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Background in the KATRIN experiment

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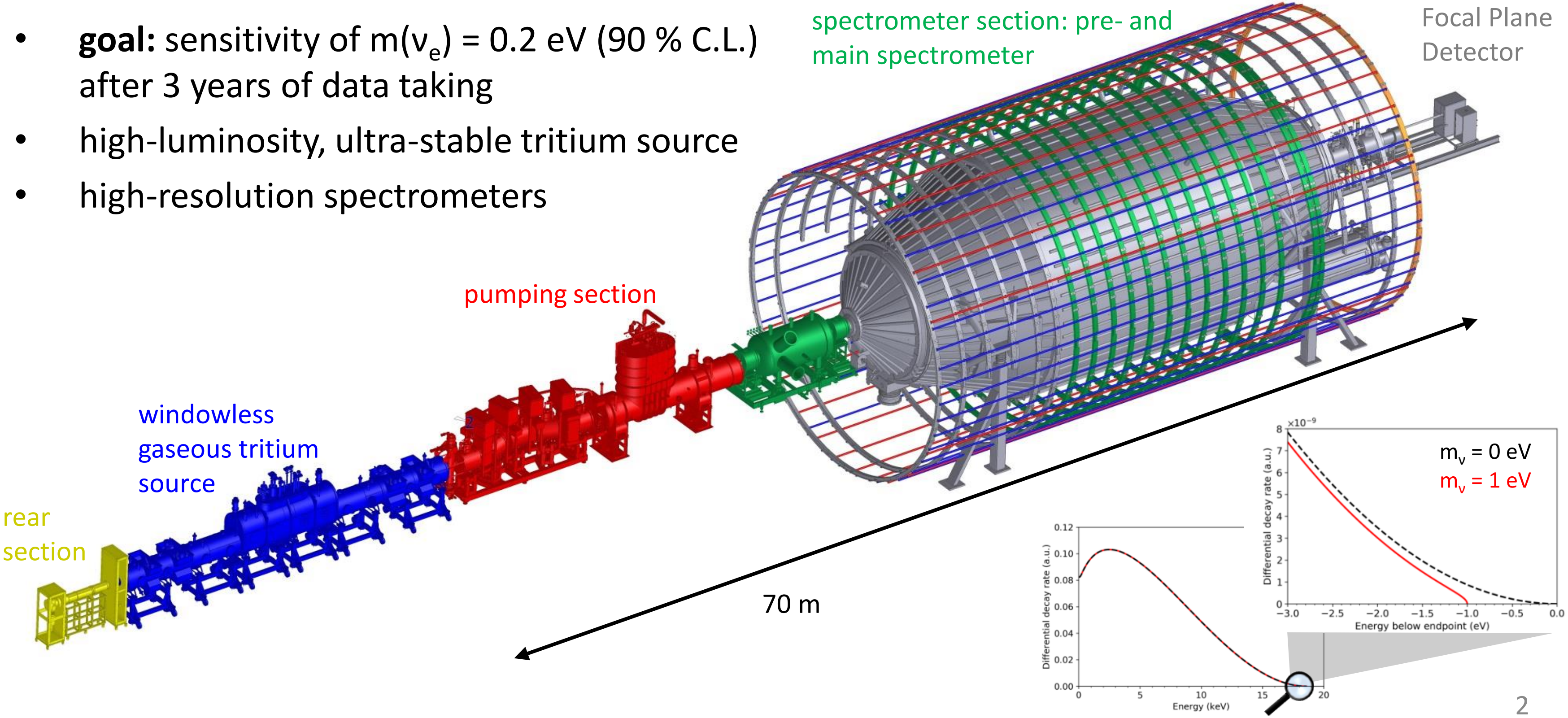
International School of Nuclear Physics 41st Course

Erice - 18.09.2019

The KATRIN Experiment

- **goal:** sensitivity of $m(\nu_e) = 0.2$ eV (90 % C.L.) after 3 years of data taking
- high-luminosity, ultra-stable tritium source
- high-resolution spectrometers



High-resolution spectrometers: MAC-E filter

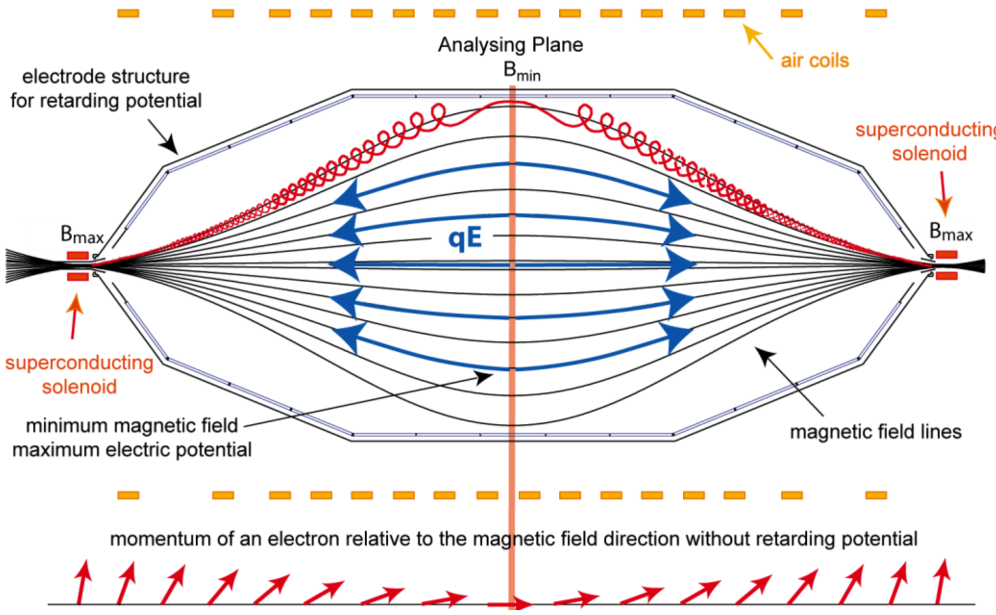
Magnetic **A**diabatic **C**ollimation with **E**lectrostatic filter

