DE LA RECHERCHE À L'INDUSTRIE

cea

SOFIA
Fission studies at GSI

Julie-Fiona Martin
for the SOFIA collaboration

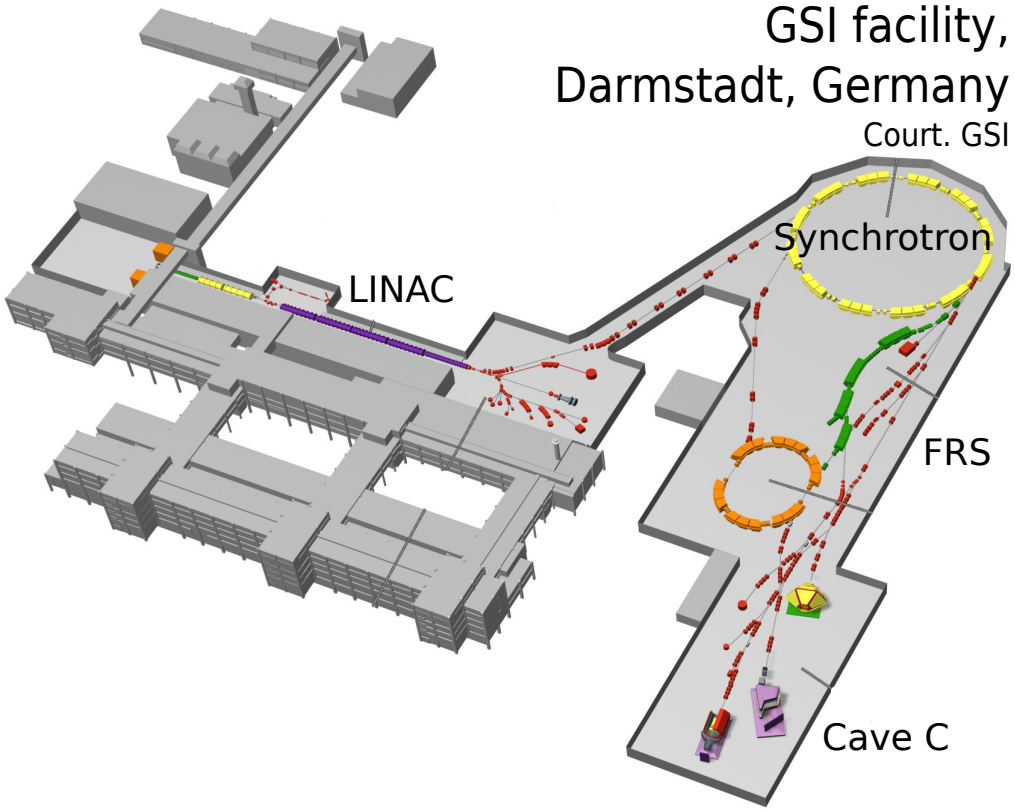
CEA, DAM, DIF

Perspective on Nuclear Data for the Next Decade - Oct. 2014

1. Intro
2. Experimental setup
   - Secondary beam
   - Fission fragments
   - Electromagnetic fission
3. SOFIA 1
   - Yields
   - Neutron multiplicity
   - TKE
   - SOFIA-1
4. SOFIA 2
5. Outlook
6. Conclusion

- Fission yields,
  Total kinetic energy,
  (and total prompt neutron multiplicity)
- Fully and simultaneously identify
  both fission fragments
- For a wide variety of fissioning systems

SOFIA @ GSI



- At GSI, Darmstadt, Germany
- Primary beam ^{238}U
- Secondary beam, of fissile nuclei
- Identification of the fissile nucleus
- Fission and identification of both fission fragments

Identification of the ions

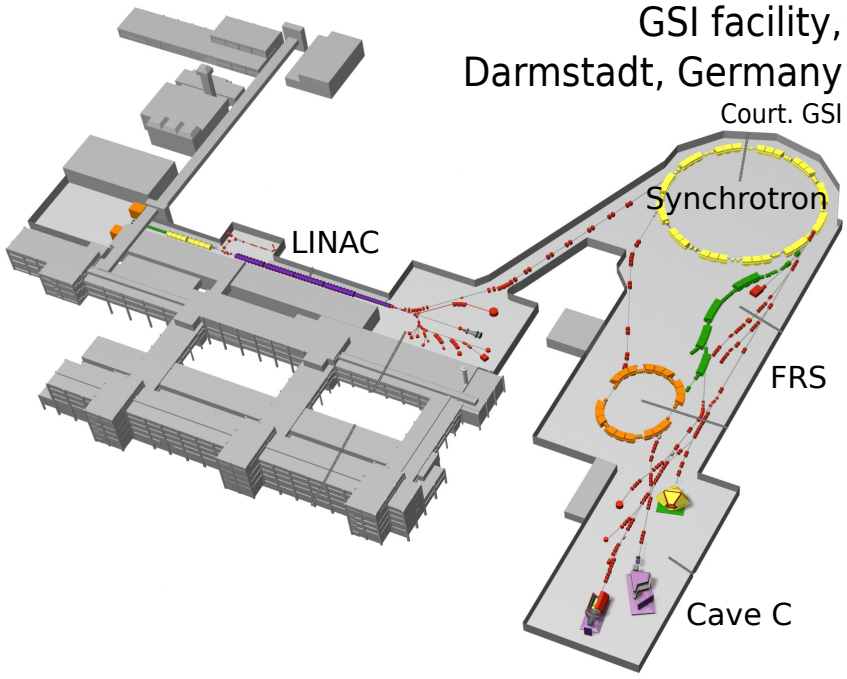
$$B\rho \propto \gamma v \frac{A}{Z}$$

- Z Charge,
  $\rightarrow \Delta E$ in an ionization chamber
- ρ Ion's trajectory curvature in a dipole
  $\rightarrow$ Dipoles and positions
- γv Lorentz factor and velocity
  $\rightarrow$ Time of flight
- A Mass

