The KATRIN experiment

Status and comissioning

living.knowledge
WWU Münster

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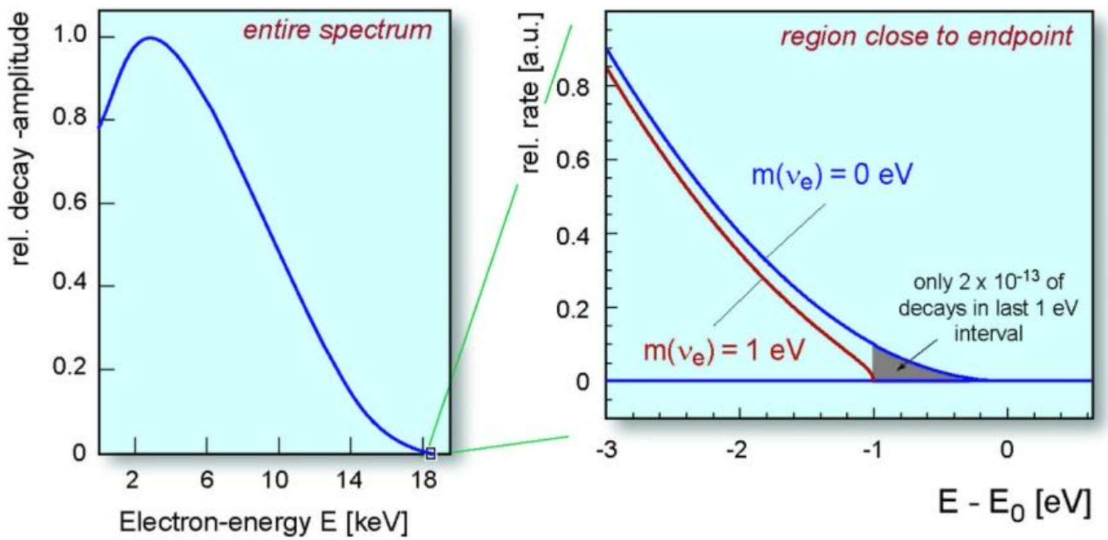
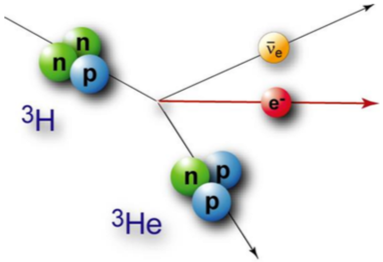
(Tritium) β-decay and neutrino mass

β-decay: $\quad {}^{A}_{Z}X_{N} \rightarrow {}^{A}_{Z+1}X_{N-1} + e^{-} + \bar{\nu}_{e}$



$$\frac{dN}{dE} = K\ F(E,Z)\ p\ \left(E_e + m_e\right)\left(E_0 - E_e\right)\sqrt{\left(E_0 - E_e\right)^2 - m\left(\bar{\nu}_e\right)^2}$$



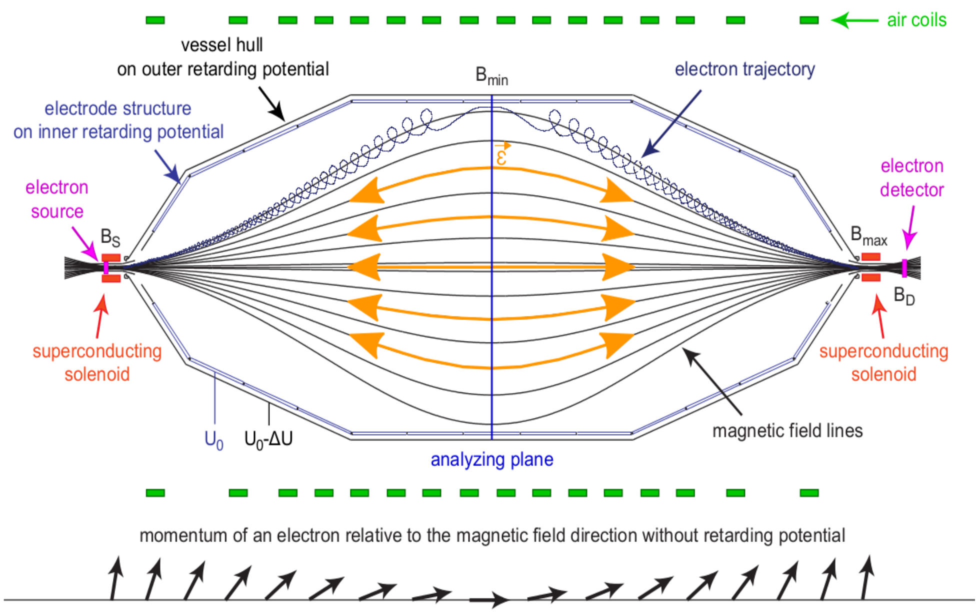
Tritium ^{3}H:
$E_0 = 18.6$ keV
$T_{1/2} = 12.3$ y

Rhenium ^{187}Re:
$E_0 = 2.47$ keV
$T_{1/2} = 4.3\ 10^{10}$ y

Holmium ^{163}Ho (EC):
$E_0 = 2.8$ keV
$T_{1/2} = 4570$ y

MAC-E Filter

Magnetic **A**diabatic **C**ollimation and **E**lectrostatic Filter:



Magnetic guiding and collimation of e⁻

- Transform $E_\perp$ to $E_{||}$

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

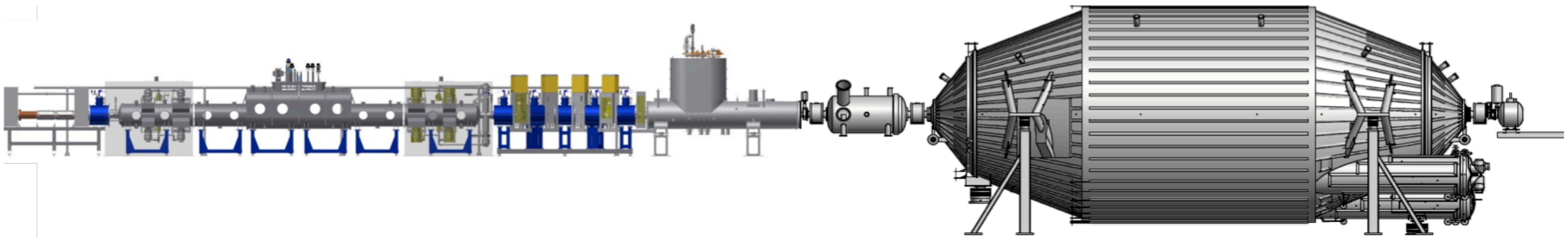
Electrostatic field for energy analysis

- Sharp transmission depending on:
  - Emission angle
  - Radius in at B_{min}

Integrated energy resolution:

$$\Delta E = E\,\frac{B_{\text{min}}}{B_{\text{max}}}$$

The KATRIN experiment



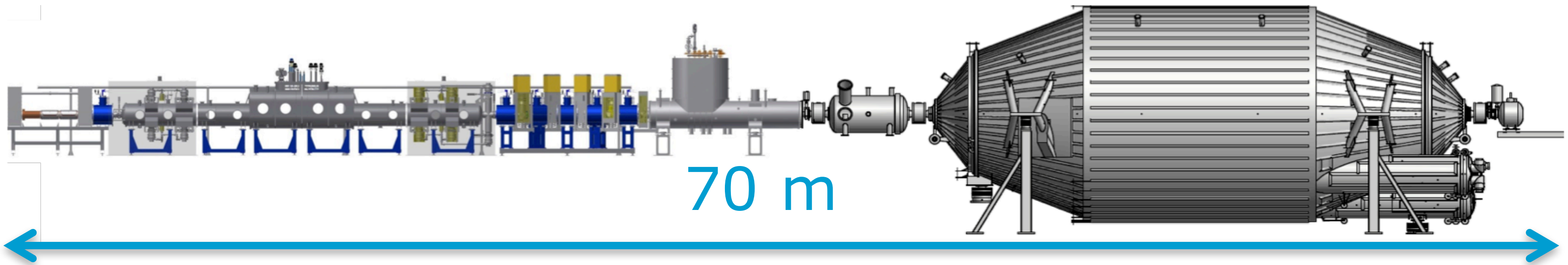
KATRIN primary goal:

- Energy filter width: $\Delta E = 0.93\ \mathrm{eV}$
- Measure neutrino mass with a sensitivity of m(ν) = 200 meV (90 % C.L.)

KATRIN beyond m(ν):

- Search for eV- and keV-scale sterile neutrinos
- Right handed currents (w/ sterile neutrinos), Lorentz invariance, …
- Technological advances in many fields

The KATRIN experiment



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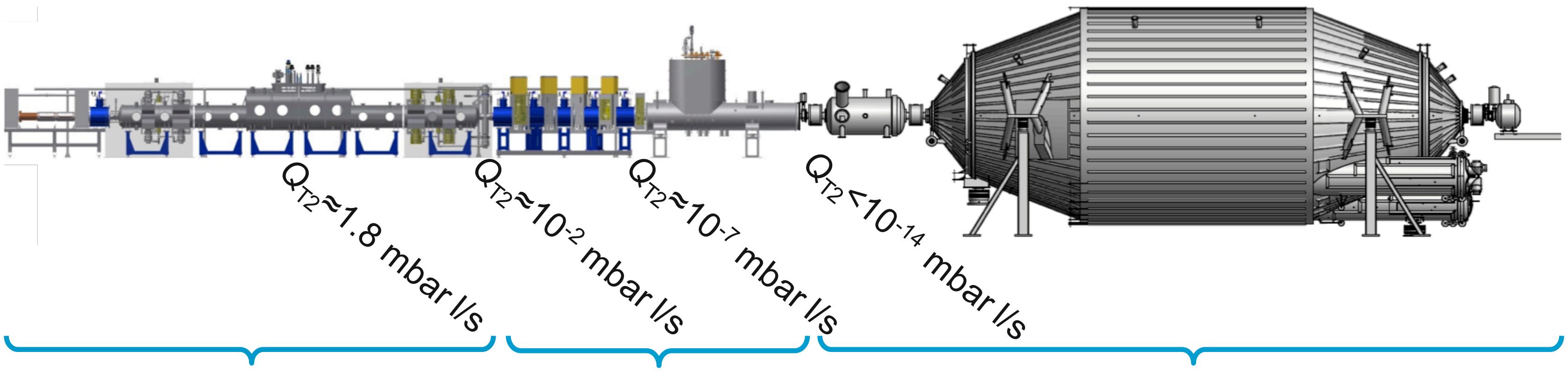


Source section:
High intensity, highly stable T_2 source

WGTS

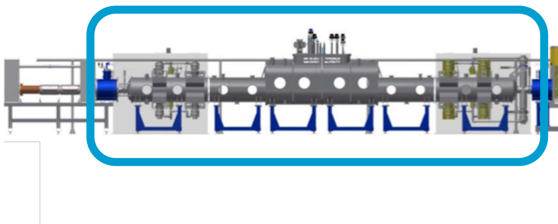
Transport section:
Tritium retention by a factor 10^{14}

DPS, CPS

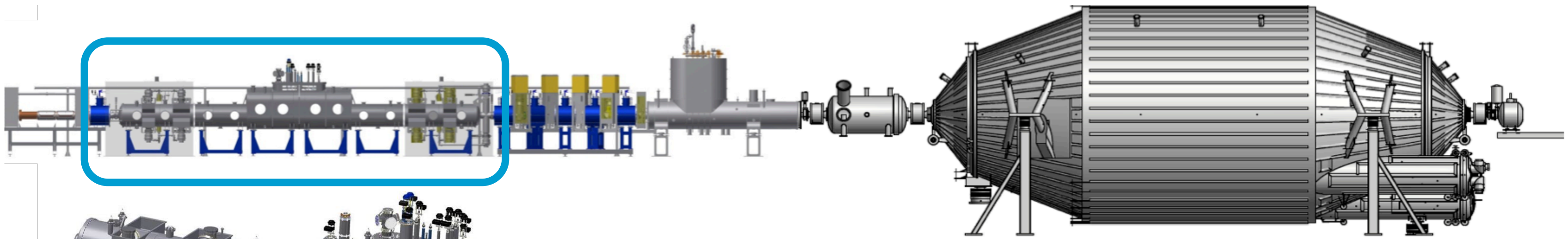
Spectrometer and detector section:
Electron analysis and detection

