Searching for Light Dark Matter with Aligned Carbon Nanotubes: the ANDROMeDa Project

RICAP 2022

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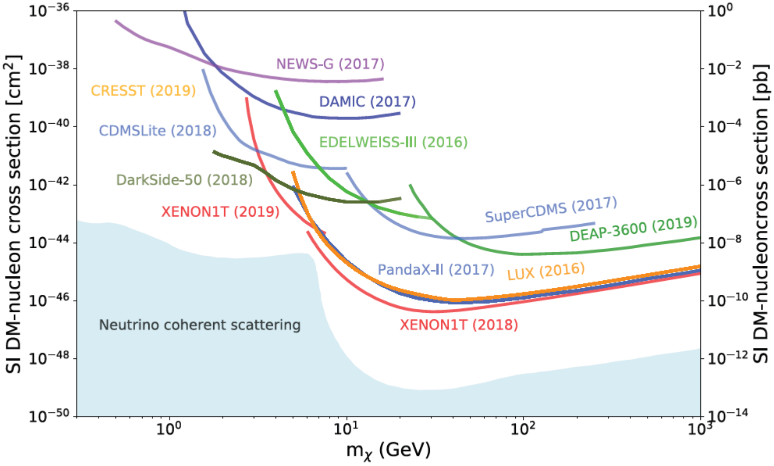
7/9/22

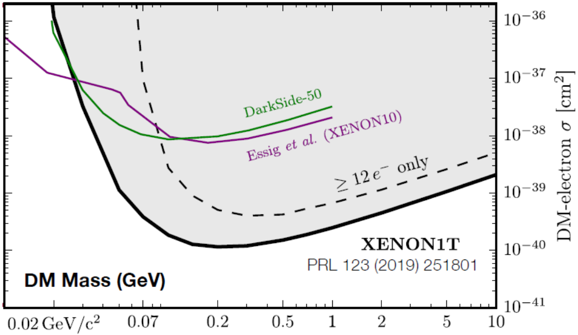
State of art: Dark Matter

- Diverse experiments with high mass target
- Exclusion Limits at high mass DM
- $M_\chi > 10\ GeV$
- Scattering $\chi + N$



Light Dark Matter

While for light dark matter:



- Need to measure lower DM masses: $1\ MeV < M_\chi < 1\ GeV \rightarrow 5\ eV < T_\chi < 50\ eV$
- Low sensitivity with current experiments
- Scattering $\chi + e^-$
- Directionality: DM wind from CYGNUS constellation

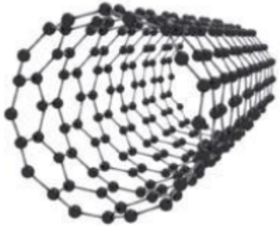
ANDROMeDa Target

ANDROMeDa target proposal:

- Carbon NanoTube as target
- CNT are 2D material:
  zero longitudinal density
- Carbon work function $\phi = 4.7\ eV$

Recoil electron has:

- Low kinetic energy (almost 5 eV)
- Short range in matter
- Same direction of DM wind



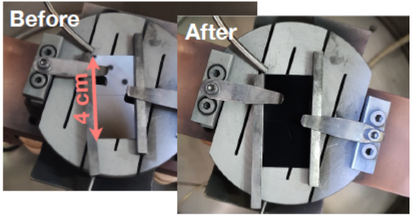
CNT

Experimental directionality:

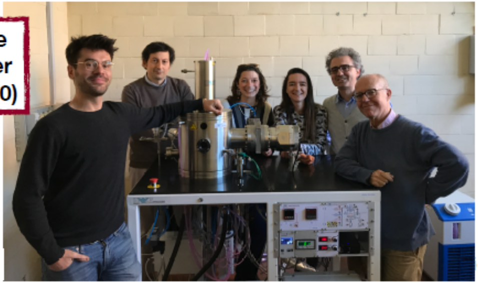
- If DM wind $\parallel$ CNT: Recoil electron gets out from target
- If DM wind $\perp$ CNT: Recoil electron is absorbed by target

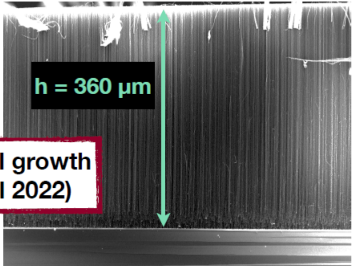
Growing CNT in Lab

- Nanotube facility in Rome la Sapienza



Installing the CVD chamber (Summer 2020)





