

The ANDROMeDa Project

Searching for Light Dark Matter with Aligned Carbon Nanotubes

Gianluca Cavoto, Carlo Mariani
Sapienza University and INFN Rome

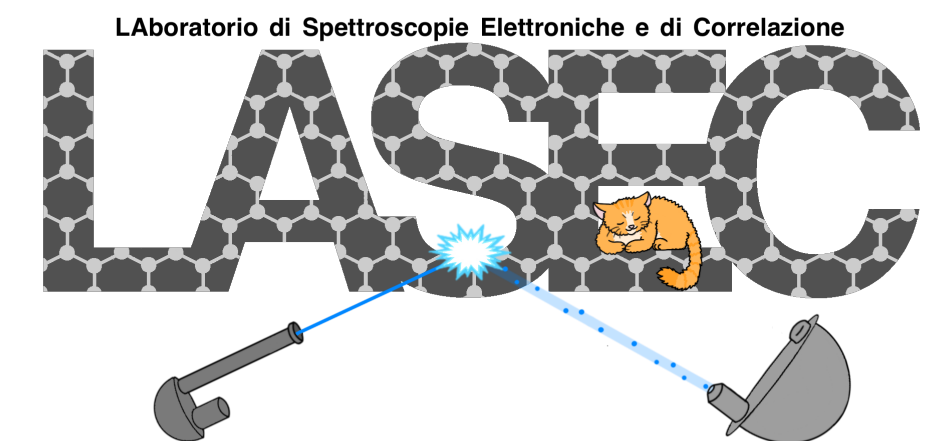
Francesco Pandolfi, Ilaria Rago
INFN Rome

Alice Apponi, Alessandro Ruocco
Roma Tre University and INFN Rome 3



ANDROMeDa

Aligned Nanotube Detector for Research On MeV Darkmatter



The ANDROMeDa Project

❖ Awarded MUR-PRIN2020 grant (1M€)

- 3-year project, started in 2022
- 3 units: INFN (F. Pandolfi, P.I.)
Sapienza (G. Cavoto)
Roma Tre (A. Ruocco)

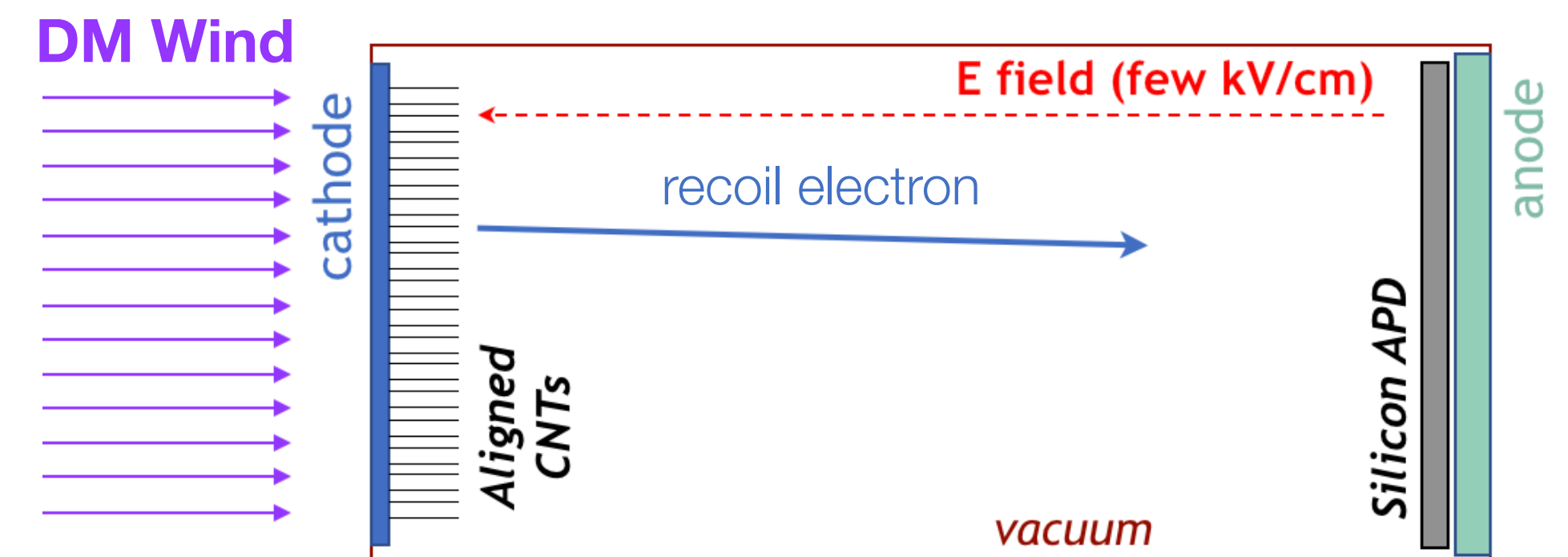
❖ **Dark-PMT:** aligned nanotubes target for electron recoil

❖ **Main objective:** have a working dark-PMT prototype by end of project



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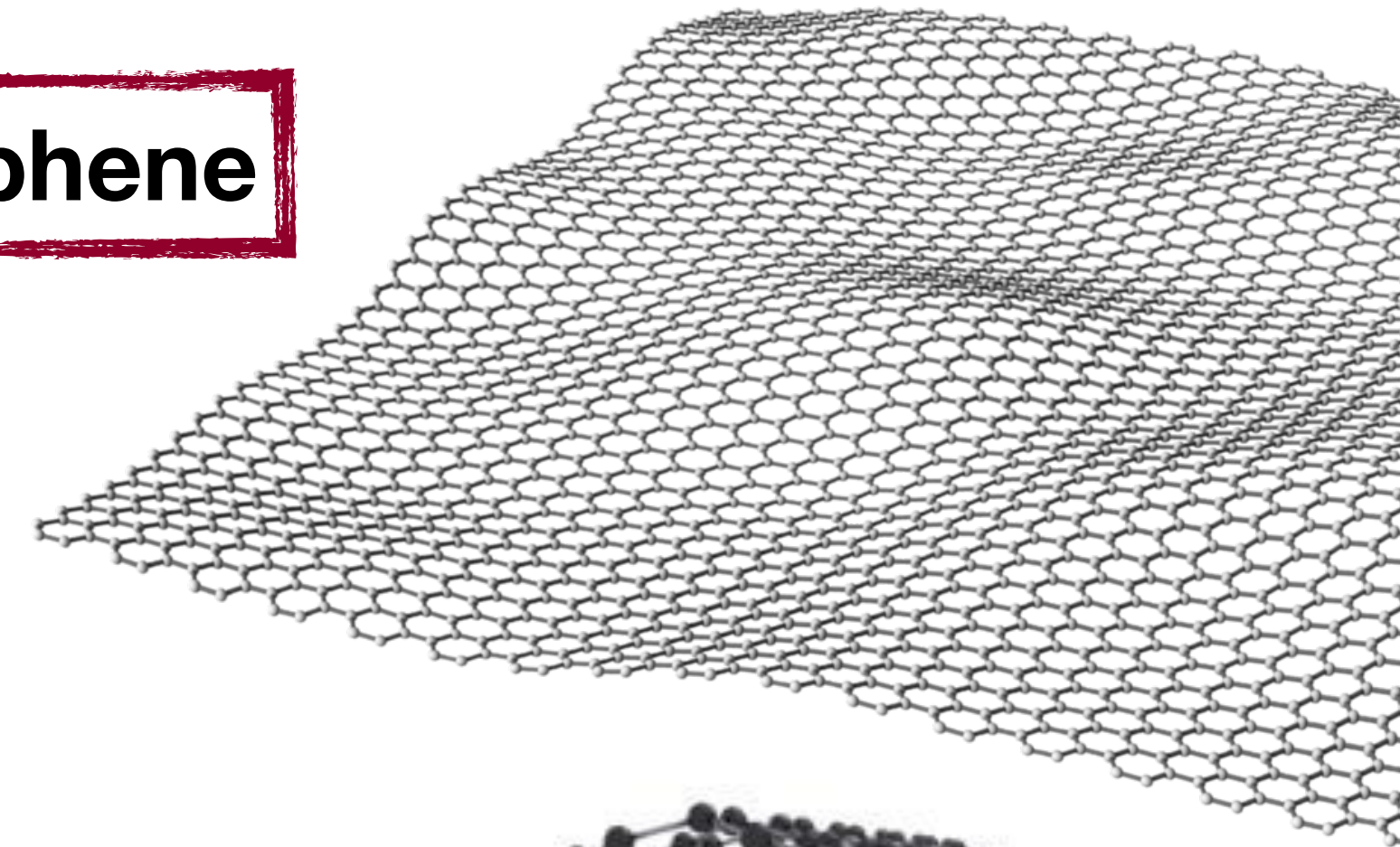
Aligned Nanotube Detector for Research On MeV Darkmatter



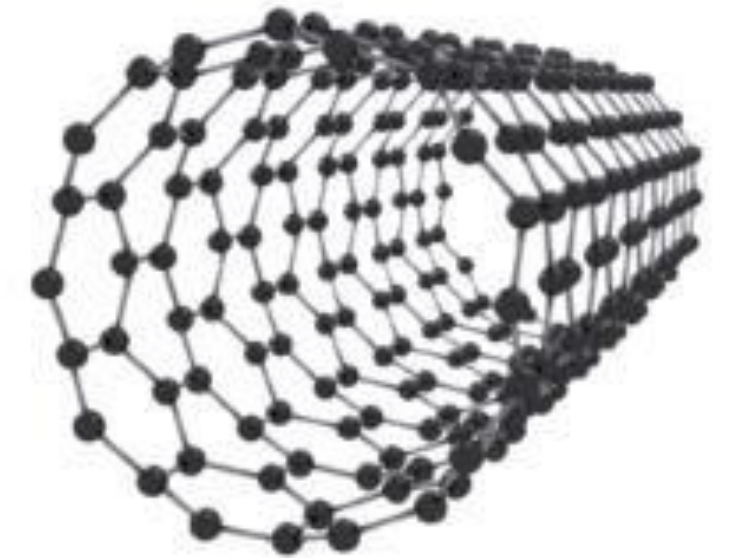
Solid State Targets: The Advantage of 2D Materials

