Tritium source systematics of the KArlsruhe TRItium Neutrino (KATRIN) Experiment

Hendrik Seitz-Moskaliuk, KIT-IEKP

Schule für Astroteilchenphysik, Obertrubach-Bärnfels, 07.10.2015-15.10.2015

Picture taken by K. Valerius

The KATRIN Experiment

VALUE (eV)		*CL%*	*DOCUMENT ID*	
< 2	**OUR EVALUATION**			
< 2.05		95	[1] ASEEV	11
< 2.3		95	[2] KRAUS	05

PDG 2014

Current model independent neutrino mass:
Best limit by Mainz and Troitsk

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m_ν < 200 meV (90 % C. L.)

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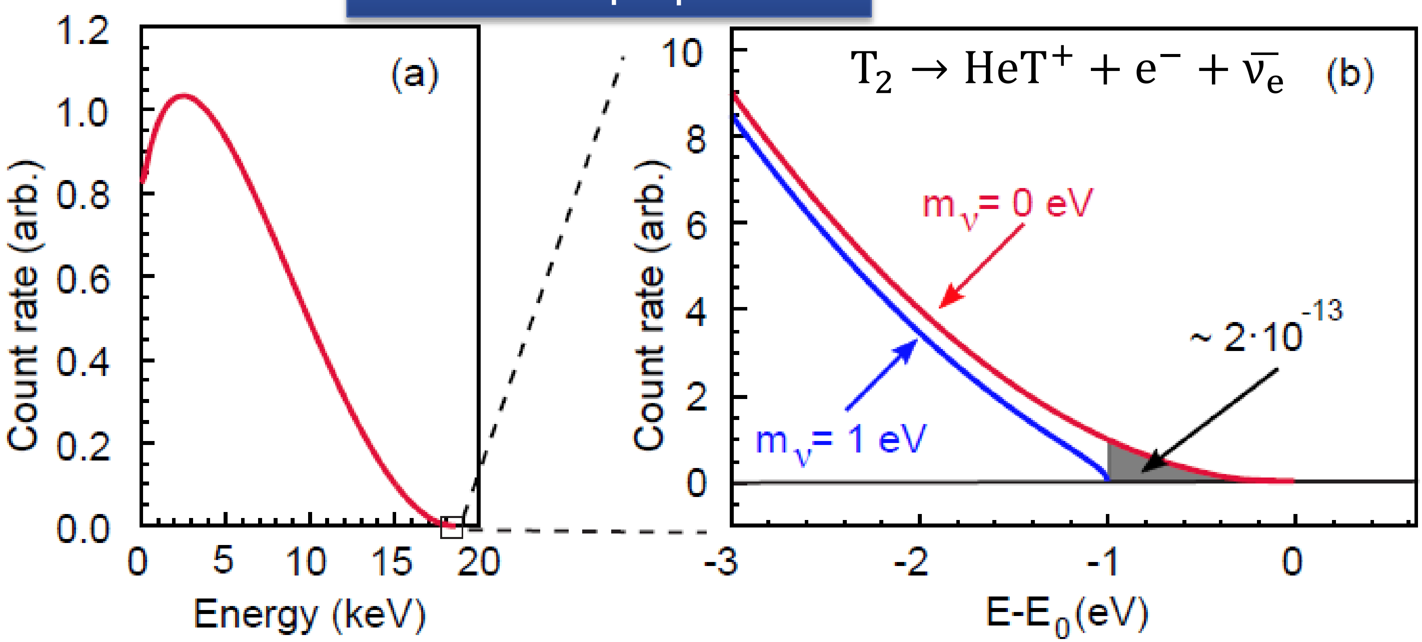
Tritium
1p, 2n
E_0=18592 eV
$T_{1/2}$=12.3 y

Differential β spectrum



Weinheimer (2003), taken from M. Schlösser, PhD thesis, KIT (2013)

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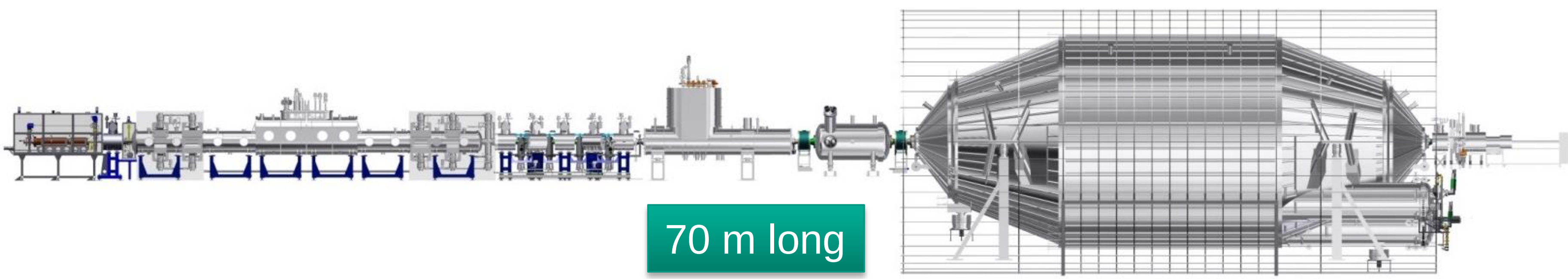

70 m long

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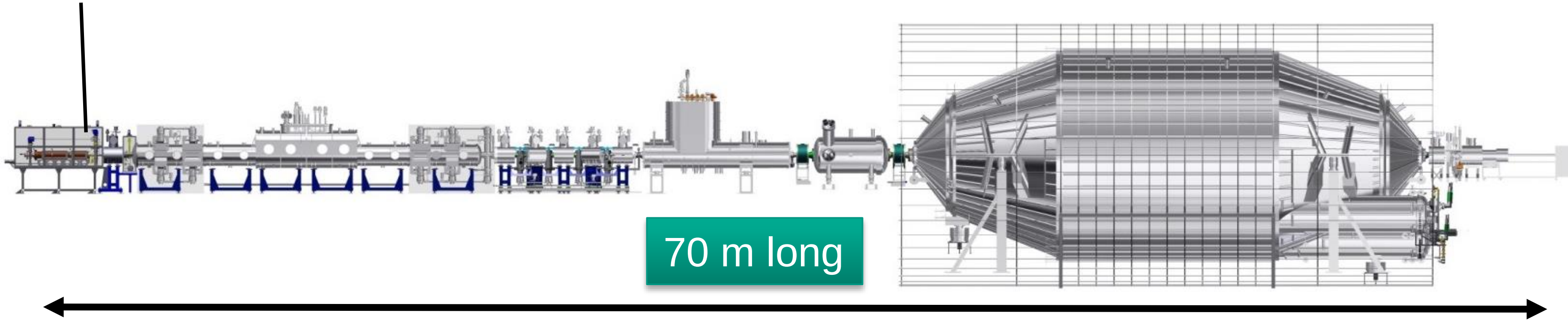

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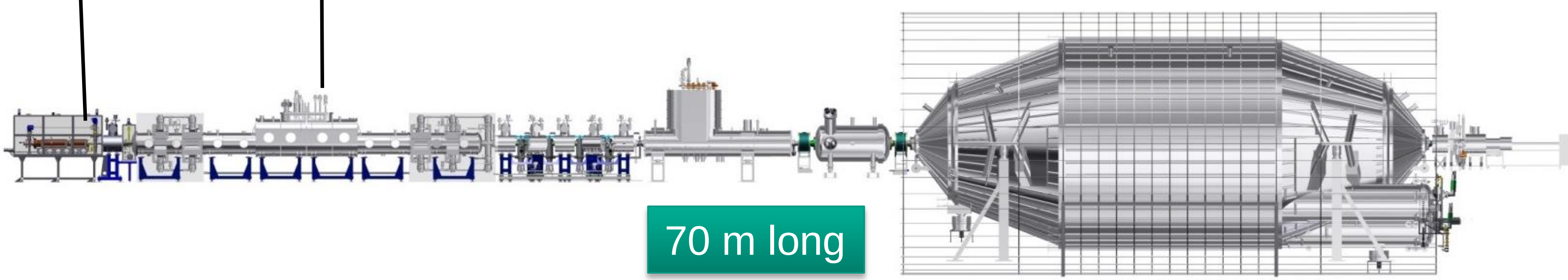
Windowless
Gaseous Tritium
Source WGTS

Rear section



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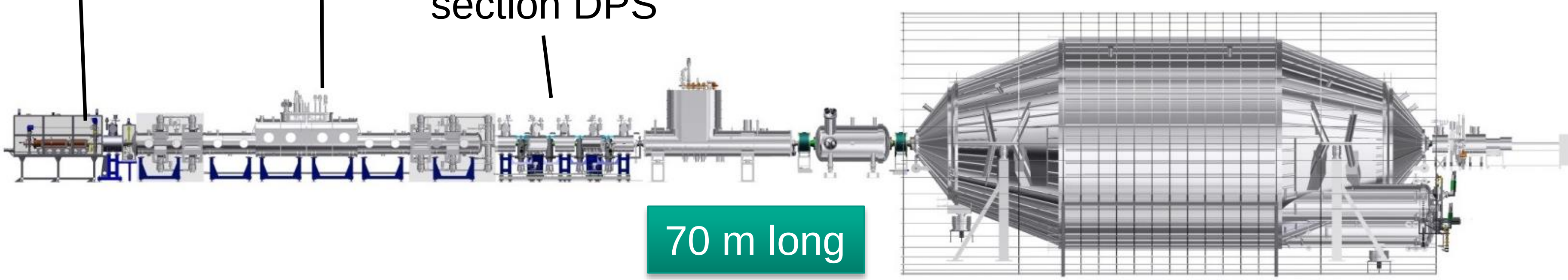
Windowless Gaseous Tritium Source WGTS

Differential pumping section DPS

Rear section



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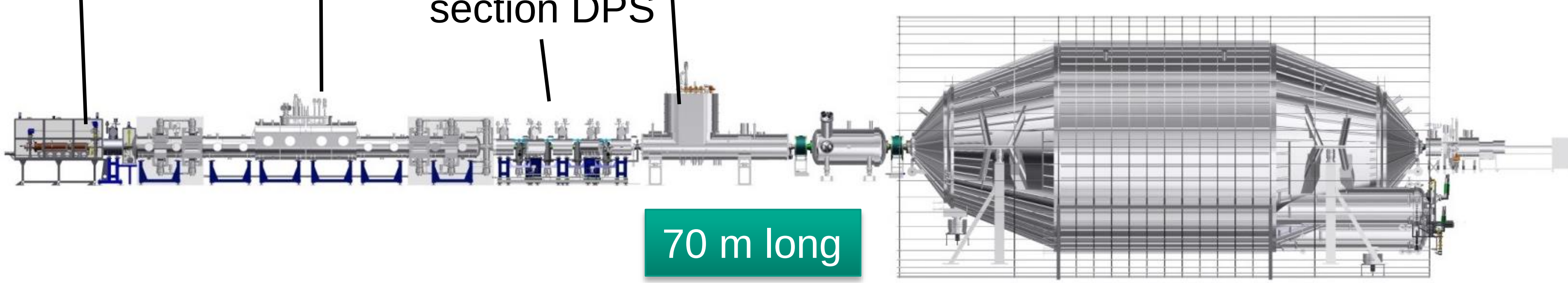
Windowless Gaseous Tritium Source WGTS

