ADVANCES IN SINGLE ION DETERMINISTIC IRRADIATION

ASIDI

- **NEW EXPERIMENT**
- **3 YEARS**
- **INFN PARTICIPANTS:** **LNL** (R.N. V. Rigato)
  TORINO (R.L. E. Vittone)
  PADOVA (R.L. S. Gerardin)
- **EXTERNAL:** **I.N.R.I.M**. (L. Boarino)

Development of an achromatic ion beam system and related diagnostics for precise sub-micrometer irradiation of materials, micro-circuits and radiation detectors

- From single-ion hit to 10^4 ions/s - Energy: 500-2200keV
- Ions: ^{1}H, ^{4}He, $^{14}N^{+}$, $^{14}N_2^{+}$
- LNL AN2000 Van de Graaff accelerator (0° micro-probe beamline)

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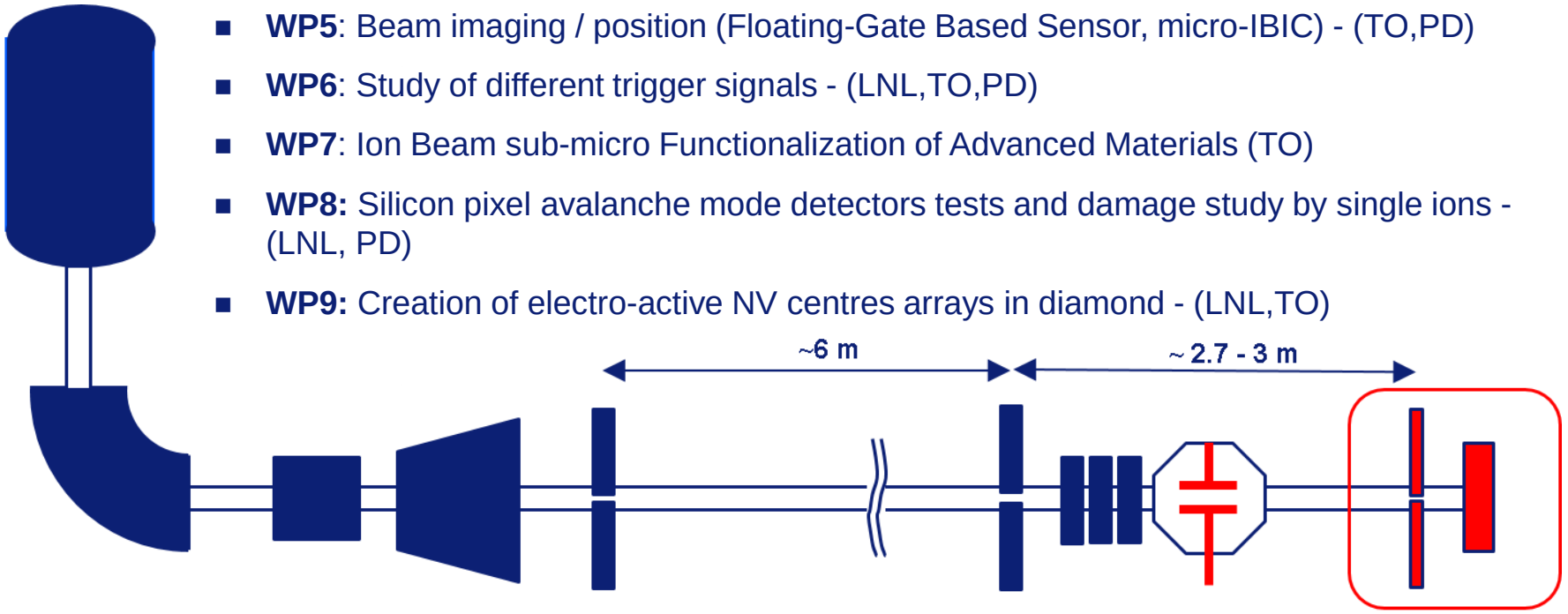
MAIN ACTIVITIES

