KATRIN experiment: status and perspectives 2013

N.A. Titov

for the KATRIN Collaboration
and
„Troitsk ν-mass“ team

Institute for Nuclear Research
60-th October Anniv. pr. 7a, Moscow 117312

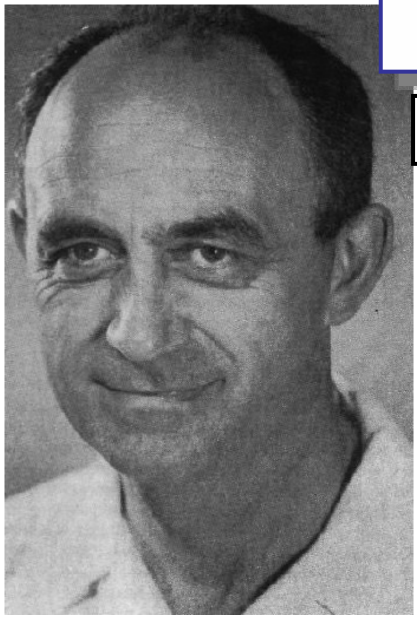
1934:Neutrino mass could be observed in the nuclear β -decay

Versuch einer Theorie der β-Strahlen. I[1]).

Von **E. Fermi** in Rom.

Mit 3 Abbildungen. (Eingegangen am 16. Januar 1934.)

E. Fermi, Z. Physik 88 (1934)



Enrico Fermi

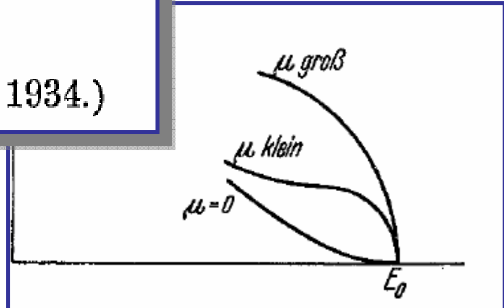
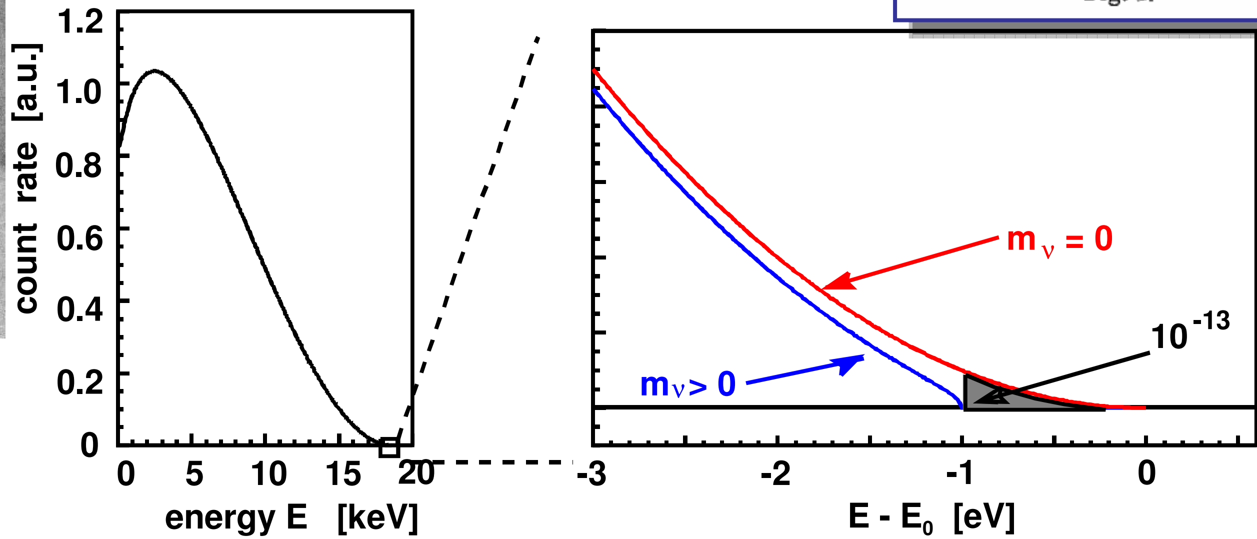


Fig. 1.



1948:First successful experiment with Tritium

$T \rightarrow {}^{3}He + e^{-} + \underline{18,6\ кэВ}$

Бруно Понтекорво

Bruno Pontecorvo

$m_{\nu} < 1$ кeV/c^{2}

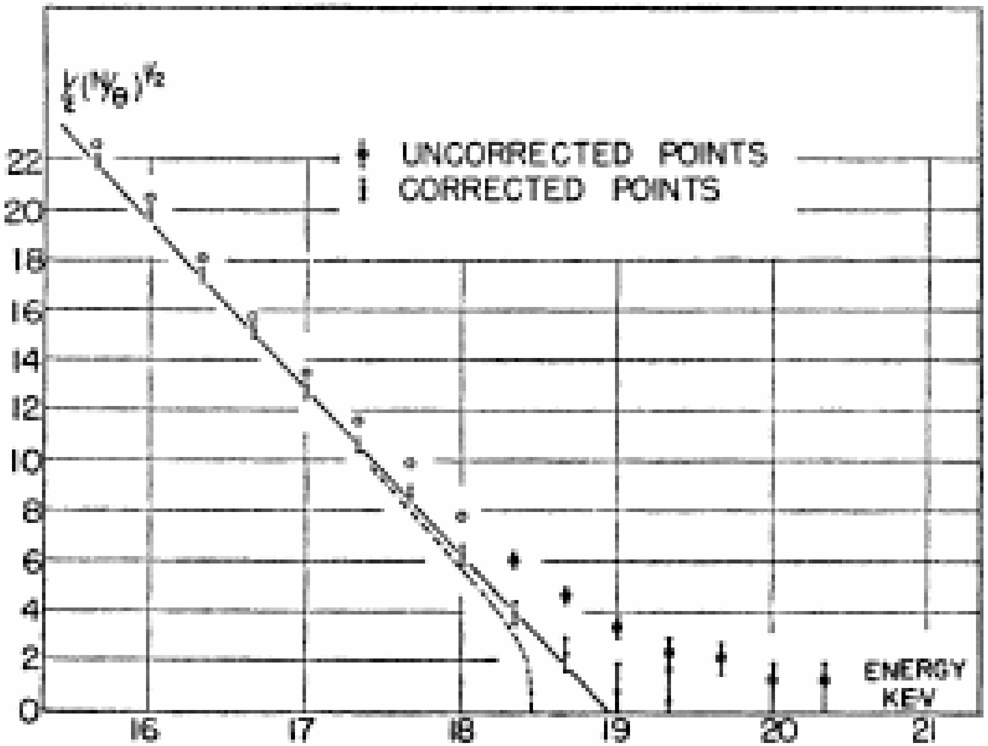


FIG. 2. "Kurie" plot of the end of the H³ spectrum. The theoretical curve (shown dotted) corresponding to a finite neutrino mass of 500 ev (or 1 kev —see text) has been included for comparison.

Hanna G.C. and Pontecorvo B., Phys. Rev. 75 (1949) 983

1983: Electrostatic spectrometer with adiabatic magnetic collimation

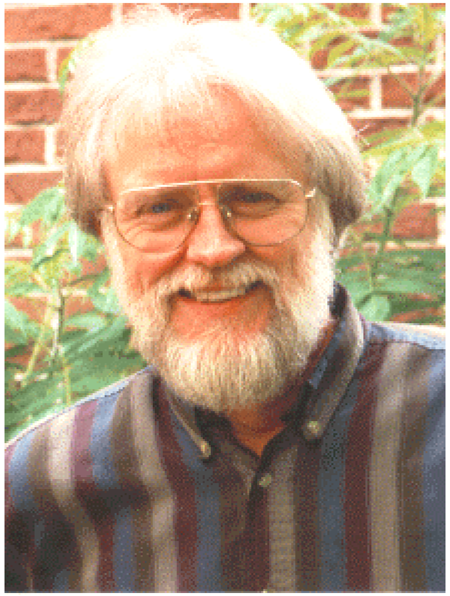
Troitsk ν-mass experiment

Petr Spivak
24.03.1911 - 30.03.1991

Vladimir Lobashev
29.07.1934 – 3.08.2011

“Great minds think alike”

Mainz Neutrino Mass Experiment



Robert B. Moore
Physics Department,
McGill University
Montreal, Canada

Ernst Otten *Jochen Bonn*
Physics Institute
Johannes Gutenberg University
Mainz, Germany

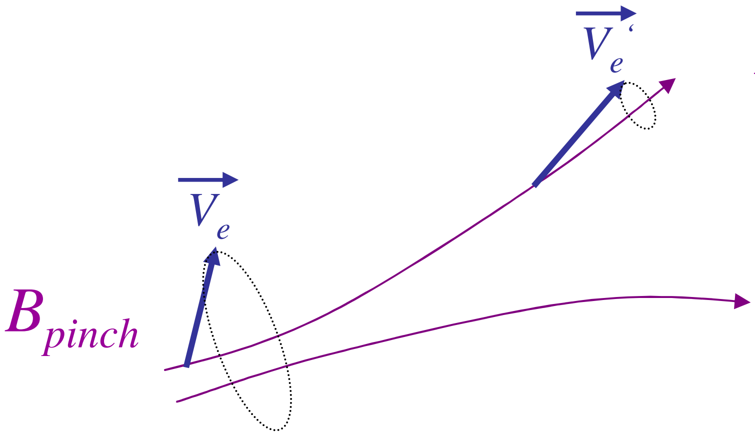
N. Titov June,27 2013

XXIX-th International Workshop on High Energy Physics
June 26 –28 of 2013, IHEP, Protvino, Russia

Electrostatic spectrometer with adiabatic magnetic collimation (MAC-E filter) Fundamentals

In the slowly varying magnetic field charged particle motion is *adiabatic*, *(first) adiabatic invariant* is conserved.

