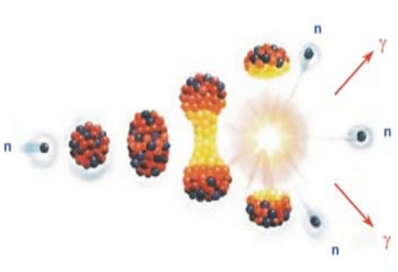


Artificial diamonds as ultra-fast fission trigger

S. Oberstedt

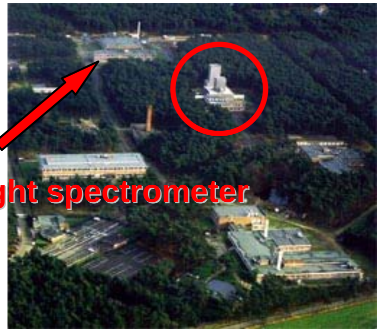
IRMM - Institute for Reference Materials and Measurements

Geel - Belgium

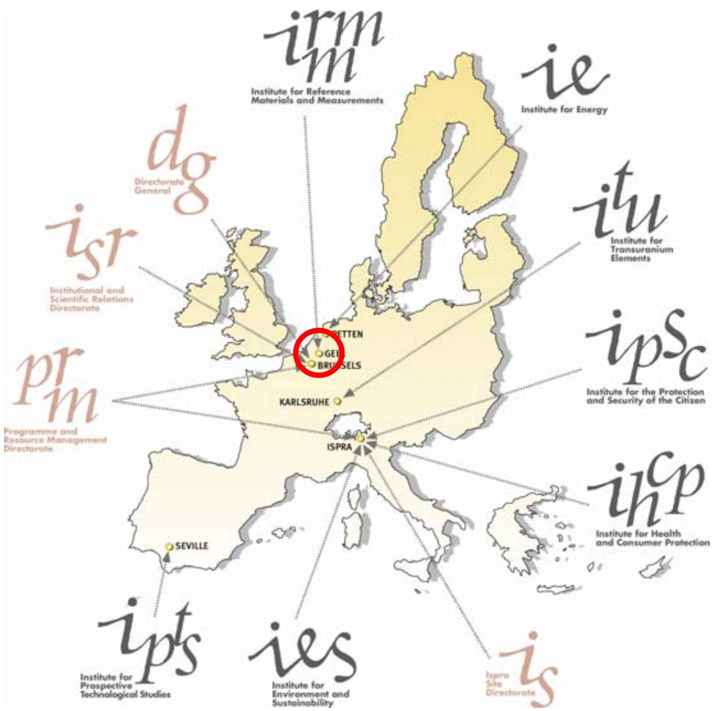
http://irmm.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

- **Introduction**
- **Concept of the TOF spectrometer VERDI**
- **Fission timing with artificial diamonds**
- **First experimental results**
- **Summary**
- **Applications in nuclear data measurements**
- **Outlook**

Introduction



GELINA neutron time-flight spectrometer



MONNET MONo energetic Neutron Tower

7 MV Van-de-Graaff accelerator (0.1 – 24 MeV)

- ^{7}LiF(p, n)^{7}Be, Ti:T(p, n)^{3}He, D_2(d, n)^{3}He, Ti:T(d, n)^{4}He
- DC ($I_{p,d}$ < 50 μA), ns-DC pulse mode (2.5 or 1.25 MHz)
- 4 + 1 non-T beam line

$\Phi_n < 10^{10}$ /s /sr

NEPTUNE isomer spectrometer

Accessible for external research groups via the EUFRAT program

http://irmm.jrc.ec.europa.eu/html/activities/eufrat/index.htm

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

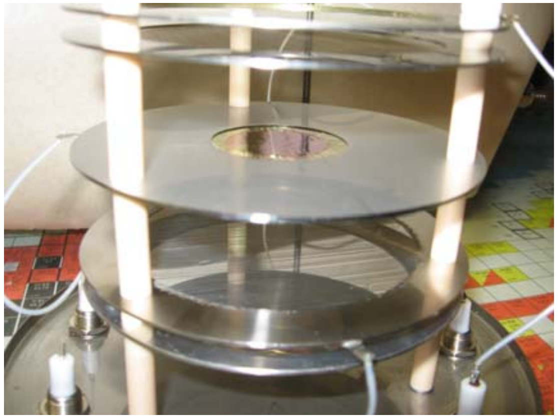
OECD
Organisation for Economic Co-operation and Development
Nuclear Energy Agency
AEN NEA

- **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**

IAEA - INDC

Motivation

- **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**

VERDI – the concept

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

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

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

➢ **complete data set: $\nu_i\{A_i^*, TXE_i, R(Z_L, Z_h)\}$**

♥ **Cosi Fan Tutte (ILL)**

VERDI – basic ingredients

Goals:

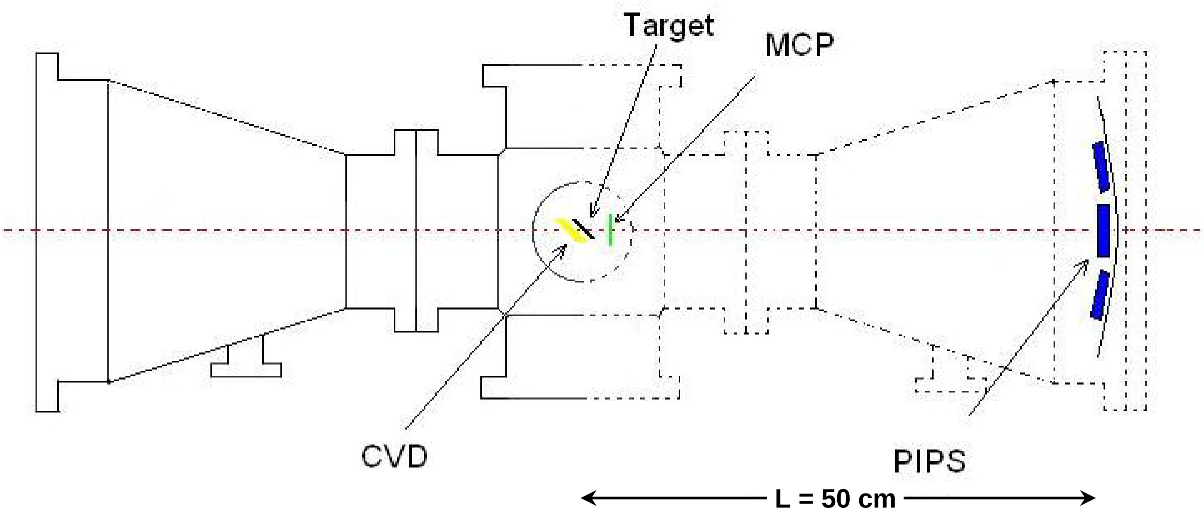
- **spectrometer efficiency $\varepsilon \approx 0.005 – 0.01$♥**
- **for a mass resolution of $\Delta A < 2$**

