S459+: Mass measurements of As, Se, and Br nuclei, and their implication on the proton-neutron interaction strength toward the N = Z line

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Super-FRS Experiment Collaboration Meeting

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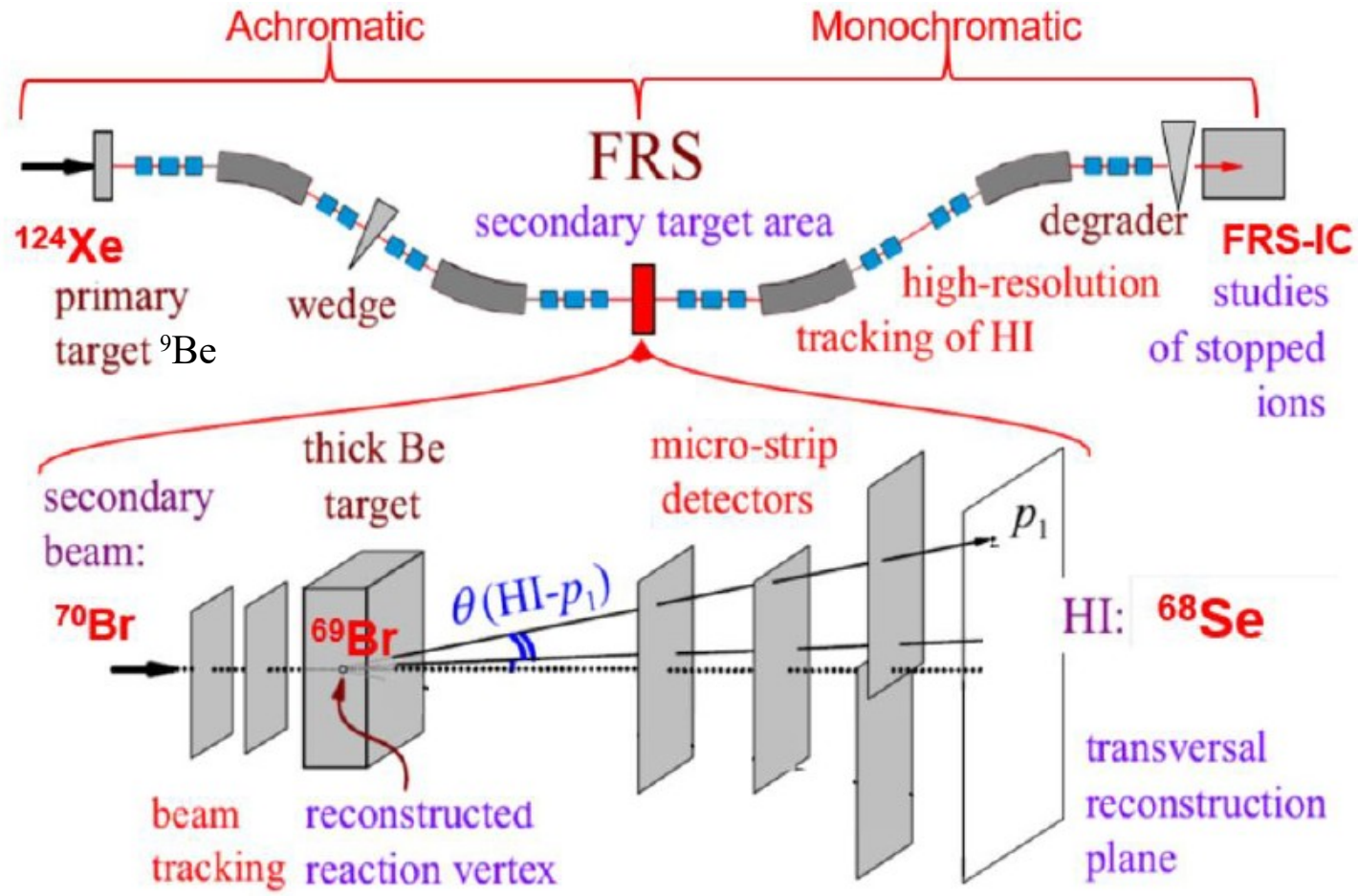
S459+: One beam, Two experiments

- Experiment **S472** of the FRS Ion Catcher Group and experiments **S459** and **S443** of the EXPERT group ran **jointly** in March 2020 (coined **S459+**)

- The two groups used **simultaneously the same primary beam** (^{124}Xe), impinging on ^{9}Be, to measure properties of exotic isotopes at and beyond the proton dripline

- The **FRS Ion Catcher** setup is at the final focus plane of the FRS (**S4**) whereas the **EXPERT** detectors are at its mid-focus (**S2**)



EXPERT

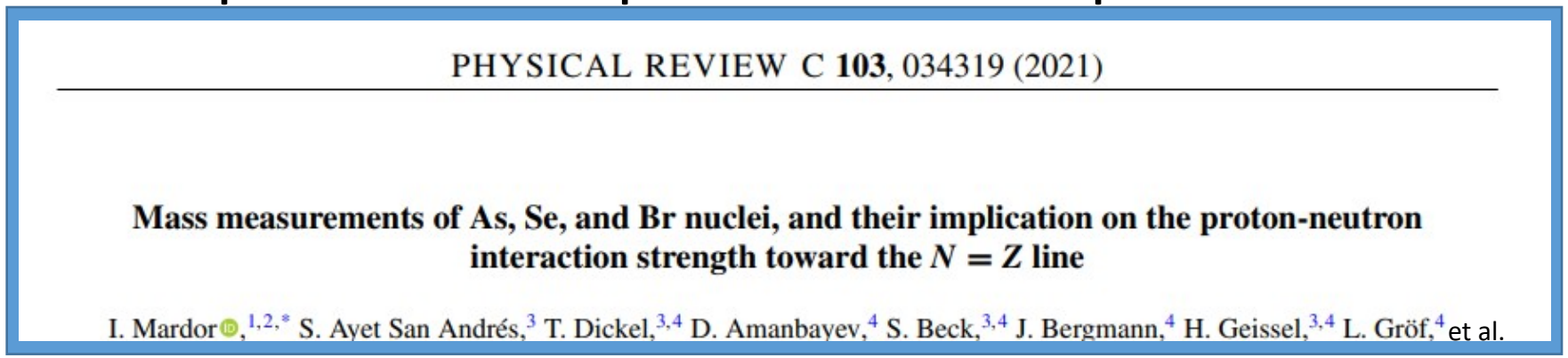
Summary

- Reached a **mass resolving power** of almost **1,000,000** with an MR-TOF MS 
  - **Mass uncertainty** of **1.7×10^{-8}** for a **stable** molecule (≈9,000 events) 
  - **Mass uncertainty** of **4.0×10^{-8}** for an **unstable** nuclide (≈500 events) 
- First direct mass measurement of ^{69}As, resolving discrepancies in indirect ones
- Our results indicate a rise with mass of δV_{pn} of odd-odd N=Z nuclei from Z = 29, which is unique to N=Z nuclei
- Overall trends of δV_{pn} at N≤Z suggest a resolution to the ^{70}Br mass discrepancy (towards 1980 end-point energy measurement, versus 2009 Penning Trap)
- **Analysis of FRS-IC part of S459+ is complete and all results are published***

*Mardor, Ayet, Dickel et al., Phys. Rev. C103, 034319 (2021)

FRS-IC part of S459+

- Physics motivation
  - Measure the masses of $^{70,\,70m}$Br, ^{70}Se and additional neighbors
    Resolve a ~500 keV discrepancy in ^{70}Br mass, Crucial impact on *Ft* (CKM matrix, CVC hypothesis)
- Technical motivation
  - Validate mass tagging with the FRS IC, to confirm the PID of the FRS and EXPERT
  - Test and validate range bunching at S4 with the new degrader system
- Outcome
  - A problem in the RF-carpet left us with **only 3 effective shifts**
  - Nevertheless, technical goals were achieved, and 4 masses near ^{70}Br were measured
  - **Analysis of FRS-IC part of S459+ is complete and all results are published**


PHYSICAL REVIEW C **103**, 034319 (2021)

