Study of Carbon NanoTubes for Light Dark Matter Detection

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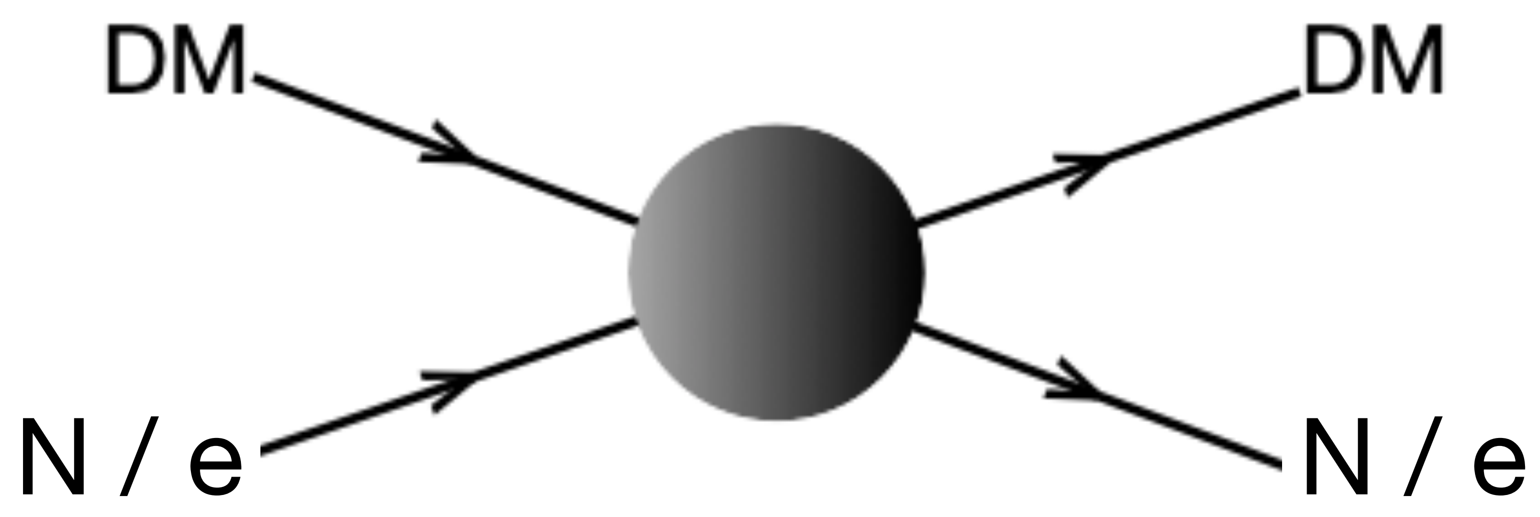
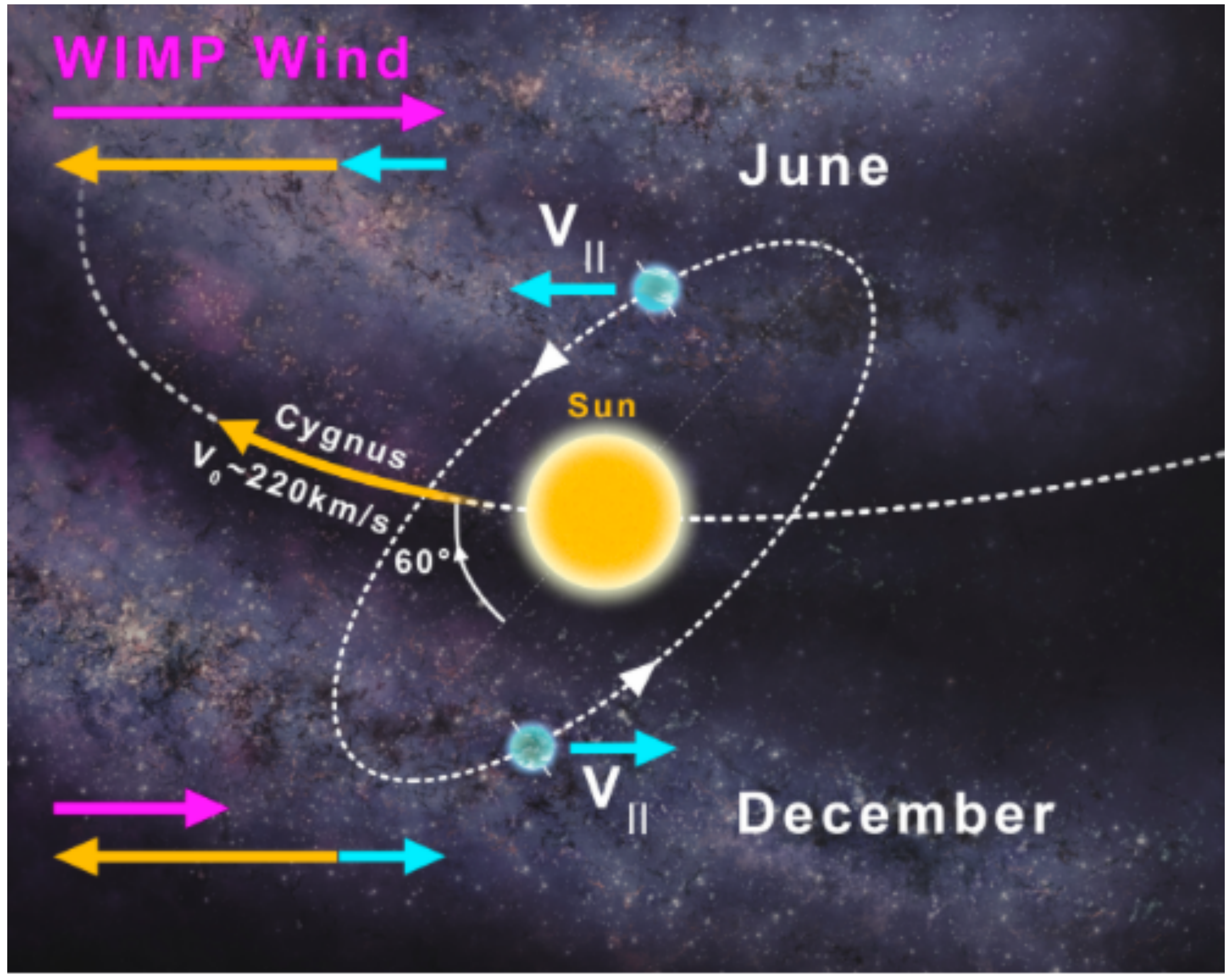
The Dark Matter Puzzle

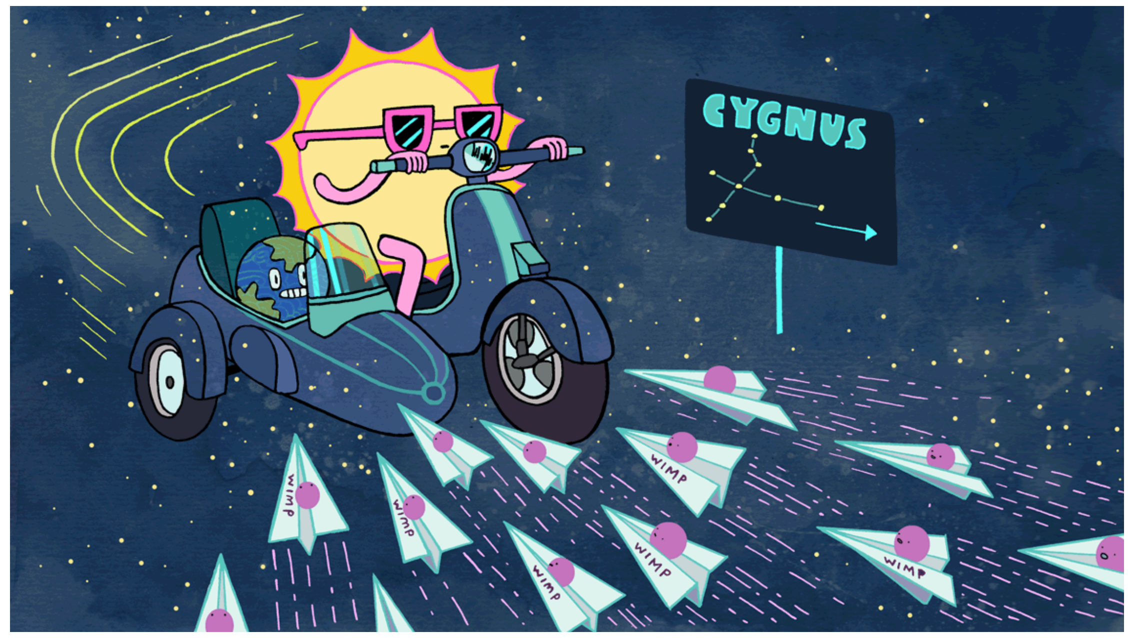
- Many evidences of the dark matter presence:
  - Gravitational effects on ordinary matter
- Several theories to account dark matter:
  - Differ on dark matter mass and coupling
- Various efforts in dark matter direct search:
  - No uncontroversial sign found yet



