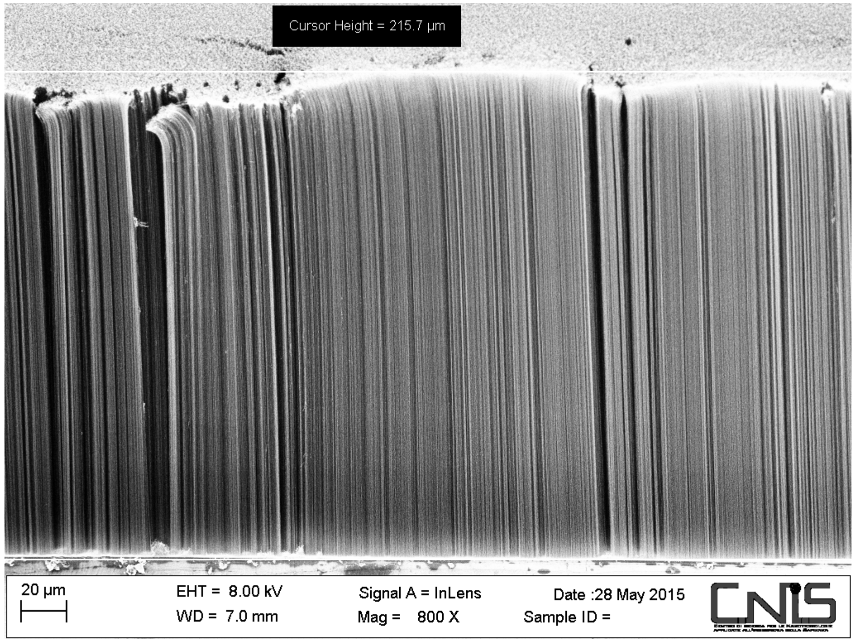


DCaNT: Directional WIMP detection with carbon nanotubes

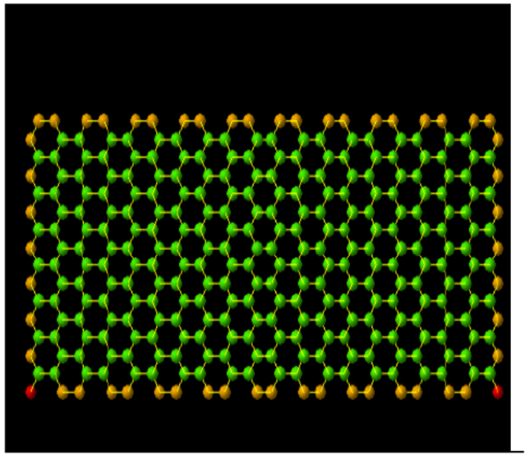
Gianluca Cavoto INFN Roma

May 4 2016

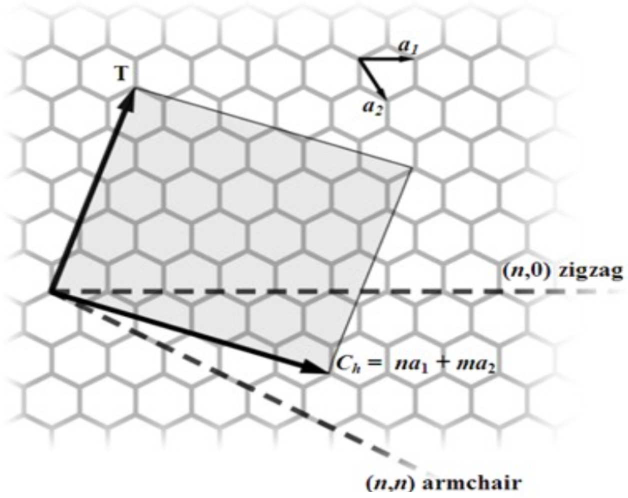
Seminario a Università di Napoli & INFN

Carbon nanotubes

Structure: Imagine wrapping a sheet of graphen into a nanotube



Shigeo MARUYAMA, Univ. Tokyo

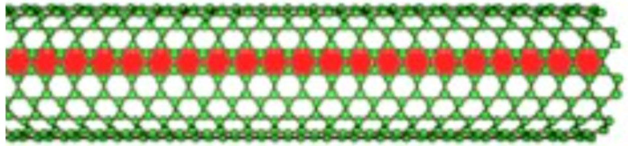


$$R = \frac{l\sqrt{3}}{2\pi}\sqrt{n^2+m^2+nm} \qquad l = 0.14nm$$

n=m → metallic

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

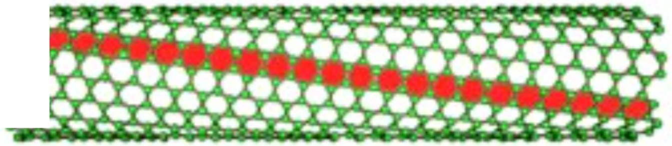
Nonchiral ('armchair') nanotube



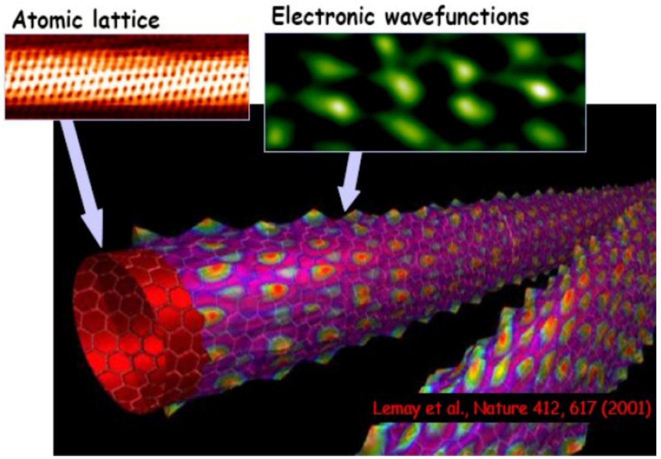
metallic

"graphene layer wrapping"

