SPARC
Stored Particles Atomic Physics Research Collaboration

SIM-X

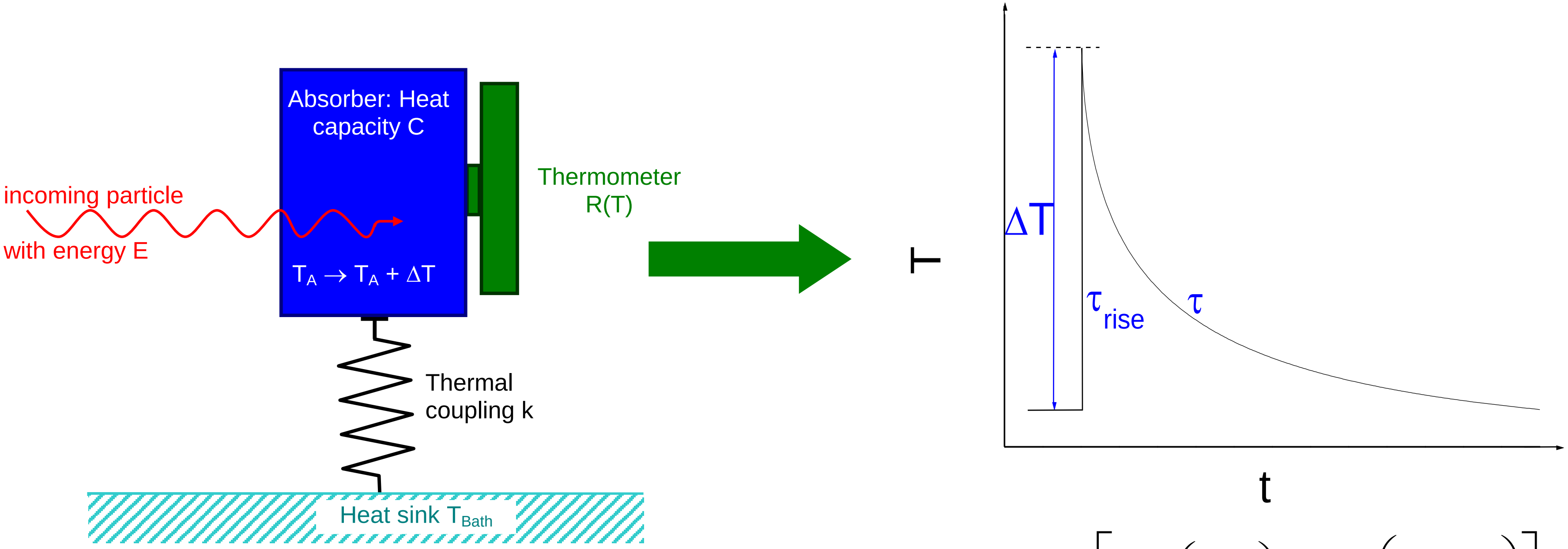
Silicon Microcalorimeters for X-ray Spectroscopy – Status and Perspectives

V. Andrianov[2,4], A. Bleile[2], A. Echler[2,3], P. Egelhof[2,3], S. Ilieva[2], C. Kilbourne[5], S. Kraft-Bermuth[1,2], D. McCammon[6], Th. Stöhlker[2], P. Scholz[1]

[1]Institut für Atom- und Molekülphysik, Justus-Liebig-Universität Gießen, Germany
[2]GSI Darmstadt, Darmstadt, Germany
[3]Institut für Physik, Johannes-Gutenberg-Universität Mainz, Germany
[4]Lomonosov Moscow State University, Moscow, Russia
[5]NASA/Goddard Space Flight Center, Greenbelt, USA
[6]University of Wisconsin, Madison, USA

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN
Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG
HIC for FAIR
Helmholtz International Center
Bundesministerium für Bildung und Forschung

Detection Principle of Microcalorimeters



$$C\cdot\frac{dT}{dt}=E\cdot\delta(t)-k\cdot T(t)+\frac{dR}{dT}I^{2}T(t)$$

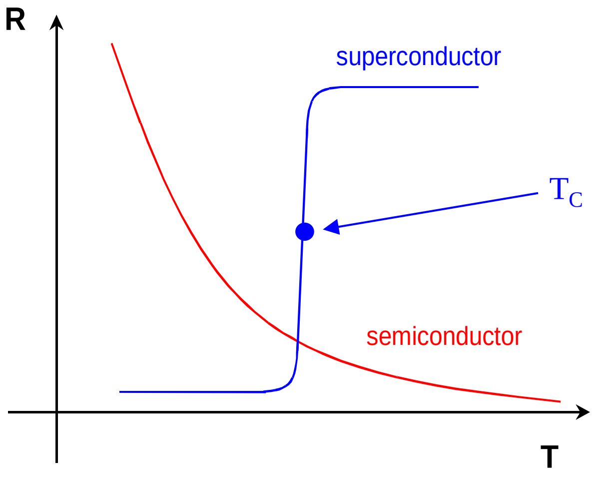
$$T(t)=\frac{E}{C}\cdot\left[\exp\left(-\frac{t}{\tau}\right)-\exp\left(-\frac{t}{\tau_{rise}}\right)\right]$$

