# *SiC membrane* devices for harsh environment applications

@Ruder Boskovic Institute, Zagreb (Croatia)

# Experiment proposal

- SiC industrially wide band-gap semiconductor
- Pixelated sensors on free-standing ultra-thin membranes
- **Goal:** response of the SiC sensors on free-standing membranes on a **wide range of T and beam intensities**
- Advantage of the capability of the facility to expose **small areas** with the beam → local effects

*materials*

MDPI

*Article*

**Electronic Properties of a Synthetic Single-Crystal Diamond Exposed to High Temperature and High Radiation**

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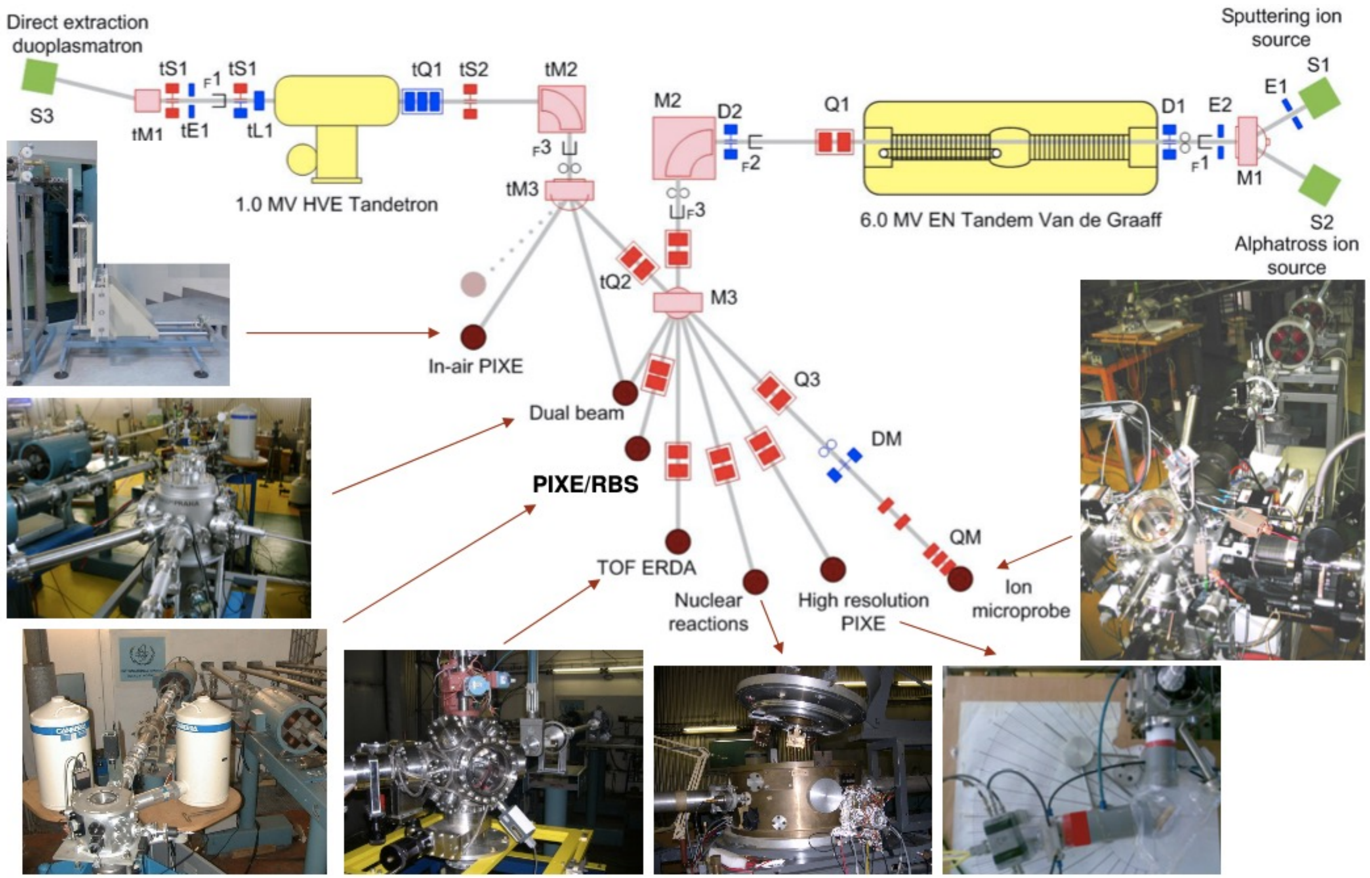
check for updates

