Study of Characterization and Applications of Diamond Detectors for Fission Fragment detector

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Motivation

Advantages of diamond detector for light ions

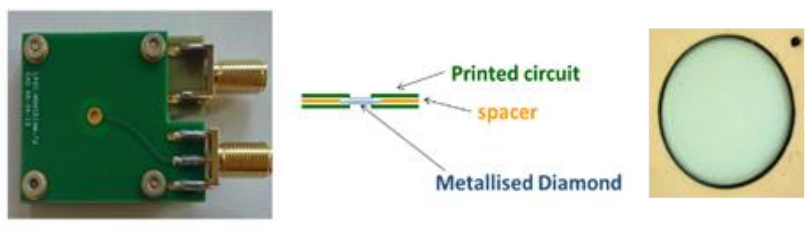
- High radiation hardness: high threshold displacement energy of 43 eV vs 25 eV for silicon
- Excellent time resolution (< few tens of ps)
- Good energy resolution (~Si detectors)
- Low noise & leakage current (5.45 eV band gap)

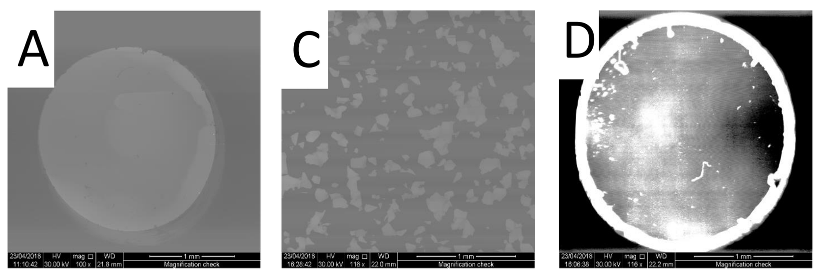
⇒**Is it suited for fission fragment detection?**

Study the response of different types of diamond detectors with neutron-induced fission fragments

- Fission fragments (0.3-1 MeV/nucleon) Time & energy resolution
- Pulse height defect: Large energy deposition @ detector surface
- Fission fragment detection efficiency
- Possible application for future fission/nuclear structure studies

Detectors





Detector Name	Manufacturer	Type	Area [mm2]	Thickness [mm]
A	Element 6	sCVD	4.5x4.5	0.517
B	Element 6	sCVD	2.4 diam.	0.05
C	Element 6	pCVD	10x10	0.3
D	DDK	pCVD	5x5	0.3
E	II-VI	pCVD	10x10	0.3
F	AUGSBURG	DOI	5x5	0.3

- Various crystal size : Thickness (50 ~517 μm) Area: 5 mm^2 ~1 cm^2
- Various crystal types: single/poly-crystalline chemical vapor deposition (s/pCVD), Diamond On Iridium (DOI)
- 30 keV electron beam induced current (eBIC) cartography
  i) Detector A (sCVD): homogeneous structure.
  ii) Detector C (pCVD): quasi-homogeneous grain structure
  iii) Detector D (pCVD): very inhomogeneous structure

