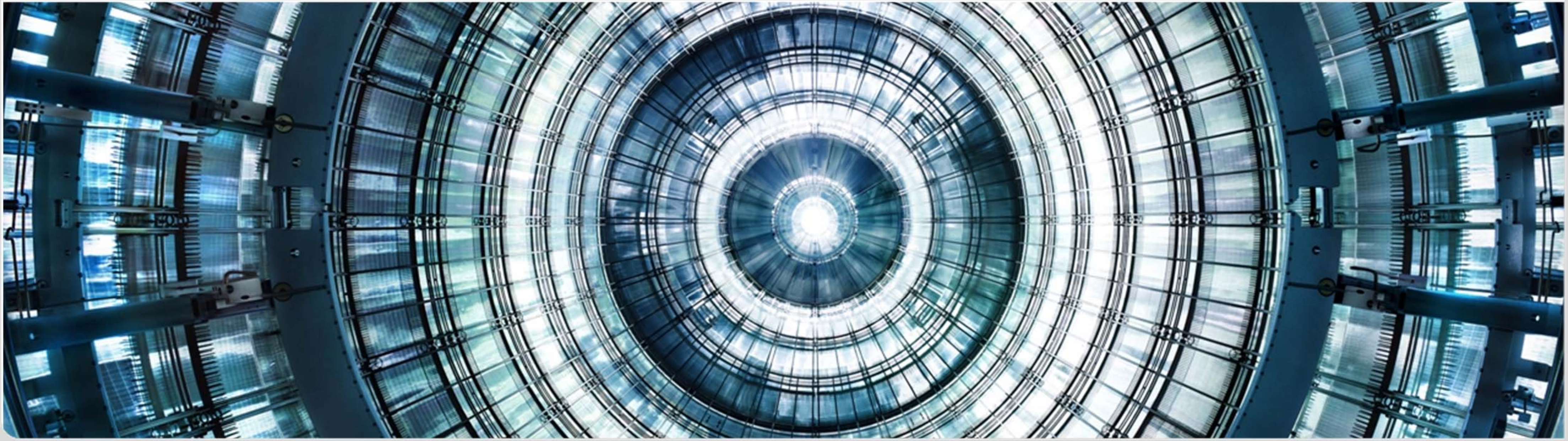
Karlsruhe Institute of Technology

KATRIN

Technical Challenges

HAP Workshop, November 26th, 2013

Markus Steidl KIT



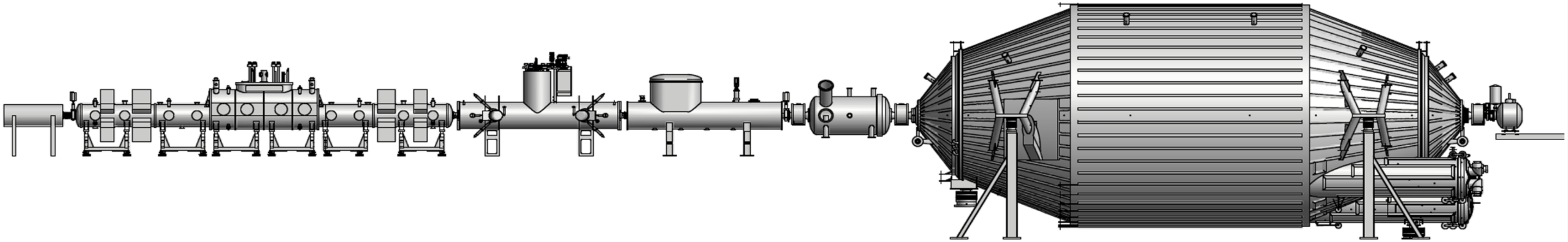
Outline

- **Introduction**
- **Technology highlights**

  - source and transport system: source temperature stability
  - spectrometer: largest UHV vessel

- **Main Focus: Focal Plane Detector**
- **Summary**

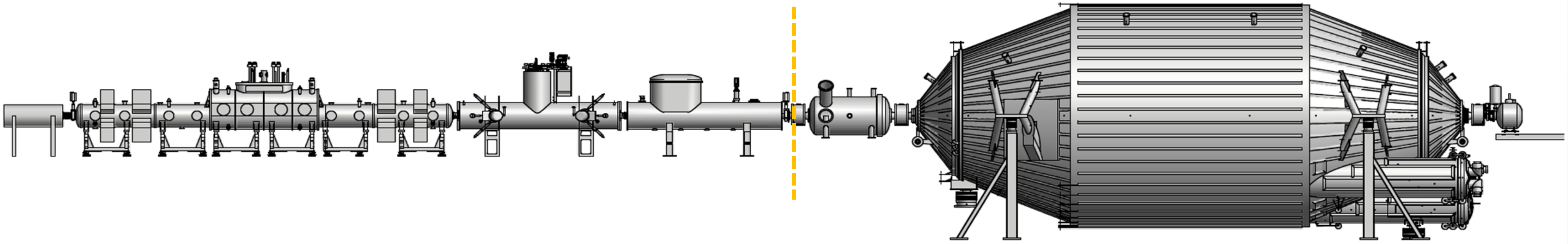
KATRIN experiment



KArlsruhe TRItium Neutrino experiment

- next-generation direct ν-mass experiment at TLK (**HGF-LKII facility**)
- international collaboration: 140 members (KIT: ~50%)
  15 institutions in 5 countries: D, US, UK, CZ, RUS
- reference ν-mass sensitivity: **$m(\nu_e) = 200$ meV**

KATRIN experiment – overview

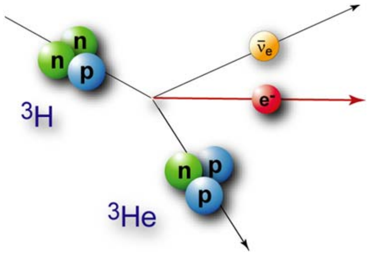


Source & Transport Section (STS)

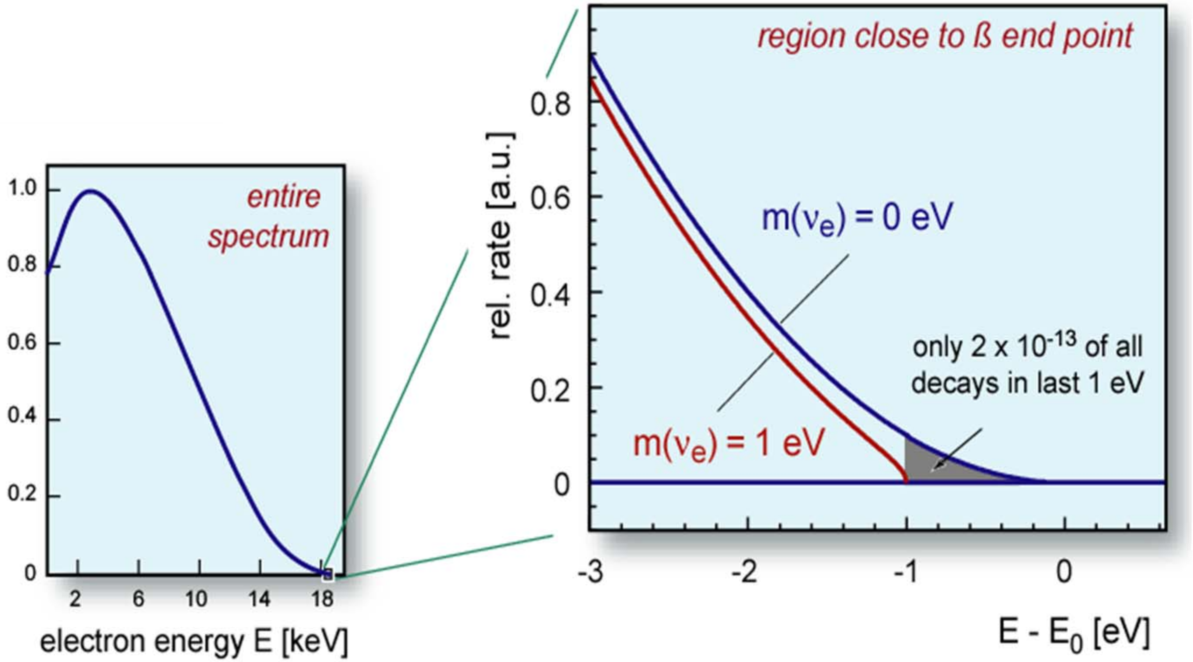
Spectrometer & Detector Section (SDS)

^{3}H: super-allowed	
E_0	**18.6 keV**
$t_{1/2}$	**12.3 y**

$^{3}H \rightarrow {}^{3}He + e^{-} + \bar{\nu}_e$

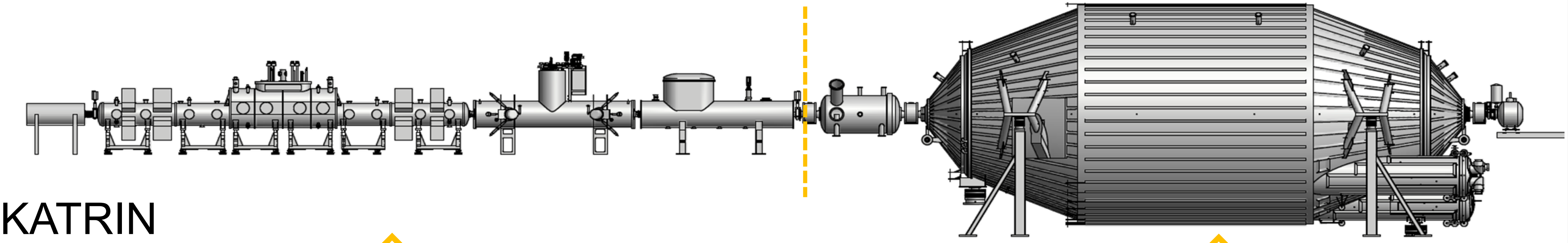


ideal ß-emitter



most sensitive method

KATRIN experiment – overview



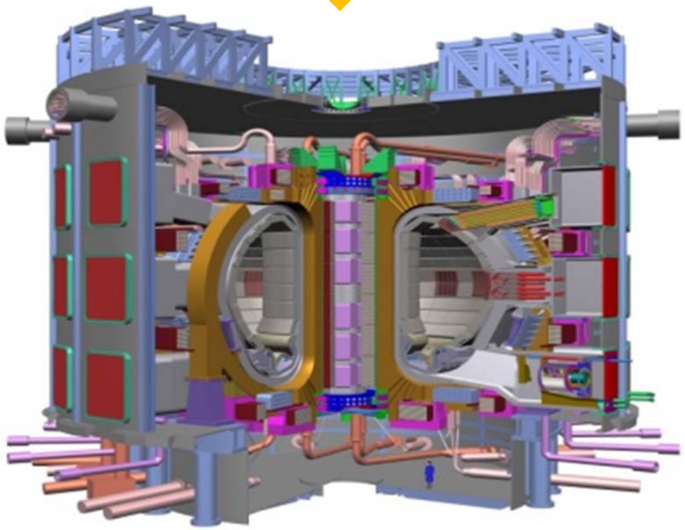
KATRIN
(2015)

1250 m^3

largest ever tritium
throughput ~ **10 kg/a**

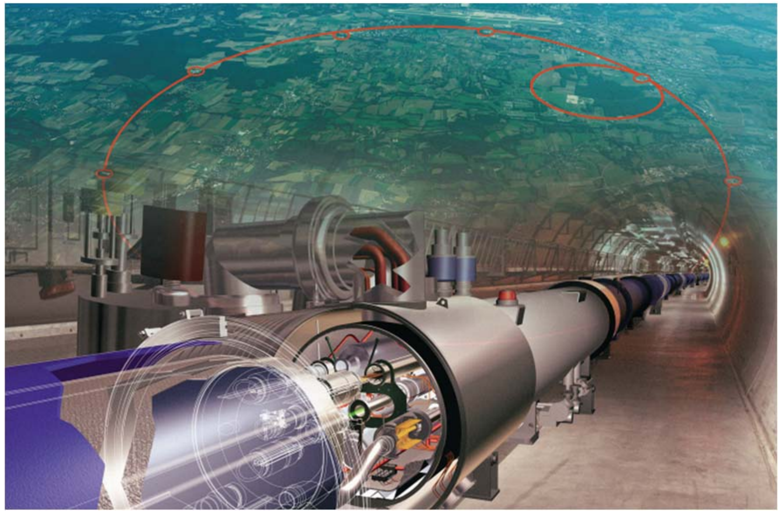
largest ever UHV
recipient (<10^{-11} mbar)

154 m^3

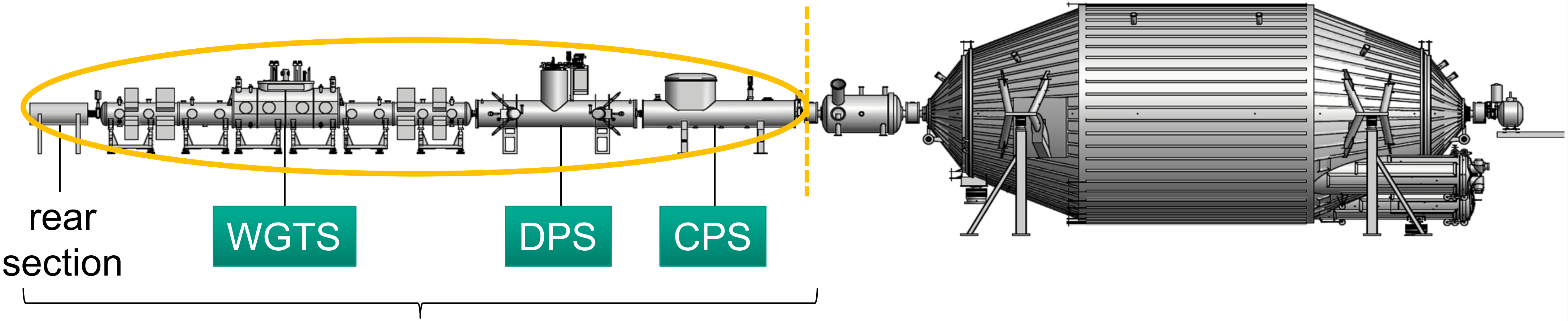


ITER
(2027)

