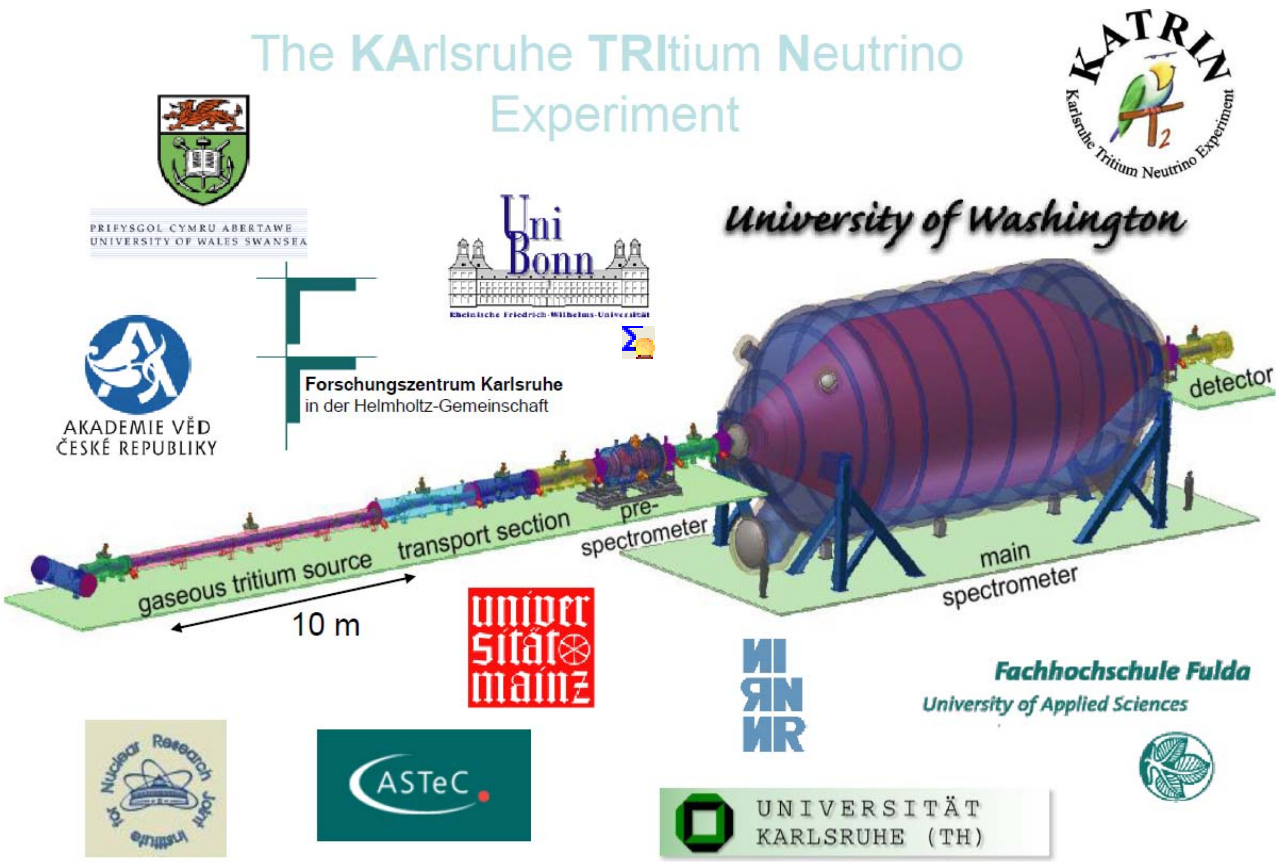
ТРИТИЕВАЯ ПЛАЗМА В ИСТОЧНИКЕ "KATRIN" ДЛЯ ИЗМЕРЕНИЯ МАССЫ НЕЙТРИНО

Установка “KATRIN”

(Ferenz Gluck, 2010)



Необходимость знания массы нейтрино

(Ferenz Gluck, 2010)

Neutrino mass value important for:

particle physics, astrophysics, cosmology

Information for neutrino mass:

neutrino oscillation experiments (SuperKamiokande, SNO, KamLand)

only $\Delta m_{\nu}{}^{2}$ **can be determined**

neutrinoless double beta decay, supernovae,
cosmological observations (galaxy redshift,
microwave background radiation)

model dependent results

Tritium beta decay:

