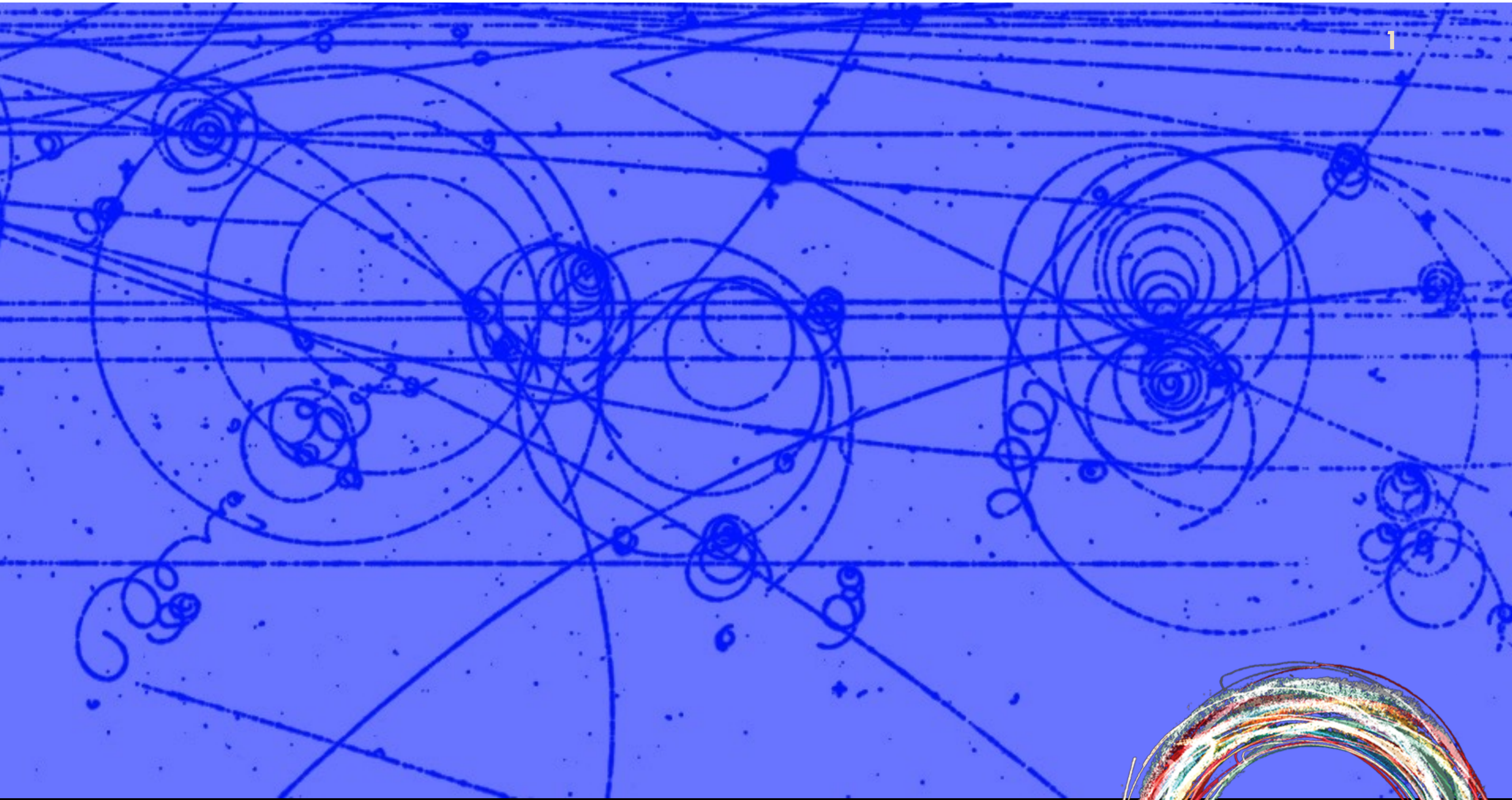


DIRECT MEASUREMENTS OF NEUTRINO MASS

PHY 493/803

Absolute measurements of neutrino mass

- Neutrino oscillations only provide mass differences between mass eigenstates
- Direct measurements of the neutrino mass
  - Infer from cosmological parameter fits
    - CMB and others
    - Large neutrino mass would contribute to structure formation in the universe
    - $\Rightarrow$ sum of neutrino masses < 0.17 eV
  - Detecting cosmic neutrinos from a supernova explosion
    - Neutrinos are produced at different energies
    - Difference in arrival time determined by relativistic γ factor
  - Measuring the end point of beta decay

Supernova 1987A

Cosmic rays from the Sun or the supernova are important sources of information about neutrinos and other particles to test predictions made by the grand unified and SUSY theories.