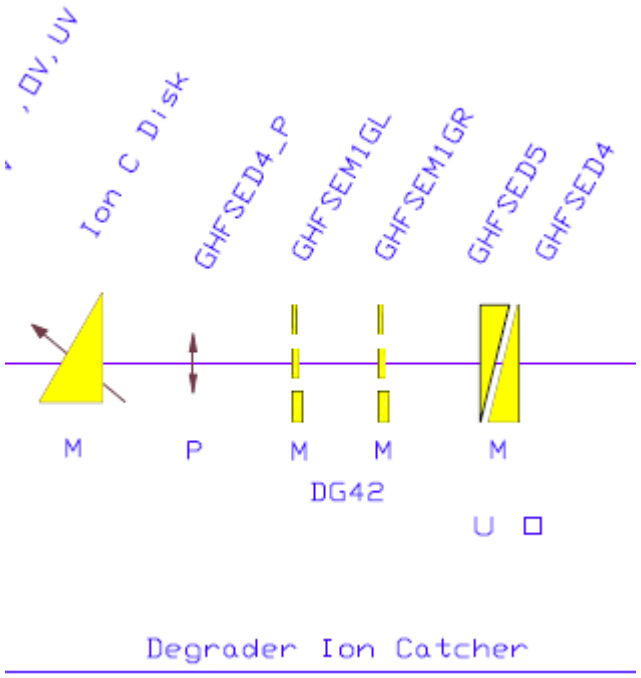
Mass measurements of As, Se, and Br nuclei, and their implication on the proton-neutron interaction strength toward the $N = Z$ line

I. Mardor,[1,2,*] S. Ayet San Andrés,[3] T. Dickel,[3,4] D. Amanbayev,[4] S. Beck,[3,4] J. Bergmann,[4] H. Geissel,[3,4] L. Gröf,[4] et al.

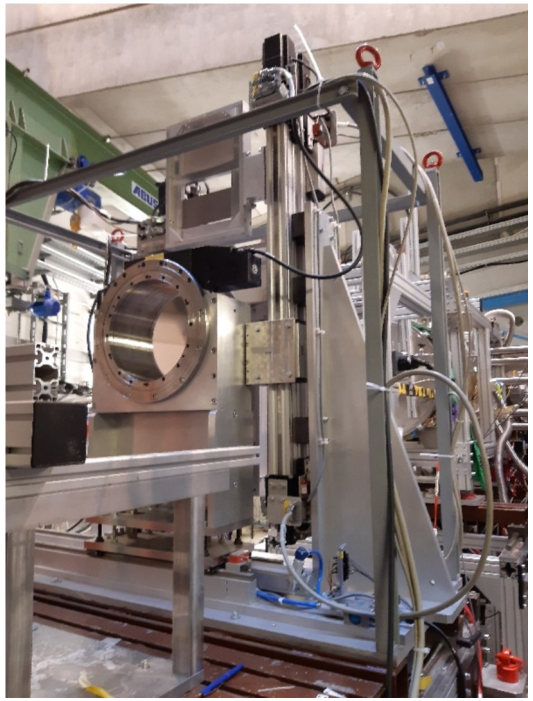
Technical Developments- Range Bunching at S4

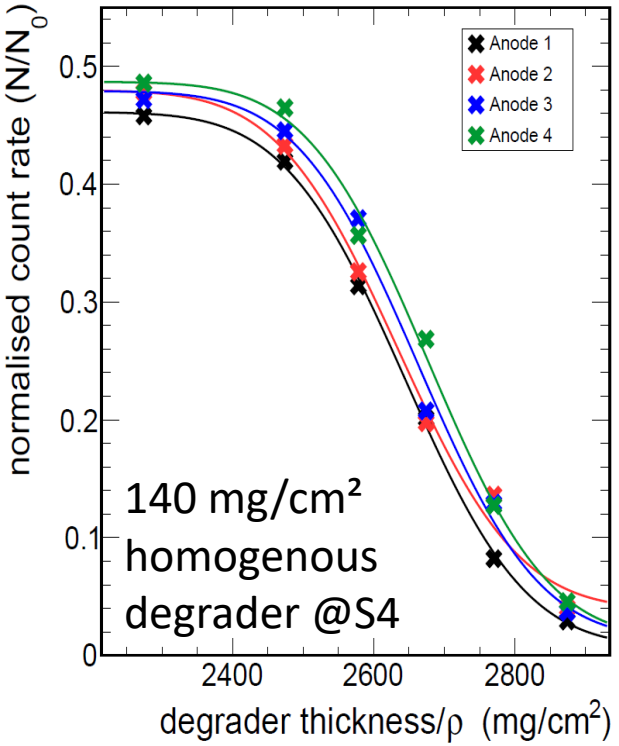
- Successful running of the Ion Catcher as an **active beam stopper**, ‘re-using’ part of the beam that went through EXPERT for additional technical and physics achievements
- First **range bunching at S4** with the new degrader system

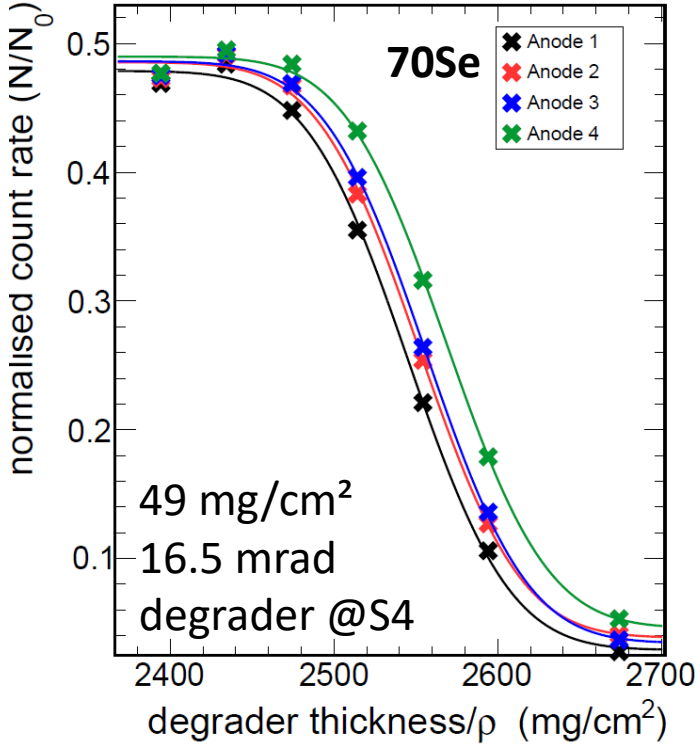
S4 degrader layout



S4 degrader ladder







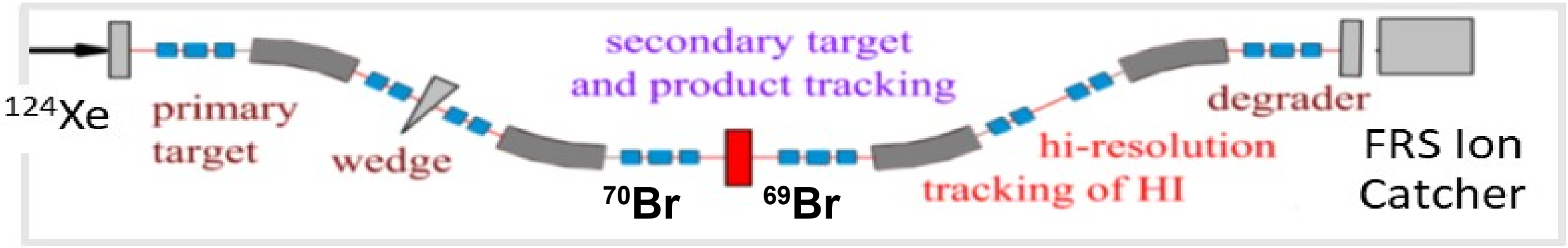
- **Mass tagging** at **A~70**, confirming particle ID system of the FRS and EXPERT
- Extension of Ion Catcher range down to **A~70 region** (Previous low was 94)

Lizzy Gröf, M.Sc. Thesis, JLU Giessen 2024

THE EXPERT TESTS

EXPERT tests, 8 shifts S443+S459 in March 2020

- Custom ion optics of FRS with a wedge at S1
- Joint run of EXPERT and FRS Ion Catcher, S475+

