Karlsruhe Institute of Technology

^{83m}Kr N-line spectrum measurement at KATRIN

Jaroslav Štorek for the KATRIN collaboration

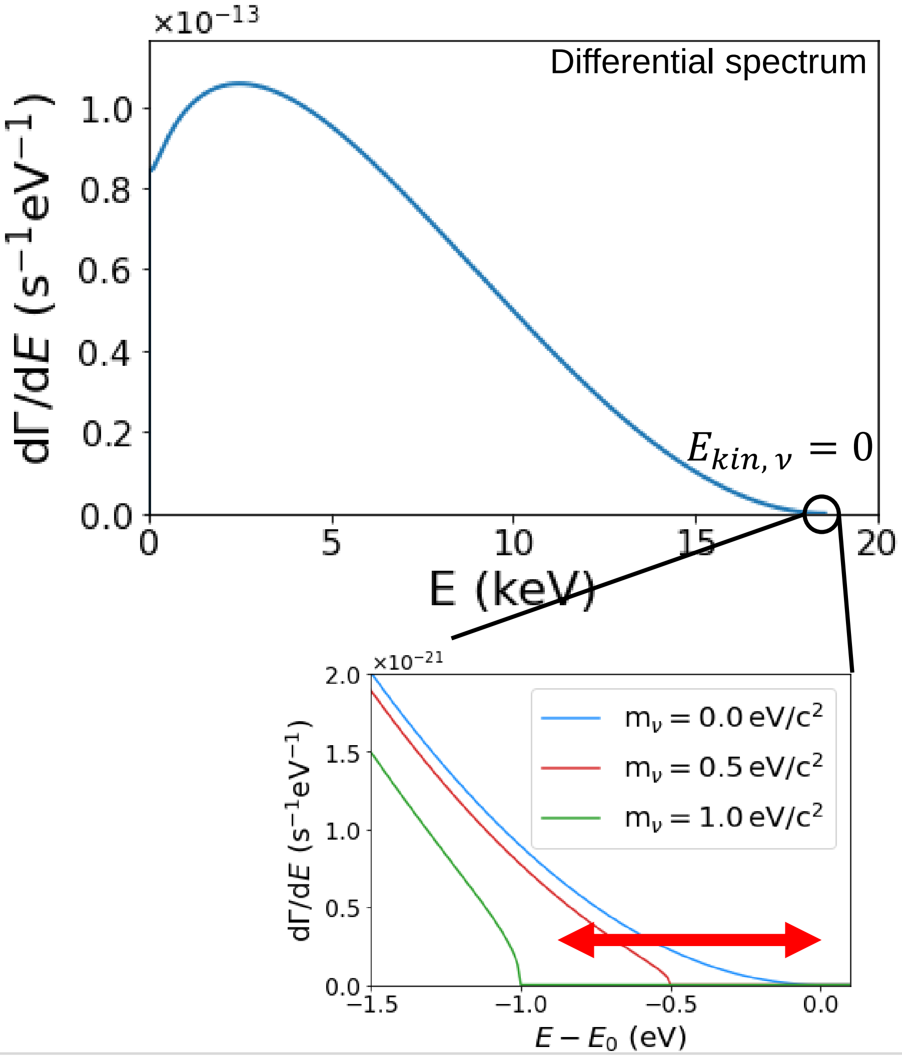
Introduction | Krypton-83m | Results

Direct measurement of neutrino mass

- Tritium beta decay kinematics
  - $T_2 \rightarrow {}^3\mathrm{HeT}^+ + e^- + \bar{\nu}_e + Q(T_2)$

