_a = \frac{d\vec{\vartheta}_a}{dt} = -\frac{e}{m_\mu c}\left[a_\mu \vec{B} - (a_\mu - \frac{1}{\gamma^2 - 1})\vec{\beta} \times \vec{E}\right]$$

Choose $\gamma = 29.3$, so the contribution of $\vec{\beta} \times \vec{E}$ is removed.
$\Rightarrow P_\mu = 3.1\text{GeV}$

$\Rightarrow$ Measure $|\vec{B}|$ and ω_a and calculate a_μ !

Measurement of ω_a

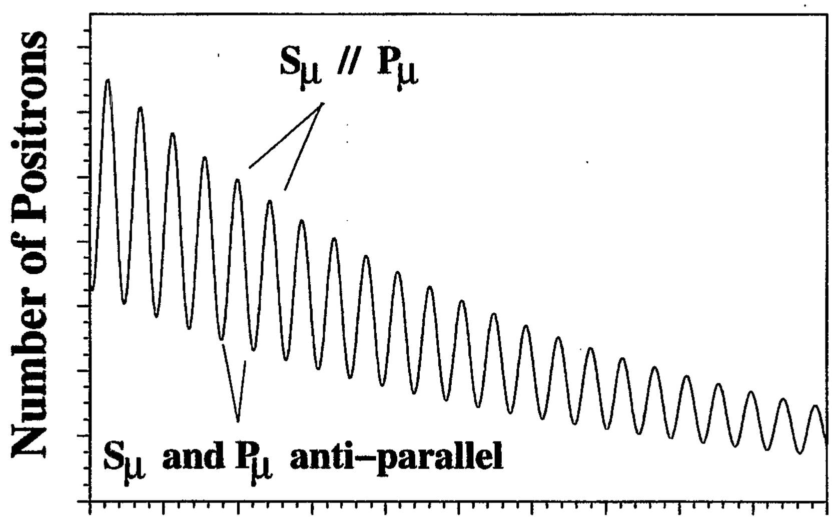
Parity violating 3 body decay : $\mu^+ \to e^+ \ \nu_e \ \bar{\nu}_\mu$



S_μ is precessing in the field $\to$ e$^+$ counting rate is modulated with the μ spin precession

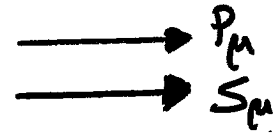
Decay Positron Spectrum :

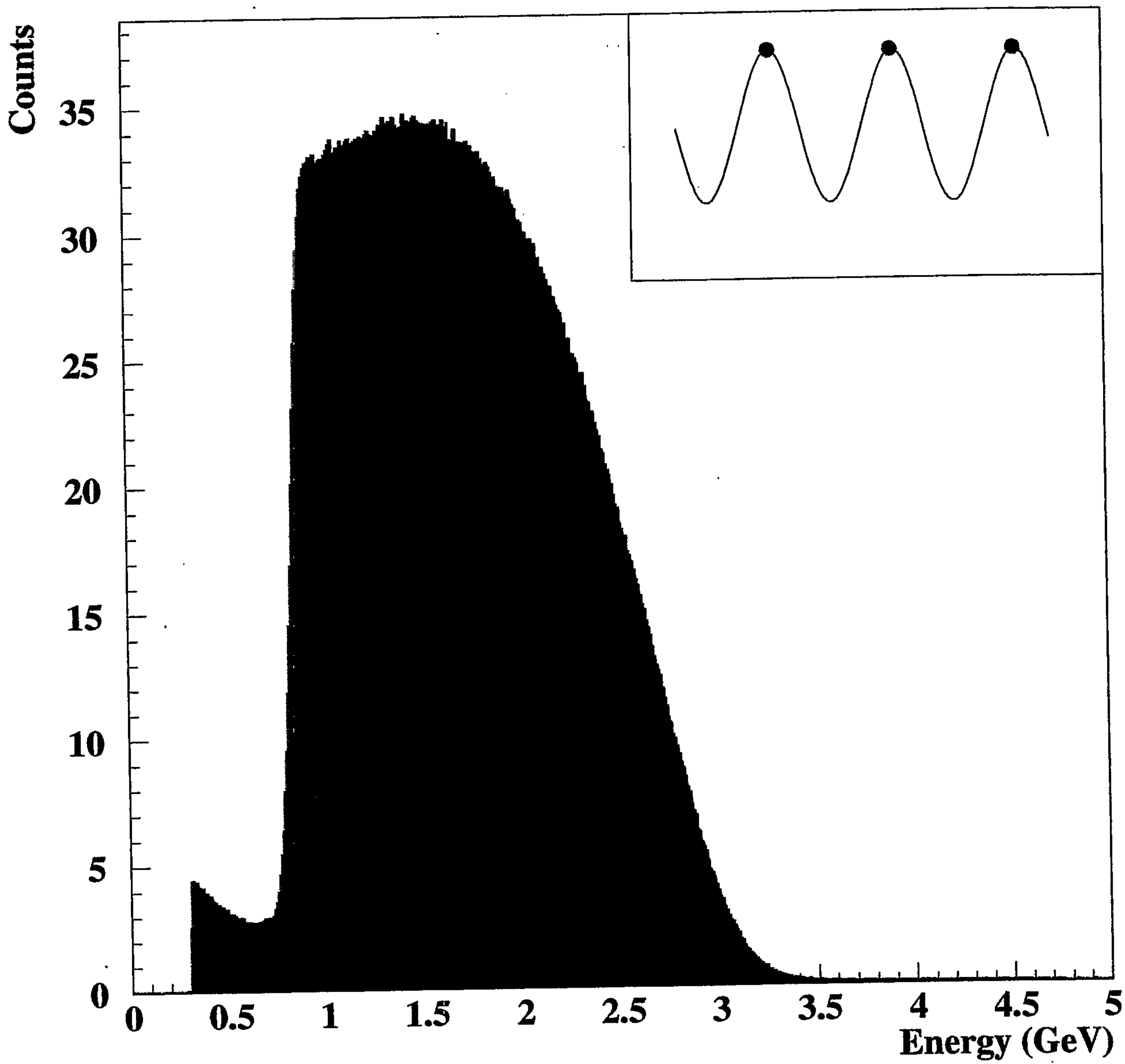
$$N(t) = N_0 e^{-t/\tau}(1 + A cos[\omega_a t + \phi])$$



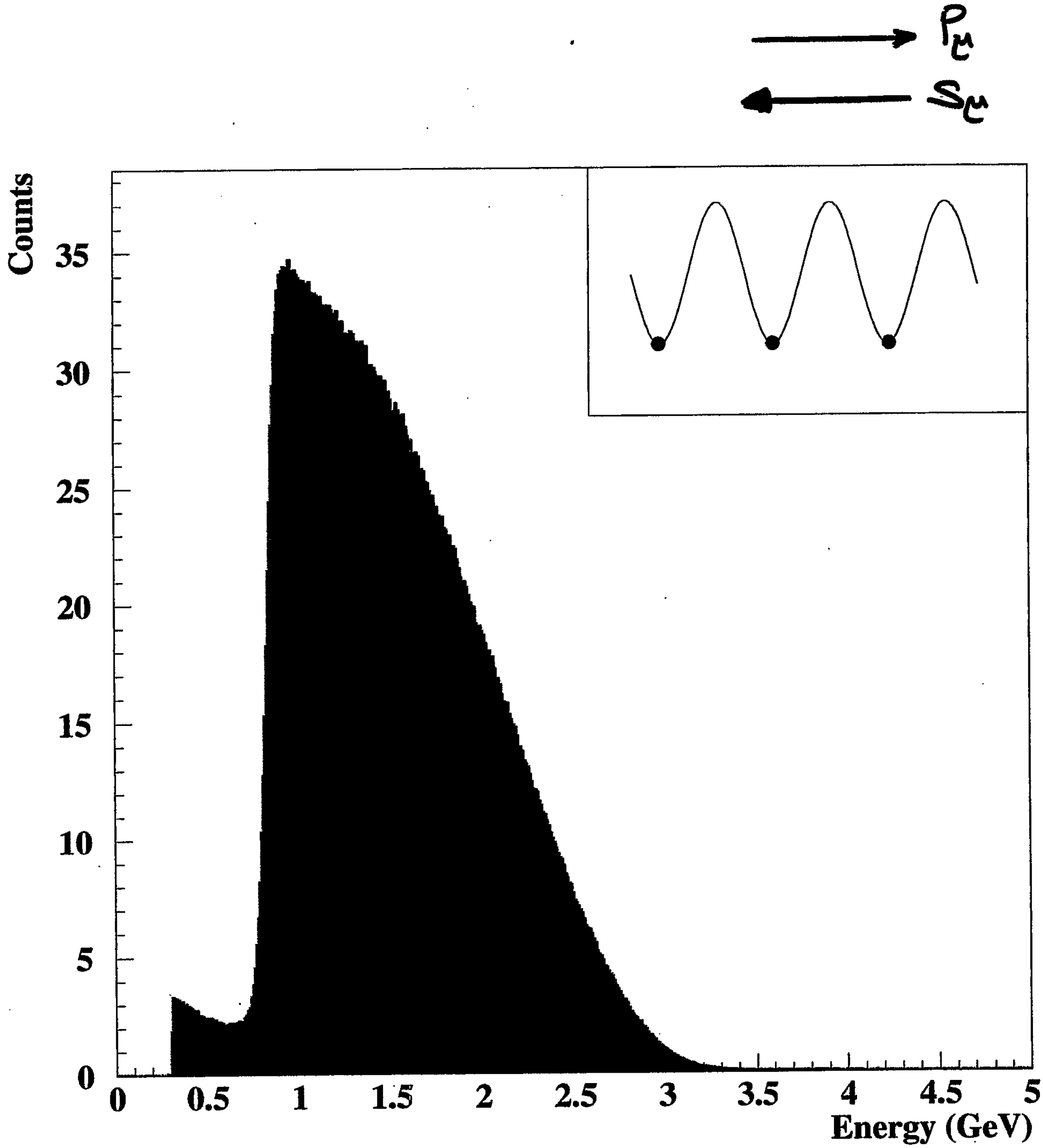
$$\frac{\Delta\omega_a}{\omega_a} = \frac{\sqrt{2}}{A\omega_a\gamma\tau\sqrt{N(E)}}$$

