Report on the AGATA experiment number 22.97: Probing nucleon–nucleon correlations in the ^{48}Ca + ^{208}Pb system below the Coulomb barrier

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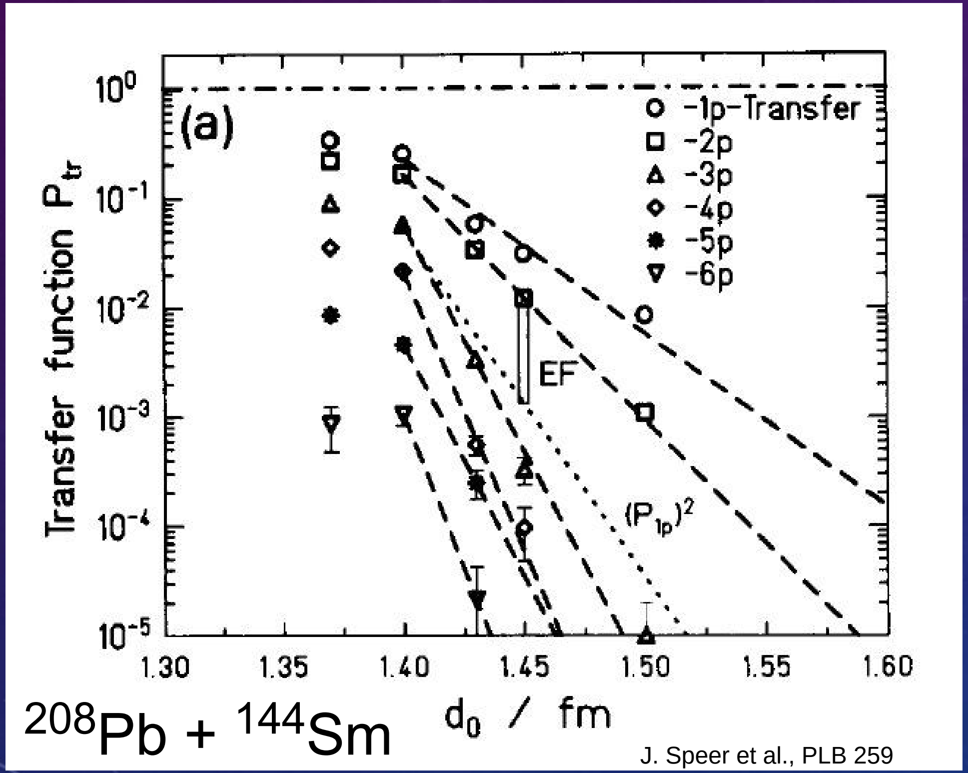
ACC meeting - AGATA Week 2026

MNT and pair transfers

Two-particle transfer processes are an ideal tool to study the dynamical aspects of pairing correlations
MNT: in selected cases simultaneous comparison of ±nn, ±pp and ±np pairs

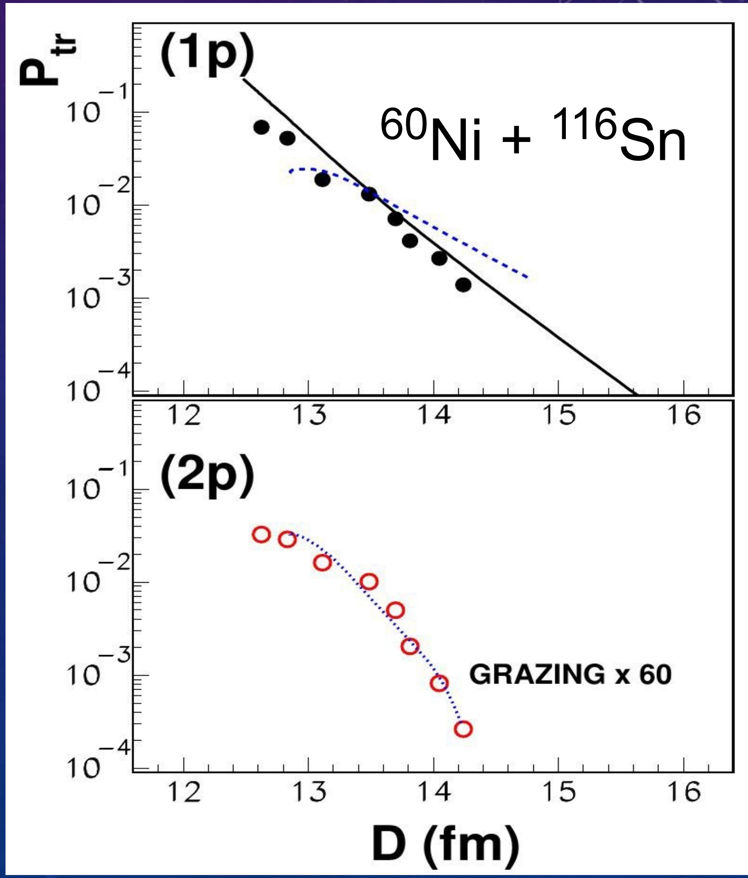
Enhancement Factor:
the ratio of the cross section to model predictions using uncorrelated states



J. Speer et al., PLB 259 (1991) 4

$$P_{tr} = \frac{d\sigma_{tr}}{d\sigma_{el}} \qquad D = \frac{Z_p Z_t e^2}{2E_{cm}}\left(1 + \frac{1}{sin(\theta_{cm}/2)}\right)$$

GRAZING calculation (independent nucleon transfer) is underpredicting experimental results for -2p channel by a factor 60



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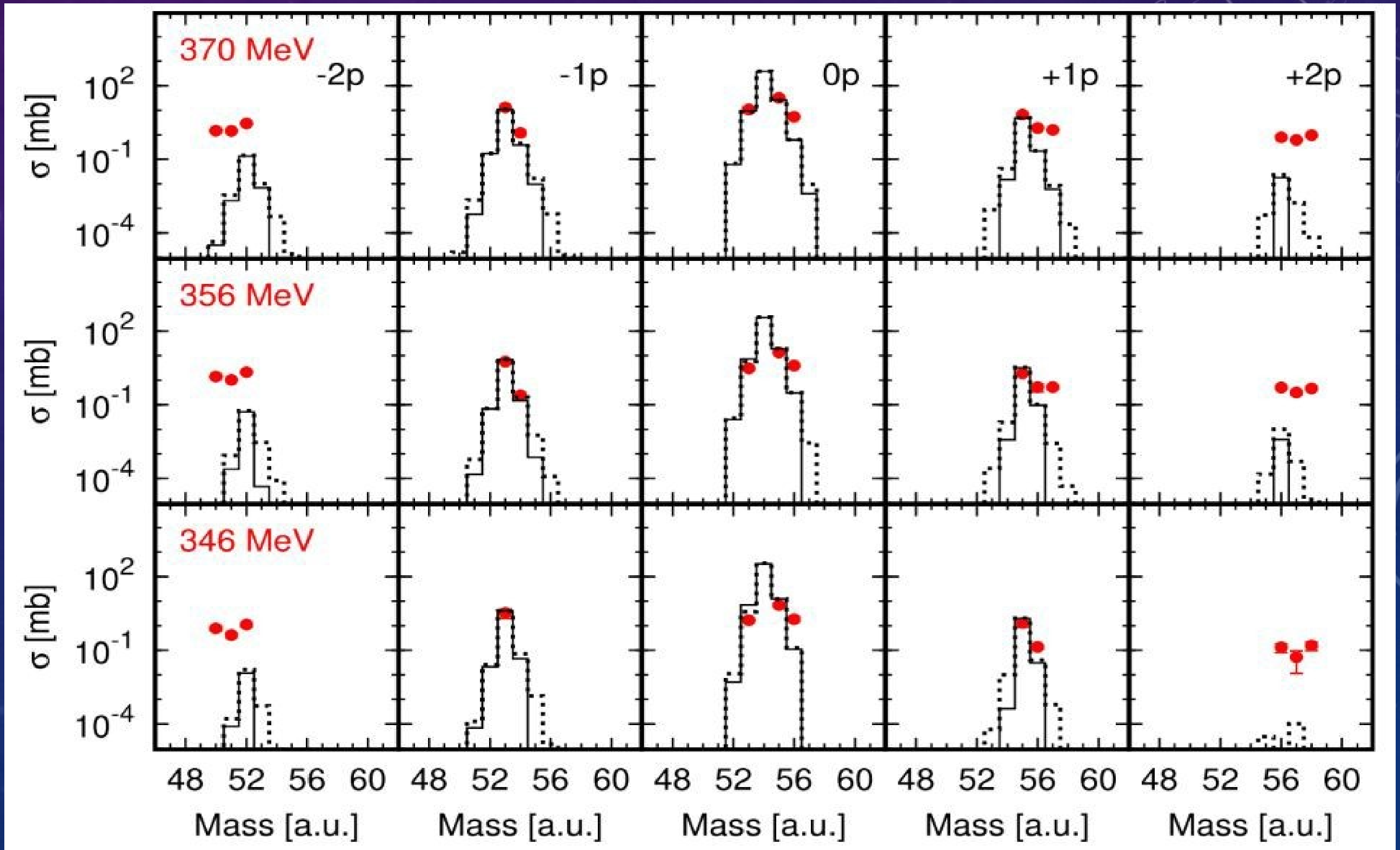
MNT reactions below the Coulomb barrier

Measurement at energies below the Coulomb barrier results in: very narrow TKEL-value distributions: no secondary effects and allow to probe nucleon-nucleon correlations as close as possible to the ground to ground states.

Proton pair transfer studies so far performed mostly above the Coulomb barrier

For the $^{92}Mo + ^{54}Fe$ system the GRAZING cross section calculation well reproduce ±1n and ±1p but underestimate the experimental cross section for the transfer of ±2n and ±2p even below the barrier



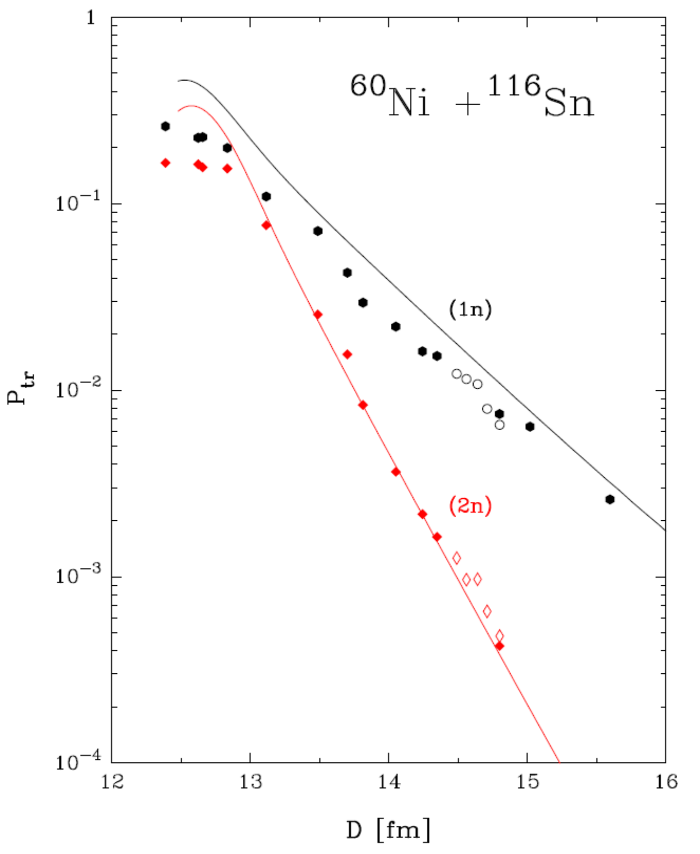
T. Mijatović Phys. Lett. B 872 (2026) 140085

MNT and pair transfers

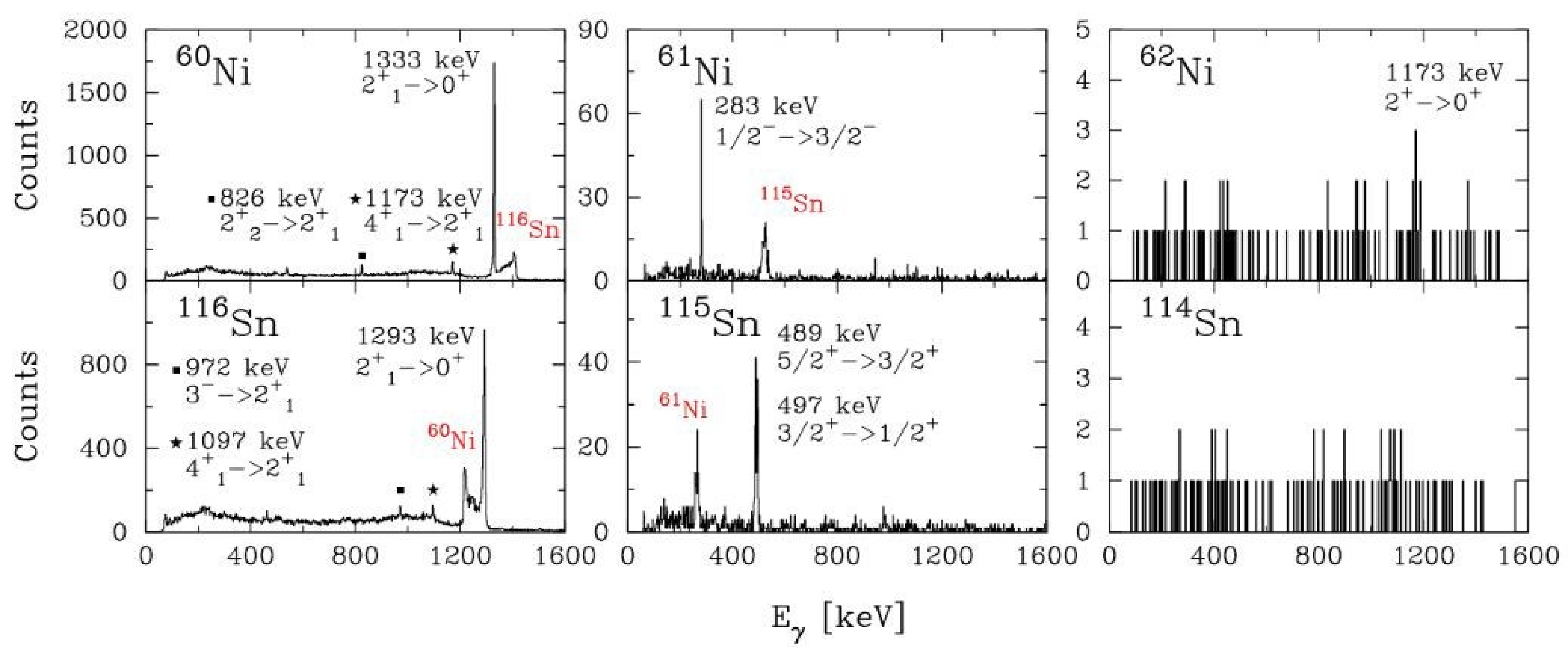
The information from the γ-spectrometer AGATA allow us to extract both the intensities of the excited states population and, using also the information measured with PRISMA, the intensities of the ground-state populations.

