DE LA RECHERCHE À L'INDUSTRIE

CVD diamond detector with interdigitated electrodes for time-of-flight measurements of low-energy ion bunches

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SUMMARY

- The stopping power of ions in plasma is a cornerstone of inertial confinement fusion
- Focus on the stopping-power peak, at beam energies of 100-500 keV/u, where modeling is most uncertain and measurements, still very scarce, are highly needed
- Energy-loss experiments are in progress at CEA-DIF on a new accelerator/laser TOF platform
- New CVD-diamond detector suited to low beam energies, with coplanar electrodes
- Detector prepared and tested with single-particles at CEA-Saclay
- Detector tested with alpha-particle bunches at CEA-DIF
- Excellent TOF resolution of 20 ps and energy-loss resolution of 0.6-2.5%

W. Cayzac et al., in preparation for Appl. Phys. Lett.

- Detector tested at RBI-Zagreb with IBIC earlier this month
- Detector efficiency not optimal, despite its excellent resolution in TOF experiments
- Electrode geometry optimization to be carried out for even better performances

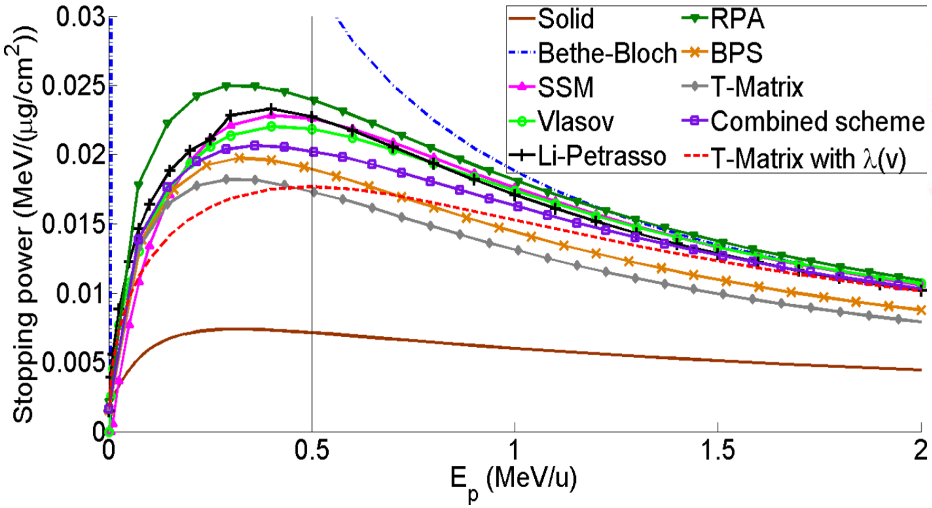
- **Collaborators :**
- **CEA-DIF** : B. Canaud, D. Deslandes, J. Fariaut, D. Gontier, E. Lescoute, J.G. Marmouget, F. Occelli, G. Oudot, C. Reverdin, J.E. Sauvestre, A. Sollier, G. Soullié, C. Varignon, B. Villette
- **CEA-Saclay** : M. Pomorski
- **GSI-Darmstadt** : A. Blazevic
- **RBI-Zagreb** : N.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

SCIENTIFIC GOALS

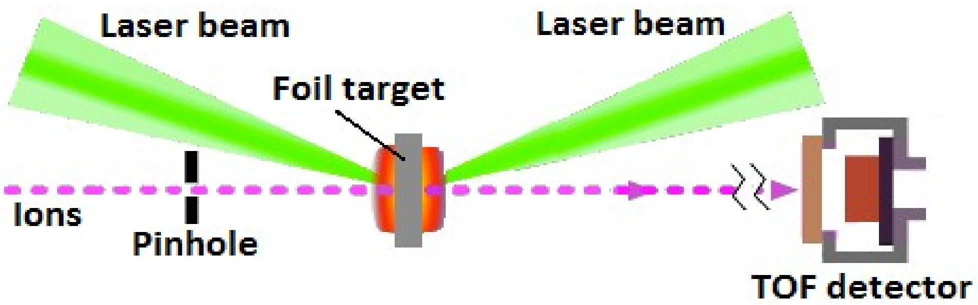
- The **stopping power (dE/dx) of ions** is a crucial quantity for :
  - -high energy density physics
  - -inertiel confinement fusion (alpha-particle heating, alternative heating schemes)

- **Up to 30% theoretical uncertainties** at the stopping-power peak, most important parameter range (Bragg peak...), scarce experimental data
- Precise measurements of the energy loss of ions are required to benchmark the models

