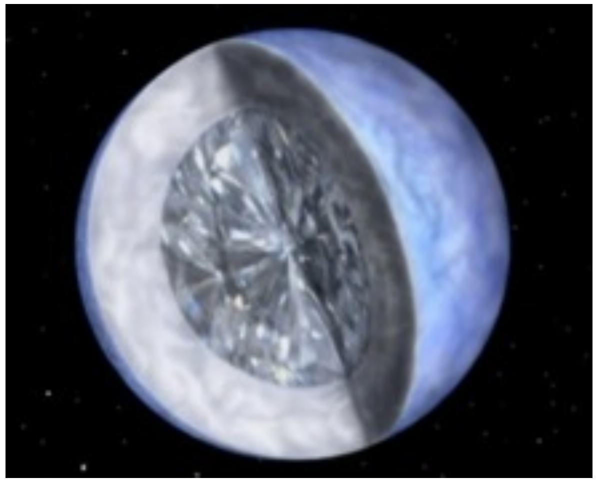
THIN ACTIVE TARGET

G. Chiodini
INFN Lecce



PADME kickoff meeting

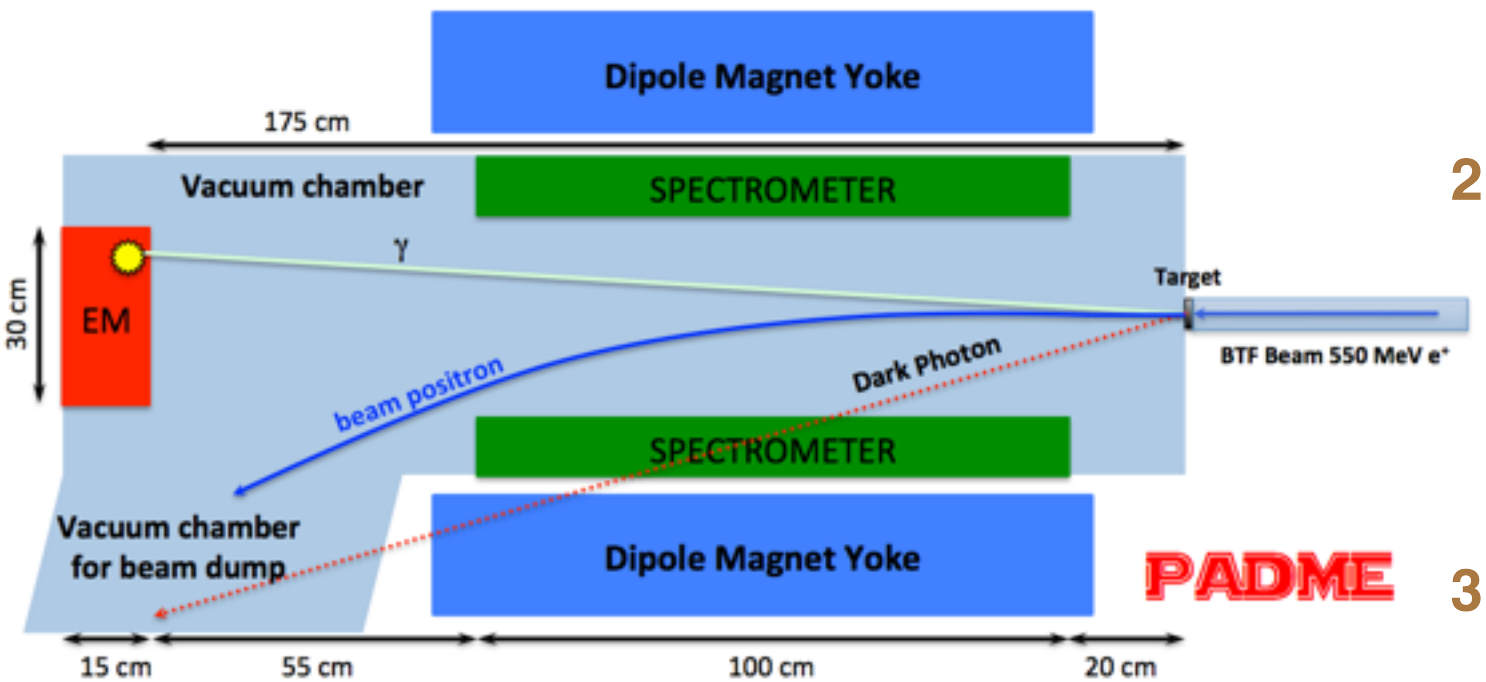
20-21 April 2015 *Laboratori Nazionali di Frascati*
Europe/Rome timezone

Overview

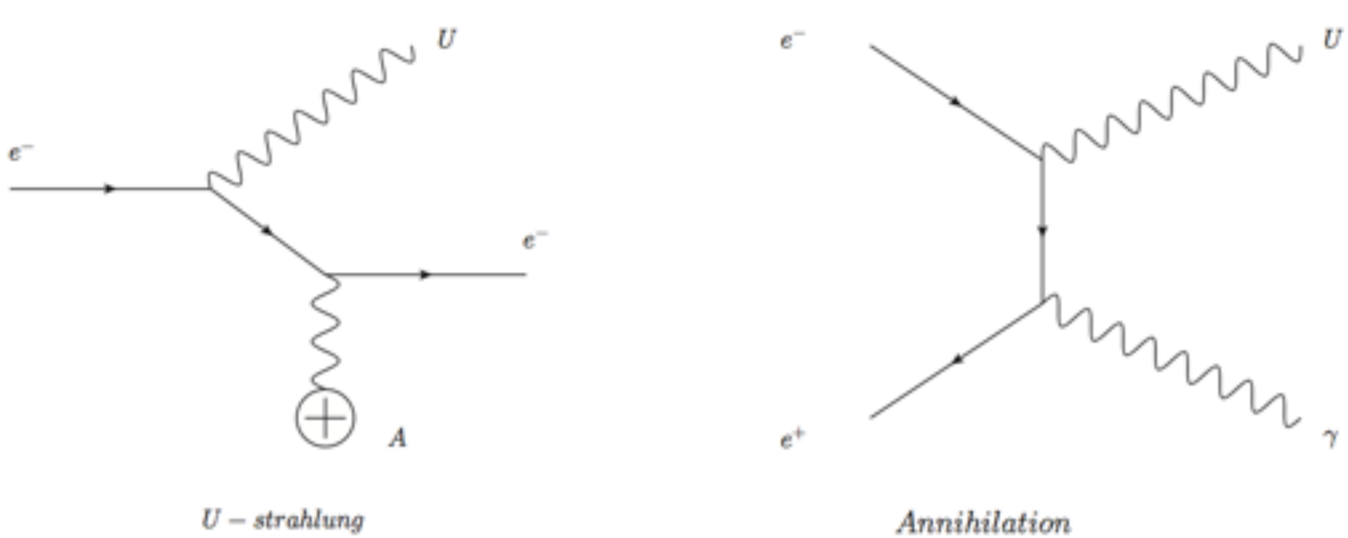
1. Introduction
2. Thin active target
3. Full carbon diamond detector
4. Thin diamond
5. Baseline design
6. Short term plans and people
7. Conclusions

Introduction

" Proposal to Search for a Dark Photon in Positron on Target Collisions at DAPHNE Linac"
M.Raggi and V. Kozhuharov. Advances in High Energy Physics, 2014 ID 959802 (2014).



1.5 mb= γ-bremsStrahlung ~ 435 x (γ-annihilation)



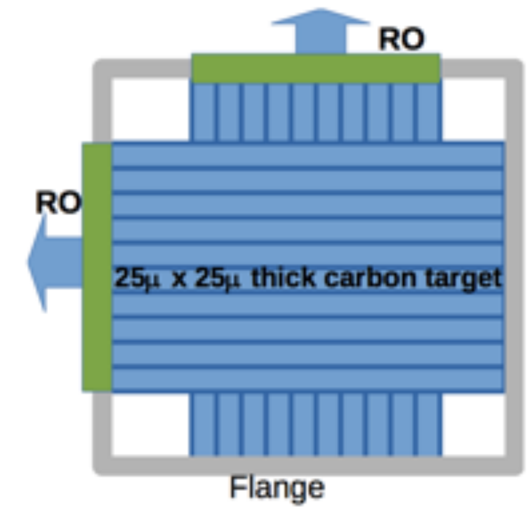
1. Annihilation/BremsStrahlung scale with 1/Z of the target
   - Carbon is low Z and self-supporting
2. Positron direction and primary vertex position necessary to close the kinematics for invisible search or reduce BG for visible search
   - Thin target: 50-100 um
3. BTF bunch features 1-2 mm spot, but due to hysteresis and stability of the currents in the magnets, long term stability no better than 5 mm.
   - Monitor bunch position with about 1 mm resolution in the X-Y plane