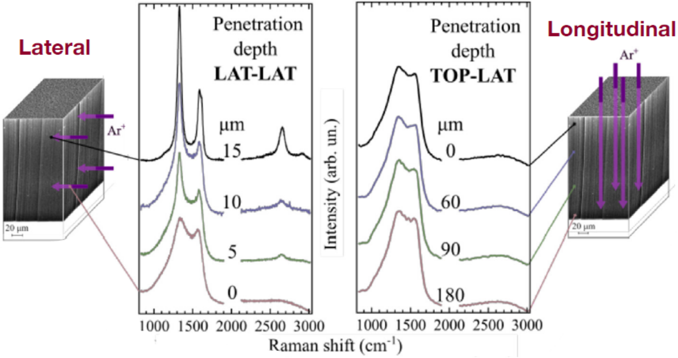
Typical growth (April 2022)

CNT: Positive ions

Ar^+ ions on CNT, the CNT degradation is:

- Lateral: **depending** Penetration depth
- Longitudinal: **indipendent** by Penetration depth

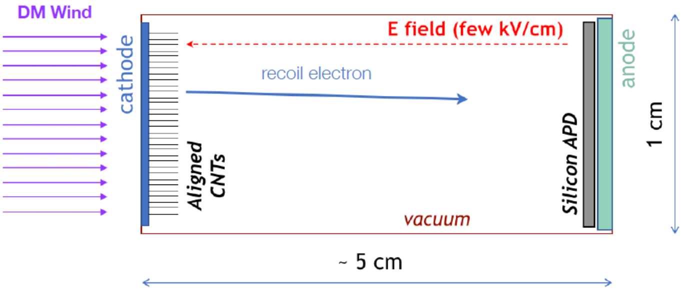
D'Acunto et al., Carbon vol. 139, pag. 768-775 (2018)



ANDROMeDa Prototype Scheme Dark-PMT

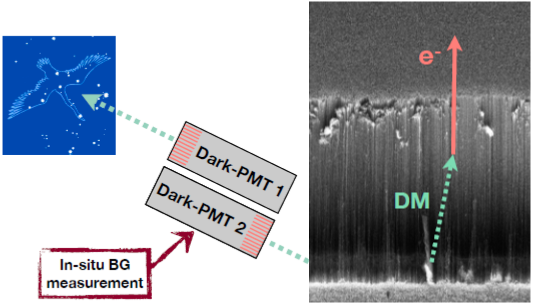
- Target: Aligned Carbon NanoTubes (CNT)
- Readout: Avalanche PhotoDiode (APD)
- Portable, cheap and easy to produce
- Unaffected by thermal noise ($\phi = 4.7\ eV$)
- Can be used at room T
- Directional sensitivity

