SIRAD
An irradiation facility for radiation damage studies

Serena Mattiazzo
Università di Padova, Dipartimento di Fisica e Astronomia
INFN Sezione di Padova

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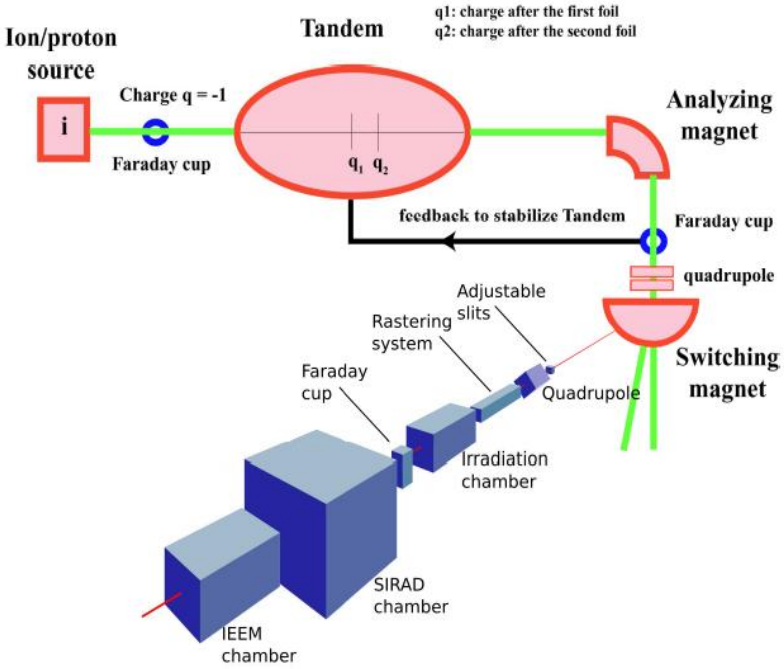
Outline

- Overview on radiation effects
- Description of the SIRAD facility
- SIRAD recent collaborations
  - General revies
  - Focus on INFN activities

THE SIRAD IRRADIATION FACILITY



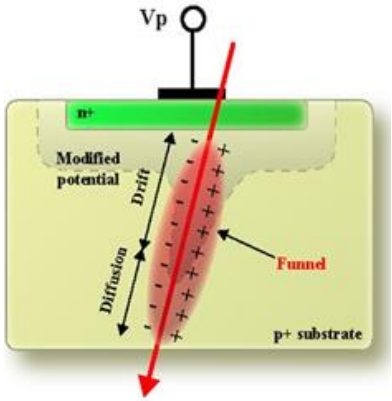
The SIRAD irradiation facility is located in the Experimental Hall 1 (beam line +70°) of the Tandem Accelerator of the LNL

Radiation Effects in Electronics

Ionization

SEE - Single Event Effects

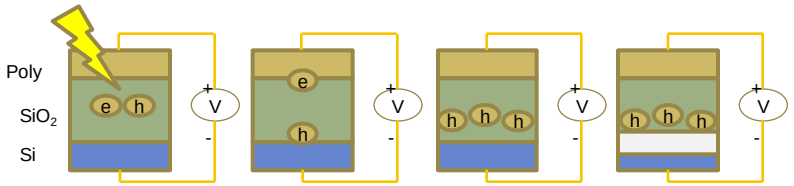
- Effect due to the passage of a single energetic ionizing particle
- Sudden large $\Delta E_{ionization}$ deposited in the "wrong" place at the "wrong" time (sensitive junction)



Cumulative

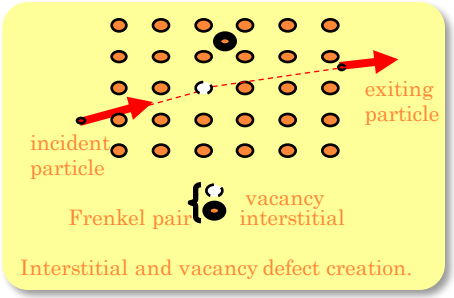
TID - Total Ionizing Dose

- Small $\Delta E_{ionization}$ deposited uniformly and delivered over a long time
- Slow drift of device parameters due to charge accumulation in SiO_2



DDD - Displacement (Bulk) Damage Dose

- Non-ionizing ΔE transfers to atomic nuclei (Coulomb nuclear interactions).
- Cumulative displacement damage of silicon lattice



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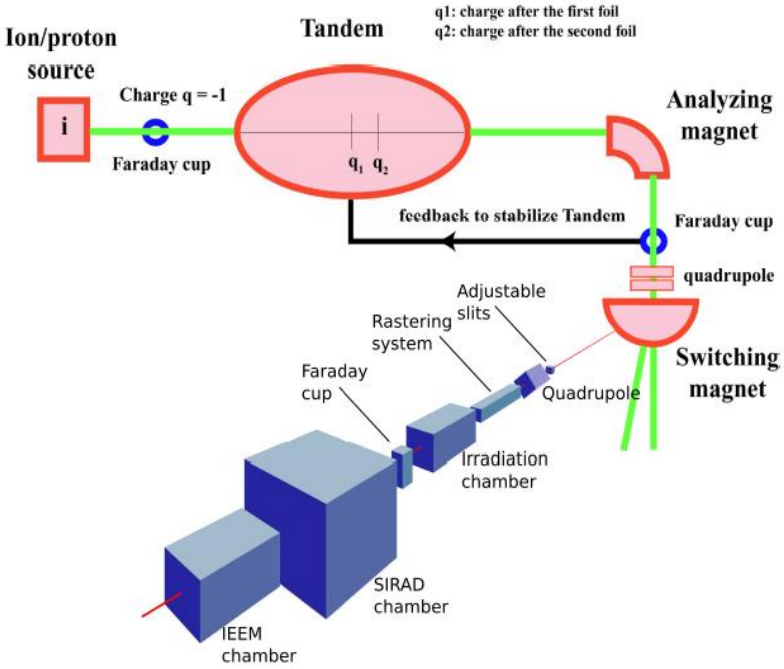
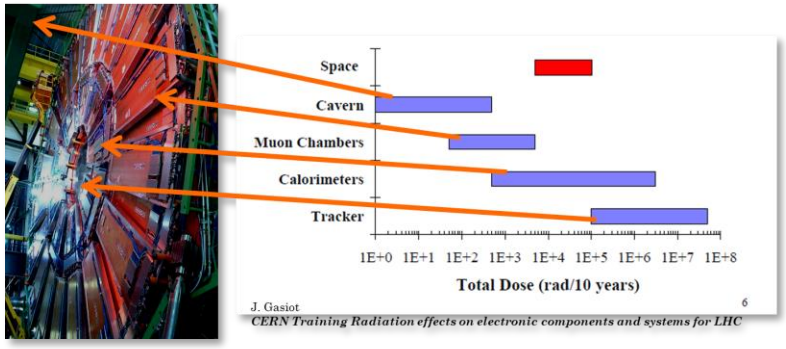