LHC



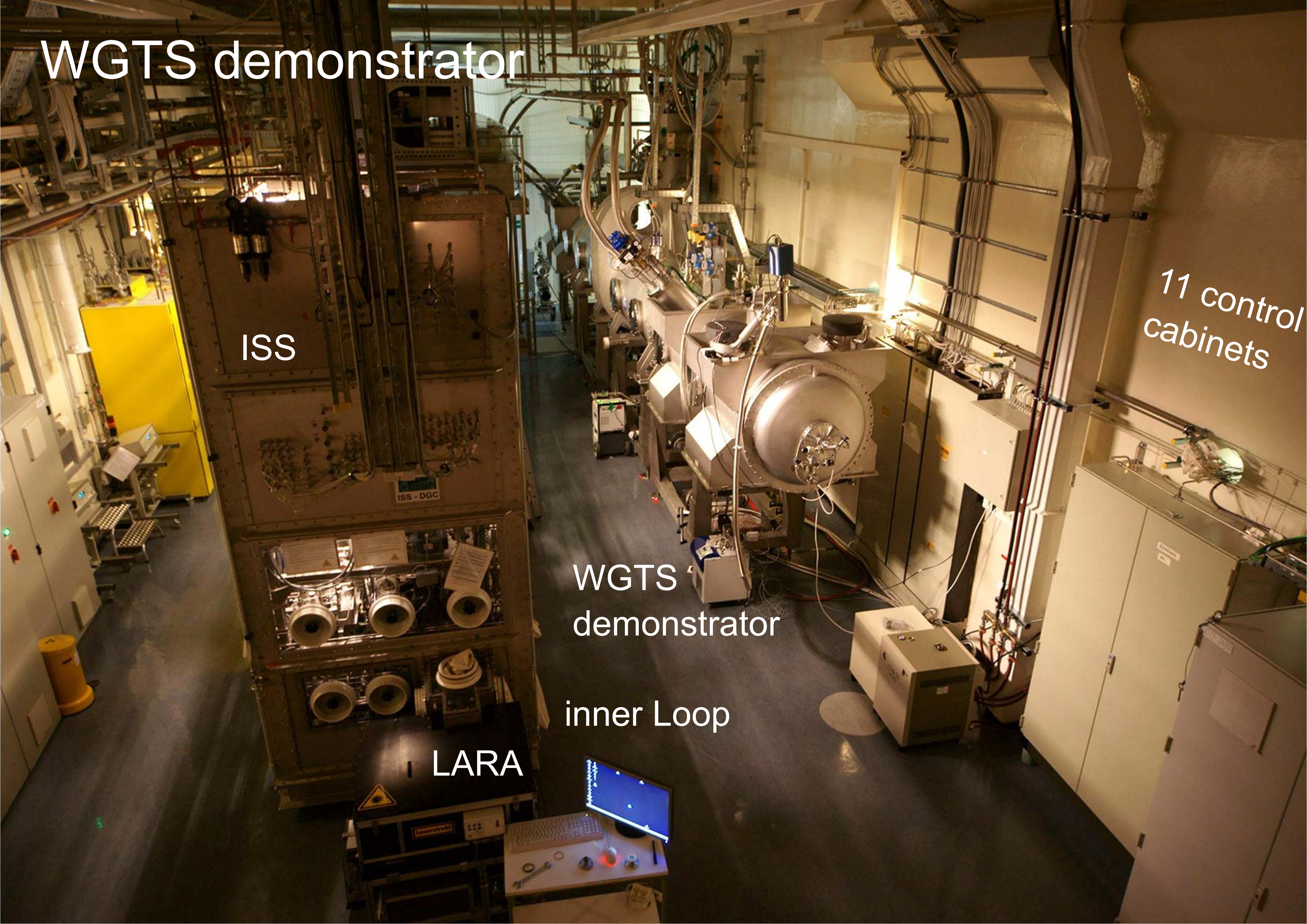
Tritium Laboratory Karlsruhe – TLK



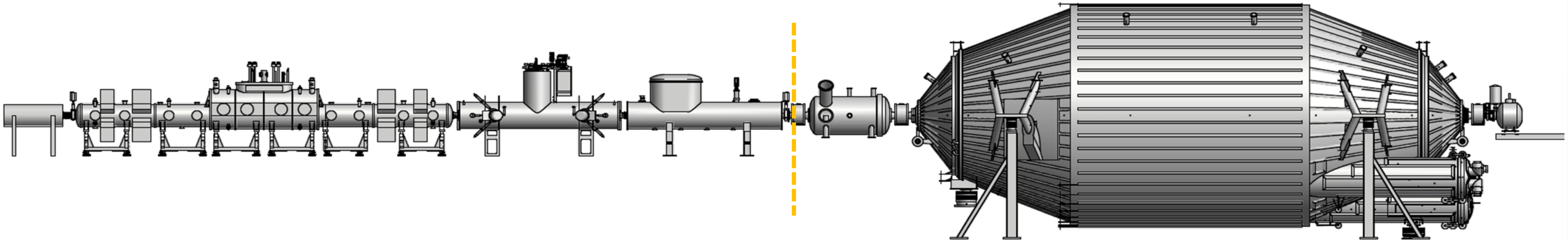
- **TLK**: unique large research facility
- **R&D**: focused on new tritium technologies

B. Bornschein et al., Fusion Sci. Techn. 60 (2011) 1088

WGTS demonstrator



KATRIN – benchmark parameters



tritium source: 10^{11} ß-decays/s
(≡ LHC particle production)

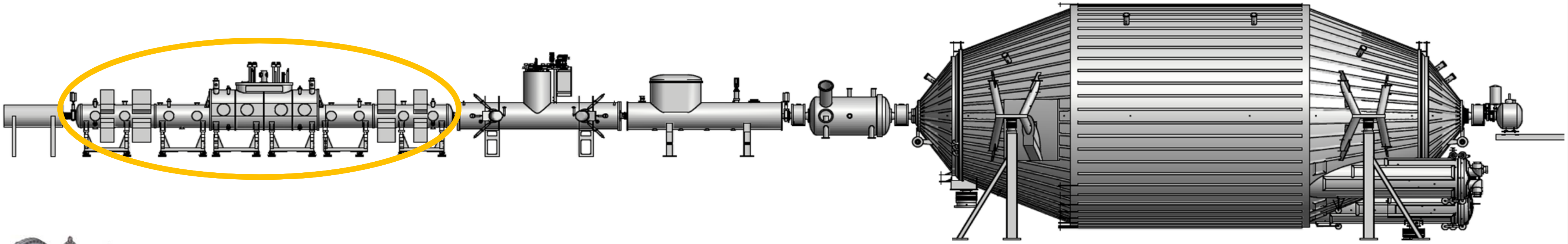
total background: 10^{-2} cps
(≡ low level @ 1 mwe)

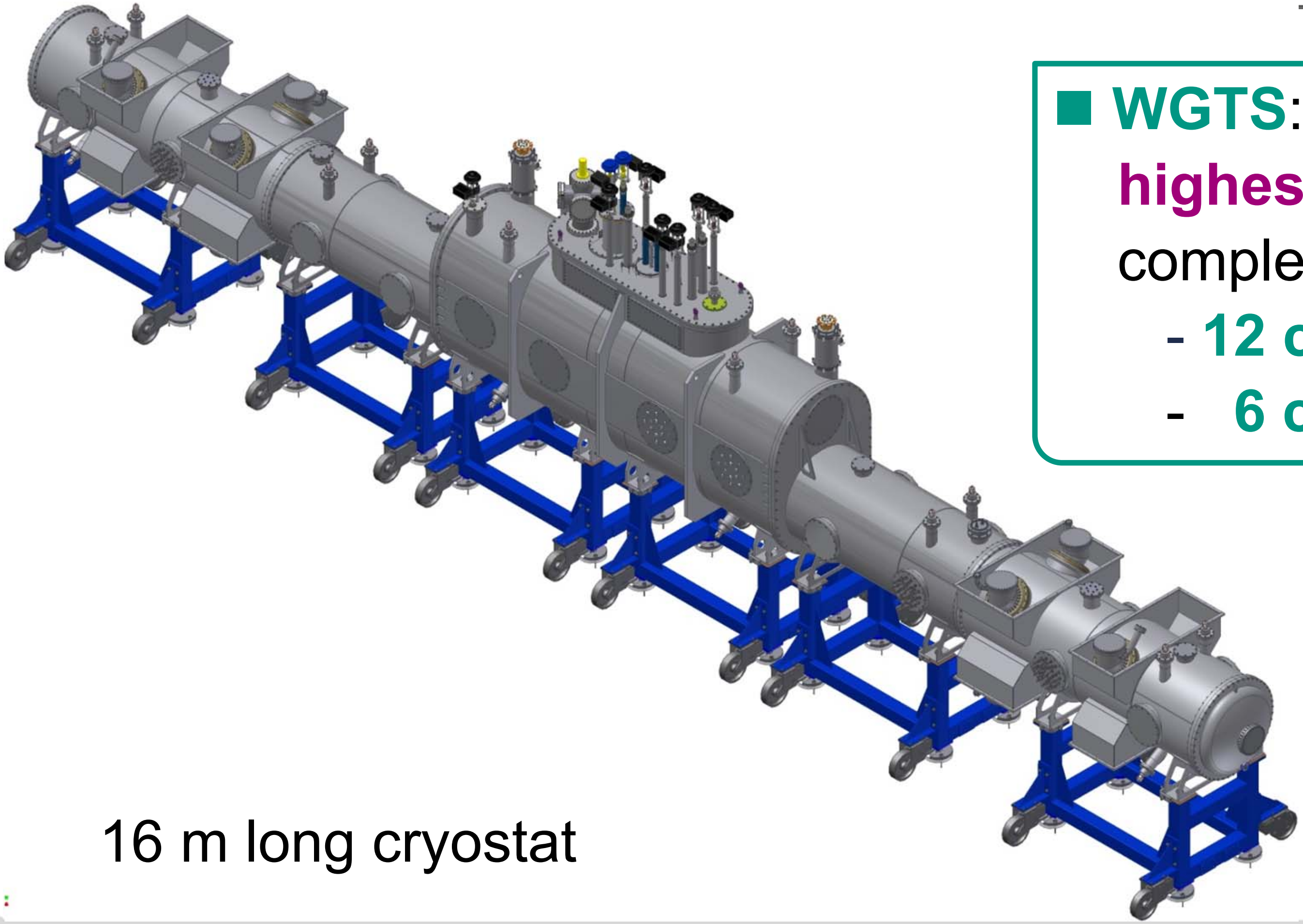
experimental challenges

- 10^{-3} stability of tritium source column density
- 10^{-3} isotope content in source
- 10^{-5} non-adiabaticity in electron transport
- 10^{-6} monitoring of HV-fluctuations
- 10^{-8} remaining ions after source
- 10^{-14} remaining flux of molecular tritium

many benchmark parameters reached or exceeded

WGTS – windowless gaseous source

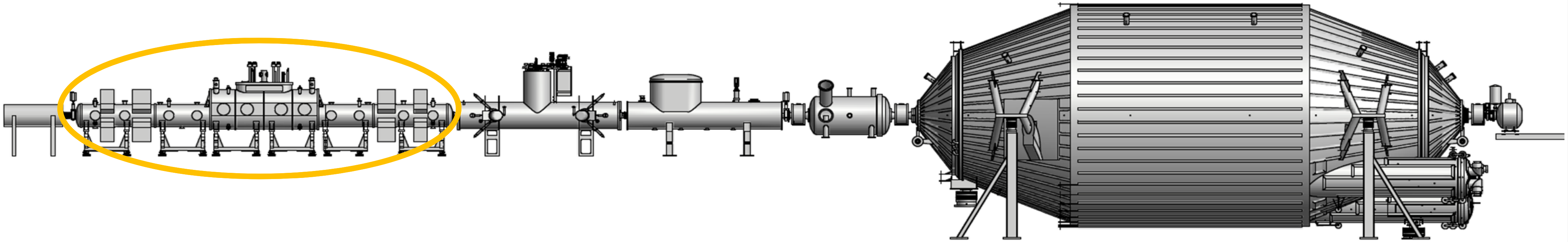


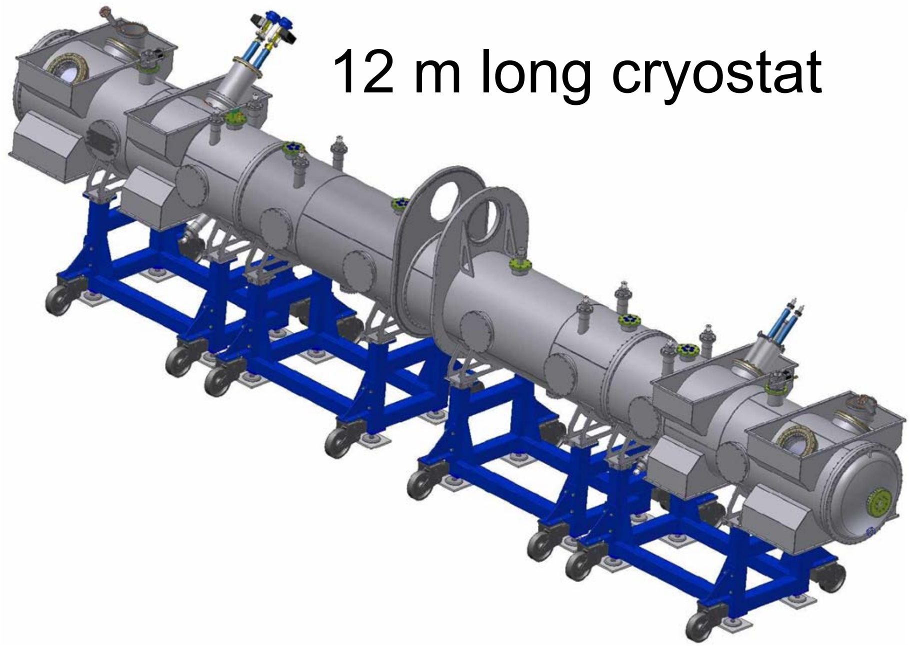


16 m long cryostat

- **WGTS**: molecular tritium source of **highest luminosity** & **stability** complex cryostat with:
  - **12 cryogenic circuits**
  - **6 cryogenic fluids**

