Identification of neutron-rich Zr isotopes with AGATA-PRISMA

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Development of the nuclear structure of neutron–rich isotopes in the Z∼38 region populated by heavy–ion induced fission

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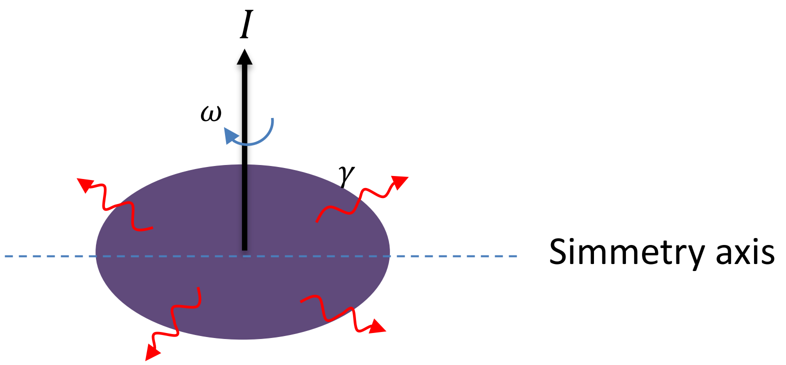
Introduction

- Description of the de-excitation process on a nuclei: A main goal on nuclear structure.
    - Does it goes trough a Collective or a Single Particle de-excitation? Or a mixing?.
    - How can the nuclear models be tested with the measurement of experimental observables? (γ-radiation, life-times, etc.).

- A <u>simple</u> perspective for even-even nuclei:

Rotation is only possible for deformed nuclei!



$$H_{rot} = \frac{I^2}{2\mathfrak{I}}$$

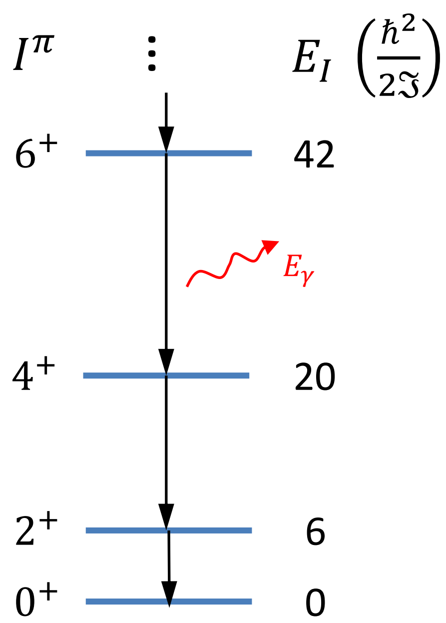
I = Collective Angular moment
$\mathfrak{I}$ = Moment of Inertia

$$I = 0,2,4,\ldots$$

Introduction

- Energy spectra for a nucleus with collective rotations:

$$H_{rot} = \frac{I^2}{2\Im} \longrightarrow E_I = \frac{\hbar^2}{2\Im} I(I+1)$$



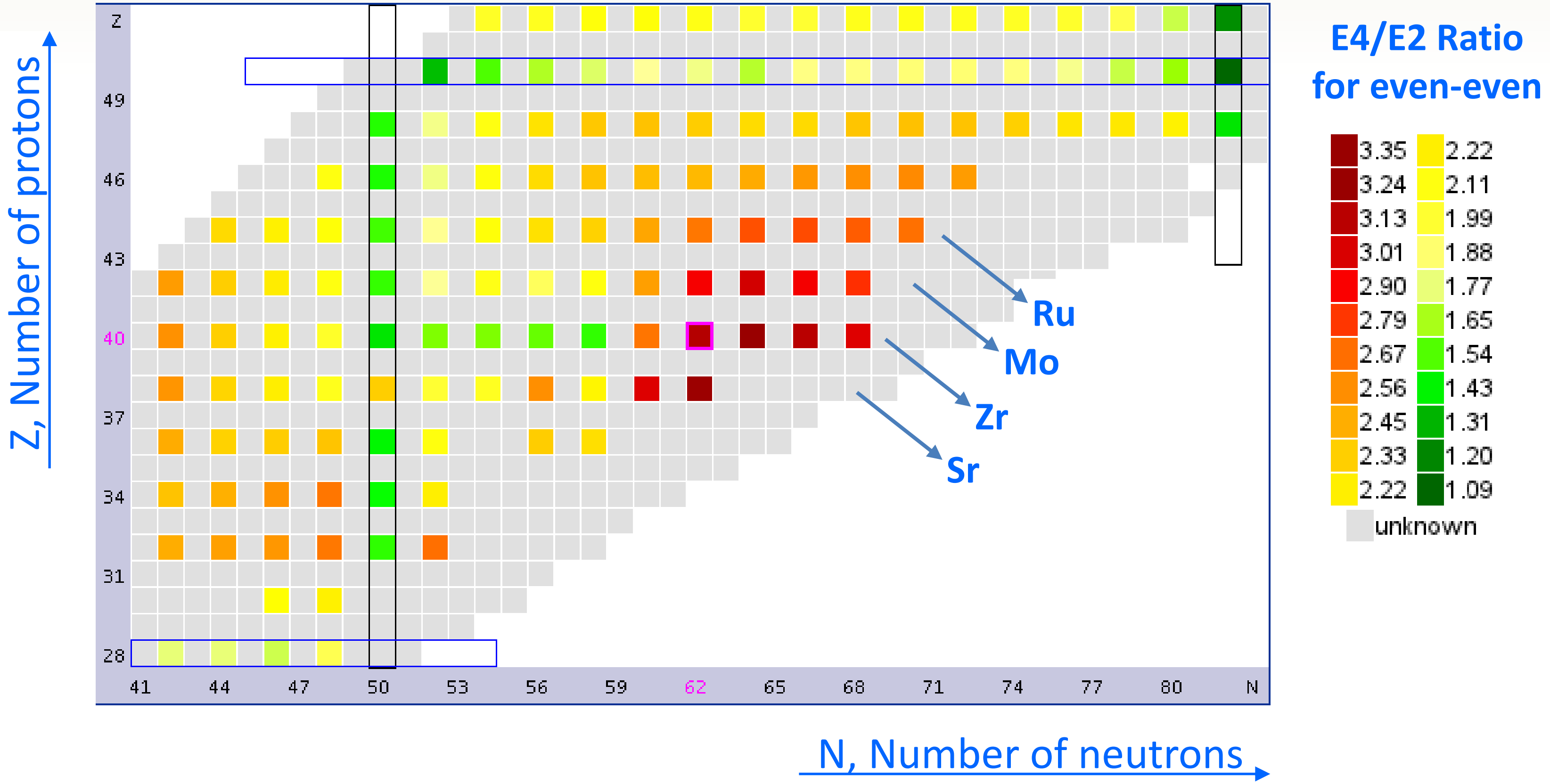
- If a nucleus shows this sort of spectrum means that its deformation is mainly axial.
- E_4/E_2 ratio as empirical criteria for the nucleus' deformation:

$$E_4/E_2 = \frac{E_\gamma(4^+ \to 2^+)}{E_\gamma(2^+ \to 0^+)} = \frac{20-6}{6-0} = 2{,}33$$

This can be measured on the lab!

Shape evolution for neutron-rich isotopes with Z~38

- The even-even isotopes in the Region of Z~40, present an interesting change in the nuclear deformation as the number of neutrons changes.
- Zr isotopes exhibit the fastest shape transition found in the nuclear landscape.



