Diamond as a solid state micro-fission chamber for thermal neutron detection

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3rd ADAMAS Collaboration Meeting @ ECT*
18-20 November, 2014
Trento

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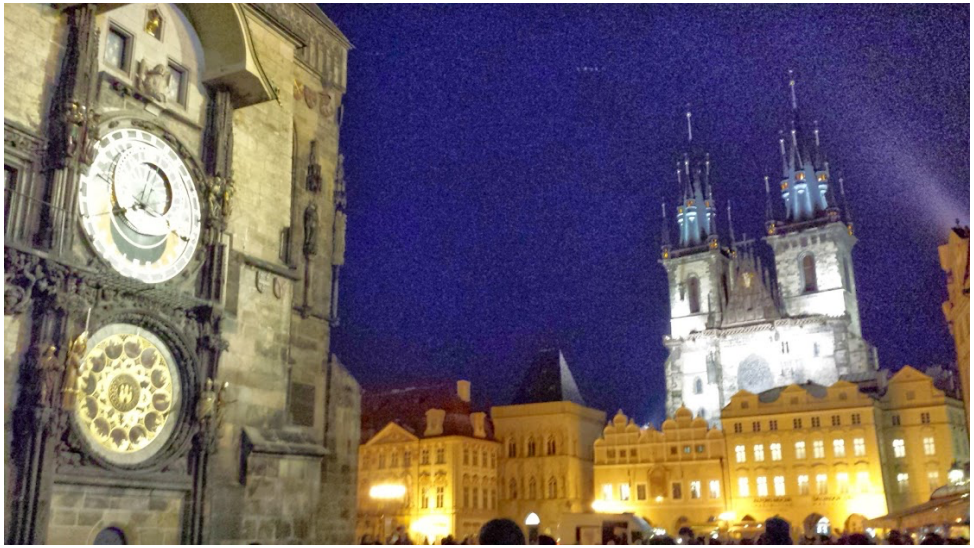
Christine Mer-Calfati
Francois Foulon

Many thanks to VR1 reactor team in Prague:

Lubomir Sklenka
Tomas Bily
Jan Rataj
and others…..



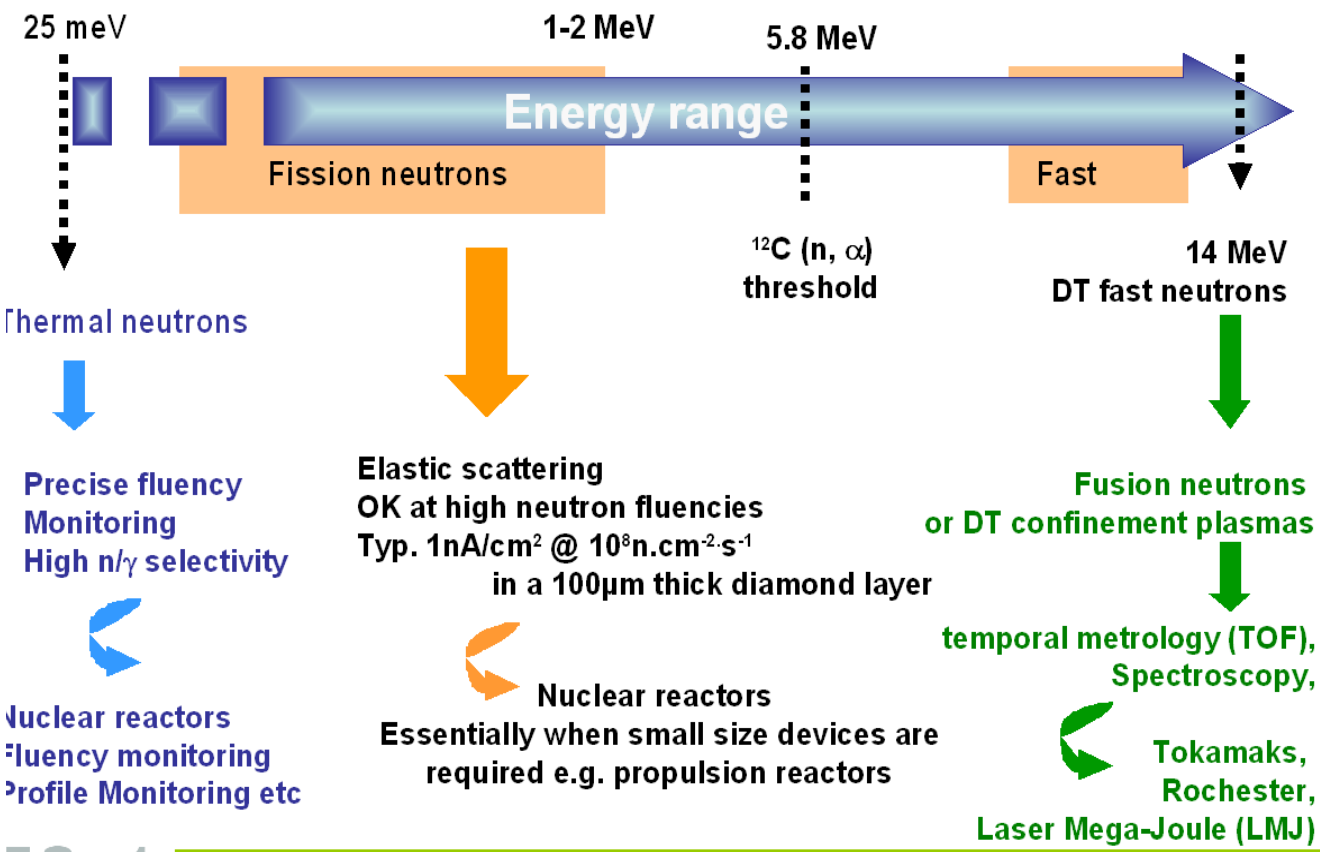
open access facility:
vyuka@ReaktorVR1.eu

request form:
reactorvr1.eu/download/request_for_access.pdf

Outline

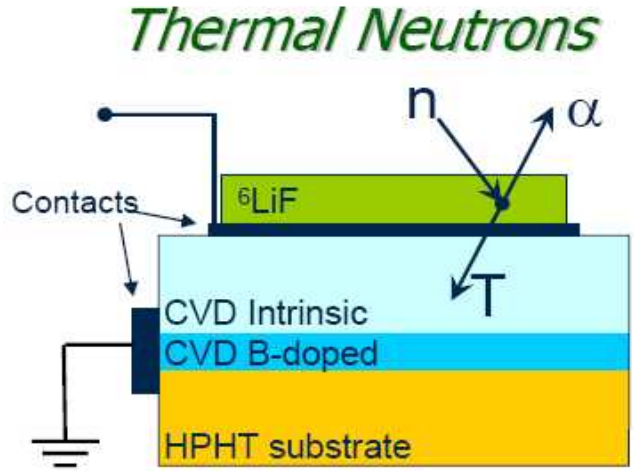
- Motivation / Previous work
- Diamond Samples / Pre-testing
- Set-up
  - VR1 reactor in Prague
  - U-235 + diamond detectors + electronics
- Some results
  - fission fragments spectra
  - linearity with flux, core-mapping
  - TCT signals + other observations……
- Summary

Neutrons detection interests for diamond …



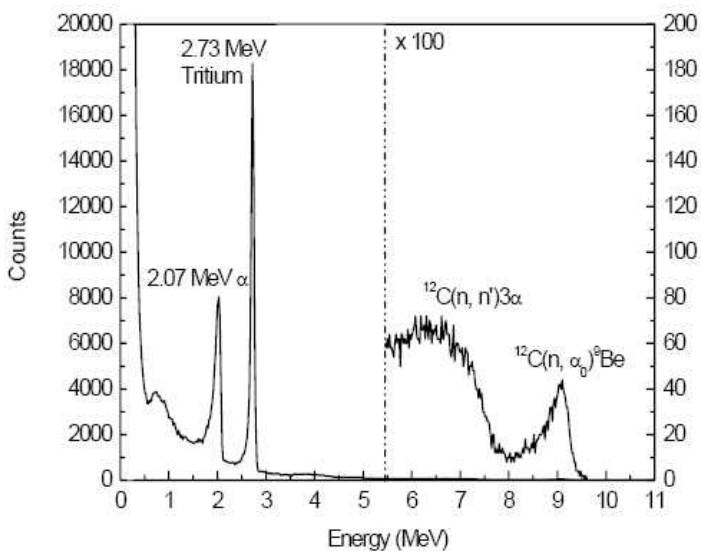
Bergonzo et al.

http://www-norhdia.gsi.de/talks/4th/G_Verona-Rinati.pdf



J.C.R. Mittani et al. / Nucl. Instr. and Meth. in Phys. Res. B 260 (2007) 663–671

Isotope	Natural abundance (%)	σ^* (barns)	Products
^{6}Li	7.4	940	^{3}H (2.75 MeV) + ^{4}He (2.05 MeV)
^{10}B	19.8	3840	^{7}Li (1.0 MeV) + ^{4}He (1.8 MeV) ^{7}Li (0.83 MeV) + ^{4}He (1.47 MeV) + γ (0.48 MeV)
^{157}Gd	15.7	255,000	^{158}Gd + γs + conversion e$^-$ + X-rays (29–182 keV)
^{155}Gd	14.8	60,900	^{156}Gd + γs + conversion e$^-$ + X-rays (39–199 keV)



Idea:

Use of fissile material as a converter eg.:

Uranium-235 —> 584 barns for fission

Only one publication with FF and natural diamond (half page) ~ 1970…

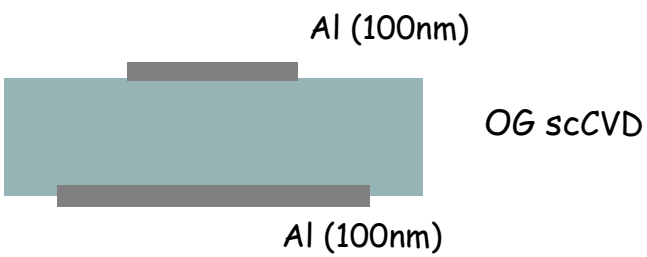
+previous work of Christine Mer et. al.

thick pcCVD+EGscCVD + high power reactor

Diamond Samples

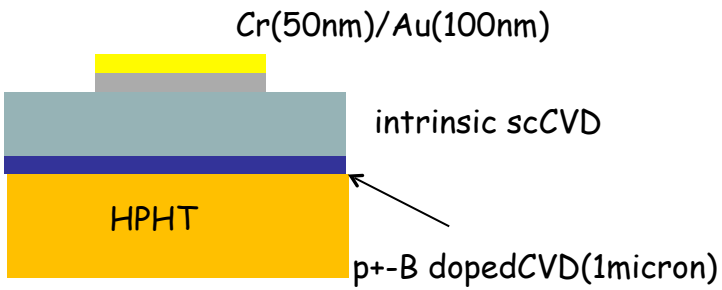
Optical Grade scCVD e6 (OGscCVD)

[N0] =< 1ppm
thickness = 17 microns
size= 3 x 3 mm (broken)
contacts = Al (1mm diam.)

