The fission fragment TOF spectrometer VERDI

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Delayed Neutron Data

- ✓ The subgroup Delayed Neutron Data of the Working Party on International Nuclear Data Evaluation Co-operation (WPEC) of the Nuclear Energy Agency (NEA-OECD) ⇒ reduce the uncertainties in the delayed neutron data for the major actinides, ^{235}U, ^{238}U and ^{239}Pu.

Generation IV reactors

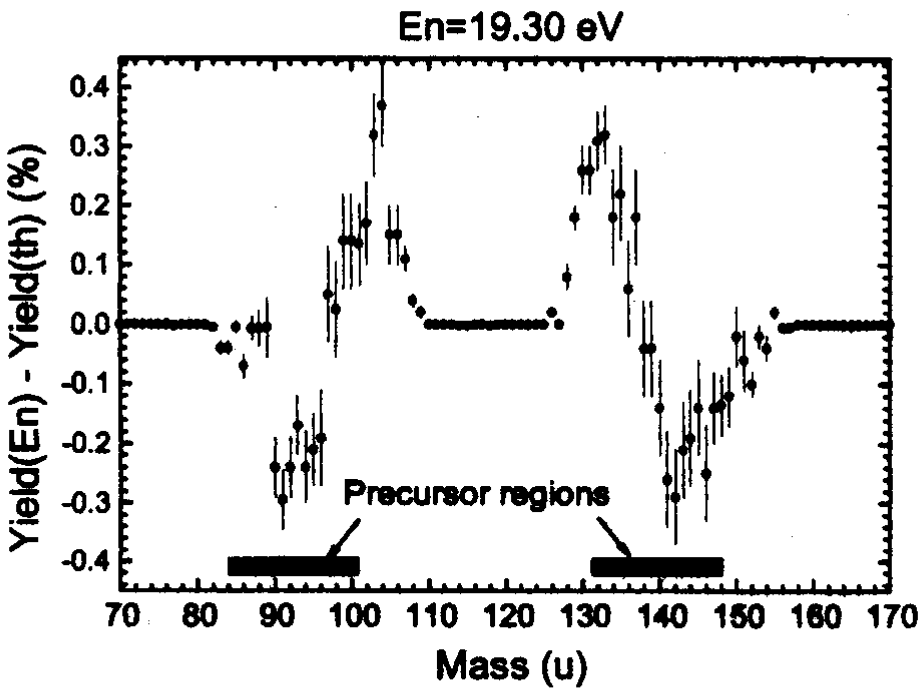
- ✓ improve nuclear safety
- ✓ improve proliferation resistance
- ✓ minimize waste and natural resource utilization
- ✓ decrease the economic cost

- ✓ delayed neutrons are responsible for the ability to control the nuclear chain reaction in a reactor
- ✓ current calculation-to-experiment discrepancies result in undesirable conservatism in design and operation of reactor control systems.

Nuclide	E_n	$\nu_{d,\,calc}$	$\nu_{d,\,exp}$	$\nu_{d,\,calc} / \nu_{d,\,exp}$
^{233}U	thermal	0.88	0.66	1.32
^{233}U	fast	0.95	0.73	1.31
^{233}U	14 MeV	0.34	0.42	0.82
^{235}U	thermal	1.71	1.65	1.04
^{235}U	fast	1.91	1.71	1.12
^{235}U	14 MeV	0.79	0.93	0.85
^{238}U	fast	4.27	4.51	0.95
^{238}U	14 MeV	2.39	2.73	0.88
^{239}Pu	thermal	0.61	0.62	0.99
^{239}Pu	fast	0.69	0.66	1.05
^{241}Pu	thermal	1.34	1.56	0.86
^{241}Pu	fast	1.45	1.63	0.89
^{252}Cf	SF	0.74	0.86	0.86

The measurement of mass- and energy-distributions of fission fragments with high resolution prior to and after prompt-neutron emission is indispensable!

The Delayed Neutron Yield has a variation of up to 3.5 %



Fragment yield differences as a function of mass (after Hambsch et al.)

VElocity foR Direct particle Identification

- ✓ **Two-arm time-of-flight sections to measure the velocity of each individual fission fragment (FF) ⇒ pre neutron-emission masses**
- ✓ **Subsequent measurement of the FF kinetic energy ⇒ post neutron-emission masses**

