Present and future of the SIRAD irradiation facility at the INFN National Laboratory of Legnaro (Padova, Italy)

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When the SIRAD irradiation facility started …

The facility was initially running in 1998 for bulk damage studies
in silicon detectors for High Energy Physics applications
in the framework of the RD48 CERN Collaboration
by proton irradiation.

The facility was then considered in 2000 for SEE studies
in microelectronics devices for Space application
in collaboration with DEI (Univ. Padova) and DIMSAT (Univ. Cassino)
by ion irradiation.

The facility has been equipped with funds from:
-Physics Departments, Univ. Padova
-INFN Section of Padova
-INFN National Laboratory of Legnaro.

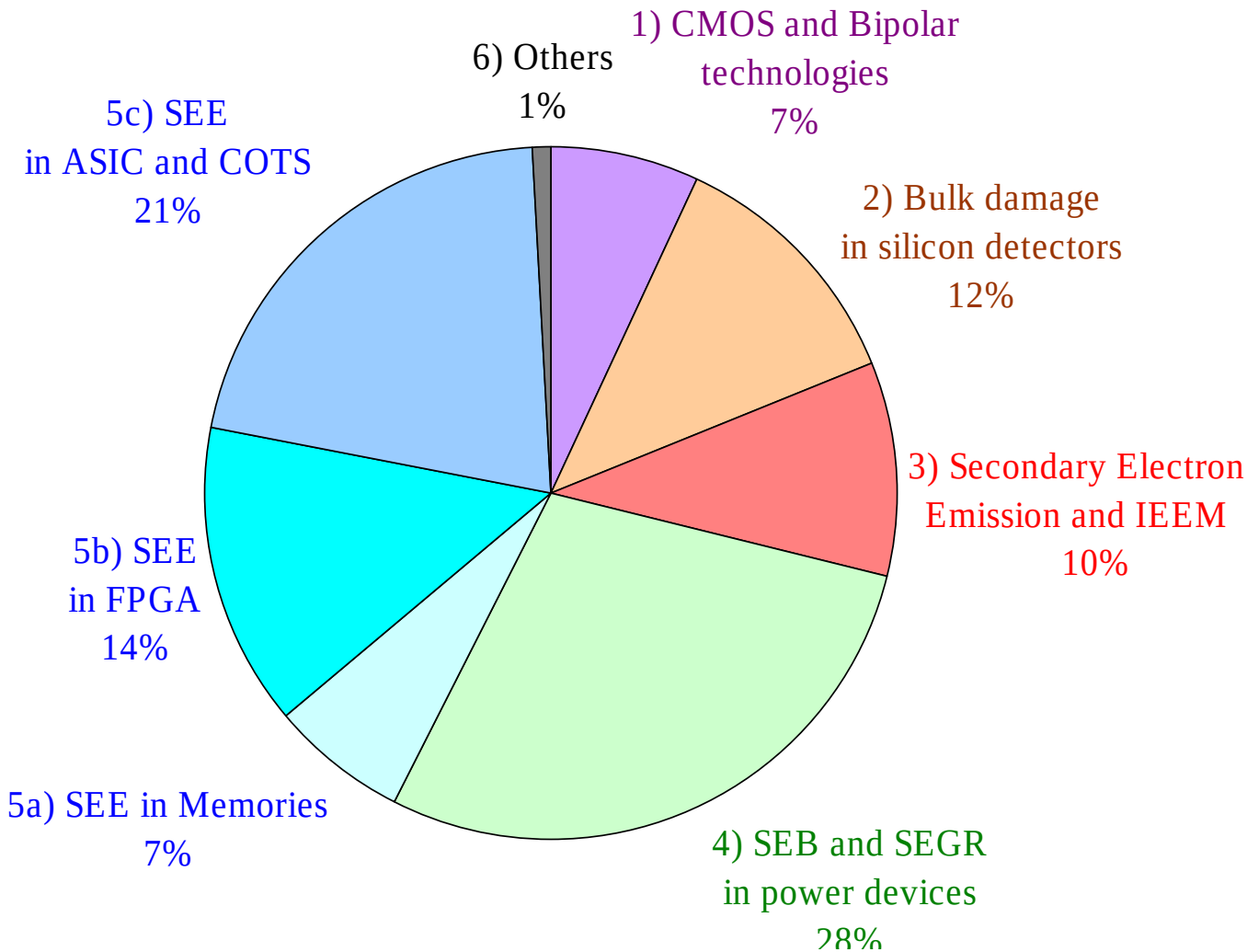
SIRAD Collaboration in Italy and abroad (2001-2004)

1) Dip. Fisica and INFN Padova
2) INFN Laboratori Nazionali di Legnaro
3) Dip. Ingegneria dell'Informazione, Padova
4) Tecnomare SpA (Venezia)
5) Center for Advance Space Optics (Trieste)
6) Dip. Fisica and INFN, Trieste
7) ITC-IRST (Trento)
8) Dip. Informatica e Telecomunicazioni, Trento
9) INAF, Sezione di Milano
10) ST Microelectronics (Agrate Brianza, Milano)
11) Dip. Elettronica, Pavia
12) Dip. Ingegneria Industriale, Bergamo
13) Dip. Fisica Sperimentale, Torino
14) Dip. Automatica e Informatica, Politecnico di Torino
15) Dip. Fisica and INFN, Bologna
16) Dip. Energetica and INFN, Firenze
17) Aurelia Microelettronica SpA (Viareggio)
18) Dip. Ingegneria Elettronica, Università Roma 2
19) INAF, Sezione di Roma
20) DAEIMI and DSM, Università di Cassino
21) ST Microelectronics (Catania)

A) Institut für Experimentalphysik (Hamburg, Germany)
B) LETI (Grenoble, France)
C) Centro Nacional de Microelectronica (Barcellona, Spain)
D) IMEC (Louvain, Belgium)
E) Philips Semiconductor (Nijmegen, Netherlands)
F) CERN (Geneve, Swizerland)
G) Helsinki Institute of Particle Physics (Finland)
H) Santa Cruz Institute for Particle Physics (California, U.S.A)