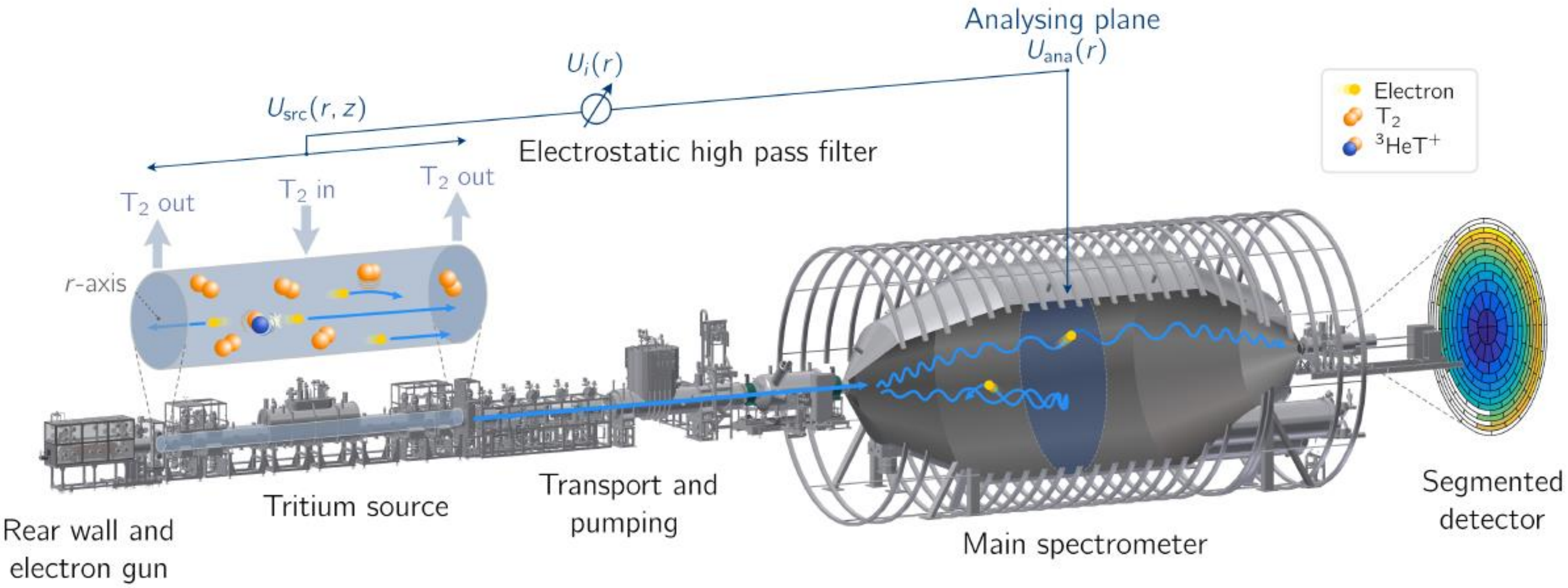
    E: ✓ measure ? ✓

    $E_{kin,\nu} + m_\nu c^2$
- Challenging because
  - Very small effect on the sub-eV scale
  - Low intensity in the endpoint region



