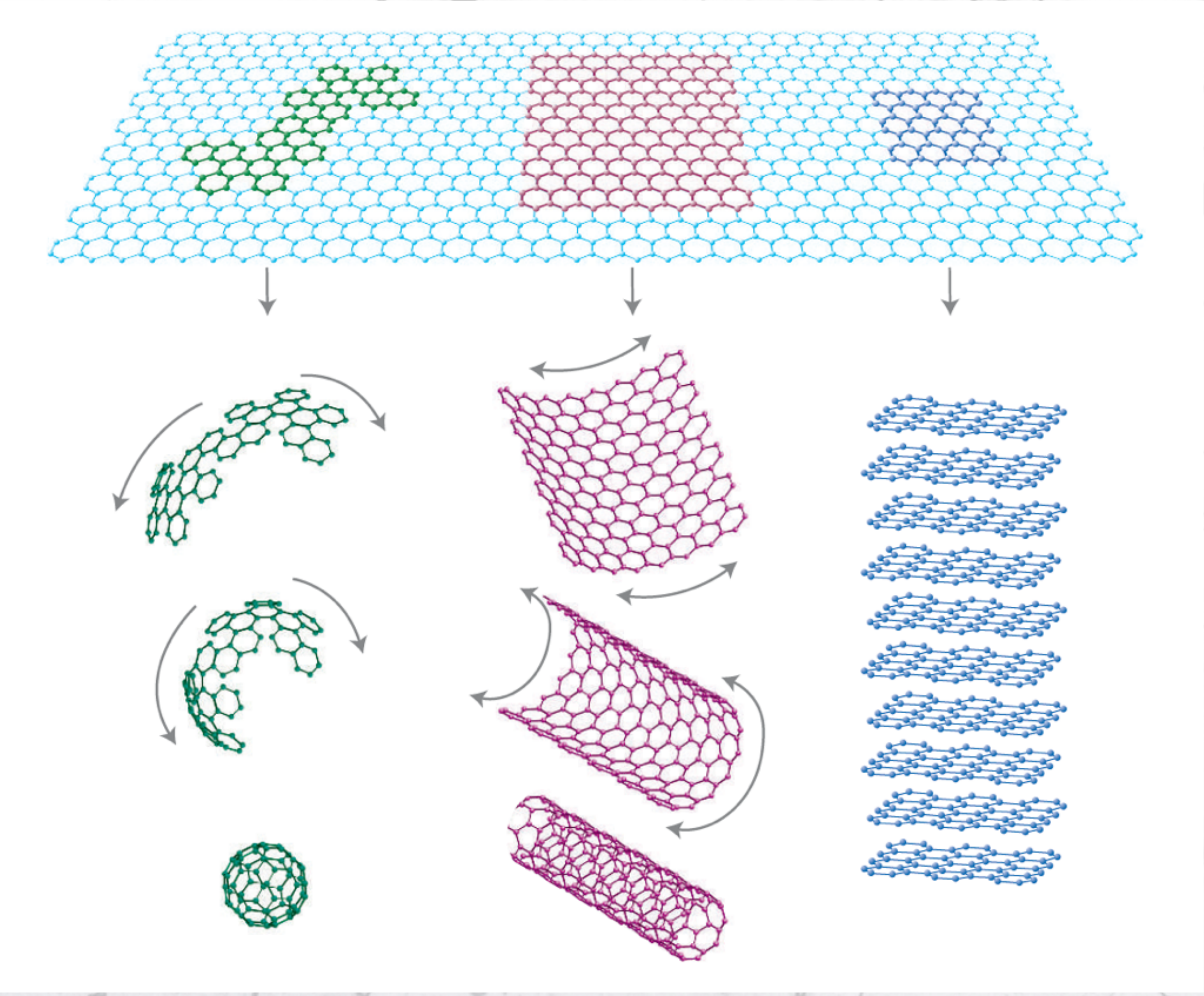
Graphene photosensors

F.Sánchez
for the IFAE-graphene:
L.Cardiel, J.Illa, T.Lux, JG.Macias

Graphene



- Graphene is a flat monolayer of carbon atoms packed into a 2D layout. (2D crystal).
- 2D crystals were believed not to exists until discovery of Graphene crystals in 2004.
- Actually Graphene is a very high quality crystal.
- But, not the only one known as of today!

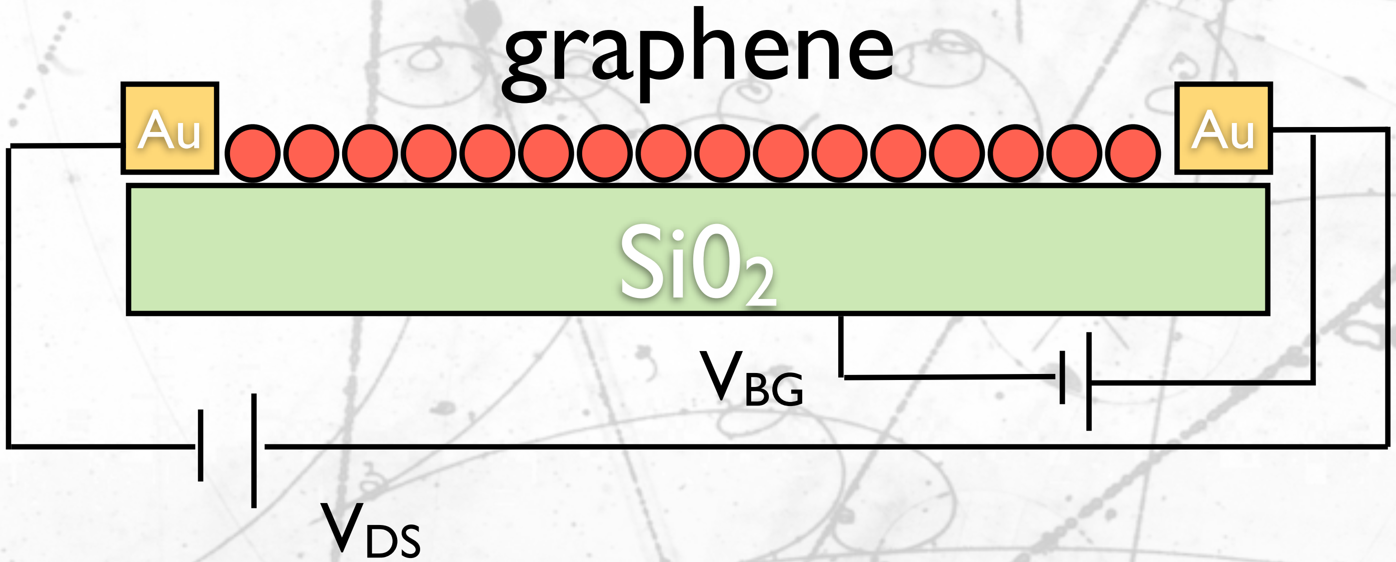
Why Graphene?

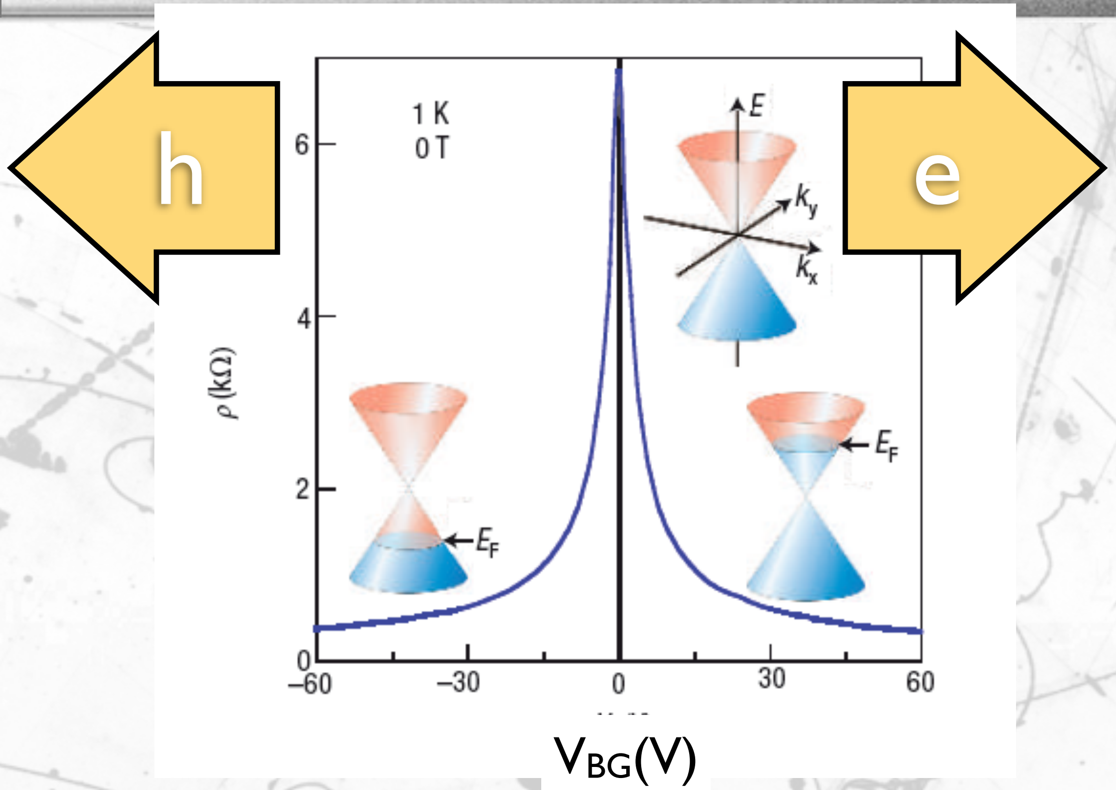
- The single layer and bi-layer Graphene behaves like a zero-gap semiconductor with only one electron type and one hole type.
  - The electronic structure evolves fast when adding layers with different electronics and optical properties.
  - The graphene can be doped altering the electronic properties of the material.
- Electron and holes has a large mobility: 15000 $cm^2 V^{-1} s^{-1}$ with large concentrations 10^{13} cm^{-2}
- Electrons interacting with the graphene lattice produce charge carriers wich are basically massless moving at the speed of light. (A charged neutrino!!!!)