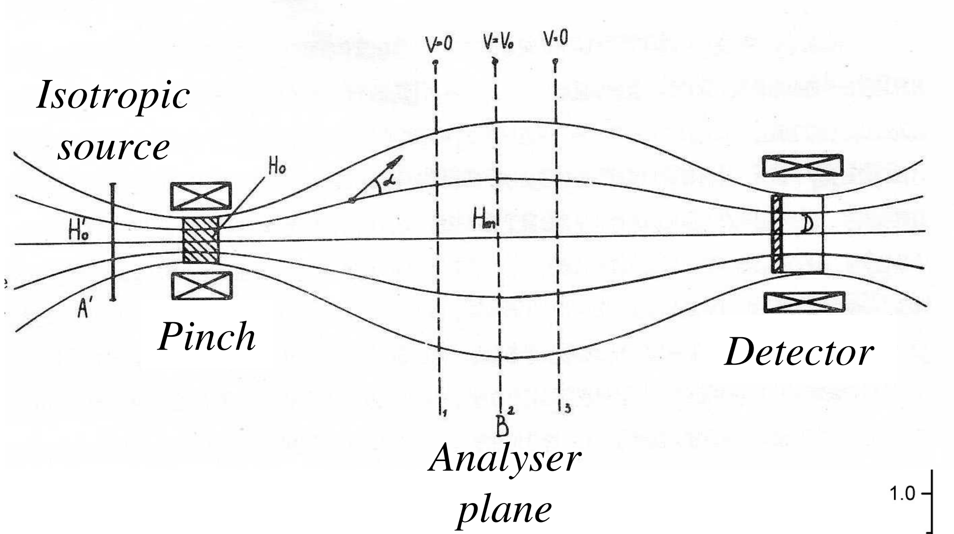
$$\mu = \frac{E_{per}}{B} = \frac{E_{tot} \cdot \sin^2 \theta}{B} \cong const$$



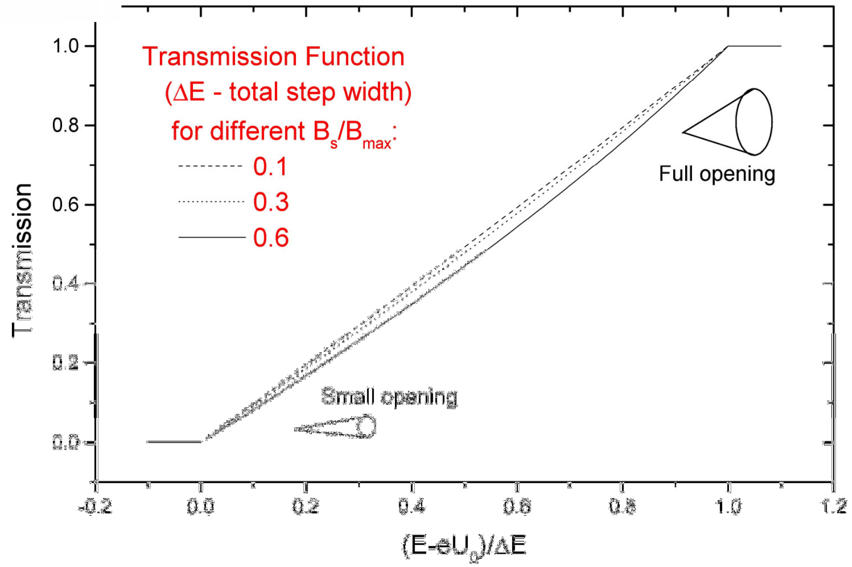
$B_{analyser} << B_{pinch}$

A particle velocity vector is aligned along the magnetic field direction during transition into weaker magnetic field

Electrostatic spectrometer with adiabatic magnetic collimation (MAC-E filter) Fundamentals



$$\Delta E = |eU_0| \frac{B_{analyser}}{B_{pinch}}$$



Spectrometer resolution

is decoupled

from the source size!

International project KATRIN (KArlsruhe TRItium Neutrino experiment)

Spectrometer Ø 10 meters

Resolution ΔE = 0,9 eV (at 18 кeV)

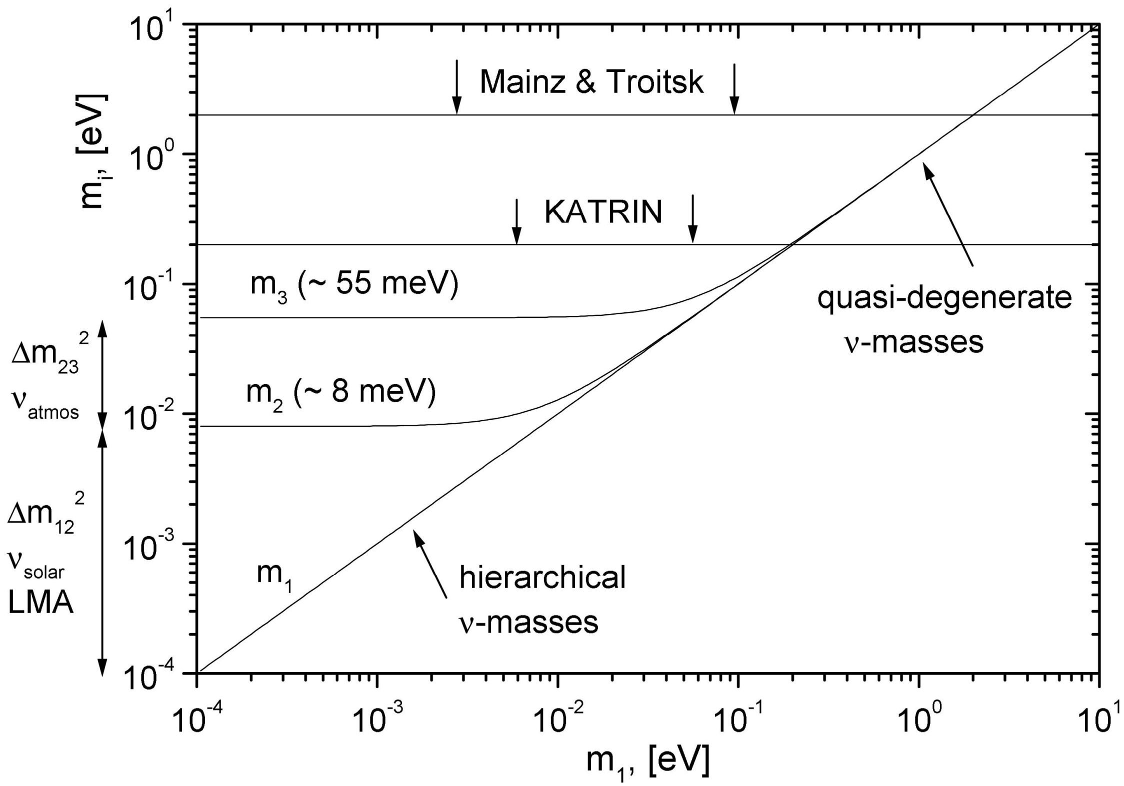
Windowless gaseous source Ø 90 mm

Column density $5 \cdot 10^{17}$ mol/см^2

Neutrino mass sensitivity
(after 3 years of data taking):

