Czech participation in the KATRIN experiment - model independent search for the neutrino mass

Seminar on Neutrino Physics in the Czech Republic,
IEAP CTU Prague, May 25, 2015

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Nuclear Physics Institute ASCR, Řež near Prague

The KATRIN Collaboration

- Czech Republic: Nuclear Physics Institute, AS CR, Rez near Prague X
- Germany: KIT-IK, KIT-IPE, KIT-ITP with TLK (formerly FZ Karlsruhe) X
- KIT-IEKP (formerly University Karlsruhe)
- Bonn University (Rheinische Friedrich-Wilhelms-Universität Bonn)
- Fulda University for Applied Science X
- Mainz University (Johannes Gutenberg-Universität Mainz) X
- MPIK Heidelberg
- Münster University (Westfälische Wilhelms-Universität Münster)
- Wuppertal University (Bergische Universität Wuppertal)
- Russia: INR Troitsk, Russian Academy of Sciences X
- Spain: Complutense university of Madrid
- US: Massuchusetts Institute for Technology
- Lawrence Berkely National Laboratory
- University of California, Santa Barbara
- University of North Carolina, Chapel Hill
- University of Washington, Seattle X

X – KATRIN founders

- Experts groups: Jefferson Laboratory/Old Dominion (US), Universidade Federal do Parana (Brasil), Aarhus University (Denmark)

KATRIN – NPI: relations, manpower, funding

- With institutions from Germany, Russia, USA NPI is a founder of KATRIN
- O. Dragoun and D. Vénos are members of the KATRIN Collaboration Board
- D. Vénos is co-leader of the task Calibration and Monitoring

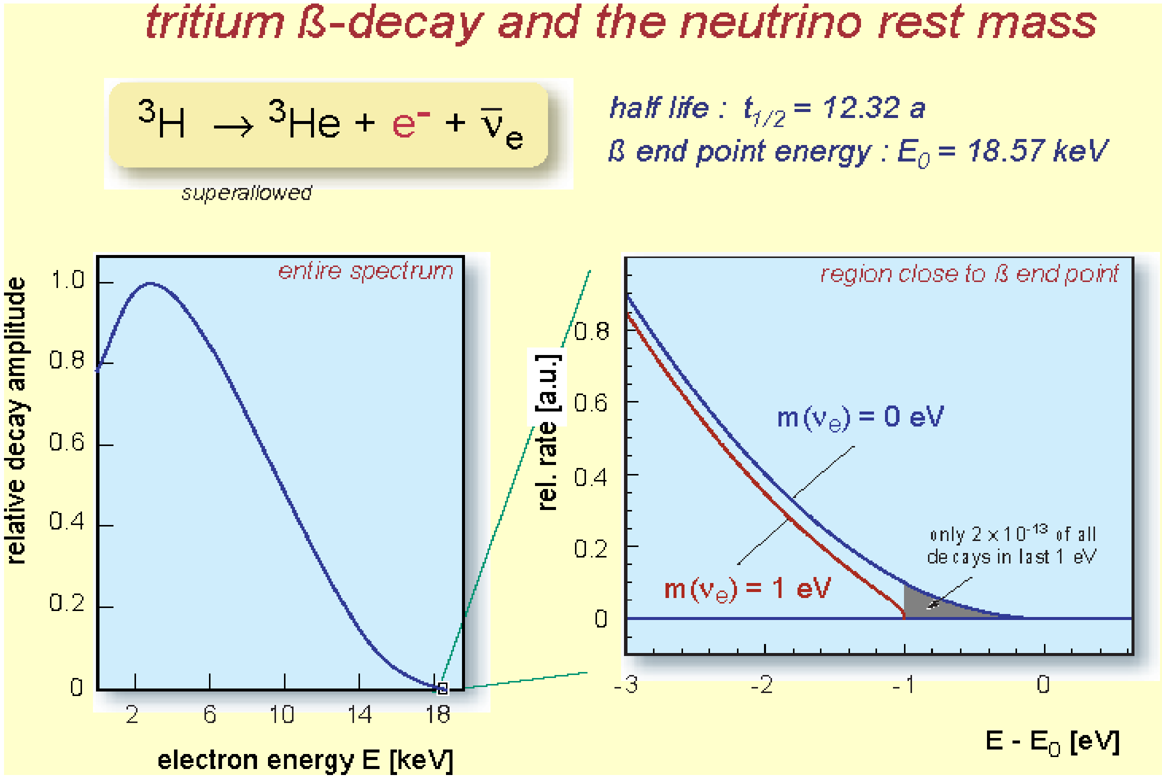
- NPI collaborators in KATRIN; relative participation (RP)