Beam time allocation at SIRAD in 2001-2004

(2179 hours => 91 days)



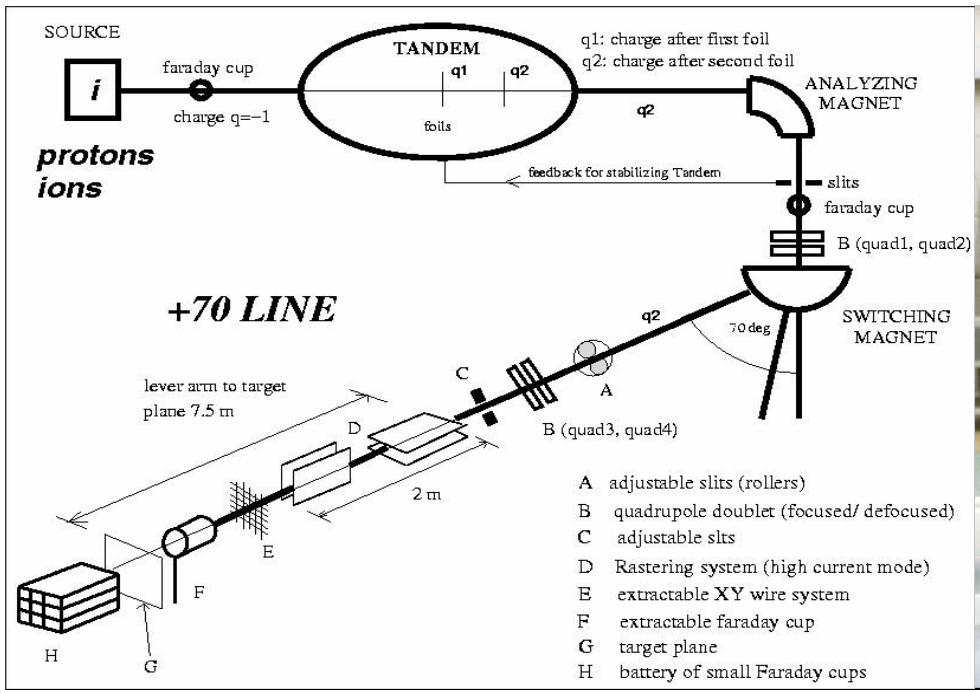
The SIRAD irradiation facility

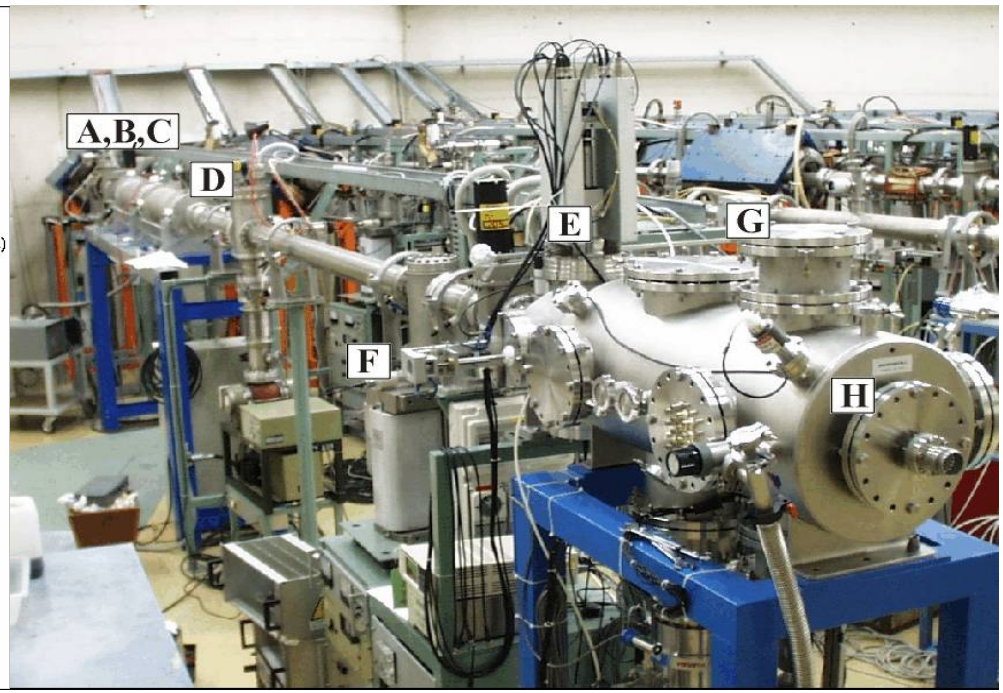
The SIRAD irradiation facility is located at the Tandem accelerator of the INFN National Laboratory of Legnaro (Padova, Italy).

Tandem accelerator:

-Van de Graaff type; **15 MV maximum voltage**; two strippers;

- servicing 3 experimental halls for nuclear and interdisciplinary Physics.





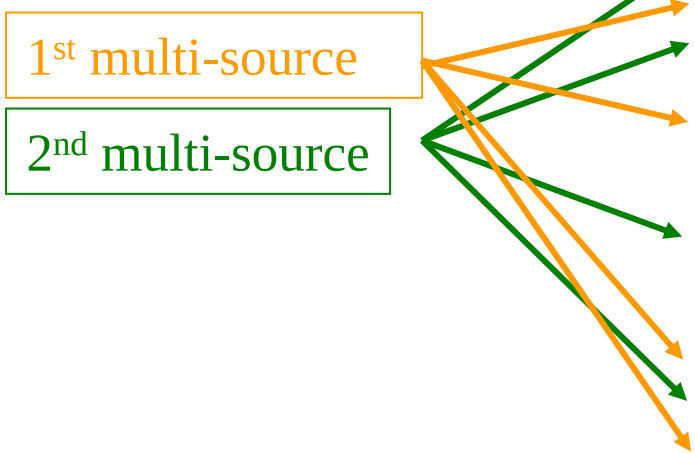
Schematics of the 15 MV **Tandem** Van de Graaff **accelerator** and of the **SIRAD irradiation facility** at the +70º beam line (left). A photograph of the SIRAD irradiation facility is also shown for completeness (right).

