RBI accelerator facility:

Capabilities of testing detectors for high energy physics by MeV energy ions

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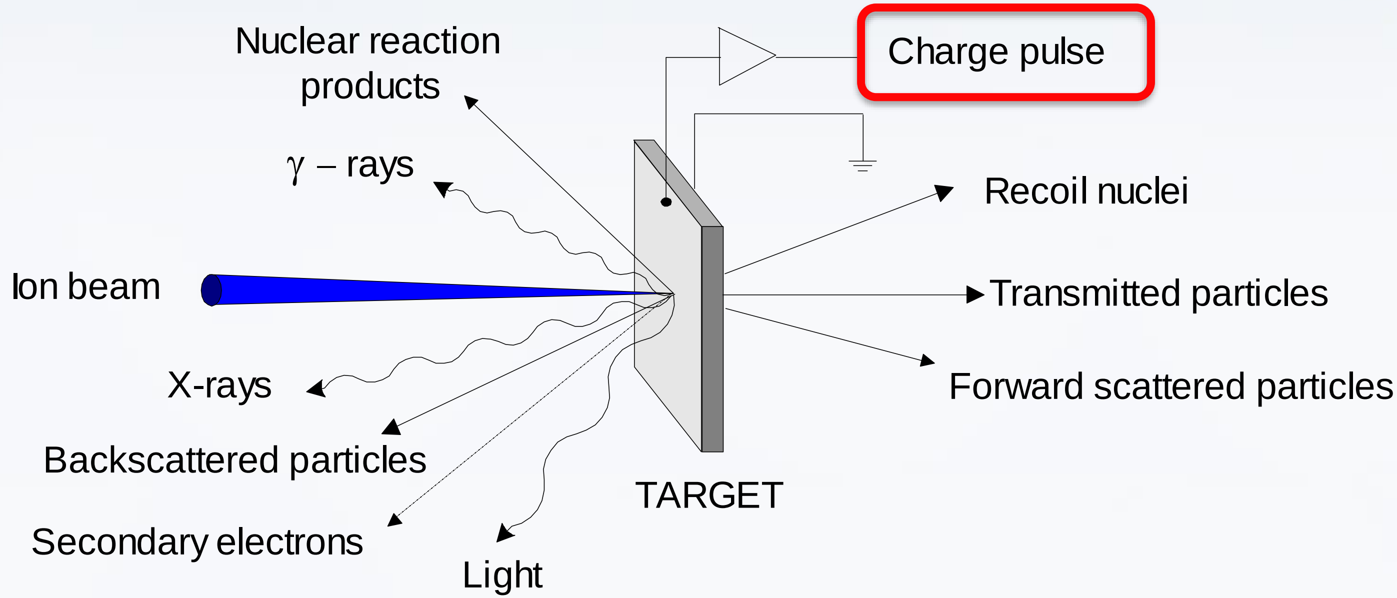
Outline:

- Laboratory for ion beam interactions
- Facility & research areas
- About the IBIC technique
- Capabilities relevant to h.e. physics
- Funding and Transnational Access

Laboratory for ion beam interactions - applications

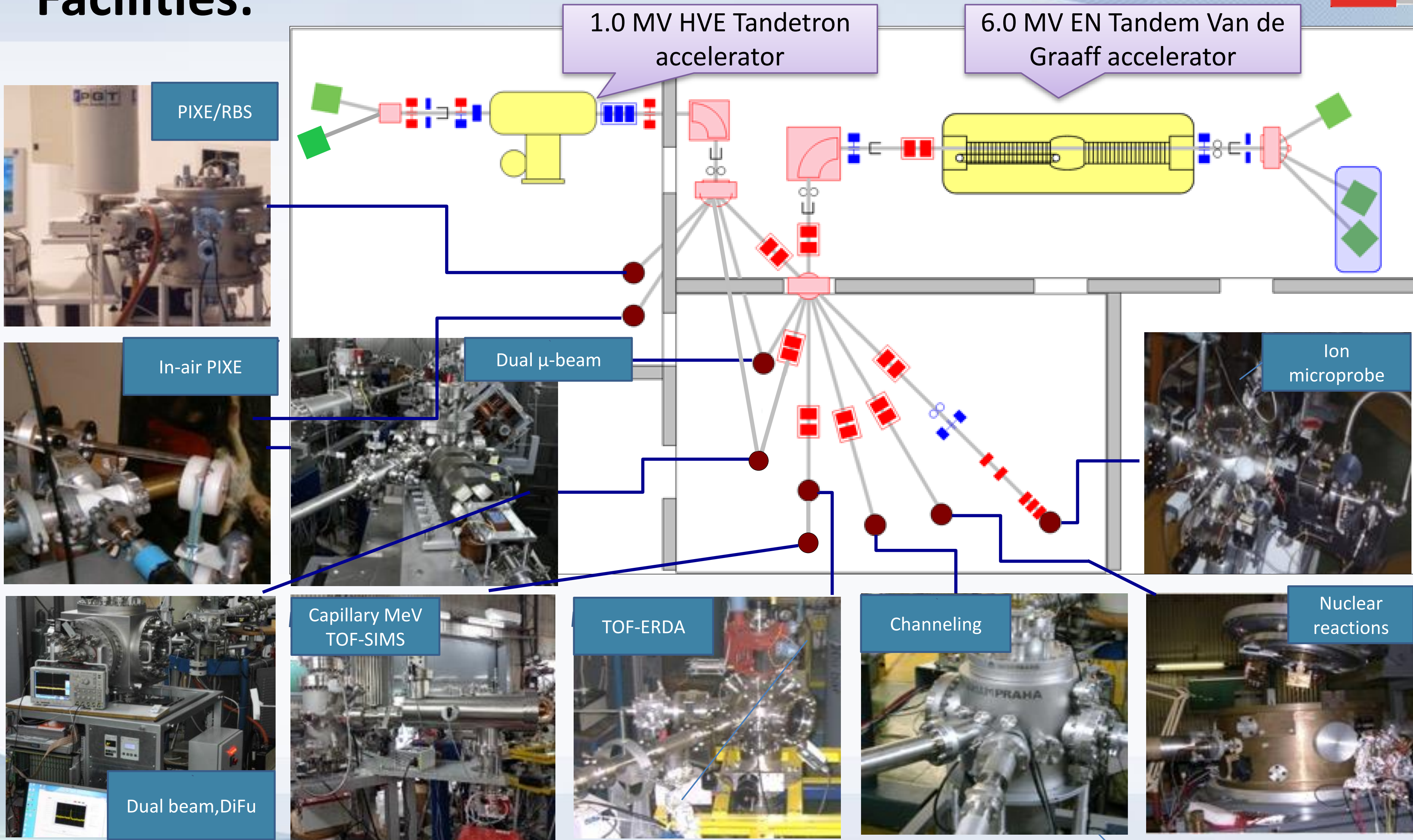


ANALYSIS (elements, isotopes) with **MeV ION BEAMS** - (nA, pA)
- elements - x-rays (**PIXE**)
  - backscattering (**RBS**)
  - recoil (**ERDA**)
- isotopes - nuclear reactions
  - γ - rays (**PIGE**)
  - particles (**NRA**)

CHARACTERISATION (density, charge transport, crystal structure, morphology,…) with **MeV SINGLE IONS** - (fA)

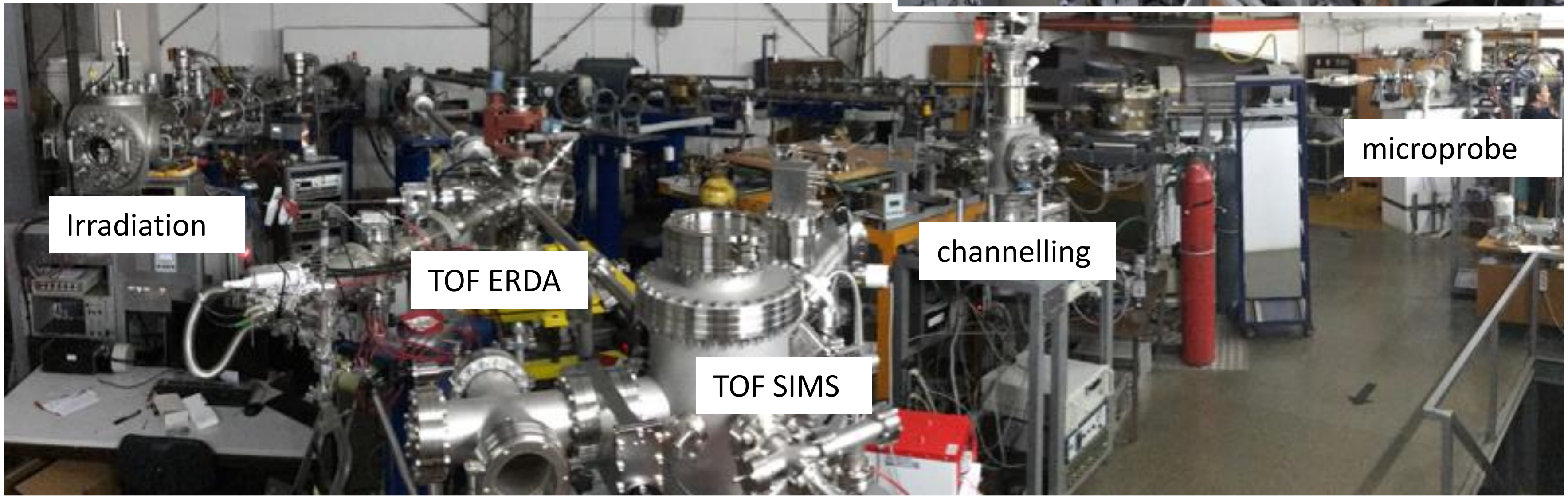
- density - transmitted ions (**STIM**)
- charge transport - charge pulse (**IBIC**)
- crystal structure - **channelling**
- morphology - secondary electrons (**SEI**)

