Karlsruhe Tritium Neutrino Experiment

Karlsruhe Institute of Technology

The Windowless Gaseous Tritium Source of KATRIN

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International School for Nuclear Physics:

Neutrinos in Astro- Particle- and Nuclear Physics

Erice 2009

bmb+f - Förderschwerpunkt

Astroteilchenphysik

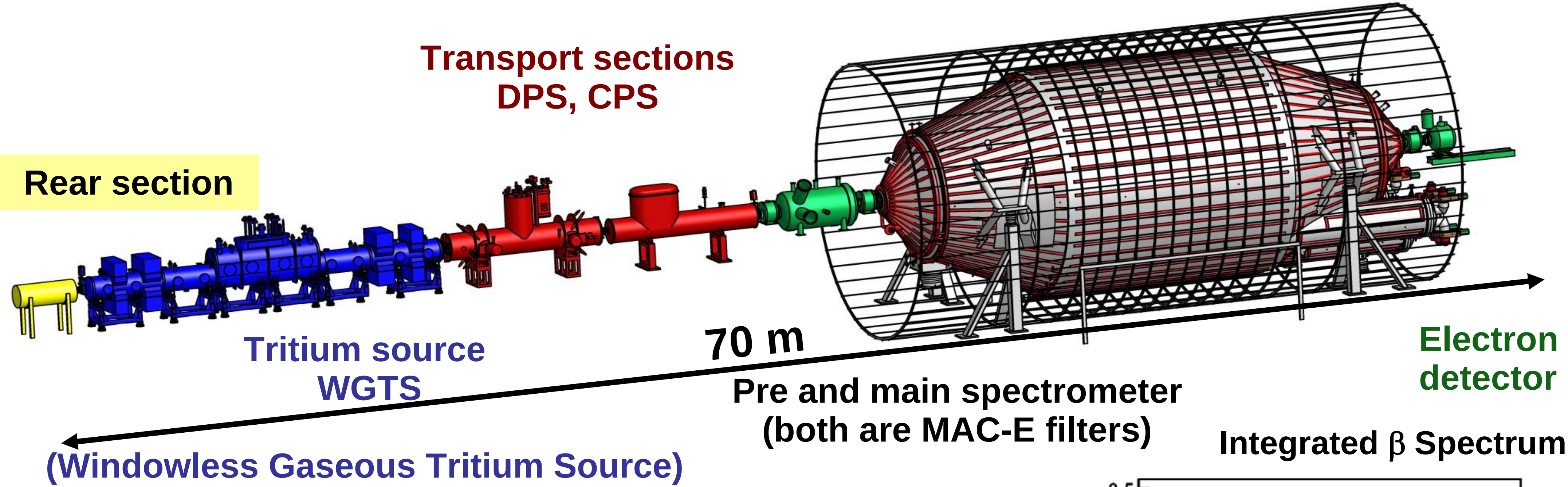
Großgeräte der physikalischen Grundlagenforschung

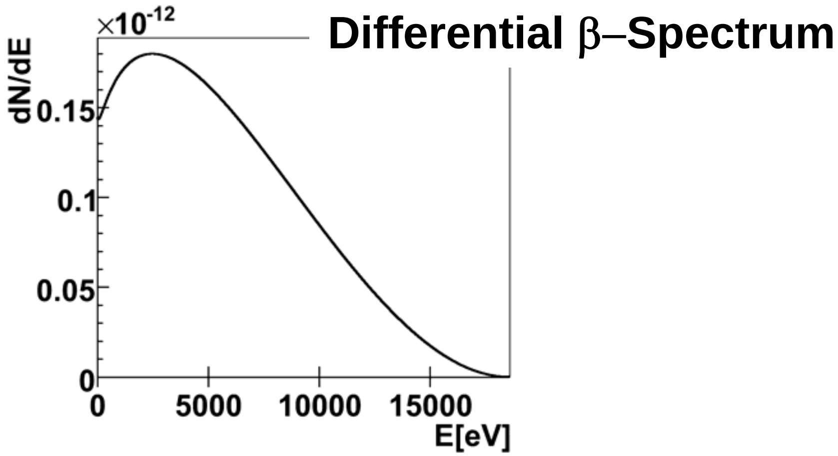
Outline

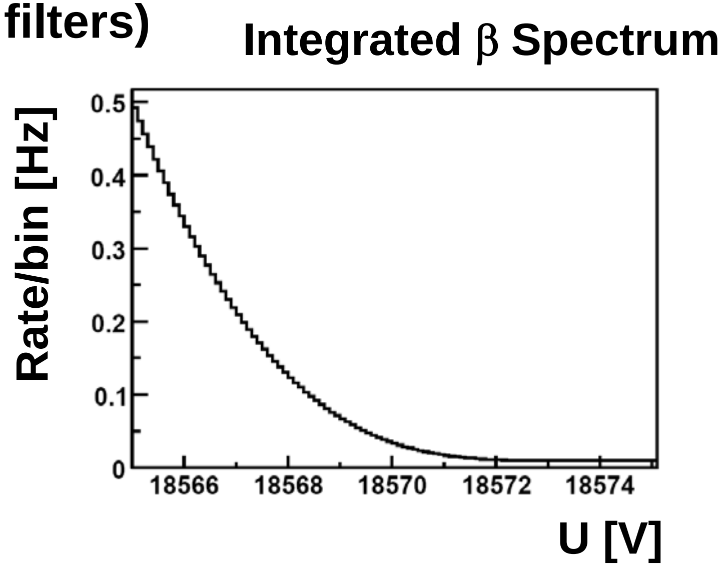
- Why is the WGTS important?
- What processes do we have to understand?
- How do experimental conditions and theoretical calculations affect the KATRIN spectrum?