- ❖ **Energy** to extract an electron from carbon
 - $\Phi_e \sim 4.7$ eV, so $K_e \sim 1-50$ eV ($m_{DM} = 10-100$ MeV)
 - Extremely **short** range in matter!
- ❖ 2D materials: electrons ejected **directly** into vacuum
 - **Graphene** and **carbon nanotubes**
- ❖ **Vertically aligned** carbon nanotubes
 - Highly anisotropic density

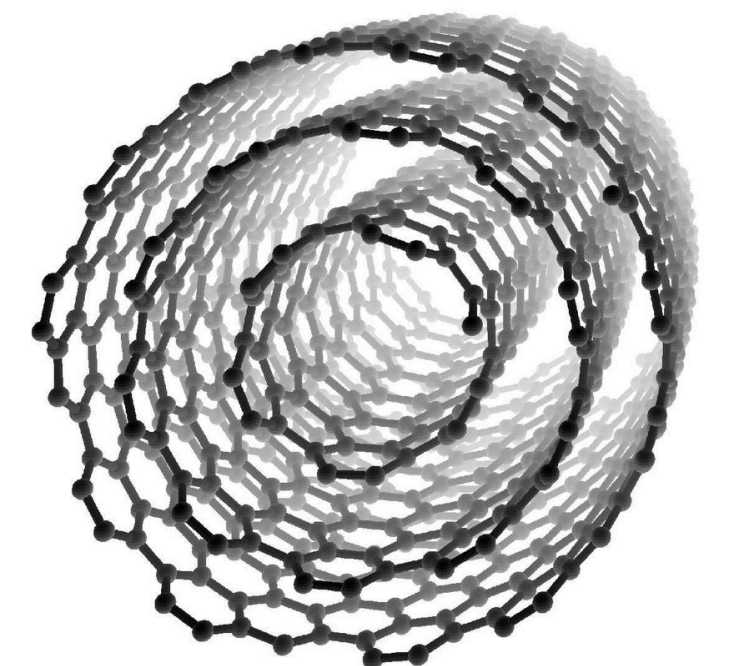
Graphene



**Single-wall
nanotube**

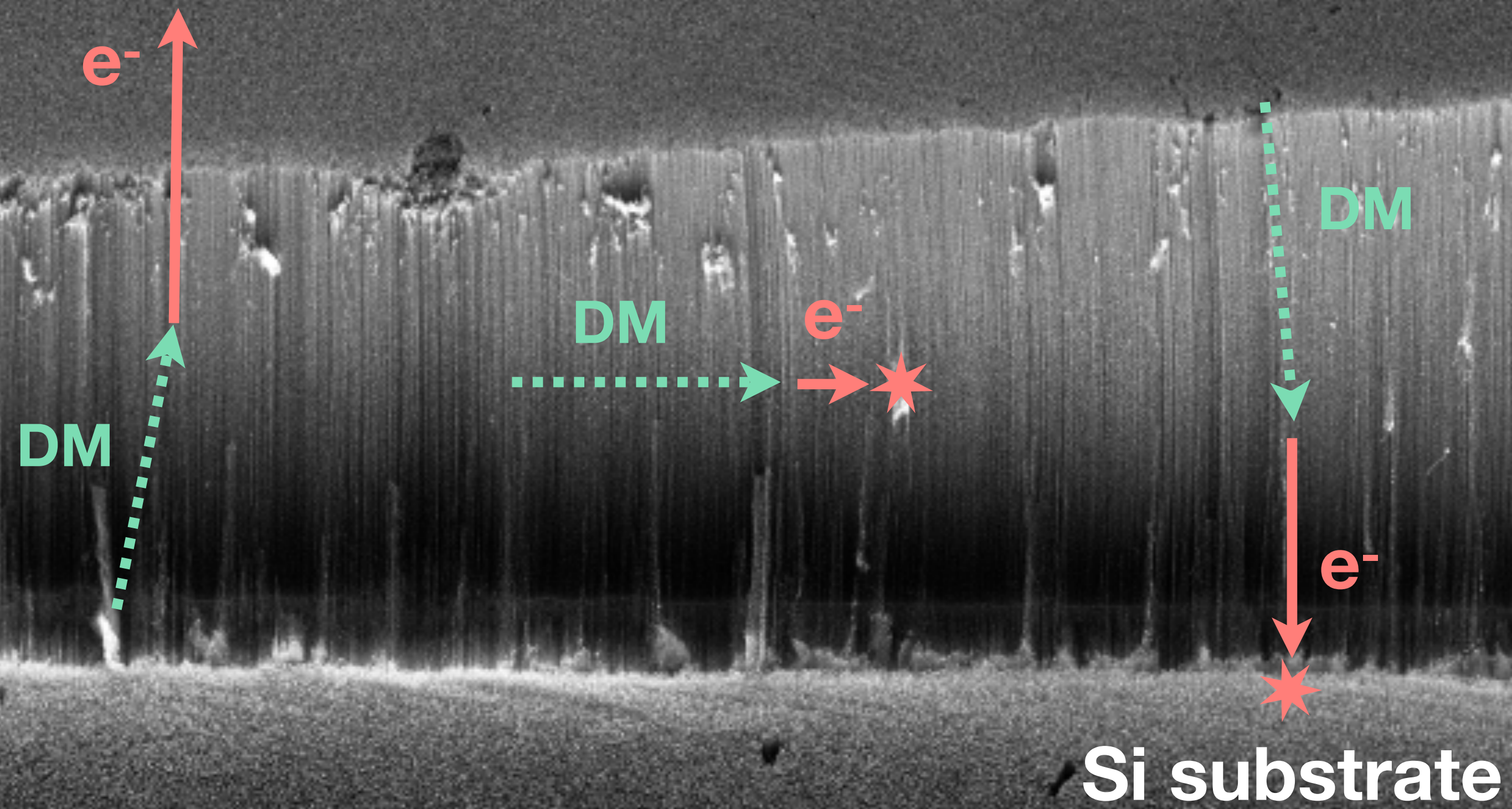


**Multi-wall
nanotube**




100 μm

Directional sensitivity by design



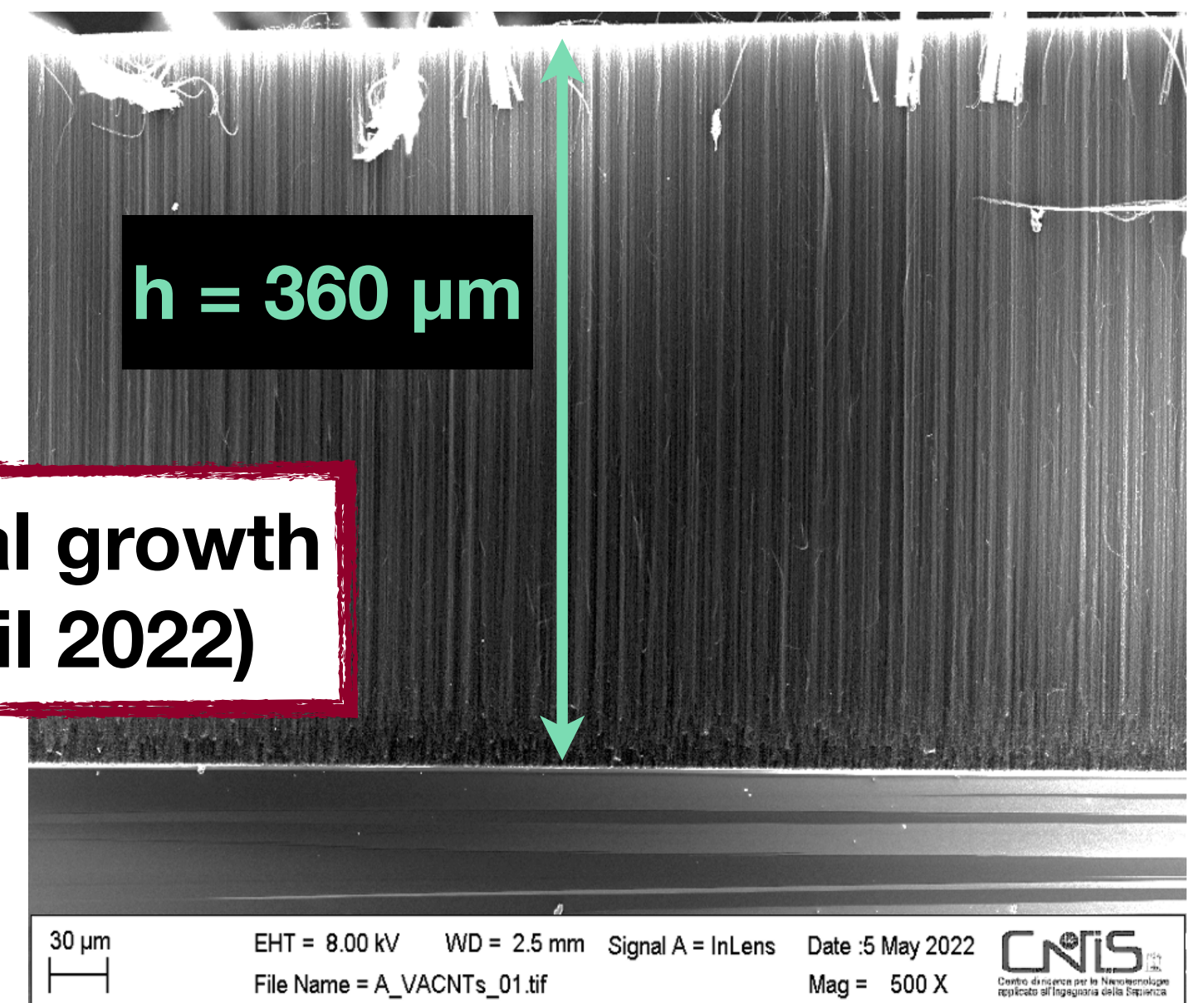
Growing Vertically Aligned Carbon Nanotubes in the Lab

