Photons from muon capture on aluminum and titanium with AlCap experiment

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Overview

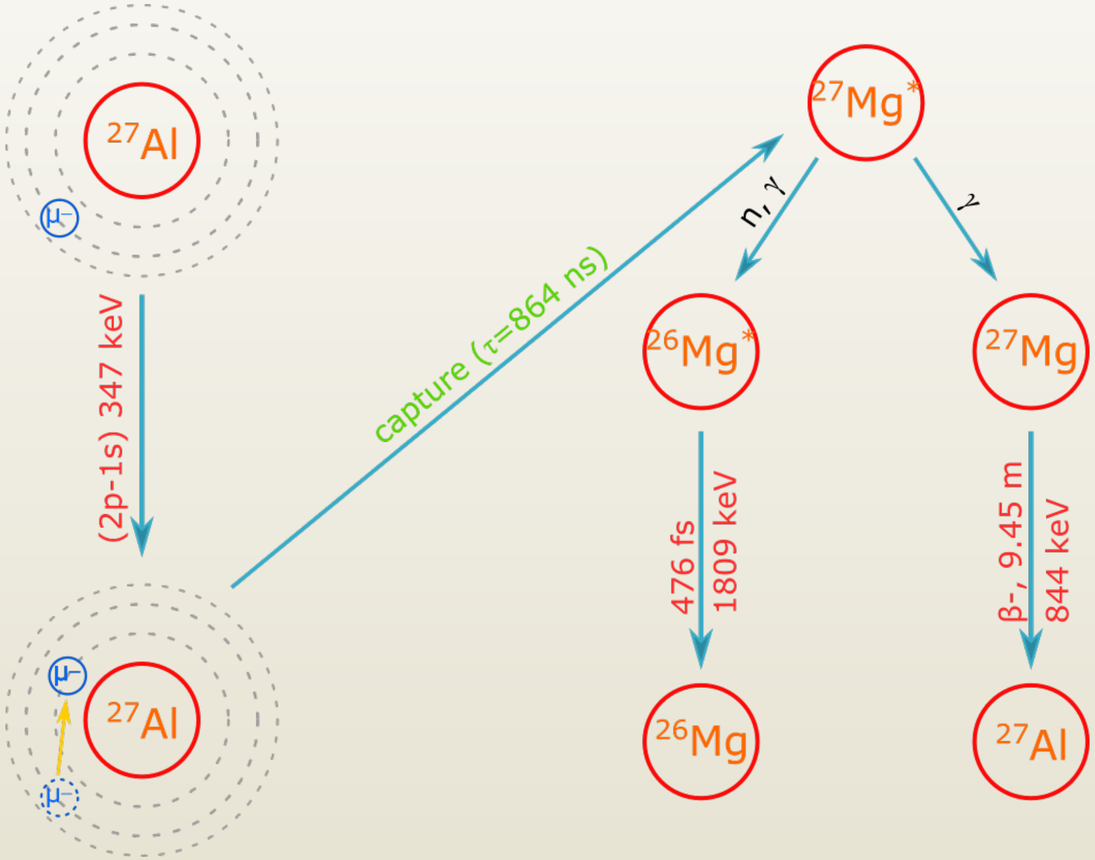
- Motivation
- Experimental setup
- Analysis
- Results
- Summary

Motivation

- Mu2e needs normalization
  - Will use 1809 keV gamma, 347 keV muonic X-rays for first run with aluminum target
  - Joint force with COMET to do the AlCap experiment
- AlCap experiment measures charged and neutral particles after muon capture on aluminum and titanium
  - protons, deuterons, tritons, alphas (see A. Edmonds' talk)
  - neutrons
  - photons: muonic X-rays, delayed gammas
    - check other materials where muons could be stopped in the real experiments