- Rise time τ_{rise} determined by resistor/capacitance of thermometer
- Signal height $\Delta T = E/C$
- Decay time: $\tau=\frac{C}{k-\frac{dR}{dT}I^2}$: 100 µs – 10 ms

I. Motivation
Why Silicon Microcalorimeters?

Resistance Thermometer:

- resistance thermometer: ΔT→ΔR→ΔU
  - ➢ for high sensitivity: high dR/dT
  - ➢ specially doped semiconductor (large dynamic range) or superconductor in phase transition (very high dR/dT)
- thermometer technology with the longest standing history, well established and reliable
- systematic effects different from magnetic microcalorimeters
  - ➢ two different yet comparable detector concepts
- simultanous measurements with two cryostats and two microcalorimeter arrays advantageous



II. Silicon Microcalorimeters for X-rays

Energies 10 – 100 keV:

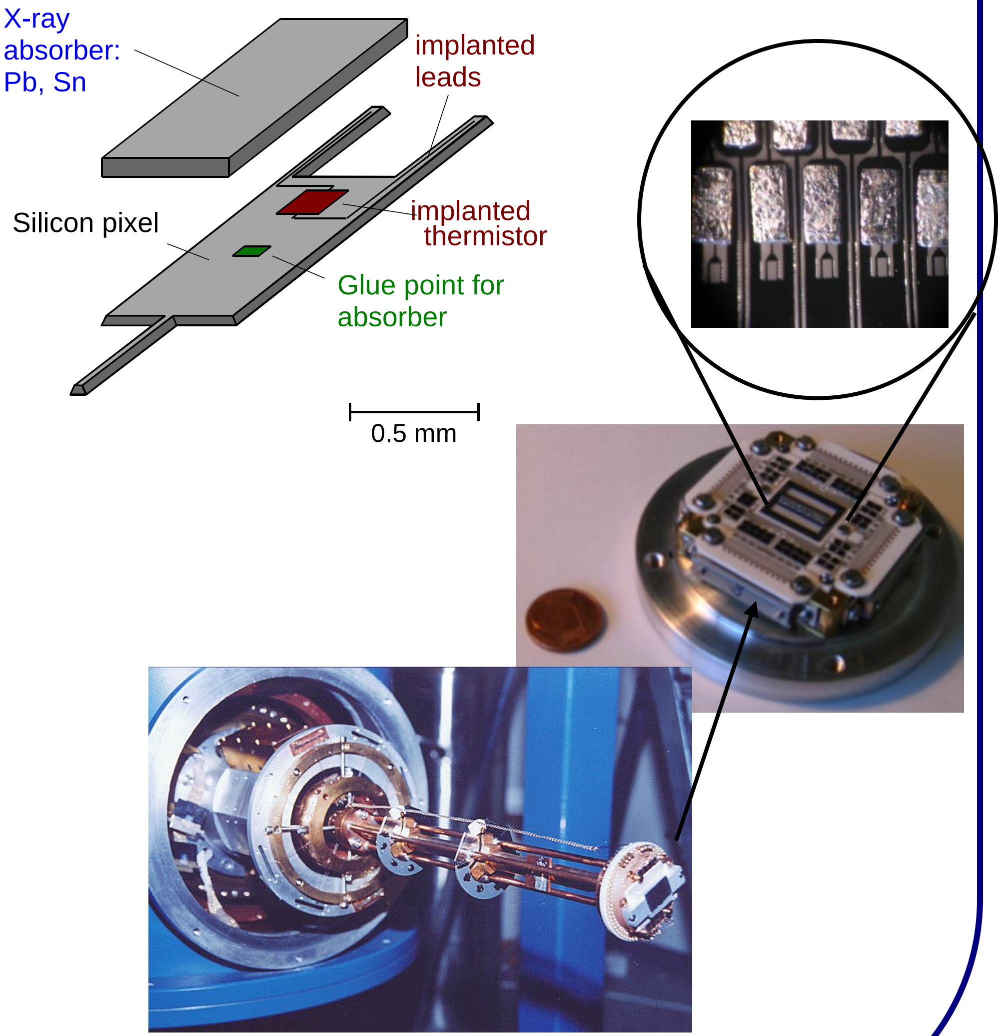
- $T_A \leq 60$ mK

Absorbers:

- superconductors for small c
- high Z material
  - Pb, Sn
  - absorber thickness: 50 - 100 µm