Example : neutrinos from 1987A supernova explosion

A star has a mass greater than roughly 11 solar masses

After all stage of fusion reactions, the iron core starts to contract under gravity

More of the outer core is burned, more iron deposited in the core, resulting in a catastrophic collapse (1.4 solar masses).

relevant reactions

$$\gamma + {}^{56}Fe \rightarrow 13 \cdot {}^{4}He + 4n$$

$$\gamma + {}^{4}He \rightarrow 2p + 2n$$

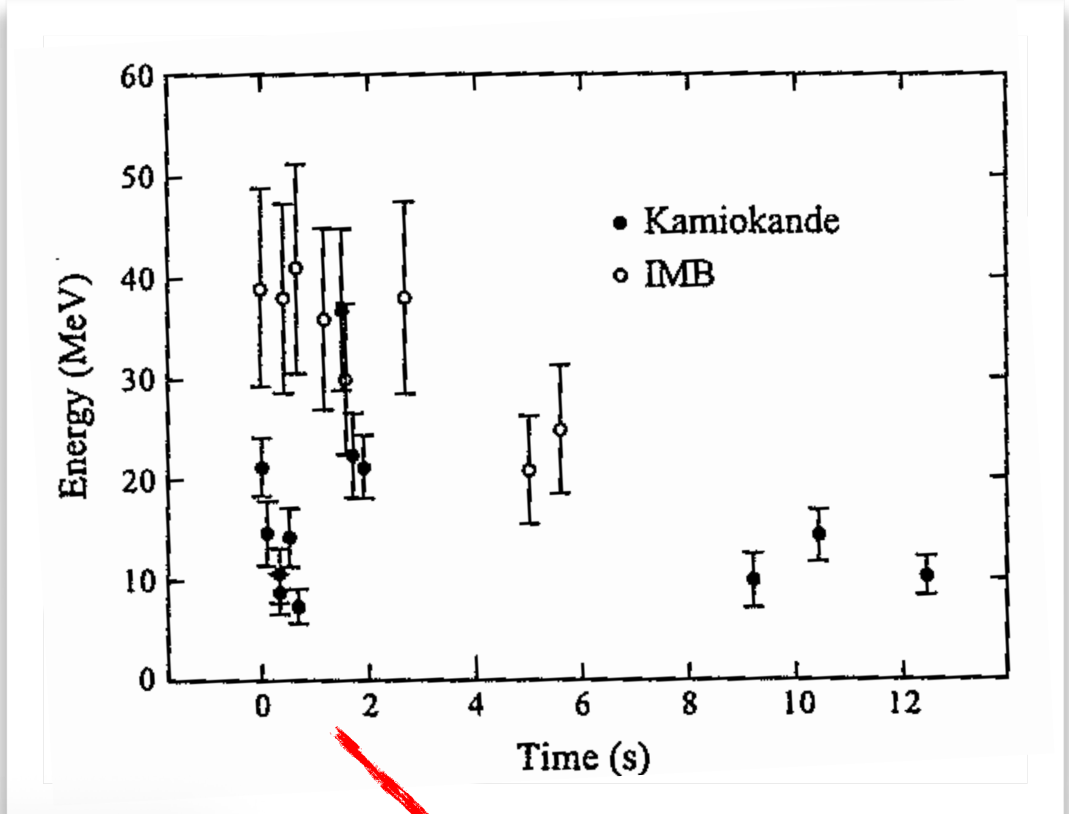
$$e^- + p \rightarrow n + \nu_e \quad \ldots \text{ neutron star}$$

Supernova 1987A

The neutrinos from SN1987A were detected by the Kamiokande (12 events) and the IMB (8 events) experiments.

