Fission yield measurements at GANIL with VAMOS and PISTA

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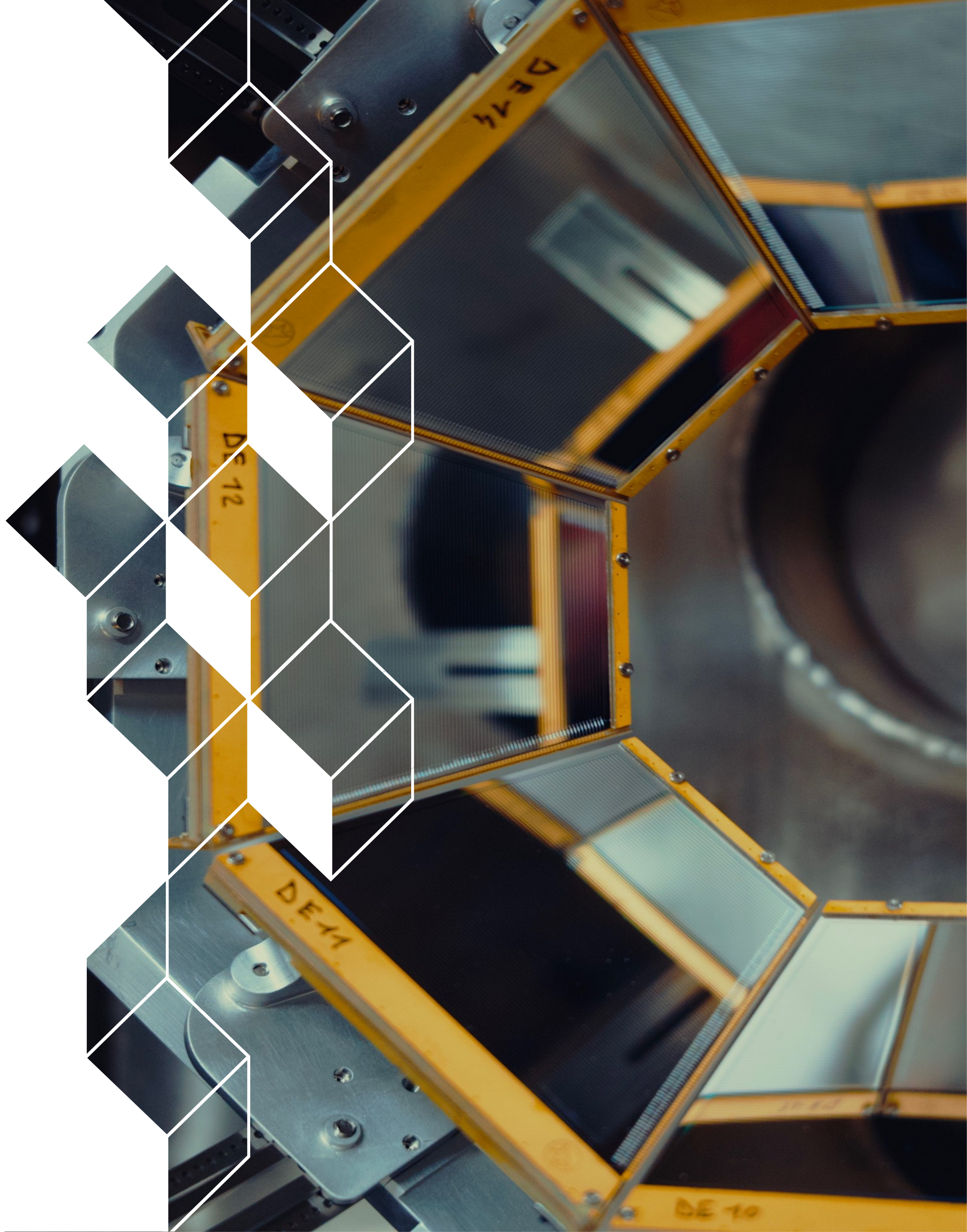
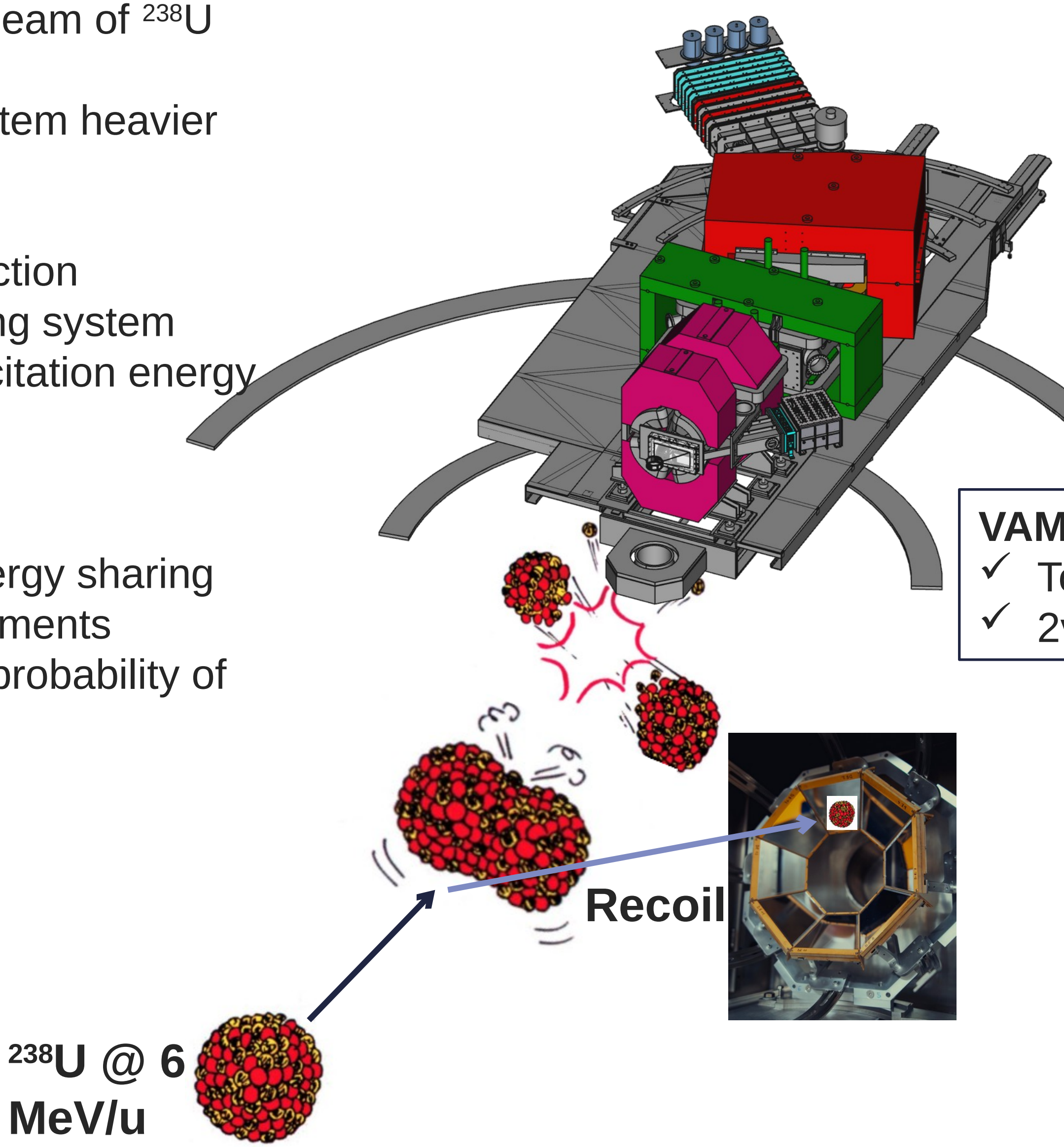


What can be done at GANIL with VAMOS

- Inverse kinematics using a beam of ^{238}U around Coulomb barrier
  - ✓ Access to fissioning system heavier than ^{238}U
- Transfer-induced fission reaction
  - ✓ Selection of the fissioning system
  - ✓ Measurement of the excitation energy event by event
- Gamma-ray spectrometer
  - ✓ Probe the excitation energy sharing between the fission fragments
  - ✓ Evaluate the excitation probability of the target-like nuclei