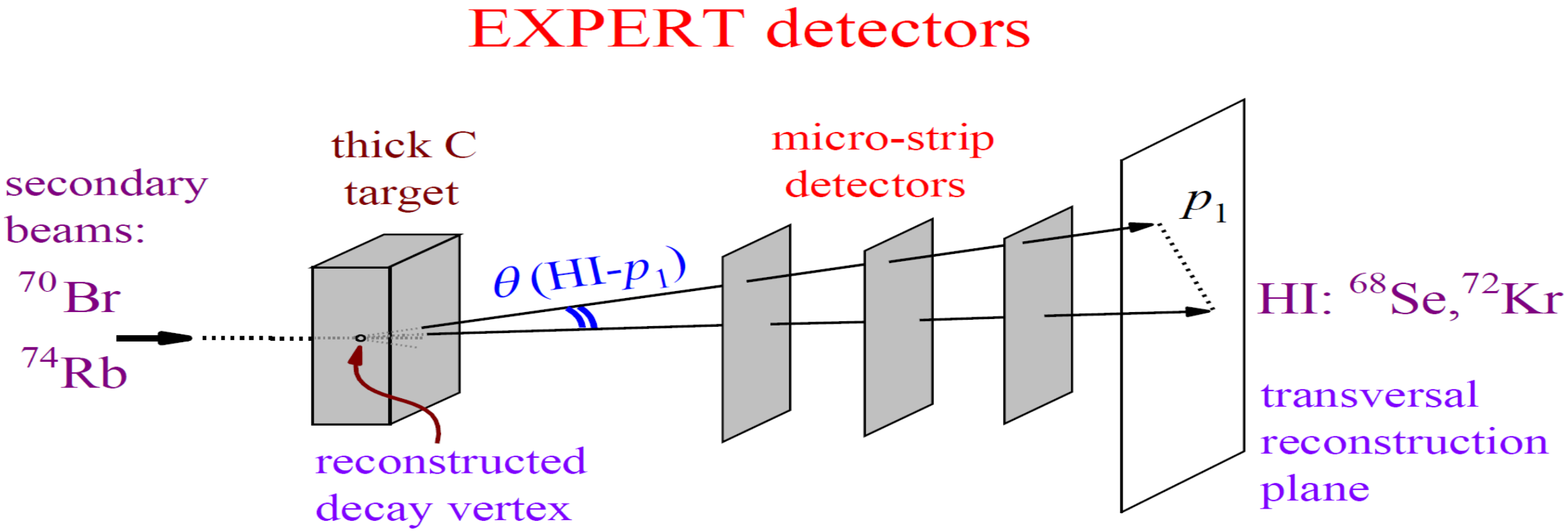


Secondary reactions $^{70}Br \rightarrow {}^{69}Br \rightarrow {}^{68}Se+p$

$^{74}Rb \rightarrow {}^{73}Br \rightarrow {}^{72}Kr+p$

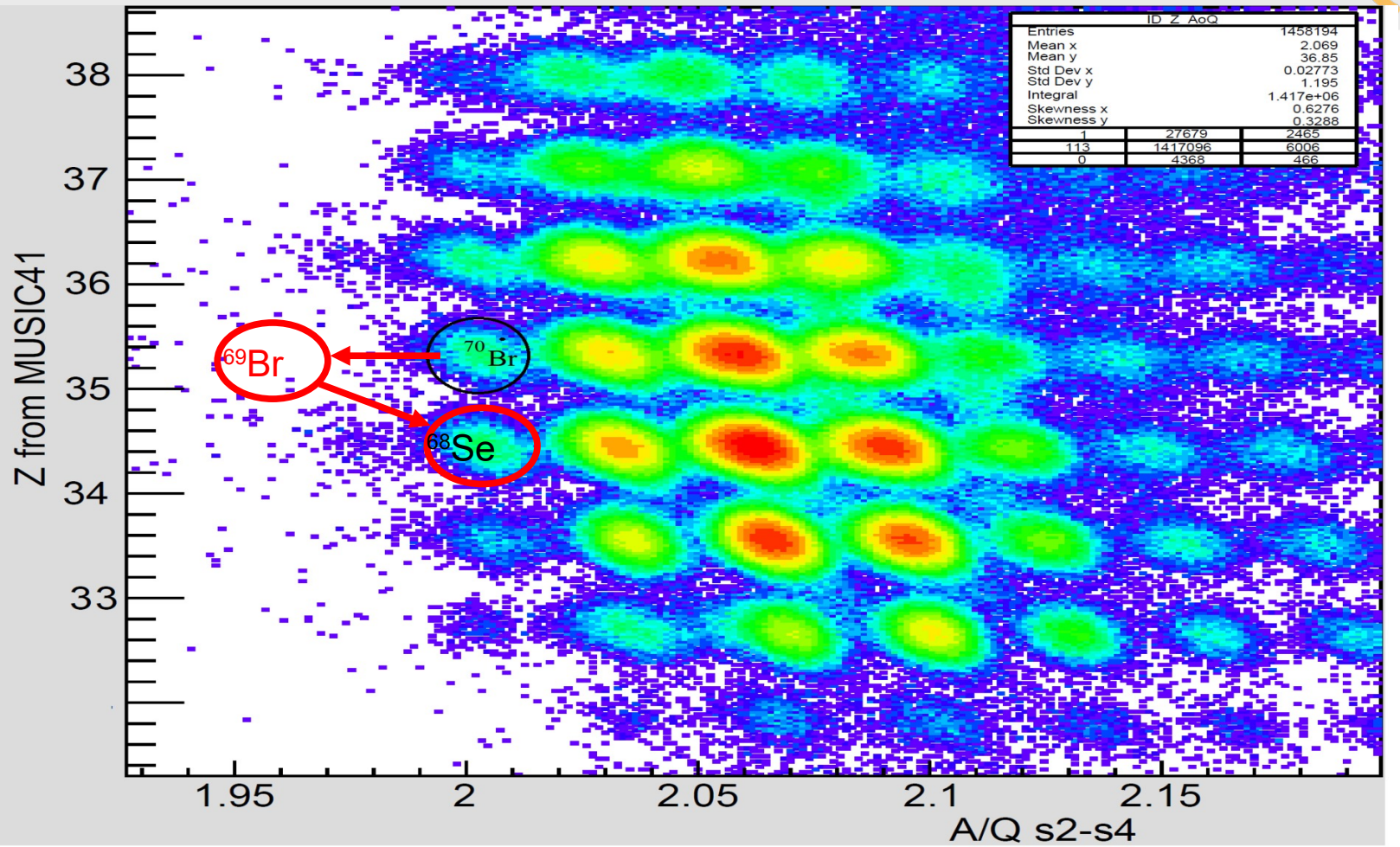
Layout of the FRS with the EXPERT and Ion Catcher

EXPERT layout at S2



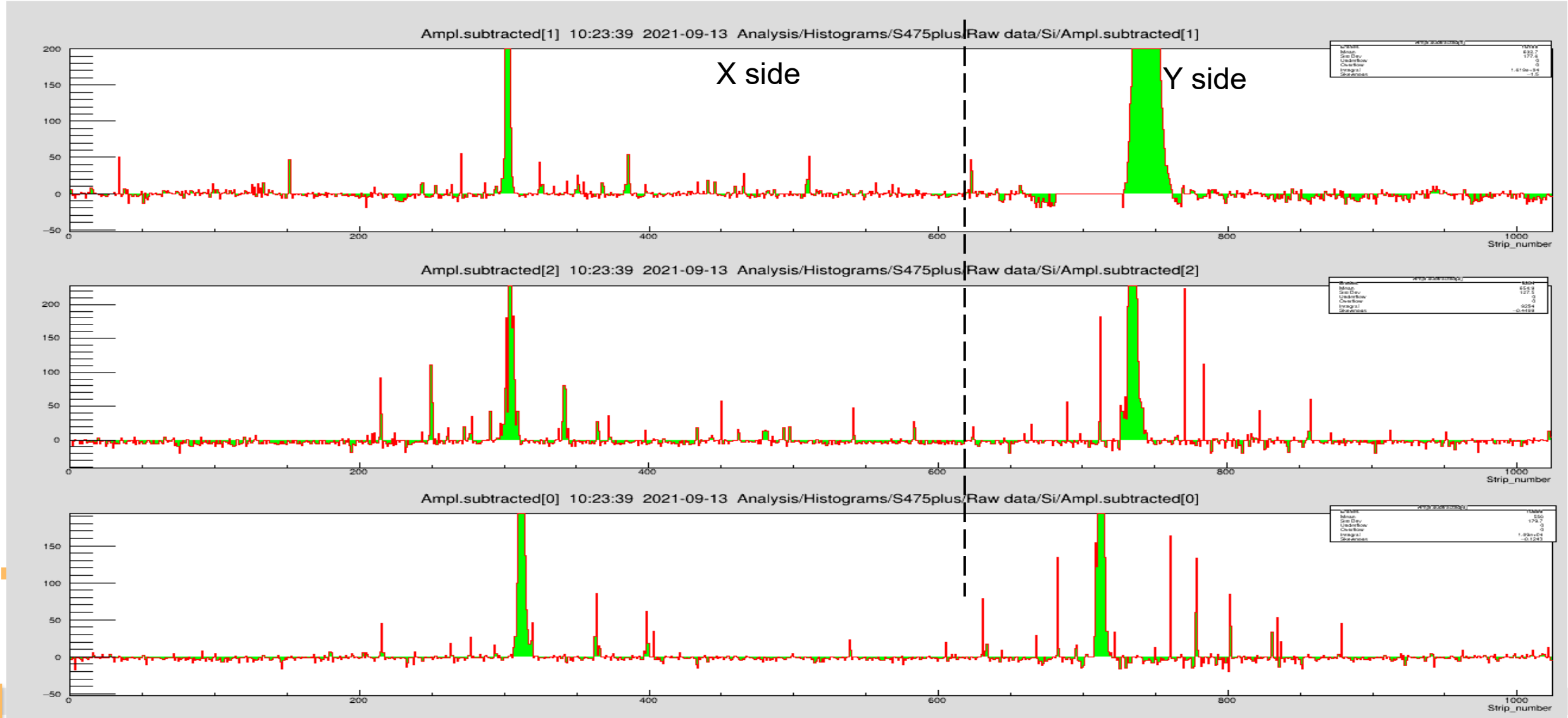
- Tests of new microstrip tracking detectors produced in Perugia University