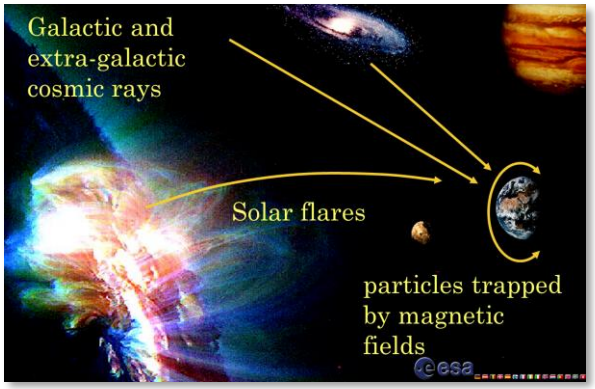
- **SEE** tests with heavy ions
- **DDD** with protons and lithium ions
- **TID** with heavy ions
- **Material modification** with heavy ions

Radiation environments of interest

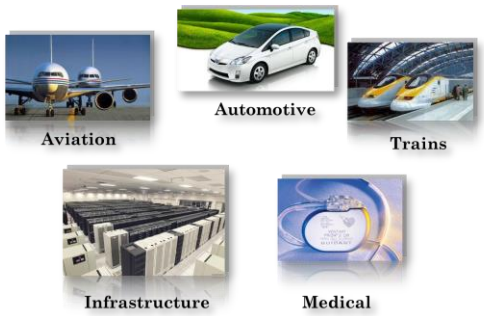
- **High Energy and Nuclear Physics Environments**



- **Space environments**



- **Everyday environments**



Ion beams available at SIRAD

- Typical ions available at SIRAD serviced by the XTU-Tandem accelerator, assuming:
  - Tandem voltage at 14 MV,
  - the most probable charge state using two strippers.
- Note: The range and surface LET are in silicon (SRIM).
- The magnetic rigidity is also tabulated. The rigidity limit of SIRAD is ~ 1.6 T-m

$$E = E_{inj} + V_0 \cdot [1 + q_1 \cdot f + q_2 \cdot (1 - f)] \qquad f = 0.25$$

Ion Species	Energy [MeV]	q_1	q_2	Rigidity [T·m]	Range in Si [μm]	Surface LET in Si [MeV×cm²/mg]
^{1}H	28	1	1	0.77	4340	0.02
^{7}Li	56	3	3	0.95	376	0.37
^{11}B	80	4	5	0.86	185	1.13
^{12}C	94	5	6	0.81	164	1.53
^{16}O	108	6	7	0.86	107	2.95
^{19}F	122	7	8	0.87	95	3.90
^{28}Si	157	8	11	0.87	61	8.58
^{32}S	171	9	12	0.89	54	11.1
^{35}Cl	171	9	12	0.93	50	12.7
^{48}Ti	196	10	14	1.00	40	20.9
^{51}V	196	10	14	1.03	38	22.6
^{58}Ni	220	11	16	1.02	37	29.4
^{63}Cu	220	11	16	1.06	34	31.9
^{74}Ge	231	11	17	1.11	33	36.9
^{79}Br	241	11	18	1.10	33	41.8
^{107}Ag	266	12	20	1.21	29	58.4
^{127}I	276	12	21	1.28	30	65.4
^{197}Au	275	13	26	1.52	26	79.1

1st multi-source (^{19}F, ^{35}Cl, ^{79}Br, ^{127}I)

2nd multi-source (^{16}O, ^{28}Si, ^{58}Ni, ^{107}Ag)

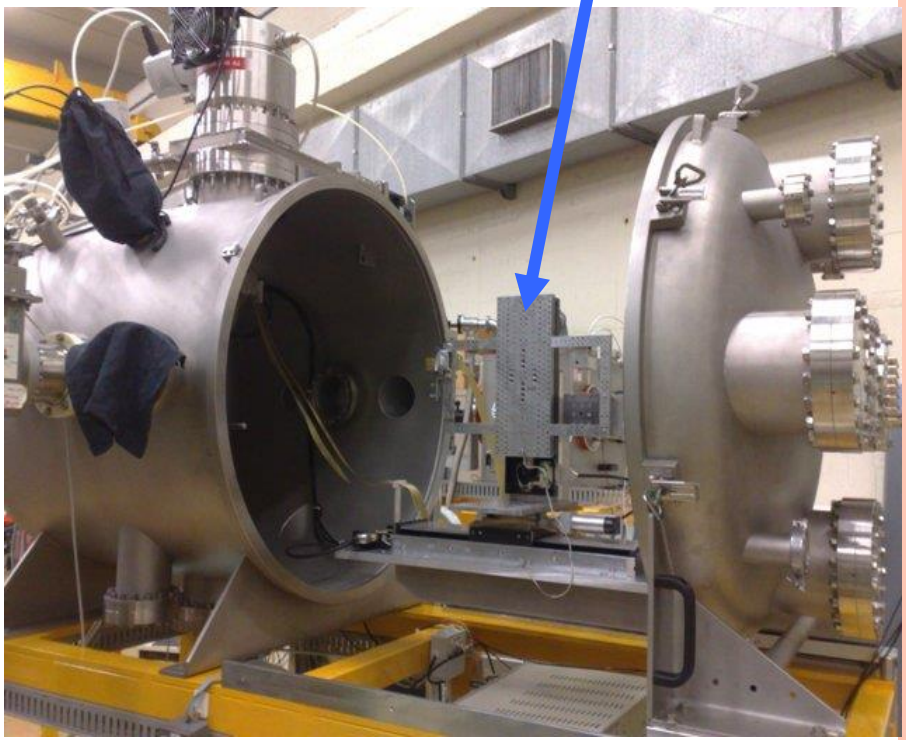
SIRAD TECHNICAL CHARACTERISTICS

The **irradiation chamber**
(active since 2006)

