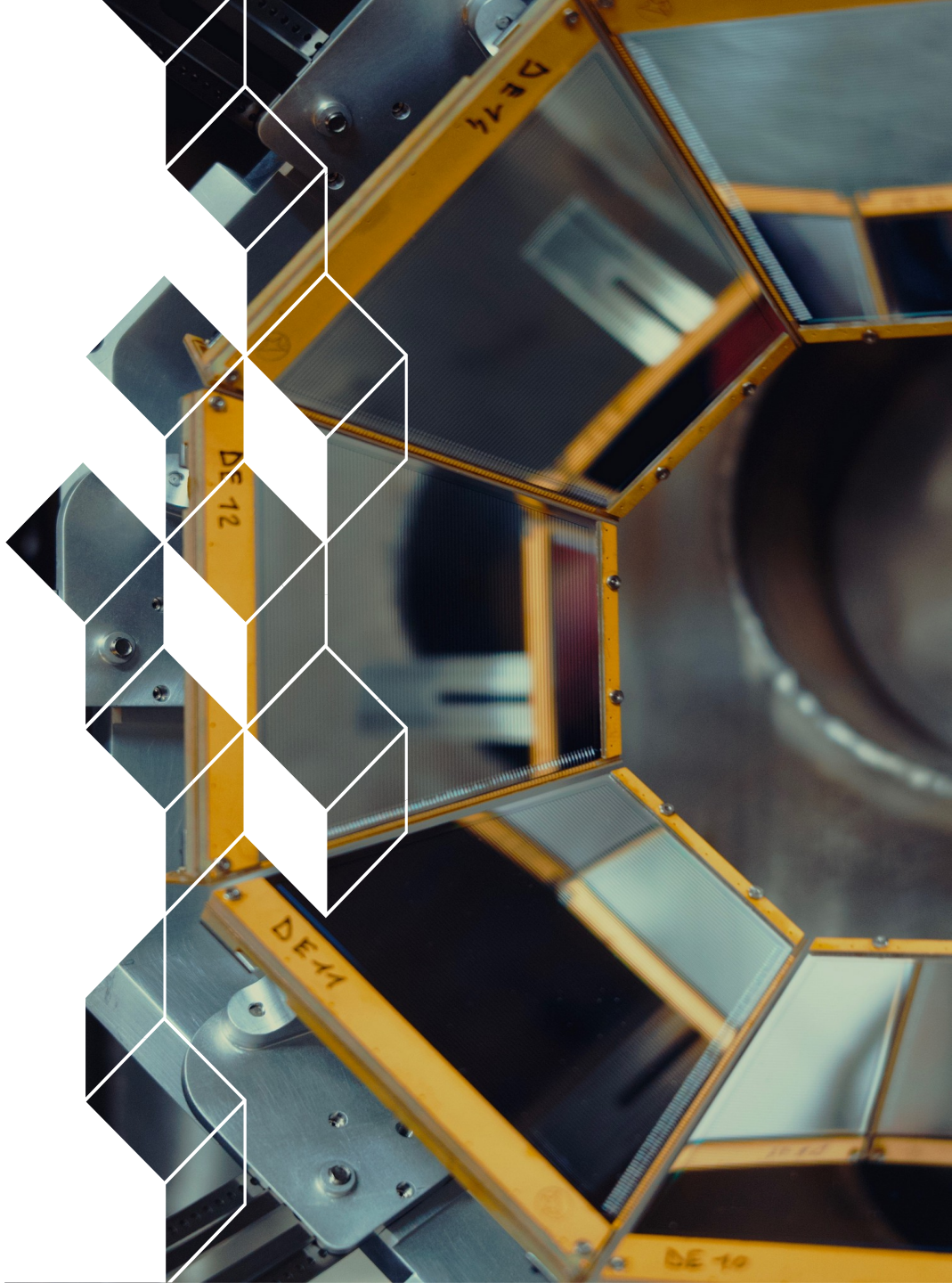
Physics at VAMOS+PISTA

Opportunities for UK Physicist at GANIL/SIRAL2

A. Lemasson[1], P. Morfouace[2,3], D. Ramos[1], J. Taieb[2,3] and the Fission@VAMOS collaboration

[1] GANIL, CEA/DRF-CNRS/IN2P3, Bd Henri Becquerel, BP 55027 Caen, France
[2] CEA, DAM, DIF, 91297 Arpajon, France
[3] Université Paris-Saclay, CEA, LMCE, 91680 Bruyères-le-Châtel, France

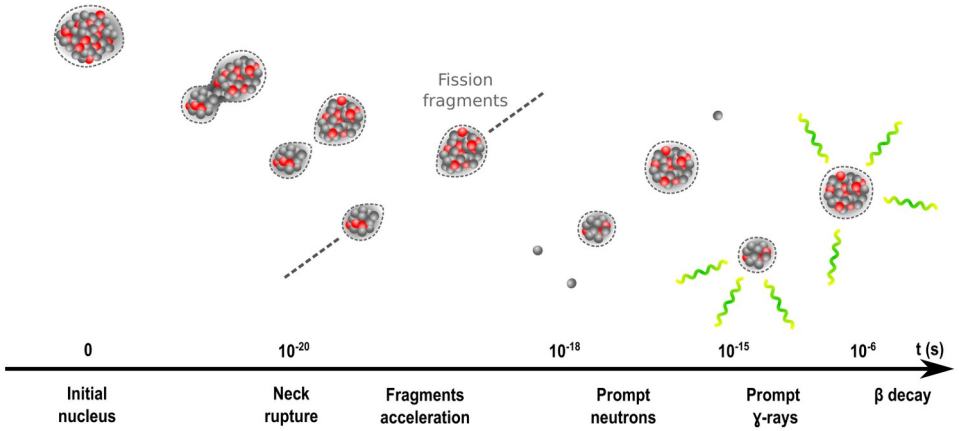


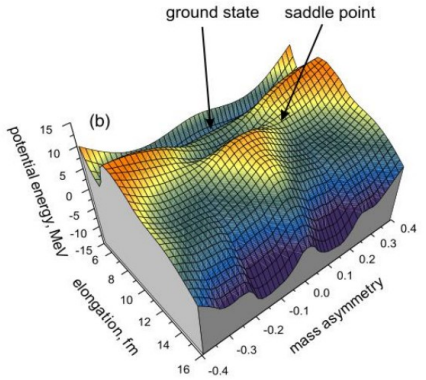
Contents

1. Fission studies at GANIL

Fission at VAMOS

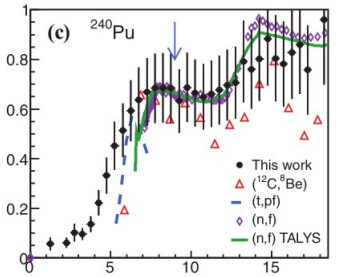
- **Key open questions**
  - Dynamical evolution of a complex quantum system.
  - At the crossroad of many research topics of nuclear physics with essential interplay between structural and dynamical properties of the nuclei.
  - Fully microscopic description of the fission process not yet availabe
- **Societal motivation**
  - Present and next-generation nuclear reactors
  - Fast neutrons
  - Accurate new data needed (^{236}U and ^{240}Pu)
- **What observables ?**
  - Direct isotopic fission fragments after neutron evaporation (secondary fission fragments)
  - Complete fission yields and evolution as a function of E*
    - *Probing the role of shell effects in fission*
  - Kinetic energies and excitation energies of the fission fragments
    - *Probing the scission configuration (A,Z and energy sharing)*
  - Fission barriers
    - Probing the potential energy surface as a function of E*
    - Exploring the fission paths (different modes of fission)