- **Our approach :** accelerator ion source, laser-induced plasma, energy loss of the ions in plasma measured by time-of-flight



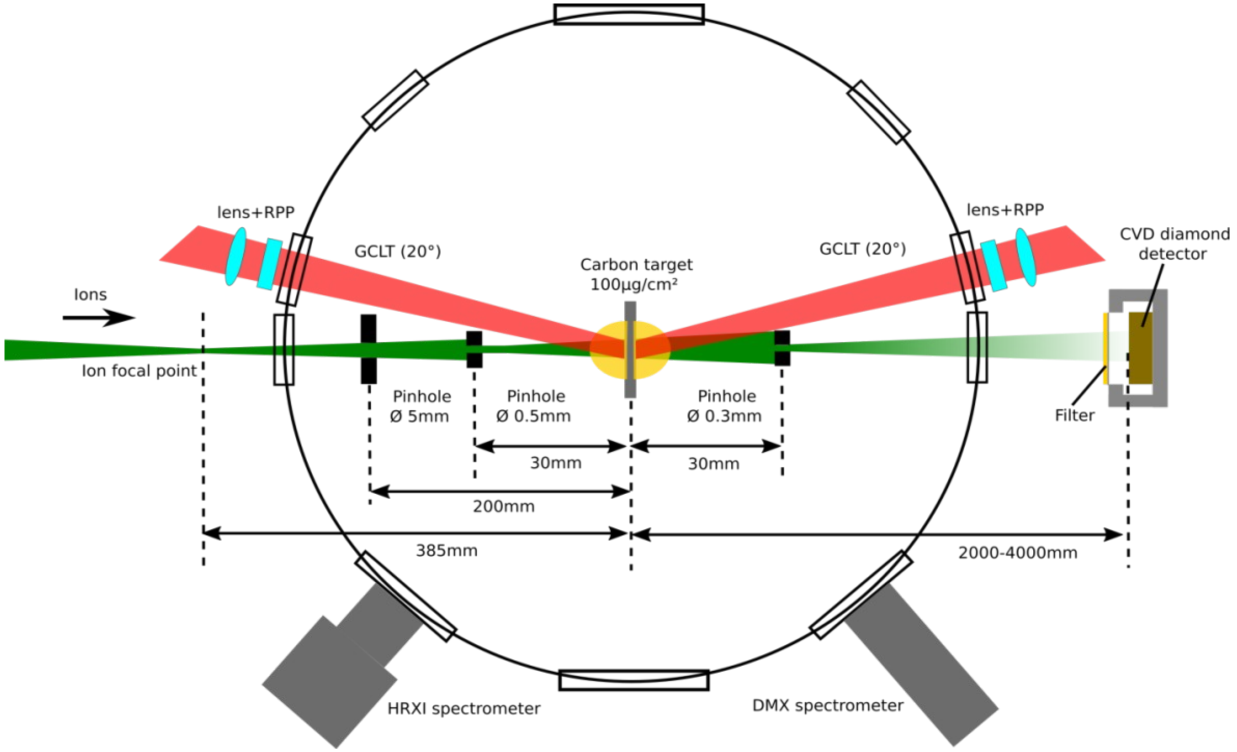
W. Cayzac et al., Phys. Rev. E 92, 053109 (2015)



- Plasma temperature Te ≤ 200 eV
- Stopping power peaks at **Ep ≤ 500 keV/u**

ENERGY LOSS EXPERIMENT AT CEA-DIF

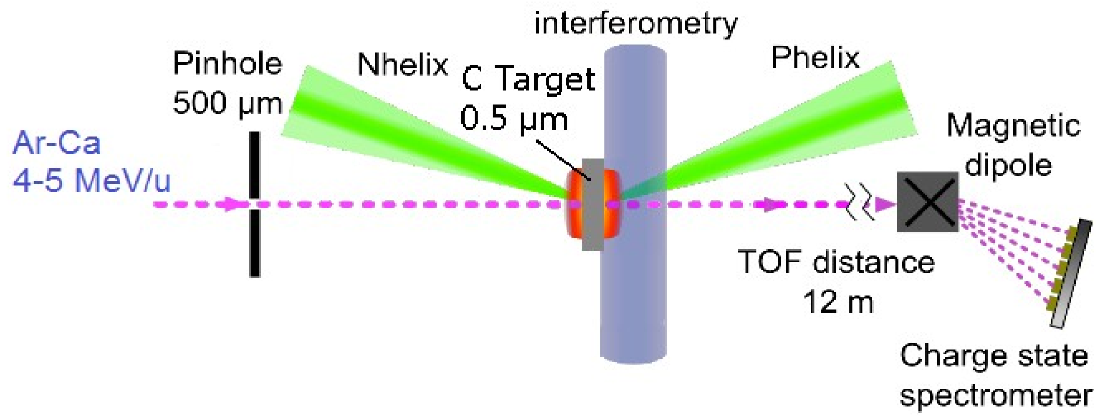
APOCALIPSE: <u>A</u>lpha and <u>P</u>roton <u>O</u>n <u>C</u>ombined <u>A</u>ccelerator and <u>L</u>aser <u>I</u>nduced <u>P</u>lasma <u>S</u>topping <u>E</u>xperiment