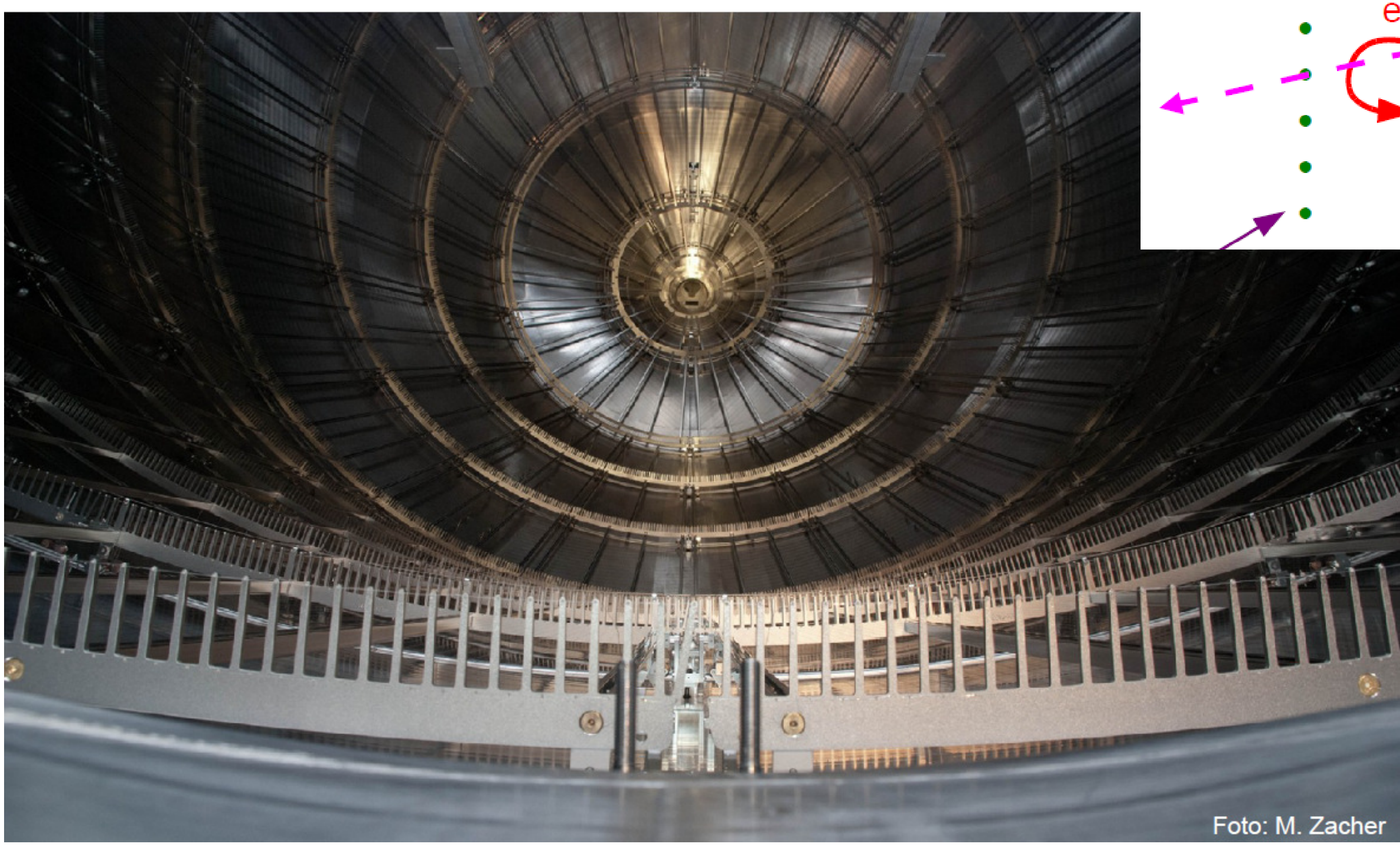
$m_\nu < 0{,}2$ эВ/с^2

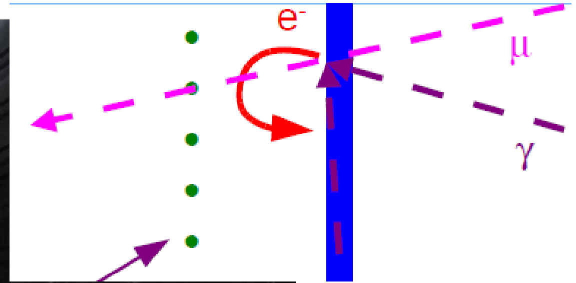
KATRIN Project



1. Confirms or excludes quasi-degenerate mass regime
2. Tests cosmological neutrino mass evaluation

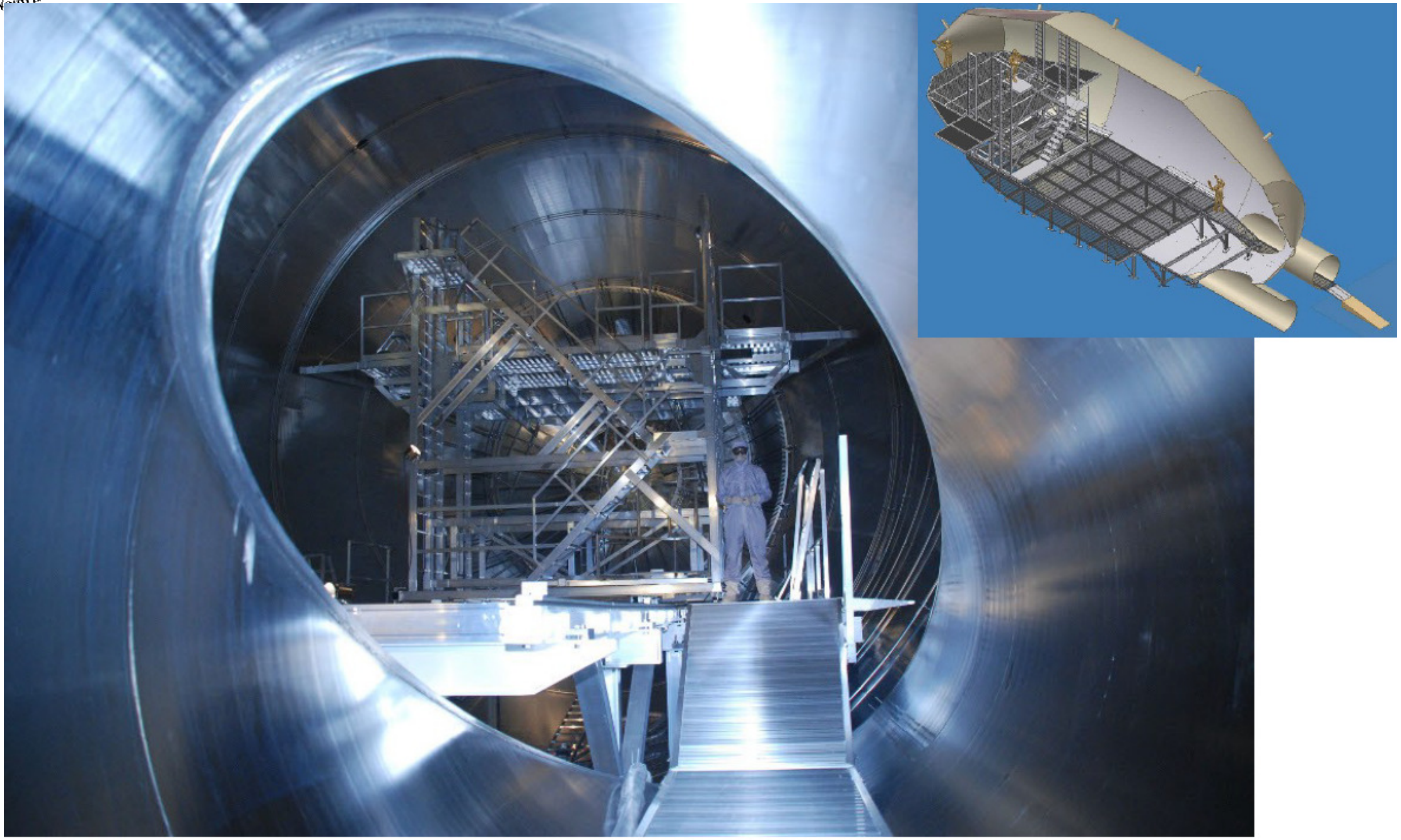
KATRIN status
Inner electrodes of the main spectrometer are installed (2012)





http://fuzzy.fzk.de/bscw/bscw.cgi/d736480/95-TRP-5210-S3-CWeinheimer.pdf

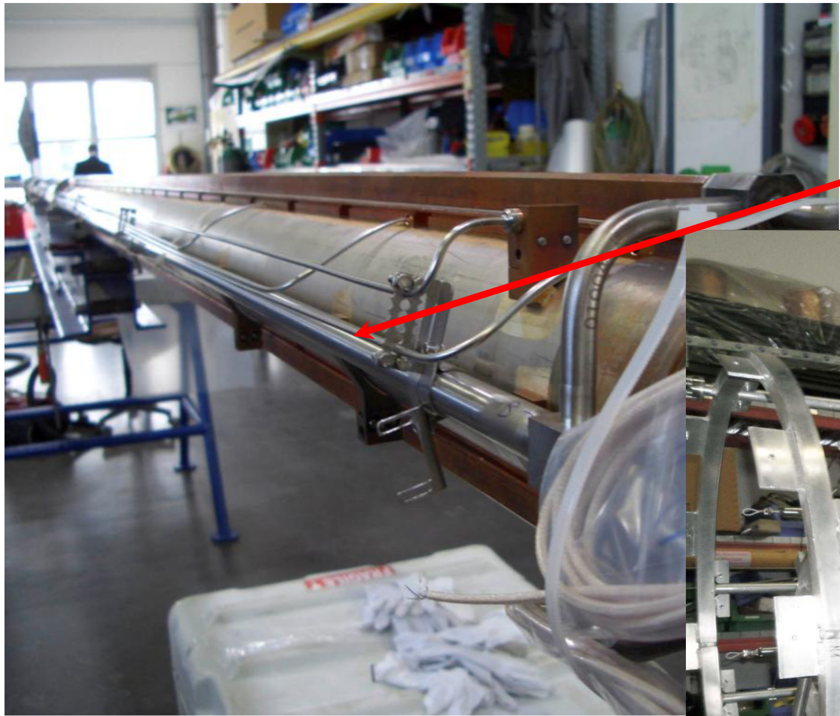
KATRIN status
Inner electrodes installation