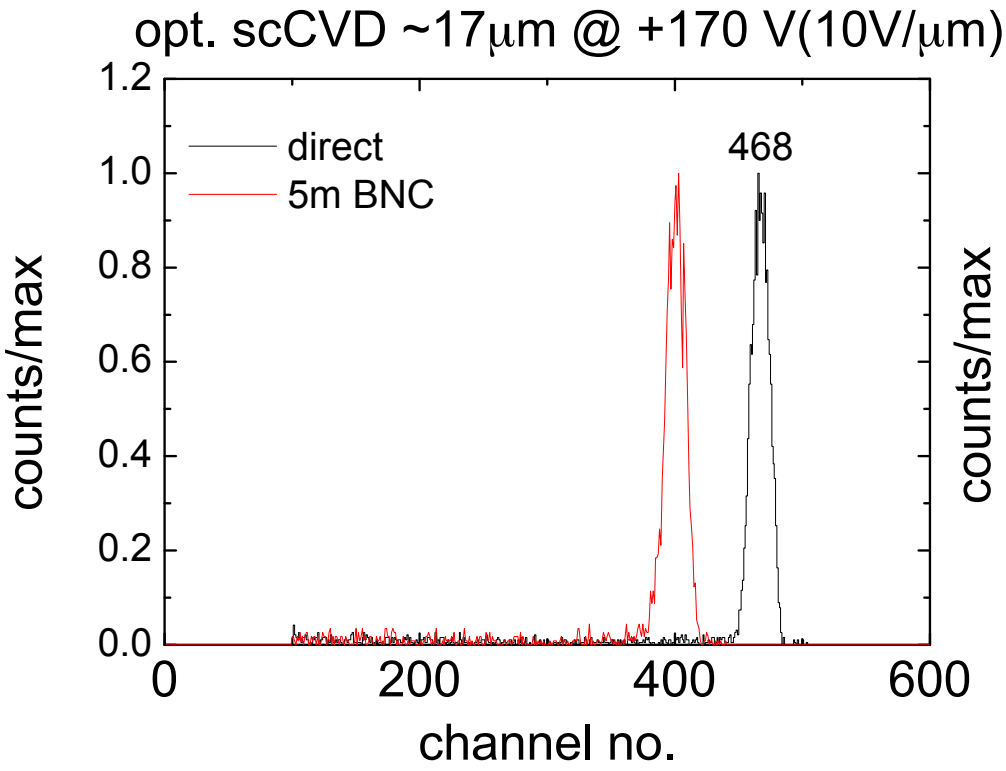


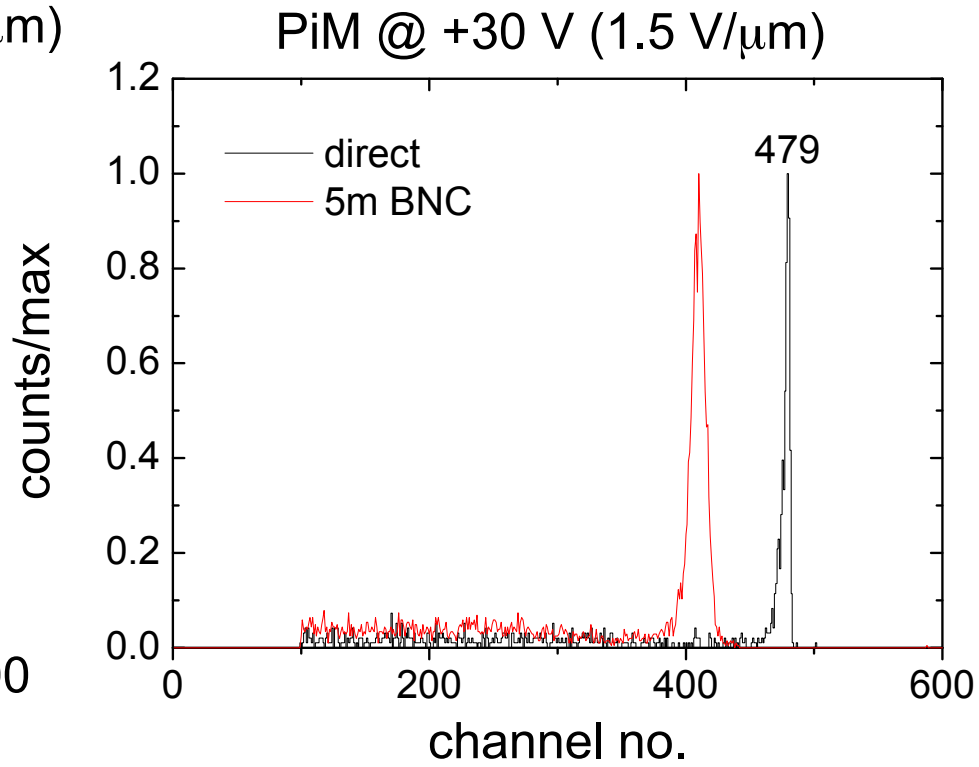
p+-intrinsic-metal structure CEA (PIM)

[N0] << 1ppm
thickness ~ 20 microns (intr.)
size= 3 x 3 mm
contacts = Cr/Au (<1mm diam.)



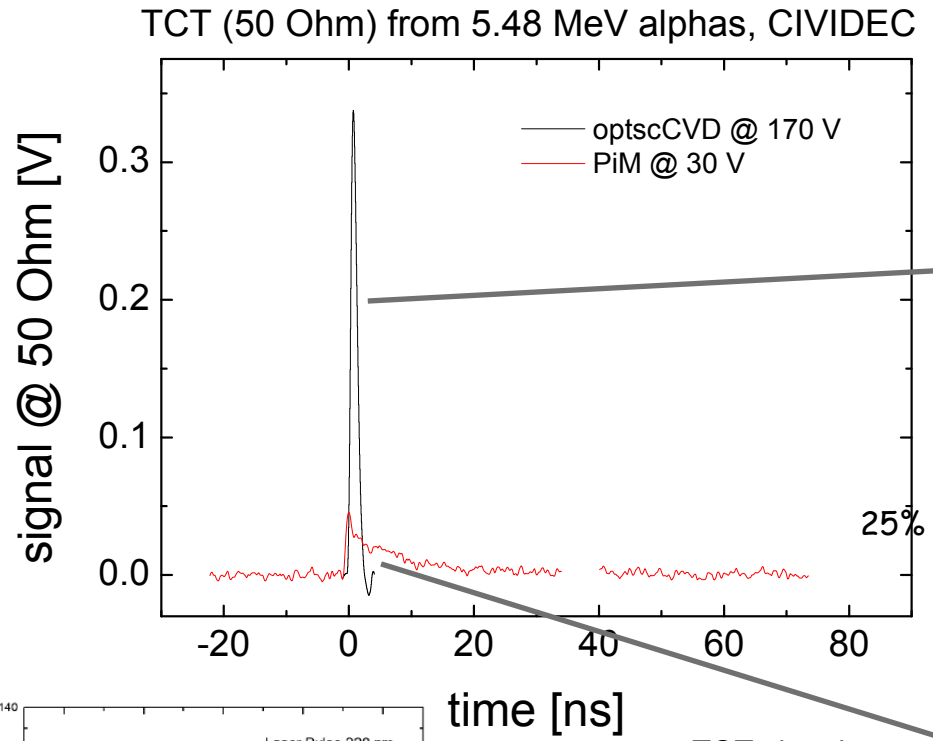
Am-241 alpha spectra 5.486 MeV in vacuum, using CSA (3micros shaping)