Experimental Setup

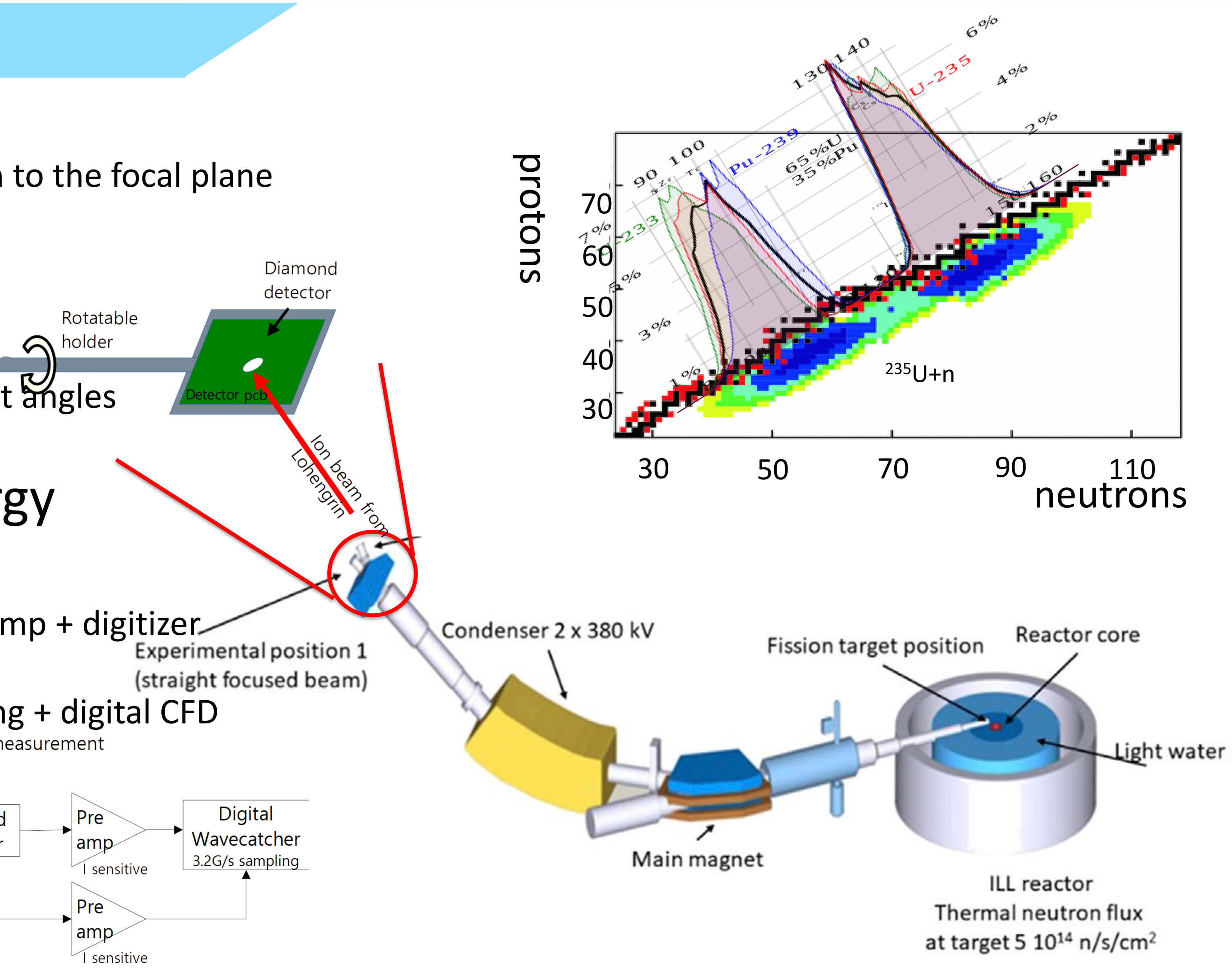
Lohengrin recoil separator

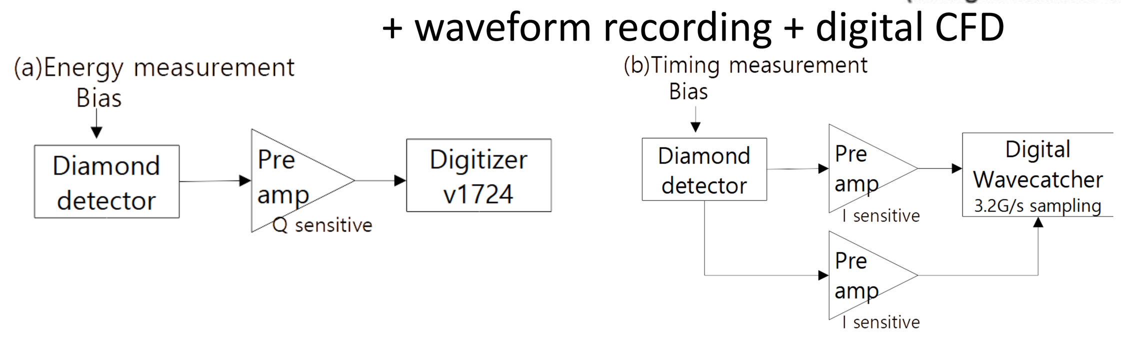
A, E separated fission fragment (FF) beam to the focal plane