Cryogenic pumping section CPS

Differential pumping section DPS

Rear section



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Cryogenic pumping section CPS

Pre spectrometer

Differential pumping section DPS

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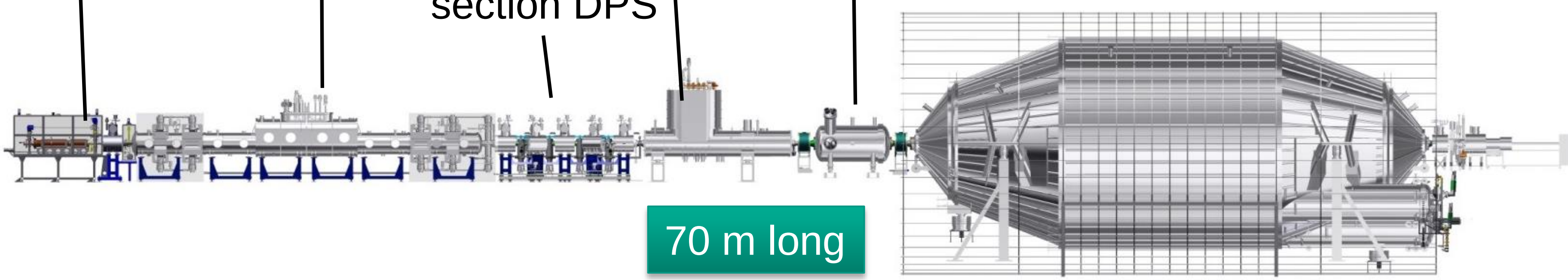

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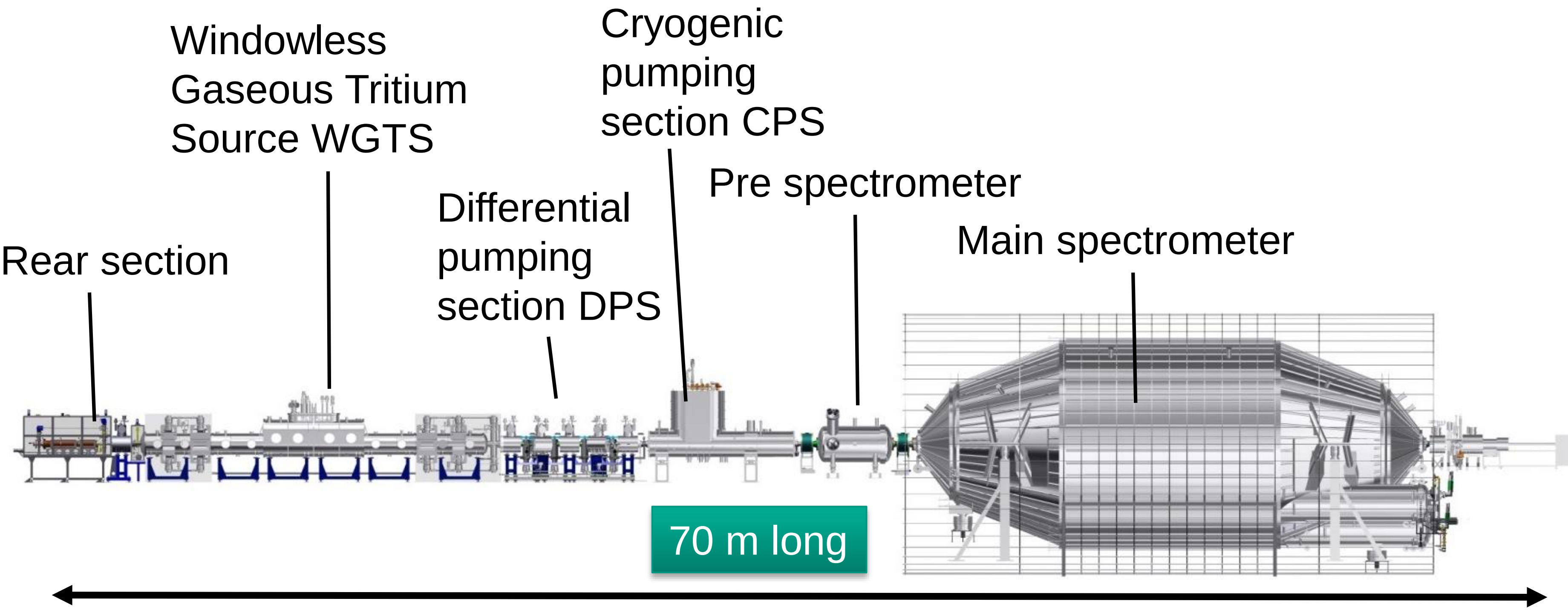

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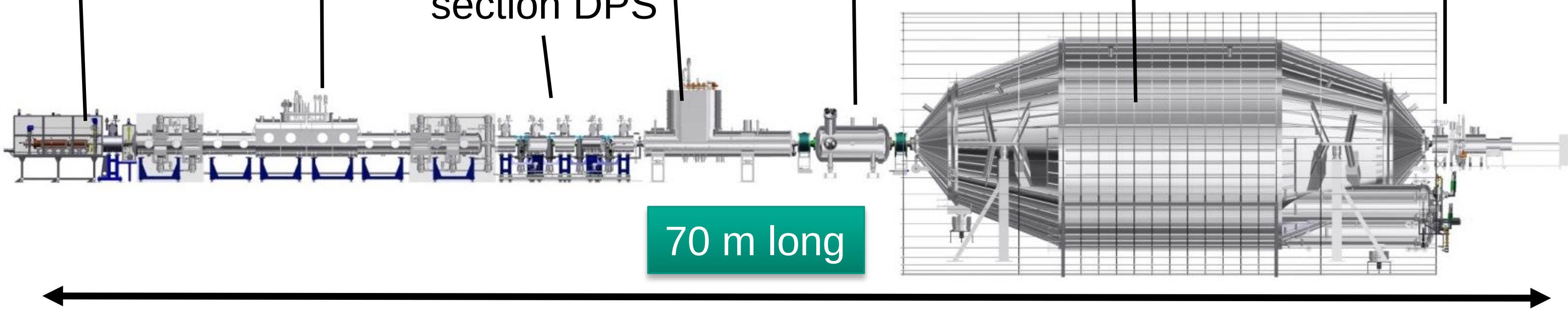
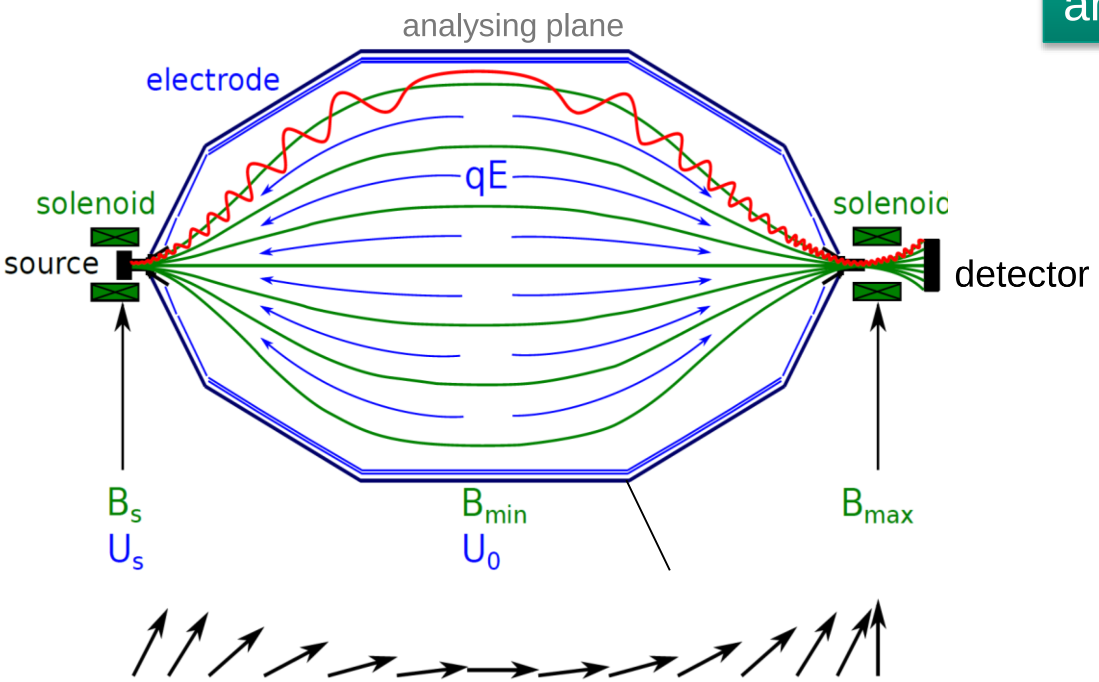


The KATRIN Experiment: MAC-E filter

Magnetic Adiabatic Collimation and Electrostatic Filter

Picard et al., 1992



$$\mu = \frac{E_\perp}{B} = \text{const.}$$

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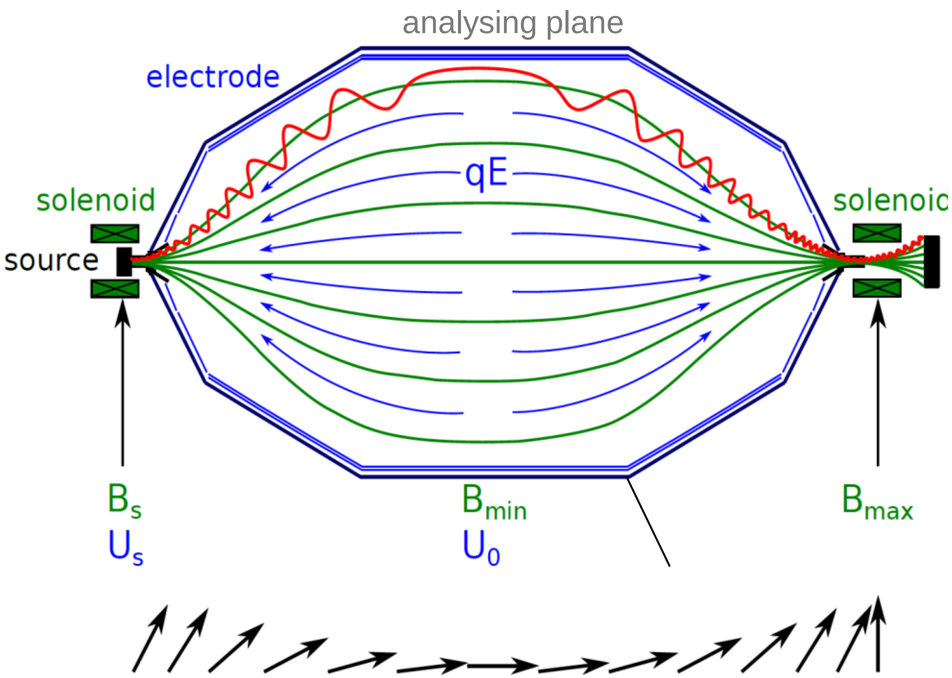

