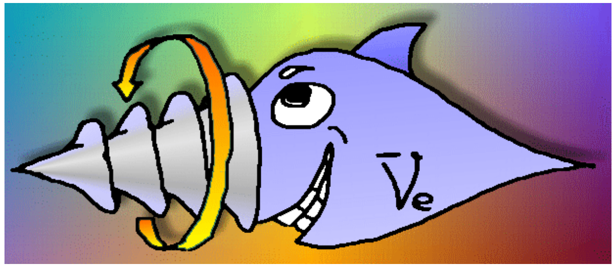
Results of the Mainz Neutrino Mass Experiment

- The Mainz Neutrino Mass Experiment
- Data from 2001
- Data from 2000
- Combined Data 1998-2001
- Conclusion and Outlook



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2003 June 28st

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Direct Measurement of m(ν_e) in Tritium-β-decay

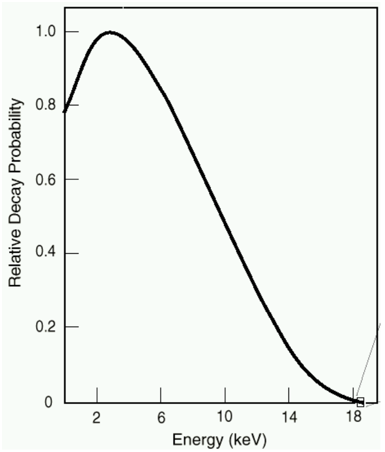
$$T_2 \rightarrow (T^3He)^+ + e^- + \bar{\nu}_e$$

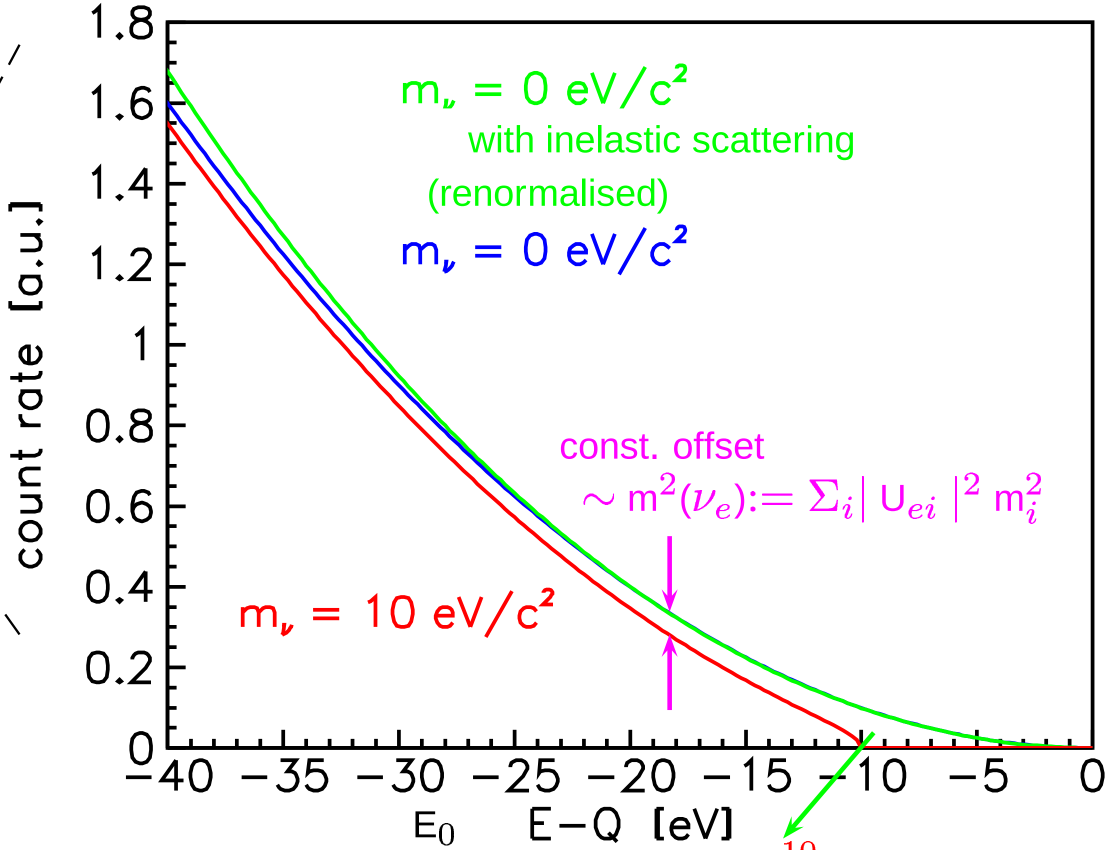
advantages: low endpoint energy: $E_0 = 18.6$ keV

reasonable half: $T_{1/2} = 12.3$ a

molecular states calculable

superallowed





$$R(E) = \frac{G_F^2 c^4}{2\pi^2\hbar^7} cos^2(\Theta_c)|M|^2 F(Z,E)\star$$
$$\underbrace{pE(E_0 - E)}_{E_\nu}\underbrace{\sqrt{(E-E_0)^2 - m_\nu^2 c^4}}_{p_\nu}$$

$\sim$ 2*10^{-10} last 10 eV

$\sim 10^{-12}$ last 2 eV

$\sim 10^{-15}$ last 0.3 eV

$\sim 10^{-18}$ last 0.03 eV

mass-energy-relation $m_\nu^2 c^4 = E_\nu^2 - p_\nu^2 c^2 \Rightarrow$

error scales with E_ν,p_ν: $\delta m_\nu^2 c^4 = 2E\delta E + 2p_\nu c^2 \delta p_\nu$