Typical ion species available at the Tandem accelerator

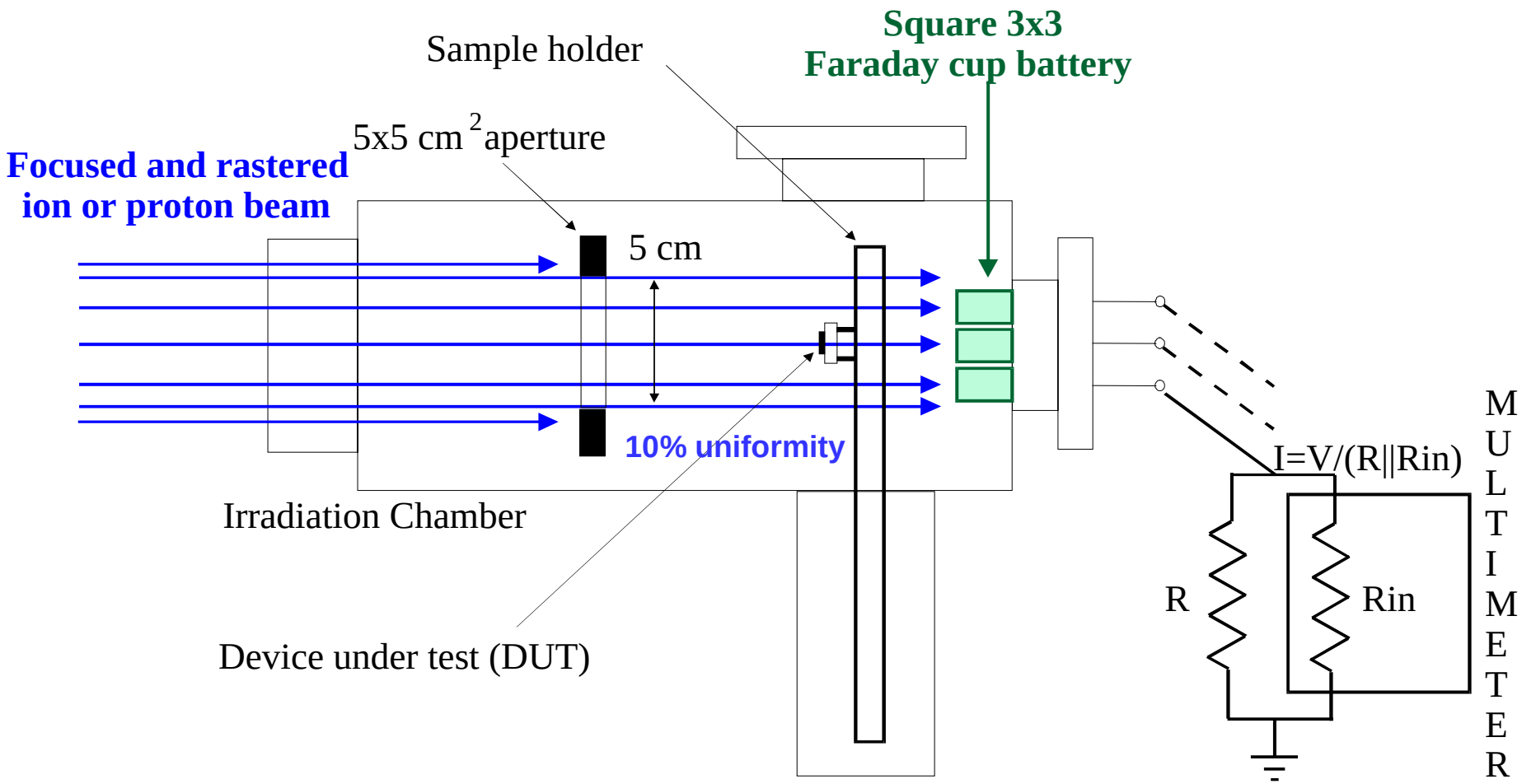
- Ion species from ^{1}H (22-30 MeV) up to ^{197}Au (1.4 MeV/a.m.u.)
- LET from 0.02 MeV×cm^2/mg (^{1}H) up to 79.1 MeV×cm^2/mg (^{197}Au)

The energy values refer to the most probable q_1 and q_2 charge state, with two stripper stations and the Tandem operating at 14 MV.

Ion Species	q_1	q_2	Energy (MeV)	Range in Si (μm)	Surface LET in Si (MeV×cm^2/mg)
^{1}H	1	1	28	4340	0.02
^{7}Li	3	3	56	376	0.37
^{11}B	4	5	80	185	1.13
^{12}C	5	6	94	164	1.53
^{16}O	6	7	108	107	2.95
^{19}F	7	8	122	95	3.90
^{28}Si	8	11	157	61	8.58
^{32}S	9	12	171	54	11.1
^{35}Cl	9	12	171	50	12.7
^{48}Ti	10	14	196	40	20.9
^{51}V	10	14	196	38	22.6
^{58}Ni	11	16	220	37	29.4
^{63}Cu	11	16	220	34	31.9
^{74}Ge	11	17	231	33	36.9
^{79}Br	11	18	241	33	41.8
^{107}Ag	12	20	266	29	58.4
^{127}I	12	21	276	30	65.4
^{197}Au	13	26	275	26	79.1