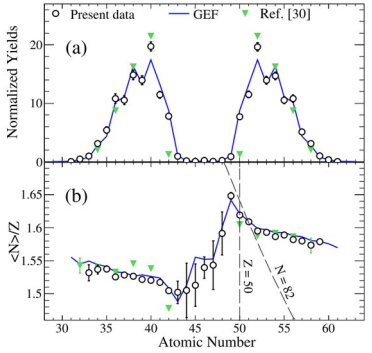




Potential Energy Surface

Fission Barrier

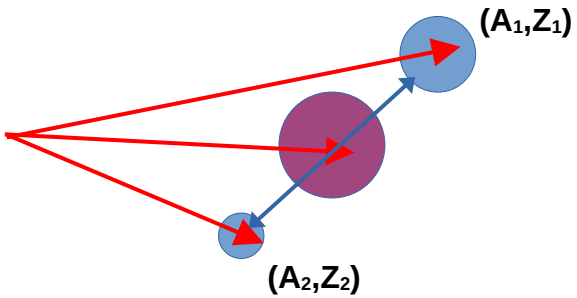




Fission Yield

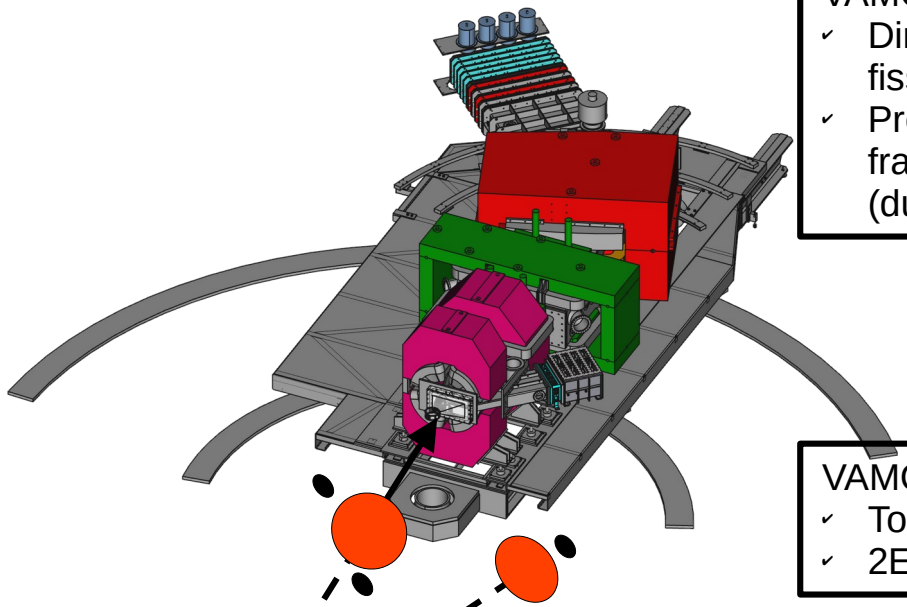
Heavy ions reactions for fission studies

- New opportunites to study fission using heavy ion reactions
  - **Fusion/Fission (VAMOS)**
  - **Transfer induced fission (VAMOS+PISTA)**
  - Electromagnetic excitation of Radioactove Beams (SOFIA at GSI)
  - Beta delayed fission
- Inverse kinematics
  - Using a ^{238}U beam at 6 MeV/u.
  - The boost provide the capability of fission-fragments nuclear charge identification.
  - Coulomb energies provide low angular straggling and small boost → enable good volicty resolution in the center of mass.
- Use of surrogate reaction
  - Access to « exotic » fissioning system, not possible in n-induced fission
  - Explore the impact of the incoming channel into the final fission fragment distributions.



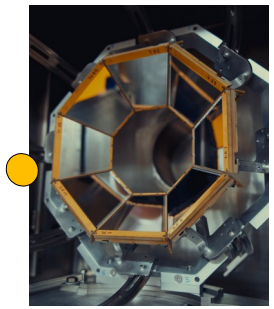
What can be done at VAMOS ?

- 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.*

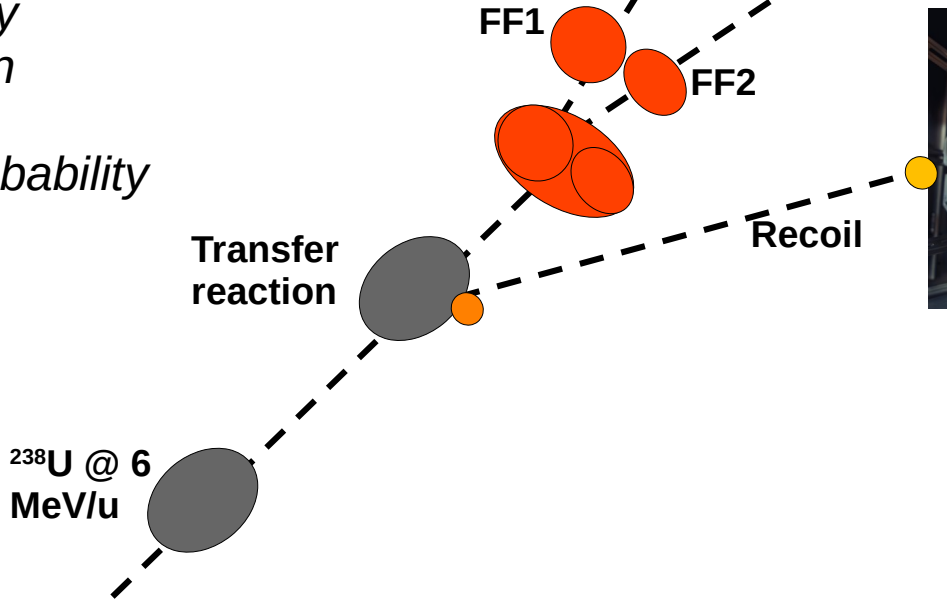


VAMOS
- ✔ Direct and complete isotopic fission fragments yields Y(A,Z)
- ✔ Precise center-of-mass fission fragment velocities isotopically (due to Coulomb barrier energies)