Model independent (kinematical), absolute neutrino mass determination

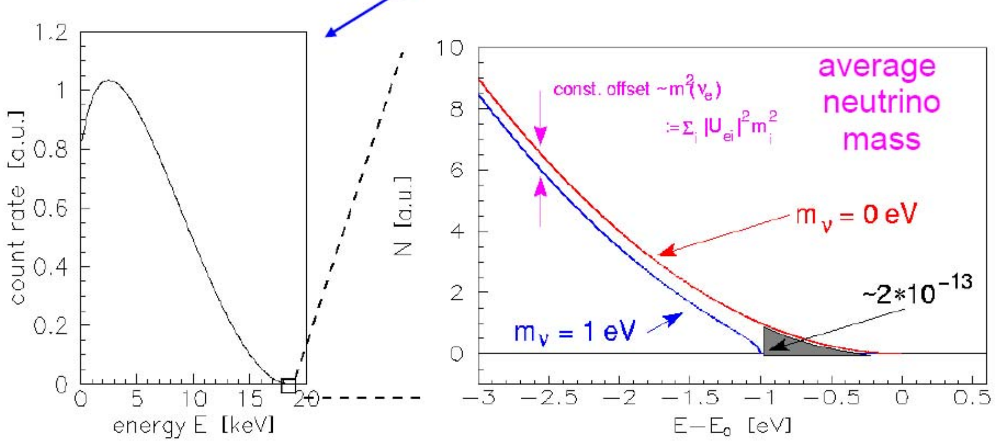
Mainz,Troitsk: $m_{\nu} <$ 2 eV, KATRIN ⟶ $m_{\nu} <$ 0.2 eV

Характер измерения массы нейтрино

Direct determination of m_ν by tritium β decay

tritium β decay: $^3H \rightarrow {}^3He^+ + e^- + \bar{\nu}_e$

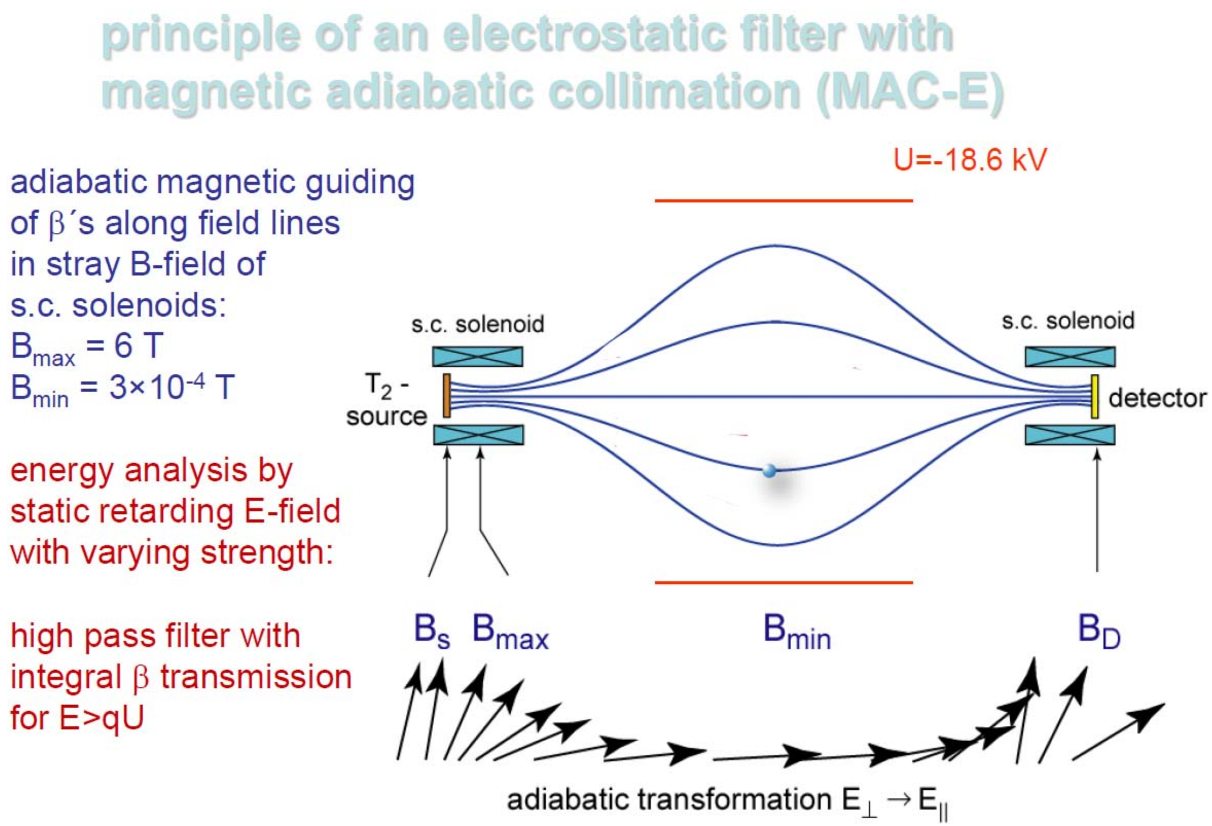
super allowed
E_0 = 18.6 keV
$t_{1/2}$ = 12.3 a



