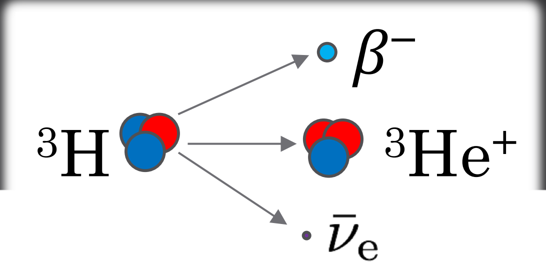
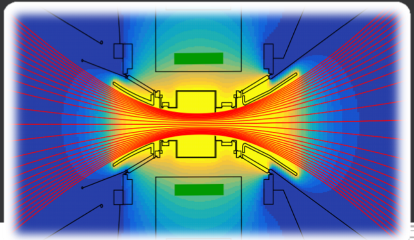
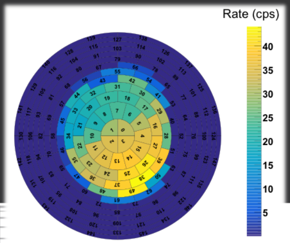
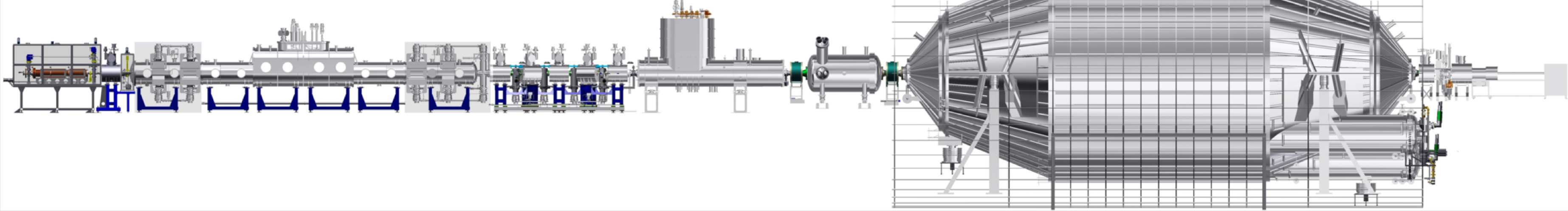
Status of the KATRIN experiment









Luke Kippenbrock

UNIVERSITY *of* WASHINGTON

CENPA
Center for Experimental Nuclear Physics and Astrophysics

PASCOS 2018

June 7, 2018

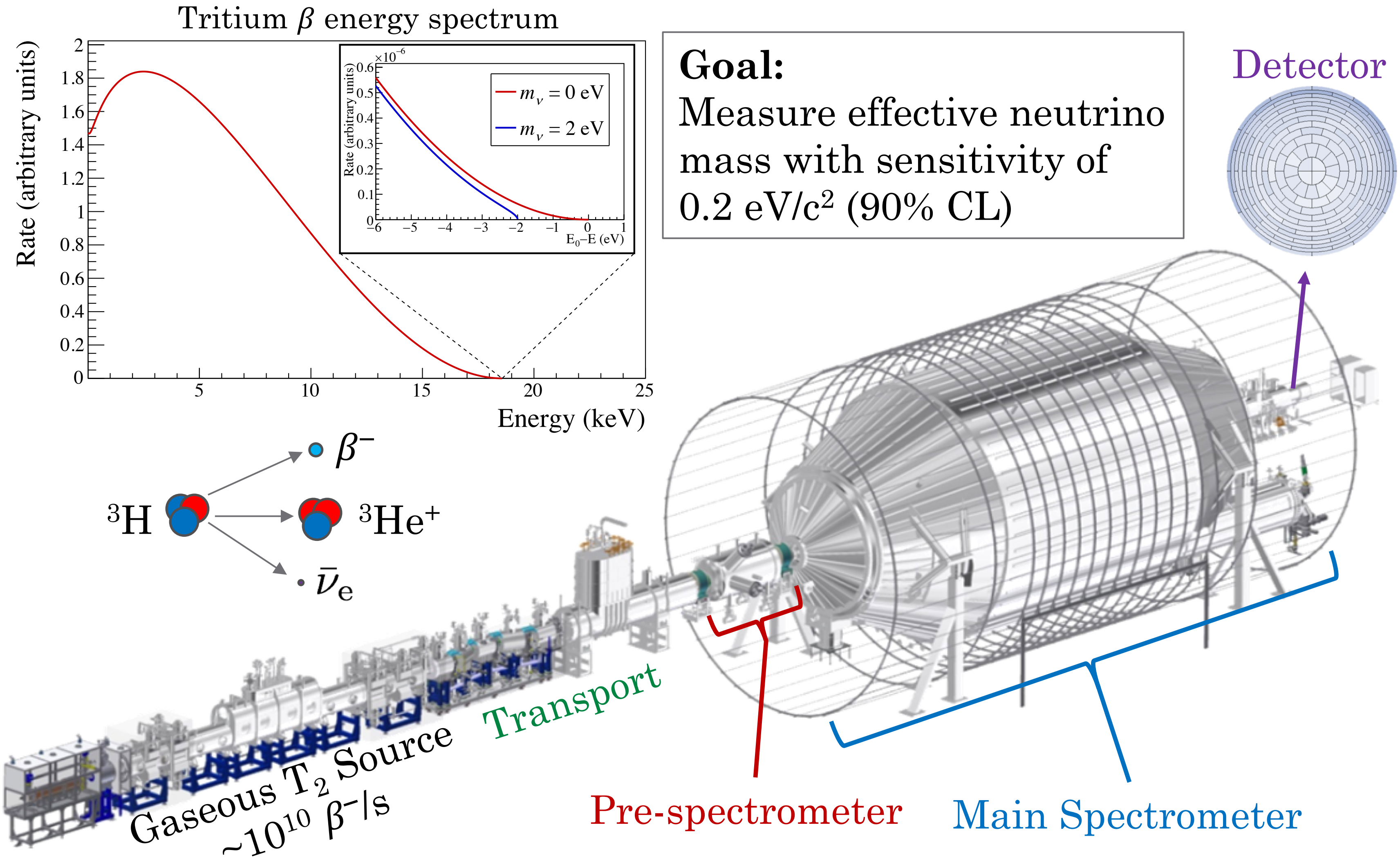
Outline

- KATRIN overview
- Measurement campaigns
  - Krypton
  - Background studies
  - First tritium
- Summary and outlook