- E Dispersion = 720 cm
- A Dispersion = 324 cm
- A/ΔA = 400-1500, E/ΔE = 100-1000
- Diamond exposed to FF beam front- and backside and under different angles (change of effective dead layer)

Digital electronics for energy and timing measurement

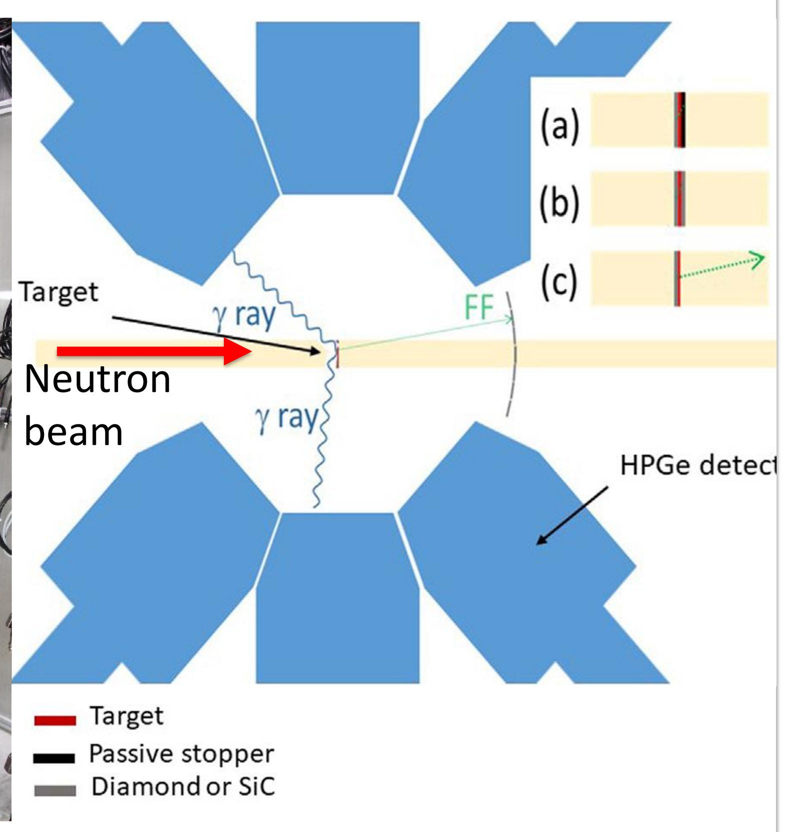
- E measurement: charge sensitive preamp + digitizer
- T measurement: current preamplifier + waveform recording + digital CFD





