NuSym21 - International Symposium on Nuclear Symmetry Energy Online Event, 22 September to 20 October 2021

Systematic analysis of nuclear reactions at intermediate energies with a neutron rich projectile on multiple targets

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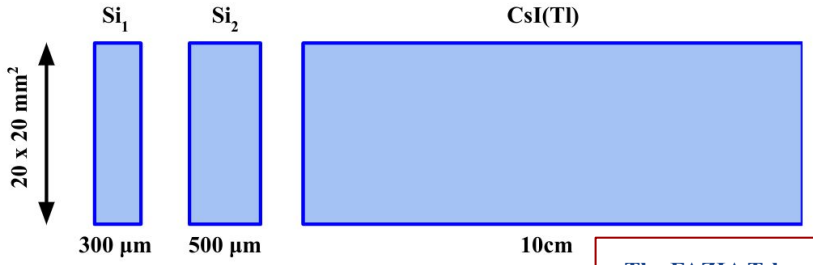
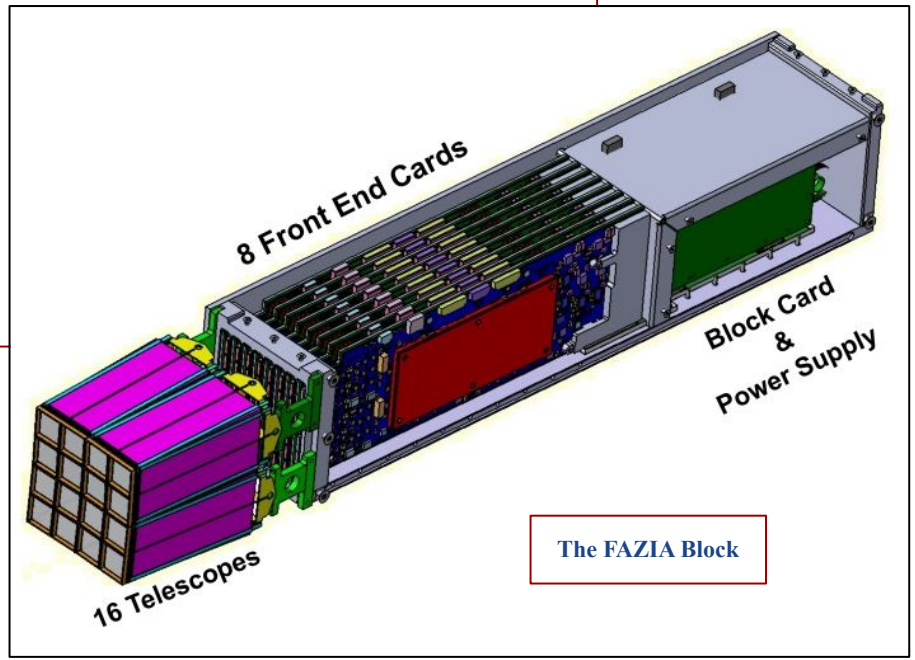
THE FAZIA DETECTOR

- FAZIA (Forward-angle A & Z Identification Array) is a charged particle multi-detector with an excellent mass resolution of up to Z~25 [1].
- Basic detection module of FAZIA is called a FAZIA Block [2,3].
- Block consists of 16 detection telescopes, each made of two Si layers (300 µm and 500 µm) and one CsI scintillator (10 cm) [4].
- Two telescopes connected to one front-end electronics (FEE) card each - total 8 FEE cards.
- Block card for output to data acquisition system and input for power supply.
- Mass resolution helps to calculate the N/Z of detected fragments up to Z~20 can be calculated.



