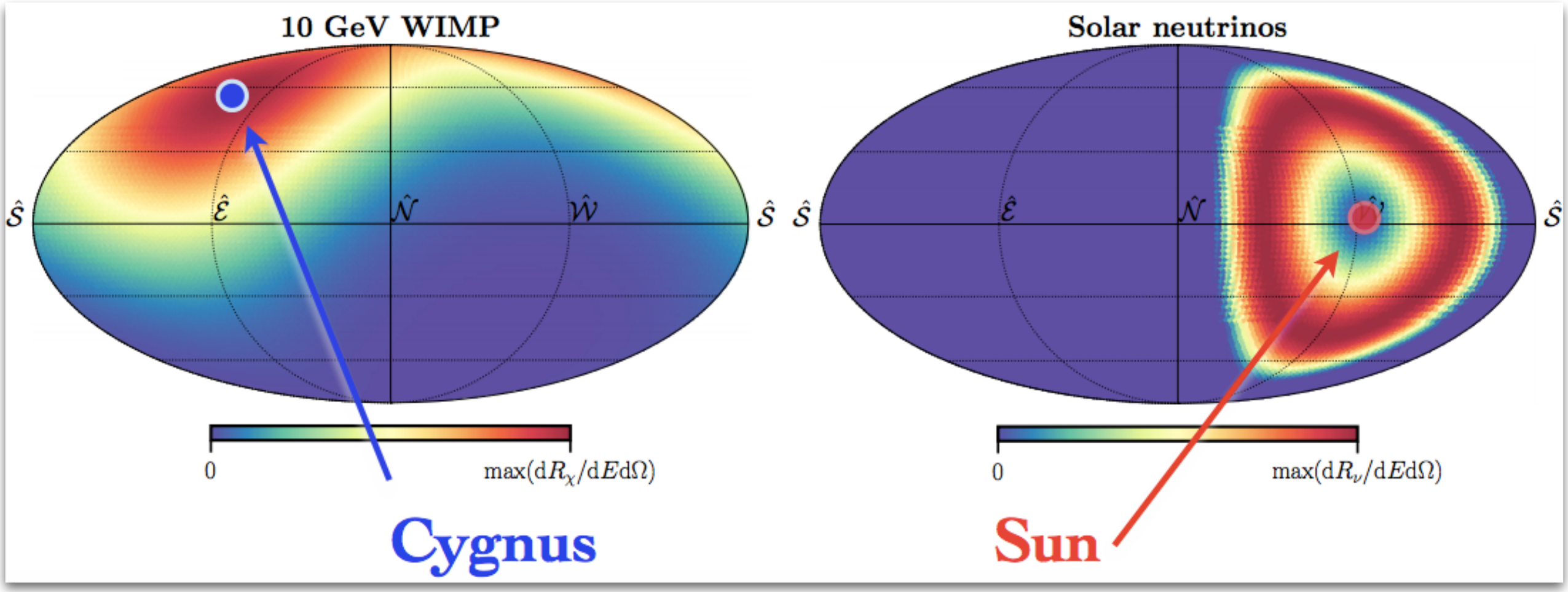
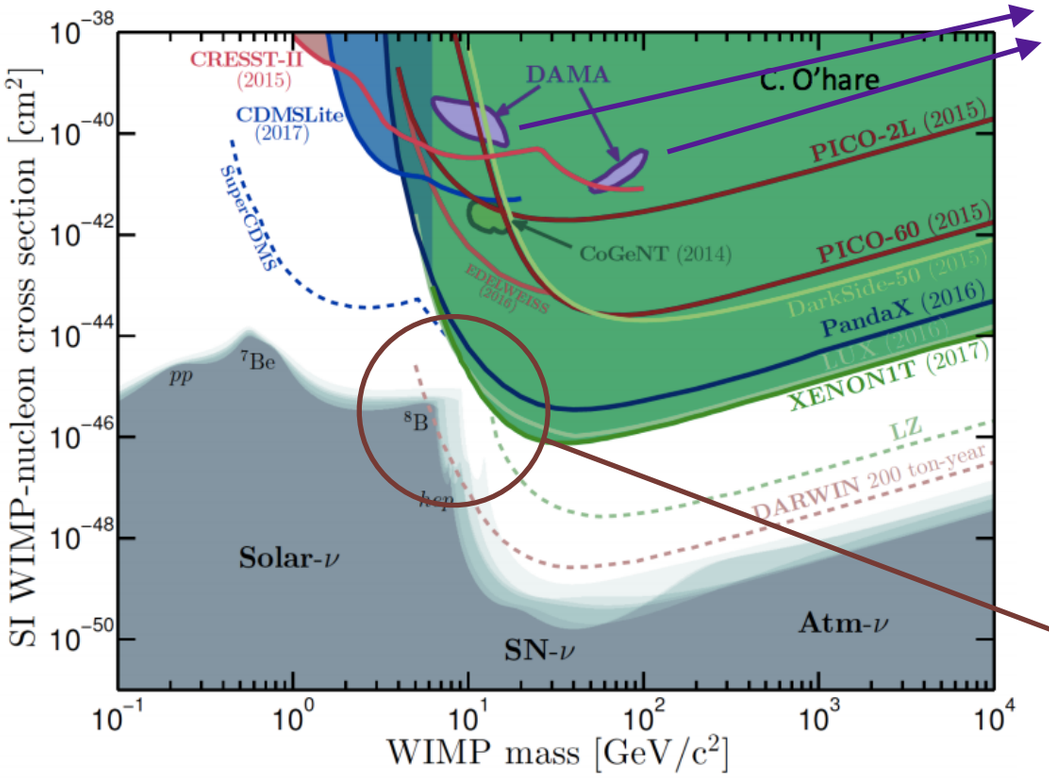


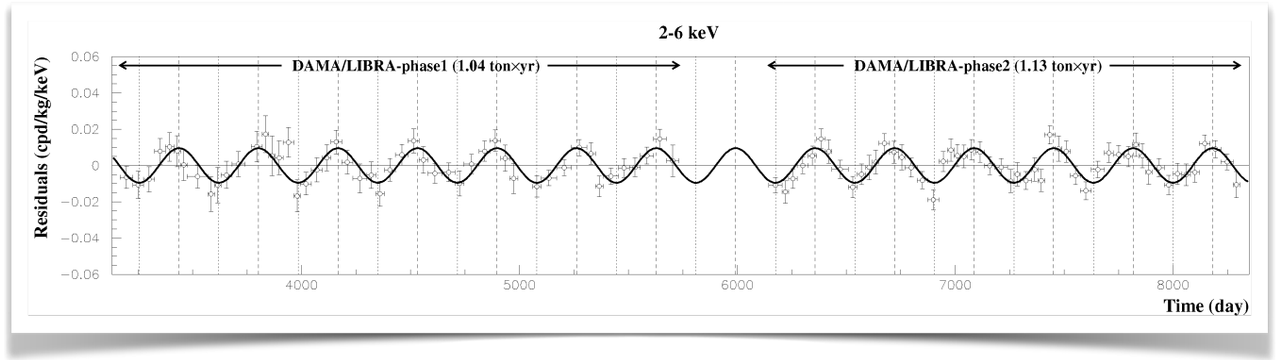
Dark Matter searches with directionality: CYGNO and ANDROMeDa

Francesco Renga
INFN Roma

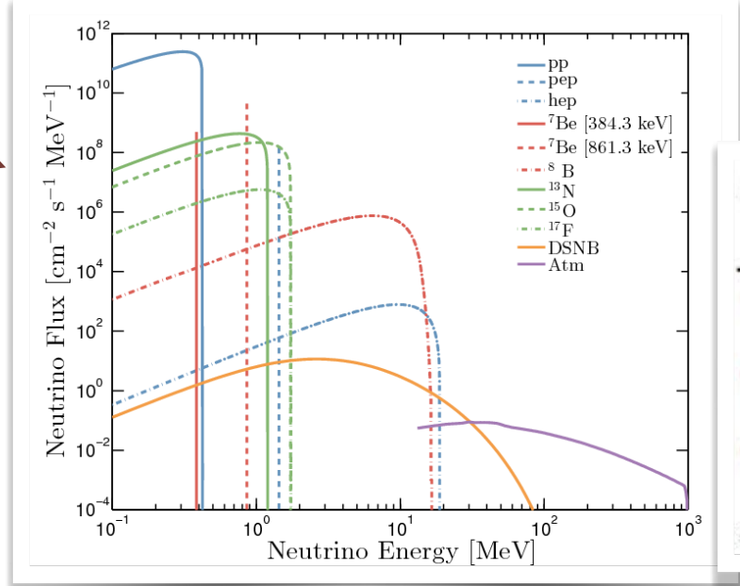
Dark Matter searches

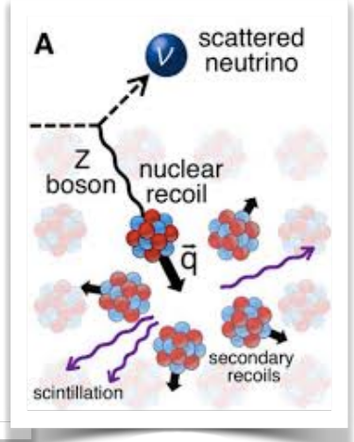
- Dark matter (DM) detectors in the GeV - TeV range exploit nuclear or electron recoils induced by DM scattering, either with or without background identification





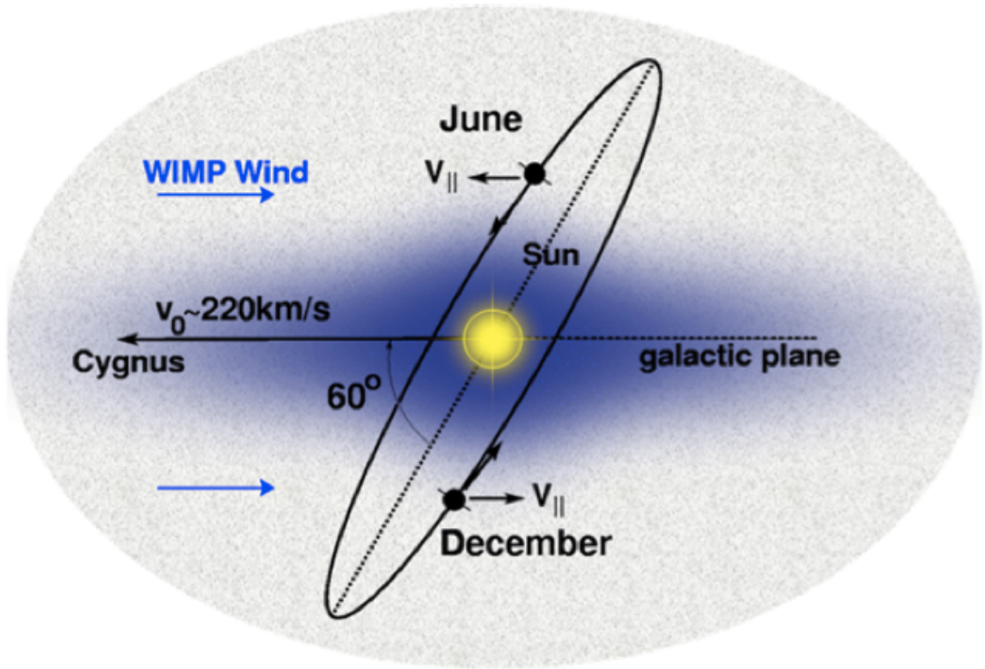
DAMA/LIBRA
Universe 4 (2018), no. 11, 116





