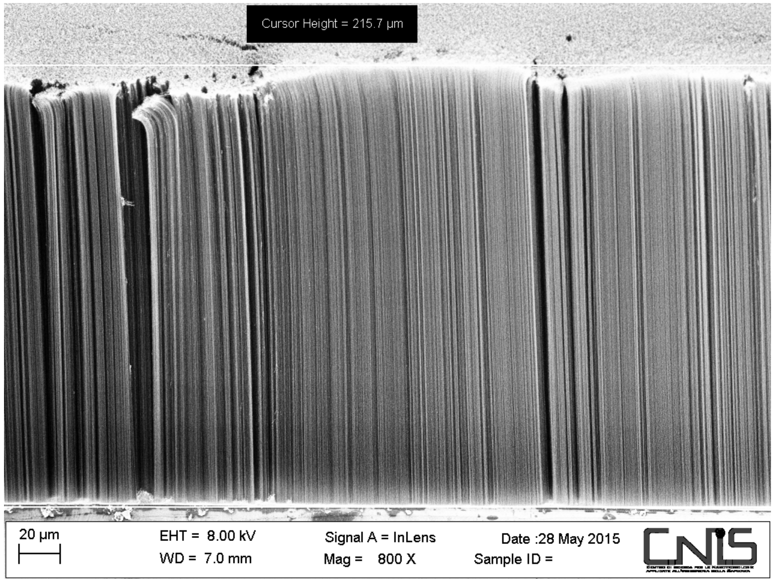


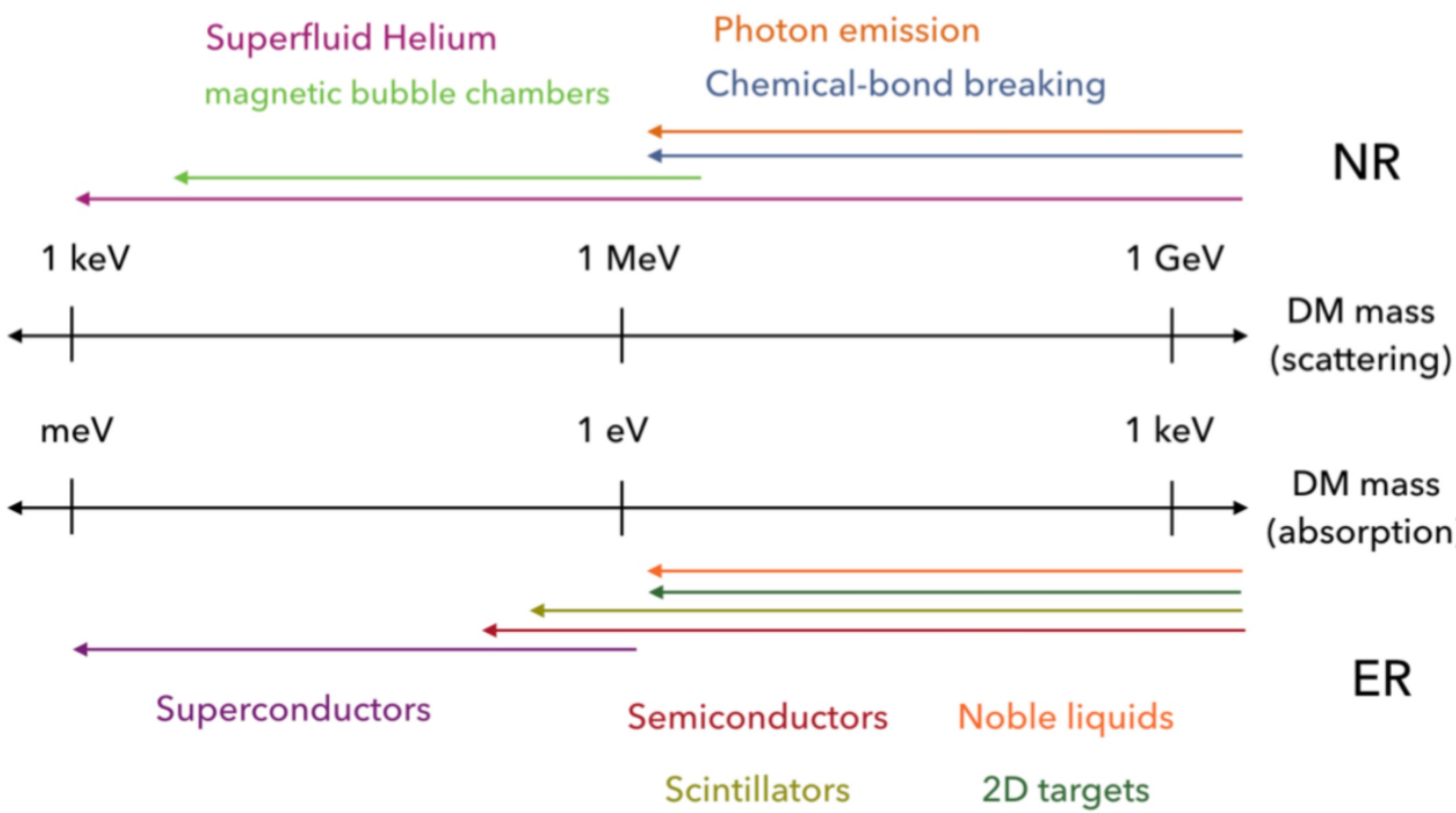
Carbon nanotubes for light dark matter directional detection

