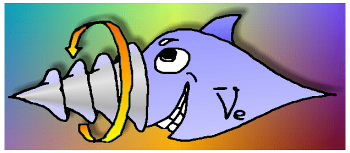
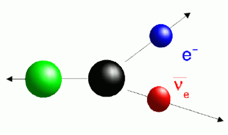


Direct neutrino mass measurements



Europhysics on Neutrino Masses and Mixings, Les Houches, June 18-22, 2001

Christian Weinheimer

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Email: christian.weinheimer@uni-mainz.de

- Introduction
- Search for neutrino masses: oscillations
  $0\nu\beta\beta$
  kinematic mass measurements
- The Mainz and Troitsk Neutrino Mass Experiments
- Future approaches
- KATRIN: A future large tritium β experiment with sub-eV sensitivity
- Conclusion

Some of the transperencies could not have been shown in the oral presentation due to time reasons

Neutrino oscillations – actual status

Experiments with

atmospheric (Super-Kamiokande) and

solar (Homestake, Gallex, (Super-)Kamiokande, SNO, . . .)

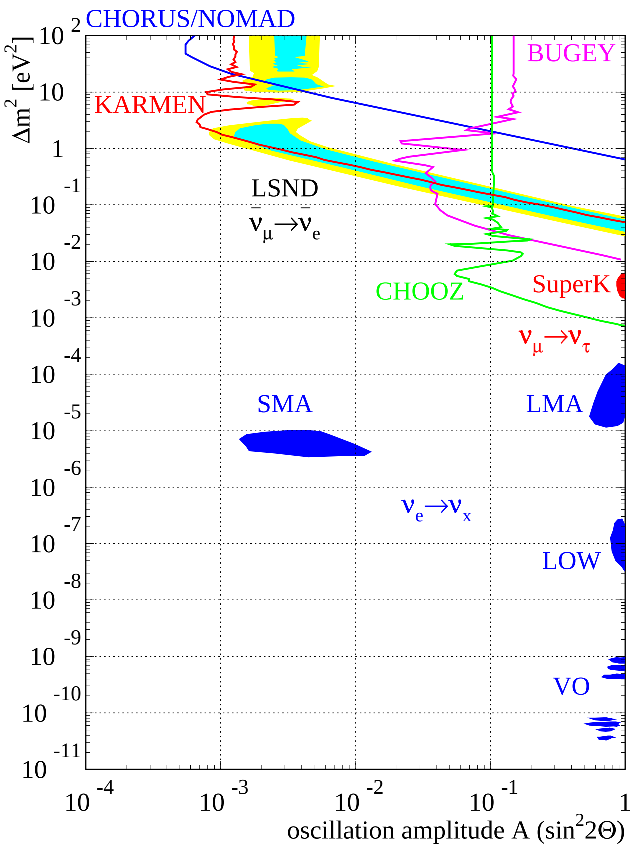
neutrinos:

⇒ Evidence for neutrino oscillations

⇒ non-trivial neutrino mixing

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

⇒ non-zero neutrino masses



neutrino oscillation evidences

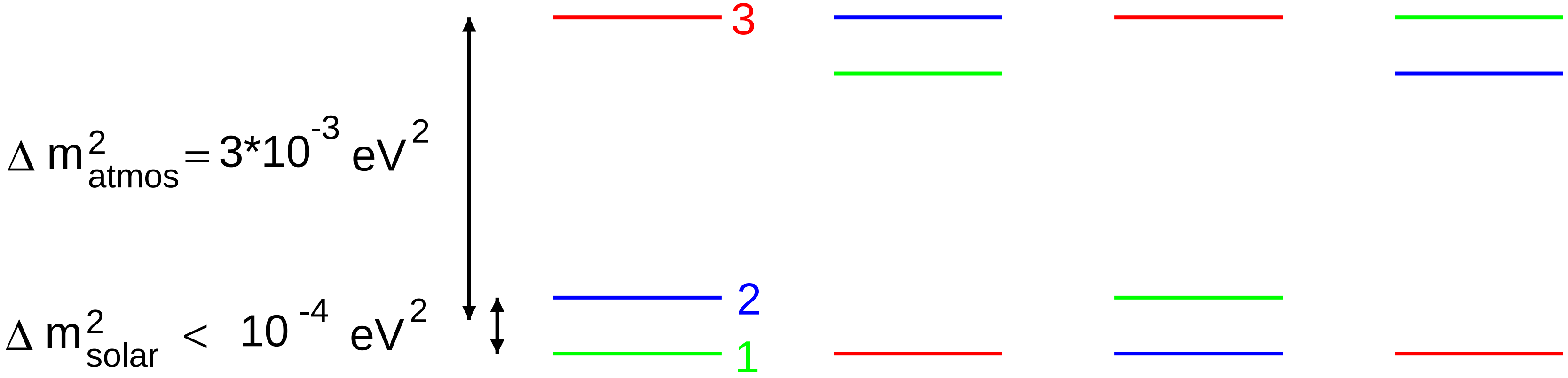
squared neutrino mass differences:

$$\Delta m^2 \leq 5 \cdot 10^{-3}\ eV^2/c^4$$

No determination of neutrino masses m(ν)

⇒ no determination of absolute neutrino mass scale

Actual neutrino mass scenarios



$\Delta m^2_{atmos} = 3{*}10^{-3}\ eV^2$

$\Delta m^2_{solar} < 10^{-4}\ eV^2$

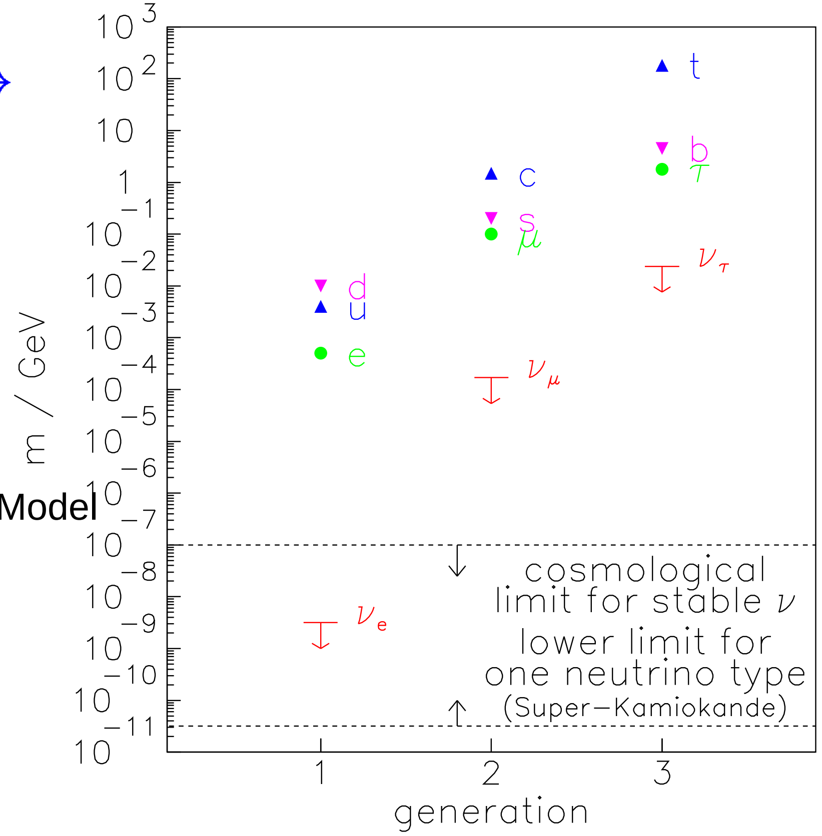
What is the absolute neutrino mass scale?

Neutrino masses & particle physics

Exp. masses of fundamental fermions →

Standard Model: $m(\nu_i) = 0$

- no explanation for values of fermion masses and mixing
- knowing $m(\nu_i)$ and ν mixing U
  $\Rightarrow$ hope to find right theory beyond Standard Model



Only relevant/possible for $m(\nu_i) \neq 0$:

- ν mixing $\Rightarrow$ ν oscillations
  (solar & atmospheric ν deficits, LSND?)
- ν decays: $\nu \to \nu'\gamma$, $\nu \to \nu' \mathrm{e}^- \mathrm{e}^+, \ldots$
- particle type: Dirac ($\nu \neq \bar{\nu}$) or Majorana ($\nu = \bar{\nu}$)

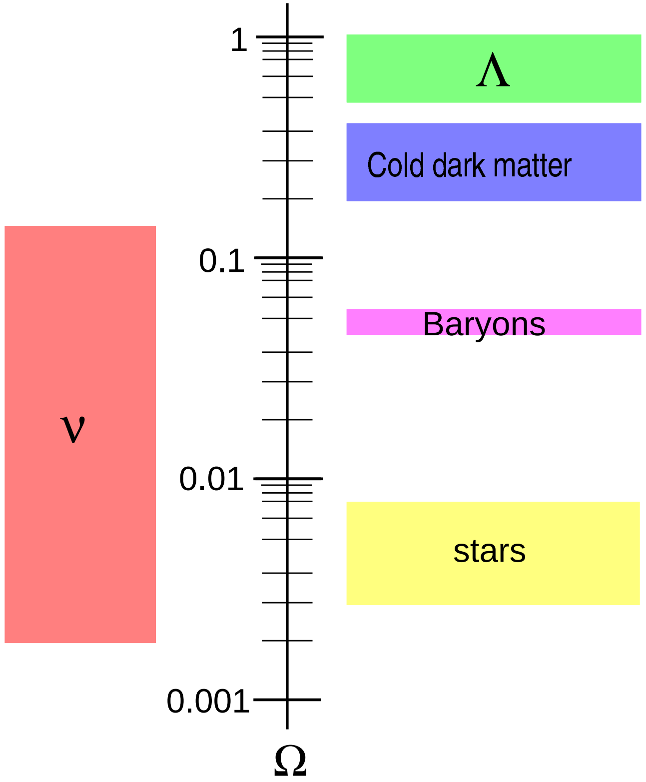
Neutrino masses & astrophysics

Current knowledge of energy and mass distribution in the universe ($\Omega = 1$, flat) →

Big Bang theory: relic neutrinos: $N_\nu \approx 10^9 N_B$

Structure formation: $\rho_\nu < 0.15 \rho_c$

- $\Rightarrow 1/3 \sum_i m(\nu_i) < 2\ \mathrm{eV}/c^2$ (for stable ν)



Neutrino mass (and mixing) concern:

- relic neutrinos, dark matter and evolution of the universe
- anisotropies of cosmic microwave background
- structure formation
- supernovae & r-process, . . .