- High pass filter:
  all electrons with $E_{||} > qU$
  pass the analyzing plane
- Energy resolution:

$$E_{\mathrm{res}} = E_{\mathrm{ret}} \frac{B_{\min}}{B_{\max}}$$

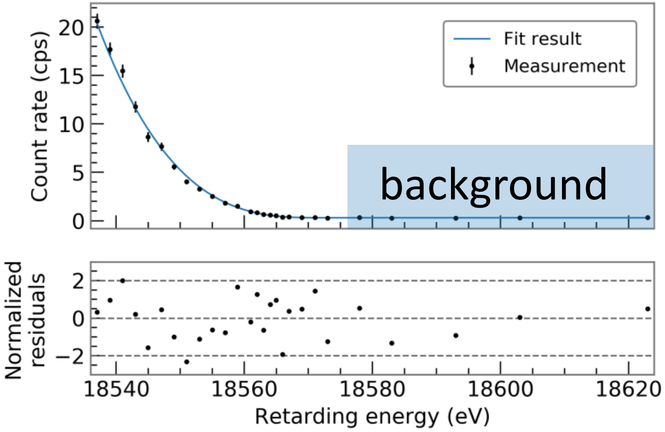
→ $E_{res} < 1$ eV at 18.6 keV

- electrons generated in the flux volume that have
  - high energies are trapped
  - low energies are transmitted

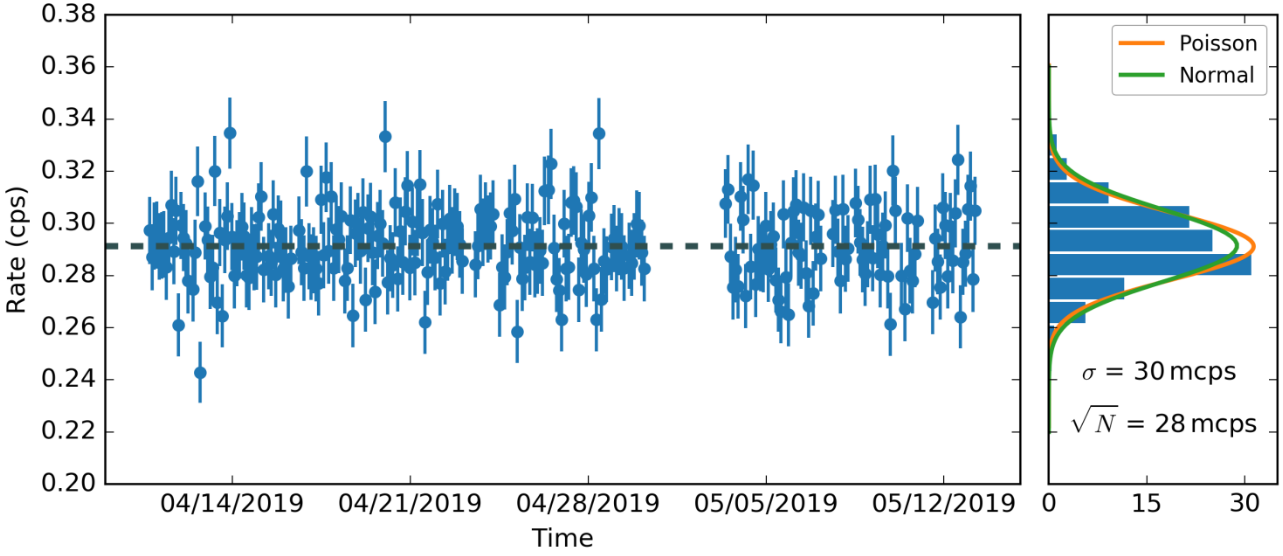


First neutrino mass measurement 2019

- 33 days of data taking (Apr – May 2019) at 25% of nominal tritium activity
- 274 "golden" tritium scans, each spends ~25% in the background region



Background during the first neutrino mass measurement

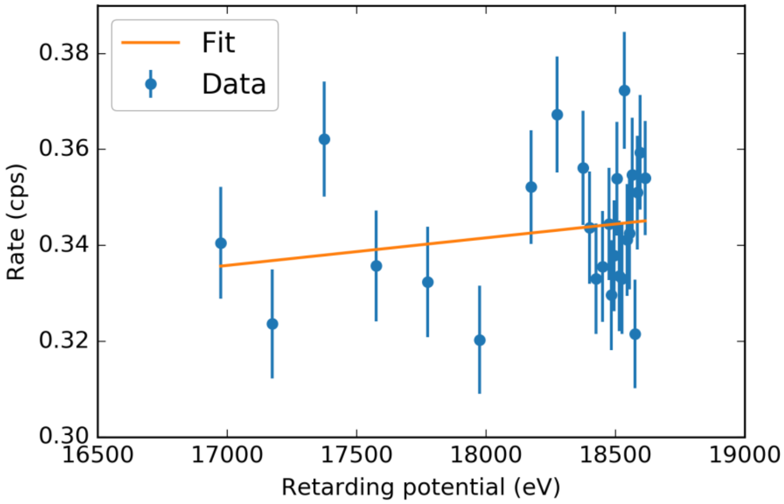


p(Poisson) < 1 %
p(Normal) ~ 45 %

- elevated, but stable background rate over whole measurement period
- events are not Poisson distributed
- distribution can be described by Poisson broadened with Gaussian