Energy Spectrum

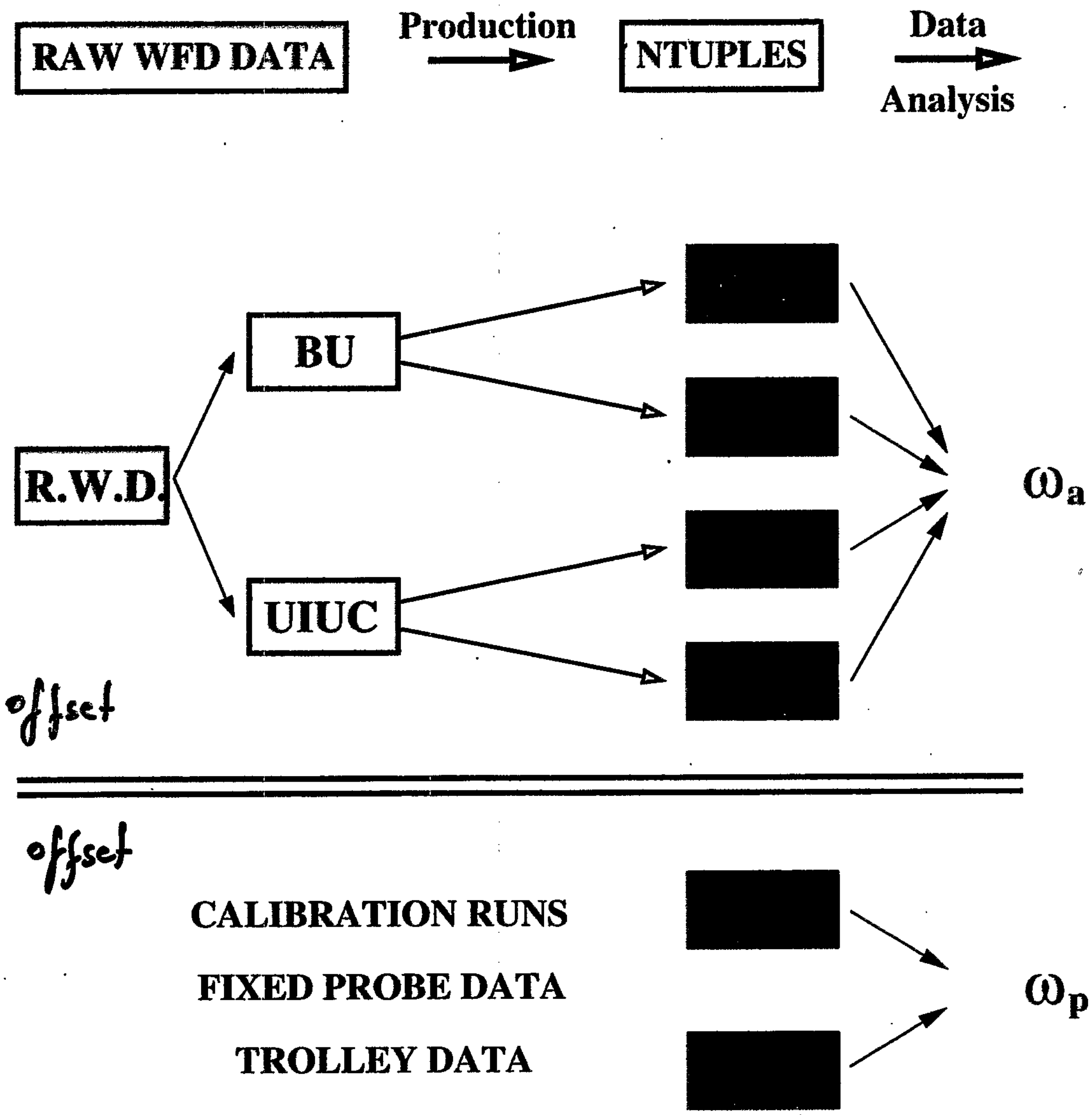




Energy Spectrum



Analysis



$$a_\mu = \frac{\frac{\omega_a}{\omega_p}}{\lambda - \frac{\omega_a}{\omega_p}} \qquad \lambda = \frac{\mu_\mu}{\mu_p} = 3.183\,345\,39(10)^*$$

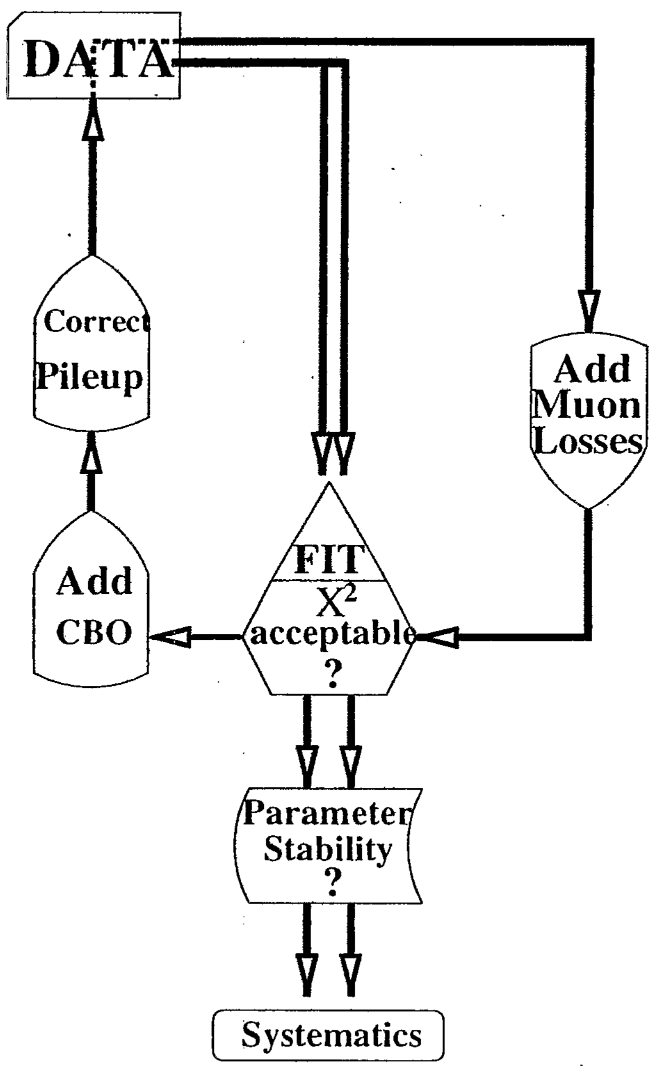
* D. E Groom et al., Review of Particle Physics, Eur. Phys. J. C**15**, 1 (2000)

