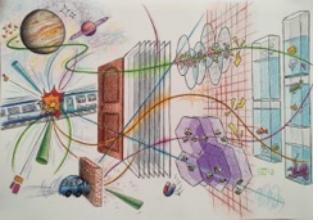


Ion beam testing (and irradiation) at RBI

DRD3

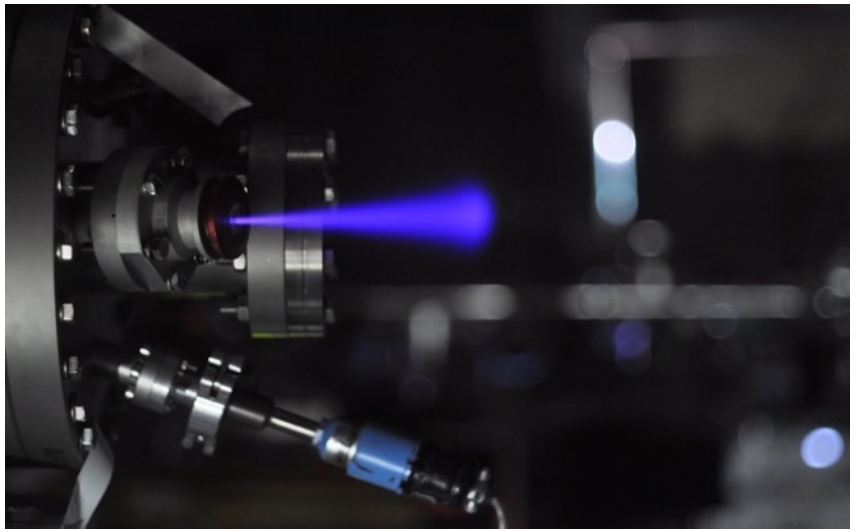
using MeV ion beams (and Co-60) access and new developments

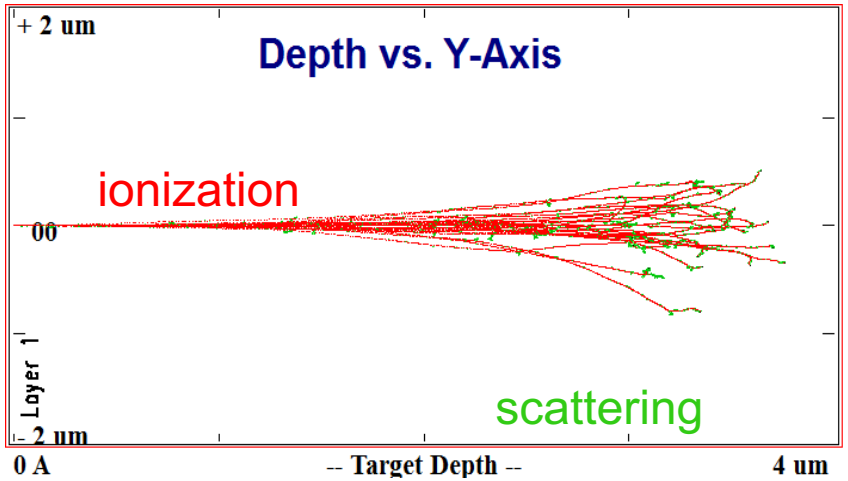
Ruđer Bošković Institute, Zagreb, Croatia

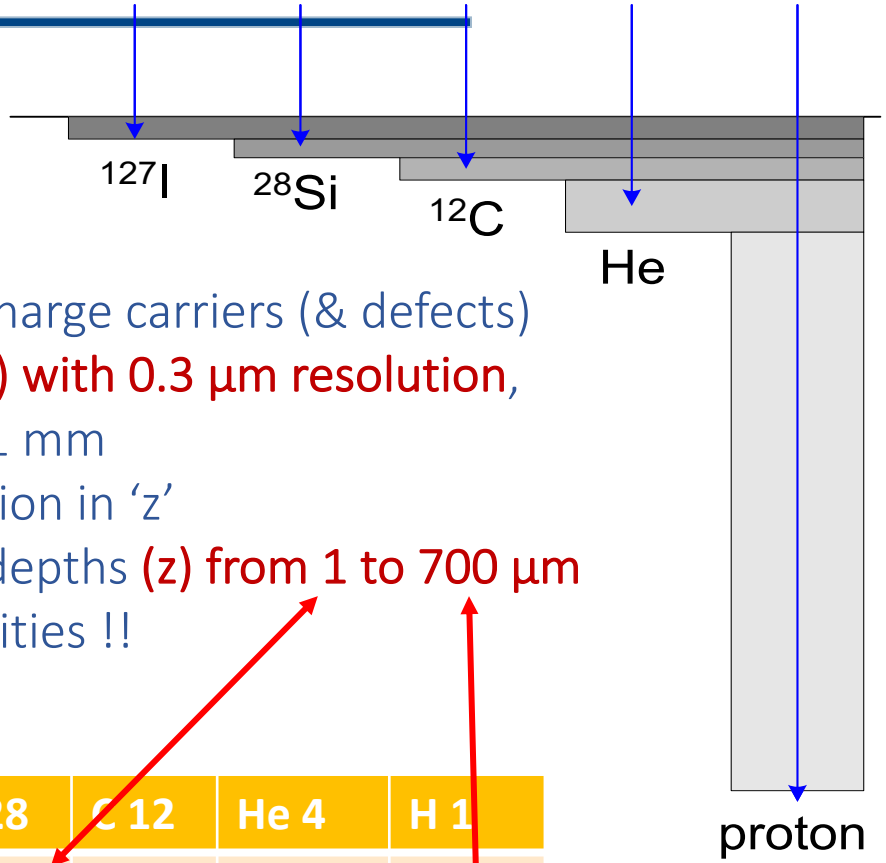
- Accelerator facility – M. Jakšić, G. Provatas, A. Crnjac, D. Cosic, S. Fazinić, M. Vićentijević
- Center for detectors sensors and electronics - A. Starodumov, T. Antičić
- Laboratory for semiconductors - DLTS etc. – I. Capan, T. Knežević
- Co-60 facility – Ž. Knežević, M. Mayer

- IBIC (Ion beam induced charge) instrumentation
- Transnational access funding modes
- IBIC and ionTCT examples of users access
- In-house (RBI) work examples
- Role of DRD3 and conclusions

IBIC – ion beam induced charge

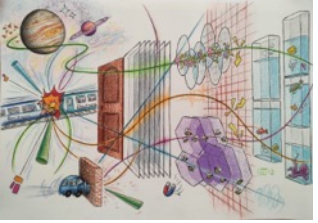






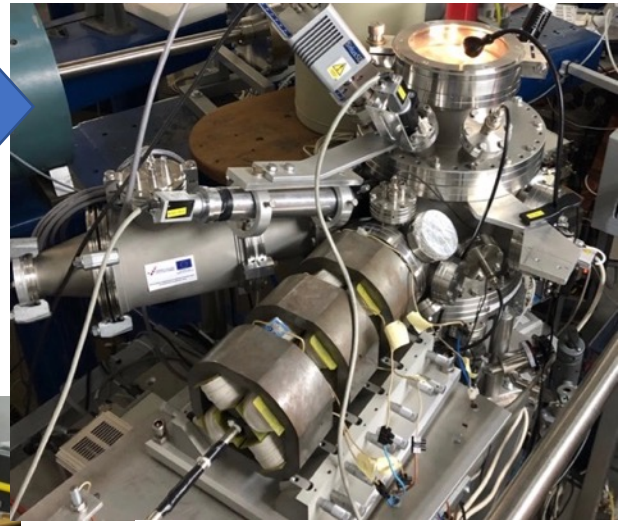
- Every single ion creates charge carriers (& defects)
- Ion microprobe gives (x,y) with 0.3 µm resolution, scanning areas up to 1 x 1 mm
- Ions maintain their direction in 'z'
- Variety of ions - probing depths (z) from 1 to 700 µm
- Variety of ionization densities !!

