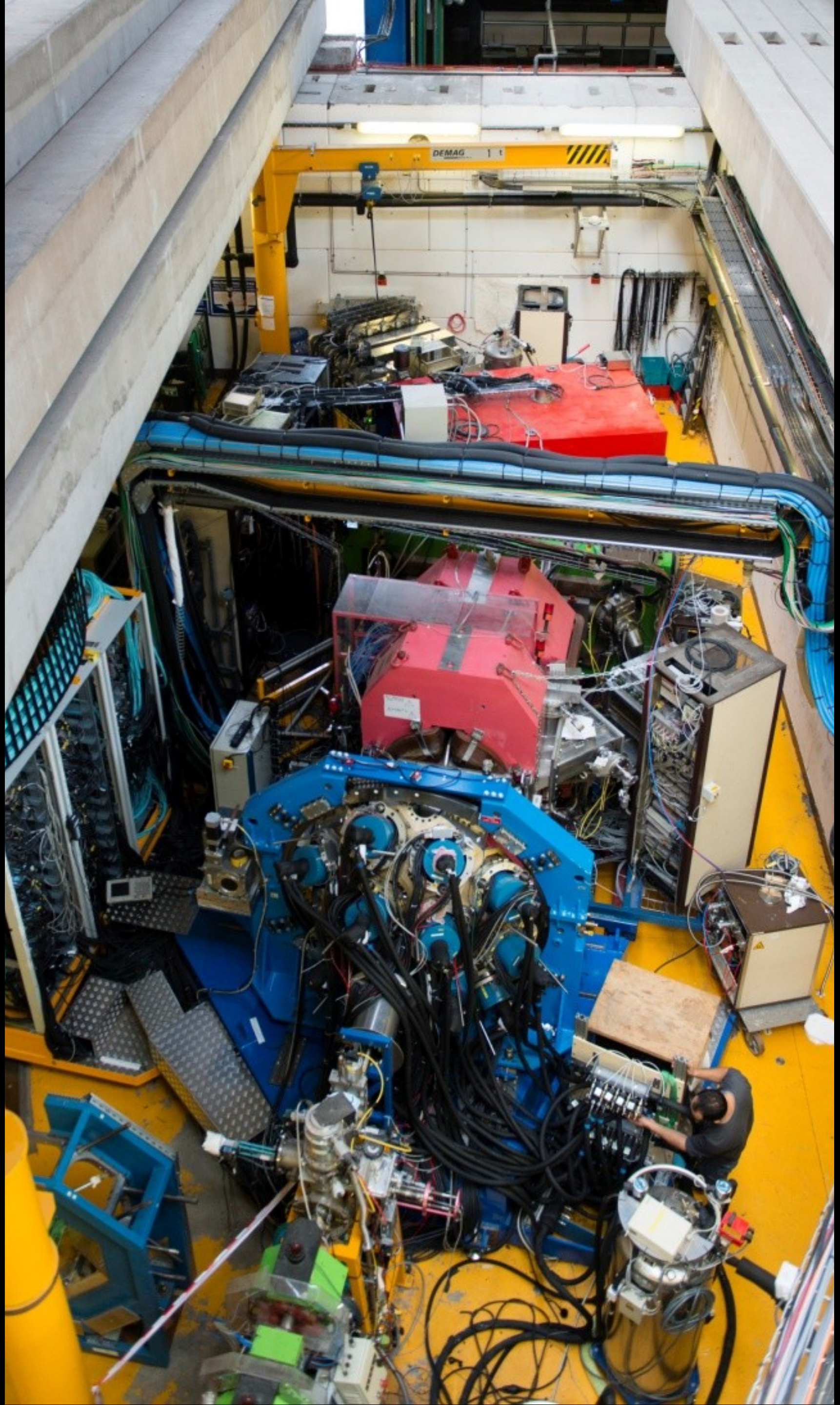
VAMOS Status and Roadmap 2022-2025

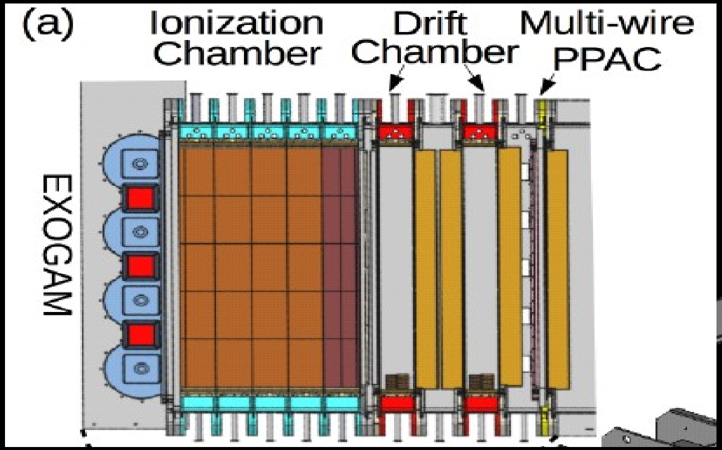
GANIL Community Meeting 2022



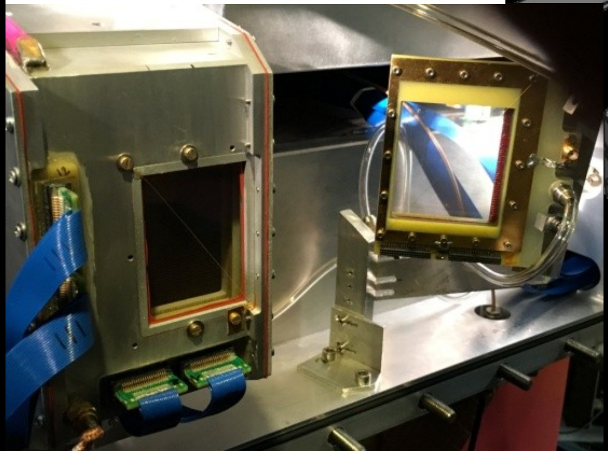
Outline

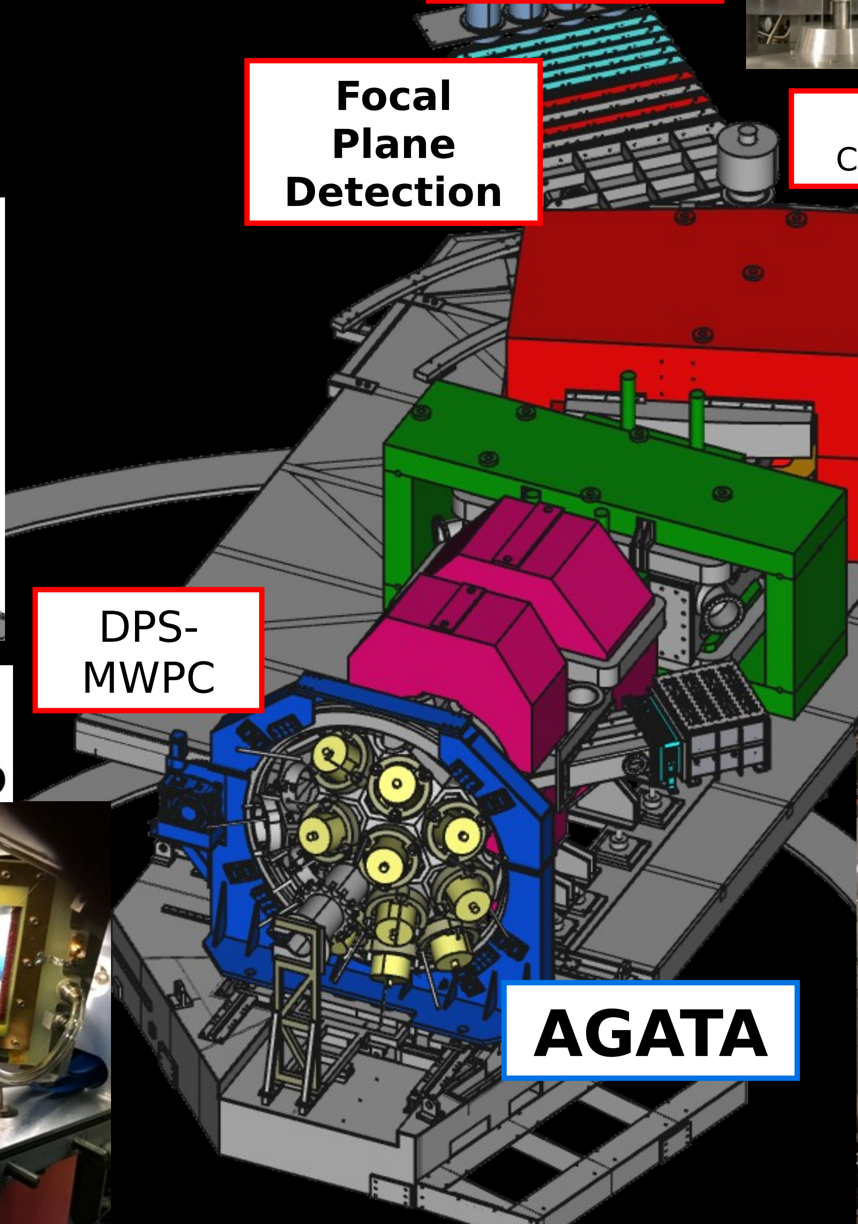
- VAMOS++ Status : a decade of continuous improvements
- Physics opportunities and roadmap 2022-2025
  - Fission of actinides
  - Fission of neutron-deficient pre-actinides