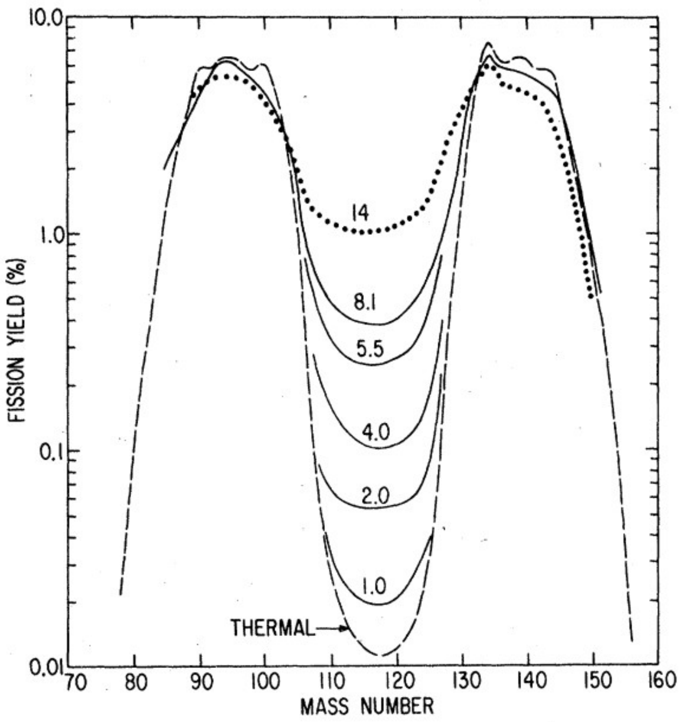
VAMOS
- ✓ Direct and complete isotopic fission fragment yields Y(A,Z)
- ✓ Precise center-of-mass fission fragment velocities

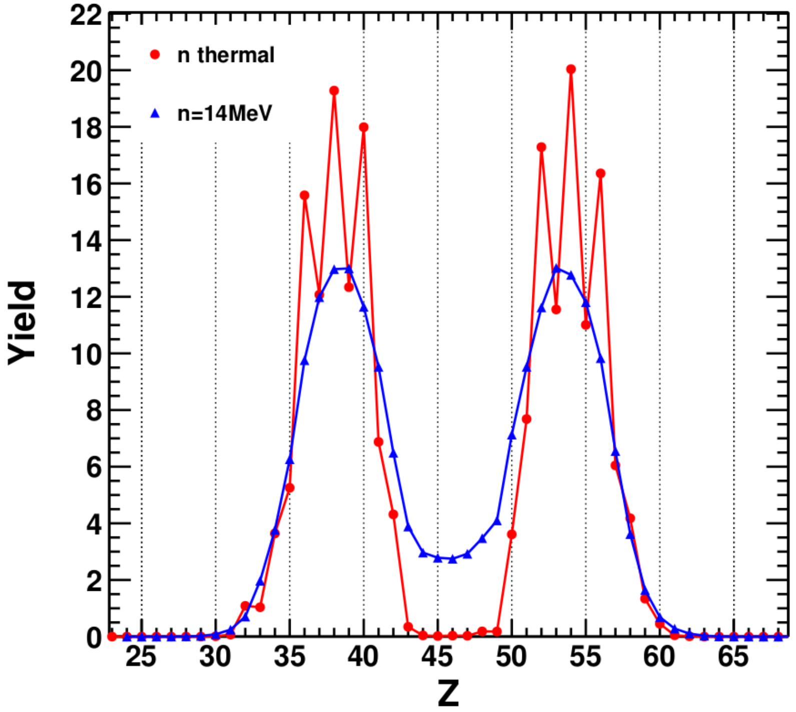


VAMOS second arm
- ✓ Total kinetic energies
- ✓ 2ν measurement

PISTA
- ✓ Characterization of the fissioning system
- ✓ A, Z
- ✓ (E_{lab},θ_{lab}) -> E*

Fission yields

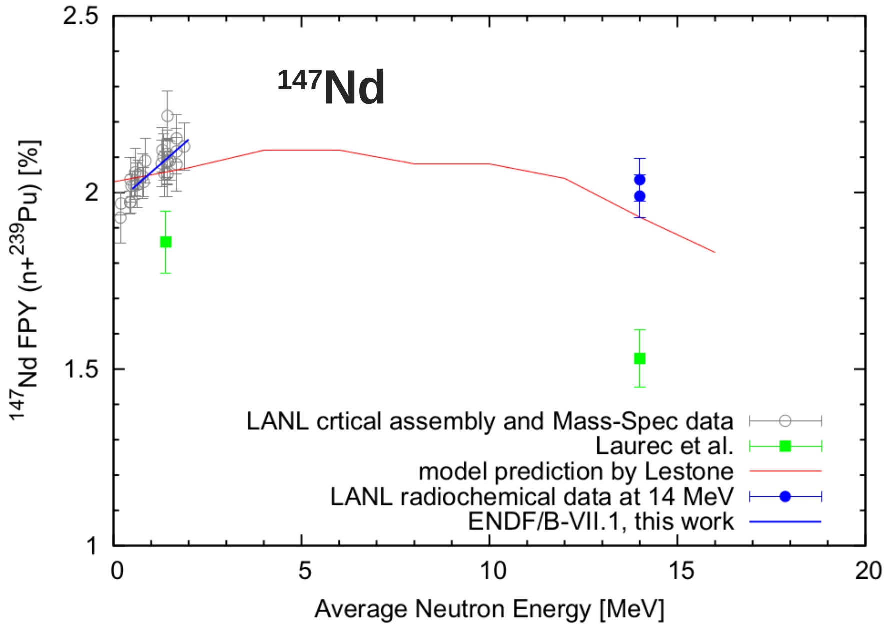




We want to measure the evolution of the fission yields as a function of the excitation energy of the fissioning system

- Shell effect damping with E*
- Excitation energy <=> incident neutron energy ($E^* = S_n + E_n$)
- Open questions about some fission yields from the neutron-induced fission of ^{239}Pu.

Evolution of fission yields with E_n



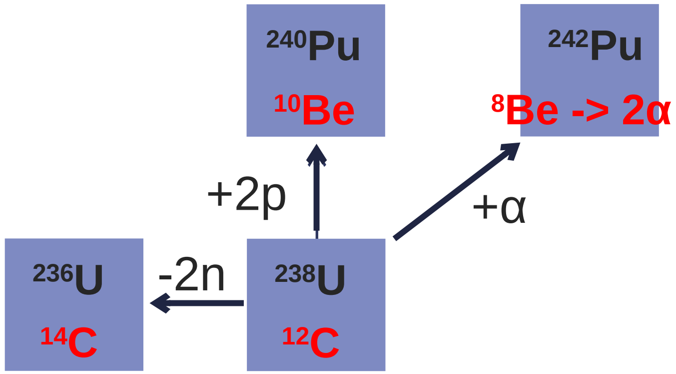
Chadwick et al. Nuclear Data Sheets 111 (2010)2923-2964

- Still open questions between different measurements.
- Measurement with fast neutrons
  - ✓ Activation -> Need to precisely know the neutron flux and seperate alpha from fission
  - ✓ Gamma spectroscopy => Need precise knowledge of the efficiency
  - – Systematic error propagation : difficult
- New precise measurement recently at TUNL and HIGS (see A. Tonchev and R. Malone)

- New experimental program in collaboration with GANIL started in 2020/2021 to develop a new silicon array called PISTA
  - ✓ Use of inverse kinematics and transfer reaction
  - ✓ Development of a new detector array to characterize the fissioning properly with the required precision in mass A, charge Z and excitation energy E* (Major step forward)

Fission studies at GANIL with VAMOS

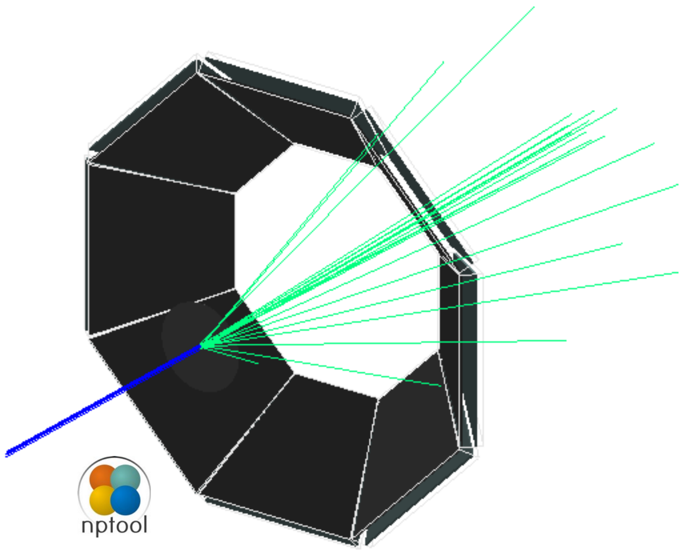
- Inverse kinematics using a beam of ^{238}U and a ^{12}C target
  - ✓ Access to fissioning system heavier than ^{238}U
- Transfer reaction around Coulomb barrier inducing the fission to access ^{236}U and ^{240}Pu fissioning systems.
- The ejectile identification allows us to properly characterize the fissioning system.
- VAMOS spectrometer
  - ✓ Identification in mass and charge of the fission fragments
- Excitation energy measured event by event => **Development of PISTA**

