“What next”-detectors: stato e possibili sviluppi in CSN5

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What Next “Mid Term”, LNF – 1-2 aprile 2015

Contesto

- CSN5 tradizionale incubatore di nuove idee
- Sinergia con altre CC.SS.NN. puo' aprire a nuove prospettive (anche in "What Next")
  - Strumento delle "call"
- Ulteriori strumenti disponibili:
  - Convenzione MEMS con FBK
  - Collaborazioni con Lfoundry e STMicroelectronics
  - Nuova opportunita': nascita del TIFPA (in collaborazione con FBK)

R&D sui rivelatori in CSN5

- Rivelatori avanzati, ma basati su paradigmi/materiali "convenzionali":
  - HEP/Astroparticle/Rare events/Biosensors
  - X-rays, Advanced Light Sources, PET/Medical imaging
- Esotici:
  - Graphene
  - SiC
- Uno sguardo al futuro
  - Alcuni R&D "physics-driven"
  - More Graphene and other 2D-materials
  - New scintillators
  - Organic
  - Nanotubes (anche IC)

Panorama attuale in CSN5 - 1

“Convenzionali”

- Sviluppo di nuovi sensori/elettronica per le prossime sfide HE/HI:
  - HVR-CCPD: hybrid pixel detectors on HV/HR CMOS substrate (evolution of the MAPS) capacitively coupled to the FEE
    - Collaboration with STMicroelectronics; NDA signed
  - SEED: development of CMOS sensors with significant depletion depth and a high degree of local signal processing
    - Collaboration with Lfoundry (Avezzano) and FBK/TIFPA
    - Access to Lfoundry CMOS technologies for both sensors and VLSI design and production
    - Complementarity with FBK

Panorama attuale in CSN5 - 2

"Convenzionali"

- Sviluppo di nuovi sensori/elettronica per le prossime sfide HE/HI:
- UFSD (Ultra Fast Silicon Detectors): thin Si detectors with internal charge multiplication
  - $\sigma_x \approx 20\ \mu m$, $\sigma_t \approx 20$ ps
  - Applications in:
    - TOF@LHC (pile-up rejection)
    - TOF with particle ID
    - Electronic microscopy
    - Beam monitor for particle therapy

ERC-Advanced 2014!

Panorama attuale in CSN5 - 3

"Convenzionali"

- Sviluppo di nuovi sensori/elettronica per le prossime sfide HE/HI:
- SCALTECH28: study of basic analog blocks in 28 nm technology node:
  - Look forward beyond CHIPIX65 (rad hardness ≥ 1 Grad)
  - Challenge: scaled technology devices have reduced analog characteristics:
    - Smaller $V_{DD} - V_{TH}$ "room"
    - Lower DC-gain
    - Gate leakage current ⇒ parallel noise

Panorama attuale in CSN5 - 4

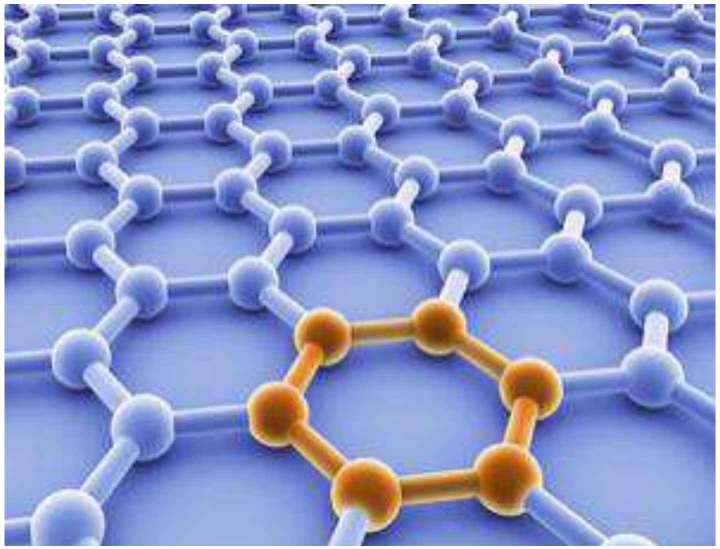
"Convenzionali"