$\boxed{\Rightarrow \text{eV neutrino masses are very important}}$

Search for neutrino masses

A) Indirect searches for neutrino masses:

Search for effects, which can only exist, if $m(\nu) \neq 0$

(and if other requirements are fulfilled)

- neutrino oscillations (ν mixing, different masses)
- neutrinoless double β decay ($0\nu\beta\beta$) (Majorana neutrinos)

B) Direct mass determinations:

No further requirements, except neutral, spin 1/2

use $E^2 = p^2 + m^2 \Rightarrow m^2(\nu)$ is observable mostly

- time-of-flight measurements

  very long distances $\Rightarrow$ very bright astrophysical sources only

  νs from Supernova 1987a (large Magellan cloud, $L = 50$ kpc)

  t=0 unknown $\Rightarrow$ use energy time-of-arrival correlation:

$$t(E) = \frac{L}{c} \cdot \left(1 + \frac{m^2(\nu)c^4}{2E^2}\right)$$

  $\Rightarrow m(\nu_e) \leq 23\, eV$ (PDG 2000)

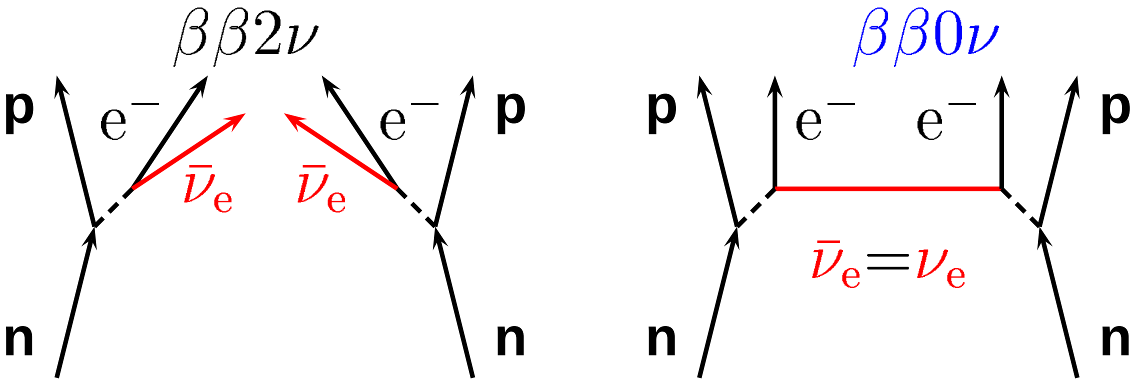
- kinematics of weak decays

  Energy and momentum conservation,

  measure charged decay products

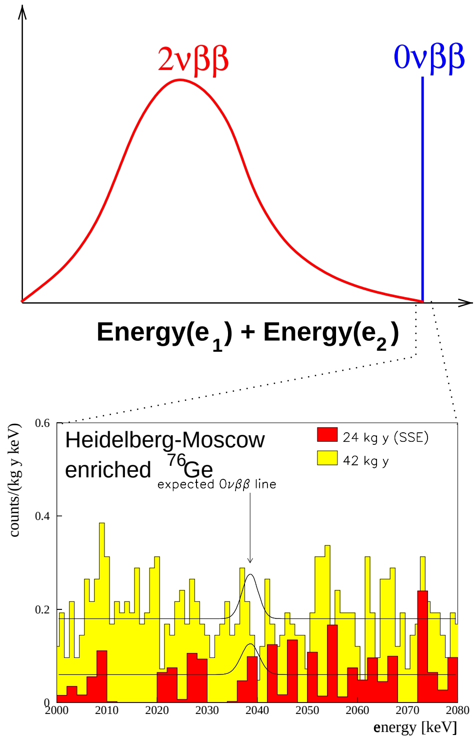
  $m(\nu_\tau) < 18.2$ MeV/c^2, $m(\nu_\mu) < 190$ keV/c^2 (95% C.L.)

Search for $\beta\beta0\nu$



— needs: ● $\bar{\nu} = \nu$ (Majorana neutrino)

● helicity flip $\rightarrow m(\nu) \neq 0$



$\beta\beta0\nu$ not observed: $T_{1/2} > 1.9 \cdot 10^{25}\ y$ (90 % C.L.)

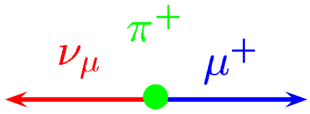
$\Rightarrow\ \mathrm{m}_{\mathrm{ee}} < 0.35\mathrm{eV}$ (90 % C.L.) (Summer conf. 2000)

(without uncertainties of nuclear matrix elements)

Determination of $m(\nu_\mu)$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$ (Two body decay)

Decay at rest:



$$|\vec{p}_\nu| = |\vec{p}_\mu|$$

$$m_\pi = E_\nu + E_\mu$$

$$\rightarrow \mathrm{m}_\nu^2 = \mathrm{m}_\pi^2 + \mathrm{m}_\mu^2 - 2 \cdot \mathrm{m}_\pi \cdot \sqrt{\mathrm{m}_\mu^2 + \mathrm{p}_\mu^2}$$

3 different Experiments:

Values from PDG2000

Pionic atoms: $\mathrm{m}_\pi = 139.570180(350)$ MeV

Myonium: $\mathrm{m}_\mu = 105.658357(5)$ MeV

Magnetic spektrometer (PSI): $\mathrm{p}_\mu = 29.791998(110)$ MeV

$\Rightarrow \mathrm{m}(\nu_\mu) < 170 \mathrm{keV}/\mathrm{c}^2 \quad (95\% \text{ c.l.})$ (K. Assamagan *et al.*, Phys. Rev. D53 (1996) 6065)

PDG2000: $\mathrm{m}(\nu_\mu) < 190 \mathrm{keV}/\mathrm{c}^2 \quad (95\% \text{ c.l.})$

Improvements expected: Factor 3 by new m_π measurement (PSI)
Factor 20 by $\pi^+ \rightarrow \mu^+\nu_\mu$ in flight (g-2, BNL)

Determination of m(ν_τ)

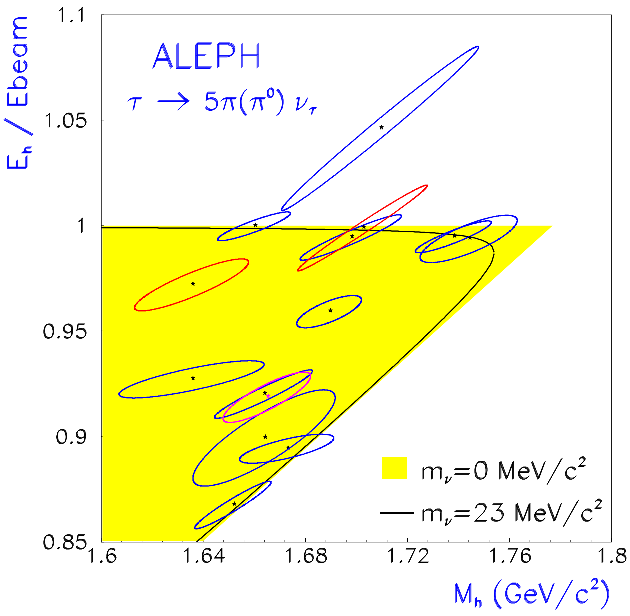
Collider experiments: e$^+e^- \to \tau^+\tau^-$

Search for rare subsequent τ decays:

$$\tau \to 5\pi\ (+\pi^o) + \nu_\tau \qquad (BR = 10^{-3})$$

“Observable”: invariant mass of the 5(6) π’s

$$M_h{}^2 = (\sum E_i,\ \sum \vec{p}_i)^2 \leq (m_\tau - m_\nu)^2$$



Lowest present limit:

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

(ALEPH)

also limits from OPAL, CLEO

Future perspectives:

- Sensitivity of 3 MeV/c^2 expected from BABAR and BELLE
  → close small cosmological window
- Further significant improvement by nearby Supernova possible!

Direct measurement of $\mathrm{m}(\nu_e)$

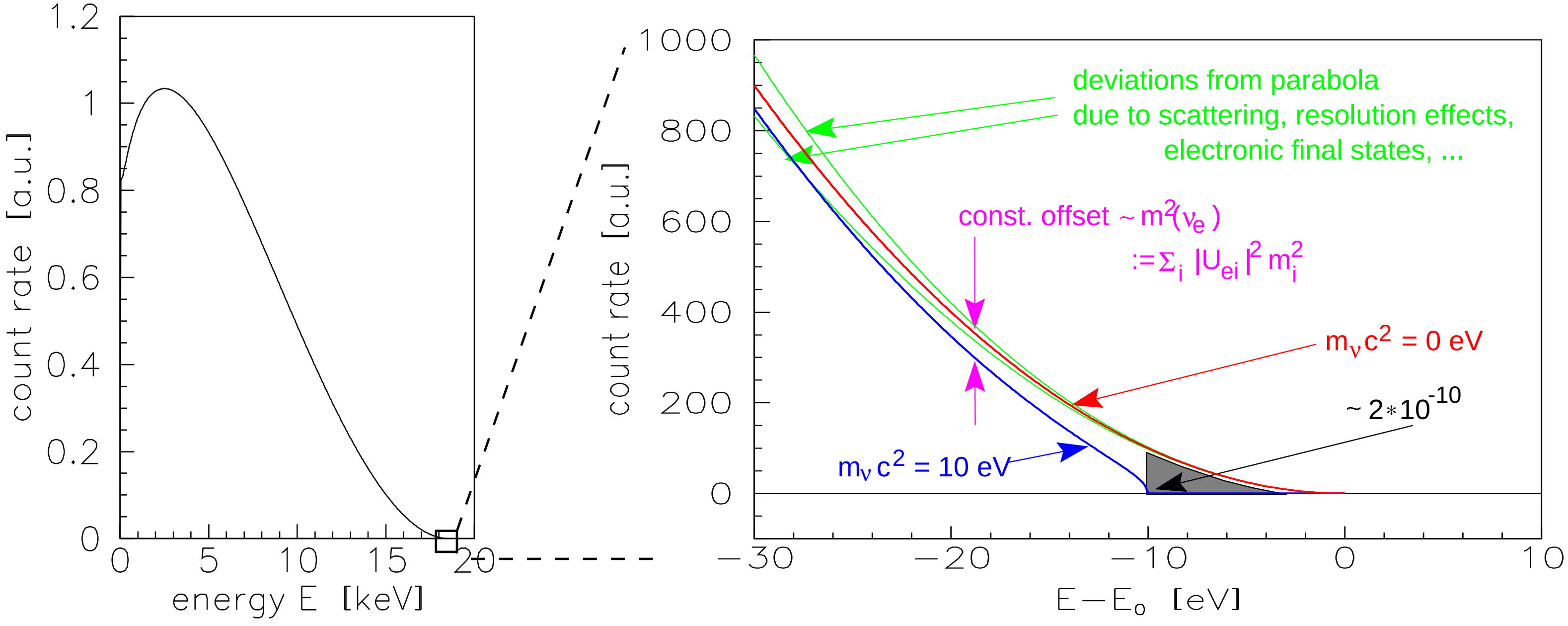
Tritium β decay:

$^3\mathrm{H} \longrightarrow {}^3\mathrm{He}^+ + e^- + \bar{\nu}_e$:

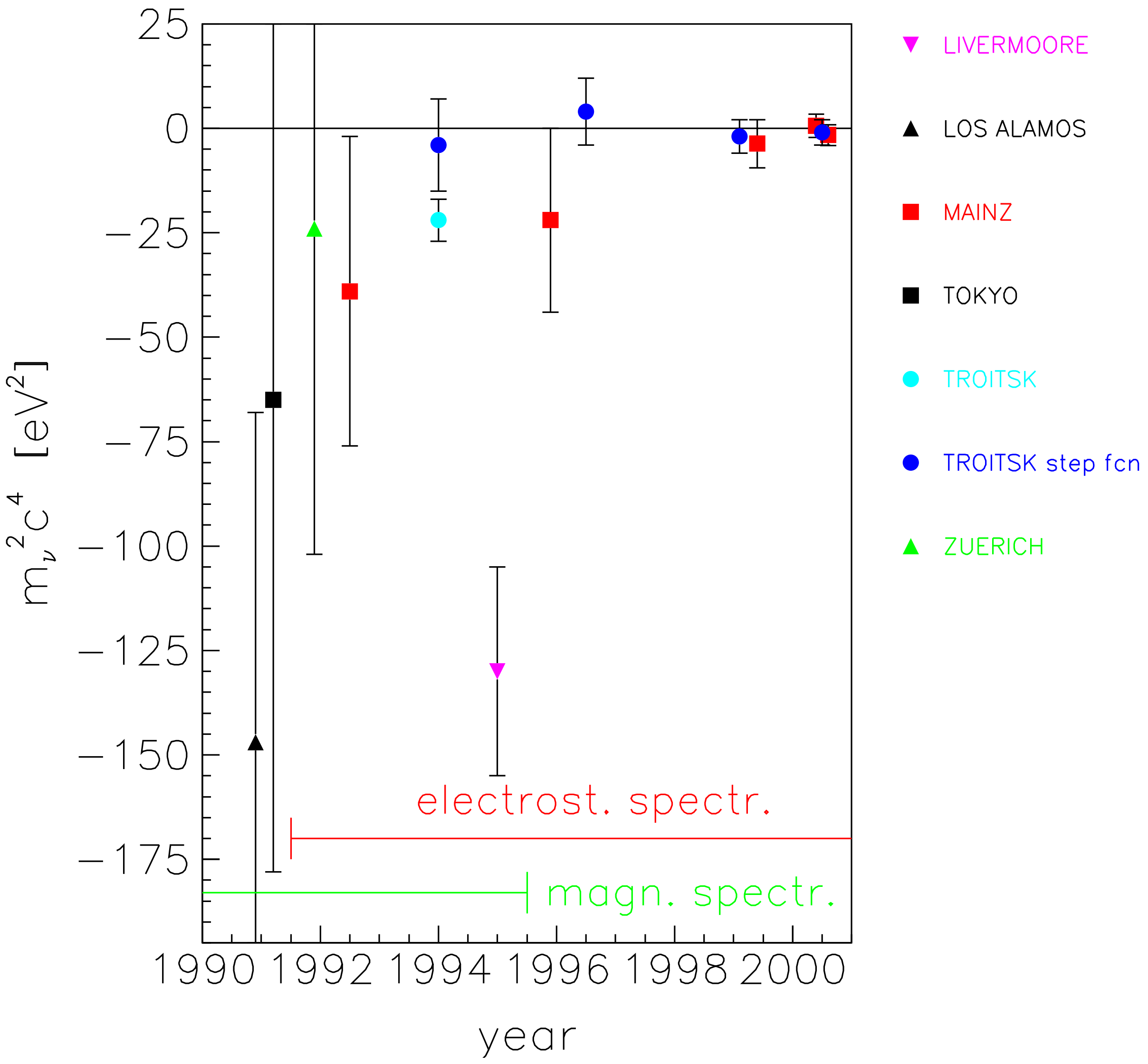
superallowed

E_0 = 18.6 keV

$t_{1/2}$: 12.3 a



Tritium β decay experiments



⇒ Huge improvement within last decade

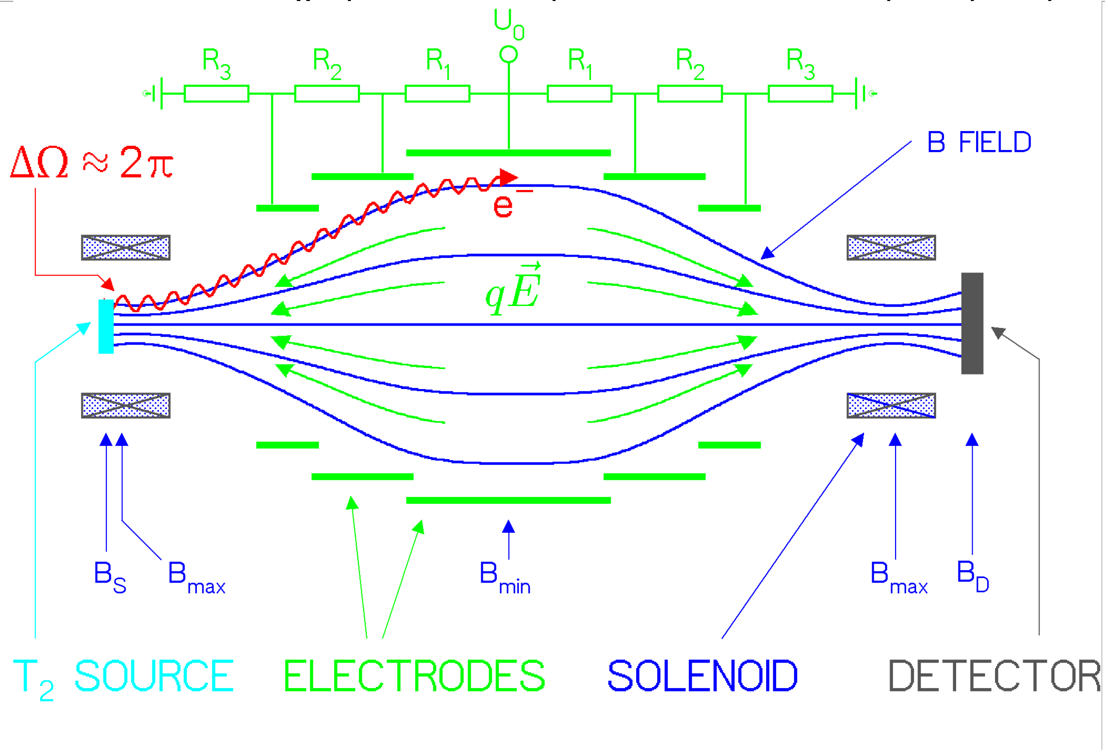
At present:

- 2 running experiments at Mainz/Germany and Troitsk/Russia
- former negative m_ν^2 values disappeared

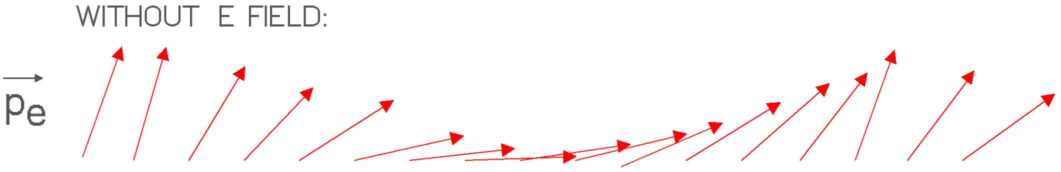
Magnetic Adiabatic Collimation

+ Electrostatic filter

“Solenoid Retarding Spectrometer” (Nucl. Inst. Meth. B63 (1992) 345)



$$\mu = \frac{E_\perp}{B} = \textbf{const.}$$



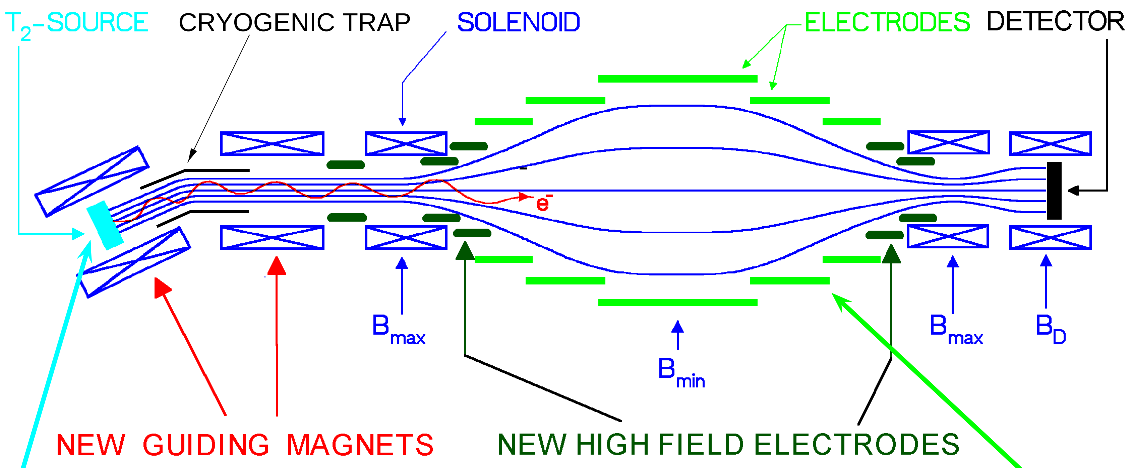
- magnetic guiding field

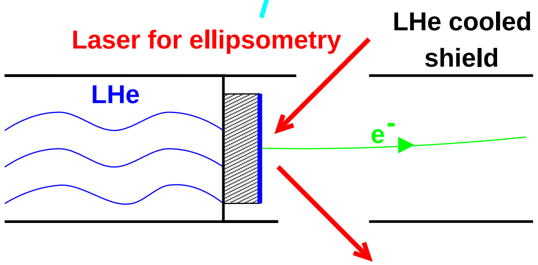
  $\rightarrow \quad \Delta\Omega \approx 2\pi$ (huge !)

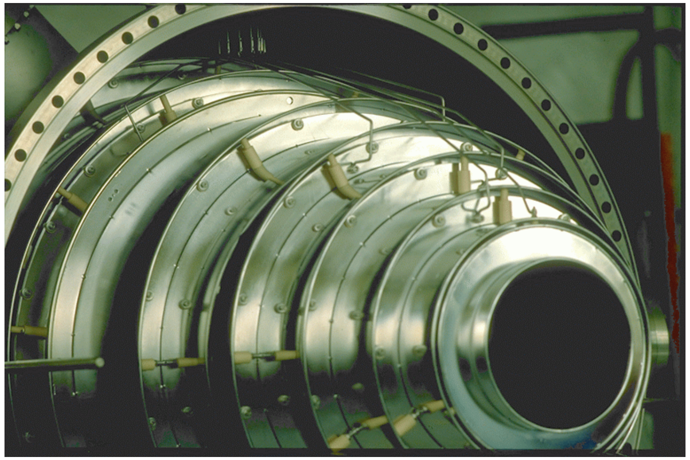
- adiabatic transf. $E_\perp \rightarrow E_{||}$ + electrostatic retardation

  $\rightarrow \Delta E = E \cdot B_{min}/B_{max} \approx 4 - 6\text{eV}$ (small !)

The Mainz setup since 1997







- T_2 film at 1.86 K
- quench condensed on graphite substrate (HOPG)
- $\approx$ 450 Å thick, area 2 cm^2
- thickness measured. by ellipsometry

Data taking in 1998 and 1999

6 Runs (labelled Q3–Q8),
7 months measurement time in total:
(possible due to automation of apparatus)

- Increasing of signal by a factor of 5

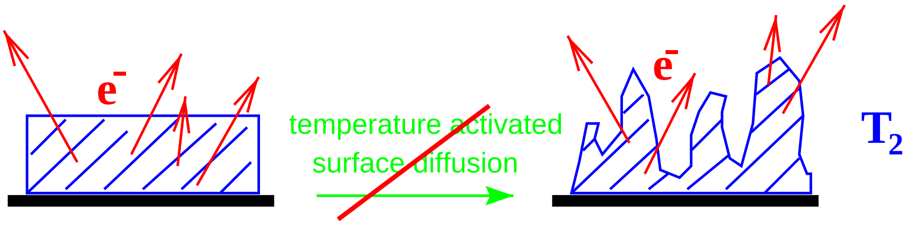
  Decreasing of background by a factor of 2

  → 10× better signal/background

- Lower T_2 film temperature: T = 1.86 K (instead of $\geq$ 3 K)

T_2: 500 Å

Graphit



~~temperature activated surface diffusion~~

(larger energy losses)

(problems of 1991 and 1994)

(→ negative m_ν^2 value problem)

