RDH/IRPT WP8 : Development of large-area monolithic 2D dosimeters made with polycrystalline CVD diamond

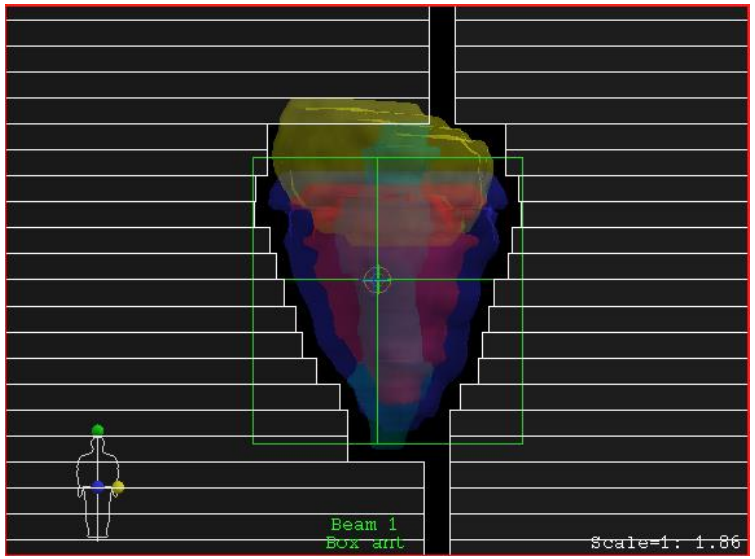
Motivation

Modern radiotherapy techniques : dose-delivery conformal to tumors to spare healthy tissues

- ✓ **Intensity Modulated RadioTherapy – IMRT**
- ✓ **Volumetric Modulated Arc Theraphy - VMAT**

→ high spatial gradients, strong variations in space and time of dose rate and energy spectrum.

Requirement: Tissue equivalent bidimensional dosimeter for pre-treatment verifications



Multi Leaf Collimator (MLC) mounted on the linear accelerator head

VMAT*: Continuous delivery modality

Intensity modulation is obtained thanks to MLC, variable dose rate and variable rotation velocity of gantry

Gantry moving continuously without dead times due to repositioning

VMAT / IMRT comparable in terms of target covering and sparing of healthy tissues ;

VMAT reduced treatment time (10-15 times)

*Cedric X Yu , **Intensity-modulated arc therapy with dynamic multileaf collimation: an alternative to tomotherapy** , Physics in Medicine and Biology 40, 1435-1449, 1995.

Diamond Dosimeters

- **it is almost water equivalent**
  - it doesn't perturb the radiation field → small fields
  - the energy is absorbed as in the water → no correction factors
- **high radiation hardness** → long term stability
- high density → high sensitivity → small dimensions
- non toxic

Natural diamond

- **very high production costs, difficult to select stones with proper dosimetric response**

Single crystal CVD (Chemically Vapour Deposited) diamond

- **grown on HPHT diamond, not available in large areas**

OUR CHOICE: Polycrystalline CVD diamond

ability to produce large area wafers of 3-5"

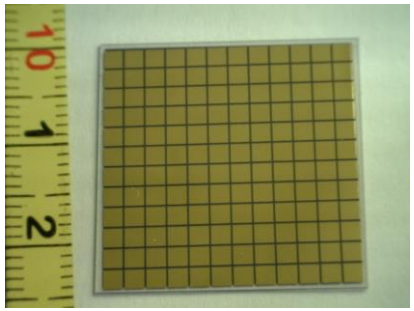
- zero/low voltage to reduce polarization effects*

*M. Bruzzi et al., Diamond & Related Materials 20 (2011) 84–92

2015 – development of a 2- polycrystalline pixel diamond dosimeter (Florence)

- Material

- Two polycrystalline diamond films
2.5x2.5cm^2 active area each, 300μm thick;
- Premium Detector Grade Element Six, UK



- Contacts

• Schottky Barriers produced @ University of Florence
•12 x 12 matrix, pixel size: 1.8x1.8 mm^2 → 288 pixels in total

- Read Out Electronics

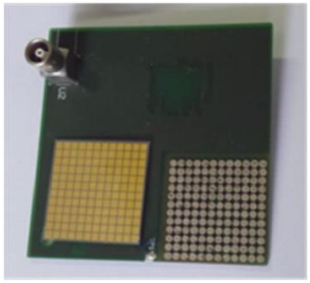
•four 64 channels 20 bit current-input analog to digital converter chips able of measuring currents from fAs to mAs; 160μs-1s integration time (50ms)
•custom printed circuit board;
•semi-rigid silver-polymer pin-contacts produced by us connecting each pixel of the 144 matrix connecting vias on PCB .

-Measurement

•Low voltage to get fast and reproducible signals;
•Device can be moved in x-y directions to cover a wider radiation field area.