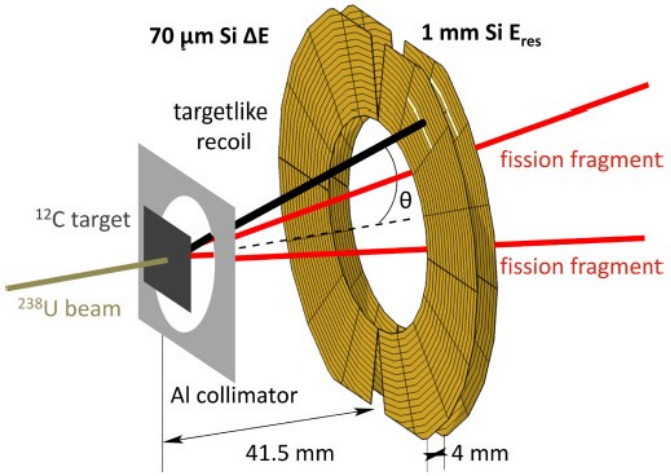
VAMOS-second arm
- ✔ Total kinetic energies isotopically
- ✔ 2E-2v measurement



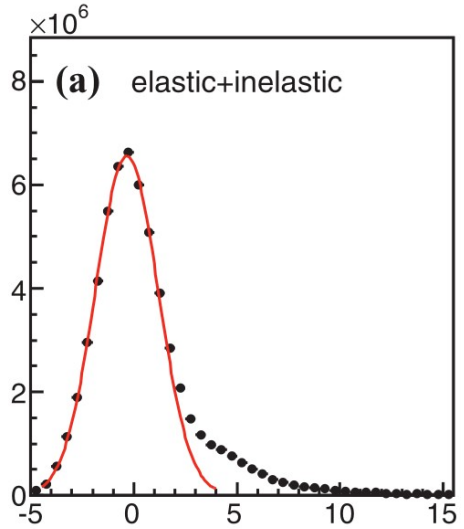
SPIDER → PISTA
- ✔ A
- ✔ Z
- ✔ (E_{lab},θ_{lab}) → E*



A rich activity with SPIDER and VAMOS

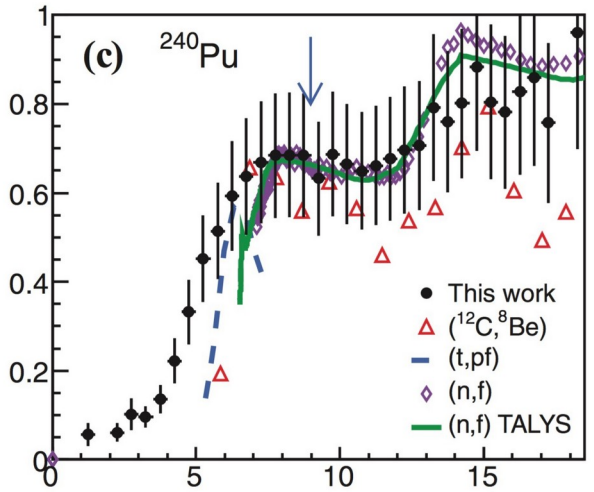


- ΔE = 70 um thickness
- E = 1 mm thickness
- 1,5 mm strips
- 22.5 deg sectors
- Angular coverage : 30 – 47 deg
- Excitation energy resoltuion : FWHM = 2.9 MeV.