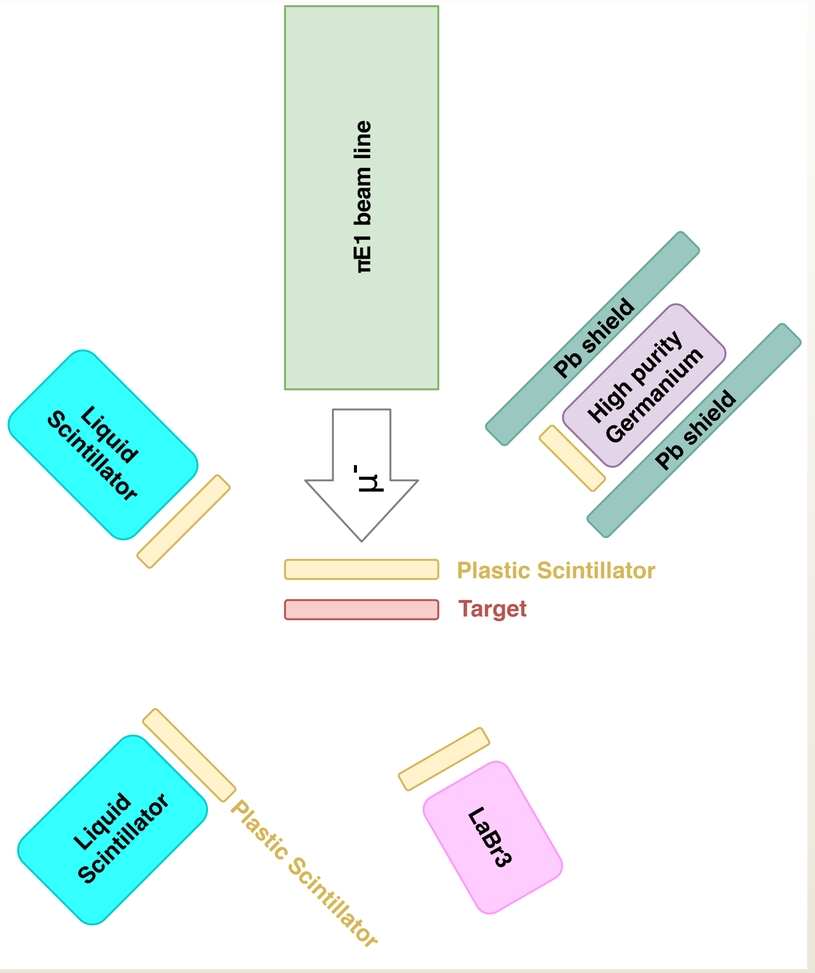
Photons from muon capture

- Prompt muonic X-ray: 347 keV
- Semi-prompt gamma: 1809 keV ($\tau = 864$ ns)

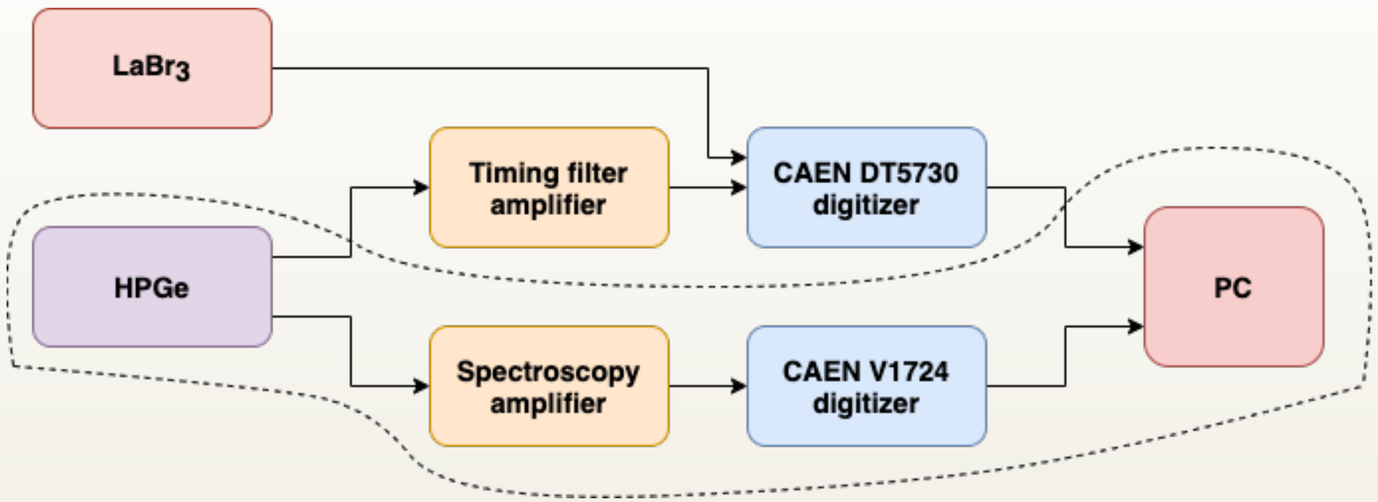


Experimental setup

- Done at PSI in 2015
- High purity germanium detector (HPGe) was used for photons measurement
- A $LaBr_3$ detector was tested
- 2 liquid scintillators used for neutron detection
- Muon momentum was tuned to stop in middle of targets



