Recent results of SOFIA

STUDIES ON FISSION WITH ALADIN

Summary of the support of NEEDS

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on behalf of the SOFIA collaboration

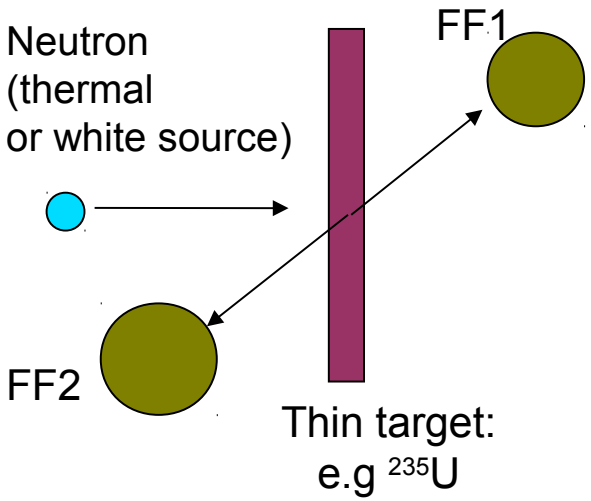
Interest for fission fragments yields

- FF are a key element of the core neutronics and fuel behavior :
  - Source of the delayed neutrons
  - Role increased with higher burn-up (30 MWj/T, then 60... 90 tomorrow?)
  - Reactivity excursions : quick accumulation of FF
  - FF are the main source of residual power (LOCA)
  - FF drive the radioactivity over the first years (used fuel handling)
- FF are a unique probe to the fission mechanism and its various modes

- The right experiment at the right time ?
  - Taking into account "real" FF in computation would be a significant step forward for safety
  - Is extremely CPU-intensive : could hardly have been done before

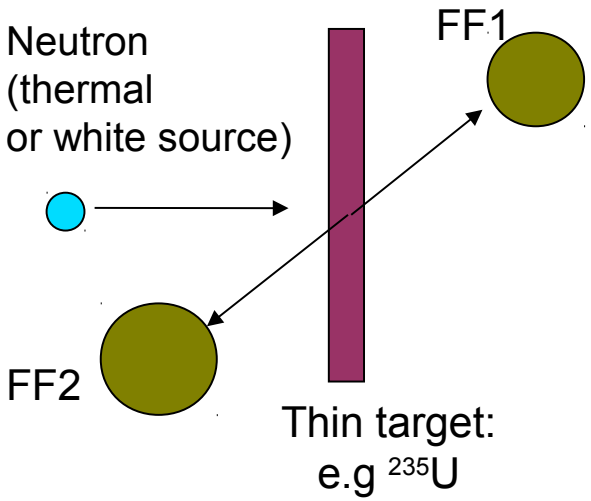
- A very incomplete knowledge :
  - Isobaric yields known, although with significant error bars for most systems
  - Only a handful of (long-lived) isotopes had their yield measured
  - Precise Z measurement is practically out of reach in direct kinematics
  - ... Inverse kinematics !

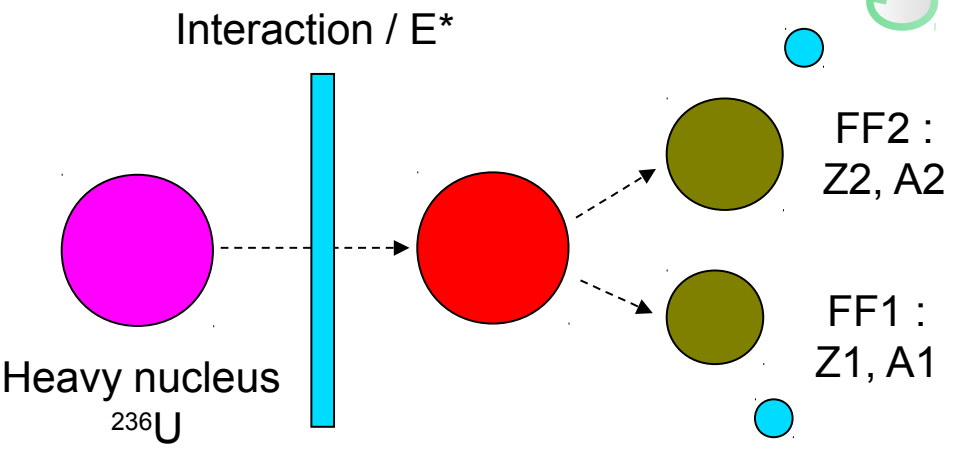
Direct kinematics vs inverse kinematics



- Target feasibility :
  - Material availability (purity)
  - Radioactivity
- Z determination for light fragments (best case)
- Low acceptance of spectrometer
- Susceptibility to the angular distribution of fragments

Direct kinematics vs inverse kinematics





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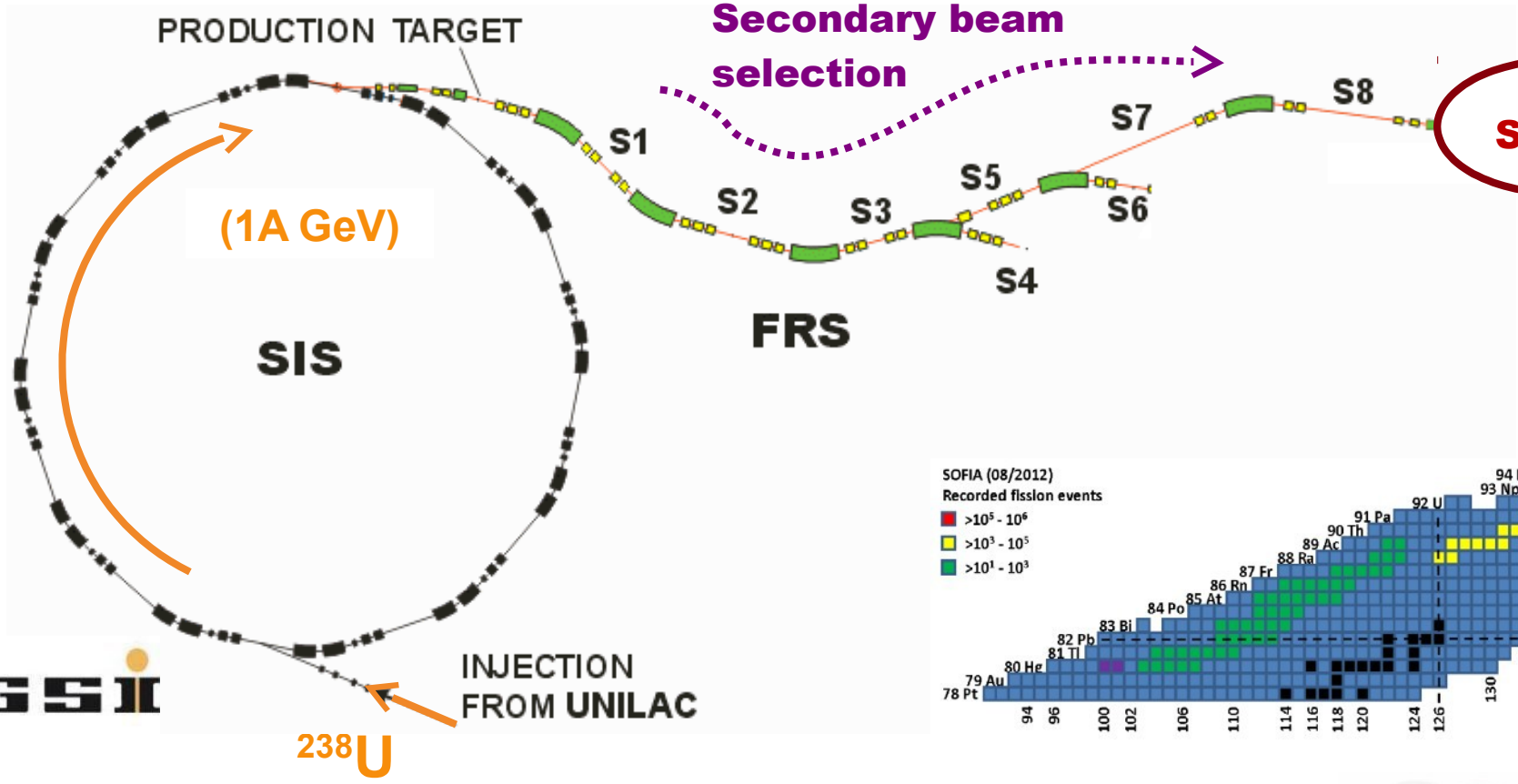
- *The actinide is the projectile*
- FiF are forward-focused : identification in a recoil spectrometer
- Secondary beam : tens of exotic actinides
- No neutron target : fission by collision or EM interaction
- *... no precise value of E**