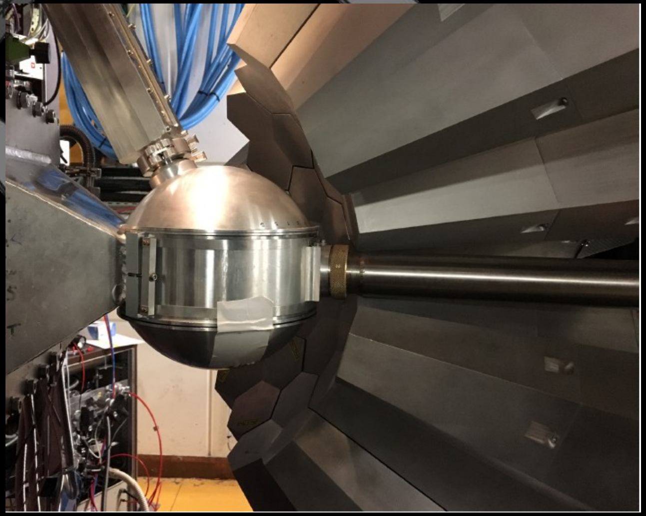
VAMOS++ large acceptance spectrometer



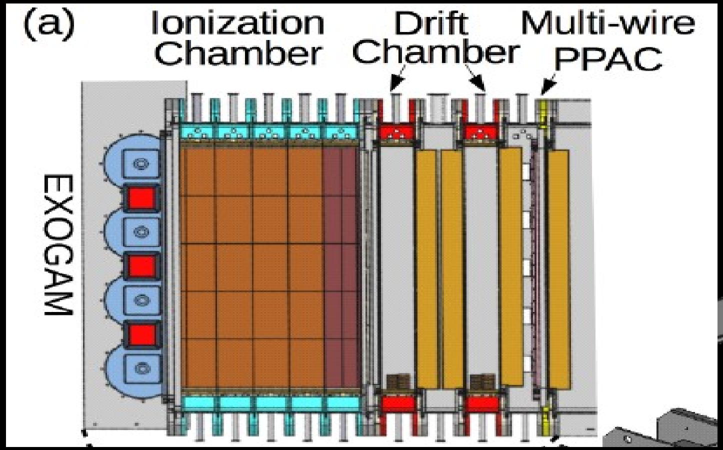
VAMOS
VARIABLE MODE SPECTROMETER



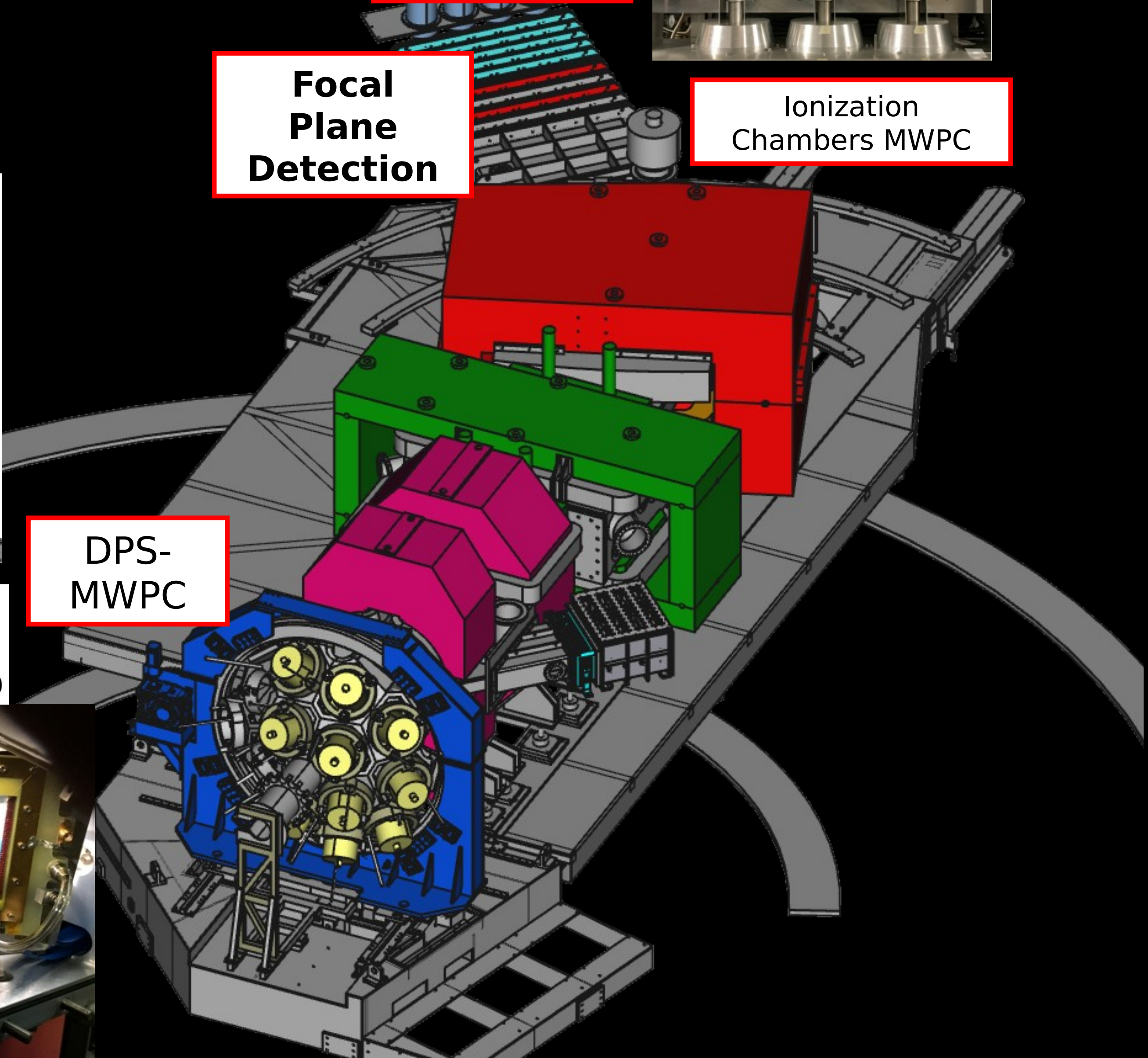




VAMOS++ large acceptance spectrometer



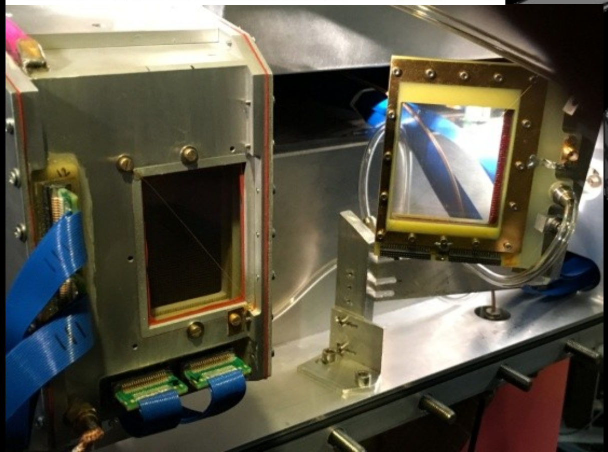
EXOGAM at Focal Plane



Focal Plane Detection

Ionization Chambers MWPC

DPS-MWPC



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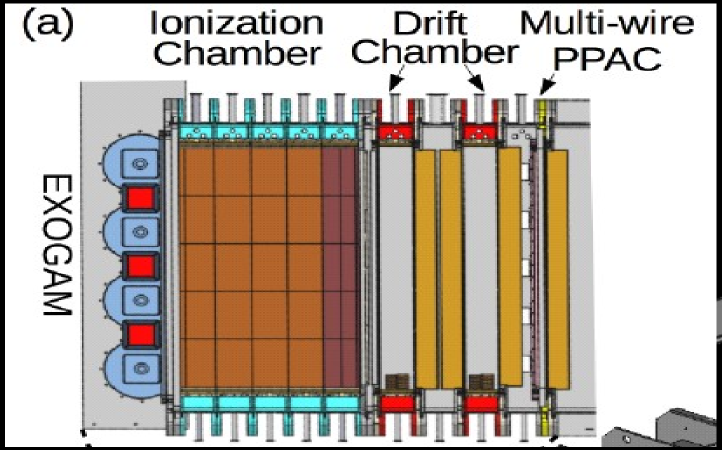
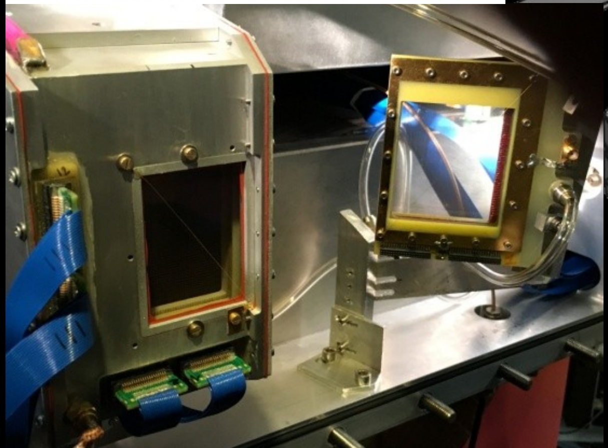
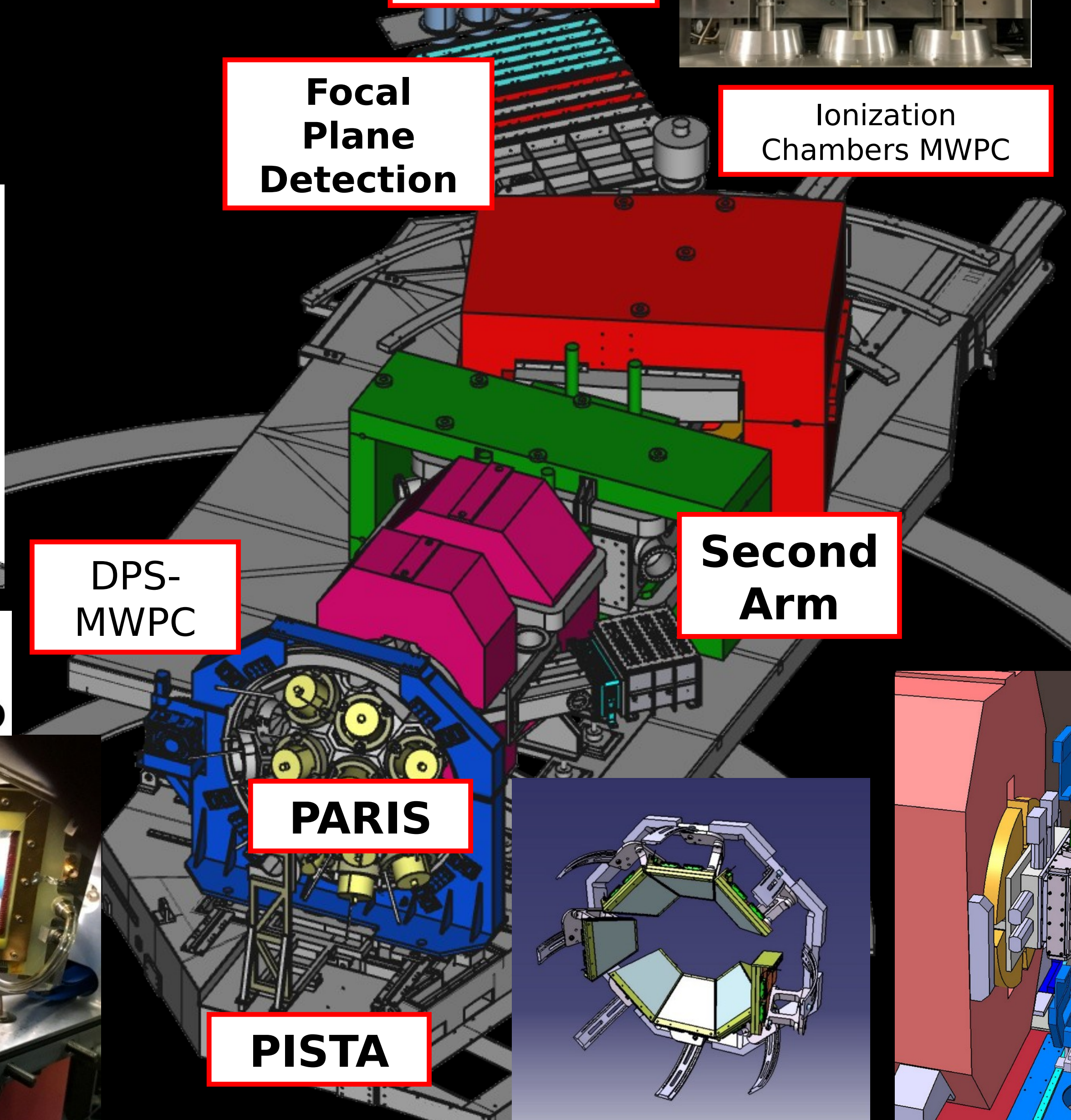
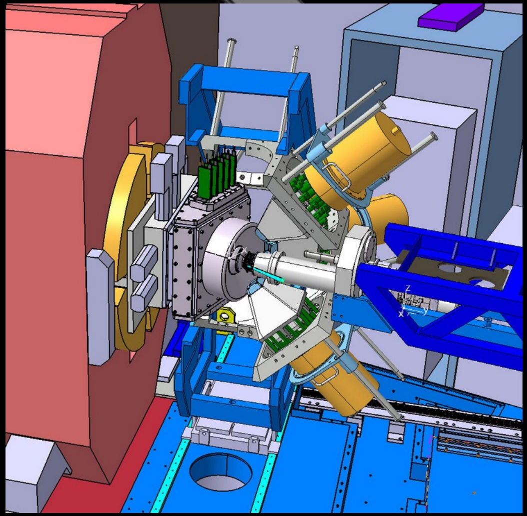








A decade of upgrade at VAMOS !

Nuclear Structure and dynamic under the magnify glass of fission in inverse kinematics !

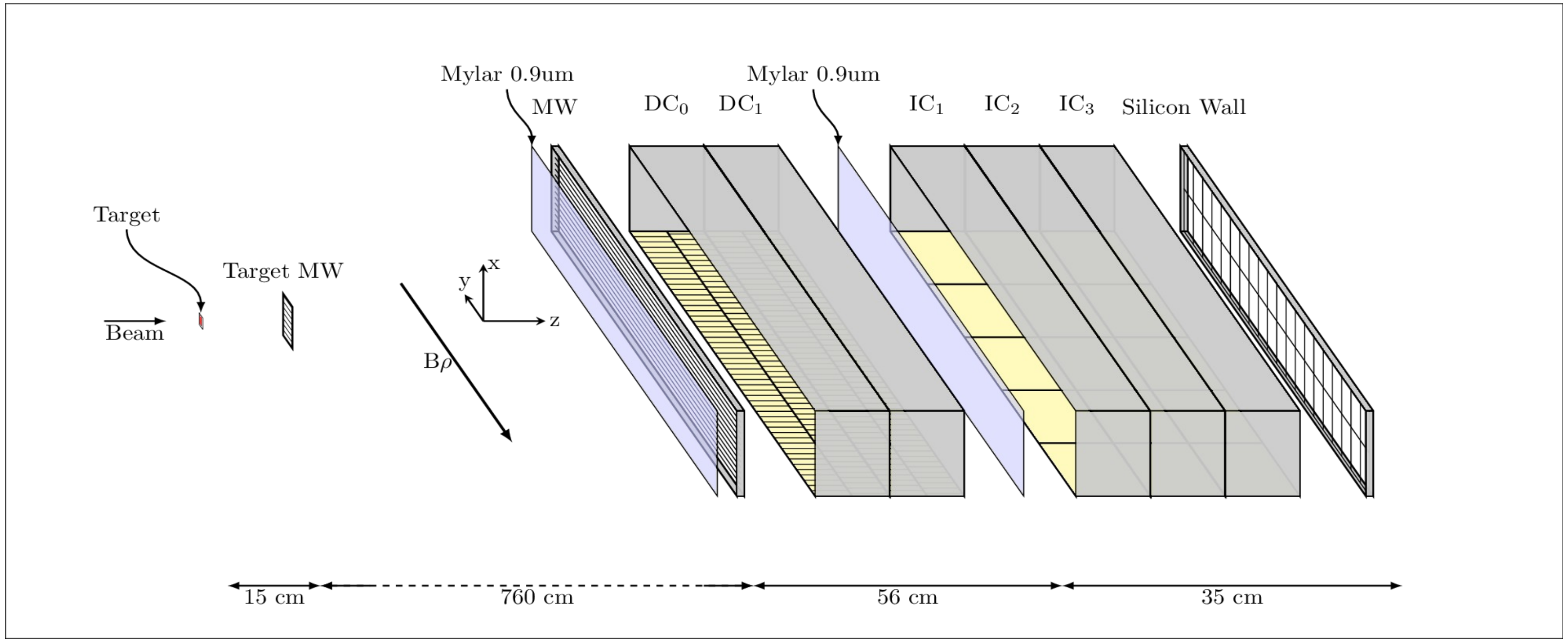
Key Dates

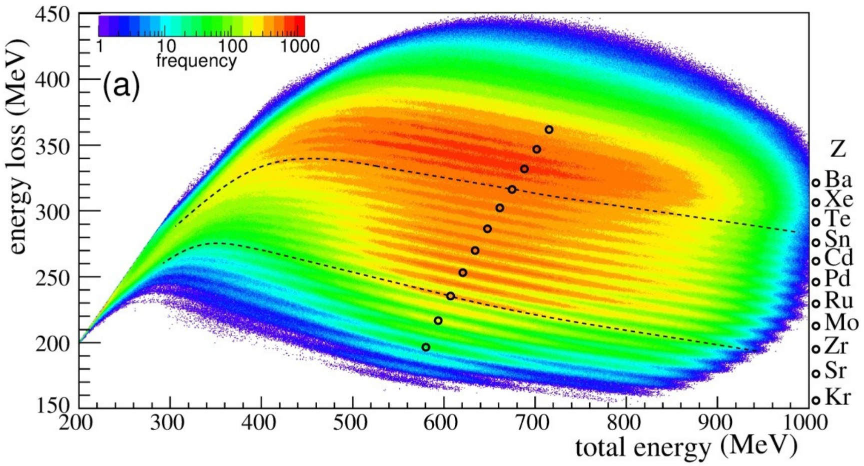
2009 : First expt FISSION@VAMOS
(VAMOS+SPIDER+EXOGAM)
2011 : Fission Fragments Spectroscpy + Dynamics
(VAMOS++ and EXOGAM)
2015-2017 : g-ray spectroscopy
(VAMOS++ and AGATA + EXOGAM)
2017 : Fission dynamics
(VAMOS++ and SPIDER)
2021 : MNT VAMOS+AGATA
2022 : Fission Dynamics
(VAMOS++ and PARIS + FALSTAFF)

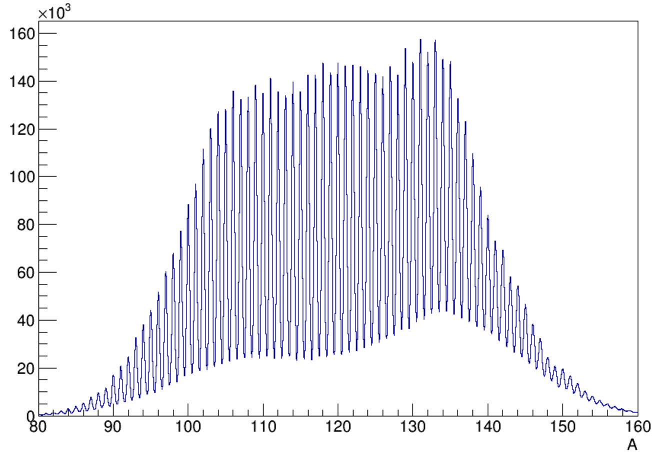
Associated devellopments

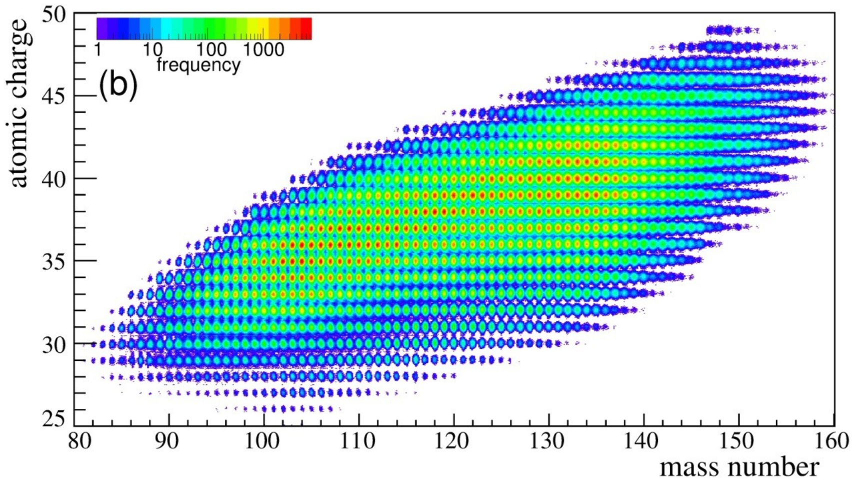
2009 : SPIDER
2011 : Upgrade VAMOS++
2014 : Silicium Dismantelling
=> Upgrade to Ionization Chambers I
2015 : Target Multiwire DPS-MWPC
2016 : Electonics Upgrade NUMEXO2 I
2017 : Upgrade MW focal plane
2019 : Electronics Upgrade to NUMEXO2 II
Dedicated MUGAST Focal Plance
2020 : Upgrade Ionization Chambers II
2021 : Replacement of Drift Chambers by PS-MWPC
2022 : Upgrade Ionization Chambers III
2023 : PISTA !

VAMOS Focal Plane 2011 (VAMOS++)



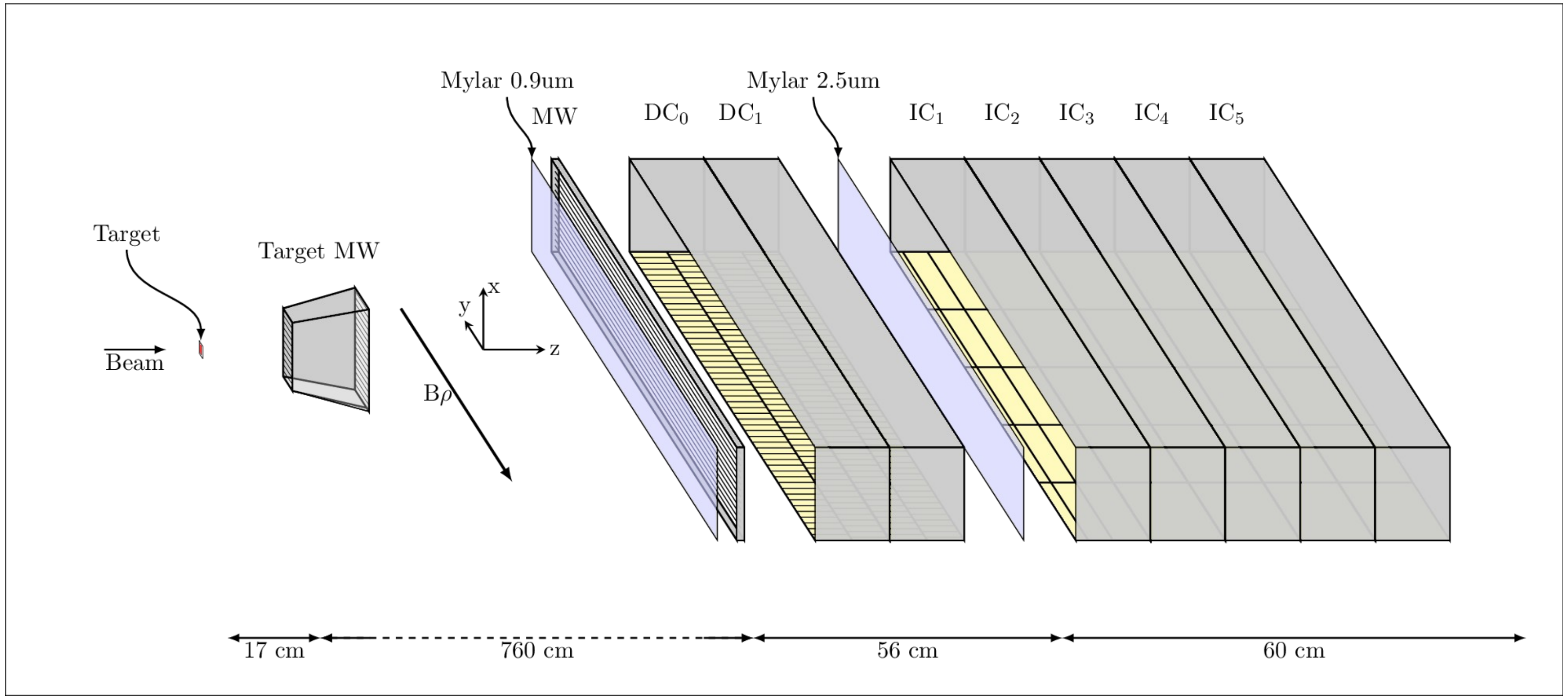


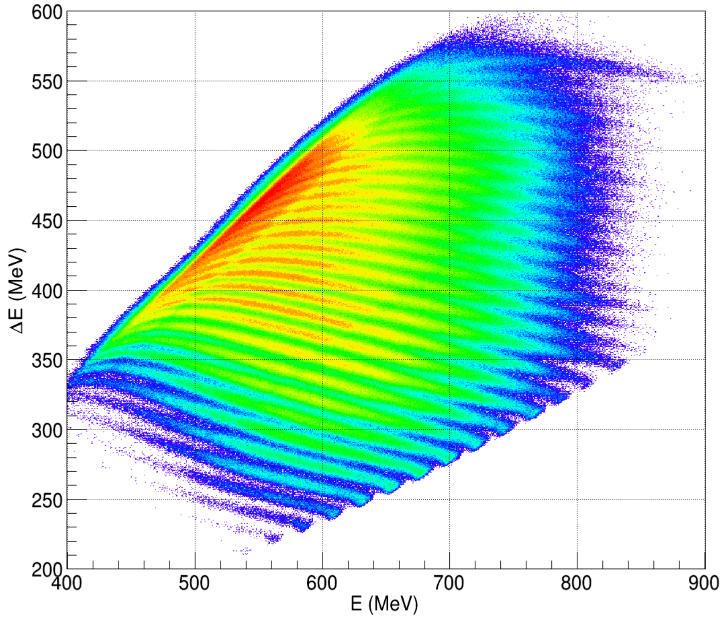


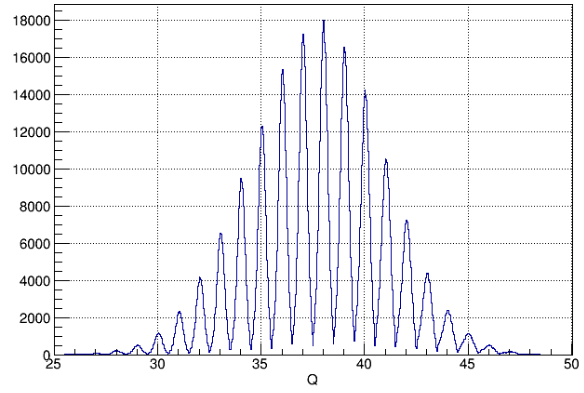


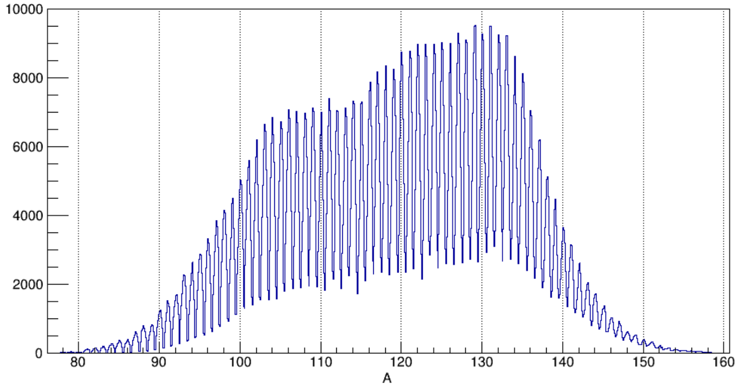
2008 – 2012:
unique performances ...