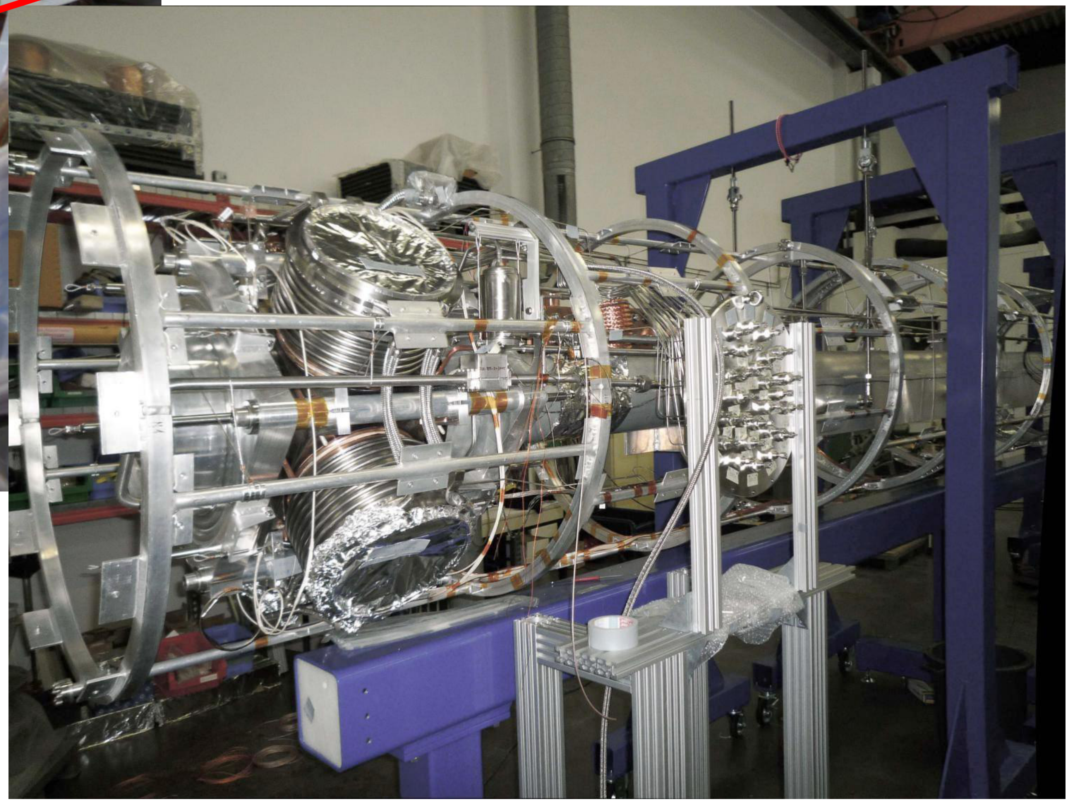


Christian Weinheimer KATRIN CM XXII, March 2012 21

WGTS demonstrator (2011)

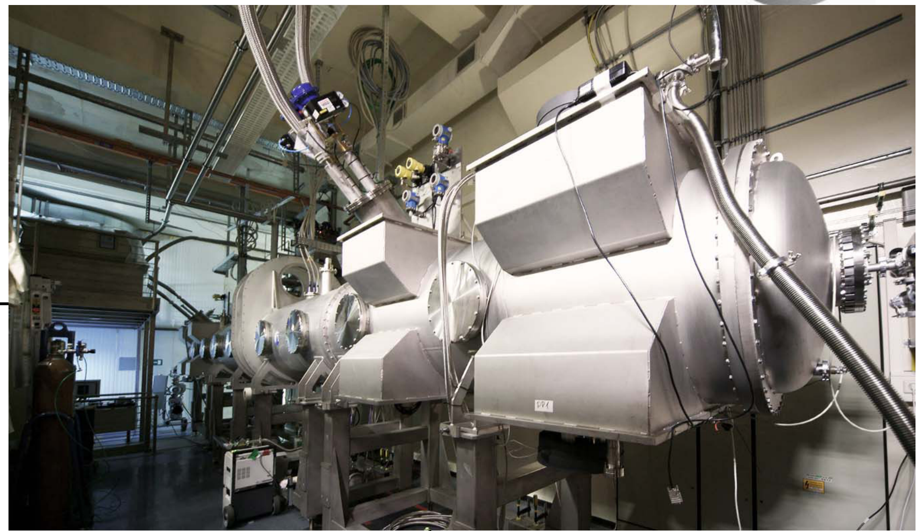
Thermal stabilization by
two faze (gaseous-liquid)
Ne loop up to 30 mK

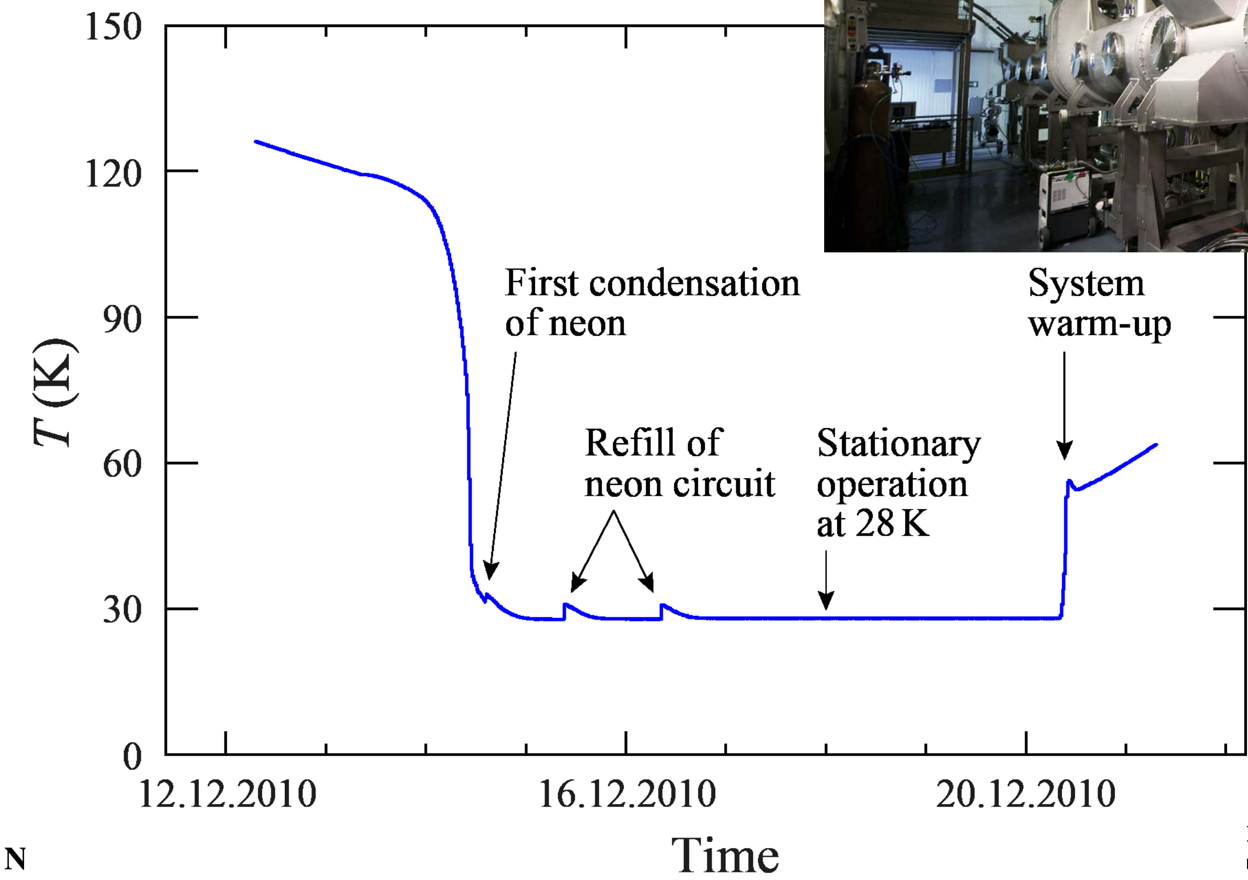




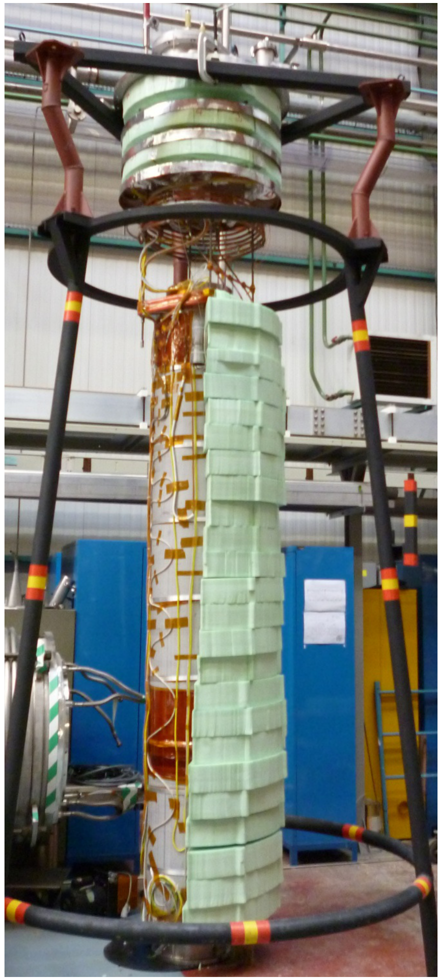
WGTS demonstrator (2011)