[www.nndcnbnl.gov/char]

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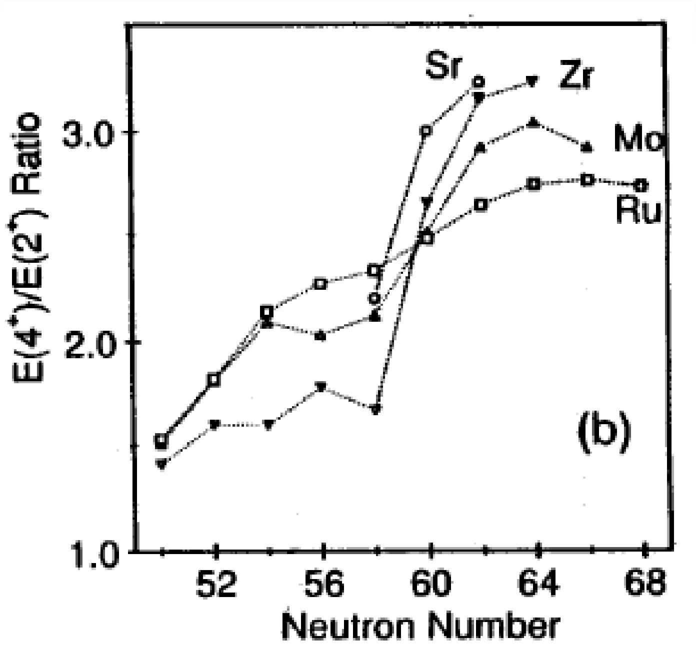
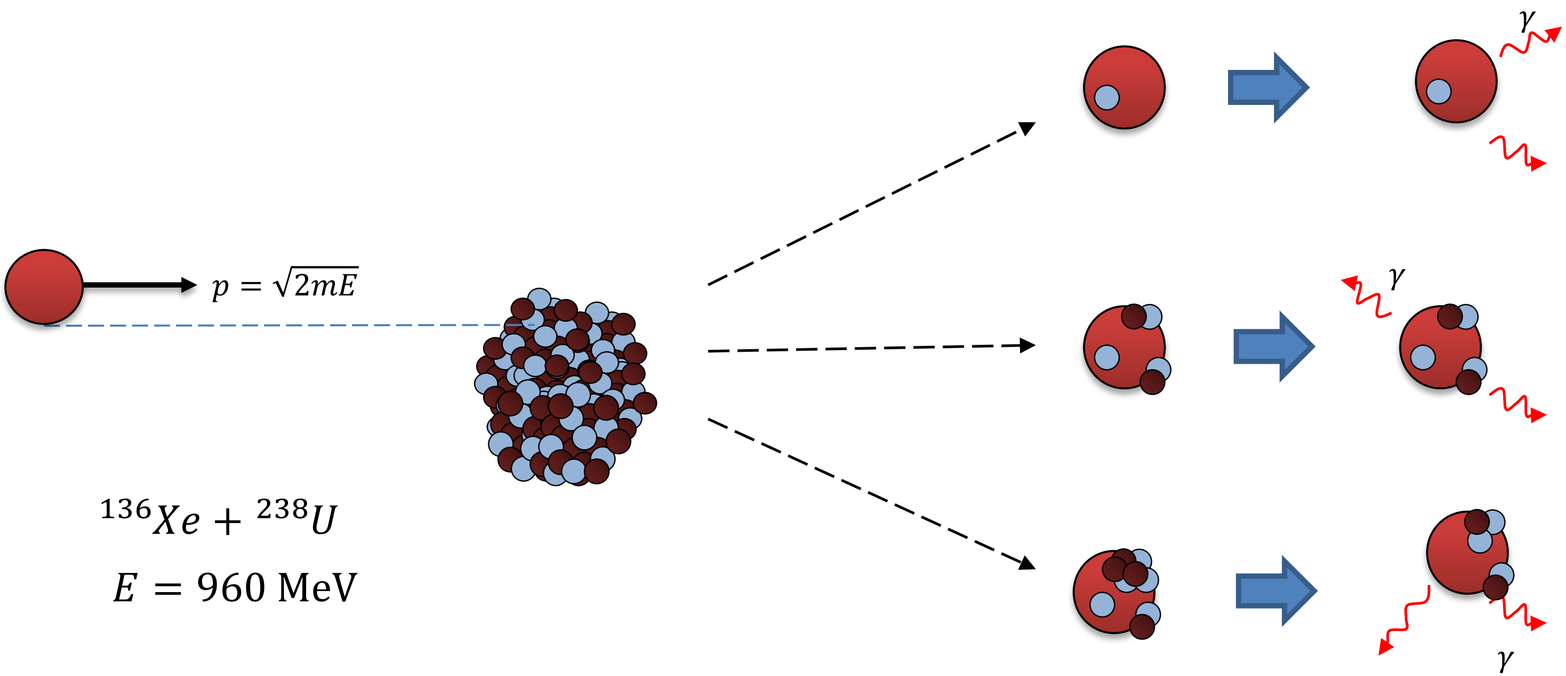


[J.L. Durell. *Proc.Int.Conf. on Spectroscopy of Heavy Nuclei*, 1990]

- More Information about Sr, Zr and Mo isotopes is needed to extend the study in this region!

Heavy-ion induced fission reactions

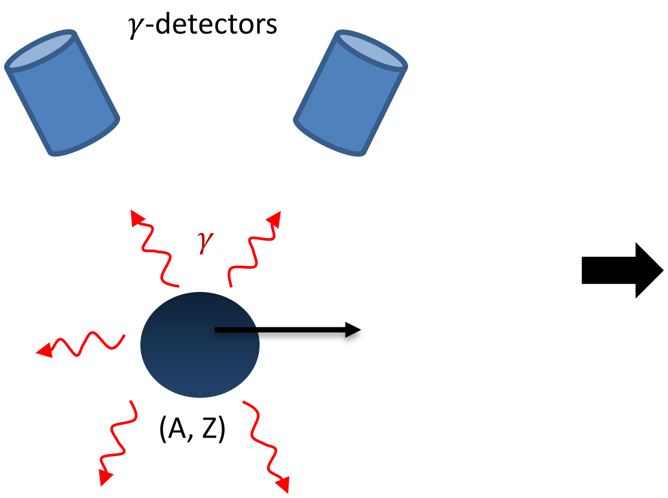
- Multinucleon transfer reactions:
  - Happens when E is much more than the Coulomb Barrier .
  - Similar **b** as in F-E reactions but the interaction time is shorter ($\sim 10^{-22}s$).
  - Both nuclei briefly graze each other exchanging some nucleons.
  - The nucleons exchange mechanism is not completely understood yet.
  - A small fraction of E is transformed in excitation energy of the exit channels



- **This reactions are able to produce neutron-rich isotopes not accessible through FER.**

γ-particle coincidence experiment

- With γ -radiation is possible to study the nuclear structure of an isotope.
- Multi-nucleon transfer reactions have more than just one *exit channel.*
- To study one particular channel it must be selected only its emitted γ-rays.
- An experimental setup that enables γ-particle coincidence is necessary.



- Lifetimes.
- Deformations.
- Band structures.
- Single particle excitations.
- etc.