Identifying a Dark Matter signal

- An **unambiguous evidence** for Dark Matter observation requires the identification of a peculiar feature



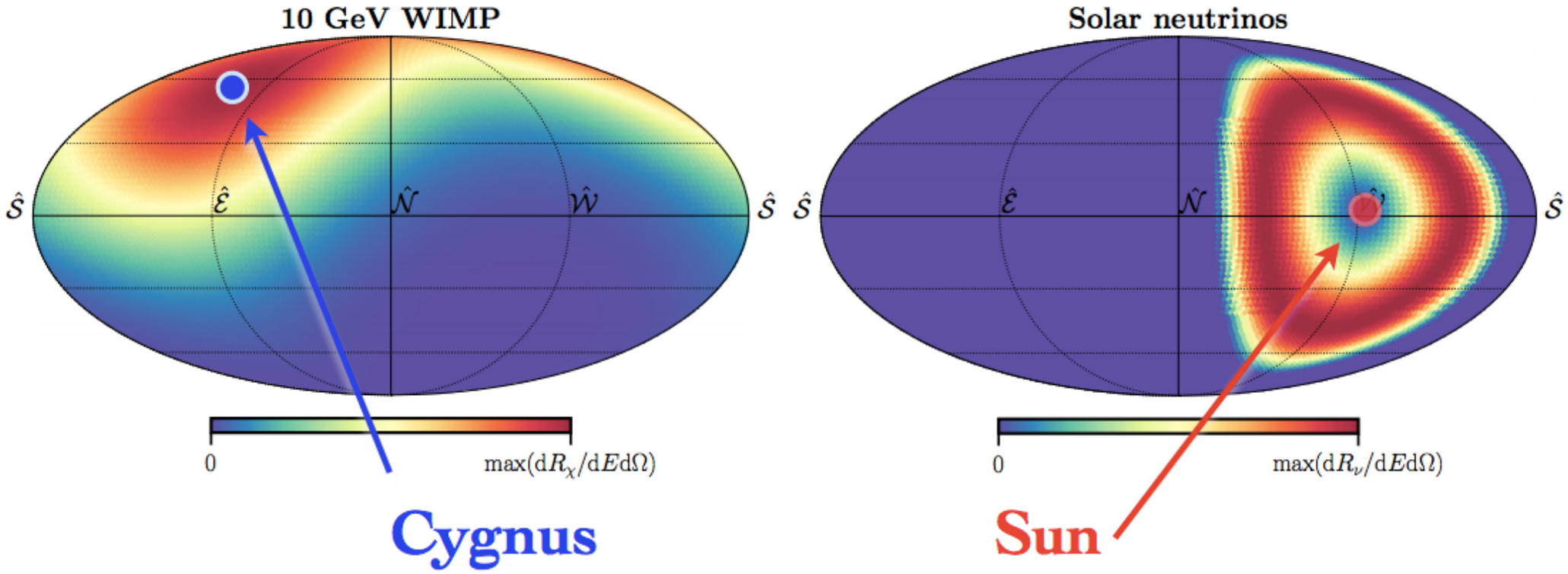
- **Discrimination** of dark matter **against coherent neutrino scattering** requires the identification of a peculiar feature

Earth motion in the DM halo enhances the cross section for particles observed in the direction of the earth motion (Cygnus constellation)

Identifying a Dark Matter signal

- An **unambiguous evidence** for Dark Matter observation requires the identification of a peculiar feature

- **Discrimination** of dark matter **against coherent neutrino scattering** requires the identification of a peculiar feature



C. O'Hare, CYGNUS2019

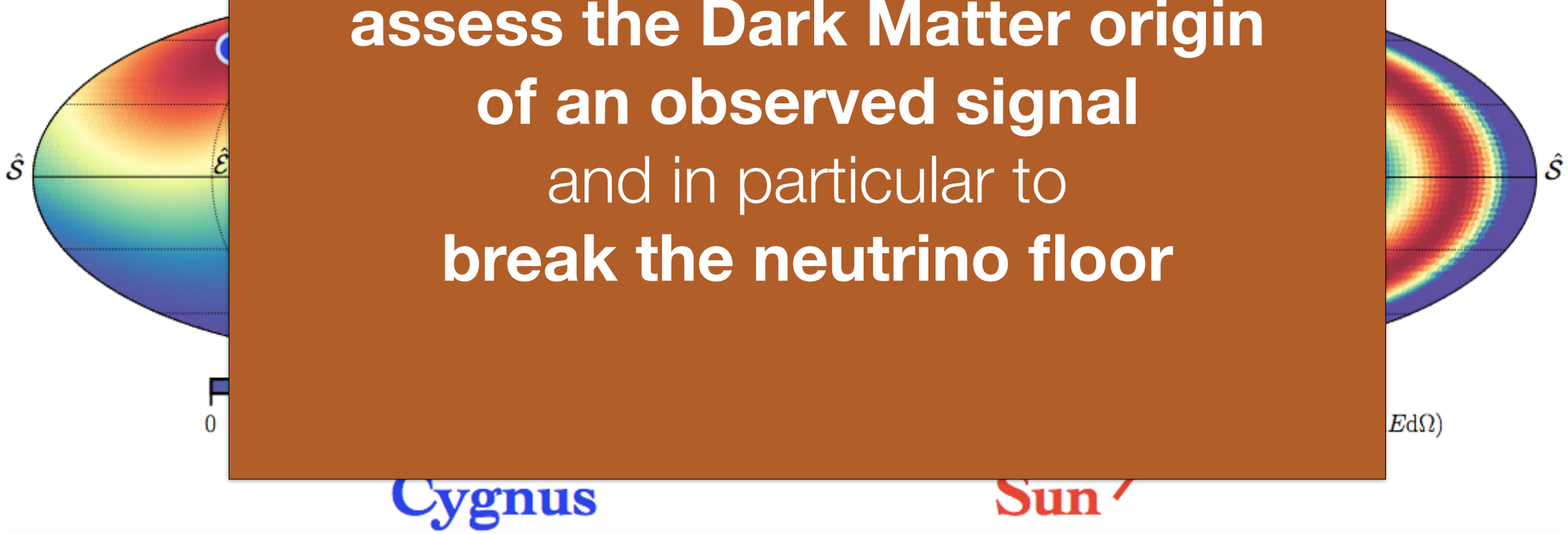
Expected rate of DM-induced recoils

Identifying a Dark Matter signal

- An **unambiguous evidence** for Dark Matter observation requires the identification of a peculiar feature

- **Discrimination** of dark matter **against coherent neutrino scattering** requires the identification of a peculiar feature

Directionality provides a unique tool to **assess the Dark Matter origin** of an observed signal and in particular to **break the neutrino floor**