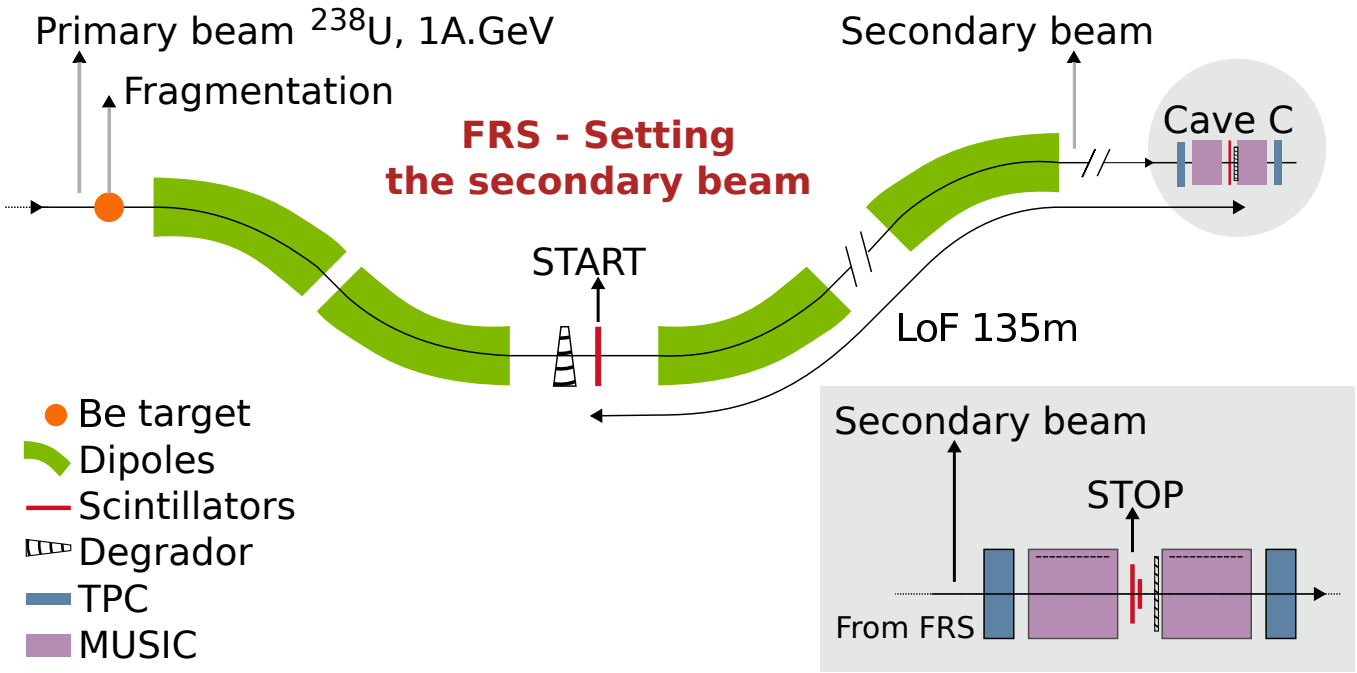
$$(Z, \rho, \gamma v) \rightarrow A$$

Three measurements for a full identification

Secondary beam



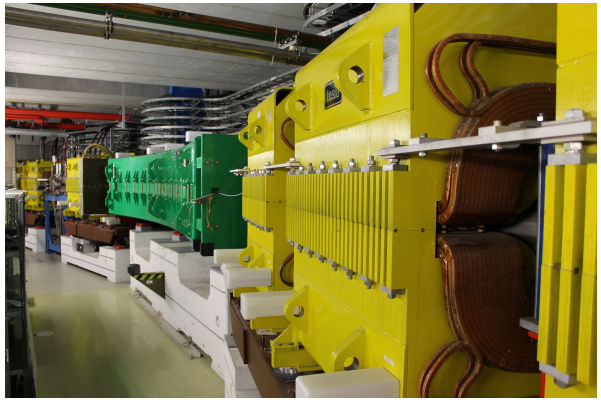
Secondary beam



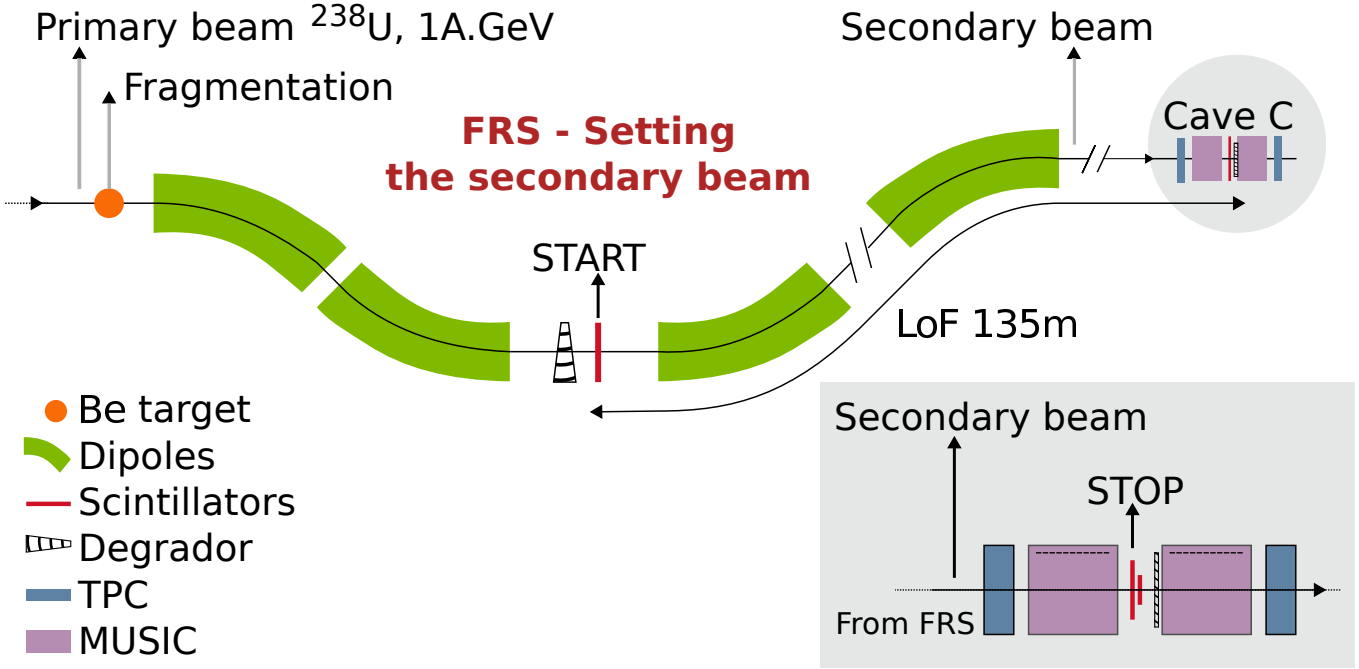
Z Charge Ionization chamber

ρ Positions

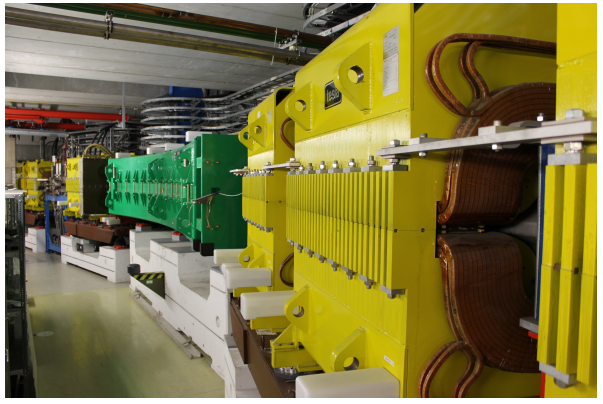
γv Velocity ToF



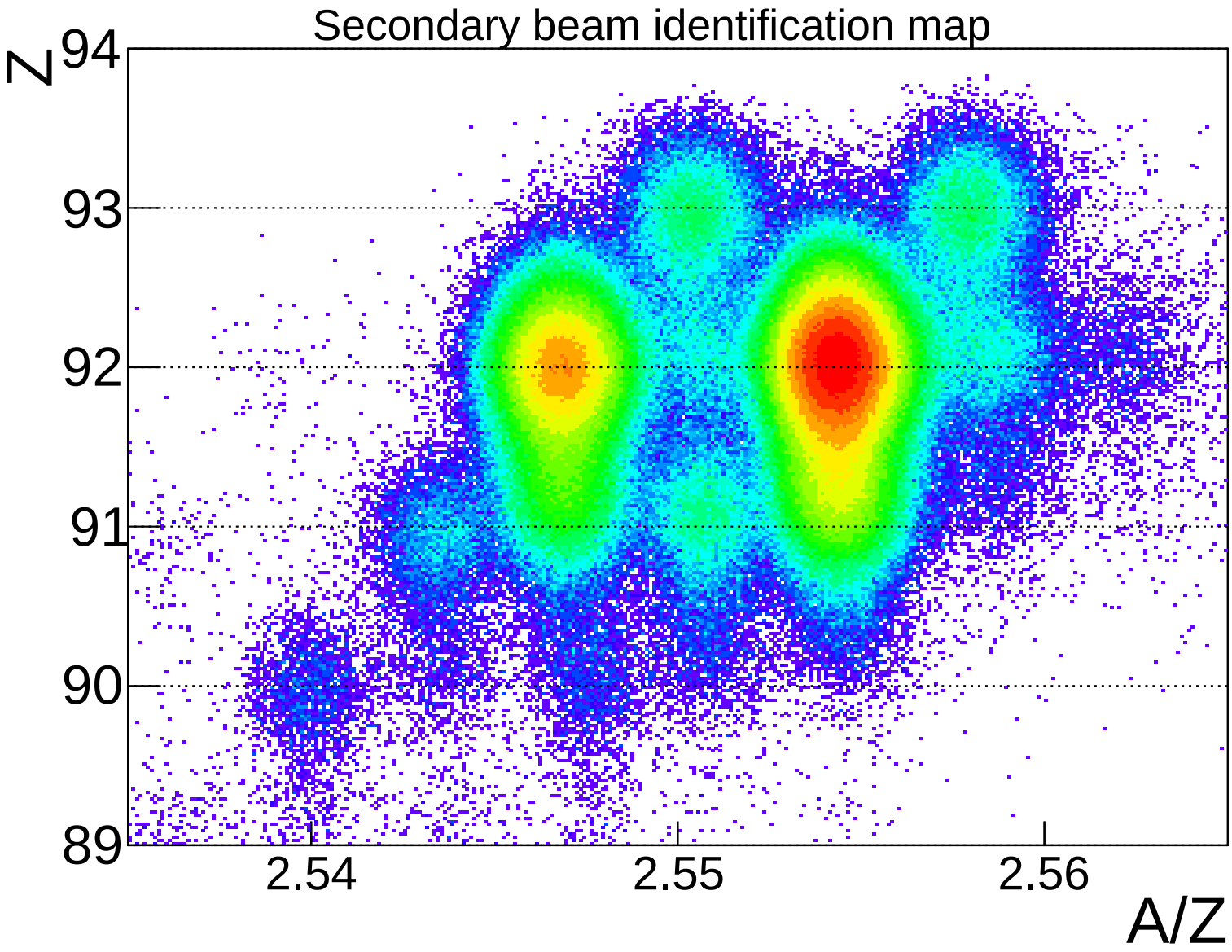
Secondary beam



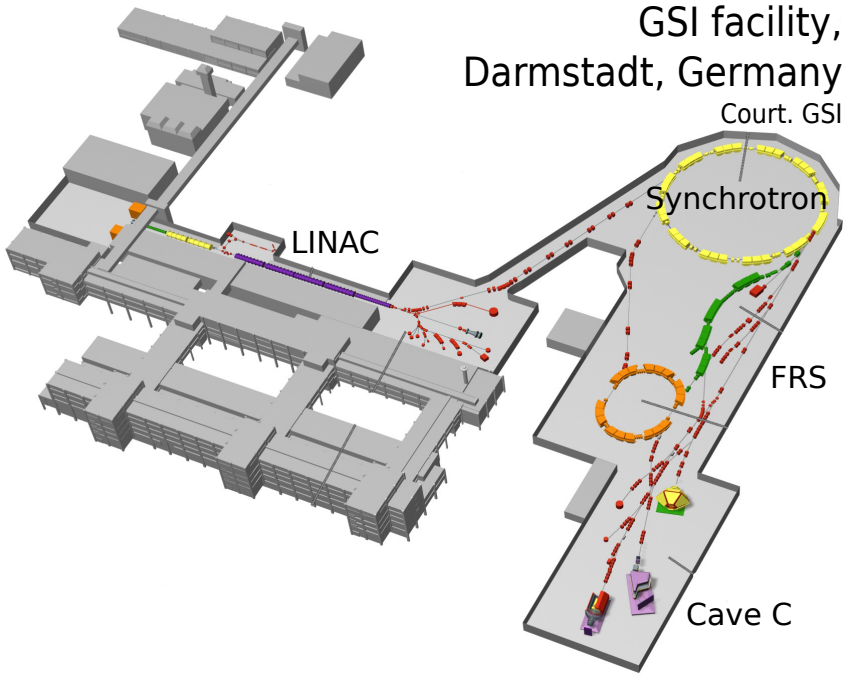
$$\left.\begin{matrix} Z \\ \rho \\ \gamma v \end{matrix}\right\} (Z, B\rho, \gamma v) \rightarrow A$$



Identification

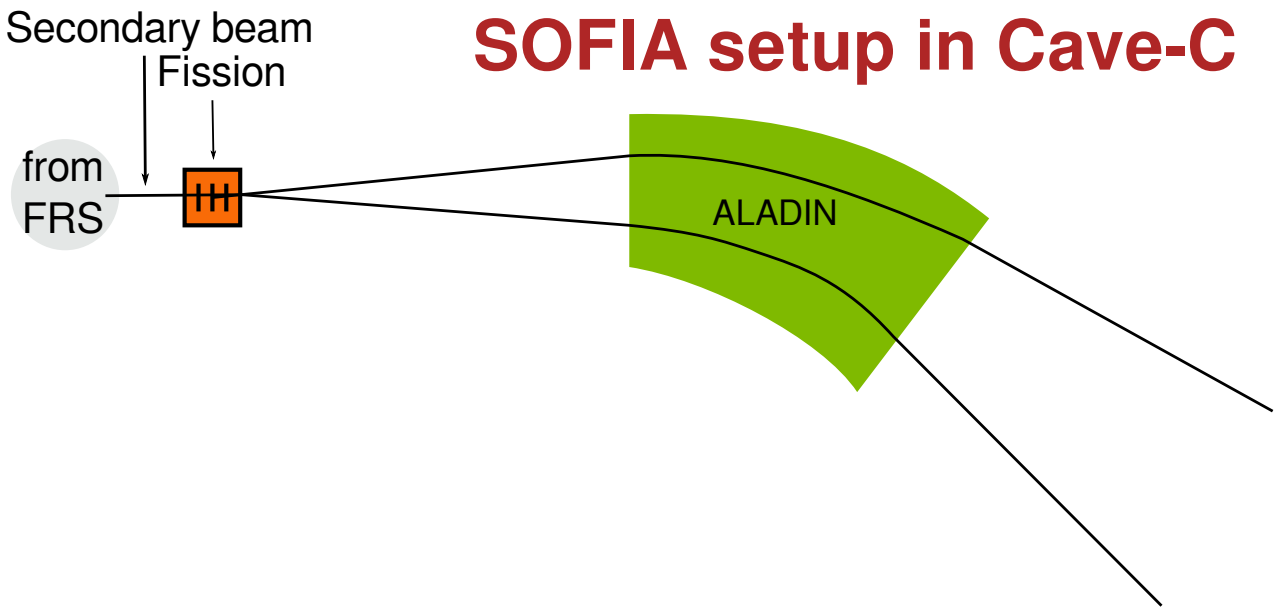


Fission fragments



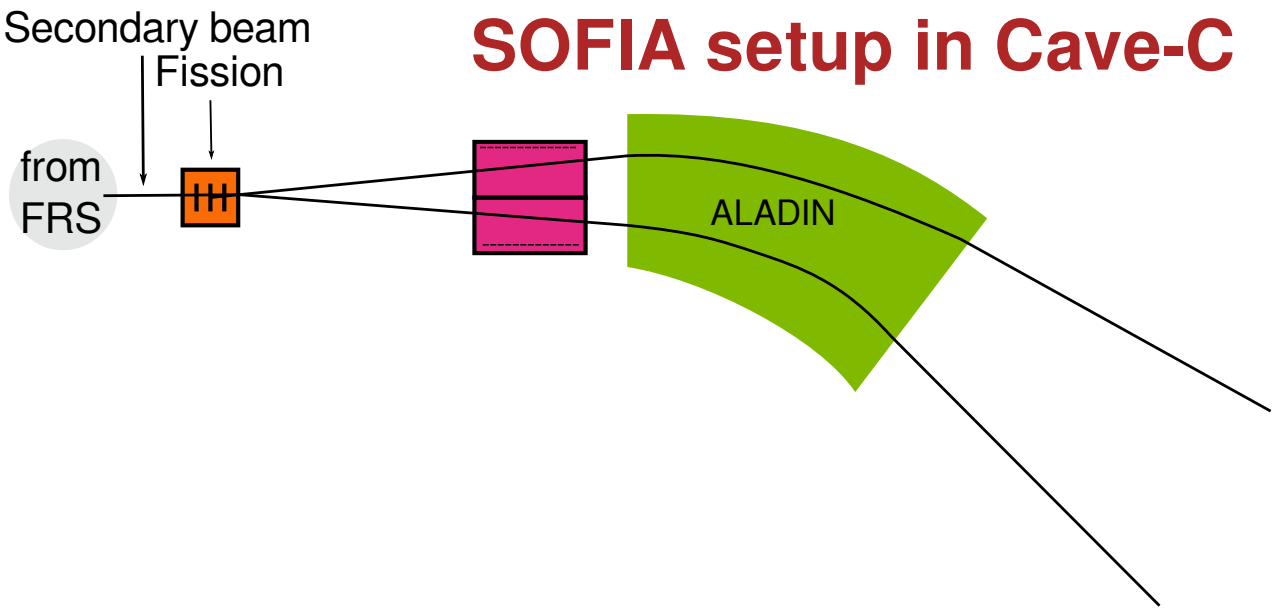
Setup SOFIA en Cave-C

ALADIN was there. All the detectors developed and built by the SOFIA collab.



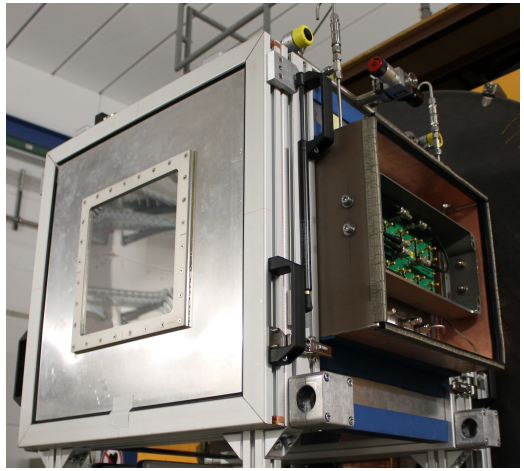
SOFIA setup in Cave-C

Active Target Fission

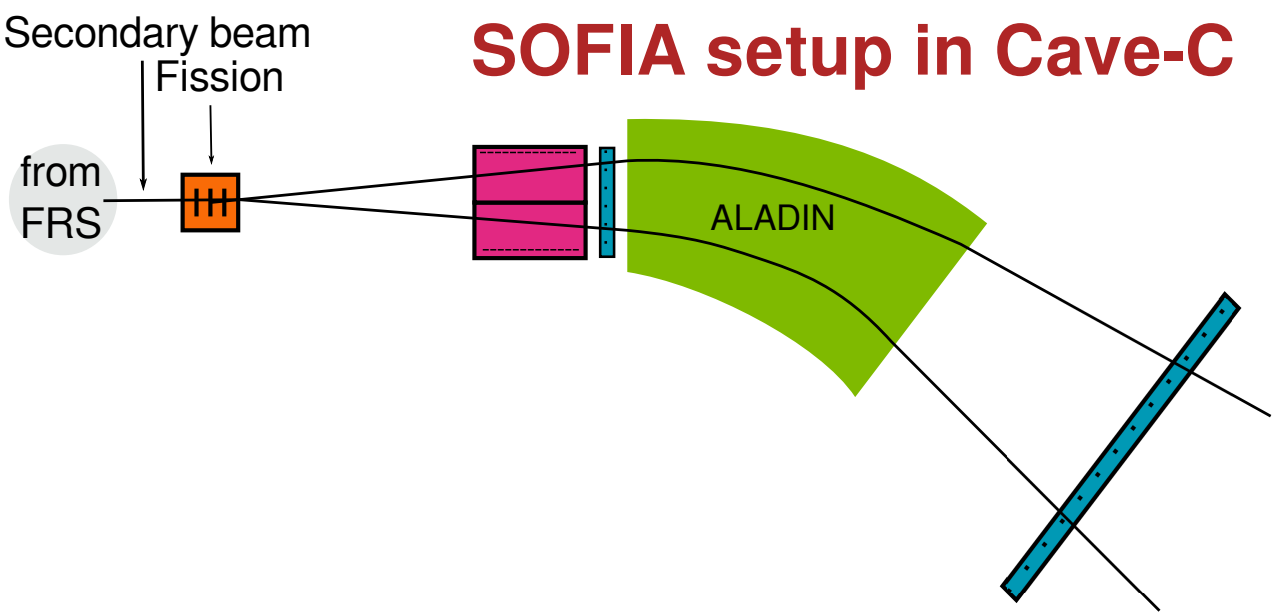


Active Target Fission

Twin-MUSIC Charges



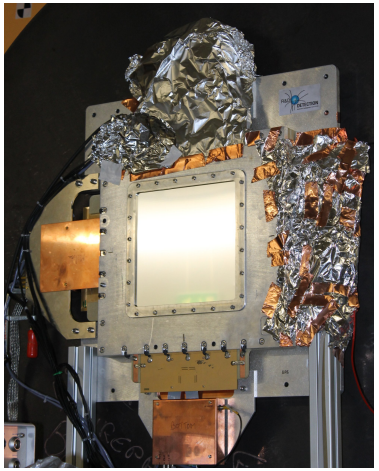
Setup SOFIA en Cave-C



Active Target Fission

Twin-MUSIC Charges

MWPCs Positions



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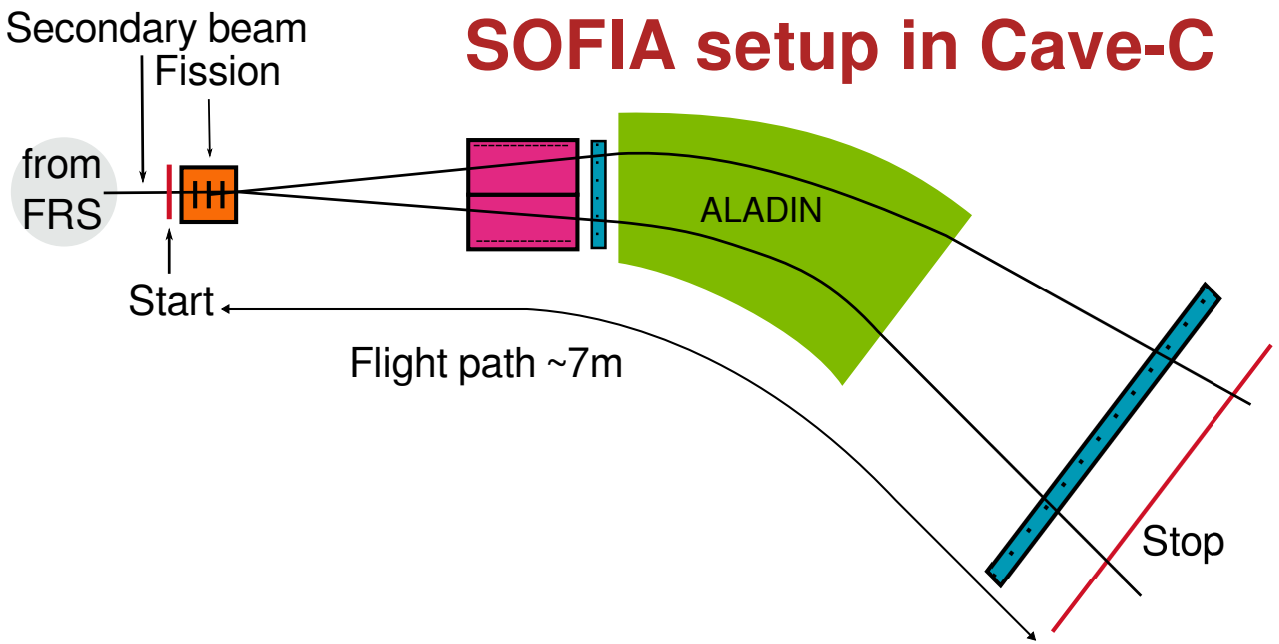