- **WP1**: Beam-line modification. Fast chopper development. Heavy ion beam preparation ($^{14}N(+)$, $^{14}N_2(+)$) – (LNL)
- **WP2**: Thermostated Chamber design. Precision Sample Holder Specs definition. – (LNL, TO, PD)
- **WP3**: Sub-micrometer collimator development (laser micro-drilling, ionized sputtering, FIB, SEM, chemical etching) - (LNL, INRIM)
- **WP4**: Hardware assembly. Micro-collimator alignment procedures (better than 0.001°). Ion Count electronics - (LNL, TO)
- **WP5**: Beam imaging / position (Floating-Gate Based Sensor, micro-IBIC) - (TO,PD)
- **WP6**: Study of different trigger signals - (LNL,TO,PD)
- **WP7**: Ion Beam sub-micro Functionalization of Advanced Materials (TO)
- **WP8:** Silicon pixel avalanche mode detectors tests and damage study by single ions - (LNL, PD)
- **WP9:** Creation of electro-active NV centres arrays in diamond - (LNL,TO)



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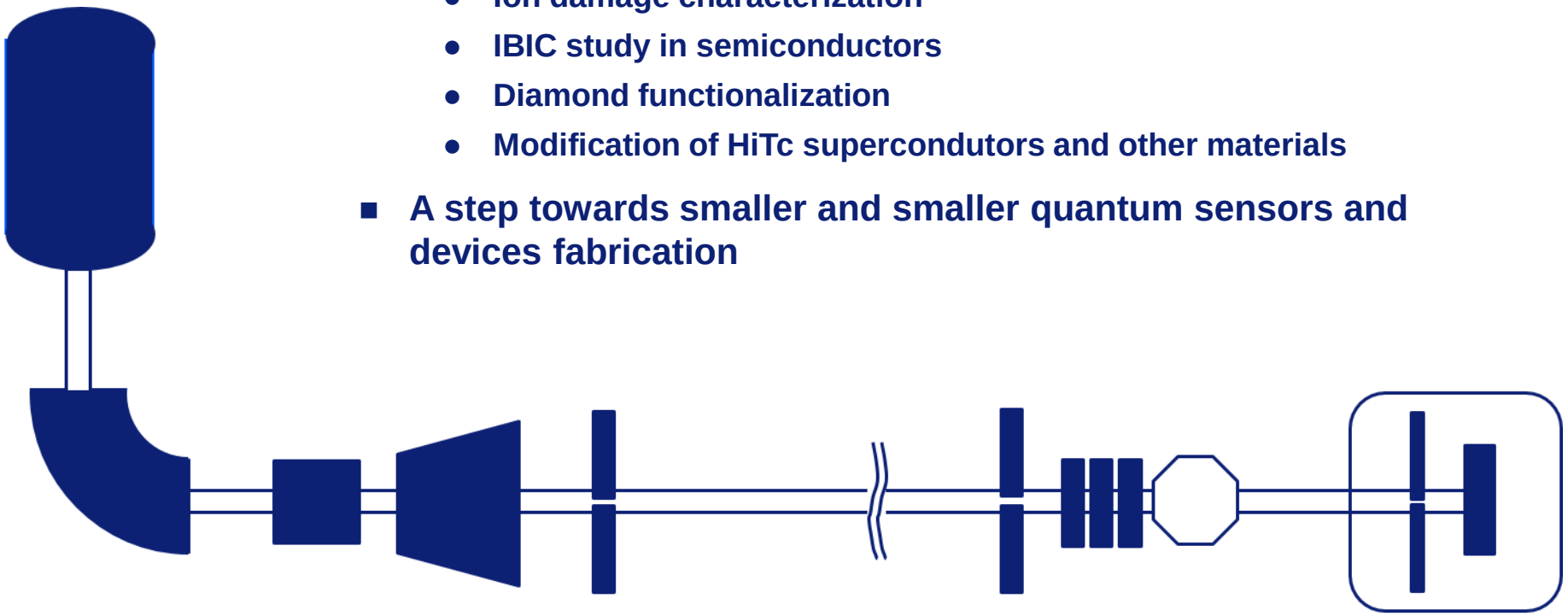
STATE OF THE ART