❖ New **state-of-the-art** nanotube facility in Rome Sapienza

- Thanks to ATTRACT funding 
- Growing nanotubes with Chemical Vapor Deposition
- Up to 400 μm in length, on different substrates

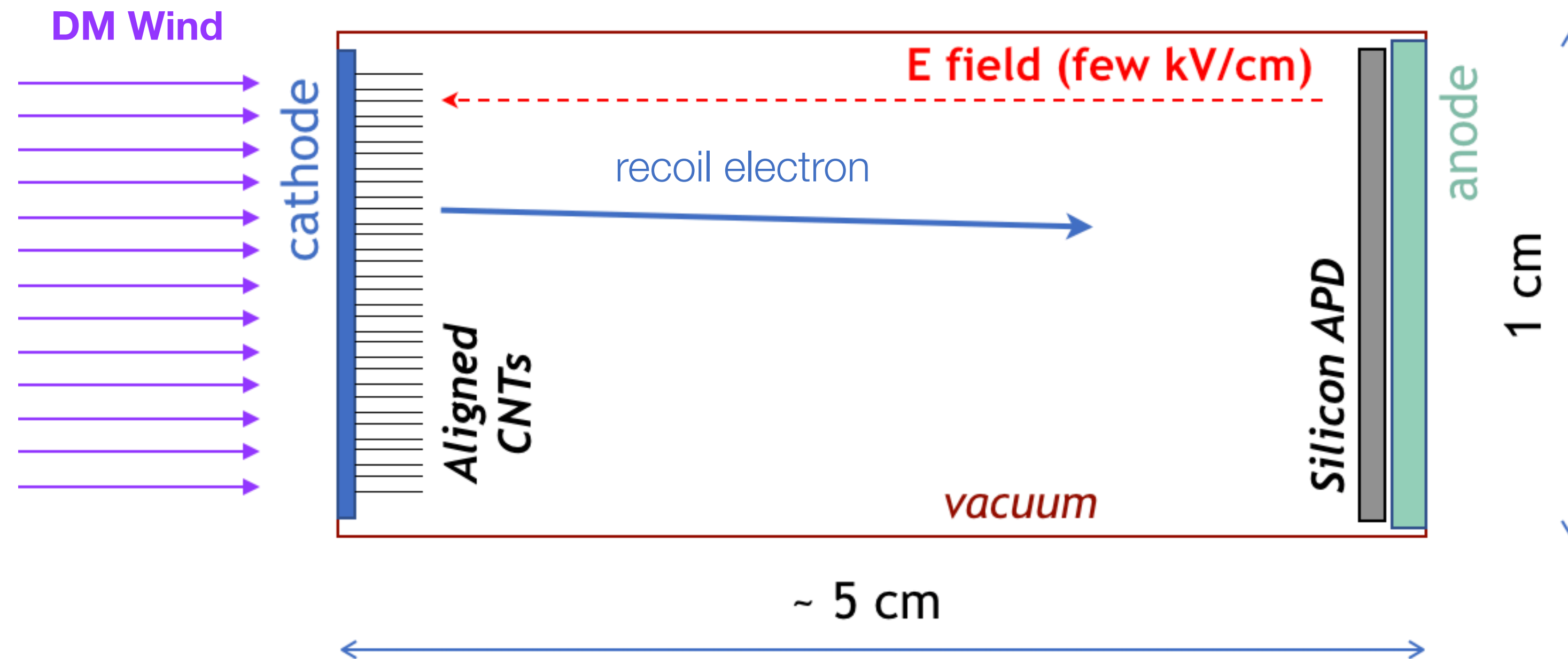


Installing the
CVD chamber
(Summer 2020)



Typical growth
(April 2022)

Nanotube Detector Concept: the 'dark-PMT'



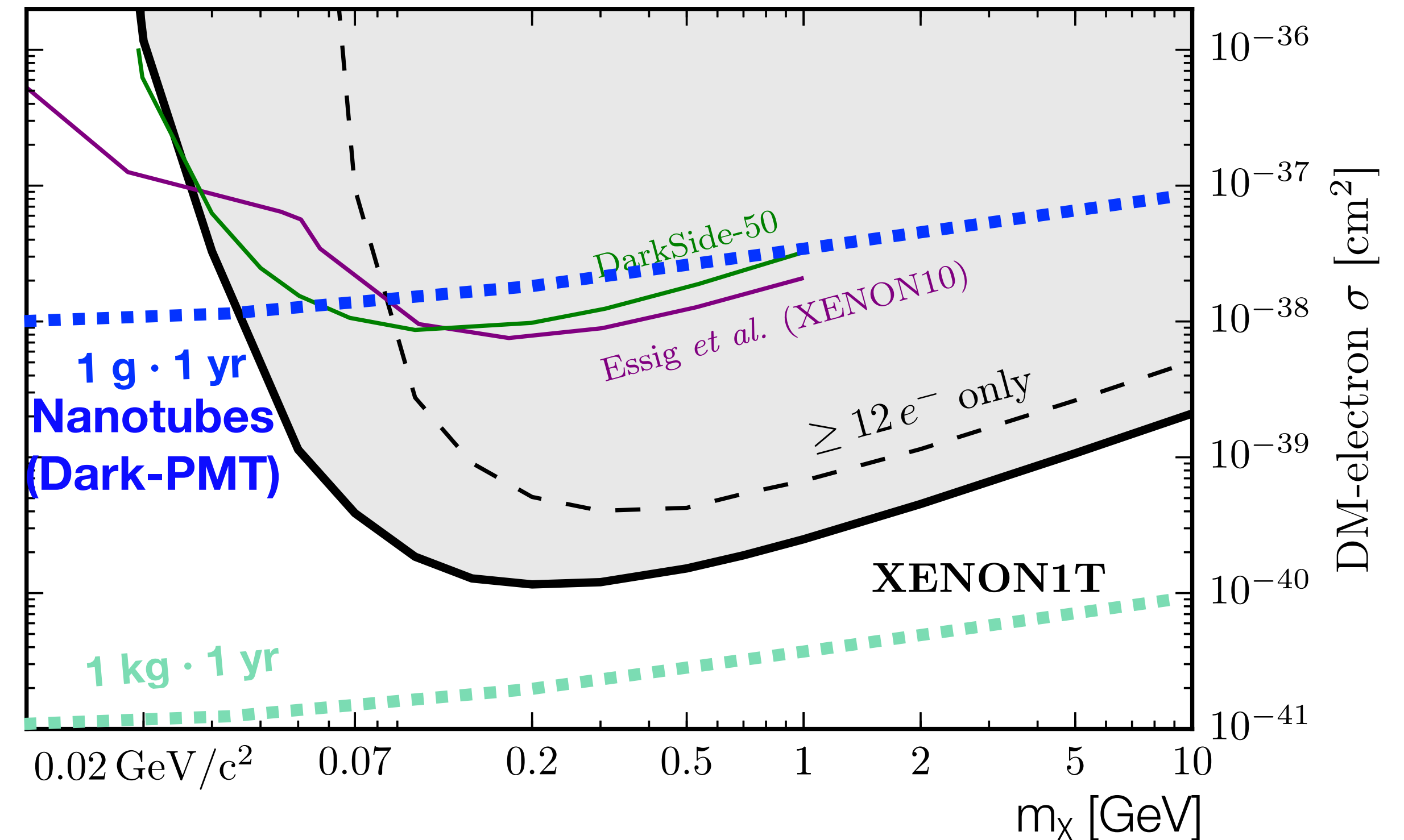
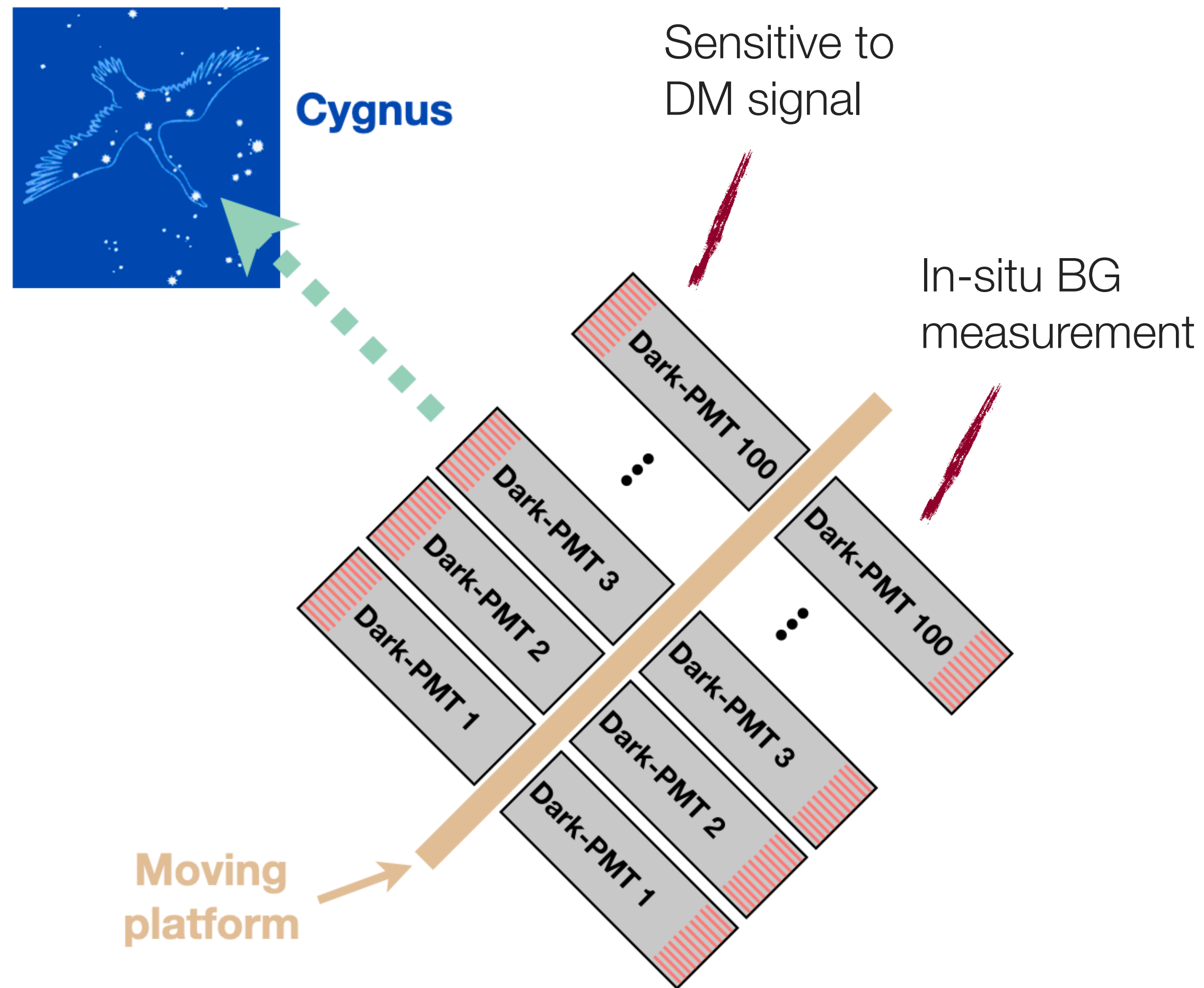
❖ 'Dark-photocathode' of aligned **nanotubes**