Gianluca Cavoto (Sapienza Univ. Roma and INFN)

PBC tech WG

Feb 25ht 2021

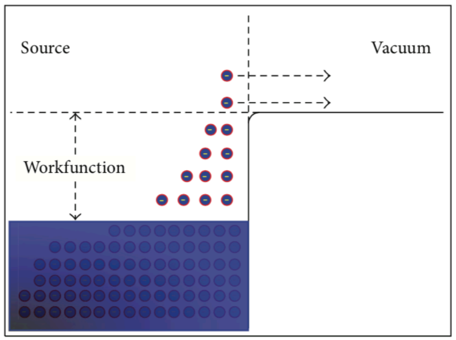
Sub-GeV dark matter



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

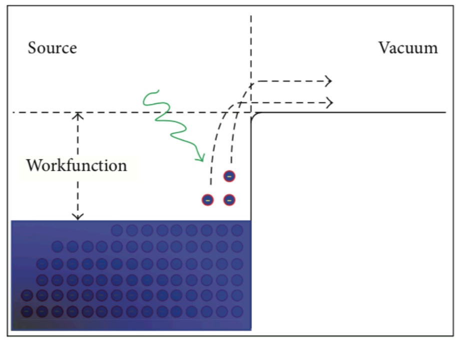
Electron emission from a cathode

Thermoionic emission

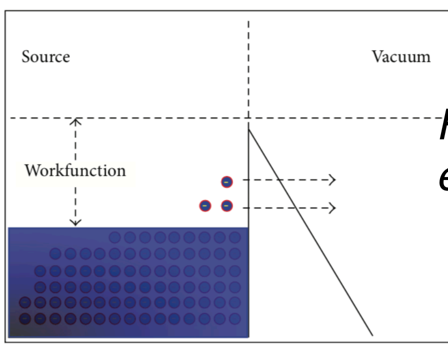


(a)

Photoelectric emission



(b)



(c)

Field emission

Work function of CNT is > 4 eV

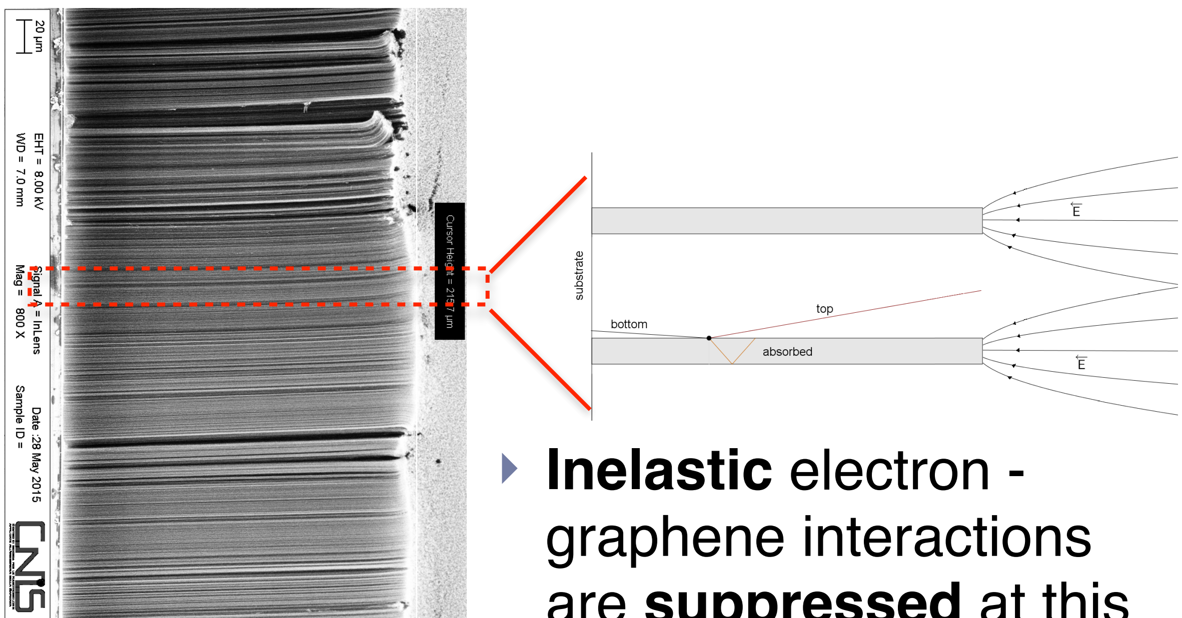
All these effects are suppressed:

a) ***room temperature is low enough,***
b) ***UV photon efficiently screened,***
c) ***E field < 100 V/μm***

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

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)