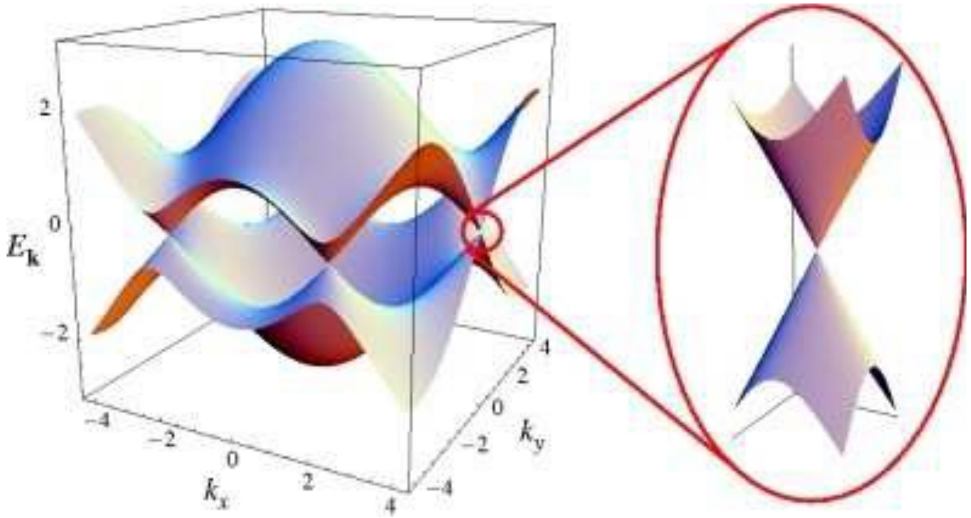
- REDSOX: Development of large area SDDs and low noise front-end electronics for X-ray spectroscopy and imaging
  - LOFT X-ray space mission
  - Applications at Advanced Light Sources
- PIXFEL : Enabling technologies, building blocks and architectures for advanced X-ray pixel cameras at FELs
  - active edge pixel sensors, low density TSVs
  - 65 nm CMOS technology for front-end and readout electronics
  - in pixel data storage and readout architectures

Panorama attuale in CSN5 - 5

"Esotici"

- R&D su sensori al graphene:
  - GBTD (2013), collaborazione con TIFPA/FBK
  - GARFIELD (2014, Grant per giovani)





Graphene

"Esotici"

- Applicazioni di interesse INFN:
  - Scintillating bolometers for DM and 0νDBD
  - CMB (if the 60-600 GHz range will be achieved)
  - Near Infrared Fluorescence (UHECR)
  - Charged particle detectors
  - Microelectronics

Panorama attuale in CSN5 - 6

"Esotici"

- CLASSIC (Grant per giovani 2015): SiC-based Cherenkov light detectors with intrinsic amplification
  - SiC characteristics
    - $E_g \approx 3E_{g,Si}$ (visible-blind, low leakage current)
    - $\mu \approx 3\mu_{Si}$ (suited for applications requiring fast response)
    - Suitable for harsh environments
  - Applications
    - Dual-readout hadronic calorimeters
    - TOF-PET with Cherenkov light sensitivity (few ps resolution)

Uno sguardo al futuro - 1

- Nuova fisica ⇔ Nuovi strumenti
  - Settori di nuova fisica:
    - Dark Matter (WIMPs e Axion-like)
    - Neutrini
    - Dark Energy
    - CMB

Uno sguardo al futuro - 2

- Possibili R&D di interesse per nuova fisica
  - Rivelatori a bassa soglia (eV) (fisica di riferimento: Assioni , Neutrini , Materia Oscura)
    - Quantum counters
    - Maser Amplifiers (lavorano al limite quantistico ⇒ sensibili a energie di frazioni di meV)
  - Amplificatori parametrici nelle microonde (fisica di riferimento: Assioni, CMB, amplificatori alternativi a HEMT)
    - Basati su giunzioni Josephson
    - Nuove tecnologie litografiche ⇒ regione delle decine di GHz
    - Uso di varicaps ⇒ frequency tunability