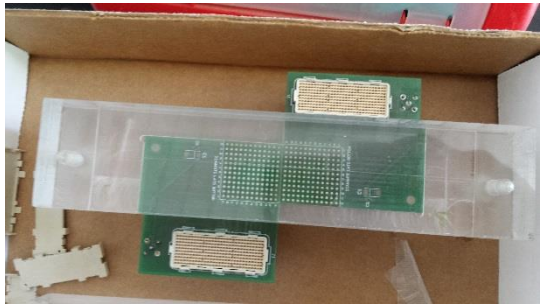
Experimental Test Set-up

LINAC @ Radioterapia AOUC Firenze

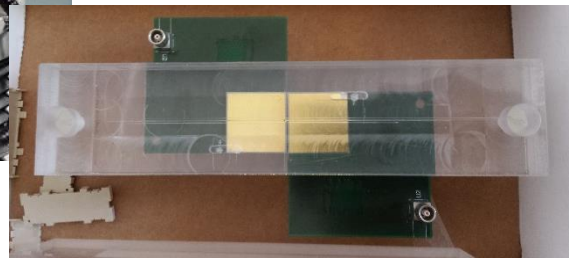


1 pCVD on PCB

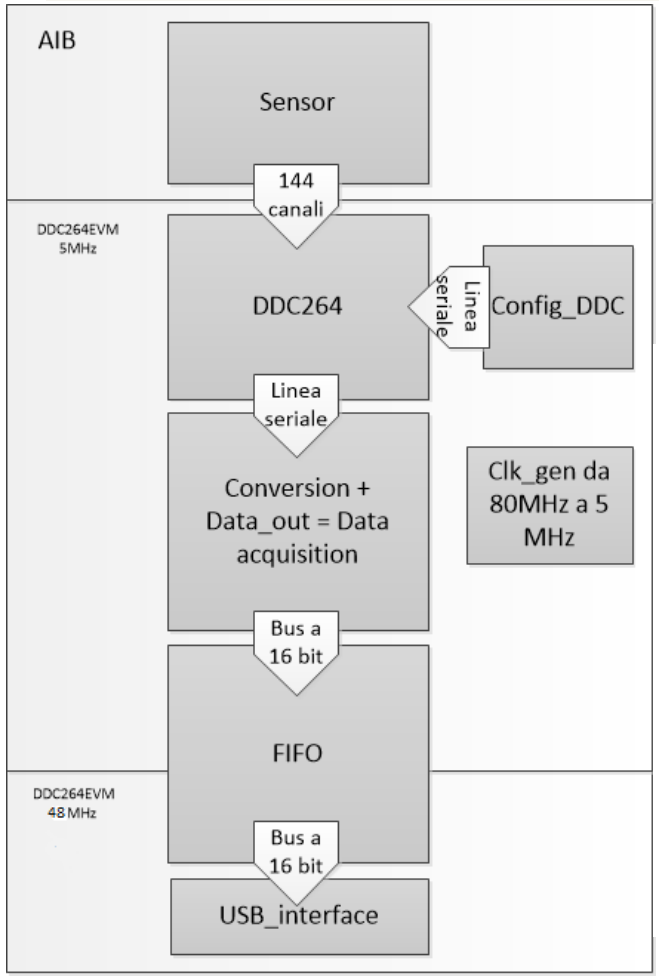
Connecting pins



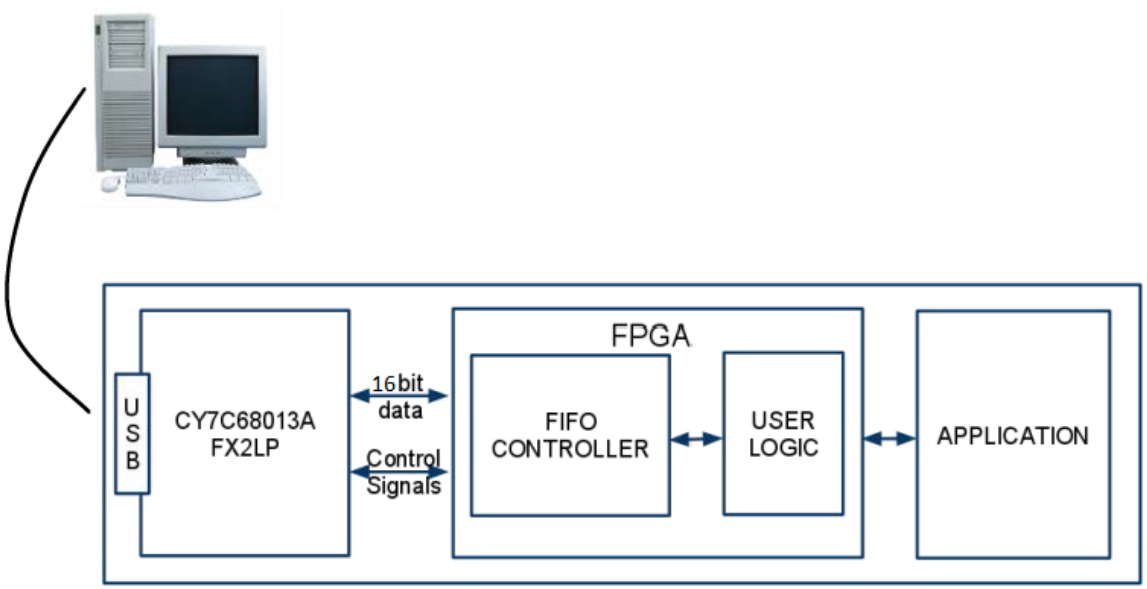
2 pCVD in PMMA /front



/rear

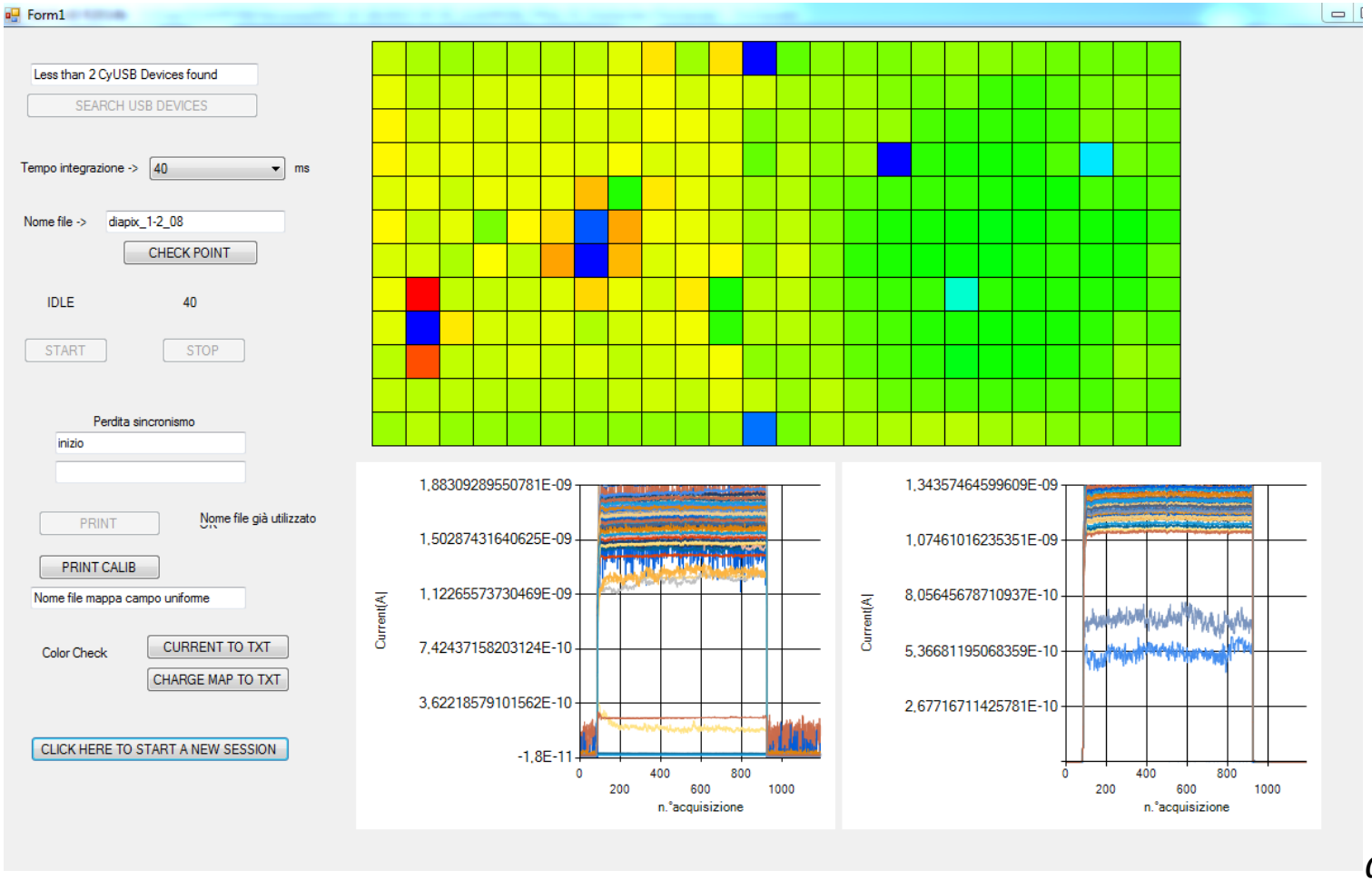


Sviluppo firmware e software di un rivelatore bidimensionale per radioterapia



