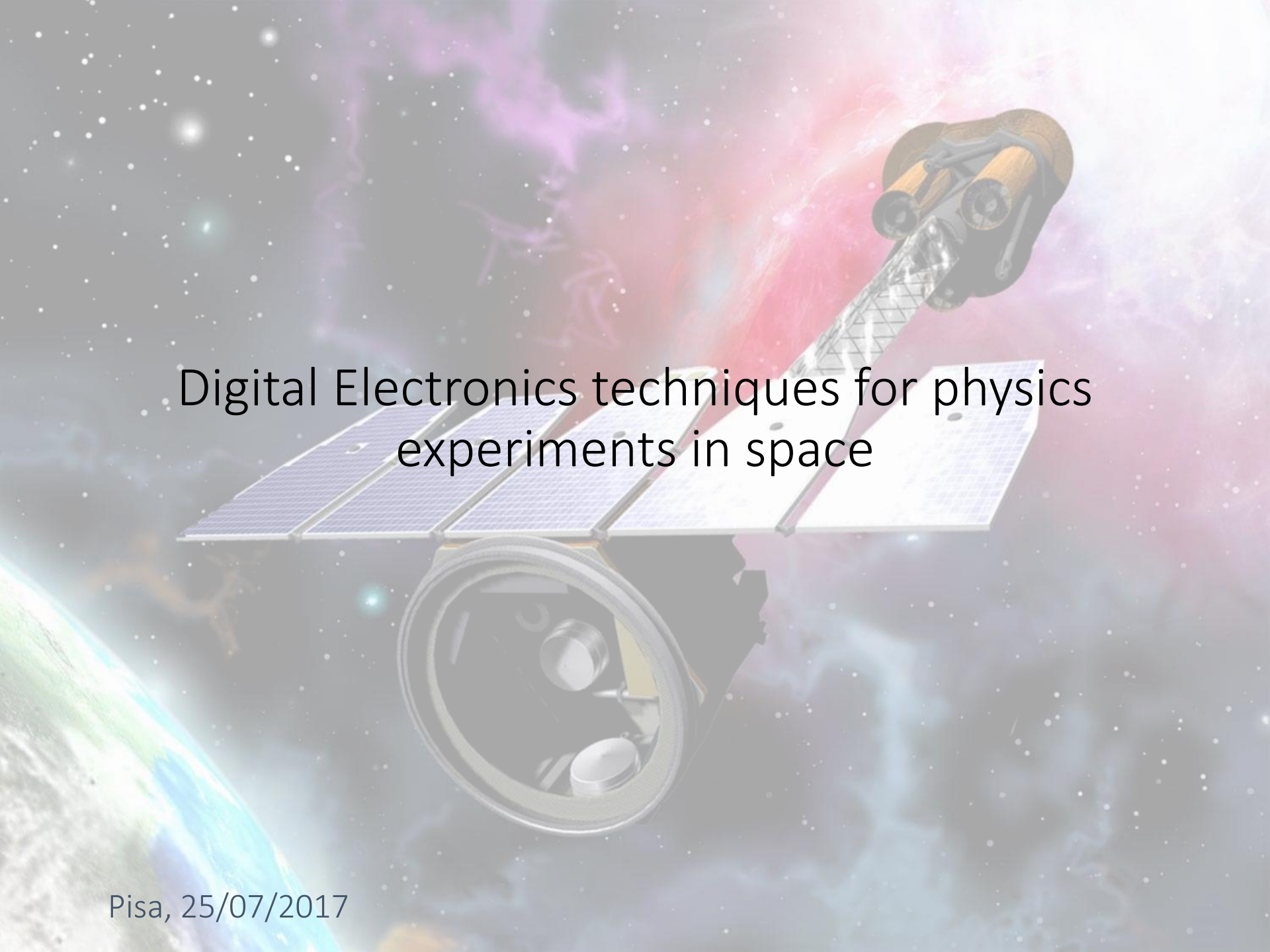


Digital Electronics techniques for physics experiments in space

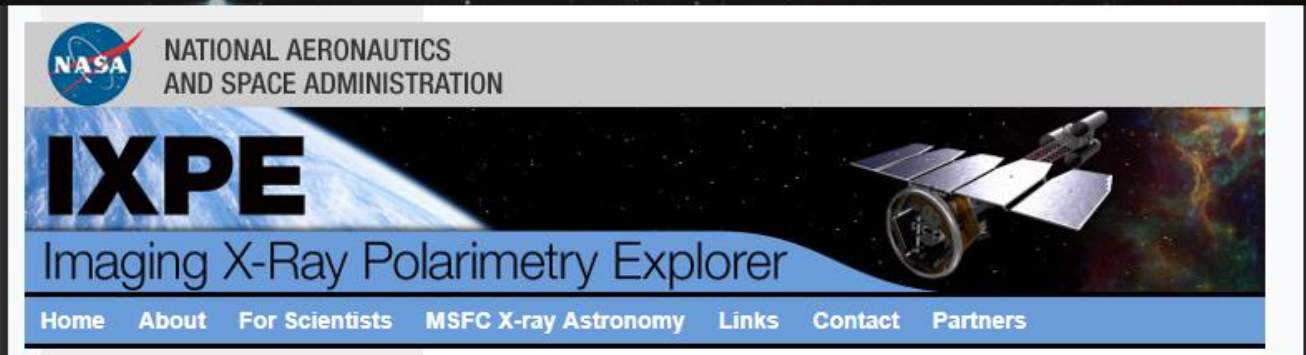
Pisa, 25/07/2017

Saverio Citraro saverio.citraro@pi.infn.it

- Ingegneria Elettronica a Pisa
- PhD Ingegneria dell'Informazione
  - INFN di Pisa, Upgrade FTK (ATLAS)
  - Elettronica per elaborazione dati dai tracciatori di ATLAS
- IXPE, Missione NASA

Summary

- Attività IXPE
- Esempi di schede Elettroniche
- Criticità in ambienti ostili
- Effetti sull’elettronica delle radiazioni ionizzanti
- Test di irraggiamento
- Conclusioni