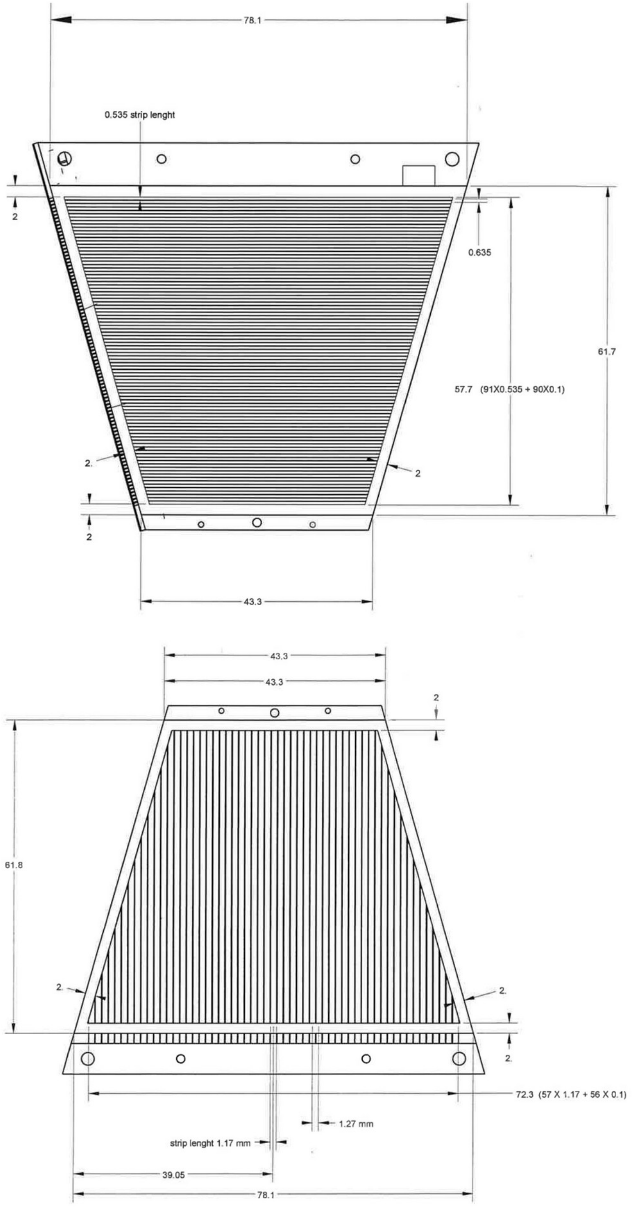


Major upgrade : PISTA

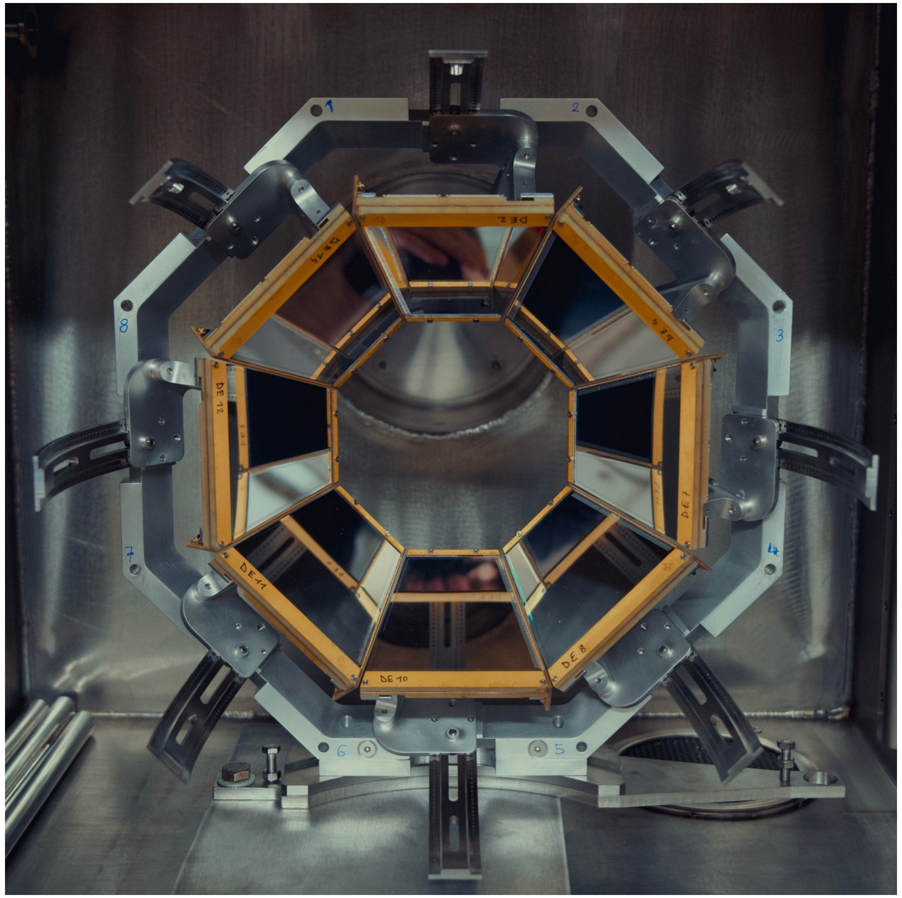
PISTA : 8 telescopes in a petal shape

- **ΔE first stage**
  - 100 um thick
  - 91 horizontal strips
  - Dynamic range : 0-60 MeV
- **E second stage**
  - 1 mm thick
  - 57 vertical strips
  - Dynamic range : 0-200 MeV





Major upgrade : PISTA

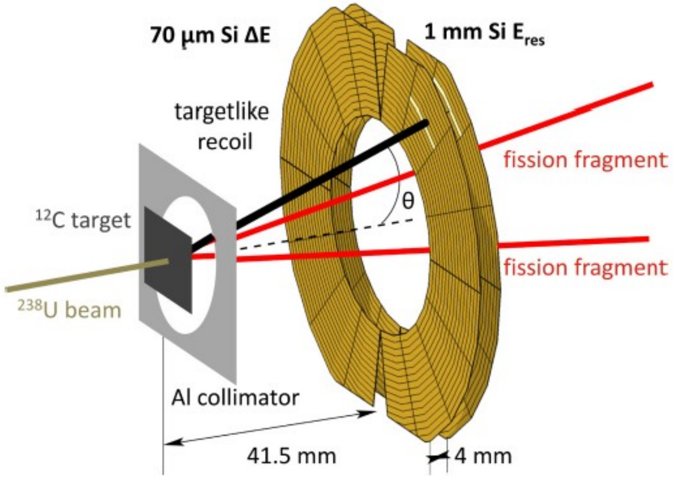


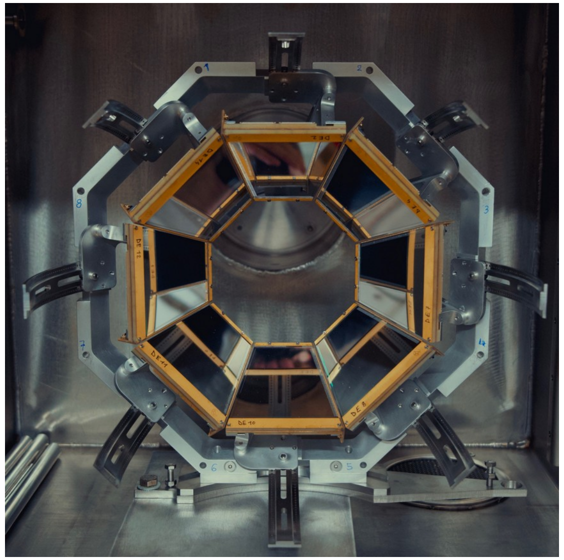
What's new with PISTA (compared to SPIDER)?