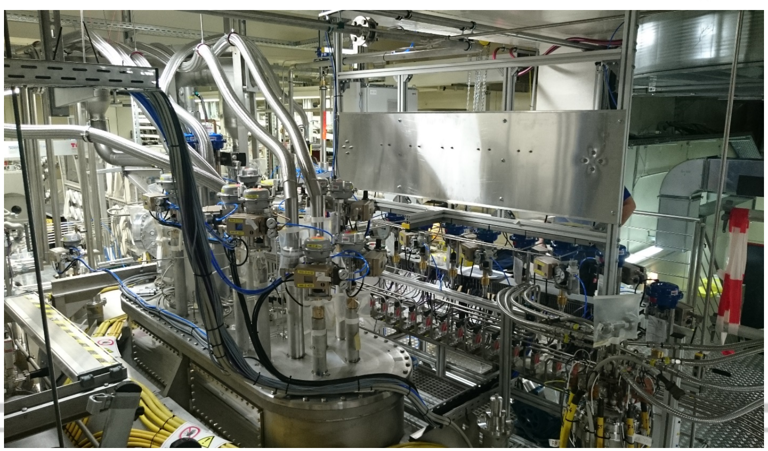
PreSpec, MainSpec, FPD

The KATRIN experiment



The KATRIN experiment

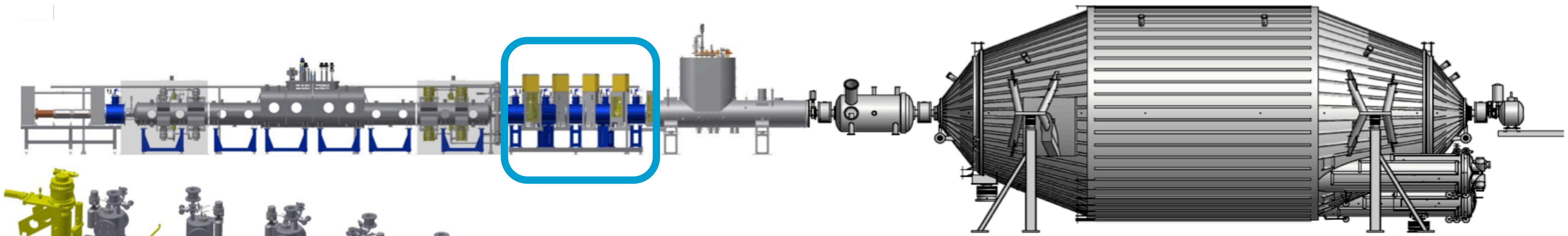


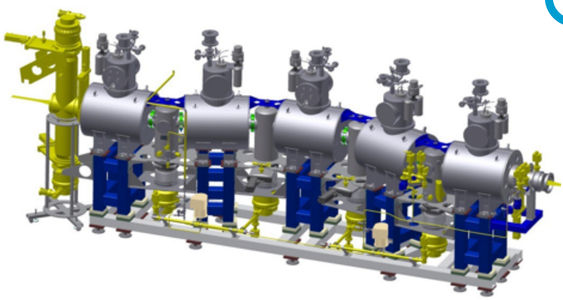


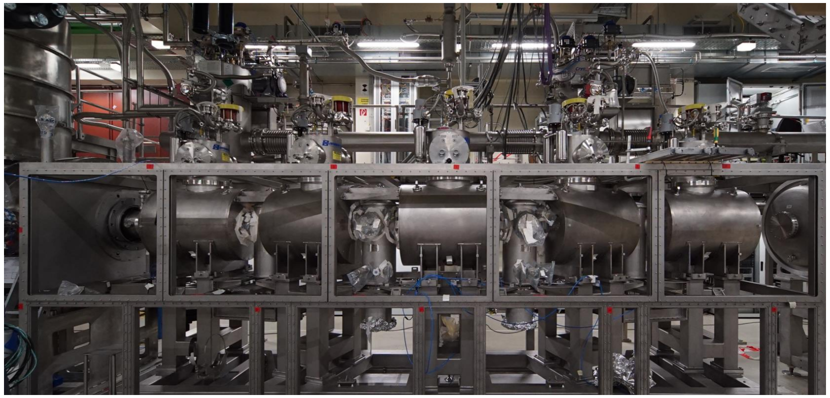
Windowless gaseous tritium source (WGTS)

- T_2 source with 1.7×10^{11} Bq
- 10 m long, ⦰ 9 cm tube
- T_2 gas, $p = 10^{-3} \dots 10^{-6}$ mbar
- Stable on 10^{-3} level
- Arrived on Sept. 10th 2015
- Installation progressing

The KATRIN experiment



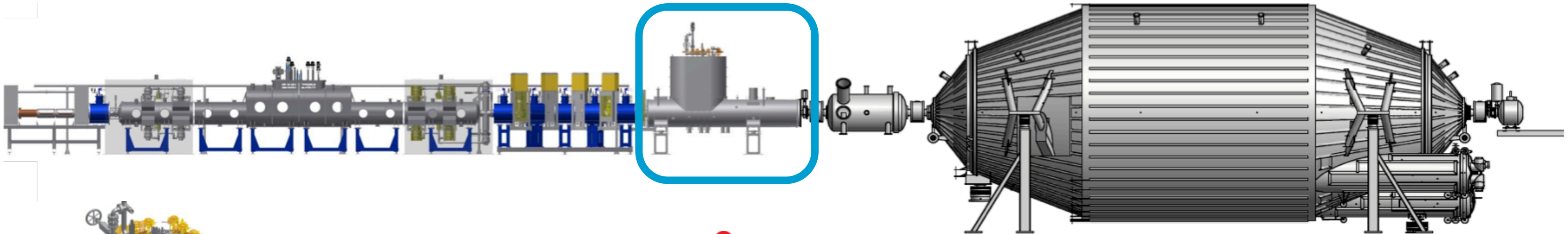


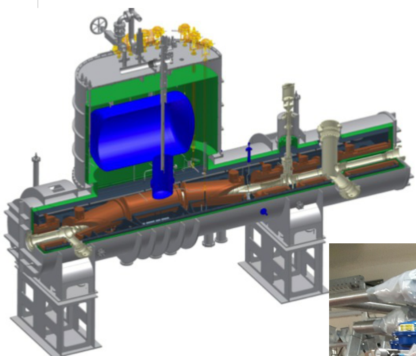


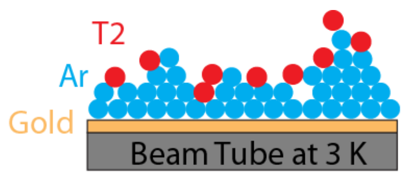
Differential pumping section (DPS)