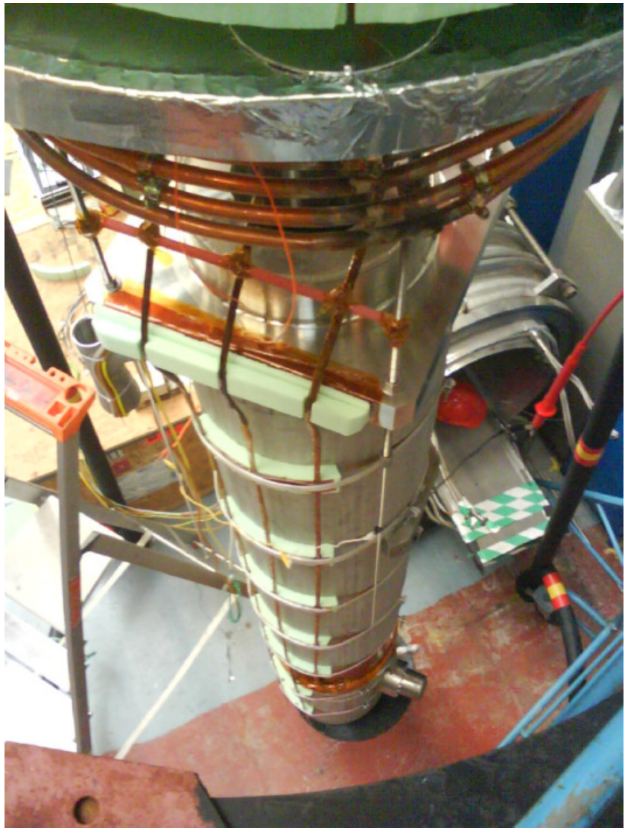
Cool-down of the WGTS-tube

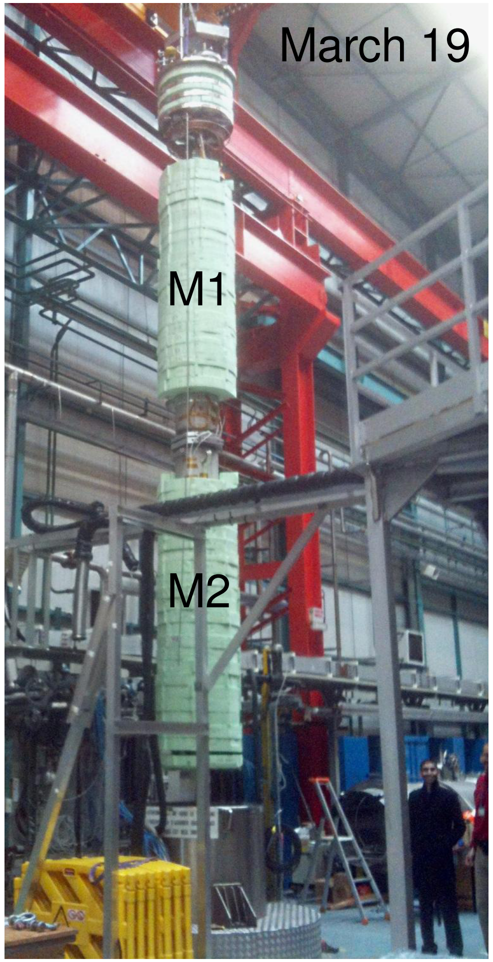




WGTS magnets – cold tests March, 2012





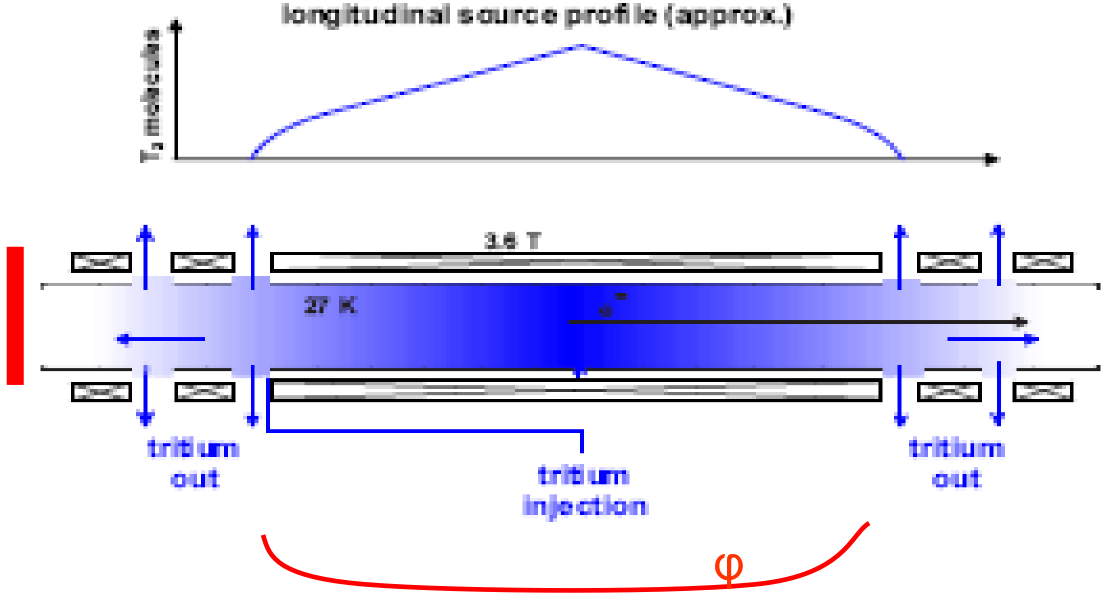


Rear Wall subproject
Space charge potential control

1. A space charge potential variation inside the WGTS brings false m_ν^2
2. Plasma is generated in the WGTS due to ionization by β- electrons
3. Ambipolar diffusion in central part (Boltzmann distribution):

$$n/n_0 = \exp(-e\varphi/kT_{el})$$

4. High plasma conductivity along magnetic field lines equals plasma potential to the Rear Wall one.



Rear Wall subproject
Space charge potential control

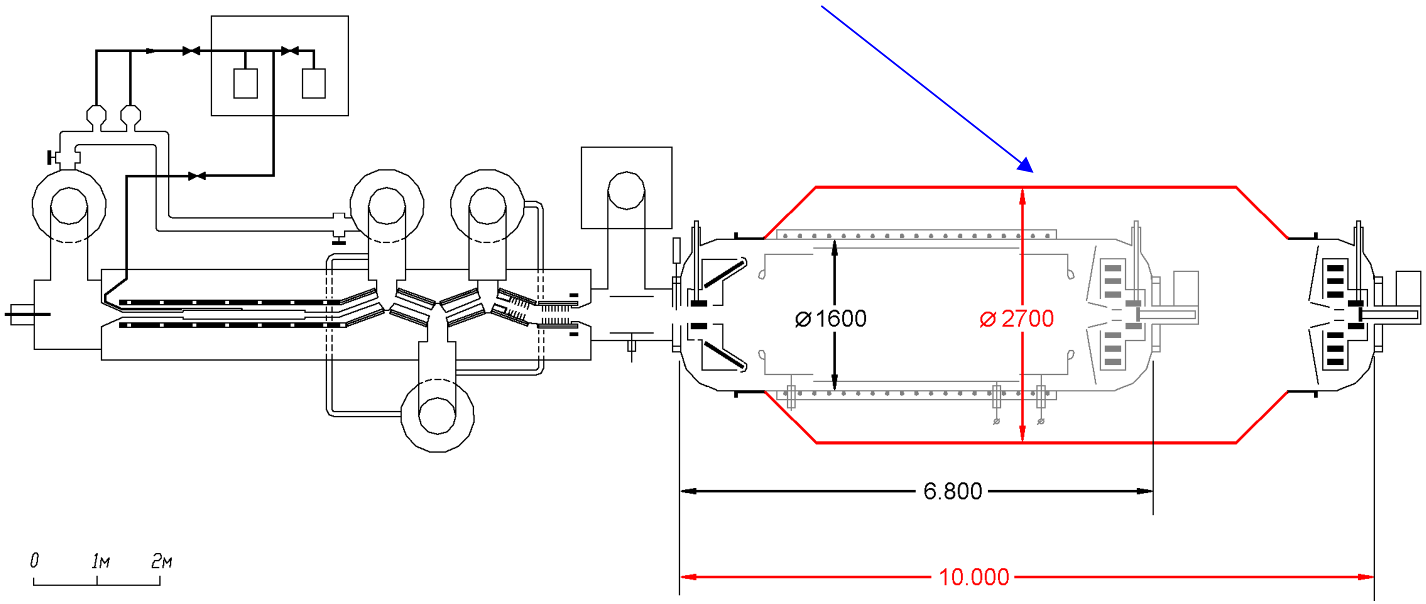
INR program:

1. Potential shift due to the hydrogen adsorption on the side walls.
2. Tritium plasma simulation with ionized hydrogen
   - "Rear Wall concept" check
   - Plasma transport
   - Ion-electron recombination in the WGTS
   - Ion removal by *ExB* drift

Experimental method – observation of the ^{83m}Kr internal conversion line position shift and line width broadening (when ^{83m}Kr and T_2 are circulating together through WGTS)

2005: Troitsk ν-масс spectrometer upgrade

By the increase of spectrometer vessel and central electrode diameters resolution was improved by factor 2!



