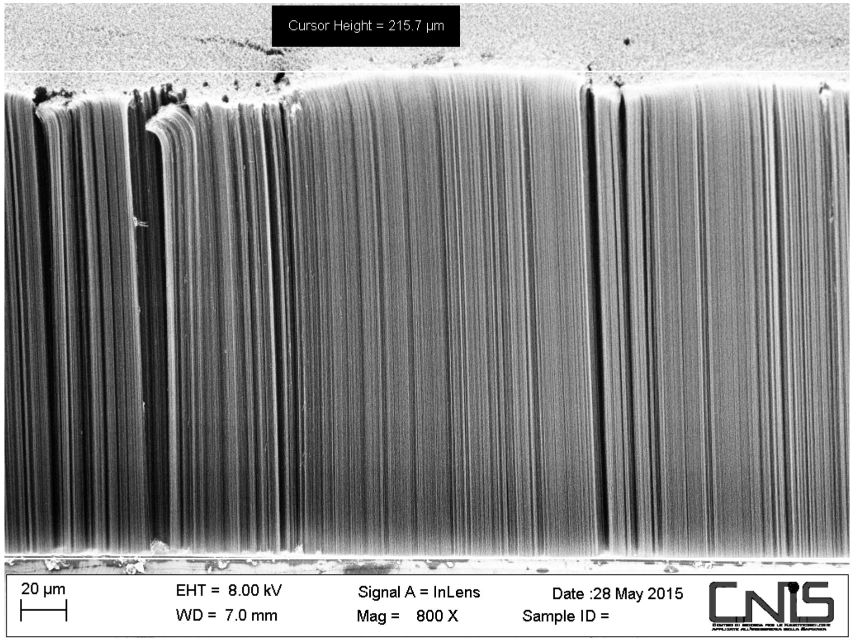



# Nano technologies for direct dark matter (and relic neutrinos) detection

Gianluca Cavoto (Sapienza Univ. Roma and INFN)

26 Jun 2018

# Outline

- **Directionality** - a tool to reject background
  - anisotropic targets (CNT)
- **Sub-GeV** dark matter
  - detecting electrons

Eventually, need to **detect**
either low energy (**keV**) **nucleus** recoils for ~1-10 GeV DM
or (**eV**) **electron** recoils for 5-100 MeV DM
(as often, we assume a DM-e or DM-nucleus elastic scattering kinematics)

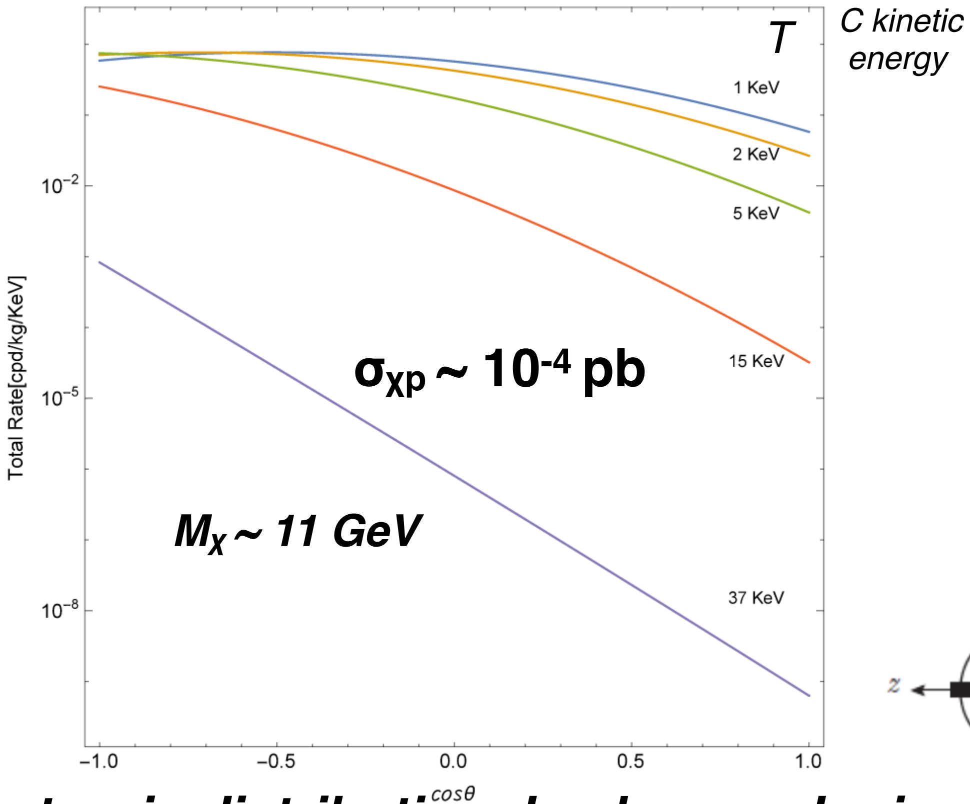
*Two parallel efforts around graphene based structure*

# Direct detection: the name of the game

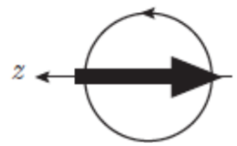
- **WIMP** model: non relativistic 10-1000 GeV particles with cross section much larger than solar neutrino weak cross section

