„Neutrino Telescopes" - 1999.

ν - Mass Direct Measurements

V. M. Lobashev

Institute for Nuclear Research
of the Russian Academy of Sciences

Kinematic approach to rest mass. Balance of momentum and energy.

ν_e $m_{\nu_e} < 2.5 eV$ $(recent \quad result)$	$n \rightarrow p + e + \nu_e;$ $T_2 \rightarrow (THe^3)^+ + e + \tilde{\nu};$ $N(E)_e;\ P_e;$ $E_0 = 18{,}573\ eV$
ν_μ $m_{\nu_\mu} < 0.17 MeV$	$\pi^+ \rightarrow \mu^+ + \nu_\mu$ $m_\pi;\quad m_\mu;\quad P_\mu;$
ν_τ $m_{\nu_\tau} < 18 MeV$	$\tau \rightarrow \underbrace{5\pi}_{\text{all charged}} + \nu_\tau$ $m_\tau;\quad P_\pi;$

Advantage of T-decay:

1. Low E_0.
2. High specific activity ($T_{1/2} = 12.26$ y).
3. Low Z.
4. Exact calculation of final state spectrum.
5. Purity from other radioactive contamination.
   Next on E_0 Ni^{63}: $E_0 = 67.0$ keV; $T_{1/2} = 92$ y.

Search for kinematical neutrino mass – main goal for study of tritium β-spectrum near end point.

Around end point spectrum shape is dominated

by phase space of neutrino

$\sim p_\nu^2$ *if* $m_\nu = 0$

$\sim p_\nu E_\nu$ *or* $E_\nu (E_\nu^2 - m_\nu^2)^{1/2}$ *if* $m_\nu \neq 0.$

Maximal sensitivity when $E_\nu \sim m_\nu$.

No lepton or flavor quantum number dependence is supposed.

m_{ν_τ}

$e^+e^- \to \tau^+\tau^-$

ARGUS (1992)

$$\tau \to 5\pi^\pm\nu_\tau$$

$$m_{\nu_\tau} < 31 MeV/c^2 \qquad 95\% \text{ C.L.}$$

CLEO II (1993)

$$\tau \to 5\pi^\pm\nu_\tau, \quad 3\pi^\pm\pi^0\nu_\tau$$

$$m_{\nu_\tau} < 32 MeV/c^2$$

ALEPH (1998)

$$\tau^- \to 3\pi^\pm\nu_\tau; \quad 5\pi^\pm(\pi^0)\nu_\tau$$

Two-dimentional (Eh, Mh inv) fit

$$\frac{\Delta P_\perp}{P_\perp} = 6\cdot 10^{-4} P_\perp \cdot GeV; \quad \Delta M \sim 10 \text{ MeV}$$

Combining 2 decay channels

$$m_{\nu_\tau} < 18.2 MeV/c^2$$

m_{ν_μ}

$\pi \to \mu + \nu_\mu$ decay at flight or at rest.

Most accurate at rest.

$$m^2_{\nu_\mu} = m^2_\pi + m^2_\mu - 2m_\pi (m^2_\mu + p^2_\mu)^{1/2}$$

$$\Delta(m_{\nu_\mu})^2 = \left[(60 \cdot \Delta m_\pi)^2 + (57 \Delta m_\mu)^2 + (75 \Delta P_\mu)^2\right]^{1/2} MeV$$

Present accuracy	2.7 ppm	0.3 ppm	3.7 ppm

A problem of negative $m^2_{\nu_\mu}$.

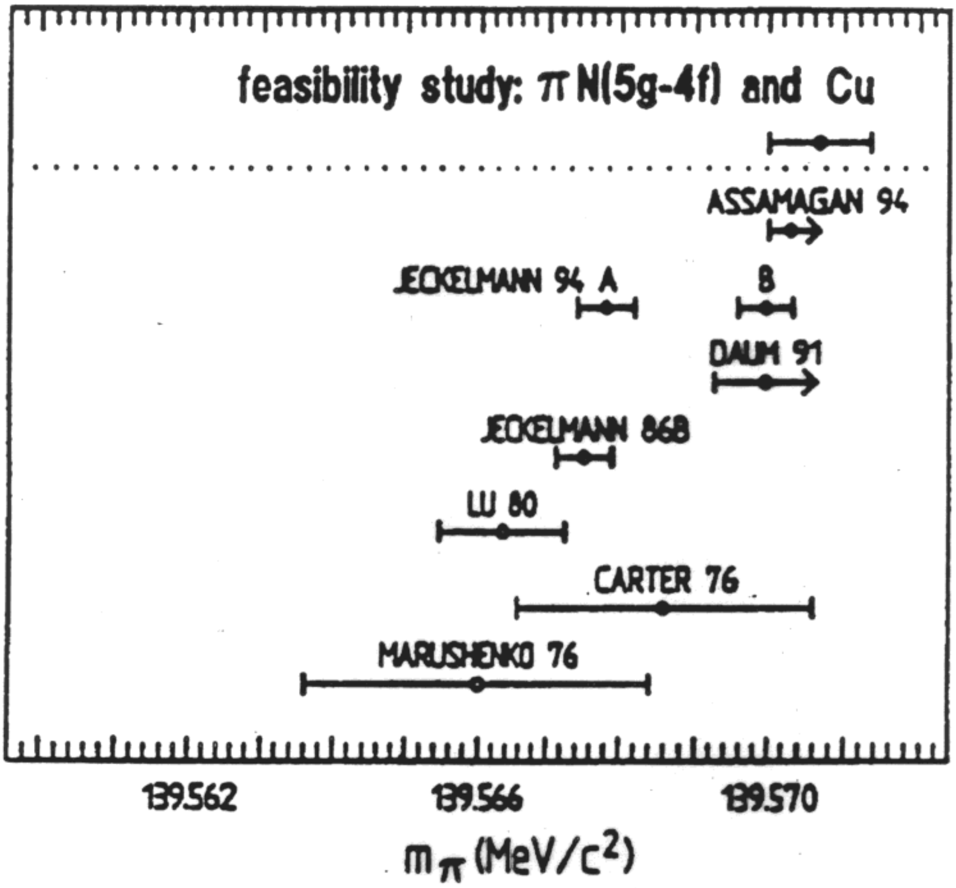
Origin – two solution of π-mass from Mg 4d→3f cryst.-diff. experiment due to uncertainty of screening factor.
(15 ppm – Jeckelmann, 94, 86)

From recent data:

$$m^2_{\nu_\mu}(A) = (-0.143 \pm 0.024) MeV^2$$

$$m^2_{\nu_\mu}(B) = (-0.016 \pm 0.023) MeV^2$$

May be resolved by better resolution of CDSp
(Is under preparation at Moscow Meson Factory)
Alternative way π - X ray from lighter element.
Now first result from new experiment at PSI πN .
Ultimate goal – relative mass of π with respect to μ from πN^{14}(5g – 4f) and $\mu O_{5\text{-}4}$ (Not achieved yet)
Accuracy for $m_\pi \sim 1$ ppm.



Discard the solution A (Jeckelmann, 94)

Remain only:

$$m^2_{\nu_\mu} = (-0.016 \pm 0.023) MeV^2$$

$$m_{\nu_\mu} \begin{cases} < 0.17 MeV & (90\% C.L.) \\ < 0.195 MeV & (95\% C.L.) \end{cases}$$

Neutrino mass and β-decay.

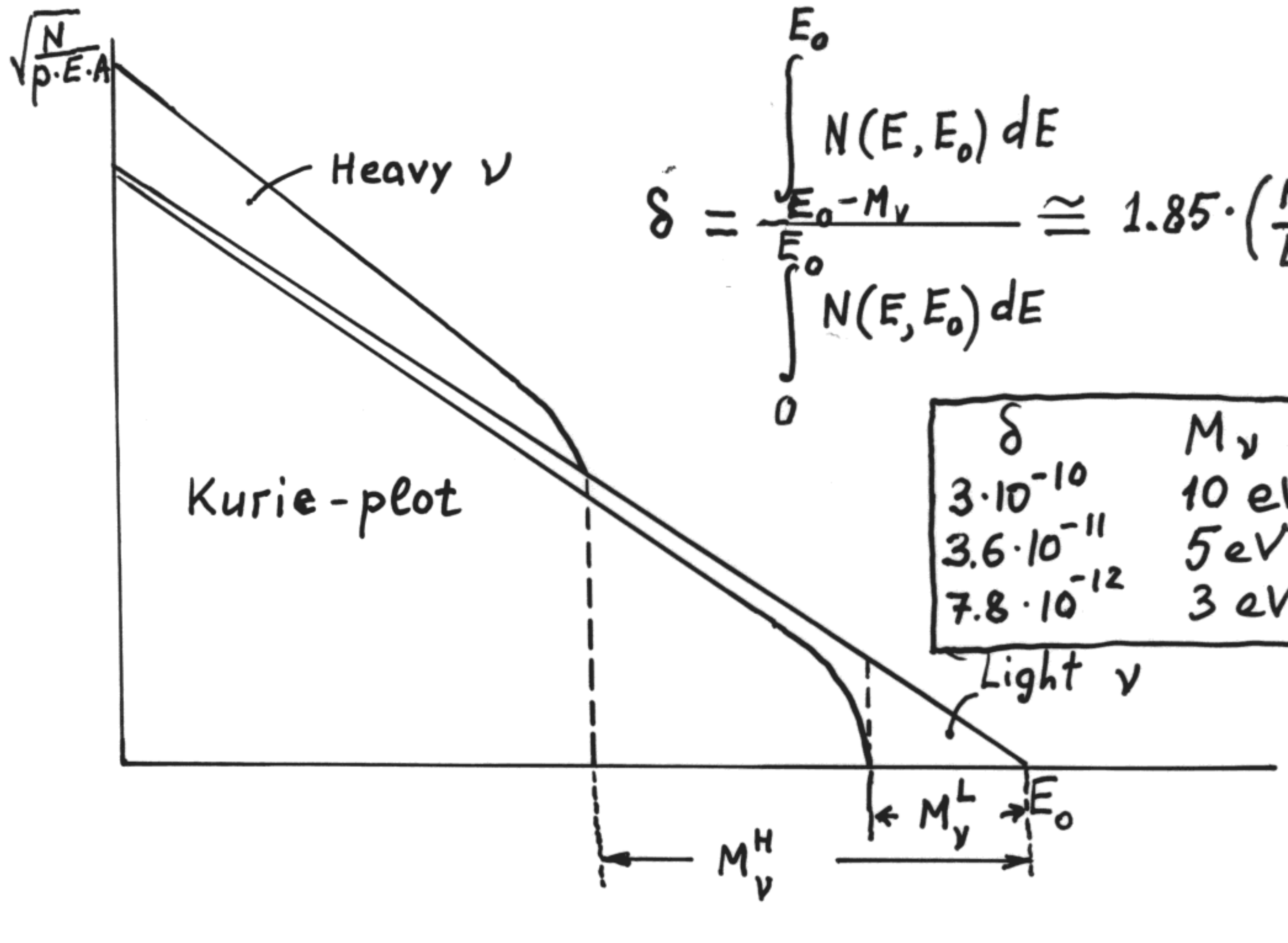
$$dN(E) = \underbrace{G_F^2 \cdot k F(Z,E)|M|^2}_{a} \cdot p_e \cdot E_e \cdot (E_0 - E)^2 \, dE \, ; \quad m_\nu \equiv 0$$

$$dN(E) = a \cdot p_e \cdot E_e (E_0 - E)\left[(E_0 - E)^2 - M_\nu^2 c^4\right]^{1/2} dE \, ; \quad m \neq 0 \, ;$$

$E_{0i} - E = \varepsilon_i$ neutrino energy

$$dN(E) = a \cdot p_e E_e \sum_i W_i \cdot \varepsilon_i^2 \cdot \sqrt{1 - \frac{m_\nu^2 c^4}{\varepsilon_i^2}} \cdot d\varepsilon \, ;$$

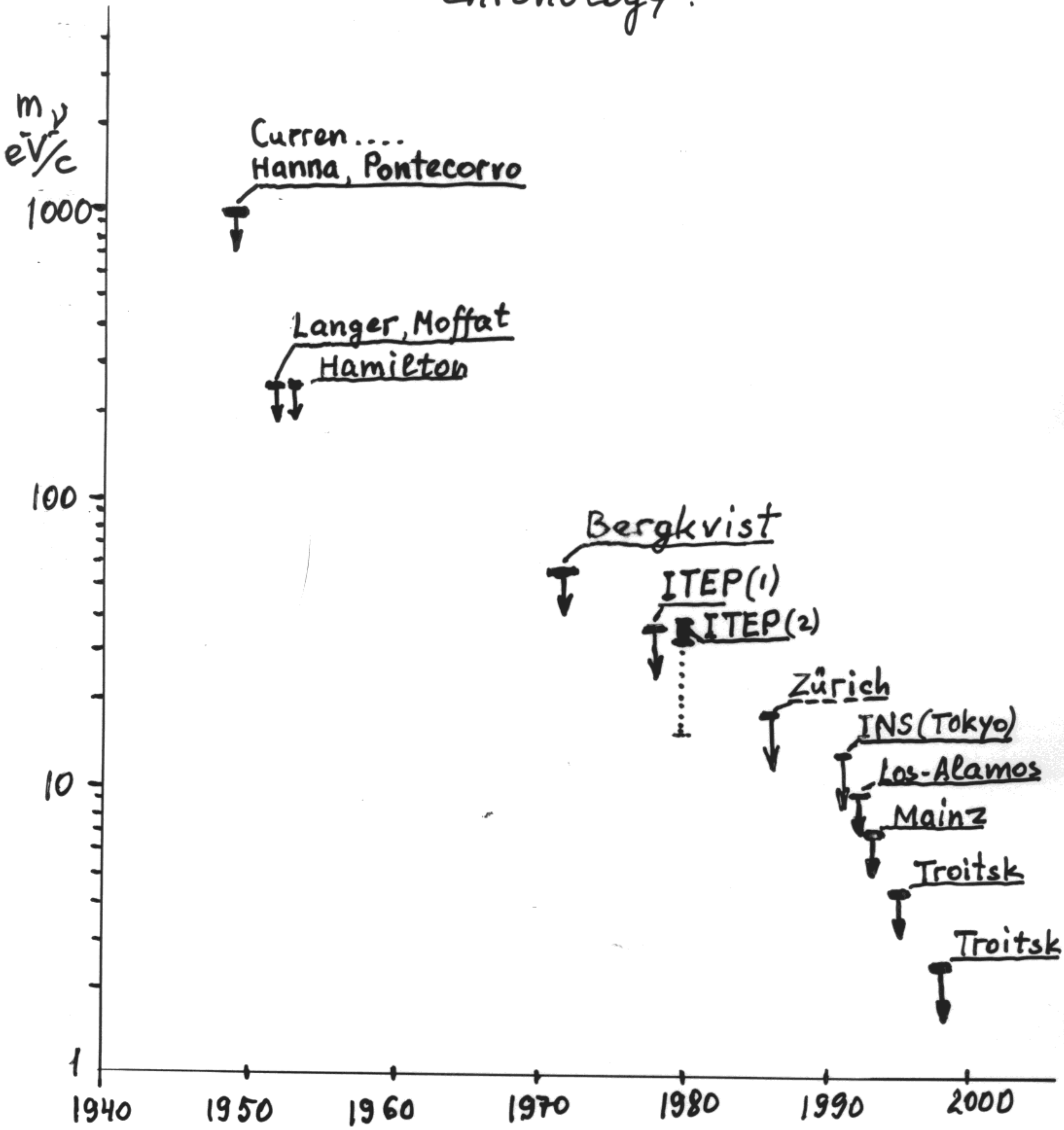
$\varepsilon_i = E_0 - E - V_i$; V_i – exitation energy of i-th final state.



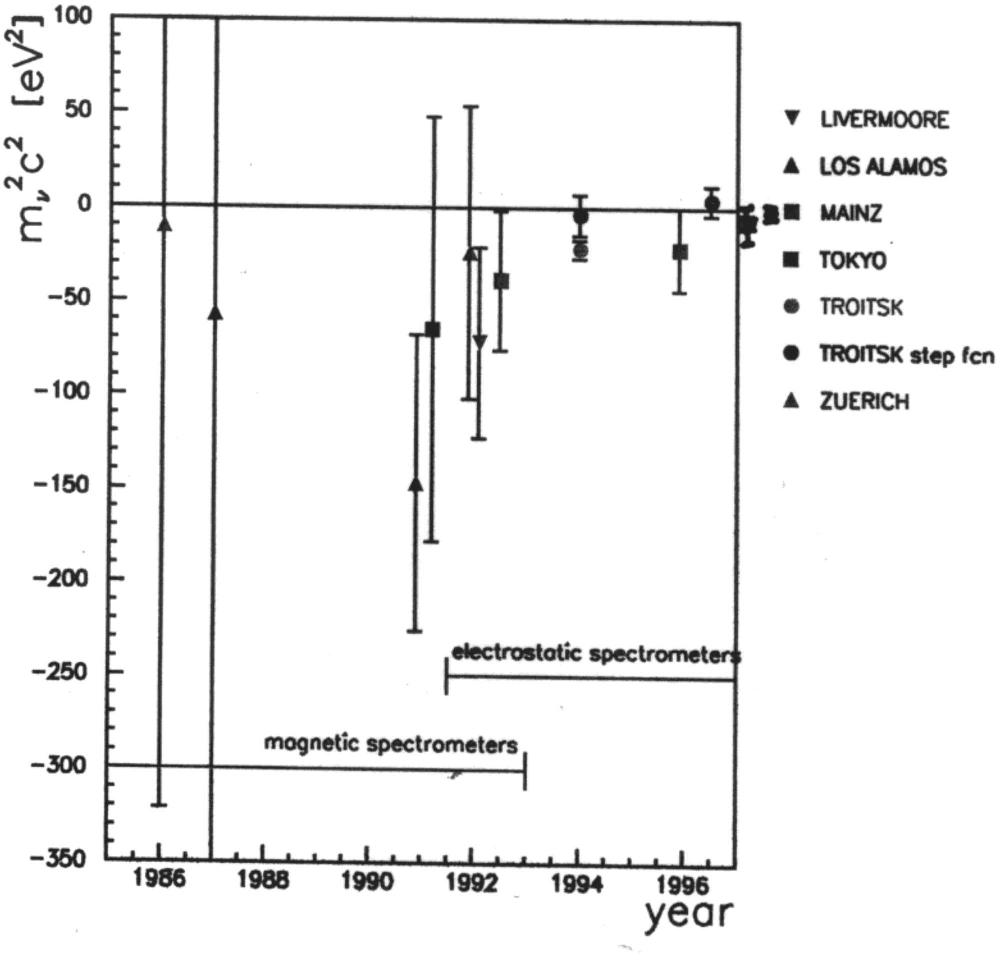
$$\delta = \frac{\int_{E_0 - M_\nu}^{E_0} N(E, E_0)\, dE}{\int_0^{E_0} N(E, E_0)\, dE} \cong 1.85 \cdot \left(\frac{M_\nu}{E_0}\right)^3$$

δ	M_ν
$3 \cdot 10^{-10}$	10 eV
$3.6 \cdot 10^{-11}$	5 eV
$7.8 \cdot 10^{-12}$	3 eV

The neutino mass in ^3T decay.
Chronology.



The last decade



- 2 running experiments (Mainz, Troitsk)
- Problem of $m_\nu^2 < 0$

  $\rightarrow$ 2 different Problems

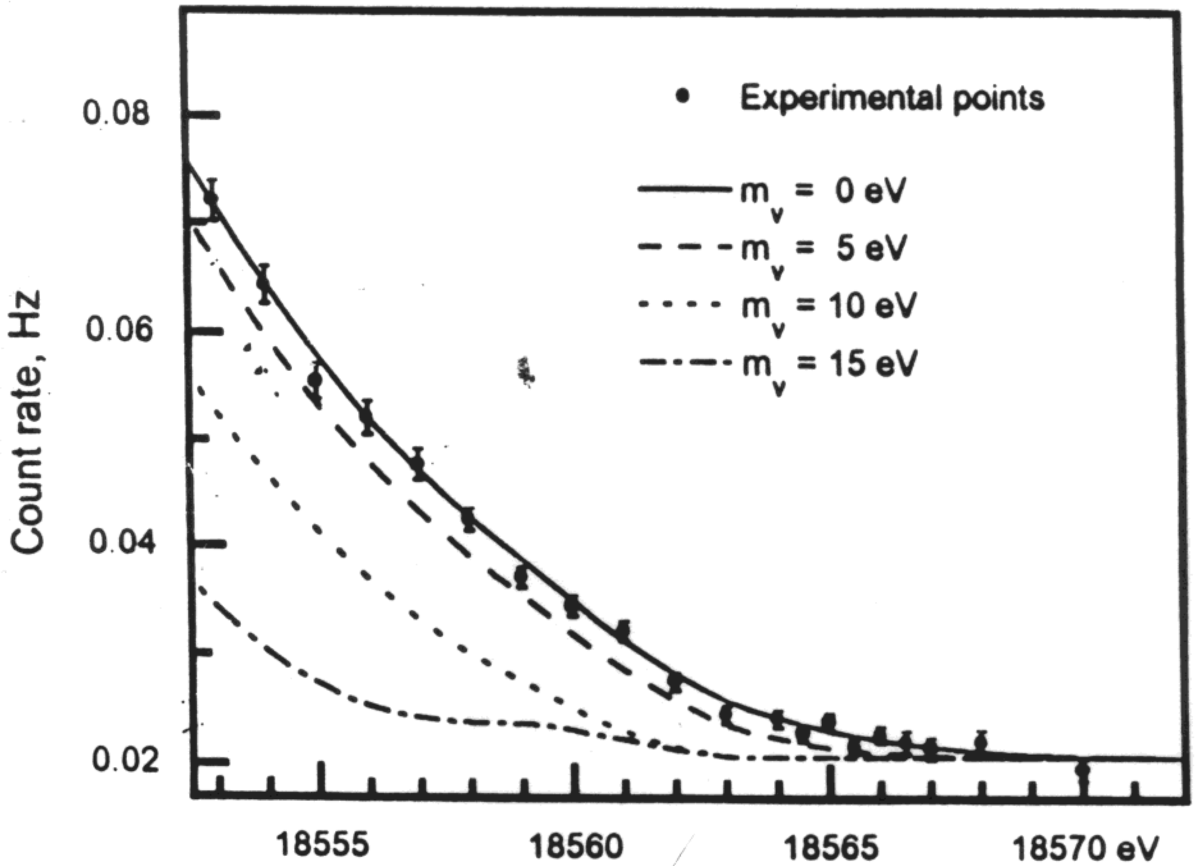


Figure 2: Part of the tritium spectrum near the end point.Solid and dotted curves present theoretical spectra (step included) with all the fitted parameters besides m_ν, that is fixed to shown figures.