Future application

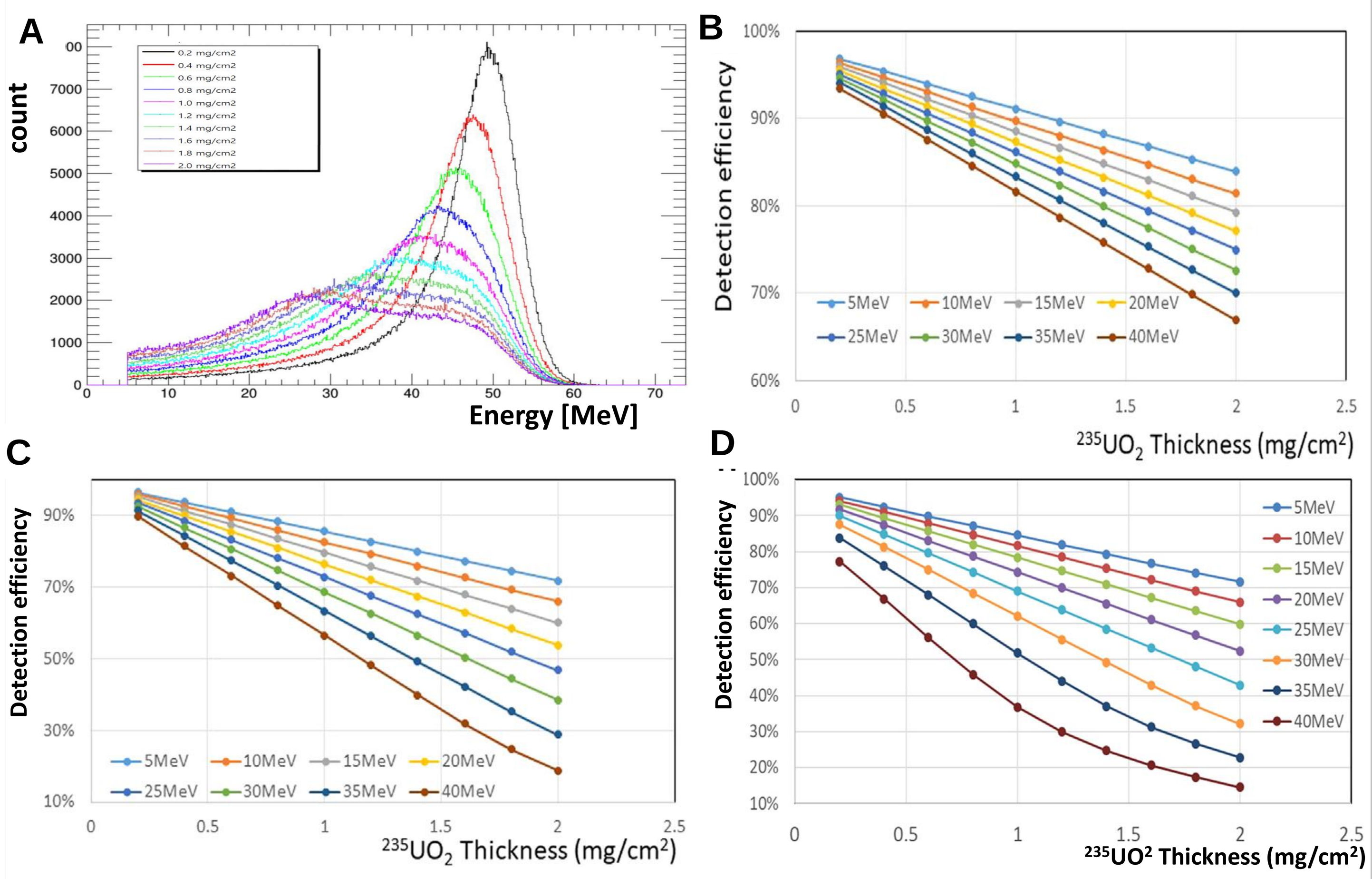
Possibility for in-beam fission fragment detection system for FIPPS



(Left) Mounting of central ring of FIPPS Ge detectors with anti-Compton shields (right) schematic of possible setup of active fission target using diamond detectors

- Diamond detector w/Sandwich configuration: Low neutron activation & high rate capability &radiation toughness
- Precise fission tagging: Combination of several FF detectors/one FF detector.

Simulated detection efficiency of diamond detector with thick fission target



Detector setup requirements

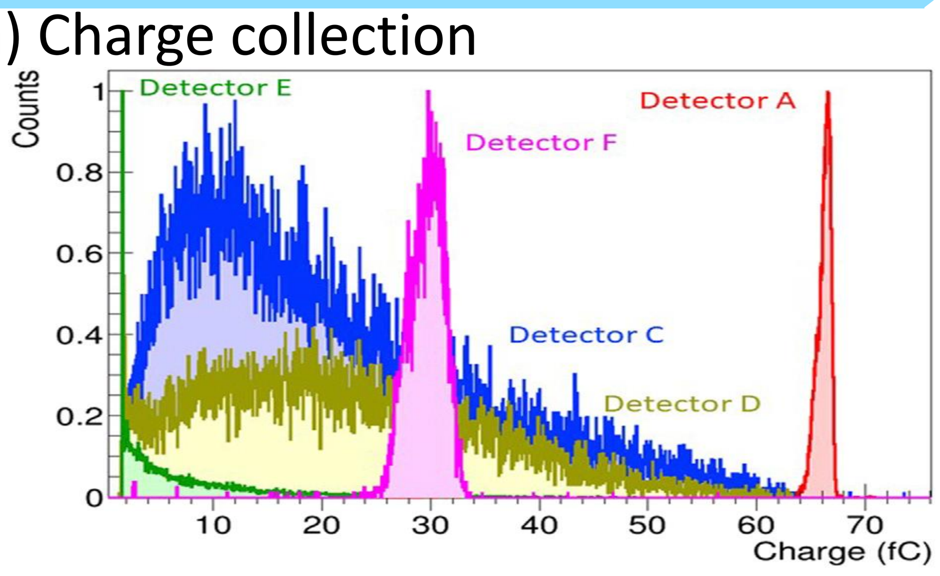
- High efficiency in-beam FF detection: sCVD diamond detectors in an edgeless mosaic arrangement
- The active area of the detector should match the target area or be larger.