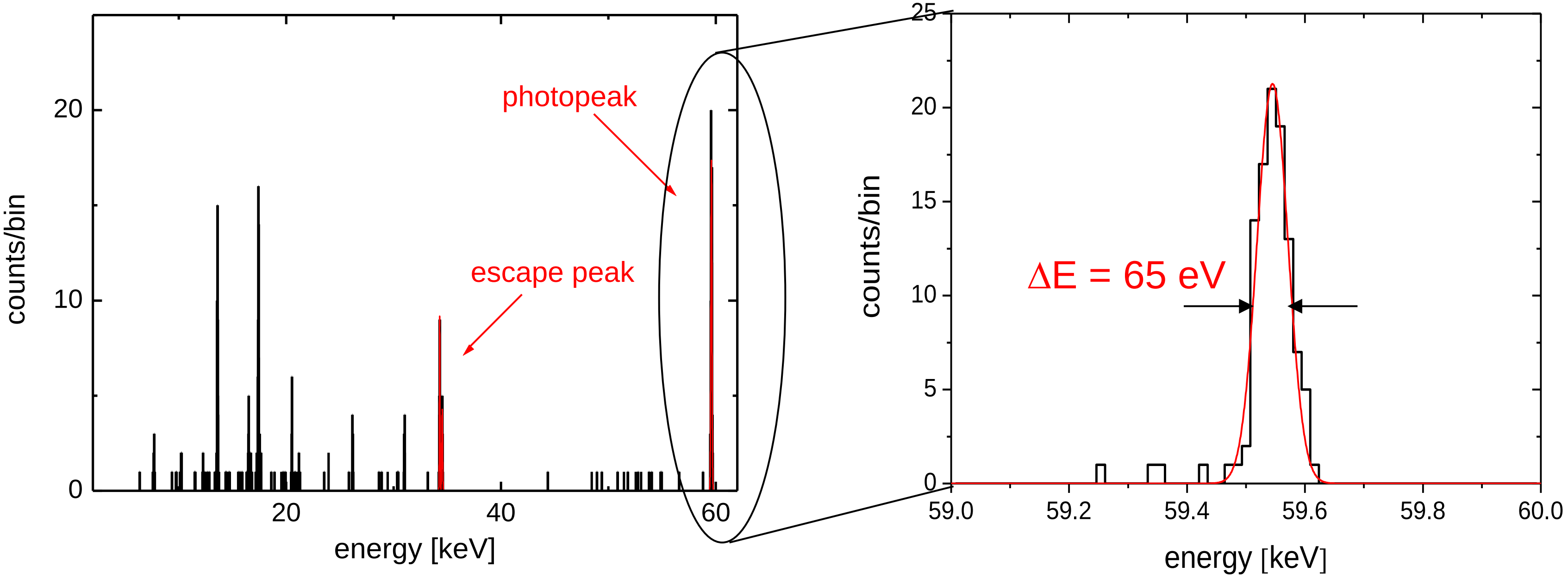
Thermistors:

- large energy range
  - Si doped with P and B
- 36 pixel detector array
  - pixel area 2 x 0.5 mm²
- developed and fabricated by Madison / Goddard and Mainz group
- (A. Bleile, J. Meier et al., AIP Conf. Proc. **605**, 2002)



Performance of Prototype Array: Energy Spectrum

Energy spectrum obtained for a ^{241}Am source with an Sn absorber (0.3 mm² x 66 µm)



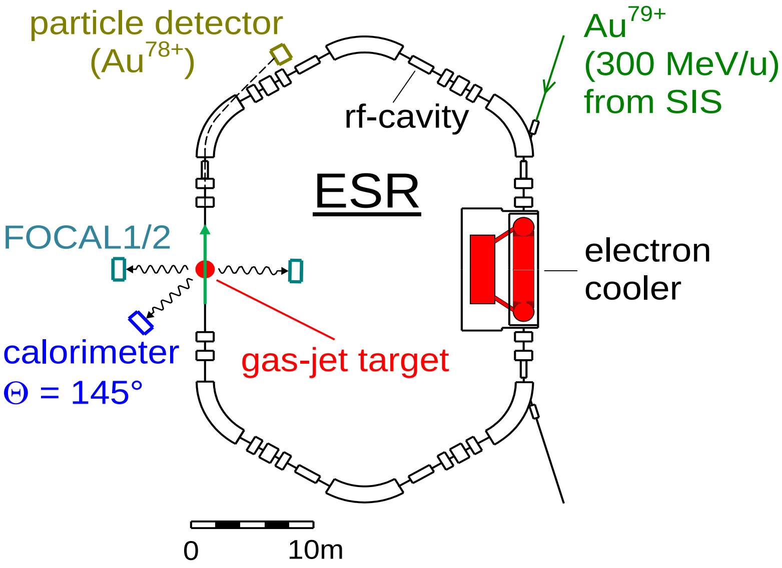
energy resolution at E = 59.5 keV: ΔE = 60 – 65 eV for Sn and Pb absorbers