Need: **very high energy resolution &**
very high luminosity &
very low background
} ⇒ **MAC-E-Filter**

Особенности электростатического фильтра

(Ferenz Gluck, 2010)



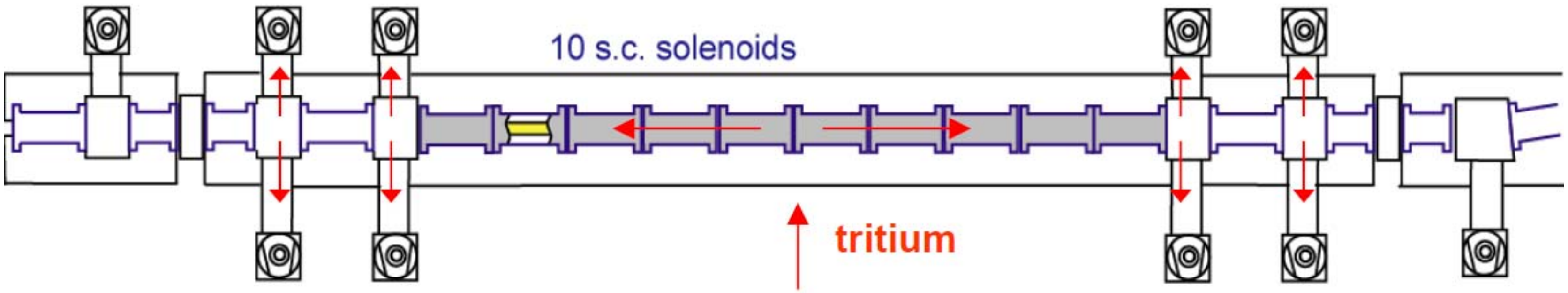
Тритиевая камера

(Ferenz Gluck, 2010)

