Development of a Dark PMT

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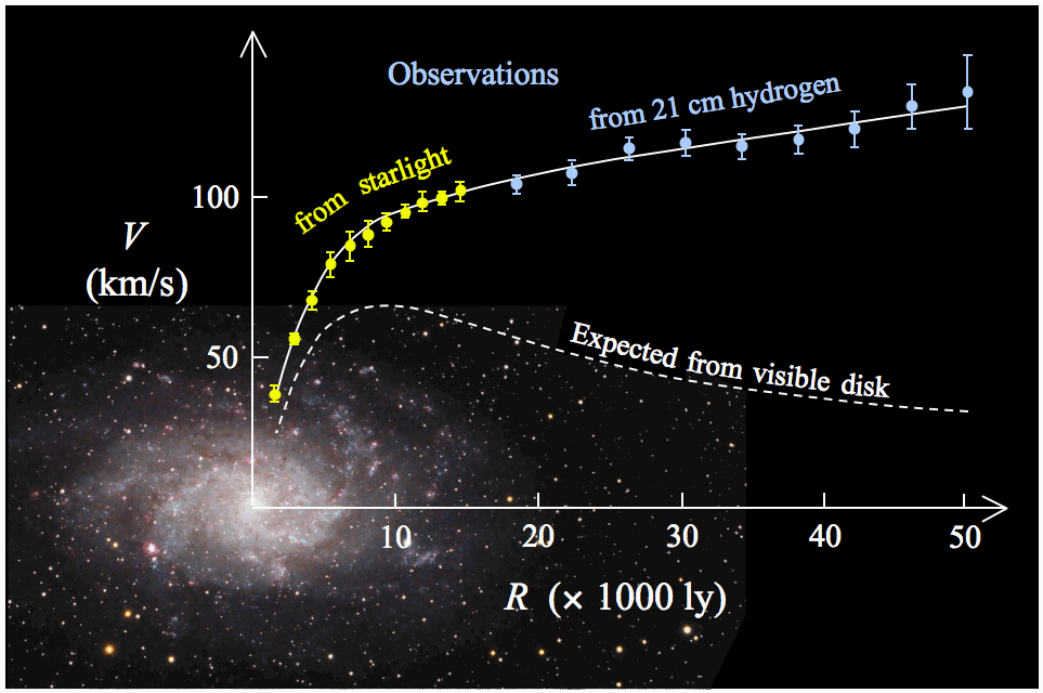
INFN Rome

PTOLEMY Meeting
LNGS, 27.11.2018

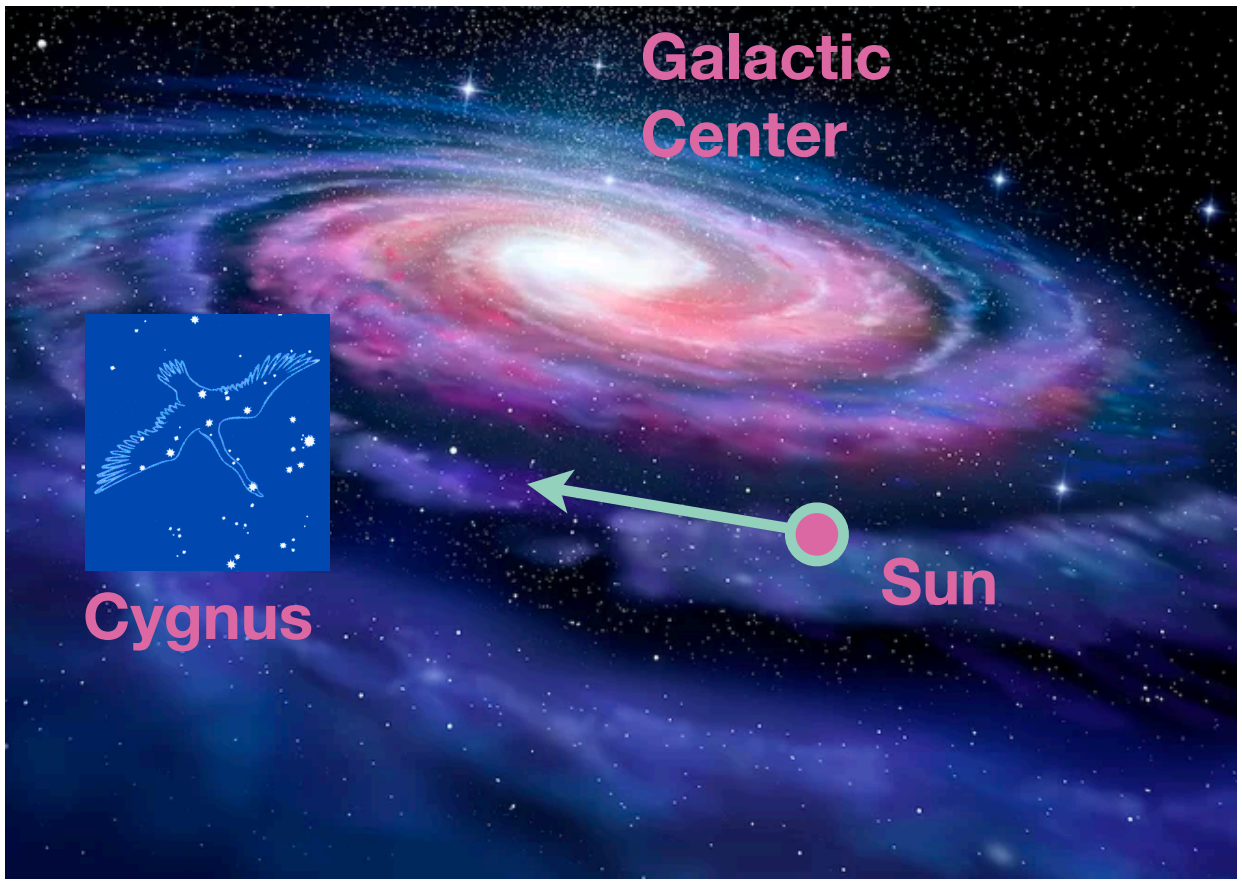
Don’t Need to Introduce Dark Matter

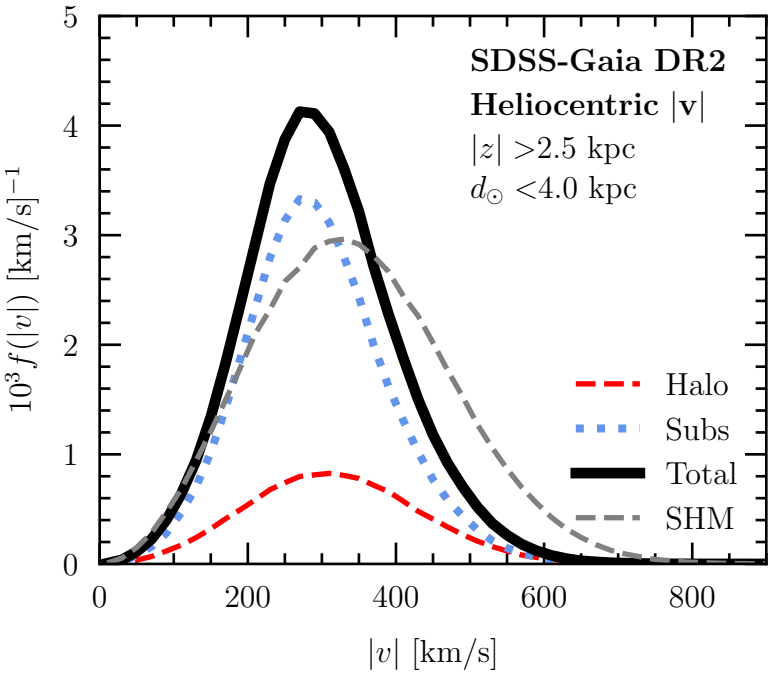


- **Anomalies** in observed universe: rotation curves, galaxy clusters, supernovae
  - **Simplest** explanation: existence of an unknown, **dark** state of matter

