Light detection for Liquid Argon experiments

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Astroparticle Physics - XXIV cycle
DarkSide Project
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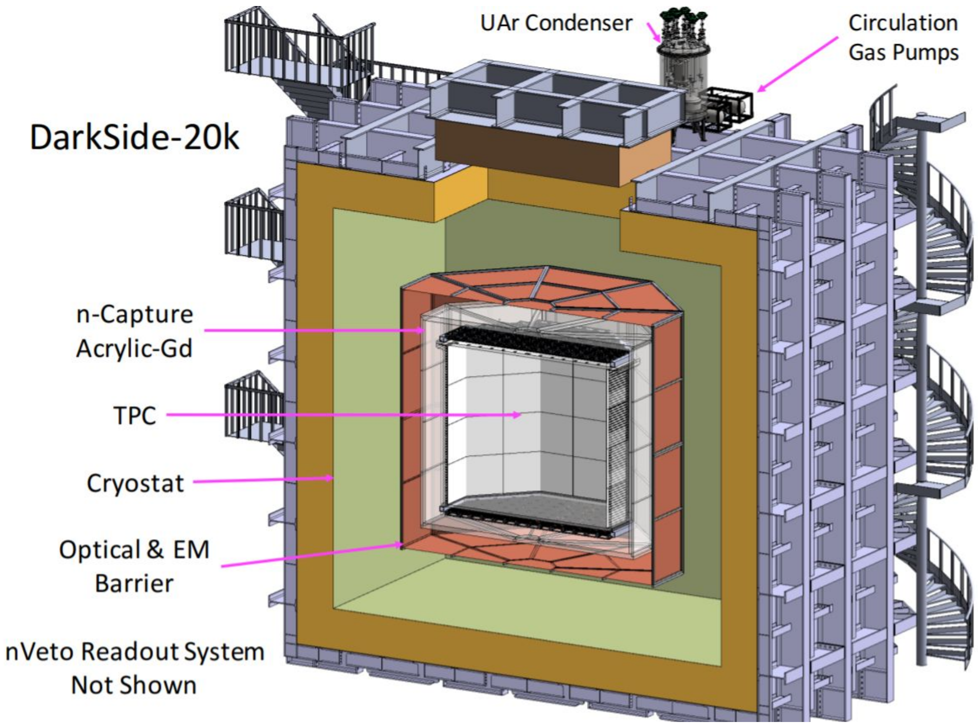
DarkSide-20k

Dual phase TPC filled with 50 tons of underground Argon (depleted in the radioactive ^{39}Ar component).

Photodetectors based on the Silicon PhotoMultiplier (SiPM) technology, with a total instrumented surface ~ 28 m^2.

Scintillation in Argon following a particle interaction in the detector medium will form the signal for SiPM photodetectors

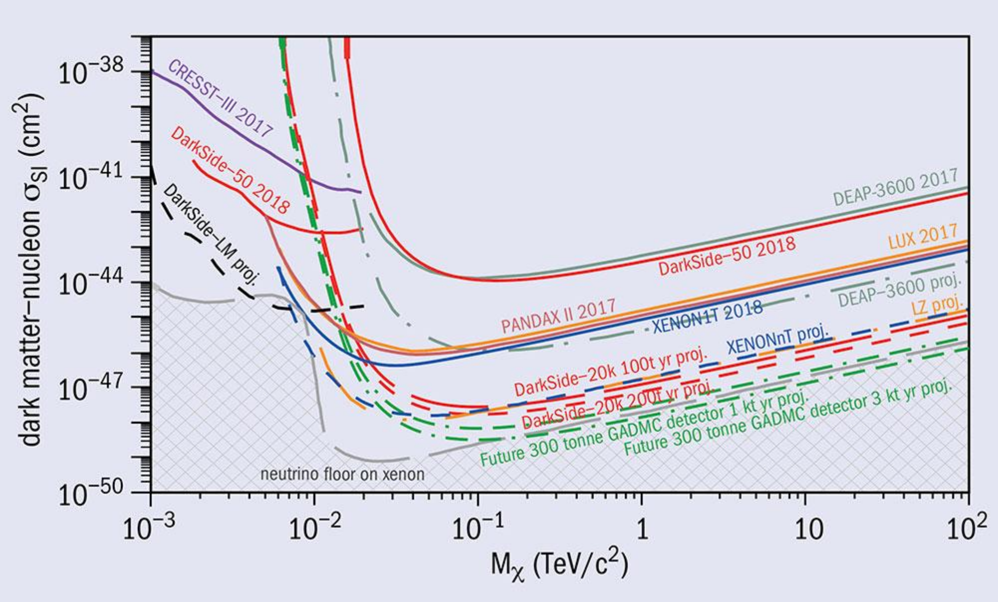


Dark Matter signal in DarkSide-20k

DS-20k will search for high-mass WIMP DM particles which will produce nuclear recoils in the energy range of 30 keV_{nr} to 200 keV_{nr}.