- ✓ Angular coverage : 30-60 deg
- ✓ Better identification of the ejectile
- ✓ High granularity means better resolution in E* (FMHW = 700 keV)
- ✓ Dedicated electronics capable of sustaining higher count rate.
- ✓ **Overall, a much better characterization of the fissioning system (A,Z,E*)**

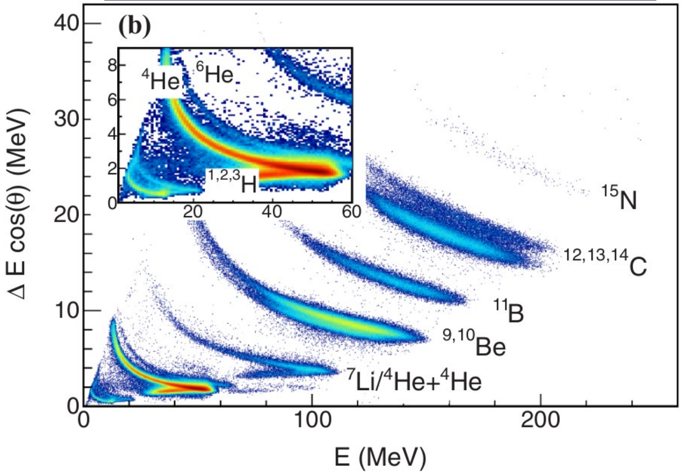
Major upgrade : PISTA

PISTA analysis done by Lucas Bégué-Guillou

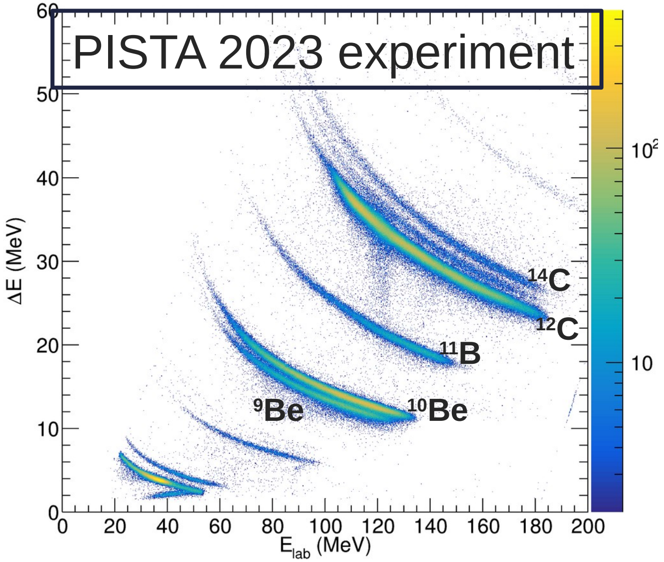




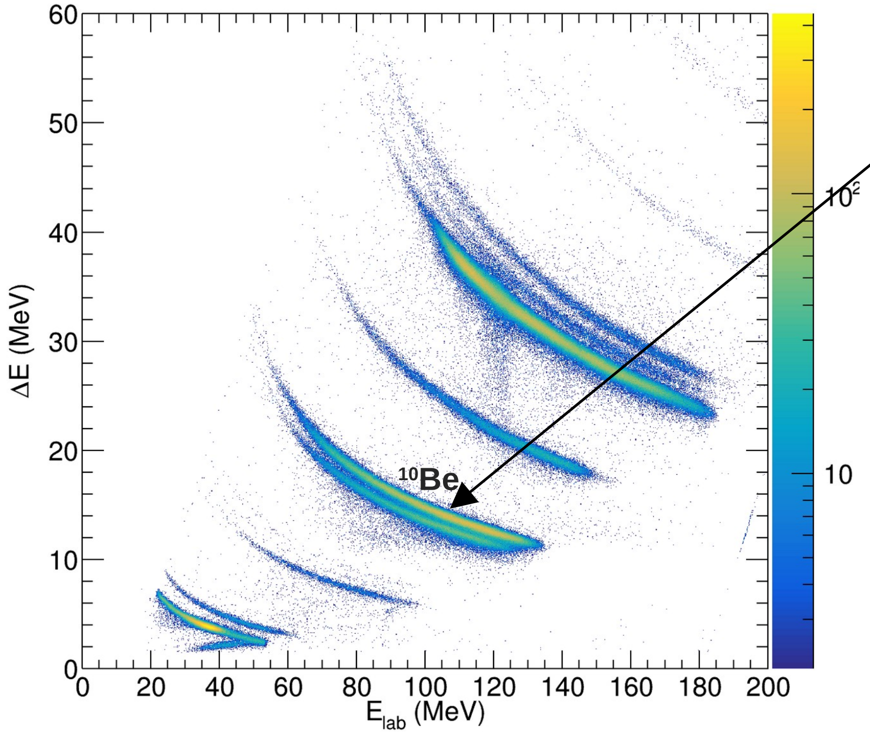
Old generation SPIDER



PISTA 2023 experiment



First PISTA experiment in 2023 : Focus on ^{240}Pu



Selection of the fissioning system: ^{240}Pu

PISTA analysis done by Lucas Bégué-Guillou
→ See POSTER

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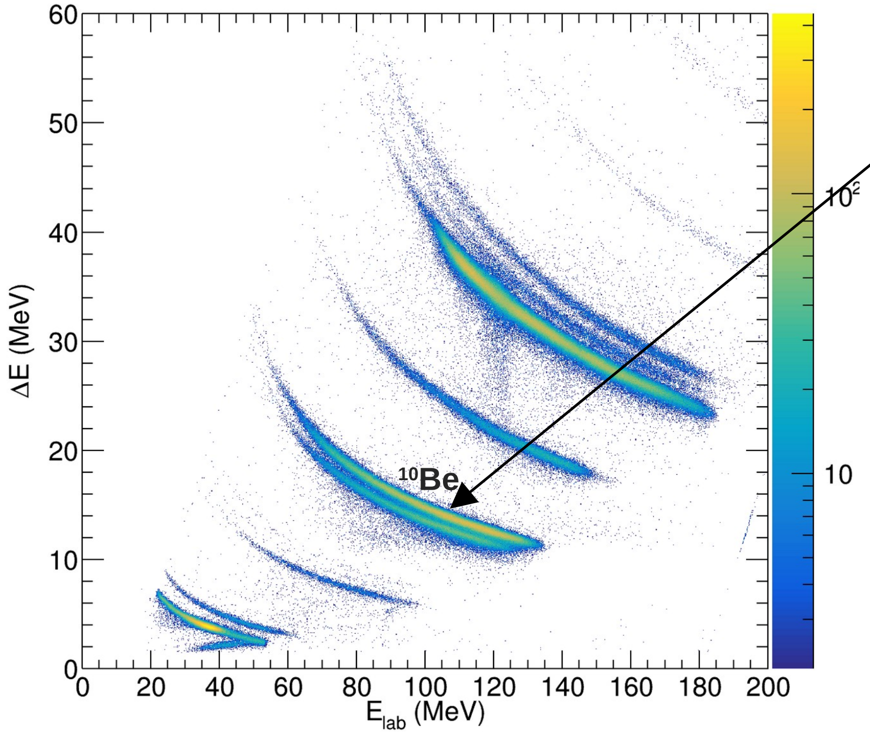
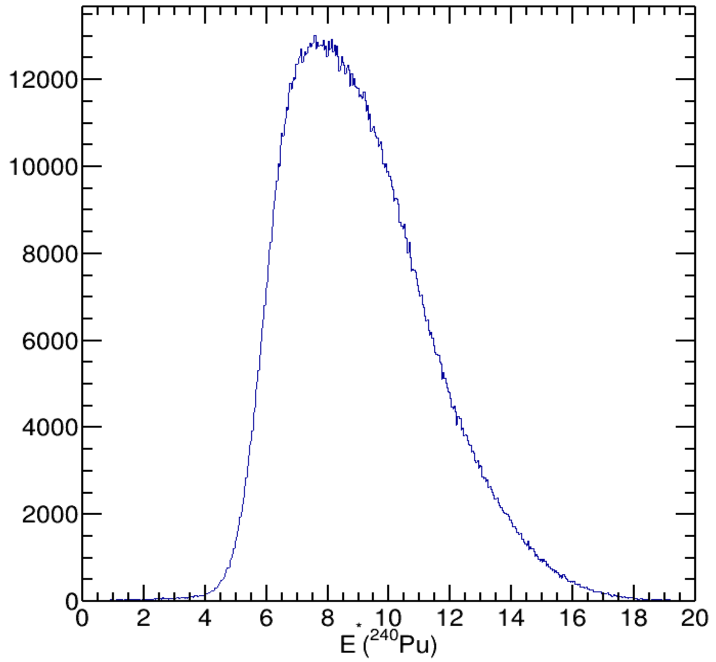