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Magnetic Adiabatic Collimation and Electrostatic Filter

Picard et al., 1992

Two solenoids define magnetic field

High pass filter due to electrostatic potential

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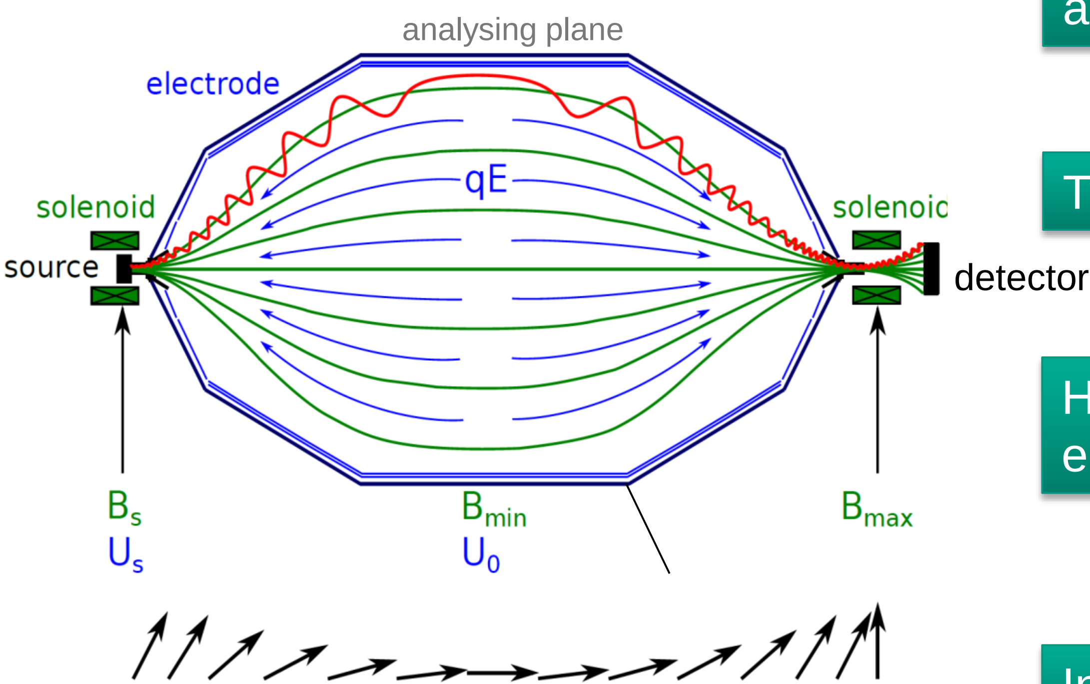

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Magnetic Adiabatic Collimation and Electrostatic Filter

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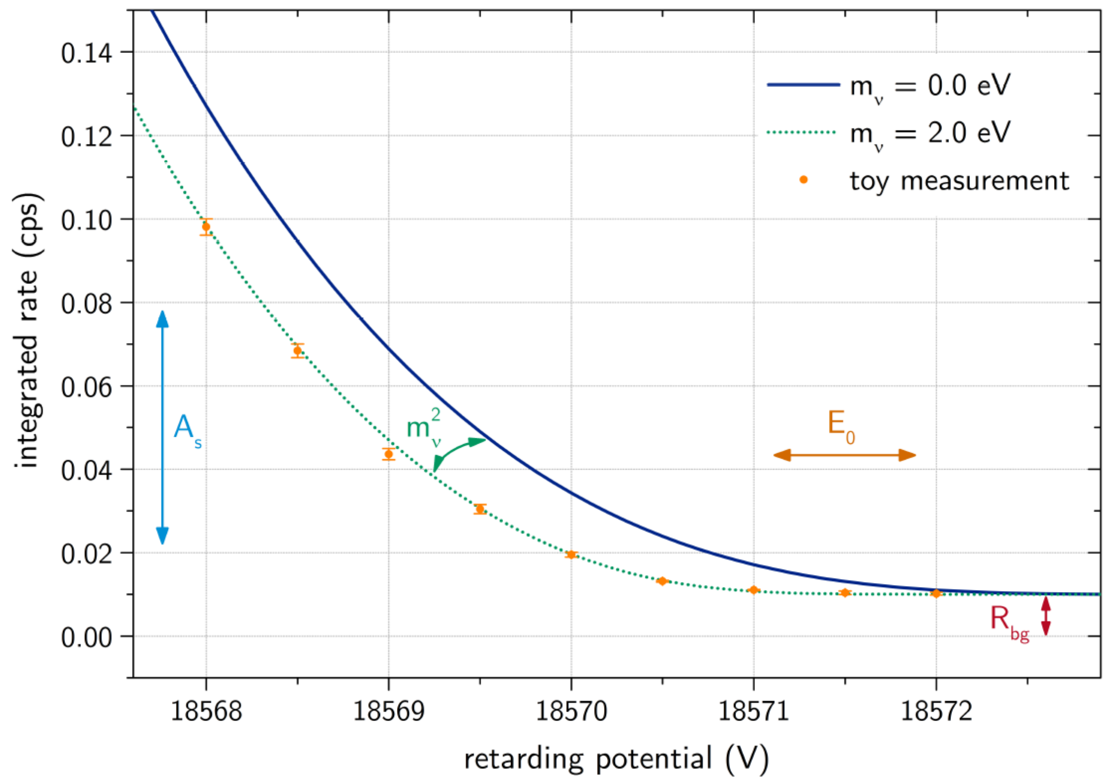
Integral measurement of β spectrum

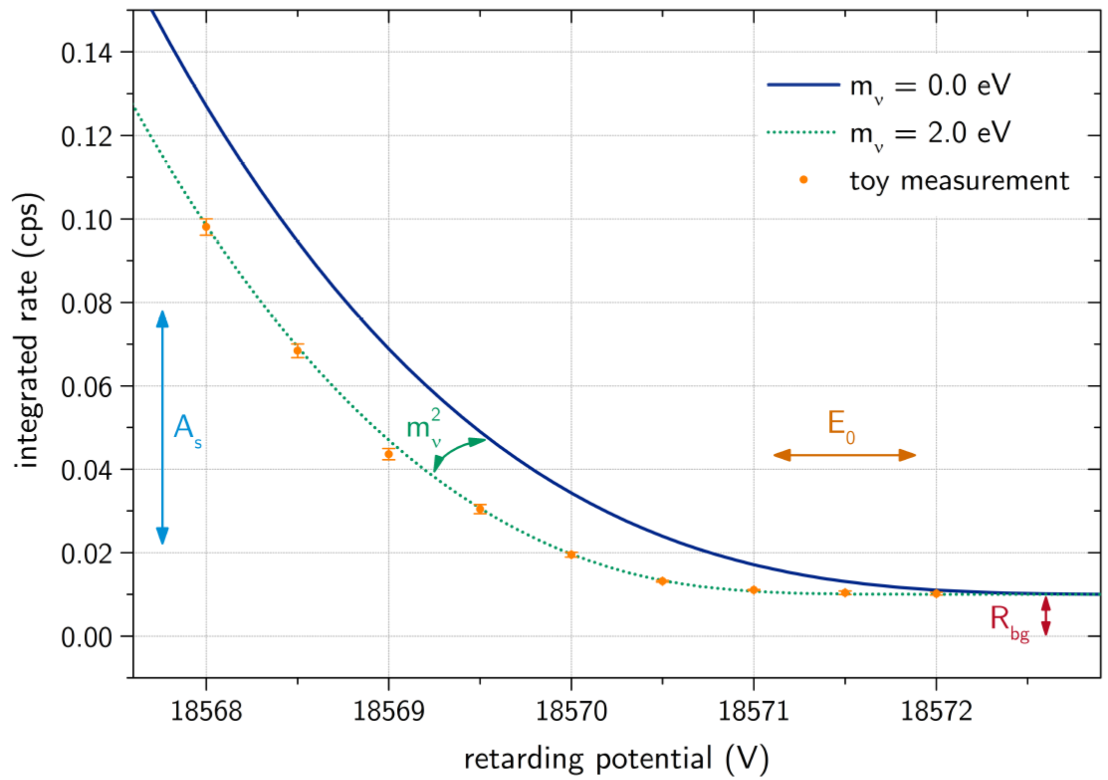
How systematics influence the sensitivity



M. Kleesiek, PhD thesis, KIT (2014)

KATRIN gets neutrino mass from fitting the endpoint region of tritium β decay.

How systematics influence the sensitivity



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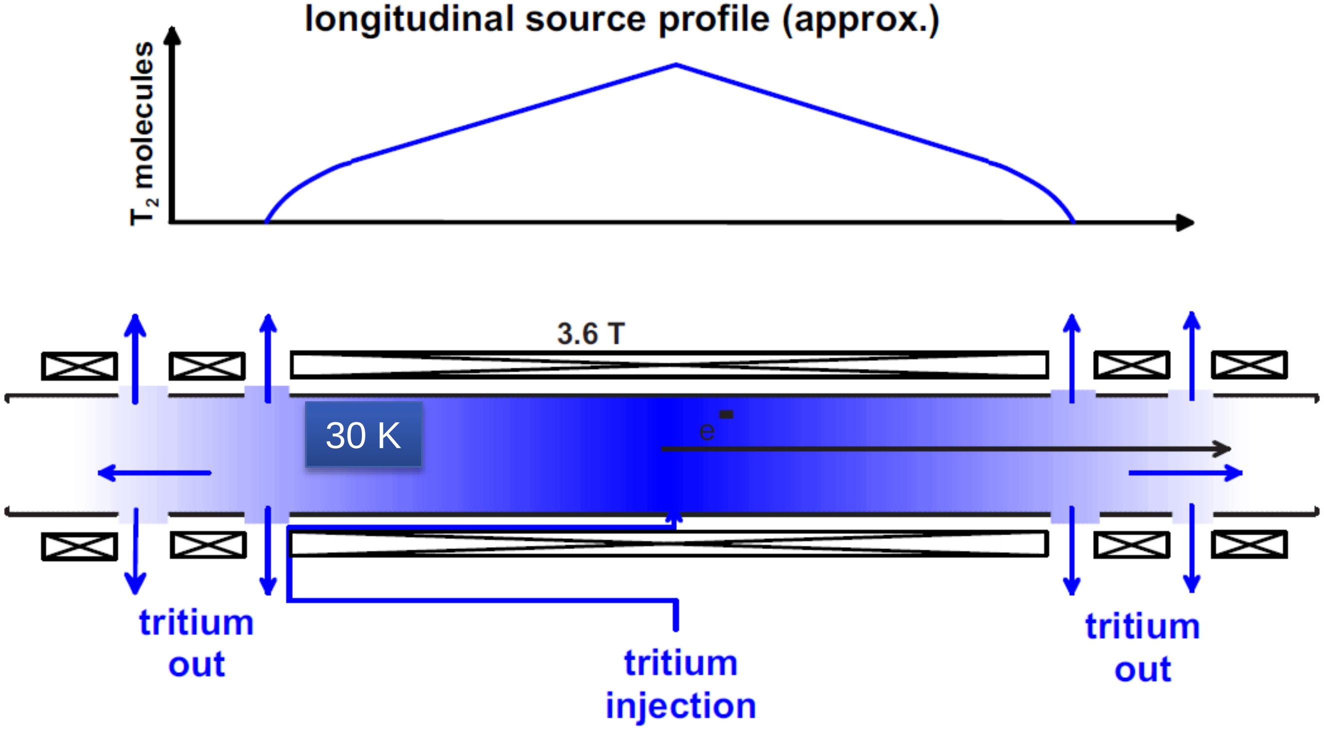
KATRIN gets neutrino mass from fitting the endpoint region of tritium β decay.

