UNIVERSITÀ DI TORINO

ICNMTA 2024

19th INTERNATIONAL CONFERENCE ON NUCLEAR MICROPROBE TECHNOLOGY AND APPLICATIONS

A multi-electrode two-dimensional position-sensitive diamond detector

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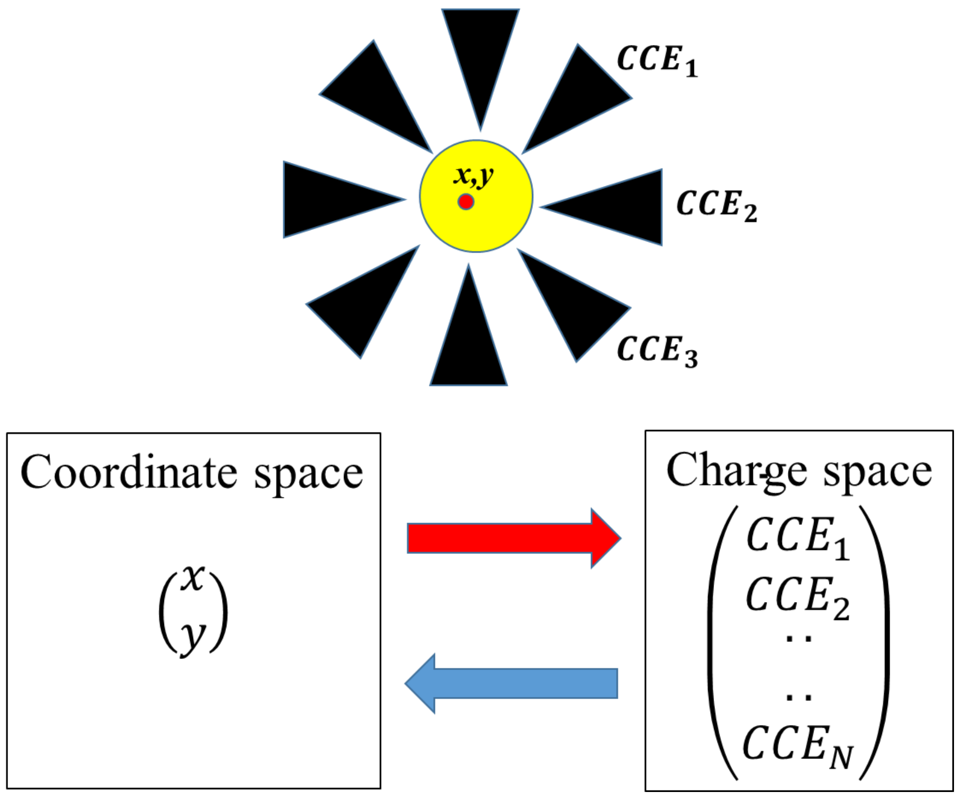
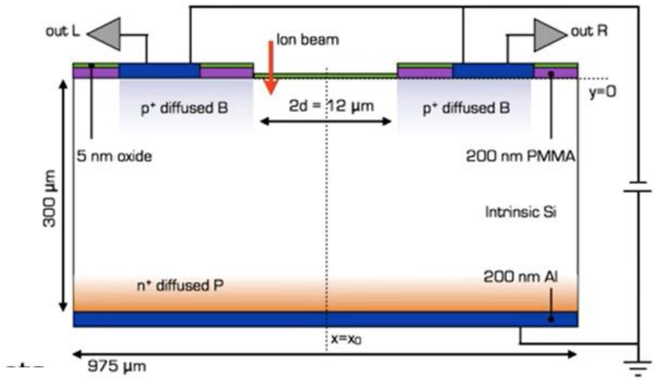
The fabrication and qualification of a mutielectrode detector able to sense the impact of individual energetic (keV or MeV) ions and concurrently able to retrieve their impinging position exploiting the induced charge shared by multiple electrodes



Nuclear Instruments and Methods in Physics Research B 269 (2011) 2336–2339

Charge sharing in multi-electrode devices for deterministic doping studied by IBIC

L.M. Jong [a], J.N. Newnham [a], C. Yang [a], J.A. Van Donkelaar [a], F.E. Hudson [b], A.S. Dzurak [b], D.N. Jamieson [a,*]



2 MeV He beam, @ NEC 5U Pelletron, Melbourne

1 µm spot size (7.3 um depth)

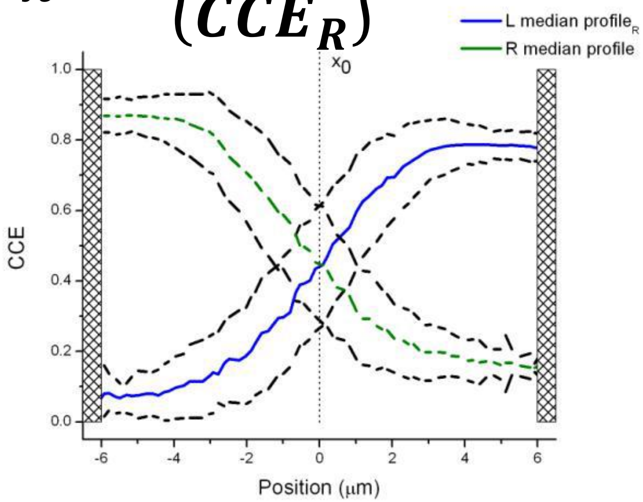
IBIC maps acquired concurrently from L and R