A NR corresponding to a DM particle interaction will give rise to a few 100 - 1000 photons in the primary scintillation event.

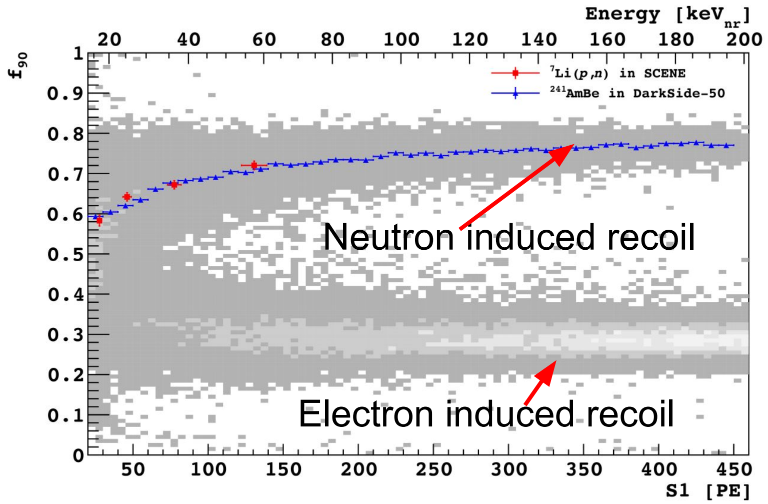
And DM interactions being very rare and low in momentum transfer, there is a need for maximizing the light collection efficiency of the detector.



LAr as detector medium

Scintillation emission at a wavelength of 128 nm with two characteristic time constants (6 ns & 1.6 μs)

The relative weight of the 2 components depends on the impinging particle type. For eg., the slow component is strongly suppressed for neutron induced recoils



Pulse Shape Discrimination (PSD) is a key feature of LAr detectors

- Rejection power (RP) larger than 10^8 against background events
- At low energy, RP is limited by statistical fluctuations of detected photons

My activity is intended to increase the LY impacting directly the physics reach of the experiment

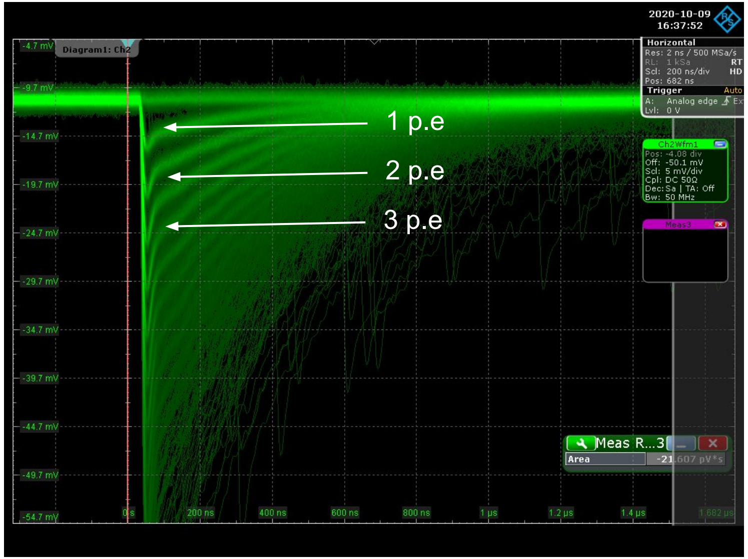
higher LY → lower threshold

SiPMs as photodetectors

A SiPM integrates a dense array of Single Photon Avalanche Diodes (SPADs), each with its own quenching resistor (R_Q) (100 - 1000s of microcells per mm^2)

Each SPAD is operated in the Geiger mode, and detects photons identically and independently.

The photocurrents from each microcell combine to form an analog output, and is capable of giving information on the magnitude of an instantaneous photon flux.



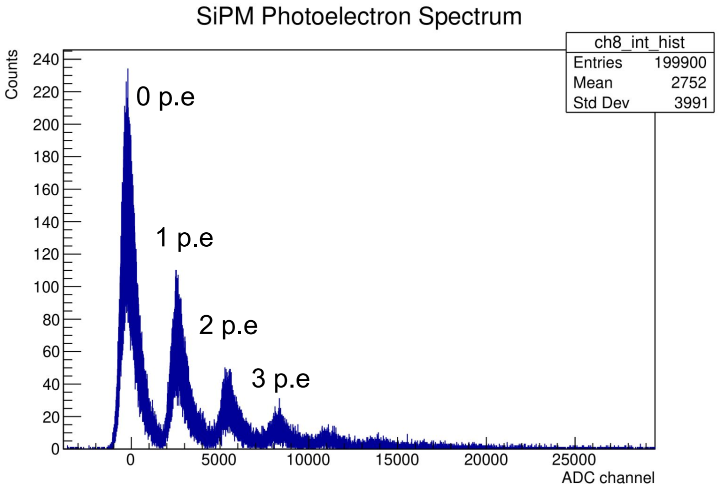


Fig: Top: SiPM response to light pulse from a laser.
Bottom: Charge spectrum of the light pulses.