Each systematic influencing shape of β spectrum at its endpoint has to be considered!

The WGTS

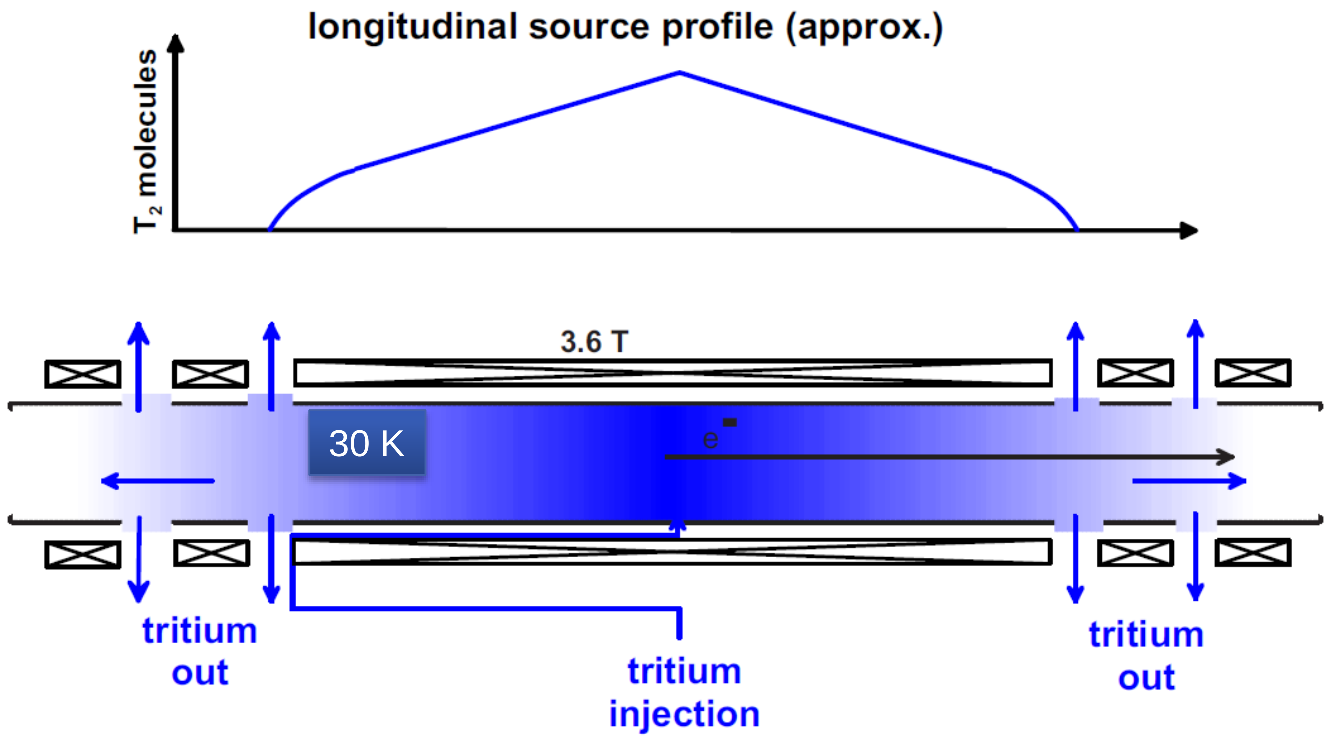
WGTS arrival at KIT in August

The WGTS



KATRIN Design Report, 2005

The WGTS

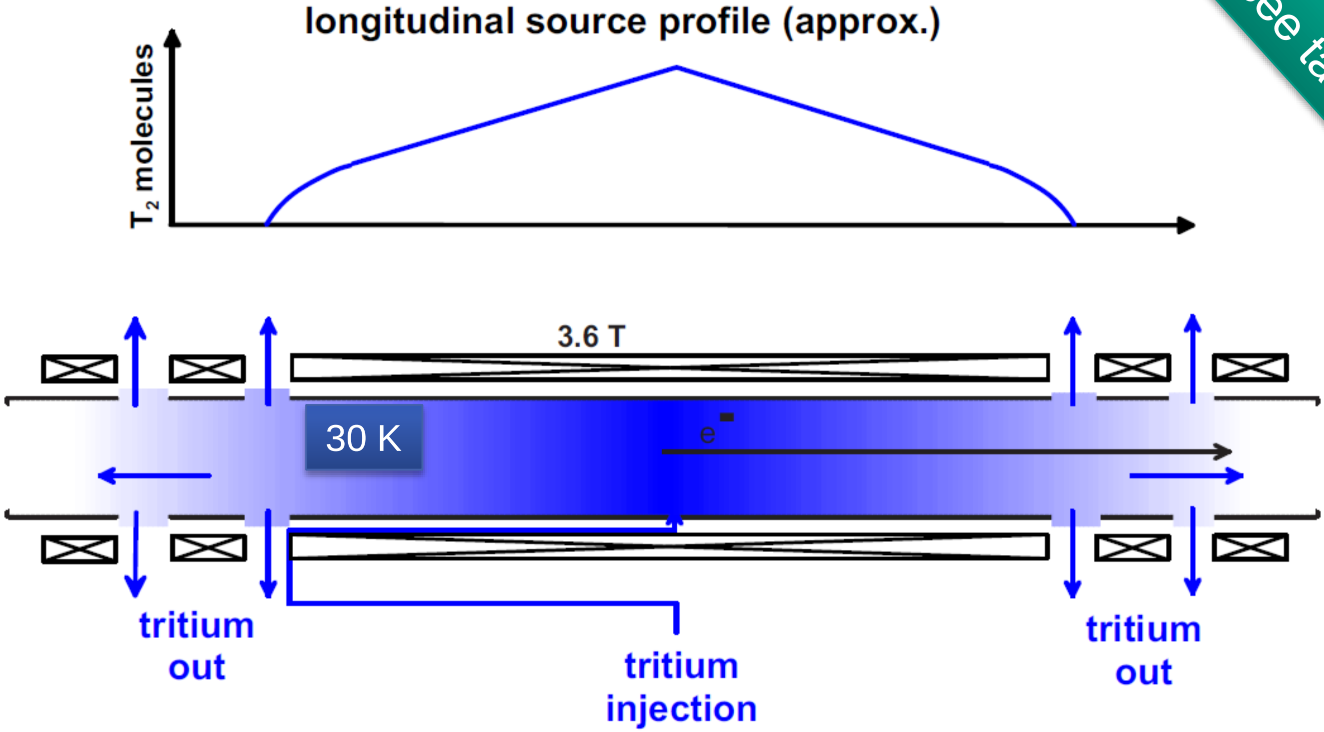


KATRIN Design Report, 2005

Parameters like temperature, tritium purity, injection pressure, … have to be stabilised on a 10^{-3} level.