Microscopic calculations:

PRISMA+AGATA experiment



D. Montanari PHYSICAL REVIEW C 93, 054623 (2016)



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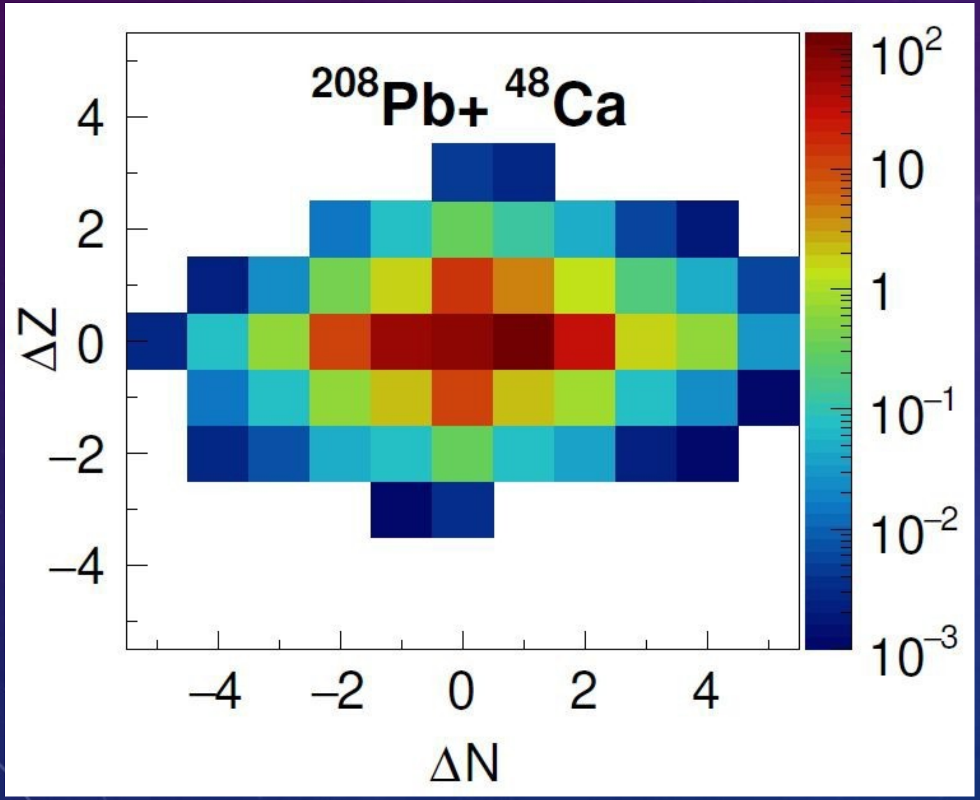
$^{48}Ca+^{208}Pb$: motivation

The ^{48}Ca + ^{208}Pb system provides a very interesting opportunity to investigate addition and removal of neutron and proton pairs, starting from closed shell configuration in Z and N for both reaction partners

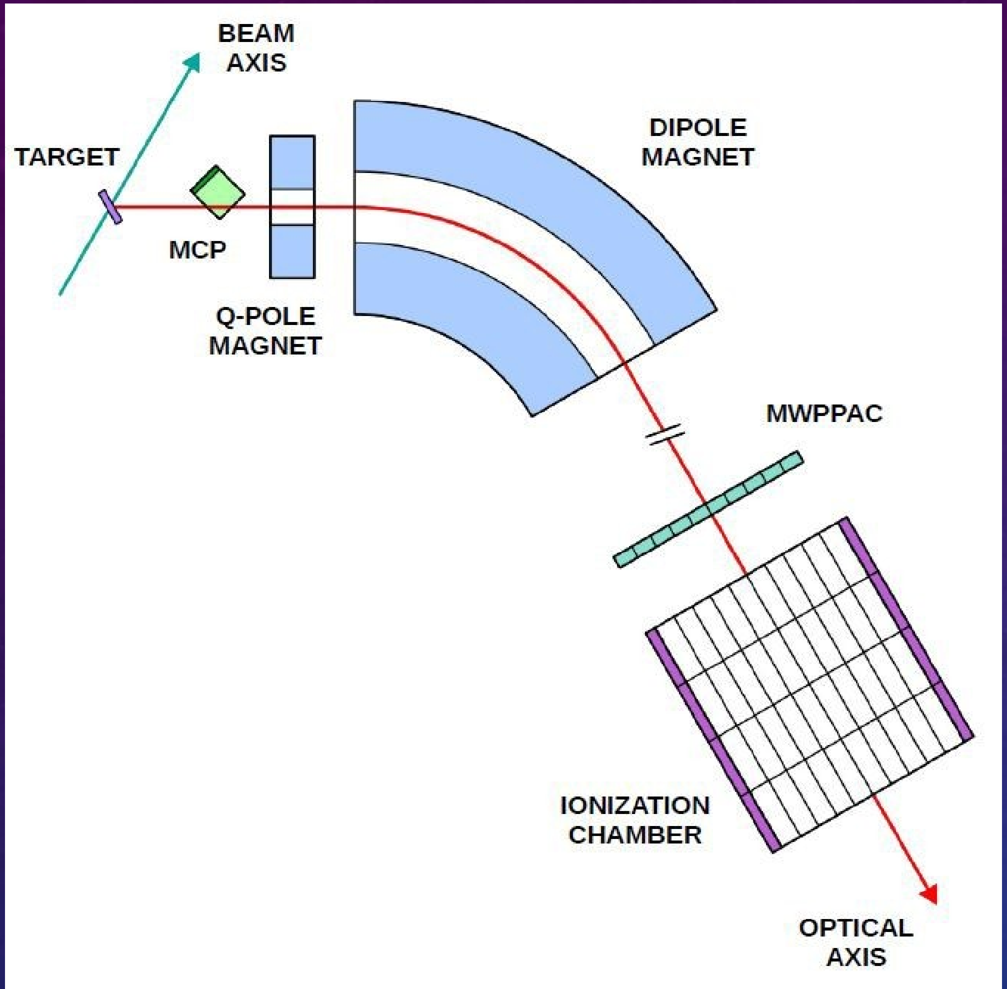
The GRAZING calculation predicts a quite symmetric population of n and p transfer channels

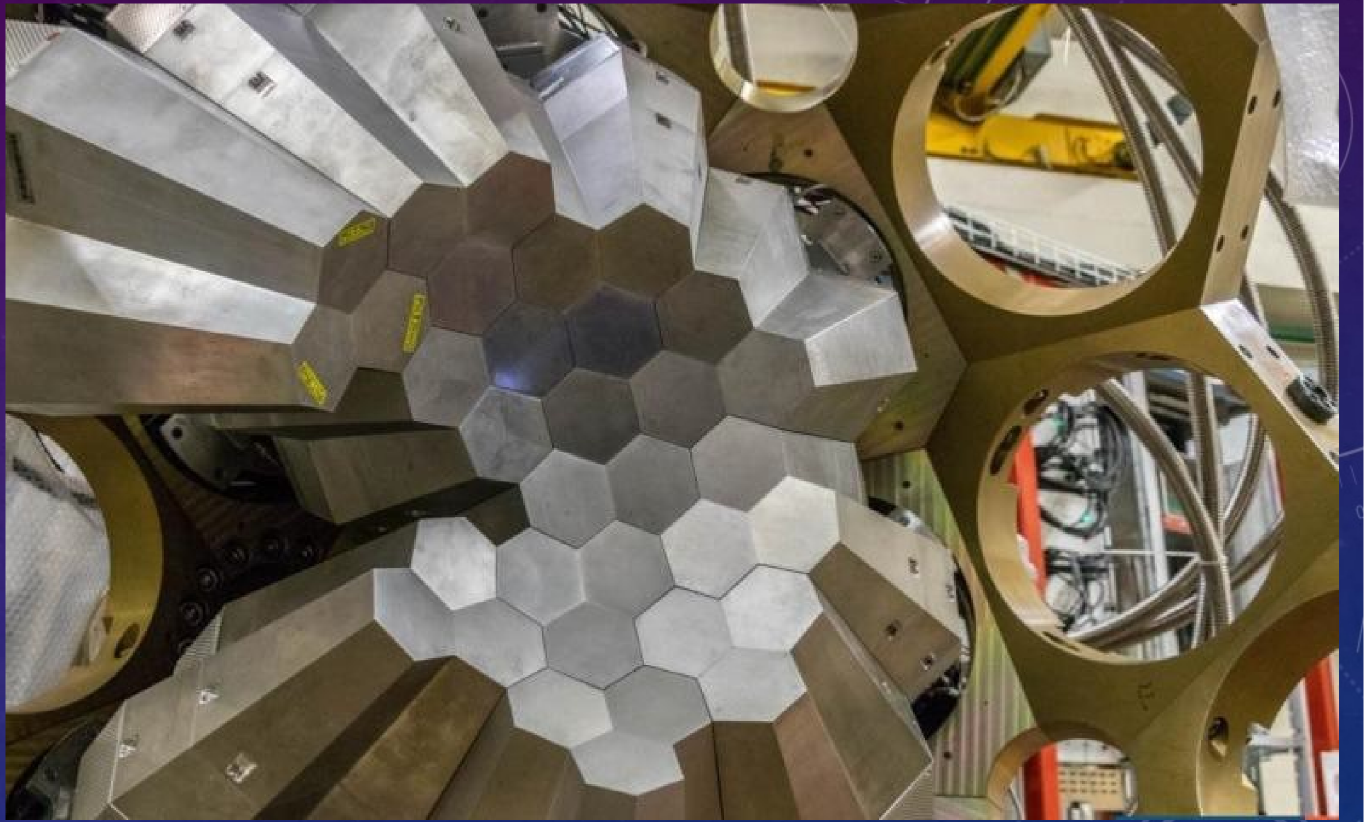


Total cross section GRAZING code calculations

- The use of closed-shell nuclei will simplify the calculations
- New information for *p* stripping and pickup channels
- Possibility to investigate correlations simultaneously for a complete set of transfer channels

Experimental Set-up





PRISMA Magnets:

- ➢ quadrupole
- ➢ dipole

Detectors:

- ➢ MCP - entrance x, y, ToF
- ➢ MWPPAC - focal plane x, y, ToF
- ➢ IC - E, ΔE

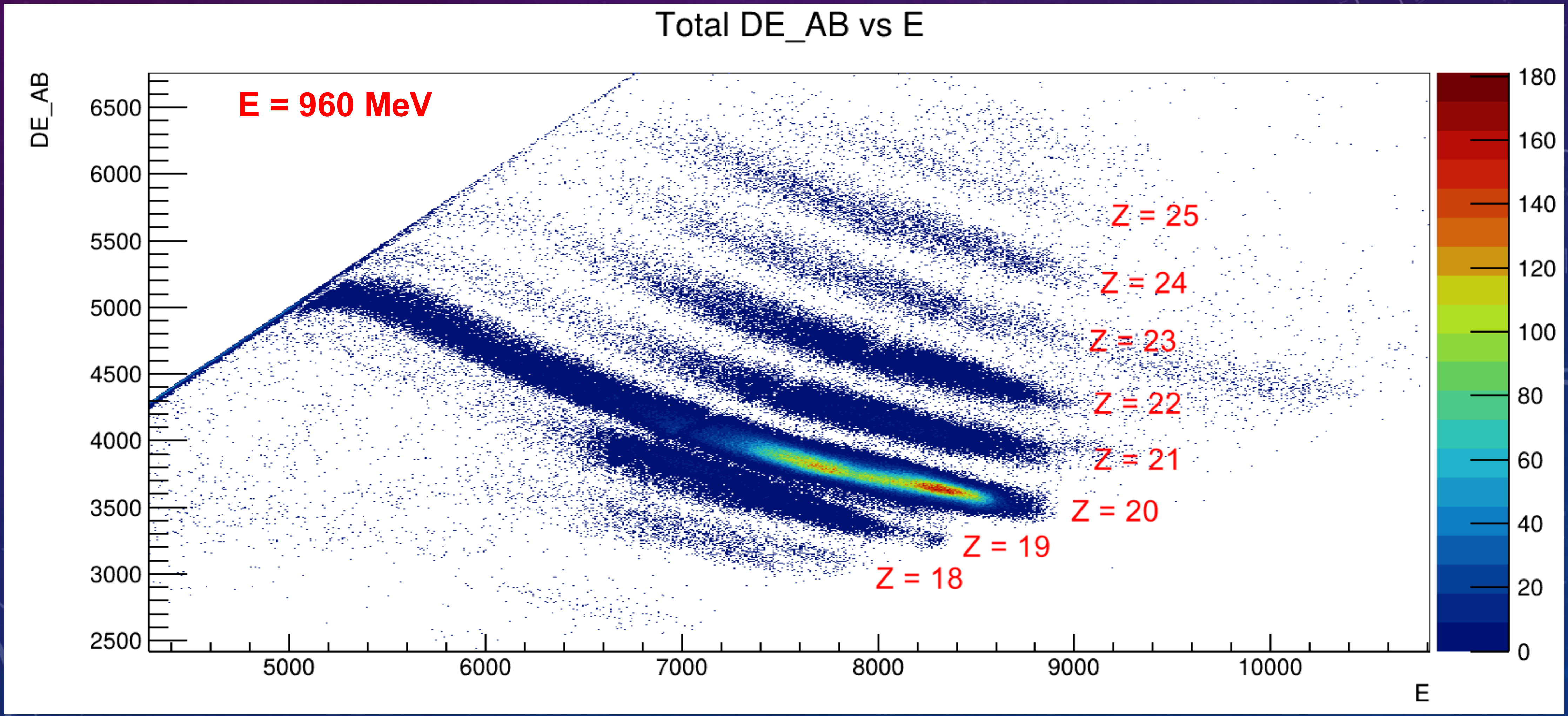
- ➢ ^{208}Pb beam:
  1. Elab = 1000 MeV
  2. Elab = 960 MeV
  3. Elab = 900 MeV
- ➢ ^{48}Ca target: 400 μg/cm^2 + 20 μg/cm^2 C

- ➢ PRISMA at 25°, AGATA opposite to PRISMA
- ➢ 34 operational AGATA crystals

Z identification

Using the information on the ΔE-E provided by the PRISMA Ionization Chamber (IC) is possible to identify the atomic number (Z) of the detected ions.