BNL based ω_a Analysis Strategy

1. Observe the expected effects in the DATA

2. Include the proper functional to describe the effects (if possible)

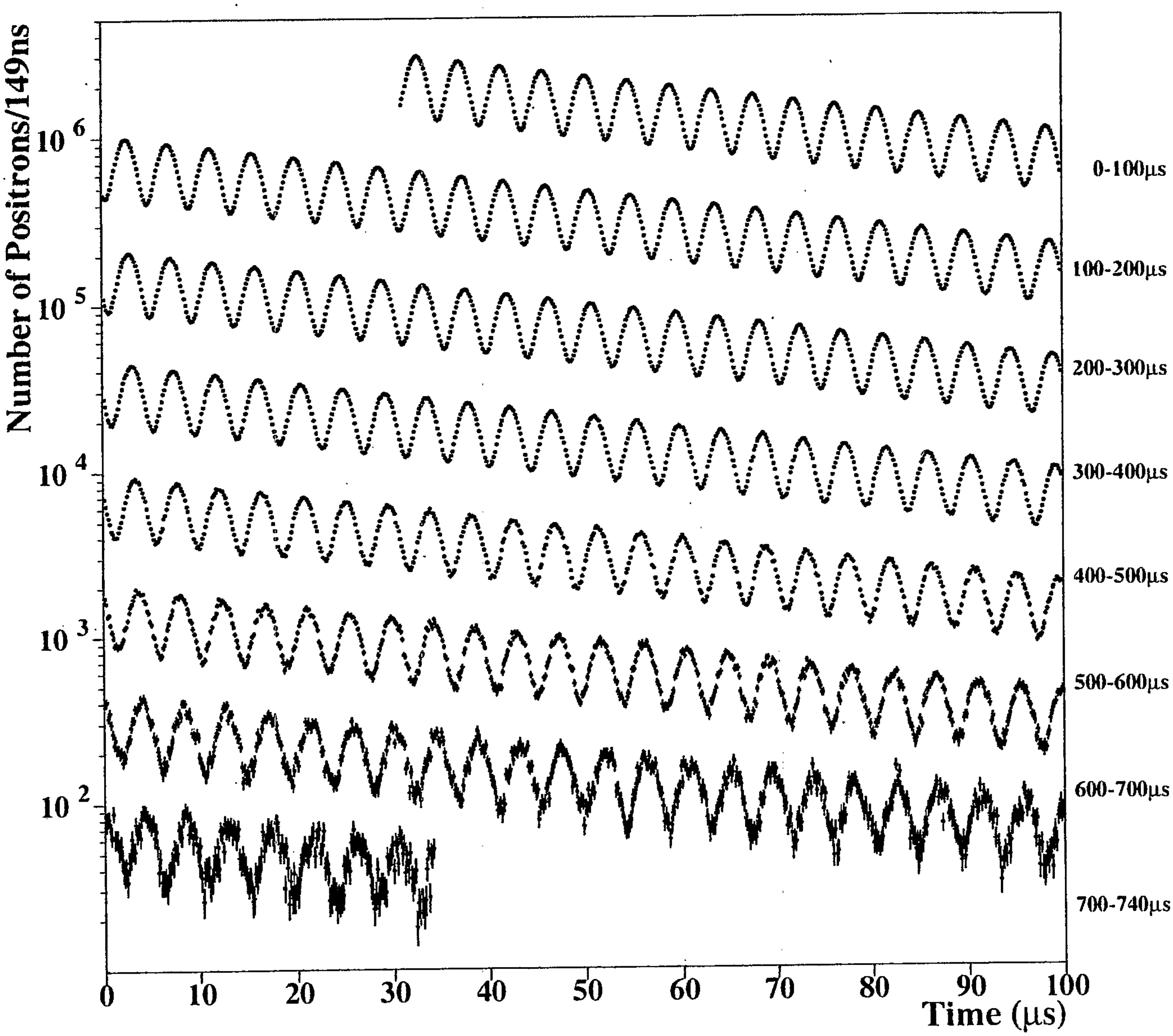
3. Try to eliminate it by removing it from the DATA



DATA Volume!

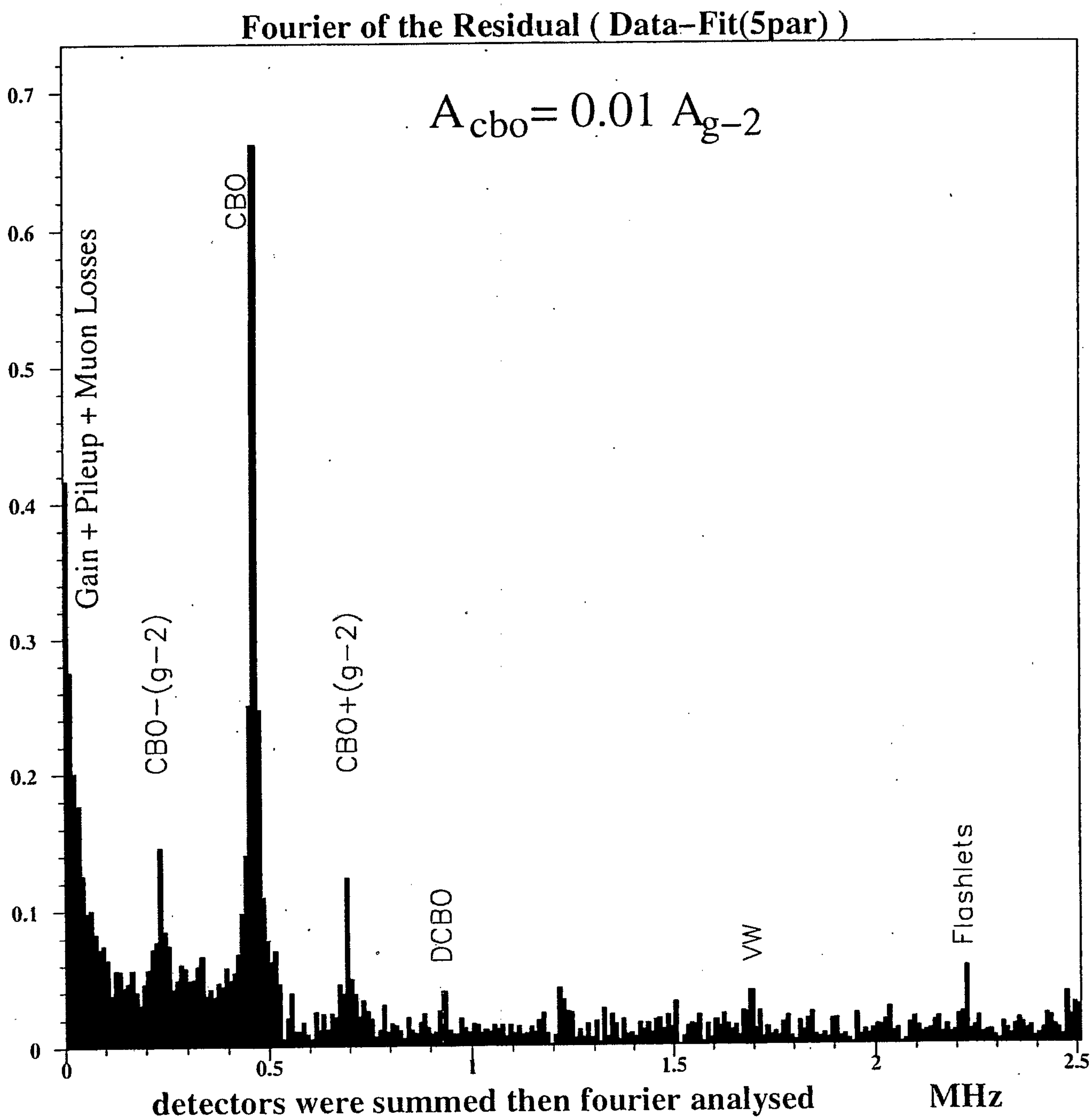
1999 Data

1B e^+

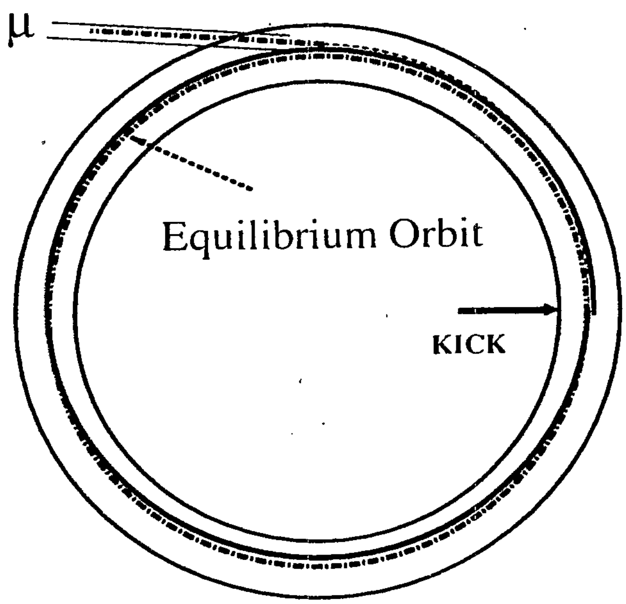


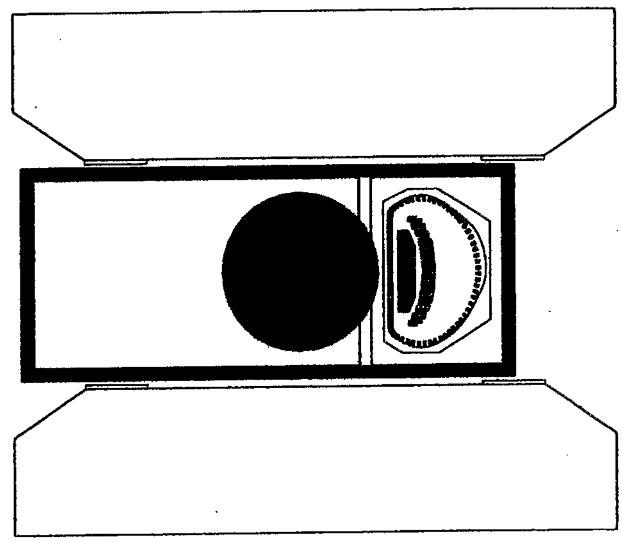
$T_{a_\mu} = 4.36\ \mu s \qquad \tau_\mu = 64.4\ \mu s$