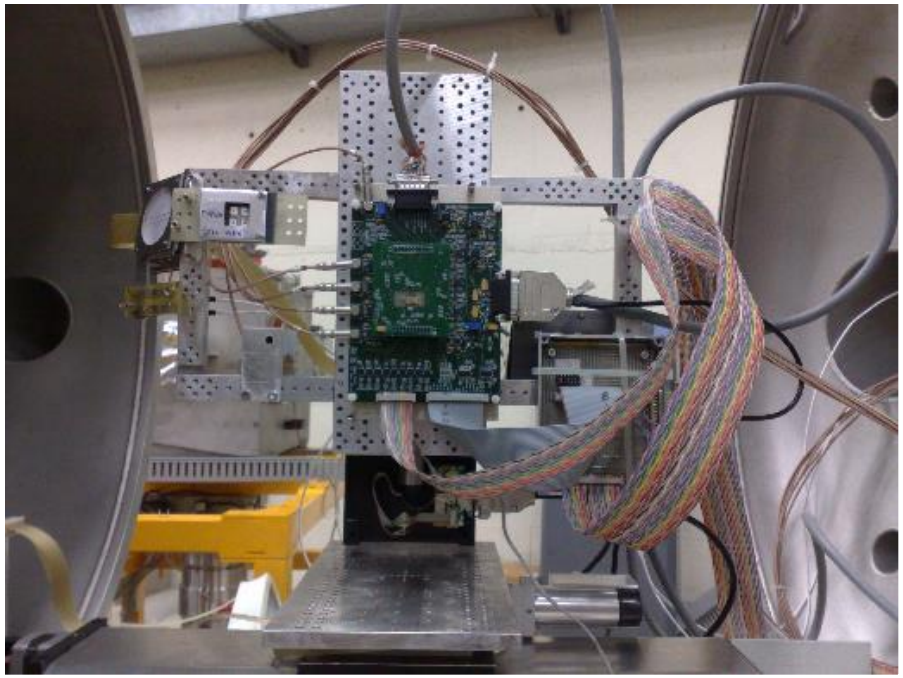
Diameter : 80 cm
Depth: 80 cm

It is used for global SEE tests, bulk damage and TID studies

The chamber is open with the **sample holder** exposed



SIRAD TECHNICAL CHARACTERISTICS

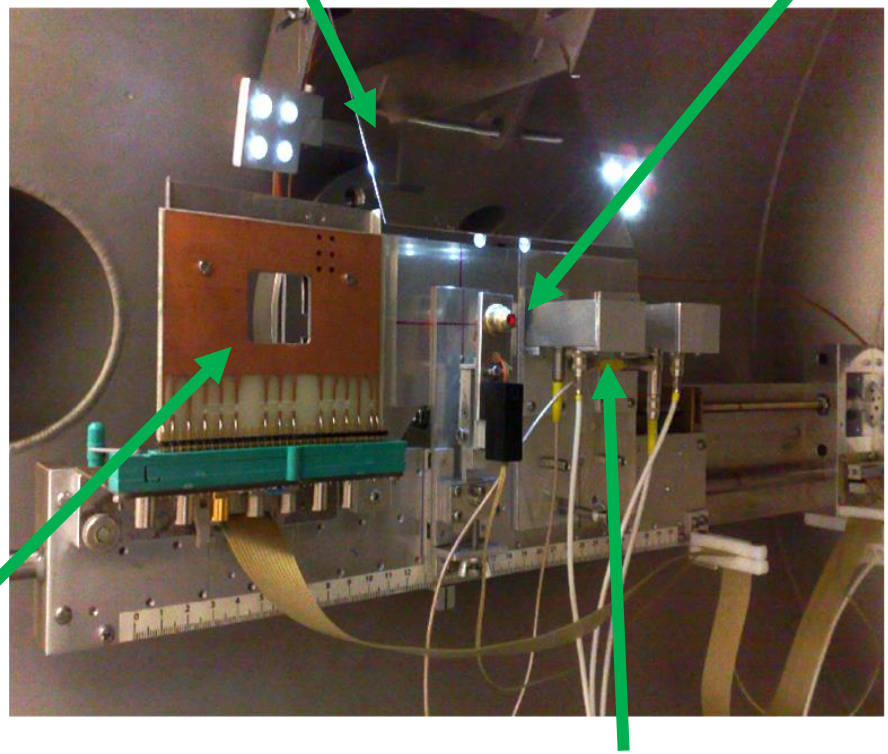


Motorized sample holder

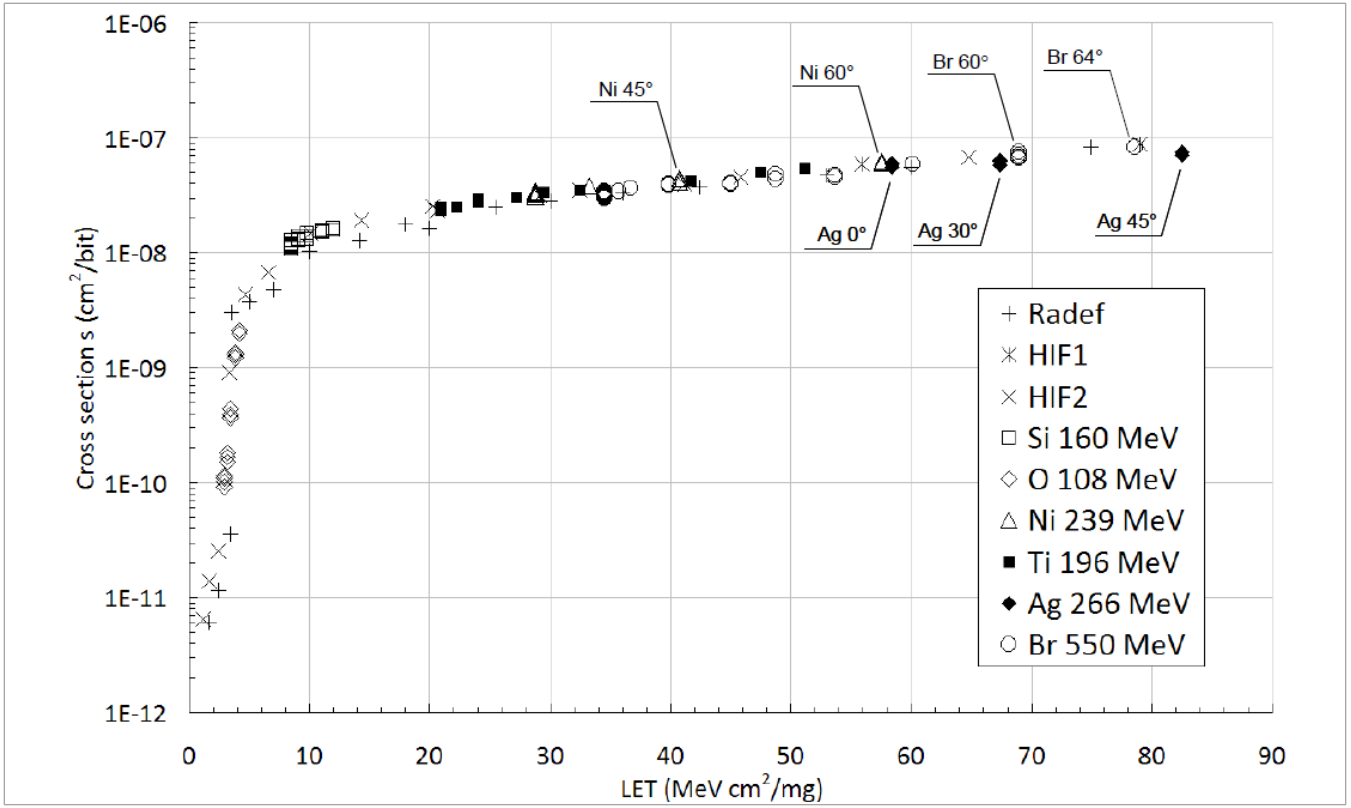
Horizontal transl.	30 cm
Vertical transl.	15 cm
Resolution	10 µm
Rotation axis	vertical, +/-80° (1° steps)