Facilities:


1.0 MV HVE Tandetron accelerator
6.0 MV EN Tandem Van de Graaff accelerator
PIXE/RBS
In-air PIXE
Dual µ-beam
Ion microprobe
Dual beam,DiFu
Capillary MeV TOF-SIMS
TOF-ERDA
Channeling
Nuclear reactions

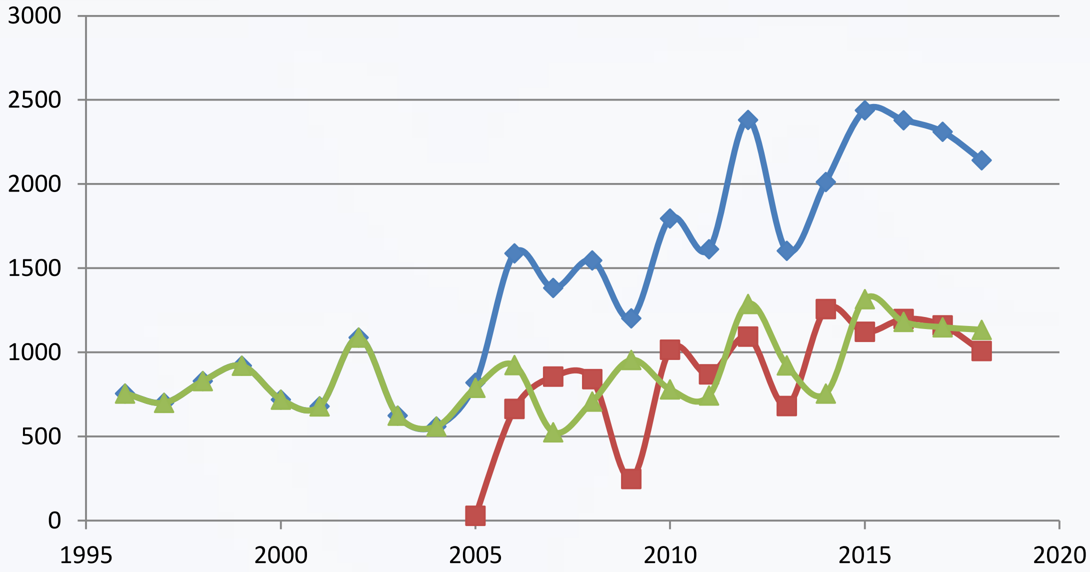
Laboratory for ion beam interactions - strategy

- Installation of all 'classical / routine' analysis and irradiation techniques !
- Expansion with unique capabilities: e.g dual beam irradiation (fusion materials); sensitive TOF techniques (SIMS – molecules; ERDA – isotopes); single ions for detector characterisation (IBIC); etc.



Facility users:

Beam time (on target):



European Union
European Regional Development Fund

CERIC
Central European Research Infrastructure Consortium

AIDA 2020

EUROfusion

CEMS
Center of Excellence for Advanced Materials and Sensing Devices

RADIATE

IAEA
International Atomic Energy Agency

IAEA/RBI agreement

New Tandetron accelerator

SPIRIT FP7

AIDA 2020

RADIATE H2020

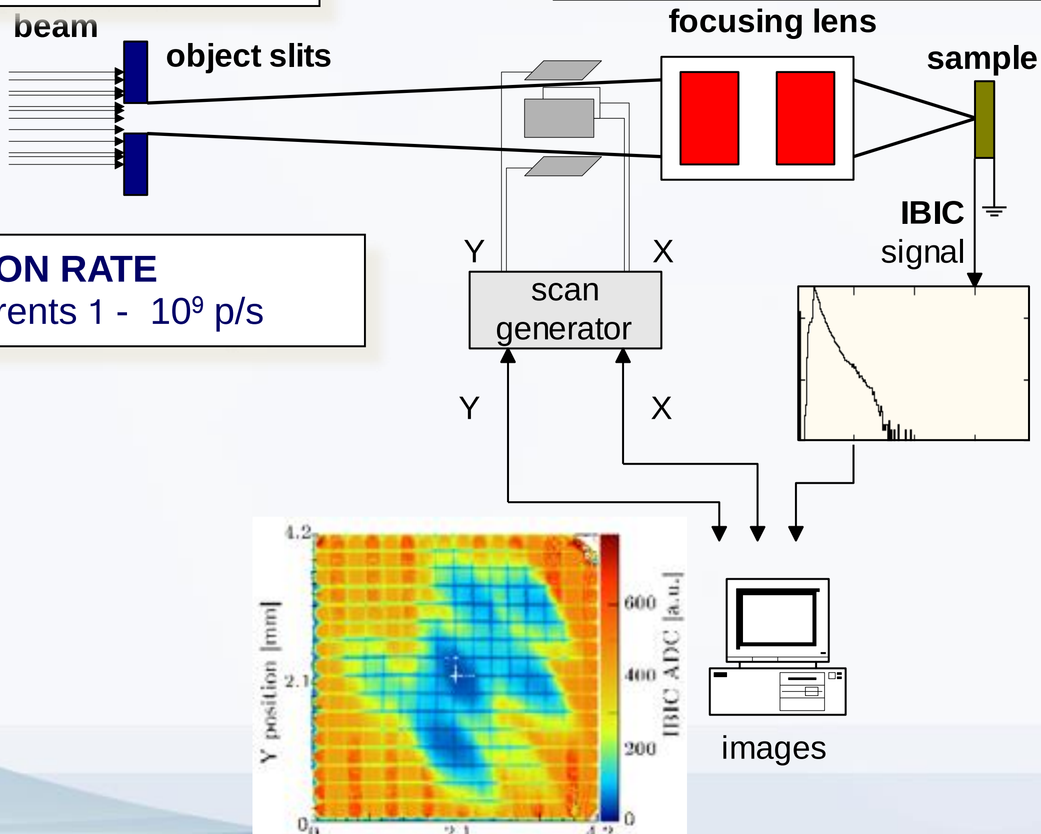
Ion microprobe – ideal radiation source for detector testing!

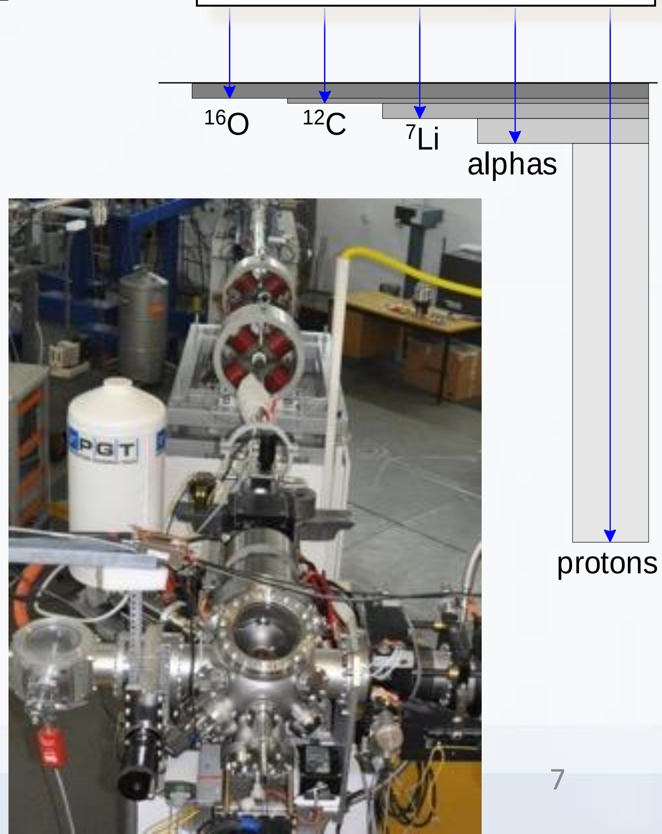
❶ IONS
- p, α, Li, C, O,..