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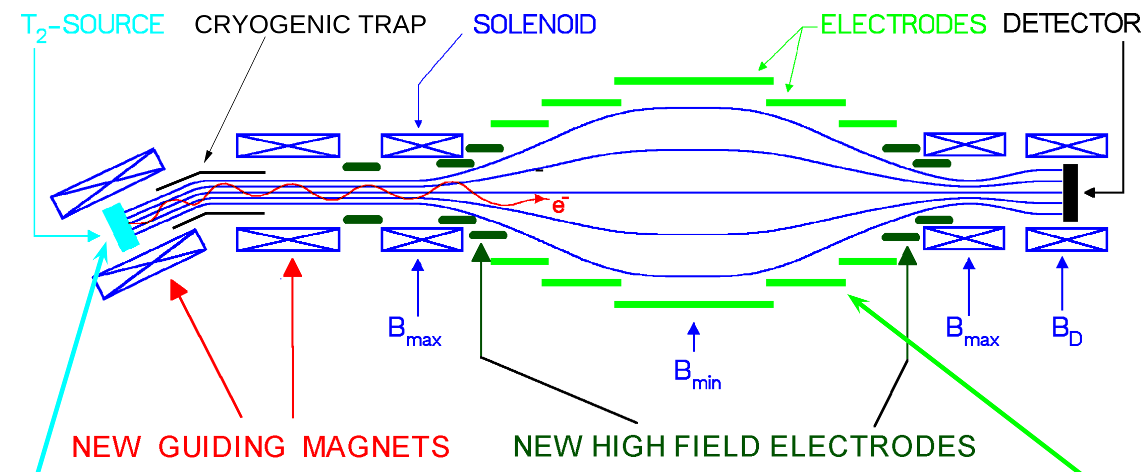
The Mainz Experiment since 1997

Magnetic Adiabatic Collimation + Electrostatic Filter

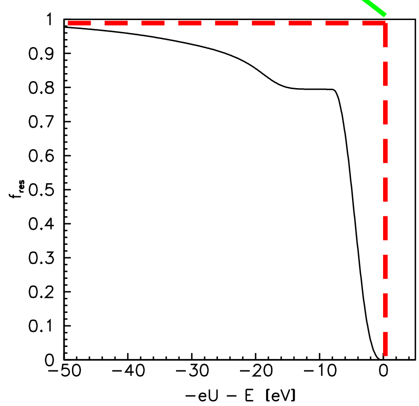


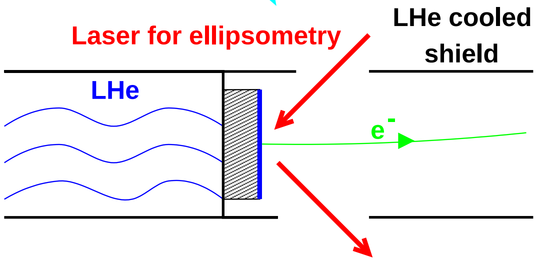
$\Delta\Omega \approx 2\pi$ ideal

$\mu = \frac{E_\perp}{B} = const.$ high-pass filter

normalised transmission function

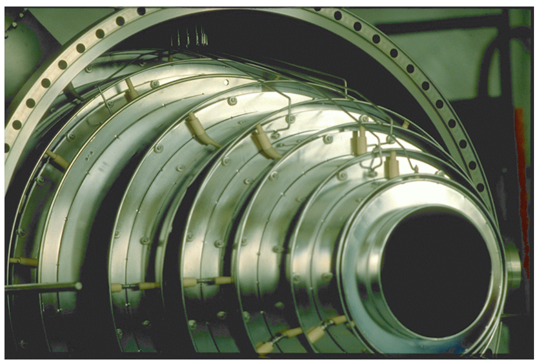
T





$$\Delta E = E_0 \cdot \frac{B_{min}}{B_{max}} \approx \text{4 - 6 eV}$$

$$E_\perp \rightarrow E_{||} + electrostatic\, retardation$$



- quenched condensed T_2 film on HOPG at 1.86 K (blue line)
- thickness measured by laser ellipsometry

  $\rightarrow$ systematic uncertainty (energy loss)
- typical source parameters:

  d $\approx$ 450 Å, $A_S = 2$ cm^2, activity $\approx$ 1 GBq

$\Rightarrow$ systematic uncertainties:

inelastic scattering, neighbour excitation, self-charging, H_2 on top

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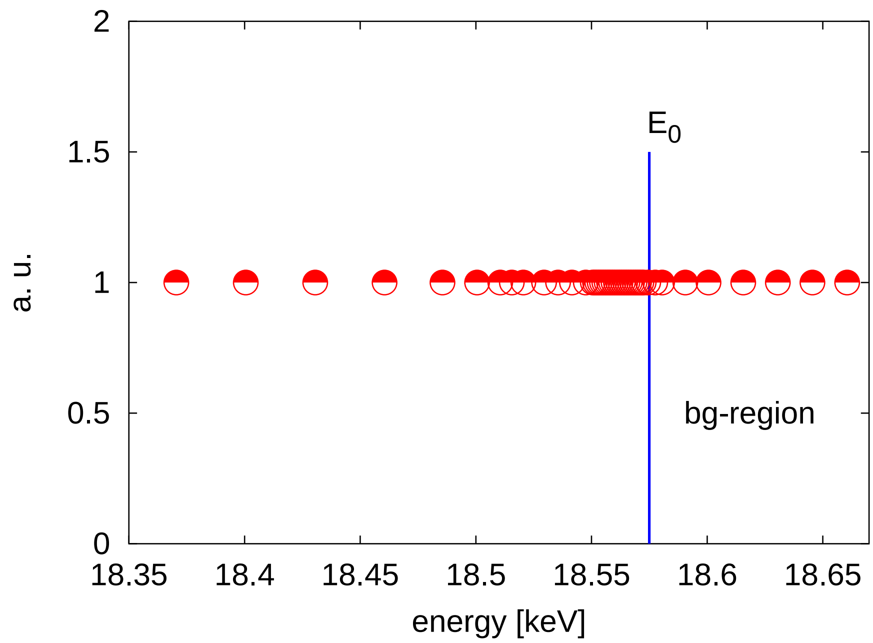
Measurement conditions



