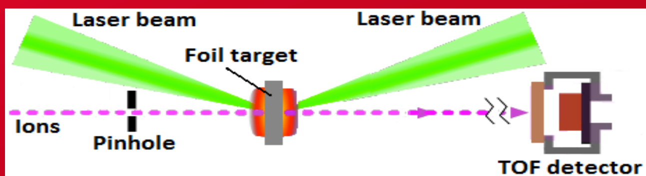
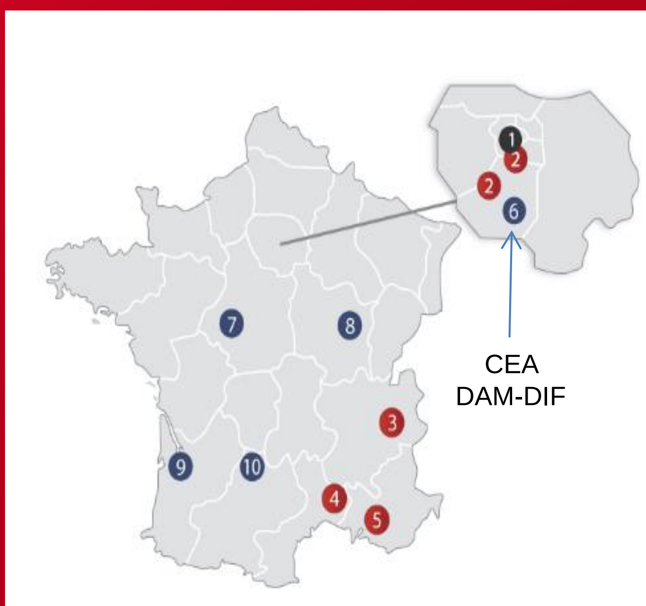
DE LA RECHERCHE À L'INDUSTRIE

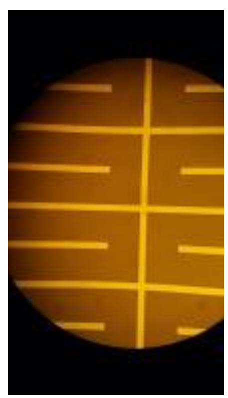




pcCVD: ***p**oly**c**rystalline **C**hemical **V**apor **D**eposition*

Determination of ion stopping power in a plasma by time-of-flight measurements of low-energy ion bunches.

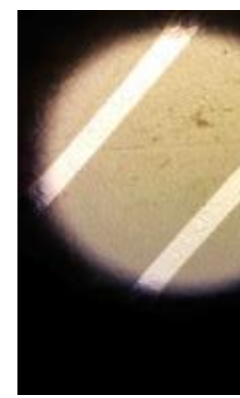
A need for a fast and efficient pcCVD Diamond detector.



J.E. Sauvestre

CEA DAM/DIF

7th ADAMAS workshop



TU Wien (Vienna), 13-14 December 2018

OUTLINE

- Scientific Goals: context of our field of research. **ICF alpha heating problematic.**
- The ***APOCALIPSE*** experiment at CEA-DIF.
  ***APOCALIPSE*: A**lpha and **P**roton **O**n **C**ombined **A**ccelerator and **L**aser **I**nduced **P**lasma **S**topping **E**xperiment
- pcCVD Diamond detector characterization with an alpha source.
- pcCVD Diamond detector characterizations : ***IBIC*** (**I**on **B**eam **I**nduced **C**harge), ***TRIBIC*** (**T**ime **R**esolved **I**on **B**eam **I**nduced **C**harge) results (done at the RBI-Zagreb ion microprobe).
  - pcCVD Diamond detector with interdigitated pattern(*) (first prototype used during the ***APOCALIPSE*** experiment)
  - pcCVD Diamond detector prototype (lower N concentration, smaller gap between electrodes) (second prototype tested at RBI to see if better performances are reached)
- Conclusion

(*) :W. Cayzac et al., *Rev. of Sci. Instr. 89*, 053301 (2018)

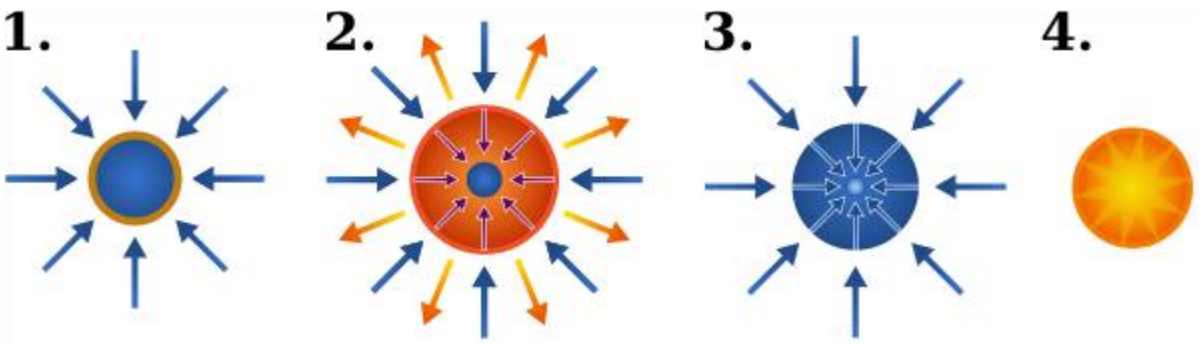
Collaborators :

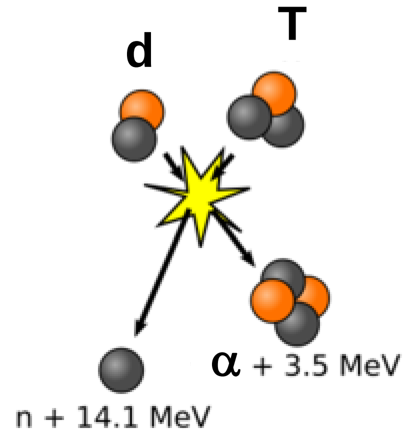
- **CEA-DIF** : W. Cayzac, B. Canaud, D. Deslandes, J. Fariaut, D. Gontier, E. Lescoute, J.G. Marmouget, F. Occelli, G. Oudot, C. Reverdin, A. Sollier, G. Soullié, C. Varignon, X. Vaisseau, B. Villette
- **CEA/LIST**: M. Pomorski
- **GSI-Darmstadt** : A. Blazevic
- **RBI-Zagreb** : N. Skukan, I. Sudic, M. Jaksic

SCIENTIFIC GOALS

- The **stopping power (dE/dx) of ions** in a plasma is a quantity of great importance for :
  - -high energy density physics.
  - -Inertial Confinement Fusion (alpha-particle heating, alternative heating schemes, target design).

$$\mathbf{S\ (E_p) = -\ (dE_p/dx)_{tot} = -\ \underbrace{(dE_p/dx)_{e-}}_{\text{Collision with } e^-} -\ \underbrace{(dE_p/dx)_i}_{\text{Collision with ions}}}$$