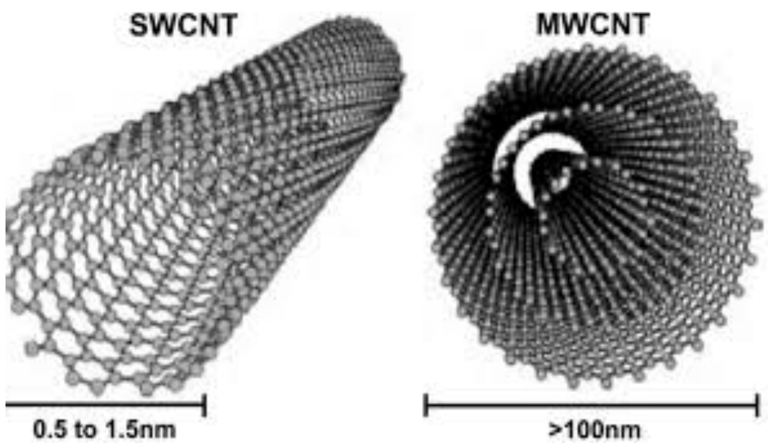
Chiral nanotube



semiconducting *or* metallic



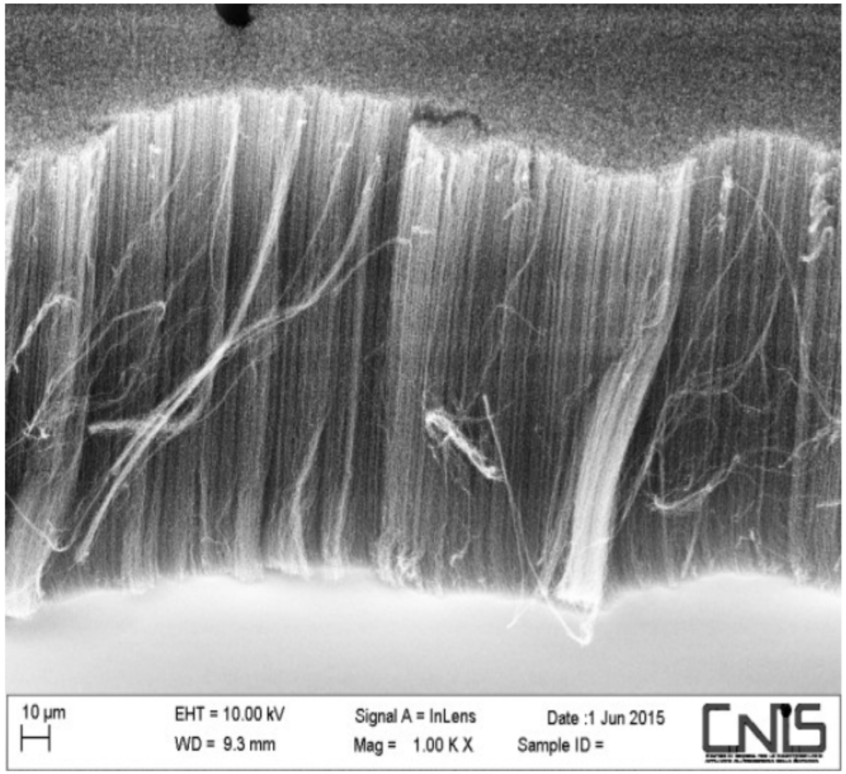
Electron orbitals on CNT surface



M.G.Betti,
C.Mariani
Sapienza
Univ. Roma

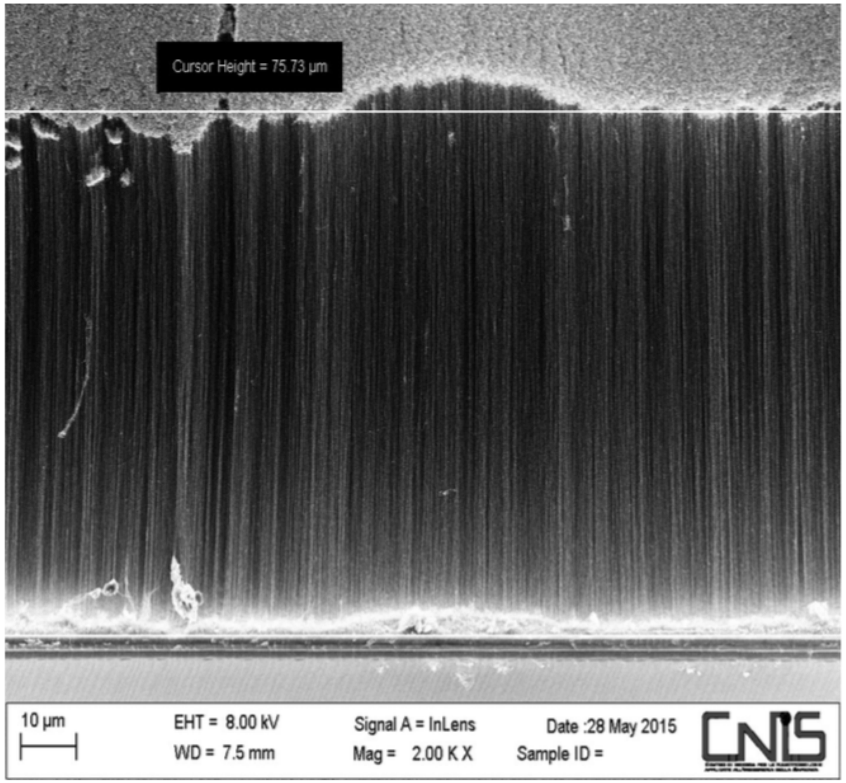
CNT with scattering electron microscope

collaboration University of Mons, Belgium



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

commercial



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

Concept of detector for WIMP based on CNT

- Use **aligned CNT** as **target** mass (~few g/cm3 density possible)
- Aligned CNTs as an **anisotropic** medium: scattered ***C*** ions are escaping from the top of the array when emitted almost parallel to CNT axes.
- **Detect** the **channeled *C*** ion in a **very thin** (low pressure) gas chamber
- Escaping ***C*** ion **energy**, ***C*** ion **range** in gas and **direction** measurements should be possible

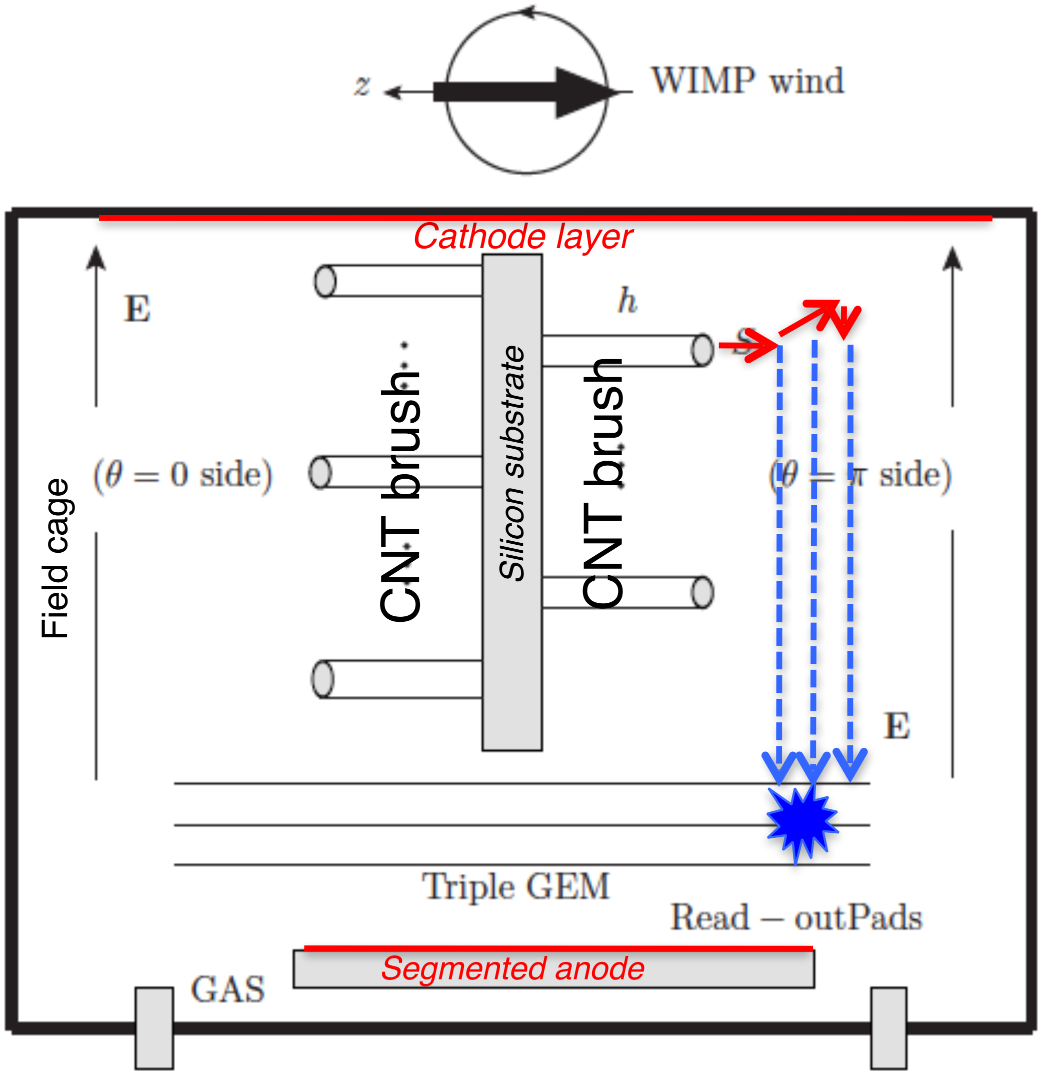
Clearly, demonstrating that a 1-100 KeV *C* ion is effectively channeled in CNT and then detectable is in order to advance with this detector concept