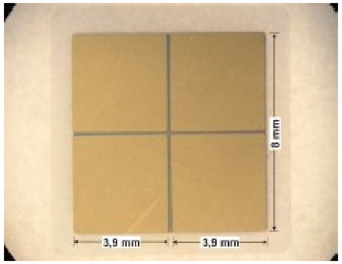


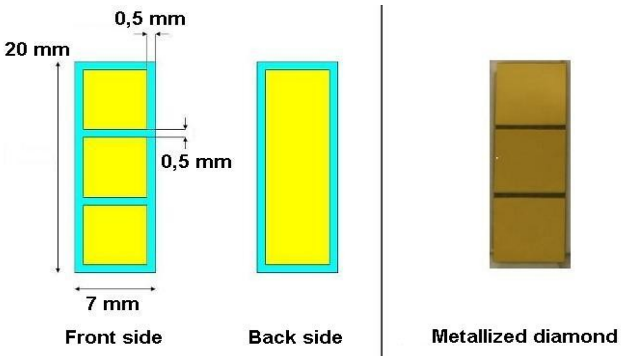
- **World-unique combination between an accelerator and an energetic laser**
- Continuation of the experiments of GSI on the UNILAC / PHELIX facilities
- TOF measurement of a bunched alpha-particle beam in a laser-induced « exploding foil » plasma
- Single-shot experiment : one of the bunches interacts with the plasma at a chosen time delay
- Detector needs high time resolution, radiation hardness, sensitivity to ion energies ≤ 500 keV/u

CVD-DIAMOND DETECTORS FOR ENERGY LOSS EXPERIMENTS AT GSI

- **High/intermediate energy ions** : Ar @ 4 MeV/u (range 22 µm)

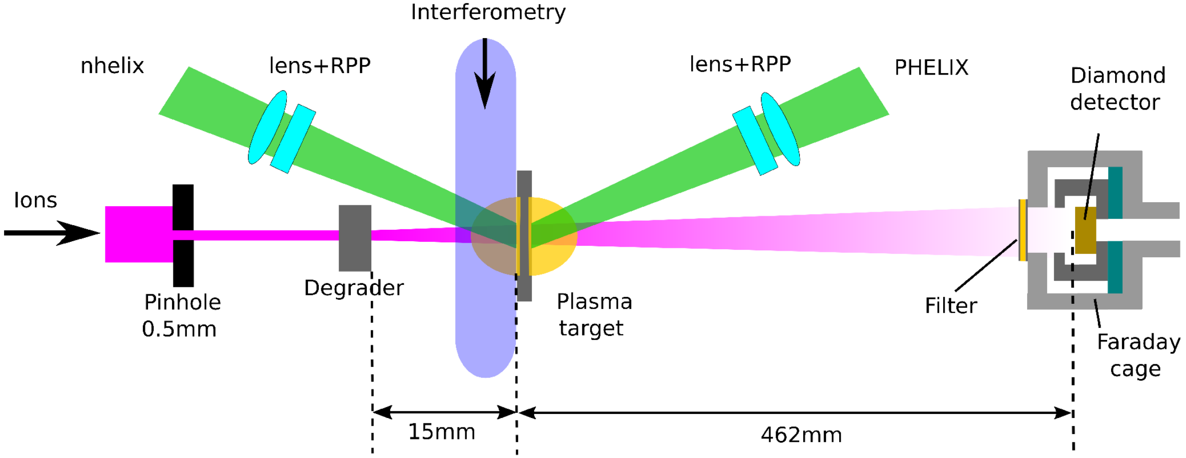


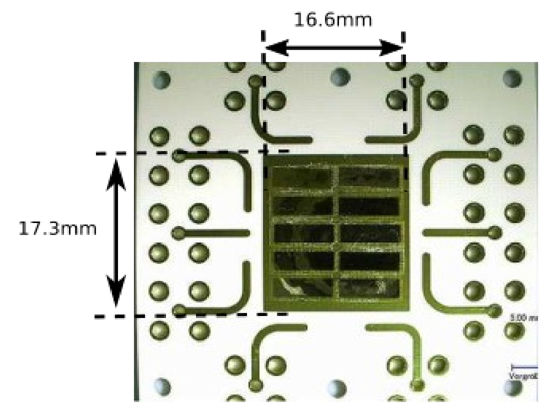




A. Frank et al., Phys. Rev. Lett. 110, 115001 (2013)
W. Cayzac et al., Rev. Sci. Instrum. 84, 043301 (2013)

- **Low energy ions** : N @ 0.6 MeV/u (range 3 µm)