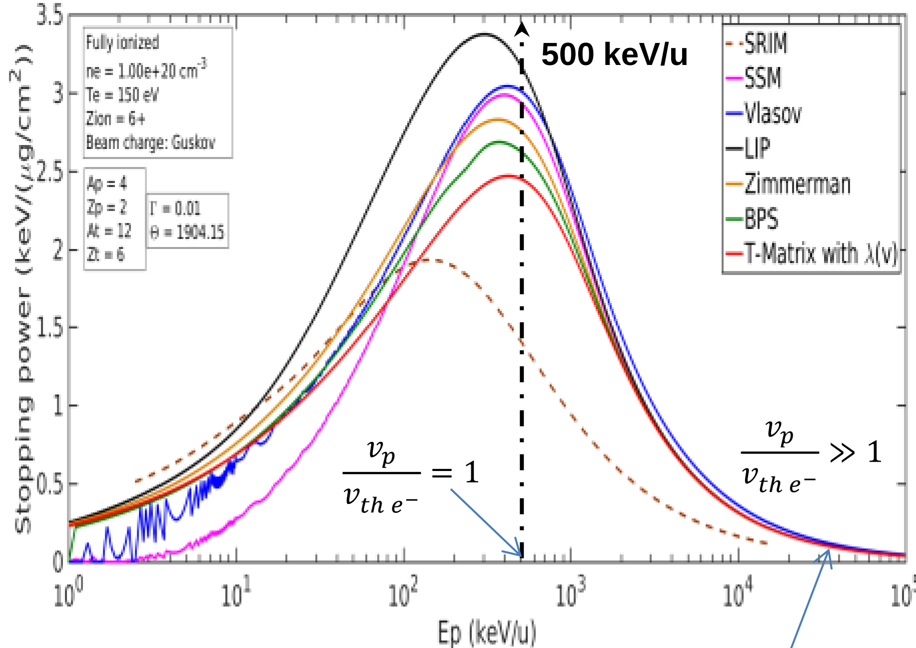


Steps **2, 3, 4**

- Alpha particles created in the hot spot slow down both in the hot spot and in the shell.
- Understanding the way they transfer their kinetic energy to electrons and ions via collision processes is crucial. It leads to our knowledge of the heating process inside the core.
- Increasing the temperature of the plasma species increases the reaction rate $<v_{rel}\sigma>$ of the (d,T) and potentially gives rise to ignition.

This depends on the stopping power S (E_p) to a large extent

SCIENTIFIC GOALS : PRESENT STATUS



Stopping-power predictions for typical conditions of induced laser plasmas encountered in our studies

- Convergent limit of the models at high projectile velocities
- Discrepancies between models appear both for ionic and electronic Stopping Power
- Scarce experimental data near thermal velocities (where large differences occur) or below (corresponding to ion energies of few hundred of keV per nucleon)
- Our experiment is focussed on electronic stopping power by means of energy loss measurements at its maximum (Bragg peak):

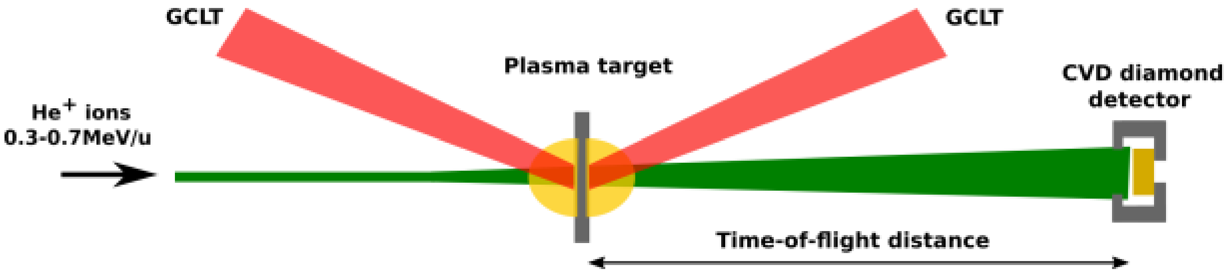
$\Delta E = -\int_0^R \left(\frac{dE}{dx}\right) dx$: energy loss R: plasma length.

SCIENTIFIC GOALS : PRESENT STATUS

- **Up to 30-50 % theoretical uncertainties** at the electronic stopping-power peak depending on plasma parameters (electronic density and temperature: n_e, T_e).

- Precise measurements of the energy loss of ions in a plasma are required to benchmark the models → Time Of Flight technique (TOF).

- As we are dealing with bunches of projectiles with various intensities (solid target, plasma, vacuum once the plasma has expanded (τ_{life} ~ 20 ns)), high flux dynamic range is a necessary condition.



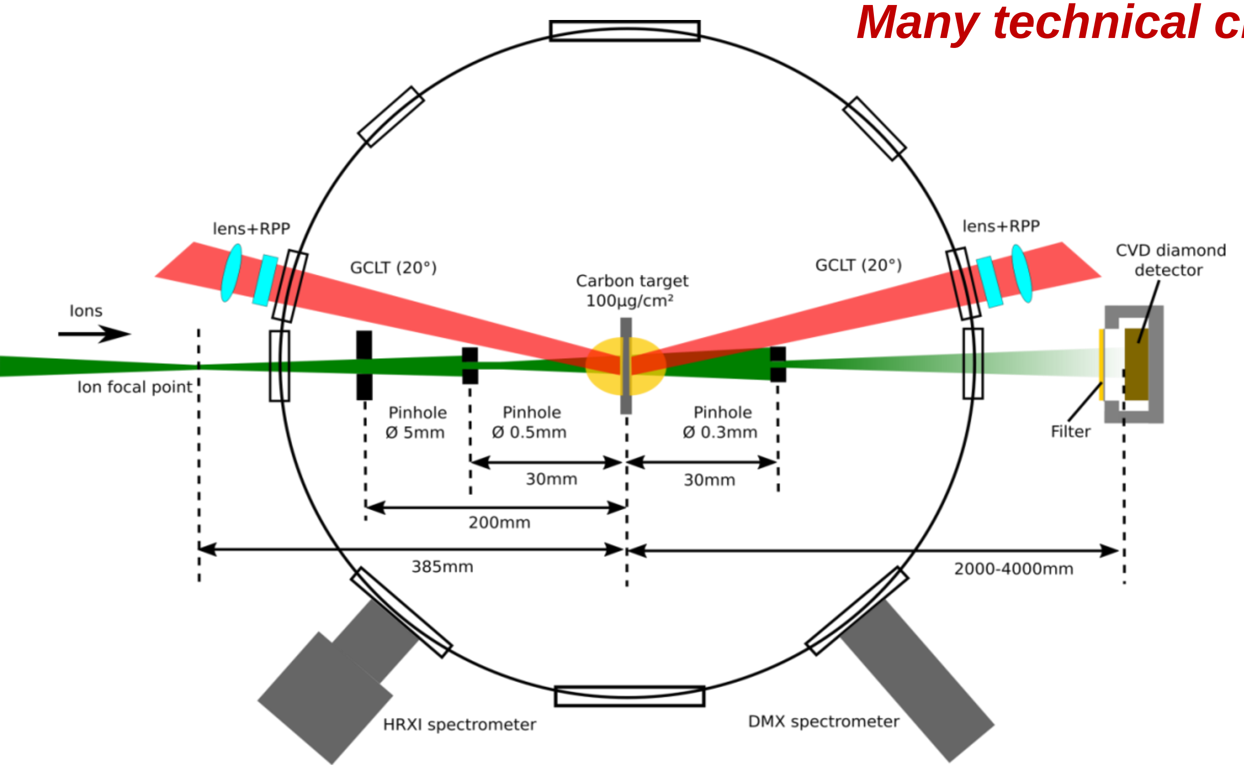
- Detector requirements :
  - fast rise time and decay time
  - radiation hard detector with high sensitivity to ions having energies ≤ 500 keV/u