Target thickness limit

- Efficiency loss: fraction of FF emitted to small angles stopped within the target+ Low detection efficiency of heavy FF (larger energy loss)
- Rapid decrease of detection efficiency as a function of target thickness
- Maximum target layer thickness of 0.56 mg cm−2 for >90% detection efficiency for single fission fragment detection

Experimental result

a) Charge collection



Typical energy distribution with 5.4 MeV α (^{241}Am)

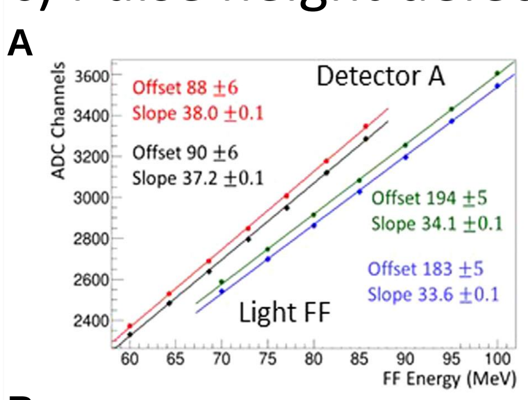
- sCVD detector: Full charge collection & ΔE/E ~1.2% .
- pCVD detector: Strongly varying charge collection across detector surface

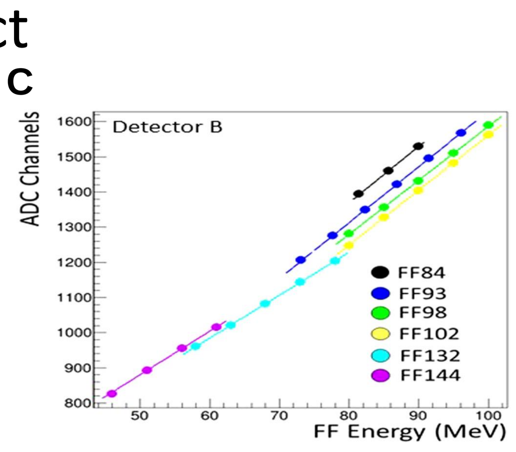
b) Detection efficiency

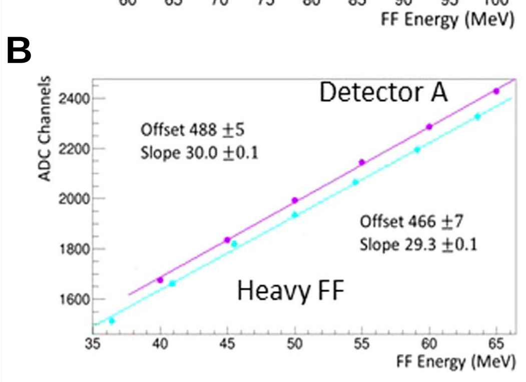
Particle	Energy [MeV]	Efficiency [%] Det A sCVD	Efficiency [%] Det D pCVD	Efficiency [%] Det E pCVD
Alpha	1.4	100.6	-	32.9
	4.5	100.7	-	-
	4.7	102.2	81.4	31.0
Fission fragment A=98	100	101.3	82.3	29.4
	90	106.9	86.7	36.2
	80	104.5	86.5	29.5
Fission fragment A=136	77	103.1	77.2	28.1
	70	98.0	85.5	30.2
	63	104.7	79.2	27.4