Experimental setup



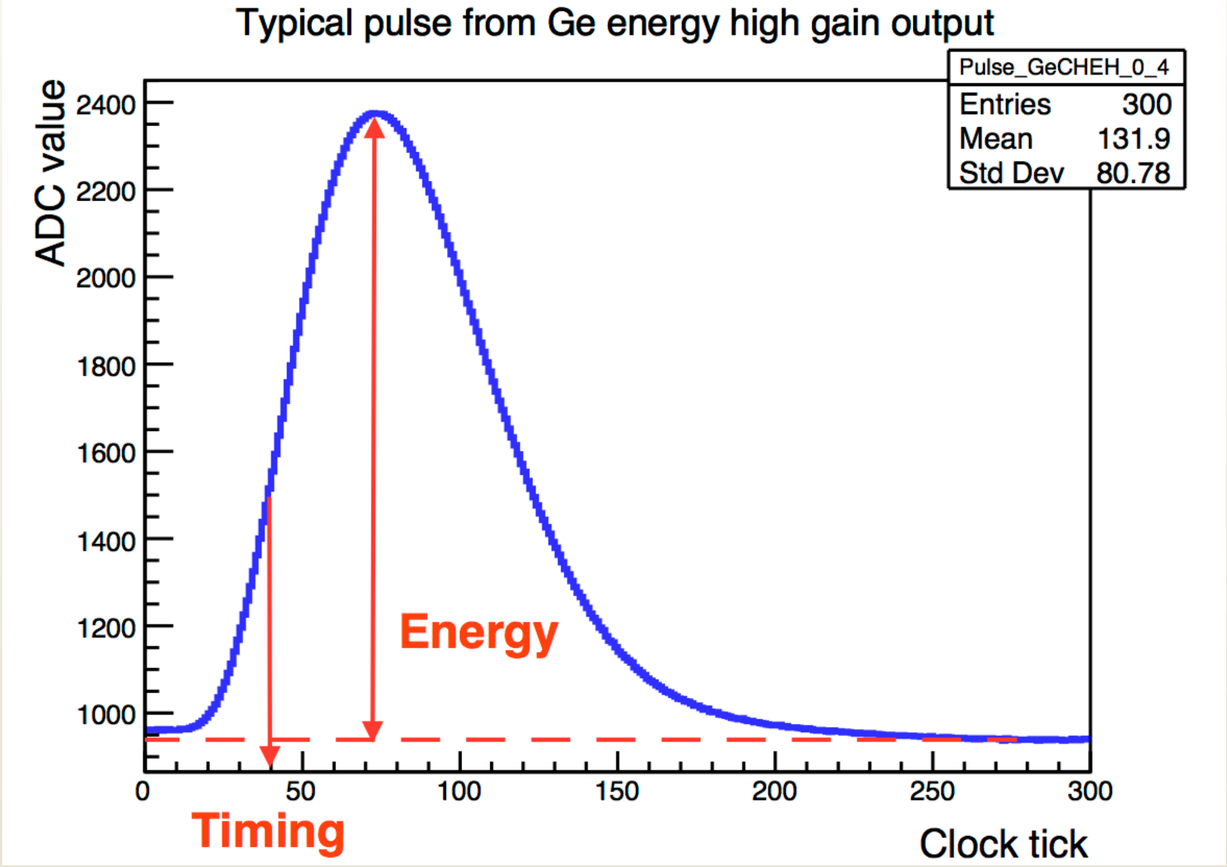
- Readout by digitizers
  - DT5730: 500 MHz, 14-bit
  - V1724: 100 MHz, 14-bit
- Only used spectroscopy amplifier output from HPGe

TABLE I. Targets for AlCap 2015 run

Target	Thickness [mm]	Muon momentum [MeV/c]	Number of muons	Comment
Al	2	33, 36	3.04×10^8	Primary target for Mu2e and COMET
Ti	1.3	36	2.07×10^8	Secondary target for Mu2e and COMET
Pb	1.5	36	9.03×10^7	Shielding material
W	0.5	36	1.73×10^7	Wires holding Mu2e stopping target
Stainless steel	0.9	36	2.51×10^7	Various structural components
Mylar	3	36	2.95×10^7	Various structural components
Polyethylene	5	36	2.77×10^7	Various structural components