Name	Position	RP (%)
Dragoun O.	scientist	100
Hanč P.	engineer	10
Kovalík A.	scientist	10
Lebeda O.	scientist	20
Ryšavý M.	scientist	20
Sentkerestiová J.	scientist	100
Slezák Martin	doctoral student	100
Špalek A.	scientist	10
Stanislav J.	technician	5
Vénos D.	scientist	100

- Funding: grants of GACR and Common project NPI Řež and JINR Dubna

KATRIN - Karlsruhe Tritium Neutrino Experiment:

direct β-spectroscopic search for $m_{\nu e}$



Neutrino mixing :

$$m_{\nu e}^2 = \sum_i |U_{ei}|^2 \cdot m_i^2$$

Matrix elements

Mass eigenvalues

Molecular tritium - $(^3H^3He)^-$ final states probabilities and excitation energies: p_j, V_j

Theor. decay amplitude:

$$dN/dE_e = K \times F(E_e, Z+1) \times p_e \times (E_e+m_e) \times \Sigma_j\, \mathbf{p_j} \times (E_0 - \mathbf{V_j} - E_e) \times [\, (E_0 - \mathbf{V_j} - E_e)^2 - \mathbf{m_{\nu e}^2}\,]^{1/2}$$

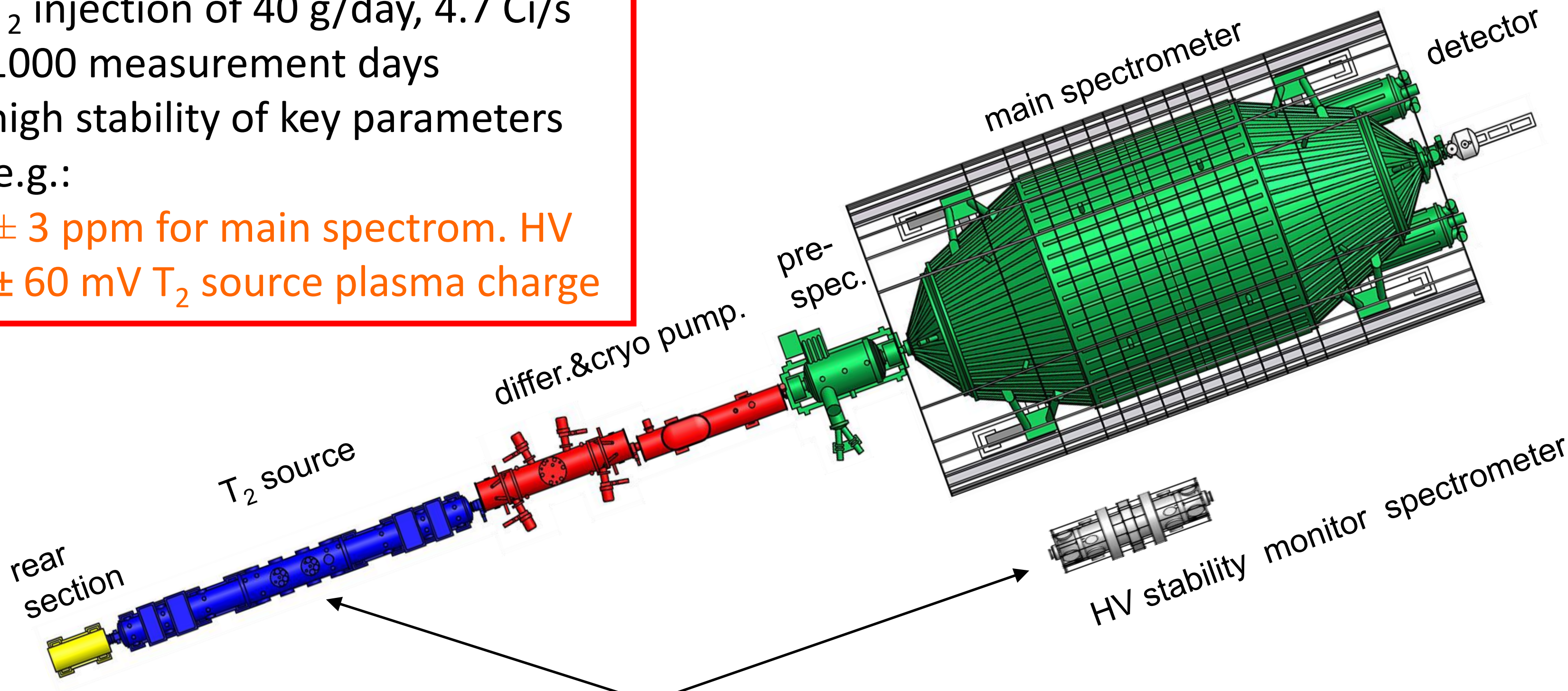
Sensitivity after 1000 measuring days:

***$m_{\nu e}$* < 200 meV** at 90 % C.L. if no effect is observed

***$m_{\nu e}$* = 0.35 eV** would be seen as **5σ effect**

KATRIN setup - with 3 MAC-E filter spectrometers

For sensitivity of 200 meV:
-high resolution: 0.9 eV
-high luminosity: 19% of 4p
-low detector back.: 10 mcps
-T_2 injection of 40 g/day, 4.7 Ci/s
-1000 measurement days
-high stability of key parameters
e.g.:
± 3 ppm for main spectrom. HV
± 60 mV T_2 source plasma charge



sources with monoenergetic electrons are developed at NPI

First test run is expected in 2017

Source of monoenergetic electrons for T_2 source

Gaseous ^{83m}Kr applied into KATRIN tritium source represents a space source, similarly to tritium, of conversion electrons (mainly K-32, L_3-32, $N_{2,3}$-32 with respective energies 17.8, 30.5, 32.1 keV) which will be used for systematic measurements:

- **space charge potential – influences tritium endpoint energy E_0**
- **space charge variation – influences $m_{\nu e}^2$**
- **check of the spectrometer response function (radial dependence, electron energy losses)**
- **check of the stability of voltages, workfunctions including**
- **calibration of KATRIN energy scale**

Development of the gaseous ^{83m}Kr electron source

^{83m}Kr ($T_{1/2}$ = 1.83 h) source is based on deposition of mother ^{83}Rb ($T_{1/2}$ = 86.2 d) into zeolite (aluminosilicate) – required source properties:
- ^{83}Rb firmly kept in the source
- ^{83m}Kr easily emanated from the source

1) krypton gas target cooled with water (target chamber) and helium gas (target input windows) was developed. Irradiation at NPI U-120M cyclotron [reaction ^{nat}Kr(p,xn)^{83}Rb, 13 bar, E_p = 26.2 MeV, I_p = 15 μA] yields 35 MBq of ^{83}Rb per hour, production of 1 GBq is possible