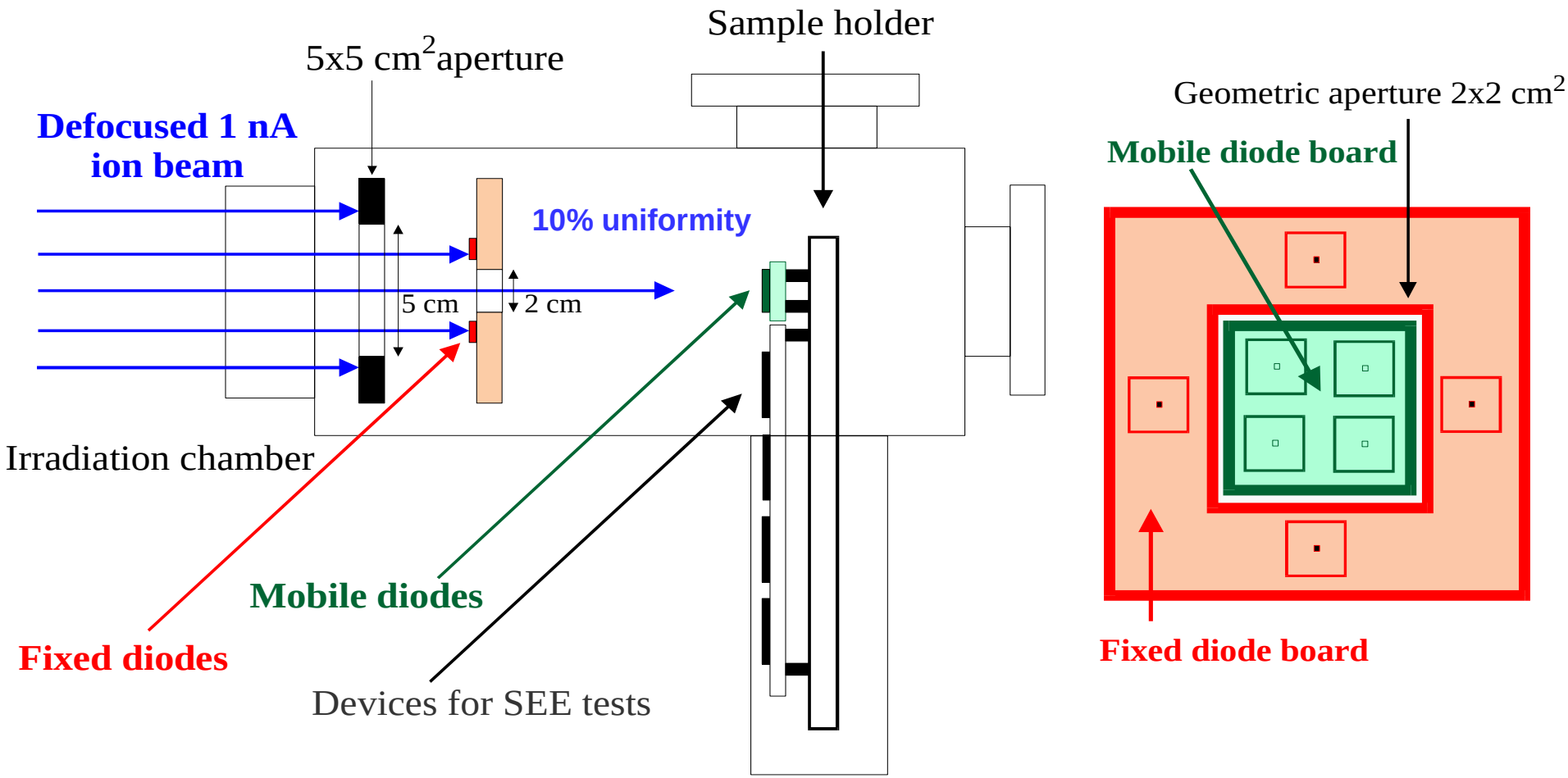


High flux (>10^8-10^9 ions/cm^2×s) irradiation set-up on 5×5 cm^2 area



The **on-line beam monitoring for rastered proton and ion beams** by the 3×3 battery of Faraday cups positioned behind the DUT: side view of the experimental setup. The aperture of each Faraday cup is 0.6×0.6 cm^2. The figure is not drawn to scale.

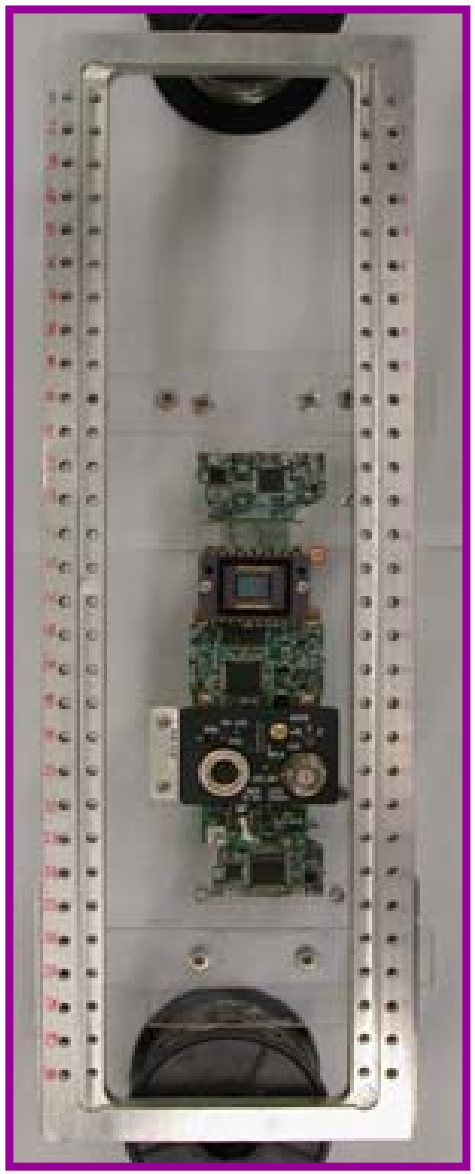
Low flux (≈10^2-10^5 ions/cm^2×s) irradiation set-up on 2×2 cm^2 area



The **on-line beam monitoring system for defocused beams** by the fixed and mobile diodes:
-left: side view of the experimental set-up;
-right: front view (transverse to the beam) of the fixed and mobile diode boards.
The mobile diodes are mounted on the sample holder with the DUT. The figure is not drawn to scale.