Mechanical design strongly related to the detector technology

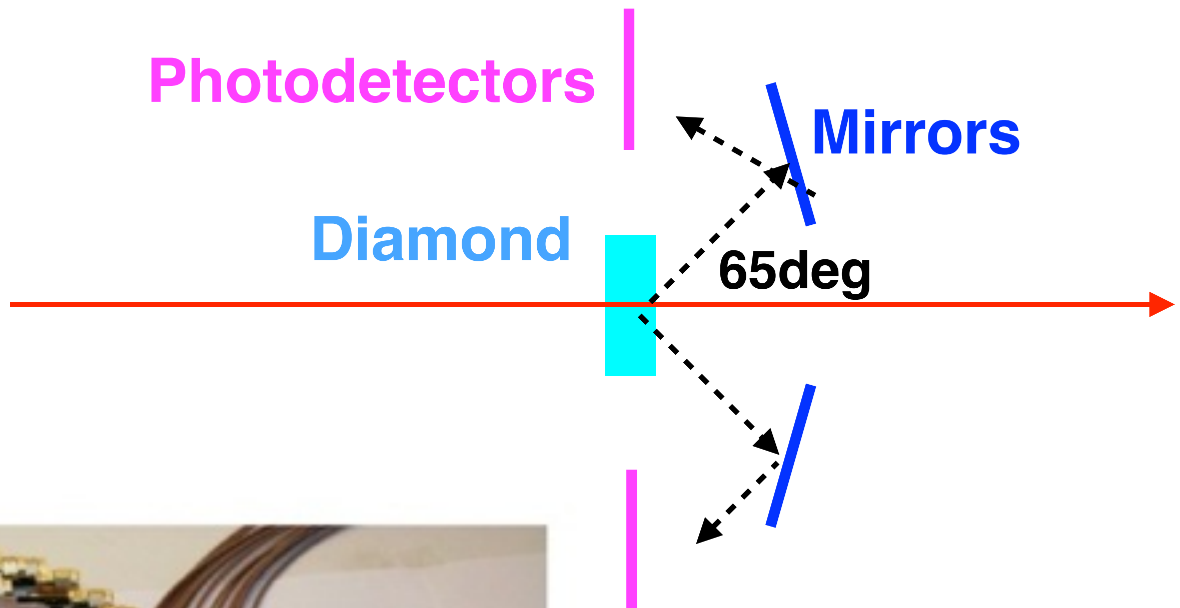
Thin Active Target

Some ideas …

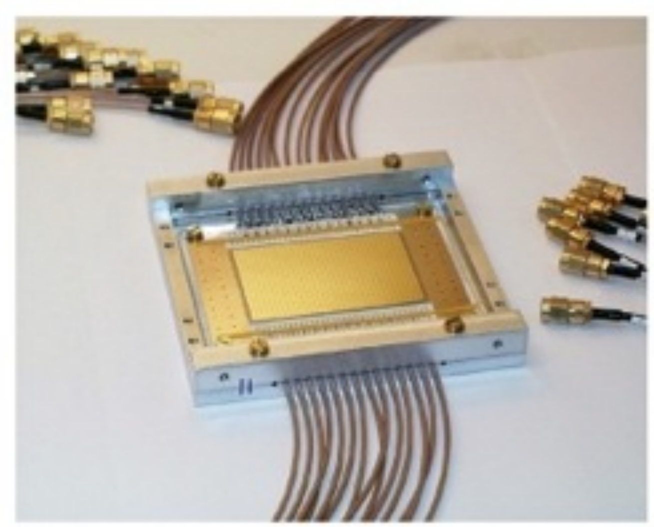
Graphite target:
- 2 planes X-Y
- 10 strips/planes
- Secondary electron emission



Diamond target:
- 1 plane
- Cherenkov light



Diamond target:
- 1 plane
- 10 strips X + 10 strips Y
- Ionization current



Beam profile at GSI with strip diamond

http://www-w2k.gsi.de/detlab/cvd/CVD-Applications.htm

“ Proposal to Search for a Dark Photon in Positron on Target Collisions at DAPHNE Linac” M.Raggi and V. Kozhuharov. Advances in High Energy Physics, 2014 ID 959802 (2014).

… and problems

Graphite target: Secondary electron emission

- Segmentation
- Electrostatic grid

Diamond target: Cherenkov light

- Signal yield
- Mechanics

Diamond target: ionisation current

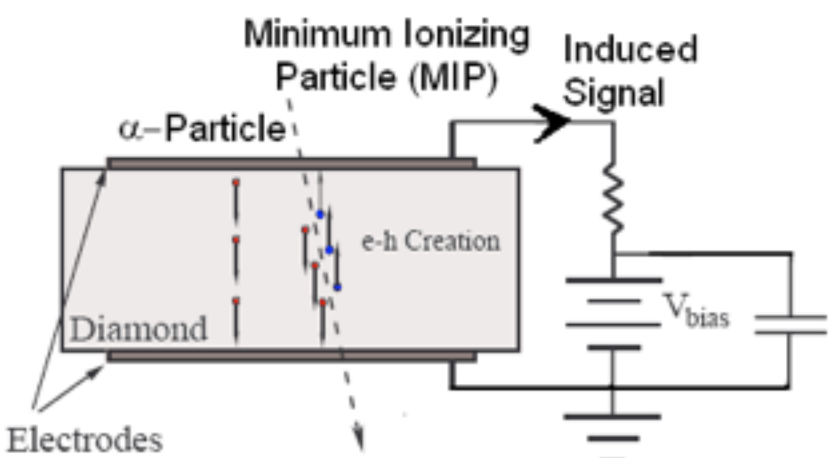
- Large size
- Polarisation and uniformity

Full carbon diamond detector

Diamond detector

Counting mode

$\lambda_h \sim \lambda_e = \lambda$ = mean free path
due to trapping and recombination

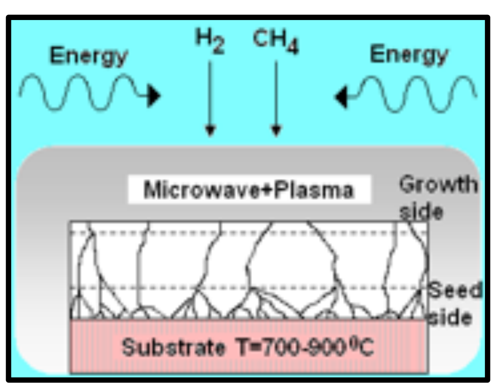


Q_{gen}=36e-/um

CCD = Charge Collection Distance

$$Q_{ind}^{MIP} = Q_0 \frac{2\lambda}{d}[1 - \frac{\lambda}{d}(1 - e^{-\frac{d}{\lambda}})] = Q_{gen} \frac{CCD}{d}$$

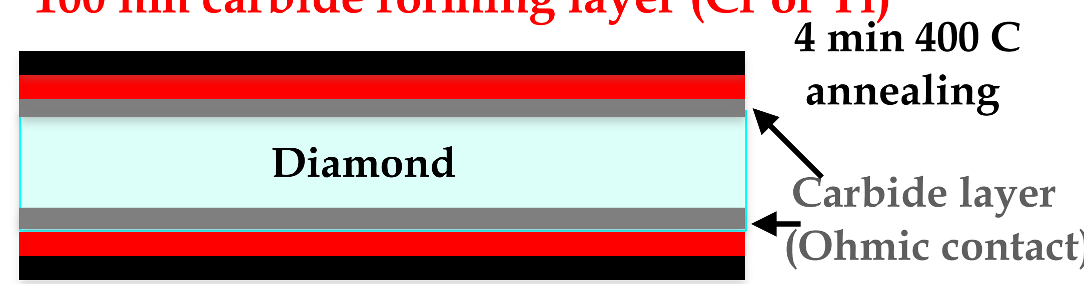
Crossing particle signal



Microwave-Plasma-Enhanced CVD
Low pressure and fairly low power
Growth rates of ~ 1μm/hour.

CVD high quality diamond
pushed by SSC and LHC

100 nm contact layer (Au or W)
100 nm carbide forming layer (Cr or Ti)

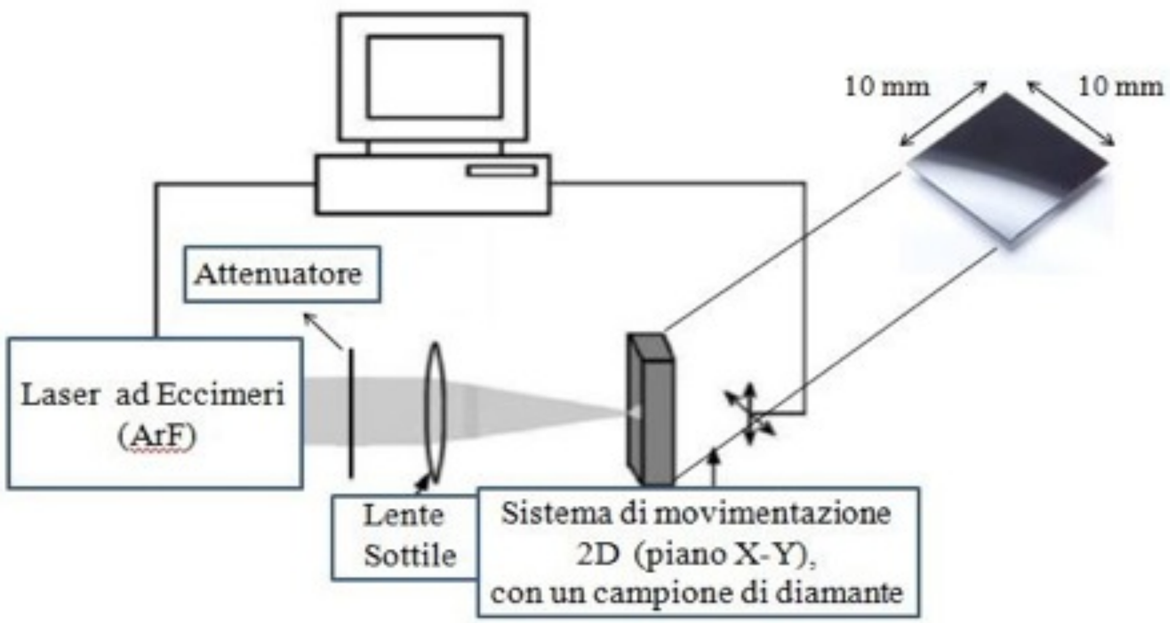


Can we avoid high Z metal layers (possible source of BG) ?
Yes, use graphitic electrodes

Graphitization on diamond

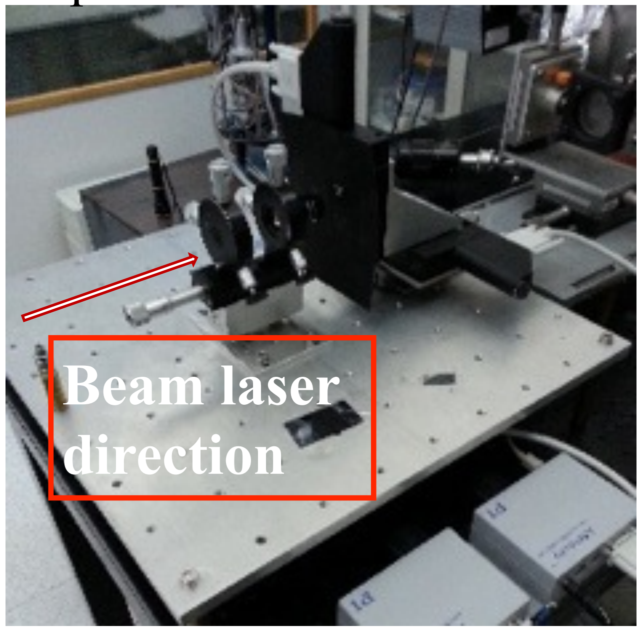
Laboratory L3 in Università del Salento
PLD (Pulsed Laser Deposition) Lab.
DIAPIX in G5 WP4: Surface Laser Graphitization.