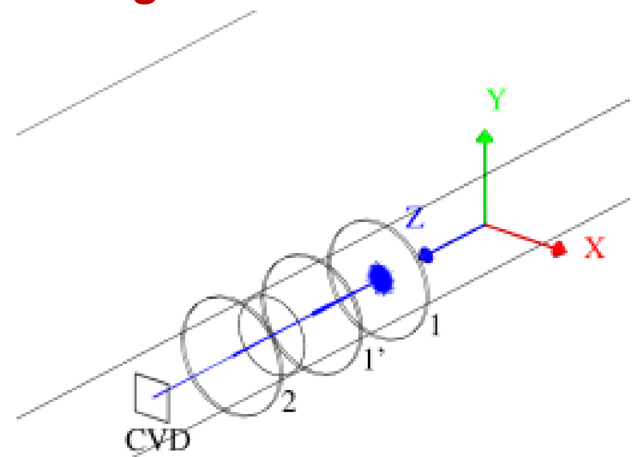
Diamond detectors are well suited ….

The *APOCALIPSE* experiment at CEA-DIF

➤ ***APOCALIPSE*: A**lpha and **P**roton **O**n **C**ombined **A**ccelerator and **L**aser **I**nduced **P**lasma **S**topping **E**xperiment

Many technical challenges to overcome





Geant4 simulation

- Beam emittance
- Beam spatial extension
- Beam temporal structure
- Set-up geometry : pinholes, angular straggling in the target

- **Alpha bunches from an accelerator synchronized with a ns laser (2*10J, 10 ns)**

- Continuation of GSI experiments (*) on the UNILAC / PHELIX facilities (heavier projectiles, higher energies, time resolution of the coplanar pcCVD detector 250 ps)

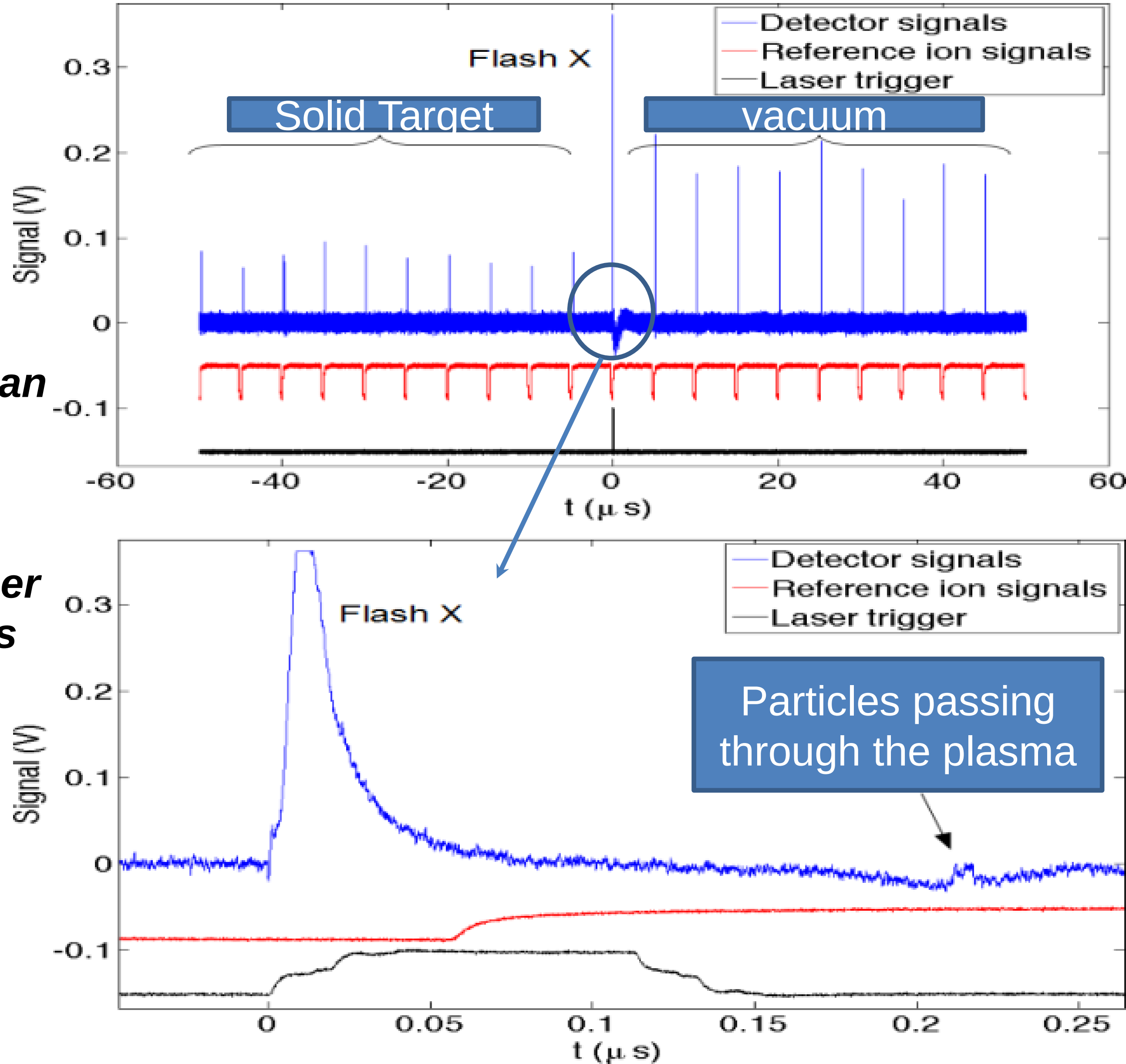
- Single-shot experiment : one of the bunches interacts with the plasma at a chosen time delay

(*): *W. Cayzac, Nature Communications 8, 2017*

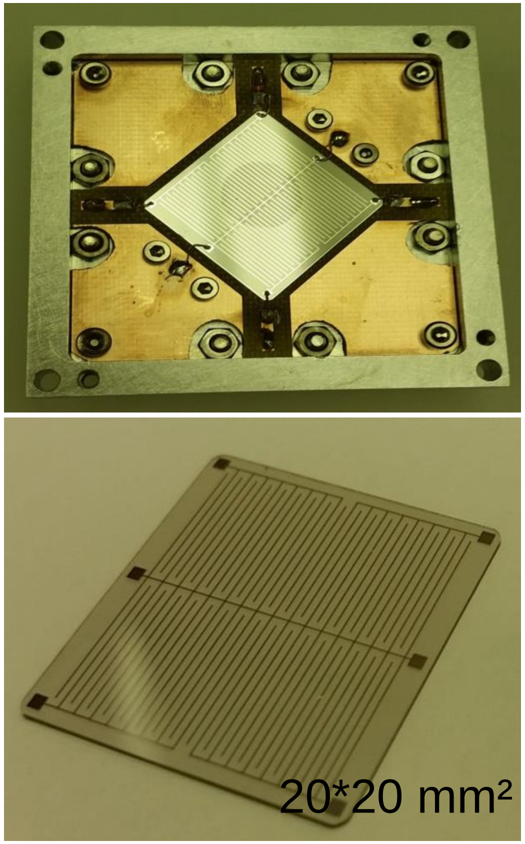
The *APOCALIPSE* EXPERIMENT AT CEA DIF
PROOF OF PRINCIPLE ACHIEVED !!!