Photon Detection Efficiency

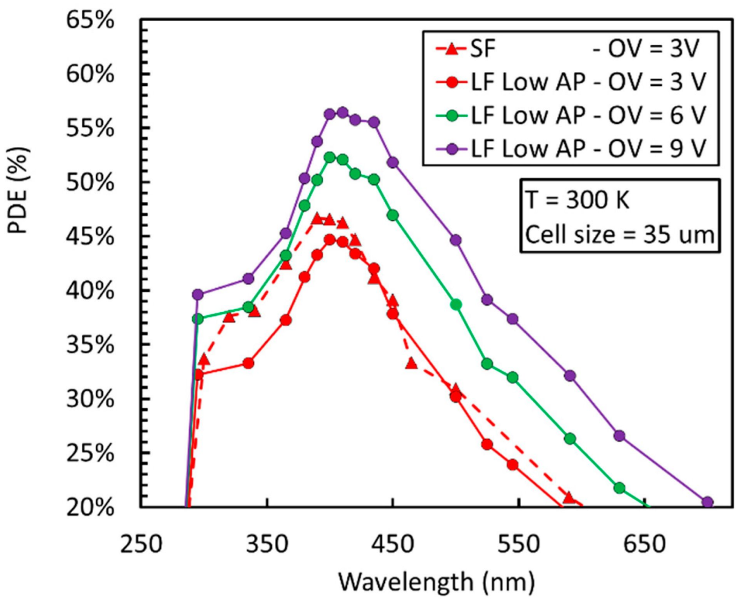
The Photon Detection Efficiency (PDE) of a SiPM is defined as:

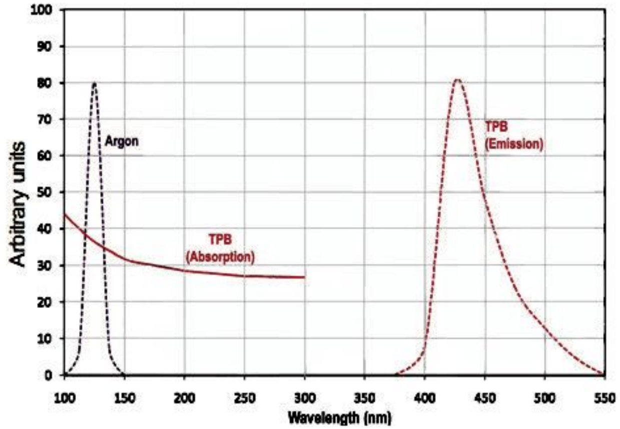
$$PDE = QE(\lambda) \,.\, P_{trig}(V) \,.\, FF$$

- QE: quantum efficiency of Si
- P_{trig}: triggering probability of an avalanche
- FF: fill factor, i.e. ratio of effective active area and overall cell area

Need for wavelength shifting for efficient detection of LAr scintillation light as QE wavelength dependent.

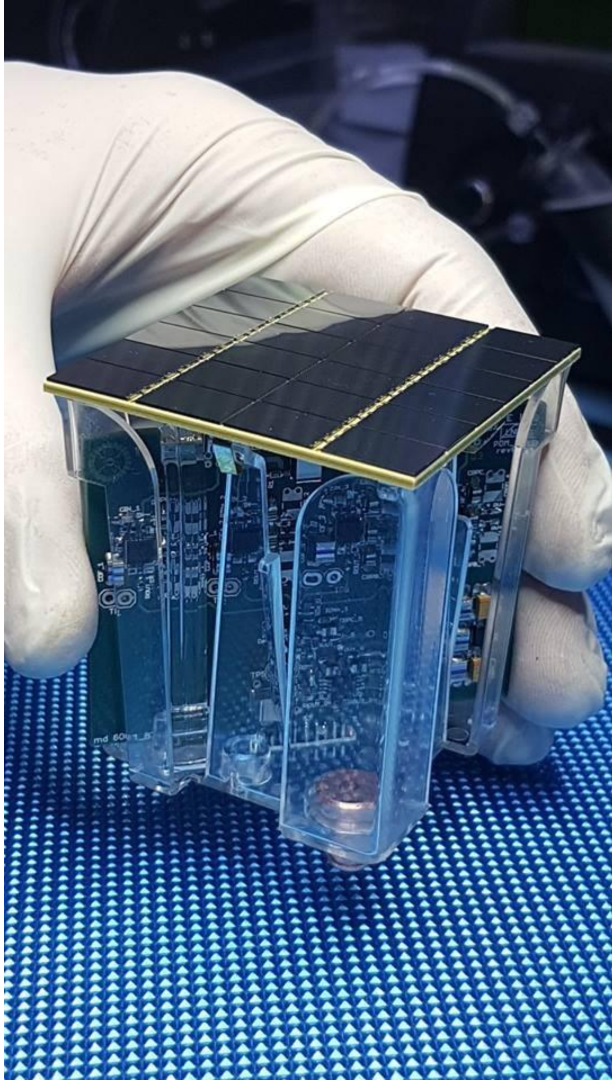
Tetra-Phenyl-Butadiene (TPB) is the most common wavelength shifter used with an emission peak around 420 nm.