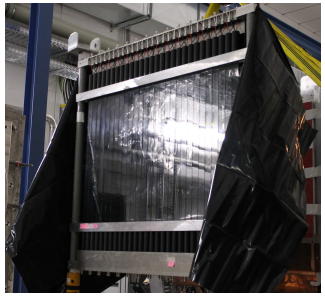
SOFIA setup in Cave-C

Active Target Fission

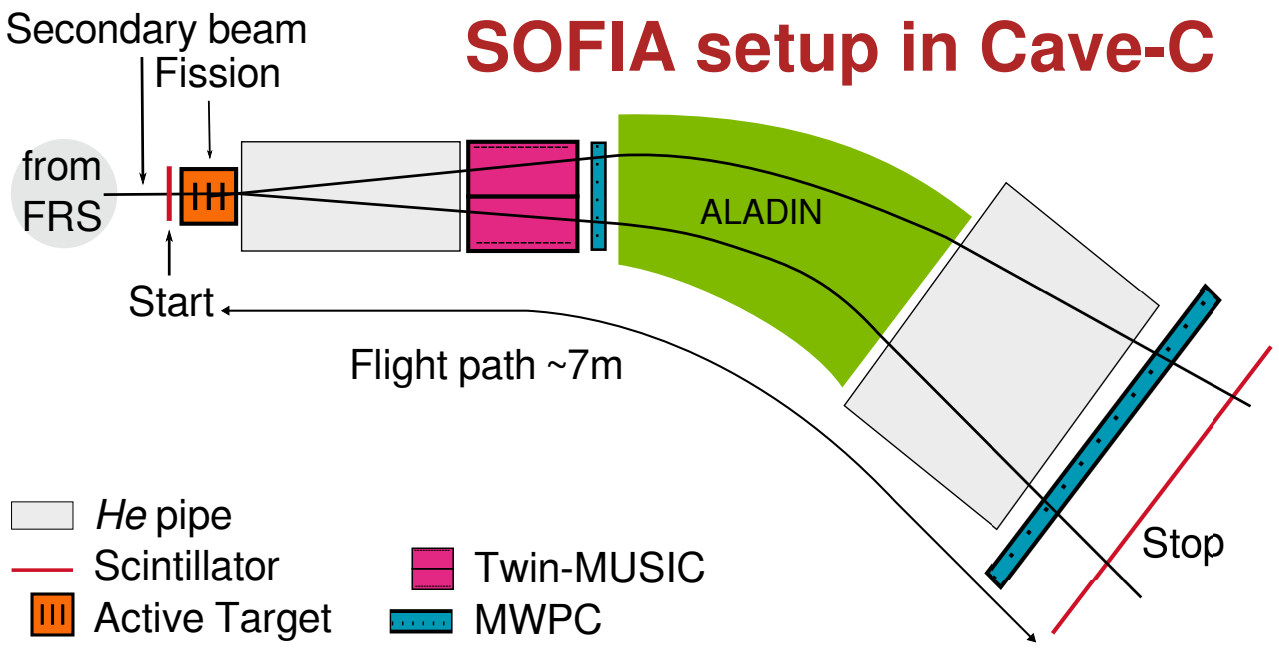
Twin-MUSIC Charges

MWPCs Positions

ToF Velocity



Setup SOFIA en Cave-C



Active Target Fission

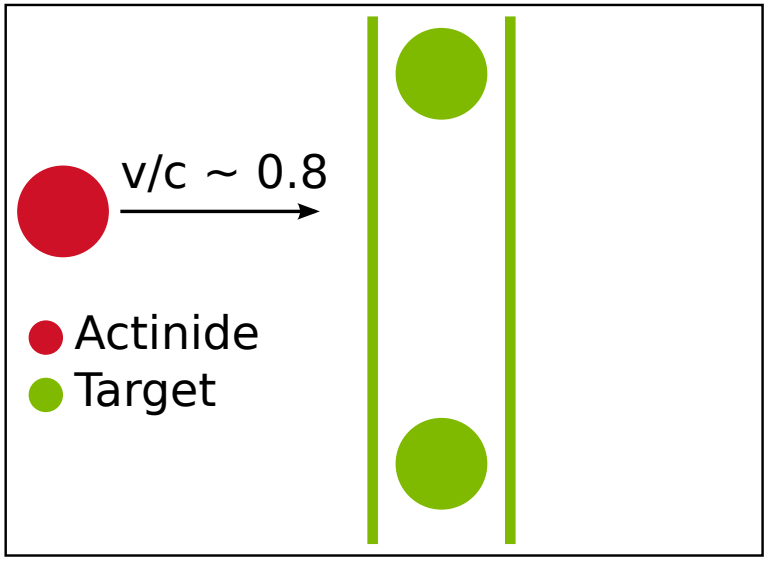
Twin-MUSIC Charges Z

MWPCs Positions ρ

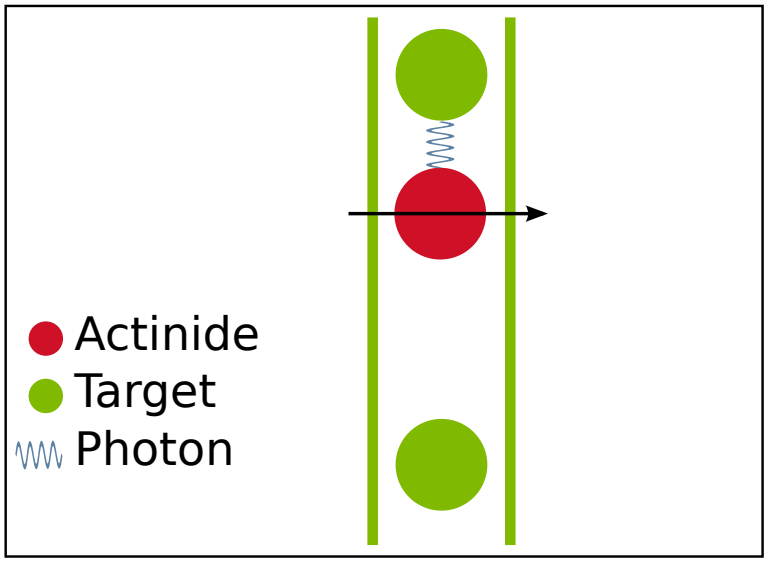
ToF Velocity γ v

$$(Z, B\rho, \gamma v) \rightarrow A$$

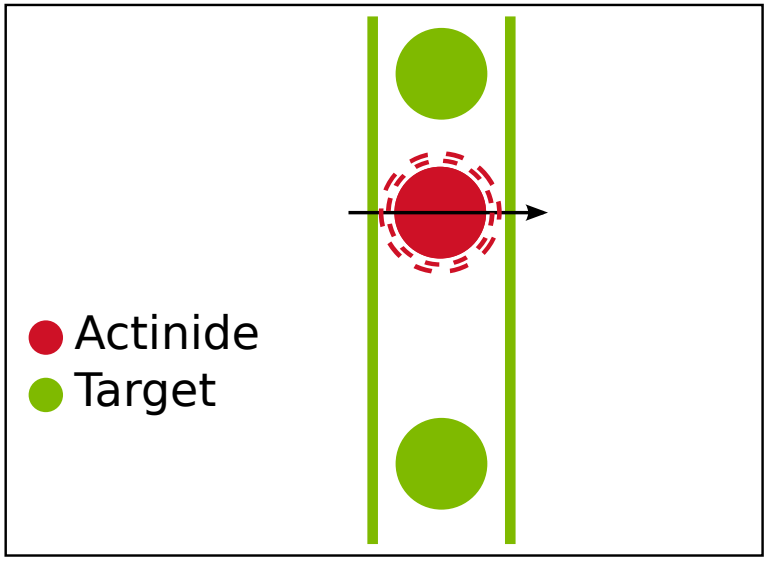
EM fission



EM fission



EM fission



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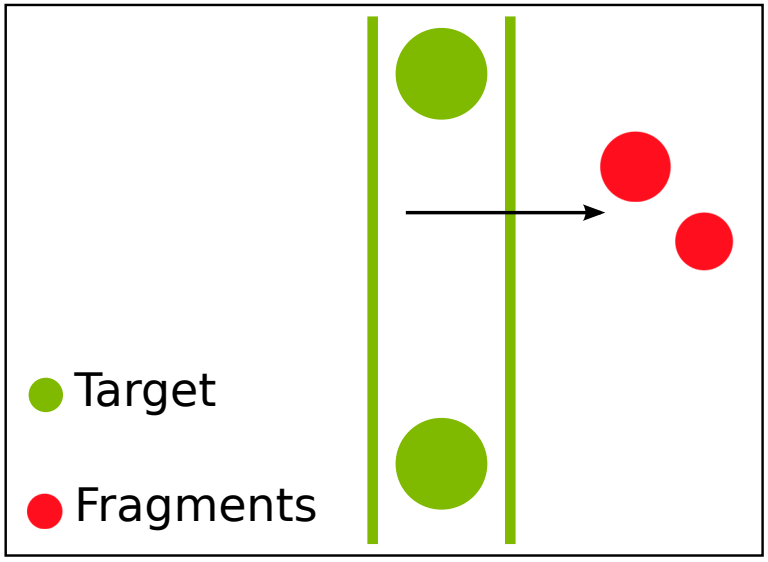
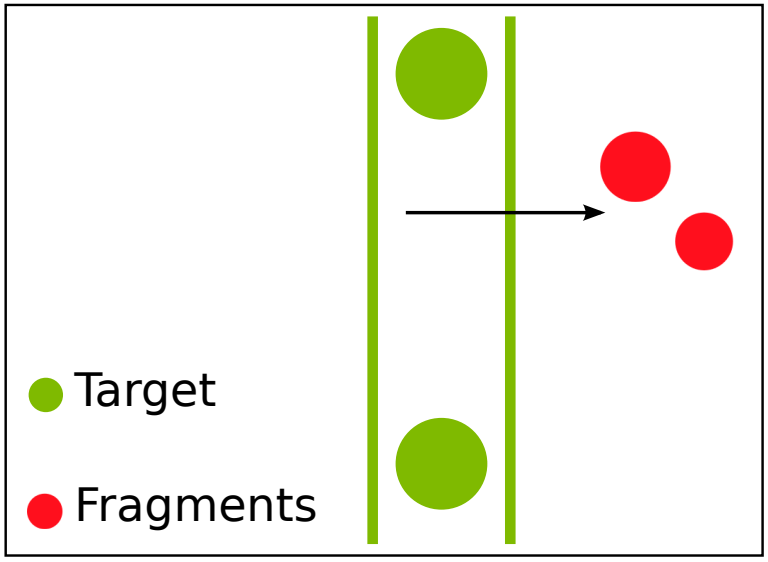
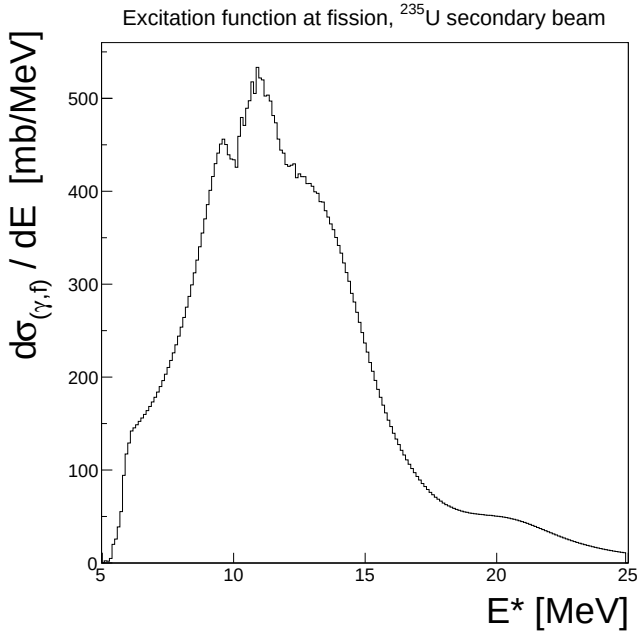


EM fission





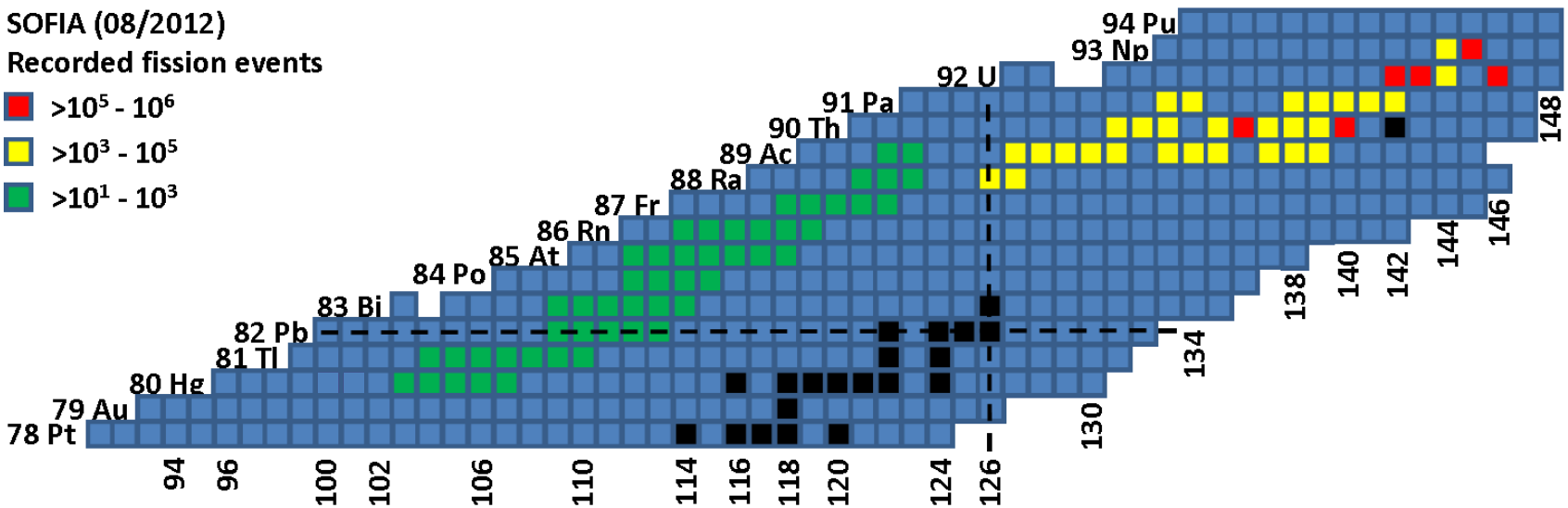
Excitation energy distribution after EM excitations