**ELASTIC scattering**
of a WIMP χ
on a C ion

*Decreasing experimental threshold*




We ***move***
with the Sun
in a galactic halo of
DM particles

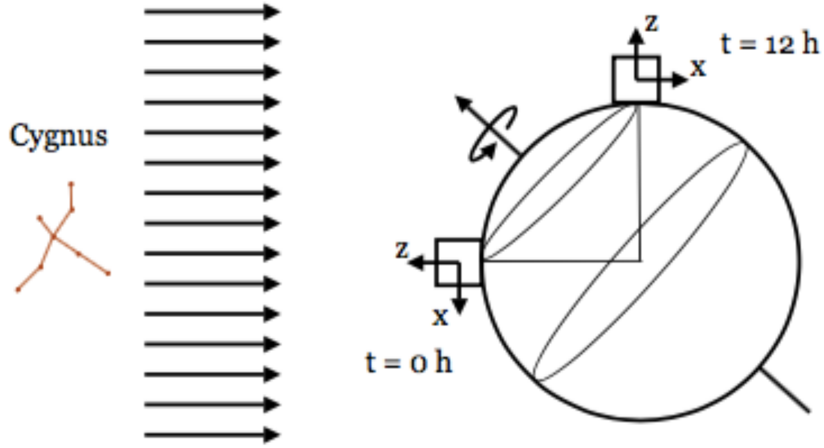



**θ = π**
***WIMP "wind"***

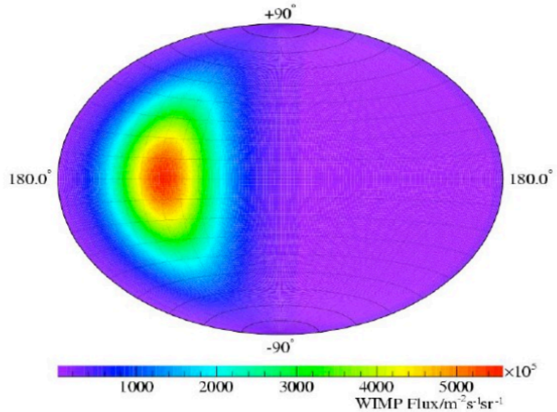
***Anisotropic distribution: background rejection***

# Directionality

- **WIMP** must appear as coming from **CYGNUS**




- Nuclear recoils must reflect this feature (*dipole* distribution)



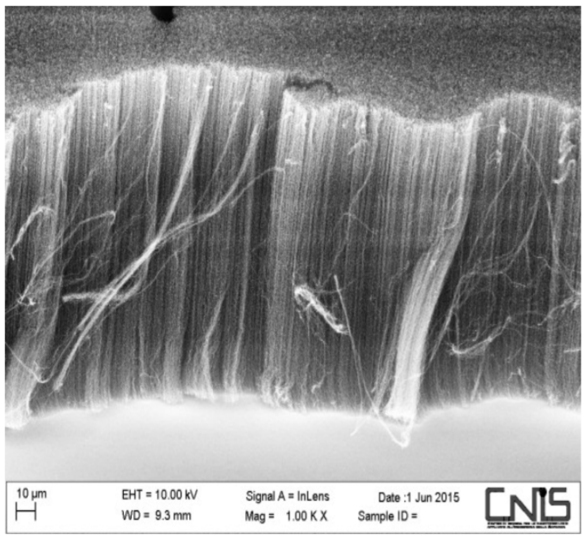

- Radioactive background is isotropic

- Solar **neutrinos** comes from the **Sun**!

# Solid target: CNT

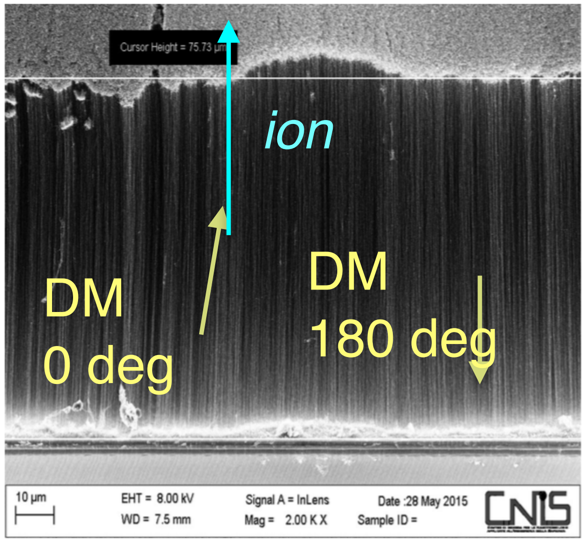
- Idea: WIMP scatters on a ***anisotropic*** target as ***aligned*** carbon nanotubes.
- Nuclear recoils are **exiting the target only** when along the CNT axis - otherwise, absorbed!

collaboration University of Mons, Belgium



length: *100 µm (can be increased)*
ext. diameter: *(20 ± 4) nm*
aspect ratio: *5x10⁴*