- Achromatic and sub-micron features in a single device
- Sub-micron precision single-ion hit
- Sub-micron imaging of MeV ions
- High value niche applications:
  - Functional analysis of electronic microdevices and detectors
  - Ion damage characterization
  - IBIC study in semiconductors
  - Diamond functionalization
  - Modification of HiTc superconductors and other materials
- A step towards smaller and smaller quantum sensors and devices fabrication



PADOVA ACTIVITES

- **Main involvement**
  - **WP5**: Beam imaging / position with Floating-Gate Based Sensor
  - **WP8:** Silicon pixel avalanche mode detectors tests and damage study by single ions - (LNL, PD)

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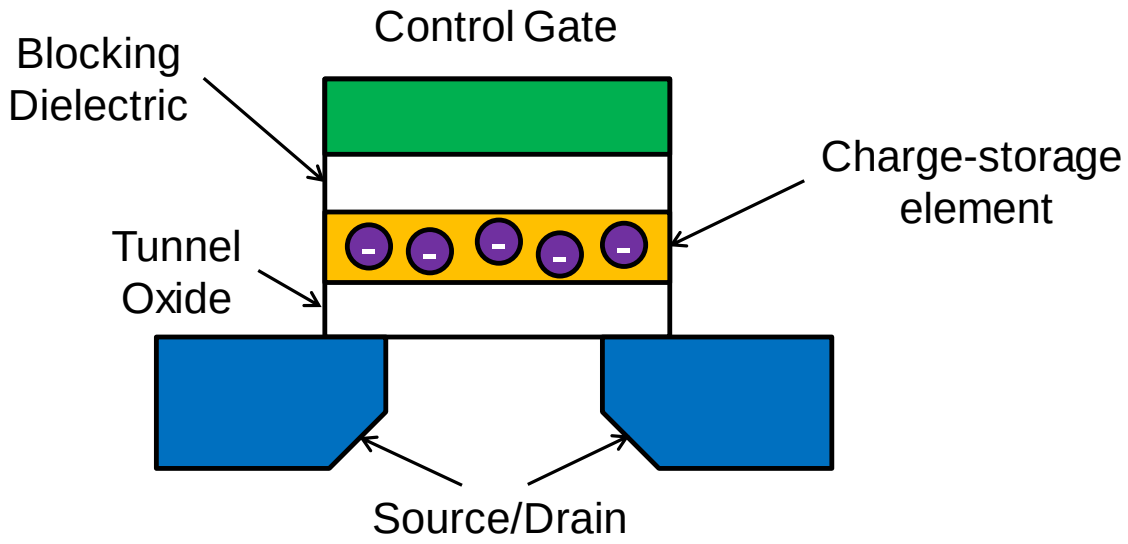
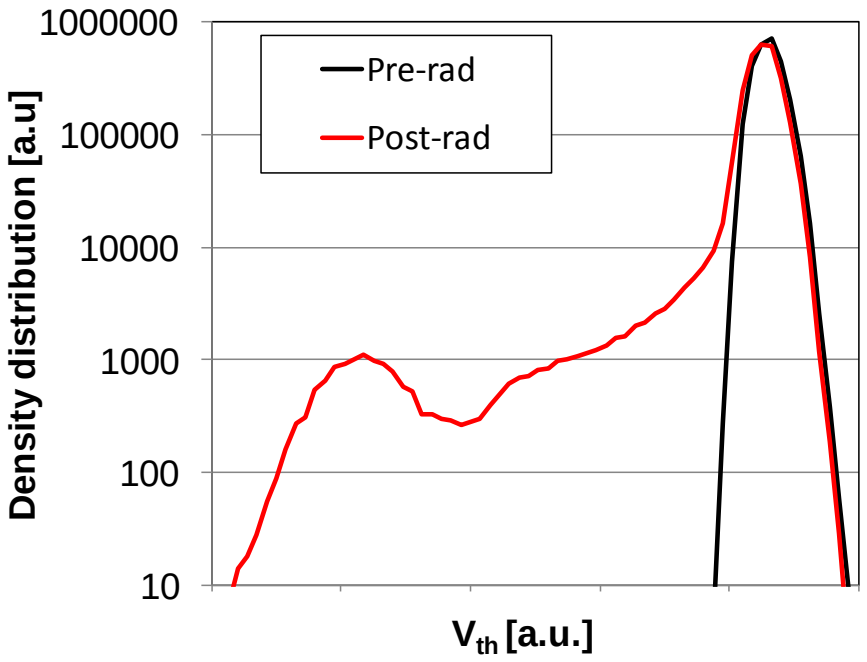
FLOATING-GATE SENSOR