Aims and overview of SOFIA

- **Isotopic yields : event-by-event A & Z identification of <u>both</u> fragments**
- Total kinetic energy, prompt neutrons number
- Measurement on a wide variety of actinides
- Low excitation energy: study of structure effects, relevant for applications



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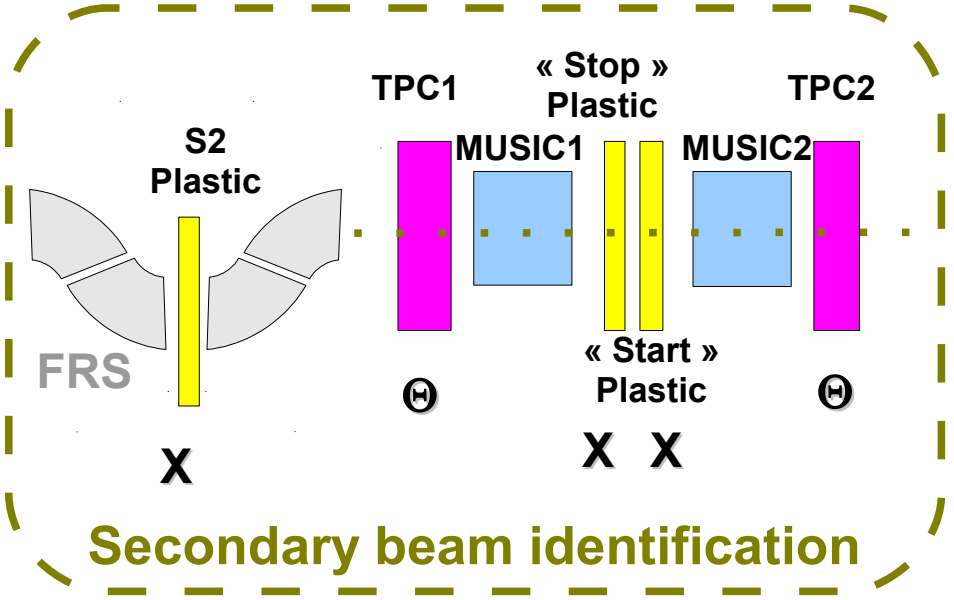
The SOFIA setup (2012 experiment)

- Our setup is a complete recoil spectrometer with dual-hit capability
  - Z obtained from ionisation chambers
  - A obtained from the Brho-ToF method: $A \propto \frac{B\rho}{\gamma v} Z$



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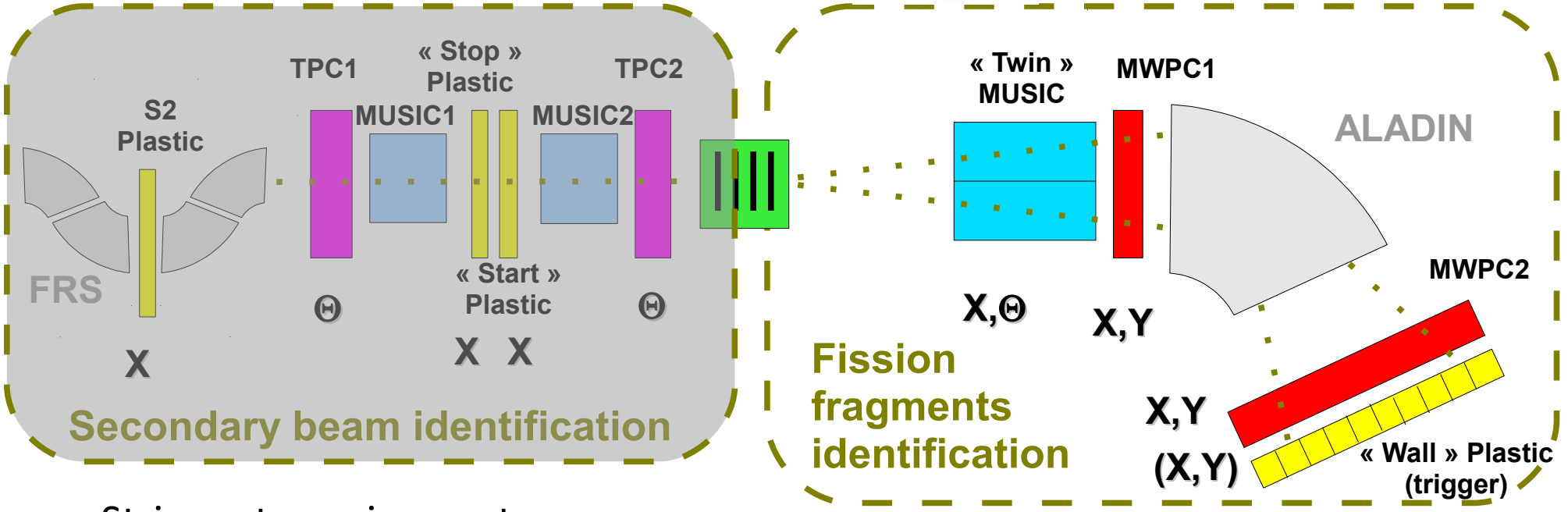

