SAPIENZA UNIVERSITÀ DI ROMA

INFN Istituto Nazionale di Fisica Nucleare

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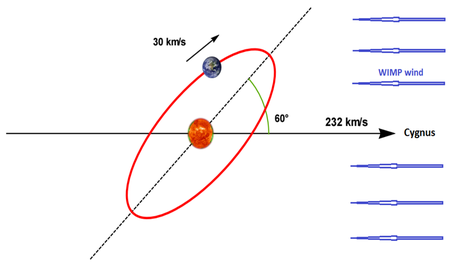
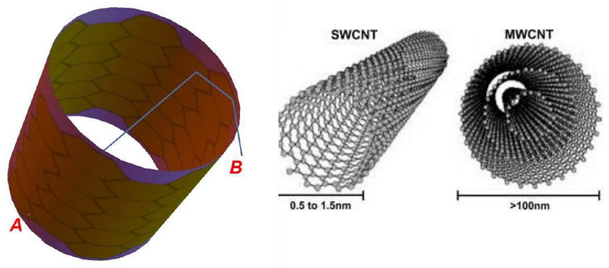
Carbon nanotubes as a target for directional detection of light WIMP

Vasile Cristian Antochi

The Idea: Using large arrays of allined Carbon Nanotubes (CNTs) opened at one end as target inside a Time Projection Chamber (TPC) could be a solution for the directional detection of Weakly Interactive Massive Particles (WIMPs)



- Assuming a halo of dark matter in the galaxy a WIMP wind is expected coming from the direction of Cygnus.
- Modulation expected due to Earth's revolution around the Sun (as observed by Dama/LIBRA experiment).
- Directionality needed to confirm Dark Matter origin

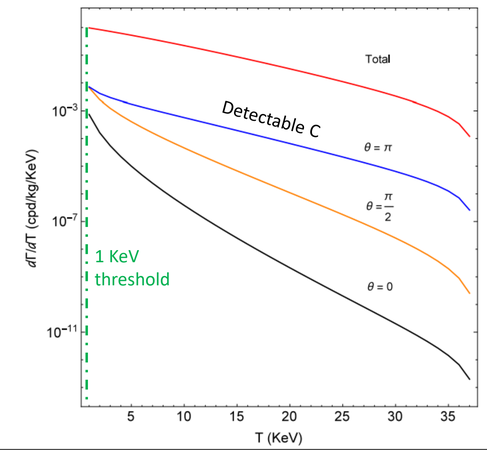


- The WIMPs interact with a Carbon nucleus in A and extract it.
- Nucleus channeled to B

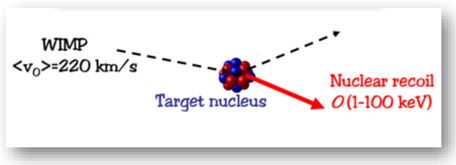
Channeling conditions:

1. Correct direction wrt CNT axis ($\theta = \pi$)
2. $E_{nuc}^{kin} \geq 1\ KeV$

Anisotropic channeling response inside a CNT

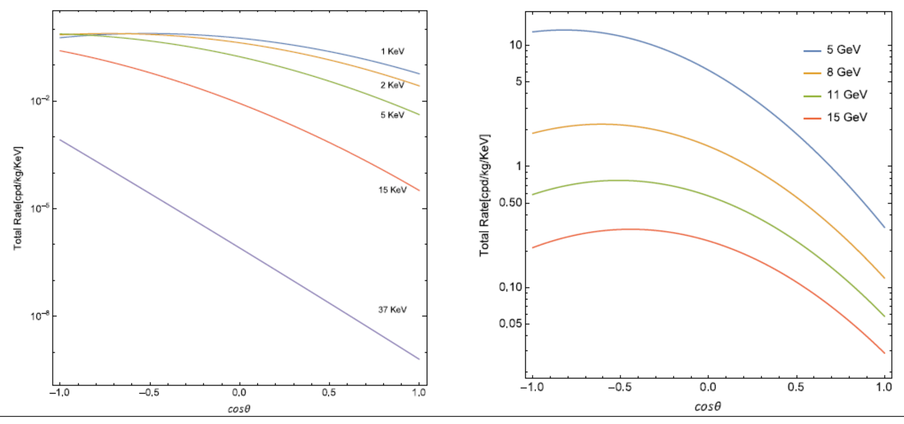


- CNT direction: from base to open cap $\theta = \pi$.
- CNT diameter: $d = 10\ nm$