- **Measuring the size of sub-μm beam and the effectiveness of the used collimators presents unique challenges**
- **This workpackage aims at developing a sensor capable of measuring the area of a sub-μm beam, using commercial planar NAND Flash memories**



RADIATION EFFECTS ON FLOATING GATES

- Radiation impinging on a floating gate causes a reduction in the stored charge
- In turn this leads to a threshold voltage shift, which, when large enough causes, an upset (error)
- A memory can be effectively turned into a radiation detector



S. Gerardin, et al., TNS 2010

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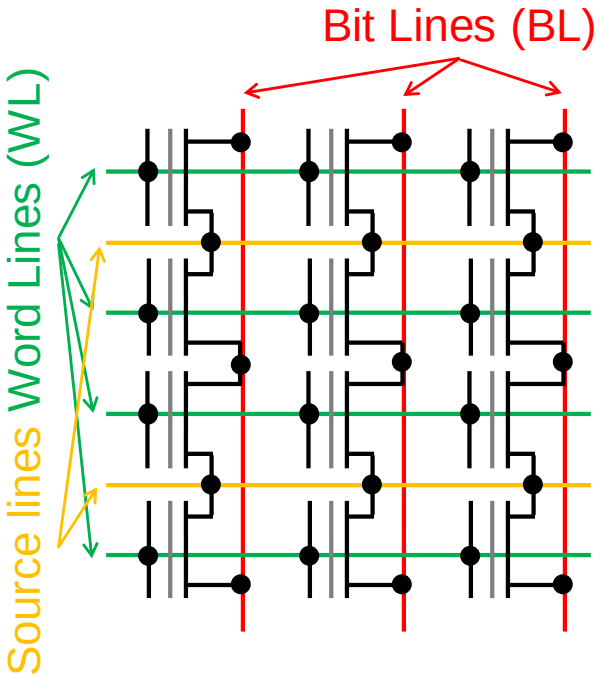
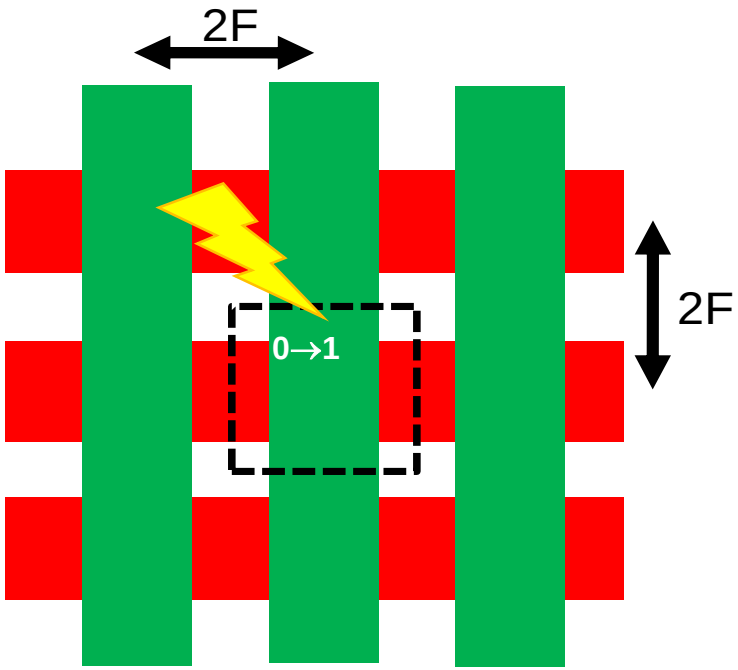
RESOLUTION

