Diamond Detectors Ltd

Diamond
Diagnostics for Research and Industry

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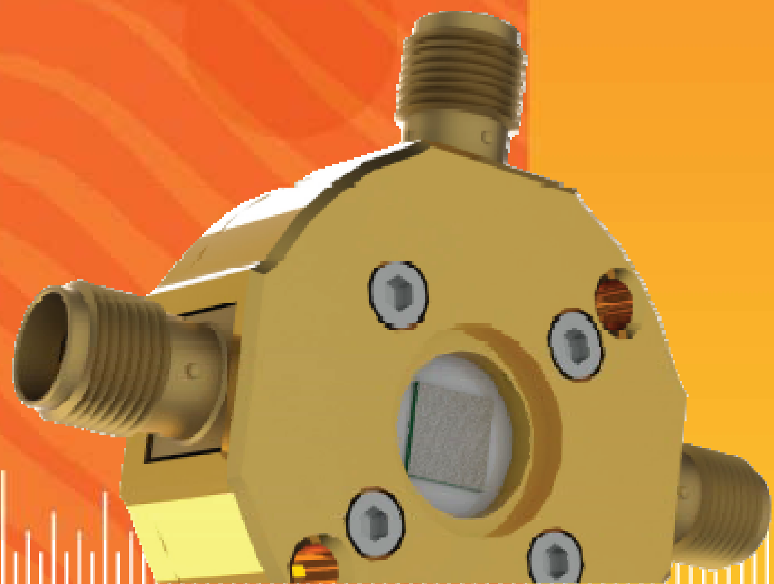
CEO
Diamond Detectors Ltd
Poole UK



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Aim of this presentation

To introduce DDL and inform the trainees on the properties of diamond and why this material is of interest for diagnostics in current and future accelerators in both research and industrial applications.

This will include a broad range of properties including its mechanical, thermal, optical and electronic properties and how they are used in various applications diagnostics from windows, screens and detectors.

We will then, by example look at some sample applications in which diamond has been or is being used in diagnostics. These will be projects that are in proposal stage having conducted or conducting tests on prototype diamond devices.

At the end of this presentation I hope to have made you aware that diamond is becoming a real alternative to traditional ion-chambers and silicon devices across a range of diagnostics.

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The brief history of Diamond Detectors Ltd

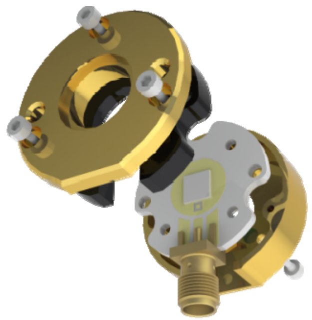
Poole, Dorset
South West England

Press release 3rd May 2007
"Element Six Spins Out New Company to Develop Diamond Detectors…."

November 2008
BAE acquires 50% share in DDL.

elementsix

BAE SYSTEMS



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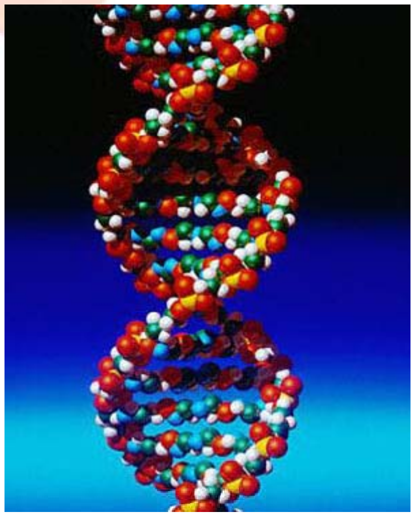
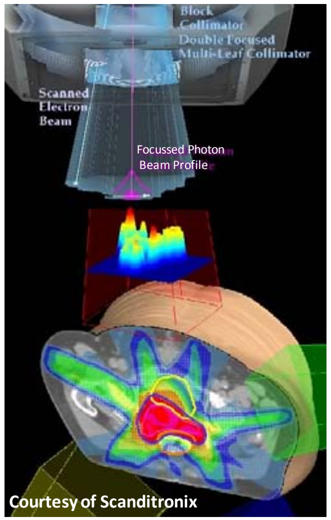
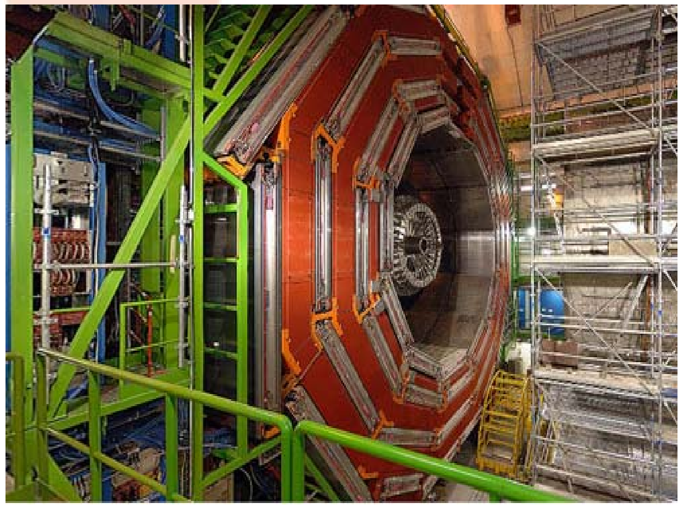
High Tech Application of Diamond

Diamond Detectors focus includes...

- Diamond Wide Band Gap Detectors. (solid state ionizing chamber)
- Diamond BDD Sensors (micro focus X-ray-Targets, Bio/Chemical apps)
- Diamond Thermal Applications to support diagnostics.
- Diamond Flat Windows (e.g Fluorescence Monitors/Windows)







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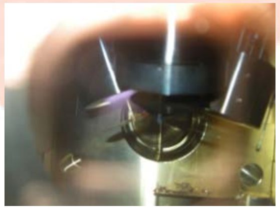
"From Concept through Design & Prototype to Manufacture"

Device Fabrication

Quazer Laser Dicing

Magnetron Sputtering



Laser cutting, dicing & sputtering system

Sputtering & E-Beam Evaporation & Milling

Metallisation

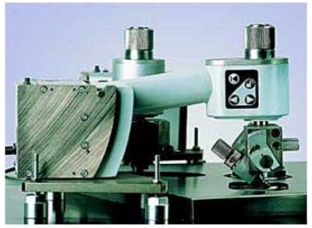
Dage 4000 Wire bond pull tester

Aluminium & Gold wedge and ball wire bonding

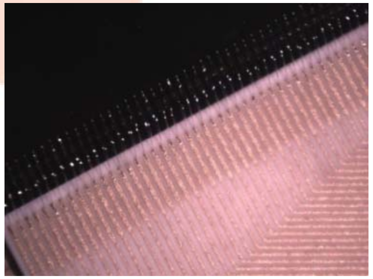
ball bonding (K&S 4124)

Optical Profiler NT9100

Semi Automatic Scaife



Lapping, Polishing and Semi-automatic scaife



Universal wedge bonder (K&S 4523)

Wire Bonding (Strip Detector)

Pixel and Strip Devices for Positional Information

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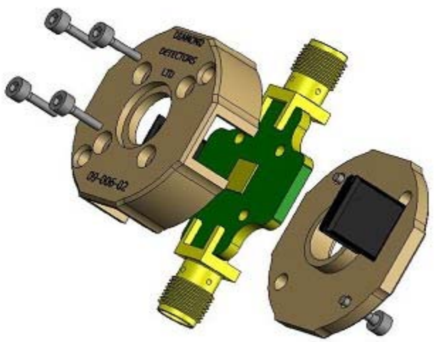
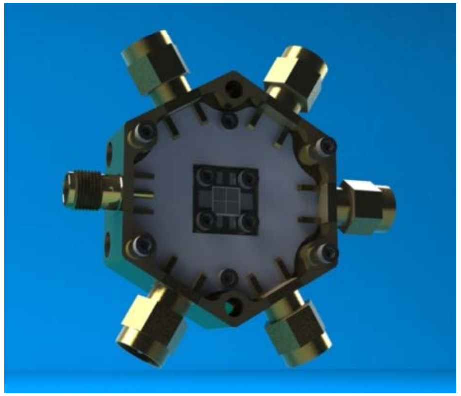
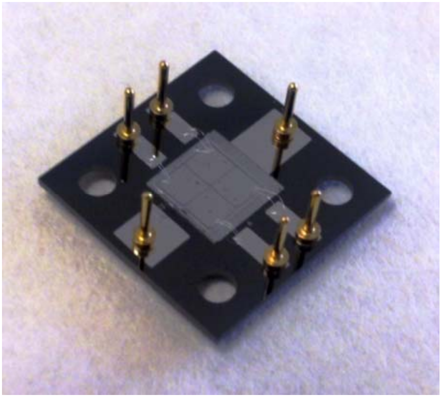
"From Concept through Design & Prototype to Manufacture"

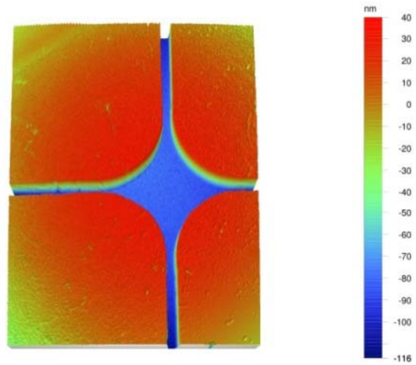
Concept - Design





Evaluation Devices





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Diamond History & Exploitation

Diamond is not a new technology and as early as 1920's highly selected natural diamonds (IIA) were being used for UV detectors.

Diamond applications have historically been limited predominantly due to the availability of suitable diamond substrates; the price of highly selected natural diamonds and the slow commercial exploitation by industry into devices.

This has been a catch-22 where one party waits upon another before making a decision to exploit the material properties. Device manufacturers have been waiting on uniform, repeatable material that is available in suitable quantities.

This was never going to happen with natural diamond products but in recent years the commercial development of synthetically grown high quality materials from companies like E6 have opened the door to companies like DDL to explore a range of diagnostic applications.

Synthetic diamond is an engineered product available in a range of grades from thermal grade products to high purity electronic grade single and polycrystalline wafers.

Diamond was synthesized for the first time by ASEA in Sweden 1953 (but first patent awarded to GE)

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More synthetic diamond produced than global natural gem production

Global Natural Diamond Production

Global Synthetic Diamond Production

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Why commercial exploitation of diamond devices has been slow:-

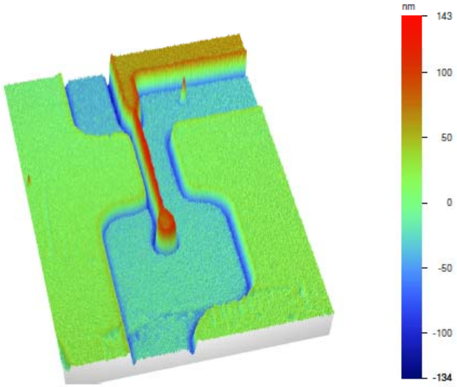
Uniform and guaranteed material supply along with significant improvements in the development of synthetic material means that companies can now look at ways of exploiting the benefits of the material. A number of challenge still exist but on the whole it is now possible to get reproducible material at reasonable cost. The second hurdle has been the skills necessary to process diamond. These although akin to other semiconductor processes do differ particularly in processing the diamond to the appropriate geometry for the application and as a wide band gap material in good electrical contacts.

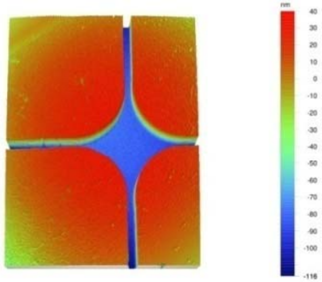
Facilities

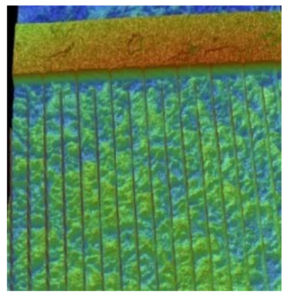
Chemistry Lab
Laser Lab
Diamond Lab
Lithography and Assembly
Clean rooms.
Mechanical & Electrical Design
Lithography/Sputtering room

Expertise

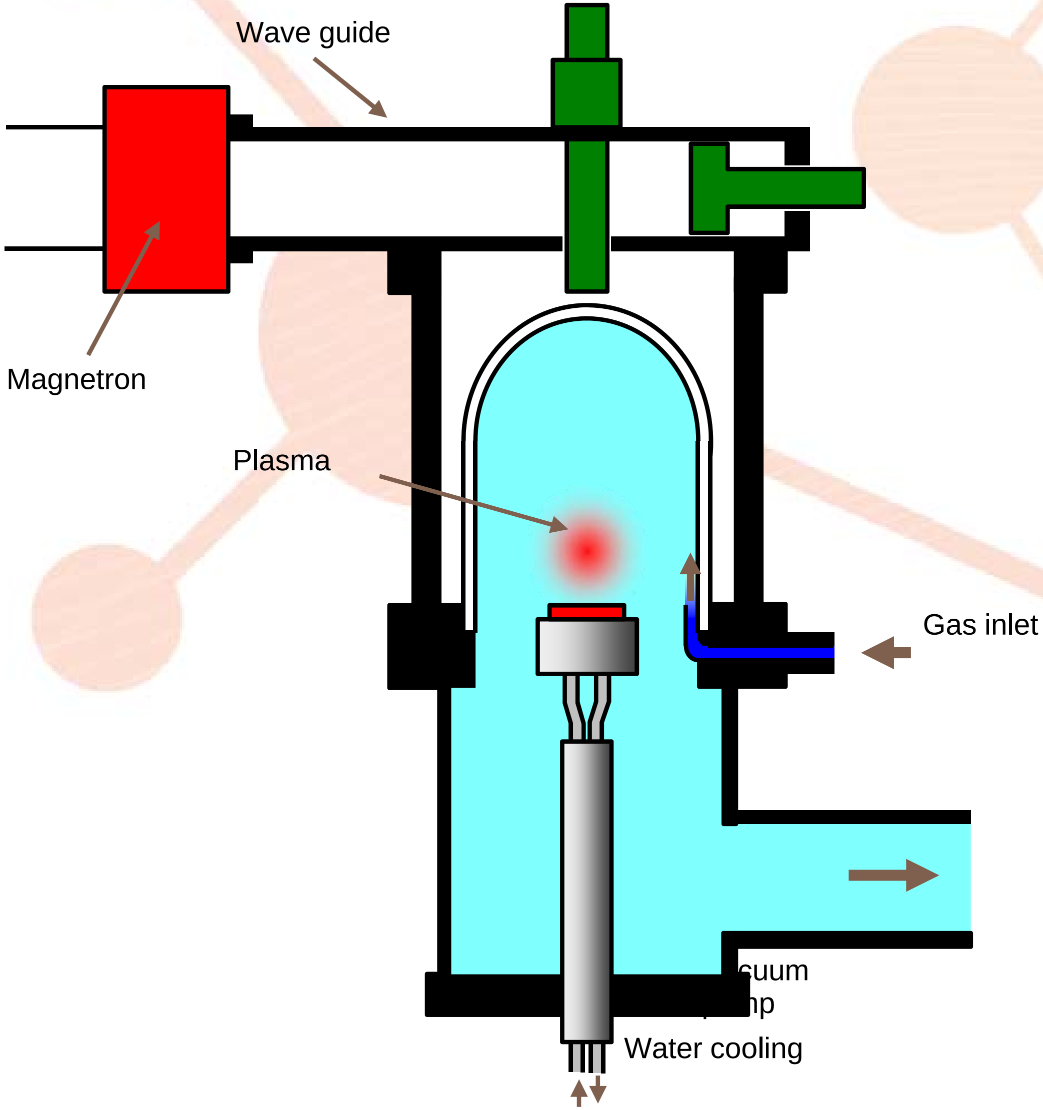
Material Processing
Laser Dicing & Shaping
Lapping & Polishing Processes
Metallization (e.g. DLC,Ti, Pt, Au, Al)
Neutron Scintillation Coating ^{6}LiF
Lithography
Die Fabrication and Test
Die/Wire Bonding.
Packaging
Characterisation.
Electronics Development







CVD Diamond


Wave guide
Magnetron
Plasma
Gas inlet
cuum
np
Water cooling

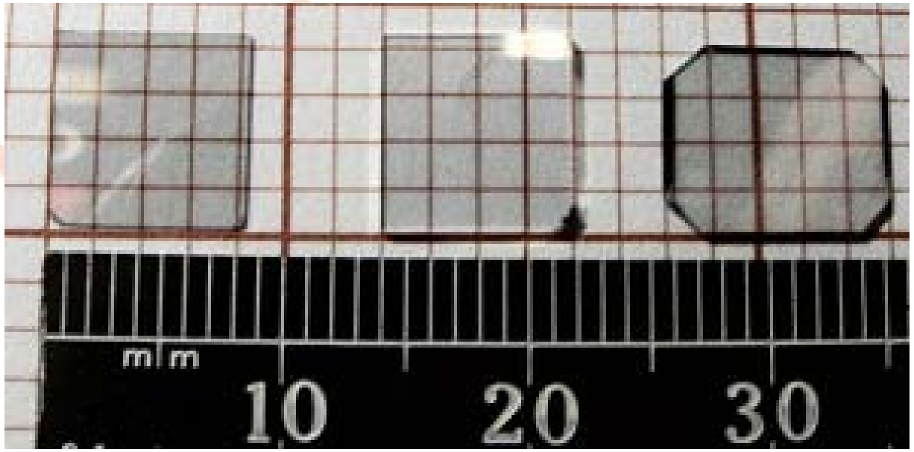
Electronic grades of CVD diamond produced