- sCVD detector: ~100% efficiency due to good charge collection efficiency
- pCVD detector: inefficient charge collection "dead areas" between grains

c) Pulse height defect





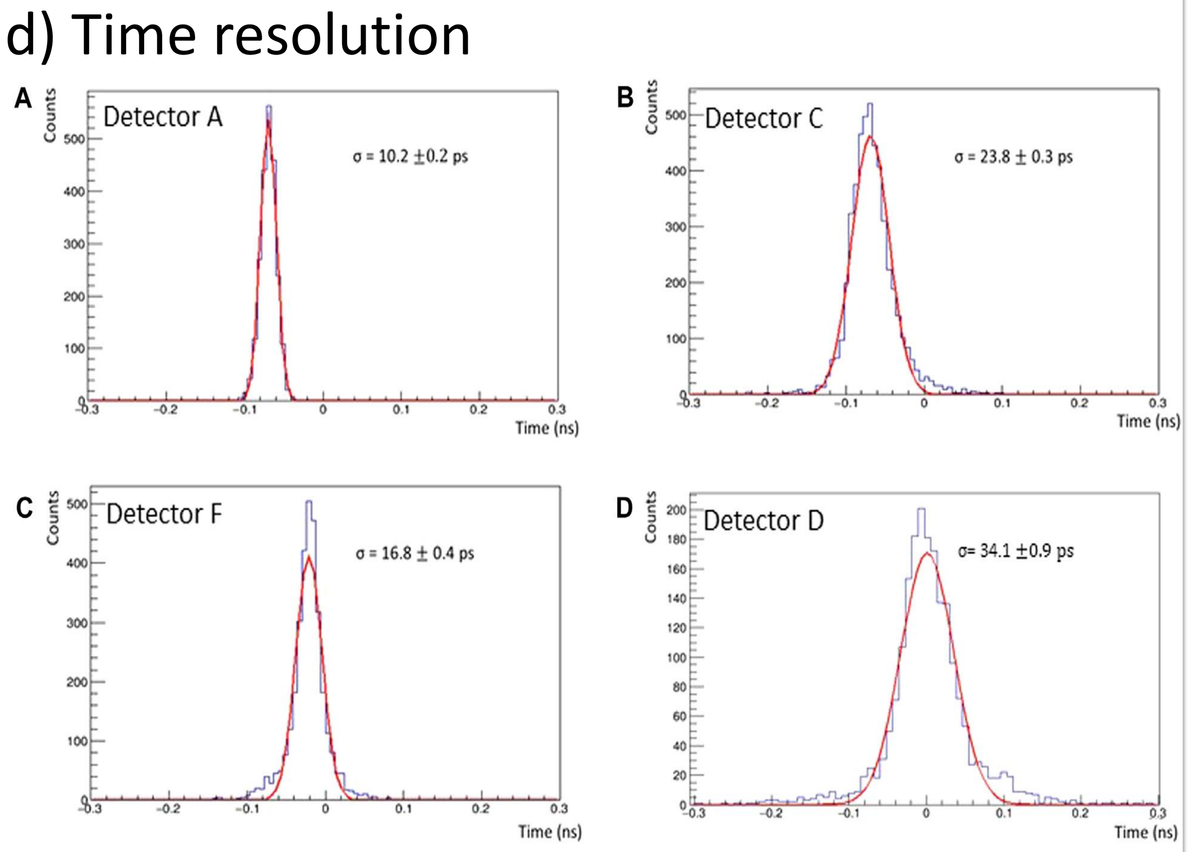


Pulse height defect for various fission fragments for sCVD detector A and B Detector A: (A) Light fission fragment (B) heavy fission fragment. Detecor B: (C) light/heavy fission fragment

sCVD detector pulse height defect (PHD)

- PHD ~ Fission fragment Z & kE
- PHD effect measurement Q(kE) for 2 sCVD detectors A & B
- Only ~50% kinetic energy registered
- The main source of PHD from plasma effect by the fission fragment

d) Time resolution



- Time difference between front/back within detectors
- Excellent time resolution sCVD & pCVD detectors, irrespective of thickness