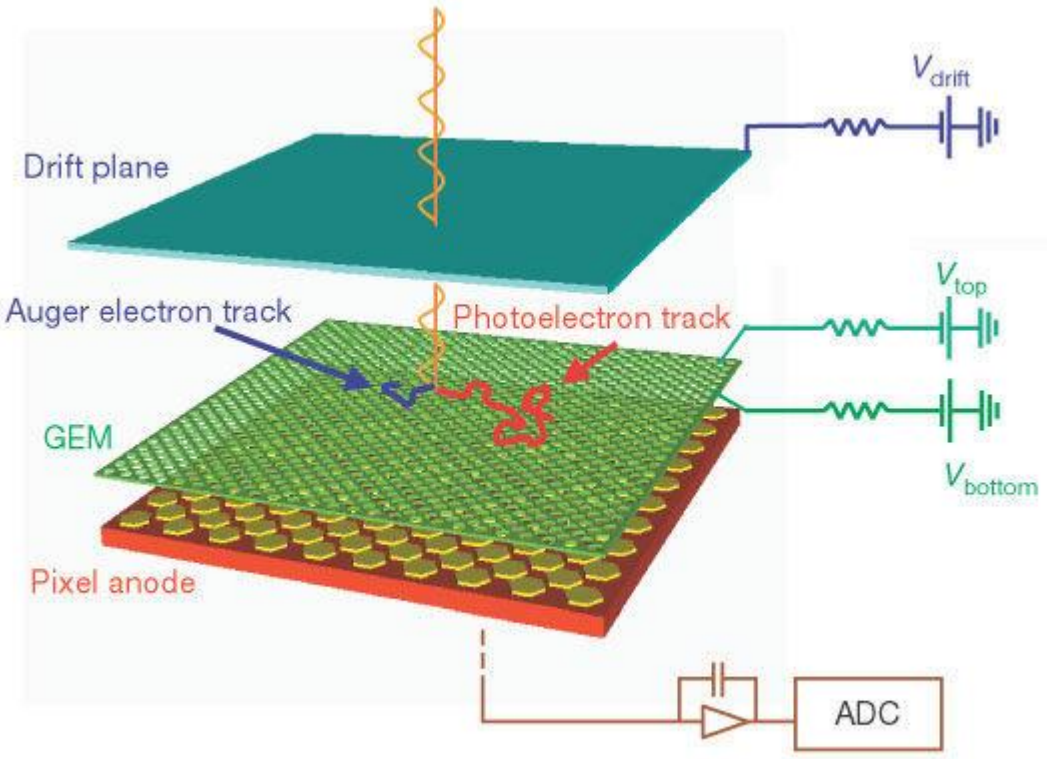
- Missione della NASA per mandare il satellite in orbita nel 2020
- Misurare la polarizzazione dei raggi X provenienti da sorgenti astrofisiche
- Il satellite sarà a circa 500 km di quota
- L'INFN di Pisa ha il compito di progettare e realizzare la Detector Unit del satellite

CUBEsat

- Satellite miniaturizzato avente forma cubica
- Volume di 1 dm^3
- Rispetto a missioni «classiche»:
  - Poco costosi
  - Orbite basse
  - Qualifiche meno stringenti
- E’ possibile avere cicli di progettazione e produzione rapidi