STLAB

Institut Ruđer Bošković

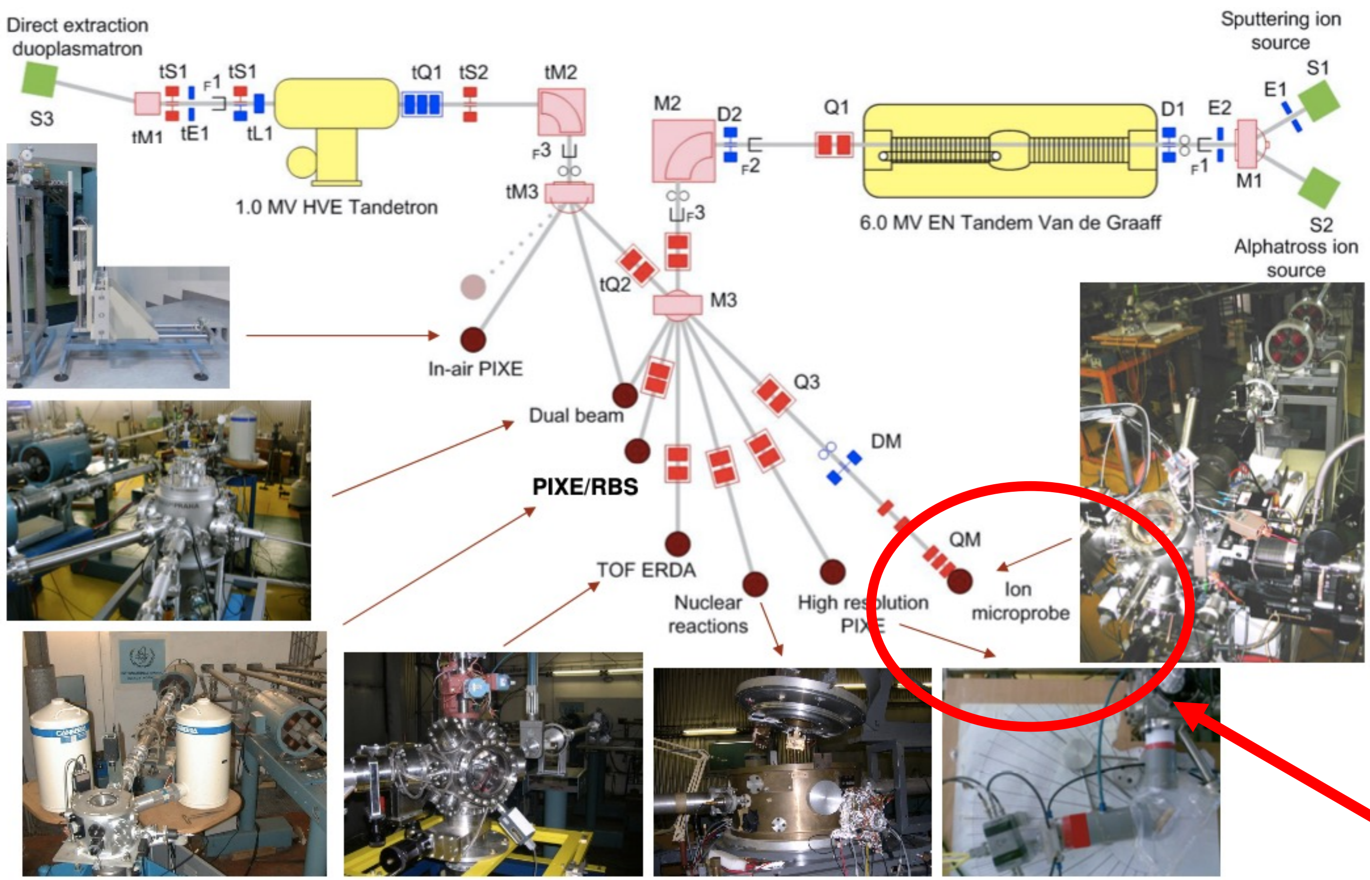
# Ruder Boskovic accelerator facility




1) **6.0 MV EN Tandem Van de Graaff accelerator** (higher energies, worse stability)
2) **1.0 MV Tandetron accelerator** (lower energies, better stability)

- 9 beam lines (2 accept from both accelerators)
- Each chamber is designed for a different purpose to cover a wide range of possible applications and techniques

# Ruder Boskovic accelerator facility




**Ion microprobe**

1) **6.0 MV EN Tandem Van de Graaff accelerator** (higher energies, worse stability)
2) **1.0 MV Tandetron accelerator** (lower energies, better stability)

- 9 beam lines (2 accept from both accelerators)
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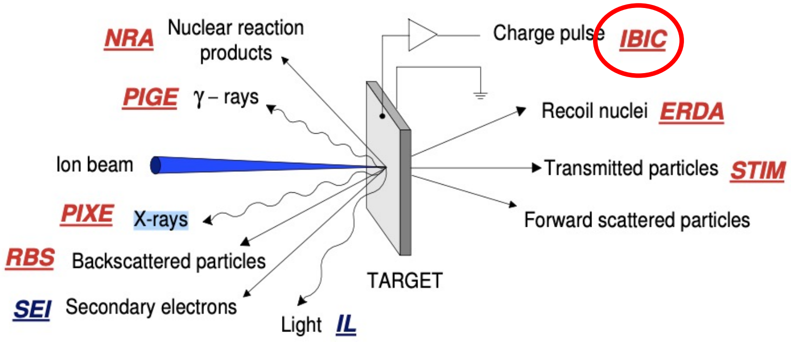
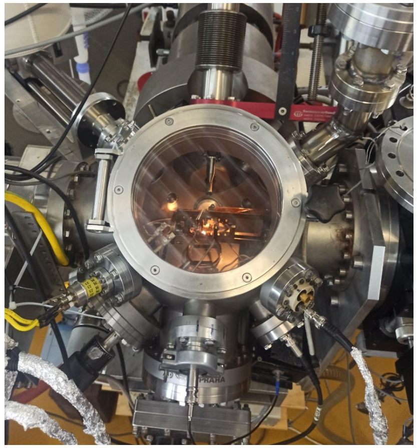
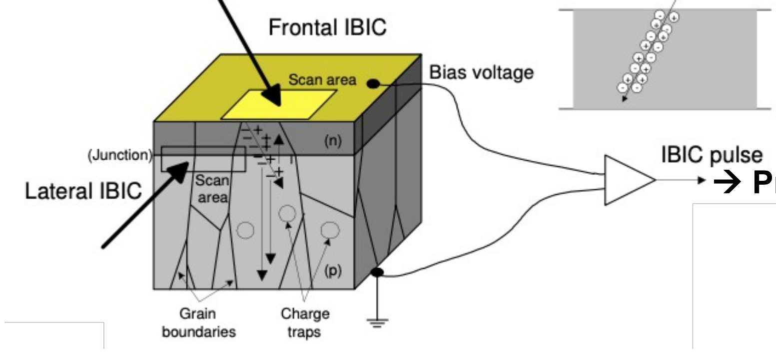
# Ion microprobe chamber



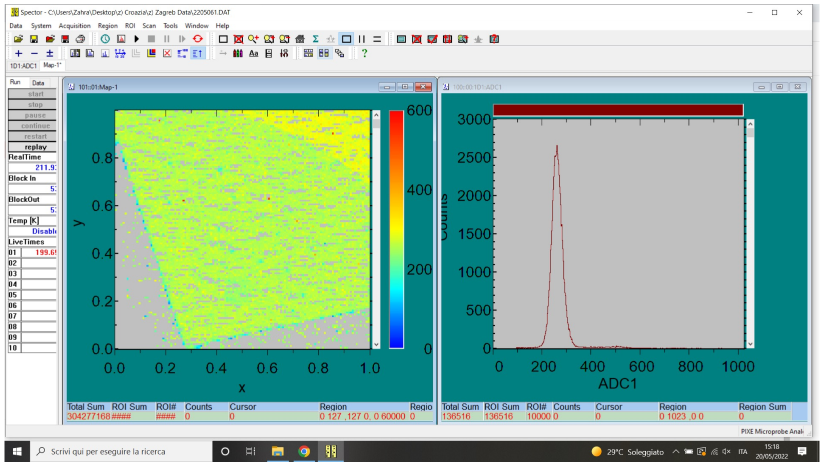



- Quadrupole lenses → focus ion beam to um size
- Spherical chamber, modular design
- Different applications
- Data acquisition and ion microbeam scanning controlled by the **SPECTOR hardware/software package**

