Status of the KATRIN Experiment

Sixteenth Lomonosov Conference on Elementary Particle Physics
2013/08/23, Moscow State University

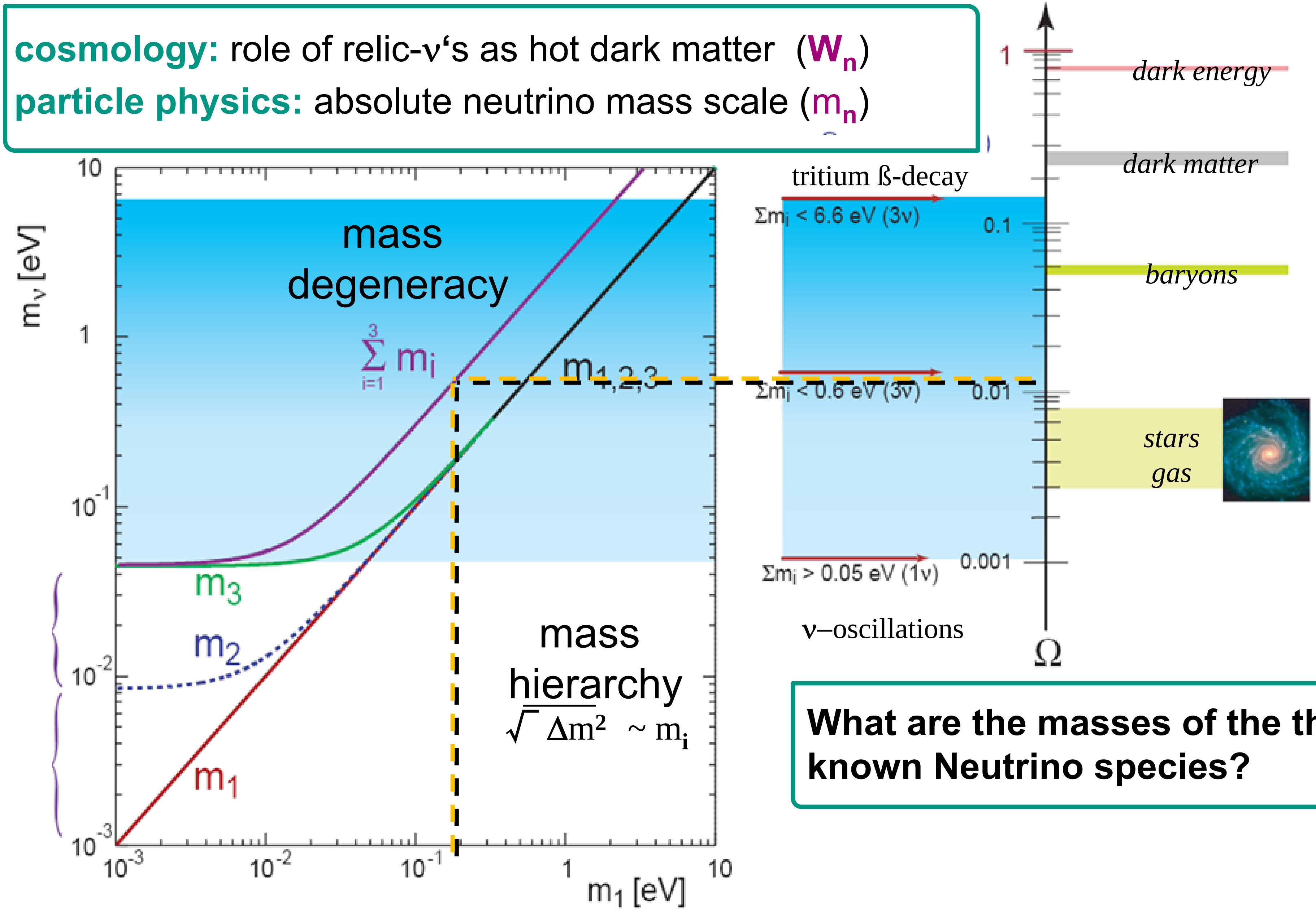
Lutz Bornschein for the KATRIN collaboration **Karlsruhe Institute of Technology**

- Brief Introduction to KATRIN
- First Measurements with Spectrometer and Detector Section (Transmission Fktn, BG Spektra, Rn related BG)
- Status of Source and Transport System

Absolute Neutrino-Mass Scale

cosmology: role of relic-ν's as hot dark matter (**W_n**)

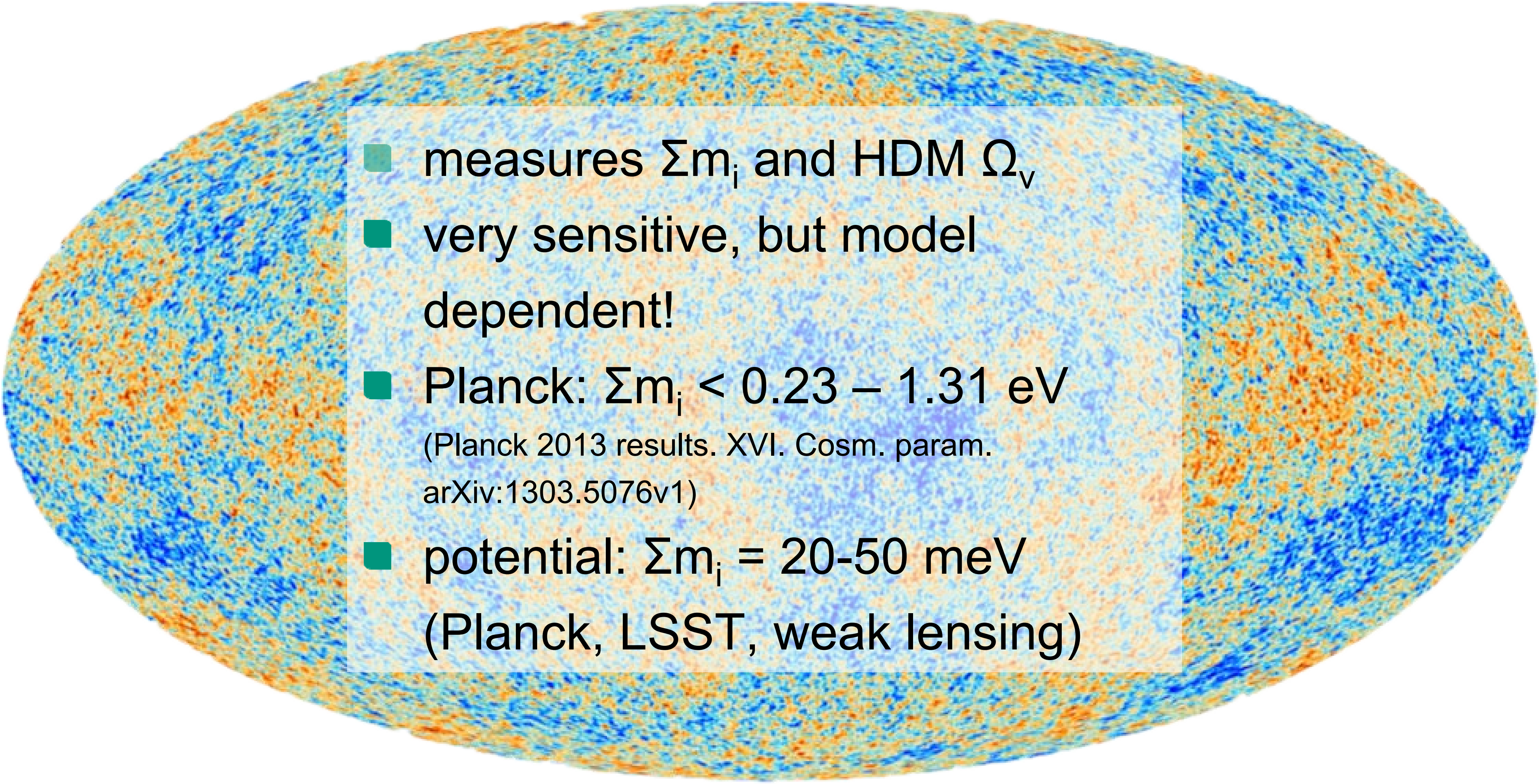
particle physics: absolute neutrino mass scale (m_n)



What are the masses of the three known Neutrino species?

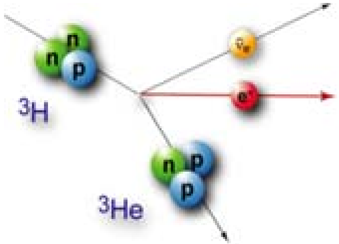
Neutrino Mass: Status and Perspectives

Input from Cosmology:

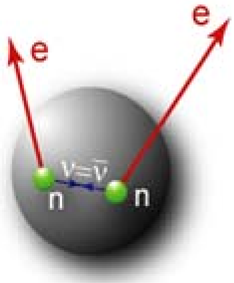


- measures Σm_i and HDM Ω_v
- very sensitive, but model dependent!
- Planck: $\Sigma m_i < 0.23 – 1.31$ eV
  (Planck 2013 results. XVI. Cosm. param. arXiv:1303.5076v1)
- potential: $\Sigma m_i = 20\text{-}50$ meV (Planck, LSST, weak lensing)

Neutrino Mass: Status and Perspectives



status and potential of
neutrino masses
in lab experiments



kinematics of ß-decay
absolute ν_e-mass: m_ν

complementary approaches

search for 0νßß
eff. Majorana mass $m_{ßß}$

model-independent

squared neutrino mass:

$$m^2_{\nu_e} = \sum_i |U_{ei}|^2 \cdot m^2_{\nu_i}$$

- direct, from kinematics
- status: $m_\nu < 2.0$ eV

(PDG using Mainz and Troitsk results)

- potential: $m_\nu = 200$ meV
- MARE, Project 8, KATRIN

model-dependent (CP-phases)

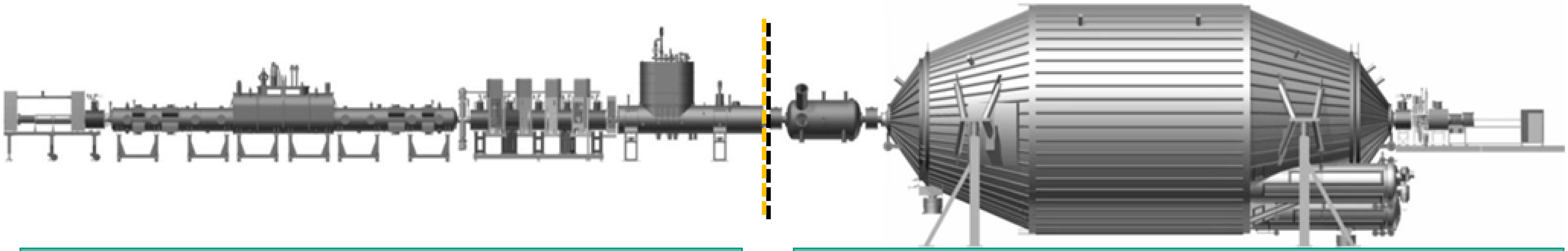
effective Majorana mass:

$$m_{\beta\beta} = \left| \sum_i U^2_{ei} \cdot m_{\nu_i} \right|$$

$$\nu = \bar{\nu}$$

- probe ν as Majorana particle:
- status: $m_{ßß} < 0.35$ eV, evidence?
- potential: $m_{ßß} = 20$-50 meV
- GERDA, EXO, SNO+, MAJORANA, Cuore, KamLAND-Zen, ...

KATRIN experiment – overview



Source & Transport Section (STS)

Spectrometer & Detector Section (SDS)

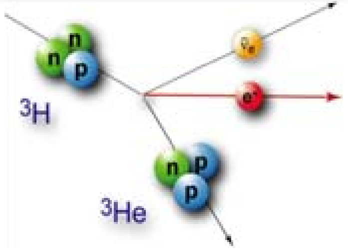
tritium source: 10^{11} β-decays/s

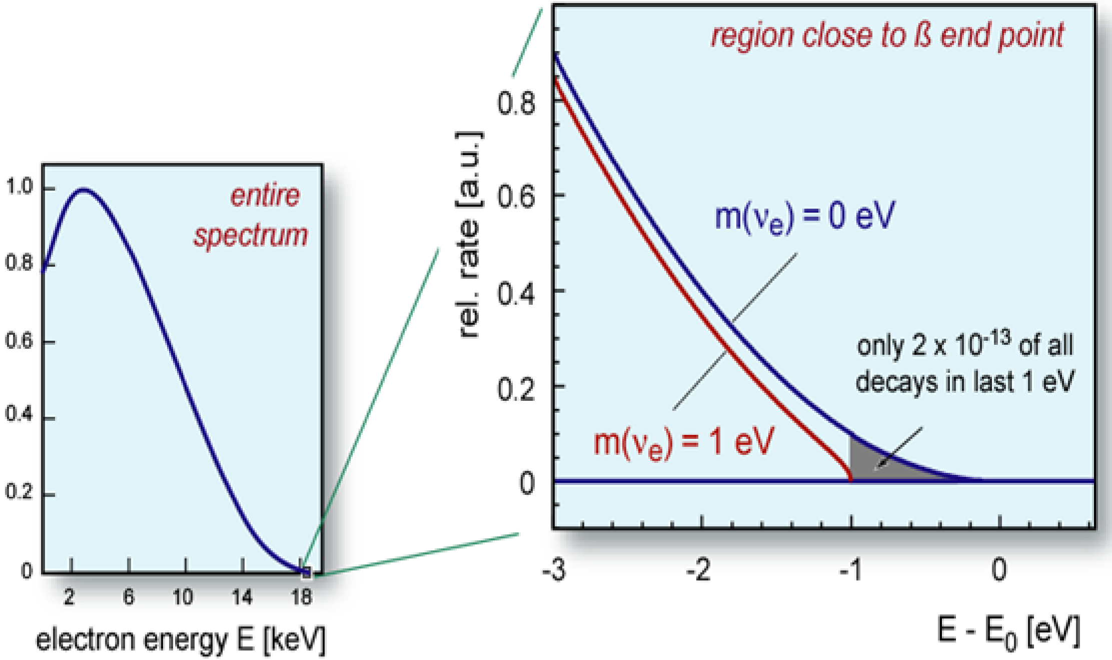
total background: 10^{-2} cps

ideal ß-emitter

^3H: super-allowed	
E_0	**18.6 keV**
$t_{1/2}$	**12.3 y**

$^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$





G. Drexlin, V. Hannen, S. Mertens, C. Weinheimer, Current Direct Neutrino Mass Experiments (Review) Advances In High Energy Physics (2013) 293986

KATRIN sensitivity

reference n-mass sensitivity

for 3 ‘full beam‘ years:

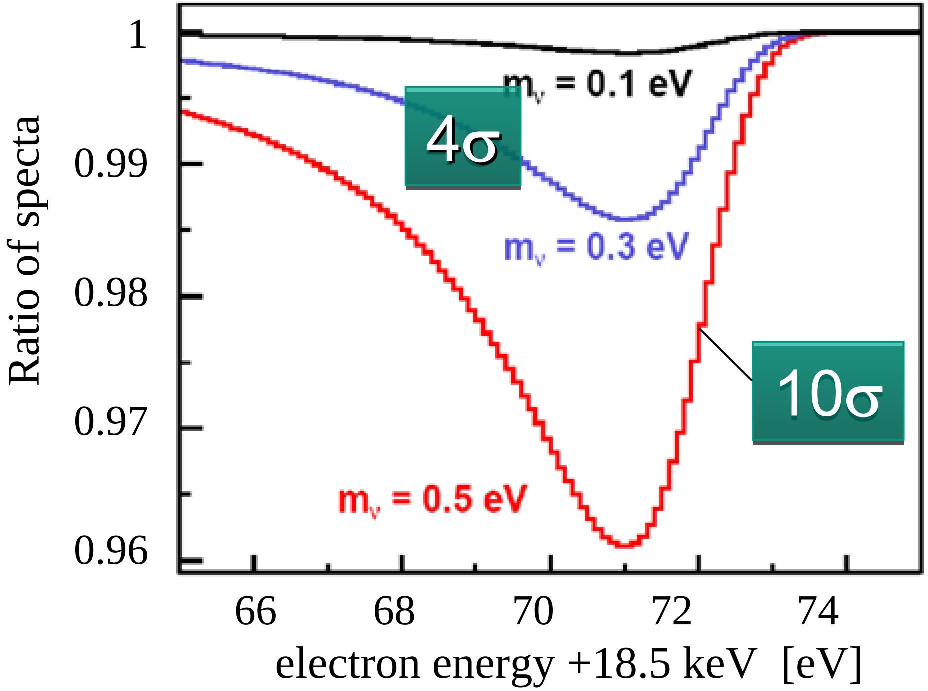
- statistical & systematic errors contribute equally:

  statistics $\sigma_{\text{stat}} = 0.018\ \text{eV}^2$

  systematics $\sigma_{\text{syst}} < 0.017\ \text{eV}^2$

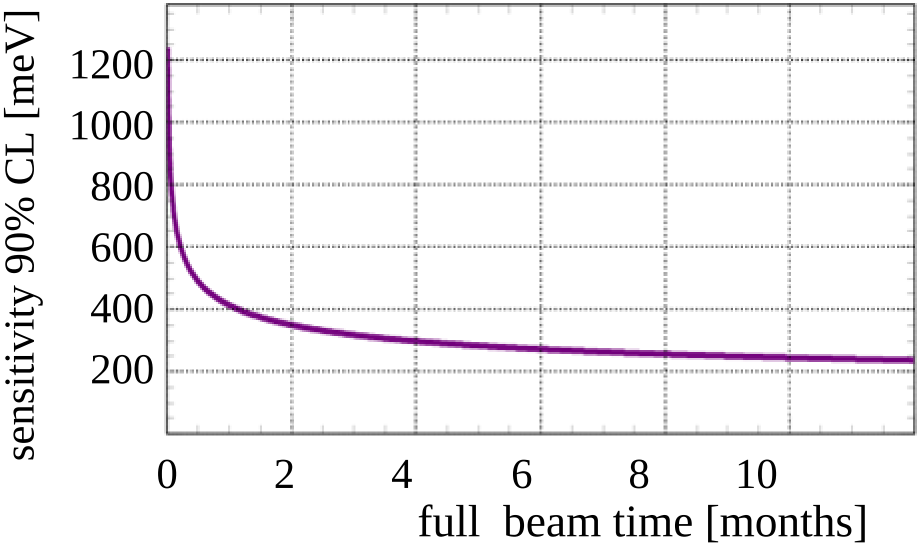
sensitivity m(ν) = 200 meV (90% CL)

350 meV (5σ)



requirements

- precise knowledge of systematics (mainly related to source properties)
- precise knowledge of spectrometer properties
- Very low background ≤ 10^{-2}cps



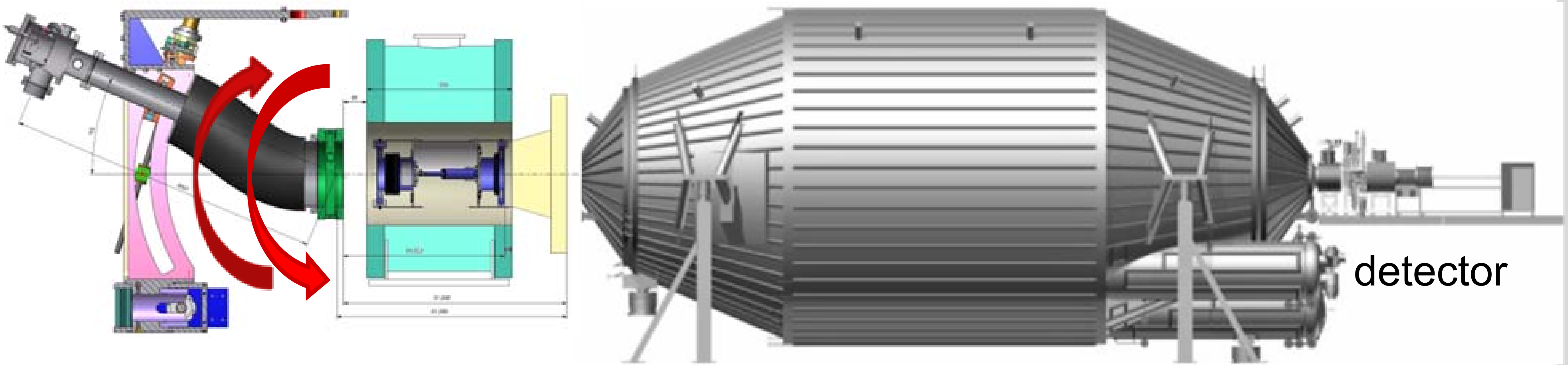
Spectrometer commissioning

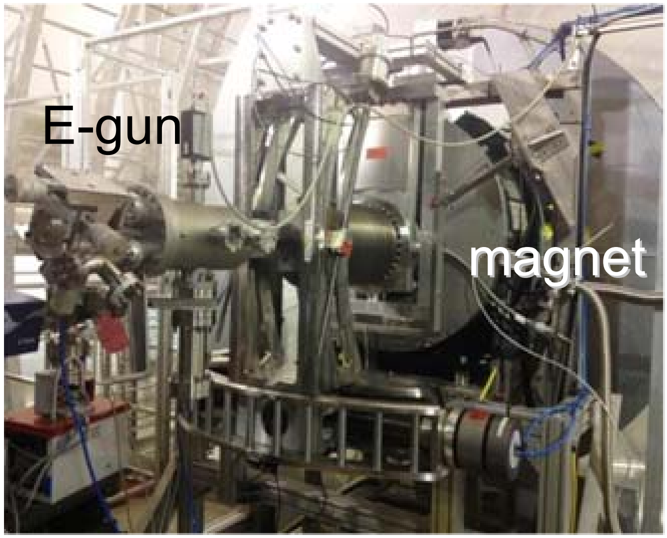
January 2012:
Inner electrode system
(24.000 wires)
completely mounted
(precision: 200 µm!)

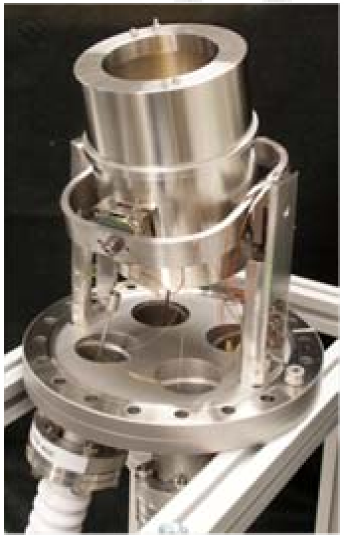
- **2013 first period of data-taking with entire spectrometer/detector**
  - successful bake-out of spectrometer vessel at 300 ºC
  - **first light achieved May 31st**
  - extensive commissioning measurements ongoing:
    - BG characteristics
    - Optimize el.-mag. Layout
    - Meas. TF with egun
    - BG removal methods

All Data Preliminary!