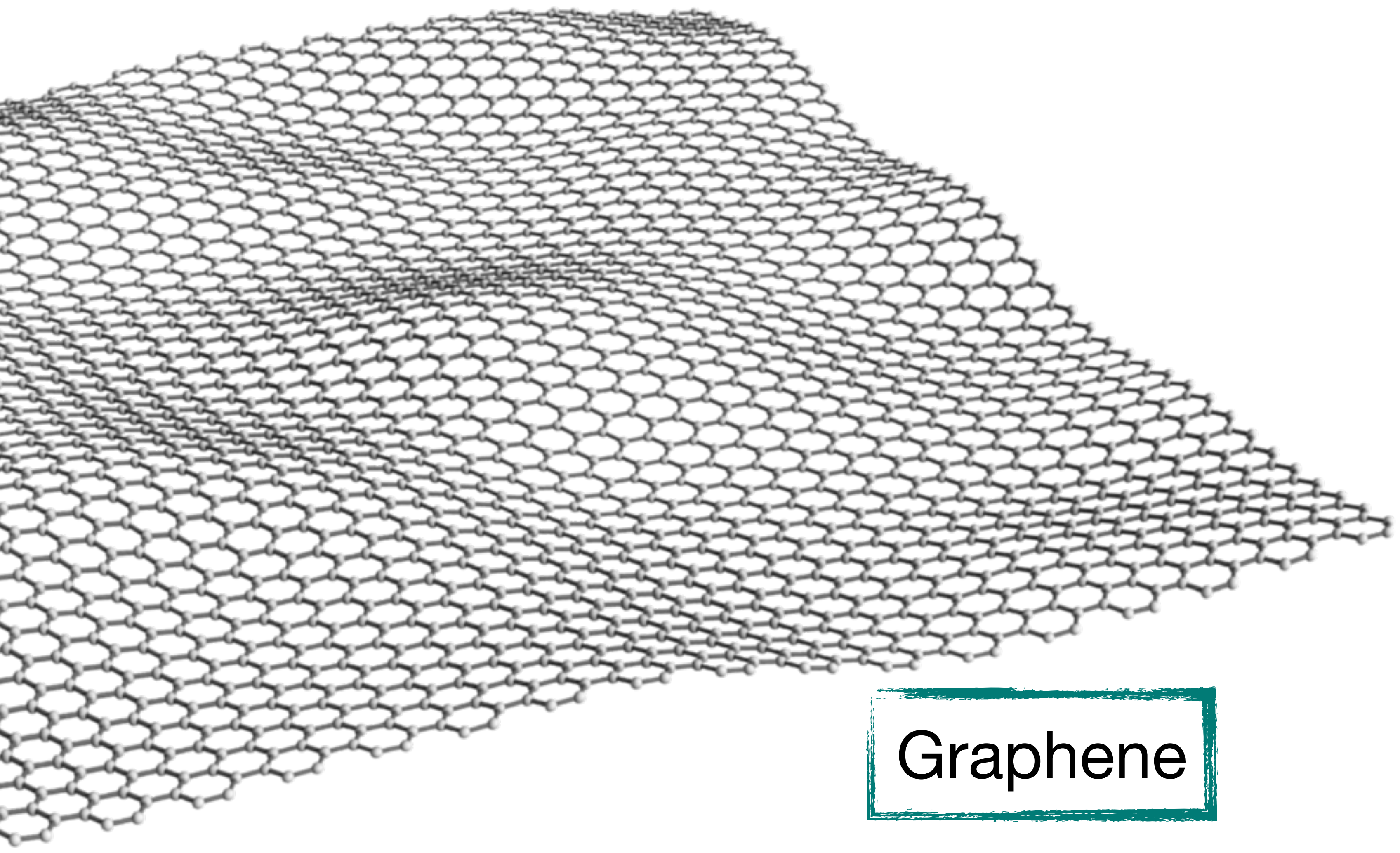
A Dark Matter Wind "Blows" from Cygnus

- Our galaxy is surrounded by a dark matter halo
- Solar System orbits with v ~ 220 km/s toward Cygnus
- "Dark matter wind" due to motion with respect to the dark matter halo rest frame
- Link scattering events with a direction in the sky map

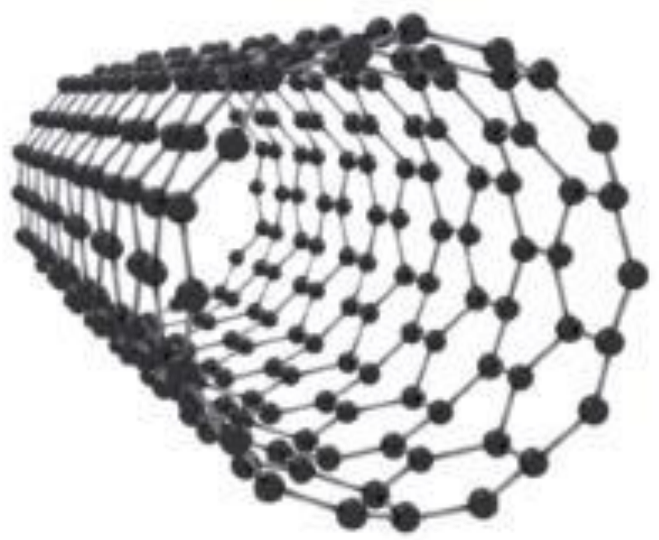




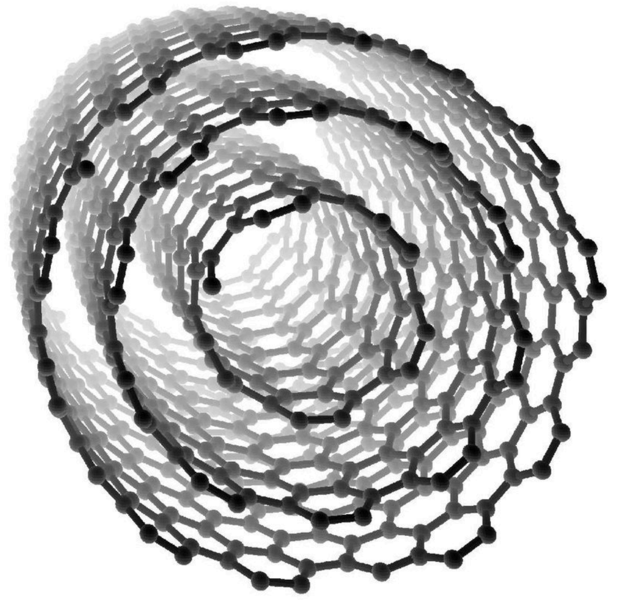
The Advantages of Vertically Aligned Carbon Nanotubes