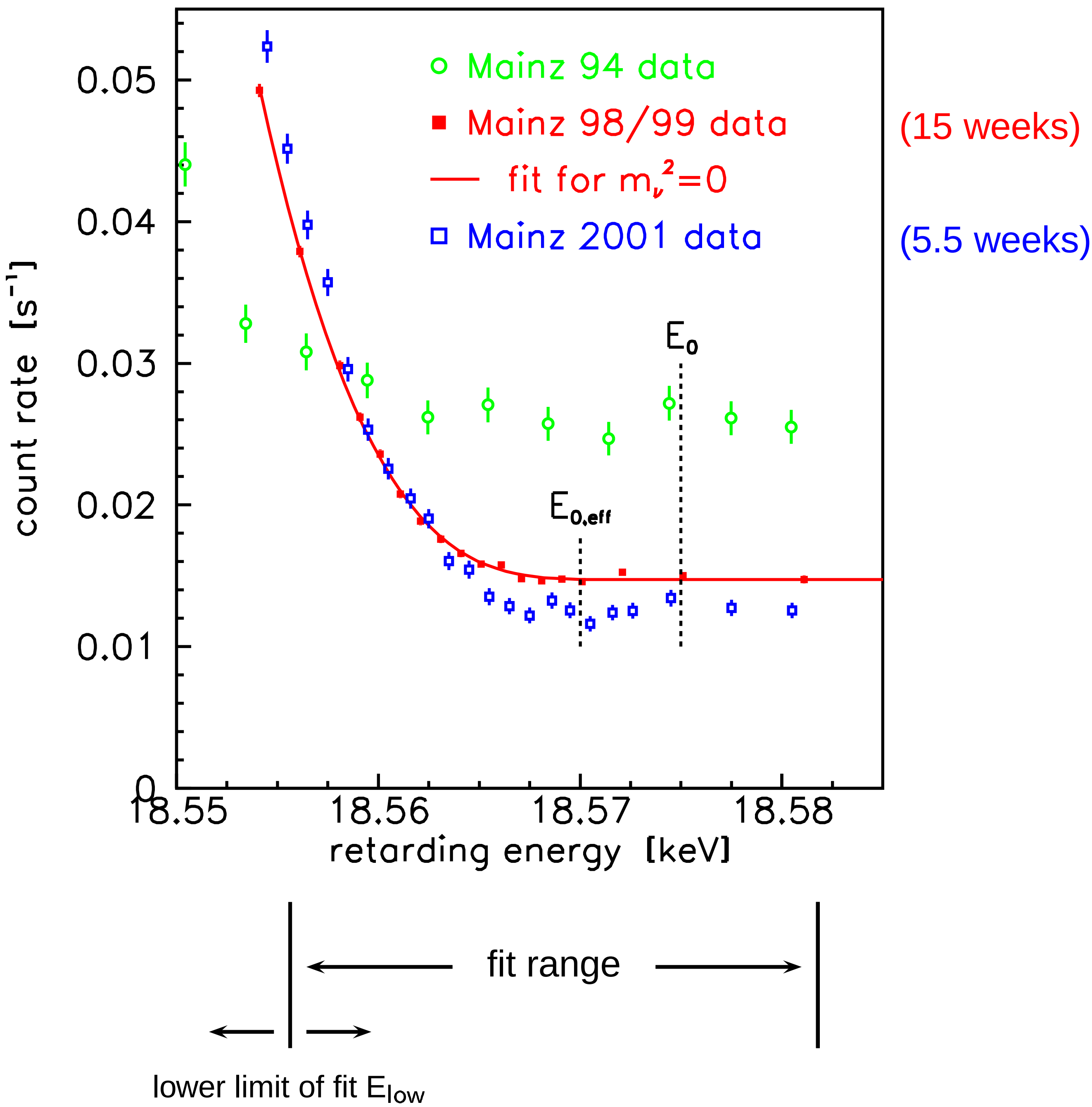
more points in background region than in 1999 measurements

measurement time per point: 20 s

Fit parameter:

- Amplitude A $\propto$ count rate
- Background level B (constant)
- Endpoint of Tritium β spectrum E_0
- Mass squared m_ν^2

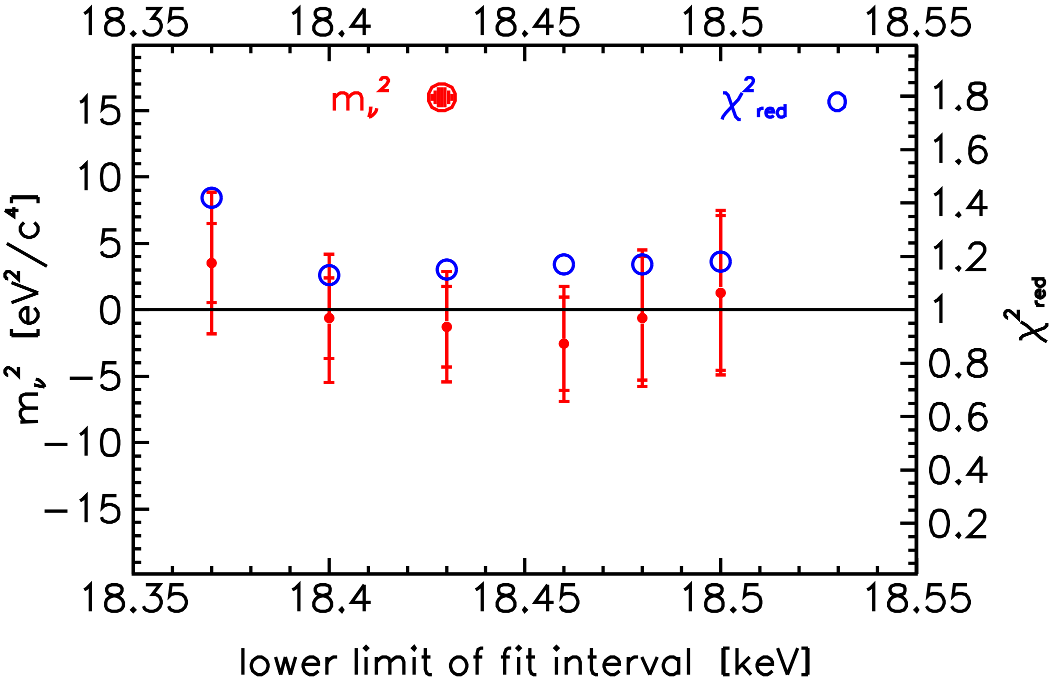
Mainz 1994 / 1998 + 1999 measurements: Q3 – Q8, Q11, Q12



