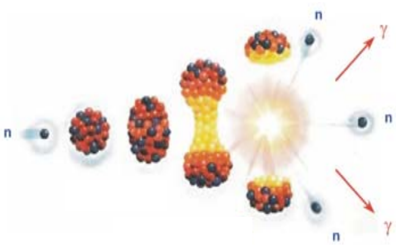


VERDI – a double (v, E) fission-fragment spectrometer

S. Oberstedt, R. Borcea, Th. Gamboni, W. Geerts, F.-J. Hambsch, A. Oberstedt[1)], M. Vidali

[1] School of Science and Technology, Örebro University, S-70182 Örebro

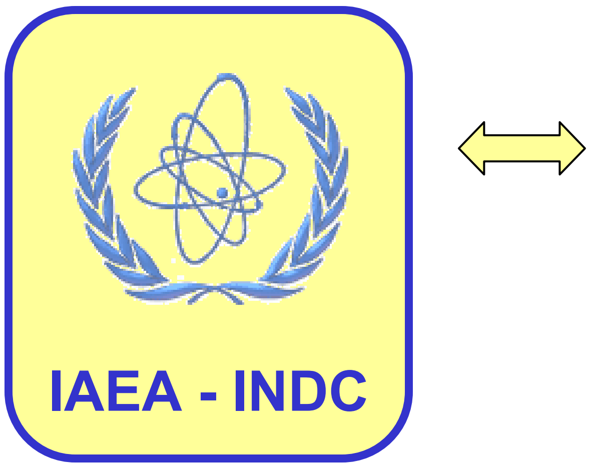
IRMM - Institute for Reference Materials and Measurements

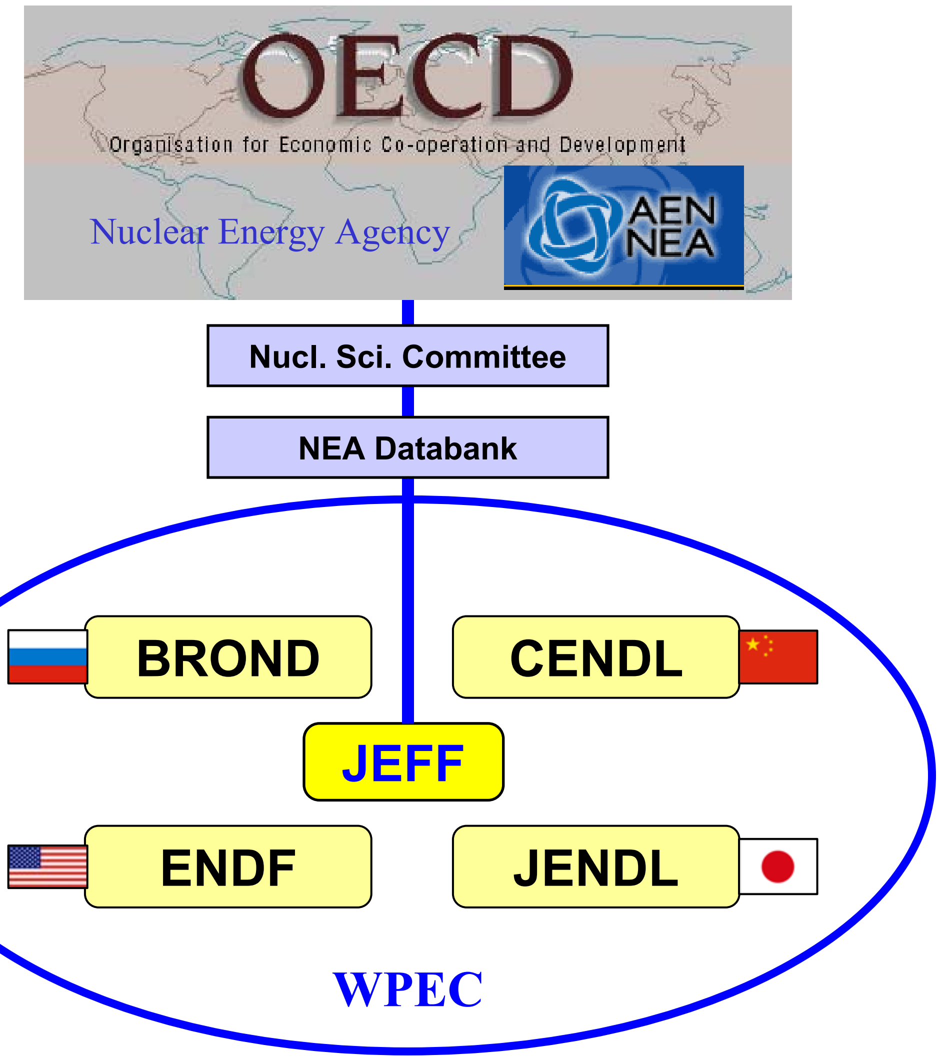
Geel - Belgium

http://irmm.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

- **Motivation**
- **Concept of the TOF spectrometer VERDI**
- **The VERDI “energy side”**
- **The VERDI “timing side”**
- **First experimental results**
- **Summary & Outlook**

Motivation





WPEC:
Working Party for
Evaluation Co-operation

JEFF:
Joint European
Fission + Fusion datafile

Motivation

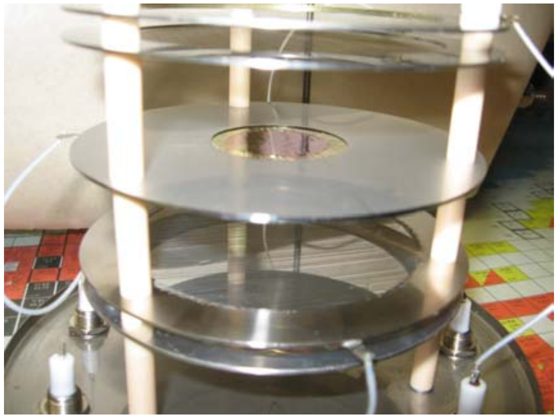
✓ **Reliable predictions on fission product yields relevant in modern nuclear applications (GEN-IV, ADS…)**

- Radio-toxicity of the nuclear waste
- Decay heat calculations
- Delayed neutron yields relevant during reactor operation

- **Prediction of fission-fragment mass and kinetic energy distributions**
- **Emission spectrum and multiplicity (as a function of fragment mass) of prompt γ-rays and neutrons**
- **Delayed neutron emission pre-cursor yields**