γ-particle coincidence experiment

- With γ-radiation is possible to study the nuclear structure of an isotope.
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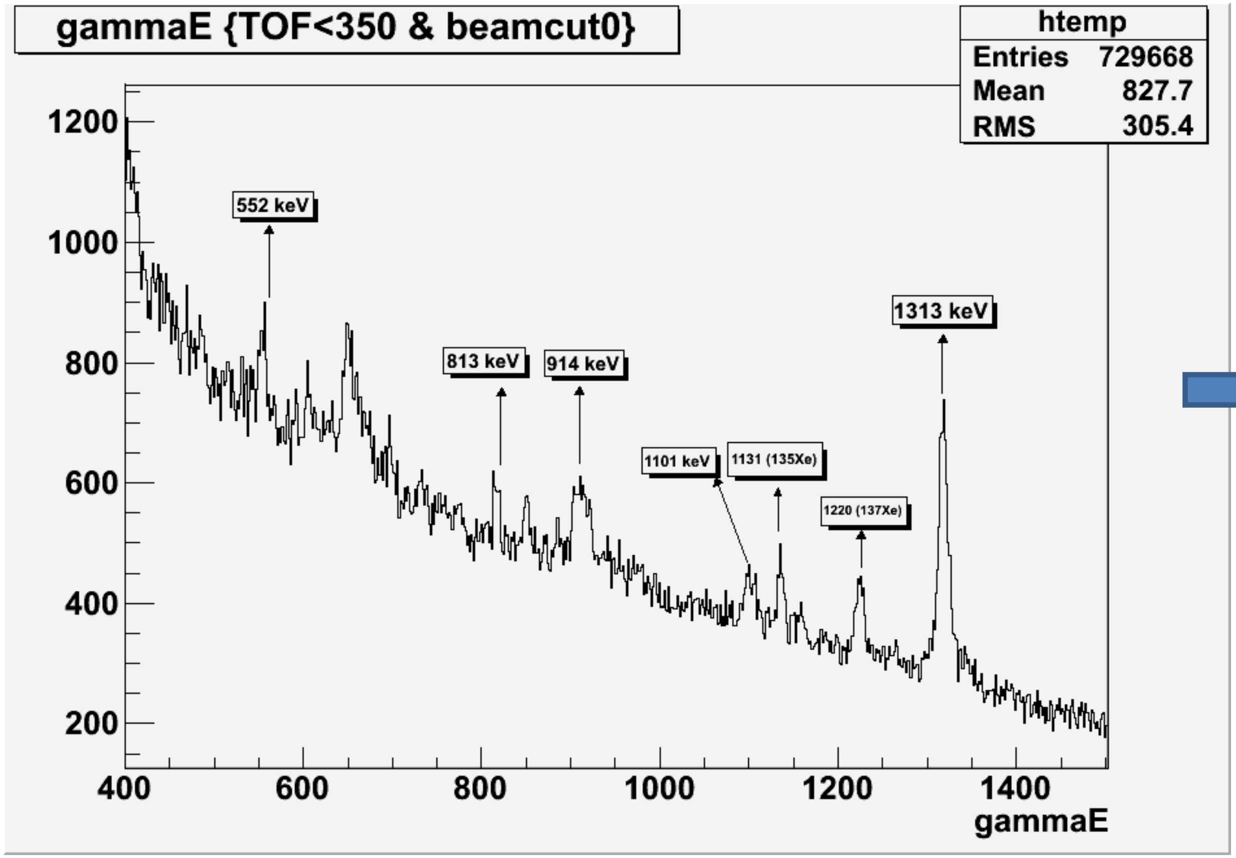
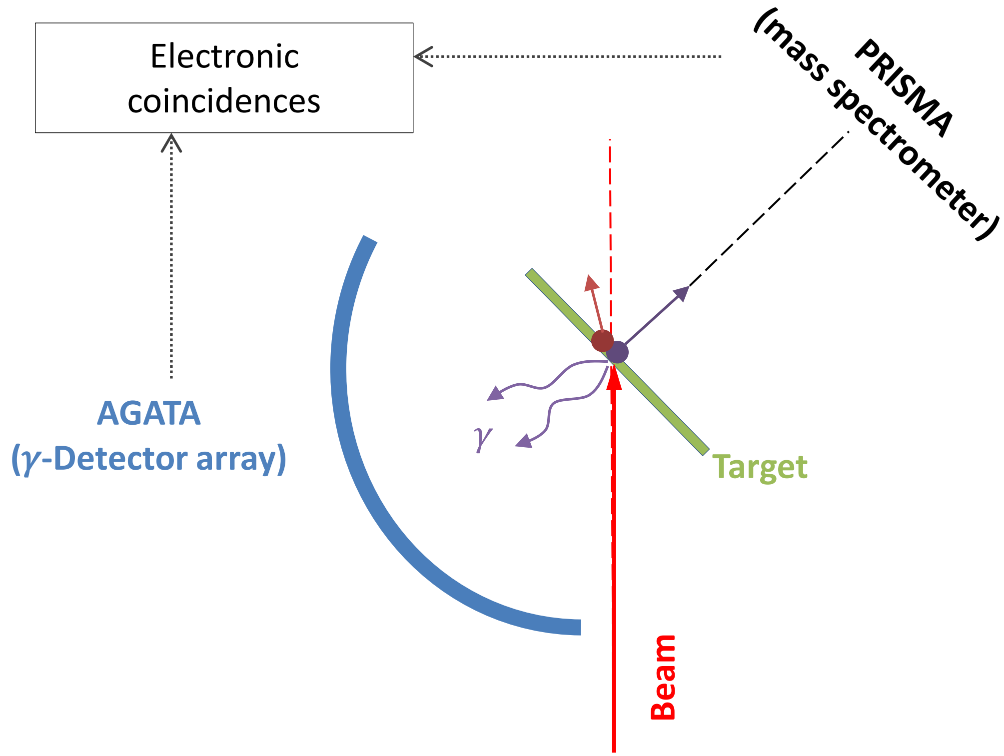


γ-espectrum obtained of the scattered Xe isotopes in the $^{136}Xe + {}^{238}U$ reaction.

The spectra of different isotopes is mixed!

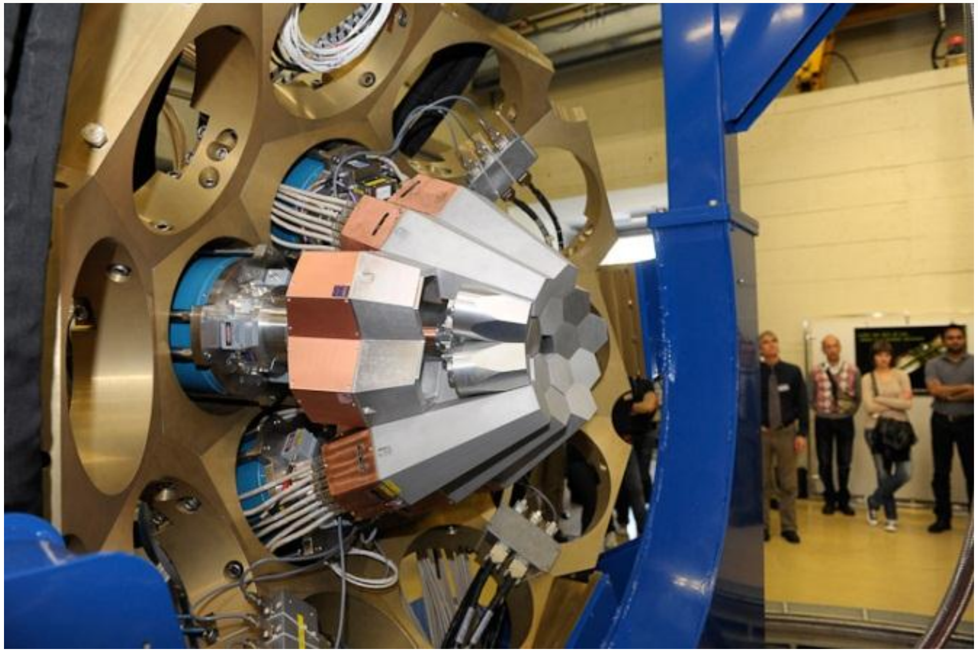
γ-particle coincidence experiment

- With γ-radiation is possible to study the nuclear structure of an isotope.
- Nuclear reactions in general have more than just one *exit channel.*
- To study the physics of a single produced nucleus is necessary to select only its emitted γ-rays.
- An experimental setup that enables γ-particle coincidence is necessary.



AGATA-PRISMA setup

- AGATA Demonstrator:

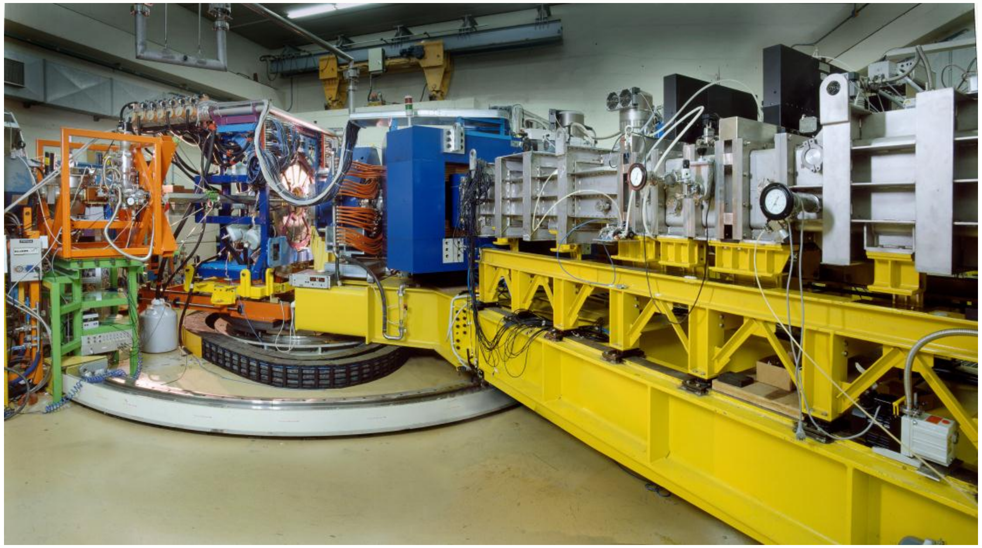


[http://www.lnl.infn.it/~spesweb/index.php/research-on-nuclear-physics/144-agata]

- γ-detector array solely built from HP Ge detectors.
- It enables the reconstruction the γ-ray trajectory via the technique of γ-ray tracking.
- The efficiency of the 4π-array is expected to be close to 50%
- AGATA-Demonstrator: is a subset of 5 detector units with full tracking capability.
- It was placed at LNL (Legnaro, Italy) during our experiment, currently is «Living» at GSI till 2014.

