NEUTRINO MASS AND ANOMALY IN THE TRITIUM BETA-SPECTRUM

presented V.M.Lobashev

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"Troitsk ν -mass" experiment

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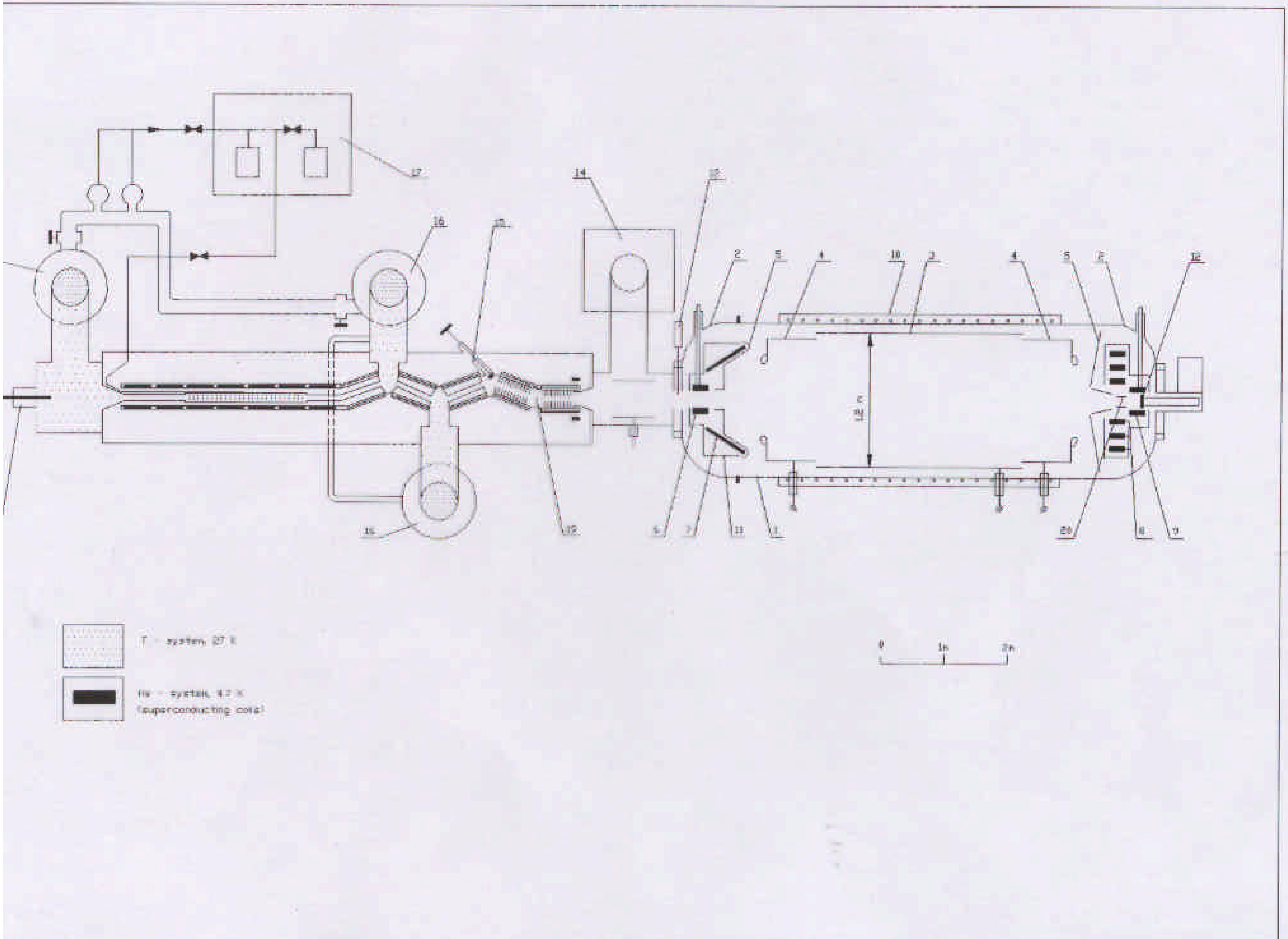

17
14
15
16
13
2
5
4
10
3
4
5
2
12
12 m
16
19
6
7
11
1
20
8
9
T - system, 27 K
He - system, 4.2 K
(superconducting coils)
0
1m
2m

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 December 98
+ 20 " " April-May 99
+ 15 " " October 99
+ 15 " " December 99

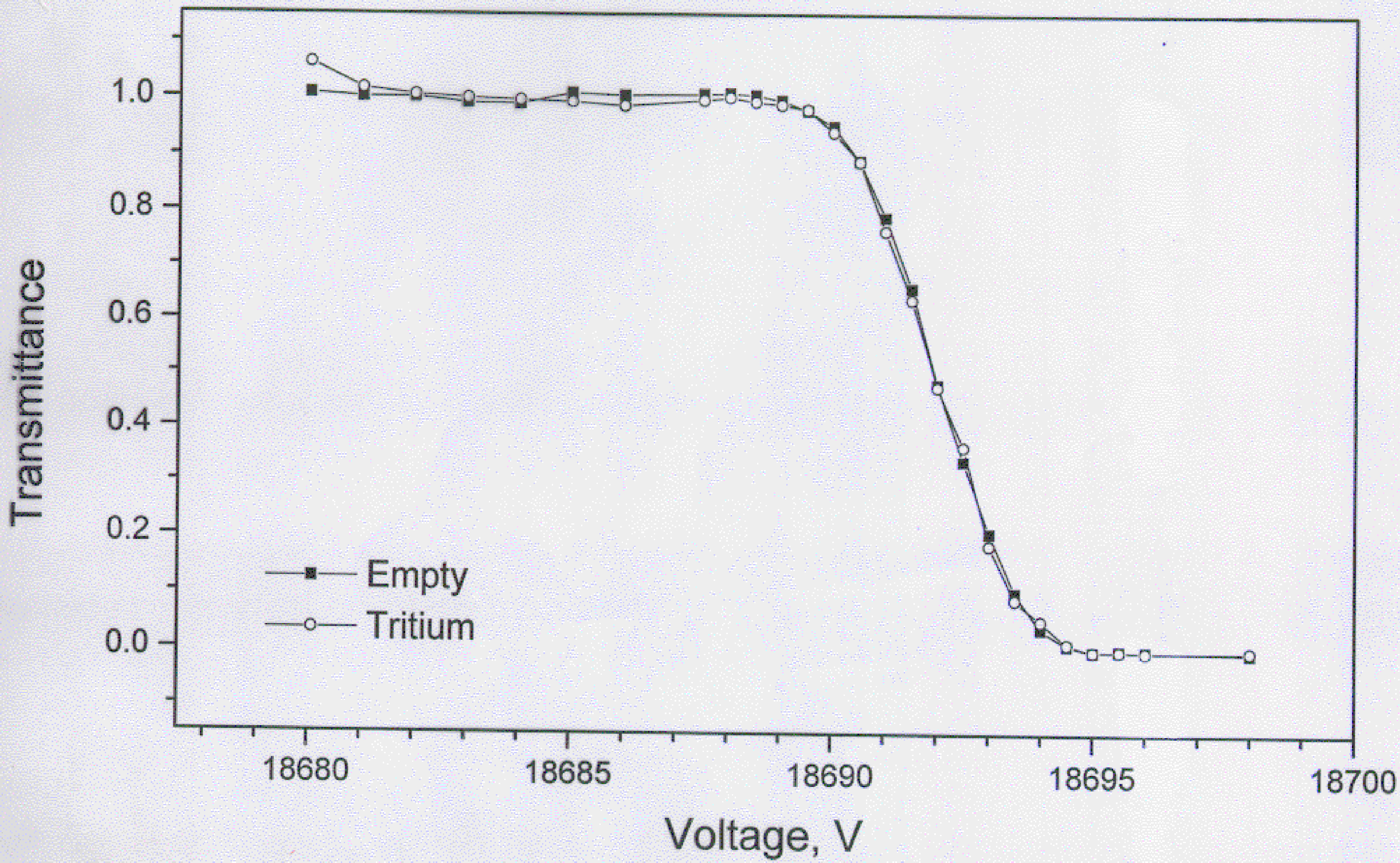
240 days

Experimental spectrum corrections.