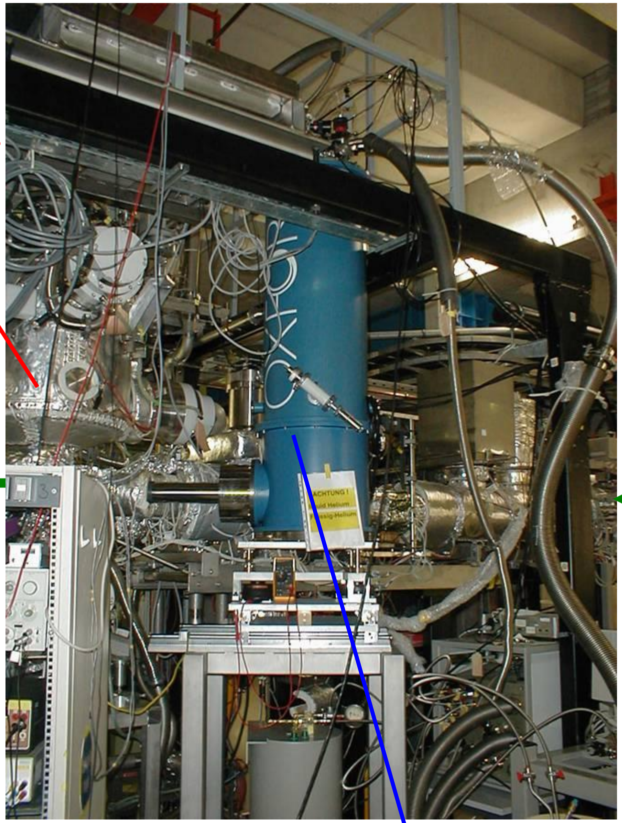
for comparison:

theoretical limit for a conventional semiconductor detector: $\Delta E_{FWHM} \approx$ 380 eV

(A. Bleile, J. Meier et al., AIP Conf. Proc. **605**, 2002)

III. First Application: The Lamb Shift Experiments at the ESR





- injection of fully stripped ions, beam cooling and deceleration
- electron capture in the gas target
- detection of the Lyman-α-radiation
- transformation of measured Lyman-α energy into laboratory frame
- joint experiments with crystal spectrometer FOCAL

Results

Two joint experiments with crystal spectrometer FOCAL

- beams: $^{207}Pb^{82+}$ at 219 MeV/u
  $^{197}Au^{78+}$ at 125 MeV/u

Doppler correction:

$$E_{emit} = E_{lab} \cdot \frac{1-\beta \cos \Theta}{\sqrt{1-\beta^2}}$$

→ angle Q and velocity β have to be known with high precision

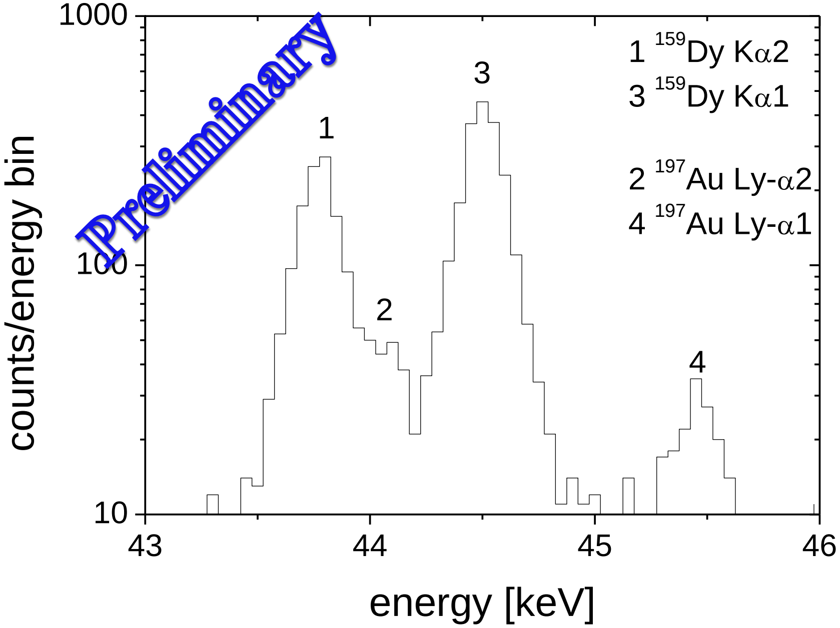
Preliminary Results:

$E(\text{Ly-}\alpha 1) = (77919 \pm 6_{stat} \pm 17_{syst})$ eV

$E(\text{Ly-}\alpha 1) = (71568 \pm 4_{stat} \pm 13_{syst})$ eV

(S. Kraft-Bermuth et al., submitted to J. Phys. B, 2015)