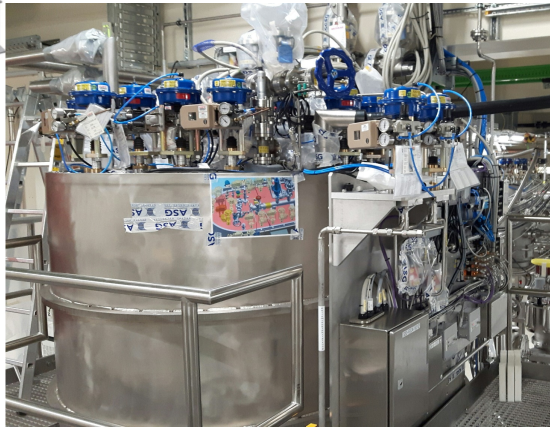
- Tritium retention by 10^5 by active pumping with 4 TMPs
- 5 superconducting solenoids
- Magnets set up & working at KIT
- Beam line assembly finishing up
- Integration into T_2 infrastructure

The KATRIN experiment





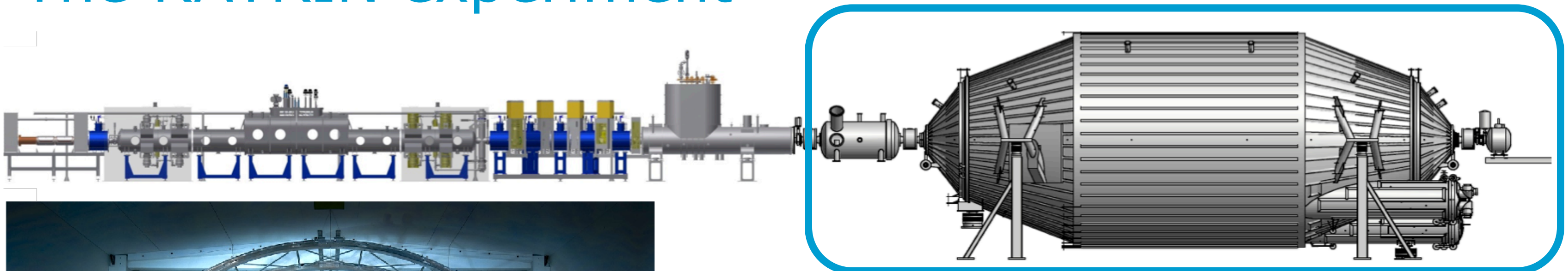


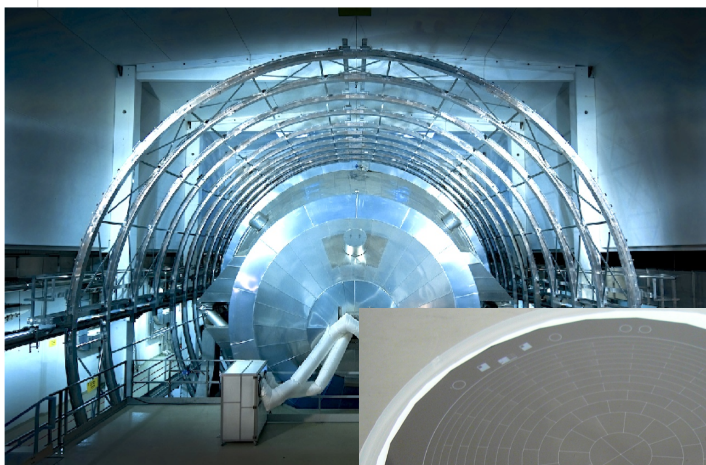


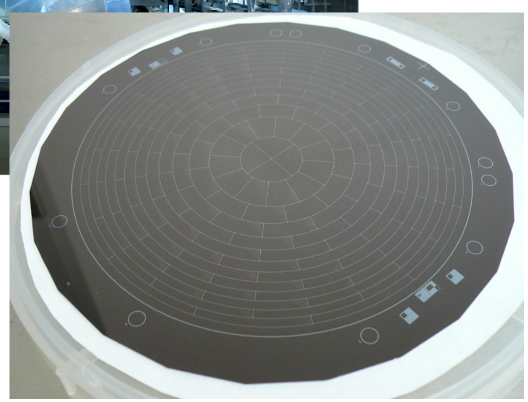
Cryogenic pumping section (CPS)

- Tritium retention > 10^7
- Cryo-pumping of residual gas
- 7 magnets @ 5.6 T
- Delivered to KIT on July 30, 2015
- Cool down is ongoing (currently <200 K)

The KATRIN experiment







Spectrometer and detector section

Tandem spectrometer setup

Pre-Spectrometer

- Pre-filter 10^{10} $e^-/s \Rightarrow 10^3$ e^-/s
- Used for R&D for Main Spec

Main Spectrometer

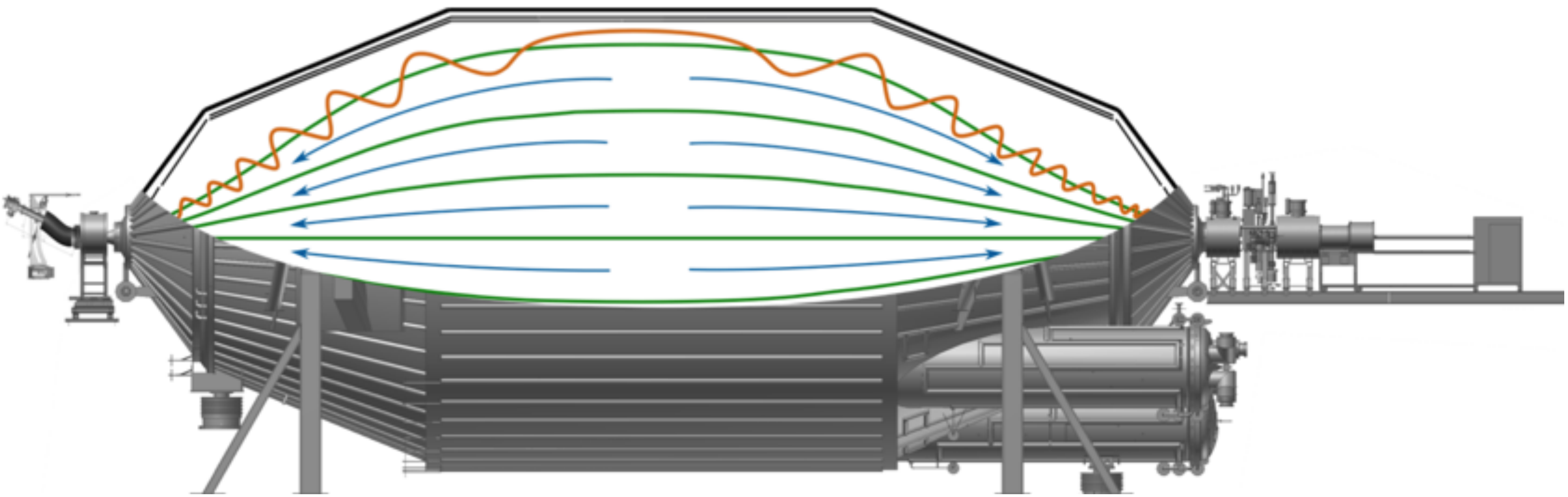
- Main energy analysis
- $\Delta E = 0.93$ eV