Dark-PMT

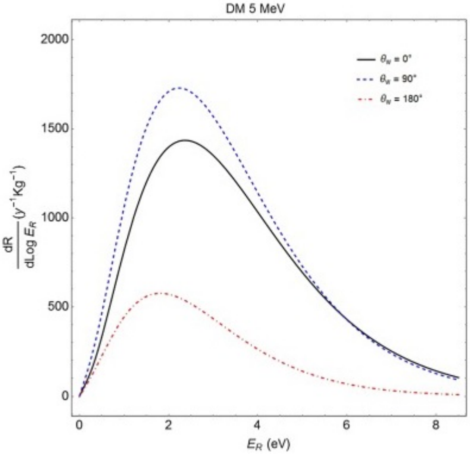


ANDROMeDa Directionality

- DM wind from CYGNUS
- Directionality with aligned CNT
- Measure $N_1 - N_2$

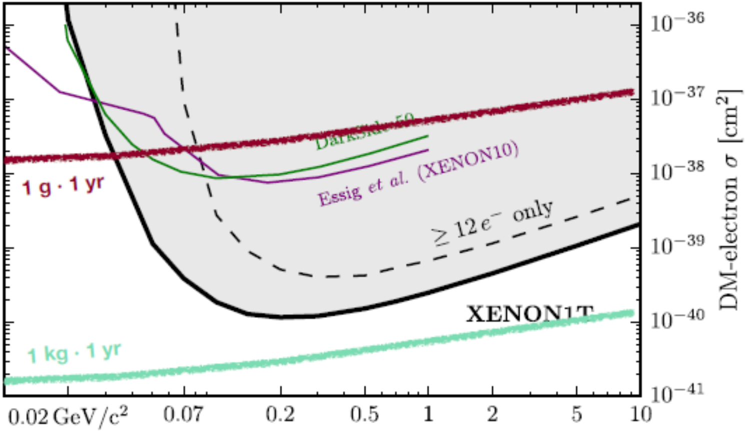


Physics Letters B 776 (2018) 338-344



Expected Exclusion limits

- CNT Density $\rho = 1\ mg/cm^2$
- $1\ g$ target: 100 Dark-PMTs with $10\ cm^2$ each PMT



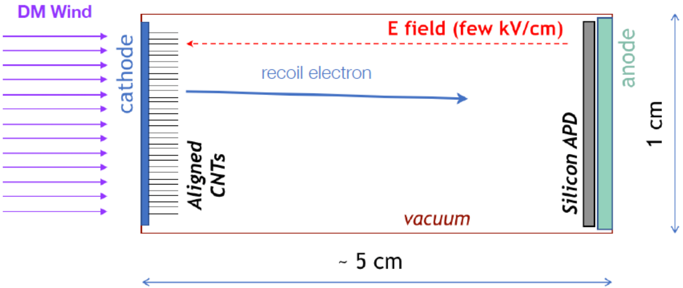
ANDROMeDa project

- Awarded PRIN2020 grant (1M €)
- 3-year project started in May 2022
- 3 units: INFN
  (F. Pandolfi)
  Università Roma la Sapienza
  (G. Cavoto)
  Università Roma3
  (A. Ruocco)
- Main goal: Dark-PMT at the end of the project

R&D Challenges

- **Minimize electron re-absorption in target**
- Detection of each single electron ($T_e \sim 5\ keV$)

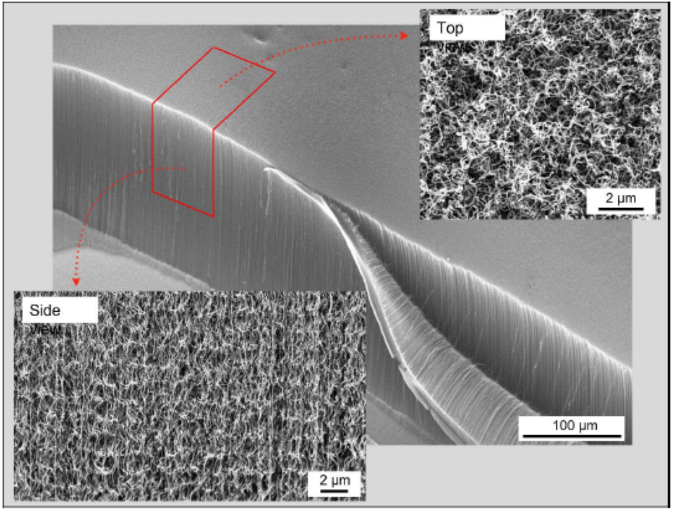
Challenges from both sides of the detector



CNT: Challenges

In CNT synthesis:

- Not aligned CNT
- Waviness
- Crust at the top
- Need to minimize both effect



CNT: Waviness

- CNTs are sustained by neighbours
- At the end of the grow there are impurities

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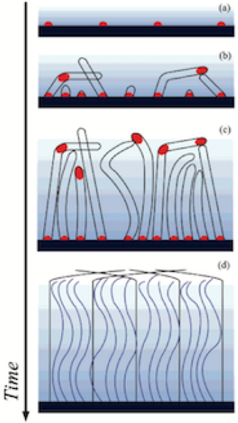
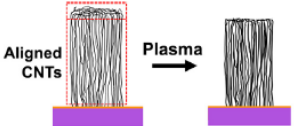
- Grow CNT in Electric field
- Uniform seeds size
- Increase seeds density
- Building new evaporation chamber in Rome