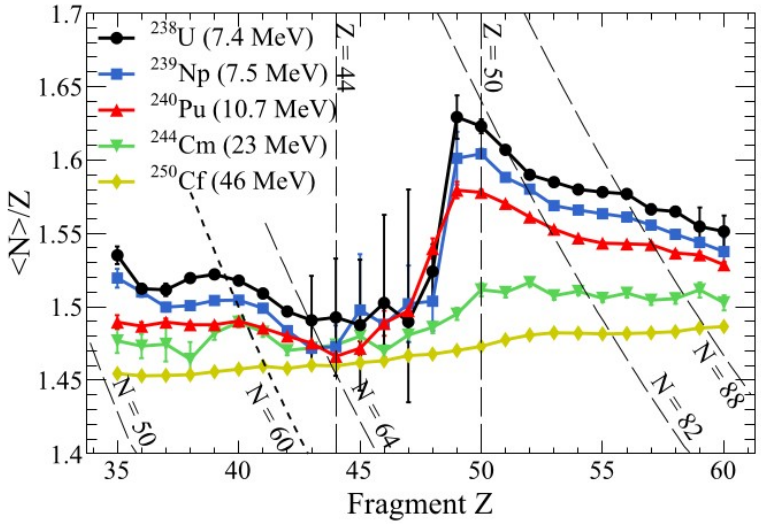


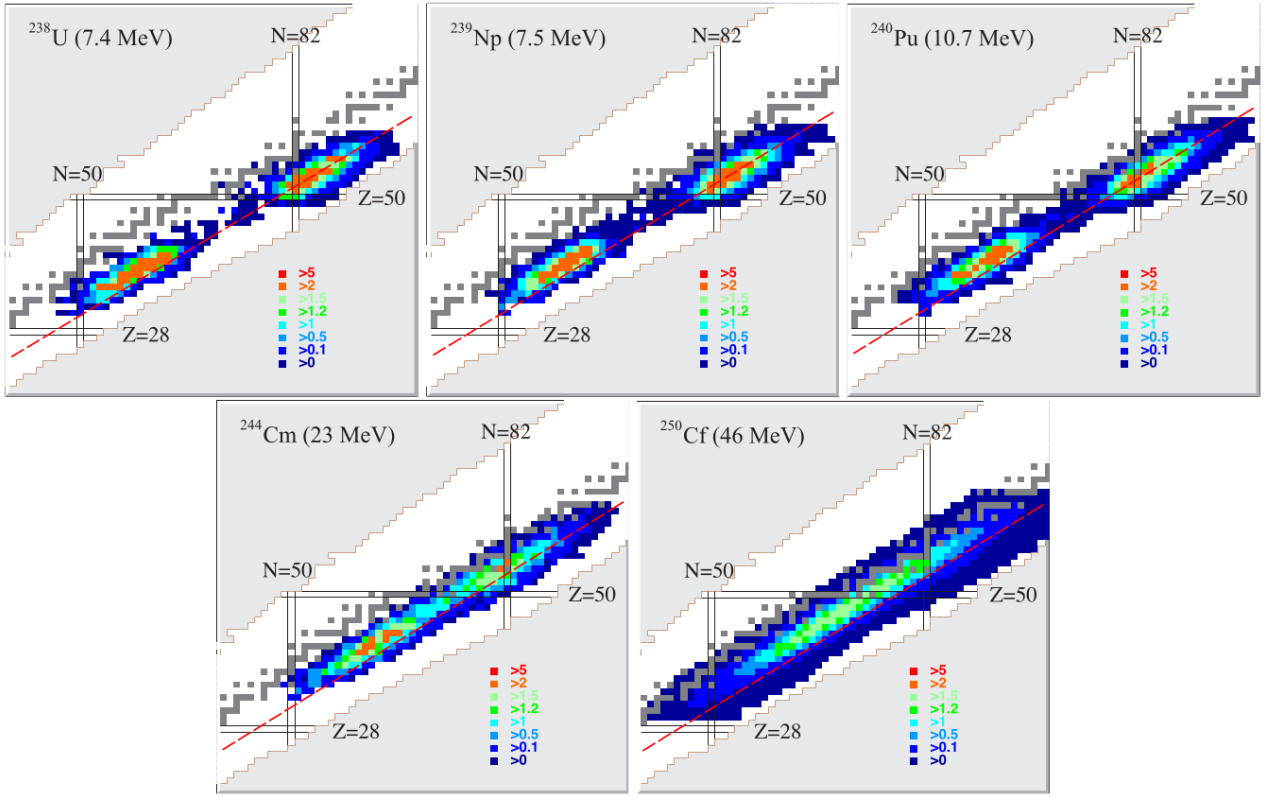
The coupling of SPIDER and VAMOS provided a lot a data already, with a limited resolution in excitation energy.

- ✔ M. Caamano et al. PRC 88, 024605 (2013)
- ✔ C. Rodriguez-Tajes et al. PRC 89, 024614 (2014)
- ✔ Ramos et al. PRC 97, 054612 (2018)
- ✔ Ramos et al. PRL 123, 092503 (2019)
- ✔ Ramos et al. PRC 99, 024615 (2019)
- ✔ ...



A rich activity with SPIDER and VAMOS





- Direct measurement of isotopic fission yields for different fissioning system, with different excitation energy
- Evidence of shell effect around Z=50 looking at the nuclear charge polarization.
- Structural effects that disappear at higher excitation energy.
- Need a better characterization of the fissioning system in A, Z **and E*.**

2. Current Status

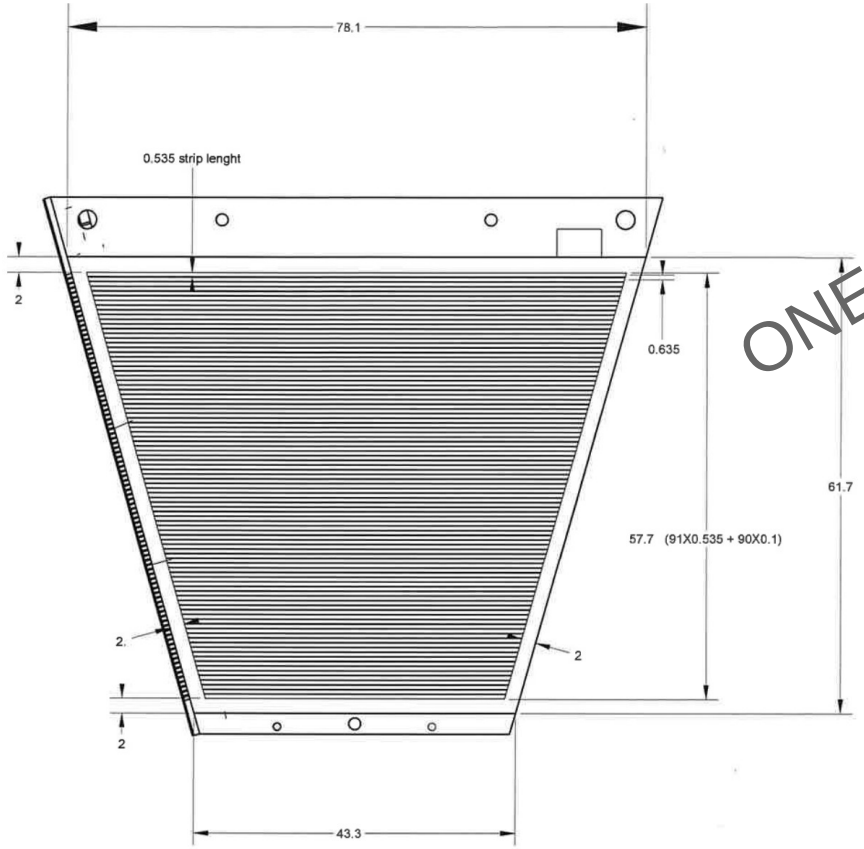
Major upgrade : development of PISTA

ΔE first stage (single sided)

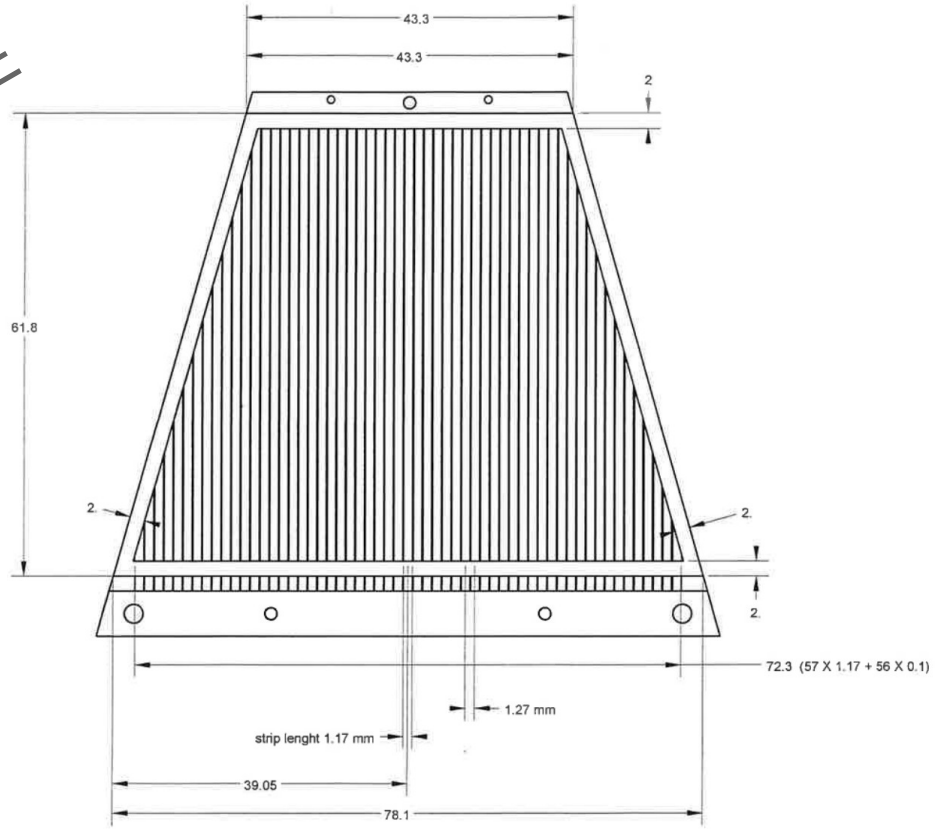
- 100 µm
- 91 horizontal strips
- Dynamic range : 0 – 60 MeV