Transmission Function Measurement





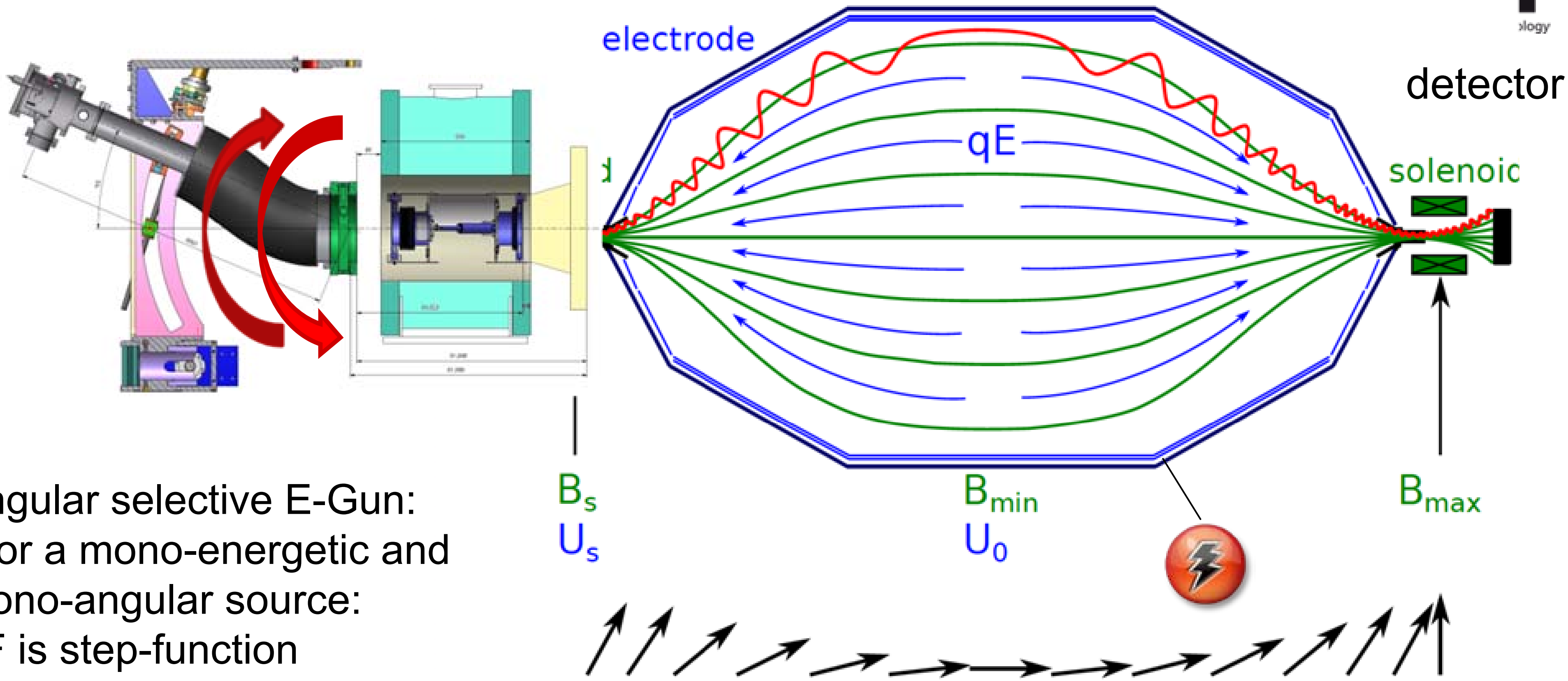


K. Valerius et al.,
Prototype of an angular-selective photoelectron calibration source for the KATRIN experiment,
JINST 6:P01002 (2011)

V. Hannen et. al., WWU Münster

Angular selective E-Gun:
- Ag layer (30 nm) on glas fiber,
back-illuminated by UV-LED or LASER (260 -310 nm)

Transmission Function Measurement

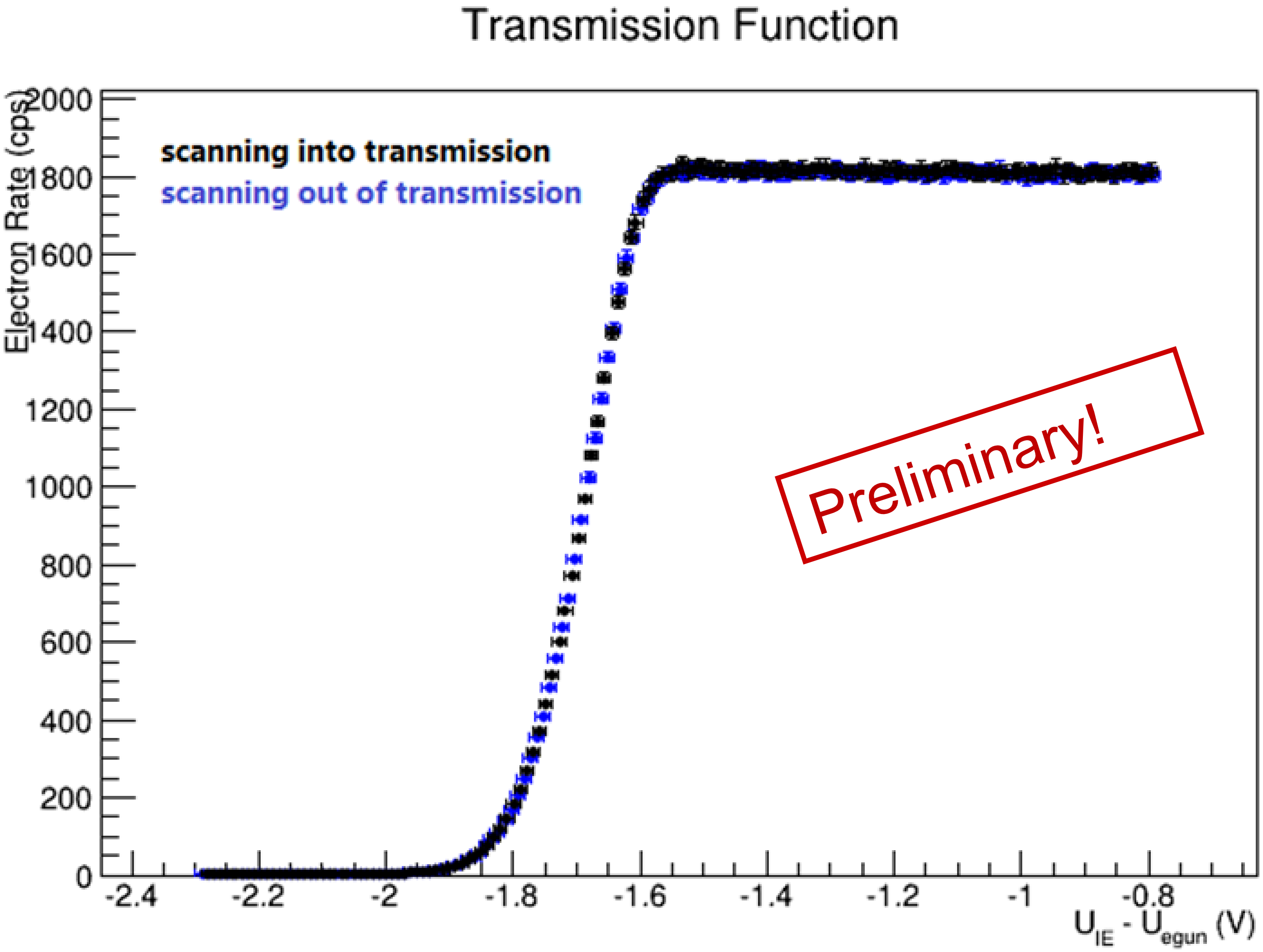


Angular selective E-Gun:
- For a mono-energetic and mono-angular source: TF is step-function

$$\mu = E_\perp / B = \text{const.}$$

energy resolution @ 18.6 eV: **$\Delta E = E \cdot B_{min} / B_{max}$ = 0.93 eV**

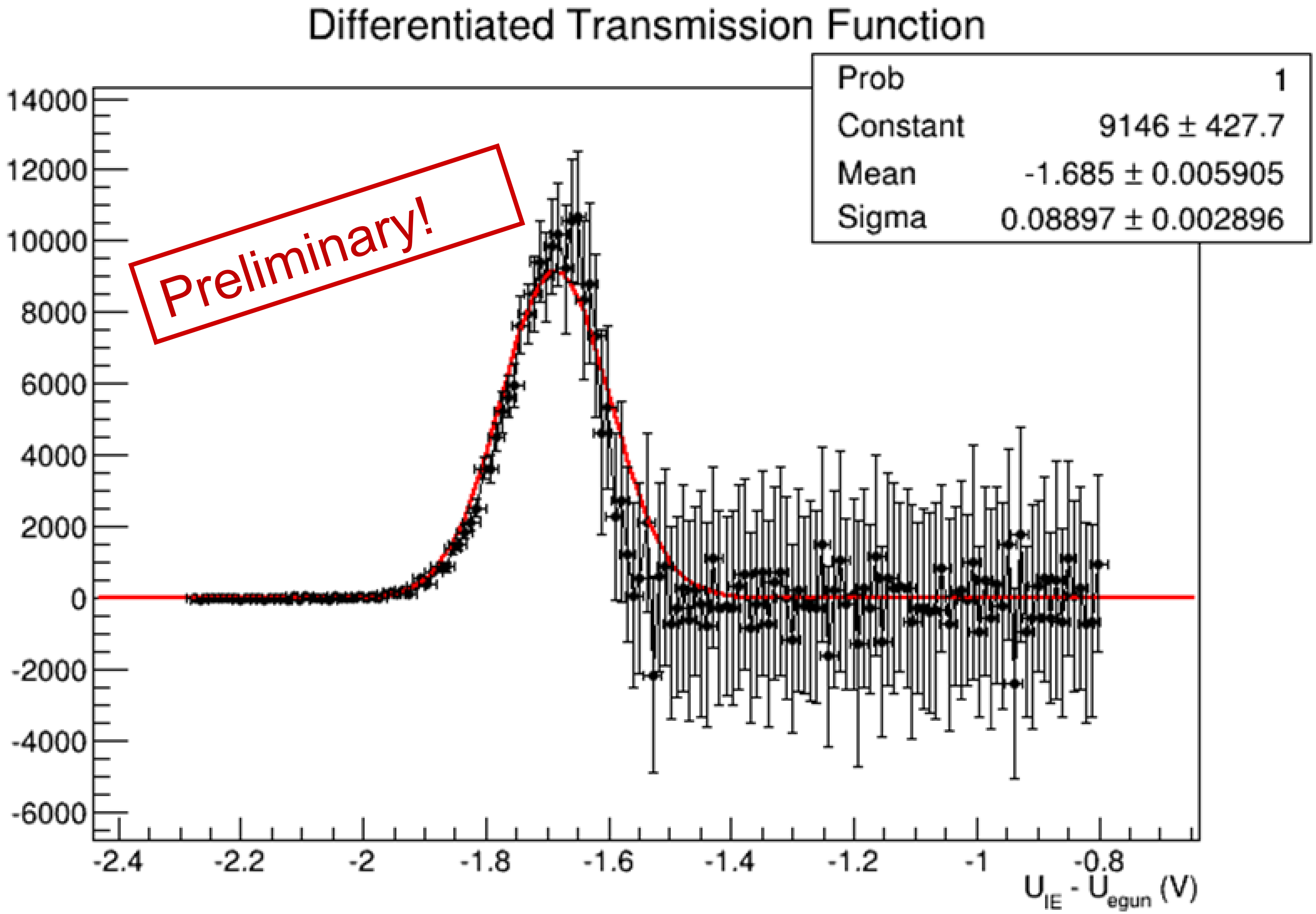
Transmission Function Measurement



Transmission function at U_0 = -200 V, UV-LED with 290nm

Energy resolution dominated by energy spread of the e-gun ~ 0.09 eV

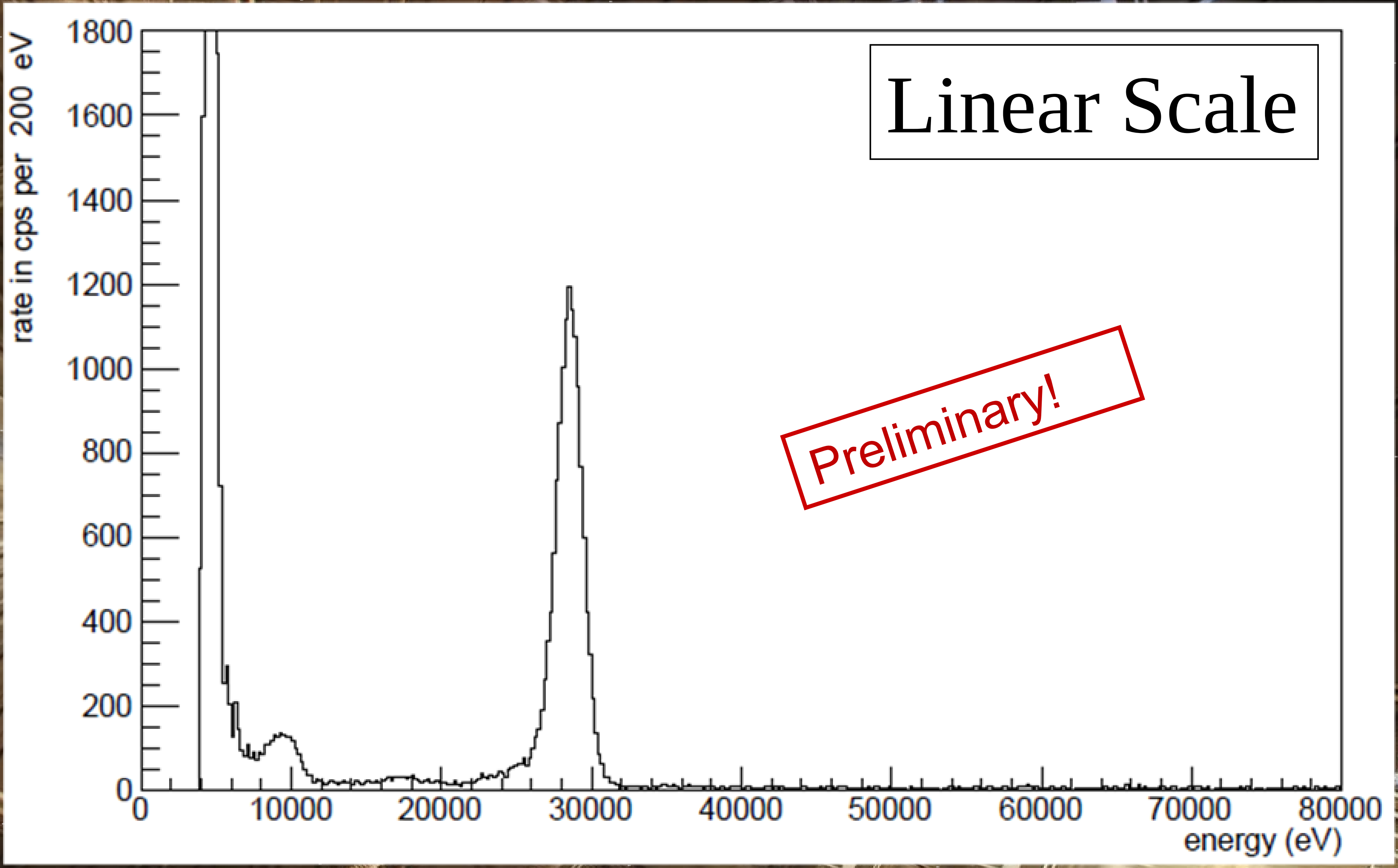
Transmission Function Measurement



Transmission function at U_0 = -200 V, UV-LED with 290nm

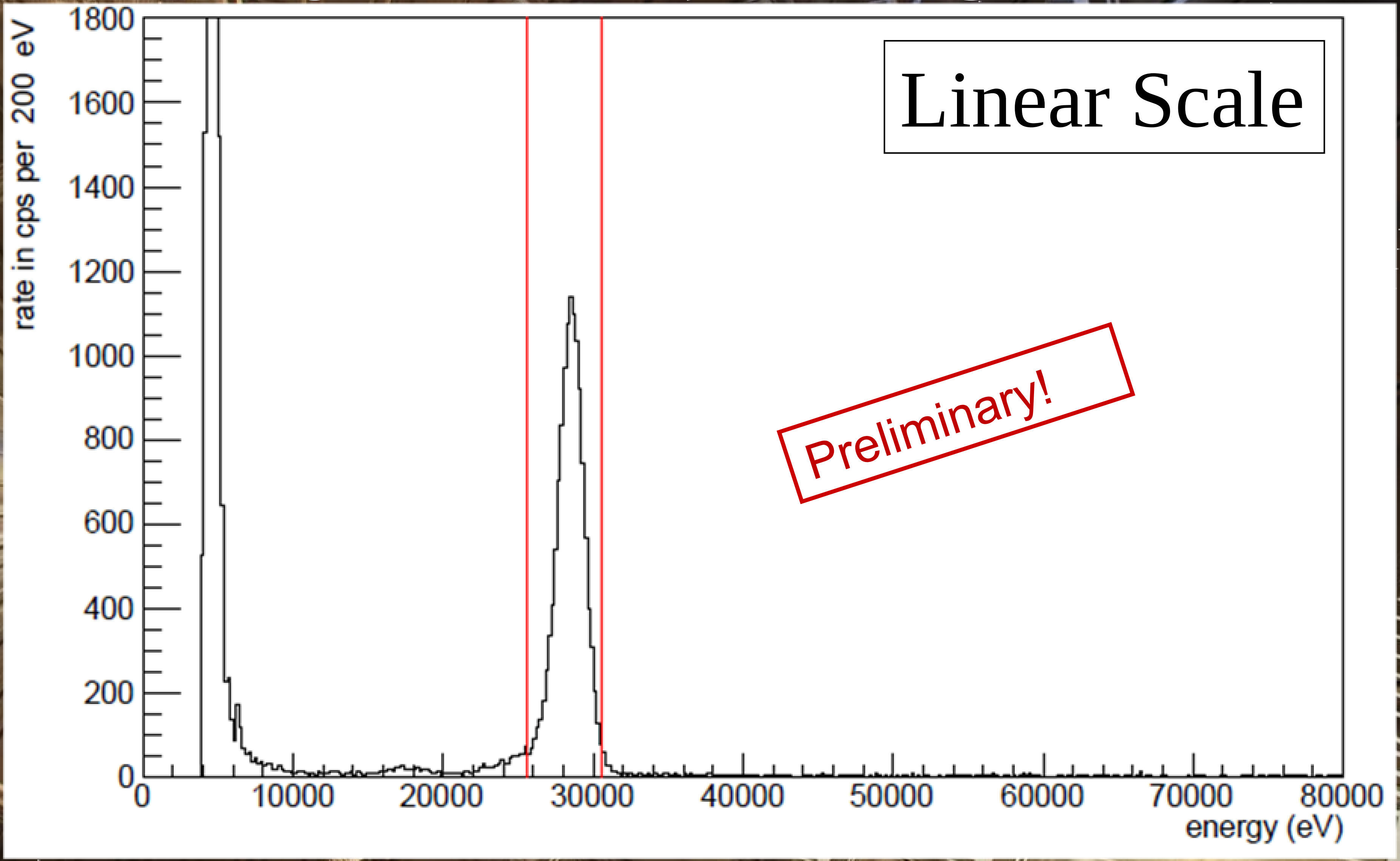
Energy resolution dominated by energy spread of the e-gun ~ 0.09 eV

First Background Measurements @ -18.6 kV



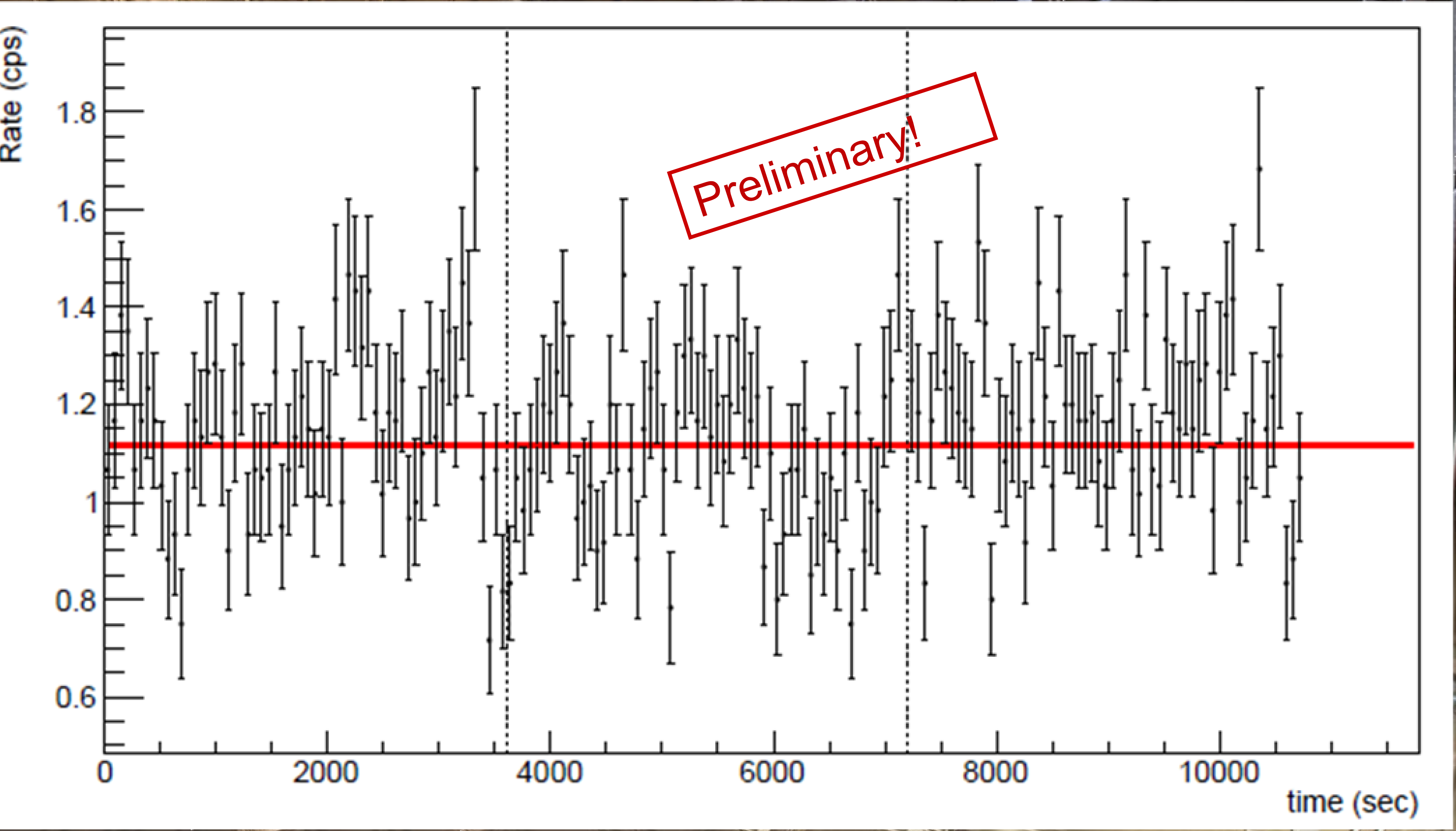
- Vessel and wire electrode on -18.6 kV
- Raw data after Energy Callibration
- Magnetic Fields: B_{max}= 5T, B_{min}= 3.8 G
- Only real time low energy threshold cut