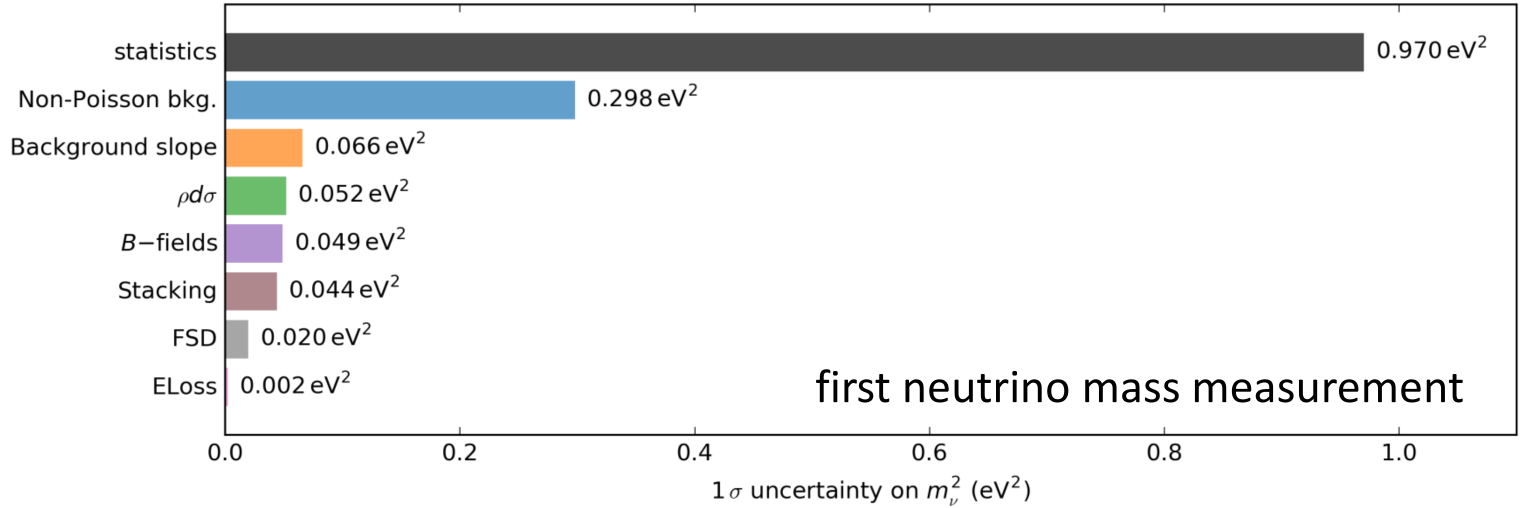
Background –
dependency on retarding potential

- 50 eV measurement point above endpoint to constrain the slope
- additional dedicated measurement to constrain retarding voltage dependence
- no indication for a significant slope, uncertainty of 5 mcps/keV



$$R(qU) = \text{const} + a \cdot qU$$
$$a = (5 \pm 5)\ \text{mcps/keV}$$

Impact of background on first neutrino mass



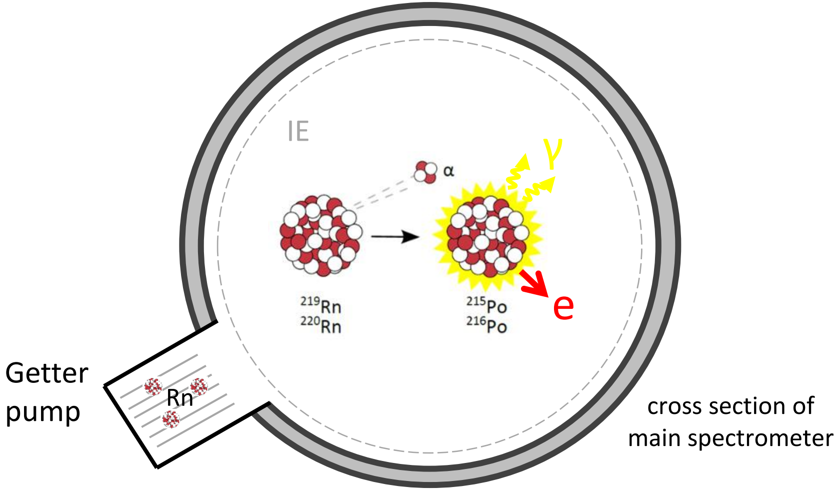
elevated background in KATRIN

- limits the neutrino mass sensitivity
- is by far the dominant systematic
  - slope
  - non-Poisson

What is the origin?