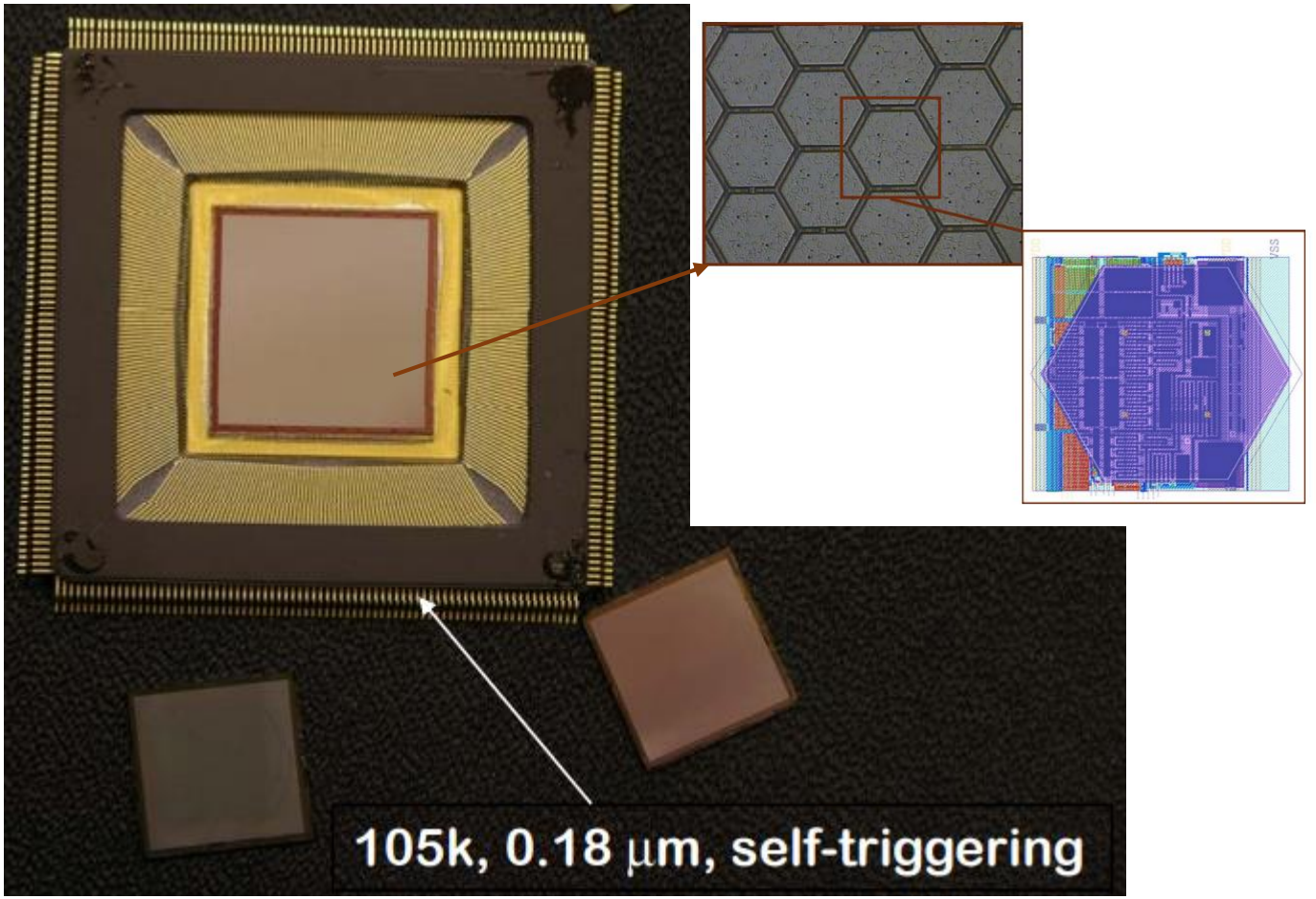
Detector

- Gas Ectron Multiplier
- ASIC: XPOL



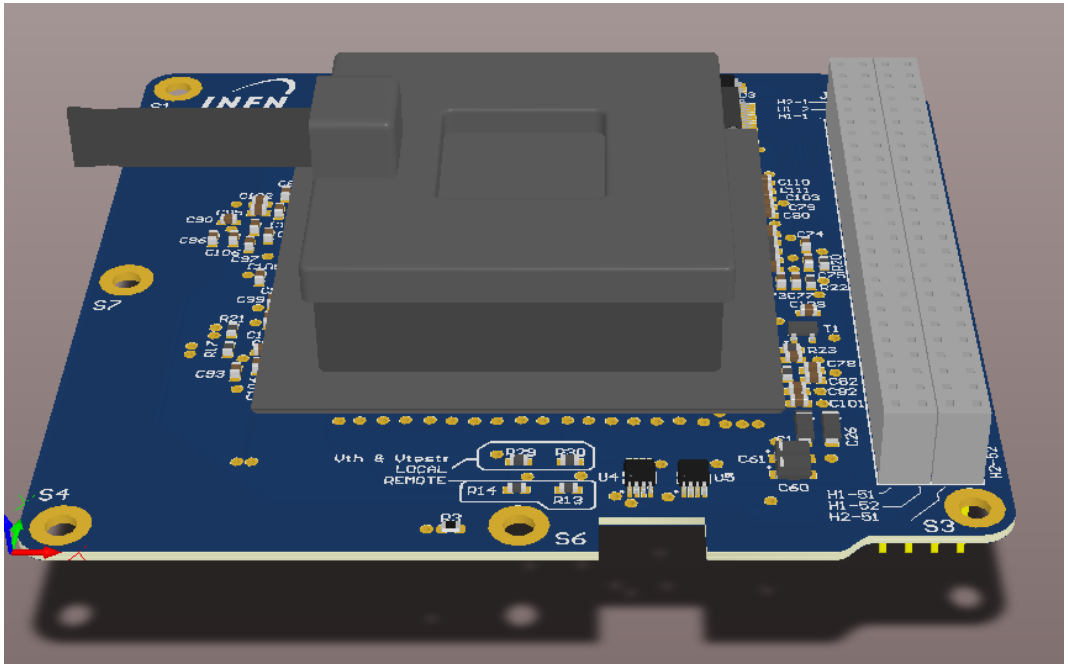
ASIC XPOL

- Gas Ectron Multiplier
- ASIC: XPOL
- 105k pixels
- 180nm



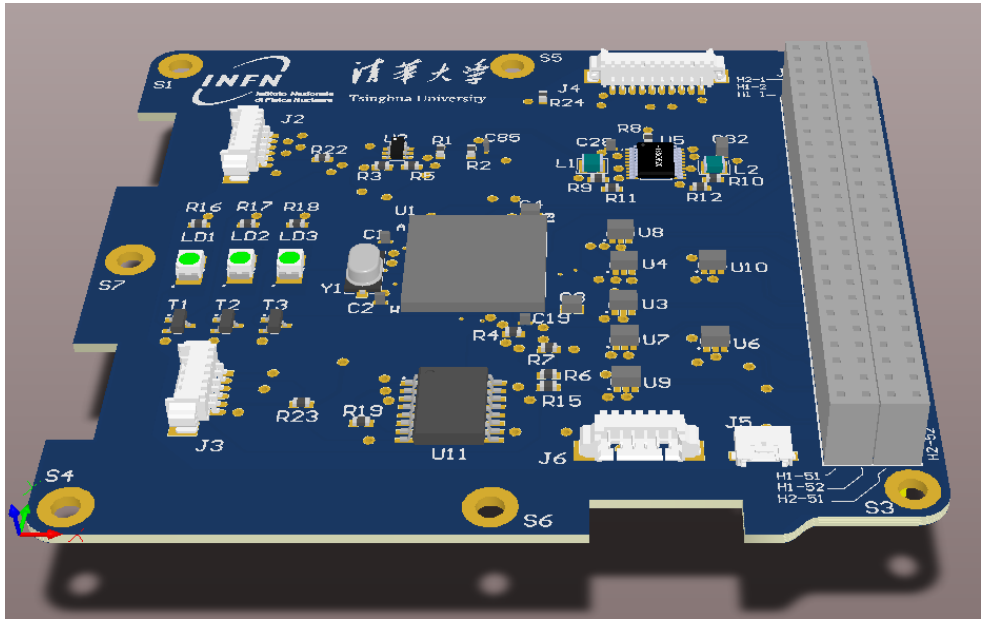
Scheda con il Detector

- Detector
- ASIC
- ADC
  - Flash 12 bits
- DACs
  - V threshold
  - V test
- Connector PC 104



Scheda DAQ

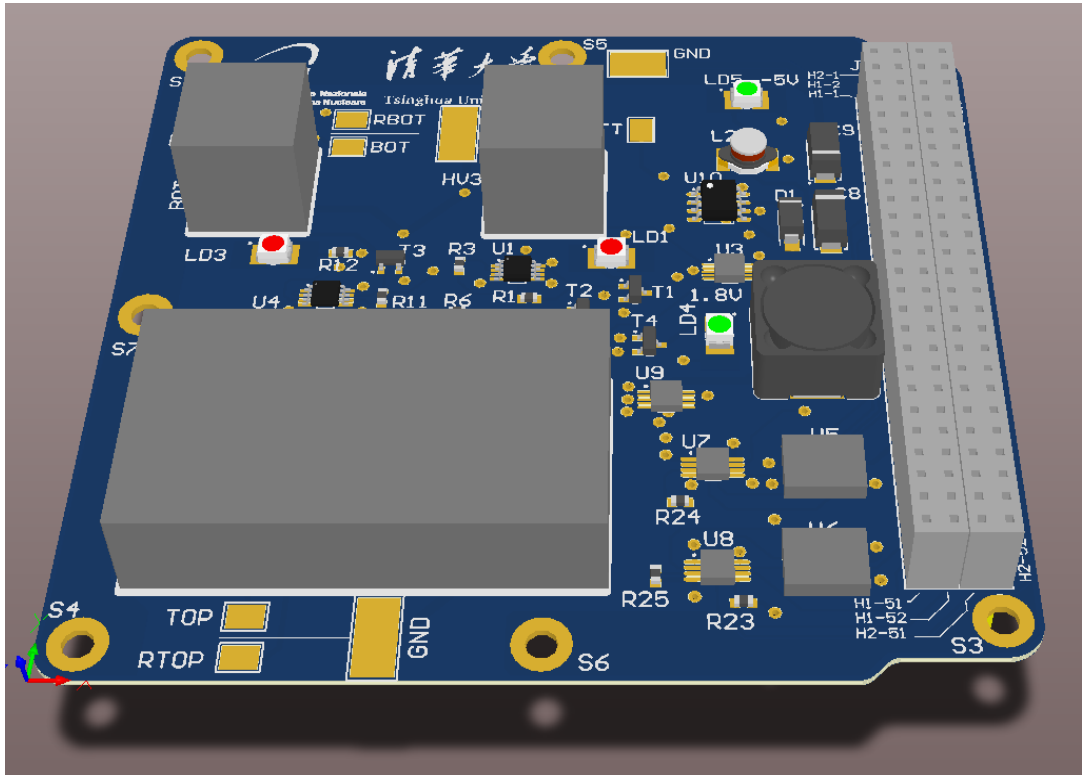
- MCU
  - Texas Instruments TMS570LC4357 Hercules™ Microcontroller Based on the ARM® Cortex®-R Core
  - Up to 300MHz
  - 125C ambient temperature
  - I2C, SPI, CAN, Timers, ADC, …
- Flash Memory 512 Mb
- Connectors
  - PC104
  - Programmer
  - Other Peripherals
- Debug LEDs



Scheda di Power

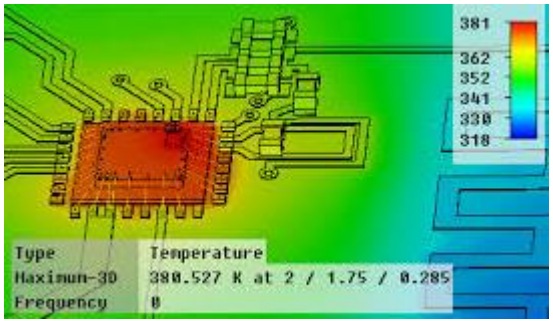
- DC-DC Converters:
  - 1.8V
  - -5V
- 3 Channels

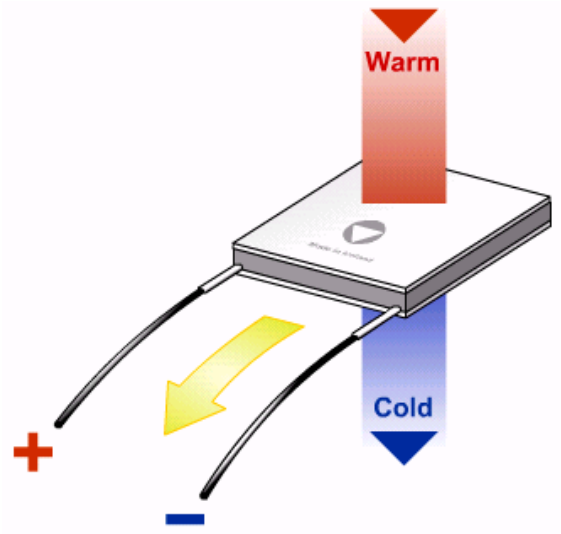
  High Voltage
  - Up to -4kV
  - Up to -1kV
  - Up to -1kV
- Latch-up Monitors
- Debug LEDs