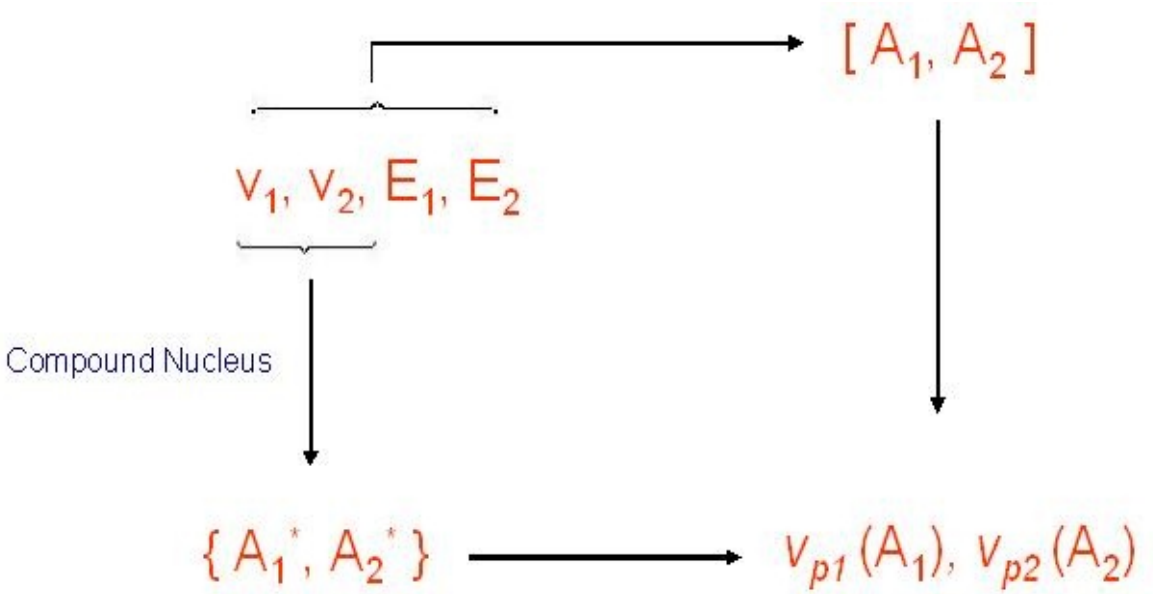
$$E \sim A\,v^2 \Rightarrow A \sim E\,t^2/l^2$$