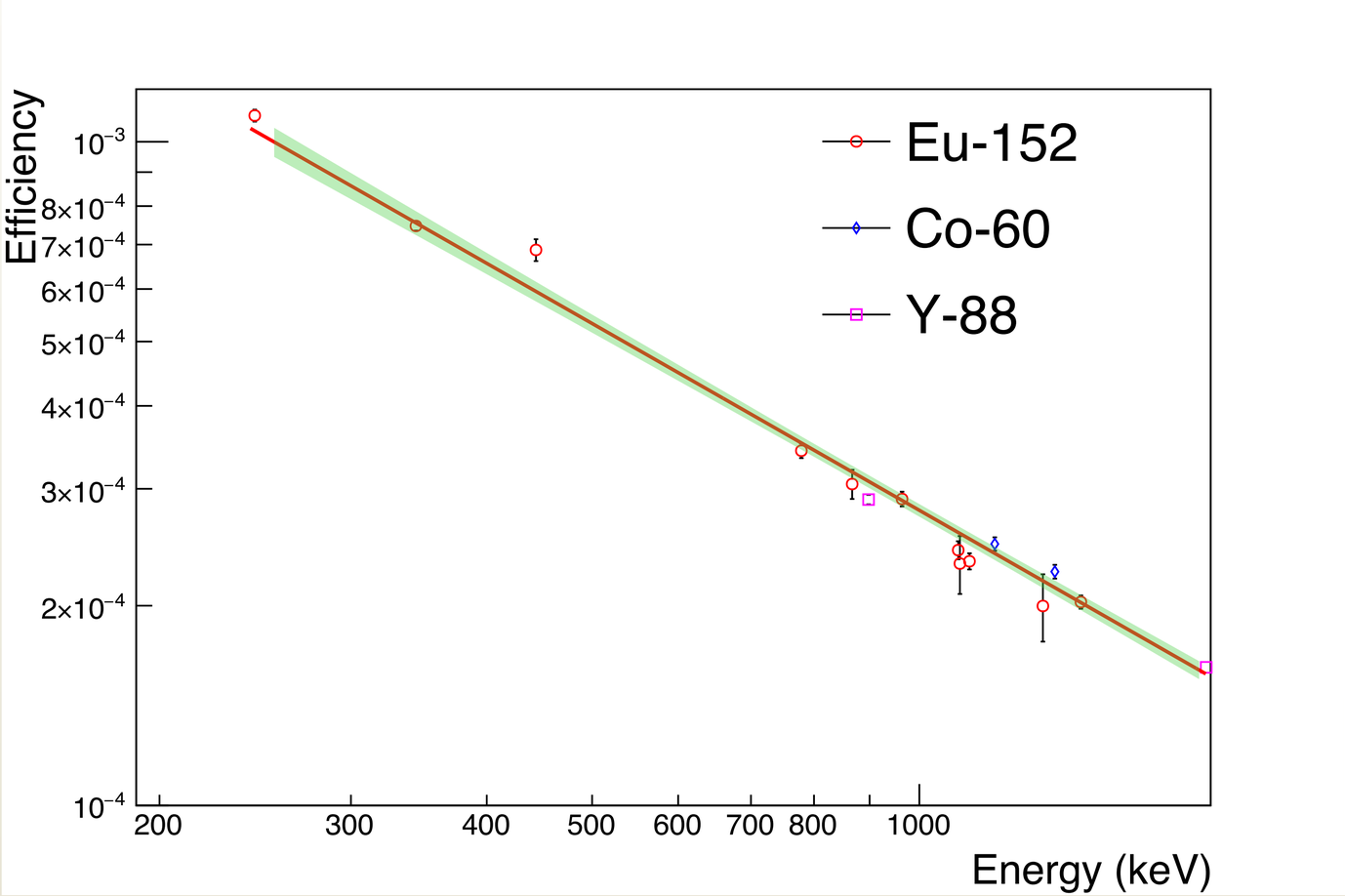
Analysis - Digital pulse processing

- HPGe pulse processing:
  - Energy is proportional to amplitude of the pulse
  - Timing is the clock tick where the traces pass 30% of the amplitude (230 ns resolution)



