X-ray measurements for electrode gap voltage verification

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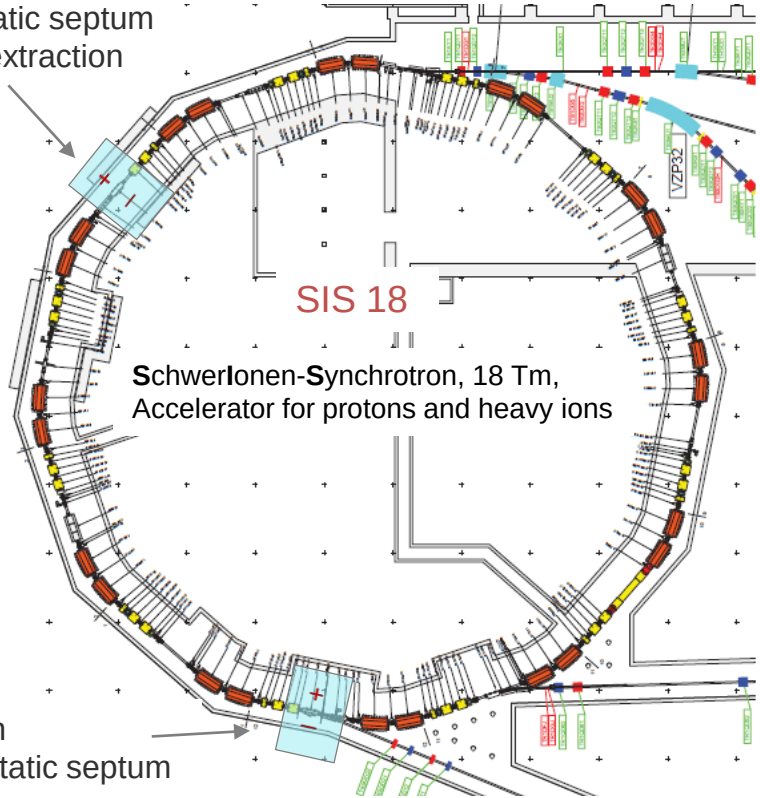
Electrostatic septa, SIS18



Electrostatic septum tank

High voltage feedthrough

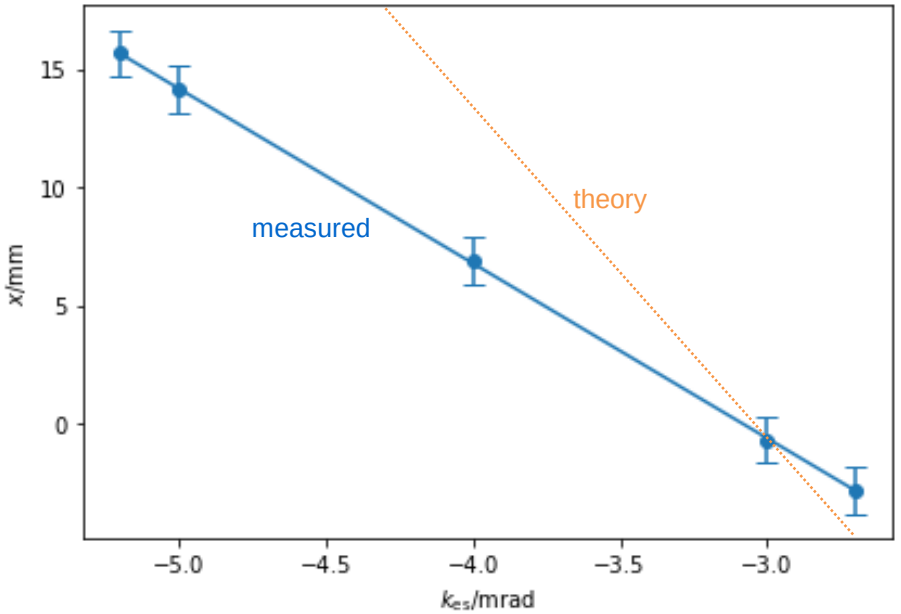
Measurement of septum voltage - Background