commercial



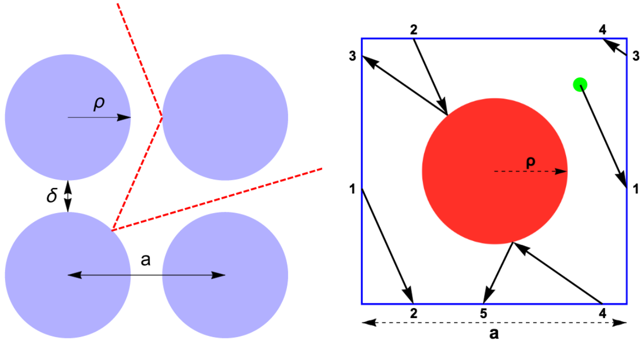

***detector side***

***absorbing substrate***

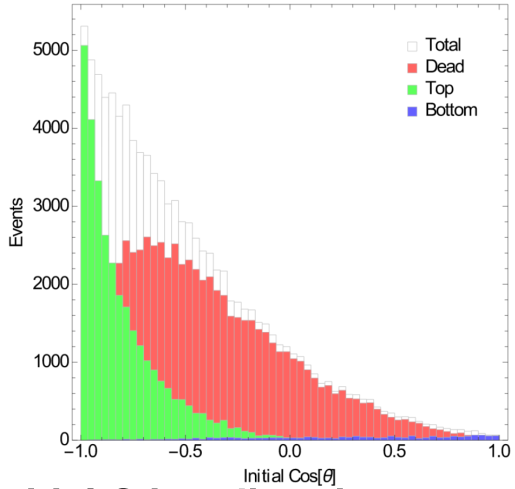
length: 75 *µm*
ext. diameter: *(13 ± 4) nm*
aspect ratio: 0.6 *x10⁴*

# C ion moving within the array

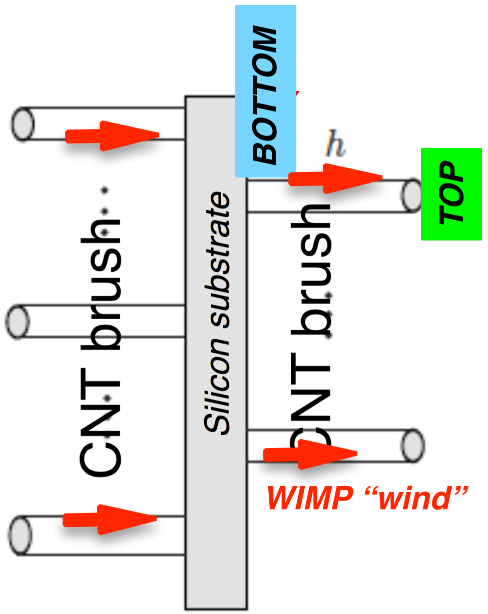
G.Cavoto et al., Eur.Phys.J. C76 (2016) no.6, 349
L.M.Capparelli et al., Phys.Dark Univ. 9-10 (2015) 24-30



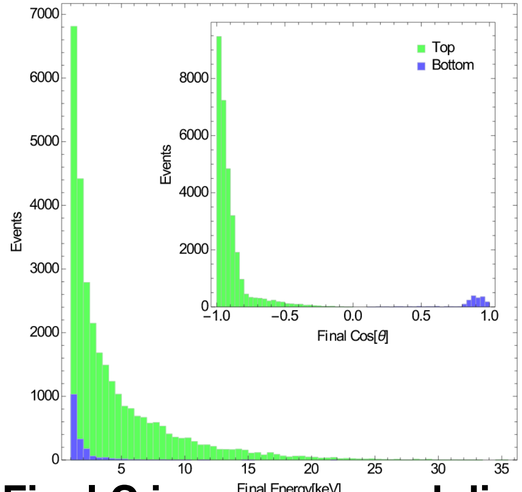
- *C* ion extracted by the WIMP feels a repulsion at the CNT wall
- Being "channeled" ?




Initial C ion direction



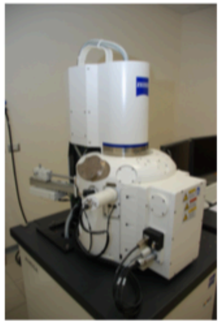

*Double CNT brush*




Final C ion energy and direction

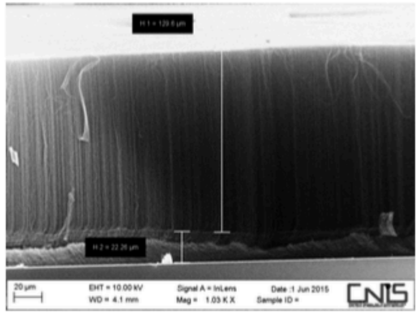
**A prediction for an "acceptance" channeling angle of 35 deg is made**

# Investigating CNT structure



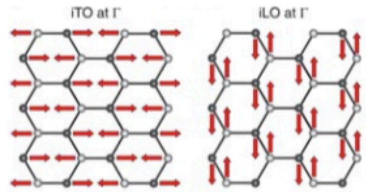
**Scanning Electron Microscopy (SEM) at sub-$\mu$m scale**

CNIS lab. @ Sapienza

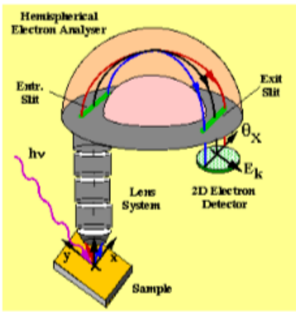


**Raman spectroscopy at sub-$\mu$m scale**

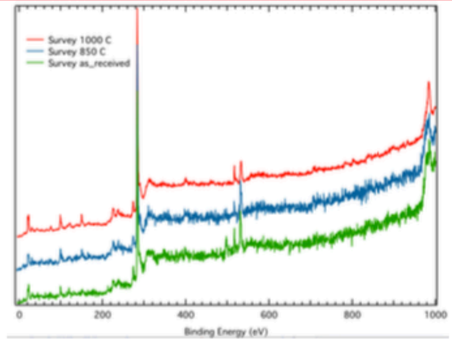
Phys. Dept. @ Sapienza




IR inelastic scattering: vibrational structure of the carbon lattice, defects, ...