Background in KATRIN

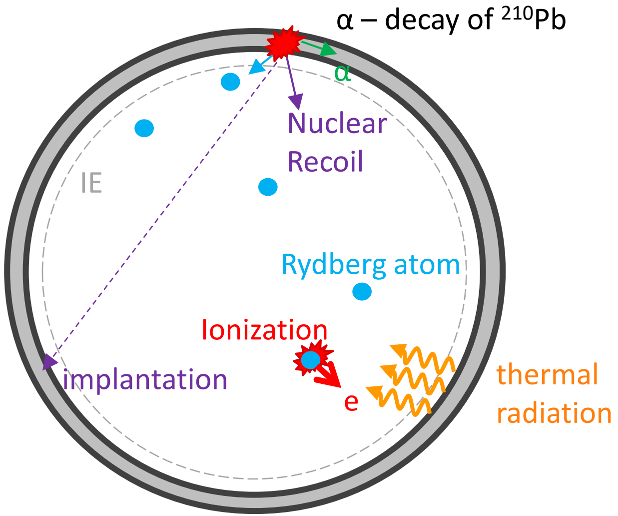
Radon induced background



- origin: residual radon from NEG pumps
- non-Poisson distributed

F. Fränkle et al, Astrop. Physics, V 35, Oct. 2011, P. 128-134,
S. Mertens et al, Astrop. Physics, V 41, Apr. 2012, P. 52-62,
N. Wandkowsky et al, 2013 J. Phys. G: Nucl. Part. Phys. 40 085102,
N. Wandkowsky et al, New Journal of Physics 15 (2013) 083040,
Görhardth et al., JINST 13 (2018), T10004

Rydberg induced background

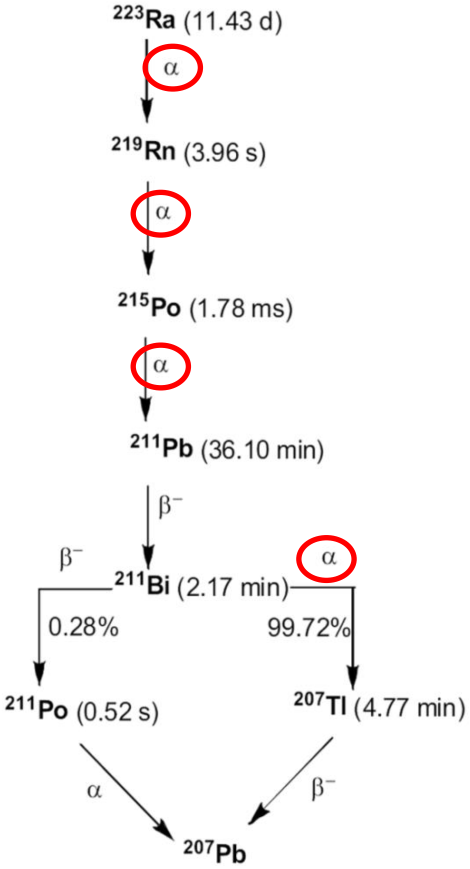


- origin: α – decays in the walls
- IE voltage dependence (field ionization)
- Poisson distributed

Characterizing the Rydberg background

- **goal**: Confirm α-decay in walls as origin
- **methodology**: generate artificial background and investigate IE dependence (idea: Ernst Otten)

- **realization**: introduce ^{223}Ra source to spectrometer
  → only short-lived isotopes
  → 4 α-decays → large Rydberg background expected



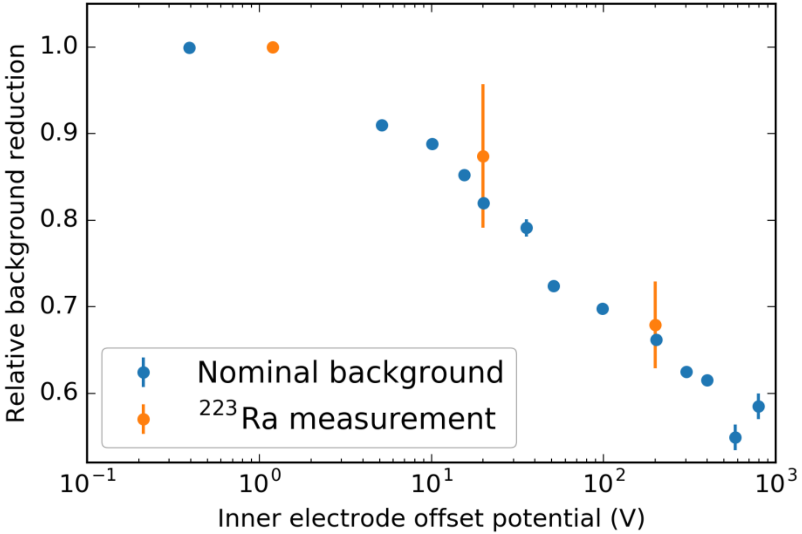
Technical implementation

- ^{223}Ra source produced at ISOLDE at CERN (thanks to K. Blaum)
- source activity of ~7 kBq during measurement
- source mounted to steel arm which is magnetically steered to MS surface level (thanks to K. Schlösser, H. Frenzel, K. Blaum)