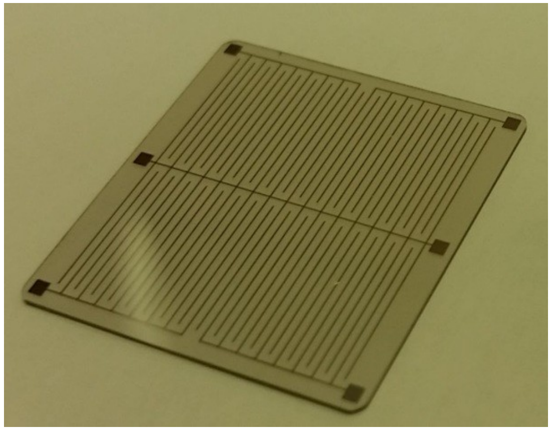


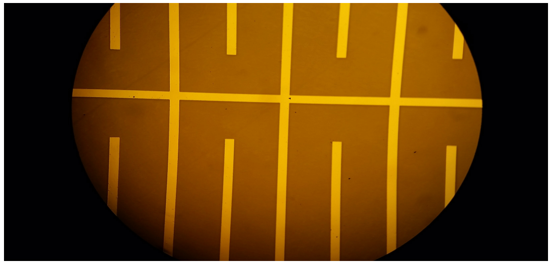


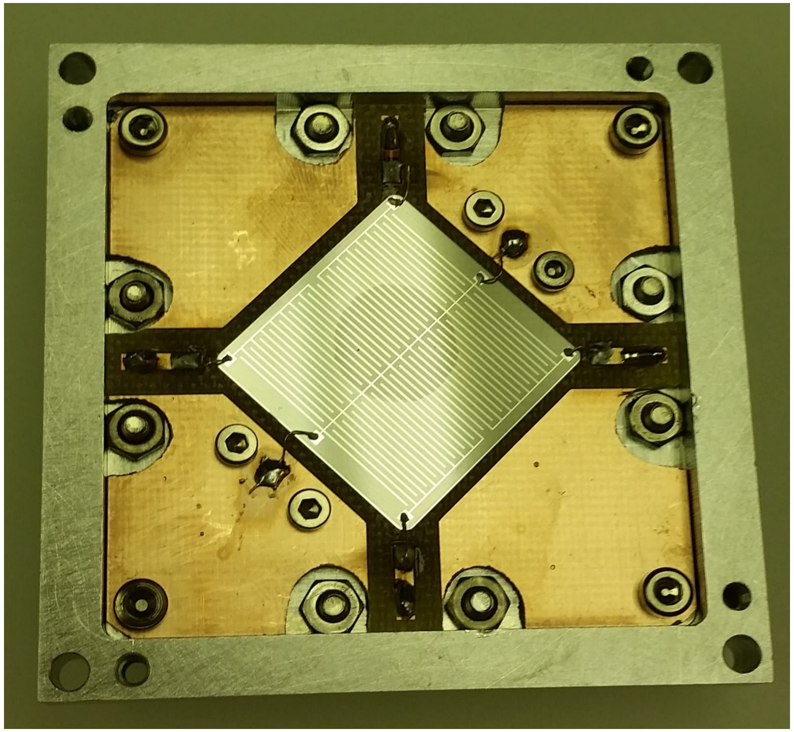
W. Cayzac et al., Nat. Commun. 8, 15693 (2017)

NEW PC-CVD DETECTOR WITH INTERDIGITATED ELECTRODES

- Previously, pc-CVD diamond with sandwich electrodes, optimal for high ion energies
- For energies ≤ 500 keV/u, ion range in diamond ~few µm → surfacic detection