Focal plane detector (FPD)

- 148 Pixel Si-PIN diode
- $\Delta E \sim 2$ keV

Everything on site

Spectrometer and Detector commissioning



Two phases: SDS-I 2013; SDS-II(a+b): late 2014 to mid 2015

Subsystems:

- Main spectrometer
- Focal plane detector
- Angular selective e⁻-source

Tests:

- Hardware, Software, Slow Control
- Transmission Properties
- Background

Spectrometer and Detector commissioning

Electron transmission properties

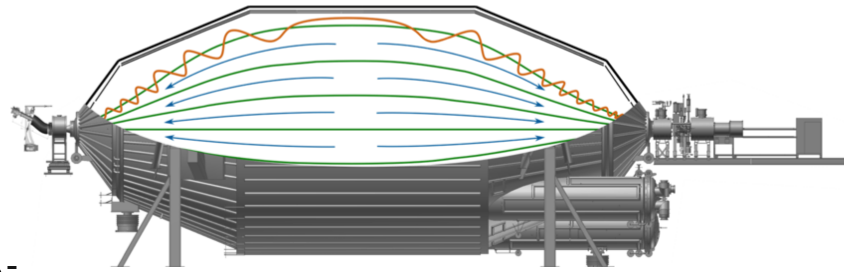
Mono-energetic, angular selective

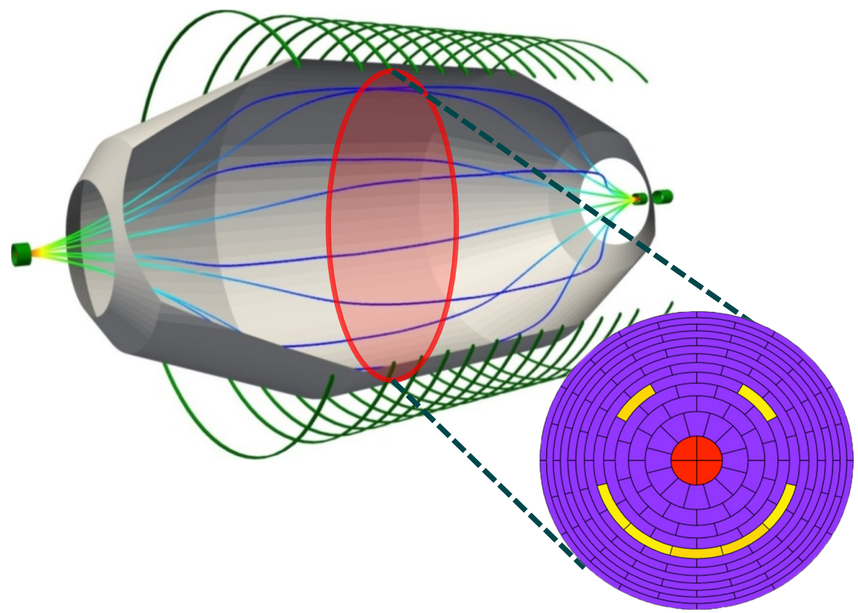
electron gun

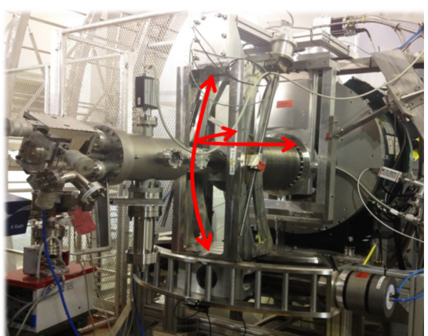
- fast non-adiabatic acceleration of e⁻ in non-parallel $\vec{E}$ and $\vec{B}$ fields