A clear separation of the different Z has been obtained with a good resolution

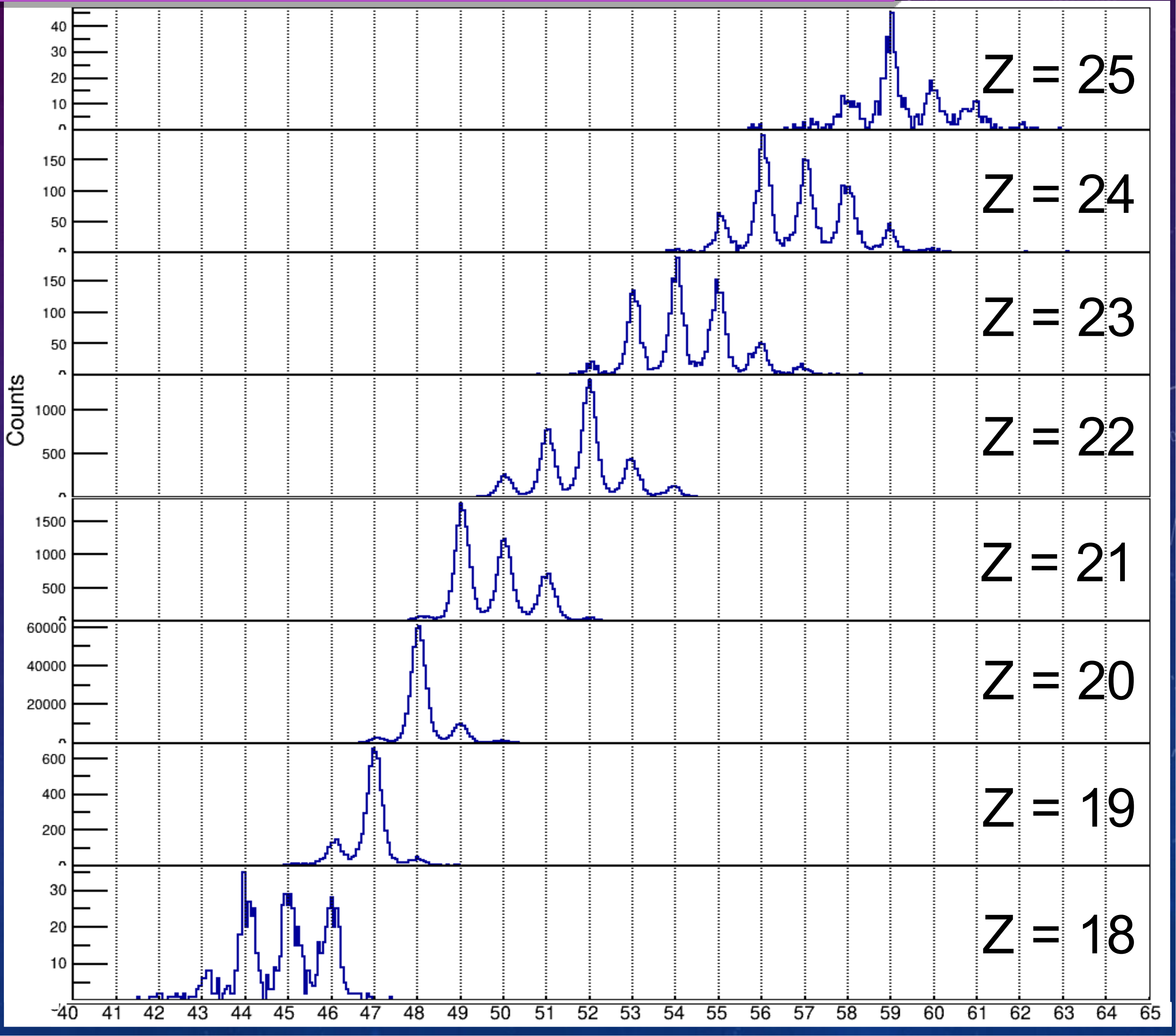


Mass identification

E = 960 MeV

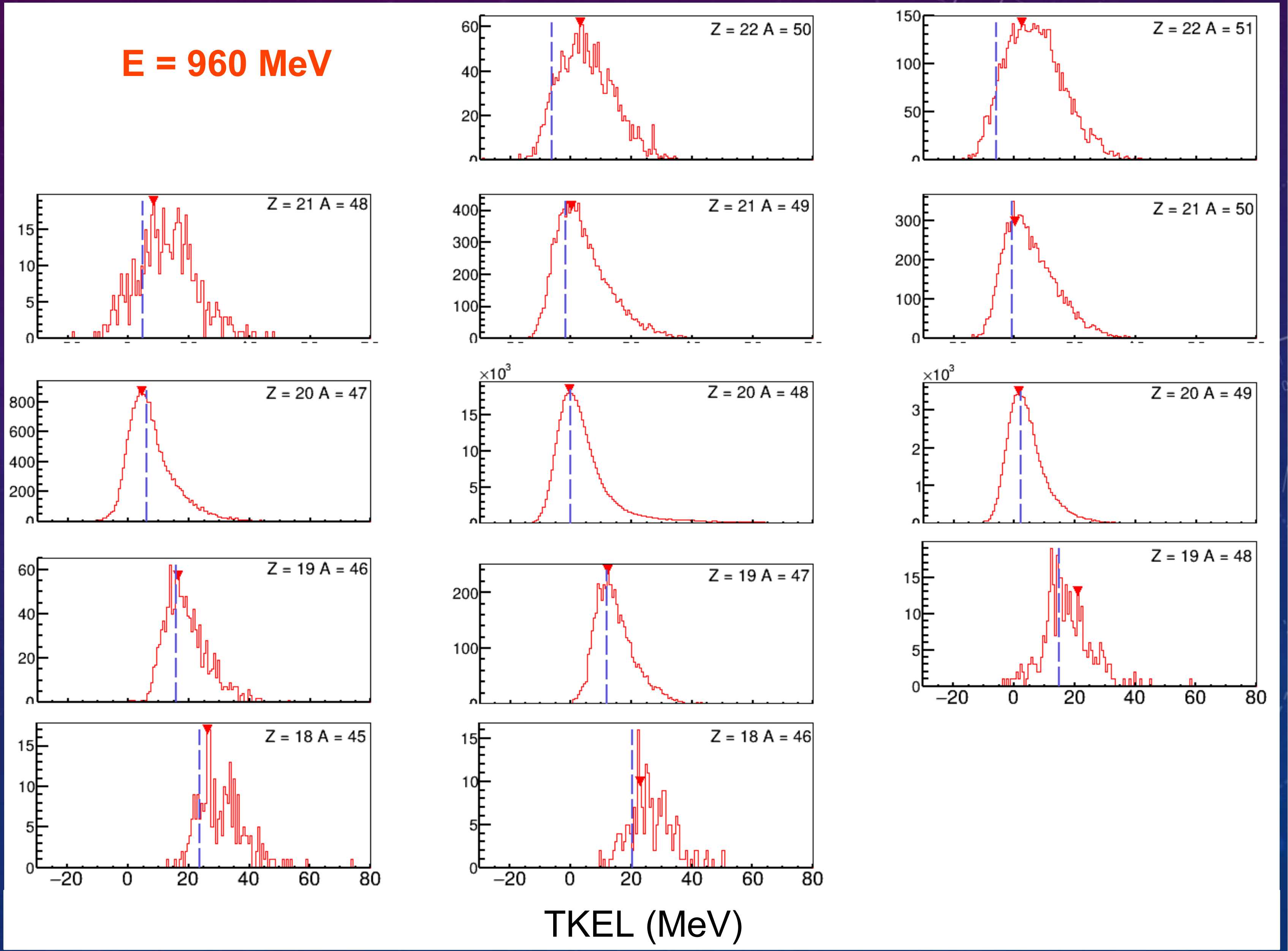
Up to five proton pick-up channels were observed, as well as proton stripping down to -2

Clear separation of multiple transfer channels and good mass resolution



TKEL distribution

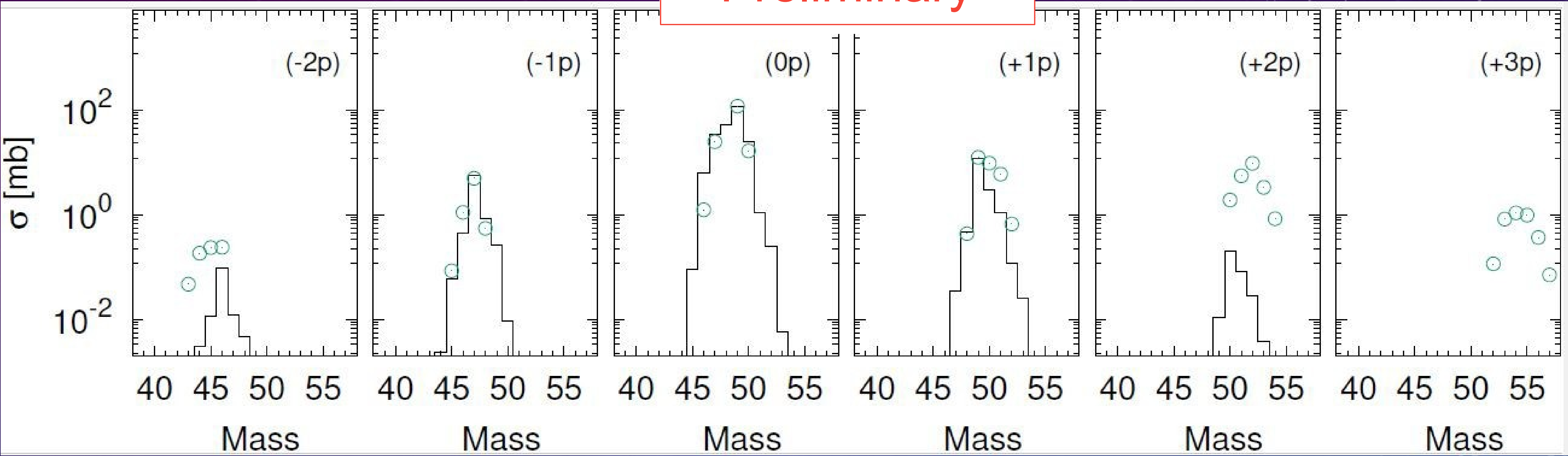
The Total kinetic energy loss (TKEL) distribution, reconstructed assuming a binary reaction and imposing the conservation of momentum, for the reaction channels in which one neutron or proton have been transferred are centred around the ground-to-ground-state transitions.
As more nucleons are transferred, a tail toward larger energy losses starts to develop, indicating that secondary processes may contribute.