⇓

unambiguous identification of the particle mass

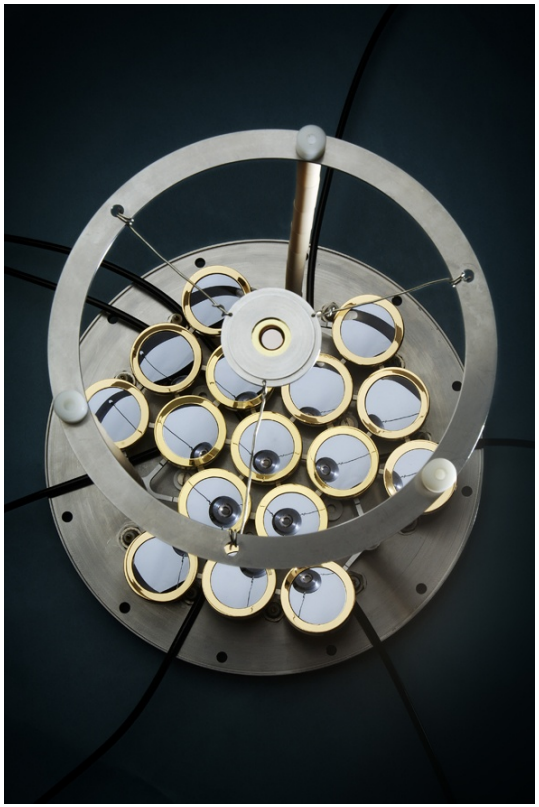
⇓

precise fission-fragment decay studies

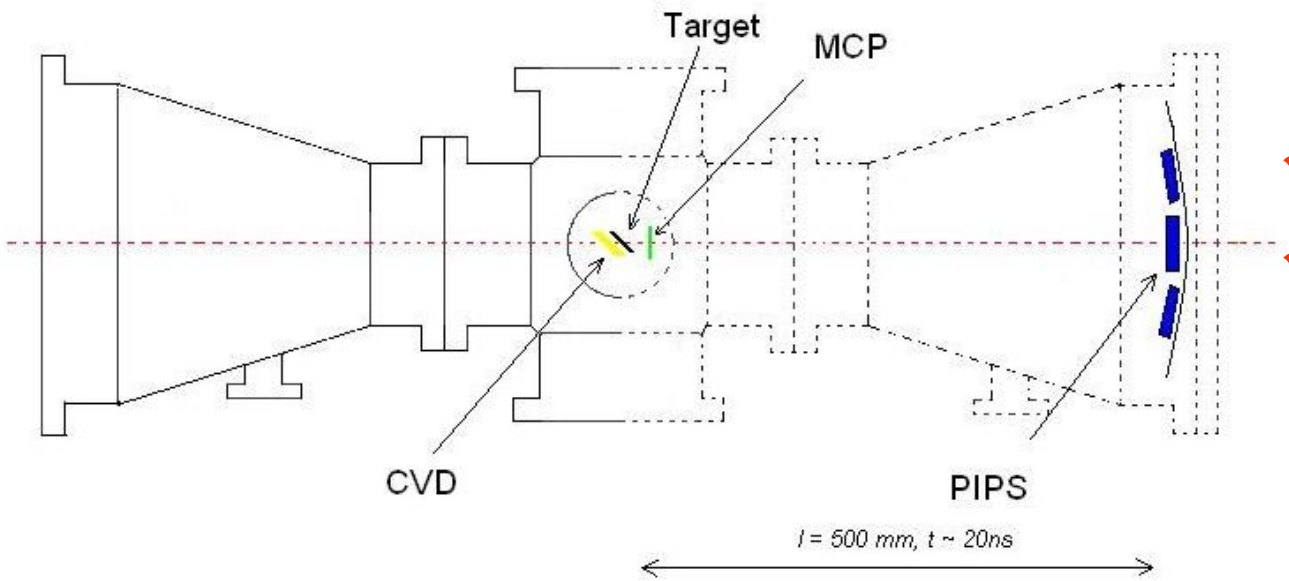


VERDI objectives

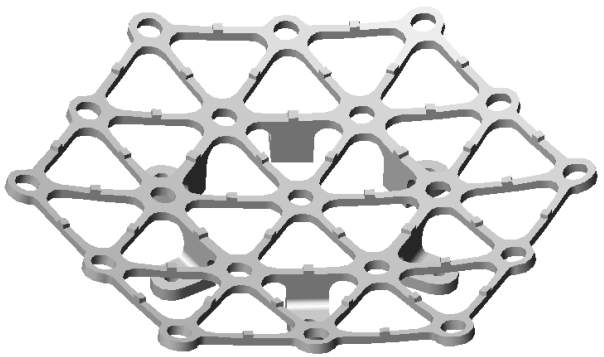
- ✓ Mass resolved post-neutron fission fragment yields;
- ✓ Mass resolved pre-neutron fission fragment yields;
- ✓ Precise delayed-neutron pre-cursor yield-distribution;
- ✓ Prompt neutron multiplicity → as a function of the fragment initial mass and kinetic energy, i.e. of the total excitation energy.

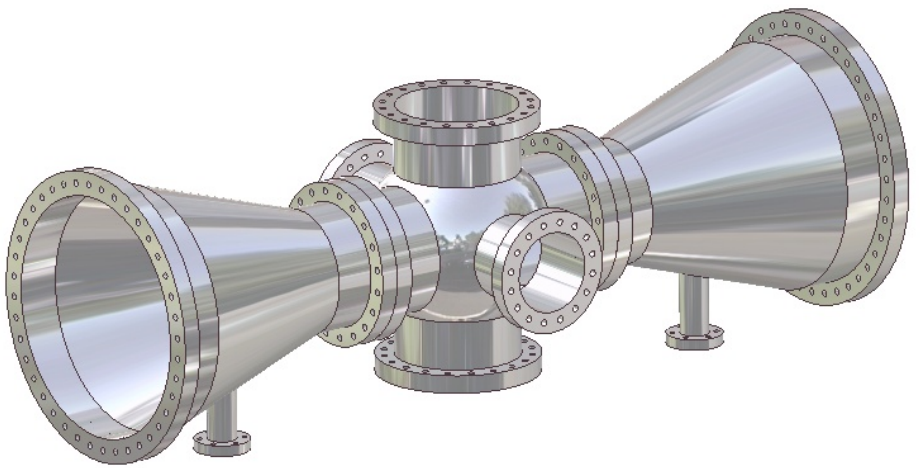


The fission fragment TOF spectrometer **VERDI**



- ✓ **2 x 19 PIPS detectors**
- ✓ **CVD and MCP ultra-fast start-timing detectors**





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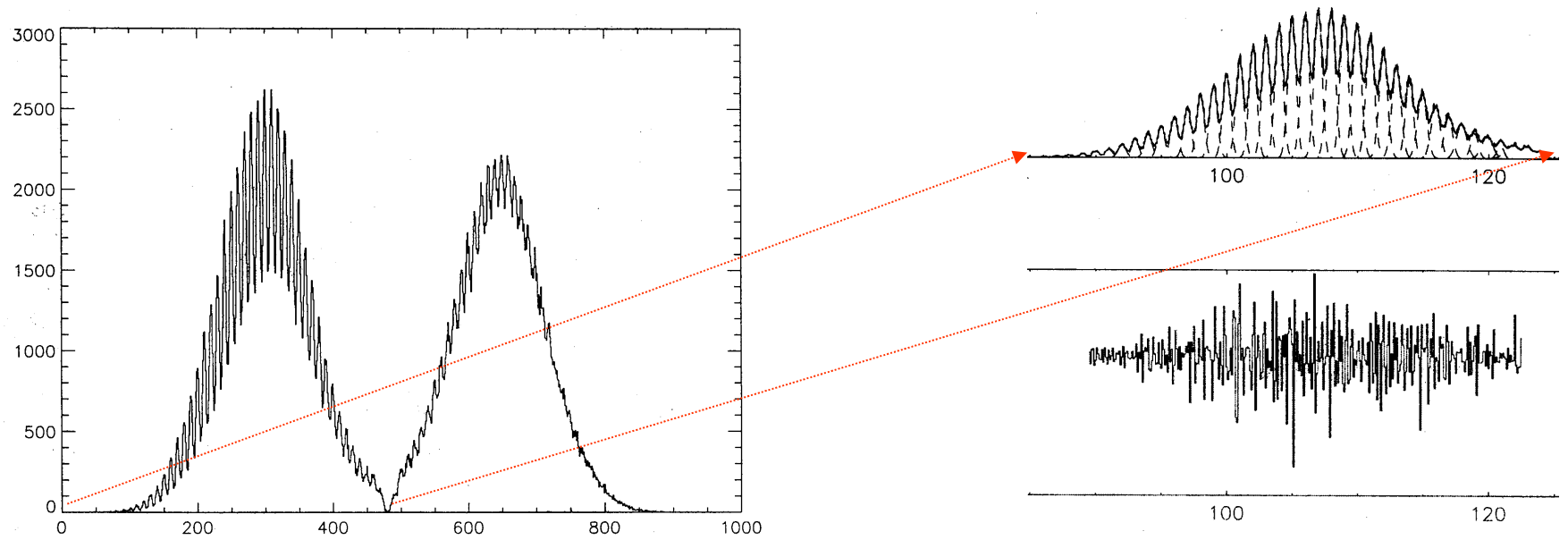


fragment mass (arbit. units)