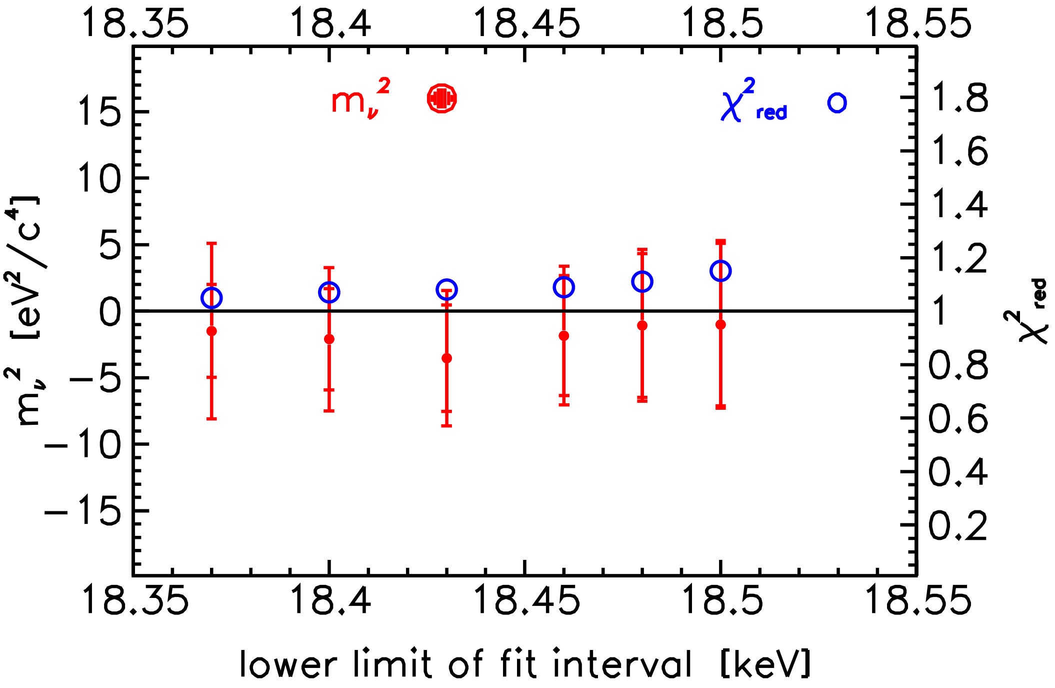
2001: lower background rate, more stable

Results from 2001 measurements

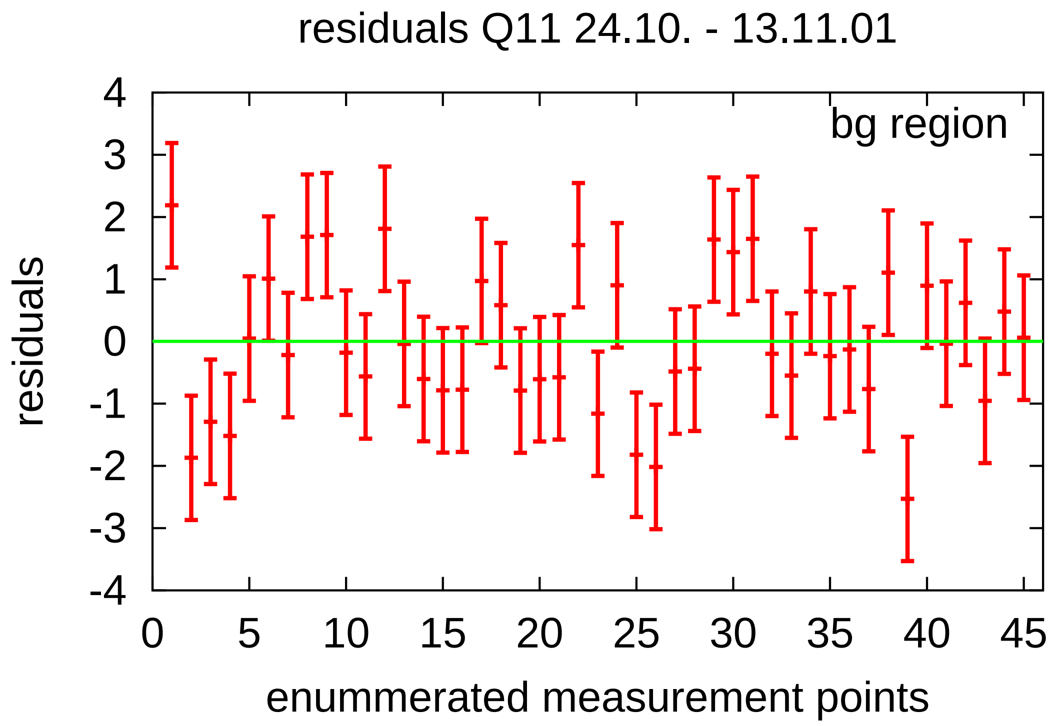
Q11 (24.10. - 23.11.01)