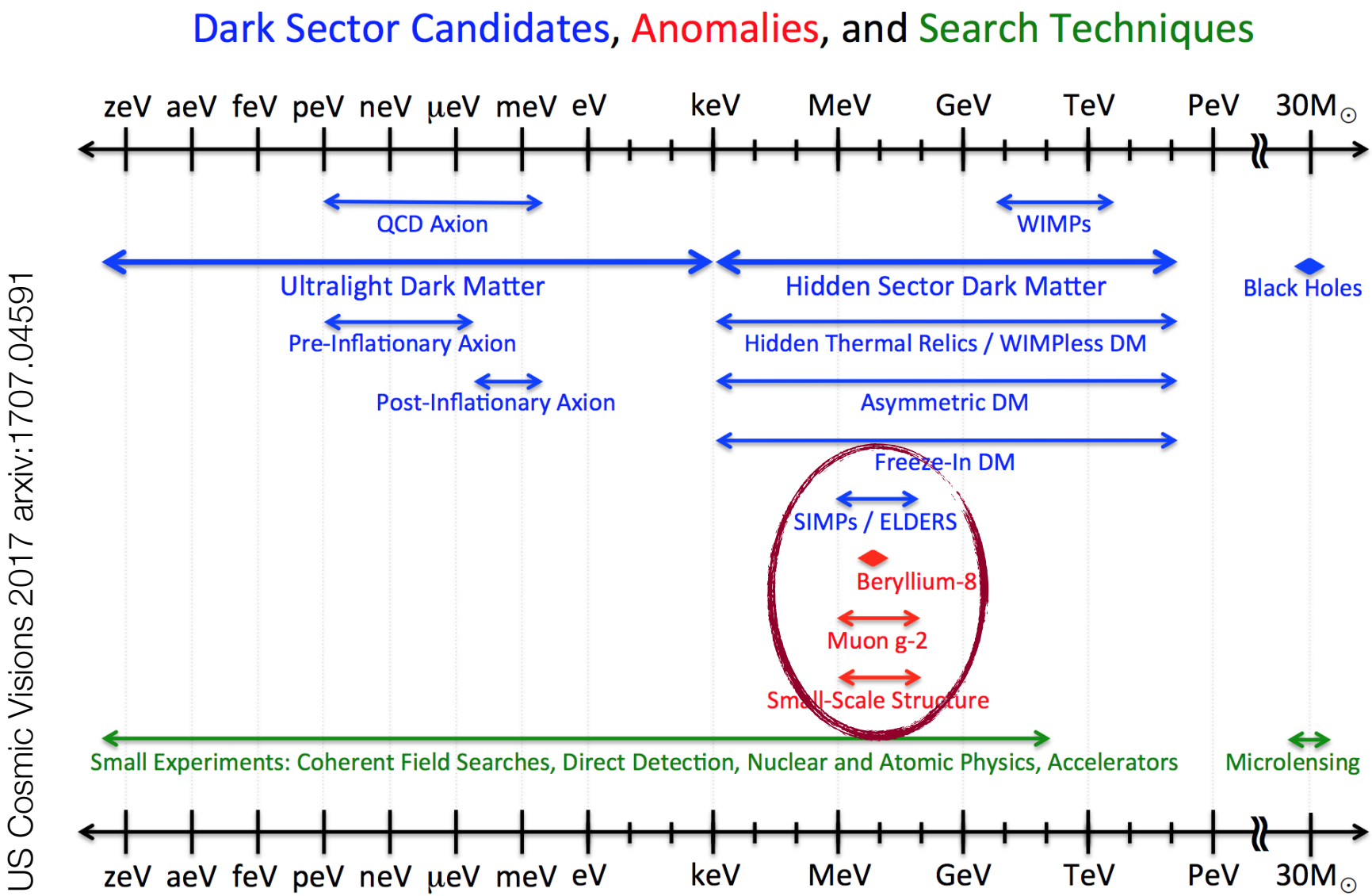
A Wind of Dark Matter from Cygnus

- If Dark Matter (DM) exists our solar system is flying **through** it
  - Apparent ‘wind’ coming from direction of **Cygnus** constellation



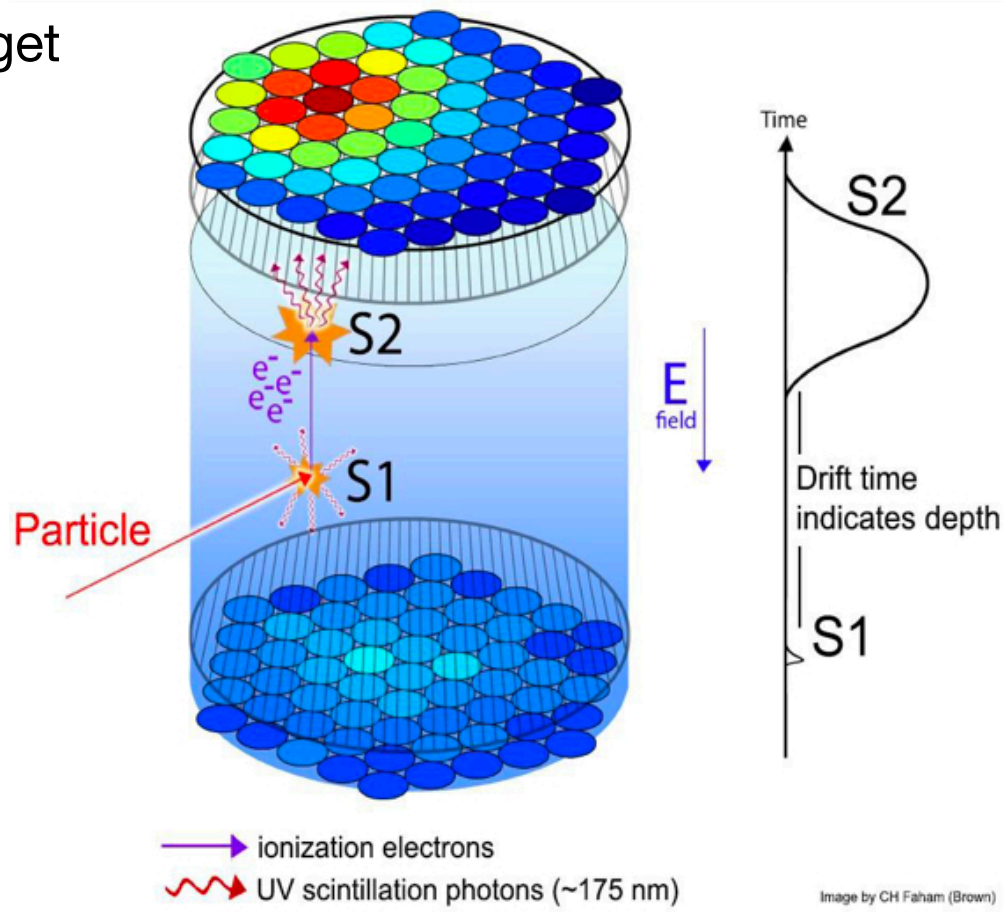


What Mass?