The WGTS

Gasdynamics simulations:
see talk by F. Heizmann



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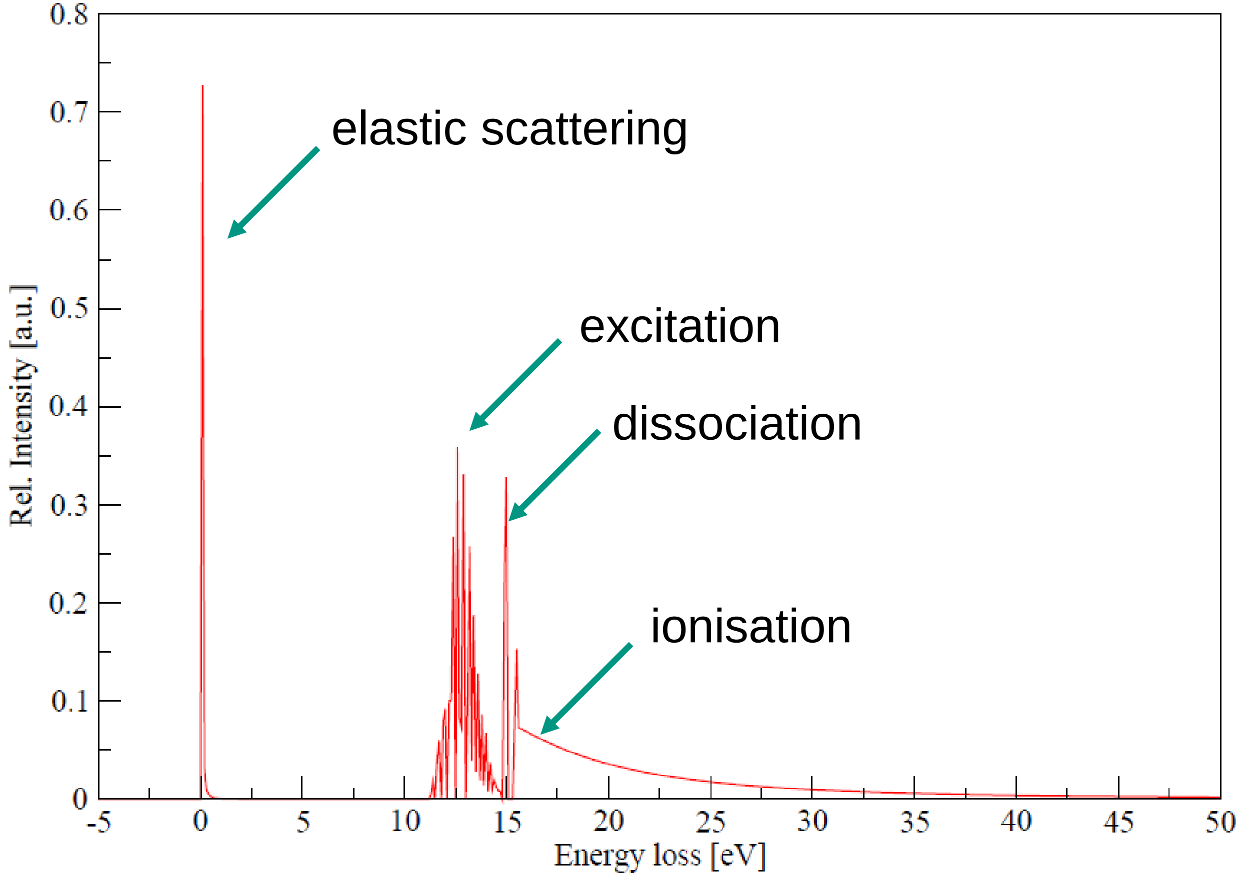
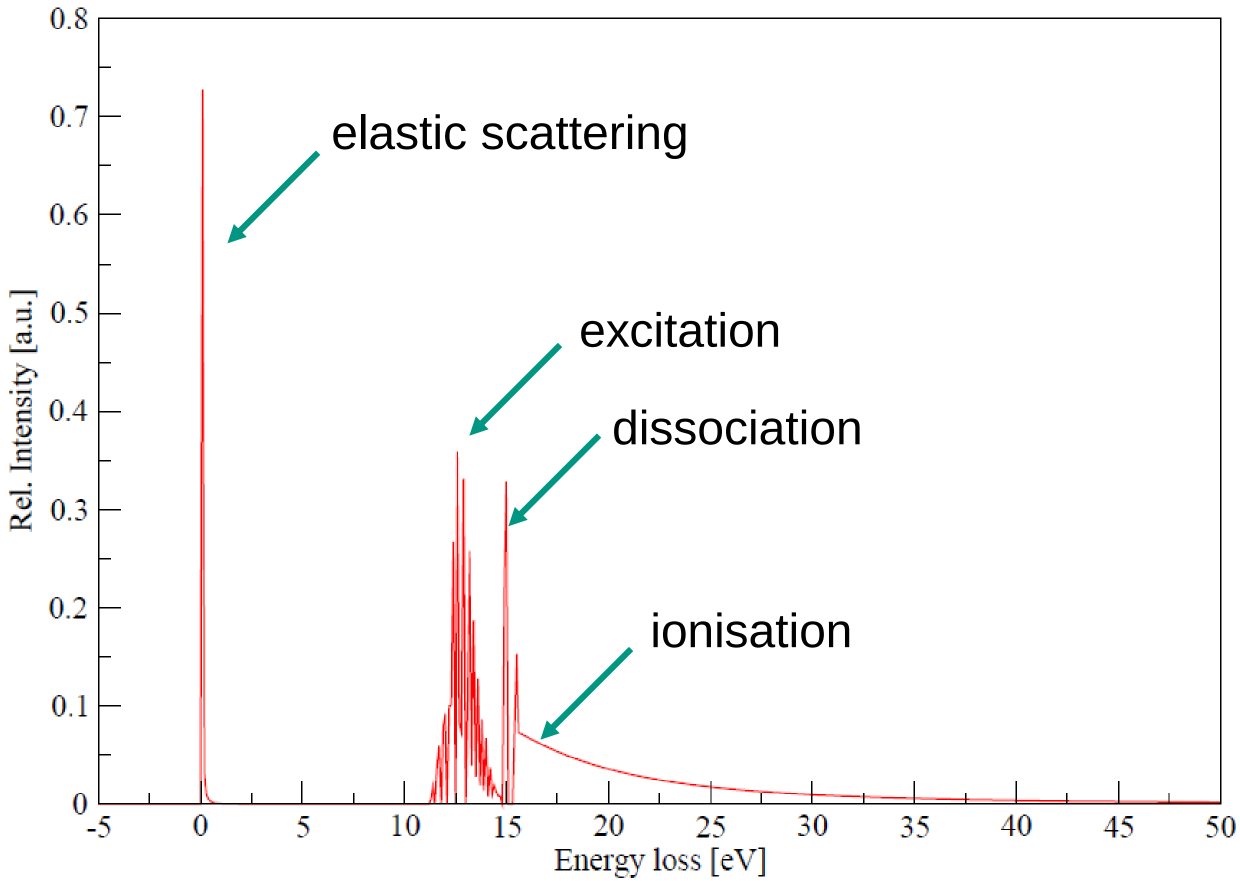
Energy loss



C. Kranz, Diploma thesis, Münster (2011)

Energy loss



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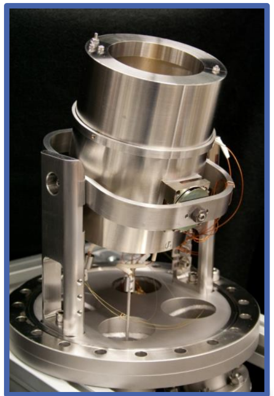
Model bases on hydrogen/deuterium data → measurement for tritium necessary

Energy loss function: measurement



Egun

P. Ranitzsch

Energy loss function: measurement

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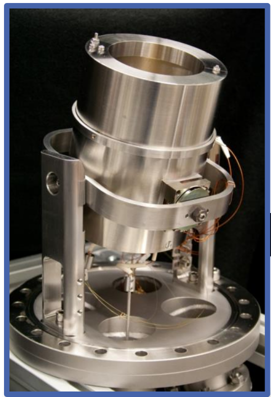

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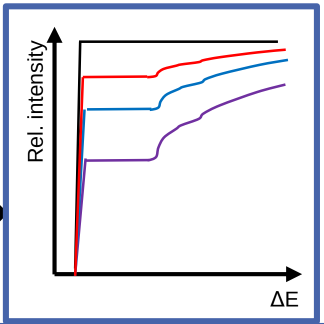

4 column densities:
[0, 0.5, 3.0, 6.0]
$*10^{17}cm^{-2}$

Energy loss function: measurement

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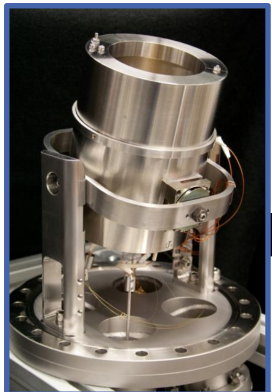

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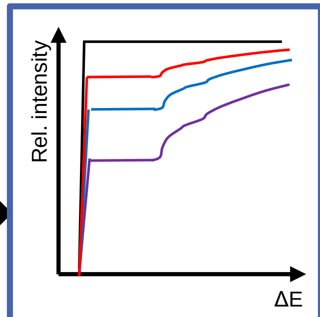

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Keloss
software
package

Energy loss function: measurement

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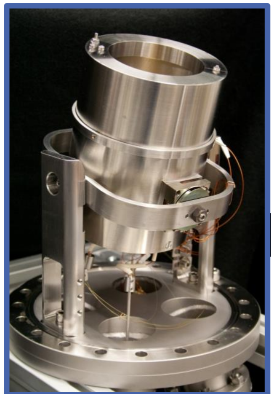

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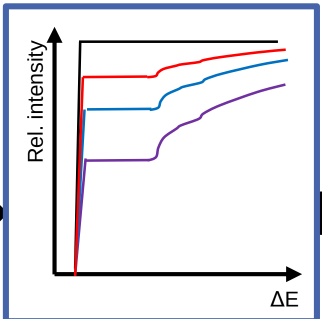

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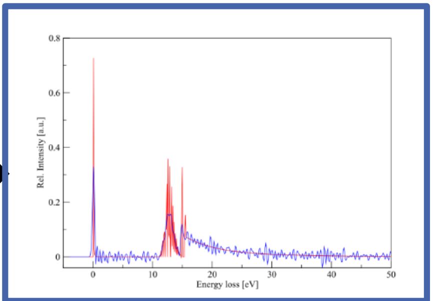
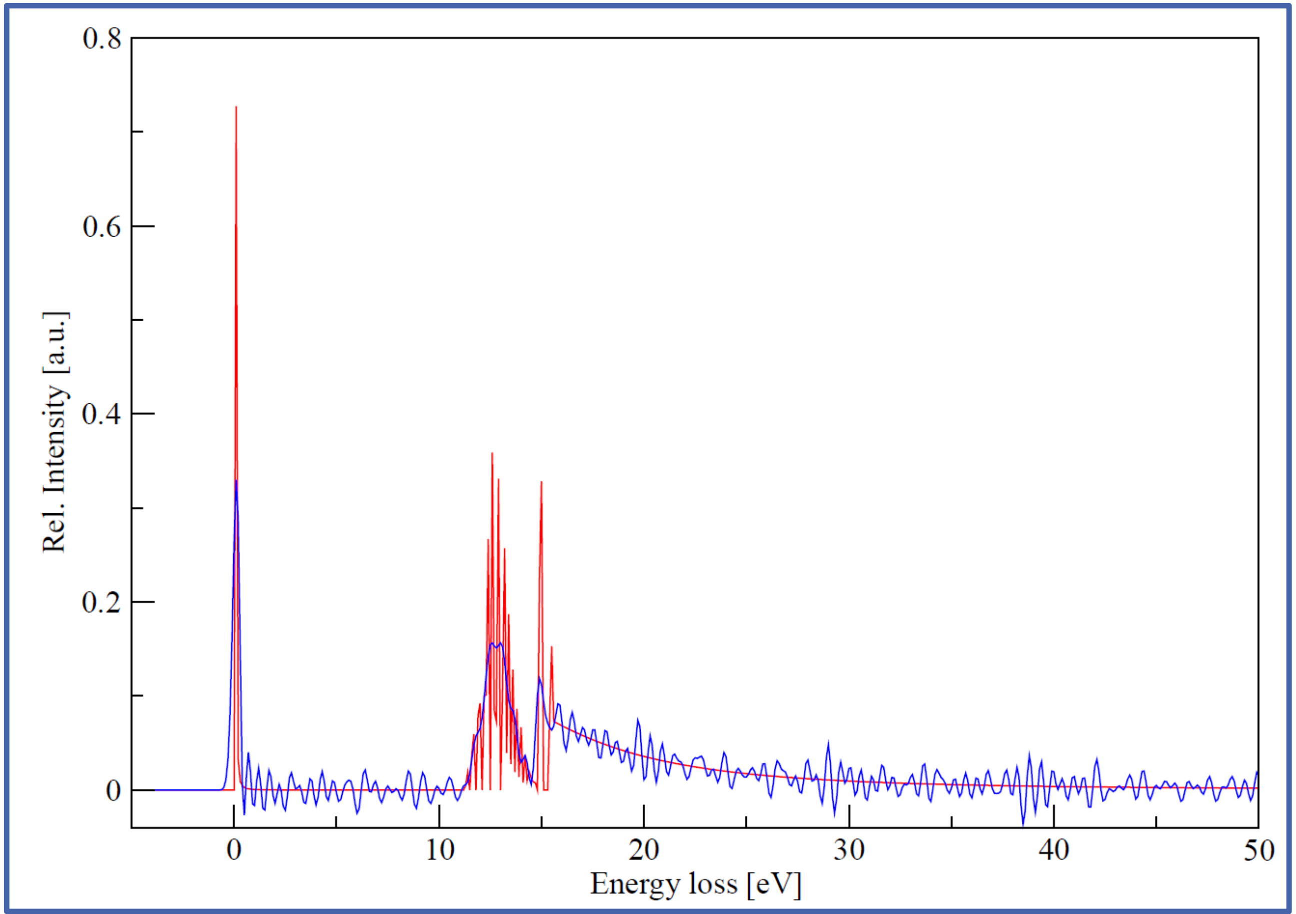