E second stage (single sided)

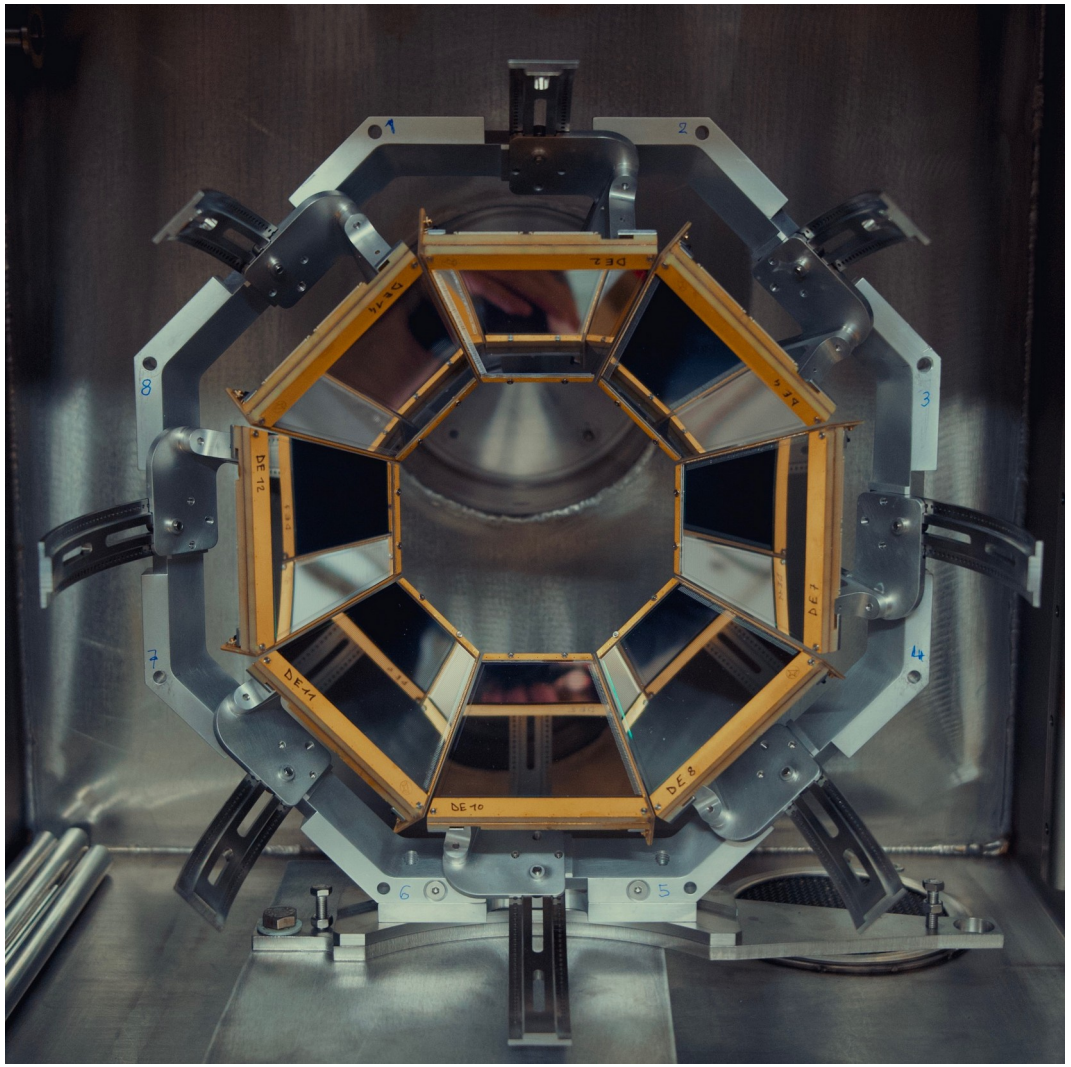
- 1 mm
- 57 vertical strips
- Dynamic range : 0 – 200 MeV



ONE TELESCOPE



Major upgrade : development of PISTA



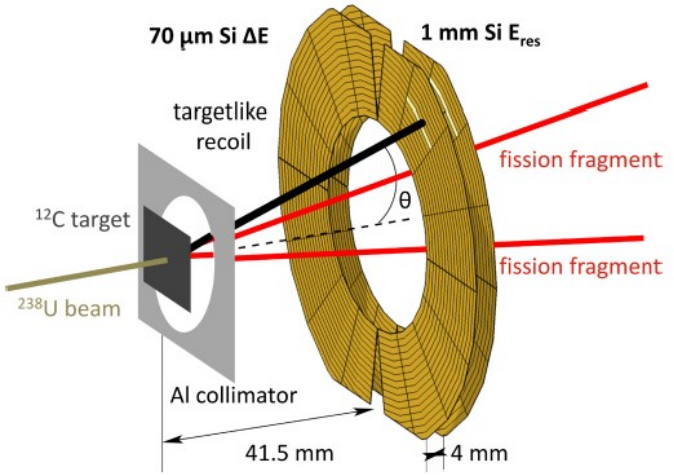
- **ΔE first stage (single sided)**
  - 100 µm
  - 91 horizontal strips
  - Dynamic range : 0 – 60 MeV
- **E second stage(single sided)**
  - 1 mm
  - 57 vertical strips
  - Dynamic range : 0 – 200 MeV