- Ejected e^- accelerated by electric field
- Detected by solid state **e^- counter**

Dark-PMT features:

- **Portable, cheap, and easy to produce**
- **Unaffected by thermal noise ($\Phi_e = 4.7 \text{ eV}$)**
- **Directional sensitivity**

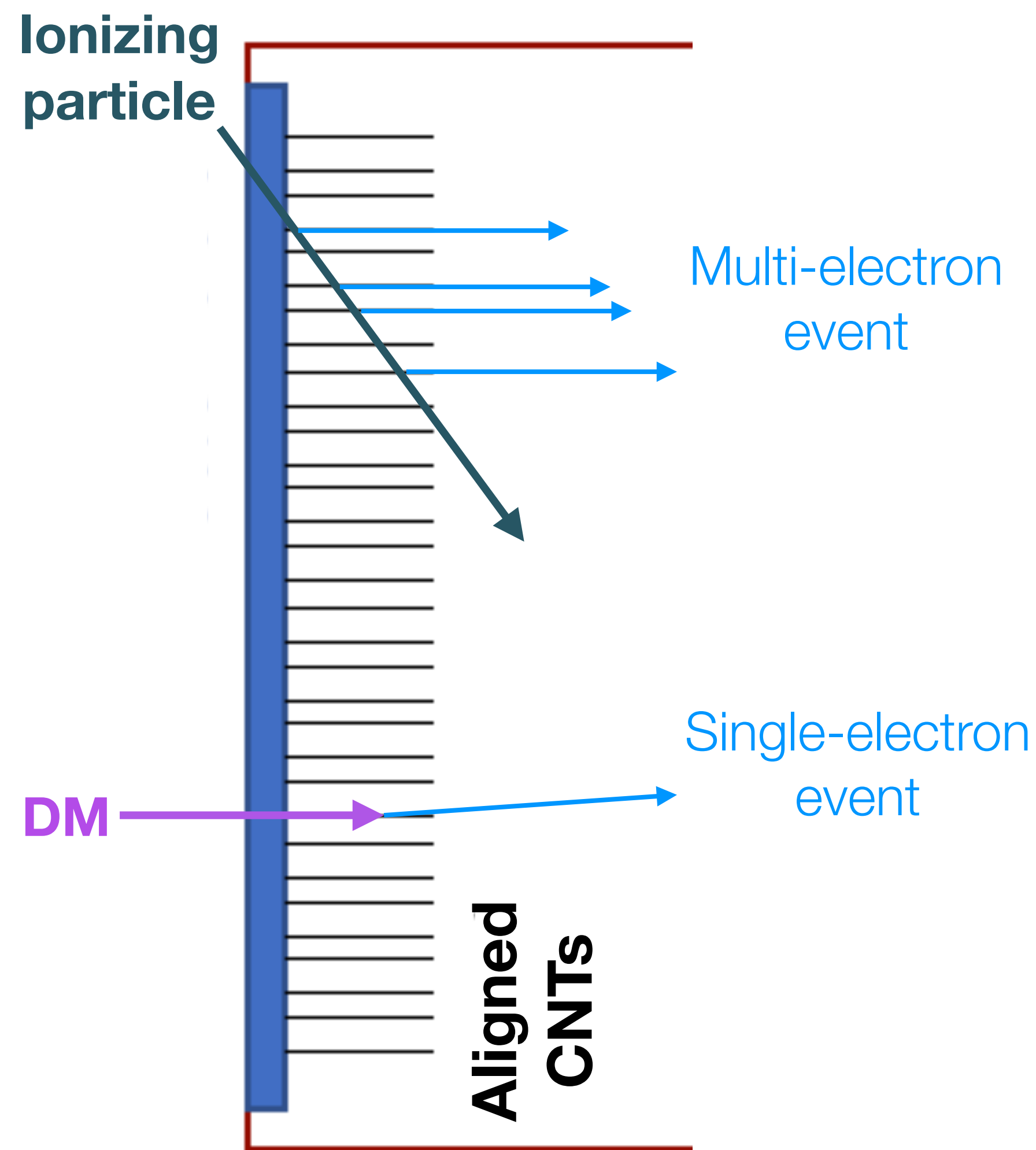
Two Arrays of dark-PMTs to Search for a Dark Matter Signal



- ❖ Expected to Extend Reach Below 40 MeV
- ❖ Sensitivity down to 5 MeV

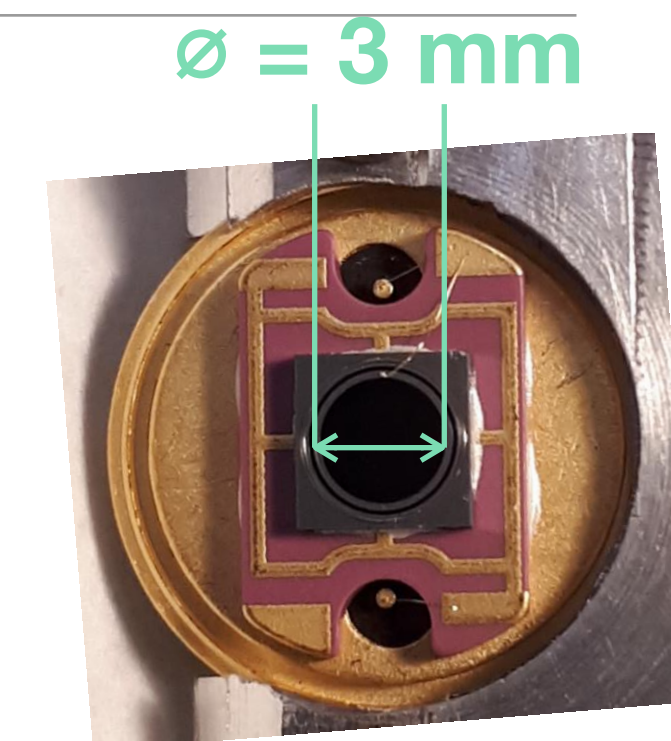
Cavoto, et al., PLB 776 (2018) 338

BG discrimination: Single-/Multi- Electron Event



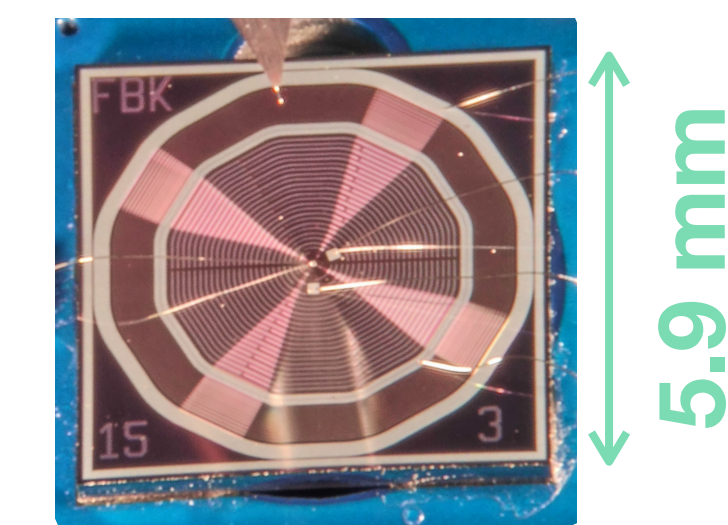
❖ Benchmark: **Avalanche Photo-Diodes (APD)**