Energy loss function

C. Kranz, Diploma thesis 2011

Energy loss function: measurement



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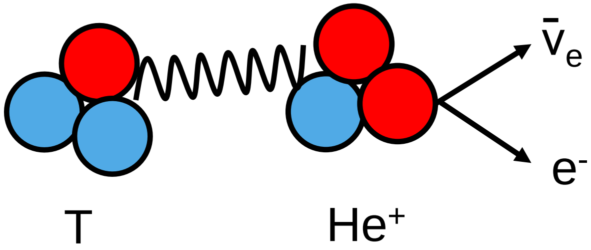
Energy loss function

Molecular final states distribution



Energy loss due to
- Electronic exc. 20 eV
- Vibrational exc. ~0.1 eV
- Rotational exc. ~0.01 eV

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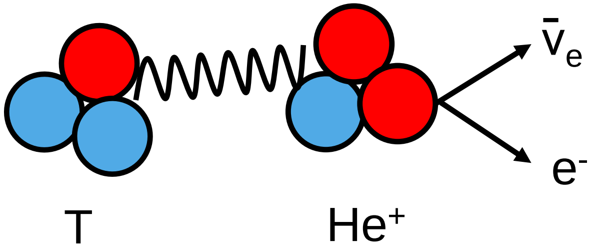

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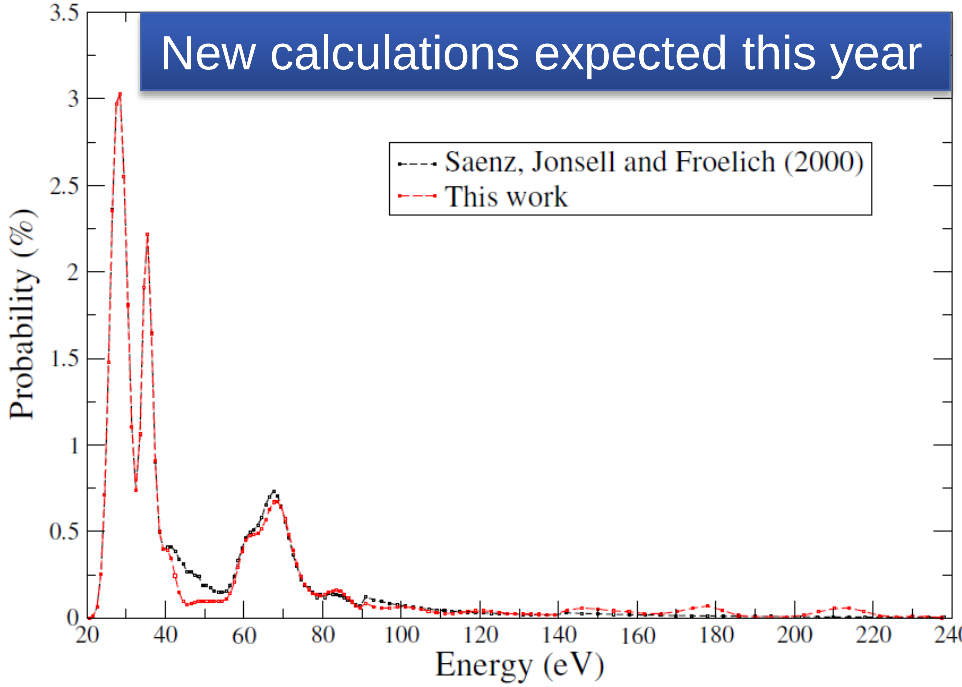
New calculations expected this year



N. Doss, PhD thesis (2007)

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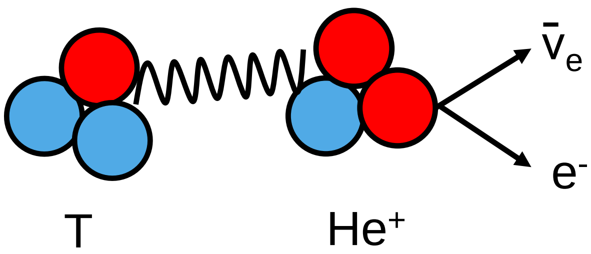

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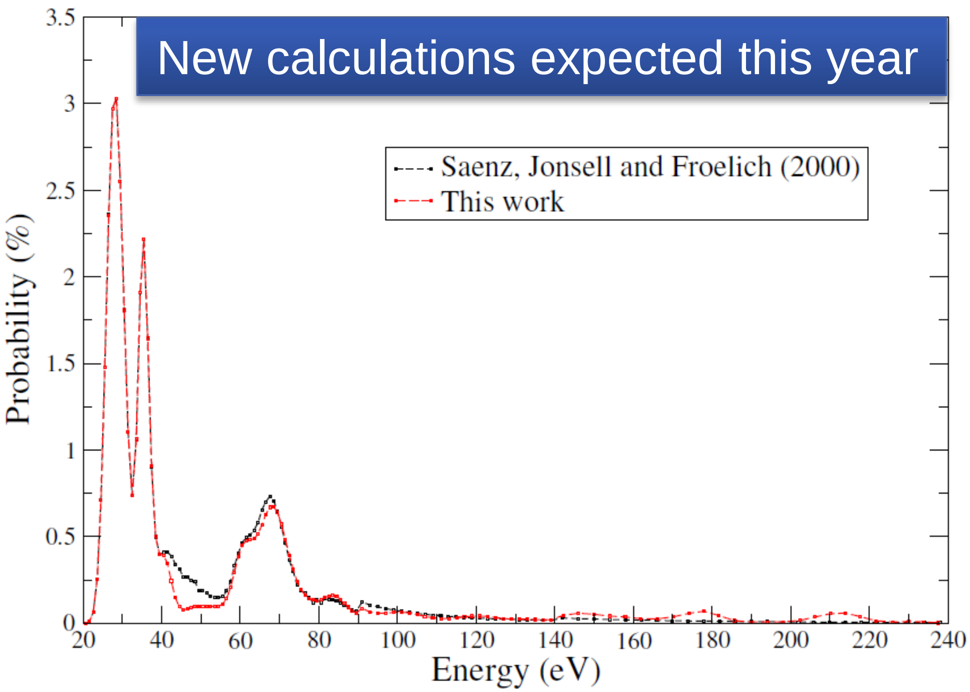

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$$\frac{\mathrm{d}N}{\mathrm{d}E_\mathrm{e}} = \frac{G_\mathrm{F}^2 m_\mathrm{e}^5 \cos^2\theta_C}{2\pi^3\hbar^7} |M_\mathrm{nuc}|^2 F(Z, E_\mathrm{e}) p_\mathrm{e} E_\mathrm{e} \cdot$$

$$\sum_{i,k} |U_{ei}|^2 P_k (E_\mathrm{max} - E_\mathrm{e} - V_k) \cdot \sqrt{(E_\mathrm{max} - E_\mathrm{e} - V_k)^2 - m_{\nu i}^2} \cdot \Theta(\mathrm{E}_\mathrm{max} - E_\mathrm{e} - V_k - m_{\nu i})$$

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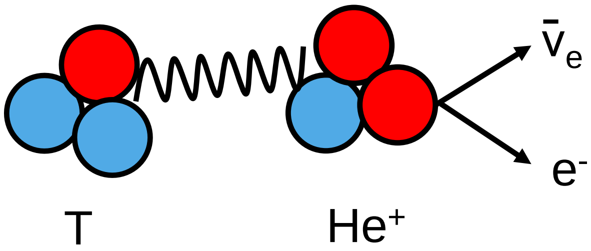

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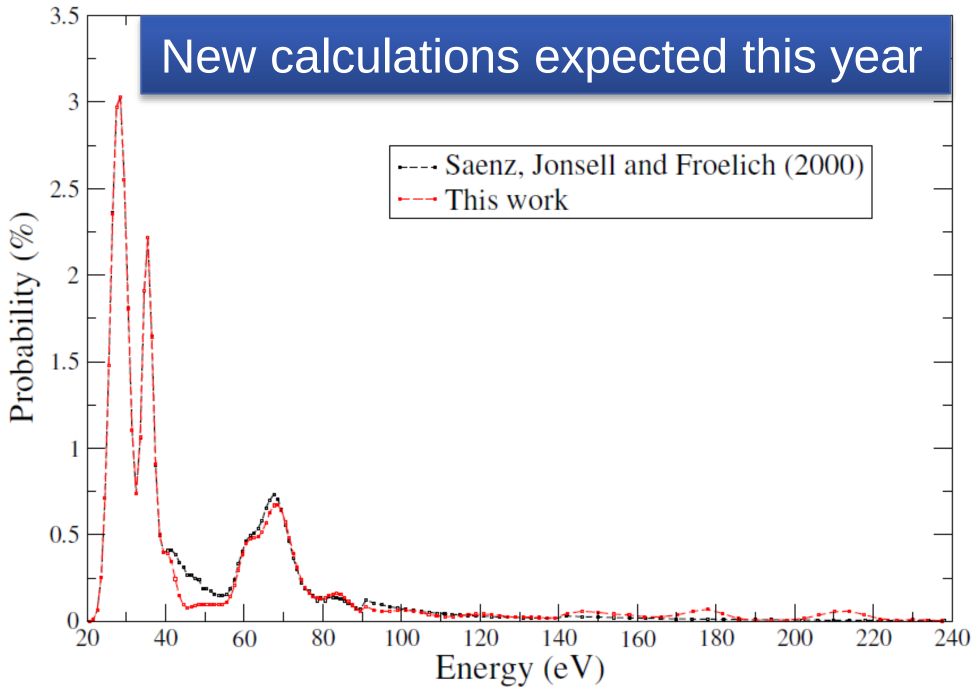

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Can be tested experimentally only in parts → rely on theory.

Further systematics

- High voltage
- Pumping speed
- Doppler effect
- Adiabaticity
- Plasma effects
- Synchrotron radiation
- Ions and Clusters
- Magnetic field
- …

Outlook: timetable

August 15: delivery of WGTS

Beginning of 2016: All connections to infrastucture made. Cooling down of WGTS.

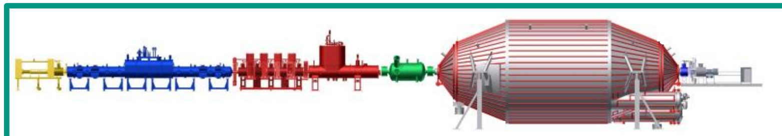
Spring 2016: test of cooled WGTS without other KATRIN components connected.