N. Titov June,27 2013

XXIX-th International Workshop on High Energy Physics
June 26 –28 of 2013, IHEP, Protvino, Russia

2009: New INR spectrometer on place!

Spectrometer outer diameter 2.75 м, length 8.10 м.

Central electrode diameter 2.20 м.

Spectrometer vessel bake-up at 200C^{o} and chilling up to 10C^{o} for vacuum better than 10^{-7} Pa.

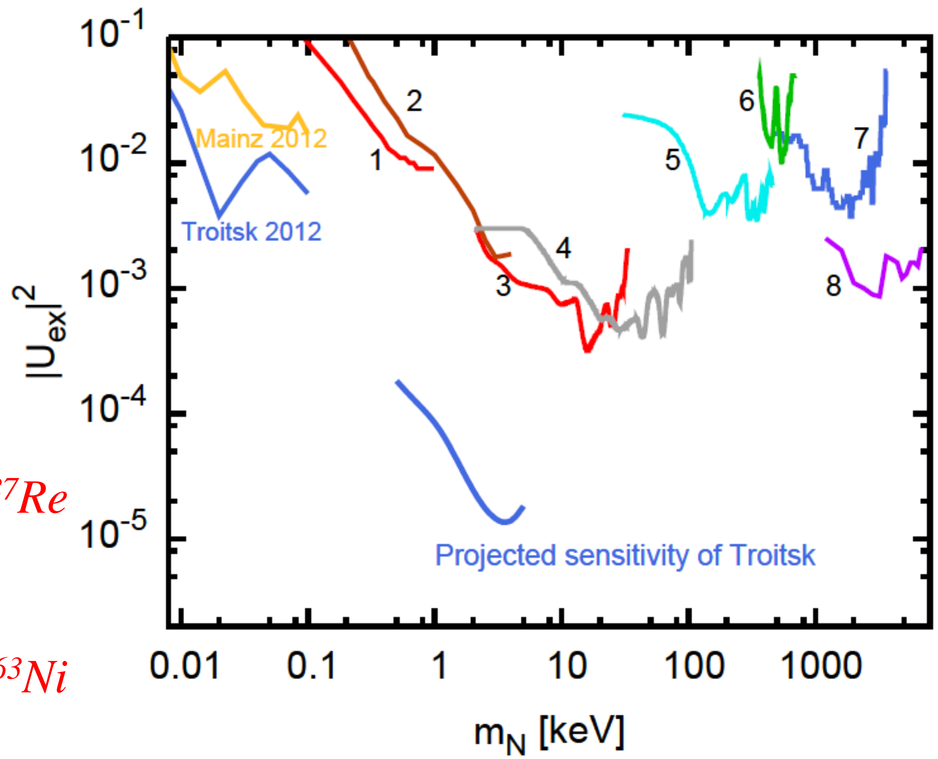
Stable operation up to 32 kV.

What's next ?
Heavy sterile neutrino search!

J. Beringer *et al.* (Particle Data Group)

PR **D86**, 010001 (2012) (URL: http://pdg.lbl.gov)

Heavy Neutral Leptons, Searches for



[1] M. Galeazzi et al., PRL 86 (2001) 1978 – *^{187}Re*

[2] **K.H. Hiddemann, H. Daniel, O. Schwentker, JPG 21 (1995) 639** – ***T***

[3] E. Holzschuh et al., PL B451 (1999) 247 – *^{63}Ni*

[4] E. Holzschuh et al., PL B482 (2000) 1 – *^{35}S*

[5] K. Schreckenbach et al., PL 129B (1983) 265

[6] M.M. Hindi et al., PR C58 (1998) 2512

[7] M. Trinczek et al., PRL 90 (2003) 012501

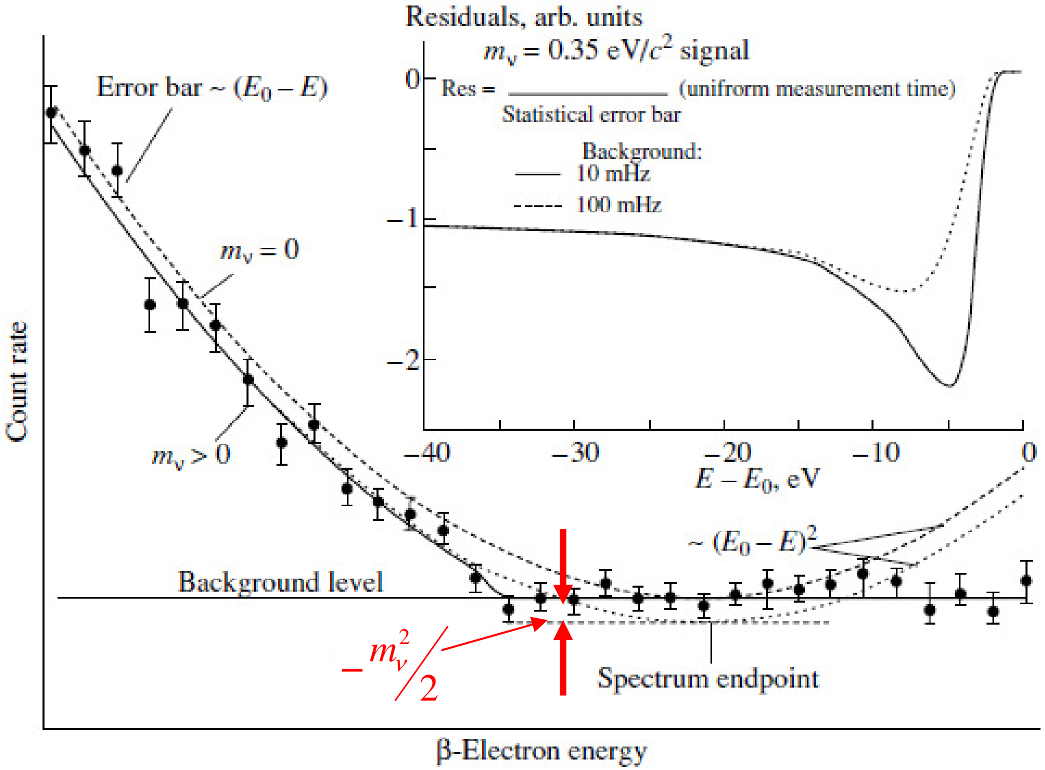
[8] J. Deutsch, M. Lebrun, R. Prieel NP A518 (1990) 149

Tritium spectrum meaurement up to ≈ 9 кeV!

Back up slides

Форма спектра при $m_\nu > 0$

$$\frac{dN}{dE} = K \times F(Z,E) \times p \times E_{tot} \times (E_0 - E) \times [(E_0-E)^2 - m_\nu^2]^{1/2}$$



$$\frac{dN}{dE} \sim (E_0-E)^2 - m_\nu^2/2$$

Electrostatic spectrometer with adiabatic magnetic collimation (MAC-E filter) Fundamentals

Adiabaticity parameter ε:

$$\varepsilon = \frac{|\,gradB\,|}{B} r_H << 1 \qquad \text{or} \qquad \varepsilon = \frac{1}{\omega_H} \cdot |\frac{\dot{B}}{B}| << 1$$