Fourier Analysis

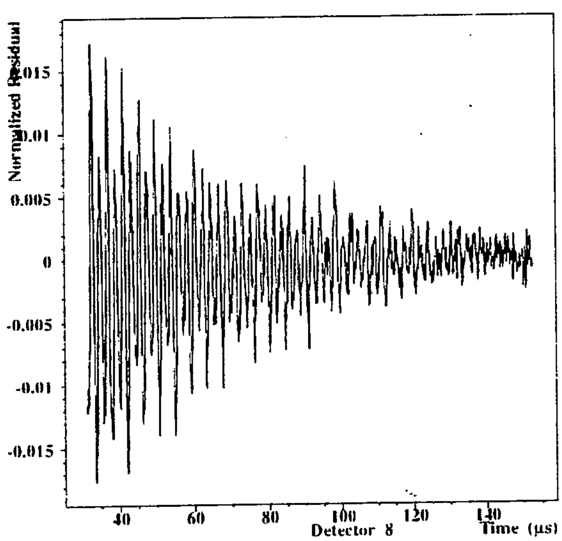


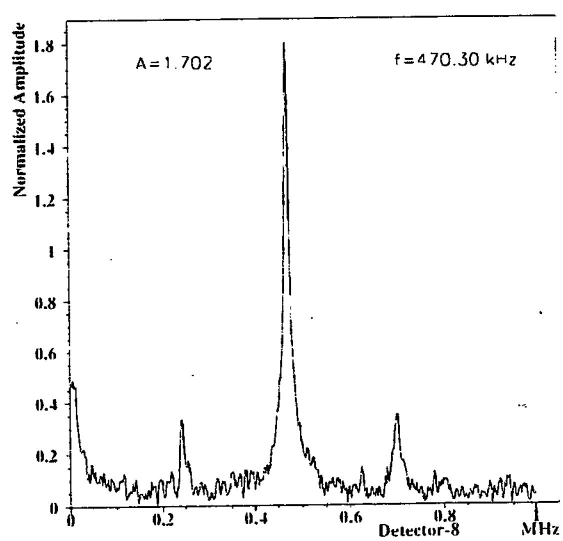
CBO(Coherent Betatron Oscillations)





Look at the residuals (DATA - 5 Parameter Fit)
Fourier Analysis of this residual → CBO





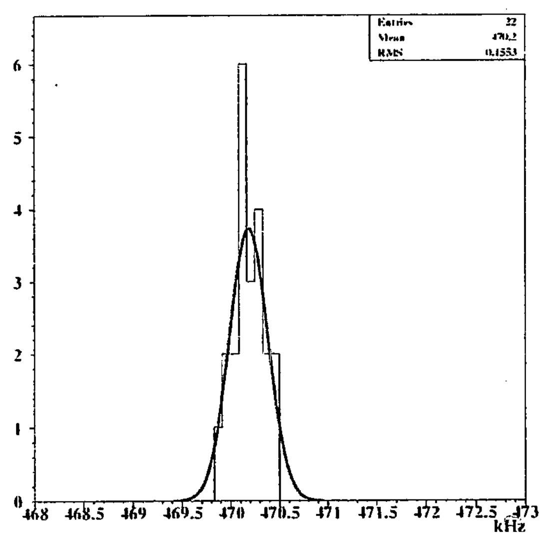
CBO

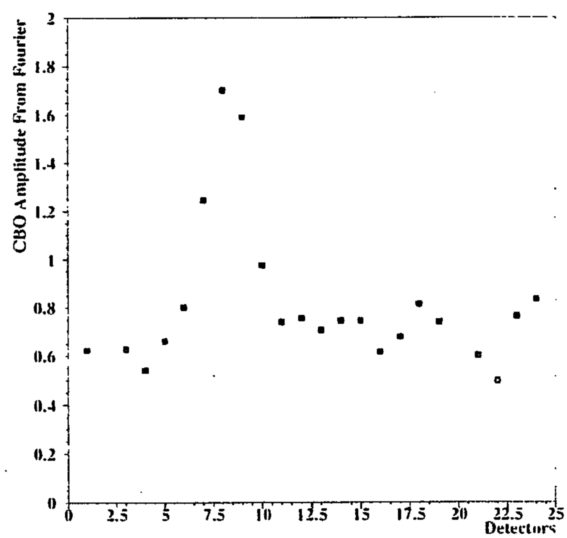
Count rate in the detectors are modulated by CBO oscillations,

$$F_{cbo}(t) \;=\; 1 + A_{cbo}\, e^{-(t/\tau_{cbo})^2}\, cos[2\pi f_{cbo} t + \phi_{cbo}]$$

A_{CBO}	:	The amplitude of CBO,
τ_{CBO}	:	The CBO lifetime,
f_{CBO}	:	470.2 kHz (fixed),
ϕ_{CBO}	:	CBO phase.

The strength depends on the acceptance of the detectors





CBO phase is different for each detector (0-2π)
The effect was reduced by 3.6 times if detectors summed up !
Systematic due to functional form of CBO 0.05ppm

Pileup

1998 → 65M e^+ 1999 → 1.4B e^+ ($E \geq 1.8$GeV)

Increasing intensity → increasing pileup

Pileup e^+ carry wrong energy and phase information for g-2

2GeV

An early to late effect caused by the change on muon intensity (due to decay) and enhanced by the Fast Rotation Factor

It can be accounted for by adding the related terms to the fitting function

$$N_0 \, e^{-t/\tau}(1 \; + \; A \; cos(w_a + \phi)) \times$$
$$[n_p \; e^{-t/\tau}(1 \; + \; A_p \; cos(w_a + \phi + \phi_{pu}))]$$

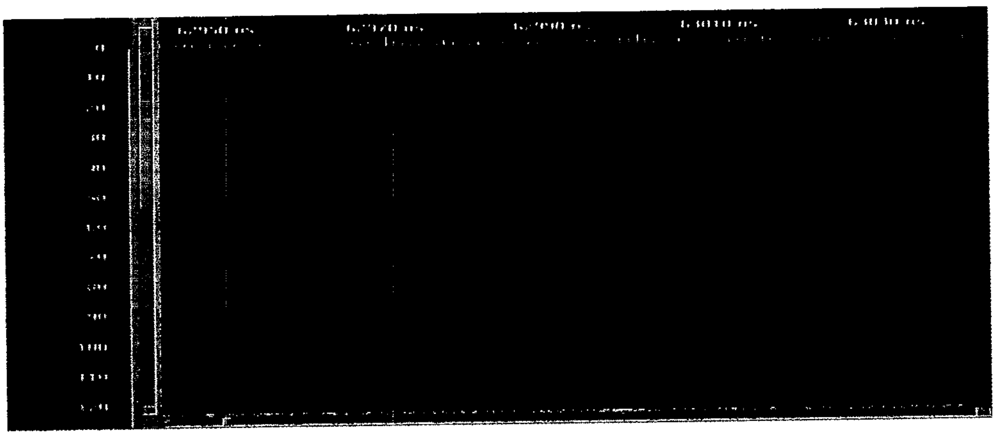
Factor two loss in the statistical error of w_a !

Therefore a different solution to the problem is neccessary

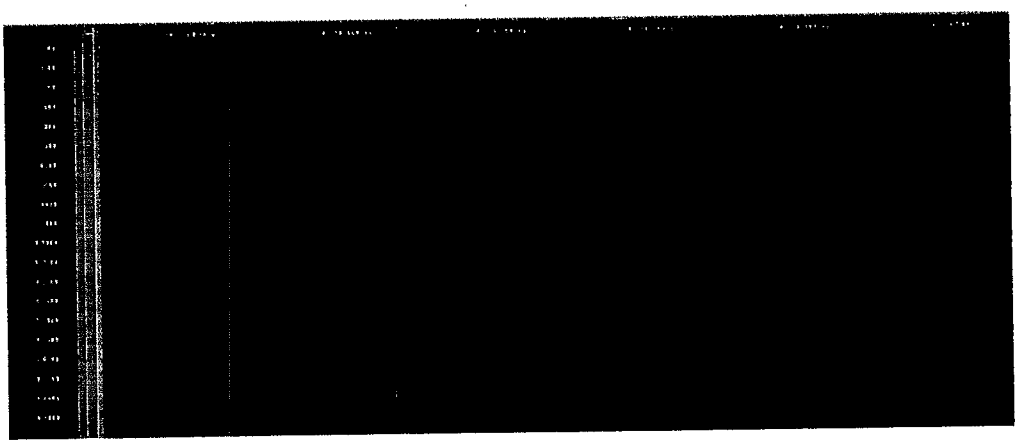
Pileup

Each positron pulse above 1GeV is digitized with a 400MHz WFD

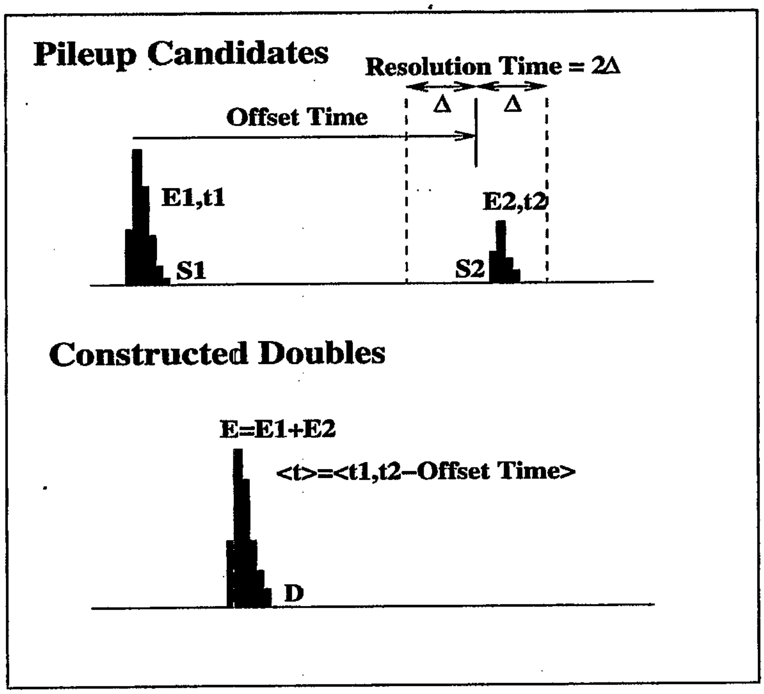
If the pulse height is above the threshold, start digitizing ("WFD Island" ≈ 80ns)