- Stringent requirements :
  - ToF measurement : 40 ps (FWHM) to accomodate the 7 m flight base
  - Position measurement : 200 µm (FWHM) on X (and 0.2 mrad on angle)
  - Energy loss measurement : 1,2% (FWHM)
- Minimal material budget (straggling) & High count rate capability

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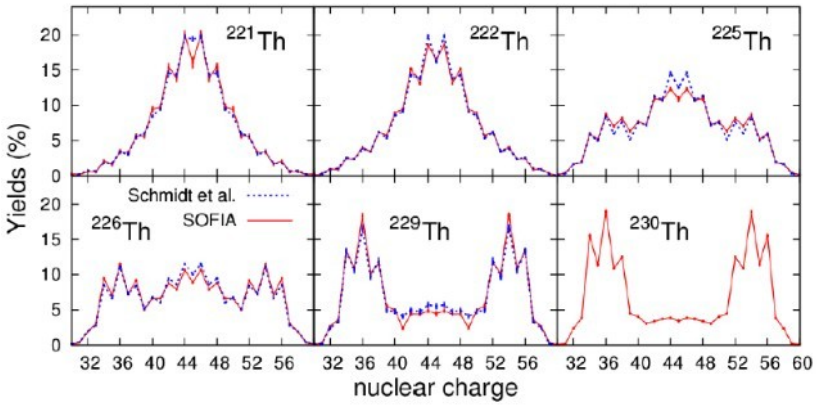
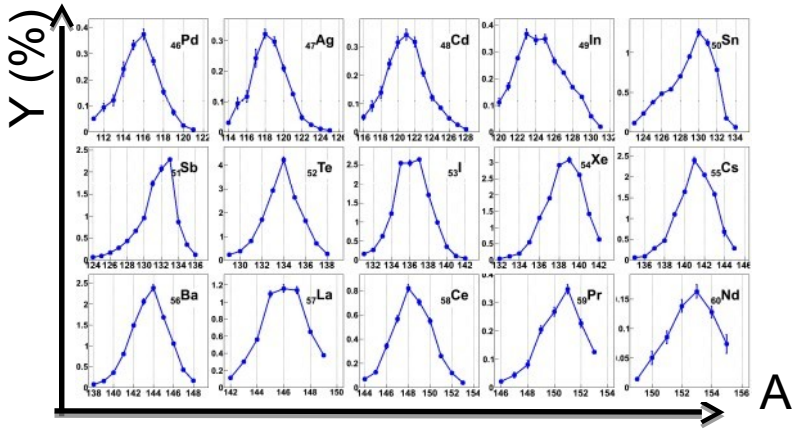
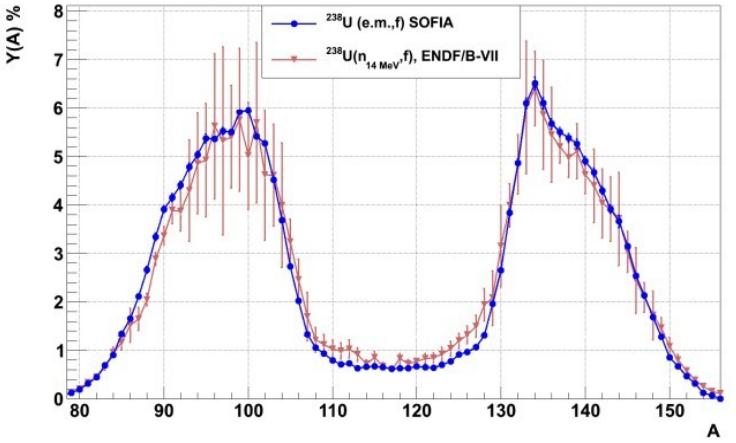
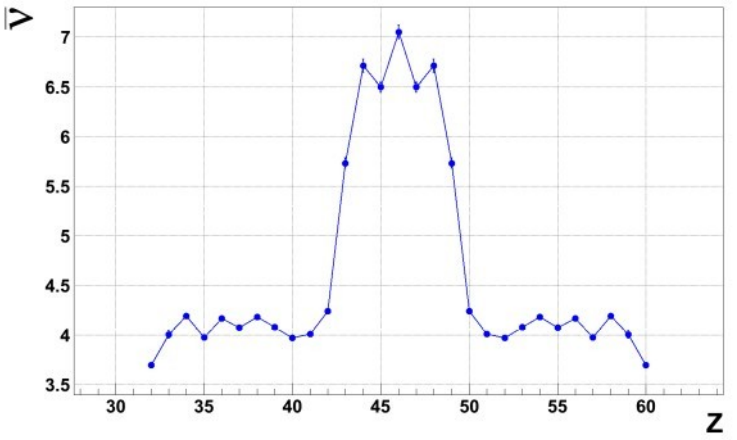
A glimpse at the results of the 2012 measurement

- All technical challenges were met (and beyond)
- Excellent Z separation, mass discrimination (FWHM 0.6 to 0.8 mass units)
- Measurement of prompt neutron yields
- Measurement of the total kinetic energy
- ^{234,235,238}U, plus ~70 proton-rich nuclei









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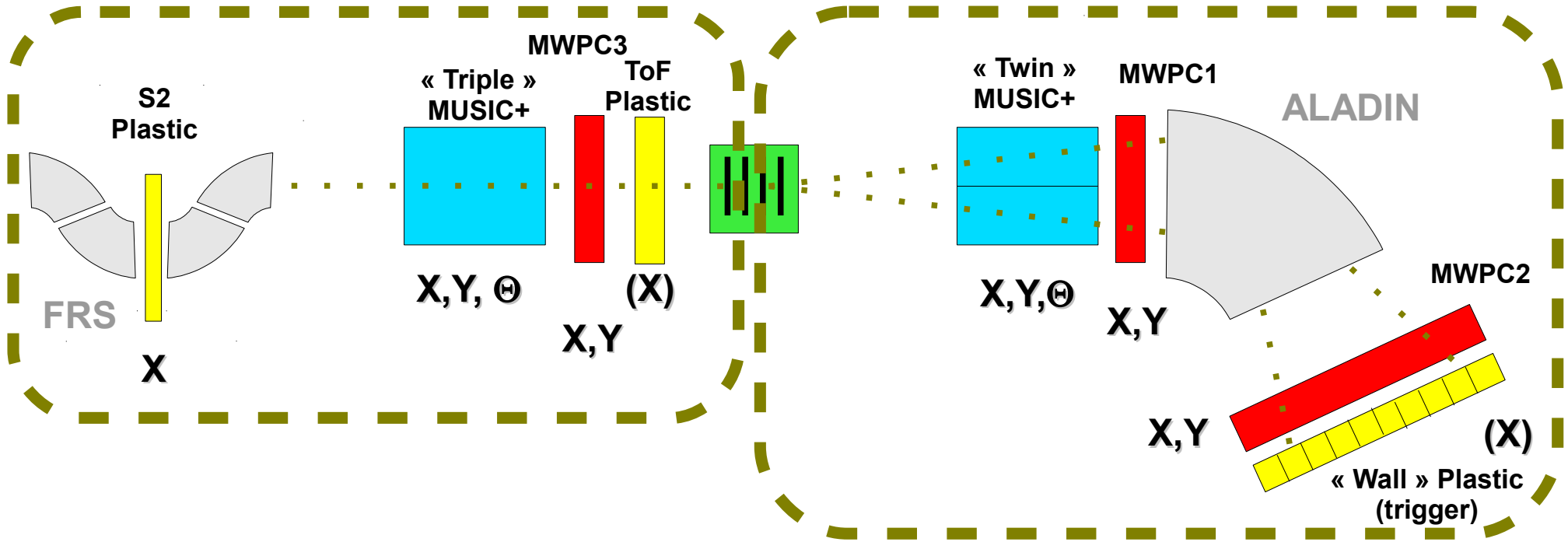
"SOFIA+" : 2014 setup upgrade