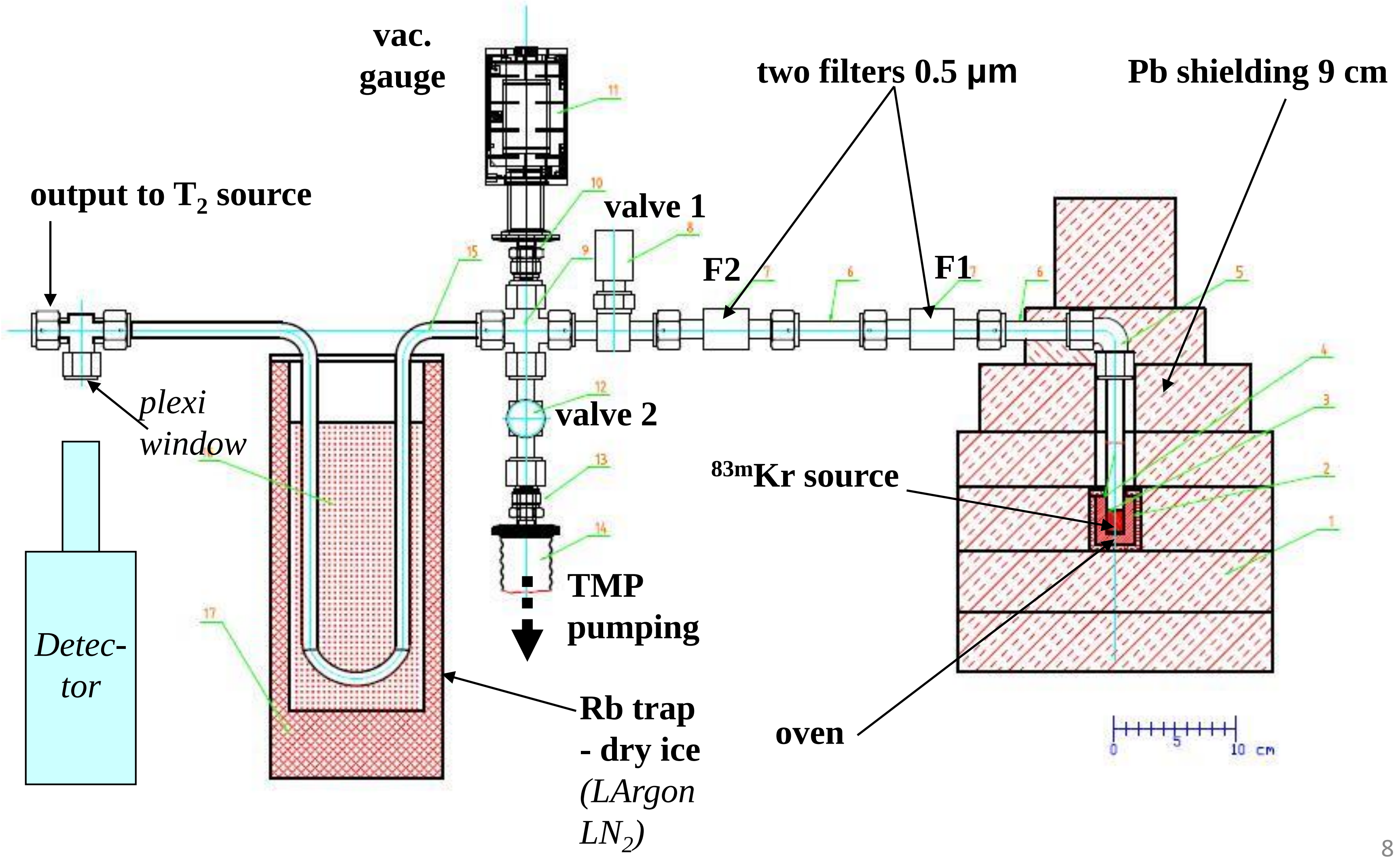
2) 26 sources, ^{83}Rb of 3,5, 30 and 97 MBq in 15 zeolite beads

3) methods for measurement of degree of ^{83m}Kr emanation from source were developed

4) different zeolite substrates (types 3A, 4A, 5A, AX) in different environments (gases [no T_2], vacuum conditions) were studied, ^{83m}Kr emanation >80 % was achieved (5A), 1 ppm of ^{83}Rb is released from source – blocked with a sintered filter (pores 0.5 μm)