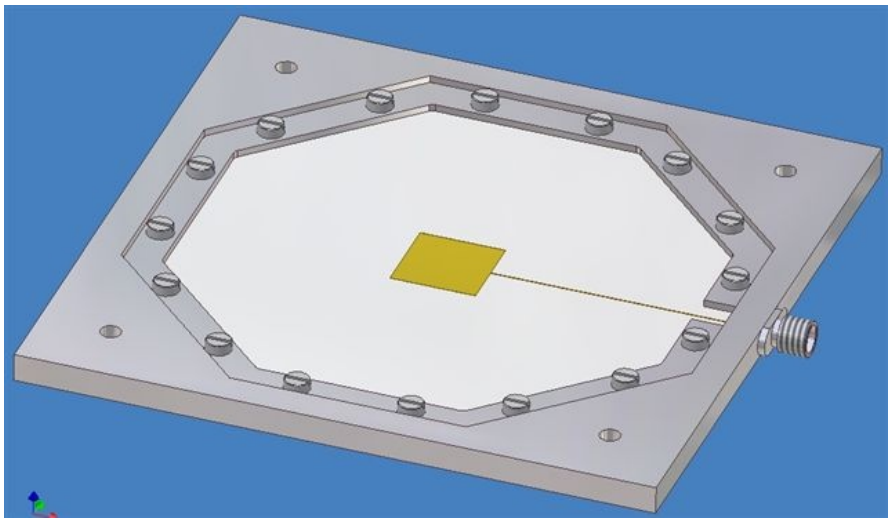
fragment mass (amu)

- ✓ **Set-up of the time-of-flight tube with an energy-sensitive detector device**
  - energy resolution : $\Delta E/E = 0.005$ for fission fragment kinetic energies
  - timing resolution : $\Delta t = 50ps$
- ⇒ **fragment mass resolution : $A/\Delta A > 130$**

For the successful construction of the high mass-resolving fission-fragment telescope very fast timing detectors are needed.

⇓

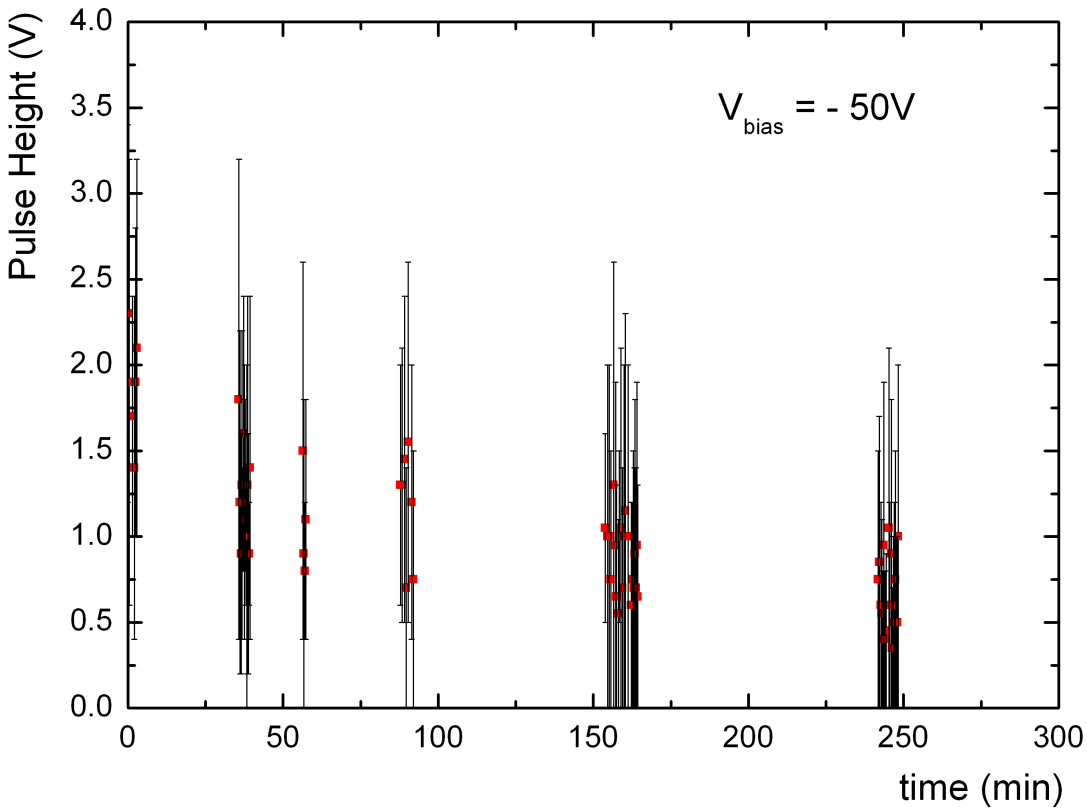
The CVD diamond detector seems to match best the technical requirements defined within the VERDI design.