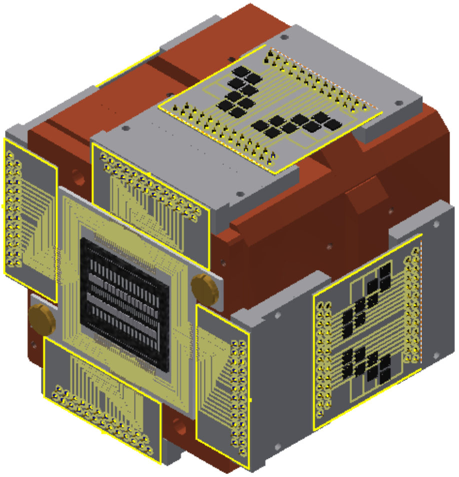
Example: Spectrum for Au



- So far good agreement with theory (V. Yerokhin and V. Shabaev, Journal of Physical and Chemical Reference Data **44** (2015) 033103)
- systematic uncertainity dominated by precision of determination of Θ (9 eV)

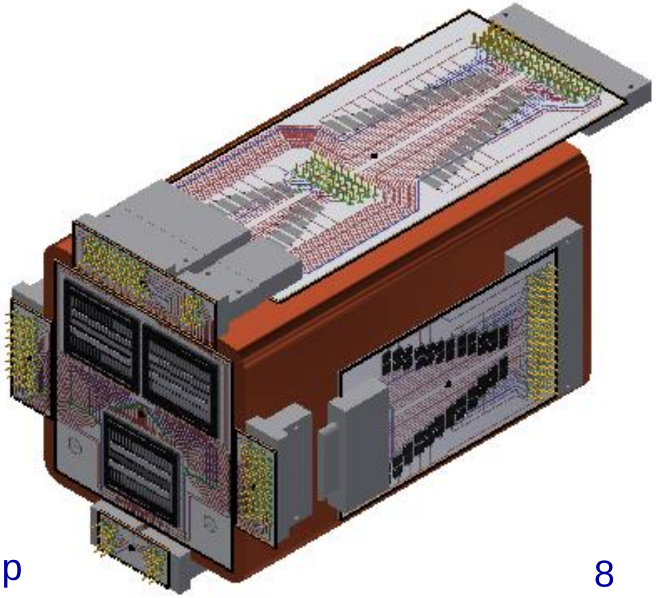
IV. New Detector Setup with 3 Arrays

- 1st step: test of a new, more compact design for 32 pixels
  - addition of low-energy pixels
  - separated load resistor boards
  - investigation of heat load and noise performance
  - tested in 2016 at ESR



- 2nd step: expand this design to 3 x 32 = 96 pixels
  - Parts in production
  - Assembly expected in 2017

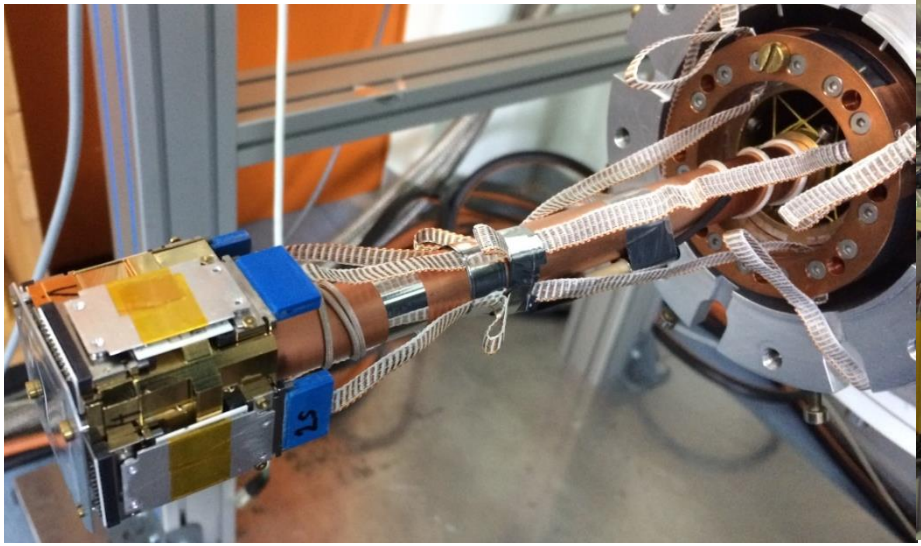
- expand readout electronics and DAQ
  - new JFET boards based on standard PCBs: easy design and production
  - New DAQ program for 96 channels