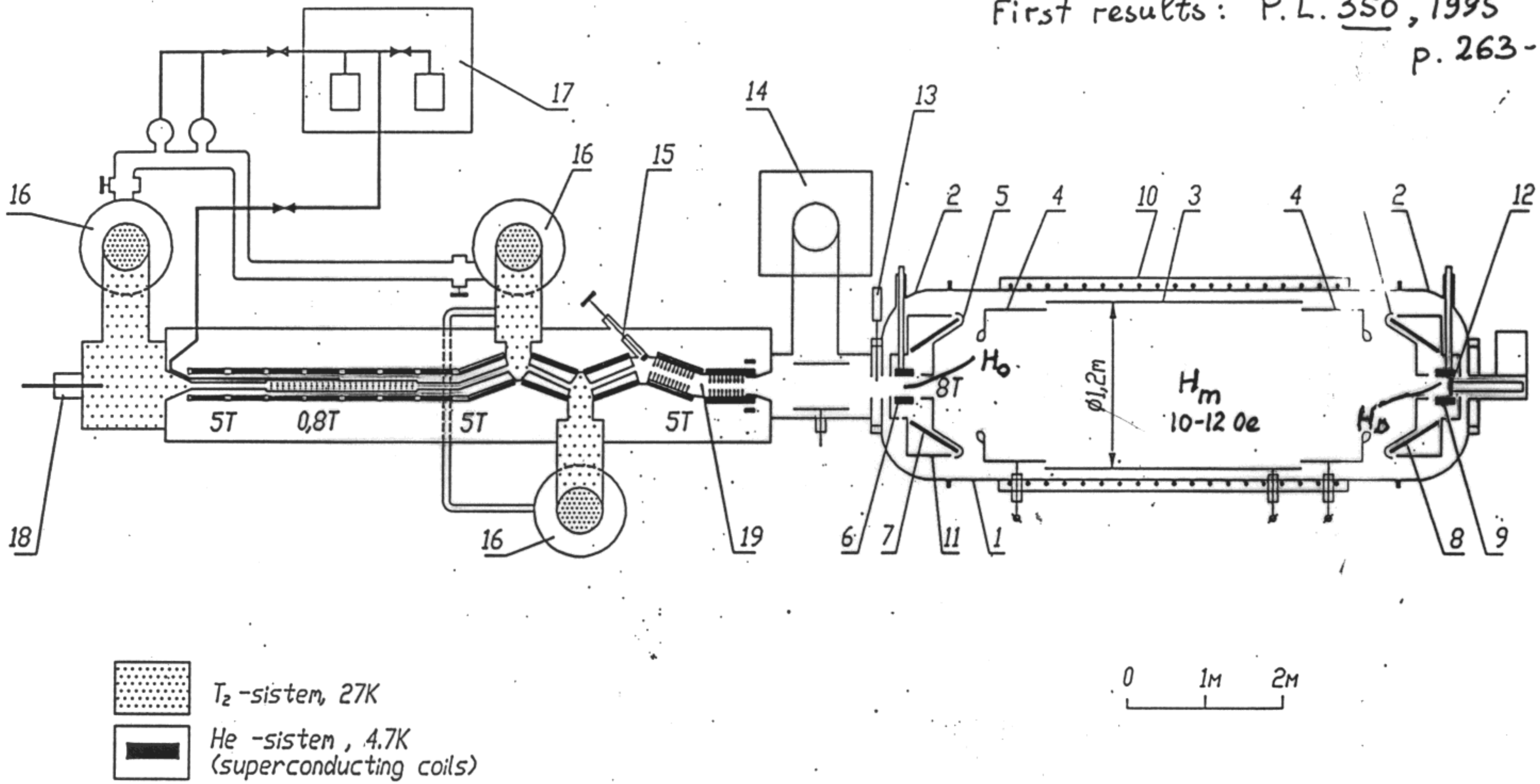
NEUTRINO MASS AND ANOMALY IN THE TRITIUM BETA-SPECTRUM

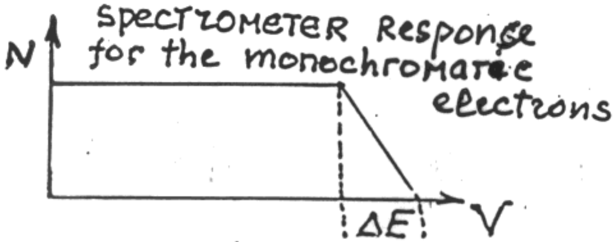
Institute for Nuclear Research
of the Russian Academy of Sciences,
60th October Anniversary prospect, 7a, 117312 Moscow, Russia
"Troitsk ν -mass" experiment
V.M.Lobashev, A.I.Belesev, A.I.Berlev, E.V.Geraskin,
A.A.Golubev, N.A.Golubev, O.V.Kazachenko,
Yu.E.Kuznetsov, R.P.Ostroumov, L.A.Ryvkis,
B.E.Stern, N.A.Titov, S.V.Zadorozhny, Yu.I.Zakharov

-int INR P-0291 (1983)

Proposal 1982 ; N[illegible] A240, 305-310 1985

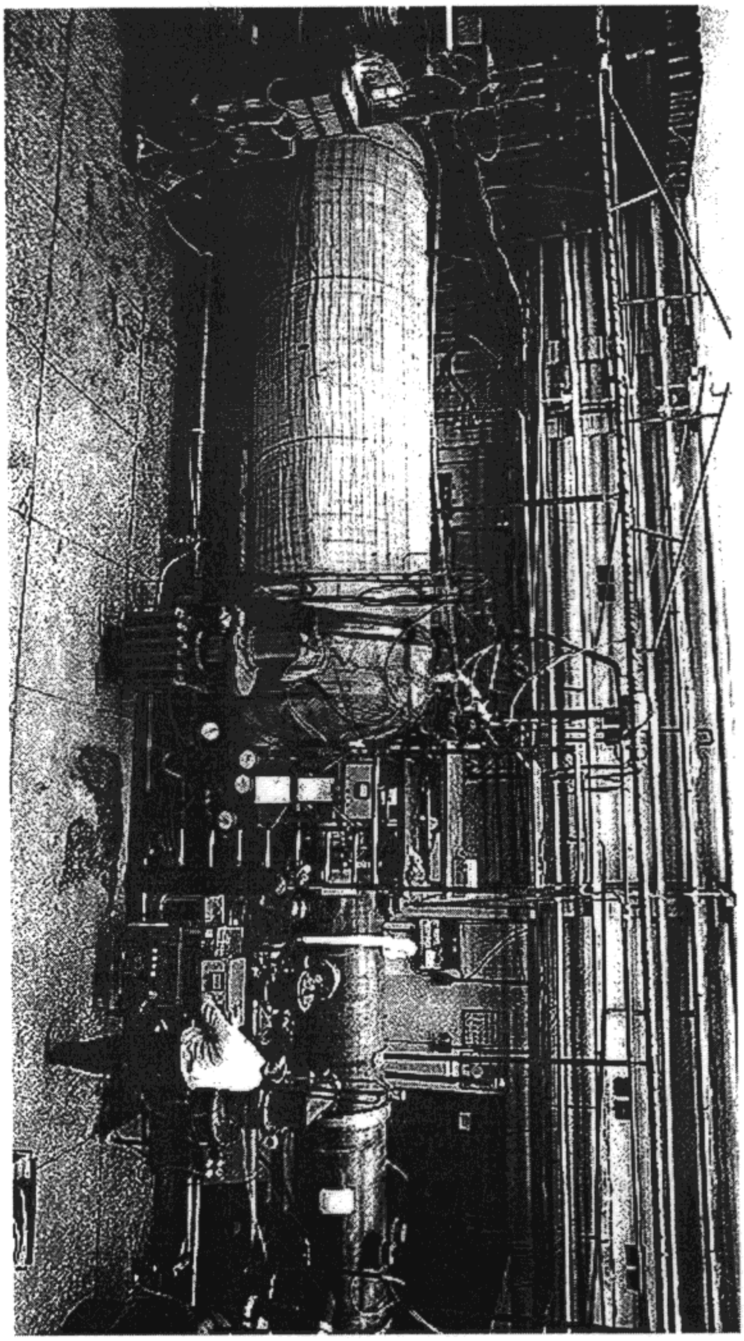
First results: P.L. 350, 1995 p. 263-271

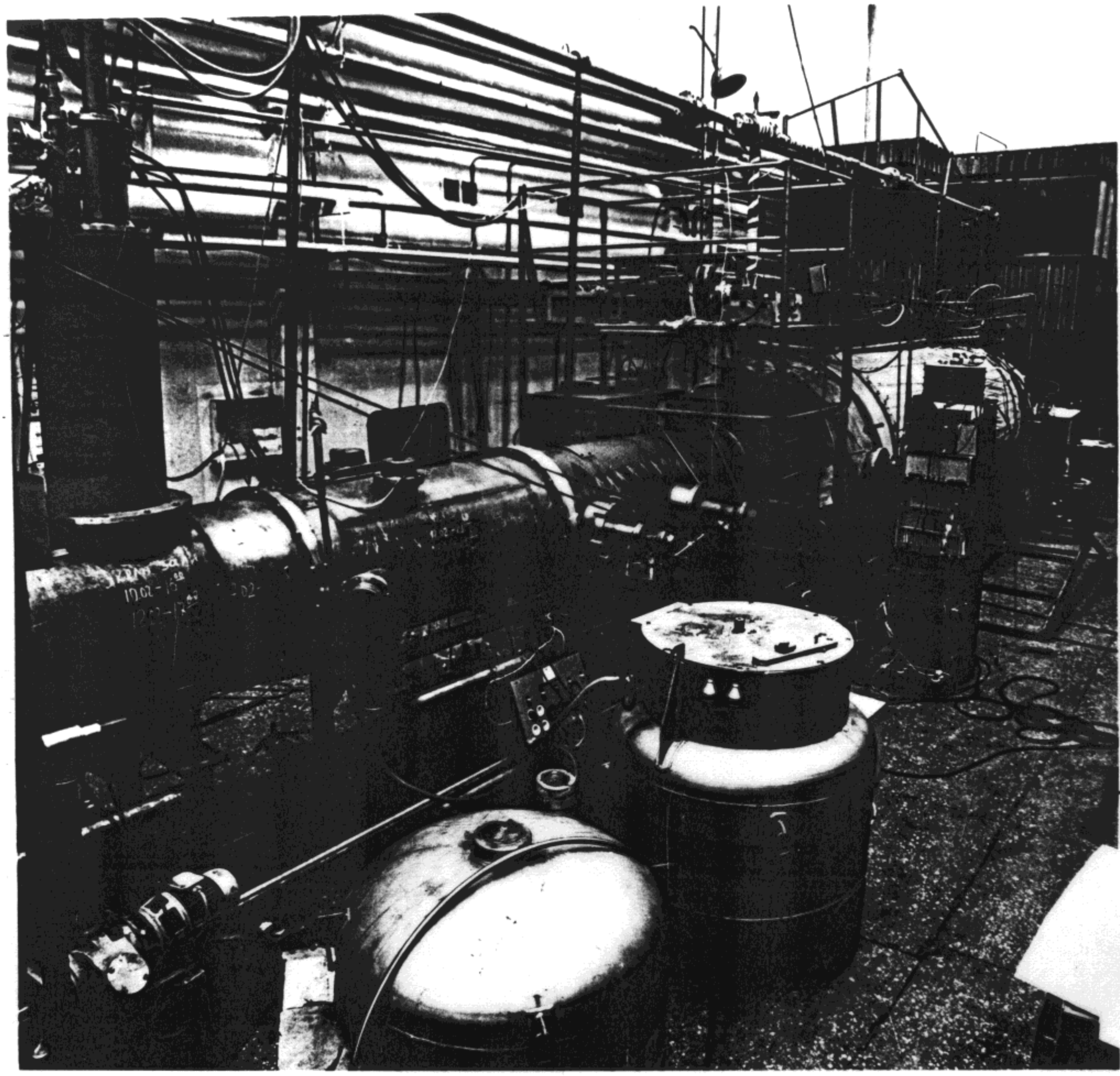


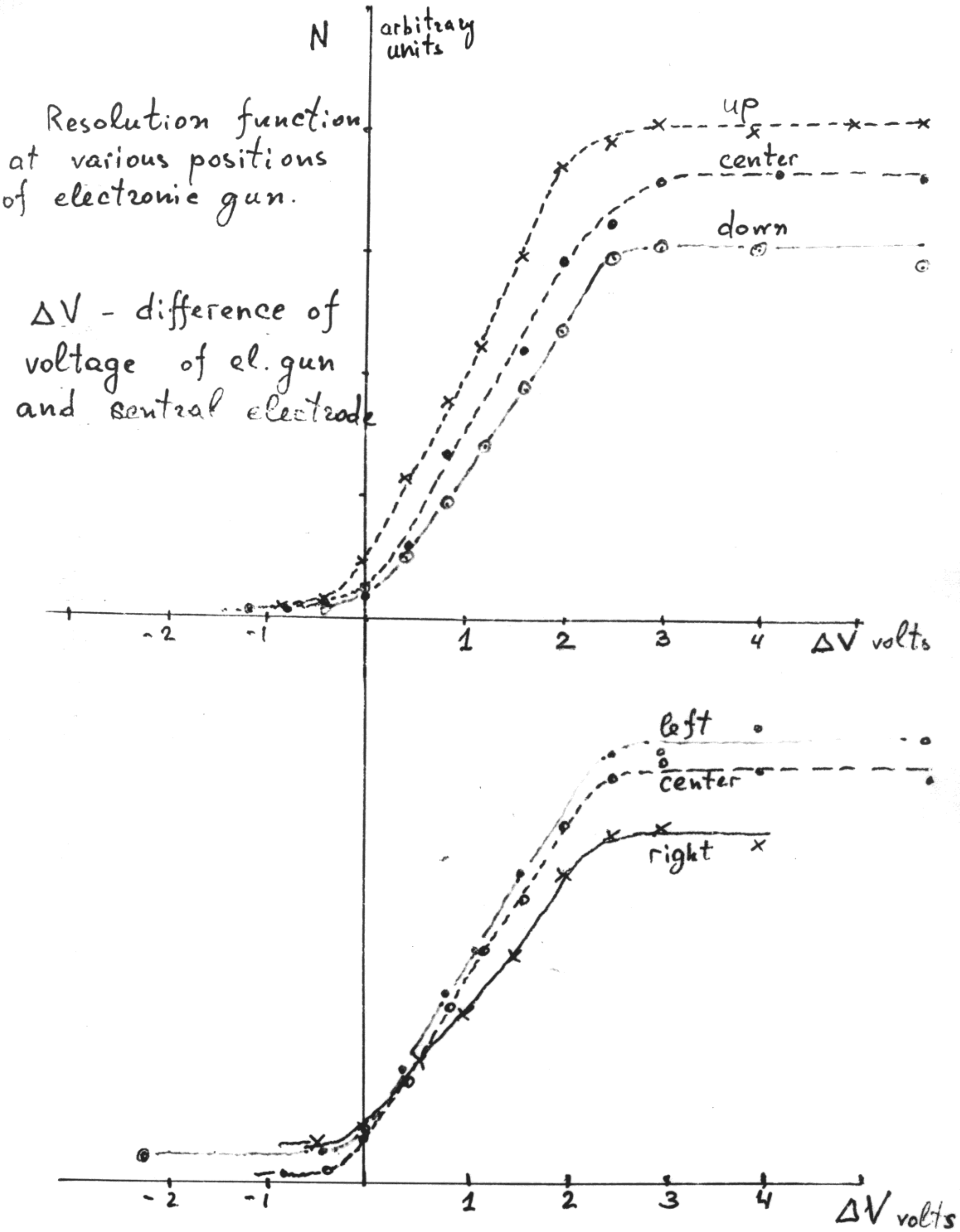


$$\Delta E = \frac{H_m}{H_o} \cdot E_o \quad ; \quad L = S_D \cdot \frac{H_D}{H_o} \cdot \frac{1}{4}$$

$$E_o = 18.6\ keV \ ; \ \Delta E = 3.5 - 4\ eV\ (FW).$$

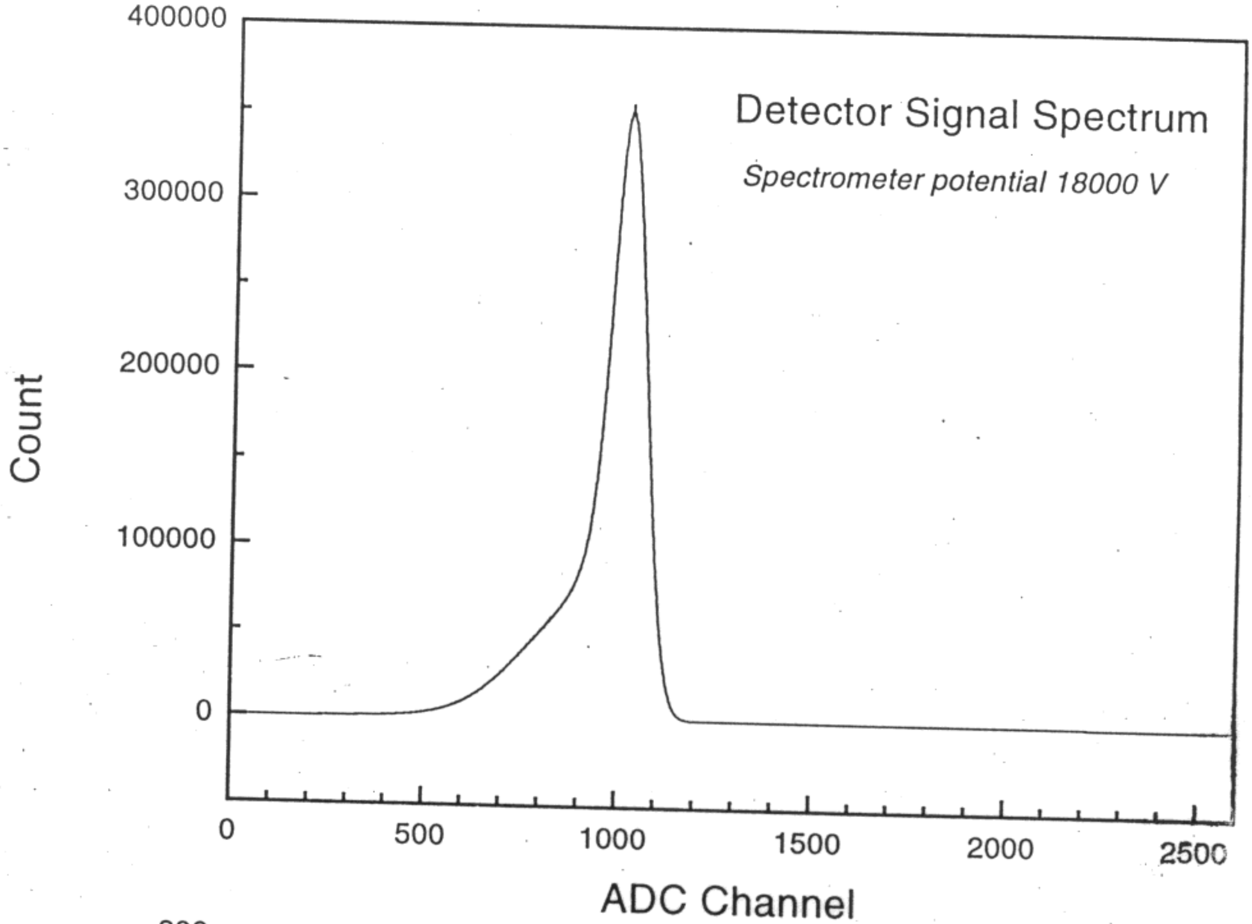


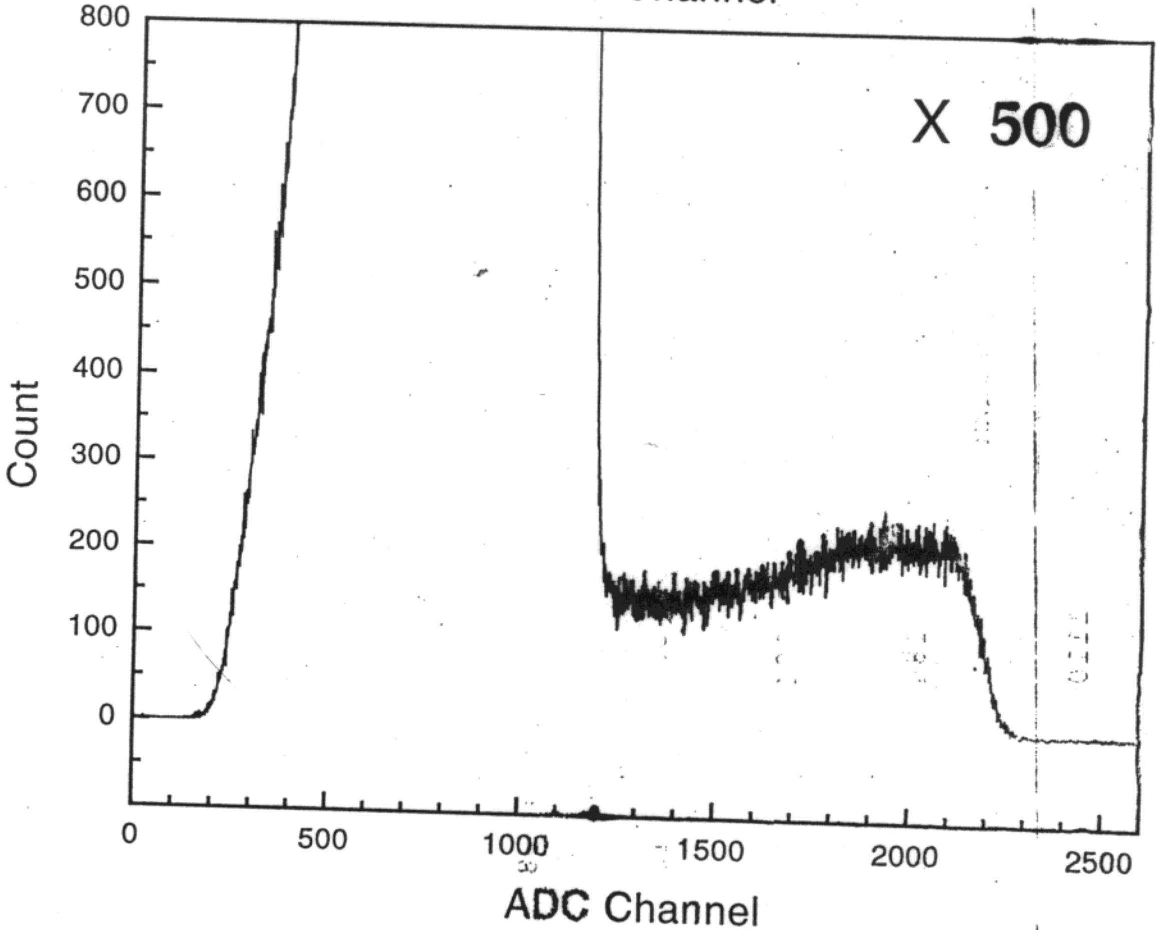




calculated FW 2.5 eV

measured FW 2.6 - 2.8 eV


Detector Signal Spectrum
Spectrometer potential 18000 V
Count
400000
300000
200000
100000
0
0
500
1000
1500
2000
2500
ADC Channel


X 500
Count
800
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
ADC Channel

Measurement procedure.

- Spectra were measured by scanning potential of spectrometer in steps 0.5÷50 V.
  Stability of potential: ± 0.15 V short-term, ~ 2 V for 3 years.
- Voltage checked at each point by comparison with two independent attenuators.
- Measurement time per point 10÷200 sec.
- Direction of scanning was reversed after each cycle.
- After ~10^3 sec. H.V. was returned to reference point (18,000 or 18,175 V).
- Maximum count rate ~ $6 \cdot 10^3$ sec^{-1}.
- Spectrum was measured for 1÷2 hours (cycle).
- Background ~12÷30 mHz independent of the spectrometer potential. Measured in the range 18,600÷19,600 V.
- Periods of running :

1994	January-February March July	3 X 12 days
1996	April - May	24 days
1997	February - March June December	40 days 10 days 20 days
1998	February June	15 days 15 days

Altogether ~180 days / 4 years.

+10 more days

Experimental spectrum corrections.

1. Search and elimination of tritium decay

   in spectrometer volume.

   5÷20 sec bunch of pulses (1÷3 $hour^{-1}$). Cut-off level ~$3 \cdot 10^{-4}$.
2. Reference counting rate (T_2 source drift).
3. Dead time and pile-up of pulses.
4. Detection efficiency (~ 0.002).
5. Amplitude window corrections.

Data for fitting.

1. Resolution function (spectrometer response) was measured or calculated from magnetic field strength.
2. Energy loss spectrum and surface density of the source.

   ⇒ Measured by transmission through the source of electron from the gun with ultraviolet photoexitation, injected from rear side.

   No-hit factor and parameters of spectrum in the approximation obtained in these measurements were then used by accounting on the monitor counting rate and tritium percentage (from mass-spectrum).
3. Final state spectrum used from Jonsell, Monkhorst.
4. Correction for trapping-effect.

Results of the measurement were fitted to calculated spectrum with 3 basic variable parameters:

A – normalization factor

b - background (constant over spectrum)

E_0 – end-point energy.