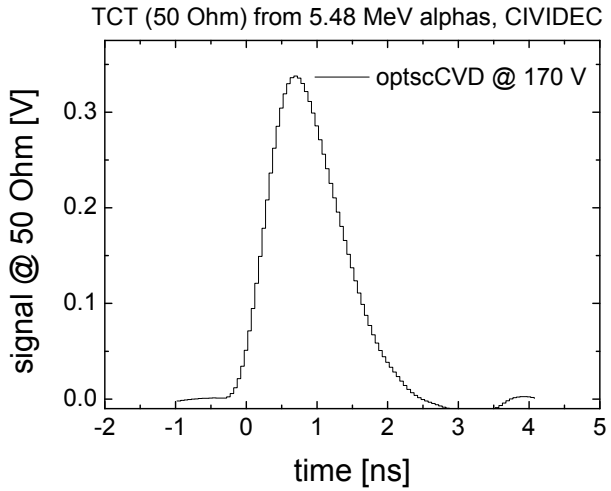


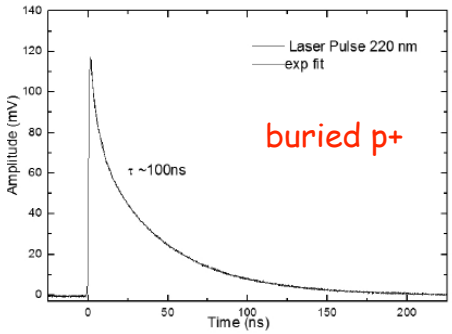


OGscCVD

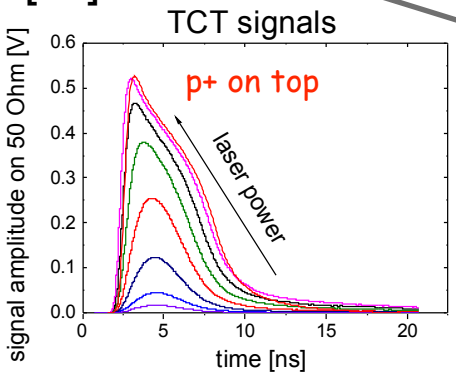
PiM

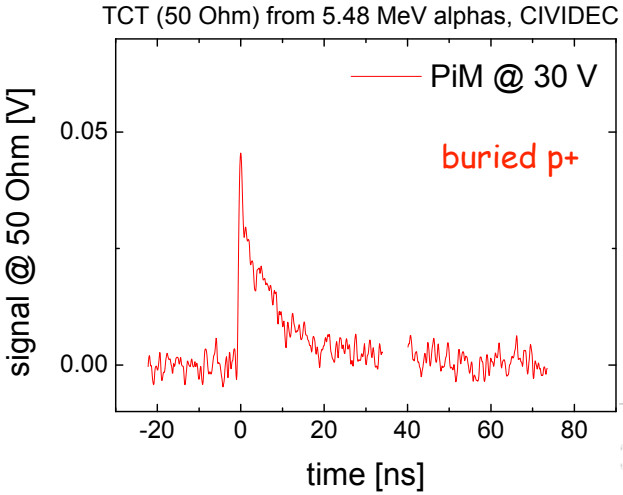




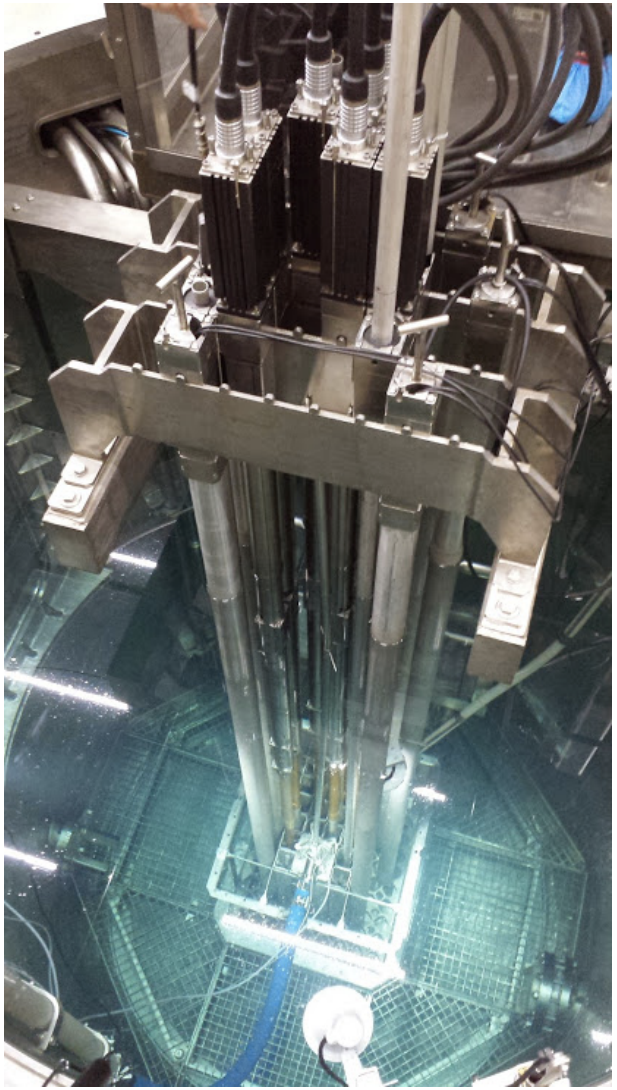


PiM, Claudio Verona Tor Vergata Univ.Rome

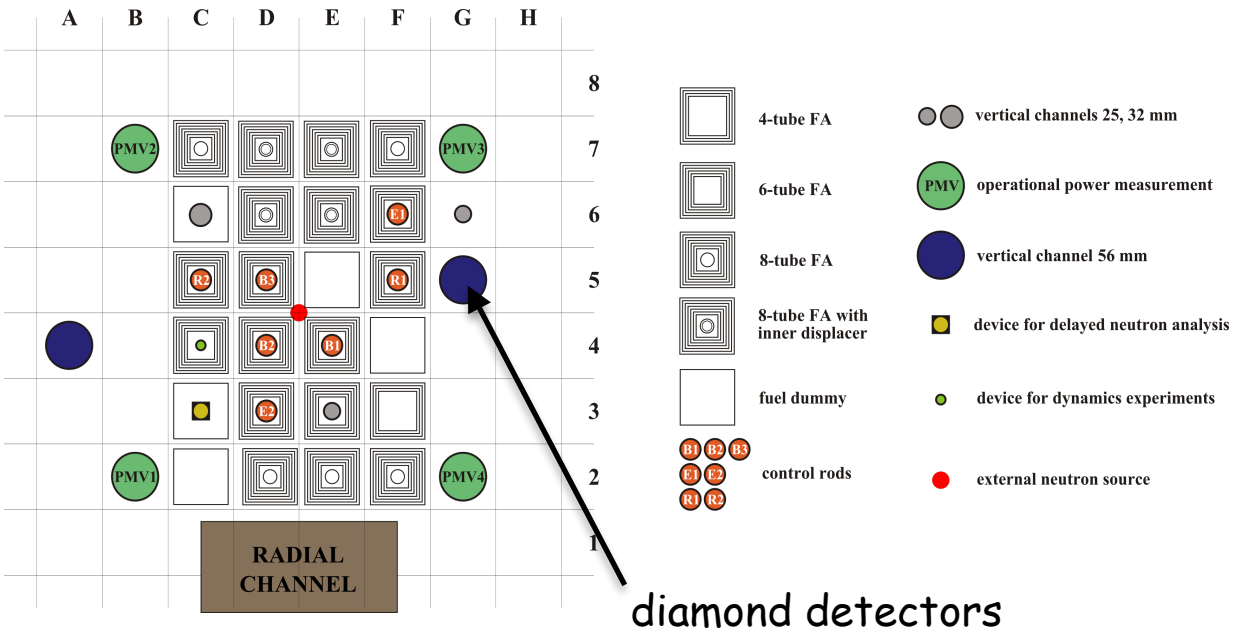




VR1 reactor in Prague

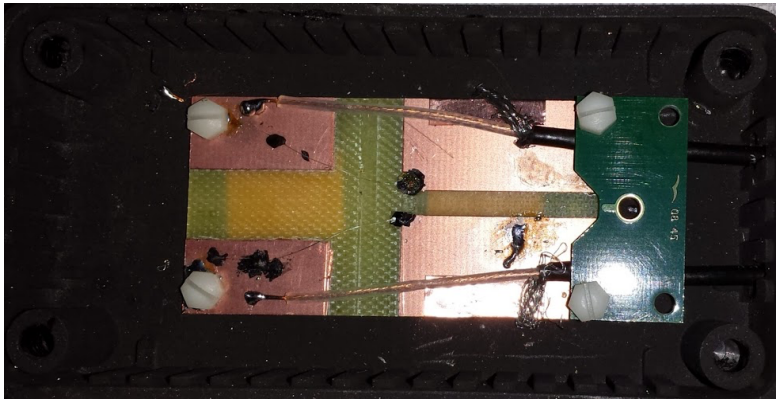


- low power research reactor (max 1kW, 1^10 n/cm2s@500W)
- light water (reflector, shielding, cooling)
- no thermal effects….

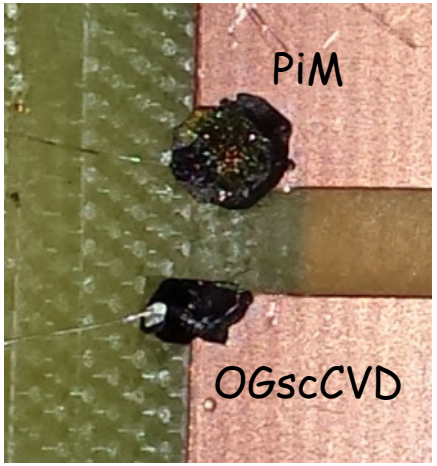


VR1 in-core fluxes correspond to external for HP reactors

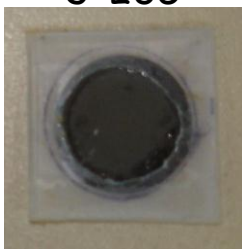
U-235 + Diamond Detectors + Electronics



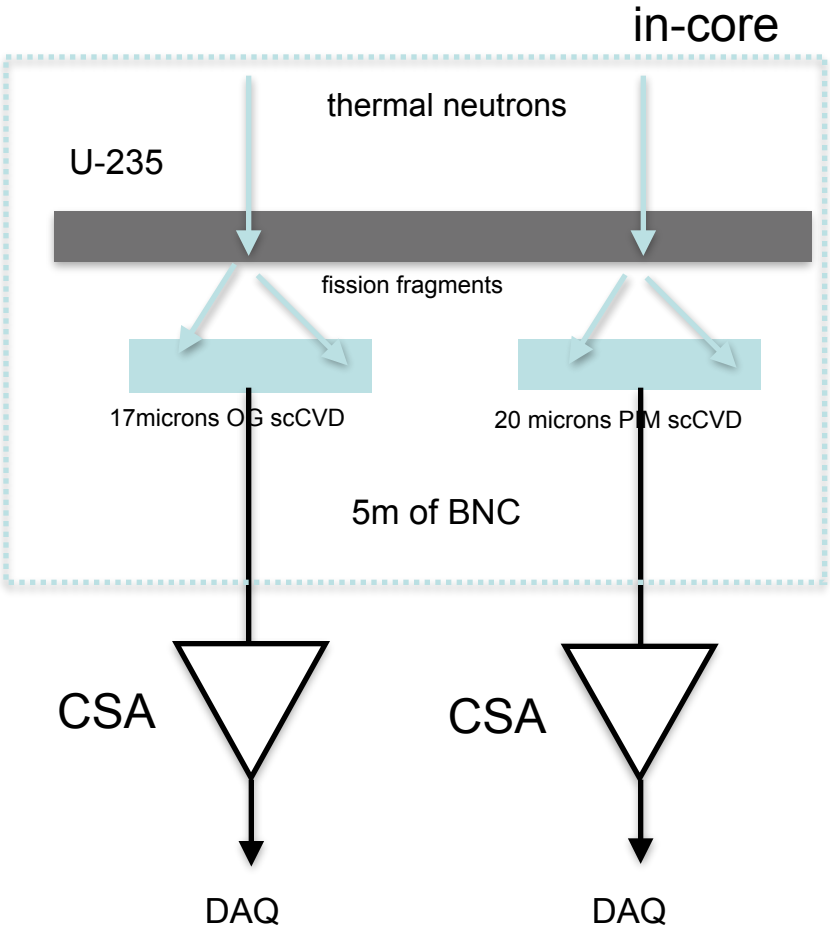
no collimator used



U-235



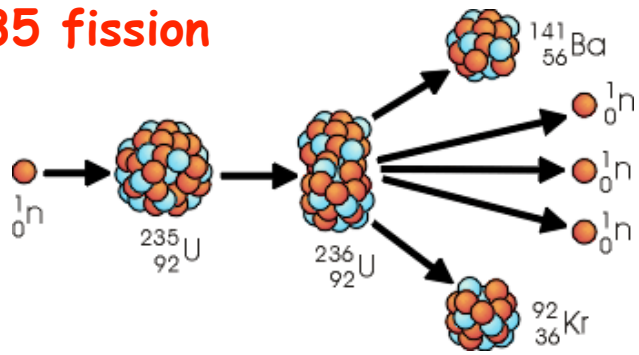
1 cm



bias voltages on read-out electrodes:
OGscCVD +170V(10V/micron) (h-drift)
PiM + 30V(~1.5V/micron) (h-drift)

U-235 + Diamond Detectors + Electronics

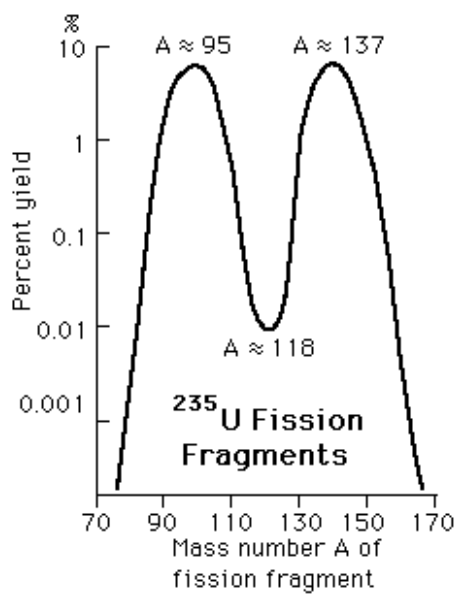
U-235 fission



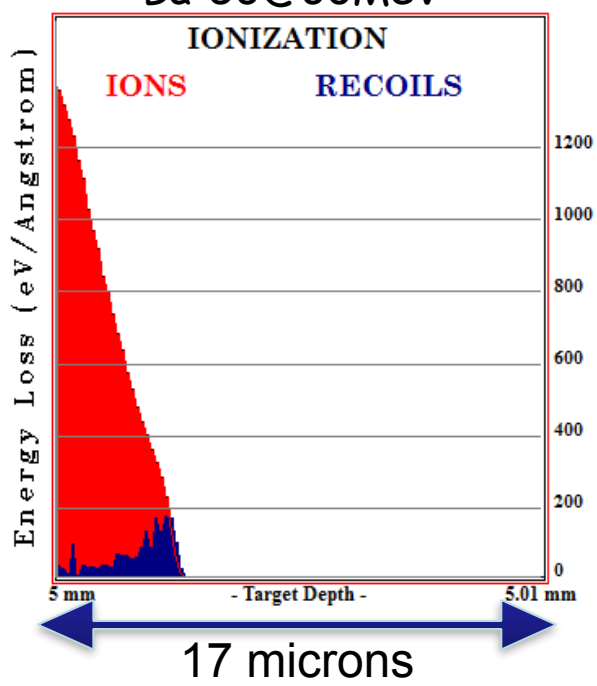
average energy to fission fragments ~170 MeV

after 5mm air (rough estimation)
~80 MeV Kr (~110 MeV)
~35 MeV Ba (~60 MeV)