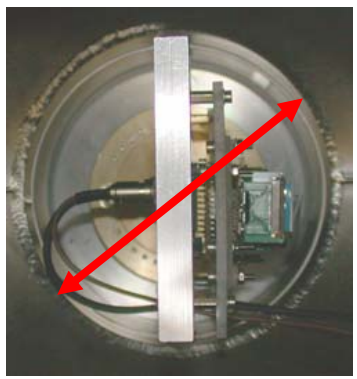
Sample holder

Sample holder: 10.2 cm (horizontal) × 33 cm (vertical) with M3 screws to fix the boards



The sample holder is vertically motorized in order to irradiate more samples without breaking the vacuum: the zone for user irradiation has a vertical amplitude of 19 cm

The boards on the sample holder including the connectors have to be inscripted in a 14 cm diameter



How to access the SIRAD irradiation facility

The time for tests/experiments is assigned on the basis of a scientific proposal evaluated by the LNL User Selection Panel (USP) two times each year:
- June for the period October-February (1st semester)
- January for the period March-July (2nd semester)

All the proposed activities for the SIRAD irradiation facility are grouped in one unique proposal submitted to USP. The assigned time is shared among the different proposed activities depending on the necessities/priorities.

Advantages:
- No charge for the approved activities;
- Possibility of free access to the LNL facilities and services (mechanical workshop, user and radioprotection services, guest house).

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Web site: http://sirad.pd.infn.it/

Beam time shift: details

Irradiation beam time shift: 24-48 hours, eventually to be shared among more groups depending on the requirements.

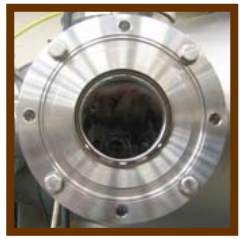
Personal support: 2 operators for running the Tandem accelerator
1 person for running the SIRAD facility (if requested by users)

Time required for beam setting: 2 hours for each ion species (average value)
6 ion species are routinely considered in 24 hours

Required vacuum level: 2-3$\times 10^{-5}$ mbar
Pumping system: scroll pump for pre-vacuum + turbo pump for high vacuum
Time required for vacuum: 30 minutes to few hours, depending on the material budget

Electrical connections and set-up

Possibility to see/illuminate the DUT: yes by a glass window



Electrical connectors on the chamber: 16 BNC + 8 High Voltage BNC (or 24 BNC)
2 connectors DSUB with 50 pin

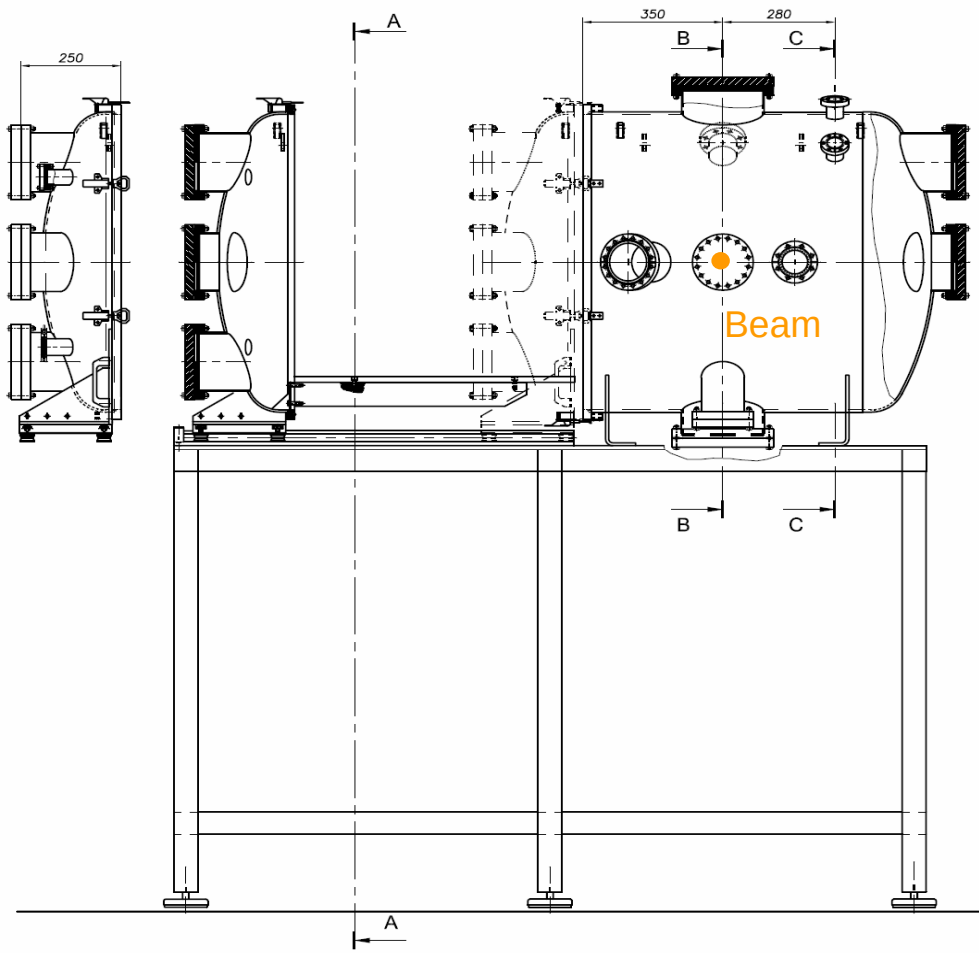
Experimental set-up: DAQ with remote PC close to the SIRAD beam line and control PC in the user box

Connections SIRAD beam line - user box: 3 network cables for computers
20 BNC connections 50 Ohm
1 video cable 75 Ohm