VAMOS Focal Plane 2016-2017



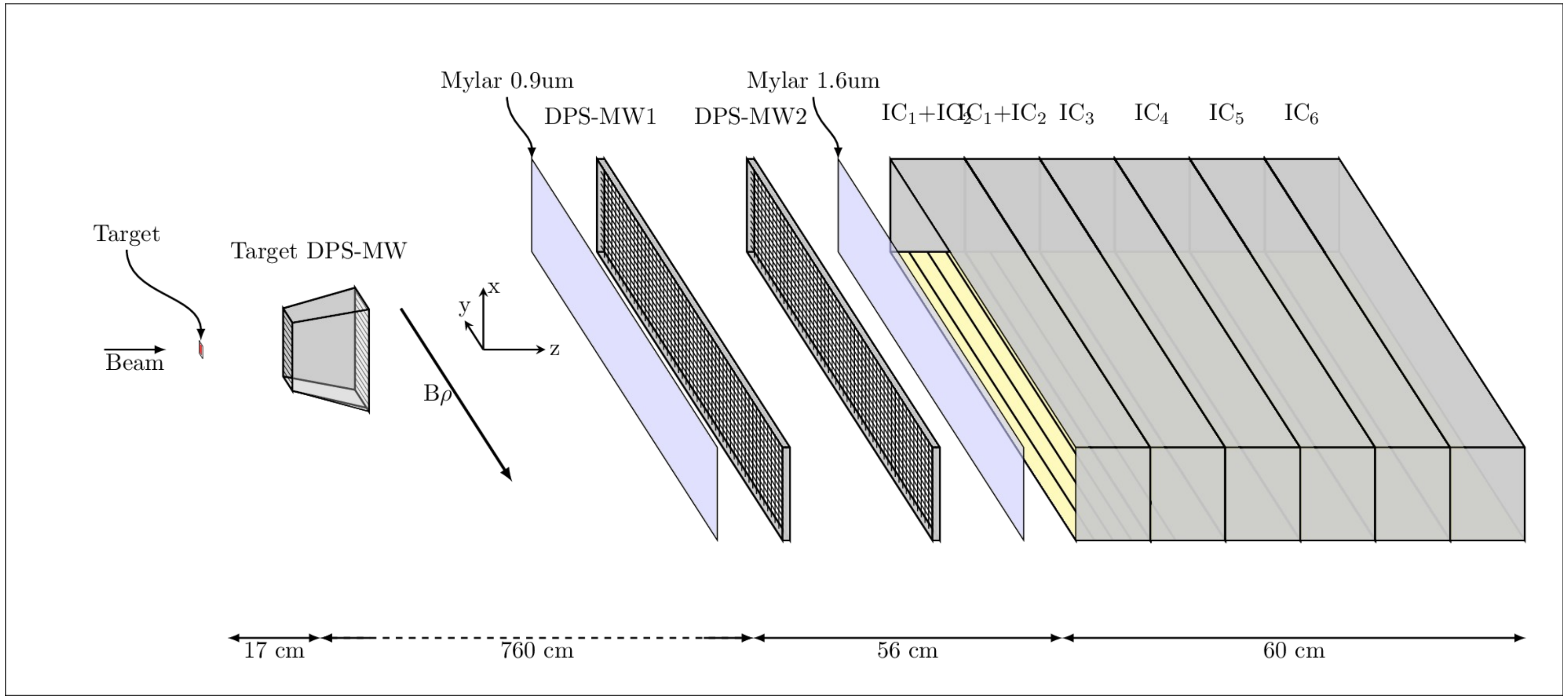


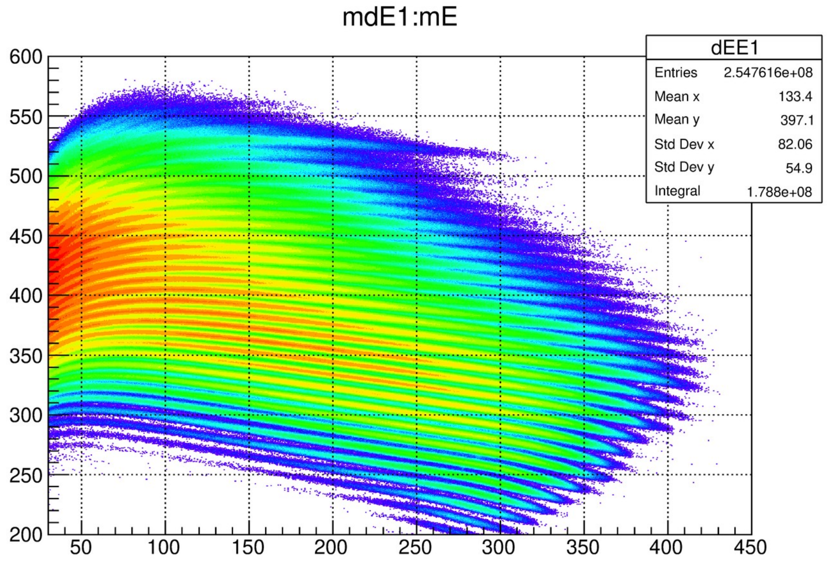


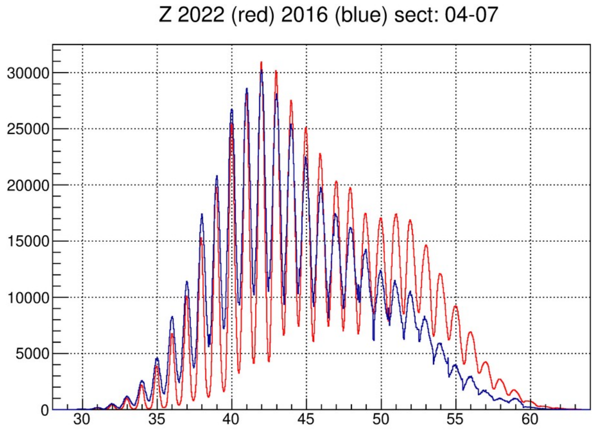


2014 – 2017:
that can be overcomed ...

VAMOS Focal Plane 2022

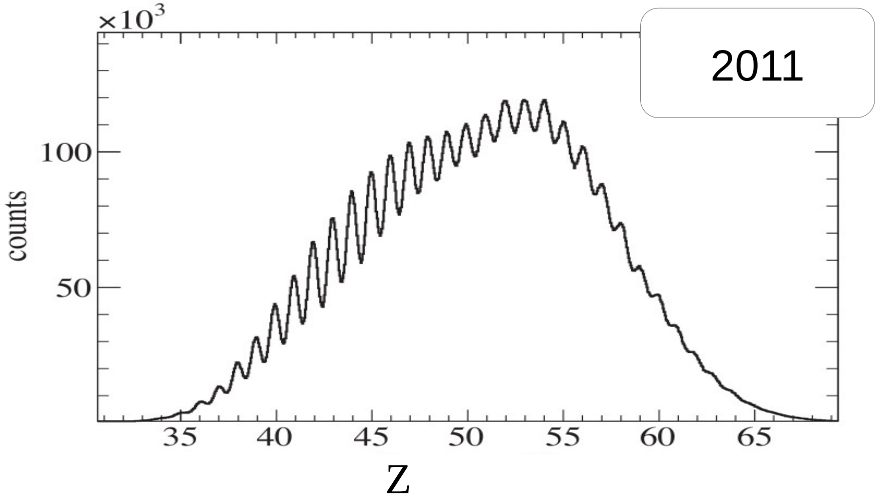




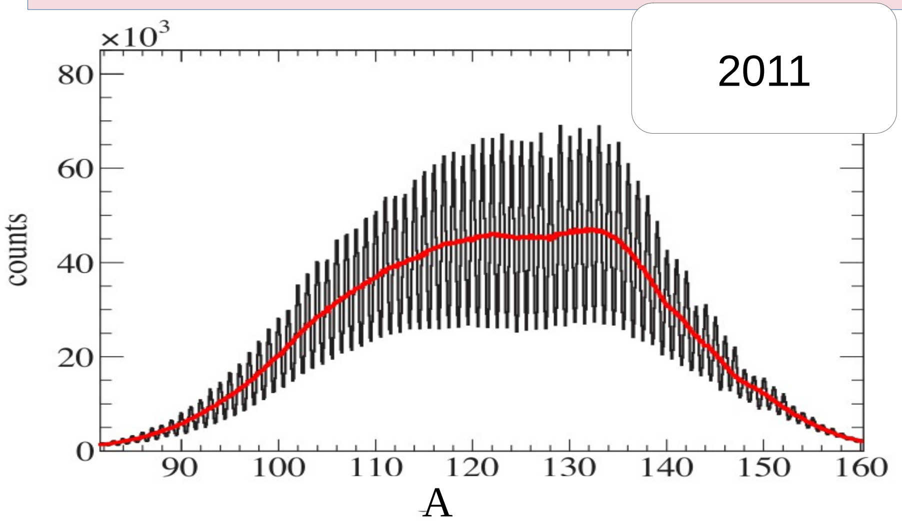


2022 : best identification performances ever !

The VAMOS learning curve



- VAMOS++
- DC + IC + Si (focal plane)



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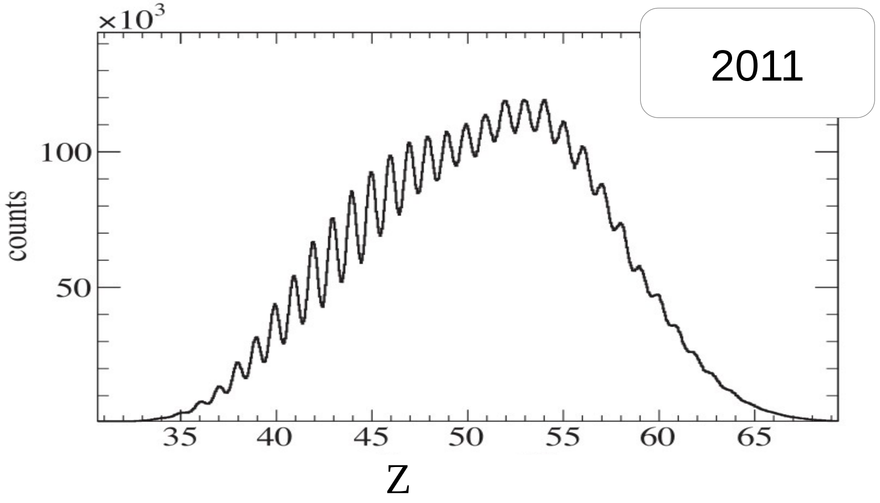
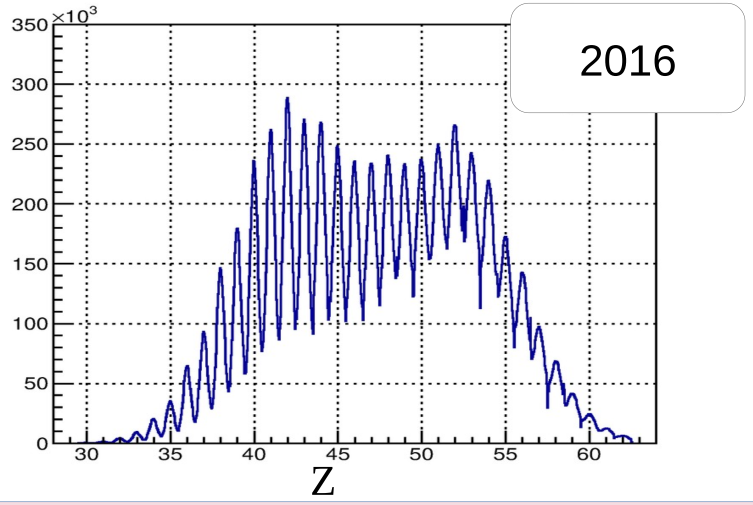
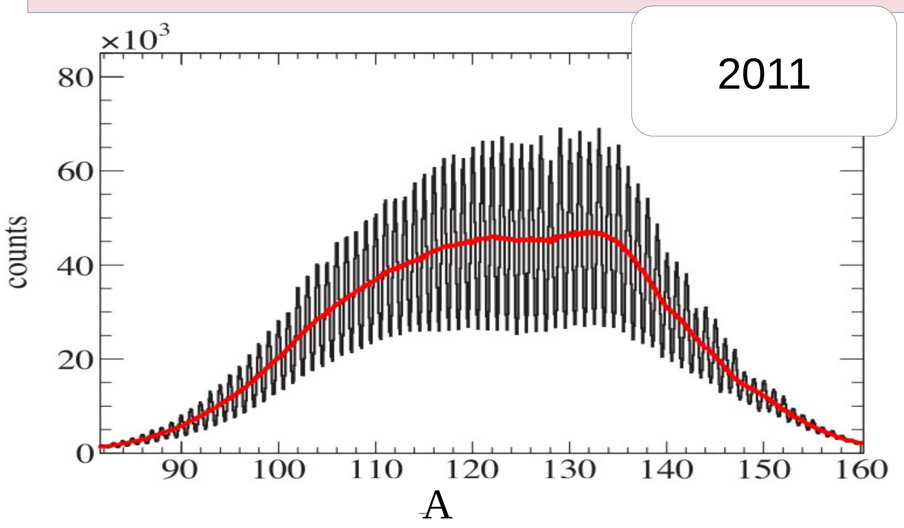
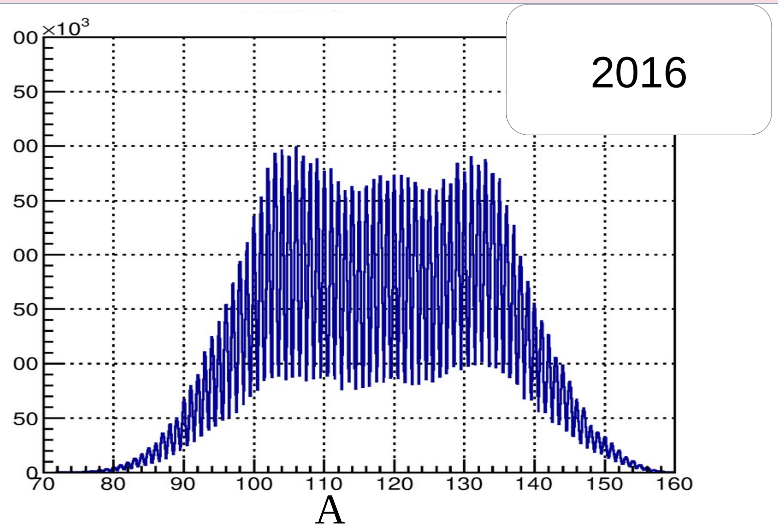




- VAMOS++
- DC + IC + Si (focal plane)

- Target PS-MWPC
- High Pressure IC
- Digital Electronics





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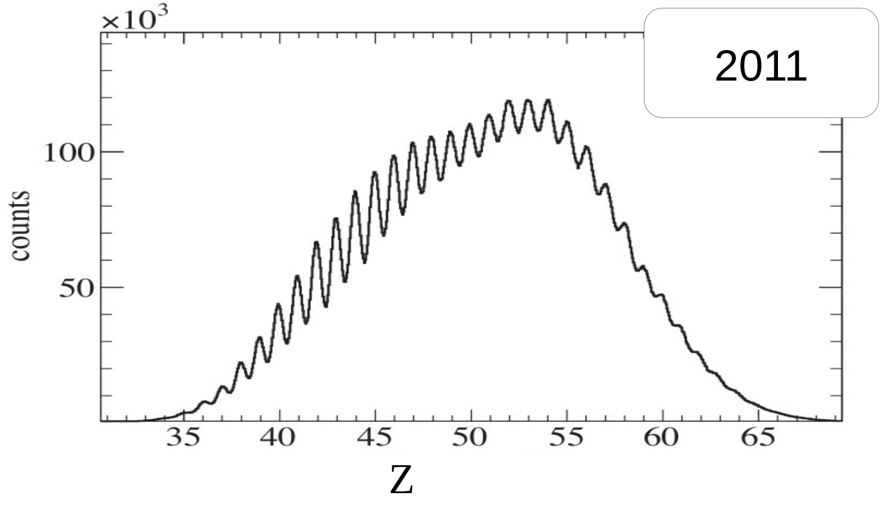
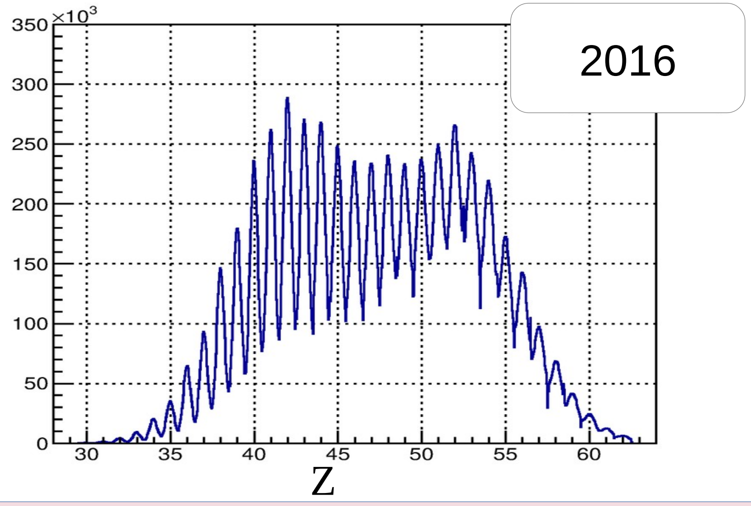
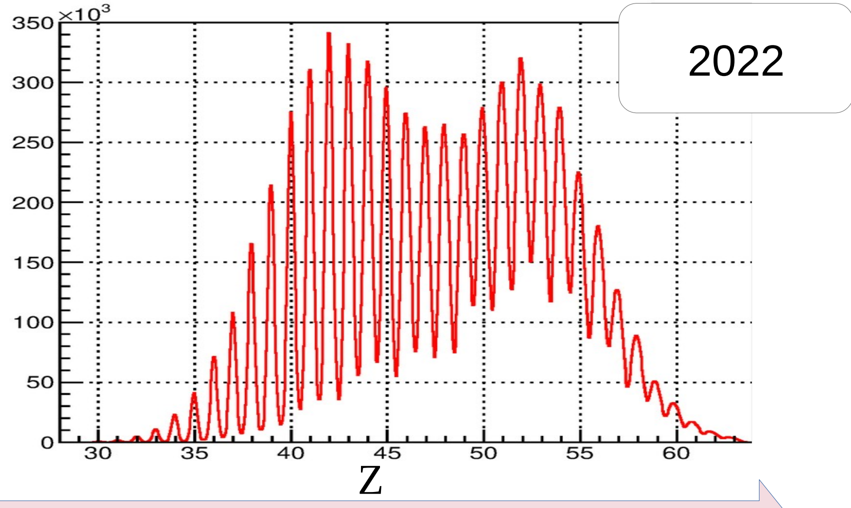