KATRIN Overview

Karlsruhe Tritium Neutrino experiment

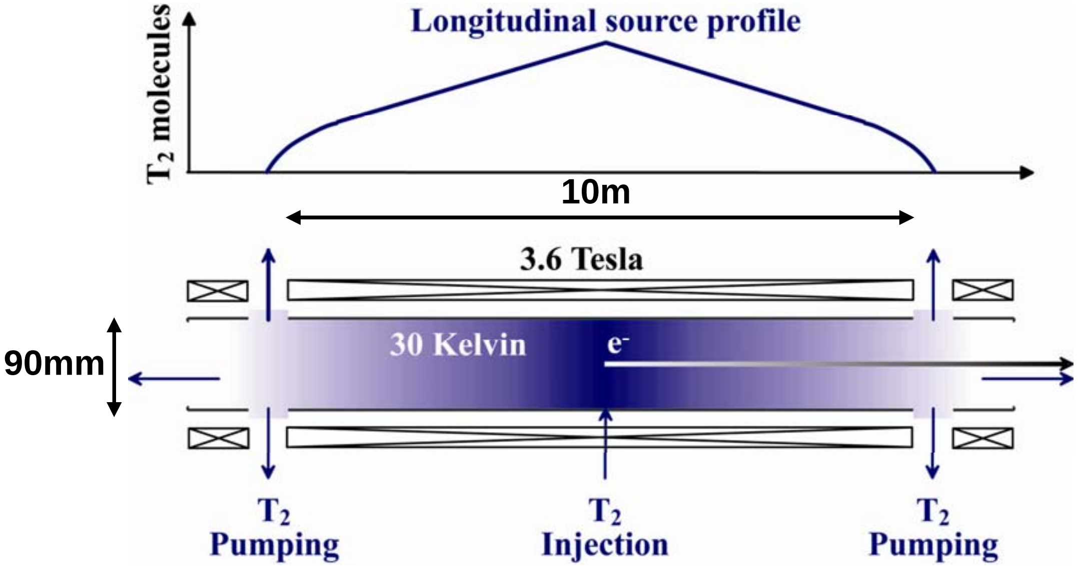






Functional description of the WGTS

Purpose: **Delivery of 10^{11} β decay electrons per second**



Requirements

→ **Stability of T_2 density profile of** 10^{-3}
= f (injection rate, purity, beamtube temperature, pump rate)

→ **For inner 9.5 m of beamtube**

- **Temperature homogeneity:** ±30 mK
- **Temperature stability:** $\pm 30\ mK \cdot h^{-1}$

Beamtube

→ **Length:**	**10 m**
→ **Diameter:**	**90 mm**
→ **Temperature:**	**30 K**

Tritium injection

→ **Flow rate:**	**$0.208\ mbar \cdot l \cdot s^{-1}$**
→ **Pressure:**	**3.35×10^{-3} mbar**

systematic errors (Katrin design report)

Source of systematic shift	Systematic shift $\sigma_{syst}(m_\nu 2)[10^{-3}\ eV^2]$
Final State Distributions	<6
Unfolding energy loss function/determination of f_{res}	< 2
ρd monitoring	$< \sqrt{5} \cdot 0.65$
HV variations	<5
Magnetic field variations in WGTS	<2

➔Understanding the WGTS is crucial!!!

WGTS Model

Experimental Input
- Temperature Readings
- Pressure Readings
- T_2 Purity (Laser Raman)
- Hall Probes
- …

Auxiliary Models
e.g. gas dynamics

Intermediate results
- Density distribution
- Scattering probabilities
- Velocity distribution
- Magnetic field

Theoretical Input
- Scattering cross sections
- Final States
- Radiative corrections
- Synchrotron radiation
- …

WGTS Model

TODAY

(simple) spectrometer model

β - Spectrum, taking into account experimental conditions and theoretical modifications

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WGTS Model

(simple) spectrometer model

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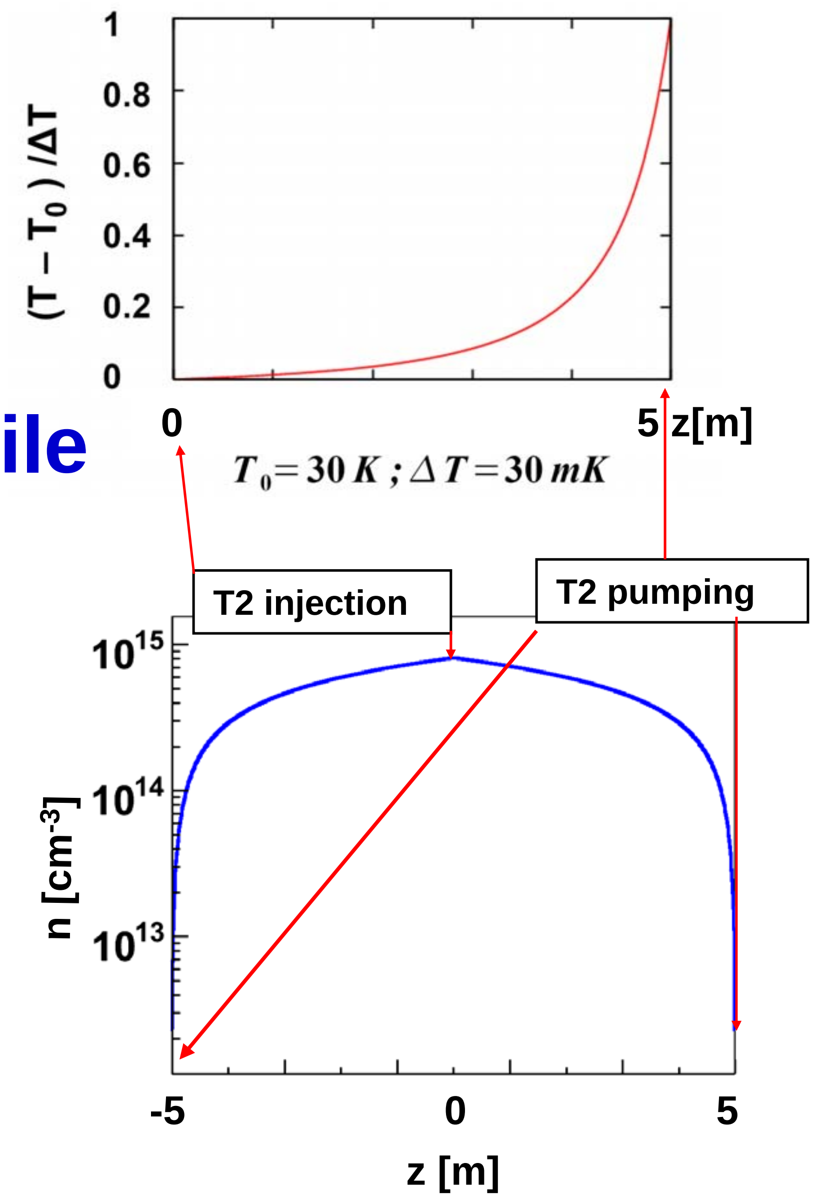
WGTS gas dynamics

- **Input:**
  - **Temperature-Profile**
  - **Inlet/Outlet Pressure**
- **Output: density + velocity profile**
- **Different flow regimes**
  - **solve Boltzmann equation**
- **Numerical code**