Analysis of the uniformity of the pixels response under a uniform beam

Current and charge response of 288 pixels (active area 5.0x2.5cm^2 in a 10cmx10cm field (V_{app} = 2V) under a conventional 6MV X beam

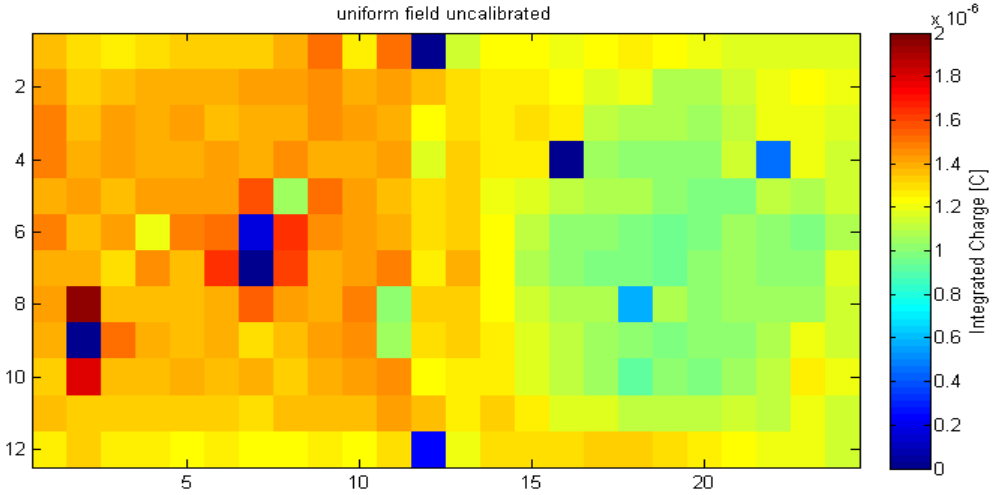


- ✓ negligible dark current → high S/N
- ✓ stable response , fast dynamics
- ✓ Spread in the sensitivity $S = \frac{dQ}{dD} \sim 20 \frac{nC}{Gy}$
- ✓ Only a few contacts not working properly