❷ ION RATE
- Currents 1 - 10^9 p/s

❸ RANGE (E)
- from 1 to 500 μm

❹ ION POSITION
- focusing and scanning



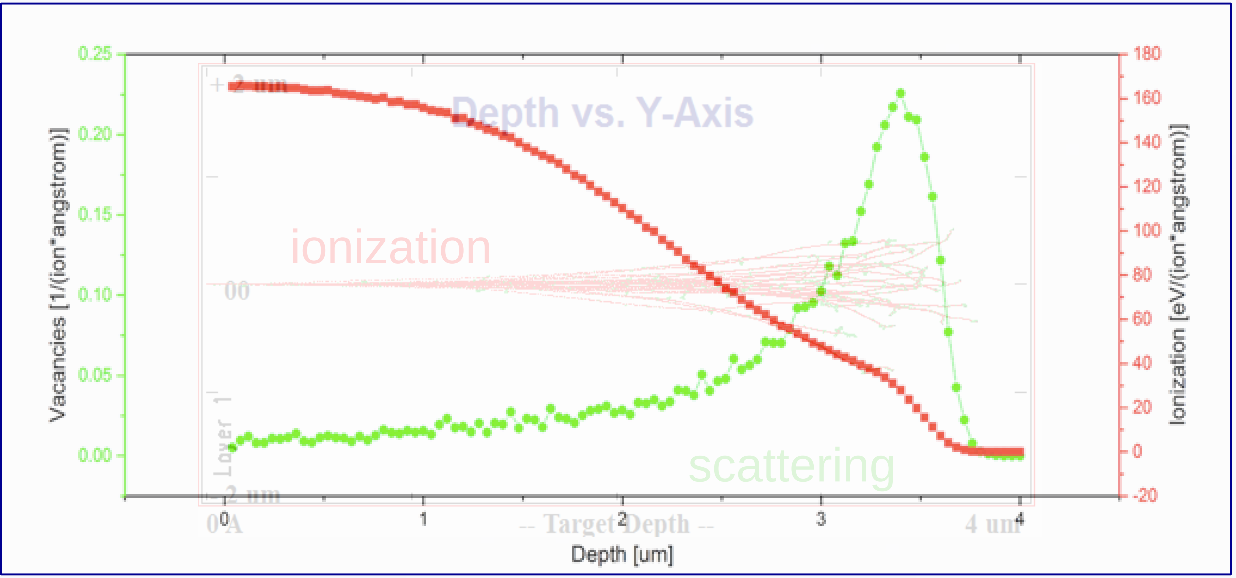


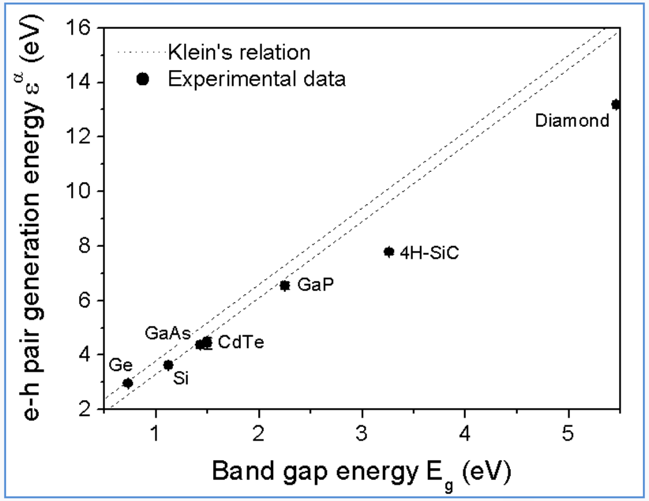
Single MeV ions – interactions with matter

a) ionisation along the ion trajectory $(dE/dx)_{el}$ → charge pairs

b) scattering on atomic nuclei $(dE/dx)_{nucl.}$ → defects

c) implantation at the end of the range → defects





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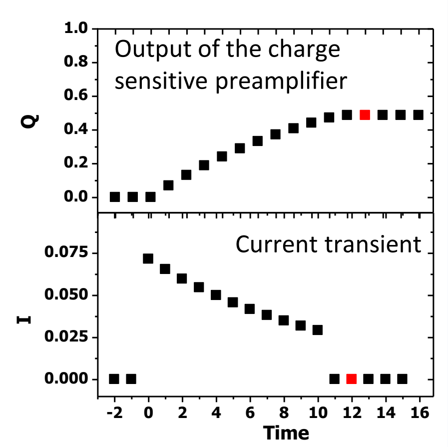
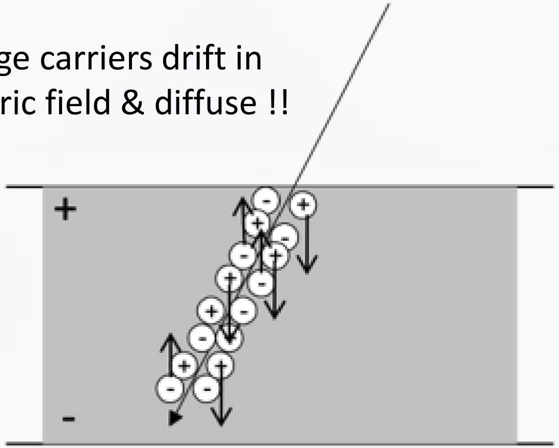
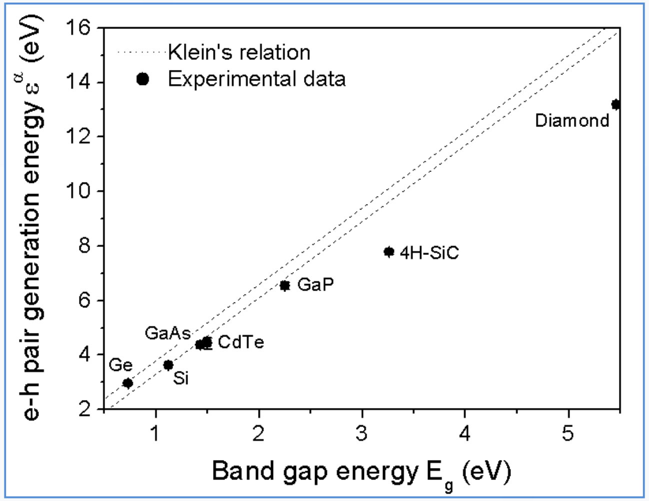


Charge carriers drift in electric field & diffuse !!

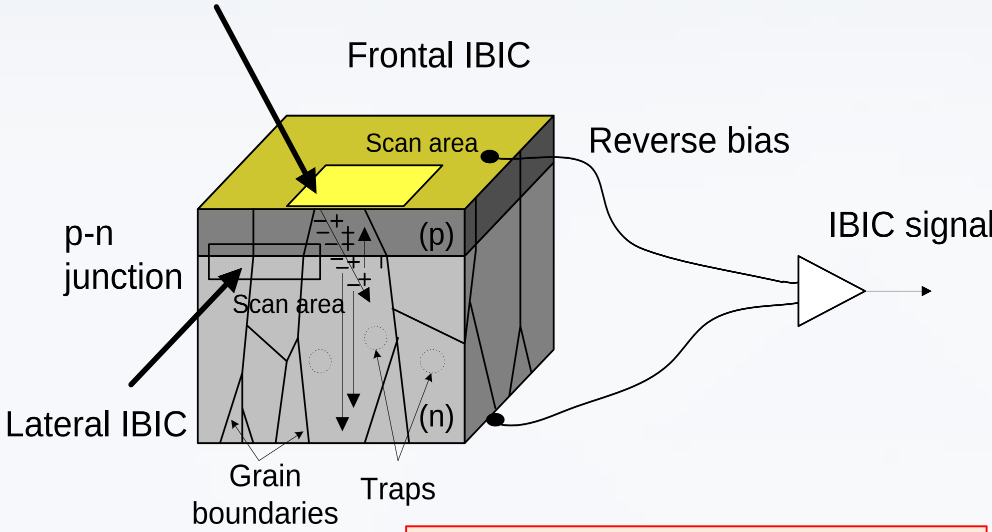


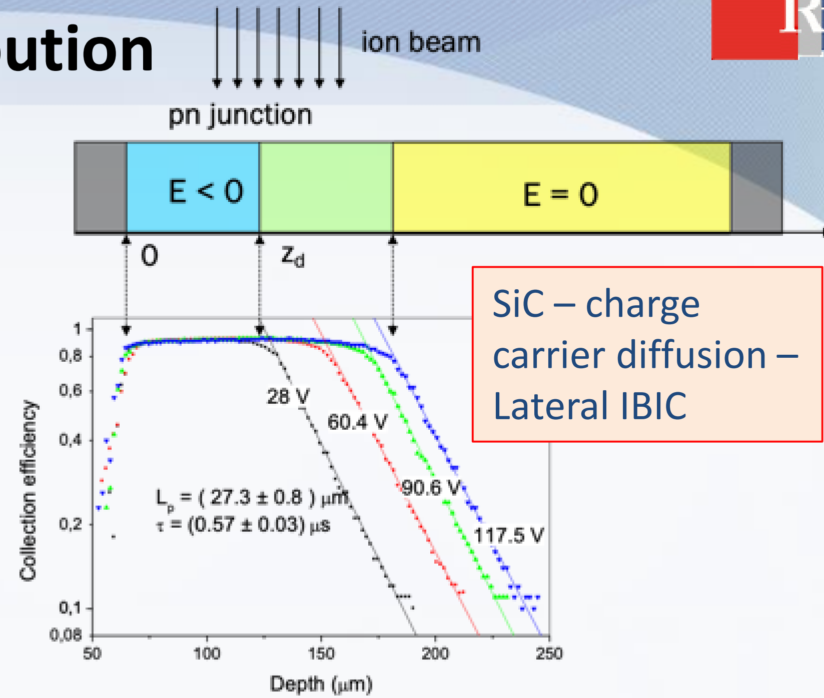


Charge / current signal height depends on:
- E (el. field)
- charge carrier mobility (μ) & lifetime (τ)