Contributo di G. Carugno

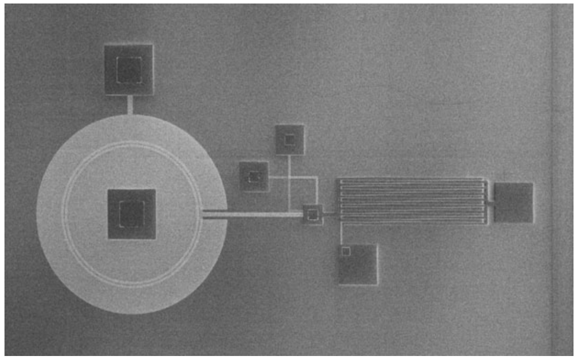
Uno sguardo al futuro - 3

- Possibili R&D di interesse per nuova fisica
  - Laser di alta potenza e alti campi magnetici (fisica di riferimento: Interazioni deboli con decadimento beta inverso e diretto e proprieta' neutrino)
    - Laser con $\sim 10^{12}$ W/cm^2 $\Rightarrow$ campi e.m. nel beam waist $\sim$ campo coulombiano
    - Interazioni atomi-laser
  - Frequency comb (fisica di riferimento: Dark Energy, Orologi Nucleari su transizioni X)
    - Per DE necessaria una sensibilita' $\sim$ cm/s · yr

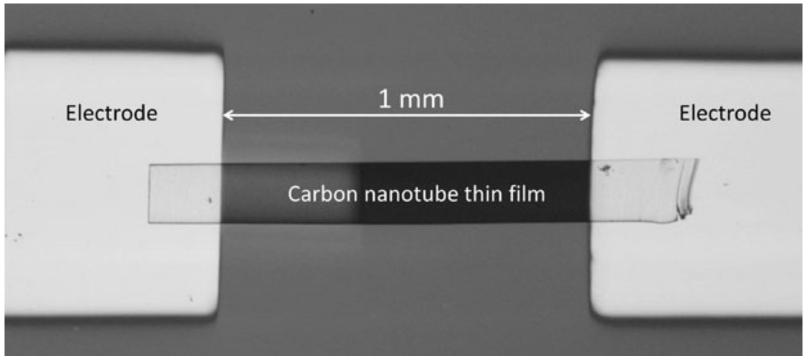
Contributo di G. Carugno

Uno sguardo al futuro - 3

- Carbon/Metal nanotubes
  - Coupled to “conventional” Si-detectors for efficient light detection (up to soft X-rays?)
  - CNT transistors/detectors
  - CNT THz detectors



M. Shulaker et al., *IEEE International Electron Devices Meeting (IEDM),* December 15 – 17, San Francisco, 2014



H. Xiaowei et. al, Nano Lett., 2014, 14 (7), pp 3953–3958

Uno sguardo al futuro - 4

- Detectors for rare events experiments
  - R&D on highly radio-pure scintillating materials, new scintillators containing interesting isotopes
  - Development of new and highly sensitive cryogenic particle detectors (TES, MKIDs, magnetic,…)
- Organic-based photodetectors
- Organic-based charged particle detectors
- New (and still dream-like) 2-D materials (but progress is being impressing…)
  - Silicene
  - Germanene
  - Phosphorene
  - …

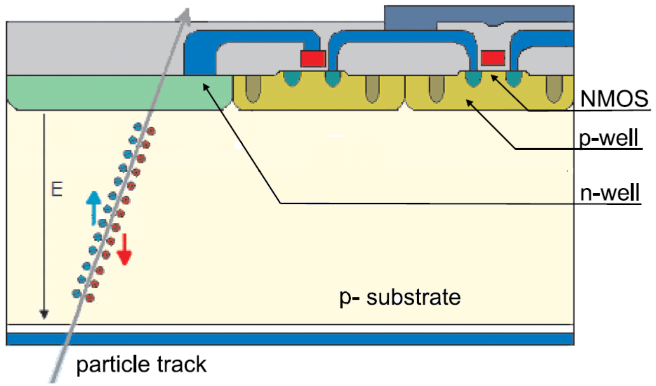
Spare slides

Panorama attuale in CSN5 - 1

"Convenzionali"

- HVR-CCPD (A. Andreazza): rivelatori a pixel ibridi su substrato HV/HR CMOS (evoluzione dei MAPS) accoppiati capacitivamente al FE
  - Monolithic Active Pixels Sensors (MAPS) are not suitable for high radiation (10 MGy), high counting rate (1 GHz/cm^2) applications, as collection time is too slow, and available technologies do not fit complexity (1 billion transistor/chip).
  - Bump-bonding is a time-consuming production step: from past experience, it takes many years.