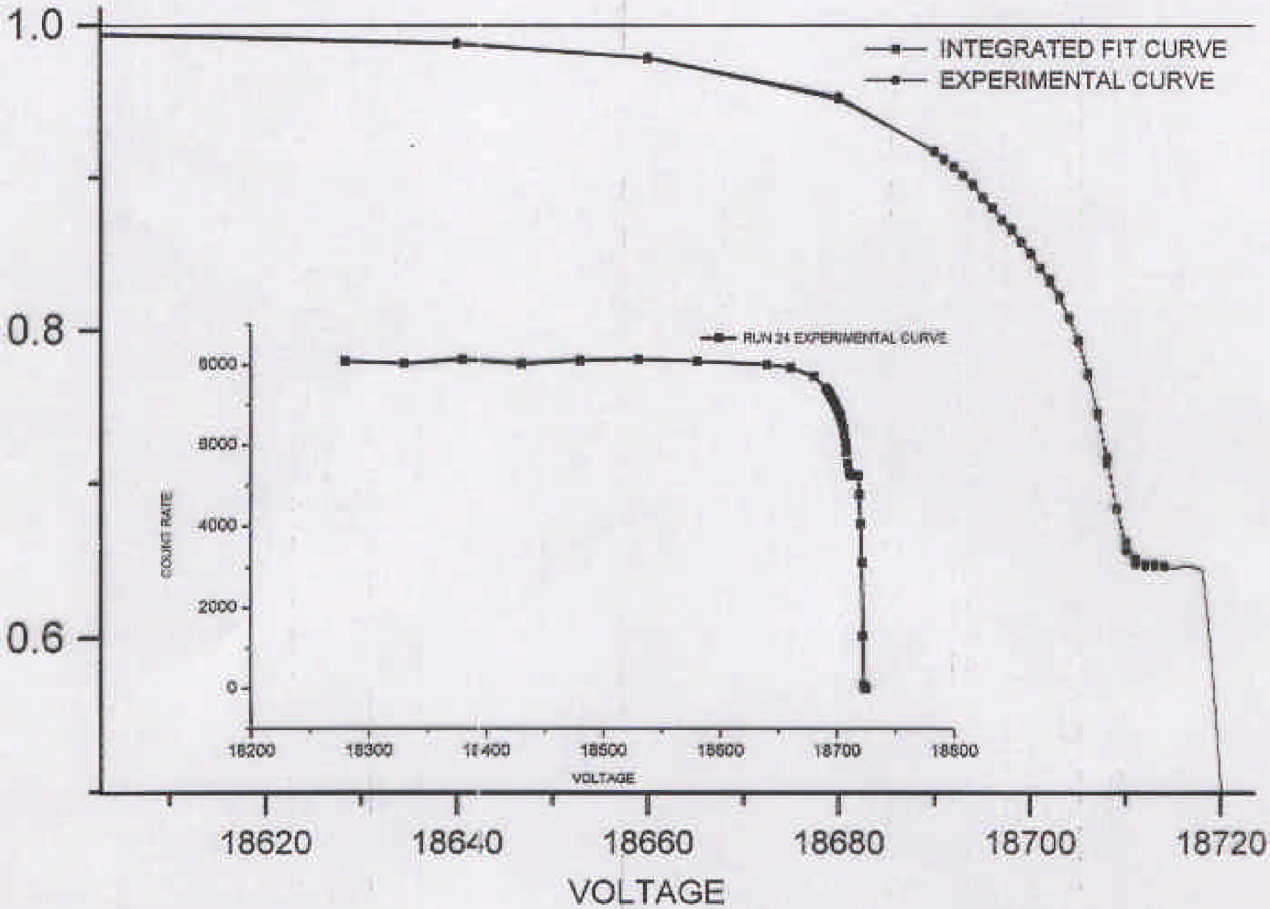
1. Search and elimination of tritium decay
   in spectrometer volume.
   5÷20 sec bunch of pulses (1÷3 hour^{-1}). Cut-off level ~$3 \cdot 10^{-4}$.
2. Reference counting rate (T_2 source drift).
3. Dead time and pile-up of pulses.
4. Detection efficiency (~ 0.002).
5. Amplitude window corrections.

Data for fitting.

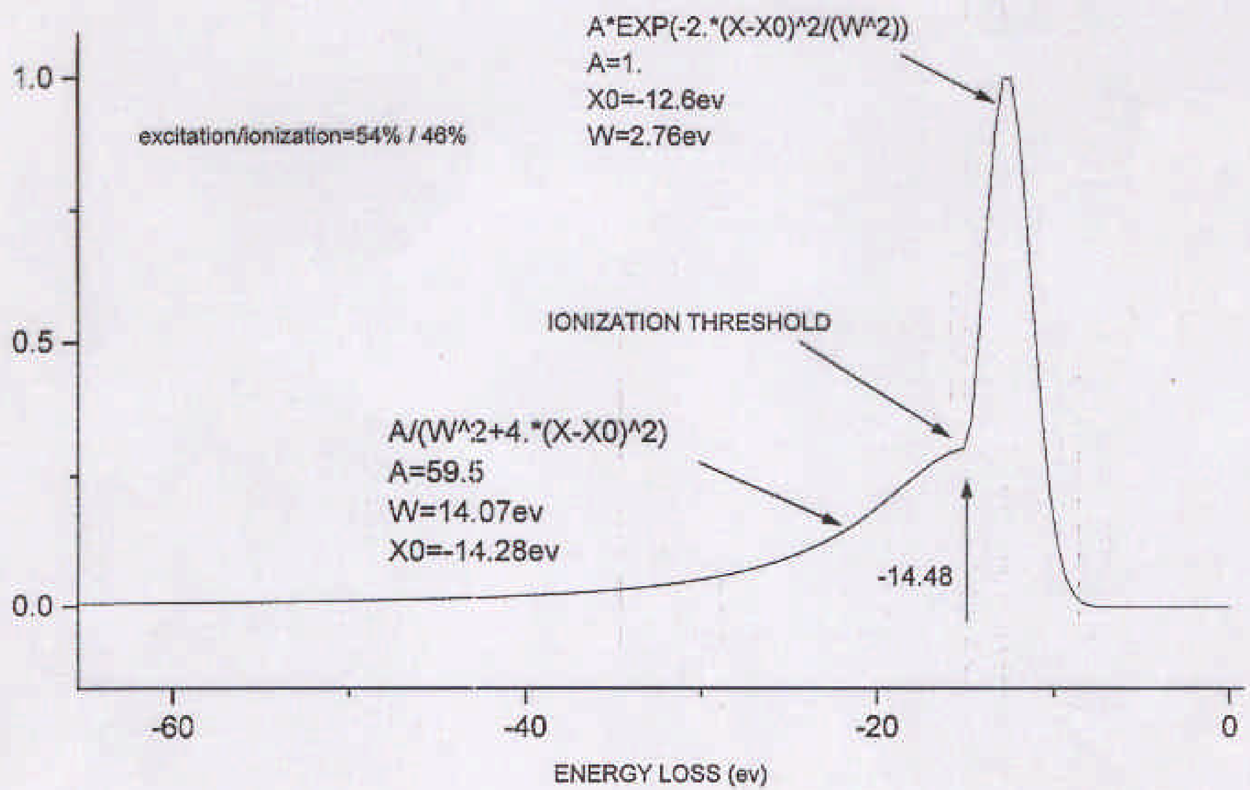
1. Resolution function (spectrometer response) was measured or calculated from magnetic field strength.
2. Energy loss spectrum and surface density of the source.
   ⇒ Measured by transmission through the source of electron from the gun with ultraviolet photoexitation, injected from rear side.
   No-hit 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.



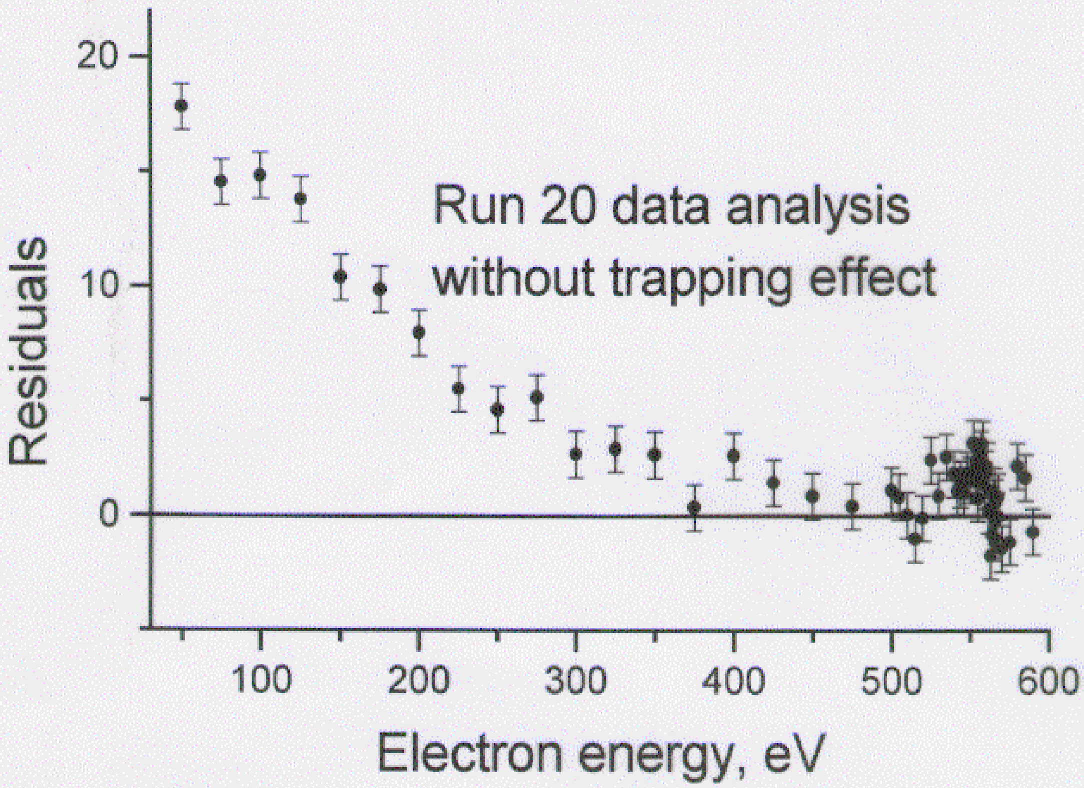
Transmittance
1.0
0.8
0.6
0.4
0.2
0.0
Empty
Tritium
18680
18685
18690
18695
18700
Voltage, V