- Simple, cost-effective
- Hamamatsu windowless APDs



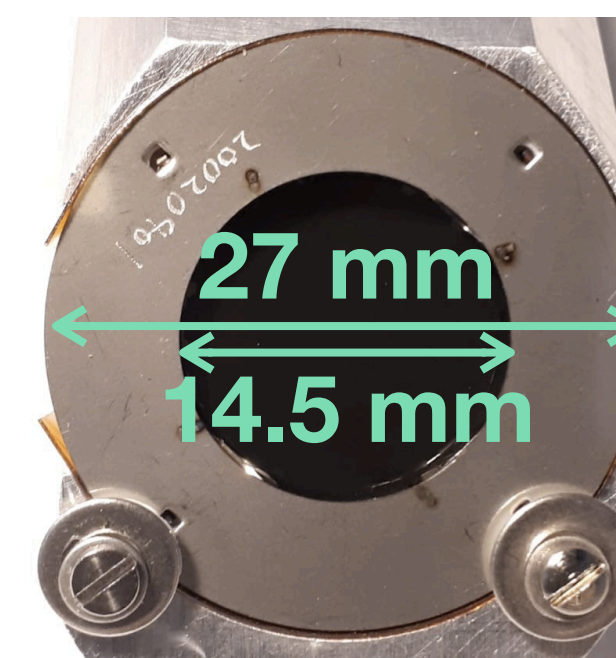
❖ Possible upgrade: **Silicon Drift Detectors (SDD)**

- Ultimate resolution
- FBK (SDD) + PoliMi (electronics)



❖ Alternative: **MicroChannel Plate (MCP)**

- Optimized for electrons
- Quite poor energy resolution



APD Characterization with 30 - 900 eV Electrons at Roma Tre

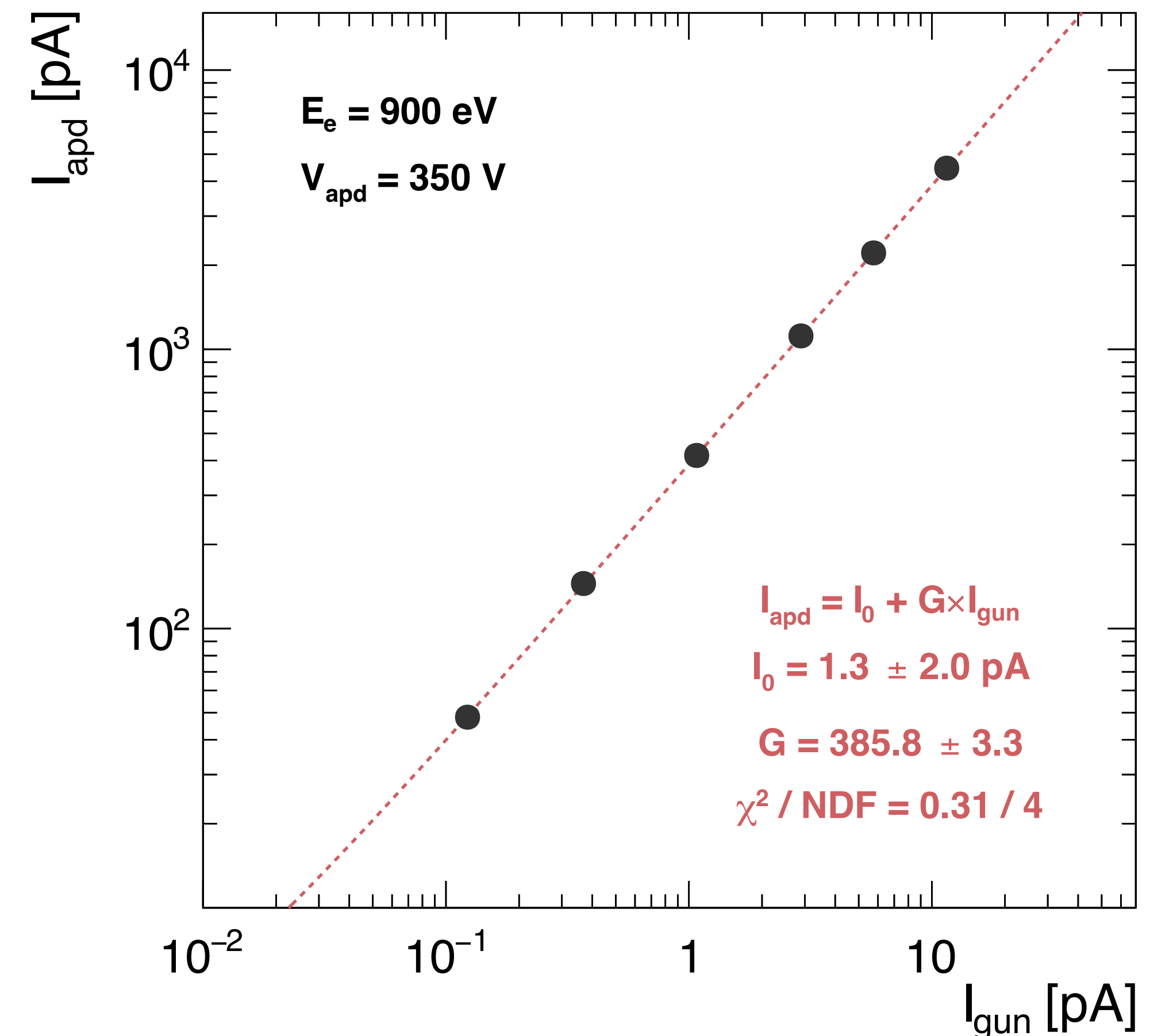
❖ **Electron gun** in LASEC Lab @ Roma Tre

- Electron energy range 30 - 900 eV
- Energy resolution 45 meV
- Stable continuous current down to a **few fA**
- Beam spot ~ 0.5 mm

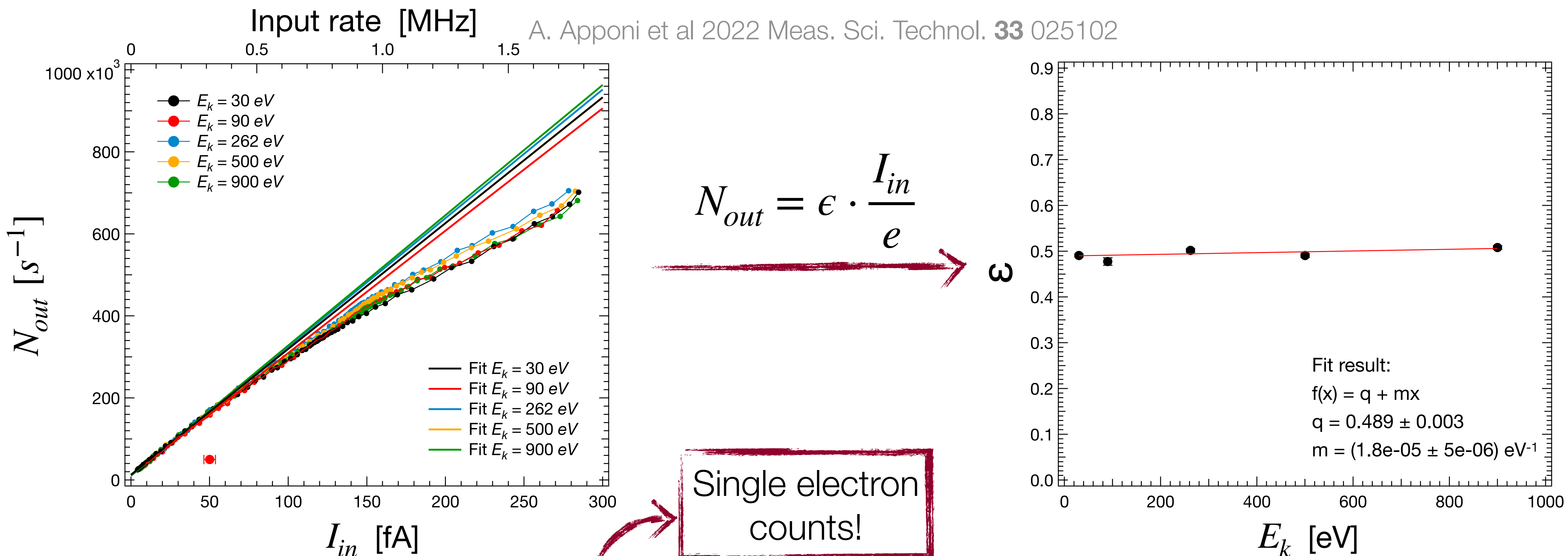
❖ Reading **APD bias current** when shooting gun on it

- Clear **linear correlation** with gun current

A. Apponi et al 2020 JINST **15** P11015



MCP Characterization with 30 - 900 eV Electrons at Roma Tre



❖ Reading **MCP count rate** when shooting continuous gun current on it

- **Absolute efficiency** ~49% constant with energy

Conclusions

- ❖ **Carbon nanotubes:** exciting new material for dark matter detectors
 - **2D** material: recoiling electrons ejected **directly** into vacuum
- ❖ **'Dark-PMT'** dark matter detector concept
 - Portable, no thermal noise, directional sensitivity
 - In principle sensitive to electron recoils of a **few eV**
 - Capable of extending reach to masses below 40 MeV
- ❖ ANDROMeDa: a **young** and **ambitious** program in Rome
 - Aiming to build **first** working Dark-PMT prototype by 2025