Comparison with GRAZING

E = 960 MeV

Preliminary

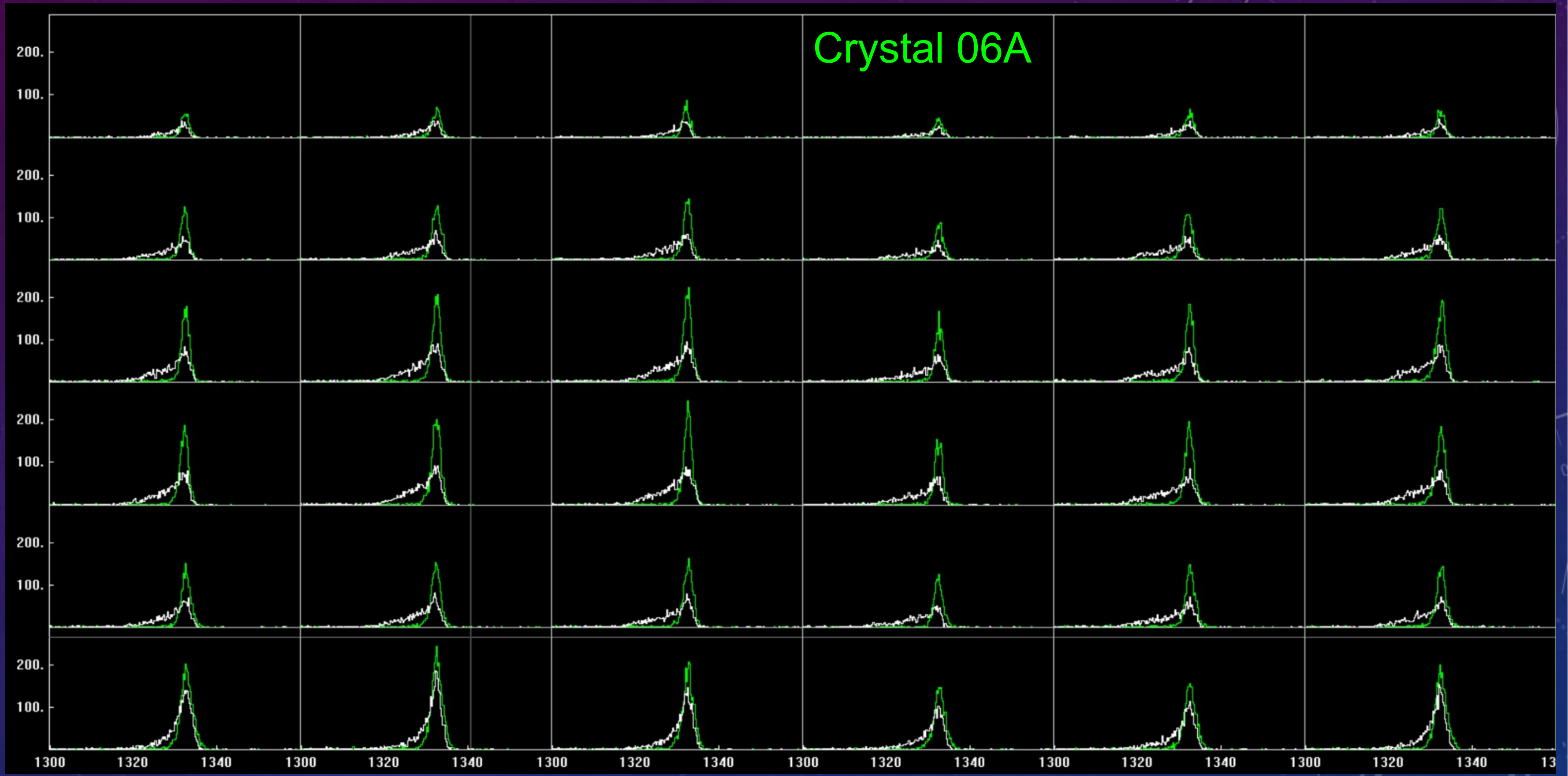


Comparison of the experimental yields and total cross section with the GRAZING calculation

There is a good agreement as long 1 proton, 1 neutron and 2 neutrons are transferred but ±2p channels are underestimated. A more detailed analysis of the TKEL and gamma spectra will help to better understand the origin of this underestimation

Neutron damage correction

- Neutron Damage (ND) from fast neutrons (E > 1 MeV) in HPGe detectors causes charge trapping and therefore energy resolution degradation
- The typical effect of this neutron damages is a left tail on the peaks.
- The objective is obtain the $\lambda_{e,h}$ (inverse electron / hole trap density) parameters that yield the best possible correction and therefore energy resolution



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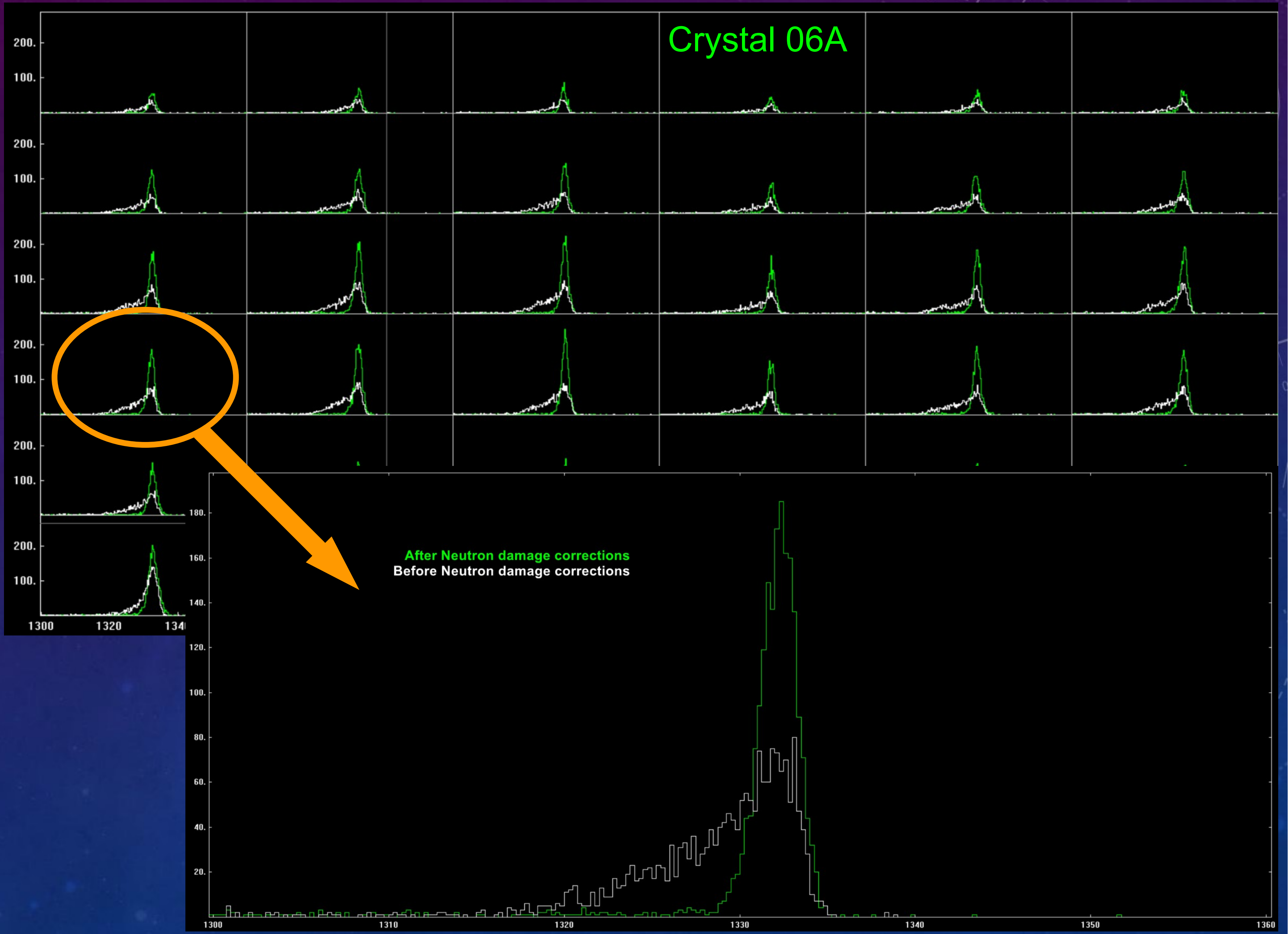
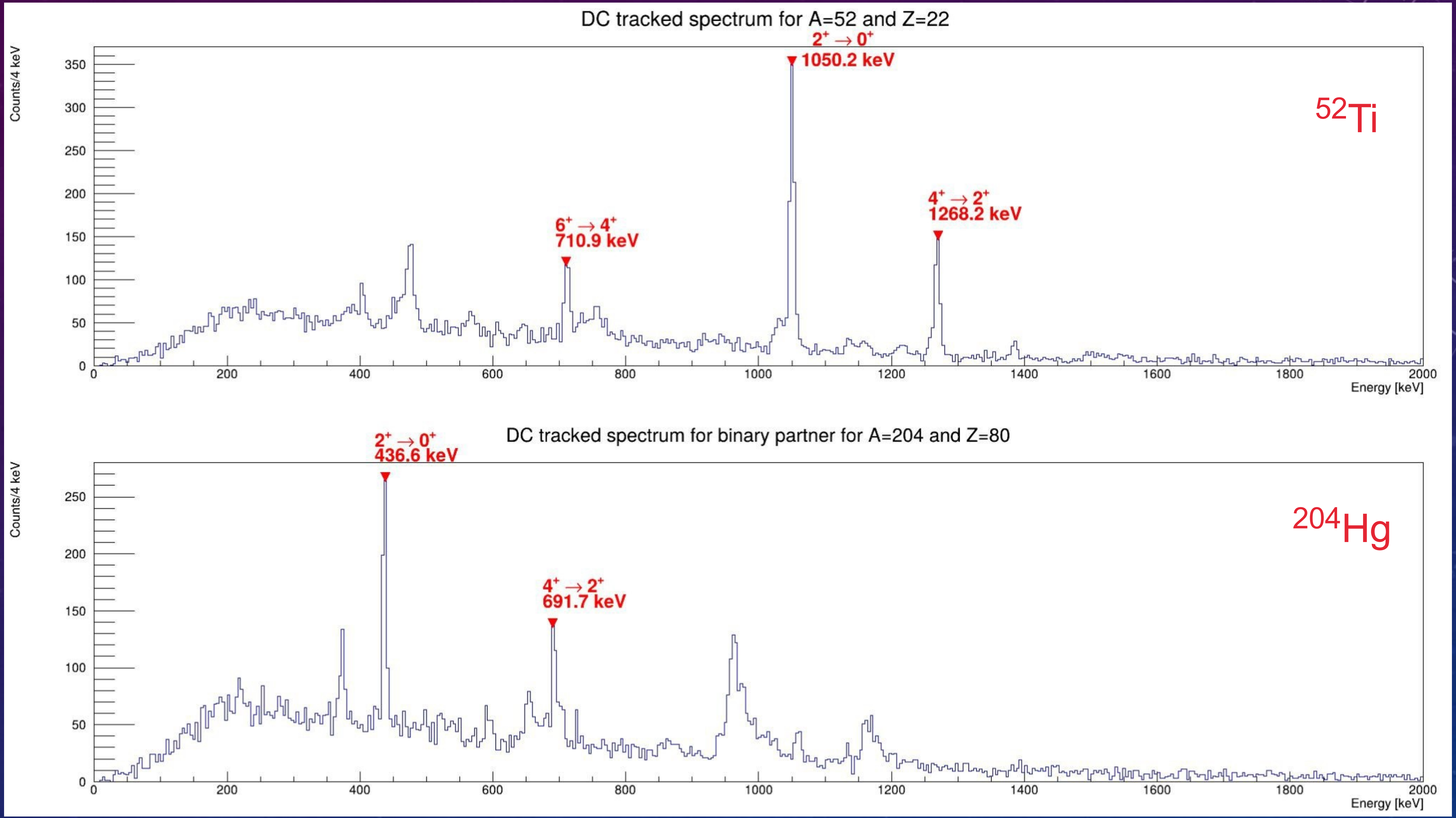
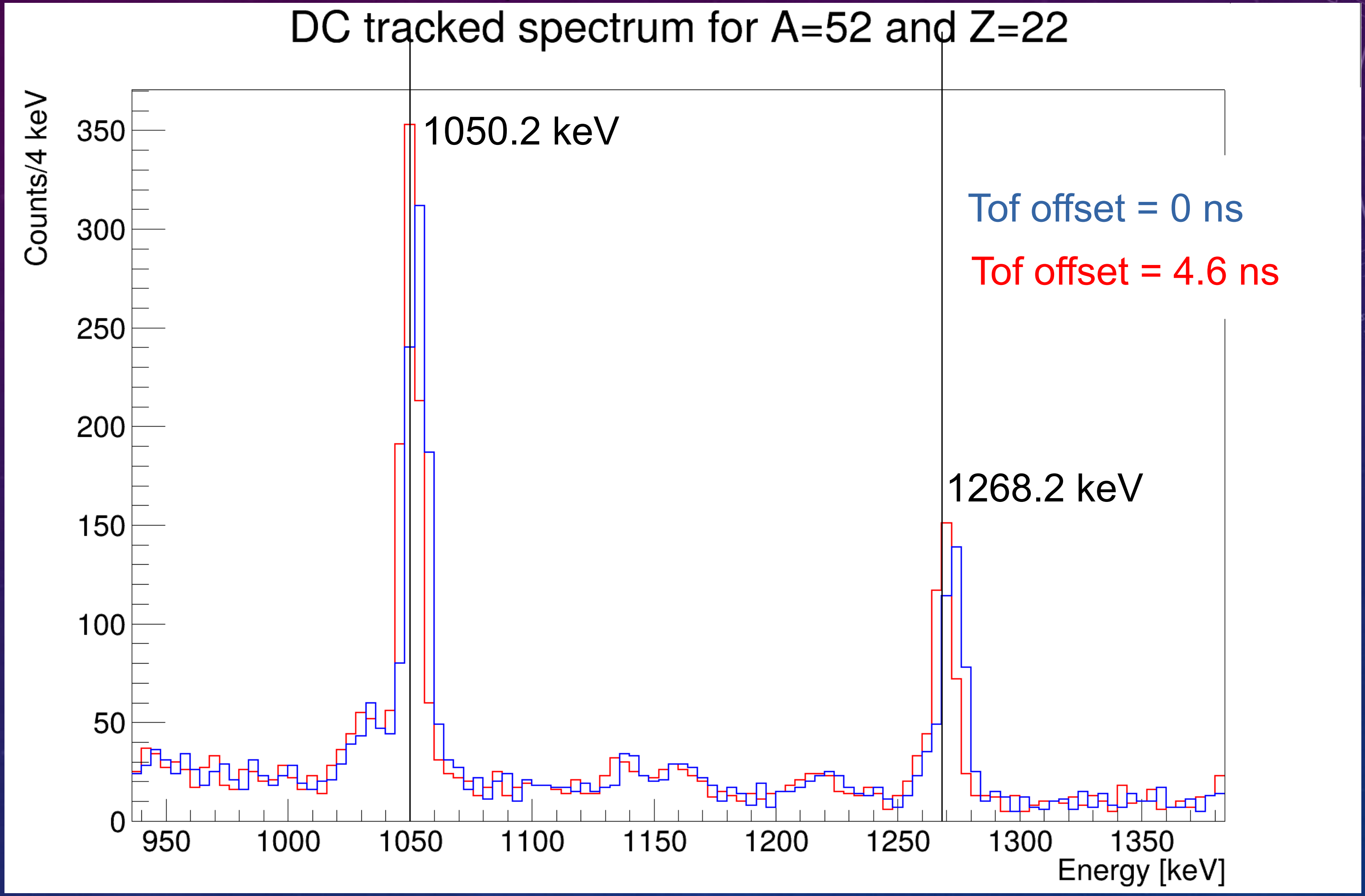


AGATA - PRISMA Coincidence Spectra



main γ lines identified for the strongest channels. For example, for ^{52}Ti (pick-up of 1 alpha particle) and the binary partner ^{204}Hg the most intense transitions are clearly recognizable.