Intrinsic Polycrystalline

μe = 1800 cm2/Vs
μh = 1000 cm2/Vs
T ~ 1-10 ns
VBD ~ 0.5 MV/cm

CCD ~250 μm at 1 V/μm field

Intrinsic single crystal



μ_e = 4500 cm^2/Vs
μ_h = 3800 cm^2/Vs
T ~ 2000 ns
V_{BD} ~ 4 MV/cm

CCD is thickness limited

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Cross Section CVD Diamond

- **Processing Diamond to Thickness**

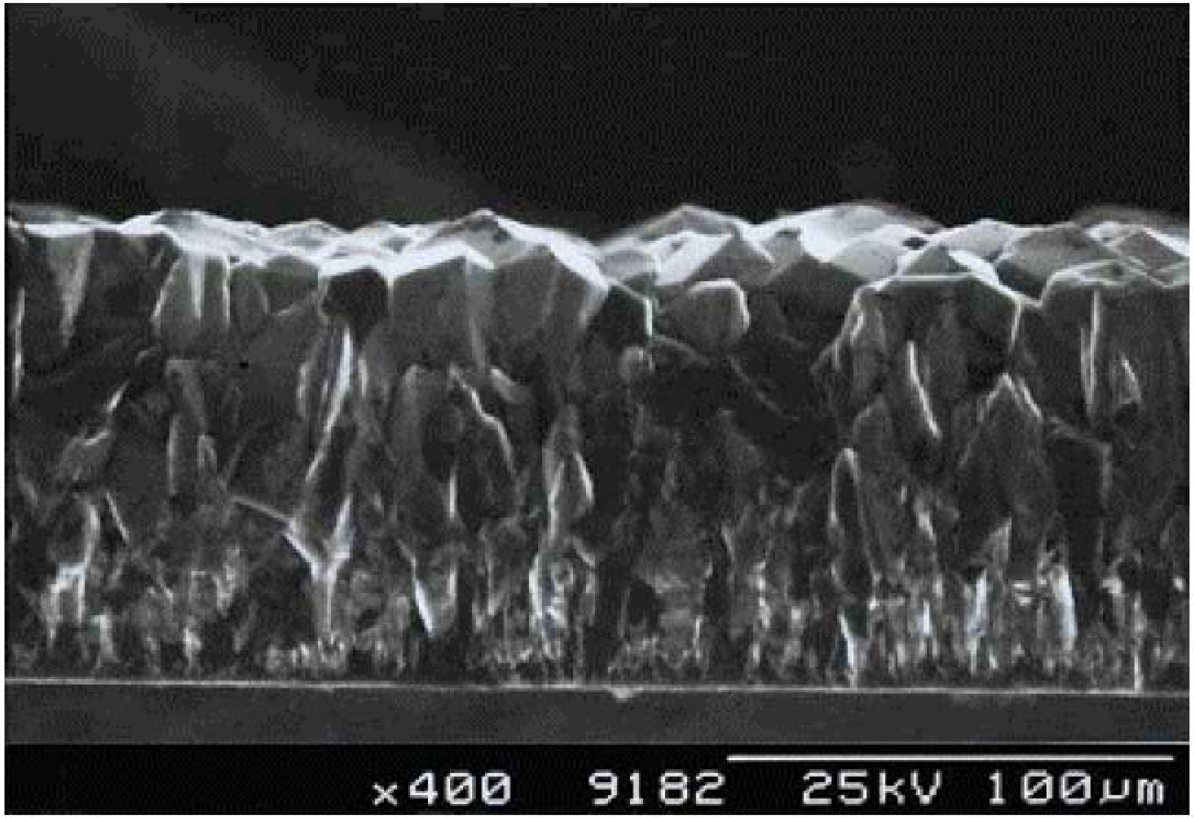


Figure 2-11: Cross-section of a 100 µm-thick CVD diamond film grown by DC arc jet. The columnar nature of the growth is clearly evident, as is the increase in film quality and grain size with growth time. (from http://www.chm.bris.ac.uk/pt/diamond/semflat.htm)

Good Wafer Unformity

	-5	-4	-3	-2	-1	0	1	2	3	4	5
5				*206	*242	1	235	207			
4			*261	*257	*261	*275	1	252	254		
3		*287	270	270	257	265	1	292	257	235	
2	*291	*265	263	282	269	288	*288	270	275	243	265
1	*291	*299	*269	286	293	270	291	286	262	243	258
0	*297	286	270	293	282	272	265	287	272	262	262
-1	*274	*304	296	270	286	279	266	277	284	268	269
-2	1	*308	*296	237	284	280	262	269	*277	282	269
-3		*248	*281	*296	*272	1	276	250	*269	262	
-4			*269	*269	*267	1	*283	155	*271		
-5				*229	*237	1	*245	*222			

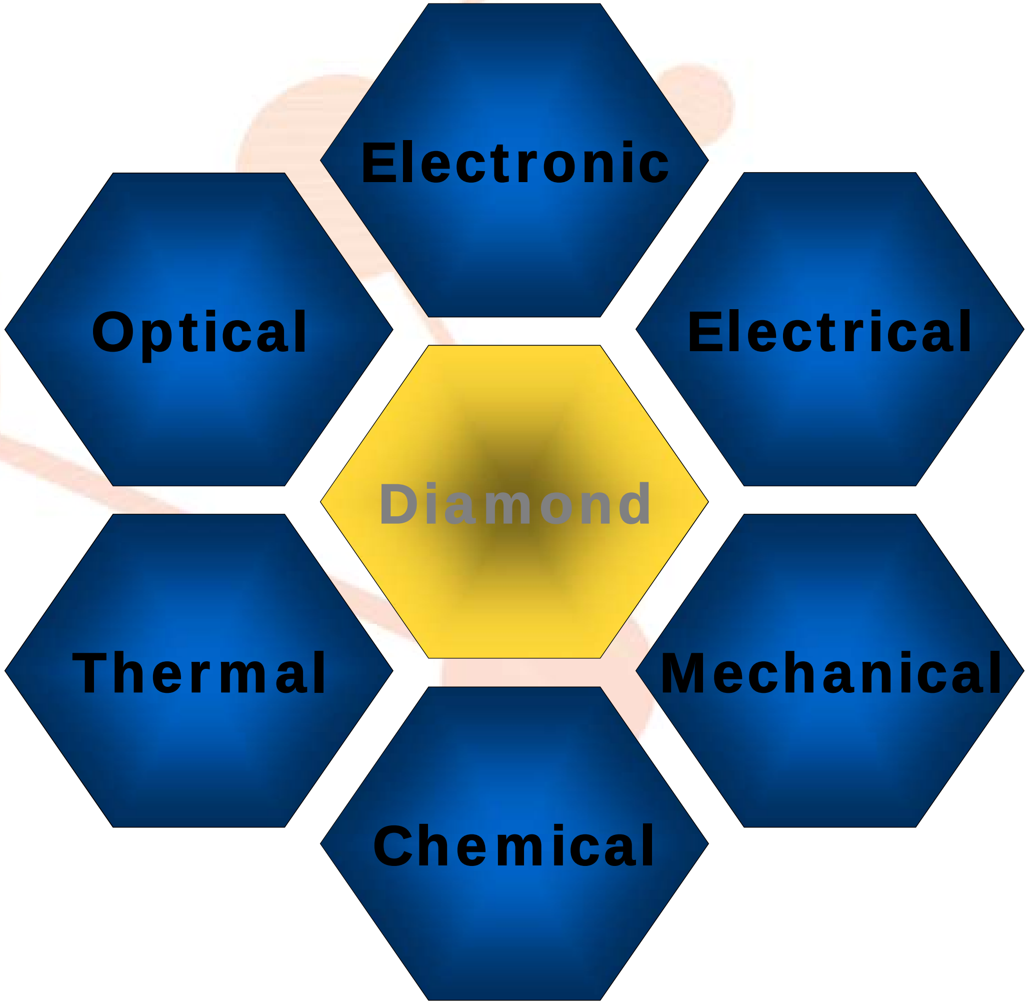
Marks the crack E=0.66V/micron

CCD > 275 um

Results courtesy Harris Kagan OSU RD42

Properties of Diamond

Highest thermal conductivity
Highest resistance to thermal shock
Low thermal expansion coefficient
High chemical (bio) inertness
Highest Young's modulus
Highest Knoop hardness
High tensile strength
Broad transmission spectrum
Good electrical insulator
Good electrical conductor (doped)
Low dielectric constant
Low dielectric loss
Wide electronic band gap 5.5ev
Radiation hard.
High electronic mobility



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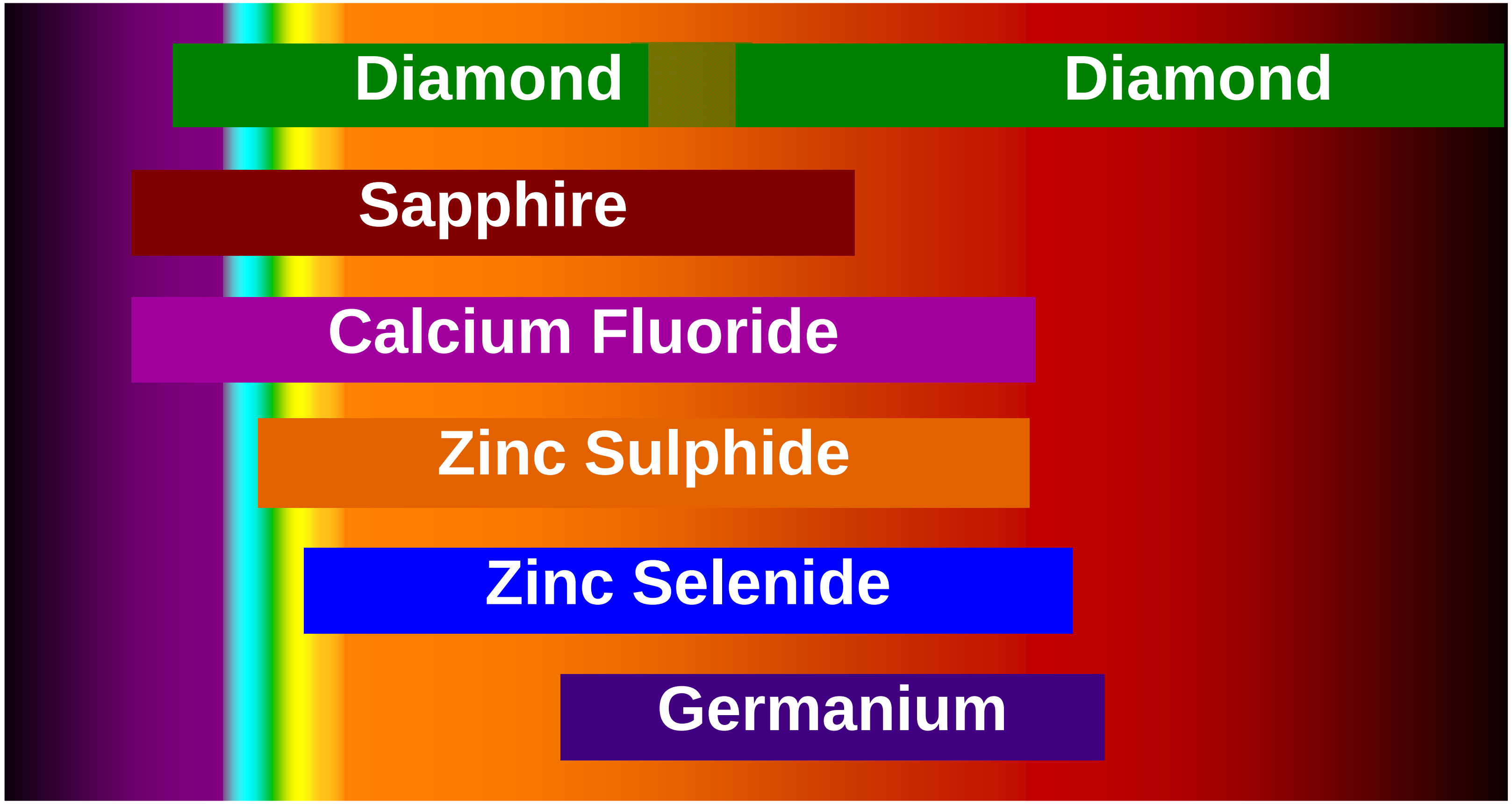
Diamond is transparent through a wider spectrum than comparable materials



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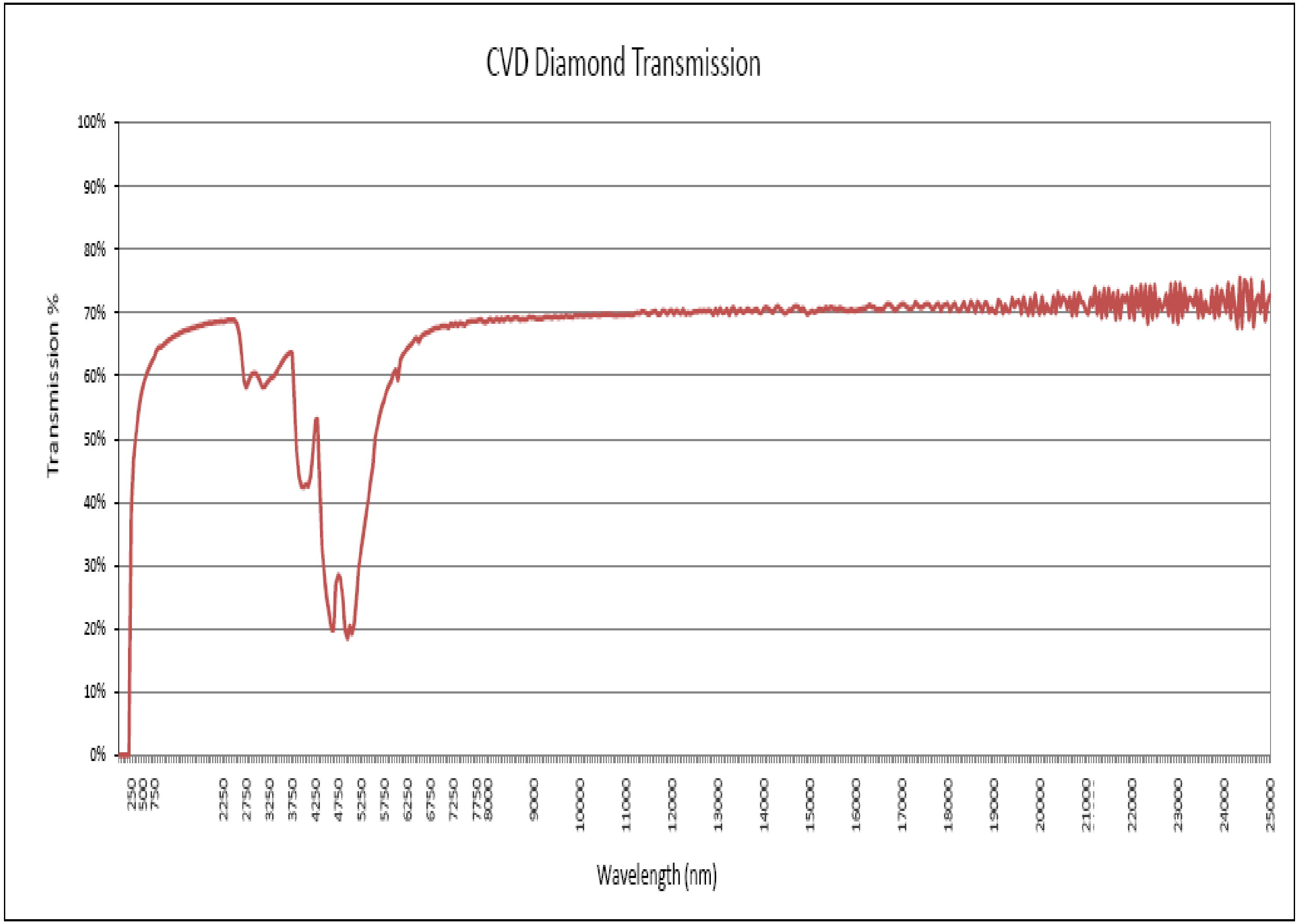

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Properties of Diamond
Mechanical & Thermal

Mechanical Properties	Polycrystalline CVD Diamond	Single Crystal CVD Diamond
Hardness (GPa)	85-100	70-100
Fracture Toughness (MPa)	5.5	3.4
Tensile Strength (MPa)	400 (growth) 800 (nucleation)	2000-3000
Compressive strength	9	9
Rain Impact DTV 2 mm drop size	525 ms^{-1}	
Sand erosion at 80ms^{-1} C25/52 sand	0.18$mgkg^{-1}$	

Thermal Properties	Polycrystalline CVD Diamond	Single Crystal CVD Diamond
Thermal conductivity @20C (W/m.K)	2000	>2000
Thermal conductivity @200C (W/m.K)	500-1500	>1000
Thermal Diffusivity (cm^2/s)	2.8 – 11.6	10-12
Thermal Expansion Coefficient	1.21	1.21
Thermal shock Figure of merit (W/m)	>1100	

Windows ,Absorbers and Thermal Management

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Properties of Diamond Optical LW-IR/THz Transmission Enabling Remote Diagnostics

Optical Properties	Polycrystalline CVD Diamond	Single Crystal CVD Diamond
Refractive Index	2.432 for L=0.5um	2.432 for L=0.5um
Absorption Coefficient 8-12um	<0.07	
Absorption Coefficient 3-5um	Min 0.8 at 3.7um	
Emissivity at 10um	0.20 at 573K 0.03 at 773K	
Integrated forward scatter 8-12um	0.10 at 0.7%	<0.6%
Integrated for scatter visible	<4%	<0.6%
Transmission 8-200um (1mm thick window)	71.4%	71.4%
Transmission 633nm (1mm thick window)	>64%	>66%

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Unique combination of properties make CVD diamond windows ideal for power transmission