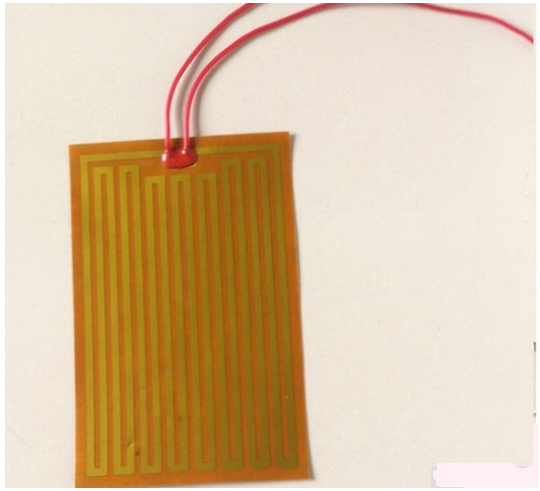


Criticità in ambienti ostili

- Presenza di Radiazioni Ionizzanti
- Vuoto: assenza di convezione
  - Controllo della temperature
  - Cicli termici
  - Peltier e Heater e radiatori
  - Componenti std MIL e SP







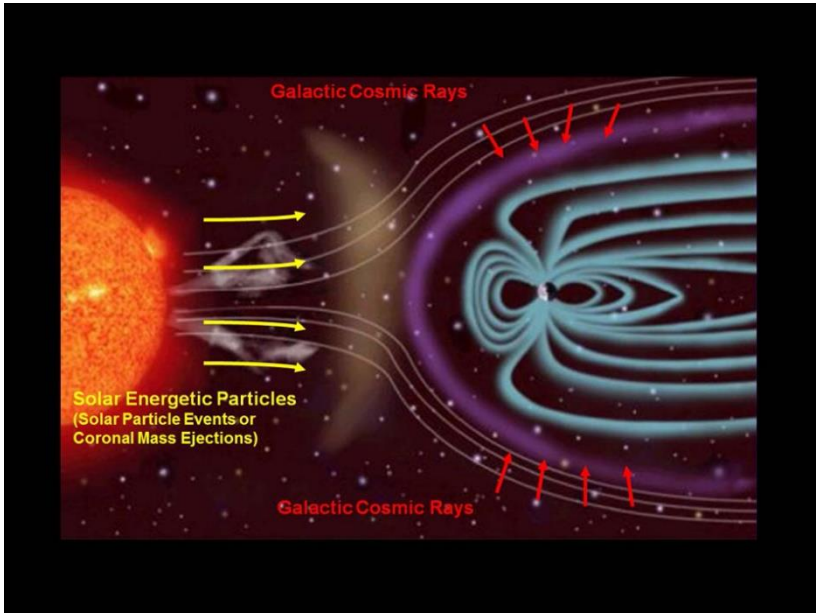
Ionizing Radiation in Space

- Galactic cosmic radiation consists of ionized atoms ranging from a single proton up to an uranium nucleus.

- The Solar wind contains ions from almost every element in the periodic table; however, it consists primarily of protons and electrons.

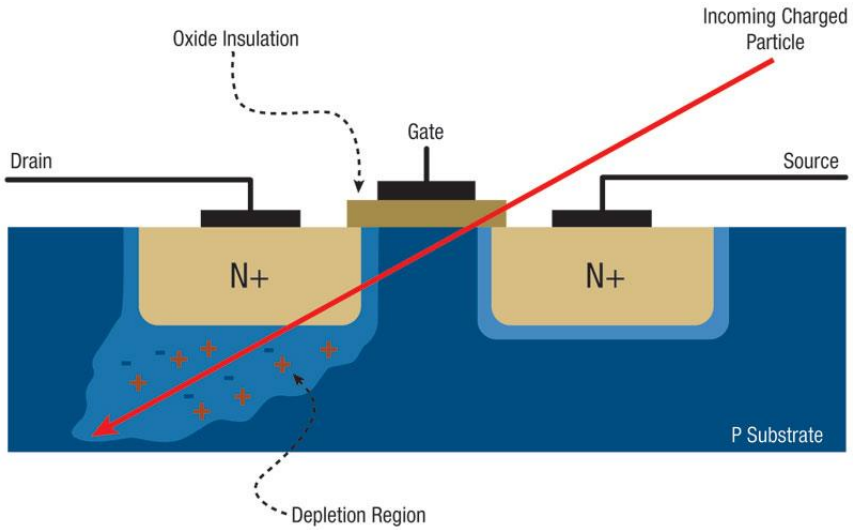
- TRAPPED RADIATION

The particles are contained in one of two doughnut-shaped magnetic rings surrounding the Earth called the Van Allen radiation belts.



Ref:1, 2, 3

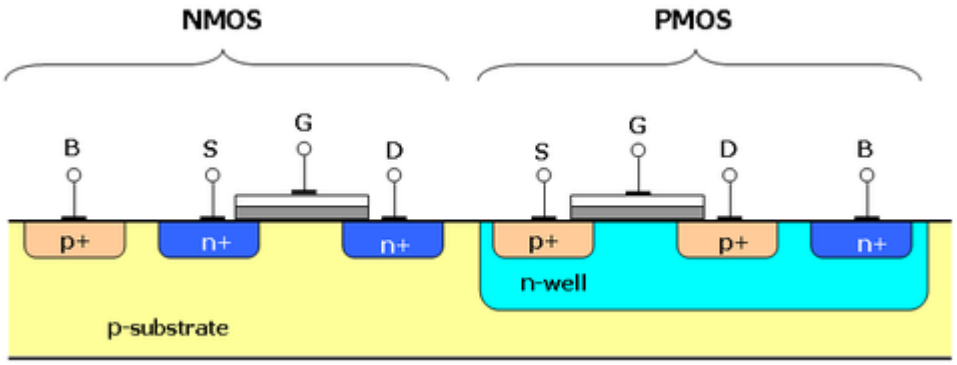
Ionizing Radiation effects on electronic devices

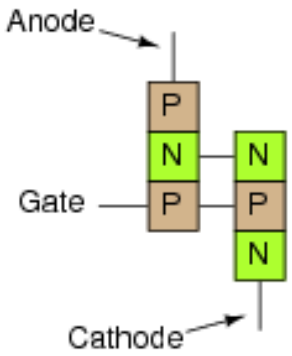


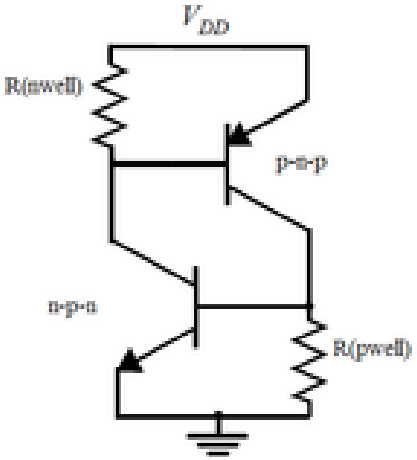
Le cararice generate possono:

- Far cambiare stato a elementi di memoria “Single Event Upset”
- Innescare fenomeni autodistruttivi. “Single Event Latch-Up”
- Contribuire alla degradazione delle prestazioni. Problema della “Total Dose”