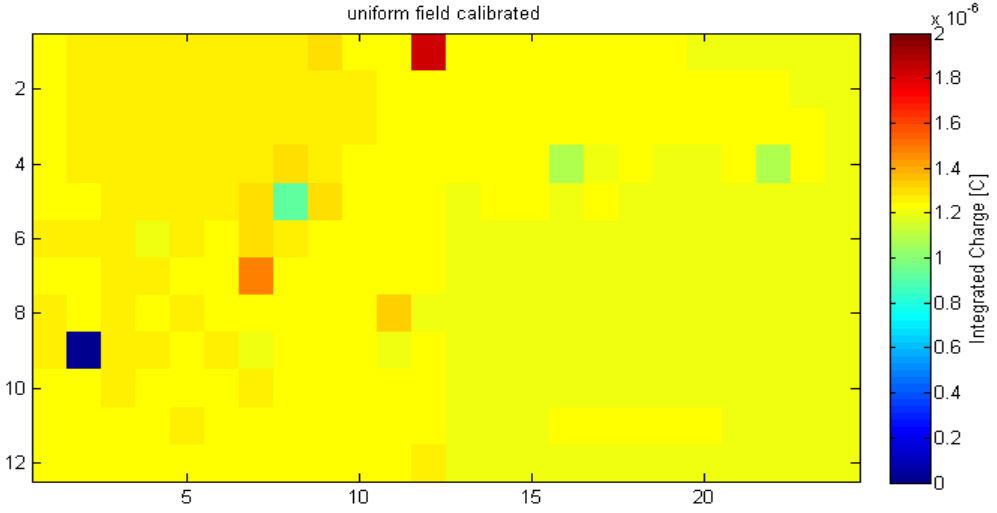
Calibration under a uniform beam

Charge response of the 288 pixels before and after calibration correction

Before calibration

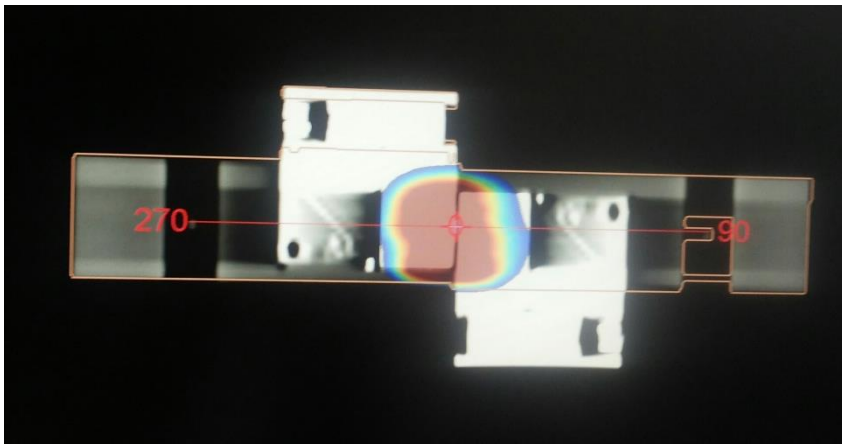


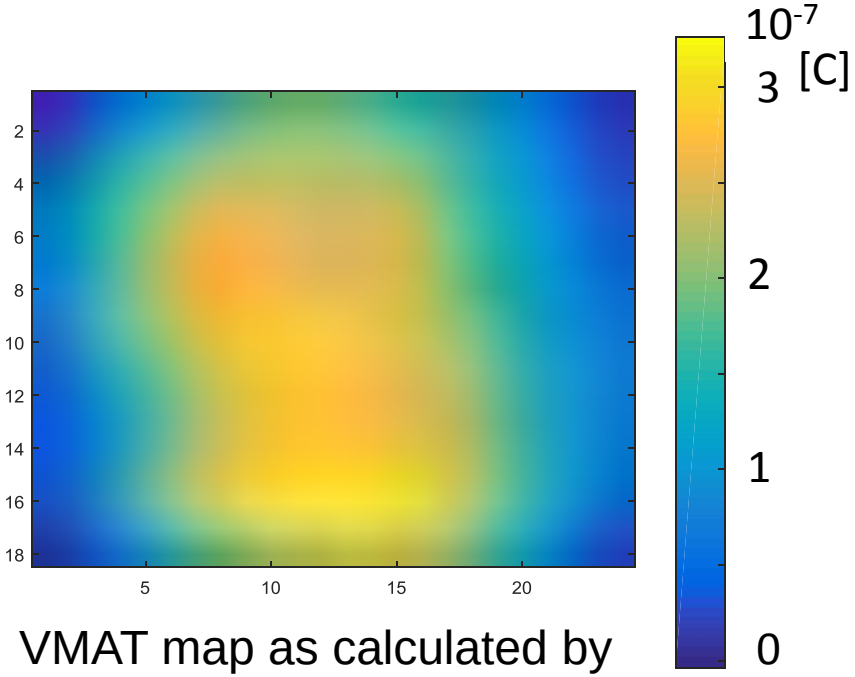
After calibration



VMAT First experimental Test