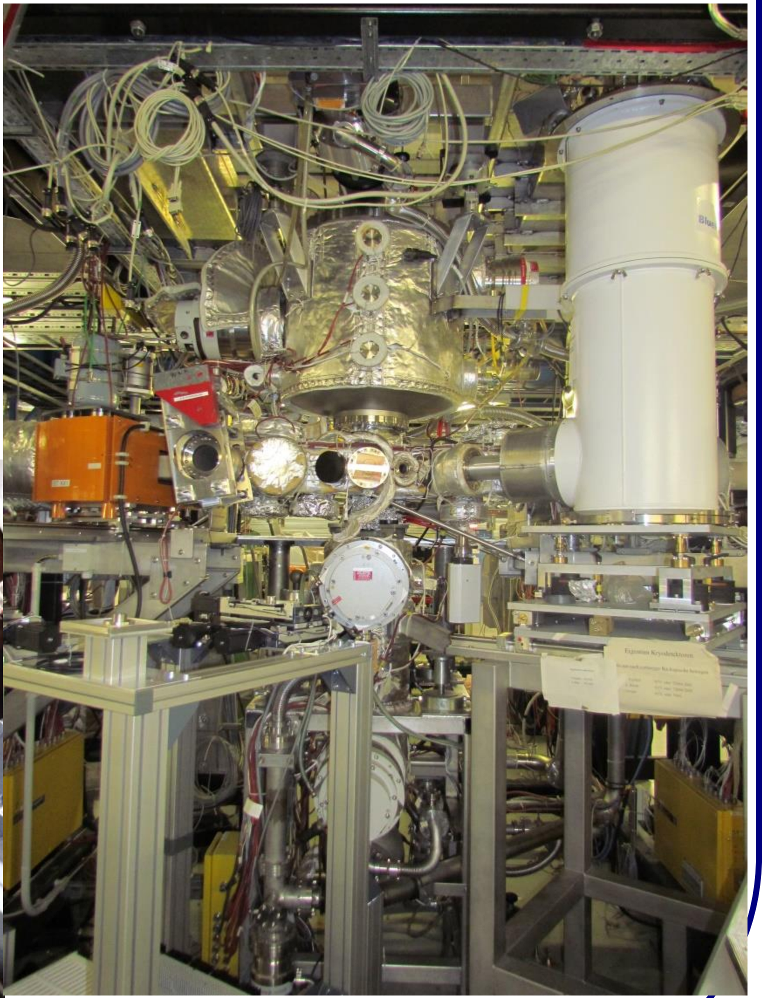


Tests at ESR 2016: Uranium

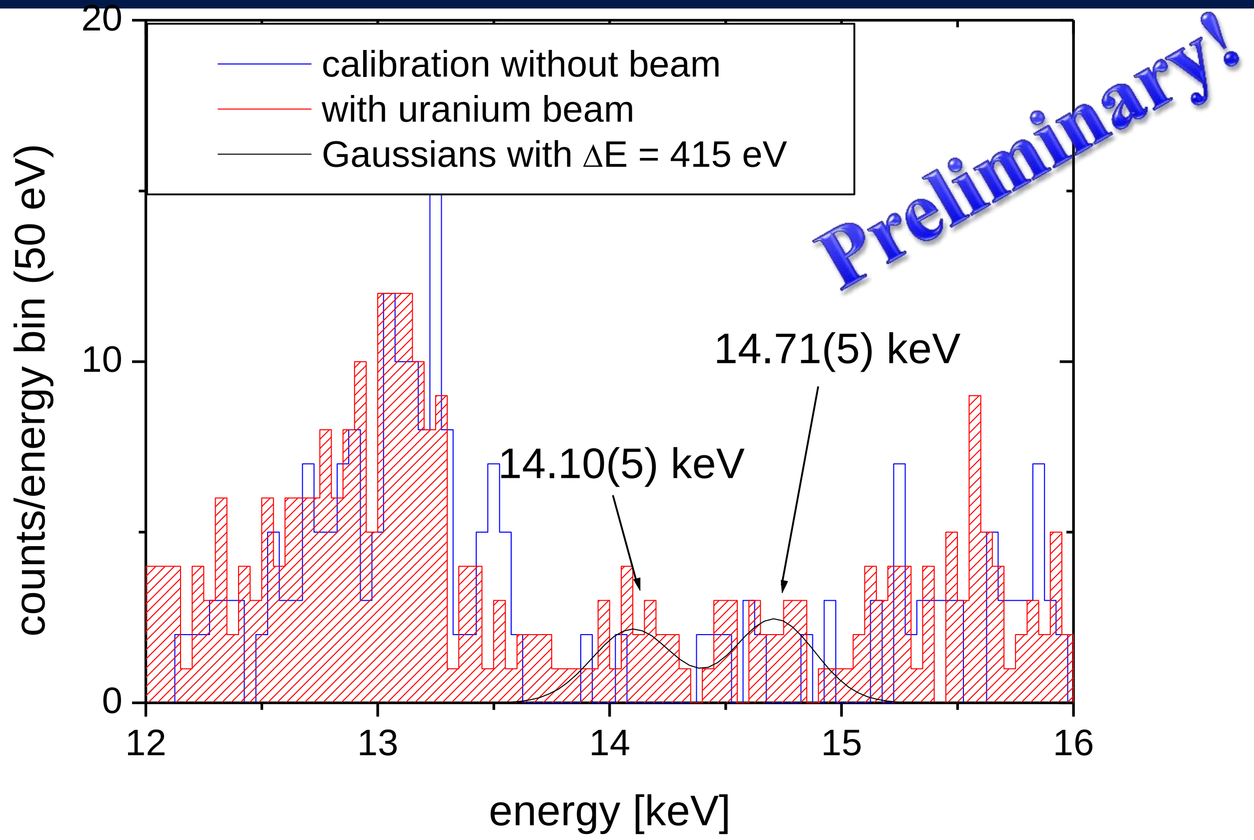
- 1st campaign: lithium-like uranium U^{89+}, E = 70 MeV/amu
    - Mostly low-energy X-ray transitions below 20 keV
    - Not optimal for our detector, which is optimized for E ~ 100 keV
    - Test of new design in laboratory very short