- For some time, it has been an open issue that the performance of the extraction electrostatic septum (ES) is not as expected, and higher voltage settings than nominal are required.
- High losses at the Magnetic extraction septum are observed for nominal settings of the ES.
- Beam optics measurements shows that the deflection angle of the ES is about 55% of what is expected theoretically.
- Electric field in the ES-gap correct, or is there some other effect that has been overlooked?
- No independent voltage measurement available. Direct measurement of the voltage at the electrodes, in vacuum, under operating conditions, is not trivial.
- Instead observation of Bremsstrahlung X-rays, generated in the electrode gap of the ES. *Idea: D. Ondreka.*

Beam position vs. extraction ES angle

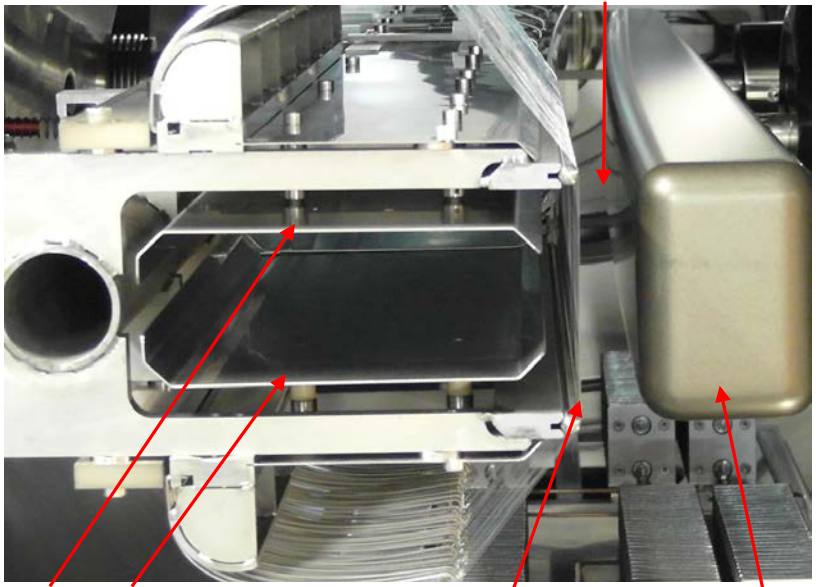
- Measurement of beam position on viewing screen after the magnetic septum, GS06DF.
- Change cathode voltage of extraction ES in terms of deflection angle setting, k_{es}.
- Measured position change: 7.4 mm/mrad
- Expected theoretically: 13 mm/mrad
- Large discrepancy, deflection of ES about 55% of expected value.

Beam position vs. ES angle setting



Measurements: D. Ondreka, 2020

Extraction electrostatic septum



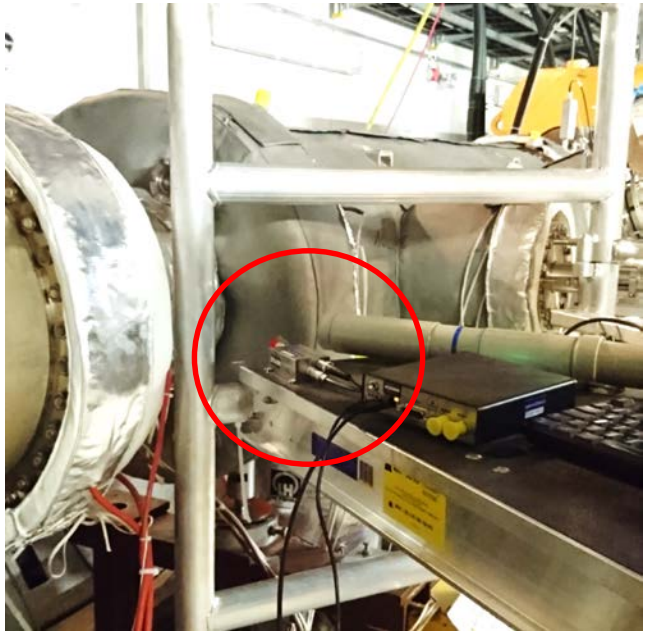
- In the direction of the beam
- Gap 18 mm, 90 kV/cm at 160 kV
- *Injection septum, opposite direction, gap ~35 mm*

- X-rays generated when electrons accelerated in the gap hit the anode wires (or other anode structures on ground potential)
- Electrons generated at the cathode by field emission