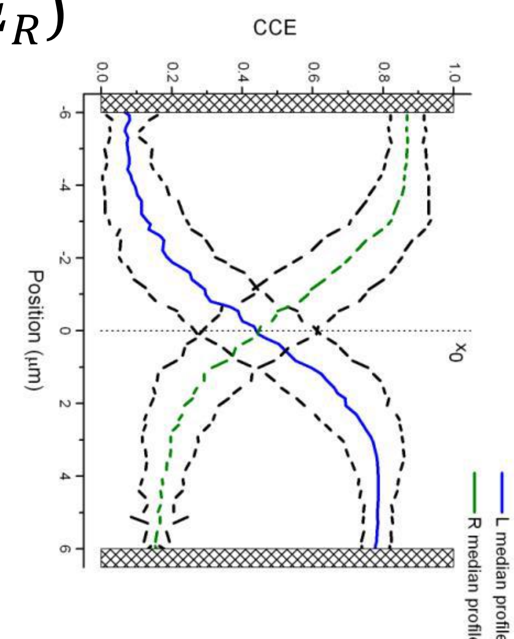
Ion impinging position
as function of the induced signals

$$\begin{Bmatrix} CCE_L \\ CCE_R \end{Bmatrix} \Longrightarrow x$$

Induced signals as function of ion impinging position

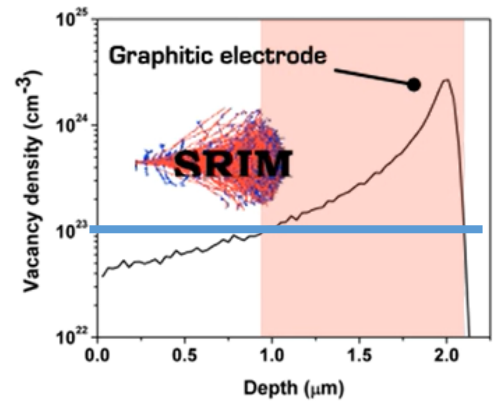
$$\boldsymbol{x \Longrightarrow \begin{Bmatrix} CCE_L \\ CCE_R \end{Bmatrix}}$$





Graphite-diamond-graphite device fabrication

4 MeV C^{3+} ion

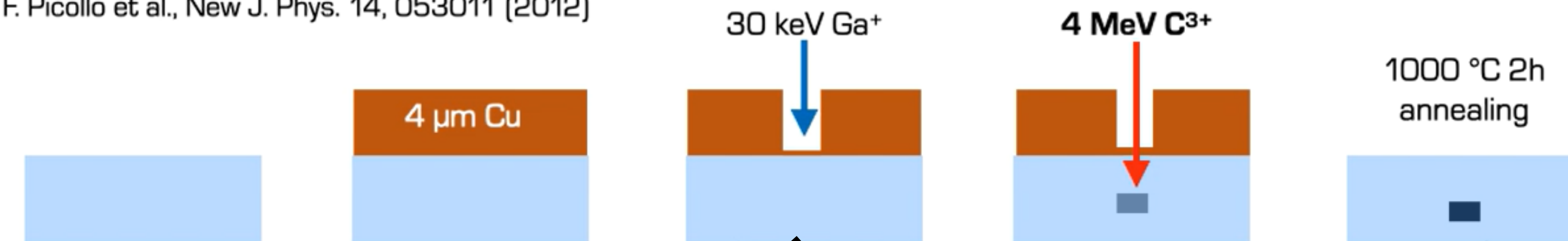


Deep Ion Beam Lithography

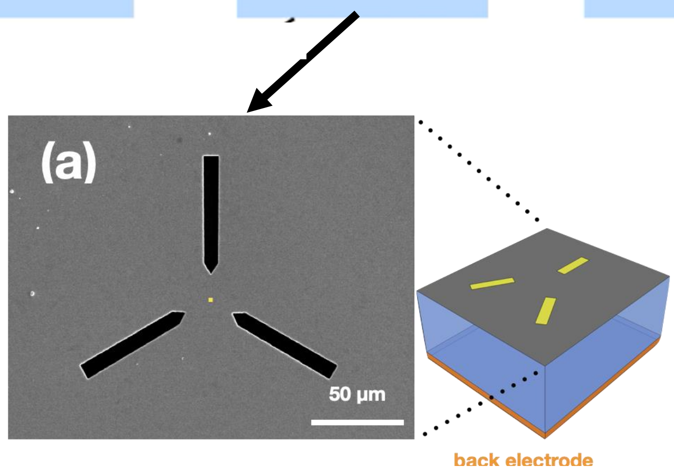
Exploitation of **MeV** ion nuclear energy loss
Cumulation of **damage** at the **end of ion range**
Amorphization of buried diamond layer

Thermal treatment: **Conductive channels** embedded in **insulating diamond**, high dielectric strenght