The polycrystalline CVD diamond detector specifications:

- **10 x 10 mm active area;**
- **100 µm thick**

Evolution of the pulse height and count rate at different bias voltages



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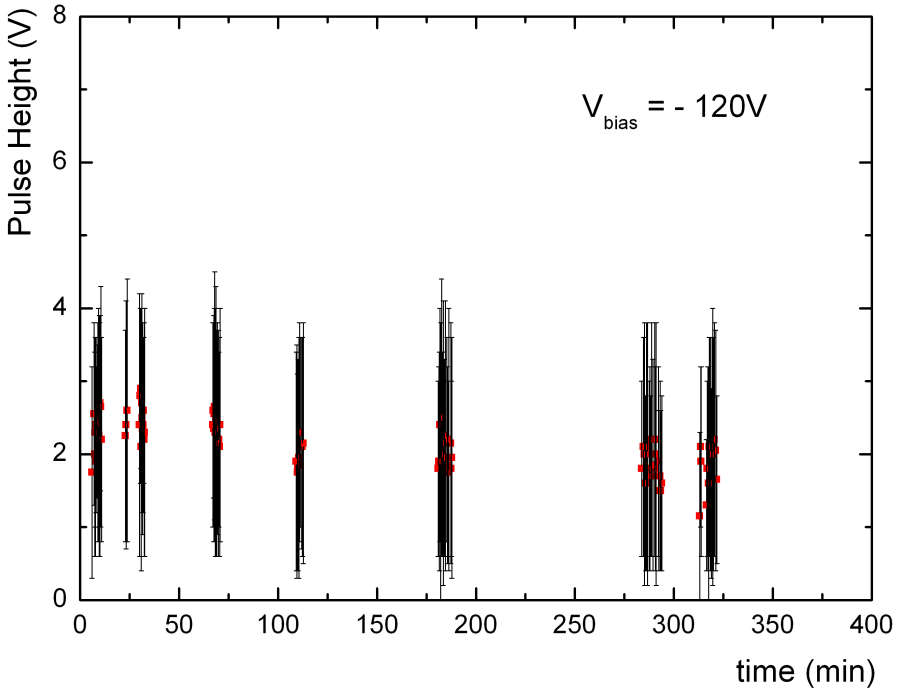

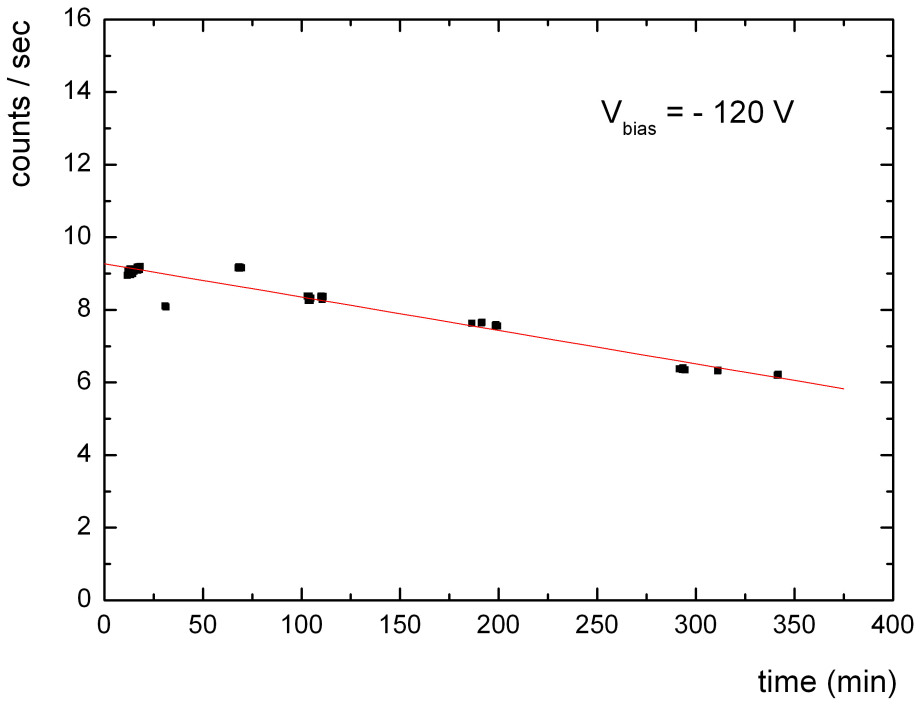

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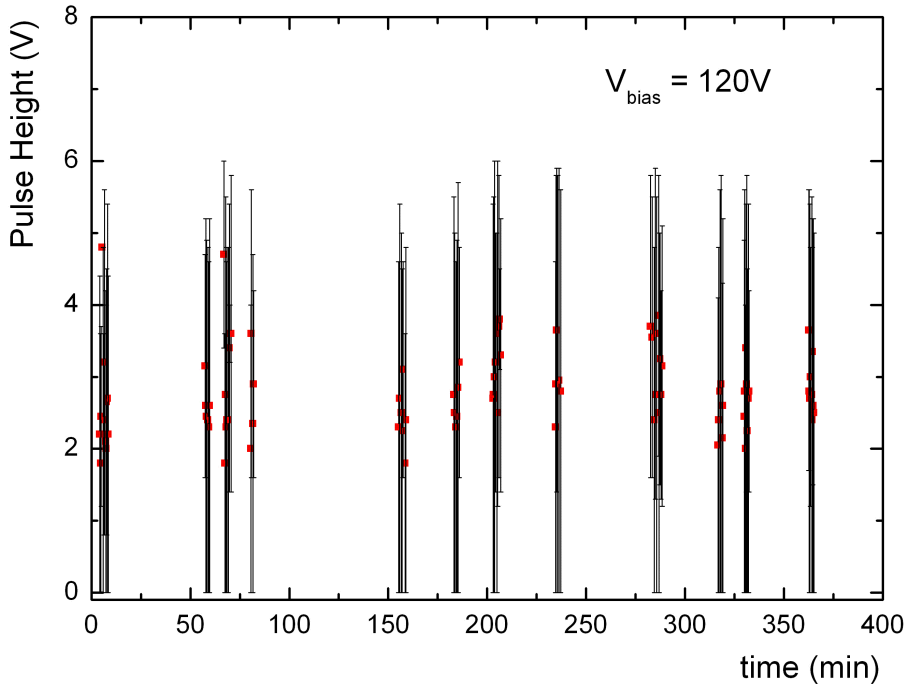