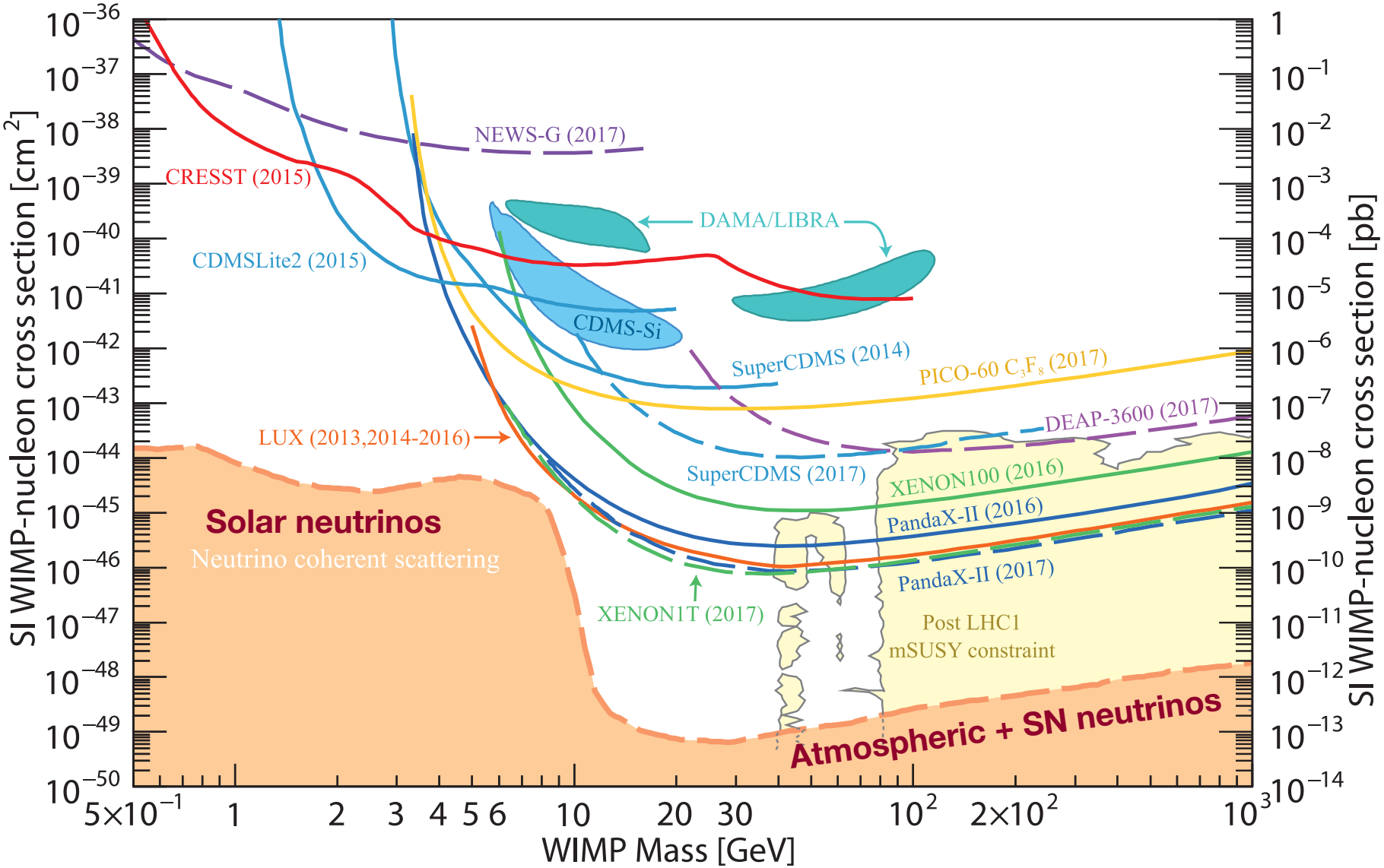

Dark Sector Candidates, Anomalies, and Search Techniques
zeV aeV feV peV neV μeV meV eV keV MeV GeV TeV PeV 30M⊙
QCD Axion
WIMPs
Ultralight Dark Matter
Hidden Sector Dark Matter
Black Holes
Pre-Inflationary Axion
Hidden Thermal Relics / WIMPless DM
Post-Inflationary Axion
Asymmetric DM
Freeze-In DM
SIMPs / ELDERS
Beryllium-8
Muon g-2
Small-Scale Structure
Small Experiments: Coherent Field Searches, Direct Detection, Nuclear and Atomic Physics, Accelerators
Microlensing
US Cosmic Visions 2017 arxiv:1707.04591

Direct Detection: Current State of the Art

- DM wind → search for interactions with matter
  - **Low** cross section → need a **big** target
- **State of the art:** Xenon dual-phase TPC
  - eg Xenon 1T here in LNGS
- DM recoils on **nuclei**
  - Energy transfer → 0 if $M_{DM} \ll M_{Xe}$
  - Main sensitivity for $M_{DM} >$ GeV
- **No** directional capabilities
  - Can't know if signal comes from **Cygnus**