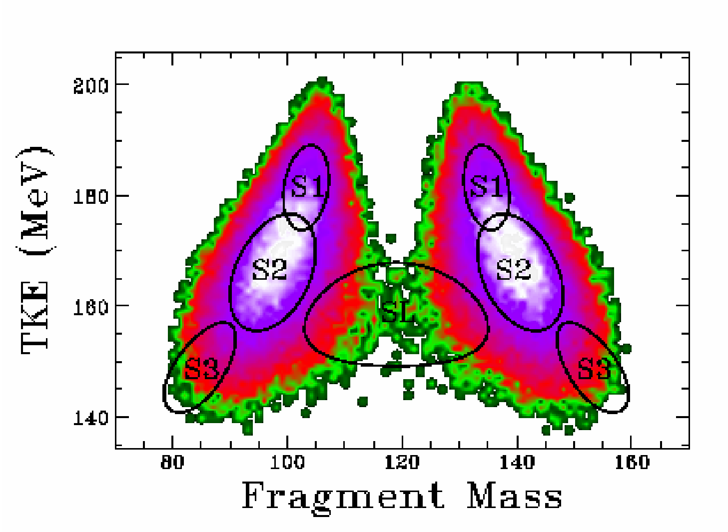
Fission-fragment characteristics

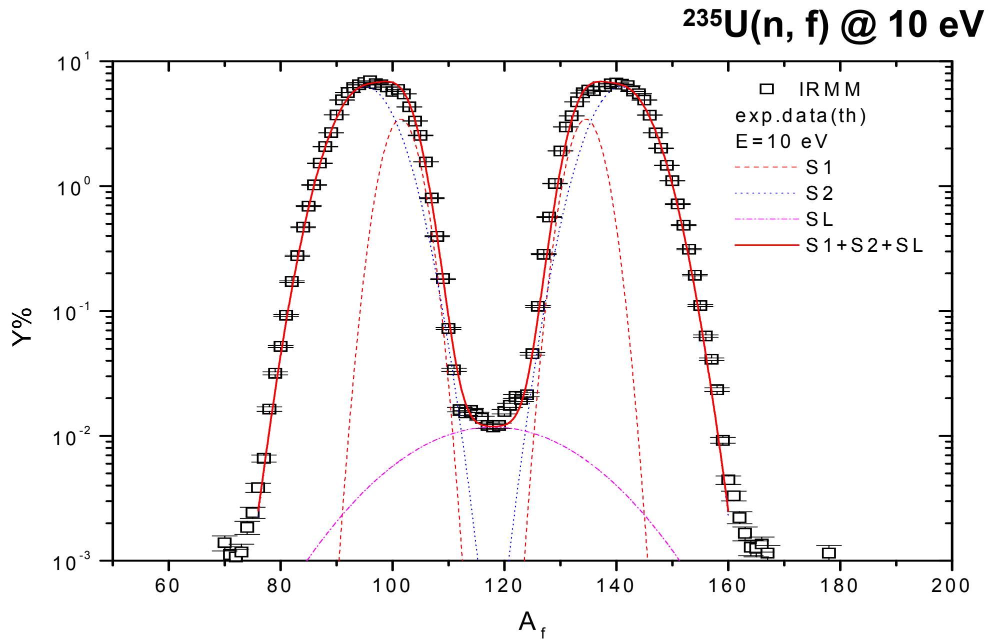
- **2E measurement with a twin Frisch-grid ionisation chamber:**

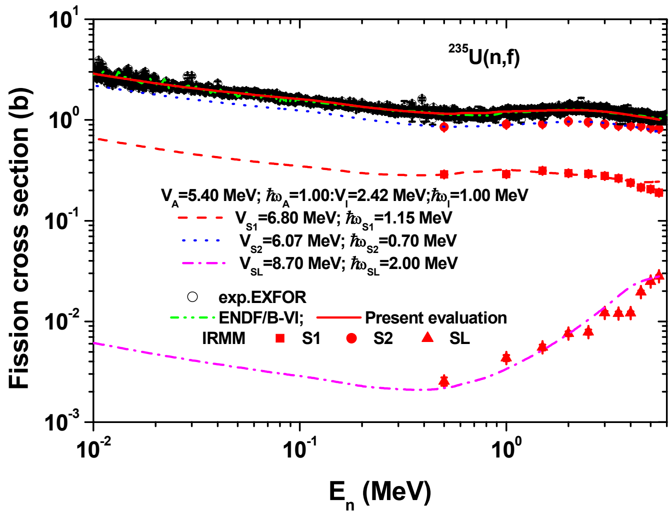


  - **Pre-neutron fragment masses and total kinetic energy iteratively determined**
  - **Using "known" prompt neutron emission data (multiplicity, TXE dependence)**
  - 😐 **Experimental neutron data only for a few isotopes**
  - 😐 **Mass resolution usually worse than 4 amu**

Fission-fragment characteristics



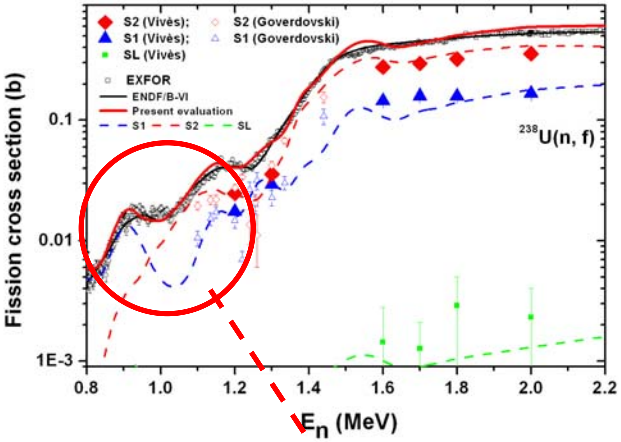


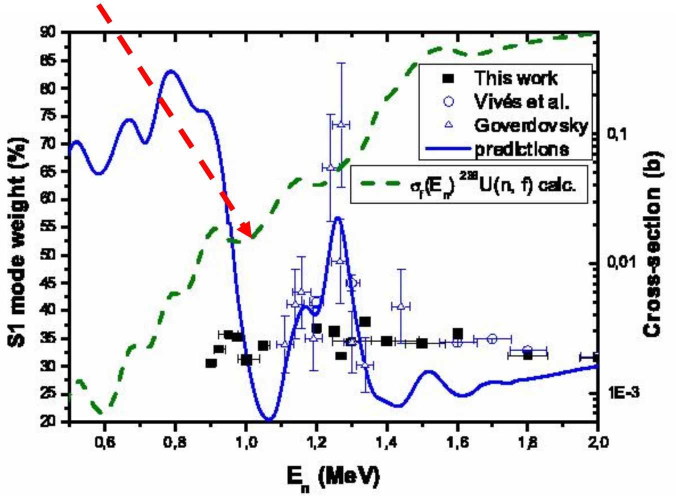


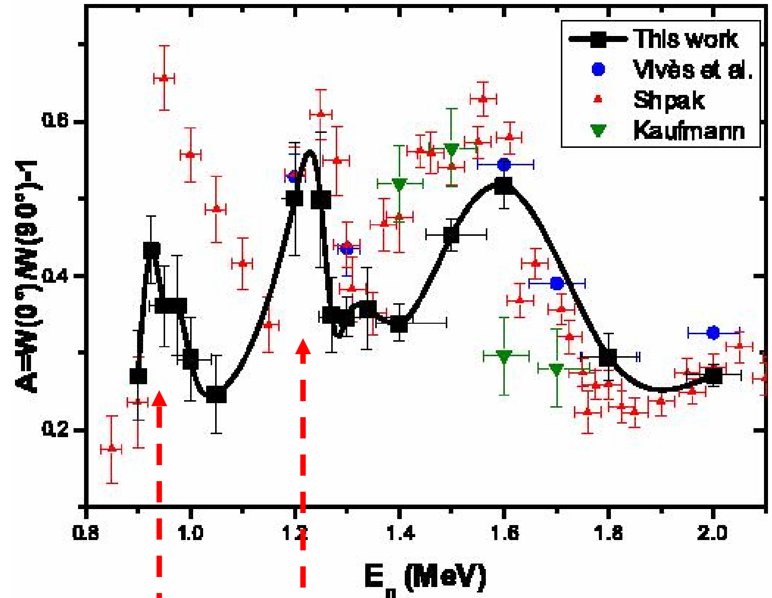
Are quantitative predictions of fission fragment yields possible ?

Fission-fragment characteristics

- ^{238}U (n, f) @ E_n = 0.9 – 2 MeV







E* ≈ 5.8 MeV

E* ≈ 6.1 MeV

E. Birgersson et al., Nucl. Phys. A817 (2009) 1-34

- **Has it to do with the 2E-technique?**

- **Is prompt neutron (ν_p) emission well under control?**

  - ☹ Uncertainty due to iterative neutron correction in a 2E-experiment
  - ❖ ...