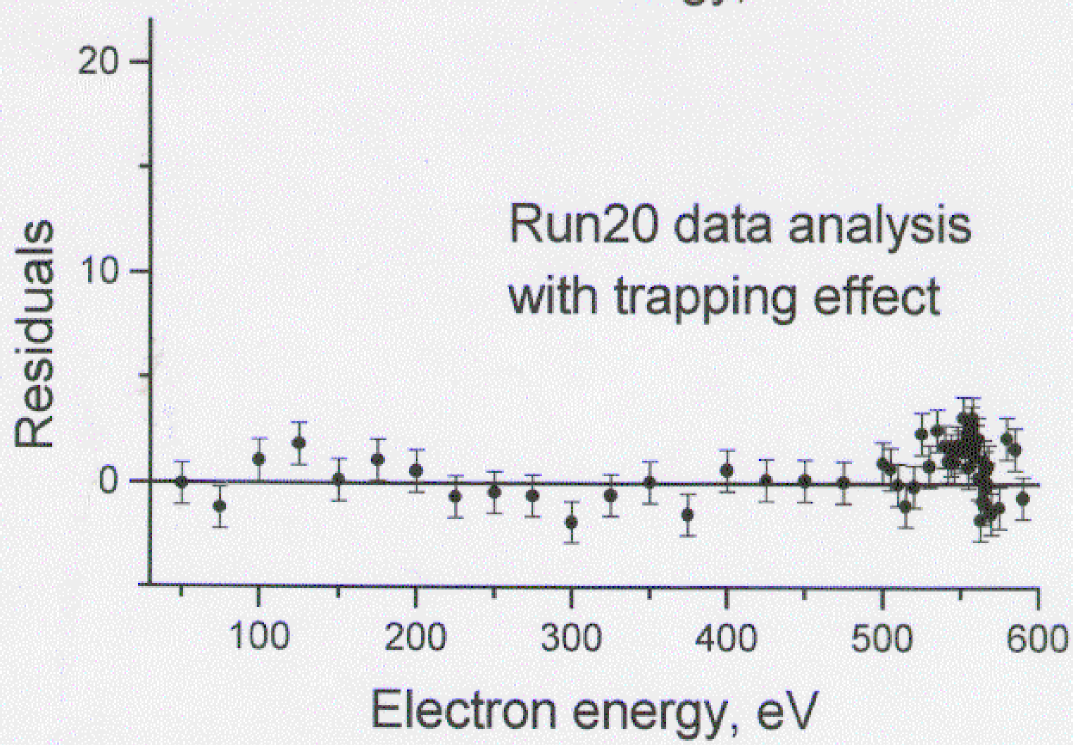
1.0
0.8
0.6
INTEGRATED FIT CURVE
EXPERIMENTAL CURVE
RUN 24 EXPERIMENTAL CURVE
COUNT RATE
VOLTAGE
18620
18640
18660
18680
18700
18720
VOLTAGE



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)