ANDROMeDa

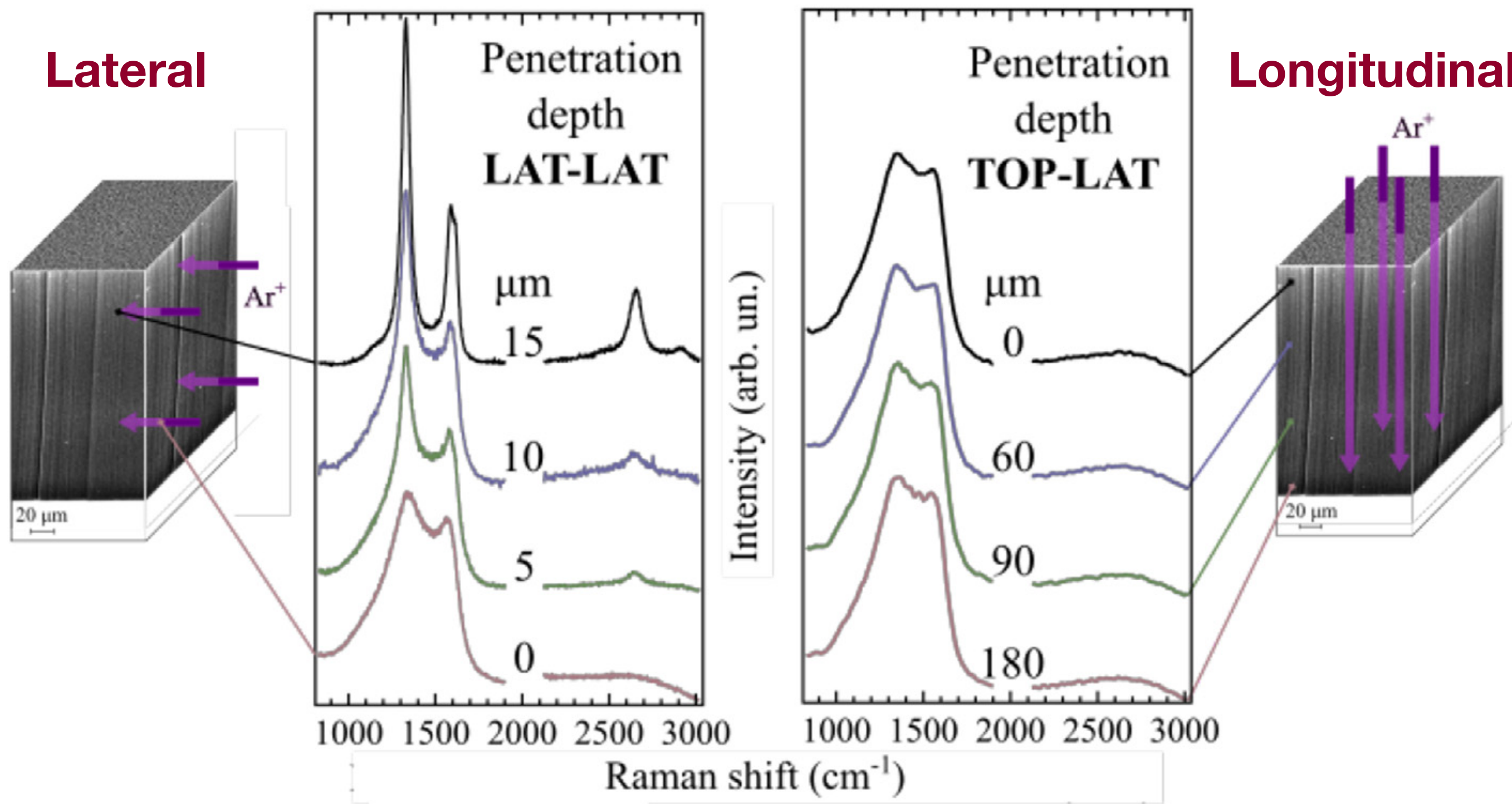
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BACKUP

Aligned Nanotubes: a Highly Anisotropic Target

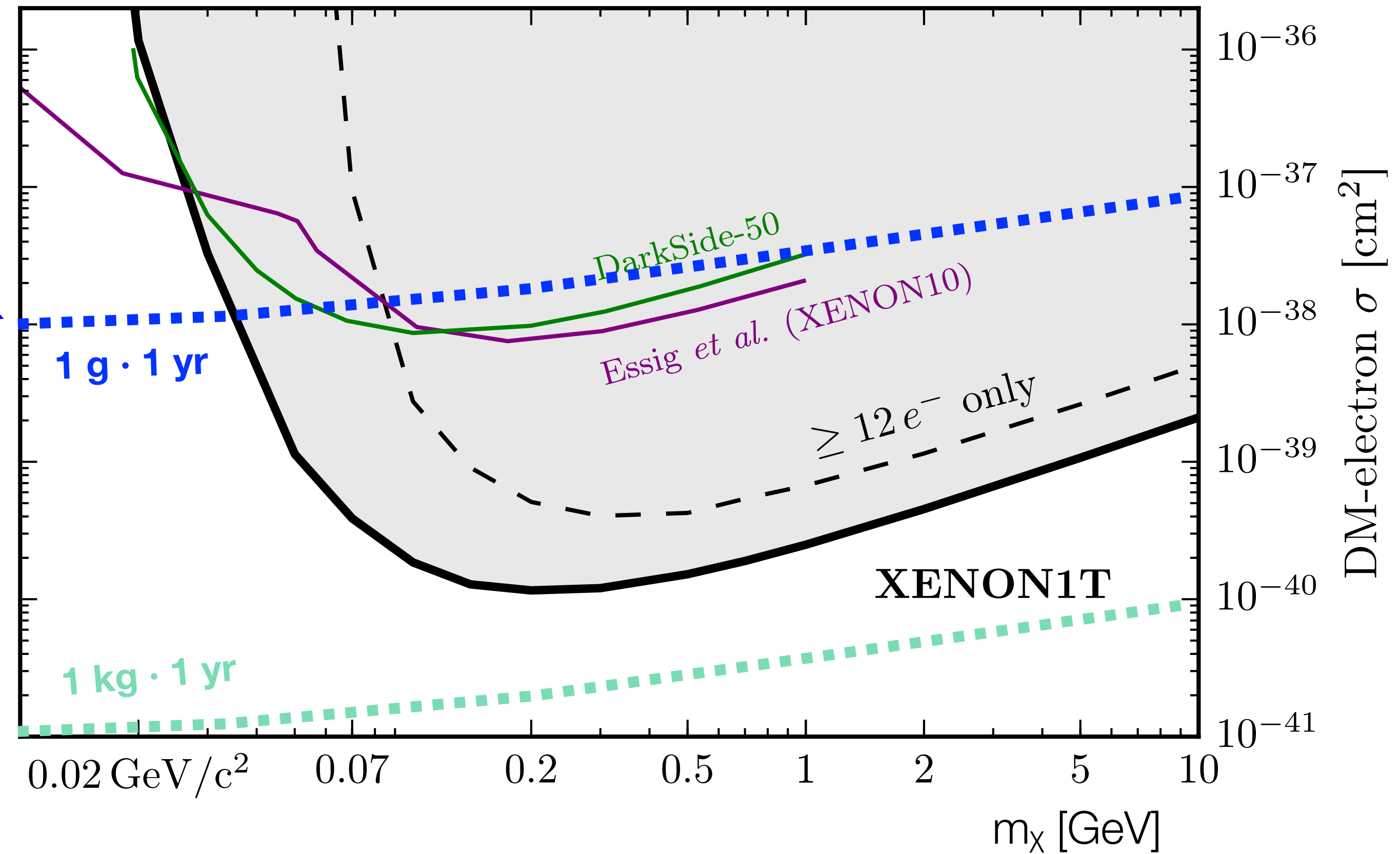
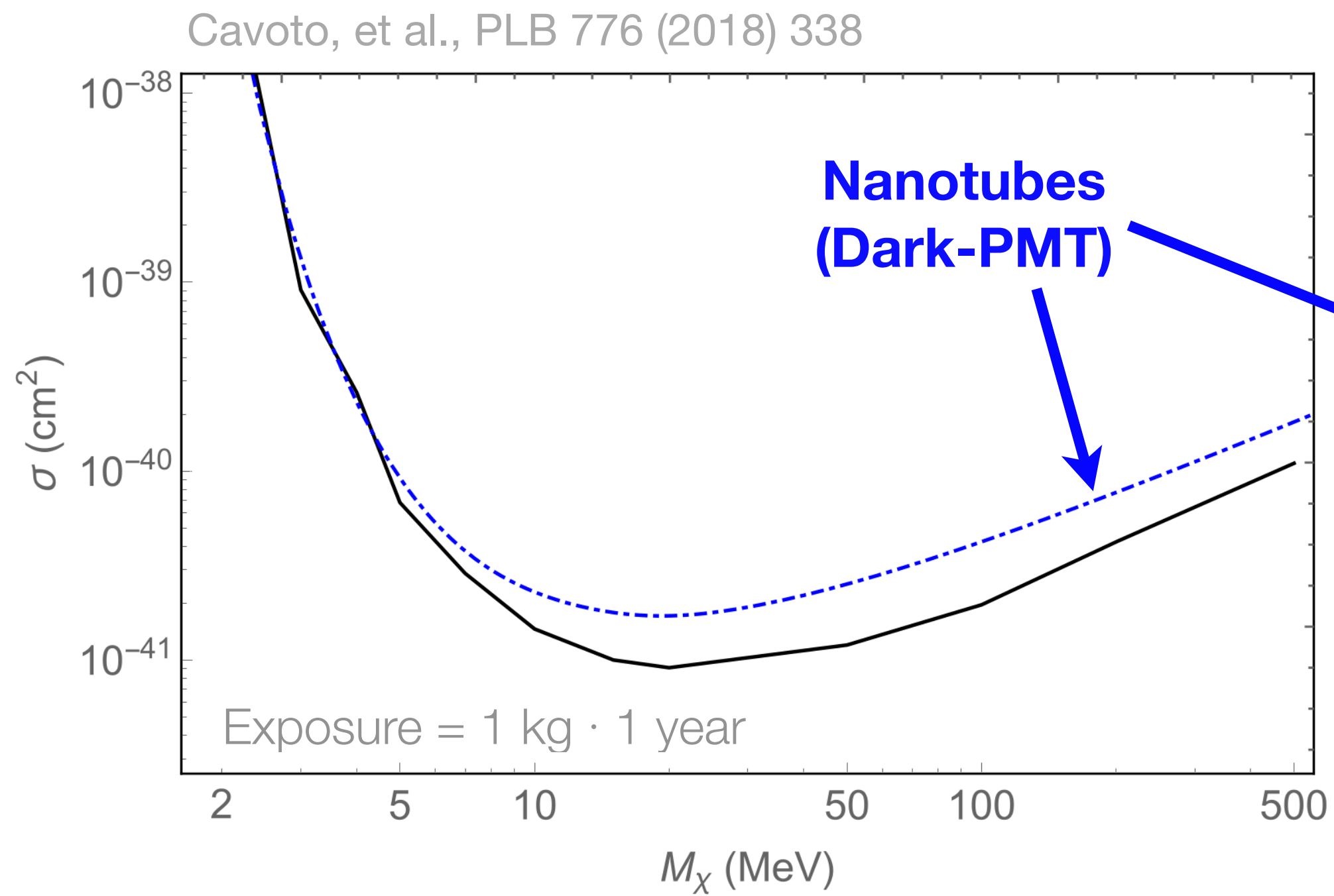
G. D'Acunto, et al., Carbon 139 (2018) 768