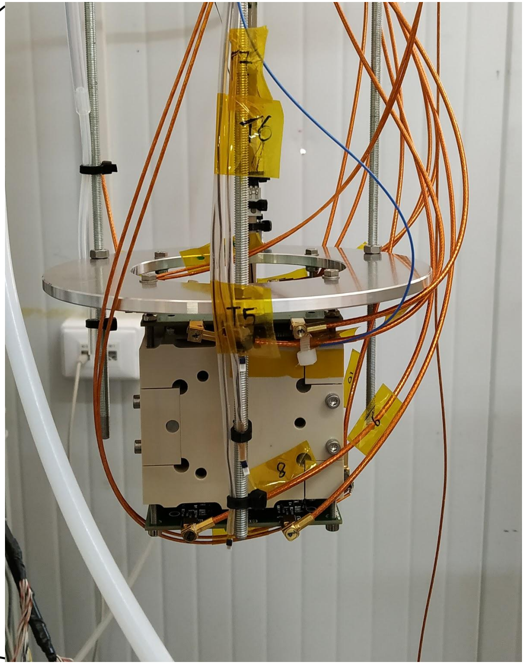


PhotoDetector Modules (PDMs)

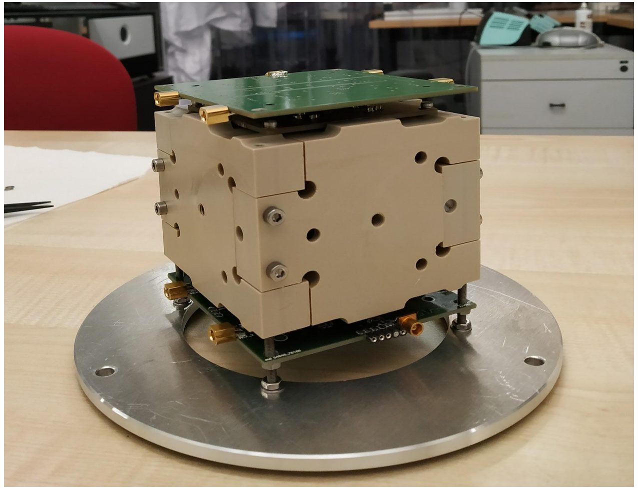
- **Light sensitive units of DarkSide-20k**
  - 24 SiPMs, each 12x8 mm^2 mounted on a tile (SiPM array)
  - Coupled with a front-end cryogenic pre-amplifier
- **Each PDM connected to a digitizer**
  - Digital processing of the acquired waveform to extract the photon arrival time and charge information.
- **Sum up the data on collected charges and time**
  - Reconstruct the original shape of light emission to extract information on the particle type and the physics of the interaction process.



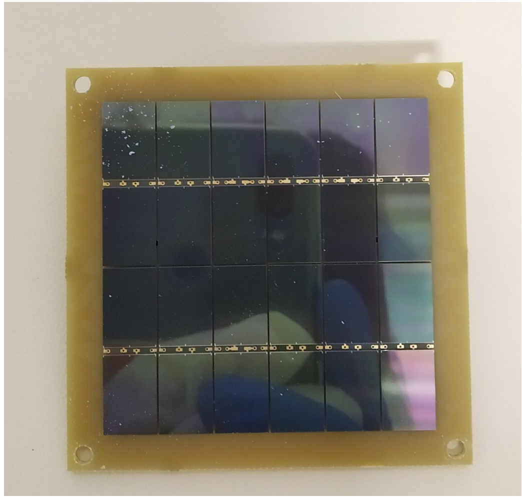
SiPM Test setup in Argon (STAR) Detector