L. Fleischmann *et al.*, J. Low Temp Phys. **119** (2000) 615,

L. Fleischmann *et al.*, Eur. Phys. J. **B16** (2000) 521

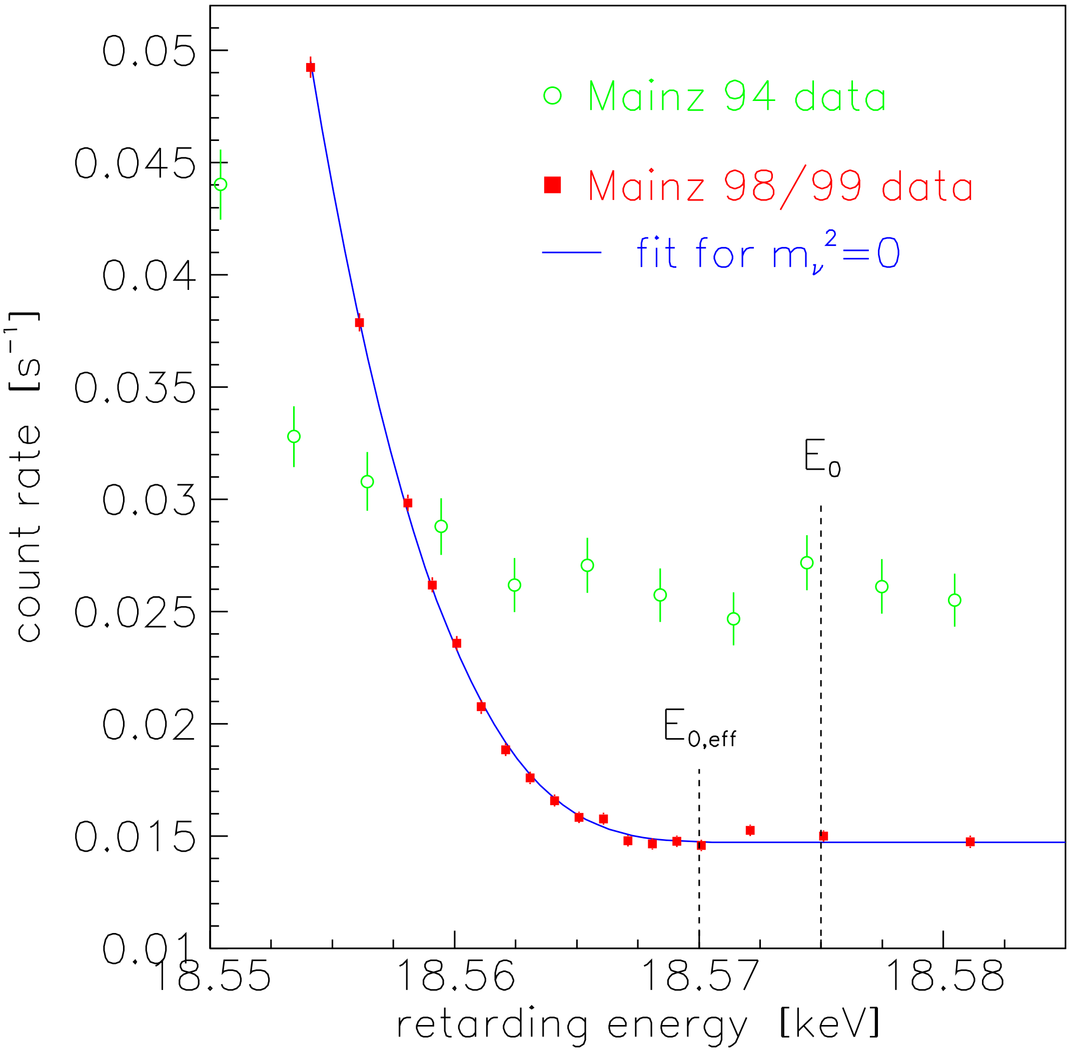
- Better spectrometer resolution: ΔE = 4.8 eV

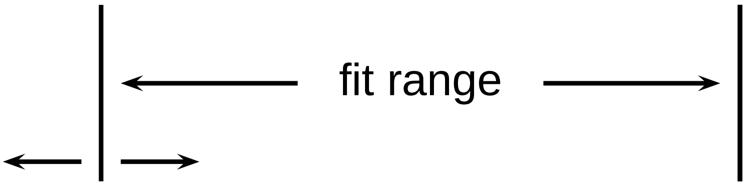
  (instead of 6.5 eV)

- More stable background:

  HF pulsing on electrodes inbetween measurements from Q5 on

Mainz 1998 + 1999 measurements: Q3 – Q8

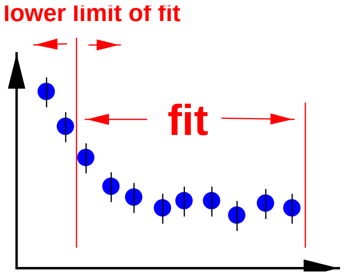


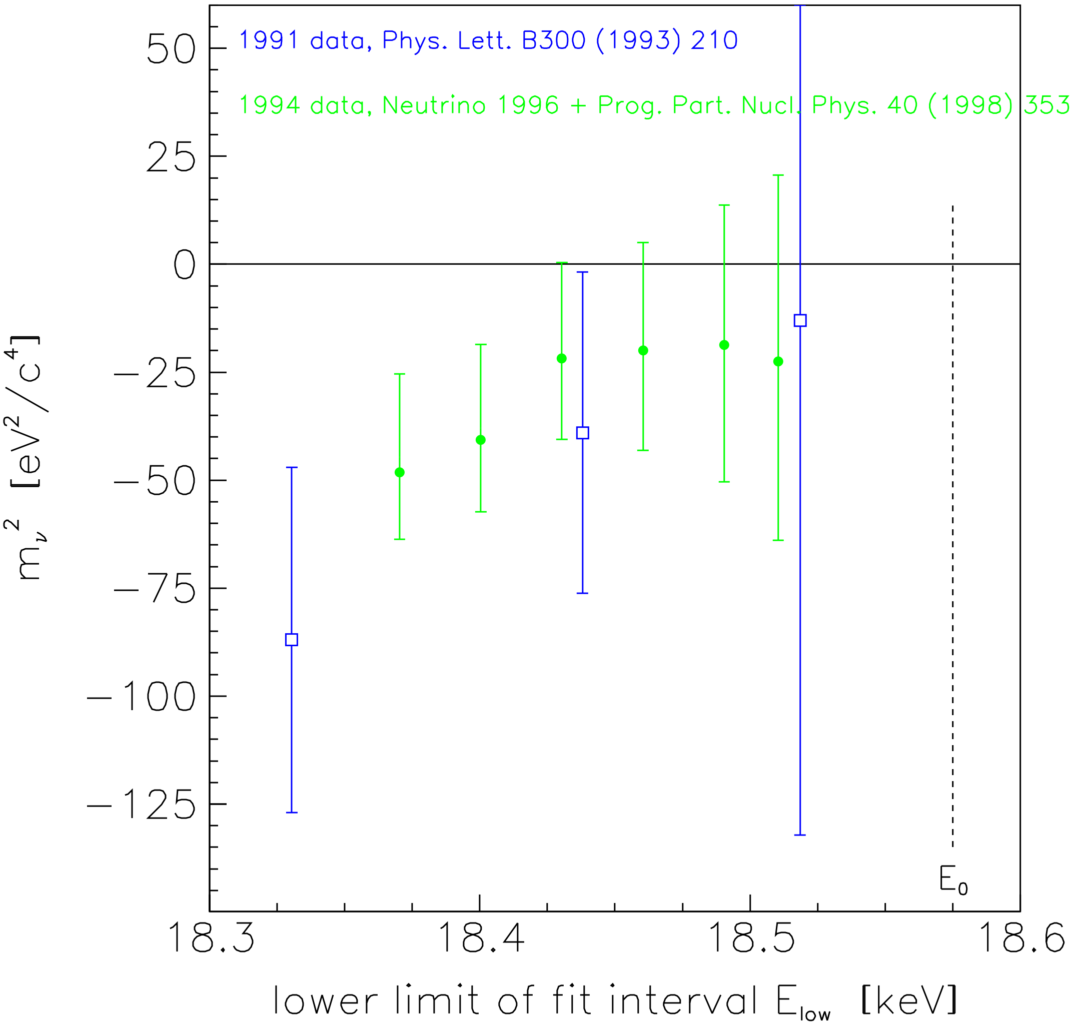


fit range

lower limit of fit E_{low}

Former problem of negative m_ν^2 at Mainz





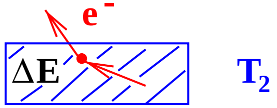
⇒ Problem of missing energy loss

was caused by roughening transition

⇒ should be solved by much lower T_2 temperatures

Systematic uncertainties

- **Inelastic Scattering** — thickness measurement: Δd = 3 - 9 ML (d = 130 ML) — (37 %)



λ_{free} = 363 +/- 19 ML (Asseev et al., Eur. Phys. J. D10 (2000) 39)

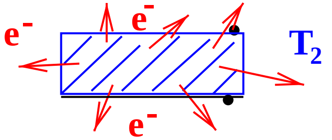
shape of energy loss function

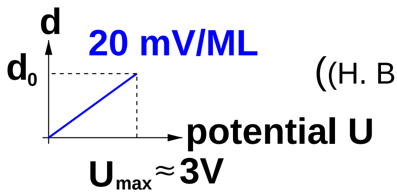
→ some differences to gaseous T_2

- **Final states** (effects due to solid state) — (35 %)
  - spectator excitation
  - changes of excited states energy levels

(take full correction as systematic uncertainty into account)

- **T_2 film charging up** — (7 %)

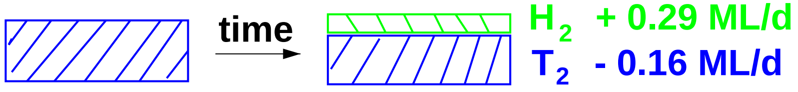




((H. Barth et al., Prog. Part. Nucl. Phys. 40 (1998) 353)

(take 20% of effect as systematic uncertainty into account)

- **T_2 film loss, H_2 coverage** — new — (21 %)



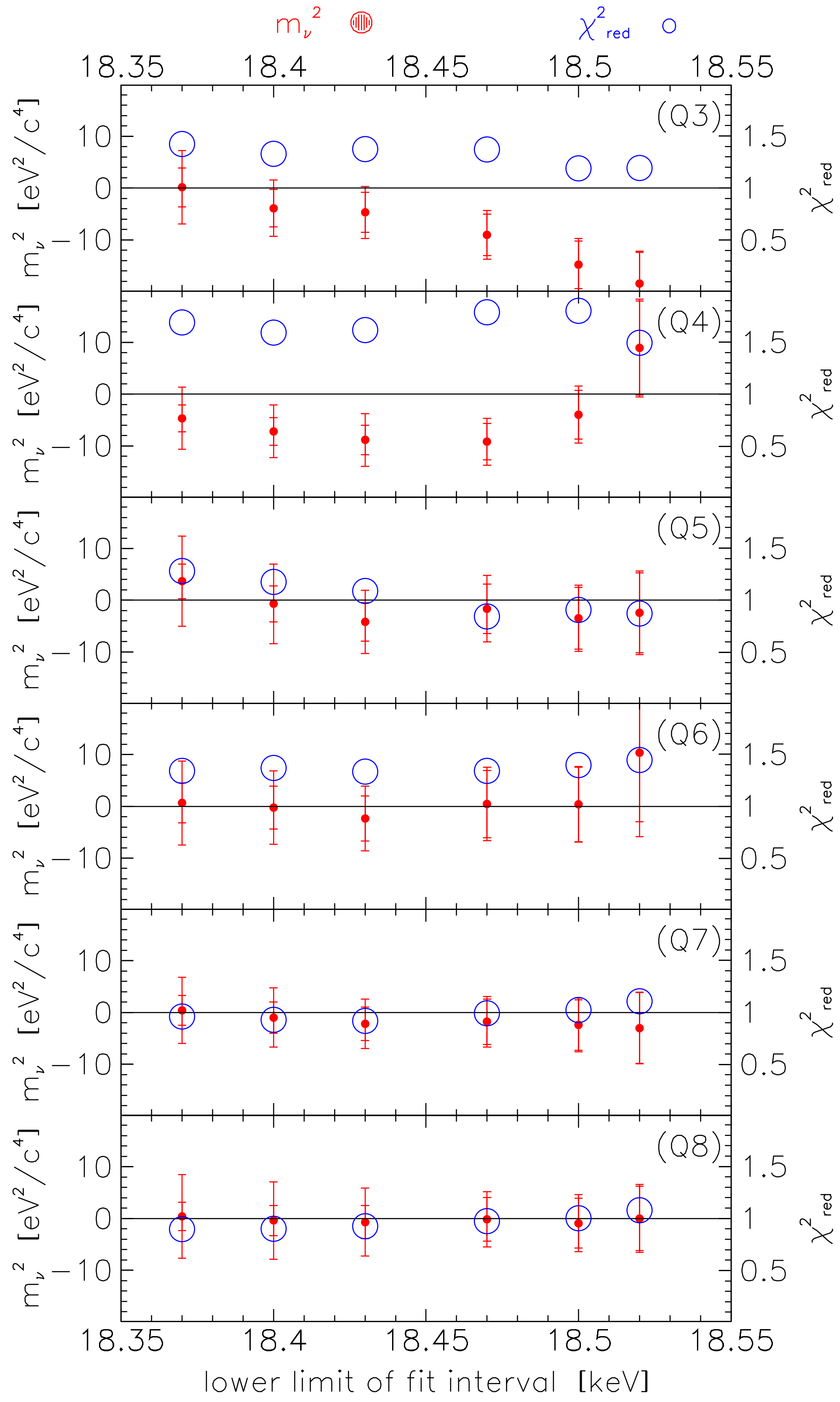
H_2 + 0.29 ML/d

T_2 - 0.16 ML/d

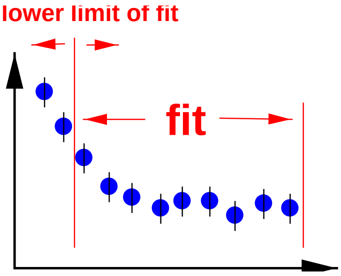
(take full correction as systematic uncertainty into account)