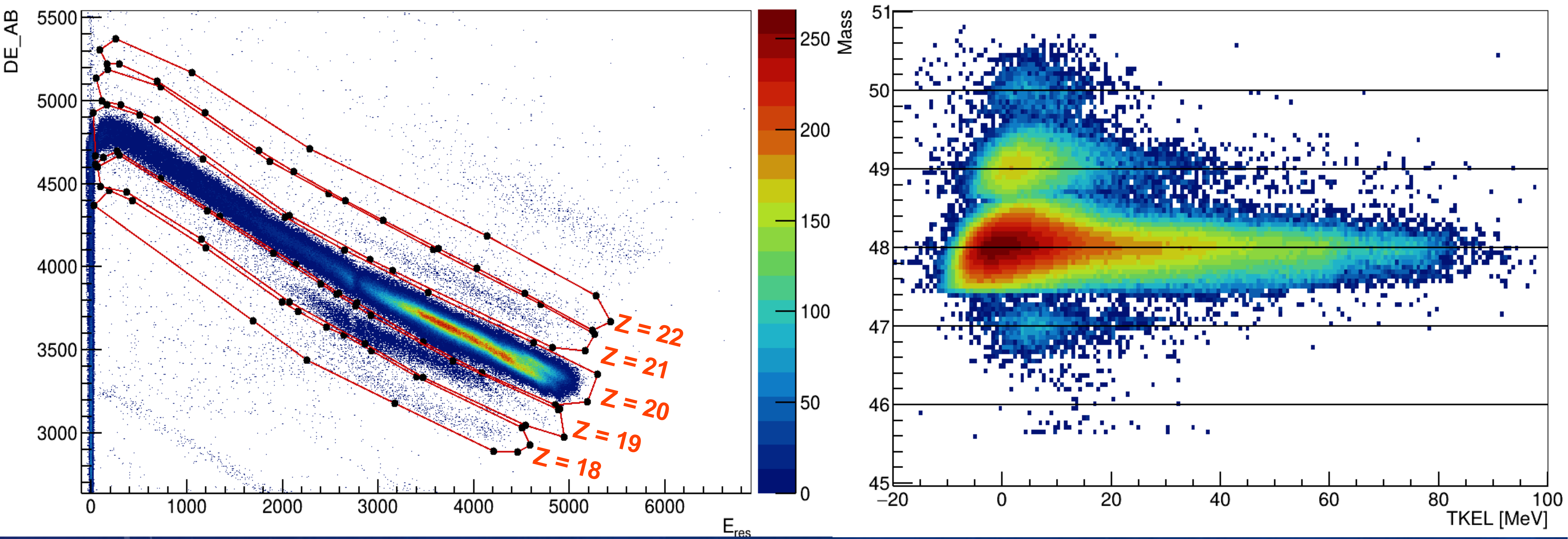
Doppler correction Optimisation



The value of the ToF offset and the beam energy has been adjusted to optimise the Doppler correction for the gamma spectra

Energy 900 MeV analysis

The same system has been measured also at the beam energy of 900 MeV (below the Coulomb barrier).



Summary

- MNT reactions below the Coulomb barrier
- We measured ^{48}Ca + ^{208}Pb system around the Coulomb barrier
- Z and q identification
- Good mass resolution obtained
- Q-value calculation
- Comparison with GRAZING
- AGATA spectra in coincidence with PRISMA for each transfer channel
- Doppler correction optimisation
- Transfer probability for +1,2n and for +1,2p transfer for two energies (900 MeV and 960 MeV) is ongoing
- The 2p channels are under predicted by theory, detailed analysis of the TKEL and gamma spectra will help to give some insight on this underestimation
- Results need to be compared also with the highest energy (1000 MeV)

Thank you for your attention!

UIP-2025-02-8168

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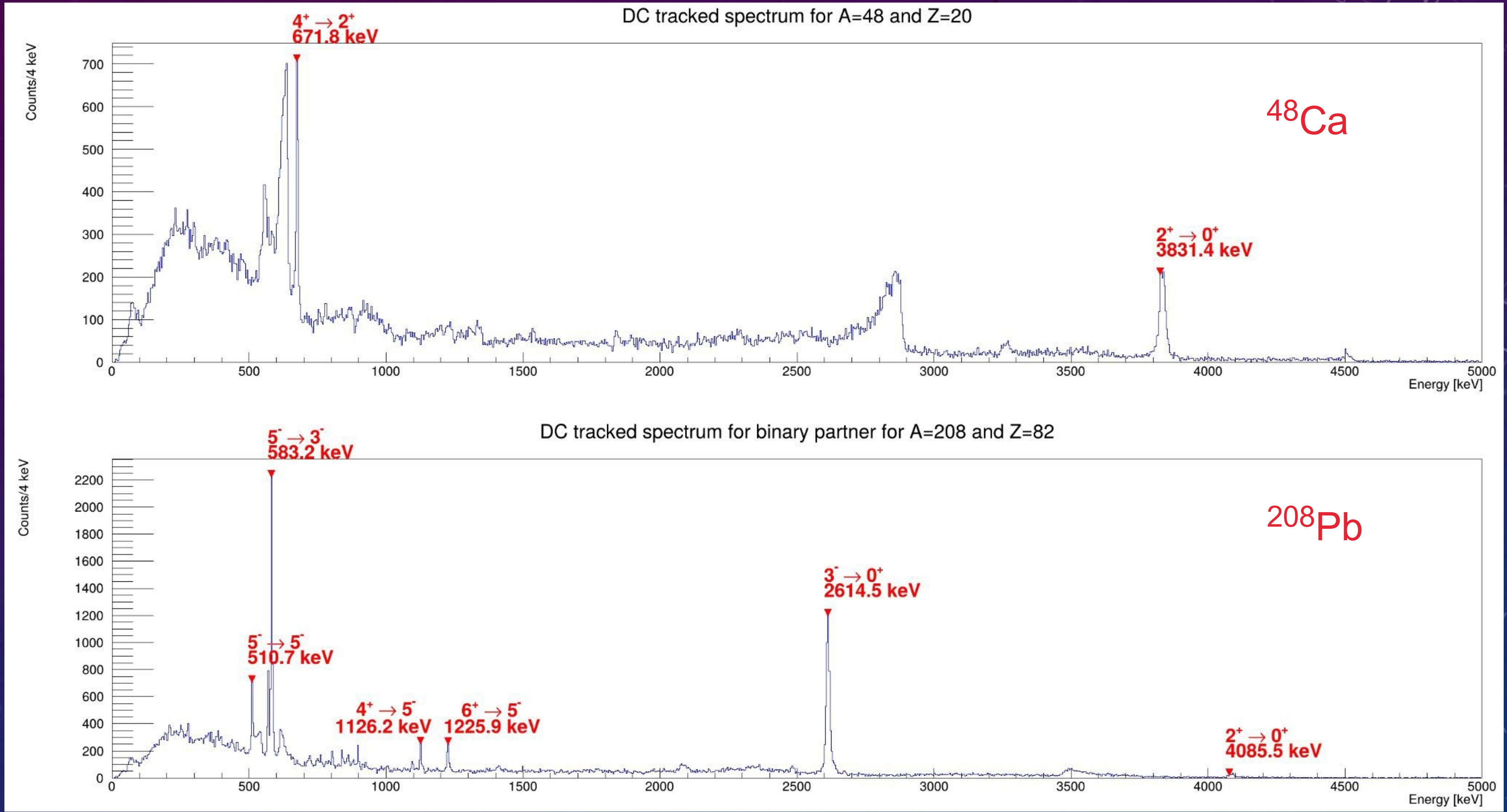
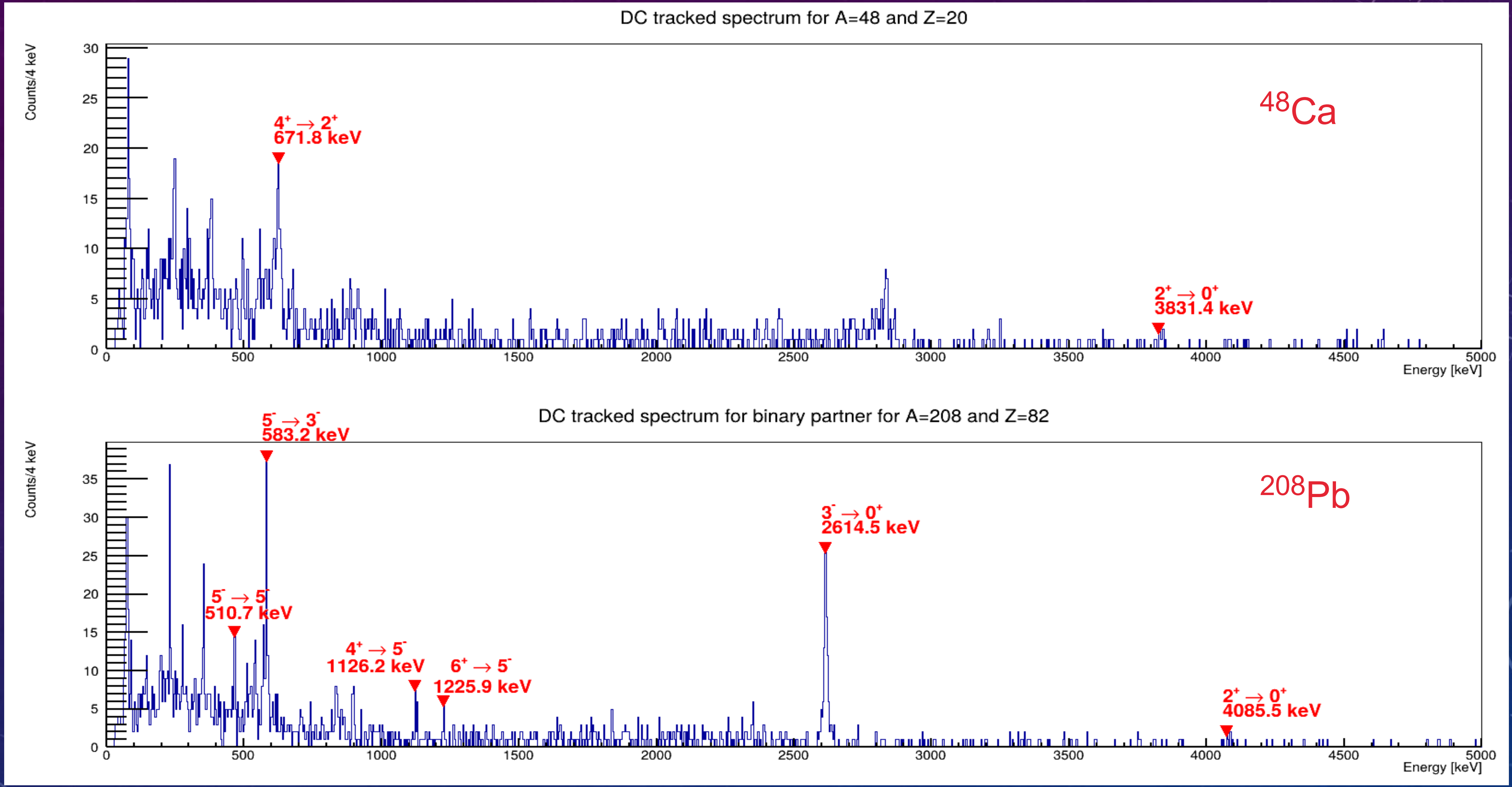
AGATA - PRISMA Coincidence Spectra



main γ lines identified for the strongest channels. For example, for ^{48}Ca and the binary partner ^{208}Pb the most intense transitions are clearly recognizable.