- Excimer laser ArF (λ=193nm, τ=20ns, F=5J/cm2);
- Optical system: collimator, pin-holes, focusing objective 15 X
- 2D X-Y sub-micron movement with step motors
- Labview automatic laser writing of predefined pattern



Laser Lambda Physics, LPX305i

Optics and XY motors

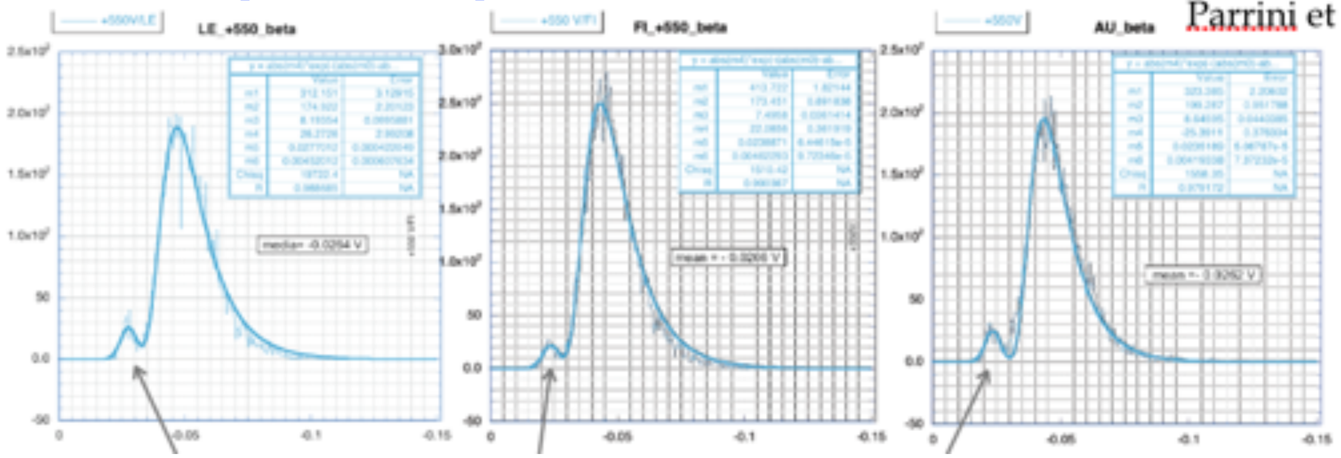


Phd E. Alemanno and Thesis's M. De Feudis

Nuclear characterisation

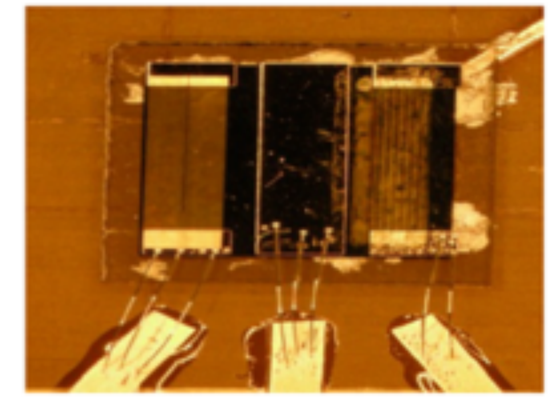
Three strips Comparative studies with beta source

Parrini et al (Firenze)

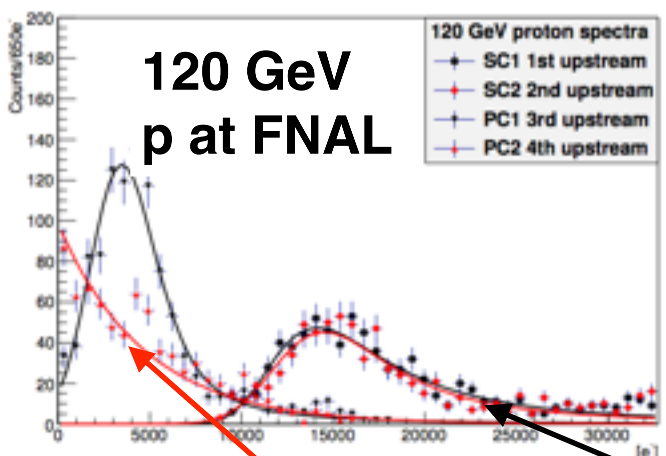


Strip contacts:

- ArF(LE)
- NbYAG(FI)
- CdAu(LE)



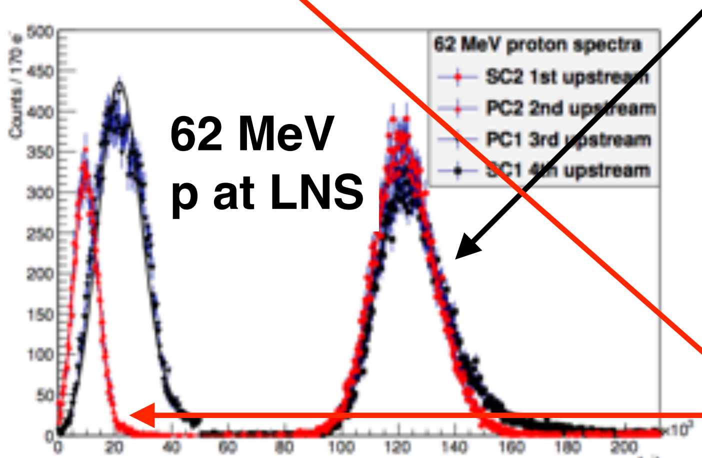
Irradiation test: $2x10^{15}$ 62 MeV protons / cm^2

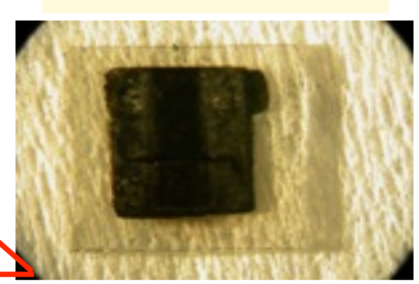


Commercial diamond

REFERENCE DETECTORS

Graphitized diamond



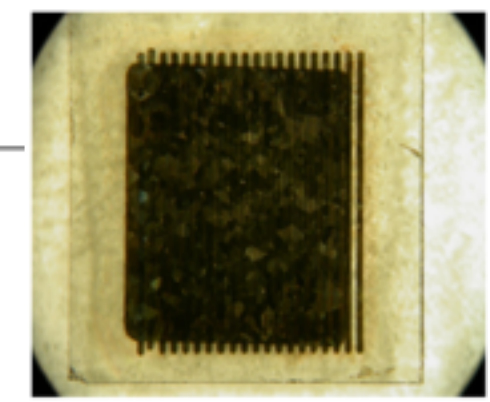


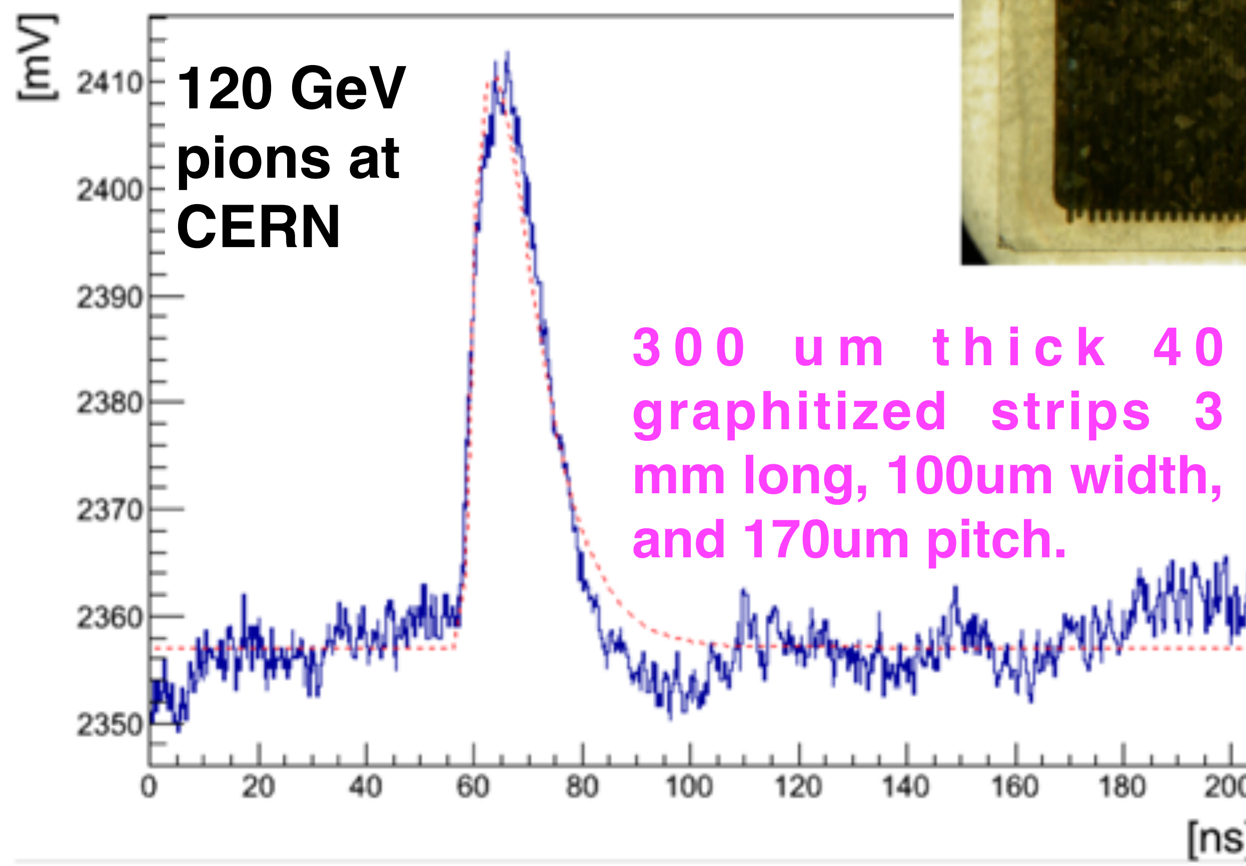
300 um thick 3x3mm2 PAD

Next irradiation in may at LNS

Chiodini et al (Lecce)

Graphitized strip diamond





300 um thick 40 graphitized strips 3 mm long, 100um width, and 170um pitch.

Thin Diamond Target

Large size thin diamond

Two 50 um samples received by Lecce in time (4 months)

Two 50 um samples and one 100 um sample order later by LNF and under delivering in time

Transportation and handling must be done with care.

One samples flew apart during gel pack opening because under tension. No chance to use 200 euro vacuum pen.