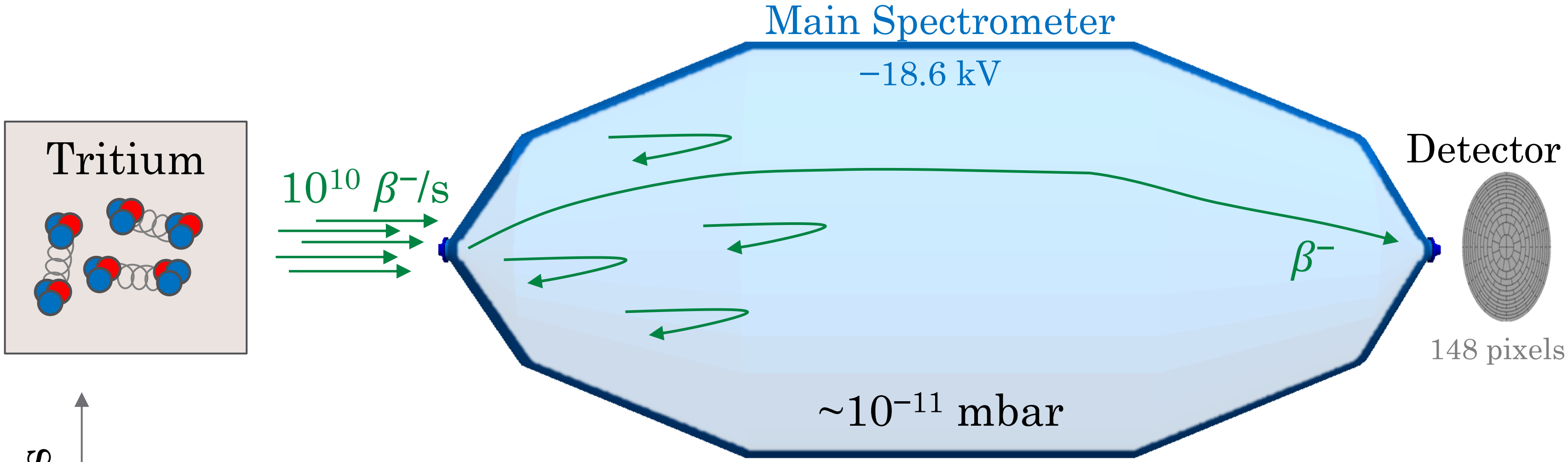

photo source: Karlsruhe Institute of Technology, www.katrin.kit.edu

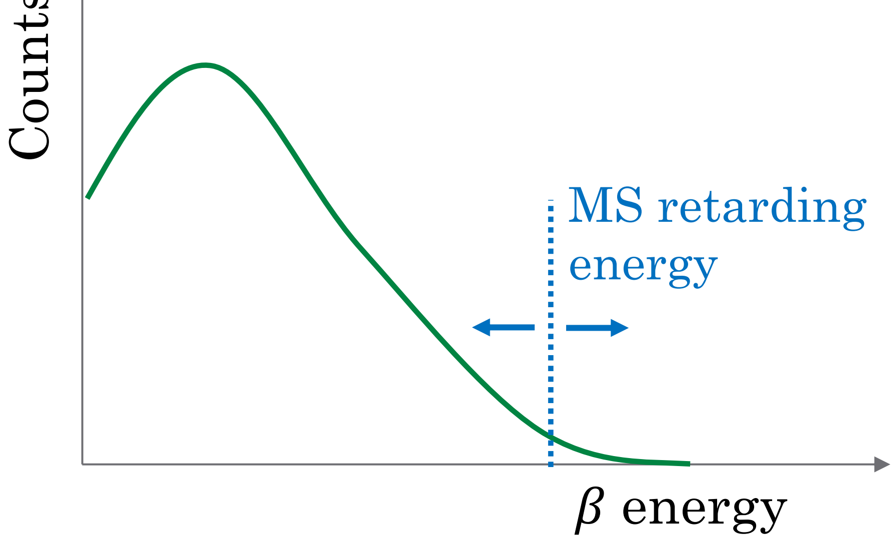
The Karlsruhe Tritium Neutrino Experiment

Goal:
Measure effective neutrino mass with sensitivity of 0.2 eV/c² (90% CL)



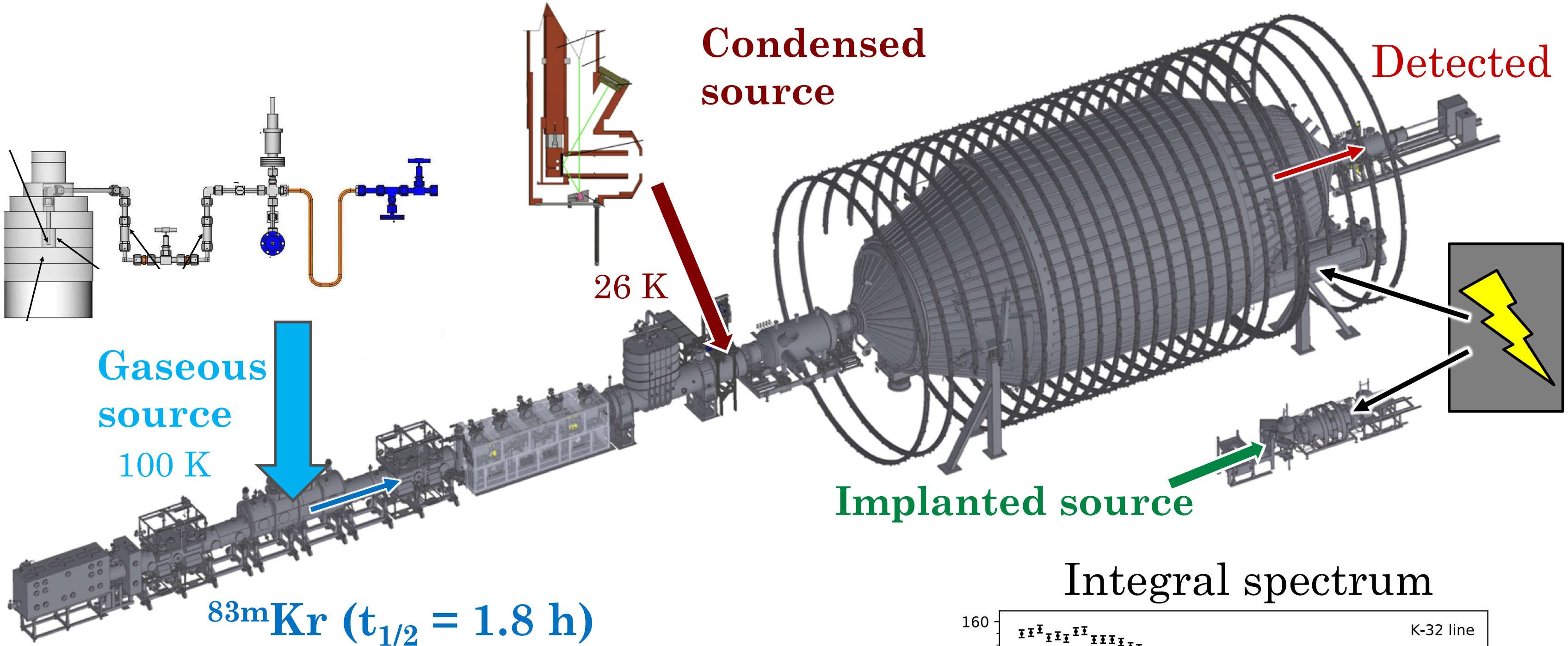
Spectrometer operation





- MAC-E filter with energy resolution of ~1 eV
- Measure integral rate for different retarding energies
- Fit the integral spectrum to obtain the neutrino mass

Krypton campaign: July 2017



Condensed source

26 K

Detected

Gaseous source

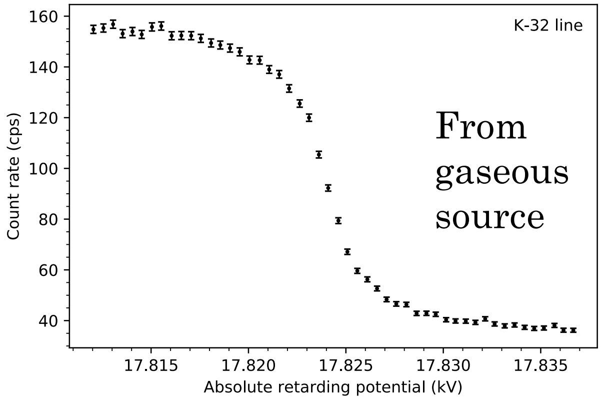
100 K

Implanted source

^{83m}Kr ($t_{1/2}$ = 1.8 h)

- Mono-energetic electron source, including K32 line (E = 17.8 keV)
- Can calibrate near tritium endpoint (E_0 = 18.6 keV)
- Measure line position and shape using the main spectrometer