Selection of the fissioning system: ^{240}Pu

Excitation energy distribution of the ^{240}Pu fissioning system



PISTA analysis done by Lucas Bégué-Guillou
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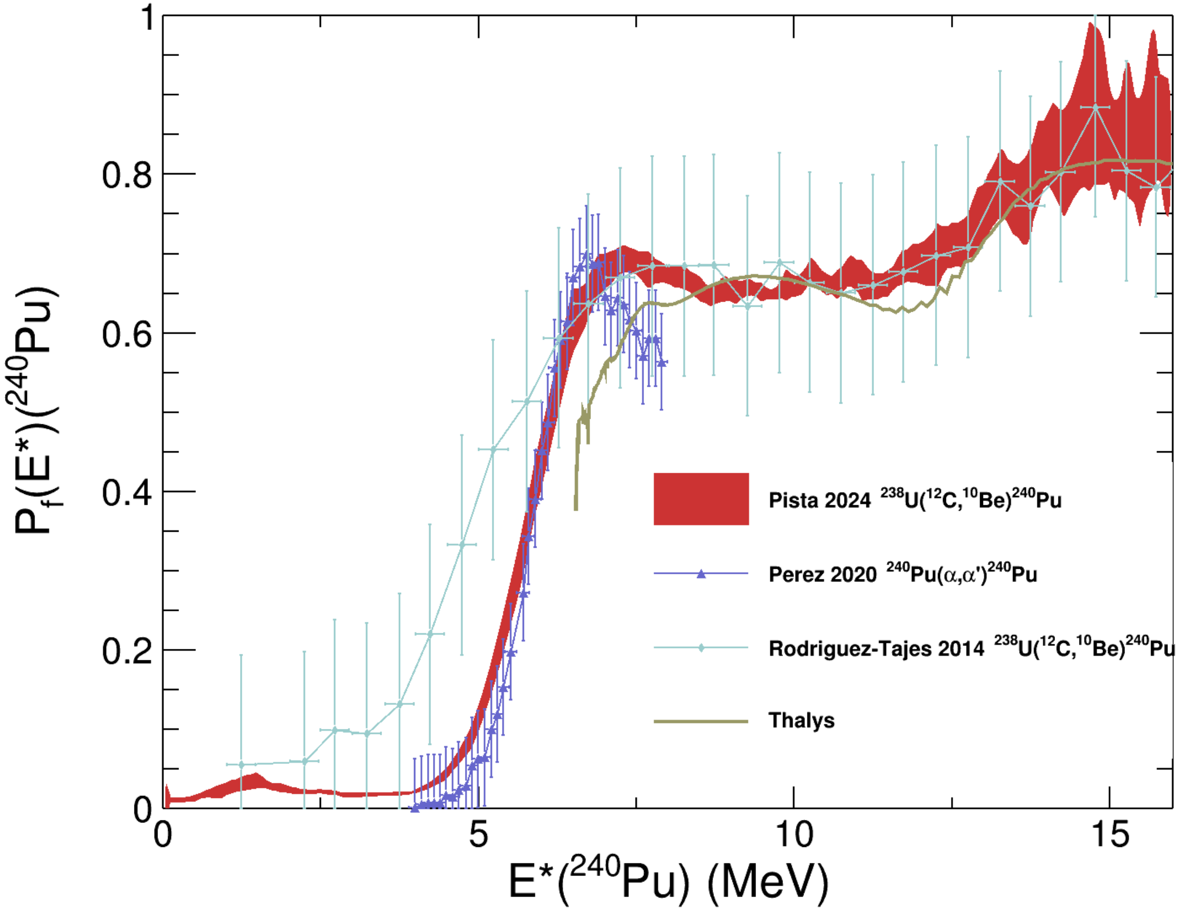
Fission probability

From the events

- in coincidence between VAMOS and PISTA
- and PISTA alone
- we can reconstruct the fission probability



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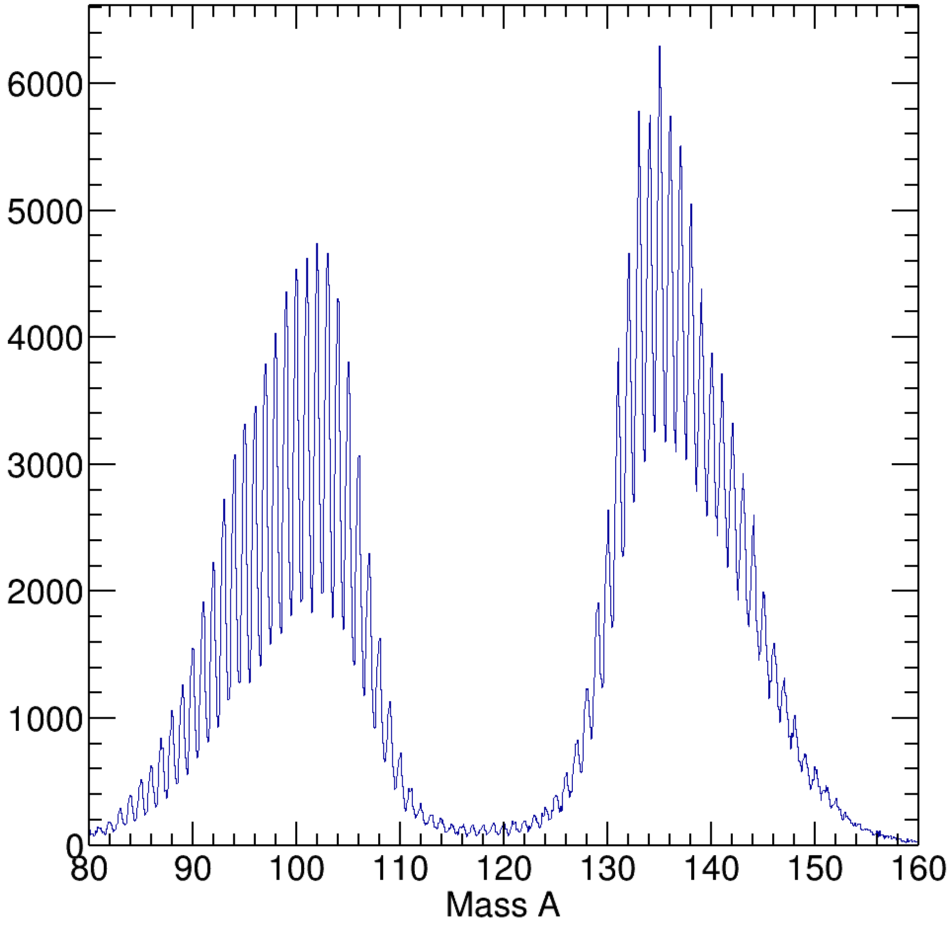
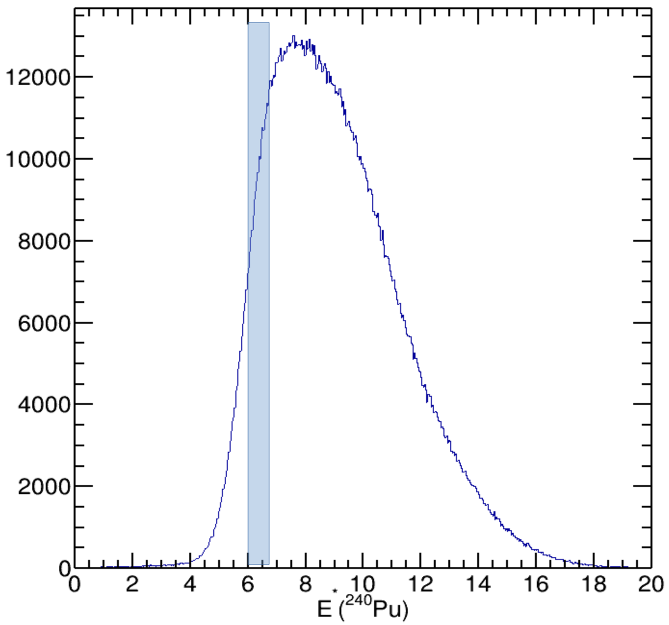
Fission yields with VAMOS