2 cm x 2 cm thin polycrystalline CVD diamond from http://www.usapplieddiamond.com

Cost:

- 1925 $ for 50 um thick sample
- 2150 $ for 100 um thick sample

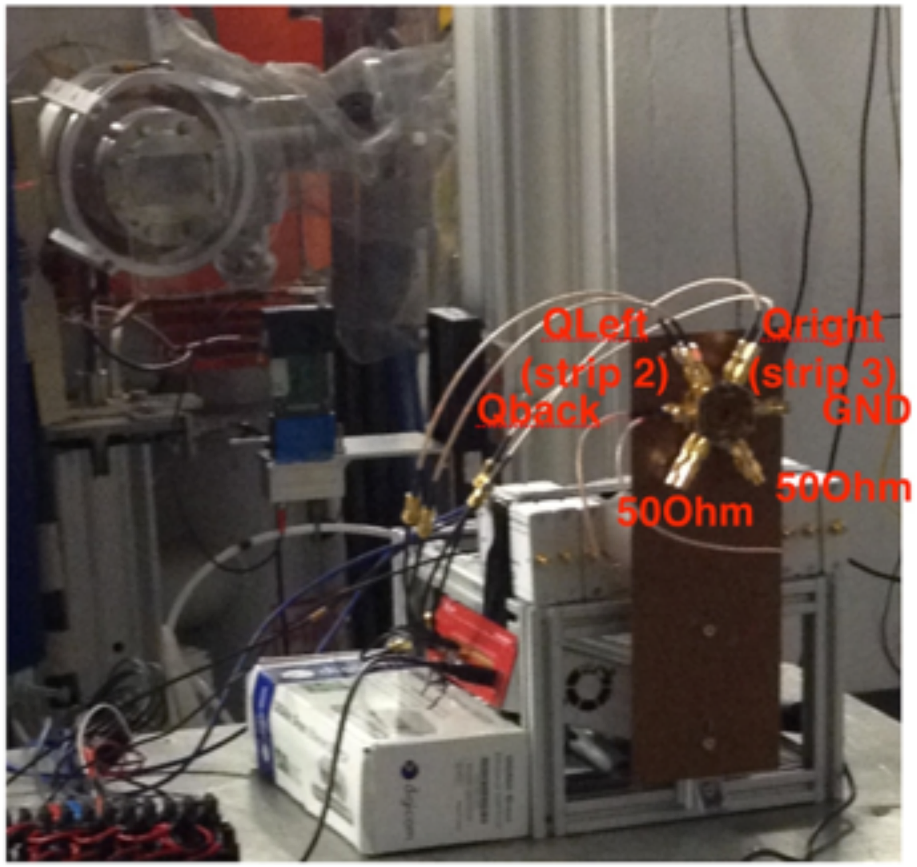
CCD:

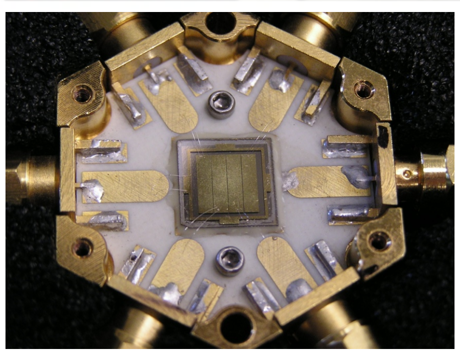
- 20 um for 50 um thick sample (720 e-/MIP)
- 40 um for 100 um thick sample (1440 e-/MIP))

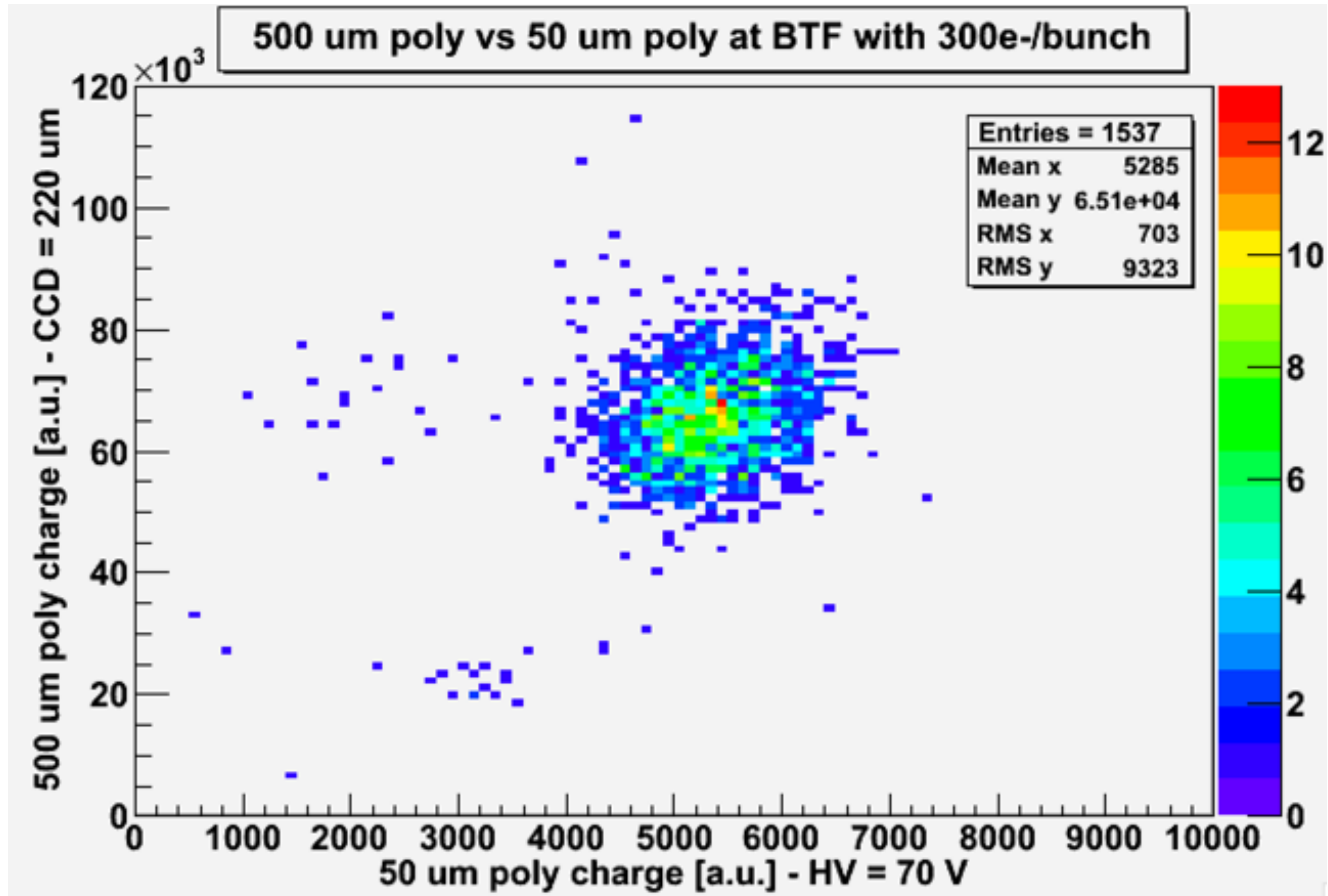
Response uniformity?

Bulk polarisation?

BTF testbeam



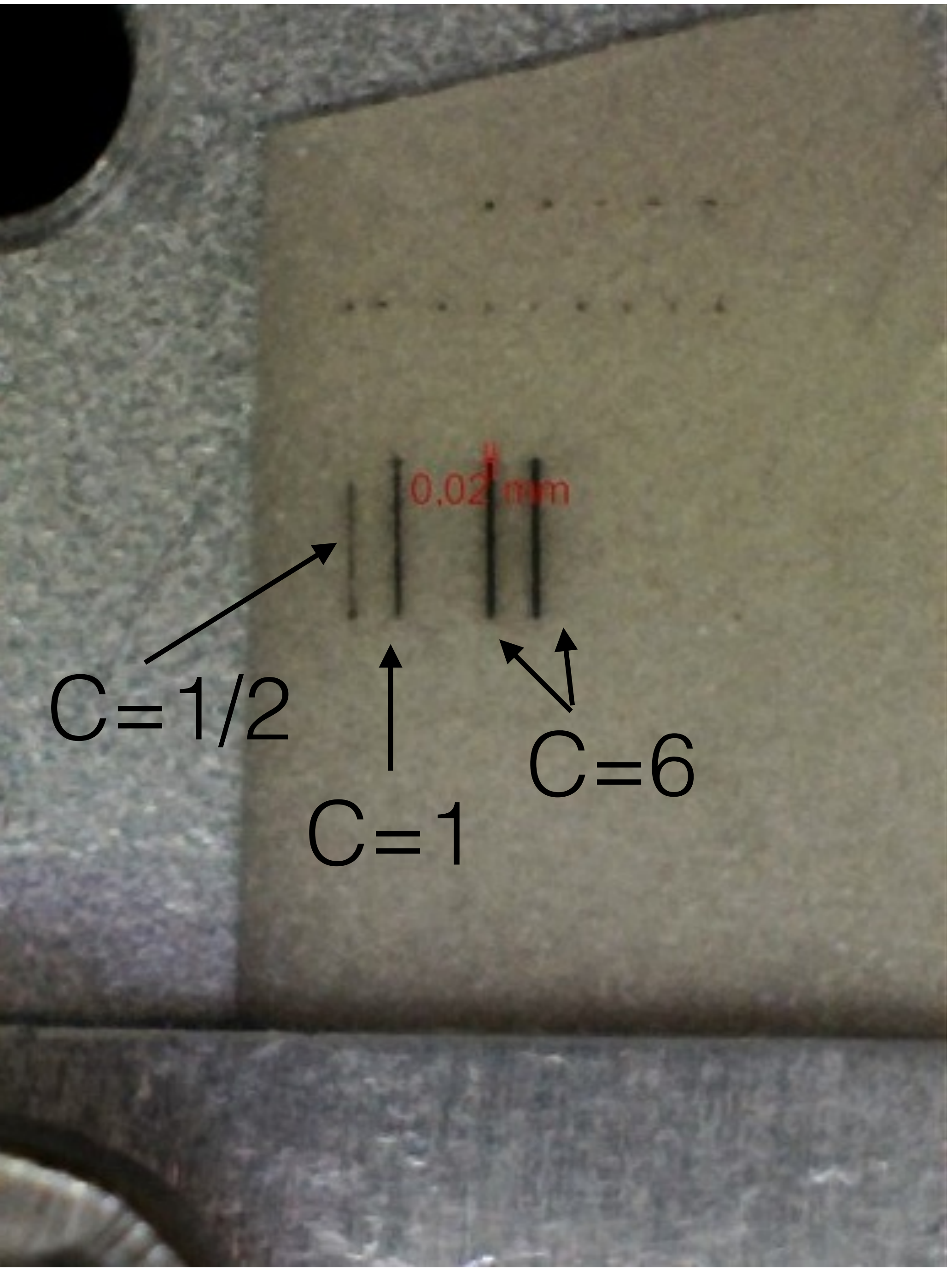




Reference diamond: 500 um thick polycrystalline with 4 metal strips (6.5 mm long, 1.5 mm pitch, 50 um separation