Integral spectrum

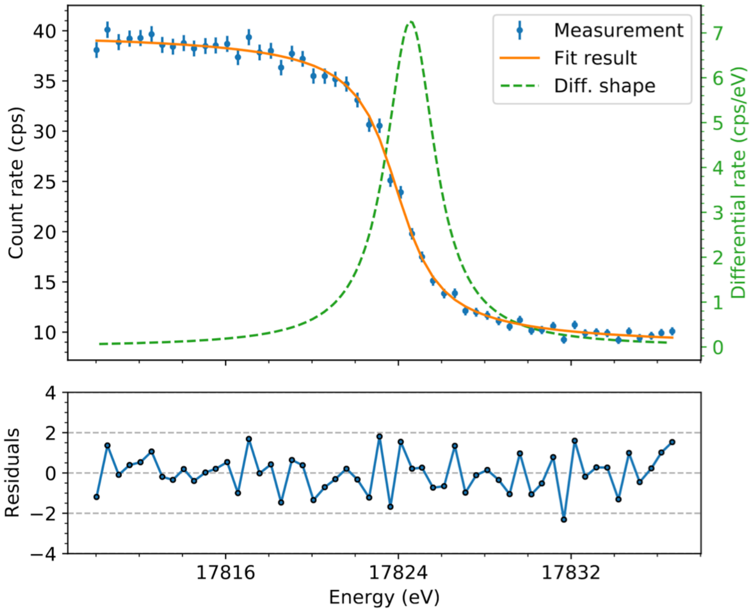


From gaseous source

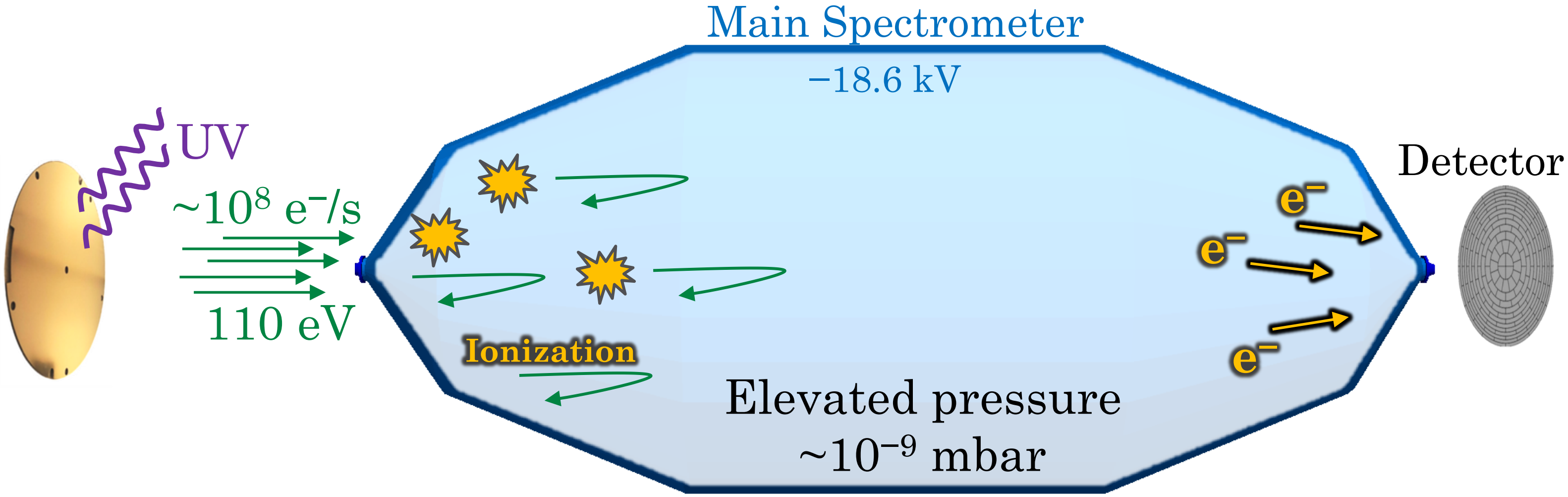
Krypton campaign: July 2017

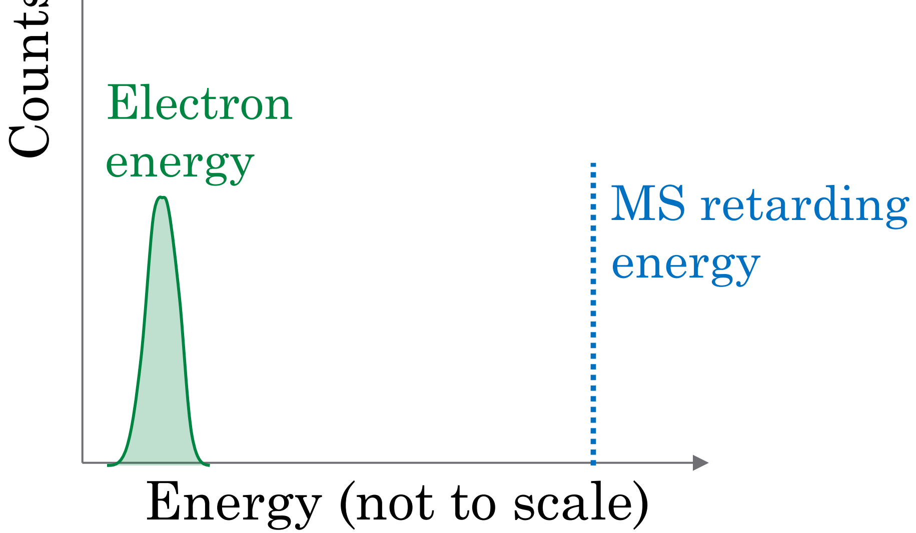
- Commissioning of ^{83m}Kr sources
  - Test stability of source temperature (gaseous source)
- High voltage stability
  - Sub-ppm level
  - Paper: Eur. Phys. J. C, 78 5 (2018) 368
- Characterize Main Spectrometer performance
  - Scan of ^{83m}Kr lines
  - Publication forthcoming
- Preparation for tritium operation
  - System performance meets/surpasses specifications
- "First Light" and Krypton technical paper
  - M. Arenz *et al* 2018 *JINST* **13** P04020

K-32 Line (from gaseous source)



Background from ionization





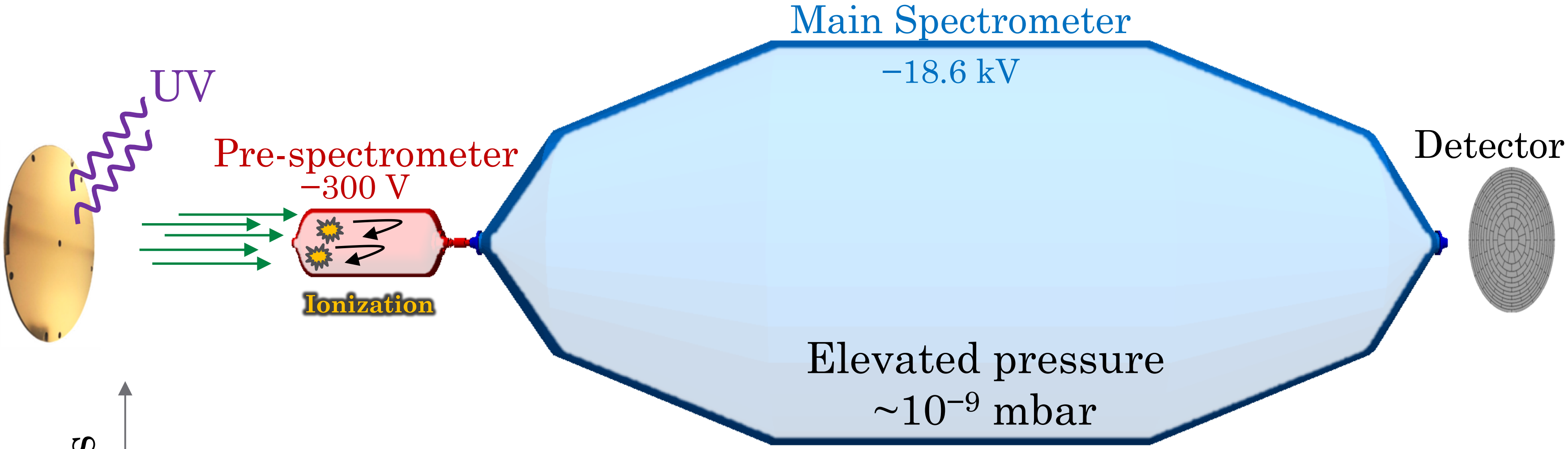
First Light:

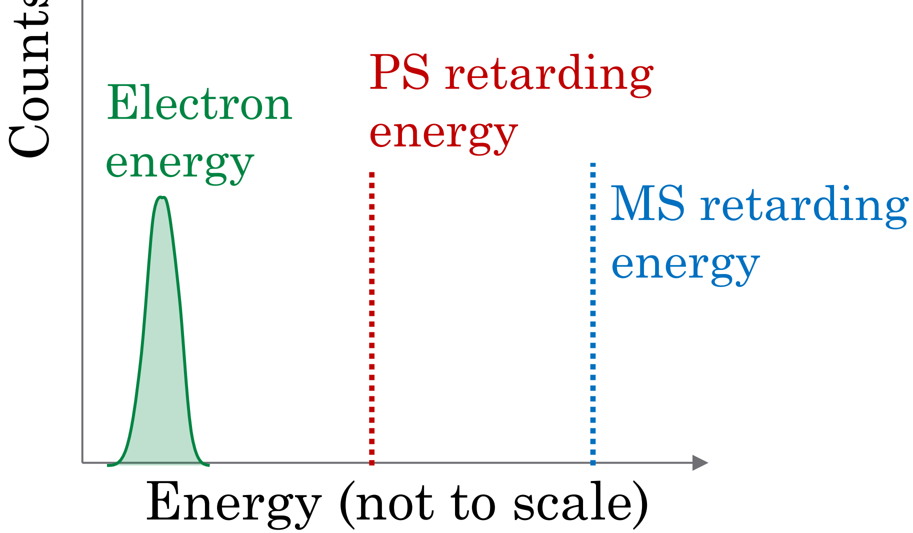
M. Arenz et al 2018
JINST 13 P04020

Electron rate (e⁻/s)	**Detector rate (cps)**
~0	**0.6**
~10^8	**2.5**

Elevated rate due to ionization

Pre-filtering electron beam





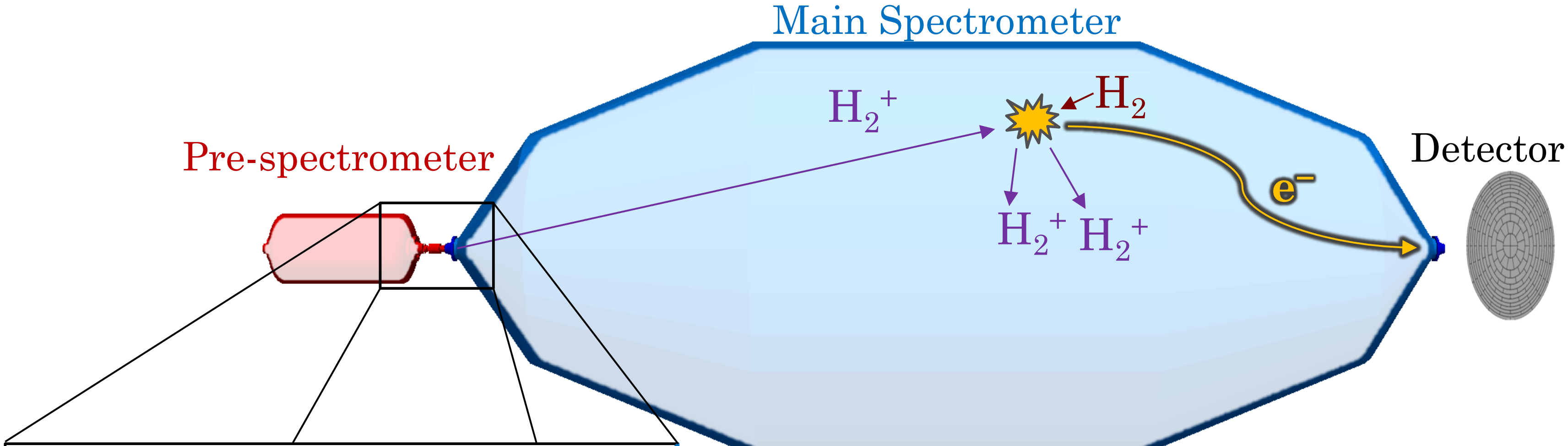
First Light:

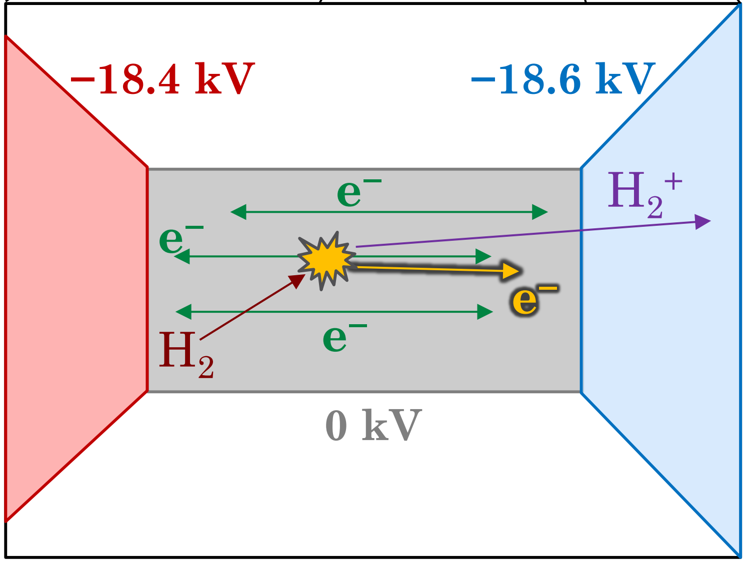
M. Arenz et al 2018
JINST 13 P04020

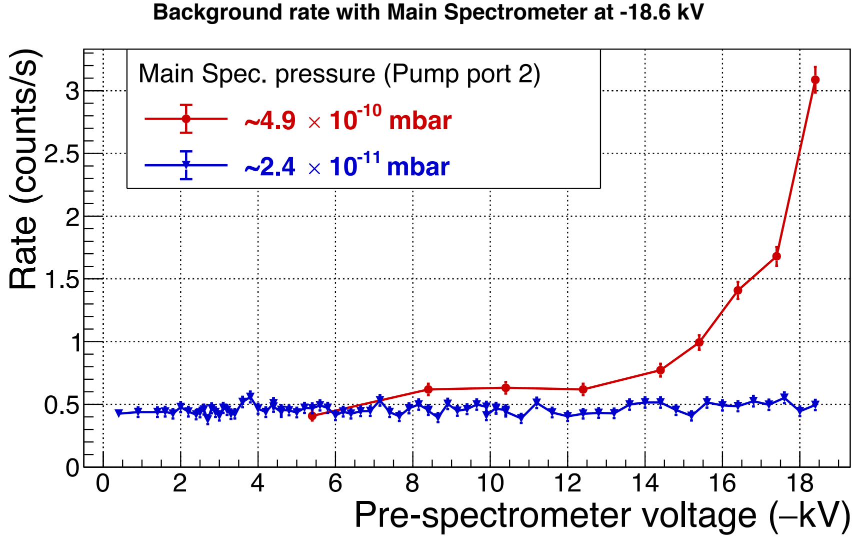
Electron rate (e^-/s)	ΔU_{PS} (V)	Detector rate (cps)
~0	**0**	**0.6**
~10^8	**0**	**2.5**
~10^8	**−300**	**0.6**