see D.Vénos et al. 2014 JINST 9 P12010

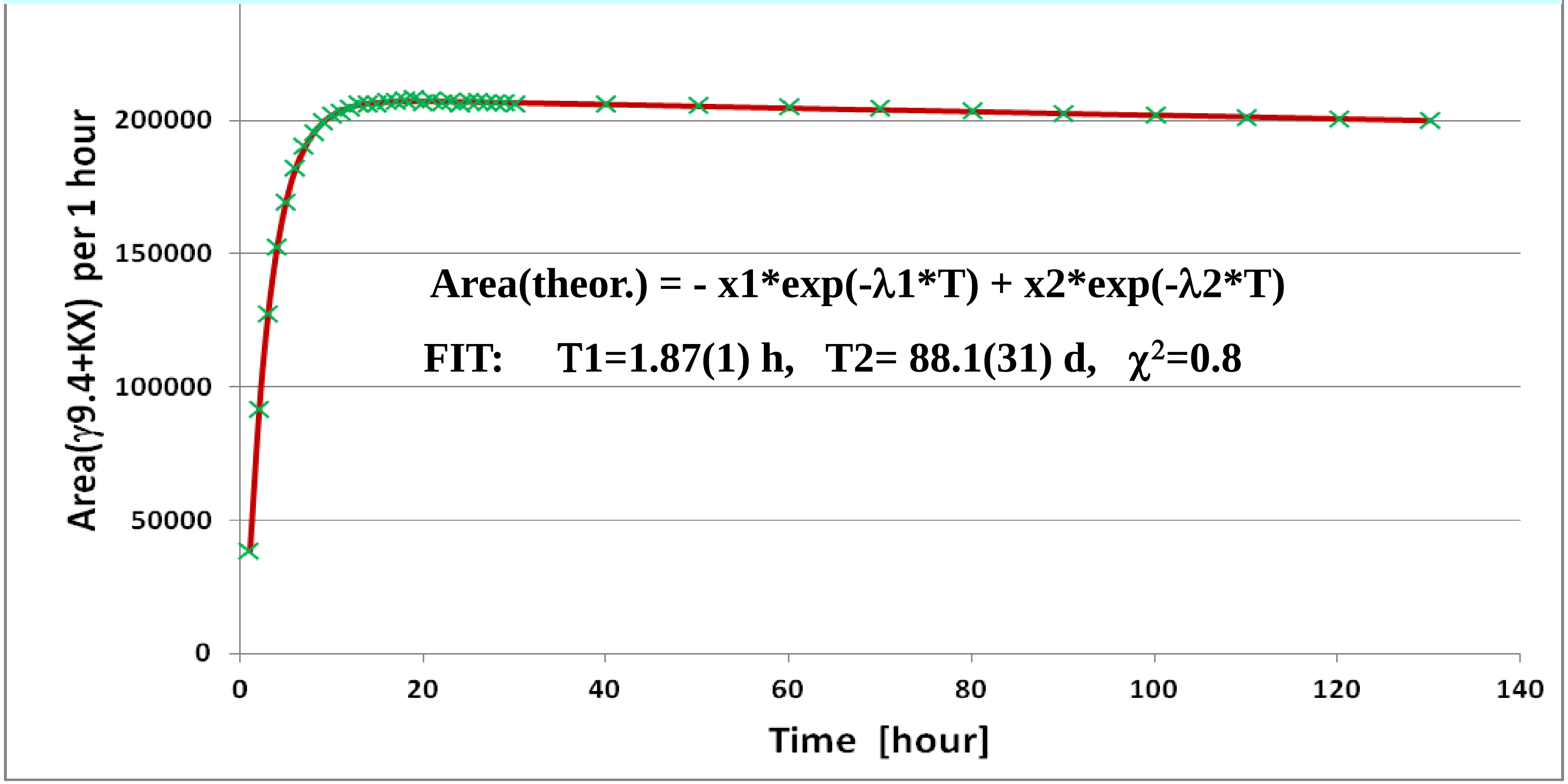
Apparatus for injection of ^{83m}Kr into tritium source
(+ Detector)