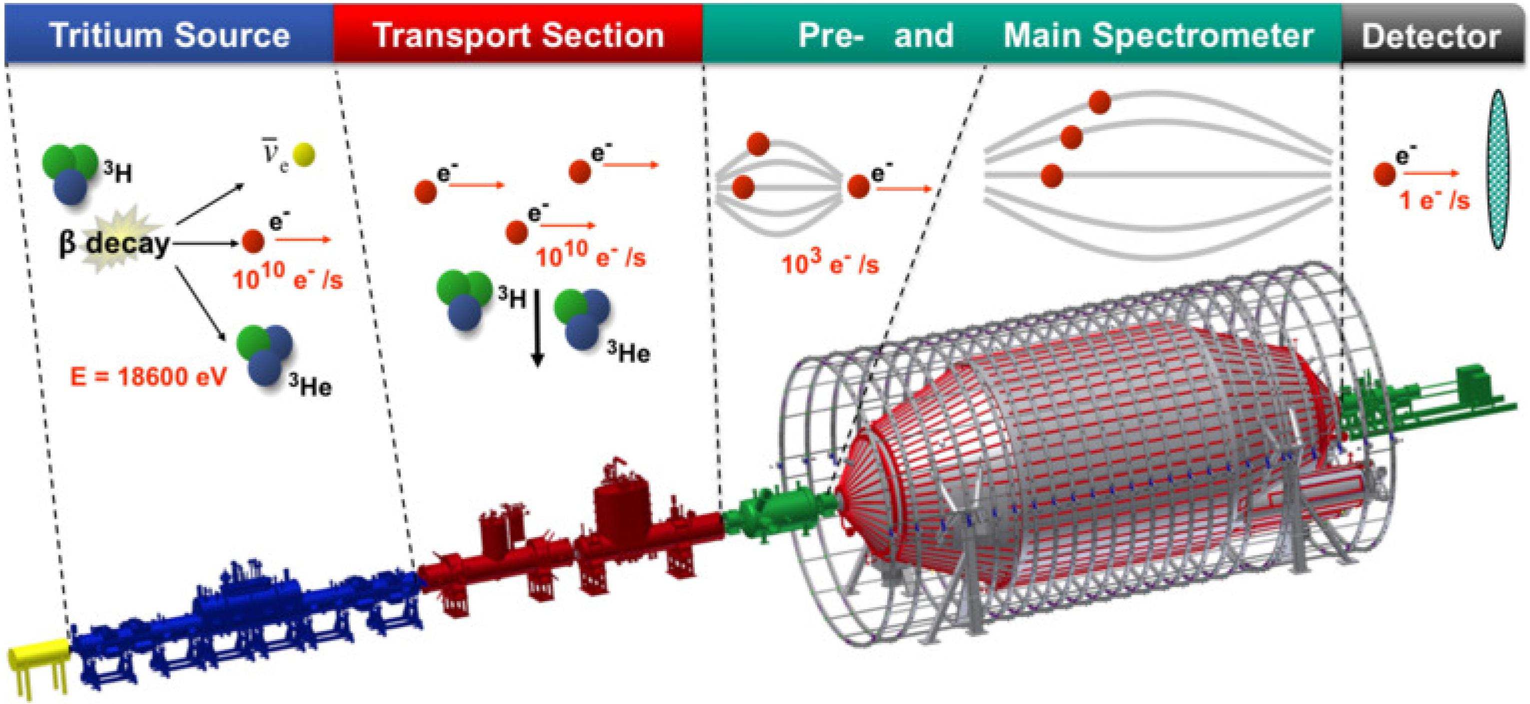
where r_H, ω_H – radius and frequency of the Larmor precession

An adiabatic invariant is preserved exponentially:

$$\frac{\Delta\mu}{\mu} \sim e^{-\frac{1}{\varepsilon}}$$

The spectrometer resolution is independent from the trajectory radius and curvature if adiabaticity parameter is small!

Продолжение поиска массы нейтрино: международный проект КАТРИН в Карлсруэ



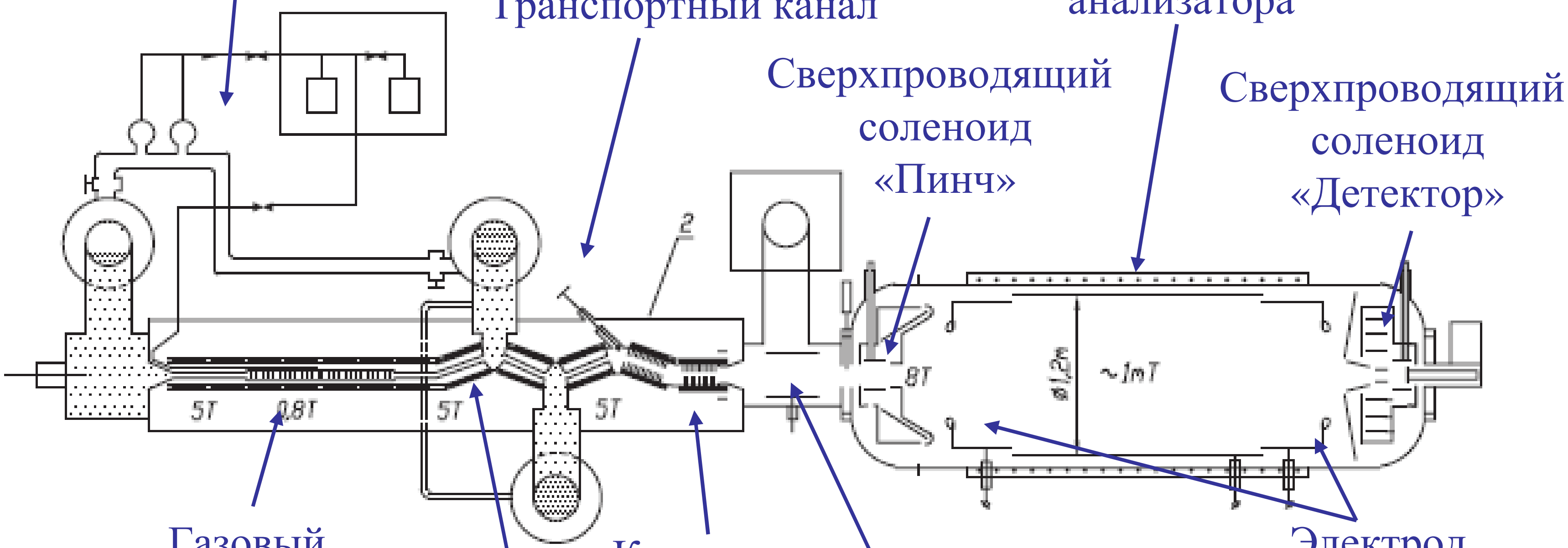
Tritium decays, releasing an electron and an anti-electron-neutrino. While the neutrino escapes undetected, the electron starts its journey to the detector.

Electrons are guided towards the spectrometer by magnetic fields. Tritium has to be pumped out to provide tritium free spectrometers.

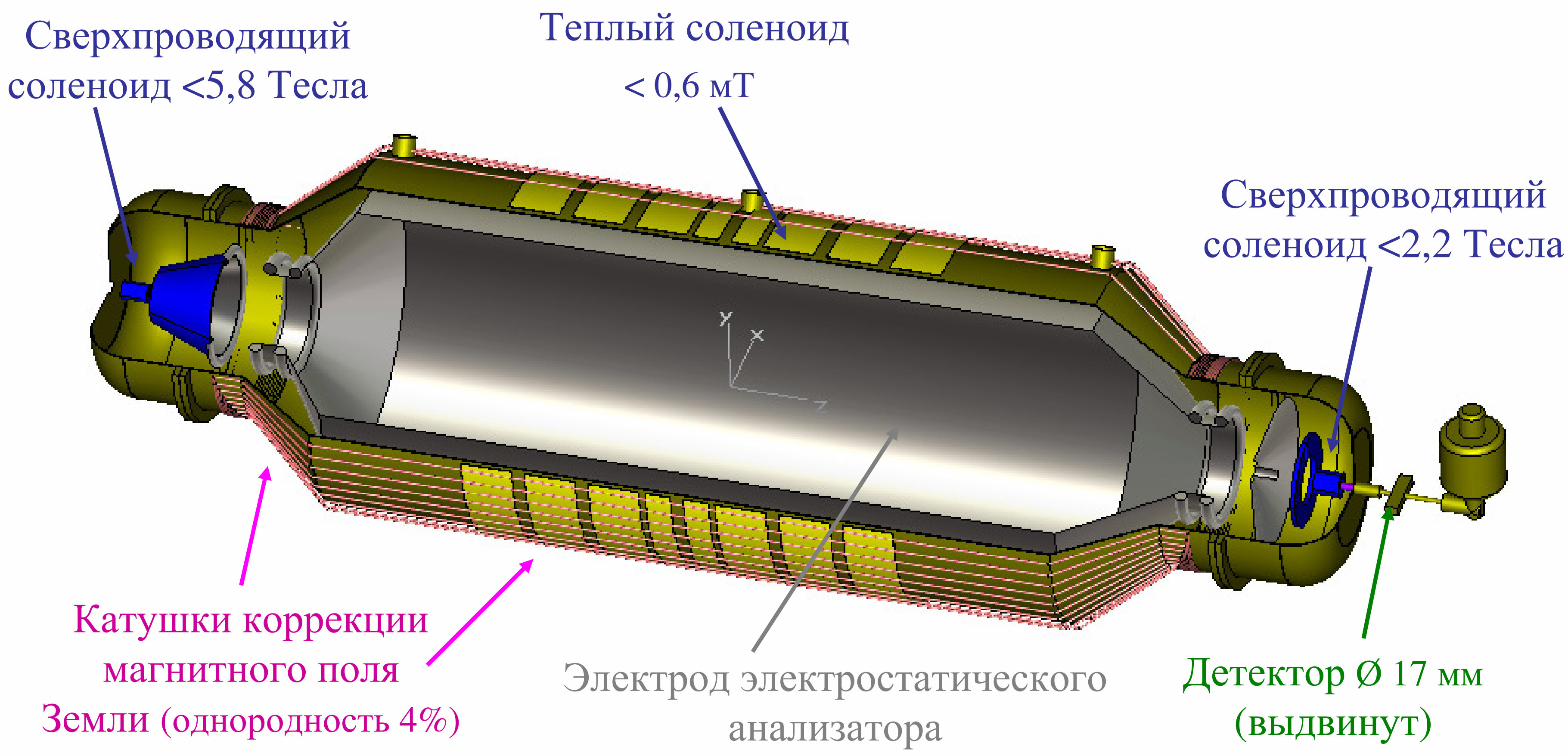
The electron energy is analyzed by applying an electrostatic retarding potential. Electrons are only transmitted if their kinetic energy is sufficiently high.