Accumulated data in S443+S459

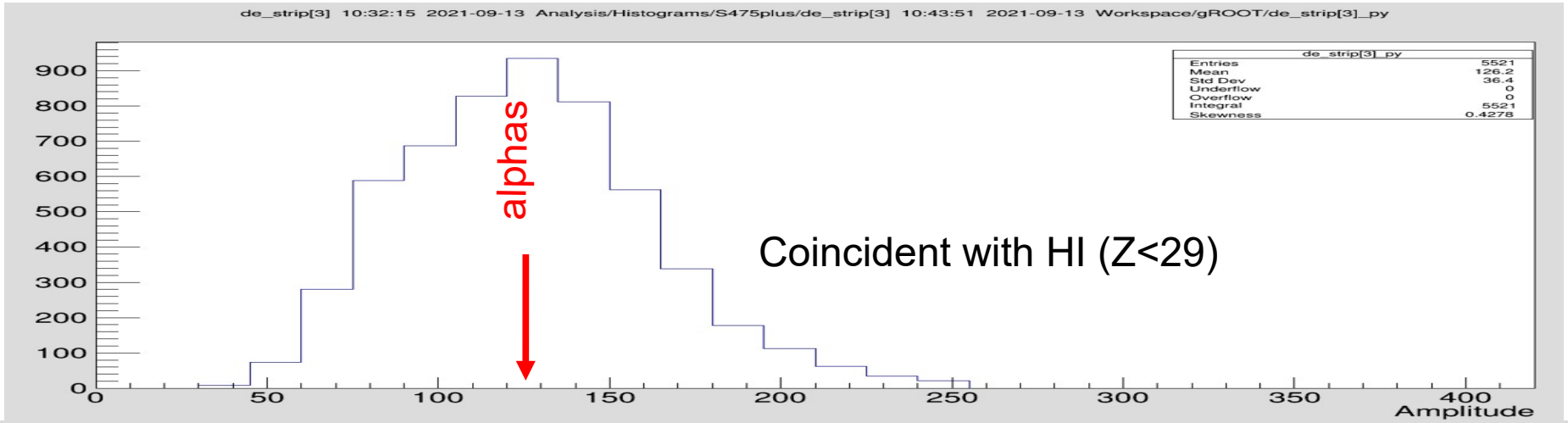


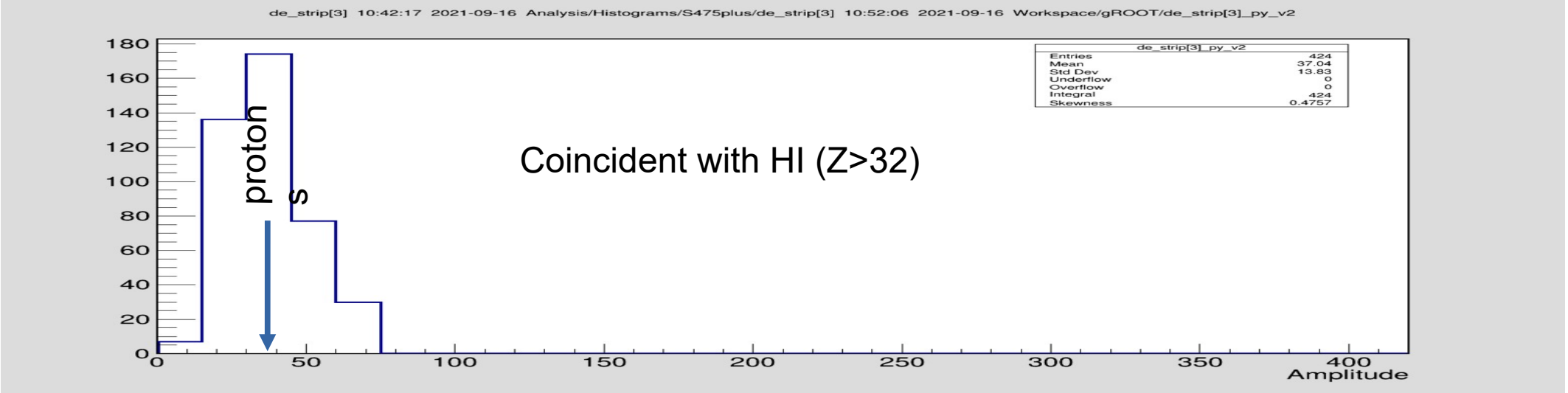
- ~10^6 ions of ^{70}Br and ^{74}Rb impinged secondary target at S2
- reaction fragments were tracked and identified at S2-S4