Scheme for detection of C ion

Low pressure gas TPC

Not to scale!

h ~100 μm
S ~ π(5)² nm²

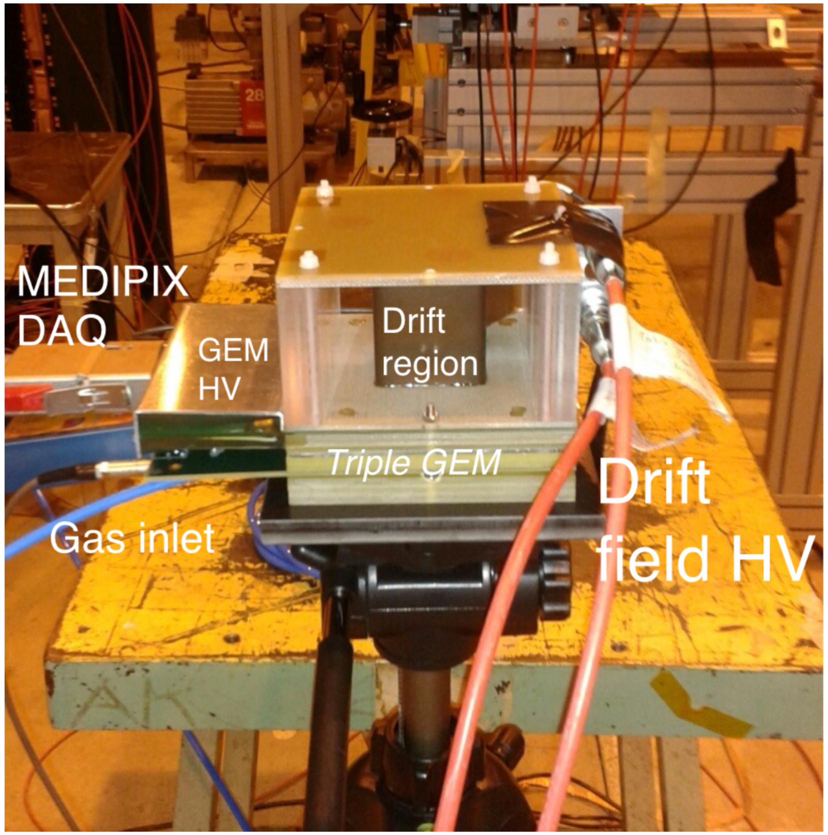


Must be able to measure:

- Kinetic **energy** (total ionization)
- **range** (segmented anode)
- **average direction** (relative electrons time-of-flight)

A TPC-GEM for the first test

- A time projection chamber with GEM amplification at anode



F.Murtas (LNF-CERN)

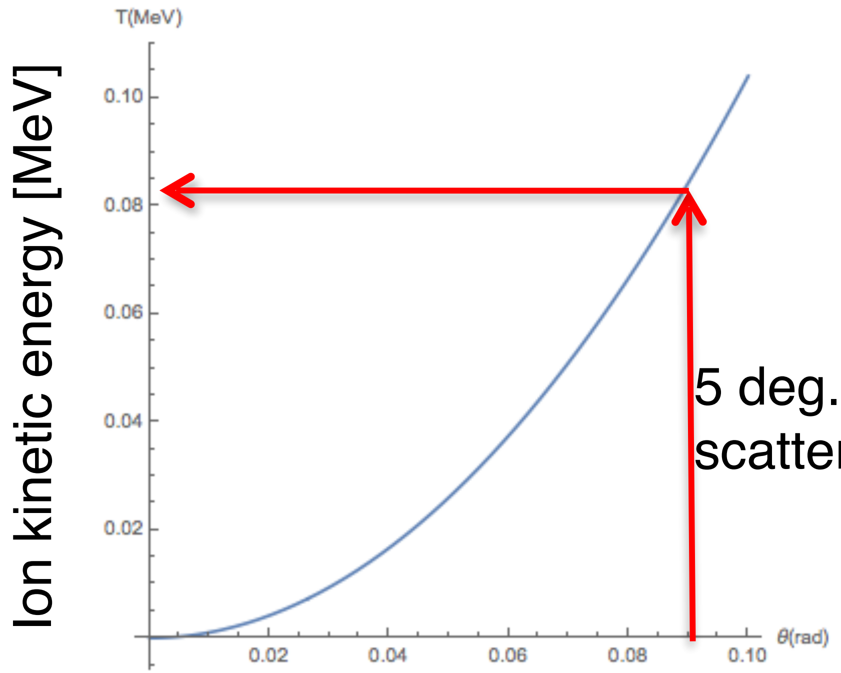
Anode is an ASIC used to read-out signals from **four** 512x512 **55μm** silicon pixel sensors (MEDIPIX)

In this configuration silicon pixels are removed: the **charge signal is generated in the Triple GEM**