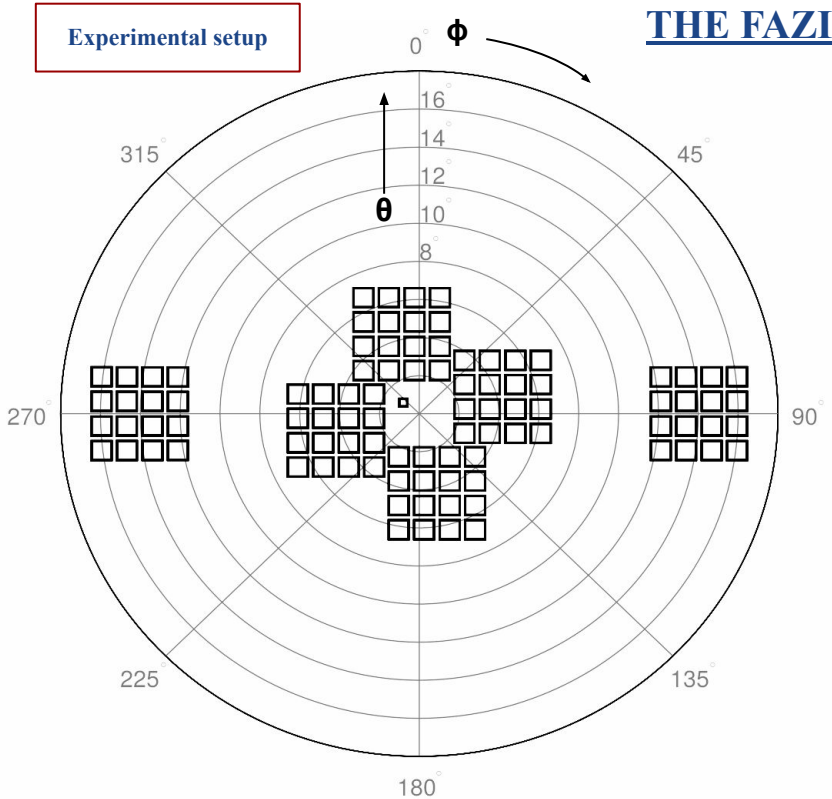
The FAZIA Telescope



The FAZIA Block

THE FAZIA-PRE EXPERIMENT

Experimental setup



- The FAZIA-PRE experiment was performed in February 2018 at the Laboratori Nazionali del Sud (LNS-INFN), Catania, Italy with 6 FAZIA blocks.
- The detector setup had an angular acceptance of θ = 2°-8° & 12°-18°.
- Aiming to investigate the effects of pre-equilibrium neutron emissions from a neutron rich projectile, on N/Z of fragments, mostly coming from excited quasi-projectiles (QP) from semiperipheral collisions.

Table 1

Projectile	$^{48}_{20}$Ca				
E_B [MeV/A]	25			40	
v_B [cm/ns]	6.81			8.51	
Target	$^{12}_{6}$C	$^{27}_{13}$Al	$^{40}_{20}$Ca	$^{12}_{6}$C	$^{27}_{13}$Al
t [μg/cm^2]	239	216	500	239	216
v_{CM} [cm/ns]	5.48	4.4	3.76	6.87	5.53
E^{av}_{CM} [MeV/A]	3.99	5.74	6.18	6.38	9.17
θ_{gr}	0.89°	1.81°	2.69°	0.55°	1.12°

- Table 1: Experimental details of FAZIA-PRE experiment: beam energy (E_B), beam velocity (v_B), target thickness (t), centre-of-mass velocity (v_{CM}), available energy in CM (E_{CM}^{av}) & grazing angle (θ_{gr})
- Table 2: N/Z of individual nuclei present in the experiment.
- Table 3: N/Z of each reaction system in the experiment.