- New MUSIC & additionnal MWPC → Secondary beam identification & tracking
- Single intermediate scintillator
- Revamped Twin-MUSIC → Improved resolution and tracking
- New MWPC read-out → Improved counting rate (x4)
- High-rate capable PM for S2
- Total flight path increased to 8 m

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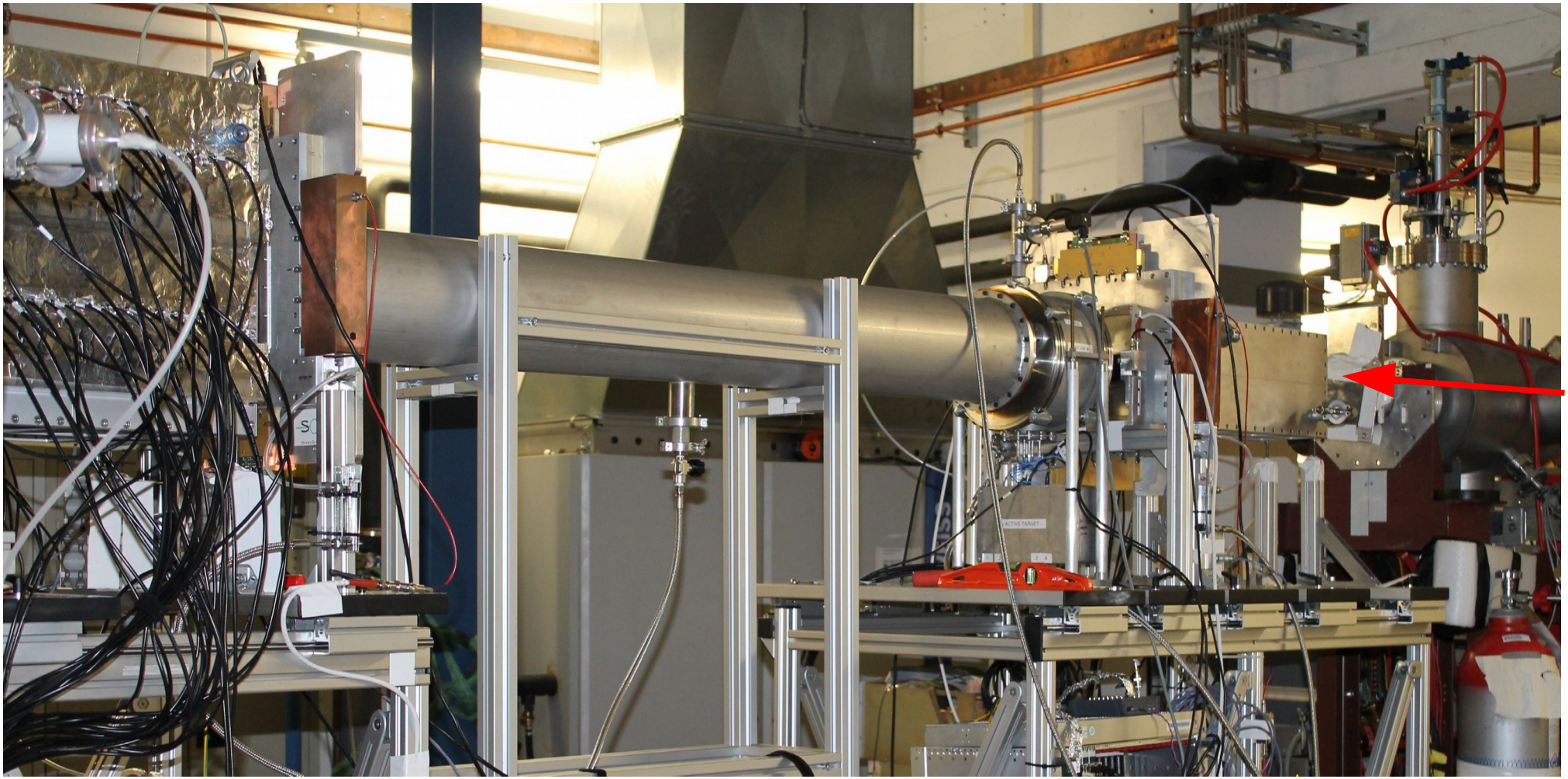
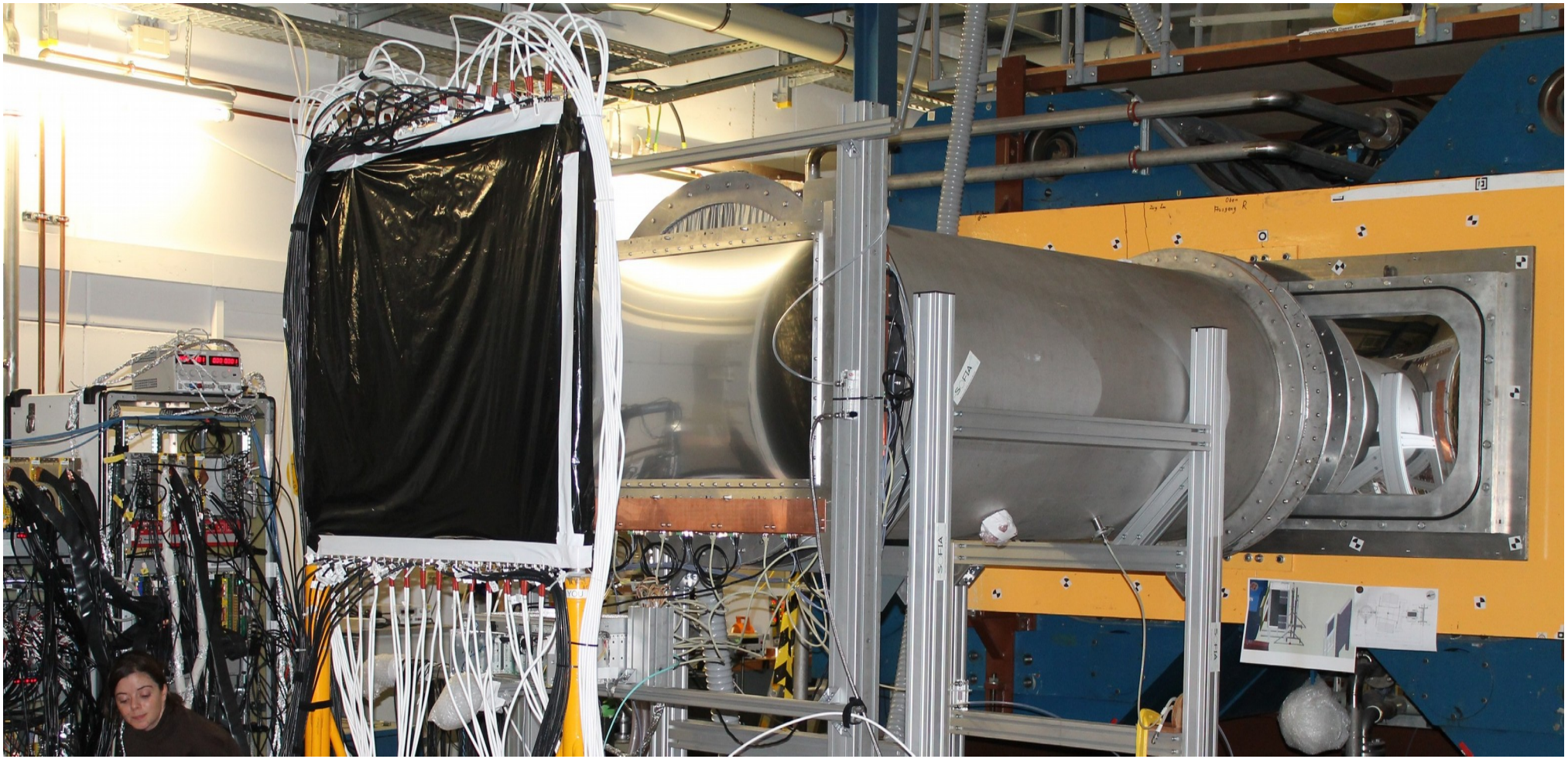
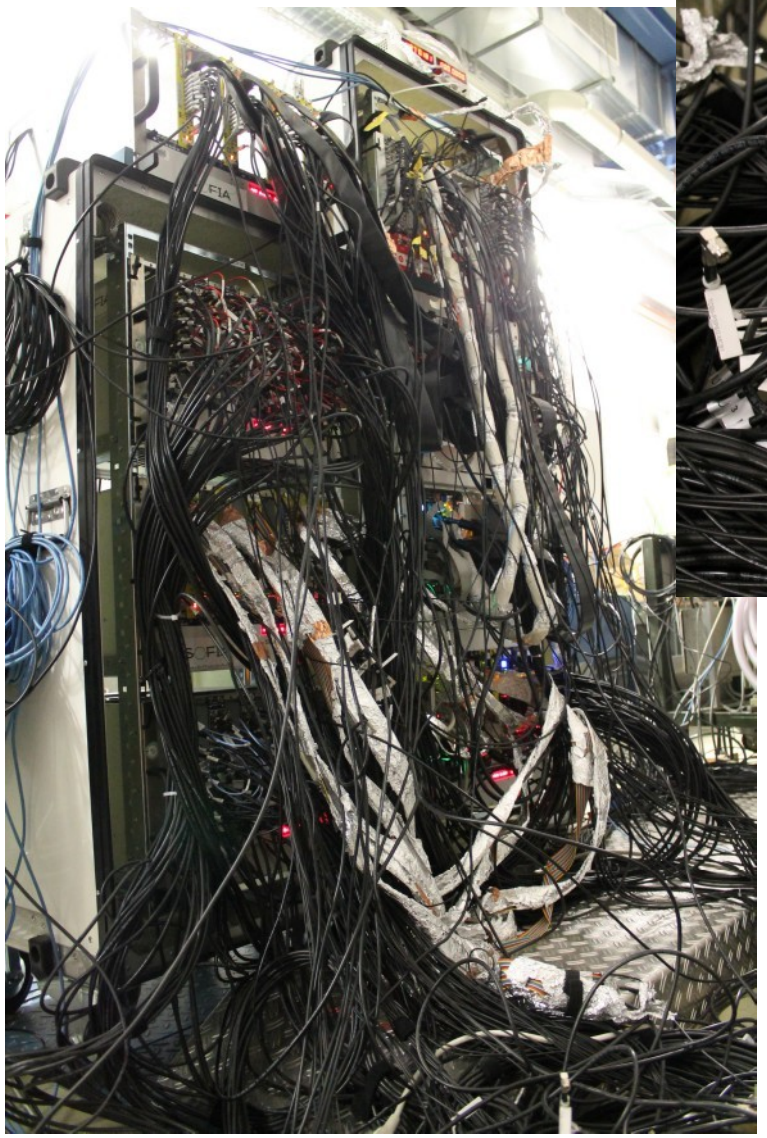
How does it look ? Upstream Aladin...