X-ray method to measure voltage

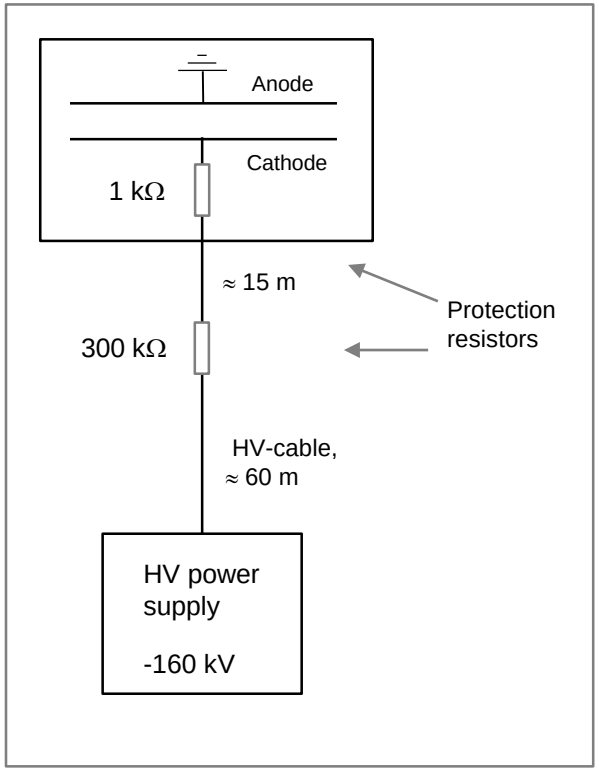
- A solid state detector, Amptek XR-100-CdTe was used to perform the measurements
- The bremsstrahlung X-ray spectrum maximum energy corresponds to the voltage of the electrode gap
- Energy calibration using Am-241 and Eu-152

Detector at upstream flange of ES



https://www.amptek.com/internal-products/xr-100cdte-x-ray-and-gamma-ray-detector

ES description and measurement set-up



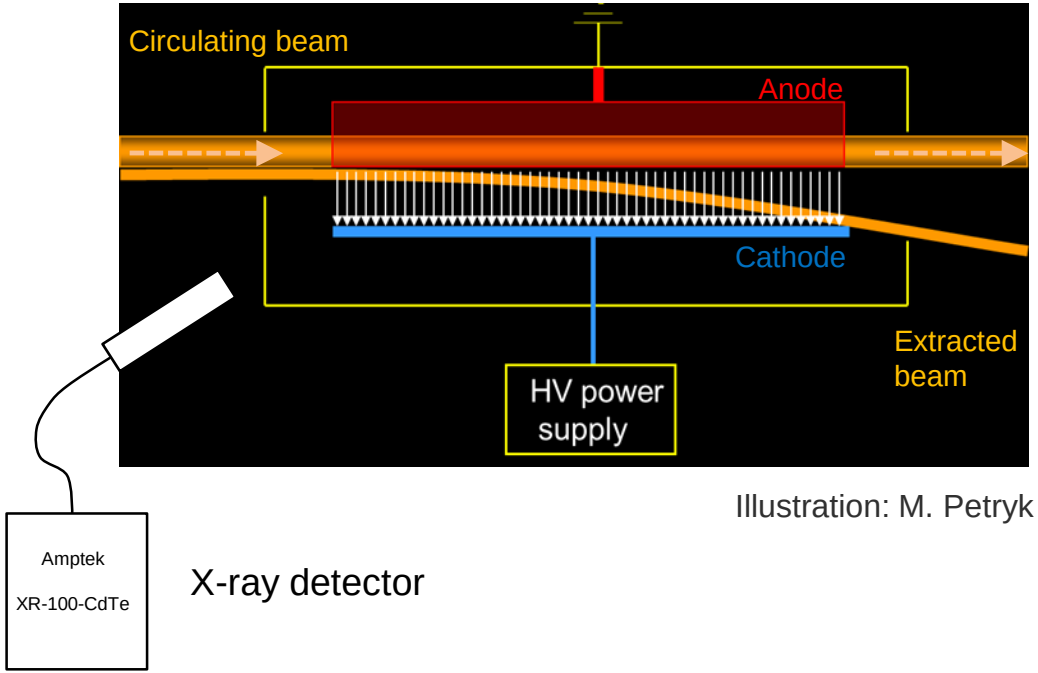
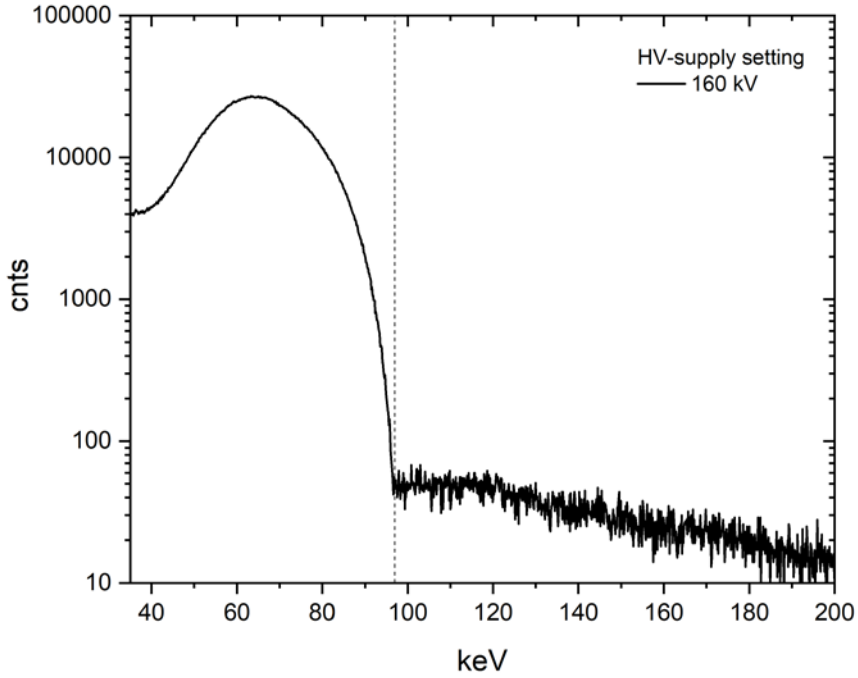