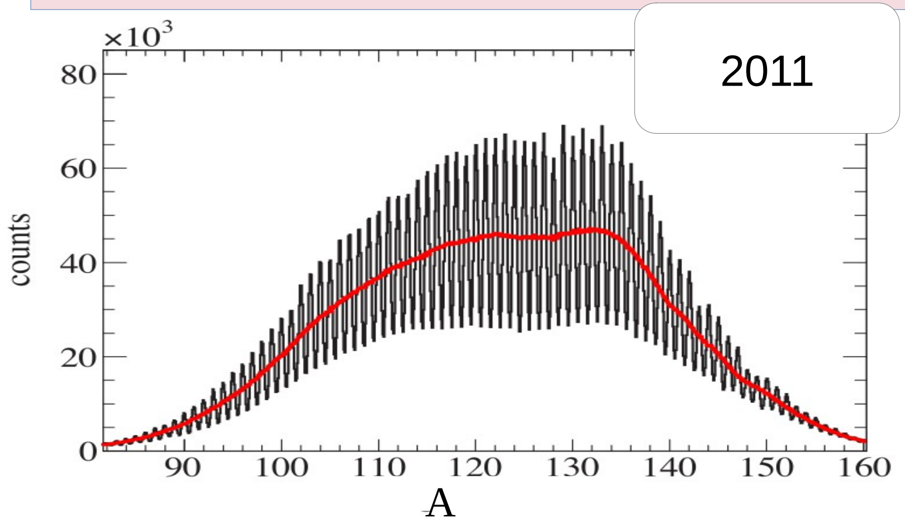


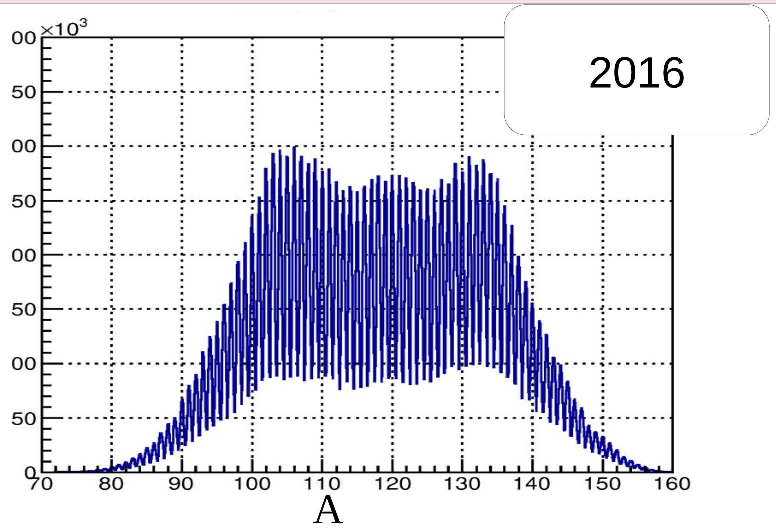


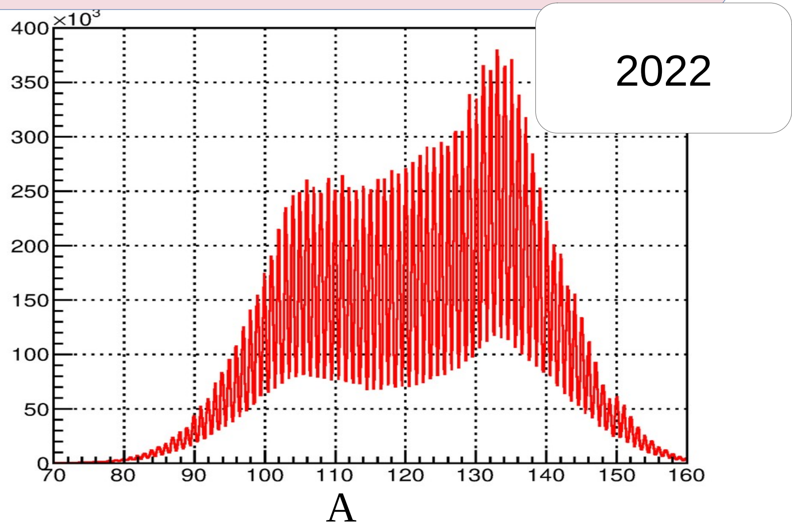
- VAMOS++
- DC + IC + Si (focal plane)

- Target PS-MWPC
- High Pressure IC
- Digital Electronics

- Focal Plane PS-MWPC
- Higher Segmentation IC
- Reconstruction Methods







VAMOS Roadmap 2022-2025

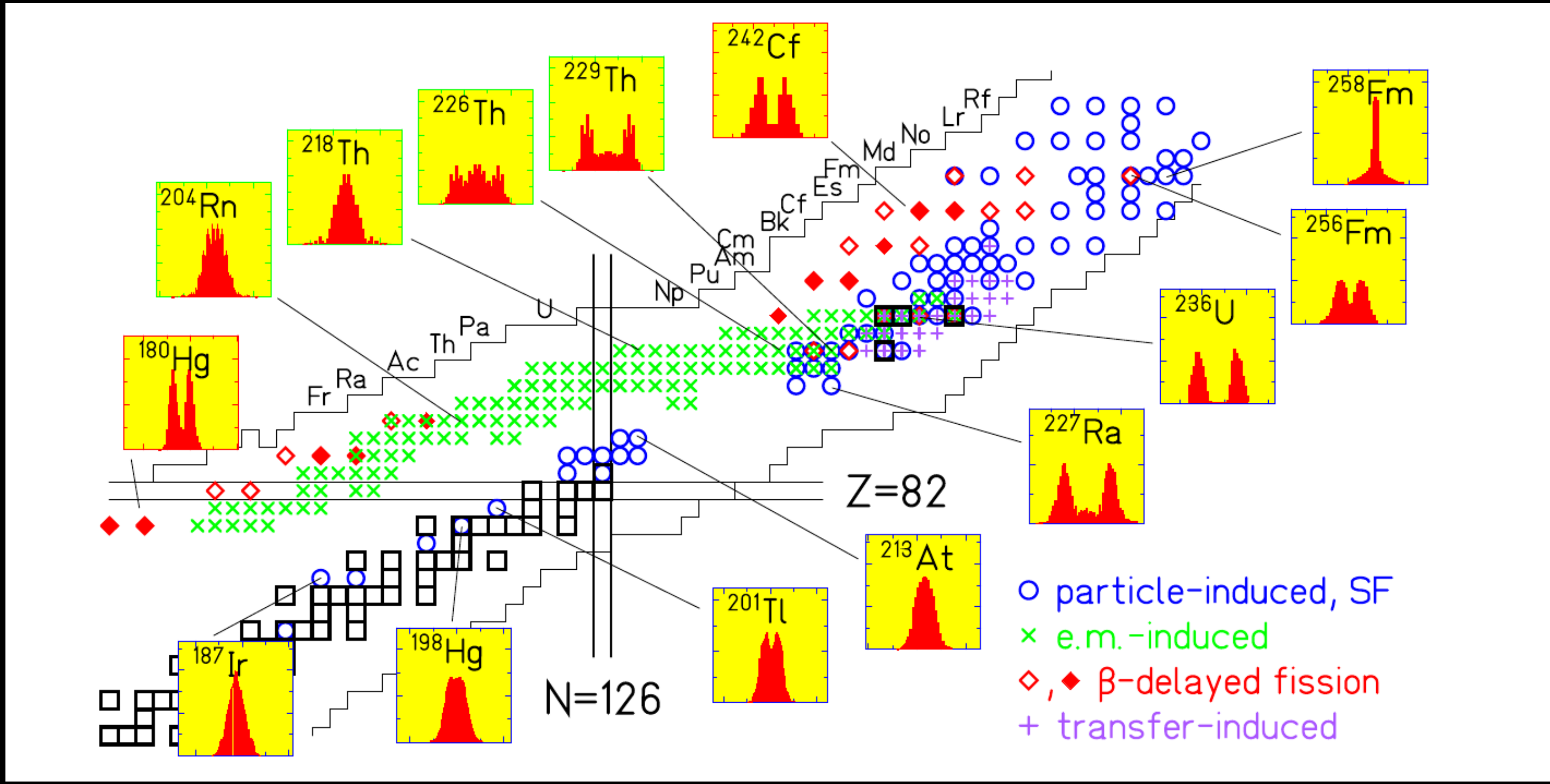
Scientific Roadmap

Fission Dynamics

- ➢ actinides
- ➢ neutron-deficient pre-actinides

Instrumental Roadmap

- PISTA
- Second Arm Detection (s)
- Gaz Cell Target

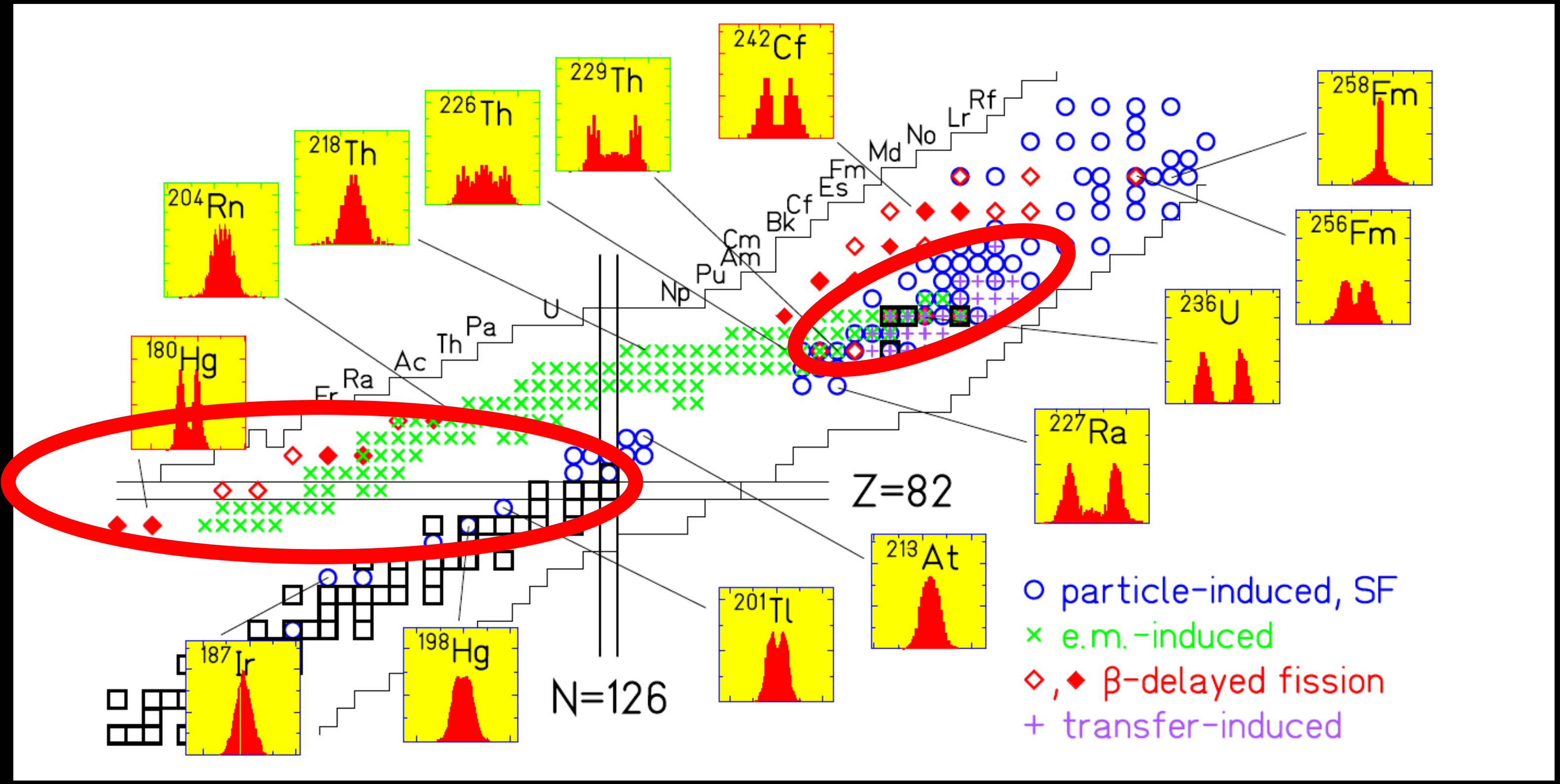


VAMOS Roadmap 2022-2025

Scientific Roadmap

Fission Dynamics

- actinides
- neutron-deficient pre-actinides



Instrumental Roadmap

- PISTA
- Second Arm Detection (s)
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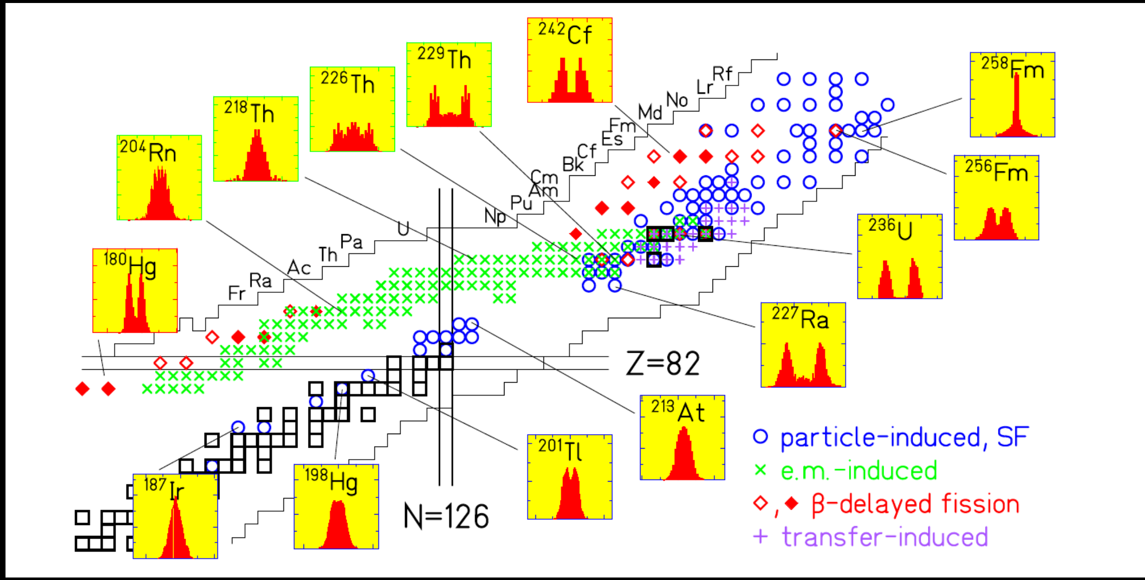
Fission Process

- Key Open Questions :
  - Dynamical evolution of complex quantum system
  - At the crossroad of many research topics of nuclear physics with essential **interplay between structural and dynamical properties of nuclei**.
  - Fully microscopic description of the whole fission process (fissioning system, fission dynamics and fission fragment distributions and properties) is not yet available

- Relevant observables for what ?
  - **Direct isotopic (A,Z) fission fragments data**
  - **Complete fission yields**
    => Probing the role of shell effect in fission and dissipation
  - **Kinetic energies and excitation energies of the fission fragments**
    => Probing the scission configurations (A, Z, Energy sharing)
  - **Fission Barriers (evolution as function of excitation energy):**