http://www.youtube.com/watch?v=sKPew-nnfog

The dosimetry systems inside the irradiation chamber



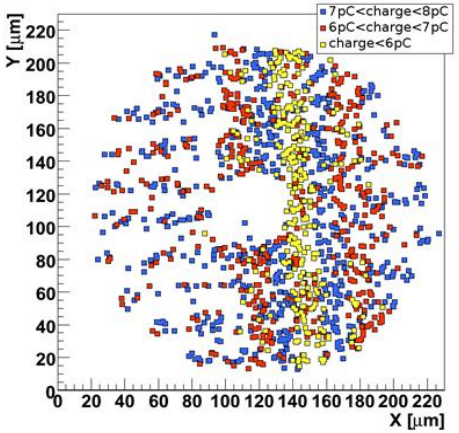
Single Event Cross section curve

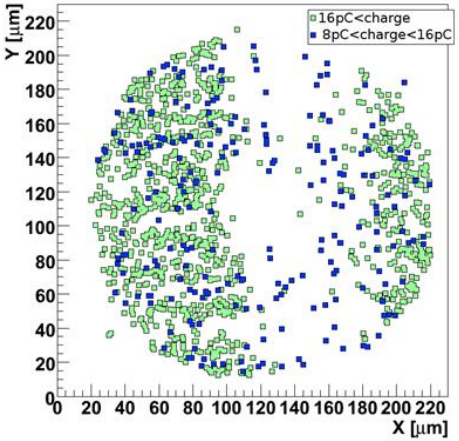


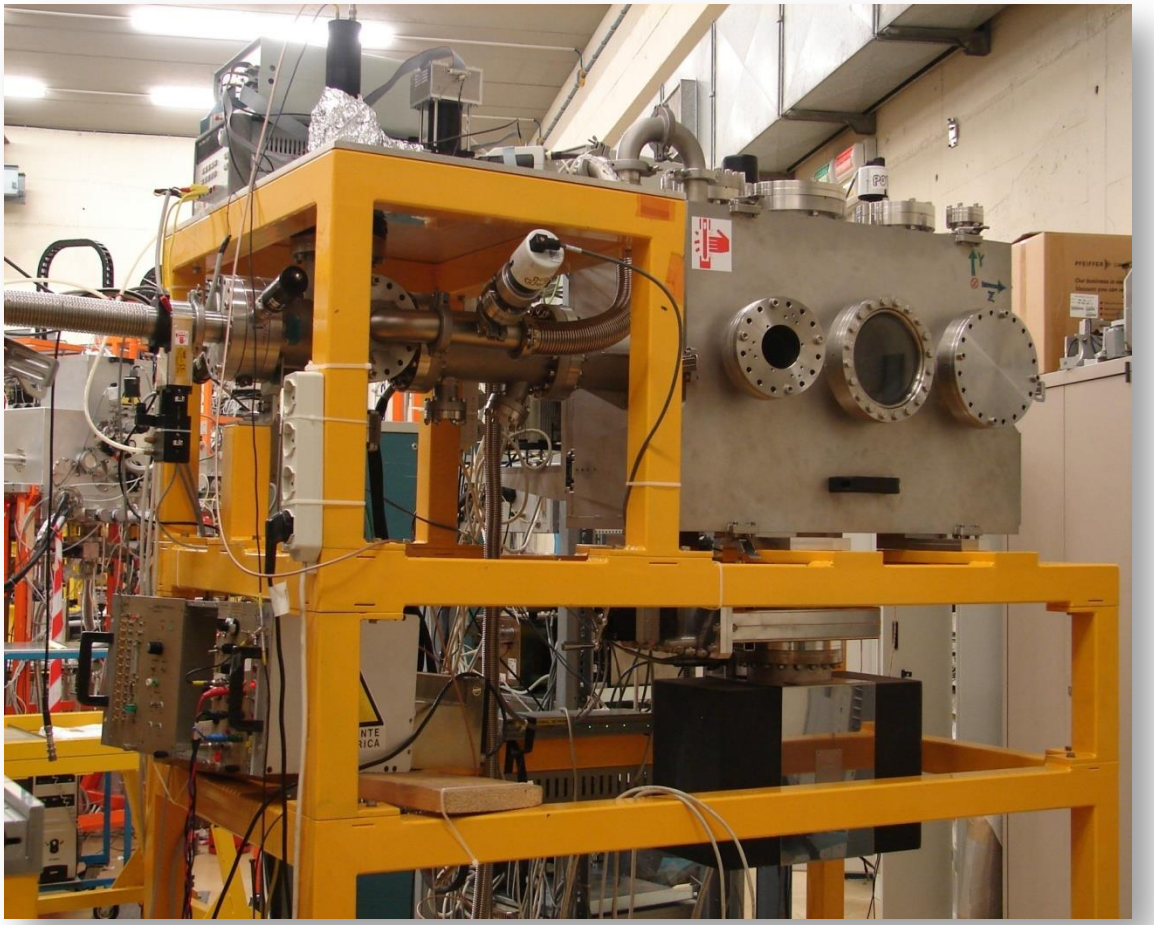
The Ion Electron Emission Microscope

- Time resolved ion induced SEE-micromapping with the IEEM:
  - single energetic heavy ion impact points are reconstructed with a resolution of a few microns at a rate of 1kHz over a circular area of 180 µm diameter.

power MOSFET device with 223 MeV ^{79}Br ions.