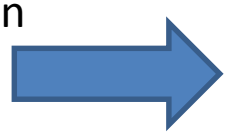
- lung cancer treatment
- 2 polycrystalline diamond dosimeters
- Active area: 5.0x2.5cm^2

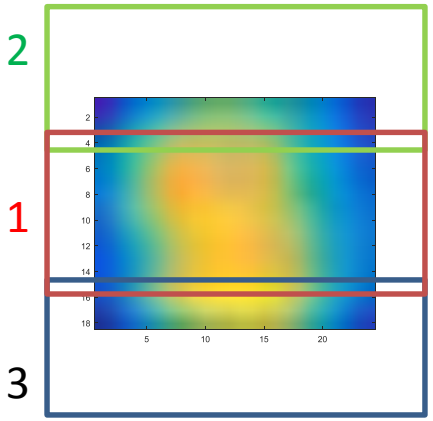




VMAT map as calculated by the TPS

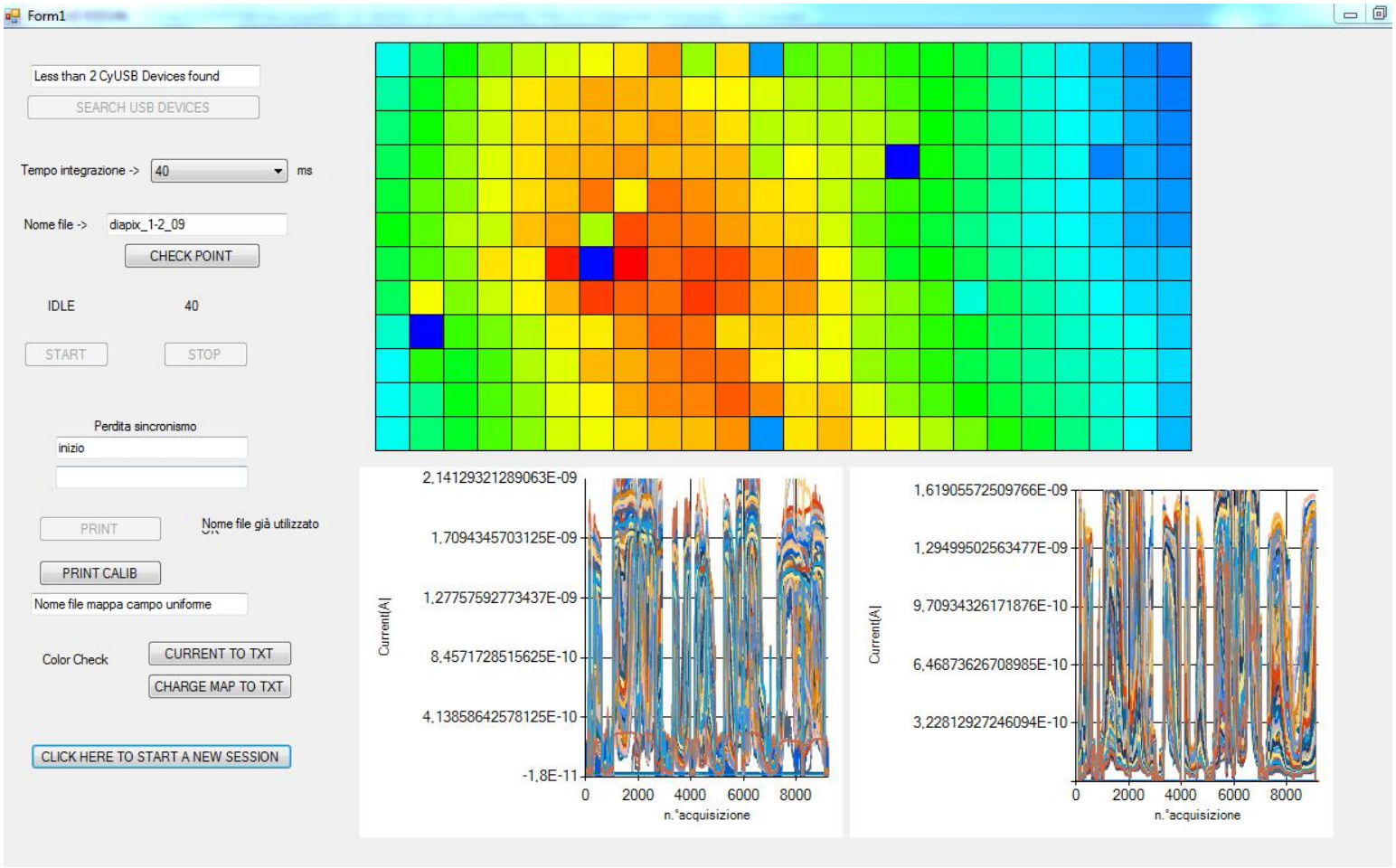
- 3 measurements : system moved ±0.4cm in the y-direction to cover the entire field