Collaboration with STMicroelectronics
NDA signed



Panorama attuale in CSN5 - 2

"Convenzionali"

- SEED (P. Giubilato, A. Rivetti): development of CMOS sensors with significant depletion depth and a high degree of local signal processing
- Collaboration with Lfoundry (Avezzano) and FBK/TIFPA
  - Access to Lfoundry CMOS technologies for both sensors and VLSI design and production
  - Complementarity with FBK

Panorama attuale in CSN5 - 3

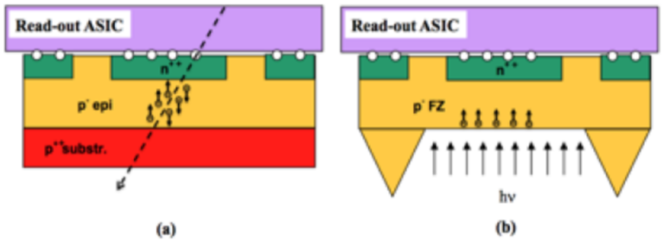
"Convenzionali"

- SCALTECH28 (A. Baschirotto): study of basic analog blocks in 28 nm technology node:
  - Look forward beyond CHIPIX65 (rad hardness ≥ 1 Grad)
  - Challenge: scaled technology devices have reduced analog characteristics:
    - Smaller $V_{DD} - V_{TH}$ "room"
    - Lower DC-gain
    - Gate leakage current ⇒ parallel noise

Panorama attuale in CSN5 - 4

“Convenzionali”

- UFSD (N. Cartiglia) (Ultra Fast Silicon Detectors):

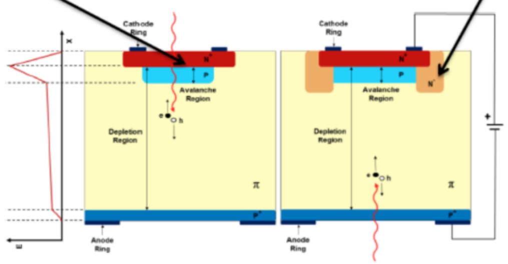


Rivelatori sottili con guadagno interno:

- Aumentare lo spessore dell’implant n^{++};
- aggiungere “deep p+” diffusion layer per avere alto campo elettrico e moltiplicazione di carica (come nei SiPM). Si lavora a basso guadagno per essere sempre attivi (GHz capabilities)
- Devono essere molto sottili
- Cambiare la forma dei sensori per evitare breakdown elettrico

Regione con alto campo elettrico e guadagno

Opzione di protezione laterale dal breakdown elettrico



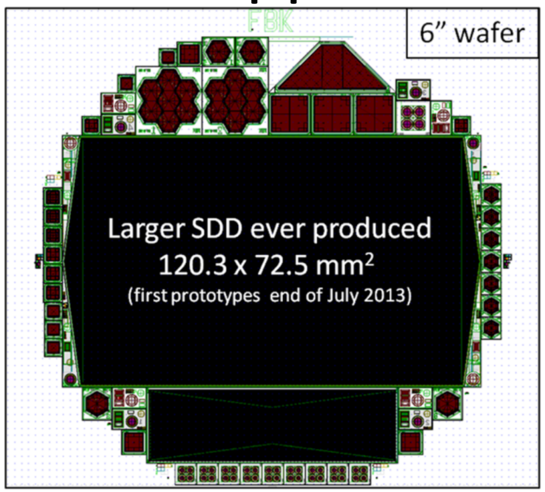
Applicazioni in
- •TOF @ LHC (pileup rejection)
- •TOF per identificazione di particelle (e.g. AMS)
- •microscopia elettronica
- •monitor di fascio per adroterapia
- •3D vision