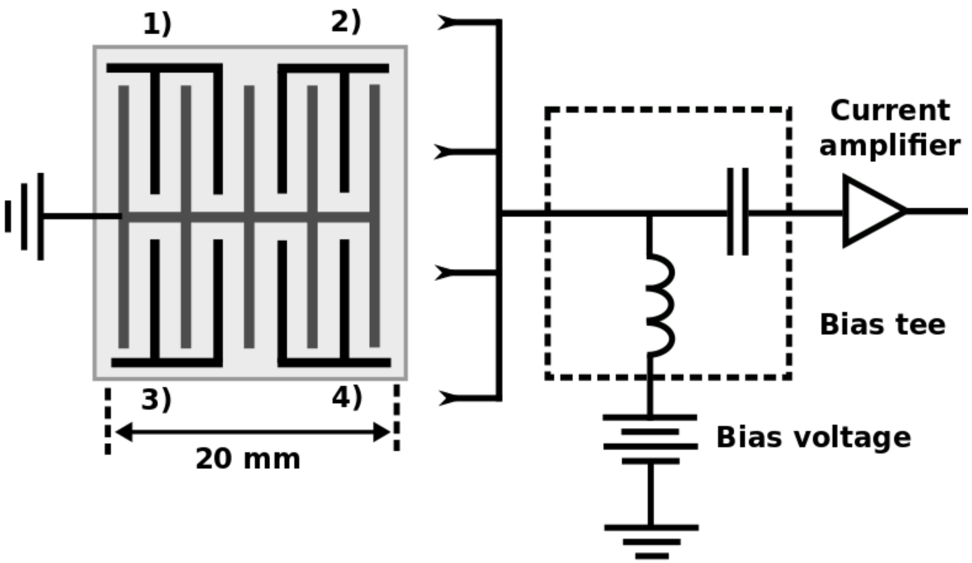


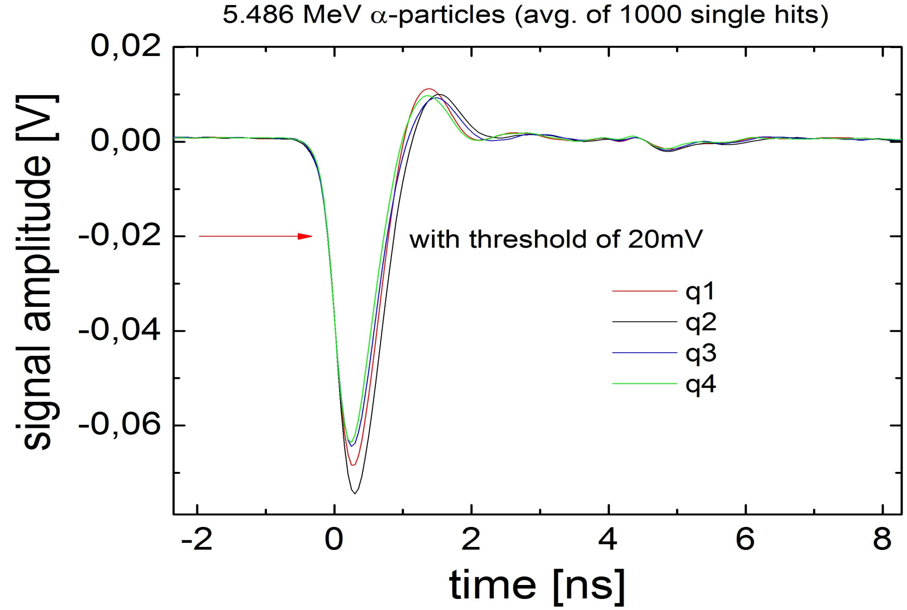




- Polycristalline from Diamond Materials, 20*20 mm², 300 µm thickness
- Aluminum electrodes (~200 nm) patterned by photolithography on growth side
- Width = 100 µm, spacing = 500 µm
- Prepared and tested at CEA-LIST