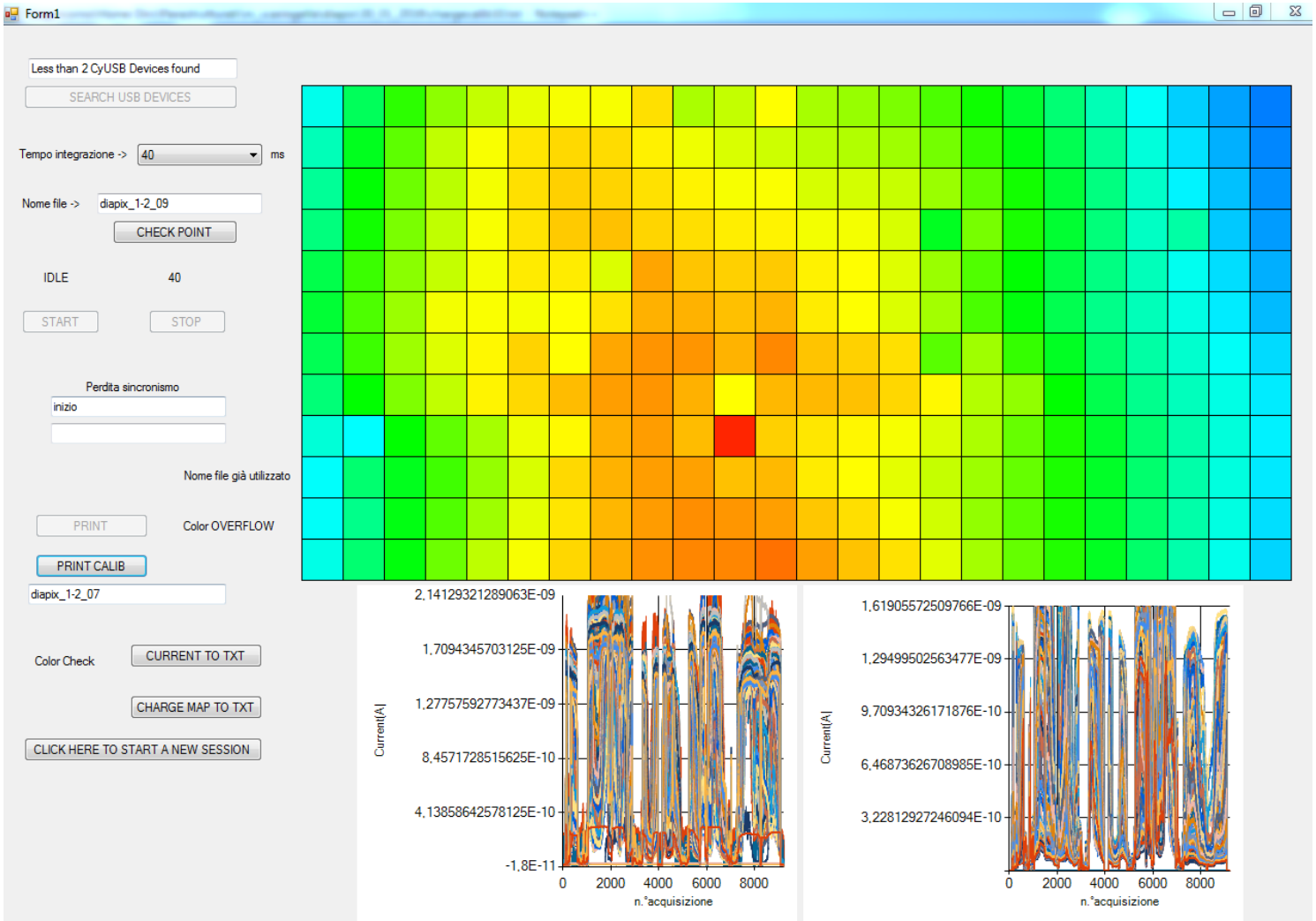


Presented at International Conference on Diamond and Carbon Materials, Bad Homburg, Germany, 8 September 2015