Silicon	I 127	Si 28	C 12	He 4	H 1
Range(µm) E=1 MeV	0.37	1.13	1.6	3.5	16.3
Range (µm) E=10 MeV	3.7	4.8	9.5	69.7	709

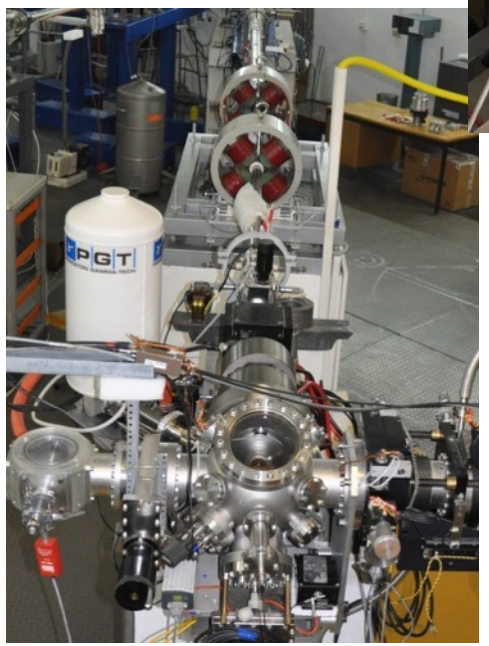


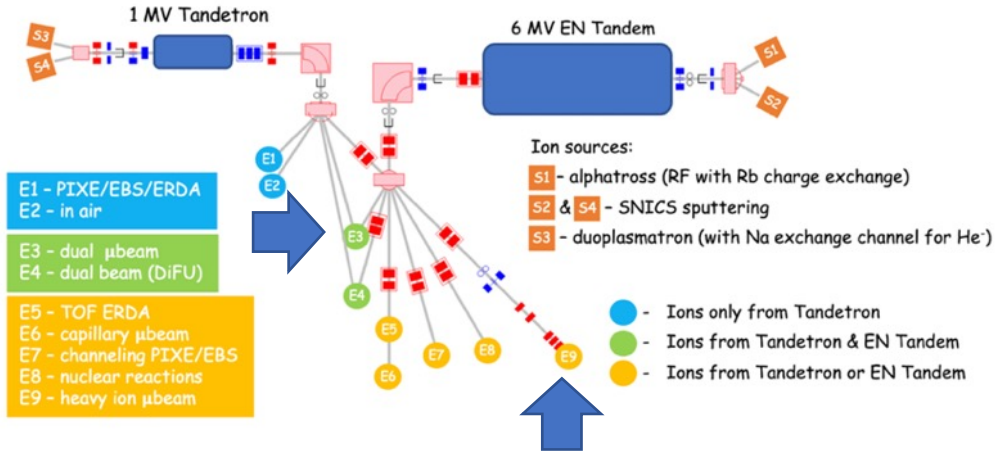
IBIC – ion beam induced charge

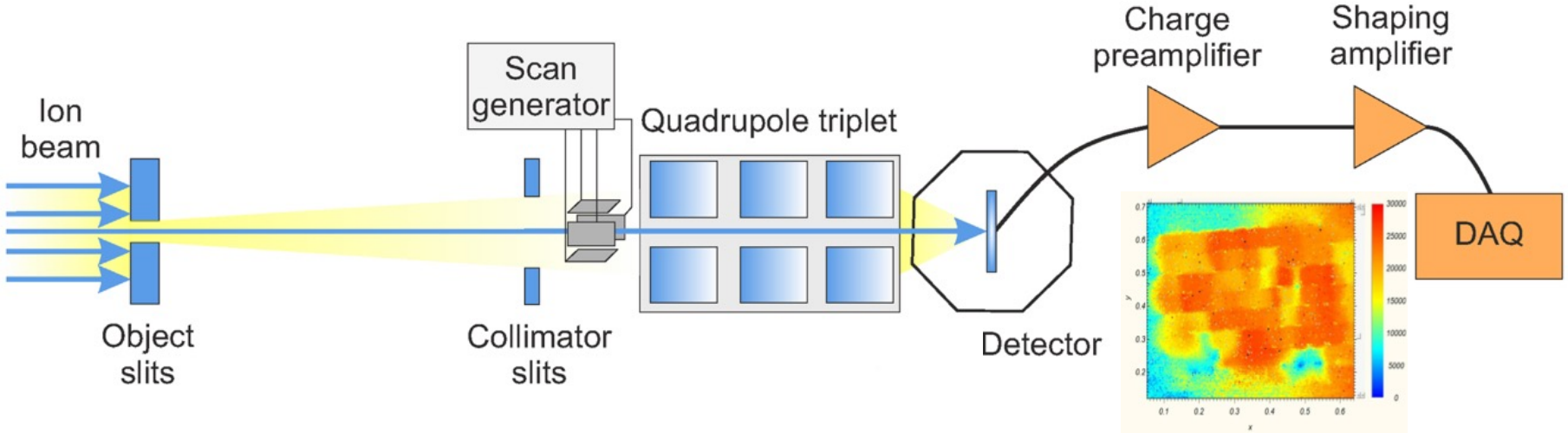
New development
Dual microbeam
(damaging & probing)

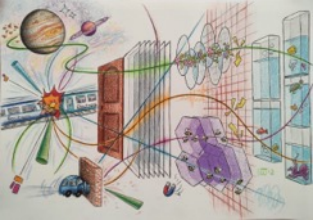


Old microbeam
(most of IBIC
capabilities)









Transnational access for detectors

DRD3

AIDA 2020

2015-2019 - Advanced European Infrastructures for Detectors at Accelerators

- AIDA-2015-1, Study of radiation damage in scCVD diamond, Jerzy Pietraszko, GSI, Germany (26-30.10.2015.)
- AIDA-2015-2, Diamond Membranes for Radioisotope Batteries, Michal Pomorski, CEA, France (15-19.2.2016.)
- AIDA-2015-4, 3D diamond, Alexander Oh, University of Manchester, UK (11-15.4.2016.)
- AIDA-2016-1, Single crystal diamond Shottky diodes for microdosimetry, Claudio Verona, Italy (24-28.10.2016).
- AIDA-2016-2, Microbeam tests of silicon telescope for dosimetry, G. Magrin, Austria (18-20.1. and 9-10.2.2017.)
- AIDA-2017-1: Diamond Membrane Microdosimeter, M. Pomorski, CEA, France (2-5.5.2017.)
- AIDA-2017-4: CVD diamond Time of Flight detector with interdigitated electrodes, W. Cayzac, France (6-10.11.2017)
- AIDA-2017-5: Polycrystalline 3D Diamond IBIC and TRIBIC characterisation, A. Oh, Manchester, UK (27.11.-2.12.2017).
- AIDA-2017-2: Analysis of graphite pillars buried in sc-CVD diamond , G. Conte, Italy (12-14.9.2017. and 20-21.3.2018)
- AIDA-2018-1: Single event upsets in CMS pixel ROC, Wolfram Erdmann, PSI Switzerland (2.7.-6.7.2018).
- AIDA-2019-1: IBIC of monolytic pixel detectors, Rogelio Pinto, University of Sevilla, Spain (19.8.-23.8.2019).