- **50 um thick sample for BTF test**
- **About 25 mm2 area**
- **Silver Paint electrod on both faces**
- **Electric contact with a clump sma connector**

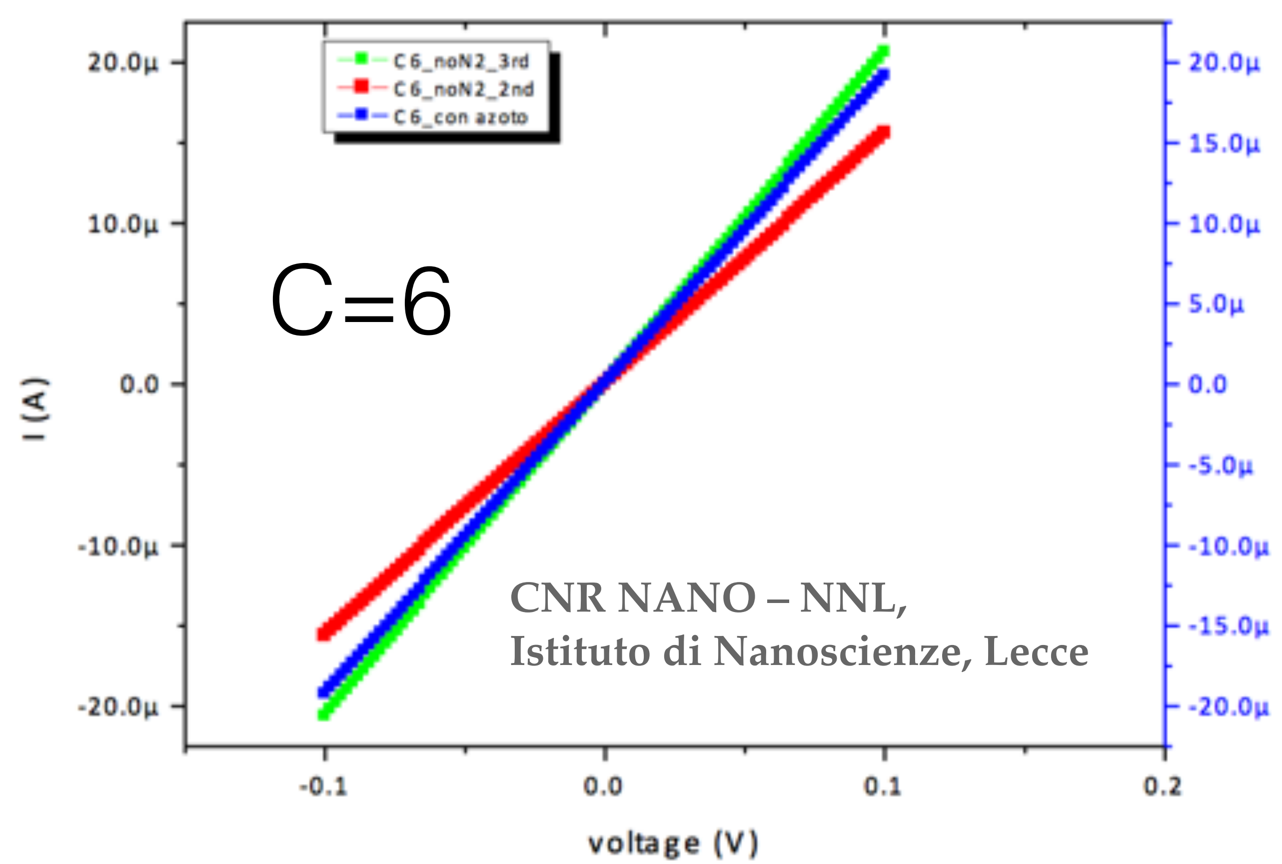
Graphitization thin diamond



C=# of up-down laser scans

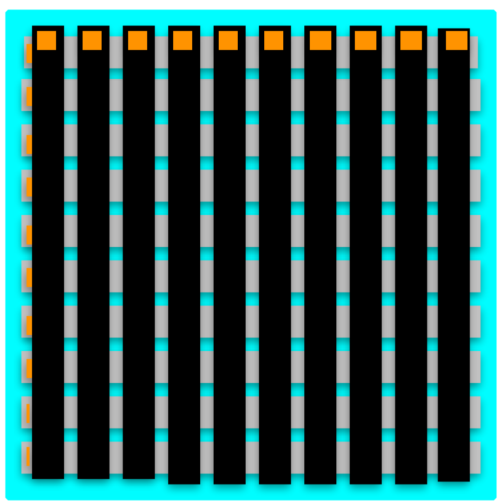
Phd M. De Feudis

- **Test structures on thin diamond done in Lecce**
- **20 um strip width achieved with the new optical setup**
- **No ohmogeneizer used (22 ke for 193 nm device)**
- **R=10k for C=1 and R=5kOhm for C=6**



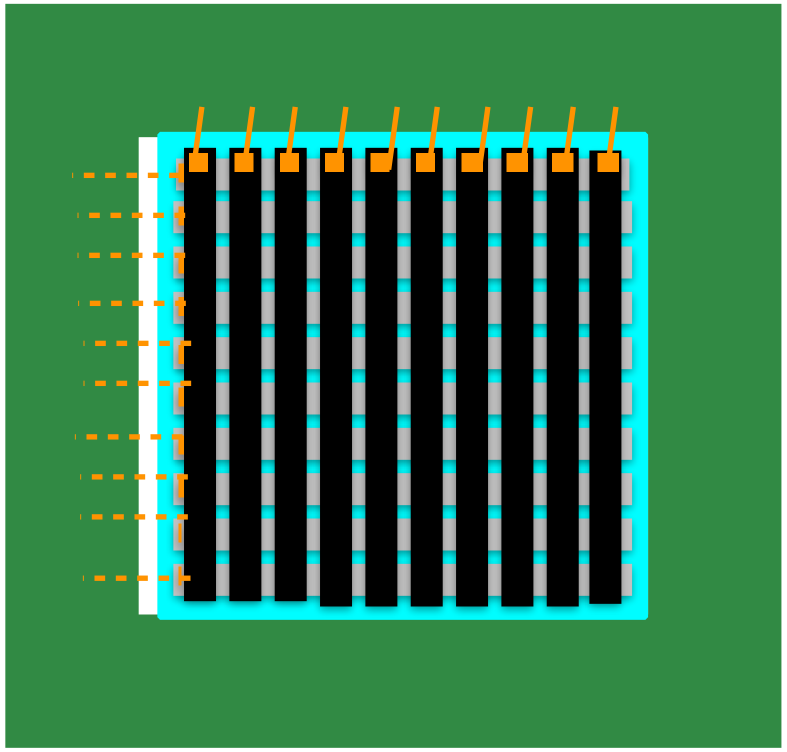
Baseline design

Thin diamond detector

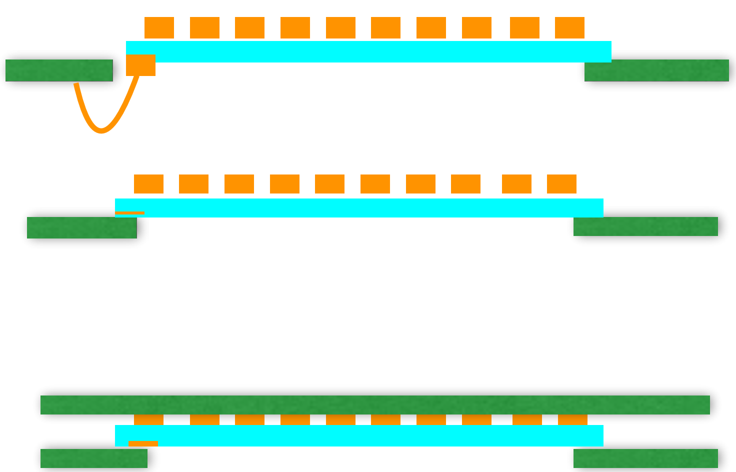


- Material : electronic grade polycristalline CVD diamond
- Area : 2 cm x 2 cm
- Thickness : 50 -100 um
- Strips : 1 mm pitch and 50 um separation
- Granularity : 10 strips X in frontplane and 10 strip Y in backplane
- Dead edge: 250 um
- Active area: 1.95 cm x 1.95 cm
- Electrodes fabrications: Nanographitic surface
- Electrodes termination: 250 um x 250 um evaporated gold layer Nanographitic surface (full carbon active target)

Assembly on PC board



- Sensor glued on PC board on three sides only
- Gluing edge 250 um length
- Wire bonding on both sides need a lot of handling and assembly fixtures
- Fourth sensor side need PC board clearance for wire bonding
    - Mechanical fragility during wire bonding
    - Considering
        - traditional hot-soldering in one view
        - glueing with conductive epoxy