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

- **radiation hardness of the time pick-up**

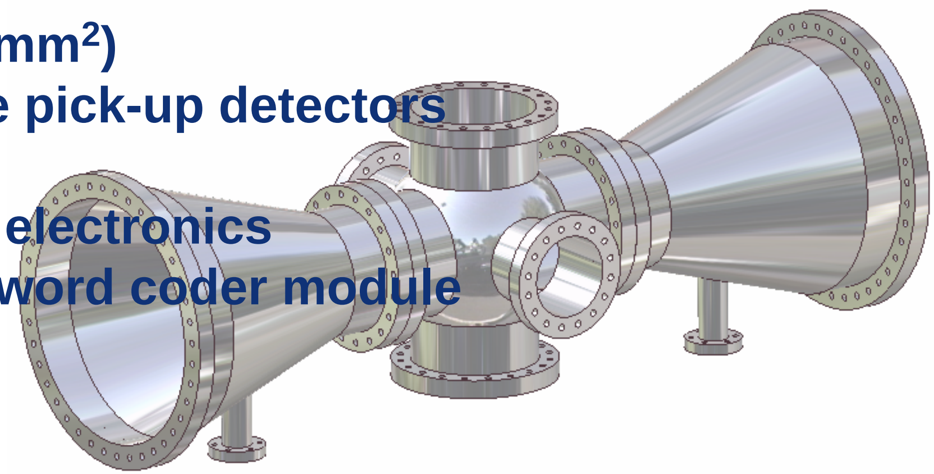
♥ **Cosi Fan Tutte ($\varepsilon \approx 5\times10^{-5}$)**

VERDI - the design



- ✓ 2 x 19 PIPS detectors (450 - 900mm²)
- ✓ 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



o Axial ionisation chamber:

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

o 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 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)???

o Diamond detectors (p/sCVDD):

- ☒ New detector material
- ☒ Relatively few experimental results

- ❖ Difficult to produce (artificial) single-crystal diamonds
- ❖ Pulse height stability of pCVDD difficult to predict and to maintain with HIPs
- ✓ Fast response and low noise, mechanically stable -> easy to handle
- ✓ Promising timing characteristics (with Ni-ion @ 30 MeV/u $\sigma_t \approx 30$ ps)
- ✓ Radiation hard

- ❖ Never tested with fission fragments (0.5 MeV/u $< E_{FF} <$ 2 MeV/u)

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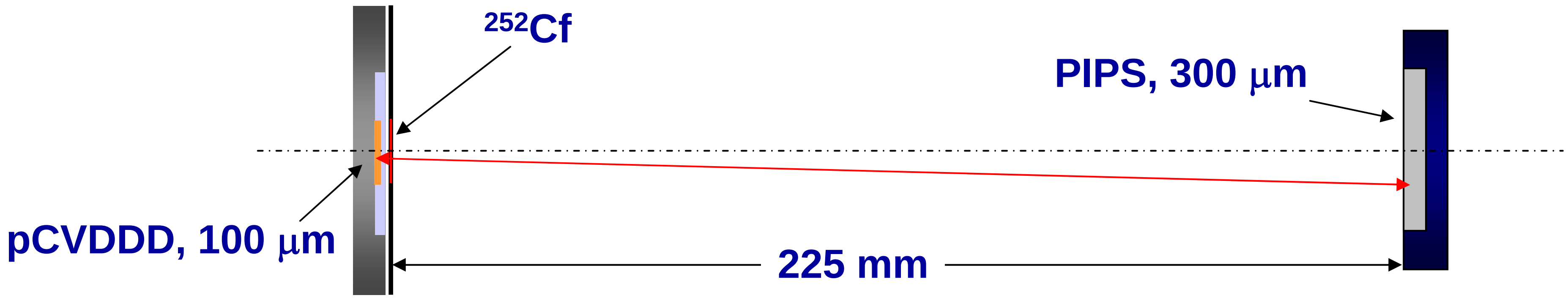
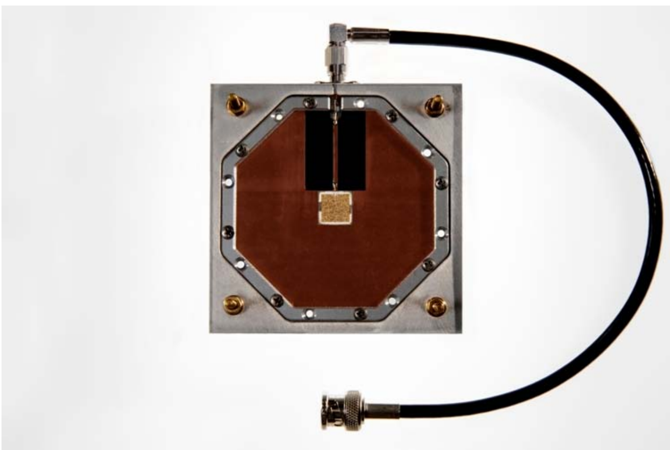
Experimental set-up

(ν, E)





pCVDD material

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

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pCVDD – pulse-height properties