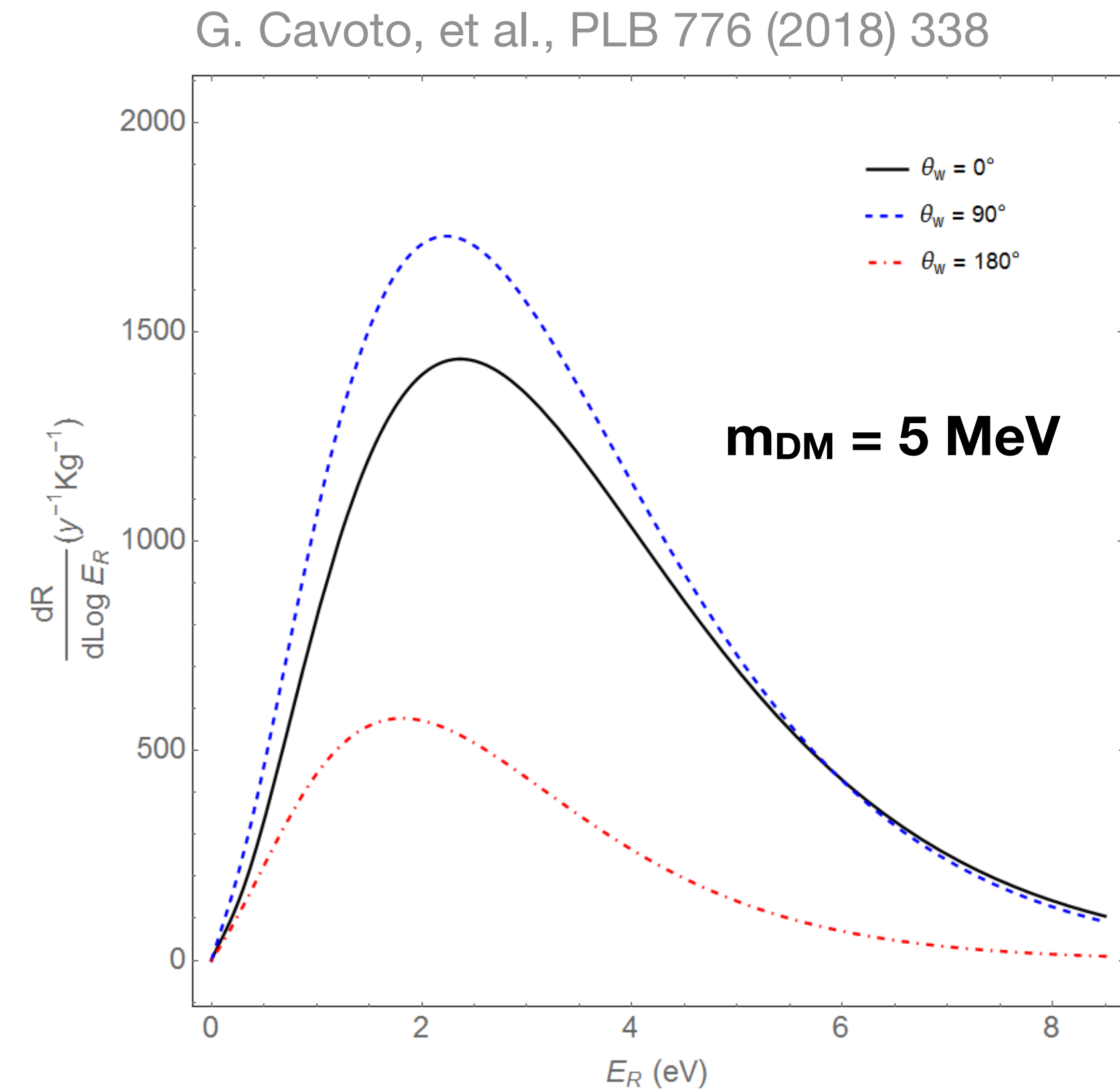
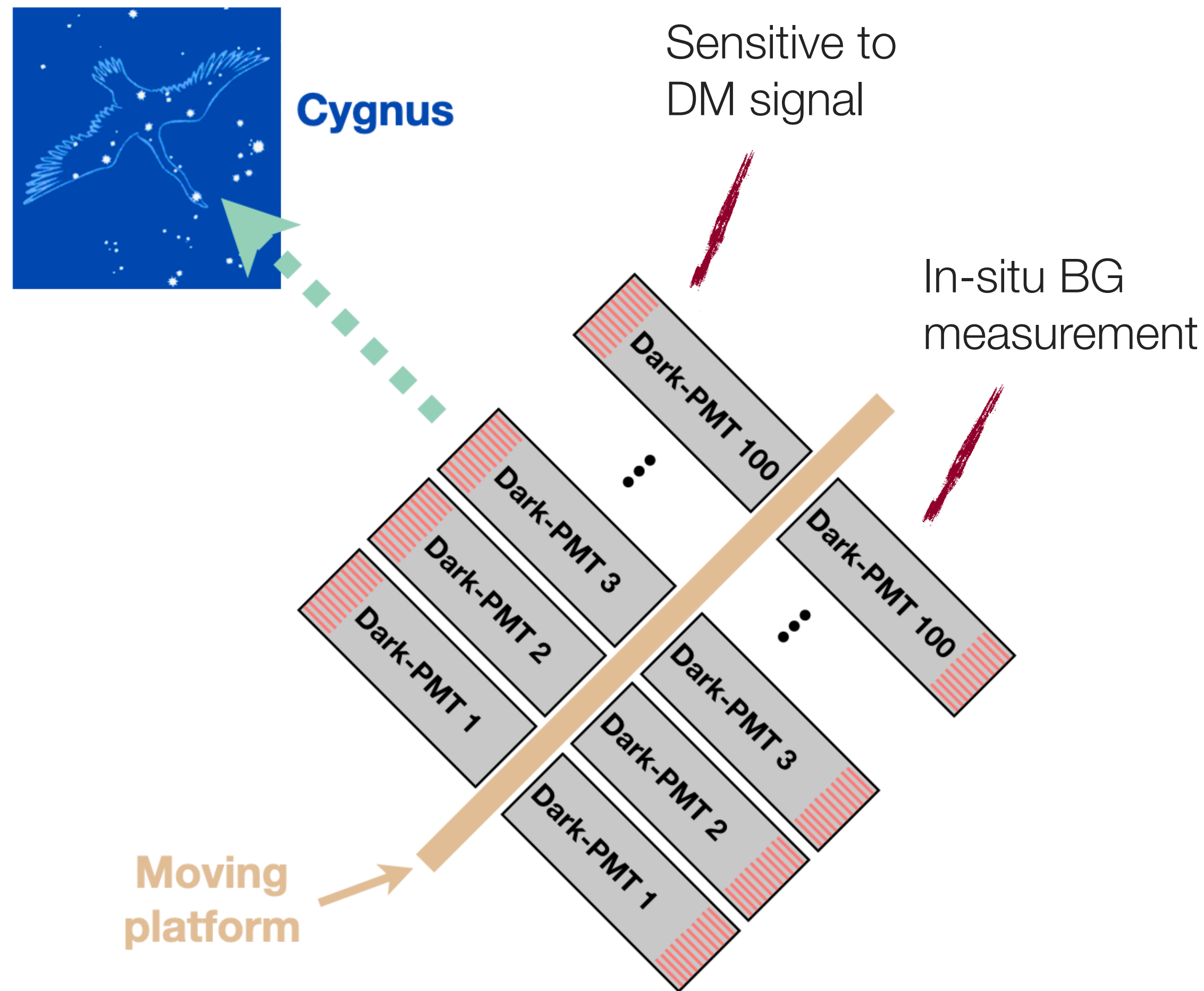
❖ Raman analysis after Ar⁺ bombardment

- **Lateral** penetration < 15 μm
- Longitudinal damage along **full** length (180 μm)
- Highly **anisotropic** density