Windows for the gyrotrons used to power thermonuclear reactors

Diamond advantage:-

1 MW CW power handling

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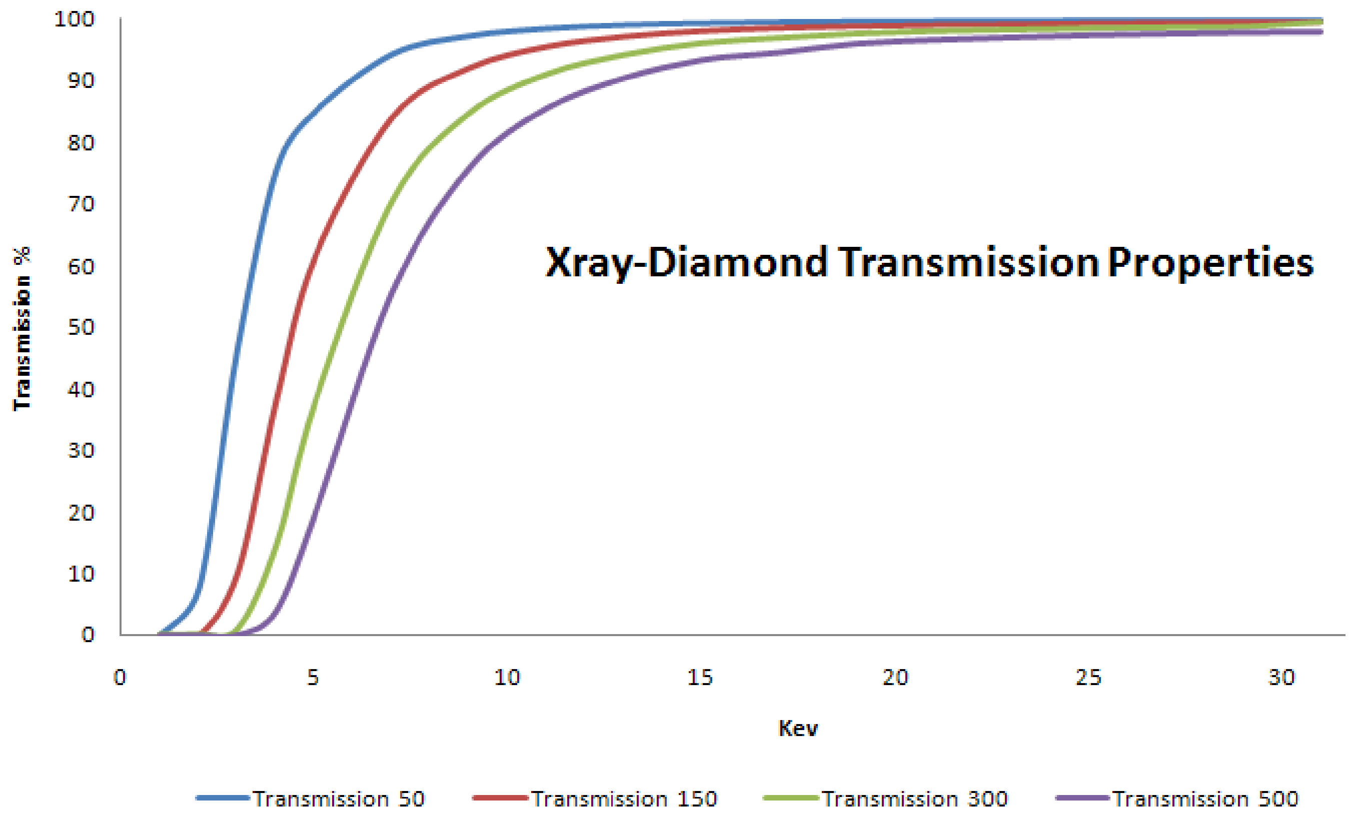
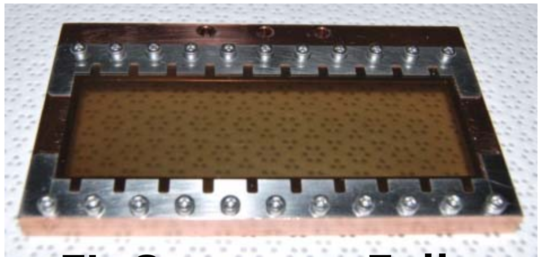
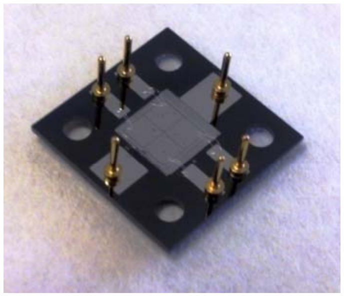
Diamond is transparent through a wider spectrum than comparable materials

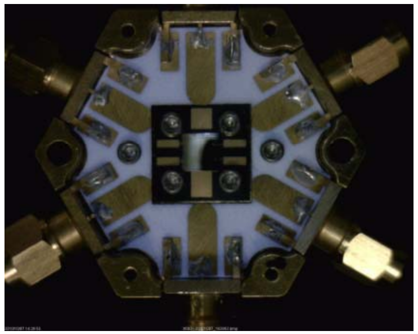




FL-Screen or Foil



QUAD-Device



Properties of Diamond Electronic

Intrinsic Material Properties Comparison

	Si	4H-SiC	GaN	Natural Diamond	CVD Diamond	Potential device application benefit
Bandgap (eV)	1.1	3.2	3.44	5.47	5.47	High temperature
Breakdown field ($MVcm^{-1}$)	0.3	3	5	10	10	High voltage
Electron saturation velocity ($x10^7$ cm s^{-1})	0.86	3	2.5	2	2	High frequency
Hole saturation velocity ($x10^7$ cm s^{-1})	n/a	n/a	n/a	0.8	0.8	
Electron mobility ($cm^2 V^{-1} s^{-1}$)	1450	900	440	200–2800	4500	
Hole mobility ($cm^2 V^{-1} s^{-1}$)	480	120	200	1800–2100	3800	
Thermal conductivity ($Wcm^{-1} K^{-1}$)	1.5	5	1.3	22	24	High power
Johnson's figure of merit	1	410	280	8200	8200	Power-frequency product
Keyes' figure of merit	1	5.1	1.8	32	32	Transistor behavior thermal limit
Baliga's figure of merit	1	290	910	882	17200	Unipolar HF device performance

Isberg, J., *et al.*, *Science* (2002) **297**, 1670

materialstoday JAN-FEB 2008 | VOLUME 11 | NUMBER 1-2

Diamond Diagnostic Detectors

Diamond radiation detectors are able to detect deep UV photons, X-rays, gamma rays, electrons, alpha particles, charged ions and neutrons, with a dynamic range in energies spanning from 5.5 eV up to GeV of cosmic rays.
Since the bandgap of diamond is 5.5 eV this leads into a negligible dark current noise at room temperature with no need for cooling.
Metal diamond interfaces play a key role in the performance of the detectors as different metallization techniques lead to either “ohmic” or Schottky electrical contacts.

Intrinsic Properties
Radiation Hardness
Wide band gap 5.5eV (no thermally generated noise)
Low Z (tissue equivalent Z=6)
Low energy absorption
High thermal conductivity
High Hole and Electron Mobility

Detector Properties
High sensitivity
Good spatial and temporal resolution achievable
Low leakage currents and stable
(< 0.01pA / pixel, ATLAS result)
Low capacitance

Device Advantages
Intrinsically simple device (no pn junction required)
can fabricate robust, compact devices
High temperature operation (no need for cooling)

Applications Include:
High Energy Physics (Beam Diagnostics)
Synchrotrons and Cyclotrons

Civil Nuclear
Reactor compartment monitoring.
Medical Therapy / Dosimetry (X-ray & CPT)

Radiation Monitoring
(nuclear, medical and oil & gas)
Deep UV (< 240nm)

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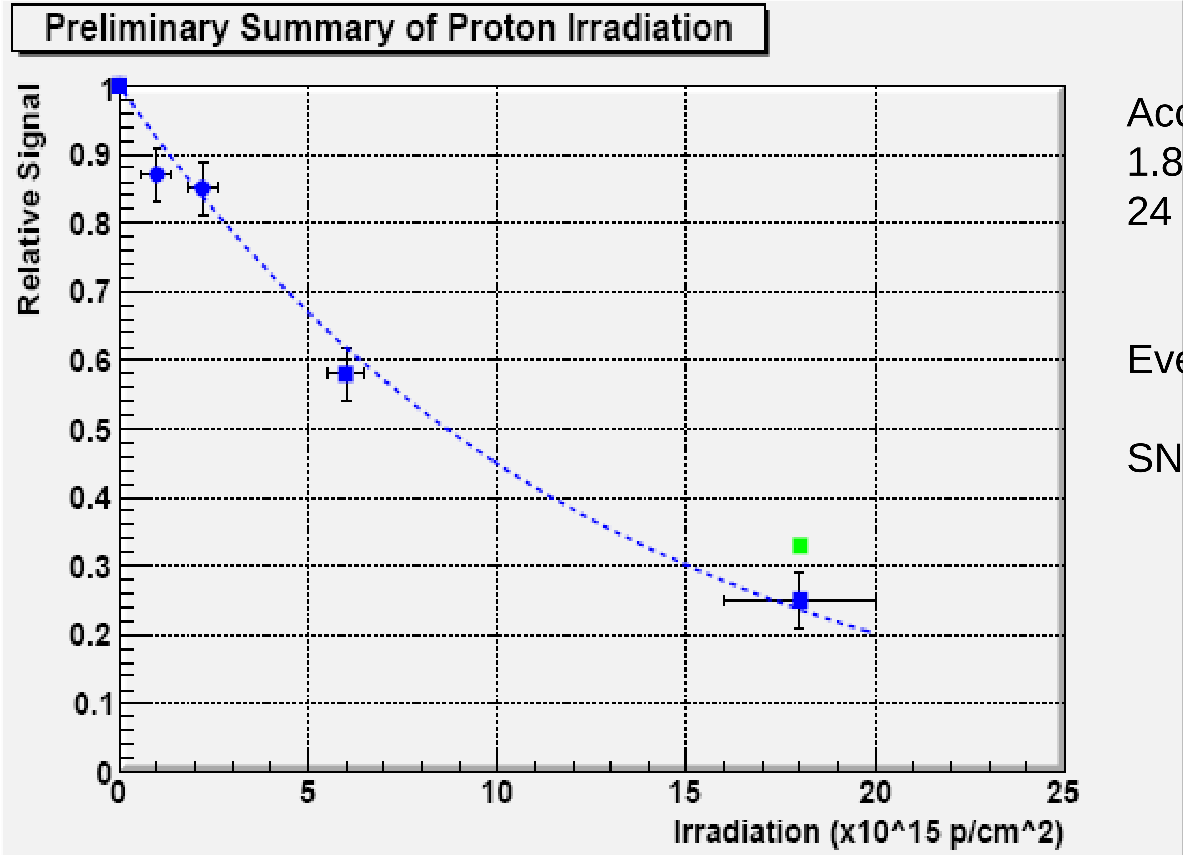
Proton Irradiation of EL Poly Tracker



Accelerated test
1.8×10^{16} p/cm^2 ~500Mrad
24 GeV protons

Even after irradiation system

SN remains with specification.

Blue E=1V/µm
Green E= 2 V/µm

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Range of Third Party Electronics available from DDL

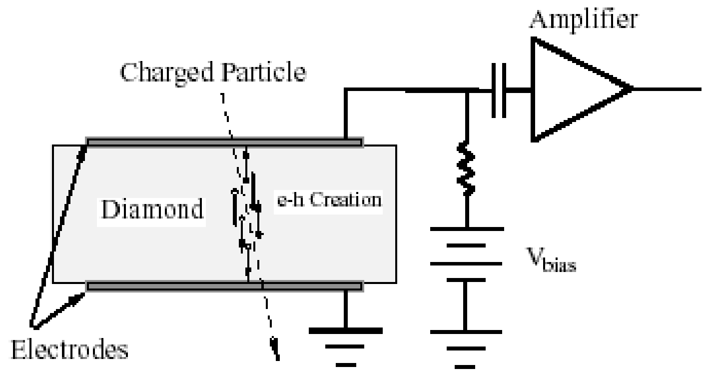
•**CIVIDEC** Preamplifier

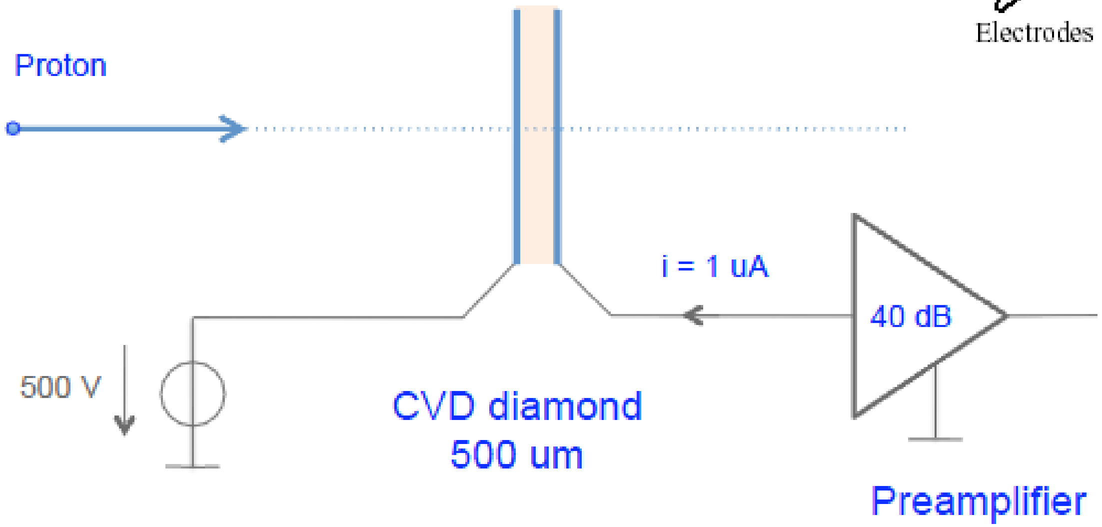
- Current amplifier
- Gain 20 dB, 40 dB
- Noise < 1 mV rms
- 4 mV/MIP max. 1 V
- Rise time < 1 ns
- Pulse width < 2 ns

• **CAEN A422A** Charge Sensitive Preamplifier

• **DBA-IV** 2 GHz broad band diamond Amplifier, with analogue gain input (fast counting and time of flight).

Principle





13ev -> 1 eh pair or a minimum ionizing particle will leave, on average, 36 electron-hole pairs per traversed micron

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What's the motivation for using Diamond in Existing and Future Particle Accelerators

The current goal of the LHC is to reveal the Higgs Boson to particle physicists. Future development of these projects, however, depend on a range of upgrades across various detectors including large area detectors for inner ring Trackers, Vertex detectors and the Forward Calorimeters (Fcal).

Currently, the LHC can run at a luminosity of up to 10^{34} protons per square centimetre per second, but beyond this, the existing detectors may experience problems.

In addition current and next generation Light Sources and XFEL machines are pushing the boundaries of detector technologies where the radiation hard properties of diamond along with its ability to deliver constant and predictable performance during and after exposure make it an ideal candidate.

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Particle Physics: Beam Diagnostics
BCM,BLM,BPM,Trackers.
(LHC projects including ATLAS,CMS and LHCb are looking at diamond)

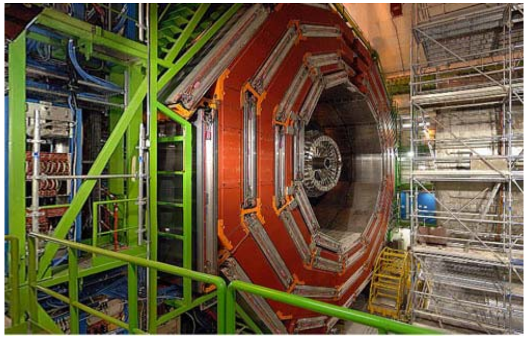
Medical Dosimetry: X-ray (IMRT) and CPT
Radiation therapy beam monitoring.

Light Sources: Protons, X-ray, UV, beam position monitoring, energy.

Fusion Experiments: (NIF, ITER)
Fast neutron measurement

Nuclear Physics
Reactor compartment, Gamma Cells
Repository storage, ponds etc

Industrial & Space
Deep UV monitoring, radiation monitoring.



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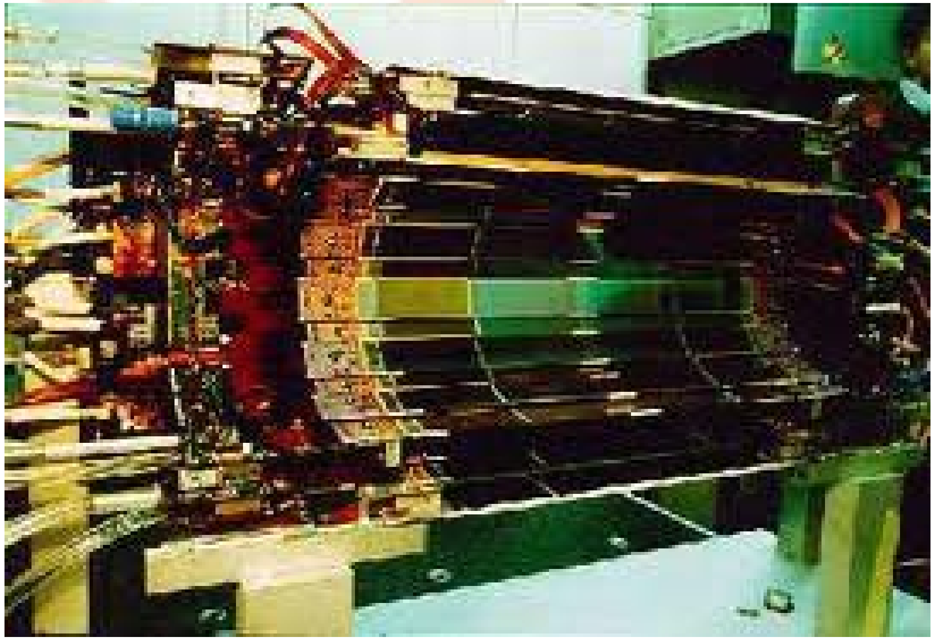
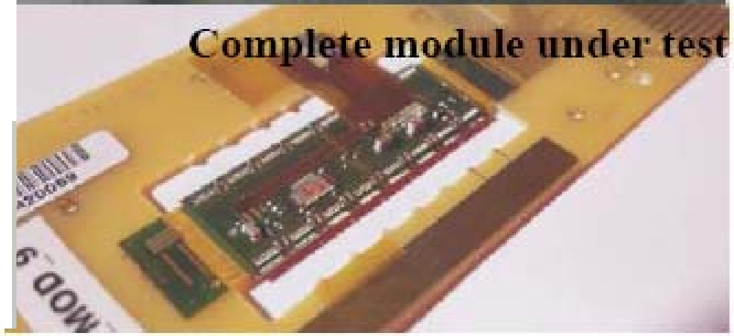
Large projects under consideration:-

- ATLAS Vertex Module
- ATLAS Forward Calorimeters
  http://www.triumf.ca/research-highlights/experimental-result/diamond-detector-irradiation-tests-success
- CMS Vertex Module
- LHCb Vertex.
- FAIR TOF.