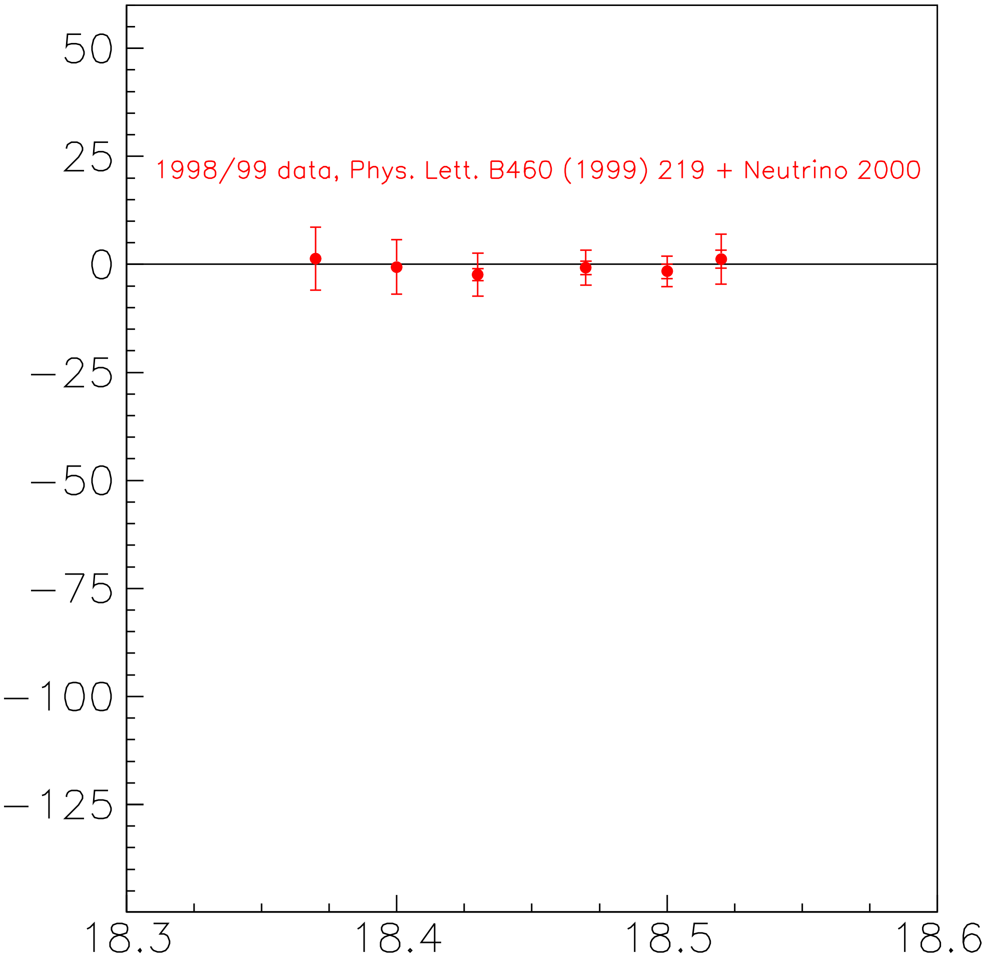
(contribution to systematic uncertainty for Q7, last 70 eV ⟵)

Fits of Mainz 1998 and 1999 data



Former problem of negative m_ν^2 at Mainz




1998/99 data, Phys. Lett. B460 (1999) 219 + Neutrino 2000

⇒ Problem of missing energy loss

was caused by roughening transition

⇒ should be solved by much lower T_2 temperatures

New results on m_ν for the Mainz data

- m_ν^2 behaviour:

$$\left.\begin{array}{l}m_\nu^2 \text{ is stable against variation of fit range}\\ m_\nu^2 \text{ is compatible with phyisically allowed range}\end{array}\right\}\text{since Q5}$$

→ no indication for any residual problem in Mainz 1999 data!

- No indication for a non-zero neutrino mass:

1. last 70 eV below endpoint (take data points > 18.5 keV)

   Q5,Q6,Q7,Q8 $m_\nu^2 c^4 = -1.6 \pm 2.5 \pm 2.1\ \mathrm{eV}^2$ $\chi^2/\mathrm{d.o.f.} = 125/121$

   $$\boxed{\to m_\nu c^2 \leq 2.2\ \mathrm{eV} \qquad \text{(95\% C.L., unif. appr.)}}$$

2. "last 15 eV"-analysis:

   take data points at 18.460 keV, 18.500 keV, $>$ 18.560 keV

   ($E_0 = 18.575$ keV)

   (result would not be affected by an eventual Troitsk-like anomaly

   at position as indicated by Q4)

   1998 $m_\nu^2 c^4 = +0.1 \pm 3.9 \pm 2.1\ \mathrm{eV}^2$ $\chi^2/\mathrm{d.o.f.} = 16.1/20$

   1999 $m_\nu^2 c^4 = +1.5 \pm 3.2 \pm 3.4\ \mathrm{eV}^2$ $\chi^2/\mathrm{d.o.f.} = 19.4/14$

   1998+1999 $m_\nu^2 c^4 = +0.6 \pm 2.8 \pm 2.5\ \mathrm{eV}^2$

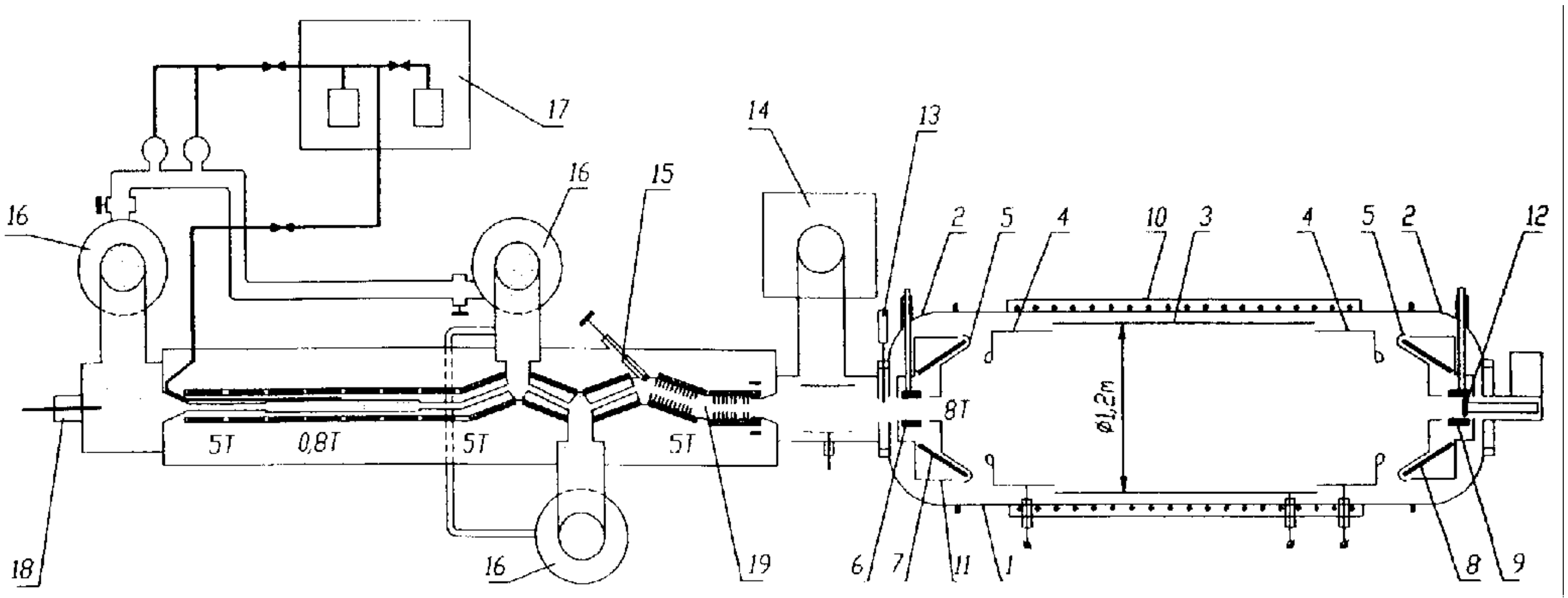
   $$\boxed{\to m_\nu c^2 \leq 2.8\ \mathrm{eV} \qquad \text{(95\% C.L., unif. appr.)}}$$

(J. Bonn et al., Nucl. Phys. B (Proc. Suppl.) 91 (2001) 273)

The Troitsk Neutrino Mass Experiment

Gaseous source, solenoid retarding spectrometer

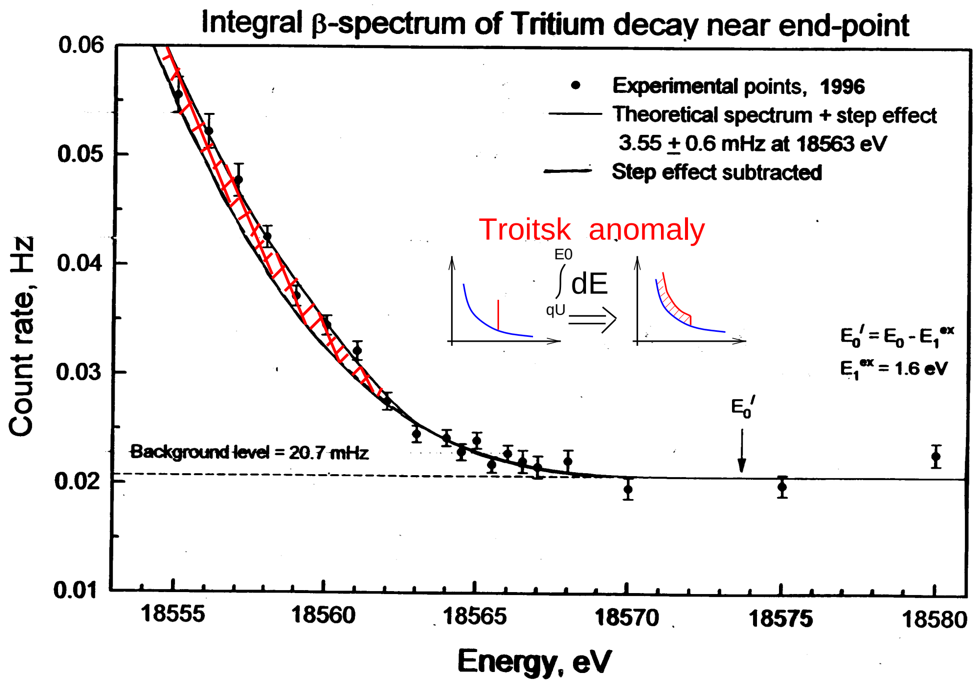
(A.I. Belesev et al., Phys. Lett. B350 (1995) 263)



The Troitsk Neutrino Mass Experiment

Similar MAC-E-Filter, but molecular gaseous T_2-Source

Observed anomalie:


Integral β-spectrum of Tritium decay near end-point

$\rightarrow$ monoenergetic line in continous β spectrum?