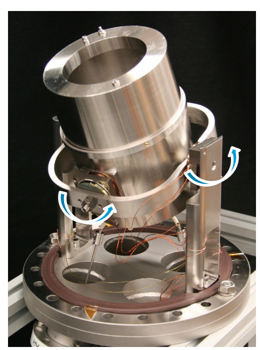
Test the effect inside MS of

- electric potential
- magnetic field









Spectrometer and Detector commissioning

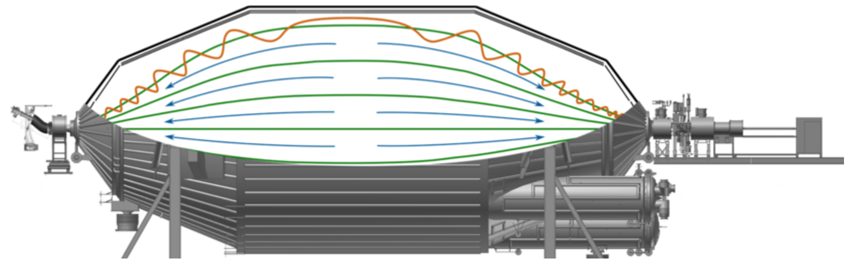
Electron Optics

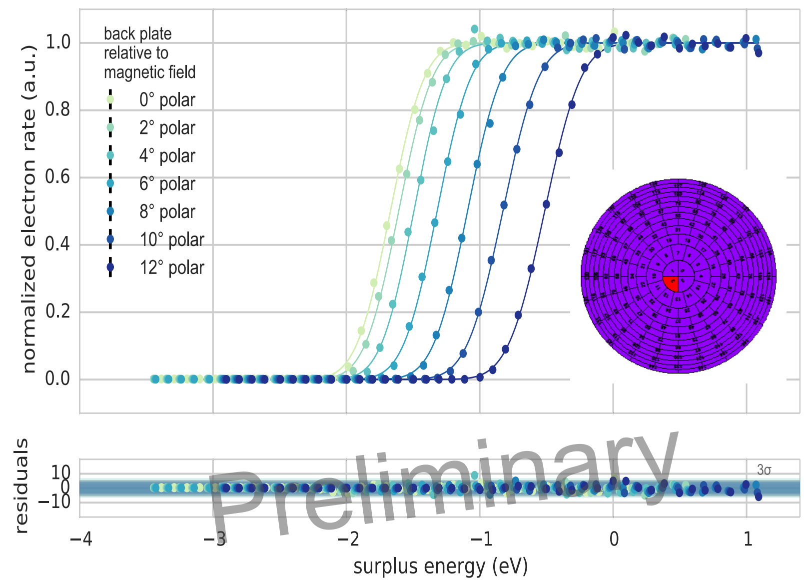
Angular selectivity shown

- Width: $\Delta E \approx 1.2\ \text{eV} \approx E\,\dfrac{B_{\text{min}}}{B_{\text{max}}}$

  $E = 18.6\ \text{keV};\ B_{\text{min}} = 0.38\ \text{mT};\ B_{\text{max}} = 5\ \text{T}$

- Consistent with calculation





Spectrometer and Detector commissioning

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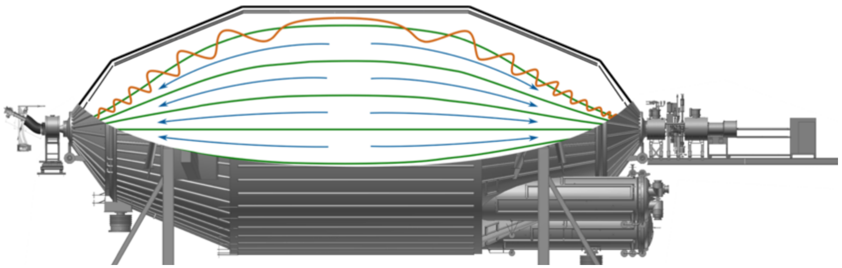
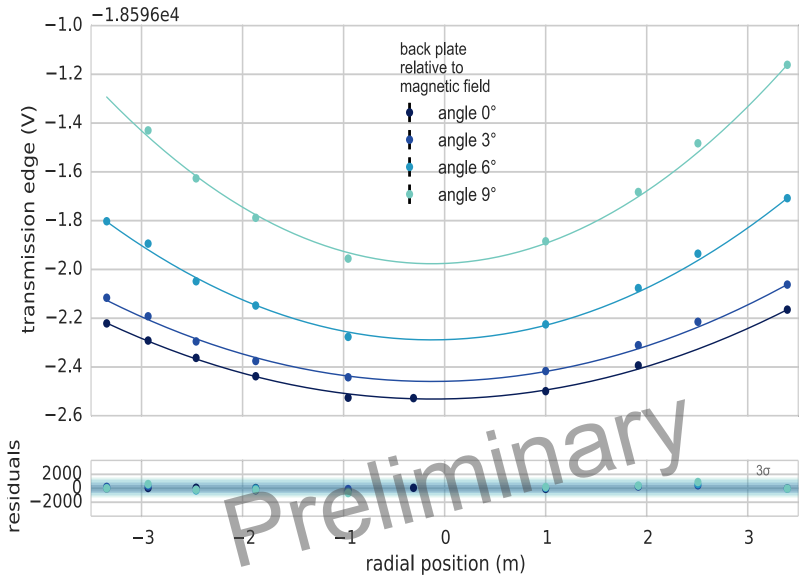
- Consistent with calculation