  - ☹ Is the dependence of ν_p on excitation energy incorrectly treated?
  - ☹ Extra/interpolation of prompt neutron data from neighbouring nuclei not correct?

  - ☹ microscopic neutron emission data do not fit to results from integral experiments (even for ^{235}U !!!)
  - ☹ although average emission energy (ε_ν) differs by only 50 keV

- **Is the multi-modal fission model not correct?**

VERDI – the concept

✓ **Simultaneous measurement of kinetic energy and velocity of both fission fragments ♥**

- 2v → pre-neutron masses, A_i* (i = l, h), TKE
- v,E → post-neutron masses, A_i, $E_{k,i}$ (i = l, h)

➢ **$\nu_i(A_i^*)$ from the difference A_i^* - A_i → TXE(A_i)**

➢ **delayed decay modes of fission fragments**

♥ **Cosi Fan Tutte (ILL)**

VERDI – basic ingredients

Goals:

- spectrometer efficiency $\varepsilon \approx 0.005 - 0.01$♥
- for a mass resolution of $A/\Delta A \geq 100$

- High resolution energy detector ($\Delta E/E = 0.006$)
- High precision (transmission) time pick-up with $\tau < 150$ ps @ L = 50cm

- radiation hardness of the time pick-up

♥ Cosi Fan Tutte ($\varepsilon \approx 5\times10^{-5}$)

VERDI – the energy side

Axial ionisation chamber:

- ✓ Simple to construct and to use
- ✓ Split electrodes allow element identification (cf. LOHENGRIN)
- ✓ No radiation damage
- ✓ Very good intrinsic energy resolution
- ✓ Timing characteristics???

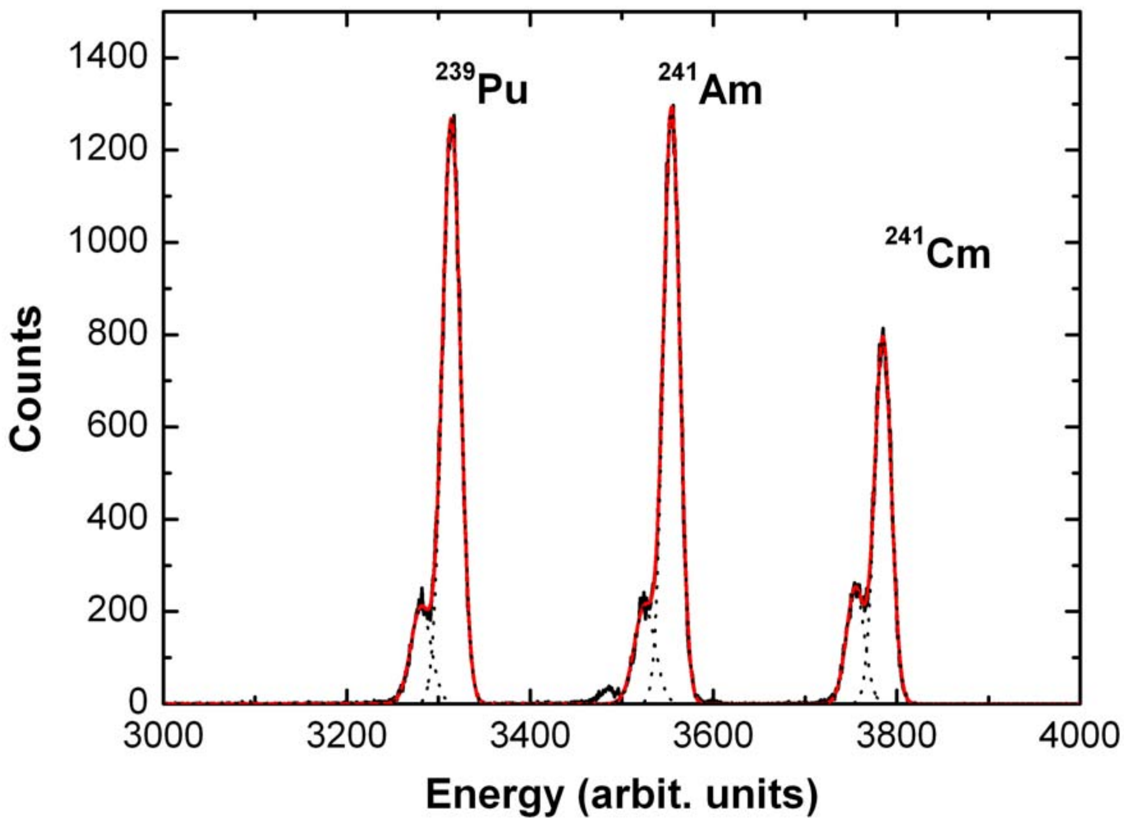
- ❖ Difficult to make a large area detector
- ❖ Energy loss in the entrance window

Large area silicon detectors:

- ✓ Relatively cheap
- ✓ Easy to use
- ✓ Excellent pulse height stability
- ✓ Excellent energy resolution
- ✓ Promising timing characteristics

- ❖ Subject to radiation damage

VERDI – the energy side



PIPS (area: 900 mm^2)

^{239}Pu, ^{241}Am, ^{244}Cm

✓ Energy resolution for α-particle kinetic energy:

δE = 0.006 → close to our design specifications for fission-fragments

VERDI – the timing side

o μ-channel plate detectors:

✓ Very good intrinsic timing characteristics

❖ Difficult to handle
❖ Requires excellent vacuum p < 10^{-6} mbar
❖ Subject to radiation damage (especially in an intense neutron field)???
❖ Difficult to build

o Diamond detectors (pc/sc-CVDD):

☒ New detector material
☒ Relatively few experimental results

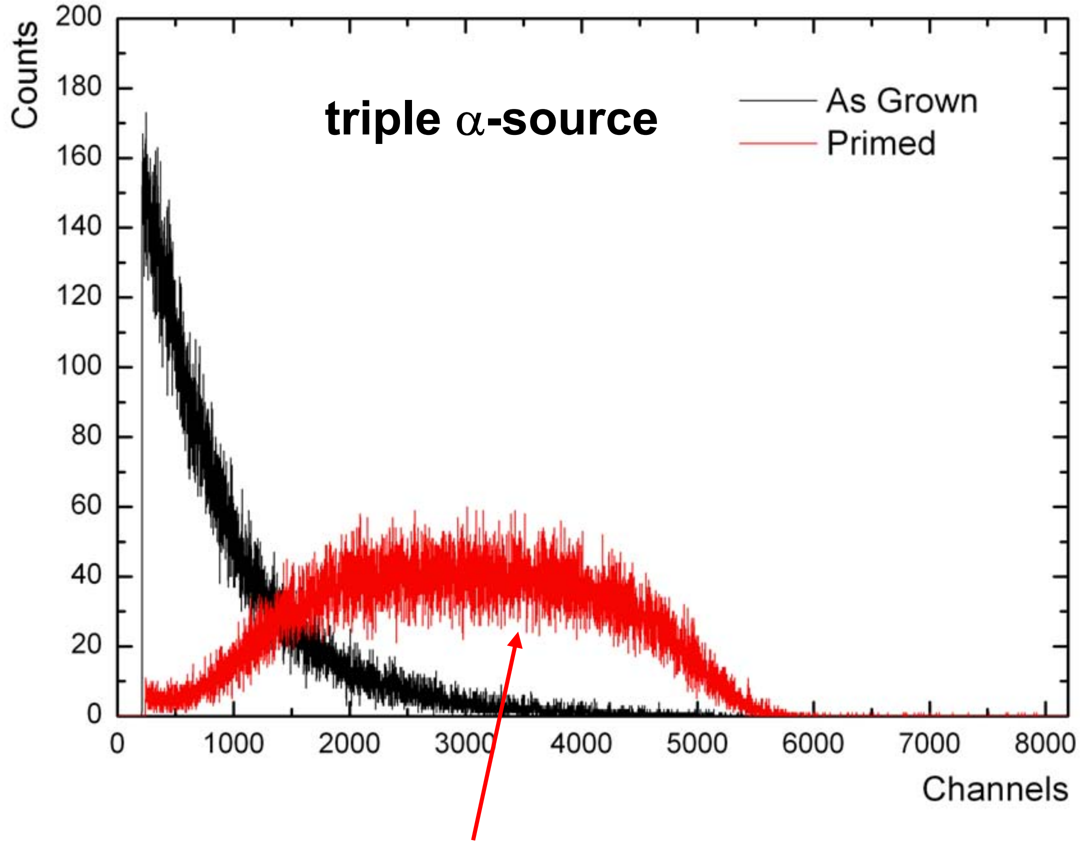
❖ Pulse height stability of pcCVDD difficult to predict and to maintain
❖ Difficult to produce (artificial) single-crystal diamonds
✓ Promising timing characteristics (with Ni-ion @ 30 MeV/u $\Delta t \approx 30$ ps)
❖ Never tested with fission fragments (0.5 MeV/u < v_{FF} < 2 MeV/u)