- In addition, NAND Flash devices have a large integration density (the highest in the industry) and are very sensitive to radiation, as shown by several publication evaluating them for use in space





Ideal cell

- State of the art devices have feature sizes (F) smaller than 20 nm
- A sensor with high spatial resolution can be developed

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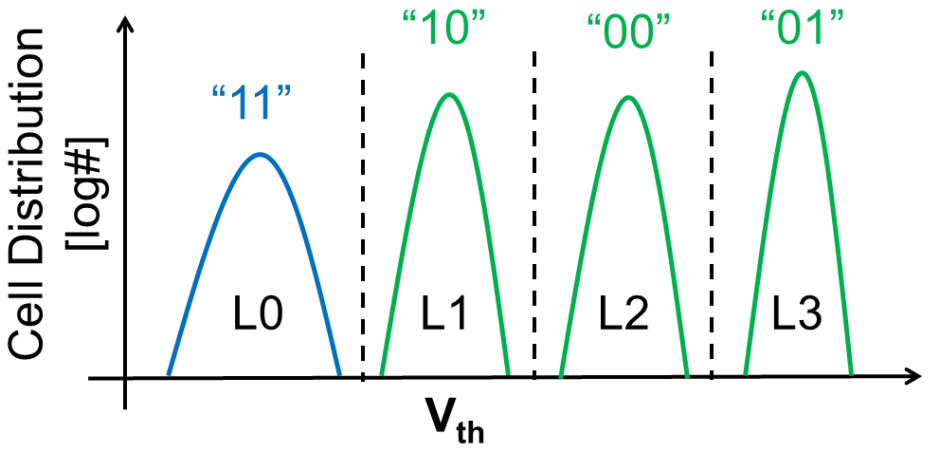
SENSITIVITY

- With multi-level cell architecture and small feature size, the cells programmed with a proper pattern can be upset by lowly-ionizing particles, with LET as low as 0.2 MeV/mg·cm^2
- However, non-volatility and the storage mechanisms make it possible to detect even lower LET with multiple strikes (charge loss by the individual strikes is additive)

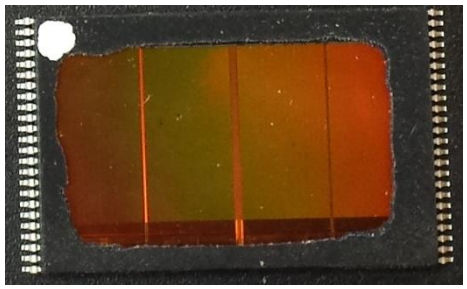


FLOATING-GATE SENSOR TASKS

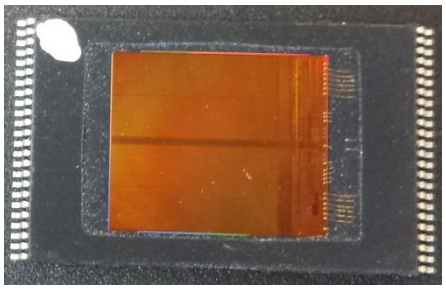
- Procurement of suitable memories with F ~ 20 nm
- Development of a control board
- Decapping of the cell array, while keeping the radiation soft control circuitry protected
- Establishment of the correspondence between electrical addresses and cell physical locations
- Simulation of the energy loss in the overlayers above the sensitive volume
- Optimization of the programming pattern to be written to the memory/sensor, in order to maximize sensitivity to radiation
- Development of a fast readout algorithm to read the memory and quickly pinpoint the area affected by the beam, while skipping errors not due to radiation (frequent in these memories)