AGATA-PRISMA setup

- PRISMA Spectrometer:

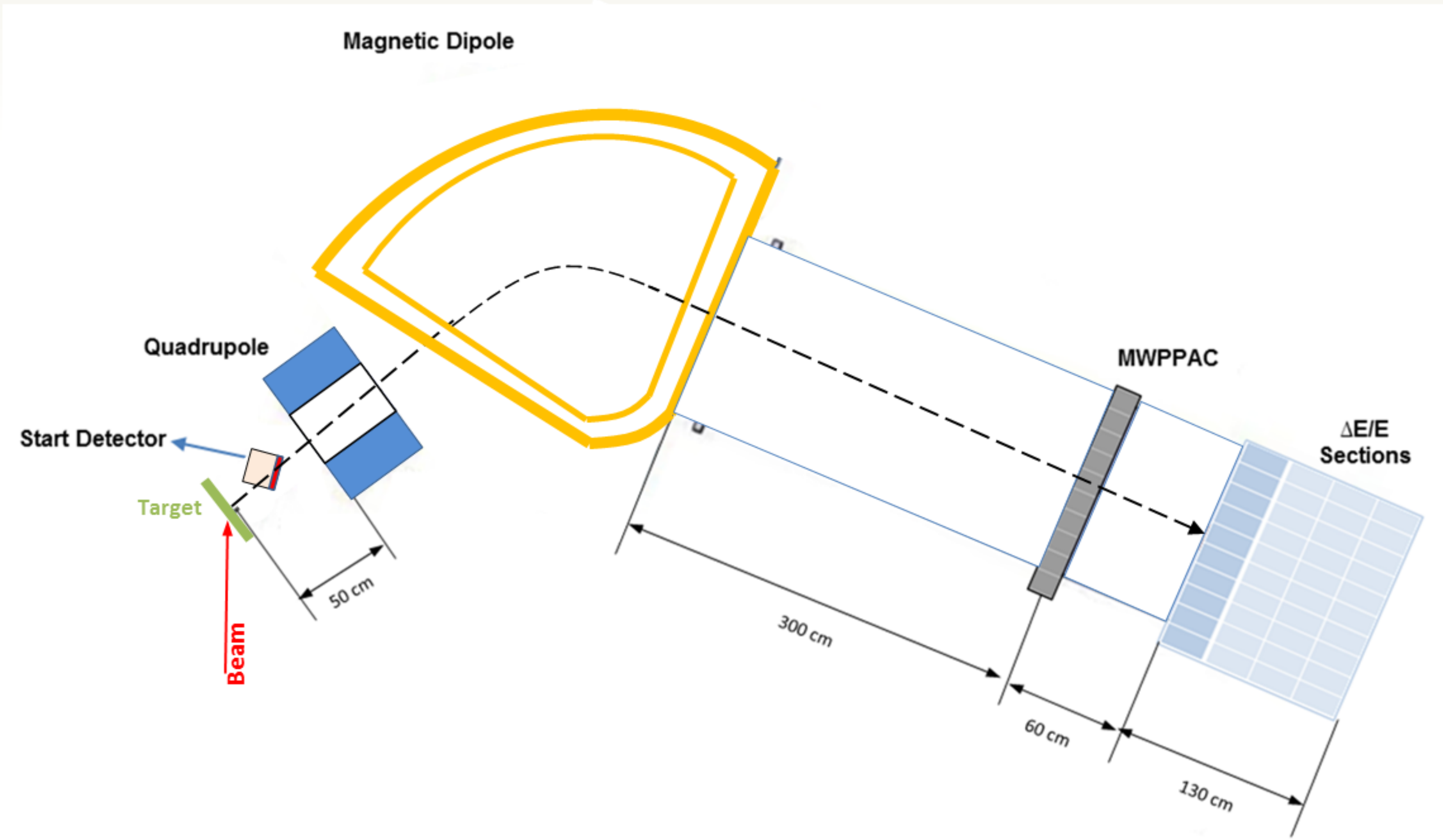


- Provides the needed information to identify the ejectiles of the nuclear reactions.
- The large solid angle acceptance enables to perform spectroscopic studies of low cross section events. $(\Delta\theta = \pm 6°, \Delta\psi = \pm 11°)$
- The Quadrupole-Dipole configuration separates ions by magnetic rigidity.
- Placed at LNL (Legnaro, Italy).

[http://clara.lnl.infn.it/images/LNLprisma19.jpg]

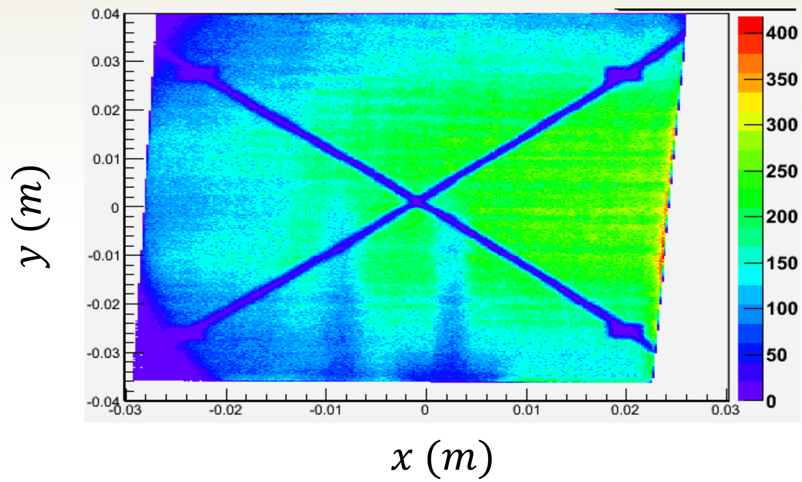
PRISMA spectrometer

- PRISMA Spectrometer:

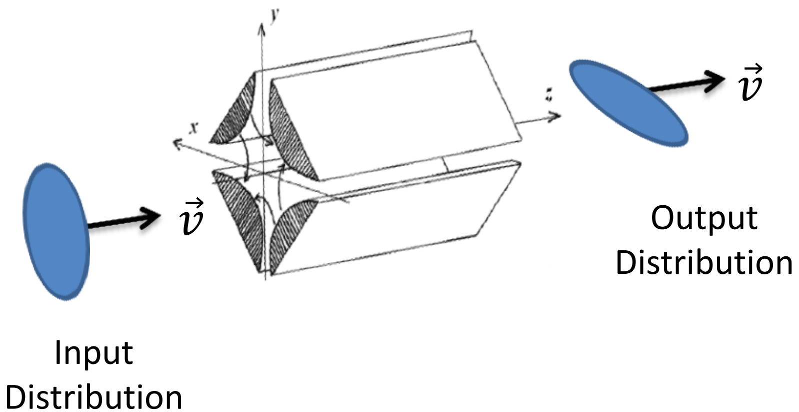


PRISMA spectrometer

- Start Detector:
  - 2D-Position Histogram of the input isotopes on PRISMA.
  - Provides the Start Signal to get the Time-Of-Flight.
  - Its signals are used to obtain length's path for each event.