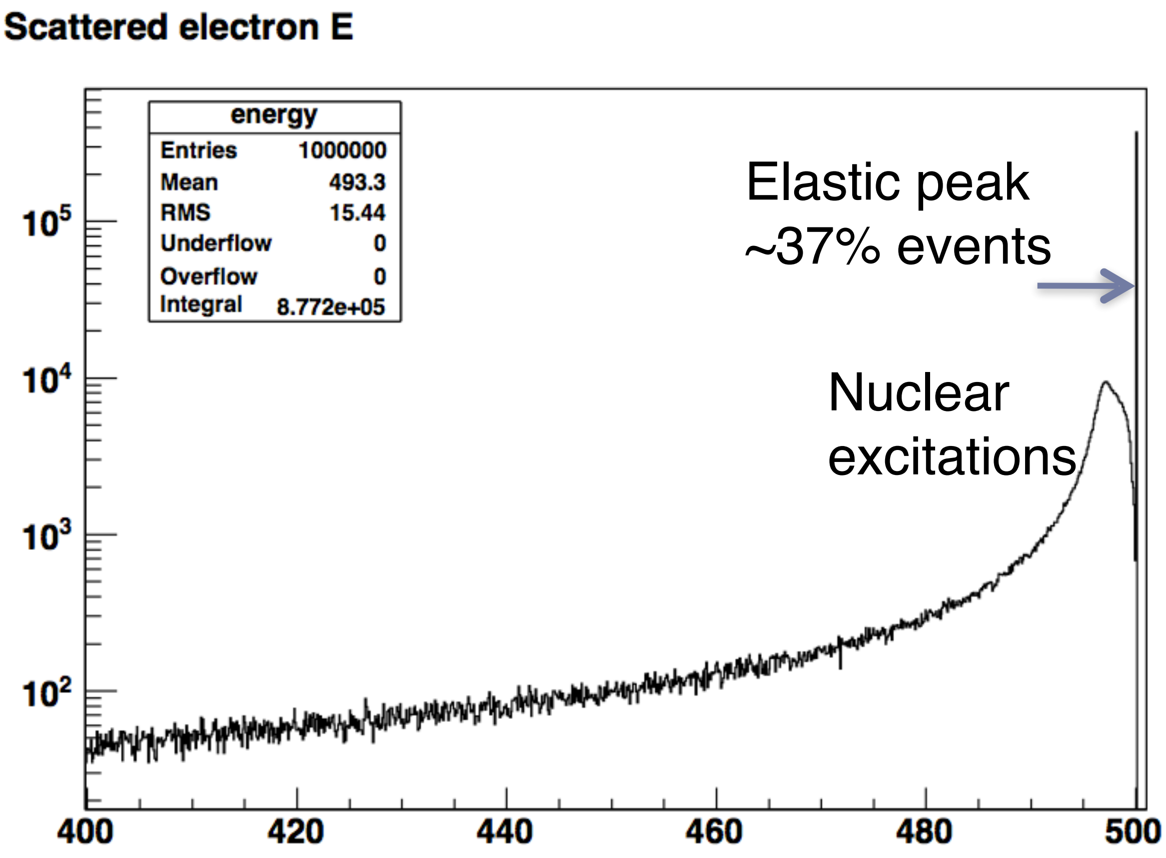
Built at INFN LNF

Experiment at Frascati BTF

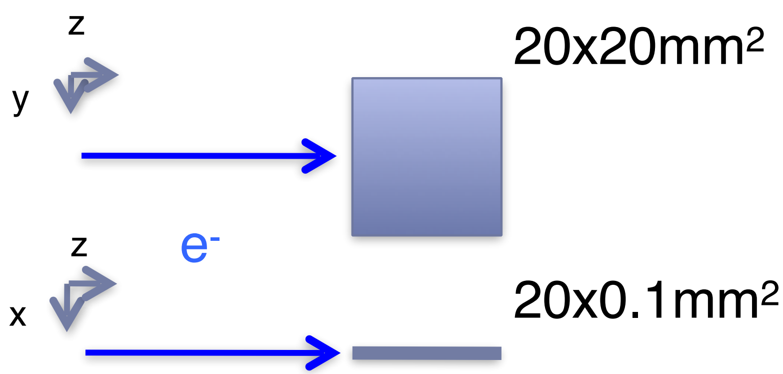
- Use electron beam at LNF BTF to "extract" carbon ions from CNT
  - One carbon ion elastically scattered by a 500 MeV electron
    - PRO: trigger on scattered electron at well defined angle: beam clearly visible
    - CON: electron beam can induce a sizeable background into TPC



Elastically scattered ions



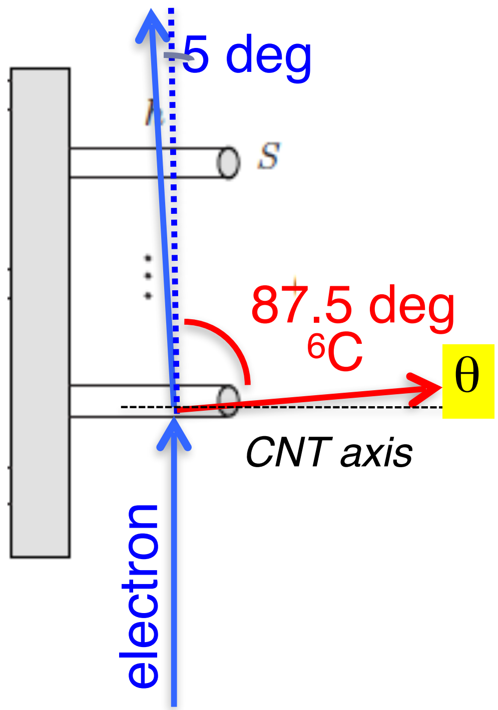
- Geant4 simulation of 500 MeV electron beam
  (no beam spread)

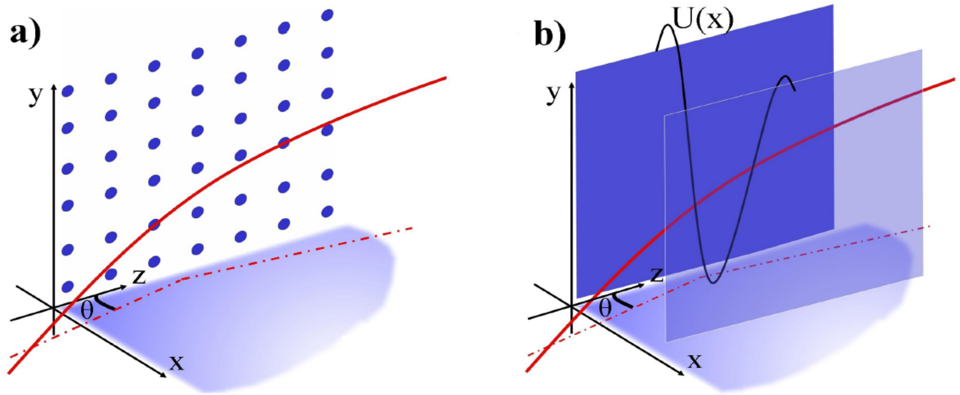


Electrons emerging from a 1 cm thick (amorphous) carbon target

Channeling of an ion

Ion elastically scattered almost at 90 degree





Critical (Lindhard's) angle

$$\theta_C = \sqrt{\frac{2U_0}{E}}$$

Potential well depth (U_0)

Particle energy (E)