Summer 2016: Connect all KATRIN components

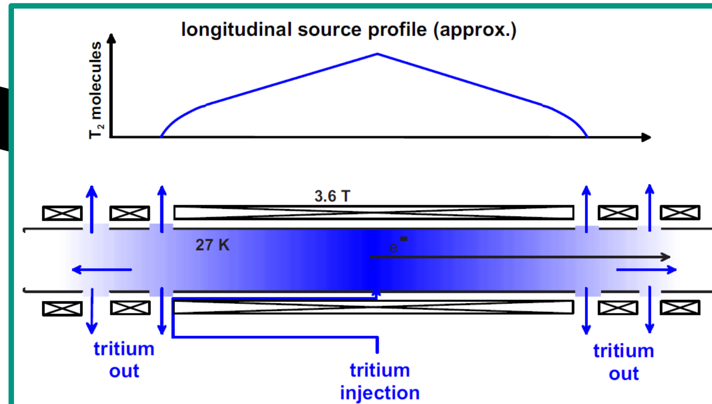
Autumn 2016: test measurements with deuterium

Winter 2016/17: start of tritium measurements

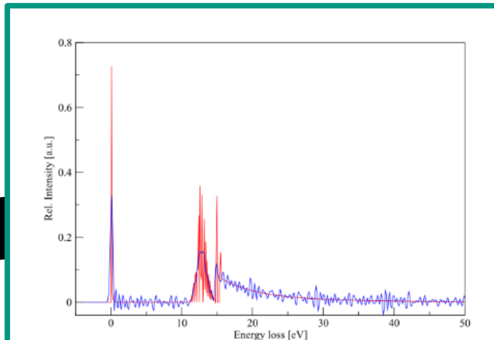
Summary

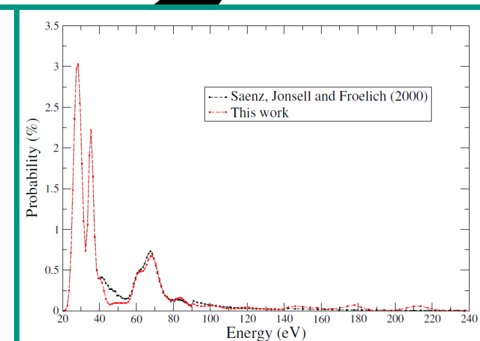


KATRIN sensitivity m_ν = 200 meV



Influenced by source systematics





Main systematics: Energy loss and FSD

Coming soon: measurements of systematics (first with D_2, then with T_2)

Thank you for your attention…

… and thanks to:

H. Robertson, UW

D. Parno, UW

L. Bodine, UW

T. James, LaserQuantum

H. H. Telle, Madrid

G. Drexlin, KIT

F. Heizmann, KIT

S. Rupp, KIT

M. Schlösser, Madrid

S. Fischer, KIT

L. Kuckert, KIT

A. Off, KIT

K. Valerius, KIT

M. Sturm, KIT

R. Größle, KIT

S. Niemes, KIT

M. Kleesiek, KIT

M. Machatschek, KIT

B. Bornschein, KIT

M. Babutzka, KIT

Total KATRIN systematic budget

source of systematic shift	**achievable / projected accuracy**	**systematic shift** $\sigma_{\mathrm{syst}}(m_\nu^2)$ $(10^{-3}\,\mathrm{eV}^2)$
description of final states	$f < 1.01$	< 6
T^- ion concentration	$< 2 \cdot 10^{-8}$	< 0.1
unfolding of energy loss func. $f(\varepsilon)$		< 6
monitoring of column density ρd	$\Delta T/T < 2 \cdot 10^{-3}$ $\Delta\Gamma/\Gamma < 2 \cdot 10^{-3}$ $\Delta\varepsilon_T/\varepsilon_T < 2 \cdot 10^{-3}$ $\Delta p_{\mathrm{inj}}/p_{\mathrm{inj}} < 2 \cdot 10^{-3}$ $\Delta p_{\mathrm{ex}}/p_{\mathrm{ex}} < 0.06$	$< \frac{\sqrt{5} \cdot 6.5}{10}$
background slope	$< 0.5\,\mathrm{mHz/keV}$ (Troitsk)	< 1.2
HV variations	$\Delta HV/HV < 3\,\mathrm{ppm}$	< 5
WGTS potential variations	$\Delta U < 10\,\mathrm{meV}$	< 0.2
WGTS mag. field variations	$\Delta B_{\mathrm{S}}/B_{\mathrm{S}} < 2 \cdot 10^{-3}$	< 2
elastic $\mathrm{e}^- - \mathrm{T}_2$ scattering		< 5
identified syst. uncertainties	$\sigma_{\mathrm{sys,\ tot}} = \sqrt{\sum \sigma_{\mathrm{sys}}^2} \approx 0.01\,\mathrm{eV}^2$	

KDR, table 6, page 217, taken from M. Kleesiek, PhD thesis, KIT (2014).

Systematics budget for 200 meV sensitivity

	KDR 200 meV sensitivity
5 independent systematics	$7.5 \cdot 10^{-3} \mathrm{eV}^2$ (each)
Total systematic uncertainty	$0.017\ \mathrm{eV}^2$
Total statistical uncertainty	$0.018\ \mathrm{eV}^2$
Sum	$0.025\ \mathrm{eV}^2$
1σ sensitivity	$0.157\ \mathrm{eV}$
Sensitivity (90 % C. L.)	$0.202\ \mathrm{eV}$