Tests of Apparatus for injection of ^{83m}Kr using 97 MBq source

1) Dose on Pb shielding surface in μSv/h: 0.20; backgr. 0.13, KATRIN limit 3.0

2) Relative amount of ^{83m}Kr measured by SSD at Apparatus output

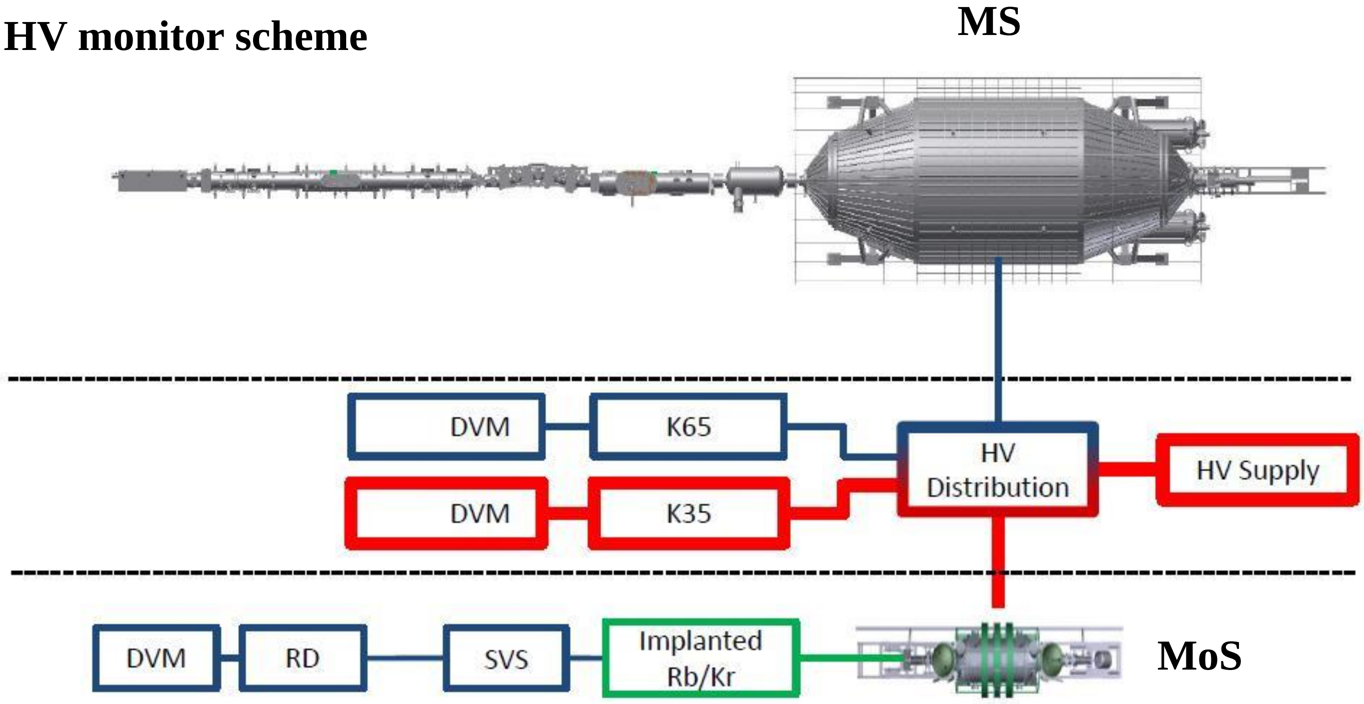


3) Activity of ^{83m}Kr in Apparatus - 73 MBq; it corresponds to ^{83}Rb activity (97 MBq)
4) Contamination with ^{83}Rb: Filter#1 2(1) Bq; Filter#2 < 0.2 Bq C.L. 95%
5) With dry ice, LArgon and LN_2 the ^{83m}Kr activity at output is reduced to 88, 41 and 1%
6) Extra result (preliminary): $T_{1/2}$(^{83m}Kr) = 1.868(2); NDS 125(2015)201 value is 1.83(2)

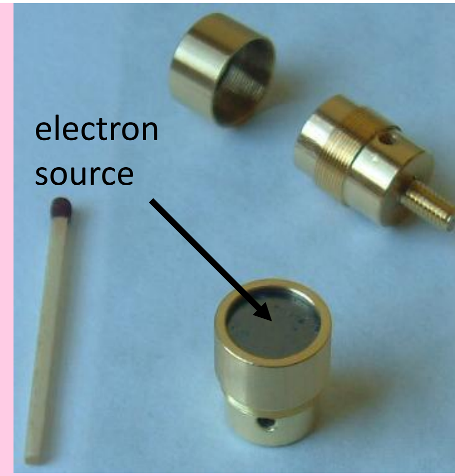
Source of electrons for monitoring spectrometer- MoS

Monitoring concept:
High Voltage (HV) of 18.6 kV at the main spectrometer (MS) must be stable at level of 3 ppm per 2 month KATRIN run. Complementary with two high voltage dividers (K35, K65) and two digital voltmeters (DVM) the HV will be monitored with MoS connected to the same HV. Any change of line position of monoenergetic electrons measured at MoS will indicate a shift of HV determined by dividers and voltmeters

HV monitor scheme



Development of electron source for MoS



Proposal: implanted ^{83}Rb(86d)/^{83m}Kr(2h) source with K-shell internal conversion electrons of krypton isomeric state transition 32.2 keV, K-32 line with energy 17824.3(5) eV

Basic source requirements:

- **K-32 energy stability at level of 3 ppm/(2 months)**
- **^{83}Rb and ^{83m}Kr firmly kept in source substrate**
- **high amount of no energy loss electrons (thin source)**