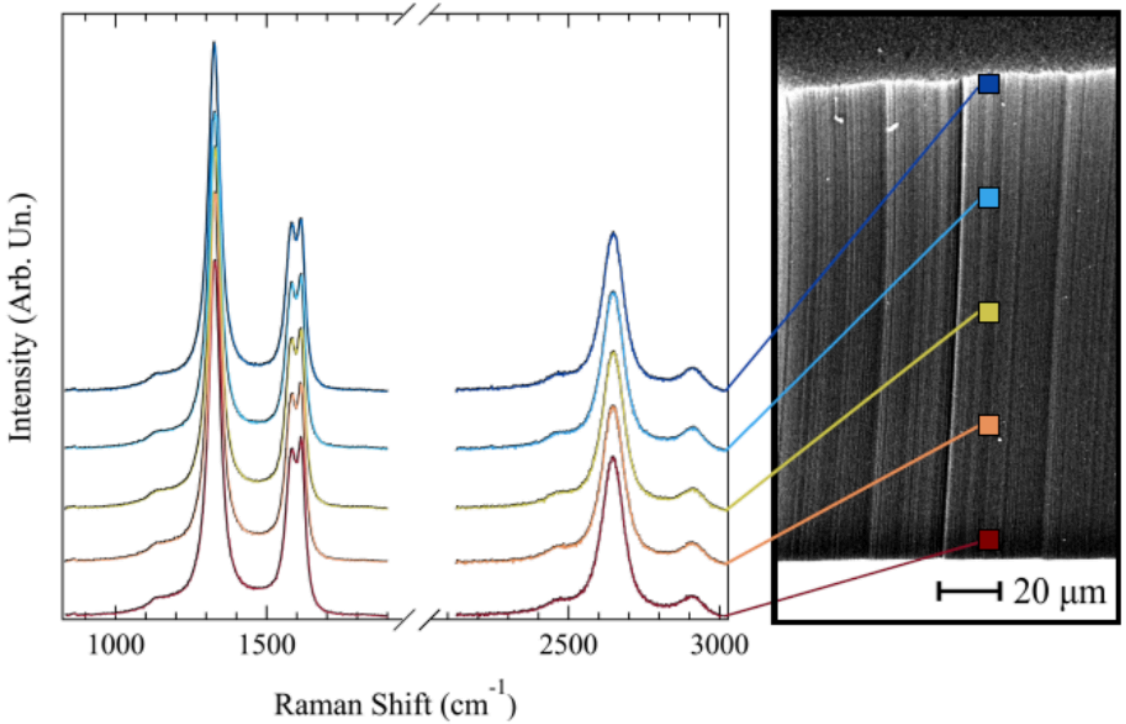



**X-ray Photoelectron Spectroscopy (XPS)** Phys. Dept. @ Sapienza and @ Univ. Mons




spectral density of electronic states: C chemical state, bonding, defects, ...