→ Ion Beam Induced Charge (IBIC)

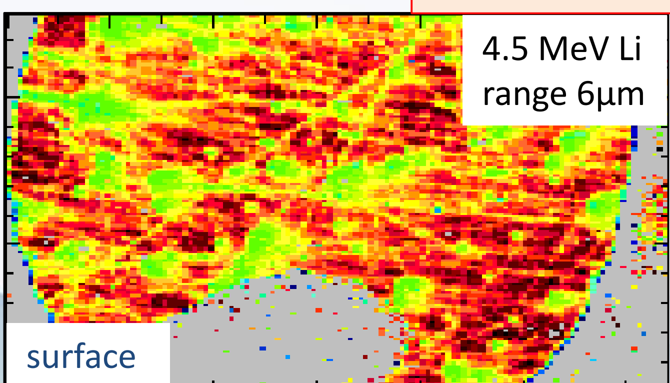
Charge collection efficiency distribution

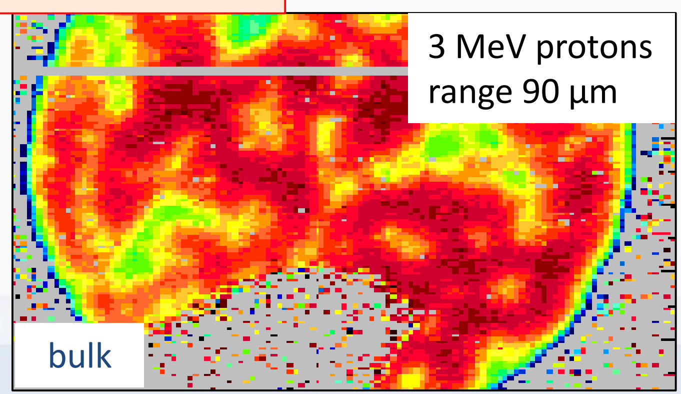




SiC – charge carrier diffusion – Lateral IBIC

Si Schottky diode – Frontal IBIC





IBIC capabilities (some were developed for AIDA2020 users)

AIDA 2020

Advanced European Infrastructures for Detectors at Accelerators

Home | Project | Activities | Transnational Access | Events | Results | AIDA | Contact

Apply for AIDA-2020 Transnational Access here!

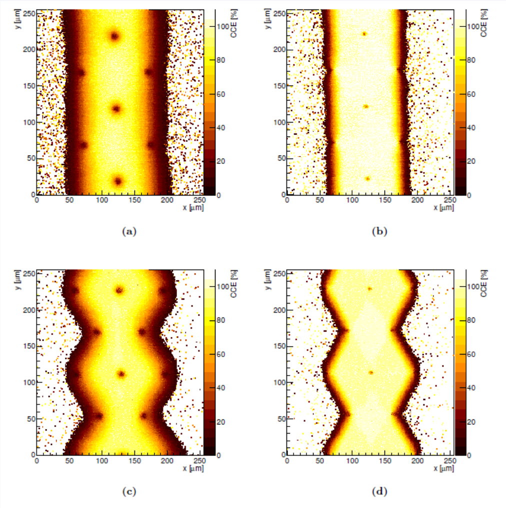
The AIDA-2020 **Transnational Access** (TA) programme includes key facilities for beam tests (CERN,DESY), irradiations (UCLouvain, KIT, JSI, UoB, CERN: IRRAD & GIF++) and detector characterisation (RBI, ITAINNOVA).

18 AIDA experiments at RBI (2015-2019)

partial list:

- **AIDA-2020-RBI-2015-1**, Systematic study of radiation damage in scCVD diamond material irradiated with relativistic Au beams, Jerzy Pietraszko, GSI Darmstadt, HADES, **Germany (26-30.10.2015.)**
- **AIDA-2020-RBI-2015-3**, Investigation of channeling depth profiles of high energy carbon and silicon ions implanted in diamond and SiC crystals for detector characterization, Michael Kokkoris, National Technical University of Athens, **Greece (23-27.11.2015.)**
- **AIDA-2020-RBI-2015-2**, Diamond Membranes for Radioisotope Batteries BATDiαm, Michal Pomorski, CEA, LIST, **France (15-19.2.2016.)**
- **AIDA-2020-RBI-2015-4**, 3D diamond, Alexander Oh, University of Manchester, **UK (11-15.4.2016.)**
- **AIDA-2020-RBI-2016-1**, IBIC characterization of single crystal diamond based Shottky diodes for microdosimetry application, Claudio Verona, 'Tor Vergata' University, **Italy (24-28.10.2016).**
- **AIDA-2020-RBI-2016-2**, Microbeam tests of silicon telescope for clynical dosimetry, G. Magrin, Austron, **Austria (18-20.1. and 9-10.2.2017.)**
- **AIDA-2020-RBI-2016-3,** Investigation of channeling depth profiles of high energy carbon and silicon ions implanted in SiC /Si crystals for detector characterization, University of Athens, **Greece (30.1.-3.2. 2017.)**
- **AIDA-2020-RBI-2017-1:** Diamond Membrane Microdosimeter, M. Pomorski, CEA, **France (2-5.5.2017.)**
- **AIDA-2020-RBI-2017-4:** Characterization of a large area CVDdiamond TimeofFlight detector with interdigitated electrodes for energyloss measurements of lowenergy ions in laserinduced plasmas , W. Cayzac, CMLA, ENS Paris, Saclay, **France (6-10.11.2017)**
- **AIDA-2020-RBI-2017-5:** Polycrystalline 3D Diamond IBIC and TRIBIC characterisation, A. Oh, Univ Manchester, **UK (27.11.-2.12.2017).**
- **AIDA-2020-RBI-2017-3:** Study of channeling depth profiles of high energy silicon ions implanted in diamond and silicon crystals at various fluences for detector characterization, S. Petrovic, Vinča, **Serbia (12-16.2.2018).**
- **AIDA-2020-RBI-2017-2:** Analysis of micrometer and millimeter-long graphite pillars buried in sc-CVD diamond , G. Conte, Roma Tre University, Rome, **Italy** (**12-14.9.2017. and 20-21.3.2018**)
- **AIDA-2020-RBI-2018-1:** Single event upsets in CMS pixel ROC, Wolfram Erdmann, PSI **Switzerland (2.7.-6.7.2018).**
- **AIDA-2020-RBI-2019-1:** IBIC of monolytic pixel detectors, Rogelio Pinto, University of Sevilla, **Spain (19.8.-23.8.2019).**