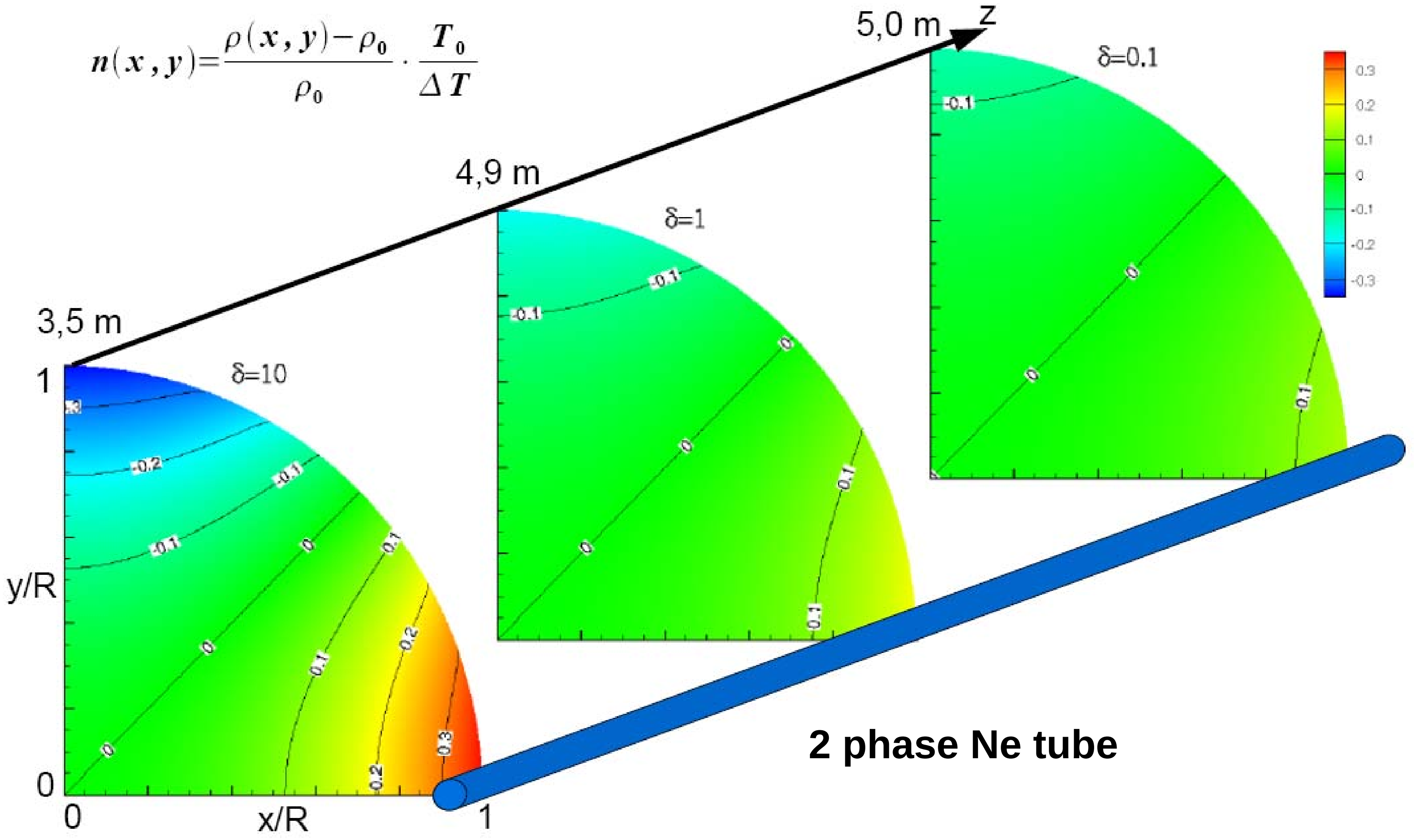
  F. Sharipov et al.

  (Univ. Parana)



First Look at Radial dependency

$$n(x,y)=\frac{\rho(x,y)-\rho_0}{\rho_0}\cdot\frac{T_0}{\Delta T}$$

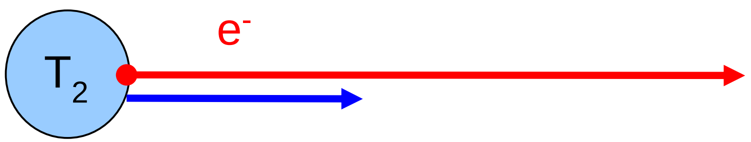


Velocity profile → Doppler Effect

- **Maxwell Boltzmann distribution + bulk velocity U_z**

$$f(\vec{r},\vec{v}) \approx \frac{n(z)}{\left(\sqrt{\pi} v_u\right)^3} \exp\left[-\frac{v_r^2 + v_\varphi^2 + (v_z - U_z)^2}{v_0^2}\right]$$

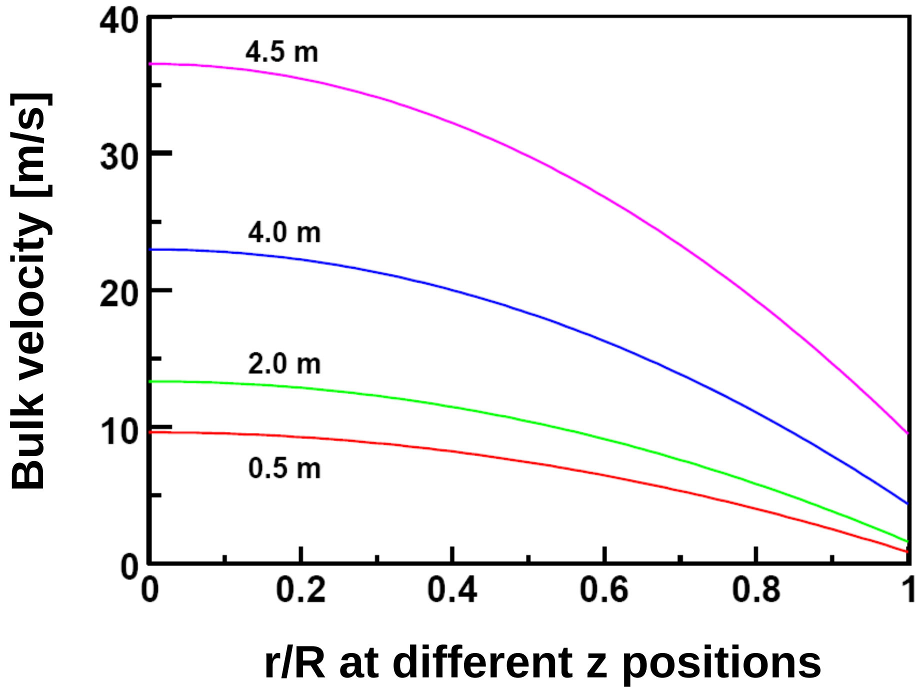
Thermal velocity ~ 288 m/s
Bulk velocity ~ 10- 40 m/s



example:

electron energy: 18575 eV (endpoint)
T_2 velocity: 288 m/s
Energy shift for parallel emission:

ΔE = 129 meV



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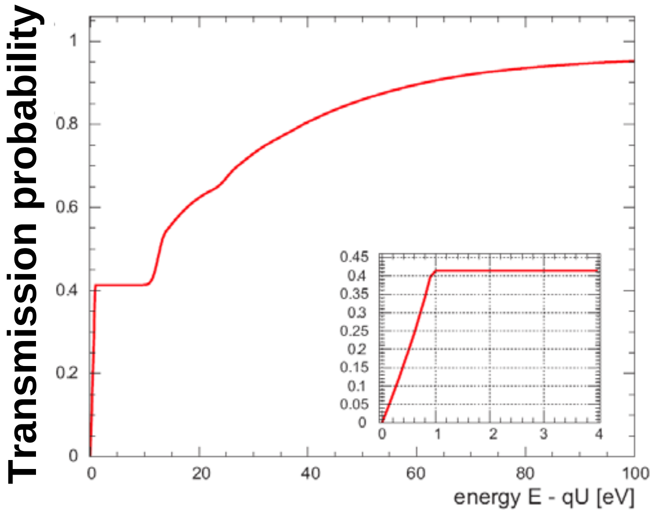
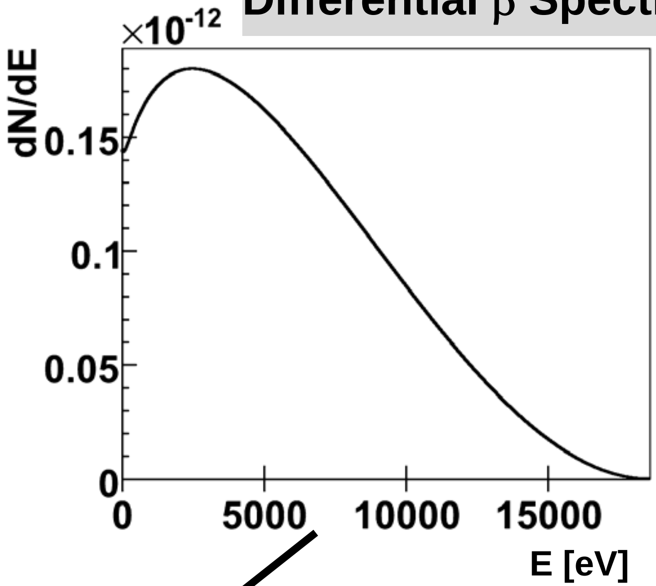
(simple) spectrometer model

β - Spectrum, taking into account experimental conditions and theoretical modifications

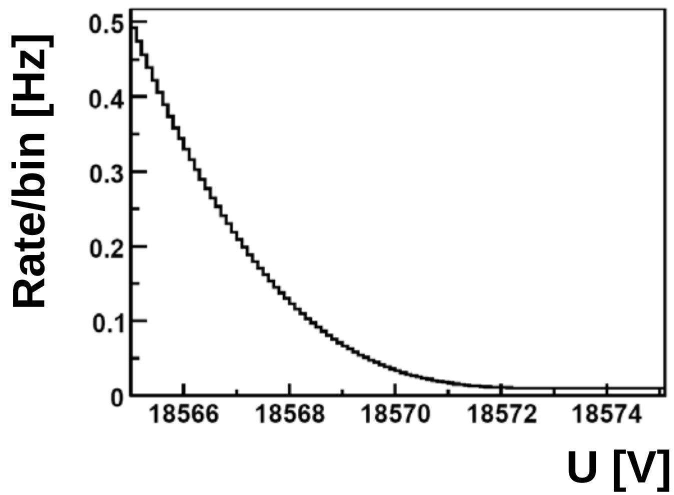
WGTS model: Principle





$$N(qU,E_0,m_\nu^2) = \int R(E,qU)\ \frac{dN}{dE}(E,E_0,m_\nu^2)\ dE\ =$$

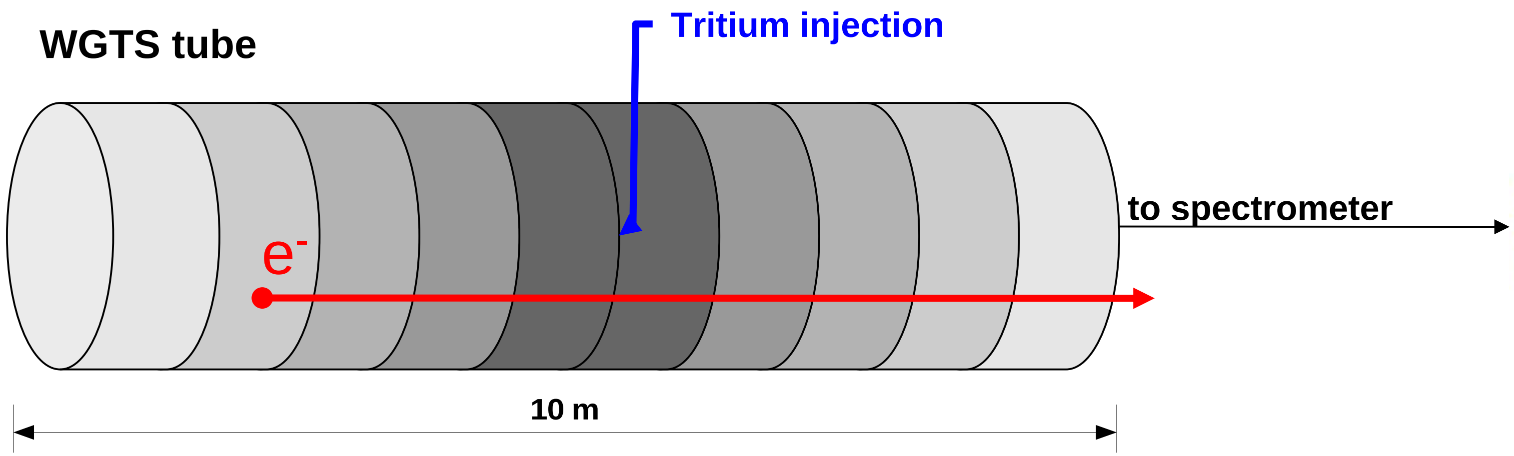
integrated β Spectrum
(Endpoint)