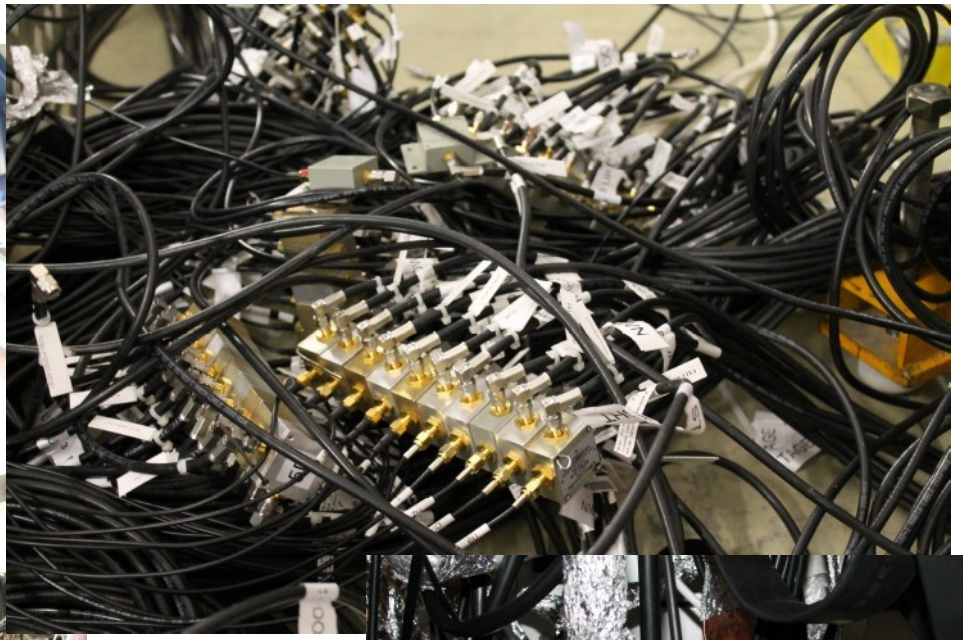


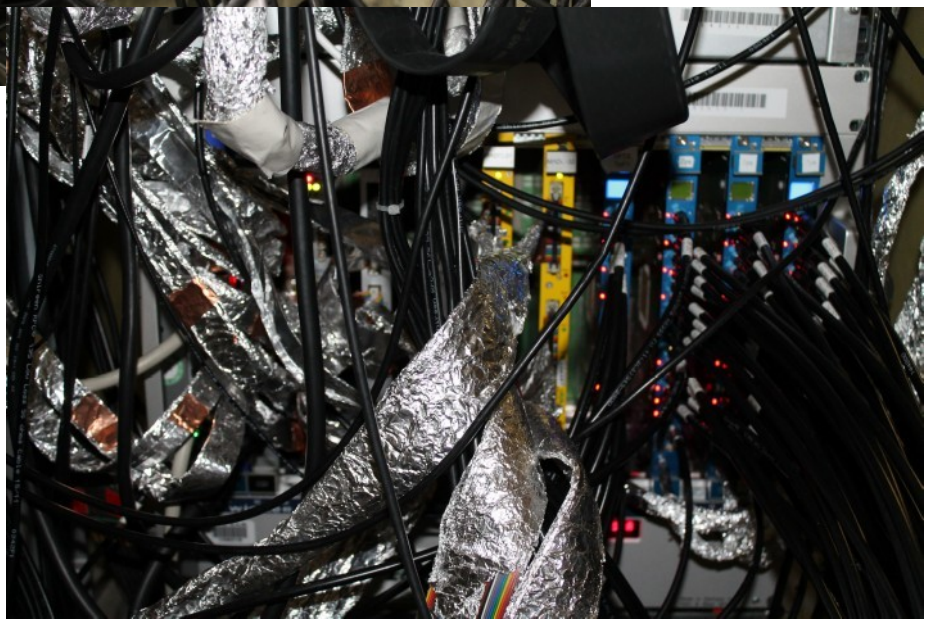
How does it look ? Downstream ot Aladin



How does it look ? Like a big mess of cables !



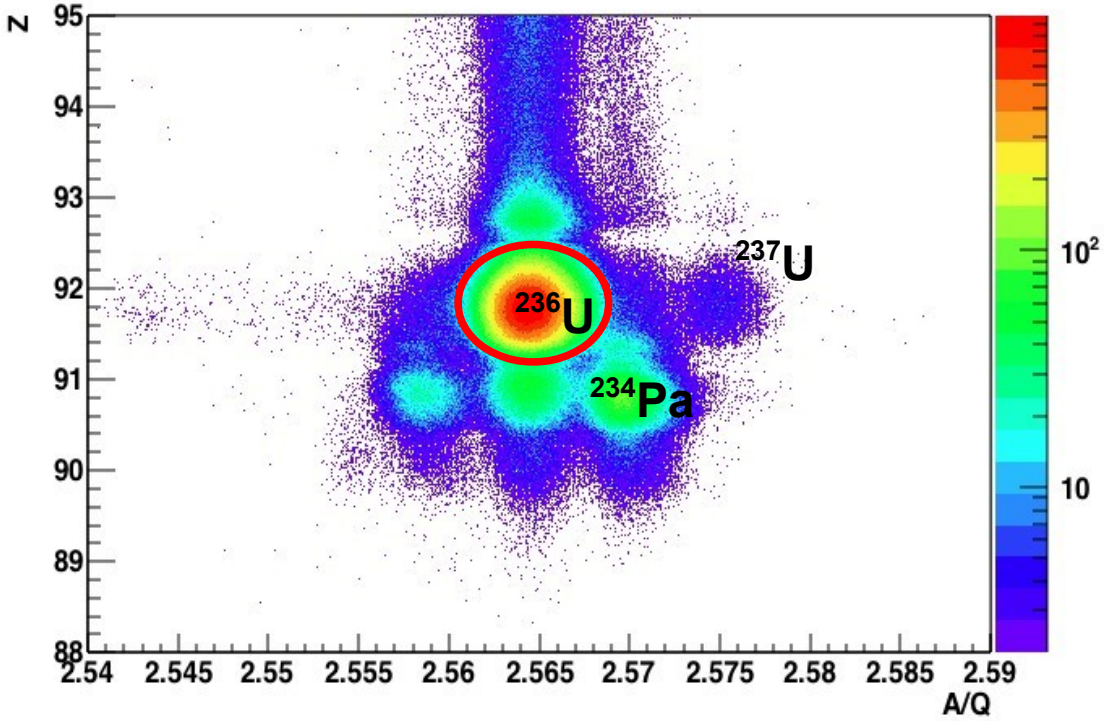


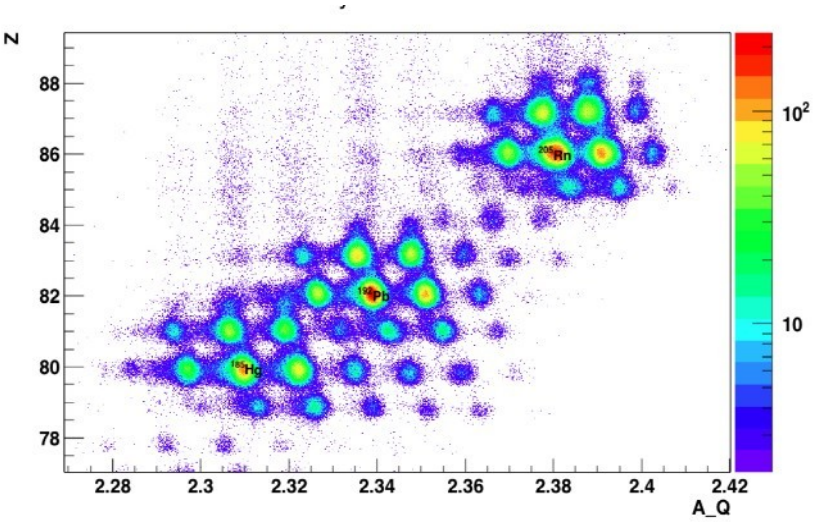


Preliminary results from the 2014 experiment

- Objective: fission of $^{236}U^{*}$ (analog of $^{235}U+n$)
- 2 millions events acquired in 20 hours of beam