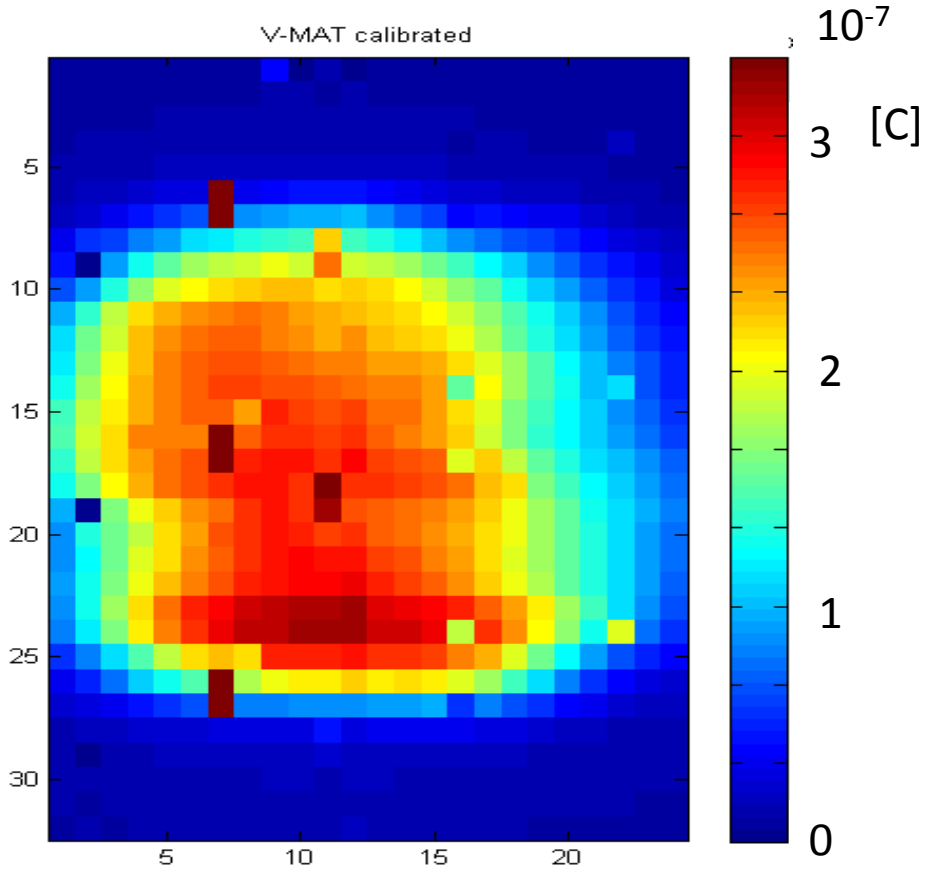
Before calibration – central sector (1)



after calibration – central sector (1)

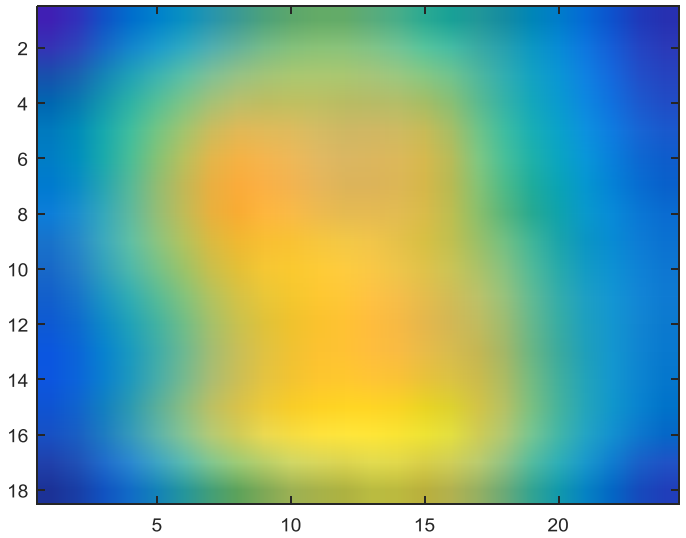


VMAT map-comparison between experimental and calculated dose maps



VMAT map **as measured by the two pCVD diamond**

Preliminary Results !



VMAT map **as calculated by the TPS**

Quantitative data analysis in progress

Activity

LE – CT – MI Bicocca

The activity is mainly devoted to demonstrate the procurement capability and quality certification of large size polycrystalline diamond sensors to be used in IMRT.

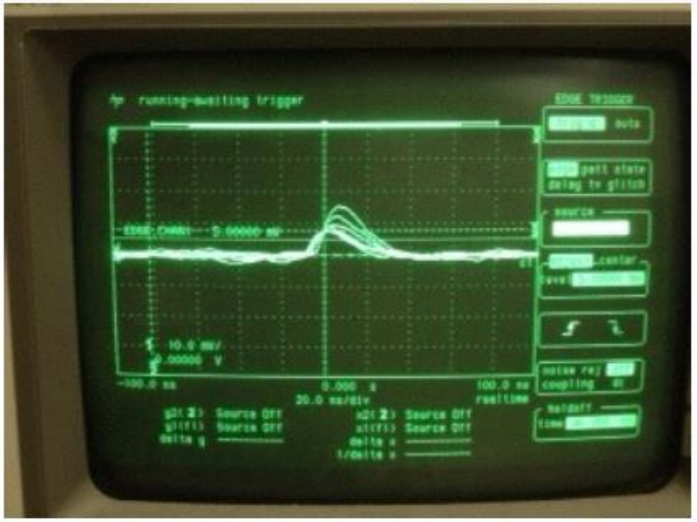
Delay in procurement of large size diamonds from II-VI USA likely due to LHC priority

Delivered in Oct 2015 (3 month delay)