1. **E. Vittone, Italy,** Differential IBIC analysis for the measurement of carrier lifetime in silicon pin diodes **(20.-22.5.2020)**
2. **M. Pomorski, France,** 3D scCVD diamond membrane microdosimeter for quality assurance in hadron therapy **(24.-27.8.2020)**
3. **A. Oh, UK,** Charge collection of 3D diamond and LGAD test detectors with the proton microbeam **(7.-11.6.2021)**
4. **R. Pinto, Spain,** Response in monolithic particle detector for the RD50 collaboration **(14.-18.6.2021)**
5. **C. Verona, Italy,** Characterization of ΔE-E single crystal diamond based telescope for microdosimetry application **(5.-9.7.2021)**
6. **E. Vittone, Italy,** Hydrogen thermal donors in silicon **(22.-24.2.2022)**
7. **C. Verona, Italy,** IBIC characterization of single crystal diamond devices for microdosimetry application **(7.-11.2.2022)**
8. **A. Oh, UK,** Investigation of charge collection of hexagonal and cubic 3D diamond detectors **(4. – 8.4.2022.)**
9. **M. Camarada, Switzerland,** Study of charge transport response of Silicon Carbide sensors **(2.-6.5.2022.)**
10. **M. Camarada, Switzerland,** Study of high temperature charge transport response of SiC **(planned for 19.-23.9.2022)**

RADIATE

2020 – 2023 Research And Development with Ion Beams – Advancing Technology in Europe

EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

Active now !! (until 2026)
https://web.infn.it/EURO-LABS/
WP4 – TA to Research Infrastructures for HEP Detectors (Detector characterisation)

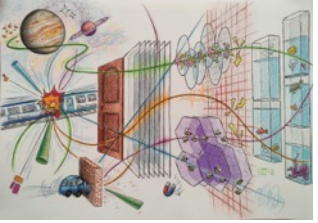
+

CERIC
Central European Research Infrastructure Consortium

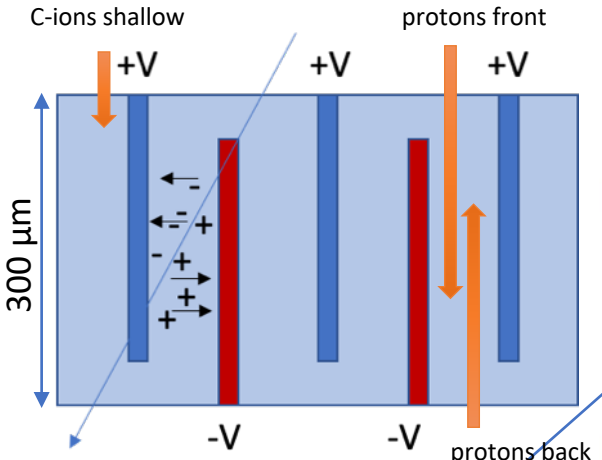
Calls for access every 6 months
https://www.ceric-eric.eu/users/open-access/

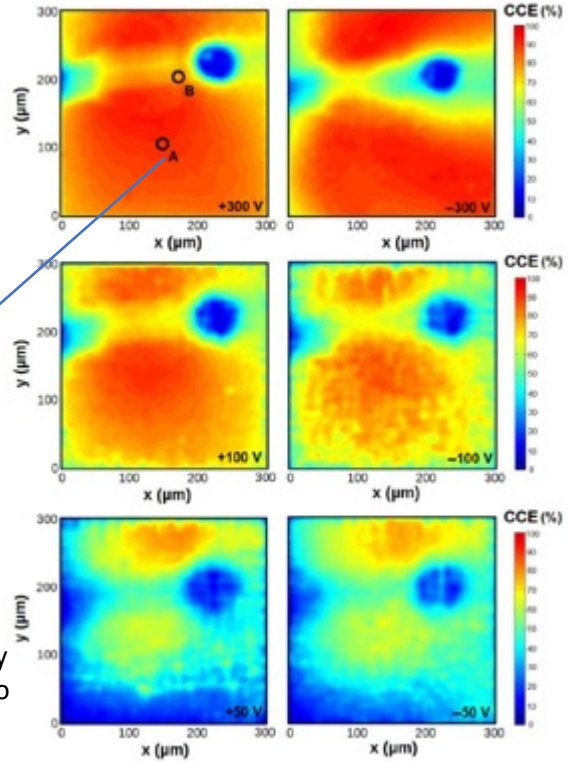
IAEA
Facilitating Experiments with Ion Beam Accelerators (CRP)

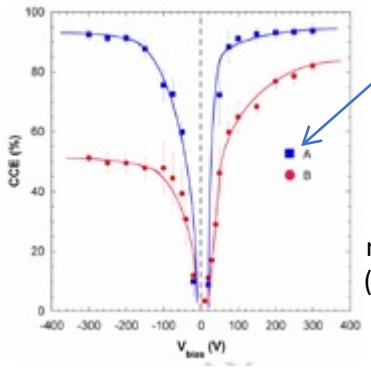
Non-European applications accepted, but difficulties for US



IBIC capabilities – deep & shallow probing



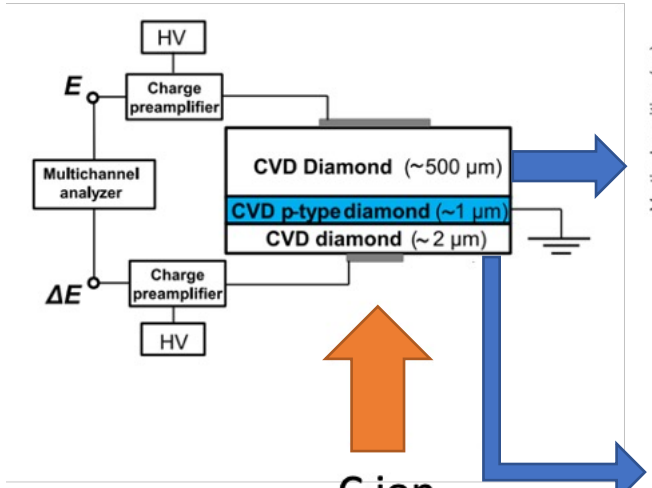


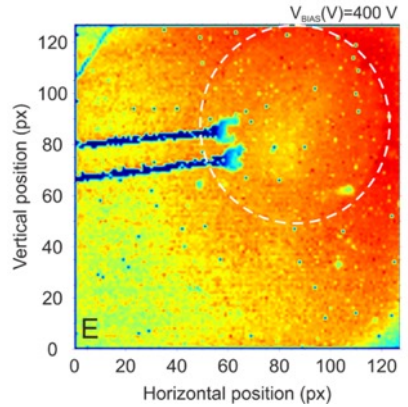


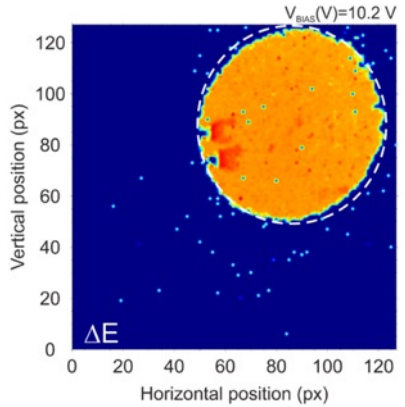
Average CCE measured far away (A) and close (B) to the pillar