$$E_{\pm}(k) \approx \hbar \nu_F |k - K|$$

Graphene might become a laboratory to study high precision QED

Electric properties



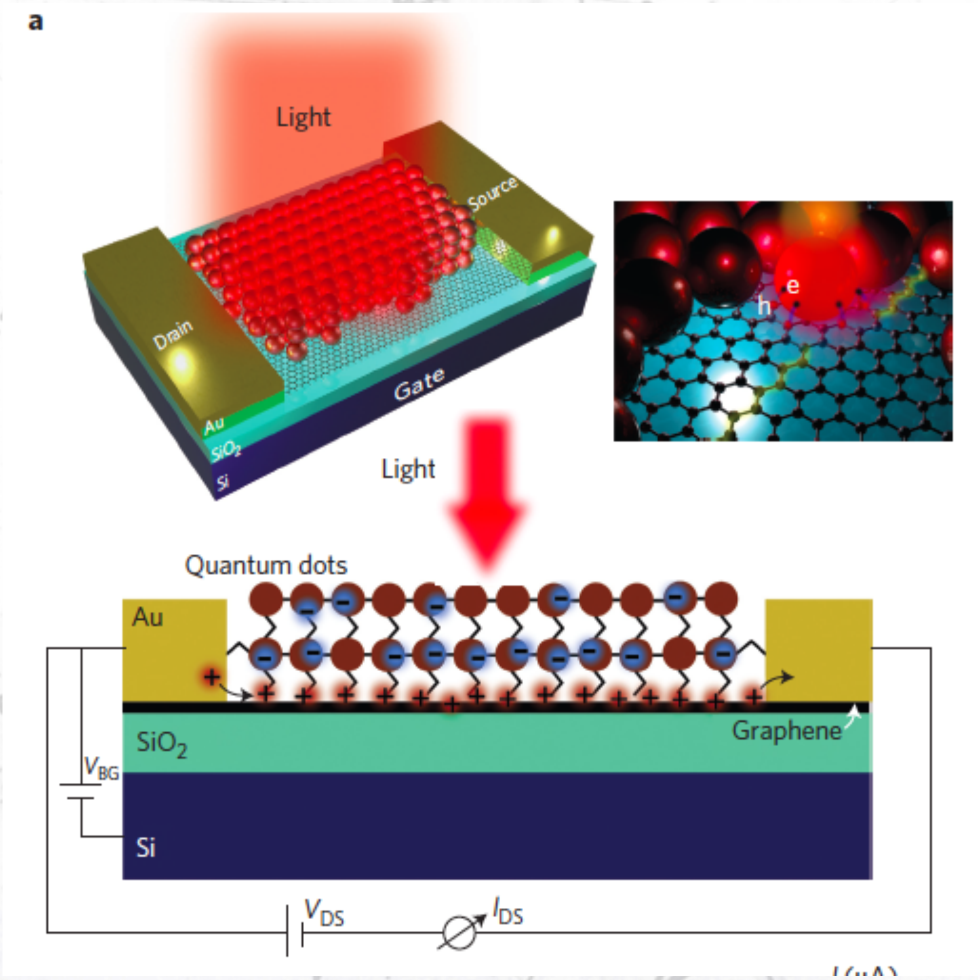


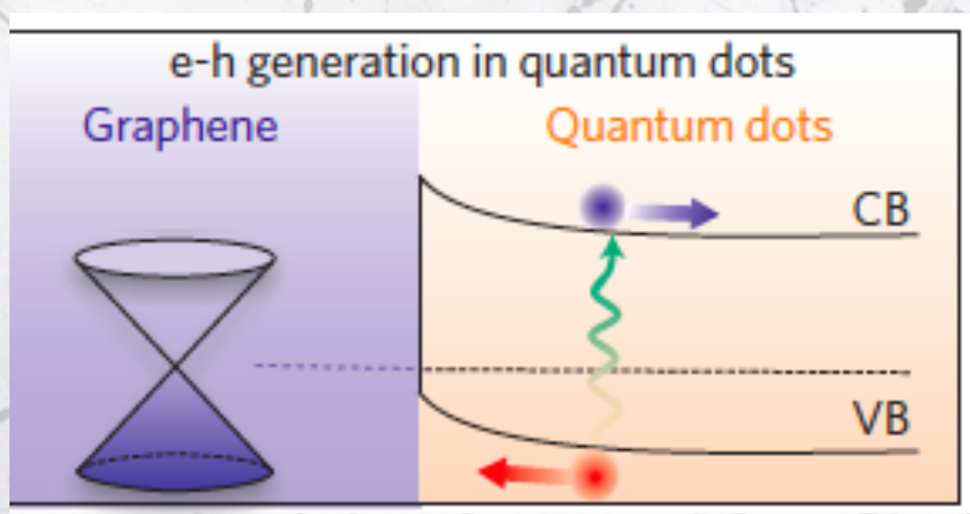
- Let's deposite a layer of Graphene on a piece of semiconductor SiO_2
- Bias the SiO2 with voltage V_{BG}.
- Check the graphene resistence.

- V_{BG} changes the level of occupancy and allows for electron or hole conduction by changing the Fermi Level.
- The maximum resistance is the so-called Dirac Point.

E(k) is the energy as function of the particle momentum.