First Background Measurements @ -18.6 kV



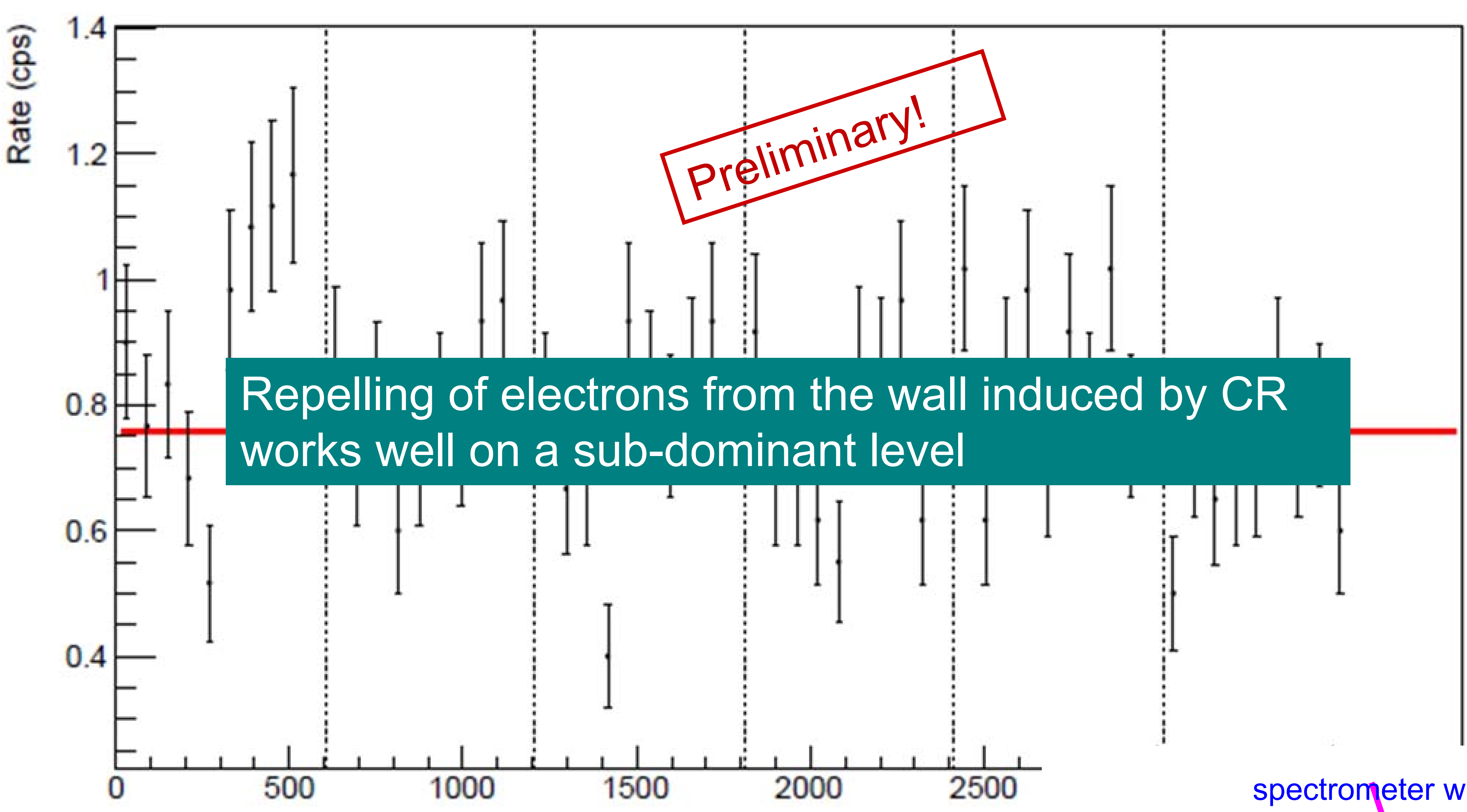
- Data after Cuts (Multipixel, Veto, Energy…)
- Red lines indicate the Region of Interest (ROI) [U_{Vessel}-3kV, U_{vessel}+2kV]

First Background Measurements @ -18.6 kV



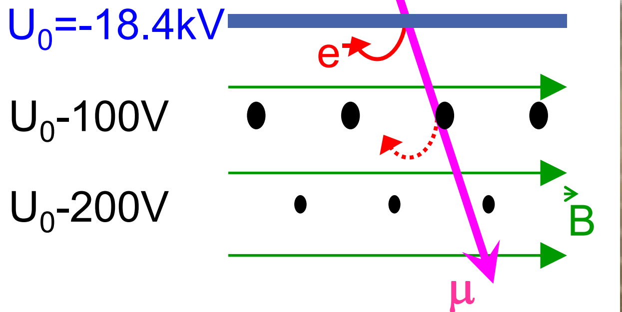
- Rate Trend after Cuts in the ROI
- Rate: 1116 ±10 mcps

First Background Measurements @ -18.6 kV/-18.4 kV



Repelling of electrons from the wall induced by CR works well on a sub-dominant level

- Rate Trend after Cuts in the ROI
- Vessel on -18.4 kV, wire electrode on -18.6 kV
- Rate: 757 ± 15 mcps

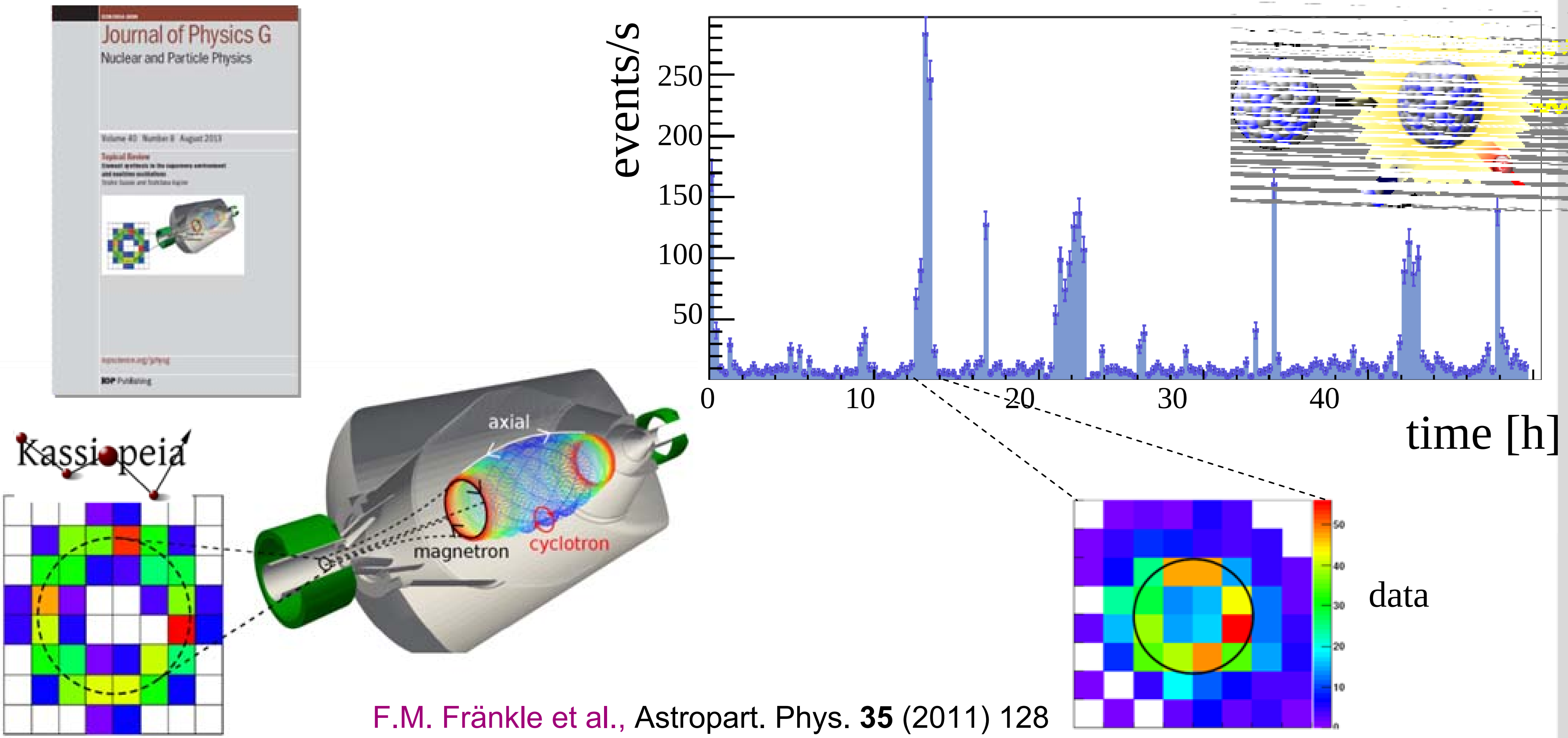


Spectrometer Background

- What do these results mean for KATRIN?

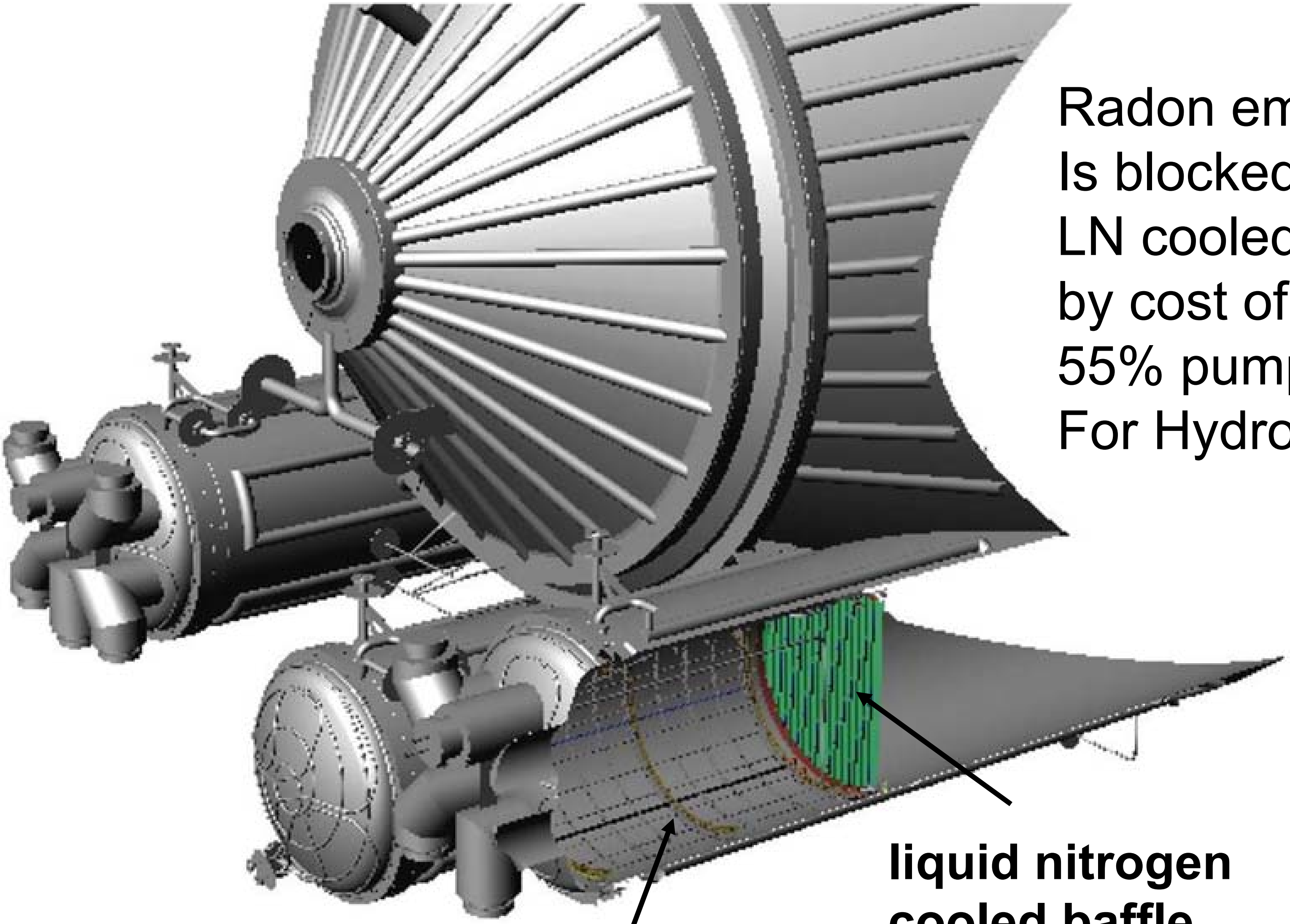
Flashback to 15th Lomonosov Conference

- **pre-spectrometer background investigations**
  - novel bg-source: ^{219,220}Rn produce electrons in the keV-range, which are trapped & generate **enhanced bg-levels for up to several hours**

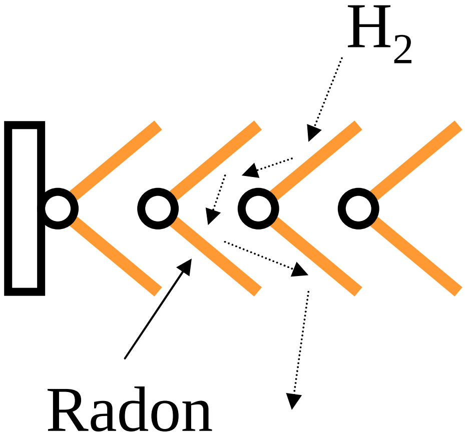


F.M. Fränkle et al., Astropart. Phys. **35** (2011) 128

Solution for the Main Spectrometer



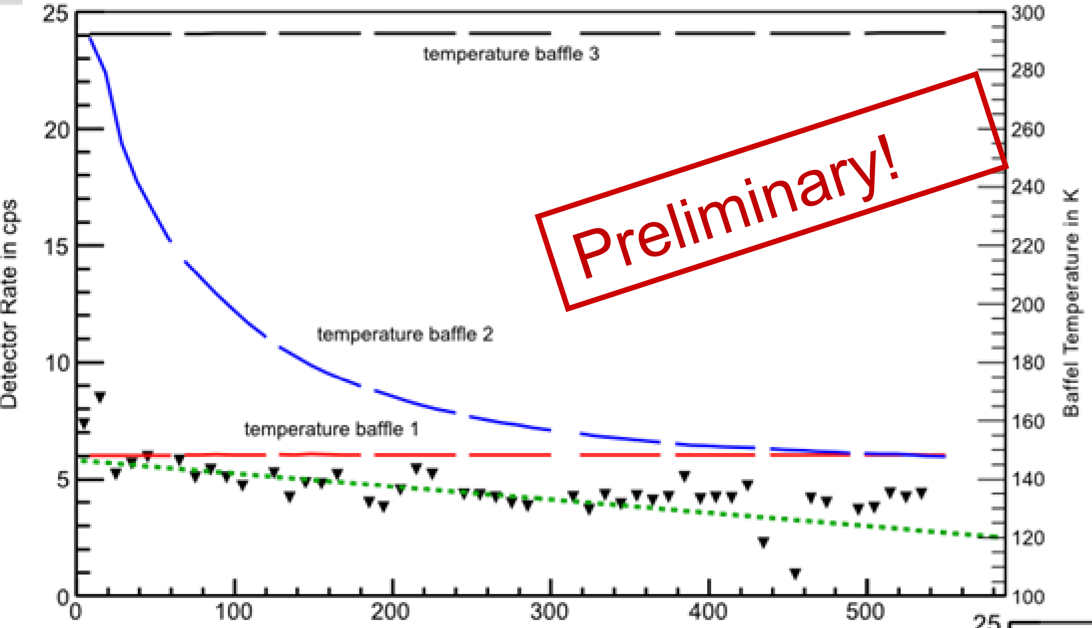
Radon emitting from getter
Is blocked by
LN cooled baffels
by cost of
55% pumping speed
For Hydrogen



NEG-pump
(3 x 1.000 m SAES St707 getter)

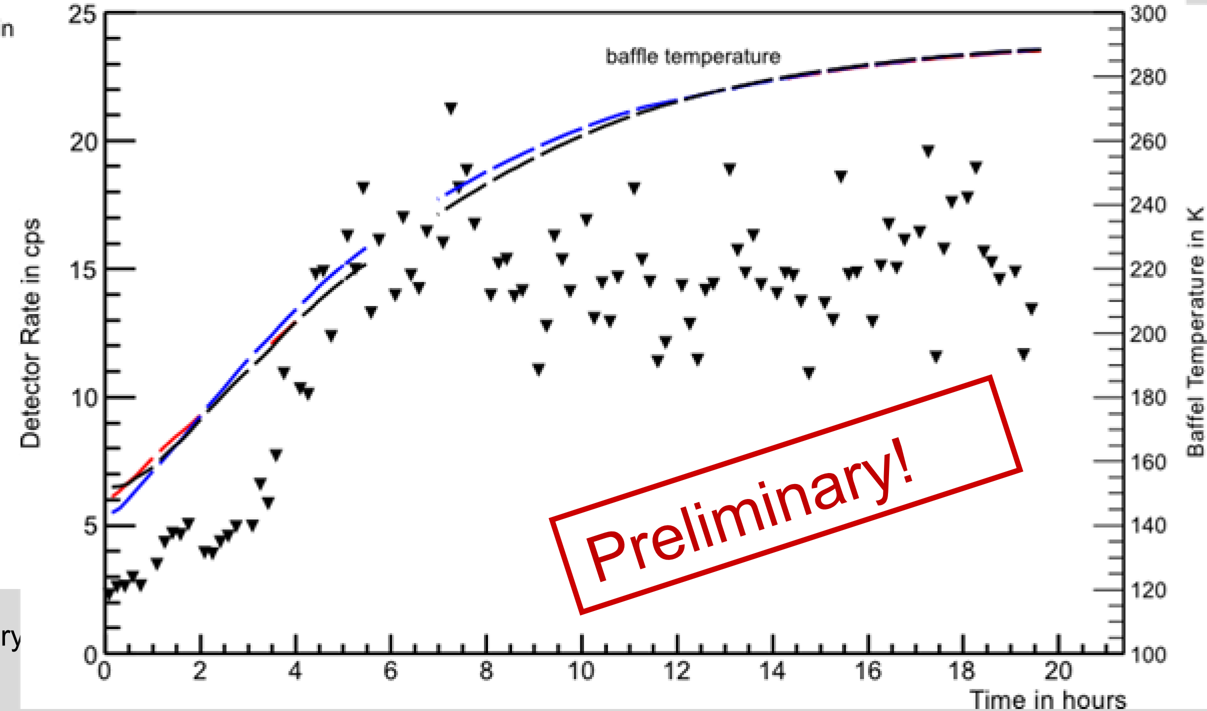
First Baffle Test

Vessel on 0V, electrodes on -600V, B_{max}=5T,



Cool down of Baffle 2,
Baffle 1 cold, Baffle 3 warm,

Warming up of all three Baffles



Background Suppression of a factor of 5
→ Not jet sufficient for KATRIN design sensitivity

Spectrometer Background: Predictions

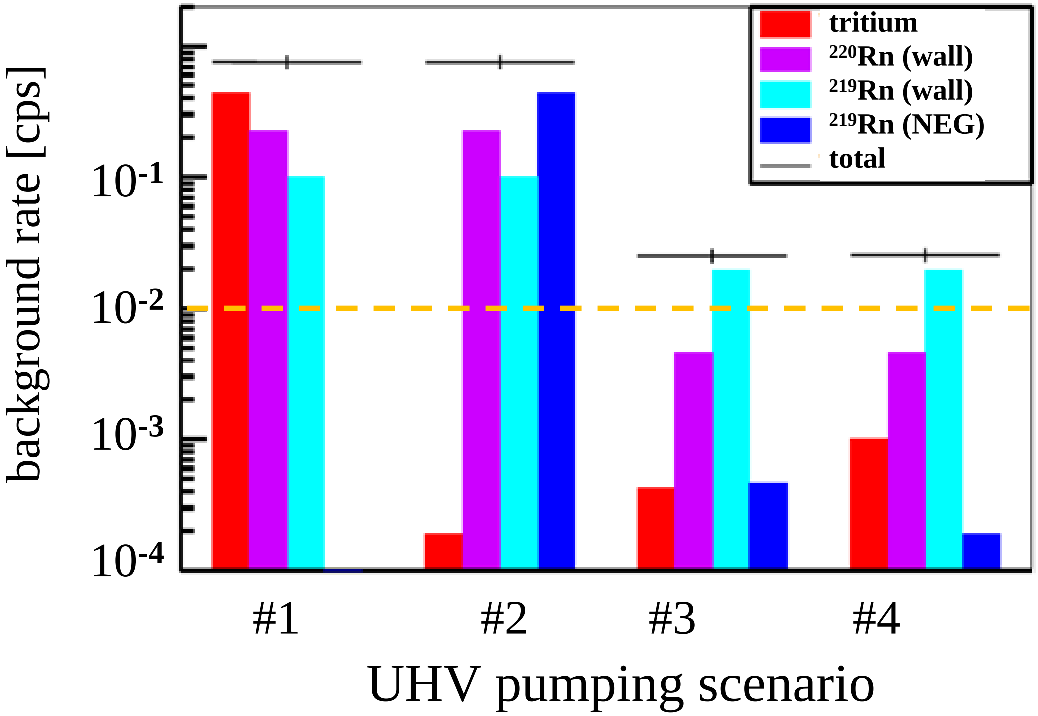
- **Implications for main spectrometer**