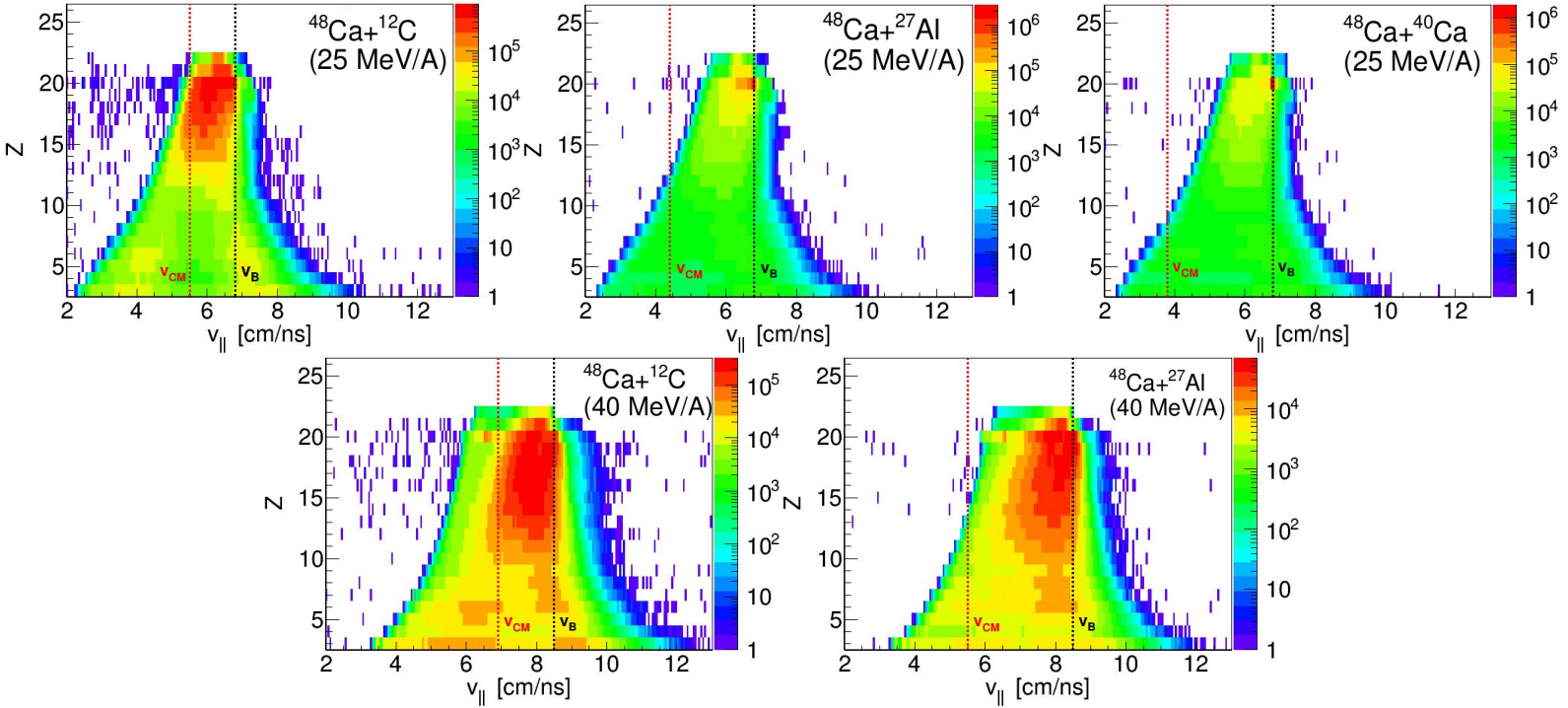
Nucleus	N/Z
^{48}Ca	1.4
^{12}C	1.0
^{27}Al	1.07
^{40}Ca	1.0