AGATA - PRISMA Coincidence Spectra

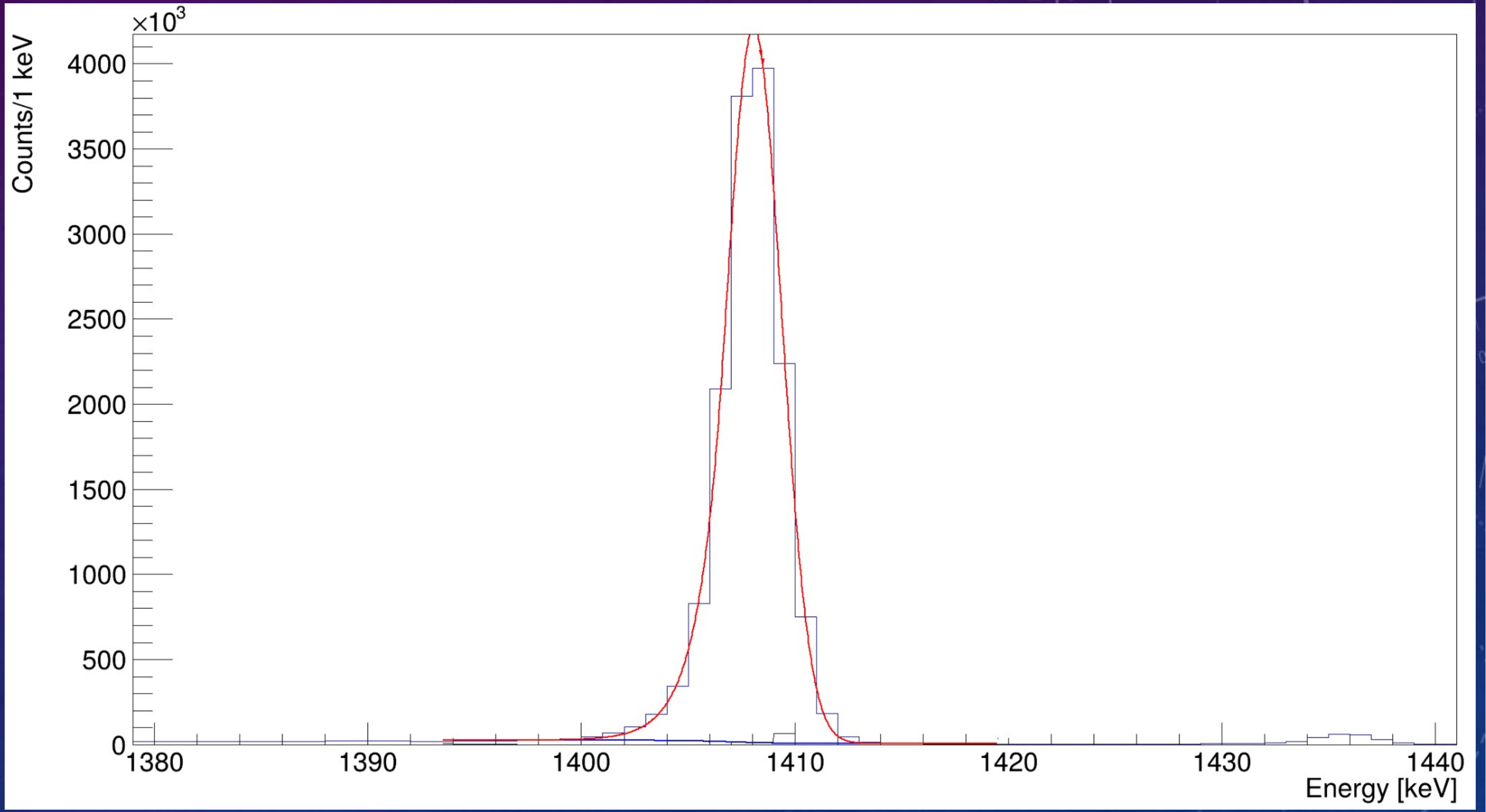


main γ lines identified for the strongest channels. For example, for ^{48}Ca and the binary partner ^{208}Pb the most intense transitions are clearly recognisable for the beam energy of 900 MeV.

^{152}Eu Energy Spectra

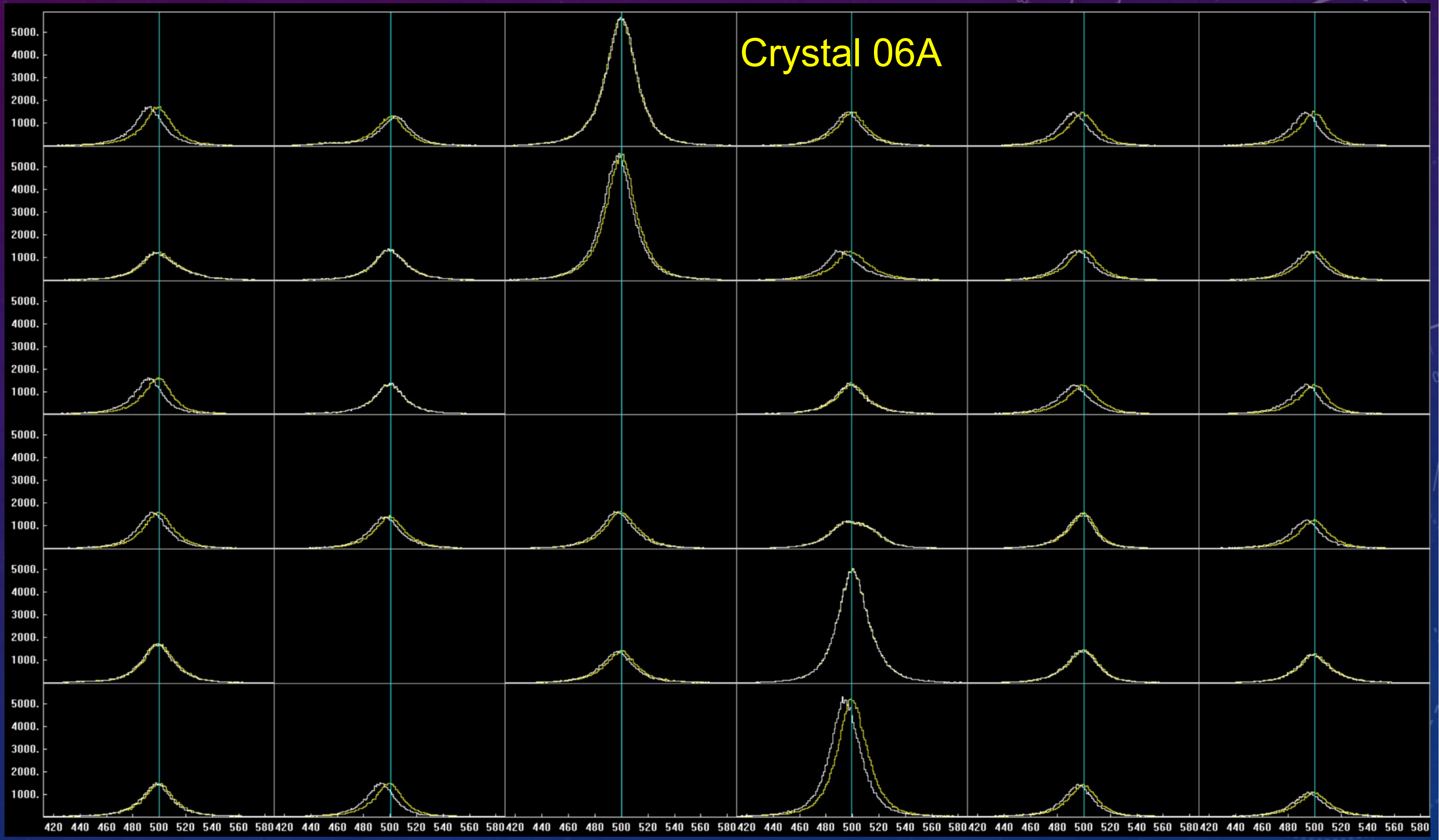
Fit Parameters:

- Energy = 1408.07 ± 0.01
- FWHM = 3.06 ± 0.01



Time alignment of the cores

- Global Time alignment consist in aligne the time difference of each crystal with all the others at the same value.
- This is important to reduce random coincidences.

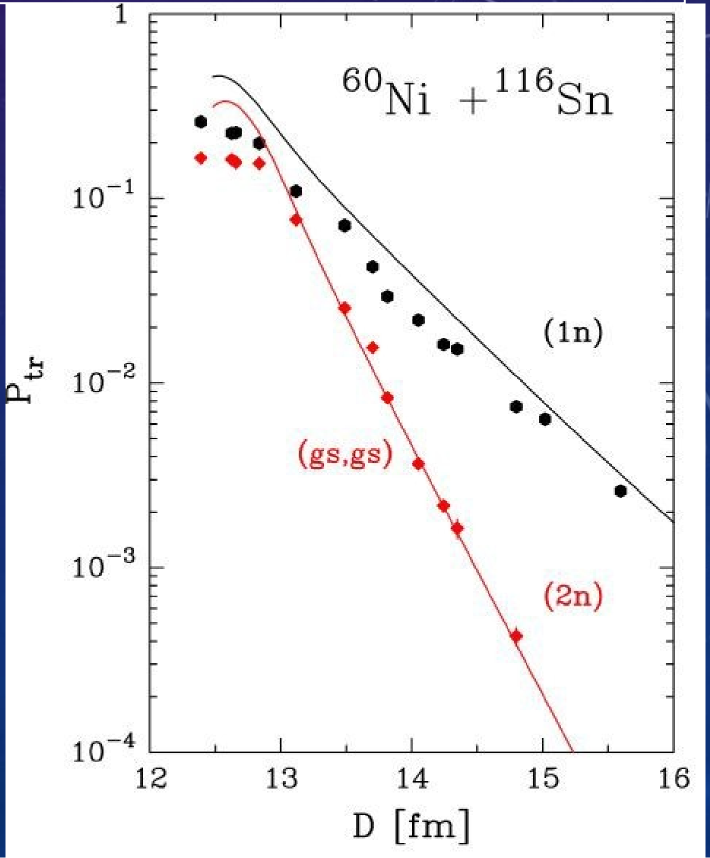


Microscopic calculation $^{116}Sn+^{60}Ni$

The calculations are performed in a distorted wave Born approximation (DWBA) by using for the wave functions of relative motion their CWKB. For the one-neutron transfer channel, the inclusive cross section is simply obtained by summing up all the contributions coming from the single particle transitions. For the two-neutron transfer channel, we included only the ground to ground state transition in the successive approximation.

For nickel, the spectroscopic factors are obtained from literature while for tin they are not well known experimentally and, therefore has been calculated them via a BCS transformation

	nlj	ϵ_j [MeV]	E_j [MeV]	V_j^2/U_j^2	B_j
^{116}Sn	$1g_{9/2}$	−16.58	7.01	0.9874	0.272
	$2d_{5/2}$	−11.51	2.35	0.8740	0.658
	$1g_{7/2}$	−10.86	1.92	0.7900	0.910
	$3s_{1/2}$	−9.70	1.56	0.4870	0.483
	$2d_{3/2}$	−9.51	1.58	0.4280	0.661
	$1h_{11/2}$	−8.12	2.25	0.1402	−0.770
	$2f_{7/2}$	−3.11	6.81	0.0134	−0.224
	$3p_{3/2}$	−1.77	8.12	0.0094	−0.134
^{60}Ni	$2p_{3/2}$	−11.33	1.56	0.33	−0.524
	$2p_{1/2}$	−9.66	1.83	0.65	−0.5
	$1f_{5/2}$	−9.33	2.05	0.4	−0.34
	$1g_{9/2}$	−5.16	5.80	0.5	0.1

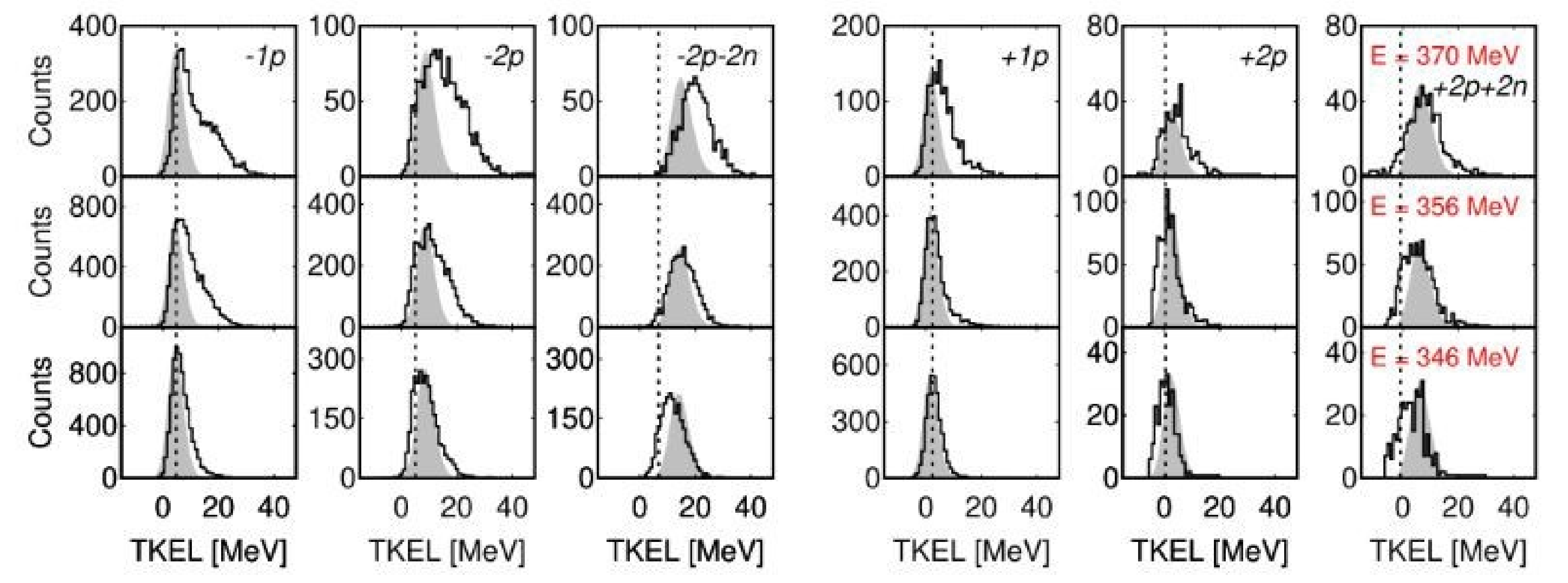


MNT reactions below the Coulomb barrier

Measurement at energies below the Coulomb barrier results in: very narrow TKEL-value distributions: no secondary effects and allow to probe nucleon-nucleon correlations as close as possible to the ground to ground states.

Proton pair transfer studies so far performed mostly above the Coulomb barrier

For the ^{92}Mo + ^{54}Fe system, below the barrier, all TKEL distributions become narrower, reflecting a transition to predominantly direct processes.