Proof of principle of such an experiment has been demonstrated !

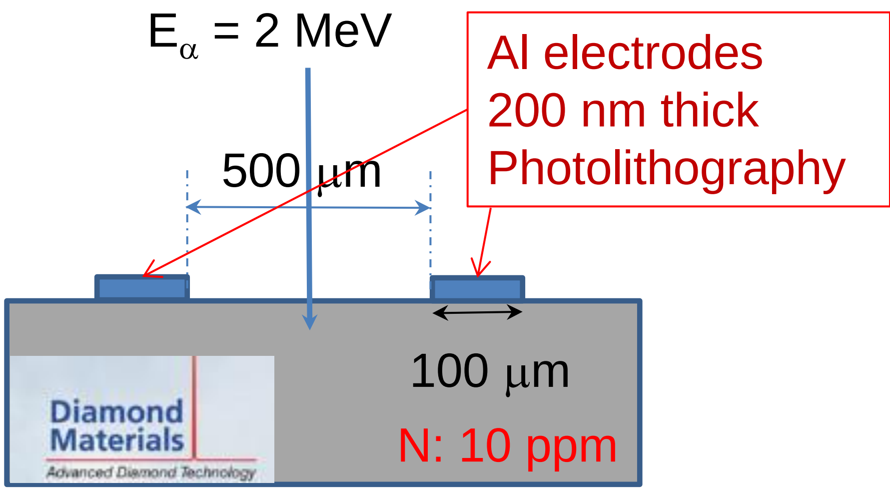
Synchronization of the laser and the alpha bunches has been reached.



INTERDIGITATED pcCVD DIAMOND USED DURING THE *APOCALIPSE* EXPERIMENT FOR TOF MEASUREMENTS



Made by M. Pomorski (CEA/LIST)

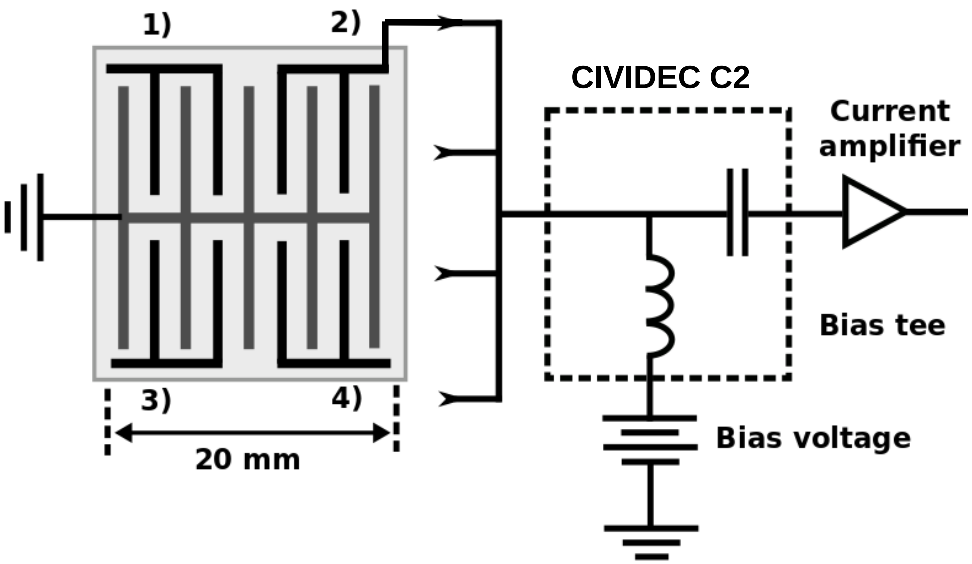


- Alpha 2 MeV: Penetration depth ~3 µm.
- Charges deposited in the vinicity of the surface of the detector.

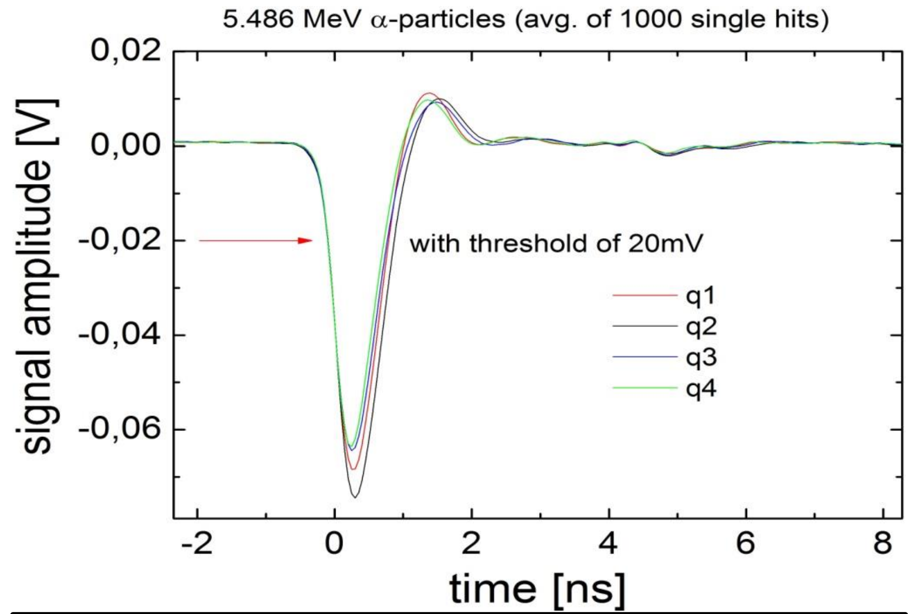
Idea:

- Use of an interdigitated pattern to improve charge collection near the surface (lateral Electric field).
- Tests at CEA/LIST by M. Pomorski with ^{241}Am alpha source.
- Characterization after the ***APOCALIPSE*** experiment at the RBI ion microprobe (Zagreb).