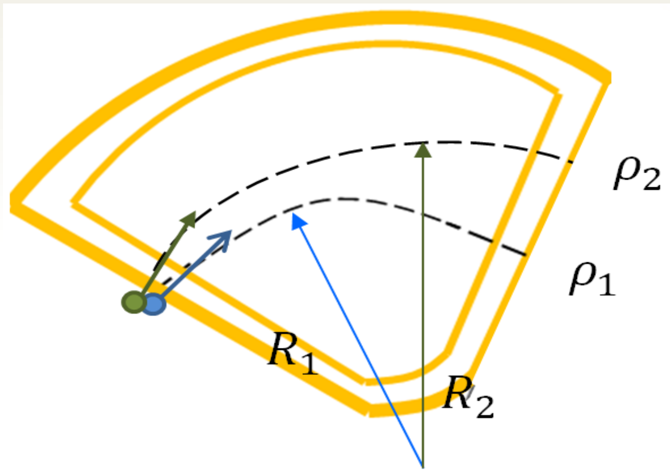


- Magnetic Quadrupole:
  - $\vec{F} = (bx)\vec{\imath} + (-by)\vec{\jmath}$
  - Its purpose is focussing the input distribution onto the vertical plane.

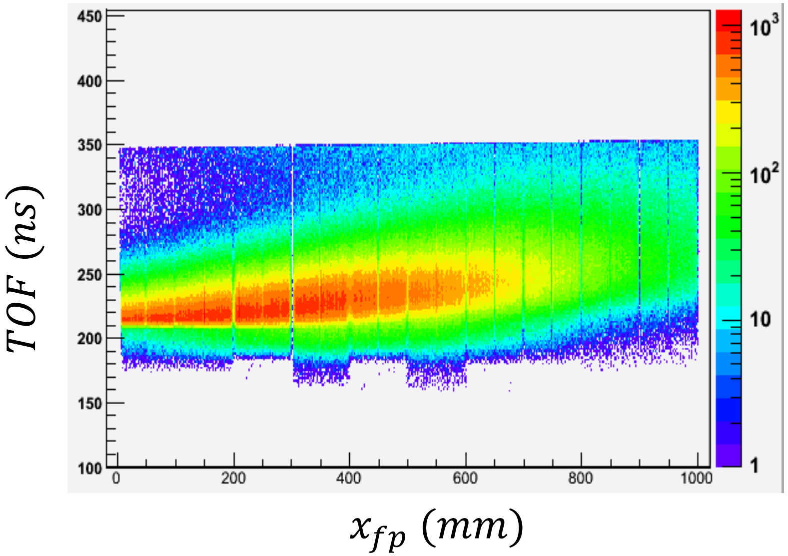


PRISMA spectrometer

- Magnetic Dipole:
  - $qBV = mv^2/R.$
  - $mv/q = BR$
  - $\rho_m = BR$
  - Ions with different magnetic rigidity ρ_m have different paths on the dipole.



- Focal Plane Detector (MWPPAC):
  - Provides position at the PRISMA's focal plane, necessary to calculate length's path for each event .
  - Provides the Stop Signal to get the Time-Of-Flight.
  - 2D-Histogram of TOF vs x_{fp}



PRISMA spectrometer

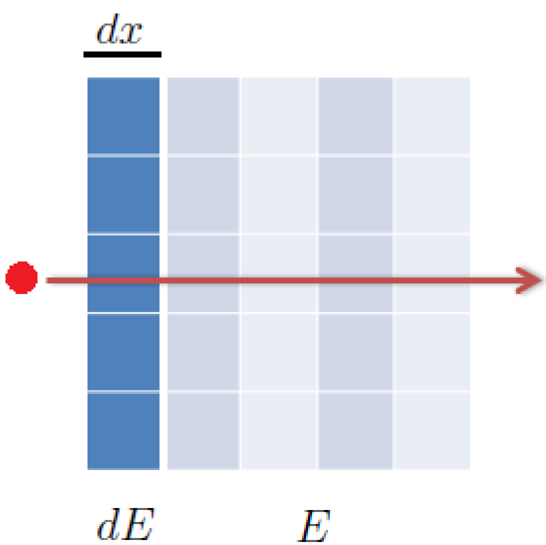
- ΔE-E detectors:
  - The energy lost by heavy ions when they go through matter is ruled by the Bethe-Bloch formula,

$$\frac{dE}{dx} = (eZ)^2 \frac{N_0 z \rho}{A m \epsilon_0} \frac{1}{(\beta c)^2} \left[\ln \left(\frac{2mc^2\beta^2}{I(1-\beta^2)} \right) - \beta^2 \right]$$

  - For non-relativistic cases (or slightly relativistic with $\beta \leq 0.1$), this equation is expressed as:

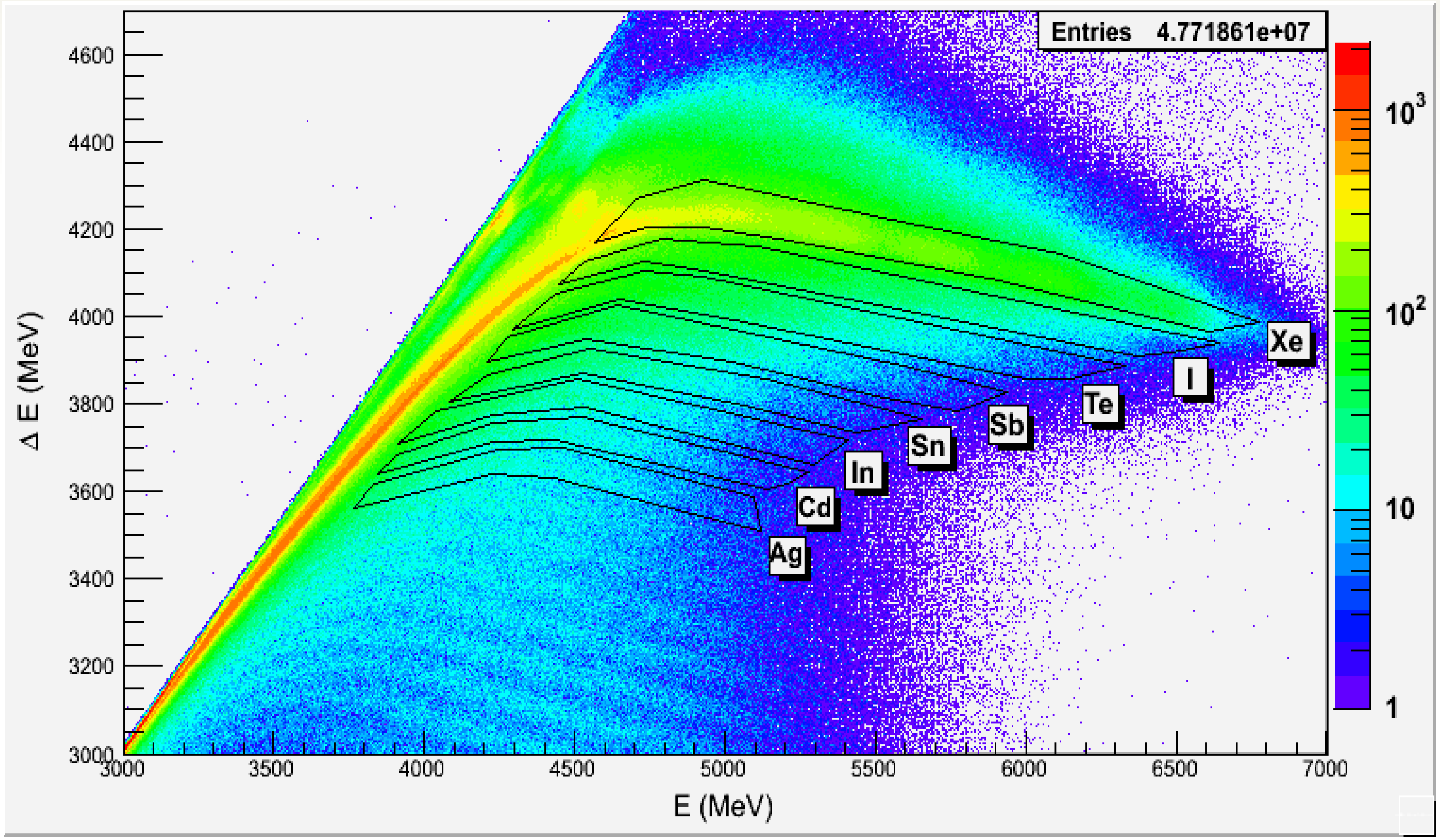
$$\frac{dE}{dx} \propto \frac{MZ^2}{E}$$

  - Practical experimental technique to distinguish nuclei with different Z:



Isotopes' identification process

- ΔE-E detectors:



- Events with same Z value are gathered by the black polygons (graphical cuts).
- From now on, the analysis is performed with only one sort of isotope (Zr).