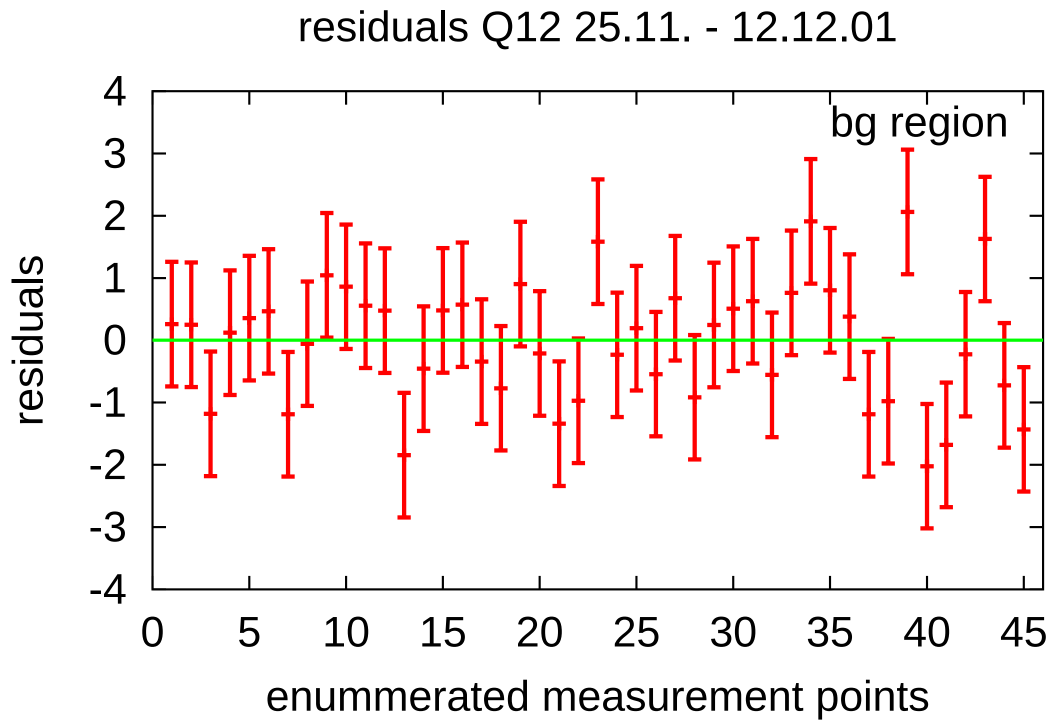


Q12 (24.11. - 06.12.01)



Residuals of Run Q11 and Q12





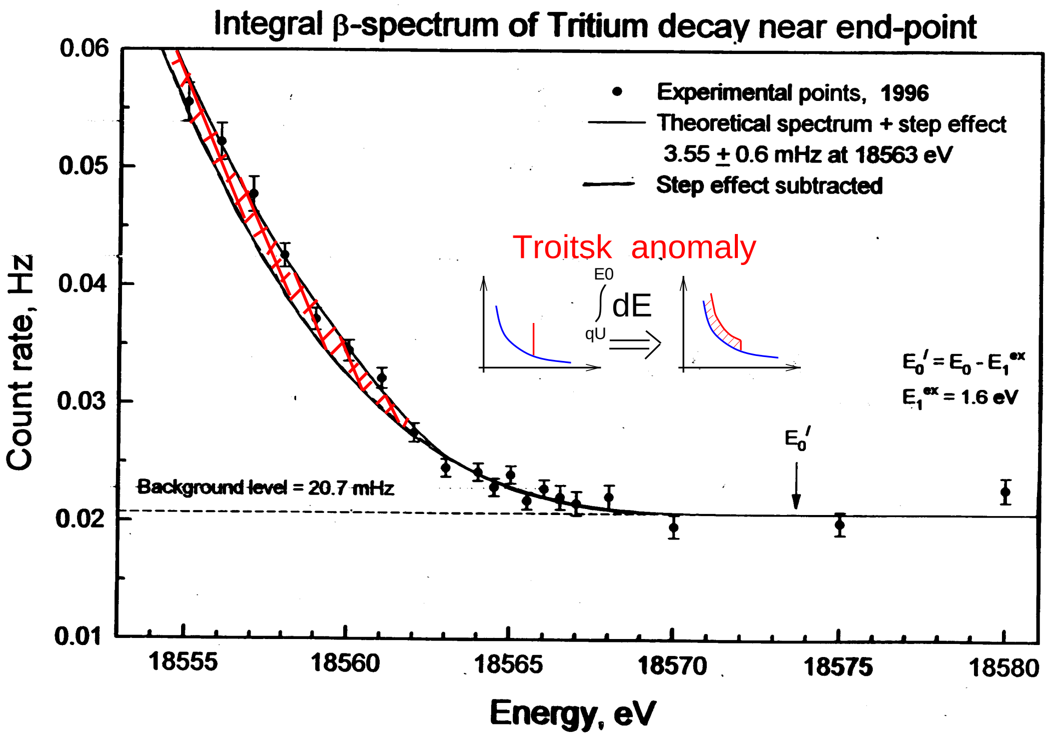
$\Rightarrow$ No hints for spectral disturbancies

Purpose of Mainz 2000 measurements

Check of Troitsk Anomaly

Tritium β-decay Experiment in Troitsk/Russia:

simular integrating spectrometer, but gaseous Tritium source



$\rightarrow$ monoenergetic line in continuous β spectrum

reported by Troitsk group (Neutrino 98, Phys. Lett. **B460** (1999) 227):

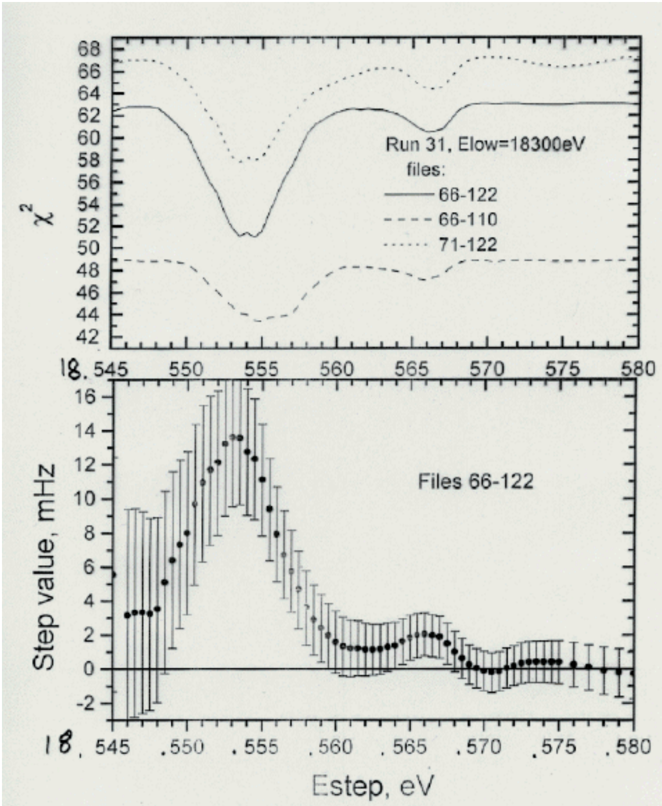
- anomaly : in all data since 1994
- amplitude : $\approx 10^{-10}$ of all decays, not constant
- position : oscillating 5-15 eV below E_0

  half year periode

simultaneous measurements
(06.-13.12.00 and 22.-28.12.00)
$\Rightarrow$ no indication for Troitsk like anomaly in Mainz data