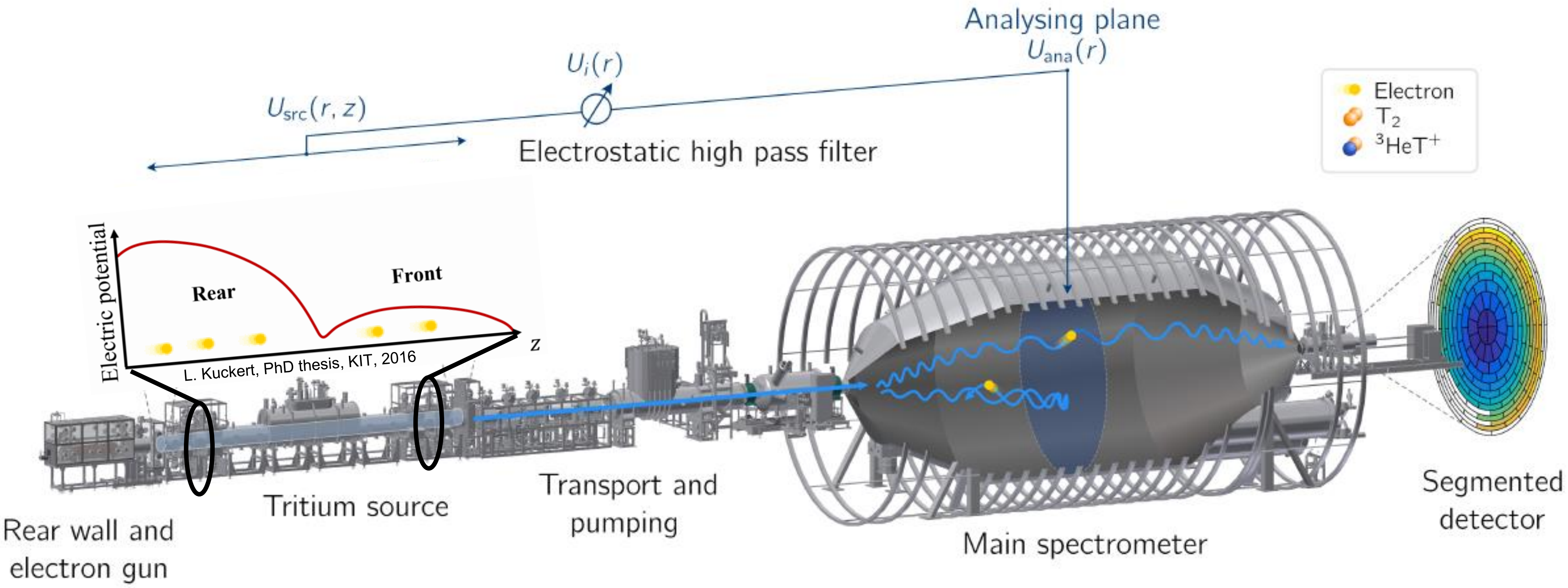
KATRIN experiment

- Energy measurement by electrostatic filter



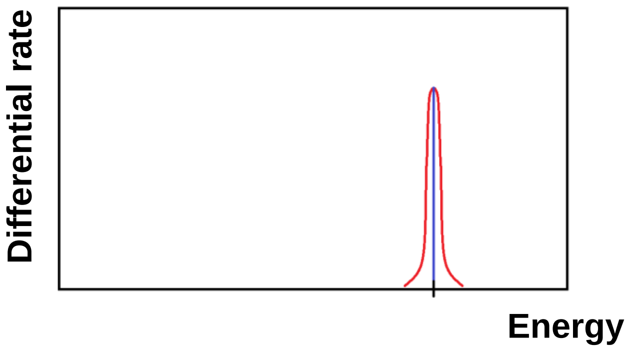
KATRIN experiment

- Inhomogeneous source potential → different energy thresholds for different z

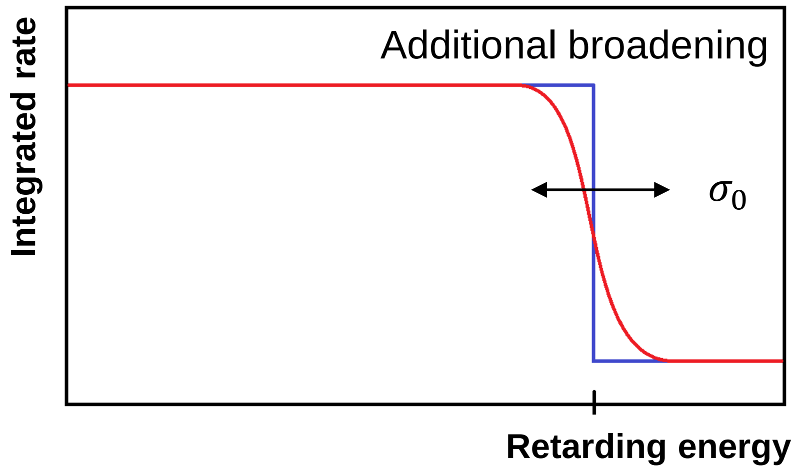


Impact of inhomogeneous potential

- Monoenergetic electrons



Homogeneous potential
Inhomogeneous potential
↕
broadening ✓



- Continuous beta spectrum
  - Total source potential systematic effect on m_ν^2: 0.02 eV²
  - Systematic budget on m_ν^2 ~ 0.017 eV² [1]