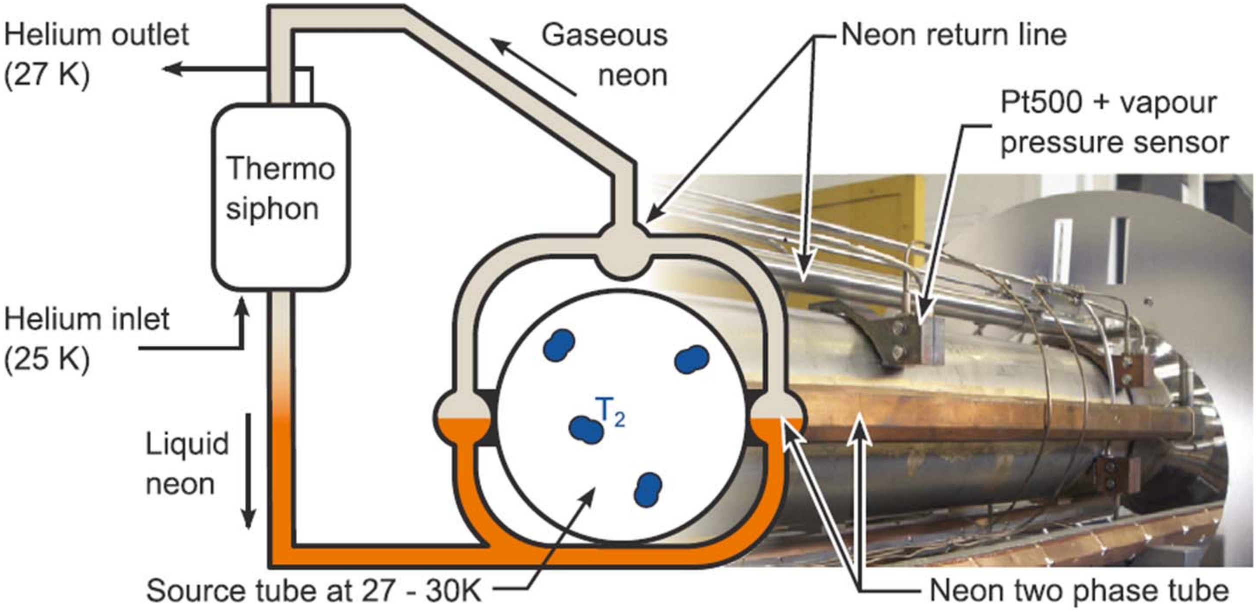
WGTS – demonstrator





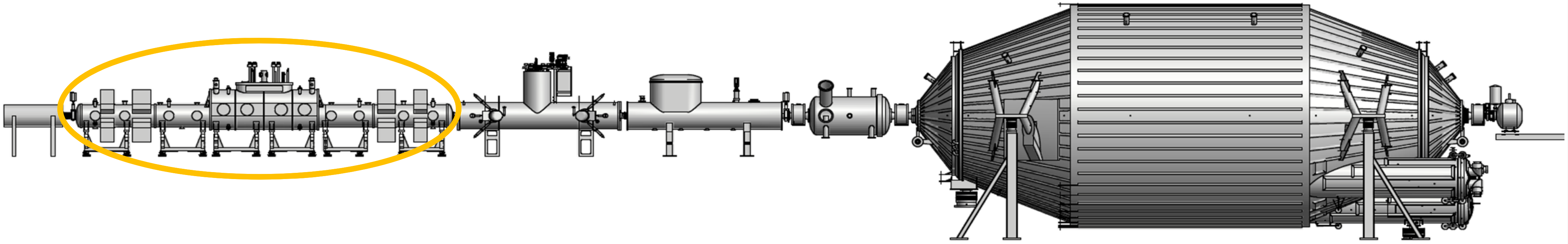
12 m long cryostat

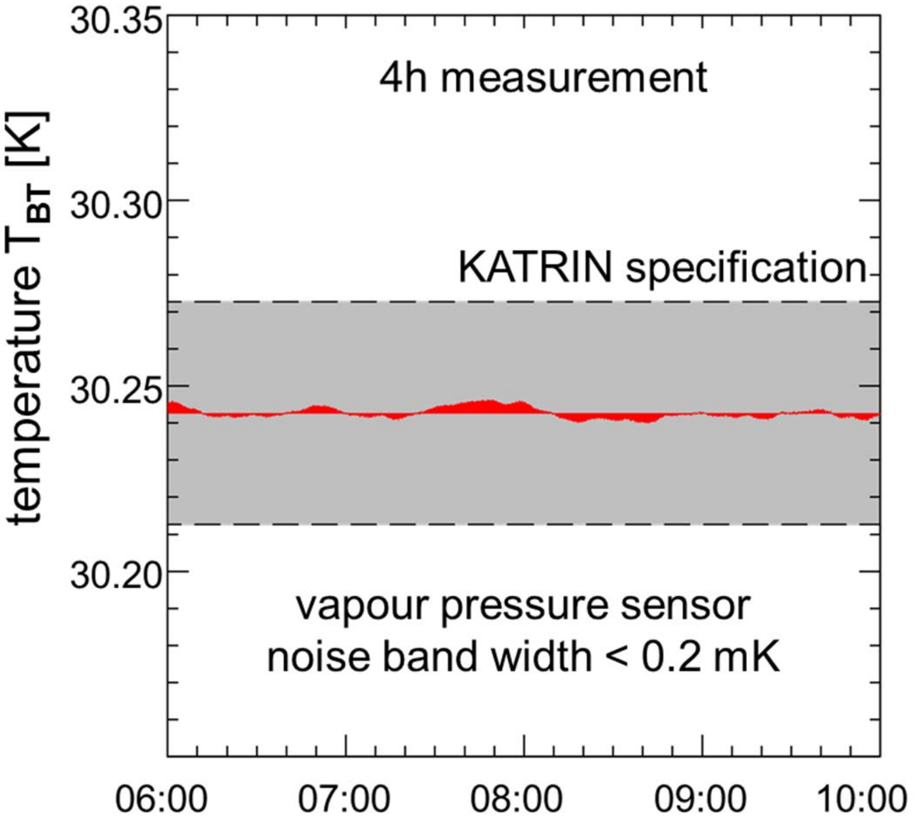
- **WGTS demonstrator**
  objective: validate novel 2-phase beam tube cooling system



S. Grohmann et al., Cryogenics 51, **8** (2011) 438

technological highlight – stability at 30K



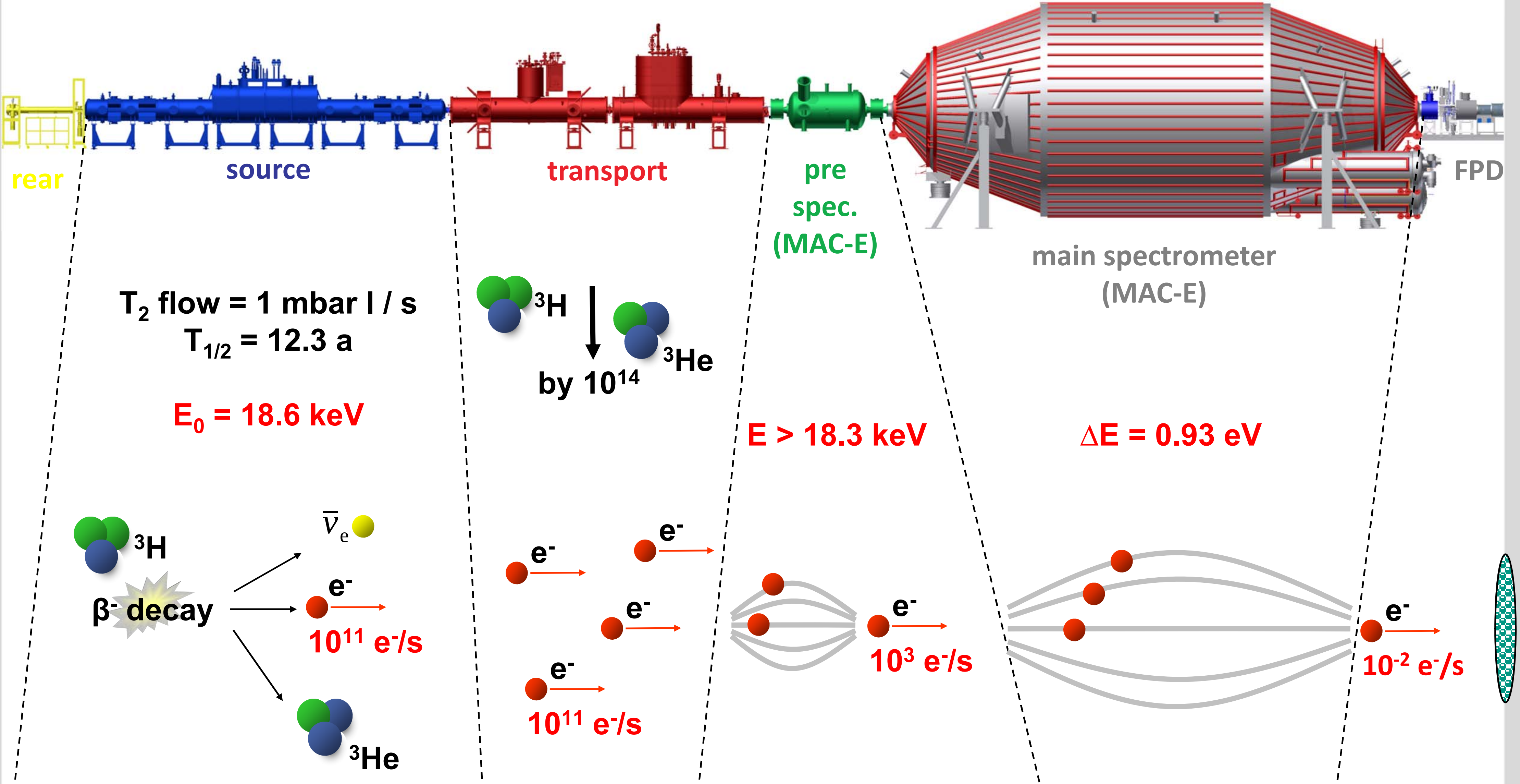


- **Technology highlight:**
  successful proof-of-principle of novel WGTS beam tube cooling system
  - data: **ΔT = 1.5 mK (1 σ)** (1 h)
  - required: **ΔT = 30 mK (1 σ)** (1 h)
  - implications:
    significantly reduced systematic errors from source fluctuations
    $\Delta\rho d/\rho d \sim \Delta T/T = 5 \cdot 10^{-5}$