Coincident measurement at Mainz + Troitsk

Troitsk

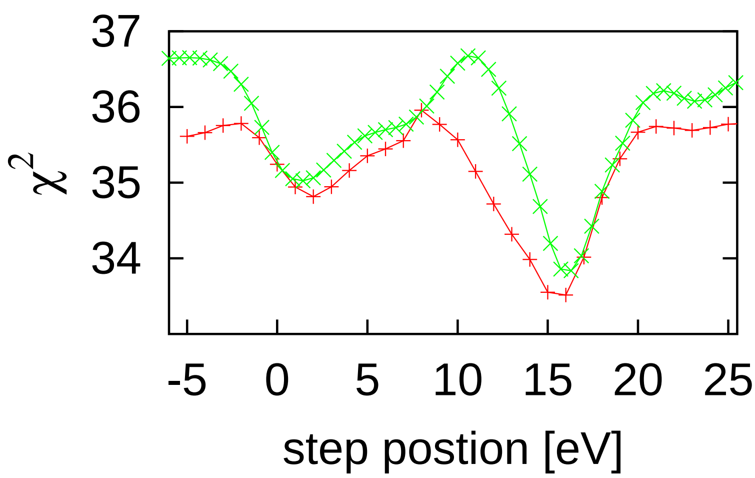


V.M. Lobashev

NANP2001

Mainz

measurement: 22. - 28.12.00

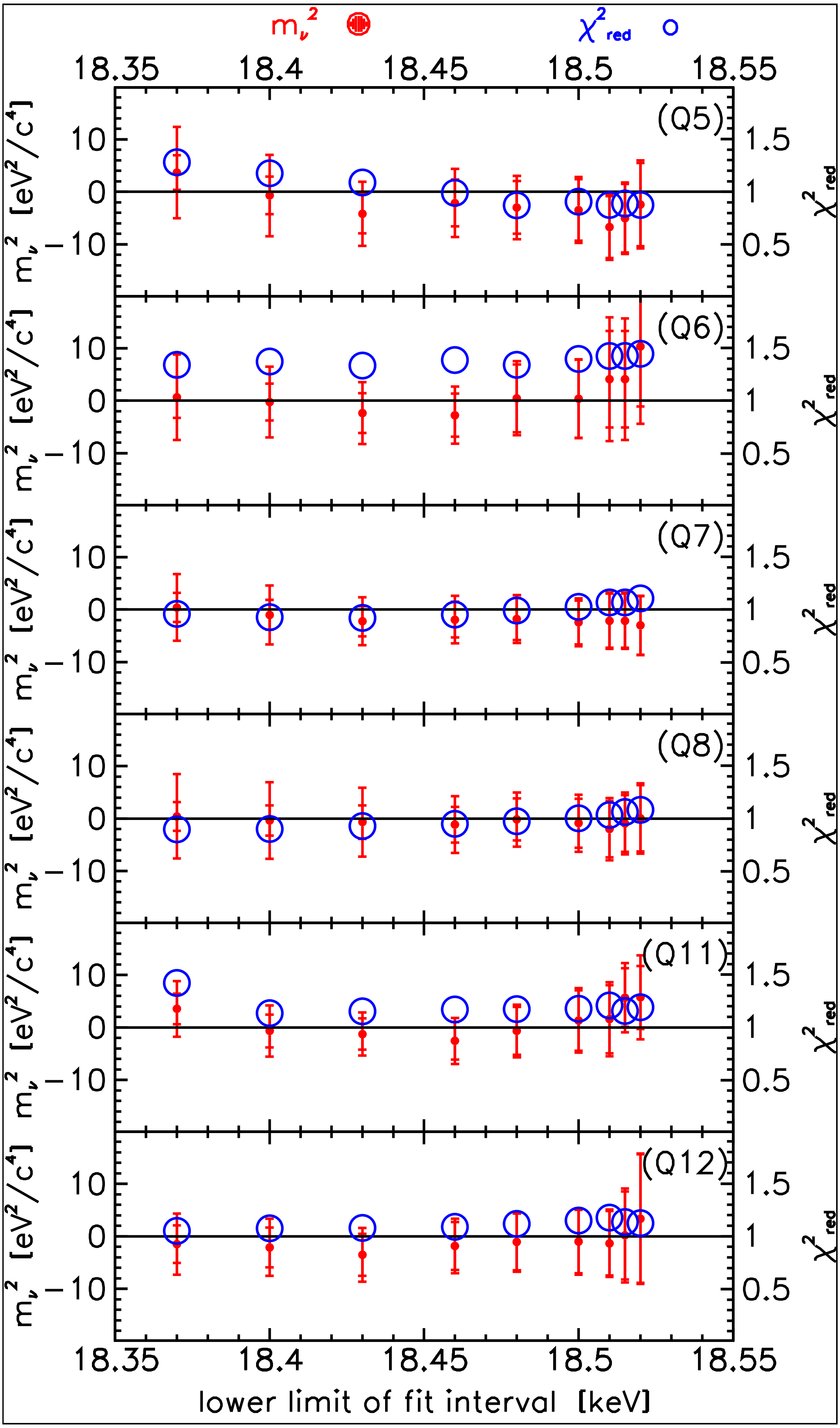


$m_\nu^2 = 0$ fixed