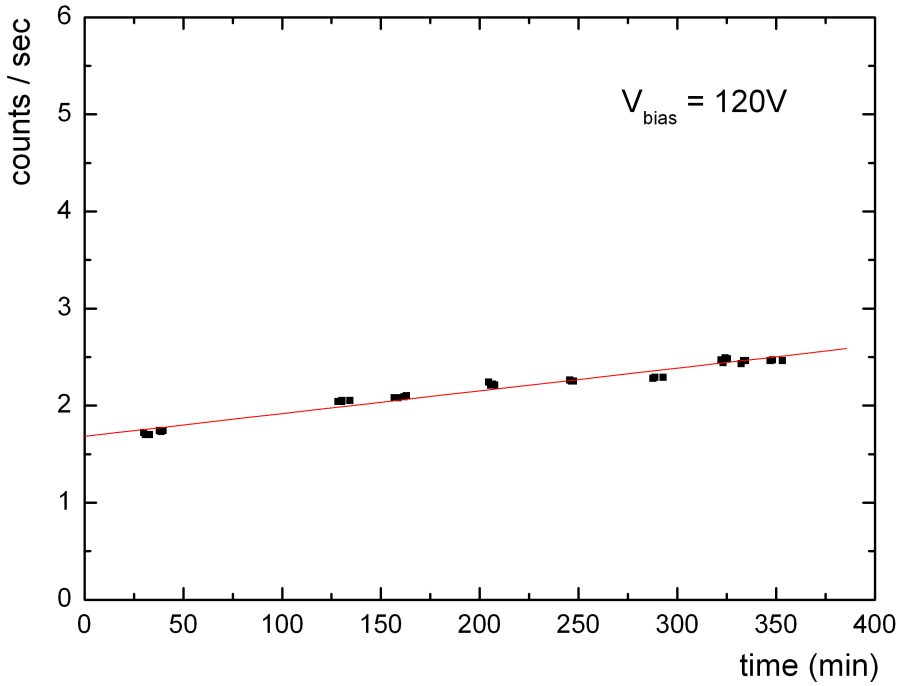

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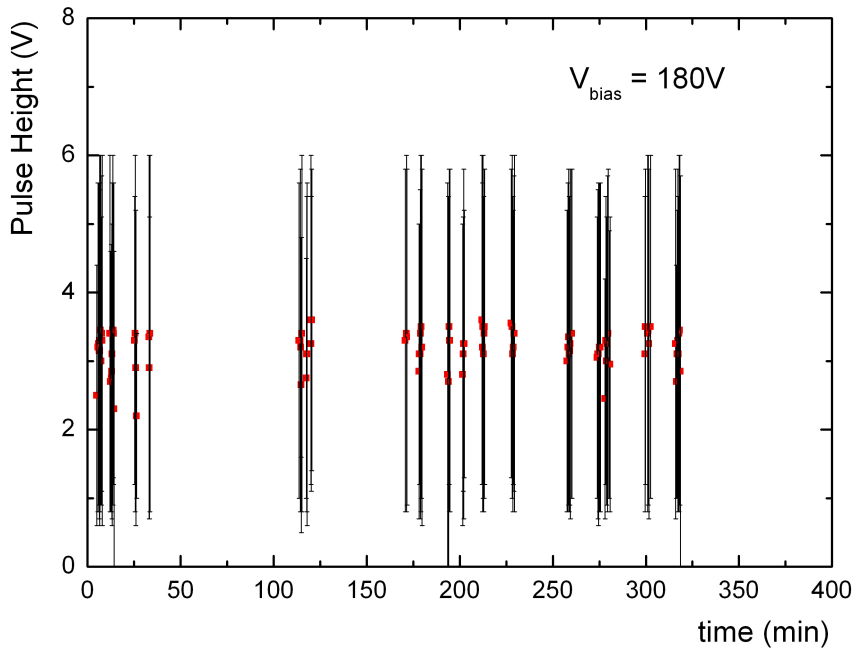