S. Grohmann et al., The thermal behaviour of the tritium source in KATRIN, acc. for publ. in Cryogenics

KATRIN Setup

Karlsruhe Institute of Technology



T_2 flow = 1 mbar l / s
$T_{1/2}$ = 12.3 a

E_0 = 18.6 keV

^{3}H ↓ ^{3}He
by 10^{14}

E > 18.3 keV

ΔE = 0.93 eV

^{3}H

β^- decay

$\bar{\nu}_e$

e^-

10^{11} e^-/s

^{3}He

e^- e^- e^- e^-

10^{11} e^-/s

e^-

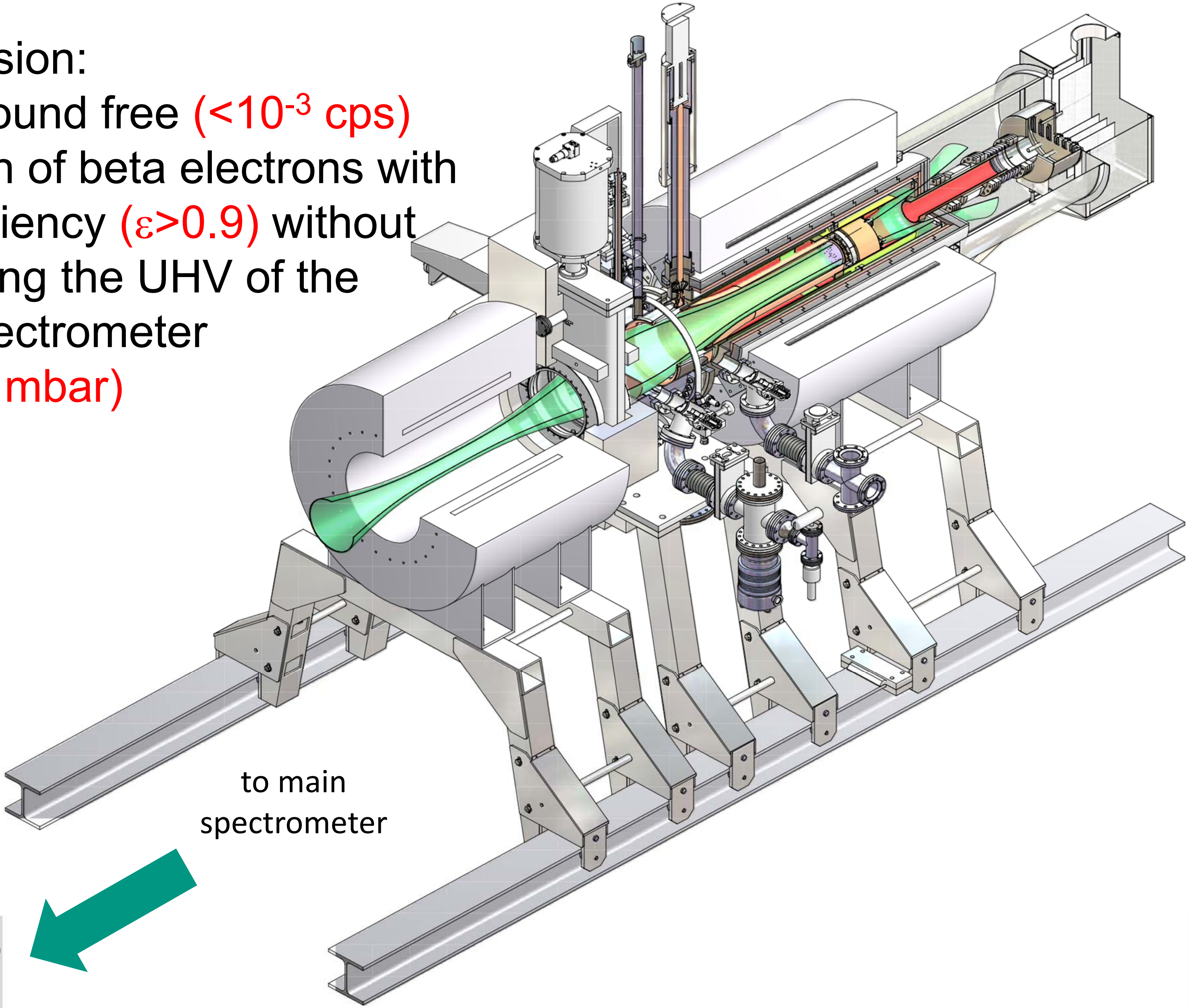
10^3 e^-/s

e^-

10^{-2} e^-/s

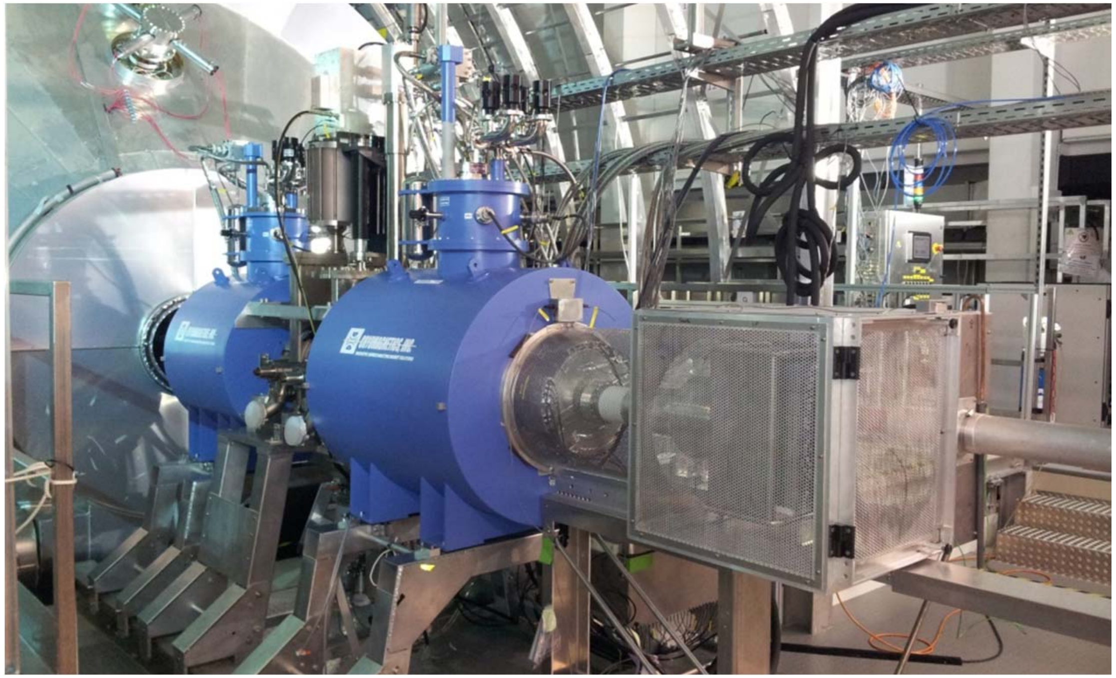
FPD Setup

The mission:
„Background free (<10^{-3} cps) detection of beta electrons with high eficiency (ε>0.9) without influencing the UHV of the main spectrometer
($p<10^{-10}$ mbar)



to main spectrometer

FPD Setup



05/2011

10/2011

07/2011: Arrival at KIT
08/2011: Assembly at KATRIN
10/2011: First data and commissioning at KIT

Detector Wafer

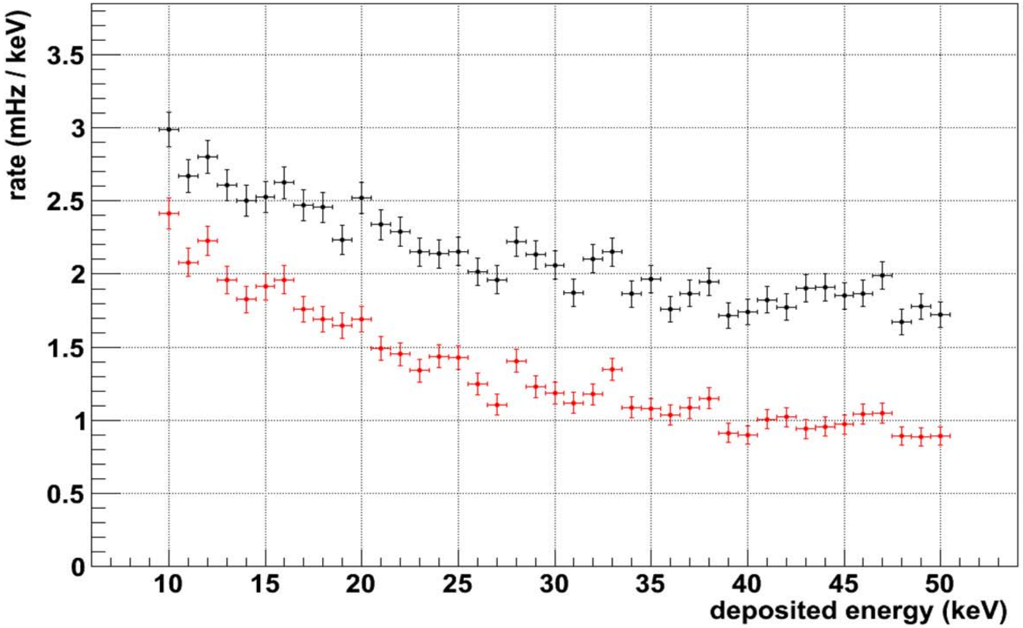
- Monolithic 148-pixel Si PIN diode by Canberra Belgium
- Thickness: 503 µm
- Diameter: 125 mm
  - Sensitive diameter: 90.0 mm
  - Guard ring: 2.0 mm
  - Bias ring: 15.5 mm
- Crystal orientation: <111>
- Unsegmented n^{++}-type side with ≈100-nm dead layer
- Segmented p^{+}-type side
  - $A_{\text{Pixel}} = 44\ \text{mm}^2$, $C_{\text{Pixel}} = 8.2\ \text{pF}$
  - Pixels separated by 50 µm with R > 1 GΩ
  - Non-oxidizing TiN coating for electrical connections

▲ detector wafer (segmented back side)

Background Reduction

- KATRIN requirement: **total background < 10 mHz**
- Active (plastic scintillators) and
  passive (low-activity 1-cm copper and 3-cm lead) shielding

- **Post acceleration** of electrons to energies with lower backgrounds, less fluorescence lines and less backscattering (up to +10 keV)



Combined E/B fields requires careful EMD design especially for ExB regions to avoid traps or discharges

Background Reduction

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- Active (plastic scintillators) and
  passive (low-activity 1-cm copper and 3-cm lead) shielding

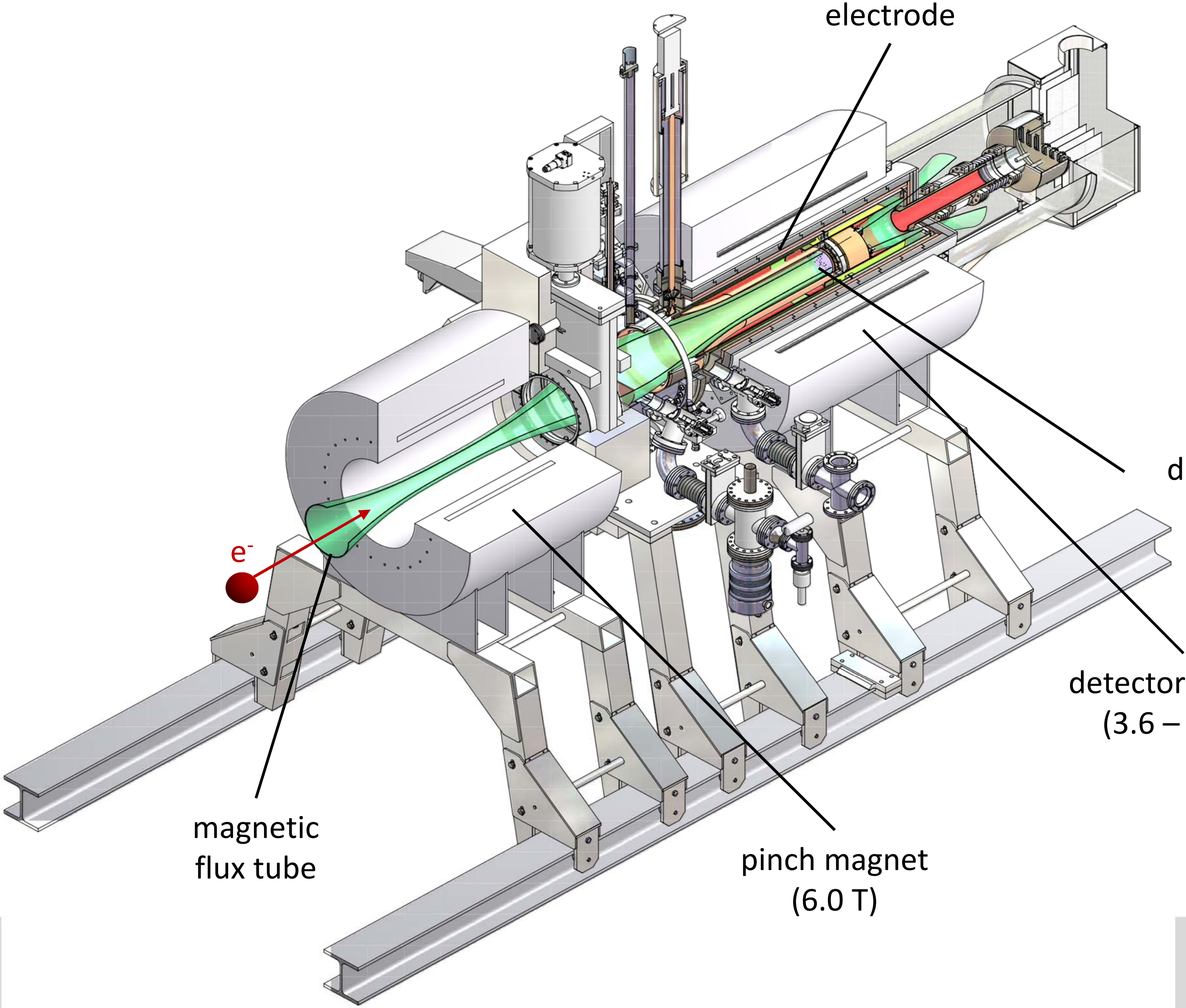
- **Post acceleration** of electrons to energies with lower backgrounds, less fluorescence lines and less backscattering (up to +10 keV)

- Boost of B_{Det} = 3.6 T to 6.0 T ➔ Reduction of sensitive A_{det} (but requires Post acceleration, that angle of incidences and thus backscattering remain sufficiently low)

- Radio assay of materials used in detector proximity

- **Spatial separation by customized mounting and connection technique**

FPD Setup



post-acceleration electrode

detector wafer

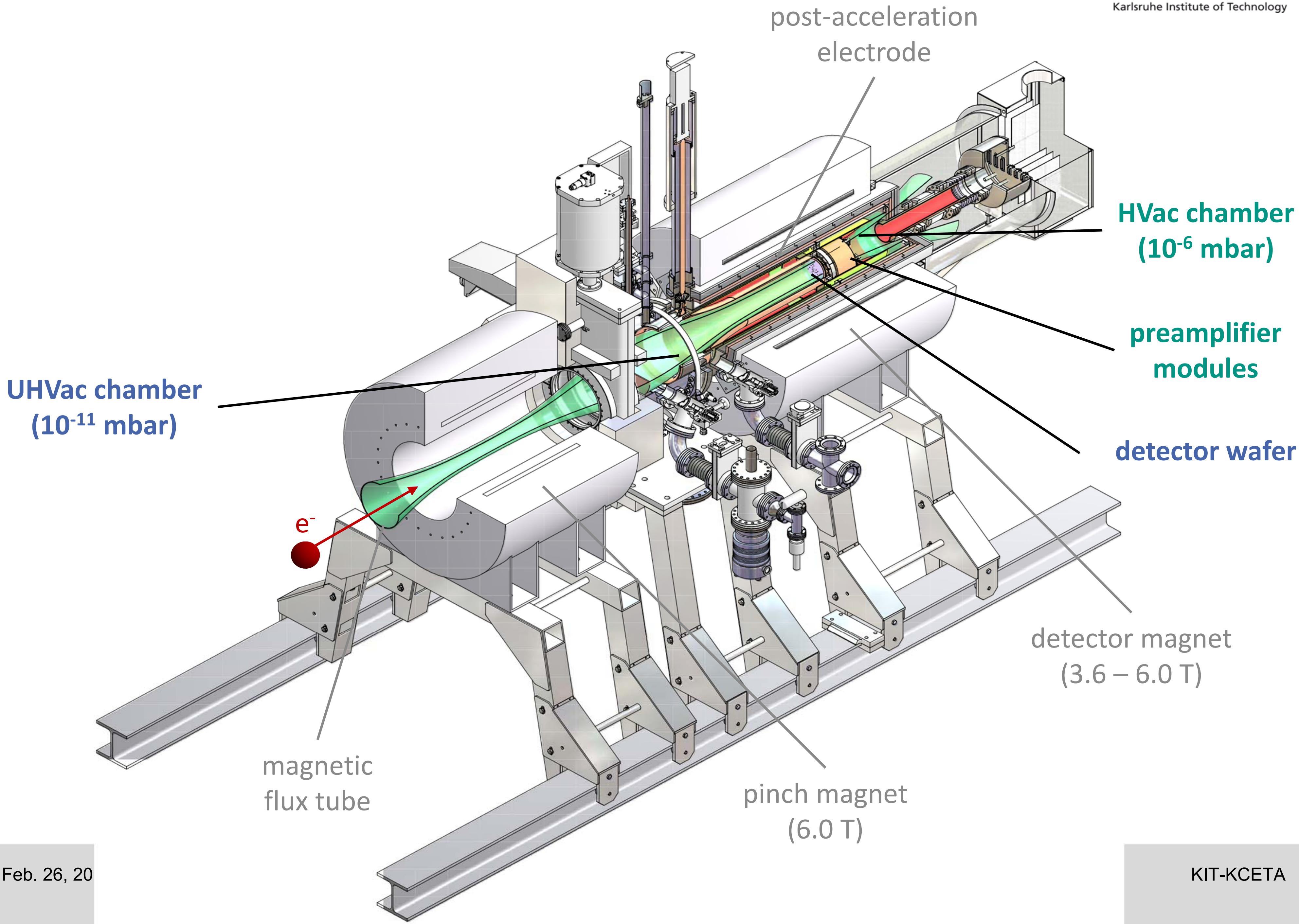
detector magnet (3.6 – 6.0 T)

pinch magnet (6.0 T)