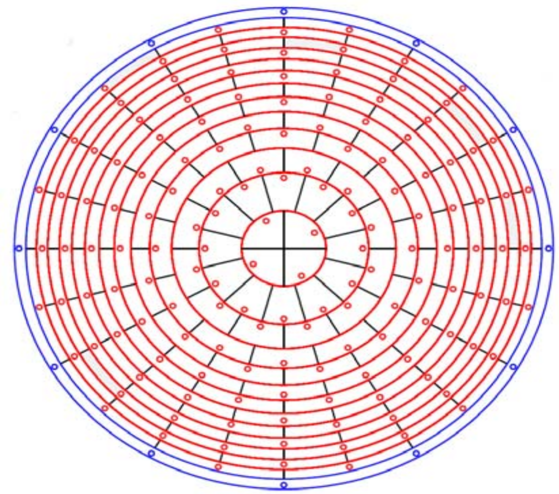


3D WGTS model

- **First WGTS model:** ***only integrated properties considered***
- **refined WGTS model (3-dimensional) to include inhomogeneities**
- **With detailed distributions:**
  Create "voxelized" β spectra

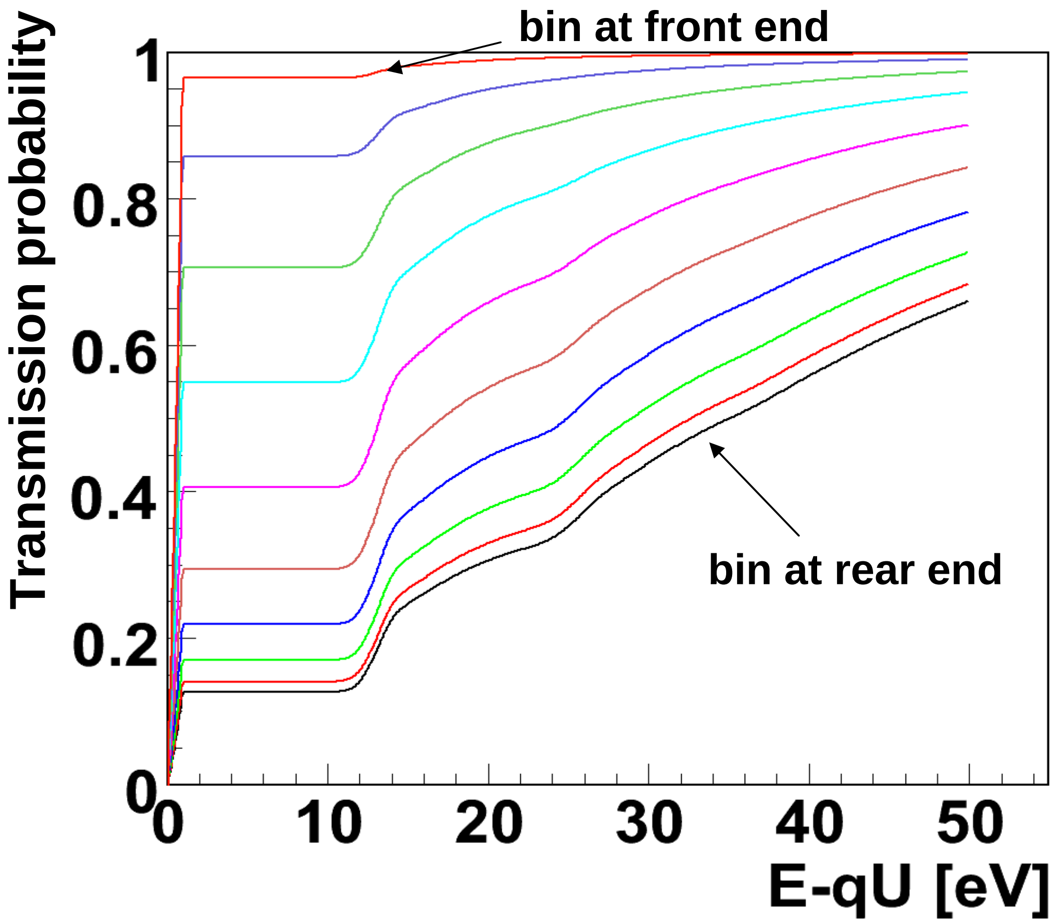
Radial pixels: detector layout

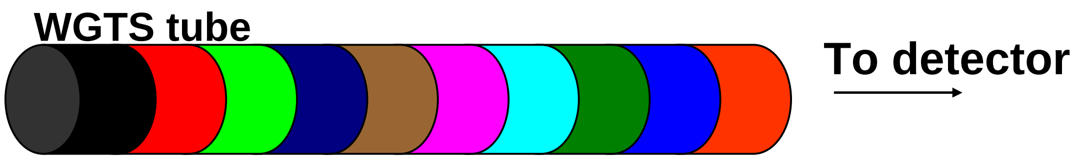


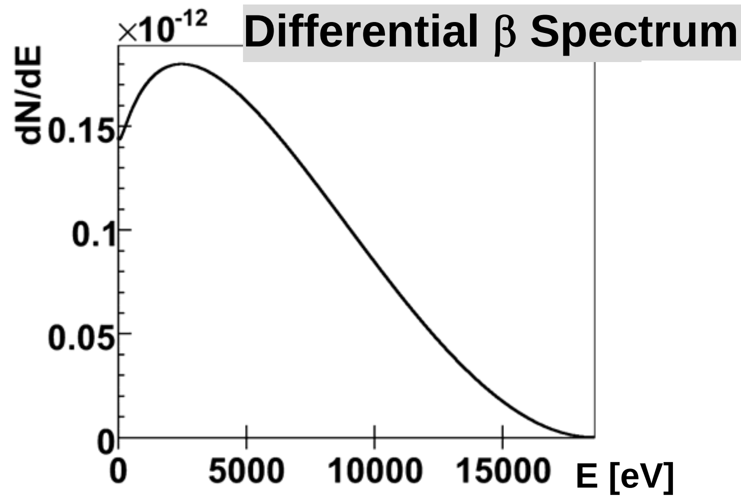


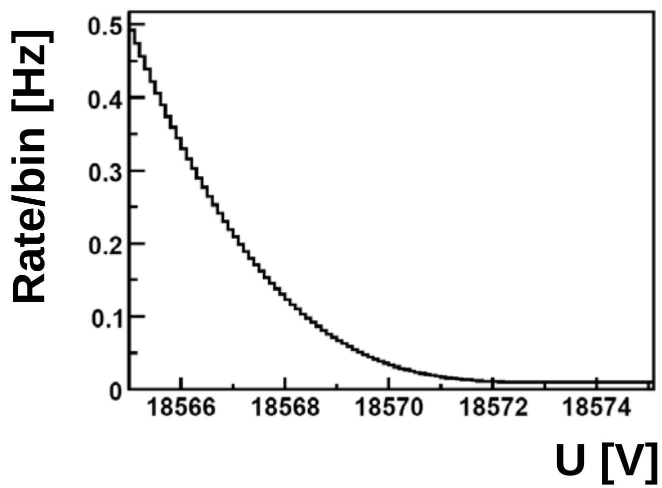
Calculation of the β Spectrum

Response functions for 10 bins