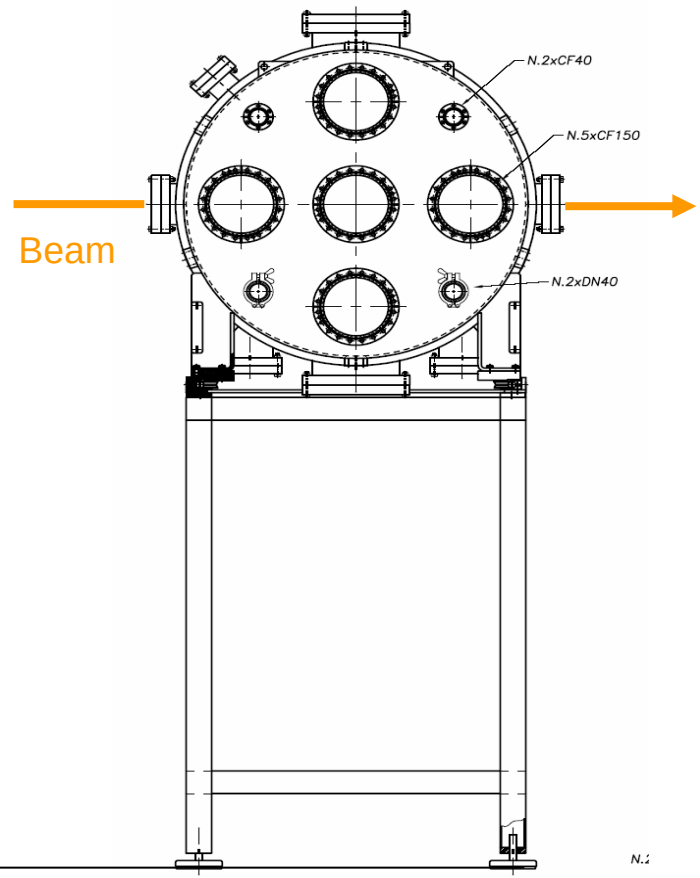
Next future upgrade for the end of 2005: the irradiation chamber