Softer Limits for Sub-GeV Dark Matter



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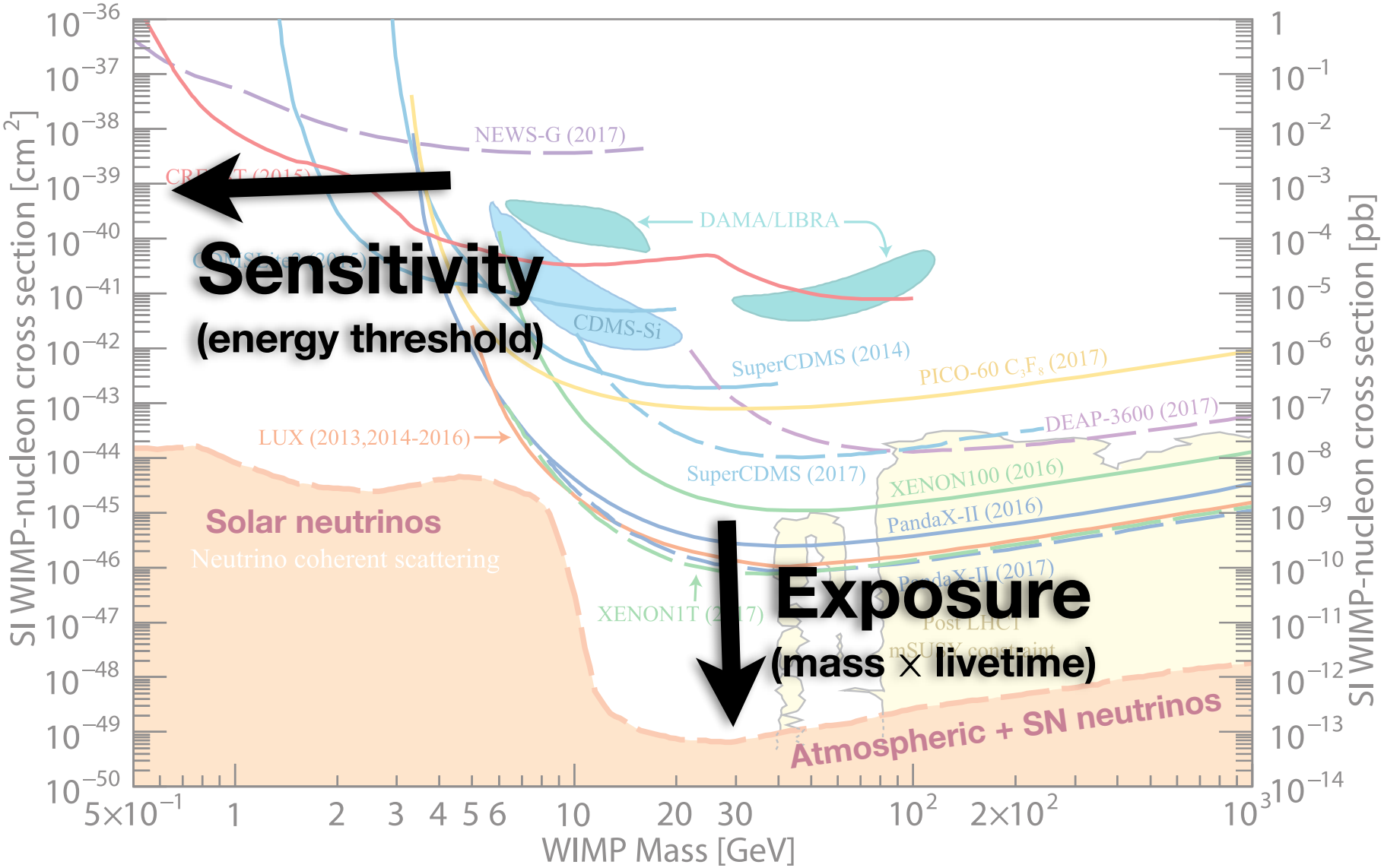

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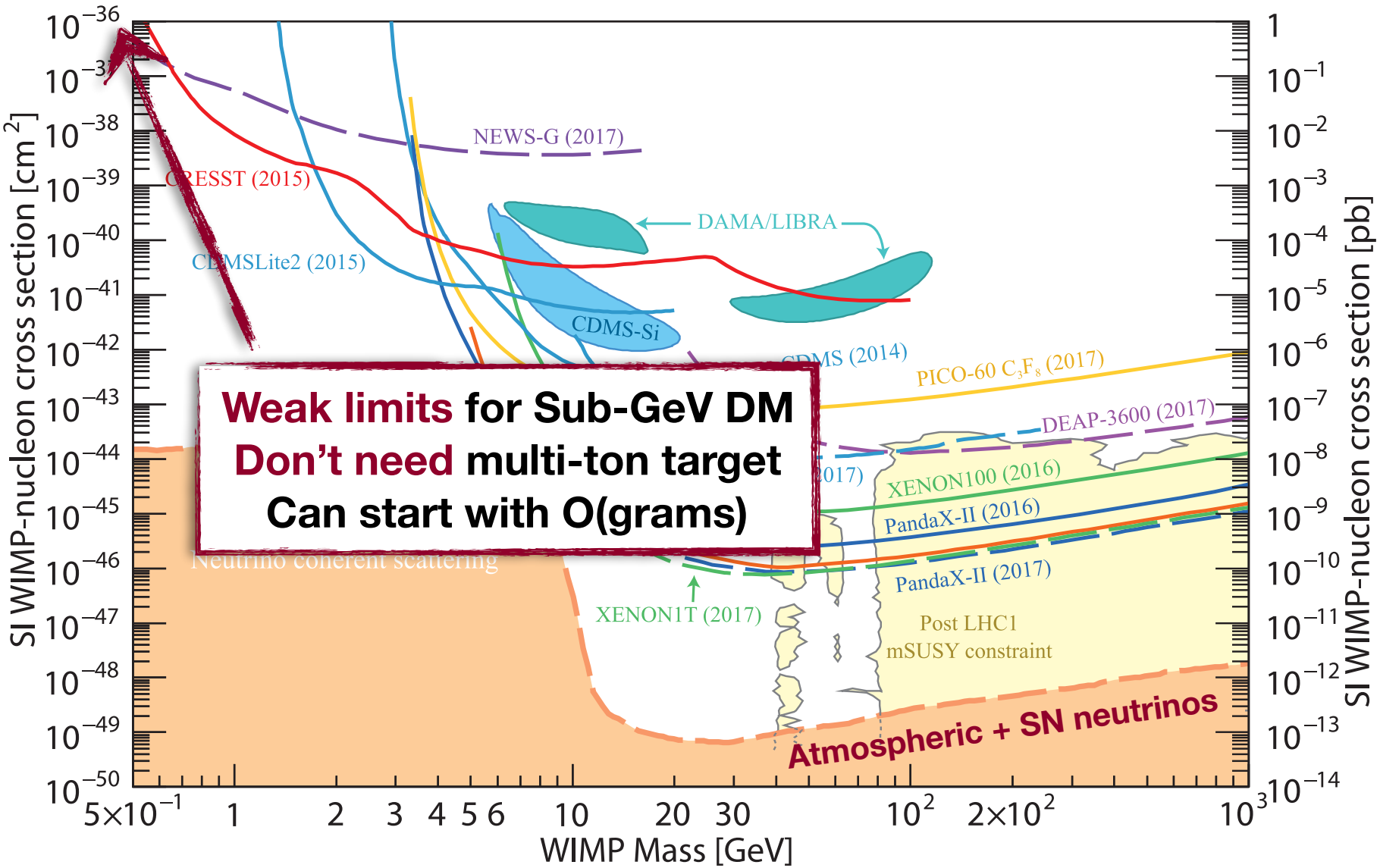
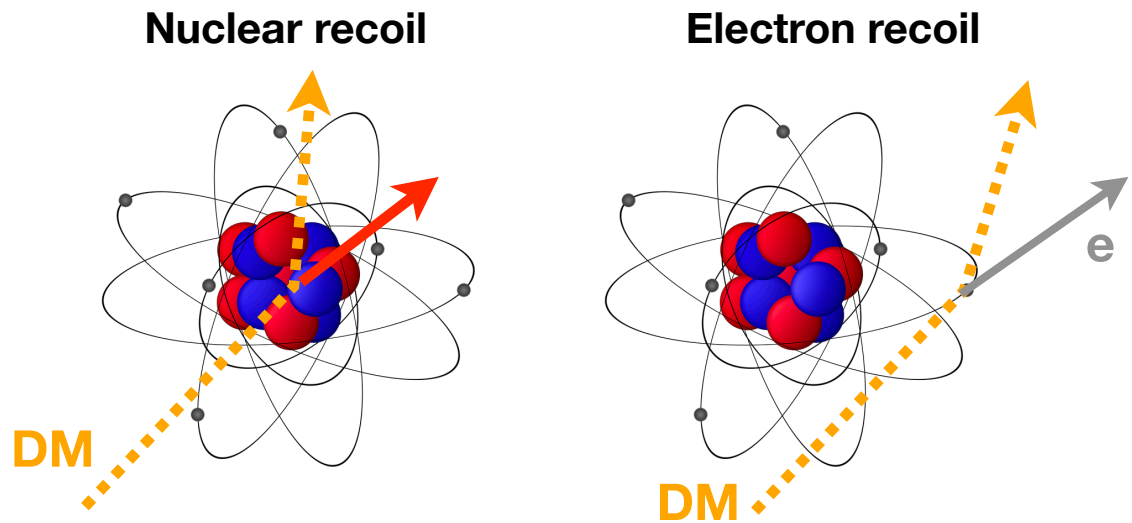
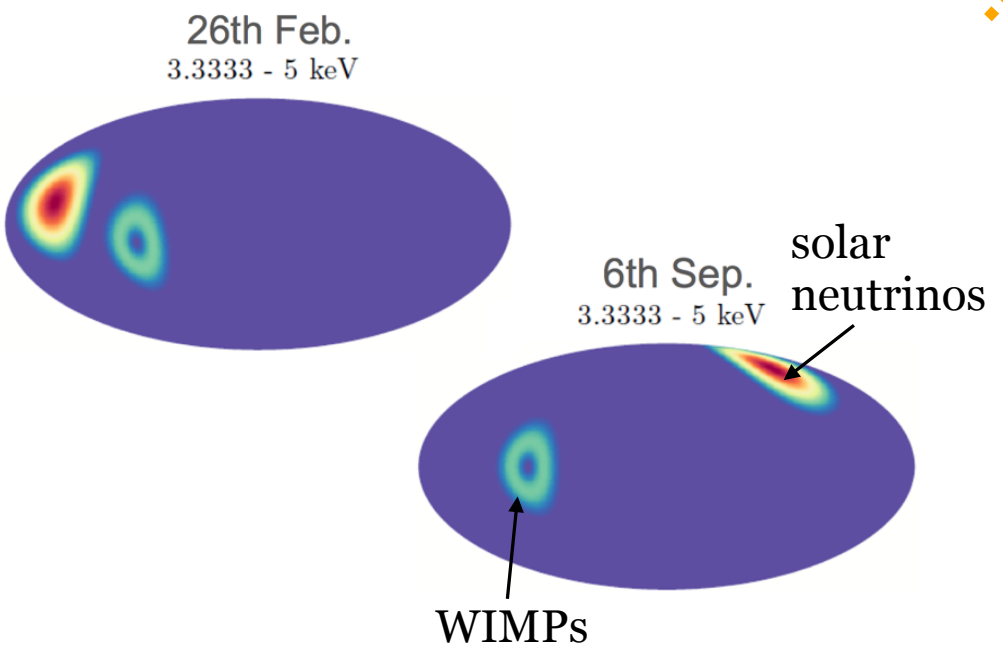