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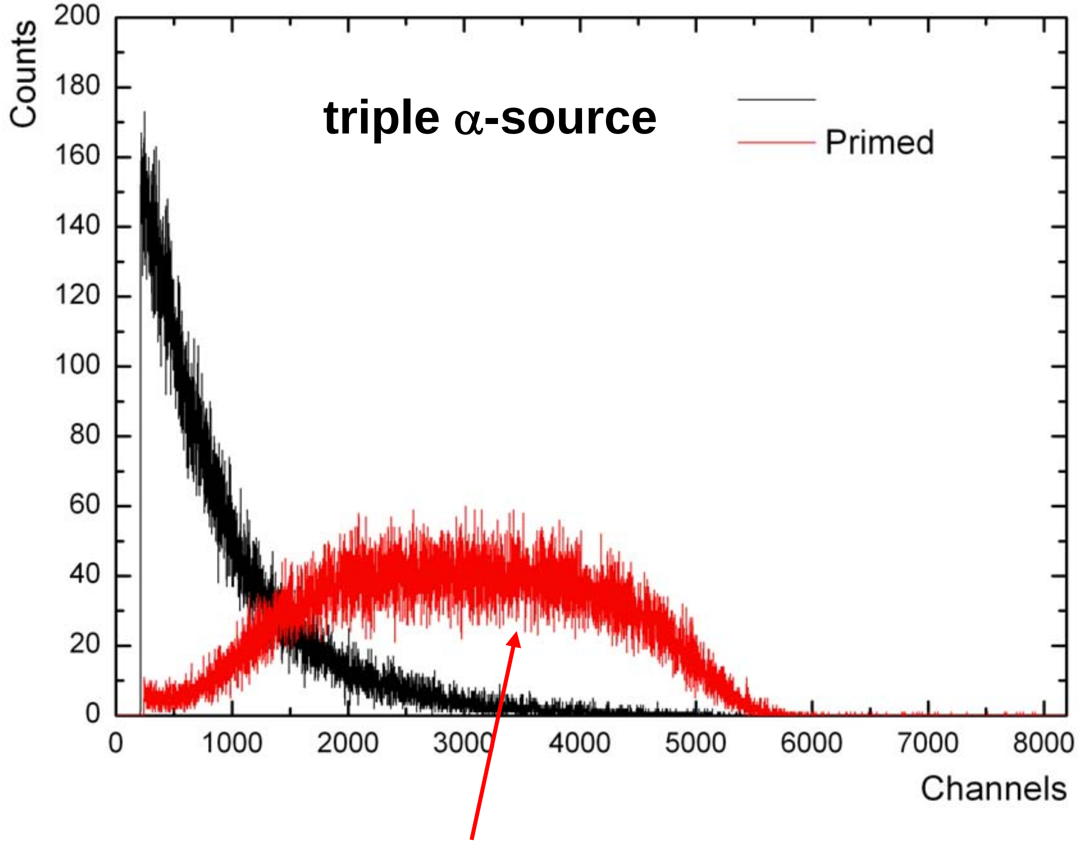
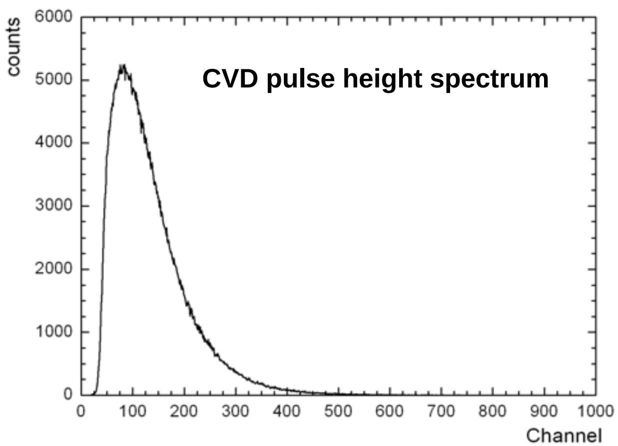
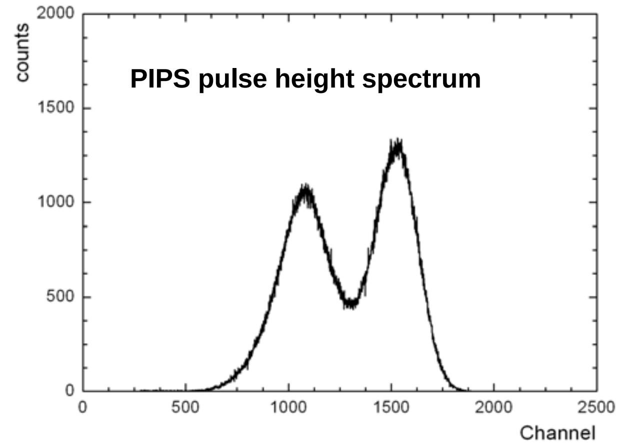
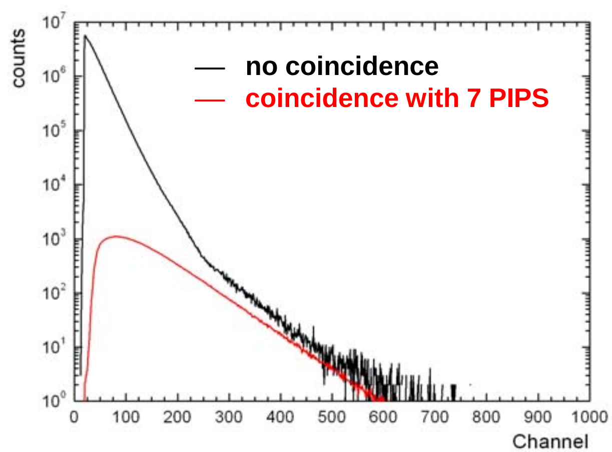


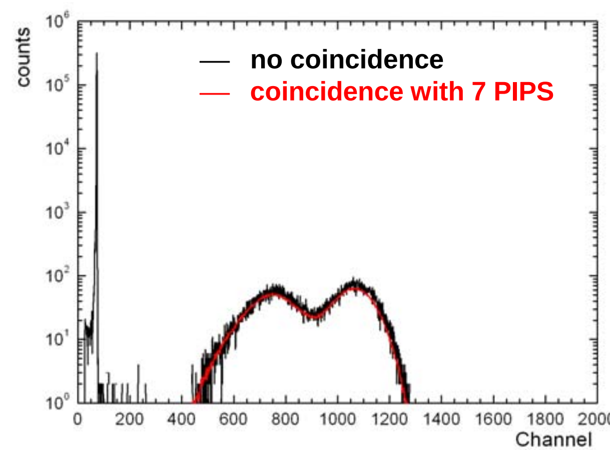
irradiated with a $^{90}Sr/^{90}Y$ β-source (3MBq, 72h)

Pulse-height “analysis”