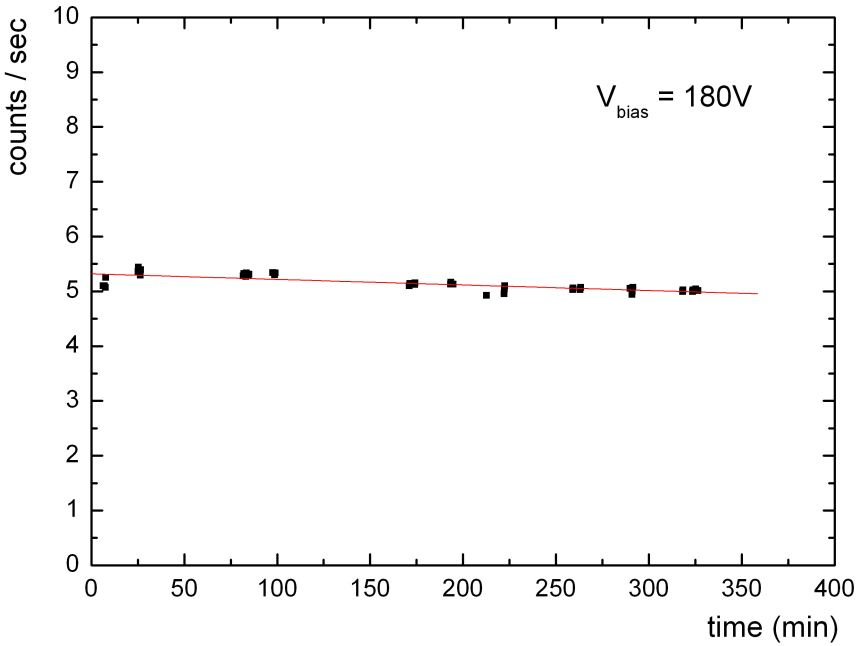
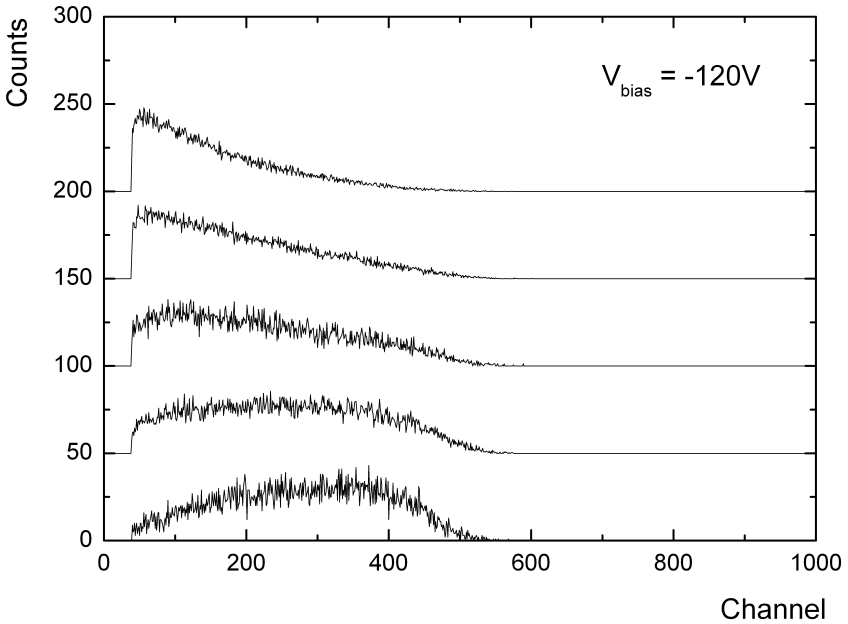
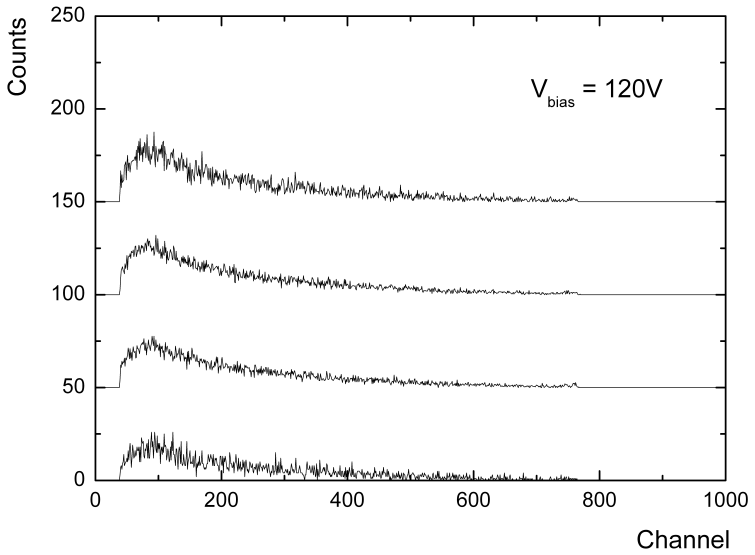
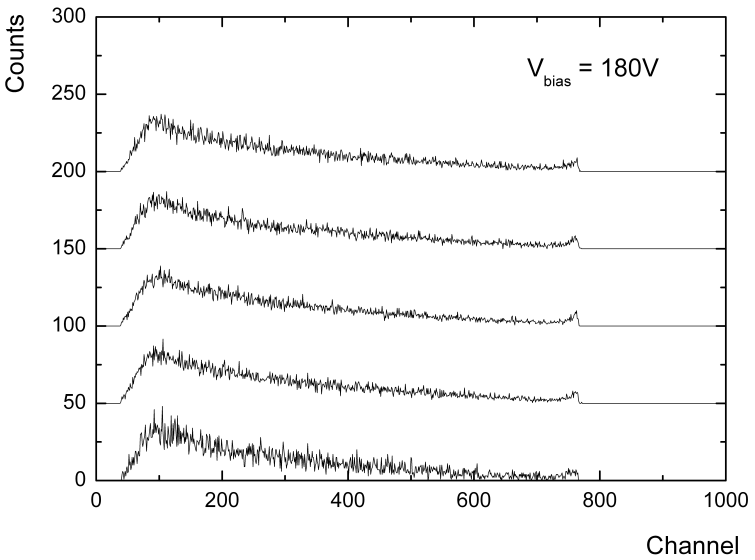