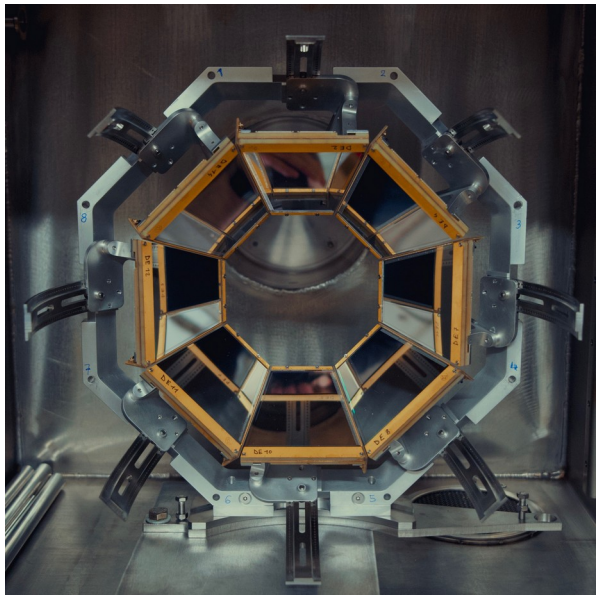
What is new with PISTA

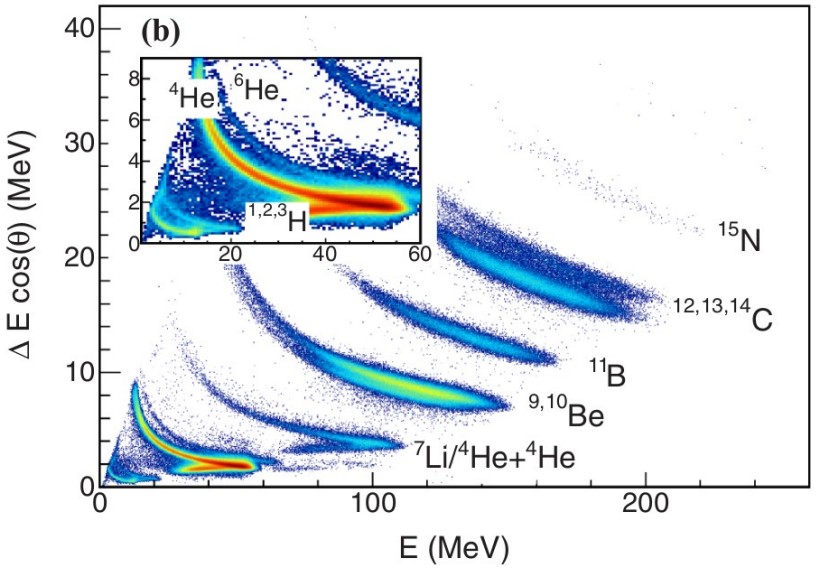
- Angular coveragte : 30 – 60 deg.
- Better identification of the ejectile.
- High granularity → better excitation energy resolution (FMWH = 750 keV).
- Dedicated electronics capable to sustain higher count rate → High statistics.

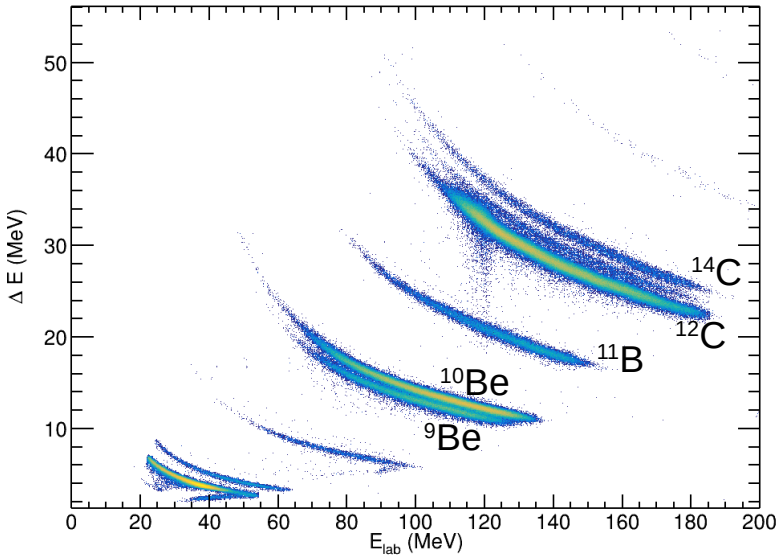
➔ **Better characterization of the fissioning system (A,Z,E*).**

Major upgrade : development of PISTA







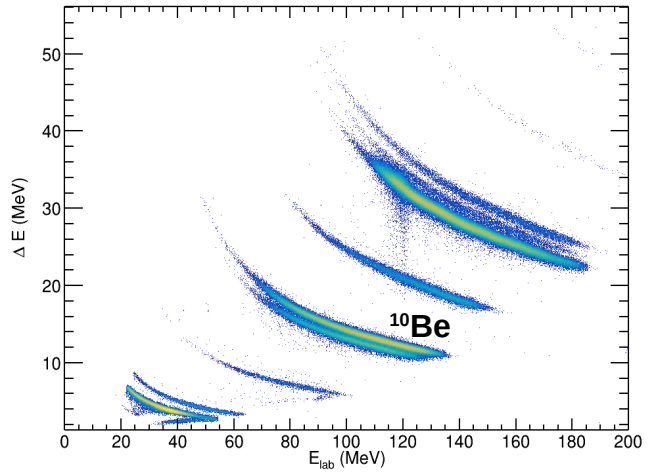


First PISTA+VAMOS experiment : E850

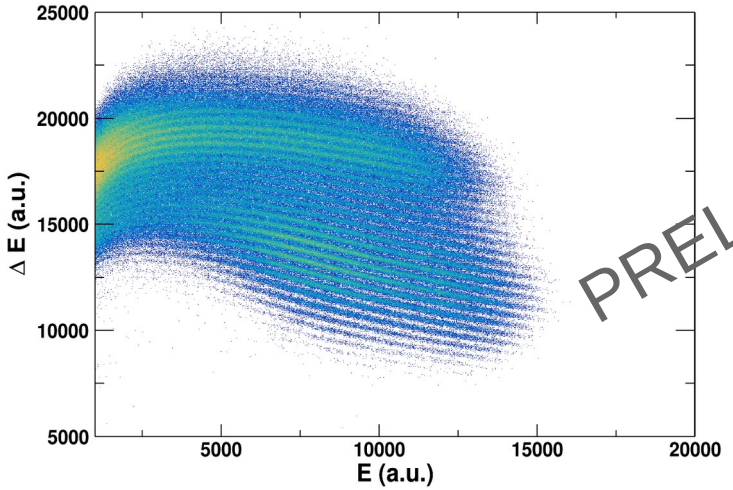
E850 experiment

- Probe shell effects damping with E*.
- Fission yields as a function of E* → Unique data set.
- Yields at threshold ↔ Equivalence of transfer-induced versus n-induced fission.
- ^{238}U at 6 MeV/u.
- 100 ug/cm² ^{12}C target.
- First coupling of VAMOS and PISTA.
- Very encouraging first results → End of E850 new April.