Raw data S443+S459

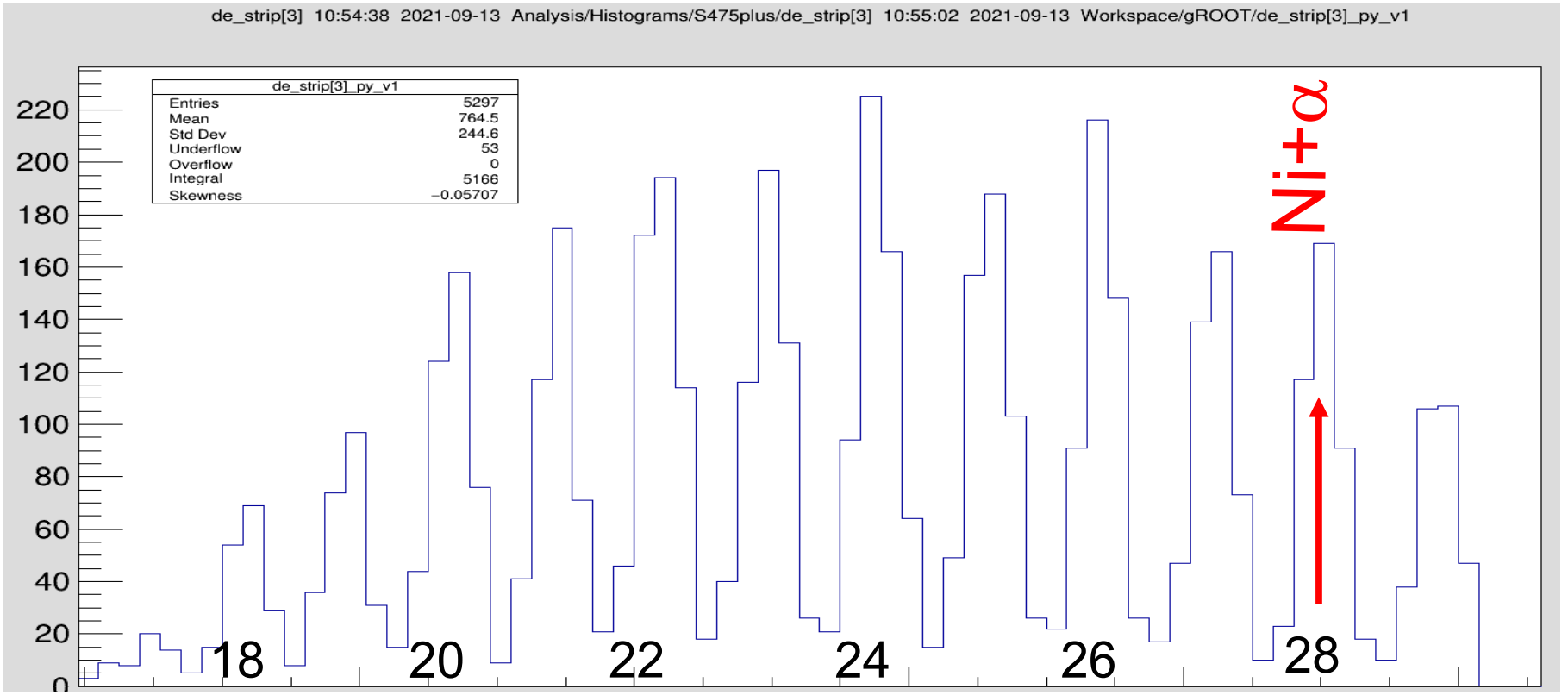


Energy loss of H and He in microstrip detectors



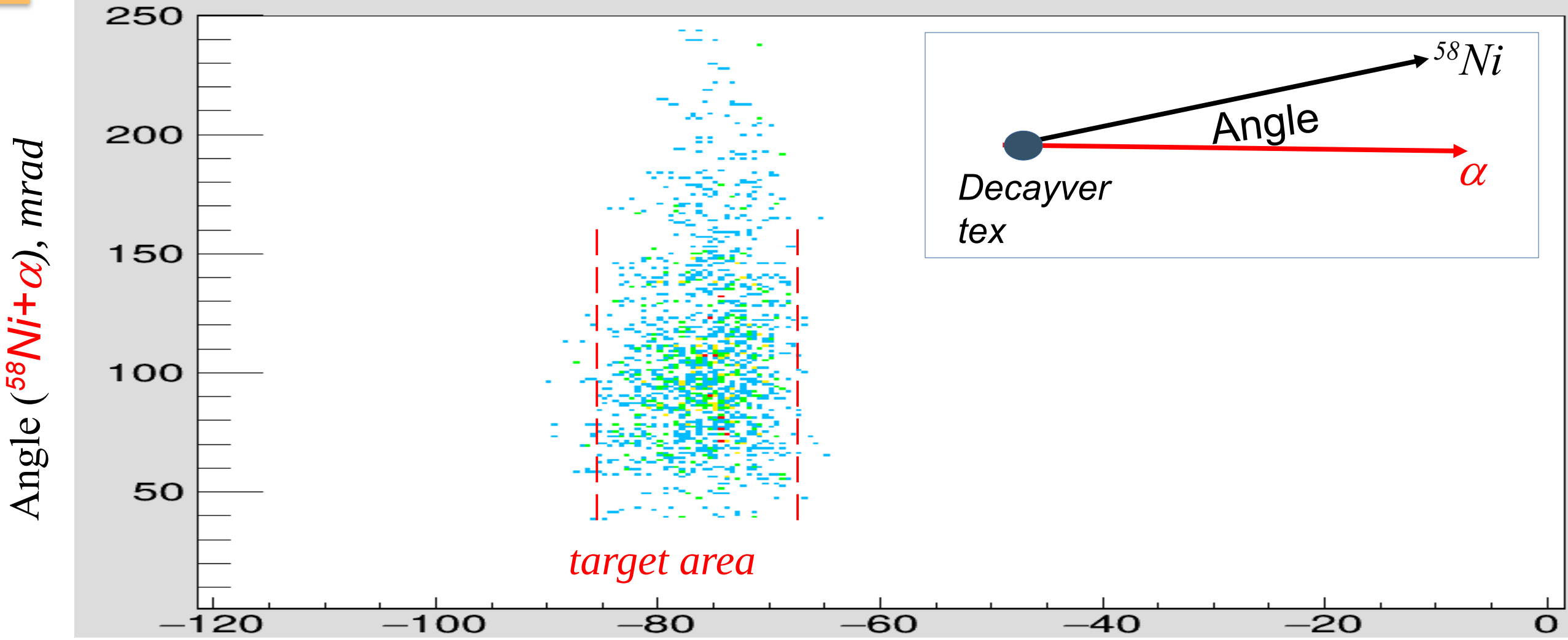


Energy loss in MUSIC gated by alphas

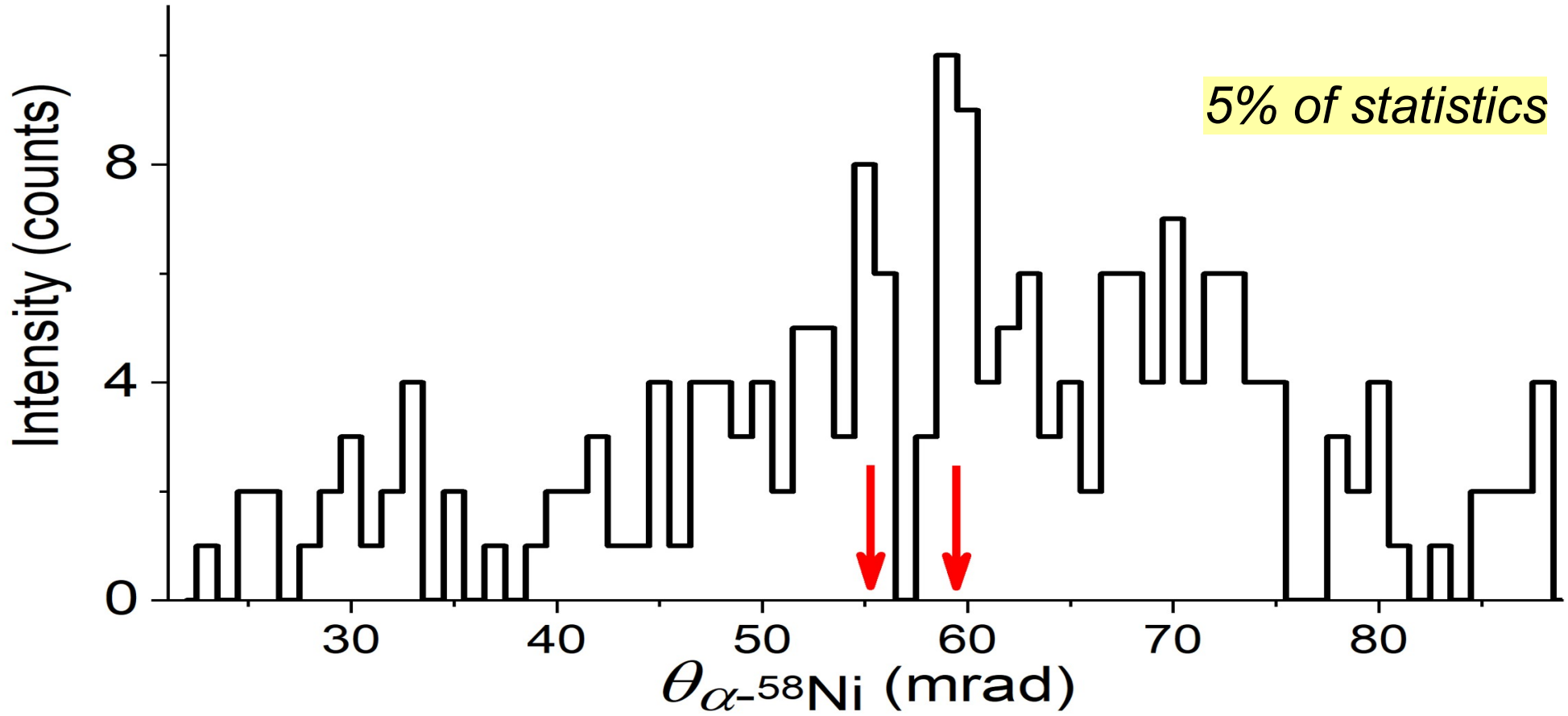


Calibration decays $^{58}Ni+\alpha$

measured by Si tracking detectors

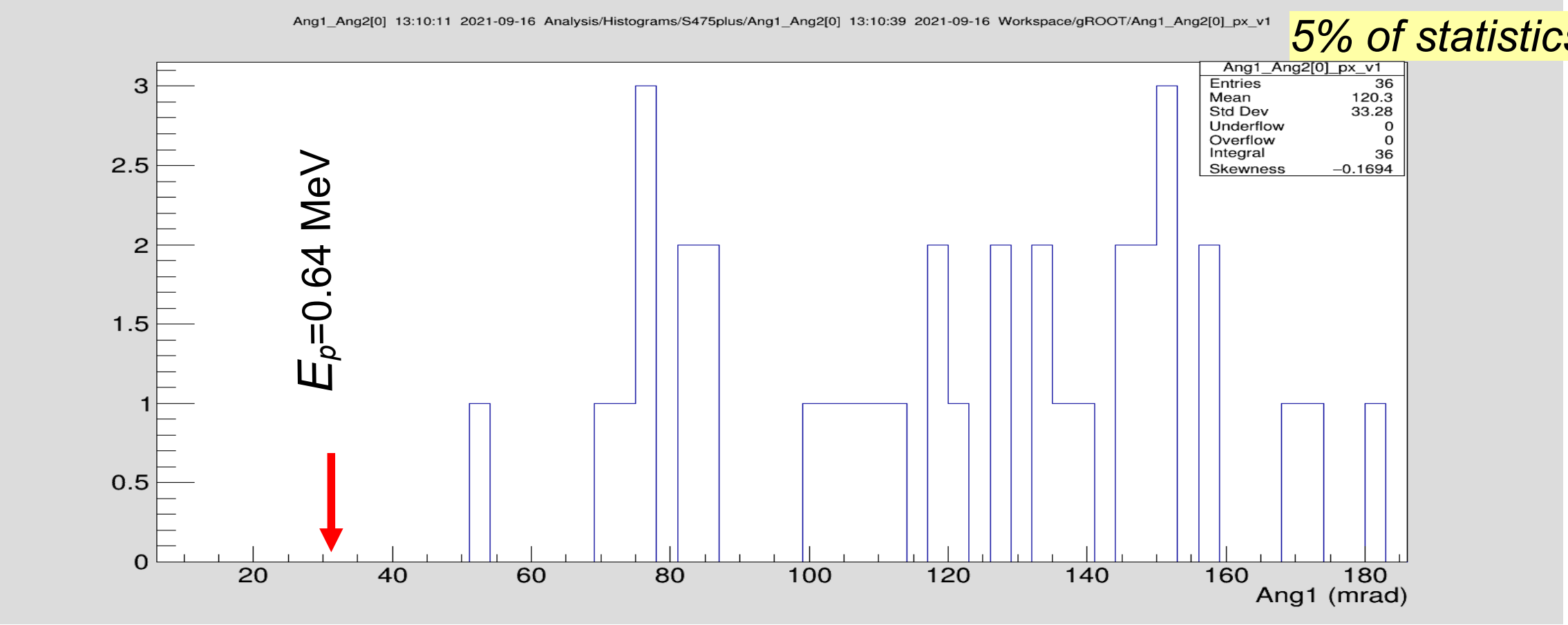


*Angular correlations ^{58}Ni-α from decays of ^{62}Zn**