F. Picollo et al., New J. Phys. 14, 053011 (2012)



3×3×0.3 mm^3 synthetic “electronic grade” <100> single-crystal diamond substrate

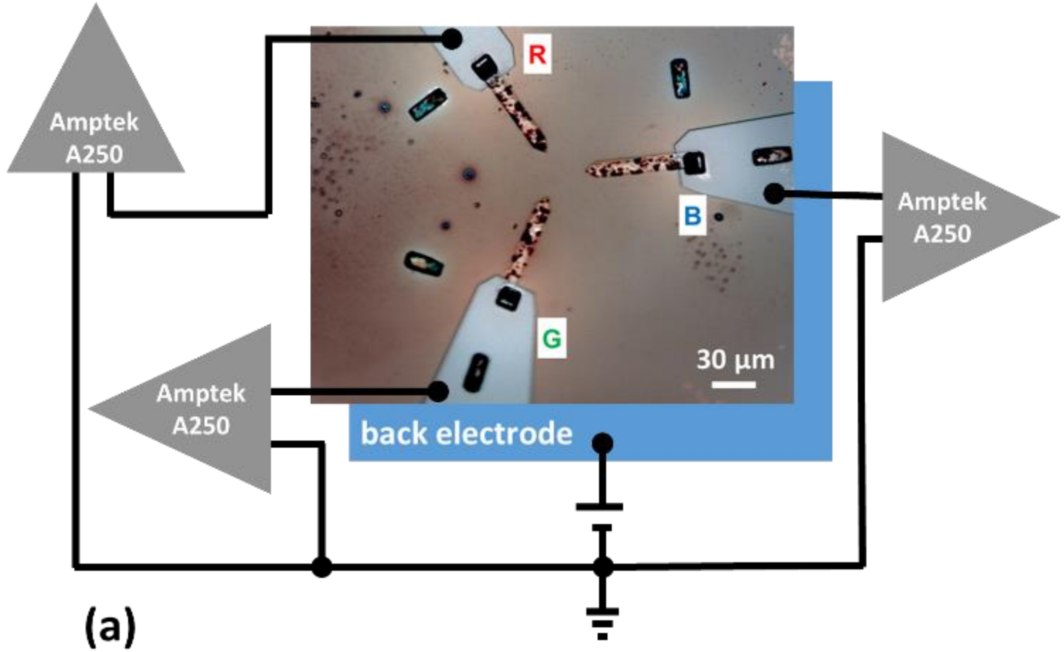


~1 µm thick graphitic electrodes at 1.5 µm depth from the diamond surface

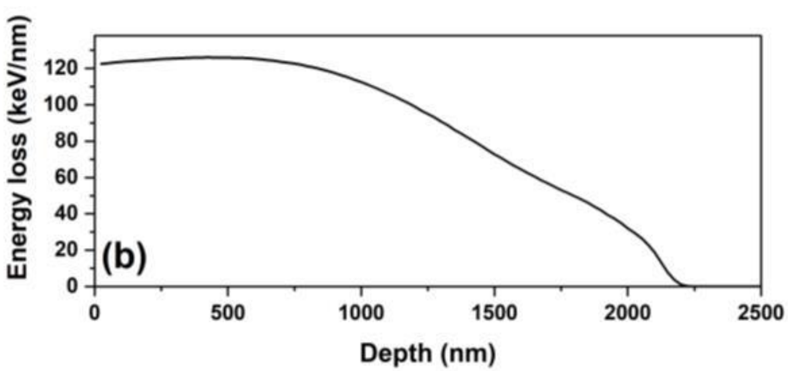
The IBIC experiment

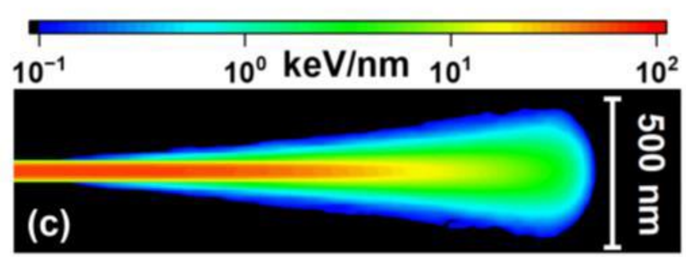
3 independent sensing electrodes
5 µm wide, 75 µm long
26 µm equilateral triangle
1 common back electrode

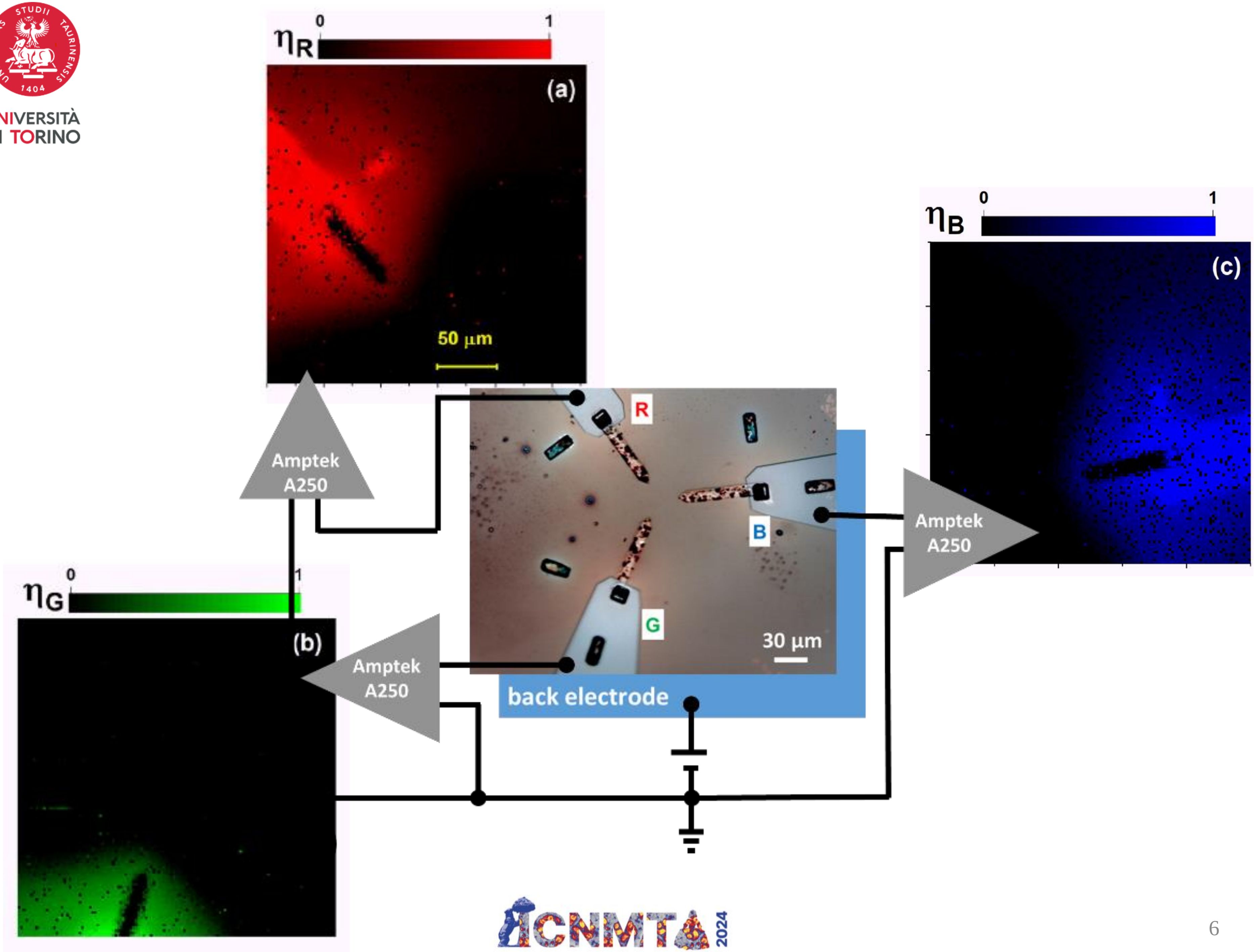
Amptek A250 preamplifier
Ortec 570 shaping amplifier
MCA interfaced with SPECTOR
Bias voltage= 60 V