Analysis - Calibrations

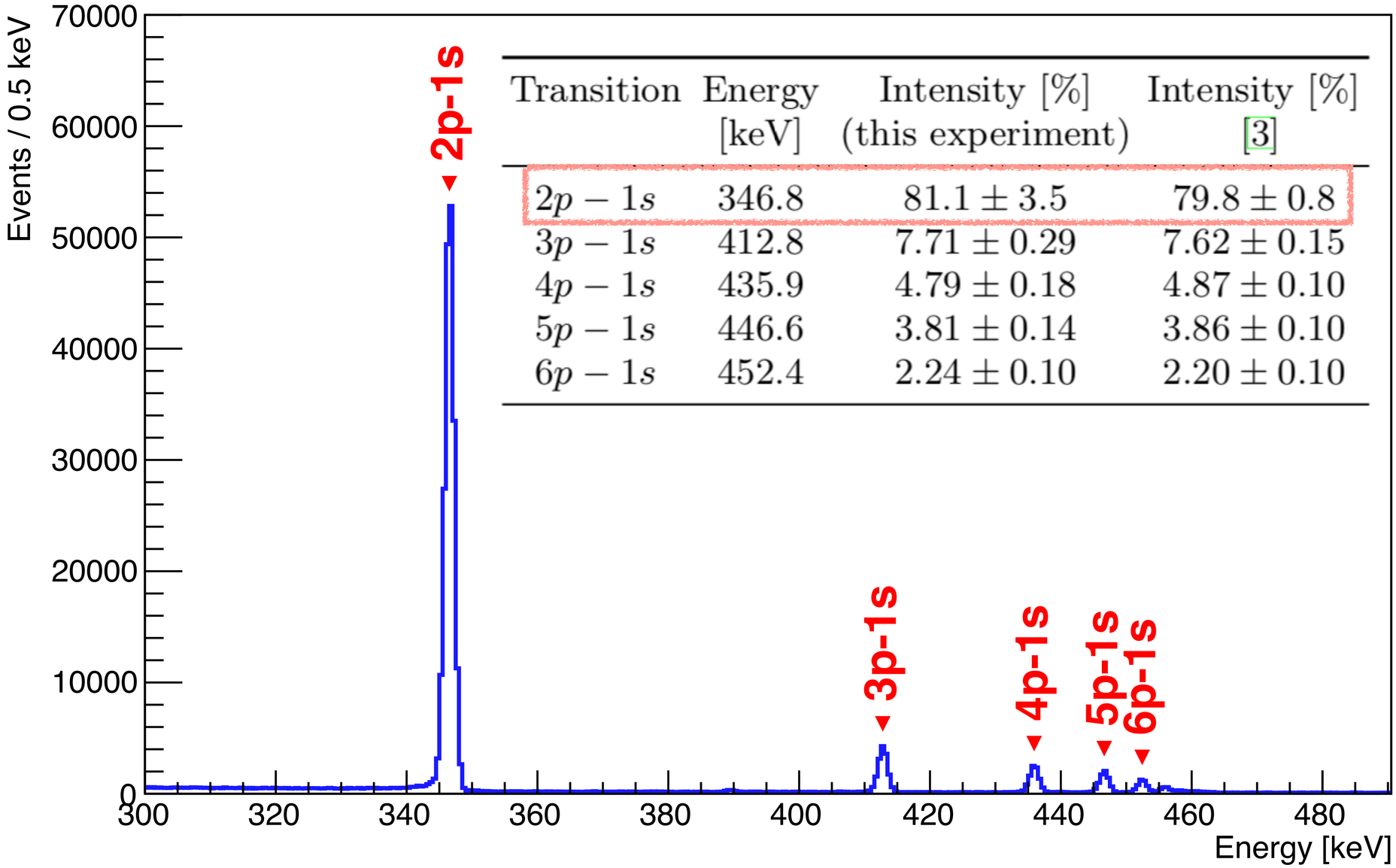
- Calibrated with sources ^{152}Eu, ^{60}Co, and ^{88}Y
  - Acceptance: $A(E) = c_1 \times E^{c_2}$



Analysis - Muon event

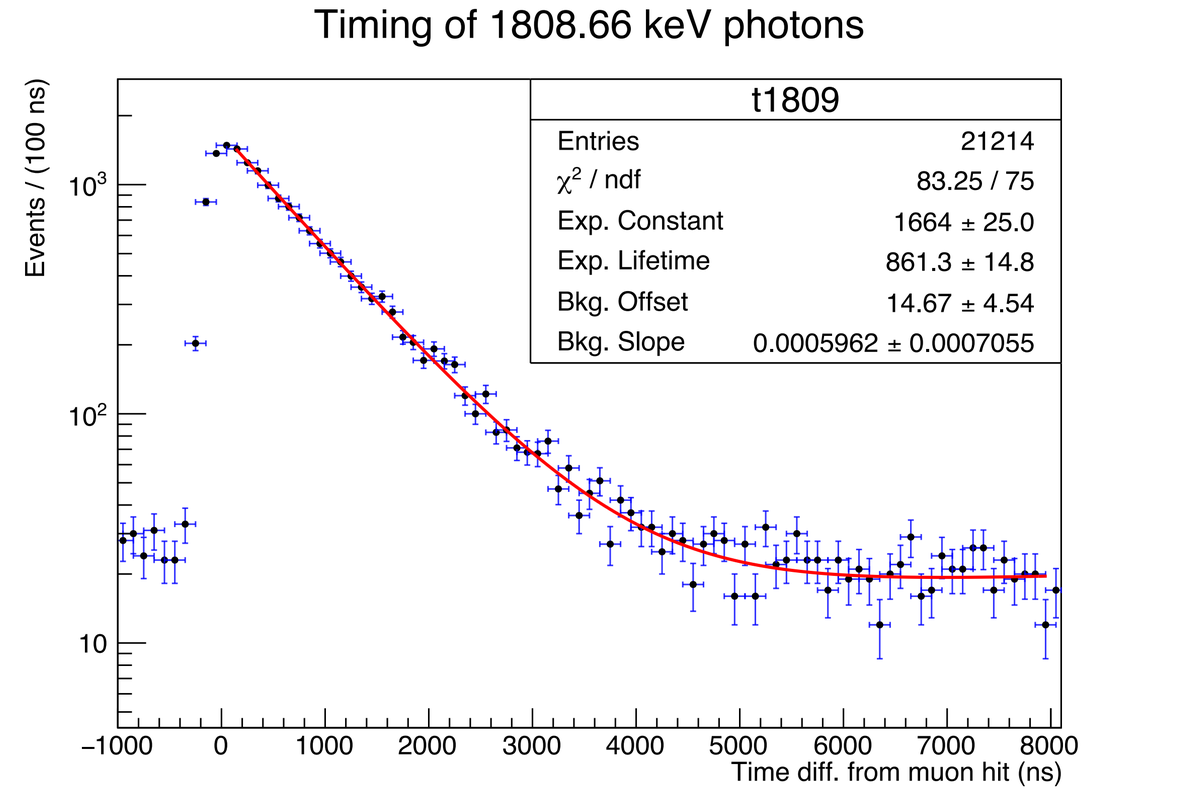
- Digitized pulses are organized into muon events:
  - A hit on the muon counter
    - if there is another hit on muon counter within +/- 5 μs, reject both
  - All hits on HPGe detector within 10 μs around the hit on muon counter
- Timing cuts
  - Muonic X-ray: +/- 300 ns around a muon counter hit
  - Delayed gamma: -300 - 5000 ns around a muon counter hit