Q. Zhang, et al., J. Phys. Chem. C 111 (2007) 14638

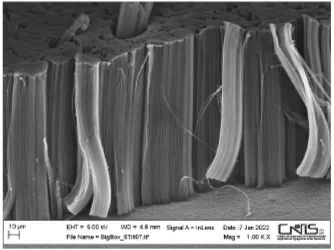


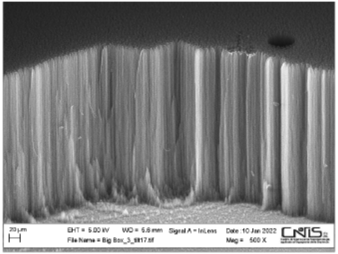
CNT: Removing Crust layer

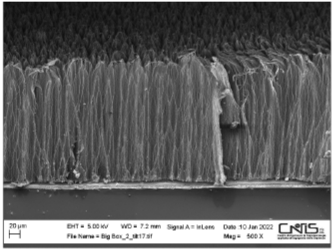
- A possibility is plasma etching after CNT grow (S.Seo,et al., Carbon,180,2021,204-214)
- Ar/O_2



Mild Ar/O_2 etching → **Modest Ar/O_2 etching** → **Aggressive Ar/O_2 etching**

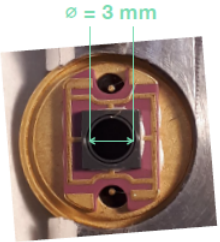

35 W

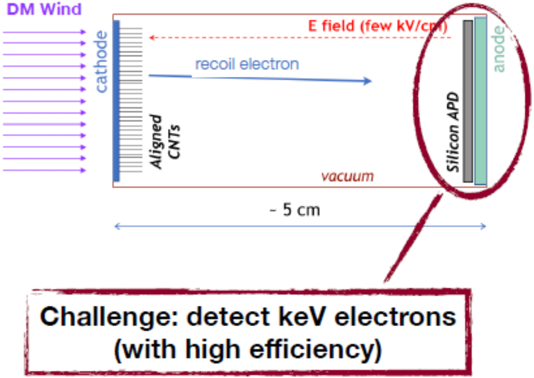

50 W


80 W

Detection: APD

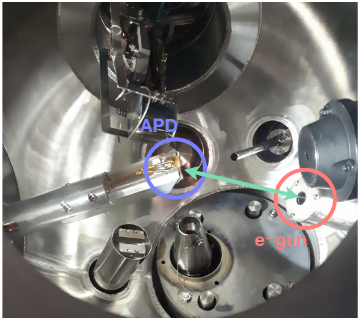
- Electrons from target accelerated to $\sim 5\ keV$
- APD are typically used for photons
- Adjusted for electron usage
- Another possibility are Silicon Drift Detectors

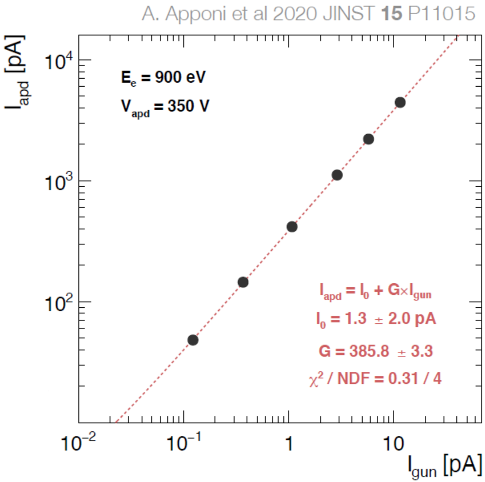




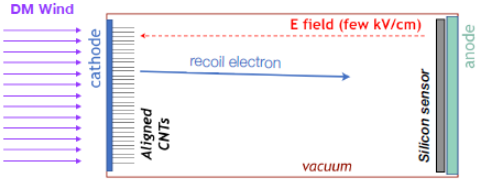
APD: Characterization

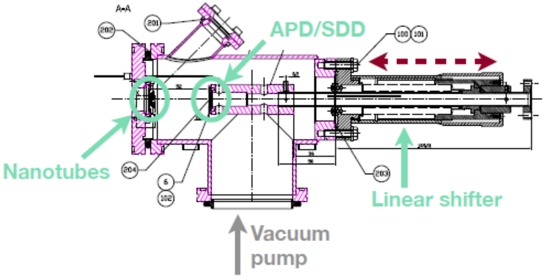
- We have characterized the APD by using an e-gun
- Reading I_{APD} by varying I_{gun}
- $E_e = 900\ eV$
- $I_{APD} = I_0 + G \times I_{gun}$