2 MeV Li microbeam
2 µm spot size
3 individual 128x128 IBIC maps





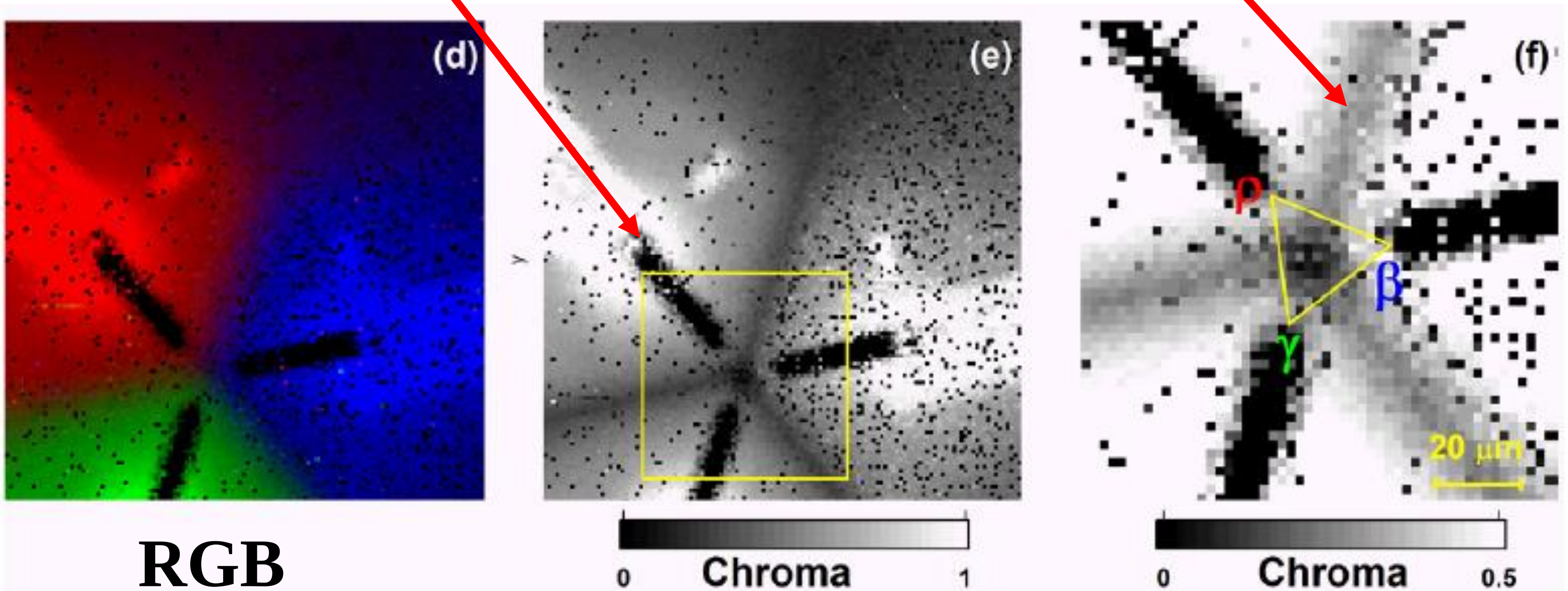


η_R
0
1
(a)
50 µm
η_G
0
1
(b)
η_B
0
1
(c)
Amptek A250
Amptek A250
Amptek A250
R
B
G
30 µm
back electrode

Snowflake's sixfold symmetry

Three main arms are the graphitic channels

three main arms correspond to the regions where charge sharing occurs between two adjacent electrodes.