Shape: cylinder
Dimensions: L=80 cm, D=80 cm
Manufacturer: RIAL Vacuum

Frontal view

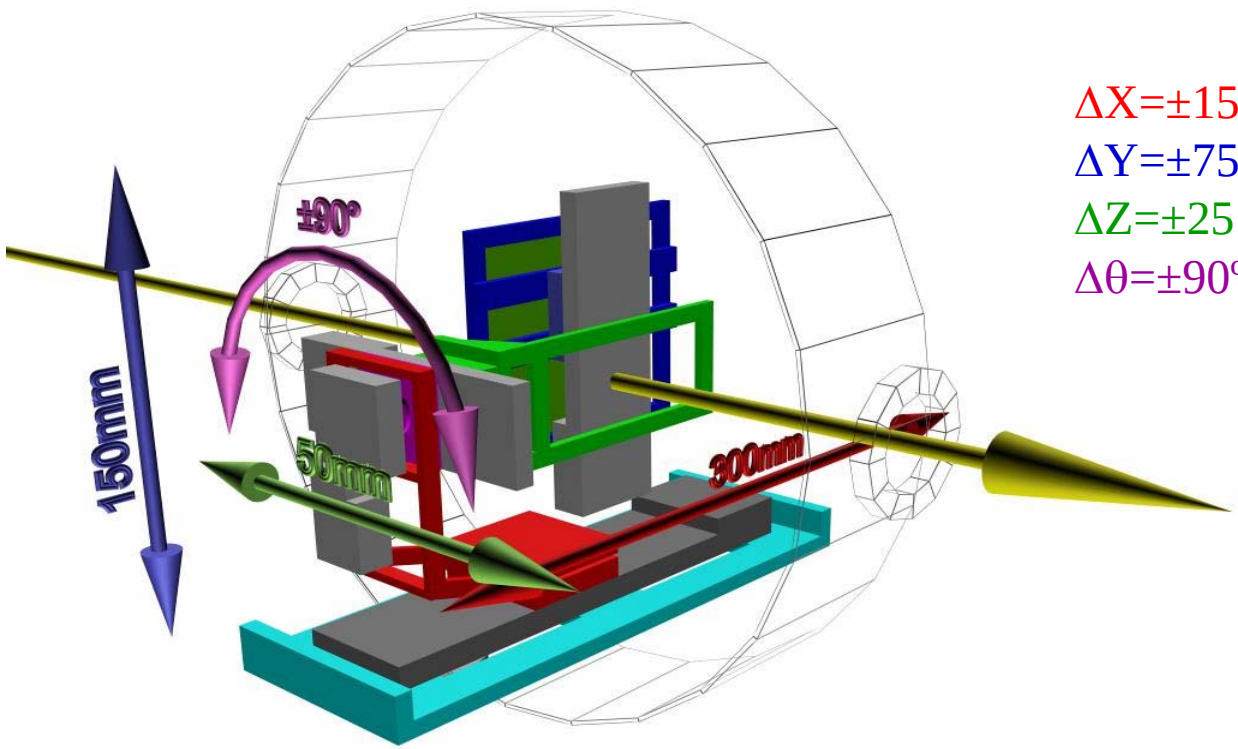


Lateral view



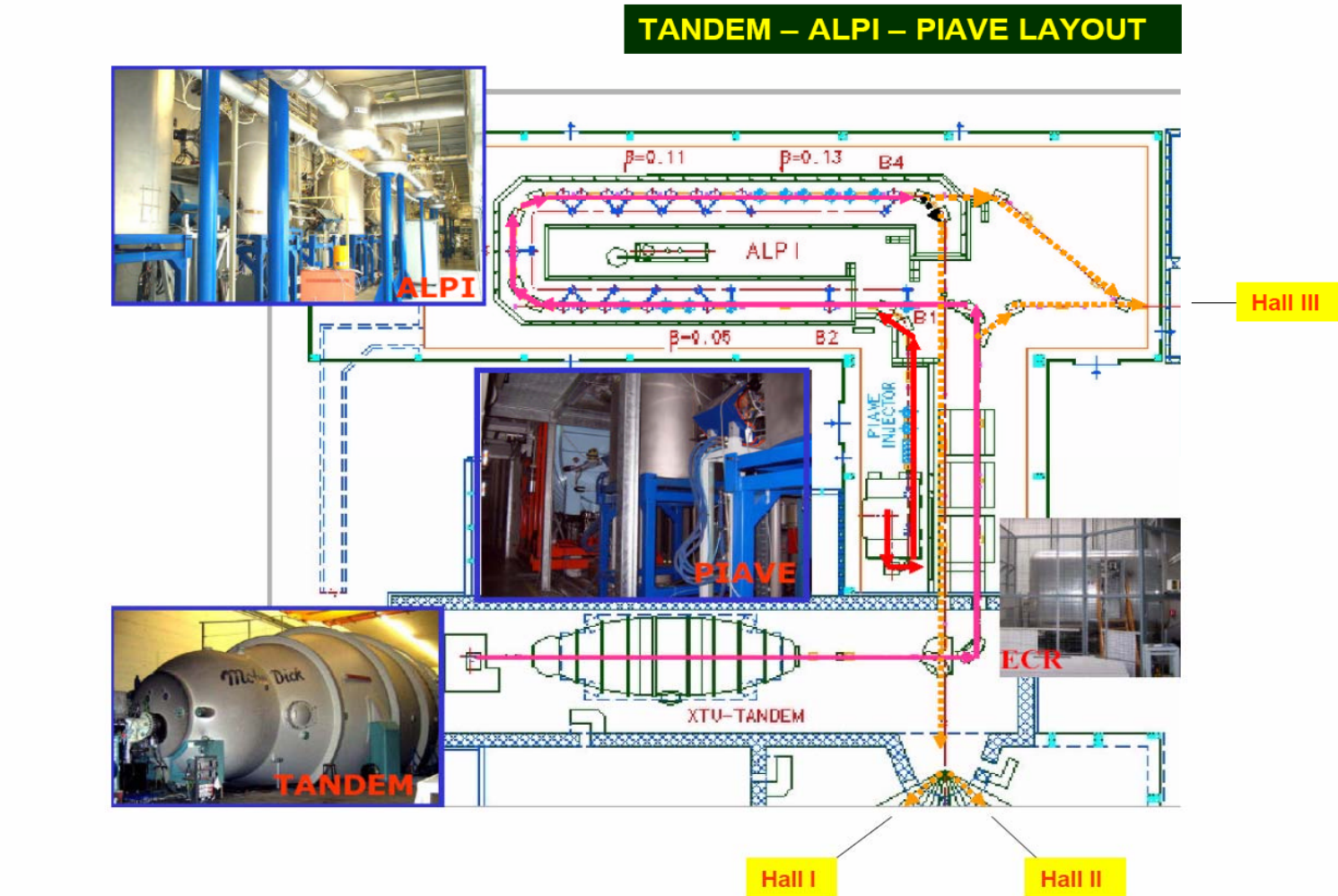
Next future upgrade for the end of 2005: motorization of the sample holder

- High vacuum motors (free air - 10^{-7} mbar operation) from PI (Germany)
- 4 axis of freedom: X, Y, Z, rotation
- Resolution on motor position better than 10 μm
- Full compatibility with SIRAD and ESA sample holders



ΔX=±150 mm
ΔY=±75 mm
ΔZ=±25 mm
Δθ=±90°

Tandem-ALPI complex



$$E_{Tandem\text{-}ALPI} = E_{Tandem} + E_{ALPI} = E_{Tandem} + Q_{Tandem} \times 35\ MeV$$

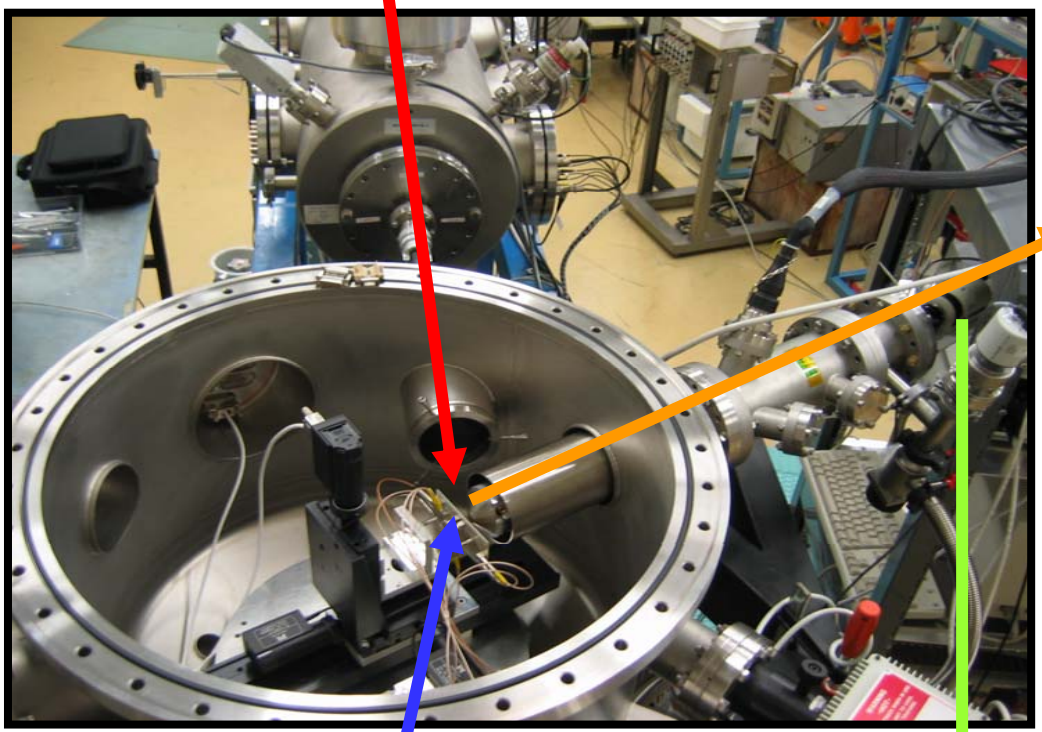
Comparison Tandem accelerator and Tandem-ALPI complex