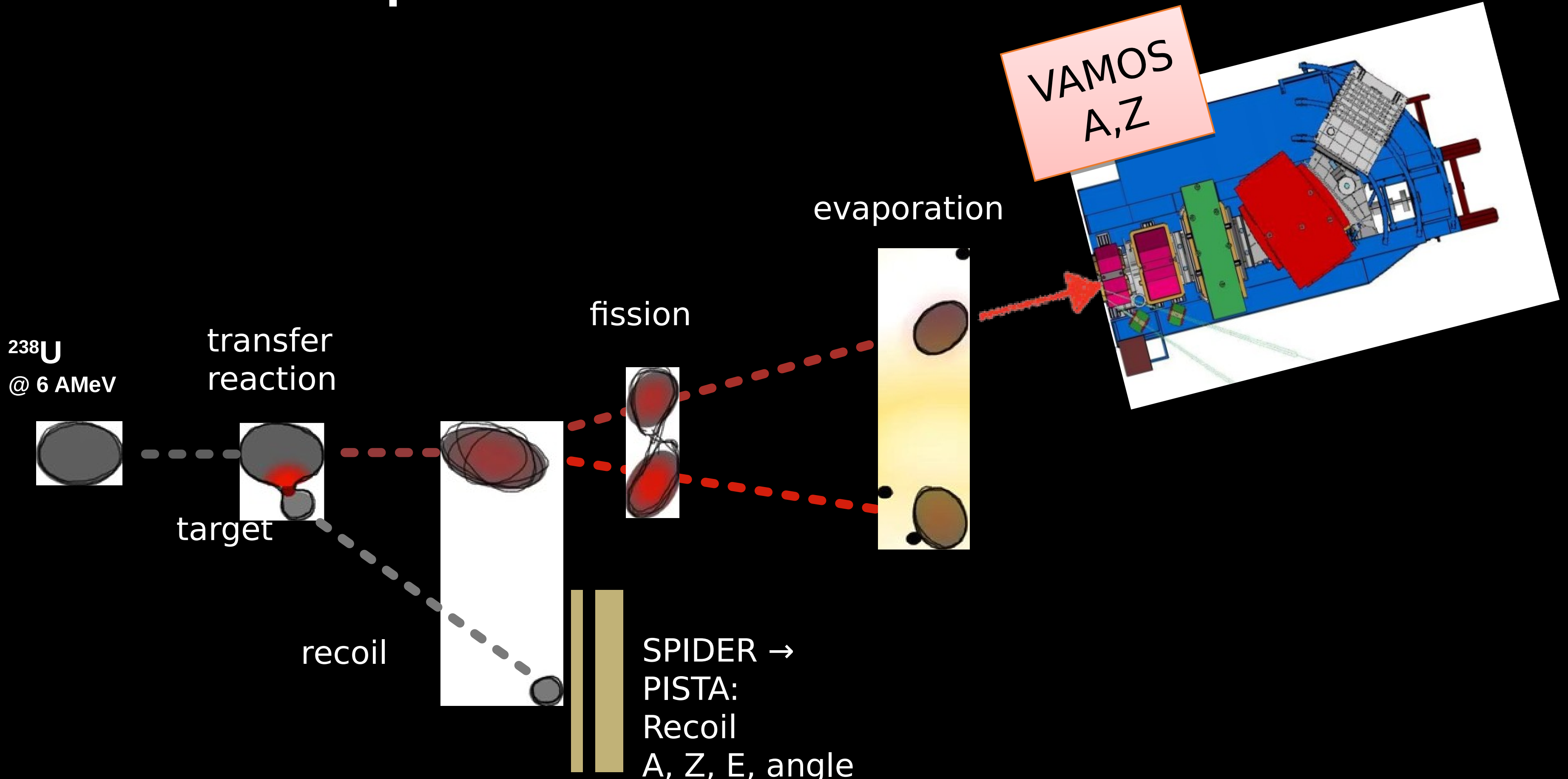
    => Probing the potential energy surface as function of E*

    => Exploring the fission paths (different modes of fission)



Changing N and Z content of fissioning systems

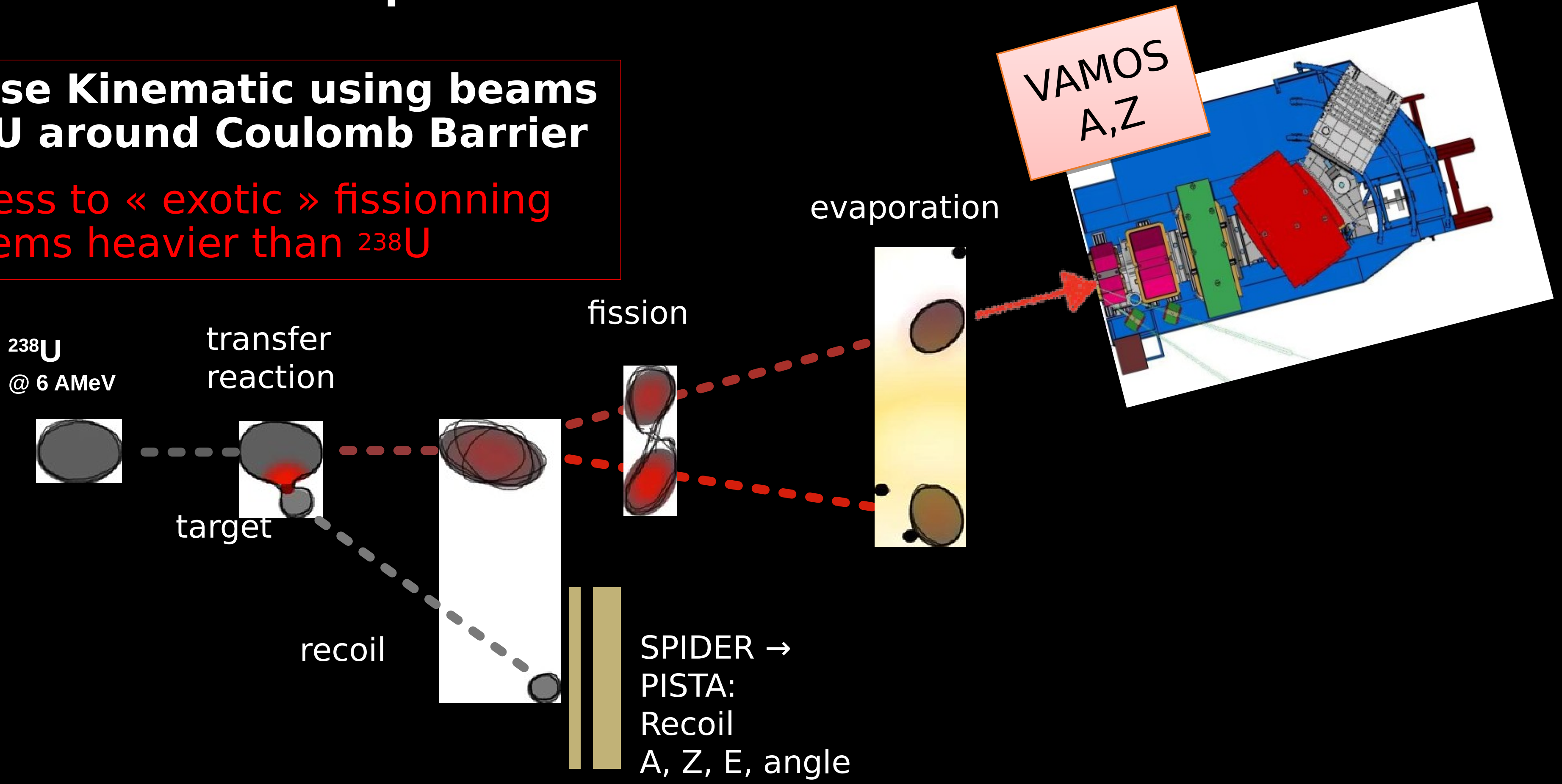
What is unique and what can be done at VAMOS ?



What is unique and what can be done at VAMOS ?

Inverse Kinematic using beams of ^{238}U around Coulomb Barrier

⇒ Access to « exotic » fissionning systems heavier than ^{238}U



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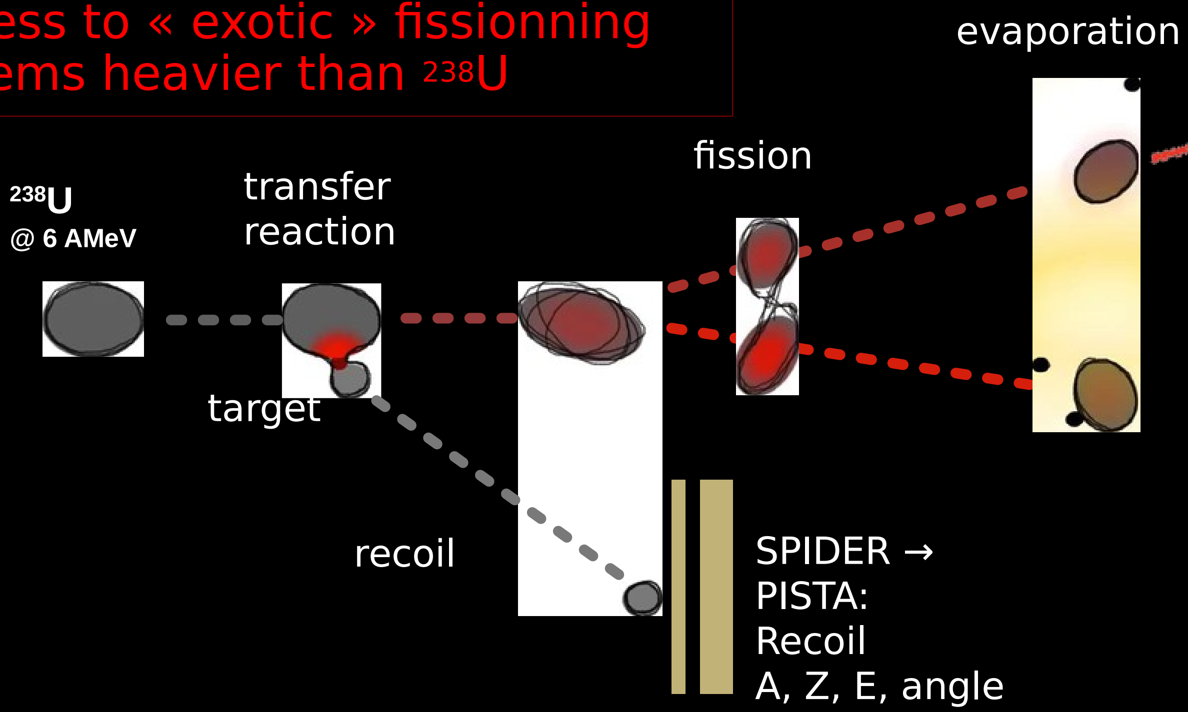

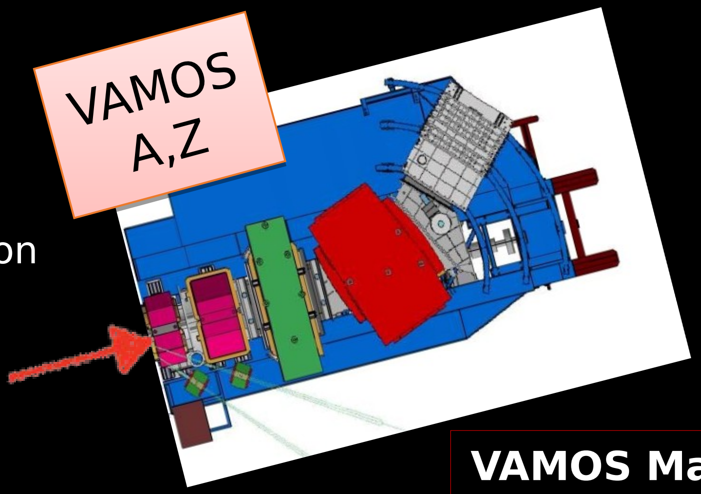

VAMOS Magnetic Spectrometer

⇒ Direct and Complete isotopic fission fragment yields

⇒ Precise center-of-mass fission fragment velocities isotopically (due to Coulomb barrier energies)

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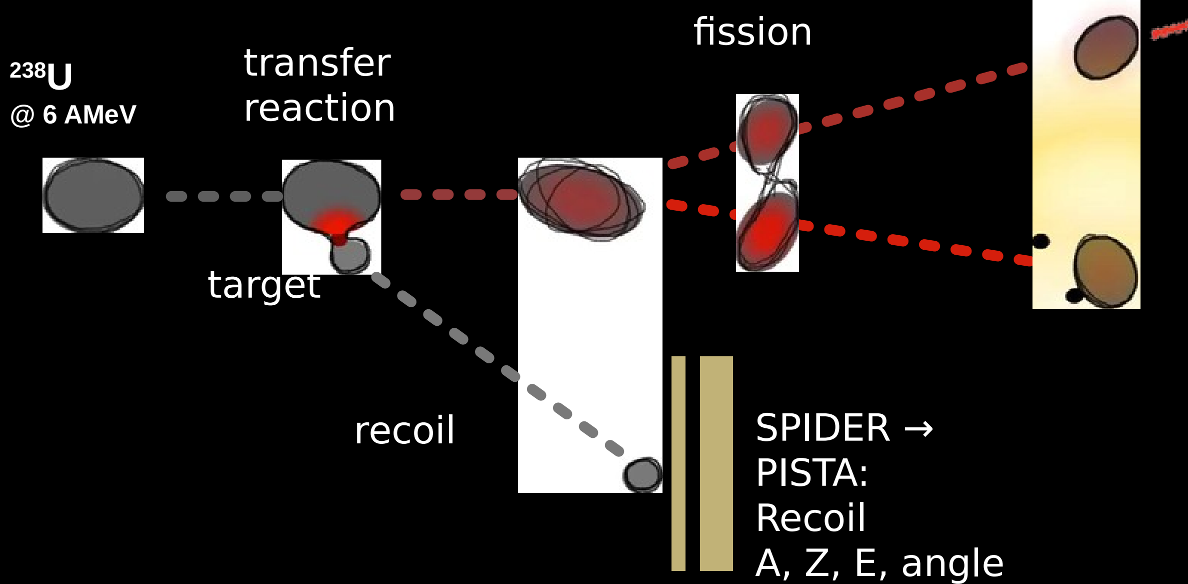

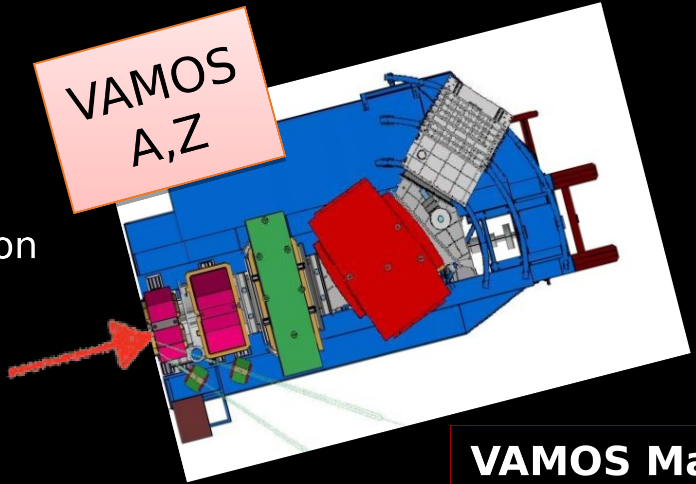

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⇒ Direct and Complete isotopic fission fragment yields

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Surrogate reactions (transfer induced fission)

⇒ Selection of the fissionning system

⇒ Measurement of the excitation energy

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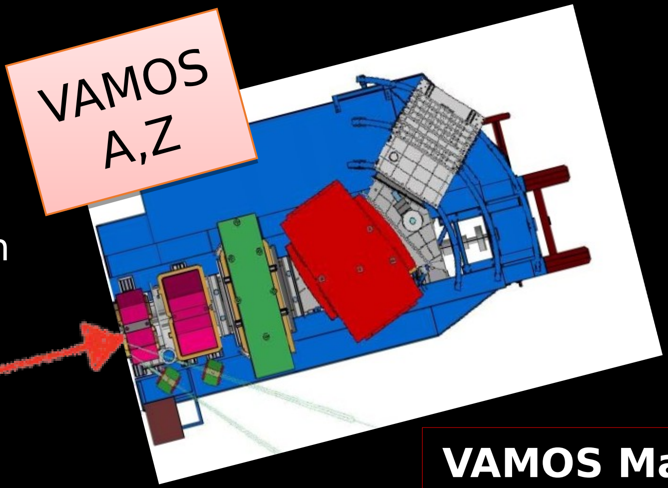

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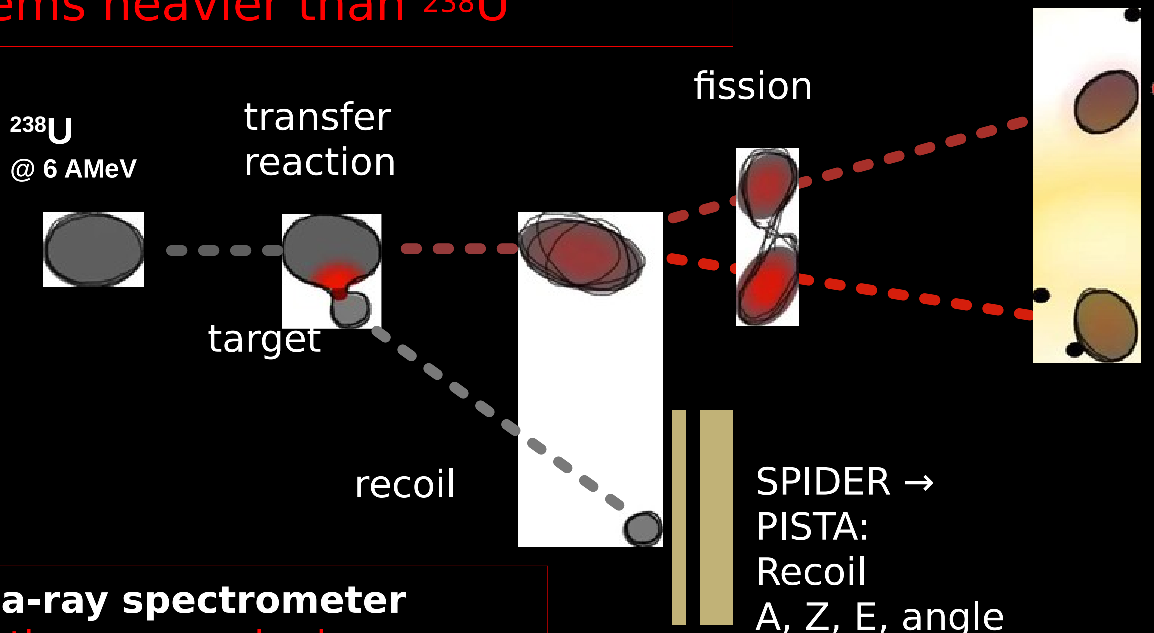