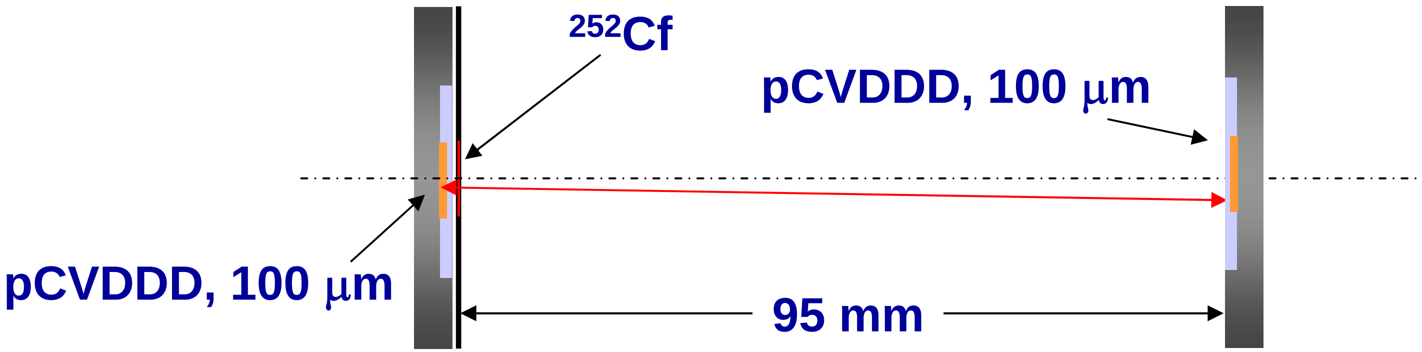


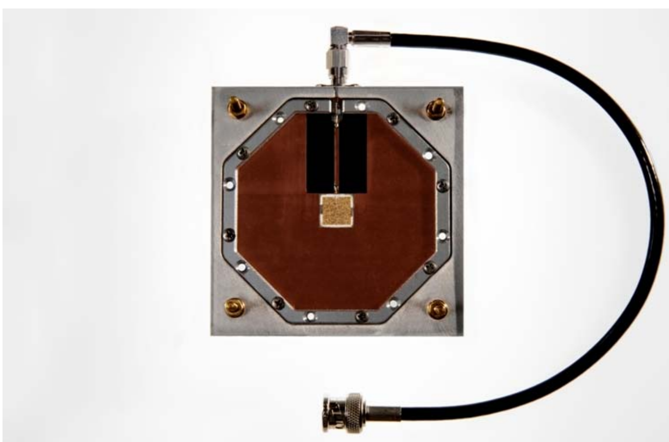






pcCVDDD - Intrinsic timing resolution

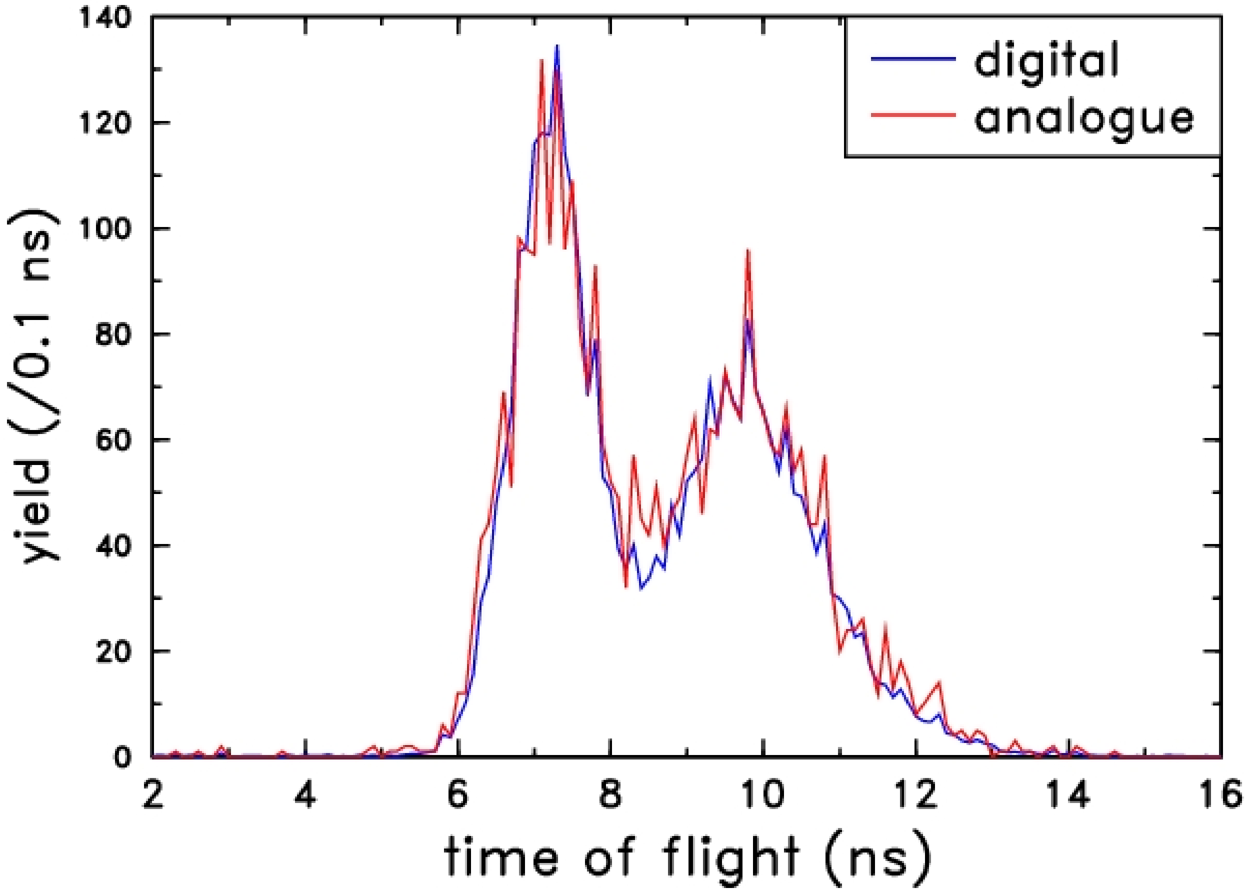




pCVDD material

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

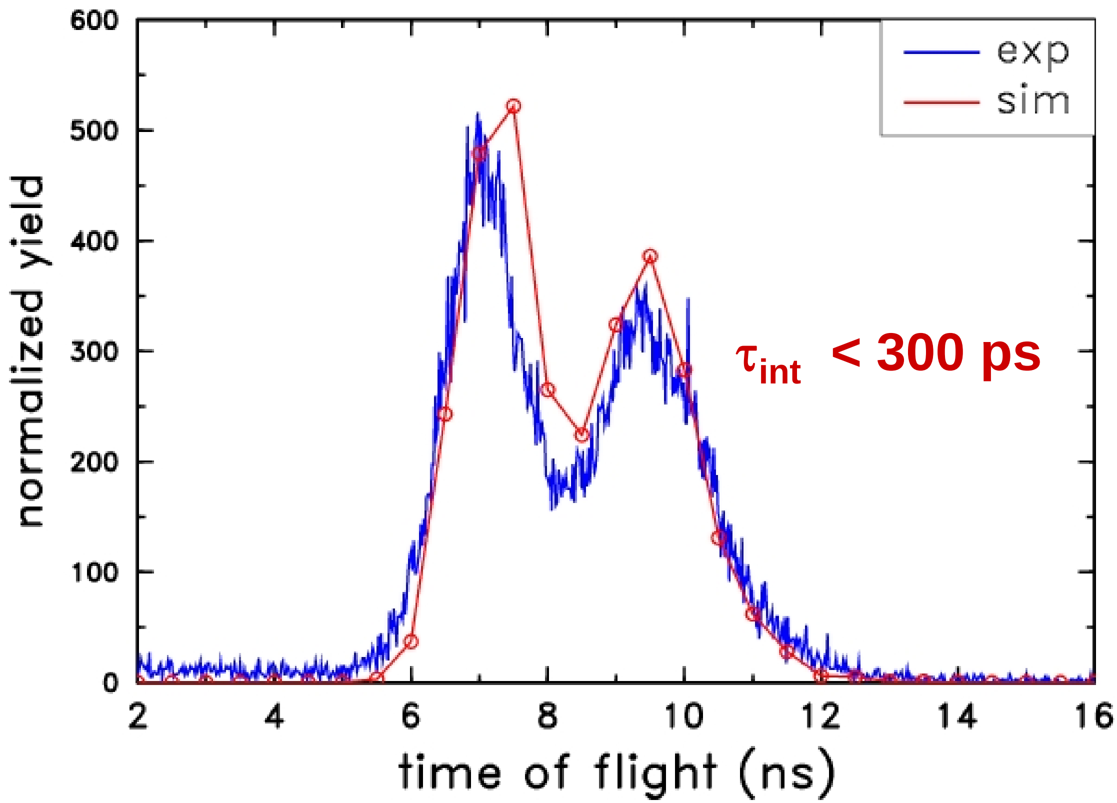
pcCVDDD - Intrinsic timing resolution



Determination of the timing resolution

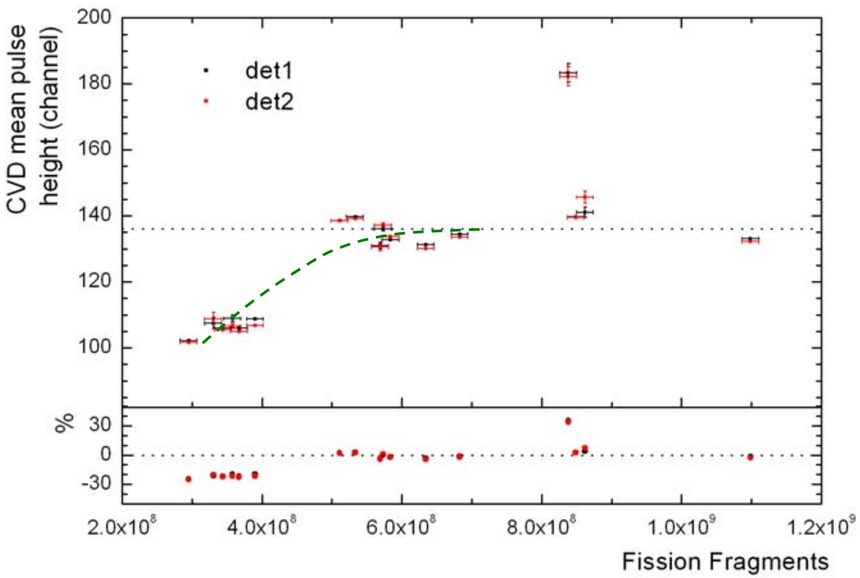
- **By means of a Monte-Carlo simulation**
- **Experimental fission-fragment distribution**
  - Post-neutron fragment yield
  - Post-neutron fragment kinetic energy
- **Geometry of the detector set-up**