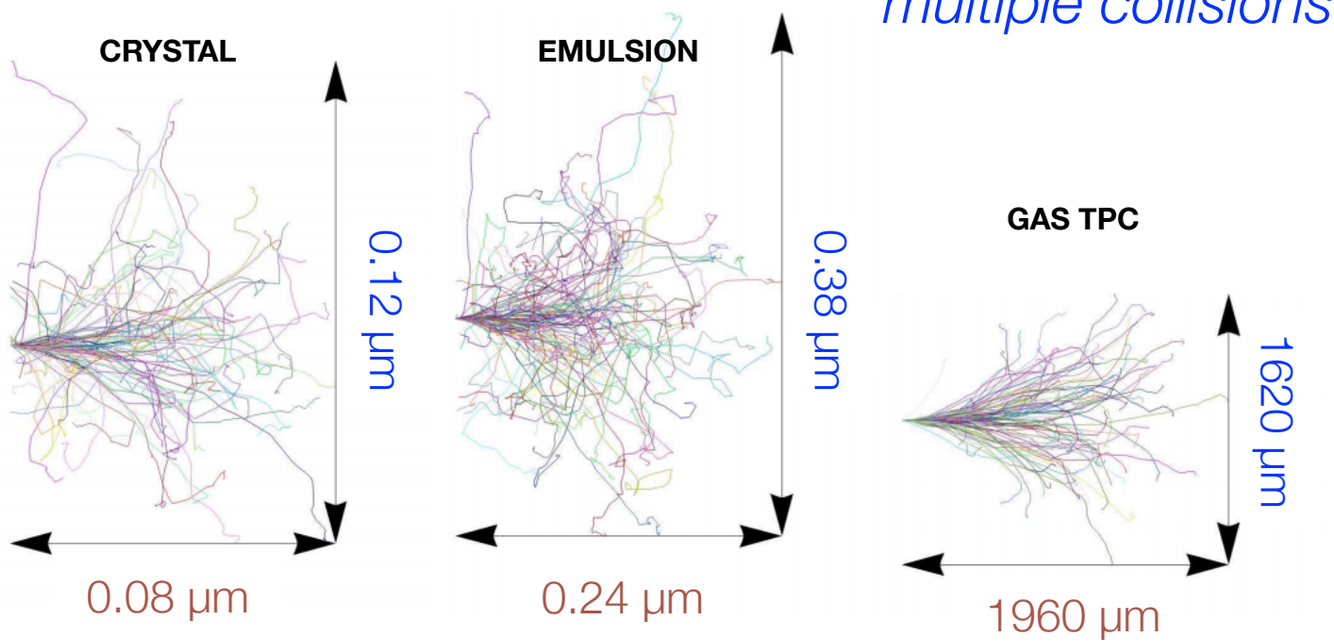


C. O'Hare, CYGNUS2019

Expected rate of DM-induced recoils

Experimental challenges of directional searches

1 TeV WIMP, max. recoil energy

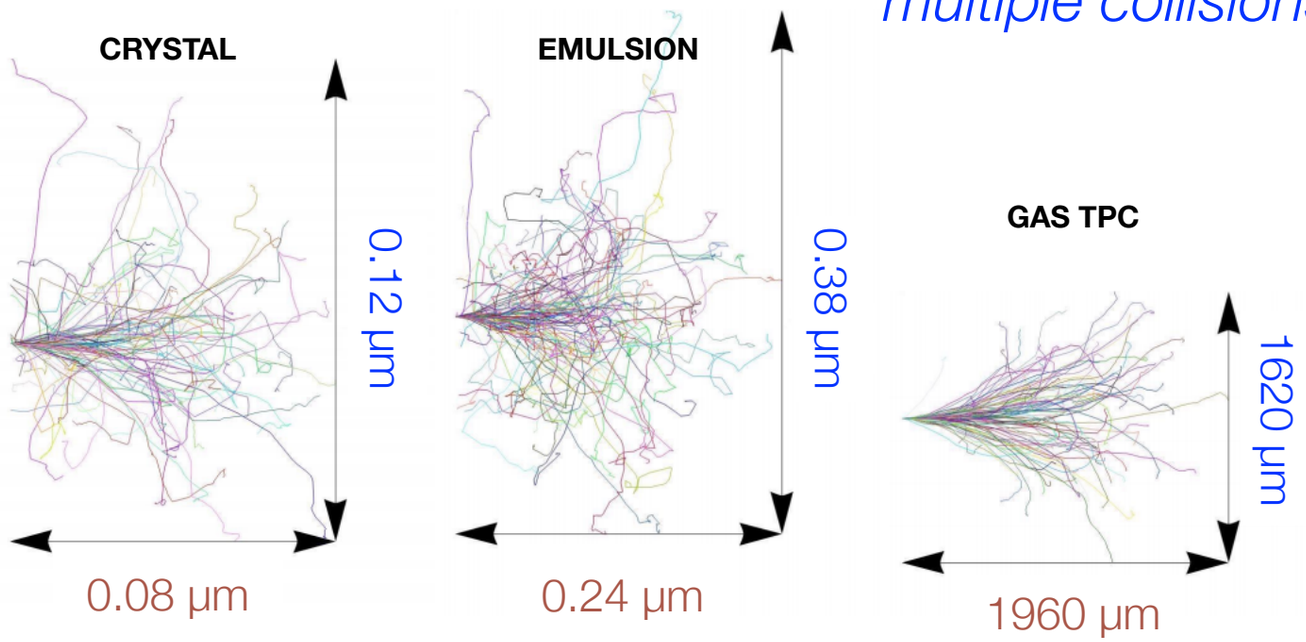


recoil direction information quickly deteriorated by multiple collisions

Very short tracks —> 3 options
1) high granularity
2) strong detector anisotropy
3) tiny statistical effects in isotropic (e.g. columnar recombination) or slightly anisotropic detectors

Experimental challenges of directional searches

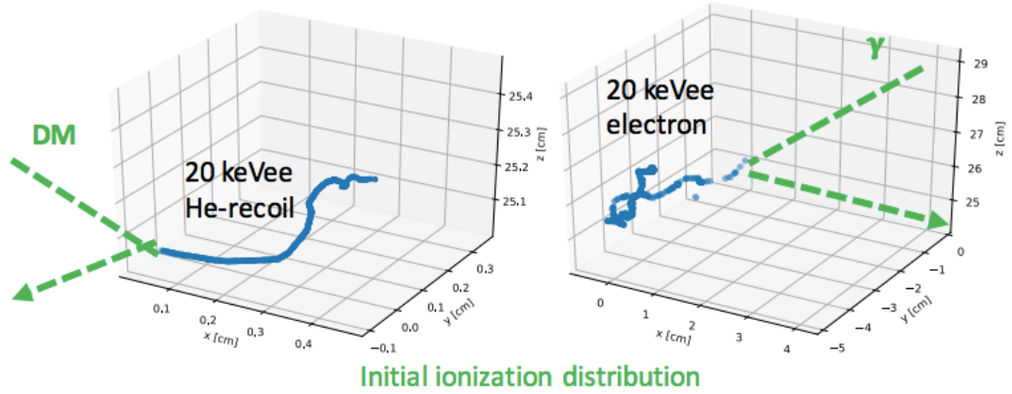
1 TeV WIMP, max. recoil energy

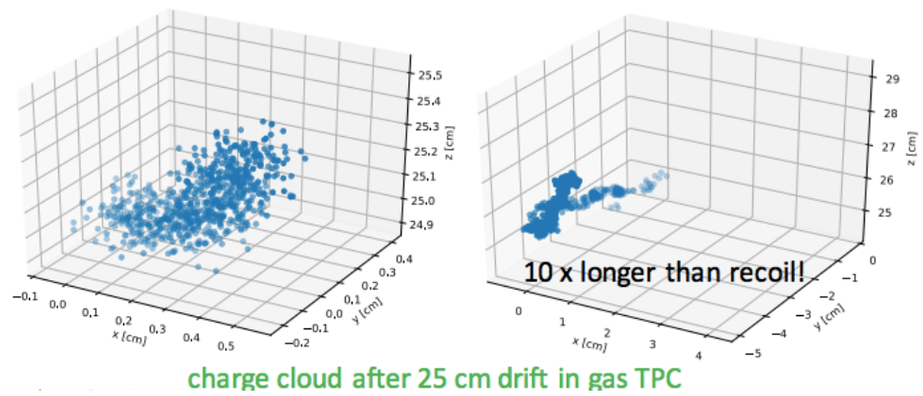


recoil direction information quickly deteriorated by multiple collisions

Gaseous TPC = low density = O(mm) tracks

Direction can be reconstructed event-by-event





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1) high granularity

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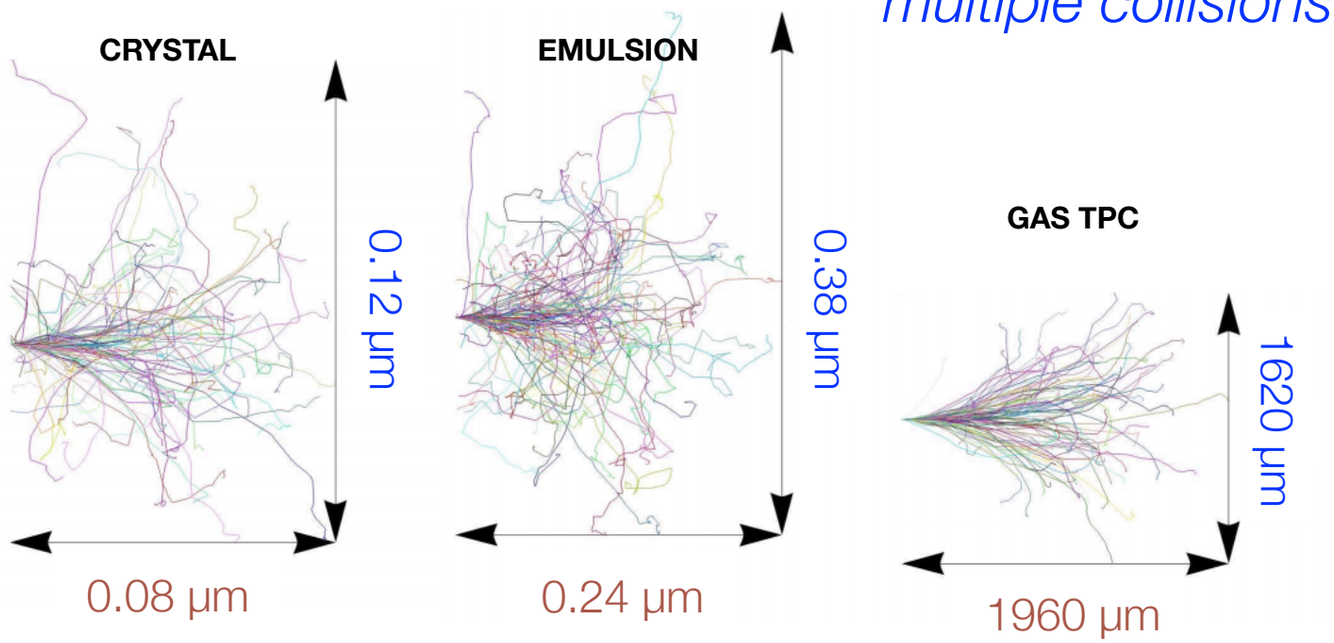
Experimental challenges of directional searches

1 TeV WIMP, max. recoil energy



recoil direction information quickly deteriorated by multiple collisions

Very short tracks —> 3 options

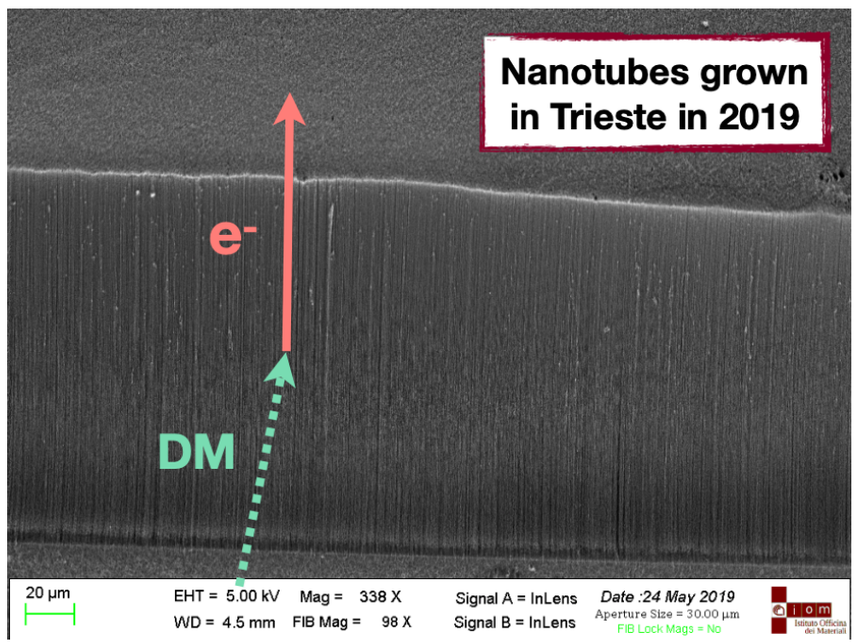
1) high granularity

2) strong detector anisotropy

3) tiny statistical effects in isotropic (e.g. columnar recombination) or slightly anisotropic detectors

Channeling in carbon nanotubes (CNTs)