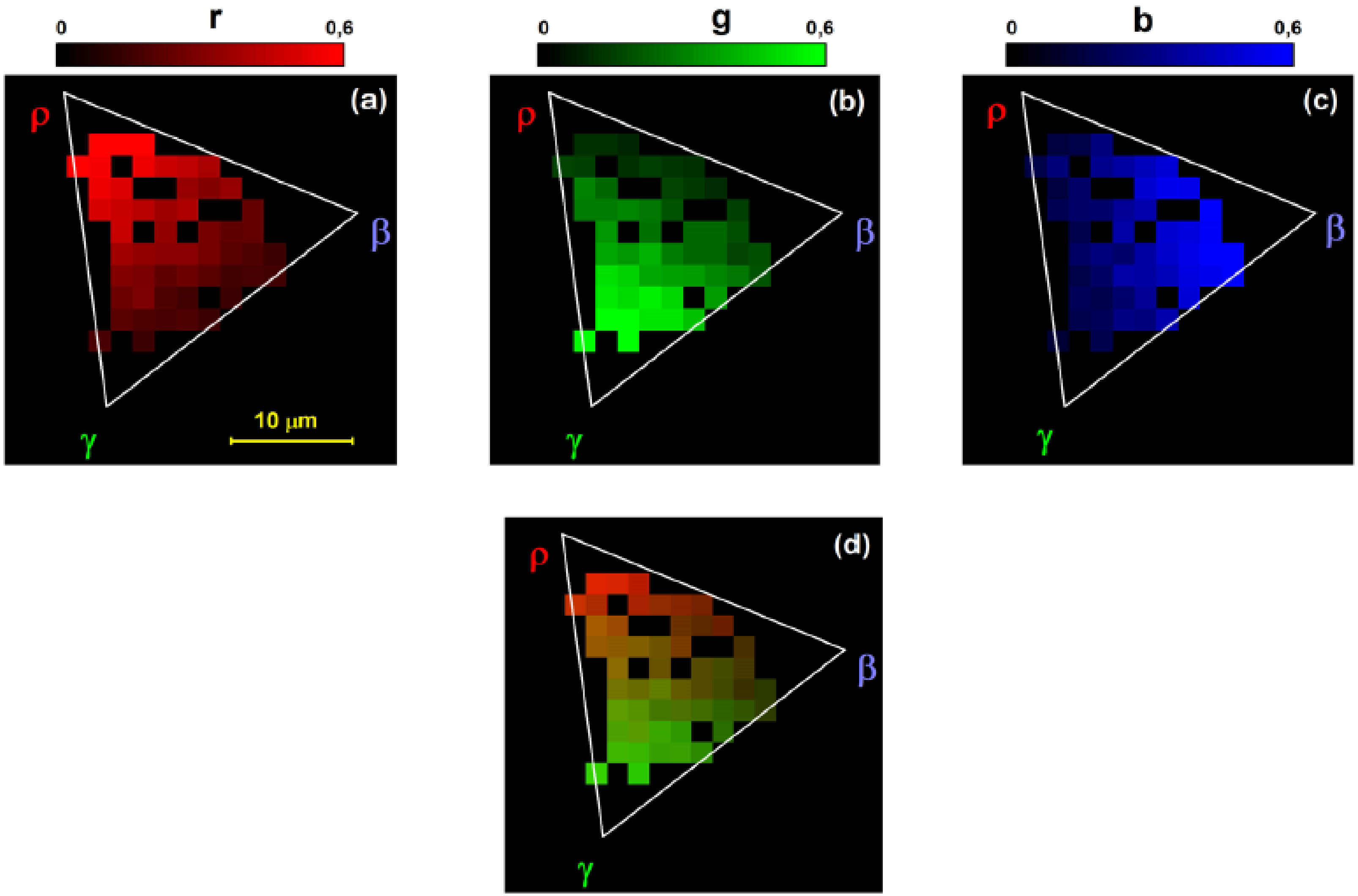


RGB

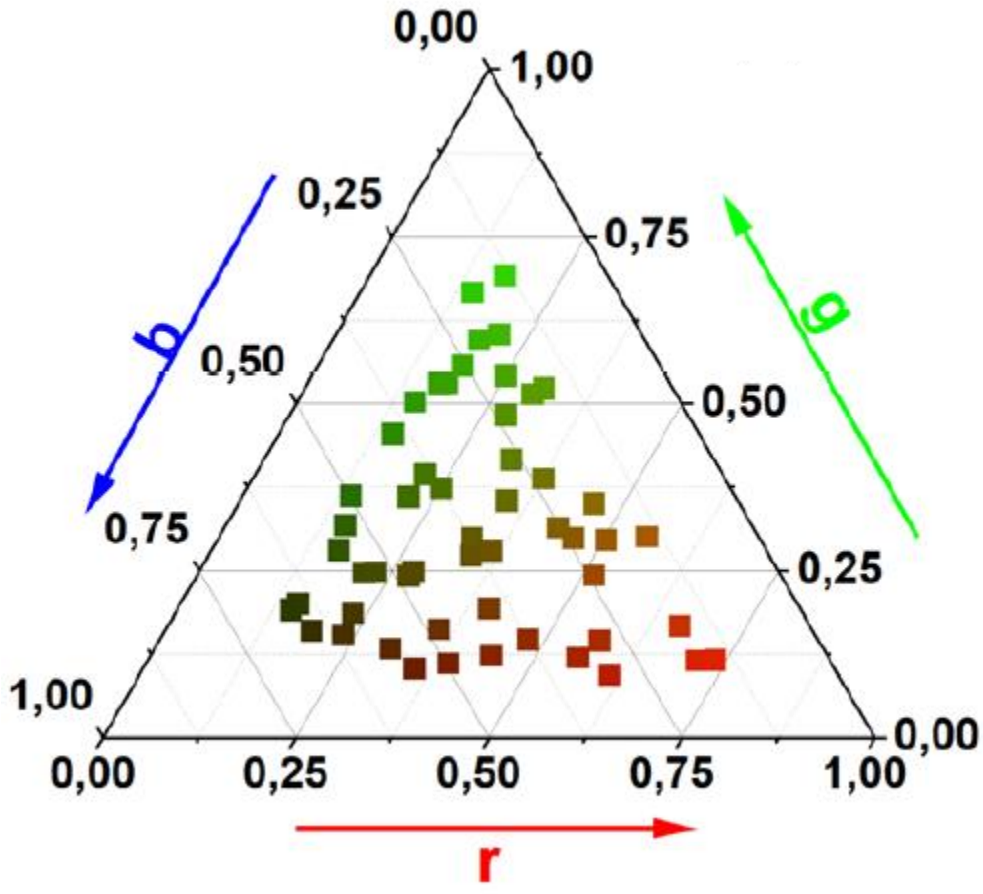
Chroma (absolute color purity)

$$Max(\eta_{R,G,B}) - min(\eta_{R,G,B})$$

$$r = \frac{\eta_R}{(\eta_R+\eta_G+\eta_B)}\ ;\ g = \frac{\eta_G}{(\eta_R+\eta_G+\eta_B)}\ ;\ b = \frac{\eta_B}{(\eta_R+\eta_G+\eta_B)}$$



The charge space



Ternary diagram -> Maxwell triangle

Search for the one-to-one correspondence (bijective function), which correlates

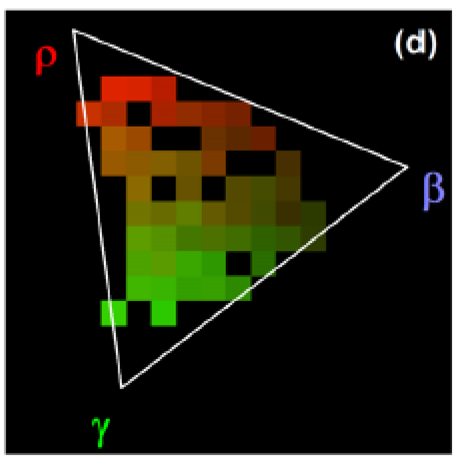
one point identified by (x,y) within the triangular region of interest