→ precise knowledge of the starting potential

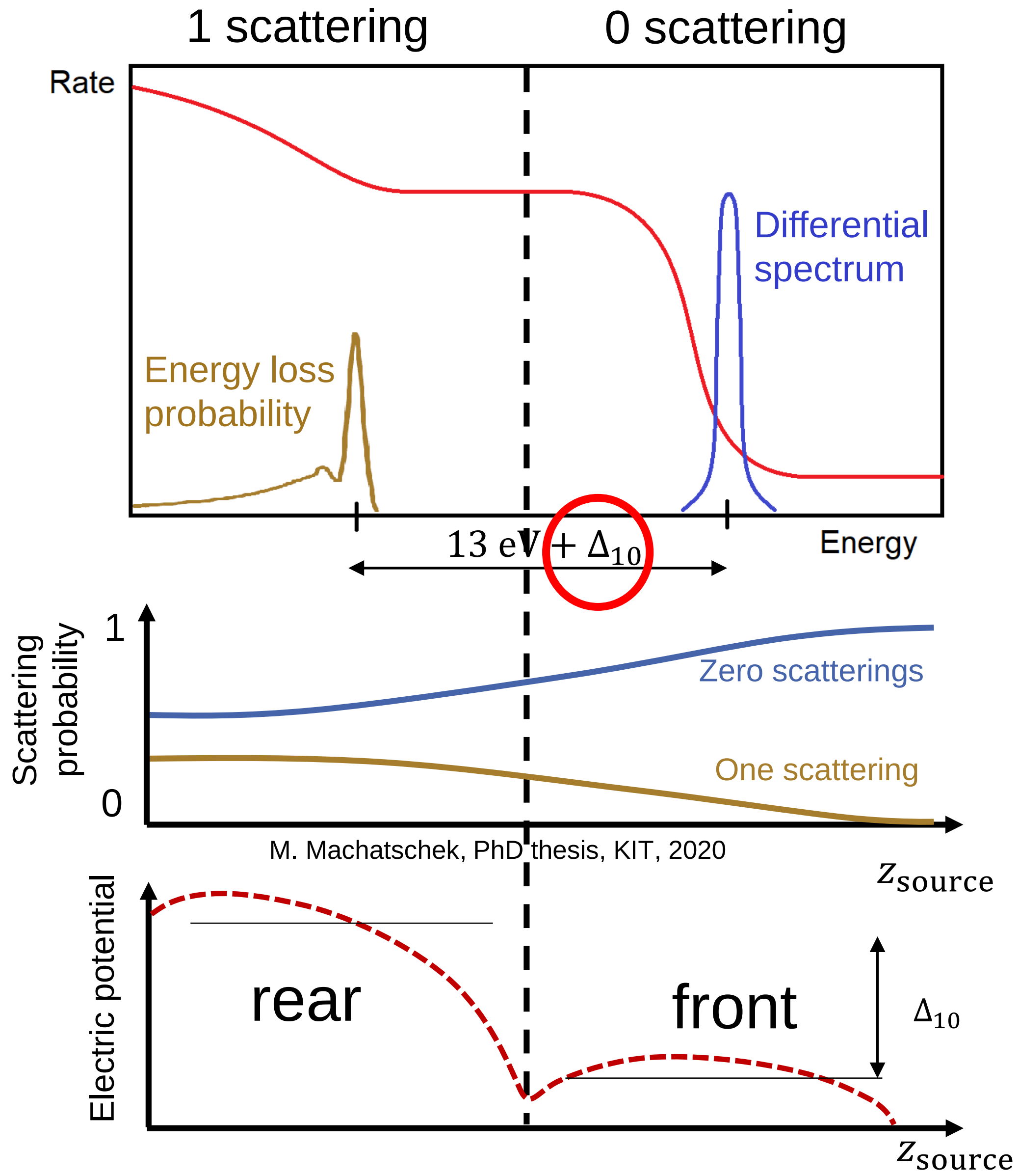
Two parameters:

a) broadening σ_0
b) energy loss shift Δ_{10}

[1] J. Angrik et al., (KATRIN), KATRIN design report. DOI: 10.5445/IR/270060419

Electron scattering off tritium molecules

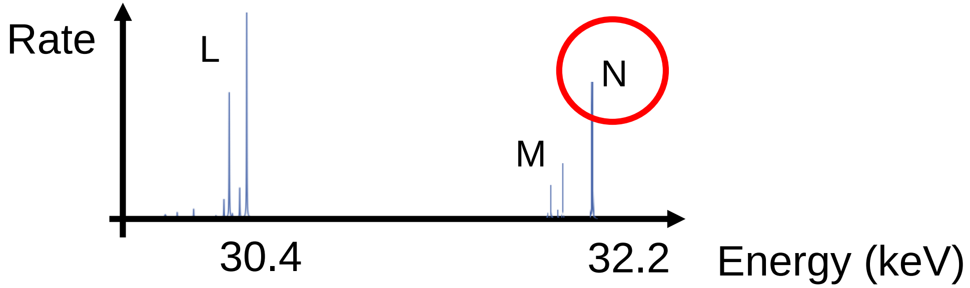
- Opens access to rear source potential
- Electron scattering on T_2 leads to minimum loss of 13 eV
- Difference of rear and front potentials: Δ_{10}
  - Direct impact on neutrino mass shift
    $$\Delta m_\nu^2 = -2\sigma_0^2 - \epsilon\Delta_{10}$$
    $$\epsilon \sim 1.2\ \mathrm{eV}$$
  - Δ_{10} sensitivity ~ 10 meV needed