## IBIC TECNIQUE

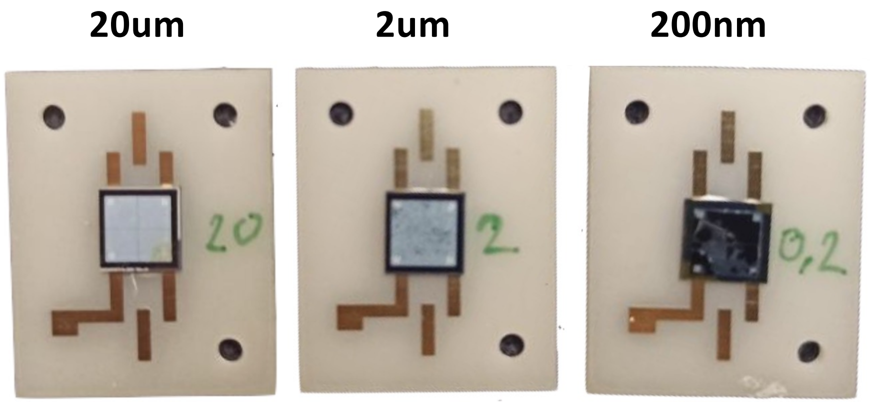


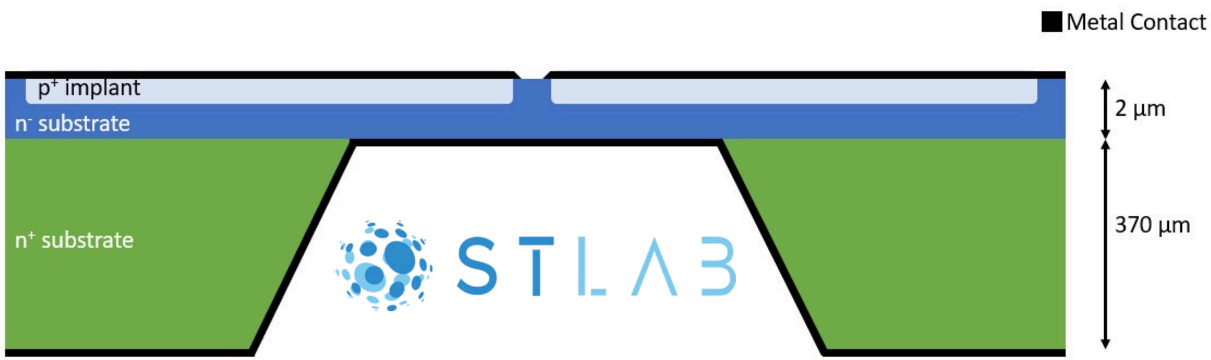

**→ Preamp → Ampl →ADC → Computer**

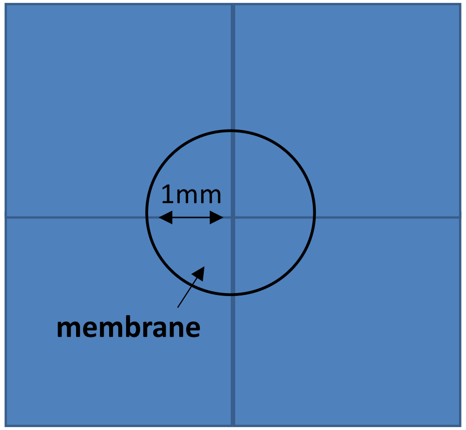


# Silicon Carbide sensors

- *SiC* d=3,12 g/cm$^3$
- “Membrane types” vs “Bulk-type”
- PIN junctons: **thin p+** (highly doped), **n-** (low doped) on top of a **n+ thick** substrate. Free-standing membranes → n+ removed by *electrochemical etching*
- Thinning procedure STLab
- 4 pixels sensors
- Circular membrane (1mm radius) of thickness **20um/2um/0.2um**



# Measurements

20um sample

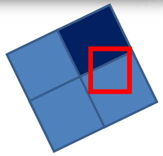
1. IBIC **@1MeV**
2. Local damage **@3.5MeV** in different areas with different fluxes in/out
3. IBIC @1MeV in damaged areas
4. IBIC @1MeV in damaged areas **increasing T**
5. Local damage **@3.5MeV @HT** (~500°C) with different fluxes in/out
6. IBIC **@1MeV** in damaged areas @RT/@HT
7. First test with 200nm sample: IBIC

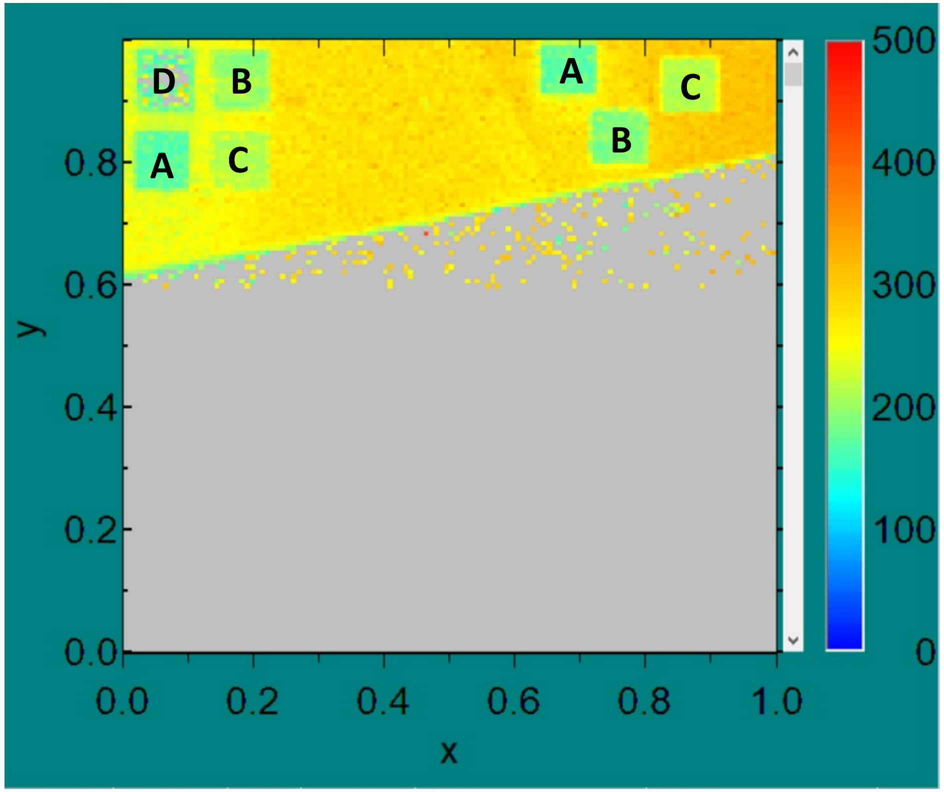
**SRIM simulation**

**1MeV p:** All energy released in 20um SiC membrane

**3.5MeV p:** completely transmitted through the SiC membrane → homogeneous demage along the trajectory.

# Damage inducement @RT






3,5 MeV p in SiC (3,12 g/cm$^3$)→ ~ 10% of E released in 20um. Bragg peak inside the 370um substrate (SRIM simulations)