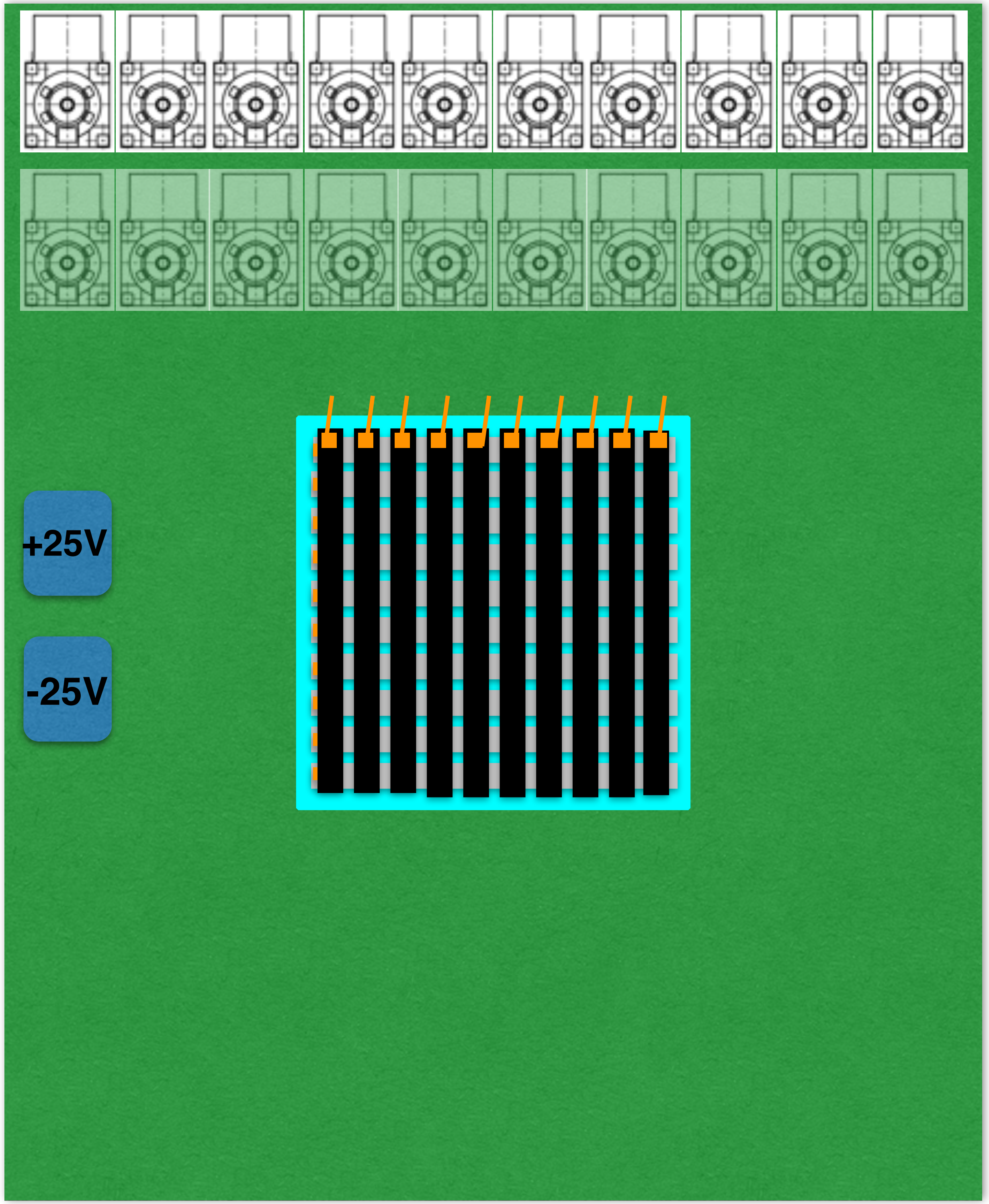


WHAT ABOUT VACUUM ?

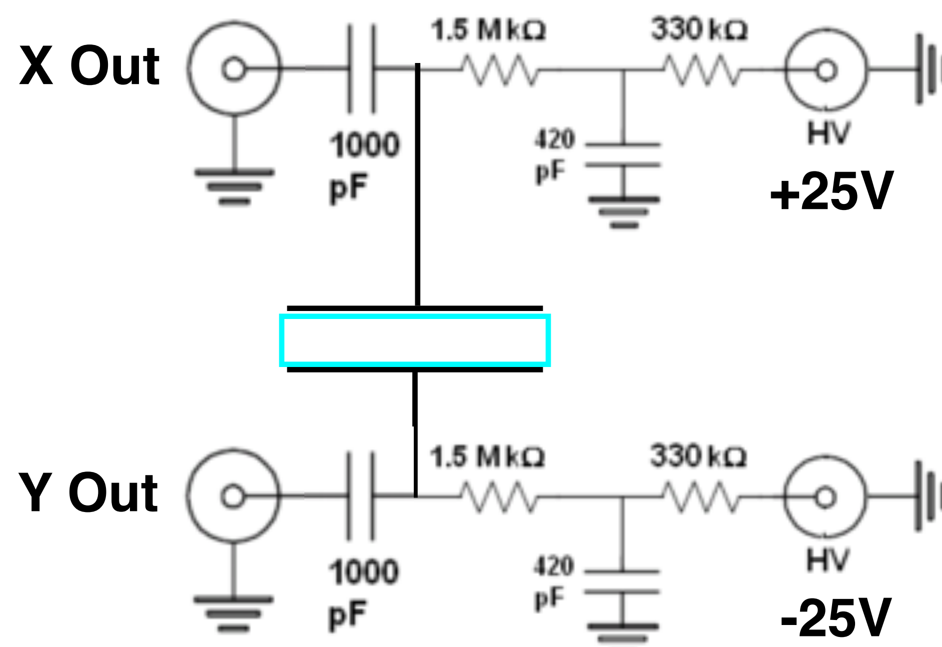
WHAT ABOUT RF PICK-UP?

Faraday cage with ground planes

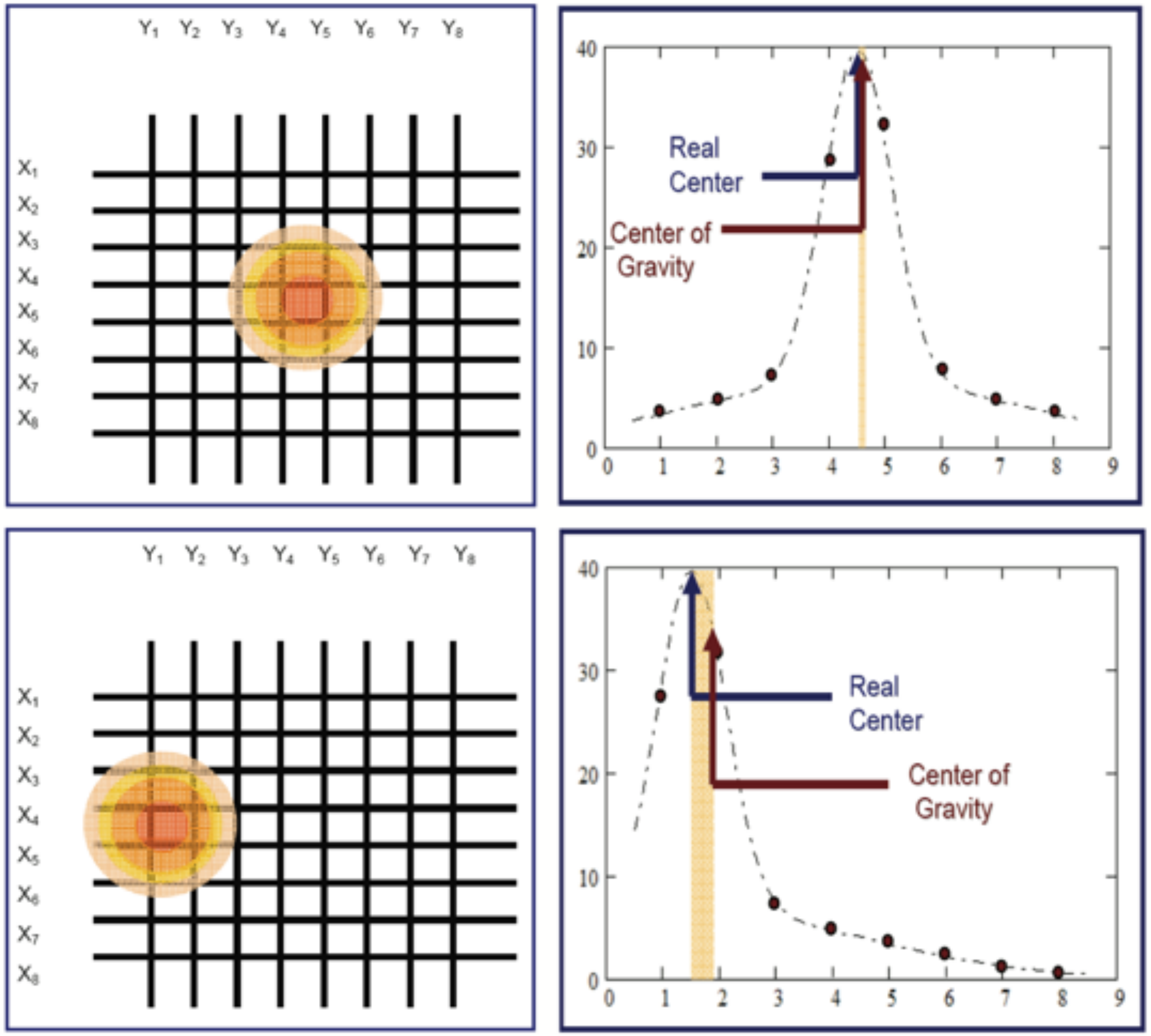
Bias and readout



- CMX RF connectors foot print 6 mm x 10 = 6 cm
- AC coupling
- HV=+/-25V
- E=1V/1um (saturated drift velocity)
- Only passive components
- FE fast charge amplifiers or RF amplifiers
- Waveform digitizer (5GS/s, 500 MHz BW, 12 bit ADC)
- Readout all bunches



Charge gravity algorithm



$$x_{measured} = \frac{\sum_{k=1}^{M} x_k q_k}{\sum_{k=1}^{M} q_k}$$

$$\frac{\delta x}{pitch} = \frac{1}{\sqrt{12}} \approx 29\%$$ ~0.3 mm

Short term plans

October 2015:

- Realise first full scale sensor
- PCB board
- Electronics
- Square wave high voltage
- 20 channel readout
- Testbeam
- Measure spatial resolution bunch by bunch vs Mimosa pixel

Interested people in Lecce

INFN Lecce

G. Chiodini (Ricercatore)
G. Fiore (Tecnico e progettista meccanico)
R. Perrino (Ricercatore)

INFN Lecce

INFN Lecce and Università del Salento

A. Caricato (Ricercatore)
M. Corrado (Tecnico di laboratorio)
M. Martino (Professore)
M. De Feudis (Dottoranda)

Laboratorio L3 Laser

C. Pinto (Tecnico elettronico)
S. Spagnolo (Ricercatore)

CNR-NANO and Università del Salento

G. Maruccio (Professore)
A. Monteduro (Dottoranda)

Nanotecnologie

Conclusions

- The thin active carbon target of PADME experiment is a small scale but challenging project
- Several technology can be exploited (SEM, Cherenkov light, solid state ionisation chamber, ...)
- The full carbon thin diamond detector solution is going to be tested pretty soon and we hope to learn a lot about:
  - mechanical assembly
  - uniformity
  - polarisation
  - RF pick-up
  - spatial resolution at BTF