✓ Radiation hard

CVD diamonds

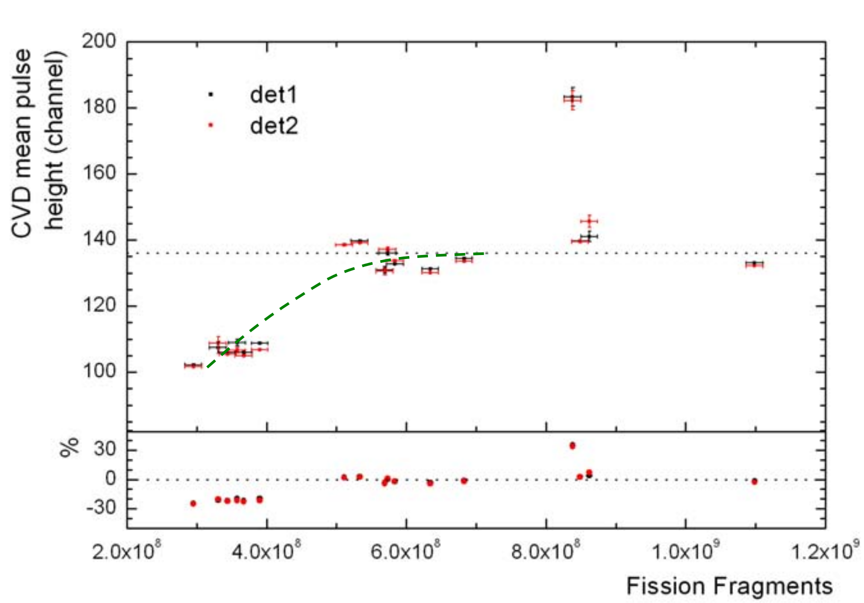
- Chemical vapour deposited (CVD) diamond
- Working principle similar to a silicon-detectors
- Poly-crystalline (pc) CVDD available
- No pulse-height resolution for pcCVDDs
- Ultra-fast timing characteristics
- Also for low-energy heavy ions?

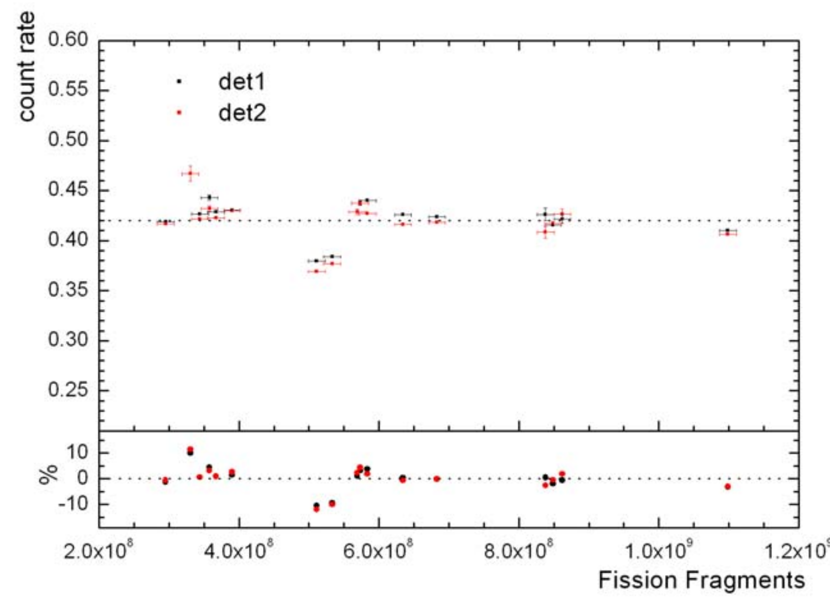
pcCVDD - material properties



irradiated with a $^{90}Sr/^{90}Y$ β-source (3MBq, 72h)

pcCVDDD – pulse-height stability

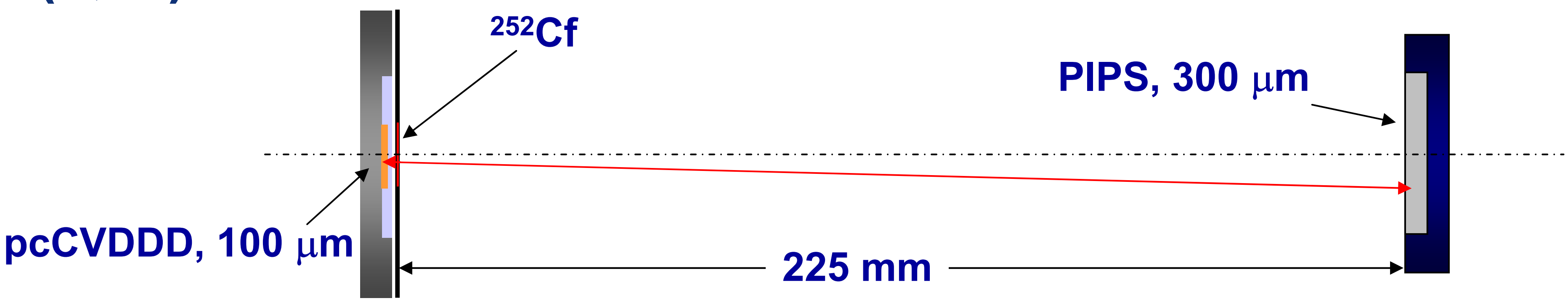


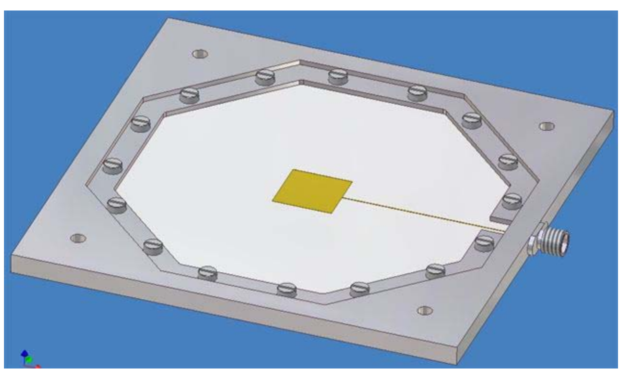


- ✓ **Pulse height stability against radiation damage up to a fission-fragment dose of at least 1.2×10^9**
- ✓ **Including an α-particle dose of 4×10^{10} and a fast neutron dose of about 5×10^{10}**