- Identification of secondary beam





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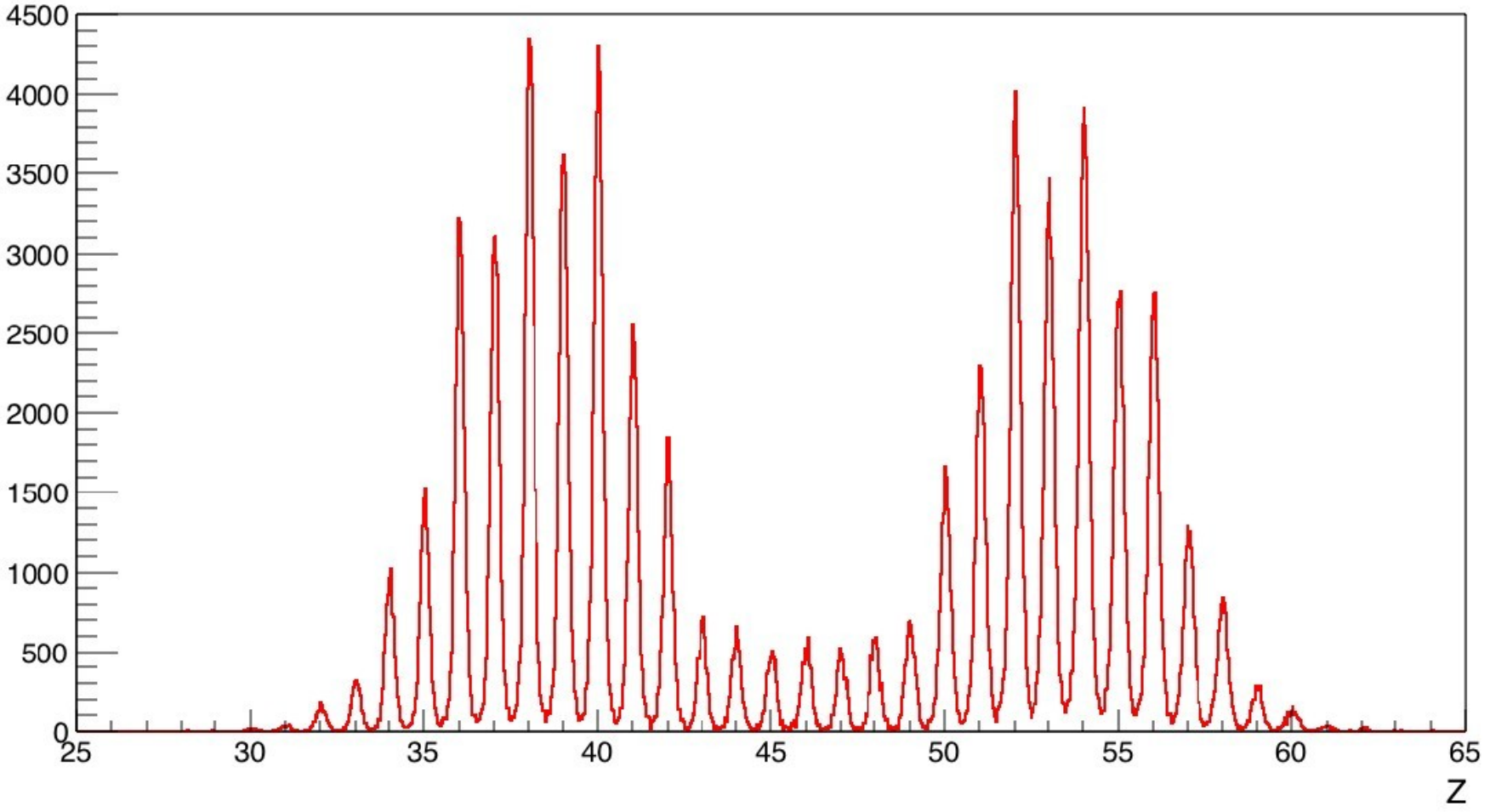
Preliminary results from the 2014 experiment

- Nuclear charge separation and identification
- Resolution : δZ ~ 0,35 FWHM



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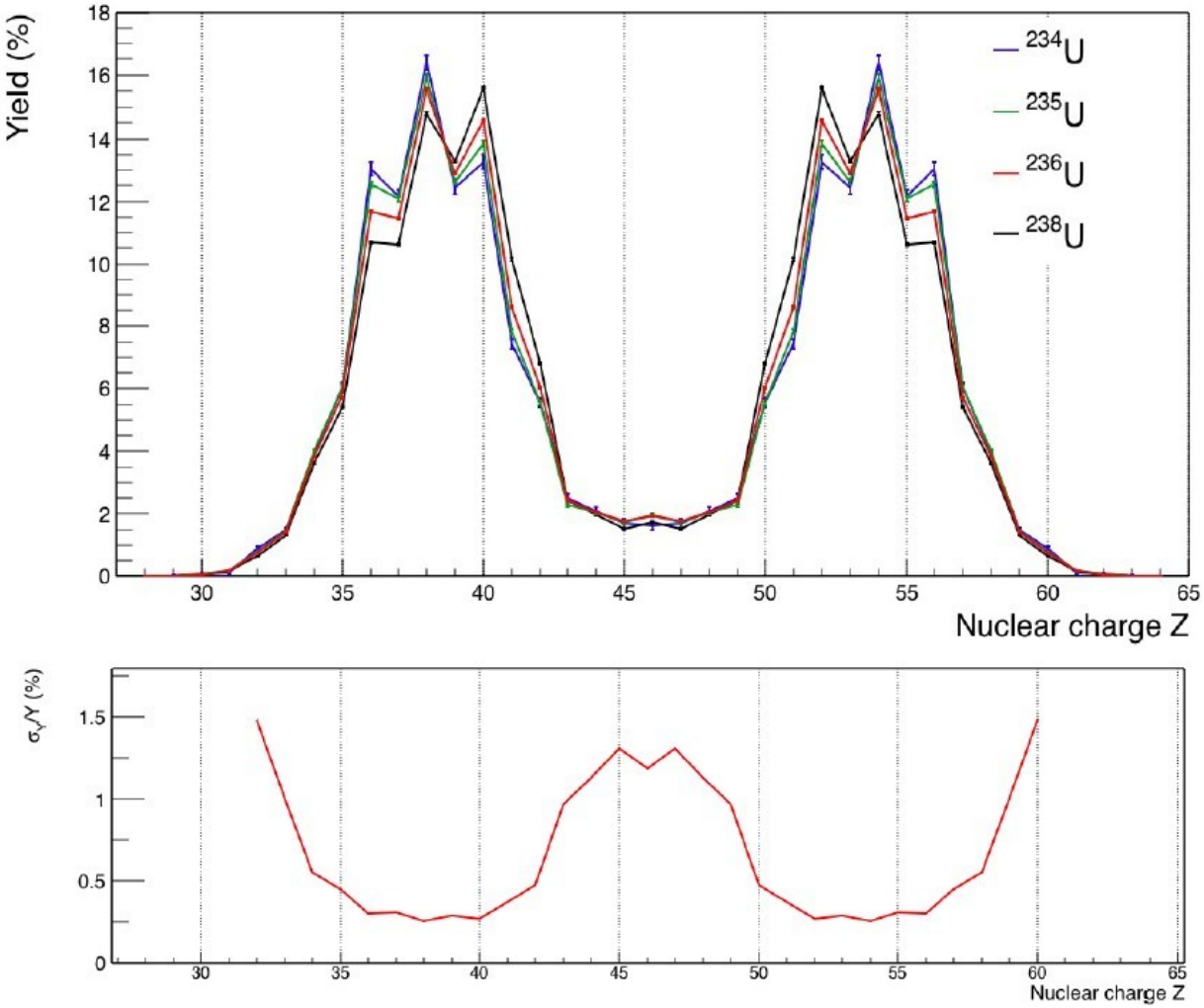
Preliminary results from the 2014 experiment