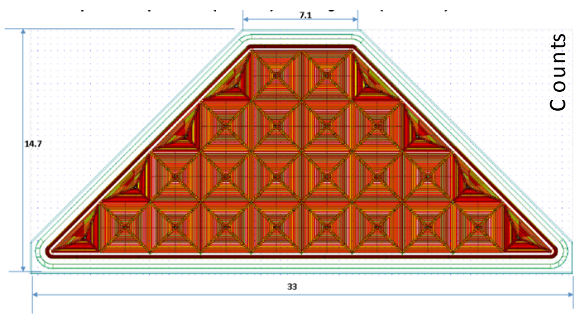
Sottomesso progetto ERC-Advanced a settembre 2014
Gennaio 2015: superata prima fase

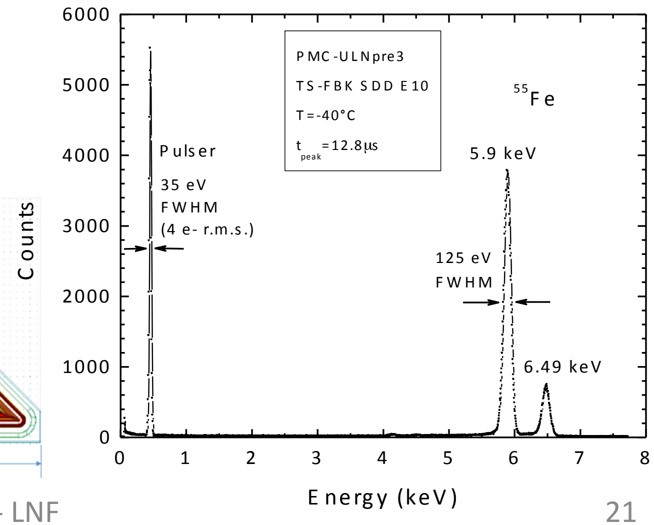
Panorama attuale in CSN5 - 5

"Convenzionali"

- REDSOX: development of large area SDDs and low noise front-end electronics for X-ray spectroscopy and imaging
  - LOFT X-ray space mission
  - Applications at Advanced Light Sources



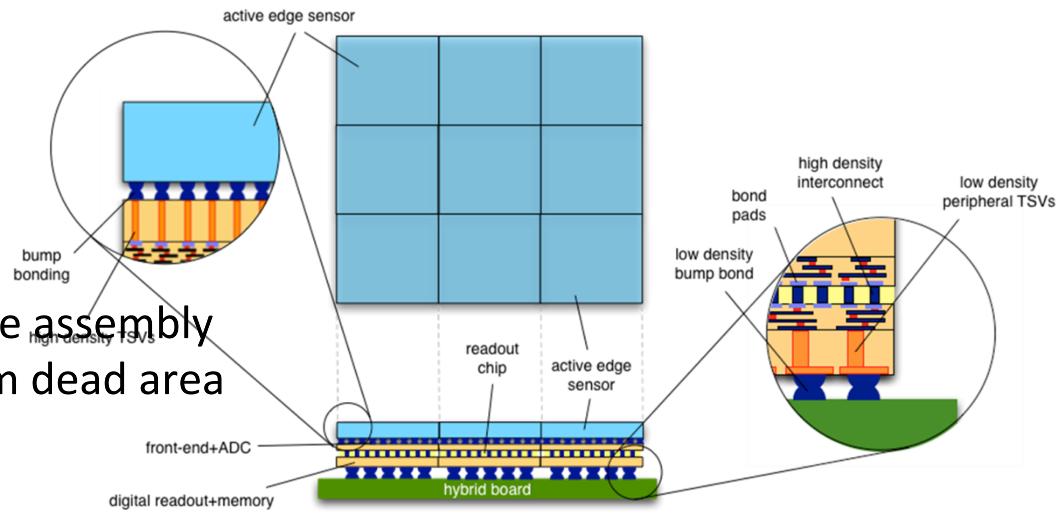




Panorama attuale in CSN5 - 6

“Convenzionali”

- PIXFEL (L. Ratti): Enabling technologies, building blocks and architectures for advanced X-ray pixel cameras at FELs
  - active edge pixel sensors, low density TSVs
  - 65 nm CMOS technology for front-end and readout electronics
  - in pixel data storage and readout architectures