Two Weapons for Sub-GeV DM Searches

- DM-**electron** scattering
  - Sensitive to **sub-GeV** M_{DM}

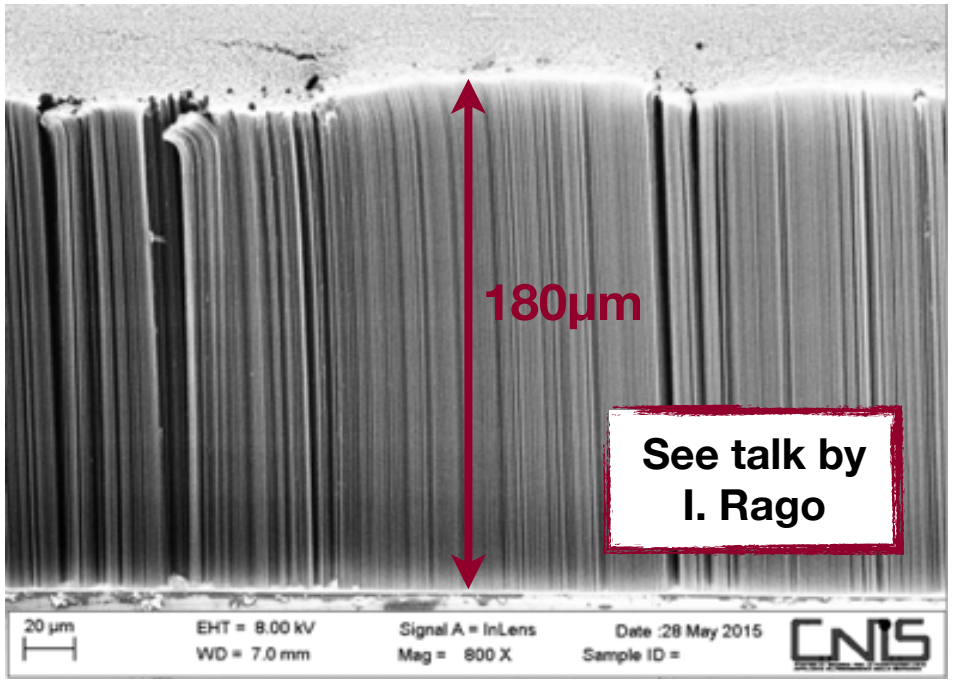


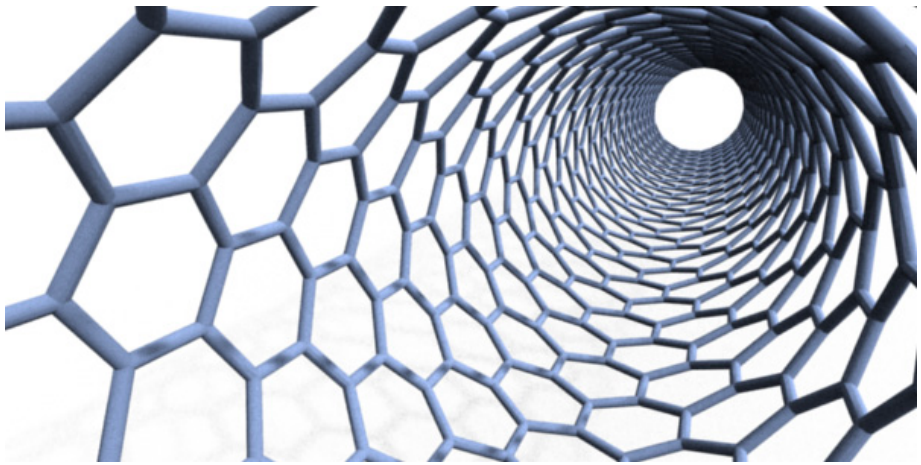


- Directionality
  - Can **link** a signal to Cygnus
  - Sun **never** overlaps with Cygnus
  - **Insensitive** to solar neutrino BG