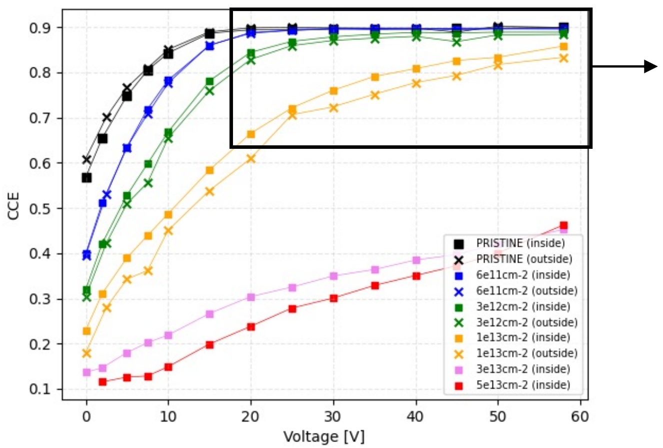
- **3,5 MeV p**: demage in 3 area outside and inside the membranes

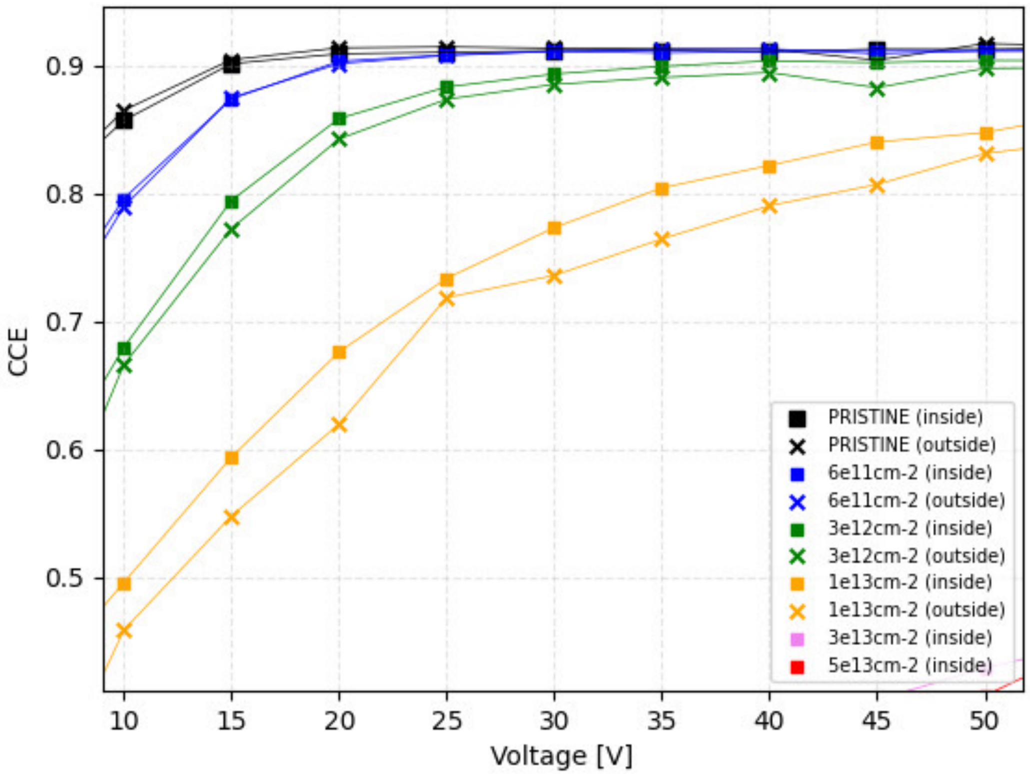
**Fluences:**

| A | B | C | D |
|---|---|---|---|
| ~$10^{13}$ 1/cm$^2$ | ~3 ·$10^{12}$ 1/cm$^2$ | ~6 ·$10^{11}$ 1/cm$^2$ | ~5 ·$10^{13}$ 1/cm$^2$ |

# CCE over damaged areas

**1 MeV p:** CCE vs BIAS over damaged areas
- CCE increases with increasing bias
- CCE is higher for regions **inside the membrane**
- More damaged regions have worse CCE



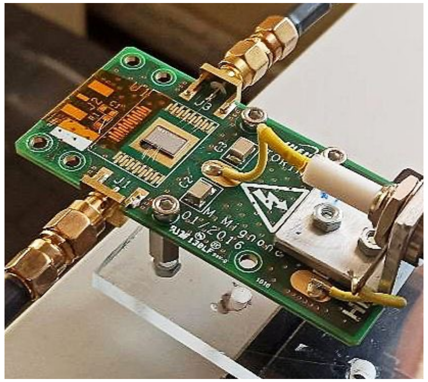
# Beam monitoring for electron FLASH beams

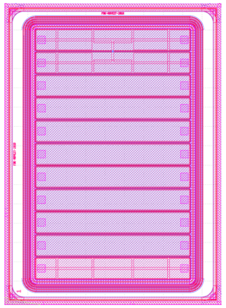
## Thin silicon sensors

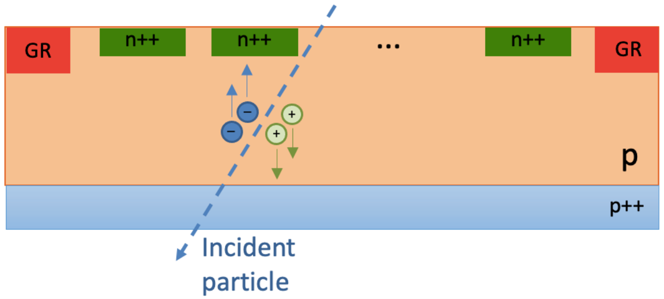
# Silicon detectors and Readout

Silicon devices in Turin: used so far for *single particle counting* → With **TERA08** signal can be integrated