AIDA-2020-RBI-2017-2

Buried graphite pillars in 3D CVD diamond, G. Conte, INFN



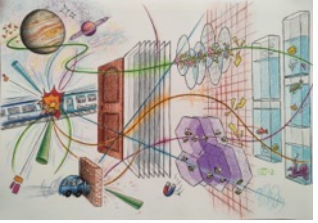




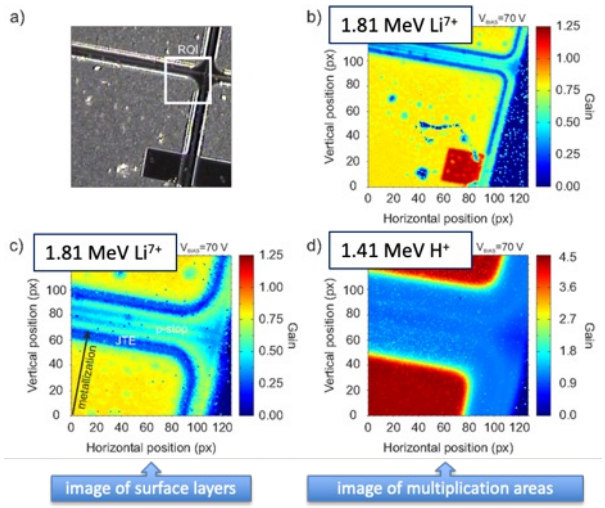
- 2.8 µm - 6.0 MeV C^{3+},
- 4.8 µm - 10.7 MeV C^{4+}
- 7.7 µm - 16.7 MeV C^{5+}
- 12.0 µm - 24.0 MeV C^{6+}

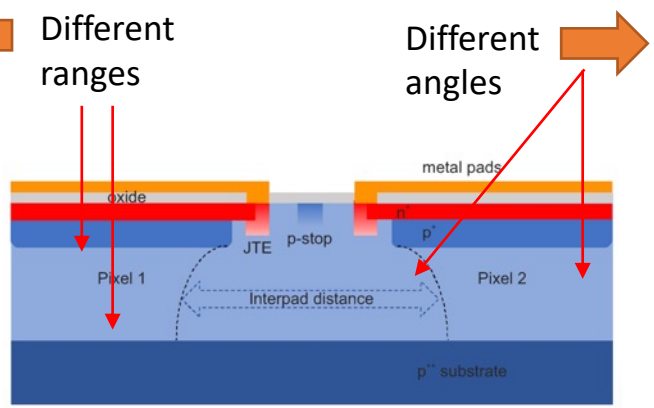
RADIATE, June 2021

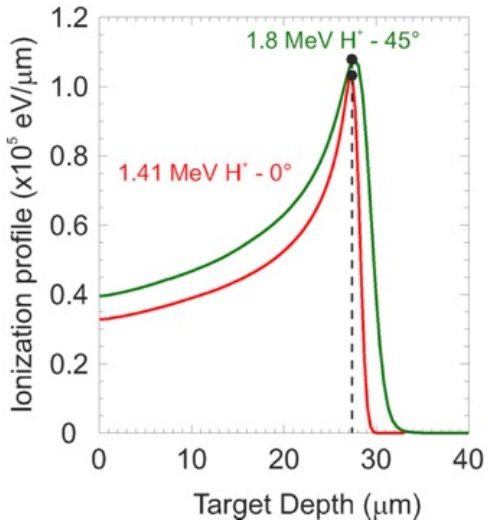
Characterisation of *Δ*E – E single diamond crystal telescope, C. Verona, University of Rome Tor Vergata

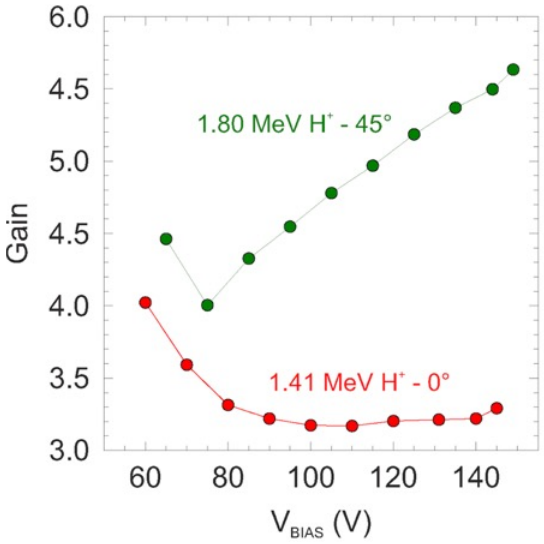


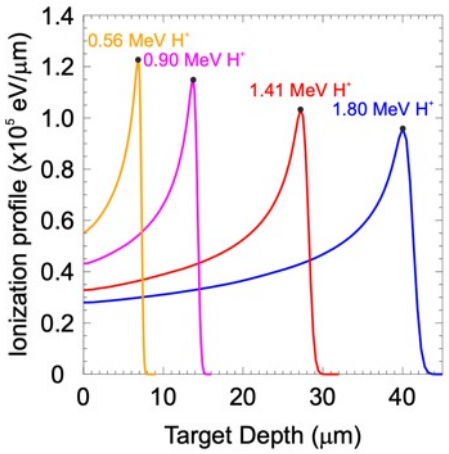
IBIC – importance of ionization profile example of LGAD

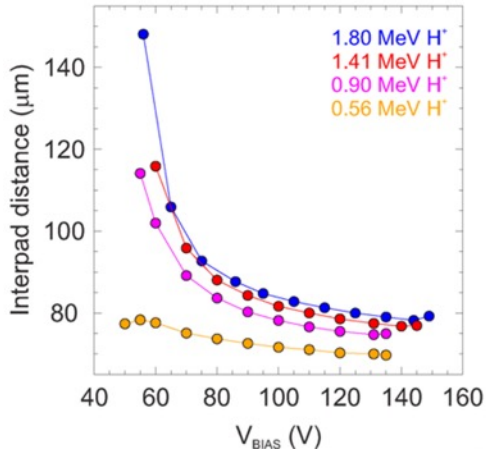








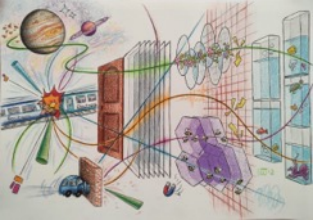




IAEA funded CRP (Coordinated Research Project)

G. Medin (Montenegro) and **G. Kramberger** (Ljubljana)

- **Interpad distance** as a function of proton energy
- Different ions & different angles result in different **gain supression** due to changes in charge cloud density in multiplication layer
- Surface layers thicknesses