Selection of the fissioning system : ^{240}Pu

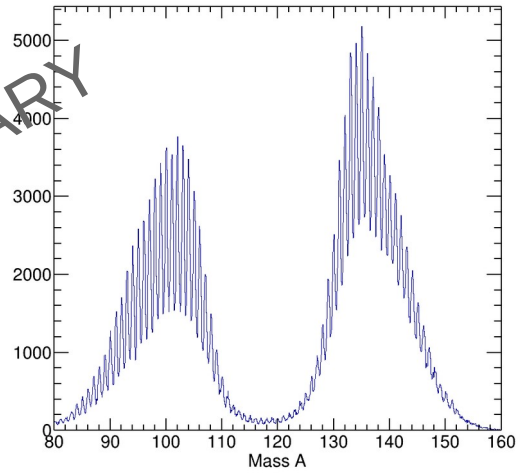


Charge distribution of the fission fragments



PRELIMINARY

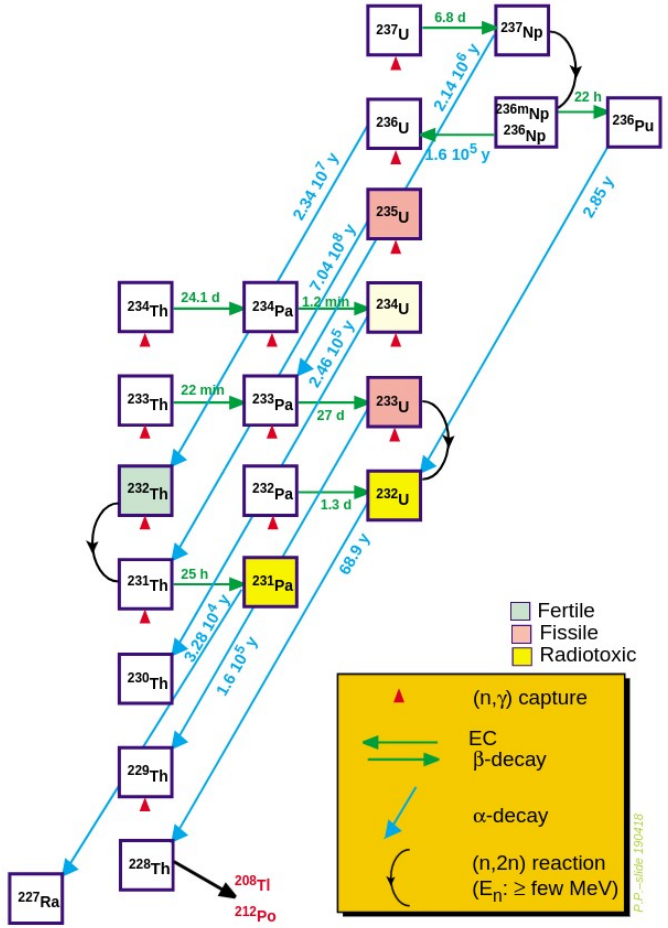
Mass of the fission fragments



4. Perspectives

Perspectives

- A rich experimental activity to come !
- End of E850 experiment next April.
- **Complete isotopic fisison yields in the Thorium region from inverse-kinematics transfer induced fission** (D. Ramos).
  - ✔ A ^{232}Th beam will produced less neutron-rich fissioning system such as ^{234}U and ^{230}Th.
  - ✔ Direct comparison of the effect of the incoming channel
    - ➔ ^{238}U(^{12}C,^{14}C)^{236}U vs ^{232}Th(^{12}C,^{8}Be→2**α**)^{236}U
  - ✔ Large number of actinides involved in the thorium fuel cycle will be produced in transfer reactions with the ^{232}Th beam with an excitation energy range equivalent to fast neutrons.
  - ✔ 12 days of beam time next March.



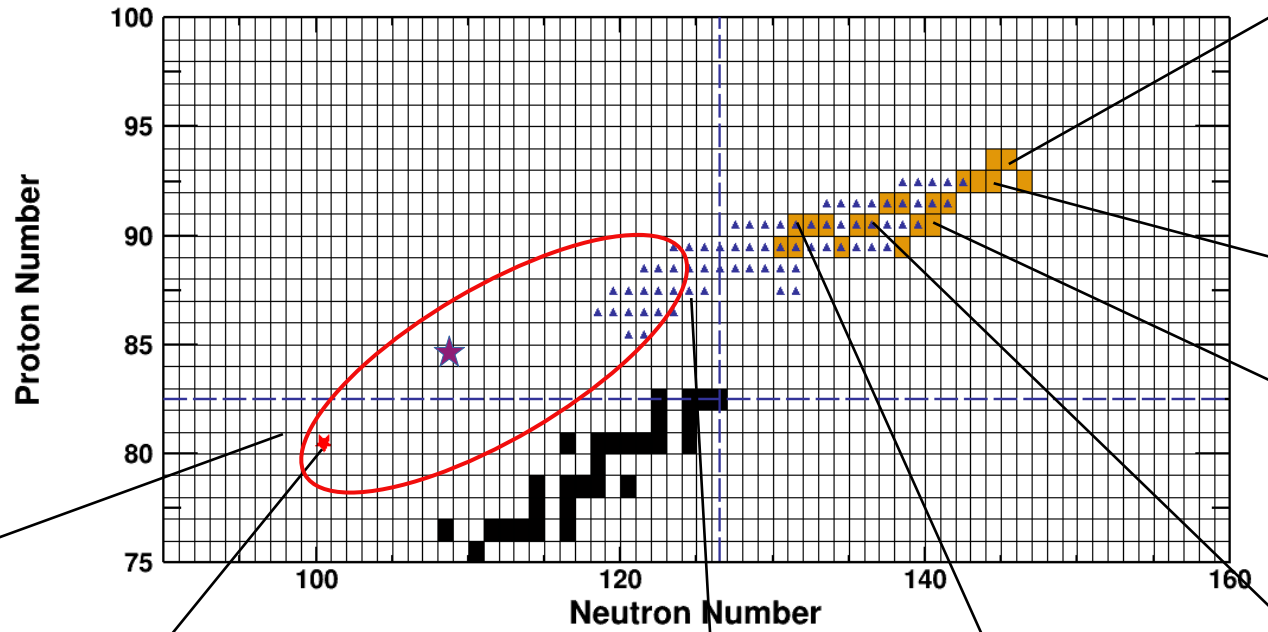
Perspectives

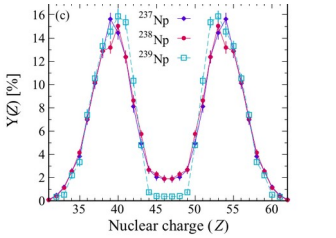
- **Origin and competition between fission modes in pre-actinides : the ^{192}Po transitional case**. (A. Lemasson)
  - ✔ Probe the origin of the new island of asymmetric fission around ^{180}Hg.
  - ✔ ^{192}Po from fusion between a beam of ^{124}Xe at 4.05 AMeV on a ^{68}Zn target → E* = 28 MeV.
  - ✔ Expected to play a pivotal role between in assessing the transtion from asymmetric to symmetric fission.