Next parameters were varied in different combination:

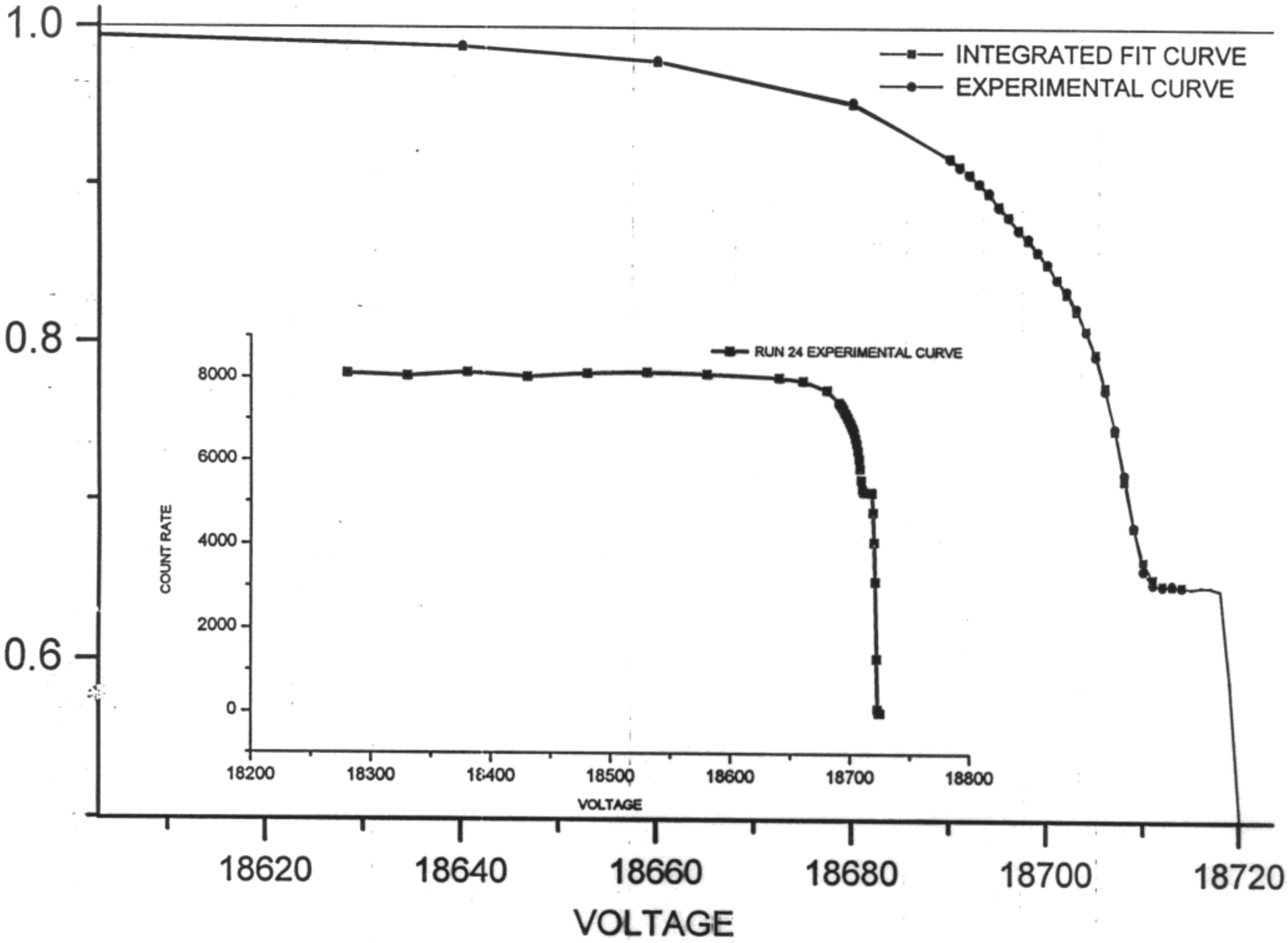
m_ν^2 + basic

E_{step}, N_{step} } Step function + basic

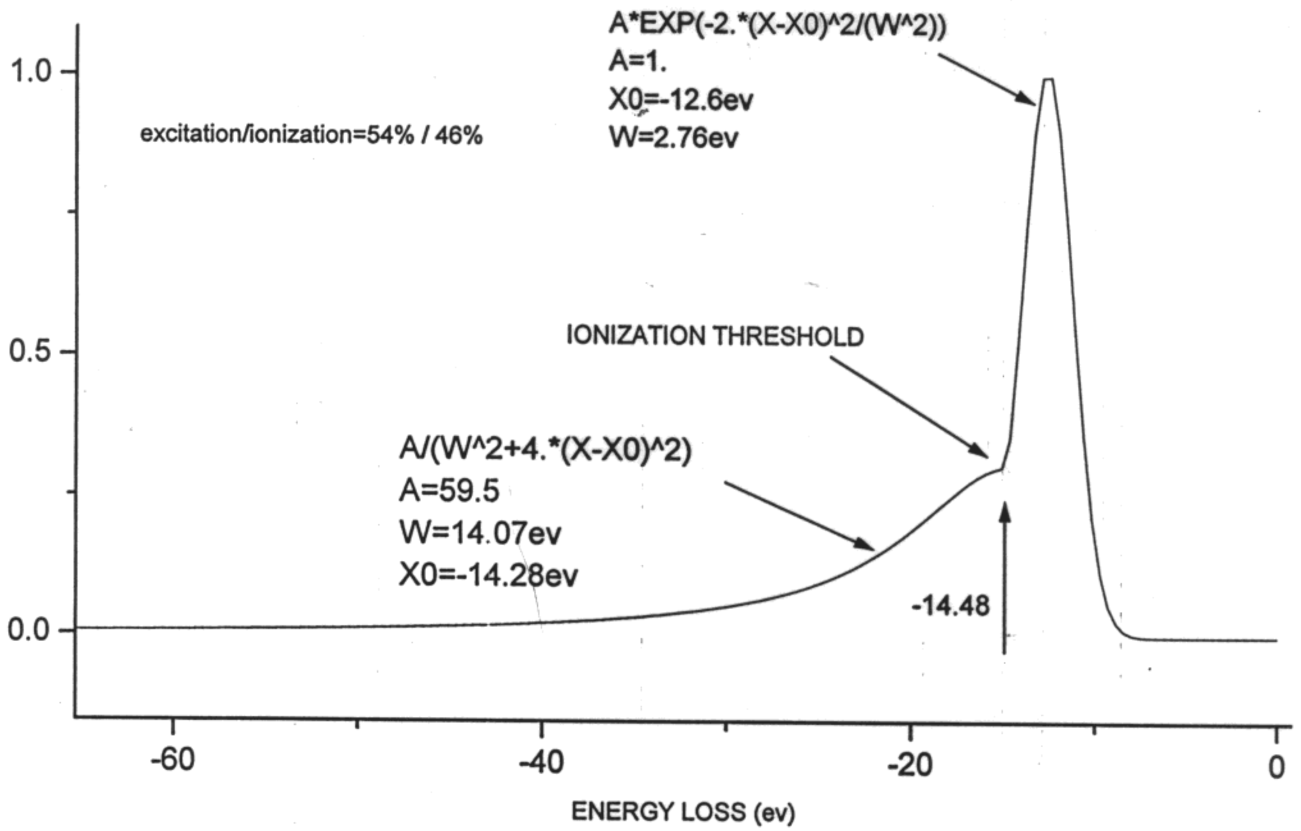
All of them variable.

Some correction factors + basic + m_ν^2 for regression coefficient determination.

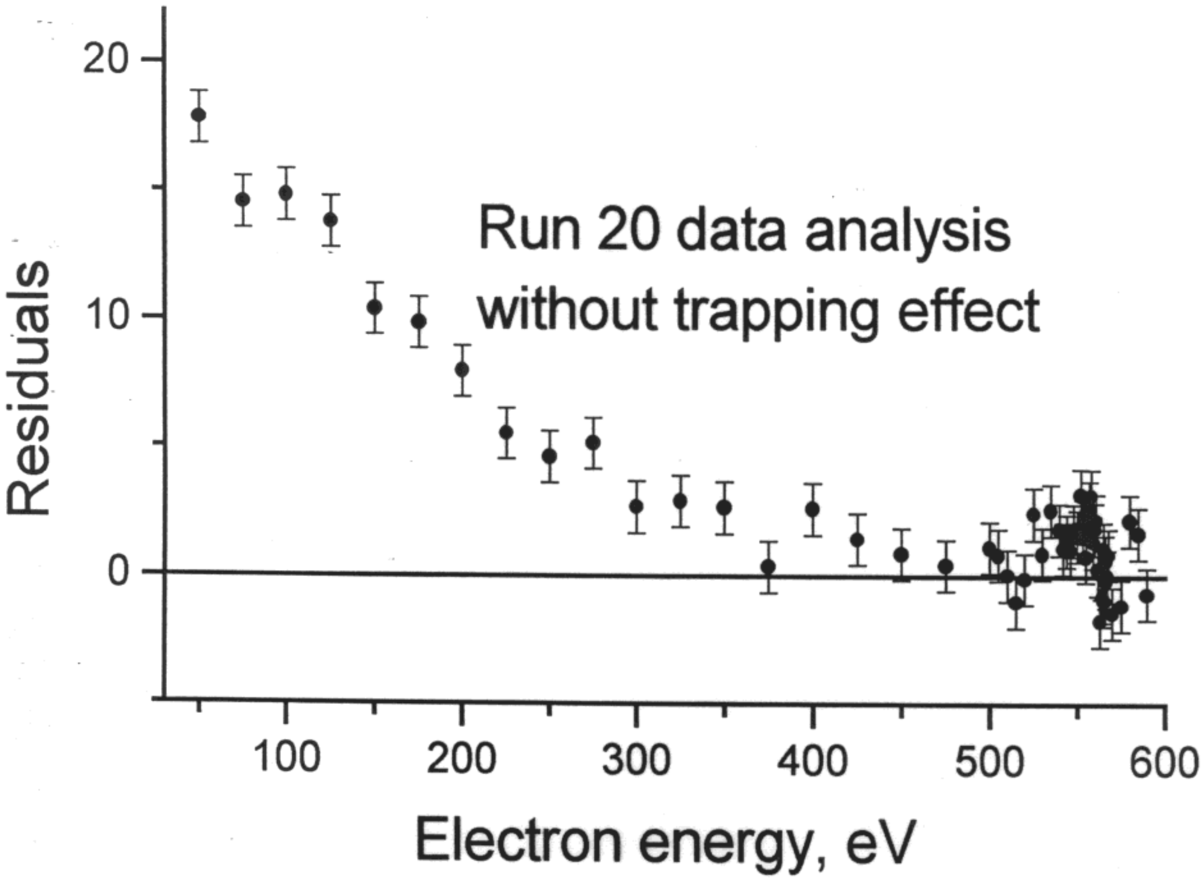
Fit by MINUIT package.



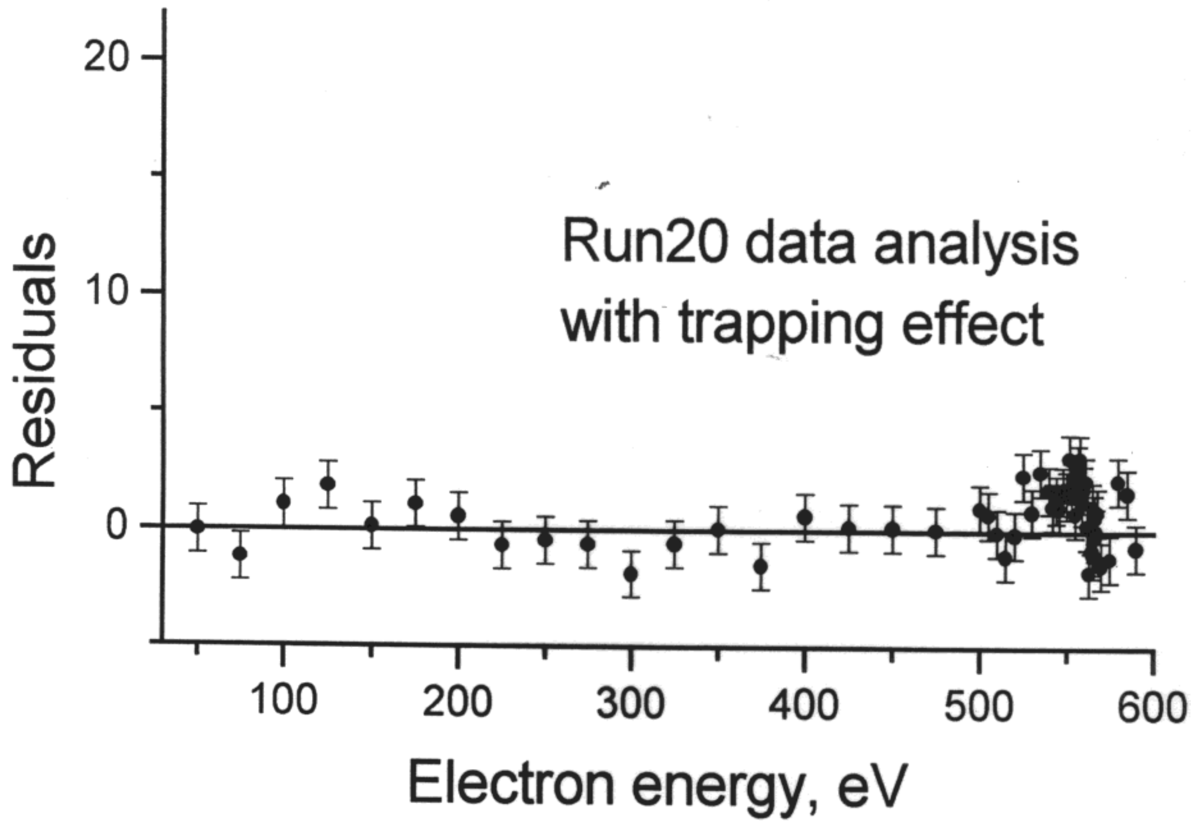
1.0
0.8
0.6
INTEGRATED FIT CURVE
EXPERIMENTAL CURVE
RUN 24 EXPERIMENTAL CURVE
8000
6000
4000
2000
0
COUNT RATE
18200
18300
18400
18500
18600
18700
18800
VOLTAGE
18620
18640
18660
18680
18700
18720
VOLTAGE



A*EXP(-2.*(X-X0)^2/(W^2))
A=1.
X0=-12.6ev
W=2.76ev
excitation/ionization=54% / 46%
IONIZATION THRESHOLD
A/(W^2+4.*(X-X0)^2)
A=59.5
W=14.07ev
X0=-14.28ev
-14.48
1.0
0.5
0.0
-60
-40
-20
0
ENERGY LOSS (ev)

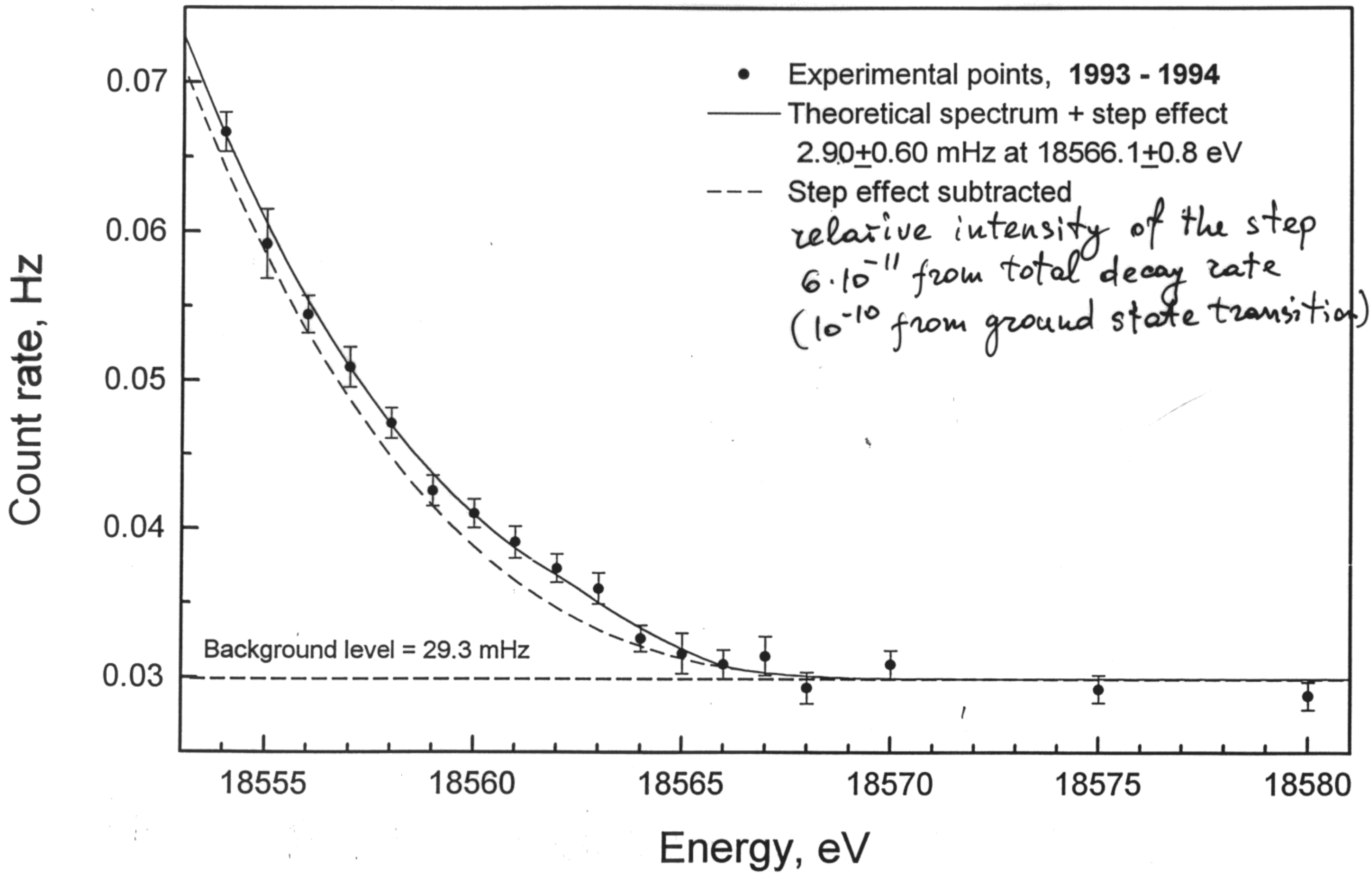


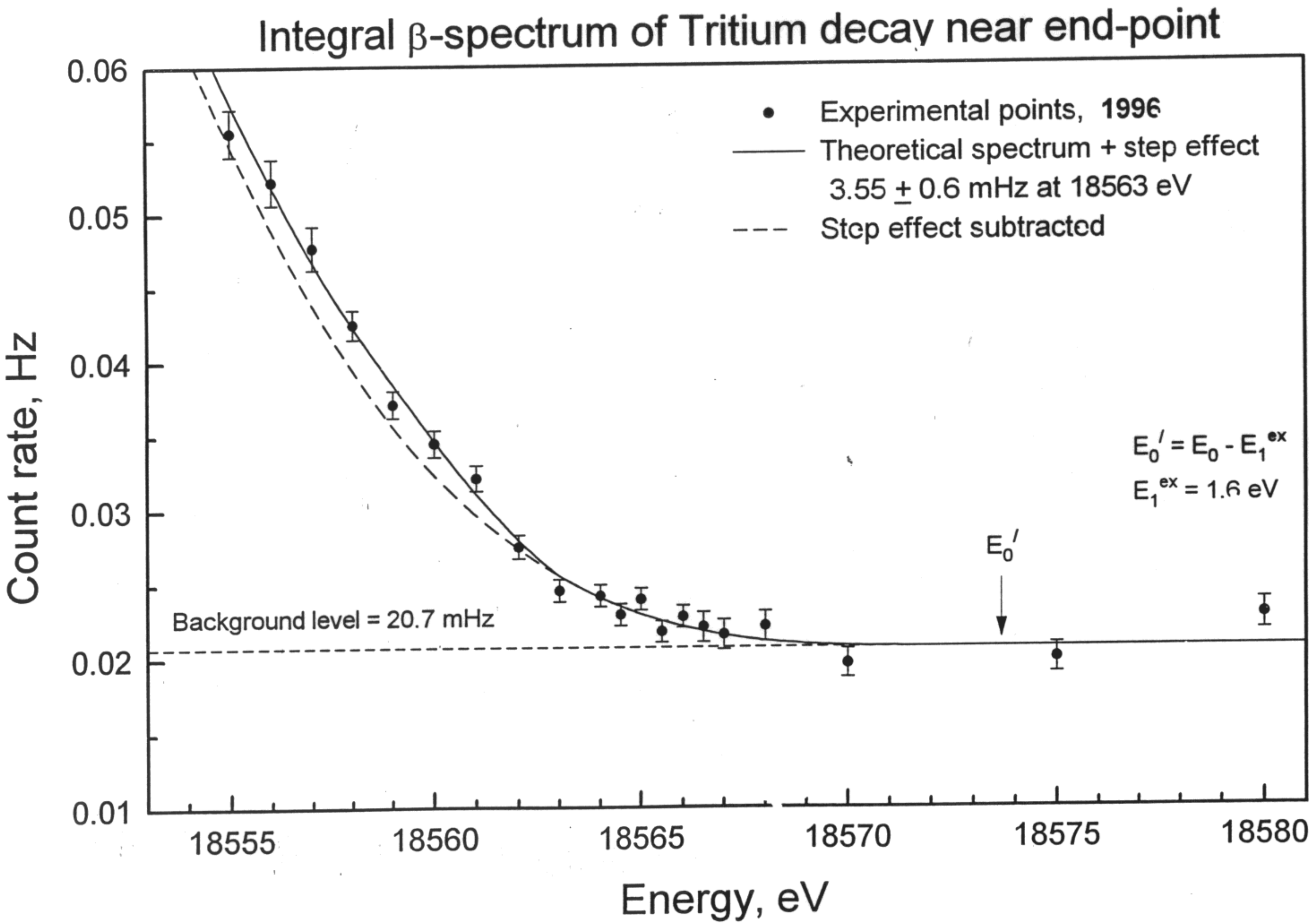
Run 20 data analysis
without trapping effect
Residuals
Electron energy, eV
20
10
0
100
200
300
400
500
600

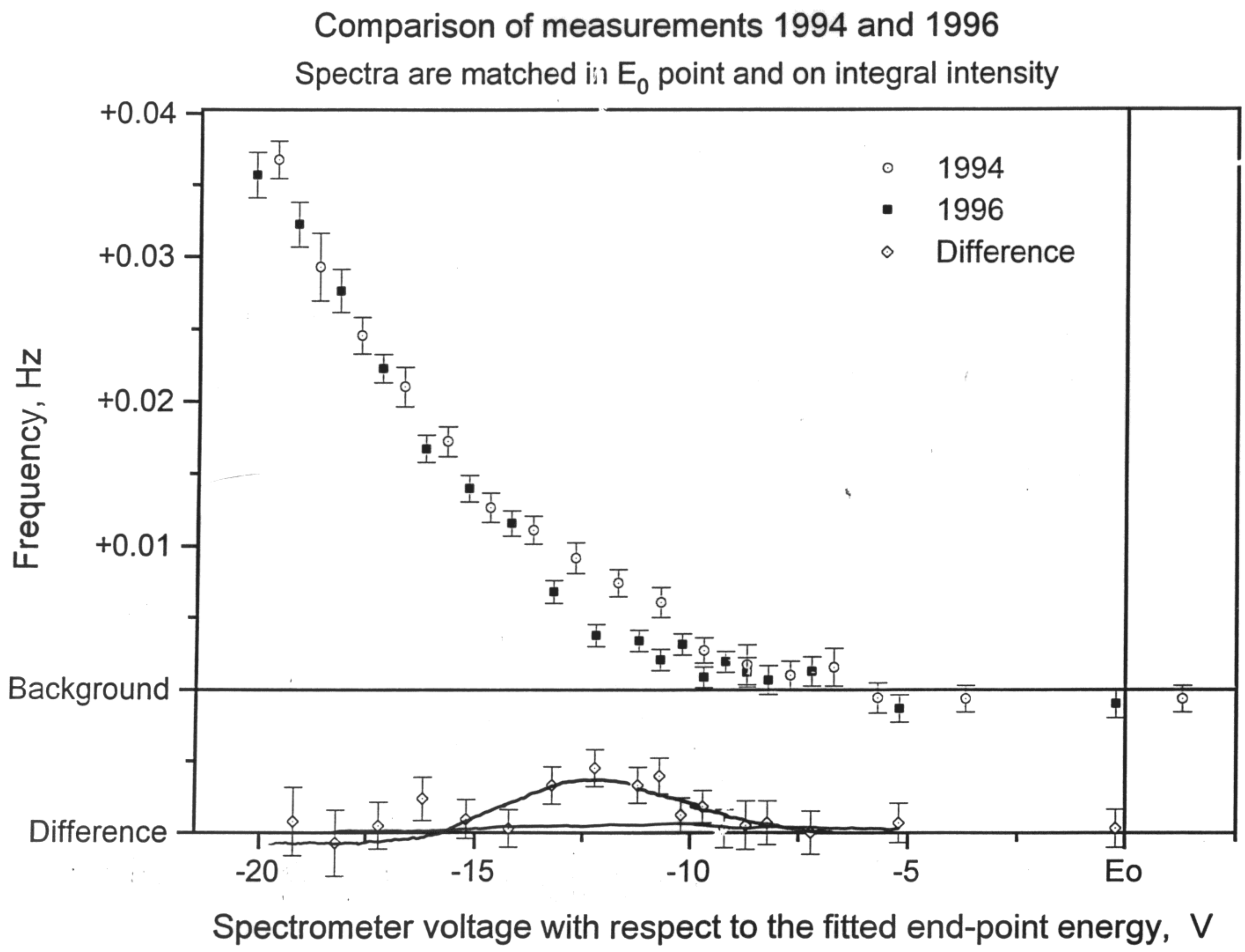


Run20 data analysis
with trapping effect
Residuals
Electron energy, eV
20
10
0
100
200
300
400
500
600