Evolution of the detection spectrum





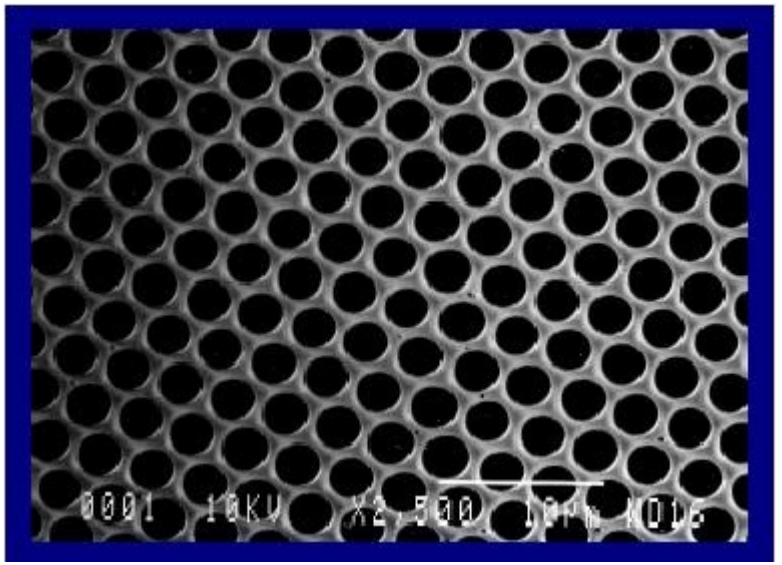


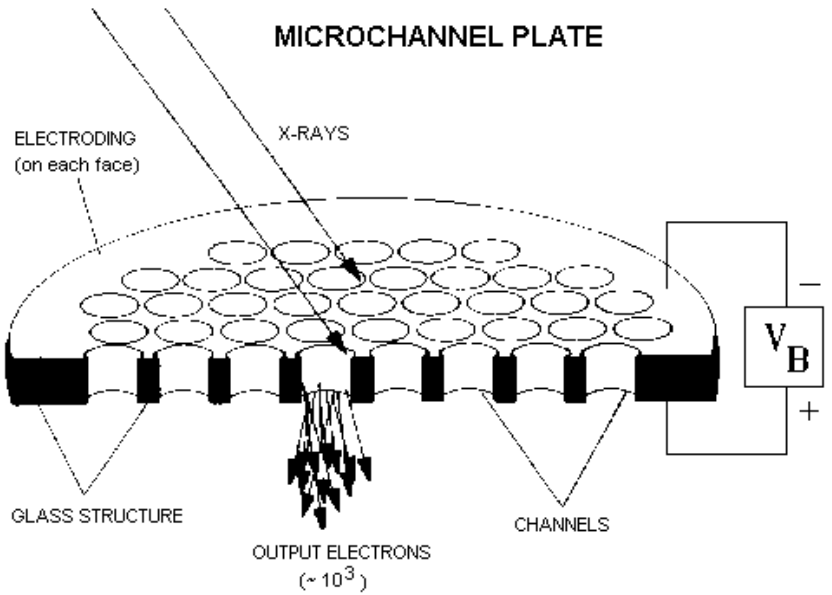
Conclusions and Outlook

- **The tested CVD detectors *do not fulfill* all technical requirements (stability, reproductibility);**
- **Implementation and test of a MCP (Microchannel Plate) detector;**
- **Optimization of the timing and energy resolution of the particle detectors.**

Microchannel Plate Detector

- a compact detector and event amplifier of energetic photons and charged particles;
- consists of about 10,000,000 closely packed channels with the diameter of each channel approx. 10 microns;

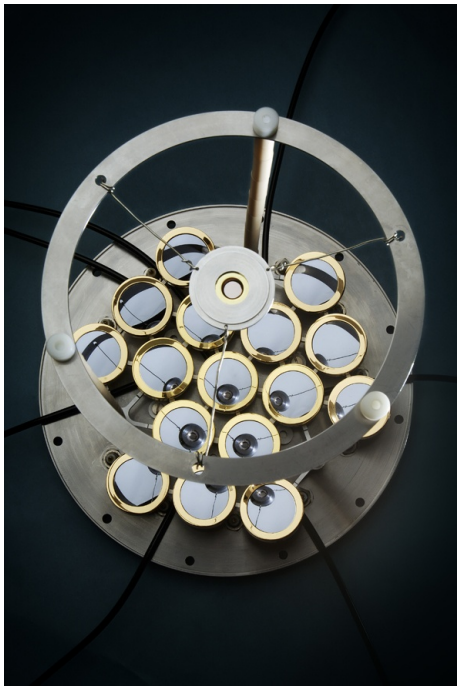




- enable single hit counting with durations in the nanosecond range, and they are unique to detect heavy ions in the keV range.

Objectives

- ✓ **Measurement of post-neutron fission-fragment distributions using a suitable spontaneous fission source;**
- ✓ **Determination of the mass-resolving power of the spectrometer;**
- ✓ **Determination of the detector efficiency;**
- ✓ **Extension of the Si-cluster to 19 detectors;**
- ✓ **Extension to a two-arm spectrometer in order to obtain pre- and post neutron fission fragment data at the same time**



this will allow for the first time a mass- and kinetic energy-resolved measurement of prompt neutron multiplicities