DETECTOR RESPONSE TO SINGLE PARTICLES



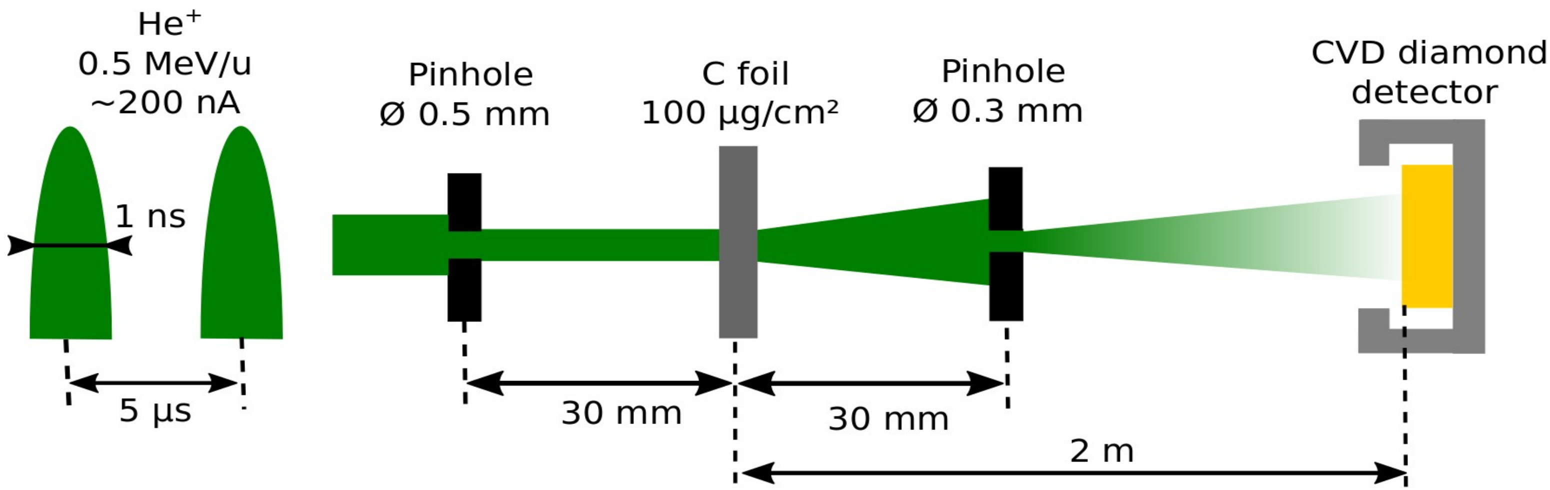


- 4 segments of 10*10 mm² for reducing capacitance
- Polarization U = +300 V
- Amplified with CIVIDEC C2 amplifier

- Test with α-particles from ^{241}Am source
- Rise time ≈ 400 ps
- Decay time ≈ 330 ps
- Signal width (FWHM) ≈ 700 ps
- **Short response**