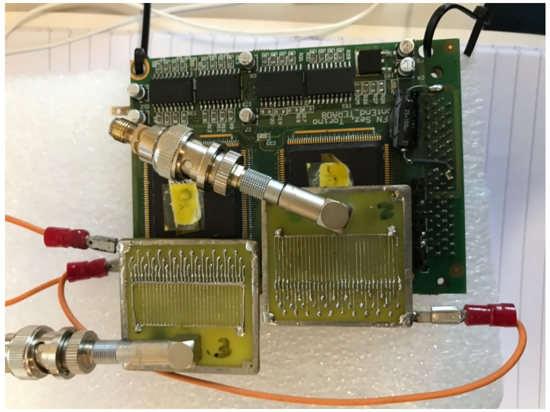
- **Silicon sensor** (strip area 2.2 $mm^2$, active thickness 45 $\mu m$, total thickness 615 $\mu m$)





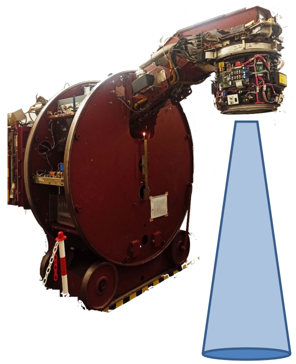



- Readout with **TERA08** (chip based on *recycling integrator* principle)



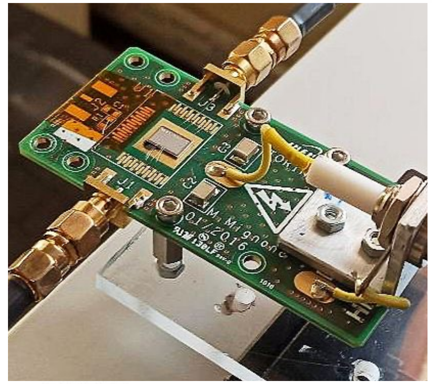
| DAQ Period ($\mu s$) | $Q_c$(fC) | Max conversion freq per chn | Max conversion (total) | Max current (for 64 CHNs) |
|---|---|---|---|---|
| 1e4 (0.01 s) | 200 fC | 20 MHz | 1280 MHz | ± 256 $\mu$A |

# Experimental setup

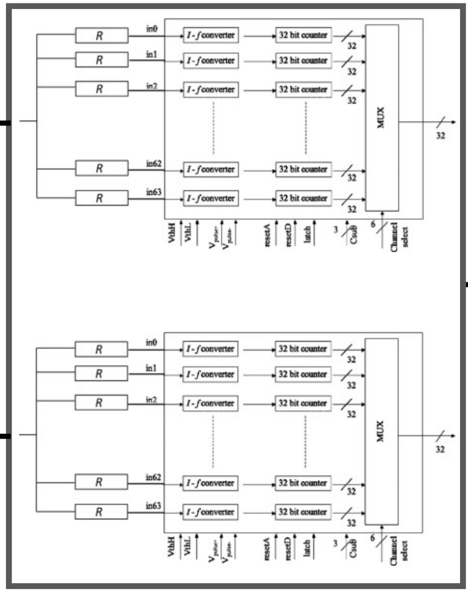


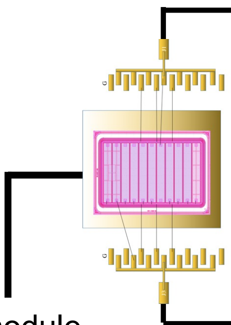
**LINAC ELEKTA**
$e^-$ beams with energy:
3.8MeV, 6MeV, 10MeV or 18MeV

- **Silicon sensor**
- **TERA08**
- National Instruments PXIe-1071 PXI Chassis
- HV module