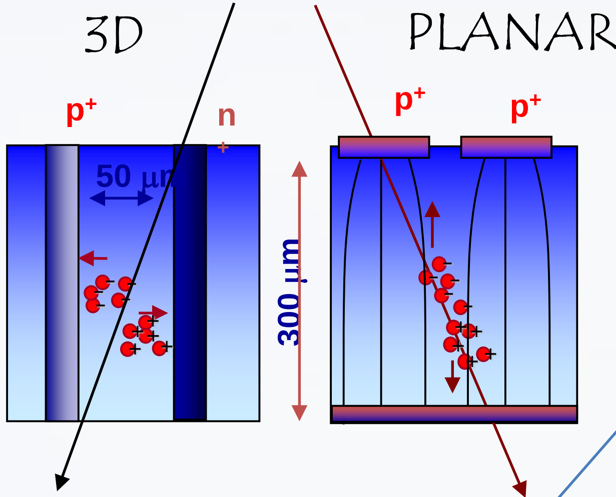
Microscopic CCE imaging of 3D detectors

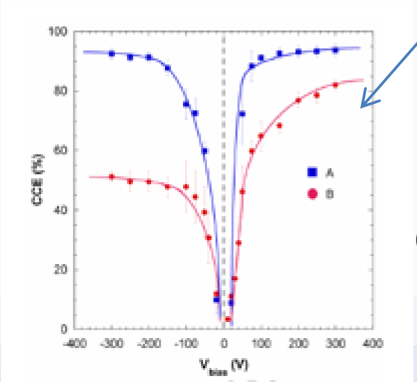


CCE maps for different biases and geometries

AIDA-2020-RBI-2015-4 and AIDA-2020-RBI-2017-5

3D diamond, Alexander Oh, University of Manchester, UK

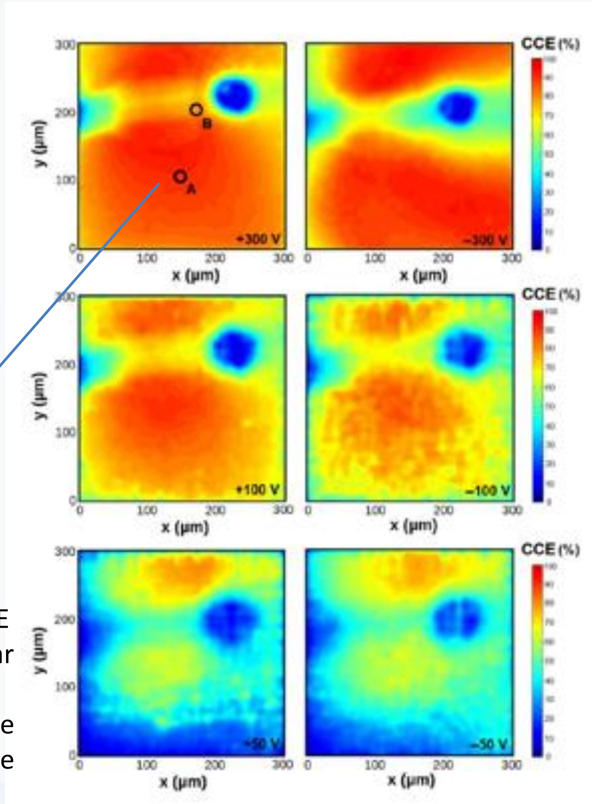




Average CCE measured far away (A) and close (B) to the pillar

AIDA-2020-RBI-2017-2

buried graphite pillars in CVD diamond, G. Conte, INFN, Italy

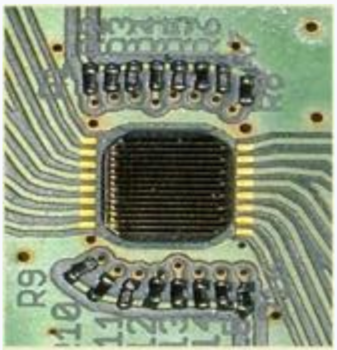


IBIC map in case of front-side irradiation at different bias voltages.

Studies of radiation hardness: Irradiation / probing concept

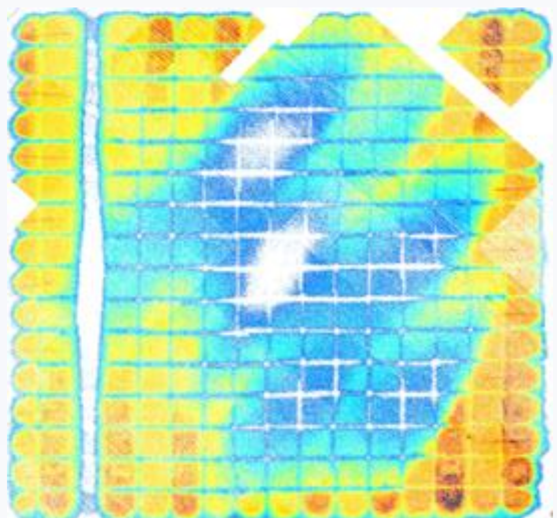
Typical experiment:

- protons of sufficient energy induce homogeneous (in depth) damage in small detector area (here 4.5 MeV protons)
- Ions that are stopped in detector probe changes in CCE (here 2 MeV protons)



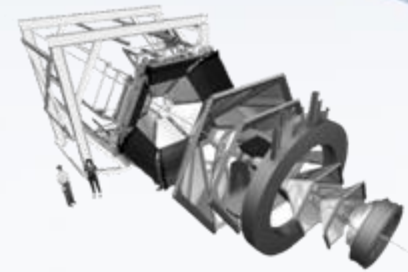
AIDA-2020-RBI-2015-1

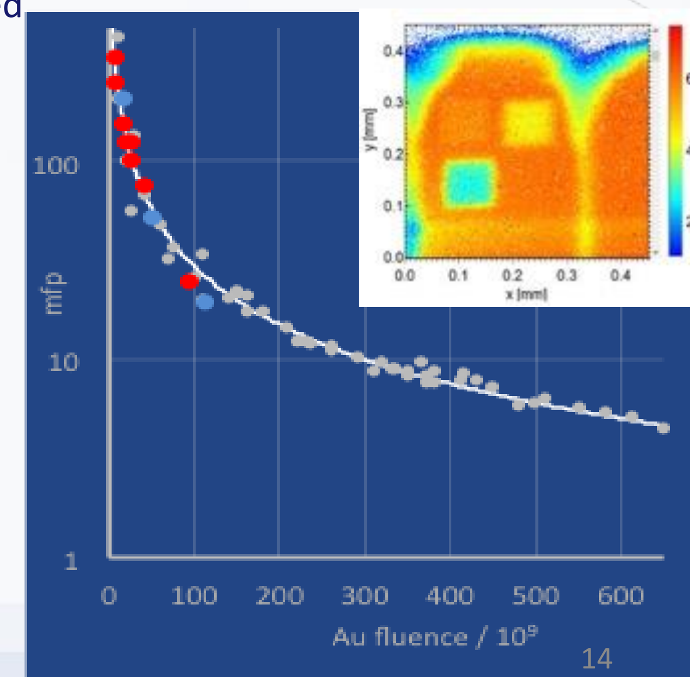
Radiation damage in scCVD diamond irradiated with Au beams, J. Pietraszko, GSI - HADES



Number of traps:

Au / $p_{4.5MeV}$ / p_{24GeV} = 1 / 30 / 2430

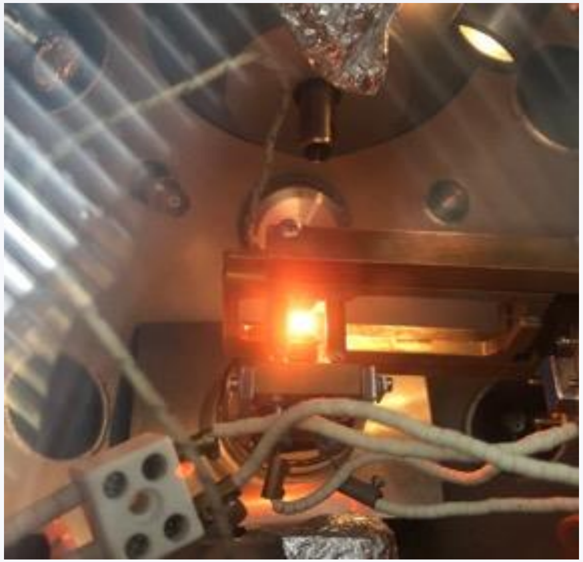


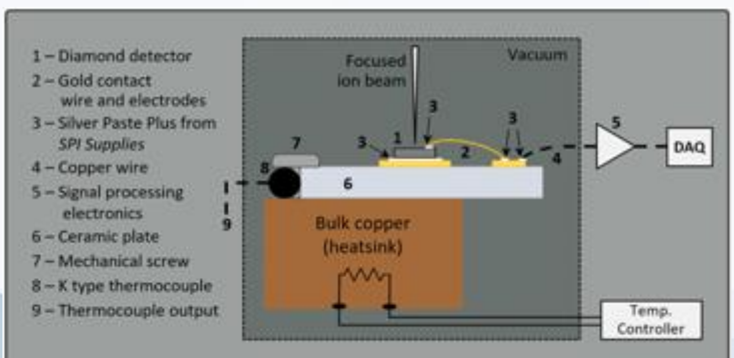


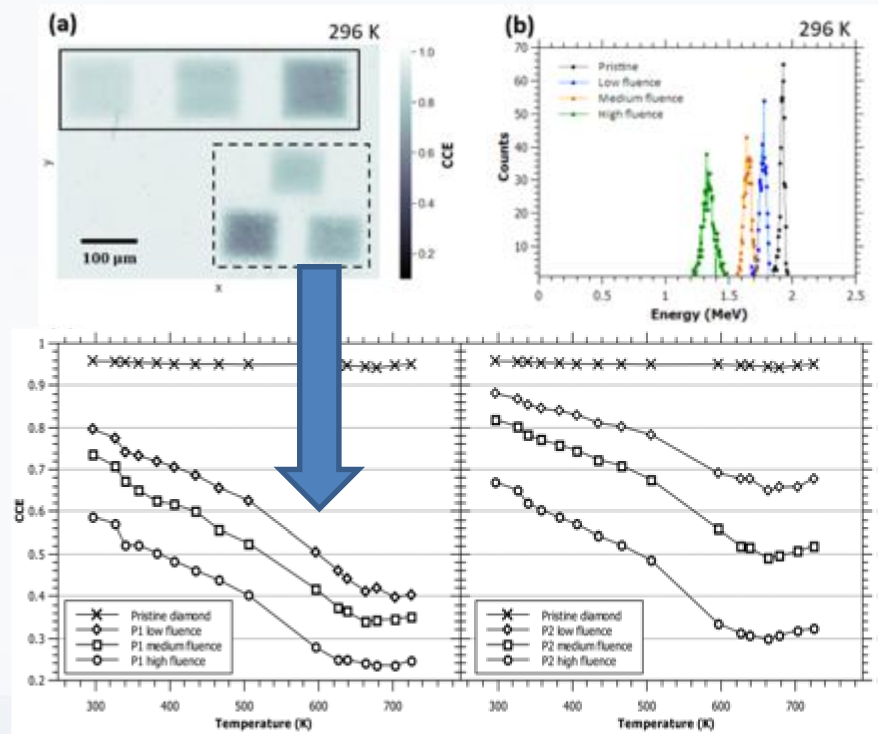
IBIC at high temperatures (up to 450 C) !!

scCVD diamond detector in the range 300-750K:

- Spectroscopic properties maintained (energy resolution degraded to 2.3% at 750 K)
- Radiation damage is more important at high temperatures !!