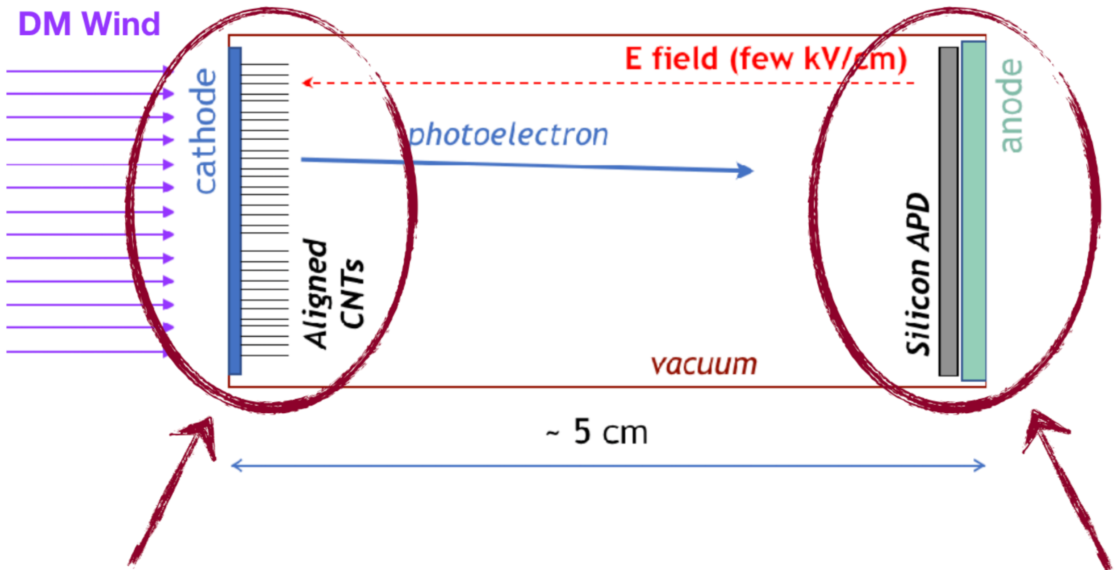
ANISOTROPIC TARGET

Directionality possibile

Need to study this using conventional *photoelectron spectroscopy*

Dark PMT concept

Inspired
By
Hybrid
Photo-Diodes



Aligned carbon nanotubes

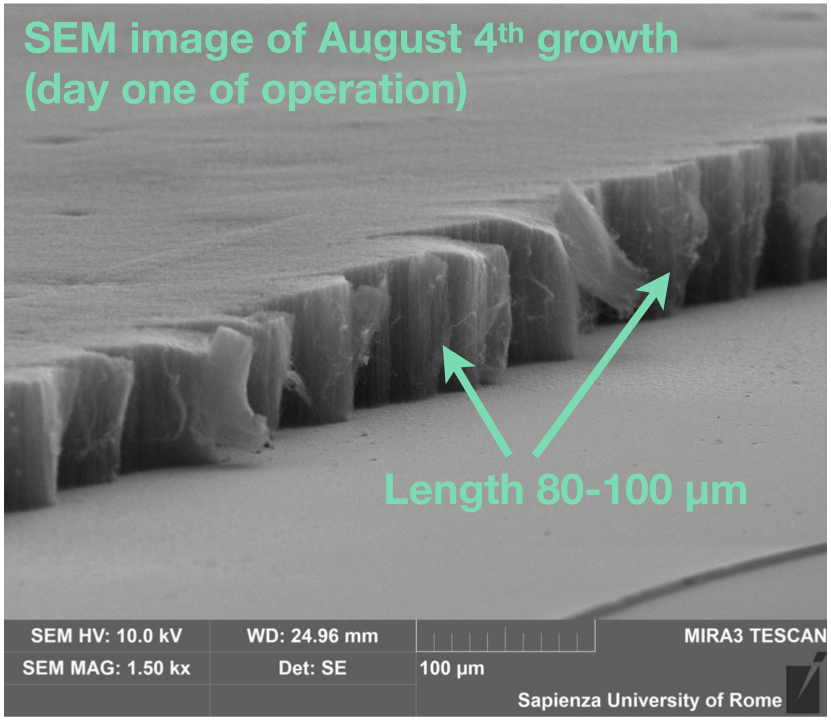
Optimize: length, density, single-wall vs multi-wall

Silicon detector for keV electrons

Optimize: technology, geometry, distance

It can be used as a UV light detector (application for astrophysics)

Growing CNT in Roma (Sapienza & INFN)



Successfully synthetized nanotubes on day one of operation of **a PE-CVD chamber**

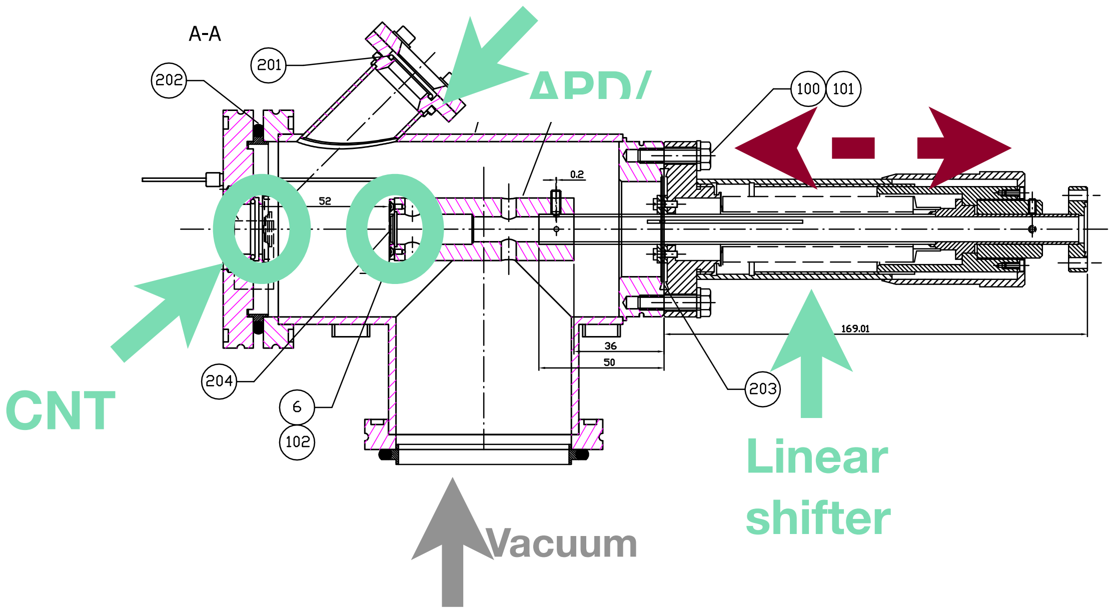
Growing CNTs on a **number** of subtrates:

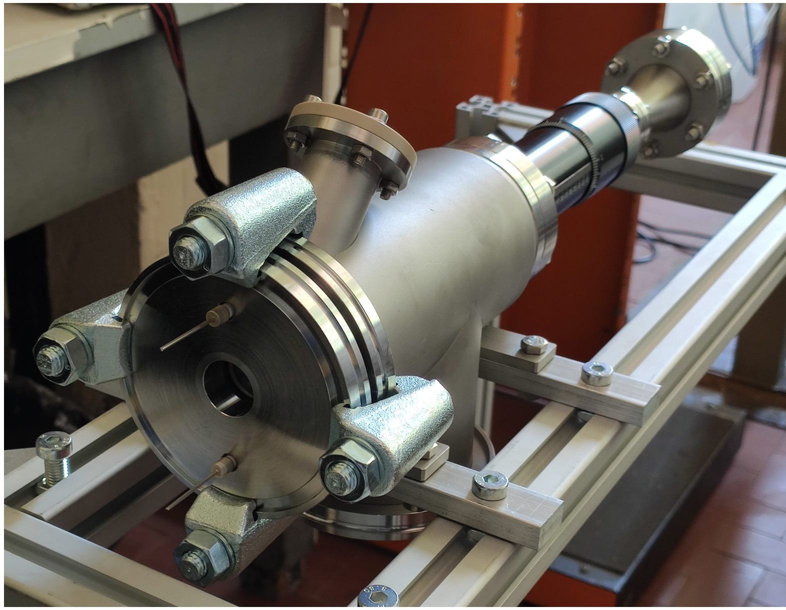
- ☑ Silicon
- ☑ Fused silica
- ☑ Basalt fibers

ATTRACT

NanoUV, P.I.: Francesco Pandolfi (INFN Roma)