In air IBIC (& SEE); providing a trigger

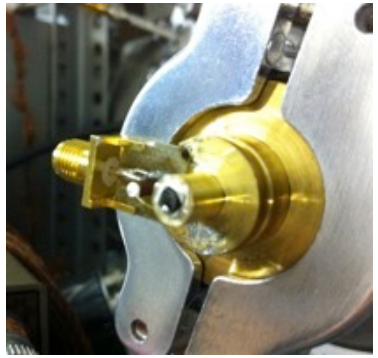
AIDA-2020-RBI-2018-1
Single event effects in CMS pixel module
Token Bit Manager Chip
Wolfram Erdemann, PSI, Switzerland

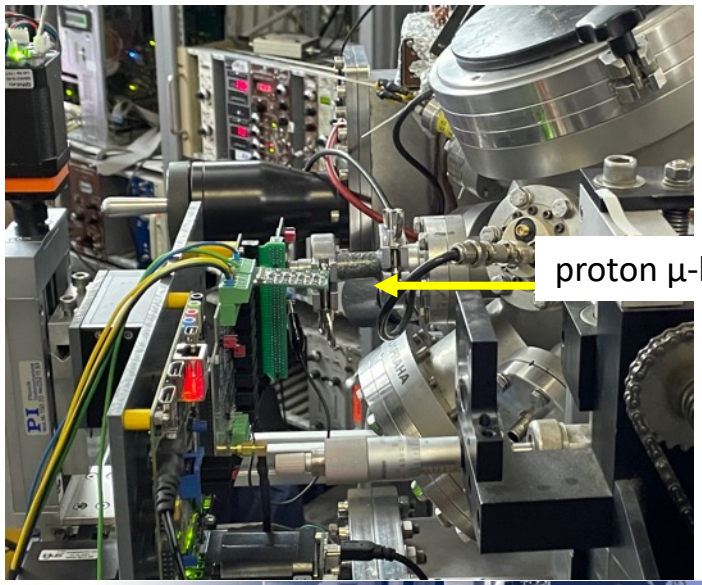
RADIATE – June 2021
Response of **monolytic pixel detectors** for RD50 collaboration
Rogelio Pinto, Uni. Seville, Spain

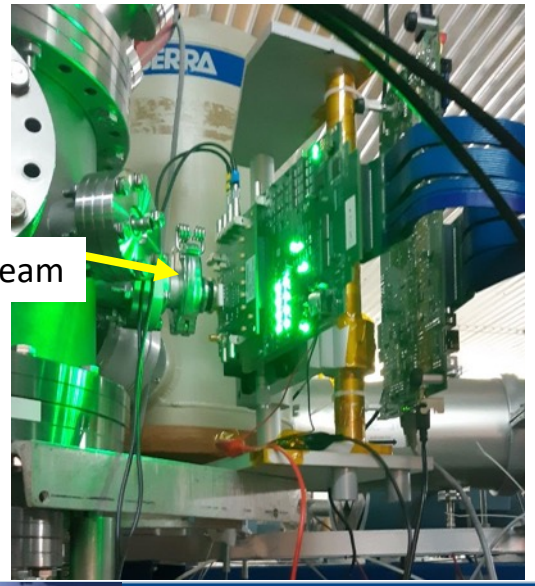
RADIATE – March 2023
Impact of HIPs on an **HV-CMOS** counting detector
Alexander Dierlamm, Karlsruhe, Germany

Energy / air path	100 nm Si_3N_4	6 µm diamond
3 MeV / 0.5 mm	1.0 µm	9.0 µm
6 MeV / 0.5 mm	0.5 µm	4.3 µm
9 MeV / 0.5mm	0.3 µm	2.9 µm

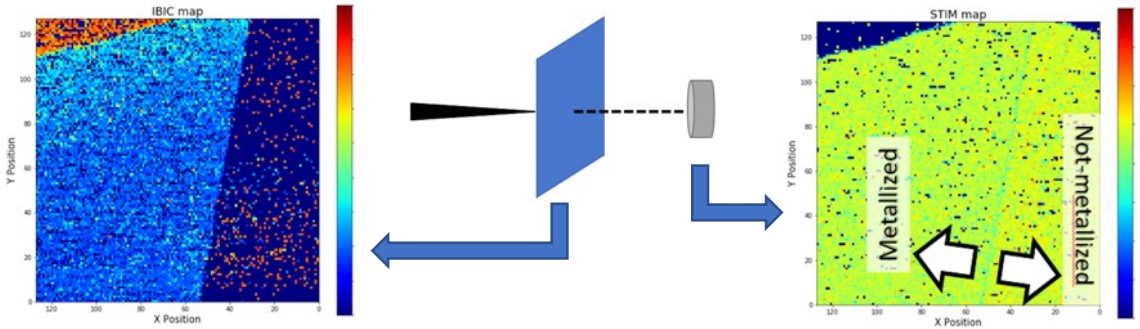
Proton microbeam spread due to scattering in SiN exit foil or **diamond membrane detector** after 0.5 mm of air



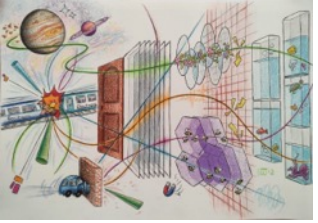




EUROLABS – March 2023
Applications of **SiC membrane** detectors
Massimo Camrada - STlab

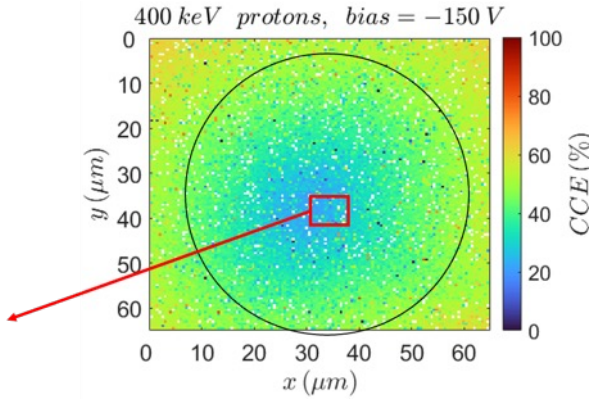


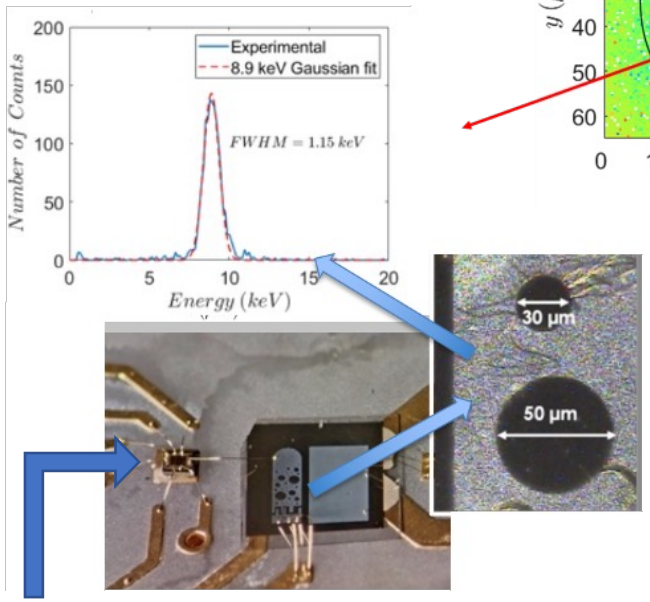
500 nm SiC membrane detector that provides a trigger !!