Graphene

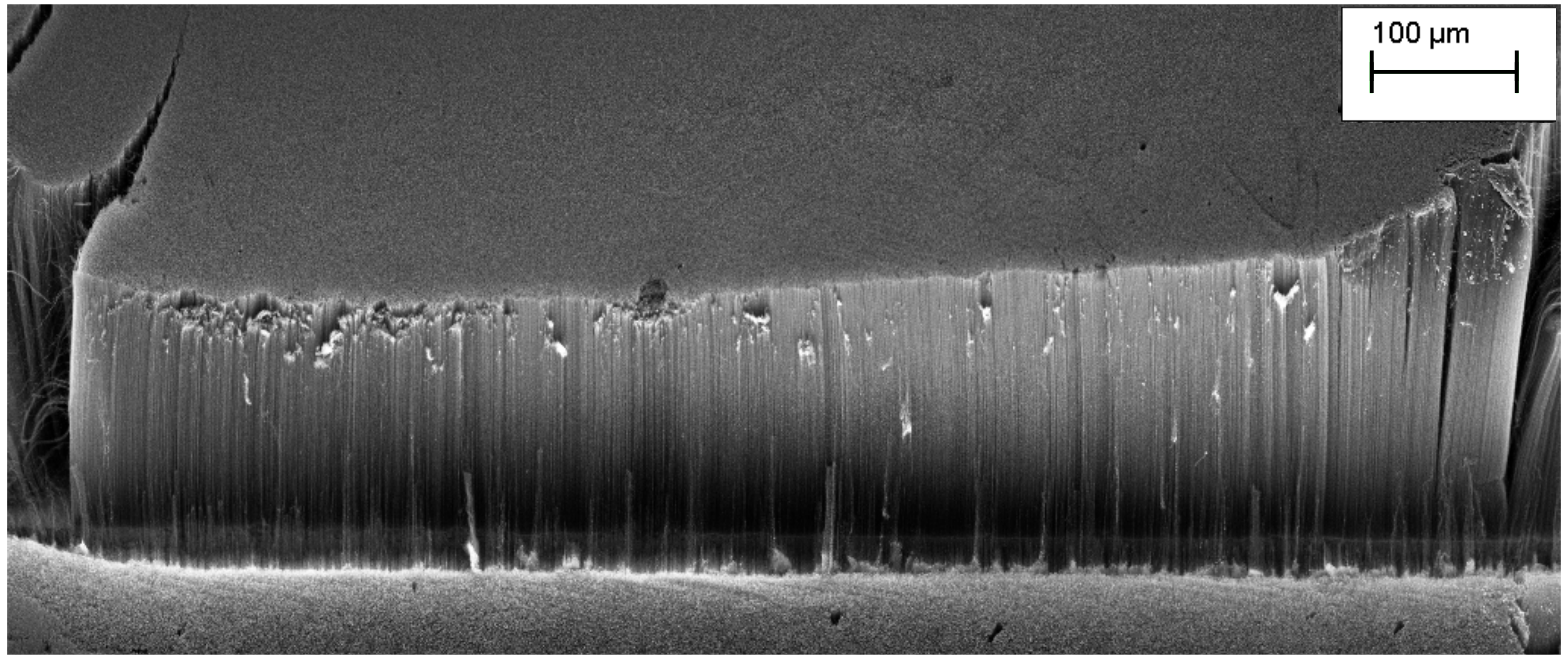


Single-wall nanotube



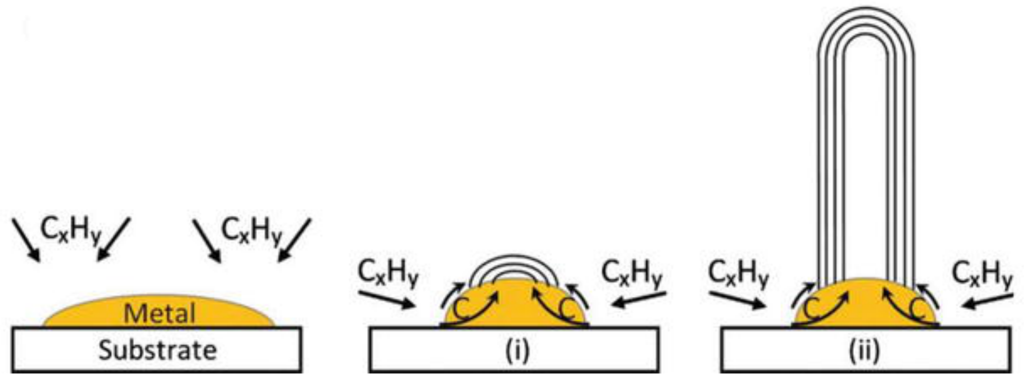
Multi-wall nanotube

- Vertically aligned carbon nanotubes (VA-CNTs)
  - Highly anisotropic density
  - Directional sensitivity by design
- Sensitivity to sub-GeV dark matter:
  - Inelastic scattering on electrons
  - Φe ~ 4.7 eV, so K_e ~ 1 - 50 eV (m_{DM} = 10-100 MeV)

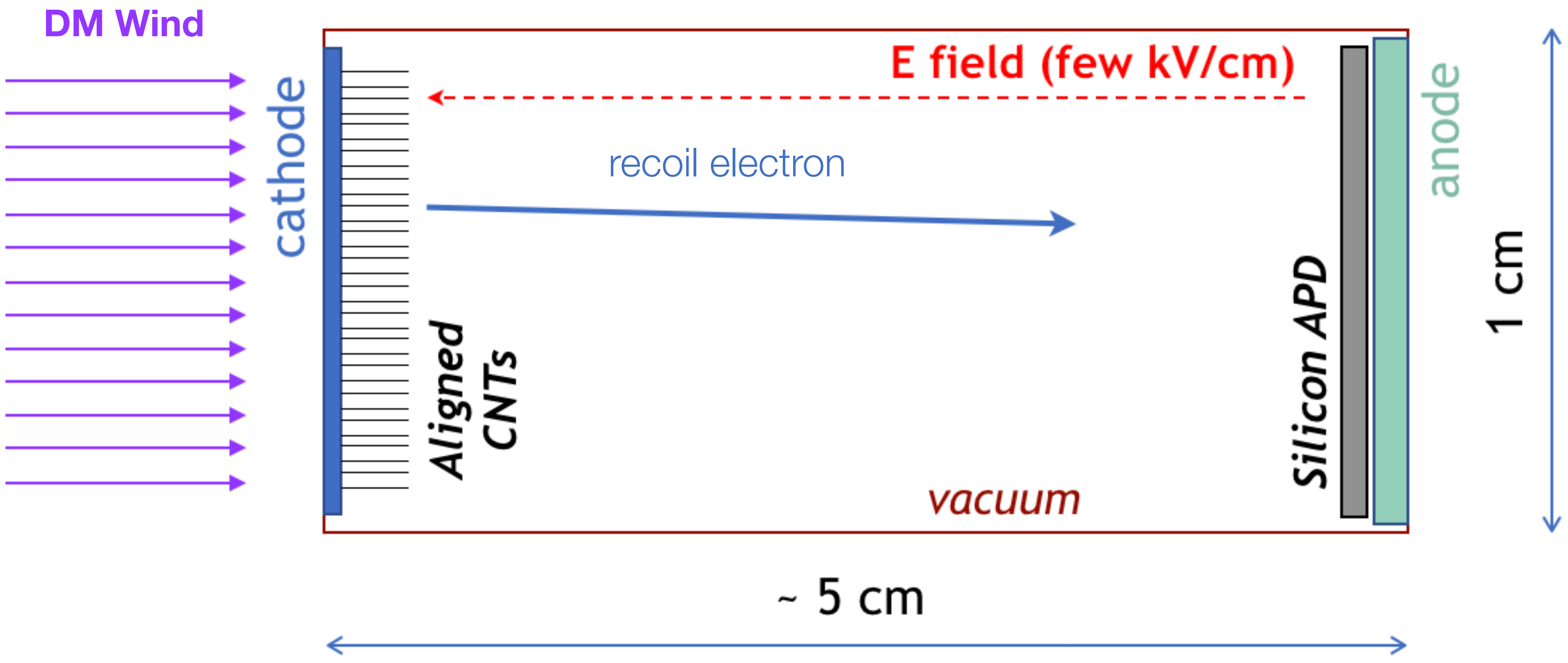


Experts in Sapienza!

CVD Growth



Novel Detector Concept: the “dark-PMT”