WARNING

non-Poissonian nature of Rn-induced background has the potential to limit neutrino mass sensitivity of KATRIN

need novel background reduction techniques

TDR-benchmark: $r_{bg} = 0.01$ cps



S. Mertens et al., Astropart. Phys. 41 (2013) 52

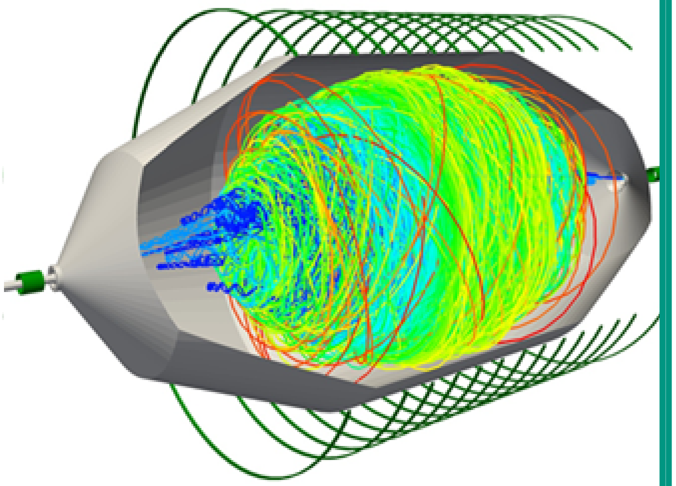
Background reduction techniques

Active methods

- fast removal of stored electrons by breaking of trapping condition

Cyclotron Resonance

- apply RF-field tuned to cyclotron frequency

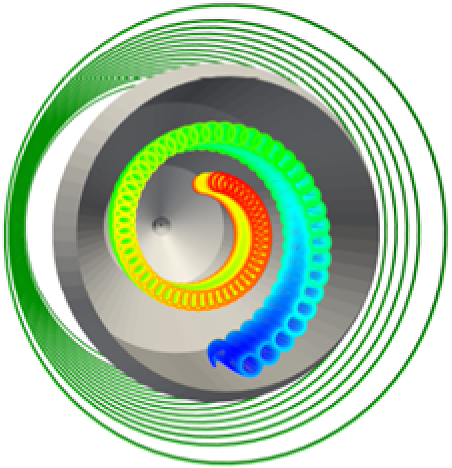


$\omega_{RF} = \omega_{cycl}$

all electron energies

Magnetic Pulse

- zero central B field to induce drift to wall

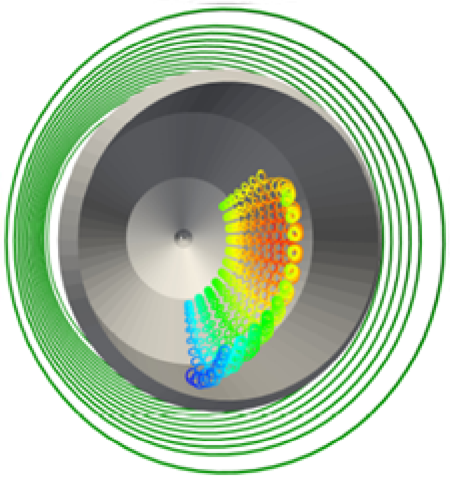


$r = m \cdot v / q \cdot B$

high energies (E > 1 keV)

Electrostatic Dipole

- apply transversal dipole to drift electrons to wall



$\vec{v} = {}^{c}/_{B^2} \cdot \vec{E} \times \vec{B}$

low energies (E < 1 keV)

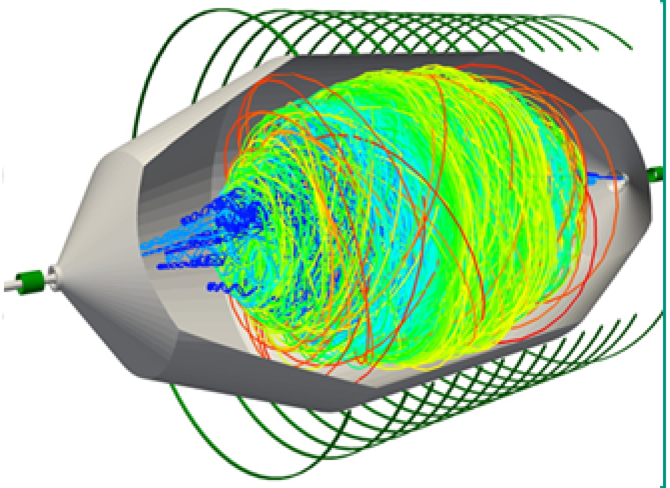
Background reduction techniques

Active methods

- fast removal of stored electrons by breaking of trapping condition

Cylclotron Resonance

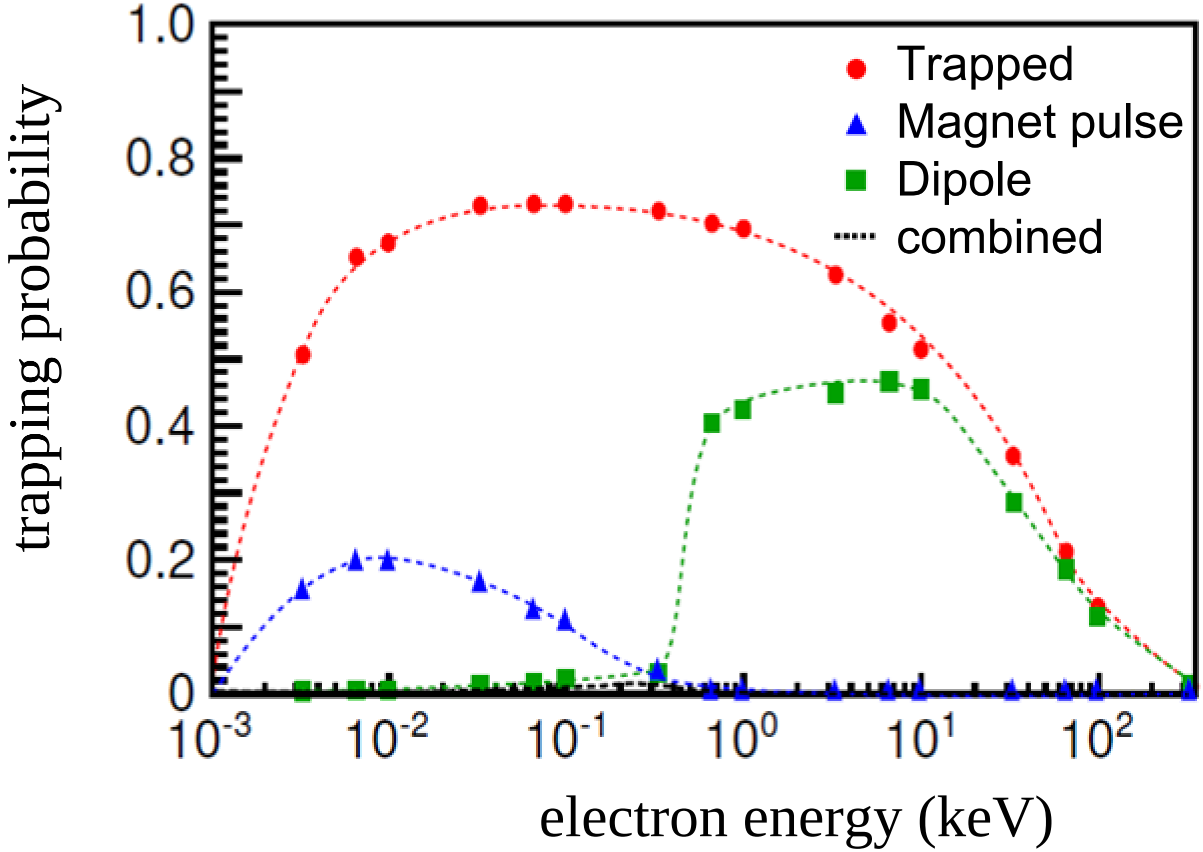
- apply RF-field tuned to cyclotron frequency



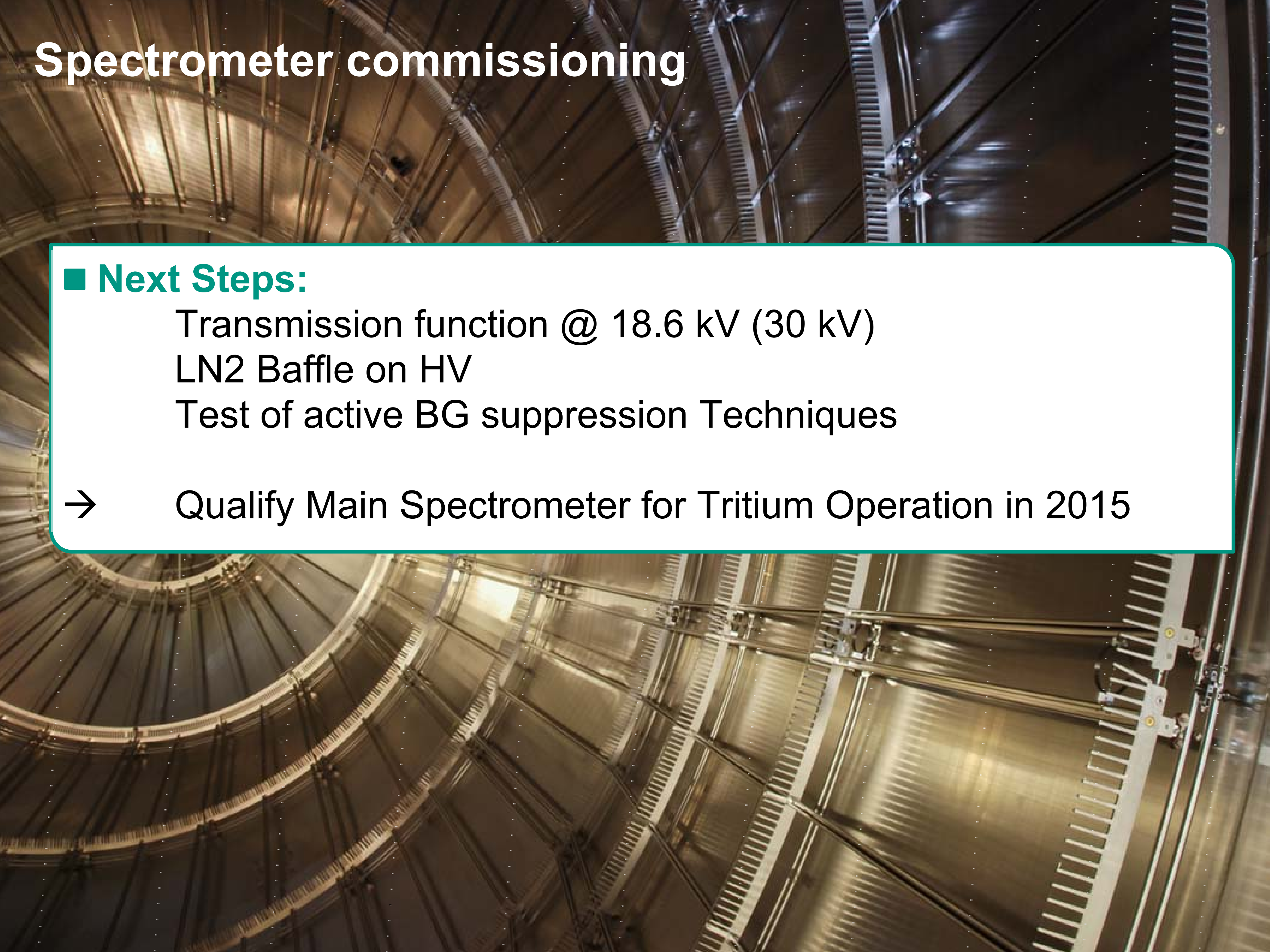
$\omega_{RF} = \omega_{cycl}$

all electron energies

Magnetic Pulse + Electrostatic Dipole



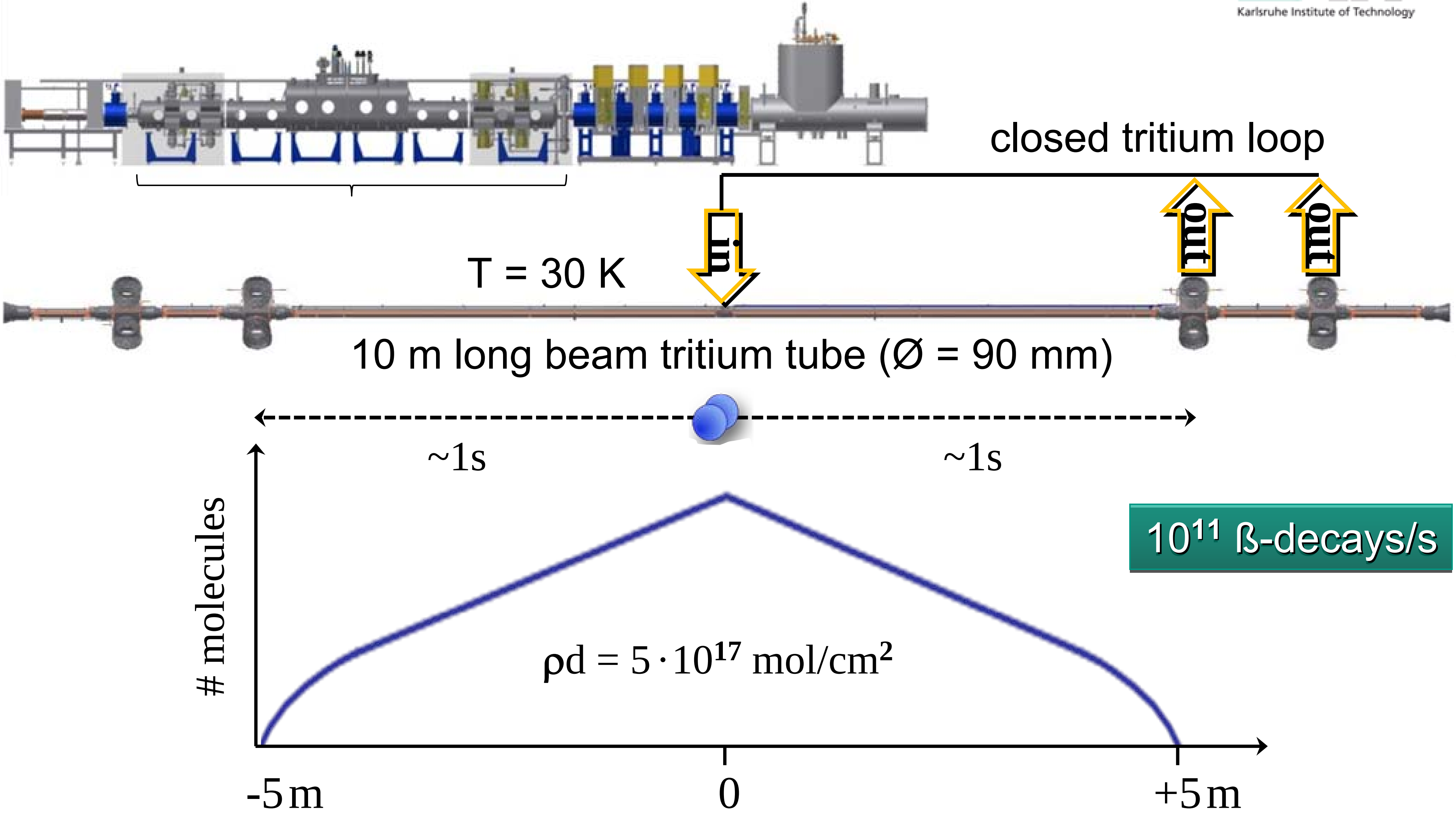
Spectrometer commissioning



- **Next Steps:**
  - Transmission function @ 18.6 kV (30 kV)
  - LN2 Baffle on HV
  - Test of active BG suppression Techniques

→ Qualify Main Spectrometer for Tritium Operation in 2015

STS: WGTS – principle



closed tritium loop

T = 30 K

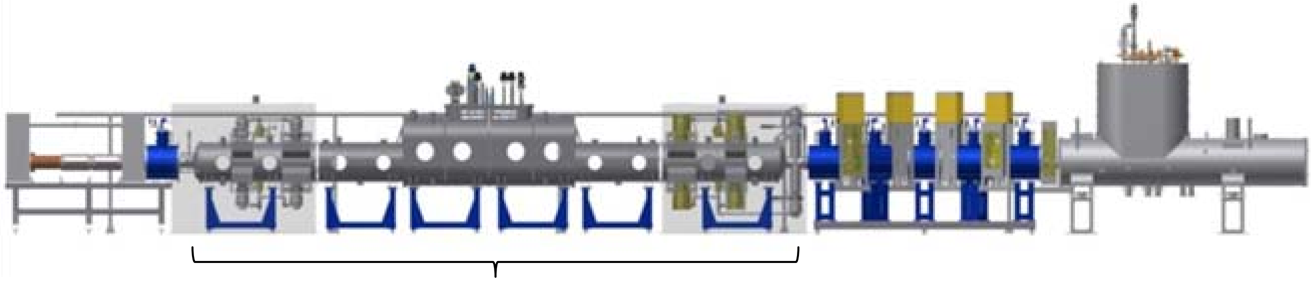
10 m long beam tritium tube (Ø = 90 mm)

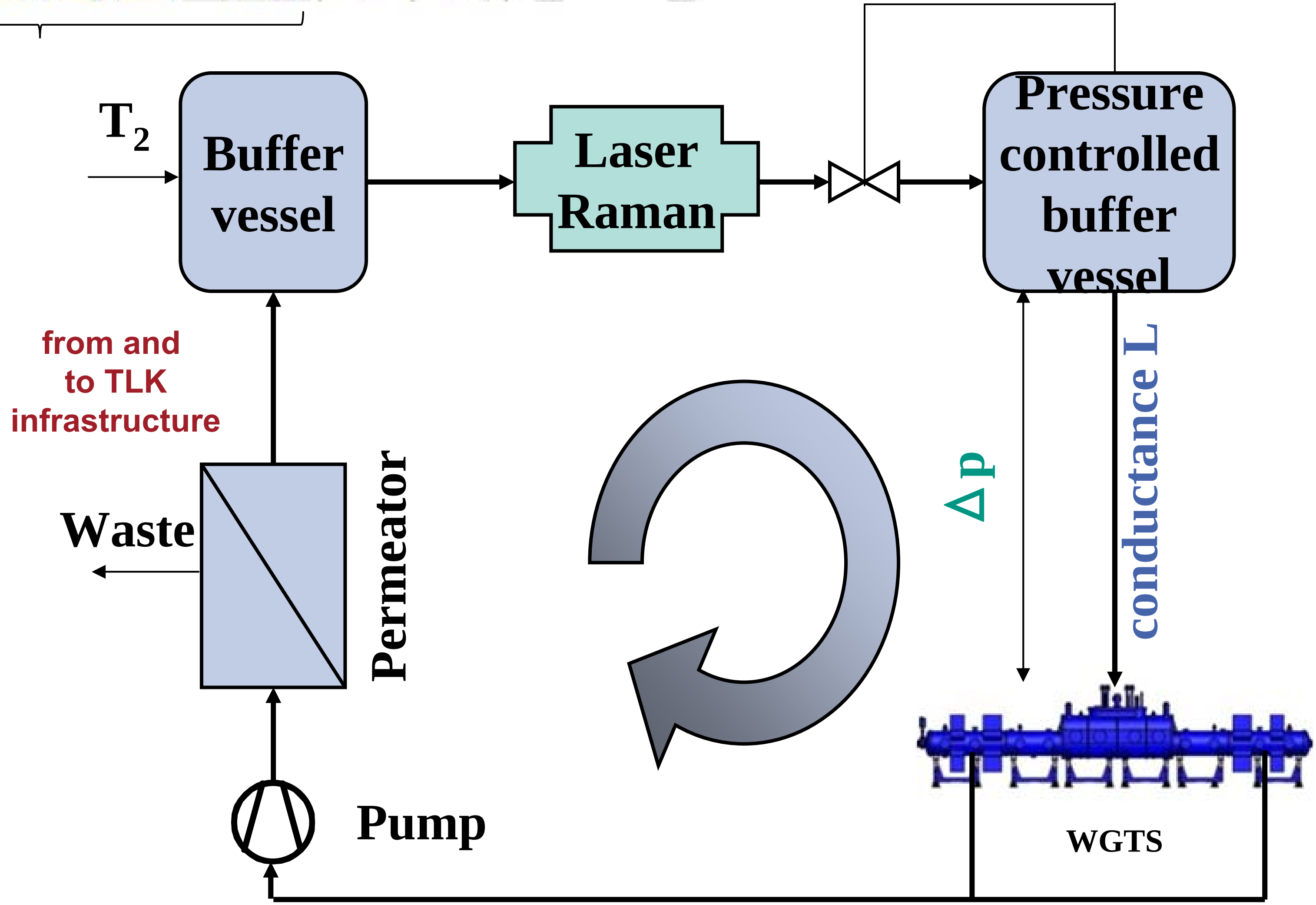
$\rho d = 5 \cdot 10^{17}$ mol/cm²

10^{11} ß-decays/s

Windowless Gaseous Tritium Source

STS: WGTS – principle:





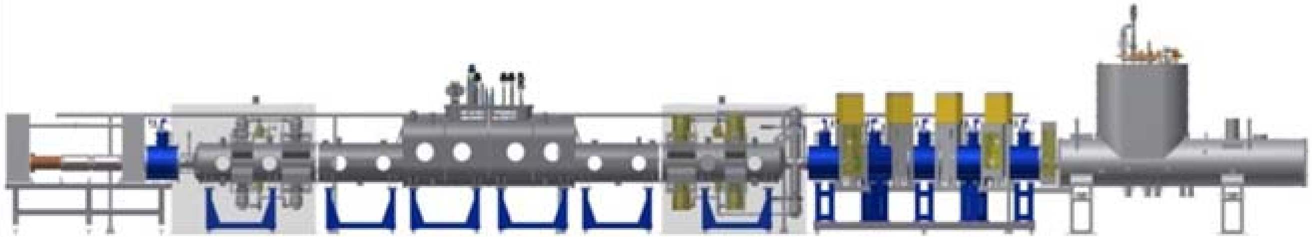
Inner loop:

stable (±0.1%) tritium injection

Outer loop:

high (>95%) and stable (±0.1%) tritium purity

Status Source and Transport Section:

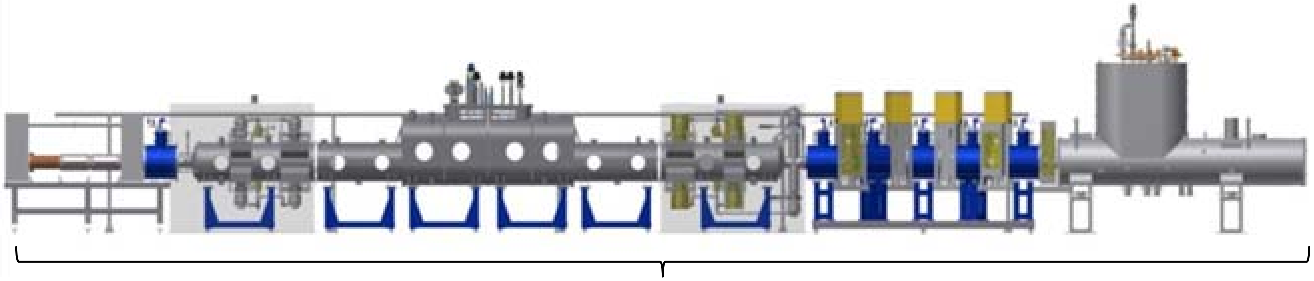


experimental challenges

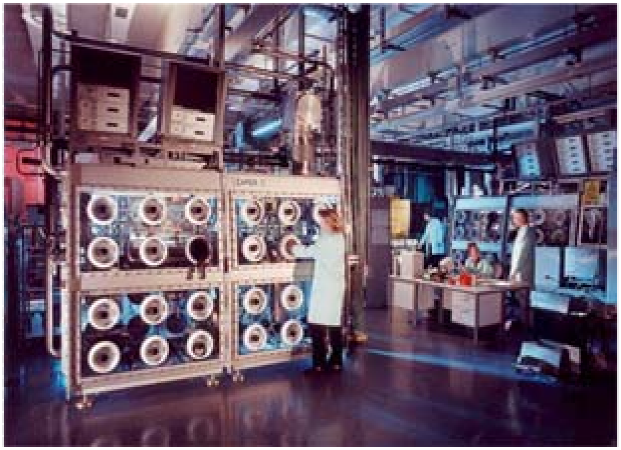
- ↳ 10^{-3} stability of tritium source column density
- ↳ 10^{-3} isotope content in source
- ↳ 10^{-5} non-adiabaticity in electron transport
- ↳ 10^{-6} monitoring of HV-fluctuations
- ↳ 10^{-8} remaining ions after source
- ↳ 10^{-14} remaining flux of molecular tritium

many benchmark parameters reached or exceeded

Tritium Laboratory Karlsruhe – TLK



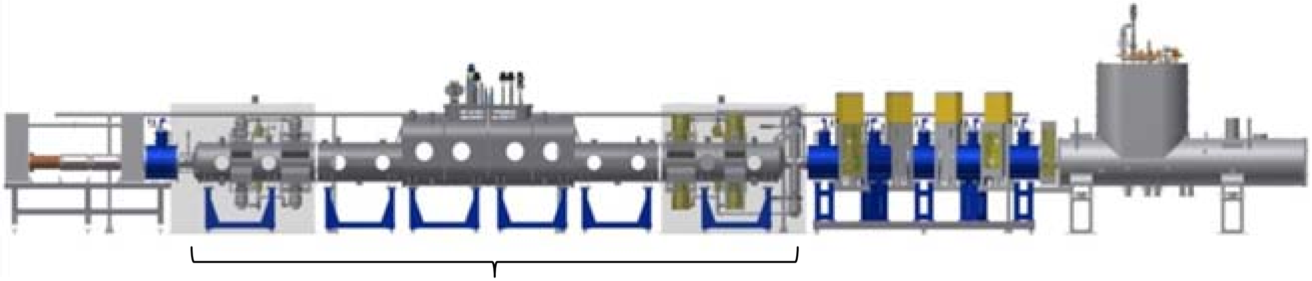
tritium bearing components

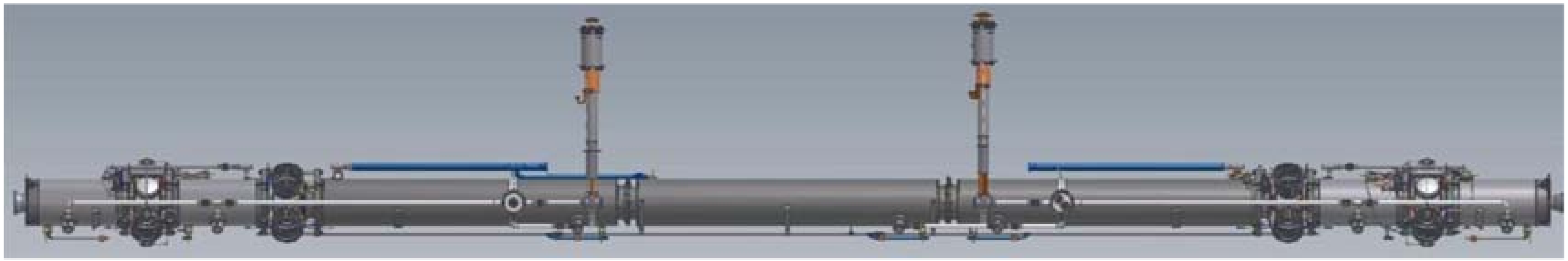


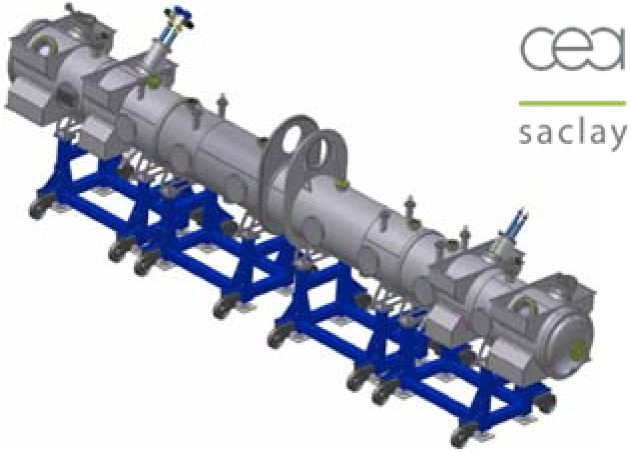
- **TLK**: unique large research facility at KIT for KATRIN and fusion (ITER)
  20 years of experience in tritium handling and processing, 24 g on-site

B. Bornschein et al., **Fusion Sci. Techn. 60 (2011) 1088**

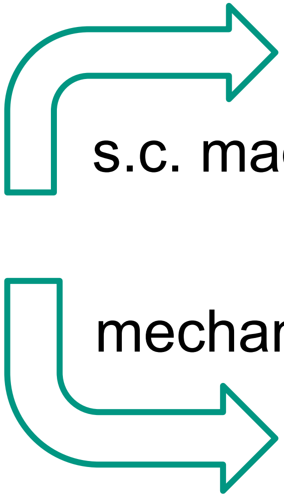
Status of WGTS





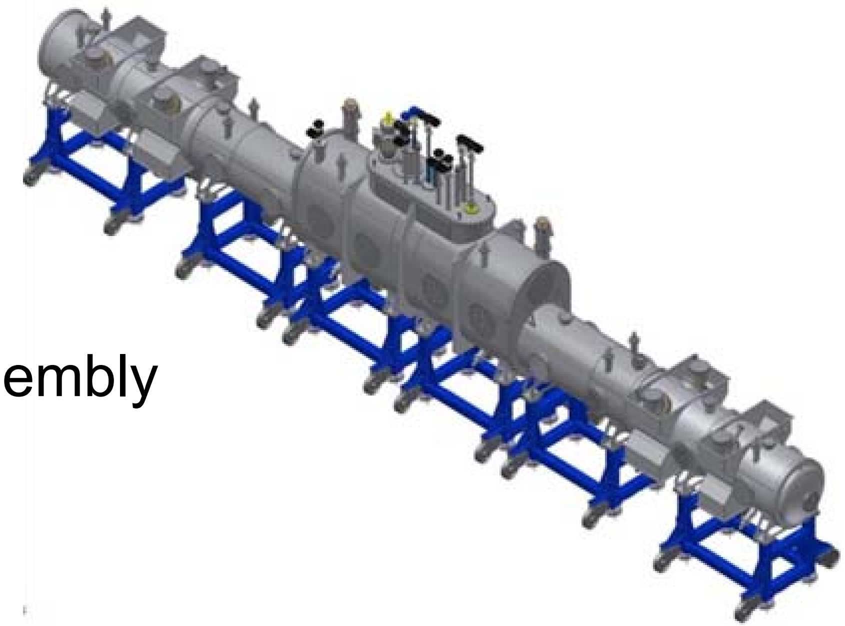


irfu
cea
saclay

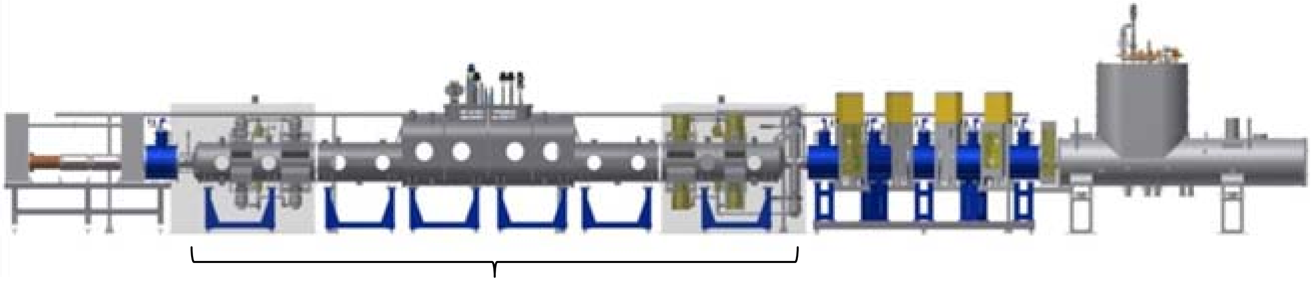


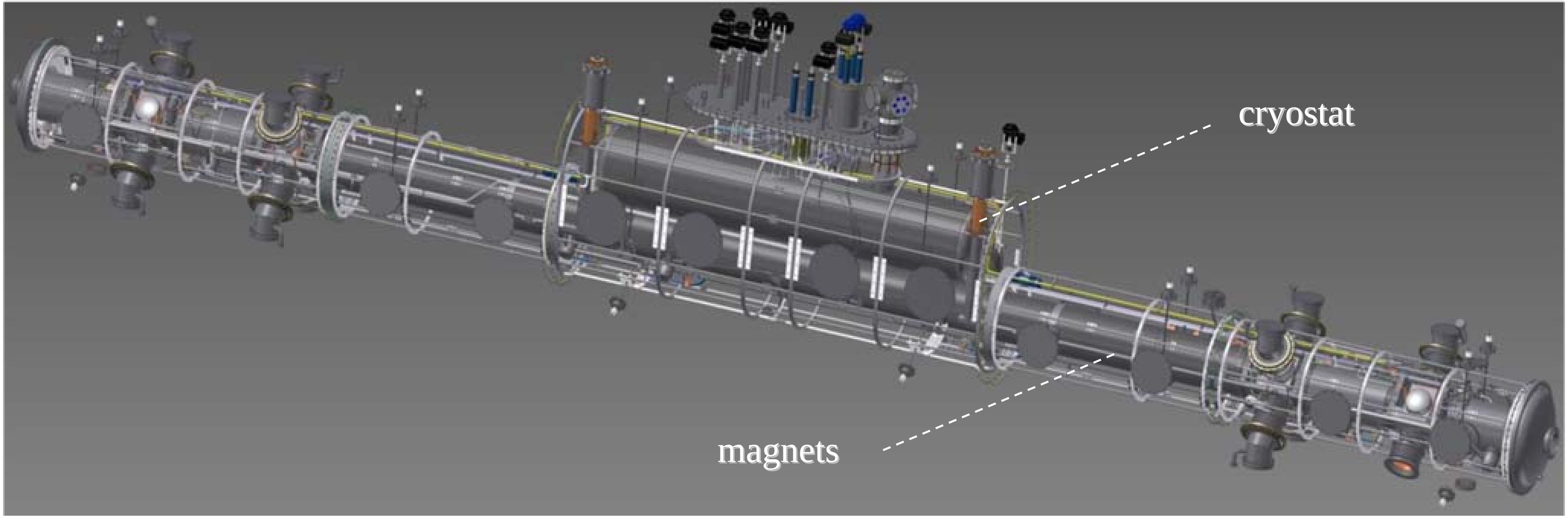
s.c. magnets

mechanical assembly



Status of WGTS

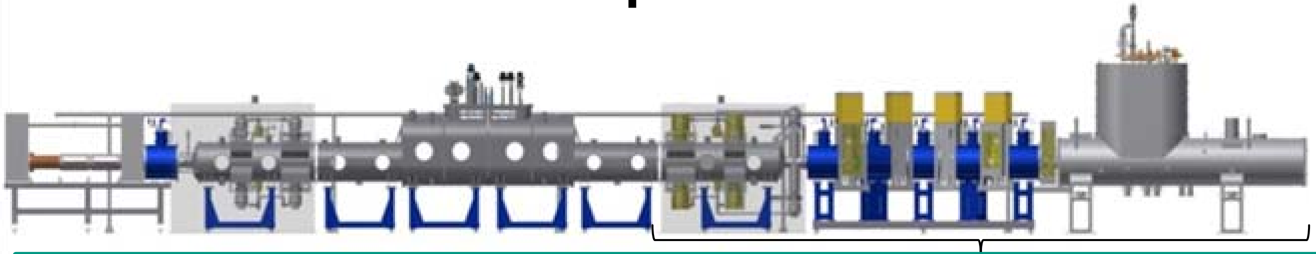




Present works:

- finalising of assembly procedure steps
- start mounting of WGTS after summer break, aim: finish cryostat in Q1/2015

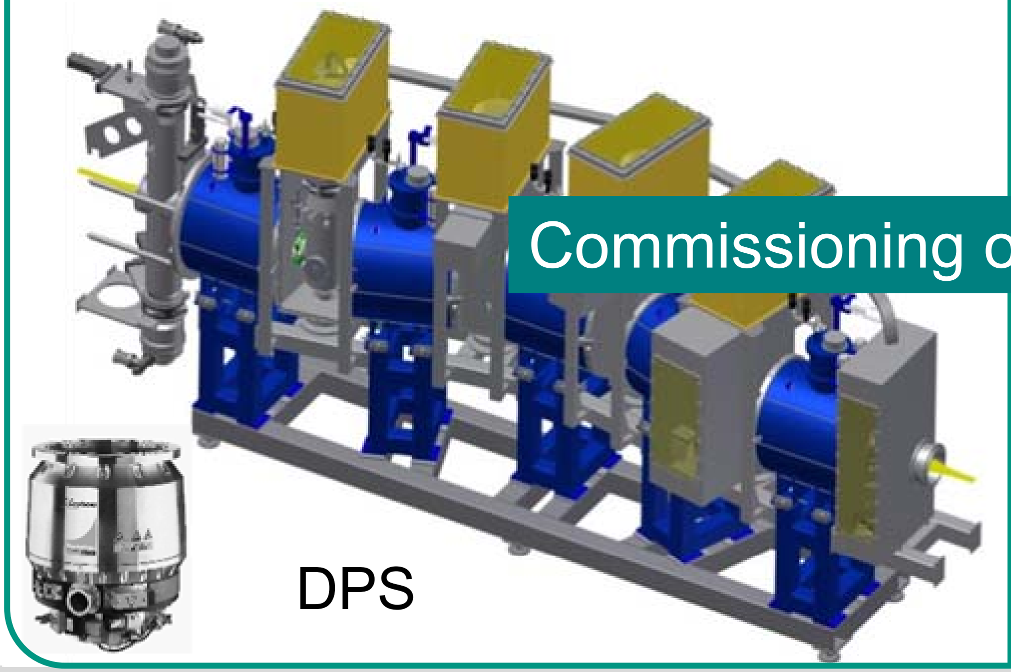
Status of Transport Section



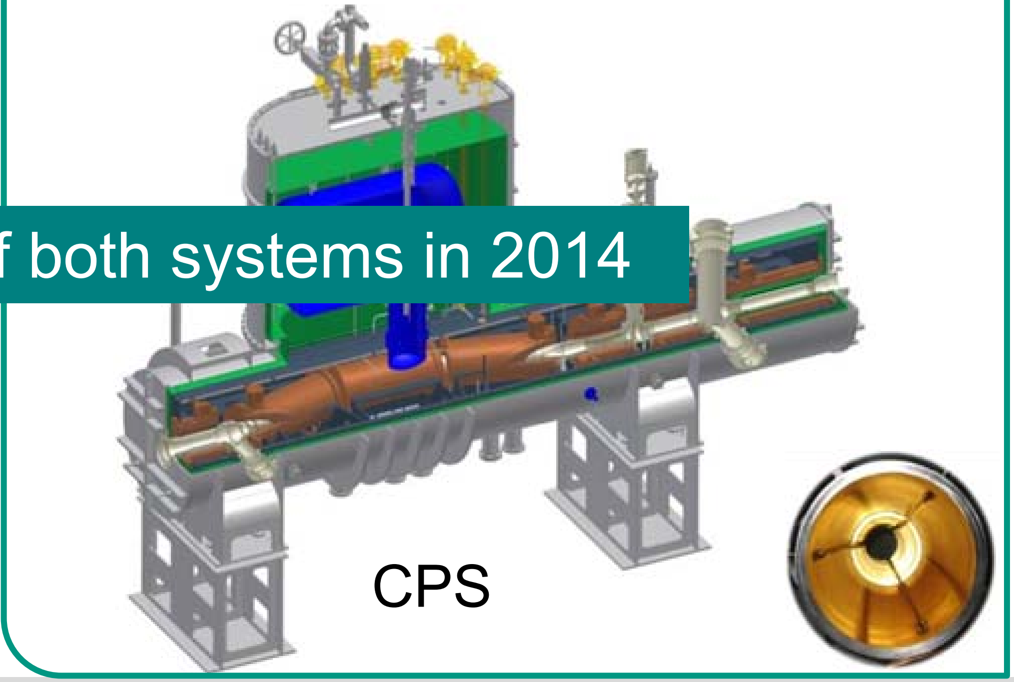
Tasks:

- Adiabatic guiding of electrons to the spectrometers
- Reduction of tritium flow rate by > 10^{14}

- **differential pumping section DPS**
  active pumping by TMPs



- **cryogenic pumping section CPS**
  cryosorption on Ar-frost



Commissioning of both systems in 2014

Summary

- Measurements with the KATRIN Spectrometer Detector System have started
- Spectrometer works as MAC-E-Filter
- Preliminary results of BG measurements confirm the predictions of simulations
- BG still to high for tritium measurements
  → use LN2-cold Baffle to freeze out Rn and apply active counter measures

KATRIN member institutes

Summary

- Building of Source and Transport Components (WGTS Cryostat, CPS, DPS, Rear System) is proceeding
- Many benchmark parameters reached or exeeded
- Commissioning of Transport Section in 2014
- Finish WGTS Cryostat Beginning of 2015

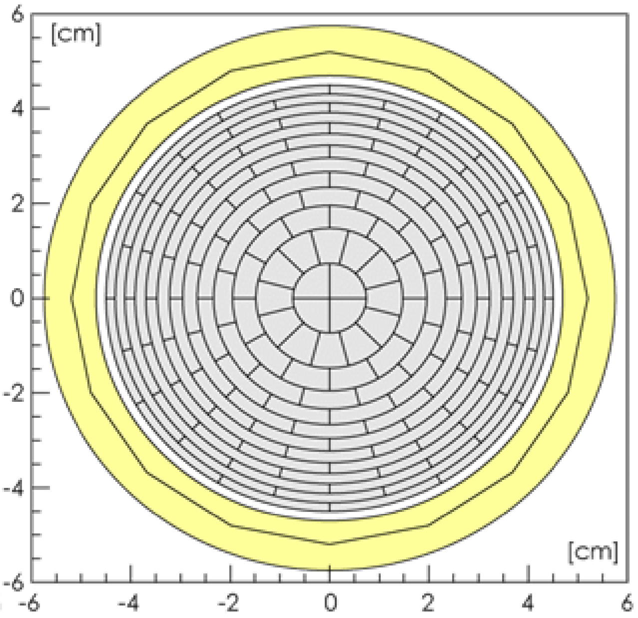
Thanks for your attention!