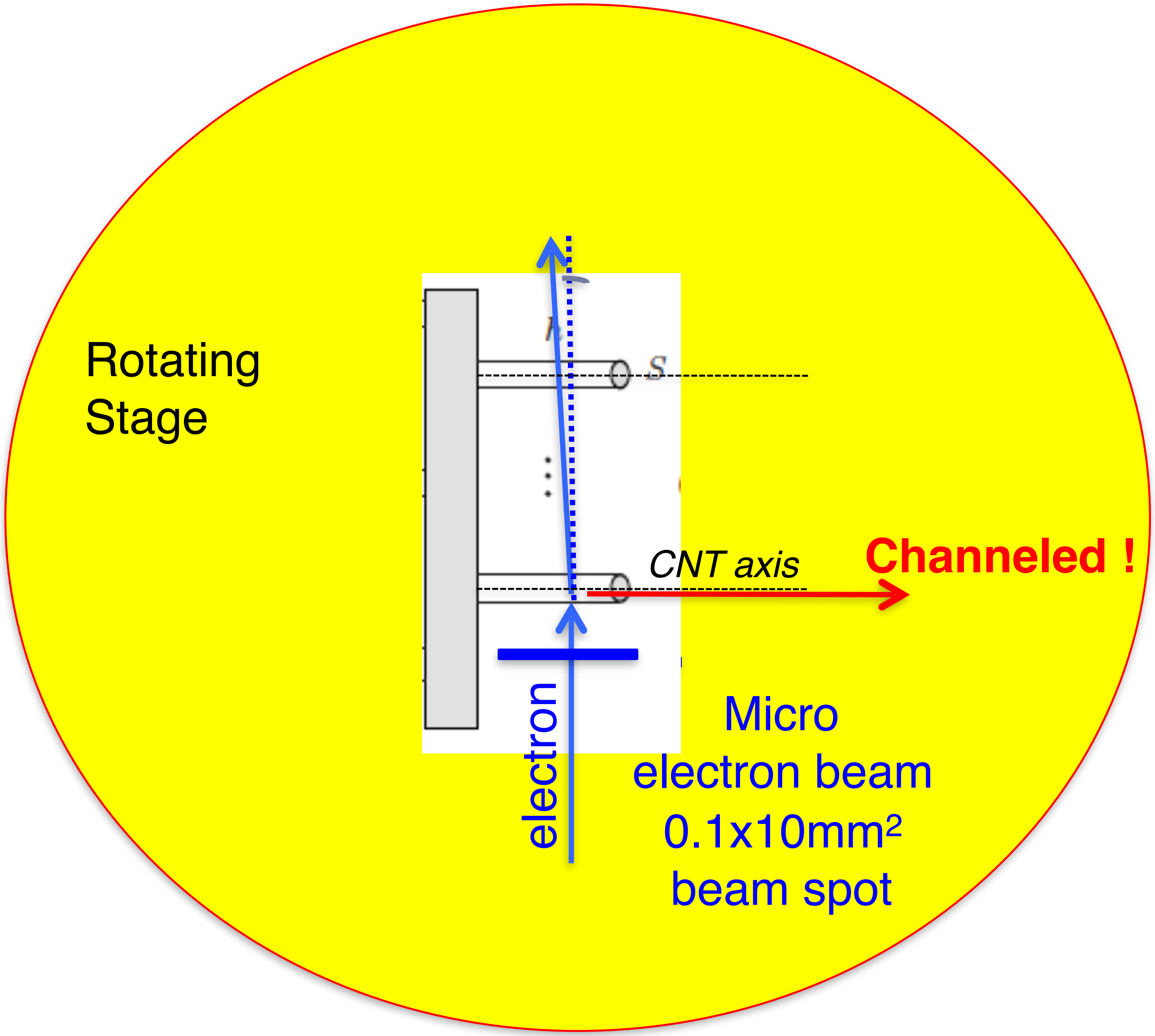
If $\theta < \theta_C$ ions are channeled!

θ_C **~ 4 deg** for ^{6}C channeling

Demonstrate ~10-100 KeV C ions are trapped.
Trapping has a larger effective θ_C **~ 35 deg**