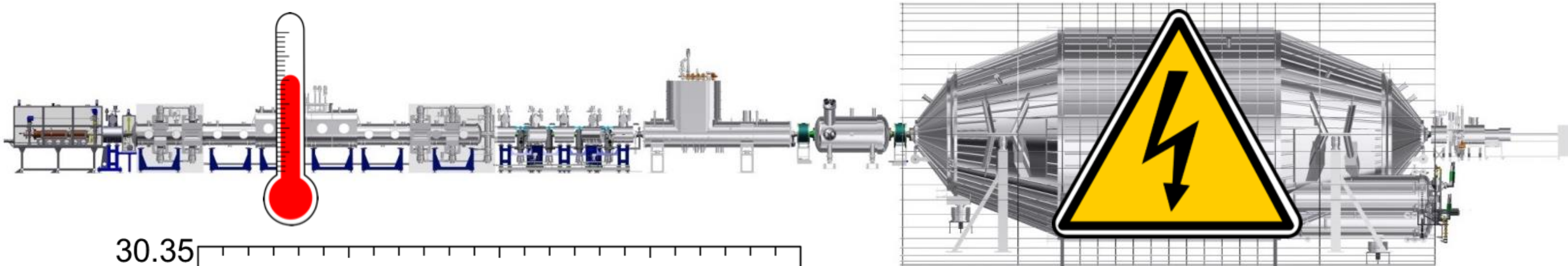
summed quadratically

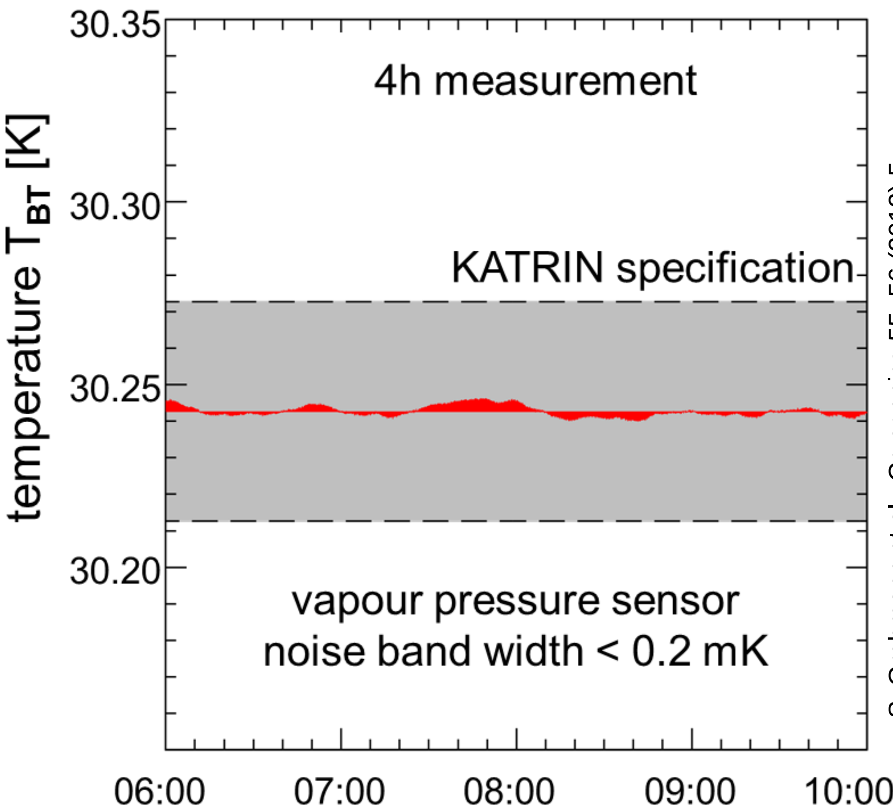
summed quadratically

square root

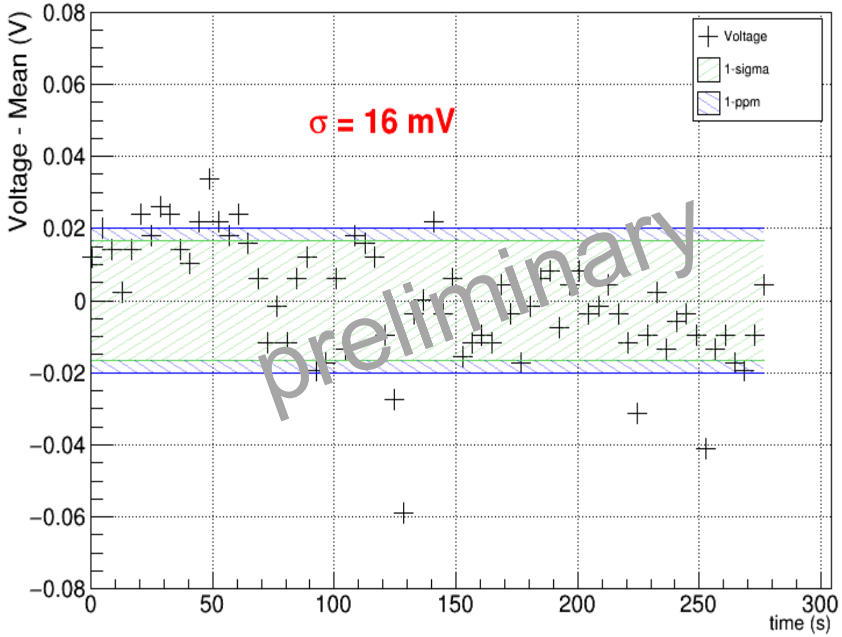
multiplied with $\sqrt{1.64}$

Temperature and high voltage stability





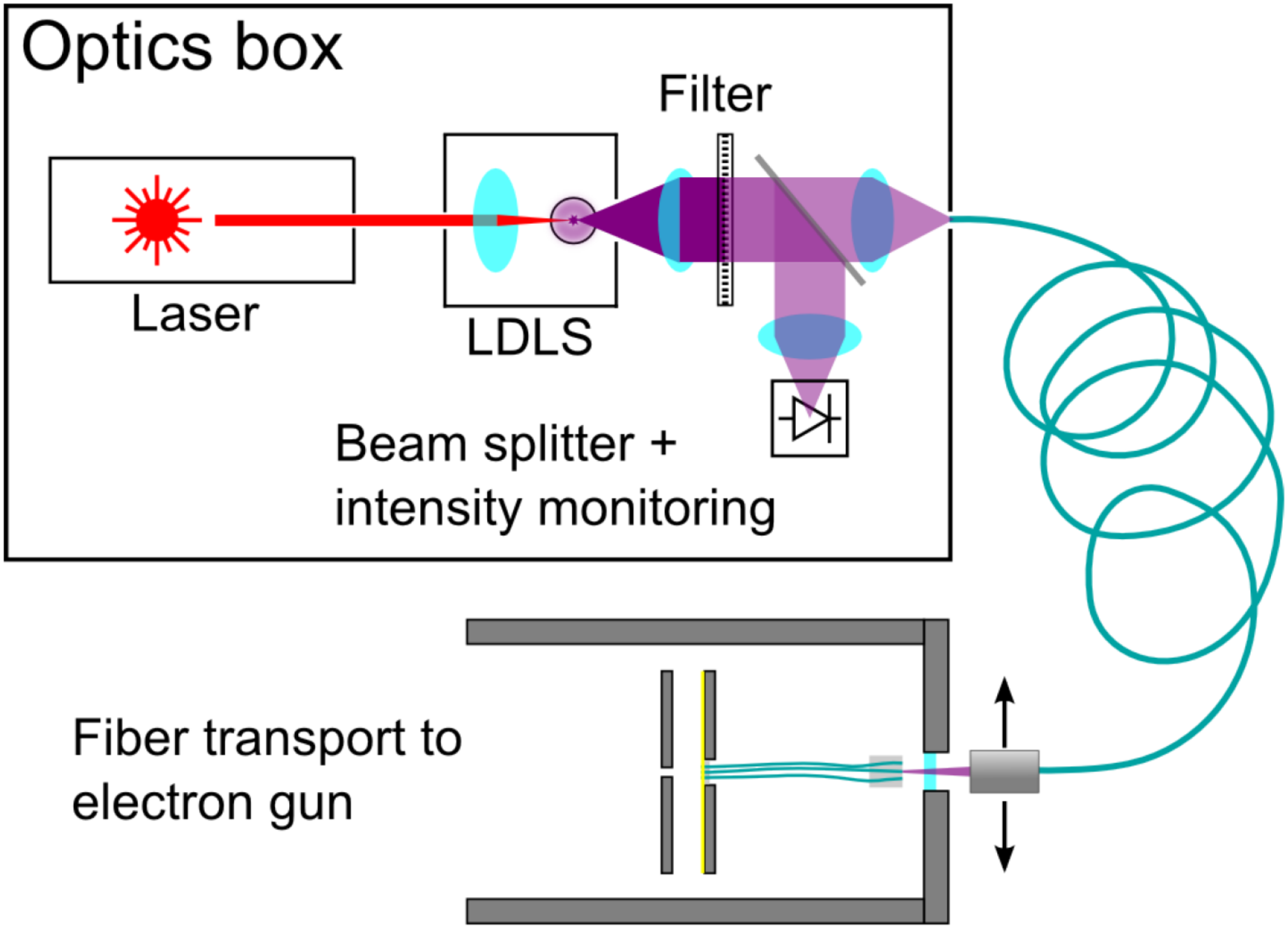
S. Grohmann et al., Cryogenics 55–56 (2013) 5



M. Erhard et al., in prep.

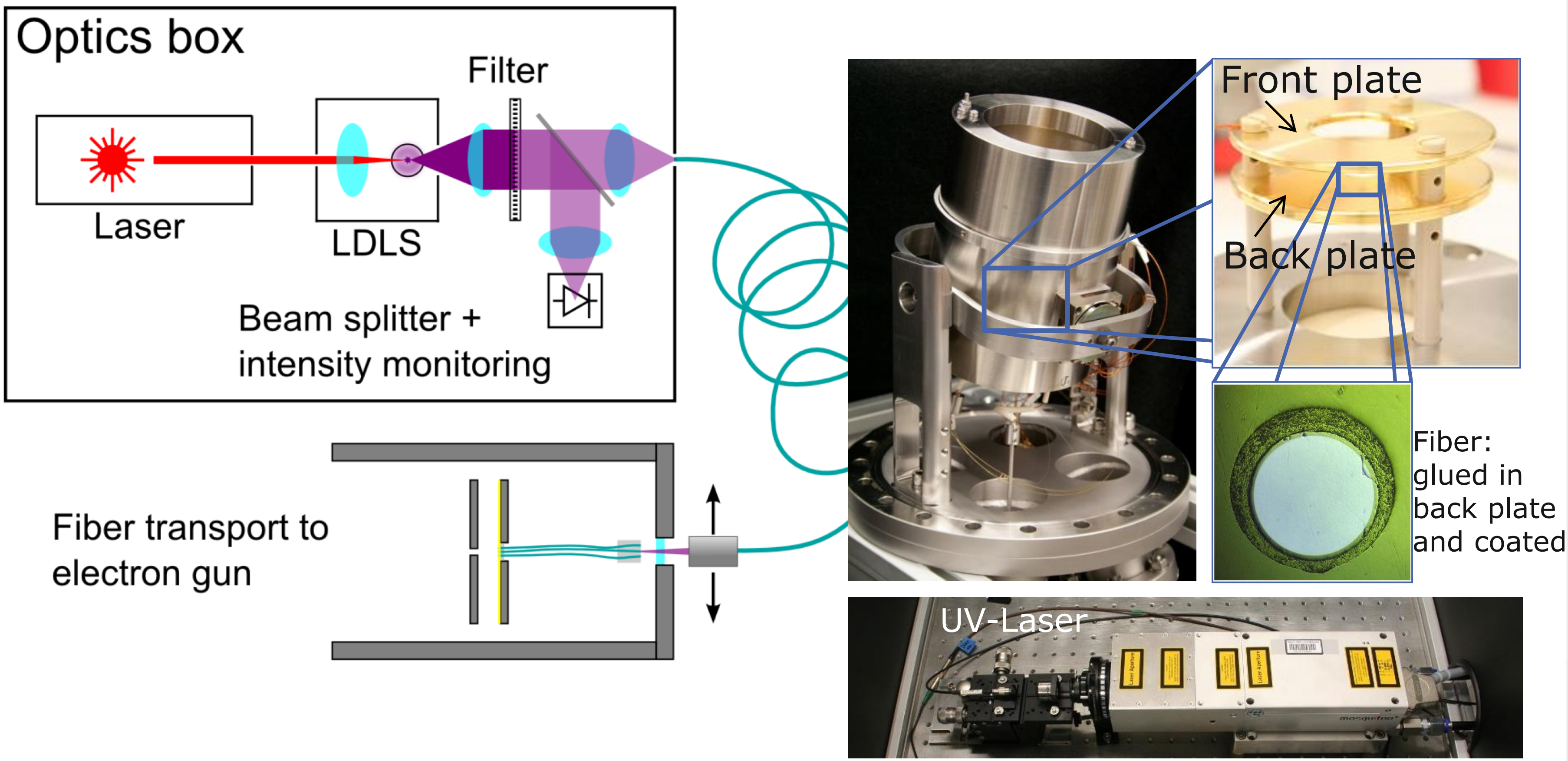
Egun

M. Babutzka, PhD thesis, KIT (2014)



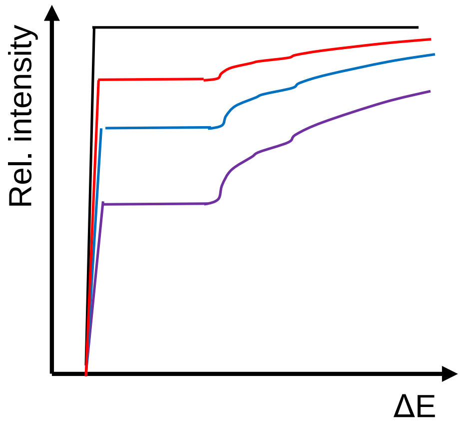
Egun

M. Babutzka, PhD thesis, KIT (2014)



Pictures taken from P. Ranitzsch, talk at KATRIN analysis workshop, Münster 2015

Deconvolute the energy loss function

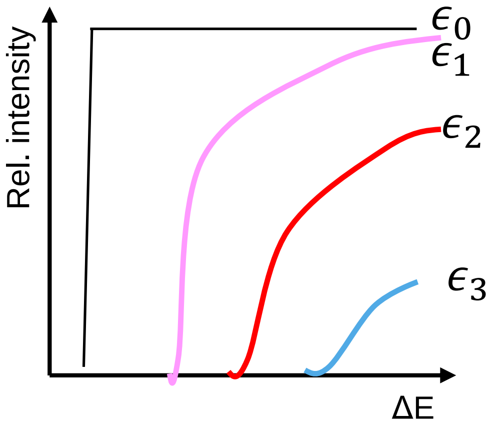


Response function

$$f_{\mathrm{res}}(E,qU) = T(E,qU) \otimes P_0 + T(E,qU) \otimes P_1 f(\Delta E) + T(E,qU) \otimes P_2\big(f(\Delta E) \otimes f(\Delta E)\big) + \cdots = P_0\epsilon_0 + P_1\epsilon_1 + P_2\epsilon_2 + \cdots$$

System of equations

$$f_{res,0} = T(E,qU) = \epsilon_0$$
$$f_{res,0.5} = P_{0,0.5}\epsilon_0 + P_{1,0.5}\epsilon_1 + P_{2,0.5}\epsilon_2 + P_{3,0.5}\epsilon_3$$
$$f_{res,0.5} = P_{0,3.0}\epsilon_0 + P_{1,3.0}\epsilon_1 + P_{2,3.0}\epsilon_2 + P_{3,3.0}\epsilon_3$$
$$f_{res,0.5} = P_{0,6.0}\epsilon_0 + P_{1,6.0}\epsilon_1 + P_{2,6.0}\epsilon_2 + P_{3,6.0}\epsilon_3$$



Deconvolute energy loss function $f(\Delta E)$

$$\epsilon_1 = T(e,qU) \otimes f(\Delta E)$$