Isotopes' identification process

- Charge state selection.
  - Combining the expressions

$$E = \frac{1}{2}mv^2, \qquad \frac{mv^2}{R} = qvB,$$

  - An expression to disentangle events with different charge-states is obtained:

$$\begin{aligned} \frac{2E}{R} &= qvB, \\ E &= \frac{qB}{2}(Rv) \end{aligned}$$

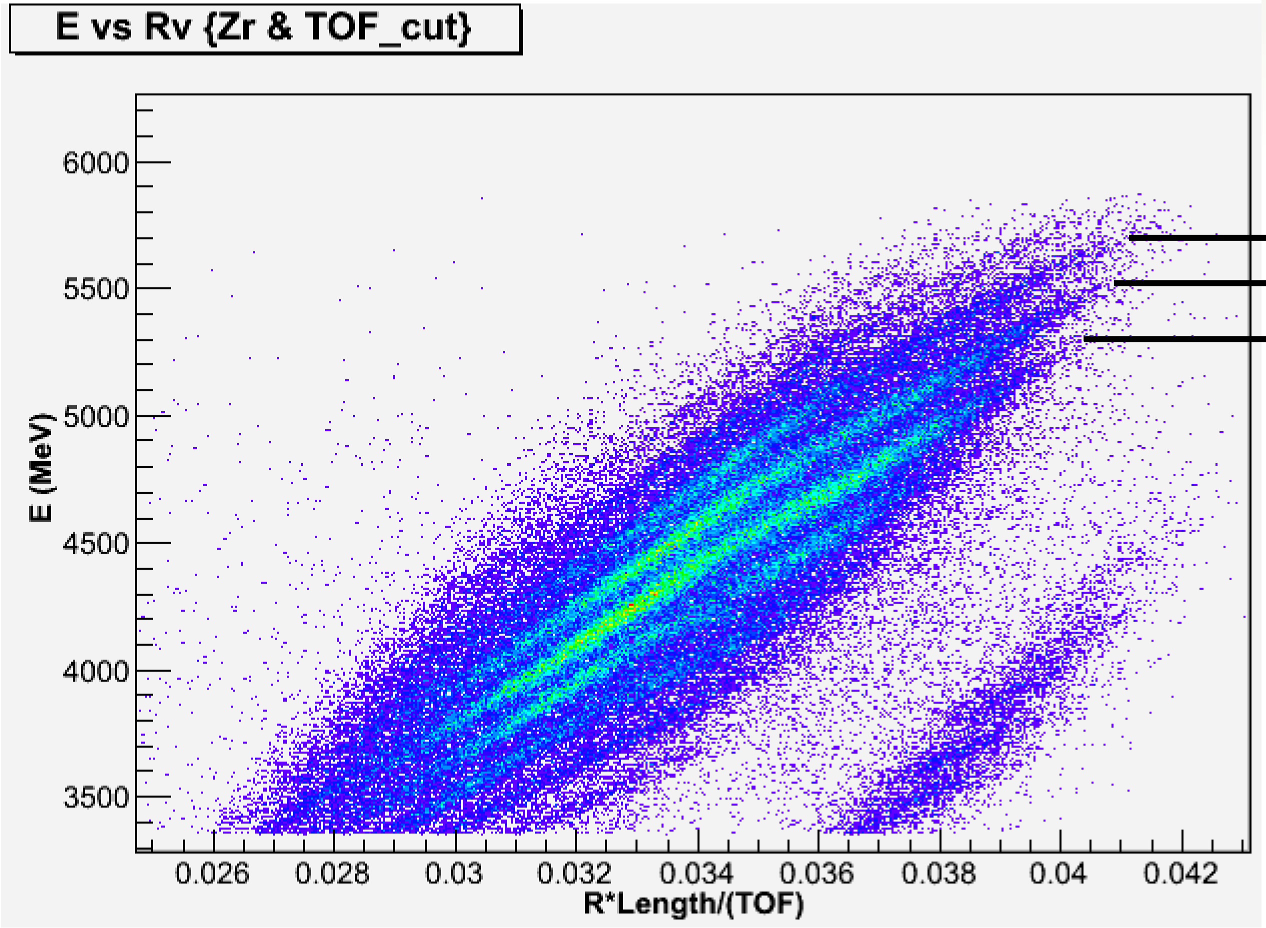
  - The velocity is obtained from the ratio between the path length and TOF, finally:

$$E = \frac{qB}{2}\left(\frac{RD}{TOF}\right)$$

➡ **This can be checked out from the experimental data**

Isotopes' identification process

- Charge state selection.