Same as photofission

$$< E^* >= 12MeV \quad \Leftrightarrow \quad 6MeV \text{ neutron}$$

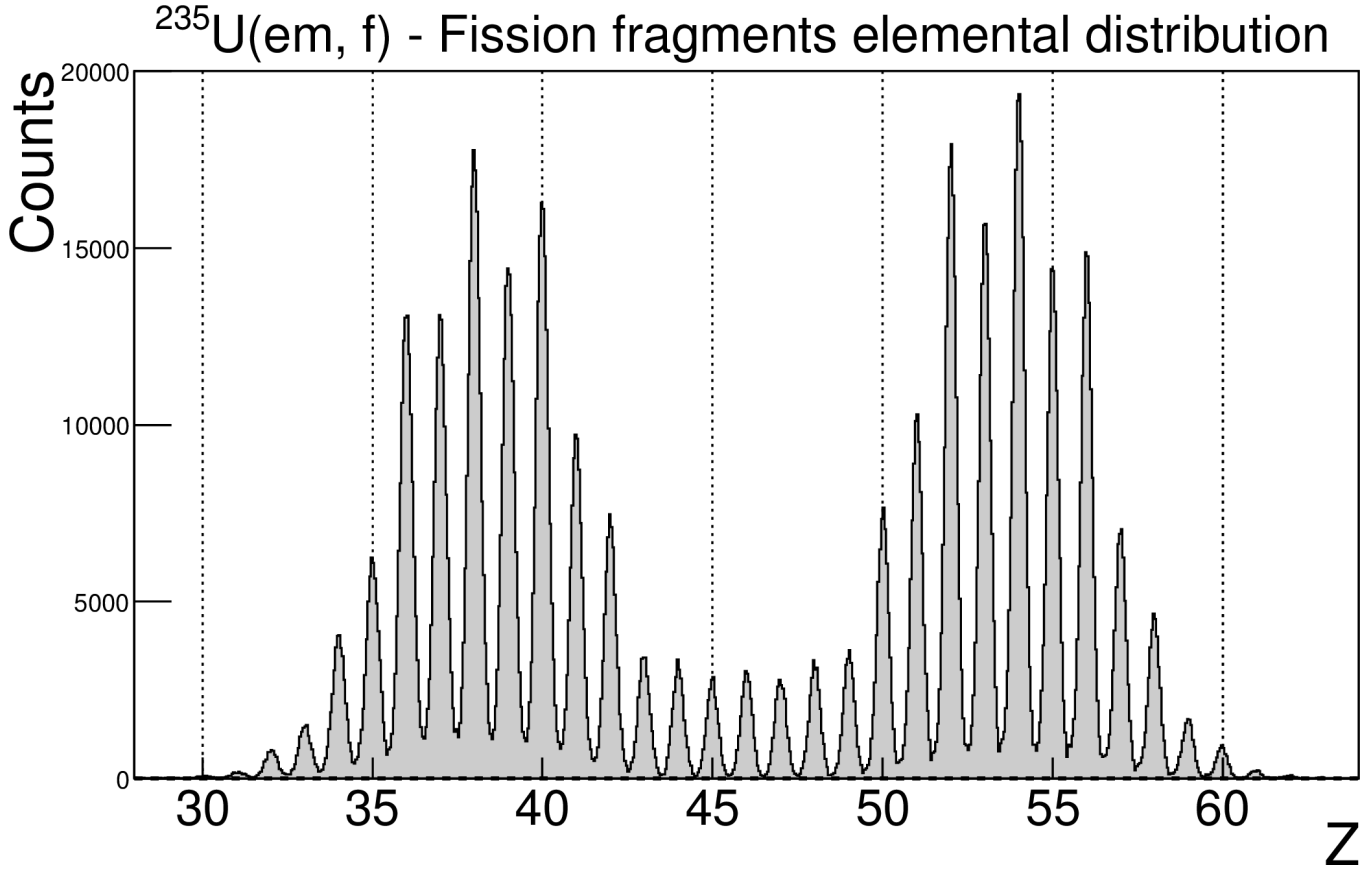
$$^{238}Np(EM, f) \approx {}^{237}Np(n_{6\ MeV}, f)$$

SOFIA-1 : 6 days in 2012



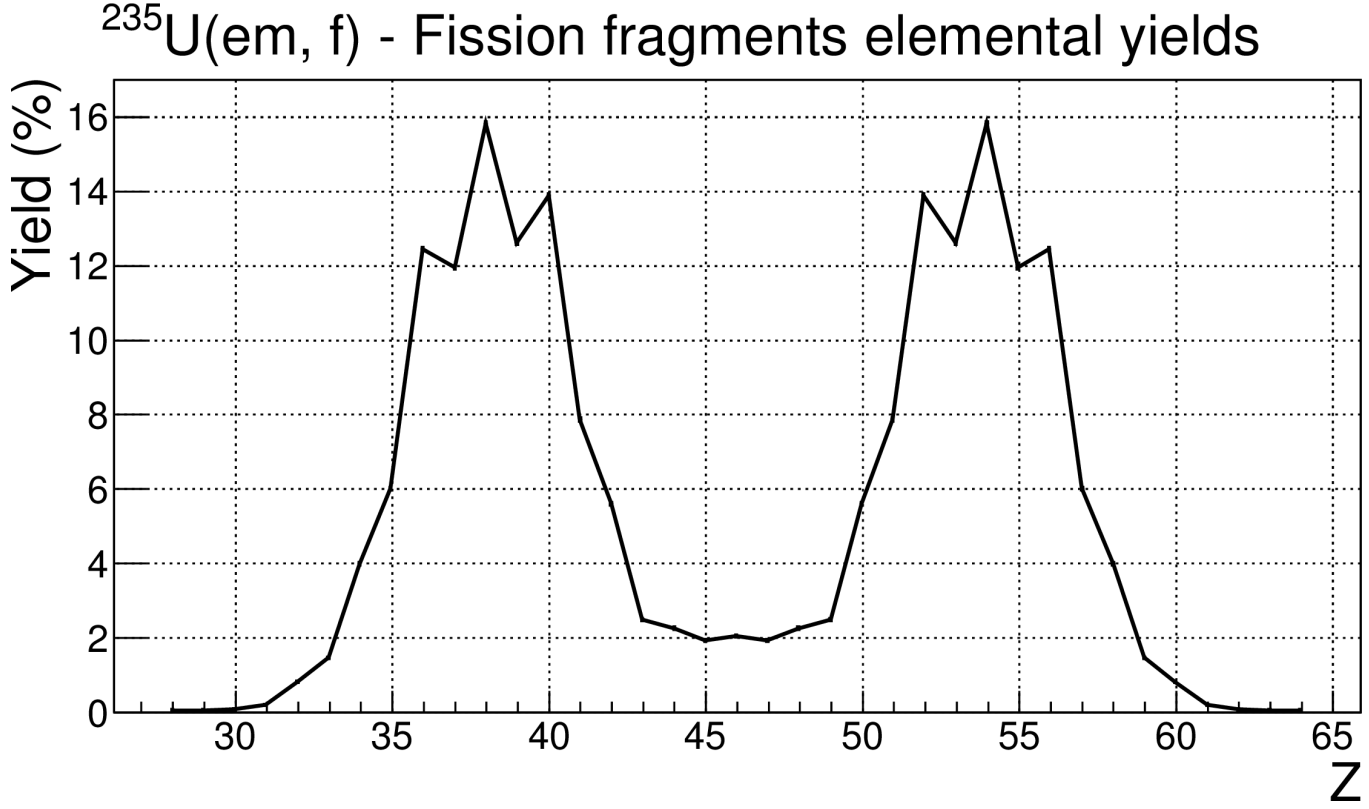
Review results, example is $^{235}U(coulex, f)$

Z yield



Complete disentanglement of charges
Landmarks : e-o staggering and $Z = 54$

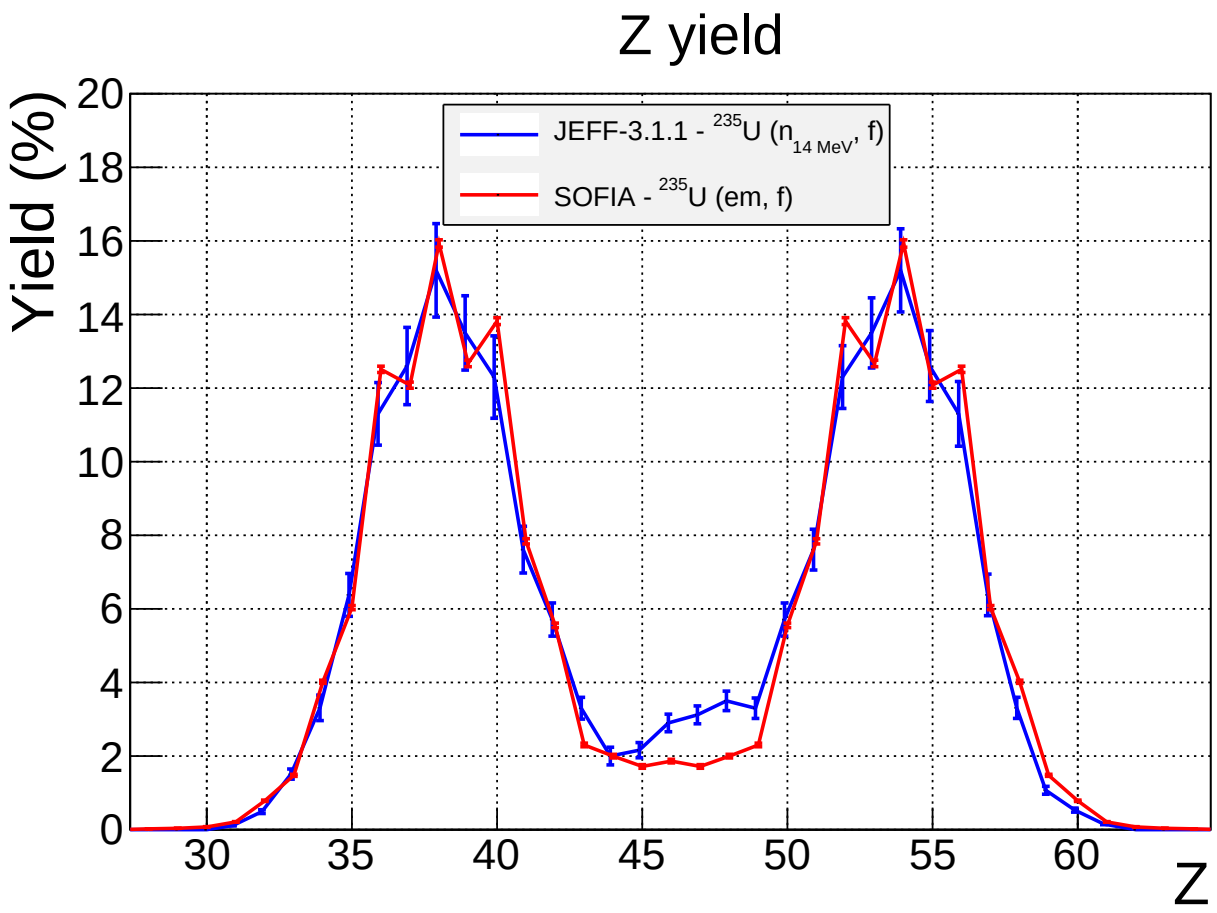
Z yield



Complete disentanglement of charges
Landmarks : e-o staggering and $Z = 54$

Such reliability on charge yields
is reachable exclusively at GSI

Z yield



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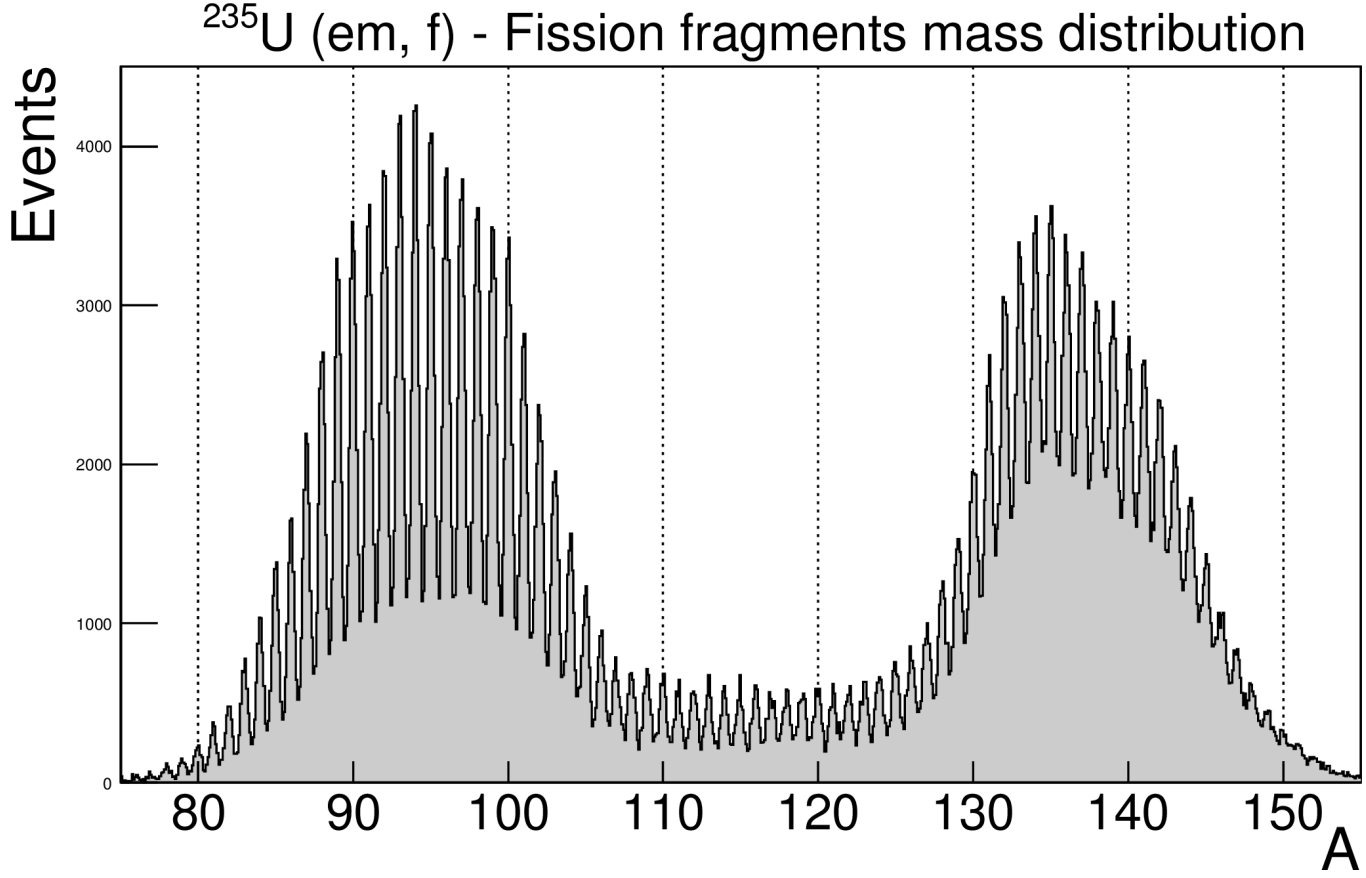
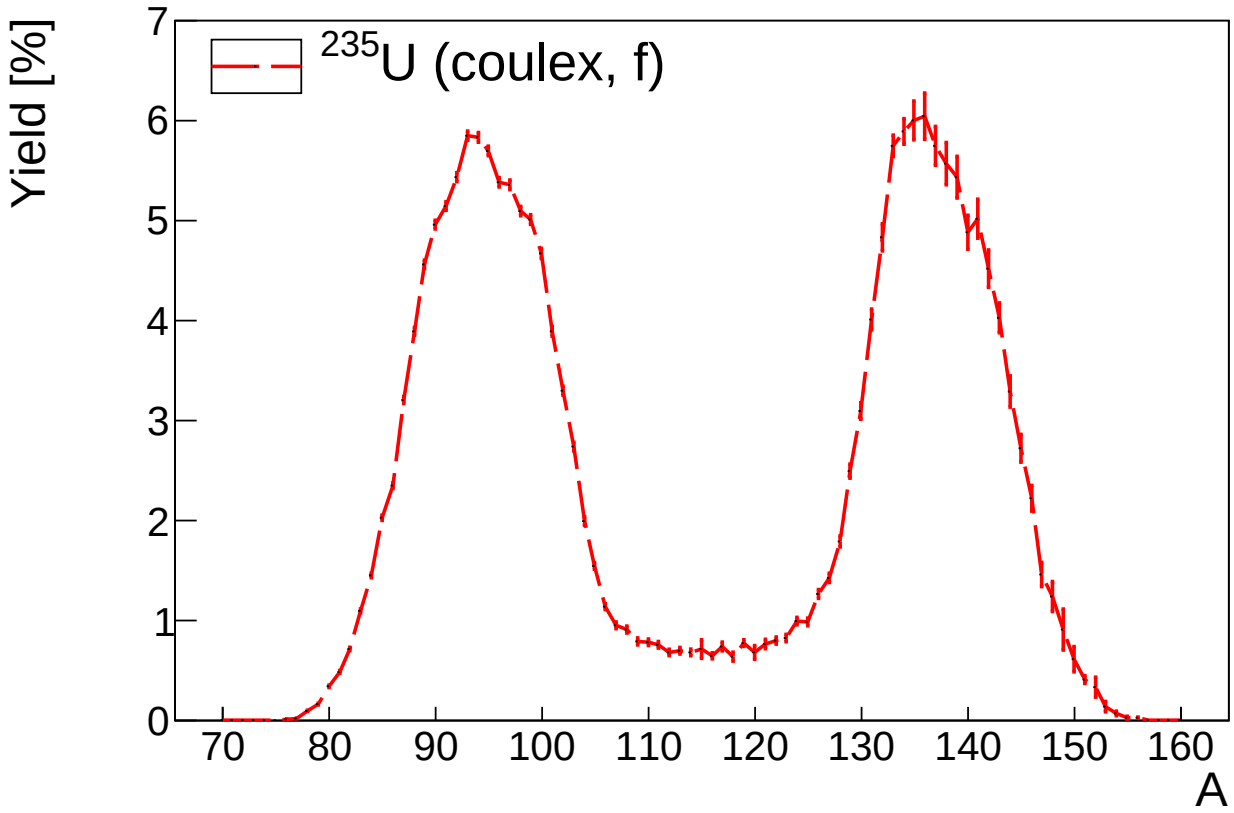
A yield