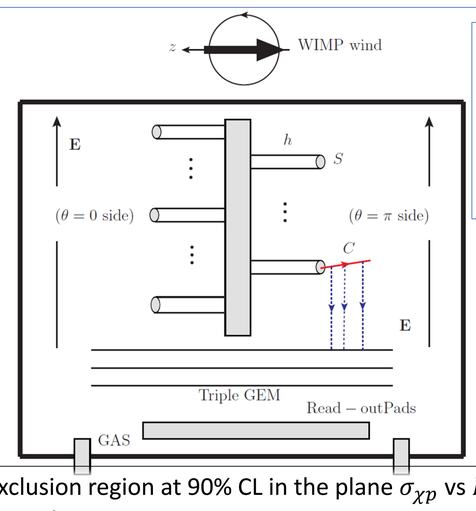


- Angular distribution of recoiling nuclei can be computed once known the direction of the WIMP wind and an approximate cross section.
- For a WIMP mass of $M_\chi \simeq 11GeV$, assumed a cross section of $\sigma_{\chi p} = 2 \times 10^{-4} pb$.

Angular distributions of the event rate for different recoil kinetic energies and different WIMP mass



The *left pannel* reports the angular distributions of the recoiling nucleus wrt. the Sun's direction, for various values of kinetic energy.
The *right pannel* shows the same angular distributions for different values of WIMP mass M_χ and recoil kinetic energy of $T = 1KeV$.

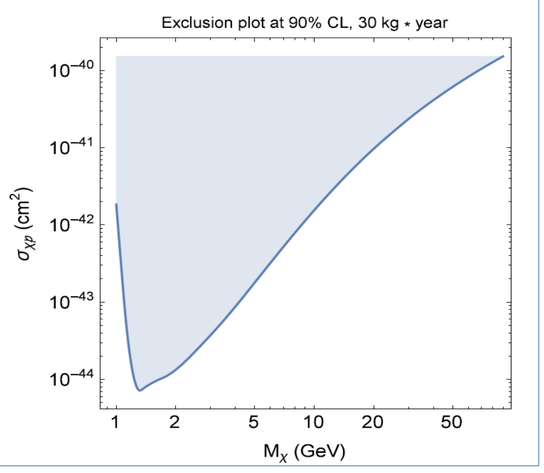


Exclusion region at 90% CL in the plane $\sigma_{\chi p}$ vs M_χ

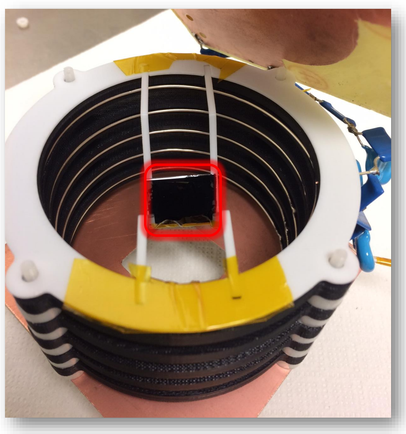
- 10 kg CNT target
- 3 years of exposure time

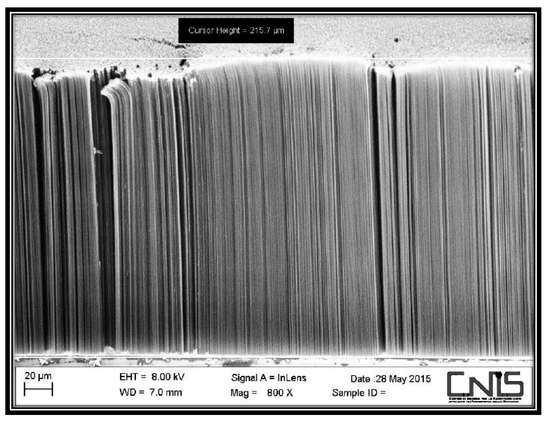
Assumed no signal events and identification and rejection of all background events. «0 background» solution is being studied (Negative Ion Drift, optical readout etc.).

- Time Projection Chamber to detect the outcoming C nucleus.
- CNT wall placed in a drift field orthogonal to the CNTs axes
- High granularity needed to observe C ion track
- Gas mixture of $He{:}SF_6$ can provide additional target for Dark Matter: SF_6 for spin dependent DM, He for spin independent
- Expected dipolar anisotropy



DCaNT experiment: The first tests with CNTs were taken at the Beam Test Facility (BTF) at LNF (Laboratori Nazionali di Frascati) structure with a TPC and a 2x2cm^2 CNT target