Troitsk (V.M. Lobashev *et al.*, Phys. Lett. **B460** (1999) 227):

- anomaly: exist in all 1994 to 1999 data
- amplitude: $\approx 10^{-10}$ of all decays, not constant
- position: oscillating between 5-15 eV below E_0 with 0.5 year period

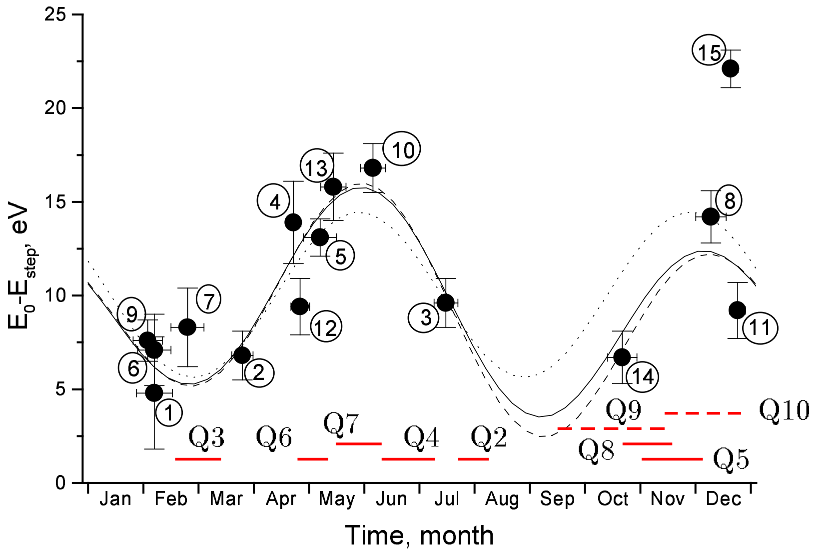
Fit of 1994–1999 data with β spectrum + free line:

$$\Rightarrow \mathrm{average}: m_\nu^2 = -1.0 \pm 3.0_{\mathrm{stat}} \pm 2.1_{\mathrm{sys}}\ \mathrm{eV}^2/\mathrm{c}^4$$

$$\Rightarrow m_\nu \leq 2.5\ \mathrm{eV}/\mathrm{c}^2$$ (95 % C.L.)

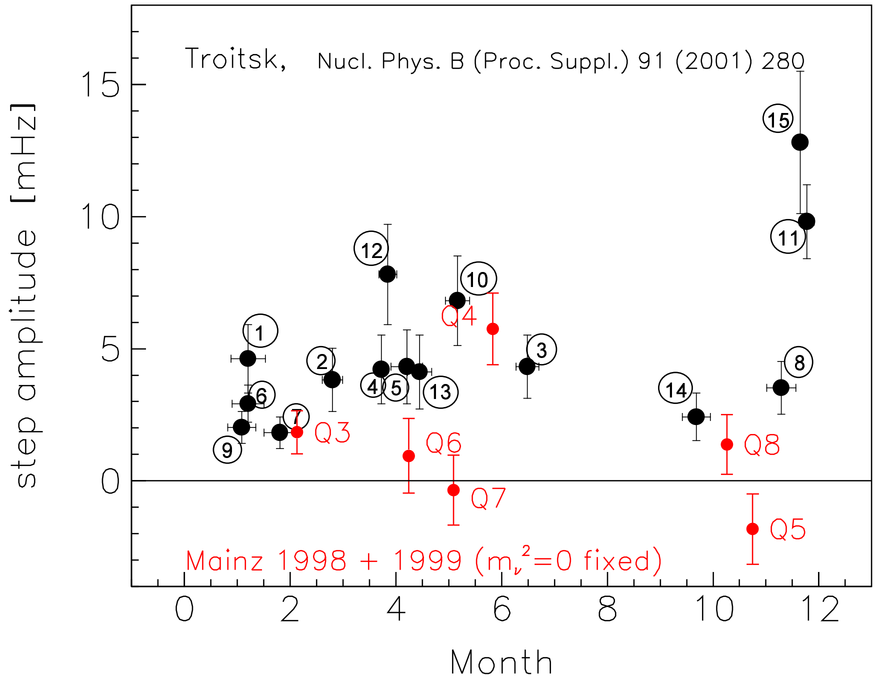
(V.M. Lobashev et al., Nucl. Phys. (Proc. Suppl.) 91 (2001) 280)

“Troitsk-Anomalie” in Mainz data?



Nucl. Phys. B
(Proc. Suppl.)
91 (2001) 280

— dates of Mainz measurements



Mainz step amplitude at Troitsk prediction

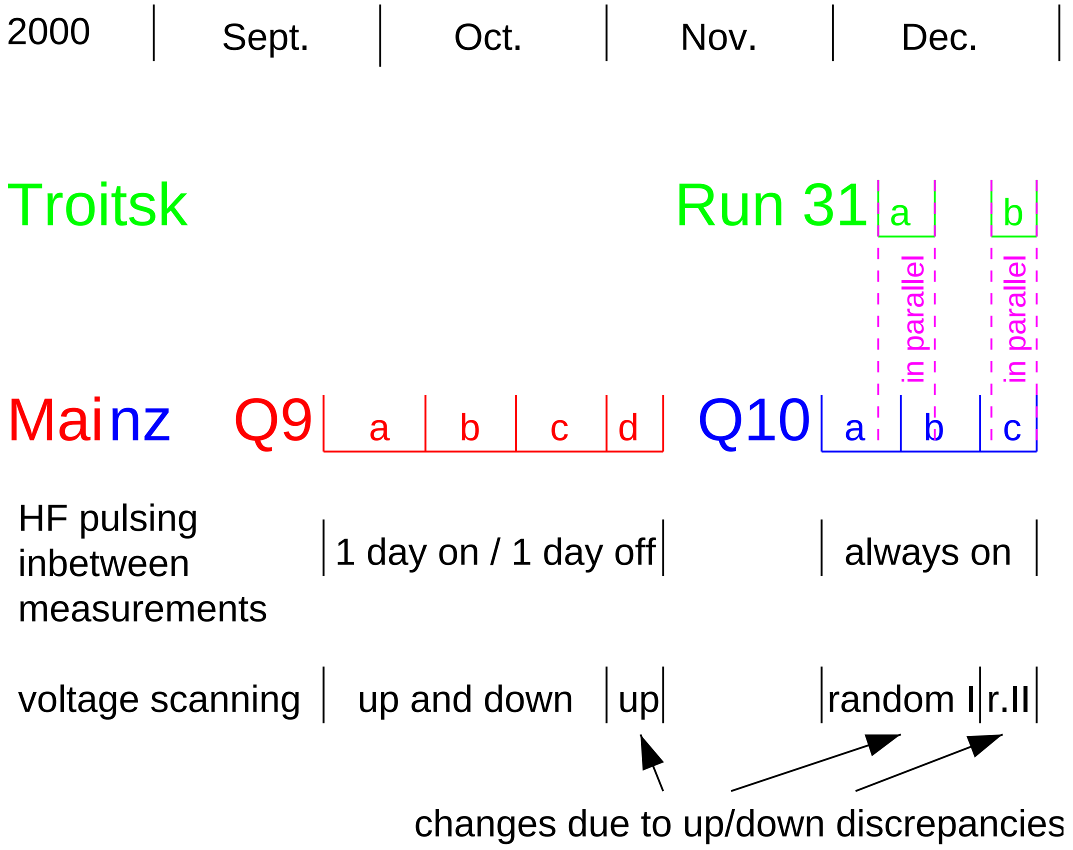
- Clear support for the “Troitsk anomaly” from 1 (Q4) out of 6 data sets, is there something different for measurement Q4?
- But parameter space, favored by Troitsk, not fully excluded
- Clear contradiction to 0.5 y periodicity
- Mainz Measurements Q9+Q10 (3 months end of 2000) (s. later)

Mainz measurements in 2000

3 Months measurements: Q9, Q10

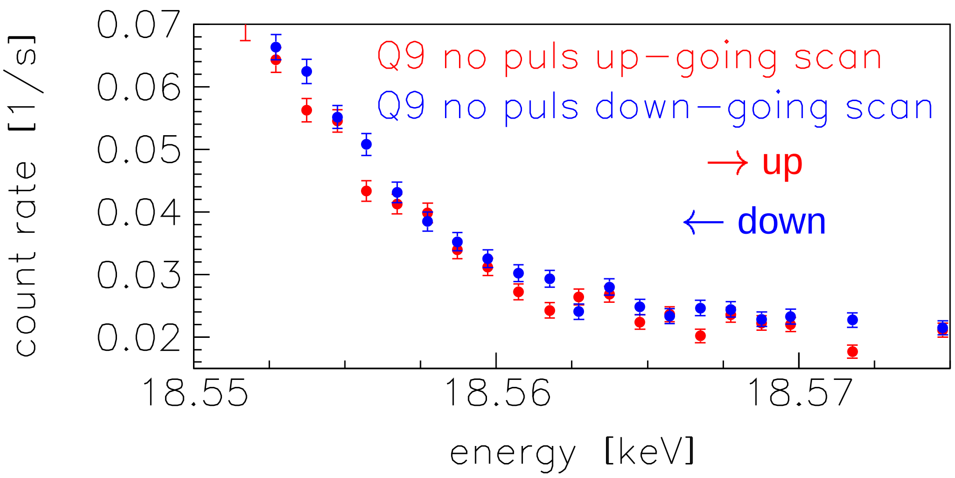
- 130 ML
- $\theta_{\max} = 61°$
- $\Delta E/E = 4.8$ eV
- HF-pulsing on a detector-side electrode after every 20 s measurement to stabilize and to decrease background

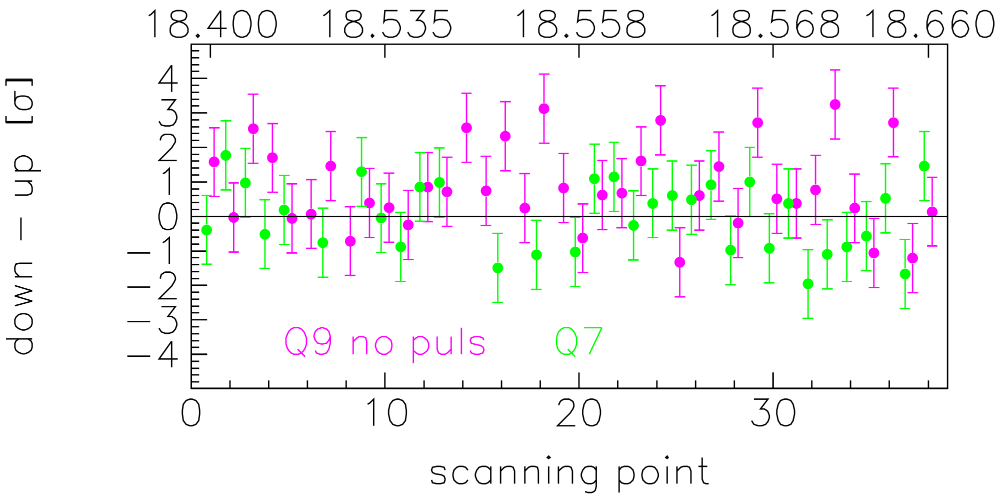
as in 1999 (Q6 – Q8)



changes due to up/down discrepancies

Down-going / up-going scan discrepancies





⇒ Hints for trapped particles

causing unregulary background !