photo by Klaus Schlösser


photo by D. Hinz

Artificial Rydberg background - results



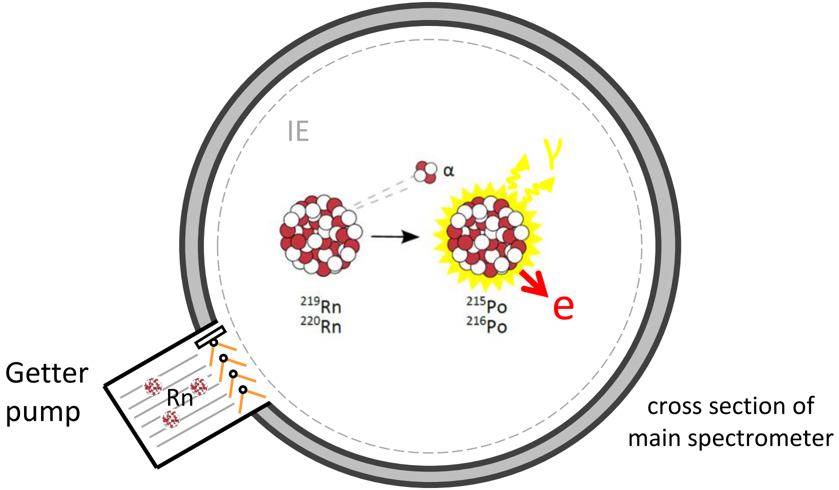
- ^{223}Ra-induced background shows the same IE dependence as the main spectrometer background

➡ confirms α-decays in the walls as the origin of the main spectrometer background

- consistent with previous results:
  F. Harms, PhD thesis
  F. Harms, DPG Spring meeting, Münster 2017
  N. Trost, PhD thesis

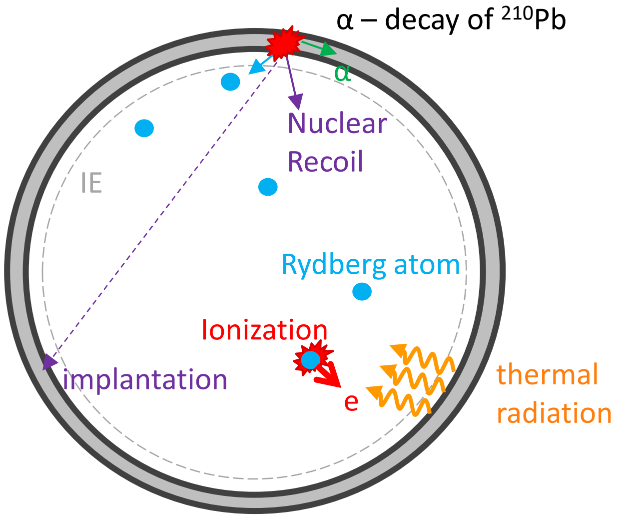
Background in KATRIN - countermeasures

Radon induced background



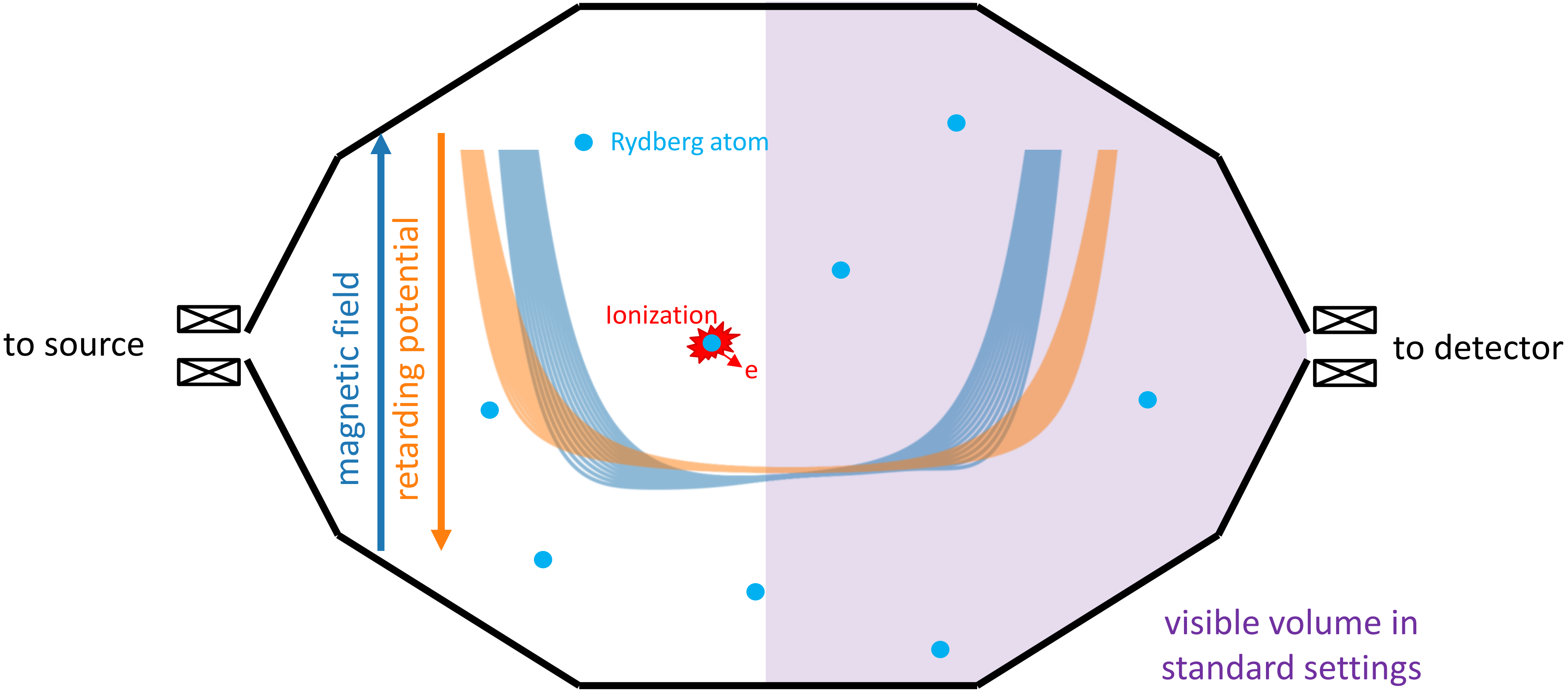
- retention by cold baffles in front of NEG pumps
- efficiency depends on baffle temperature and surface conditions (e.g. adsorbed water ice)
- ➡ baking of baffles prior to next measurements