TERA08

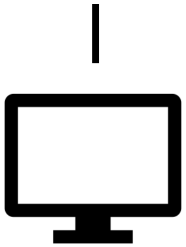


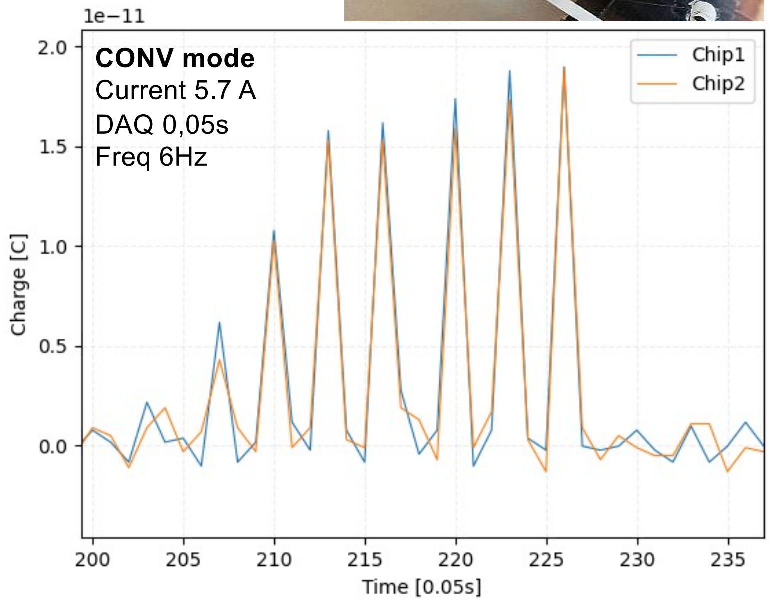


Silicon sensor

HV module

National Instruments PXIe-1071 PXI Chassis

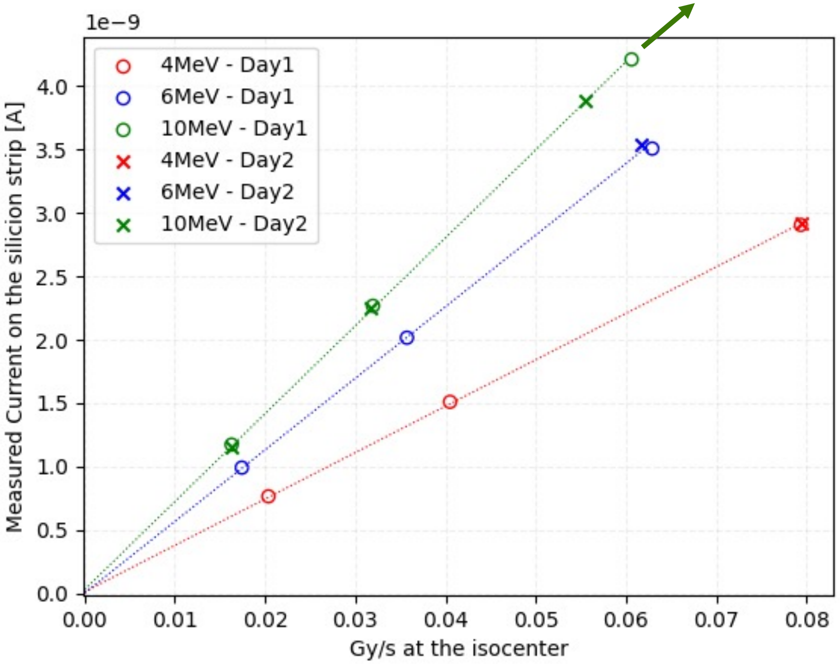


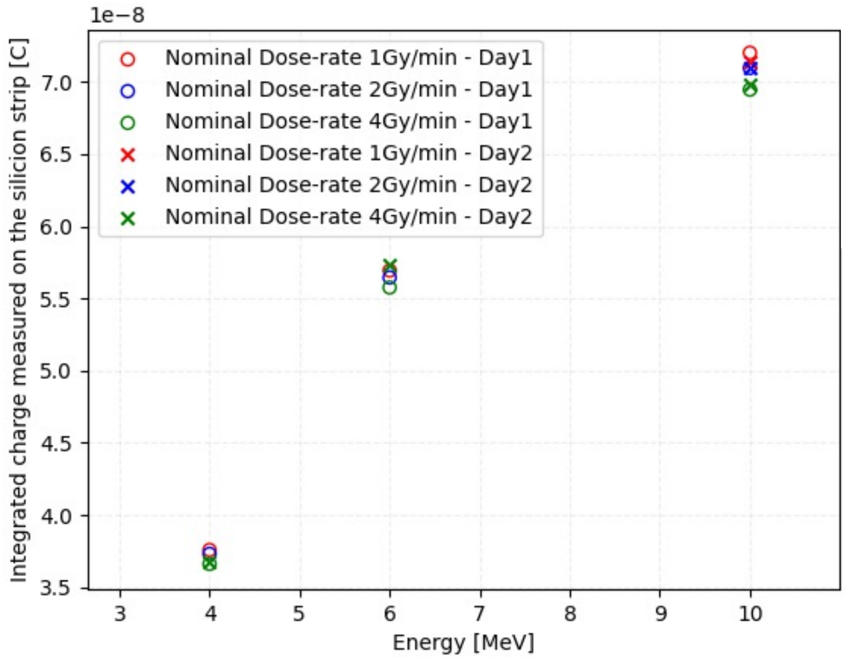


# First tests with electrons beams

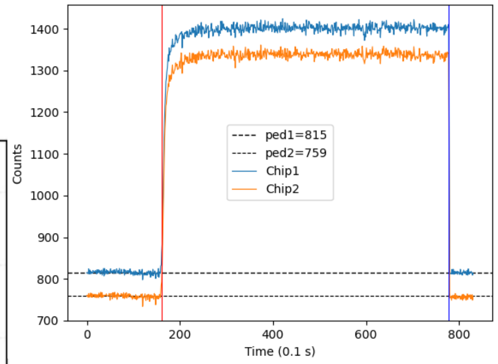
- Conventional beams at **LINAC Elekta SL18**
  - Linearity and reproducibility

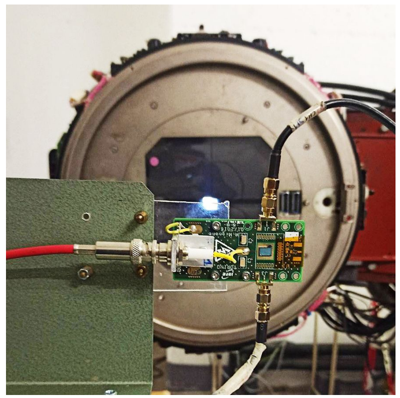
0.0016% TERA08 saturation




**Example of data acquisition**



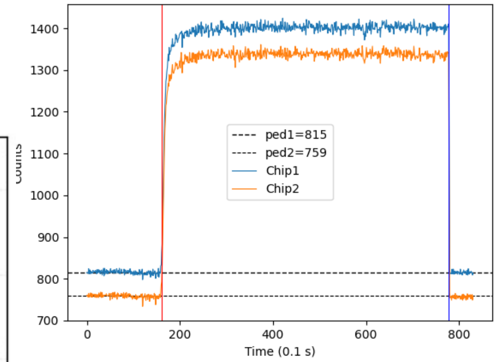
We expect to be able to measure up to **few kGy/s** (10MeV, present sensor + readout configuration )

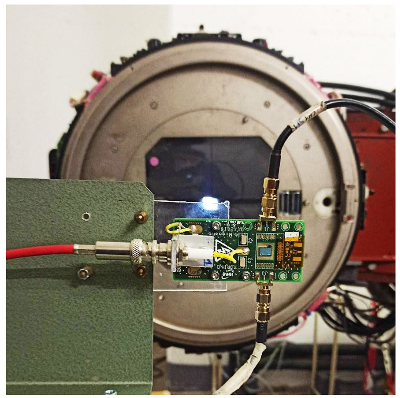
Elekta

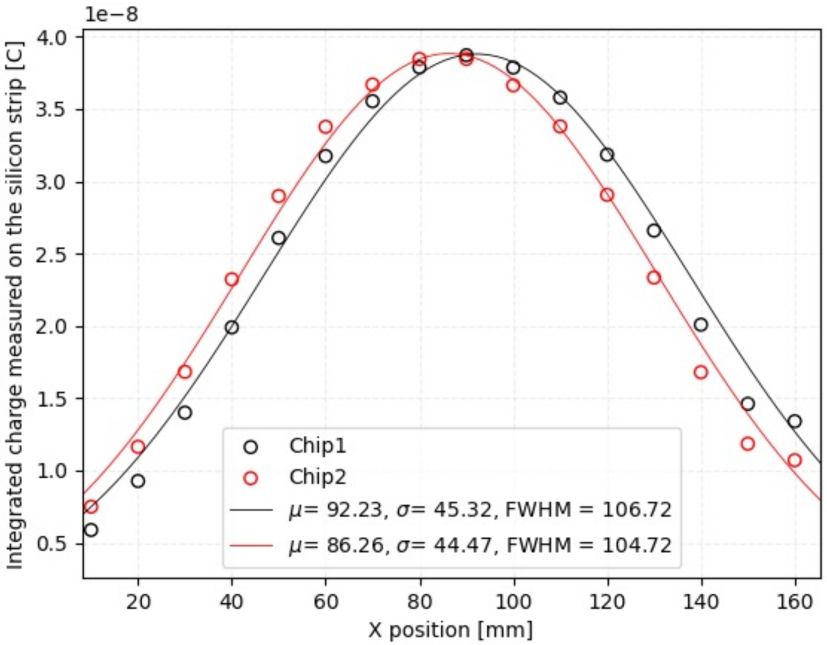
# First tests with electrons beams

- Conventional beams at **LINAC Elekta SL18**
  - Beam shape and relation with distance