Diamond Pixel Monitors (Tracker Modules proposed for sLHC)

- 1 full (16 chip) pCVD module
  - Test beam at DESY and CERN
  - Irradiated to $5x10^{14}$ p/cm^2
  - SPS test beam 3 weeks ago
- 1 single-chip scCVD module
  - CERN SPS test beam
  - Irradiated to $5x10^{14}$ p/cm^2
  - SPS test beam 3 weeks ago
- 1 single-chip pCVD module
  - Irradiated to $2x10^{15}$ p/cm^2



Data courtesy Wiliam Trischuk

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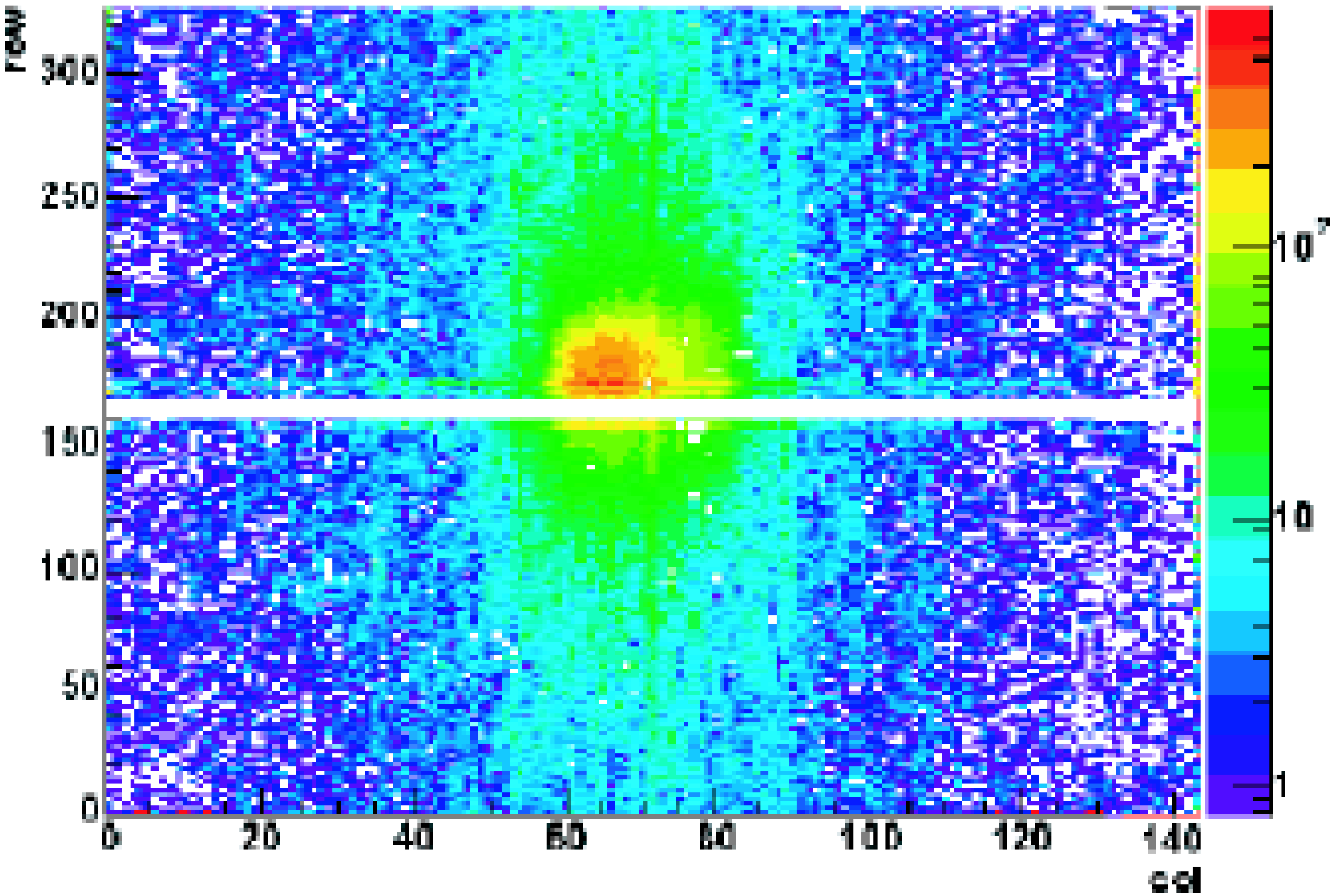
Electronic Grade Polycrystalline Diamond Detector



Data courtesy Harris Kagan

Imag
CERN

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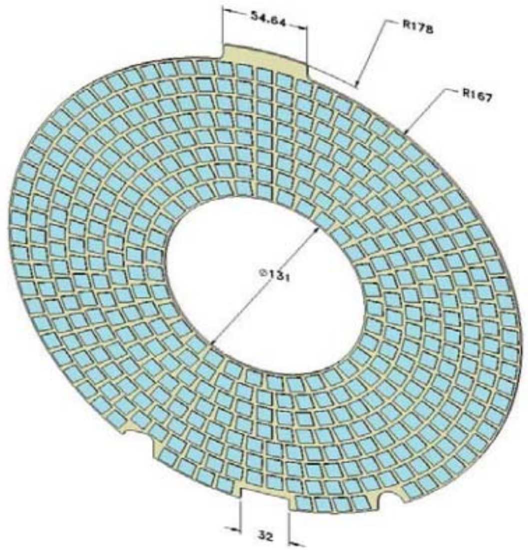
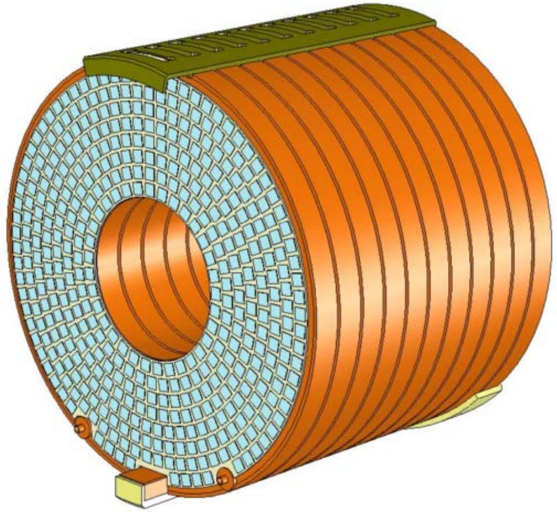
ATLAS Forward Calorimeters Upgrade Proposal Recent Results 2010

Diamond Detector Irradiation Tests Success
13 October 2010

Particle physicists from the ATLAS groups at Carleton, Montreal, Toronto, Victoria, and TRIUMF have confirmed that diamond detectors can withstand the impact of 10^{17} protons per square centimetre.

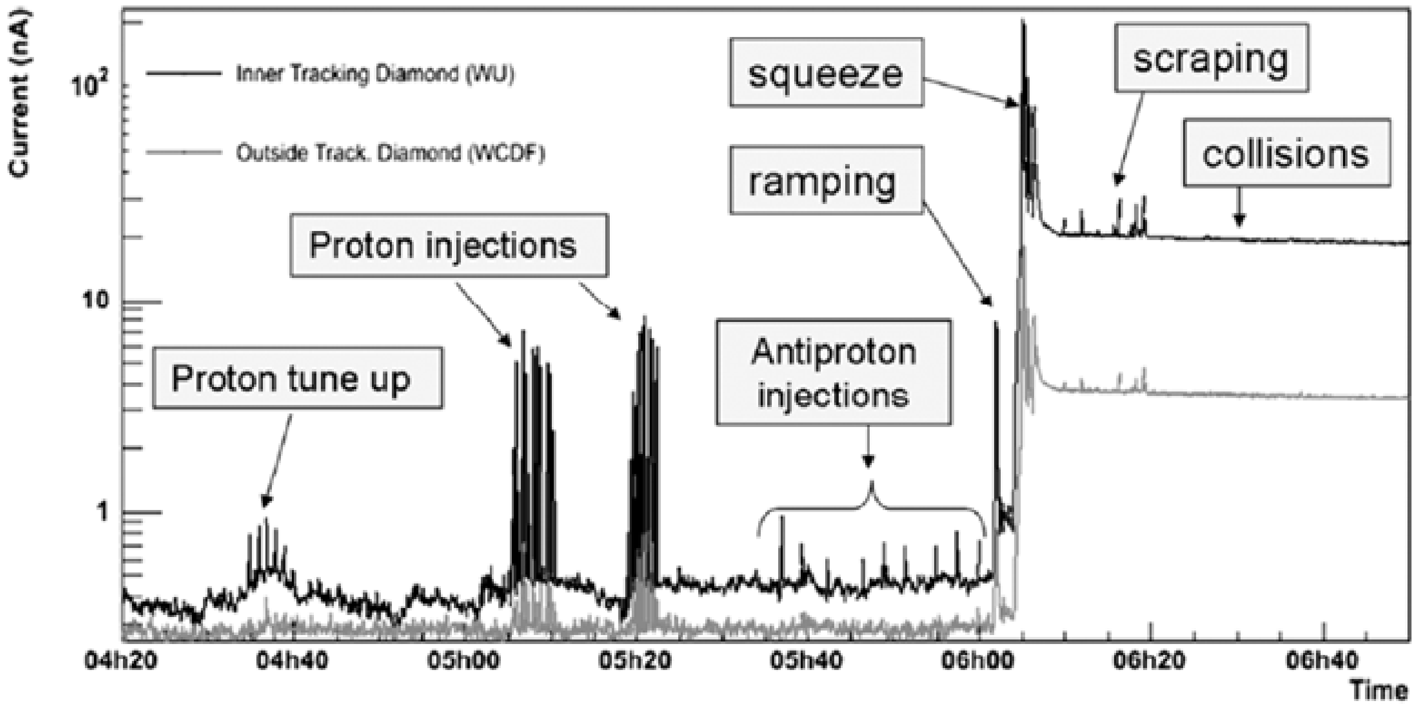
This is relevant to the High-Luminosity Large Hadron Collider (HL-LHC), a proposed upgrade to the LHC for 5-10 years from now, which would increase current luminosity (the rate of proton collisions) by a factor of 10 to improve statistical measurements and help uncover rare high-energy processes. These tests were conducted at the Neutral Beam Irradiation Facility (NBIF) in the TRIUMF cyclotron vault from May 1 to August 1, 2010, and in TRIUMF Beam Line 1A (BL1A), one of TRIUMF's main beam lines, in the first two weeks of September.





http://www.triumf.ca/research-highlights/experimental-result/diamond-detector-irradiation-tests-success

The Tevatron collides beams of protons and antiprotons with a centre of mass energy of 1.96 TeV

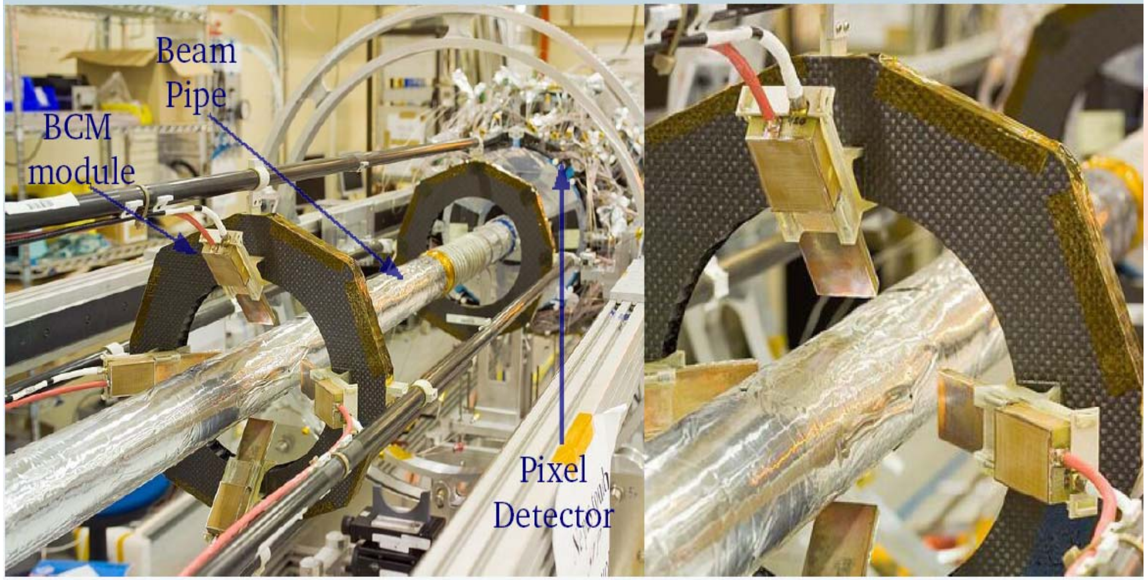


The above shows the diamond current during beam injection versus time at CDF 1.96TeV. The black trace is a diamond device inside the tracking volume, the grey outside. Note the structure is very clear from the diamond inside the tracking volume, which is at a radius of 2cm from the beam line while the grey trace is less distinctive and located at 20cm radius.

Diamond Beam Condition Monitors CERN

- measurement every proton bunch crossing (25 ns)
- place 2 detector stations at $z = \pm 1.9$m:
  - secondary particles from **collisions** reach both stations at the same time (6 ns after collisions)
  - secondary particles from upstream **background** interactions reach nearest station 12.5ns before secondary particles from collisions (6 ns before collisions)
  - use "**out of time**" hits to identify the background events
  - use "**in time**" hits to monitor luminosity

BCM modules were installed on Beam Pipe Support Structure in November 2006 and lowered into ATLAS pit in June 2007



Requirements:

- fast and radiation hard detector & electronics:
  - rise time ~1ns
  - pulse width ~3ns
  - baseline restoration ~10ns
  - ionization dose ~0.5 MGy, 10^{15}particles/cm^2 in 10 years
- MIP sensitivity

Data courtesy Harris Kagan

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Conclusions from the Collider Detector Fermilab (CDF)

"Diamond detectors work well in beam condition monitoring and abort systems.

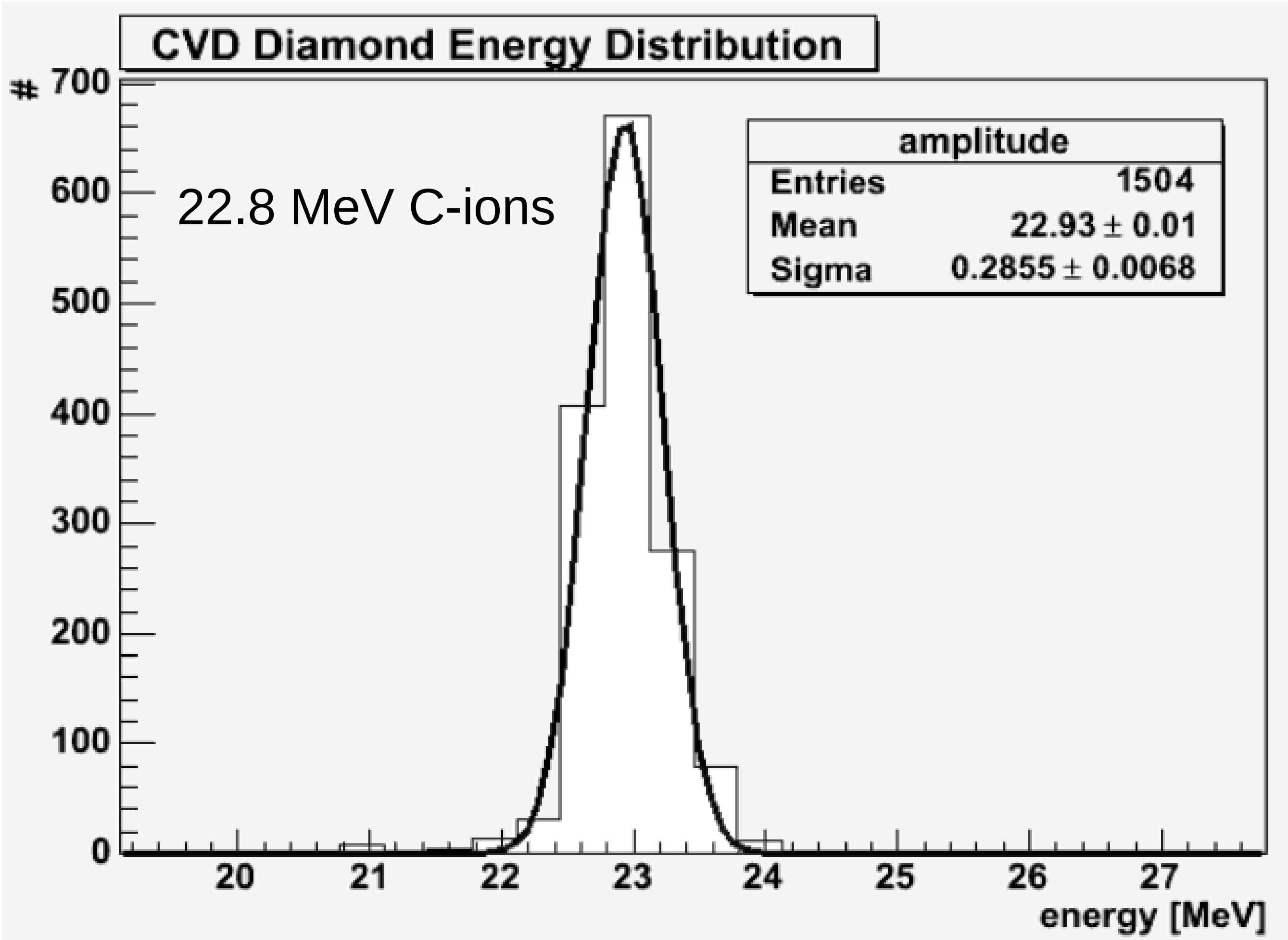
Compared to traditional beam loss monitoring systems, diamond sensors are smaller and can be placed closer to the beam line and to radiation-sensitive devices in high energy physics experiments.