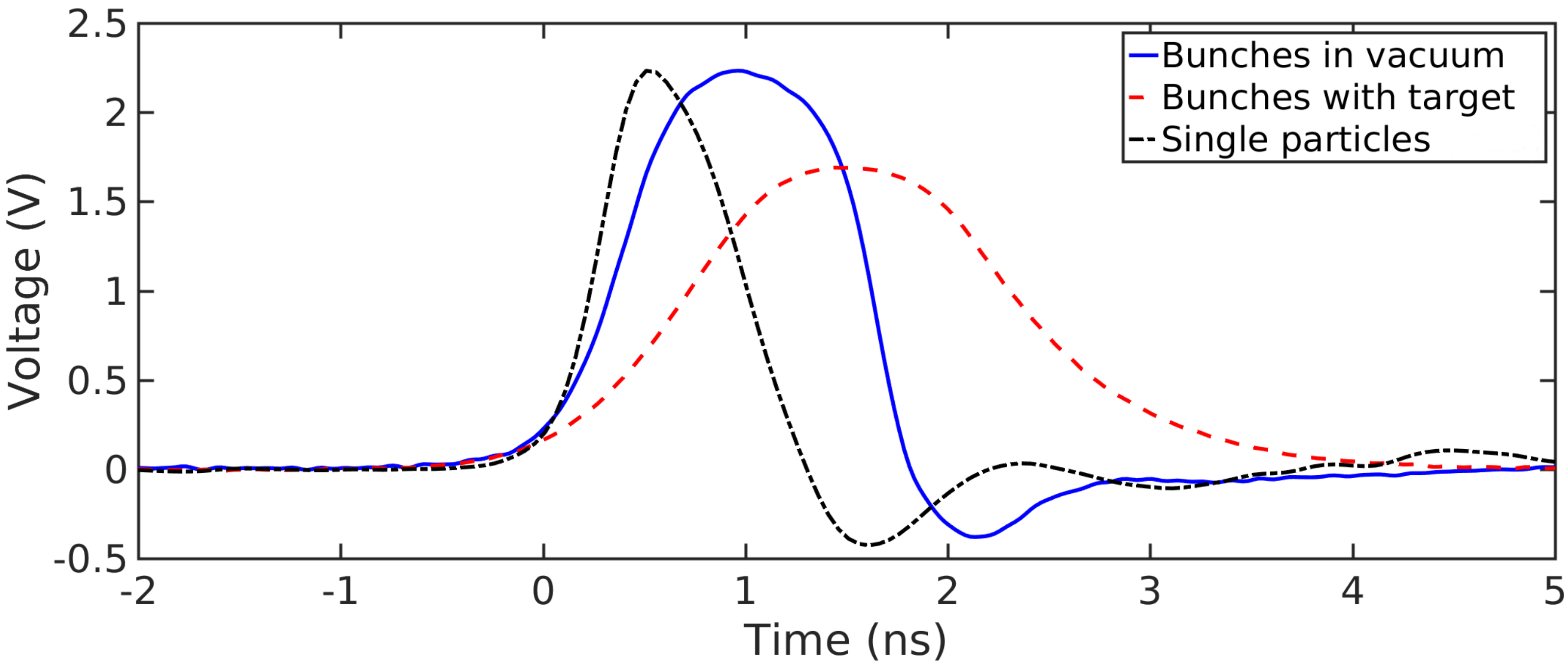
DETECTOR TEST WITH ION BUNCHES

- 4MV Van-de-Graaff accelerator of CEA-DIF, can generate protons and alphas at 0.5-4 MeV
- **Bunched alpha-particle beam at 2 MeV**, 5 µs period and ~200 nA current
- **Mobley compression** gives short bunches of 1-2 ns at FWHM
- Two optional pinholes for beam collimation
- Setup design following GEANT4 simulations of beam transport



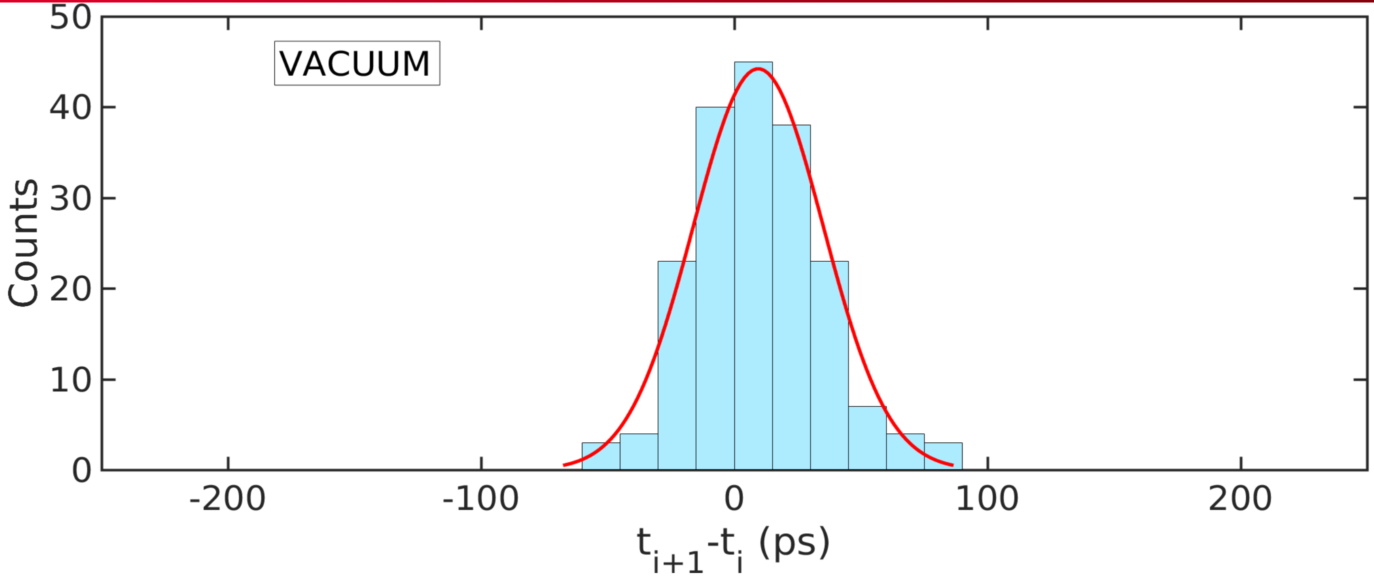
- TOF setup for energy-loss measurements in the C foil with a 2m flight distance
- Energy loss from comparing TOF of bunches after the solid and the plasma target and TOF of bunches propagating in vacuum
- Measurements in vacuum to determine the detector TOF resolution
- Measurements with the target to evaluate resolution on energy-loss

DETECTOR RESPONSE TO 2 MEV ALPHA BUNCHES



- Signals shown here without beam collimation
- Short bunches + short detector response → **bunch signals of 1-2 ns**
- Detector resolution evaluated in vacuum and with target over 200 bunch signals