# Raman scattering characterisation

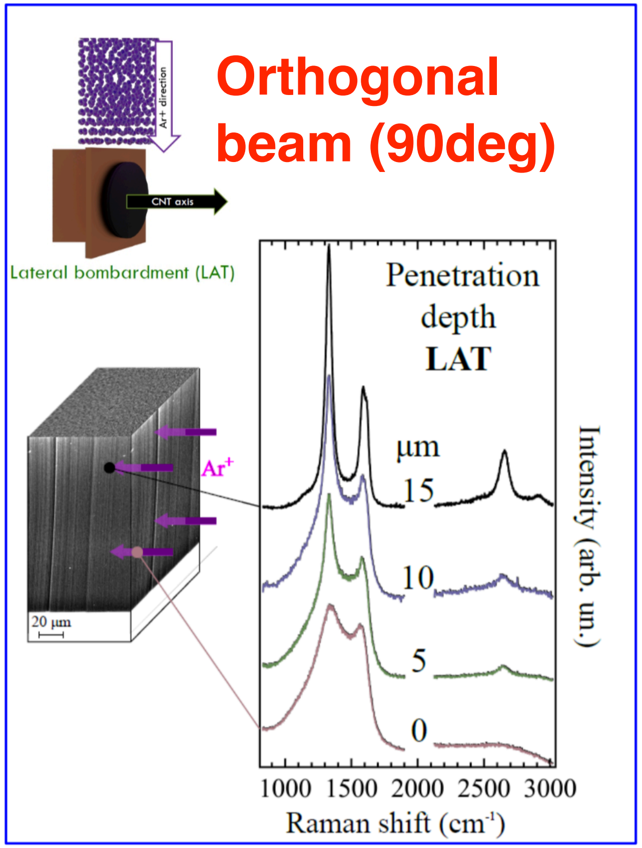


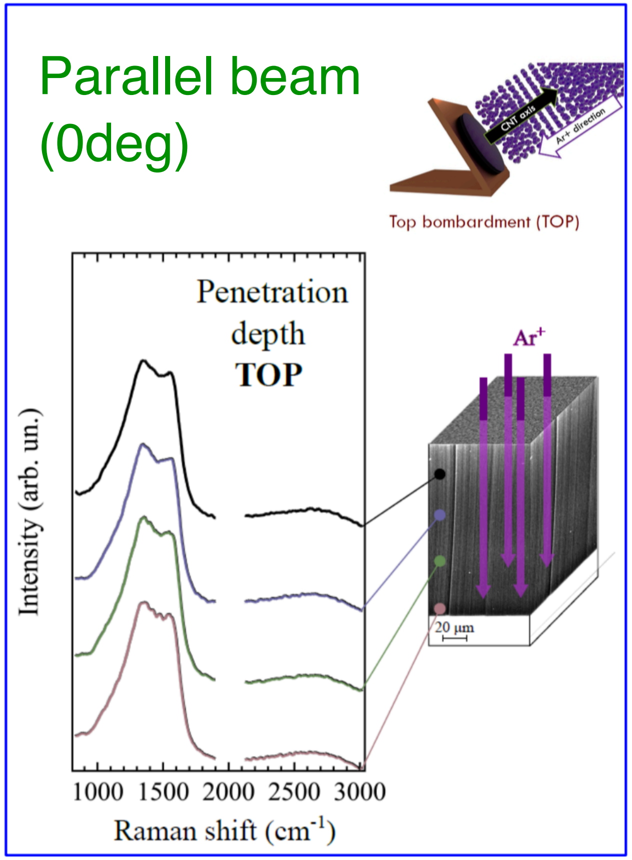

***Very good quality CNT***

- Spatially resolved, can asses the quality of the CNT bonds at **various heights** of the target
- Light can be focused at **various depths** in the interior of the target (up to few 10 µm)

# $Ar^+$ ion beam on CNT

- 5 keV $Ar^+$ beam onto a CNT at ***different*** angles with respect to CNT axis




G.D'Acunto et al. to appear in ***<u>Carbon</u>***

Number of **defects** measures the **penetration** of Ar ions
When Ar beam **aligned** with CNT, defects present **at all the heights**
When Ar beam **orthogonal** to CNT, defects present **only on the surface**

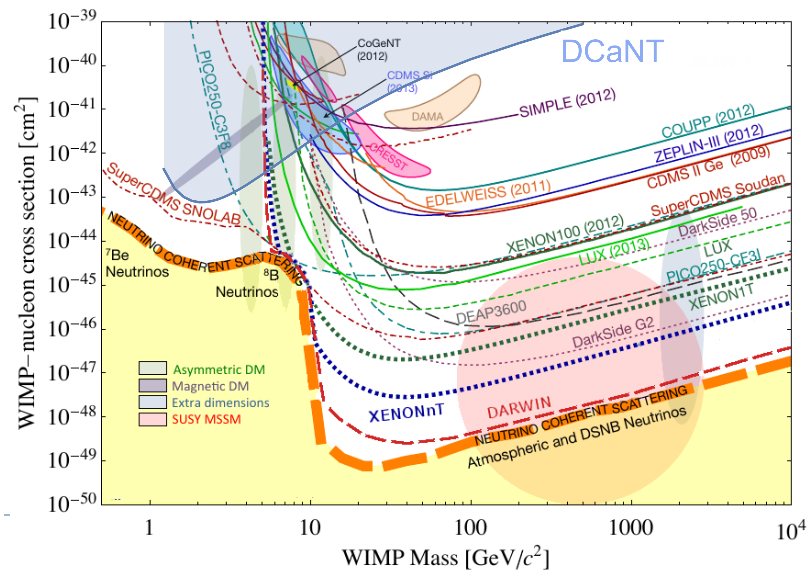

SAPIENZA UNIVERSITÀ DI ROMA

# Towards a prototype detector

- More tests going-on, **different angles,** different beam intensity, different kinetic energy (< 1 keV)
- Try to confirm the **prediction of 35 deg critical angle** for channeling (ion trapped within the interstices among CNT)

- If confirmed, try to detect a **single scattered C ions**
  - use a relativistic electron beam to scatter C out of the CNT

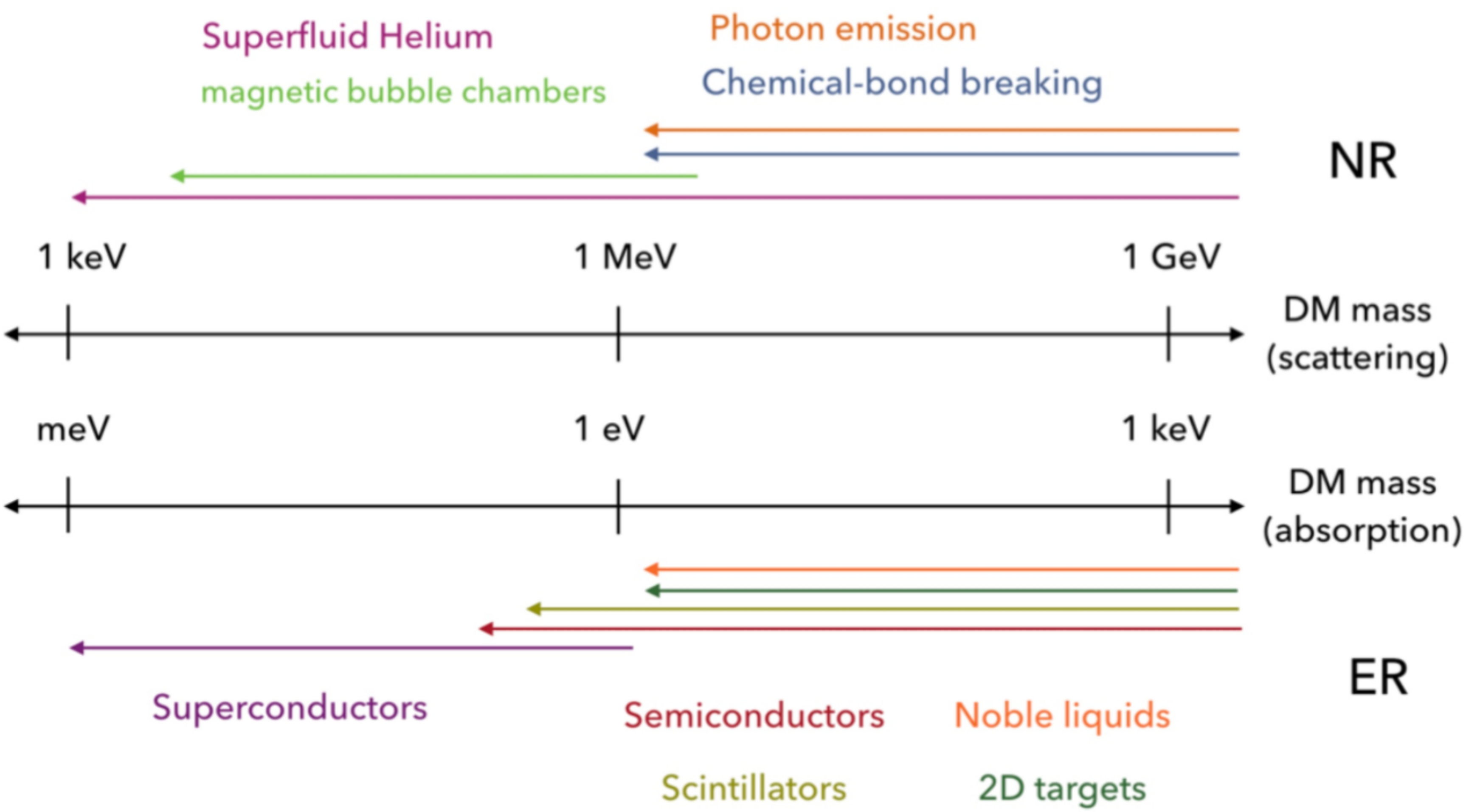
- Eventually, build a prototype DM detector *exploiting rate asymmetry*