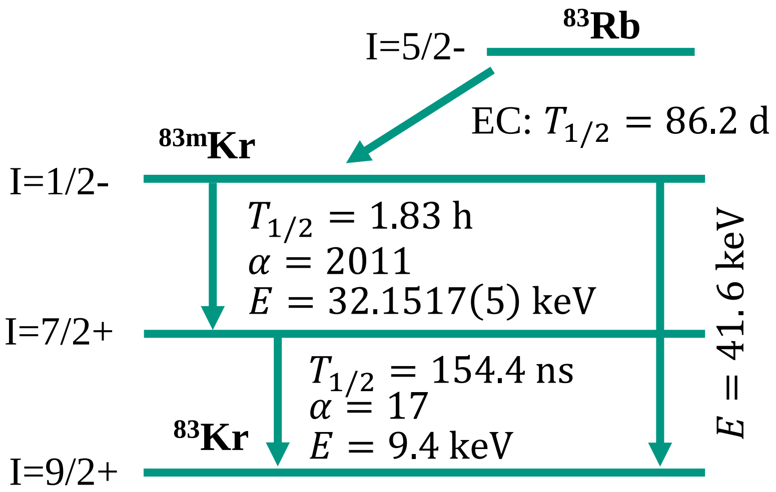


Krypton-83m

Krypton electron source

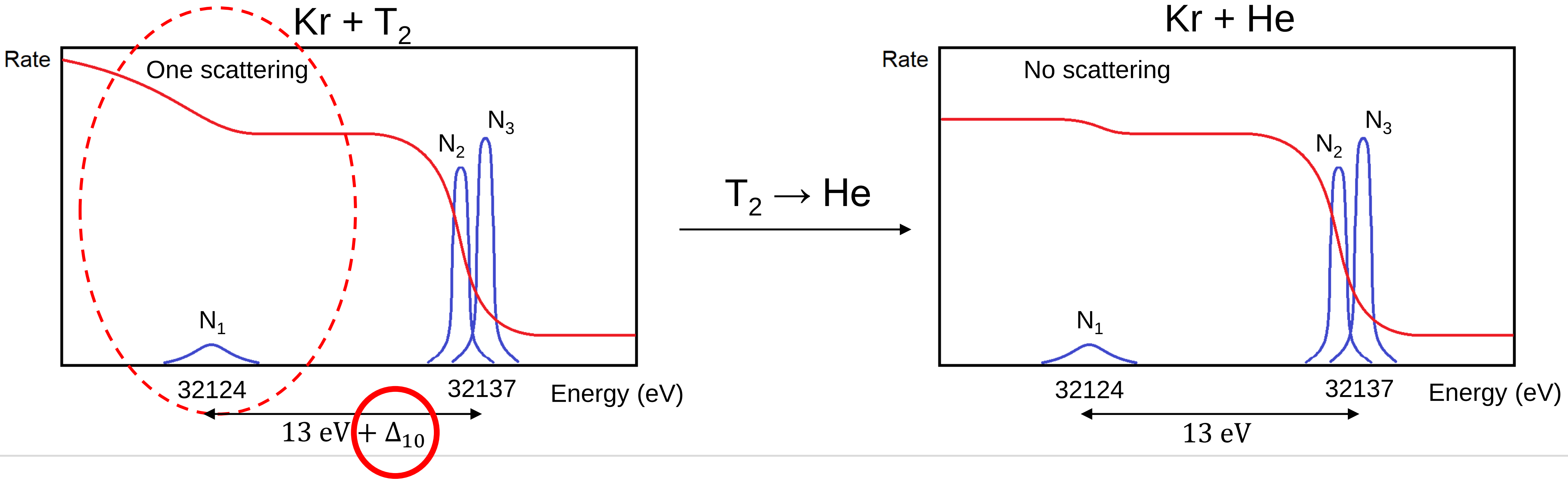
- Krypton-83m because
  1. Gaseous – mix krypton with tritium and obtain the same spatial distribution
  2. Decays fast – no contamination
- Two gamma transitions at 32.2 keV and 9.4 keV
- Weak 41.6 keV line is also present
- Highly converted into electrons
  - Discrete quasi-monoenergetic spectrum
  - Negligible line widths of N shell lines





Improve Δ_{10} by measuring N1 line

- Not well known N_1 line lies in the T_2 scattering region → substitute T_2 by He
- Electron scattering off helium induces minimum energy loss of 21 eV
- Precise knowledge of N_1 line contribution
  → smaller uncertainty of Δ_{10}
- Reach mV uncertainties of the starting electric potential with keV lines