In addition, they show a larger sensitivity to radiation and a faster response. These features allow better monitoring of beam conditions and, therefore, more effective protection against beam instabilities.

The diamond-based beam condition monitoring system at CDF has been running stably for more than a year and its abort functionality has recently been commissioned."

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 55, NO. 1, FEBRUARY 2008

Energy Resolution

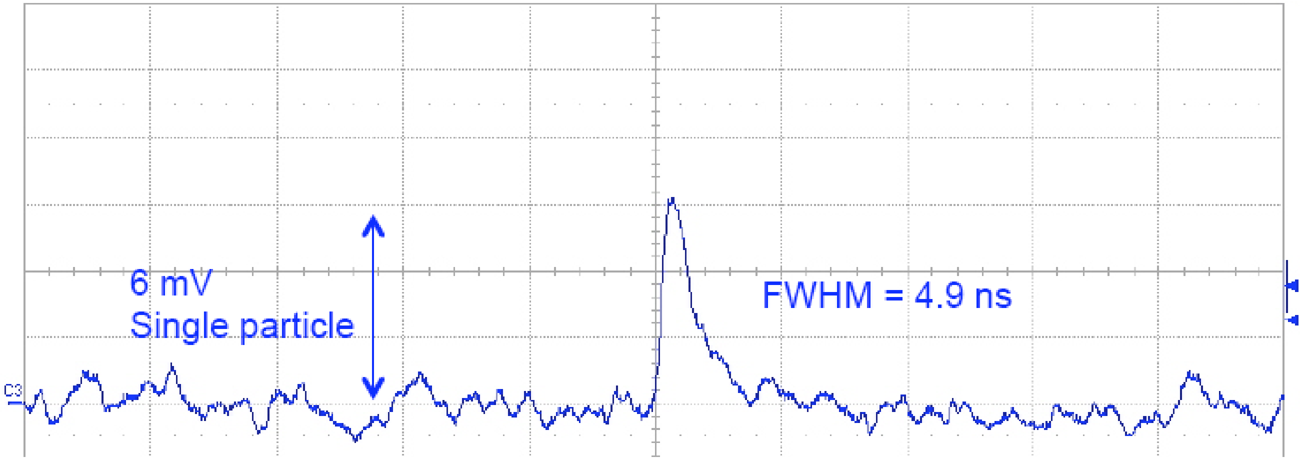


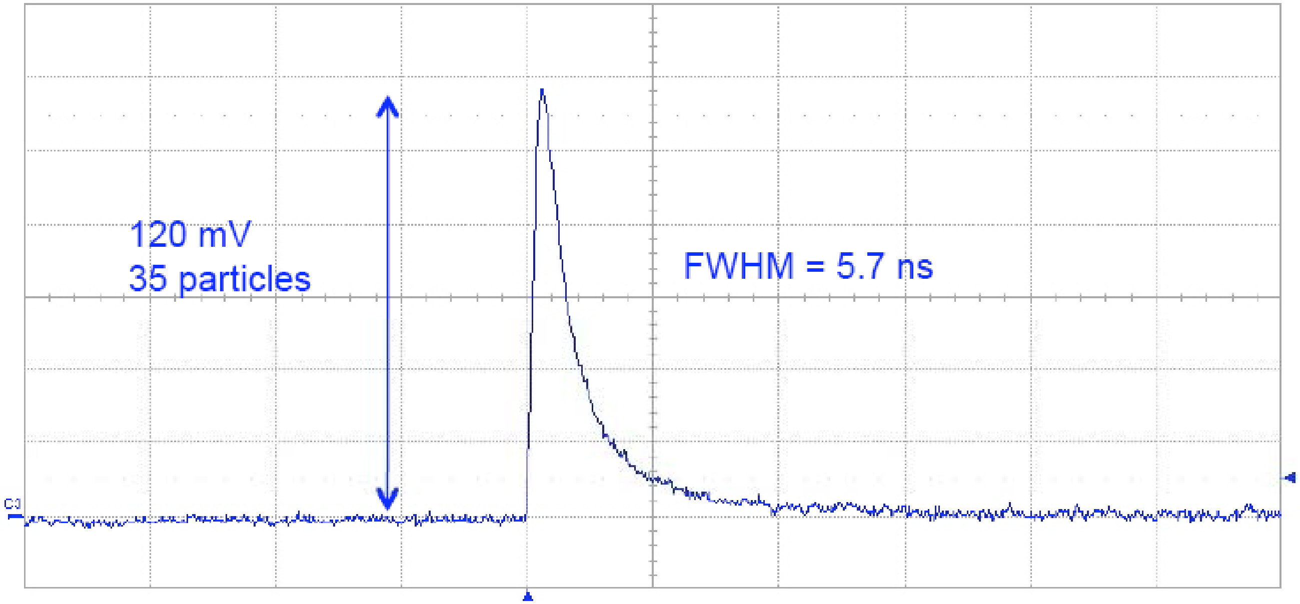
Energy measurement
(resolution, 0.6% @ Isolde 22.8 MeV C-ions 10micron penetration , sCVD).

Data courtesy of CIVIDEC

Diamond Detectors Ltd

Example CERN :- Single and Bunch Particle Detection:-





Data courtesy of CIVIDEC/CERN, trace using ZTEC ZT4211LXI Oscilloscope

Diamond Detectors Ltd

Diamond Detectors as Beam Monitors

"Erich Griesmayer, Bernd Dehning, Daniel Dobos, Ewald Effinger (CERN, Geneva)"

The diamond beam monitor is a solid-state ionization chamber that stands out due to its fast and efficient charge collection and its high radiation tolerance.

The diamond technology gives a charge collection time of less than 1 ns and lifetime studies made at CERN with 24 GeV protons showed a decrease in performance of only 50% at 10 MGy, which make this device particularly well adapted to applications in particle accelerators.

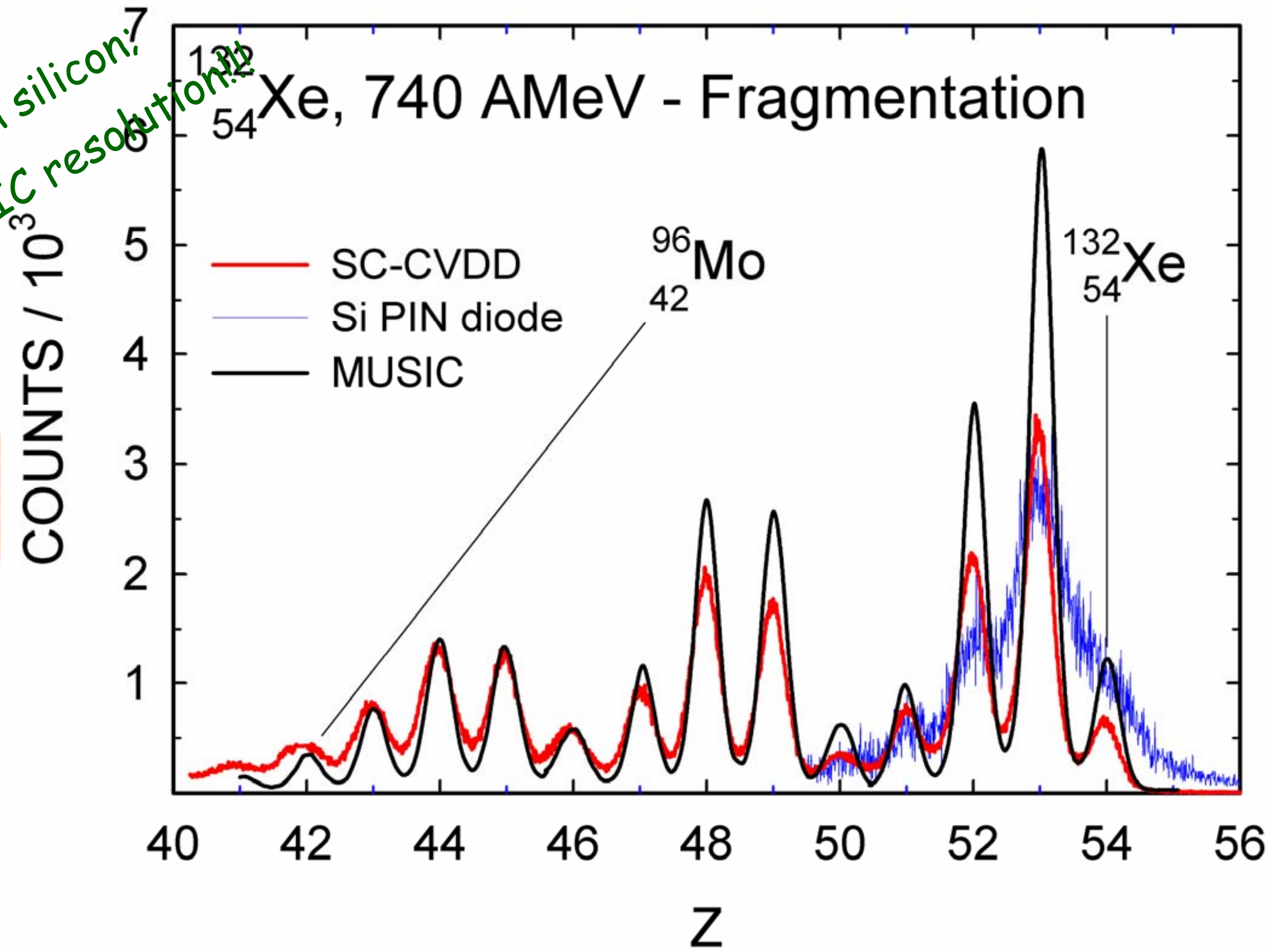
A poly-crystalline CVD diamond beam monitor has been evaluated as a beam halo loss monitor for the CERN LHC accelerator. Despite the read-out being made through 250 m of cable, the tests showed a good signal-to-noise ratio of 6.8, an excellent double-pulse resolution of less than 5 ns and a high dynamic range basically unlimited except by the electronics.

A single-crystalline CVD diamond beam monitor was built and tested in cooperation with Bergoz Instrumentation for ISOLDE at CERN for the HIE-REX upgrade. This device was used to measure the beam intensity for particle counting and for measuring the beam energy spectrum. An energy resolution of 0.6% and a time resolution of 39 ps were measured for a carbon ion energy of 22.8 MeV.

Research Heavy Ion-Beams at GSI

scCVDD Beam Tests (GSI)
Spectroscopic Properties

scCVDD better than silicon;
approaching MUSIC resolution!!



Data courtesy of Eleni Berdermann GSI 2010

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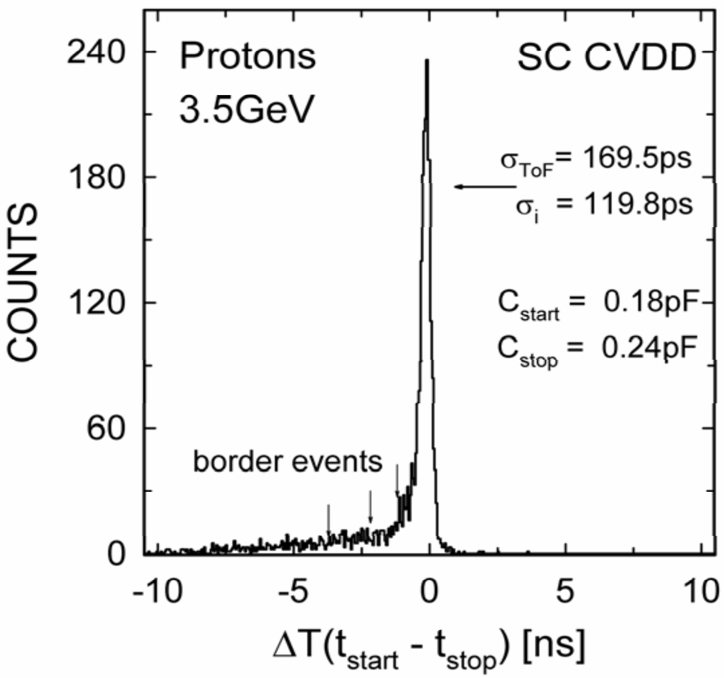
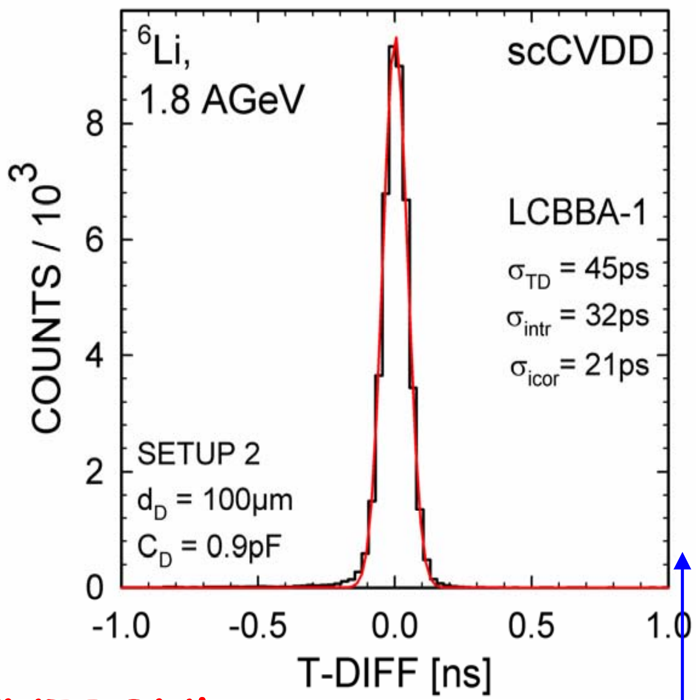
scCVDD Beam Tests (GSI)

Towards best timing for MIPs

Both sensors: d ≈ 330μm;
Old FEE design (May 2006)



Both sensors: d = 100μm;
New FEE design (Oct 2009)



ATTENTION!

^{6}Li signal is f1 = 9 times higher because of Z=3 but f2 = 3.3 lower because of thicknesses, meaning in total : f = 2.7 higher than of relativistic protons.

Data courtesy of Eleni Berdermann GSI 2010

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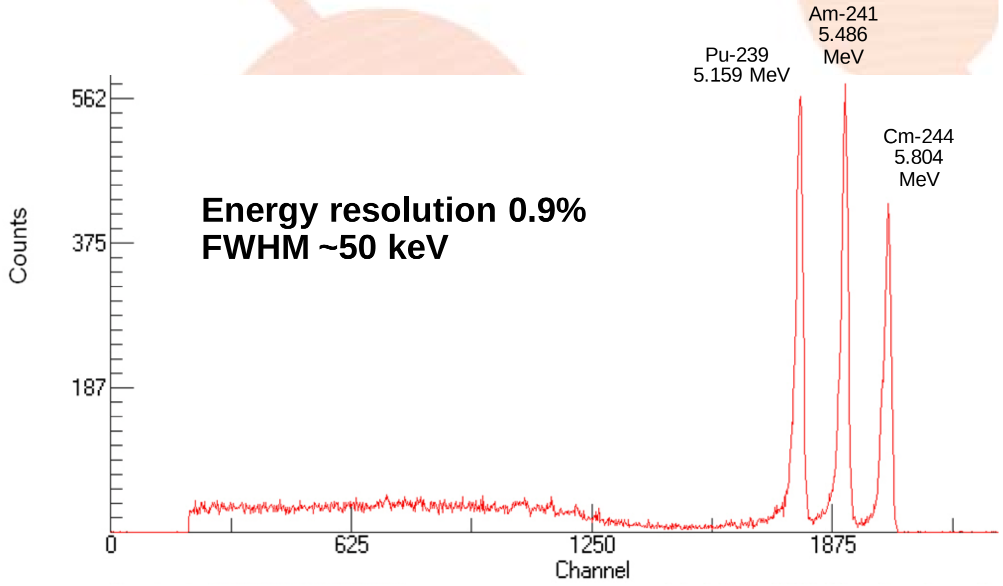
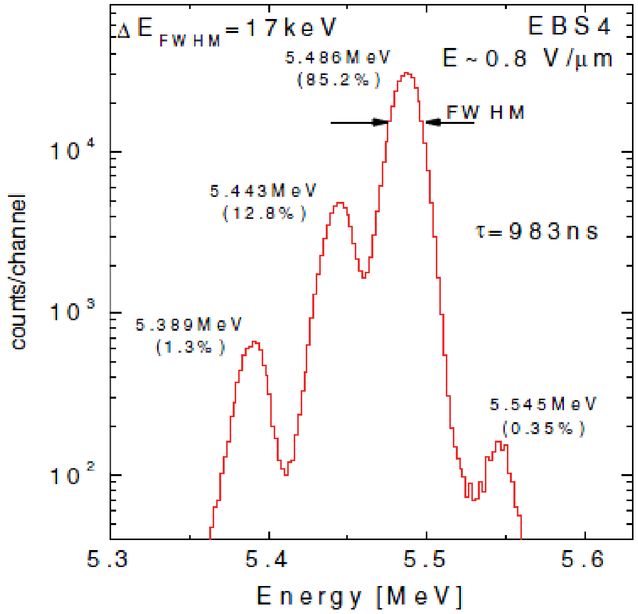
Mixed Nuclide alpha Source Spectrum

High Purity single-crystal Diamond Detector



J. Dueñas et al., Department of Applied Physics GEM, University of Huelva, Spain



E. Berdermann GSI (Germany) and Kaneko JAEA (Japan) have both demonstrated FWHM of ~17 and 20keV respectively

phys. stat. sol. (a) 203, No. 12, 3152–3160 (2006) / DOI 10.1002/pssa
Nuclear Instruments and Methods in Physics Research A 422 (1999)

Diamond Detectors Ltd

Research Beam Diagnostic summary:-

•Halo measurements at LHC (2ns double pulse resolution).