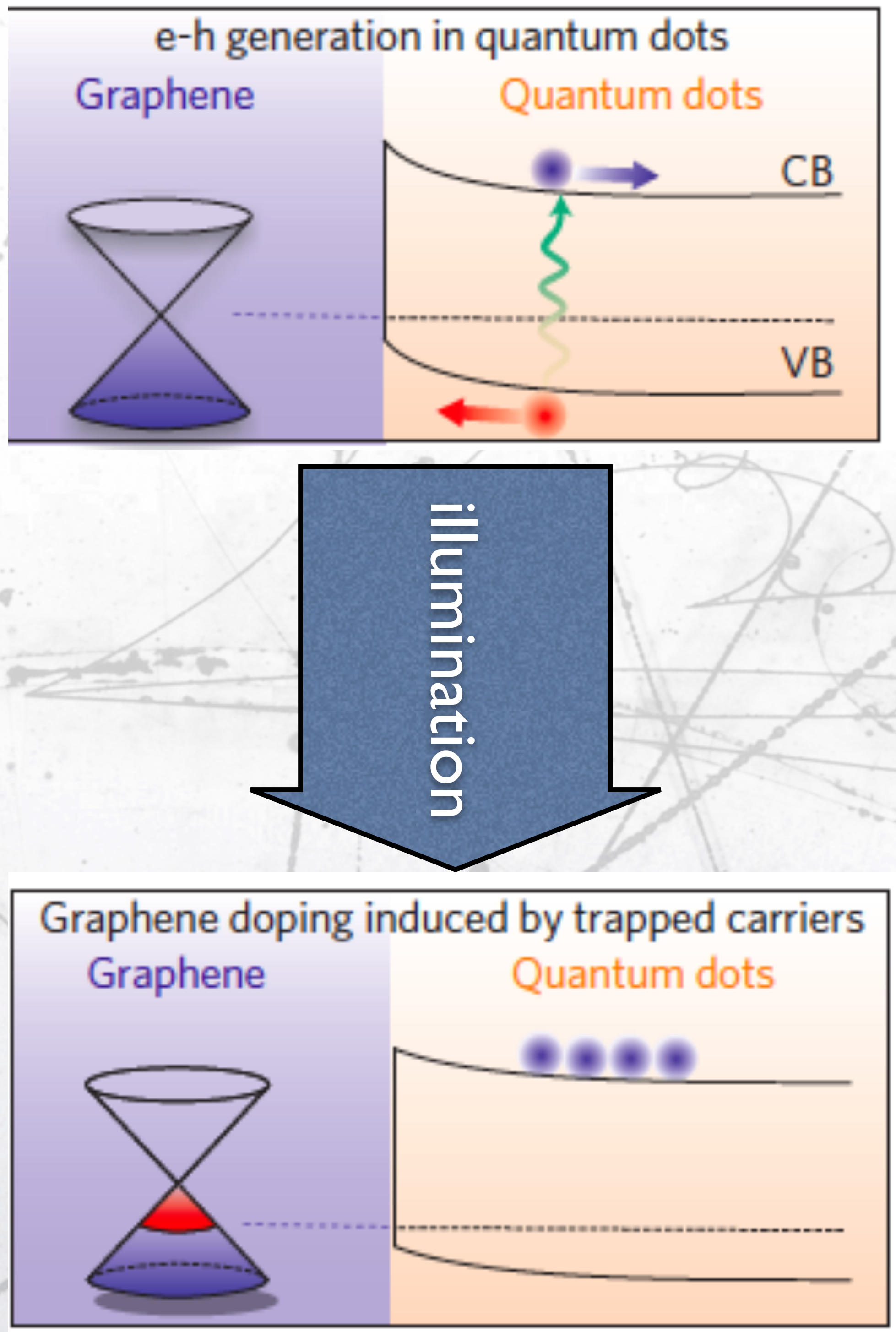
As photosensors





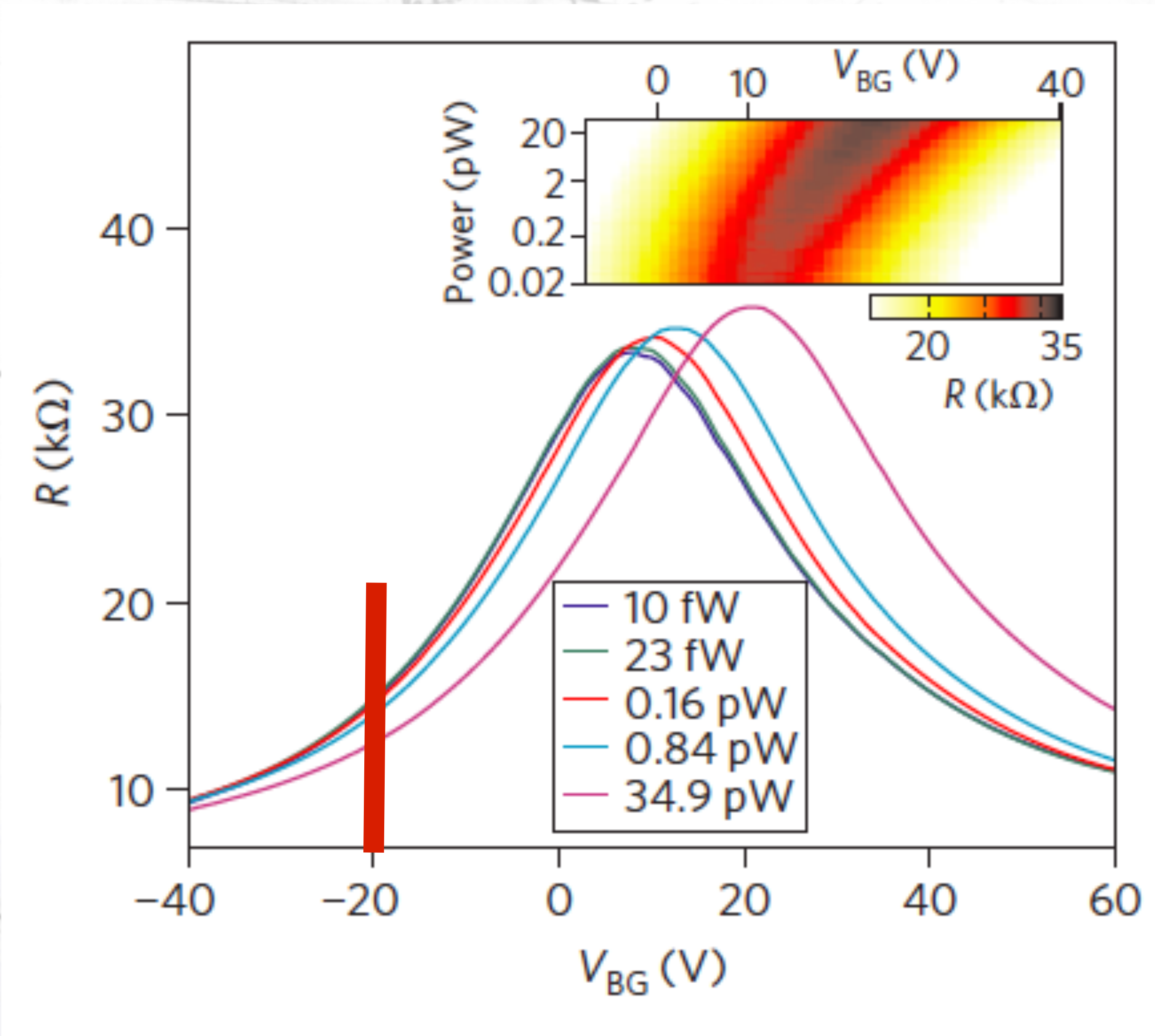
- Graphene along is not expected to show photocurrent because of the fast recombination of the charge carriers.
- Now let's dope the graphene with quatum dots: nano particles of PbS with 900 to 1500 nm.
- First effect is that the Dirac point shifts from ~50 to ~120 V:
  - there is an electric field induced in the surface between Si and graphene that is compensated by V_{BG} such that it equals the new Dirac value (V_D)

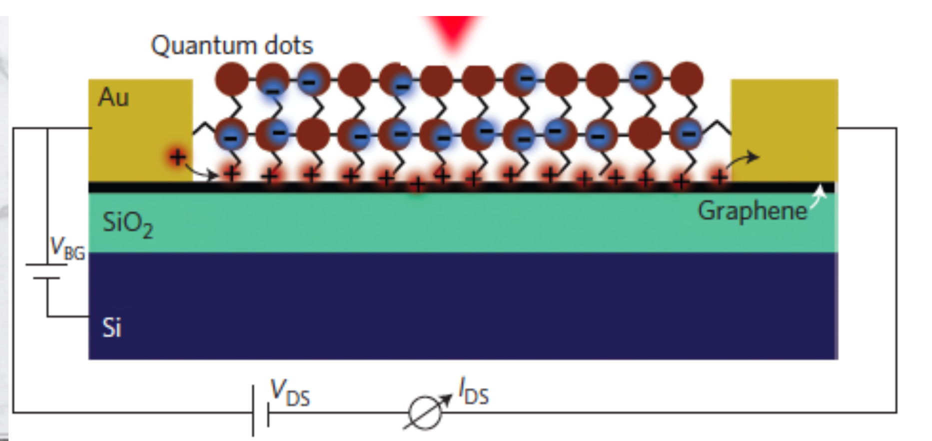
As photosensors



- Light is absorbed by the quantum dots:
  - holes are transfered to the graphene.
  - electrons are trapped in the quatum dots for some time.
  - The Dirac point voltage is then shifted (different surface E field).
  - If the Vg is not changed, the resistance of the graphene changes.!