Red arrows point to the known 10.3 and 13.4 MeV states in ^{62}Zn known from the ^{58}Ni(^{6}Li,d)^{62}Zn* and ^{64}Zn(p,t)^{62}Zn* reactions.

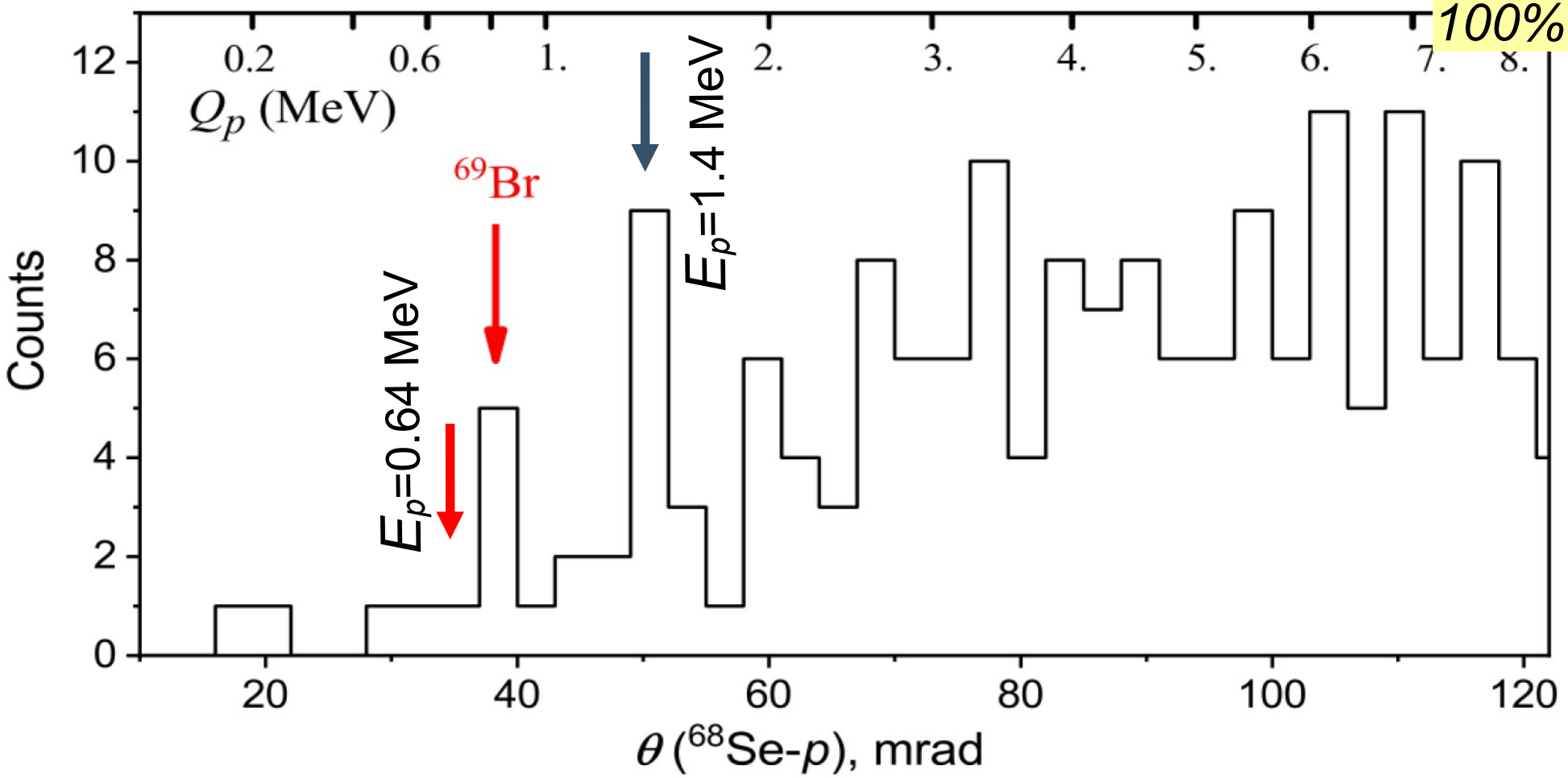
Angular correlations ^{68}Se-p from decays of ^{69}Br



Red arrow points to the expected ground state of ^{69}Br

Angular correlations ^{68}Se-p from decays of ^{69}Br

100% of statistics



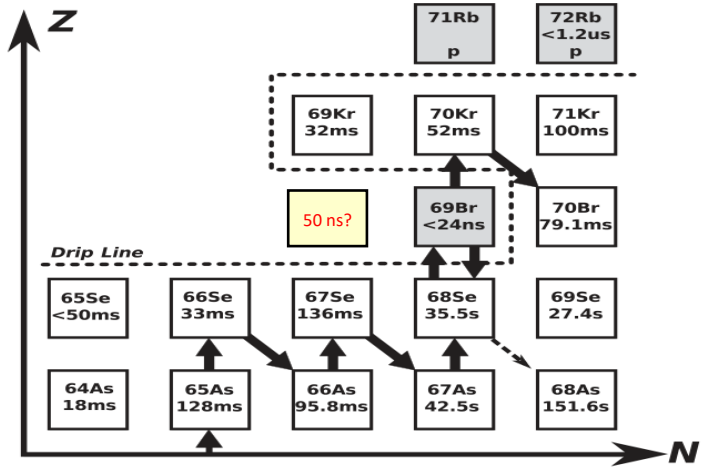
Red arrows point to the expected ground state and observed first excited state of ^{69}Br at 0.8 MeV