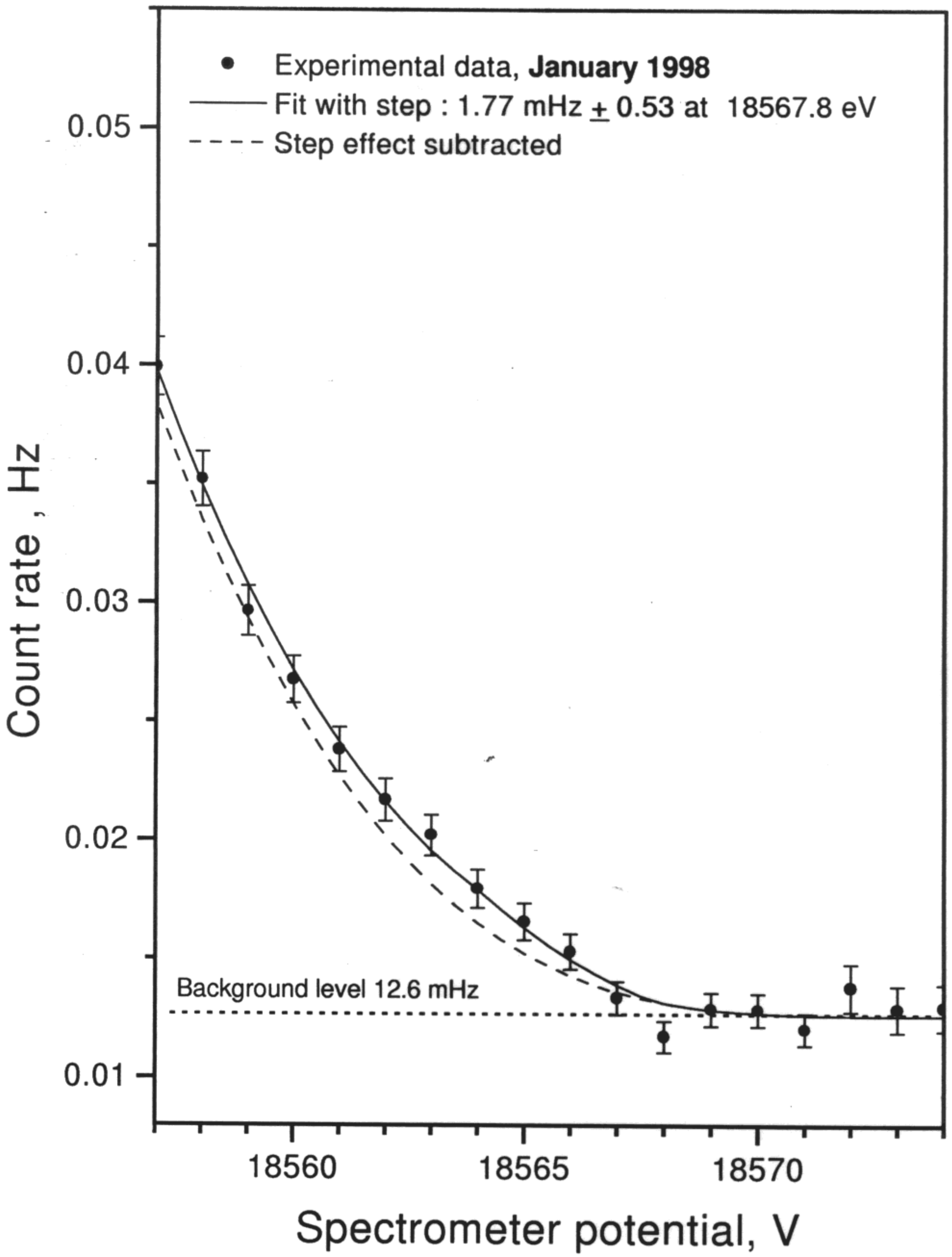
Integral β-spectrum of Tritium decay near end-point



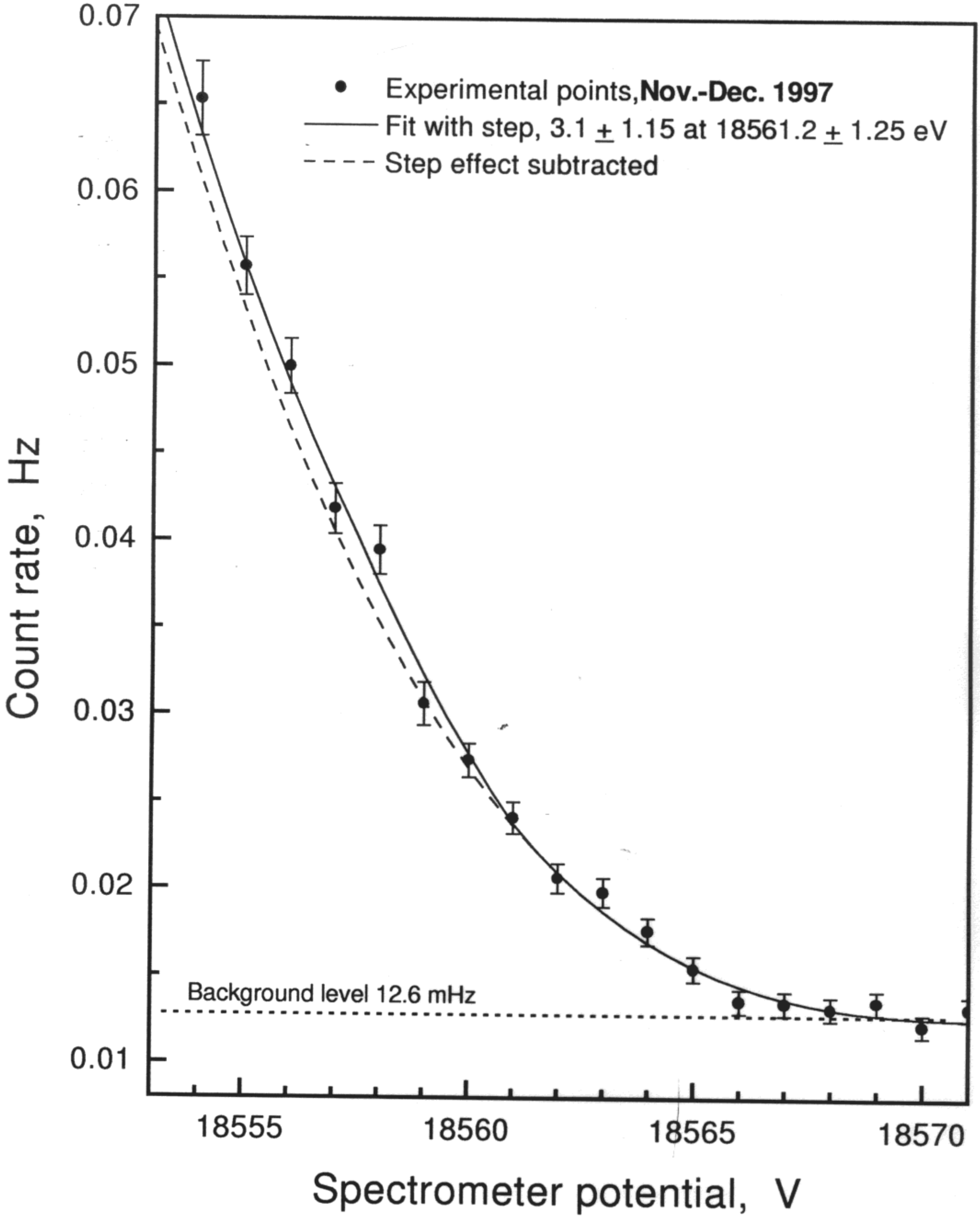

Integral β-spectrum of Tritium decay near end-point
Count rate, Hz
0.06
0.05
0.04
0.03
0.02
0.01
Experimental points, 1996
Theoretical spectrum + step effect
3.55 ± 0.6 mHz at 18563 eV
Step effect subtracted
E0/ = E0 - E1ex
E1ex = 1.6 eV
E0/
Background level = 20.7 mHz
18555
18560
18565
18570
18575
18580
Energy, eV

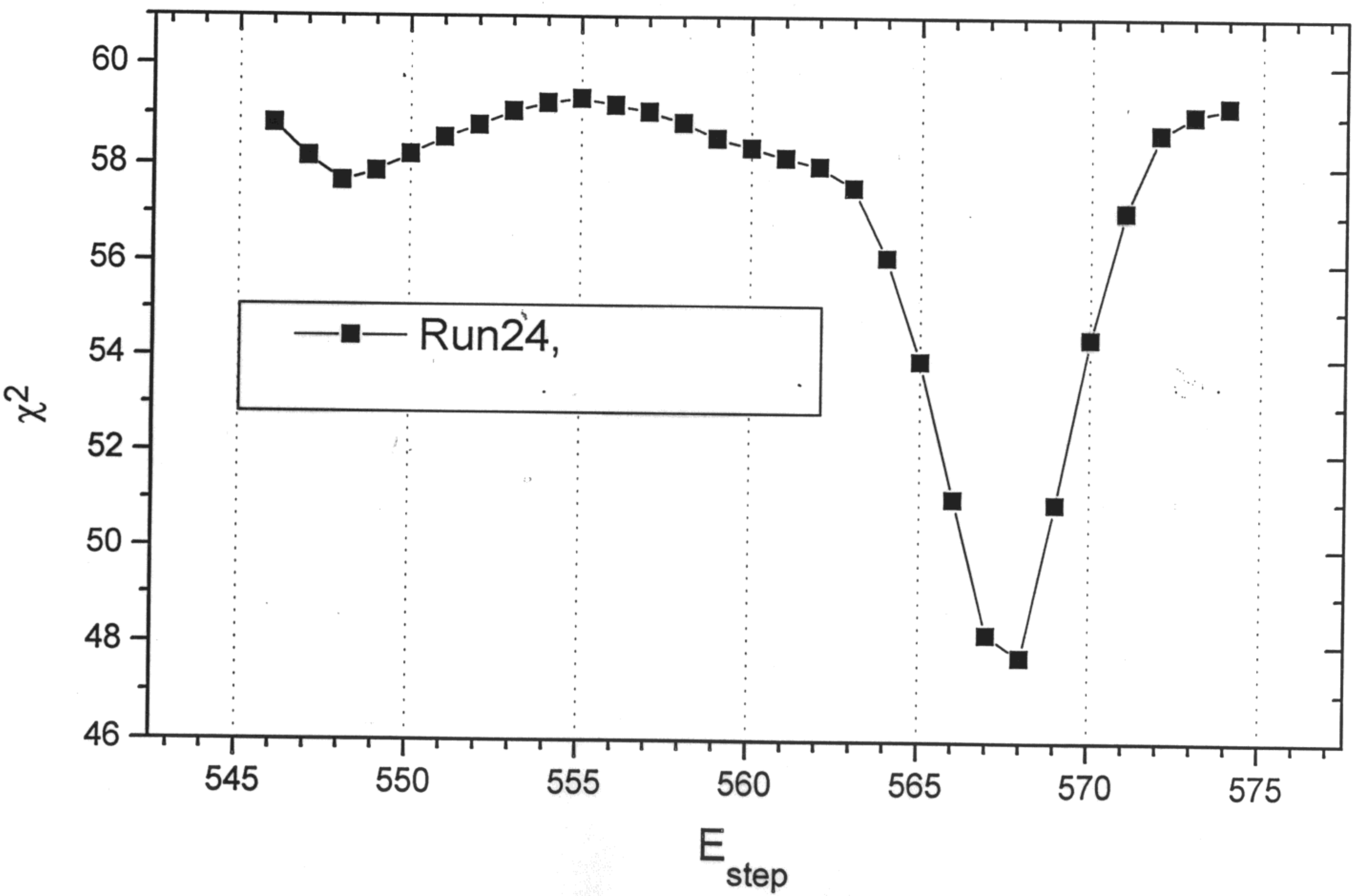


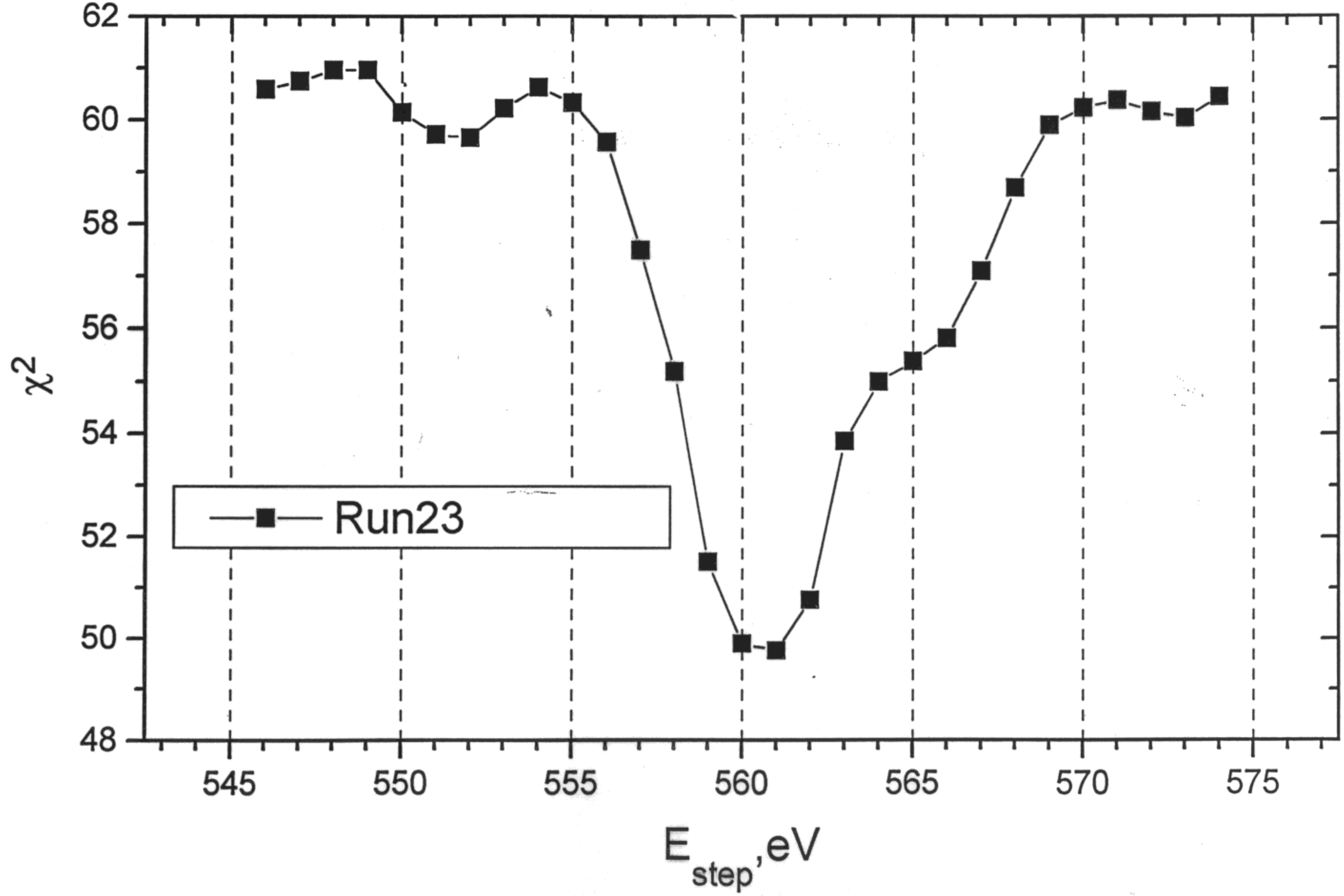
Comparison of measurements 1994 and 1996
Spectra are matched in E_0 point and on integral intensity
Frequency, Hz
+0.04
+0.03
+0.02
+0.01
Background
Difference
1994
1996
Difference
-20
-15
-10
-5
Eo
Spectrometer voltage with respect to the fitted end-point energy, V



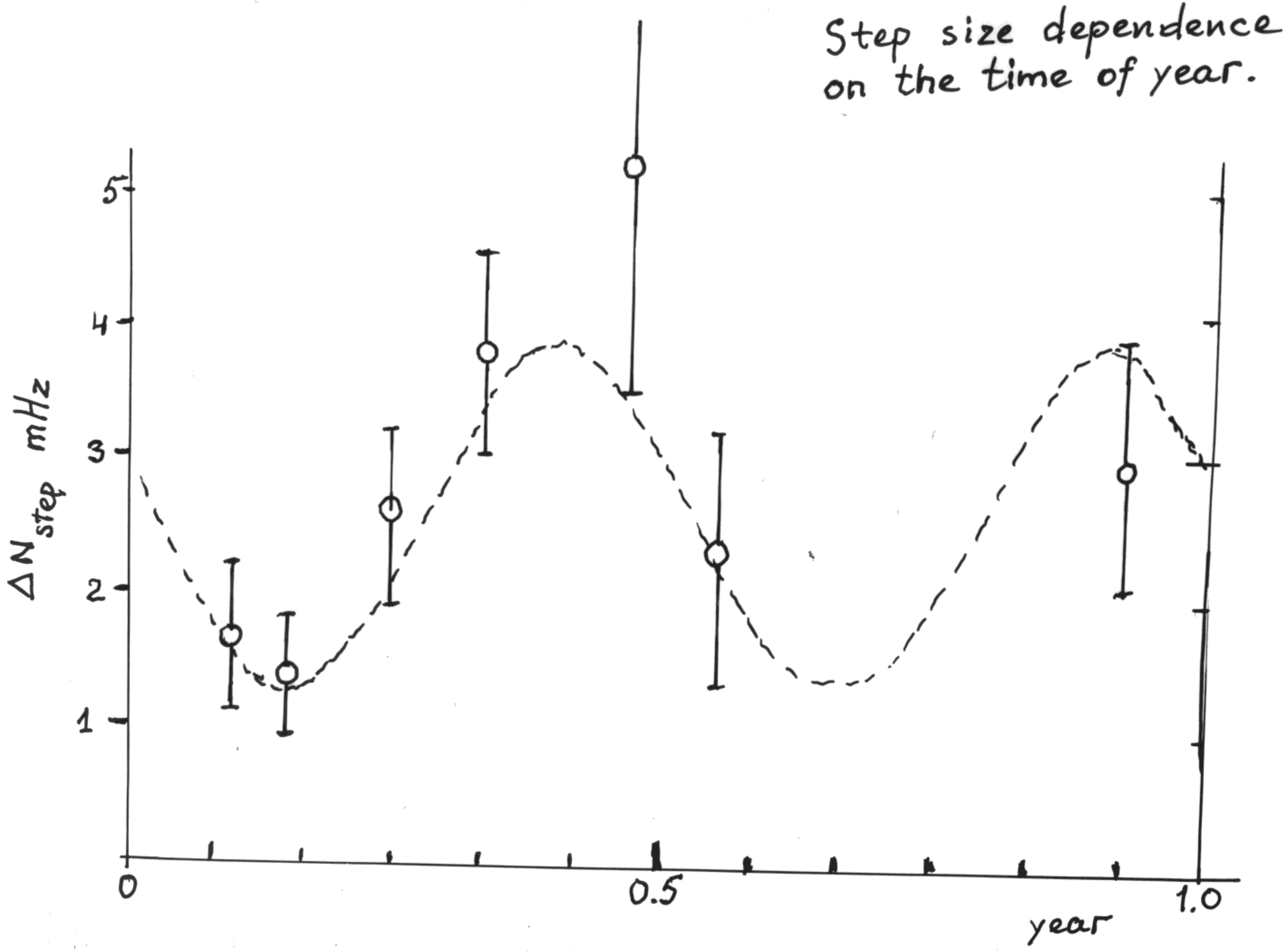
Experimental data, **January 1998**
Fit with step : 1.77 mHz ± 0.53 at 18567.8 eV
Step effect subtracted
Background level 12.6 mHz
0.05
0.04
0.03
0.02
0.01
Count rate , Hz
18560
18565
18570
Spectrometer potential, V


0.07
0.06
0.05
0.04
0.03
0.02
0.01
Count rate, Hz
Experimental points, **Nov.-Dec. 1997**
Fit with step, 3.1 ± 1.15 at 18561.2 ± 1.25 eV
Step effect subtracted
Background level 12.6 mHz
18555
18560
18565
18570
Spectrometer potential, V