Illustration: M. Petryk

X-ray detector

Extraction septum – X-ray measurements

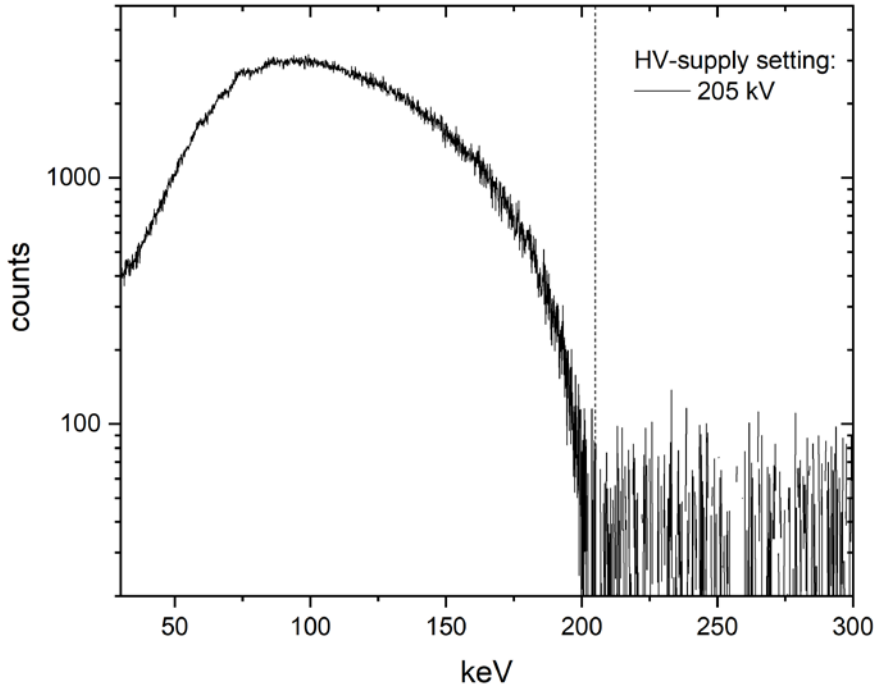


Bremsstrahlung x-ray maximum energy - voltage of the electrode gap
Uncertainty, high energy cut-off, about ± 1 kV

- First X-ray spectrum measurement, ES
- Energy cut-off about 60% of what is expected from HV-supply setting, consistent with beam optics observations.