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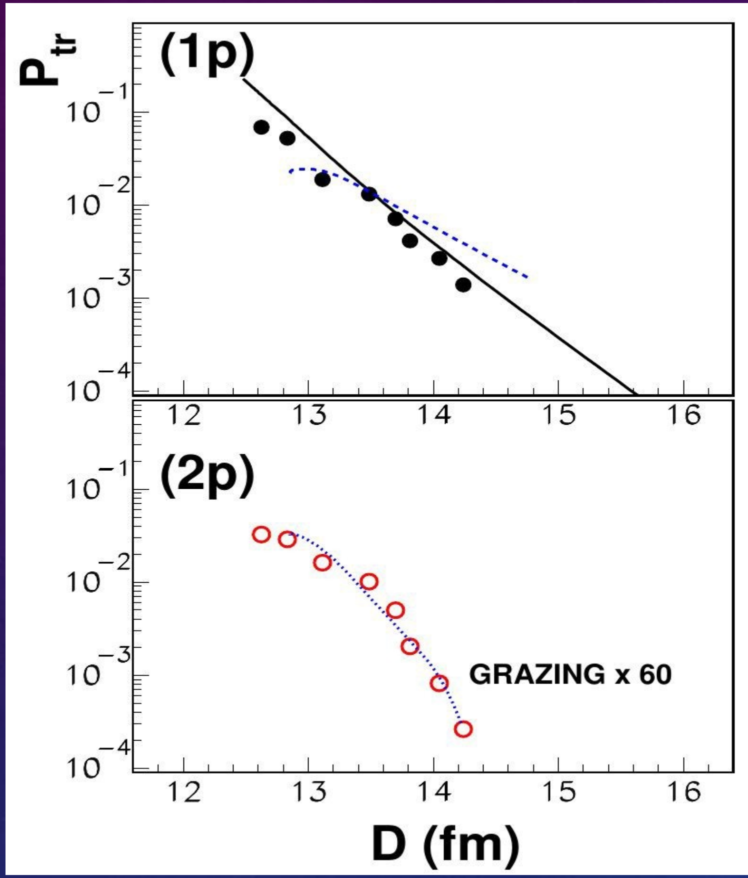
Proton transfer channels: $^{116}Sn+^{60}Ni$



GRAZING calculation (independent nucleon transfer) is underpredicting experimental results for -2p channel by a factor 60

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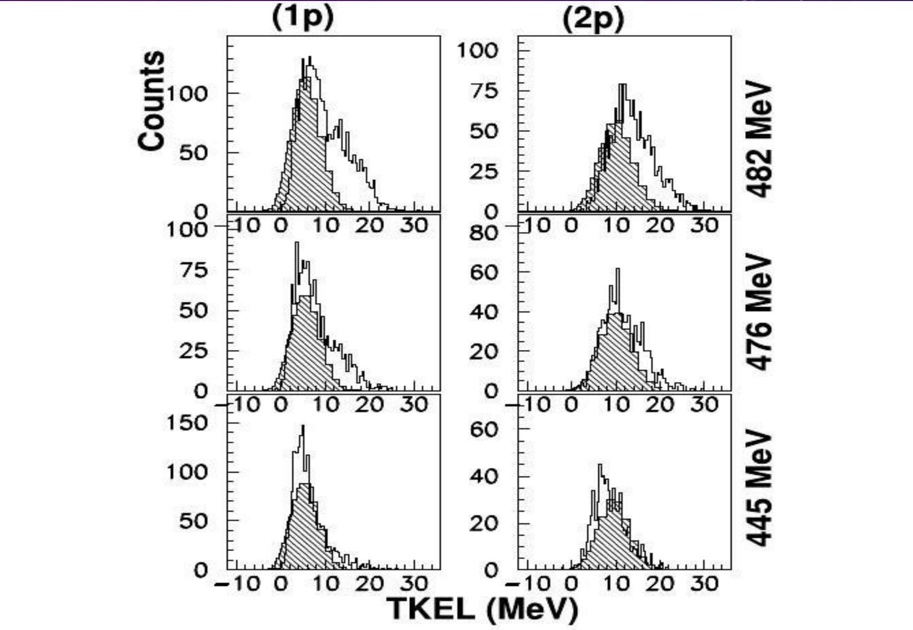


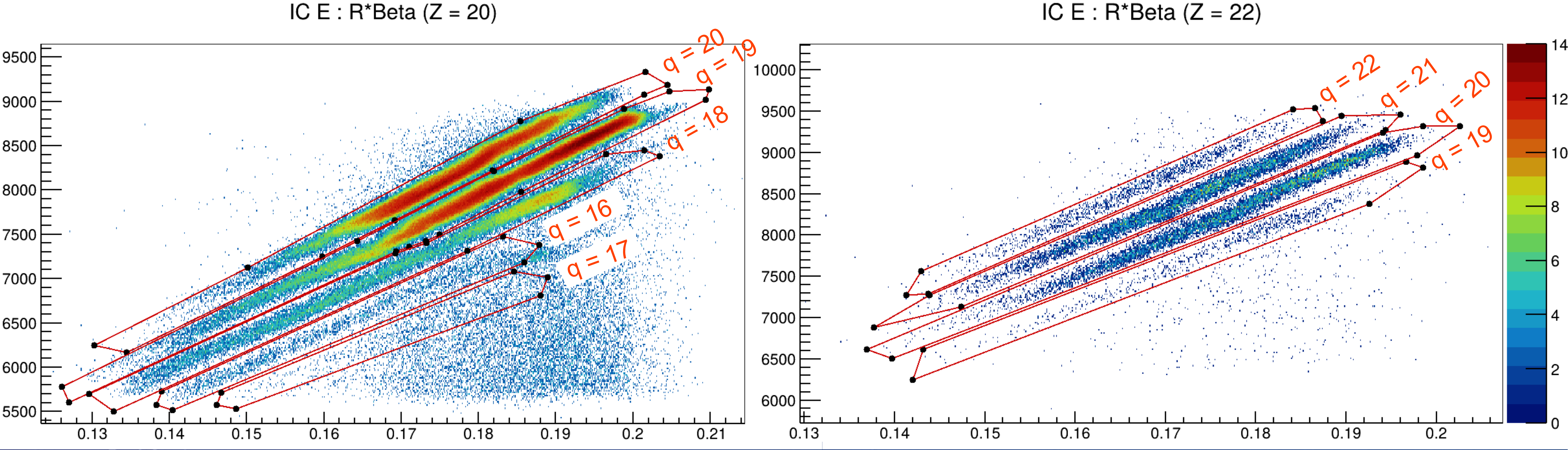
Fig. 2. TKEL spectra obtained for the pure one-proton stripping, (1*p*), and pure two-proton stripping, (2*p*), transfer channels at three representative bombarding energies, above (upper), near (middle), and below (lower) the Coulomb barrier (E^B_{lab} = 462.2 MeV). The results of the GRAZING code calculation are plotted as shaded histograms.

- More data needed for *p* transfer channels in different systems
- We propose to study *n*-rich system and both *p* stripping and pickup channels

Atomic charge state identification

The atomic charge state (q) can be recognized from the relation between the total energy obtained from the IC (E_{IC}) and the product of the curvature radius and the ions speed (Rβ) From

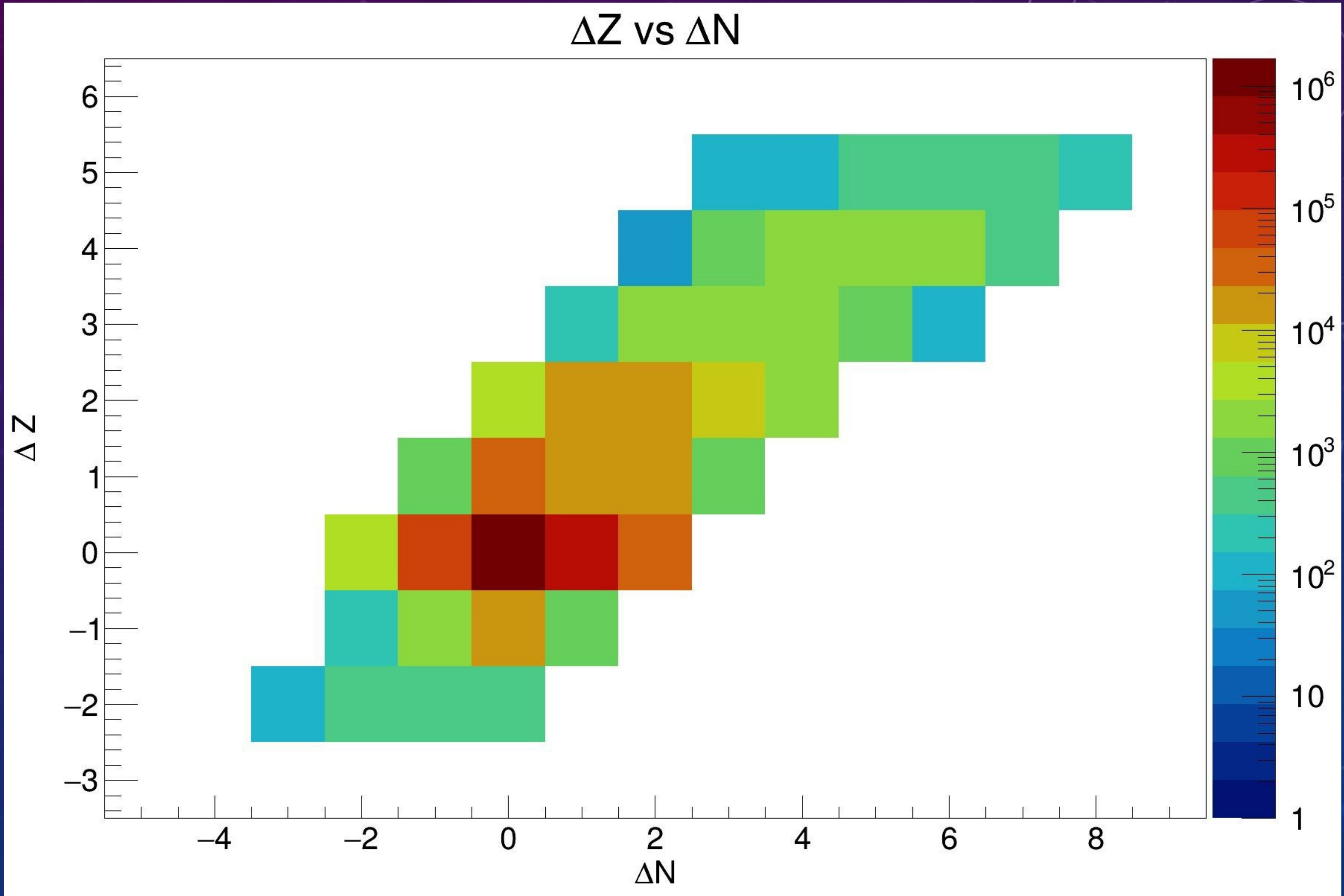
the E_{IC} vs Rβ matrix the different charge states can be identified for each value of Z.



Mass identification

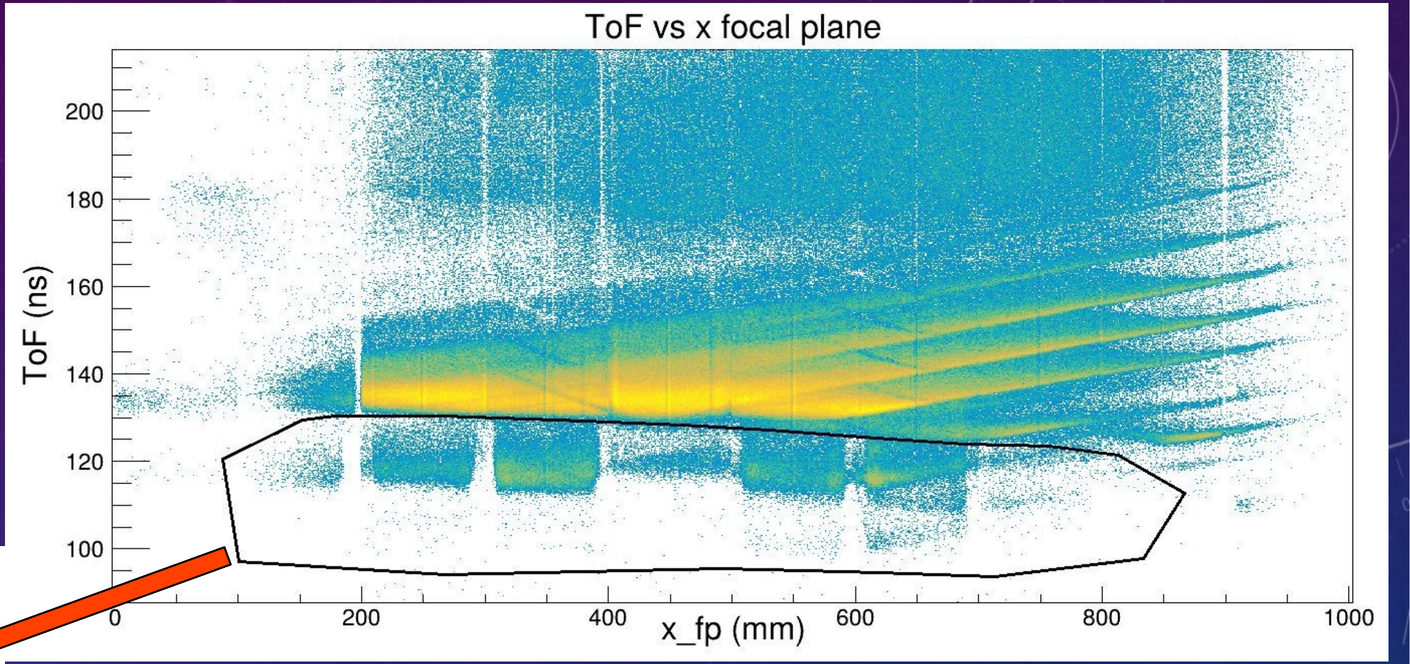
Up to five proton pick-up channels were observed, as well as proton stripping down to -2