Gamma-ray spectrometer

⇒ Excitation energy sharing between the fission fragments

Surrogate reactions (transfer induced fission)

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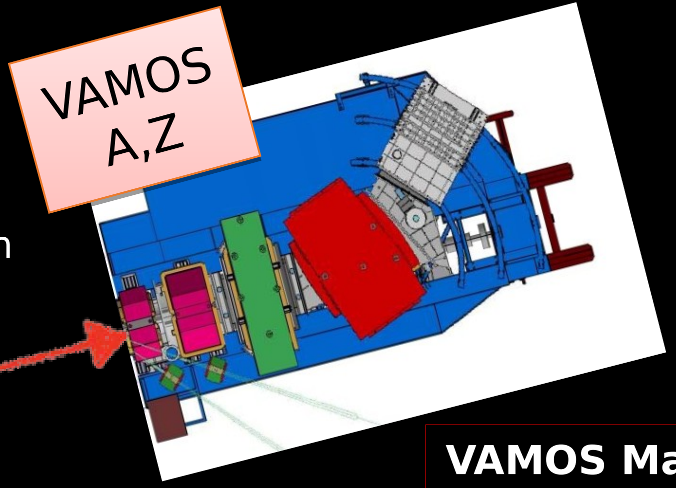

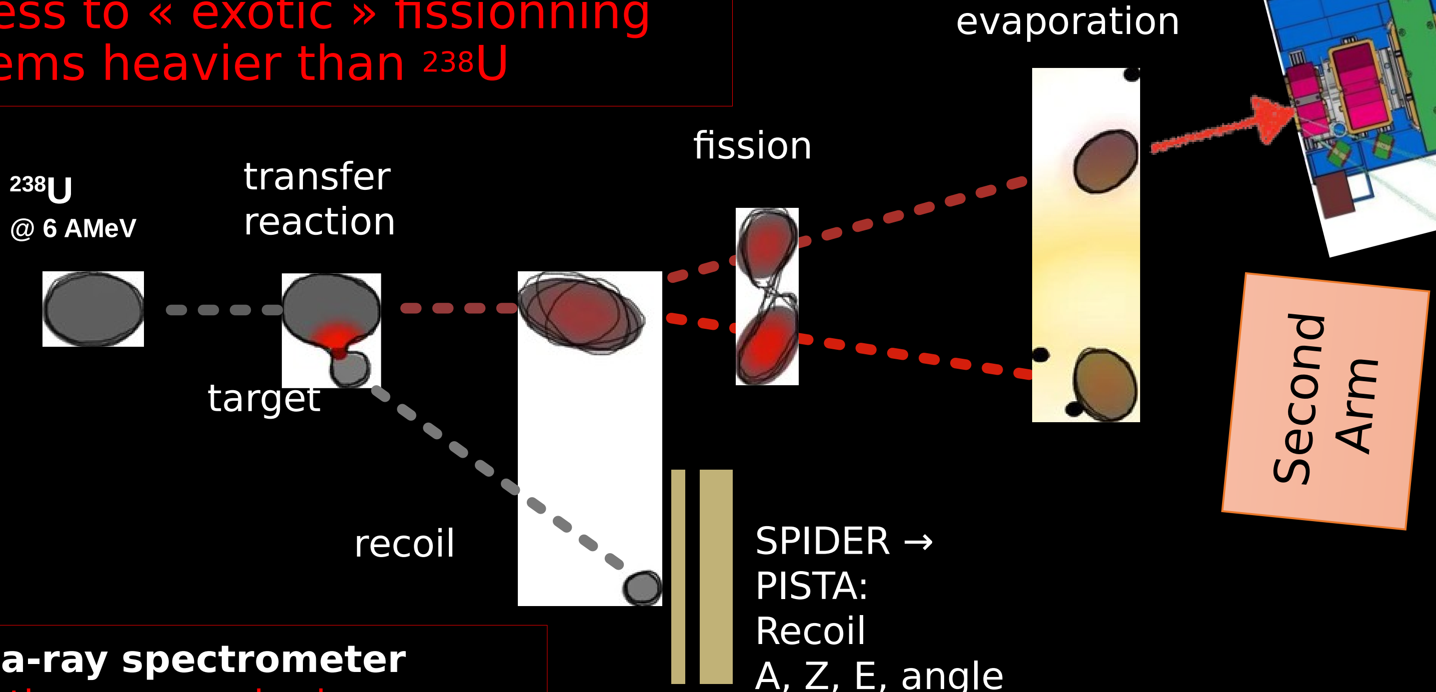

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Gamma-ray spectrometer

⇒ Excitation energy sharing between the fission fragments

Surrogate reactions (transfer induced fission)

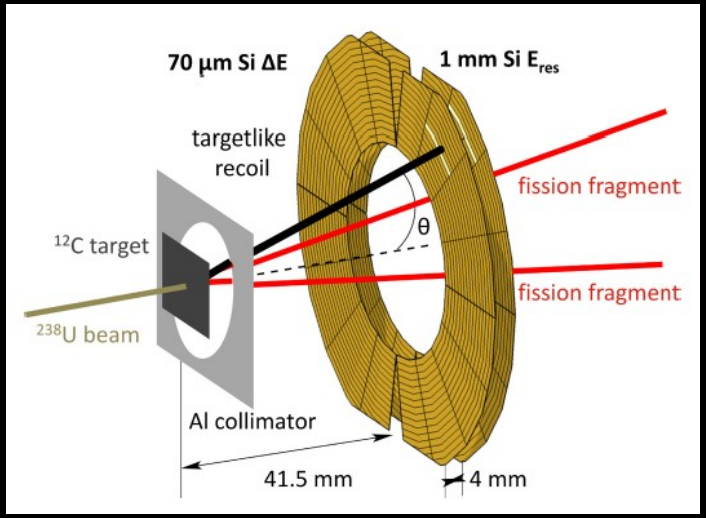
⇒ Selection of the fissionning system

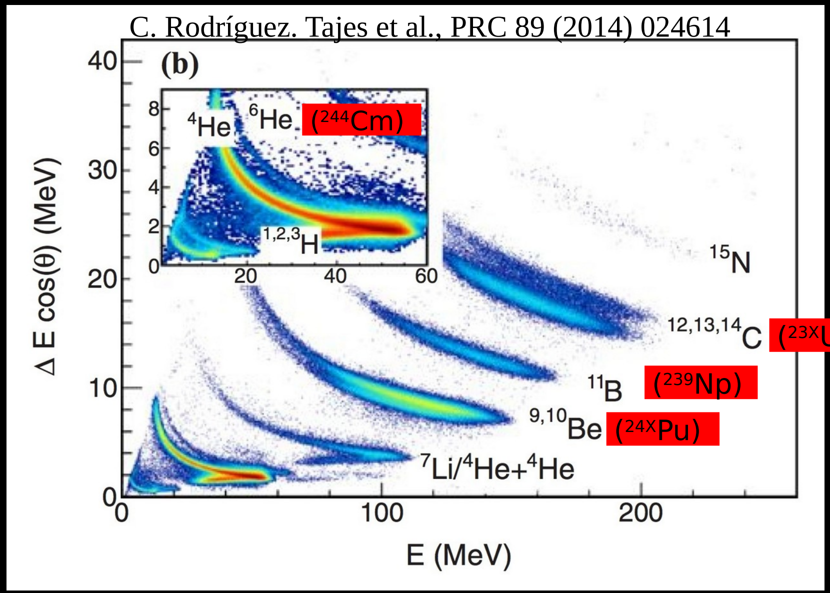
⇒ Measurement of the excitation energy

VAMOS Second Arm

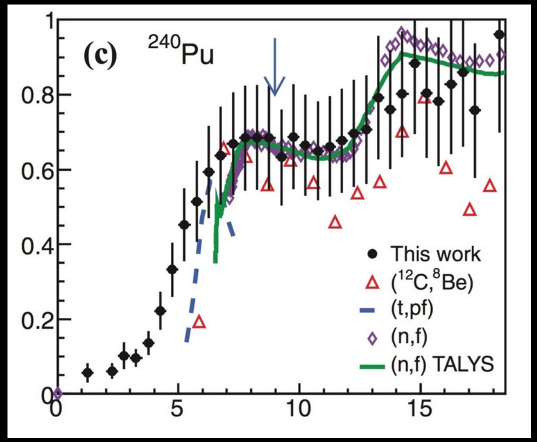
⇒ Total Kinetic energies isotopically using the second arm (presently, only averaged without second arm)

SPIDER annular segmented dE-E silicon telescope provides the selection of the fissioning system and its excitation energy

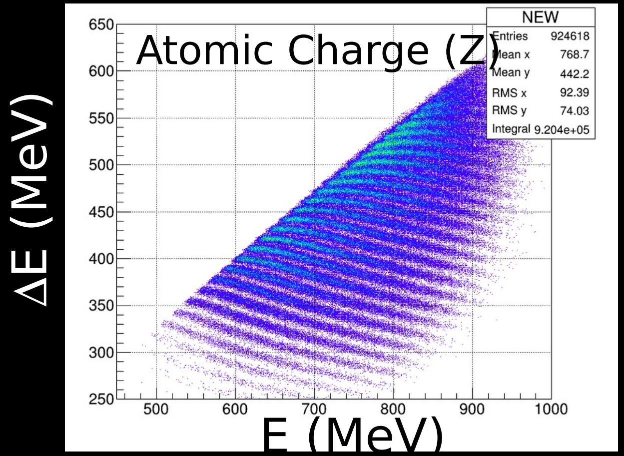


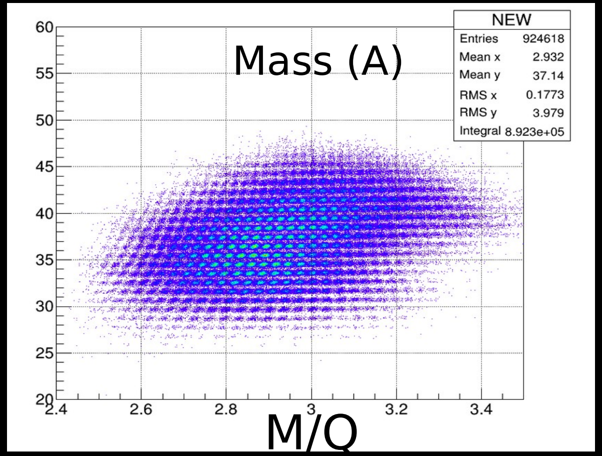


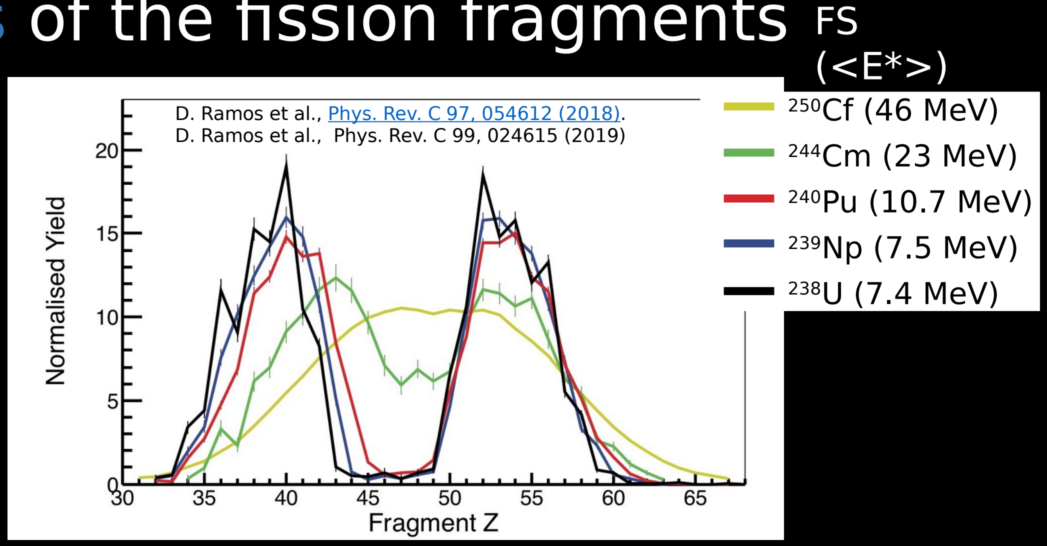
Fission probability



VAMOS magnetic spectrometer provides the isotopic identification and the complete yields of the fission fragments







VAMOS among others

	VAMOS (GANIL)	SOFIA (GSI)	JAEA	n-induced*
Complete Fission Yields	Yes	Yes	Yes	No
Isotopic Fission Yields	Yes	Yes	No	No
Exotic Fissioning Systems	Yes	Yes	Yes	No
Heavier than ^{238}U	Yes	No	Yes	Yes (long lived)
Excitation Energy Control	Yes (Improving)	(ongoing)	Yes	Yes
Both Fragments Detection	(ongoing) Yes	Yes	Yes	Yes
Isotopic scission Kinetic Energy	(ongoing) Yes	No	No	No

* n-TOF, Licorne, NFS/GANIL

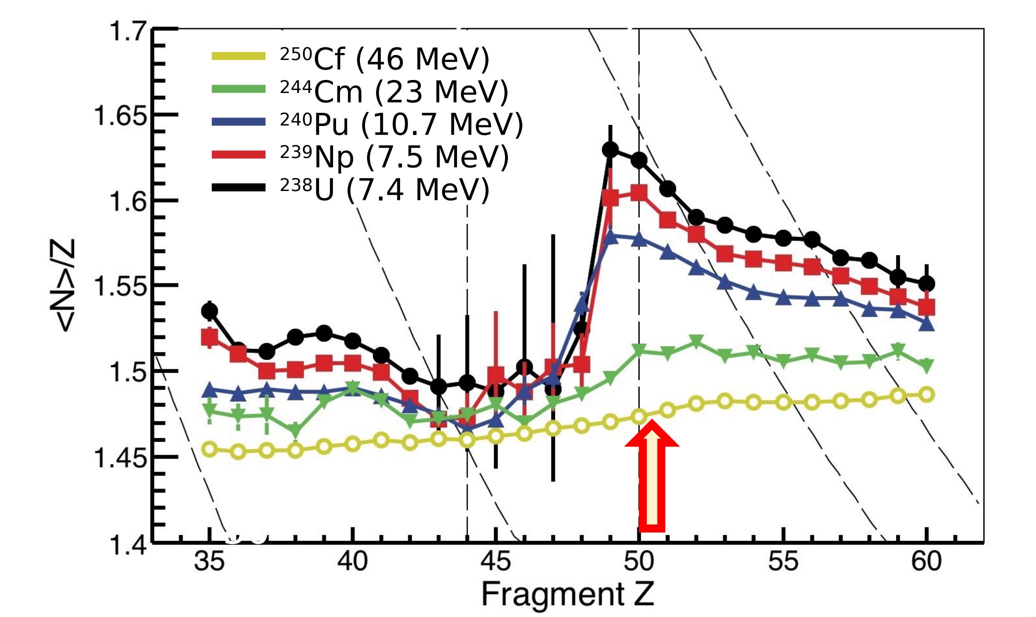
Collaboration

- Univ. Santiago de Compostella
- CEA/DAM
- CNRS/IPHC
- CNRS/CENBG
- York University
- IUAC, Dehli
- GANIL

Publications on Fission Dynamics

M. Caamaño et al., Phys. Rev. C **92**, 34606 (2015).
C. Rodríguez-Tajes et al., Phys. Rev. C **89**, 24614 (2014).
M. Caamaño et al., Phys. Rev. C **88**, 24605 (2013).
D. Ramos et al., Phys. Rev. C **97**, 054612 (2018).
D. Ramos et al., Phys. Rev. C **99**, 024615 (2019).
D. Ramos et al. Phys. Rev. Lett. **123**, 092503 (2019).
D. Ramos et al. Phys. Rev. C (2020)
C. Schmitt et al. Phys. Rev. Lett. (2021)
A. Jinghan et al. Phys. Rev. C (2022).