HV read-out (kV)	X-ray cut-off (keV)
160	~ 98

Injection septum – X-ray measurements

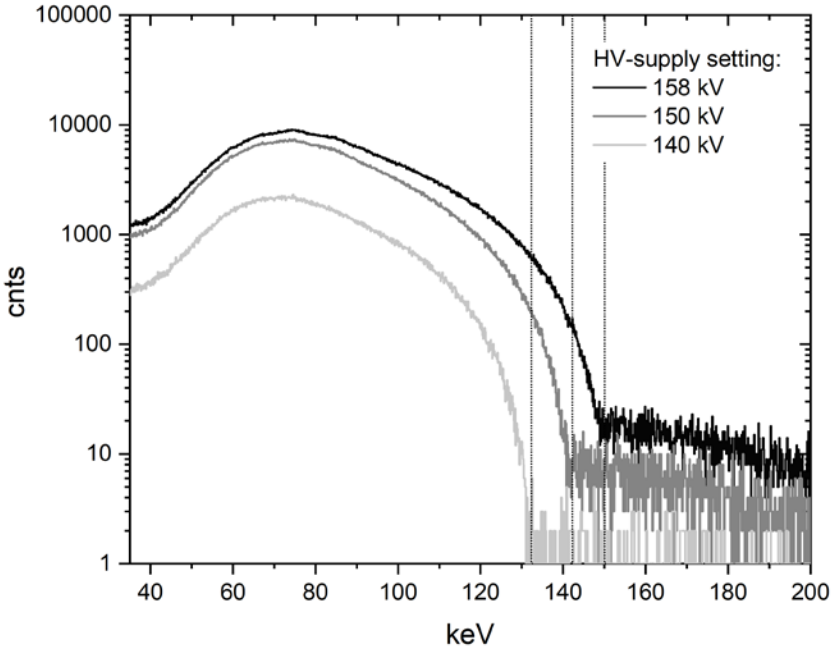


- Injection septum comparison.
- Energy cut-off corresponds to HV-supply setting

HV read-out (kV)	X-ray cut-off (keV)
205	~ 205

Extraction septum—spare HV supply

X-ray spectra for different voltage settings

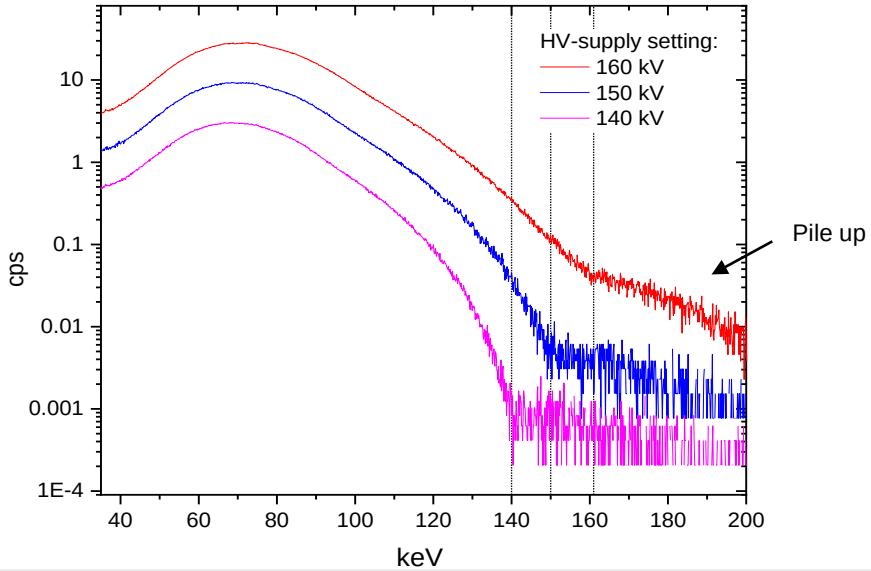


- HV probe measurements off-line confirmed HV-supply voltage was defective
- HV supply replaced, with a spare supply.
- Energy cut-off corresponds to HV-setting (about 8 kV lower)