SIRAD COLLABORATION IN 2013-2019

- Univ. e INFN Padova
- Univ. e INFN Milano-Bicocca
- Univ. e INFN Torino
- Univ. e INFN Ferrara
- INFN Pisa
- INFN Trieste
- Univ. and INFN Padiva
- INFN Roma-Tor Vergata
- Univ. Cassino
- INAF IAPS
- ENEA

- CERN
- EPFL
- IFIN-HH
- Micron Technology
- ESA
- NASA-JPL
- Technical University of Braunschweig
- CEA-LETI
- STMicroelectronics

2013-2019: HEP APPLICATIONS

- **CHIPIX65** (INFN Padova, INFN Torino, INFN Bari, INFN Pavia, INFN Pisa, INFN Milano, CERN)
  - Study of Single Event Effect (SEE) on pixel readout integrated circuits in 65nm for HL-LHC upgrade
- **LHCb** (INFN Ferrara, CERN, IFIN-HH)
  - Radiation hardness tests and qualification for SEE of the read-out electronics chain for the Upgrade of the LHCb RICH detectors at CERN and Radiation hardness (SEE) on FPGAs in the context of LHCb Upgrade
- **PANDA** (INFN Torino)
  - Single Event Upsets (SEU) in the ToPix4 ASIC for the pixel detector readout of the PANDA experiment
- **ALICE** (INFN Padova, INFN Torino, CERN)
  - Study of proton-induced bulk damage on the prototype pixel and SEU tests of the GBLD laser driver for sensors for the ALICE ITS upgrade
- **CMS** (INFN Padova, INFN Pavia, INFN Trieste, CERN)
  - TID effects on CMS muon barrel detector Electronics, bulk damage on SiPM for the CMS HCAL upgrade and SEE on RPCs (Resistive Plate Chamber) Front-End Board for the CMS Muon System at HL-LHC
- **SCALTECH28** (INFN Padova, INFN MI Bicocca, CERN, EPFL)
  - Study of Single Event Effects (SEE) on a flip flop based shift register in a 28nm High-K CMOS technology for future HEP experiments
- **APOLLO** (INFN Padova, INFN Roma, CERN, Cassino University, Padova University)
  - SEE tests on LV Power Supplies for the next High Energy physics experiments

2013-2019: SPACE AND OTHER APPLICATIONS

- **Università di Padova – DEI** (Dipartimento di Ingegneria dell'Informazione)
  - SEE on non volatile Flash memories, non volatile phase change memories (PCM), non volatile resistive memories (RRAM), SRAM and flip flop in BCD technology, GaN transistors and MIM capacitors, in collaboration with Micron Technology, ESA, NASA-JPL, Technical University of Braunschweig, CEA-LETI, STMicroelectronics

See Gerardin's talk

- **IXPE** (INFN Roma Tor Vergata, INFN Pisa, INAF IAPS)
  - Single Event Latchup (SEL) and SEU sensitivity of the ASIC in the Gas Pixel Detector of the X-ray Imaging Polarimetry Explorer satellite mission

space

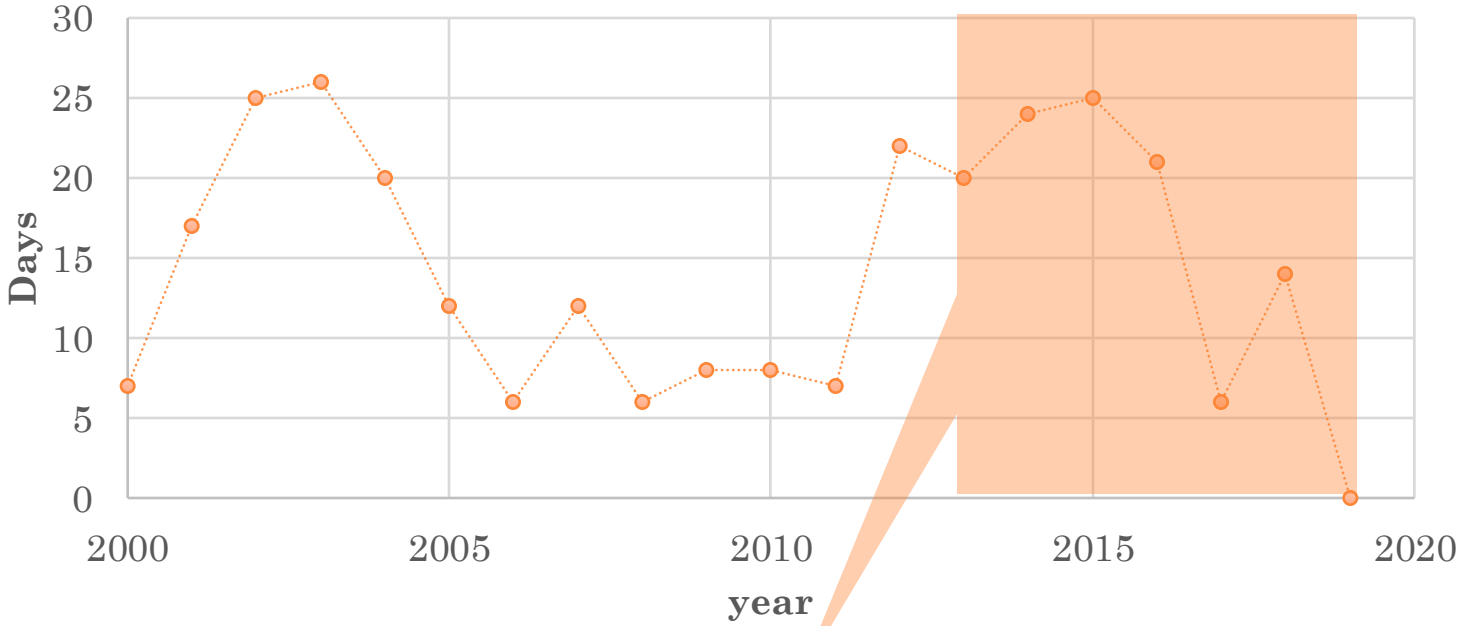
- **Università di Cassino e del Lazio Meridionale** (Dipartimento di Ingegneria Elettrica e dell'Informazione)
  - Single Event Effects in Power MOSFETs