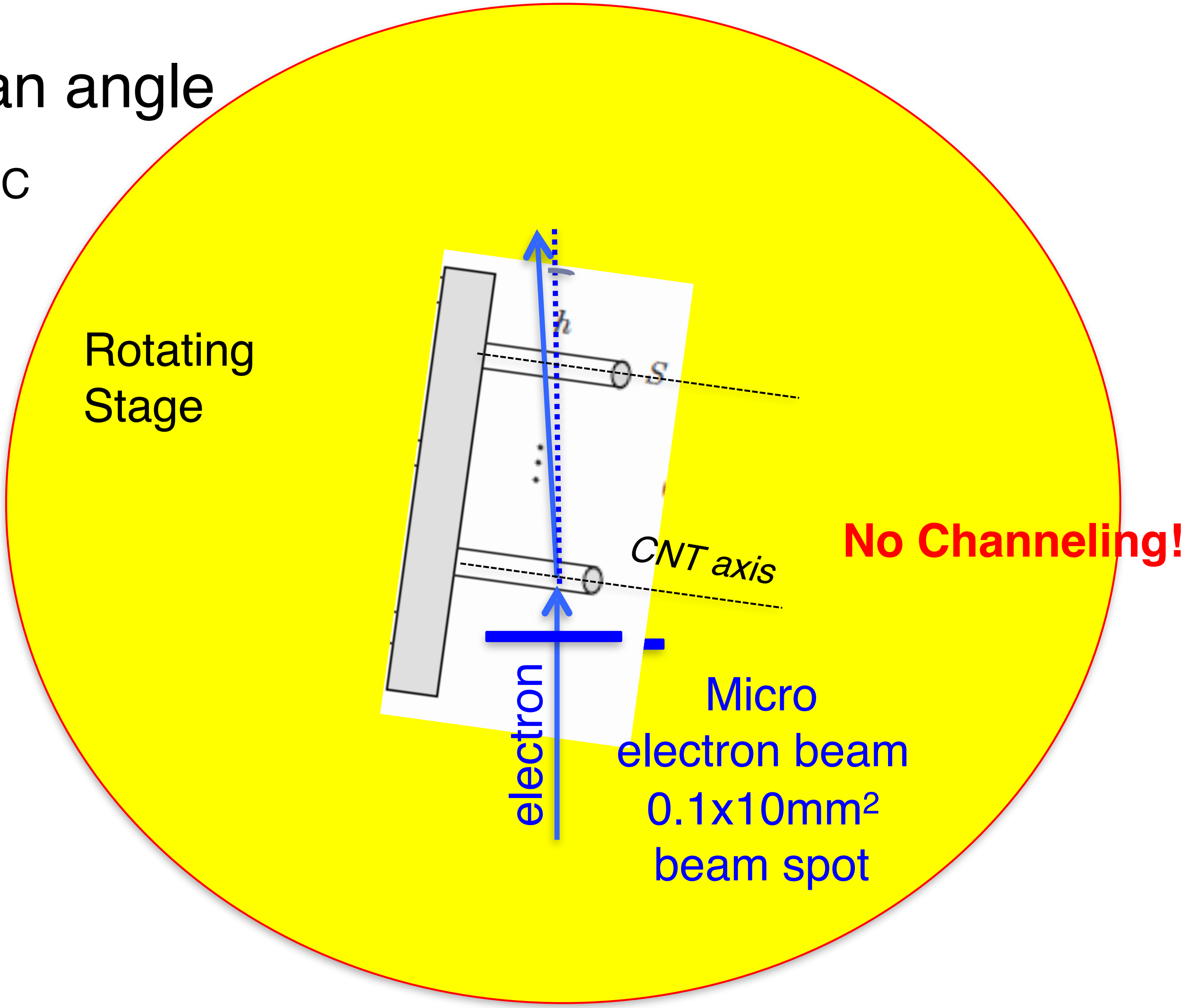
Experiment at BTF:channeling

$\theta < \theta_c$

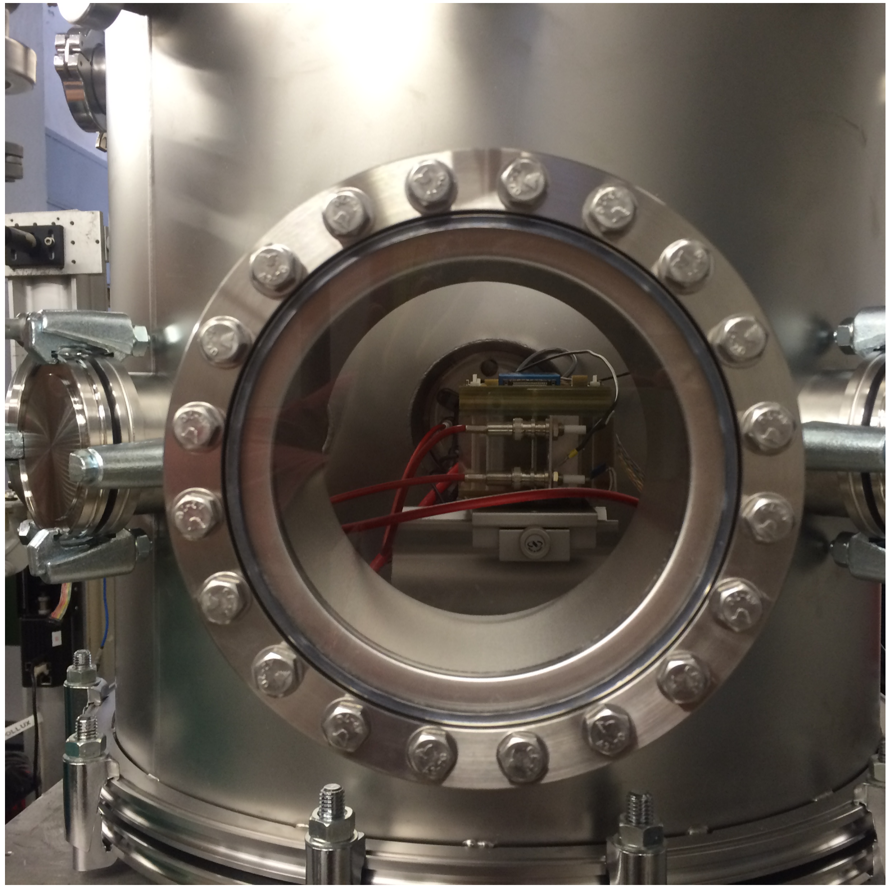


Experiment at BTF

Rotation by an angle wider than θ_C

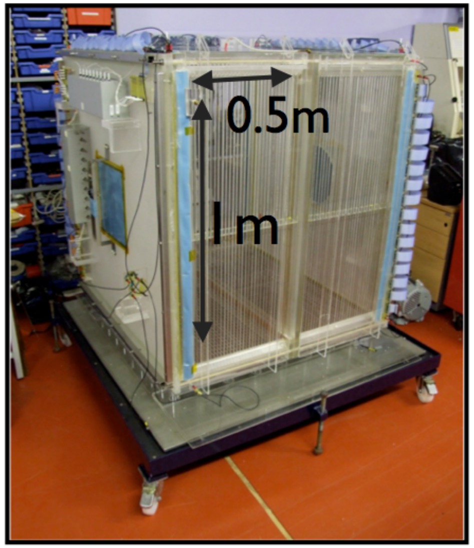


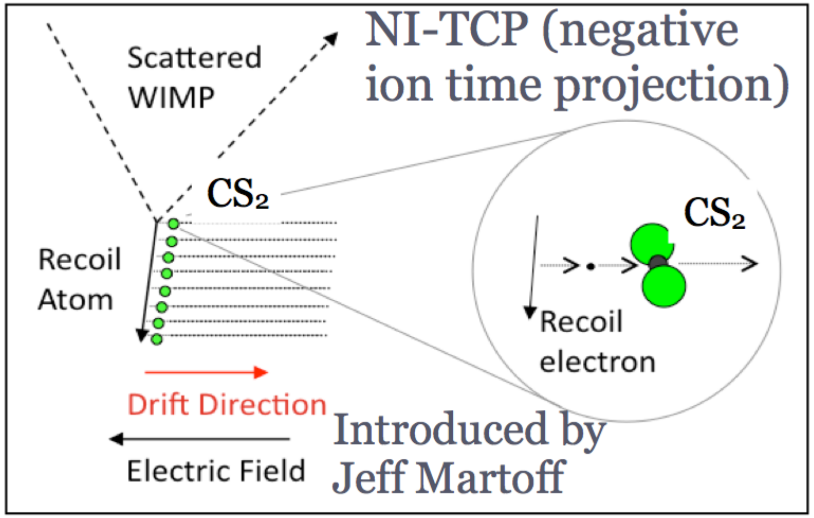
Low pressure vessel

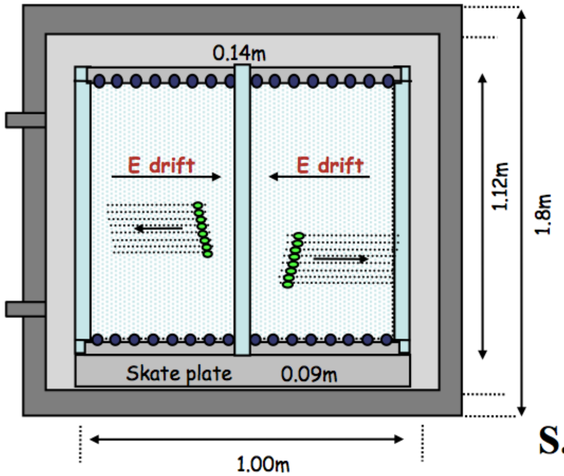


First test with BTF beam in collaboration with NITEC project (E.Baracchini)

DRIFT concept





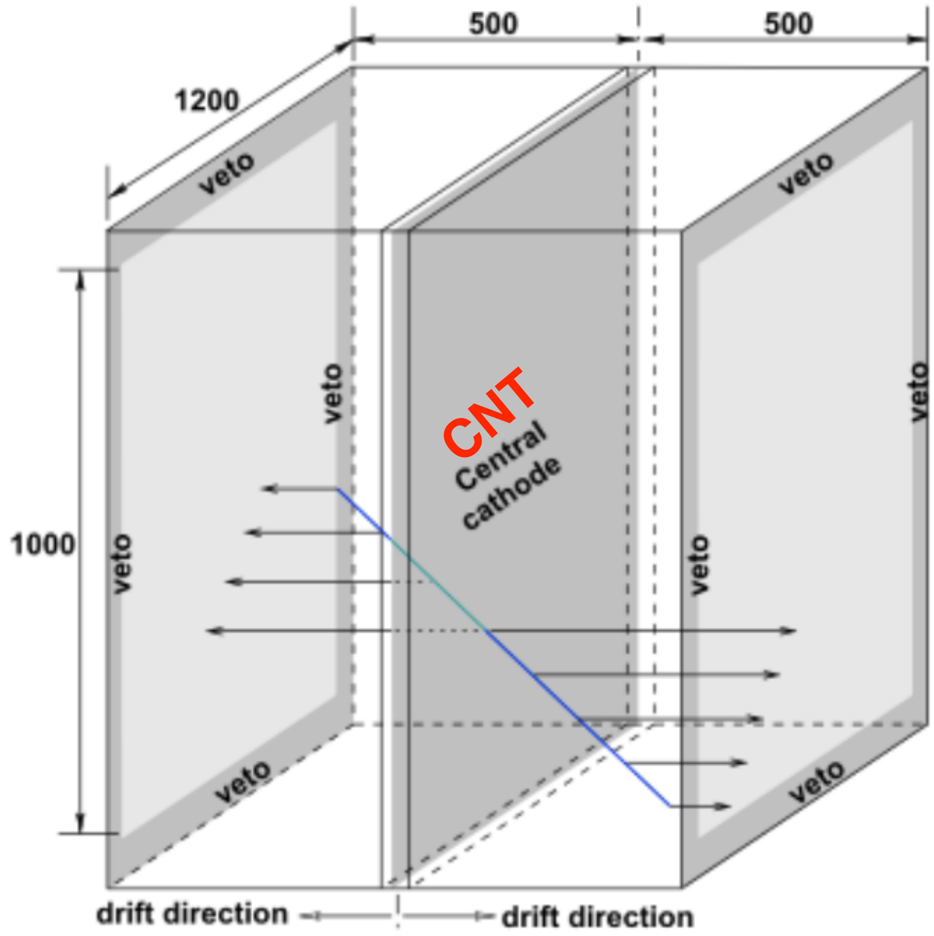


S.