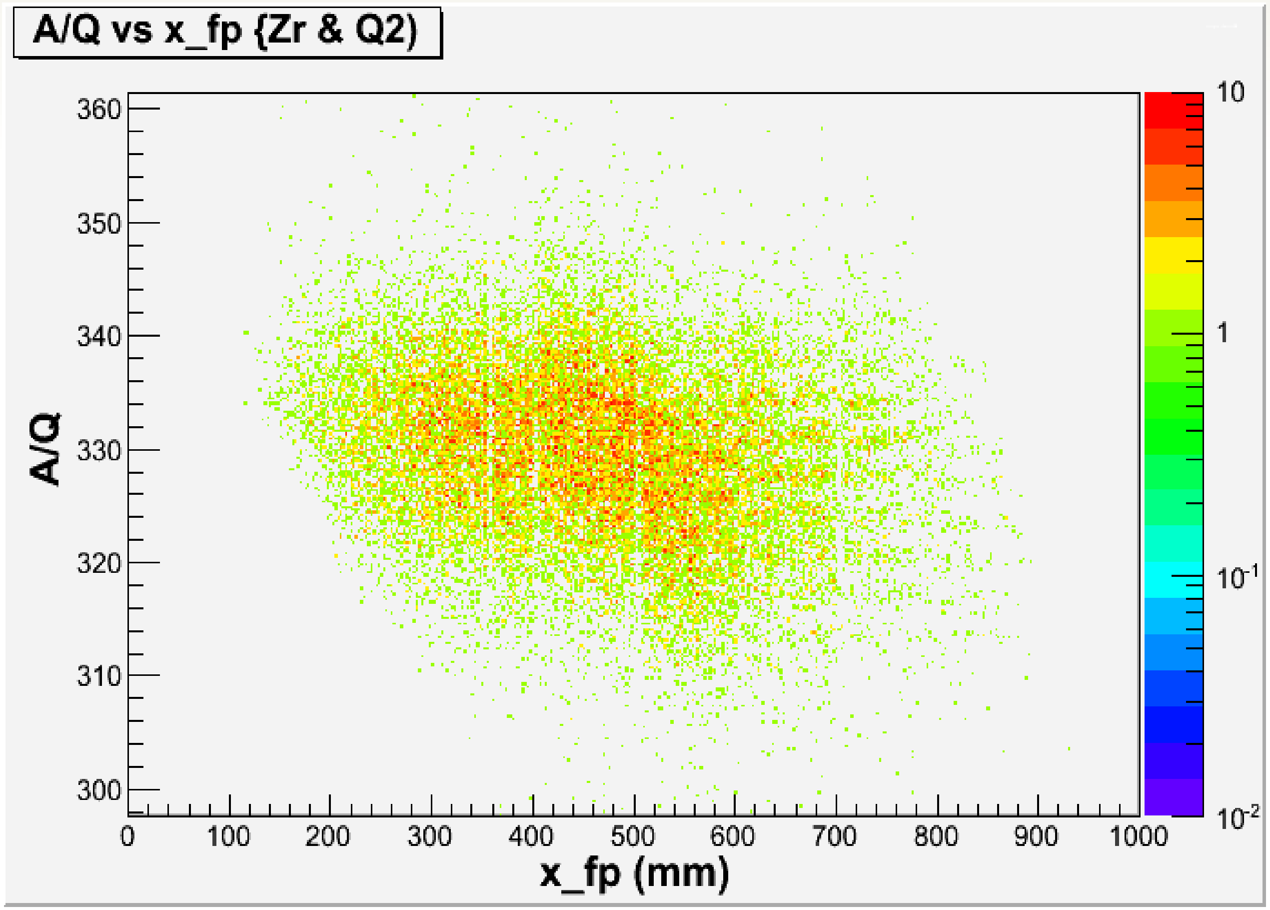


$$q1 = 35$$
$$q2 = q1 - 1 = 34$$
$$q3 = q1 - 2 = 33$$
$$\vdots$$

$$E = \frac{qB}{2}\left(\frac{RD}{TOF}\right)$$

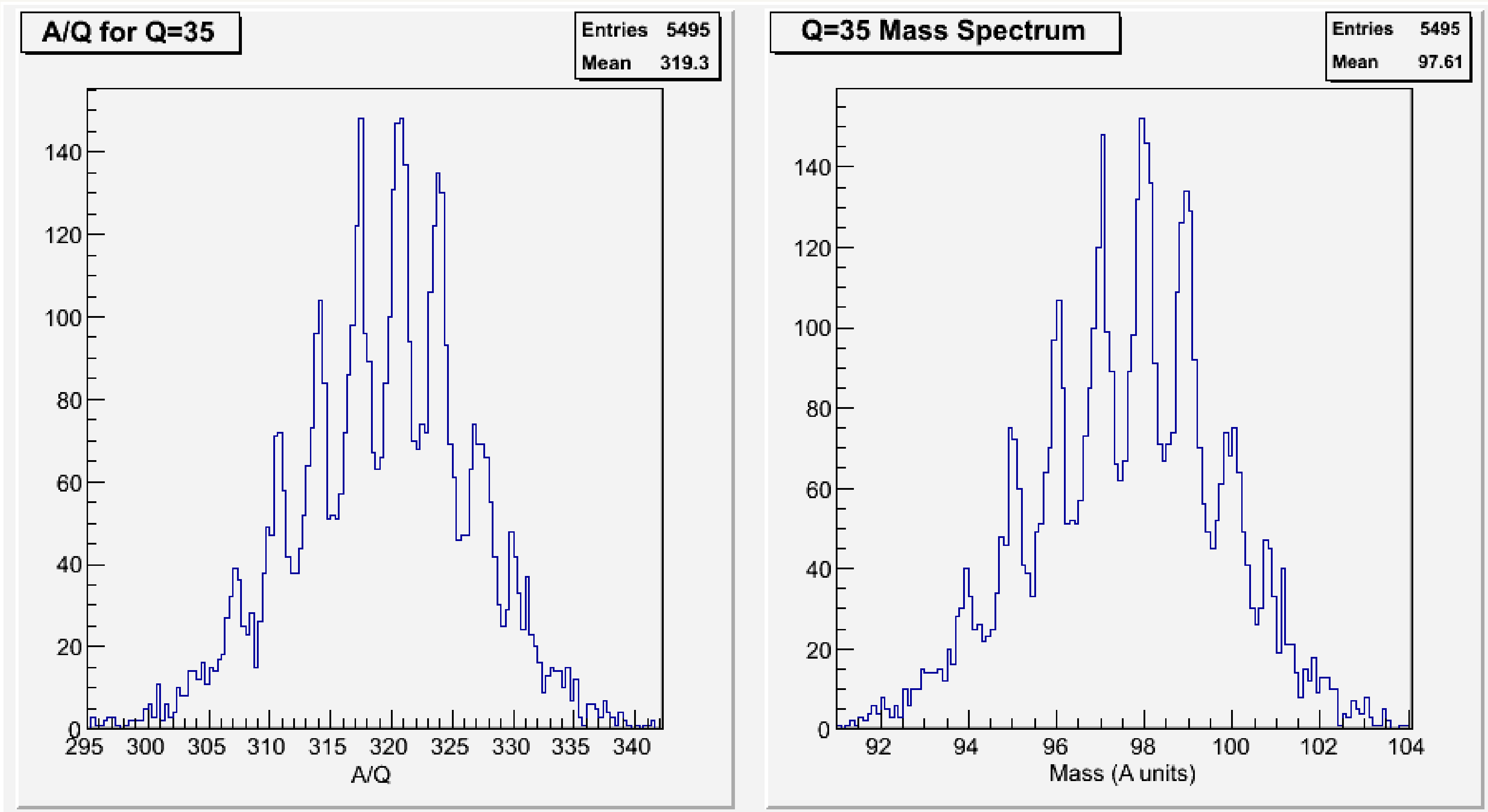
Isotopes' identification process

- A over Q separation.



Isotopes' identification process

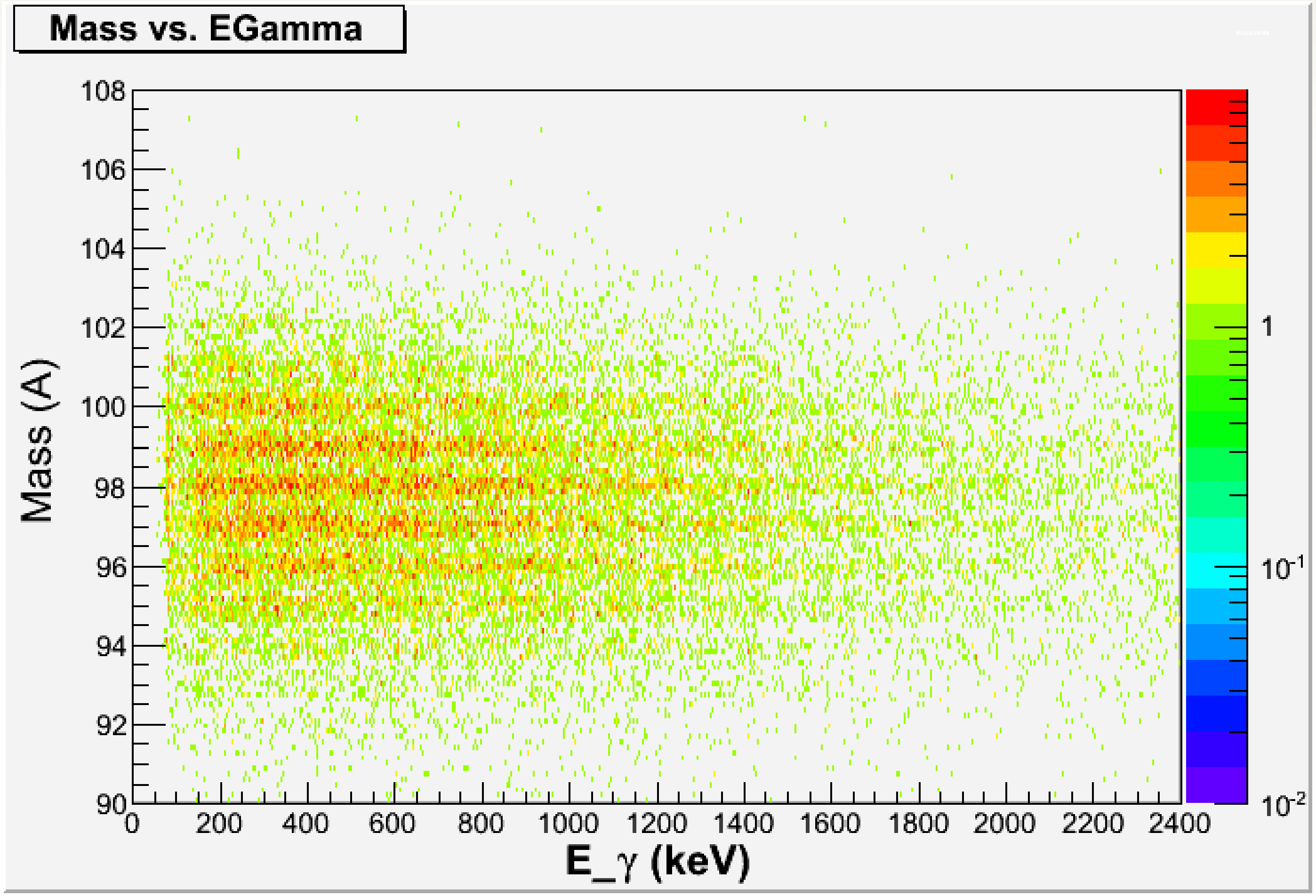
- Mass Calibration.



- Each A/q spectrum is calibrated to a mass units (linear calibration).