Only electron recoils in a specific direction can be efficiently reconstructed



The CYGNO project

ROME GROUP MEMBERS

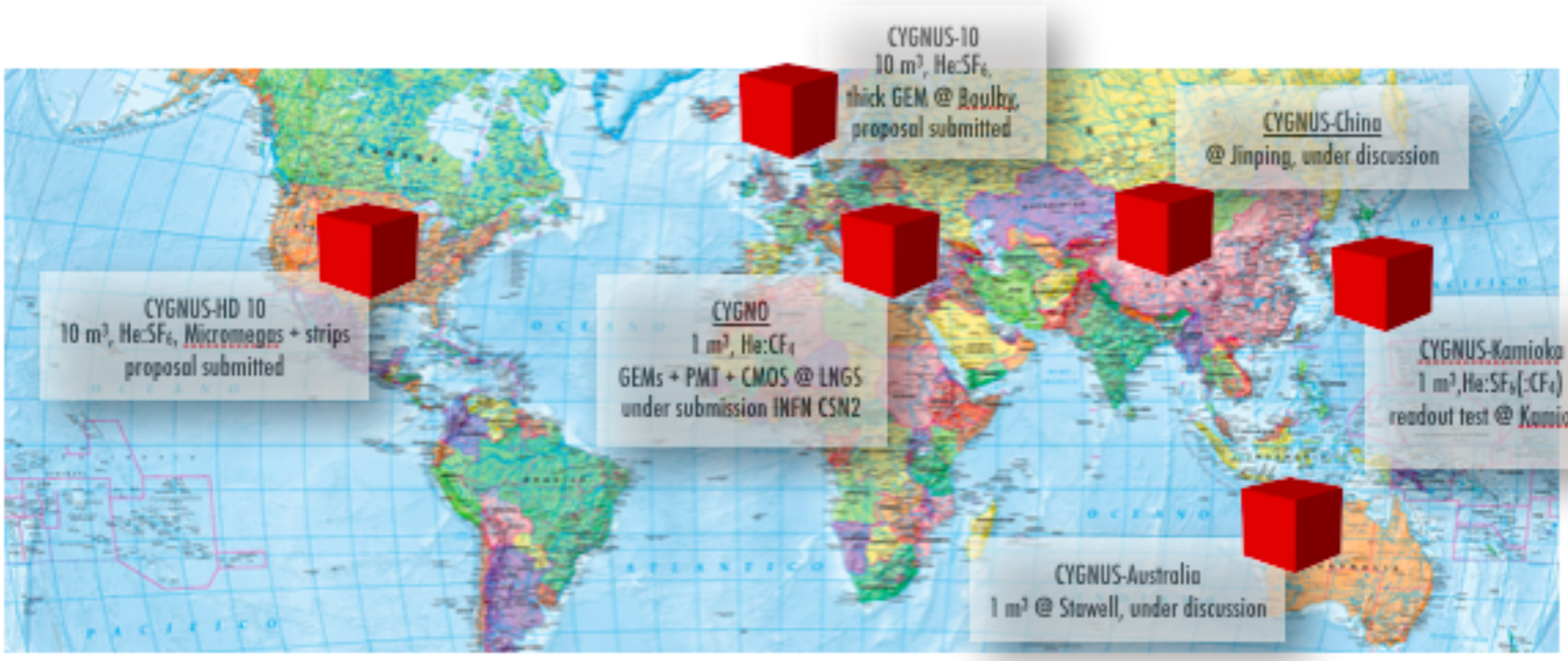
Gianluca Cavoto
Emanuele Di Marco
Giulia D'Imperio
Francesco Iacoangeli
Andrea Messina
Stefano Piacentini
Davide Pinci,
Francesco Renga (local reference person)

ESSENTIAL BIBLIOGRAPHY

F. D. Amaro *et al.*, *Instruments* 6 (2022) 1, 6
E. Baracchini *et al.*, *Measur.Sci.Tech.* 32 (2021) 2, 025902
E. Baracchini *et al.*, *JINST* 15 (2020) 10, P10001
V. C. Antiochi *et al., JINST* 13 (2018) 05, P05001

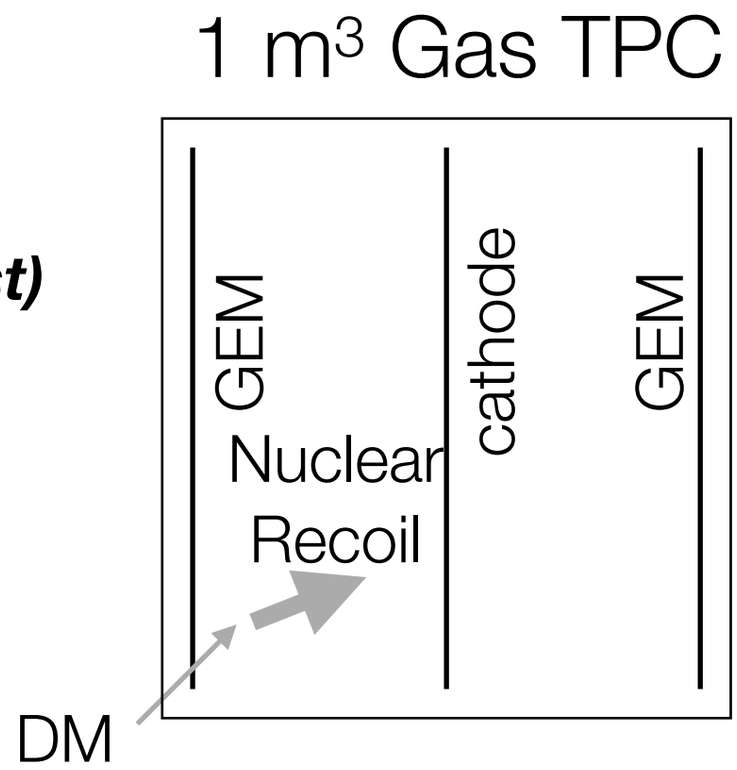
A worldwide community

- The CYGNUS network connects several experimental efforts around the world for the search of dark matter with gaseous directional detectors



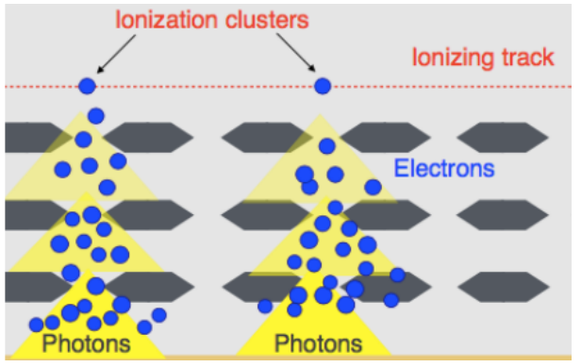
The CYGNO project

- ***Helium-CF_4 gas mixture:***
  - Helium —> light, O(GeV) dark matter sensitivity
  - Fluorine —> Spin-dependent sensitivity
- ***GEM with double optical readout (high granularity + fast)***



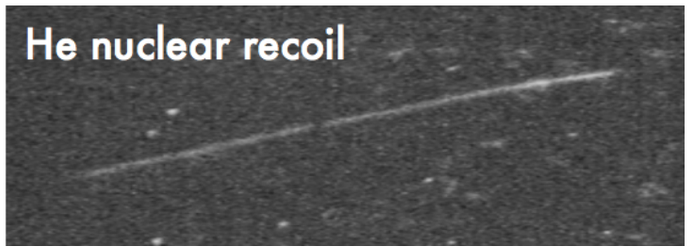
- To be installed at **Laboratori Nazionali del Gran Sasso**
- Synergy with **INITIUM ERC Grant** (E. Baracchini - negative ion drift with $He:CF_4:SF_6$):
  - reduce the electron diffusion
  - improve fiducialization

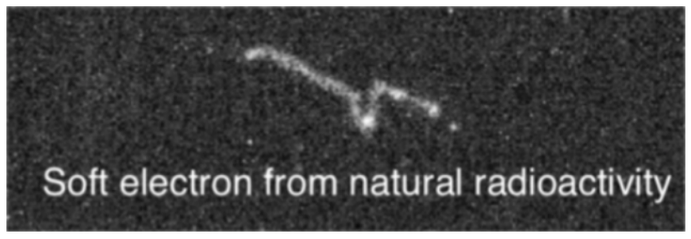
Optical readout of GEMs



In He:CF_4 mixtures (typ. 60:40), scintillation light is produced in the avalanche

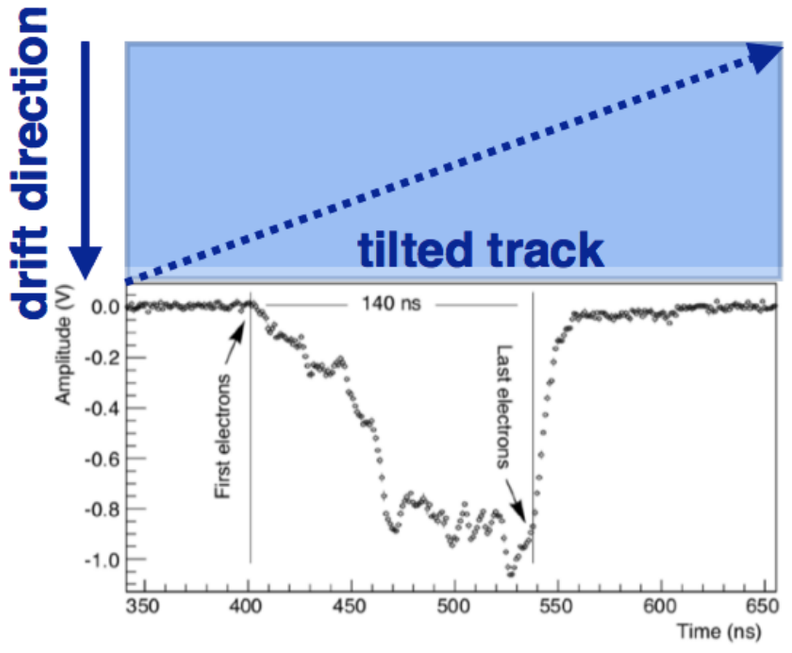
- Light readout with a sCMOS camera allows for a high granularity imaging of the event





- Pioneering work at INFN Rome (Marafini, Pinci)

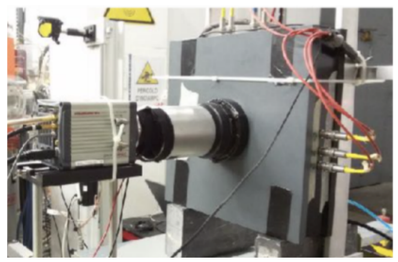
- Light readout with fast detectors (PMT, SiPM) allows for reconstruction of the event topology in the 3rd dimension

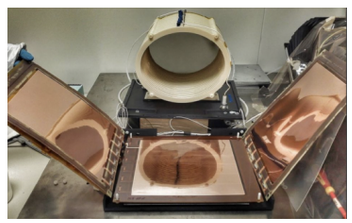


The CYGNO roadmap

2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

ORANGE LEMON



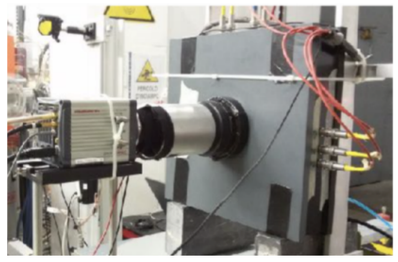


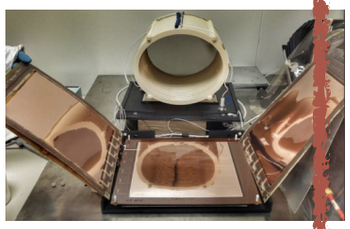
10x10x1 cm³ **20x24x20 cm³**

The CYGNO roadmap

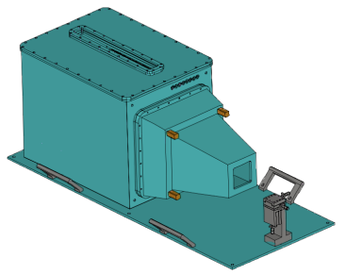
2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