RBI projects - low noise electronics

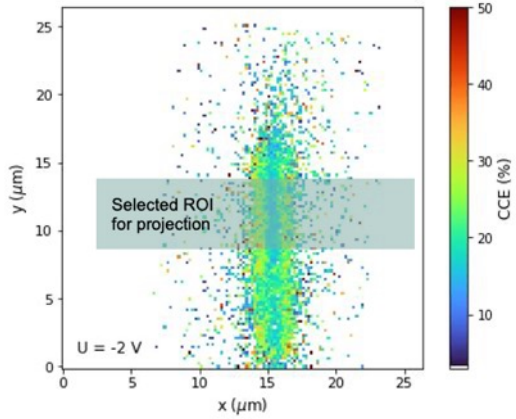
Deterministic ion implantation in diamond!!
e.g. NV centers



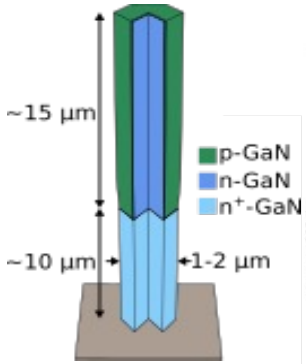


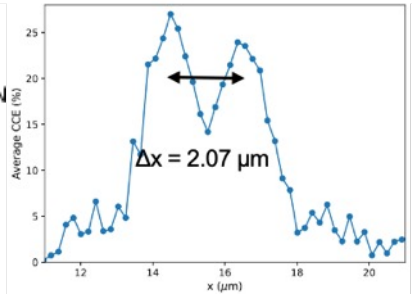
Low noise charge sensitive preamp (XGLab CUBE PRE031) enables detection of signals > **1 keV in diamond** !!!
(**M. Vićentijević et al. RBI**)

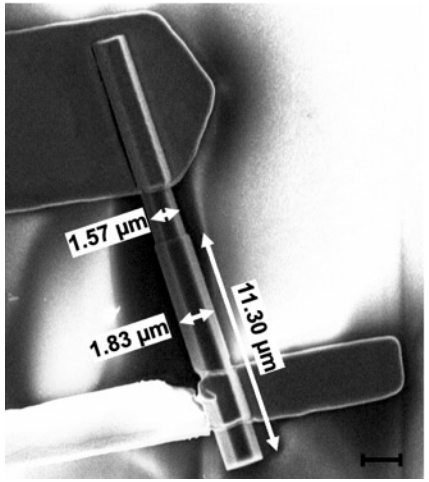
GaN microwire detectors (for dosimetry)
D. Verheij et al. IST Portugal & RBI
1 MeV Si ions of 0.3 μm resolution



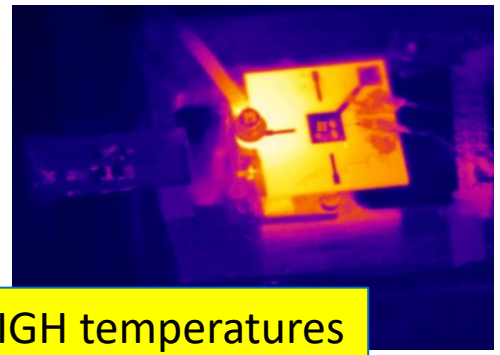
The IBIC signal is only detected in the core-shell region of the microwire







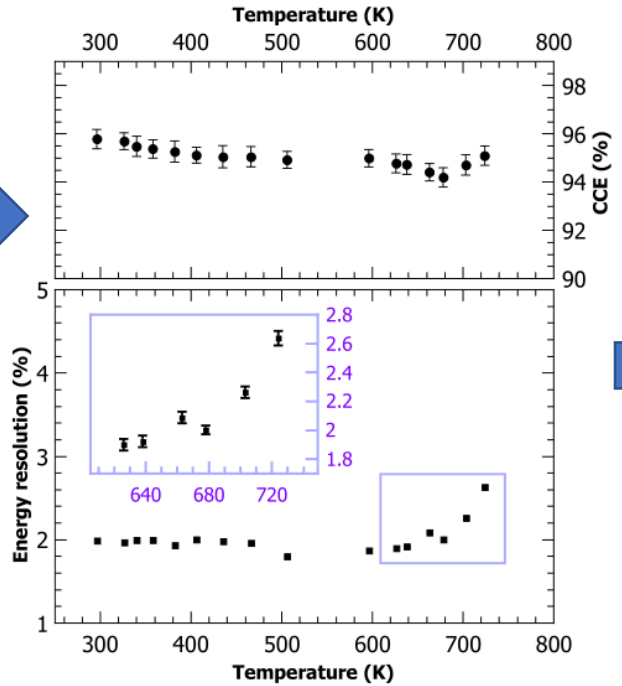
High/low temp. + time resolved IBIC

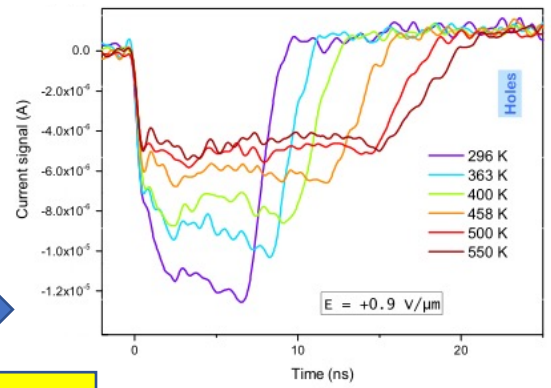


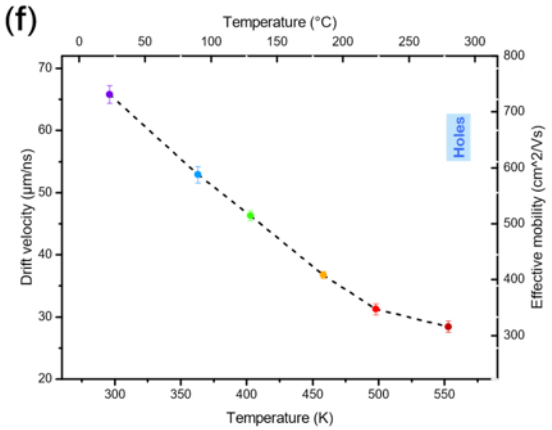
HIGH temperatures

Resistive heating of detectors up to 450 C (diamond)

(A. Crnjac et al. RBI)