As photosensors

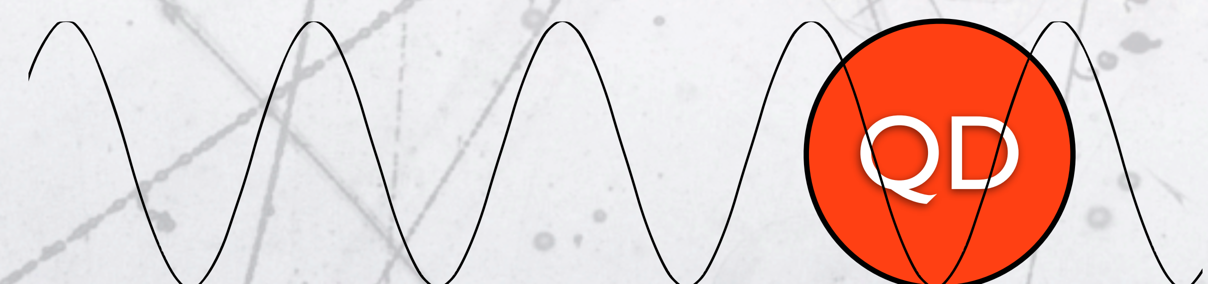


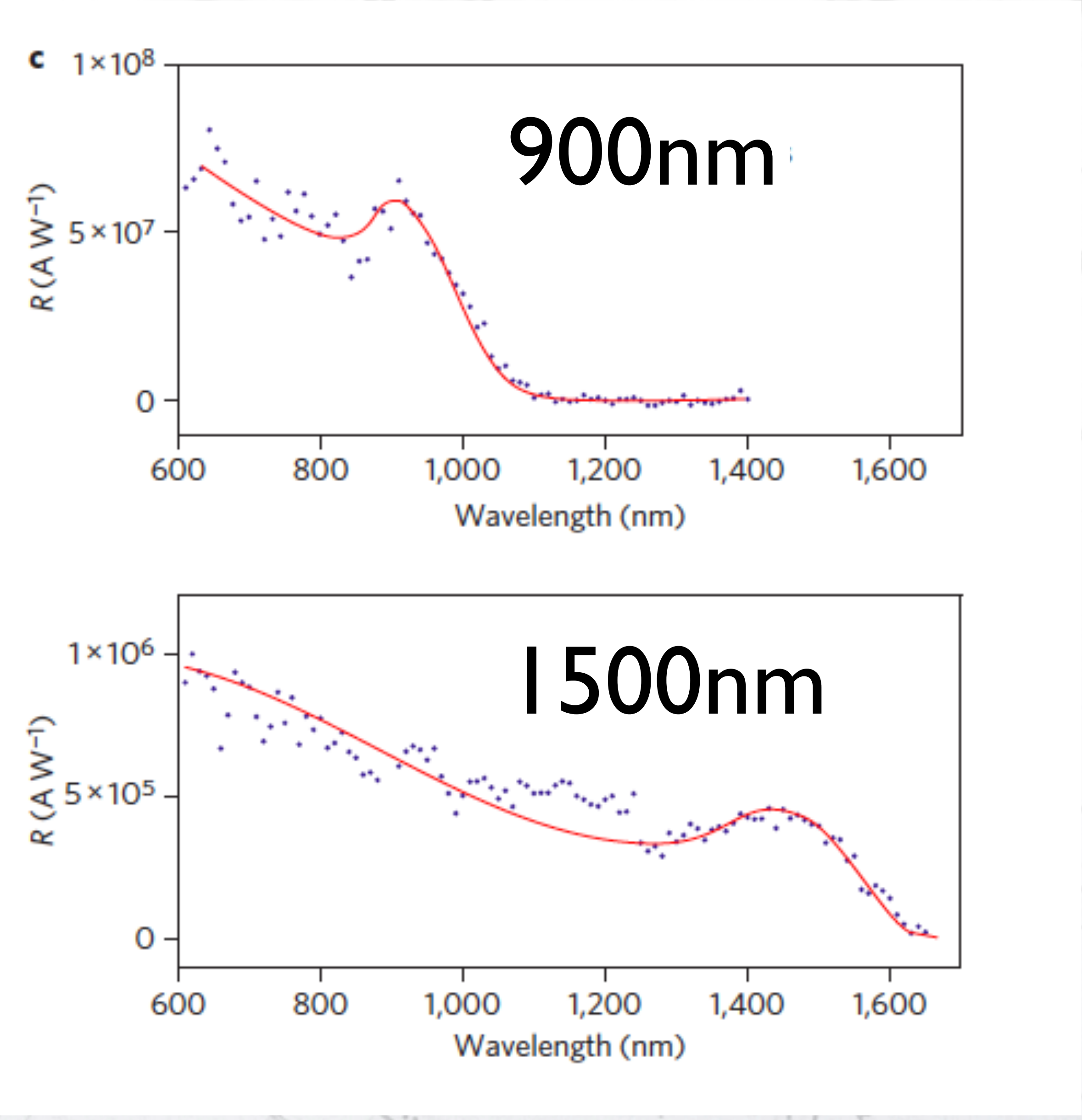


- The Dirac point shifts in the presence of light.
- Maintaining the V_{BG} we should see a change in the resistance of the graphene.
- This is measured as a change in the current over the V_{ds}.
- For the full time the electron remains in the quatum-dot (~10ms) the resistance is changed.
  - Gain = (I_{light} - I_{dark}) Δt

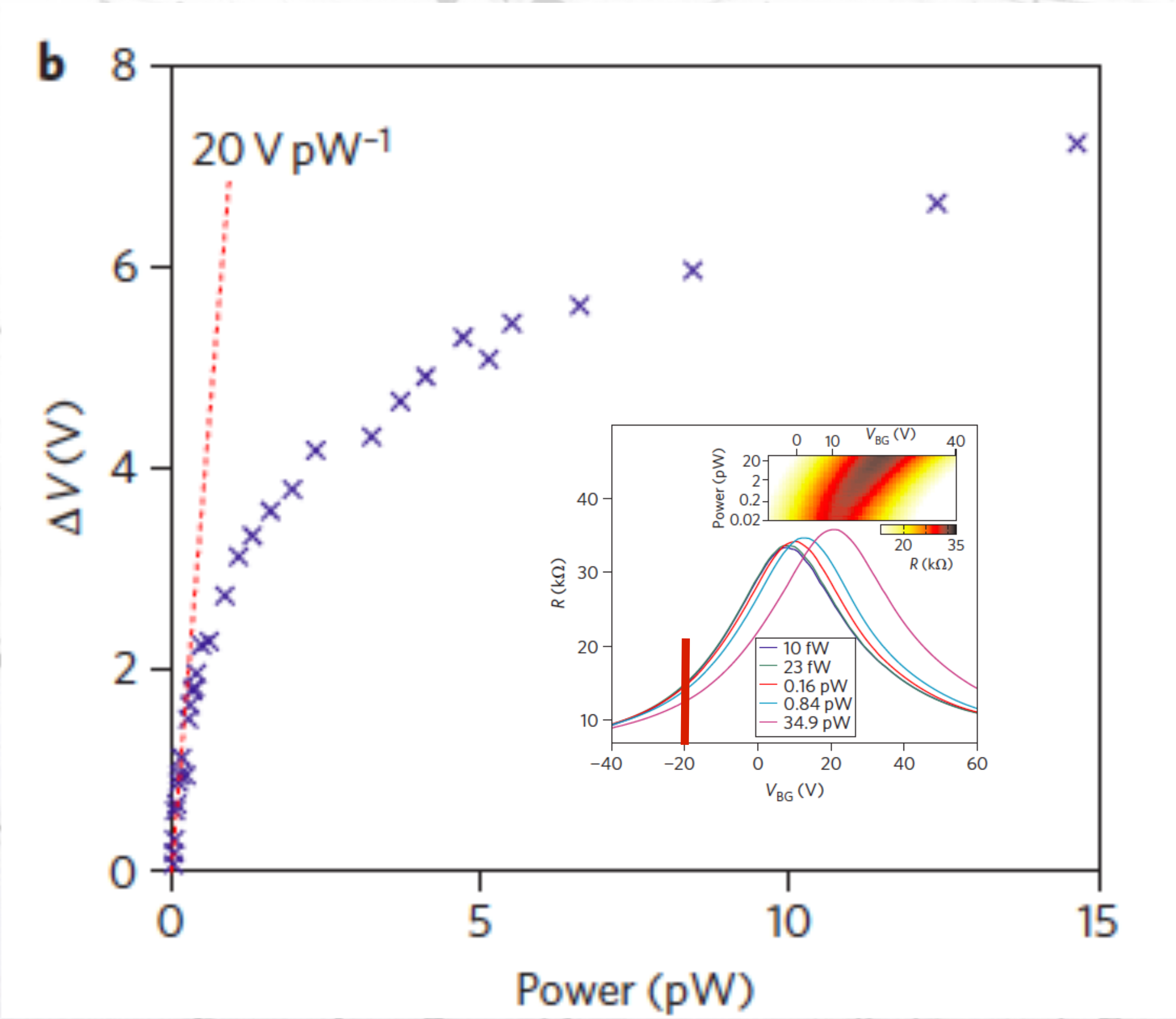
Quantum dots

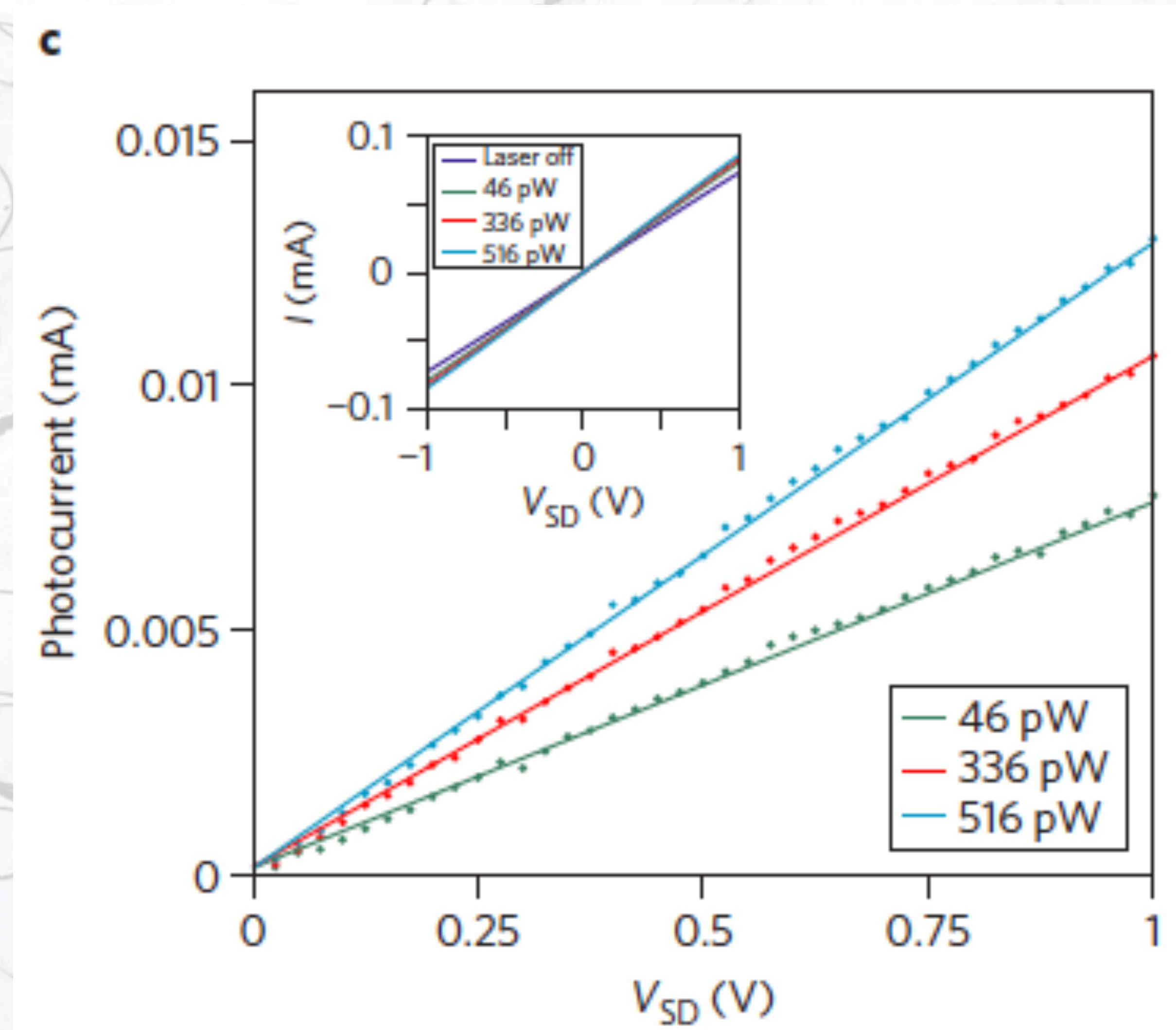
- Quantum dots has large absorption probability for photons with λ ~ diameter…
- and below, but it shows a clear cut off for lower energies.