Table 2

System	N/Z total
^{48}Ca+^{12}C	1.31
^{48}Ca+^{27}Al	1.27
^{48}Ca+^{40}Ca	1.2

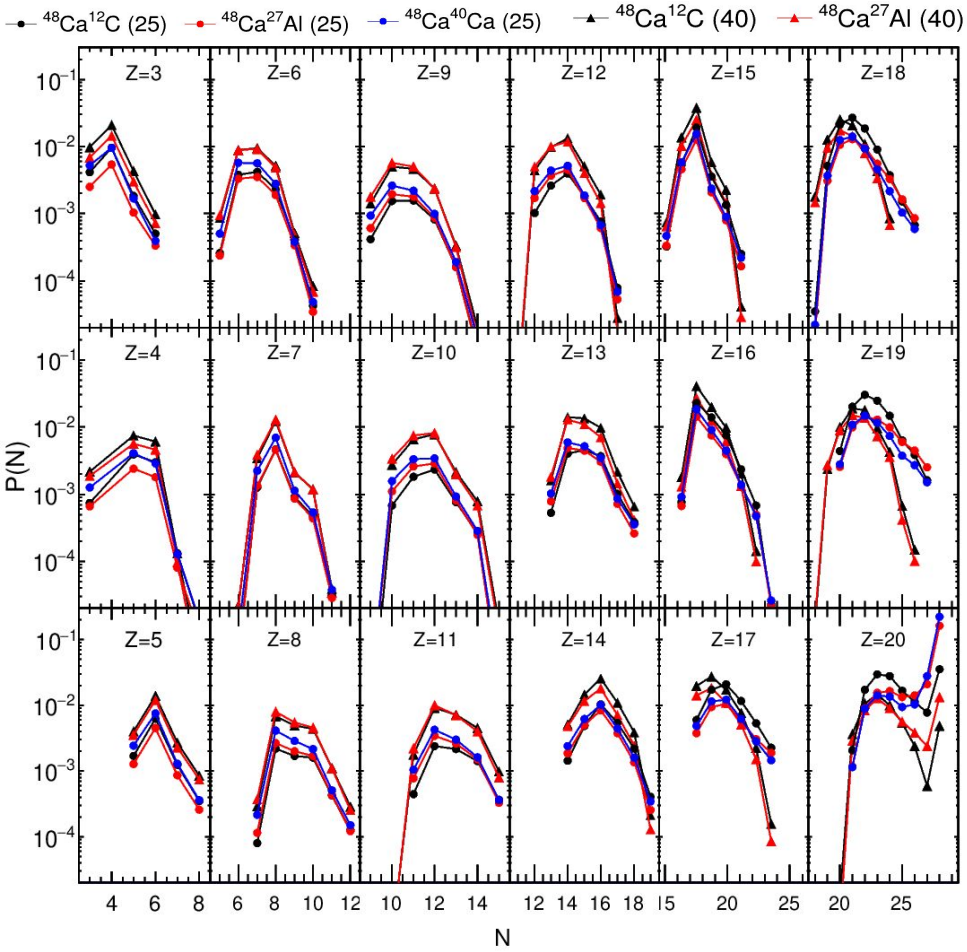
Table 3

THE FAZIA-PRE EXPERIMENT



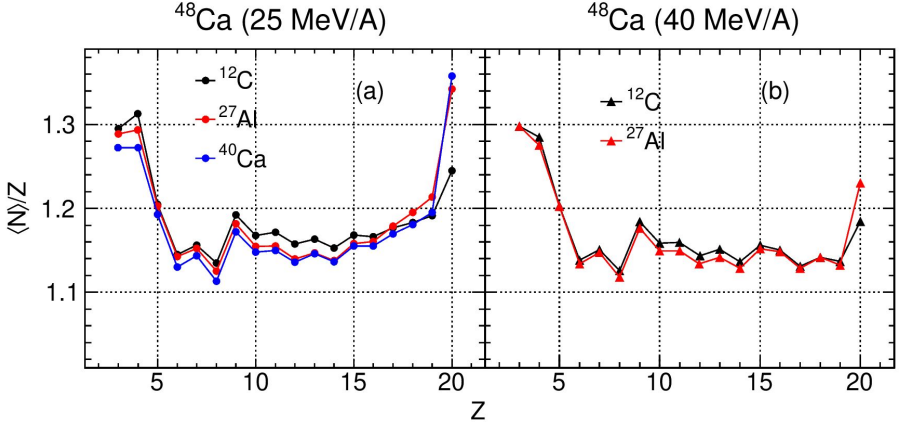
- Charge (Z) and longitudinal velocity ($v_{||}$) correlation show the detection of mostly QP fragments near beam velocities v_B (black dotted lines) corresponding to the beam energies. The centre-of-mass velocities v_{CM} (red dotted lines) are also marked.
- The isotopic resolution of FAZIA up to Z~20 is sufficient to study full range of fragments in this experiment as the projectile is at Z=20 ($^{48}_{20}$Ca).