Experimental set-up

(ν, E)

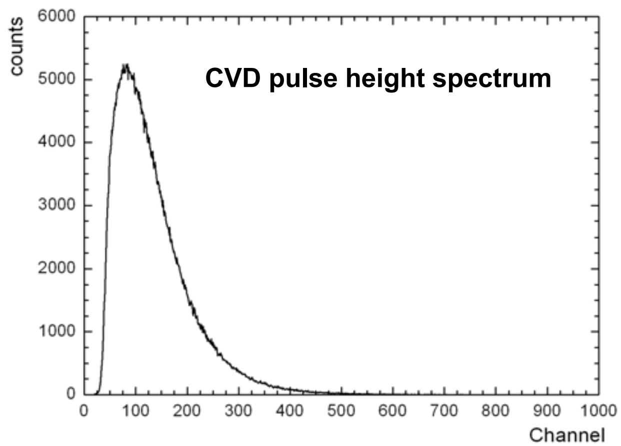


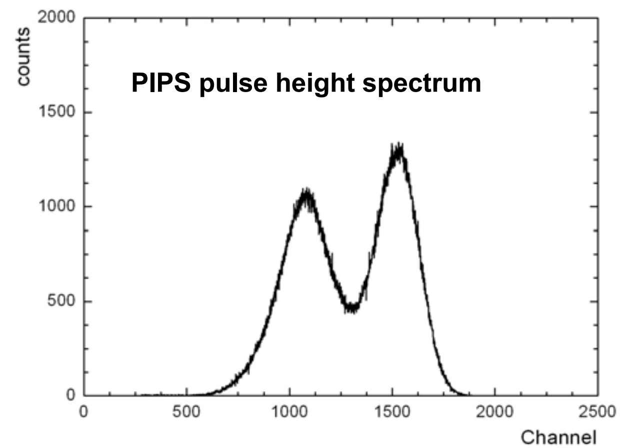


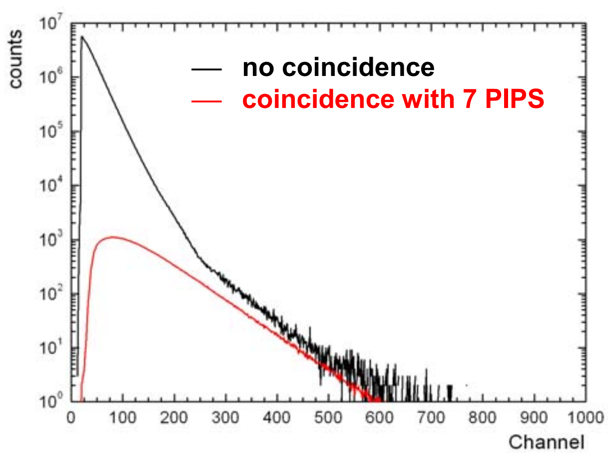
pcCVDD material

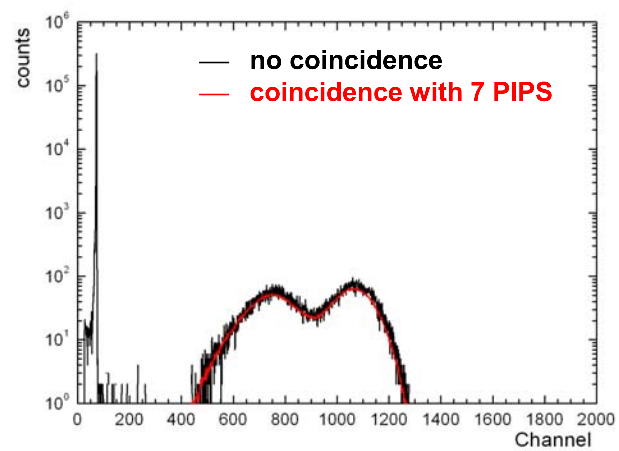
- ✓ size: 1×1 cm^2
- ✓ thickness: 100 μm

Pulse-height "analysis"