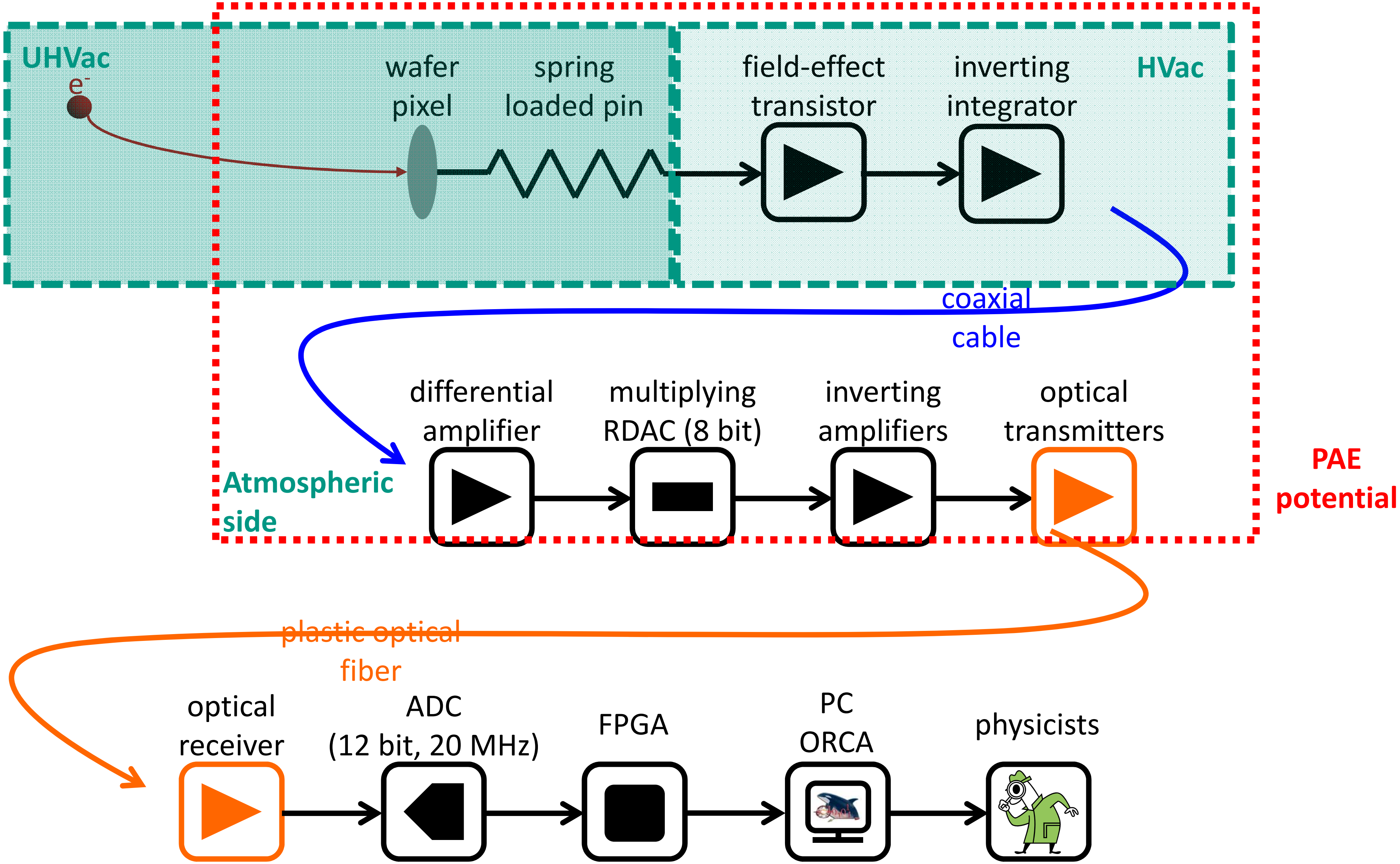
magnetic flux tube

e^-

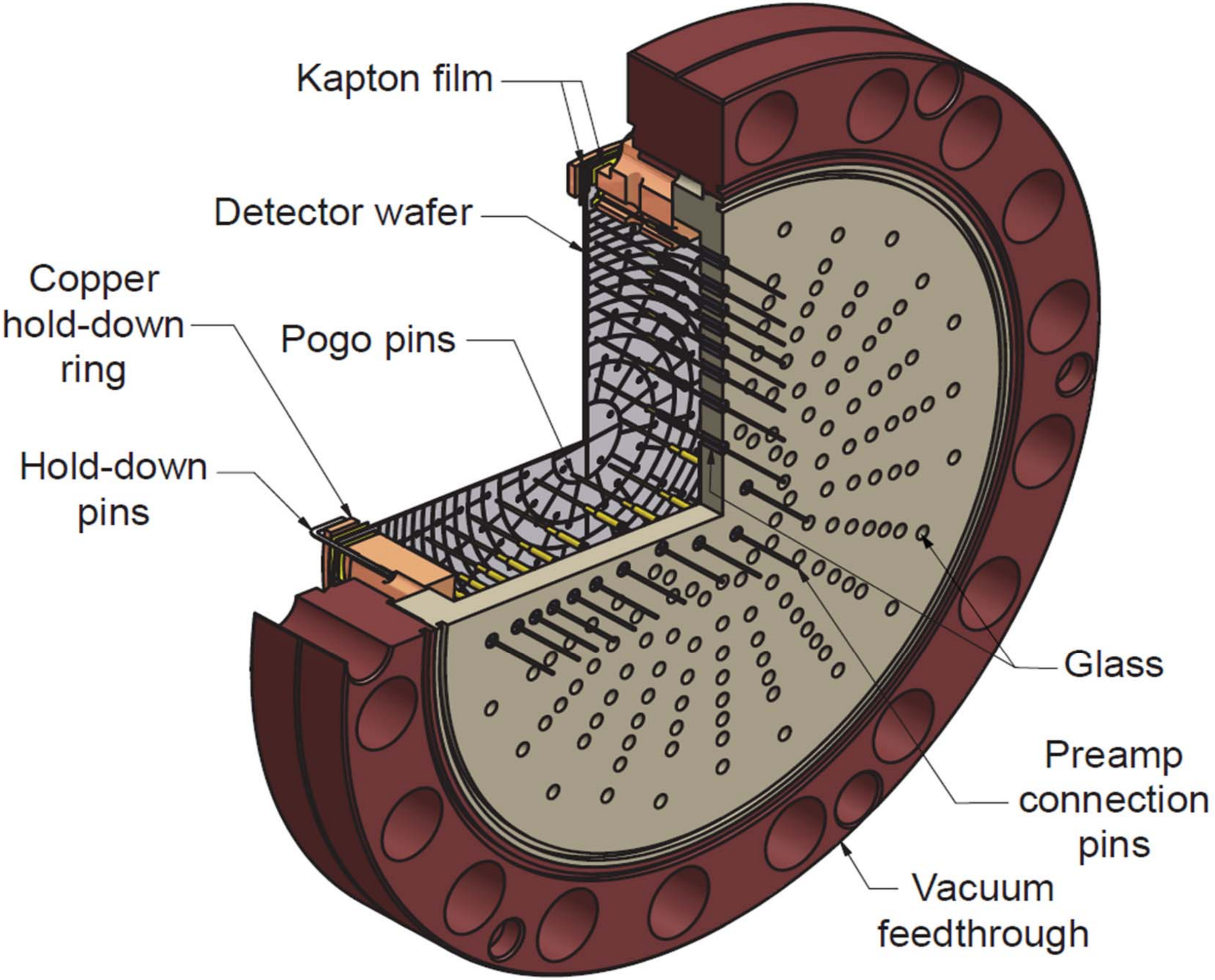
FPD Setup


post-acceleration electrode
HVac chamber (10^{-6} mbar)
preamplifier modules
UHVac chamber (10^{-11} mbar)
detector wafer
e^-
detector magnet (3.6 – 6.0 T)
magnetic flux tube
pinch magnet (6.0 T)