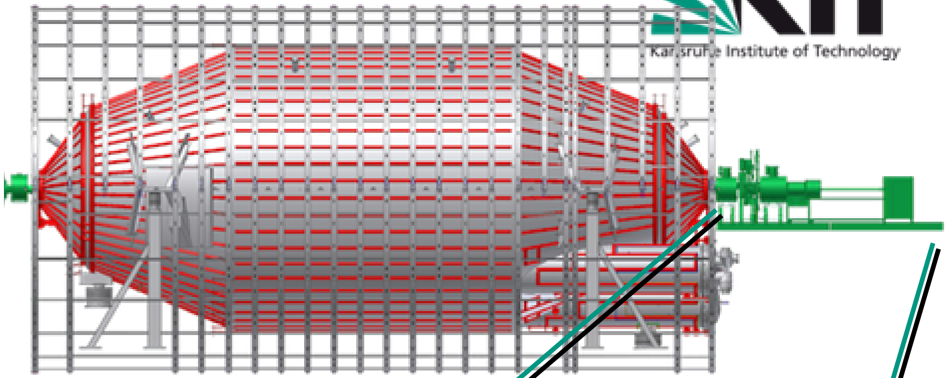
- **KATRIN member institutes**

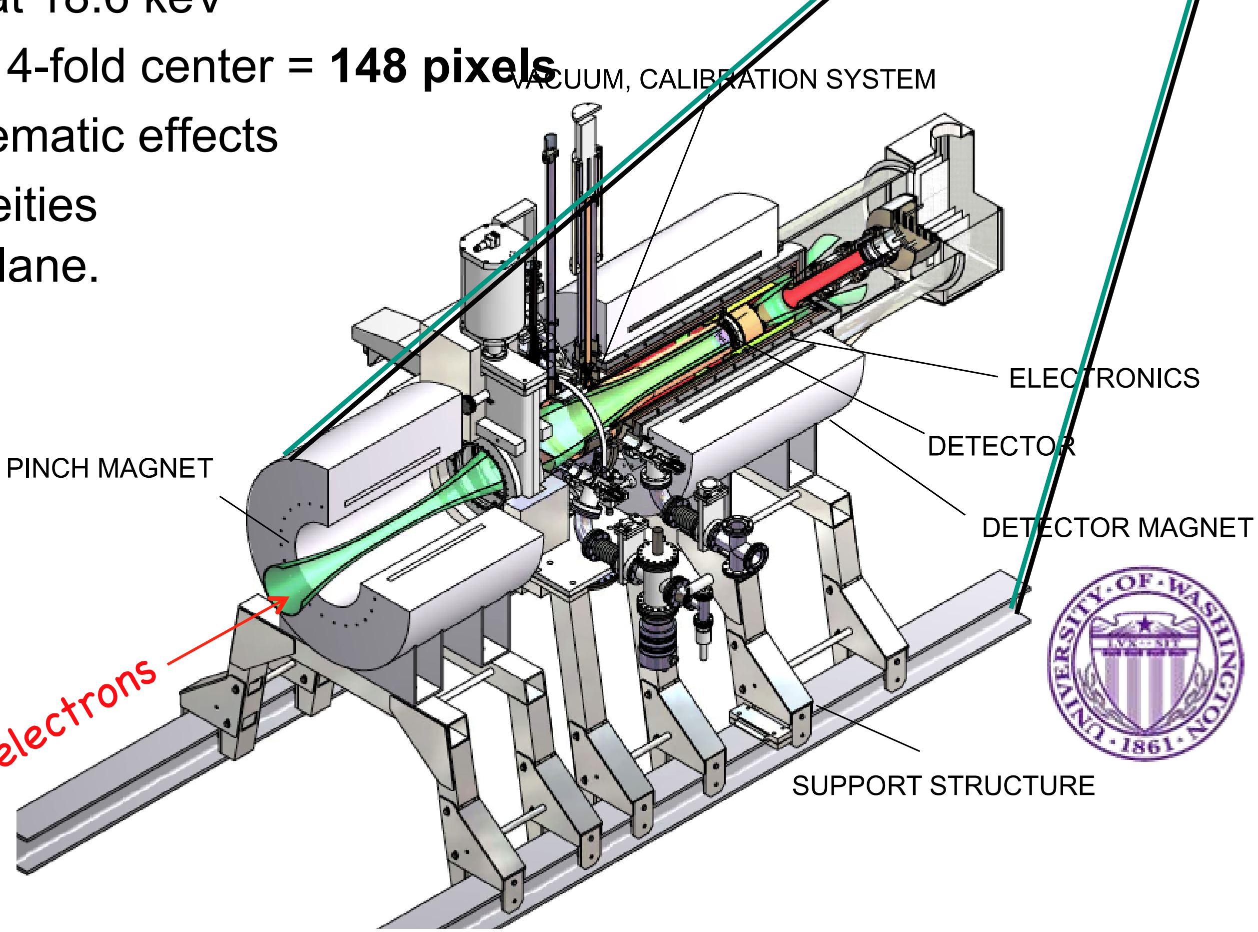
- Back up slides

KATRIN Main Detector

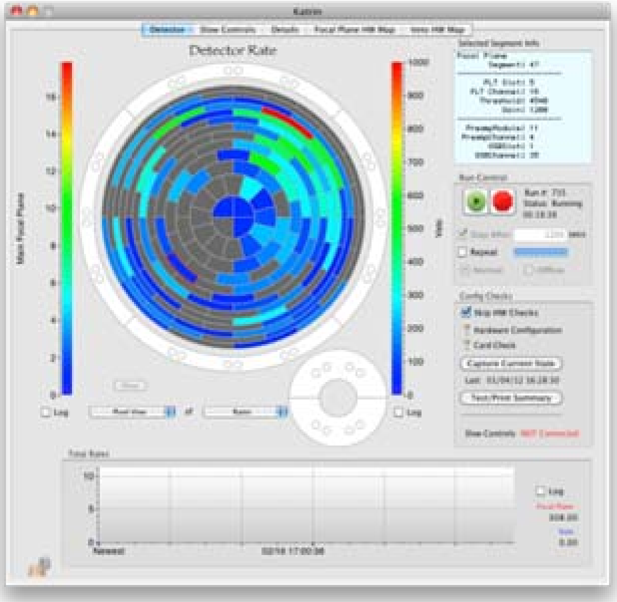
- Si-PIN diode
- detection of transmitted β's (mHz to kHz)
- **low background for T_2 endpoint investigation**
- high energy resolution:
  ΔE = 1.48(1) keV (FWHM) at 18.6 keV
- 12 rings with 30° segmentation + 4-fold center = **148 pixels**
  - minimize bg, investigate systematic effects
  - compensate field inhomogeneities of spectrometer's analyzing plane.

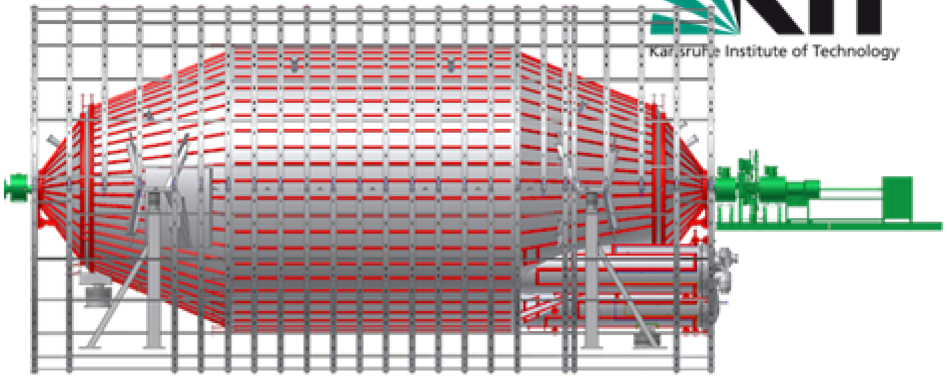


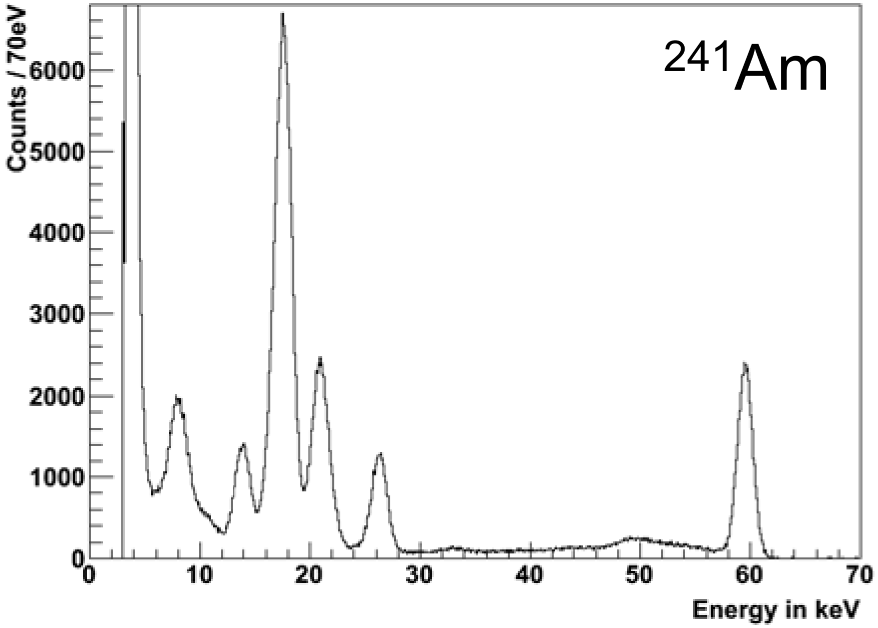




KATRIN Main Detector



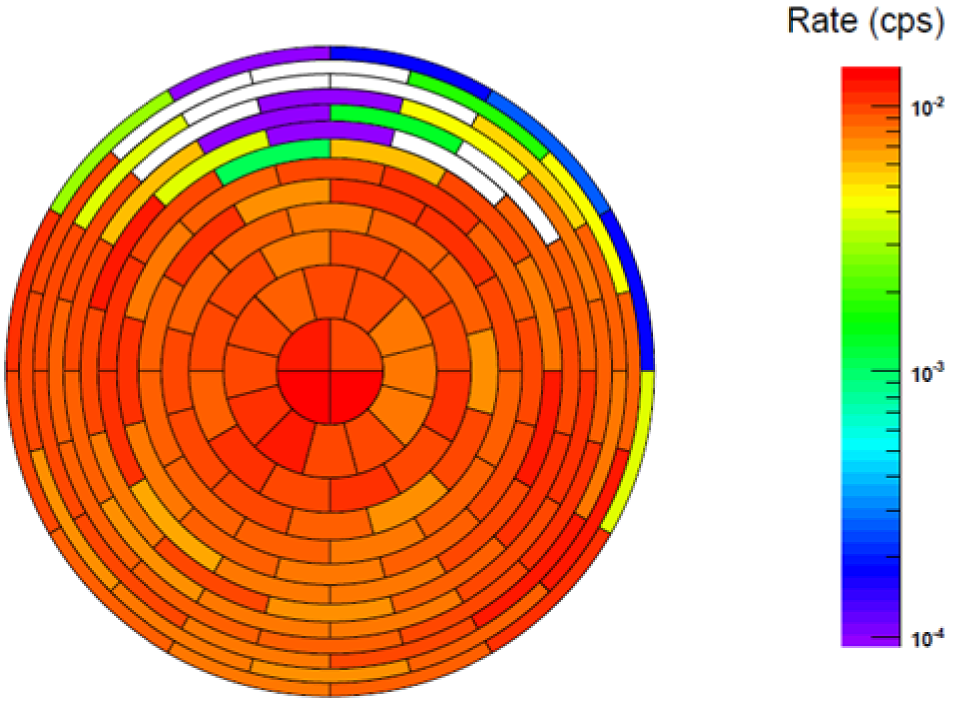


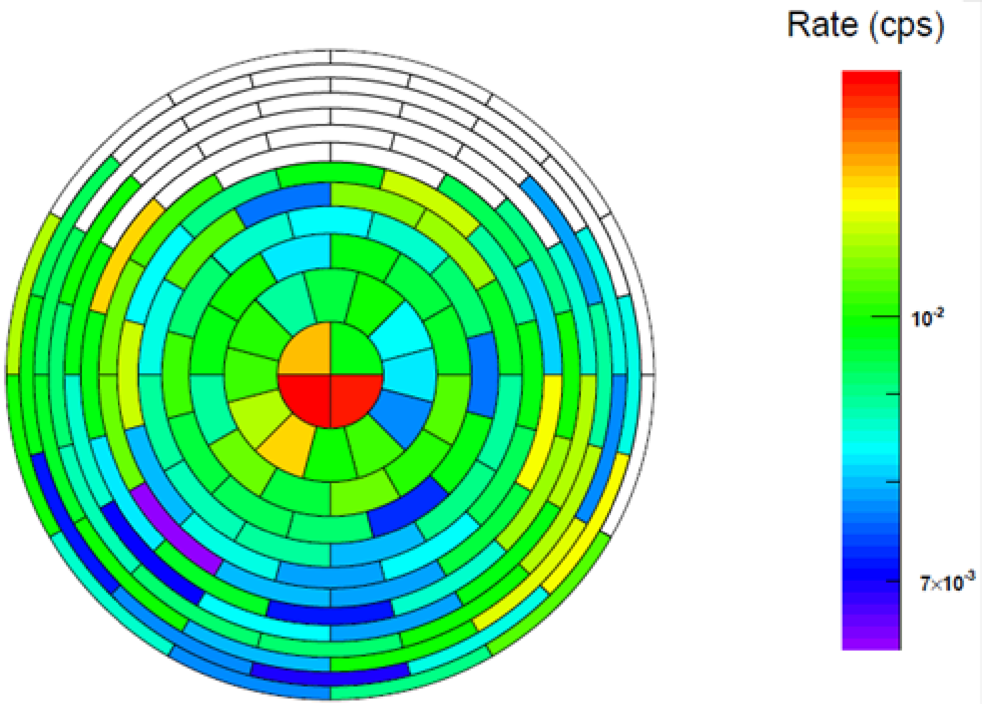


- detector commissioning completed
- first light from spectrometer – May 2013

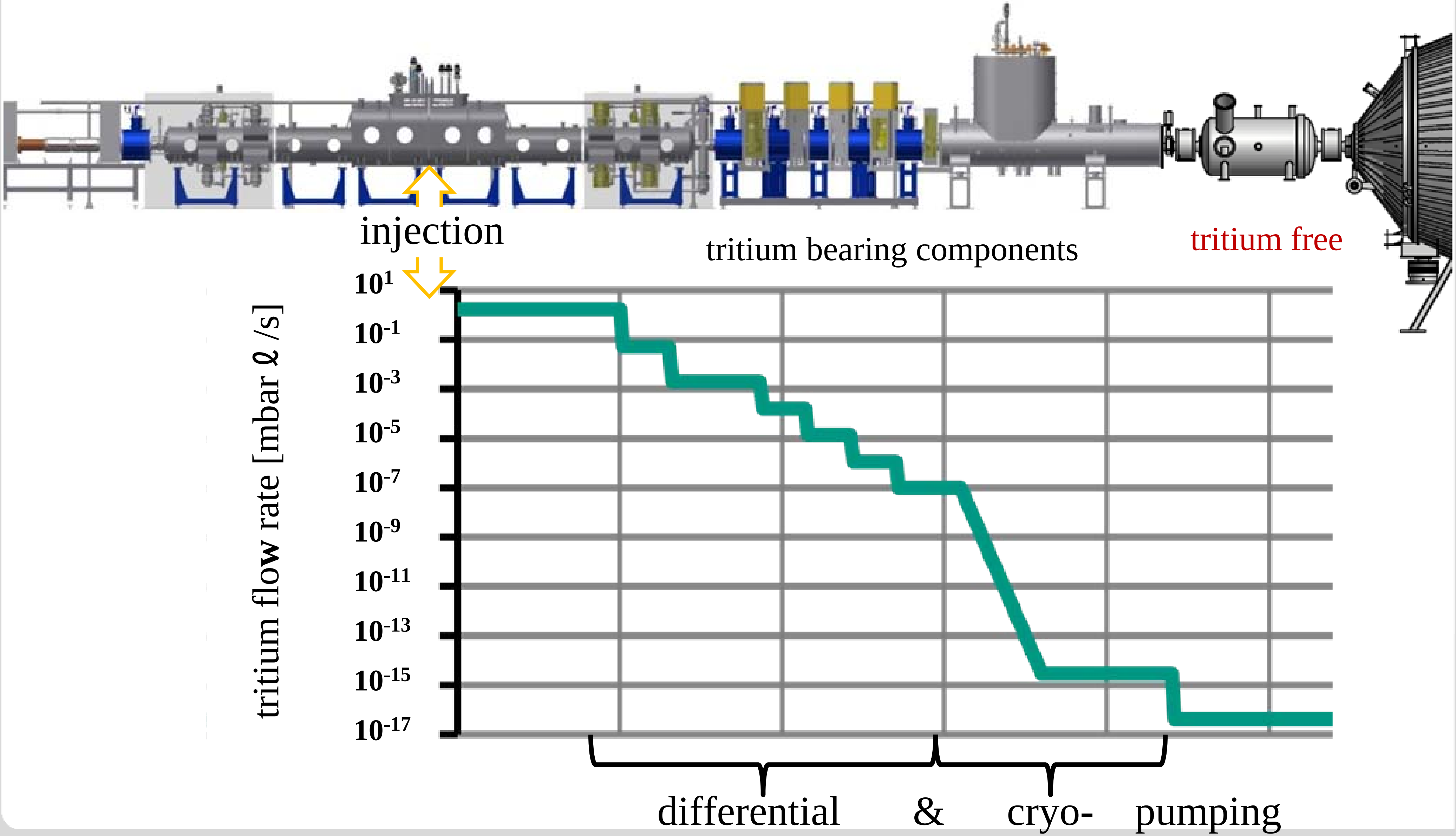
Pixelviews

- Multipixel cut applied. I.e. events with a time difference below 1us on FPD are assumed to be induced by charge sharing on the wafer between neighbored pixel. In background measurements this cut should not affect the ‚good events' due to the high interarrival times at a rate of ~1cps.
- Veto cut applied. I.e. events on the FPD which are in a coincidence frame of (-1us,+1us) with events of the detector veto are excluded. Small impact!
- Measurement with vessel and inner electrodes at 18.6 kV.
- energy ROI (U_Vessel-3keV, U_Vessel+2keV).
- **Left:** All pixels included.
- **Right:** Cut on all pixels which see the flapper valve (flappercut) or the detector vacuum chamber (detectorcut) due to the misalignment of the FPD system.



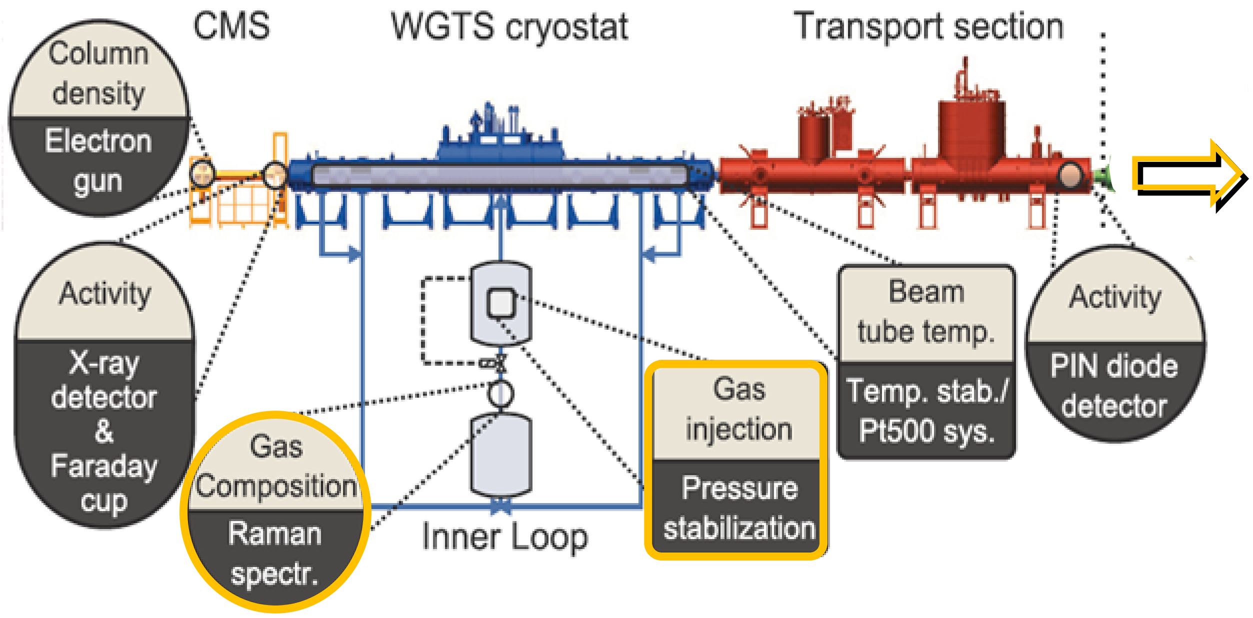


tritium retention techniques

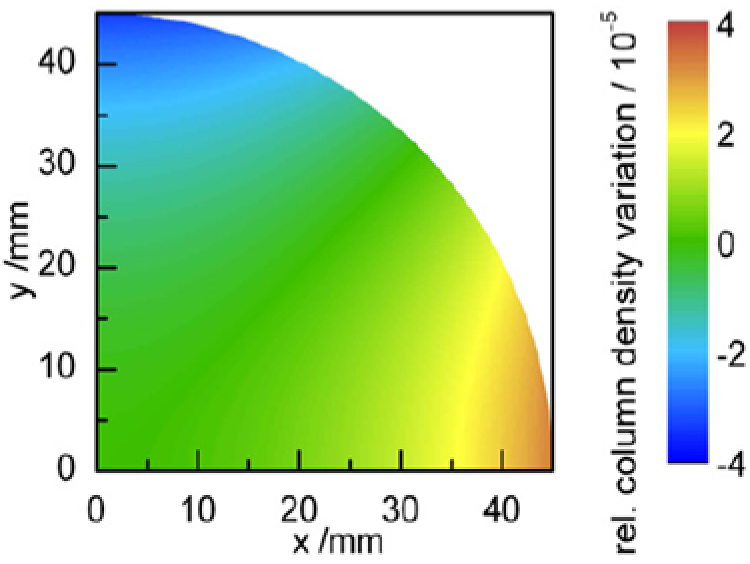


Investigation of source systematics

- **control of source systematics:**
  - near-time control/monitoring systems for key parameters ☑
  - successful large-scale test experiments (WGTS demonstrator) ☑
    - improved source modelling: quasi-3D gas flow ☑