BACK-UP

Spatial resolution

N=electrons per bunch
M=6 sigma bunch width in terms of strip pitch

$$\frac{\delta x^{strip}}{pitch} = \frac{1}{\sqrt{12}} \approx 29\%$$ ~0.3 mm

$$\frac{\delta x^{charge}}{pitch} = \frac{\delta q_e}{q_e} \times \sqrt{\frac{M}{N}} \times \sqrt{M} = \frac{\delta q_e}{q_e} \frac{M}{\sqrt{N[=20000]}} \approx 2\% M$$ ~0.06 mm for M=3

$$q_e = CCD[=10\mu m] \times 36e^-/\mu m \approx 360e^-$$

$$\delta q_e^2 = (Noise)^2 + Straggling^2 = (1000e^-)^2 + (360e^-)^2 \approx (1000e^-)^2$$

$$(\frac{\delta q_e}{q_e})^2 \approx 3^2$$

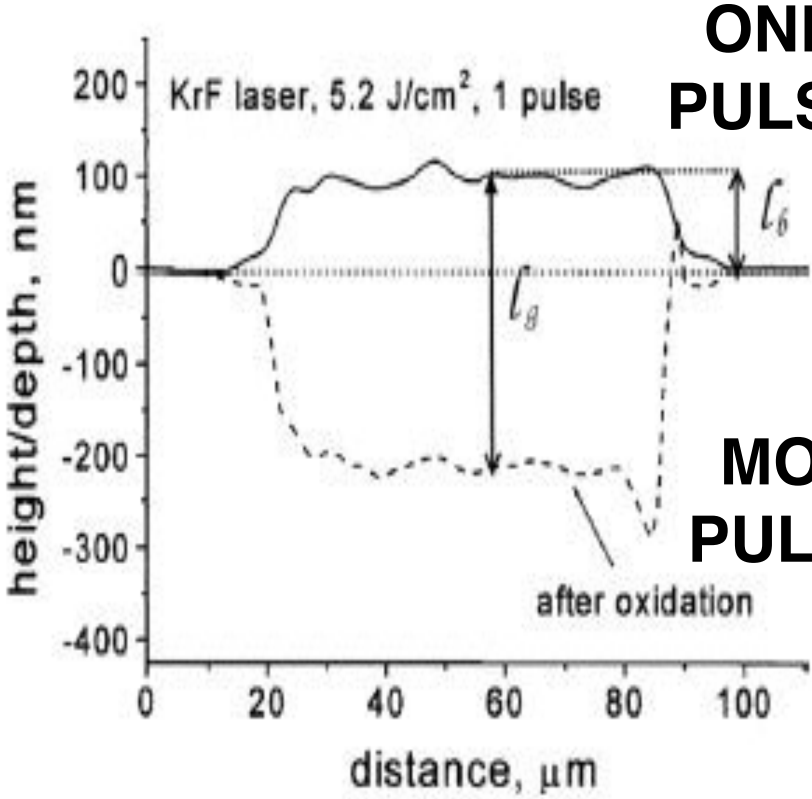
$$\frac{\delta x^{uniformity}}{pitch} = \%(?)\sqrt{M}$$

5% or 10% or 50% ?

Fraction of millimetres of spatial resolution per bunch should be feasible in nominal conditions: e-/bunch=20000, front-end noise=1000e-. good diamond uniformity, no strong polarisation phenomena.

BUT TESTBEAM RESULTS MUST PROVE IT

Laser irradiation and thermal annealing



ONE PULSE

MORE PULSES

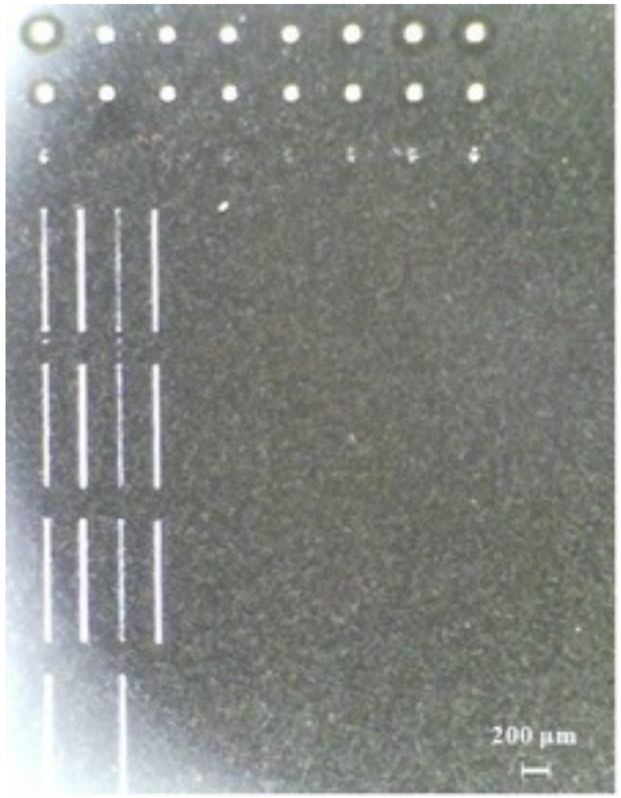
- First pulse creates a thermal wave propagating 100 nm in diamond
- $T > T_g \approx 700°C$ causes diamond-graphite phase change.
- Further pulses strongly absorbed by graphite layer
- $T > T_S = 4000°C$ causes graphite sublimation

Density
- **Diamond = 3.5 g/cm^3**
- **Graphite = 1.9 g/cm^3**

Thermal expansion:
- **Diamond ≈ 1.18 $\times 10^{-6}$ K^{-1}**
- **Graphite = 2-6 $\times 10^{-6}$ K^{-1}**

OXIDATION AT HIGH TEMPERATURE:
- **GRAPHITE REMOVAL (Annealing: T=600°C, 150 min., in air)**

BUMP AND VALLEY THICKNESS MEASURED BY AFM BEFORE AND AFTER ANNEALING
- **Graphite layer thickness measured by the difference**



Test structures

•Spot:
- F = 5 J/cm^2 , N = 1, 2, 4, 8;
- F = 7 J/cm^2 , N = 1, 2, 4, 8.

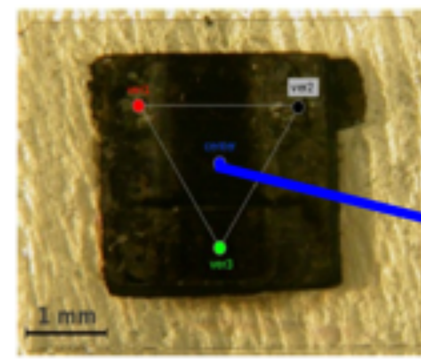
•Strips:
- F = 5 J/cm^2 , C = 6, 8;
- F = 7 J/cm^2 , C = 2, 6, 8.

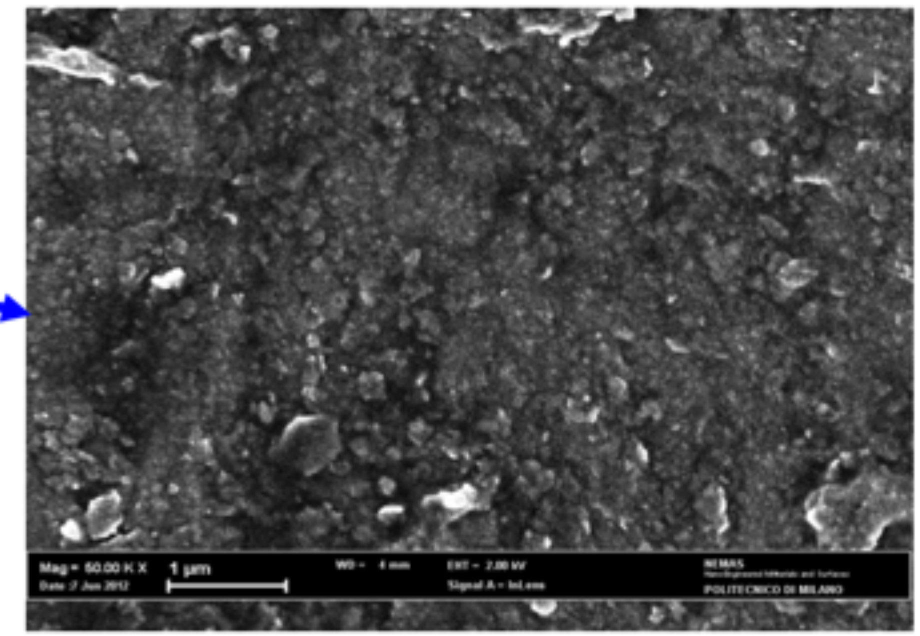
Thesis's M. De Feudis

Morphological and structural analysis

- ➢Scanning electron microscope (SEM)

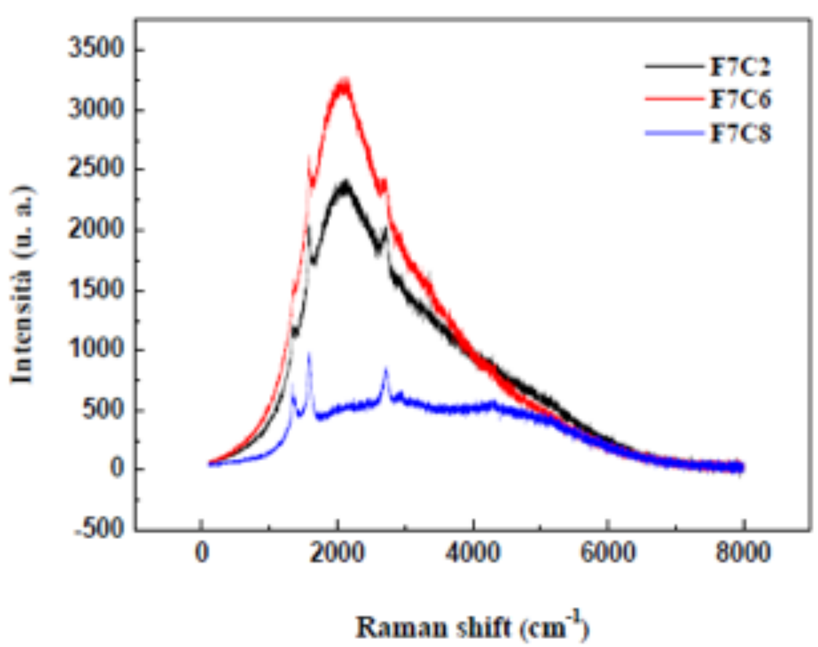
  LABORATORIO L3 – Univeristà del Salento , Lecce