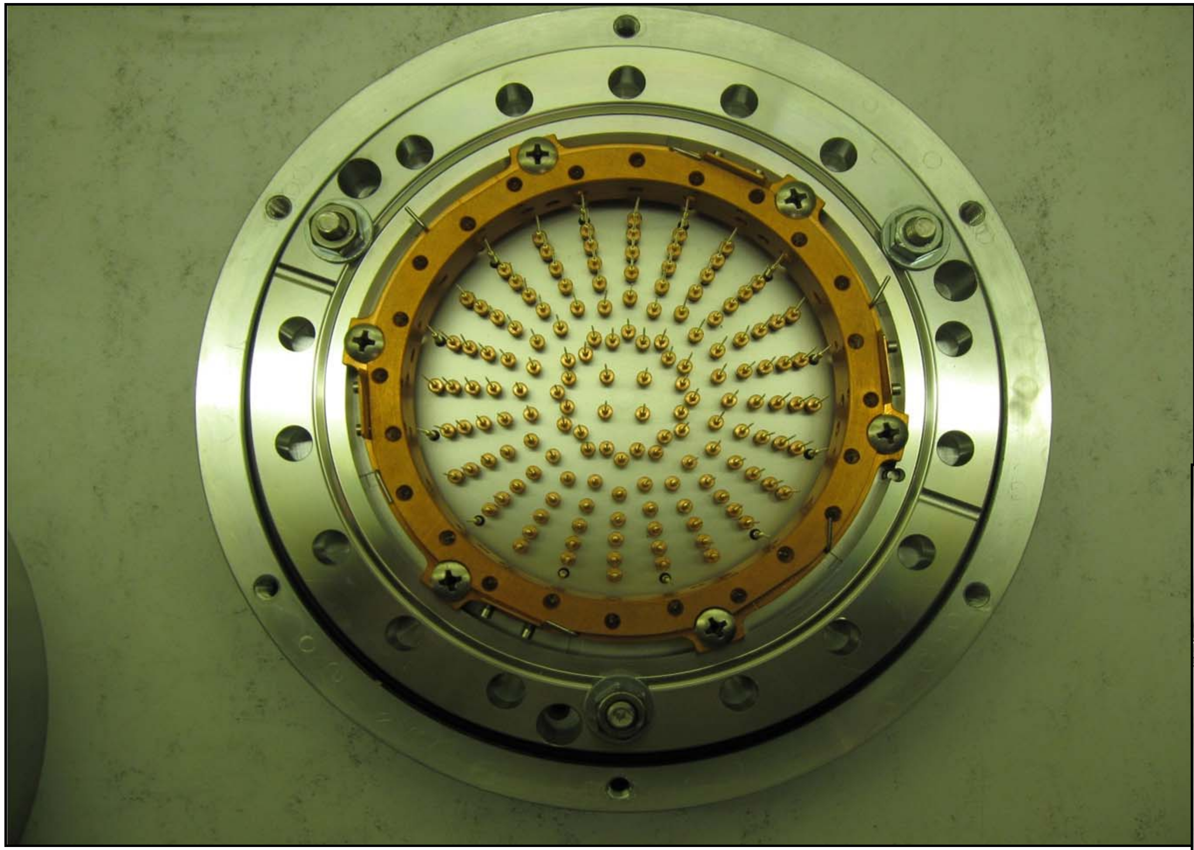
Signal Processing



Customized Connection Technique



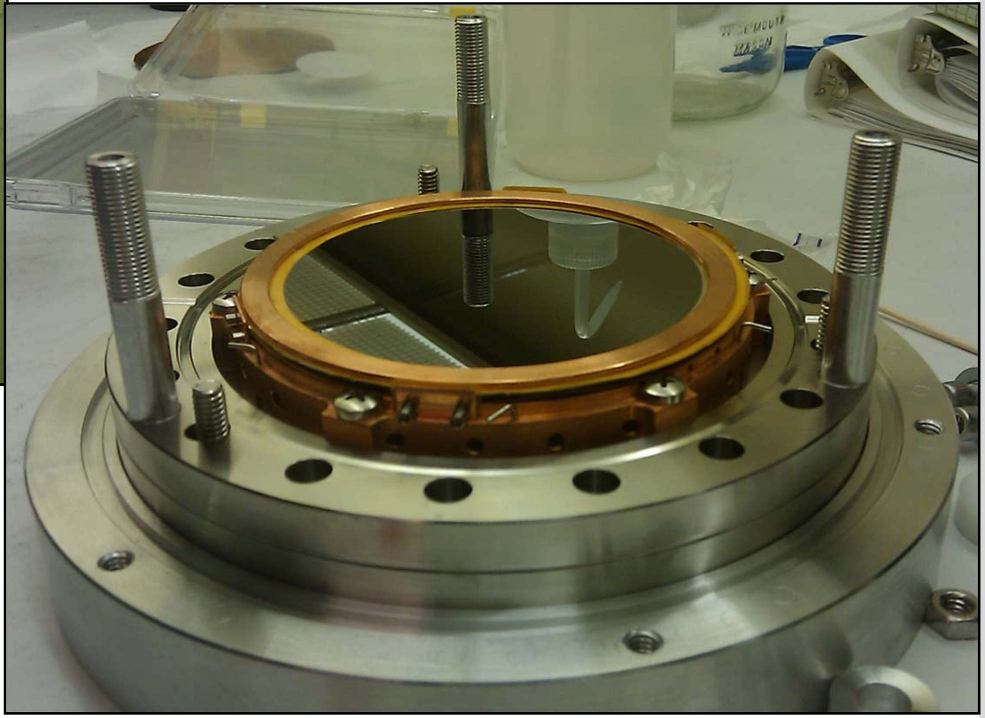
Customized Connection Technique



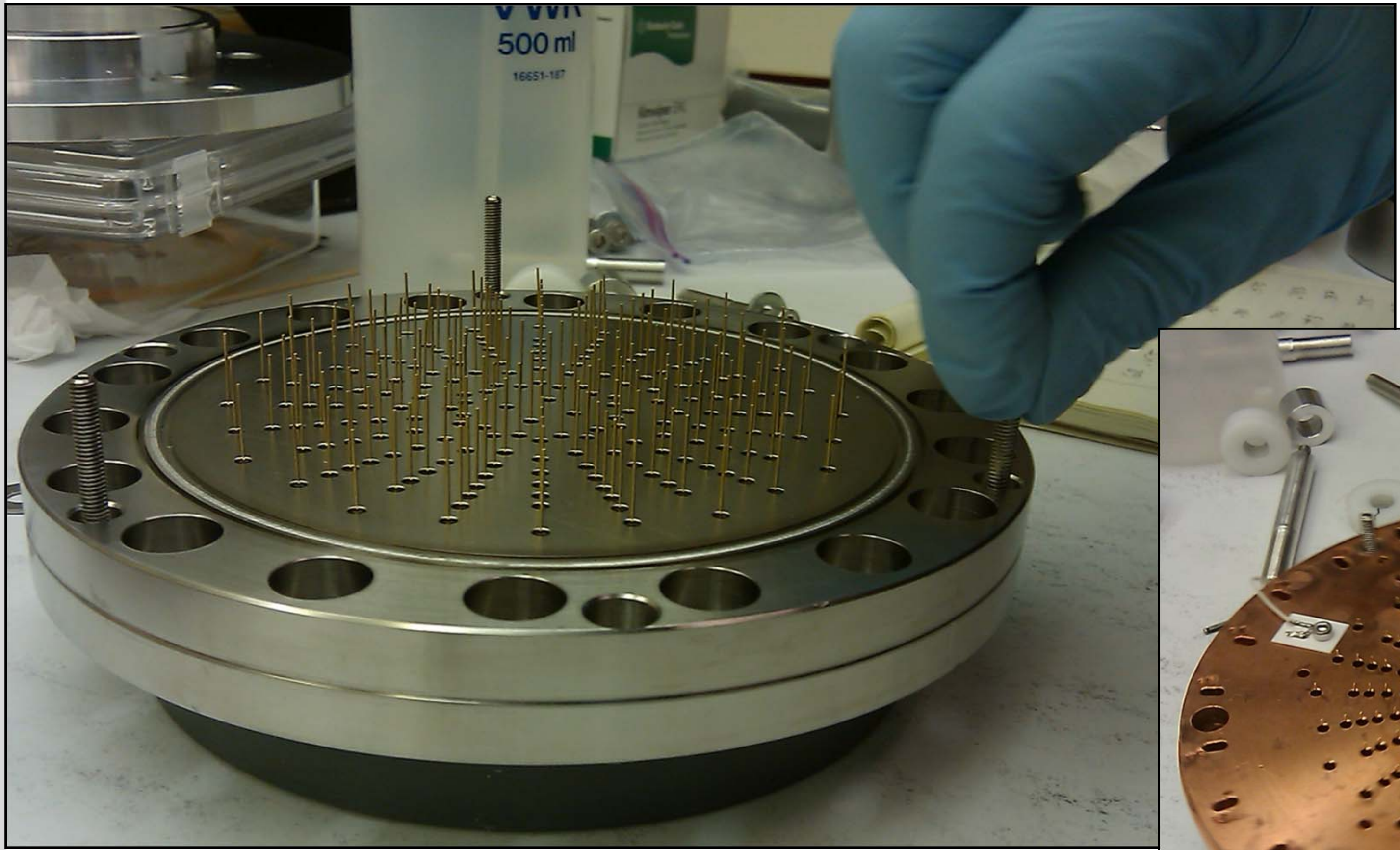
▲ feedthrough flange (front side)
with 184 spring-loaded pins
(148 pixels, 12 guard-ring contacts,
24 bias-ring contacts) + shielding

spring-loaded pin ▶

detector wafer mounted
on feedthrough flange ▼

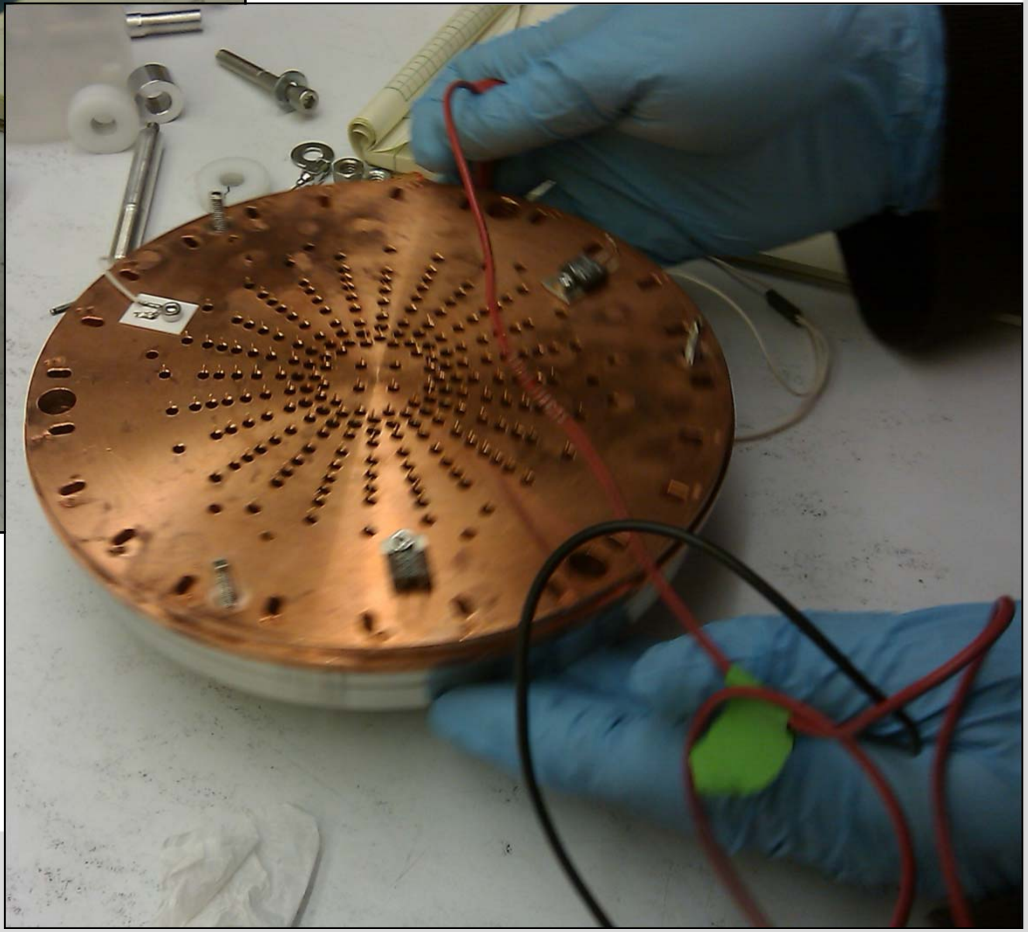


Customized Connection Technique

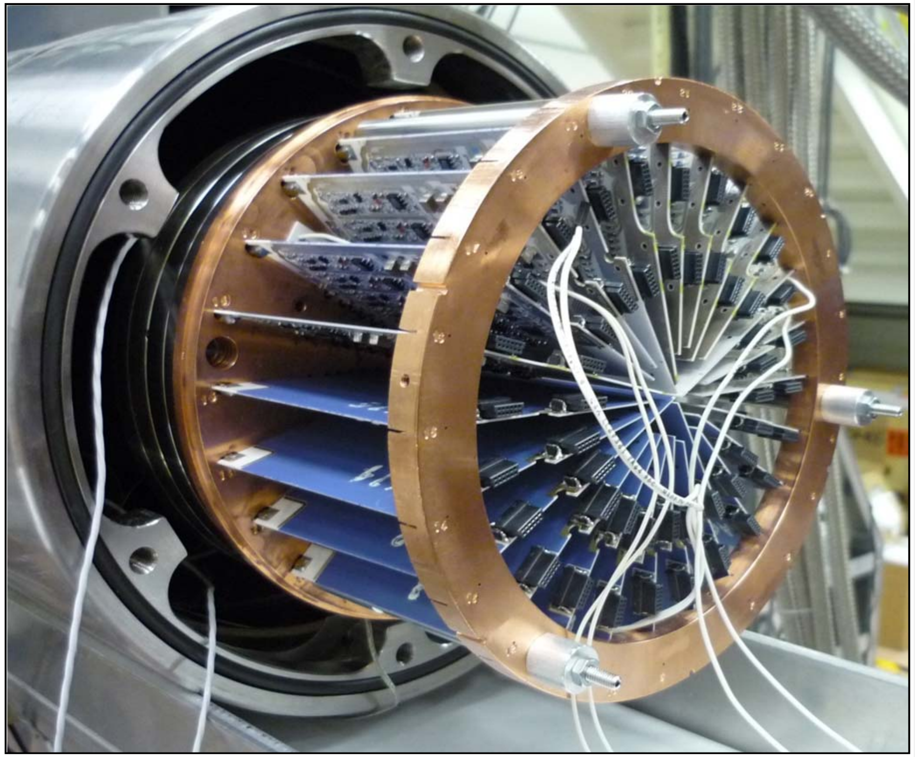


▲ feedthrough flange (back side)

copper plate mounted
on feedthrough flange ▼



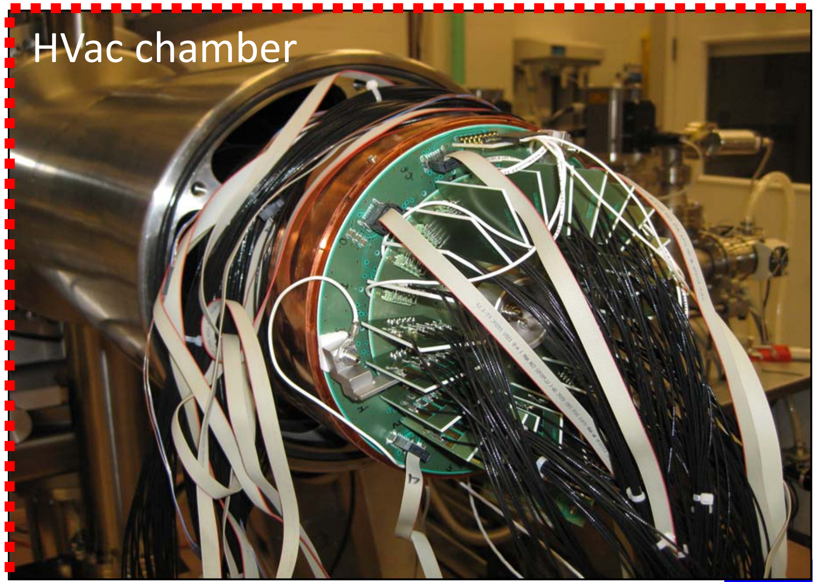
Preamplifier Modules



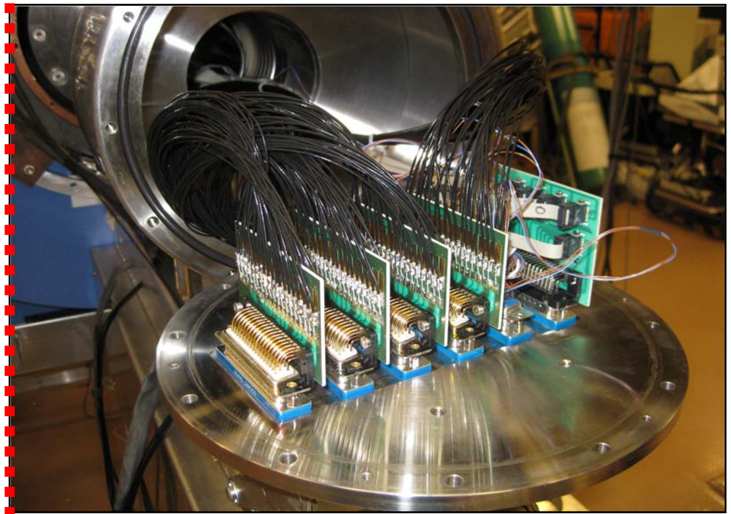
▲ preamp carrousel
with 24 modules mounted

- In-house production IPE
- Classical charge sensitive
- 6 and 7 channels per module
- FET: BF862, 0.8 nV/√Hz
- OpAmp: AD829 , 1.7 nV/√Hz
- Feedback: 0.5 pF, 20 MΩ
- Power: ≈0.75 W per module
- Radio assayed selection of ceramic boards
- Test charged injection
- Leakage current monitoring of each pixel
- Temperature monitoring of each module
- Selectable dynamic range (up to ≈300 keV)
- Protection schemes against transients induced by discharges