See Velardi's talk

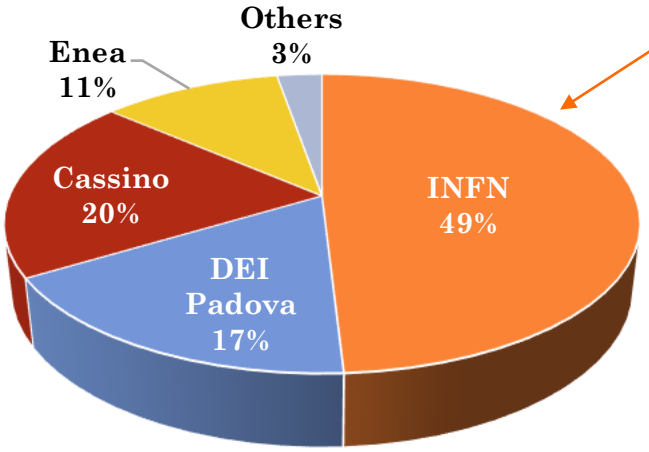
- **ENEA**
  - Investigation of the effect of high fluence irradiation on the swelling and microstructural behavior of DS4 steel and on of anti corrosion coatings for high temperature operation
- **TERA** (INFN Torino)
  - SEU test of the Tera ASIC (hadron beam monitoring in cancer treatment)

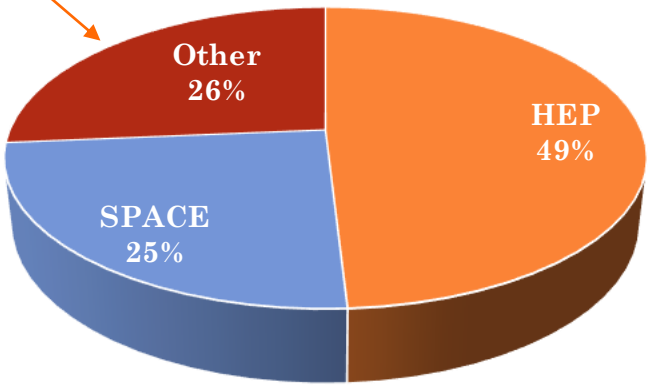
other

BEAMTIME ALLOCATION (2000-2019)