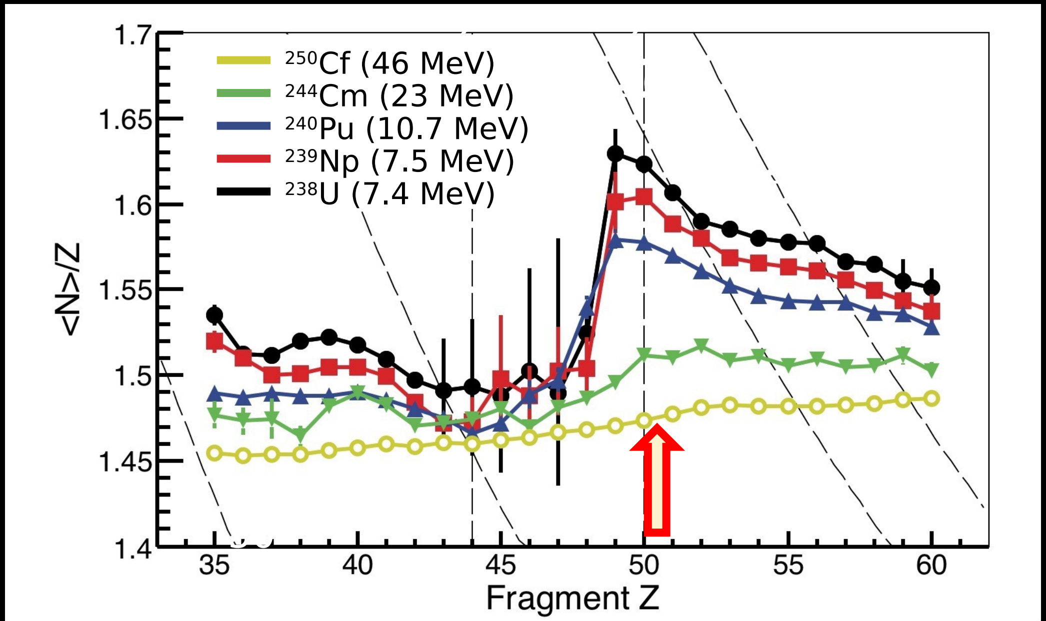
D. Ramos, et al. PRC (2019)



Fission of Actinides

Key questions

- **Driving Shell Effects** => Y(A,Z), Scission Information (TKE, Mn)
- **Excitation energy sharing** : Prompt Neutron multiplicities f(Z)
- **Angular Momentum in Fission** => Y(A,Z) for different entrance channels, gamma rays



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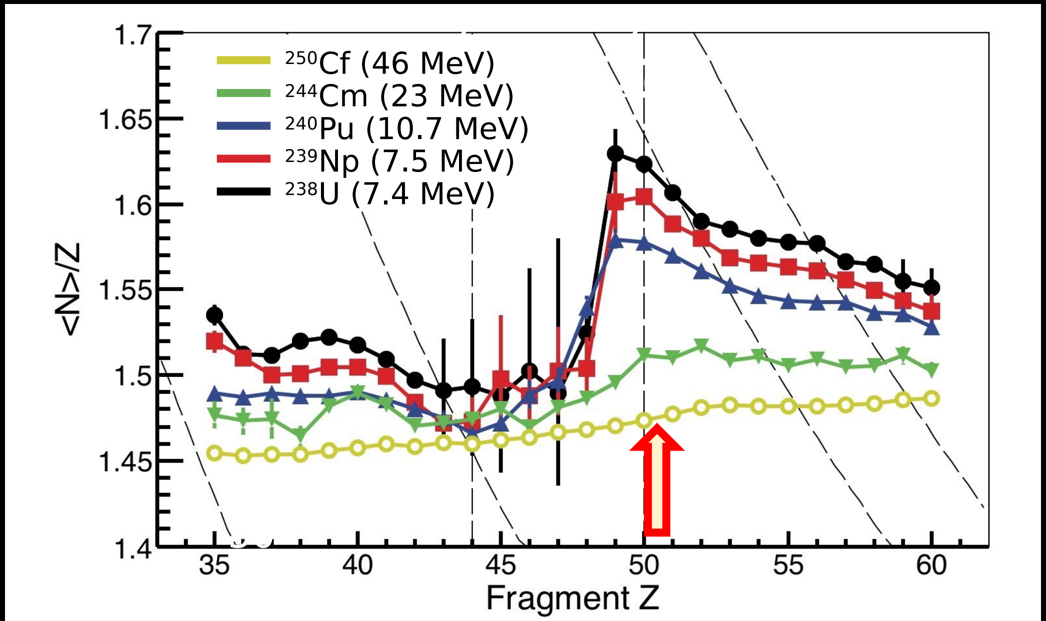
- **Angular Momentum in Fission** => Y(A,Z) for different entrance channels, gamma rays



Experimental Opportunities

- **VAMOS : Isotopic Yields => <N>/Z**
- **PISTA : Entrance Channel Characterization (A,Z,E*)**
  - Isotopic Yields as function of E* with unprecedent resolutions (< 1MeV)
  - Exotic transfer channels populated with different entrance channel
- **Second Arm(s) : Scission**
  - 2-v method to obtain scission Information (TKE, Prompt Neutron Multiplicities)
- **^{232}Th Beams**
- Gamma-rays (PARIS, EXOGAM)

Fission of Actinides

Key questions

- **Driving Shell Effects** => Y(A,Z), Scission Information (TKE, Mn)
- **Excitation energy sharing** : Prompt Neutron multiplicities f(Z)
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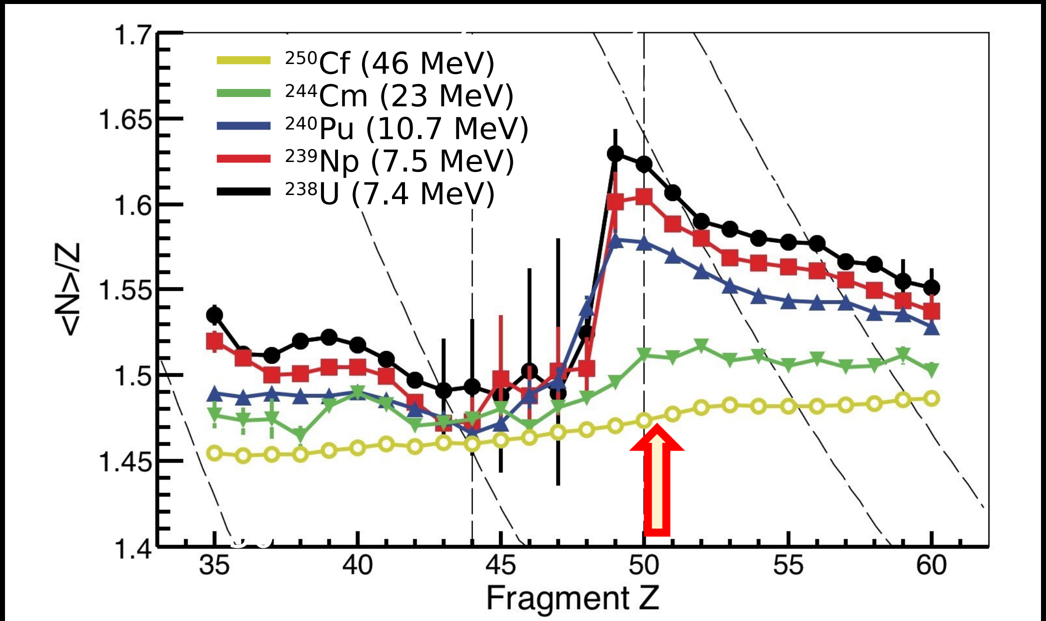

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*Precise ^{235}U and ^{240}**Pu** FF as function of E_X*

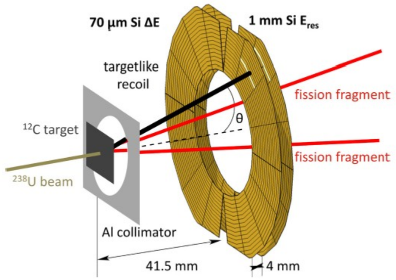
^{238}U @ 6 MeV/u + ^{12}C → ^{235}U / ^{240}Pu

*Fission around the **Th region***

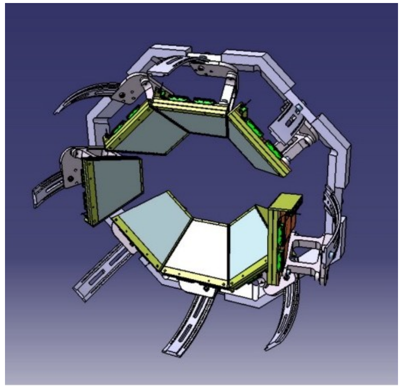
^{232}Th @ 6 MeV/u + ^{12}C → $^{230-232}$Th / ^{233}Pa / ^{234}U

Upgrade from SPIDER to PISTA

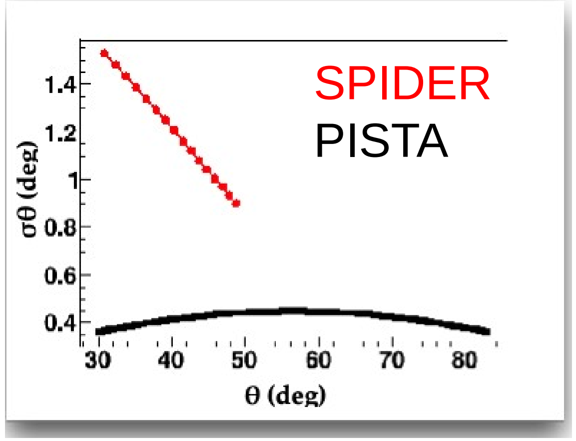
SPIDER



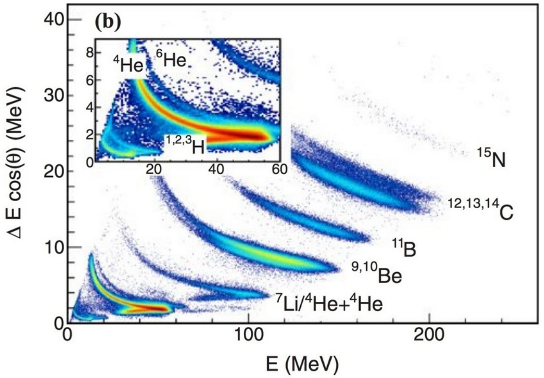
PISTA

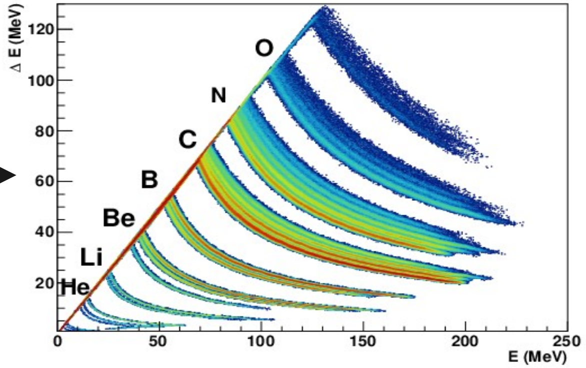


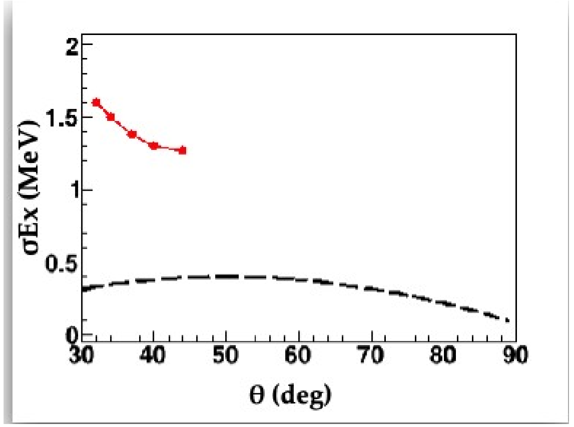
Higher Segmentation =>
Excitation Energy Resolution < 1 MeV



Particles Identification





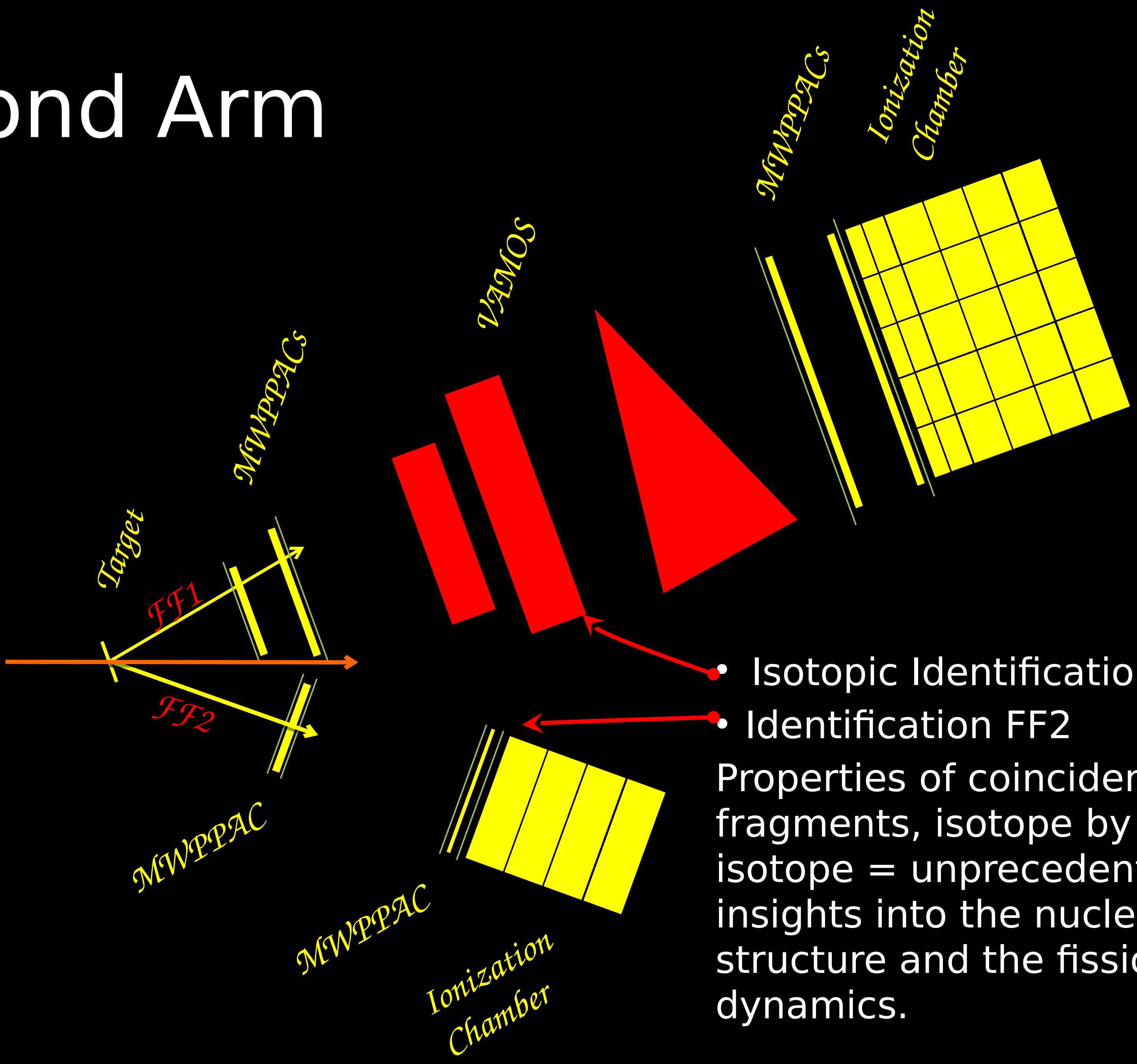


Experimental Campaign 2023-2024

^{238}U+^{12}C,^{232}Th+^{12}C - Collaboration CEA/DAM /GANIL

- Higher particle-identification capabilities
- Higher energy resolution (2.5 MeV → **0.7 MeV**)
- Larger angular coverage

Second Arm



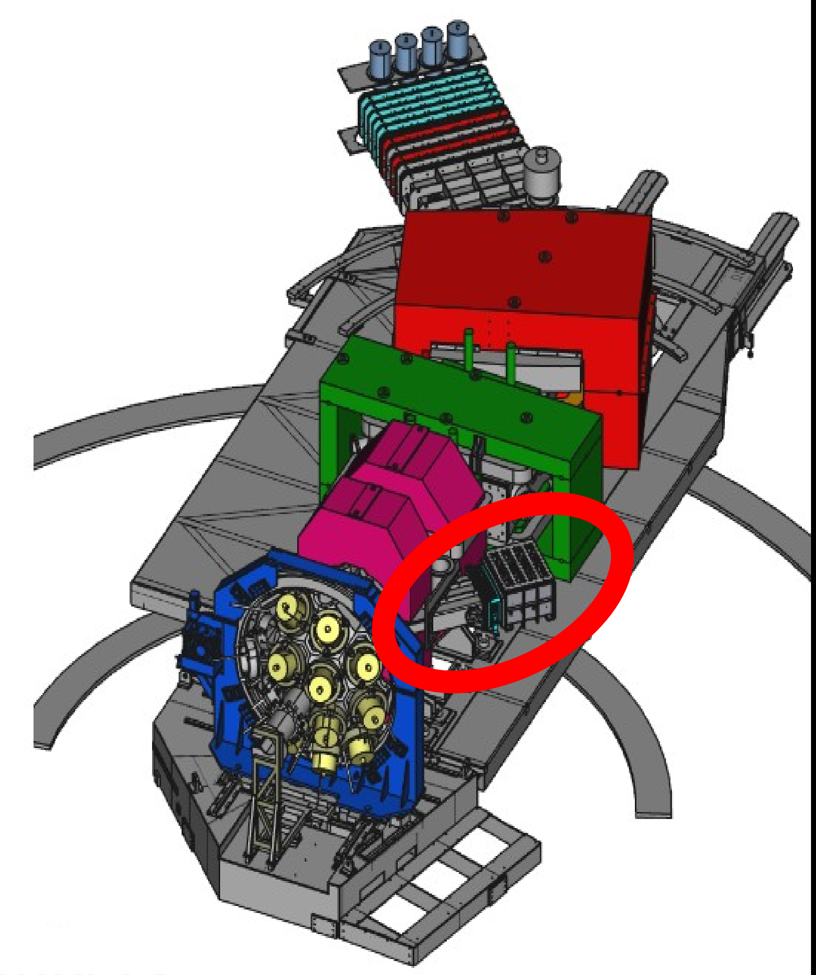
- Isotopic Identification FF1
- Identification FF2

Properties of coincident fragments, isotope by isotope = unprecedented insights into the nuclear structure and the fission dynamics.