- Width of gaussians 0.58 – 0.75 *u FWHM*
- Statistical uncertainty : ranging from 1.6 % to 3%

A yield



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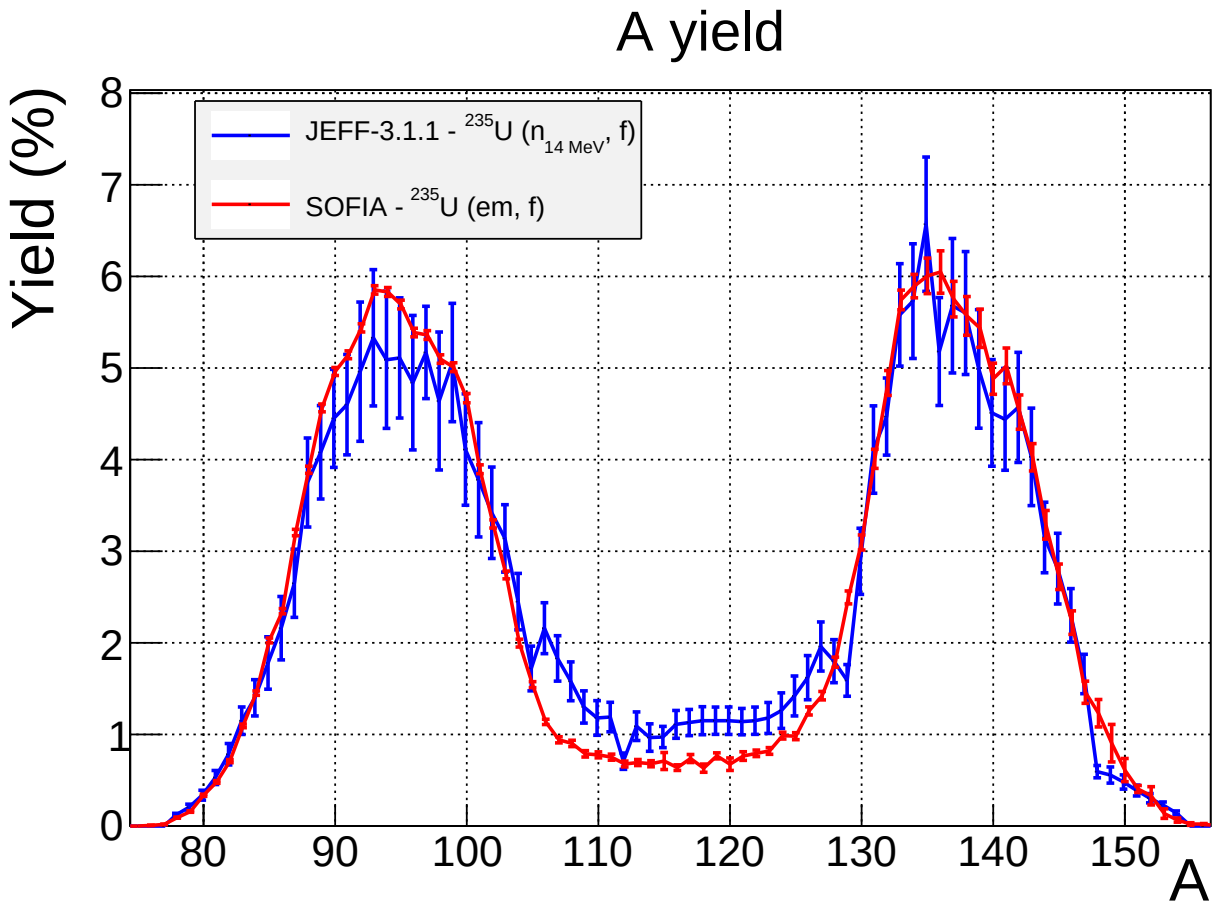

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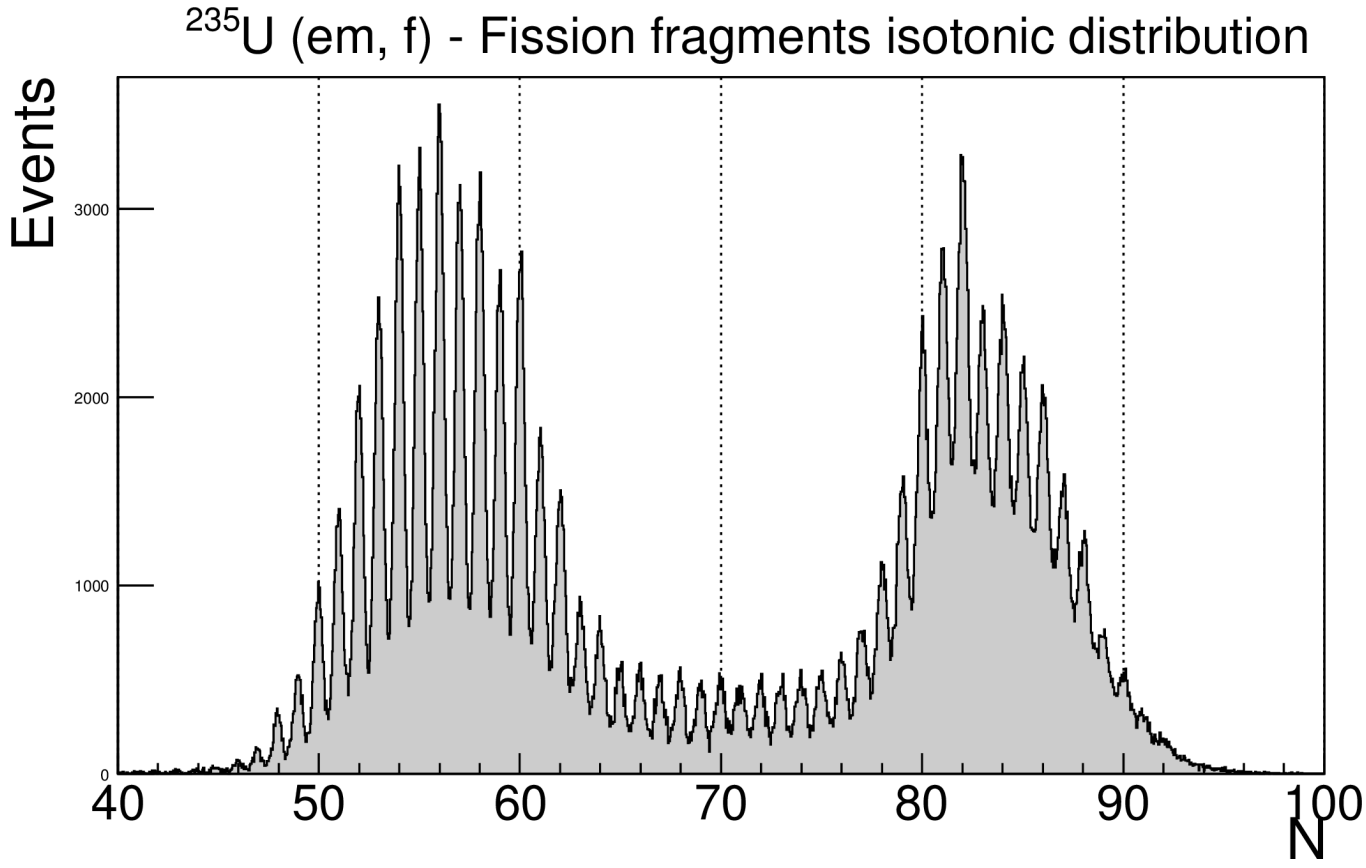
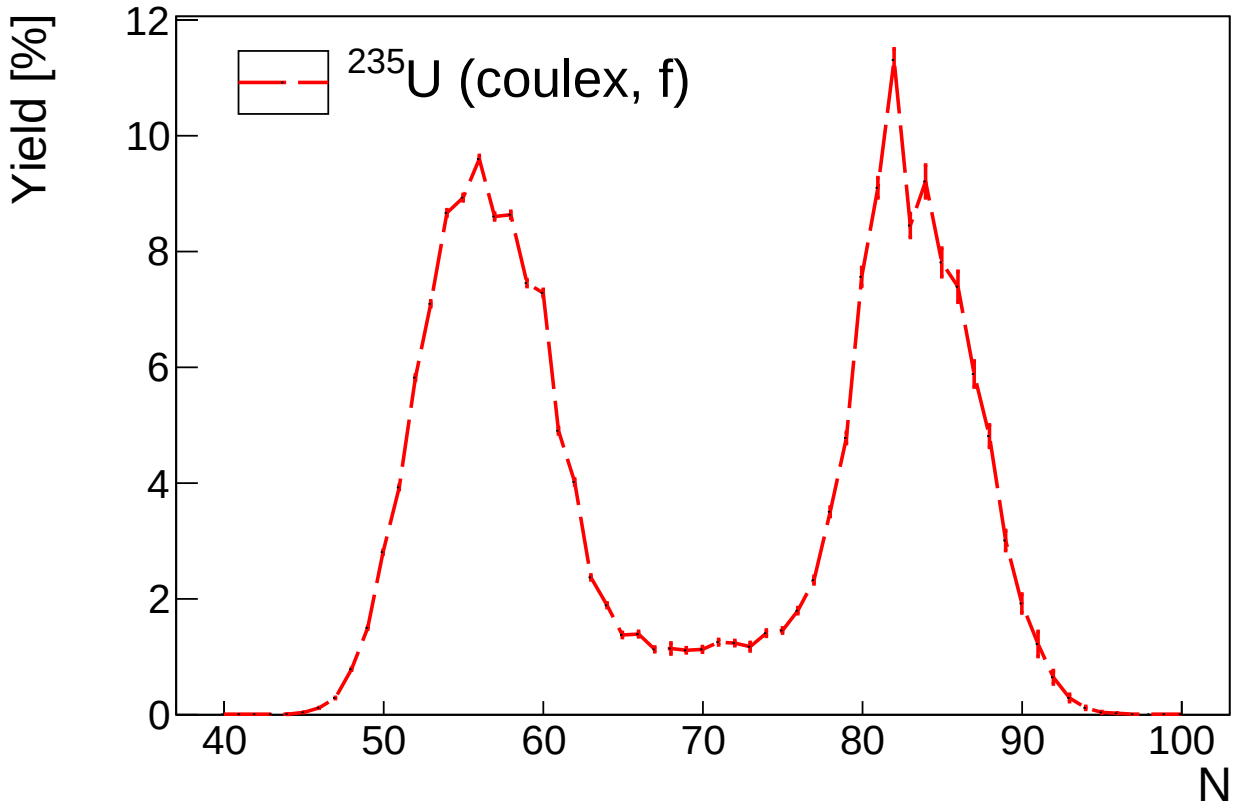
N yield



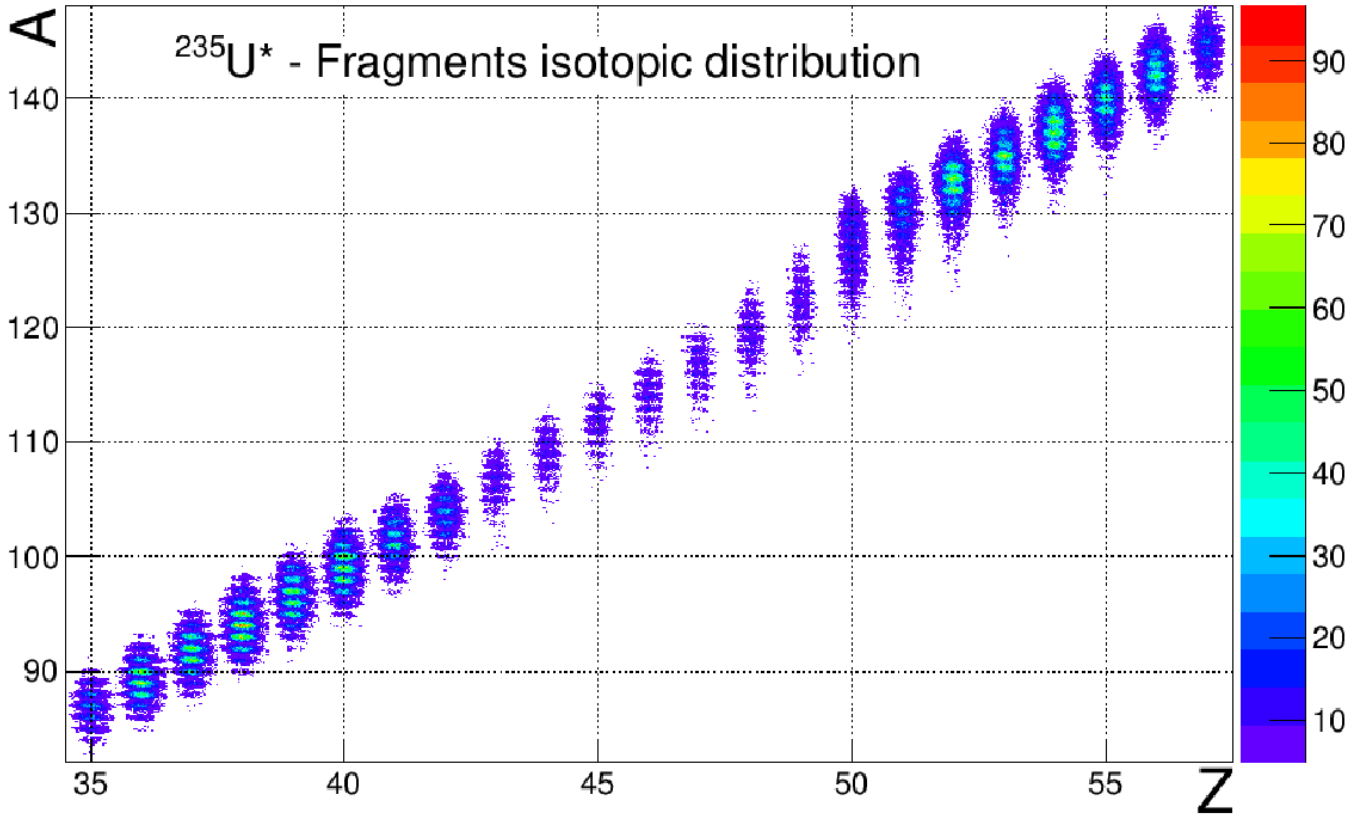
- $N = A - Z$
- Landmarks : e-o staggering and $N = 82$