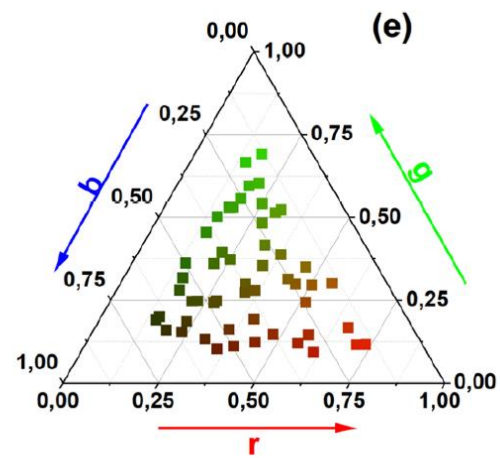
to

one point identified by (r,g,b) in the charge space

Coordinate space $\begin{pmatrix} x \\ y \end{pmatrix}$

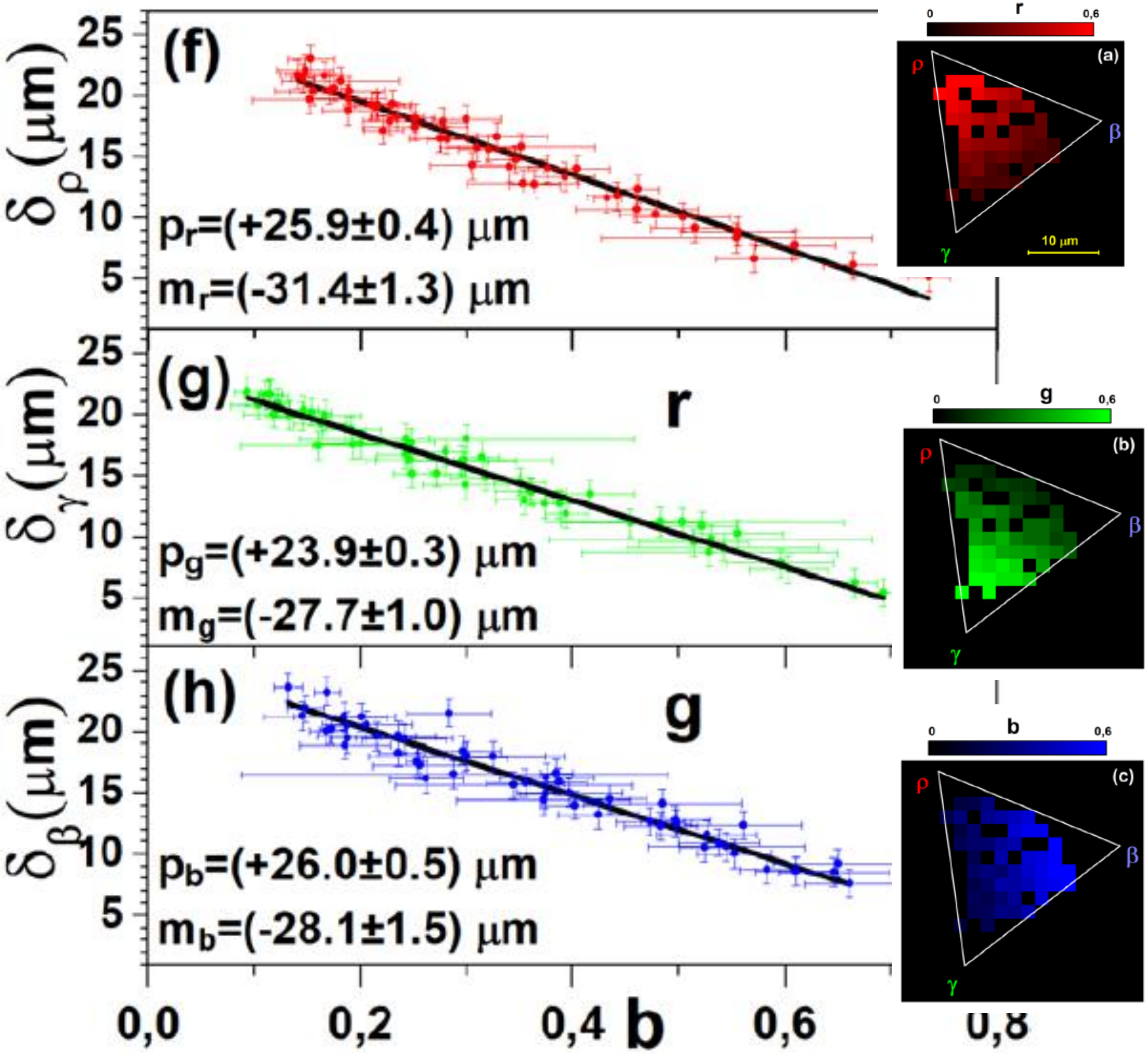
Charge space $\begin{pmatrix} r \\ g \\ b \end{pmatrix}$