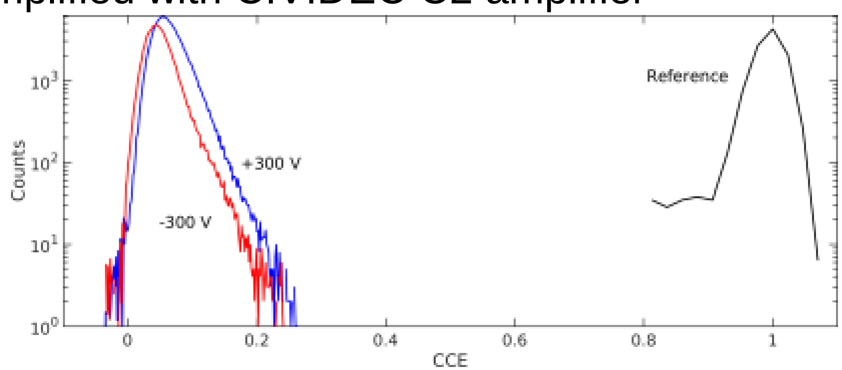
pcCVD DIAMOND DETECTOR CHARACTERIZATION WITH AN ALPHA SOURCE AT CEA/LIST



Standard electronic set-up



4 segments of 10*10 mm² for reducing capacitance
Bias U = + 300 V
Amplified with CIVIDEC C2 amplifier



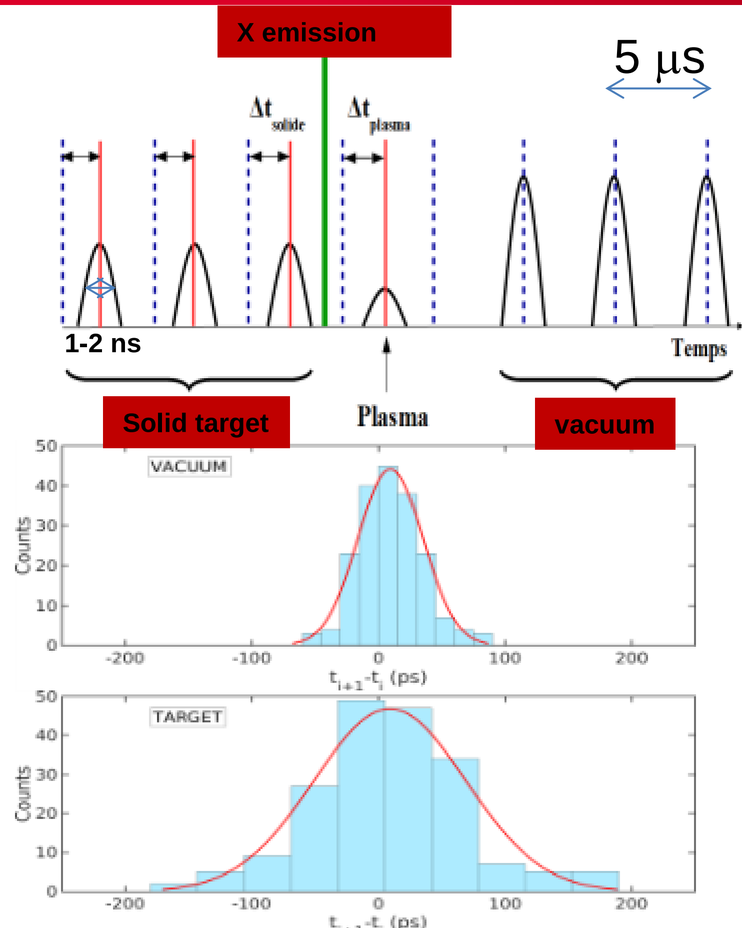
W. Cayzac et al., *Rev. of Sci. Instr. 89*, 053301 (2018)

Test with α-particles from ^{241}Am source

- Rise time ≈ 400 ps
- Decay time ≈ 330 ps (Olthuis* 103 ps)
- Signal width (FWHM) ≈ 700 ps
- **Fast response**
- Low leakage current (≤ 150 nA)
- Small CCE (Charge Collection Efficiency)
  - 6.5% CCE U = + 300 V
  - 5 % CCE U= - 300 V

*:W. Olthuis et al.,Sensors and Actuators B : Chemical, 24(1), 1995.

DETECTOR RESPONSE TO PARTICLES BUNCHES DURING *APOCALIPSE*



TOF distance ~ 2 m

Plot of the individual average (t_{i+1} –t_i) of 200 bunches (gaussian fit)

$$\delta t = \sigma(t_{i+1} - t_i)/2.$$

δt_{vac} = 20 ps → $\delta(E_{vac})$= 0.4 keV

δt_{target}= 40 ps →$\delta(E_{target})$= 0.7 keV.

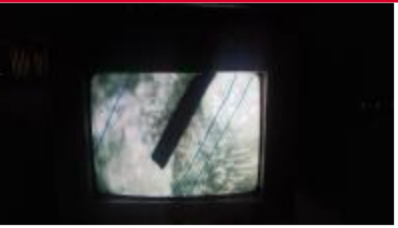
Precision on the energy loss → 0.6 % for 500 keV/A alpha

Rise time ~ 400 ps
Decay time ~100 ps

Excellent TOF resolution ~ 20 ps (at best for vacuum case) allowing the discrimination of the different stopping power models (*).

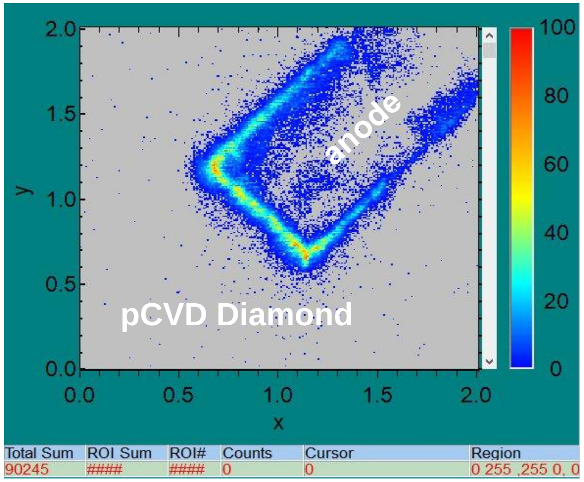
(*): W. Cayzac et al., *Rev. of Sci. Instr. 89*, 053301 (2018)

IBIC CHARACTERIZATION OF THE DETECTOR RBI-Zagreb ION MICROPROBE (Nov. 2017)

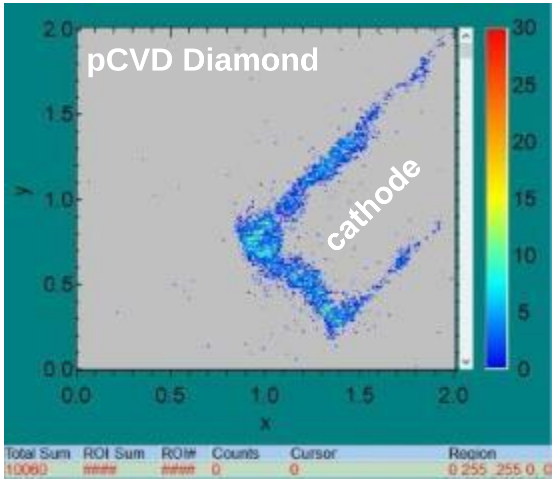


- Microprobe Campaign at RBI-Zagreb (**N. Skukan, I. Sudic, M. Jaksic**)
- ^{16}O → 12.5 MeV

  ^{4}He → 2 and 8 MeV ~1000 pps (scanned regions: 250 μm*250 μm)
- Space resolved characterization of the detector response across its surface with IBIC