N yield



- $N = A - Z$
- Landmarks : e-o staggering and $N = 82$

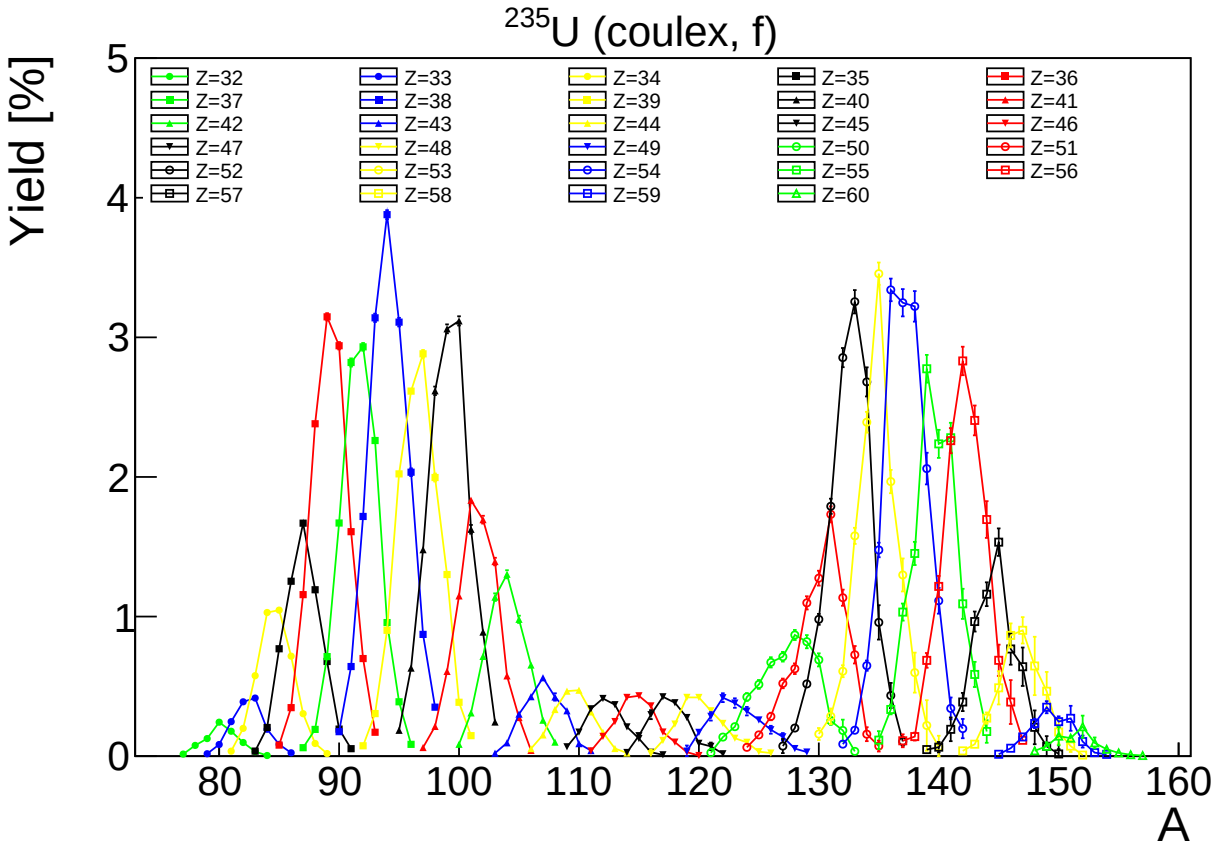
Isotopic yield



Very high resolution

Heavy fragments are more demanding

Isotopic yield



Very high resolution

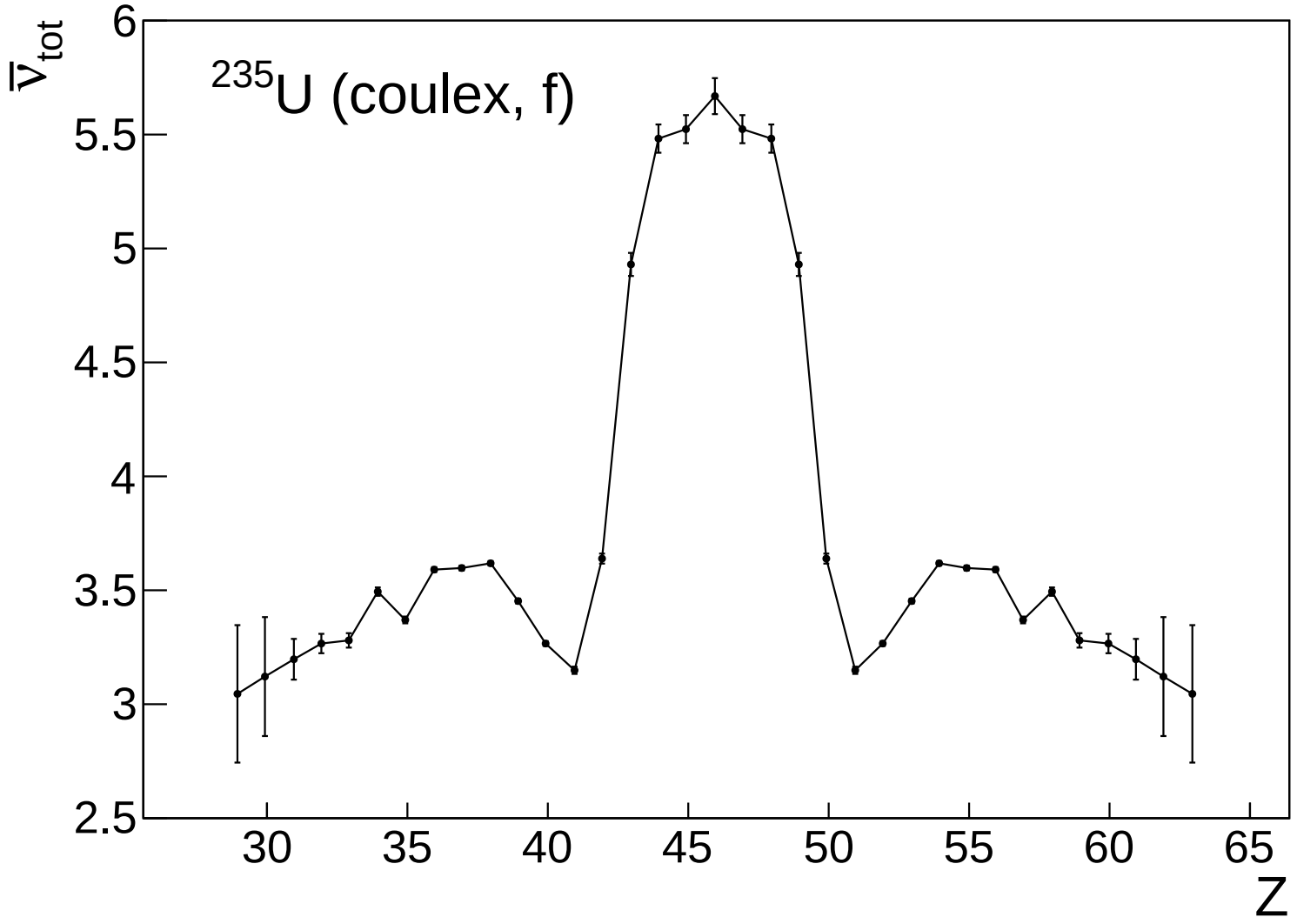
Heavy fragments are more demanding

Neutron multiplicity

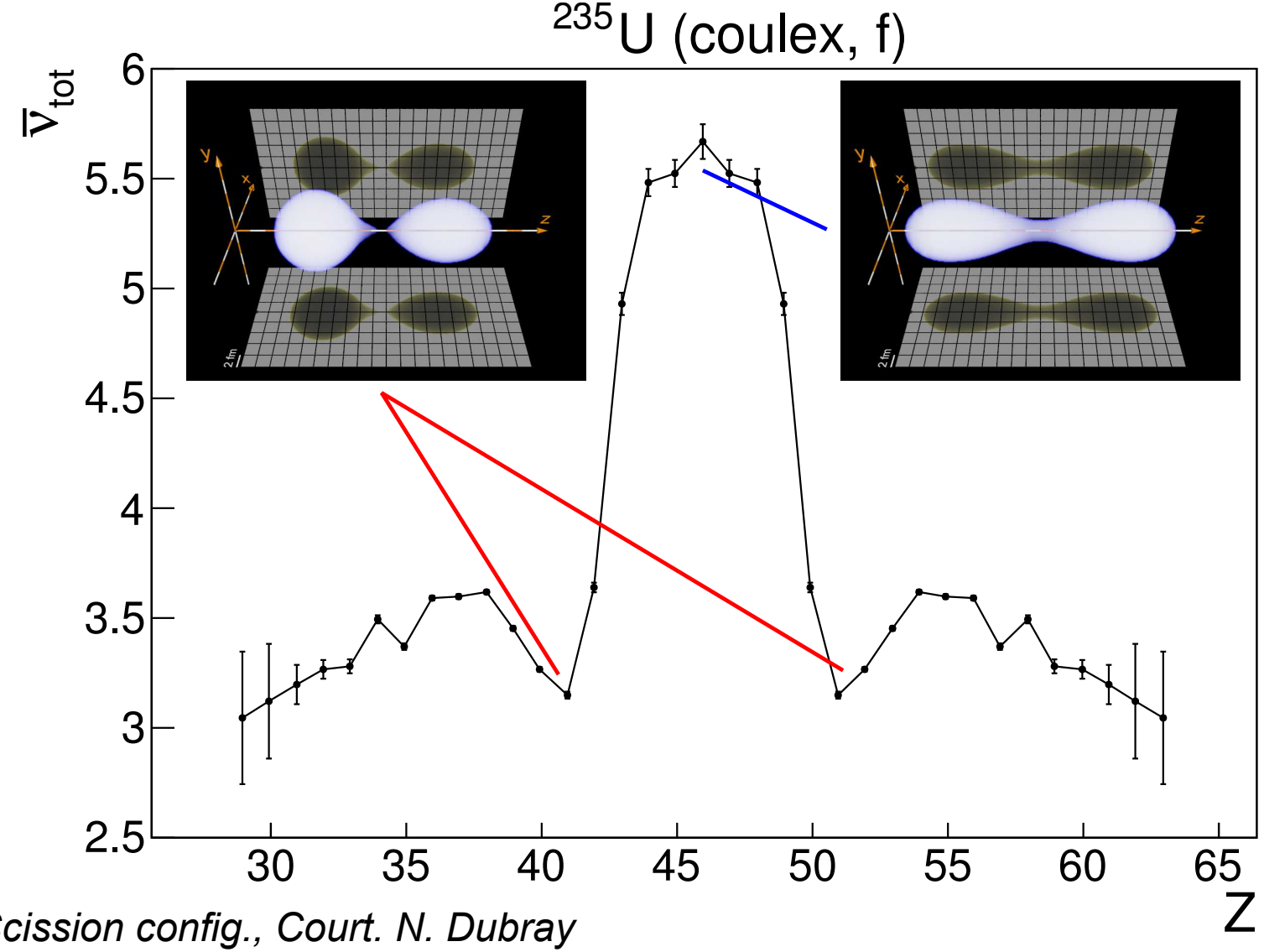
ν_n

- Indirect neutron multiplicity measurement :
  $\nu_n = A - (A_L + A_H)$
- Made possible by excellent resolution on mass