Single Event Latch-Up (SEL)

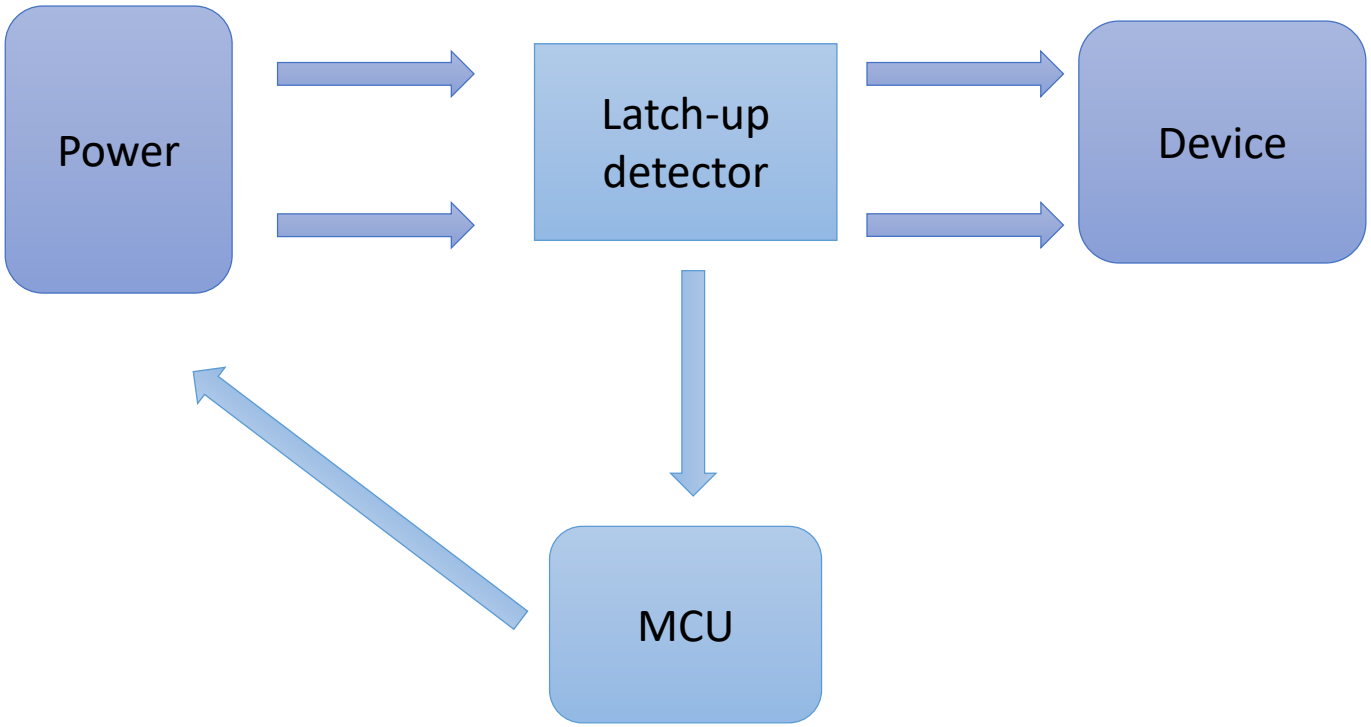






- CMOS process
- SCR parasite
- Self-sustaining event with a positive feedback
- If it is not interrupted, it will destroy the ASIC

Latch-Up Detector

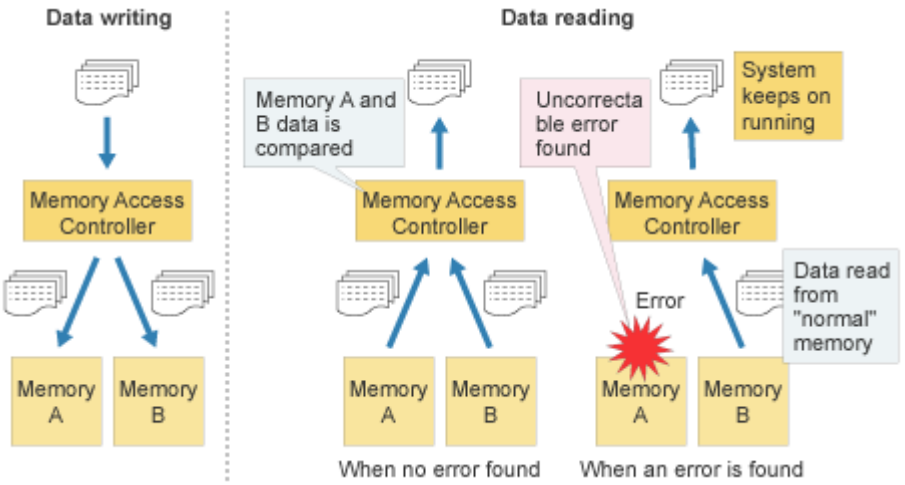


Single Event Upset (SEU)

- E’ un bit flip in un elemento di memoria
  - 1 -> 0 oppure 0 -> 1

- Per proteggersi da questo tipo di problemi:
- Elementi di memoria ridondanti

- Es: 2 memorie che contengono le stesse informazioni



Radiation Test

- Prima di prendere le contromisure
- Capire la suscettibilità del sistema ai SEU e SEL
- Si effettuano te di irraggiamento con ioni pesanti o con raggi X
- Si verificano le funzionalità del sistema sotto test

Vi racconto l'esperienza di alcuni test di irraggiamento fatti per l'ASIC XPOL

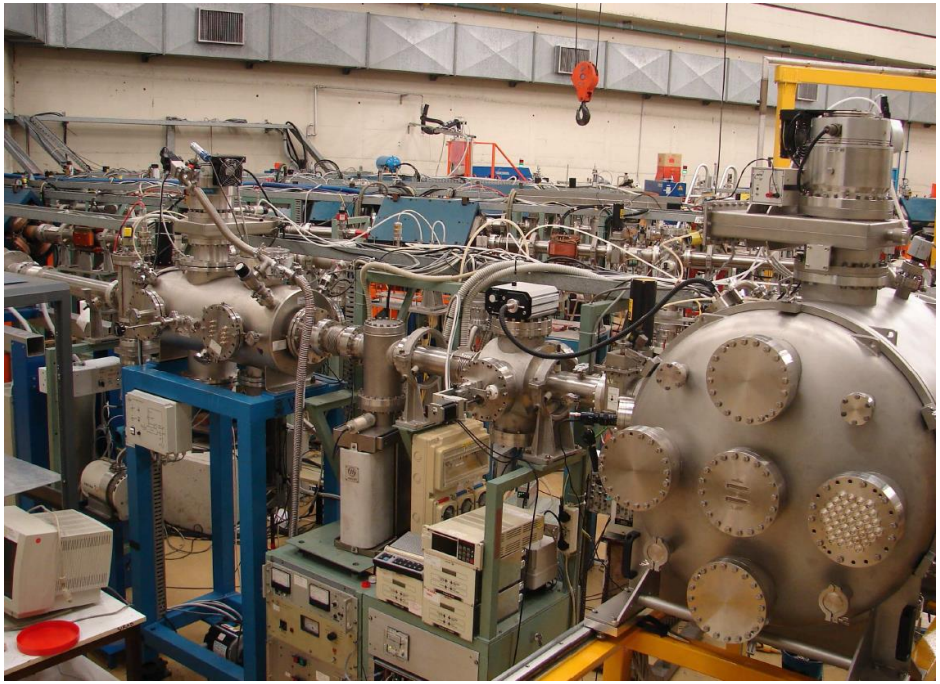
Radiation Test

- Laboratori Nazionali di Legnaro
- Device under test: XPOL ASIC, CMOS 180nm
- Support qualification process for ESA
  - ESCC Basic Specification No. 25100
- Monitor Single Event Upset (SEU)
- Monitor Single Event Latch-Up (SEL)
- Check the functionality after the total Ionizing dose