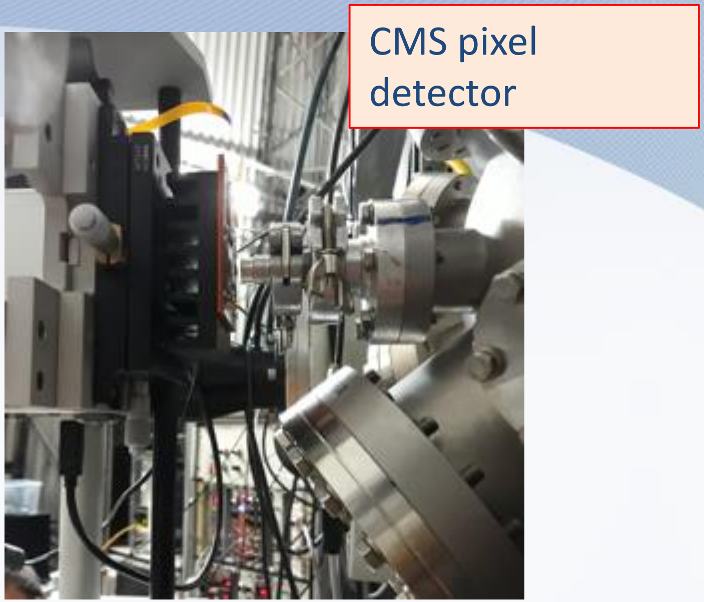






A. Crnjac et al., Materials 13 (2020) 2473

In air IBIC (with micrometer spot size)

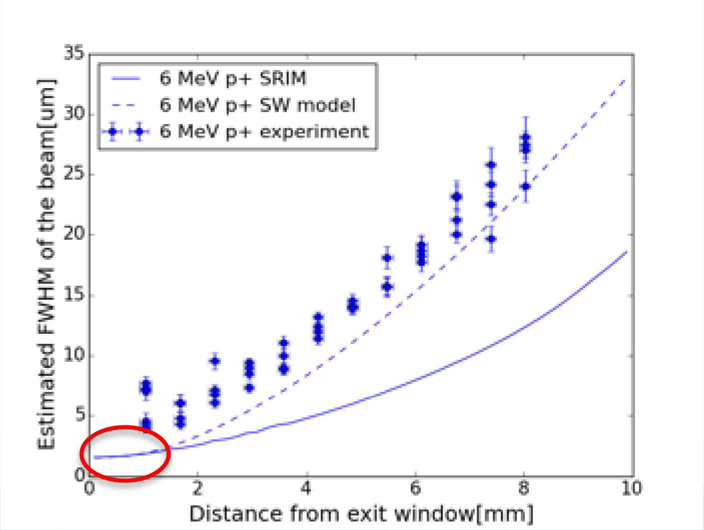


- Large detector structures (e.g. high energy physics detectors) can not be tested in small vacuum chamber
- Alternative – in air microbeam !
- But - beam spot degradation !

Energy / air path	100 nm Si_3N_4	6 μm diamond
3 MeV / 0.5 mm	1.02	9.0
3 MeV / 2.0 mm	4.39	30.6
6 MeV / 0.5 mm	0.50	4.3
6 MeV / 2.0 mm	2.06	14.8
9 MeV / 0.5mm	0.34	2.9
9 MeV / 2.0 mm	1.40	9.9

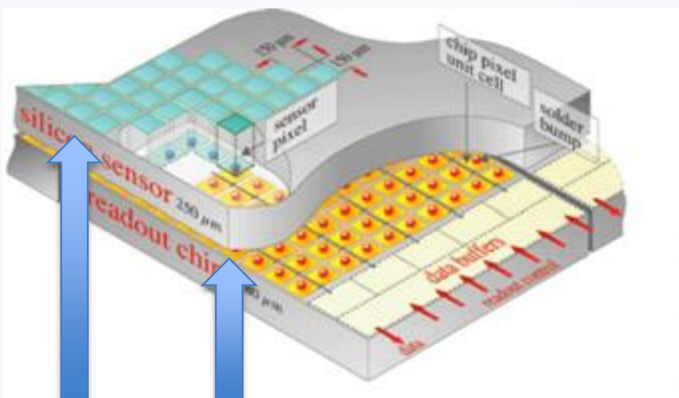
SOLUTION for micrometer range beam resolution:

- SiN exit foil
- up to 2 mm working distance
- Proton energy > 6 MeV !!



In air IBIC for single event effects

- The CMS (Compact Muon Solenoid) inner barrel pixel detector has integrated silicon pixels and readout chip (ROC), where occasional memory soft errors occur.
- Total 48 million pixels in CMS
- Minimum ionizing particles are supposed to be responsible for SEU in pixel readout chain (tested at PSI)



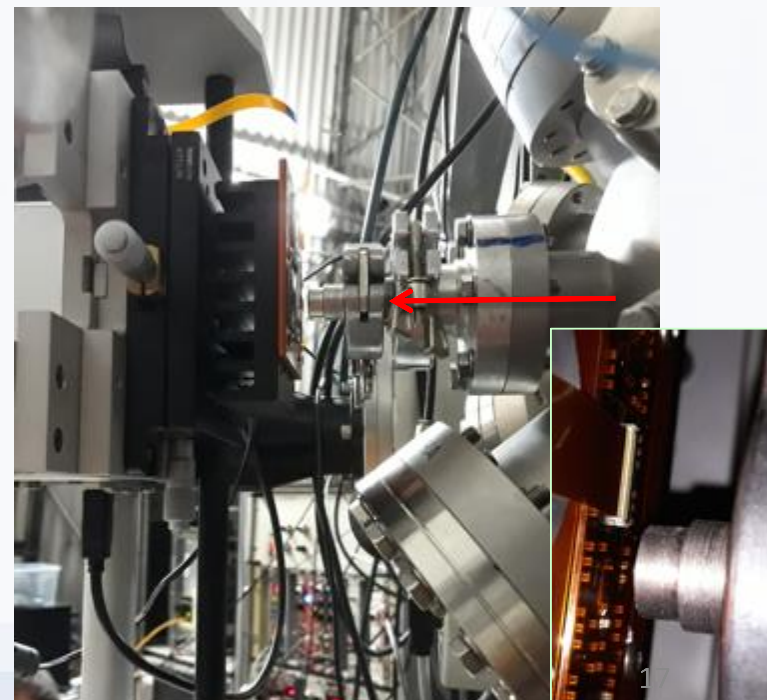
Long range
6 MeV protons
(chip alignment)

Short range
heavy ions – 16 MeV C ions
(single event upsets)

AIDA-2020-RBI-2018-1

Single event effects in CMS pixel ROC

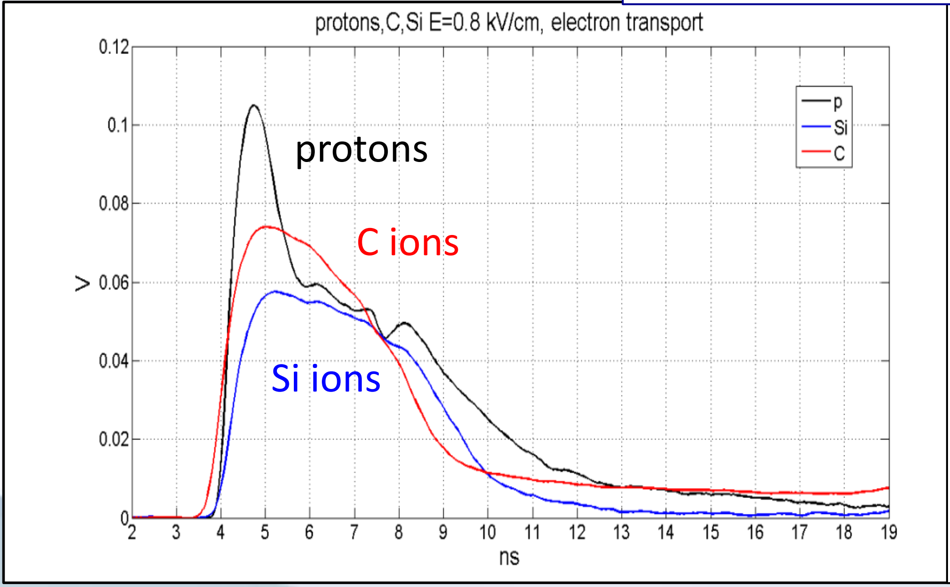
W. Erdemann, PSI, Switzerland

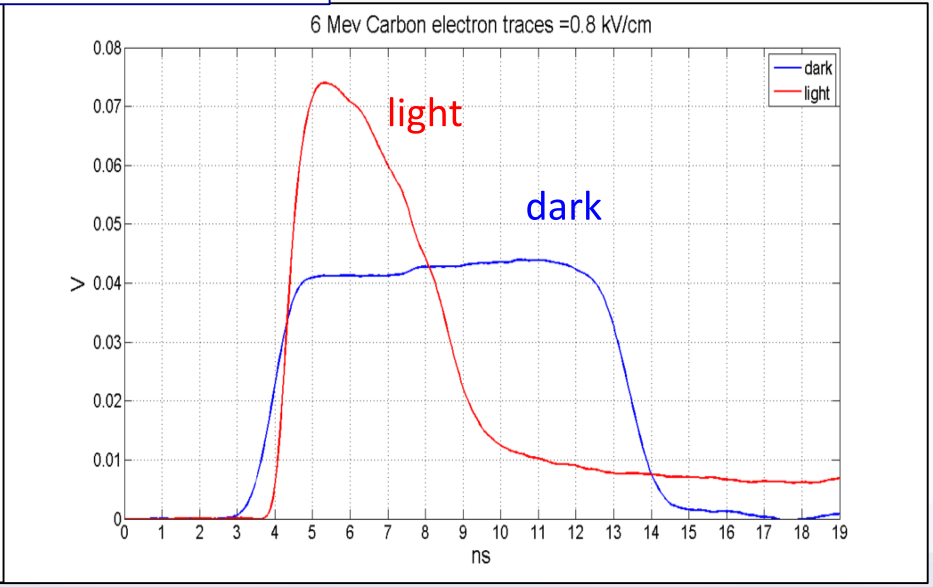


ion TCT (transient current technique)