DETECTOR RESOLUTION FOR 2 MEV ALPHA BUNCHES



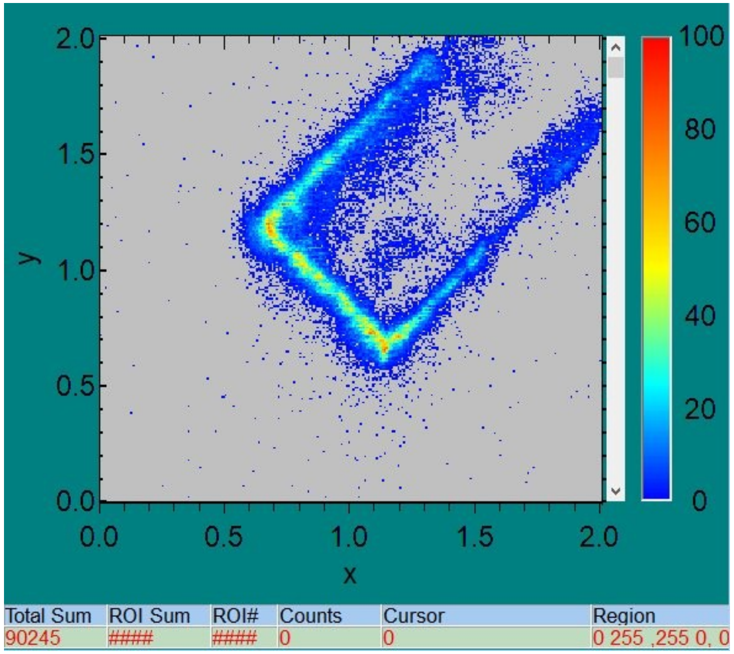
- **With propagation in vacuum**
  - TOF (intrinsic) resolution δt_{vac} = σ(ti+1-ti)/√2 ≈ **20 ps**
  - Energy resolution δE_{vac} ≈ 0.4 keV at target position
  - $\delta E_{vac}/E \approx 0.02\%$

- **With the 100 µg/cm² carbon foil (Energy loss ΔE ~144 keV) and TOF distance = 2m**
  - TOF resolution $\delta t_{foil} \approx 40$ ps
  - Energy resolution $\delta E_{foil} \approx 0.7$ keV, $\delta E_{foil}/E \approx 0.04\%$
  - Energy loss in the target resolved to $\delta\Delta E = \sqrt{(\delta E^2_{vac} + \delta E^2_{foil})} \approx 0.8$ keV (0.6%)

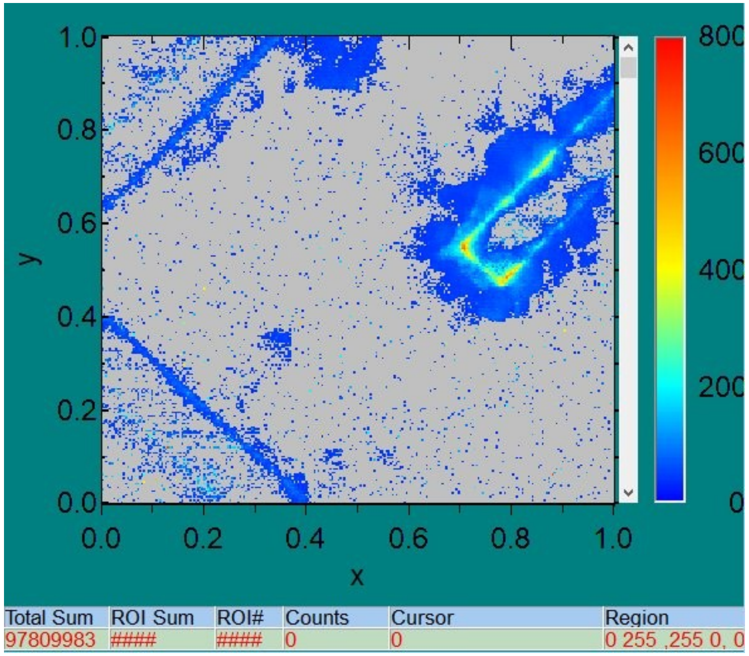
- **Allows very precise energy-loss measurements**

IBIC CHARACTERIZATION OF THE DETECTOR

- Interdigitated electrodes generate a spatially non-uniform electric field
- More detailed characterization of the detector response accross its surface with IBIC
- Measurements at RBI ion microprobe in Zagreb in November 2017, data under analysis



Alphas 2 MeV, +500 V



Oxygen 12.5 MeV, -500 V

- Charge collection lower than expected, and essentially concentrated at electrode edges
- Electrode geometry will be optimized with the help of these data and of field simulations for enhancing the charge collection and optimizing the signals

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THANK YOU FOR YOUR ATTENTION