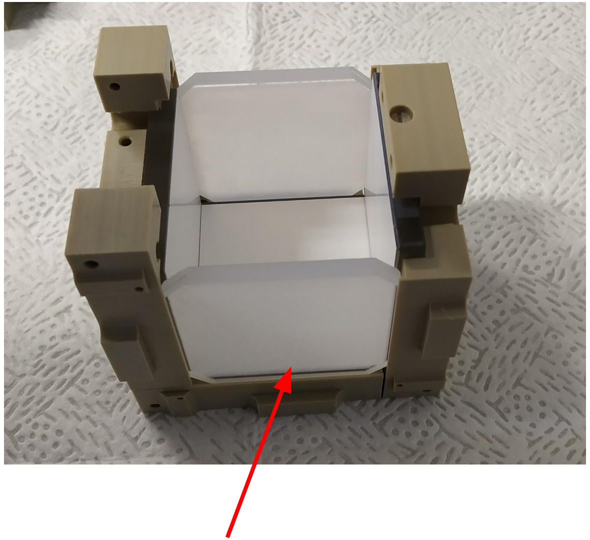
Detector components



Fully assembled detector with readout electronics

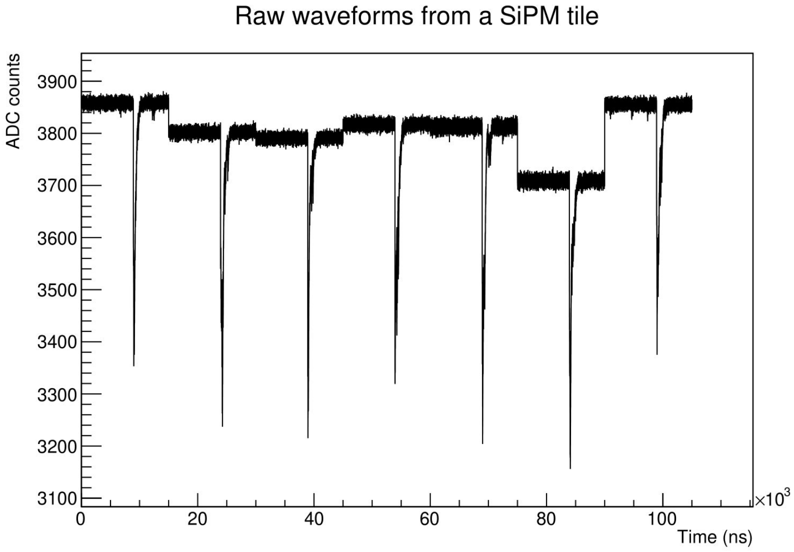


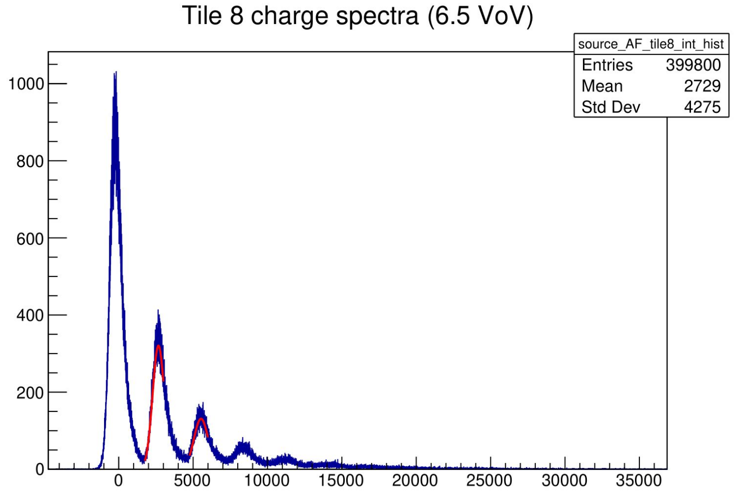
SiPM photodetector array

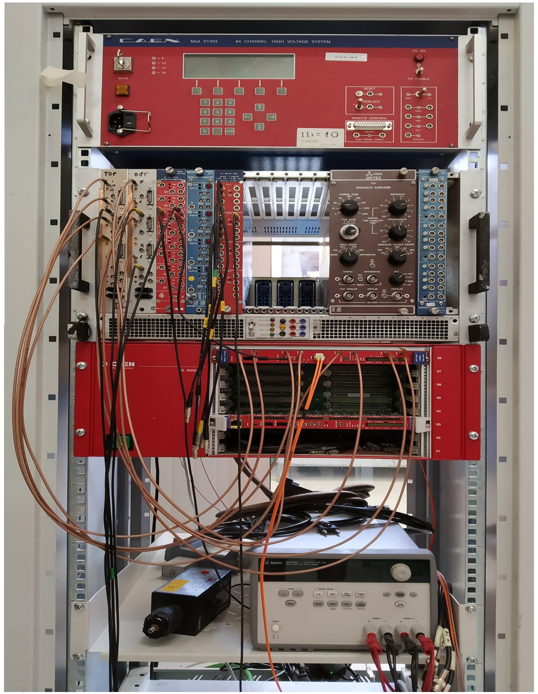


Detector side walls made up of light reflectors and wavelength shifter material (TPB)