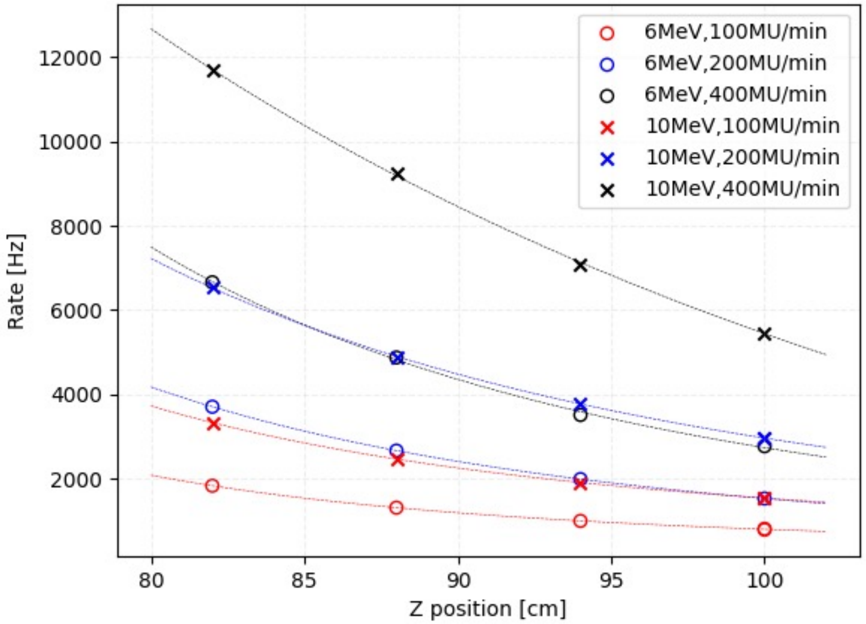
**Example of data acquisition**






6MeV, 200 MU/min, 50 MU tot, FS 10X10cm$^2$
**FWHM compatible with field size**

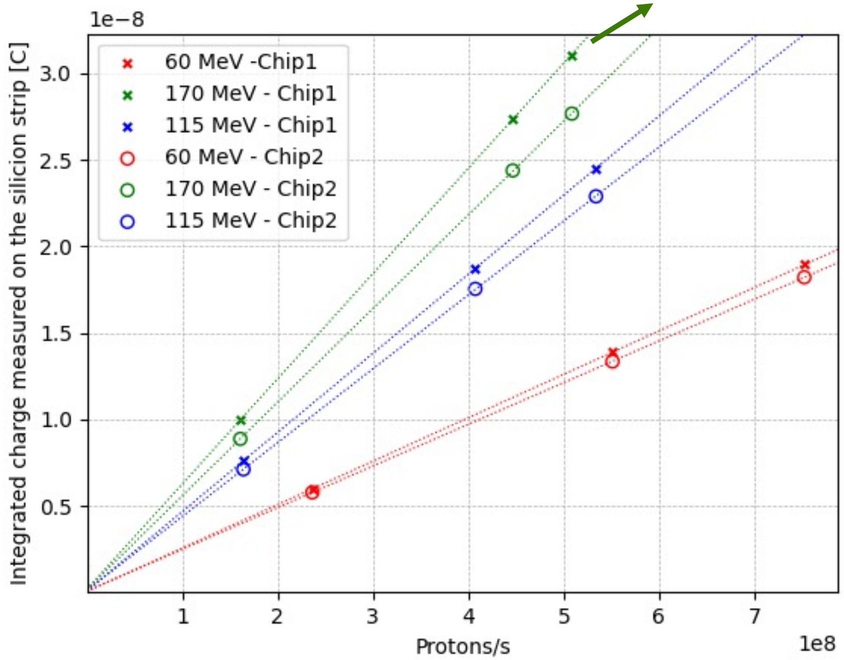



Rate measured as a function of the distance. The data were fitted with the function **$y=a+b/(x-c)^2$**

# First tests with protons beams


- **CNAO**, National Center of Oncology Adrotherapy
- Different fluxes: $10^9$, $10^8$ ,$5x10^8$ protons/spill
- Different energies: 60, 115, 170 MeV

0.0121% TERA08 saturation



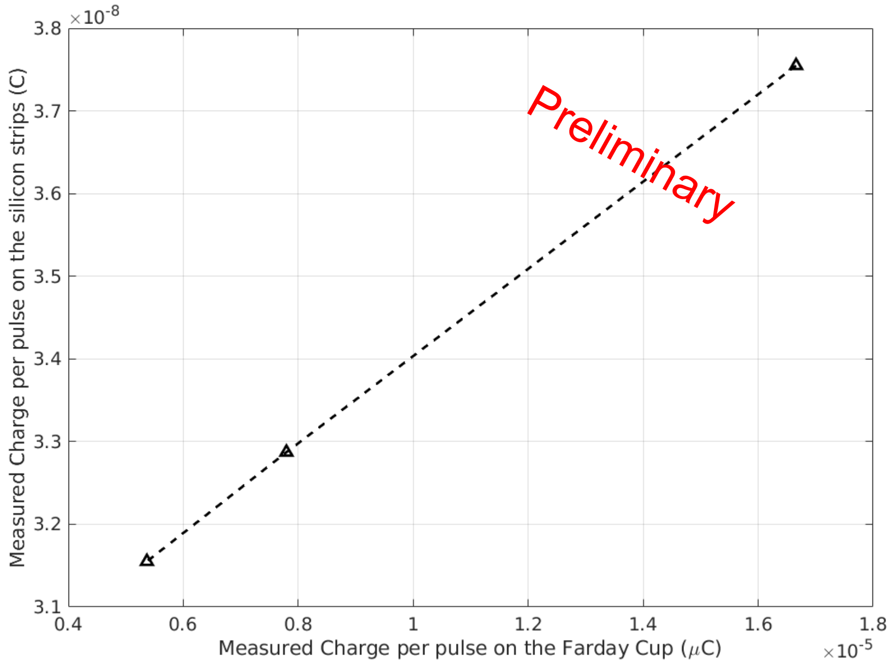

For 60-230 MeV and the present sensor + readout configuration we expect to be able to measure up to **$10^{12}$ – $10^{13}$ p/s.**