Develop a four-side buttable module for the assembly of large-area detectors with no or minimum dead area to be used at FEL experiments

Panorama attuale in CSN5 - 7

"Convenzionali"

- DINAMO (F. Picollo, Grant giovani 2014): development of ion-beam nanofabrication techniques in diamond for applications in bio-sensing

MeV Deep Ion Beam Lithography (DIBL)

State of the Art Nanofabrication techniques (FIB + EBL)

Micro and nano fabrication technique integration

+

Artificial Diamond

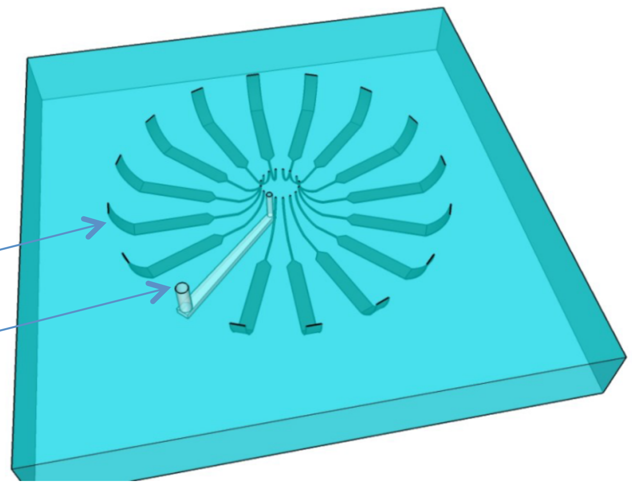
⇩

Biosensors

A bio-compatible and transparent diamond active substrate for interfacing with Cellular biosensor:

•chemical interfacing ⇒ fluidic structures

•electrical interfacing ⇒ electrodes for cells

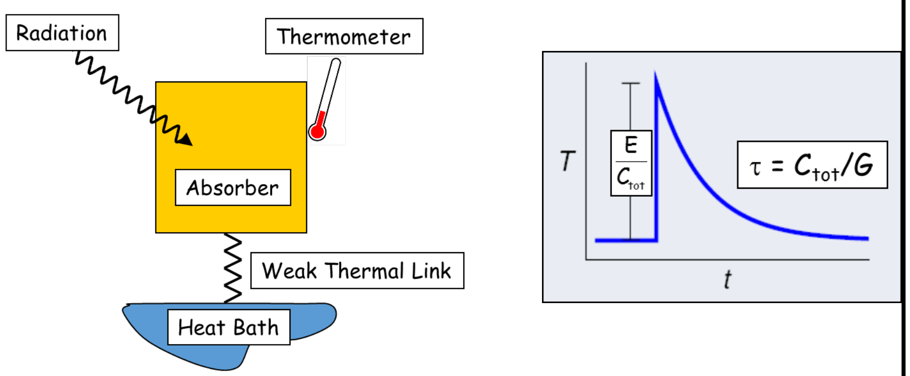


Panorama attuale in CSN5 - 9

"Esotici"

- GBTD: Graphene Based Thermal Detector

Rivelatore Termico

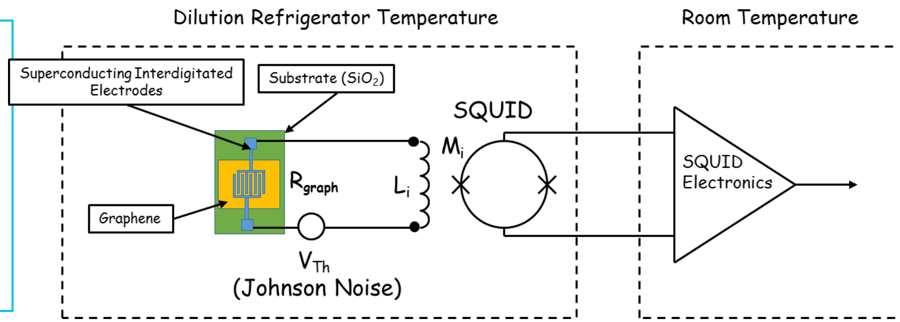


In generale, le prestazioni di un rivelatore termico migliorano riducendo temperatura e capacità termica

Il gas di elettroni bidimensionale del grafene a T<1K può essere un rivelatore termico quasi ideale di radiazione elettromagnetica (λ>400nm)

Problema: Non ci sono caratteristiche del grafene facilmente misurabili che dipendono dalla temperatura (in particolare a T<1K). Come si misura la T del grafene-assorbitore?