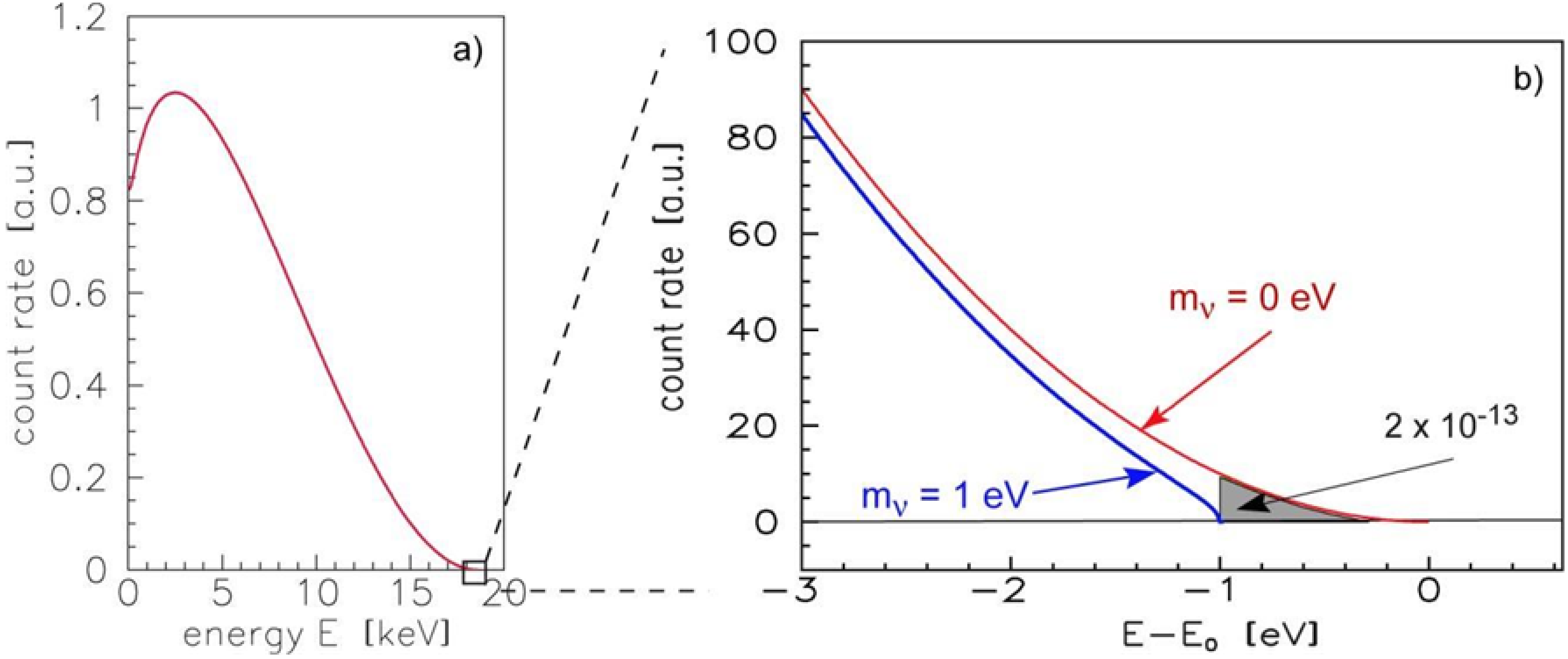


column density profile



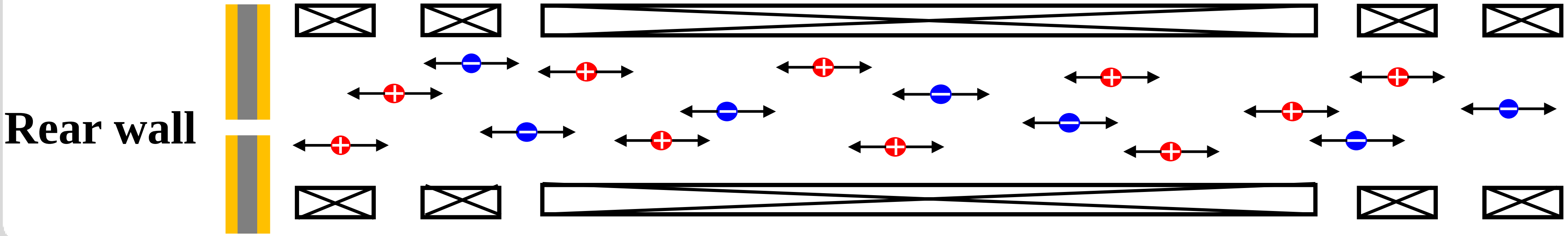
M. Babutzka et al., New Journal of Physics 14 (2012) 103046

Activity monitoring of the WGTS

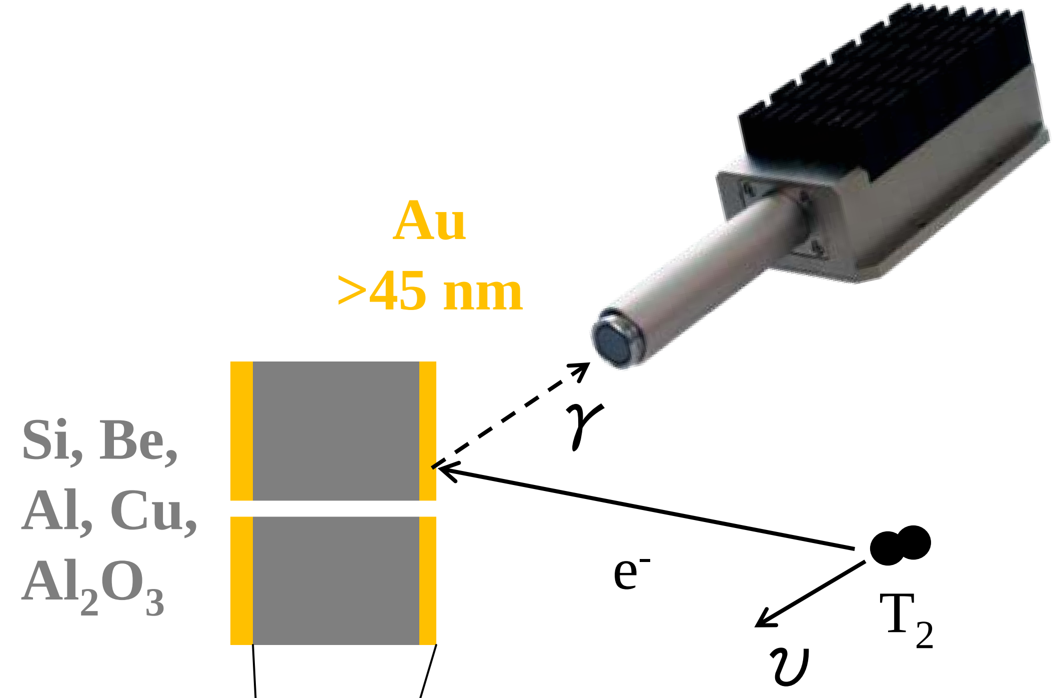


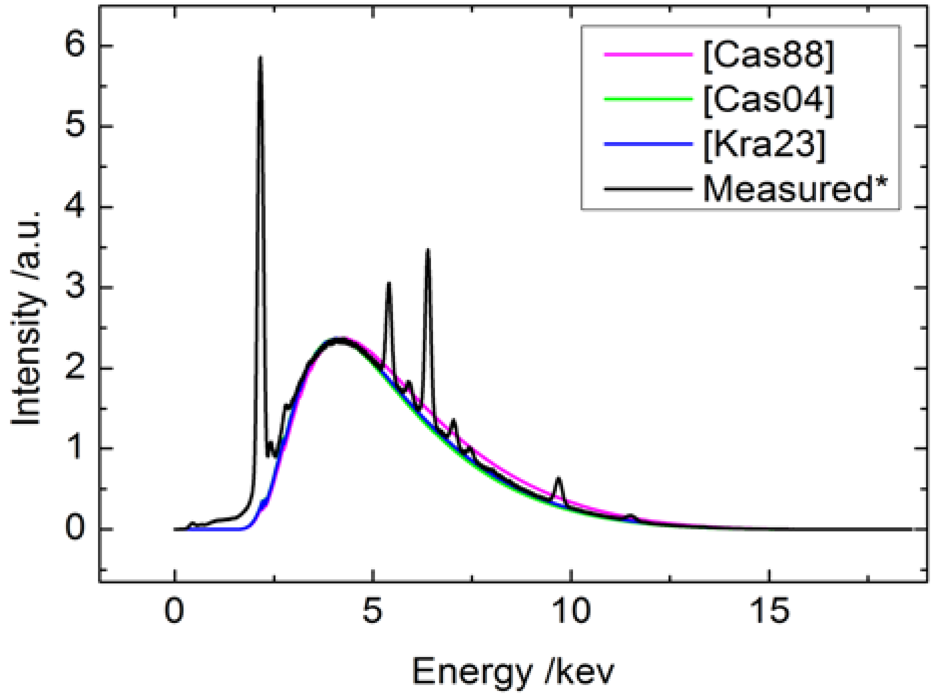
WGTS strength = $\mathbf{A_Q} \cdot \rho d \cdot \varepsilon_T$

Required stability ≤10^{-3}
t_{meas} ≤ 1000 s



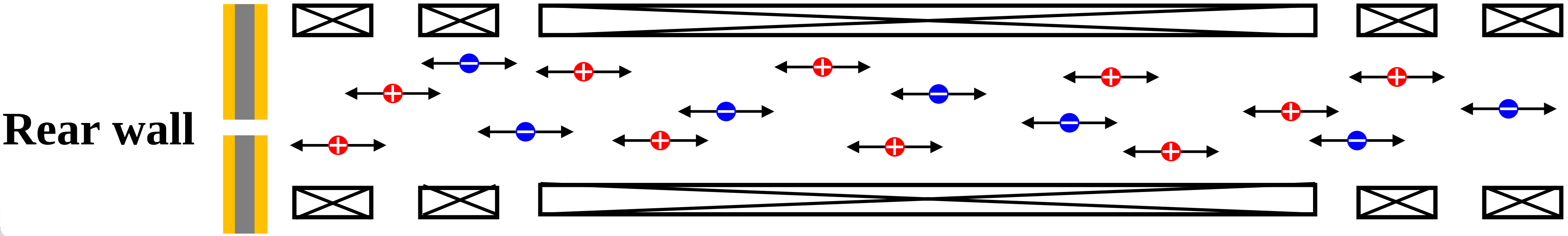
Beta Induced X-ray Spectrometry (BIXS)



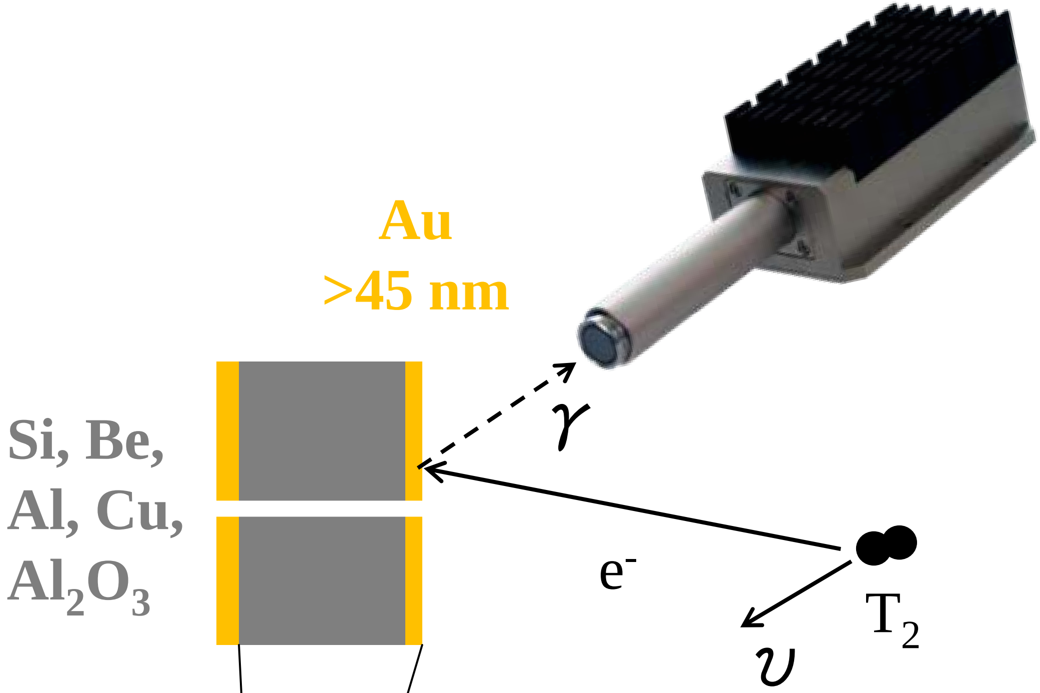


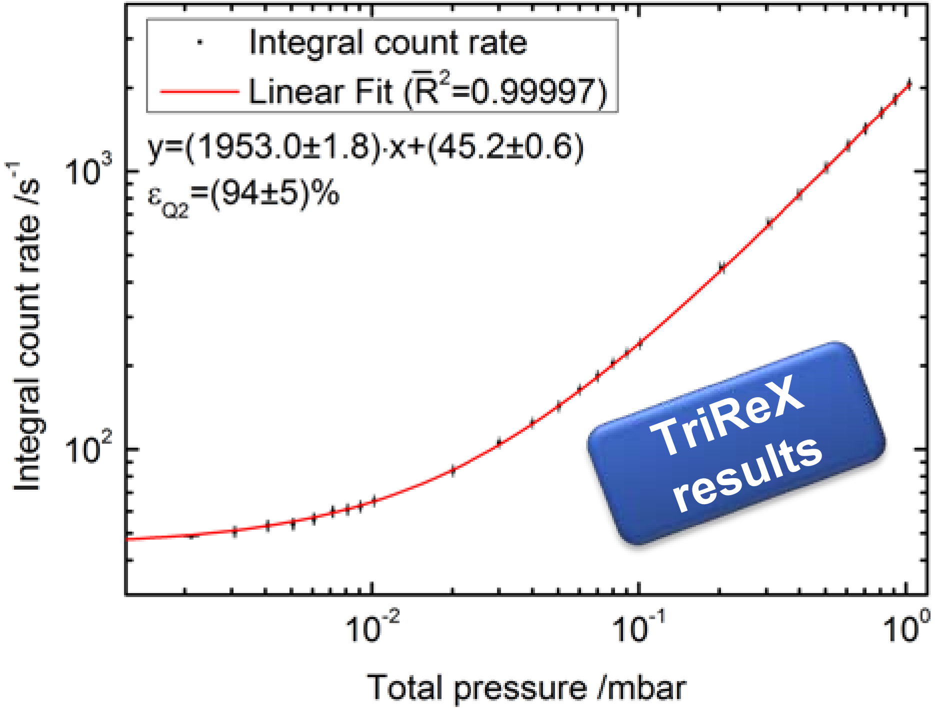
$$\text{WGTS strength} = \mathbf{A_Q} \cdot \rho d \cdot \varepsilon_T$$

Required stability ≤10^{-3}
t_{meas} ≤ 1000 s



Beta Induced X-ray Spectrometry (BIXS)

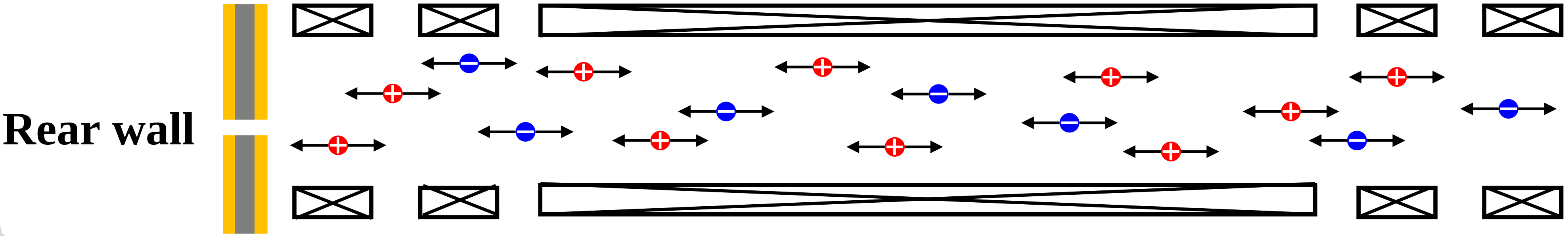




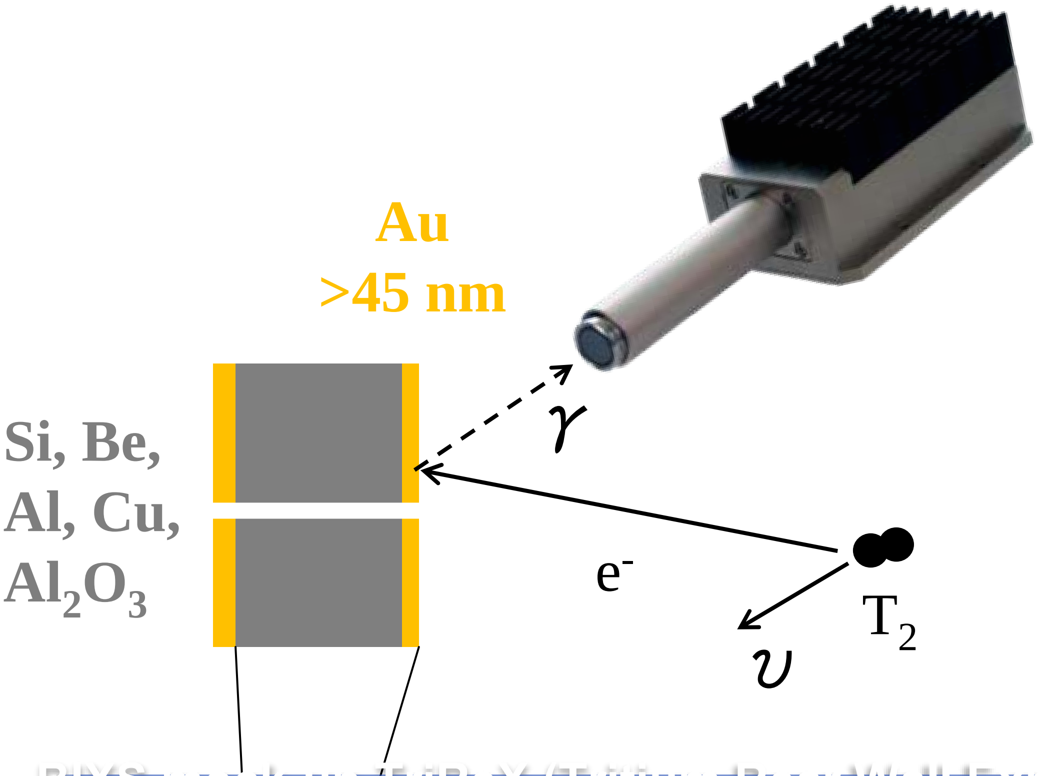
TriReX results

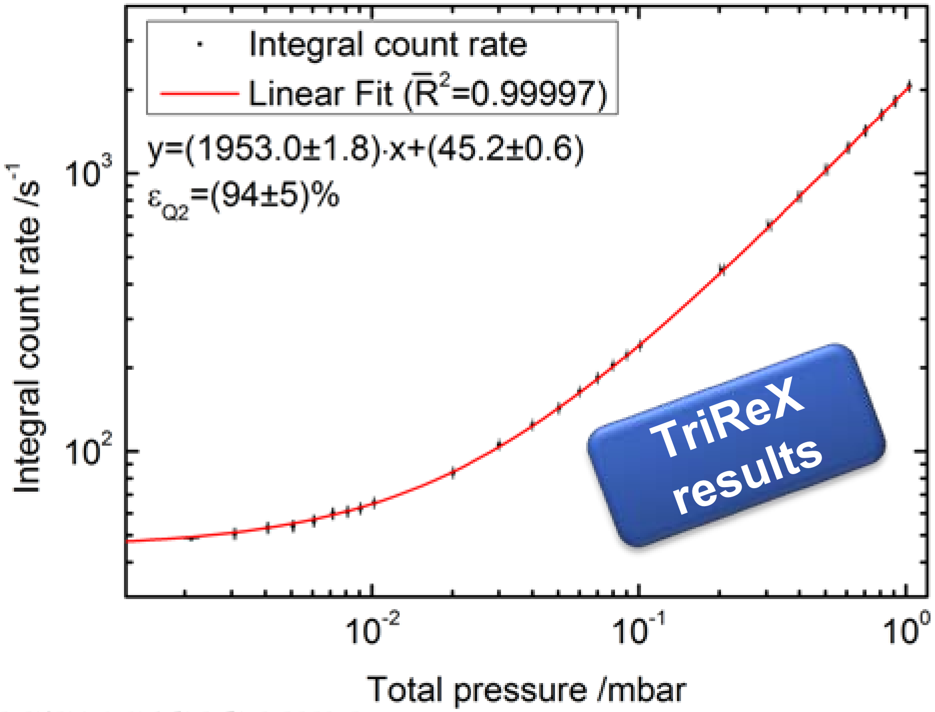
$$\text{WGTS strength} = \mathbf{A_Q} \cdot \rho d \cdot \varepsilon_T$$

Required stability ≤10^{-3}
t_{meas} ≲ 1000 s



Beta Induced X-ray Spectrometry (BIXS)





TriReX results

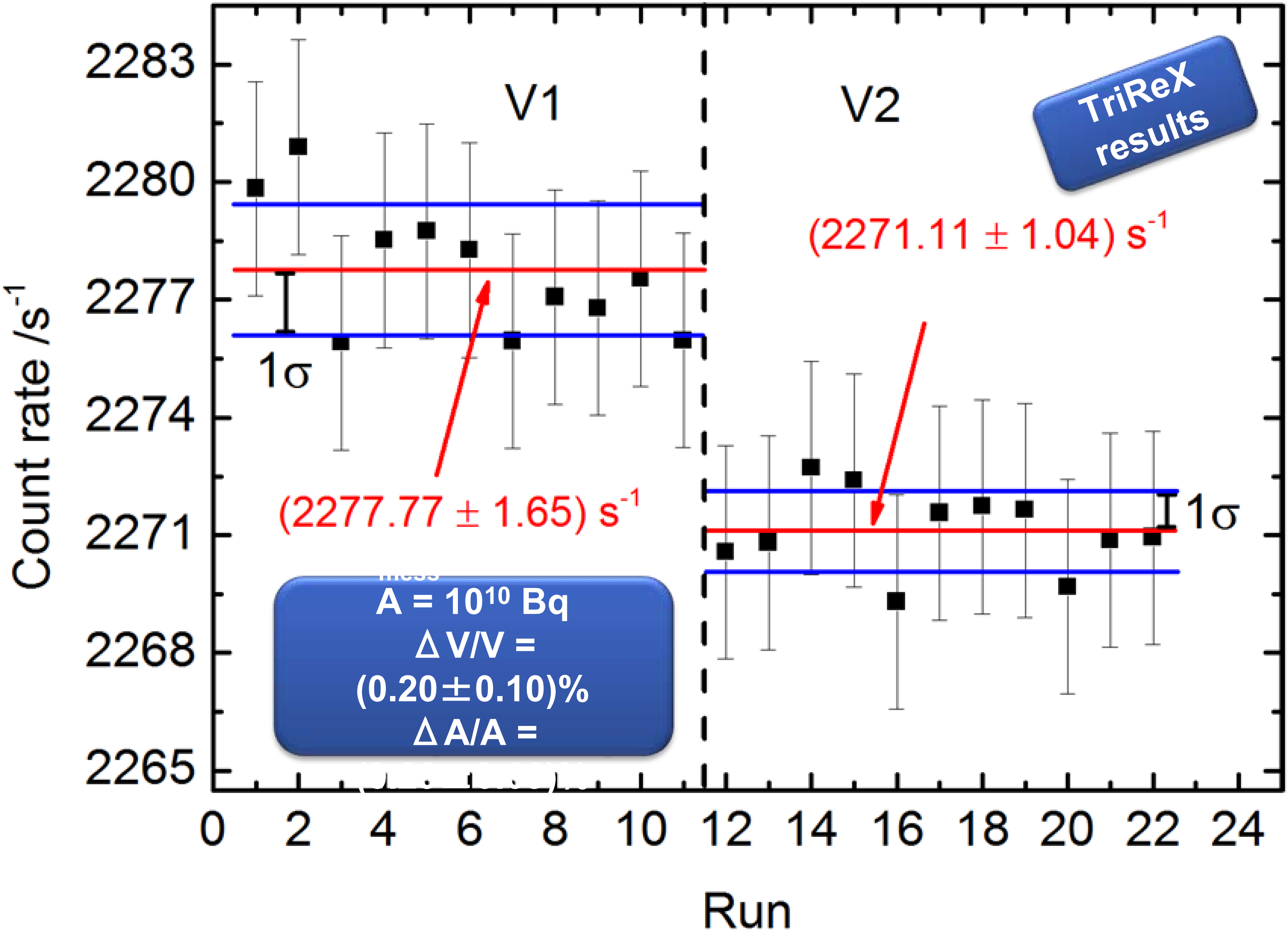
y ≤10^{-3}
s

BIXS mock-up TriReX (Tritium Rear Wall Experiment) shows:
linear detector response
0.1% activity changes detectable in <1000s (count rate >10^4 cps at 10^{11} Bq)
200 μm Be-window is an efficient permeation barrier