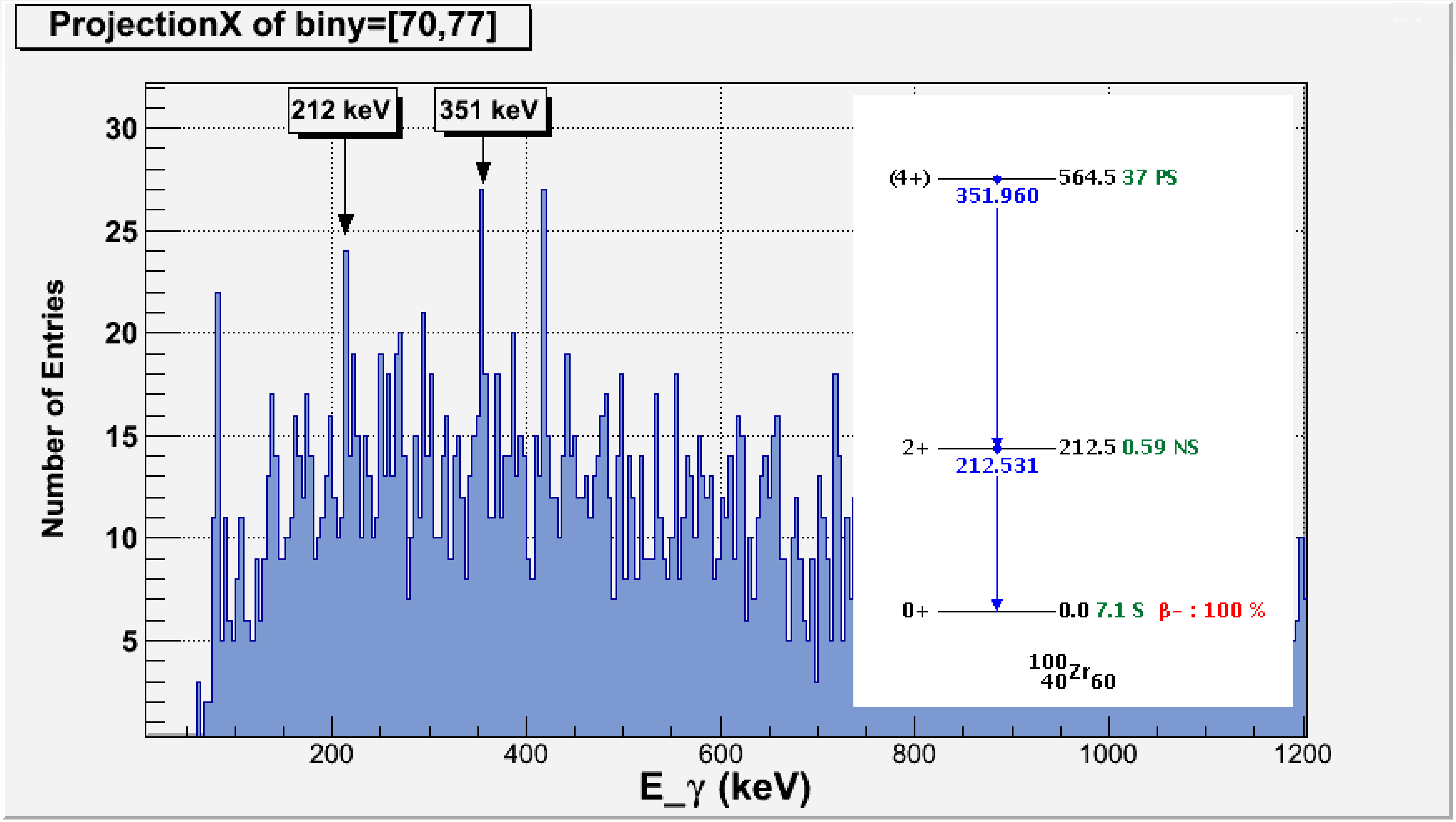
Isotopes' identification process

- Mass-γ Energy Matrix.



Results

- γ-rays in coincidence with mass 100 and 102 for Zr isotopes.



Results

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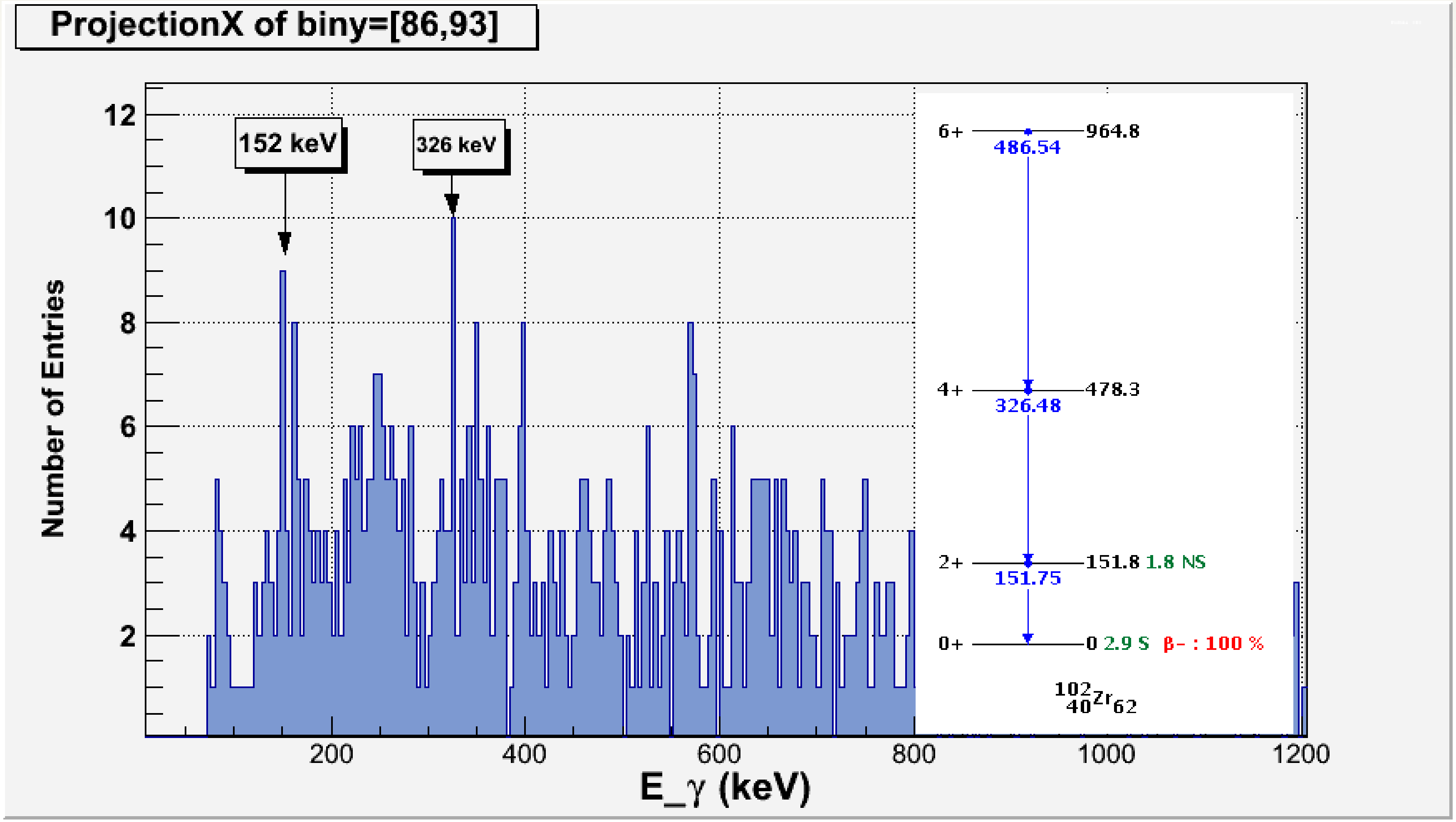

Conclusions

- ***First*** results are clear evidence for the population of 100Zr and 102Zr. Approx. 15% of the statistics has been processed.
- Problems with the pressure in the IC array for $x_{fp} < 600$, prevents a clear A/Q separation.
- It is possible to identify the peak of 104Zr in the current Mass Spectrum. Therefore, it is possible to get some coincident γ-rays after the analysis of the full statistics.
- Construction of γ- γ matrices to get clean spectra is one of the next steps in the analysis.

MUCHAS
GRACIAS!!