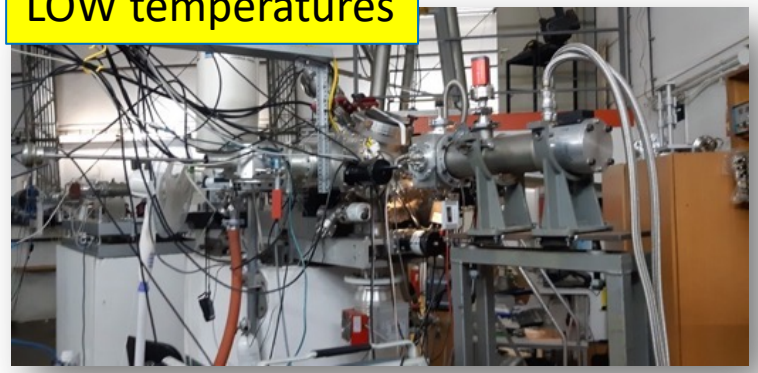


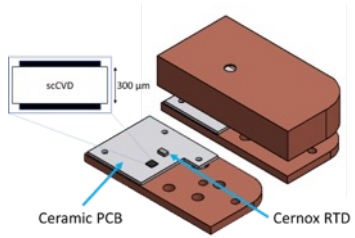




Ion-TCT provides direct evidence of charge carriers mobility vs. temperature

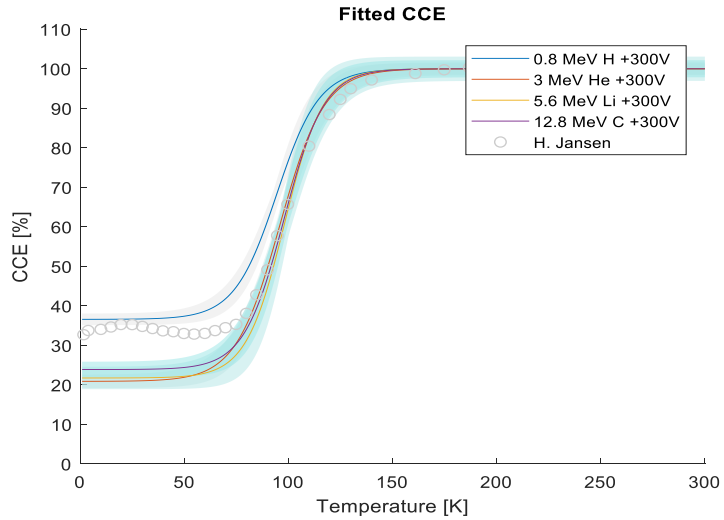
LOW temperatures





Cryo cooler (down to 40 K) for CCE studies in diamond **(D.D. Cosic et al. RBI)**

Decrease of efficiency for diamond at T<100 K !!

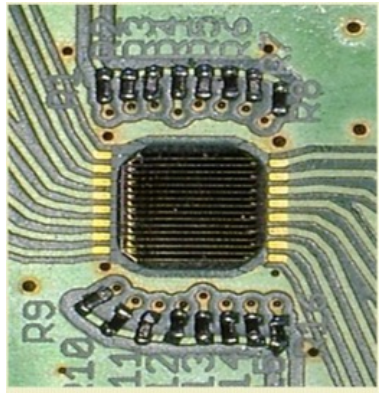


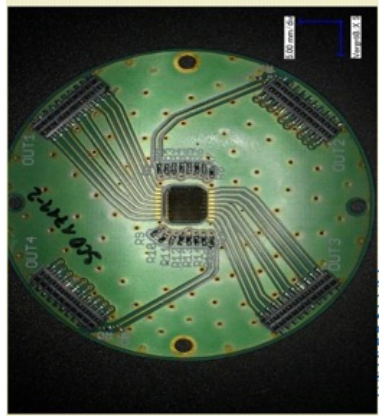
Radiation hardness – irradiation by protons

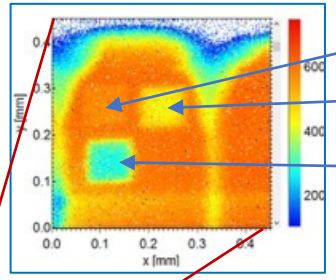
AIDA-2020-RBI-2015-1

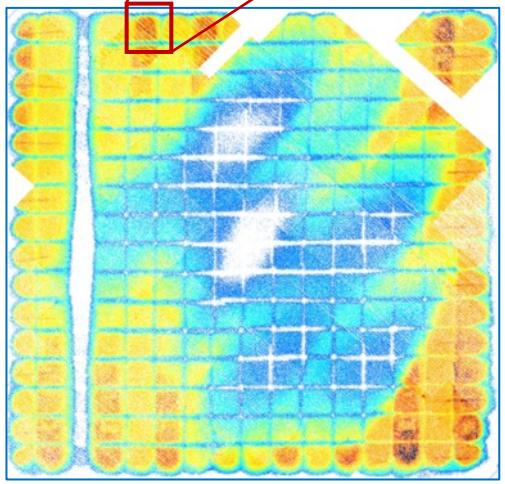
Radiation damage in scCVD diamond material irradiated with relativistic Au beams at HADES

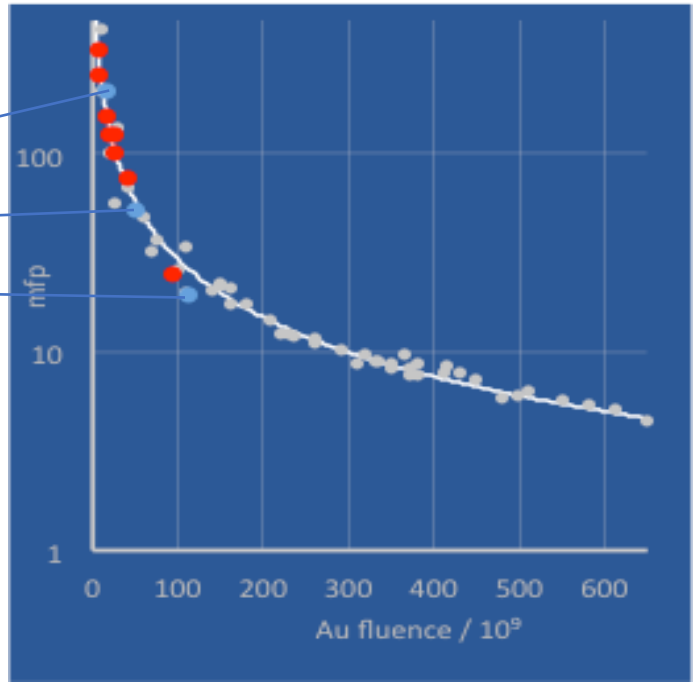
Jerzy Pietraszko, GSI Darmstadt, Germany