- **Variation of the time-resolution parameter until reproduction of the measured time distribution**

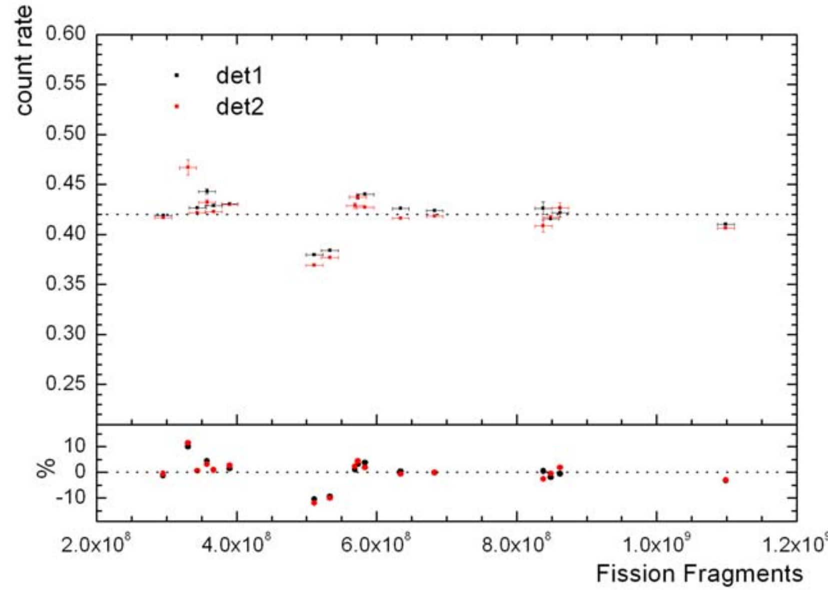
pcCVDDD - Intrinsic timing resolution



- **Timing resolution very good but worse than expected from HI experiments**
- **Don't forget! Here, we have a largely mixed particle beam in A and E_{kin}**

pcCVDDD – pulse-height stability

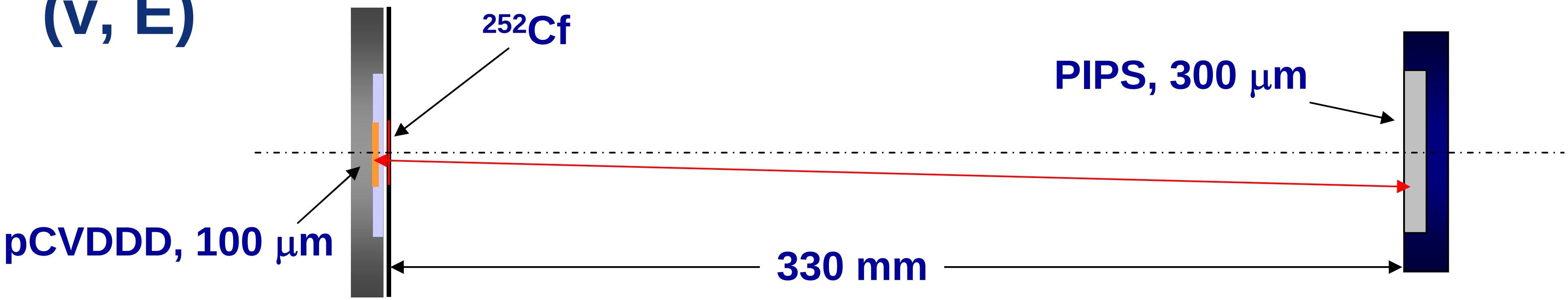




- ✓ **Pulse height stability against radiation damage up to a fission-fragment dose of at least 2×10^9**
- ✓ **Including an α-particle dose of 6.5×10^{10} and a fast neutron dose of about 7.5×10^9**

VERDI - the timing resolution

(v, E)