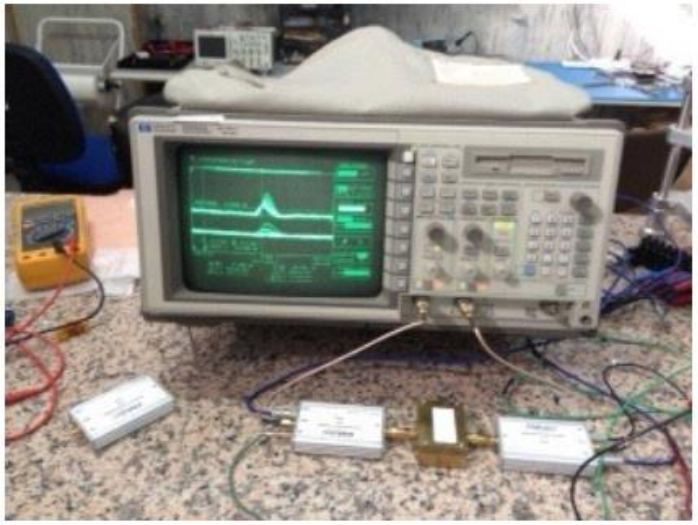
Your PO N°	Our PO N°	order date	P/N	Description	Ordered qty	Shipped qty	up date on situation - April 2015
CA5335108	5466	07.02.2013	864625	diamond windows 20 x 20 x 0.5 mm	2	0	(2) - ship from USA 07/06/15
CA5800201	5517	10.03.2014	864625	diamond windows 20 x 20 x 0.5 mm	6	0	(6) – ship from USA 07/06/15
CA5854697	5526	12.02.2014	220398	diamond windows 25 x 25 x 0.5 mm	2	0	(2) – ship from USA 06/21/15

To be delivered in Mar 2016 (8 month delay)

Preliminary test with CR



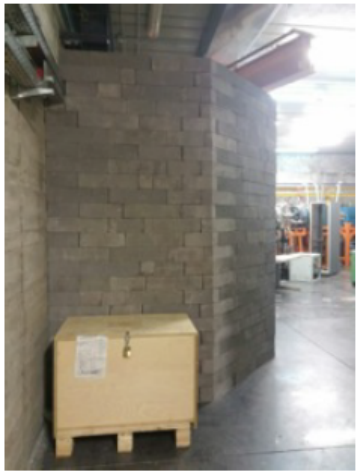
Charge collection distance
CD ~ 300 um
(Quite good)

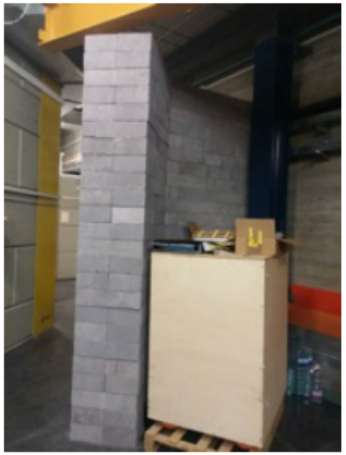


CR coincidence between the two 2x2x0.05cm3 II-VI diamond

NEXT: Accurate efficiency mapping with beta source and laser under way

Infrastracture at LNS





Concrete shield already operational at zero degree line for all users

Further instrumentation for users under procurement:

- XZ Device Under Test movement system remotely controlled
- Multi-channel electronics to readout a segmented Secondary Electron System by DC

Under conceptual design:

- Segmented Secondary Electron System (for example Ta foils)
- Custom made in air Faraday Cup

2015 - Papers and Conferences

Conferences:

M. Bruzzi et al., Extraction of VMAT 2D maps of dose with a large-area monolithic bidimensional dosimeter made with polycrystalline CVD diamond
Talk at International Conference on Diamond and Carbon Materials, Bad Homburg, Germany, 8 September 2015

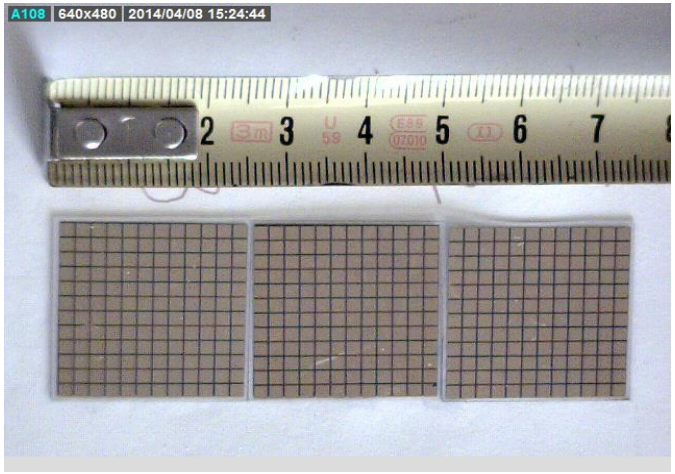
Papers:

- Zani, M.; Scaringella, M.; Talamonti, C.; et al. Bidimensional polycrystalline CVD diamond detector for Intensity Modulated Radiation Therapy pre-treatment verifications JOURNAL OF INSTRUMENTATION Volume: 10 Article Number: C03046 Published: MAR 2015

- Chiodini, G.; Fiore, G.; Perrino, R.; et al., Diamond detector time resolution for large angle tracks, NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT Volume: 796 Pages: 38-41 Published: OCT 1 2015

WP8 Program 2016

- Tests and data analysis with the 2 diamond system with IMRT/VMAT beams;
- Development of the PCB electronic readout for 3 diamonds (7.5x2.5cm^2);
- First tests with the 3 diamond system;
- Comparison of uniformity tests with cce (beta) and radiotherapic beam X6MV
- Possible upgrade to a 4-diamond system including one sample from the Lecce Group to cover a 10x2.5cm2 area.



Thank you!