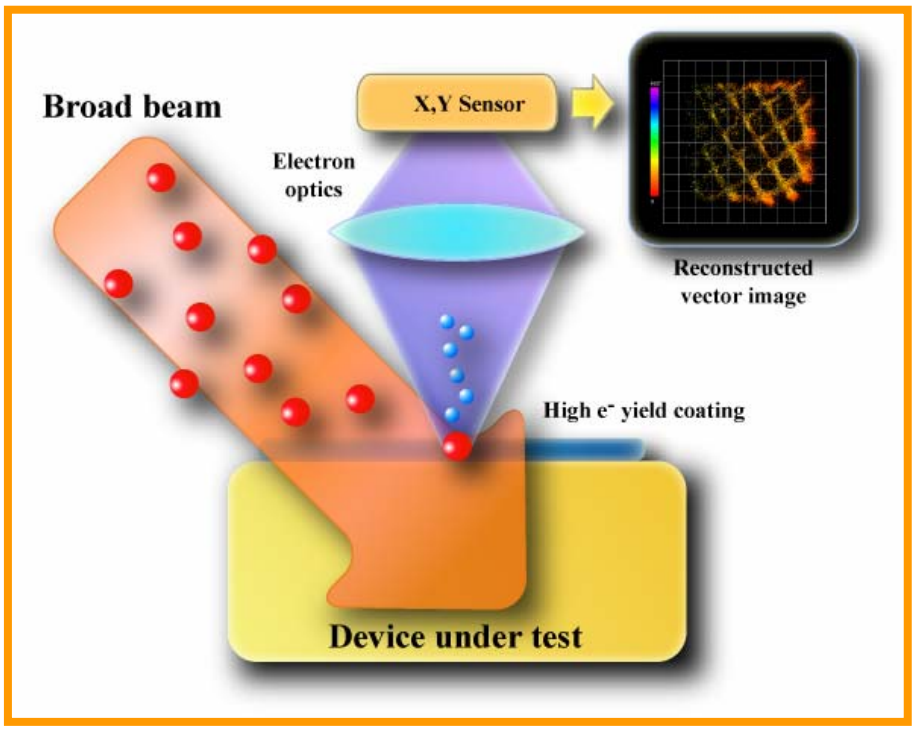
			Tandem			Tandem-ALPI		
Ion Species	q_1	q_2	Energy (MeV)	Range in Si (μm)	Surface LET in Si (MeV×cm^2/mg)	Energy (MeV)	Range in Si (μm)	Surface LET in Si (MeV×cm^2/mg)
^{1}H	1	1	28	4340	0.02	-----	-----	-----
^{7}Li	3	3	56	376	0.37	-----	-----	-----
^{11}B	4	5	80	185	1.13	-----	-----	-----
^{12}C	5	6	94	164	1.53	-----	-----	-----
^{16}O	6	7	108	107	2.95	-----	-----	-----
^{19}F	7	8	122	95	3.90	-----	-----	-----
^{28}Si	8	11	157	61	8.58	542	373	3.9
^{32}S	9	12	171	54	11.1	591	311	5.2
^{35}Cl	9	12	171	50	12.7	591	268	6.2
^{48}Ti	10	14	196	40	20.9	686	188	10.9
^{51}V	10	14	196	38	22.6	686	171	12.2
^{58}Ni	11	16	220	37	29.4	780	147	17.3
^{63}Cu	11	16	220	34	31.9	780	135	19.1
^{74}Ge	11	17	231	33	36.9	826	121	23.8
^{79}Br	11	18	241	33	41.8	871	112	28.1
^{107}Ag	12	20	266	29	58.4	966	83	49.4
^{127}I	12	21	276	30	65.4	1011	77	61.8
^{197}Au	13	26	275	26	79.1	1185	69	92.4

The Ion Electron Emission Microscope (IEEM)

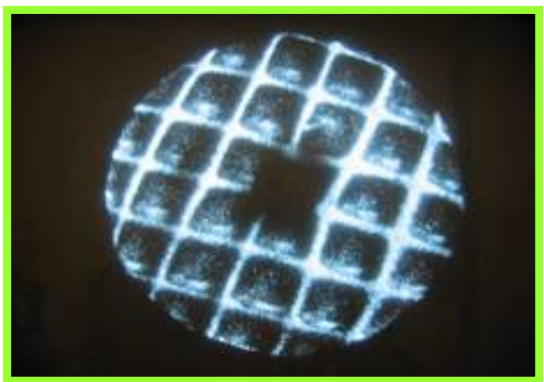
223 MeV Br ion beam

Purpose: Single Event Effect mapping





- **Lattice step: 40 μm**
- **Structure width is about 6 μm**
- **The lattice is made by copper**
- **Sub-μm sample holder**



Conclusions

- The SIRAD irradiation facility at the 15 MV TANDEM accelerator:
  - Ion species from ^{1}H (23-30 MeV) up to ^{197}Au (1.4 MeV/a.m.u.)
  - LET from 0.02 MeV×cm^2/mg up to 79.1 MeV×cm^2/mg
  - High (>10^8-10^9 ions/cm^2×s) and low (10^2-10^5 ions/cm^2×s) flux set-up
  - **New irradiation chamber and sample holder (compatible with ESA standards)**
  - **Potentiality to increase the ion energy of Q_{Tandem}×35 by ALPI**
  - **Ion Electron Emission Microscopy capability**
- The 7 MV CN accelerator:
  - Monochromatic neutron spectra: D(d,n)^{3}He, T(d,n)^{4}He, ^{7}Li(p,n)^{7}Be
  - Continuous neutron spectra: ^{9}Be(d,n)^{10}B
  - Thermal neutrons: ^{9}Be(d,n)^{10}B with moderator
- Total dose tests:
  - X-rays: W (L-lines at 7-12 keV) and Mo (K-lines at 17-20 keV) anode; dose rate: 120 rad(Si)/s.
  - γ-rays: ^{60}Co source with 1-5 rad(Si)/s dose rate (D=20-45 cm).

CN accelerator: neutron beams

Table II
Neutron sources at the CN accelerator

Formula	E_{beam} (MeV)	I_{max} (nA)	Spectra	$E_{neutrons\ at\ 0°}$ (MeV)	Reference
D(**d**,n)^{3}He	2-7	100	Monochromatic	5-10	Rev. Mod. Phys. (1956) 103-134
T(**d**,n)^{4}He	2-7	100	Monochromatic	18-24	Rev. Mod. Phys. (1956) 103-134
^{7}Li(**p**,n)^{7}Be	2-7	500	Monochromatic	0.2-5	NIM A 238 (1985) 443-452
^{9}Be(**d**,n)^{10}B	2.6-7	300	Continuos	0.06-11.4	NIM A324 (1993) 239-246
^{9}Be(**d**,n)^{10}B with moderator	2.6-7	300	Thermal	$<0.4\times10^{-6}$	NIM A489 (2002) 347-369