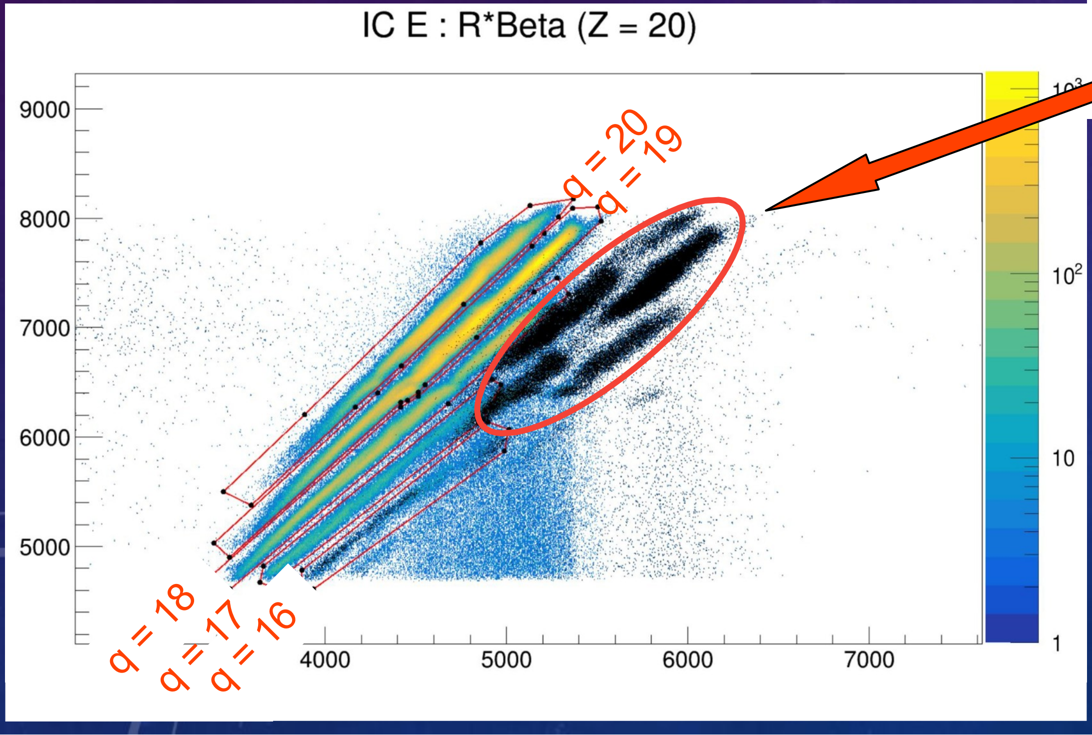
For neutrons the observed channels are up to eight neutron pick-up, as well as stripping down to -3



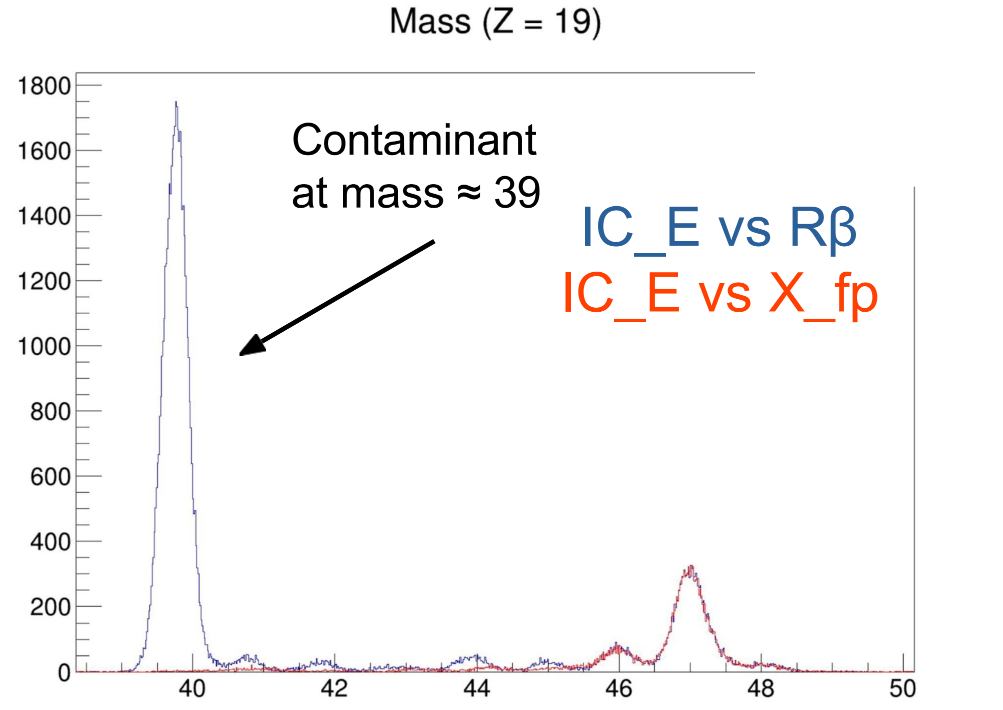
Atomic charge state identification

Charge state identification using E_{IC} vs Rβ.
Repetitions in the time of flight spectrum can be seen in the E_{IC} vs Rβ spectra

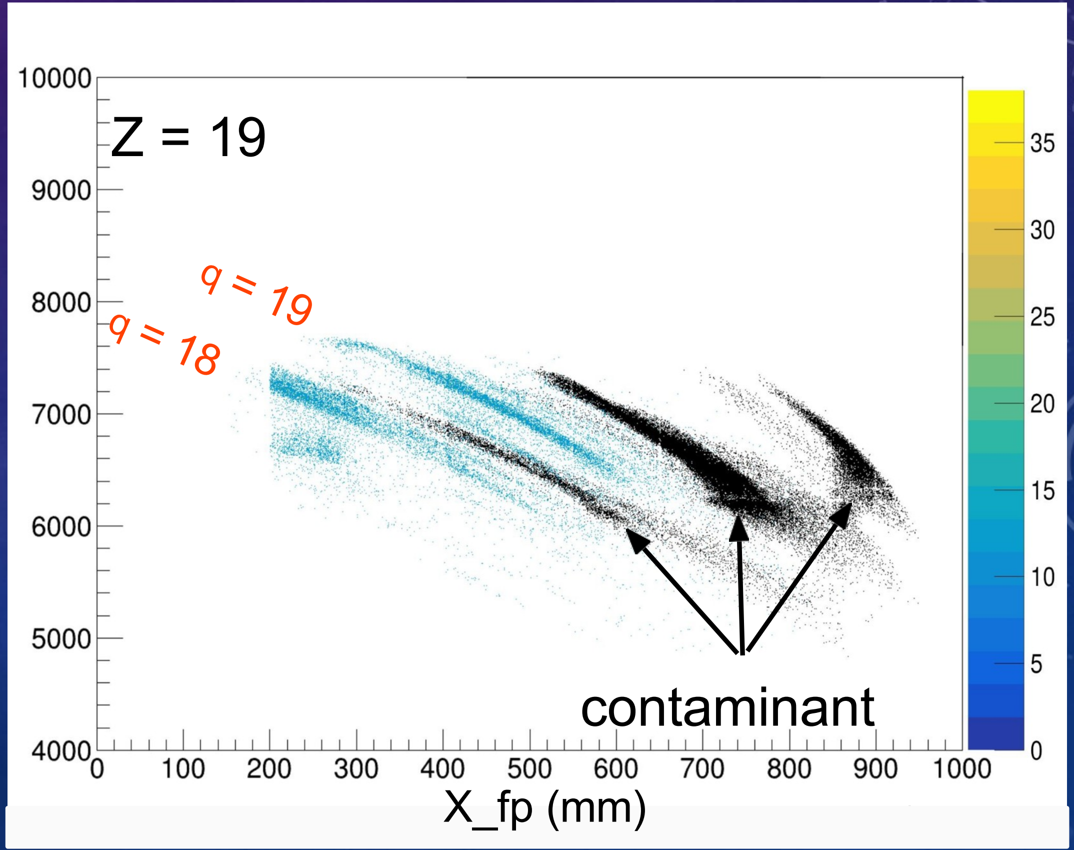




Mass contaminant

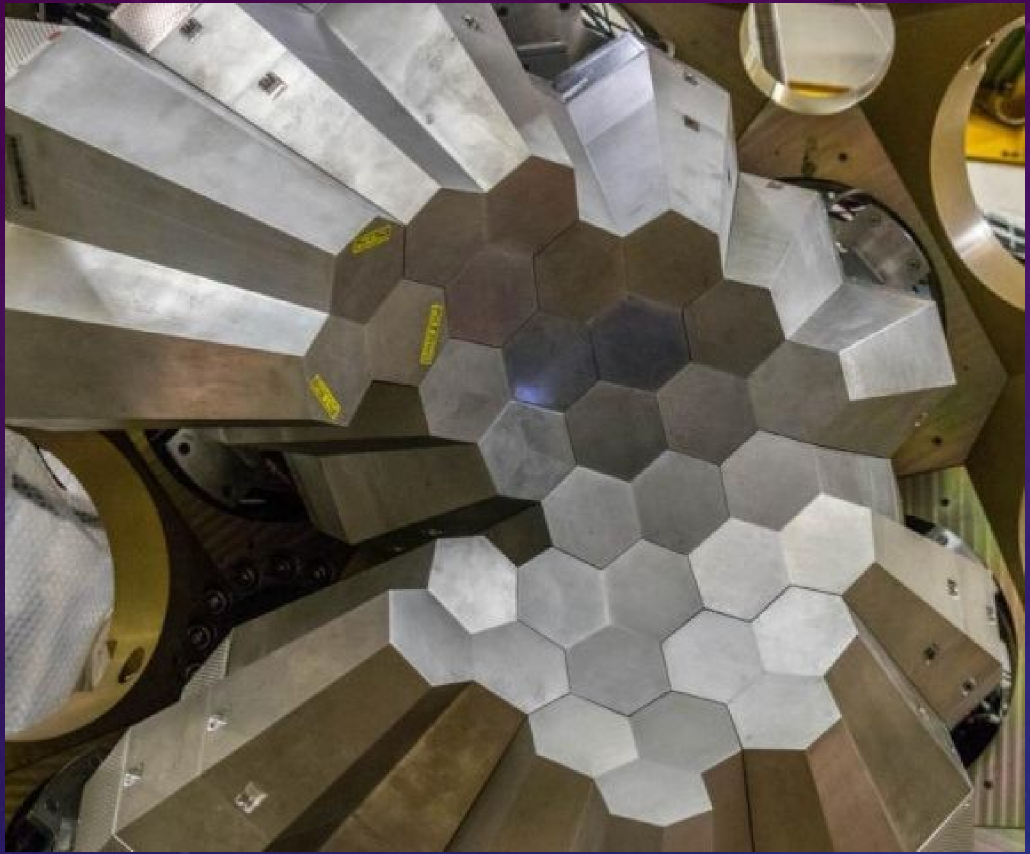


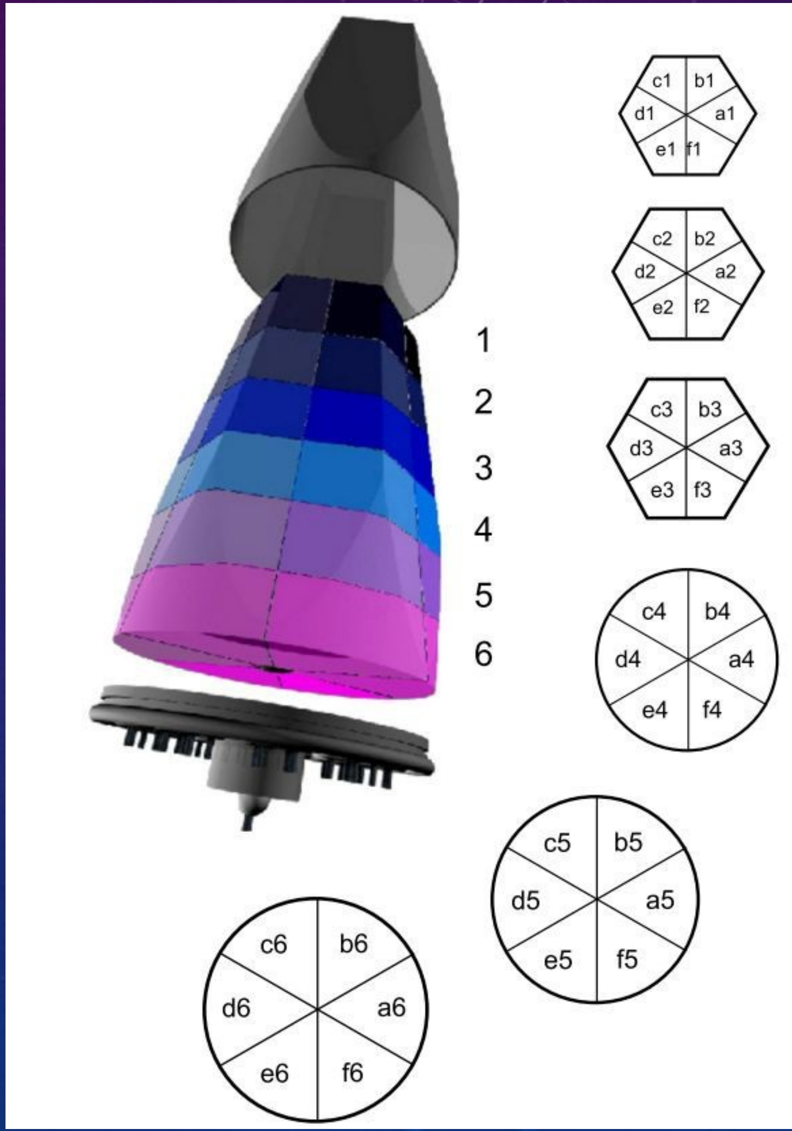
- ➢ Presence of contaminant in mass spectra for Z = 19 and Z = 18
- ➢ The reason is still not clear, most likely be caused by the presence of ^{39}K in the target



The contaminant can be removed thanks to the Energy vs x focal plane spectrum where there is good separation between contaminant and Ca-like events

The γ-spectrometer AGATA





- 34 High Purity Germanium (HPGe) crystals
- Each crystal is segmented longitudinally and radially in 6 sections for a total of 36 sections
- Very precise estimation of the position of interaction of the photons (within 4 mm)
- Tracking algorithms to reconstruct the events from γ-rays Compton scattering

S. Akkoyun et al. Nucl. Instrum. Methods Phys. Res. A 668 (2012), p. 26
J.J. Valiente-Dobon et al., Nucl. Inst. Meth. Phys. Res. A 1049, 168040 (2023)