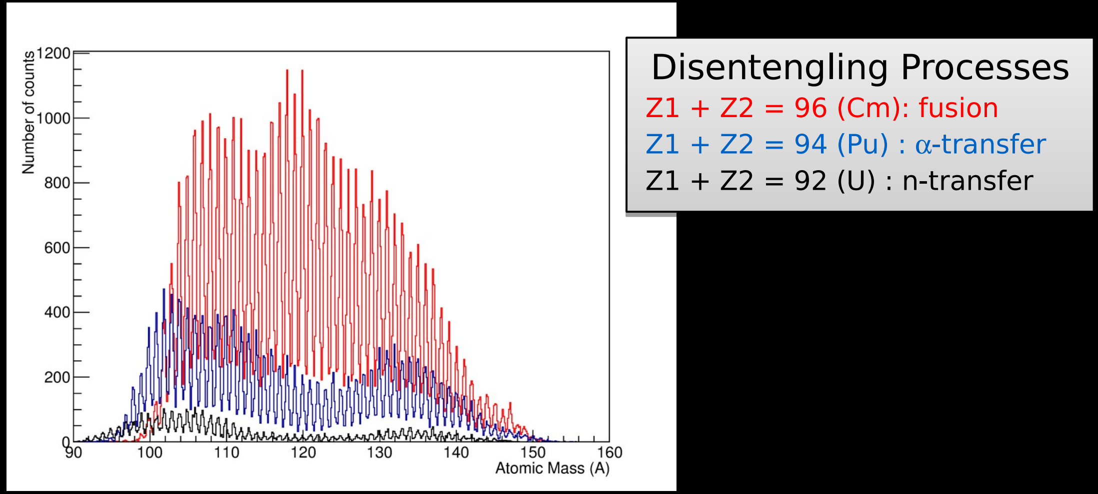
Coincident Fission Fragments detection

Second Arm Detection system(s)

- Isotopic fission fragments identificaton at the Scission Point
- Isotopic neutron evaporation measurements



First attempt 2016 : MWPC + IC (Z) U+Be 6.2MeV/u



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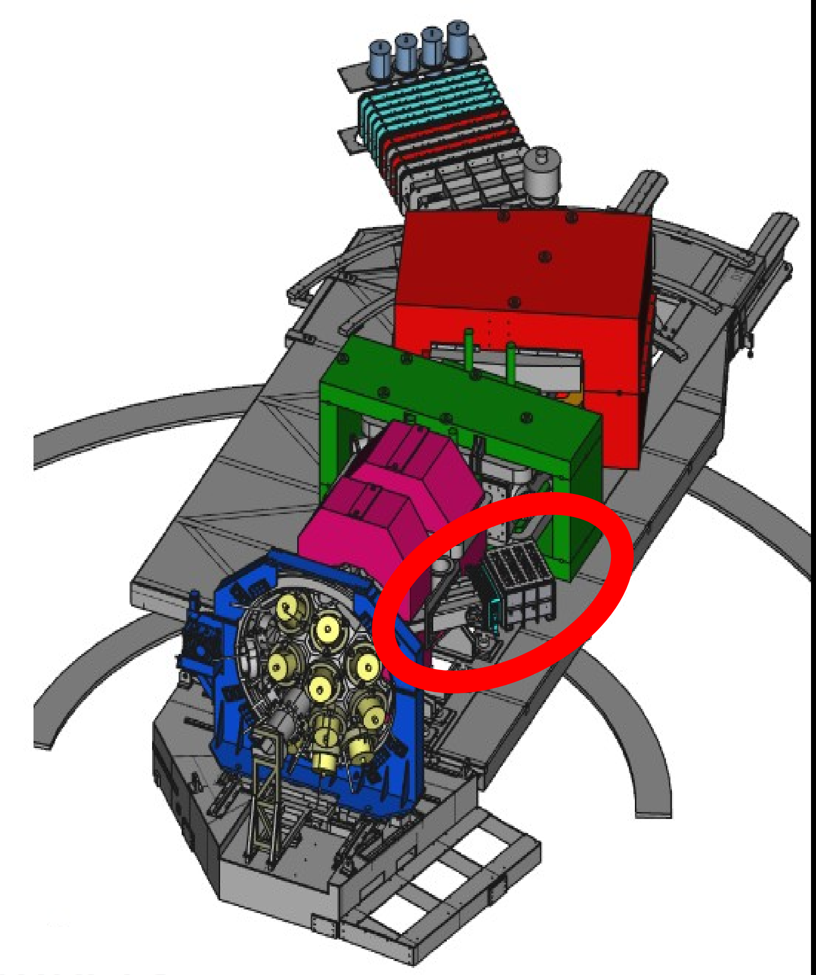

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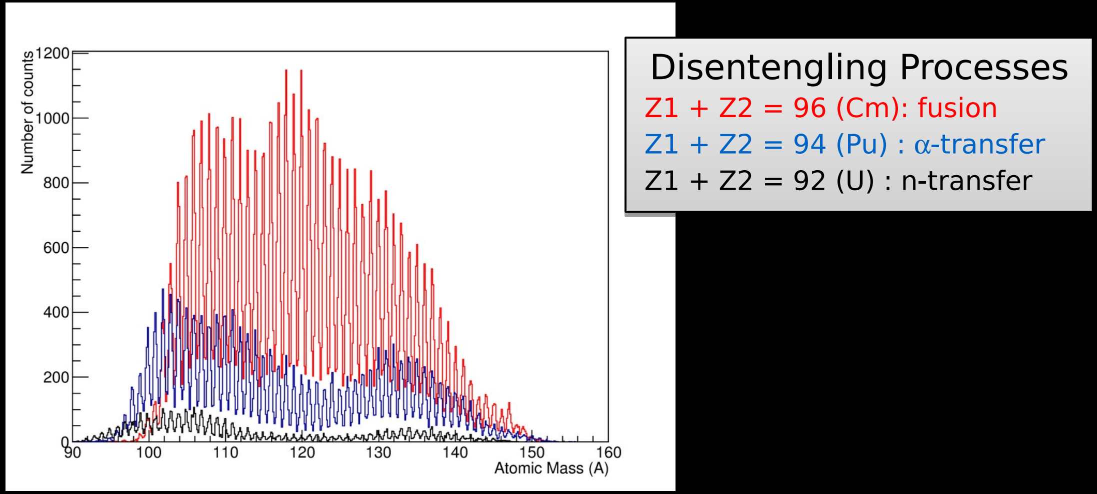


However the most pertinent information will come from the Time Of Flight

Goals : Pre neutron evaporation mass and TKE

=> 2v method is the main goal

=> high resolution TOF (<100ps) over 2m

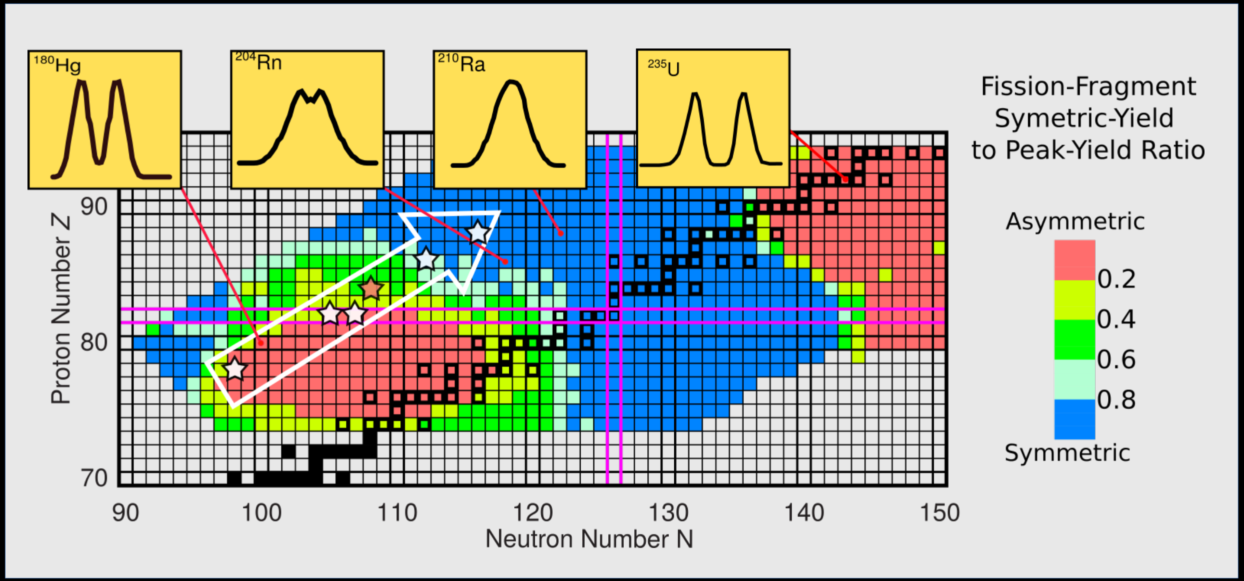
Next Major devellopment of VAMOS

Studied options with platic scintillator (stop) and electrostatic mirror (start)

Fission of pre-actinides

Key Questions

- Island of Assymetric Fission and competition between assymetric and symmetric fission
- « Universal » driving effects of protons from pre-actinide to actinides



Experimental opportunities

- **Isotopic identification in VAMOS   Y(A,Z)**
- **Very Different N/Z compared to actinides**
- **Second Arm (2v method) : A**pre, **Mn**
- Gaz cell Target => Low E*, Inverse Kinematics+
- Challenges : Low Energy of recoils,
  Low Cross sections

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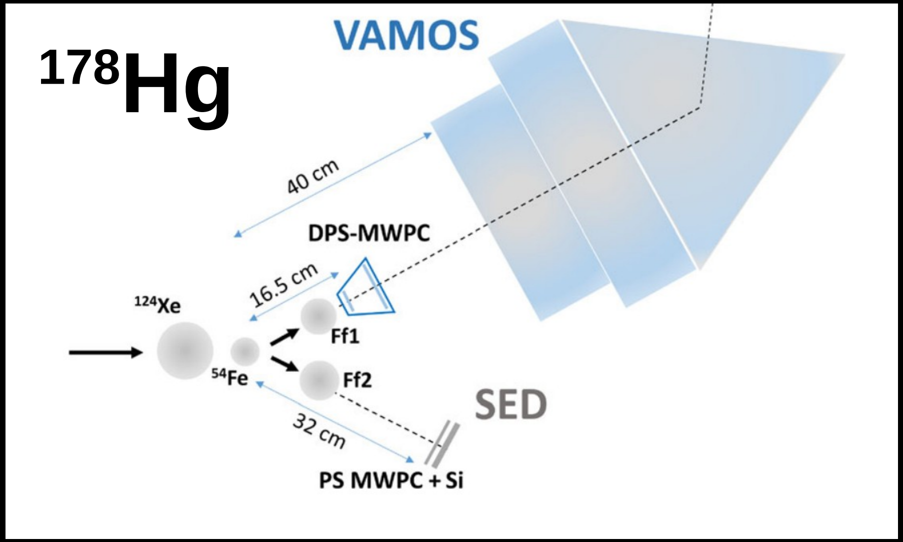

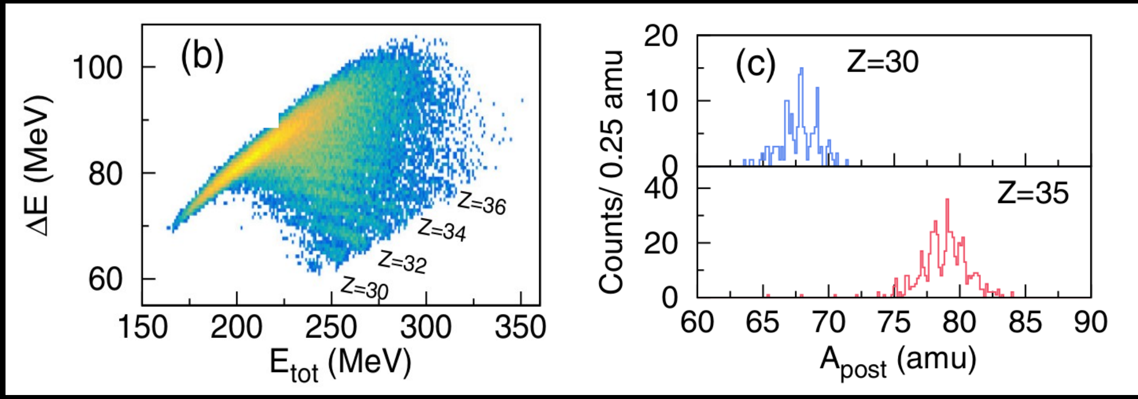

C. Schmitt et al. PRL 126, 132502 (2021)
A. Jinghan et al. PRC 2022

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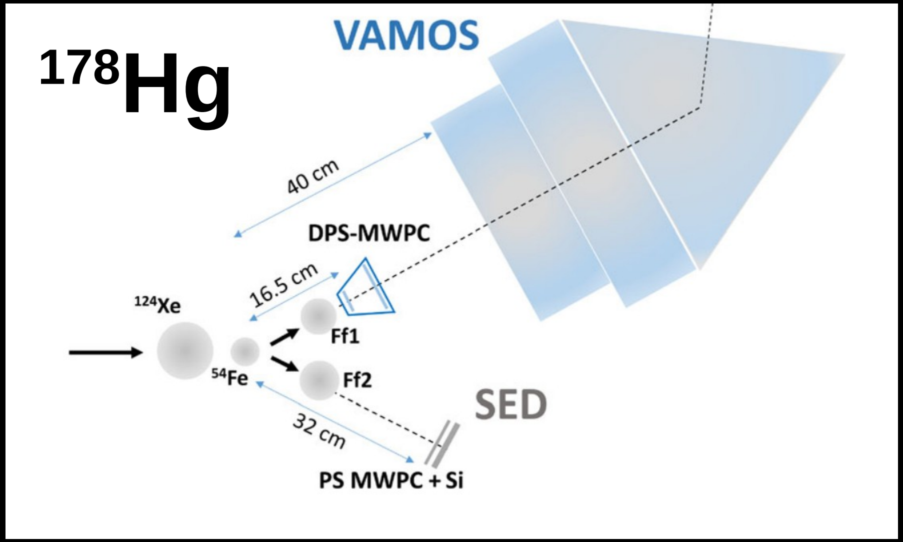

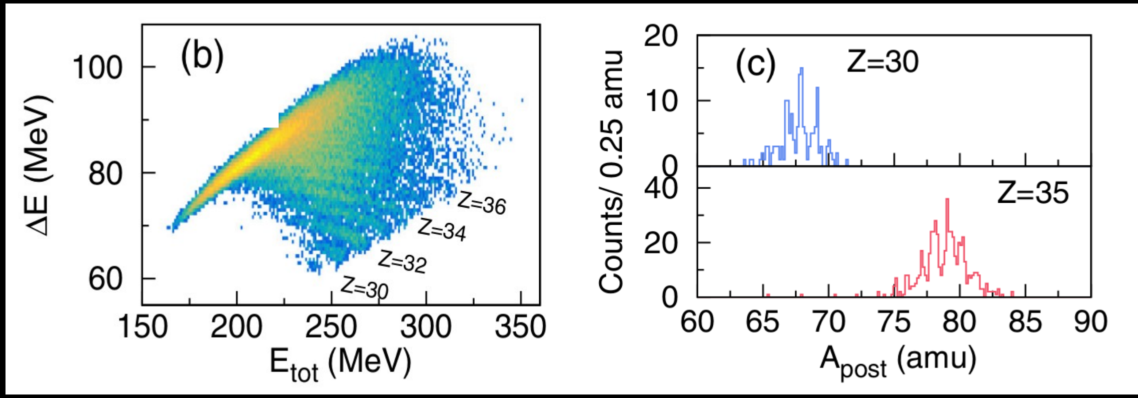

C. Schmitt et al. PRL 126, 132502 (2021)
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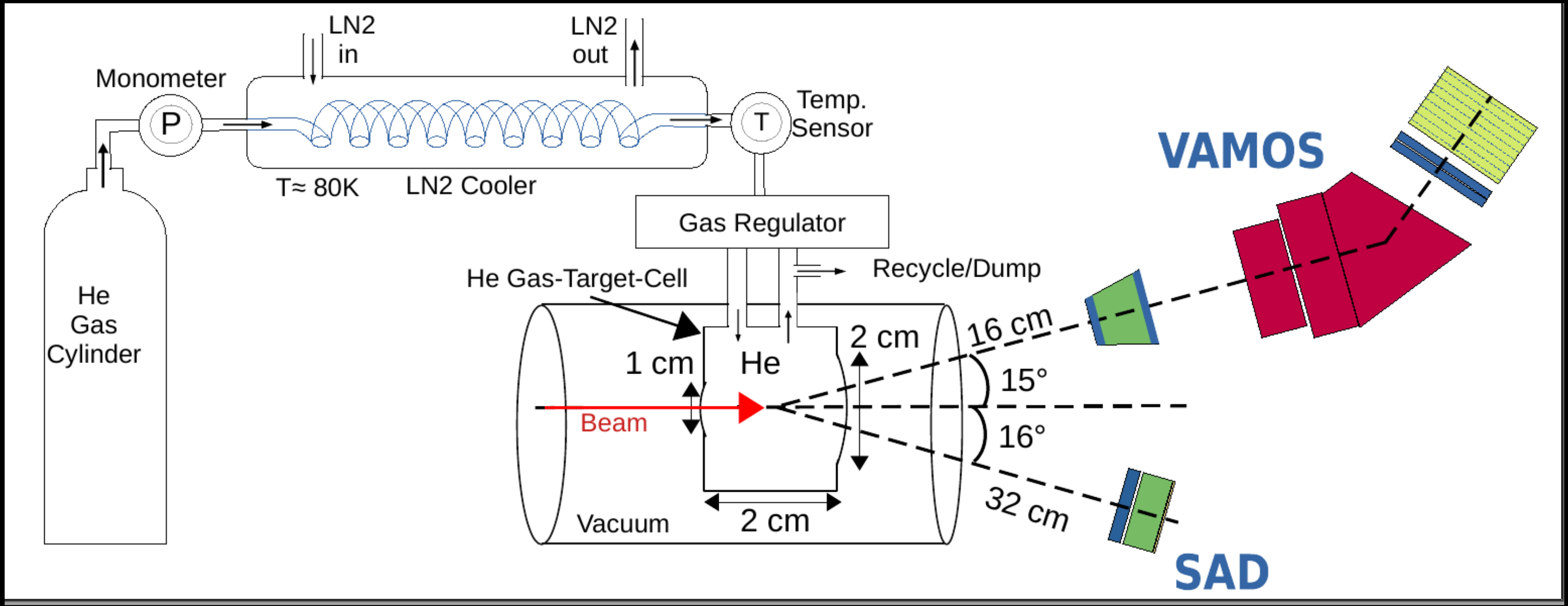
- ^{124}Xe+^{68}Zn → ^{192}Po (N/Z = 1.29)
- ^{206}Pb+^{4}He → ^{210}Po (N/Z = 1.5)

(Cooled) Gaz Cell Target + Second Arm



- Cooled He Gaz Cell at 193K
- Inverse Kinematics + Low E* (fusion ^{206}Pb + ^{4}He) where Shell Effect dominates
- Second arm (MWPC+IC+Si?)
  - Selection of reaction channel
  - TKE, Pre evaporation mass
- Possible extension to other gases and actinides studies

Outlook

- After 20 years, VAMOS provides unprecedent identification capabilites in particular for Fission Fragments => a continuous improvements strategy
- Clear and Intense Roadmap for 2022-2025
  - Unique scientific opportunities to unravel the driving mechanisms of low energy fission over the nuclear chart
  - Based on an instrumental roadmap (PISTA, Gaz Cell, Second Arm(s), +?)
- Open for propositions beyond 2025

/!\ Open Postdoc position 2023-2025

Thank you for you attention !

and thanks to all collaborators
involved in the VAMOS program