•Reproducible for low intensities.

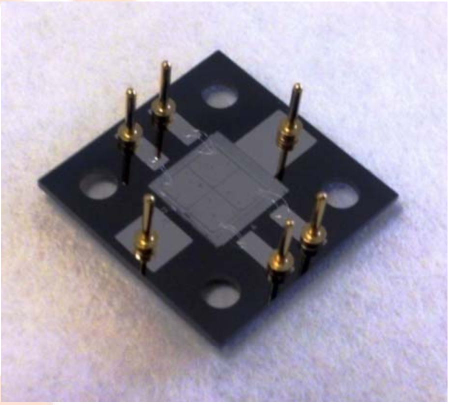
•Beam intensity monitoring (wide dynamic range).

•Beam Position Monitoring (micron accuracy x,y)

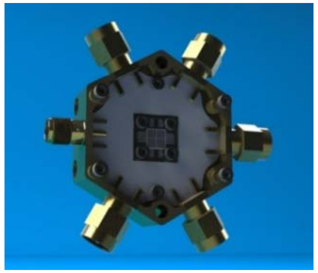
•Energy measurement (resolution better than 1%)

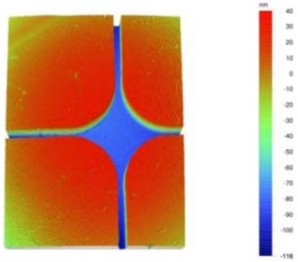
•Particle counting (up to GHz).

•TOF measurements (30ps resolution).



Kay Wittenburg
"You do not need a BLM System as long as you have a perfect machine without any problems. However, you probably do not have such a nice machine, therefore you better install one."





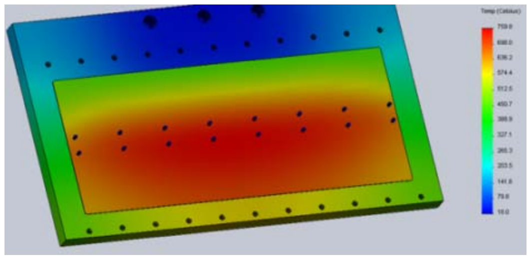
Deutsches Elektronen Synchrotron
DESY, Hamburg, Germany

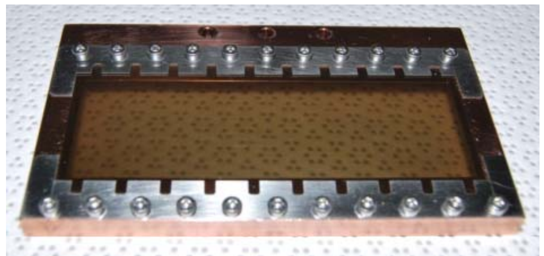
Fluorescence Detector for Light Sources

A range of different poly CVD diamond grades have been successfully evaluated for use as a large area fluorescence detector at DLS

Why diamond :-

- **Excellent Thermal Conductivity-** can withstand heat-load of white beam Therefore can provide continuous white beam monitoring - unique!
- **Excellent Mechanical Stability-** can provide a vacuum barrier. Therefore can act as window and beam position monitor
- **Low absorption of X-ray and visible light**
- **Can be brazed or diffusion bonded**
- **Thin samples allow attainment of higher spatial resolution due to the focal plane of the imaging camera**





Diamond Detectors Ltd

Industrial Applications Radiotherapy Beams

The instrumentation used to this purpose consists of electron accelerators , cobalt irradiators, charged particles etc which are calibrated to give the dose calculated for each specific treatment.

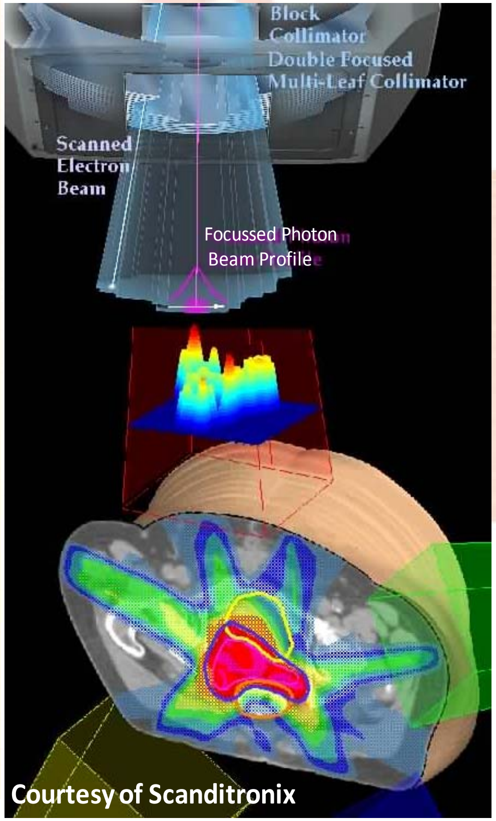
The aim of the external radiotherapy is to destroy the cancerous cells by irradiation with minimum damage on healthy tissue.

A principal goal of a treatment is to control the dose received by the patient during the treatment and the beam calibration.

Typically, air cavity ionization chambers are dedicated to this measurement due to their dimension and detection volume, these have a weak dependence with respect to the energy of the irradiation beam.

The emergence of new irradiation techniques like IMRT implies improvement of measurements techniques. The juxtaposition of several “small” beams makes minimizing the size of the detector desirable. Employing a semiconductor processes with a radiation hard, tissue equivalent detector like diamond simplifies the calculation and minimize the perturbation of the detector response.

Industrial Application Radiotherapy Beams IMRT



Narrow high energy photon beams are increasingly used in modern radiotherapy (RT) and especially in intensity modulated RT (IMRT-beamlets) and sterostactic radiosurgery (SRS/SRT) applications.

Accurate measurement of the doses and beam profiles are required as input to the treatment planning. In order to apply modern RT techniques with high precision the complex 3D dose patterns delivered must be well understood. The accuracy of the beam profile measurements is crucial for the planning of a successful treatment.

These small photon beam measurement devices are ideally tissues-equivalent, do not perturb the radiation beam and exhibit energy, dose rate and directional independence in addition o radiation harness.

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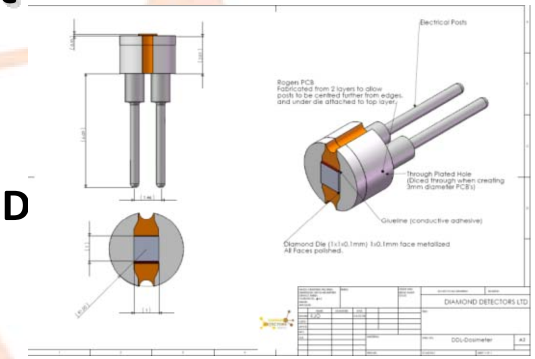
X-ray Sensitivity Comparison for Different Dosimeter Types



Higher sensitivity of High Purity SC CVDD

Smaller devices

Improved spatial resolution

	E6 HP SC CVD diamond	Commercial Silicon dosimeter	Air-filled Ionisation chamber
Sensitivity (nC/Gy)	240	74	7.5
Active Detector Volume (mm^3)	0.3	0.2	120

Data for samples irradiated in a 6MV photon beam with a 10cm x 10cm field at a source-to-detector distance of 100cm, courtesy of Scanditronix

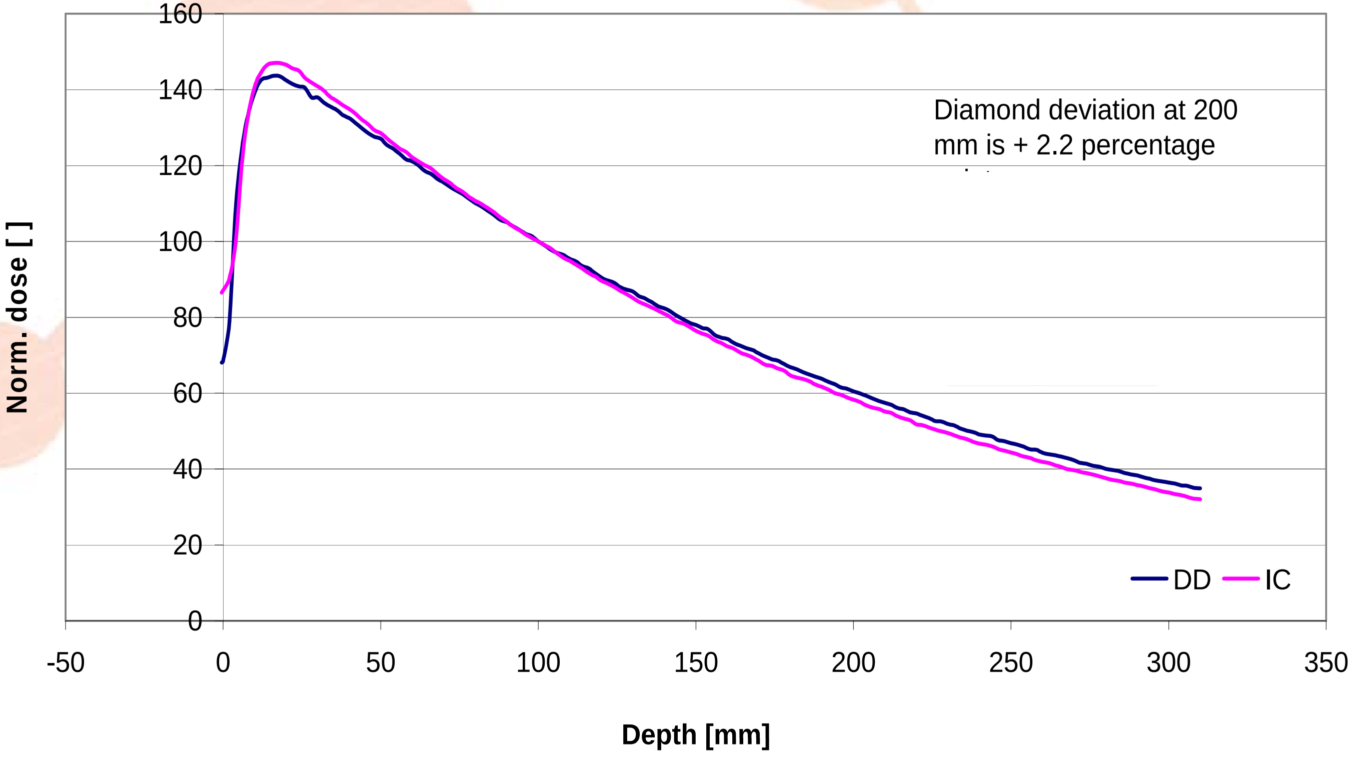
X-ray Sensitivity for Different *Diamond* Types

Sample Type	Dose Rate (Gy/min)	Signal (nC/Gy/mm^3)	Priming (Gy)
E6 High Purity SC CVDD	0.5	308	0
E6 Standard purity SC CVDD	2	26	3
Commercially available natural diamond dosimeter	2	48	8

Data for samples irradiated with 5MV X-ray beam courtesy of Scanditronix

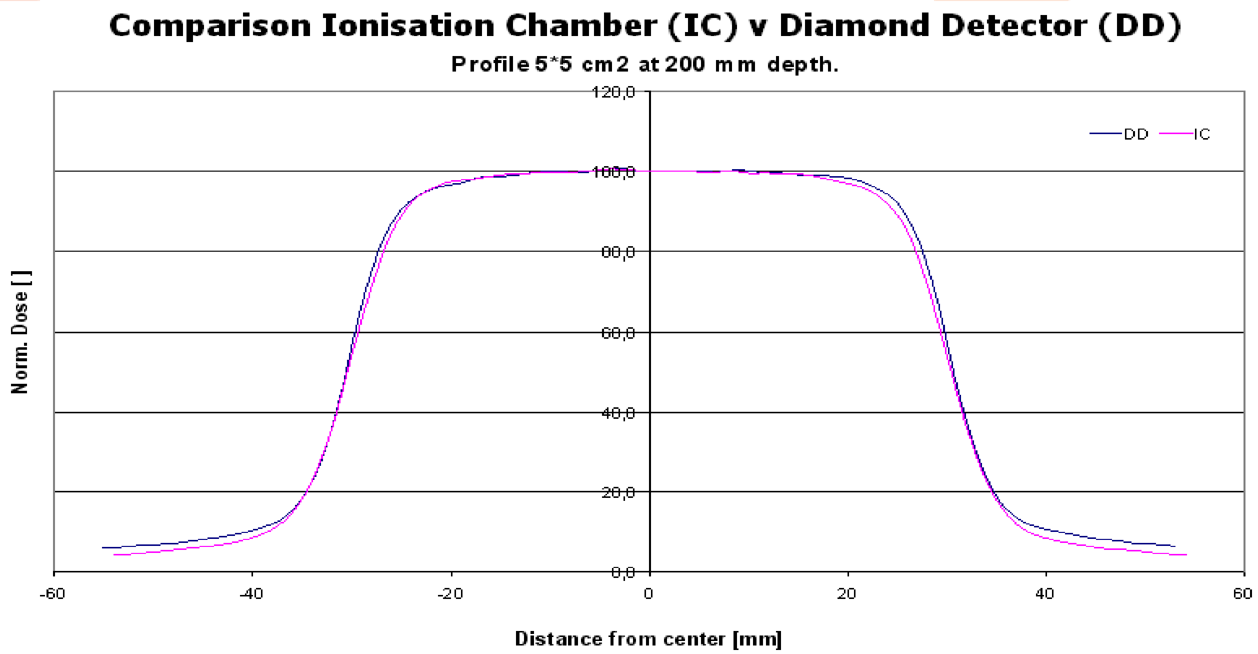
High Purity SC CVD diamond gave ~6x signal of commercially available natural diamond dosimeter

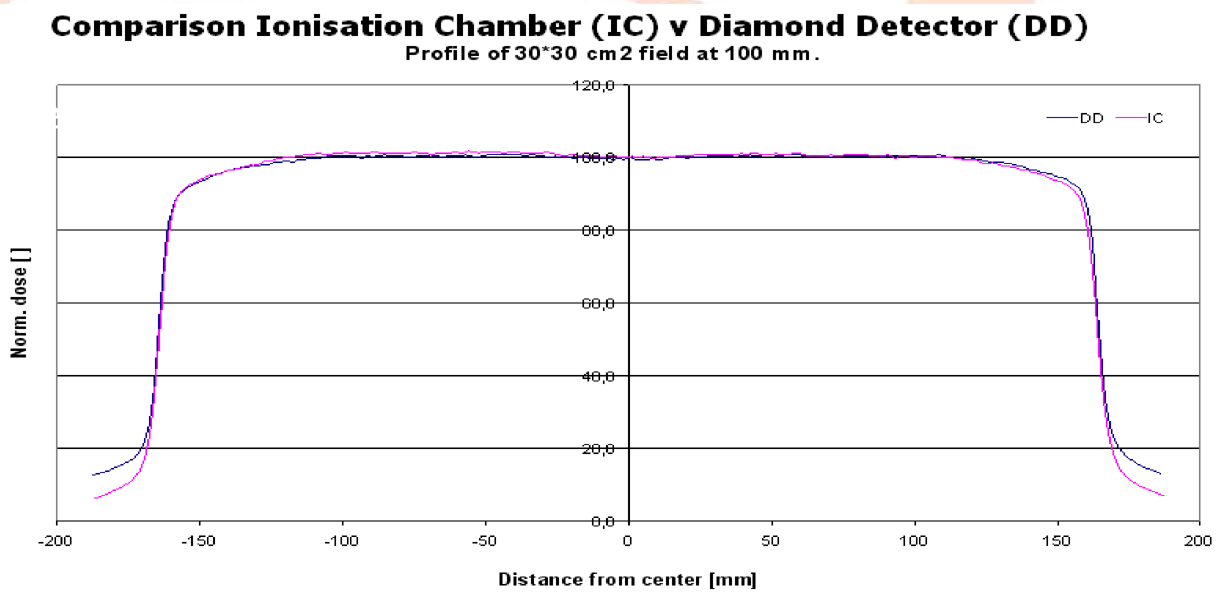
Industrial Application Radiotherapy Beams IMRT (comparison diamond v ion-chamber Dose v Depth)



Data courtesy Dr. Camilla Rönnqvist (IBA)

Diamond Detectors Ltd





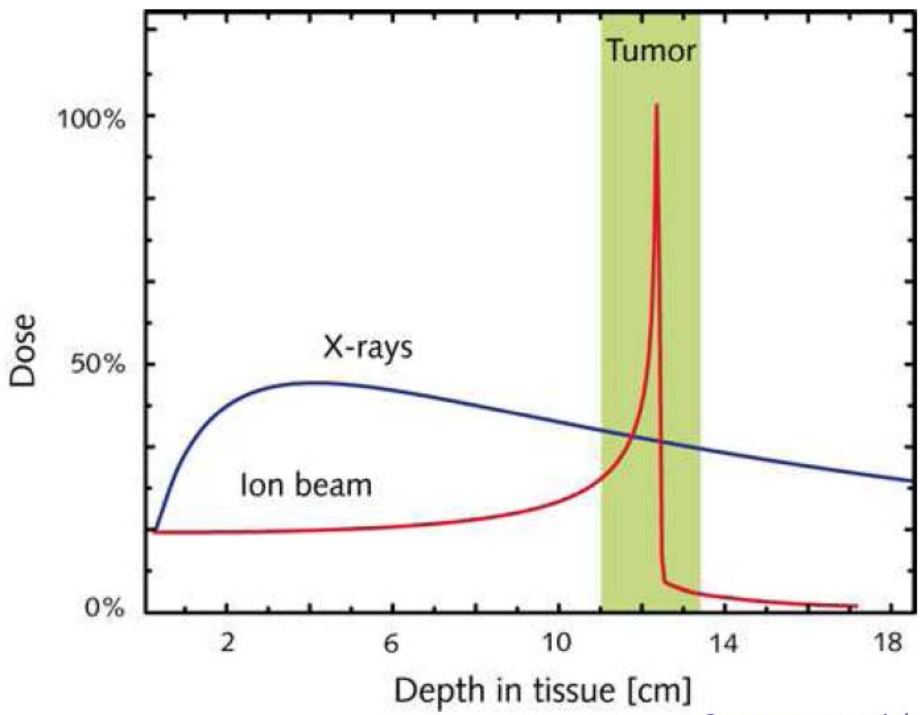
Data courtesy Dr. Camilla Rönnqvist (IBA)

Diamond Detectors Ltd

Industrial Application Radiotherapy Beams CPT

Charge Particle Radiotherapy High Energy Beams

It is estimated that 30% of all patients treated with conventional radiation would receive a better treatment with CPT.