ORANGE | LEMON | LIME





10x10x1 cm³ 20x24x20 cm³

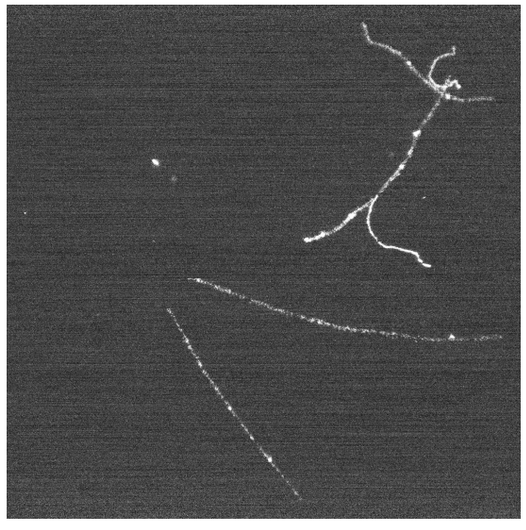


33x33x50 cm³ (54 l)

After a long campaign of overground tests, now under **commissioning underground at LNGS**

Data taking with different shields to validate the background simulations

Neutron flux measurement

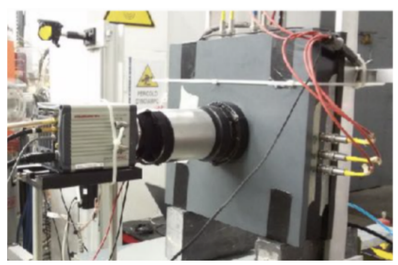


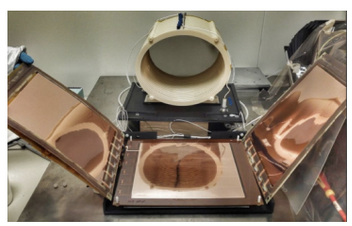
one of the first pictures underground

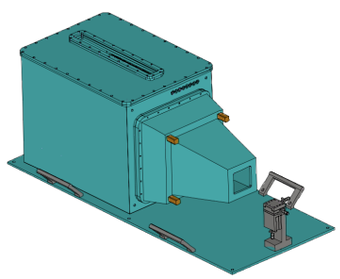
The CYGNO roadmap

2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

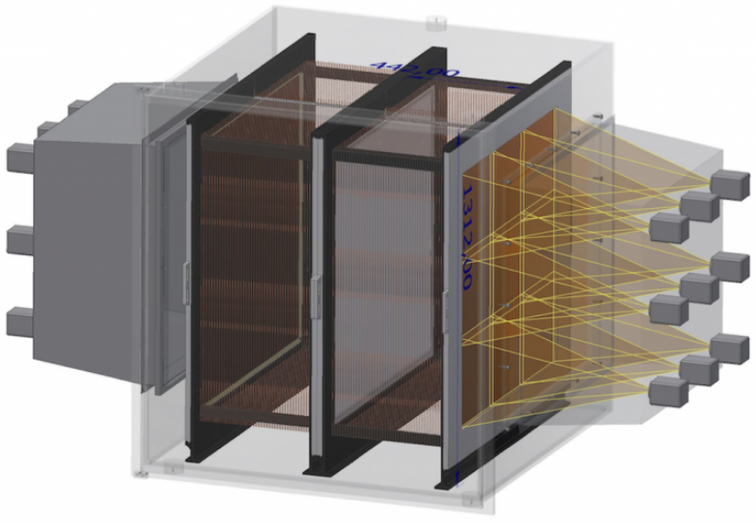
ORANGE | LEMON | LIME







10x10x1 cm³ **20x24x20 cm³** **33x33x50 cm³ (54 l)**



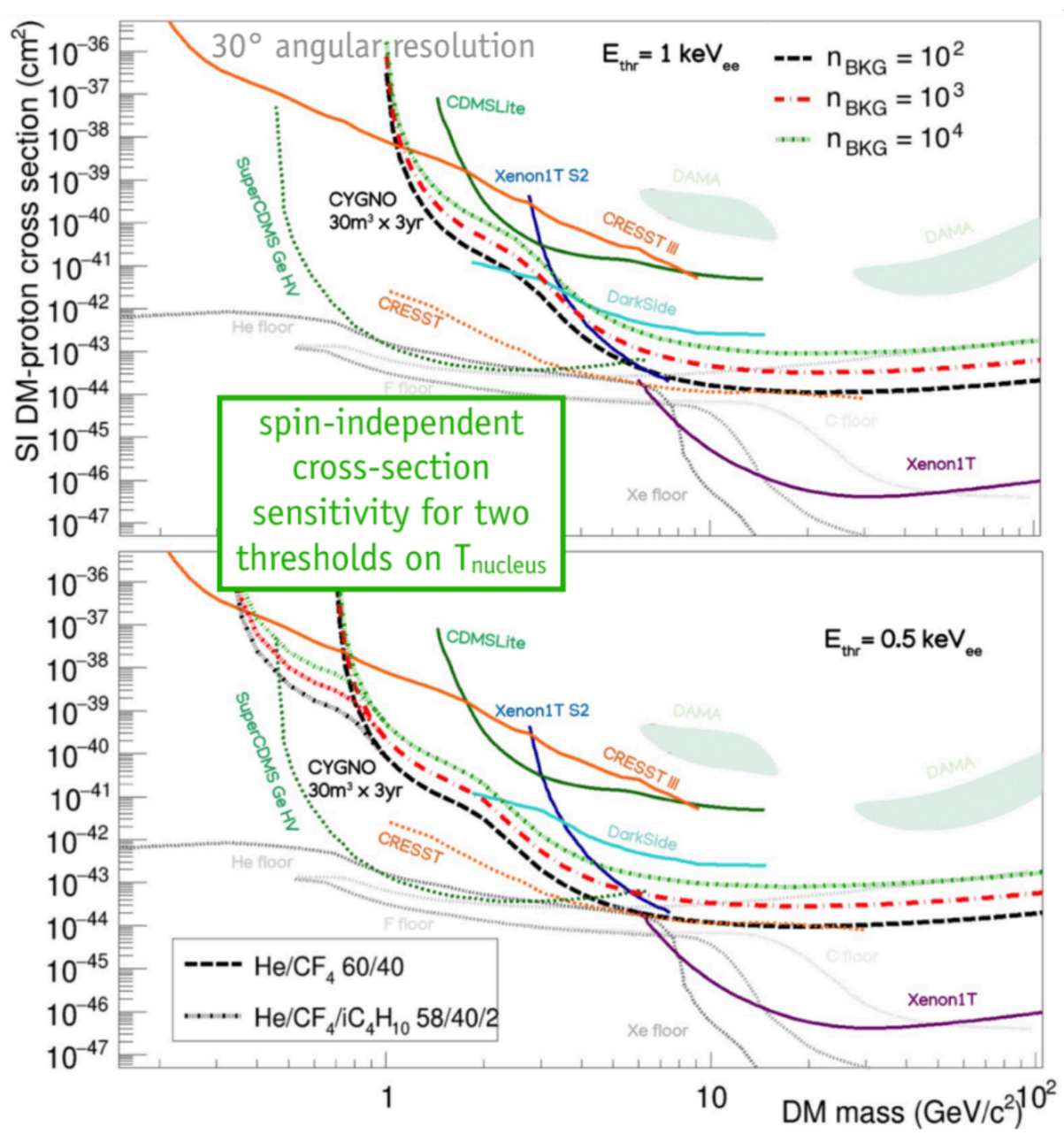
CYGNO

DESIGN | CONSTR. | RUN

100x100x100 cm³ (1 m³)
the demonstrator for a
multisite directional Dark Matter observatory

Critical issues and Sensitivity

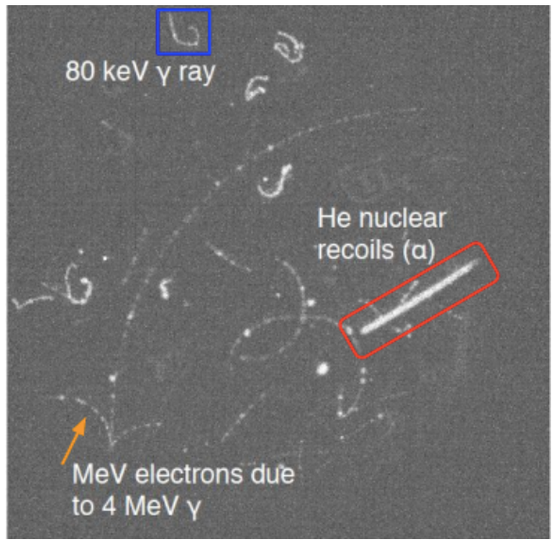
- gamma radioactivity from sCMOS camera and optics, extremely difficult to shield
  - 10^6 electron recoils/year/m^3
  - dedicated R&D activities to develop radiopure devices
- Non-linearities from GEM saturation
  - dedicated calibrations and software compensation algorithms

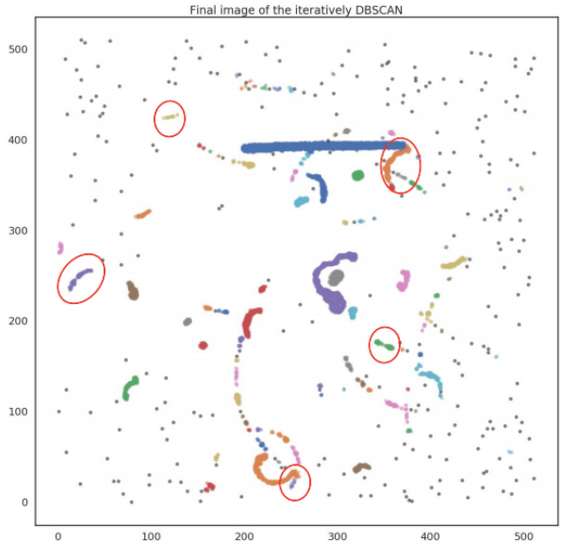


INFN Rome/Sapienza role

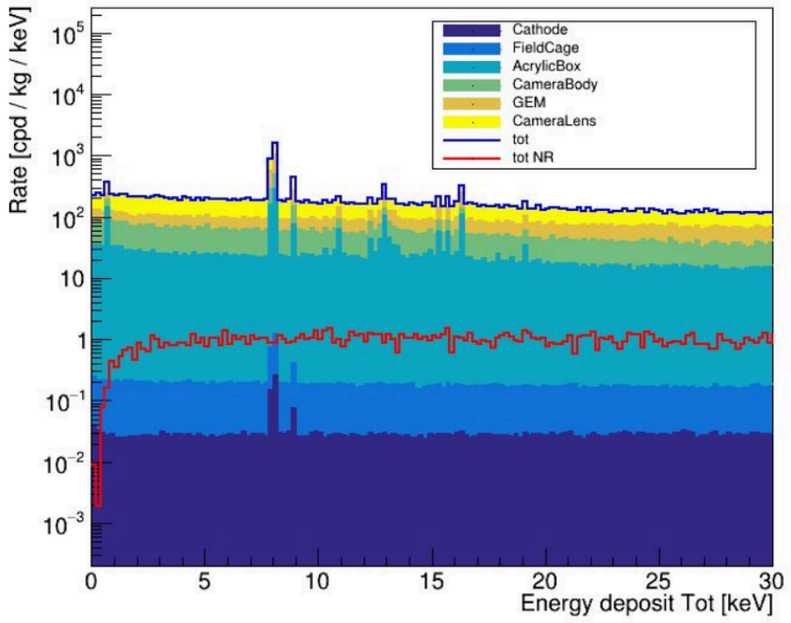
- The group at INFN Rome/Sapienza is in charge for some of the most critical issues for the future of the project:
  - background (radiopurity, simulations, identification)
  - data acquisition