Radiation Test

- SIRAD irradiation facility

- LET :
  - from 0.02 MeV x cm^2/mg (^1H)
  - up to 81.7 MeV x cm^2/mg (^{197}Au)
- Flux :
  - 10^2 - 10^5 ions/cm^2 /s
  - irradiation on a 2 X 2 cm^2 area



Radiation Test

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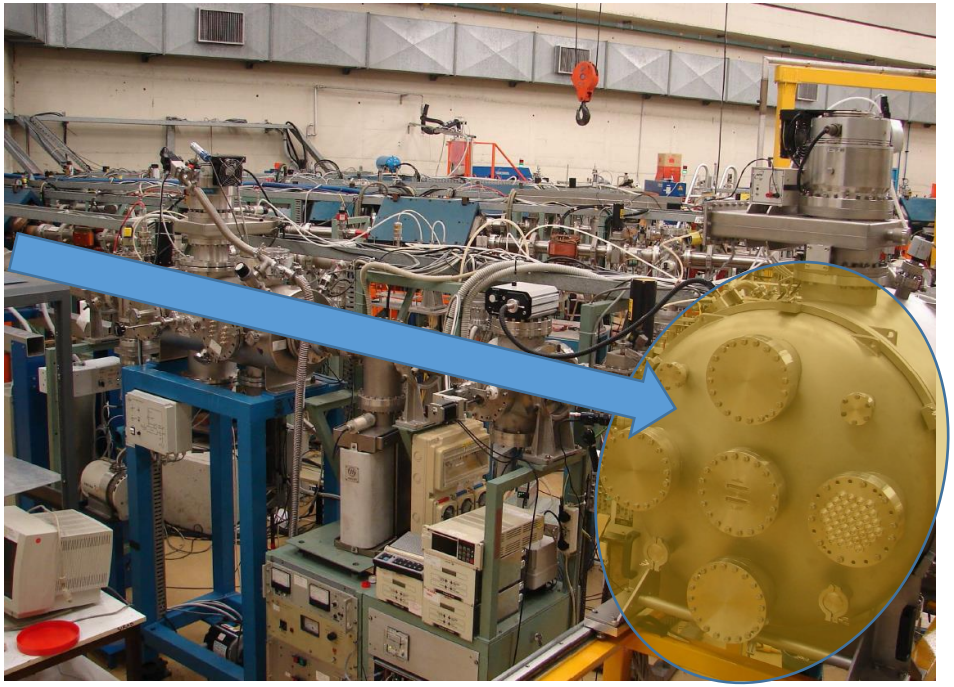
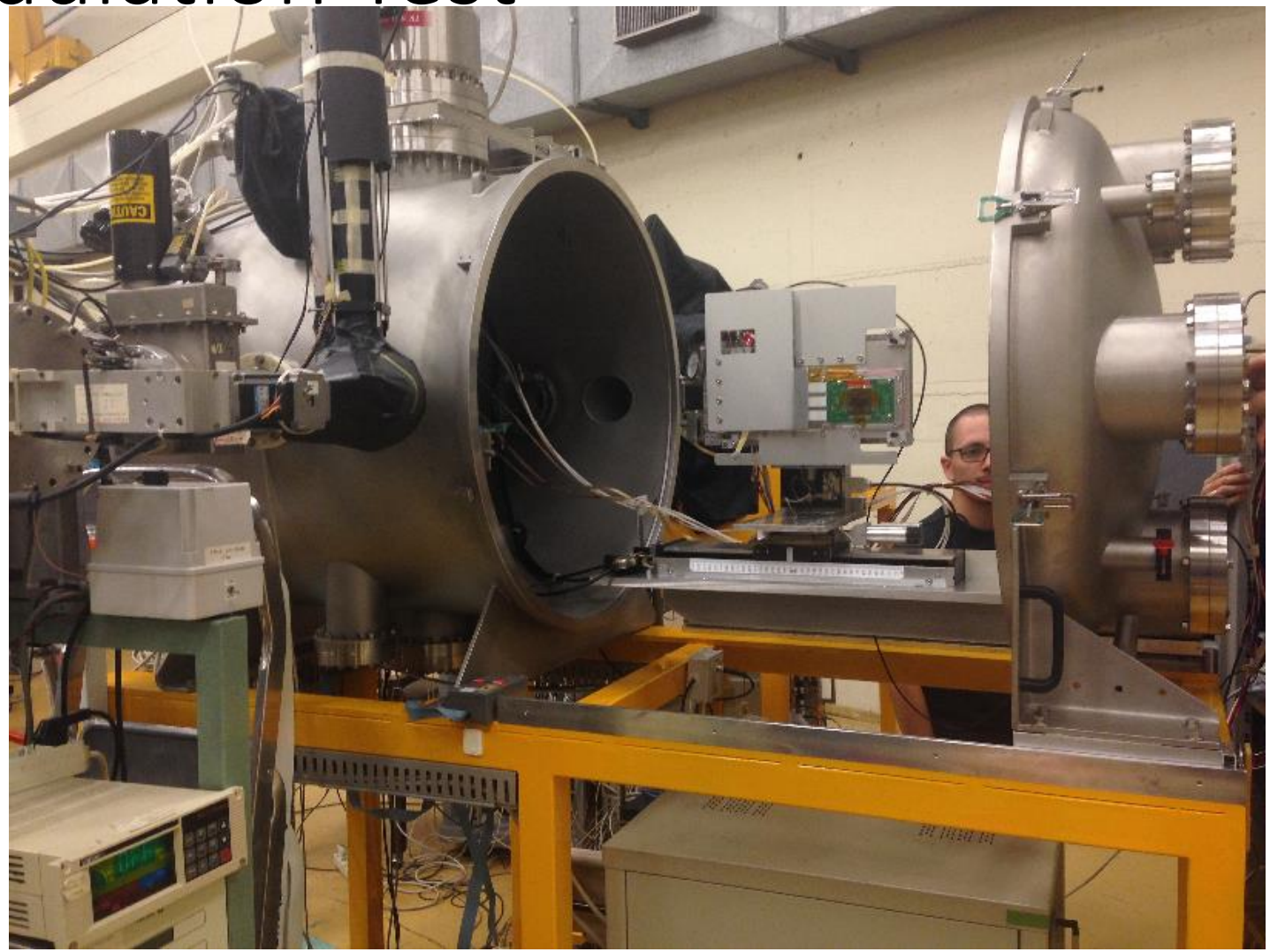
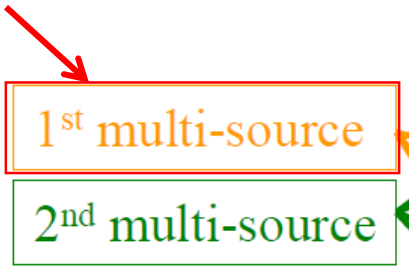