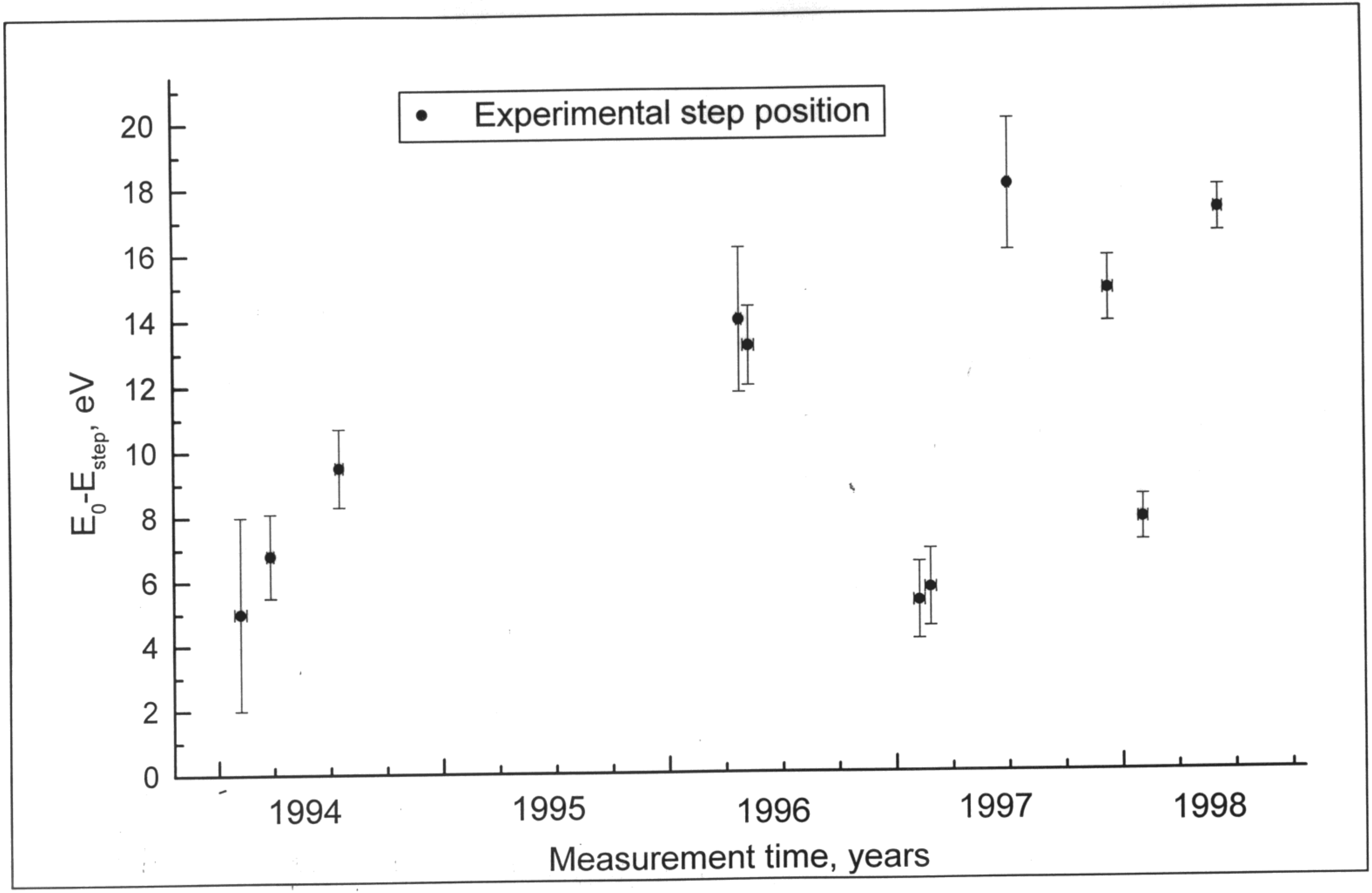

Run24,
60
58
56
54
52
50
48
46
χ2
545
550
555
560
565
570
575
Estep



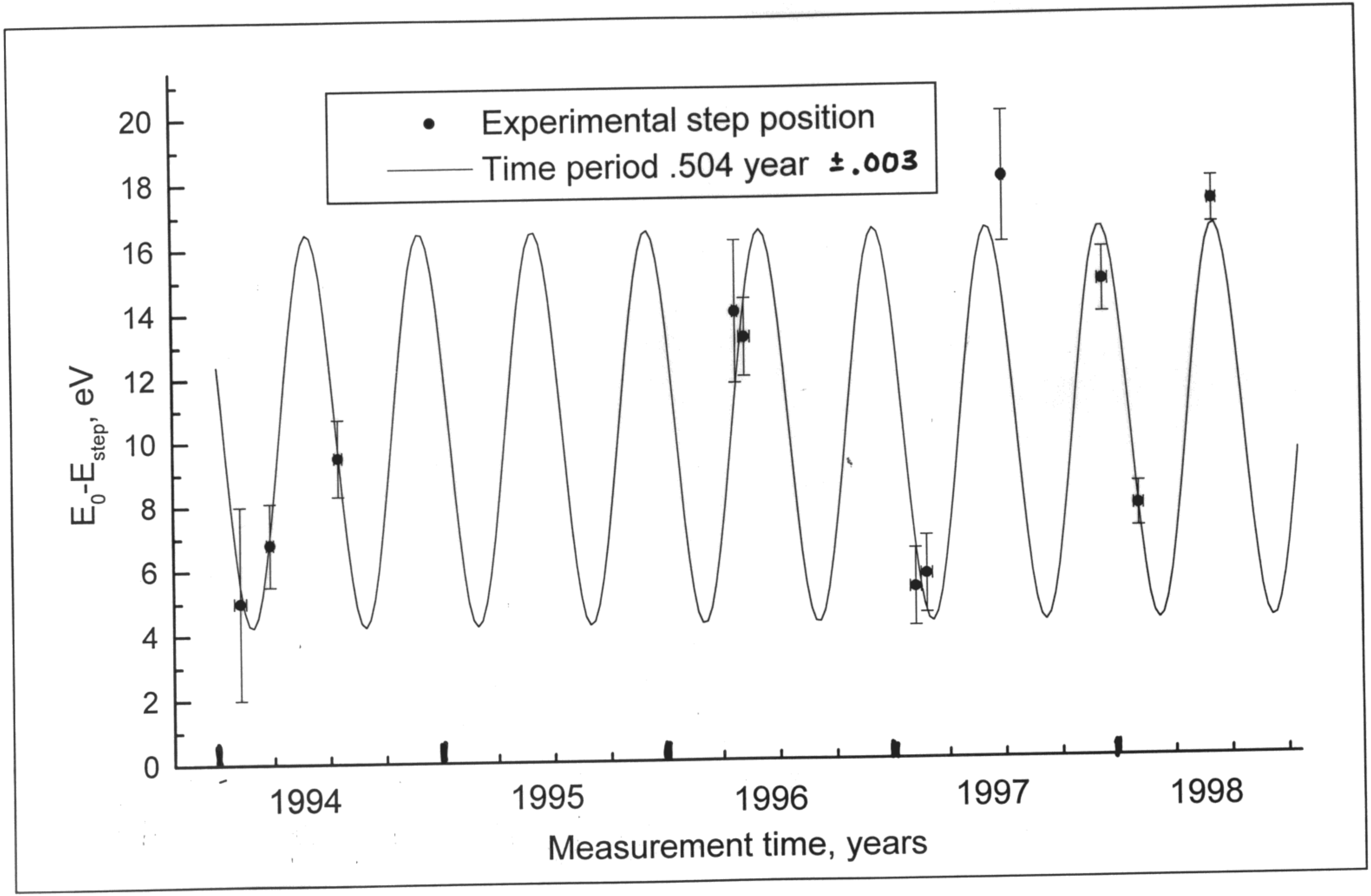
62
60
58
56
54
52
50
48
χ2
Run23
545
550
555
560
565
570
575
E step ,eV



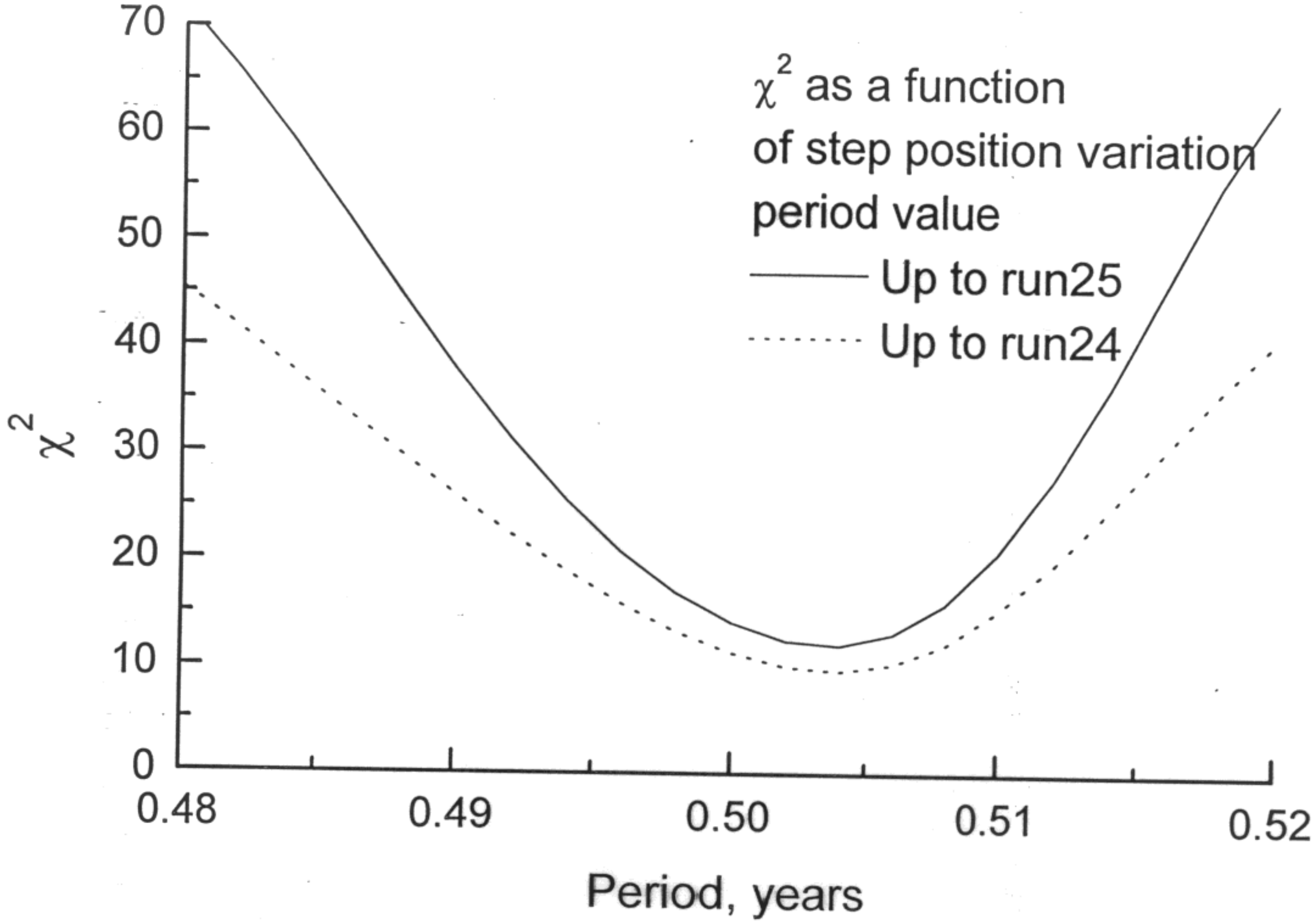
Step size dependence
on the time of year.
ΔN step mHz
1
2
3
4
5
0
0.5
1.0
year



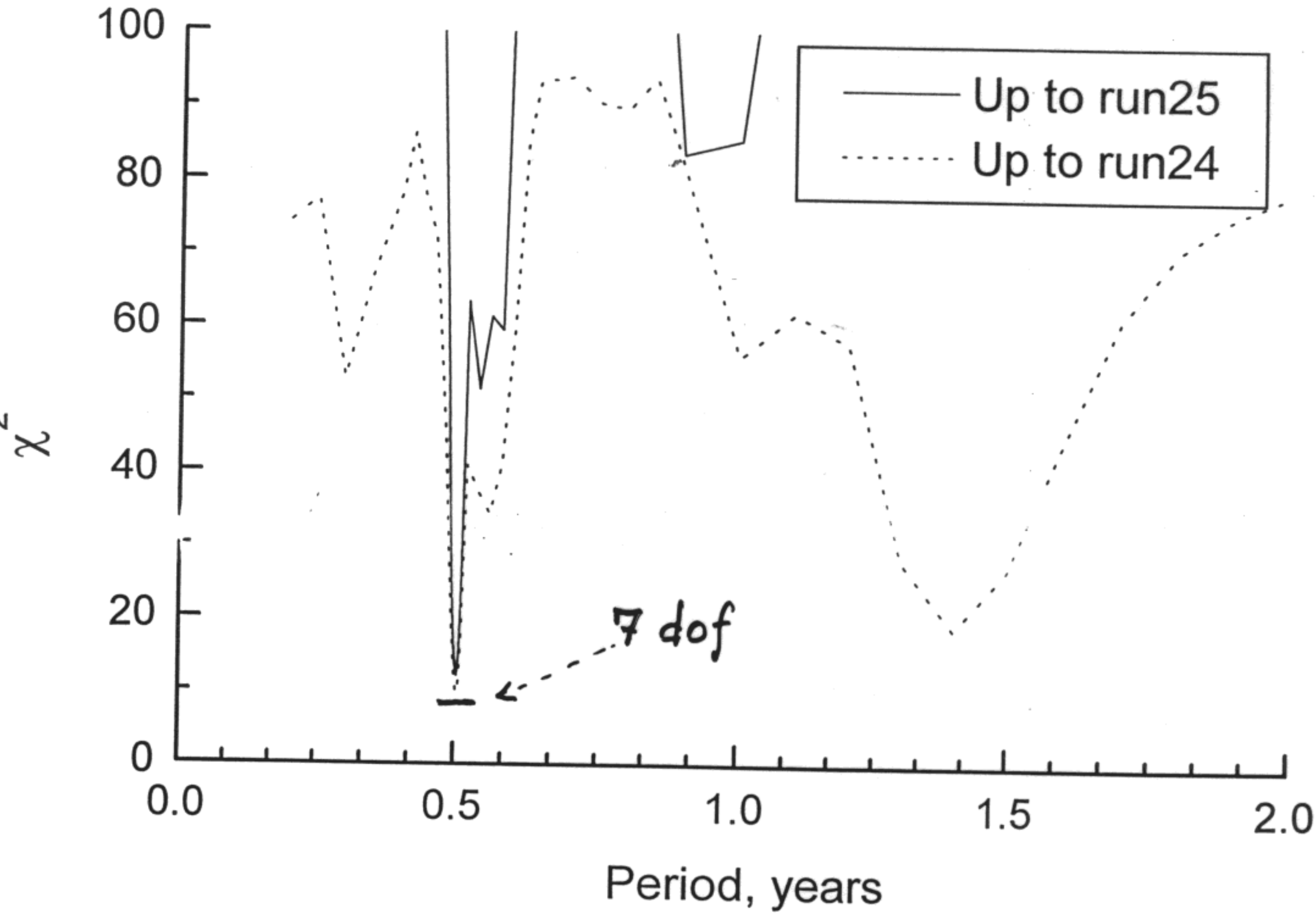
Experimental step position
E_0-E_{step}, eV
0
2
4
6
8
10
12
14
16
18
20
1994
1995
1996
1997
1998
Measurement time, years



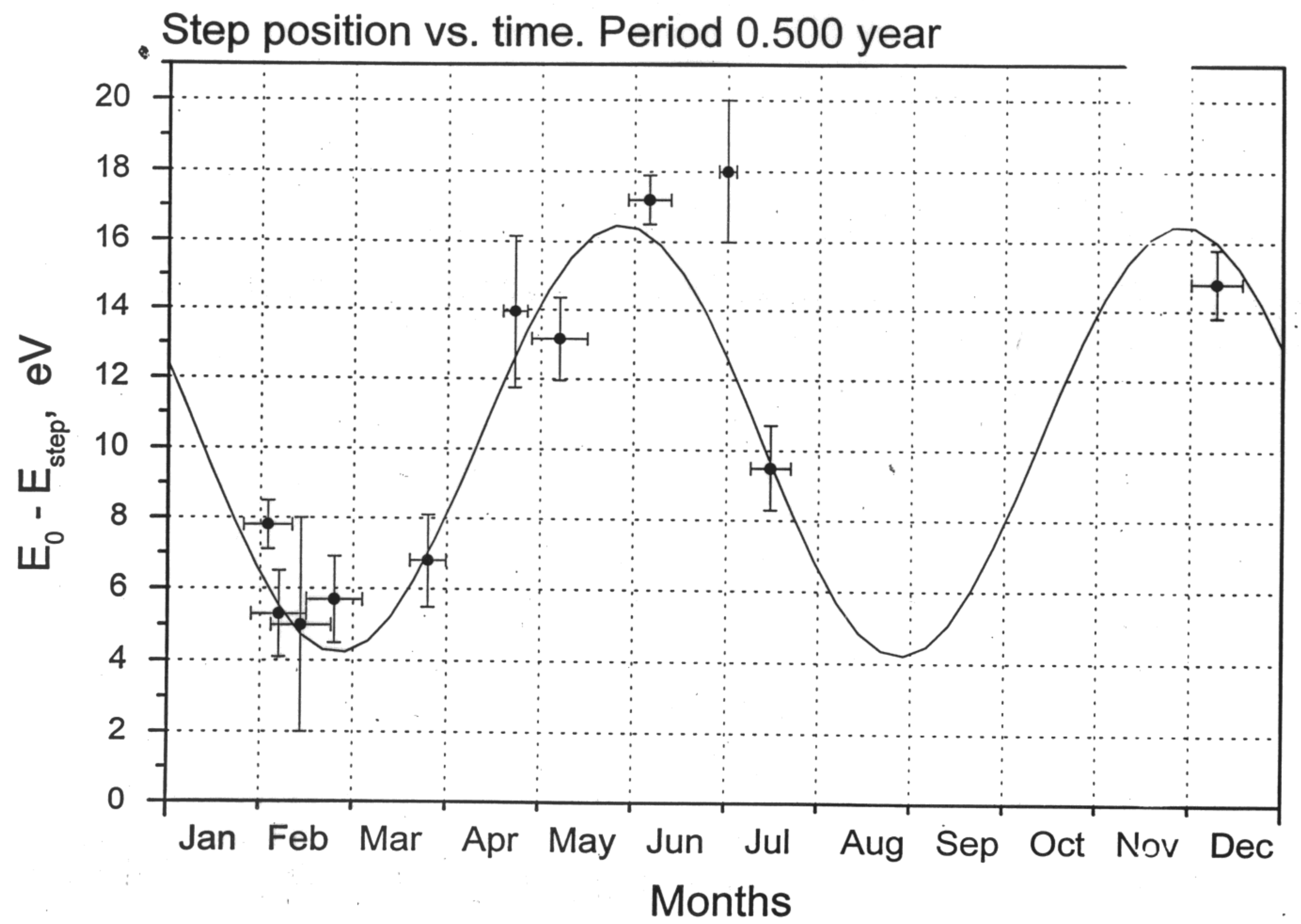
Experimental step position
Time period .504 year ±.003
E_0-E_{step}, eV
0
2
4
6
8
10
12
14
16
18
20
1994
1995
1996
1997
1998
Measurement time, years



70
60
50
40
30
20
10
0
χ^2
0.48
0.49
0.50
0.51
0.52
Period, years
χ^2 as a function
of step position variation
period value
Up to run25
Up to run24



100
80
60
40
20
0
χ^2
0.0
0.5
1.0
1.5
2.0
Period, years
Up to run25
Up to run24
7 dof


Step position vs. time. Period 0.500 year
E0 - Estep, eV
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Features of the bump (step) effect.

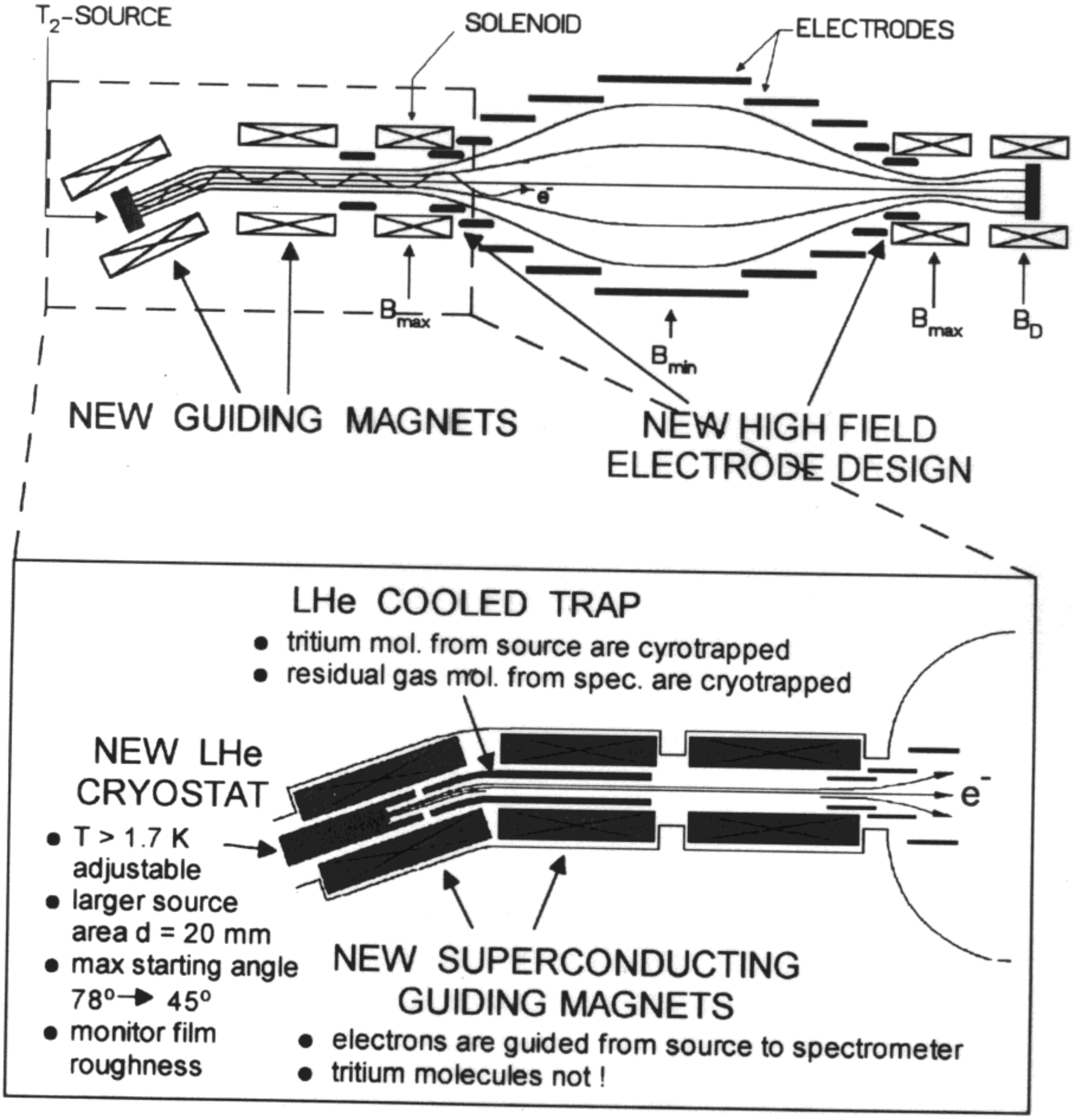
1. Width ≤ 7 eV. (From comparison of Runs 94-96).
2. Integral intensity $\sim 1.0 \cdot 10^{-10}$ of ground state transition intensity.
3. Energy position $E_{step} = 5 \div 15$ eV below end point, periodically varying with calendar time.
4. Period of variation 0.504 ± 0.003 years.
   Intensity correlates with the energy position. (partially)
5. Phase of variation corresponding to max E_{step} at 1-10 June and 1-10 December.
6. No dependence on the magnetic field setting in the spectrometer and source.
7. Bias of the source voltage (+15V) shifts the bump together with spectrum.
8. No radioactive admixture in the source.
   Admixture of T^0, T^-, T_3^+ in the source $<< 10^{-4}$.

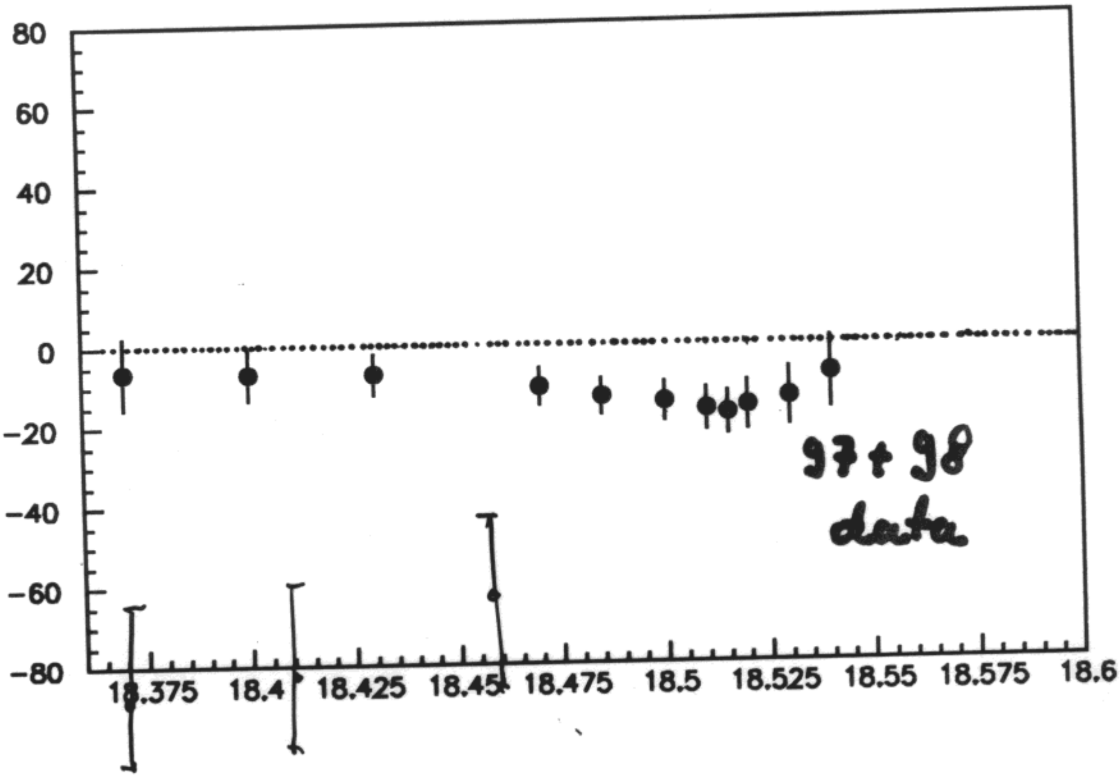
New feature – change in a week scale.

There is no rational explanation of this phenomenon by some systematics or **known** effects.

Exotic (irrational) explanations appears to be excusable in this situation.