A New Idea: Carbon Nanotube Target

- Arrays of **carbon nanotubes** (CNTs)
  - Diameter: 20 nm
  - Length: up to ~ 300μm
- **Highly anisotropic** material
  - 'Hollow' in tube direction

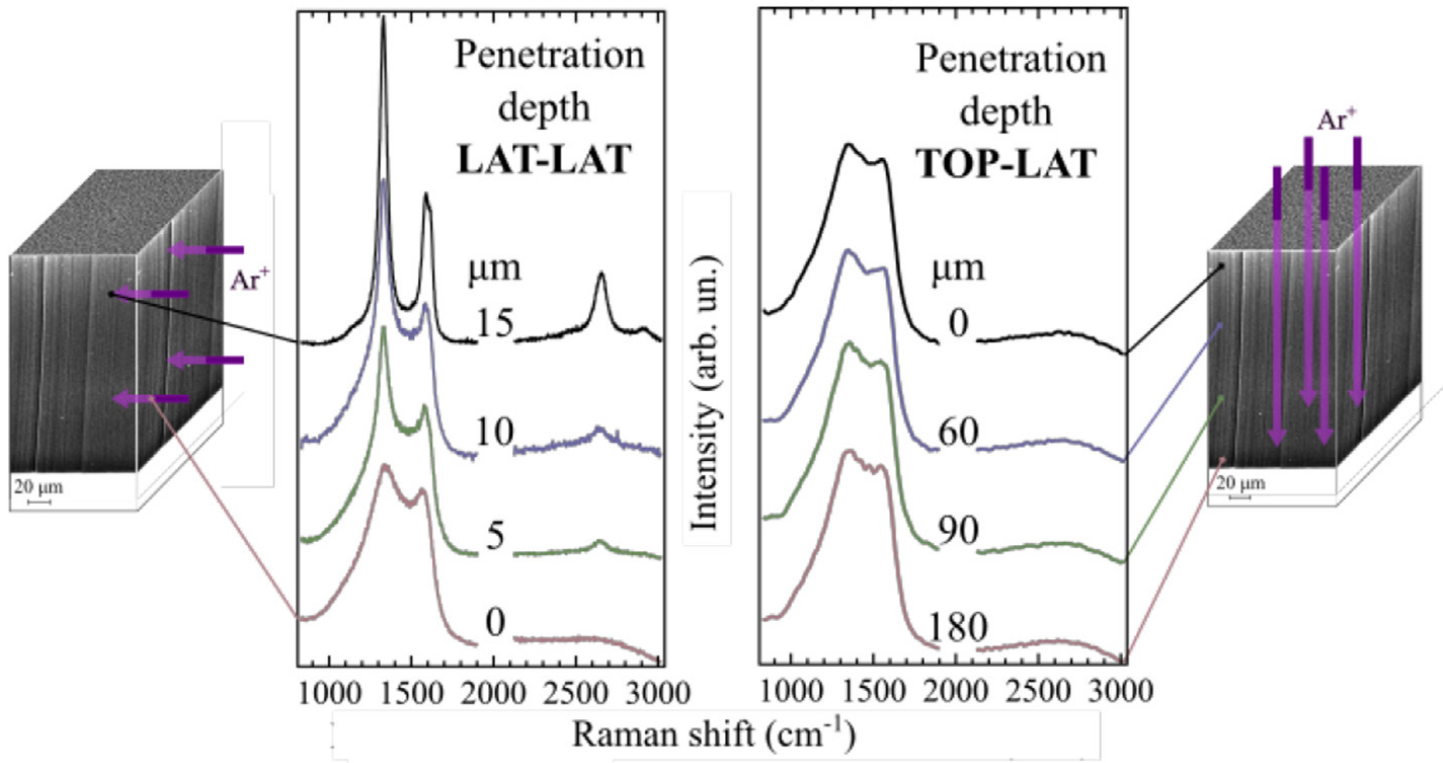




- Carbon **work function**: 4.3 eV
  - **Unaffected** by thermal noise
  - Sensitive to UV light ($\lambda < 290$ nm)

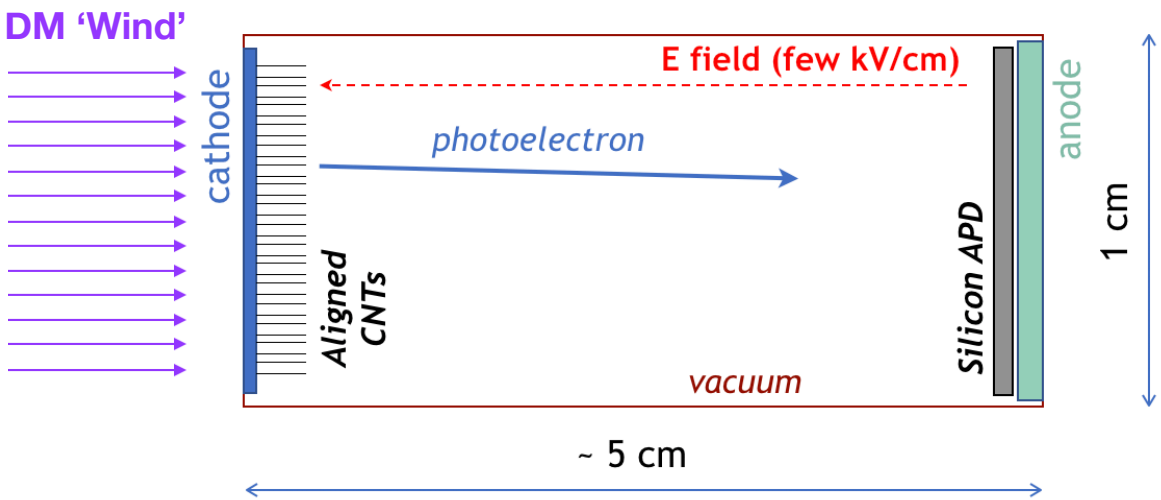
‘Channeling’ Through the Tubes

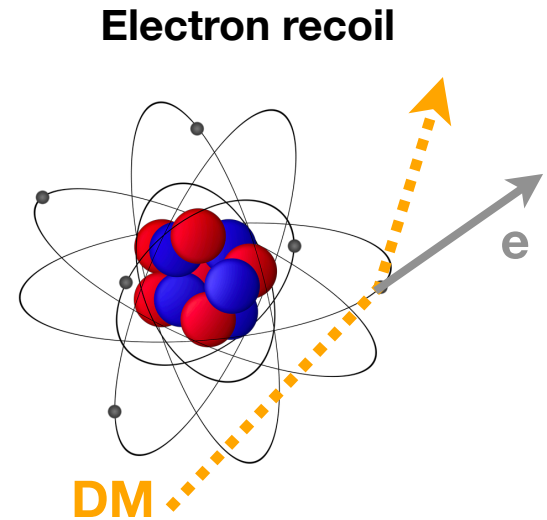
G. D’Acunto, et al., Carbon 139 (2018) 768