Expected dark-PMT Sensitivity

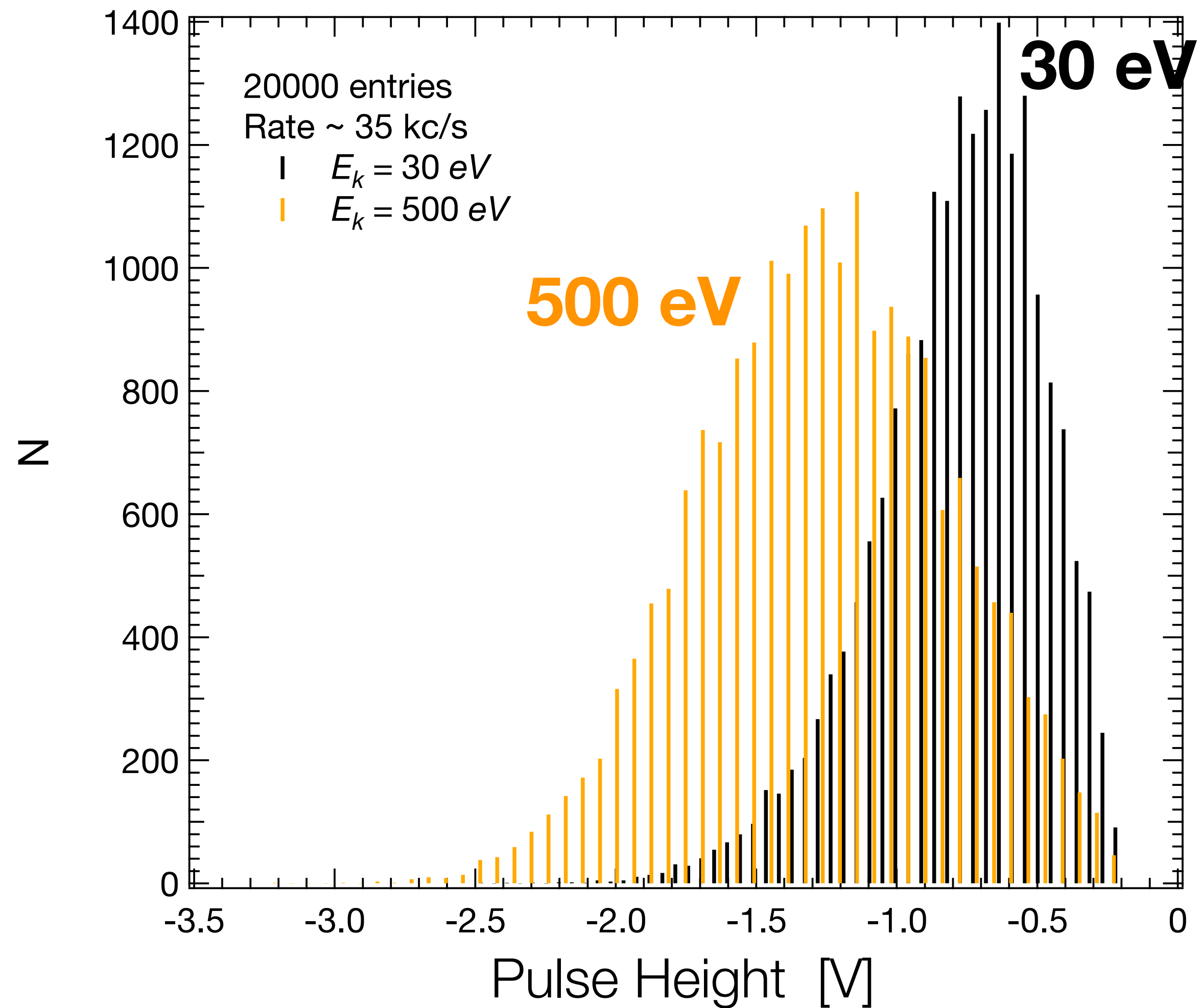


Two Arrays of dark-PMTs to Search for a Dark Matter Signal



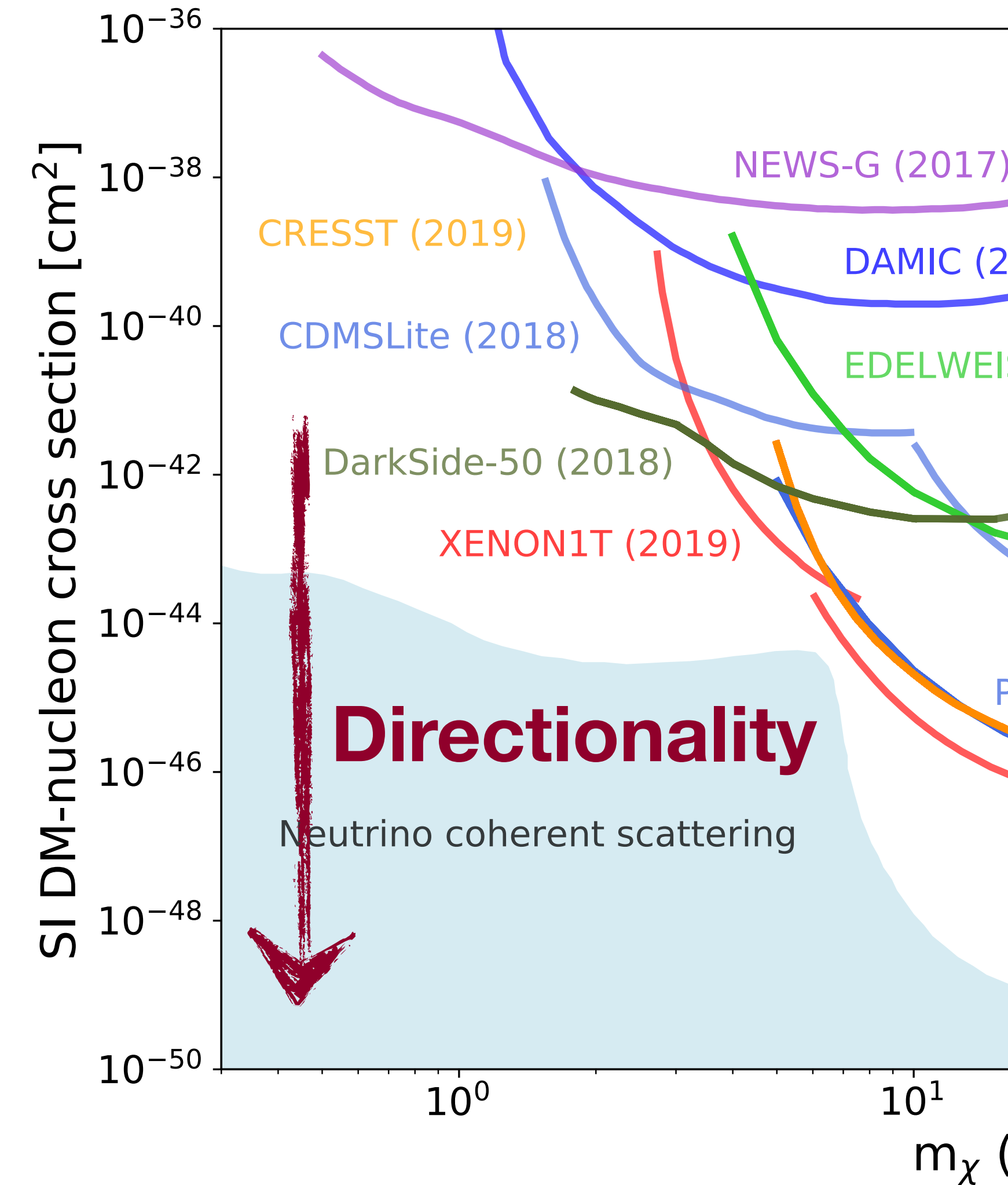
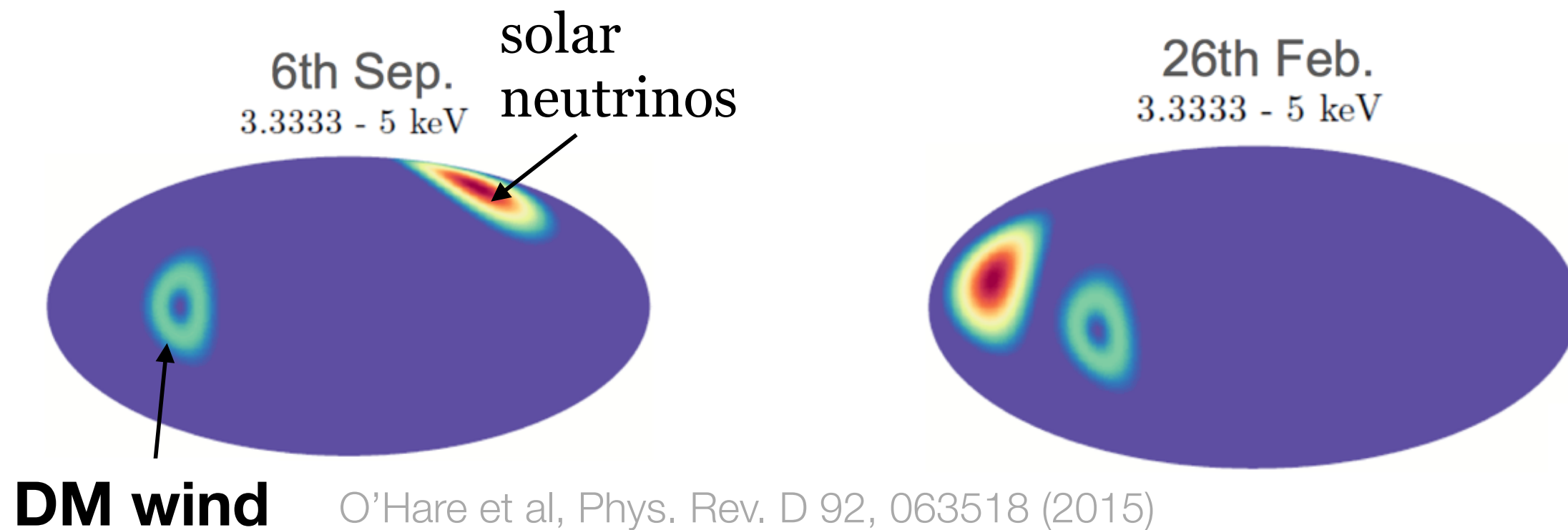
In principle sensitive to eV electrons!

MCP Pulse Height Distribution



Directionality To (One Day) Pierce Neutrino Floor

- ❖ **Directionality:** link a signal with region of the sky
 - DM ‘wind’ expected to come from **Cygnus** constellation
- ❖ But **also** to be insensitive to neutrino floor
 - Low mass neutrino floor mostly from **solar** neutrinos
 - Cygnus **never** overlaps with Sun



Dark-PMT Prototype 'Hyperion-II' Taking Data in Rome