WGTS - Windowless Gasous Tritium Source

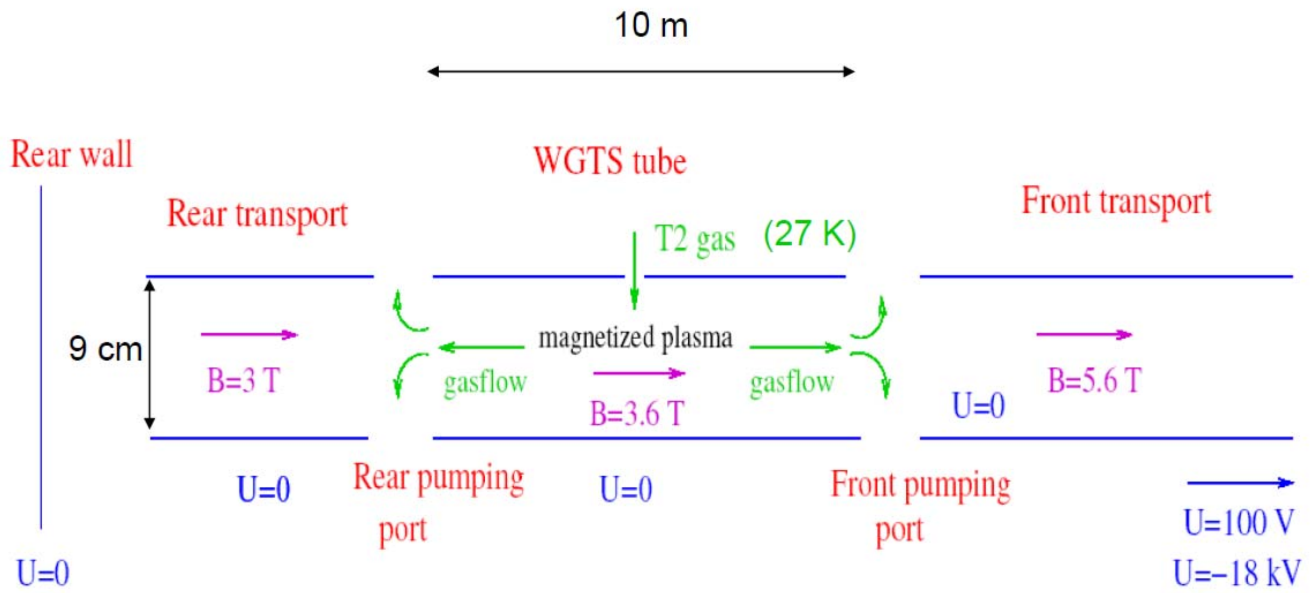
WGTS : maximum T_2 luminosity & minimum systematic effects
adiabatic electron transport in strong magnetic field & tritium diffusion

parameters : L = 10 m, Ø = 90 mm, B_S = 3.6 T, purity > 95% T_2 (±1%)
T=27 K, column density ρd : $5 \times 10^{17}\ T_2 / cm^2$



$10^{12} mol / cm^3$ $10^{15} mol / cm^3$ $10^{12} mol / cm^3$

Транспортная система



Source−transport system of KATRIN

(simplified picture)

gasflow time: 1 s

(Ferenz Gluck, 2010)

Измерение массы нейтрино

(Ferenz Gluck, 2010)

<u>Neutrino mass measurement by gaseous T_2 source:</u>

Los Alamos, Livermore, Troitsk

Negative m_ν^2 anomaly (Troitsk: step in electron spectrum).

Solid state T_2 source in Mainz, important systematic effect is the source charging (el. potential in decay point changes).

Unknown spatial or time variation of source potential (σ_{U_S}) $\Rightarrow$ systematic effect:

$$\delta m_\nu^2 = -2\sigma_{U_S}^2$$

(H. Robertson, N. Titov).

KATRIN: 0.2 eV neutrino mass sensitivity (Mainz, Troitsk: 2.2 eV) $\Longrightarrow$ reliable understanding of systematic effects is important

Процессы с участием трития

(Ferenz Gluck, 2010)

Physical processes:

- Beta decay: $T_2 \rightarrow (HeT)^+ + e^- + \bar{\nu}_e \Rightarrow$ positive ions, primary electrons
- Ionization: $e^- + T_2 \rightarrow T_2^+ + e^- + e^- \Rightarrow$ positive ions, secondary electrons
- Dissociative attachment $\Rightarrow$ negative ions (T^-)
- Chemical reactions of positive ions $\Rightarrow T_3^+, T_5^+, \ldots$
- Electron-ion recombination (volume)
- Collisions of ions and electrons with T_2 molecules (elastic; inelastic: ionization, elect. excit., vibr. and rot. excit.; superelastic)
- Gas flow

Образование и распад ионов трития

(Ferenz Gluck, 2010)

β decay

$$T_2 \to (HeT)^+ + e^- + \bar{\nu}_e$$

($4 \cdot 10^6$ decays/cm^3/s in middle of KATRIN source tube).

Also: He^+, T^+ (by dissociation from excited states).