Dark-PMT prototype at INFN Roma

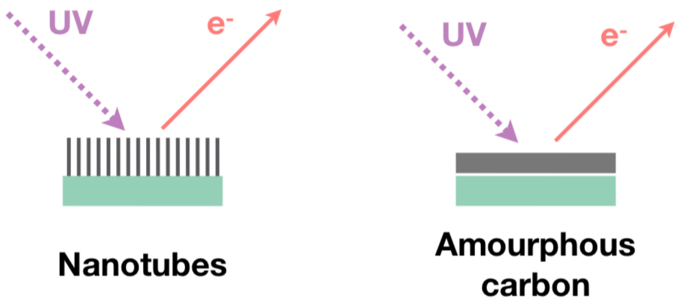


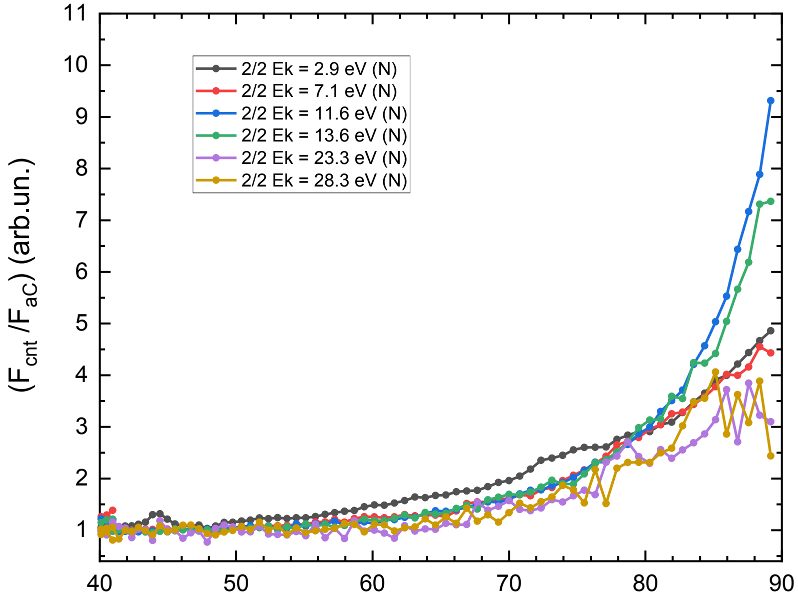


- Operating it with Avalanche PD or Silicon Drift Det.
- Coupled to UV sources

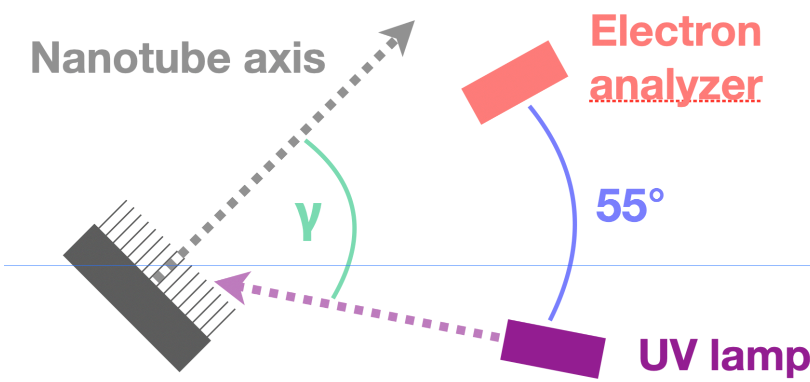
CNT characterization with UV light

- Large UHV chamber at Roma Tre LASEC labs
  - Equipped with UPS, XPS, e⁻ energy loss analysis
- Performed UPS characterization of **nanotubes**
  - And compared them to **amorphous carbon**





- Evidence of CNT anisotropy
- Further study with **synchrotron** light



Outlook

- **Nanomaterial** can be exploited as element of novel particle detectors
  - **Aligned CNT** can be a directional target for MeV DM (unique !)
  - Also graphene G-FET.
- Synergy with other projects
  - ***Ptolemy***, searching for neutrino cosmological background using **tritiated graphene target** for neutrinos
- Requires collaboration with condensed matter experts
- We might profit of CERN experience with vacuum, HV, materials, …

Contributors

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Università degli Studi Roma Tre

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- Alessandro Ruocco

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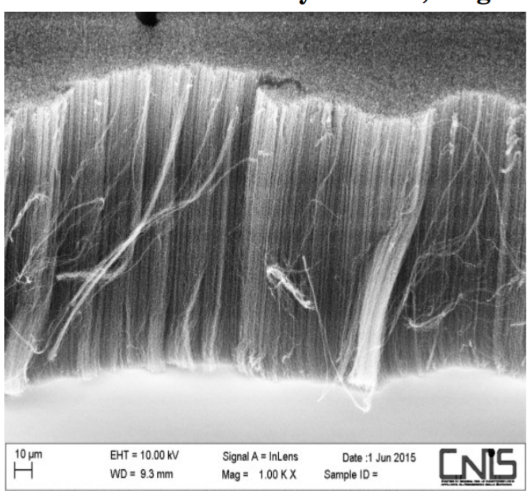
Back-up slides

Solid target: CNT

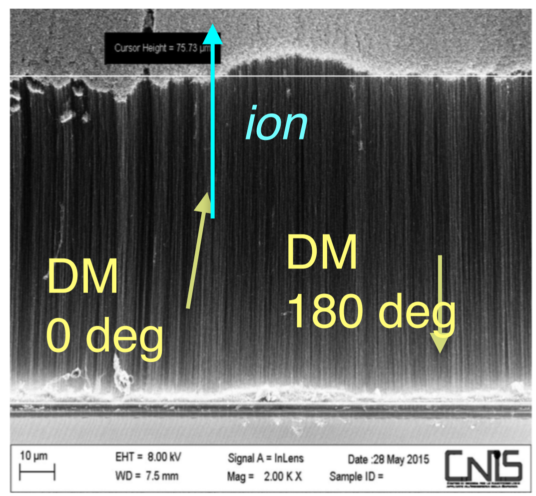
- Idea: WIMP scatters on a ***anisotropic*** target as ***aligned*** carbon nanotubes.
- Nuclear recoils are **exiting the target only** when along the CNT axis - otherwise, absorbed!