As photosensors





For low power, the response is linear with light intensity.

The response is typical of a resistance.

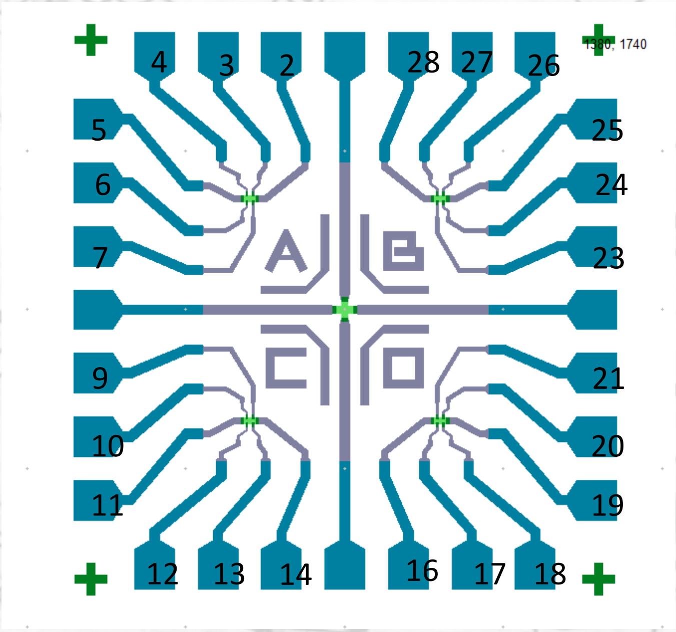
Graphene @ IFAE

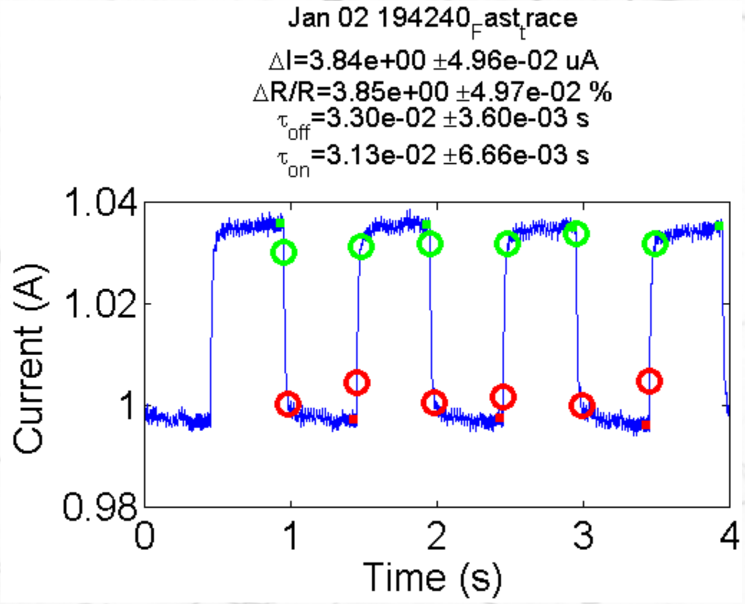
- In October IFAE started a collaboration with the ICFO to develop a readout for a highly integrated pixelized graphene photosensor.
- The purpose of the IFAE is twofold:
  - characterise from the electronics point of view the device (noise, …)
  - develope a low consumption readout system that can be integrated in an ASIC.
- The group got support by the IFAE Severo Ochoa.

IFAE motivation to join effort is explained later

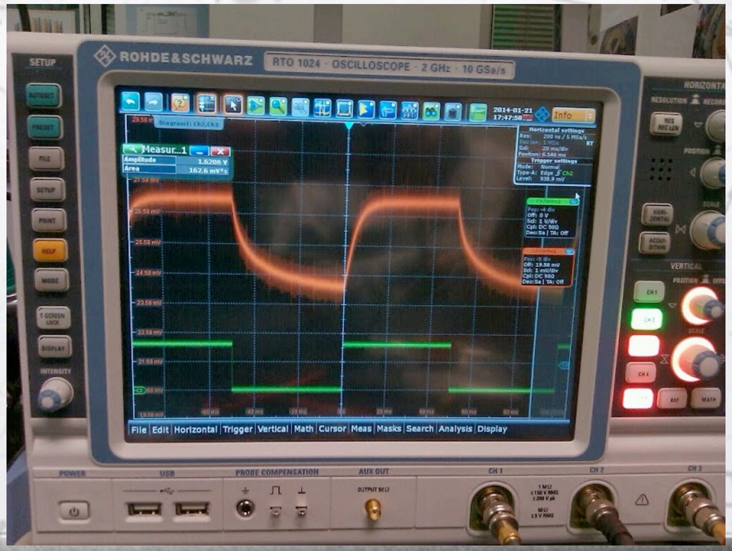
Graphene @ IFAE

- ICFO provided 4 graphene sensors doped with 985 nm in January.