m_ν^2 free

Result: No indication for Troitsk Anomaly

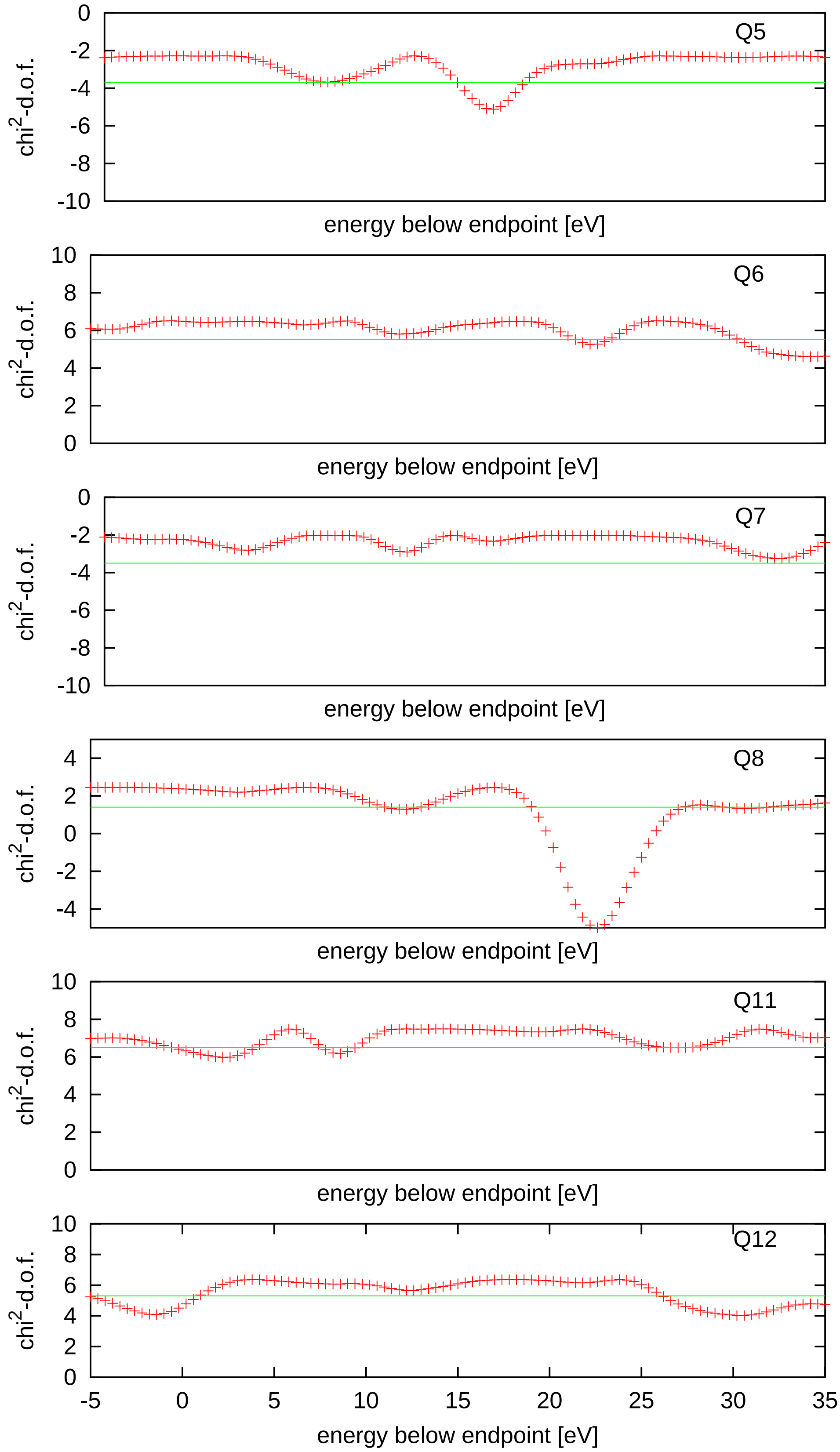
Results of the measurements 98/99/2001



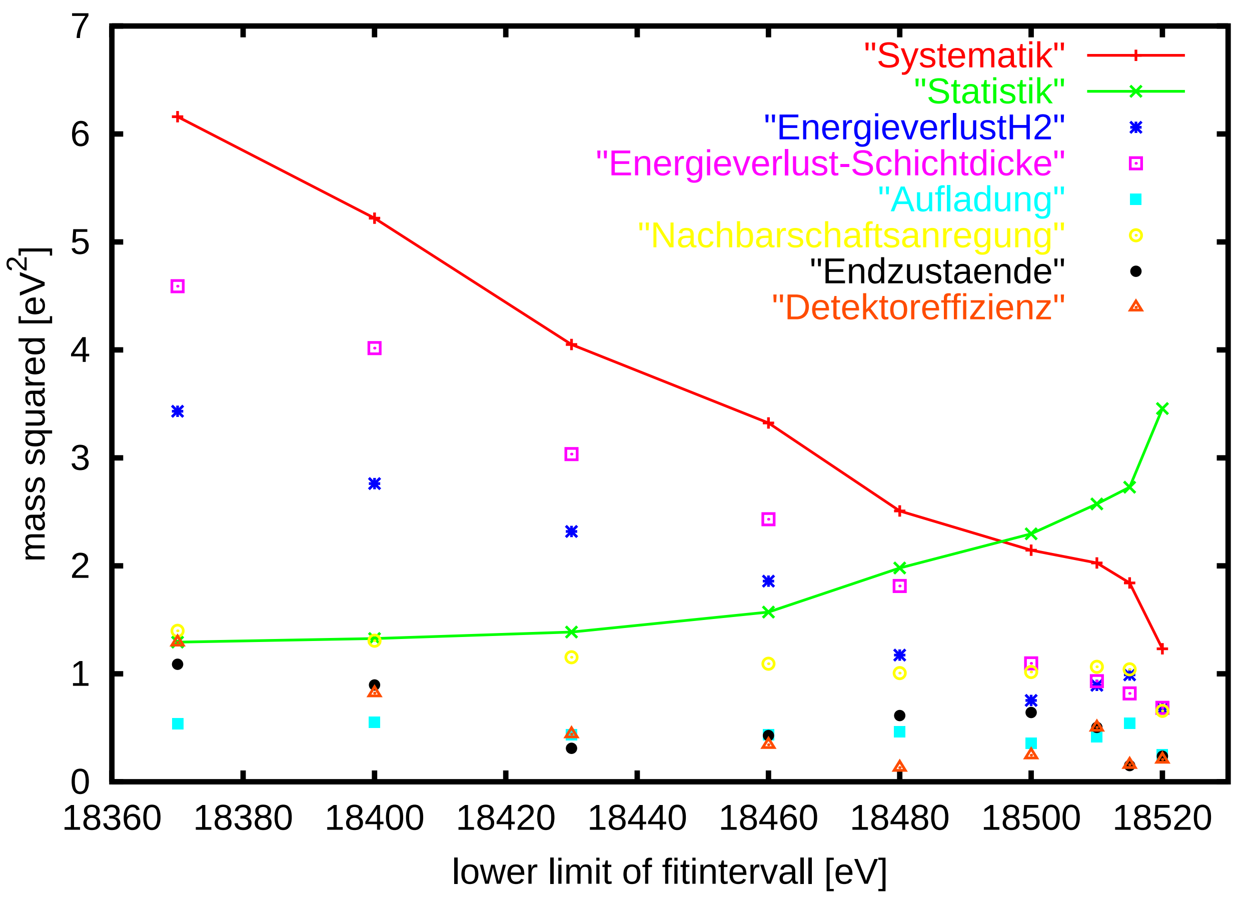
Troitsk anomaly in Mainz data?