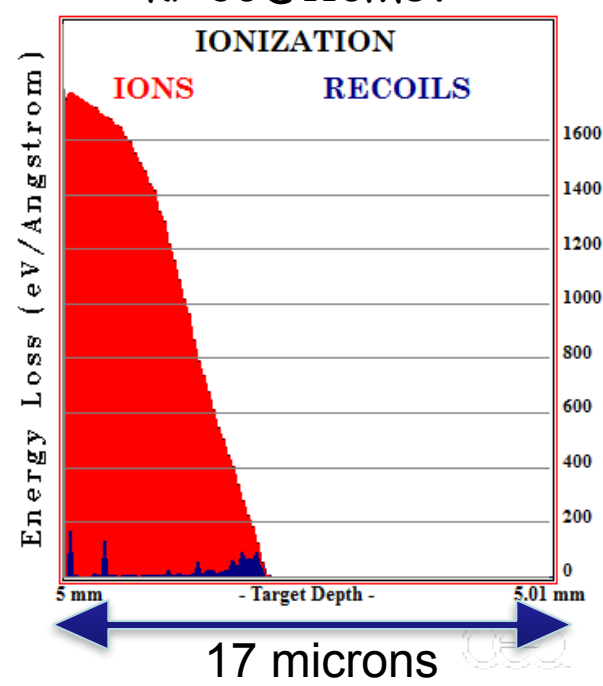
+ alpha decay with 4.679 MeV



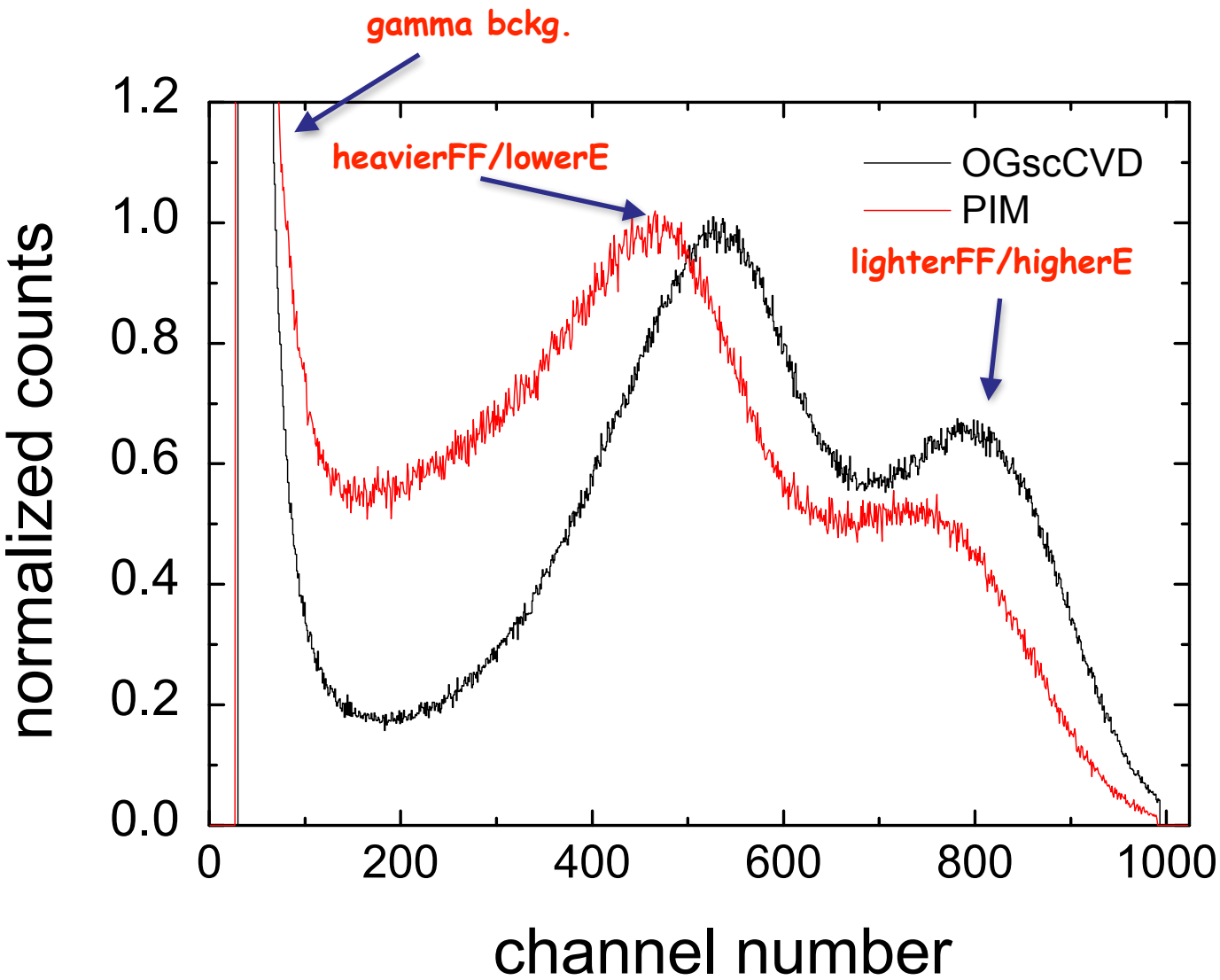
Ba-56@60MeV

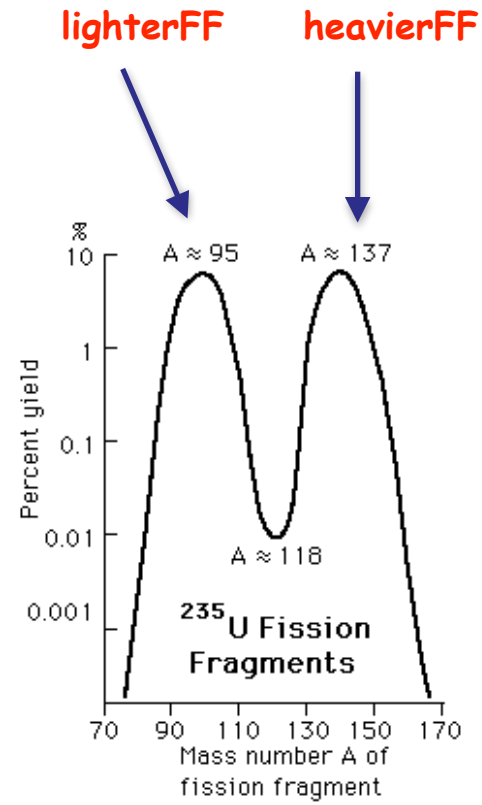


Kr-36@110MeV



Fission Fragments Spectra

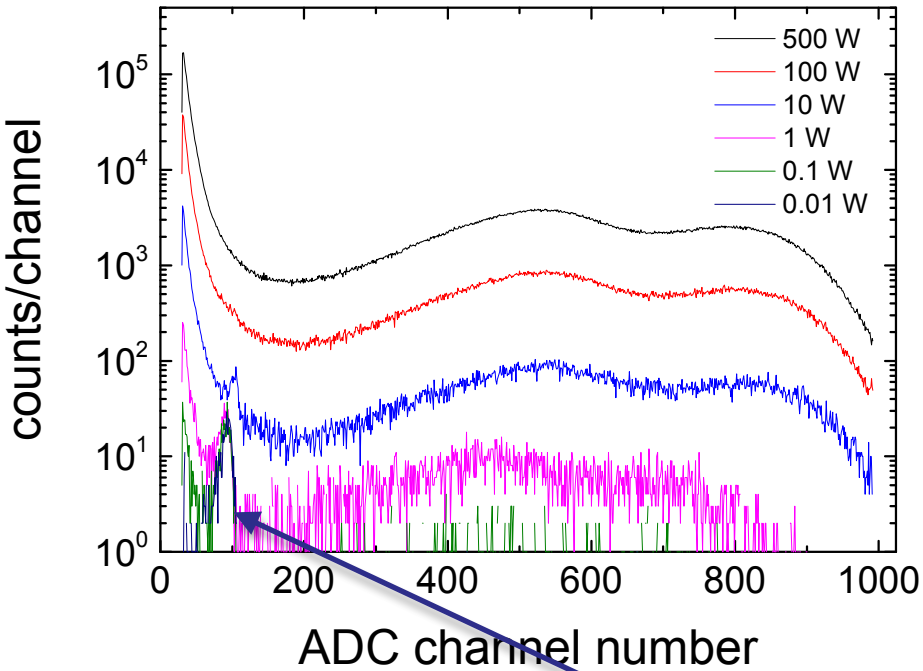




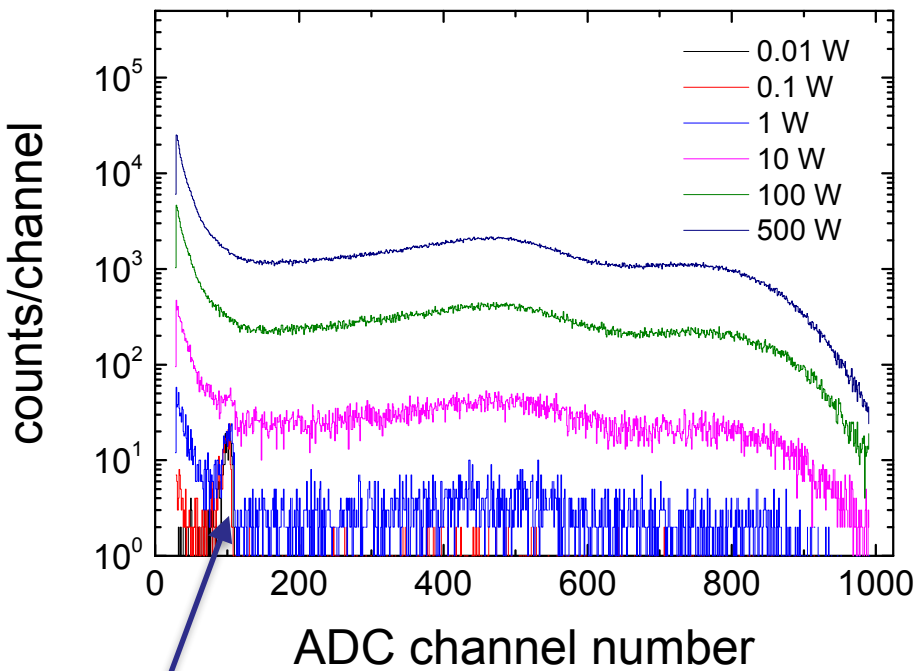
average energy
to fission fragments
~170 MeV

Fission Spectra with Increasing Power

OGscCVD



PiM



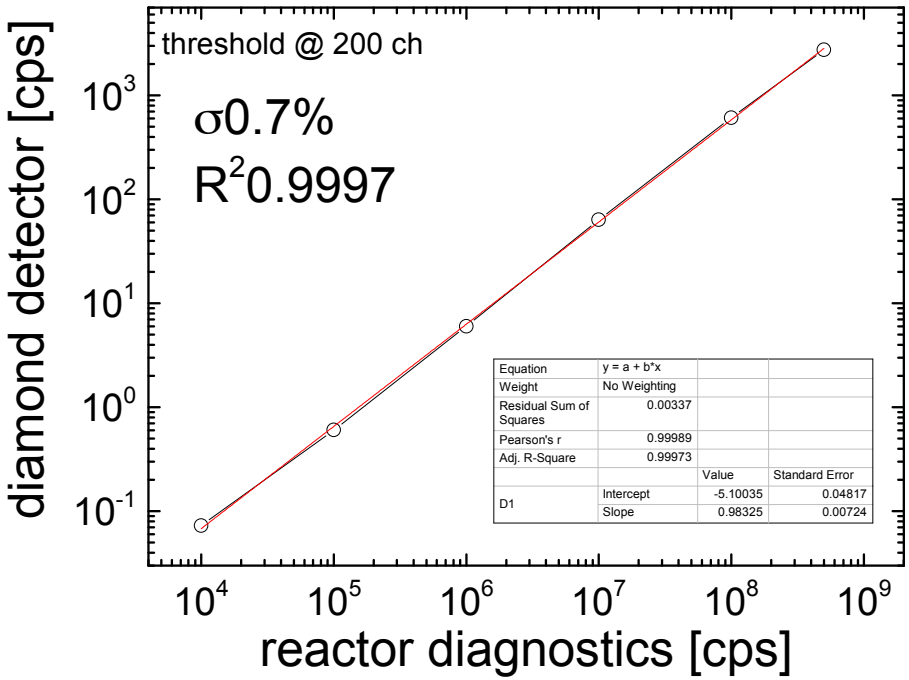
alpha-peak@~4.679MeV

~ 10 min acquisition time

100W ~ 2E9 n/cm2.s (core center)

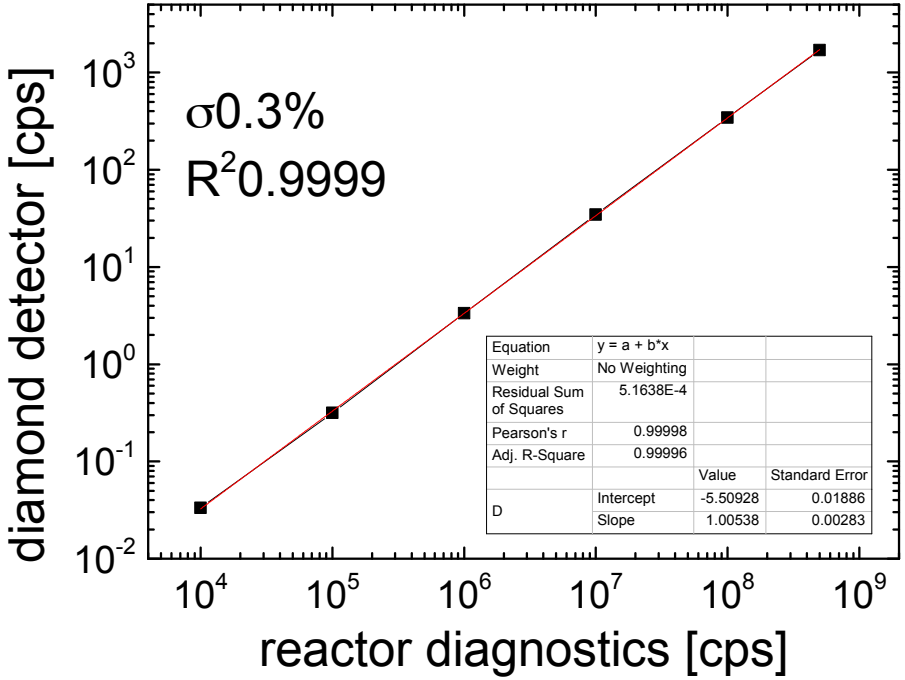
Linearity with Flux

OGscCVD



Equation	y = a + b*x		
Weight	No Weighting		
Residual Sum of Squares	0.00337		
Pearson's r	0.99989		
Adj. R-Square	0.99973		
		Value	Standard Error
D1	Intercept	-5.10035	0.04817
	Slope	0.98325	0.00724