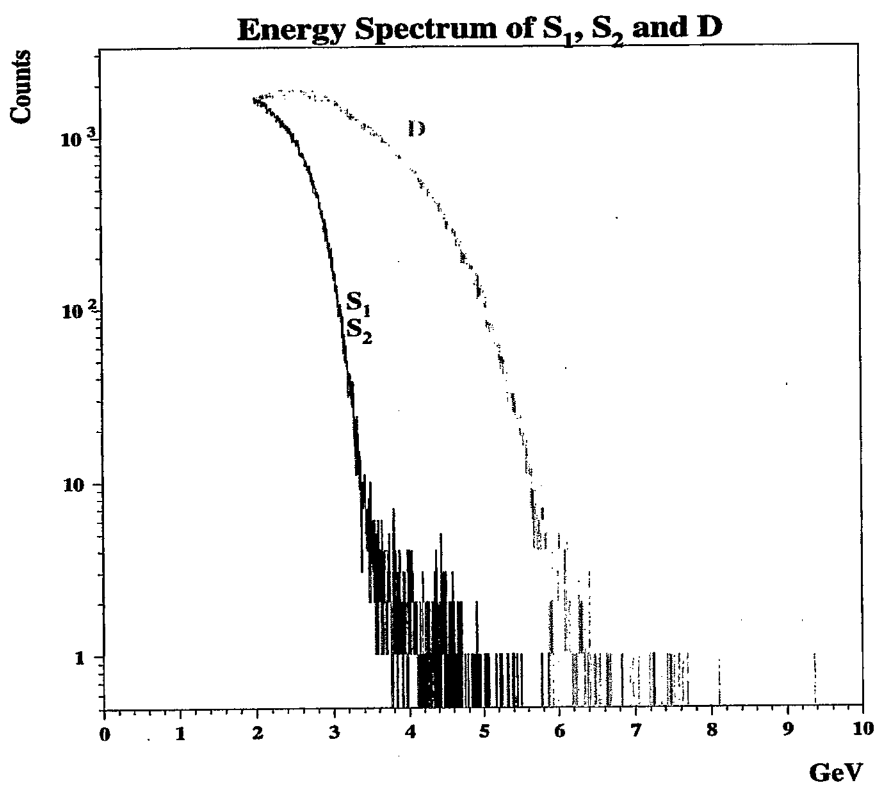
If there are pulses after the main triggering pulse on the same island (shadow pulses).



Pileup

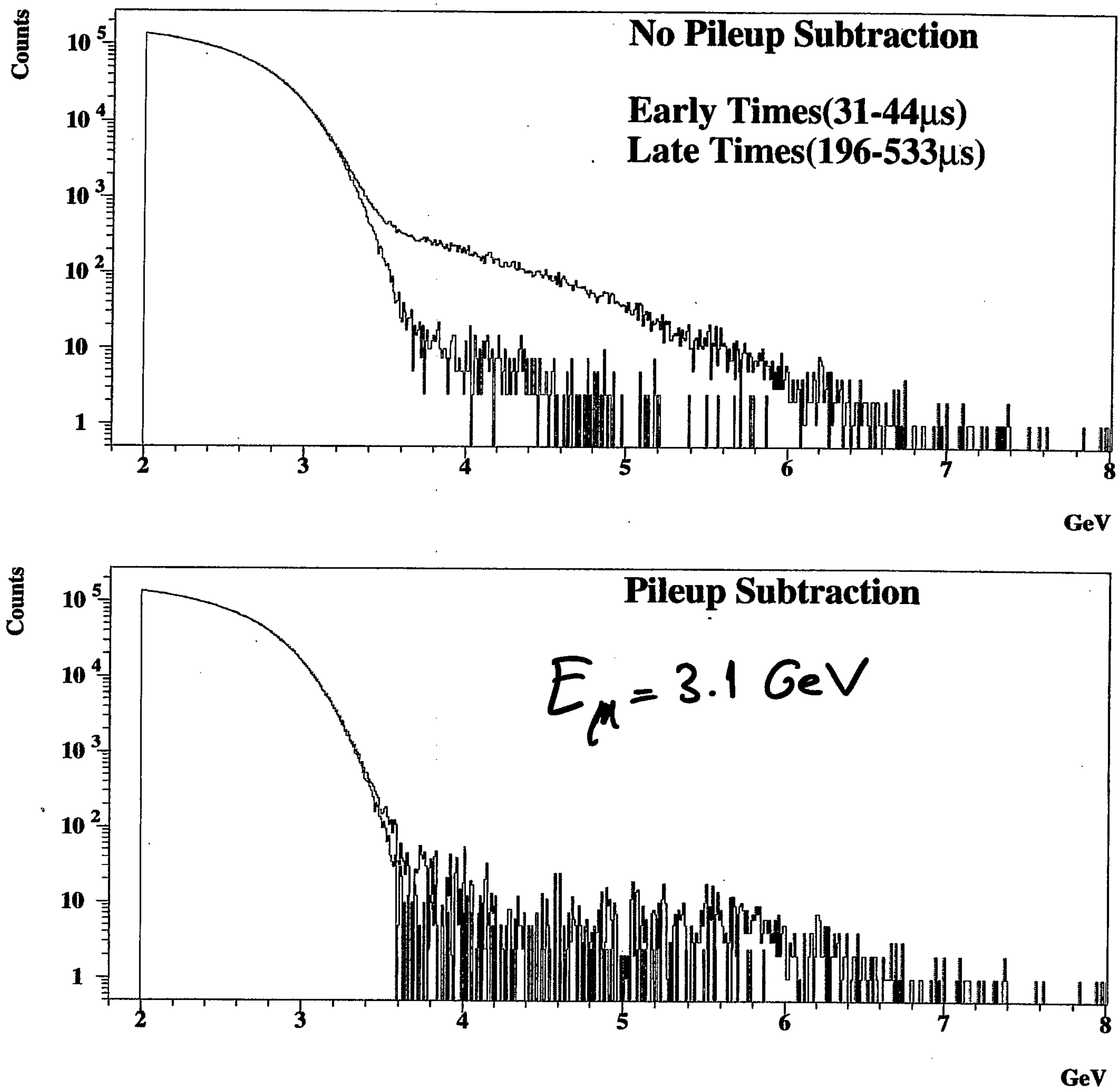


Pileup Candidates
Resolution Time = 2Δ
Δ
Δ
Offset Time
E1,t1
E2,t2
S1
S2
Constructed Doubles
E=E1+E2
<t>=<t1,t2–Offset Time>
D