The fine structure of current transients induced in detectors by single ion can be used for different studies such as: particle recognition, dependences on position (lateral/edge TCT), operating codition, dependence on temperature, etc

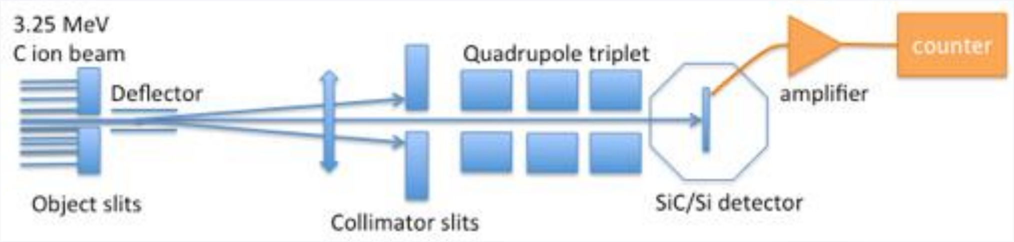
TCT on CVD diamond detectors



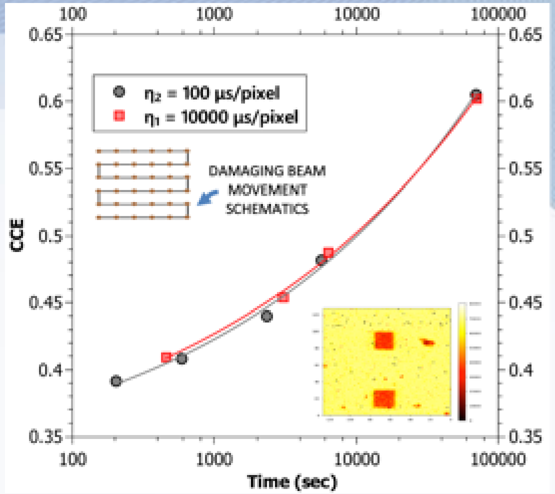


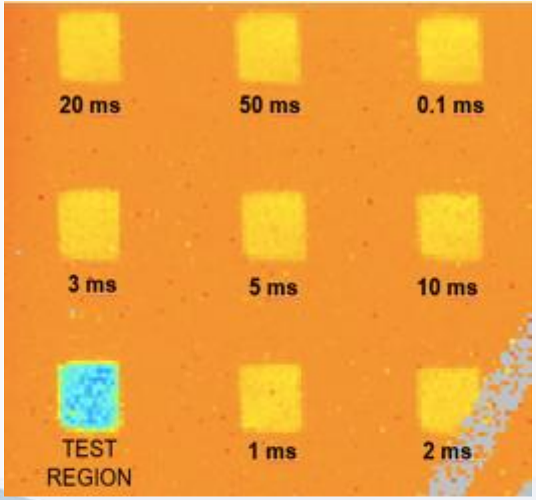
Pulsed beam IBIC

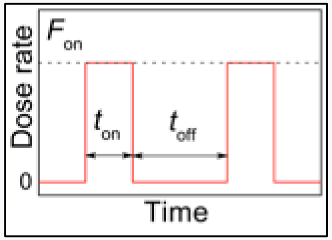
studies of dynamic annealing in silicon and SiC



Sequences of beam-off and beam-on cycles are controlled by DAQ.





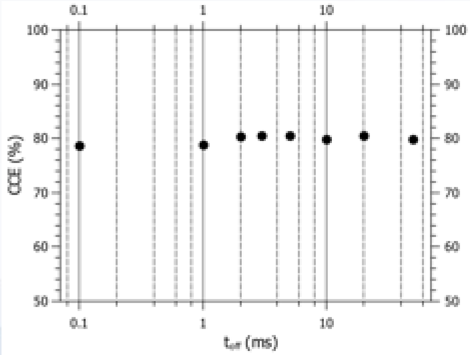


t_{on} = 1 ms

t_{off} = 0.1 to 50 ms

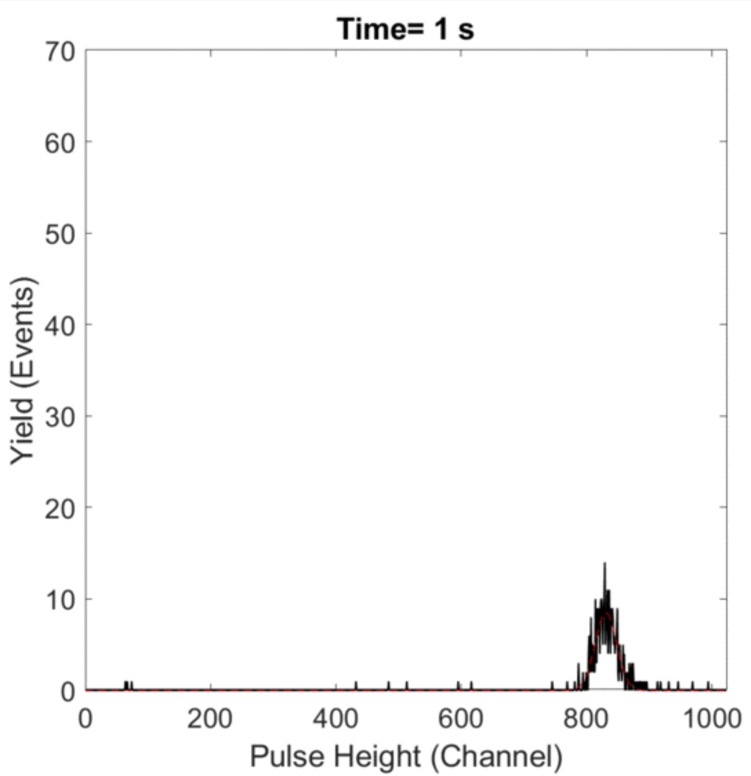
Irradiation and IBIC probing:

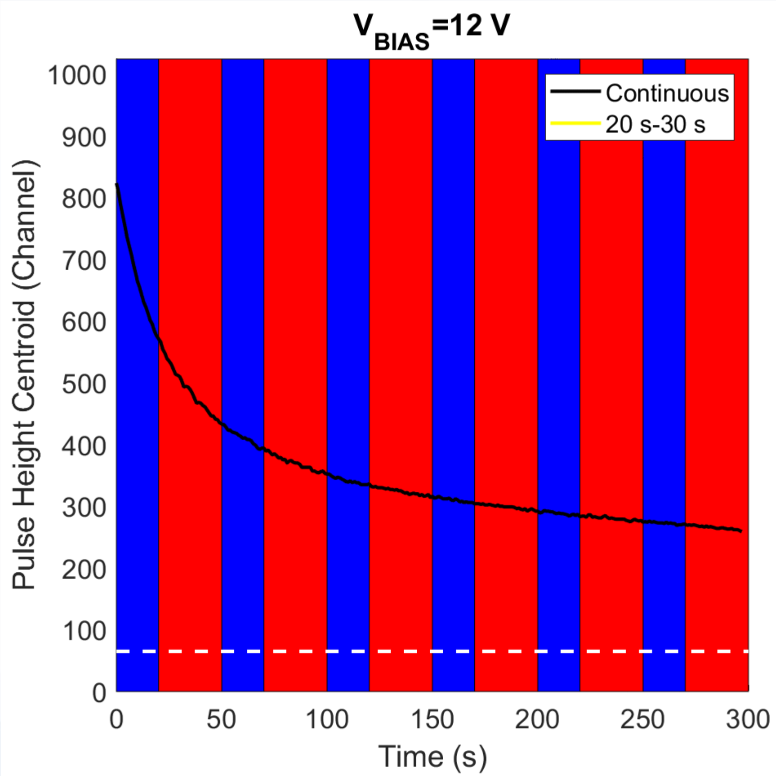
- 400 pulses of 3.25 MeV C ions (both irradiation and IBIC probing)
- Ion range 3.5 µm in Si (as for 1 MeV He ions)
- fluence:
  346 μm^{-2} (Si)
  33 μm^{-2} (SiC)