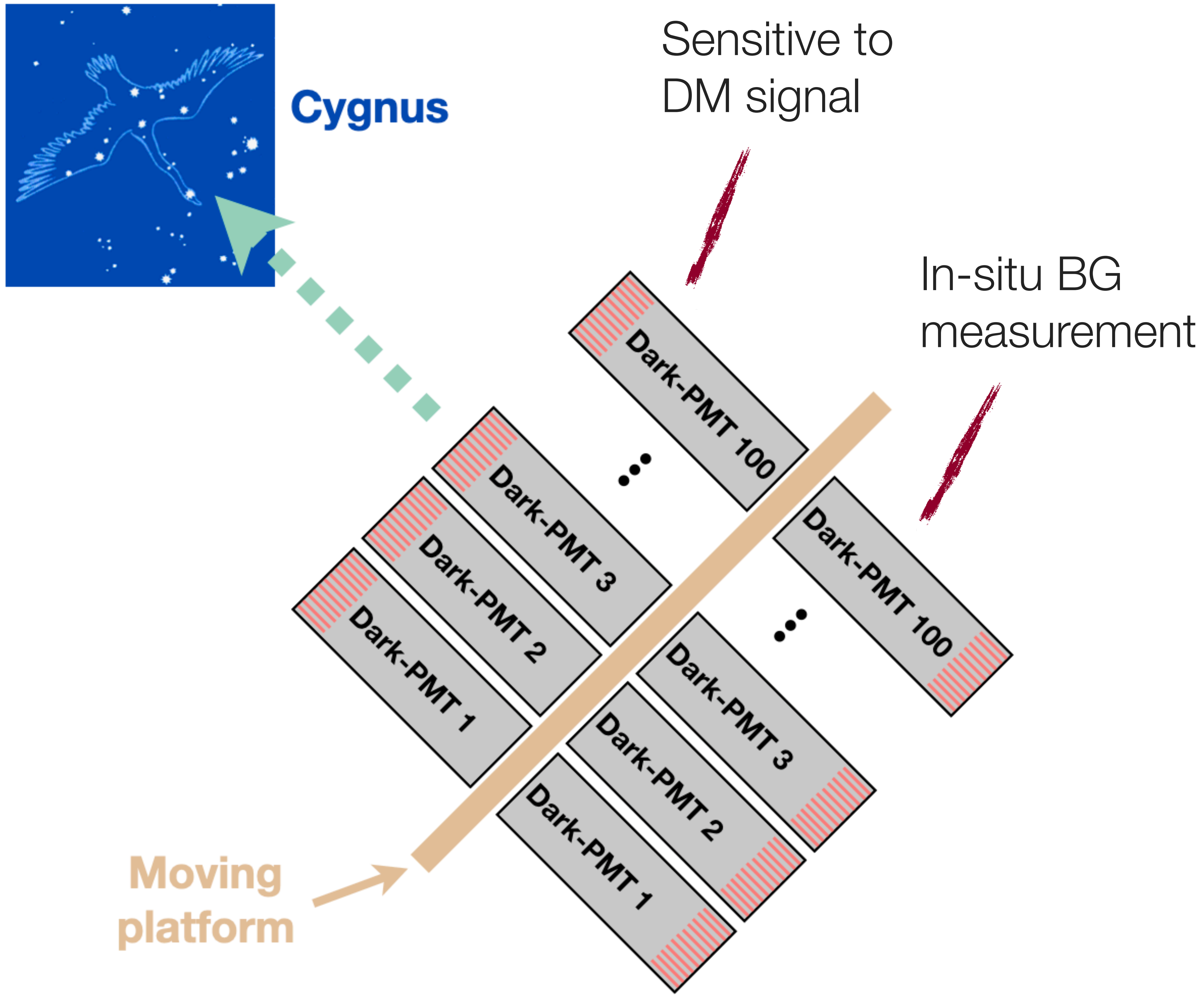


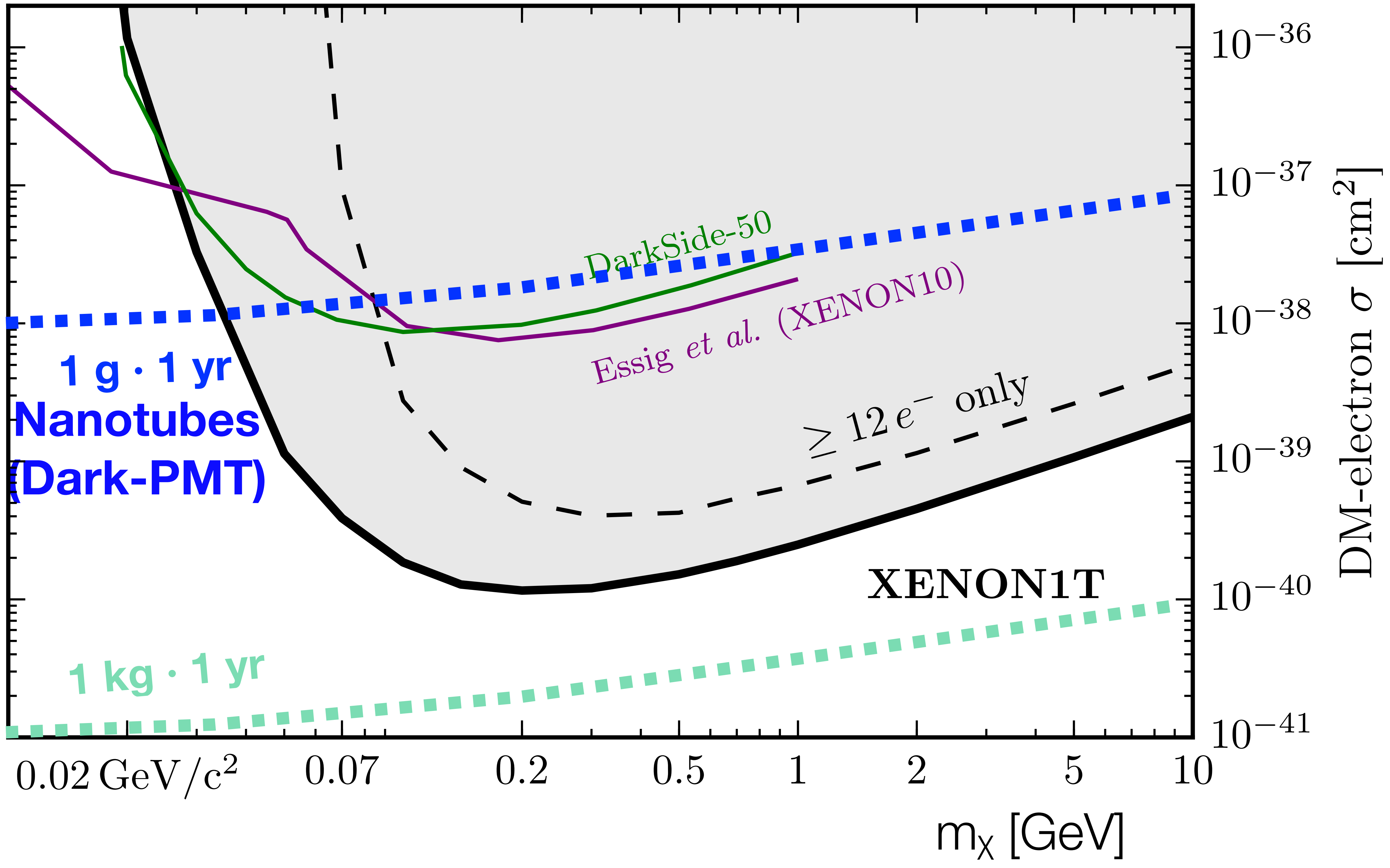
- ✤ ‘Dark-photocathode’ of aligned nanotubes
  - Ejected e- accelerated by electric field
  - Detected by solid state e- counter

<u>Dark-PMT features:</u>

- Portable, cheap, and easy to produce
- Unaffected by thermal noise (Φ_e = 4.7 eV)
- Directional sensitivity

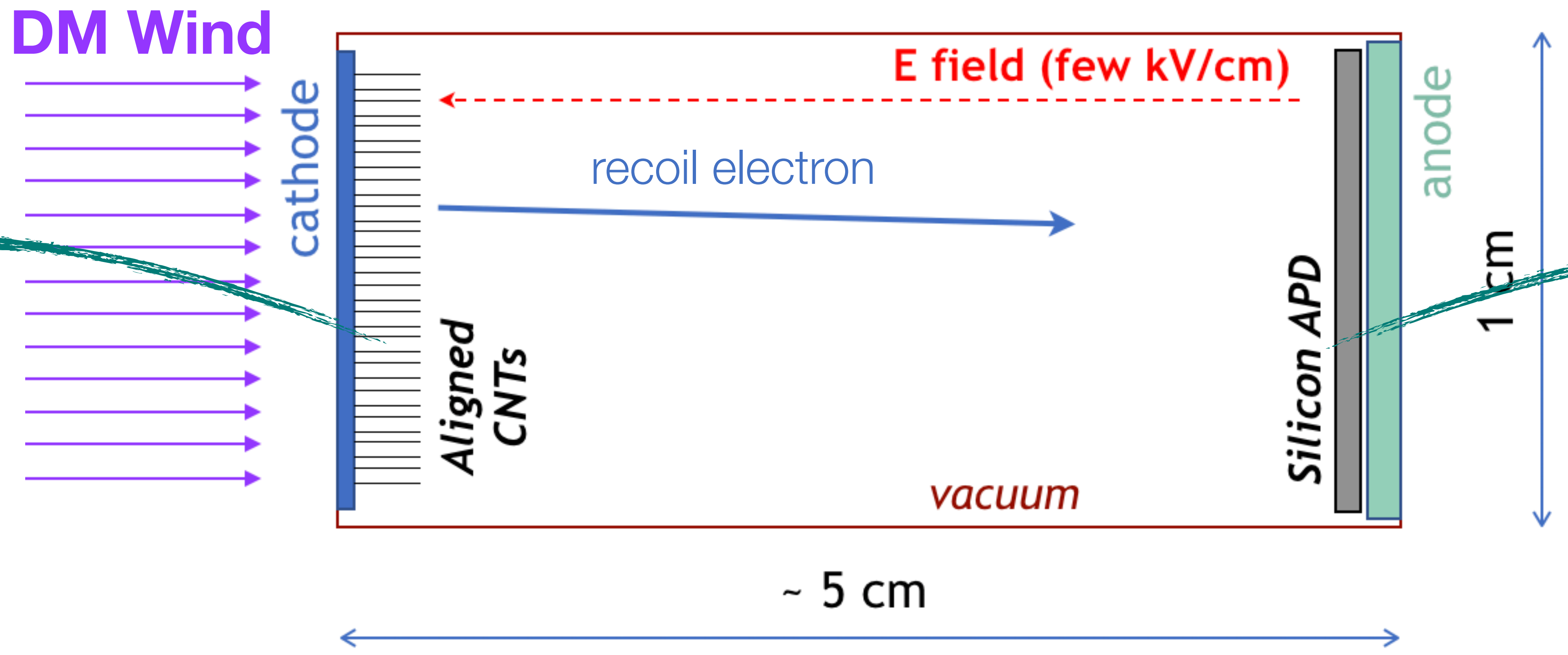
Two Arrays of dark-PMTs to Search for a Dark Matter signal