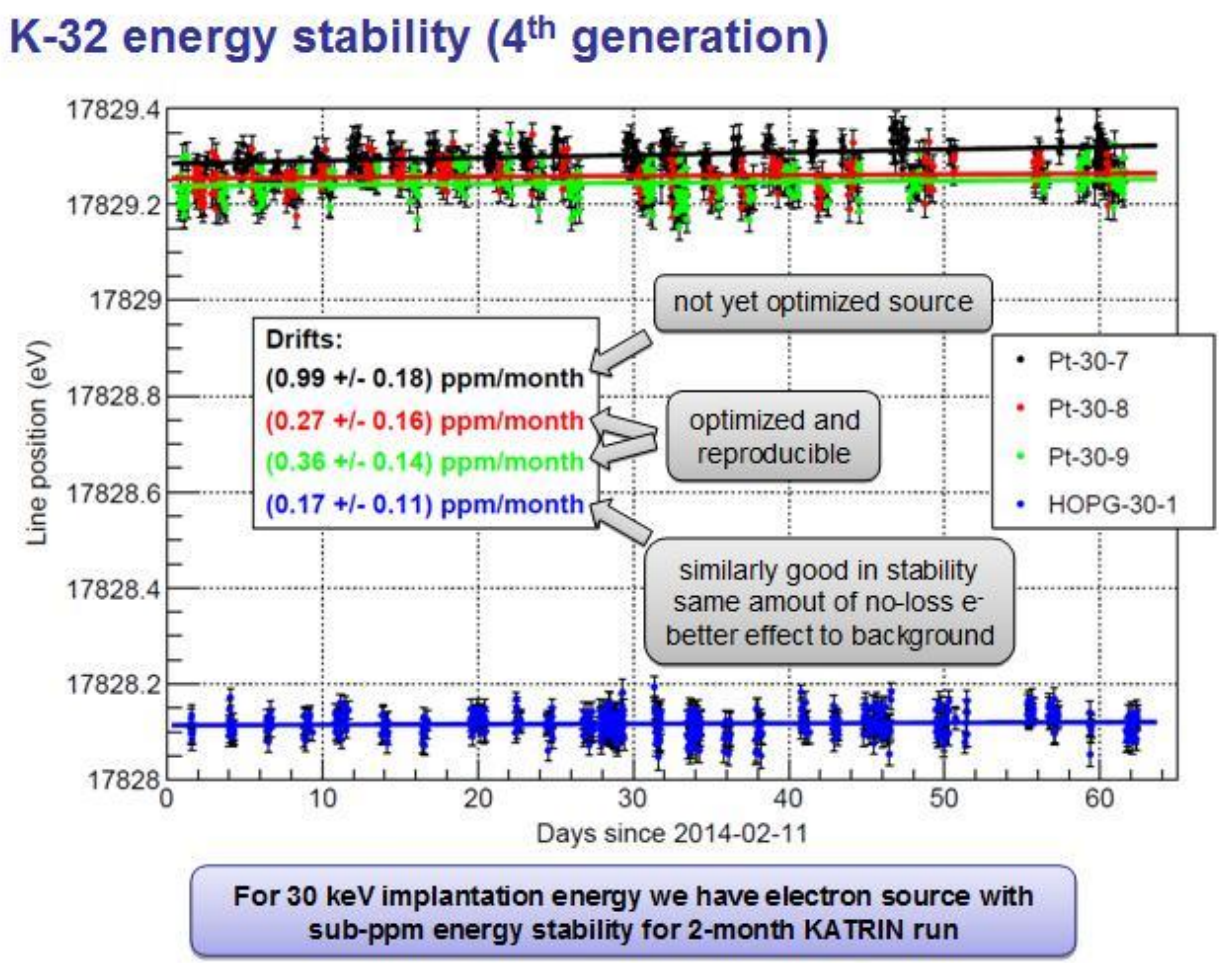
Production of ^{83}Rb at Řež U-120M cyclotron using krypton gas target, deposition of ^{83}Rb into furnaces, transport of furnaces to Bonn mass-separator, implantation of 30 keV ^{83}Rb ions into Pt substrates, transport to KIT

Tests of ^{83}Rb/^{83m}Kr sources at KIT MoS:

- **^{83}Rb activity determined with SDD detector, usually ~3.0 MBq per source**
- **^{83}Rb areal distribution in the sources with Timepix detector**
- **retention of ^{83m}Kr in sources using SDD > 90 %**
- **measurement at MoS for stability of K-32 electron energy were accomplished for altogether of 14 electron sources of different parameters,**
  observed: - linear change of K-32 el. energy with time,
  - the energy drift amounts 0.6 ppm/(2month) – 5× better than the limit
  - the reproducibility in source production was proved
- **additional: study of implantation at lower ^{83}Rb energy with substrate HOPG and possible dependence of energy drift on ^{83}Rb volume density**