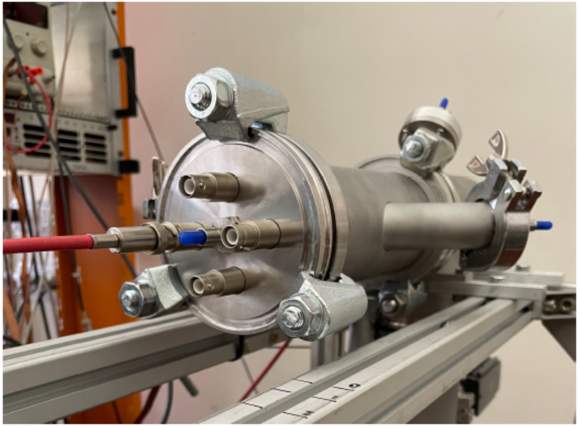




Andromeda: Dark-PMT Prototype







Conclusions

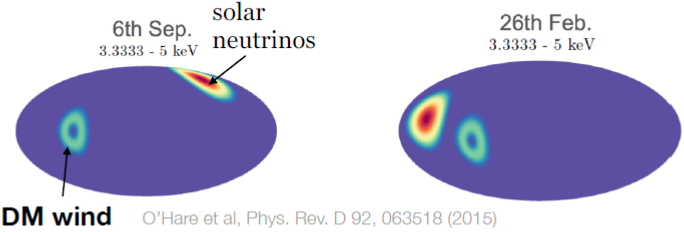
- DM mass region not much explorated
- Light DM detection by using Dark-PMT
- Dark-PMT:
  Portable, no thermal noise
  Directionality
- CNT: 2D material
- We are opening positions:
  Post-Doc INFN (Dark-PMT prototyping, electronics)
  Post-Doc Roma Tre (nanotube spectroscopy)
- Contact: francesco.pandolfi@roma1.infn.it

First Dark-PMT prototype in 2025

Backup slides

DM wind direction

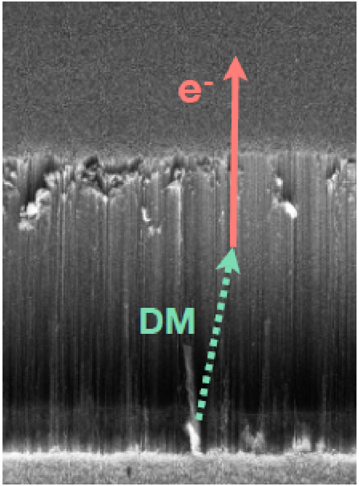
- Neutrino floor from Sun
- Cygnus never overlap Sun



O'Hare et al, Phys. Rev. D 92, 063518 (2015)

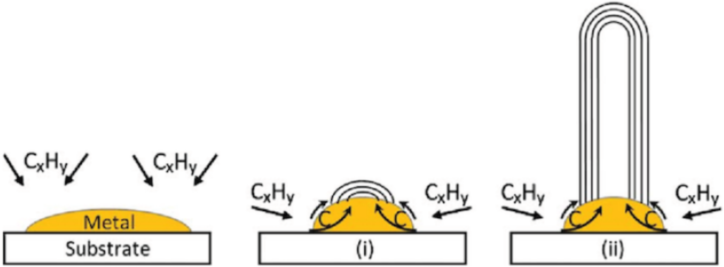
Target: CNT

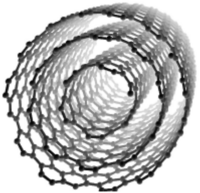
- CNT: lenght $=$ up to 300 μm, width $\simeq 5$ nm
- Directionality
- Recoil electron has almost the direction of χ