Potential drop towards center

- ΔU = 0.3 … 1.0 V
- Consistent with simulations

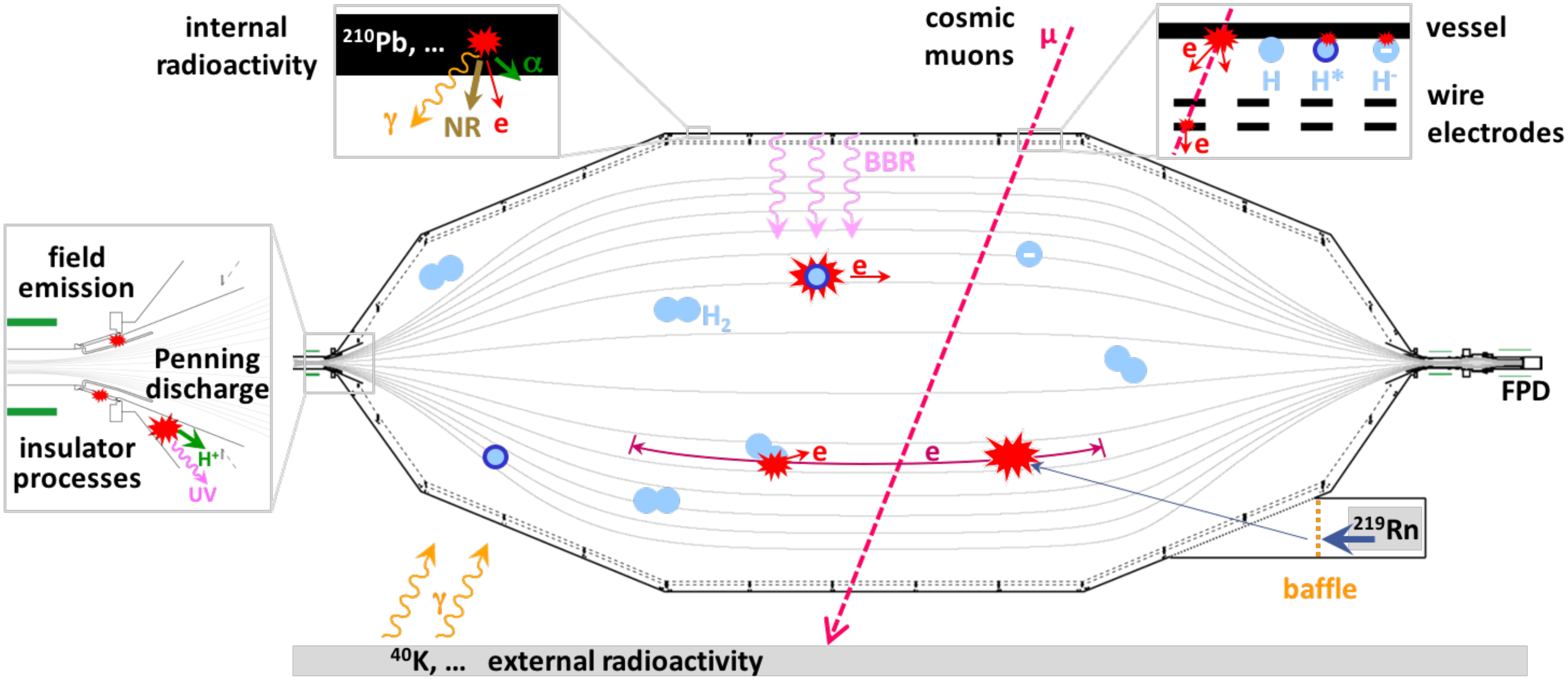
Detailed analysis ongoing





Spectrometer and Detector commissioning

Background processes



Spectrometer and Detector commissioning

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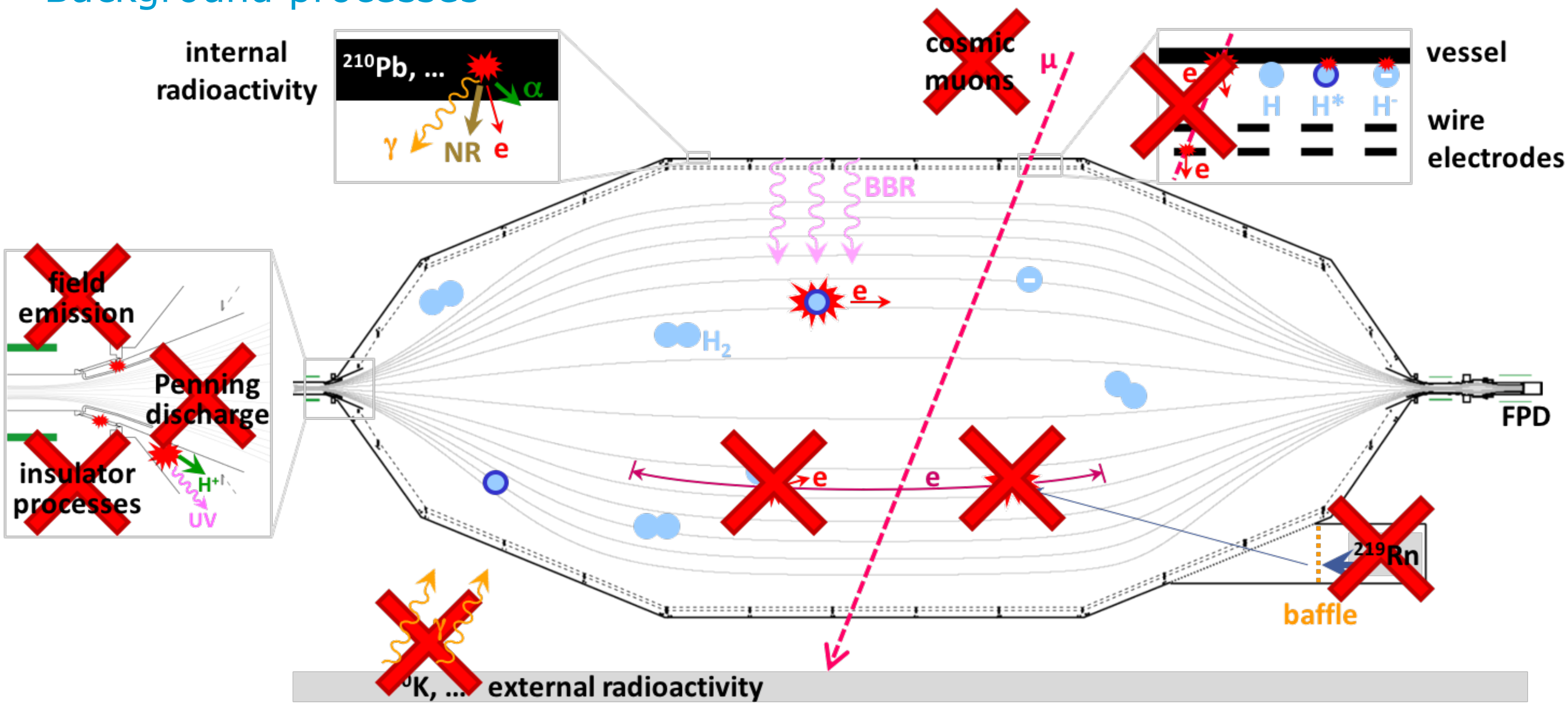
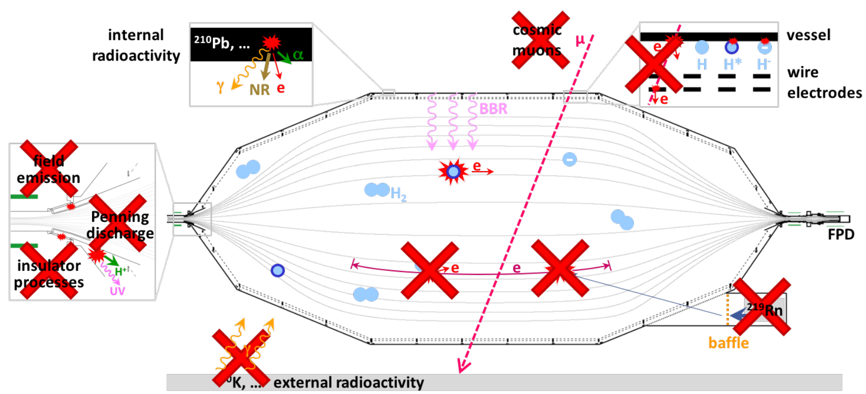