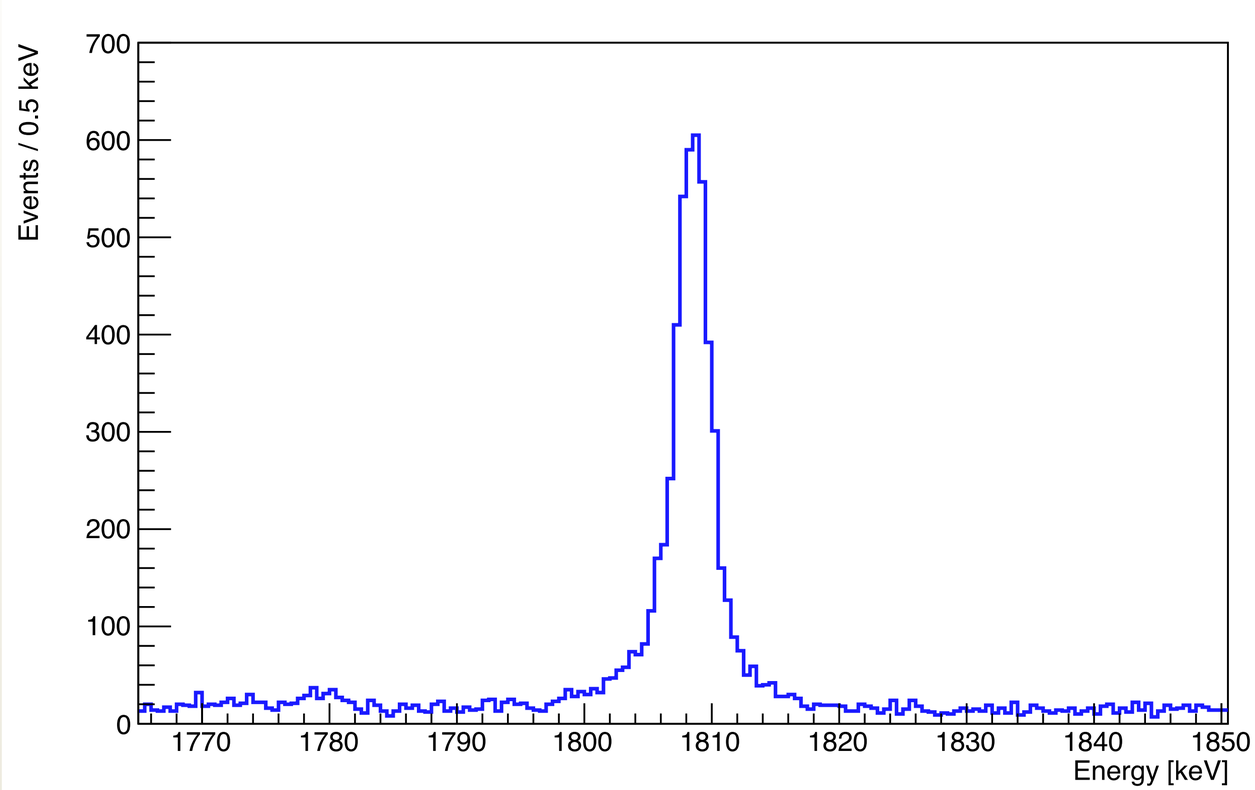
Results - Muonic X-rays from aluminum



Transition	Energy [keV]	Intensity [%] (this experiment)	Intensity [%] [3]
$2p-1s$	346.8	81.1 ± 3.5	79.8 ± 0.8
$3p-1s$	412.8	7.71 ± 0.29	7.62 ± 0.15
$4p-1s$	435.9	4.79 ± 0.18	4.87 ± 0.10
$5p-1s$	446.6	3.81 ± 0.14	3.86 ± 0.10
$6p-1s$	452.4	2.24 ± 0.10	2.20 ± 0.10