- DRIFT has been operating in Boulby since 2001
- DRIFT-I -> DRIFT-II (a-e)
- DRIFT-IId volume = 0.8 m^3, ~40 Torr gas
- MWPC readouts (NIMA, **555** (2005) 173)
- Negative CS_2 anion drift to limit diffusion (PRD, **61** (2000) 1)
- Phenomenal Compton background rejection (AstroPle, **28** (2007) 409)
- Many gas mixtures possible
- DRIFT-IId used a 30-10 Torr of CS_2-CF_4 to optimize for spin-dependent limits, 139 g target mass. (AstroPle, **35**(2007) 397)

A prototype for a CNT DM detector

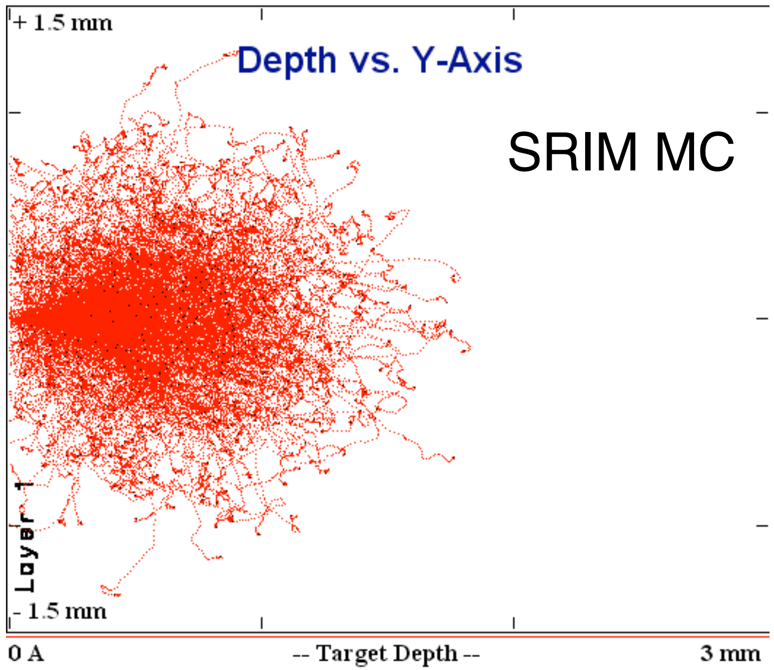
- If channeling of C ion is demonstrated, build a prototype for large scale readout
- Re-use the experience of directional DM low p gas detector (*DRIFT*)
  - ***Increase target mass putting CNT on the central cathode.***

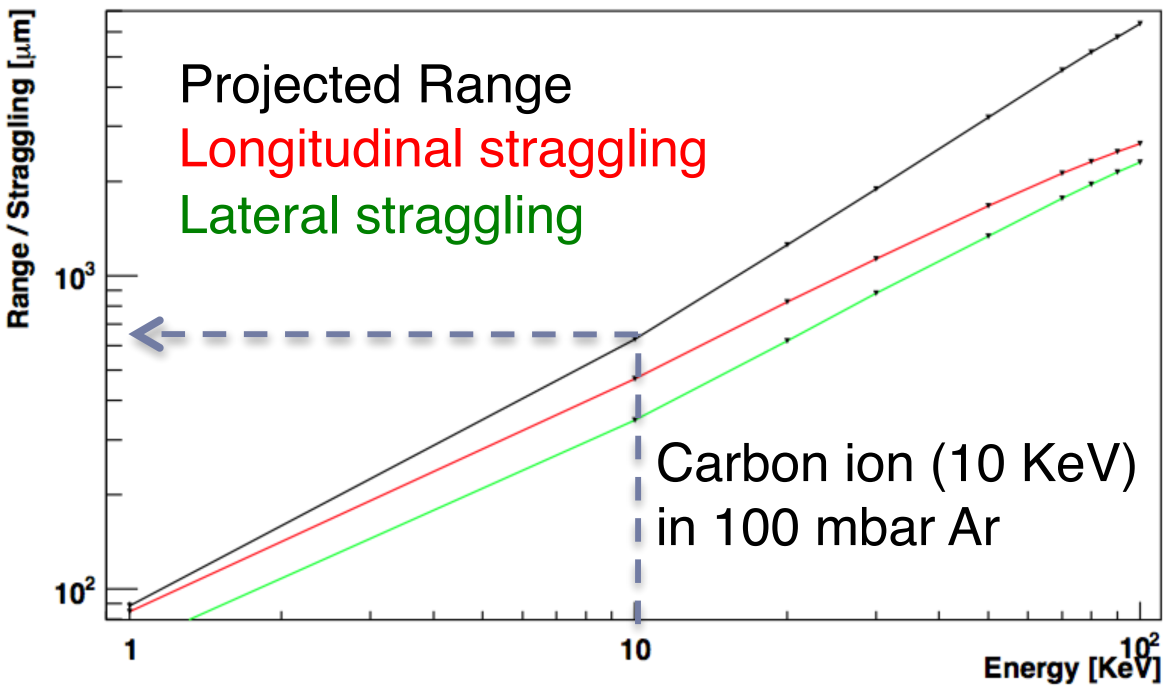


Low threshold on C detection is the crucial limit

Range of few KeV ion in Ar

Carbon ion (10 KeV)
in 3mm thick 100 mbar Ar





Even with large spread of ionization, the range measurement might help to identify the signal