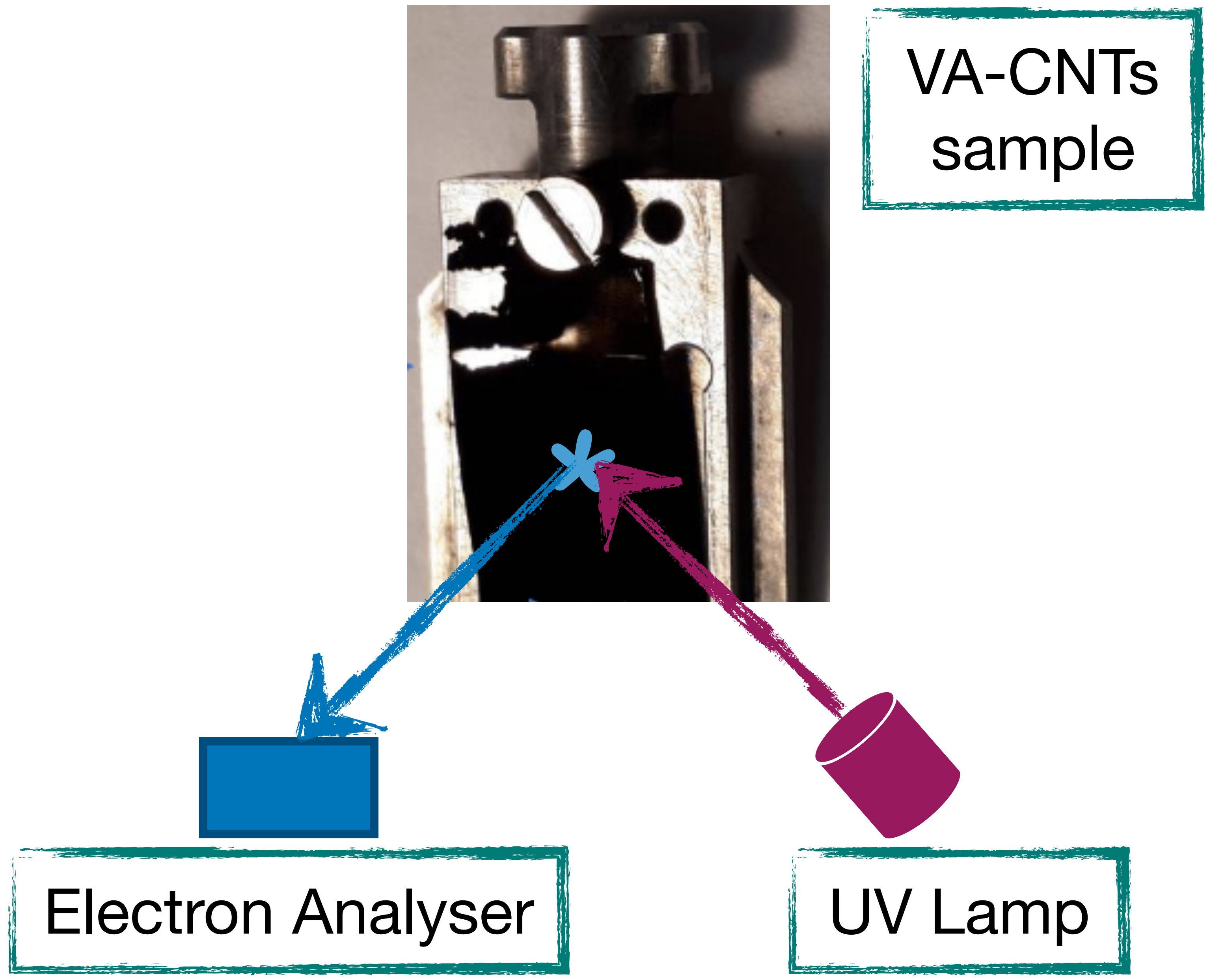


- Light dark matter direct detection
  - Cross-section range still relatively unexplored
  - ~grams targets are competitive

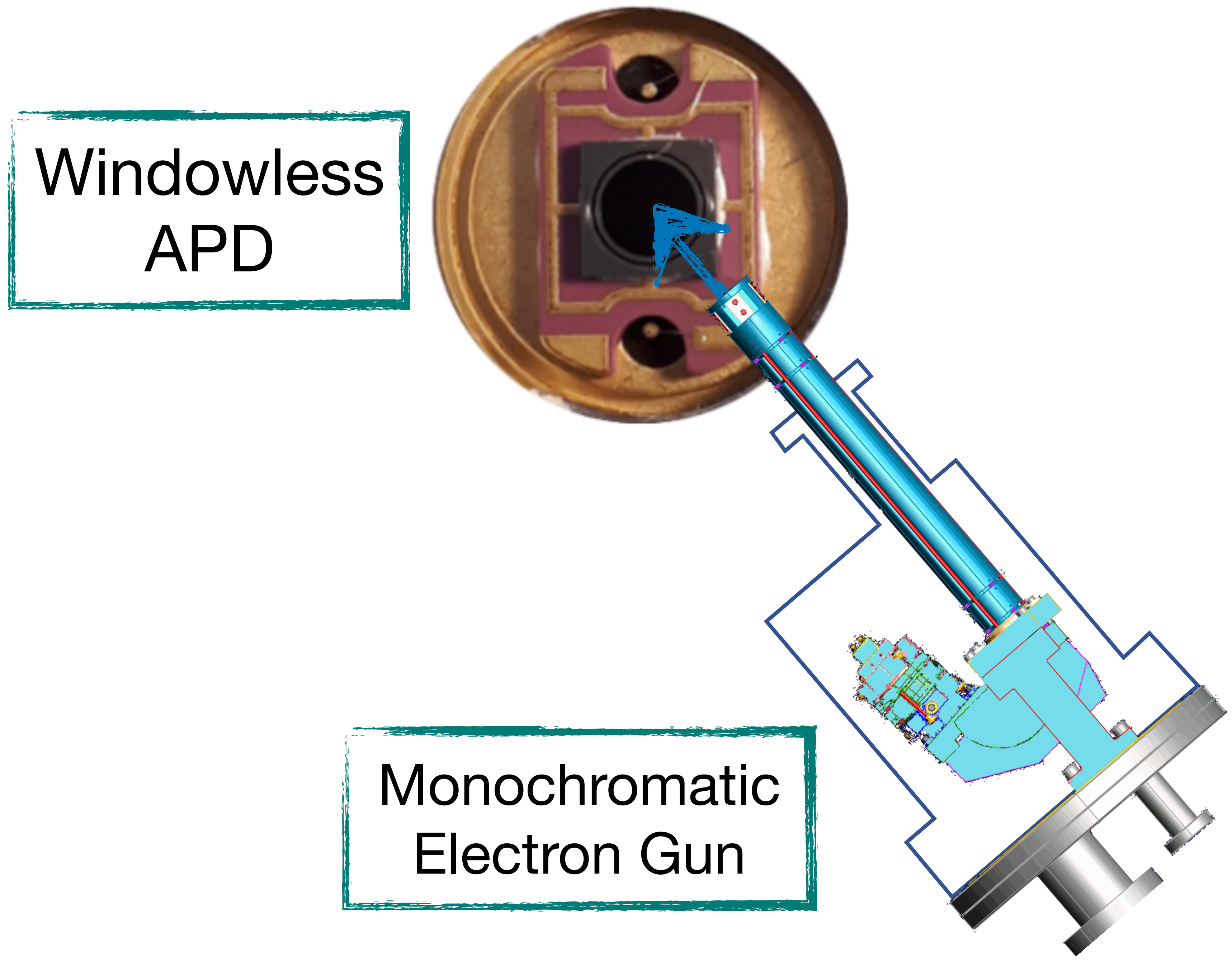
Challenges on Both Sides of the dark-PMT



Test Anisotropy with UV-Photoemission Spectroscopy (UPS)