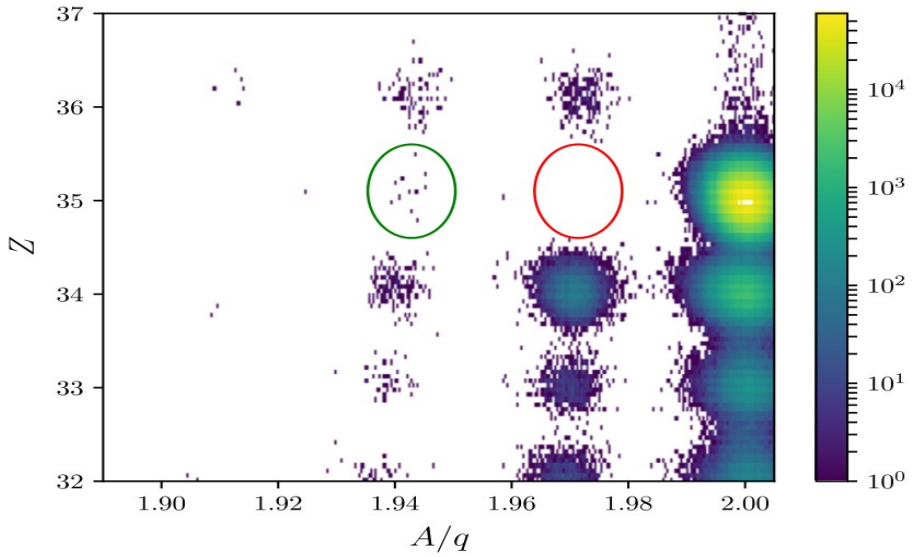
Experiment G22-0115: Study of a nuclear sandbank at the proton unbound bromine isotopes

M. Pfützner, D. Kostylewa, and the Super-FRS EC

Most p-rich bromine isotopes:

- ^{69}Br as a bypass of the rp-waiting point at ^{68}Se
  - decay energy controversy
  - half-life unknown
- ^{68}Br found to live longer than ^{69}Br! Similarly, ^{72}Rb lives longer than ^{73}Rb → **nuclear sandbank?!**
- 9^+ isomer in ^{70}Br for reaction studies





Wimmer et al., PLB 795 (2019)

We propose to study ^{68,69}Br at the FRS using in-flight decay spectroscopy at S2 and isomer spectroscopy at S4

production: **^{78}Kr** @ 900 MeV/u + Be → **^{70}Br**

- verify isomeric ratio for 9^+ in **^{70}Br**
- -1n → **^{69}Br**: p-resonances (p+^{68}Se) and $T_{1/2}$
- -2n → **^{68}Br**: measure $T_{1/2}$ by TOF (S2-S3-S4), and excited states (p+^{67}Se)

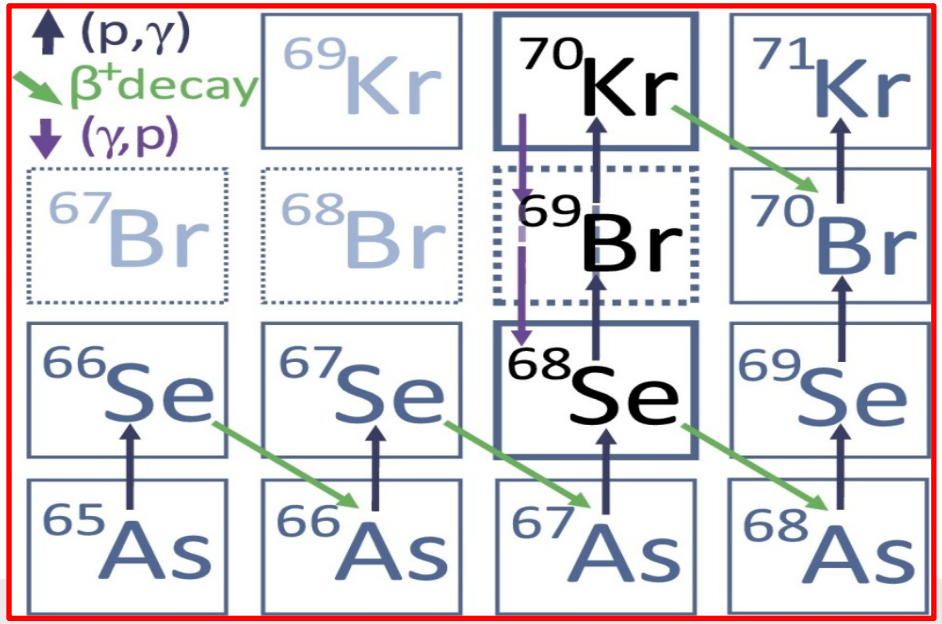
Beamtime : granted 12 shifts

Current status of data analysis S443+S459

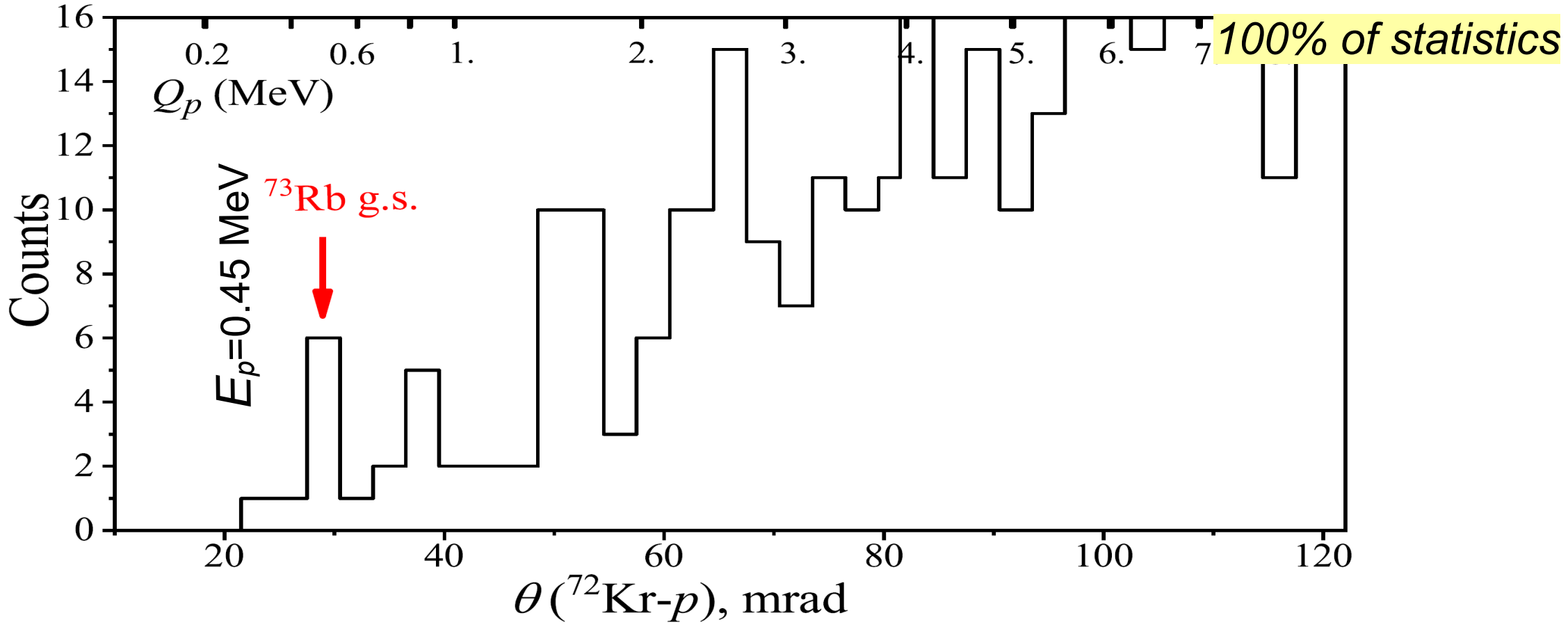
- Decay energies and life-times of ^{69}B and ^{73}Rb isotopes are aimed
- Calibrations of tracking are done by known alpha decays of ^{62}Zn
- Expected of ~700 and ~350 1*p*-decays in-flight of states in ^{69}Br* and ^{73}Rb*, respectively

To do: unpack 95% data and sort for ^{68}Se+*p*, ^{72}Kr+*p decays*

Part of scenario of synthesis of elements in Universe, *i.e.* the *rp*-process around the waiting point ^{68}Se



Angular correlations ^{72}Kr-p from decays of ^{73}Rb



Red arrow points to the expected ground state of ^{73}Rb, which differs from 0.64 MeV reported by D.Hoff et.al., Phys. Rev. C 102, 045810 (2022)

Reflections on the S443+S459 run

- Production ratios of ^{69}B and ^{73}Rb were <1% of total RIB at S4.
  Their rates were of 5 ions/s.
  Custom ion optics TA-S2 ahromatic with a wedge at S1, and
  S2-S4 low-dispersion settings with a monohromatic wedge at S4.