pCVDD material

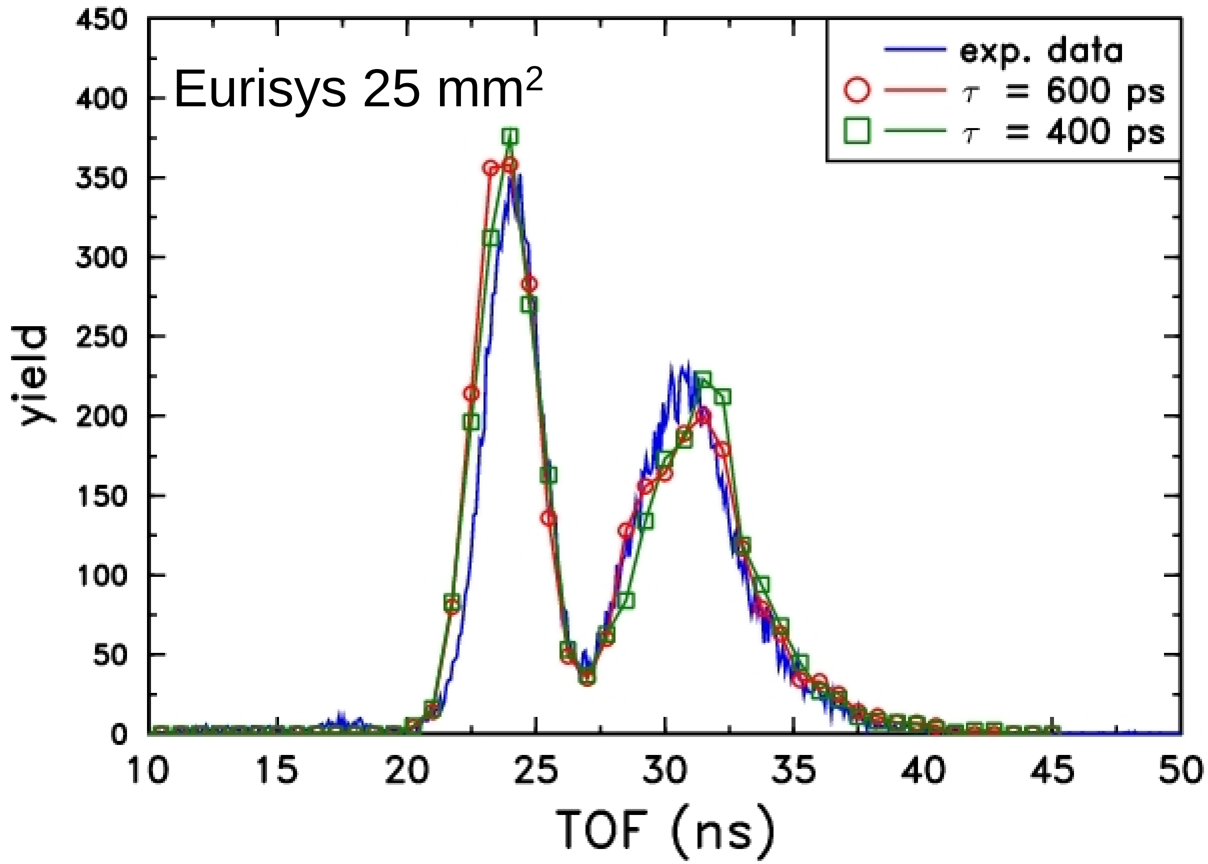
- ✓ size: 1×1 cm^2
- ✓ thickness: 100 μm