The neutrino mass can be estimated from the data using the time of the arrival for each neutrino (ν_i):

$$t_i = t_0 + \left(\frac{L}{c}\right)\left(1 + \frac{m^2c^4}{2E_i^2}\right)$$



The time difference is then:

$$(\Delta t)_{ij} = t_i - t_j = \frac{Lm^2c^4}{2c}\left(\frac{1}{E_i^2} - \frac{1}{E_j^2}\right)$$

$$m_{\bar{\nu}_e} \leq 20\ \text{eV}$$

Direct measurements of neutrino mass

Oscillation experiments tell us mass differences but not absolute values

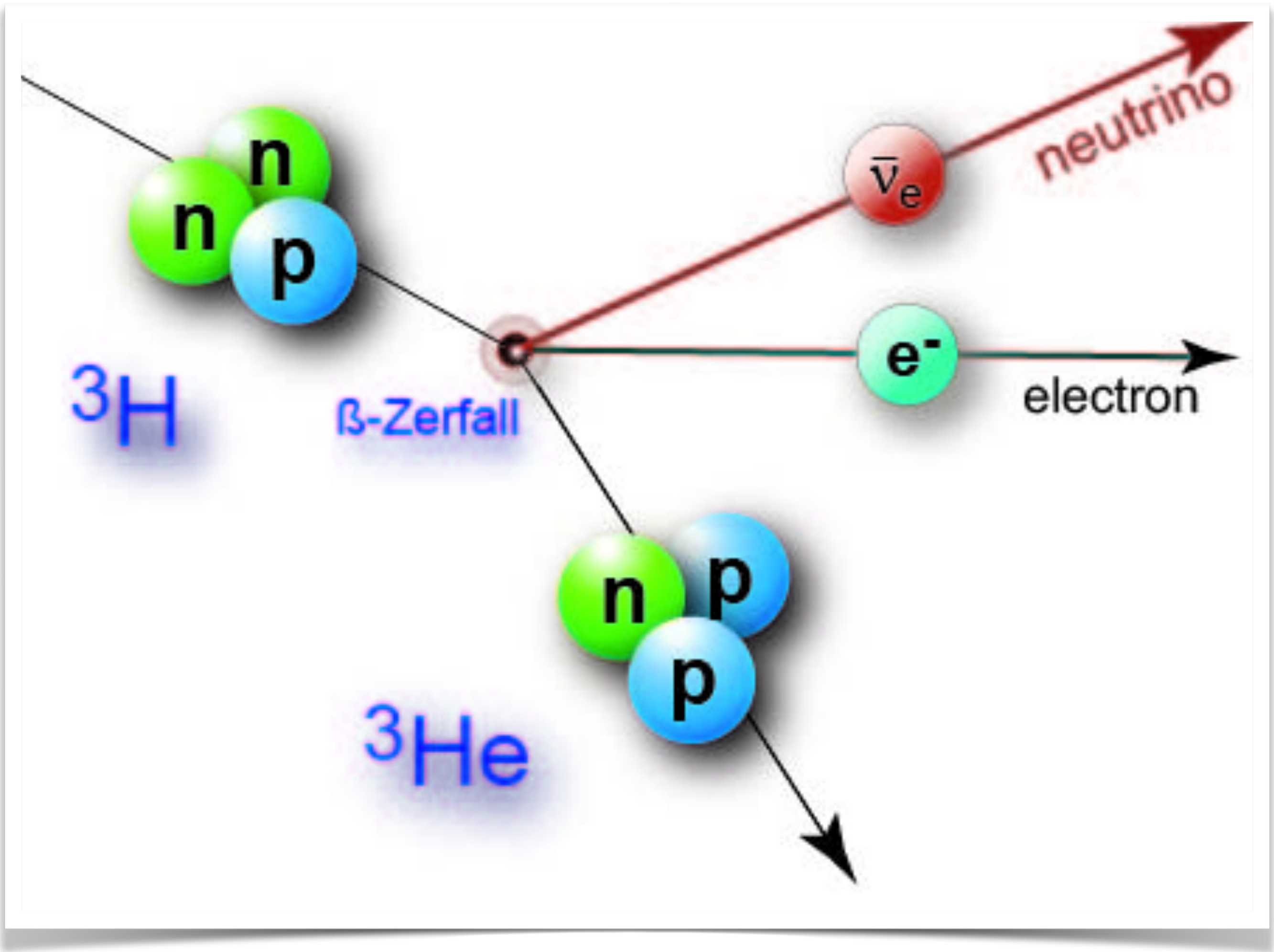
Direct measurements:

ν Flavor	Mass Limit	Process
ν_e	$m_\nu < 2$ eV	${}^3\mathrm{H} \rightarrow {}^3\,\mathrm{He} + e^- + \bar{\nu}_e$
ν_μ	$m_\nu < 190$ keV	$\pi \rightarrow \mu + \nu_\mu$
ν_τ	$m_\nu < 18.2$ MeV	$\tau \rightarrow 3\pi + \nu_\tau$

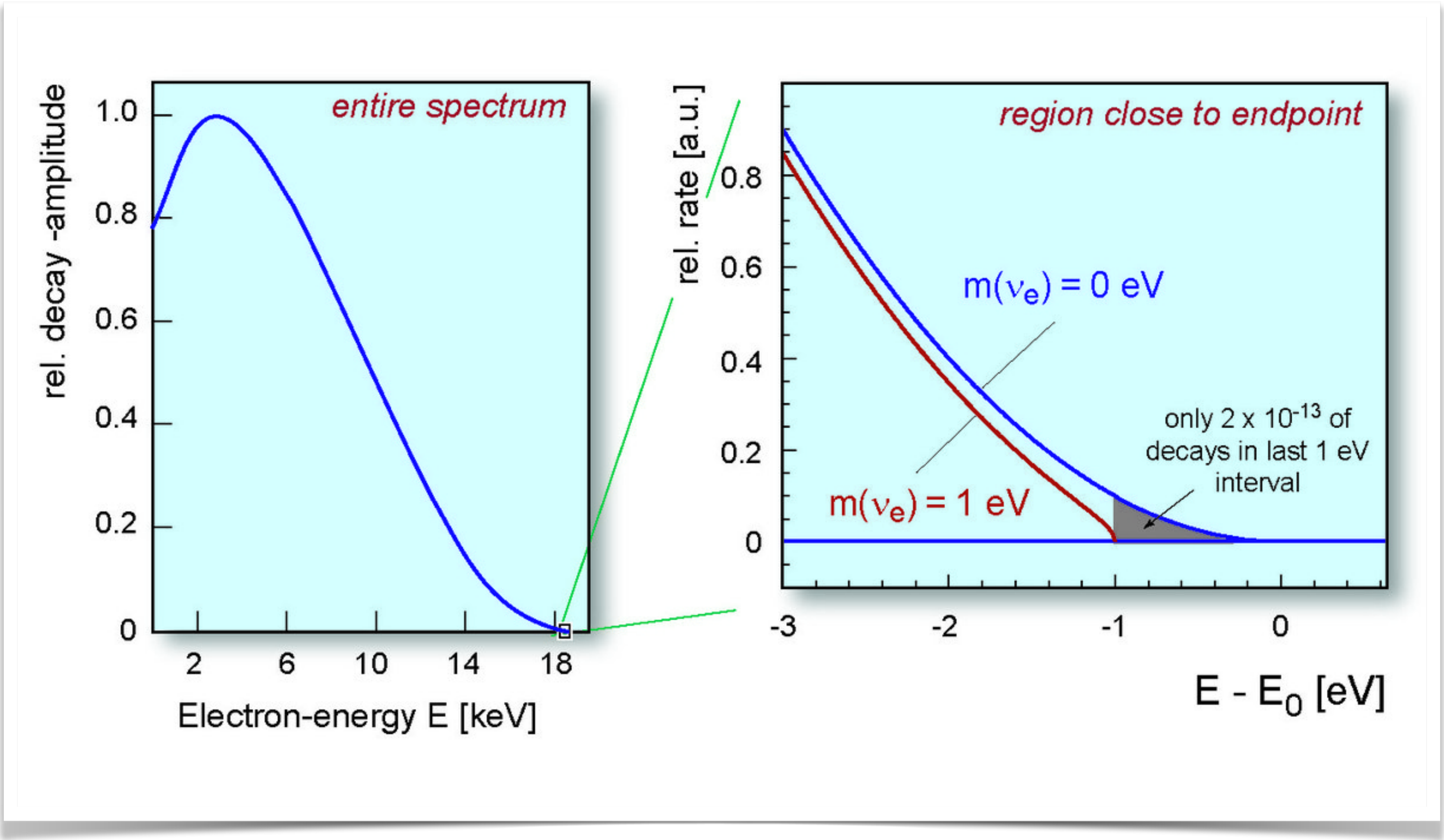
But:
- This is not measuring mass Eigenstates
- Interpretation is based on weak decays - it depends on what a neutrino actually is.
- Neutrino and anti-neutrino masses don't have to be the same

Mass of the Electron Neutrino from Tritium decay

Tritium decay can be a very effective way to probe the neutrino mass.
The decay products can be measured very carefully to work out the kinematics.