Source: www.gsi.de

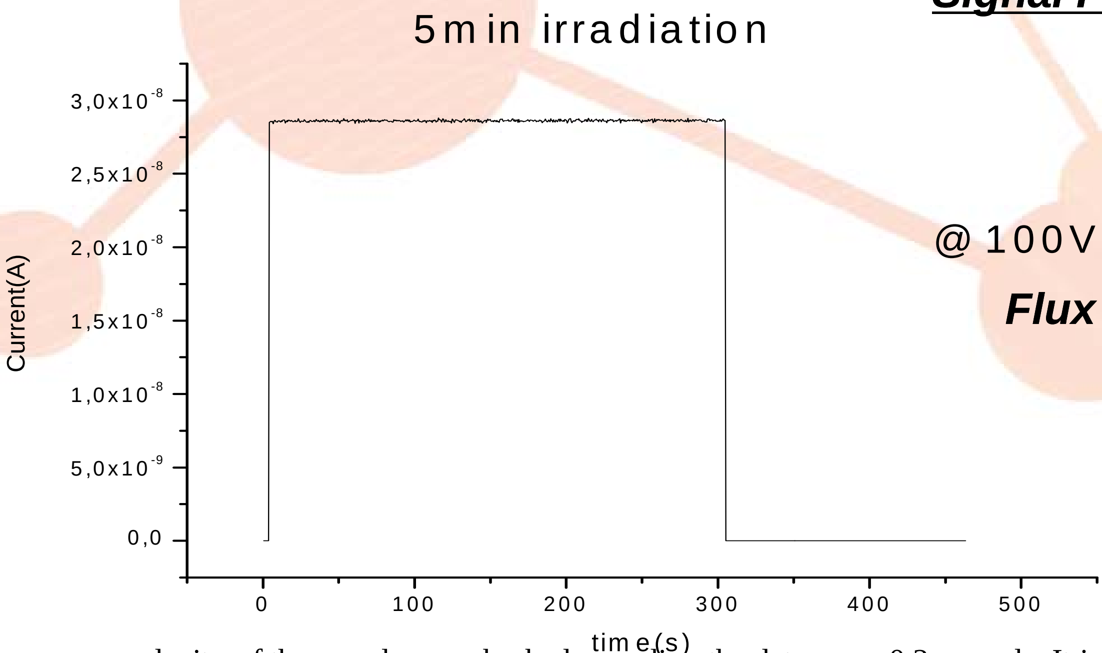
Tumour depth up to 30cm

Proton beam 200MeV
Carbon beam 4800MeV

Can now treat previously
In-operable cancers
Due to high accuracy of placement and
Low Dose to surrounding tissue

Radiotherapy Dosimetry
Co-60 1.17-1.33 MeV photons

Next positive biases were applied (500V, 250V, 100V, 50V, 10V). For these biases the sample showed very good behavior under irradiation. For example, considering a bias of 100V the sample shows very fast response while the source is switched on/off, absence of priming effect and very low fluctuation of the signal (that is below 0.5%). The signal to noise ratio is very high and abou S/N ~ $3.3\cdot10^4$.



Signal Fluctuations < 0.5 %
S/N > 10^4:1

@ 100V

Flux > 10^7 photons/s cm^2

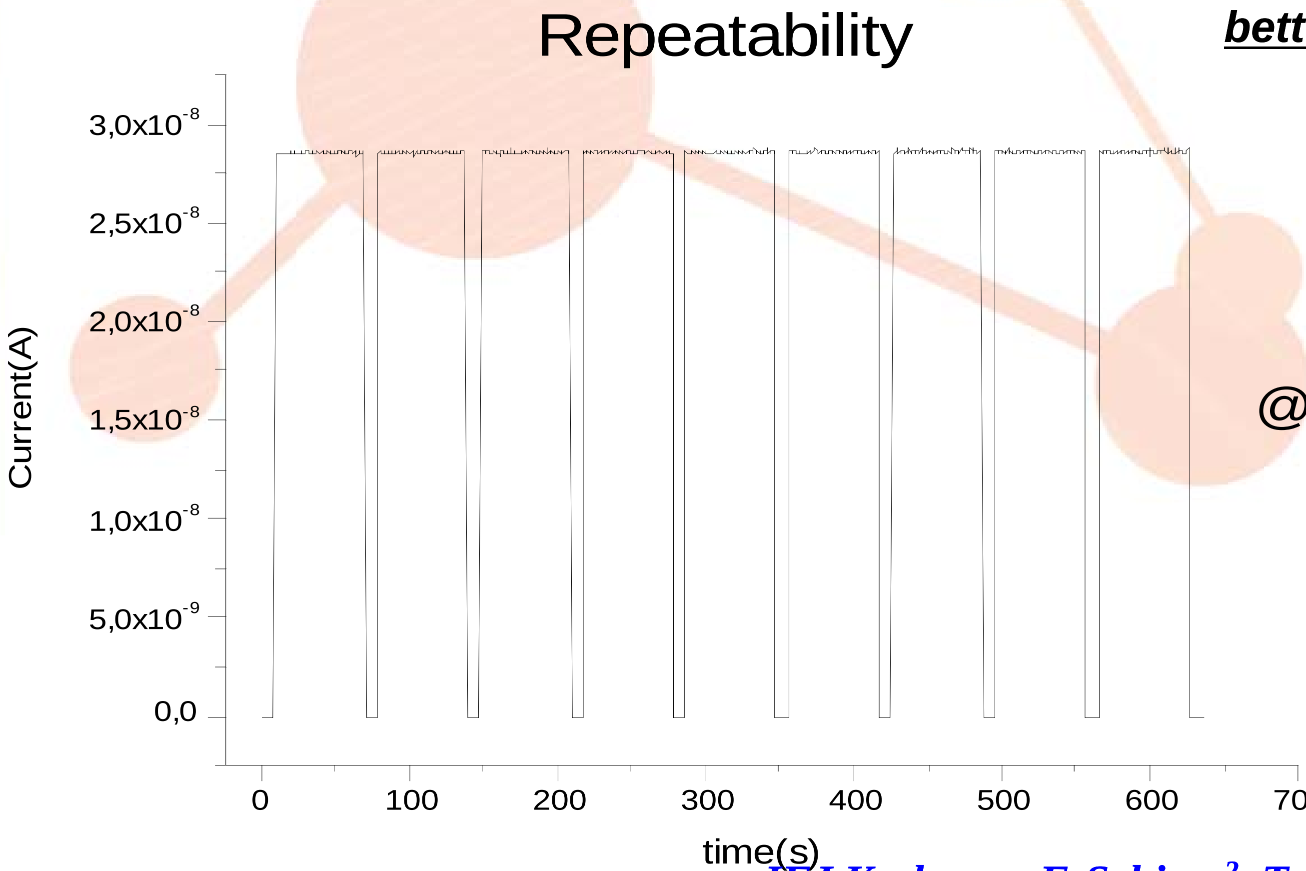
The response velocity of the sample was checked recording the data every 0.2 seconds. It is possible to see that when the source is switched on the sample reach the stabilization in a time that is less then 0.2 seconds.

IFJ Krakow, F. Schirru[2], T. Nowak[2], B. Marczewska[2]

Radiotherapy Dosimetry
Co-60 Response

To check the repeatability of the signal, one measurement was repeated several times at the same operating conditions. Each measurement in this case lasts one minute with a break of about 10 seconds. Taking the integral of each pulsed irradiation and averaging the values of area a coefficient of repeatability below 0.5% was found.

better than 0.5 %



@100V

IFJ Krakow, F. Schirru[2], T. Nowak[2], B. Marczewska

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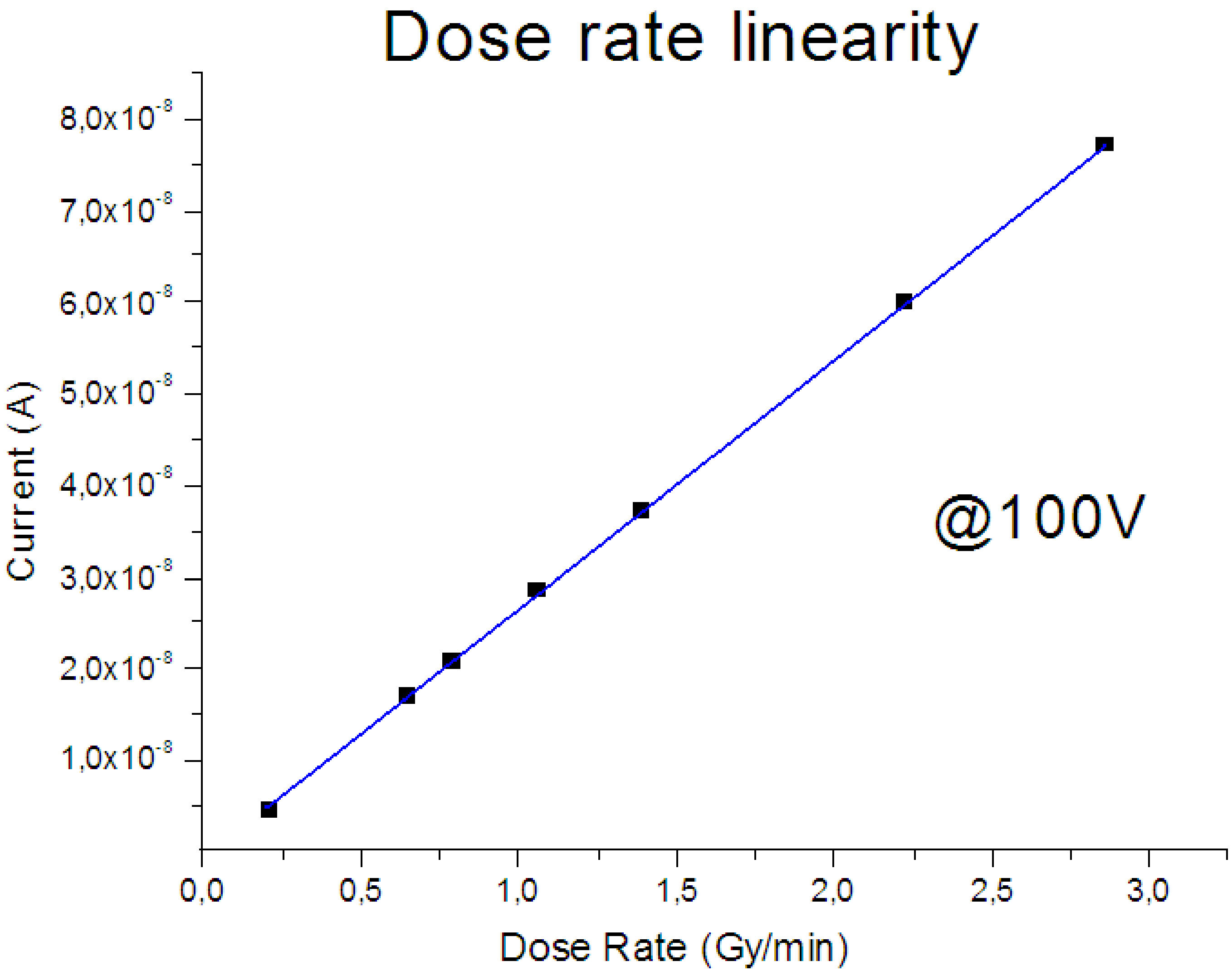
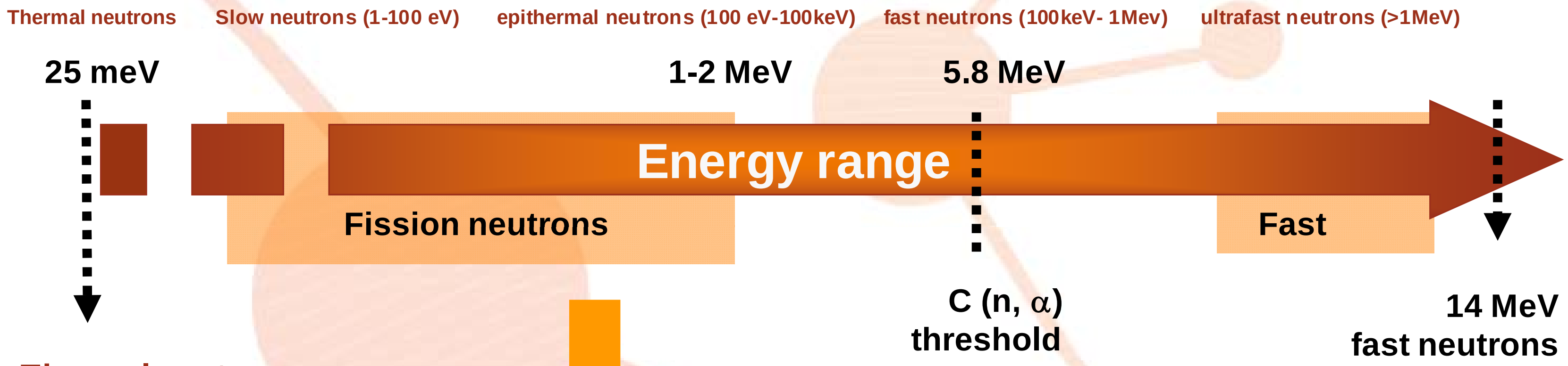
Radiotherapy Dosimetry
Co-60 Response



IFJ Krakow, F. Schirru[2], T. Nowak[2], B. Marczewska[2]

Diagnostics in Neutron Beams



Thermal neutrons

Precise fluency
Monitoring
High n/γ selecivity

Nuclear reactors
Fluency monitoring
Profile Monitoring etc

Elastic scattering
OK at high neutron fluencies
Typ. 1nA/cm @ 10 n.cm s
in a 100µm thick diamond layer

Nuclear reactors
Essentially when small size devices are required
e.g. propulsion reactors

Fusion neutrons
or confinment plasmas

temporal metrology (TOF),
Spectroscopy,

Tokamaks,
Rochester,
Laser Mega-Joule (LMJ)

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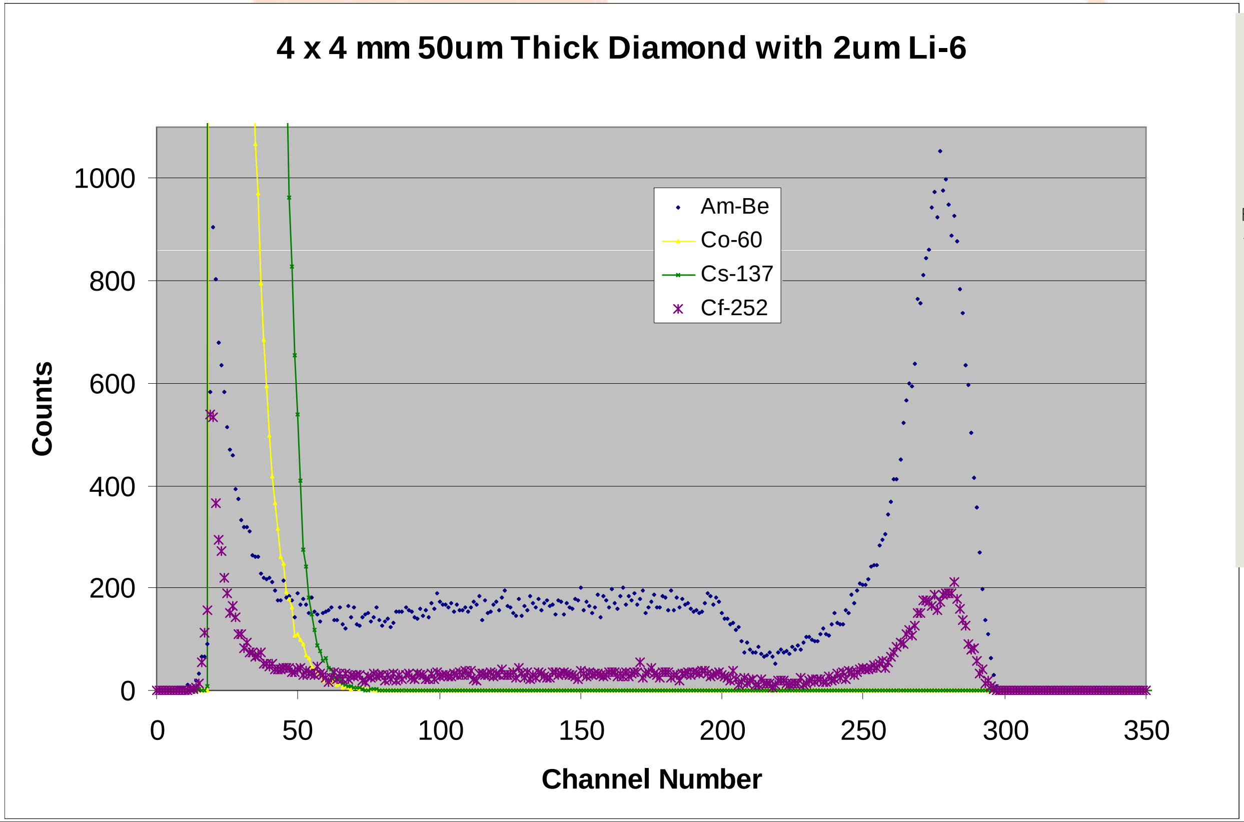
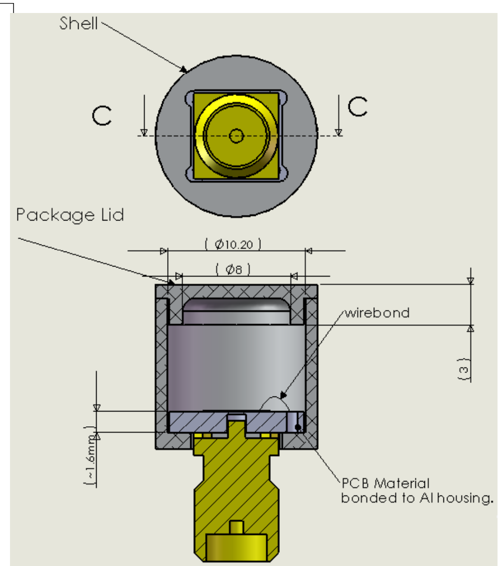
Thermal Neutrons

Diamond has been identified as an alternative detector technology for the detection of thermal and fast neutrons. Diamond coated with ^{6}LiF can be used for the detection of 2MeV alpha particles from the (n $\rightarrow$ α) reaction. Alternative conversion layers include ^{10}B or plastic for proton recoil detection.