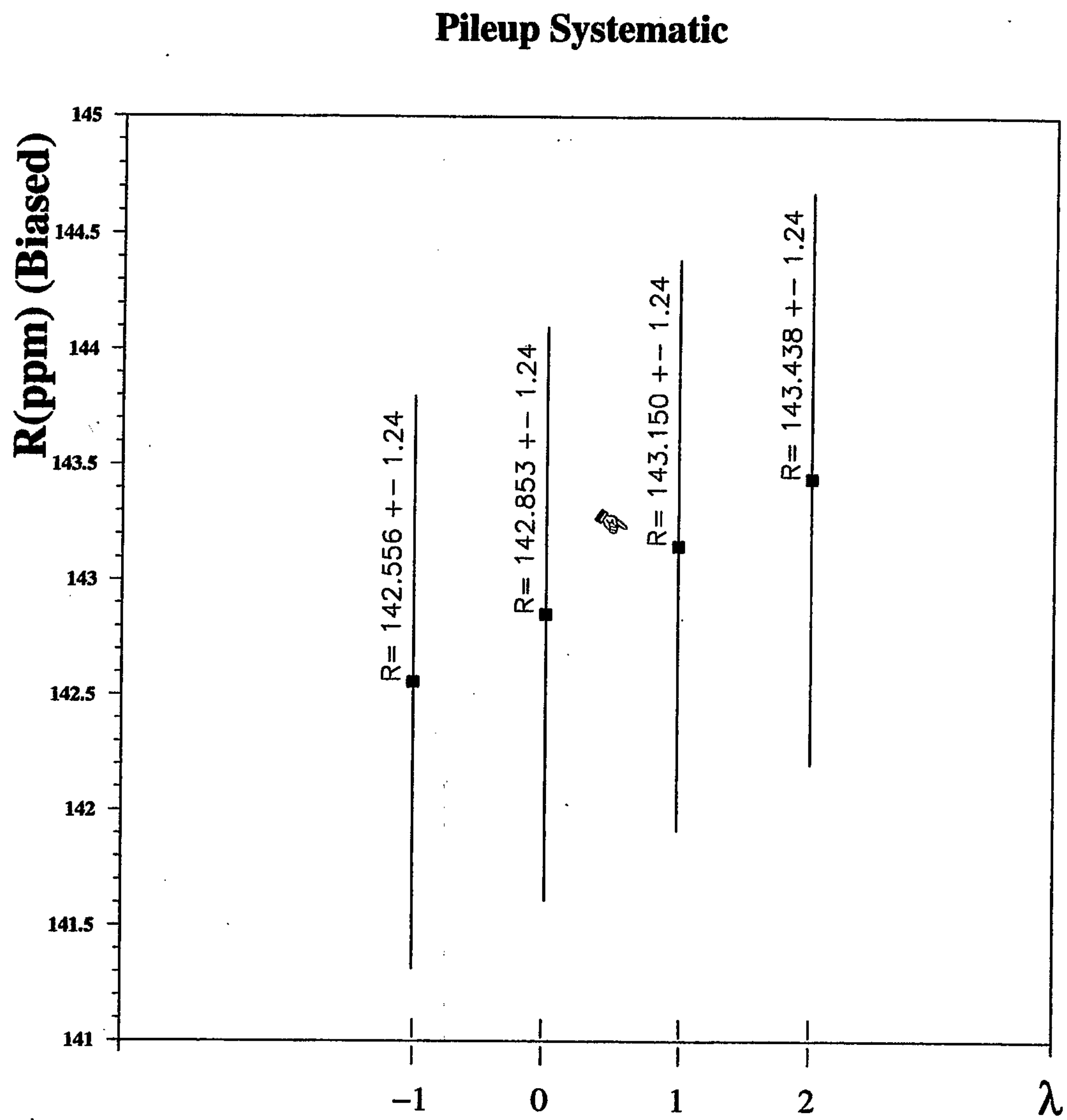


Energy Spectrum of S1, S2 and D
Counts
GeV
D
S1
S2
10 3
10 2
10
1
0
1
2
3
4
5
6
7
8
9
10

Energy Spectra



Pileup



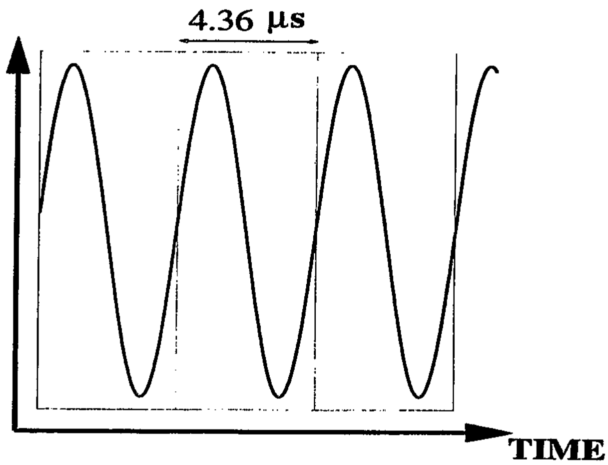
$$Data \quad - \quad \lambda \; Pileup$$

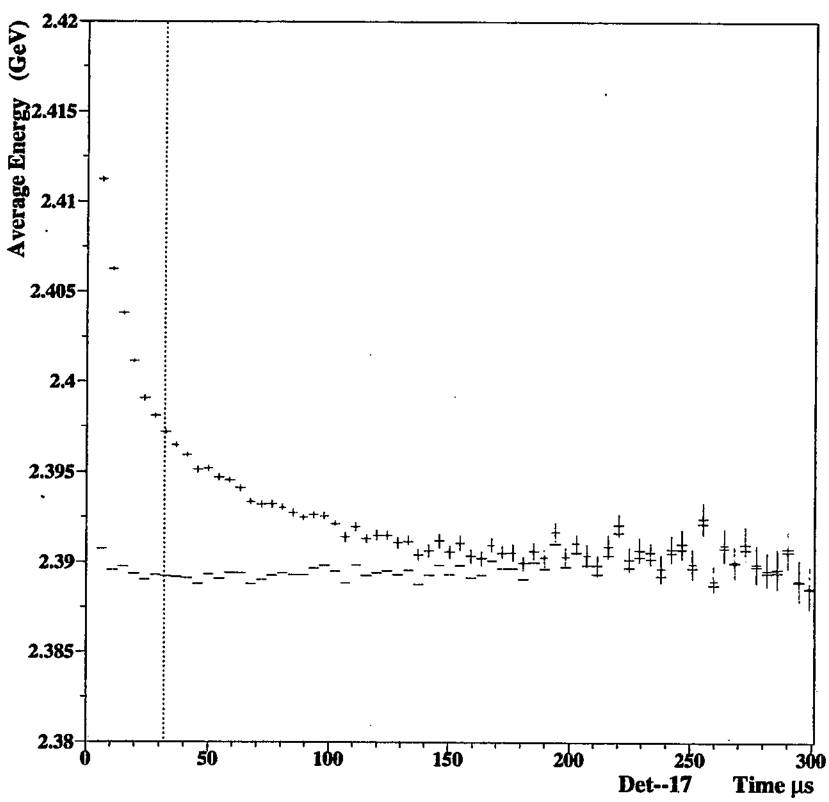
No pileup subtraction →0.3ppm

Gain

Average Energy

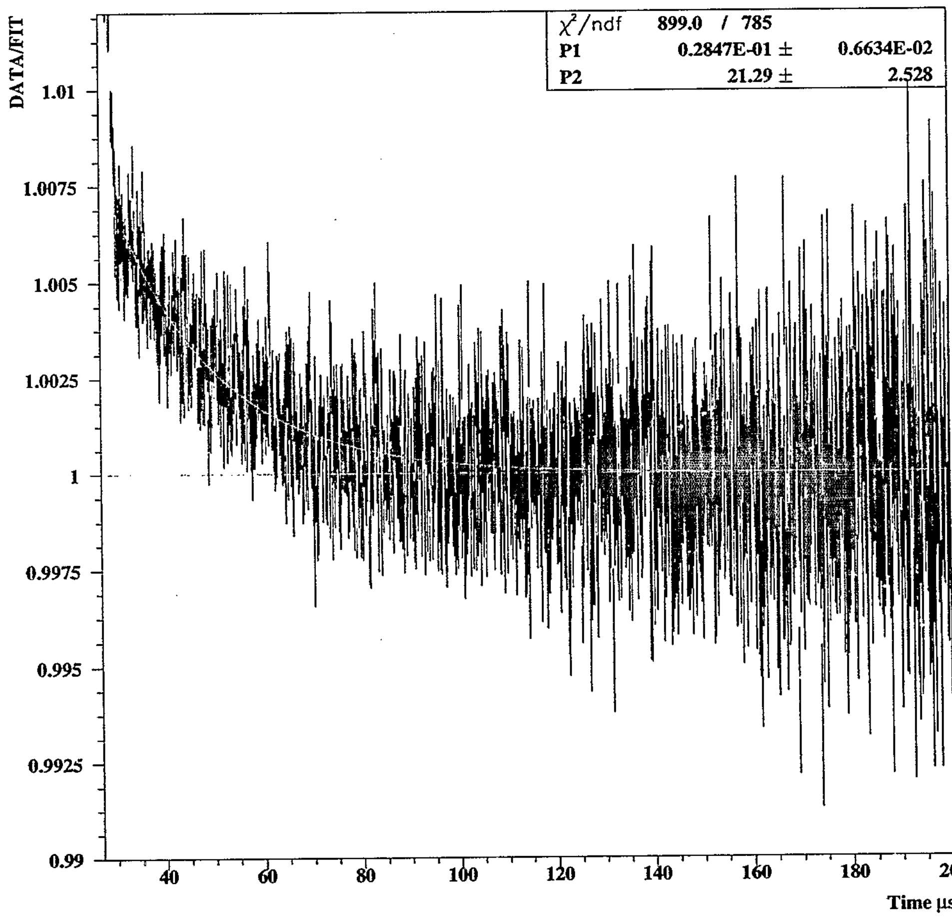
$$\overline{\mathbf{E}} = \frac{\sum_i \mathbf{E_i}\ \mathbf{n_i}}{\sum_i \mathbf{n_i}}$$