At the end of their journey, the electrons are counted at the detector. Their rate varies with the spectrometer potential and hence gives an integrated β-spectrum.

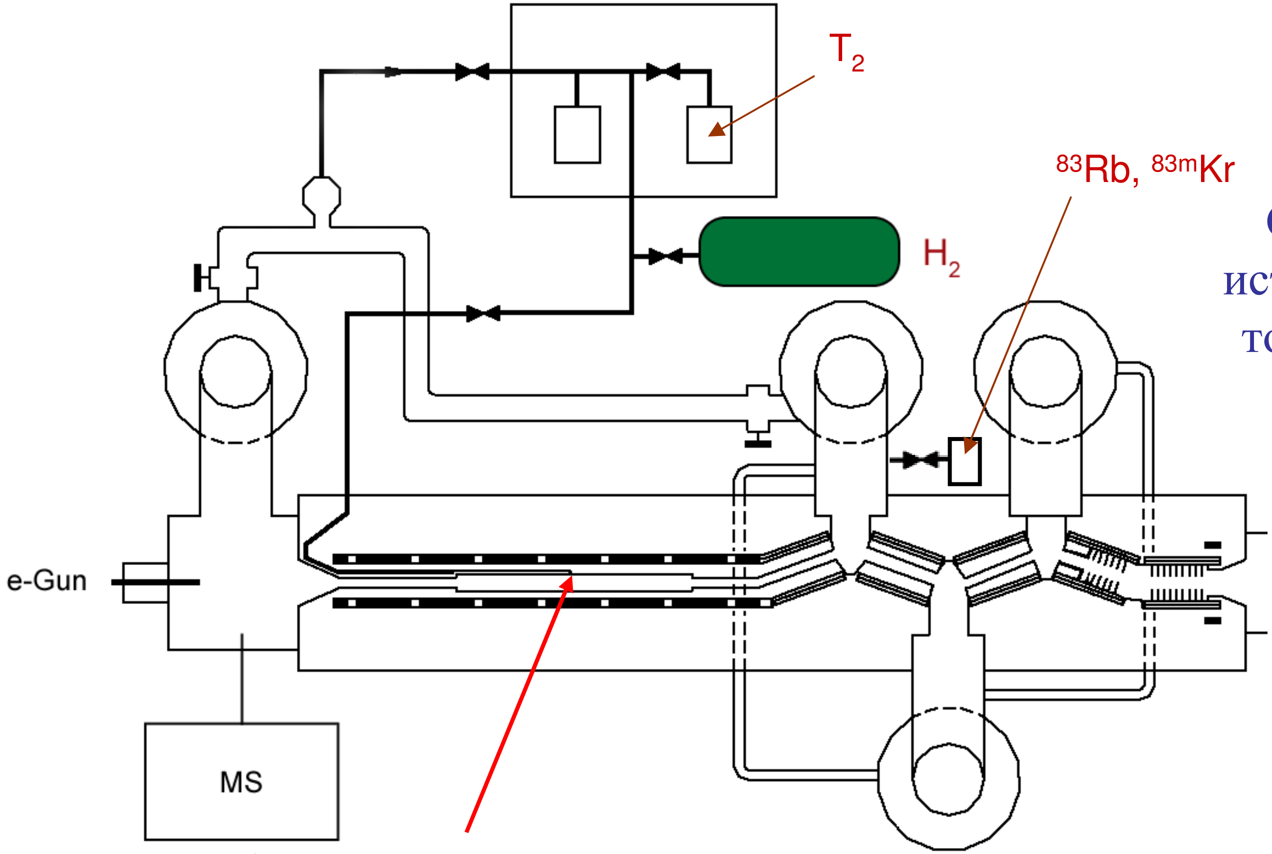
Установка «Троицк ν-масс»



Новый спектрометр: модель



Источник
Экспериментальные возможности



Трубка источника подогревается

Светимость газового источника *5,4 стер · см^2*, толщина *1·10^{17} мол/см^2*

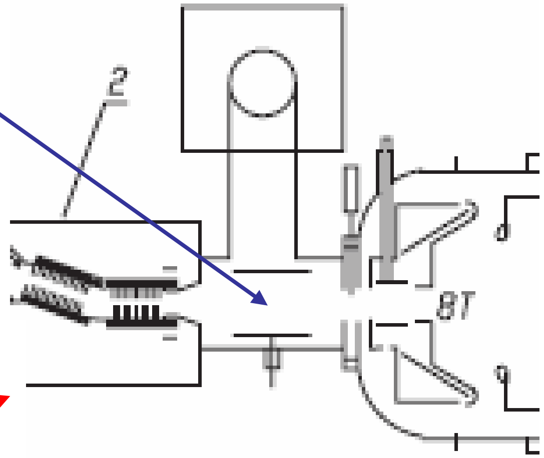
Температура газа в источнике
20К … 110К

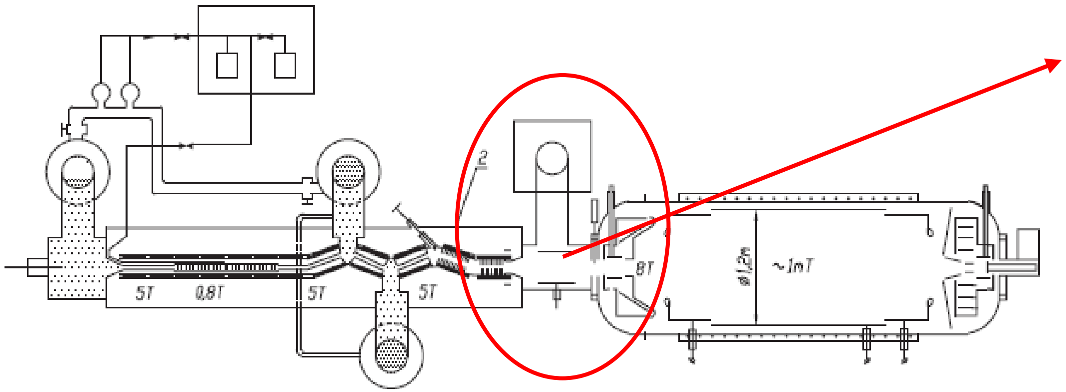
N. Titov June,27 2013

XXIX-th International Workshop on High Energy Physics
June 26 –28 of 2013, IHEP, Protvino, Russia

Источник
Дополнительные возможности

Оборудование станции
для твердых источников
или диагностической аппаратуры
на месте предварительного спектрометра



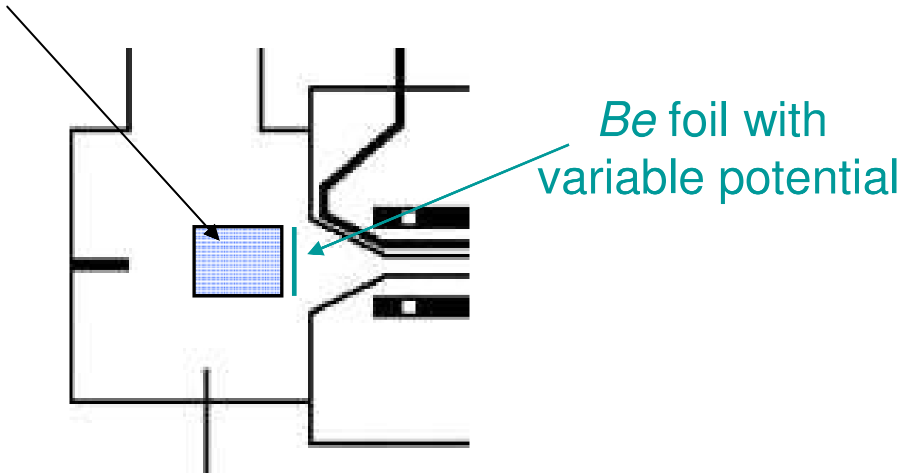


Исследование систематики газового источника

1.Влияние объёмного заряда

Потенциал объёмного заряда исследуется в измерениях спектров электронов внутренней конверсии ^{83m}Kr при совместной циркуляции с тритием или водородом, ионизованным внешним источником электронов:

Электронная пушка с широкой апертурой помещается в вакуумный пост насоса в задней части источника.



Исследование систематики газового источника

2. Рекомбинация ионов в газовом источнике и удаление ионов в скрещенных *ExB* полях