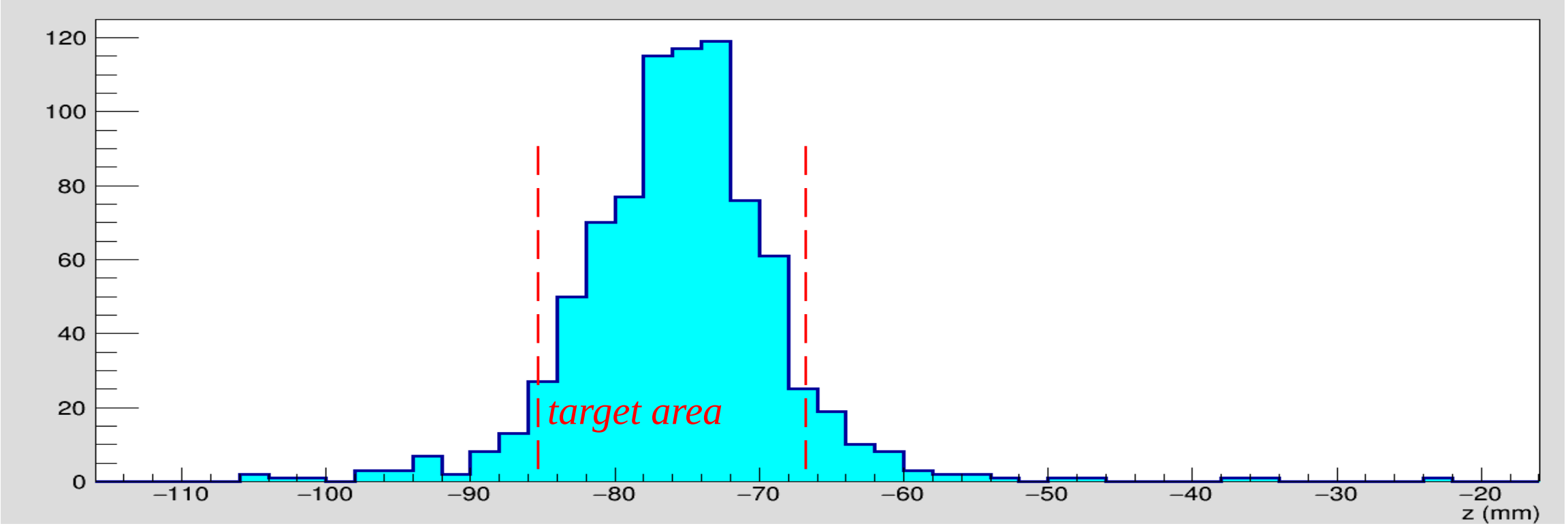
- Limitations of <800 event/s due to data transfer.
  Selective trigger and higher writing rates (local DAQ for microstrip detectors) will help.

- Short time of ~0.5 h for a change between the EXPERT and Ion Catcher measurements is needed.

Backup slides

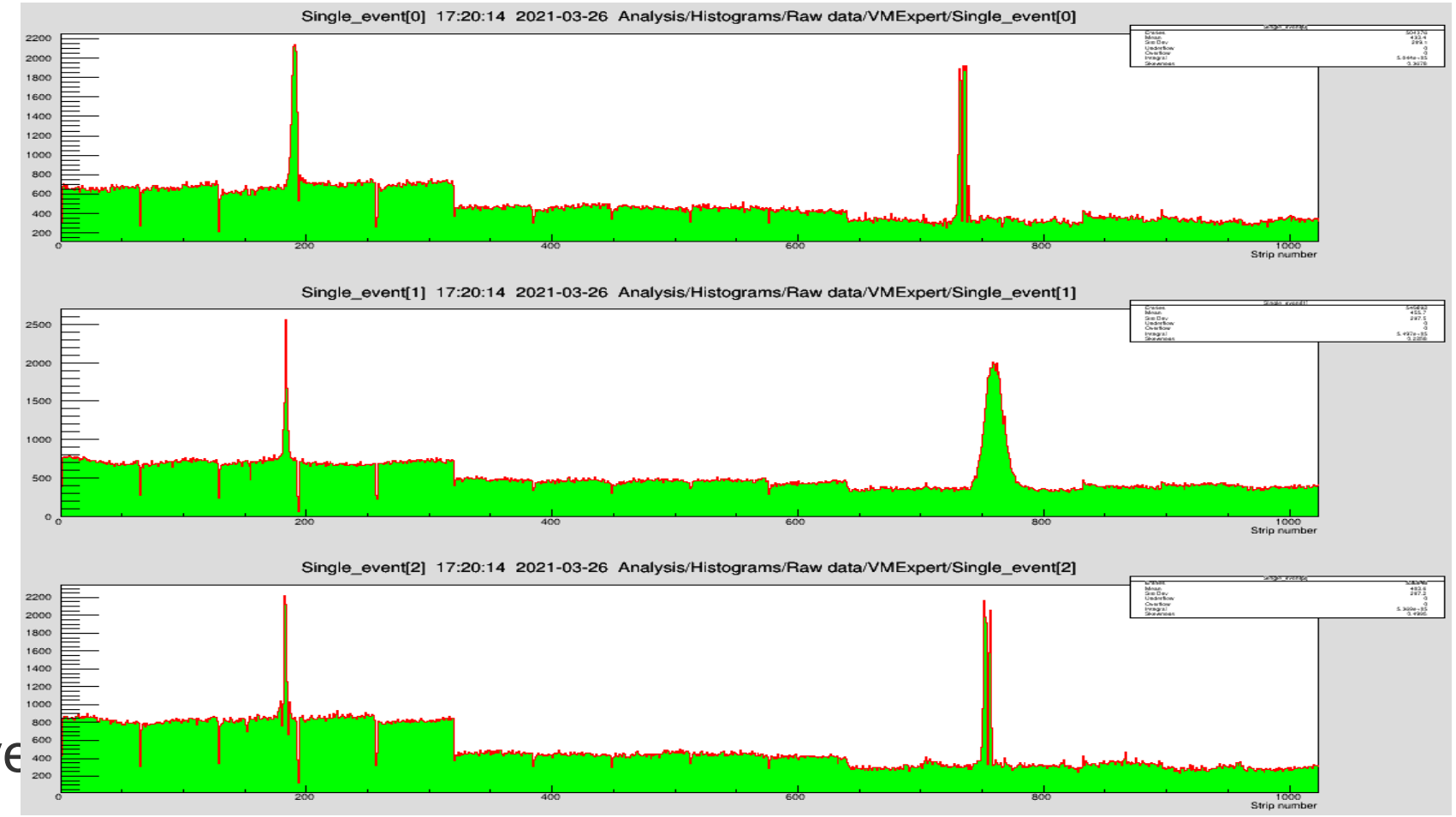
Calibration decays $^{62}Zn^* \rightarrow {}^{58}Ni + \alpha$

measured by Si tracking detectors



Vertex distribution of decay events along a beam direction Z

Raw data S443+S459



- Single eve

Expected extra output from the S443+S459 data

- The **isomer ^{70m}Br(9^{+})** was produced at RIKEN in fragmentation of ^{86}Kr (40% of ^{70}Br g.s.)

- Strong isomer mixture in fragmentation of ^{124}Xe is possible as well

- Reactions with beam of isomer **^{70m}Br(9+)** may be investigated,
- e.g., -1*n* channel populating an unknown excited state in ^{69}Br
- or inelastic scattering **^{70m}**Br(9+)$\rightarrow$^{69m}Se(9/2+)+*p*

- Structure of *N*=*Z* nuclei with *T*=0 *p*-*n* coupling, e.g. see
- ‚*Mirror-symmetry violation in bound nuclear ground states*‘
- by D.E.M. Hoff *et al.,* Nature 580 (2020)