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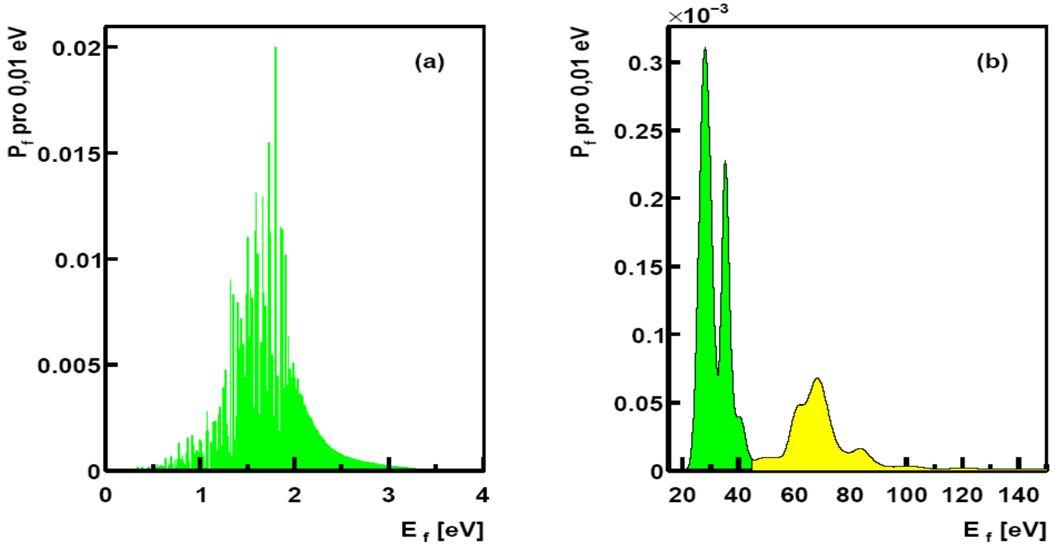
Final State Distribution

Daughter molecule (^{3}HeT / ^{3}HeD) has rotational/vibrational/electronic excitations

➔ additional energy loss

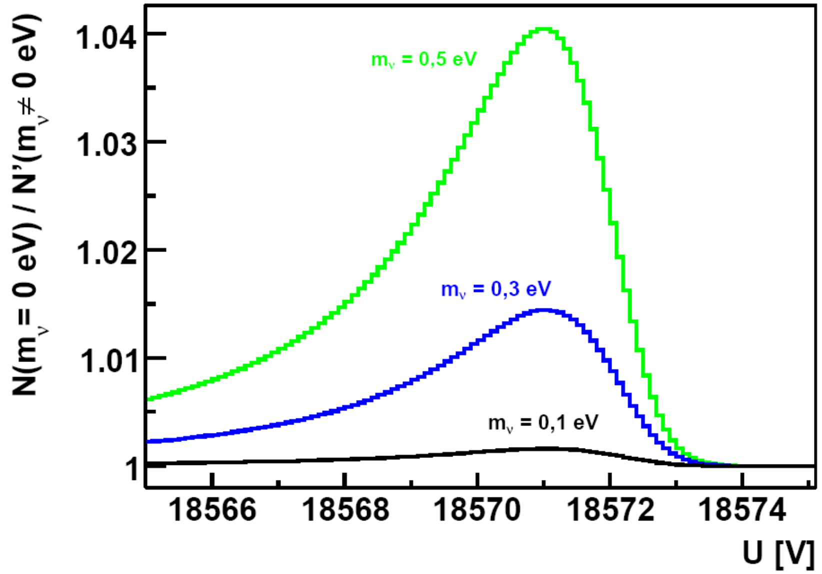
➔ modified β Spectrum

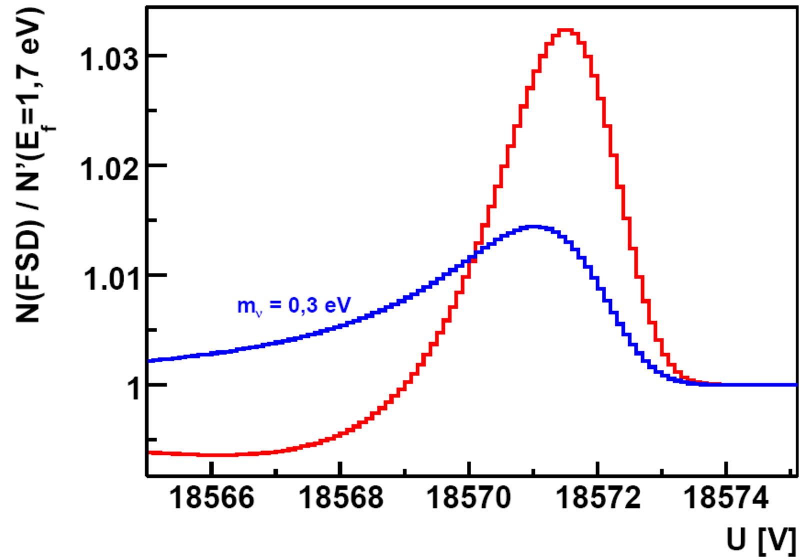
$$\frac{dN}{dE} \propto \sum_f P_f \left(E_0 - E_f - E\right)\sqrt{\left(E_0 - E_f - E\right)^2 - m_\nu^2}\;\Theta\left(E_0 - E_f - E - m_\nu\right)$$