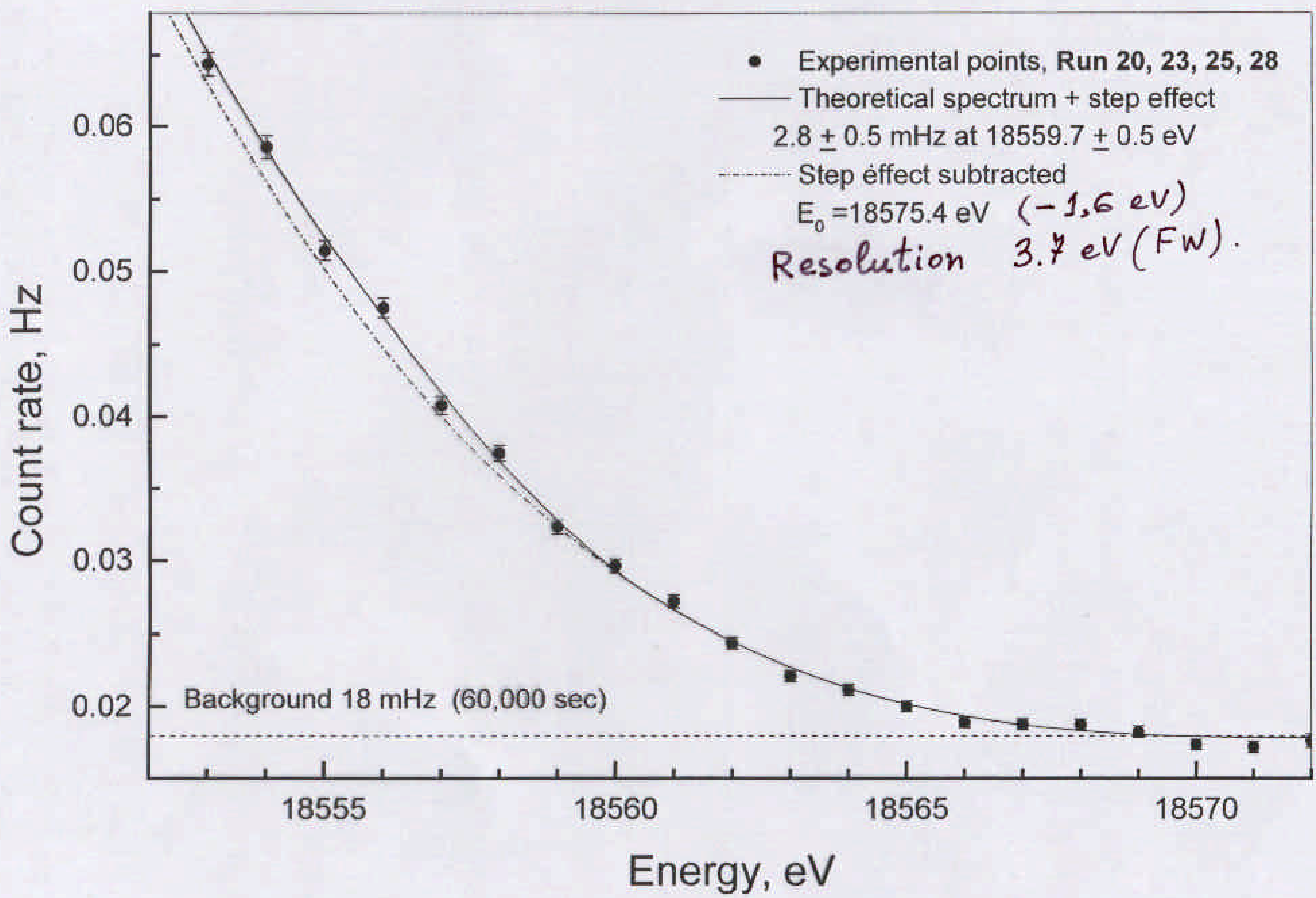


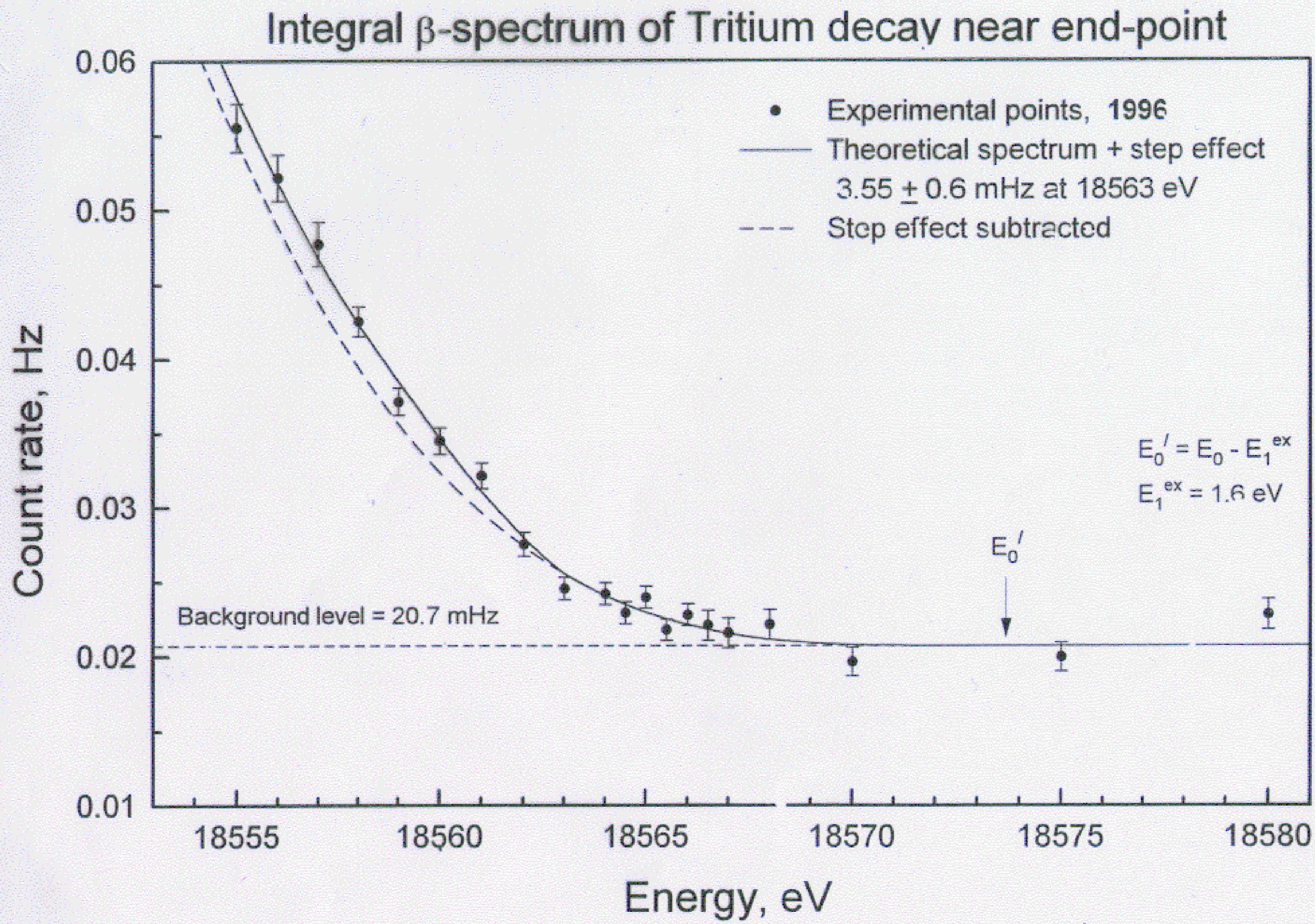
Run 20 data analysis
without trapping effect
Residuals
20
10
0
100
200
300
400
500
600
Electron energy, eV



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

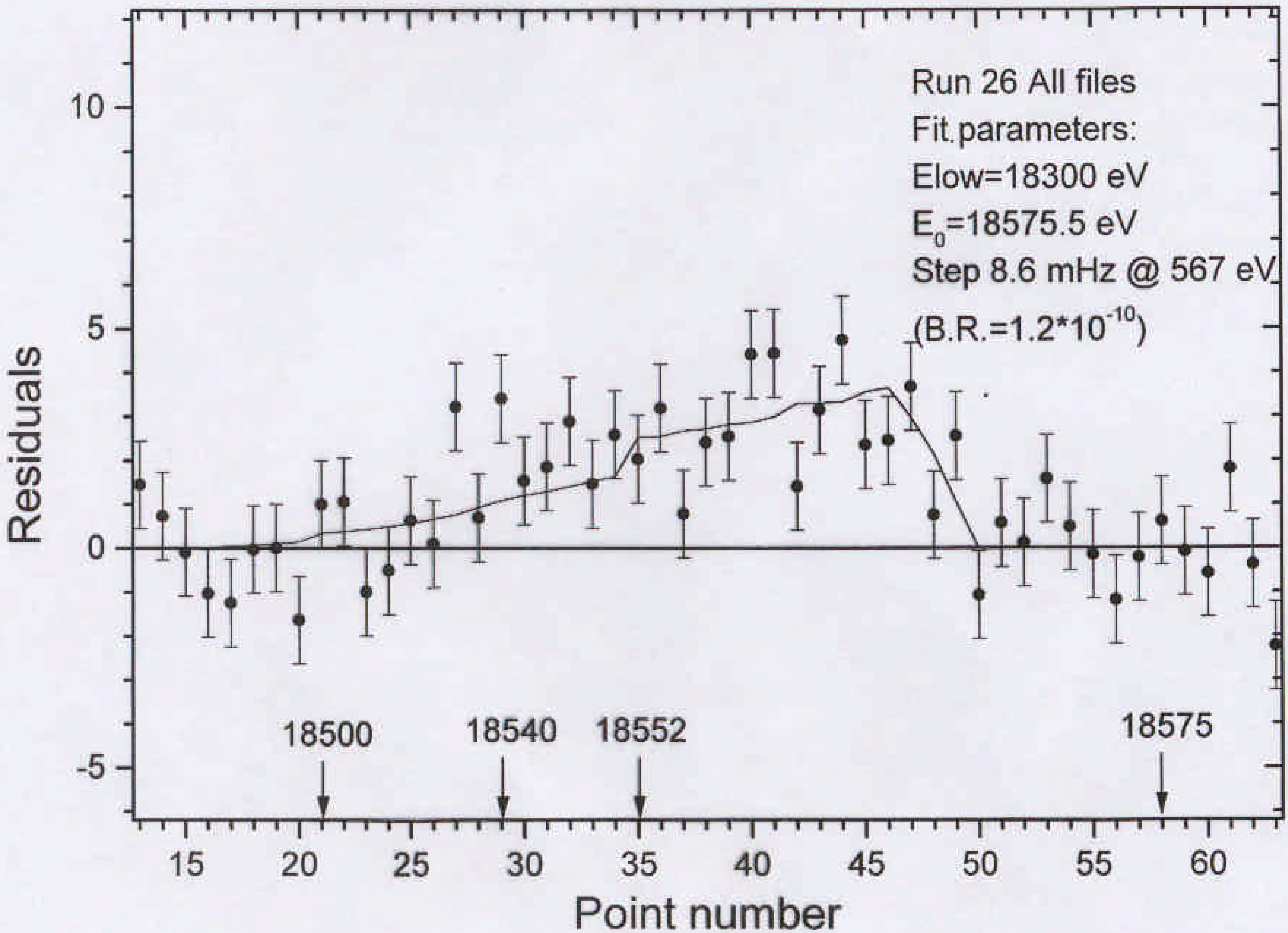
Inetgral β-spectrum of Tritium decay near end-point