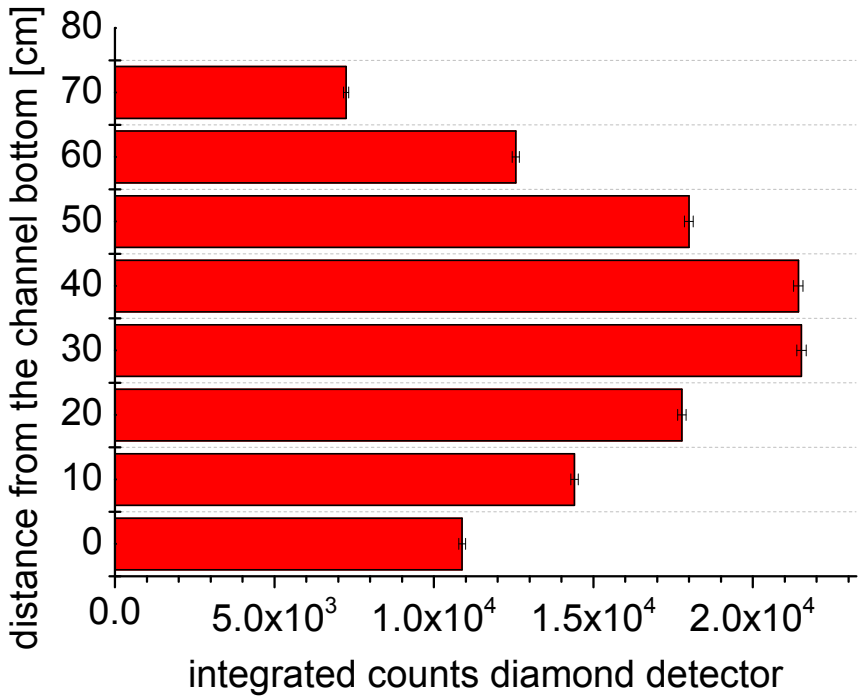
PiM



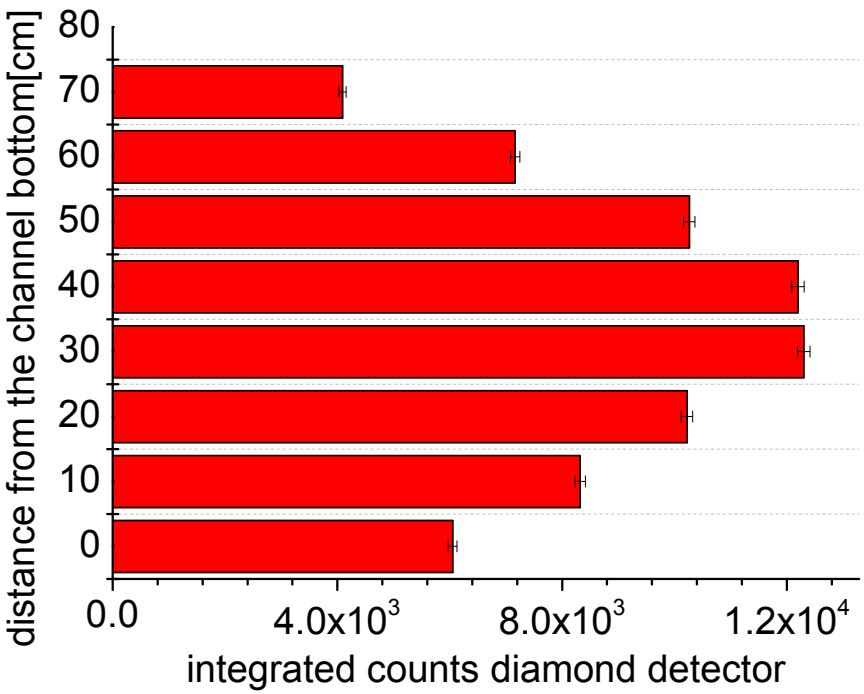
Equation	y = a + b*x		
Weight	No Weighting		
Residual Sum of Squares	5.1638E-4		
Pearson's r	0.99998		
Adj. R-Square	0.99996		
		Value	Standard Error
D	Intercept	-5.50928	0.01886
	Slope	1.00538	0.00283