- Evidence for Ar^+ ion **channeling**
  - Along **full** CNT length (180μm)
  - Side penetration < 20 μm
- Electron ‘channeling’ (filtering)
  - Still needs to be **proven**
  - **Main objective** of 2019 R&D

So Here's The Idea: A 'Dark-PMT'





- CNT array serves as 'dark'-photocathode
  - DM extracts **photoelectron** of few eV
  - e^- escapes **only** if in CNT direction
- Electron then **accelerated** by E field
  - Hits silicon detector with E ~ **few keV**

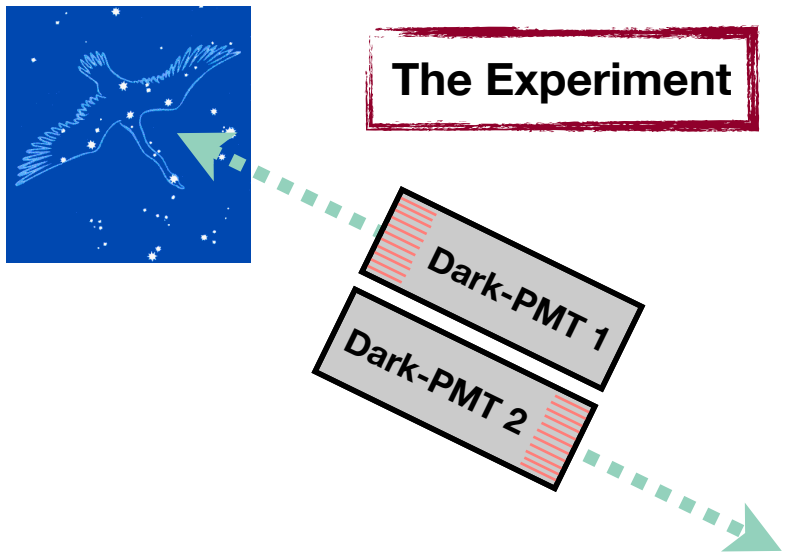
$E_{DM} \sim 1/2\ M_{DM}\ (v/c)^2$

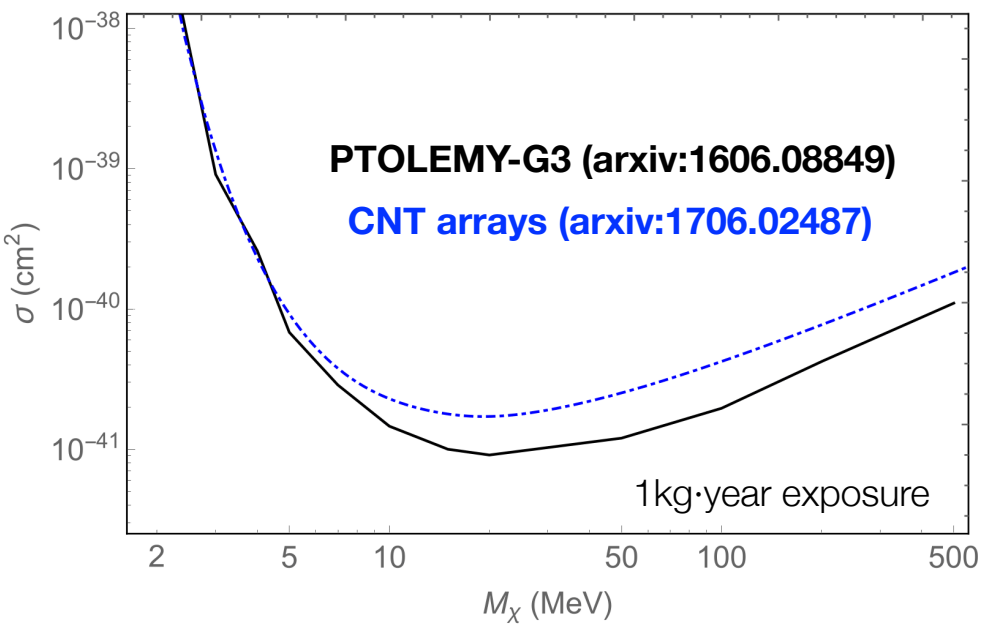
with v = 300 km/s:
$E_{DM} \sim 0.5\ (M_{DM}/\text{MeV})$ [eV]

so if **all** E transfered to e^-:
$E_e \sim$ 5-50 eV (for M_{DM} = 10-100 MeV)

The Experiment: Two Dark-PMTs

- One pointing to Cygnus, one **orthogonal**
  - Search variable: N_1-N_2
  - In-situ BG measurement (for **free**)
  - (Could also measure ^{14}C activity?)