Alphas 2 MeV, + 500 V



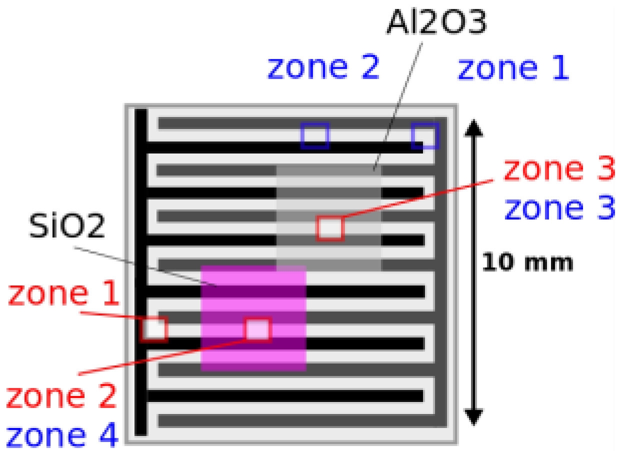
Alphas 2 MeV, - 500 V

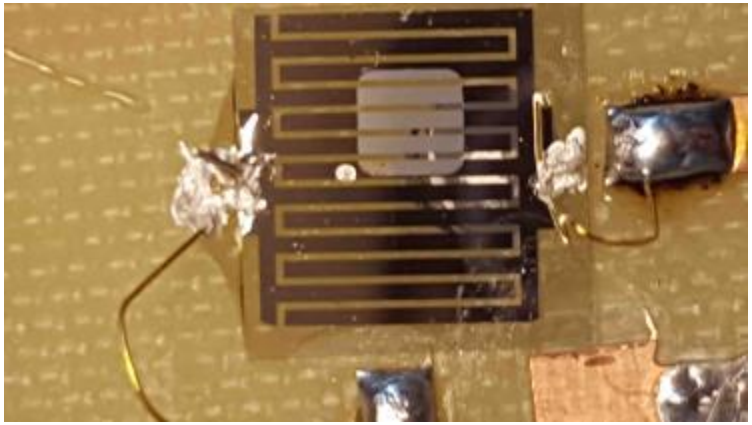
- ✓ CCE essentially concentrated at electrode edges explaining the low efficiency (→low signals) observed during the ***APOCALIPSE*** experiment. Many particles of interest, even if they reached the detector, are not detected! → poor statistics, worse TOF resolution.
- ✓ Charge collection efficiency slightly higher with positive bias as for alpha particles tests performed at CEA/LIST (**M. Pomorski**)

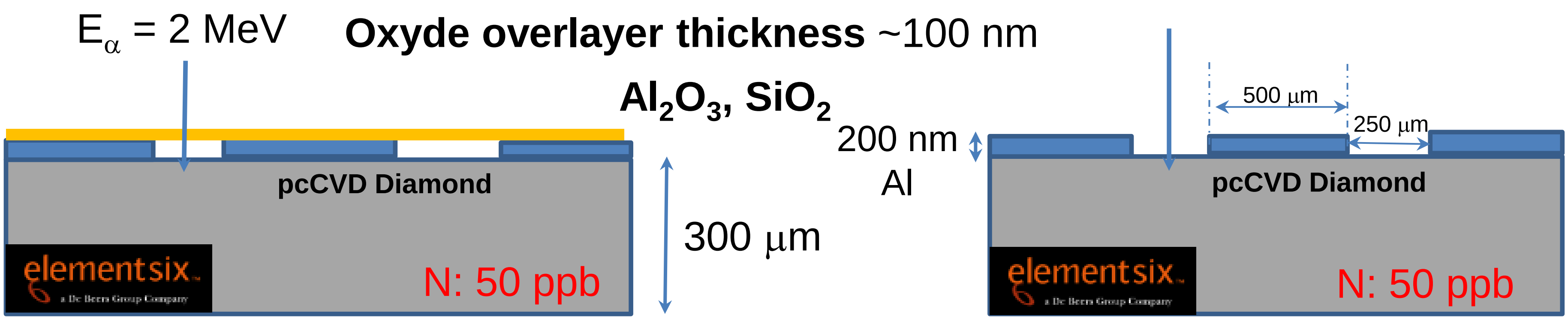
BUT: Detector Efficiency = Active Surface/Effective Surface ~ 2%→ too low !!!

NEW pcCVD PROTOTYPE

Made by M. Pomorski (CEA/LIST)





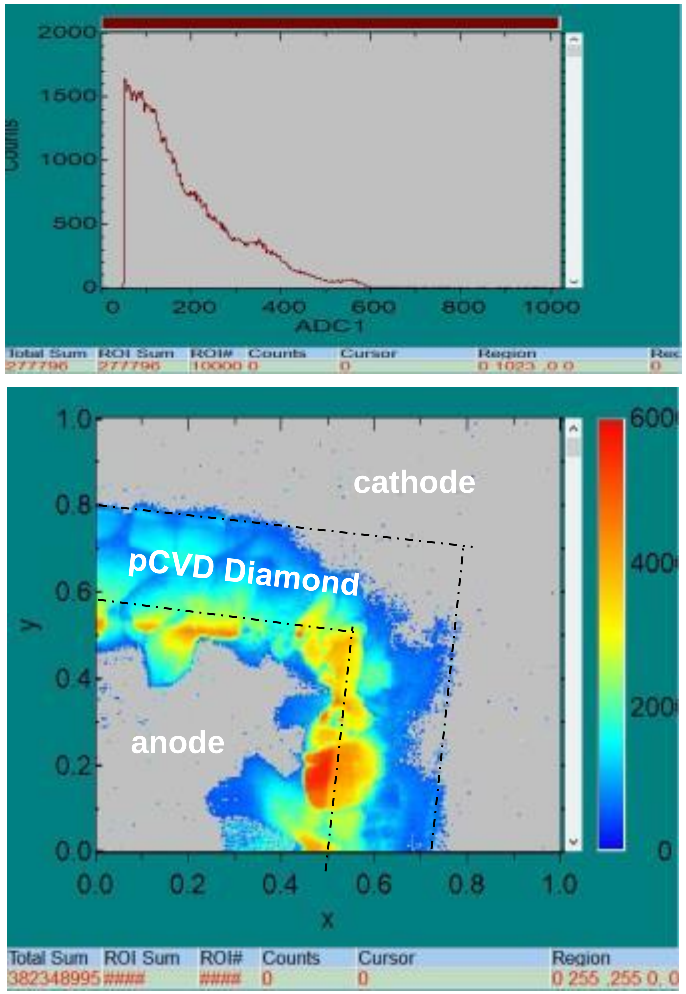


- Smaller gap between electrodes: 500 μm (***APOCALIPSE***) → 250 μm (**new prototype**)
- Three order of magnitude less N concentration(*) than the previous ***APOCALIPSE*** pcCVD
- Different regions have been scanned allowing comparisons with or without the presence of an oxyde overlayer