- Need stringent cuts to through out bad data
- No statement on m_ν (yet)
- No hints for Troitsk-like anomaly in Mainz data, especially for runs done in parallel with Troitsk

Present status and questions

Situation in the field:

- Evidence for neutrino oscillations is very serious
- Probably very small squared mass differences $\Delta m^2 \leq 5 \cdot 10^{-3}\ eV^2$
- Probably very large mixing $\sin^2(2\Theta) \approx 1$ (at least partially)
- Oscillation experiments: $\Rightarrow$ no absolute neutrino mass scale
- Current tritium experiments: sensitivity limit of 2 eV

Possible scenarios

- Hierachical neutrino mass scenario:

  Δm^2 small $\longrightarrow$ all neutrino masses are small

  $\Rightarrow$ no significant contribution to dark matter

  seesaw mechanism, but naturally no large mixing
- Degenerate neutrino mass scenario:

  $\Rightarrow m(\nu_1) \approx m(\nu_2) \approx m(\nu_3) \approx m(\nu)$

  Interesting mass range: $<$ 2 eV:

  $\Rightarrow$ significant contribution to dark matter possible

Urgent questions

- Expect much better data from planned oscillation experiments

  $\Rightarrow$ absolute neutrino mass scale?
- Which is the right theory beyond the Standard Model?

  $\Rightarrow$ degenerated and hierarchical neutrino masses?
- Expect very stringent CMBR data from Planck/Map

  $\Rightarrow$ neutrinos relevant for dark matter and CMBR anisotropies?

$\boxed{\Rightarrow \text{need sub eV sensitivity on neutrino mass}}$

Which way to go ?

- **Wait for next galactic supernova:**
  - $\oplus$ eV sensitivity for $m(\nu_\mu)$ and $m(\nu_\tau)$
  - $\ominus$ $\geq$ 1 eV sensitivity for $m(\nu_e)$,
    limited by supernova time structure
  - $\ominus$ 1-3 supernovae per century in our galaxy
- **Search for $\beta\beta 0\nu$:**
  - $\oplus\oplus$ Next generation experiments very sensitive: $<$ 0.1 eV
  - $\ominus$ Only sensitive to Majorana-type neutrinos
  - $\ominus$ Cancelations possible: $m_{ee} = |\sum U_{ei}^2 m(\nu_i)|$
- **Other β decays and cryogenic bolometers:**
  - $\oplus$ Exciting new detector technology
  - $\oplus$ In principle scalable
  - $\ominus$ Microbolometers (^{187}Re) are still under development.
    → expected sensitivity for near future: $\approx$ 10 eV
- **Tritium β decay:**
  - $\oplus$ First MAC-E filters work successfully at Mainz and Troitsk
  - $\oplus$ Improvement by upscaling expected
  - $\ominus$ Would like to have non-integrating mode
    also with large luminosity and high energy resolution due to:
    Troitsk anomaly, tachyons, right-handed currents, ...
  - $\oplus$ → time-of-flight modus (MAC-E-TOF)

$\Rightarrow$ would like a have a

next-generation $\beta\beta 0\nu$ experiment

AND a

next-generation tritium β experiment

Future $0\nu\beta\beta$ experiments

Common features:

- detector mass: $\mathcal{O}$(1) t
- sensitivity on m_{ee}: $<$ 0.1 eV
- ultralow background required

Proposed experiments:

- Cuore

  ^{130}Te as TeO$_2$ crystals, cryogenic bolometer,

  Cuoricino will start in summer 2001
- Exo

  ^{136}Xe in TPC, Ba$^+$ daughter tagged by resonant laser
- Genius

  enriched ^{76}Ge, shielded by LN$_2$ tank, test facility approved
- Majorana

  enriched ^{76}Ge, transition to excited states
- Moon

  (enriched) ^{100}Mo foils between spatial resolving scintillators

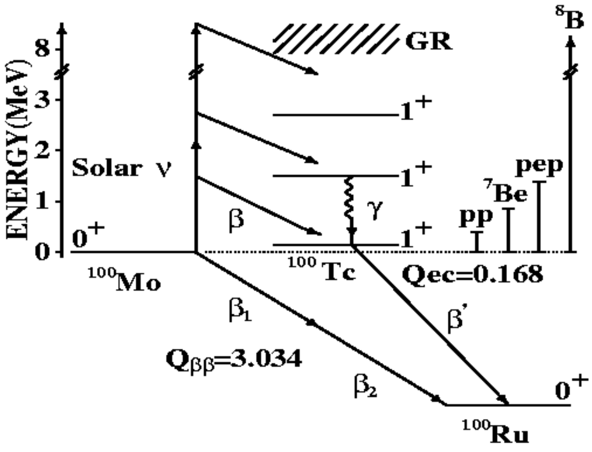
Special level sceme:

$\Rightarrow$ $\beta\beta0\nu$ experiments

could also act as very interesting

low threshold & real time

solar neutrino spectrometers



Direct $m(\nu)$ measurement and $\beta\beta0\nu$

Direct neutrino mass measurement

if neutrino masses are not resolved $\Rightarrow$ average neutrino mass

e.g. $m^2(\nu_e) = \sum |U_{ei}^2| m^2(\nu_i)$ (incoharent sum)

$0 \leq |U_{ei}^2| \leq 1 \Rightarrow$ real average, no cancelations possible

$\beta\beta0\nu$ (Majorana neutrinos required):

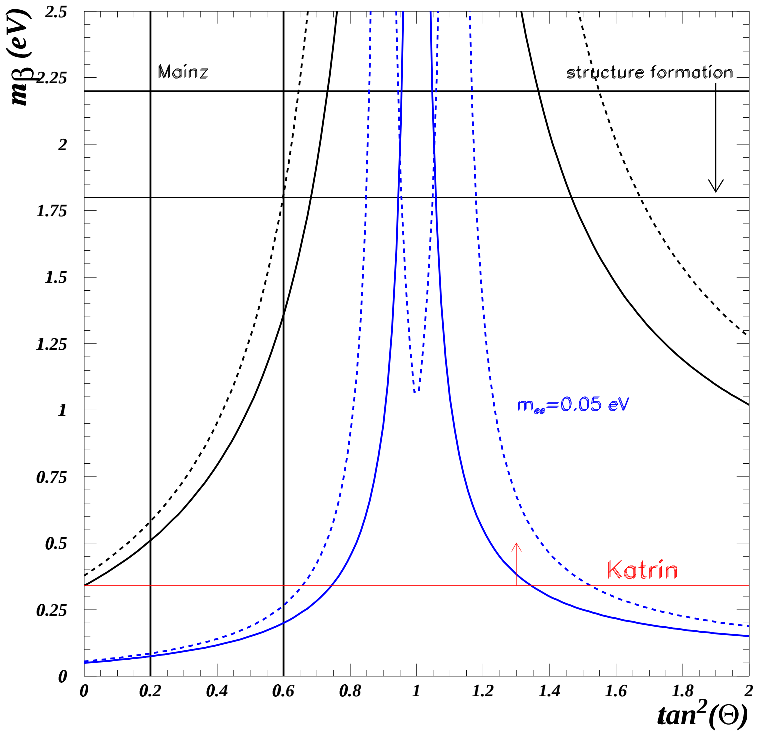
$m_{ee}(\nu) = |\sum |U_{ei}^2| e^{i\phi_i} m(\nu_i)|$ (coharent sum)

ϕ_i are describing CP and Majorana phases $\Rightarrow$ cancelations possible

degenerated neutrino masses $m(\nu_1) \approx m(\nu_2) \approx m(\nu_3) \approx m$

β-decay: $m(\nu_e) \approx m$ $\beta\beta0\nu:\ 0 \leq m_{ee}(\nu) \leq m$

(depending on “solar mixing angle” Θ)



current exp.

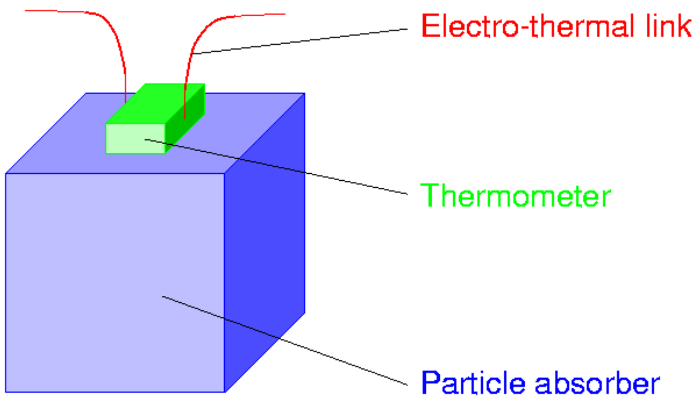
– – $|U_{e3}|^2 = 0.05$

— $|U_{e3}|^2 = 0$

future tritium, $0\nu\beta\beta$ exp.

Y.Farzan, O.L.G.Peres
and A.Yu.Smirnov
hep-ph/0105105

Calorimetric experiments



Basic idea: β electron emitting crystal = cryodetector

- ⊕ one final state: excitation by excited electronic states and inelastic scattering is collected
  $\Rightarrow$ less systematic uncertainties !
- ⊕ free choice of β emitter $\Rightarrow$ ^{187}Re: E_0=2.5 keV
  $\Rightarrow$ interesting fraction is bigger by $E_0(T)^3/E_0(Re)^3 \approx 400$
- ⊕ experiment scalable to large arrays

- ⊖ energy resolution $>$ 10 eV, tails
- ⊖ detector measures whole β spectrum
  pile-up: $\Rightarrow$ detector arrays needed

- groups working at Genova* and Milano/Italy
- expected sensitivity for near future: 10 eV/c^2
- significant improvement by better energy resolution and larger arrays expected !

* limits on heavy ν admixture: M. Galeazzi et all., PRL 86 (2001) 1978

KATRIN: A new Large Tritium β Experiment

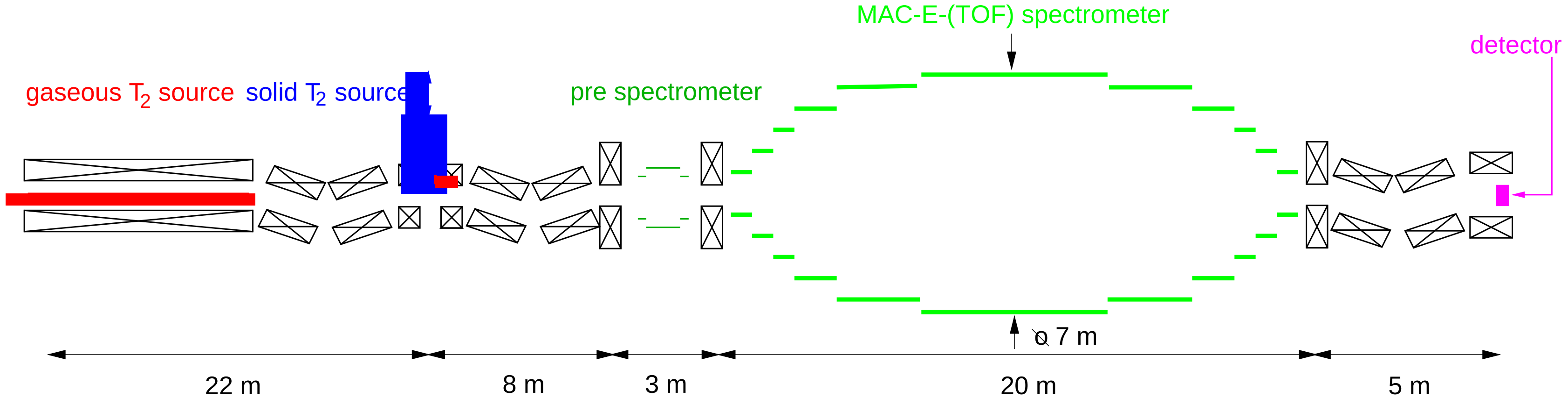
Physics aim: sensitivity on m$_\nu$ < 1 eV

- 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!