@100W

OGscCVD

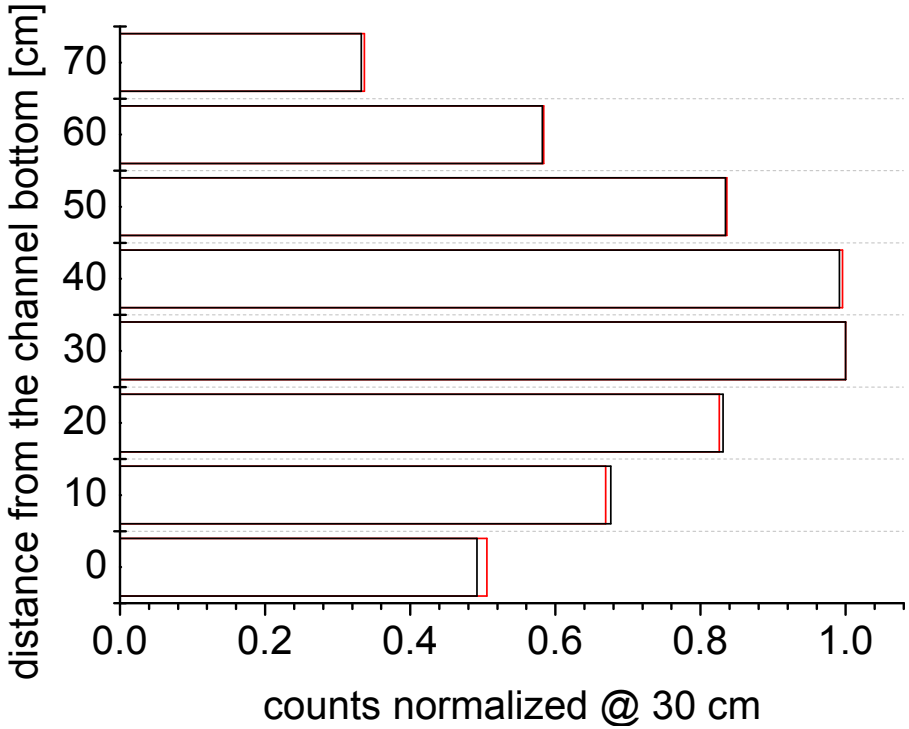


PiM

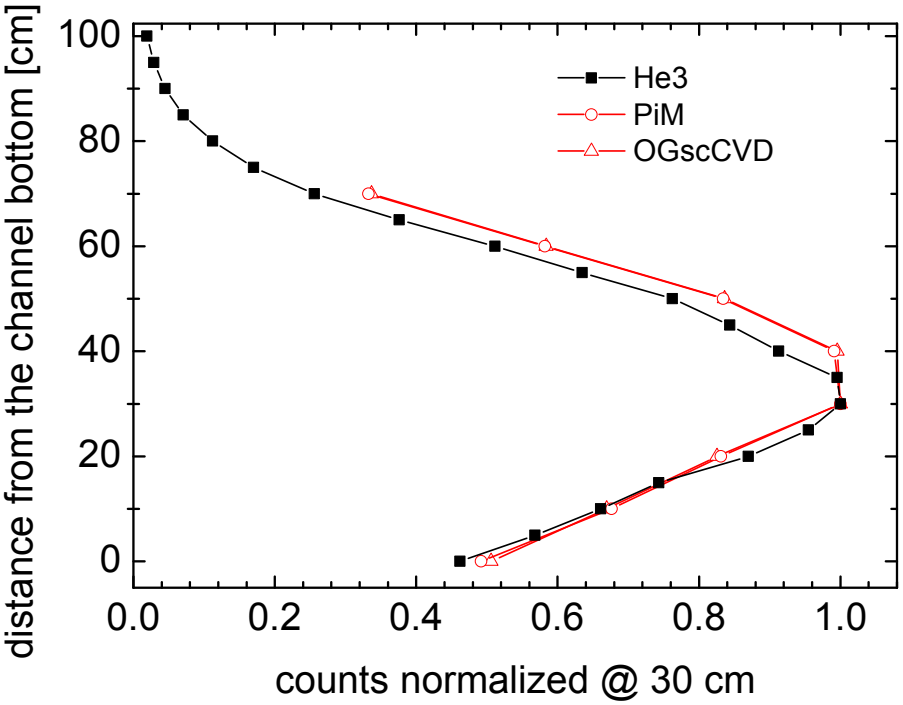


@100W

OGscCVD + PiM

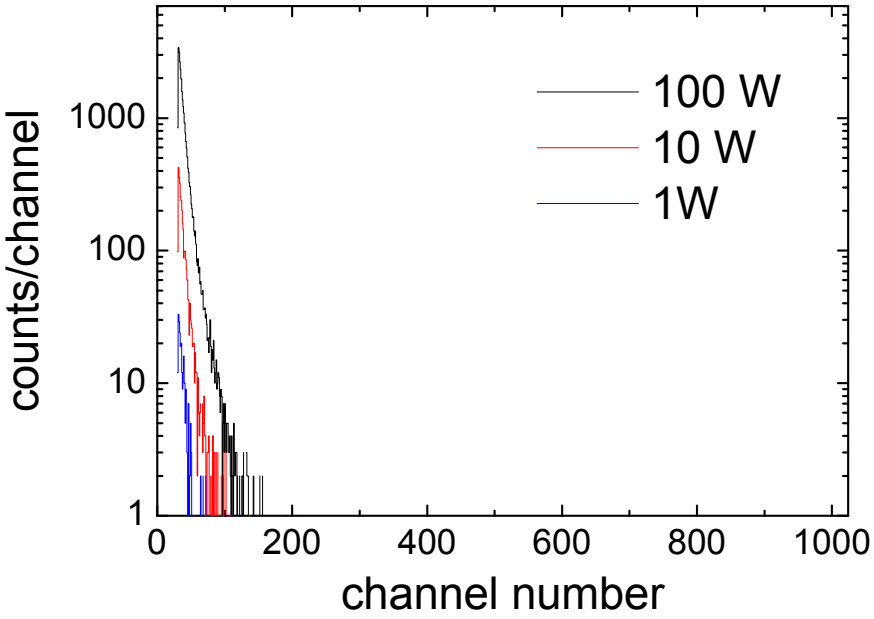


OGscCVD + PiM + He3

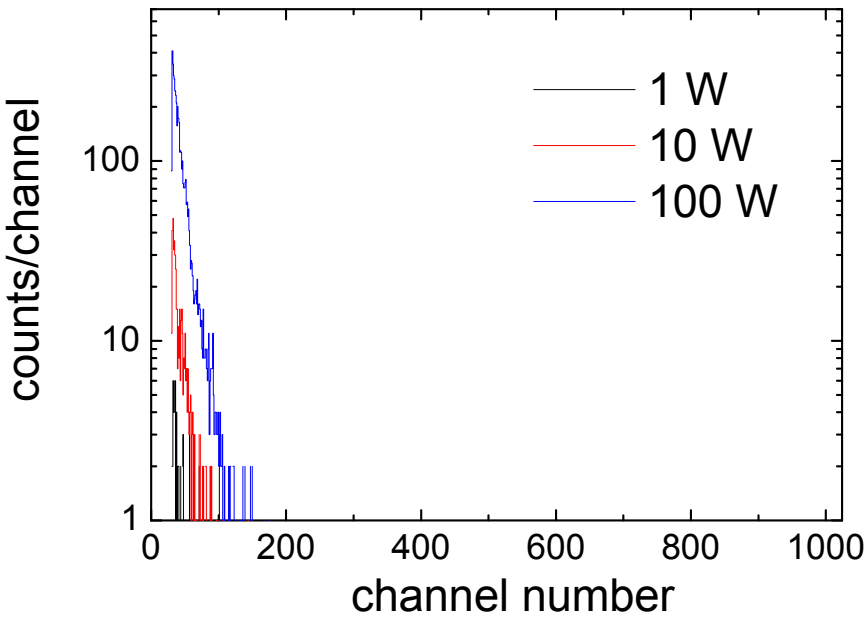


Gamma Background

OGscCVD



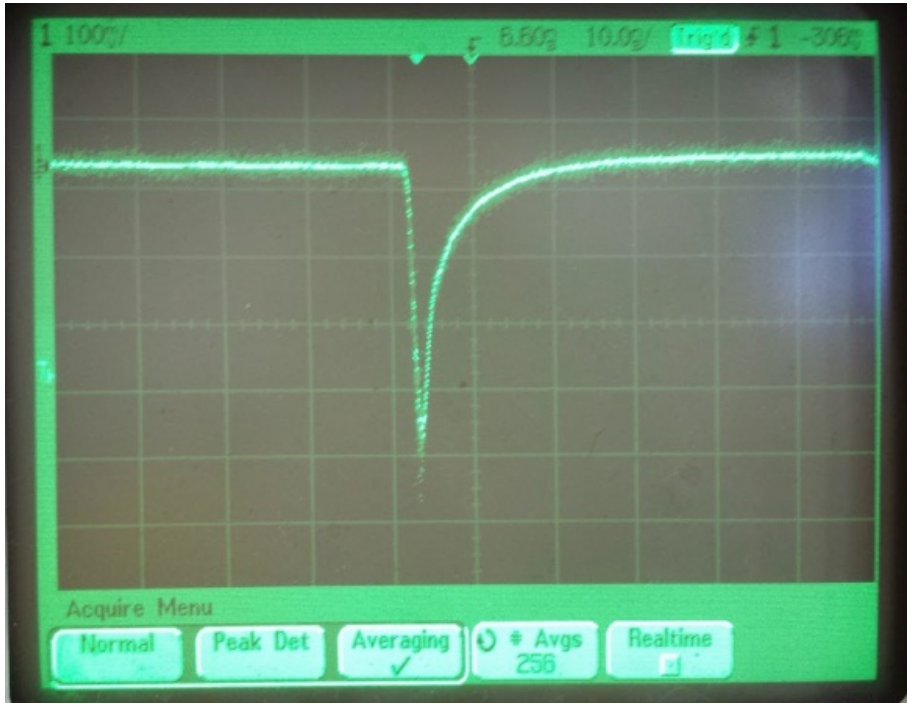
PiM



TCT Signals for OGscCVD

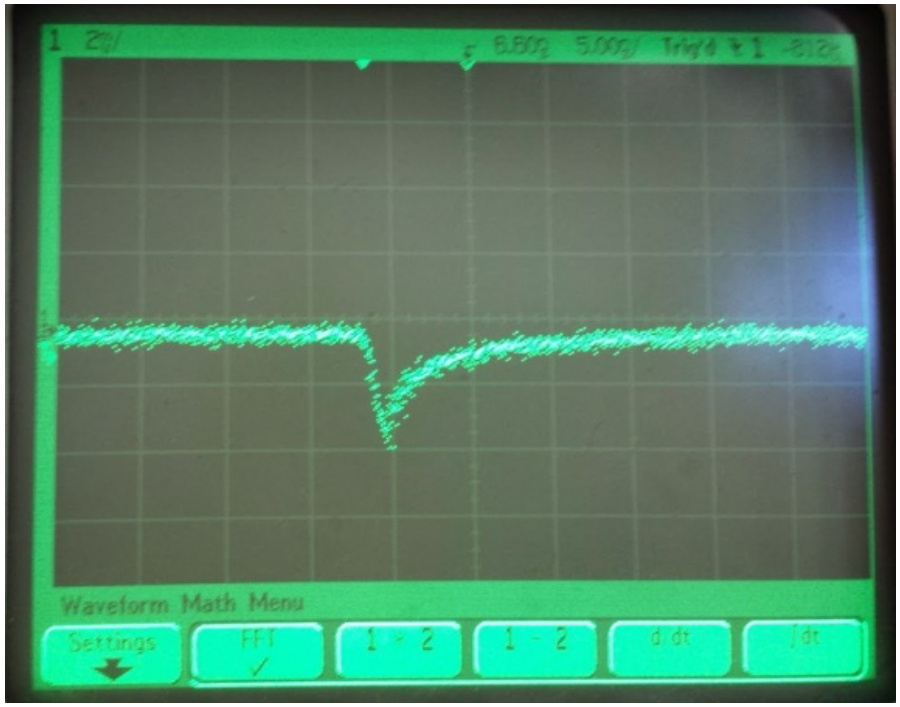
350 MHz DSO@50 Ohm + 5m BNC

CIVIDEC 40dB amplifier

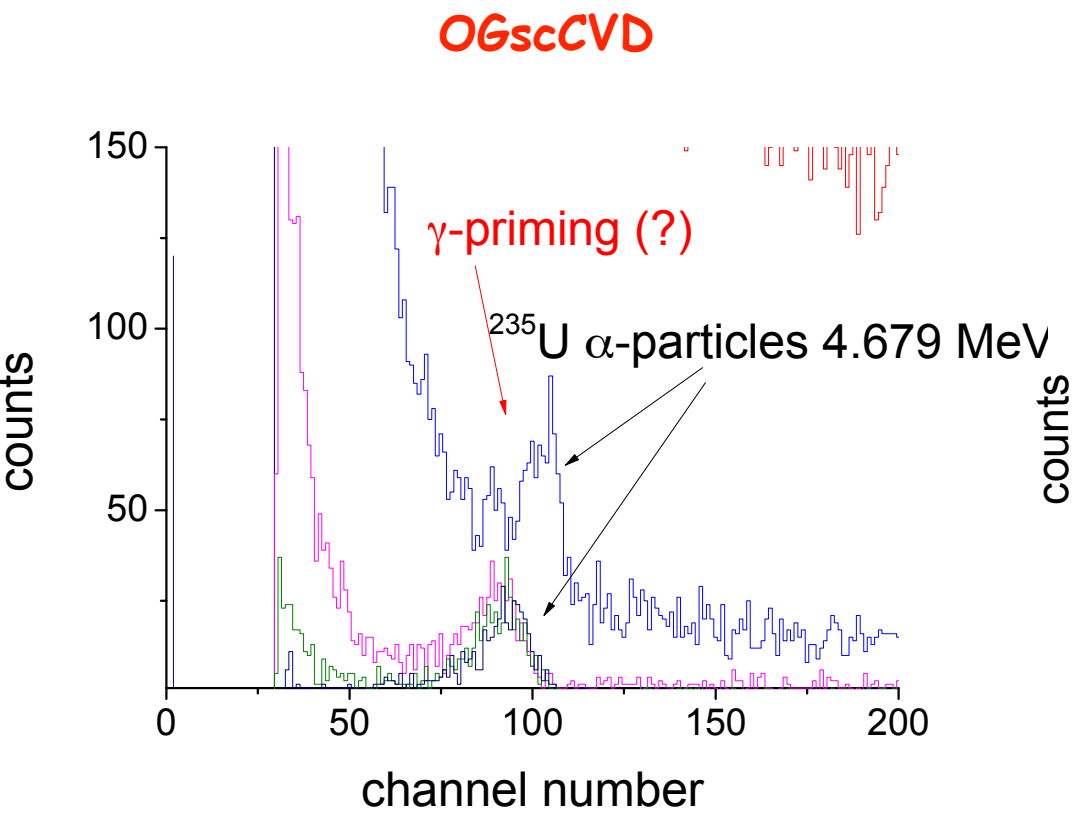


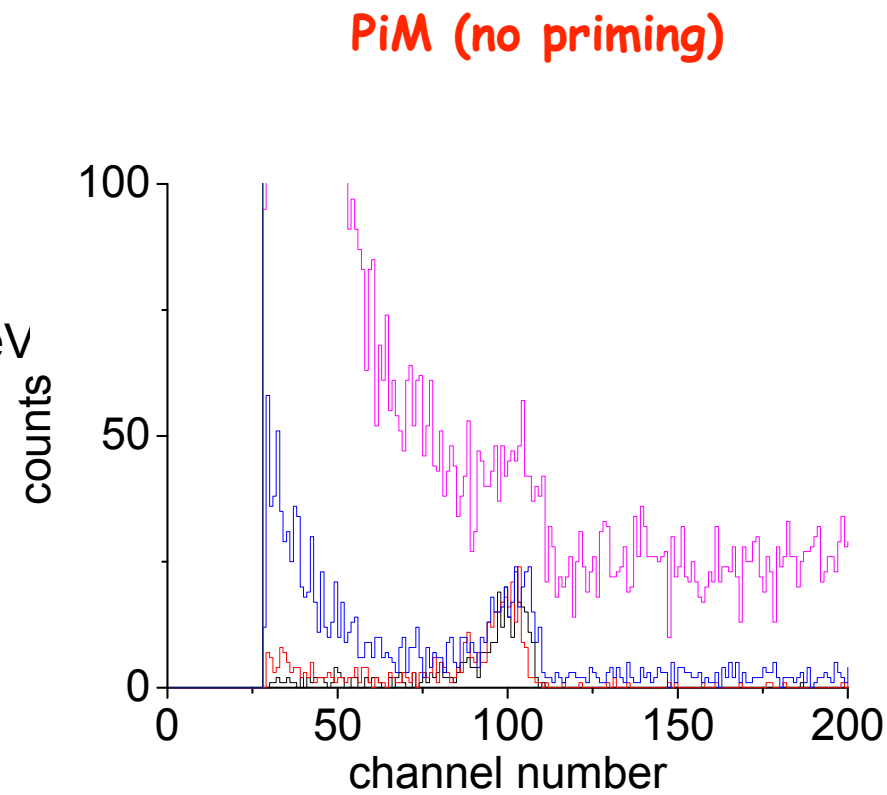
y 100mV/div ; x 10ns/div

no amp, just bias-T



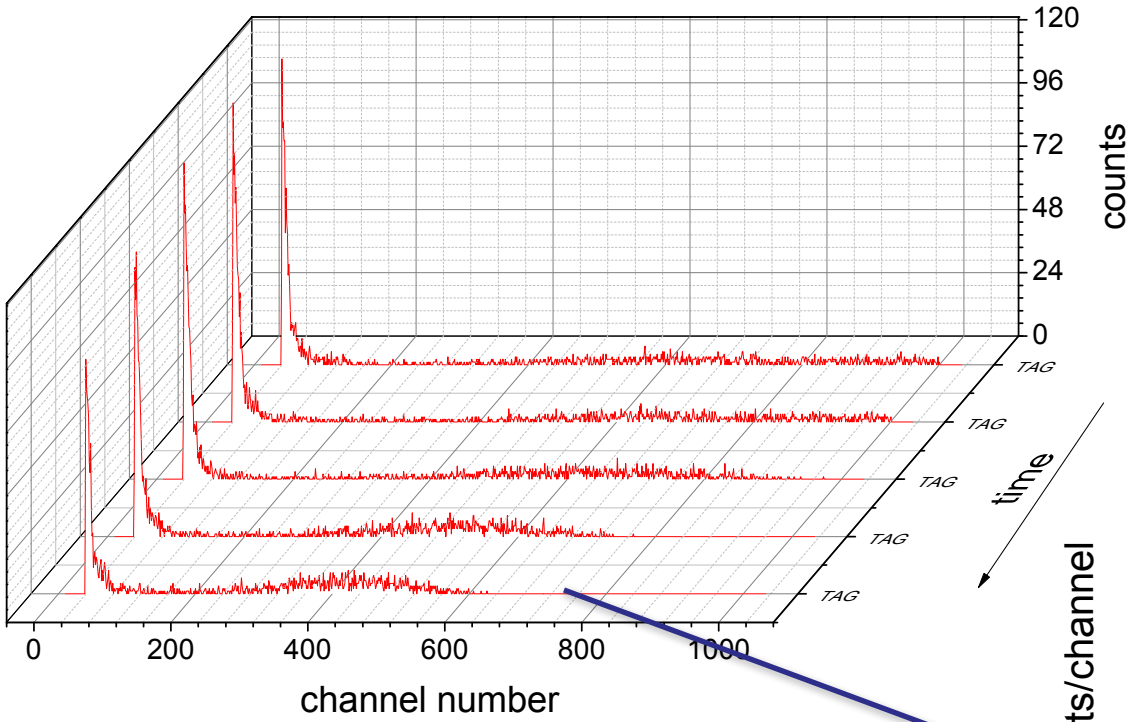
y 2mV/div ; x 5ns/div

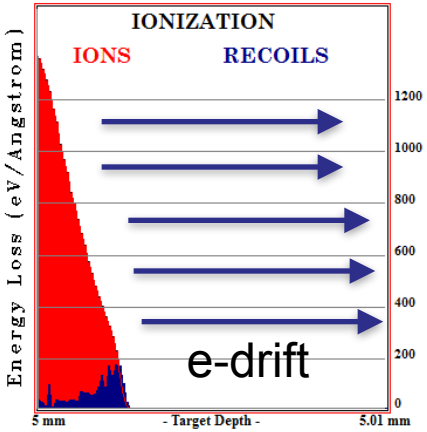

OGscCVD
γ-priming (?)
235U α-particles 4.679 MeV
counts
channel number
0
50
100
150
200