BUT memory effect was measured B/S ≈ 0.7% (after 30 days @ 1 mbar)

[Roe12] Activity monitoring of a gaseous tritium source by beta induced X-ray spectrometry

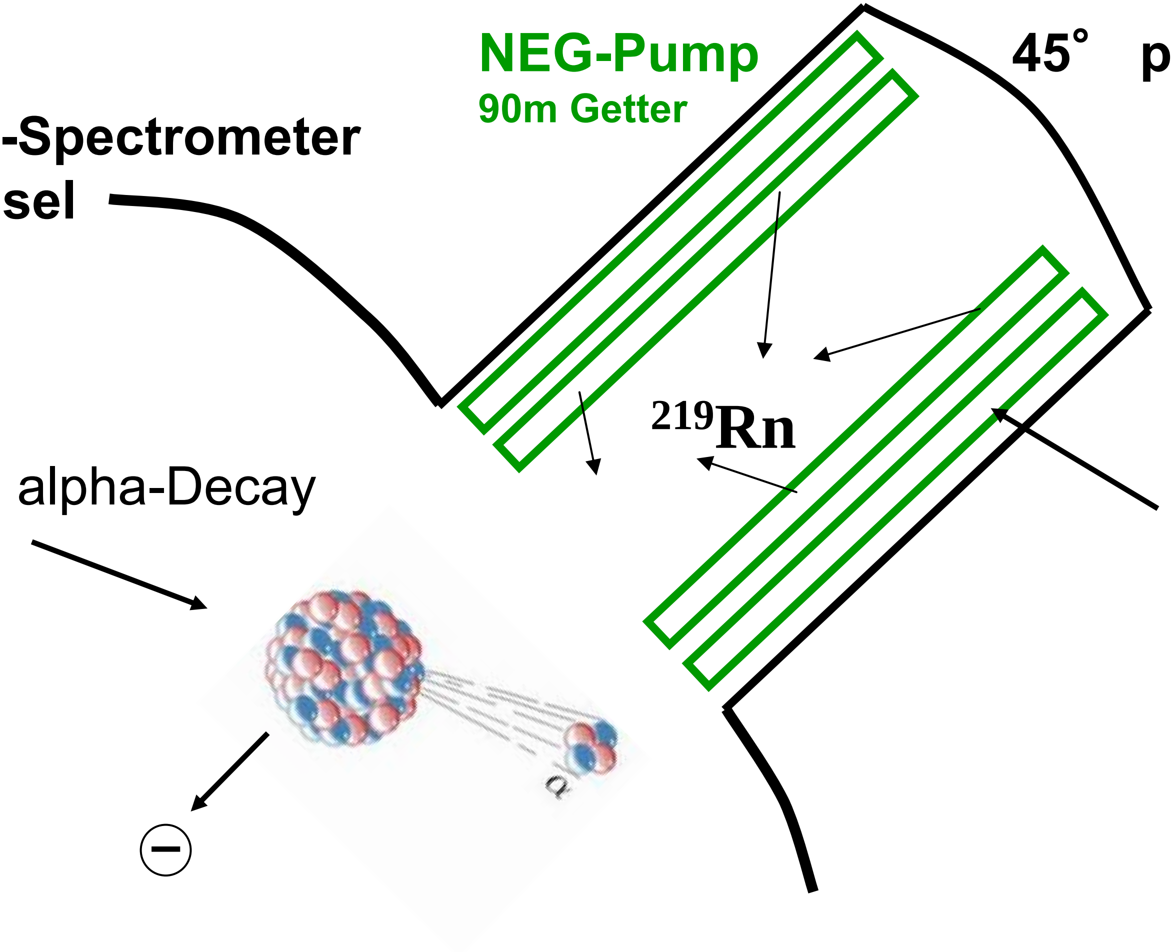
Activity change on the 0.1% level in TriReX



TriReX results

A = 10^{10} Bq
Δ V/V =
(0.20±0.10)%
Δ A/A =

Radon Emanating from the Getter-Pump



NEG-Pump

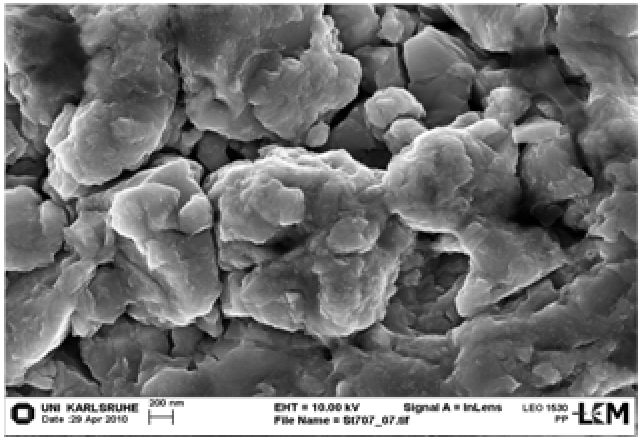
90m Getter

45° pump port

Pre-Spectrometer vessel

^{219}Rn

Radon alpha-Decay

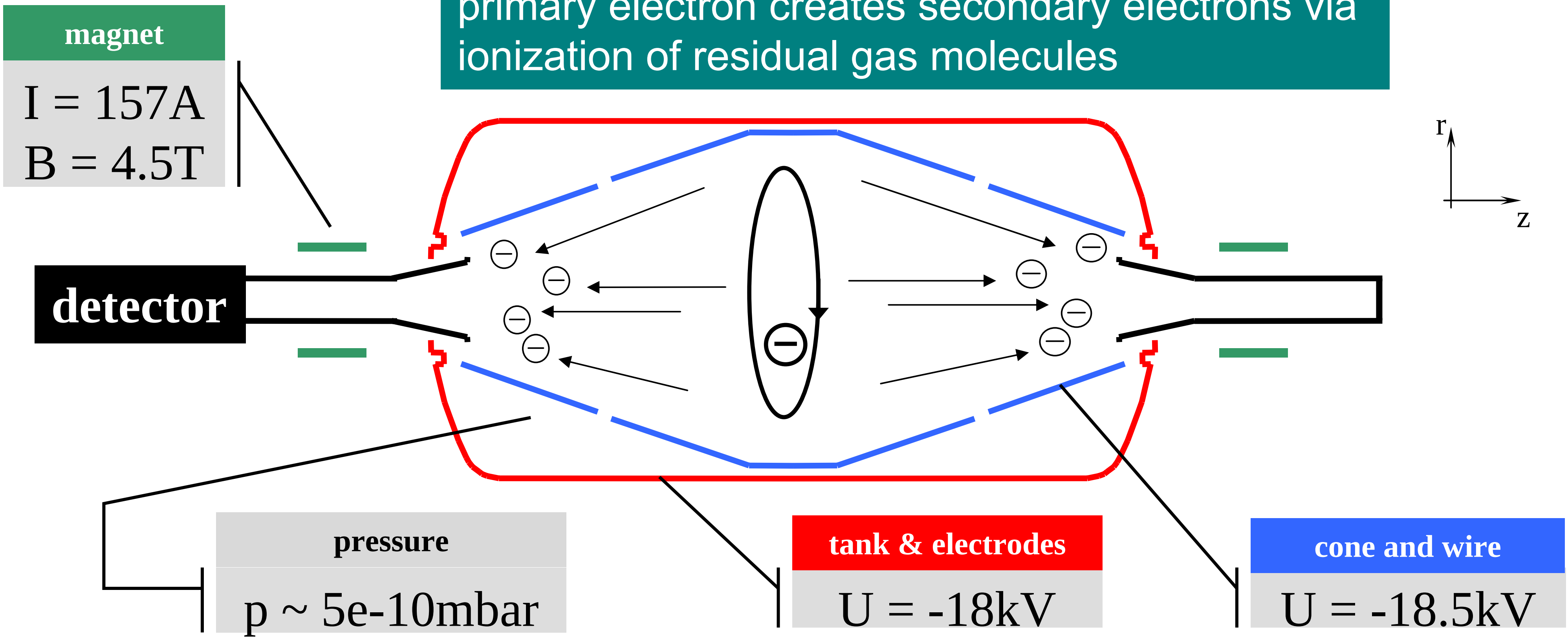


A(Rn-219) ~ 8 Bq
released activity ~1‰

Radon is not affected by electric or magnetic fields
→ can decay inside the volume of the spectrometer.

alpha-Decays in the Pre-Spectrometer

Spectrometers are like magnetic bottles:
primary electron creates secondary electrons via ionization of residual gas molecules



magnet

I = 157A
B = 4.5T

detector

pressure

p ~ 5e-10mbar

tank & electrodes

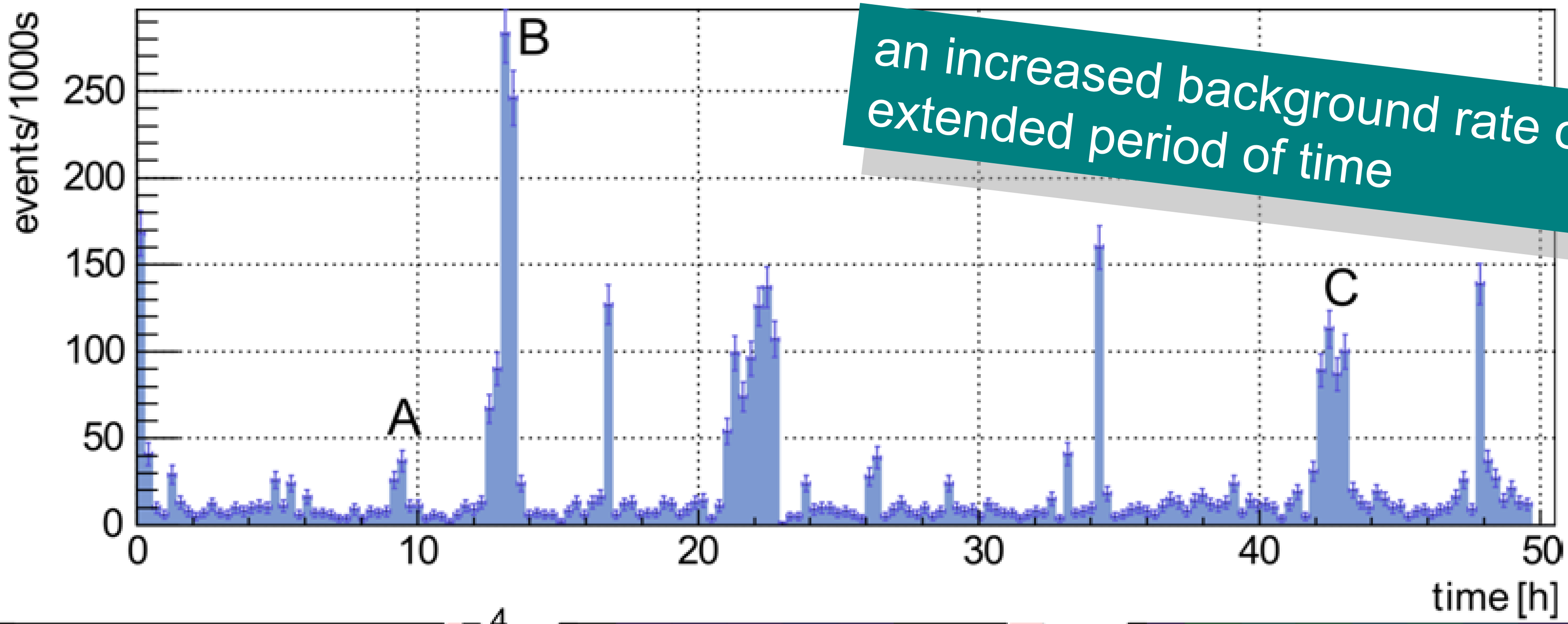
U = -18kV

cone and wire

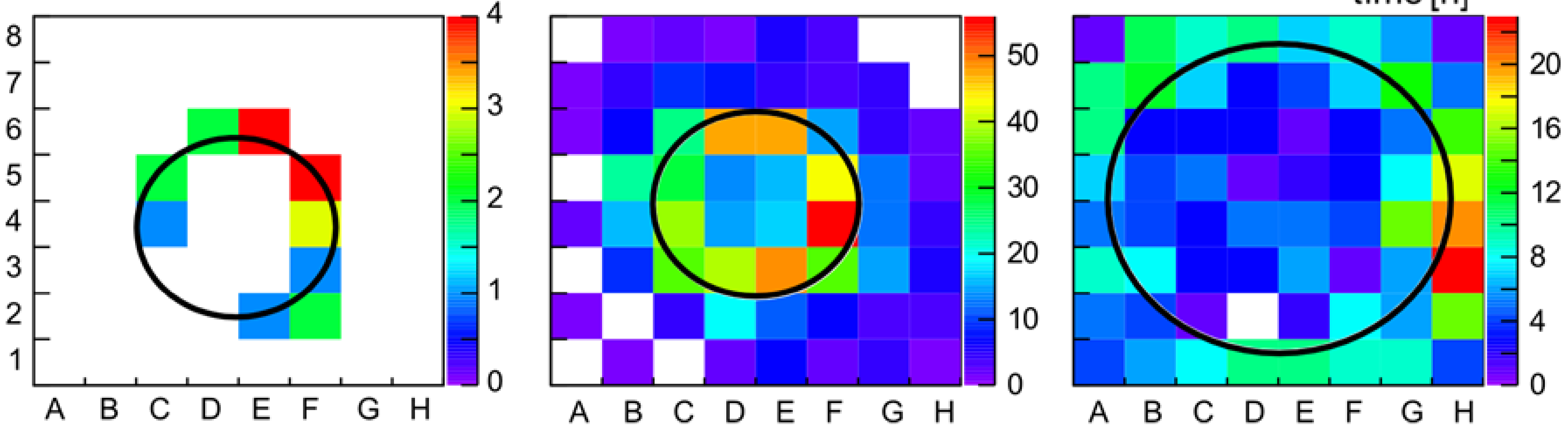
U = -18.5kV

a single trapped electron produces thousands of secondary electrons

Result: Time Dependent Background

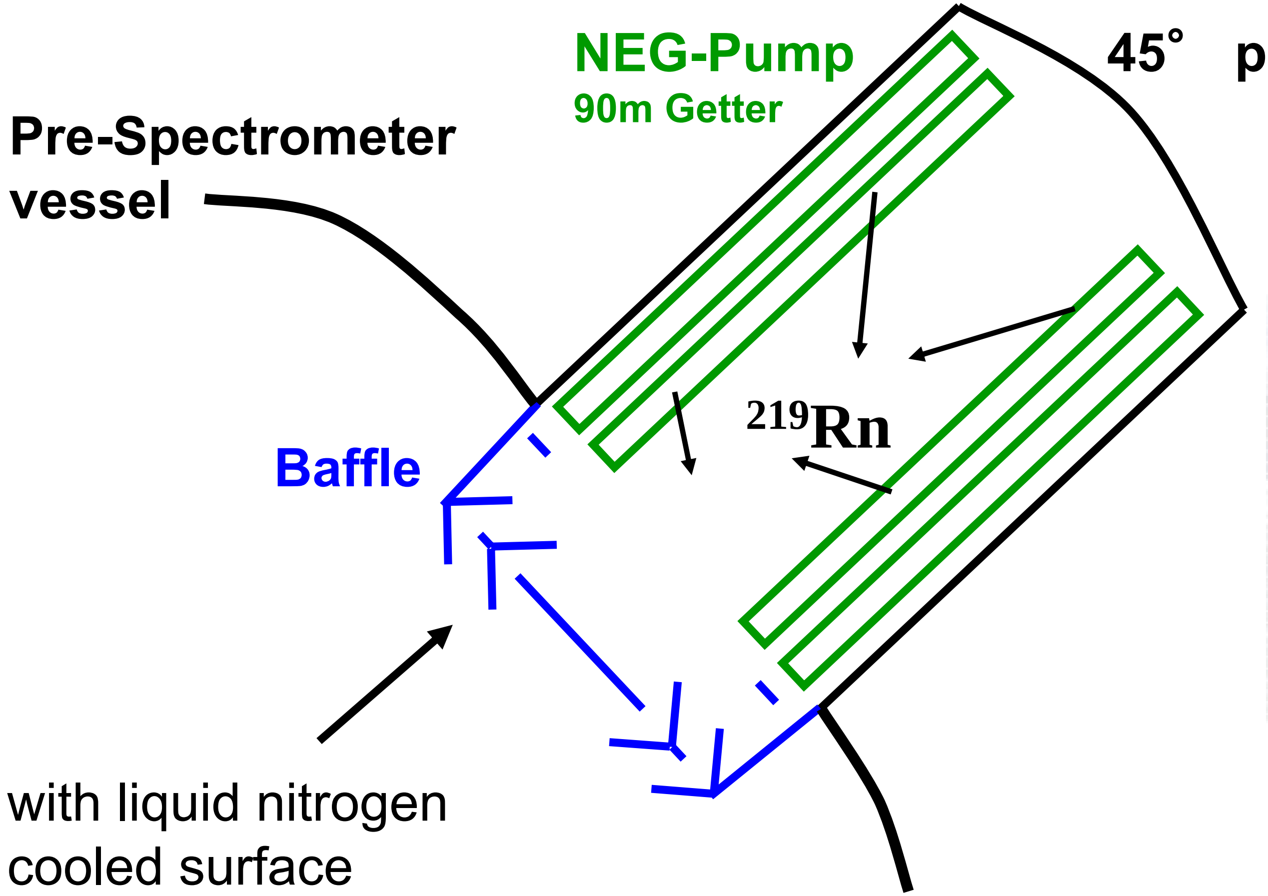


an increased background rate over an extended period of time



F. M. Fränkle et. al.:“Radon induced background processes in the KATRIN pre-spectrometer “, Astroparticle Physics Vol. 35, Iss. 3, October 2011, 128-134

Baffle Setup at Pre-Spectrometer

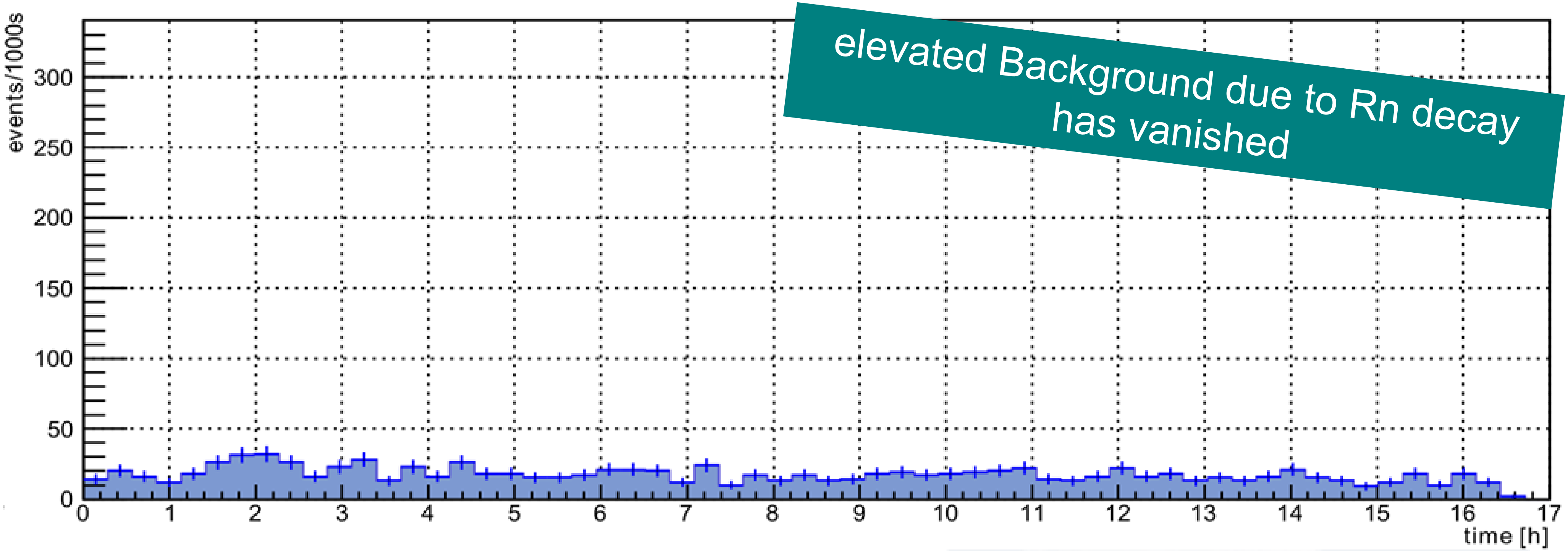


45° pump port

no line of sight between pump and vacuum chamber

Radon emanating from the getter freeze to the cold surface of the Baffle

Baffle Setup at Pre-Spectrometer



elevated Background due to Rn decay has vanished

Pre-Spectrometer measurements showed:
a Baffle in combination with a cold trap will be essential for successful main spectrometer experiments.

➔ currently installed at the main spectrometer