Rate remains at reference value

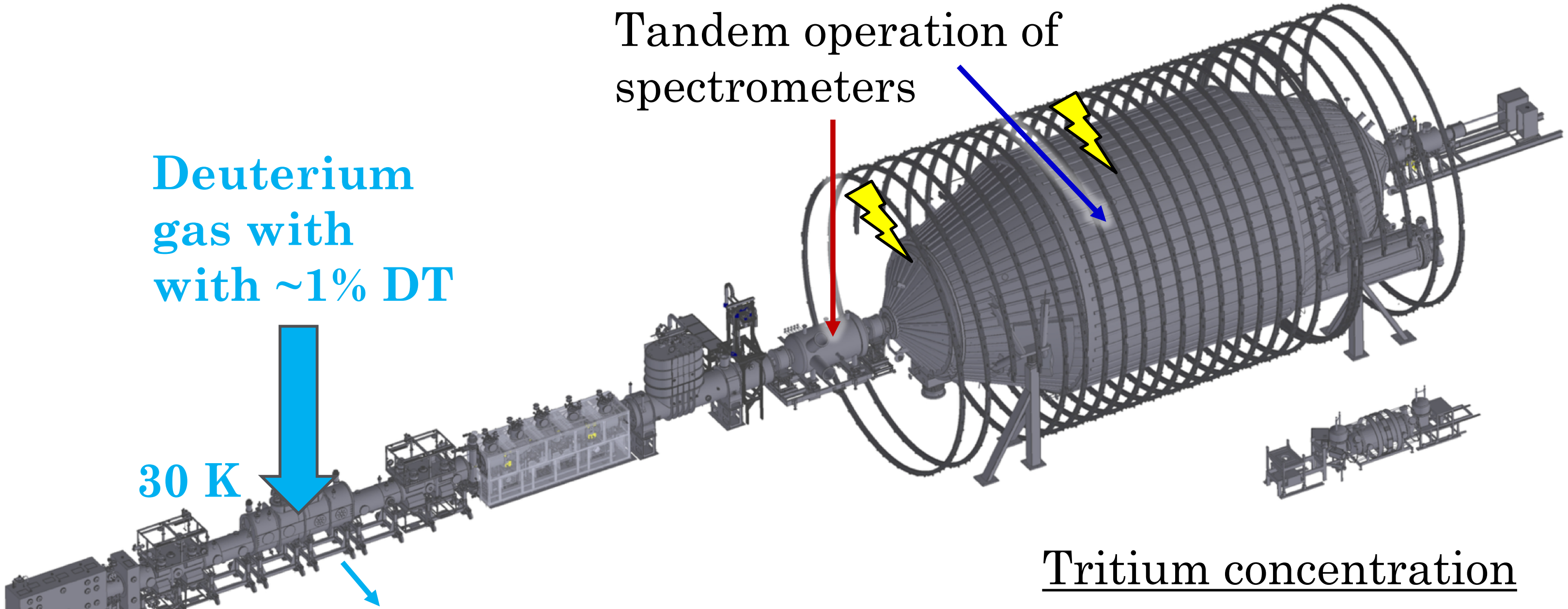
Penning trap background







Very first tritium: May 2018

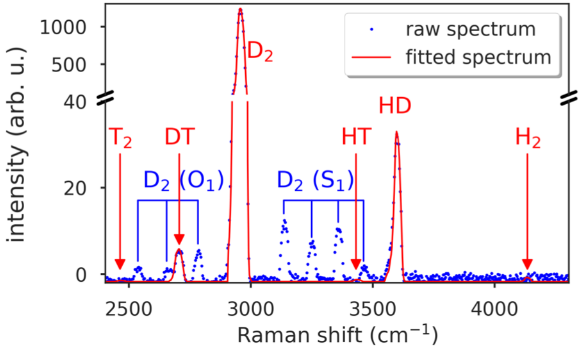


Tandem operation of spectrometers

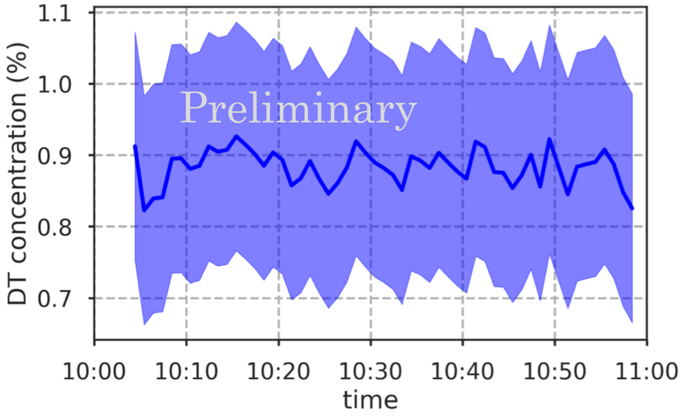
Deuterium gas with with ~1% DT

30 K

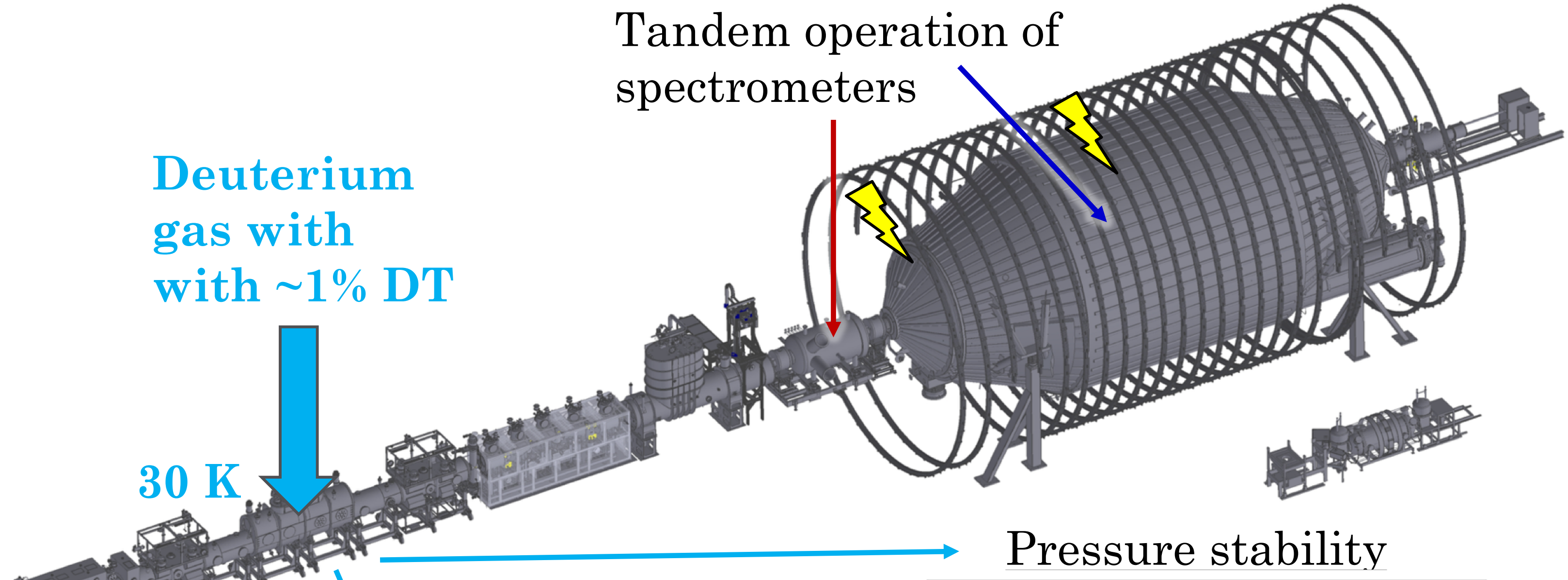
Laser Raman spectroscopy



Tritium concentration



Very first tritium: May 2018

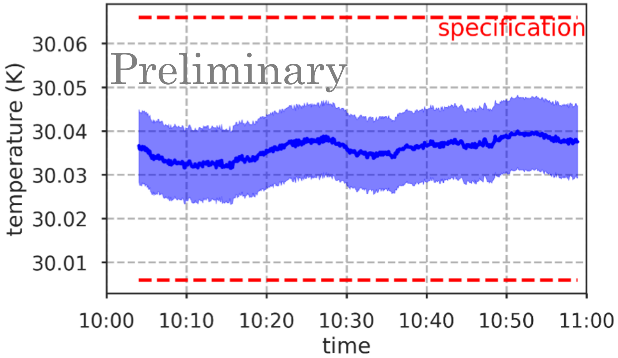


Tandem operation of spectrometers

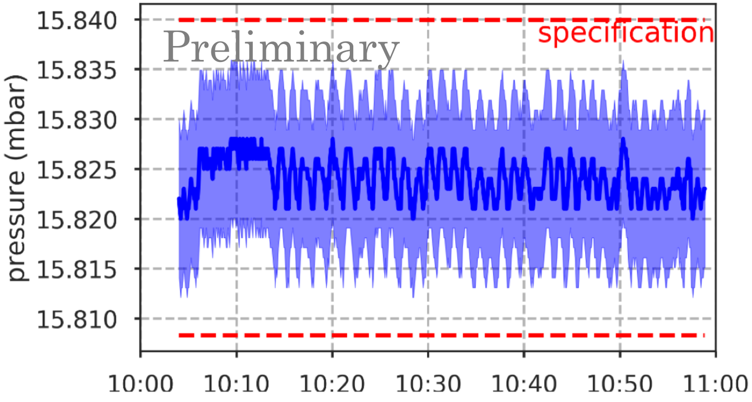
Deuterium gas with with ~1% DT

30 K

Temperature stability

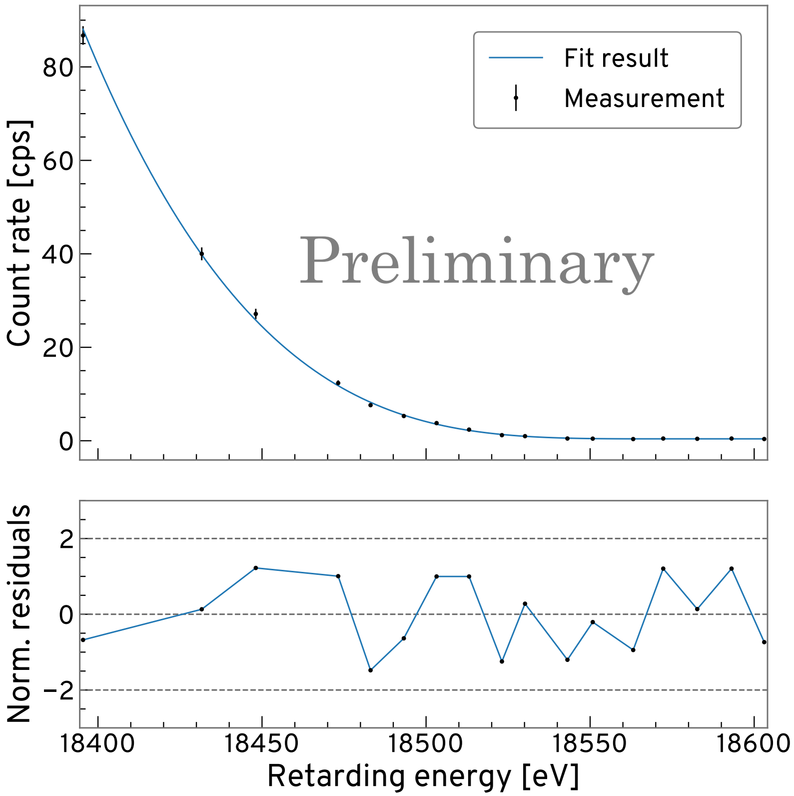


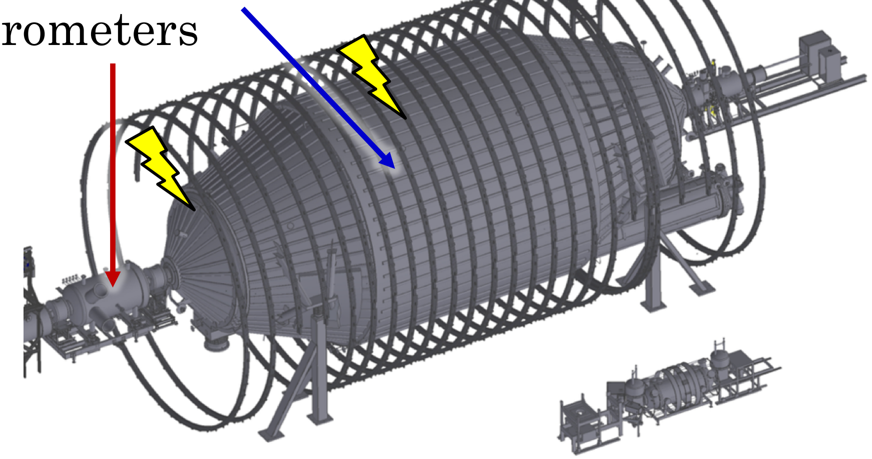