The improved Mainz Setup

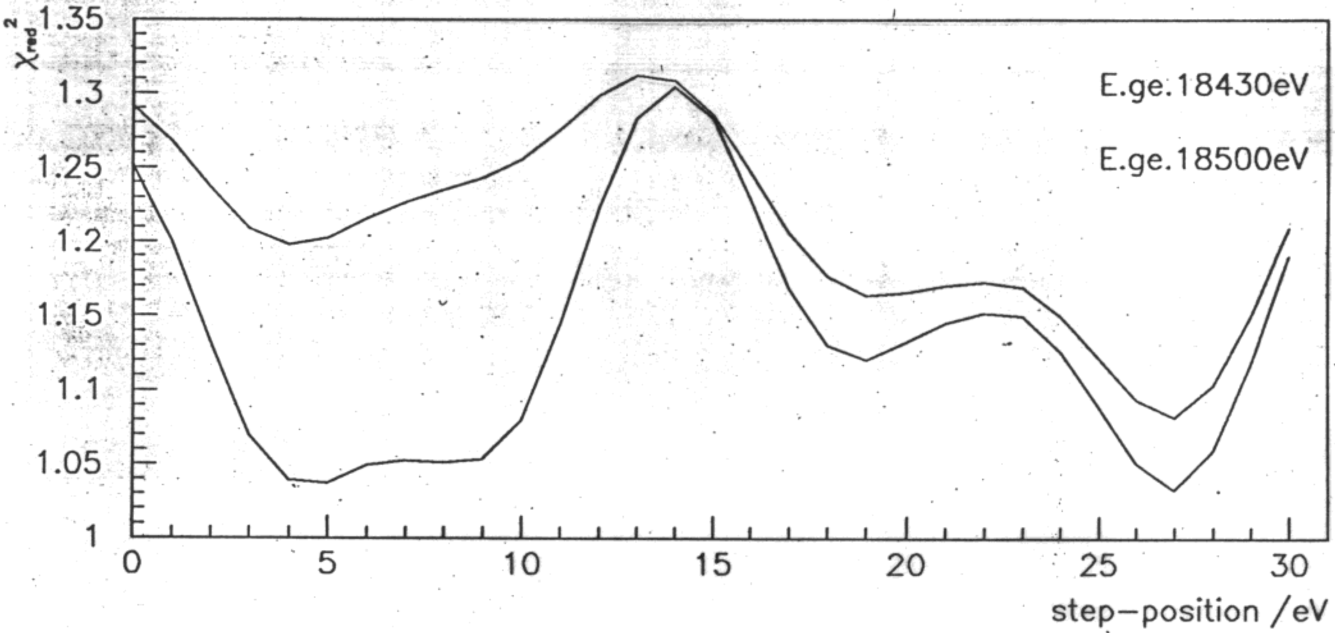


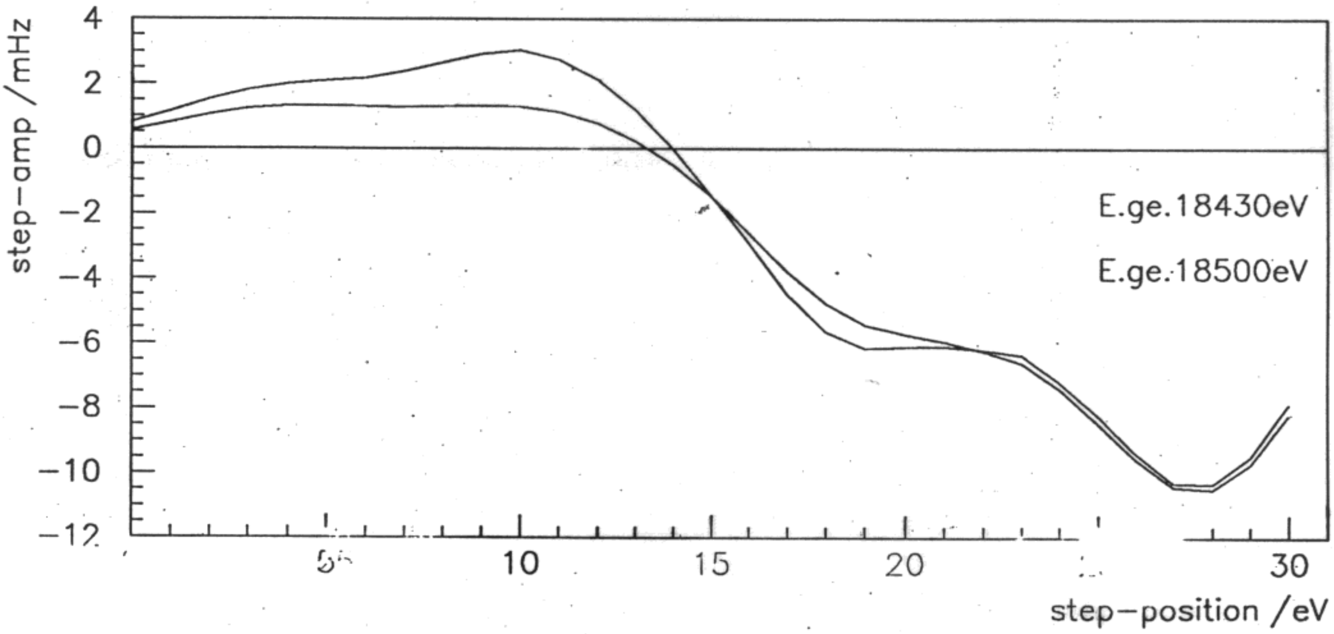


80
60
40
20
0
-20
-40
-60
-80
18.375
18.4
18.425
18.45
18.475
18.5
18.525
18.55
18.575
18.6
97 + 98
data

93 (spring 98)

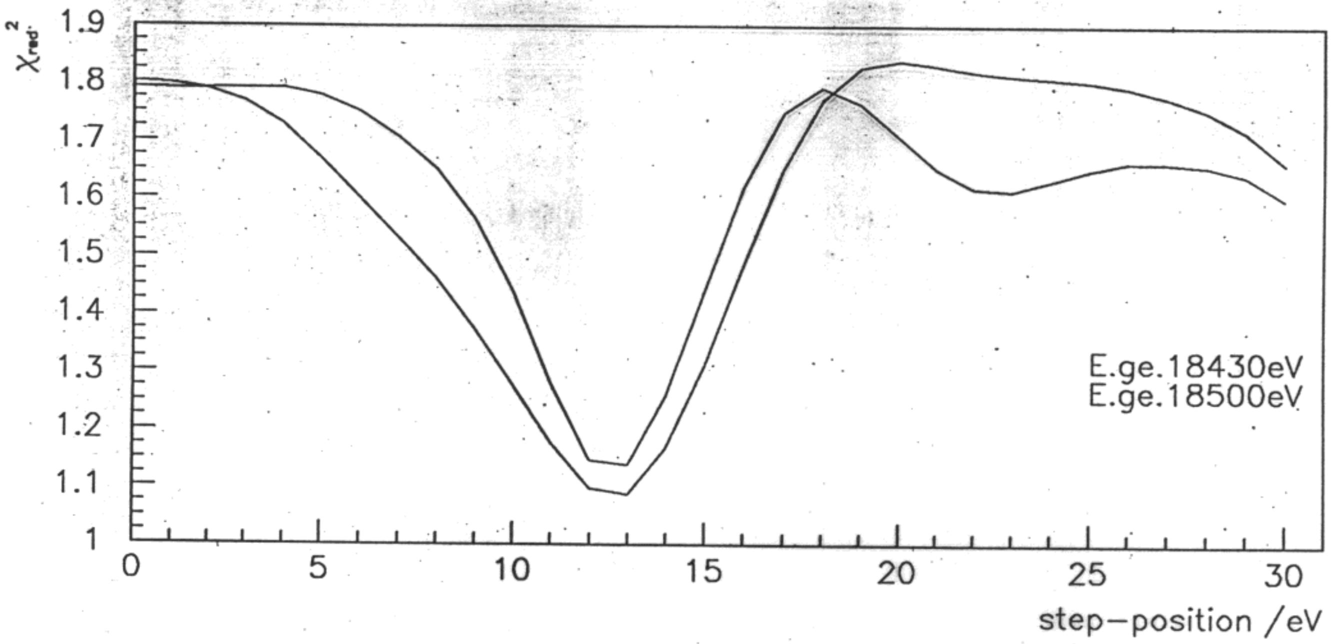
$m^2 = 0$ fixed

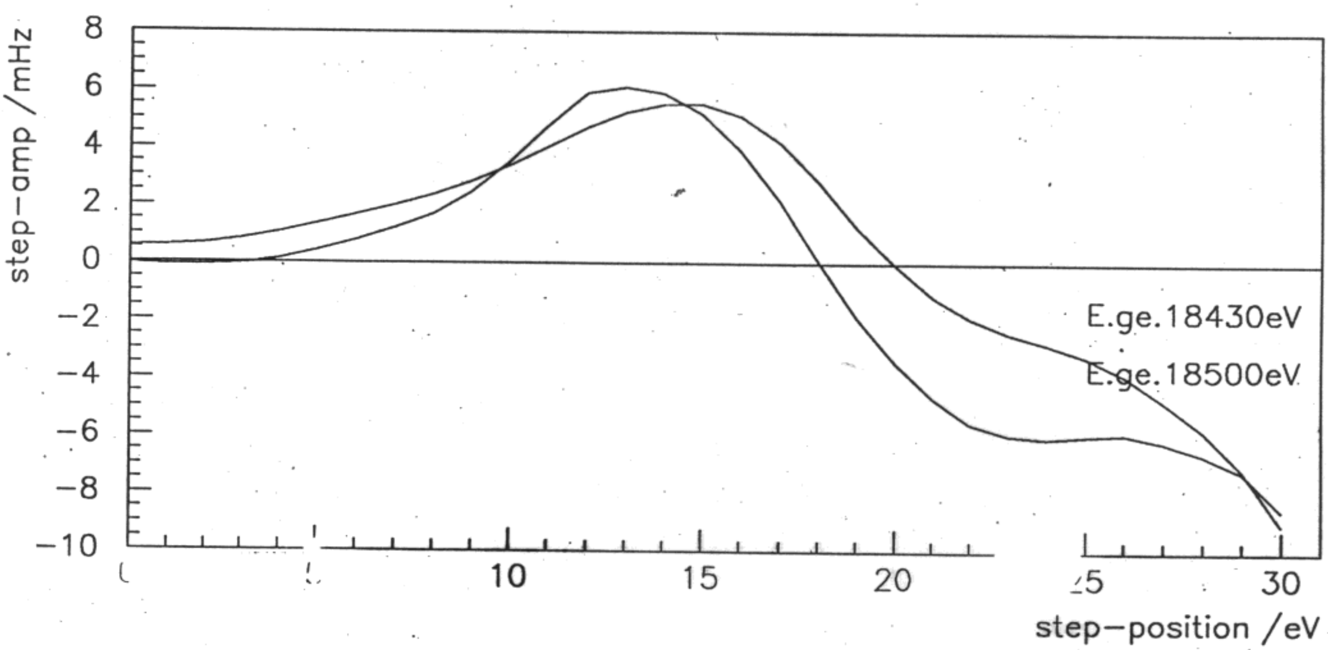


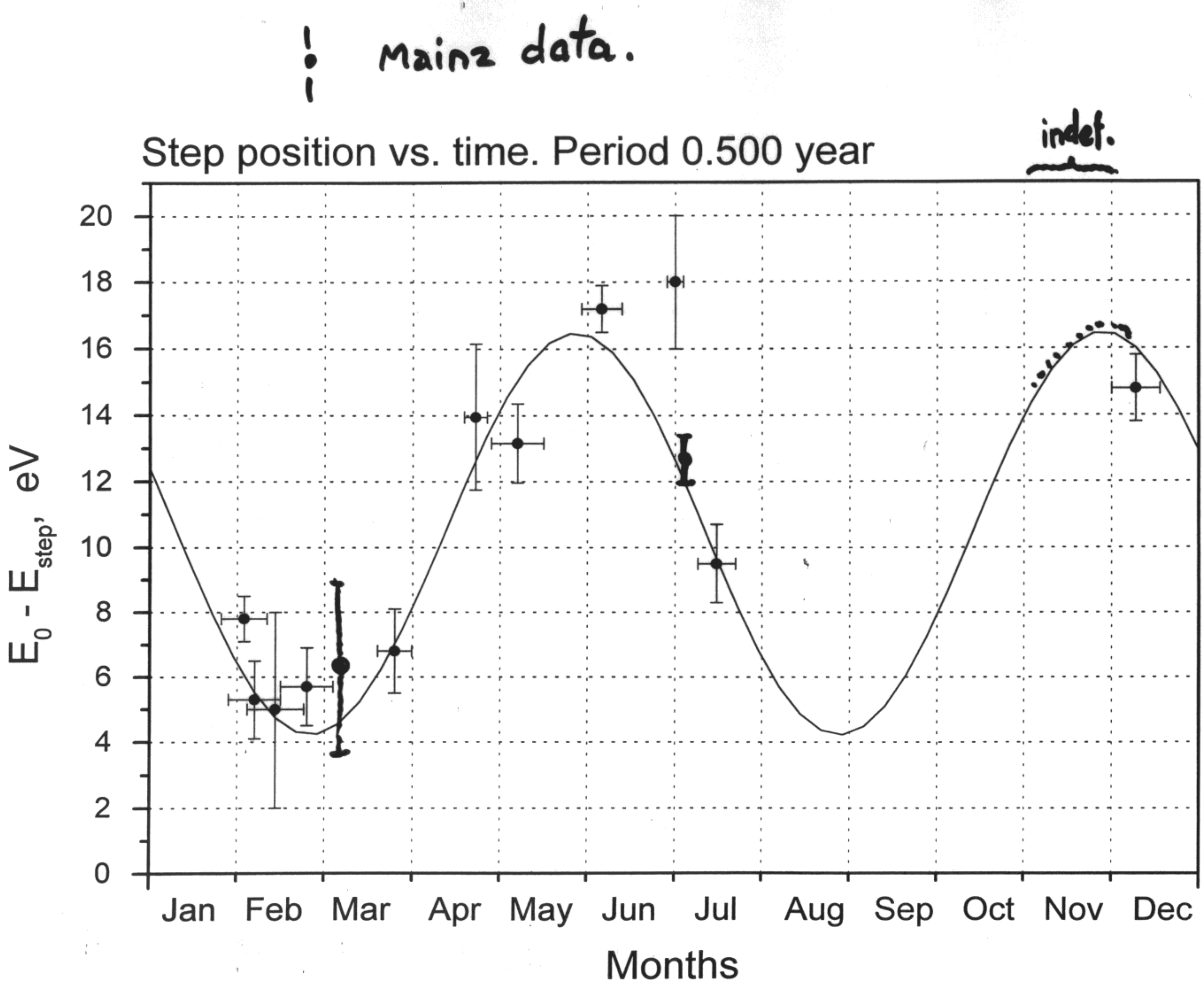


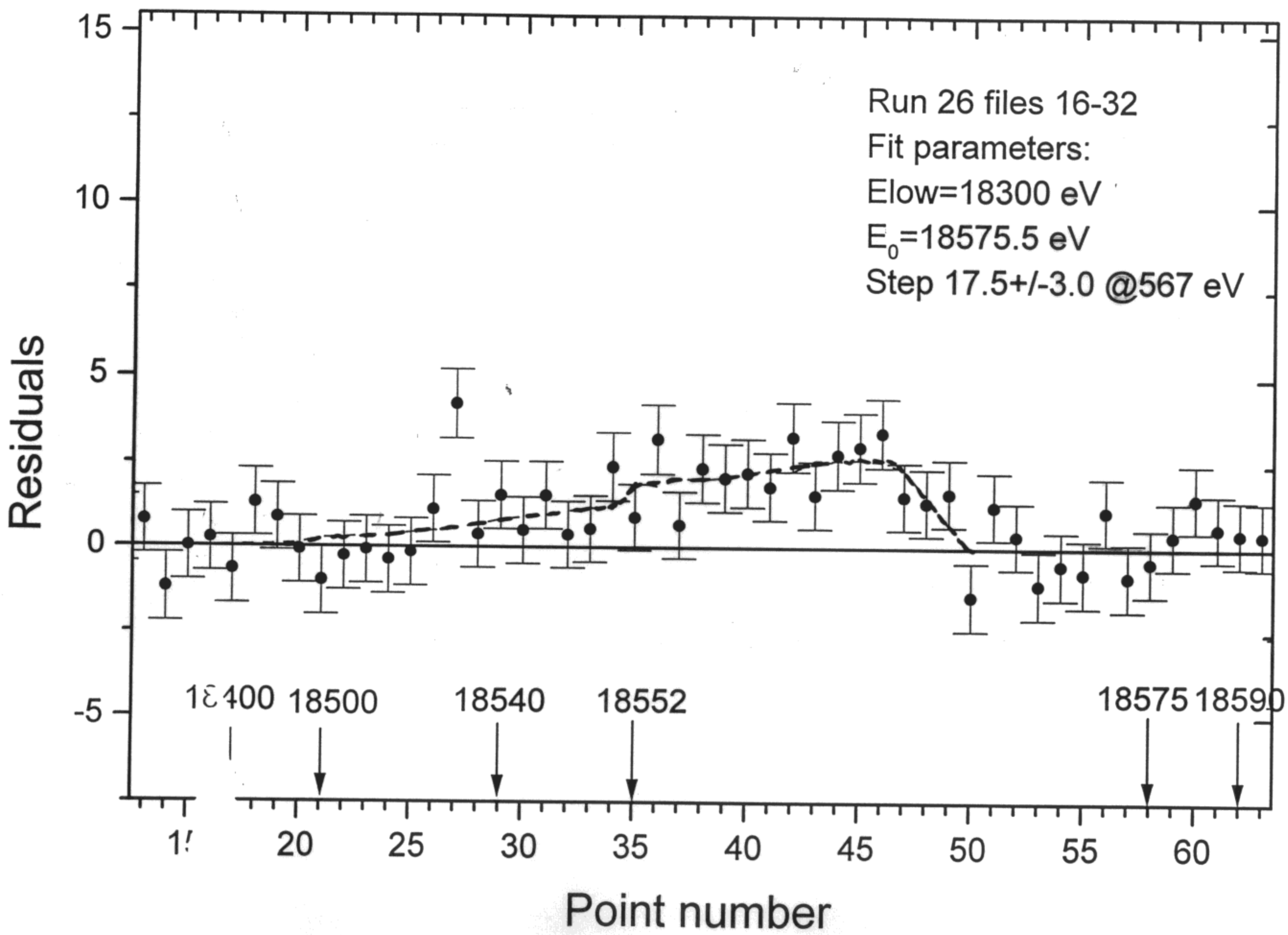
94 (summer 98)

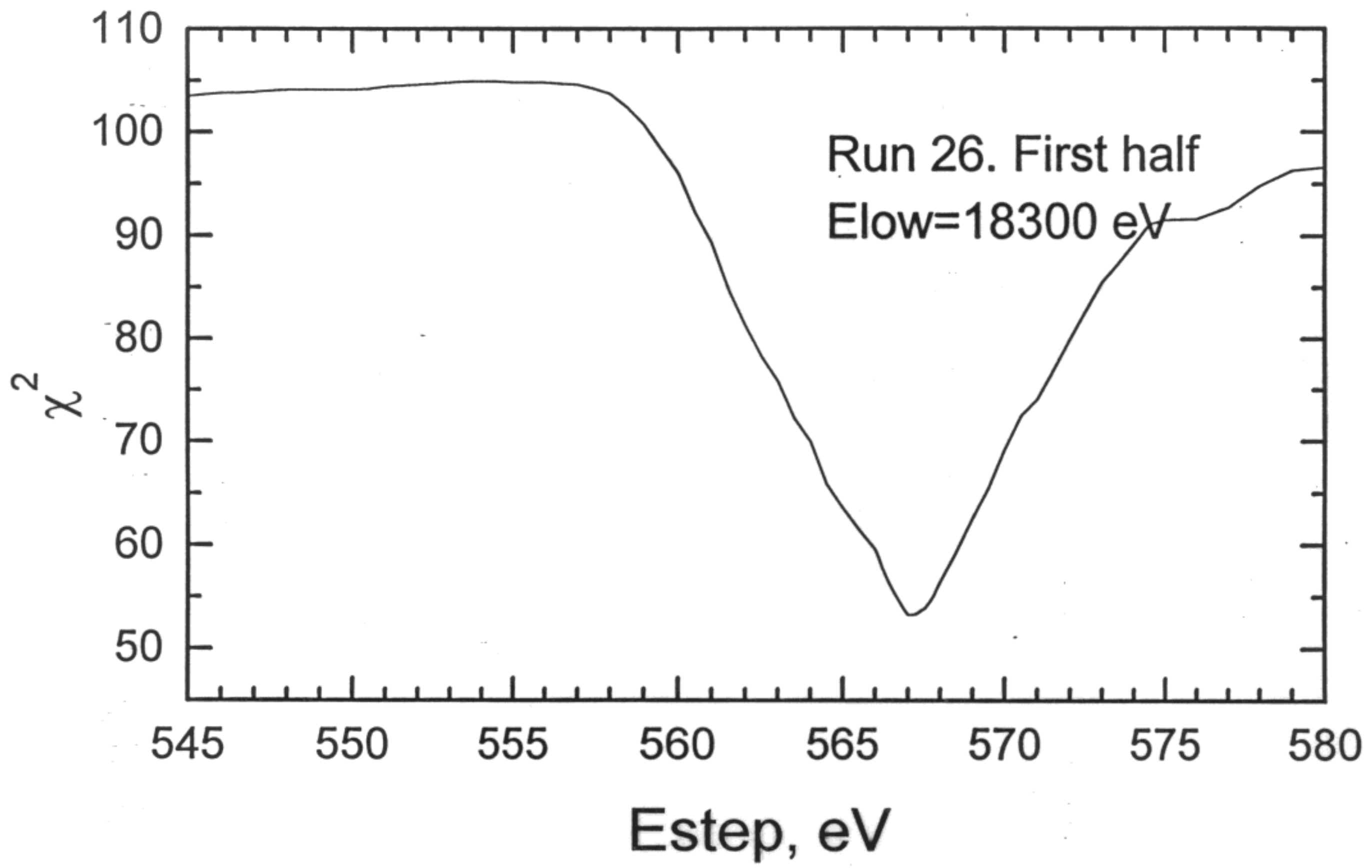
$m^2 = 0$ fixed



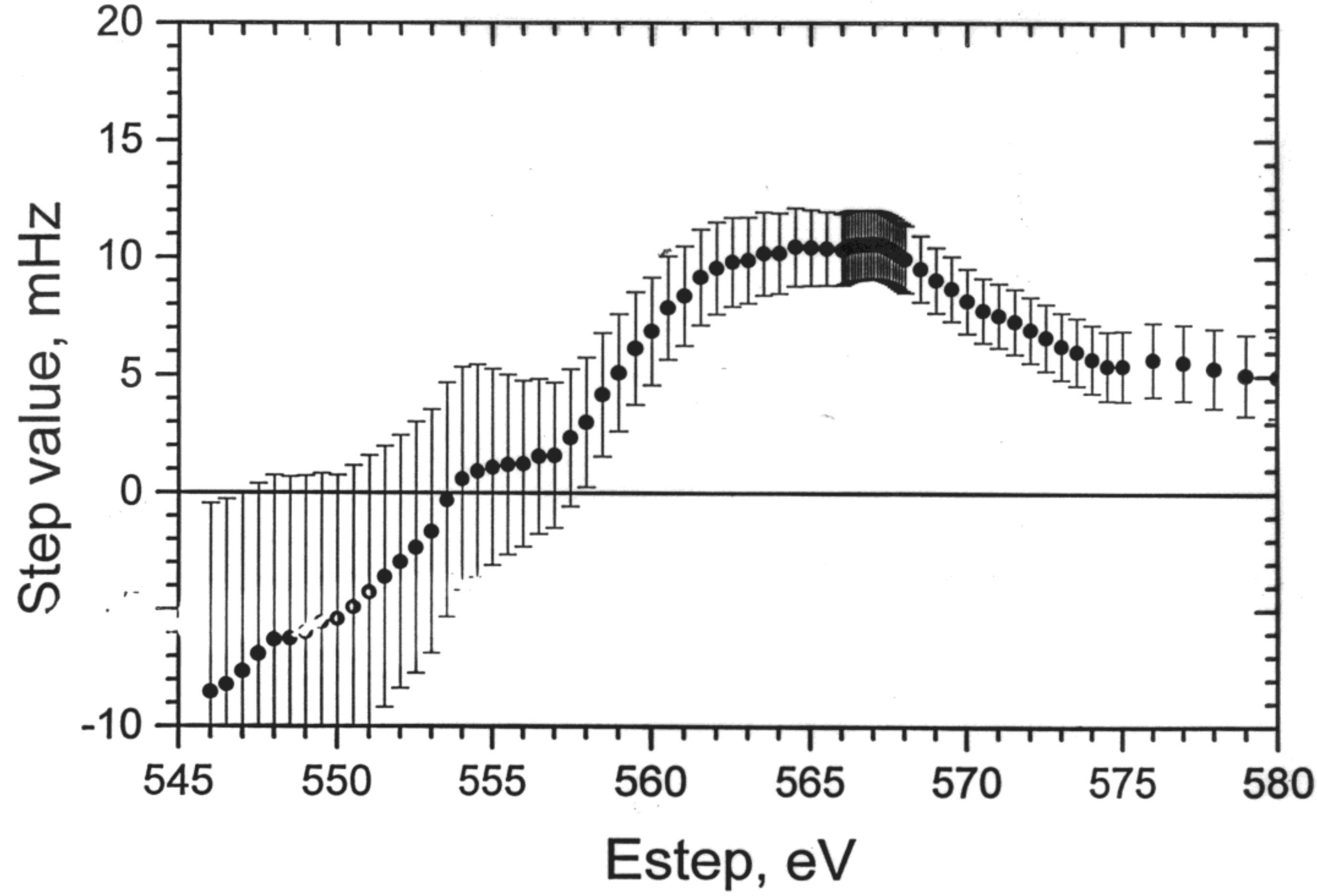



Mainz data.
Step position vs. time. Period 0.500 year
indef.
$E_0 - E_{step}$, eV
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