various PIPS detectors

- ORTEC 900 mm^2
- CANBERRA (same specs.) ☒

- ✓ Eurisys (25 mm^2)
- ✓ *CANBERRA (450 mm^2)*

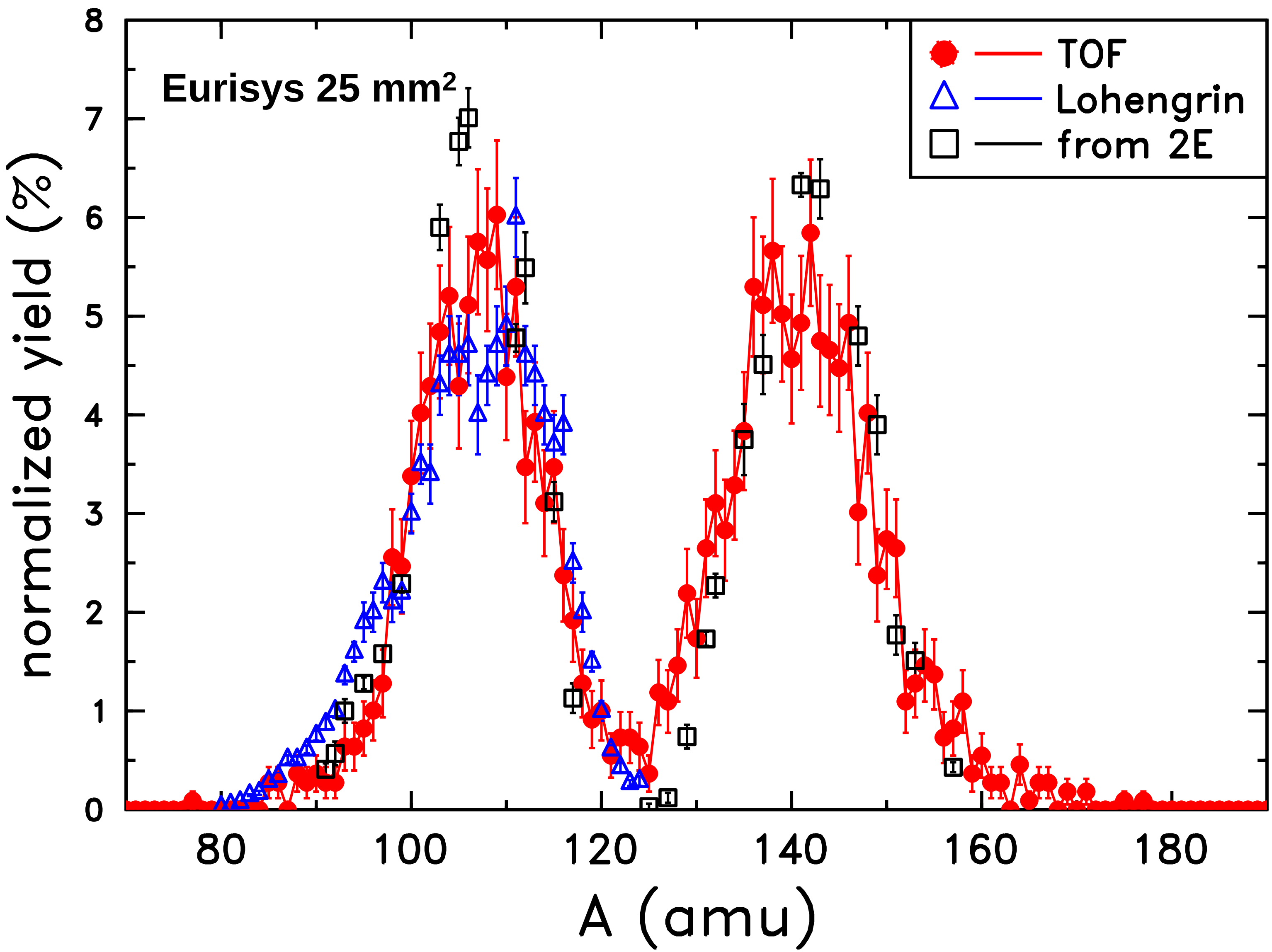
VERDI - the timing resolution



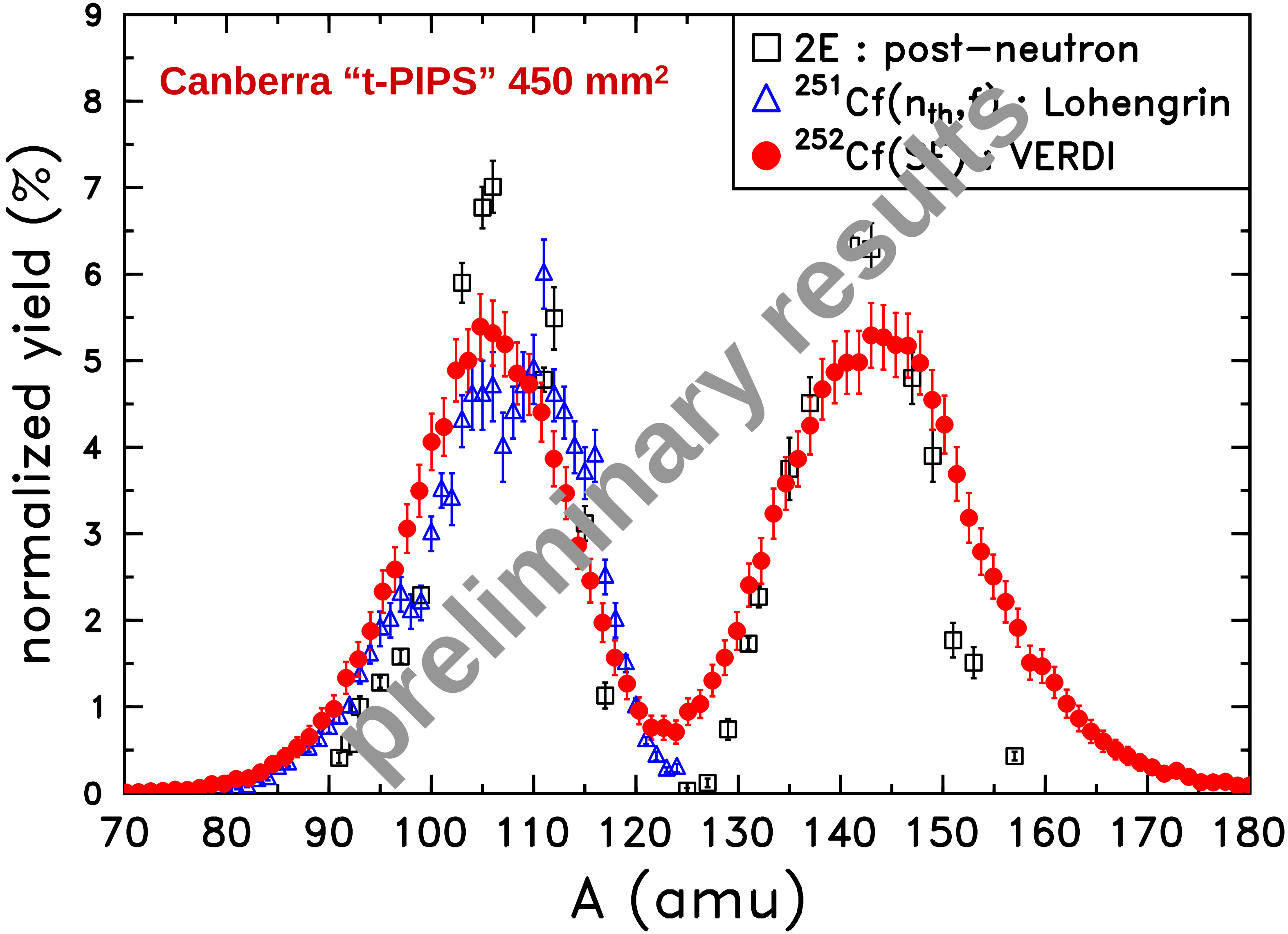
VERDI – data analysis

- ✓ **Energy calibration from reference distributions published in "*The Nuclear Fission Process*"**
- ✓ **Channel-to-time conversion making use of published ^{252}Cf mean-velocity data**
- ✓ **Pulse-height defect correction applied (Schmitt calibration)**

VERDI – FF distributions



VERDI – FF distribution



Summary

✓ Artificial diamonds have a timing resolution τ < 300 ps for a mixed low-energy heavy-ion beam (= FF)

☺ pCVDD detectors may be used for fission-fragment timing

☺ radiation hardness of the pCVDD start trigger proven

✓ Fission-fragment timing resolution of the (v, E) fission-fragment spectrometer τ < 600 ps