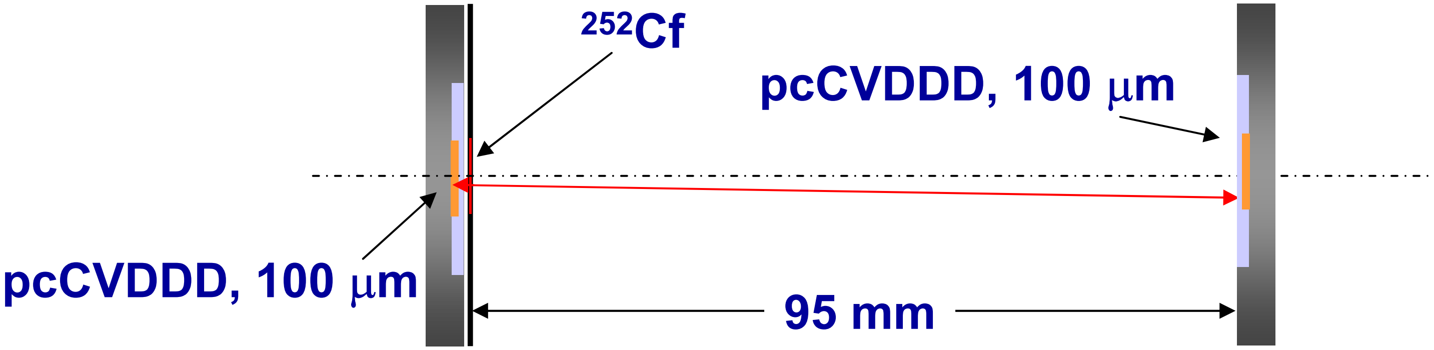


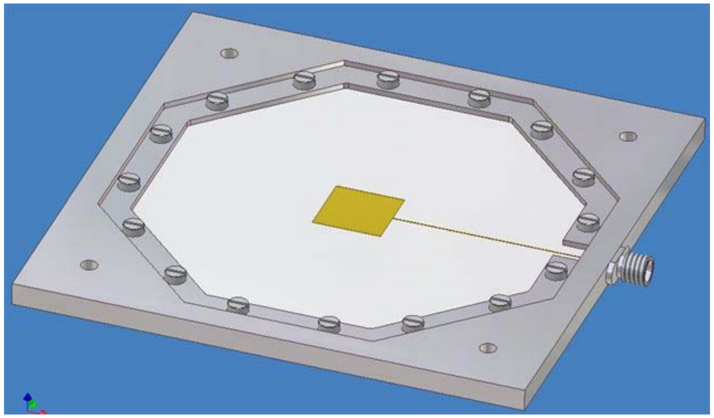






pcCVDDD - Intrinsic timing resolution





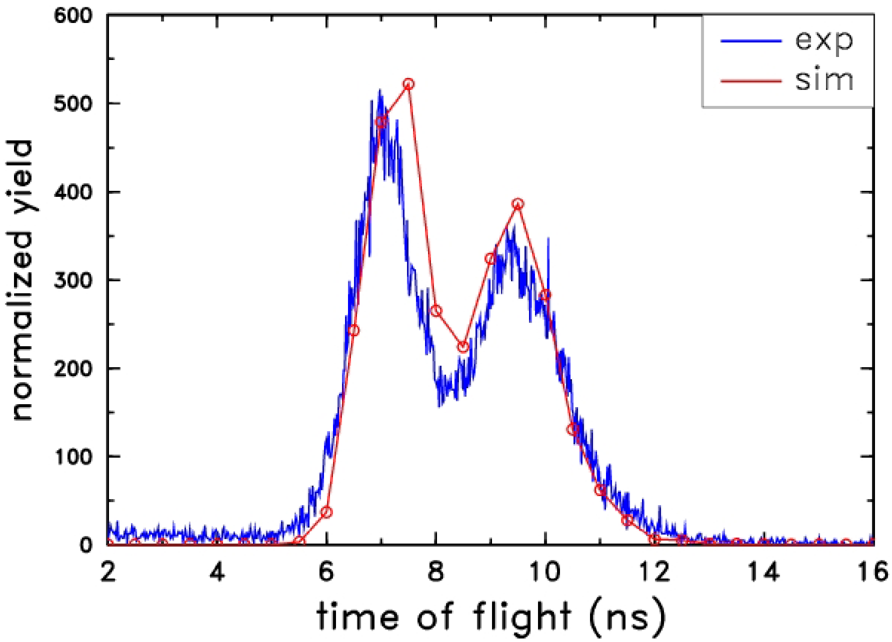
pcCVDD material

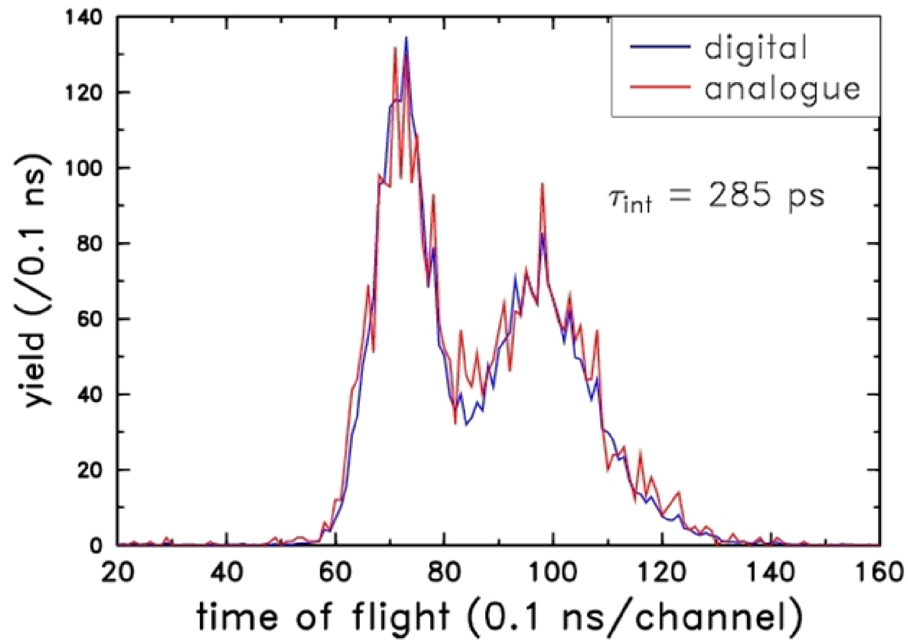
- ✓ size: 1×1 cm^2
- ✓ thickness: 100 μm

Determination of the timing resolution

- **By means of a Monte-Carlo simulation**
- **Experimental fission-fragment distribution**
  - Post-neutron fragment yield
  - Post-neutron fragment kinetic energy
- **Geometry of the detector set-up**
- **Variation of the time-resolution parameter until reproduction of the measured time distribution**

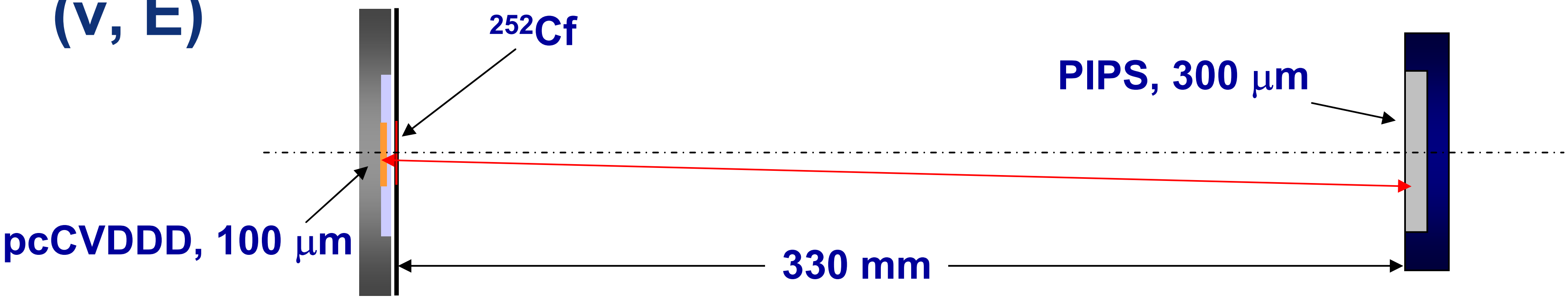
pcCVDDD - Intrinsic timing resolution





VERDI - the timing resolution

(v, E)



pcCVDD material

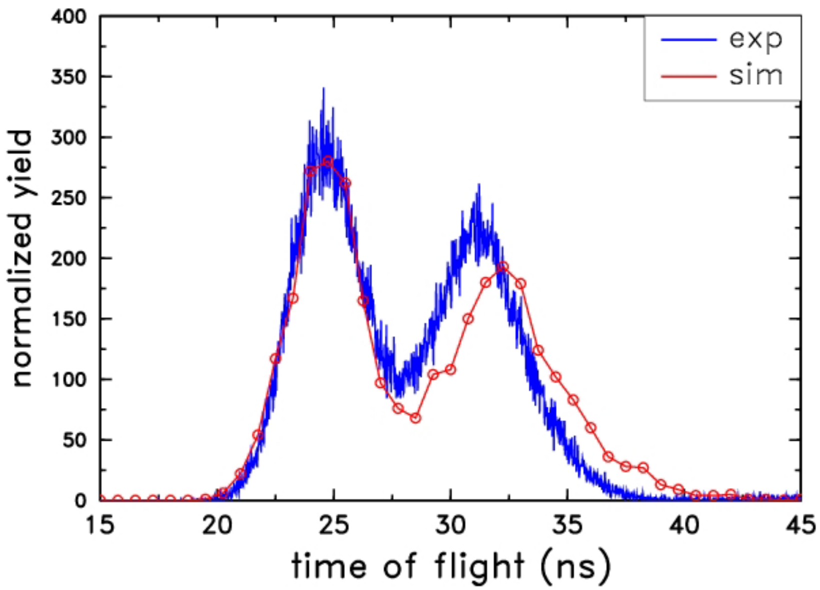
- ✓ size: 1 × 1 cm^2
- ✓ thickness: 100 μm

Up to 7 PIPS detectors

- ✓ ORTEC 900 mm^2
- ✓ CANBERRA (same specs.) ✗
- ✓ CANBERRA (450 mm^2)
- ✓ Eurysis (40 mm^2)