Neutron multiplicity

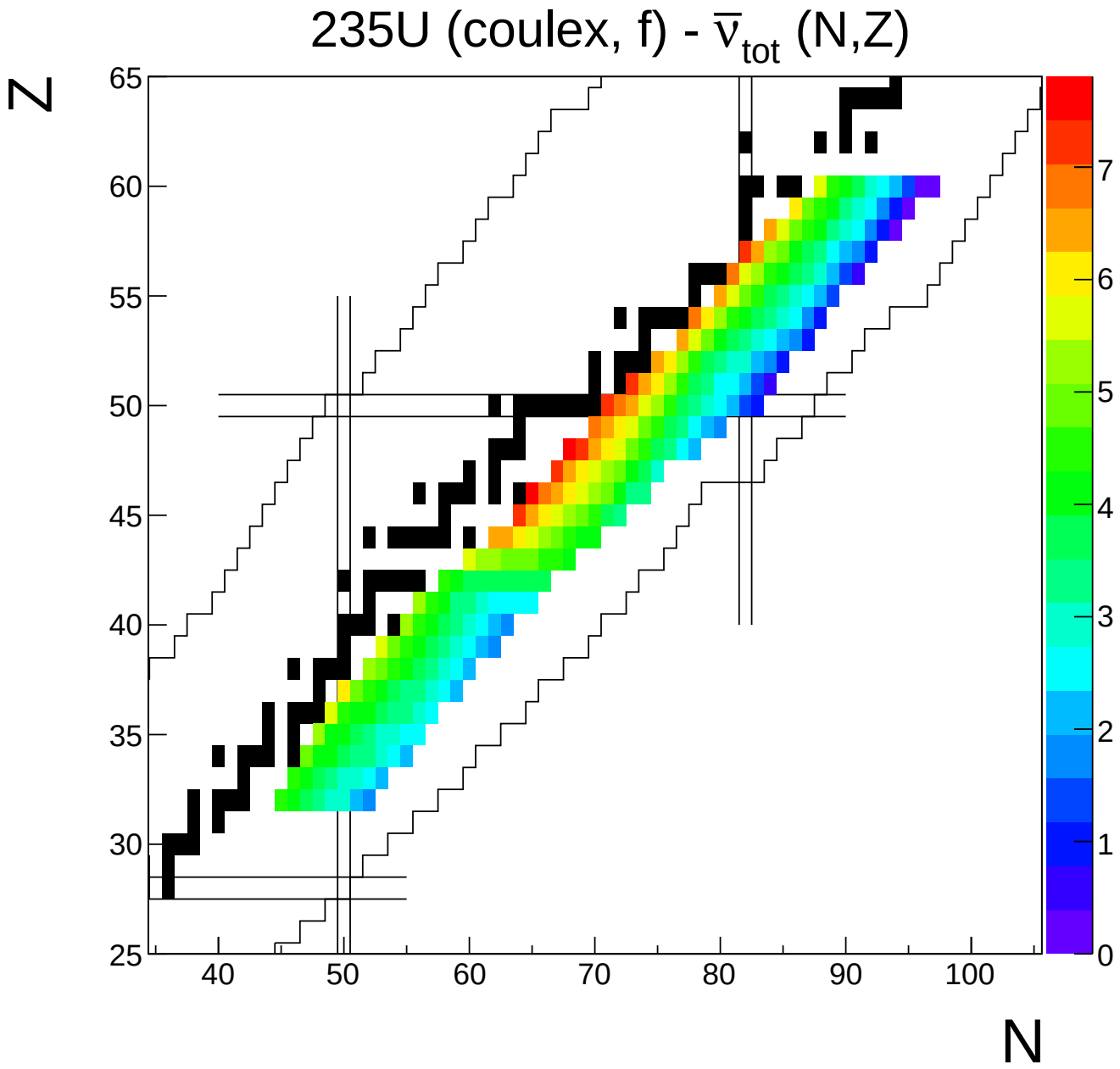


Neutron multiplicity

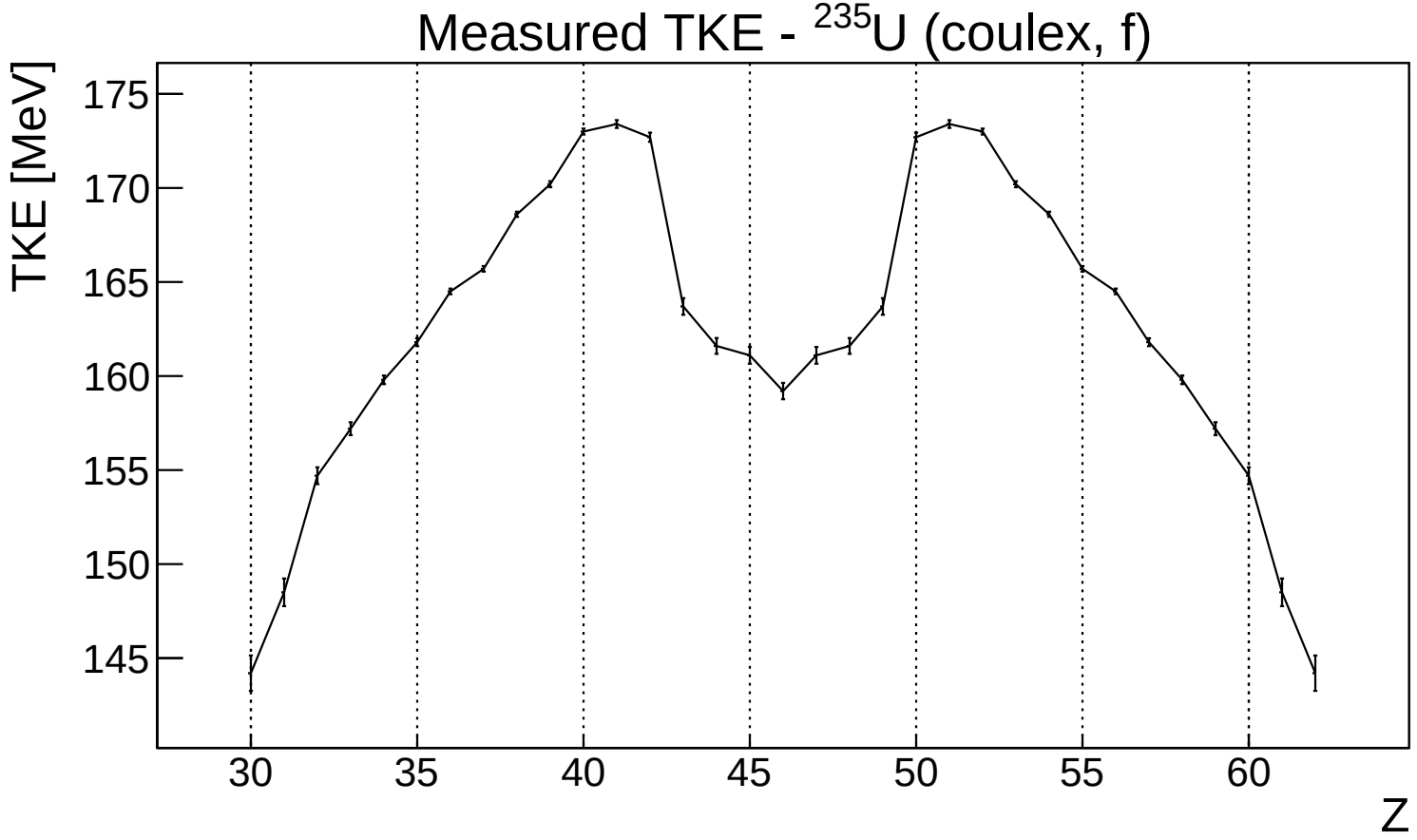


Scission config., Court. N. Dubray

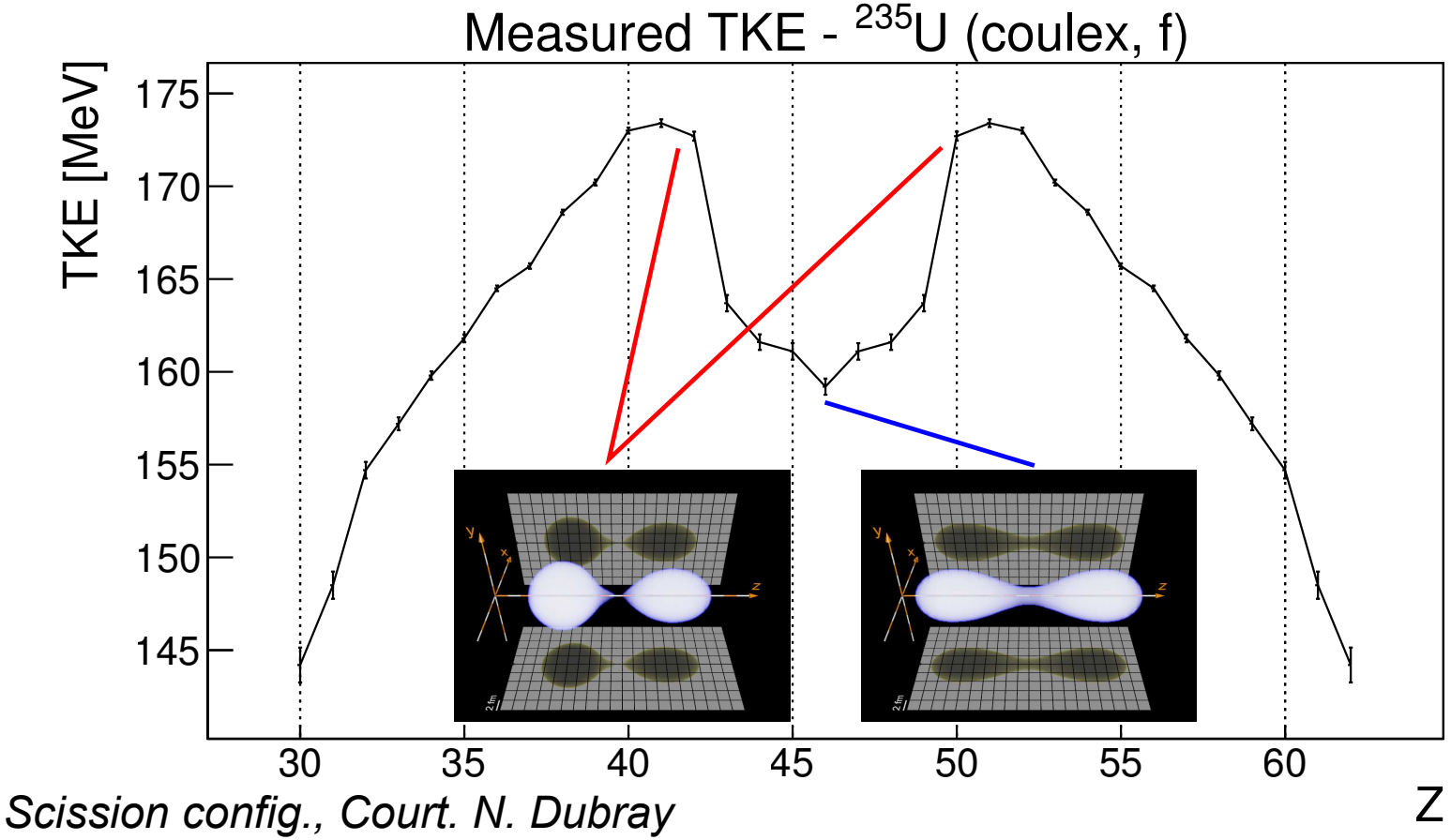
Neutron multiplicity



Total kinetic energy

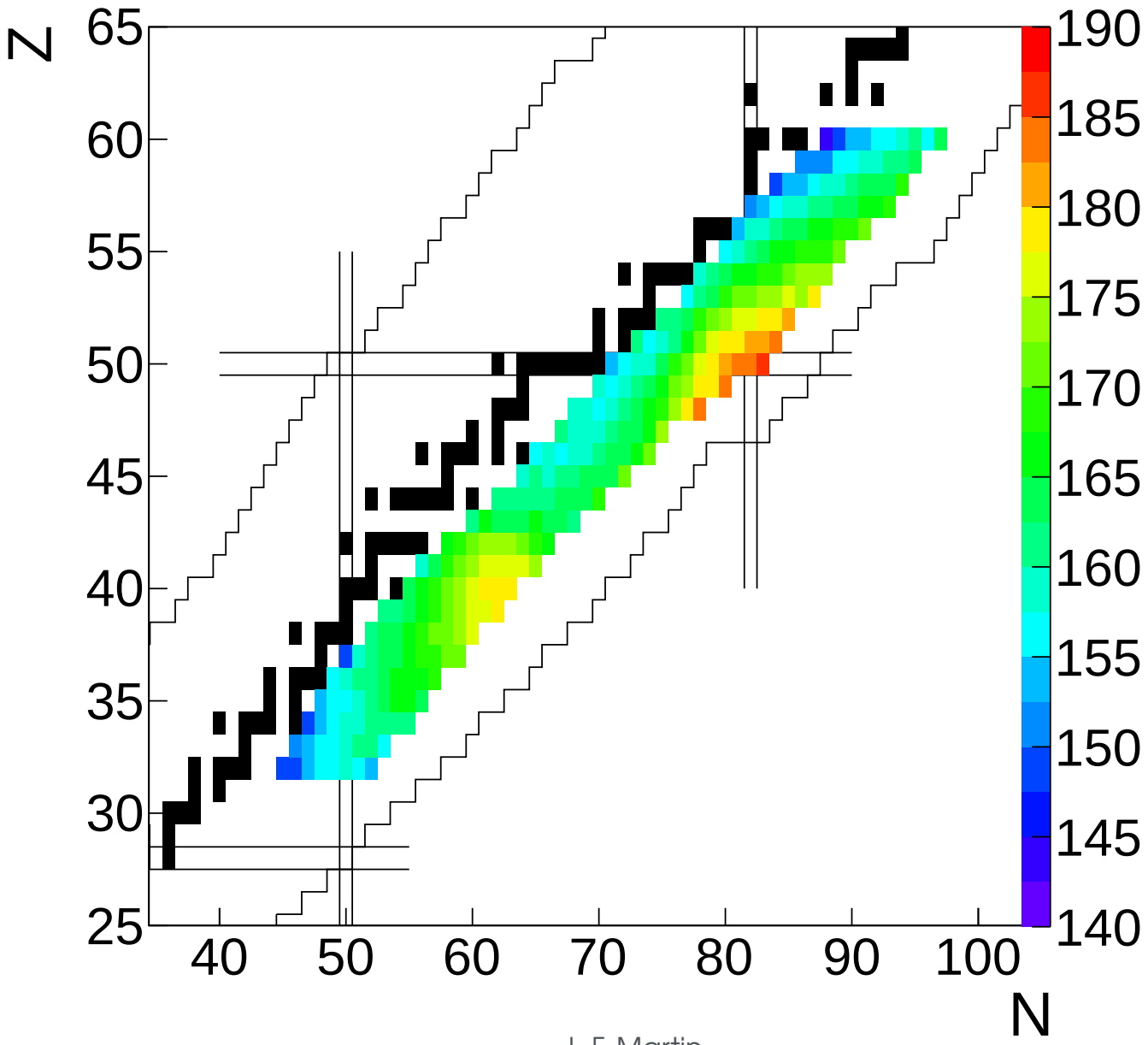


Total kinetic energy



Scission config., Court. N. Dubray

Total kinetic energy



SOFIA-1

SOFIA-1, August 2012

- SOFIA-1 has been a success
- For the very first time, both fission fragments fully identified, simultaneously
- Z, A, N and isotopic yields
- Prompt neutron multiplicity and total kinetic energy
- 80 fissioning systems, some measured for the first time

But...