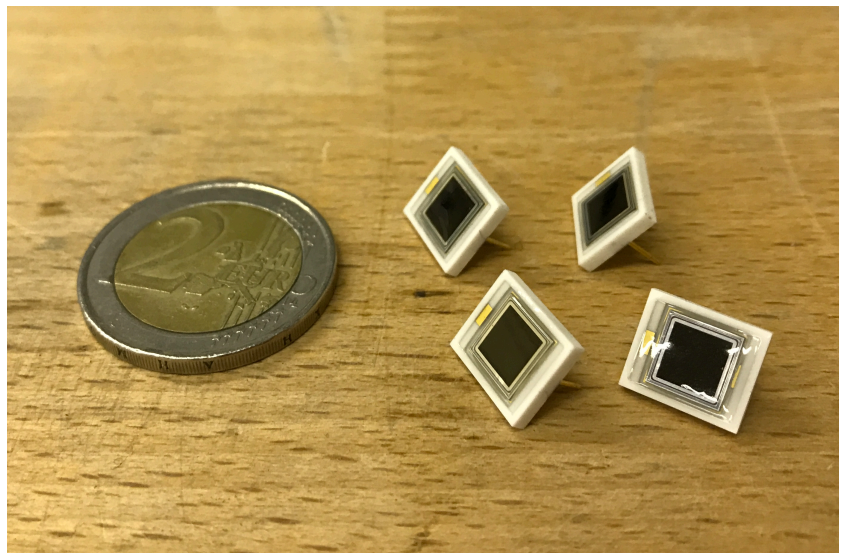


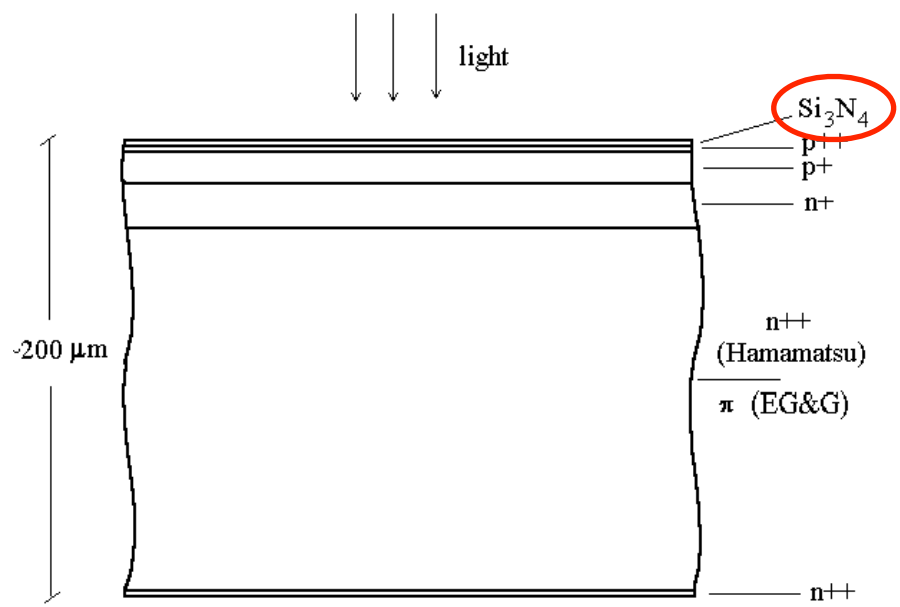


- **Competitive** sensitivity for MeV DM
  - **Comparable** to PTOLEMY-G3

Electron Detector: Silicon APD for Now

- Need to detect electrons with E ~ few keV
- **First try** will be with silicon APDs
  - **Know-how** in Rome (CMS)
- Commercial APDs (Hamamatsu) **designed for photons**, not electrons
  - Protective ceramic **window**
  - Would **absorb** electrons
- Ordered **window-less** APDs
  - And with **reduced** passivation layer



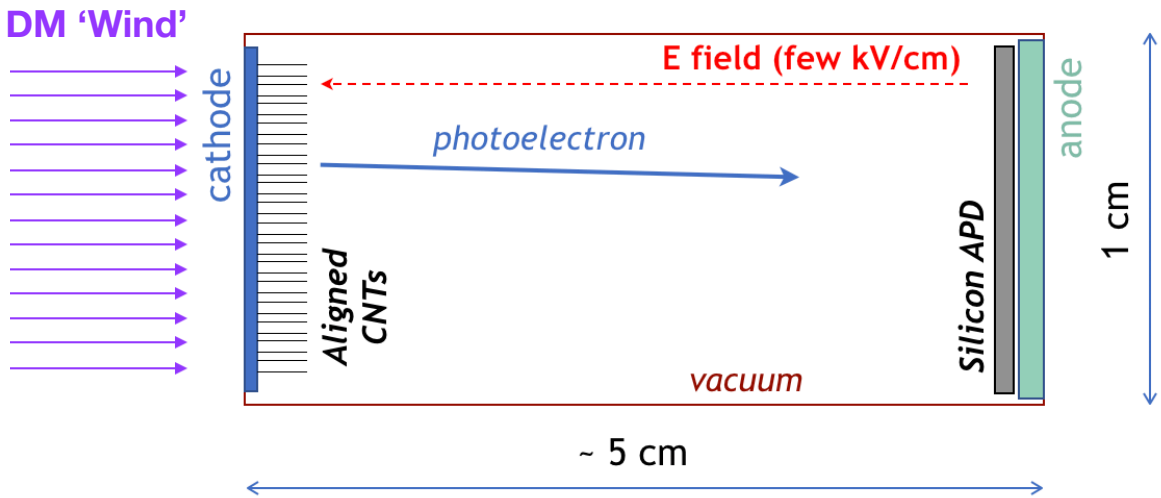


Electron Detector Efficiency Measurement

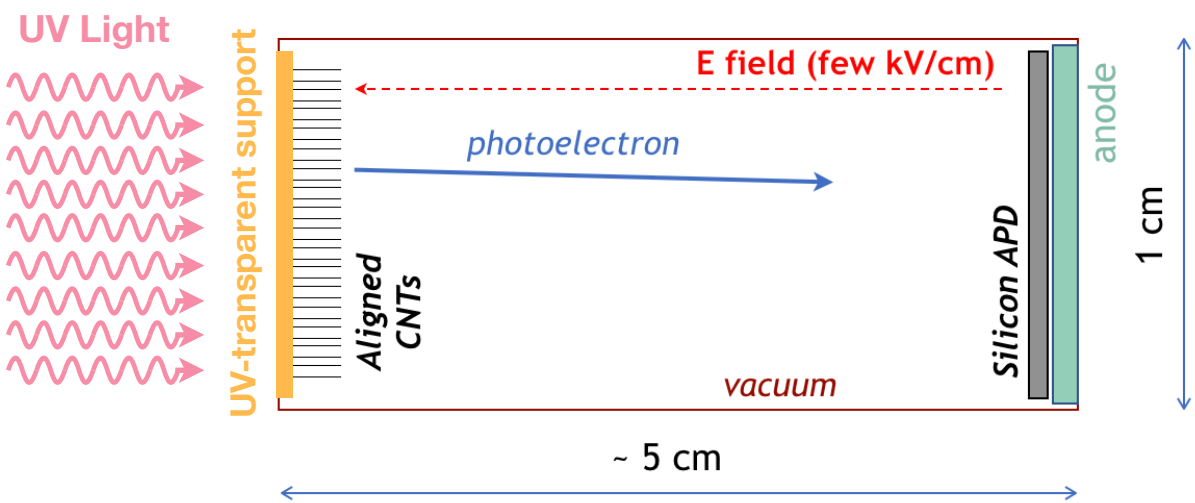
Istituto Nazionale di Fisica Nucleare

- Crucial point: single-electron **efficiency**
  - For E_e ~ few keV
- Will use **electron gun** facility in Roma Tre
  - Energy **up to 500 eV** (can improve)
  - Capable of stable currents ≲ 150 fA
  - Monitored w/ picoamperometer (0.01 fA)
  - Working in **ultra-high vacuum**
- Will take place in **beginning of 2019**

First Step: Building a 'Dark-PMT$_{UV}$'



Dark-PMT



Dark-PMT$_{UV}$

Dark-PMT: A Timeline

November 2018 Order of customized silicon APDs

February 2019 Measurement of APD keV-electron efficiency

March-April 2019 Growth of CNTs on UV-transparent substrate (target: 300 μm)

Summer 2019 Assembly of Dark-PMT$_{UV}$ prototype (UV-transparent substrate)

Autumn 2019 Test Dark-PMT$_{UV}$ performance with UV lamp

Conclusions

Istituto Nazionale di Fisica Nucleare

- Large (ton) mass detectors: **no signal** of heavy DM
  - Approaching the neutrino ‘floor’
- There is a **case for sub-GeV DM** (eg SIMPs)
  - And limits are **much weaker**: don’t need tons, could start with **grams**
- **Carbon nanotubes**: an interesting material
  - ‘Hollow’ in one direction
- We propose to build a light DM detector based on arrays of CNTs
  - Sensitive to **direction** of DM signal
- Working on having a ‘dark-PMT’ prototype by **end of 2019**