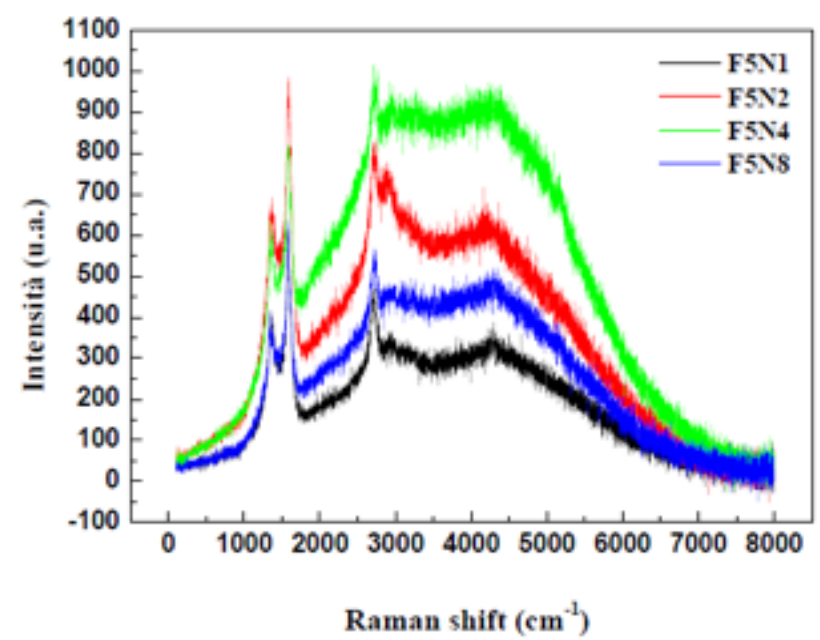




- ➢ micro-Raman and Photo-Luminescence spectroscopy

  (Centro Studi Nucleari "Enrico Fermi", Politecnico di Milano)





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Geometrical and electric characterisation

- Microscopia a Forza Atomica (AFM)

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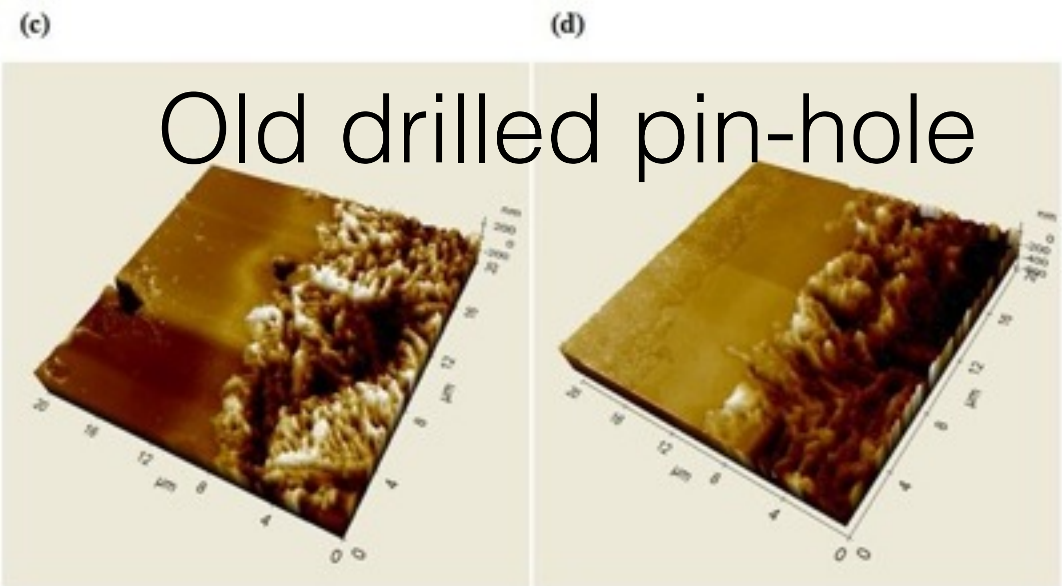
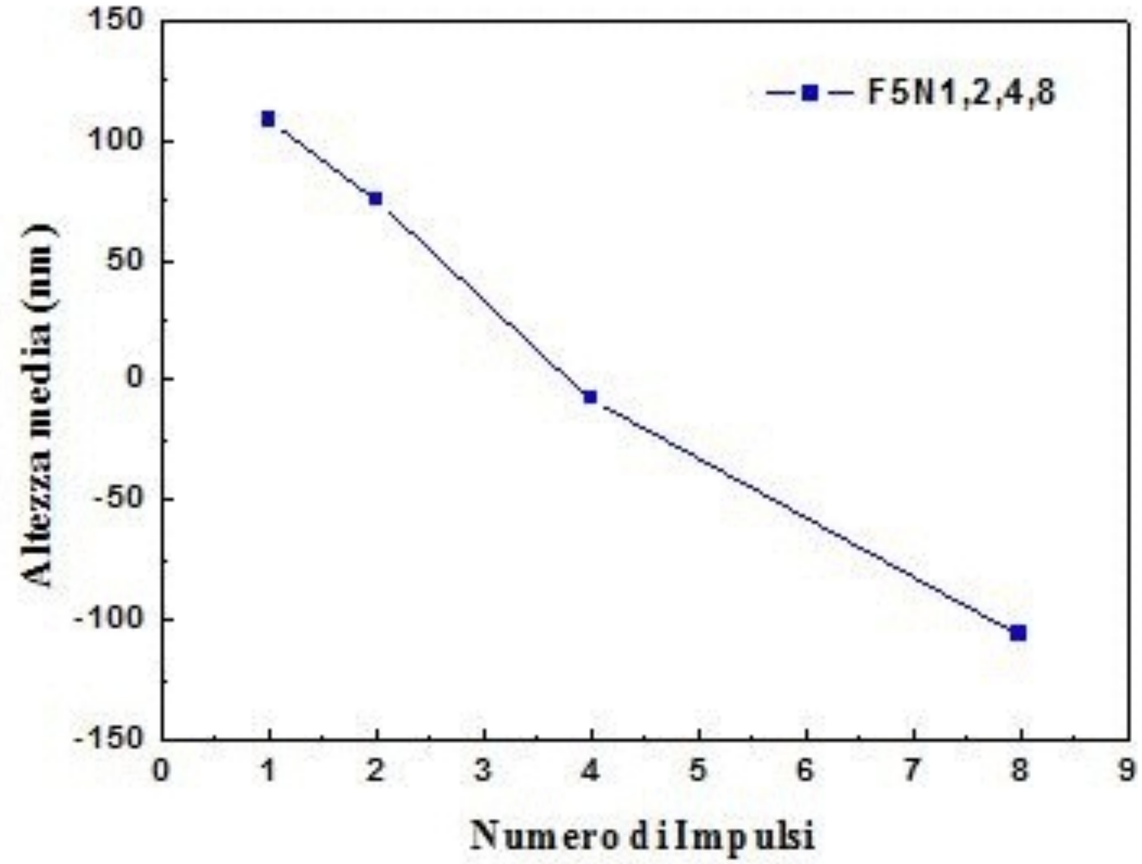
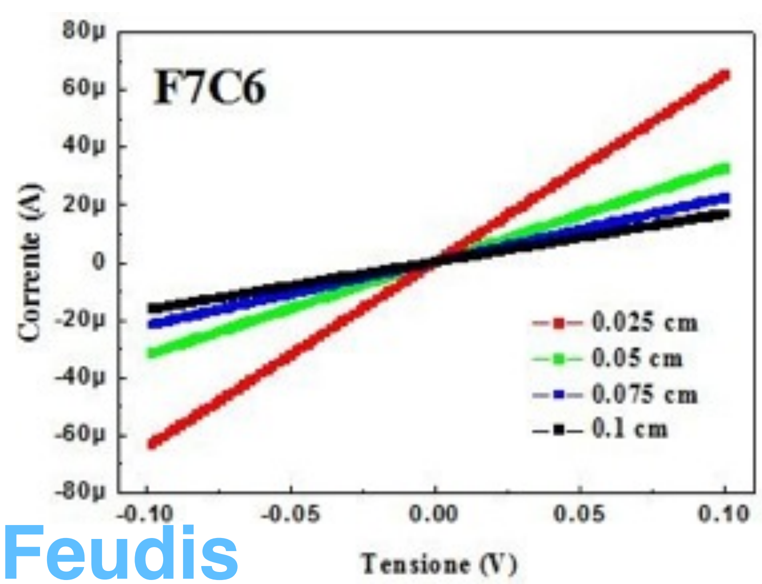
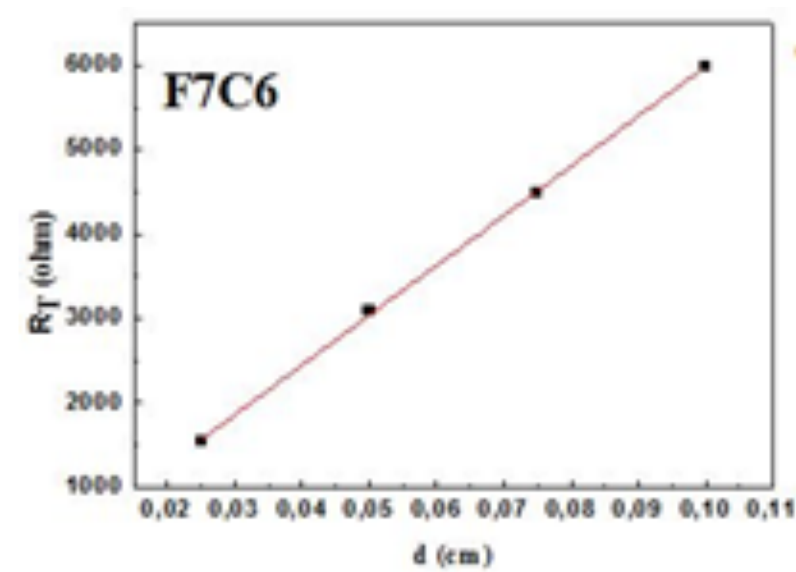




- Electrical measurements

CNR NANO – NNL, Istituto di Nanoscienze, Lecce





$\varrho = (4.0 \pm 0.8) \times 10^{-3}\ \Omega$ cm

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