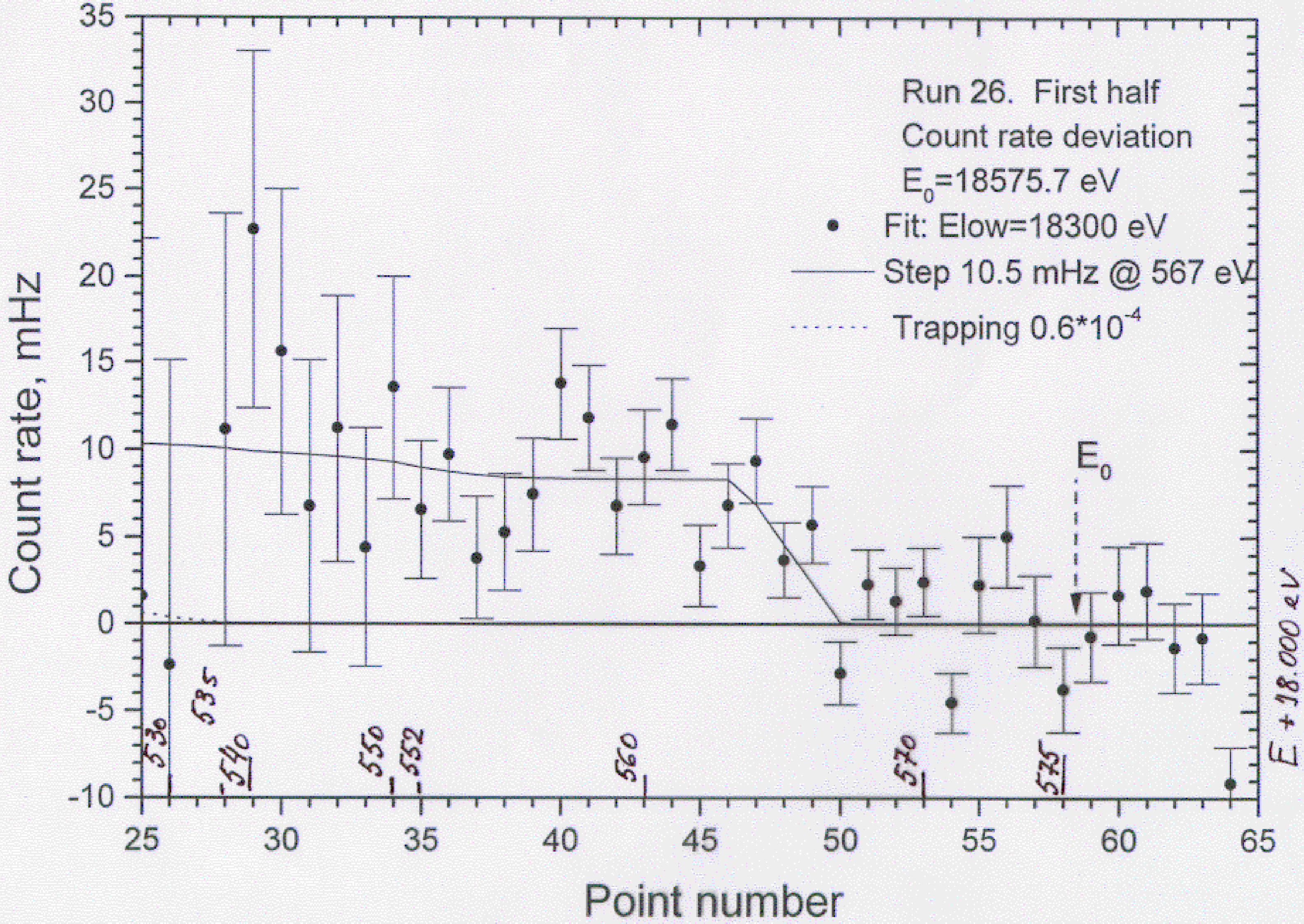


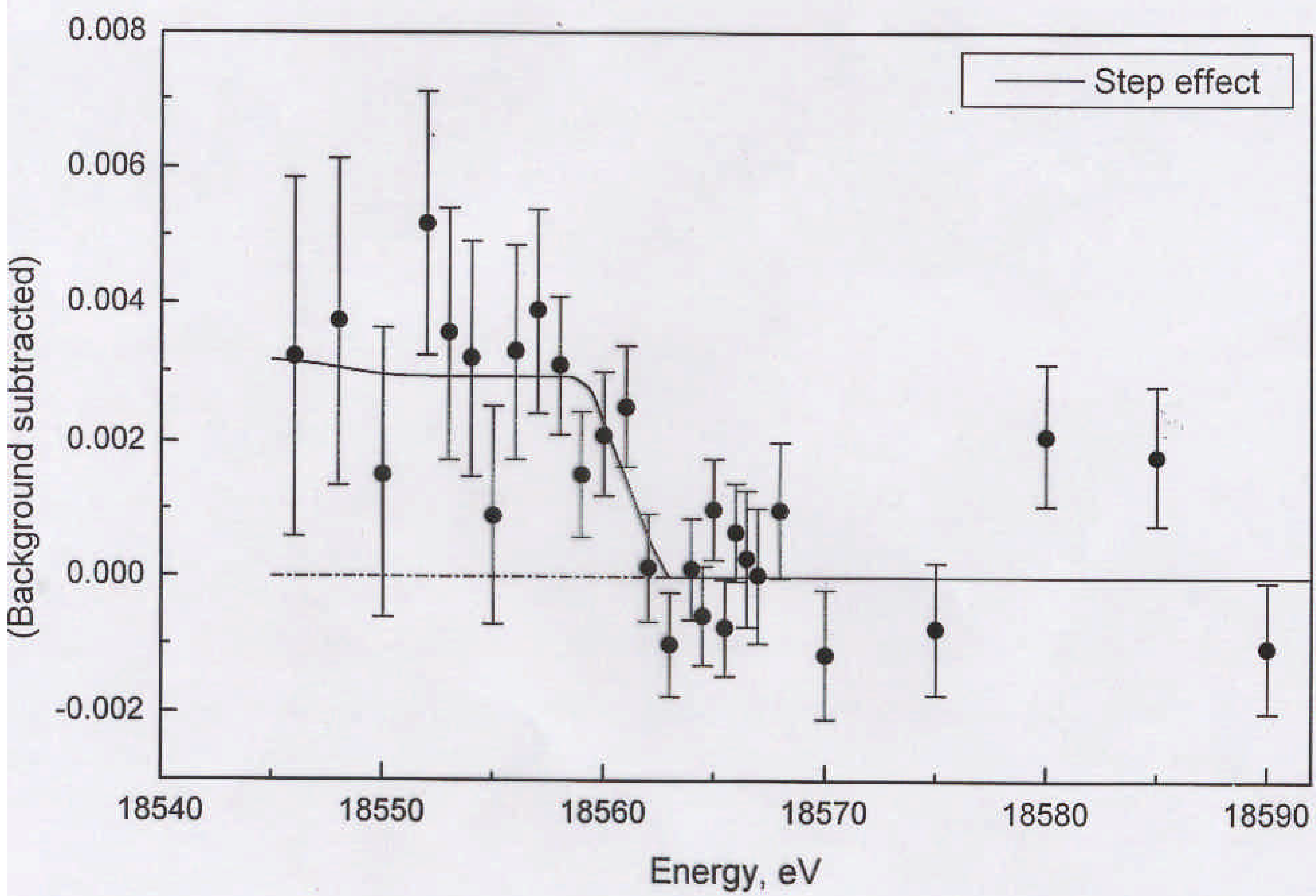
Integral β-spectrum of Tritium decay near end-point
Experimental points, 1996
Theoretical spectrum + step effect
3.55 ± 0.6 mHz at 18563 eV
Step effect subtracted
$E_0' = E_0 - E_1^{ex}$
$E_1^{ex} = 1.6$ eV
E_0'
Background level = 20.7 mHz
Count rate, Hz
0.06
0.05
0.04
0.03
0.02
0.01
18555
18560
18565
18570
18575
18580
Energy, eV