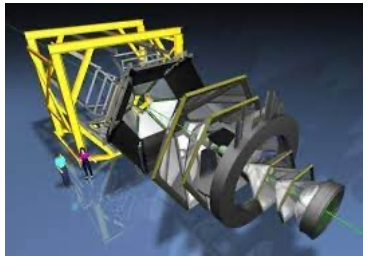




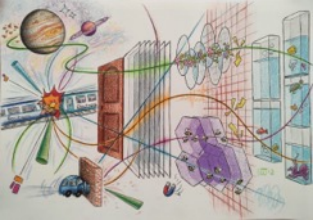




HADES experiment at GSI

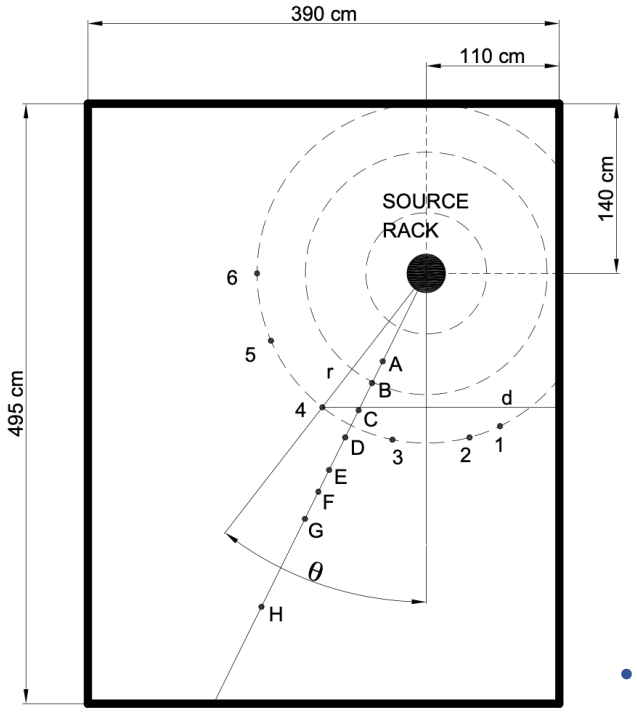


- Comparison of CCE degradation in pixels by fluence !
- Number of vacancies for protons extrapolated: Au / $p_{4.5MeV}$ / p_{24GeV} = 2430 / 30 / 1

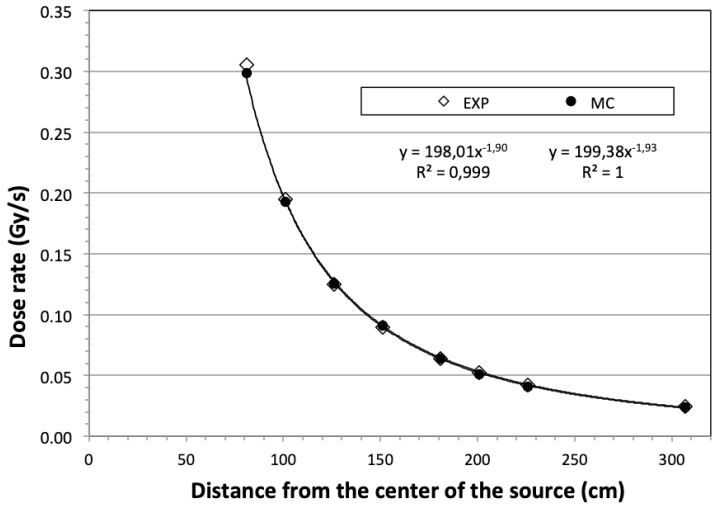


Radiation hardness – irradiation by Co-60 gammas

Operated by Radiation Chemistry & Dosimetry Lab (Ž. Knežević & M. Mayer)
+ Experimental Physics Division (A. Satrodumov, others…)



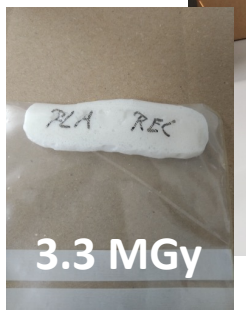
Irradiation room



- Panoramic Co-60 1.17 and 1.33 MeV gamma source, 24 pencils, total activity 1.2 PBq
- Dose rate: center of the source **1.6 MRad/h**
- **Need to substitute 50% of Co60 in coming years (~€0.5M)**

Irradiation experience in 2018-2022

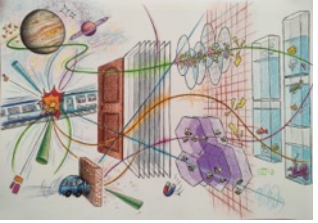
- CMS pixel readout chips and modules;
- different types of 3D printer filaments (1);
- various silicon and epoxy glues ;
- diodes with temperature control (2);
- powered DMAPs diodes (3)



(1)

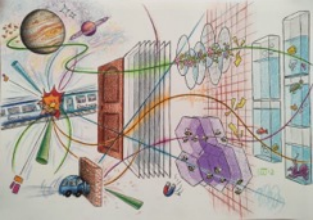
(2)

(3)



Possible benefits of DRD3

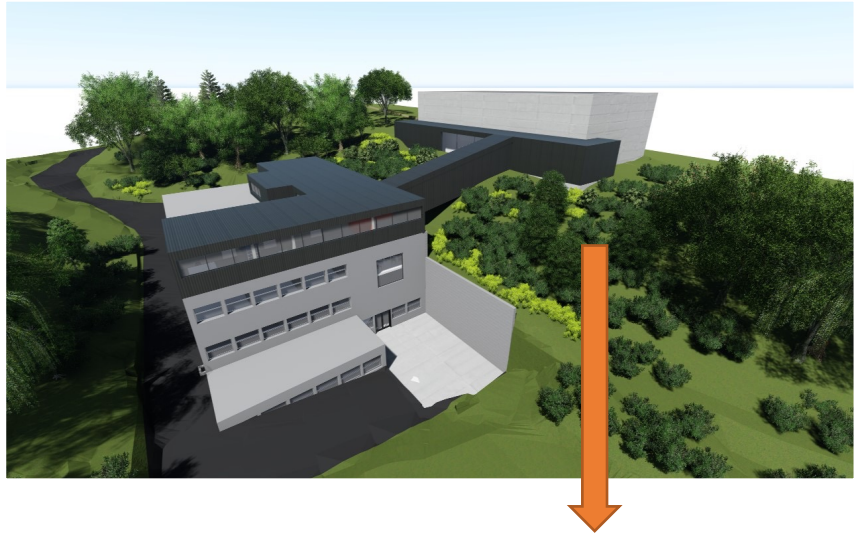
- To enable easier access to detector characterisation facilities (incl. IBIC @ RBI) to non-European researcher teams
- Training visitors to detector characterisation infrastructure to increase awareness of technique capability
- Training visitors from infrastructure to research teams developing detectors to increase knowledge about the most important problems and needs of the community
- Gathering complementary research groups that can benefit from collaboration
- Redefining priorities of detector characterisation technique, according to the needs
- Else?

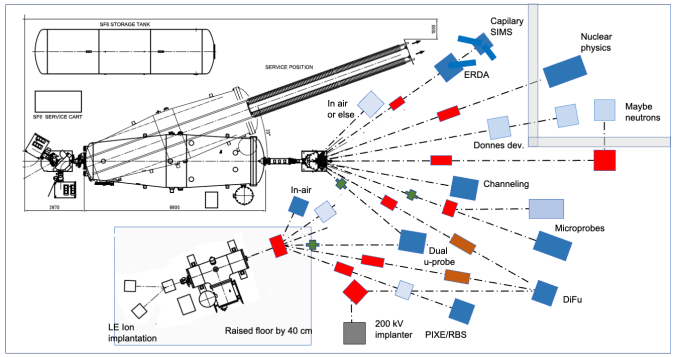


Conclusions

New developments / milestones

- Dual microprobe – simultaneous damaging and probing
- In-air IBIC capabilities (detector handling, inert atmosphere, DAQs,…)
- Diamond detector based devices / extreme fluences & temperatures / thin membranes for trigger (&SiC)
- New 5.0 MV accelerator and hall in 2025.





Blue sky research:

- ✓ Low noise IBIC system applications: single ion implantation - NV centers
- ✓ New detector materials and devices (microscopic sensors, position sens...)
- ✓ …