➔ not optimized cryogenic setup





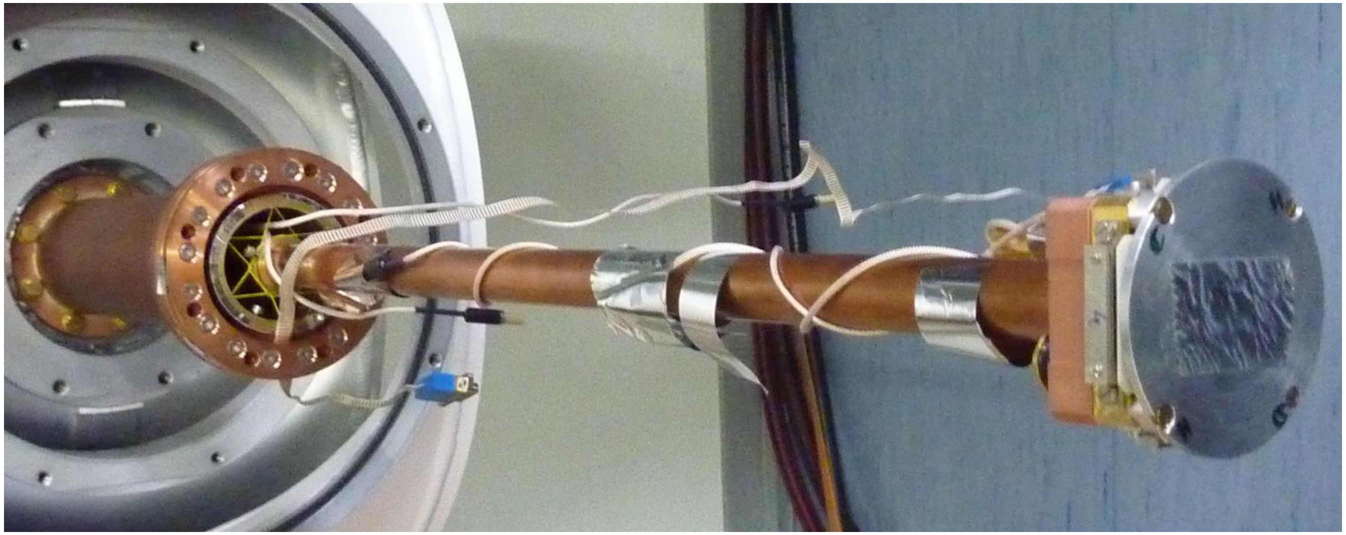
Tests at ESR 2016: Uranium



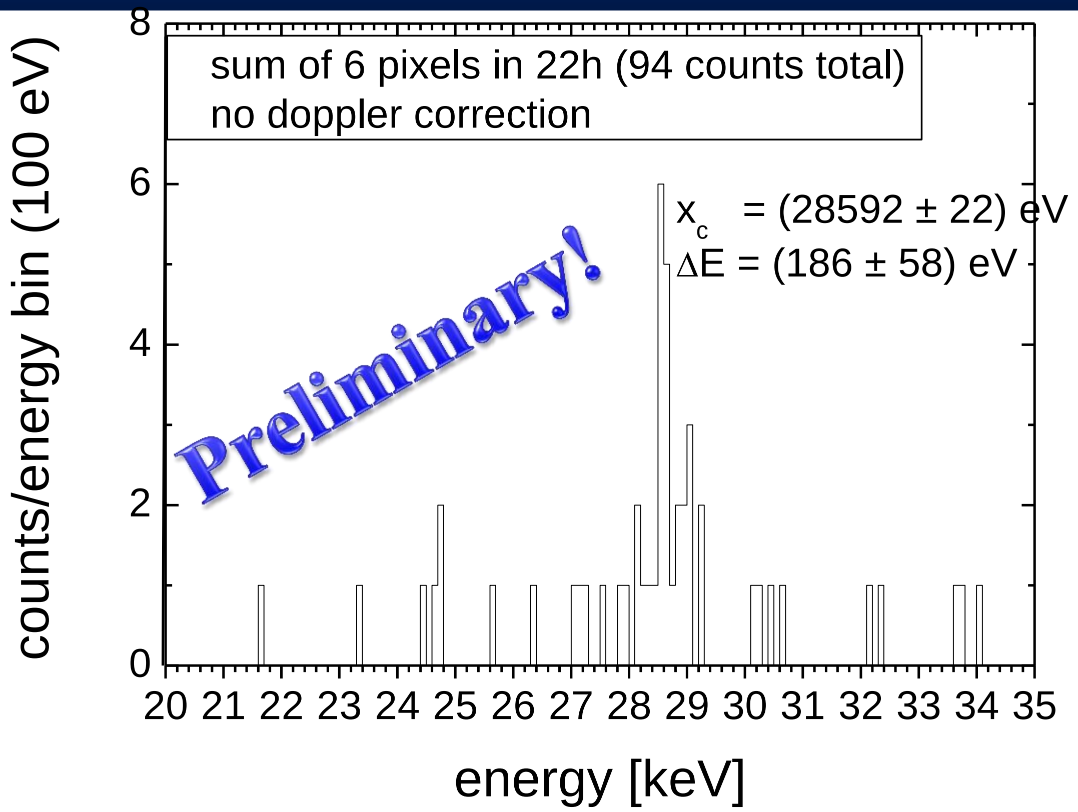
- Strong background from calibration sources
- Energy resolution around 400 eV @ 30 keV
- Main limitation: small signal amplitude due to bad thermal contact between detector and cryostat → currently under investigation

Tests at ESR 2016: Xenon

- 2nd campaign: hydrogen-like xenon Xe^{53}+, E = 6 MeV/amu
  - X-ray energies ~ 30 keV (Lyman-α lines)
  - Count rate very low due to low ion energies (beam life time)
  - Used „old“ detector from Lamb Shift measurements in the new cryostat



Tests at ESR 2016: Xenon



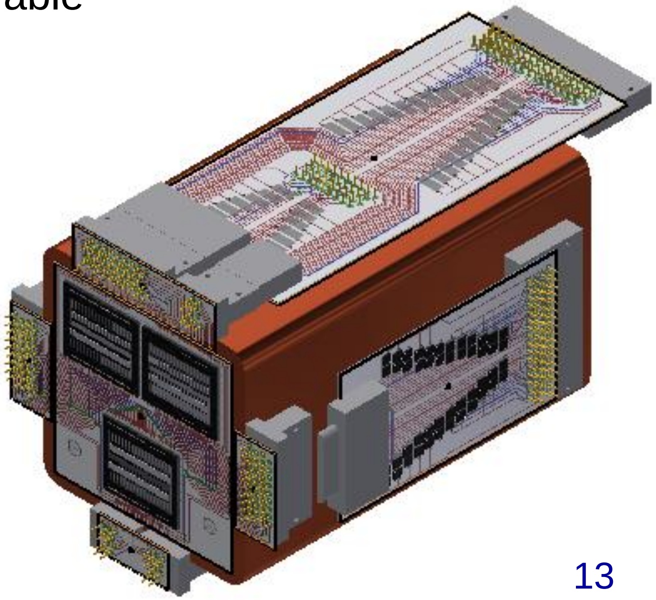
- Calibration sources removed, separate calibrations at beginning and end of run
  - ➢ Possible due to very stable operation of cryostat (no temperature drifts)
- Energy resolution ~200 eV (same as for Lamb Shift experiments)
- Analysis still in progress

V. Conclusion and Perspectives

- First test of SiM-X at ESR was successful
  - ➢ cryostat operated without problems at ESR for 7 weeks
  - ➢ maintained very stable operating temperature
    - ➔ measurements without permanent calibration possible
    - ➔ measurements at very low event rates for Xenon

- Performance of old „Lamb Shift“ detector array in new cryostat: $\Delta E \sim 200$ eV for 10 pixels (comparable to Lamb Shift measurements)
- Performance of new detector setup not yet comparable
  - ➢ cryogenic setup needs to be optimized
  - ➢ investigation in progress

- For larger array with 96 pixels
  - ➢ TDR approved end of last year
  - ➢ All parts are ready or in production
  - ➢ Assembly expected beginning of 2017
  - ➢ Ready to use in 2018 for experiments



Special Thanks to

- P. Scholz (Ph.D. student) and A. Echler (PostDoc)
- T. Gassner, P.-M. Hillebrand, J. Glorius and Y. Litvinov for the organization before and during the experiment
- all ESR group and GSI accelerator crew for excellent beam conditions
- our co-experimenters for the very good cooperation

Thank you for your attention!