# First tests with protons beams

- Exploration test at **Ruvo di Puglia facility:** prototype of a linear proton accelerator
- $10^{13}$ protons/s and FWHM~mm, Energies: 102MeV, 84MeV, (58MeV), Pulse duration ~4us ($4x10^7$ protons)

***Flash?***

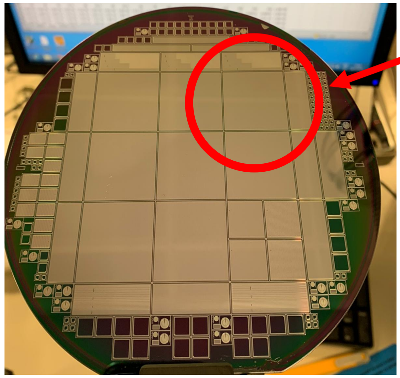
- 84MeV proton beam
- $Q_{/pulse}$ on the silicon strip vs $Q_{/pulse}$ on the Faraday cup (+GAF)
- $1.6x10^{-11}$C → 0.1387 Gy/pulse → 10Gy/s avg DR
- But distance from beam erogation = 1.3m



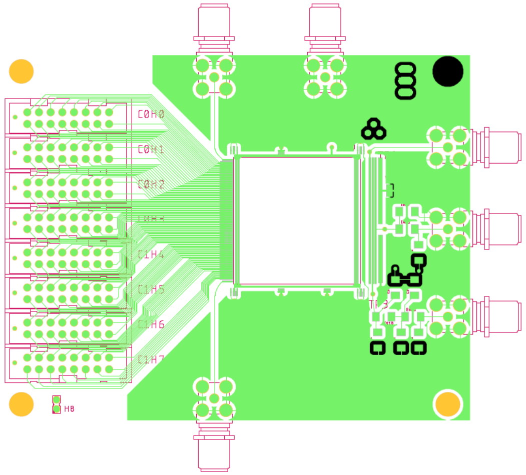
# Next steps: TERA09


- Frontend chip based on 64 charge recycling CHNs
- Extended current range with respect to TERA08
- Preliminary design and test phase (**Thanks to Valerio Pagliarino**)

Larger sensor: **Area 2.7×2.7 cm$^2$** and **146 strips** of ~3mm$^2$ area (144 with gain, 2 no gain)



Detector board

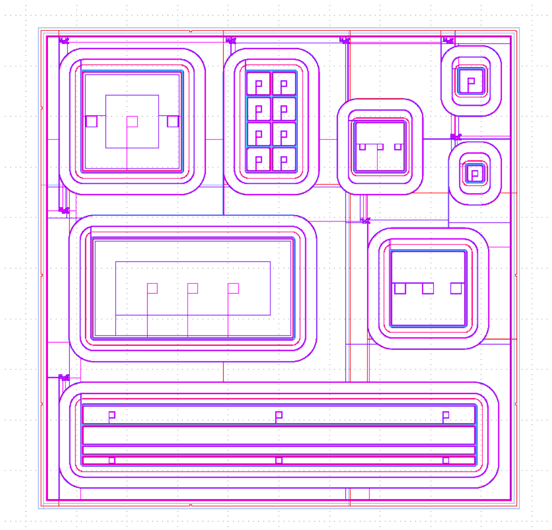


TERA09

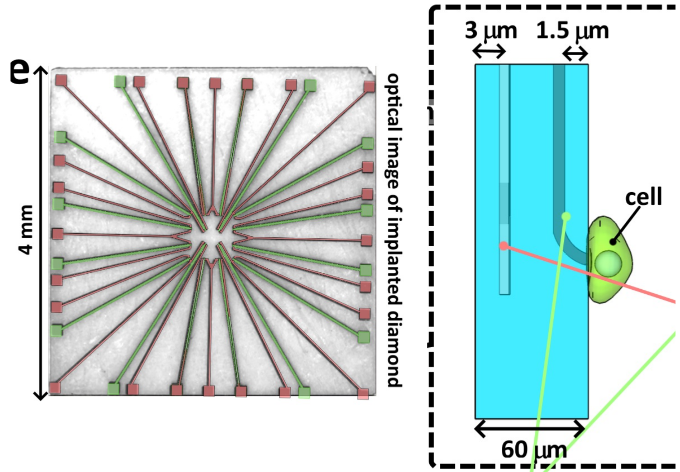
| | |
|---|---|
| **Current range** | 100 pA-100 µA |
| **Max conversion freq** | 62.5 MHz |

# Next steps: New detector production

- **New production ongoing**
- (Thanks to Valentina Sola, INFN colleague).
- 4 different substrate thicknesses: 15, 20, 30, and 45 $\mu m$
- Very small active areas : from 2mm$^2$ up to 0.03mm$^2$



- **Diamond detector**
- Electrodes will be deposited at different depths (create different thicknesses on the same sensor)
- Diamond by Rinati and Marinelli is a dosimeter: very small by definition
- We work on beam monitors: we would like to cover a few cm$^2$ (ok for irradiating cells)



# Future beam tests

COMING SOON
4-5 October


Centro Pisano Flash Radiotherapy

TIFPA - Trento Institute for Fundamental Physics and Applications

LinearBeam, Ruvo di Puglia

# Conferences

AAPM 2022
JULY 10–14 | WASHINGTON, DC
64TH ANNUAL MEETING & EXHIBITION

(poster)

10-14 Lug

17-20 Ago

ecmp 4th
Dublin 2022

125 YEARS SIF
1897-2022

12-16 Set

30 Nov - 2 Dic


(poster)


THANK
YOU!

# References


[1] Vignati, Anna, et al. "Beam monitors for tomorrow: the challenges of electron and photon FLASH RT." *Frontiers in Physics* (2020): 375.

[2] Cirio, Roberto, et al. "A simple method to increase the current range of the TERA chip in charged particle therapy applications." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 798 (2015): 107-110.

[3] Ashraf, Muhammad Ramish, et al. "Dosimetry for FLASH radiotherapy: a review of tools and the role of radioluminescence and Cherenkov emission." *Frontiers in Physics* 8 (2020): 328.

[4] Schüller, Andreas, et al. "The European Joint Research Project UHDpulse–Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates." *Physica Medica* 80 (2020): 134-150.

[5] Lempart, Michael, et al. "Modifying a clinical linear accelerator for delivery of ultra-high dose rate irradiation." *Radiotherapy and Oncology* 139 (2019): 40-45.