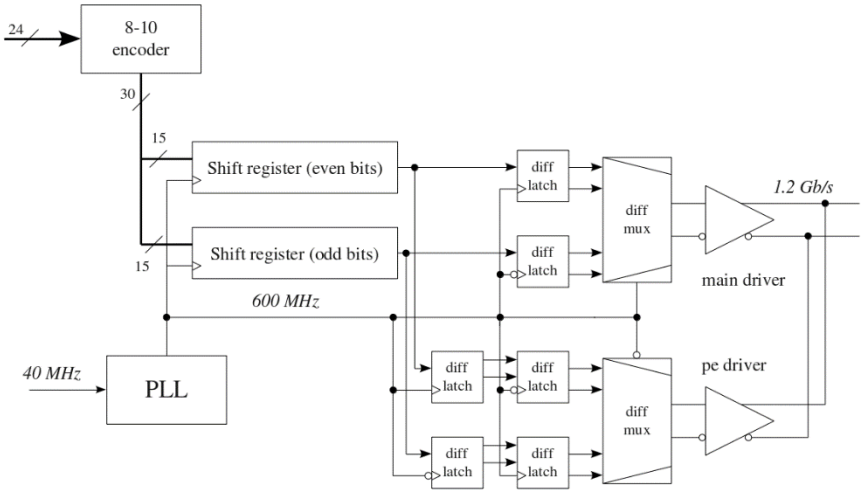


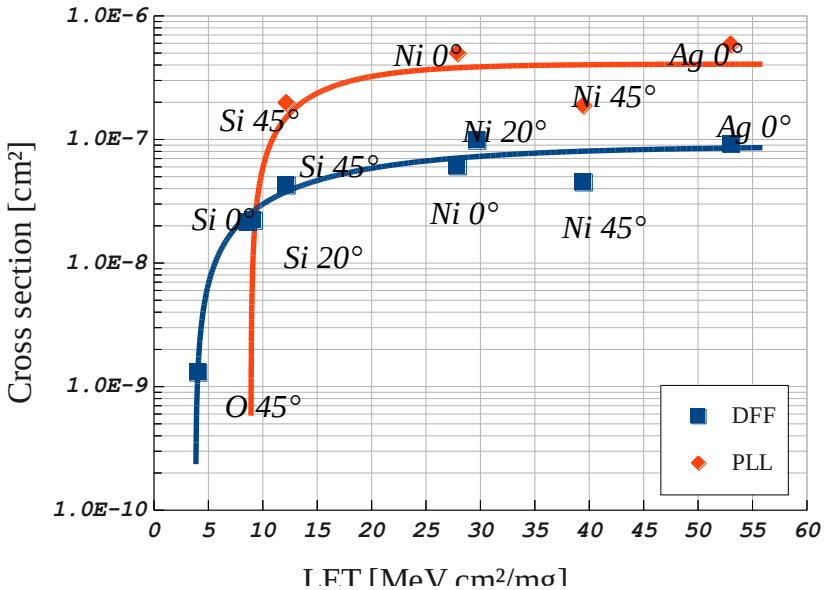
2013-2019



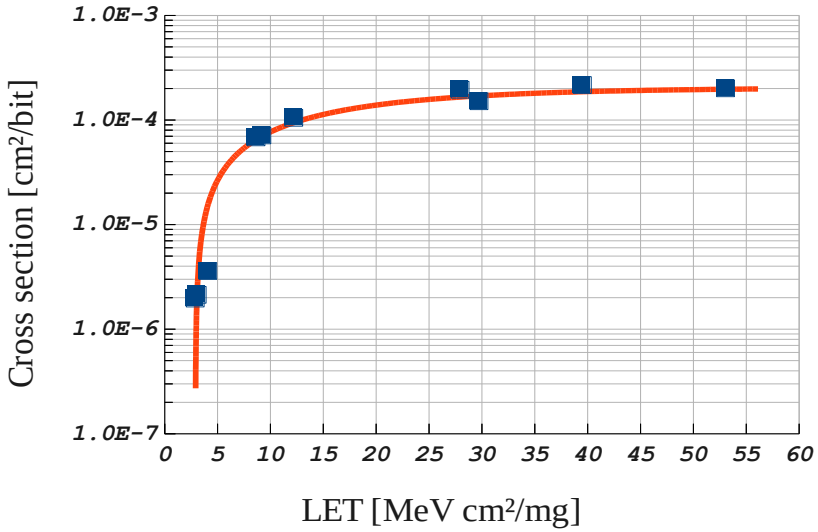


SEU Test on the ALICE ITS ALPIDE DTU

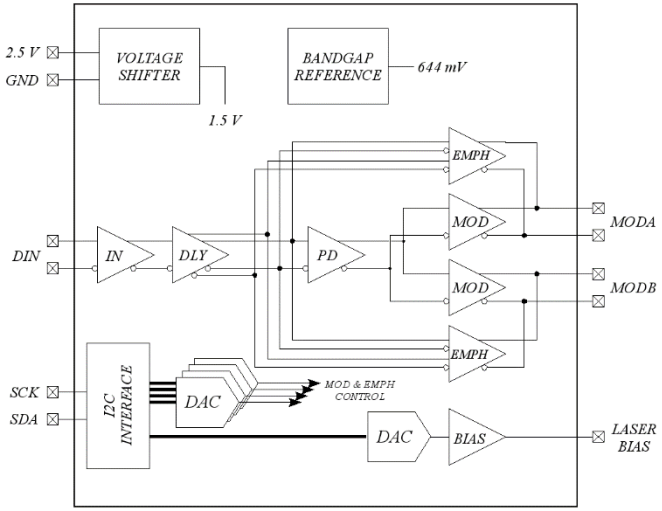


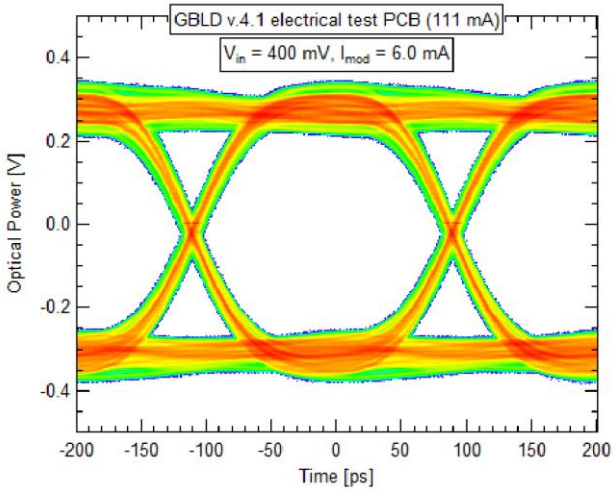


- Data Transmission Unit (DTU) for the ALPIDE ASIC for the ALICE experiment
  - Data rate : 1.2 Gb/s
  - Input clock : 40 MHz
  - Double Data Rate
  - SEU tolerant *(tested at SIRAD)*
  - Installation ongoing

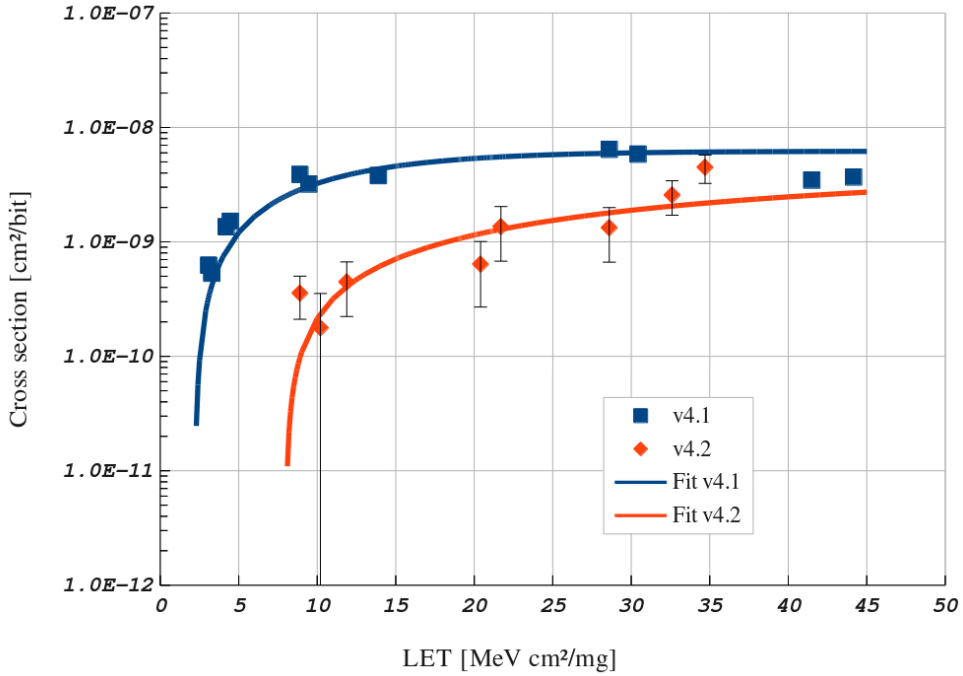


SEU TEST ON GBLD CHIP



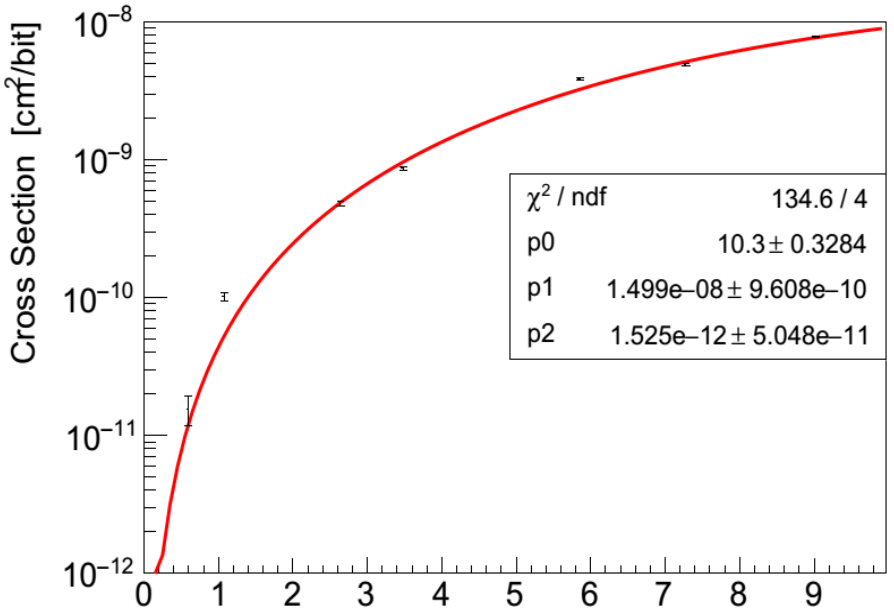


- GBLD is a radiation tolerant laser driver for the GigaBit Transceiver (GBT) project (which, in its turn, is part of the "Radiation Hard Optical Link Project" which aims at developing a radiation hard bi-directional optical link for use in the LHC upgrade programs)
  - Data rate : 5 Gb/s
  - Laser types : EE and VCSEL
  - Technology : CMOS 130 nm
  - SEU tolerant *(tested at SIRAD)*
  - ~91000 chips produced