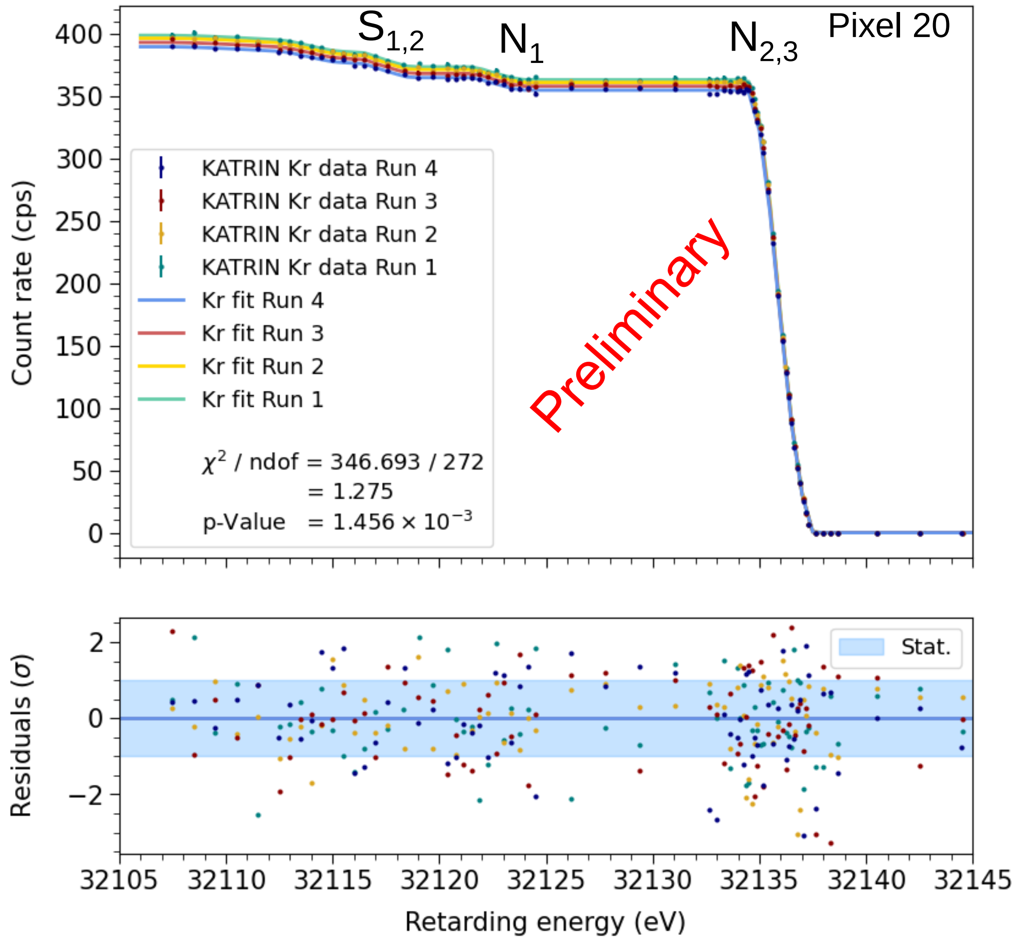
Results

Measurement results

- Strong rubidium source (10 GBq)
- 77 scan steps, 16 mins per step
- Foreseen uncertainties:

	Foreseen σ	Literature σ [2]
E_{N1}^{rel} [eV]	$\mathcal{O}(10^{-2})$	$\mathcal{O}(10^{-1})$
Γ_{N1}^{2} [eV^2]	$\mathcal{O}(10^{-3})$	$\mathcal{O}(10^{-2})$
I_{N1} [%]	$\mathcal{O}(10^{-4})$	$\mathcal{O}(10^{-4})$

- Uncertainty of N_1 line parameters is influenced by spectrum complexity
  - Shake lines, 41 keV line
  - 35 fit parameters, 7 of interest