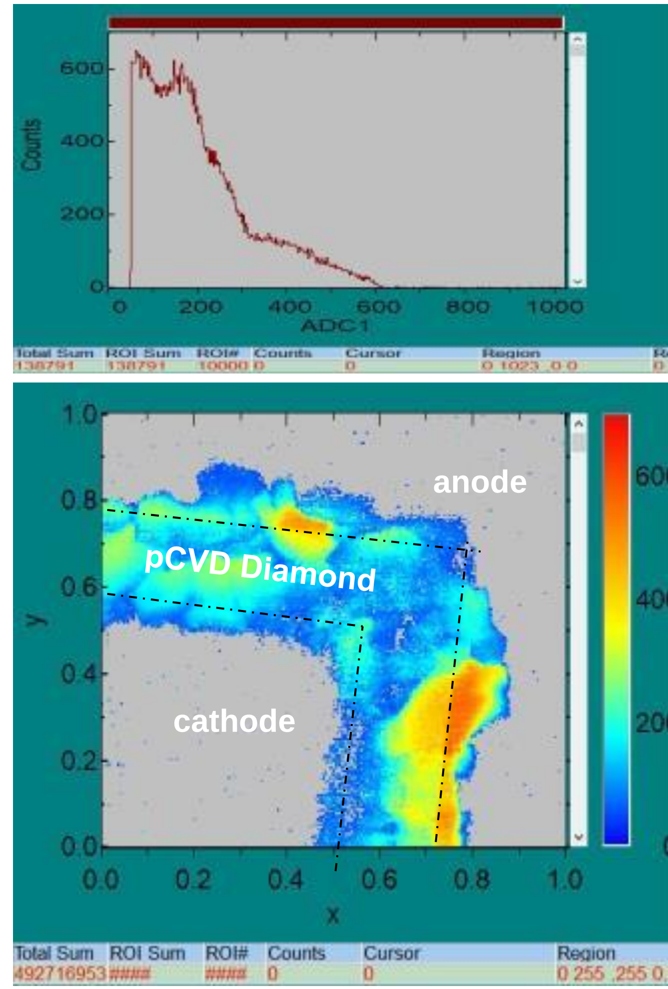
(*): Nam et al. Radiat. Eff. Defects Solids 116, 233 (1991)

NEW PROTOTYPE - IBIC MEASUREMENTS
2 MEV ALPHA

NO
OXYDE OVERLAYER



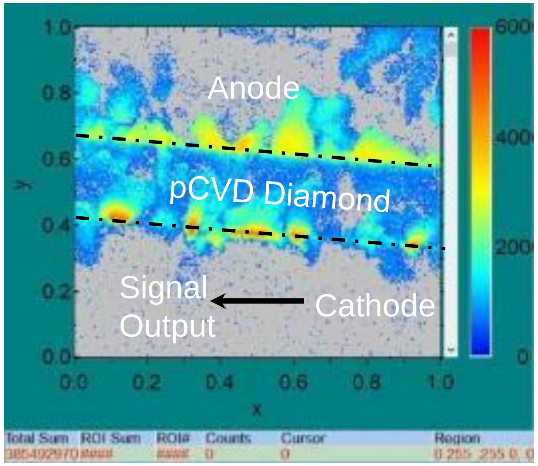
HT = + 300 V

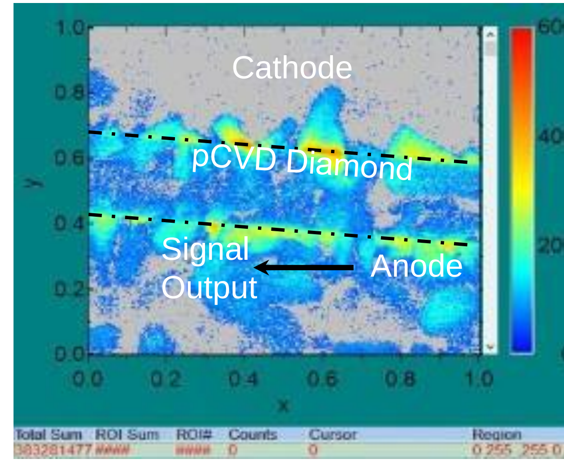


HT = - 300 V

- Grains clearly visible
- Higher CCE at electrode edges
- Efficient in the expected area between the electrodes (the gap)

NEW PROTOTYPE - IBIC MEASUREMENTS 2 MEV ALPHA

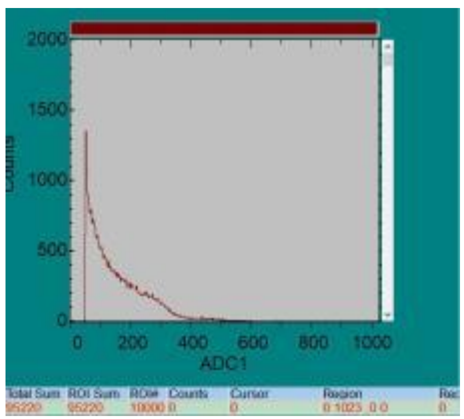


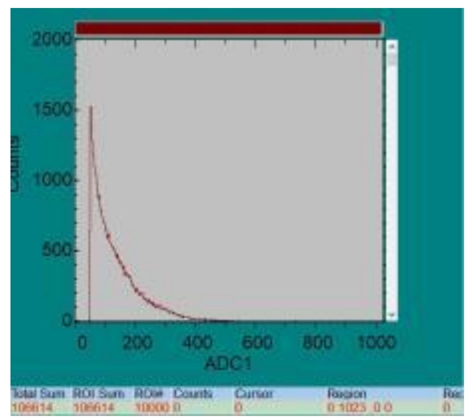


Al_2O_3

OXYDE OVERLAYER

HT = + 300 V

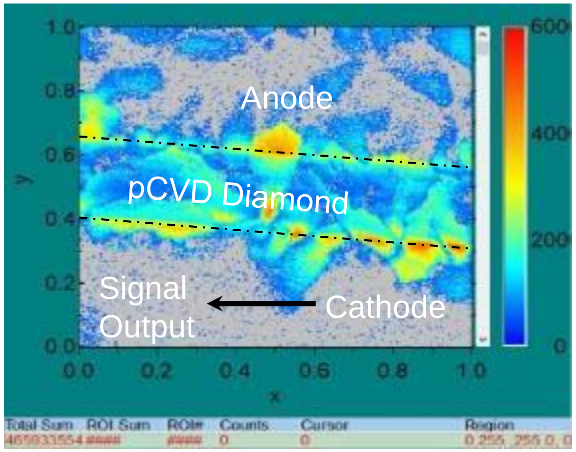




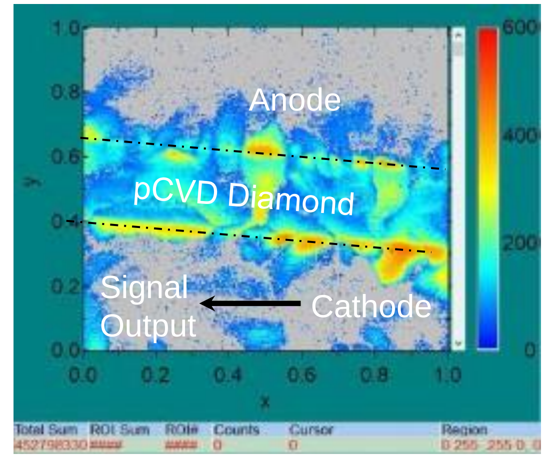
HT = - 300 V

- Detector is active between the electrodes (as wished originally) with a higher CCE still near the edges as observed with the previous pcCVD detector.
- Rapid fall off of the electric field. Detector is also active under the electrodes near the edges.