2 additional fit parameter: amplitude and position of line

criteria: improvement in χ^2: at least 6 units, positiv amplitude



Contributions to systematic uncertainties of total data set



- total systematic uncertainty
- total statistical uncertainty
- energy loss due to H_2 on top
- energy loss due to thickness
- self charging
- neighbour excitation
- final states
- detector efficiency

C. Kraus

New results on m_ν for the Mainz data

- m_ν^2 behaviour:

  m_ν^2 is stable against variation of fit range

  m_ν^2 is compatible with physically allowed range

  $\rightarrow$ no indication for any residual problem in Mainz 1999 and 2001 data!

- No indication for a non-zero neutrino mass:

- analysis of last 70 eV below endpoint (take data points > 18.5 keV)

Q5,Q6,Q7,Q8	$m_\nu^2 c^4 = -1.6 \pm 2.5_{stat} \pm 2.1_{sys}$ eV^2	$\chi^2/\text{d.o.f.} = 125/121$
Q11	$m_\nu^2 c^4 = +1.3 \pm 5.8_{stat} \pm 2.2_{sys}$ eV^2	$\chi^2/\text{d.o.f.} = 42/36$
Q12	$m_\nu^2 c^4 = -1.0 \pm 6.1_{stat} \pm 1.7_{sys}$ eV^2	$\chi^2/\text{d.o.f.} = 41/36$
Q5,Q6,Q7,Q8,Q11,Q12	$m_\nu^2 c^4 = -1.2 \pm 2.2_{stat} \pm 2.1_{sys}$ eV^2	$\chi^2/\text{d.o.f.} = 208/193$

$\rightarrow m_\nu c^2 \leq 2.2$ eV (95% C.L., unif. appr.)

sensitivity = 2.4 eV (95% C.L., unif. appr. for $m_\nu c^2 = 0\, eV$)

Mainz setup is modified for systematic investigations to prepare KATRIN

A new Large Tritium β Experiment: KATRIN

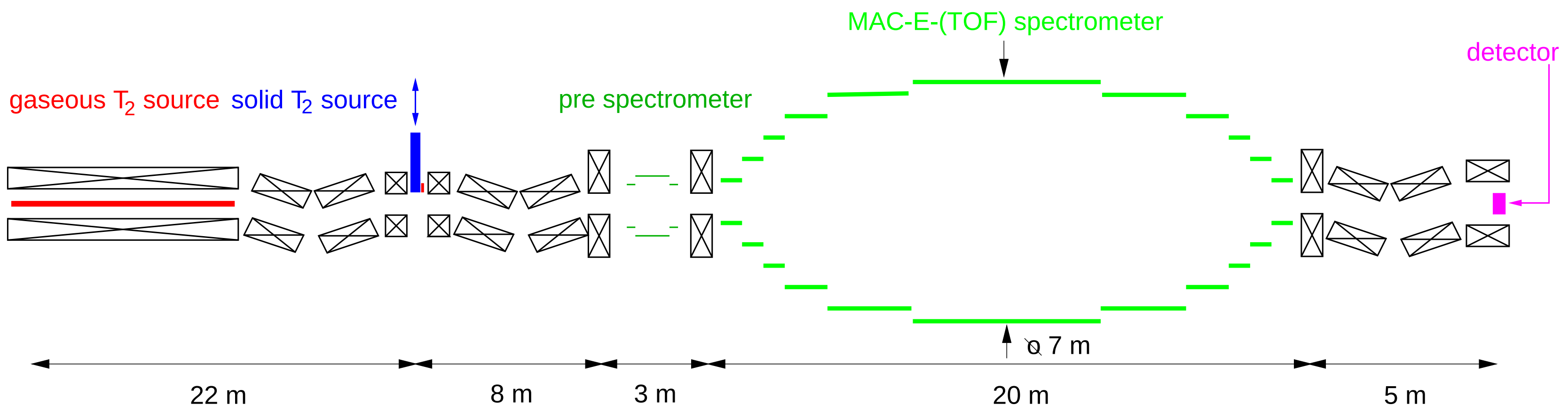
Physics aim: sensitivity on $m_\nu < 1$ eV

- Absolute neutrino mass scale / electron neutrino mass
- Degenerated and hierarchical neutrino masses?
- Neutrino masses relevant for dark matter or CMBR?

Tritium β decay: presently the only way to probe directly sub-eV ν-masses!

$\longrightarrow$ Proposal for a large spectrometer, 7 m in diameter (LOI hep-ex/0109033) $\longrightarrow$ 10 m in diameter
based on the MAC-E principle (Mainz, Troitsk)
to be built at Forschungszentrum Karlsruhe/Germany (Tritium-laboraty)

- Collaboration: Bonn, Fulda, Karlsruhe, Mainz, Prague, Seattle, Swansea, Troitsk



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Goals of the new proposed Tritium-β-decay-Experiment KATRIN

Karlruhe Tritium Neutrino Experiment

$\rightarrow$ absolute mass scale for neutrino mass
How far can we go with MAC-E-Filter-principle?

sensitivity:

- (no signal): $m_\nu \leq 0.2$ eV/c^2 (90 % c.l.)
  equal contributions of statistical and systematic uncertainties

discovery potential:

- m_ν = 0.35 eV (5 sigma)
- m_ν = 0.30 eV (3 sigma)

Time scale

- 01/2001 international workshop
- 06/2001 collaboration formed, LOI (hep-ex/0109033)
- 2003 first components (prespectrometer, magnets)
  $\rightarrow$ proposal
- 2004-2006 construction phase
- 2007 first data taking