✓ Very much competitive with MCP detectors

✓ Post-neutron mass resolution @ flight path L = 50 cm of ΔA = 2.2 -2.8 achieved

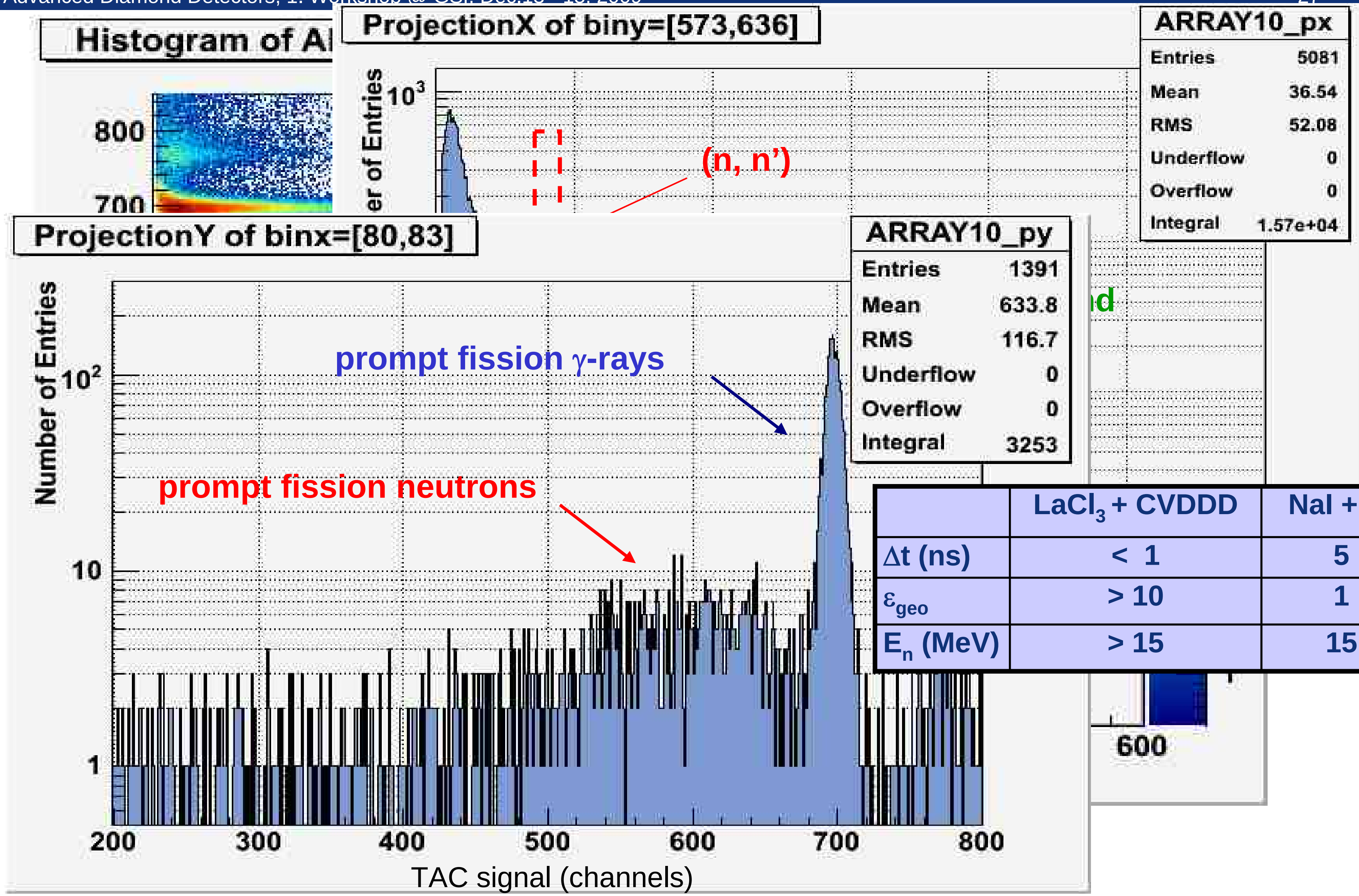
Future improvements

- **Fission-fragment timing resolution τ < 200 ps**
- **VERDI with mass resolution $\Delta A \approx 1.5$ possible**
  - higher electric fields, E_{CVDD} > 2V/µm, to compensate for plasma delay
  - Segmented electrodes to decrease capacitance
  - faster electronics and "cabling"
  - includes work on timing characteristics of large-scale energy detectors
- **Work on a fast radiation-hard transmission trigger device (possibly with energy resolution)**
- **VERDI will allow the consistent measurement of pre- and post neutron fission fragment data**
- **Prompt neutron emission data Y(A*, TKE; TXE)**

Applications in nuclear data measurements

- ✓ **Fission fragment spectrometry in the presence of a high alpha activity (MA: ^{241,243}Am, ^{243,245}Cm, but also ^{239}Pu)**
- ✓ **High resolution neutron-induced cross-section measurements for MA**
- ✓ **Correlated prompt particle emission data (neutron and γ-ray spectra as well as multiplicity data)**
- ✓ **…**

Lanthanum halide detector + pCVDDD



	$LaCl_3$ + CVDDD	NaI + IC
Δt (ns)	< 1	5
ε_{geo}	> 10	1
E_n (MeV)	> 15	15

The near future

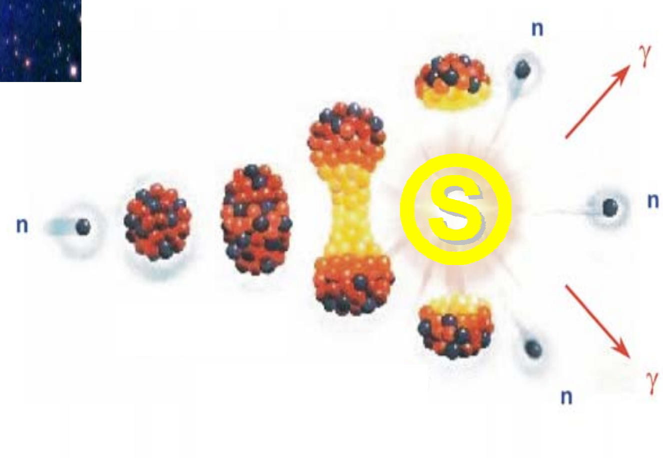
✓ First experiment @ KFKI beginning 2010 (EFNUDAT)

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

✓ pCVD diamond transmission detector

- ✓ under investigation
- ✓ thickness around 5 μm, 8-fold segmented
- ? first (weak) α-particle signals
- ✓ extremely difficult to get electrical contact (now glued)
- tests with fission fragments soon ☺

Nothing without a good team!



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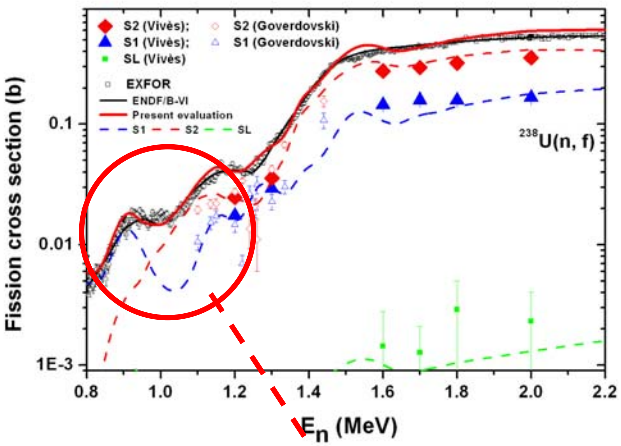
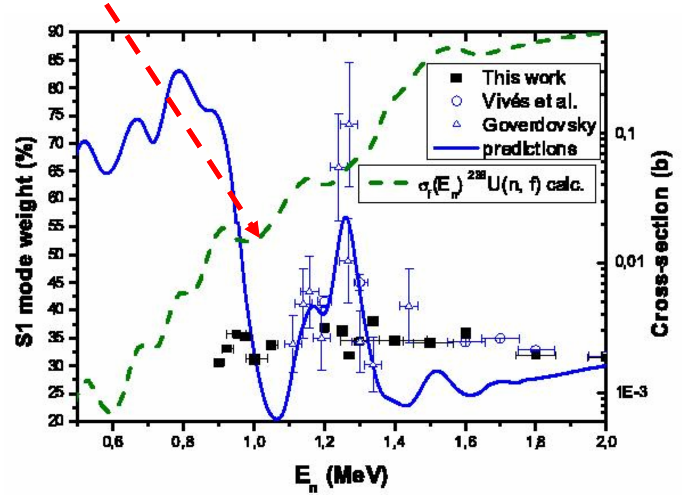
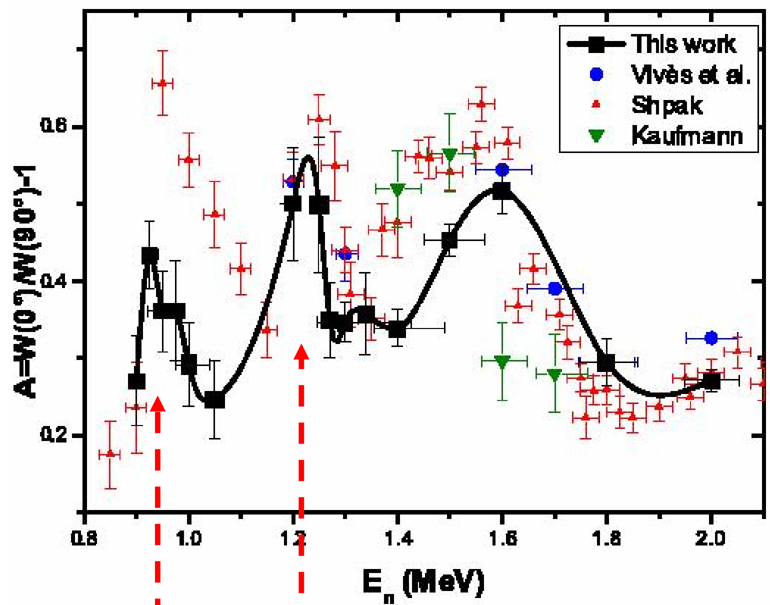
Motivation

- ^{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