Pressure stability



Very first tritium: May 2018

Integral beta spectrum



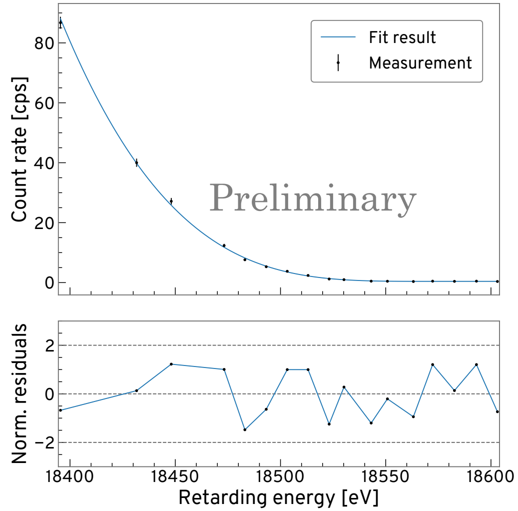


Tandem operation of spectrometers

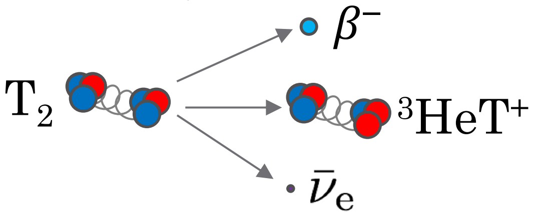
- Data agrees with expectations
- Good fit
  - χ^2/dof = 15.0/14, statistical only
  - Systematics are still being investigated

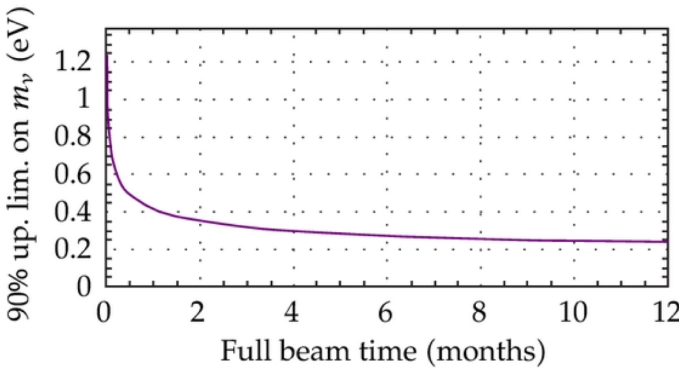
Summary and Outlook

- Very successful measurement campaigns
  - Spectral scanning with $^{83\mathrm{m}}$Kr
  - Background studies
- First tritium
  - Apparatus meets stability requirements
  - Preliminary spectra agree with expectations
  - Data-taking is happening right now!
  - Commissioning will continue this year