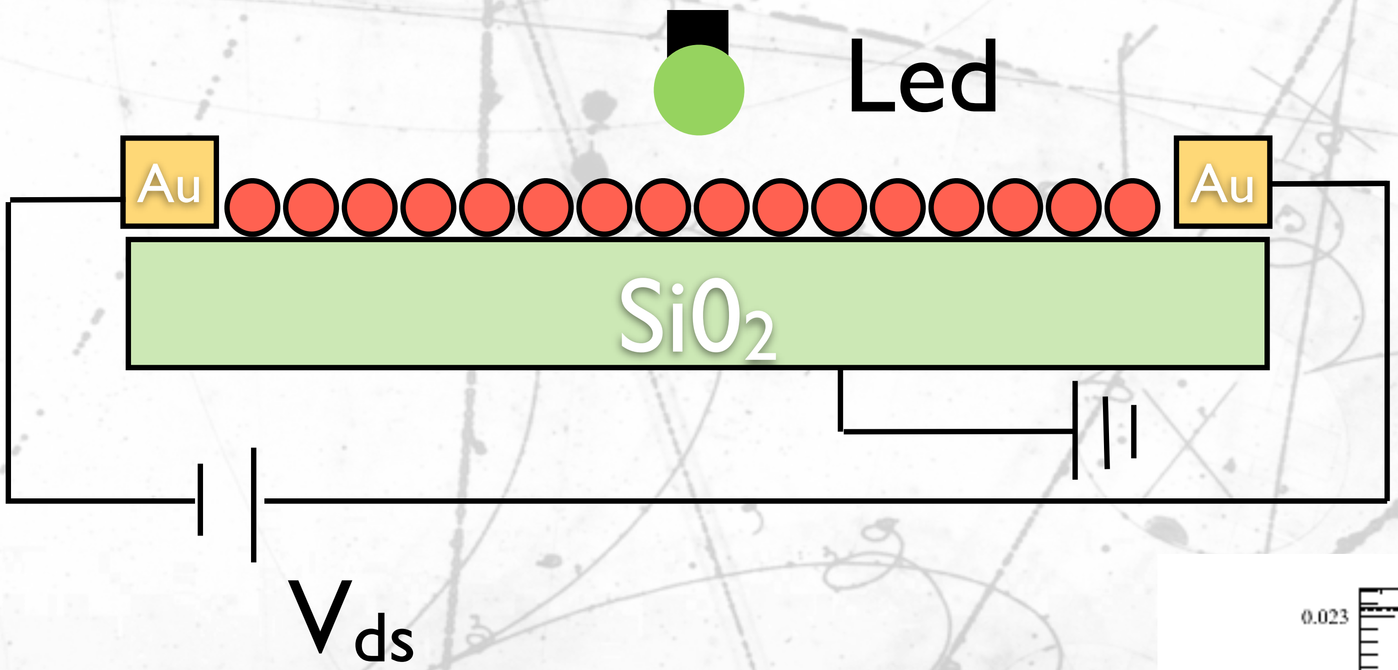


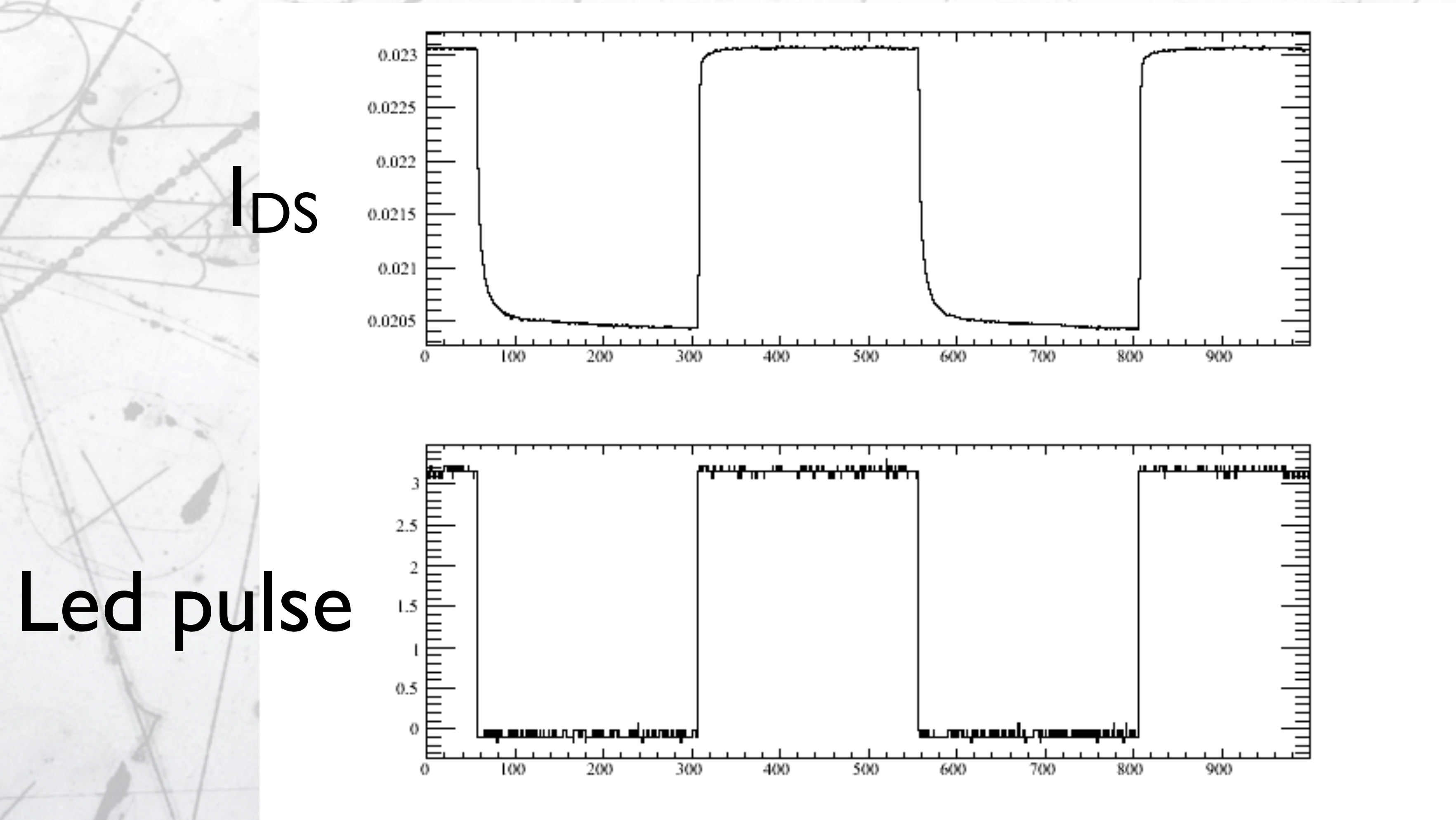


- We saw the first response at the end of January.