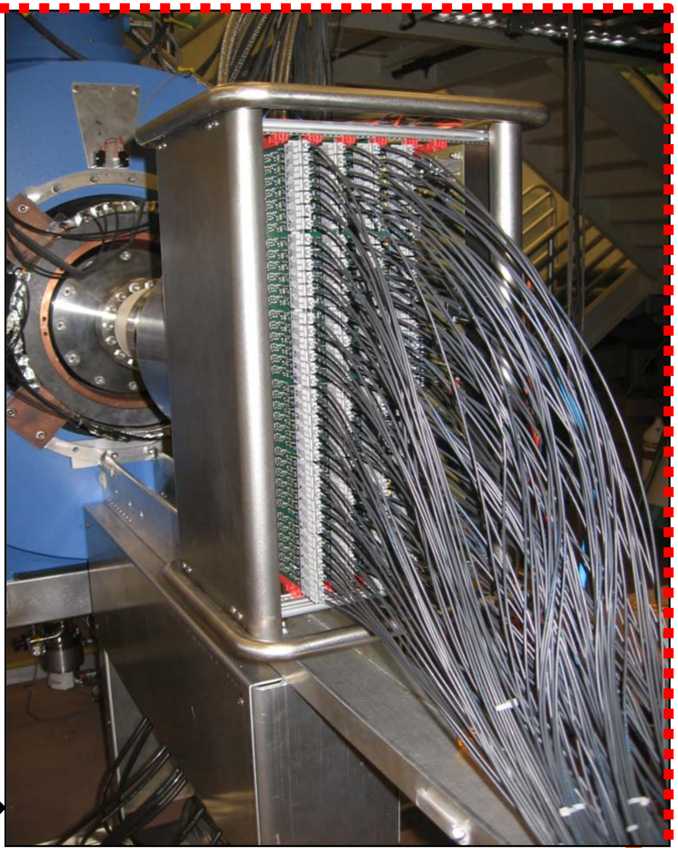
DAQ Chain



▲ preamp carrousel mounted



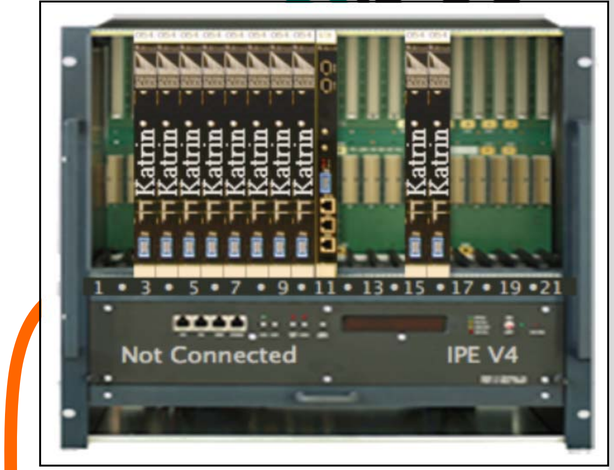
▲ end flange (HVac → Atm)



▲ optical sender boards

optical fiber link ▶

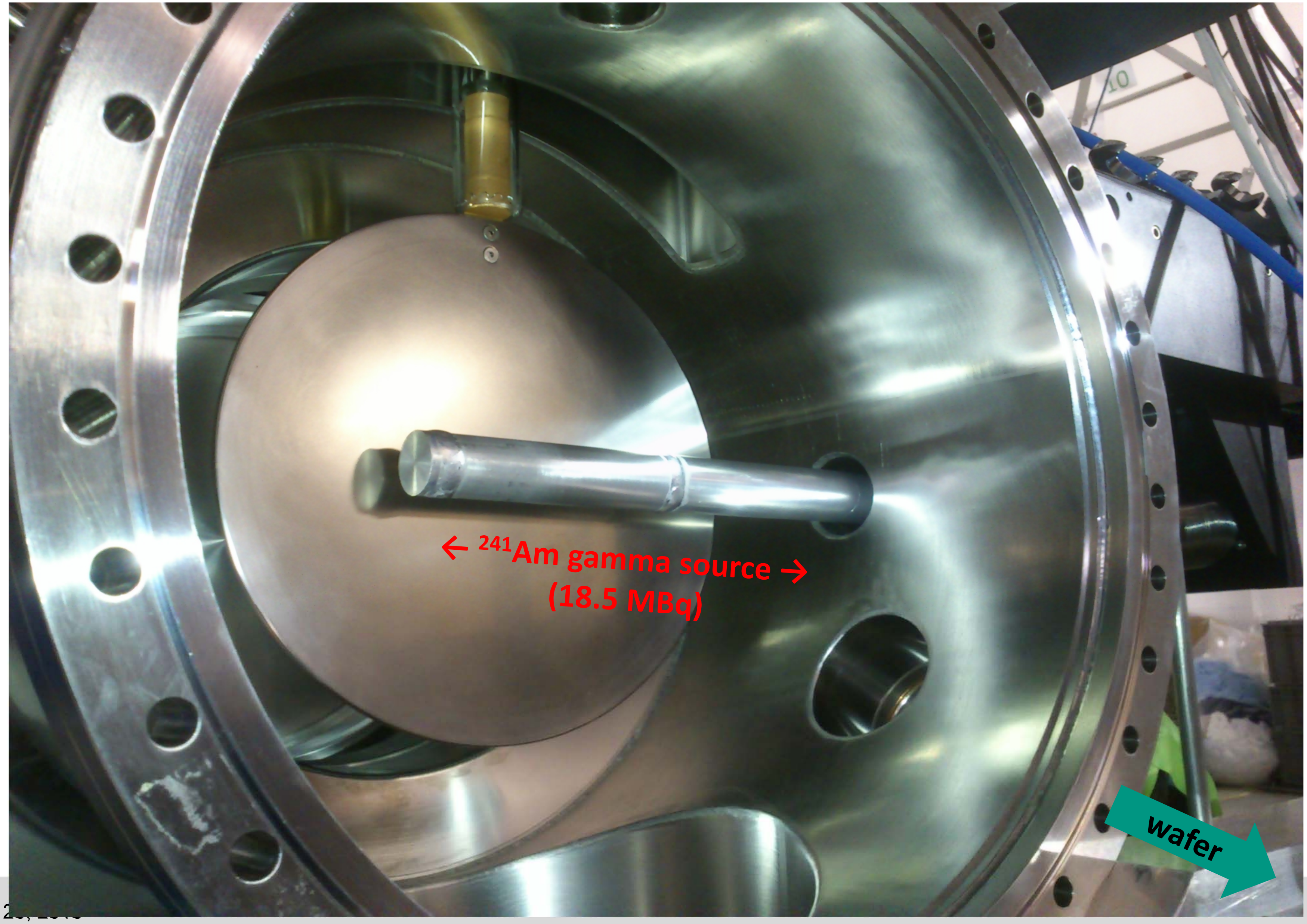
PAE potential



IPE crate v4

- Optical receiver boards
- 20 MHz sampling, 12 bit ADCs
- Processing and triggering via FPGA, trapezoidal filter
- Trace mode: < 10^3 cps
- Energy event mode: < 10^5 cps
- Histogram mode: < 10^6 cps

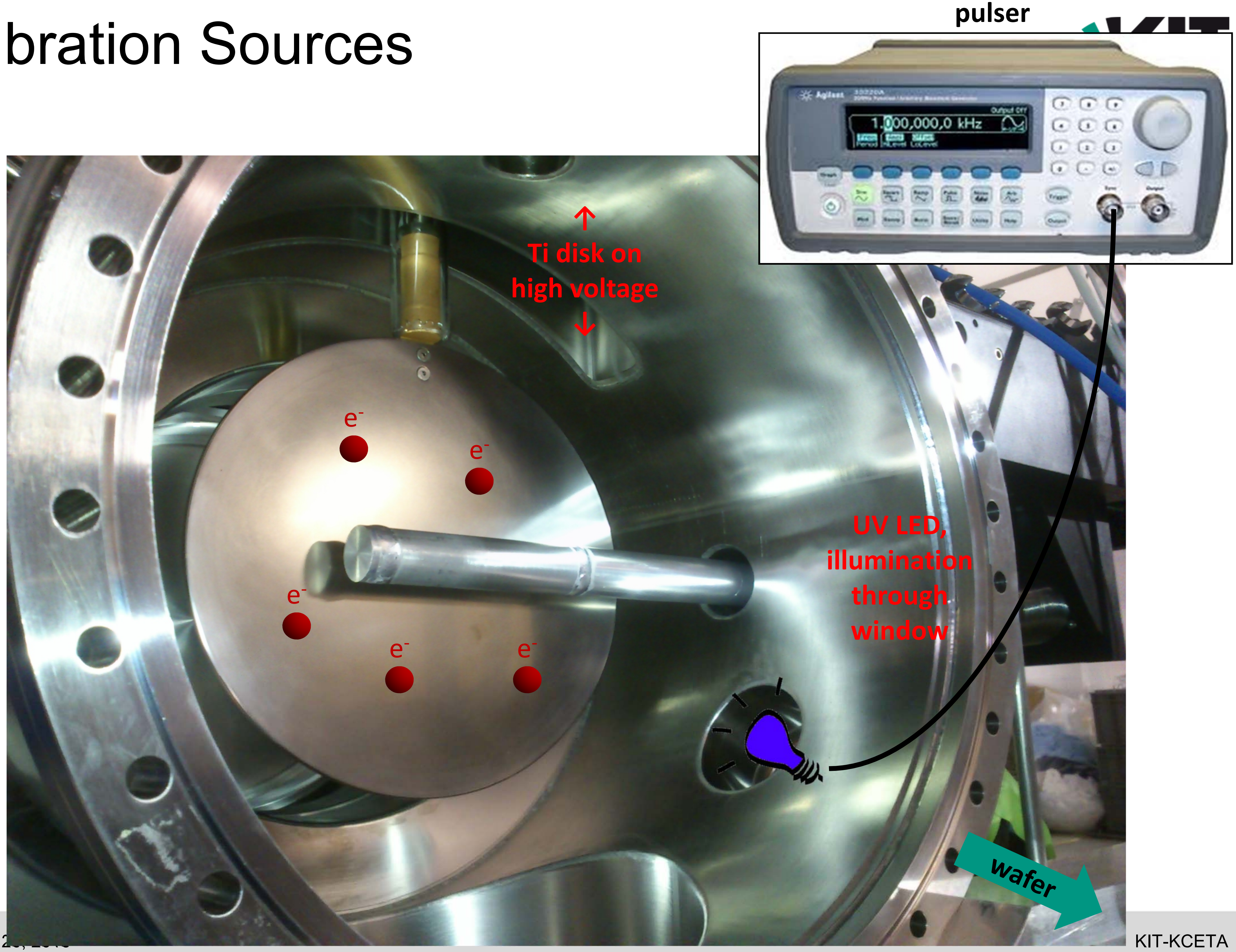
Calibration Sources



← ^{241}Am gamma source →
(18.5 MBq)

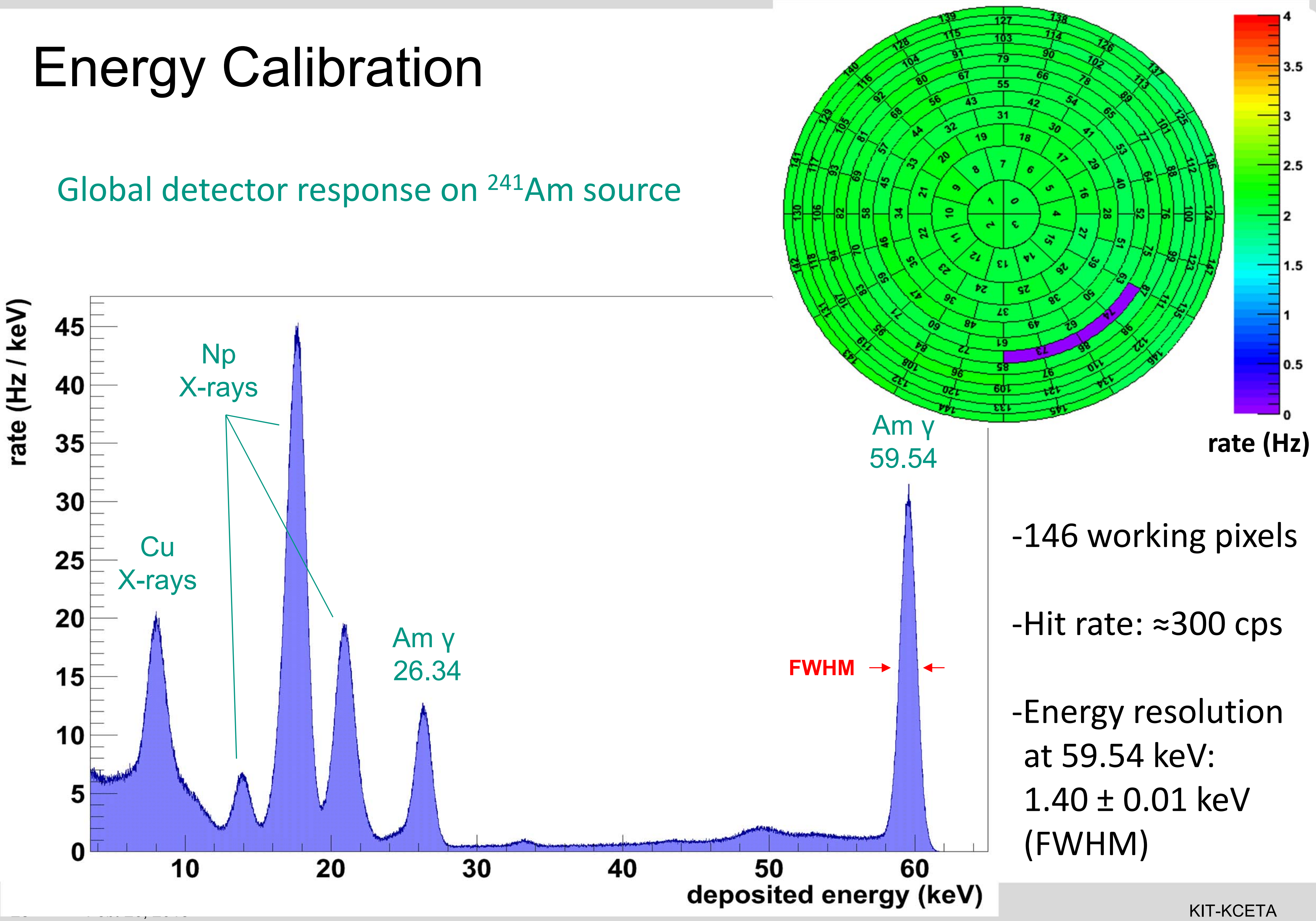
wafer

Calibration Sources



Energy Calibration

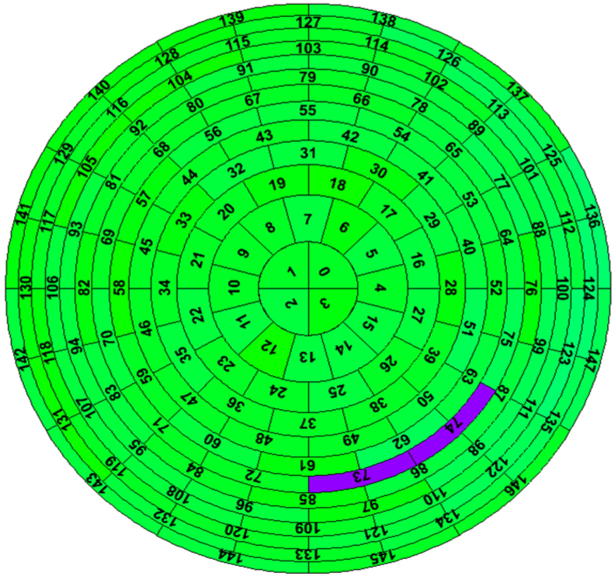
Global detector response on ^{241}Am source