- 5 years of measurements planned, looking for:
  - Effective neutrino mass
  - Sterile neutrinos
  - BSM physics





Drexlin, G. *et al.* Adv. High Energy Phys. (2013) 293986

Thank you

KATRIN funded by:

Germany
- Helmholtz Association (HGF)
- Ministry for Education and Research BMBF
- Helmholtz Alliance for Astroparticle Physics (HAP)
- Helmholtz Young Investigator Group

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- Ministry of Education, Youth and Sport
- Cooperation with the JINR Dubna

United States
- Department of Energy
  - **grant #DE-FG02-97ER41020**

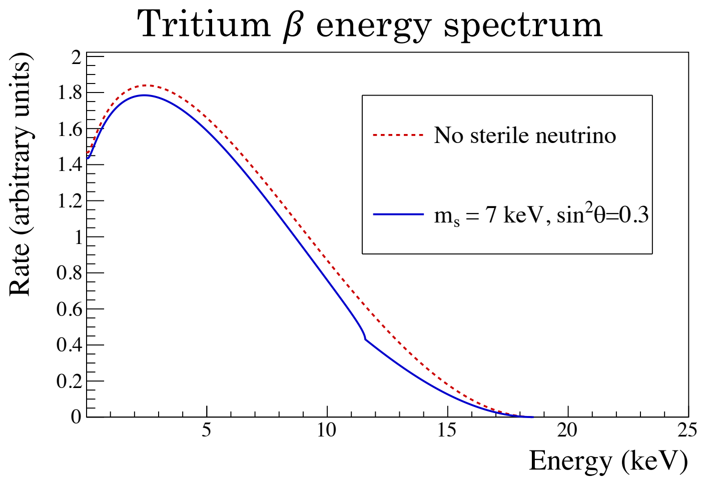
KATRIN collaboration:

- Academy of Sciences of Russia, INR Troitsk
- Karlsruhe Institute of Technology
- Lawrence Berkeley National Laboratory
- Max Planck Institut für Kernphysik, Heidelberg
- The Massachusetts Institute of Technology
- University of Applied Science, Fulda
- University of Bonn
- University of Münster
- University of North Carolina
- Complutense University of Madrid
- University of Washington
- University of Wuppertal
- Max Planck Institute for Physics, Munich
- Technical University of Munich
- Humboldt University of Berlin
- Case Western Reserve University
- Carnegie Mellon University
- The Czech Academy of Science, Újf Prague
- French Alternative Energies and Atomic Commission, Paris

Sterile neutrinos and BSM physics

Sterile neutrinos result in a "kink" in the beta decay spectrum

- Search at the keV-scale and also eV-scale



New physics can be probed by looking for distortions near the endpoint in the beta spectrum

- Non V−A contributions
- Violations of Lorentz invariance
- Tachyonic neutrinos

See:

- KATRIN Design Report 2004, FZKA scientific report 7090.
- Mertens et al. JCAP02(2015)020
- Steinbrink et al. JCAP06(2017)015

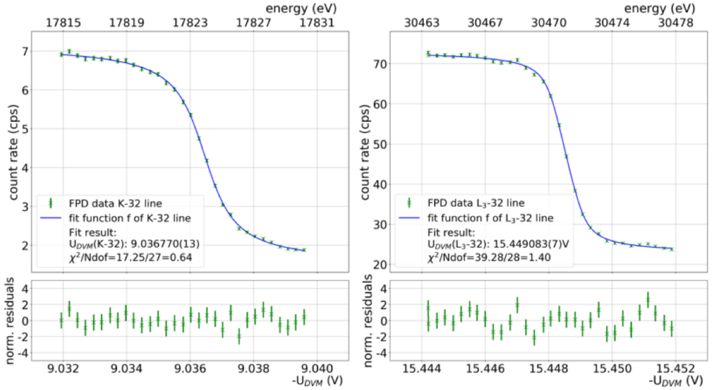
Neutrino mass

- Direct measurement (kinematics)
  - Measure effective electron antineutrino mass
  - Nearly model independent
    - Must understand final states distribution for T_2
- Cosmology
  - Measure sum of neutrino masses
  - Depends on cosmological model
- Neutrinoless double-beta decay
  - Measure coherent sum (contribution of phases from mixing matrix)
  - Requires neutrinos to be Majorana particles
  - Uncertainty on nuclear matrix elements

Reference:
G. Drexlin, V. Hannen, S. Mertens, and C. Weinheimer, "Current Direct Neutrino Mass Experiments," Advances in High Energy Physics, vol. 2013, Article ID 293986, 39 pages, 2013. https://doi.org/10.1155/2013/293986.

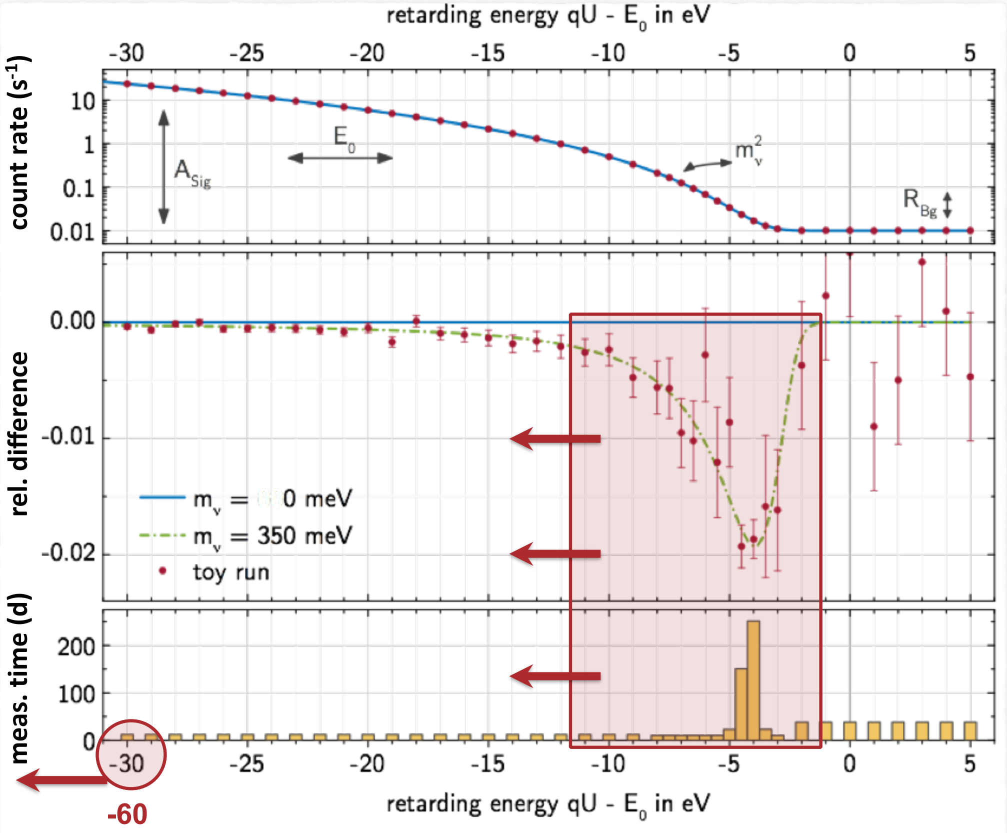
High voltage stability

- Measure the voltage difference between two ^{83m}Kr lines
- HV divider scale factor
  - 2017 krypton value = 1972.449(10)
  - 2013 value = 1972.4531(20)
  - ΔM/M = −2(5) ppm over four years