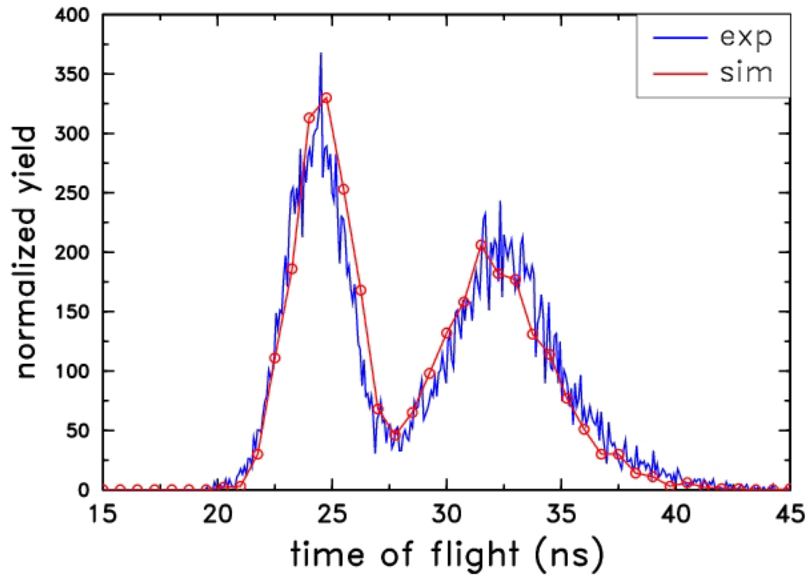
VERDI - the timing resolution

Ortec PIPS 900 mm^2



~~$\Delta t < 1.0$ ns~~

Eurysis 40 mm^2

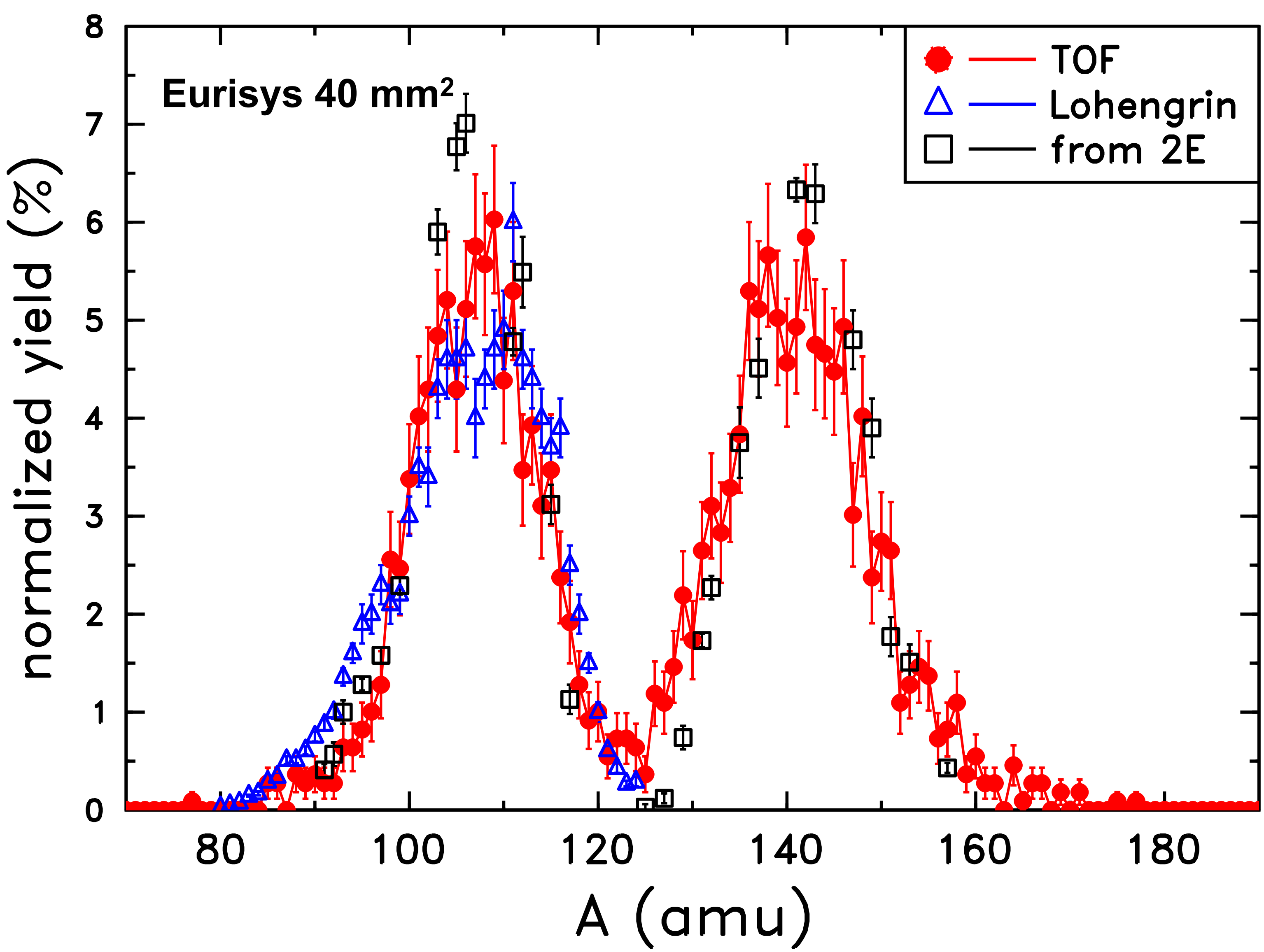


$\Delta t < 0.6$ ns

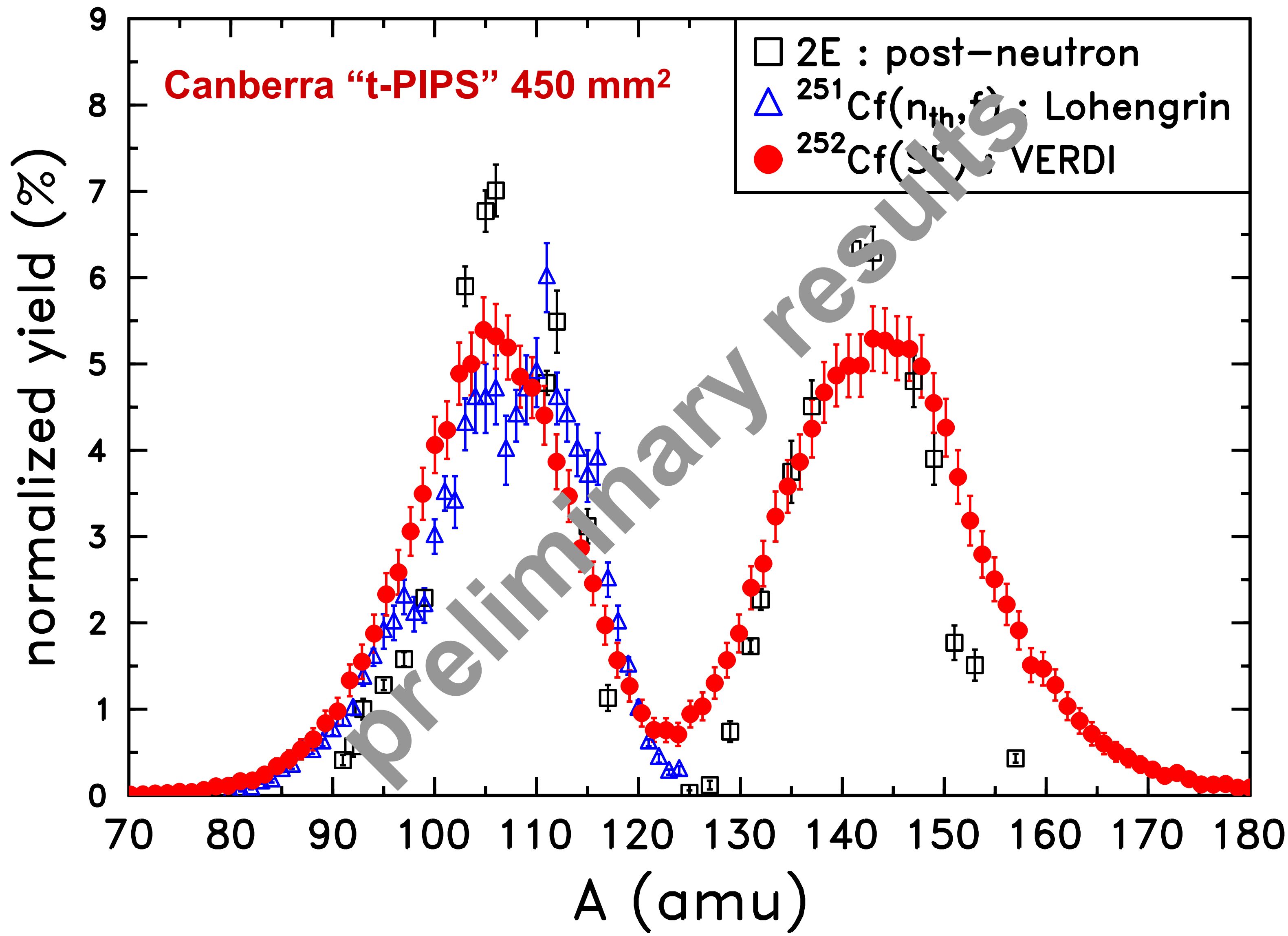
VERDI – data analysis

- ✓ Energy calibration from reference distributions published in "*The Nuclear Fission Process*"
- ✓ Channel-to-time conversion making use of a trend established from $^{233,235}U$ and ^{239}Pu data
- ✓ Pulse-height defect correction applied (Schmitt calibration)