Gamma Insensitive Thermal Neutron Device

The plot below illustrates the detector response to various sources. It can be clearly seen that both the ^{137}Cs and ^{60}Co gamma sources only deposit energy up to channel 81, approximately 600keV, while both the neutron sources produce a peak at channel 280 from the (n $\rightarrow$ α) reaction.





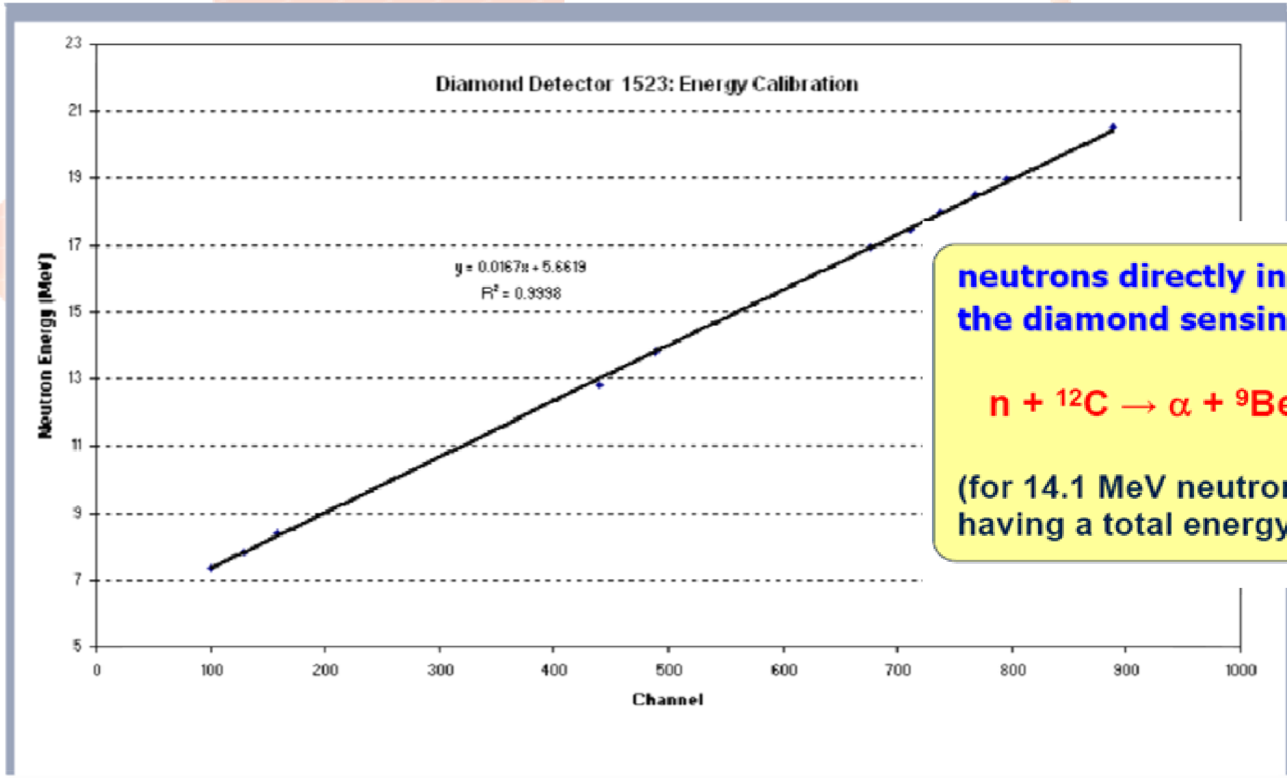
Data courtesy BAE-Systems

Fast Neutrons

The measurements were carried out recording the Pulse Height Spectrum of the recoiling charged particles produced in the diamond with the neutron interaction.

The diamond was successfully tested for several neutron energies.

The aim of the work was to determine the response of a diamond detector to neutrons with different energies and in particular of the $^{12}C(n,\alpha)^{9}Be$ reaction in order to determine the potentiality of diamond detectors as high resolution fast neutron spectrometers.



neutrons directly interact with ^{12}C in the diamond sensing layer:

$$n + {}^{12}C \rightarrow \alpha + {}^{9}Be - 5.7\ \text{MeV}$$

(for 14.1 MeV neutrons) with α and Be having a total energy of 8.4 MeV

Data courtesy Frascati

Diamond Detectors Ltd

14 MeV Neutron pulse sc CVD Diamond Detector+2GHz amplifier)

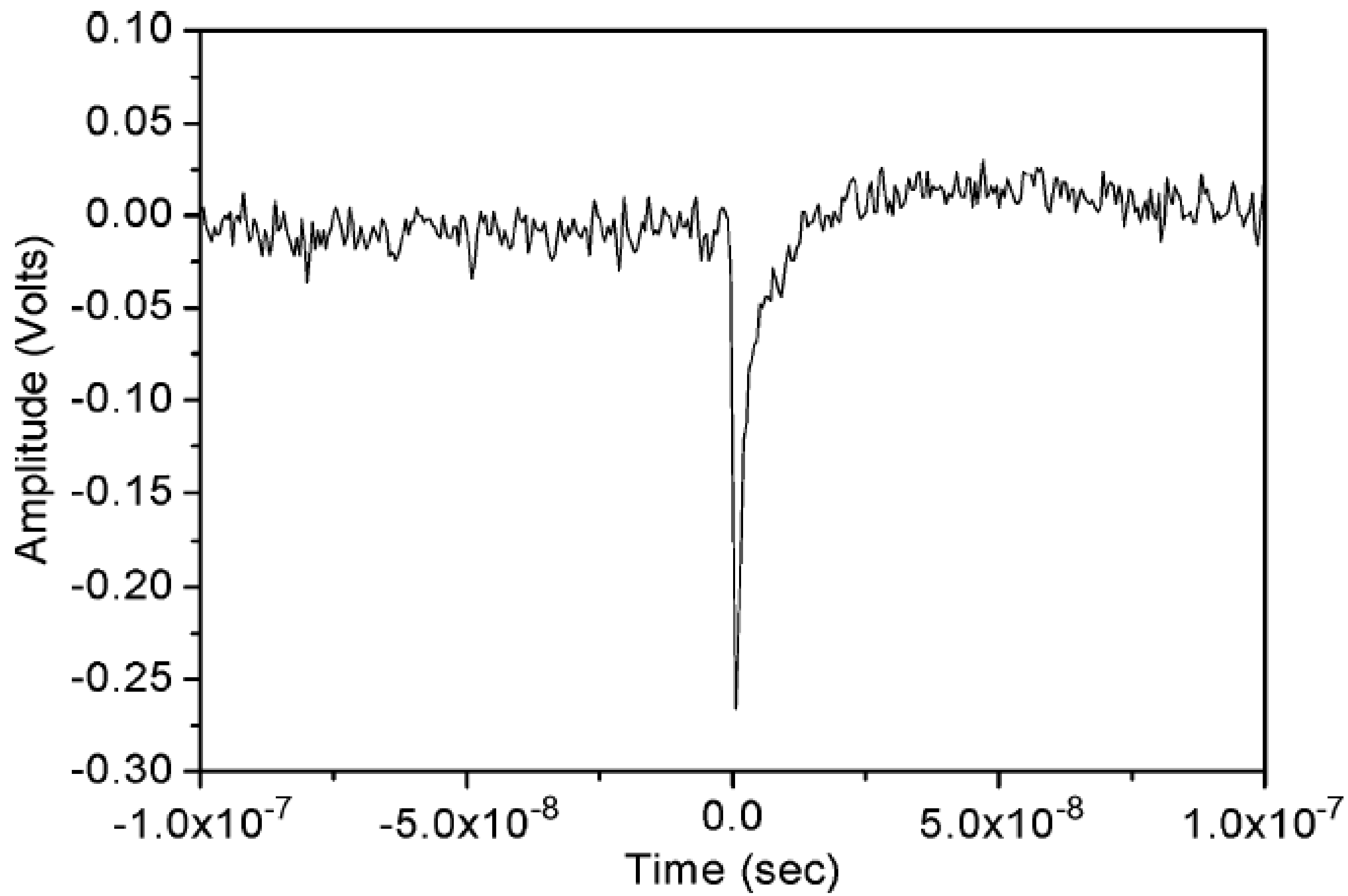


Fig. 6. Output pulse produced by a DBA preamplifier connected to a SCD diamond detector irradiated with 14 MeV neutrons.

Data courtesy Frascati

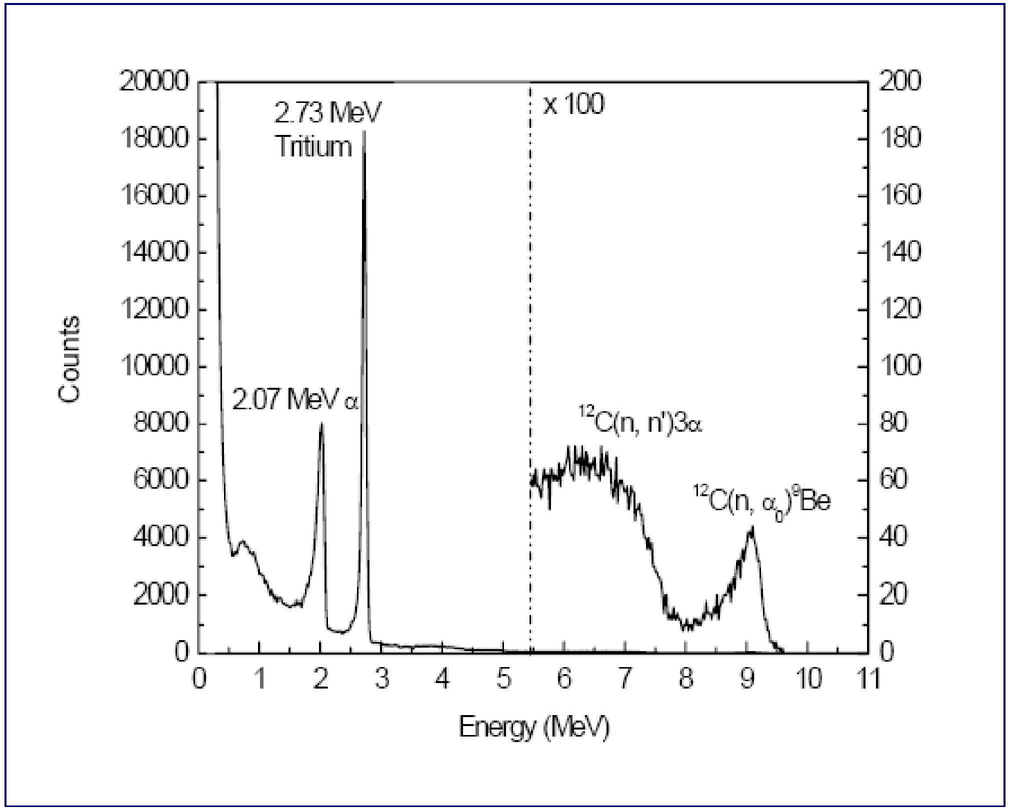
Diamond Detectors Ltd

- Thermal neutrons where produced by slowing down a fraction of the 14.8 MeV neutrons produced at FNG by a 10 cm PMMA moderator

- Both the 2.06 Mev α and the 2.73 MeV Tritium peaks originated by thermal neutrons interactions are clearly resolved

- The width of the two peaks is due to the energy loss of the produced particles inside the LiF layer. In particular, the 2.06 MeV α peak is broader than the Tritium peak due to the higher stopping power of α particles in LiF

- The 9.1 MeV $^{12}C(n, \alpha_0)^9Be$ reaction peak can be noticed as well, demonstrating the possibility of simultaneous detection of thermal and fast neutrons



Università di Roma "Tor Vergata", Italy

Diamond Detectors Ltd

UV detector developments

- ***Deep UV (sub 240nm) is detected in the first few microns within the diamond. This makes the surface preparation and contact fabrication very important. Both single crystal and poly crystal devices have been evaluated by academic groups.***

Unique properties for deep UV:

- ***High UV/visible discrimination***
- ***Radiation Hardness***
- ***Fast response time…***
- ***Low noise – Low dark current***
- ***High UV/neutron discrimination***
- ***Harsh Environment operation (ITER relevant)***

- **VUV sensors for solar observation from satellites**
- **EUV and VUV plasma spectroscopy and plasma monitoring in fusion reactor**
- **Applications in deep UV photolithography**

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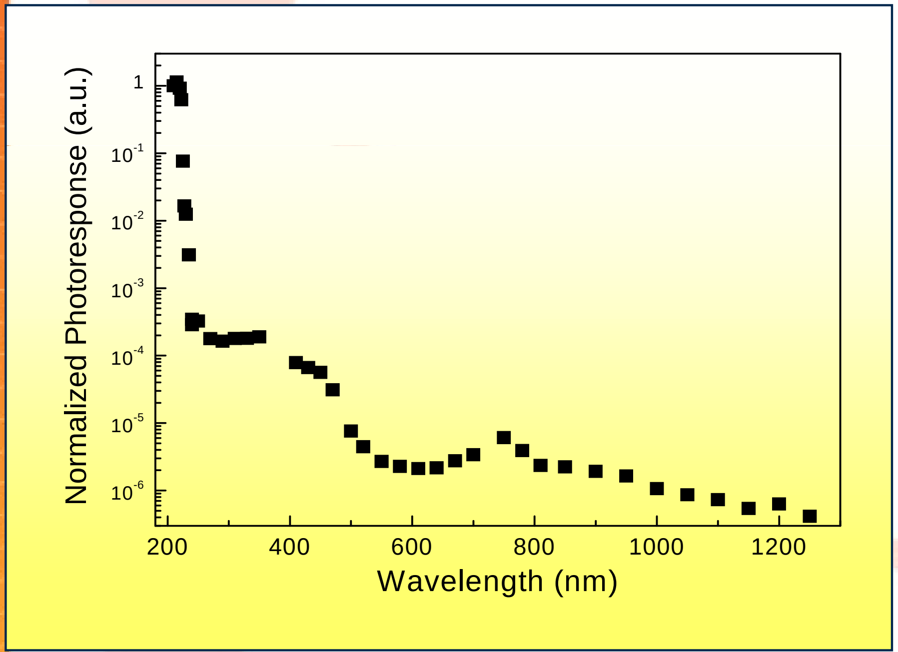
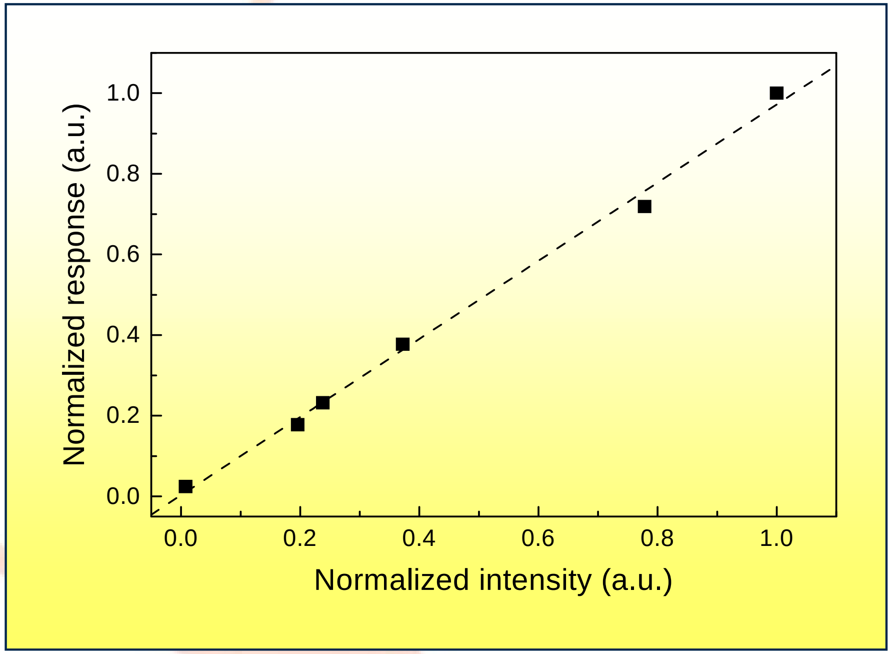
UV Pulsed mode measurements





- ✓ ***Stable and highly reproducible detector response***
- ✓ ***Undesirable memory effects as well as pumping ARE NOT OBSERVED***
- ✓ ***Detector response as a function of the calculated incident energy***
- ✓ ***Good linear behaviour***

Results from ENEA C.R. Frascall, University of Rome.

Diamond Detectors Ltd

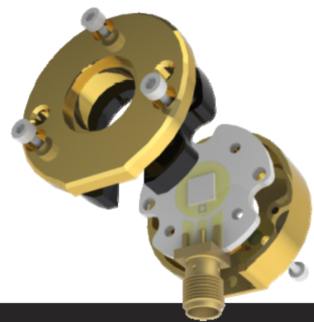
Aim of this presentation

- To introduce DDL and inform people on the properties of diamond.

- Demonstrate by example diamond diagnostic applications.

- Ensure people are aware that diamond is becoming a real alternative to traditional ion-chambers and silicon devices across a range of diagnostics.

Thank you



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Thank you