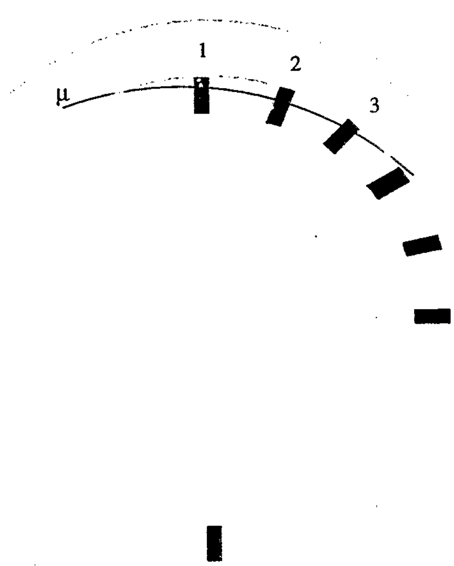




Muon Losses

After Pileup Subtraction and including CBO



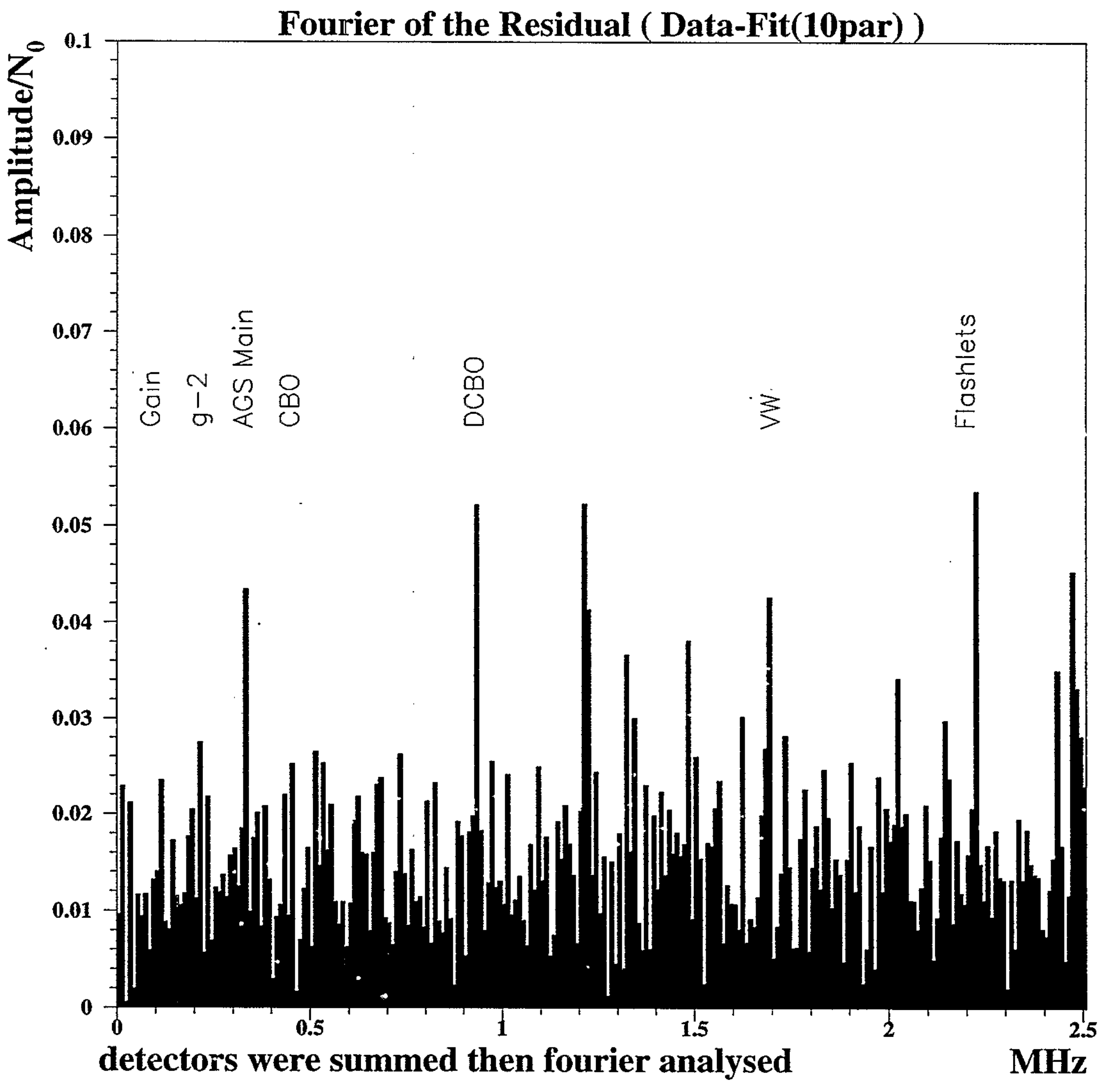


Calorimeters : allmost no energy deposition
FSD's : Hits to any finger

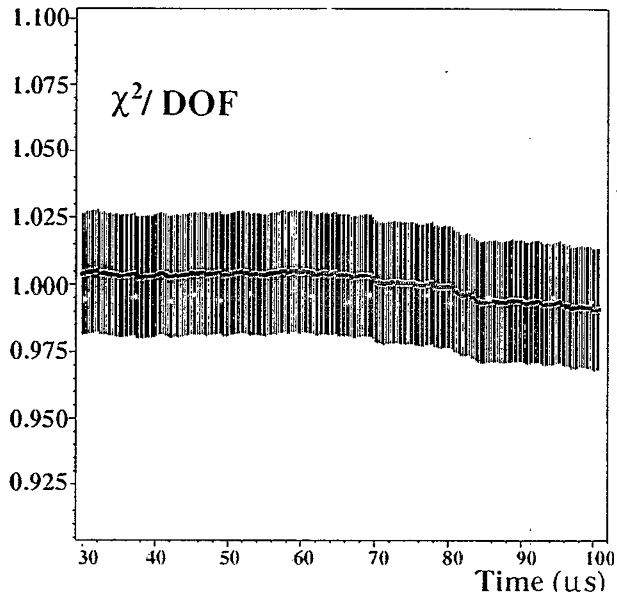
Fiting Function

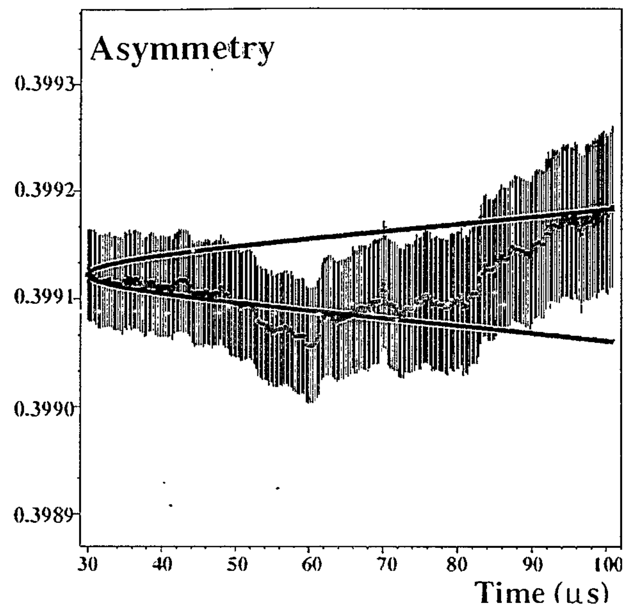
$$F_{id}(t) = N_0\ e^{-t/\tau}\ (1\ +\ A\ cos[w_a t\ +\ \phi])$$
$$F_c(t) = 1 + A_c\ e^{-(t/\tau_c)^2}\ cos[w_c t + \phi_c]$$
$$F_l(t) = 1 + A_l\ e^{-(t/\tau_l)}$$

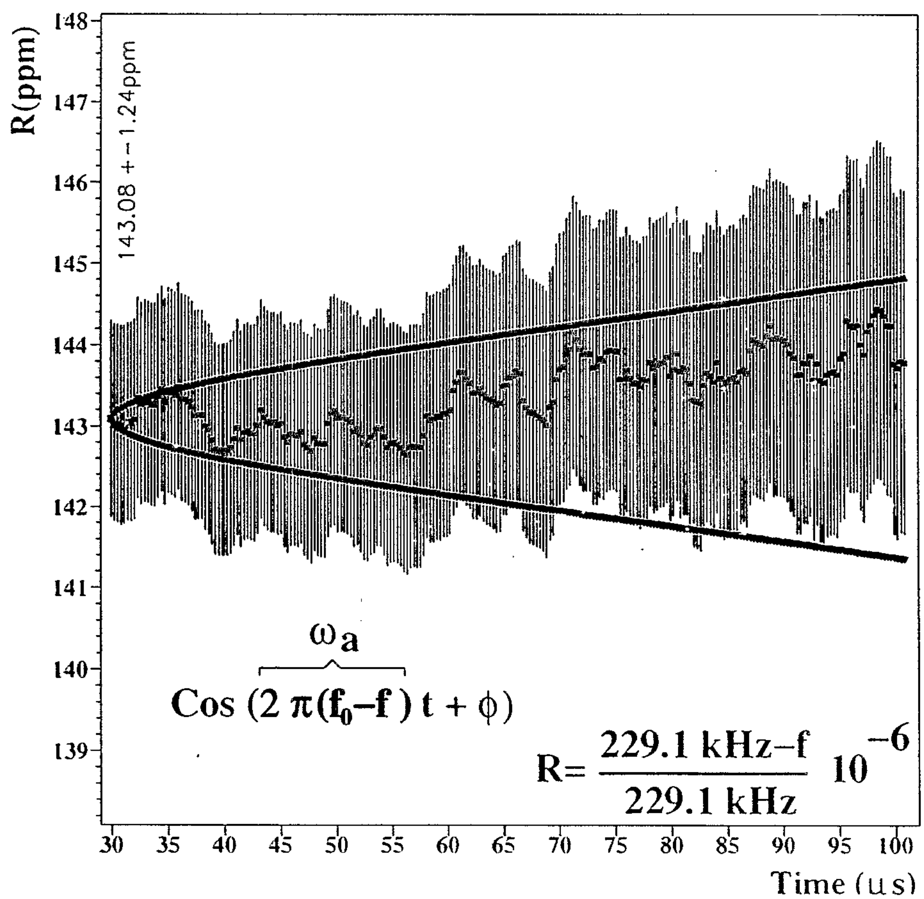
$$F\ =\ F_{id}(N_0, \tau, A, \omega_a, \phi)\ .\ F_c(A_c, \tau_c, \phi_c)\ .\ F_l(A_l, \tau_l)$$