Results - 1809 keV gamma from aluminum

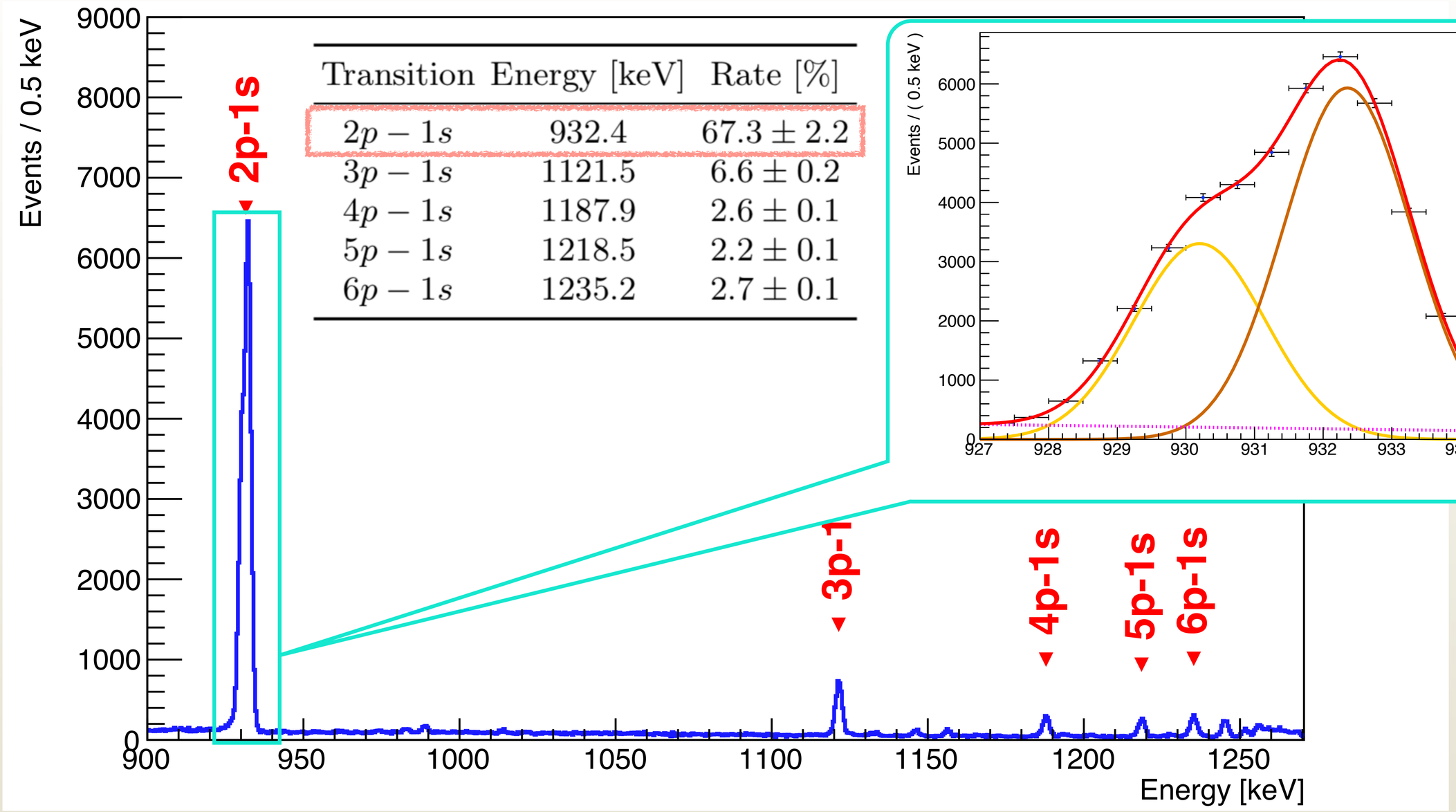




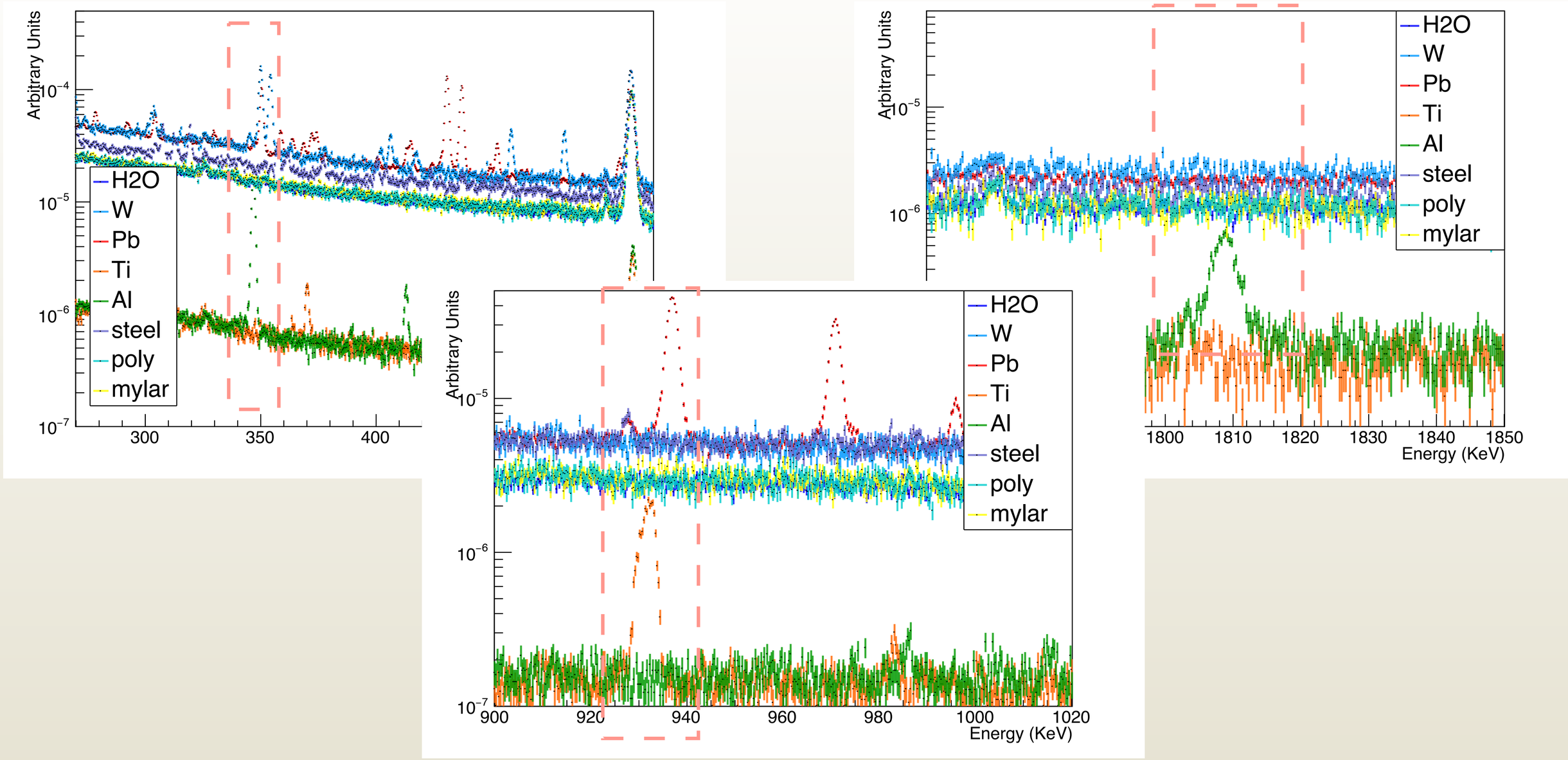
- Lifetime of muons in aluminum: 864(4) ns
- Emission rate: $53.8 \pm 2.6\,\%$ per muon capture
  - Consistent with previous value at $51 \pm 5\,\%$

Results - Muonic X-rays from titanium

Transition	Energy [keV]	Rate [%]
$2p-1s$	932.4	67.3 ± 2.2
$3p-1s$	1121.5	6.6 ± 0.2
$4p-1s$	1187.9	2.6 ± 0.1
$5p-1s$	1218.5	2.2 ± 0.1
$6p-1s$	1235.2	2.7 ± 0.1



Results - Interferences



Summary

- AlCap measures charged and neutral particles from muon capture on aluminum & titanium
- Important photons
  - 347 keV X-rays (Al): $79.8 \pm 0.8\,\%$ (new result is consistent)
  - 1809 keV gammas (Al): $53.8 \pm 2.6\,\%$
  - 932 keV X-rays (Ti): $67.3 \pm 2.2\,\%$
- Interferences:
  - 347 keV X-rays (Al) has interferences from W and Pb
  - 932 keV X-rays (Ti) has interferences from Pb, and stainless steel
  - 1809 keV gammas (Al) is clean