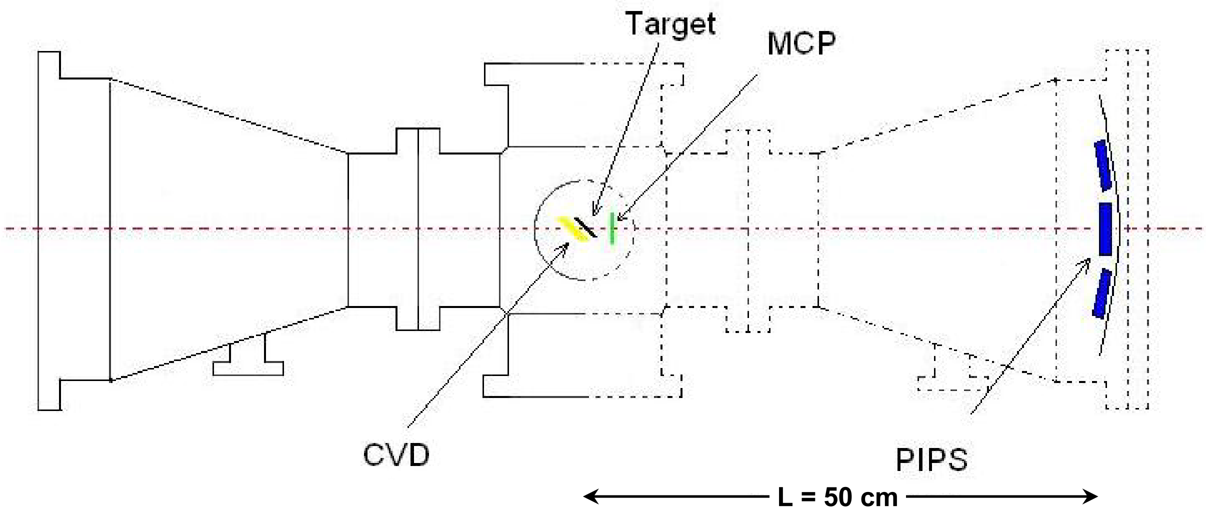
VERDI – FF distributions



VERDI – challenges

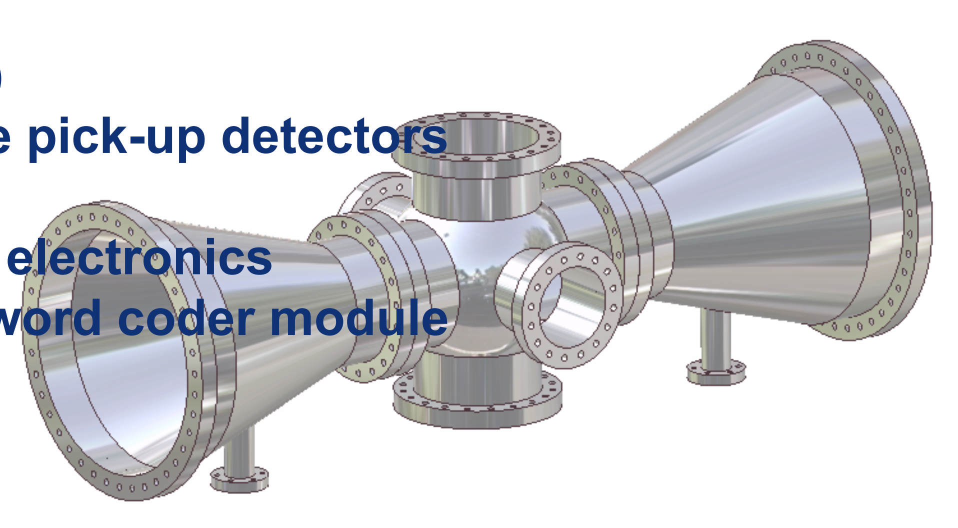


VERDI - the design



- 2 x 19 PIPS detectors (450 mm^2)
- pcCVDD (or MCP) ultra-fast time pick-up detectors

- set-up can be handled with NIM electronics
- development of an AMUX + tag-word coder module



Summary

- ✓ Post-neutron mass resolution ΔA = 2.2 -2.8 achieved

- ☺ pcCVDD detectors may be used for fission-fragment timing

- ☺ radiation hardness of the pcCVDD start trigger proven

- ☺ spectrometer efficiency $\varepsilon \approx$ 0.5%

Summary

✓ Fission fragment timing resolution τ < 300 ps possible

✓ VERDI with mass resolution $\Delta A \approx 1.5$ possible

😐 To reach at τ < 200 ps seems challenging

☺ VERDI will allow the consistent measurement of pre- and post neutron fission fragment data

☺ Prompt neutron emission data Y(A*, TKE; TXE)

The near future

✓ First experiment @ KFKI beginning 2010 (EFNUDAT)

- (v, E) experiment: $^{235}U(n_{th}, f) \Rightarrow Y(A, E_k)$
- with a 1×1 cm^2 4-fold segmented pcCVDDD
- $\Phi_{n,th} \approx 5 \times 10^7/s/cm^2$: **$c_{th}$ > 2 FF/s or 10^6 FF/(120 h) per detector**
- prompt fission γ-rays using the CVDD detector as fission-trigger (→ A. Oberstedt *et al.*)

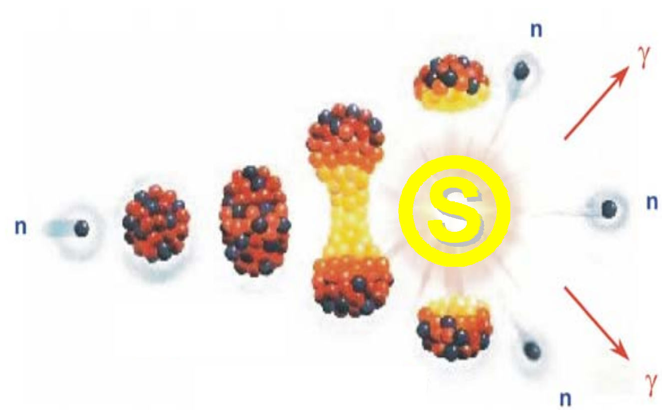
✓ pcCVDD transmission detector

- ✓ under investigation
- ✓ thickness around 5 μm, 8-fold segmented
- ✓ first (weak) α-particle signals extracted
- ✓ Extremely difficult to achieve electrical contact
- Test with fission fragments soon ☺

o Construction of a μ-channel plate detector…

Nothing without a good team!

R. Borcea
F.-J. Hambsch
Van de Graaff technical team



A. Oberstedt Örebro University