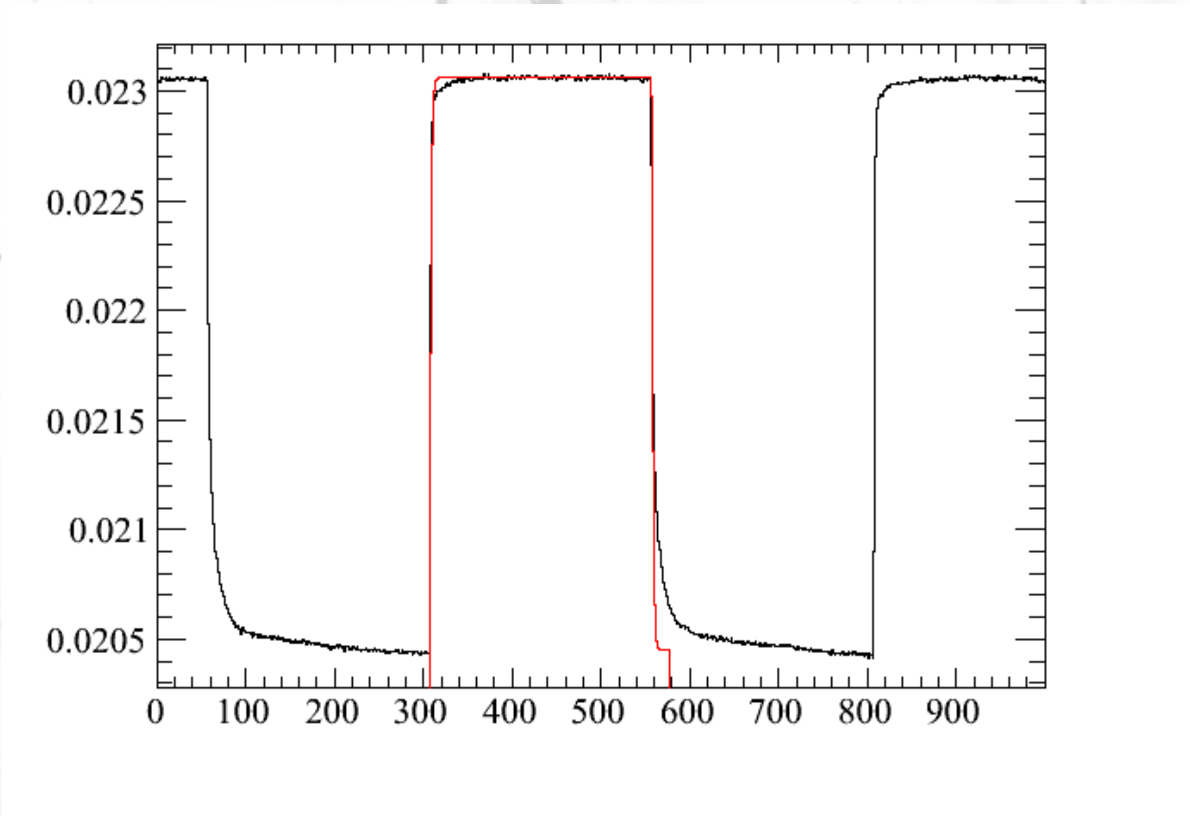


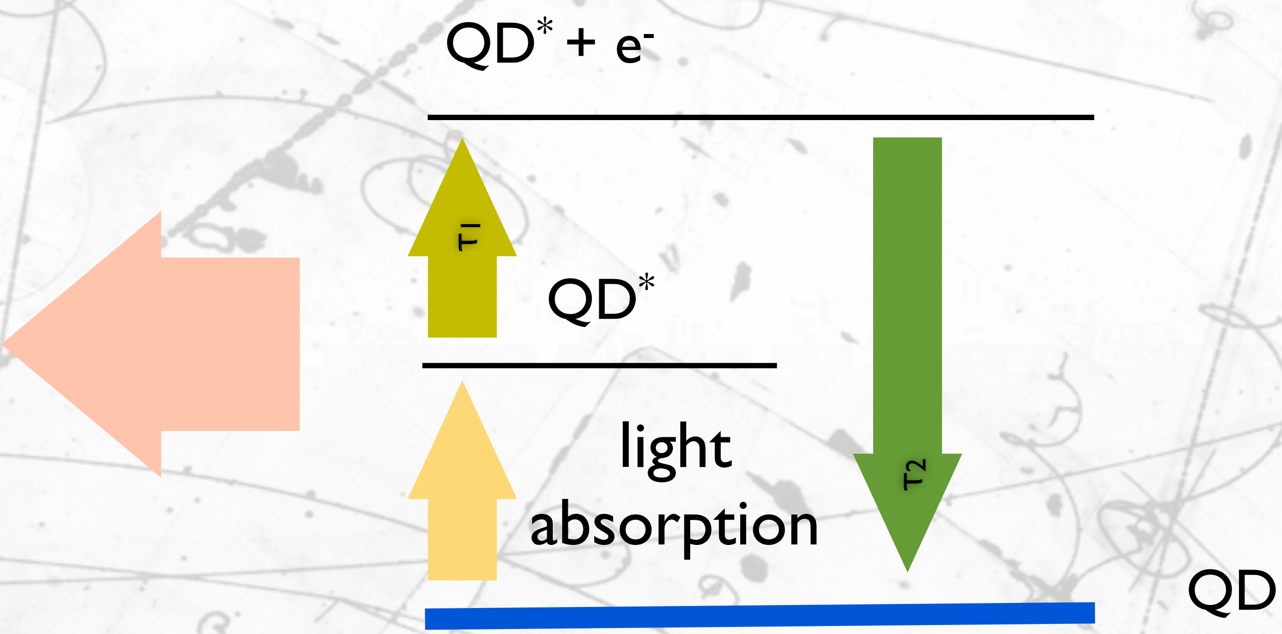
Graphene @ IFAE



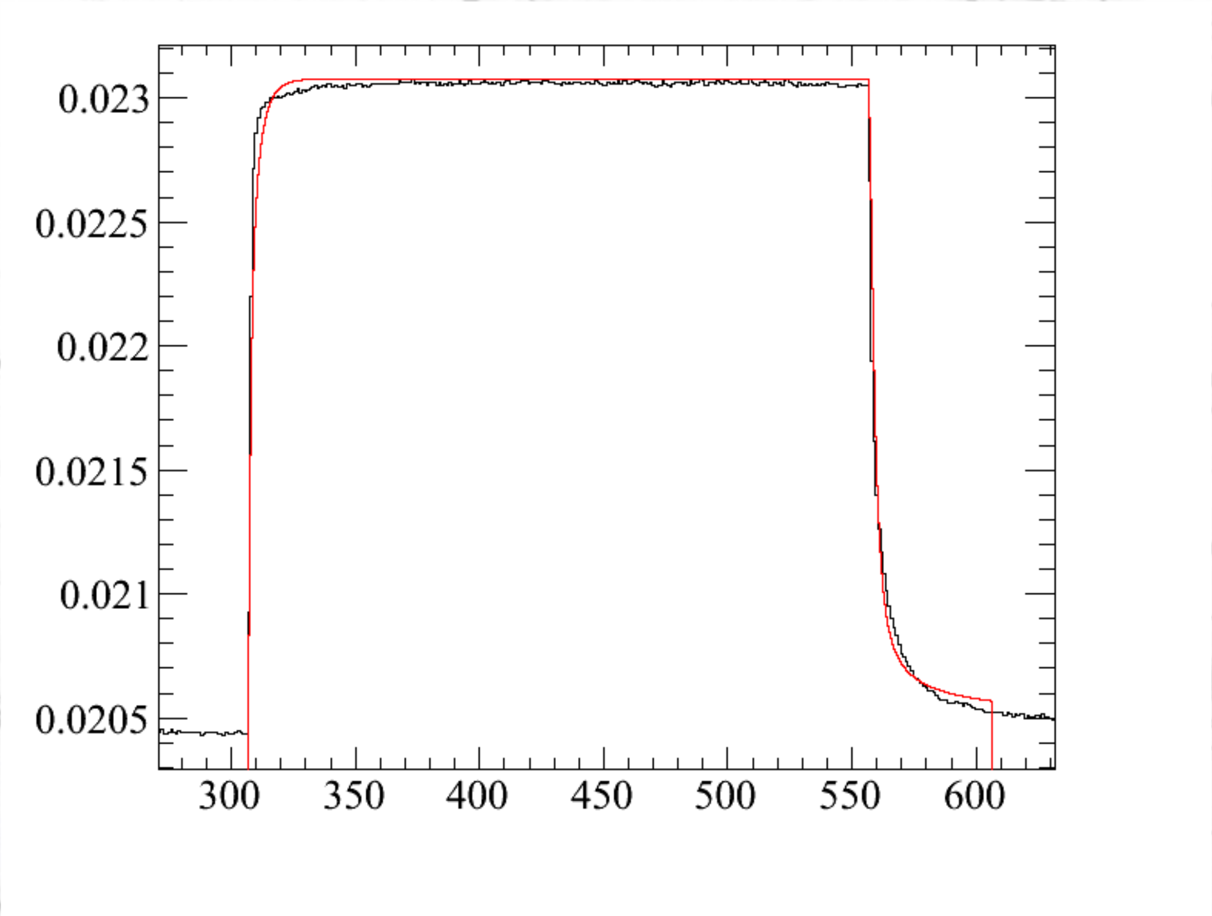


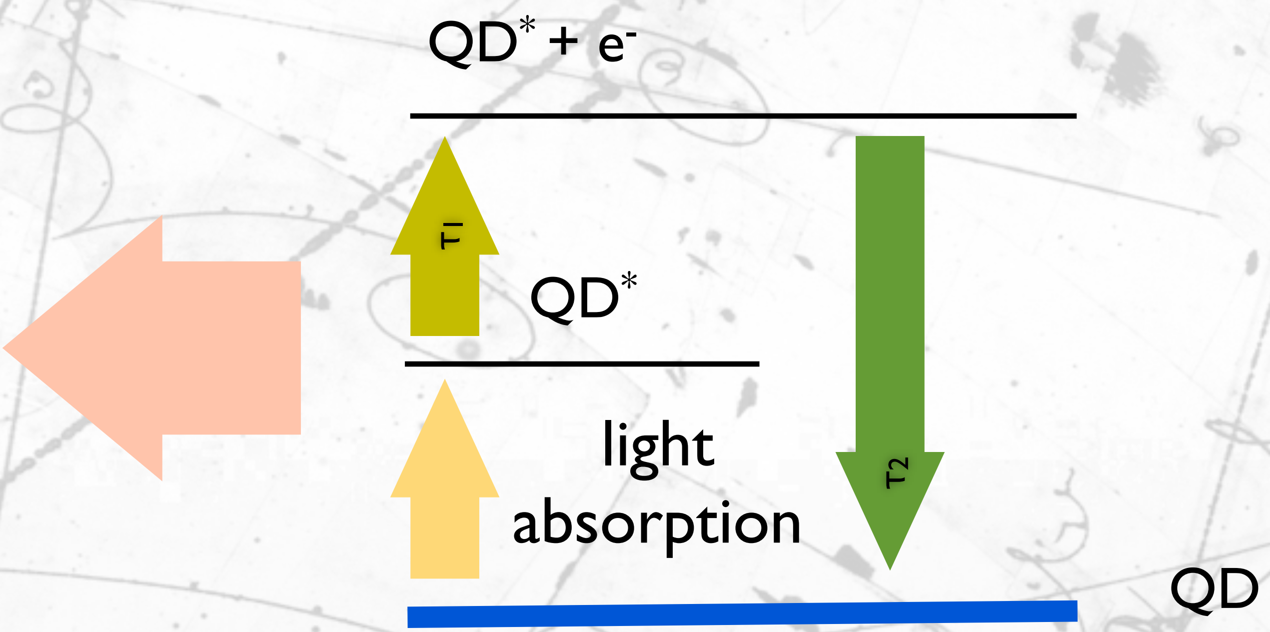
Graphene @ IFAE





- Trying to understand the response shape.
- This is important to understand the dynamics of the photosensors → keep trying!.





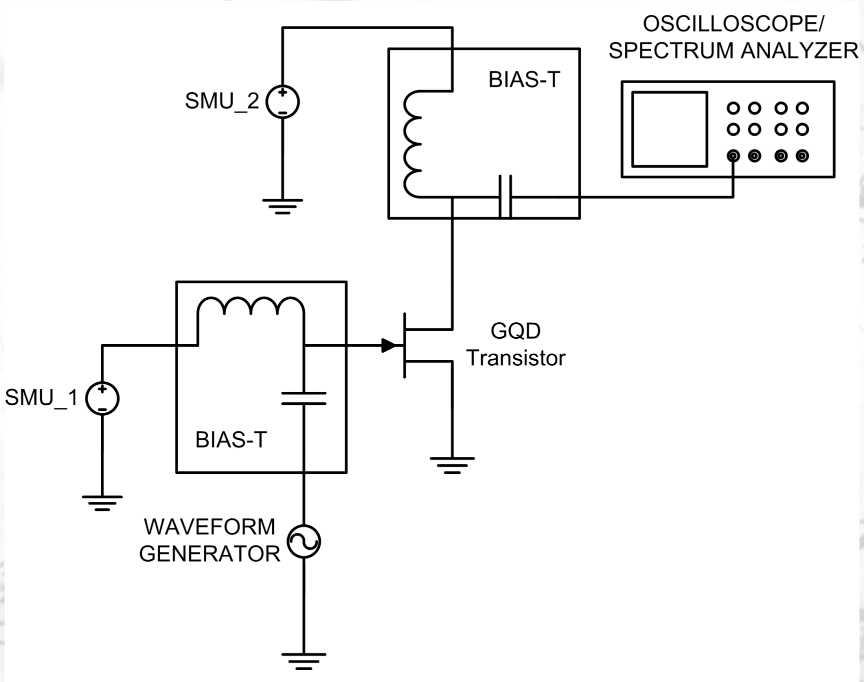
- Another alternative model:
  - The transition probability is function of the separation of the energy level and ocupancy.
  - With a $\tau_{1,2} = f\,(\,N_{QD^* + e^-})$