→ Proposal for a large spectrometer, 7 m in diameter
based on the MAC-E principle (Mainz, Troitsk)
to be built at Forschungszentrum Karlsruhe/Germany

- Currently groups from Karlsruhe, Mainz, Troitsk and Fulda are working on design studies



Actual design study

Analysing plane of spectrometer: as large as possible,

since $A_{analyze}$ naivly scales with $1/m_\nu^4$:

- Improvement in $m(\nu)$

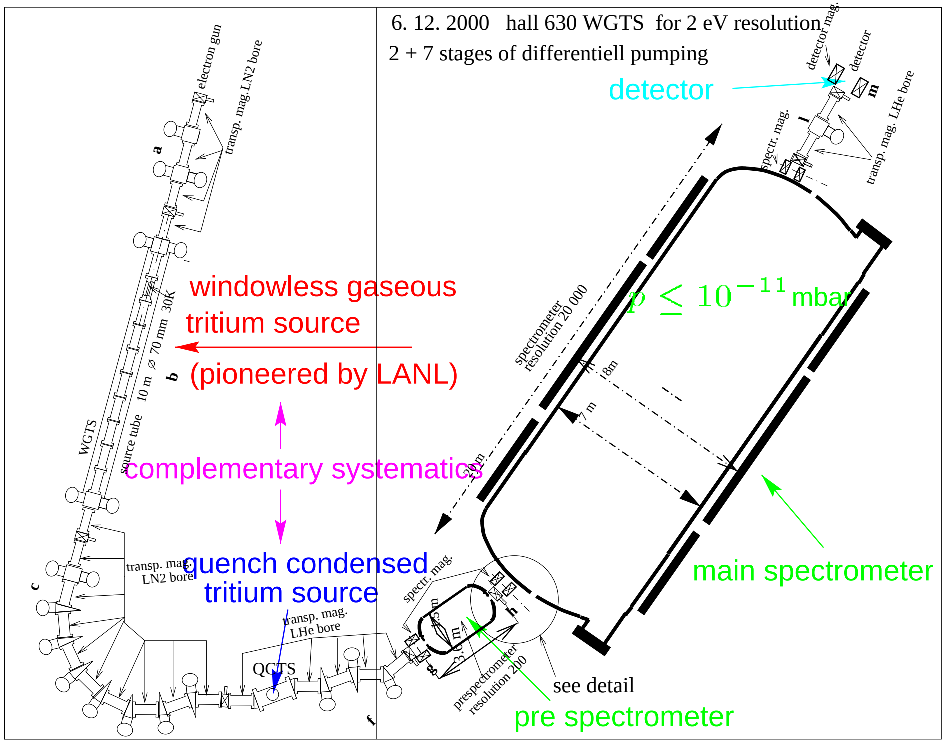
  $\Rightarrow$ needs improvement in

  $$1/\Delta E \propto A_{analyze} \propto d_{analyze}^{1/2}$$

- Improvement in $m(\nu)$

  $\Rightarrow$ needs improvement in luminosity

  $$\mathcal{L}^3 \propto A_{analyse}^3 \propto d_{analyse}^{3/2}$$



but additional gain factors:

- Systematic uncertainties
- Source column density
- measurement time
- measurement point distribution
- . . .

Systematic uncertainties

The smaller the neutrino mass,
the smaller the region of interest below the β endpoint

$\Rightarrow$ Excited electronic final states ($\Delta E_{exc} \geq 27eV$) do not play a role !

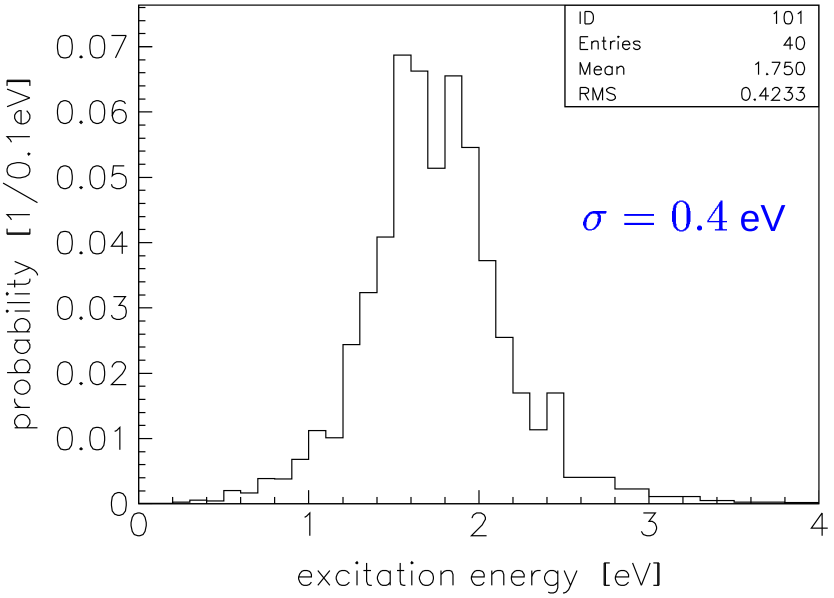
$\Rightarrow$ Inelastic scattering in the T_2 source ($\Delta E_{sca} \geq 13eV$) is not big !

is relevant since MAC-E-filter response function has no tails!

$\Rightarrow$ one well-defined final state similar to cryogenic detectors

Systematic uncertainties

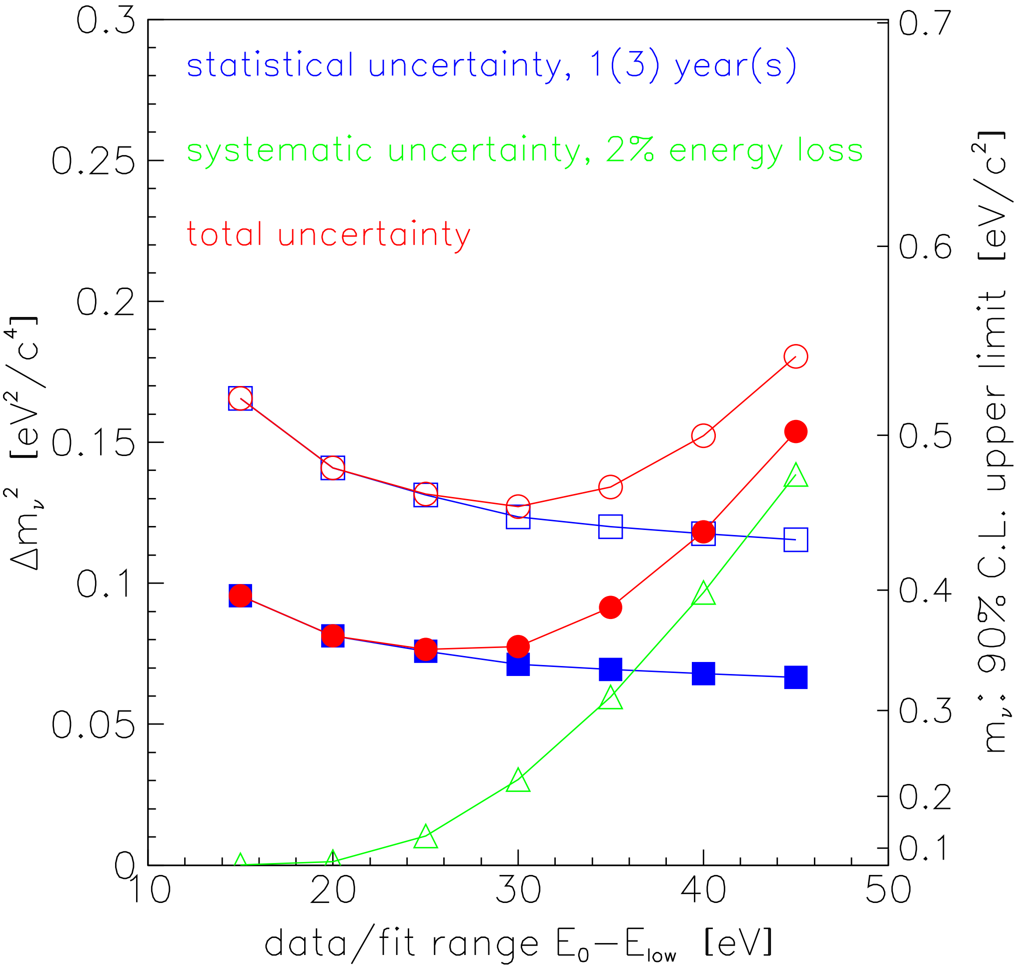
- Rotation-vibration excitation of final ground state



- Inelastic scattering (sys. uncert.: Troitsk: $\approx$ 3 %, Mainz: $\approx$ 6 %)
- Solid state effects (for quench-condensed source only)
- Stability of settings (HV, source activity, source purity, ...)

Simulation of the sensitivity on m_ν

First simulation with conservative assumptions:



energy resolution: 1eV

source area: 29 cm^2

gaseous source column density: 5 $10^{17}/cm^2$

max accepted starting angle: 51°

background rate: 11 mHz

$\Rightarrow$ **Sensitivity on m_ν of $\leq 0.4\ eV/c^2$**

Status of KArlsruhe TRItium Neutrino experiment

Working group active since more than one year

- Forschungszentrum Karlsruhe/Germany

  IK: H. Blümer, G. Drexlin, K. Eitel, . . .

  TLK: R.D. Penzhorn, M. Glugla, R. Lässer
- Mainz University/Germany

  E. Otten, J. Bonn, Ch. Weinheimer, . . .
- INR Troitsk/Russia

  V. Lobashev, O. Kazachenko, N. Titov, . . .
- Fachhochschule Fulda/Germany

  A. Osipowicz
- ***Neutrino Masses in the sub–eV Range***

  International workshop on future direct measurements of the electron neutrino mass and their implications

  Bad Liebenzell / Schwarzwald , Germany, January 18 – 21, 2001

  http://www-ik1.fzk.de/tritium/liebenzell/

  paper: http://www-ik1.fzk.de/tritium/

New collaborators:

- UW Seattle: H. Robertson, J. Wilkerson, . . .
- Academy of Sciences, Rez near Prague: A. Kovalik, O. Dragoun, . . .

2001
- Forming of collaboration
- Publication of letter of intent, proposal
- Dedicated change of Mainz setup for background investigations

2002
- Start of build-up phase, . . .

Summary

- Neutrino masses
  - Atmospheric and solar neutrino experiments ⇒ neutrino oscillations ⇒ $m(\nu) \neq 0$
  - Particle physics: neutrino mass scale, degenerated or hierarchical neutrino masses
  - Cosmology: dark matter, structure formation, influence on CMBR, . . .

- Direct neutrino mass experiments
  - Upper limits: $m(\nu_\tau) < 18.2$ MeV, $m(\nu_\mu) < 190$ keV, $m(\nu_e) < 2.2\ (2.5)$ eV (95 % C.L.)
  - Electron neutrino mass: ⇒ precision measurement of the tritium β spectrum

    Bolometer (^{187}Re) fascinating, multi-purpose, but still behind
  - Successful development of MAC-E-Filter principle (Mainz, Troitsk)
  - Mainz: systematics of T$_2$ films (roughening transition, inel. scattering, self-charging)

- KATRIN: A large tritium β experiment (FZ Karlsruhe, Mainz, Troitsk, . . .)
  - currently only direct neutrino mass determination with sub-eV sensitivity ($\leq$0.4 eV)

    ⇒ key experiment for the mass of the neutrino
  - based on MAC-E-Filter (+ MAC-E-TOF Mode)
  - new collaborators: UW Seattle, Academy of Sciences Rez/Prague
  - International Workshop: January 18. – 21. at Bad Liebenzell/Germany was very successful