Spectrometer and Detector commissioning

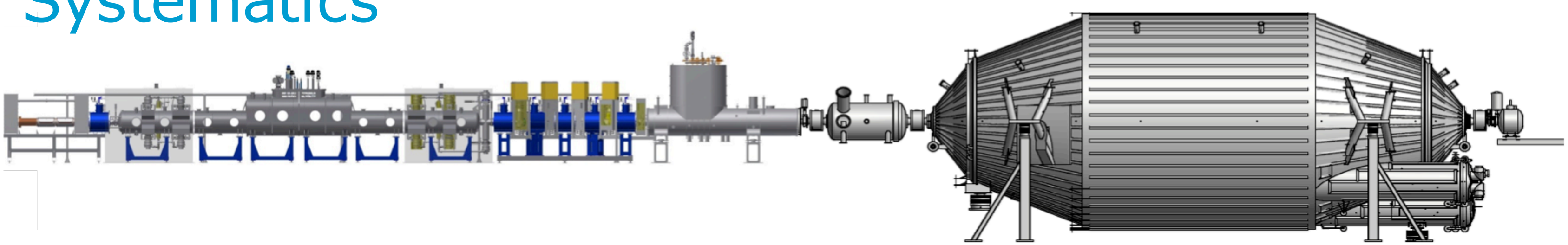
Background processes

- Most known and understood background sources excluded
- Remaining background level: ~312±3 mcps (design goal 10 mcps)
- Current working theory:

  Internal radioactivity + neutral messenger particle
- Third commissioning phase in autumn



Systematics



5 major systematics contributions

Final states: new evaluation coming

(A. Saenz et al. PRL **84** (2000) 242)

Energy loss function: within specifications

(angular defined e-gun, paper in internal review)

Column density: Tests during STS III

(angular defined e-gun, Electron rate measurements, Raman spectroscopy…)

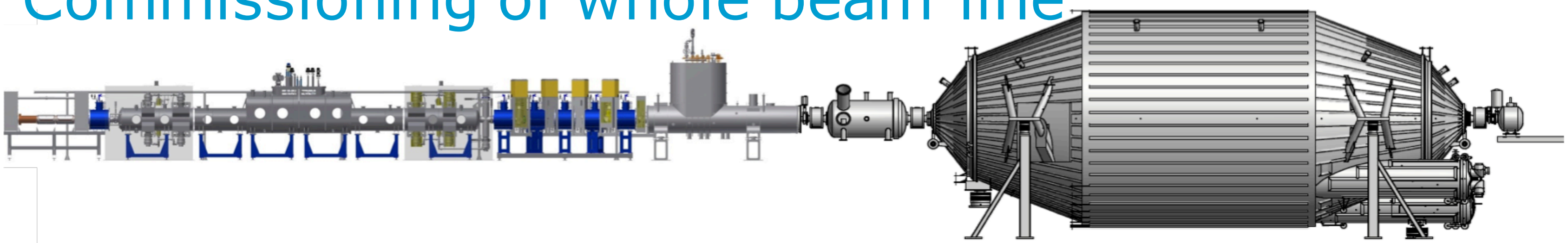
HV variations: within specifications

(Precision HV dividers, monitor spectrometer, Active post-regulation)

Elastic scattering

source of systematic shift	**achievable / projected accuracy**	**systematic shift** $\sigma_{\text{syst}}(m_\nu^2)$ $(10^{-3}\,\text{eV}^2)$
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	$\Delta T/T < 2 \cdot 10^{-3}$ $\Delta\Gamma/\Gamma < 2 \cdot 10^{-3}$ $\Delta\varepsilon_T/\varepsilon_T < 2 \cdot 10^{-3}$ $\Delta p_{\text{inj}}/p_{\text{inj}} < 2 \cdot 10^{-3}$ $\Delta p_{\text{ex}}/p_{\text{ex}} < 0.06$	$< \frac{\sqrt{5} \cdot 6.5}{10}$
background slope	$< 0.5\,\text{mHz/keV}$ (Troitsk)	< 1.2
HV variations	$\Delta HV/HV < 3\,\text{ppm}$	< 5
WGTS potential variations	$\Delta U < 10\,\text{meV}$	< 0.2
WGTS mag. field variations	$\Delta B_S/B_S < 2 \cdot 10^{-3}$	< 2
elastic $e^- - T_2$ scattering		< 5
identified syst. uncertainties	$\sigma_{\text{sys, tot}} = \sqrt{\sum \sigma_{\text{sys}}^2} \approx 0.01\,\text{eV}^2$	

Commissioning of whole beam line



All sub-systems come online right about now

Combined commissioning:

- Interaction of different sub-systems
- Guide electrons from start to end
- Start with inactive source gases (H_2, D_2)
  - Proposals in internal review
- Slowly increase tritium content (point of no return)

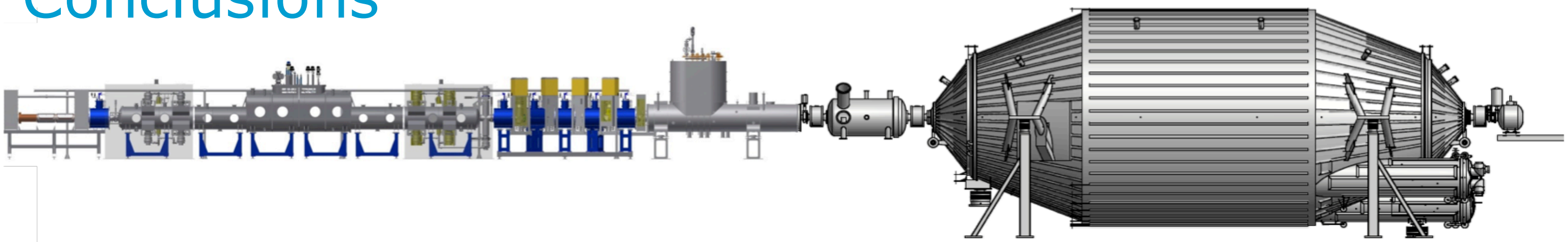

KATRIN

KATRIN-STS
Operational Readiness Phase III

Measurement Proposals
for the inactive (non-tritium)
commissioning phase IIIa

version 1.1
24 Feb. 2016

Conclusions



The KATRIN experiment

- Complete beam line on site since Sept. 2015
- Final assembly, site acceptance tests and commissioning ongoing
- Successful SDS commissioning phases already done ➔ more to come
- Combined commissioning of whole system in late-2016
- First light (tritium) runs in 2017

Thank you!