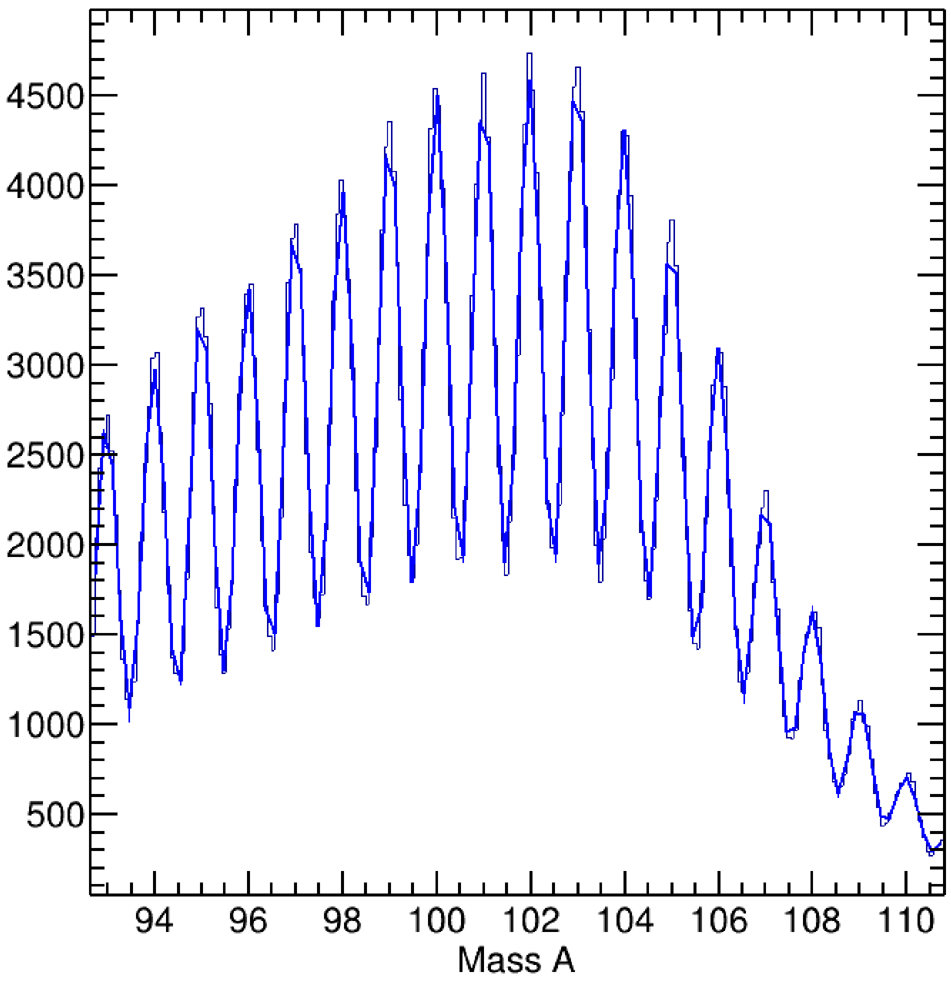
- **Mass distribution**
  - Typical resolution of ΔA/A=0.8%



Fission yields with VAMOS

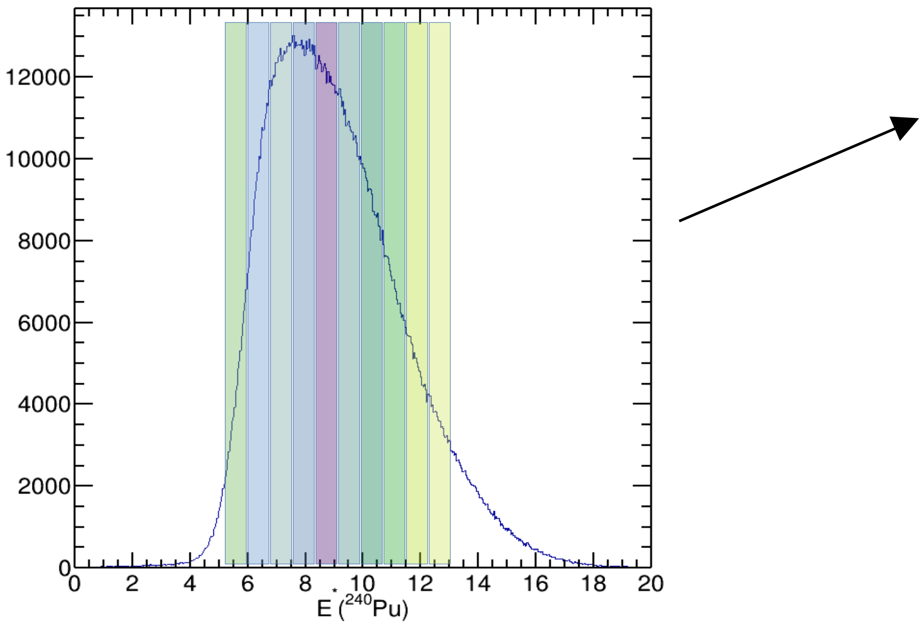
- **Mass distribution**
  - Typical resolution of ΔA/A=0.8%
  - For a given excitation energy range (bin of 1 MeV) we get the mass yield using a multi-gaussian fit.