Characterise Avalanche PhotoDiode (APD) response to low-energy electrons

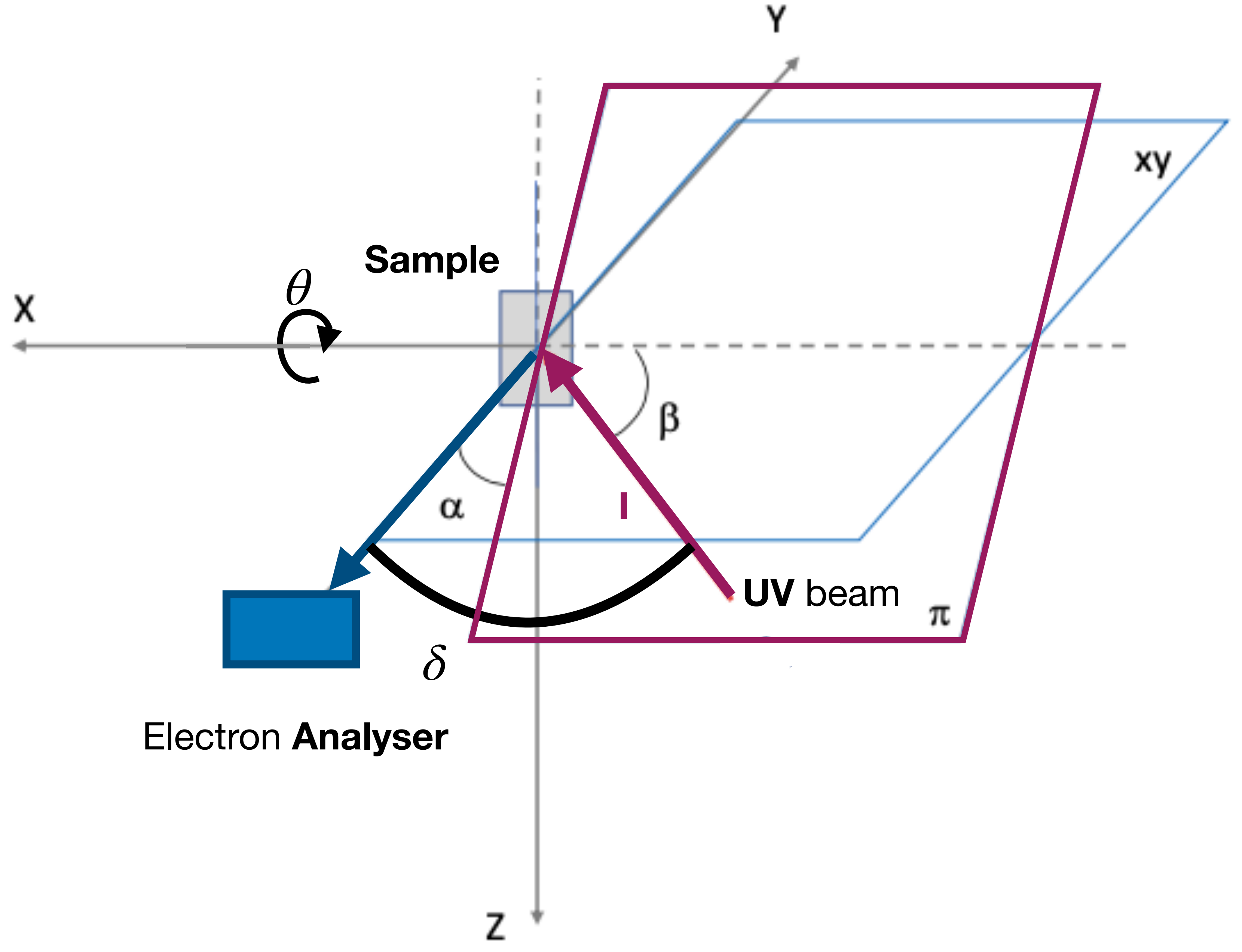


LAboratorio di Spettroscopie Elettroniche e di Correlazione

VA-CNTs Anisotropy? - Complex Geometry

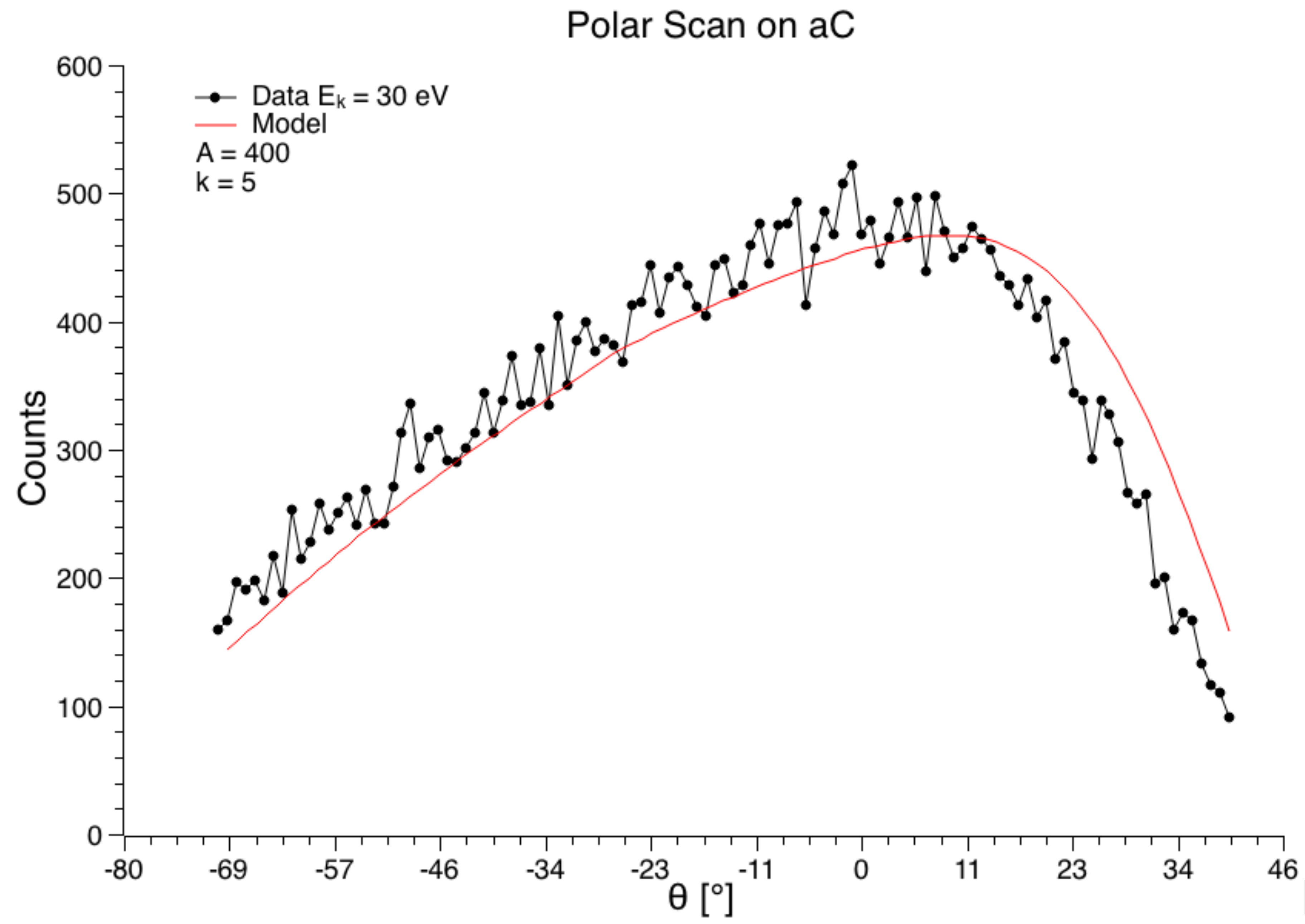
- UV-Photoemission Spectroscopy (UPS)
  - Complex experimental geometry
  - Geometric model built

$$N(\theta) = A\left[\left(1-\frac{1}{1+e^{-k(\theta-\theta_0)}}\right)\cos\theta + \frac{1}{1+e^{-k(\theta-\theta_0)}}\begin{cases}\dfrac{d_e^V}{\sin\left(tg^{-1}(\,tg\,\beta\,\sin(\alpha+\theta)\,)\right)}\,\dfrac{\sin\beta\,\cos(\alpha+\theta)}{d_{UV}\sin\beta\,\cos\alpha} & \theta > \theta_c \\ \dfrac{d_e^H\cos\theta}{\cos\left(tg^{-1}(\,tg\,\beta\,\sin(\alpha+\theta)\,)\right)}\,\dfrac{\sin\beta\,\cos(\alpha+\theta)}{d_{UV}\sin\beta\,\cos\alpha} & \theta \le \theta_c\end{cases}\right]$$