Radiation Test



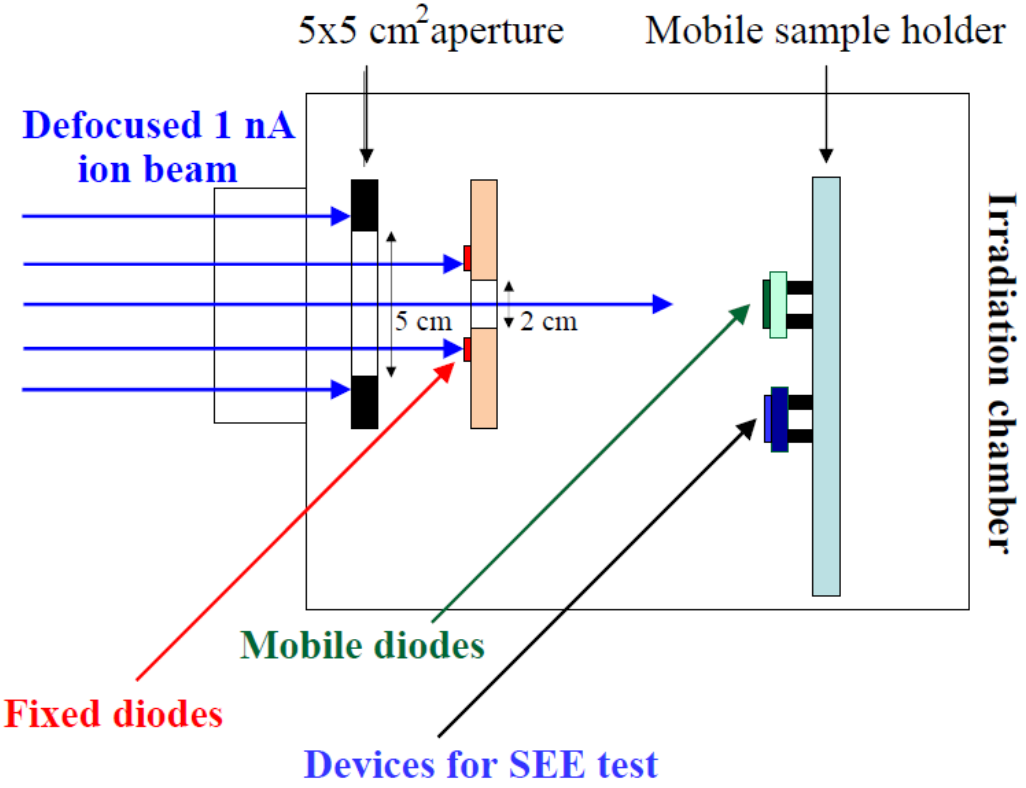
Radiation Test: Ion Species

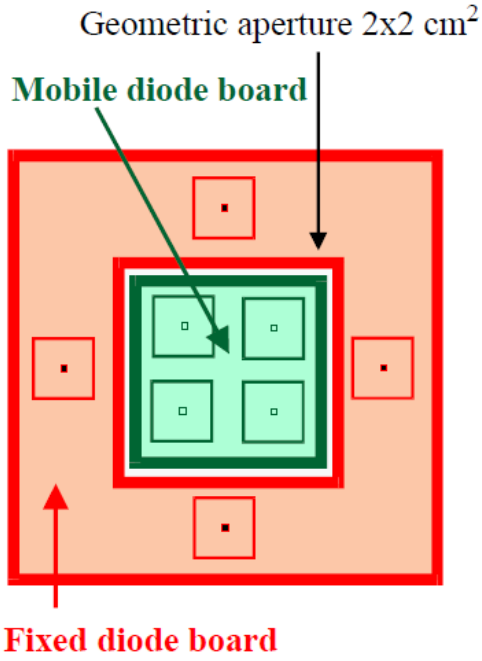


The energy values refer to the most probable q_1 and q_2 charge state, with two stripper stations, and the Tandem operating at 14 MV.

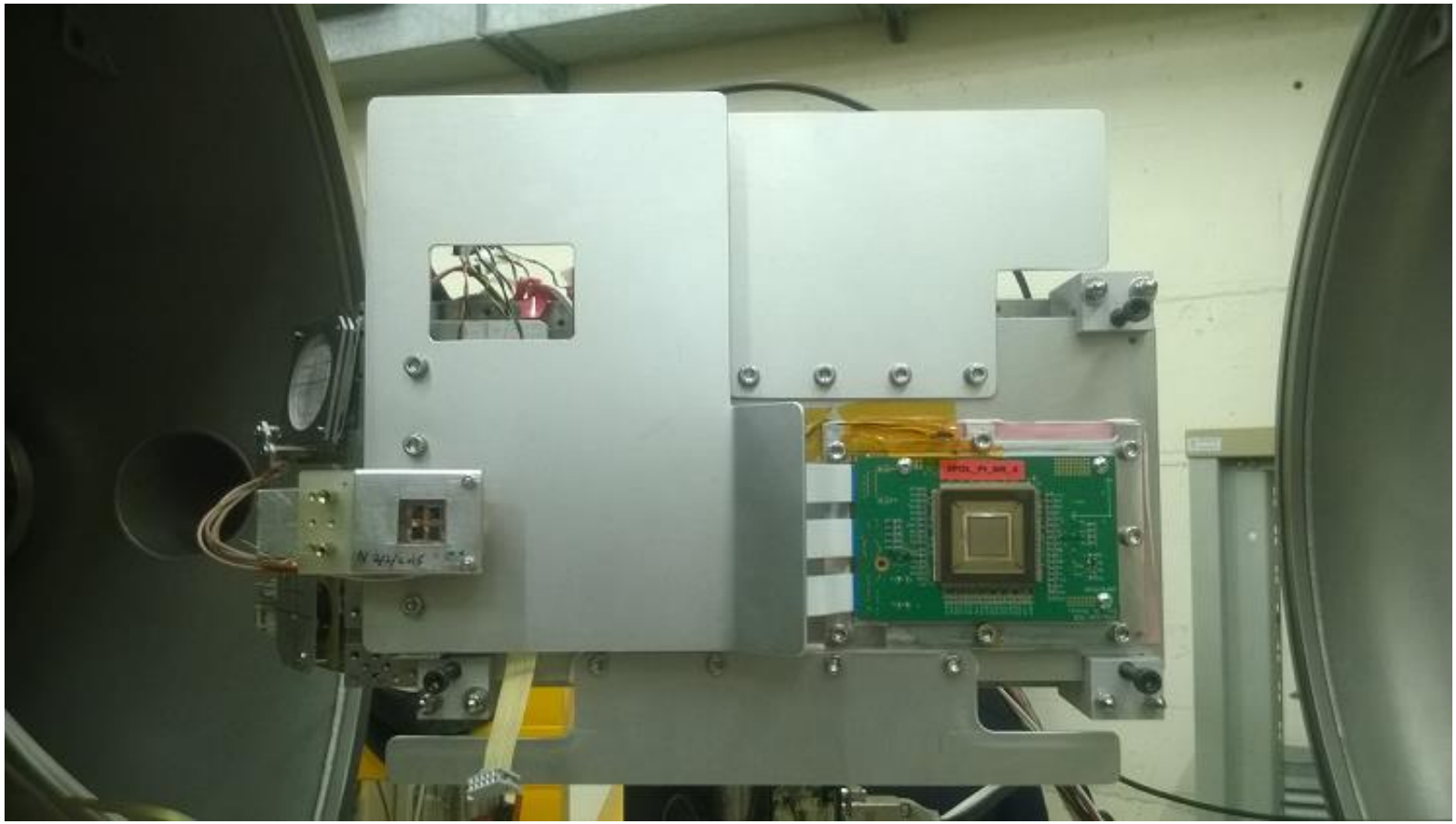
Ion Species	Energy (MeV)	q_1	q_2	Range in Si (μm)	Surface LET in Si (MeV×cm²/mg)	
^{1}H	28	1	1	4390	0.02	
^{7}Li	56	3	3	378	0.37	
^{11}B	80	4	5	195	1.01	
^{12}C	94	5	6	171	1.49	
^{16}O	108	6	7	109	2.85	
^{19}F	122	7	8	99.3	3.67	←
^{28}Si	157	8	11	61.5	8.59	
^{32}S	171	9	12	54.4	10.1	
^{35}Cl	171	9	12	49.1	12.5	←
^{48}Ti	196	10	14	39.3	19.8	
^{51}V	196	10	14	37.1	21.4	
^{58}Ni	220	11	16	33.7	28.4	
^{63}Cu	220	11	16	33.0	30.5	
^{74}Ge	231	11	17	31.8	35.1	
^{79}Br	241	11	18	31.3	38.6	←
^{107}Ag	266	12	20	27.6	54.7	
^{127}I	276	12	21	27.9	61.8	←
^{197}Au	275	13	26	23.4	81.7	