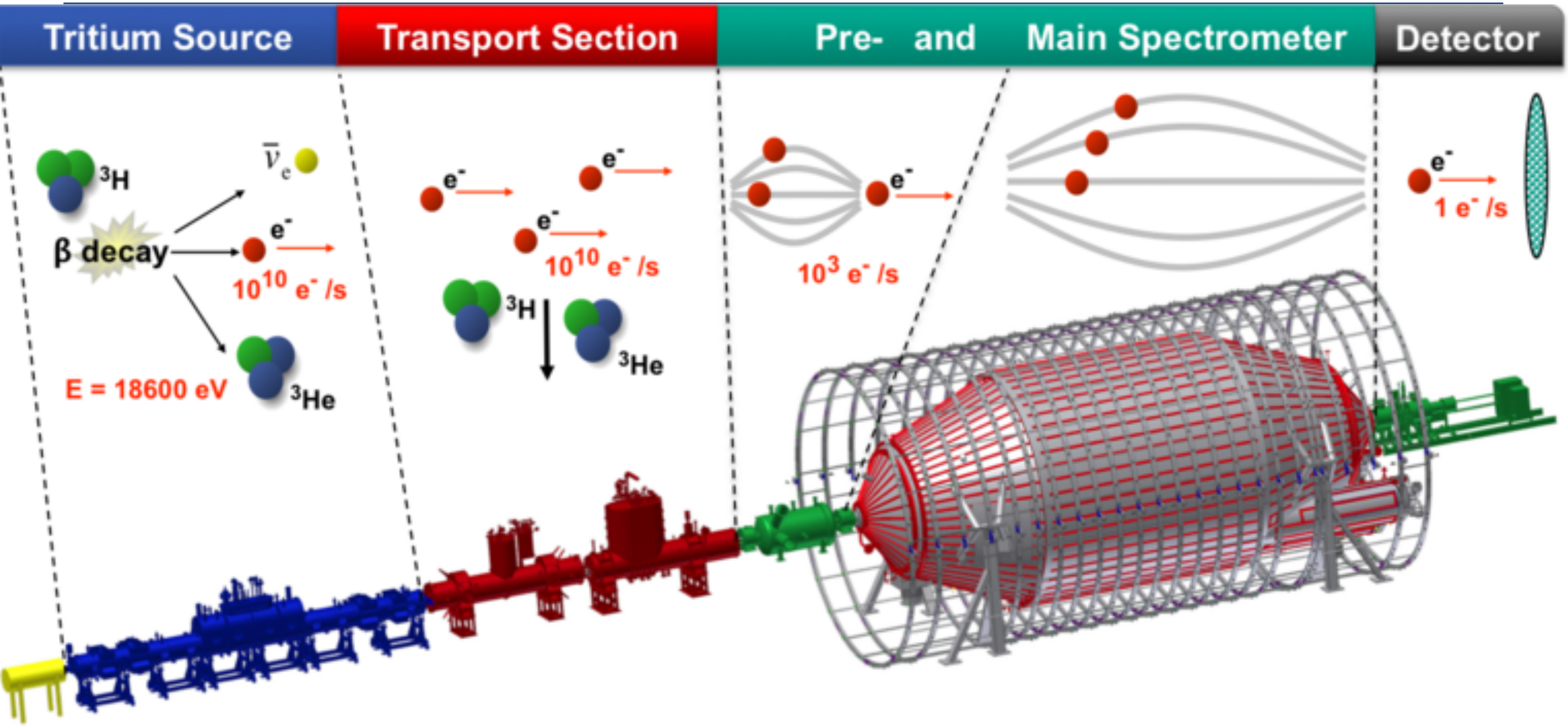


Tritium decay electron energy spectrum



Measurements like this tell us $m(\nu_e) < 2$ eV

The KATRIN Experiment



Tritium decays, releasing an electron and an anti-electron-neutrino. While the neutrino escapes undetected, the electron starts its journey to the detector.