Doss/Tennyson

Effect of m_ν



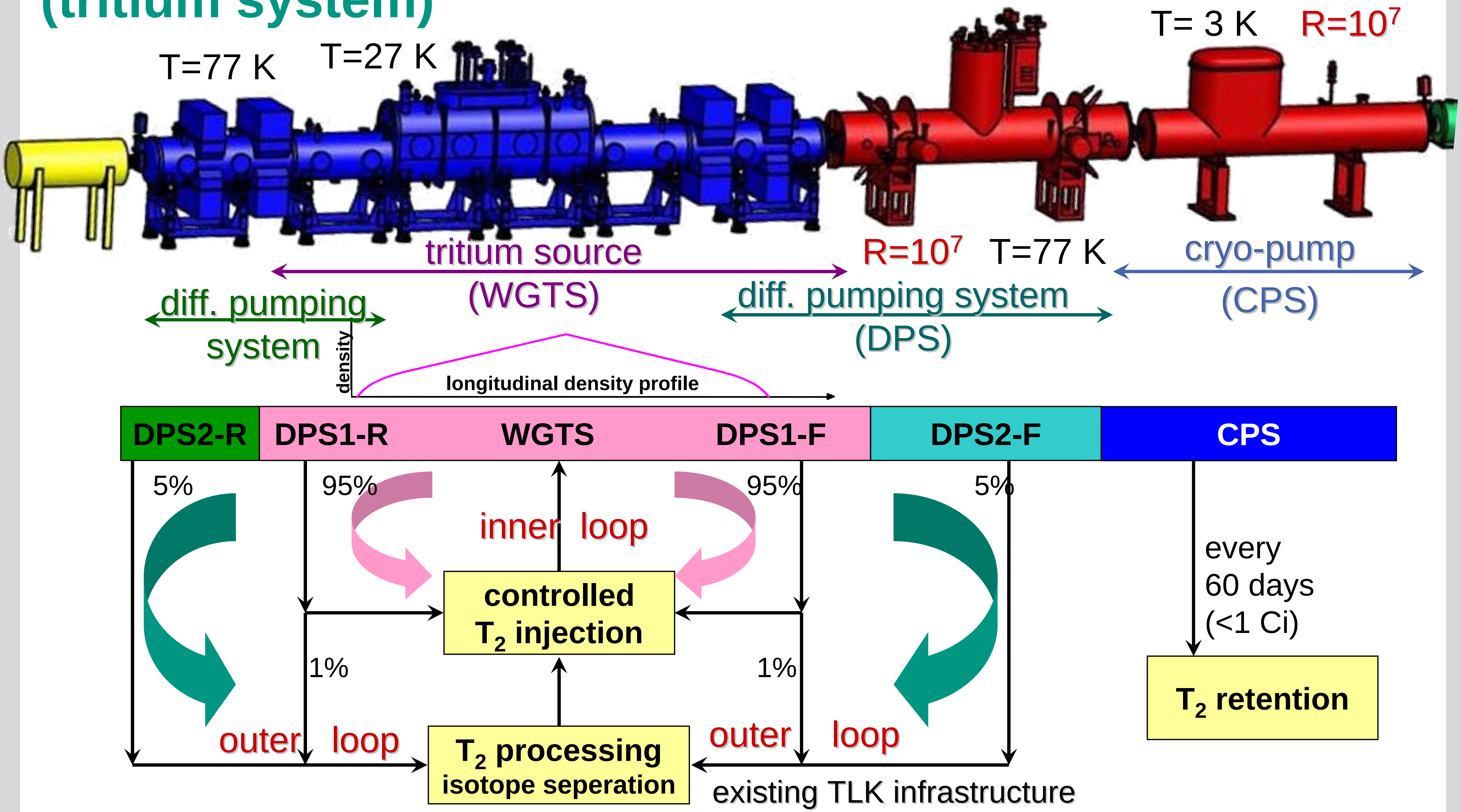


Summary & Outlook

- Understanding the WGTS is important for KATRIN systematics
- Broad range of physics
- 3D WGTS model:
  - Calculation of β – Spectrum for segments of the WGTS
- Validation with test experiments and monitoring
  - Next: “Demonstrator” measurements end of this year

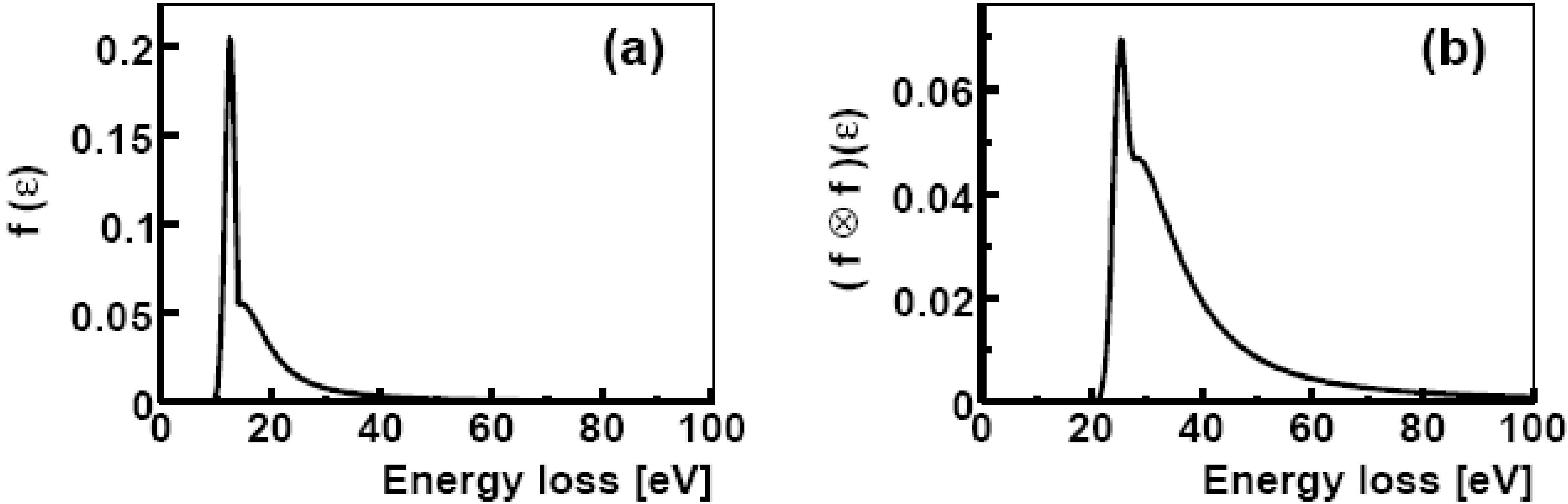
Backup

Source and transport section (tritium system)