37

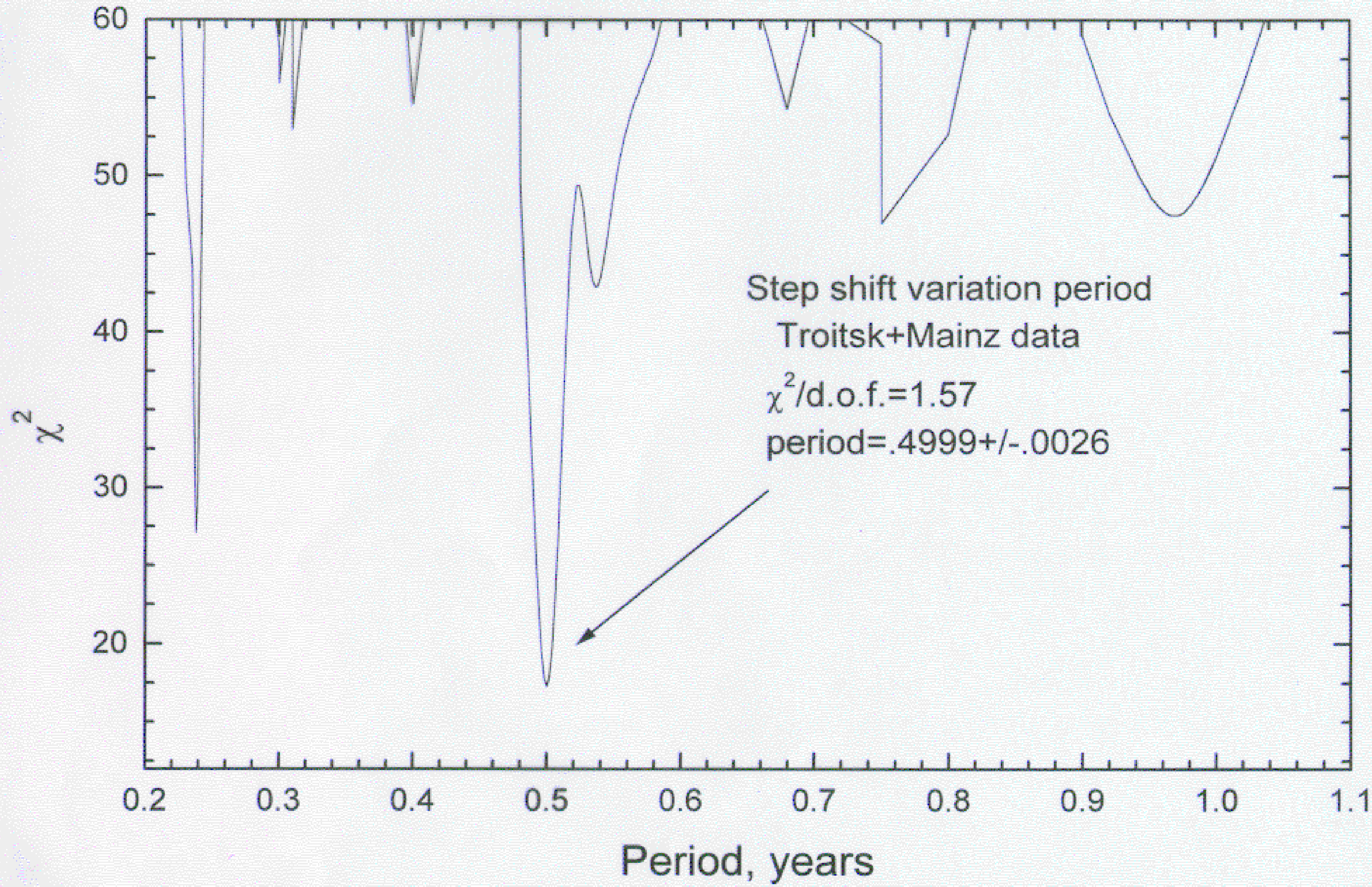


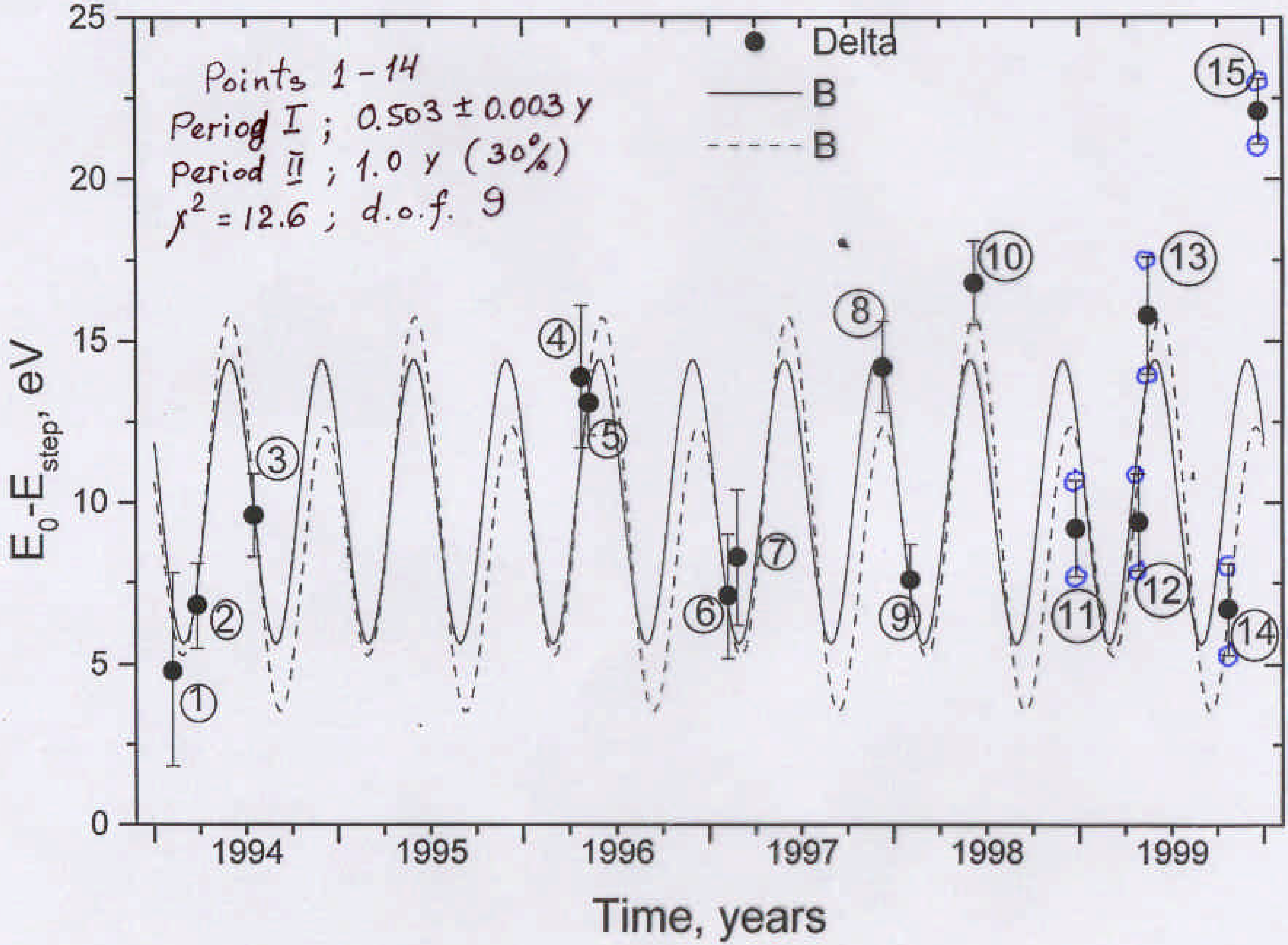
Run 26 All files
Fit.parameters:
Elow=18300 eV
E0=18575.5 eV
Step 8.6 mHz @ 567 eV
(B.R.=1.2*10^-10)
Residuals
10
5
0
-5
18500
18540
18552
18575
15
20
25
30
35
40
45
50
55
60
Point number


Run 26. First half
Count rate deviation
E0=18575.7 eV
Fit: Elow=18300 eV
Step 10.5 mHz @ 567 eV
Trapping 0.6*10-4
E0
Count rate, mHz
Point number
530
535
540
550
552
560
570
575
E + 18.000 eV

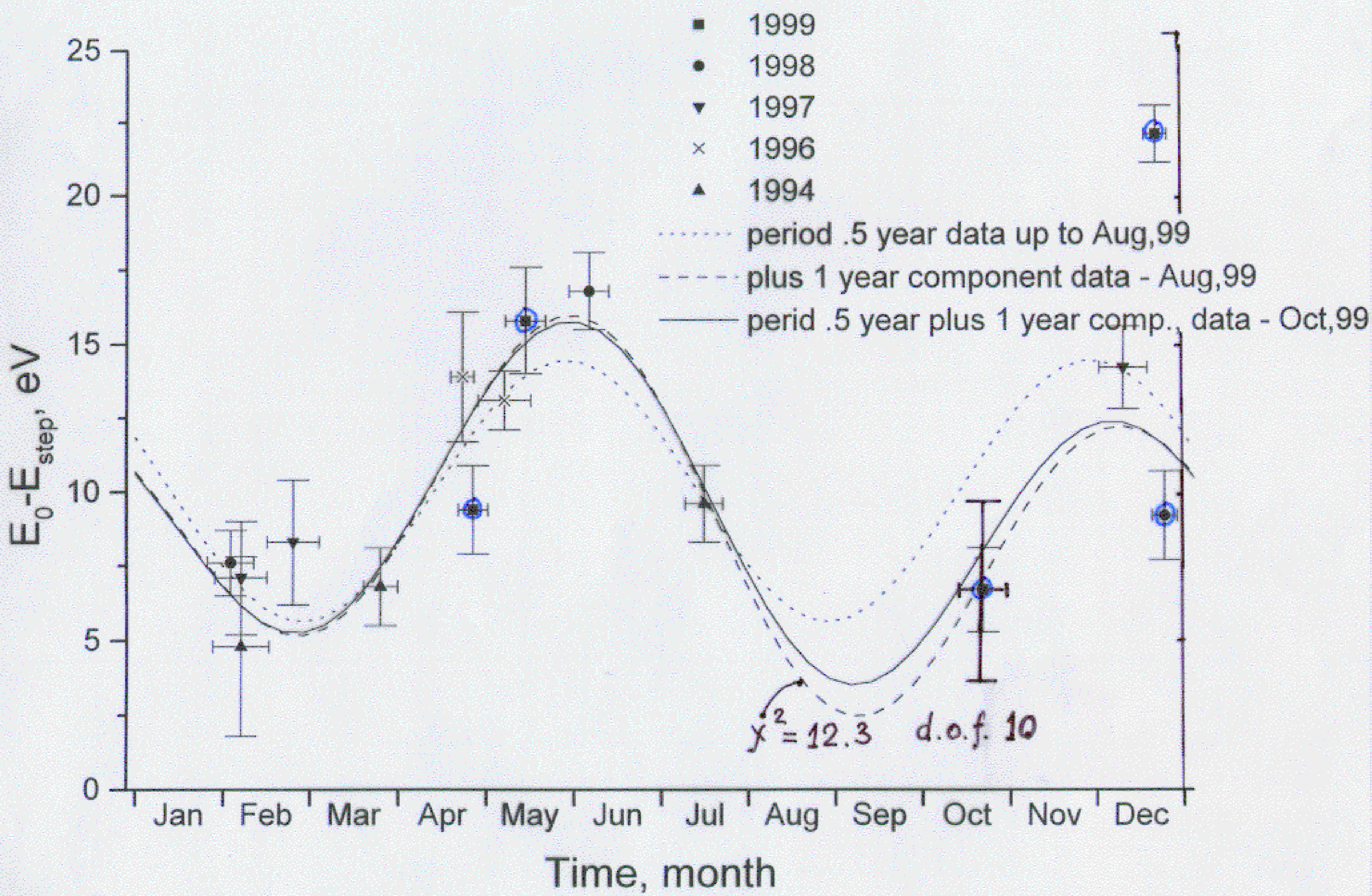


Step effect
(Background subtracted)
0.008
0.006
0.004
0.002
0.000
-0.002
18540
18550
18560
18570
18580
18590
Energy, eV