Data Acquisition & SiPM gain calibration

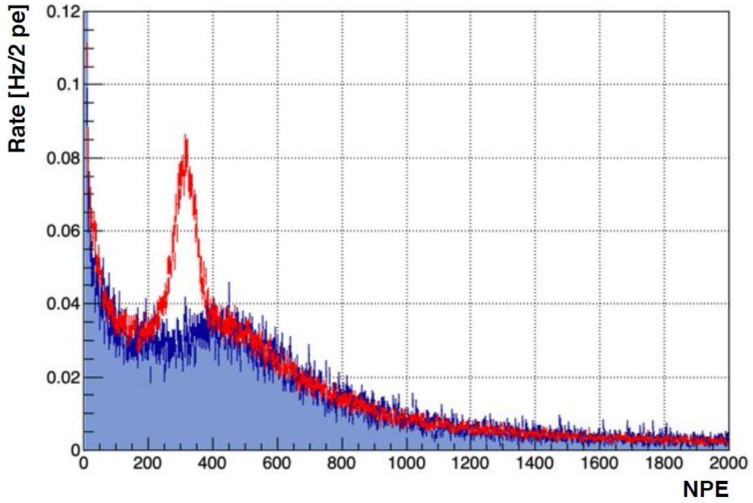


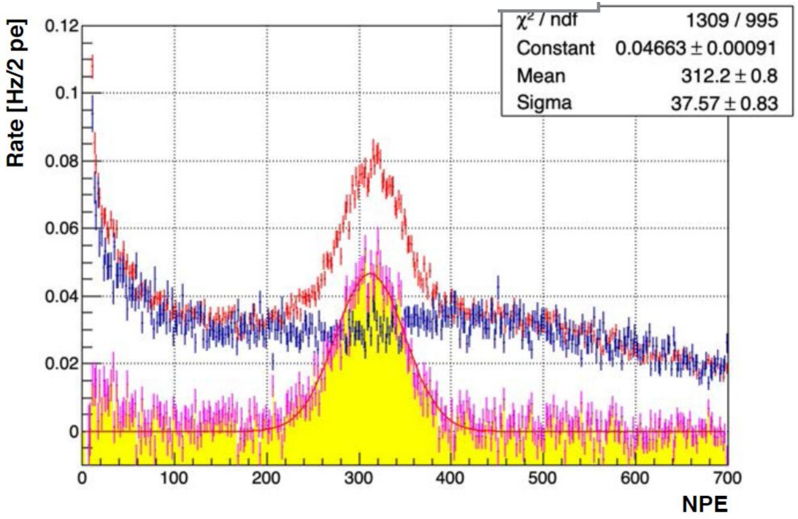




DAQ system

Standard laser source





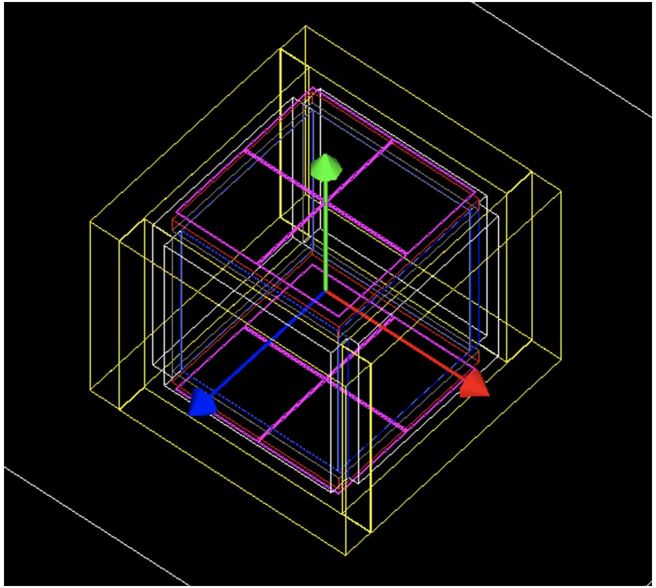
Measurement of LAr scintillation light

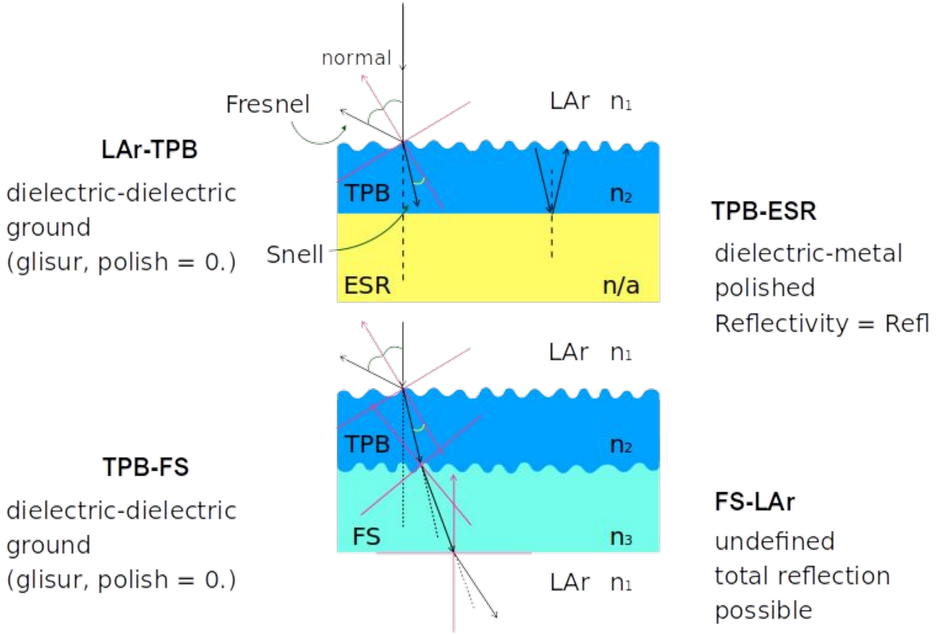
$$ {}^{241}_{95}\mathrm{Am} \xrightarrow{432.2\mathrm{y}} {}^{237}_{93}\mathrm{Np} + {}^{4}_{2}\alpha^{2+} + \gamma 59.5409\mathrm{keV} $$

Am-241 source

Detector Simulation

Optical surface Model 1

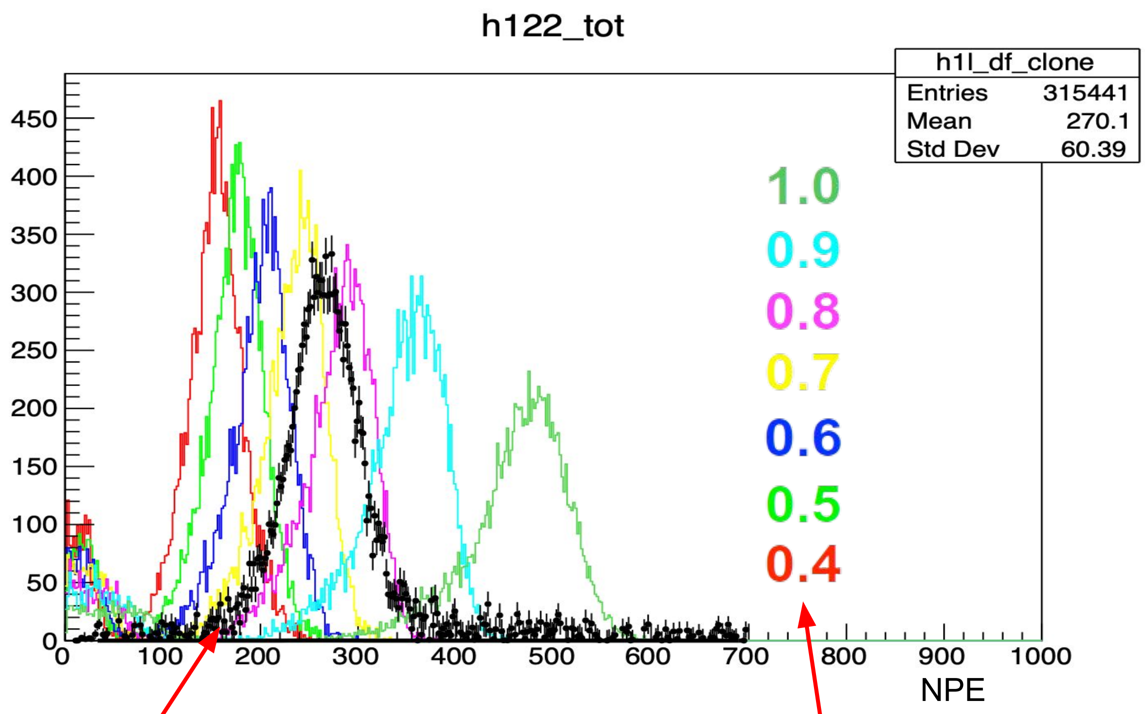




Performed using GEANT4 simulation package.

Detector geometry defined and two different models for the optical surfaces used for testing the hypotheses.

Detector Simulation



Comparison with the data (black)

Reflectivities used in the simulation runs

Fig: Simulation run to obtain an estimate of the reflectivity of the light reflectors

Perspectives for the future work

- Investigation of other wavelength shifters by carrying out a measurement of the relative LY between TPB and PolyEthylene Naphthalate (PEN) by running two small detectors in the same LAr chamber contemporarily. This is of primary importance for the DS-20k veto.

- Developing a prototype detector with a 4-pi SiPM readout, which is a plausible solution to circumvent the pile-up from ^{39}Ar in future multi-ton scale detectors, thus extending their physics reach.