SEU TEST ON THE PASTA CHIP

- PASTA: custom readout circuit of silicon double-sided micro-strips of the PANDA MVD
  - ASIC developed by JLU Giessen, FZ Juelich and INFN Torino
  - Chip developed in 110 nm UMC technology
  - Radiation tolerant circuits to Single Event Upset (SEU) effects are implemented

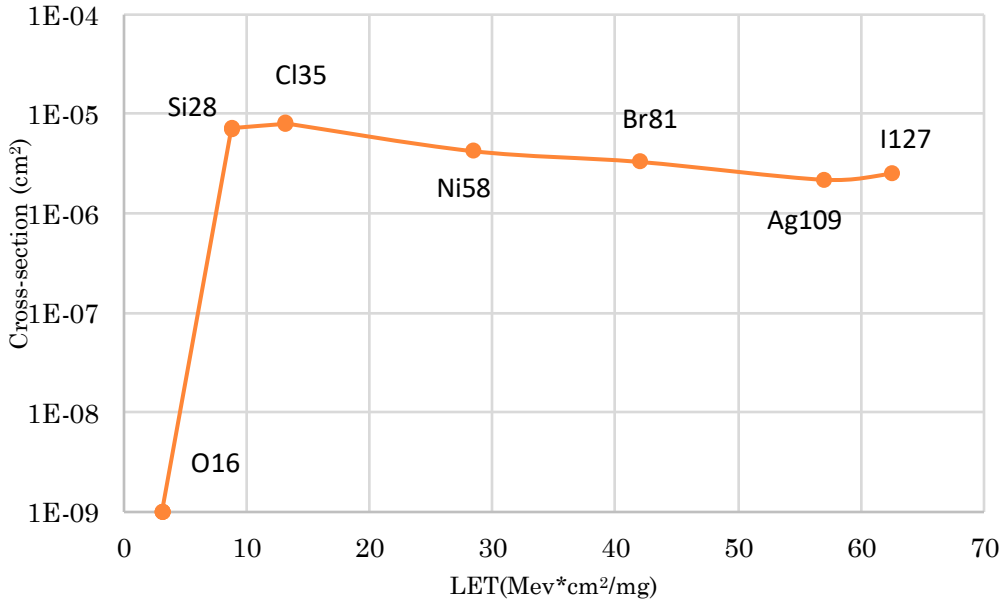


"Study of SEU effects in circuits developed in 110 nm CMOS technology» D. Calvo, et al. Presented at TWEPP2019

- Test on the channel configuration register have been performed at SIRAD
- The obtained result is adequate since the number of upsets expected in the micro-strip detector equipped with 3112 electronics readout chips, is less than 1 bit flip per hour taking into account that an evaluated particle flux of 5×10^4 hadrons/cm^2 contribute to upset effects.

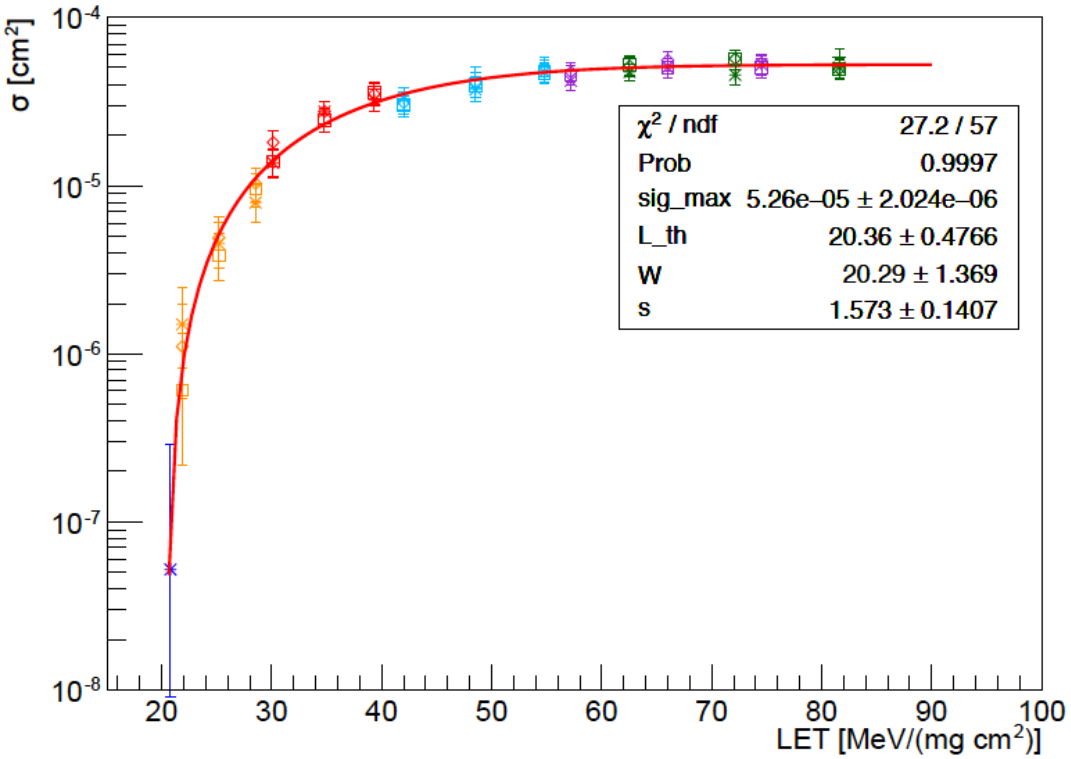
SEU Test on MZMD chip

- The MZMD chip has been designed and produced for the PHOS4BRAIN INFN Gr V experiment: PHOtonic Systems for Broad Rad HArd INterconnect
- It implements two 5 Gbps drivers for Silicon-Photonics Mach Zehnder Modulators and a high-speed serializer
- It is fabricated in 65 nm TSMC technology implementing RHBD techniques like Enclosed Layout, CML and double-long transistors.



SEU test for LHCb RICH Detector Upgrade

- Different irradiations performed in the period 2014-2018
  - Heavy ions and 28 MeV protons
- Radiation hardness characterization of the prototype and production versions of the CLARO ASIC (8 ch. ampl./discr. designed by INFN Ferrara/Milano-Bicocca/AGH-Krakow) and PMT glass transmittance
- Tests at SIRAD were instrumental to assess the CLARO performance



Spokeperson: Massimiliano Fiorini, Università and INFN Ferrara

Conclusions

- SIRAD is a strategic facility for INFN activities to validate electronics which has to survive in radiation harsh environmenst in HEP experiments

- SIRAD collaboration is well established but we are now suffering from shortage of beamtime and of manpower

(INTER)NATIONAL SCHOOL