HV voltage (kV)	X-ray energy cut-off (keV)	Current (μA)	Eq. dose rate (μSv/h)
140	132	20	25
150	142	30	70
158	150	60	150

Extraction septum—repaired HV supply (2021-11)

- First HV-supply repaired at the manufacturer, aged capacitors replaced, and recalibrated.
- The voltage is now correct.
- Problems with pile-up due to high count rate, give uncertainty in read out of HV cut-off.
  (need to move detector or use shielding--limited measurement time)



Set voltage (kV)	Energy cut-off (keV)	Current (μA)
140	140	30
150	150	40
160	~161	180

Electrostatic Septa: Sparking for Heavy Ions

- Observation from beam time 2021 in SIS18
  - Frequent sparking for heaviest ions (Pb, U) at 10^9/s
  - High septum voltage (~142 kV) for the first time
- Machine experiment to compare ions
  - Argon (low mass) vs. Bismuth (high mass)
  - High intensities during spill (~10^{10}/s)
  - Looking at vacuum and sparking rate
- Open questions
  - Dependence of sparking rate on
    - intensity and beam loss at septum
    - ion mass (dE/dx) and charge state
    - vacuum pressure in septum tank
  - Origin of sharp intensity drop during sparking
  - Ways of lowering sparking rate
- Next step: improve diagnostics
  - Save all data from ES, DC trafo, BLMs, vacuum
  - Offline analysis looking for correlations

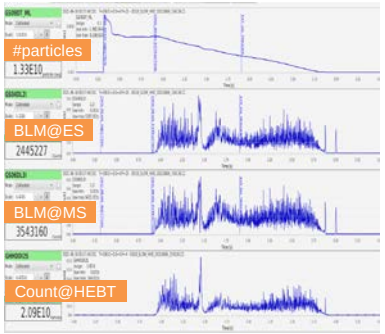
From: D. Ondreka, Monday 23/1

	Low mass	High mass
Ion	$^{40}Ar^{18+}$	$^{209}Bi^{26+}$
E [MeV/u]	1000	200
Intensity [1/s]	$2.3 \cdot 10^{10}$	$2.3 \cdot 10^{10}$

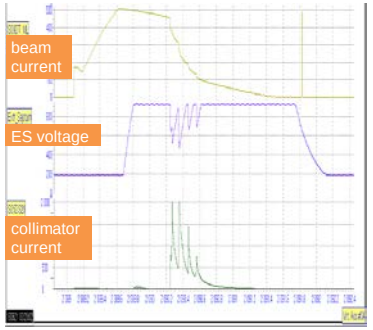
Vacuum activity for Ar (left) and Bi (right)

Sparking signature for high mass/low charge state Bi^{26+}

Spike on BLMs and counters



Instantaneous vacuum degradation



Summary

- Measurements of X-ray Bremsstrahlung spectra showed that the voltage of the extraction septum was about 60% of expected value (98 keV instead of 160 keV).
- Consistent with recent beam optics observations that the deflection angle from the ES is about 60% of expected.
- After repairing defective high-voltage supply the voltage at the ES is now correct, with lower losses at the magnetic septum.
- With correct voltage of the ES, the problem with high-voltage sparking becomes more severe at maximum ridigity/voltage. Further studies are needed to understand influence of beam intensity, ion species and vacuum.
- **The X-ray method of measuring the voltage in-situ has proven to be a useful tool, relatively simple and fast, for determining the voltage of the electrostatic septa.**

- For more info, see proceedings IPAC 2022
  accelconf.web.cern.ch/ipac2021/papers/thpab157.pdf