- We missed $^{236}U \approx^{235} U + n$

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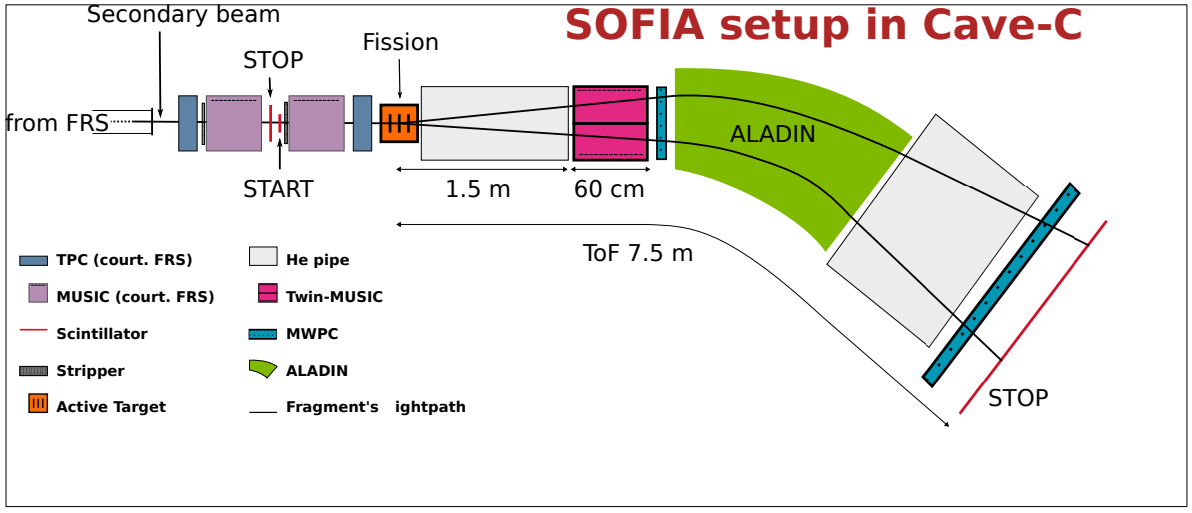
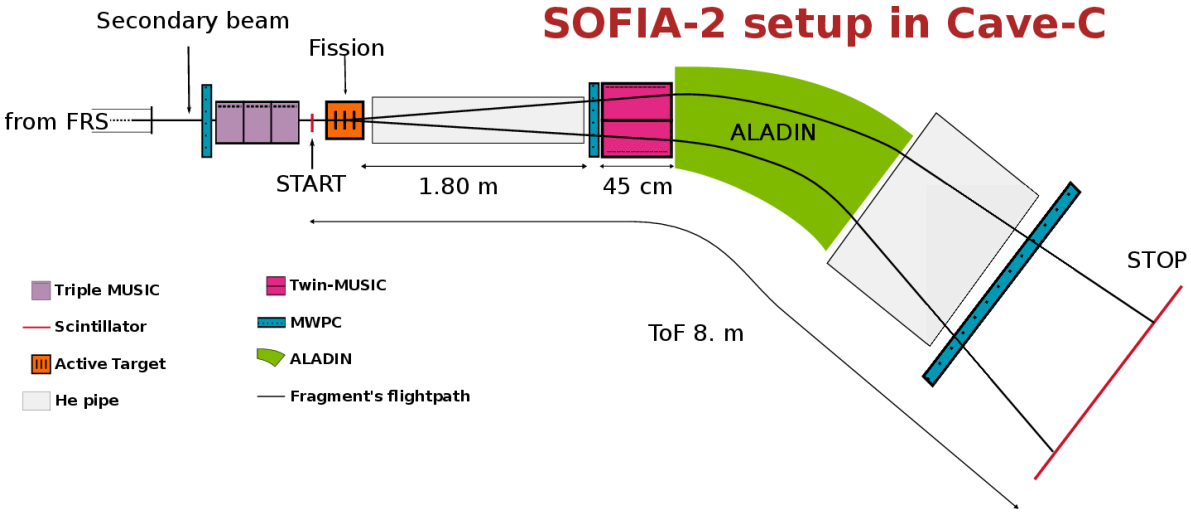
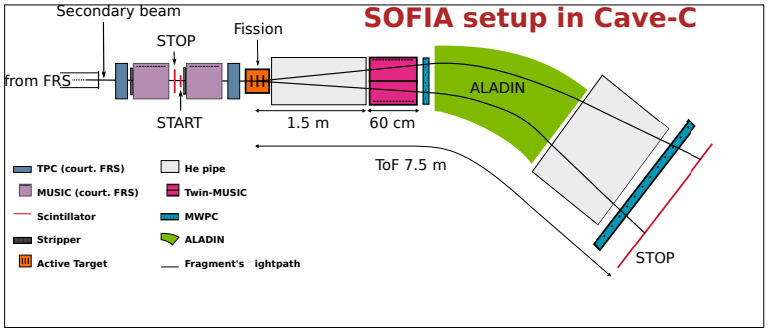
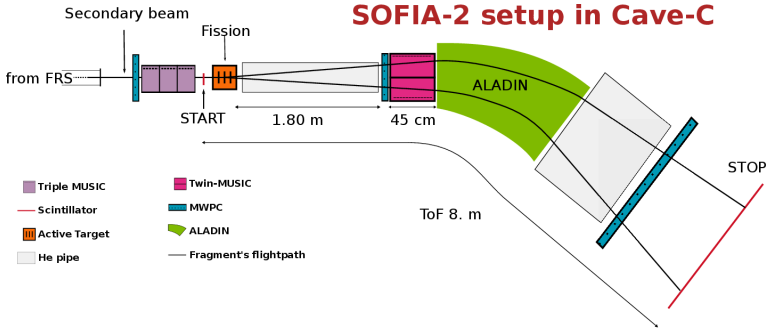
SOFIA-2 is planned for now !
Beam 22-24th october, 2014


SOFIA setup in Cave-C
Secondary beam
STOP
Fission
from FRS
START
1.5 m
60 cm
ALADIN
ToF 7.5 m
STOP
TPC (court. FRS)
MUSIC (court. FRS)
Scintillator
Stripper
Active Target
He pipe
Twin-MUSIC
MWPC
ALADIN
Fragment's ightpath


SOFIA-2 setup in Cave-C
Secondary beam
Fission
from FRS
START
1.80 m
45 cm
ALADIN
ToF 8. m
STOP
Triple MUSIC
Scintillator
Active Target
He pipe
Twin-MUSIC
MWPC
ALADIN
Fragment's flightpath

SOFIA-2

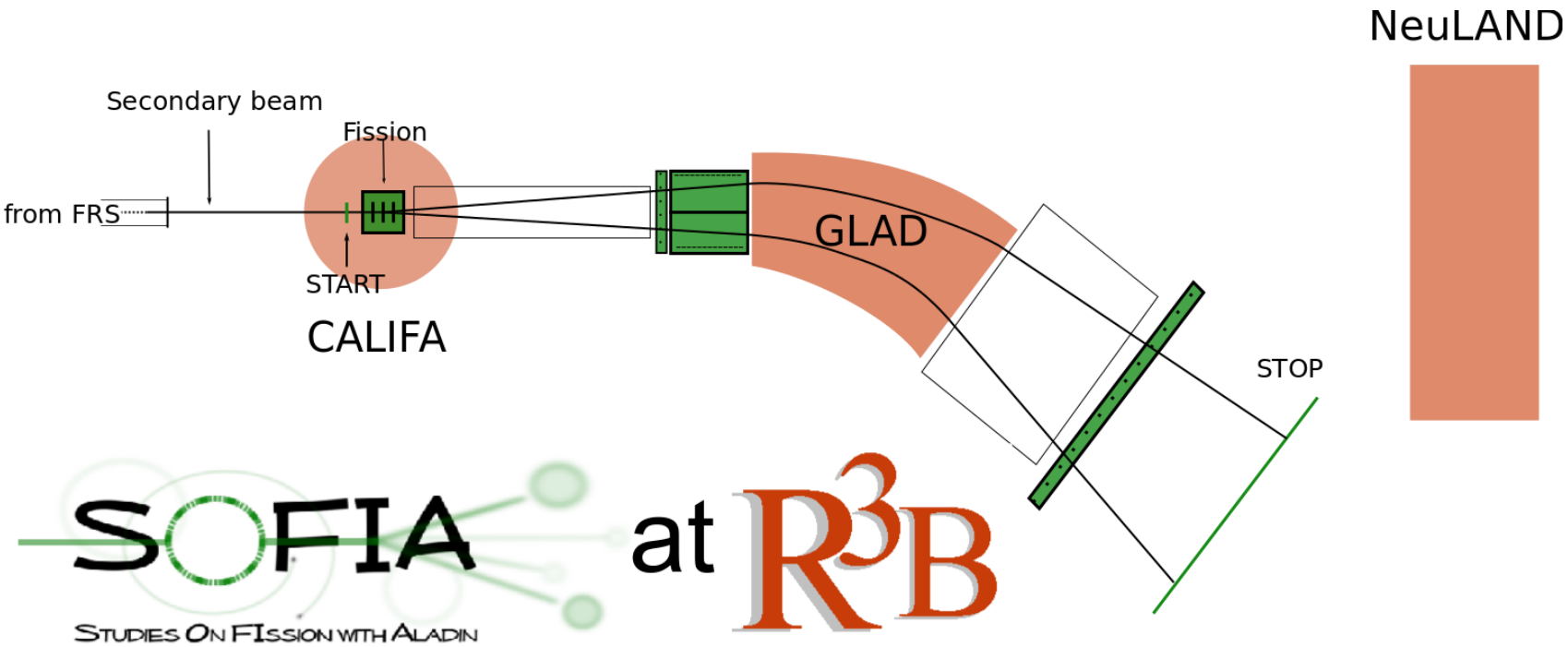




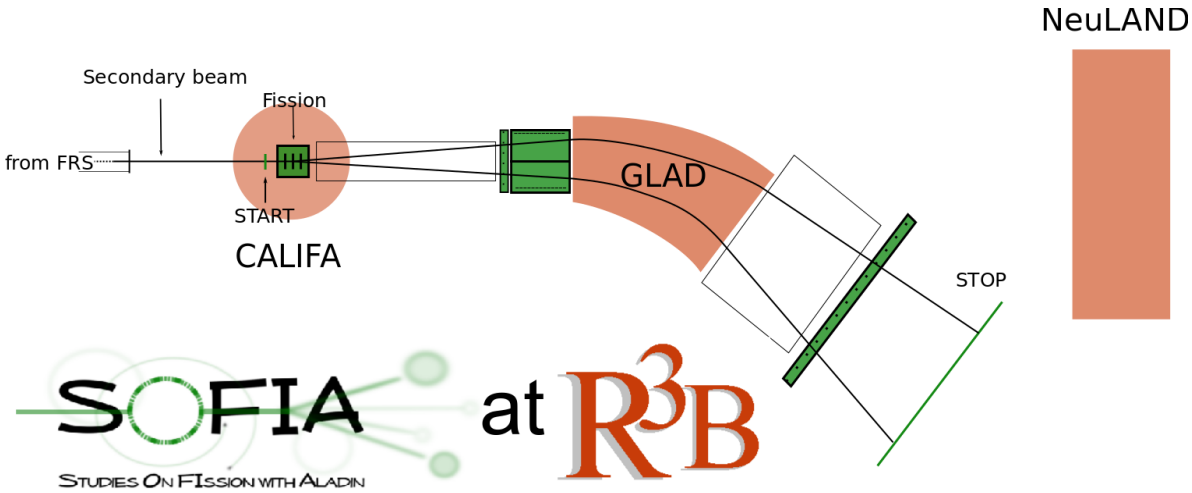
- All the same, but all improved !
- Efficiency was 75%, it becomes 95%
- Max count rate was $2kHz$, it becomes $4 - 5kHz$
- ^{236}U is to be measured with high statistics

Outlook, 5 years

Within 5 years, SOFIA at R3B
The experimental area Cave C is to be ugraded, to
R3B = Reactions with Relativistic Radioactives Beams



Outlook, 5 years



GLAD New dipole, more powerful -> better resolution on mass measurement

CALIFA Calorimeter -> fission γ, multiplicity and total energy

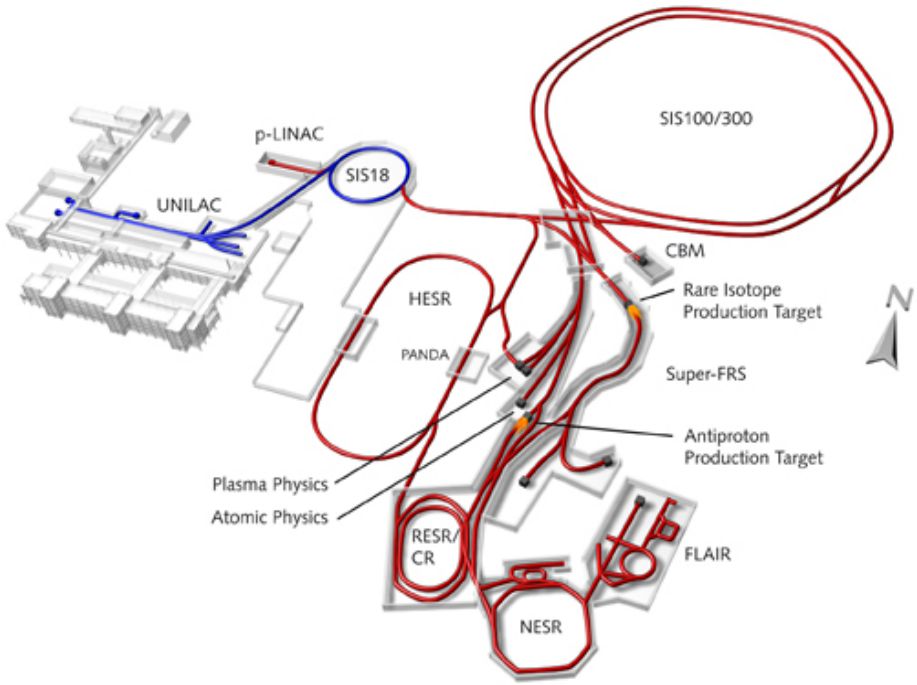
NeuLAND Neutron detector -> assign prompt neutron to each fragment

Also, considering ^{242}Pu as primary beam.
Access fission of heavier actinides : Am, Pu, Np...

Outlook, a long time

SOFIA at ELISE = fELISE

Complete revolution as compared to first steps of SOFIA

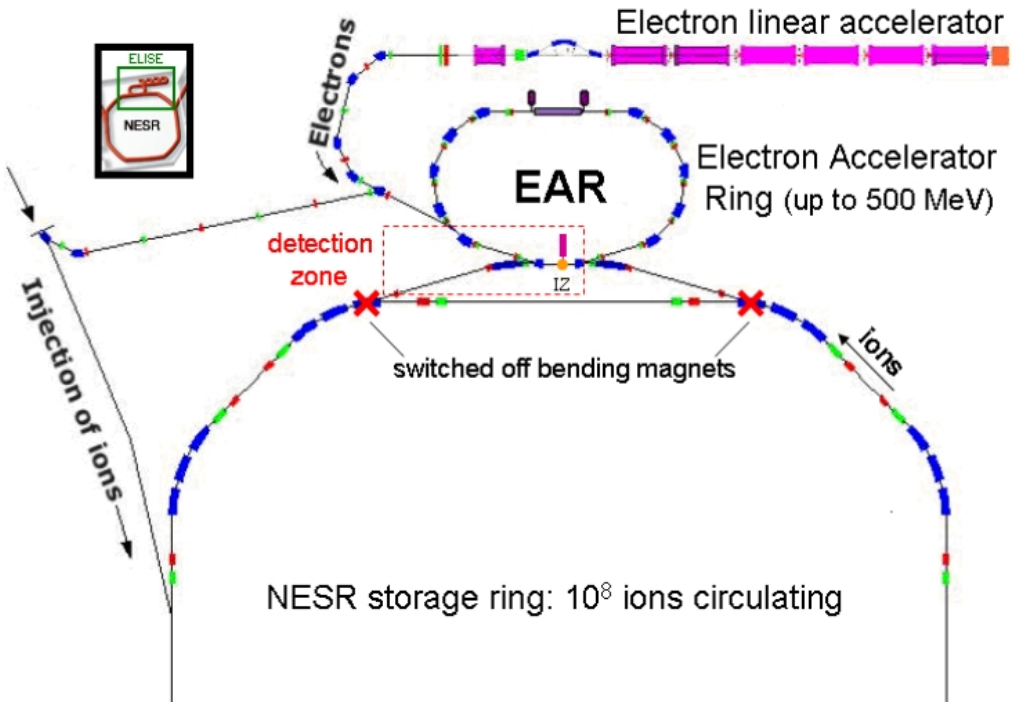


- ^{238}U primary beam accelerated through LINAC, SIS
- Fragmentation reaction to produce secondary beam
- Selection of ions of interest through SuperFRS
- Injection of pure 2y beam into storage ring NESR

Outlook, a long time

SOFIA at ELISE = fELISE

Complete revolution as compared to first steps of SOFIA



- Electron ion scattering
- Excitation of ion known on an event-by-event basis
- De-excitation through fission
- Identification of the fragments

Conclusion

SOFIA-1

- SOFIA-1 in Aug. 2012
- Fission observables are Z, A, N and isotopic yields, and TKE and total prompt neutron multiplicity
- For the very first time, both fragments are fully and simultaneously identified
- With unprecedented resolution
  - Paramount for the applications...
  - But we missed $^{236}U \approx ^{235}U + n$!
- Over 80 nuclei
  - Overview on the nuclear landscape

Conclusion

SOFIA-1

SOFIA-2

- SOFIA-2 in Oct. 2014 (now !)
- The principle stays the same, but the whole setup is improved
- Higher geometrical acceptance, higher counting rate
- We are ready for ^{236}U !

Conclusion

SOFIA-1

SOFIA-2

And then ?

- First step : SOFIA at R3B
  - evolution of the setup
  - Horizon 2017
  - Better mass resolution
  - New observables : prompt neutron multiplicity per fragment, prompt γ emission
- Further down the line : SOFIA @ FAIR/ELISe
  - (r)evolution of the setup
  - fission induced by electron-ion scattering
  - excitation energy known on an event-by-event basis

Thank you !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