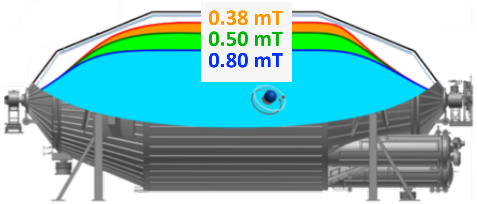
- HV is stable at the <u>sub-ppm</u> level over 2 months (assuming constant drift), which is the planned measurement interval for KATRIN
- Compare with 3 ppm requirement from KATRIN Design Report 2004
- For details see the recent publication:
  - Eur. Phys. J. C, 78 5 (2018) 368
  - DOI: https://doi.org/10.1140/epjc/s10052-018-5832-y

Sensitivity and background



- Relative **shape** measurement of **integrated β spectrum**
- Allows to reach sensitivity of **240 meV** even without further mitigation of Rydberg backgrd:

1. Optimize signal/bg by shifting qU steps to lower energies
2. Extend data range to E_0-60 eV
3. Fiducialize flux tube at slightly lower energy resolution



From presentation by Kathrin Valerius (KIT)

Magnetic Adiabatic Collimation with an Electrostatic Filter

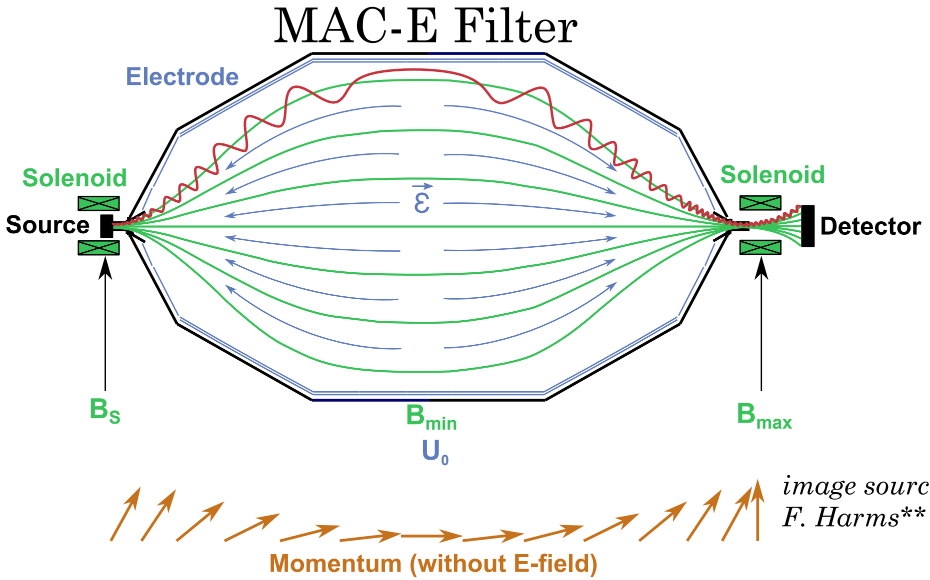
- Smoothly change magnetic field → magnetic moment will be conserved
  - Decrease B, decrease $E_\perp$
  - Convert $E_\perp$ into $E_\parallel$

$$\mu = \frac{E_\perp}{B}$$

- Good energy resolution requires a large spectrometer!

$$\frac{\Delta E}{E} = \frac{B_{\text{min}}}{B_{\text{max}}}$$

$$\Phi = \int \vec{B} \cdot d\vec{A}$$

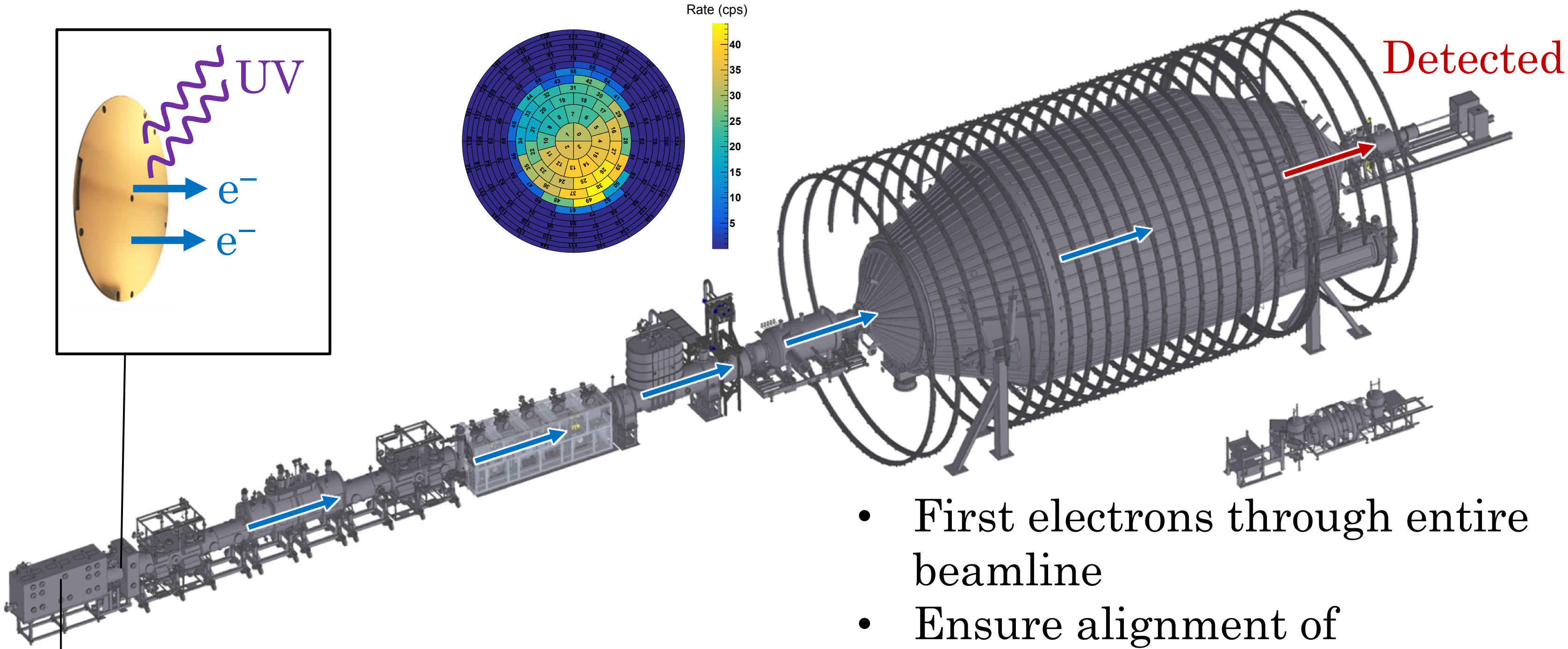


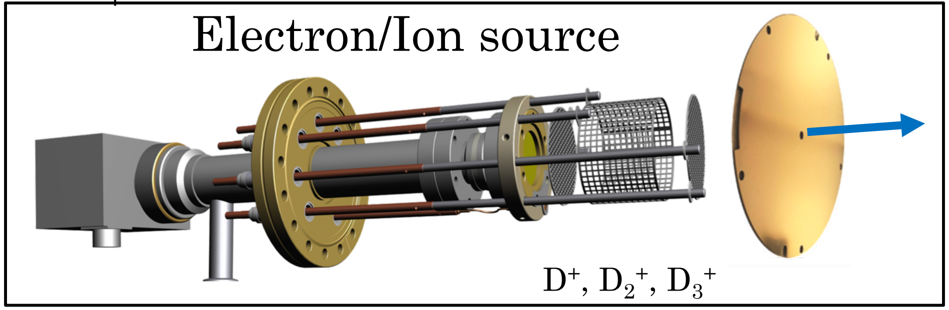
MAC-E Filter

*image source: F. Harms***

*****F. Harms. PhD thesis, Karlsruhe Institute of Technology, 2015.*

First Light: Autumn 2016




Electron/Ion source

- First electrons through entire beamline
- Ensure alignment of components and magnets
- Test methods for ion blocking and ion removal
- Technical paper:
  - M. Arenz *et al* 2018 *JINST* **13** P04020