STUDYING X-RAY SPECTRA OF THE SIS18 ELECTROSTATIC SEPTA TO MEASURE THEIR ELECTRIC FIELD

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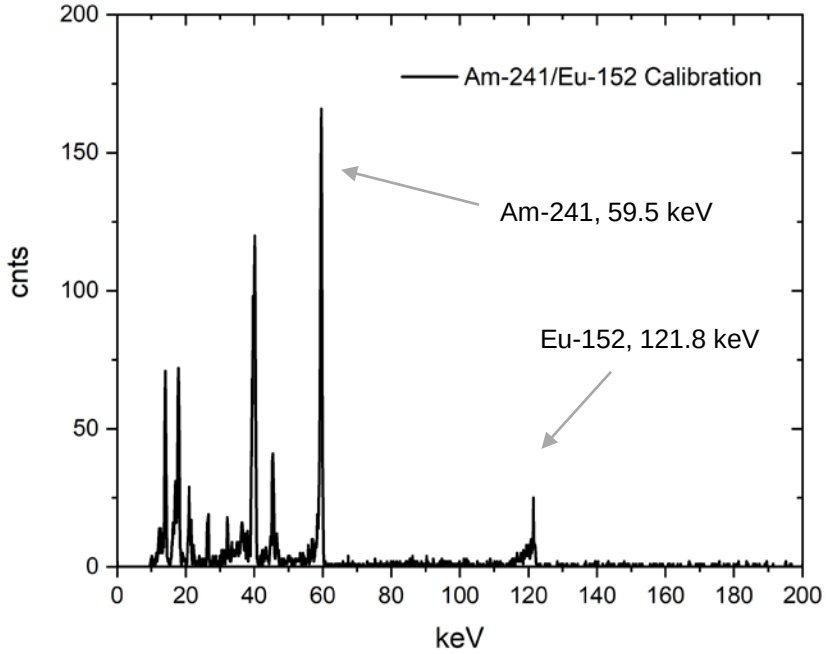
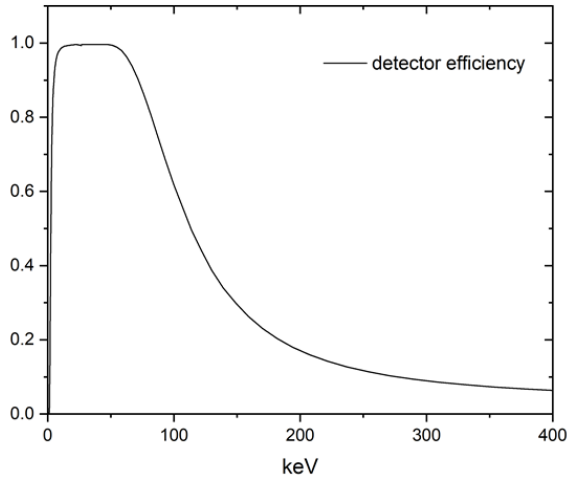
  - SIS/SYS: D.Ondreka, P. Spiller, J. Stadlmann.

CdTe-detector, energy calibration and efficiency

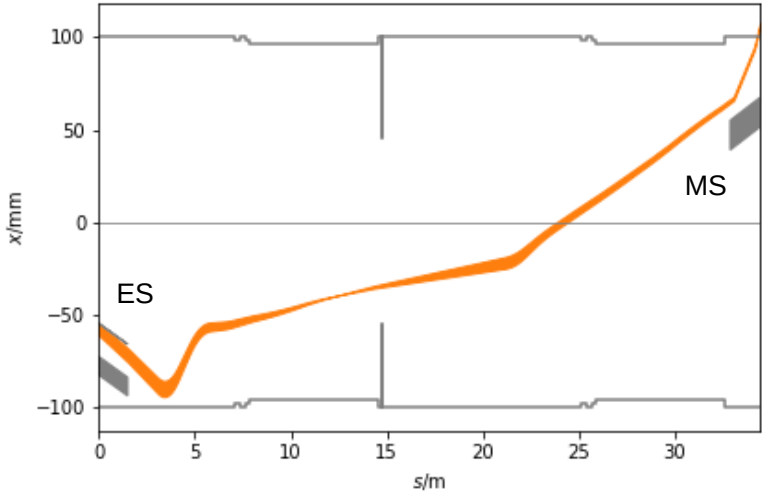
Calibration with gamma emission lines from Am-241 and Eu-152.



Detector efficiency



Extracted beam in SIS18



ES – Electrostatic extraction septum
MS – Magnetic extraction septum

Nominal deflection angle, 2.5 mrad at 18 Tm (5500 MV) and 90 kV/cm field.

Overview of GSI and FAIR – Facility for Antiproton and Ion Research