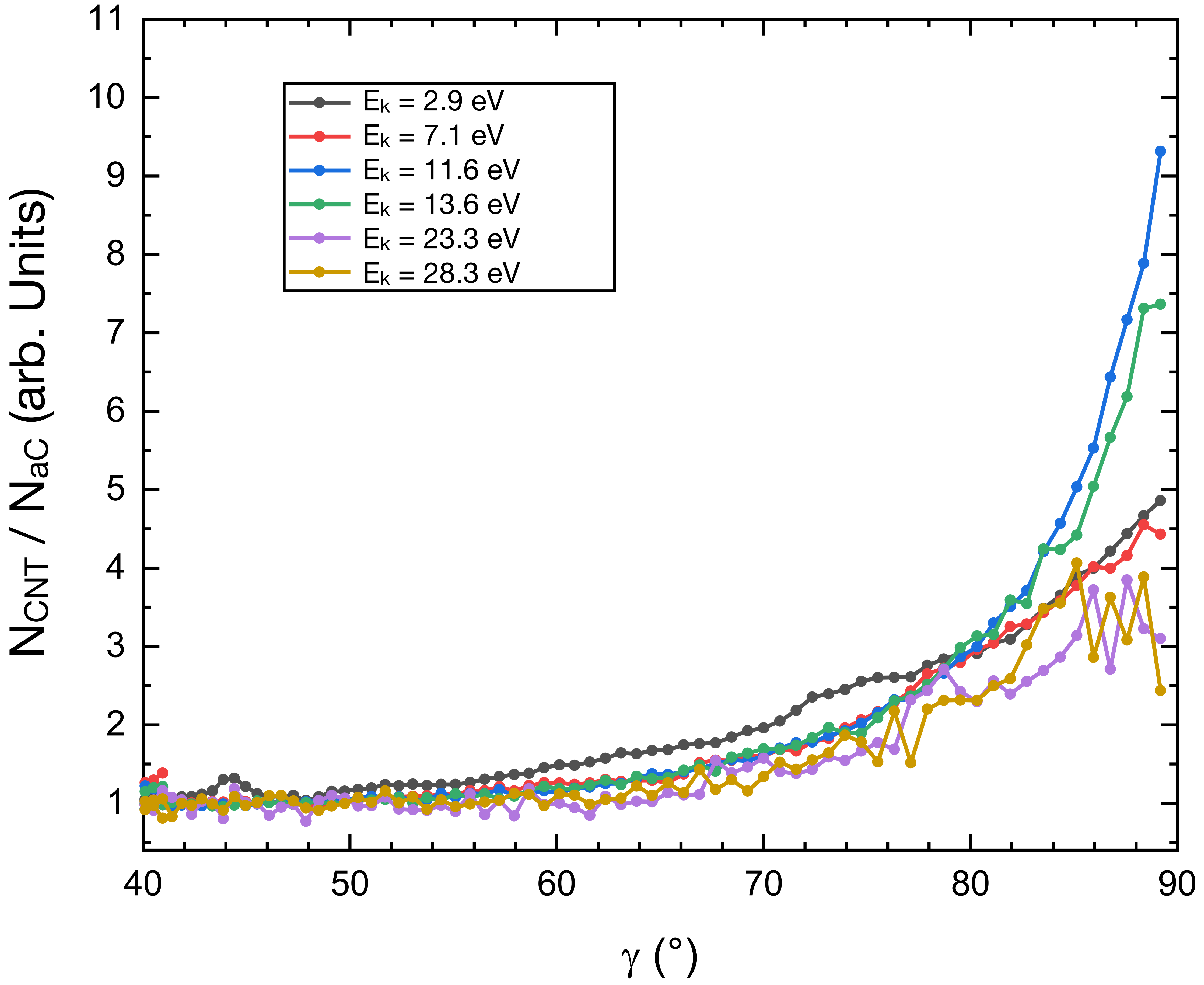


- Amorphous carbon (aC)
  - Disordered system
  - No preferential directions

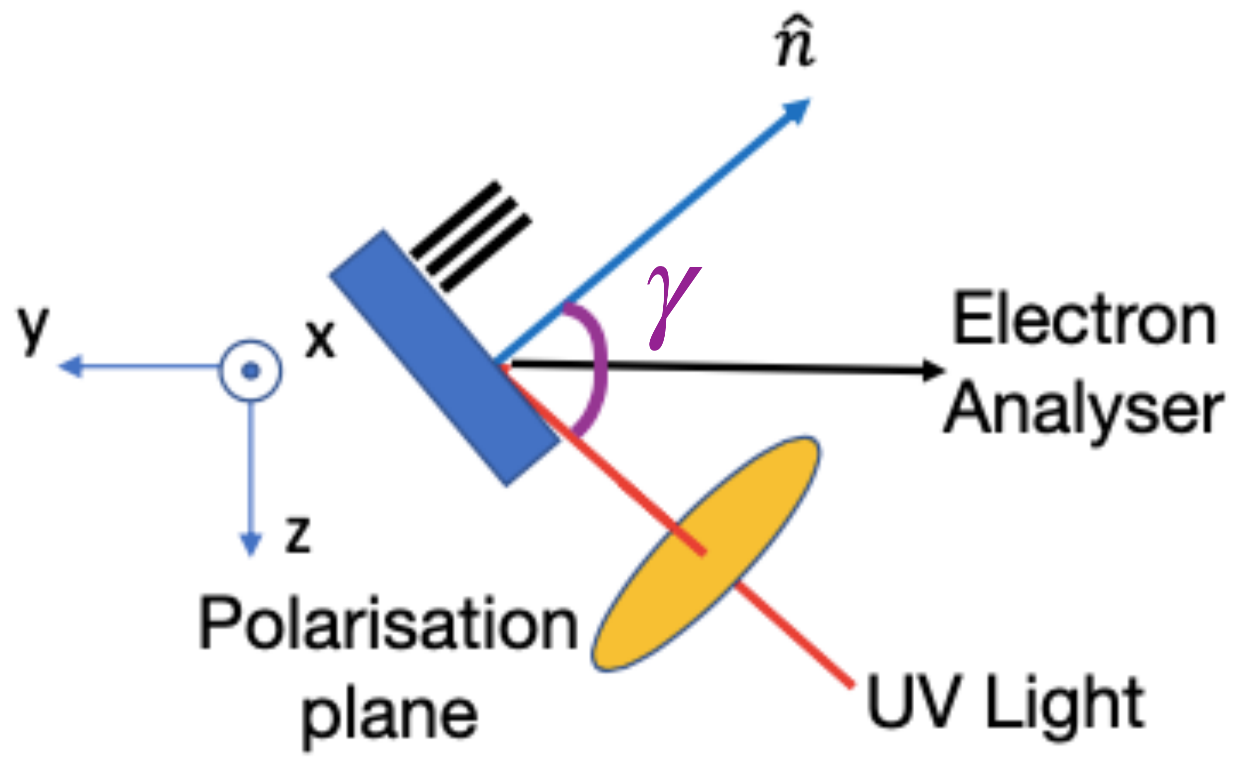
- aC data represent experimental angular efficiency
  - Compare with VA-CNTs data
  - Any anisotropy?



A First Sign of VA-CNTs Anisotropy



- VA-CNTs data over aC data ratio
  - Signal enhancement indicates anisotropy



Windowless APD Can Detect Low-Energy Electron Currents

- ✤ Electron gun in LASEC Lab @ Roma Tre
  - Electron energy: 30 < E < 1000 eV
  - Energy resolution 45 meV
  - Beam spot ~ 0.5 mm
  - Stable continuous current down to a few fA
- ✤ Reading APD bias current when shooting gun on it
  - Clear linear correlation with gun current

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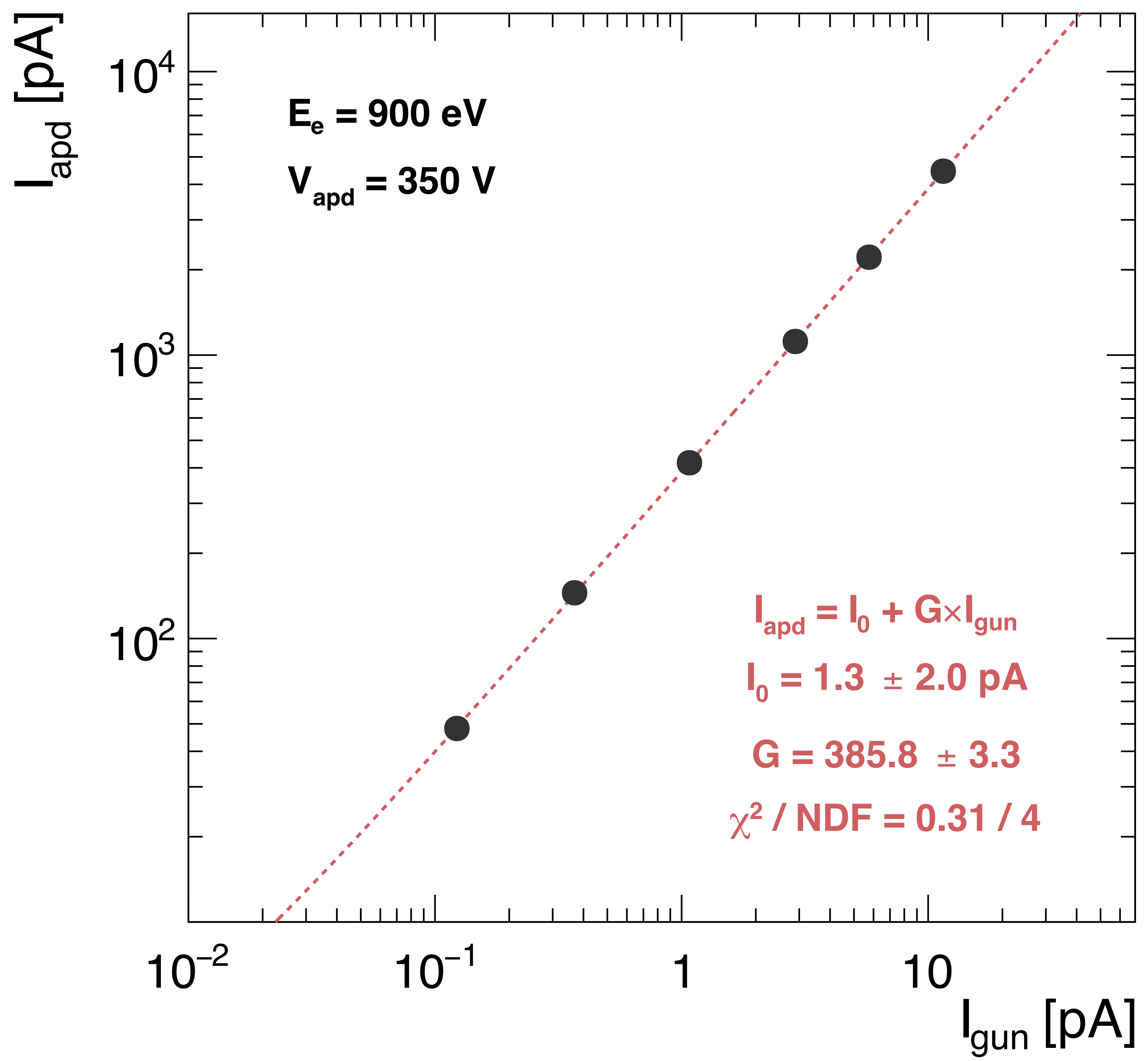