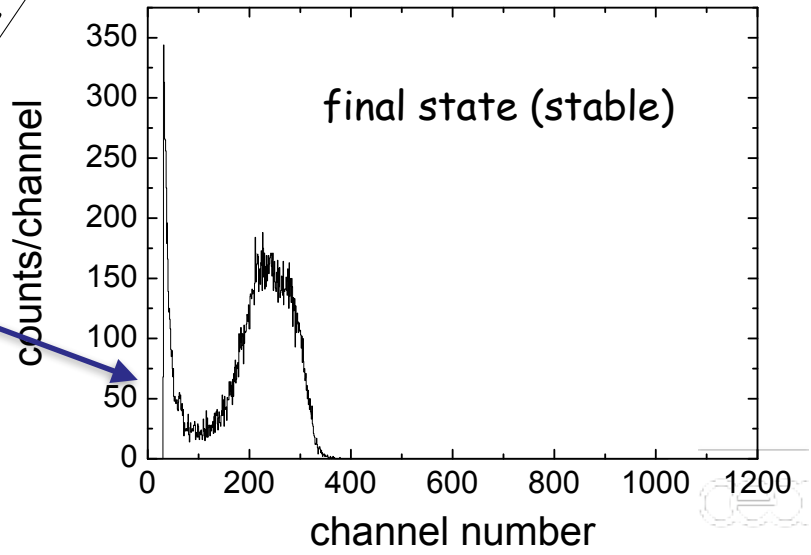

PiM (no priming)
counts
channel number
0
50
100
150
200

Some More Observations

Polarisation of OGscCVD@-170V majority of e-drift



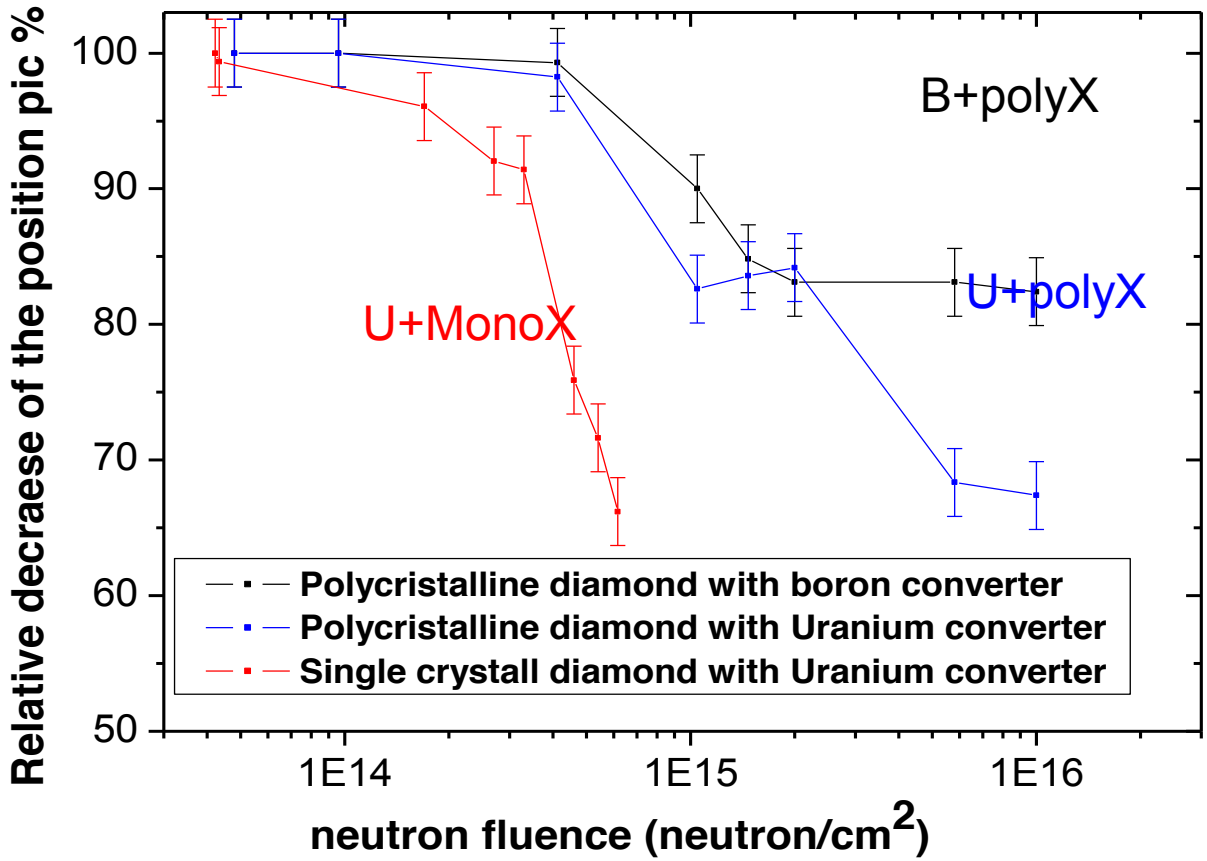




strong electron trapping in OGscCVD…..

Radiation Hardness Issue

From previous work, Christine Mer et. al MonoX=EGscCVD ~200 microns thick



should be better for thin detectors, and even better for membranes……

Summary and Outlook

- use of U-235 as converter material - with FF of high energy
- diamond micro-fission chamber based on 'cheap' OG material concept proved:
    - stable operation (FF up to 5kHz tested), perfect linearity
    - high n/gamma ratio
    - possibility to operate with no amps…maybe HTemp etc……

some open questions:

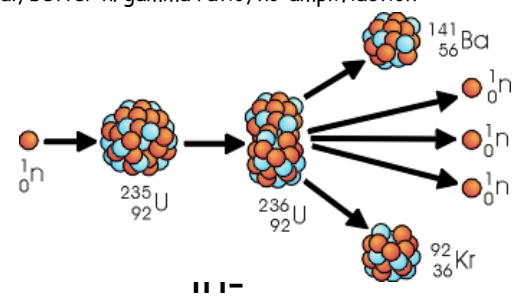
- sensitivity, RH

What can be 'easily' improved:

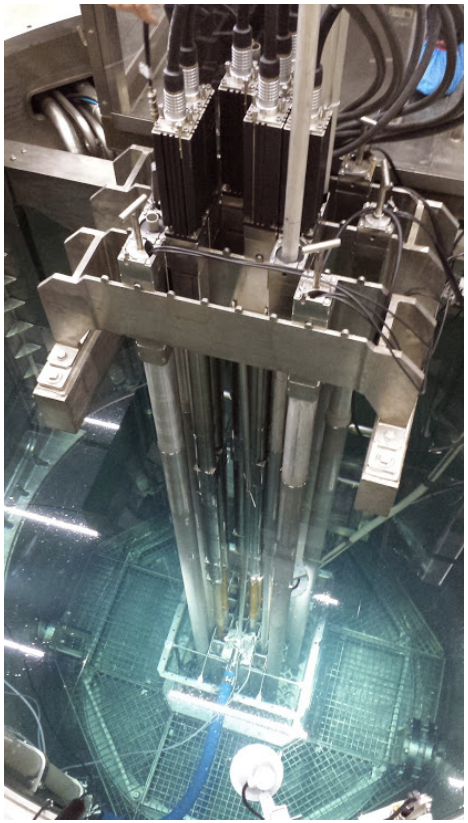
- sensitivity/count rate x100 —> larger samples+contact size+sandwich conf.
- larger TCT signals —> better electronics, U-235 precipitation on diamond
    - (Philippe talk)
- better gamma/neutron ratio —> U-235 electro-precipitation on diamond
- improved RH —> membrane OGscCVD, thinner i-layer = no implantation

Diamond as micro solid-state fission chamber:

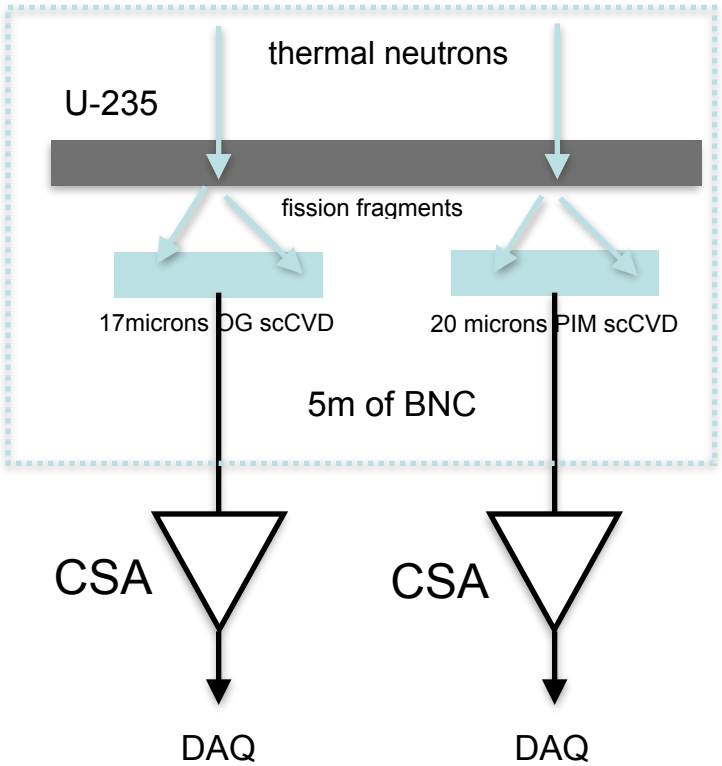
U-235- lower crossection, but heavy fragments large signal, better n/gamma ratio, no-amplifiaction needed



VR1 training reactor in Prague



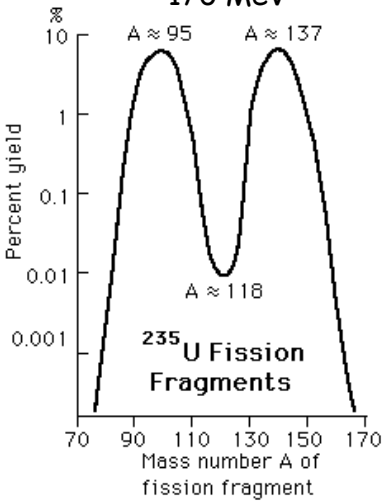
facility with open access please contact:**lubomir.sklenka**@fjfi.cvut.cz