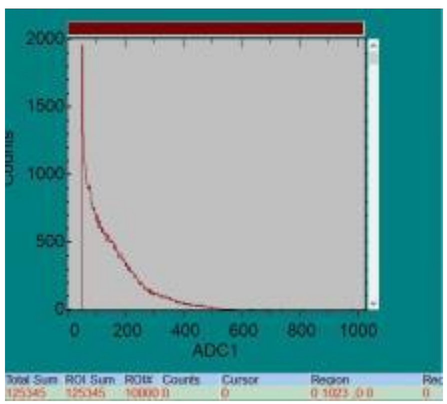
NEW PROTOTYPE - IBIC MEASUREMENTS
2 MEV ALPHA

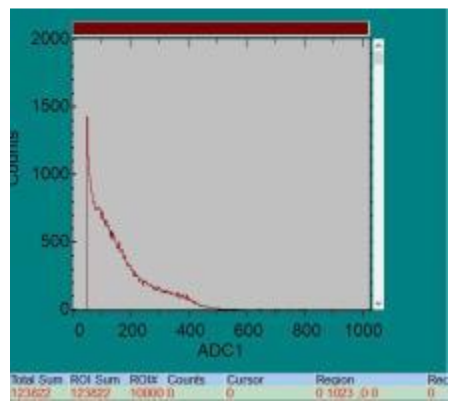


SiO_2
OXYDE OVERLAYER



HT = + 300 V



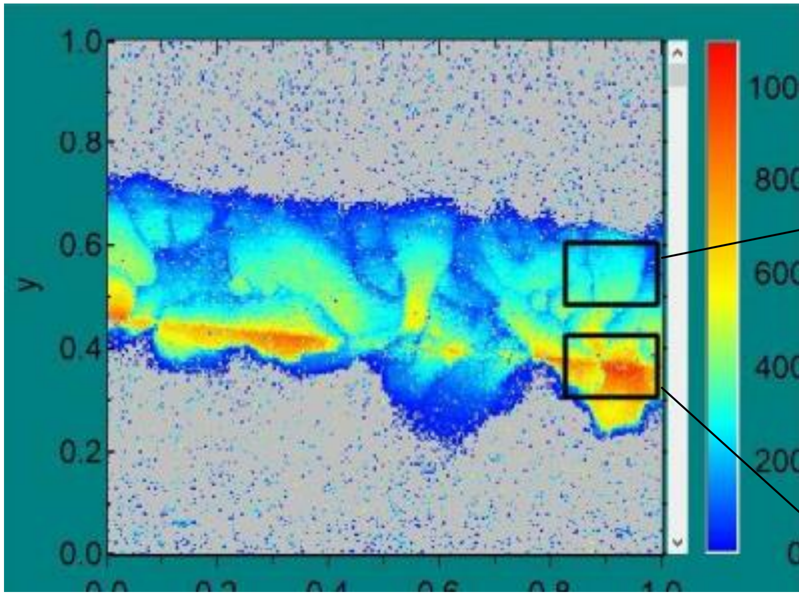


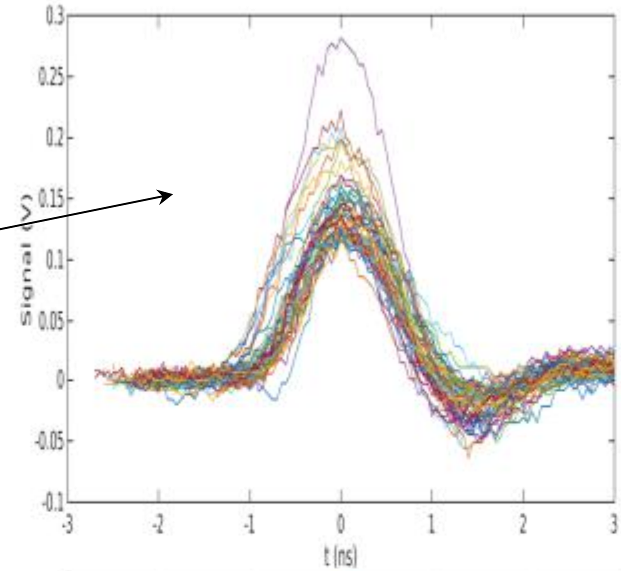
HT = - 300 V

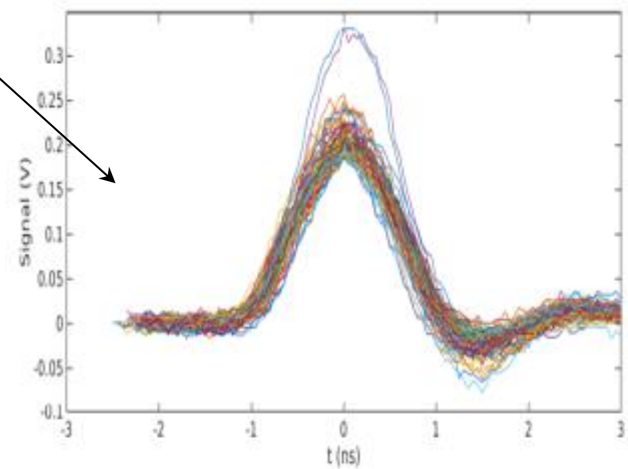
- Less CCE (but both e- and h are collected near the edges) than without oxyde overlayer.
- Seems to be more efficient in the gap (influence of the grains, dependence with the region scanned, less N concentration)

NEW PROTOTYPE - TRIBIC MEASUREMENTS 12.5 MEV OXYGEN

Oxygen Ion 12.5 MeV







σ = 1,18 ns

RC = 149 ± 28 ps   (Olthuis* et al. 166 ps)

Fast rise time response of the second prototype

W. Olthuis et al.,Sensors and Actuators B : Chemical, 24(1), 1995.

NEW PROTOTYPE – IBIC & TRIBIC MEASUREMENTS 2 MEV ALPHA

- Fast rise time observed ~150 ps.
- **Active area is now between** the electrodes as expected initially (thanks to lower N concentration)
- Still a higher charge collection near the edges maybe due to the rapid fall off of the electric field lines as the ion impact distance from the electrodes increases.
- Higher detection efficiency than the APOCALIPSE prototype but electrode width has to be decreased to improve the detection efficiency and thus the statistics of the measured TOF signal (recall that <average> over all TOF of ions passing through the plasma)
- Oxyde overlayers for alphas at 2 MeV displays a lower CCE. Differences occur if depth penetration and energy deposition is higher (oxygen ions at 12.5 MeV).

CONCLUSION

- Stopping power of ions in a plasma is a complicated issue that requires high-precision measurements.

- Proof of principle of a new experiment has been done at CEA-DIF (***APOCALIPSE)*** but efforts have still to be done concerning both plasma diagnostics and time of flight detectors.

- Excellent Time Resolution of the ***APOCALIPSE*** pcCVD diamond detector with interdigitated pattern

  BUT : Poor detection efficiency leading to poor statistics and high error bars

- New pcCVD Diamond detector with interdigitated pattern prototype is promising:

  - No clear effects due to the presence of oxyde overlayers for $E_\alpha \leq 2$ MeV
  - Fast rise time and decay time response observed.
  - Lower N concentration improves the detection efficiency in the gap region.
  - Lowering the finger widths (small inter electrode gap : active region) could improve the detection efficiency.

- Clearly, Alpha tests are not sufficient to characterize such devices and ion microprobe measurements are crucial for a better understanding of the pcCVD diamond detector electrical properties.

THANK YOU FOR YOUR ATTENTION

- We thank the operating staff of the RBI ion Microprobe for delivering a beam of excellent quality and for their support during the experiment.

- The microprobe characterization part of this project has been funded with support from AIDA2020.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168