collaboration University of Mons, Belgium



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

commercial



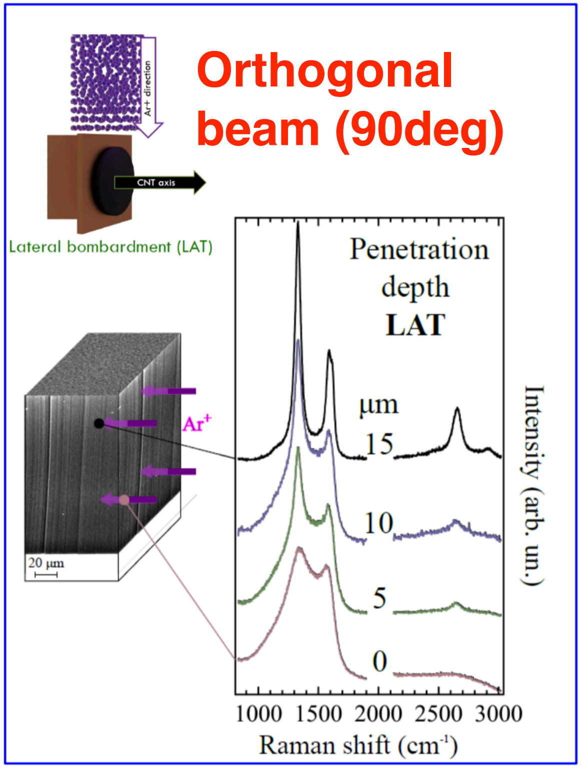
detector side

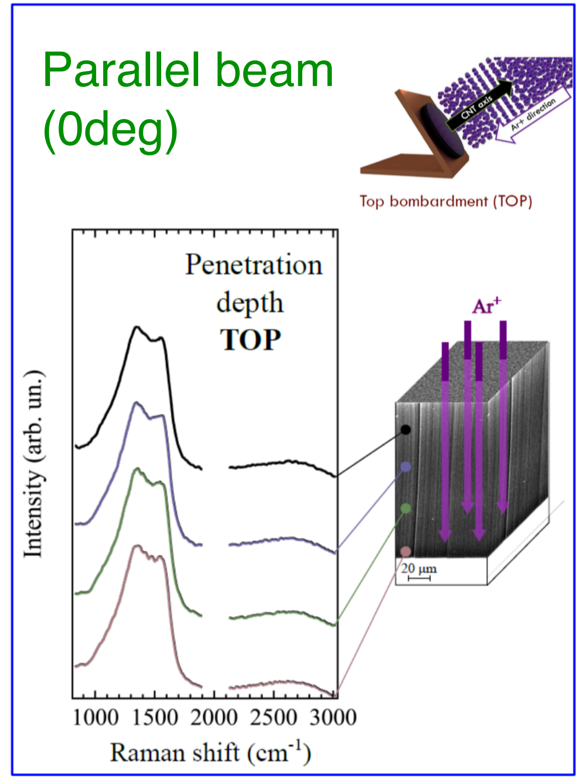
absorbing substrate

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

Ar+ ion beam on CNT

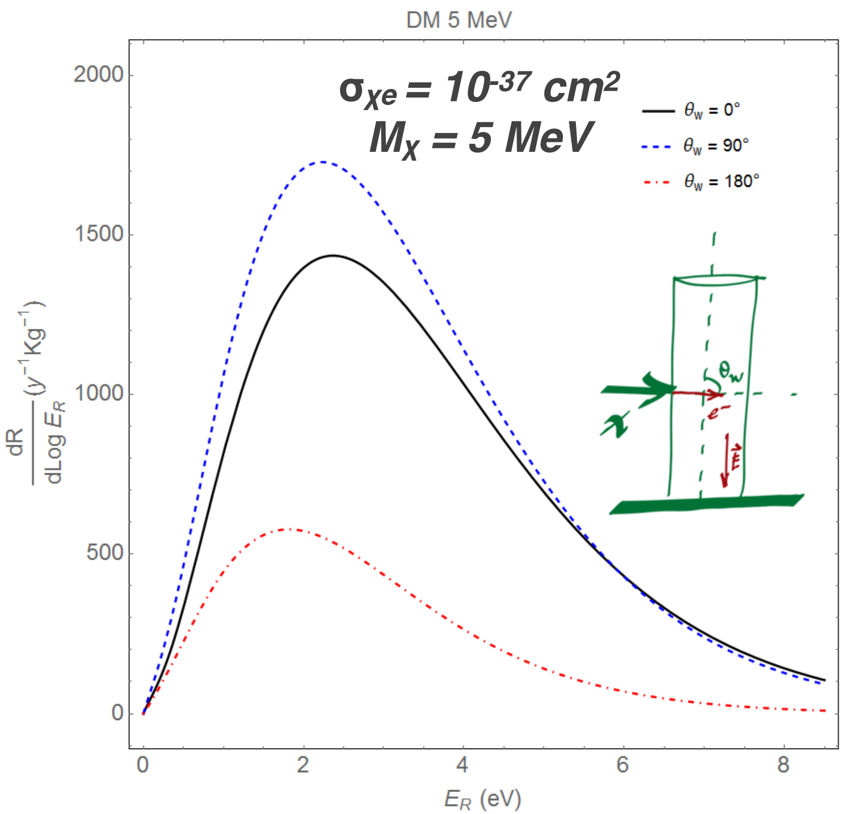
- 5 keV Ar+ beam onto a CNT at ***different*** angles with respect to CNT axis





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**

Directionality



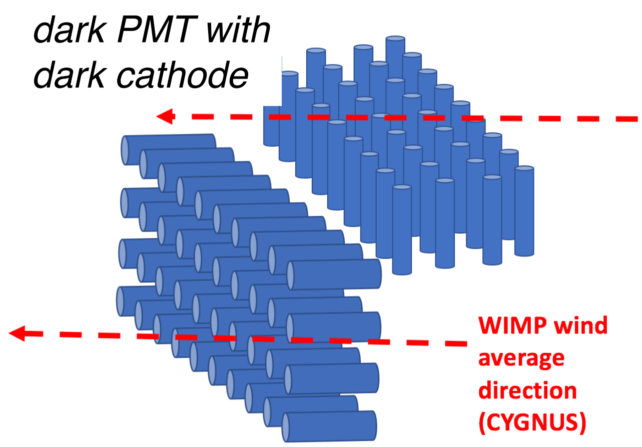
Different rate at different angles $\boldsymbol{\theta_w}$