Background identification algorithms

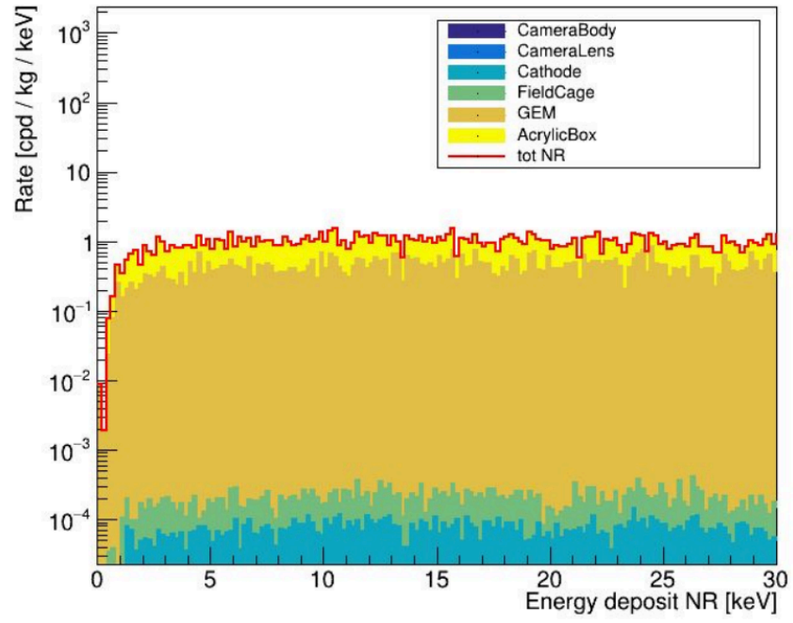




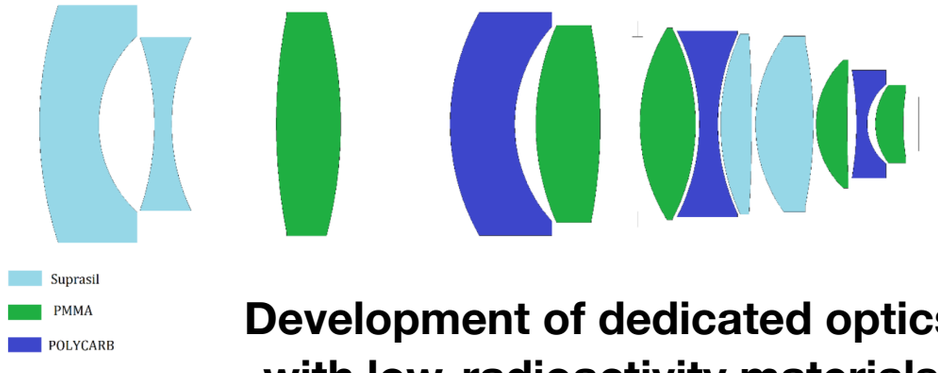
- **ER rate [1-20] keV = 2.3x10^6 cts/yr**



- **NR rate [1-20] keV = 1.1x10^4 cts/yr**



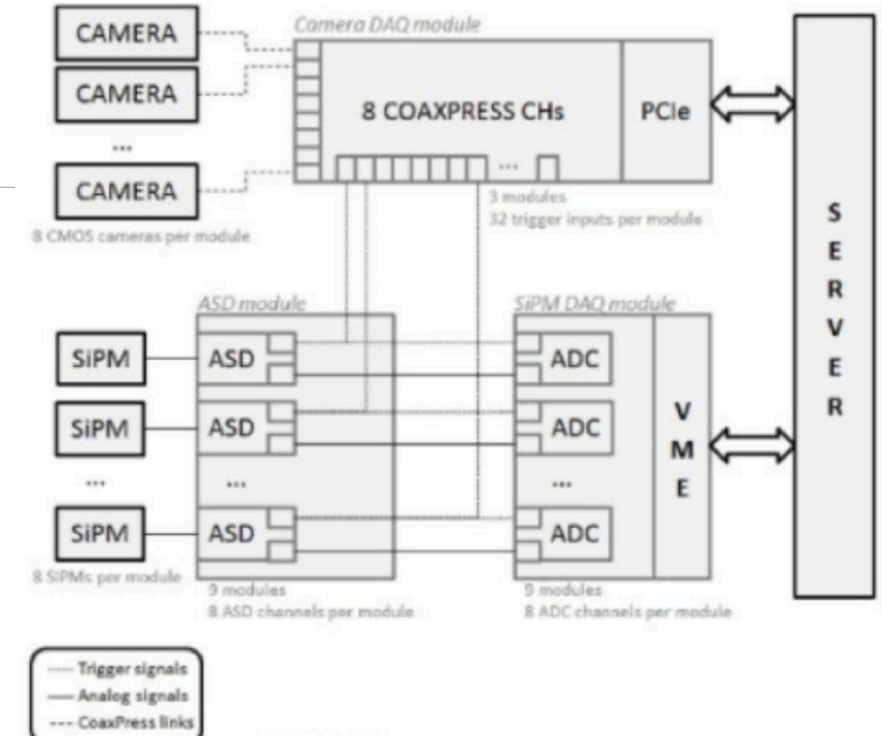
Detailed simulation models

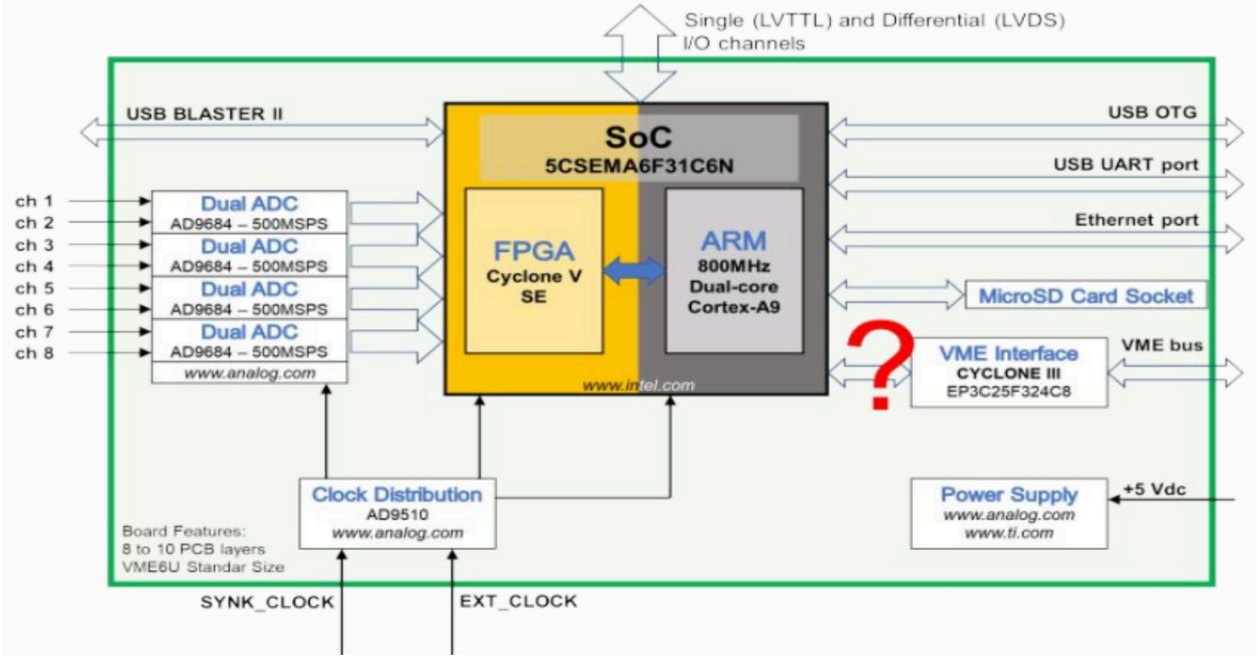


Development of dedicated optics with low-radioactivity materials

INFN Rome/Sapienza role

- The group at INFN Rome/Sapienza is in charge for some of the most critical issues for the future of the project:
  - background (radiopurity, simulations, identification)
  - data acquisition





Run Status

Run 1302 Running (Stop, Pause)	Start: Mon Jun 13 14:48:00 2022	Running time: 0h03m10s
	Alarms: On	Restart: Sequencer	Data dir: /data01/data/

1655124481 14:48:01.416 2022/06/13 [Sequencer,INFO] Run #1302 started

Equipment

Equipment +	Status	Events	Events[/s]	Data[MB/s]
Trigger	cygnus_daq@localhost	57	0.3	3.448
CATHODE	Ok	4	0.0	0.000
GasSystem	Ok	4	0.0	0.000
HV	Ok	4	0.0	0.000
Environment	Partially disabled	3	0.0	0.000

Logging Channels

Channel	Events	MB written	Compr.	Disk Level
#0: run01302.mid.gz	73	214.434	35.0%	9.1%
Lazy Label	**Progress**	**File Name**	**# Files**	**Total**

Clients

mhttpd [localhost]	Sequencer [localhost]	SC Frontend [localhost]
cygnus_daq [localhost]	Logger [localhost]	midas2cloud [localhost]
middleware [localhost]		

Simultaneous acquisition of fast (PMT, SiPM) and slow (sCMOS) devices with custom DAQ boards (in collab. with UFJF - Brazil)