**Sensitivity for a 0.4 kgy exposure**

- What if dark matter is not so massive ?
  Scattering over the target ***electrons***

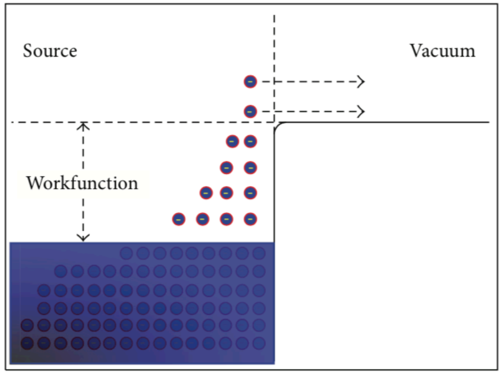
# Sub-GeV dark matter




US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report : https://arxiv.org/abs/1707.04591

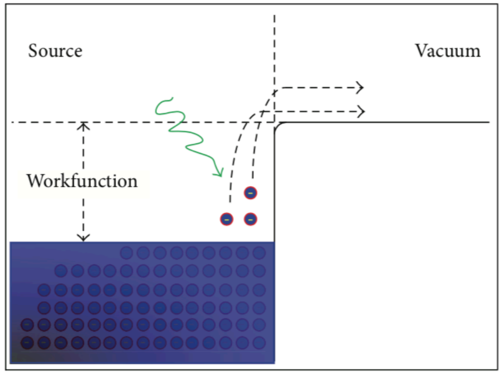
# Electron emission from a cathode

*Thermoionic emission*

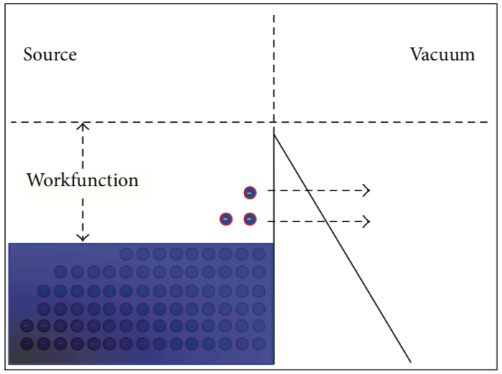



(a)

*Photoelectric emission*




(b)




(c)

*Field emission*

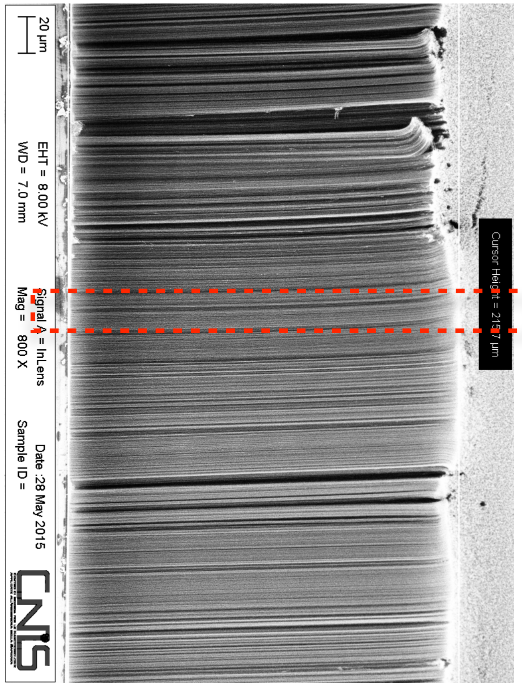
*What about a DM particle scattering off an electron ? a **dark-cathode** ?*