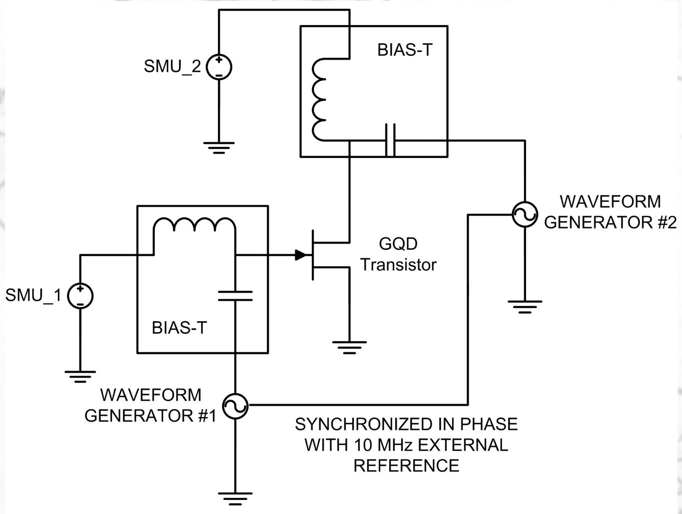
Graphene @ IFAE

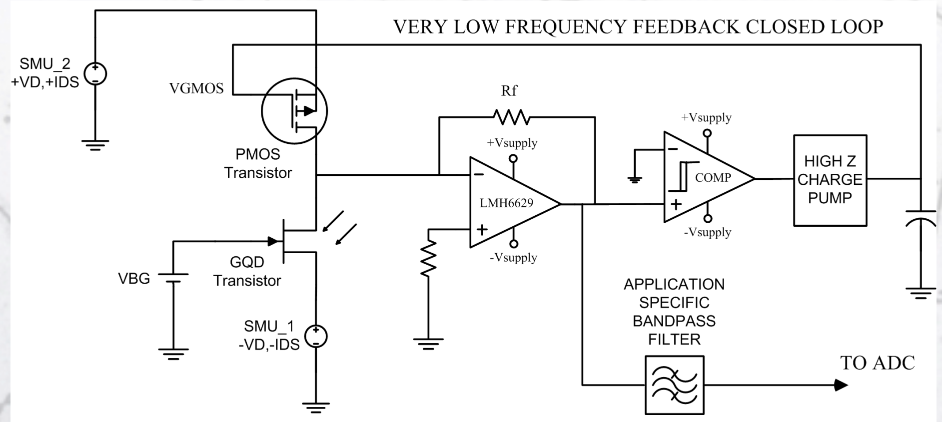
- The main problem of graphene readout is that it is pure resistive: there is always a continuous current through the device.
- How to read the graphene reducing the total current?:
    - pulsing/sampling the readout.

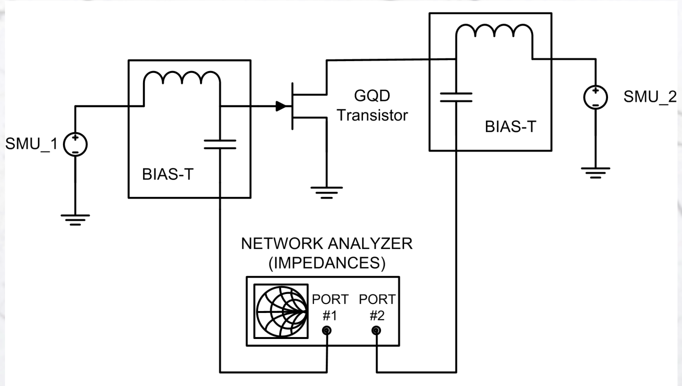
    - reducing the V_{DS} to the minimum (noise?).
    - Sinusoidal V_{DS} so the integral of current = 0.
    - Compensating the current.

Graphene @ IFAE









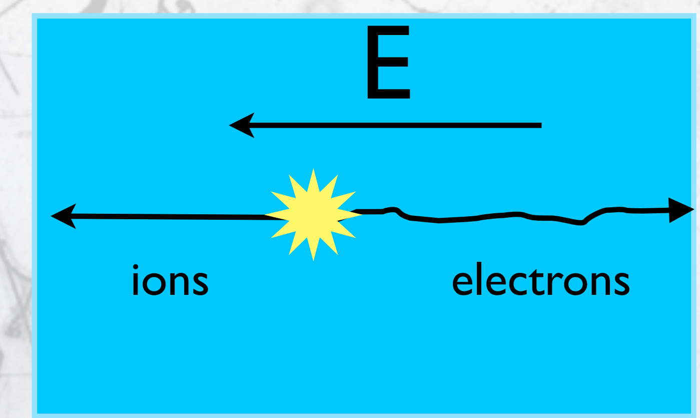
Graphene @ IFAE

- The project is getting momentum.
- Two weeks ago we posted proposal to the EU FP7 graphene flagship to develop a readout ASIC for an array of 64x64 pixels for an infrared camera.
- The project is supported by ICFO but they could not participate to be already part of the graphene flagship.
- Three partners:

The future

- This collaboration allows us to get hands into the technology but we want to go further:
  - applications in HEP as photosensors:
    - cheap to produce
    - large area coverage,
    - tuning of wavelengt, check options for UV and DUV for noble gas scintillator.
  - IFAE neutrino is interested in investigating the posibility of detecting ions from a TPC ionization: ions act as quantum dots or excite quantum dots.
    - Precise positioning, small attachment, no gain needed, ...

Graphene TPC ?



traditional TPC

Final remarks

- This is not the only concept of graphene photosensor, actually the readout for GImaging should probably adapt to the other options.
- We are starting to look into these devices:
  - A lot of fun!
  - We are just at the beginning of understanding them and exploring possible applications.
  - We would like to share the developments with the IFAE to explore possible synergies with other groups.

Additional slides

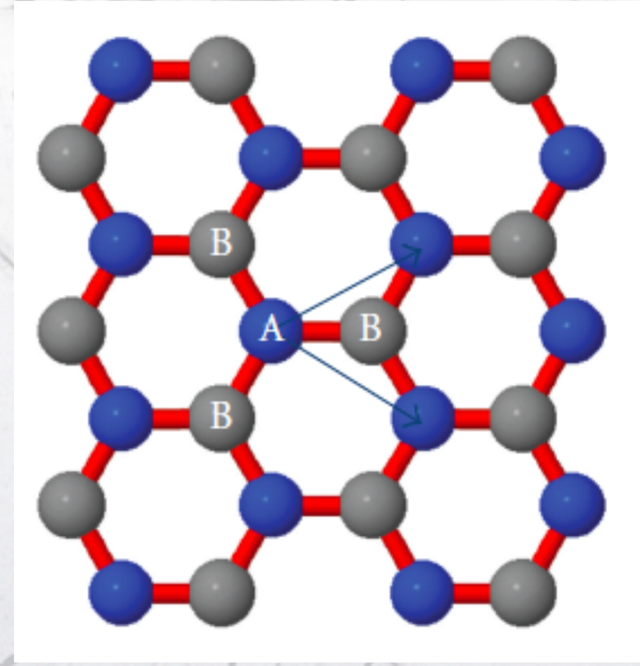
Dispersion relation

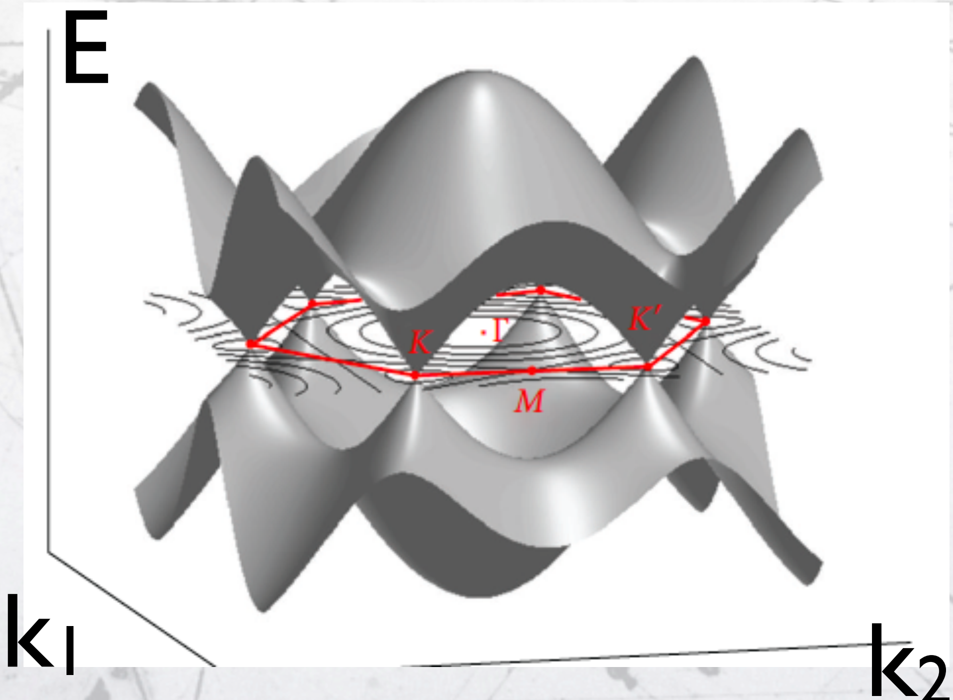
$$H_{\vec{k}} = \begin{pmatrix} 0 & 2.7e^{i\vec{k}\vec{a}_1} + 2.7e^{i\vec{k}\vec{a}_2} + 2.7e^{i\vec{k}\vec{a}_3} \\ 2.7e^{-i\vec{k}\vec{a}_1} + 2.7e^{-i\vec{k}\vec{a}_2} + 2.7e^{-i\vec{k}\vec{a}_3} & 0 \end{pmatrix}$$

$$\vec{a}_1 = (1,0)$$

$$\vec{a}_2 = (-1/2, \sin\pi/3)$$

$$\vec{a}_2 = (-1/2, -\sin\pi/3)$$





Dirac points are the connection between valence (lower surface) and conduction bands (higher surface).