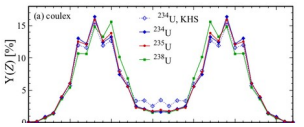
K.-H. Schmidt *et al.* NPA **665** (2000) 221

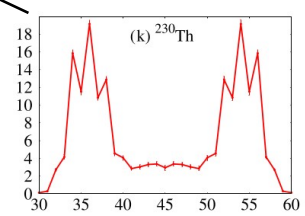
SOFIA

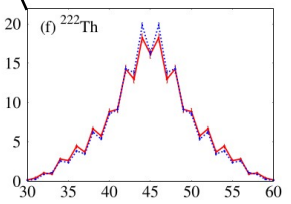
J.-F. Martin *et al.* Phys. Rev. C **104**, 044602 (2021)

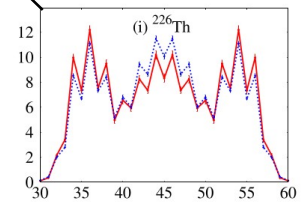




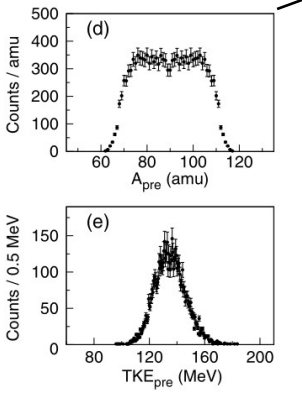




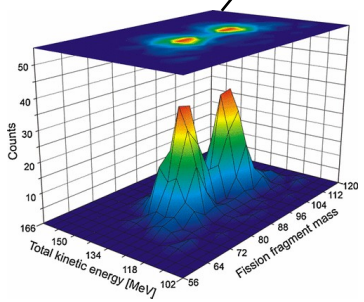




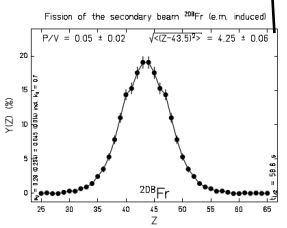
A. Chatillon *et al.* Phys. Rev. C **99**, 054628 (2019)



C. Schmitt *et al*. Phys. Rev. Lett. **126**, 132502 (2021)



A. N. Andreyev *et al*. Phys. Rev. Lett. **105**, 252502 (2010)

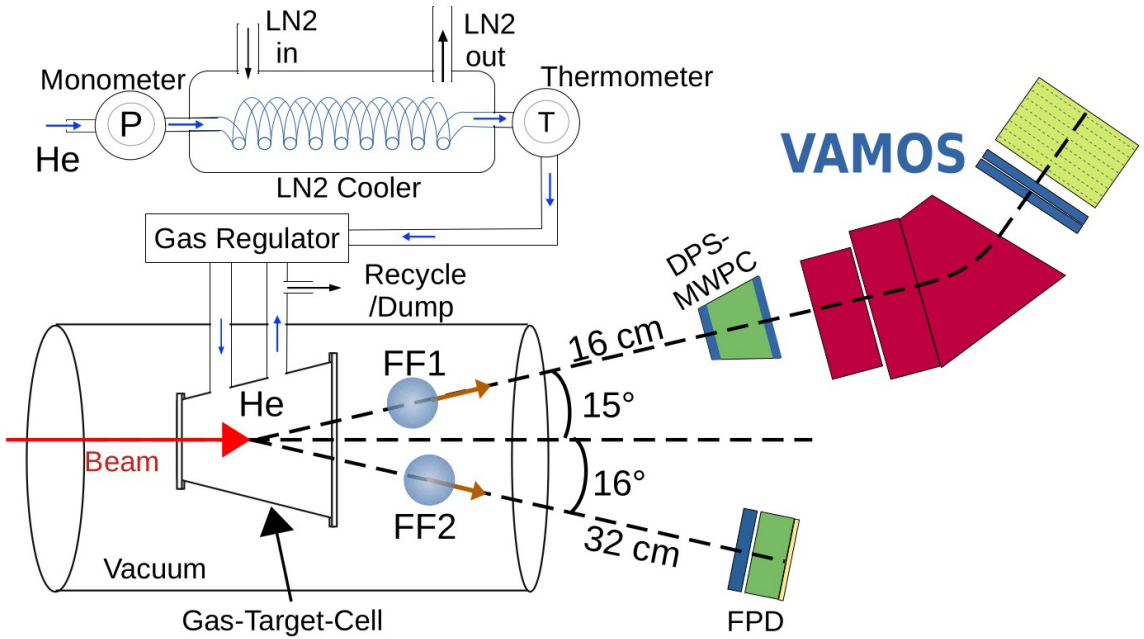


S. Steinhauser *et al.* Thesis work

Perspectives

- **Isotopic distribution measurement of fission fragments for ^{210}Po**. (N. Kumar)
  - ✔ New experiment proposed for next PAC
  - ✔ ^{210}Po produced from fusion at low excitation energy from ^{206}Pb+**α**
  - ✔ Development of a new cooled He Gas-Target Cell.
  - ✔ Development of the second arm with the Fragment Partner Detector (FPD).

- **A new ^{235}U beam at GANIL ?** (CEA DAM)
  - ✔ Proposed as a letter of intent for the next PAC
  - ✔ Access different systems.
  - ✔ But also ^{236}U (from (^{9}Be,^{8}Be→2**α**) one-neutron transfer reaction) with higher statistics.



Conclusion

- The use of inverse kinematics around Coulomb barrier at VAMOS coupled with PISTA is a unique experimental setup worldwide
  - For the complete characterization of the fissioning system (A,Z,E*).
  - For the full isotopic identification of the fragment distribution and their TKE.

- Further improvement for the experimental setup are on-going
  - Second arm : Fragment Partner Detector (FPD) to determine the TKE and Z of the second fragment.
  - A new Cooled He Gas-Target Cell to populate fissioning system through fusion a low excitation energy.

- A lots of experiments accepted and submitted
  - A lots of scientific activities in the coming years

Thank you