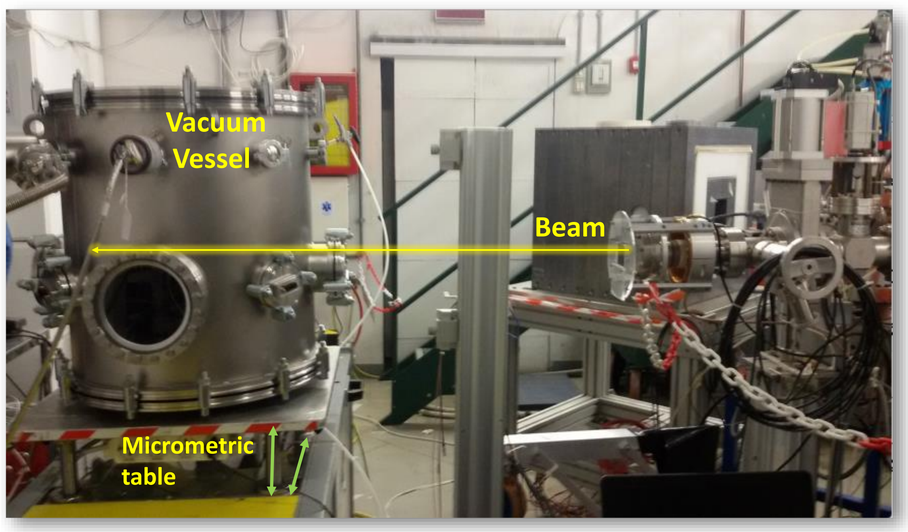


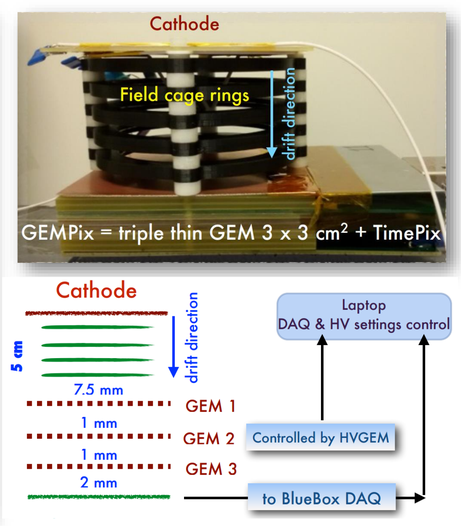
Prototype TPC:

- 5 cm drift field
- Triple thin GEM $3cm \times 3\ cm$
- HV-GEM alimentation module (developed at LNF)
- TimePix chip readout (charge collection and programmable clock): perfect solution for slow electronics

CNT target:

- $2 \times 2\ cm^2$ target
- Silicon growth base
- 200µm thick Multi Wall Carbon Nanotube (MWCNT) forrest
- Allegedly semiconductor material





The TPC was put inside a inox steel vacuum vessel on a precision goniometer and the vessel was set on the micrometric table of the BTF. This way beam angle and height could be easilly controlled remotely. The BTF beam is a 450 MeV electron beam with the possibility to modify the intensity and the dimensions.
In this configuration different gas mixtures at different pressures were studied with positive results: electron drift in $Ar{:}CO_2{:}CF_4$ and confirmation of negative ion drift in SF_6.

Simulation of Drift Field

ANSYS Maxwell simulations of the entire geometry of the experiment performed to study the drift field and possible modifications due to the target:

- Perfectly uniform without target
- Si base only (semiconductor material) gives slight field distortion; negligeable effect
- Si base + conductive Carbon (graphite) target modifies significantly the drift field
- Minimal distortion with horizontal target

Vertical configuration tested experimentally

More complex solutions to reduce the distortion effects are being studied (conductive strips at variable potential, gradient of potential along the growth base etc.)

Tracks registered in $Ar{:}CO_2{:}CF_4$ @300 Torr (Confirmed with SF_6 @150 Torr)

The electron beam was sent at various heights in order to study the response of the CNTs inside the TPC.

- Direct images of the beam projection recorded with TimePix chip
- Strong distortion effects seen near the CNT target observed, comparable to simulation
- Distortion incompatible with semiconductor hypotesis

Future tests at BTF (June 2017) will test the horizontal target configuration and optical read-out.

[1] L.M. Capparelli, G. Cavoto, D. Mazzilli, A.D. Polosa, *Directional Dark Matter Searches with Carbon Nanotubes,* arXiv:1412.8213v3 [physics.ins-det] 5 Dec 2015
[2] G. Cavoto, E.N.M. Cirillo, F. Cocina, J. Ferretti, and A.D. Polosa, *WIMP detection and slow ion dynamics in carbon nanotube arrays,* arXiv:1602.03216v2 [physics.ins-det] 10 Jun 2016