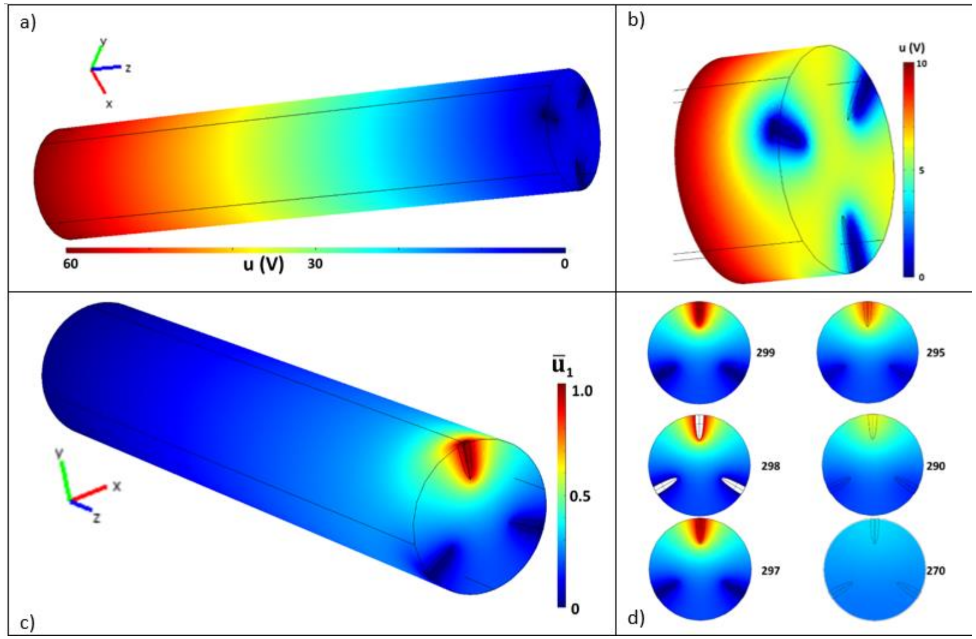




$\delta_{\rho\gamma\beta}$ = distance from the vertex

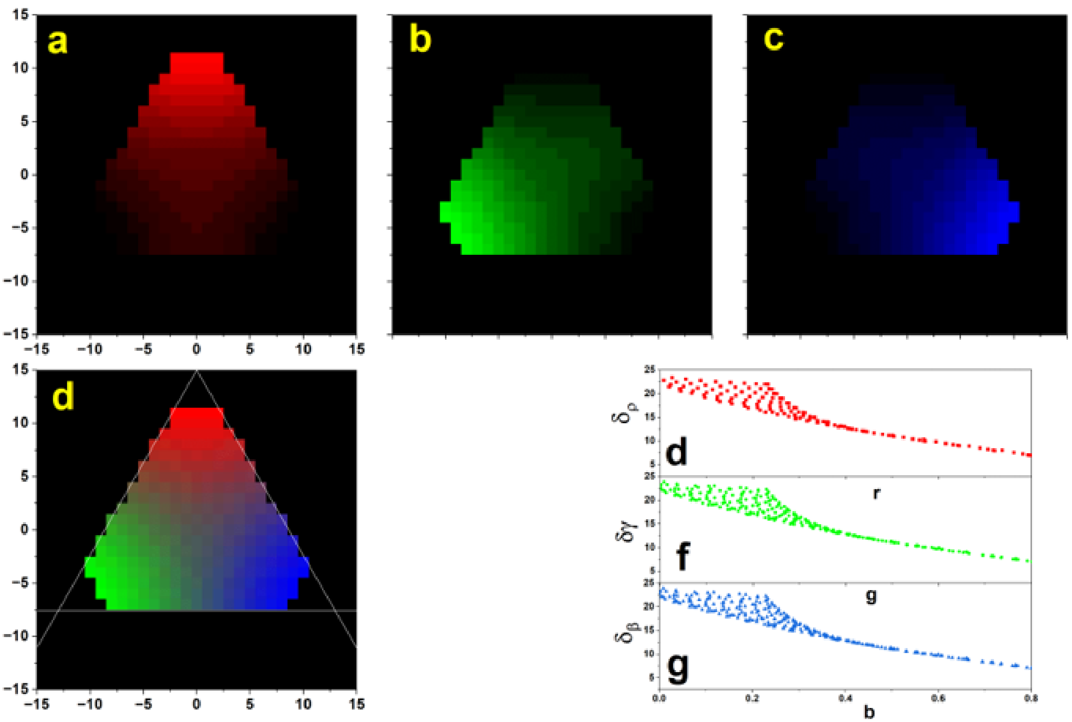
$$\begin{cases} \delta_\rho = p_r + m_r \cdot r, \\ \delta_\gamma = p_g + m_g \cdot g, \\ \delta_\beta = p_b + m_b \cdot b, \end{cases}$$





Electrostatic potential

Gunn weighting potential



Simulated r,g,b maps

Coordinate space $\begin{pmatrix} x \\ y \end{pmatrix}$

Charge space $\begin{pmatrix} r \\ g \\ b \end{pmatrix}$

$$\begin{cases} \delta_\rho = p_r + m_r \cdot r, \\ \delta_\gamma = p_g + m_g \cdot g, \\ \delta_\beta = p_b + m_b \cdot b, \end{cases}$$

Coordinates of the vertex

$\rho \Longrightarrow (x_\rho, y_\rho)$

$\gamma \Longrightarrow (x_\gamma, y_\gamma)$

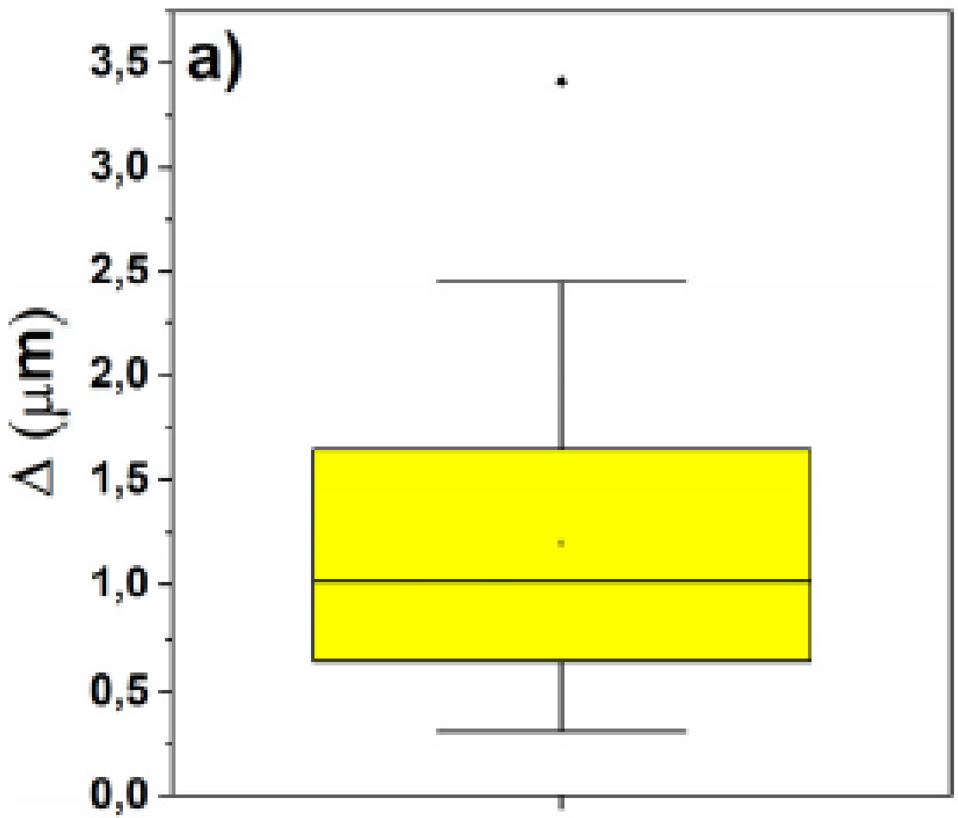
$\beta \Longrightarrow (x_\beta, y_\beta)$

$$x_{pred} = +\frac{1}{2}\frac{y_\beta\left(\delta_\rho^2 - x_\rho^2 - y_\rho^2 - \delta_\gamma^2 + x_\gamma^2 + y_\gamma^2\right) + y_\gamma\left(\delta_\beta^2 - x_\beta^2 - y_\beta^2 - \delta_\rho^2 + x_\rho^2 + y_\rho^2\right) + y_\rho\left(\delta_\gamma^2 - x_\gamma^2 - y_\gamma^2 - \delta_\beta^2 + x_\beta^2 + y_\beta^2\right)}{(y_\beta - y_\rho)(x_\gamma - x_\rho) - (x_\beta - x_\rho)(y_\gamma - y_\rho)},$$