Parameter Stability





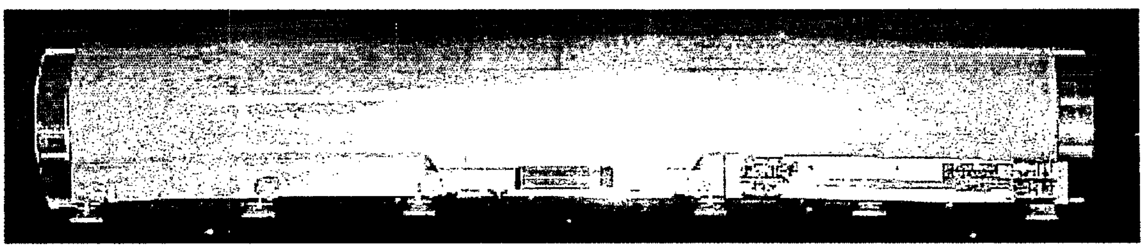


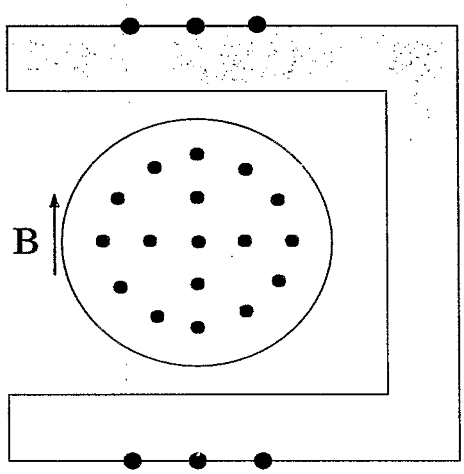
B Field Measurements

Two complementary methods for the field measurement

- Fixed NMR probes
  366 Fixed NMR probes
  Distrubuted around the ring
  Continuous measurement

- Beam Tube Trolley
  17 NMR probes
  Field measurements in the vacuum
  2-3 times a week





ω_a, ω_p Systematics

ω_a	
Pileup	0.13ppm
AGS Background	0.10ppm
Lost muons	0.10ppm
Timing Shifts	0.10ppm
E-field and vertical betatron oscillations	0.08ppm
Binning and fitting procedure	0.07ppm
Coherent Bettron Oscillations	0.05ppm
Beam debunching/randomization	0.04ppm
Gain changes	0.02ppm
Total	0.3 ppm

For ω_p total systematics 0.4ppm, mostly from calibrations and inflector fringe field.

Results

E821(99) : $a_\mu = 11\,659\,203(15) \times 10^{-10}$ $(1.3ppm)$

SM : $a_\mu = 11\,659\,159.6(6.7) \times 10^{-10}$ $(0.57ppm)$

Difference : $a_\mu(exp) - a_\mu(SM) = 43(16) \times 10^{-10}$ (2.6σ)

Possibilities

- A statistical fluke (1% prob.),
- Experimental analysis "wrong" ($4\times$ more data in 2000),
- Theory "wrong" (new results a_μ^{had} from Novasibirsk, BES and Cleo),
- New physics, for example Superymmetry !

Right now

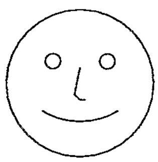
Running with μ^- (3.5B events) $\rightarrow$ Test of CPT violation

2000 at a Glance

$\approx$ 4B e^+ collected ($E > 2$ GeV, $t > 30\mu$s)

25% of the each run available on the disk !

Purpose : Quick look $\rightarrow$ run selection, energy calibrations, etc..



New inflector magnet $\rightarrow$ No inflector fringe field, (σB $\Downarrow$ Systematics due to Infl. Fr. Field was 0.2ppm at 1999)

Sweeper magnet installed $\rightarrow$ Flashlet level reduced 1 order of magnitude ($126ppm \rightarrow 10ppm$) (+ the efforts from AGS)

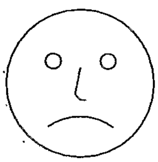
Quads stored the muons up to 1.4 ms

$1/25^{th}$ **Quads were suppressed**, in order to have enough flashlets to do systematics

Factor 2-3 less **Muon Losses** compared to 1999 (may no need to fit it !, "preliminary")

2000 at a Glance

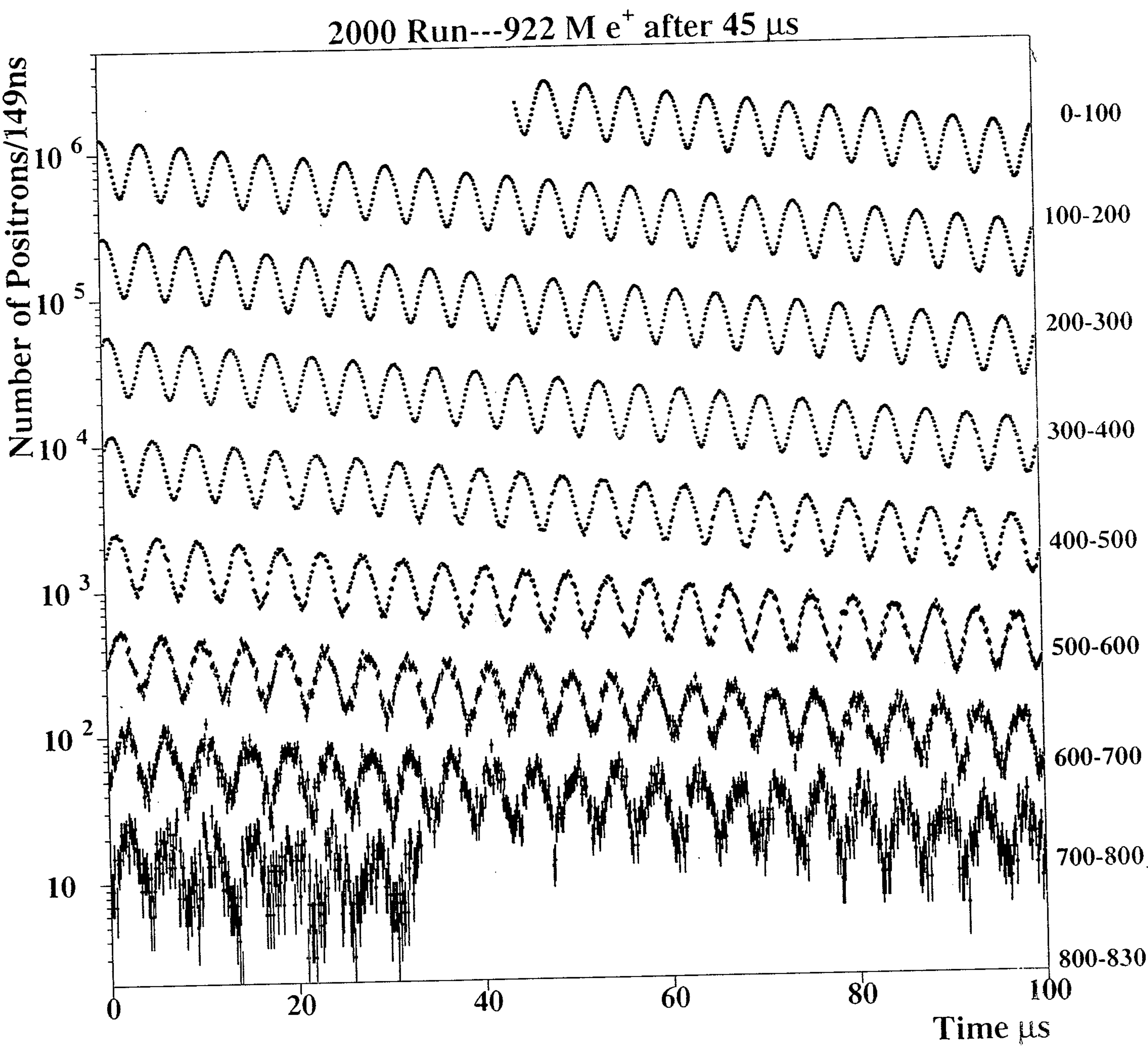
The aim : **MORE DATA** $\leftarrow$ Increasing intensity (opening up the beamline collimators)



Pileup increased ($\approx$ factor 2)
Solution from 1999.

High flash level, some detectors gated on **as late as 45μs**
Puting the detectors together and fitting it ($< 45\mu$s) ?
More likely will concentrate on the analysis of individual detectors

Increased the **hardware thresholds** upto 1.3 GeV
Difficulty on the pileup subtraction for $E > 2$ GeV
No big problem, missing parts are small in numbers and in asymmetry


2000 Run---922 M e+ after 45 μs
Number of Positrons/149ns
10 6
10 5
10 4
10 3
10 2
10
0-100
100-200
200-300
300-400
400-500
500-600
600-700
700-800
800-830
0
20
40
60
80
100
Time μs

2001 at a Glance

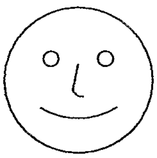
Excellent Run

$\approx$ 3.5B e^- collected ($E > 2$ GeV, $t > 30\mu$s)

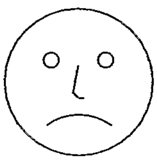
Production, parallel with the data taking

Purpose : During the data taking to monitor as many parameters as possible

Beam quality (like IC/SEC)
Muon losses continuously monitored
Energy calibrations, thresholds and gate-on times of the detectors
From the fits, parameters such as lifetime.



Energy thresholds ; All detectors $E \geq 0.9GeV$
Gate on Times ; All detectors $t \leq 25\mu s$
Two different focusing index ; n=0.122, n=0.143
Better understanding of CBO,
Trolley Position measurement improved.



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