- -146 working pixels
- -Hit rate: ≈300 cps
- -Energy resolution at 59.54 keV: 1.40 ± 0.01 keV (FWHM)

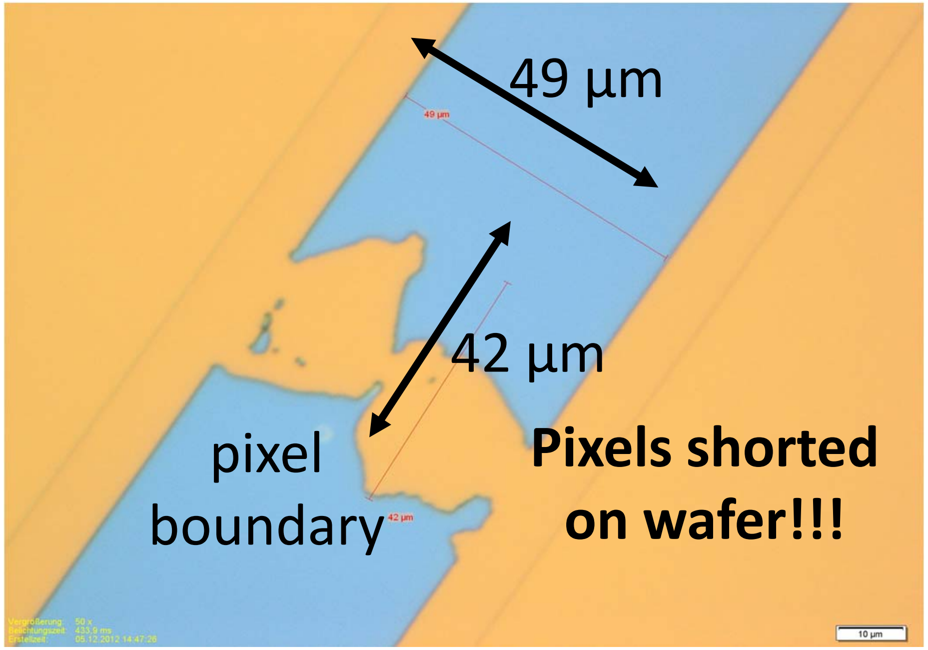
98,6 % working pixels

Wafer #96728



measured
resistance
between
pixels
#73 and #74:
➔ R = 44 Ω

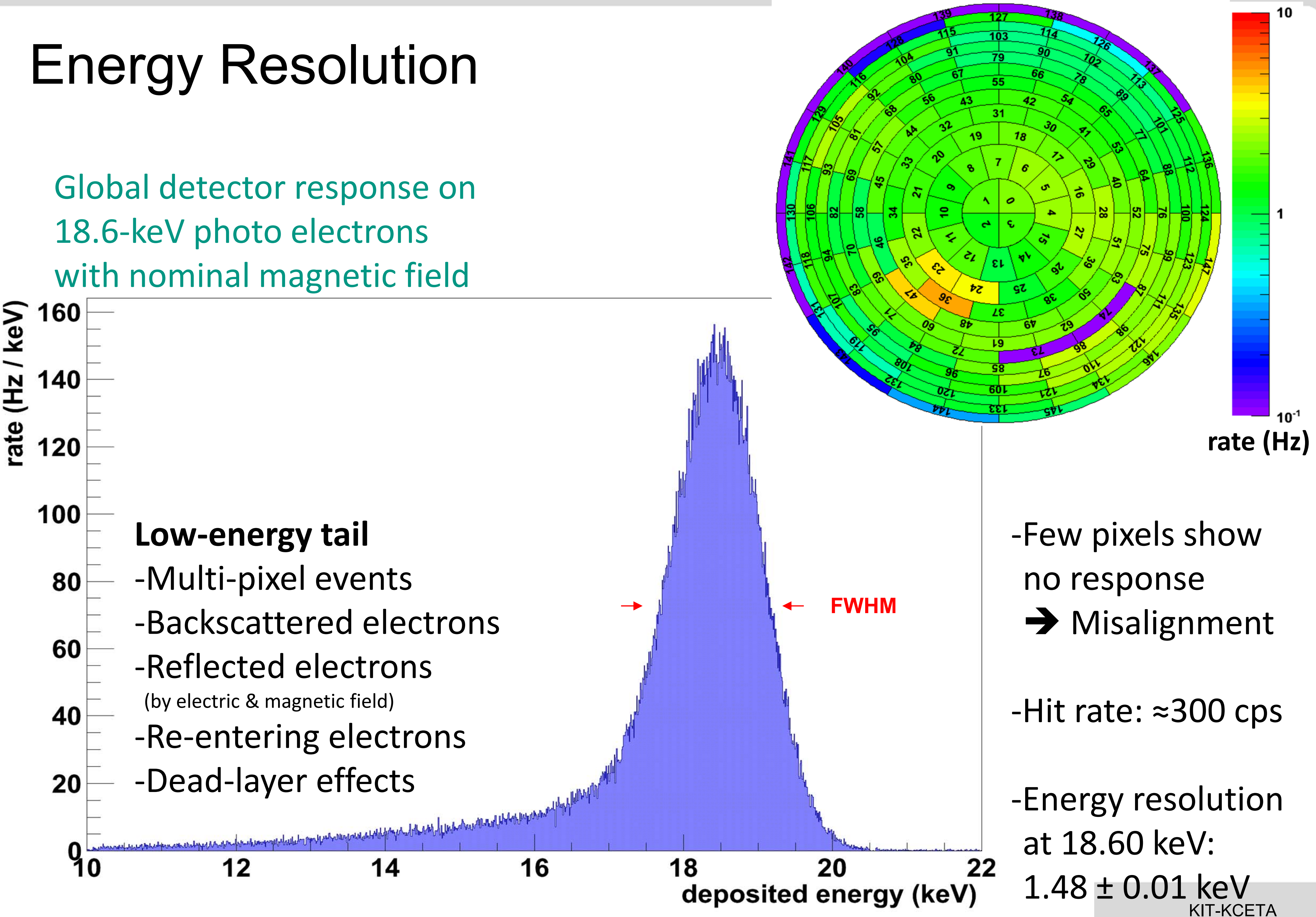
microscope



Pixels shorted on wafer!!!

Energy Resolution

Global detector response on
18.6-keV photo electrons
with nominal magnetic field



Low-energy tail

- -Multi-pixel events
- -Backscattered electrons
- -Reflected electrons (by electric & magnetic field)
- -Re-entering electrons
- -Dead-layer effects

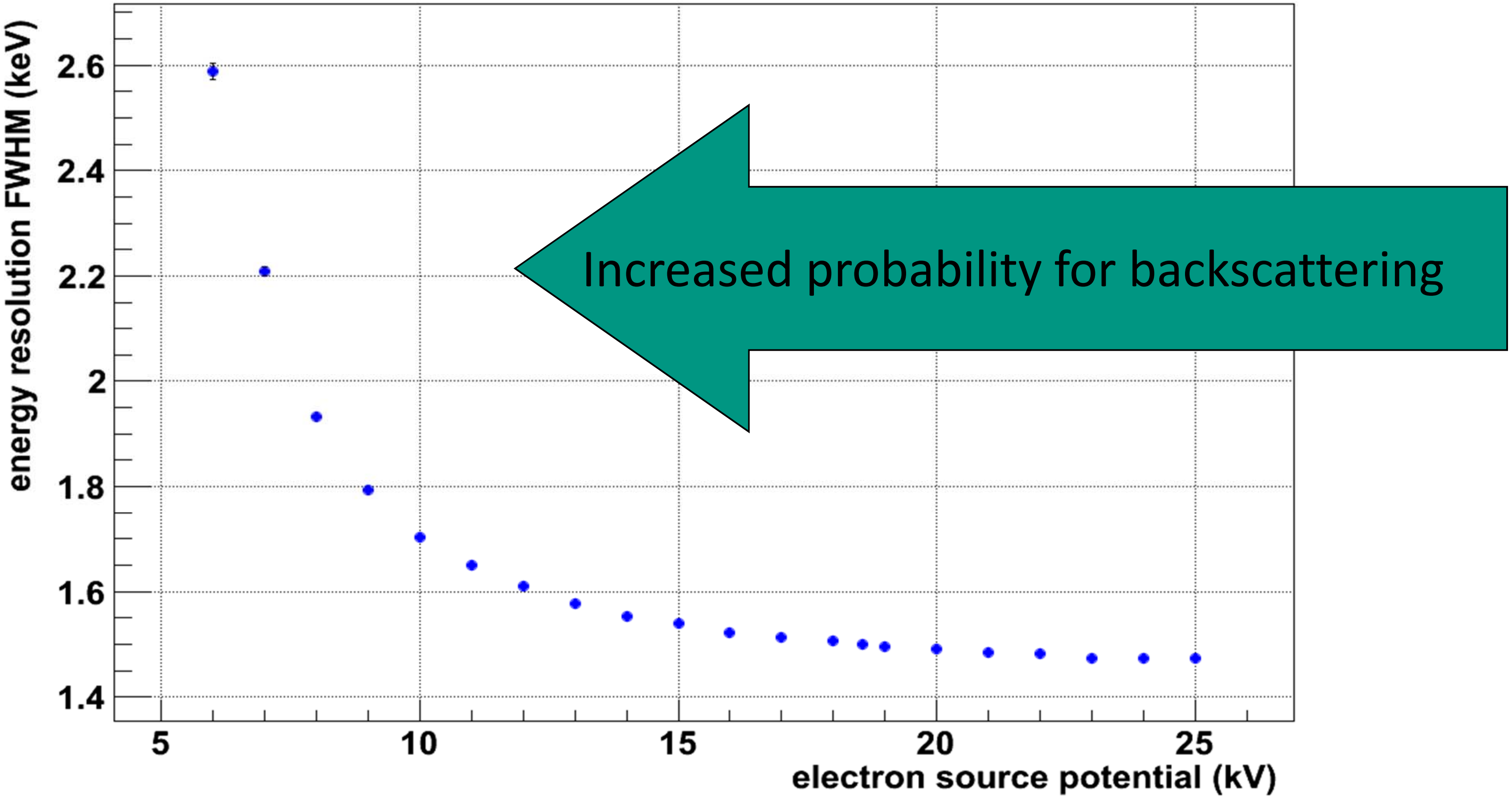
-Few pixels show no response
➔ Misalignment

-Hit rate: ≈300 cps

-Energy resolution at 18.60 keV: 1.48 ± 0.01 keV (FWHM)

Energy Resolution

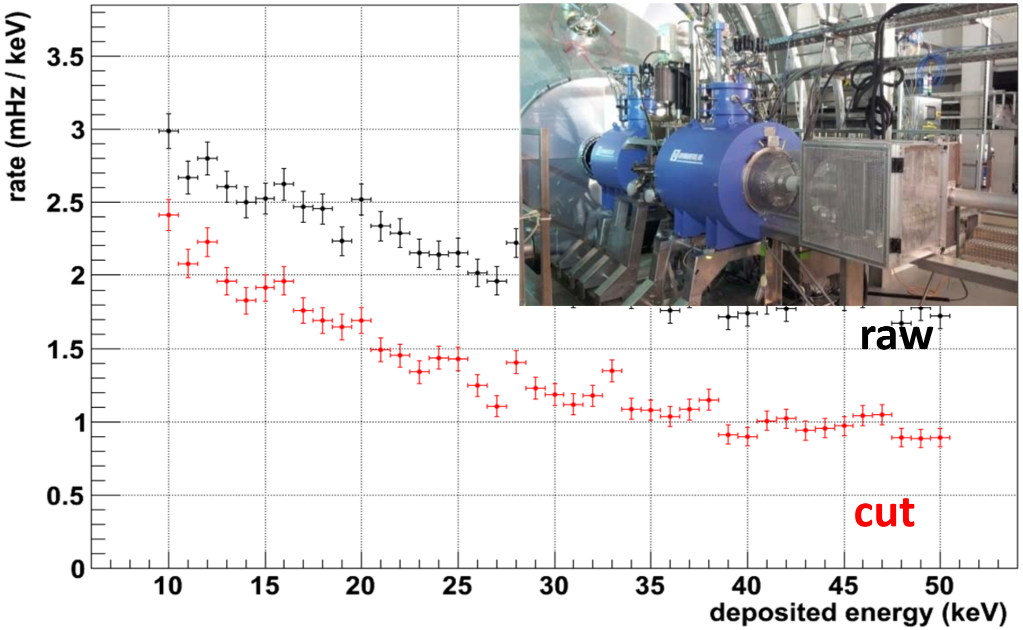
Global detector response on mono-energetic photo electrons with nominal magnetic field



Increased probability for backscattering

Summary FPD

Customized 5“ inch pin-diode with segmentation pattern optimized for KATRIN is ready for first measurements of Main spectrometer characteristics



Customized mounting and connection scheme to suppress backgrounds by natural radioactivity has been successfully implemented. The measured background is in concordance with GEANT simulations.

The next ½ year:

- Proof of Low Background Performance (i.e. with PA andVeto)
- Optimizaion of FPGA code for encountering pile-up effects

Summary

- KATRIN currently being set up hosts a couple of technical challenges over a wide range of applications
- Commissioned: High precision HV divider, Laser-Raman spectroscopy, WGTS cooling system, Main Spectrometer UHV (in progress), detector, …
- Systems come one by one into commissioning phase, still many important commissionings to come

Acknowledgments
to Johannes Schwarz and Guido Drexling for providing many slides