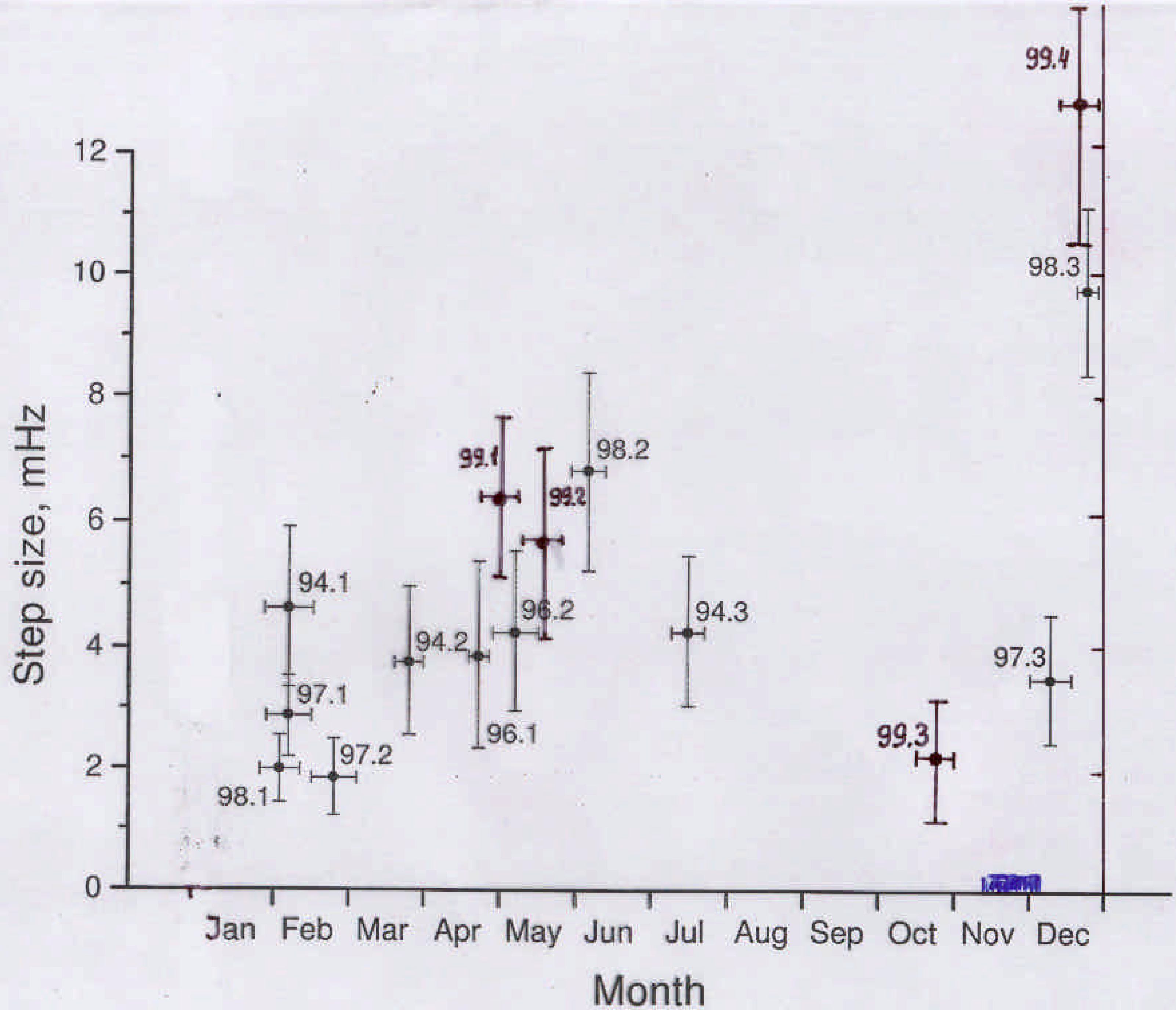

Step shift variation period
Troitsk+Mainz data
χ²/d.o.f.=1.57
period=.4999+/-.0026
χ²
60
50
40
30
20
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Period, years



Delta
B
B
Points 1 - 14
Period I ; 0.503 ± 0.003 y
Period II ; 1.0 y (30%)
χ^2 = 12.6 ; d.o.f. 9
E0-Estep, eV
Time, years
25
20
15
10
5
0
1994
1995
1996
1997
1998
1999
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15



E_0-E_{step}, eV
0
5
10
15
20
25
1999
1998
1997
1996
1994
period .5 year data up to Aug,99
plus 1 year component data - Aug,99
perid .5 year plus 1 year comp., data - Oct,99
$\chi^2 = 12.3$ d.o.f. 10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time, month



Step size, mHz
0
2
4
6
8
10
12
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
98.1
97.1
94.1
97.2
94.2
96.1
99.1
96.2
99.2
98.2
94.3
99.3
97.3
98.3
99.4

The possible systematic biases for m_ν^2.

1. Resolution function uncertainty. Measured by electronic gun.
   Is in accordance with magnetic fields setting. No problem

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). $\sim 10^{-3}$

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. Accuracy of calculation depends only on the ratio of energy loss c.s. to large angle scat. c.s.

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
   $2 \cdot 10^{-9} \cdot 3 \cdot 10^{2} \cdot 10^{2} \approx 10^{-4}$:

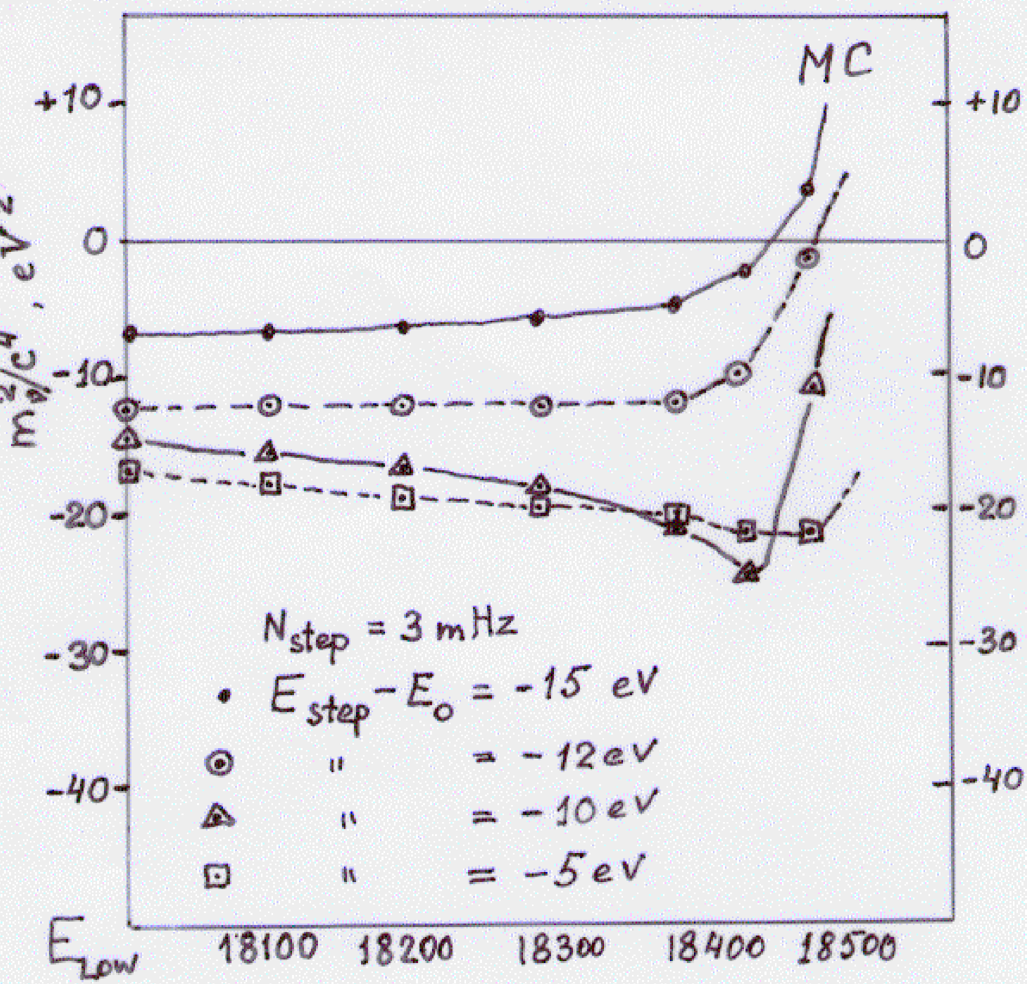
   No effect up to 10^{-1} … $5 \cdot 10^{-2}$ relative abundance.