This is not a conclusion

- ‘Dark-PMT’ dark matter detector concept
    - Portable, no thermal noise, directional sensitivity
    - In principle sensitive to electron recoils of a few eV
- Vertically-aligned carbon nanotubes
    - First sign of anisotropy
- Windowless APD characterisation
    - Low-energy electron current detected
- News from 2020
    - ANDROMeDa: Awarded PRIN2020
    - 3-year project started in 2022
    - Aiming to build first working Dark-PMT prototype by 2025

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INFN Istituto Nazionale di Fisica Nucleare

LAboratorio di Spettroscopie Elettroniche e di Correlazione LASEC

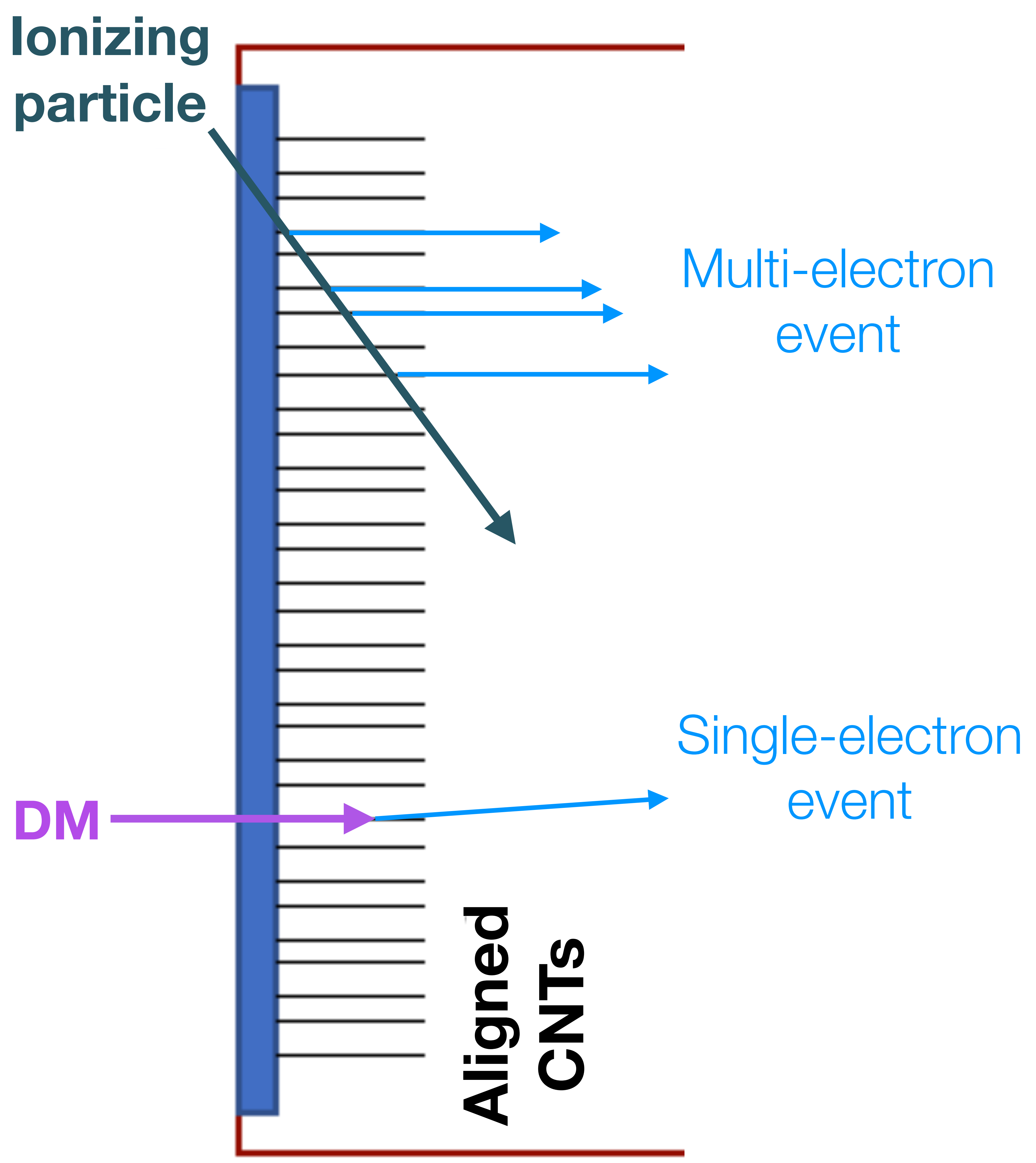
ROMA TRE UNIVERSITÀ DEGLI STUDI

ANDROMeDA

Aligned Nanotube Detector for Research On MeV Darkmatter

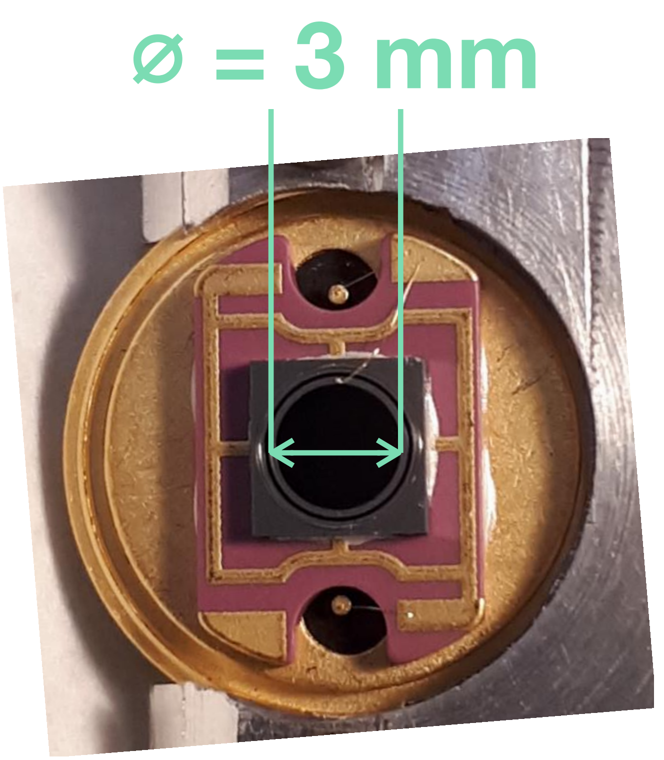
Backup

Detectors for keV Electrons



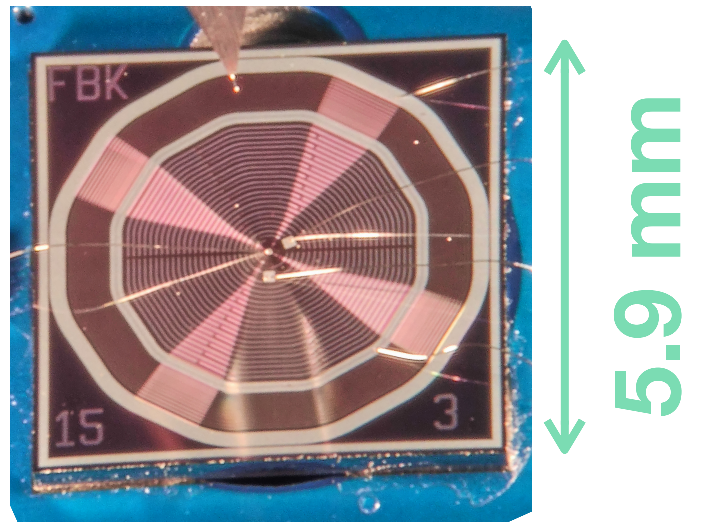
✤ Benchmark: Avalanche Photo-Diodes

- Simple, cost-effective
- Hamamatsu windowless APDs



✤ Possible upgrade: Silicon Drift Detectors

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



APDs and SDDs ‘born’ as photon detectors