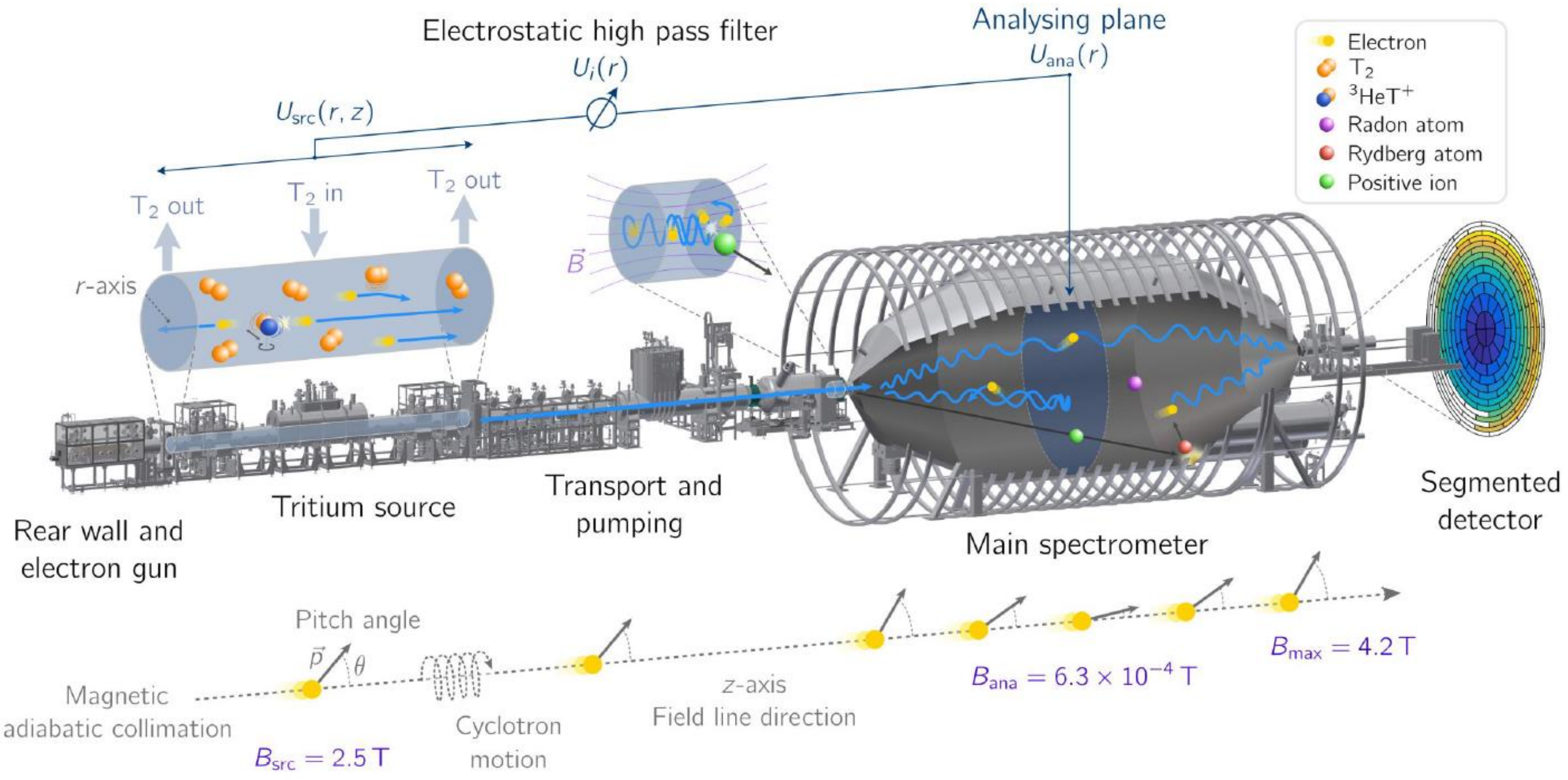
[2] D. Vénos *et al* 2018 *JINST* **13** T02012

Summary and outlook

- KATRIN perfoms precision measurement of tritium beta spectrum
- Determine the source potential by ^{83m}Kr monoenergetic electrons
- Knowledge of N_1 line decreases uncertainty on electric potential observables
- Successful preliminary fits
- Complex N + shake line spectrum due to integrated mode
- Outlook:
  - Improve our model for 41 keV line and shake lines

Thank you for your attention!

Backup



Electrostatic high pass filter
$U_i(r)$
Analysing plane
$U_{ana}(r)$
$U_{src}(r, z)$
Electron
T_2
$^3HeT^+$
Radon atom
Rydberg atom
Positive ion
T_2 out
T_2 in
T_2 out
r-axis
$\vec{B}$
Rear wall and electron gun
Tritium source
Transport and pumping
Main spectrometer
Segmented detector
Pitch angle
$\vec{p}$
θ
Magnetic adiabatic collimation
$B_{src} = 2.5\,T$
Cyclotron motion
z-axis
Field line direction
$B_{ana} = 6.3 \times 10^{-4}\,T$
$B_{max} = 4.2\,T$