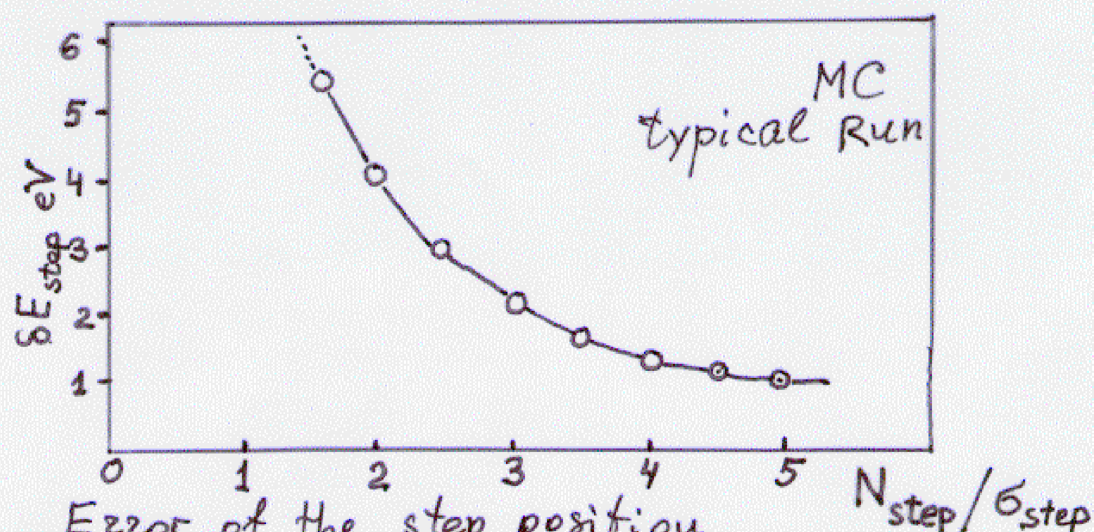
No contamination
No charging of the source
No neibour exitation effects
No possible radiation effects.

E_{low} eV	*Trapping* 20 %	*Source effective thickness* 7 % now 3%	*Ratio* P_{ex}/P_{ion} 10 %	*Dead time* 0.1μsec	*Final states spec.* (*FSS*)	*Total syst. error*	Fit error	Fit + syst. error
17800	4.9	7.0	9.4	1.95	8.2	15.2	5.0	
17900	4.1	6.9	9.4	1.2	7.0	14.3		
18000	3.4	6.65	8.9	0.7	5.8	13.0	5.8	14.2
18100	2.3	6.0	7.2	0.4	3.3	10.2	6.6	12.1
18200	1.2	4.55	4.8	0.1	1.1	6.8	6.2	9.2
18300	0.7	3.85	3.7	0.03	0.2	5.35	6.6	8.5
18350	0.4	2.9	2.3	0.01	0.2	3.8	7.0	8.0
18400	0.2	2.4	1.5	0.0	0.3	2.85	7.4	7.9
18450	0.1	1.8	0.5	0.0	0.3	1.9	8.0	8.2

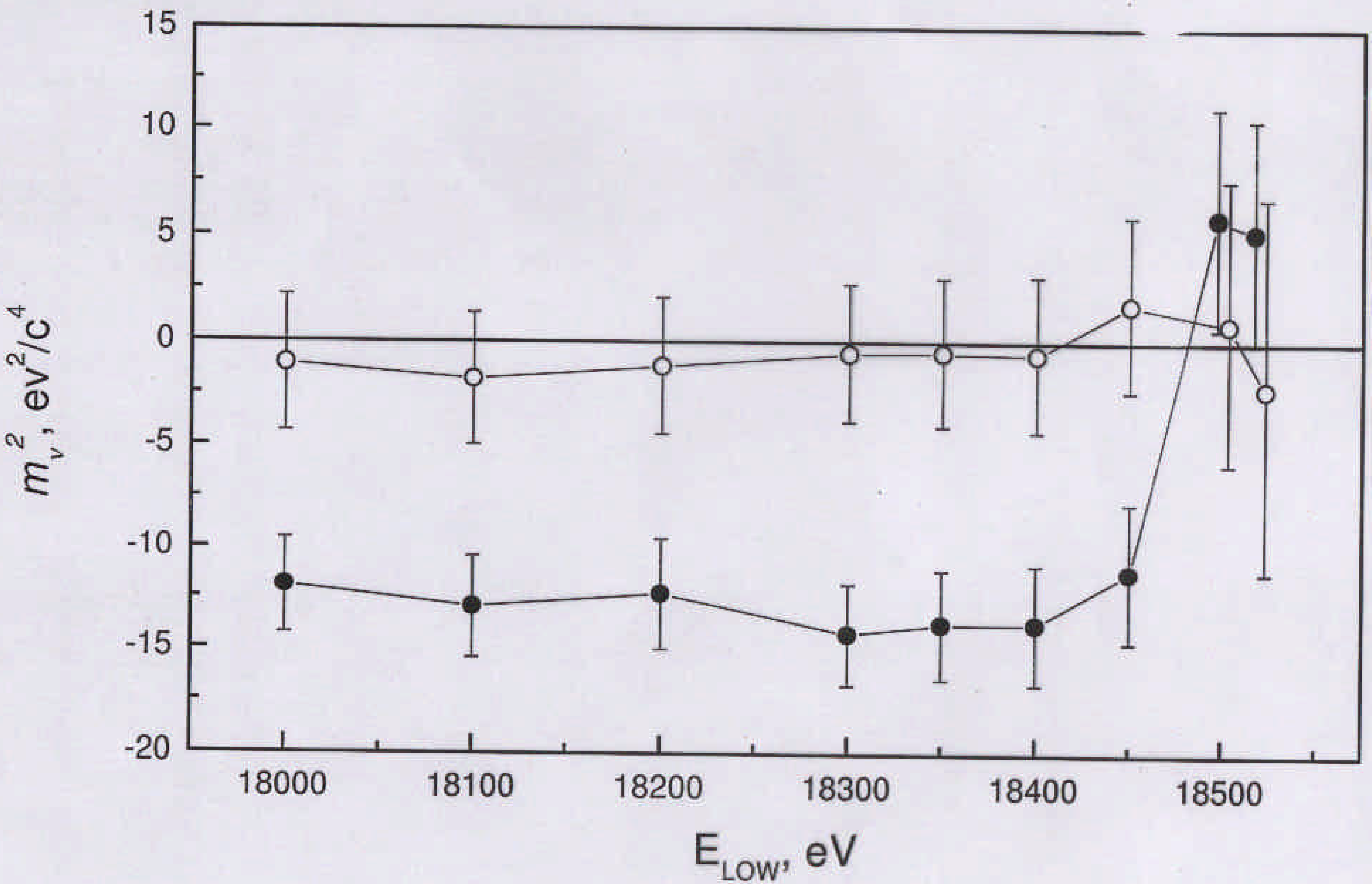
Table 3: *Variation of the fitted m_ν^2 for different E_{low} on variation of correction factors in the 96 data analysis. The Δm_ν^2 are given in eV^2/c^4.*

m_ν^2 dependence on E_{Low} at step fixed.





Error of the step position in dependence on its significance.



15
10
5
0
-5
-10
-15
-20
m_ν^2, eV^2/c^4
18000
18100
18200
18300
18400
18500
E_{LOW}, eV

Neutrino mass results.

Year		Mass	
1994		$m_\nu^2 = -2.7 \pm 10.1$ (fit) ± 4.9 (syst), cV^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	
1999	1	$m_\nu^2 = +1.6 \pm 5.6$ (fit) ± 2.0 (syst)	
Combined 98		$m_\nu^2 = -2.0 \pm 3.5$ (fit) ± 2.1 (syst), eV^2/c^4	
" 99		$-1.0 \pm 3.0 \pm 2.1$	
m_ν Bayessian limit:		$m_\nu < 2.5\ eV/c^2$ at 95% C.L.	