Pulsed beam IBIC
studies of polarization in diamond

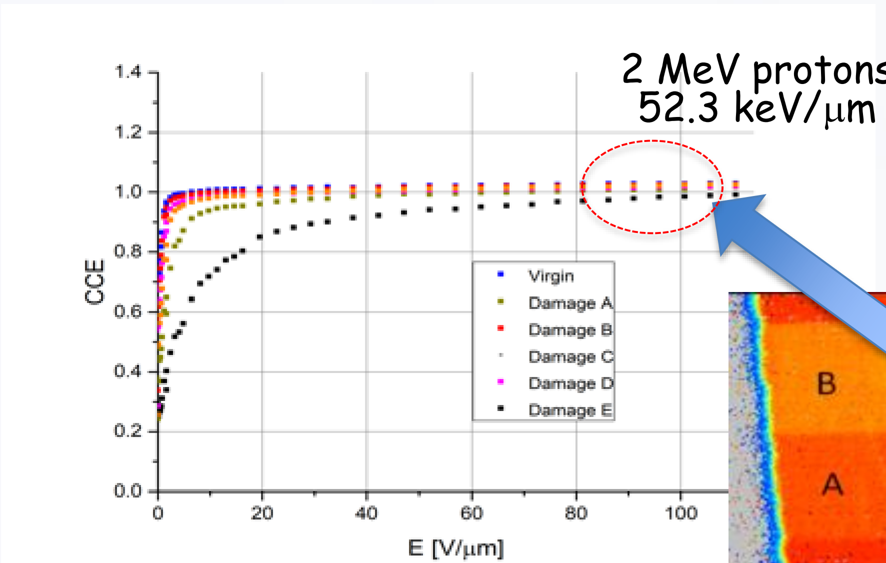
Polarization (accumulation of space charge) in diamond is serious problem. One of ways to mitigate polarization problem is switching the bias from positive to negative in sequences, or as shown here by only switching bias on and off:

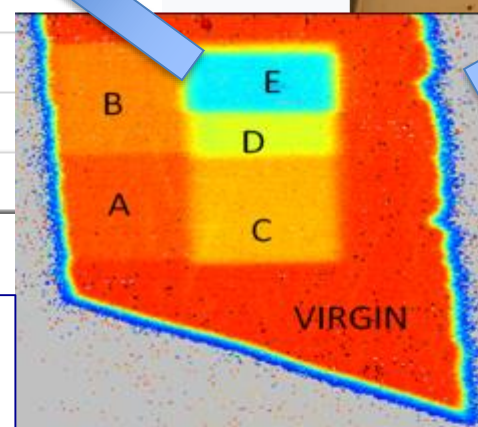


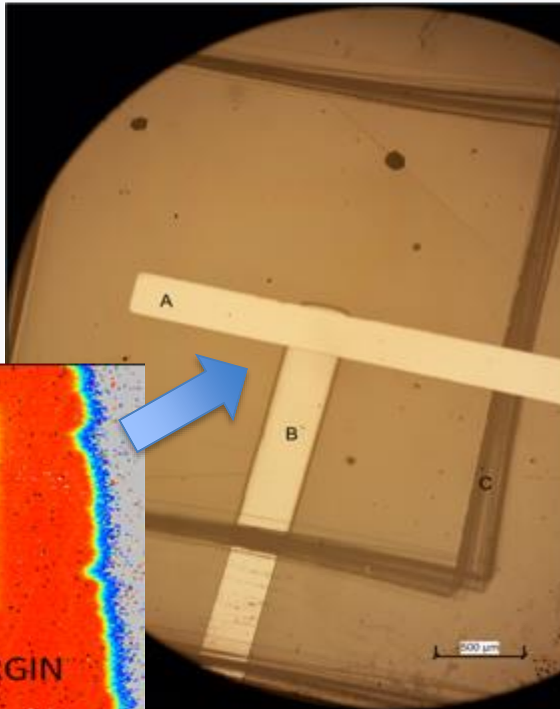


Extreme radiation hardness in thin diamond membranes

By the application of high electric fields (20 – 100 V/um) in diamond membrane detector, we were able to operate diamond without losing CCE, up to fluences of $5 \cdot 10^{15}$ of 10 MeV protons/cm^2 !! (approaching 10^{17} n_{eq})





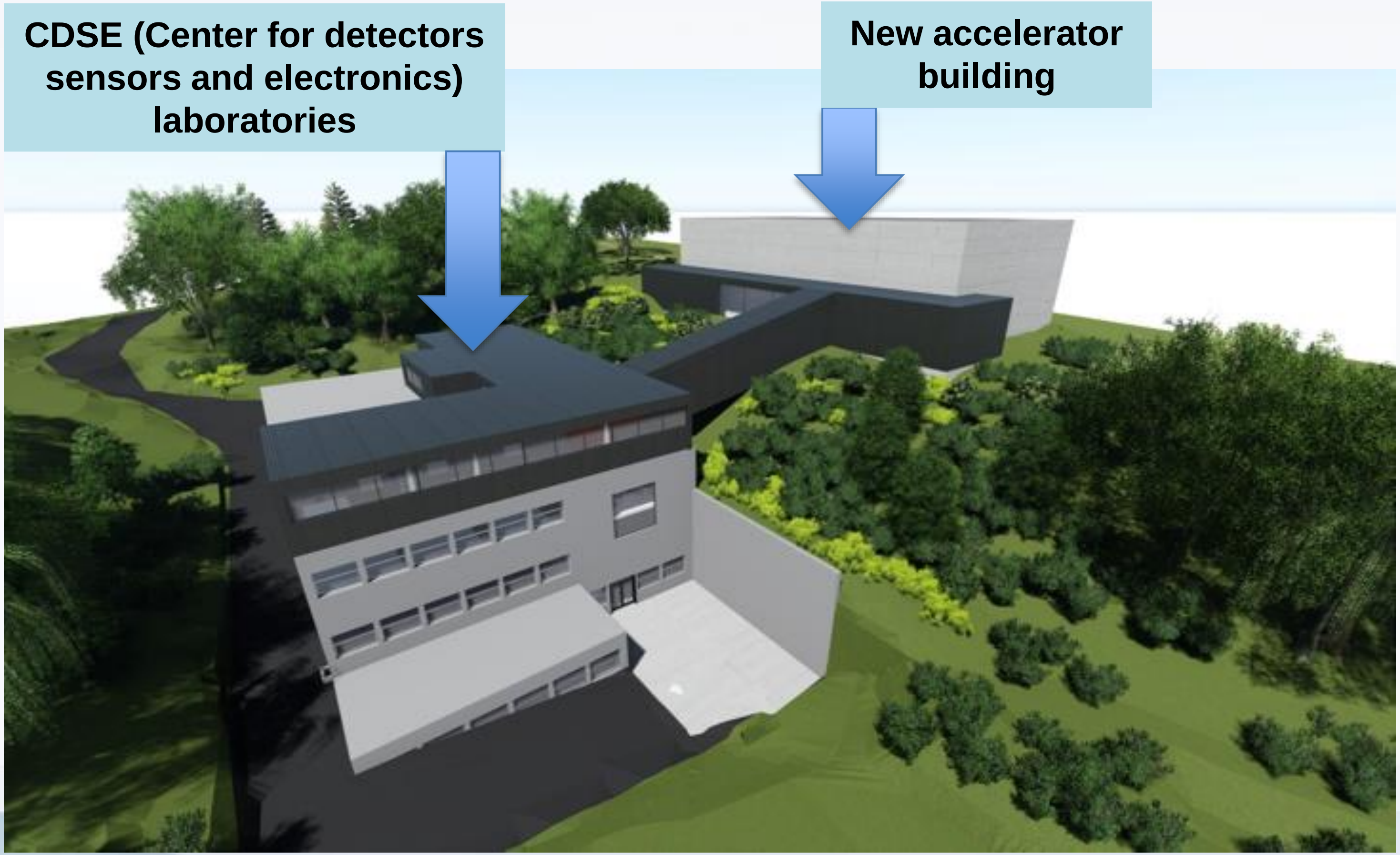


N. Skukan et al., Extreme radiation hardness and signal recovery in thin diamond detectors, AIP Advances 2019.

Overview of future upgrades

The O-ZIP project

Signed this week !!



Overview of future upgrades

The AIDAinnova project (from 2021)

WP4: Upgrade of Irradiation and Characterization Facilities

Task 4.2. Micro-beam Upgrade at RBI Accelerator Facility

- *Upgrade the RBI Accelerator Facility (RBI-AF) infrastructure for detector characterisation and radiation hardness studies at microscales, including upgrade of hardware and data acquisition and control system tooptimise the facility operation and quality of results*

Instead of conclusion: Transnational Access to RBI through RADIATE project

https://www.ionbeamcenters.eu

RBI IBIC facility is accessible through Transnational Access funding of RADIATE project:

- User selection panel reviews proposals
- Response time is max. 2 months
- After proposal submission, RBI allocates beam time, so if accepted it is possible to perform measurements within 3 months
- During the Covid-19 travel bans, remote operation is possible
- Project funds travel, accommodation and daily allowance