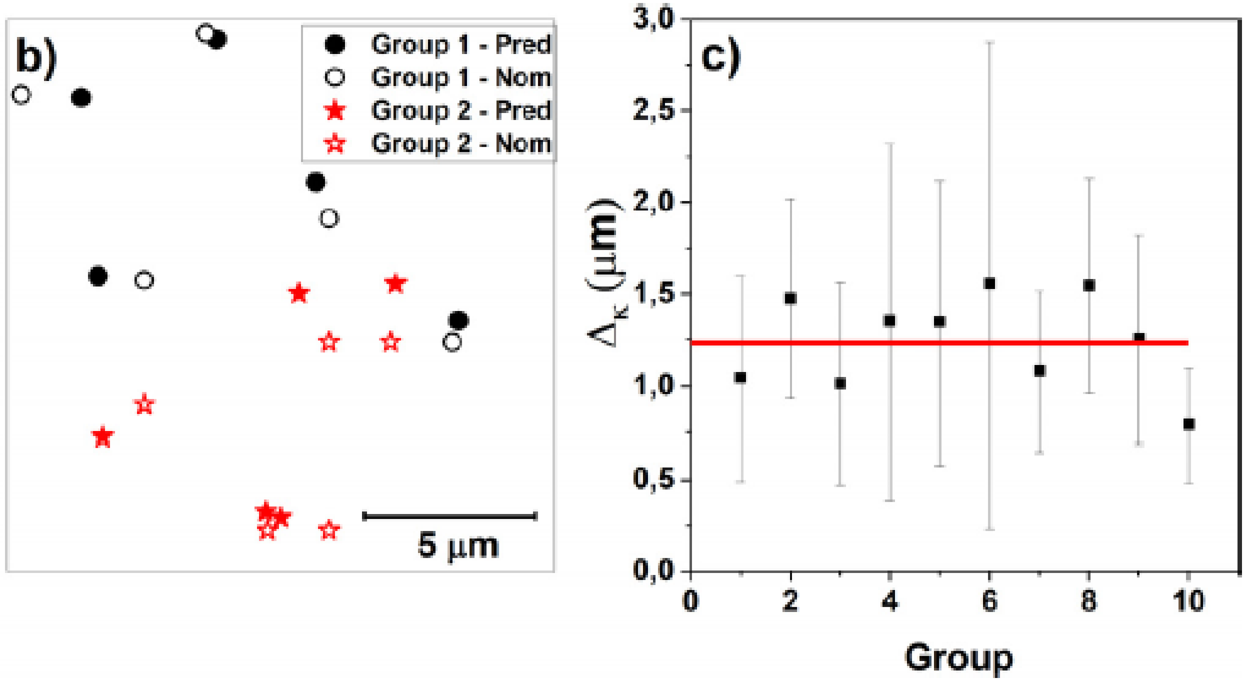
$$y_{pred} = -\frac{1}{2}\frac{x_\beta\left(\delta_\rho^2 - x_\rho^2 - y_\rho^2 - \delta_\gamma^2 + x_\gamma^2 + y_\gamma^2\right) + x_\gamma\left(\delta_\beta^2 - x_\beta^2 - y_\beta^2 - \delta_\rho^2 + x_\rho^2 + y_\rho^2\right) + x_\rho\left(\delta_\gamma^2 - x_\gamma^2 - y_\gamma^2 - \delta_\beta^2 + x_\beta^2 + y_\beta^2\right)}{(y_\beta - y_\rho)(x_\gamma - x_\rho) - (x_\beta - x_\rho)(y_\gamma - y_\rho)}.$$

Boxplot of the distribution distances D_i of the nominal impact point position from the predicted impact point,

$$\Delta_i = \sqrt{(x_{pred,i} - x_{nom,i})^2 + (y_{pred,i} - y_{nom,i})^2}.$$



Predictive accuracy of the model through the tenfold cross validation test.



The 52 data points were randomly assigned to ten groups, containing five points identified by the three "charge" coordinates (r, g, b) relevant to the nominal point of coordinates (x_{nom}, y_{nom}).
In turns, the remaining 47 points were used to build the above described model to evaluate the predicted impact point (x_{pred}, y_{pred}).

Conclusions

- Fabrication of a diamond multielectrode detector by DIBL
- Characterized by IBIC (2 MeV Li ions)
- Sharing of the induced charge among the three sensing electrodes
- 3D Model
- CCE decreases lineary vs. the distance of the impact point from the electrodes
- Trilateration approach to retrieve the two-dimensional position of impact of each ion with a spatial uncertainty of **3 µm** over a triangular region with 26 µm side.

Limitations

Intrinsic: straggling

Instrumental:

- Resolution of the IBIC maps (2 µm)
- Electronics: spectral resolution - 20 keV

Applications:
Micro-radio biology

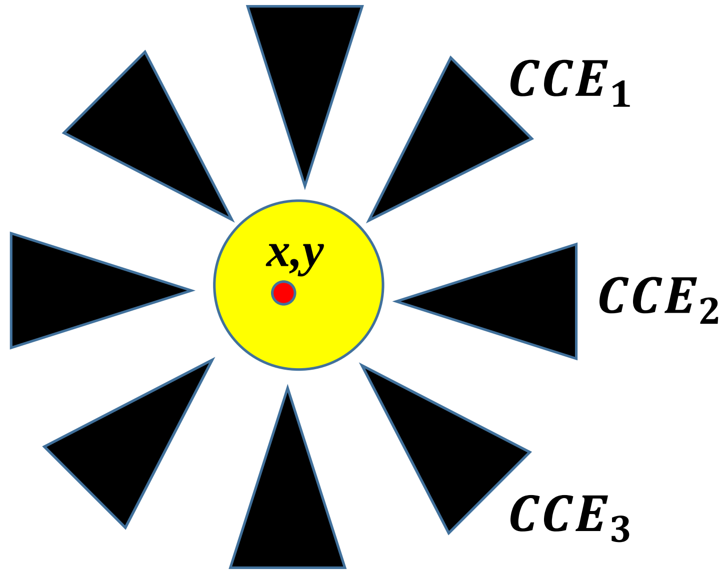
S. Ditalia Tchernj et al. Appl. Phys. Lett. 124, 223502 (2024);

Poster id. 32: **IBIC analysis of a linear position sensitive detector: model and experiment**

Sviatoslav Ditalia Tchernij
Federico Picollo
Jacopo Forneris

Georgeos Provatas
Zdravko Siketic
Milko Jaksic

Matteo Campostrini
Valentino Rigato



Coordinate space

$$\begin{pmatrix} x \\ y \end{pmatrix}$$

Charge space

$$\begin{pmatrix} CCE_1 \\ CCE_2 \\ .. \\ .. \\ CCE_N \end{pmatrix}$$