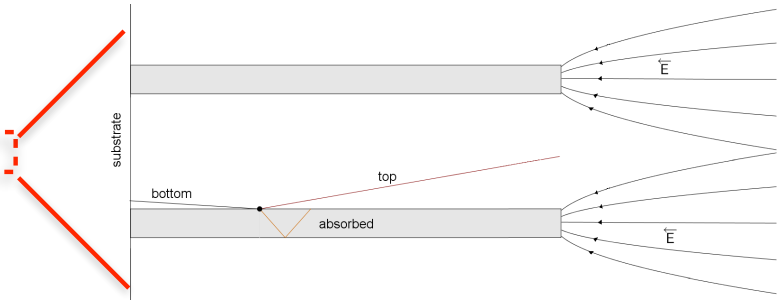
Work function of CNT is > 4 eV

*All these effects are suppressed: room temperature is low enough, UV photon efficiently screened, E field < 100 V/µm*

# Electron emitted from aligned CNT

- Electron extracted by a DM scattering
  - ***Few eV energy*** electrons are recoiling off



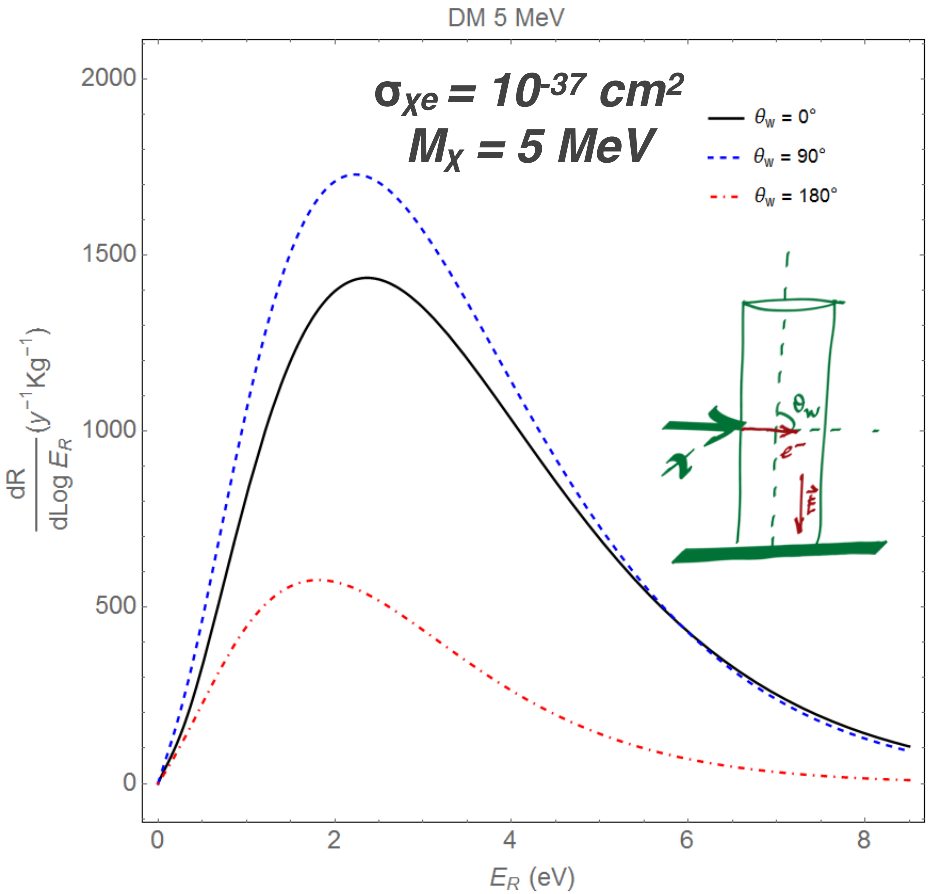



Electron collected by an external electric field ***E***

**Inelastic** electron - graphene interactions are **suppressed** at this energy (compare ***e*** wavelength)

- electrons can be *transmitted*, *reflected* *absorbed* by a graphene sheet
- absorption ~ $10^{-3}$
  (but no good data available)

# Directionality




Different rate at
different angles ***θw***

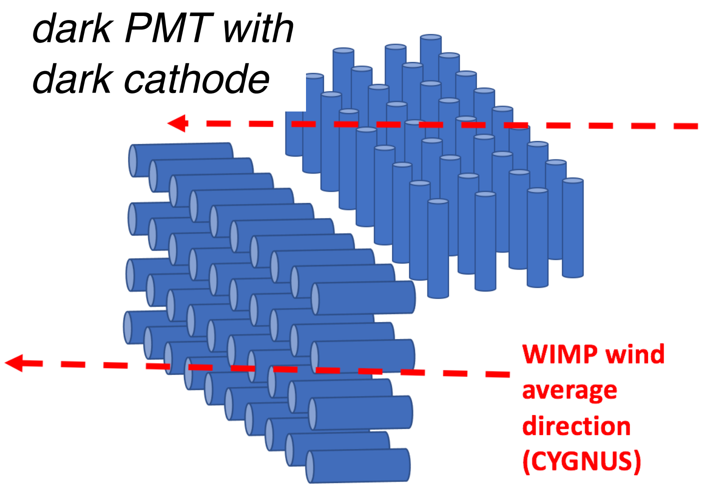
$\theta_W$ ~90 preferred by
graphene electron wave function