First Applications

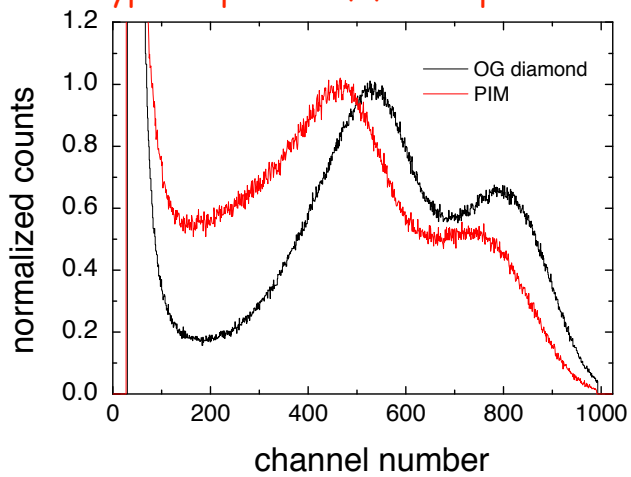
In-core thermal neutron monitoring

average energy fission fragments ~170 MeV

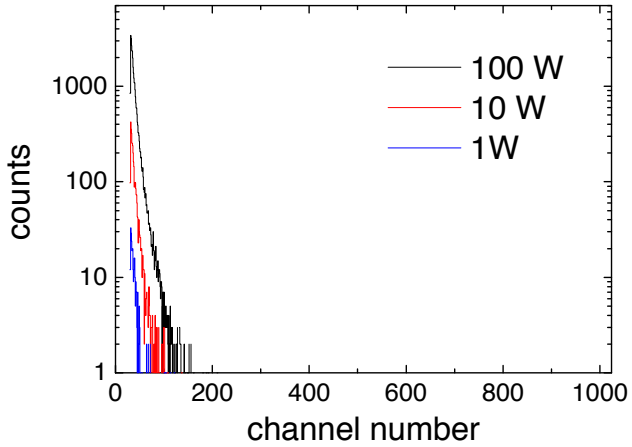


U-235 alpha 4.679 MeV

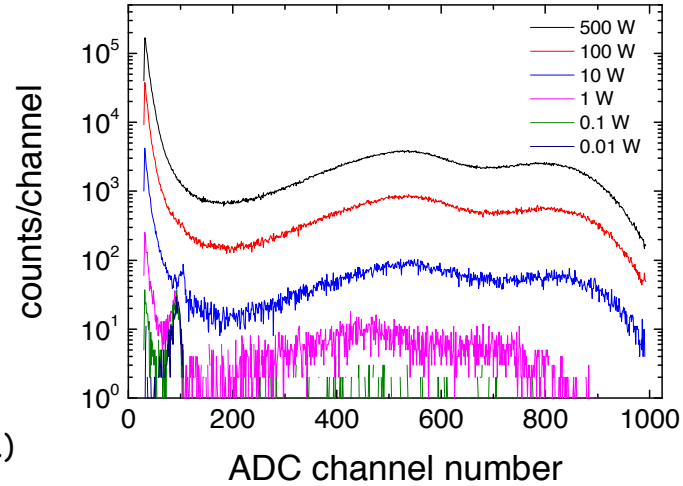
typical spectra of fission products



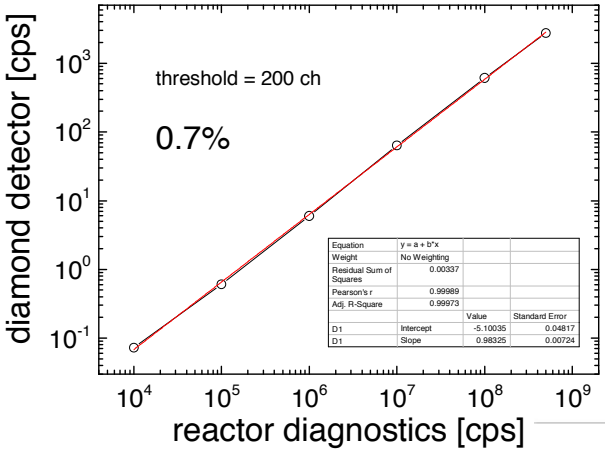
gamma background



varying reactor power (acq. 10min)



linearity vs. reactor diagnostics



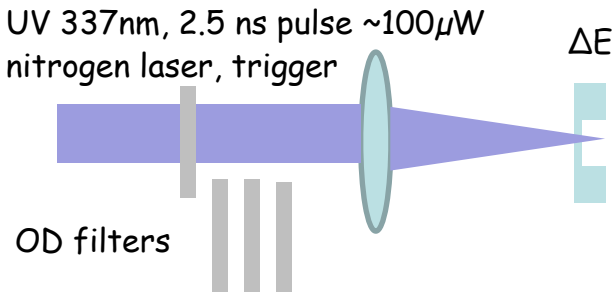
easy to optimise:

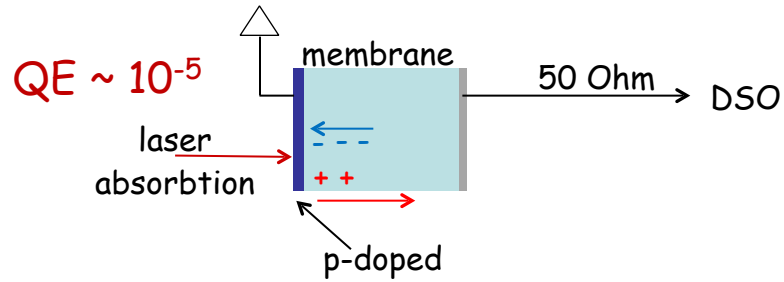
- U-235 deposition onto diamond
- thinner membrane (RH, gamm/n)
- larger surface, sandwiching (sens.)

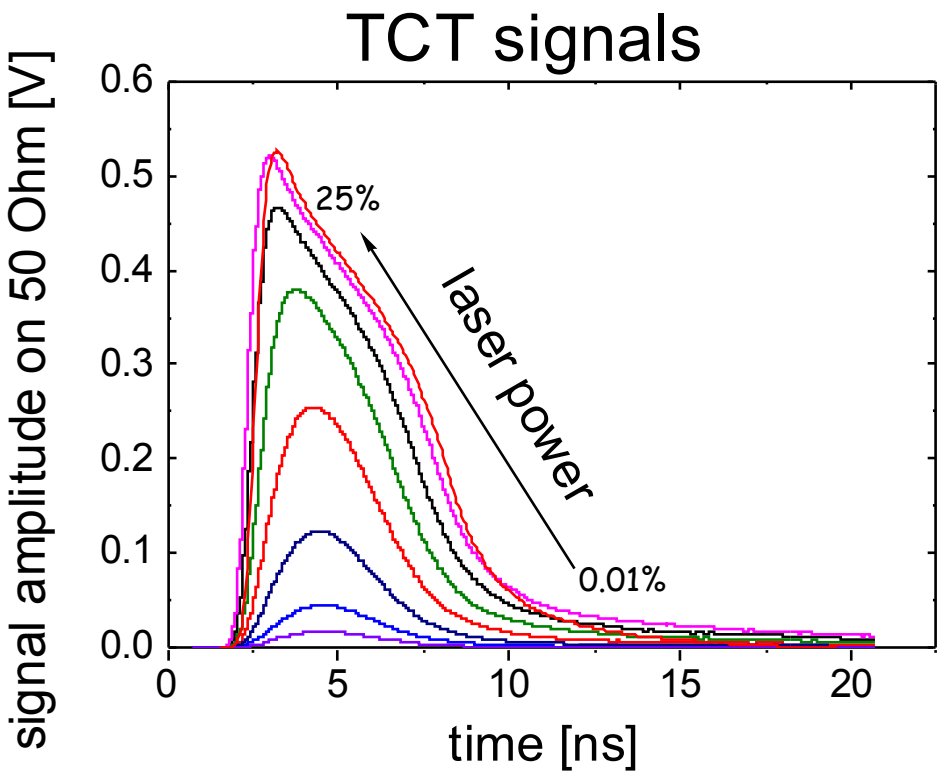
Thanks for your attention!

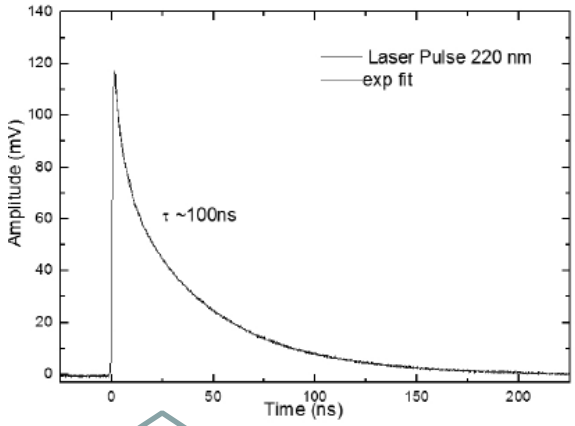
Electronic Properties

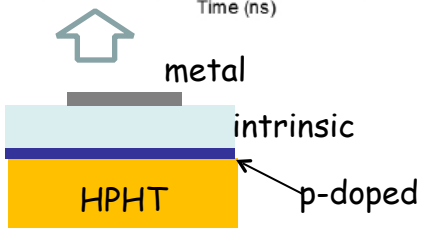
UV 337nm laser TCT Photovoltaic Mode (zero-bias)











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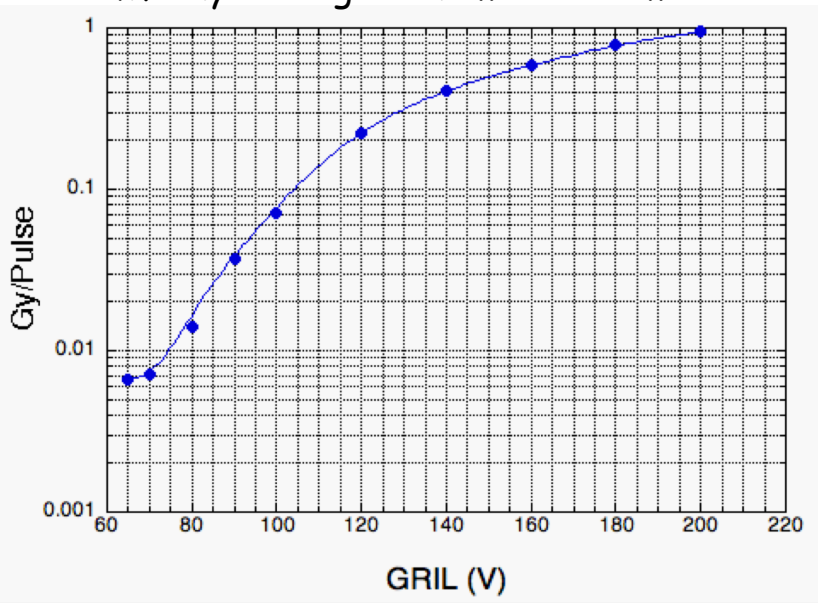
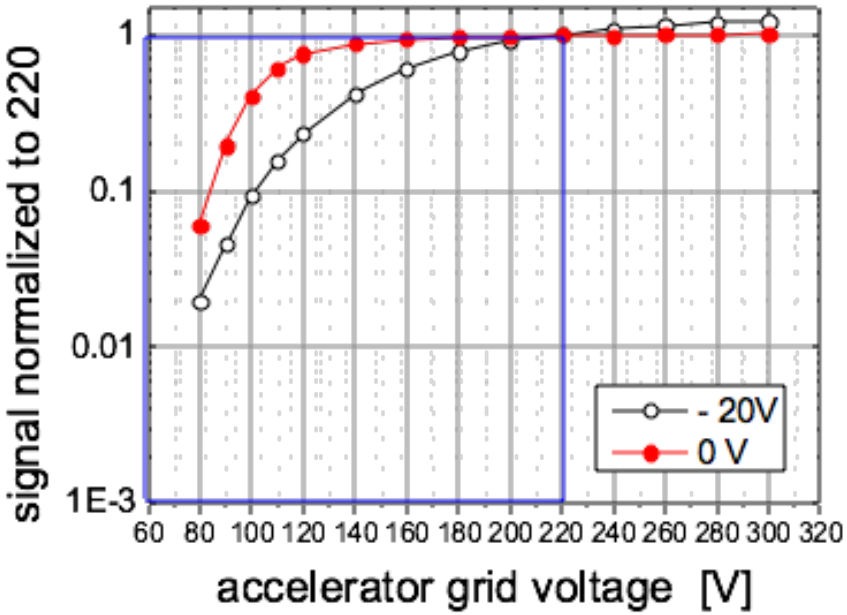
First Application

PIM Membrane 'Dosimetry'

Methyl Viologen chemical dosimeter



PIM membrane 'dosimeter'



First Application

Zero-Bias Compared to 'Normal' Operation (bias-T – 20V applied)