Stability of K-32 electron energy at MoS

taken from contribution by M. Slezak at KATRIN CM (2014)



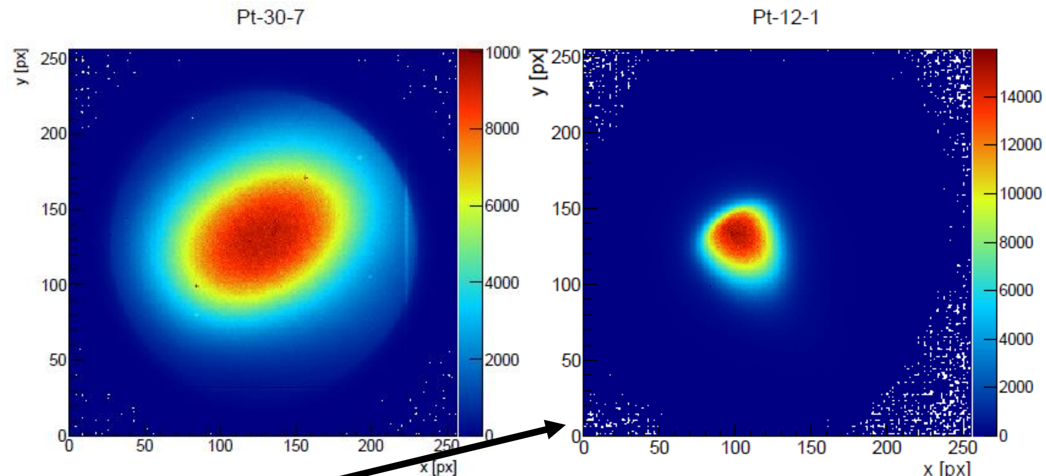
The development of the electron source for the KATRIN MoS is finished

see: M. Zbořil et al. 2013 JINST 8 P03009, M.Erhard et al. 2014 JINST 9 P06022
M. Slezák et al. 2013 JINST 8 T12002

Timepix detector helps in development of the implanted source

Timepix - source geometry

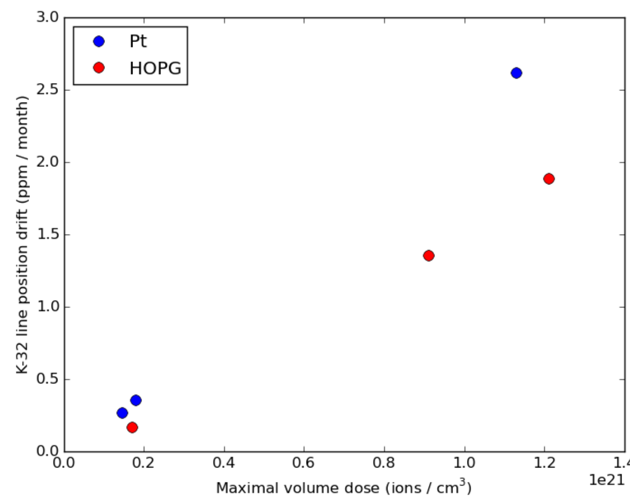
radiographic image for Pt30-7 and Pt12-1



Activity spot for lower implantation energy appeared to be smaller.

Using radiogr. image, source activity and depth profile (SRIM calculation) of ^{83}Rb the maximal volume dose [^{83}Rb ions/cm3] was calculated. The trend for linear ? dependence of energy drift on max. volume dose was observed. Further study of this effect is in progress.

Energy drift trend for 6 sources



Outlook

Plans for rest of 2015

Gaseous ^{83m}Kr source

1) Complete the Apparatus tests (NPI)
2) Measure ^{83m}Kr emanation from zeolite placed in T_2 (~10^{-3} mbar) (KIT)
3) Prepare proposal for the commissioning of Apparatus with T_2 source

Implanted ^{83m}Kr source

1) Complete development of implantation procedure at low ^{83}Rb ions energy (Bonn, KIT)
2) If possible, test of the full monitoring concept (i.e. MS and MoS connected with common HV) for period a month or longer (KIT)

KATRIN websites

- NPI Řež http://ojs.ujf.cas.cz/katrin/
- KIT Karlsruhe http://www.katrin.kit.edu/

Thank you for your attention

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