Rydberg induced background



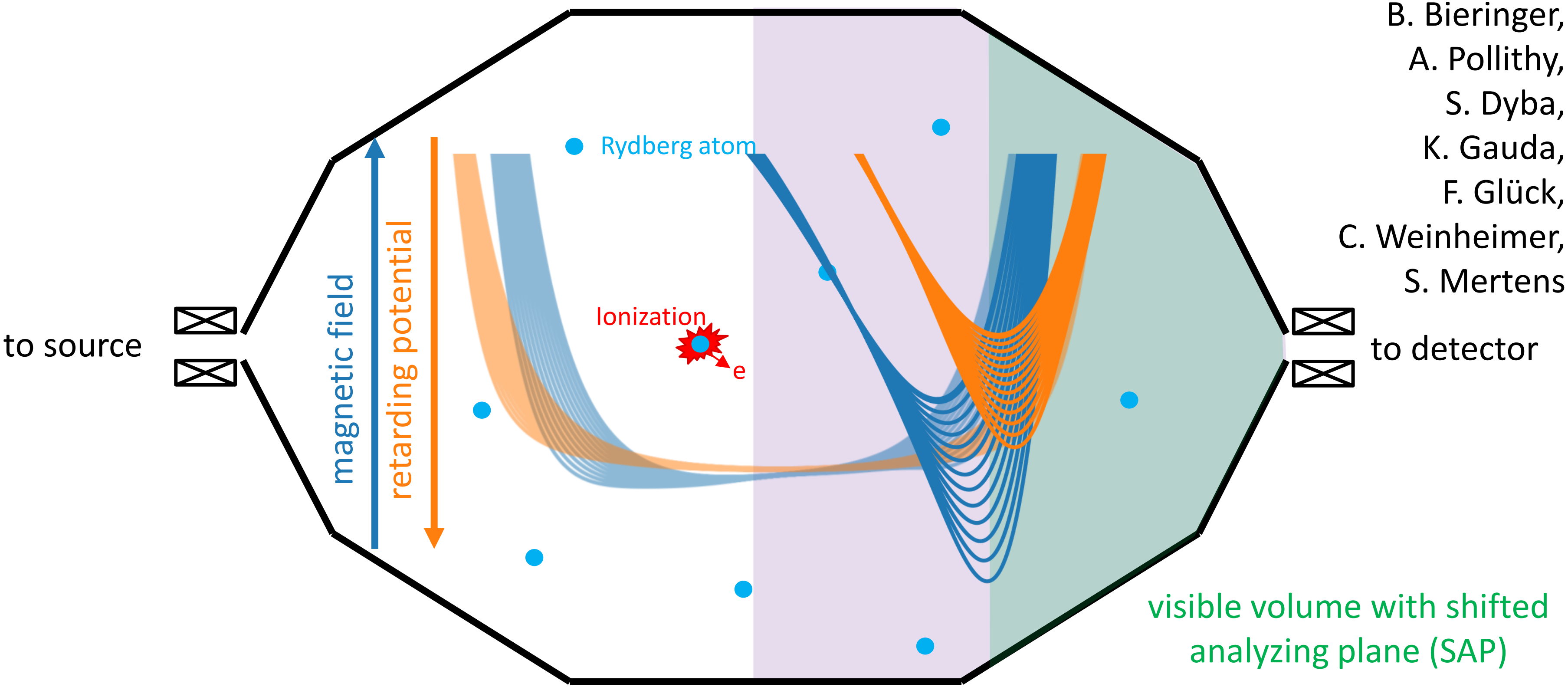
- background proportional to volume
- ➡ decrease "visible" volume