Radiation Test: Beam Monitor





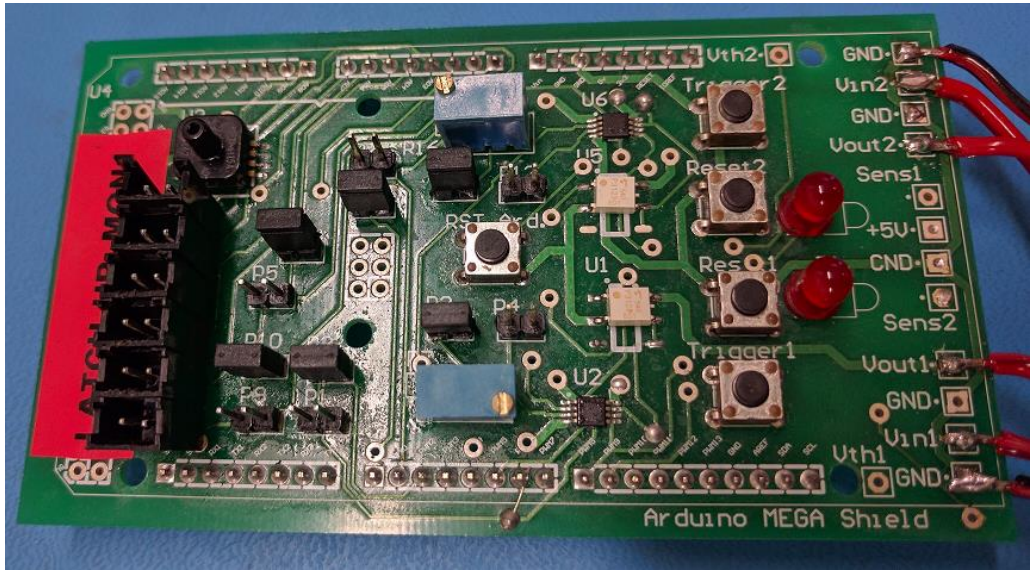
Radiation Test



- Power dissipation (~5 W) is critical in the vacuum chamber

Temperature Sensors

- Six Temperature Sensors on board
  - FPGA
  - ASIC XPOL
  - ADC
  - DC-DC 1.8V
  - DC-DC 3.3V
  - Spare



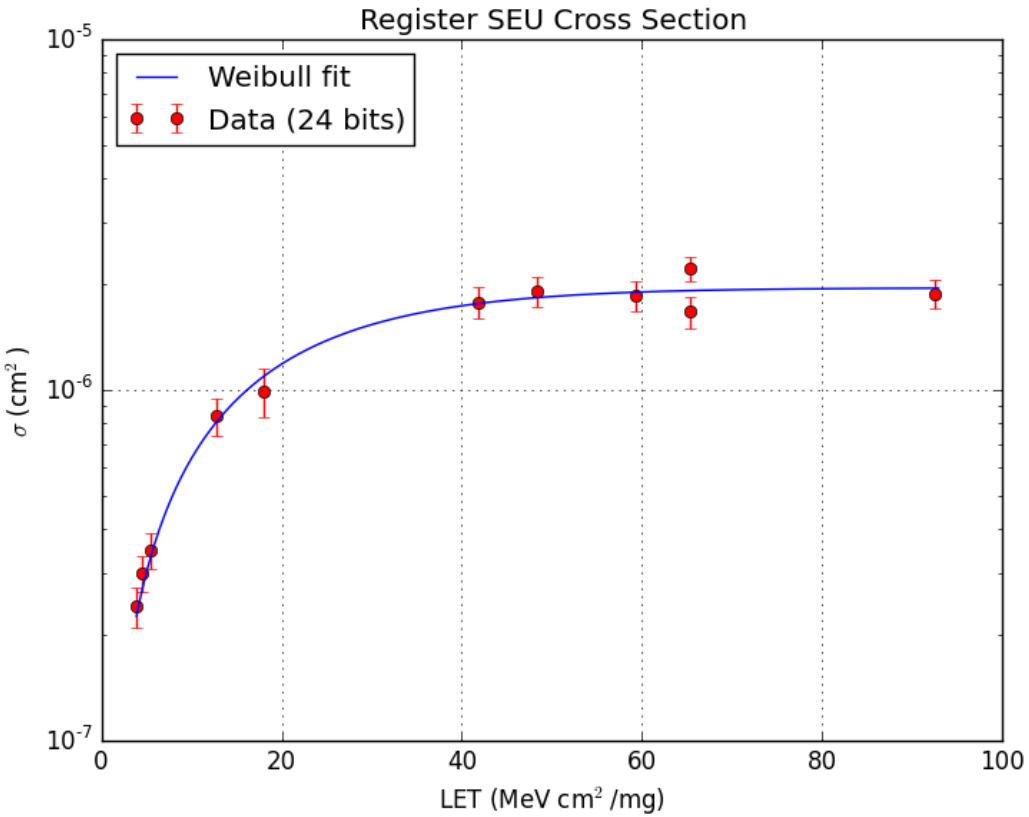
Irradiation Test

- 4 ion species (F, Cl, Br, I) with increasing number mass
- Cumulative dose ~700Krad, room for TID effects search in ASIC performance

N. of Runs	24		Tot. Irradiation Time [hrs]	29.90
N. of Configurations	23		Tot. Time Pedestal [hrs]	4.53
N. of SEU Pedestal Tests	11		Tot. Time Registers [hrs]	23.63
N. of SEU Register Tests	12		Nominal* Test time [hrs]	48.00
			*includes installation and beam setup	
Average Flux [ions/(cm^2 * s)]	4.69E+04		Average Fluence [ions/cm^2]	1.15E+08

Results

- Write / Read Memory



Conclusioni

- La progettazione elettronica per lo spazio deve tener conto di:
  - Vuoto, problemi termici
  - Radiazioni Ionizzanti

- Per progettare sistemi che funzionano in questi ambienti bisogna utilizzare componenti elettronici che:
  - Funzionano a temperature in range militare -55°C / +125°C
  - Sono immuni o poco suscettibili ai fenomeni: SEU, SEL.
  - Funzionano anche dopo aver ricevuto una dose di radiazione maggiore di quella alla quale verranno esposti.

- Se un componente non ha queste qualifiche bisogna quindi eseguire test di irraggiamento per qualificarlo.

Grazie