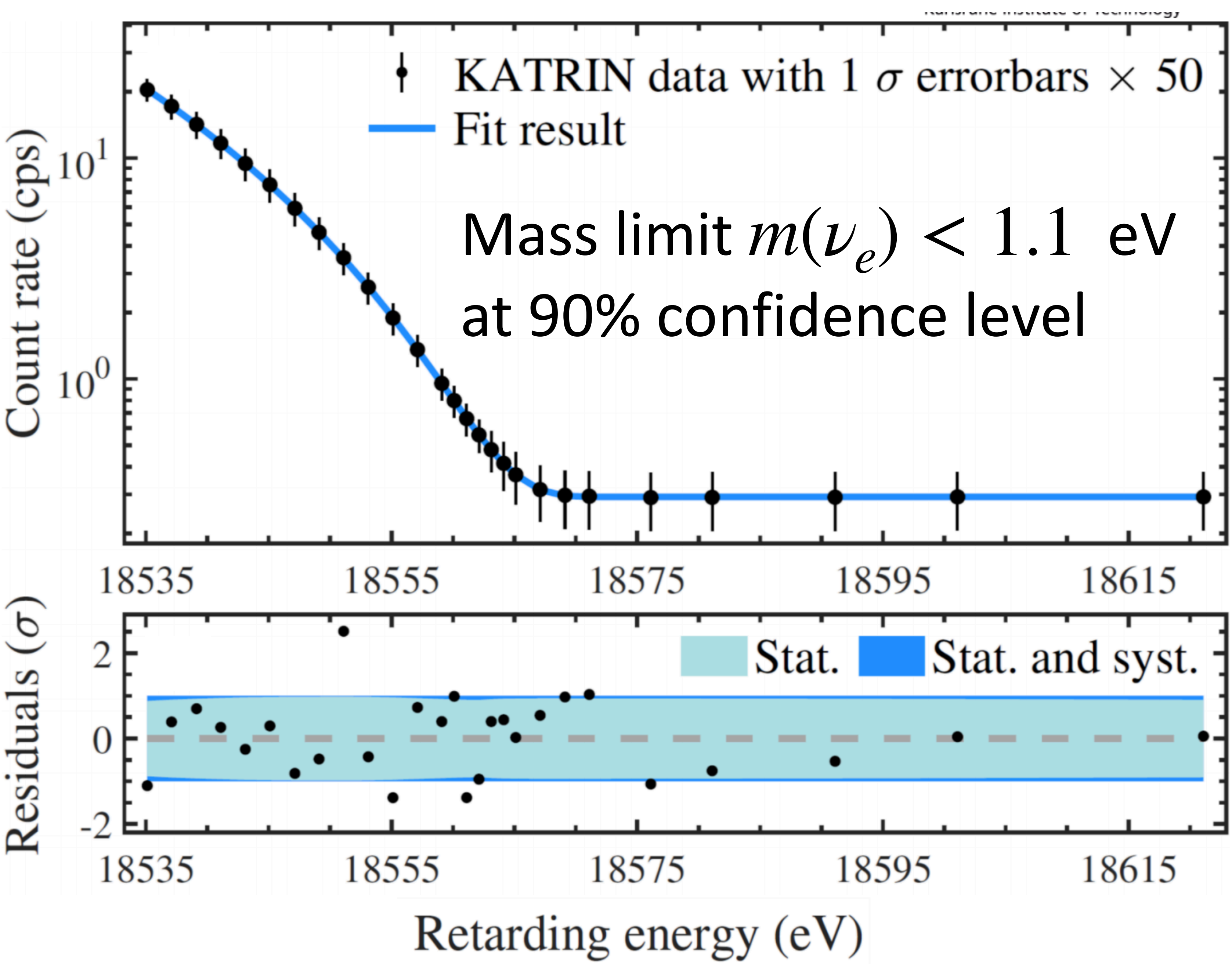
Electrons are guided towards the spectrometer by magnetic fields. Tritium has to be pumped out to provide tritium free spectrometers.

The electron energy is analyzed by applying an electrostatic retarding potential. Electrons are only transmitted if their kinetic energy is sufficiently high.

At the end of their journey, the electrons are counted at the detector. Their rate varies with the spectrometer potential and hence gives an integrated β-spectrum.

Transporting the Katrin spectrometer

Katrin measurement



Mass limit $m(\nu_e) < 1.1$ eV
at 90% confidence level