θ_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



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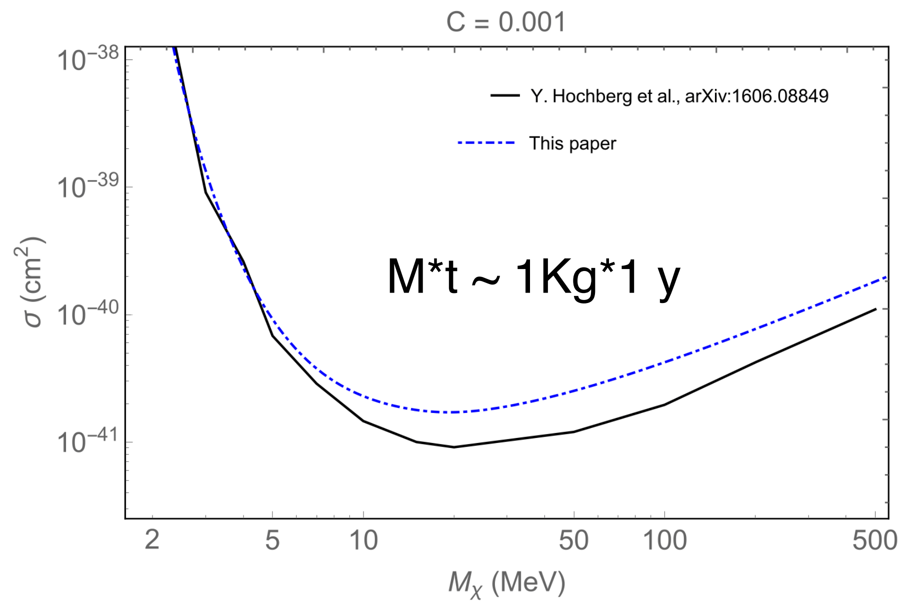
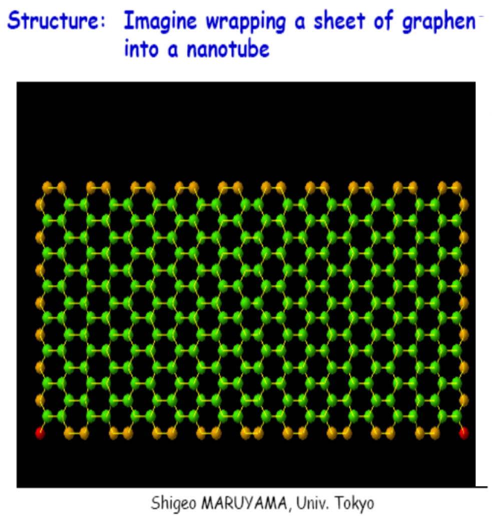
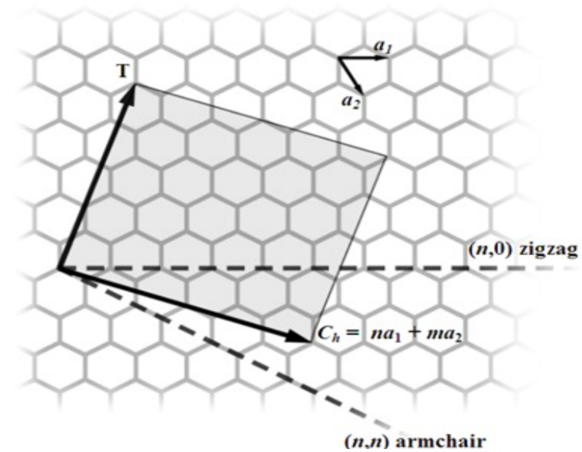
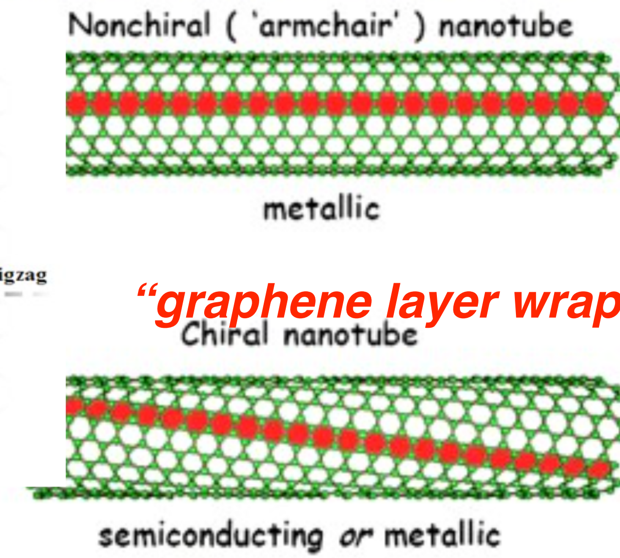


- Two arrays of *dark PMT* *(~10^4 units, 10mg dark cathode mass each)*

Carbon nanotubes





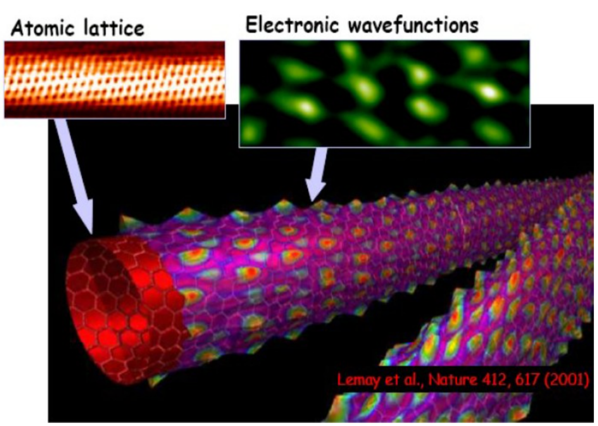


"graphene layer wrapping"