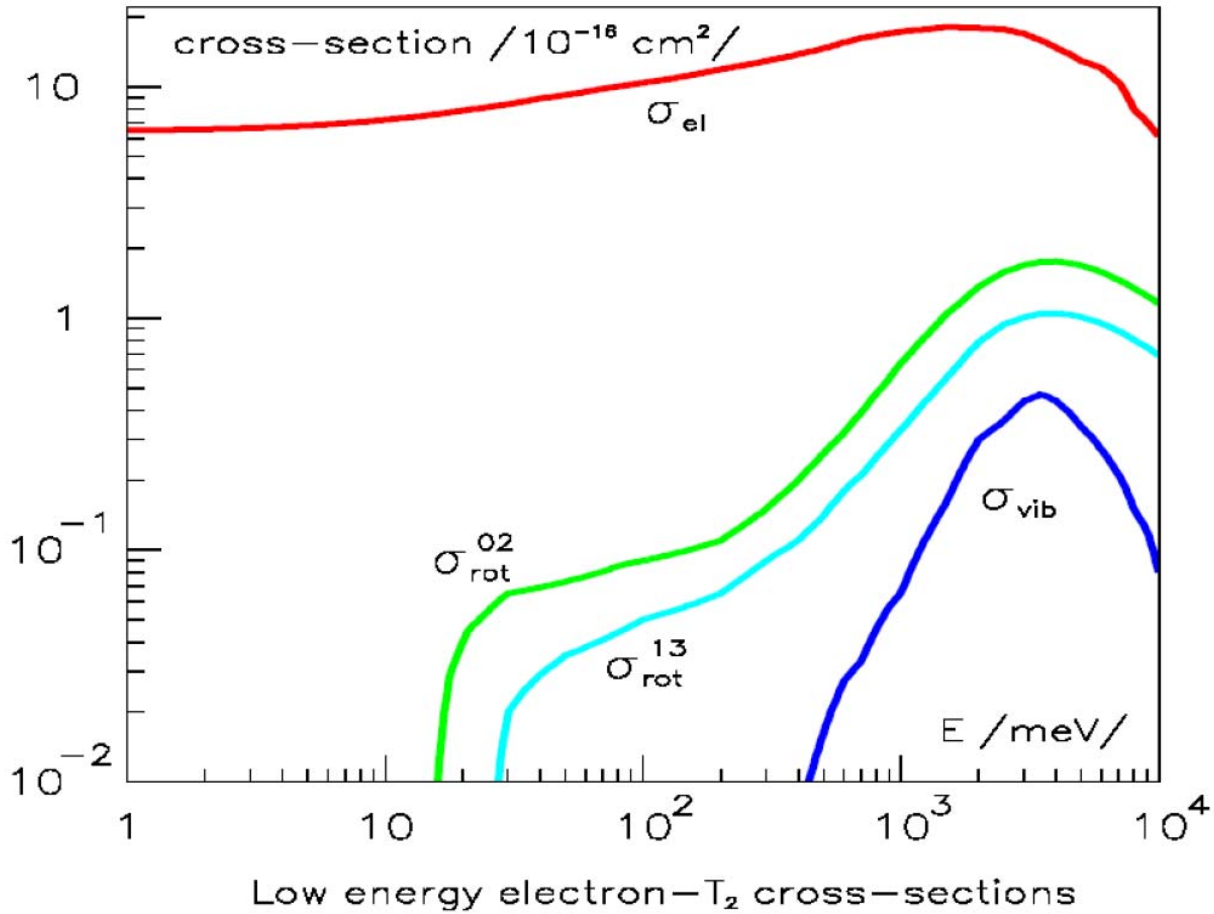
β decay electrons: high energy (few keV), small scatt. cross section
$\rightarrow$ they leave very fast the source tube ($\approx \mu s$)

Positive ions: thermalize with T_2 gas, spend much time ($\approx 1s$) in source tube.

$\Longrightarrow$ positive space charge potential from β decay

(KATRIN: $\Phi \approx 2$ V, without small energy electrons)

Сечения процессов с участием молекул трития



Phelps 1962

Самосогласованное поле в тритиевой камере

$$j = \left(\frac{dN_i}{dx} \right) x = -D_i \frac{dN_i}{dx} + EK_i N_i \,, \quad \frac{dE}{dx} = 4\pi e N_i$$

Решение при $D_i=0$:

$$j = j_o \frac{x}{L}, \quad E = E_o \frac{x}{L}, \; N_i = N_o, \varphi = \varphi_o \frac{x^2}{L^2}$$

При условиях установки :

$$j_o = 9 \cdot 10^8 cm^{-2} s^{-1}, \quad E_o = 0.39 \frac{V}{cm}, \; N_o = 900 cm^{-3}, \varphi_o = 48V$$