- Preliminary results on Z yields
- High statistics on ^{236}U fission : $\sigma_Y/Y < 0,5\%$ at max yields, < 2% at symmetry



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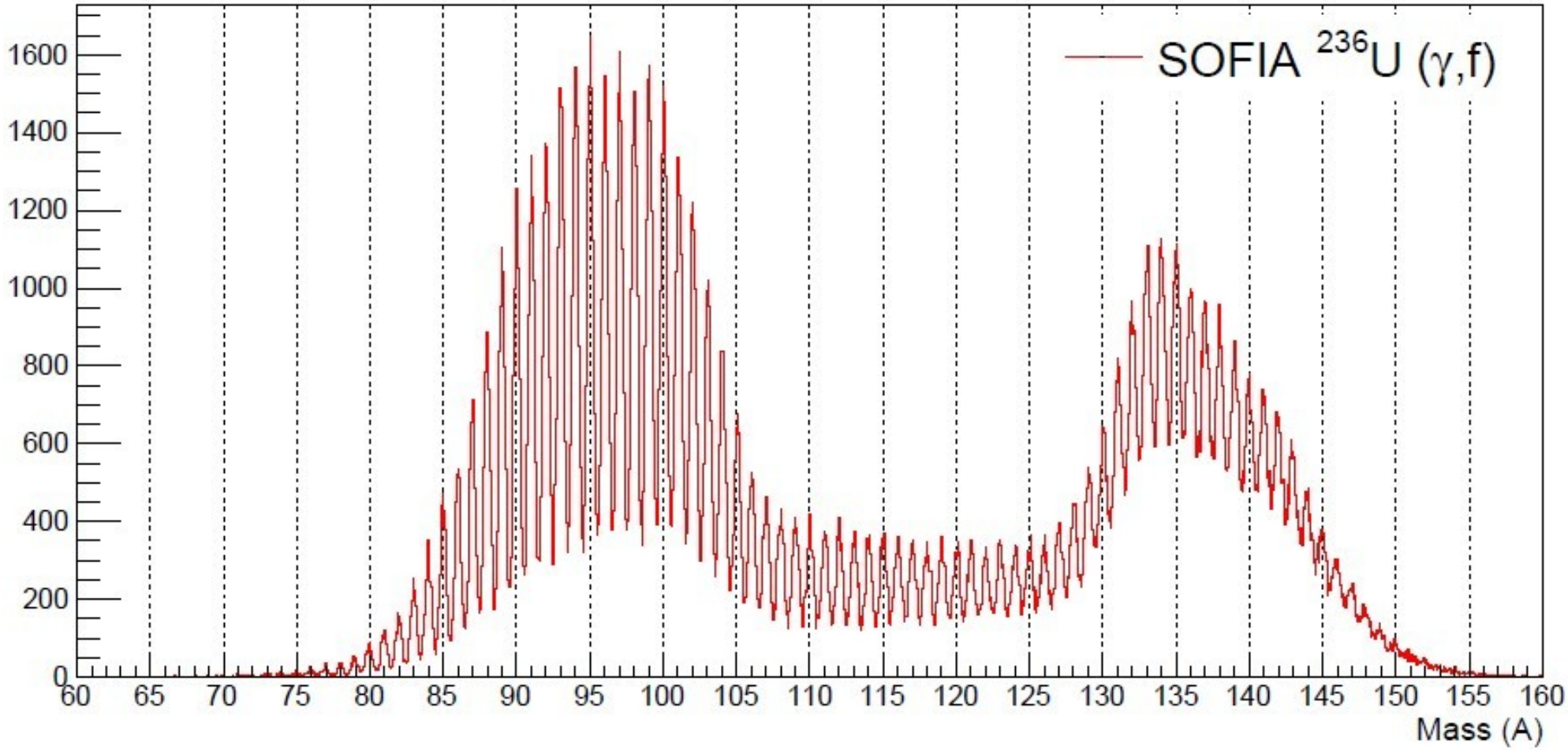
Preliminary results from the 2014 experiment

- First hints : 0,5 FWHM for light fragments, 0,8 for heavy
- Still room for improvements



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Financial support from NEEDS

- 22 k€ allocated in 2014
  - New read-out for MWPC (FEBEX system)
  - New photomultipliers (special versions, 10 MHz capable)
  - Travel expenses for the (many) tests and the (damn short) experiment

- 20 k€ allocated in 2015
  - CNRS part credited by the end of August : not spent yet !
  - Foreseen : renewal of MWPC front-end (VMM2 chips)
  - CEA : development of new preamps for the Twin-MUSIC
  - Upcoming test beam time in 2016

- Part of the upcoming nuclear data project NACRE

Outlook and perspectives

- Two SOFIA runs (2012 and 2014) to measure isotopic yields in low energy fission
  - ► High statistics data on ^{235,236,238}U
  - ► Nuclear charge resolution of 0,35 charge unit FWHM over the whole range
  - ► Mass resolution of 0,6 mass unit FWHM (light group)
  - ► Ongoing analysis of ^{236}U(γ,f)
  - ► More than 2.10^{6} fission events → high precision on nuclear charge yields : < 0.5 % at maximum yield

- The new R^{3}B setup offers further opportunities when FAIR will start (2018?)
  - ► Coupling of SOFIA with neuLAND (neutron wall) for neutron tagging
  - ► Coupling of SOFIA with CALIFA for prompt gamma calorimetry

- Development of a ^{242}Pu beam ?
  - ► Access to fission of ^{240}Pu*, ^{239}U* ...
  - ► Overlap with GANIL transfer measurements
  - ► Important cost due to decontamination requirement : political support required