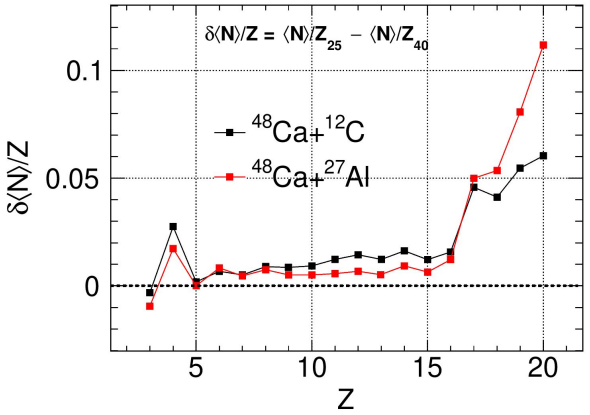
DATA ANALYSIS



- **N distribution plotted using N=A-Z, to obtain the ⟨N⟩ for each Z (= 3 - 20) for all systems from FAZIA-PRE data.**
- **The relative yield of neutrons increases with increasing target mass: more dissipative collisions with increasing target mass.**
- **Systems at 40 MeV/A have higher relative yield than systems at 25 MeV/A up to Z~16 and lesser for Z>16, as one approaches projectile Z (here, = 20): increased multi-fragmentation at higher beam energy.**
- **For Z ≤ 6, relative yield of ^{27}Al target systems is the least at both beam energies due to its lowest proton and neutron separation energies [5]. Light fragments escape in all directions before reaching the detector placed at very forward angles.**
- **For Z=20, the relative yield is highest for all systems at N=28, pointing towards an abundance of projectile-like fragments (PLFs).**

DATA ANALYSIS





- ⟨N⟩/Z plotted as a function of Z w.r.t. target mass for both beam energies. The range of fragment ⟨N⟩/Z stays between that of projectile and target.
- The fragment ⟨N⟩/Z observed to be decreasing with increasing target mass: with increasing target mass, more dissipative collisions lead to higher rate of isospin equilibration, decreasing the fragment ⟨N⟩/Z.

- For beam energy dependence, the difference between fragment ⟨N⟩/Z from 25 and 40 MeV/A systems was taken:

$$\delta\langle N\rangle/Z = \langle N\rangle/Z_{25} - \langle N\rangle/Z_{40}$$

- Expected → the interaction time and nucleon exchange between the participants reduces with increasing beam energy. Thus, an N-rich projectile should produce fragments with relatively higher ⟨N⟩/Z at higher beam energy because of detection of mostly QP region.
- Observed → the δ⟨N⟩/Z is positive for almost all Z: the fragment ⟨N⟩/Z decreases with increasing beam energy.
- Explanation → pre-equilibrium neutron emission increases with beam energy [6], thus decreasing overall N/Z of the system and consequently the fragment ⟨N⟩/Z.

SUMMARY & CONCLUSION

- **FAZIA is a charged particle multi-detector with an excellent mass resolution of up to Z~25.**
- **FAZIA-PRE experiment was performed at LNS-INFN, Catania in Feb 2018 aiming to investigate effects of pre-equilibrium neutron emissions from a neutron rich projectile, on N/Z of fragments.**
- **^{48}Ca projectile was bombarded on ^{12}C, ^{27}Al and ^{40}Ca targets at 25 MeV/A and on ^{12}C and ^{27}Al targets at 40 MeV/A.**
- **The data obtained mostly had QP fragments due to very forward angles ($\theta = 2^{o}$-8^{o} & 12^{o}-18^{o}) of the detector setup.**
- **A full range of N distributions for Z=3-20 was obtained for all reaction systems as the projectile Z was within the particle identification capability of FAZIA.**
- **The fragment $\langle N \rangle / Z$ was investigated w.r.t. target mass and beam energy.**
- **The fragment $\langle N \rangle / Z$ was found to be decreasing with increasing target mass.**
- **The fragment $\langle N \rangle / Z$ was found to be decreasing with increasing beam energy.**

The FAZIA Collaboration

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THANK YOU !