Target: CNT growing

Chemical Vapor Deposition Technique





Multi-wall nanotube

CNT: Waviness

At *nm* scale there is CNT waviness

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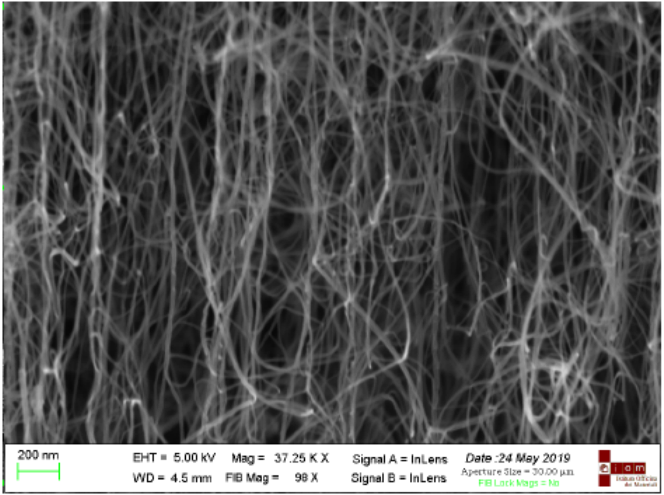
Difficult electron detection



CNT: Waviness

- A possibility is to increase seeds density
- Uniform seeds size
- Grow CNT in Electric field
- Building evaporation chamber in Rome

	Current	**Goal**
Seed density (cm^{-2})	10^{10}-10^{11}	$> 10^{12}$
Seed size (nm)	15-30	5 (±20%)

CNT: Recoil electron

- Low Energy χ
  Low Energy e^-
- C work function $\phi = 4.7\ eV$

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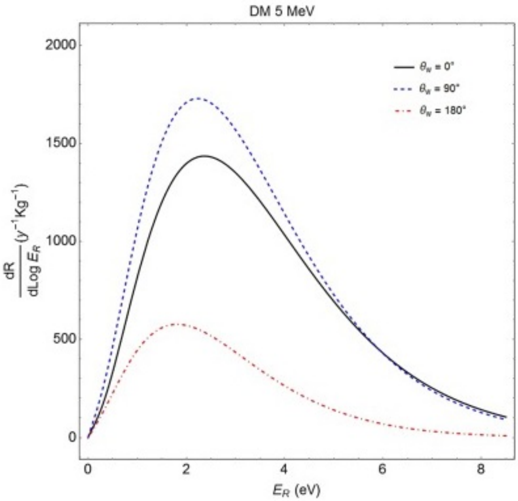
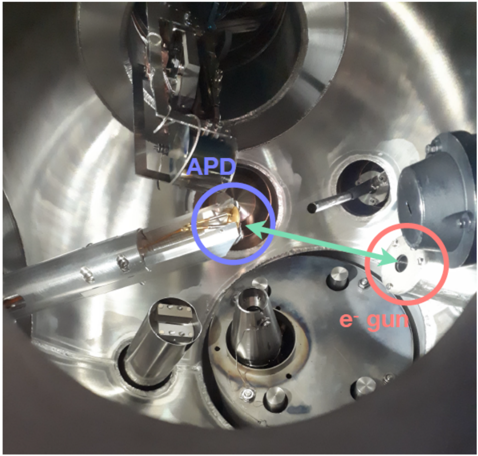
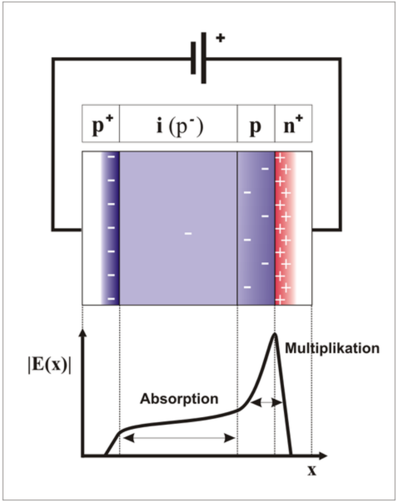


APD: characterization with e-gun

- Electron energy $30 < E < 1000\ eV$, $\sigma_E < 0.05\ eV$
- Gun current $I \simeq 1\ pA$
- Single electron
- Beam entirely on APD



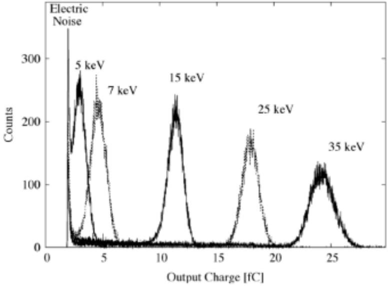
APD



Electron detection

- APD can measure single e^- if $E_e > 5keV$
- SDD has better resolution at low energies

S. Kasahara, et al.,
IEEE Trans. Nucl. Sci. **57** (2010) 1549



G.Gugiatti, et al.,
NIM A **979** (2020) 164474