FG SENSOR PROGRESS

- Procurement of suitable memories with F ~ 20 nm
  - 25-nm Single Level Cell (SLC) and Multi-Level Cell (MLC) Micron NAND Flash Memories have been procured
    - SLC: part number 29F32G08ABAAAWP (in the following indicated as MN)
    - MLC: part number 29F32G08CBACAWP (in the following indicated as MG)
- Development of a control board
  - First version of control board has been developed: low performance, off-line read-out only.
- Decapping of the cell array, while keeping the radiation soft control circuitry protected
  - Memories were successfully decapped with an acid attack



Decapped SLC NAND Flash



Decapped MLC NAND Flash

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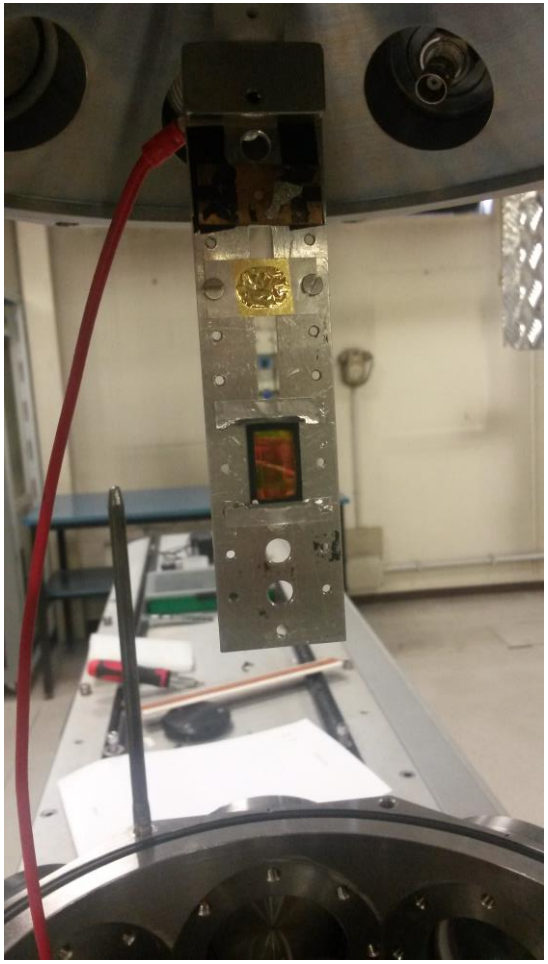
FG SENSOR PROGRESS

- Memories tested during two beam shifts at AN2000 (23-24/4/18 and 15/5/18)
  - With the Beam focused to μm size, errors were observed and the number was in reasonable agreement with the expectations
  - Beam size measurement requires precise establishement of the correspondence between electrical addresses and cell physical locations (not yet complete)
  - Irradiation with beam rastering didn't give the expected results
    - Limited time was available for this test
  - The concept is very promising, but there are some inconsistencies to be solved



NAND Flash mounted on the sample holder inside the irradiation chamber at the AN2000 accelerator