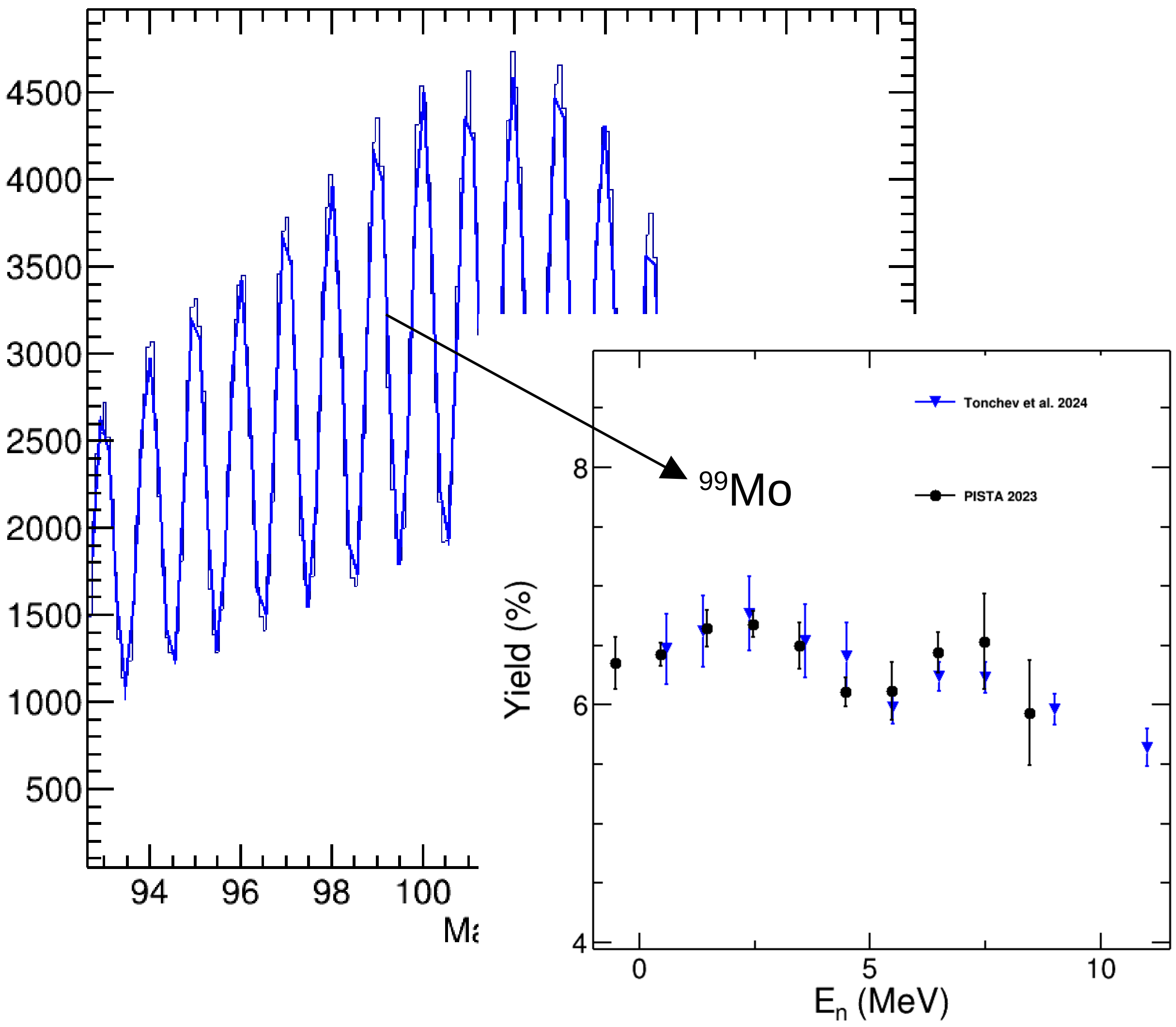




Fission yields with VAMOS

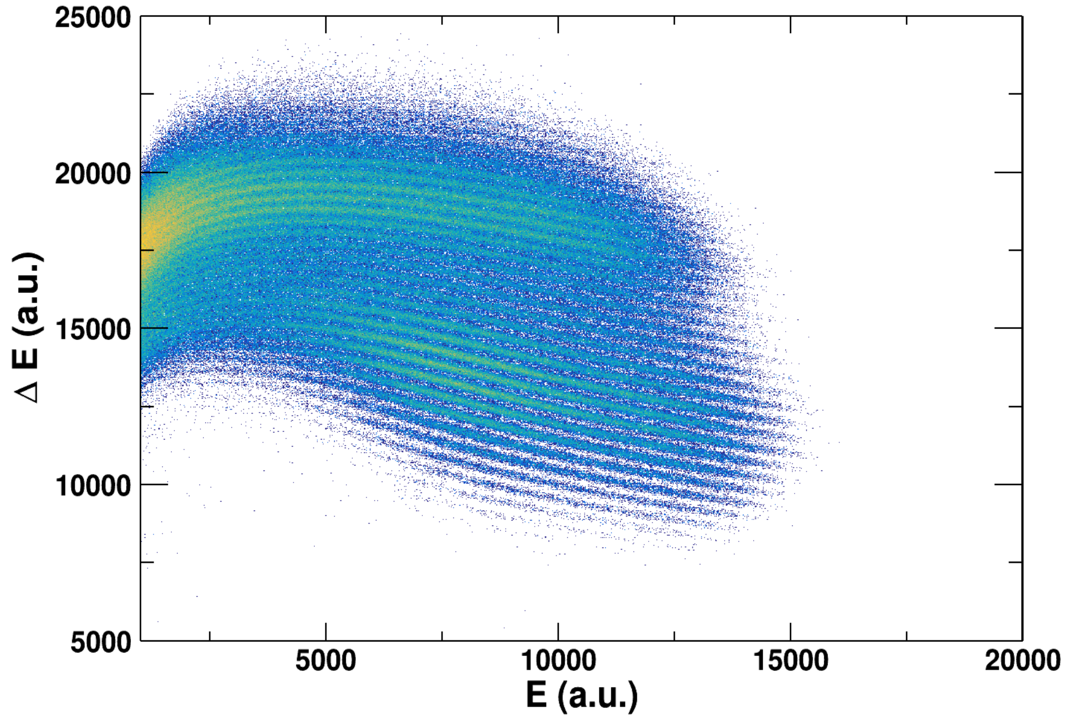
- **Mass distribution**
  - Typical resolution of ΔA/A=0.8%
  - For a given excitation energy range (bin of 1 MeV) we get the mass yield using a multi-gaussian fit.
  - Same work for different excitation energy → Yield evolution

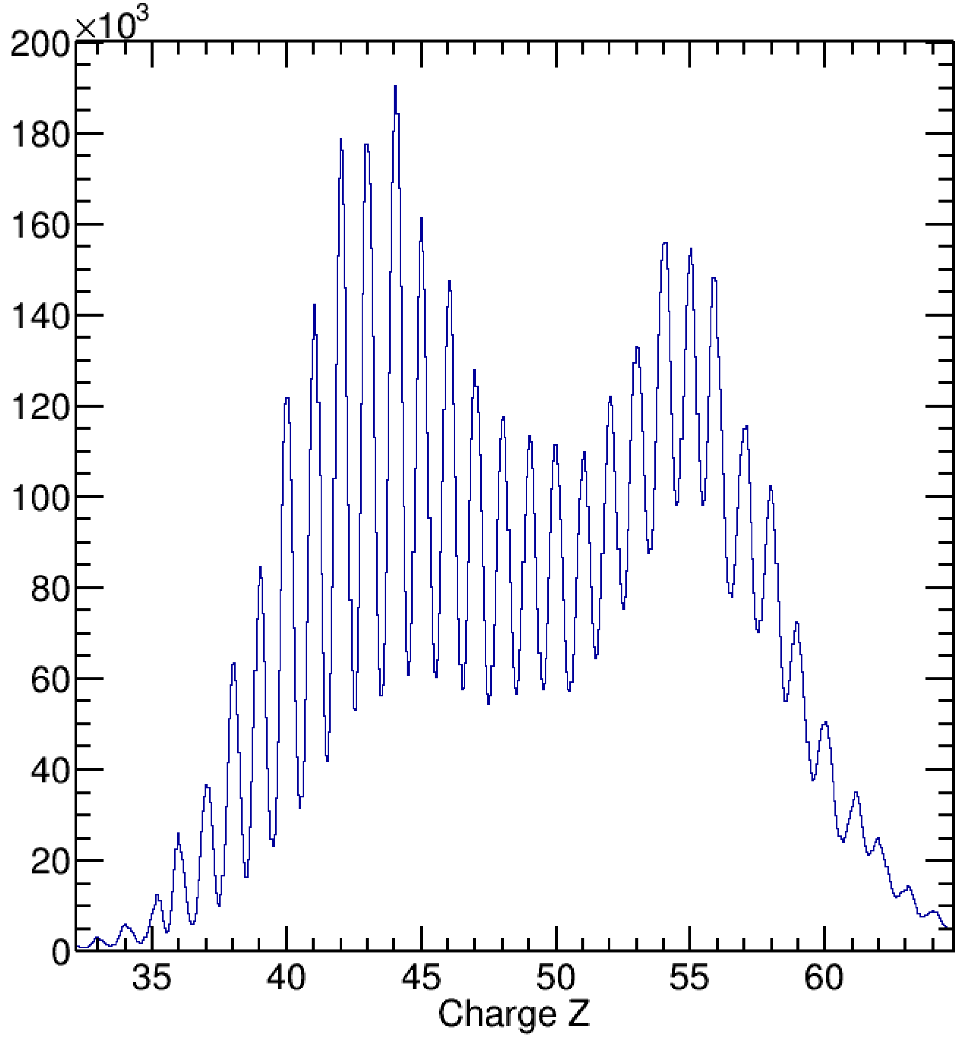




Fission yields

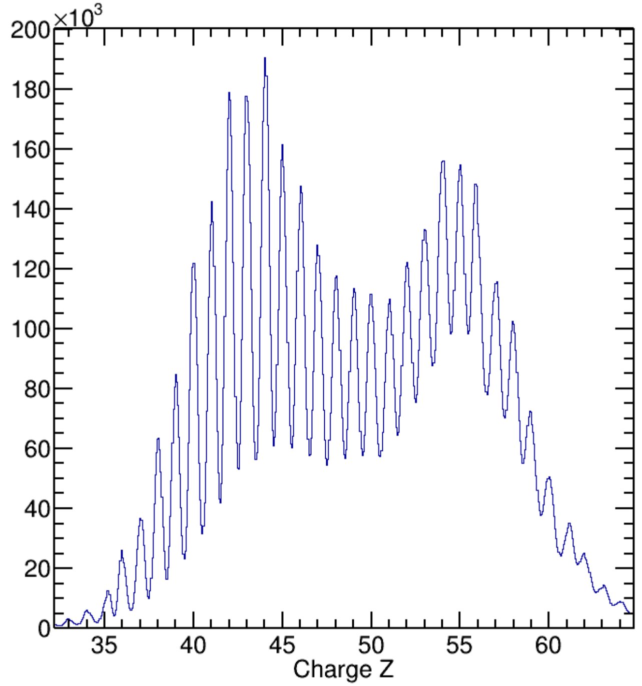
- **Charge distribution**
  - Determined by ΔE/E in the VAMOS ionization chamber
  - Typical resolution of ΔZ/Z=1.5%