Mitigating the Rydberg background

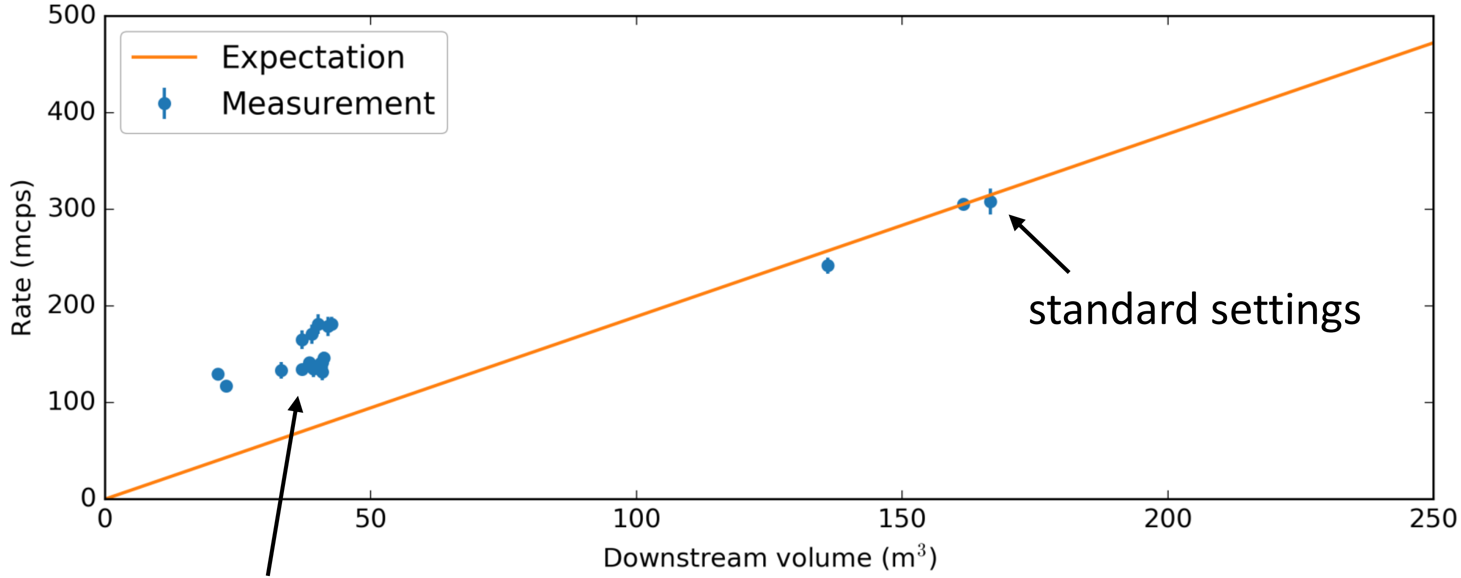


Mitigating the Rydberg background

SAP team:
A. Lokhov,
B. Bieringer,
A. Pollithy,
S. Dyba,
K. Gauda,
F. Glück,
C. Weinheimer,
S. Mertens



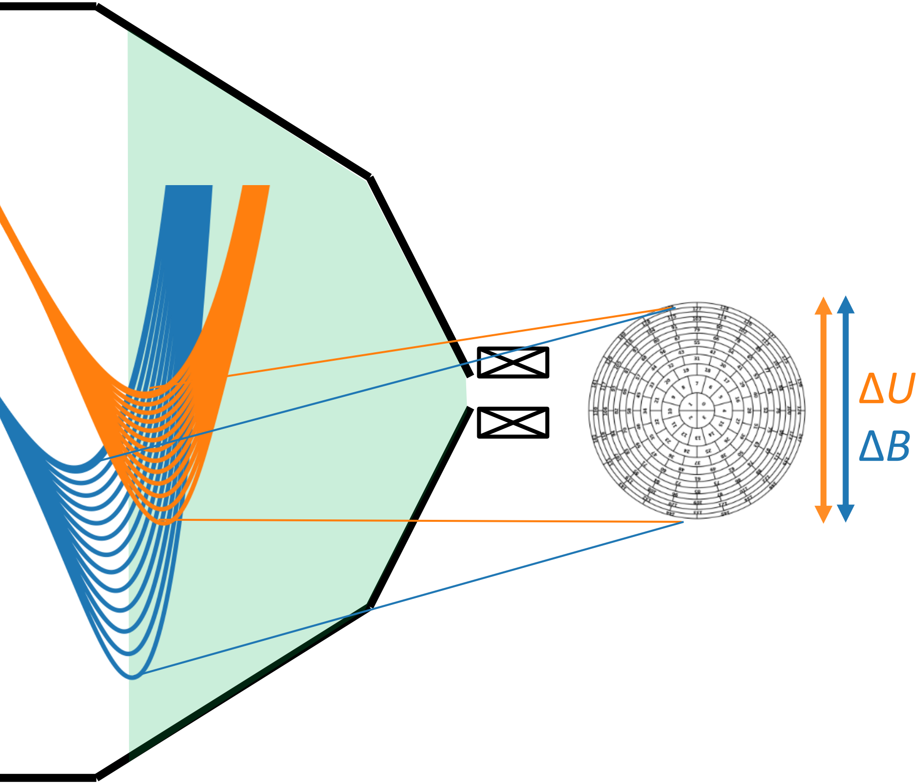
Mitigating the Rydberg background



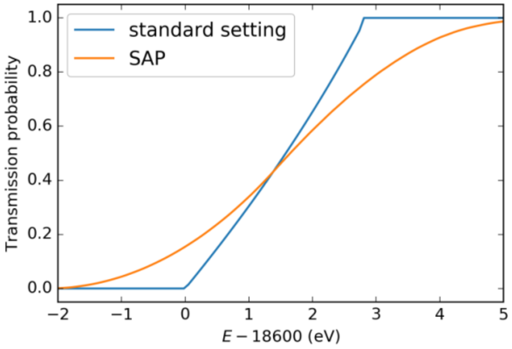
various SAP configurations
reduction limited by residual
Radon background
eliminated after bake-out