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FG SENSOR PROGRESS

- **Irradiation runs at AN2000 (23-24/4/18 and 15/5/18)**

Run #	Beam shift	Irradiated device	Beam shape	ϕ [protons/cm^2/s]	Φ [protons/cm^2]
2	24/04/2018	MN#115	Circular, 2-μm diameter	$3.18 \cdot 10^7$	$9.55 \cdot 10^8$
3	24/04/2018	MN#115	Circular, 2-μm diameter	$3.18 \cdot 10^7$	$9.55 \cdot 10^9$
4	24/04/2018	MN#115	Circular, 2-μm diameter	$3.18 \cdot 10^7$	$2.86 \cdot 10^{10}$
5	24/04/2018	MG#112	Circular, 2-μm diameter	$3.18 \cdot 10^7$	$3.8 \cdot 10^9$
6	24/04/2018	MG#112	Circular, 2-μm diameter	$4.77 \cdot 10^7$	$1.4 \cdot 10^{10}$
7	24/04/2018	MN#115	Circular, 2-μm diameter	$1.59 \cdot 10^8$	$1.435 \cdot 10^{11}$
100	15/05/2018	MN#115	Circular, 2-μm diameter	$1.78 \cdot 10^9$	$4.01 \cdot 10^{11}$
101	15/05/2018	MN#115	25-mm horizontal line	$1.12 \cdot 10^8$	$2.02 \cdot 10^{11}$
102	15/05/2018	MN#115	25-mm vertical line	$1.12 \cdot 10^8$	$2.02 \cdot 10^{11}$
103	15/05/2018	MN#115	Circular, 2-mm diameter	$1.78 \cdot 10^9$	$5.22 \cdot 10^{11}$
104	15/05/2018	MN#115	25-mm horizontal line	$2.24 \cdot 10^8$	$6.56 \cdot 10^{11}$
105	15/05/2018	MN#115	25-mm vertical line	$2.24 \cdot 10^8$	$6.56 \cdot 10^{11}$

FG SENSOR PROGRESS

- Simulation of the energy loss in the overlayers above the sensitive volume
  - GDML model is under development for use in Geant4.
- Optimization of the programming pattern to be written to the memory/sensor, in order to maximize sensitivity to radiation
  - Not yet started
- Development of a fast readout algorithm to read the memory and quickly pinpoint the area affected by the beam, while skipping errors not due to radiation (frequent in these memories)
  - Not yet started

INNOVATIVE SENSORS

Goals:

1) Response of sensitive area of pixelated detector structures to the impact of single charged ionizing particles on very accurately localized positions (sub-micron resolution)

2) Radiation damage due to localized impact of ionizing particles on sensitive area and ancillary structures (e.g. guard regions) including RO electronics

Detector examples of interest

- state of the art light sensors → Silicon photo-multipliers
- innovative pixels sensors for charged particles
- Feasibility studies under way

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PEOPLE AND FTE (TBC)

PADOVA (2018)	
Simone Gerardin	**25**
A. Pacagnella	20
Jeff Wyss	30
Stefano Bonaldo	35
Dario Bisello	
Gianmaria Collazuol	
FTE	**1.1**

- INRIM (Luca Boarino)

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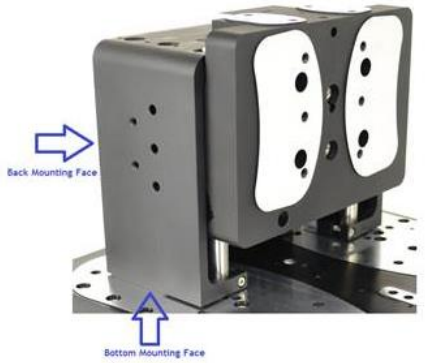
PRELIMINARY BUDGET

SERVICES

- 2018 PADOVA: 1.5 mesi uomo elettronica (PCB assembly only, PCB design is done at DEI)



Sub-micrometer accuracy positioning of devices and detectors to ions.

Precision alignment of sub-micrometer slit with incoming ion beam (<<0.001°, with micrometer displacement)

	2018 (k€)	2019 (k€)	2020 (k€)
LEGNARO	**182**	**69**	**58**
CONSUMABLE	30	30	20
DURABLE		15	15
APPARATA	148	20	20
SOFTWARE			
TRAVEL	4	4	3
TORINO	**37**	**47**	**35**
CONSUMABLE	20	20	20
DURABLE	10	20	5
APPARATA			
SOFTWARE			
TRAVEL	7	7	10
PADOVA	**18**	**29**	**29**
CONSUMABLE	8 (14)	14	14
DURABLE	7 (12)	12	12
APPARATA			
SOFTWARE			
TRAVEL	3 (7)	3	3
TOTAL	**237**	**145**	**122**