The ANDROMeDa project

ROME GROUP MEMBERS

G. Cavoto
C. Mariani
F. Pandolfi
I. Rago

ESSENTIAL BIBLIOGRAPHY

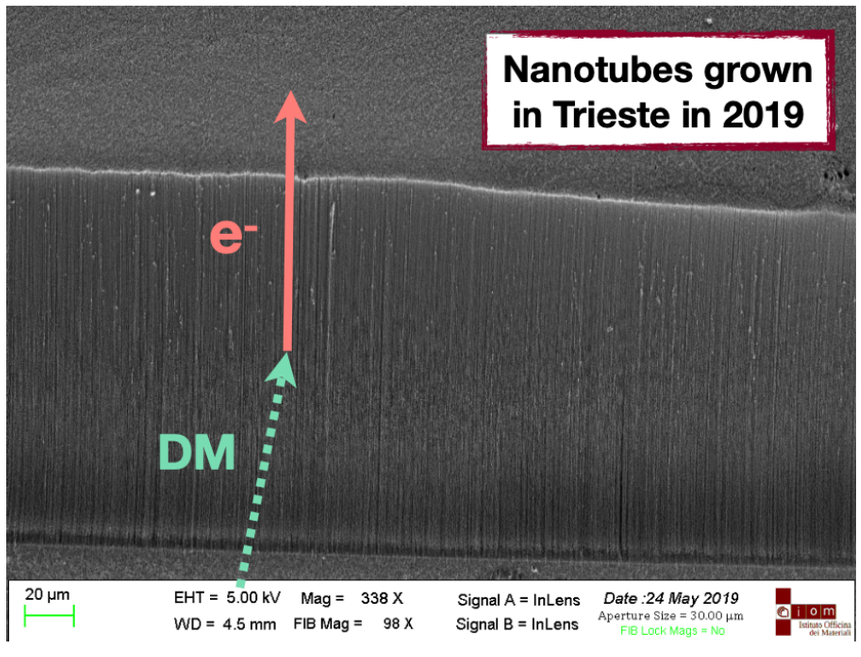
G. Cavoto *et al.*, *PLB 776 (2018) 338*
G. D'Acunto *et al.*, *Carbon 139 (2018) 768–775*
A. Apponi *et al.*, *JINST 15 (2020) 11015*
F. Pandolfi *et al.*, *J. Phys.: Conf. Ser. 2156 (2021) 012051*

The ANDROMeDa Project

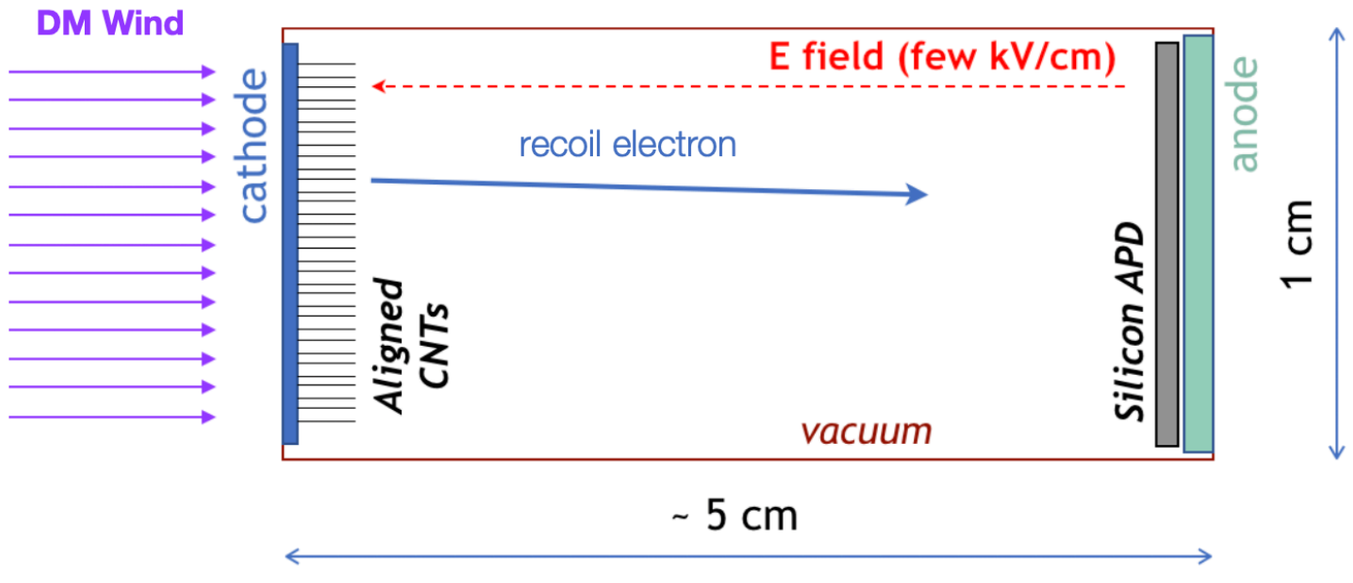
- The Strongly Interacting Massive Particles (SIMP) DM hypothesis requires sub-GeV particles to fit cosmological constraints
  - very low nuclear recoil energies —> light nuclei and extremely low thresholds are required
  - better look for electron recoils

PRIN 2020

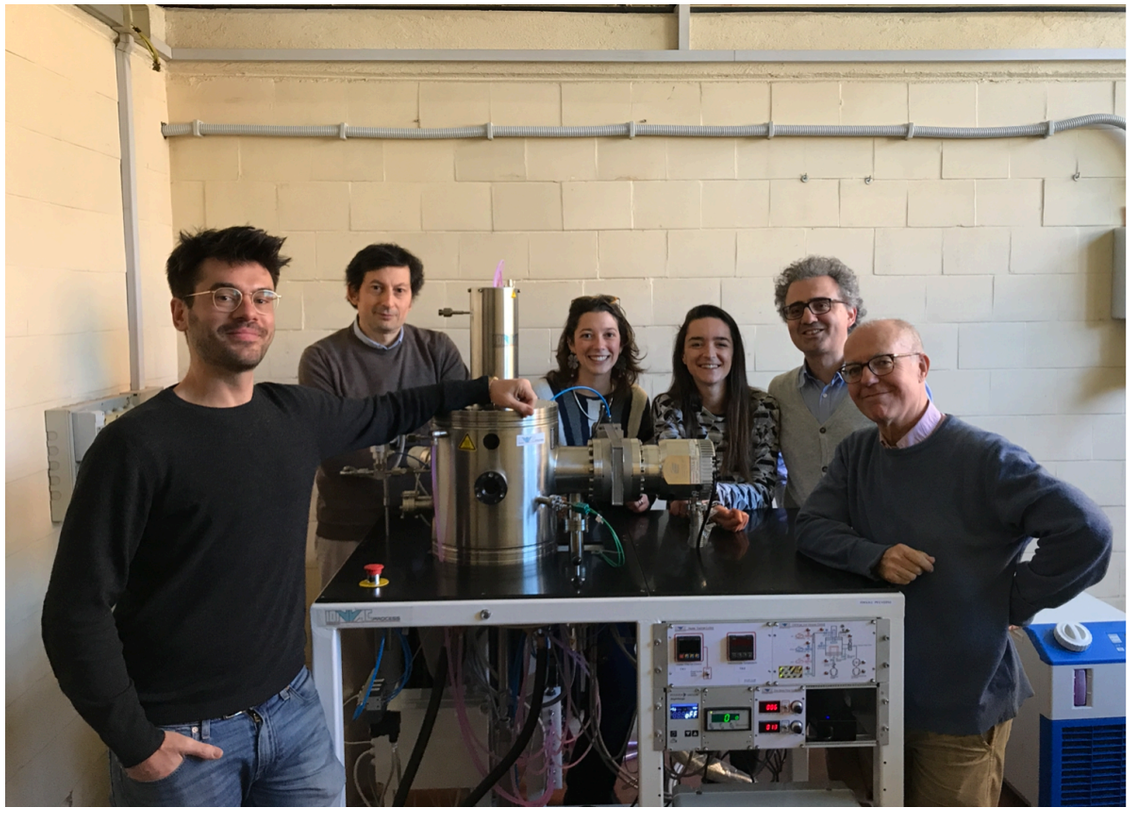
- Exploit channeling in CNTs

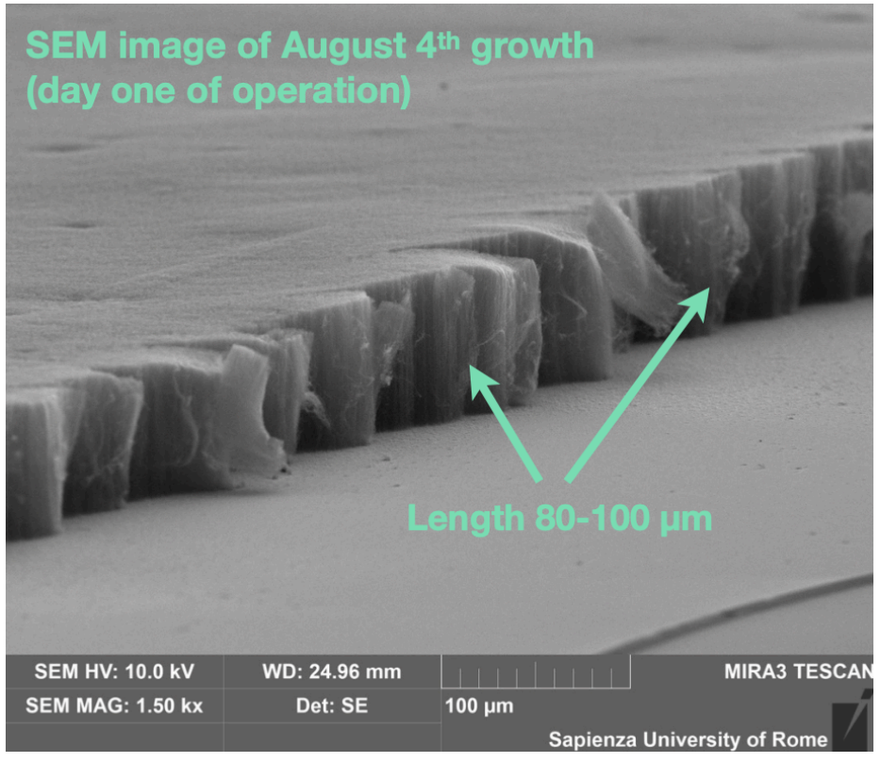


The "Dark PMT"

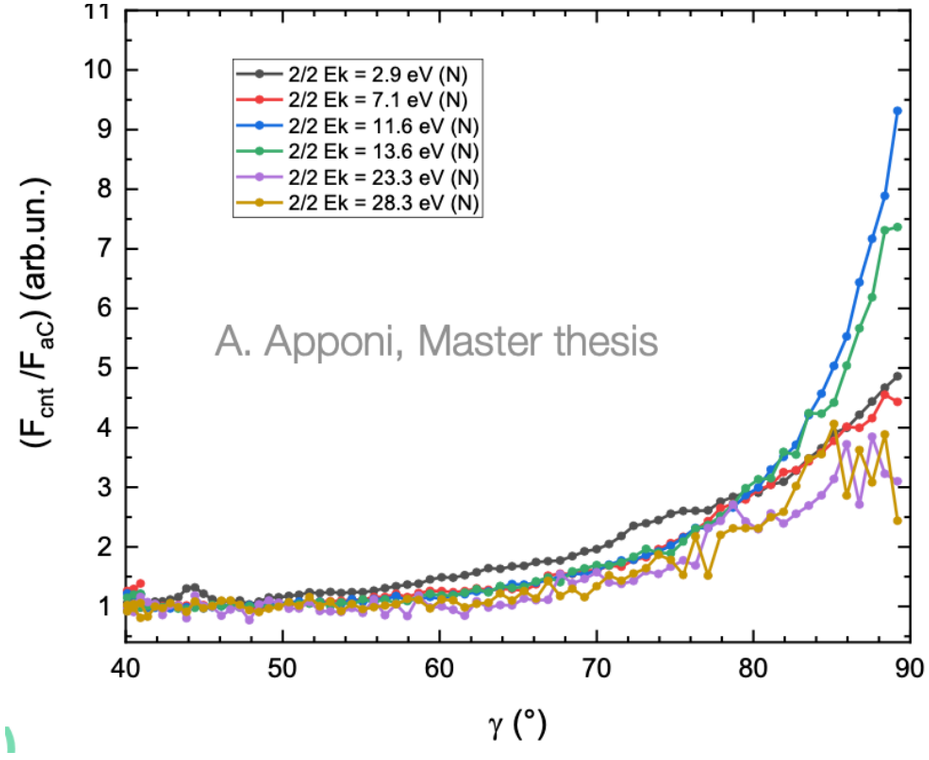


Activities at INFN Rome/Sapienza





- A facility to synthetize nanotubes was established
- Anisotropy of electron emission under UV light was observed
- Upgrades ongoing