Functionalization

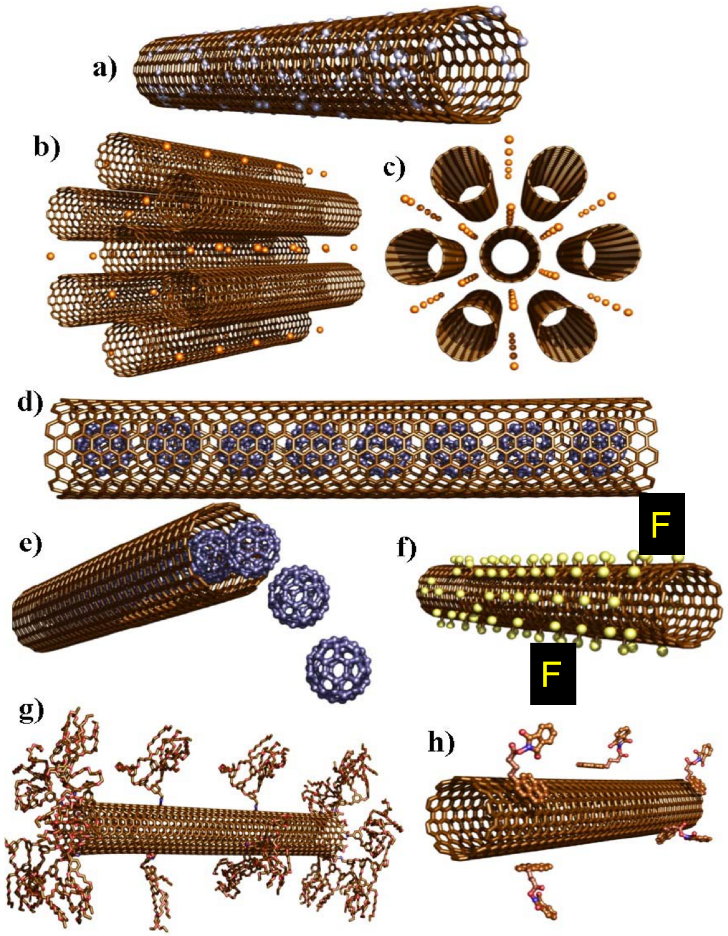
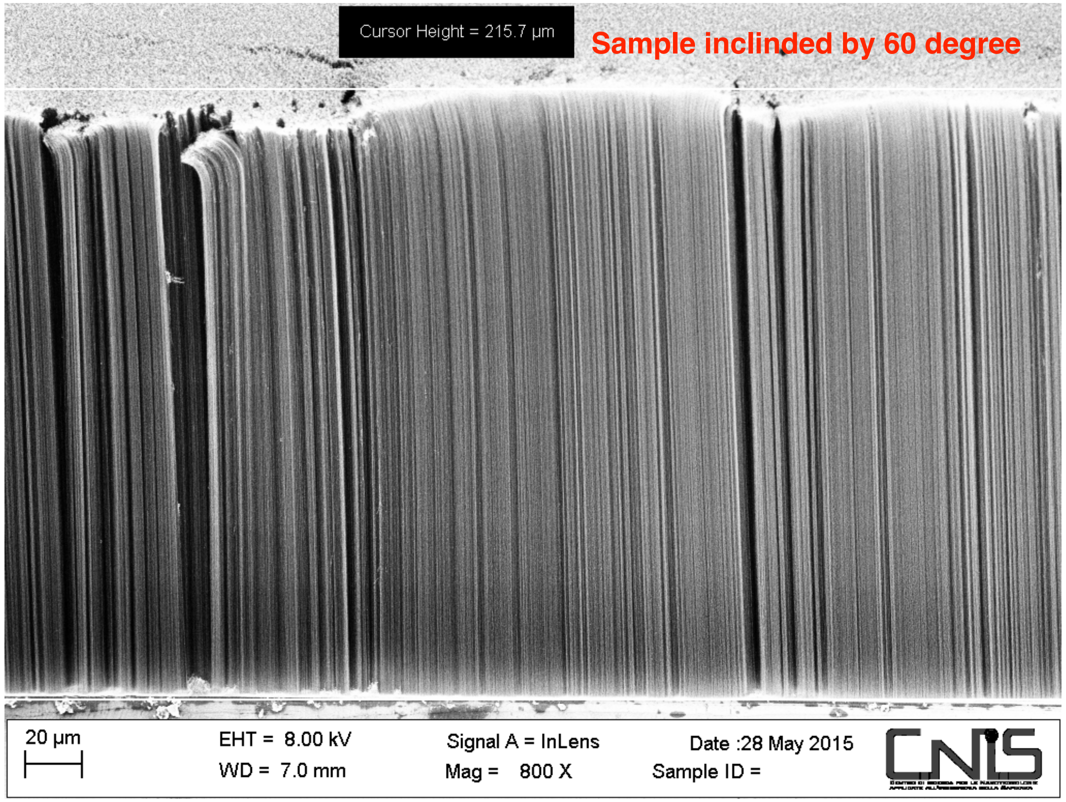


Figure 8. Different approaches to chemical modification of carbon nanotubes. (a) substitutional doped single-walled nanotubes (either during synthesis or by post-growth ion-implantation), (b,c) nanotube bundles intercalated with atoms or ions, (d,e) peapods: SWNTs filled with fullerenes (other endohedral fillings are possible), (f) fluorinated tubes, (g) covalently functionalised tubes and (h) functionalised nanotubes *via* π-stacking of the functionality and the tubes.

- CNT can be very efficiently **doped**
- **Alkali metal** can be bonded to CNT surface (Na,Cs,…) or F.
- WIMP can scatter on Na, Cs, … and these ions can then be channeled

How to pack enough mass ?



SEM image of NanoLab aligned CNT on mm Si substrate

First test shows $<10^{-3}$ contamination of Fe (“seed”) and O.

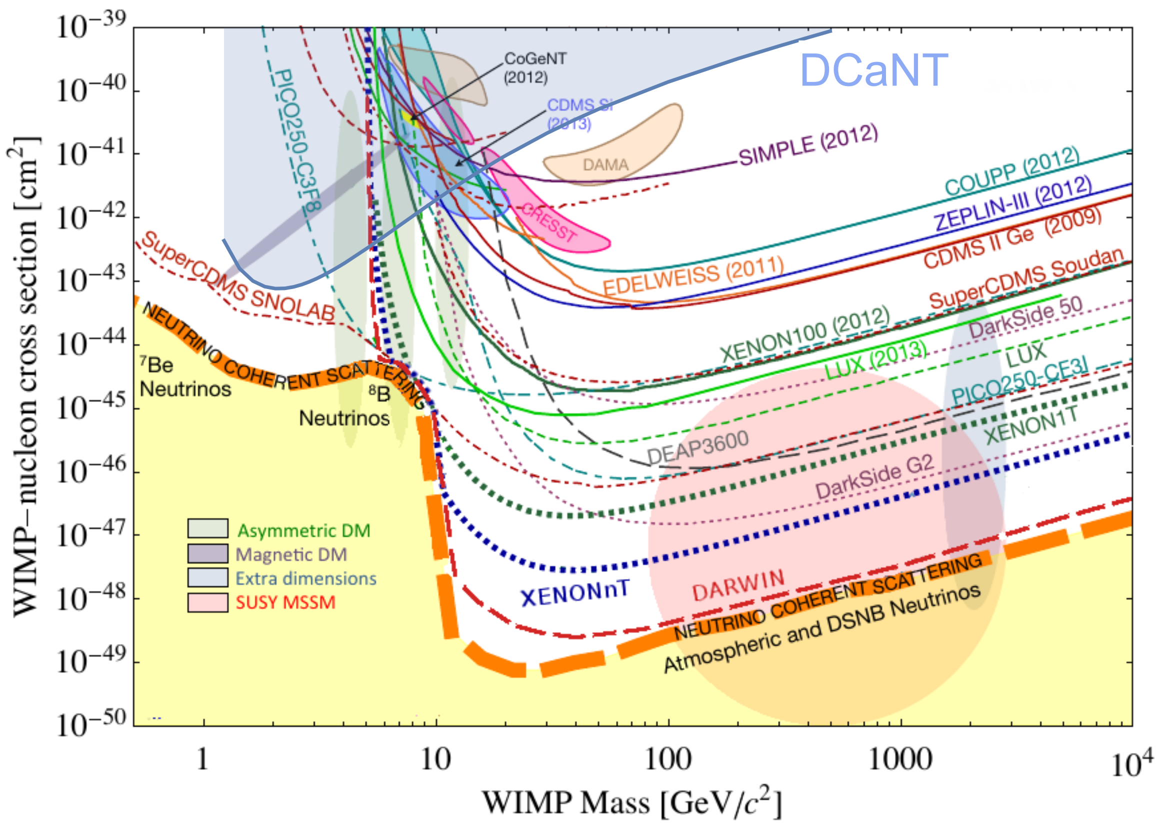
- Simple-man calculation for 1 m^2 layer - 100 layers detector
- ρ=5 nm and h =300 µm
- number CNT per layer (single wall) ~ 2 m^2/a^2
- Surface density of a graphene layer: 1/1315 g/m^2

a [nm]	CNT detector mass [kg]
11	11.8
30	1.6
45	0.7
58	0.4

Impact of a CNT based detector

- 100 layers, 1 m^2 each.
- With compact readout, it can have a few m^3 volume
- To be rotated tracking CYGNUS direction

Sensitivity for 0.4 kgy (CNT array trapping C ions detected downto 1 KeV)



Observing C ion emerging from CNT arrays is the first step!

INFN CNS5 has financed it