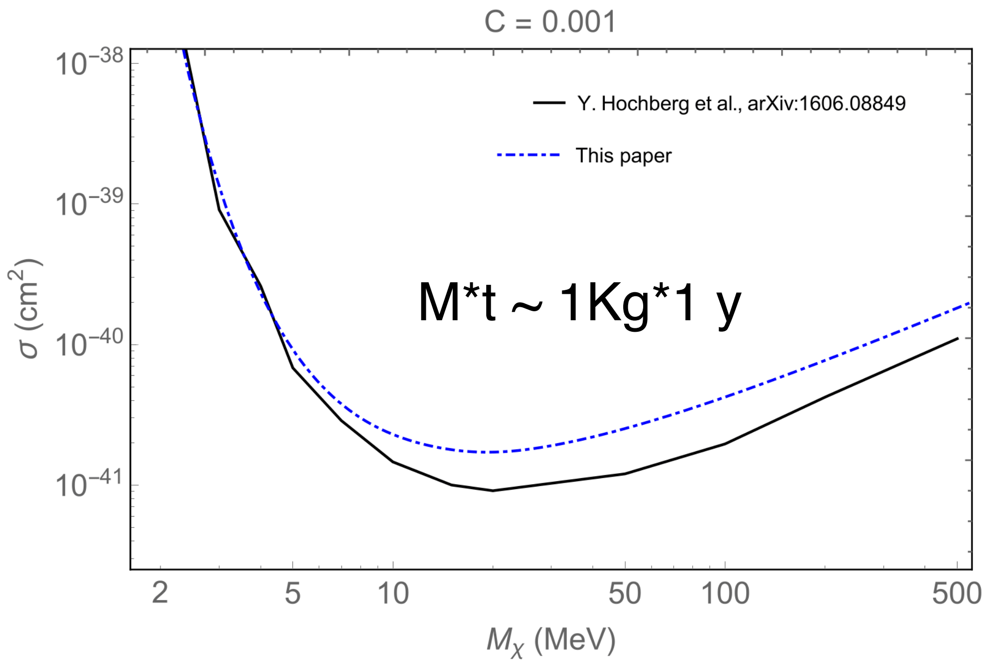
- A rate **asymmetry** can be measured by comparing two CNT target orientation

**With an exposure of 100g * 200 day a 5σ non null asymmetry can be measured**

# Sensitivity region

G.Cavoto et al, Phys.Lett. B776 (2018) 338-344

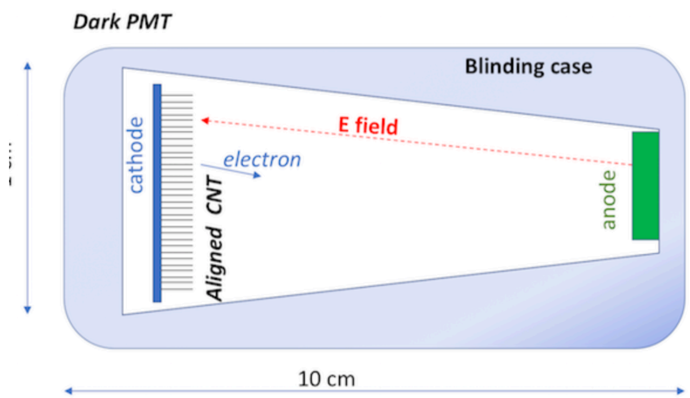



- Two arrays of *dark PMT*
  *(~$10^4$ units, 10mg dark cathode mass each)*

# Towards a dark PMT demonstrator

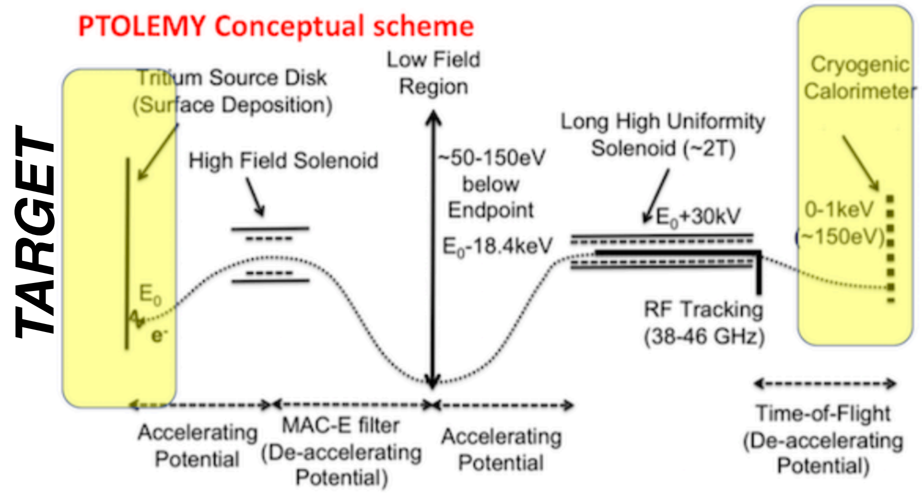
- Build a dark PMT prototype out of a CNT as a cathode, an electric field and an electron sensors (an avalanche photodiode in vacuum).
  - ***A few eV single electron detector***



# Detecting relic neutrinos, PTOLEMY

- **Synergy** with **PTOLEMY**
- (PonTecorvo Observatory for  Light Early universe Massive neutrino Yield).

- *PTOLEMY's concept uses a target of* ***tritium doped graphene layers*** *as relic neutrinos target*




- Need to asses the **radioactivity of graphene based structure:** a dark PMT could be a tool for it
- **Electron - graphene interactions** must be studied.

# My conclusion

- New concepts for innovative detector are likely to require new materials not widely used in the particle physics community yet.

- DM direct detection based on the simple paradigm of elastic scattering
  - ***a low DM mass implies to detect a  faint kinetic energy particle***

- ***Materials as the aligned CNT are packing enough mass but are leaving empty space to let recoiling nuclei or electrons to propagate.***

- ***aligned CNT can be oriented towards CYGNUS: directional DM detection***