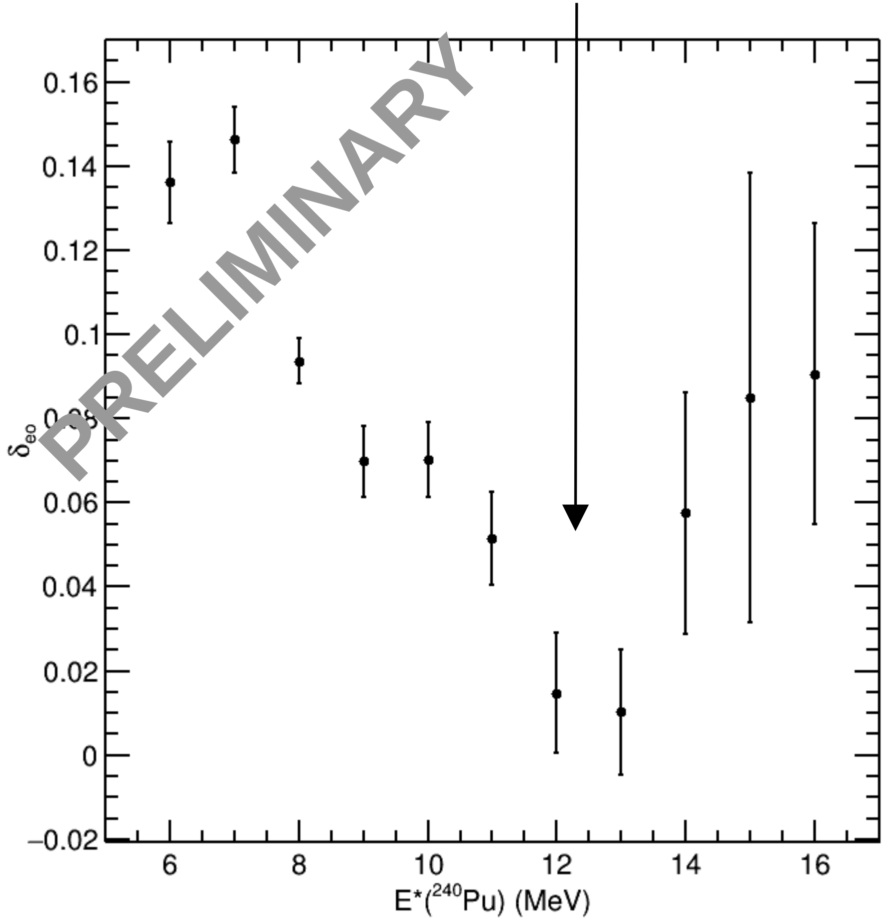


Fission yields

- **Global odd even staggering**
  - Multi gaussian fit per bin of 1 MeV in excitation energy
  - $\boldsymbol{\delta_{eo} = (\Sigma Y_e - \Sigma Y_o)/(\Sigma Y_e + \Sigma Y_o)}$
  - Decrease of δ_{eo} with excitation energy until the second chance of fission.



Second chance of fission

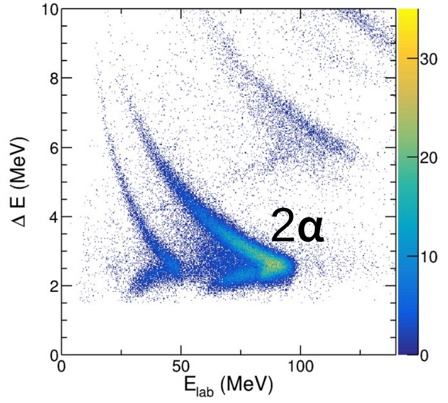


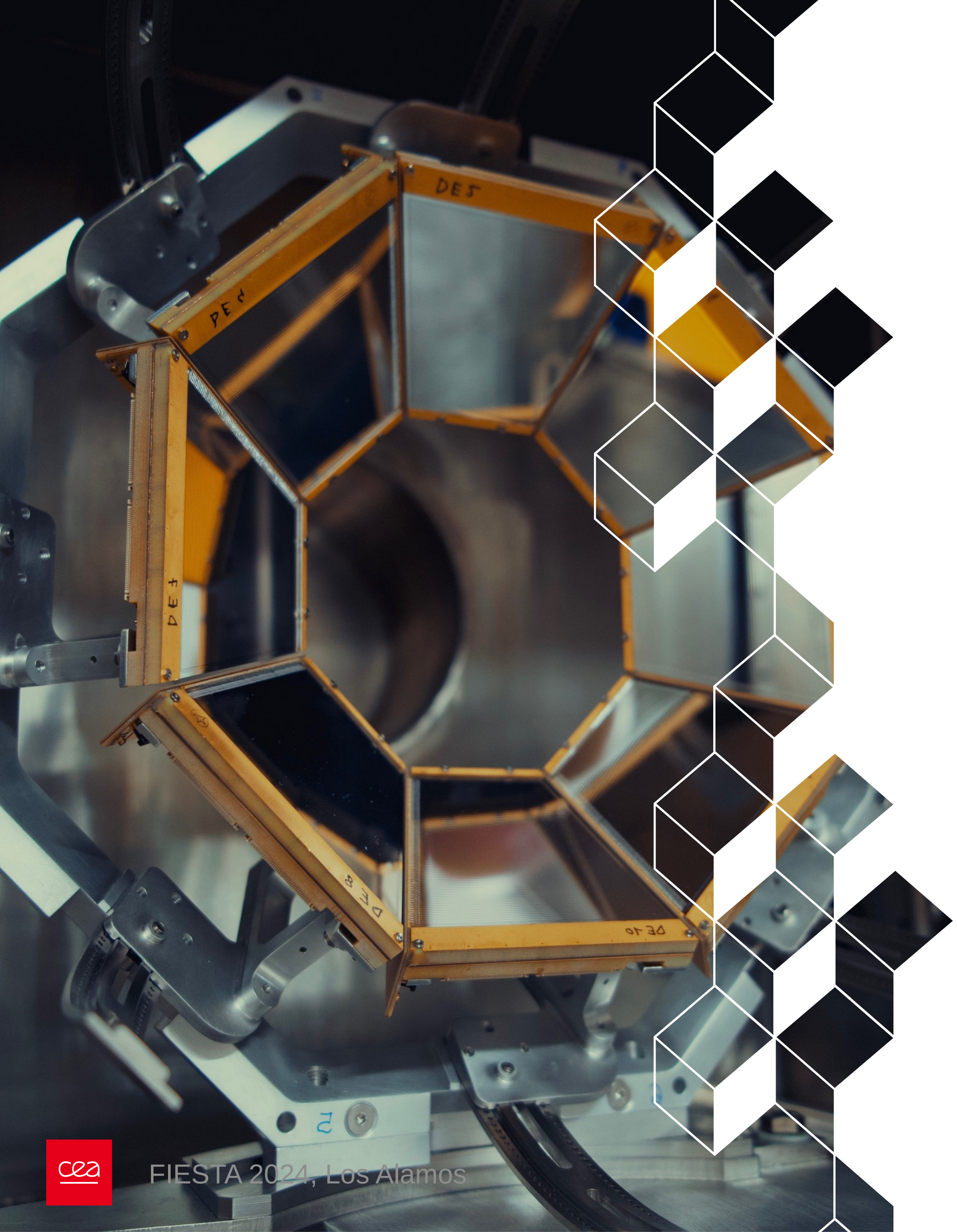
Conclusion

- First analysis of the data from VAMOS and PISTA are very encouraging
  - PISTA allows a better characterization of the fissioning system (A_{CN},Z_{CN},E*).
  - VAMOS provide a good resolution in both charge and mass of the fission fragments.
  - For ^{240}Pu the excitation range is about 6 < E* < 16 soit **0 < E_n < 10 MeV**

- We are able to compare the mass yield evolution with the latest results from TUNL
  - We will be able to compare all masses in a systematic way
  - Check the effect of the incoming channel for different energy!
  - Measure of the charge to probe shell effects and odd-even effect with excitation energy.

- Other systems will also be investigated such as ^{242}Pu (Théodore Efremov thesis) populated from **α** transfer giving ^{8}Be→ 2**α**
  - Channel strongly populated
  - The high granularity of PISTA makes it very efficient to detect the 2**α** events.





Thank you