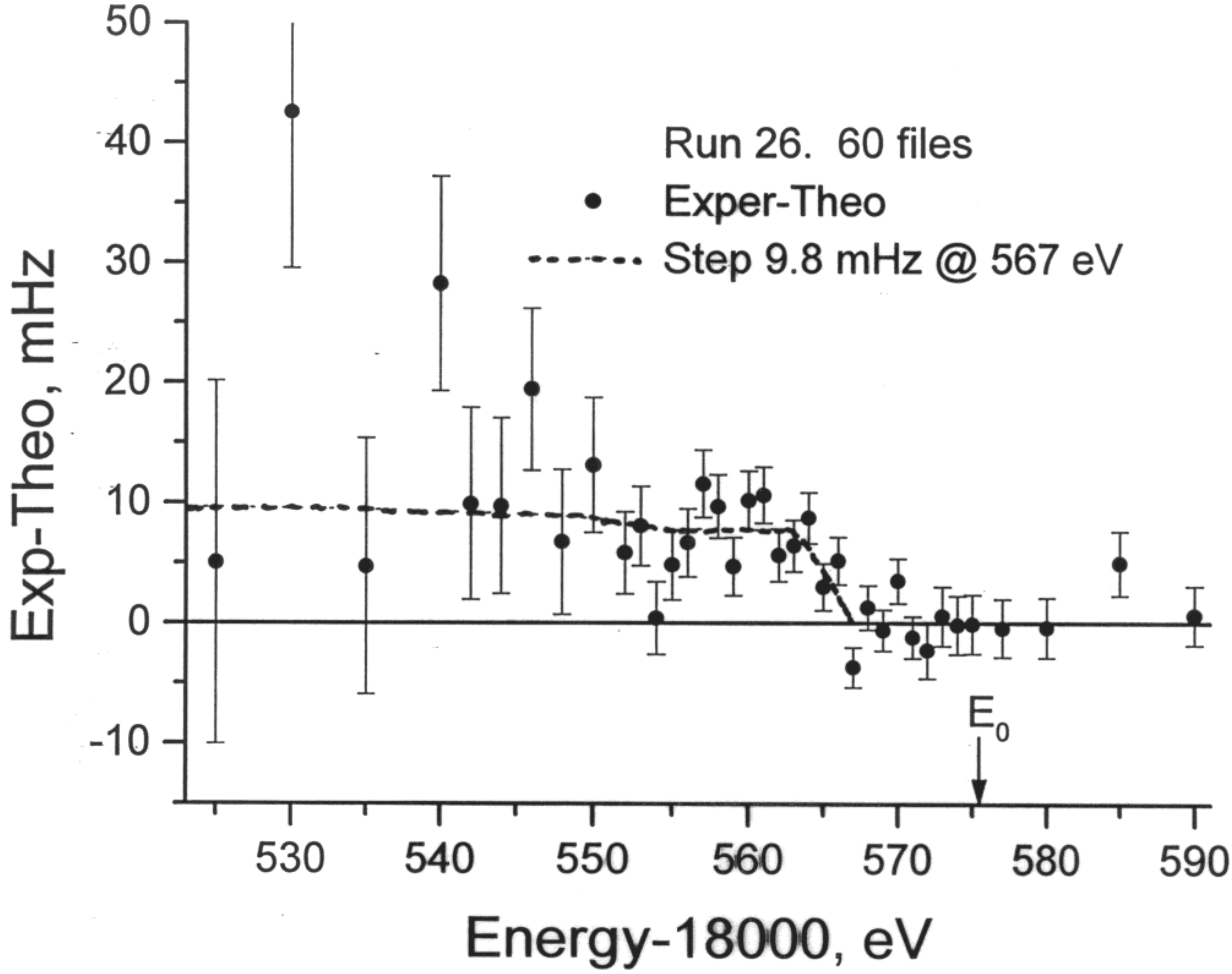

Run 26 files 16-32
Fit parameters:
Elow=18300 eV
E0=18575.5 eV
Step 17.5+/-3.0 @567 eV
Residuals
Point number
18500
18540
18552
18575
18590



Run 26. First half
Elow=18300 eV
χ^2
110
100
90
80
70
60
50
545
550
555
560
565
570
575
580
Estep, eV



Step value, mHz
20
15
10
5
0
-10
545
550
555
560
565
570
575
580
Estep, eV



Run 26. 60 files
Exper-Theo
Step 9.8 mHz @ 567 eV
Exp-Theo, mHz
Energy-18000, eV
E0
50
40
30
20
10
0
-10
530
540
550
560
570
580
590

Exotic explanation of the bump (step) by the old speculation.

Capture of the relic neutrino

$$\nu + {}^3H \rightarrow {}^3He + e + Q \qquad \sigma = 0.77 \cdot 10^{-44}\, cm^2$$

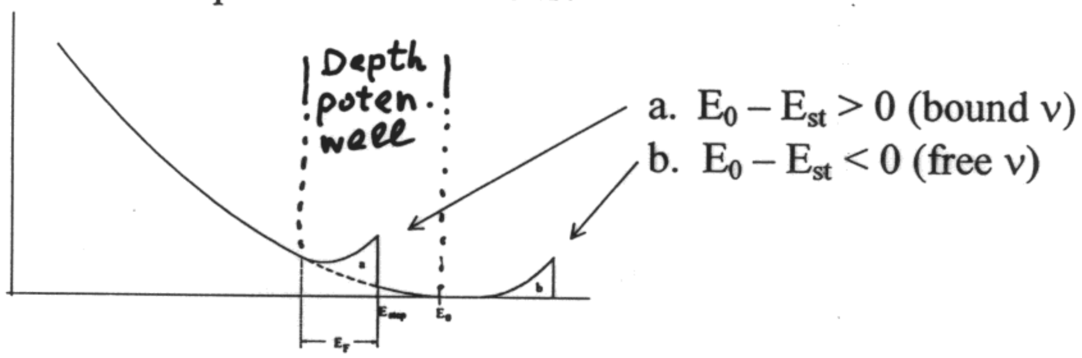
No energy threshold for ν-capture. But!

Branching ratio 10^{-10} corresponds to: $0.5 \cdot 10^{15}$ ν/cm^3

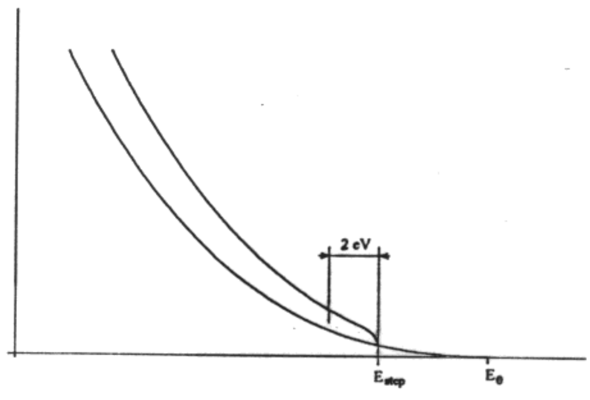
(average cosmological $\sim 10^2$ ν/cm^3).

If ν are cold and degenerated $E_{Fermi} \approx 5 \div 6$ eV.

Differential spectrum of electrons:

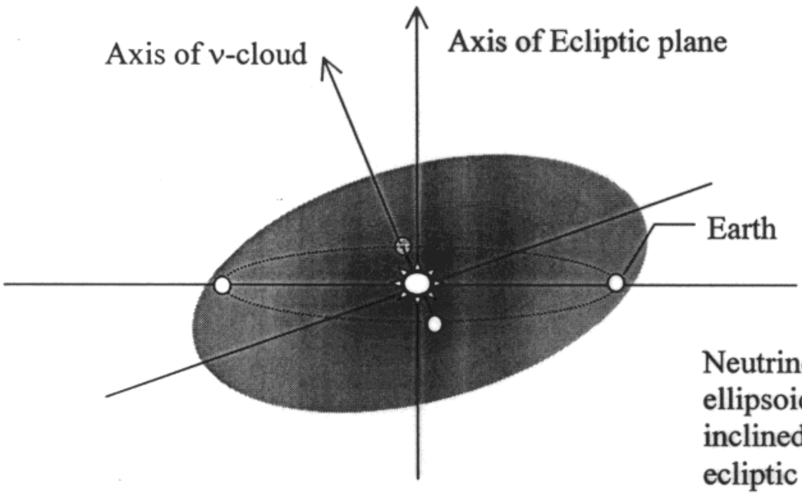


Integral Spectrum:



Modulation period 0.5 year imply the size of ν-cloud ~1÷3 A.U. and couple ν-cloud to Sun. Clustering avoid contradiction with average ν-density.

$E_0 - E_{step} > 0$ imply that E_ν is negative
Common sense interpretation ν - are in potential well.
Well depth $E_0 - E_{step} + E_F \approx 20$ eV. ÷ 10 eV
Good for coupling ν in cluster.
Origin of the potential → Mohapatra & Nussinov, P.L. 1997, ?
But contradiction with experimental observation of bump below the end-point.
Assuming inhomogenity of potential over the ν-cloud one may visualize the origin of 0.5-year modulation.



Neutrino cloud is a flattered ellipsoid with symmetry axis inclined with respect to ecliptic plane.

Maxima of $E_0 - E_{step}$ corresponds to Sun rotation axis being perpendicular to direction Sun-Earth.
It is possible that axis of ν-cloud is inclined in the same direction as the Sun rotation axis. (?)
The picture looks attractive, but rises many questions:

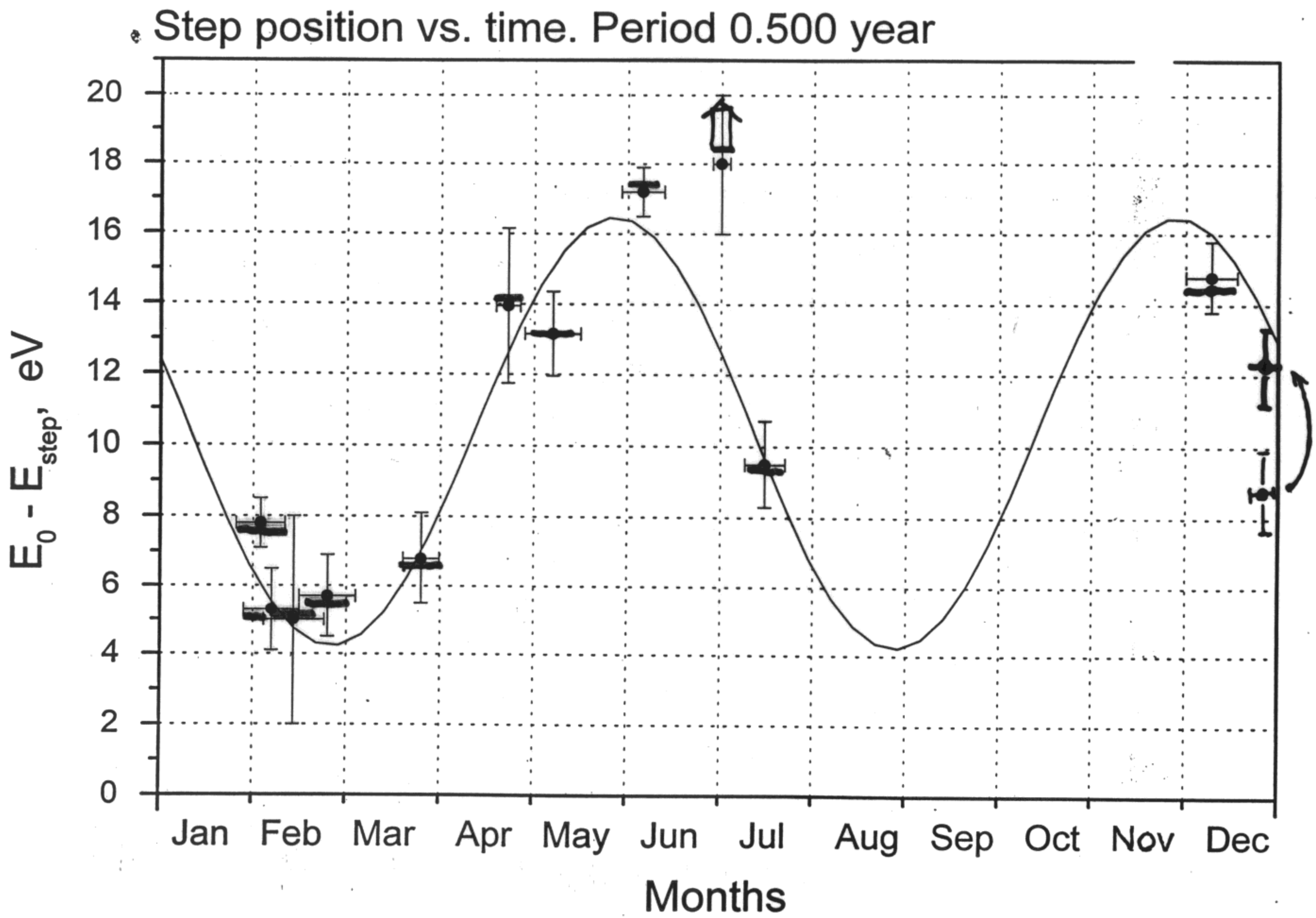
- Is trapping of neutrino possible?
- Is negative E_ν possible?
- What interaction provides trapping?
- Massless (or small mass) ν?

Theor. attemp. Viollier, Marx, Stephenson .... Mc.Kellar Goldman

Present consideration (Stephenson et al. Int. Jour. Modern Physics A, Vol. 13 (16) (1998) 2765)
$M_\nu > U_{trapping}$ (~20 eV)

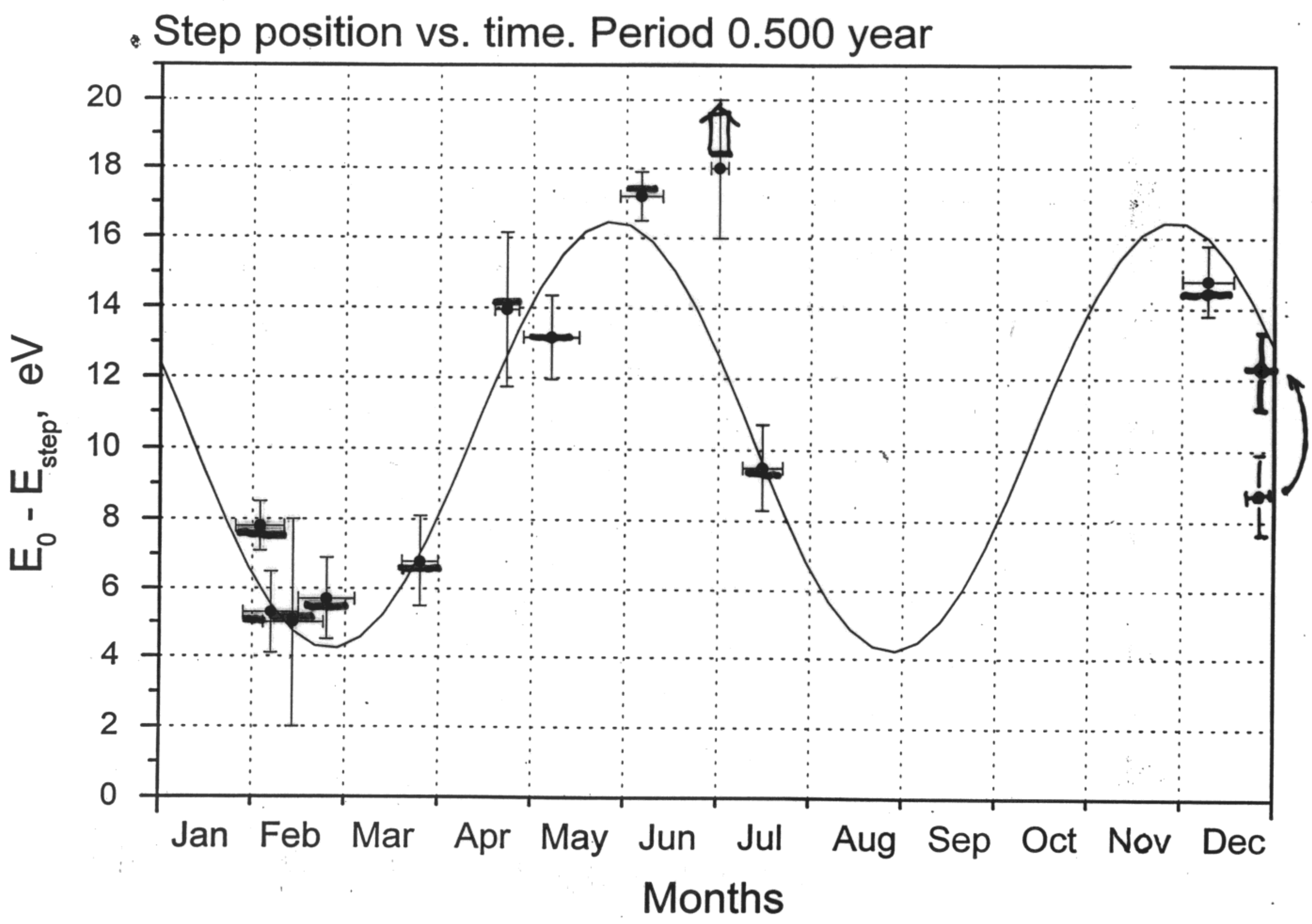
$(E_0 - E_{step}) < 0$	Again contradicts to experiment.

$-V = E_0 - E_{step} + E_F$



Step position vs. time. Period 0.500 year
E0 - Estep, eV
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

$-V = E_0 - E_{step} + E_F$



Step position vs. time. Period 0.500 year
E0 - Estep, eV
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Shape of β-spectrum near end-point.

Differential spectrum: $m_\nu = 0 \quad N(\varepsilon) \sim \varepsilon^2$

$m_\nu \neq 0 \quad N(\varepsilon) \sim \varepsilon\sqrt{\varepsilon^2 - m_\nu^2}$

$m_\nu << \varepsilon << E_0$; $\boxed{N(\varepsilon) \sim \varepsilon^2 - m_\nu^2/2;}$

Integral spectrum: $m_\nu = 0 \quad N(\varepsilon) \sim \varepsilon^3$

$m_\nu \neq 0 \quad N(\varepsilon) \sim (\varepsilon^2 - m_\nu^2)^{3/2}$

$m_\nu << \varepsilon << E_0$; $\boxed{N(\varepsilon) \sim \varepsilon^3 - 3\varepsilon\, m_\nu^2;}$

Maximum sensitivity:

- Differential sp. $\varepsilon = m_\nu$.
- Integral sp. $\varepsilon = e_m$;
  $N(\varepsilon_m) \cong N_{bkg}$.

The possible systematic biases for m_ν^2.

1. Resolution function uncertainty. Measured by electronic gun.
   Is in accordance with magnetic fields setting.

2. Energy loss spectrum and effective thickness.
   Measured by means of transmission of electron through the source in the range of E_{Loss} 0÷200 eV.
   May be calculated from counting rate, luminosity of the spectrometer and T_2 – concentration.

3. Backscattering in the source (on the rear wall).
   Small, due to adiabaticity (rear wall is in the weak magnetic field).

4. Electron detection efficiency (energy dependence).
   Small, but nonzero due to some backscattering of the electrons on the detector surface with energy loss less than E_e-E_{Spectr}.

5. Background energy dependence.
   No dependence in the range 18,600 – 19,600 V within ± 5%.

6. Trapping effect in the source. It has been calculated. Valid only for large interval for the analysis.

7. Trapping in the spectrometer. Yet not spotted.

8. Absence of T^0, T^-, T_3^+ in the source.
   No other impurities (25 K).
   Limit of abundance of atoms and ions below
   $2 \cdot 10^{-9} \cdot 3 \cdot 10^2 \cdot 10^2 \approx 10^{-4}$:

   No effect up to $10^{-1} \ldots 5 \cdot 10^{-2}$ relative abundance.

The m_ν problem.

Shape of the β-specrum near end-point.

If $E_0 - E \equiv \varepsilon_\nu$; E_0 – end point energy.