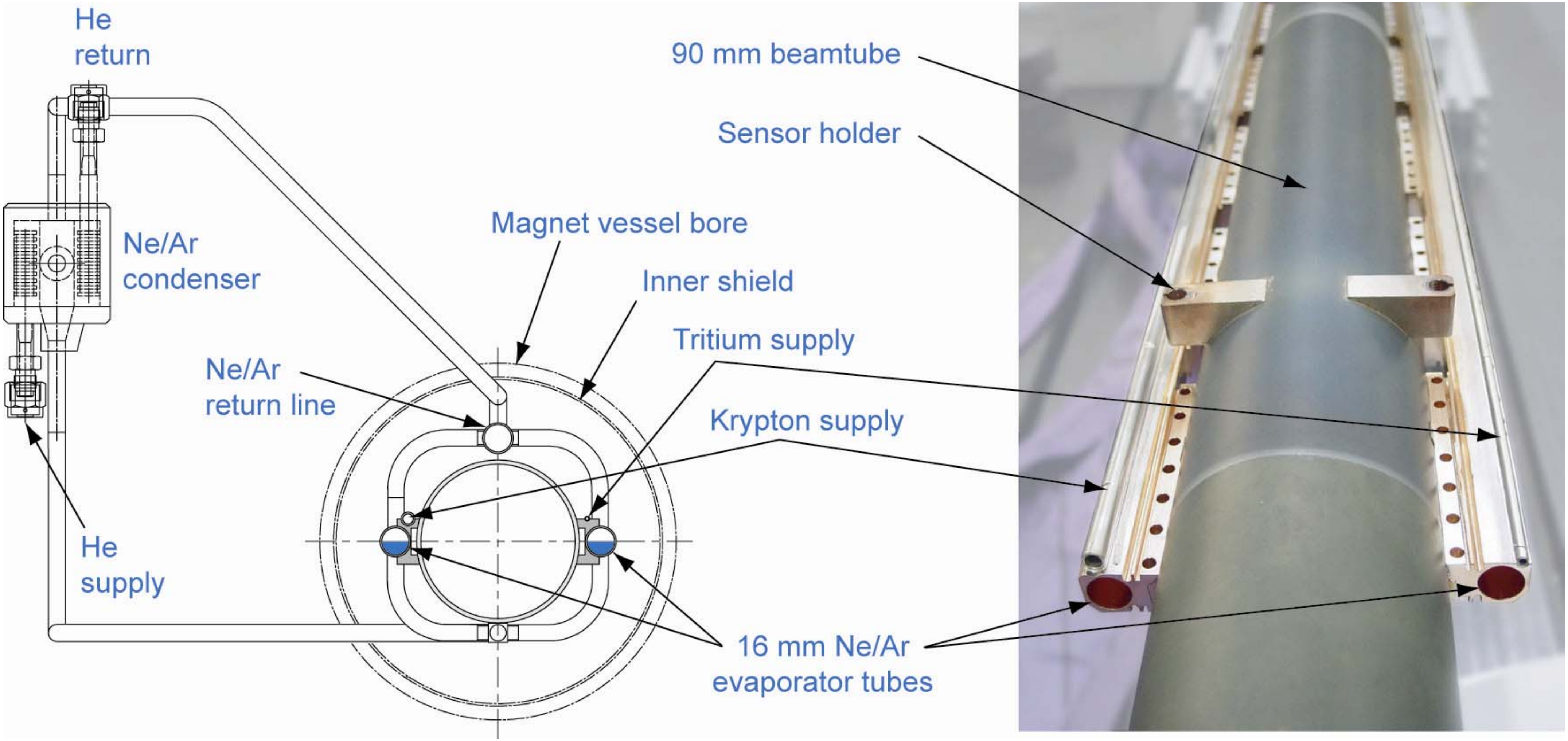
Energy loss of electrons in Tritium

For 1 (a) or 2 interactions (b)



Aseev et al. Eur. Phys. J. D **10**, 39{52 (2000)

BT cooling – Ne/Ar thermosiphon

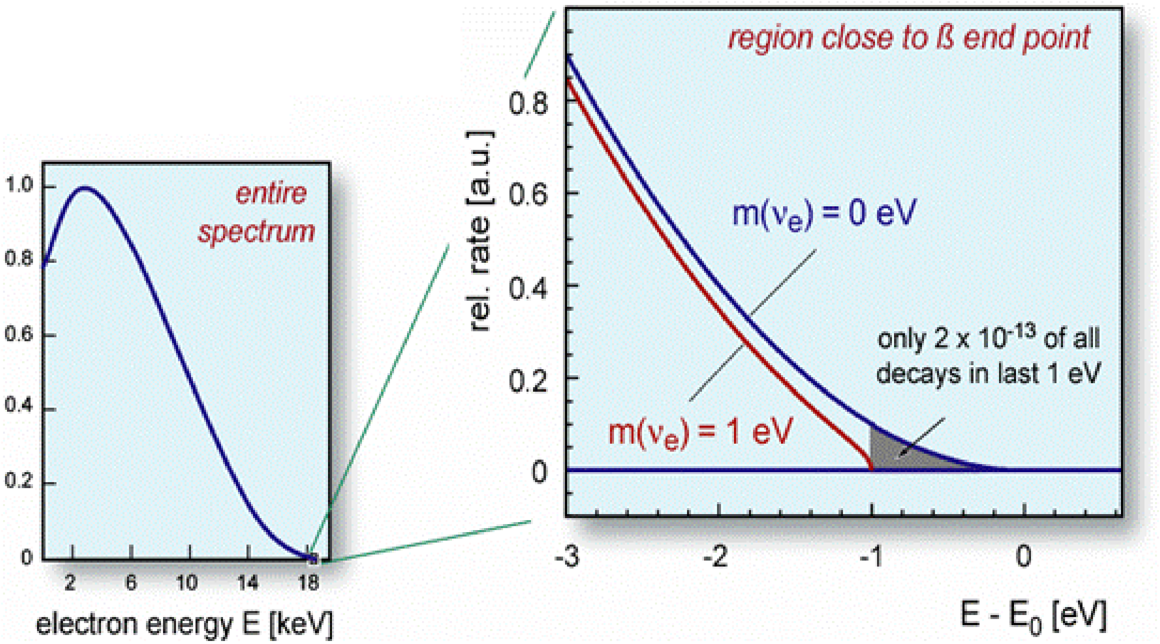


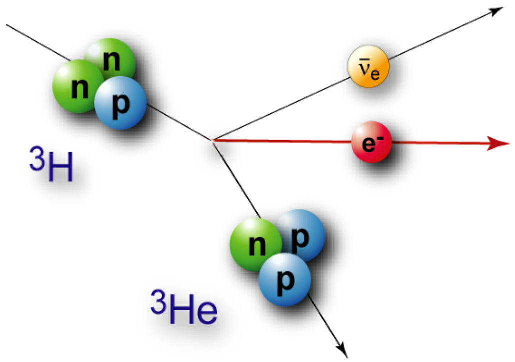
Neutrino mass and β-decay

kinetic measurement of the neutrino mass

$$\frac{d\Gamma}{dE} = C\, p\,(E+m_e)\,(E_0-E)\,\sqrt{(E_0-E)^2 - m_{\nu_e}^2}\,F(E)\,\theta(E_0-E-m_{\nu_e})$$

experimentally observable





T_2:

halflife 12.3 a

E_0: 18574 eV