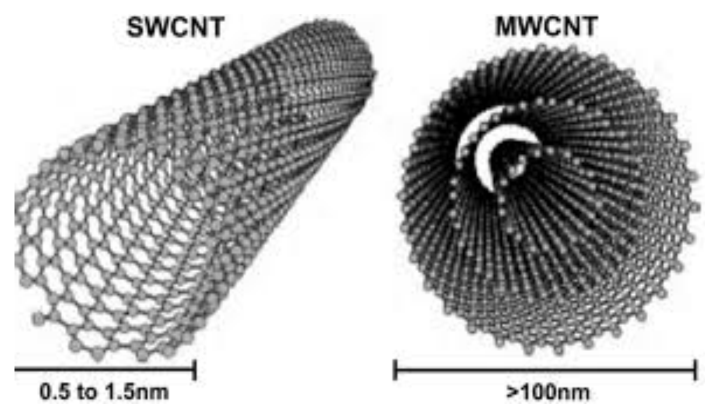
$$R = \frac{l\sqrt{3}}{2\pi}\sqrt{n^2 + m^2 + nm} \qquad l = 0.14nm$$

n=m → metallic

n – m= multiple of **3 → semiconducting**

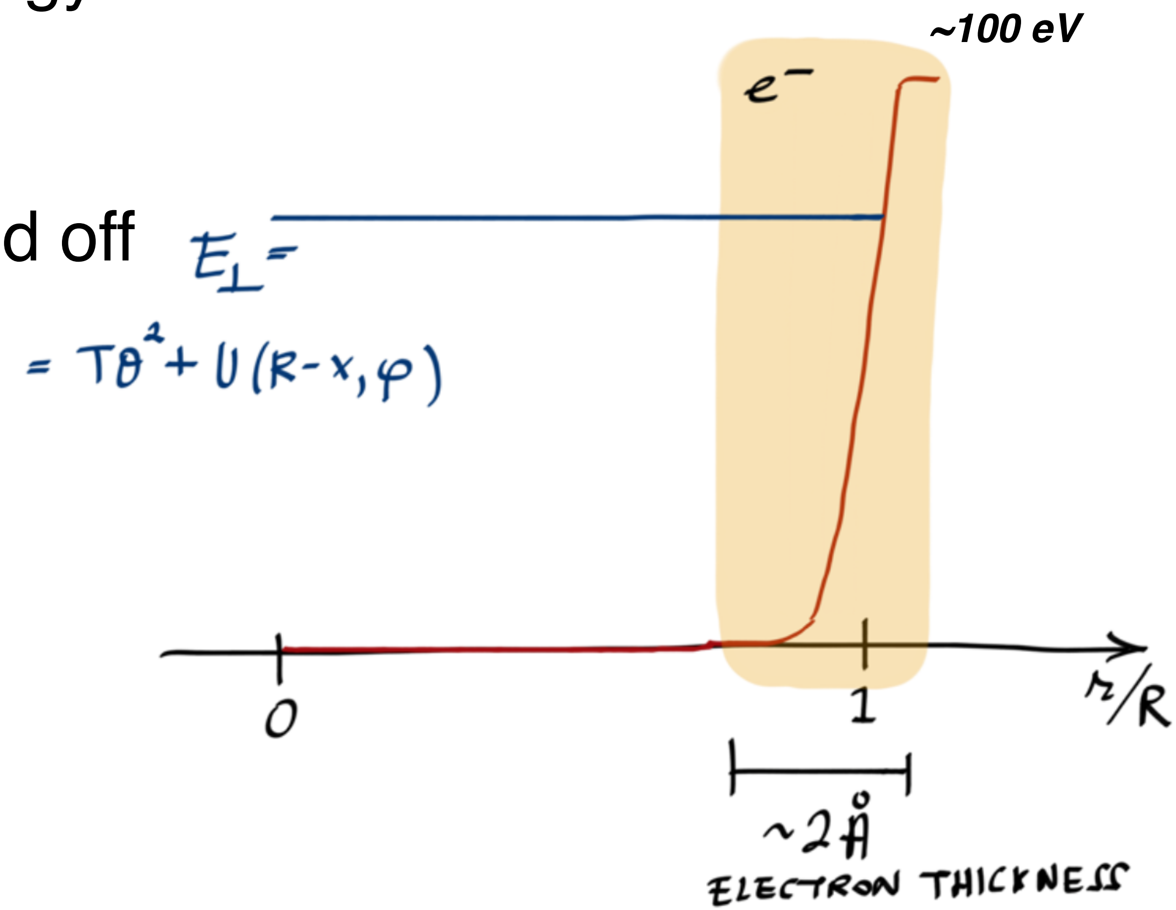


Electron orbitals on CNT surface



CNT as a potential well

- Transverse energy is **conserved**
- $^{6+}$***C*** ion scattered off the CNT are **channeled in the CNT**
- Little effect of electrons on CNT surface



CNT anisotropic medium

- **Aligned and oriented CNT "brush"**
  - *Recoiling **C** ions are emerging from CNTs with different rates* **depending** on CNTs **orientation.**
  - When ***C*** ions are **not channeled** they are **absorbed** within the brush
- Effect of rechanneling or **inter-CNT trapping** NOT included HERE