Integral spectrum near end-point

$$F(E, E_0, Z\ \ldots) \simeq A\varepsilon_\nu^3$$

$\mp m_\nu^2$ – effect: $$A(\varepsilon^3 \pm \frac{3m_\nu^2}{2} \cdot \varepsilon)$$

step function: $$A\varepsilon^3 + \begin{cases} 0, & \varepsilon < \varepsilon_{step} \\ B, & \varepsilon > \varepsilon_{step} \end{cases}$$

- Efficiency correction

  $A\varepsilon^3(1 + \alpha\varepsilon + \beta\varepsilon^2)$

- Backward scattering

  $A\varepsilon^3(1 + k_b\varepsilon)$

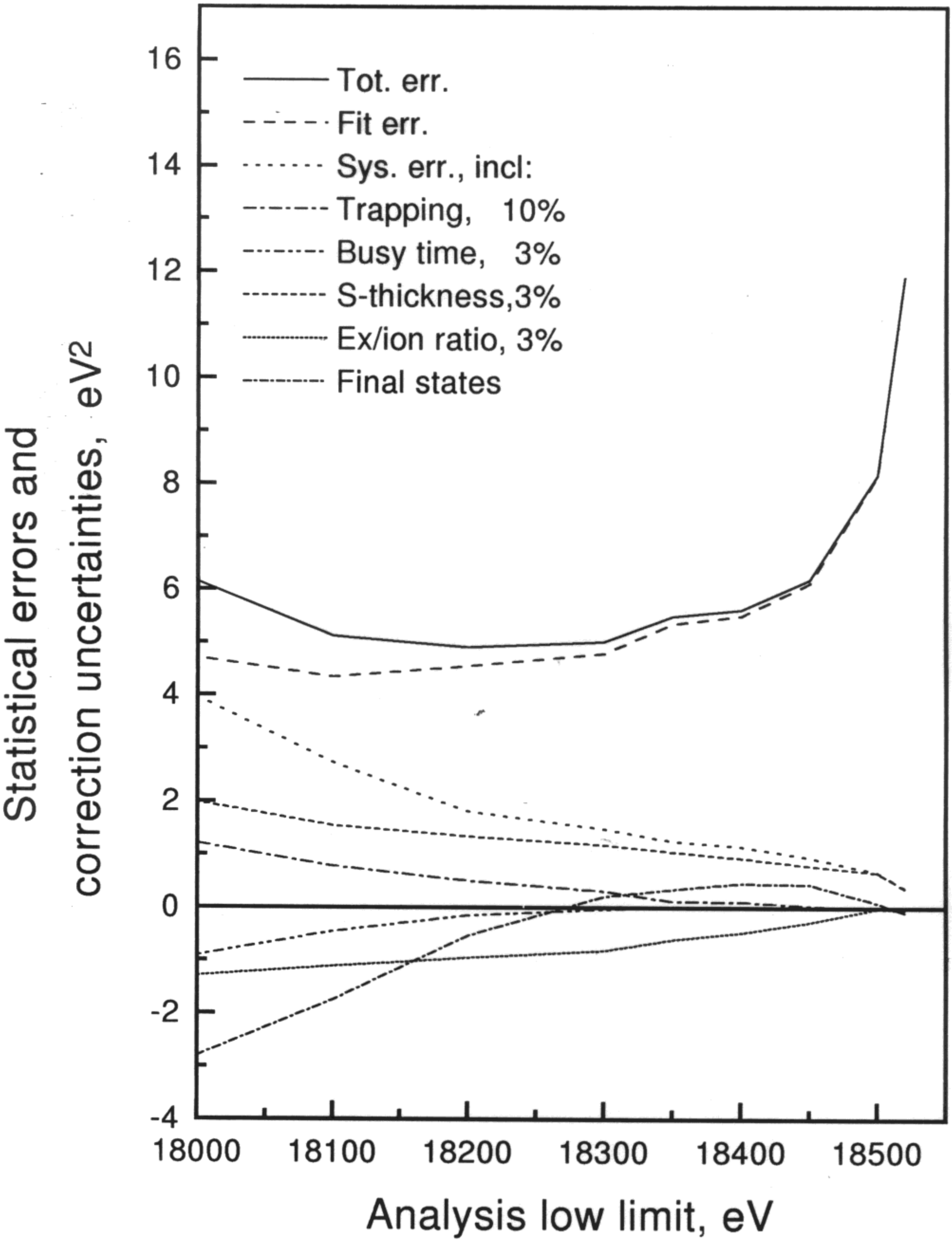
- Trapping effect

  $A\varepsilon^3(1 + k_{tr}\varepsilon)$

- Dead time correction

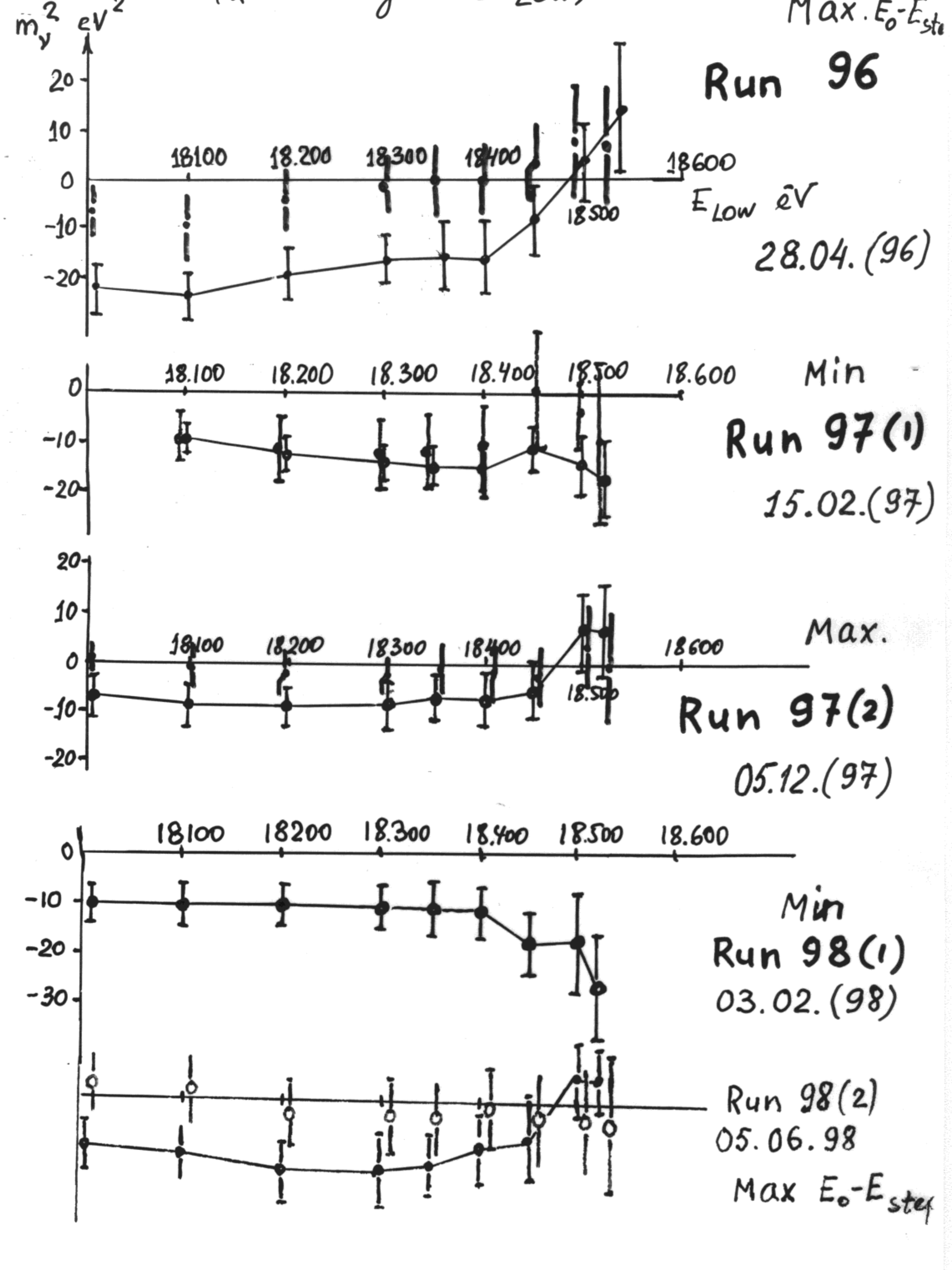
  $A\varepsilon^3(1 + m\varepsilon^3)$

} Dependence of m_ν^2 on E_{LOW}



Tot. err.
Fit err.
Sys. err., incl:
Trapping, 10%
Busy time, 3%
S-thickness,3%
Ex/ion ratio, 3%
Final states
Statistical errors and correction uncertainties, eV^2
Analysis low limit, eV
16
14
12
10
8
6
4
2
0
-2
-4
18000
18100
18200
18300
18400
18500

Dependence of the fitted m_ν^2 on the lower boundary of the part of the spectra in analysis (E_{Low}).



Neutrino mass results.

Year		Mass
1994		$m_\nu^2 = -2.7 \pm 10.1$ *(fit)* ± 4.9 *(syst)*, eV^2/c^4
1996		$m_\nu^2 = +0.5 \pm 7.1$ *(fit)* ± 2.5 *(syst)*, eV^2/c^4
1997	1	$m_\nu^2 = -8.6 \pm 7.6$ *(fit)* ± 2.5 *(syst)*, eV^2/c^4
	2	$m_\nu^2 = -3.2 \pm 4.8$ *(fit)* ± 1.5 *(syst)*, eV^2/c^4
1998	1	*Fit for combined* m_ν^2 *and* ΔN_{step} *is uncertain*
	2	$m_\nu^2 = -0.6 \pm 8.1$ *(fit)* ± 2.0 *(syst)*, eV^2/c^4
Combined		$m_\nu^2 = -2.0 \pm 3.5$ *(fit)* ± 2.1 *(syst)*, eV^2/c^4
m_ν Bayessian limit:		$m_\nu < 2.5\ eV/c^2$ *at 95% C.L.*

What's the further?

1. Better statistics and more measurements this year, as a proof of periodicity.
   - Improvement 2 times is possible on present set-up.

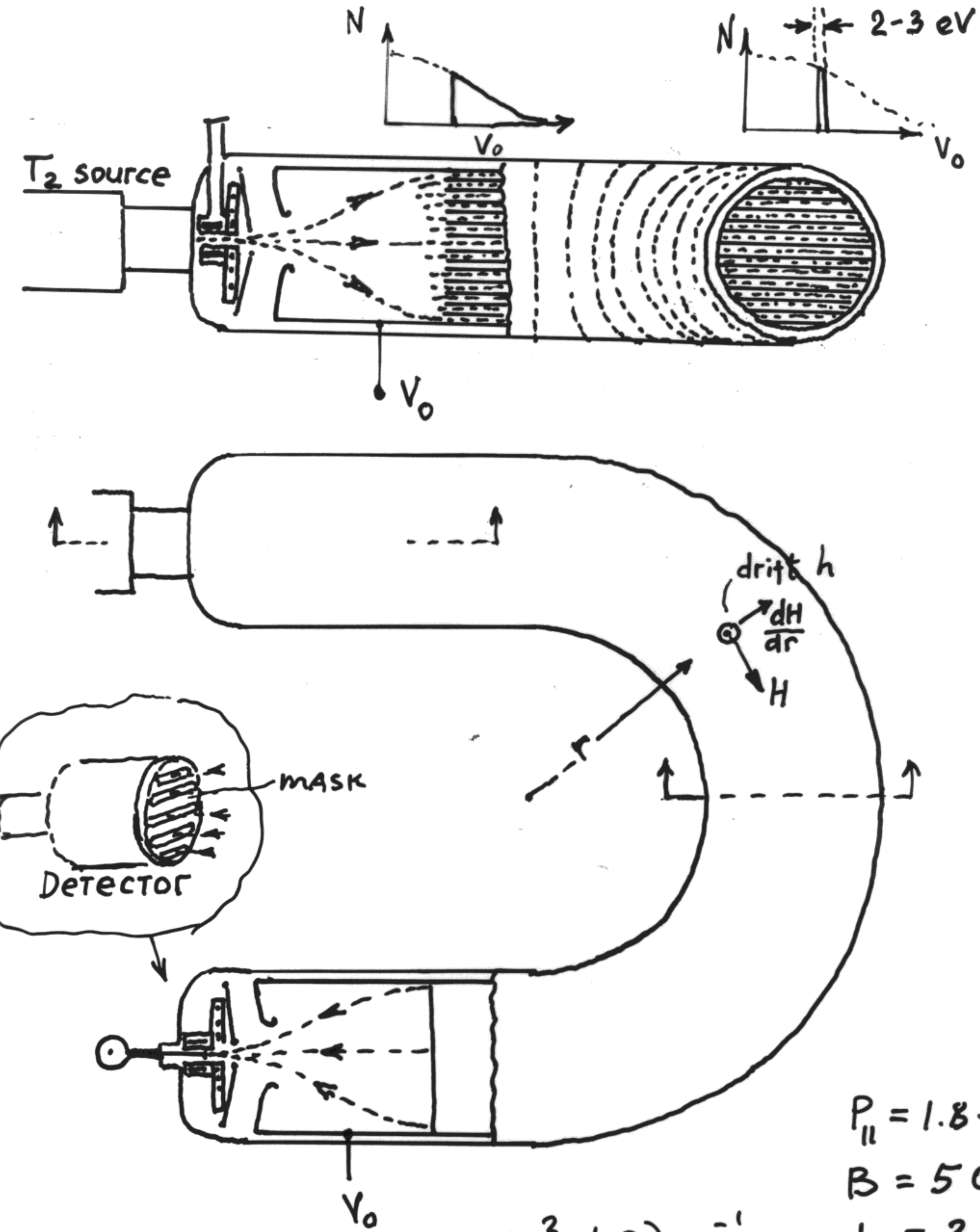
2. Synchronous measurement with Mainz group.
   - Now in progress.

3. Proof of universality of the effect:
   - Measurement of partial spectra to exited final states. $E_{ex} = 28 \div 35$ eV.
   - Practically possible with differential spectrometer.

4. Shape of the bump:
   - Needs new device.

5. Improvement of m_ν:
   < 1.5 eV at present set-up
   < 0.6 eV at new device.
   $m_\nu \sim 1 \div 1.5$ eV may exist if LSND observation is valid.

ADIABATIC DIFFERENTIAL SPECTROMETER.



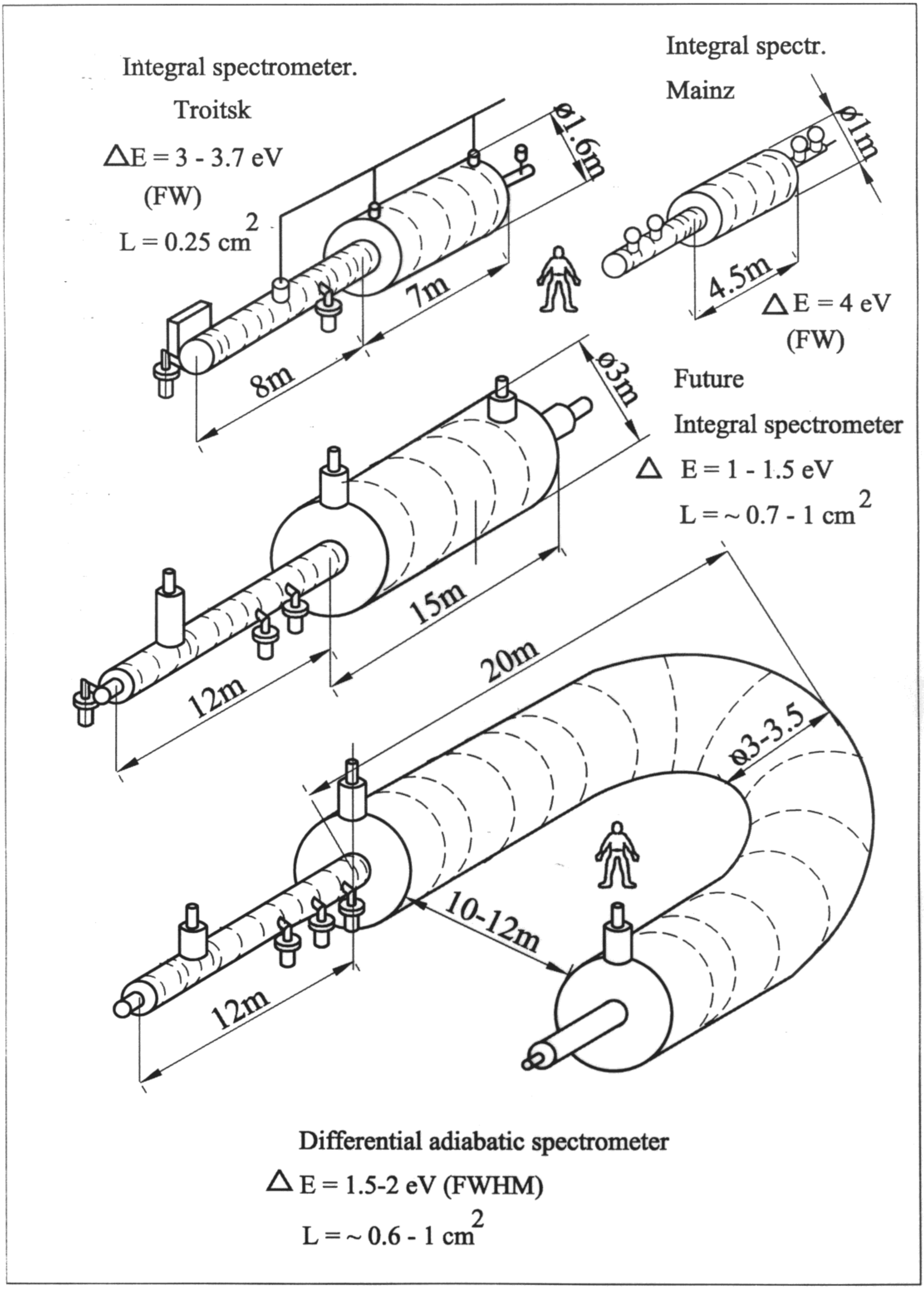
$P_{\parallel} = 1.8\cdot 10^{3}\ eV/c$

$B = 5\ Oe$

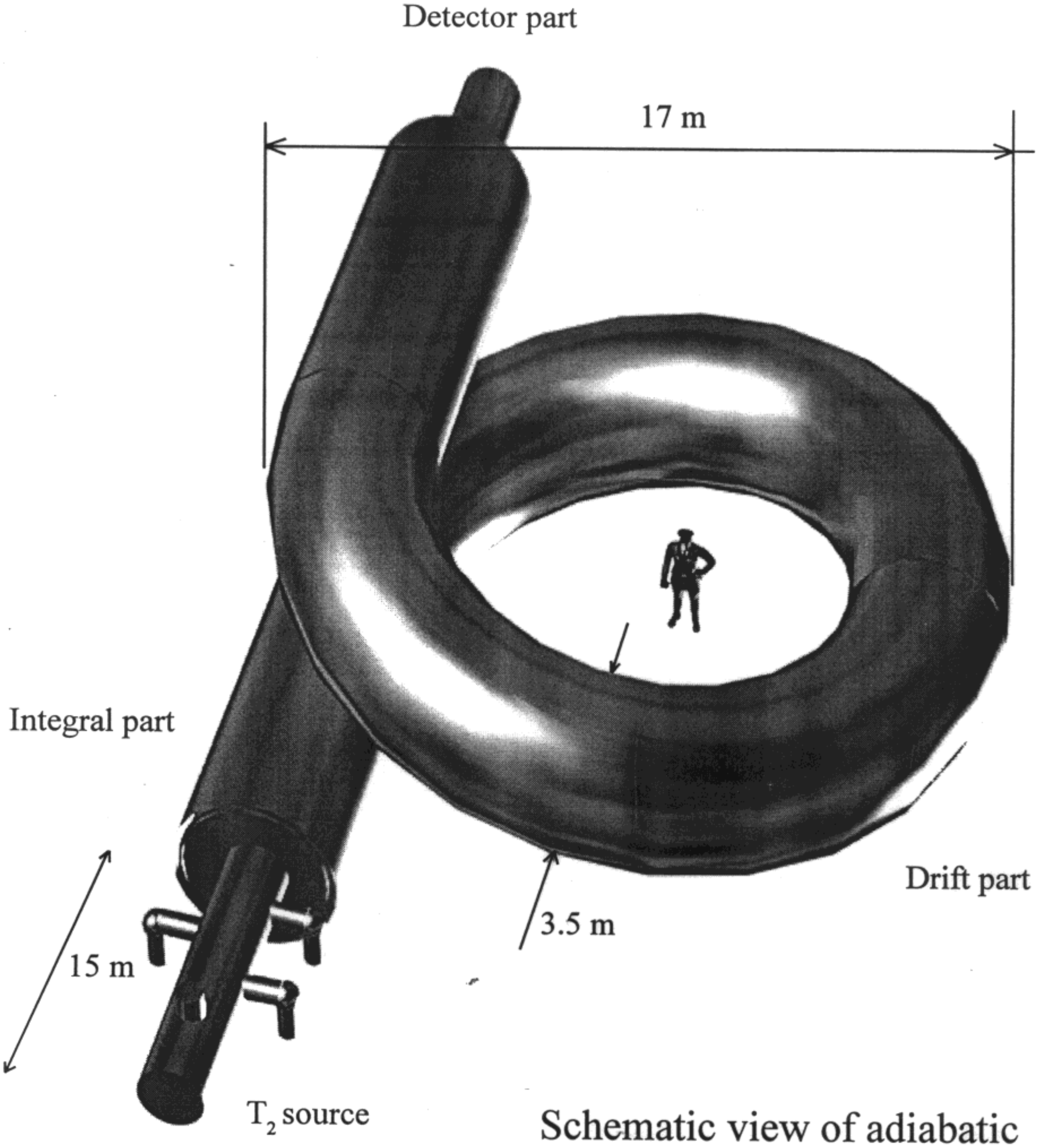
$h = 3.6\ cm$

$$h \sim \left[\frac{d\bar{B}}{dr}\times B\right] \qquad |h| = \frac{S}{R}\cdot\frac{(P_{\parallel}^{2}+\frac{1}{2}P_{\perp})\cdot P_{\parallel}^{-1}}{0.3\cdot 10^{9}\cdot B}$$

$h - m,\ B \rightarrow T,\ P \rightarrow eV/c$

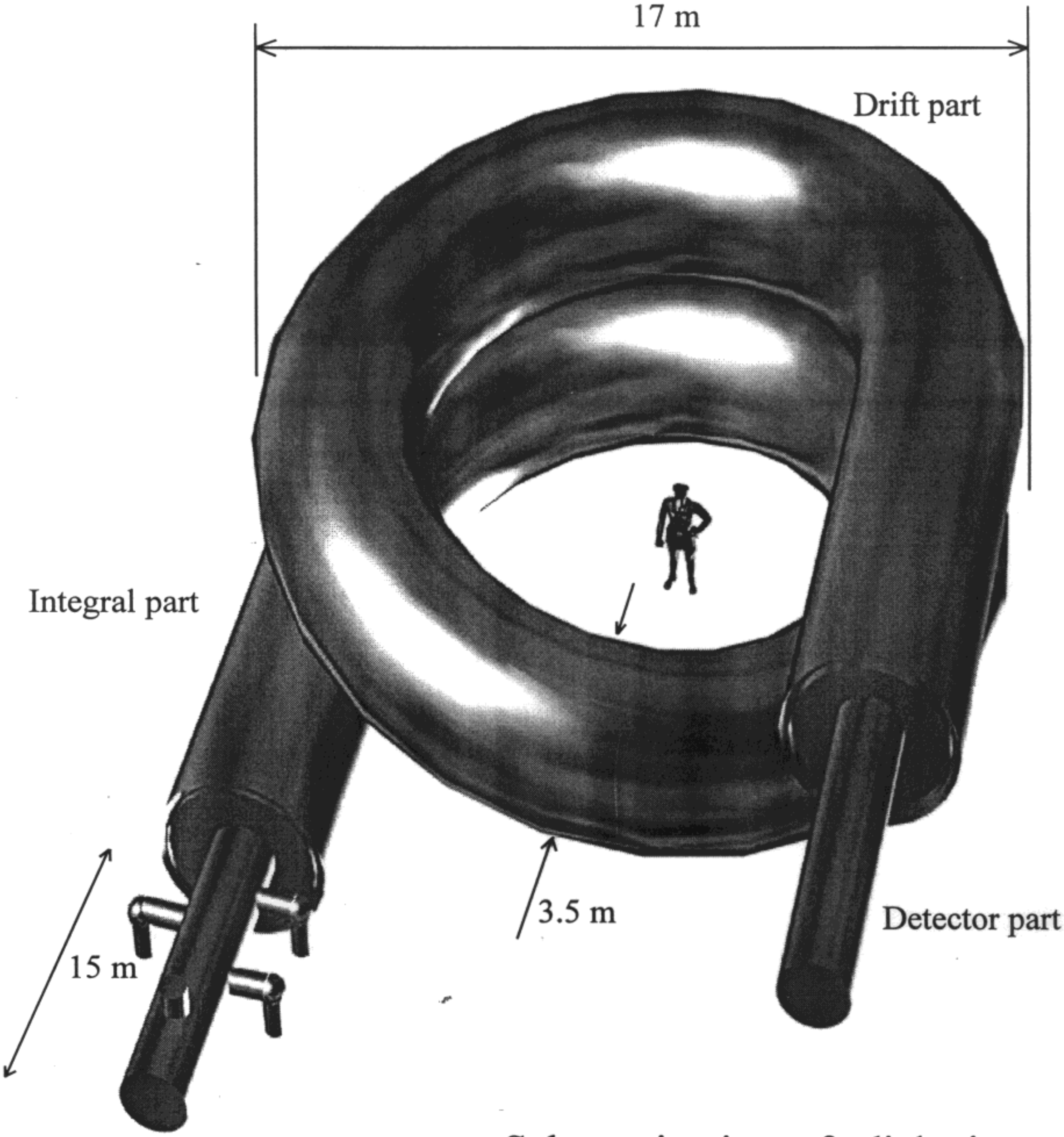


Integral spectrometer.
Troitsk
ΔE = 3 - 3.7 eV
(FW)
L = 0.25 cm2
ø1.6m
7m
8m
Integral spectr.
Mainz
ø1m
4.5m
ΔE = 4 eV
(FW)
ø3m
Future
Integral spectrometer
Δ E = 1 - 1.5 eV
L = ~ 0.7 - 1 cm2
15m
12m
20m
ø3-3.5
10-12m
12m
Differential adiabatic spectrometer
Δ E = 1.5-2 eV (FWHM)
L = ~ 0.6 - 1 cm2



Schematic view of adiabatic differential spectrometer with 2π drift angle

Resolution 1.5 eV (FWHM)
Luminocity ~ 0.5 cm^2



Schematic view of adiabatic differential spectrometer with 3π drift angle

Resolution 1.5 eV (FWHM)
Luminocity ~ 0.7 cm²

Conclusion.

- “Troitsk ν-mass” set-up measured end-part of the tritium beta-spectrum during 4.5 years with resolution 3.5÷4.5 eV and statistics $10^2 \div 10^3$ more than experiment before 1993.
- Shape of the spectrum proved to be in accordance with classical shape besides area ~15 eV below end-point, where small bump (10^{-10}) relative intensity was observed, periodically moving within 5÷15 eV with period 0.5 year.
- Main feature of the effect may be phenomenologically interpreted as capture of relic neutrino from the cloud around the Sun if to neglect the origin of the cloud. This effect produce significant interference to neutrino mass deduction but being accounted for allows to obtain upper limit $m_\nu < 2.5$ eV/c^2.
- New facility is needed.