➡ background reduction by more than factor of 2

Shifted analyzing plane - challenges

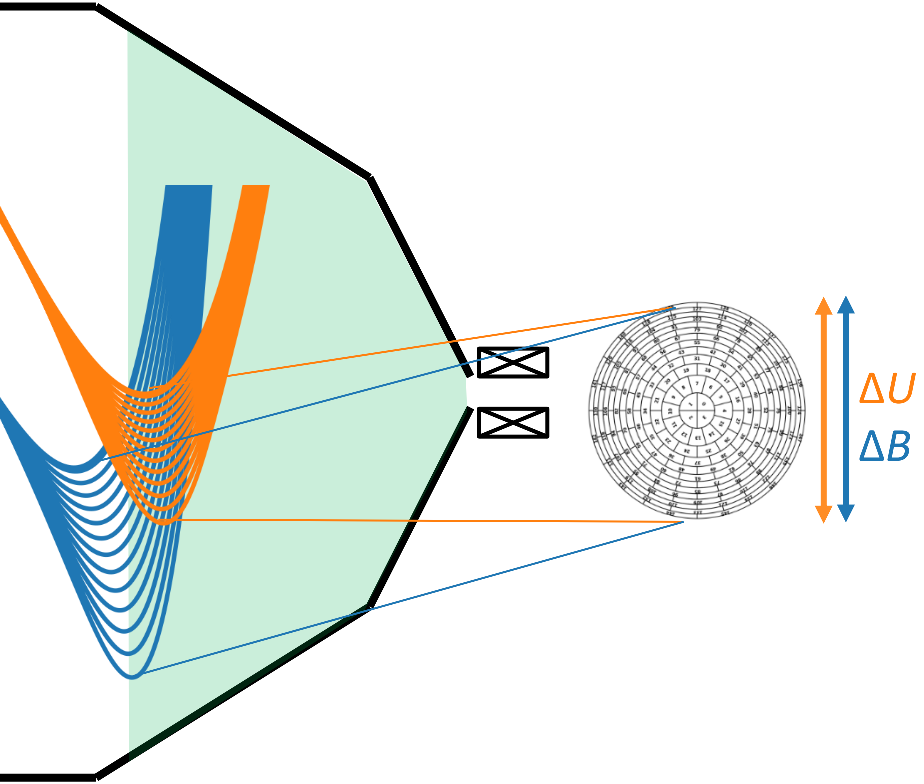


- Large inhomogeneity of magnetic field and potential
- needs to be taken into account in the analysis
- fields need to be determined precisely



averaged transmission function

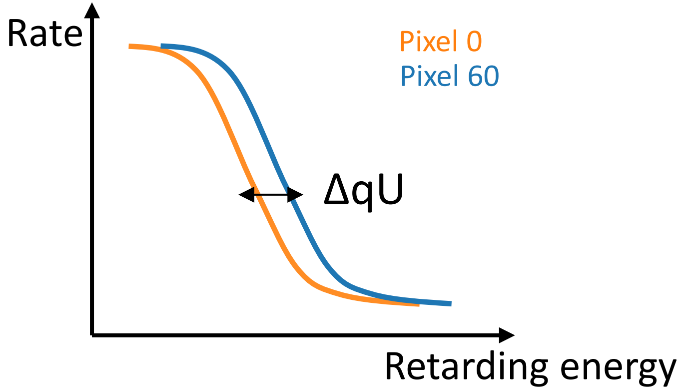
Field determination in KATRIN - ΔU



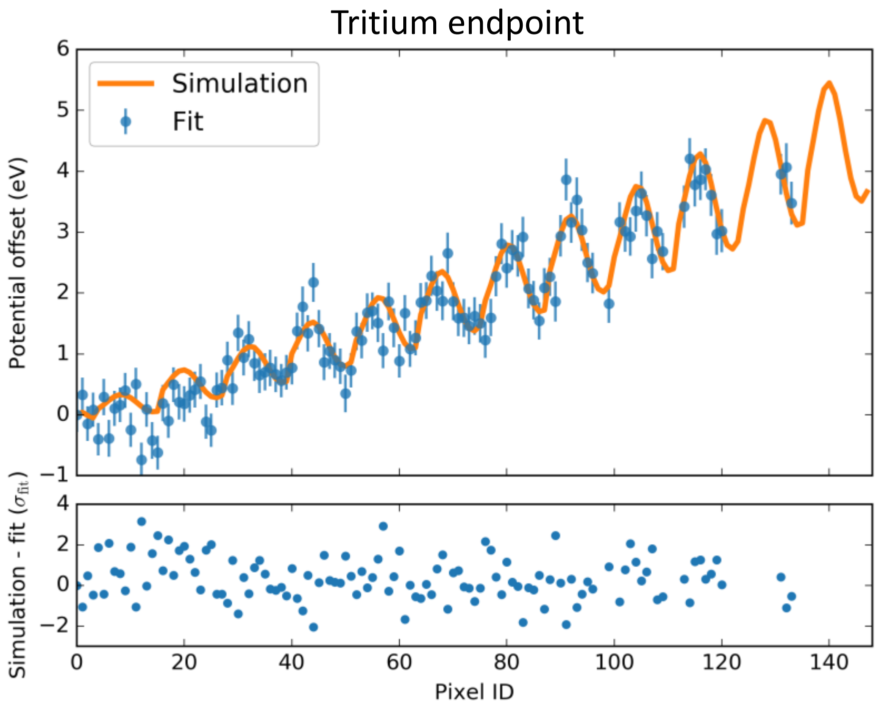
- each pixel detects a rate corresponding to a different retarding potential

→ **Tritium**: shift of endpoint

→ ^{83m}**Kr**: shift of line position



Field determination in KATRIN - ΔU



- good agreement
- dominated by statistics

Conclusion

- Background during first neutrino mass measurement:
  - stable but not Poisson distributed
  - dominating systematic because of elevated background and low statistics
- origin of the KATRIN background: Radon & Rydberg induced background

➡ non-Poisson
➡ retention by improving baffle performance

➡ Poisson & proportional to volume
➡ mitigation by shifted analyzing plane

- shifted analyzing plane:
  - background reduction successfully demonstrated
  - first results towards a full field characterization were obtained
- Stay tuned for future results!