Soluzione: Stimo la T dal rumore termico (Johnson) prodotto dalla resistenza di un foglio di grafene usando un amplificatore SQUID (Noise Thermometry)



Panorama attuale in CSN5 - 10

"Esotici"

- GARFIELD: Graphene Active Films for Electronic Devices and Radiation Detection
  - 2 units: INFN (LNF) and CNR (IFN & IMM)
  - Graphene CVD facility@LNF
  - Objectives:
    - Implementation of a full-capability GR platform @ LNF-INFN (Material Science Lab)
    - Development of GR-based detectors for application of interest to the INFN
    - Synergy with GBTD: Si/SiO_2 6" wafers (FBK standard) are fully compatible with the GARFIELD CVD facility

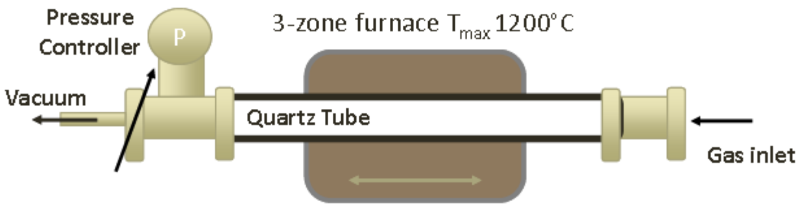
1) Synthesis of monolayer graphene via CVD on Cu films

2) Development of g-based detectors (prototypes/proof-of-concepts)

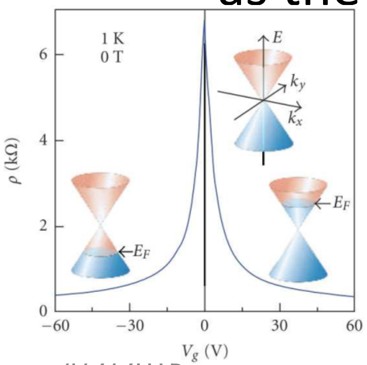
Panorama attuale in CSN5 - 10

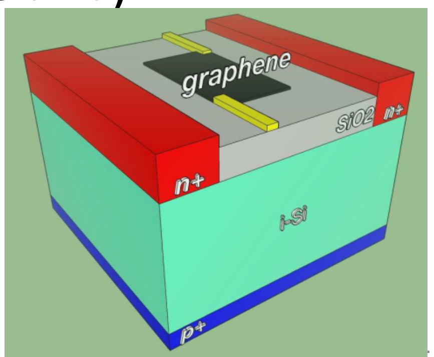
“Esotici”

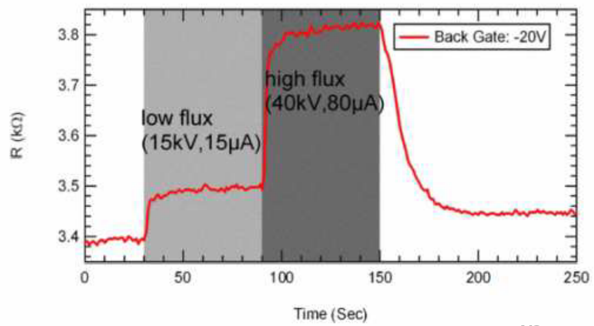
- GARFIELD



- G-FET detectors:
  - Usually graphene as active layer;
  - GARFIELD approach: graphene as “field sensor” device (i.e. used as the gate of the FET)







Uno sguardo al futuro - 2

- More Graphene…
  - Necessary to further promote the synergy of the efforts
  - A dedicated call towards a future H2020 leap?

Uno sguardo al futuro - 4

- Detectors for rare events experiments
  - R&D on highly radio-pure scintillating materials, new scintillators containing interesting isotopes
- Detectors for DM search with anisotropic response (directionality of DM candidates inducing nuclear recoil). Different strategies:
  - Anisotropic scintillators such as ZnWO4
  - (Again): CNT (1-D device!)