Activities at INFN Rome/Sapienza

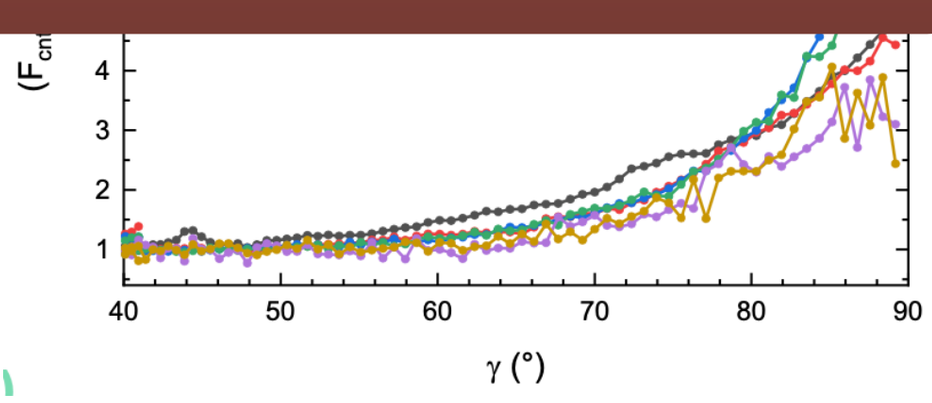
Critical issue: improving the parallelism of CNTs

Upgrade: full growing process on-site (evaporation of iron on the substrate + annealing + nanotube growth)

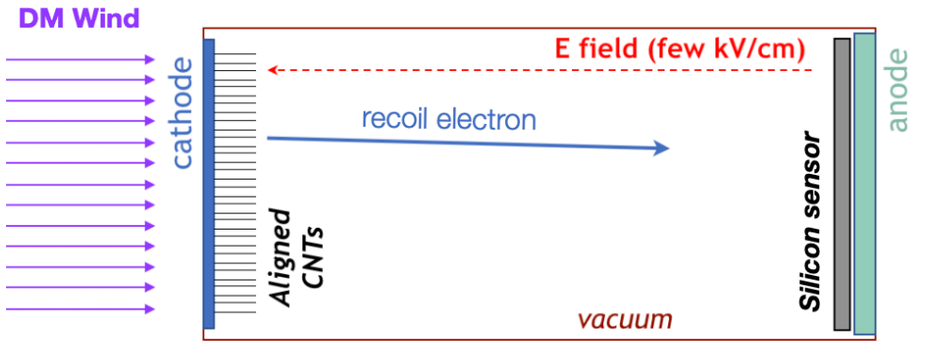
Goal: a new growing technique to get an unprecedented CNT alignment

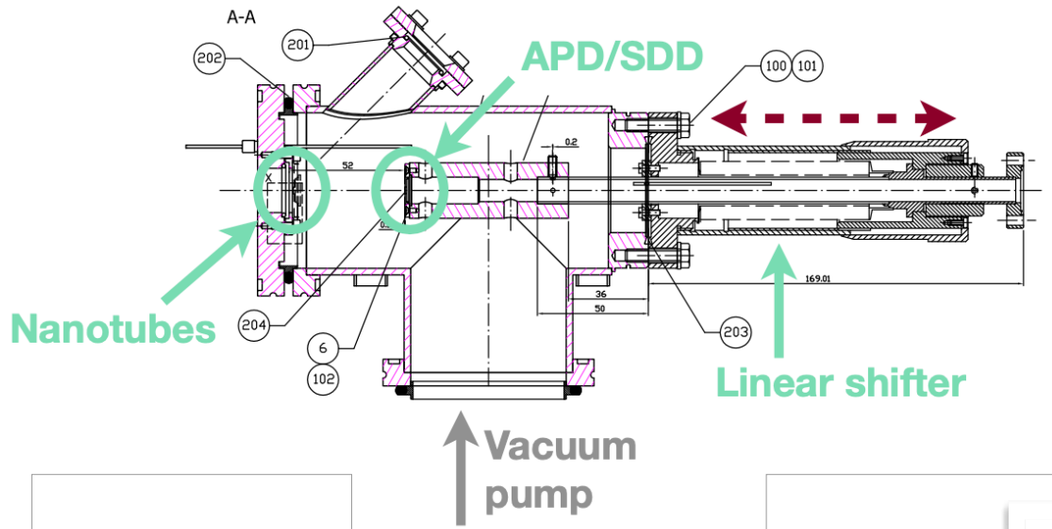
- A facility to synthetize n
  established
- Anisotropy of electron e
  light was observed

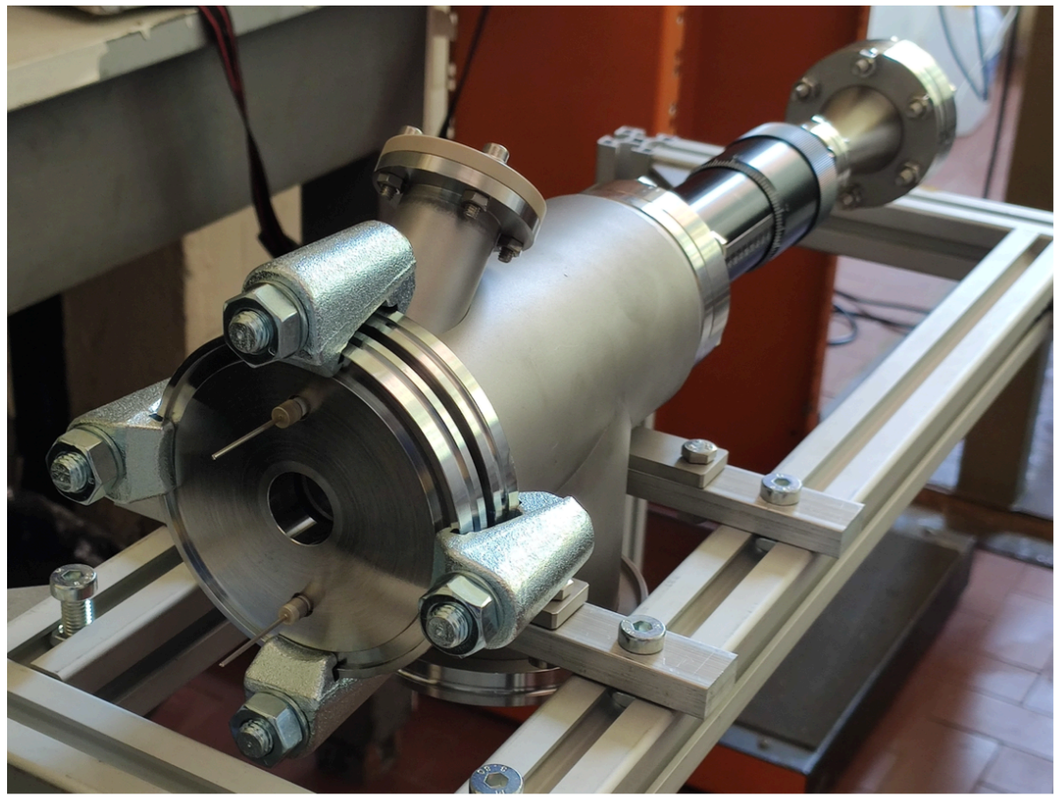
- Upgrades ongoing



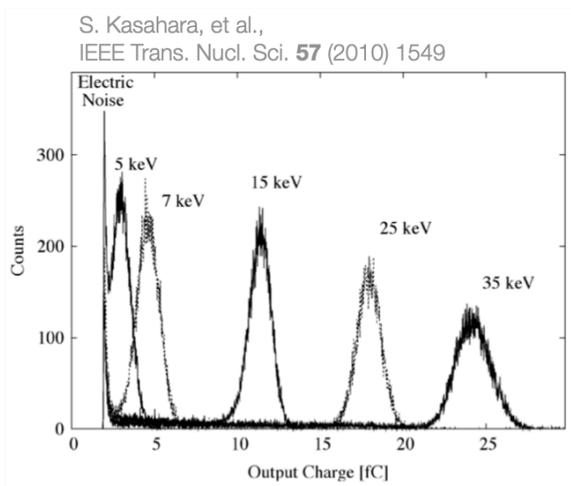
The Dark-PMT prototype





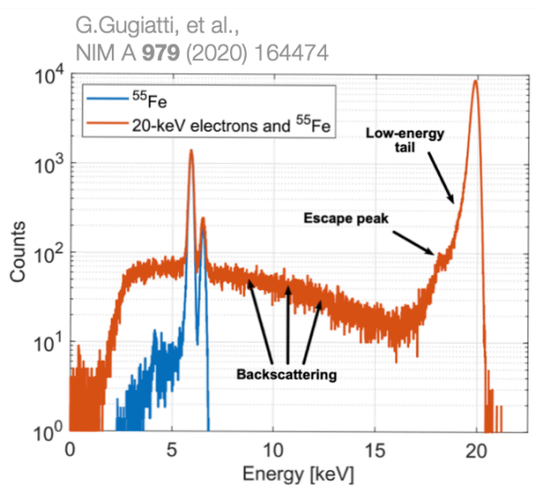


- 2 e- detector options considered
  - Avalanche photo-diode (APD)
  - Silicon drift detector (SDD)



❖ **APDs** can measure single e-

- But **only** if E_e > 5 keV



❖ **SDDs**: excellent resolution

- But higher complexity/costs

Technological applications

- UV light detection
  - 100 k€ ATTRACT grant (completed)
- Carbon nanotubes for biosensors
  - 13 k€ Sapienza grant on going
- Antibacterial films
  - in collaboration with Univ. di Bologna
- Development of composite materials with nanotubes
  - in collaboration with INFN HAMMER (Hub for Additive Manufacturing @ LNGS)
  - deposited patent for CNT-reinforced copper (*Dragon Copper*)

Conclusions

- Dark Matter with directional capabilities with CYGNO and ANDROMeDa:
  - enhanced sensitivity to GeV and sub-GeV Dark Matter
  - aim at limits competitive with non-directional experiments
  - **the path toward a dark matter astronomy**