- Collaborating with the DS-Software group for the software development and its application to Proto-1t, a one-ton scaled down prototype of DS-20k, which will start data taking in the next year.

Thank you!

The Dark Matter Puzzle

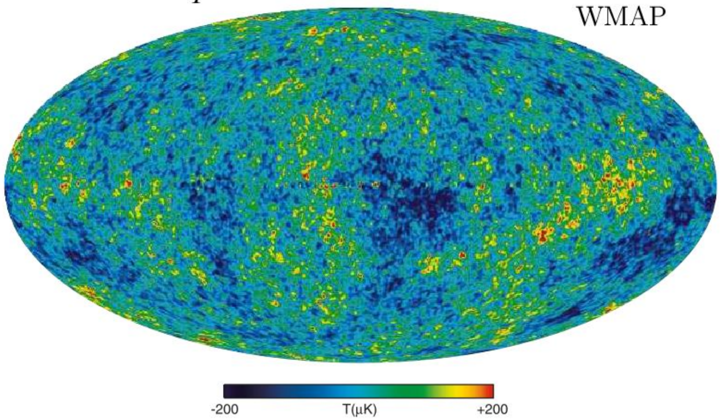
An unknown component of the universe, whose presence is inferred from observational data at different length scales.

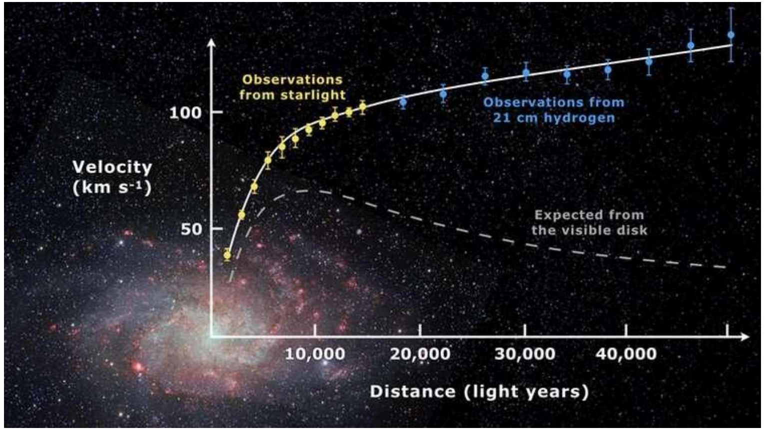
Key Observations: CMB temperature anisotropies, Gravitational lensing, Galactic rotation curves

Plausible explanations:

- Modified Newtonian dynamic models
- Massive astrophysical compact halo objects
- Dark Matter particles such as, sterile neutrinos, WIMPs, Axions

$$T = 2.725°K, \quad \frac{\delta T}{T} \sim 10^{-5}$$





Search for the Dark Matter particle

- **Production at particle accelerators**
- **Signals from annihilation and decay products**
- **Direct detection**

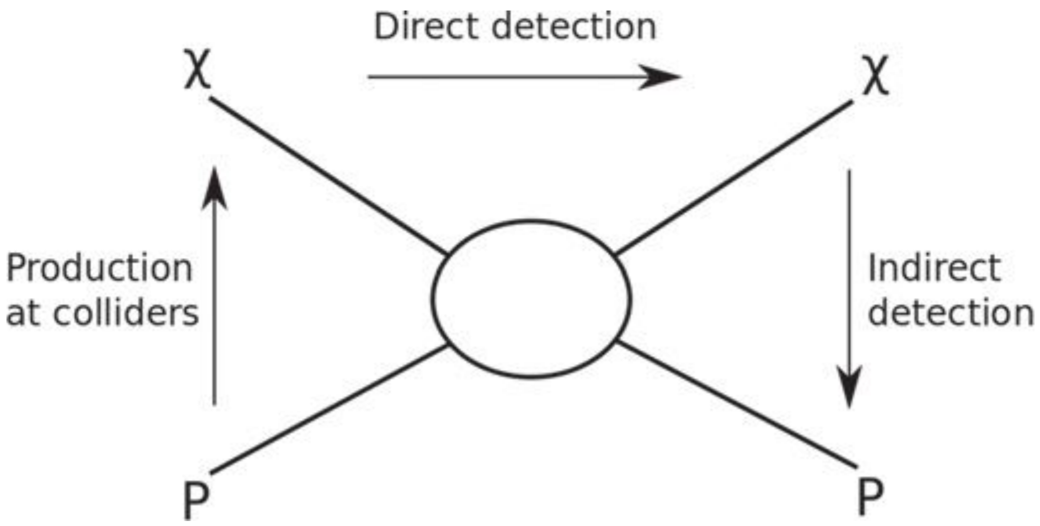


Fig (1): Possible dark matter detection channels

Experimental techniques for direct detection

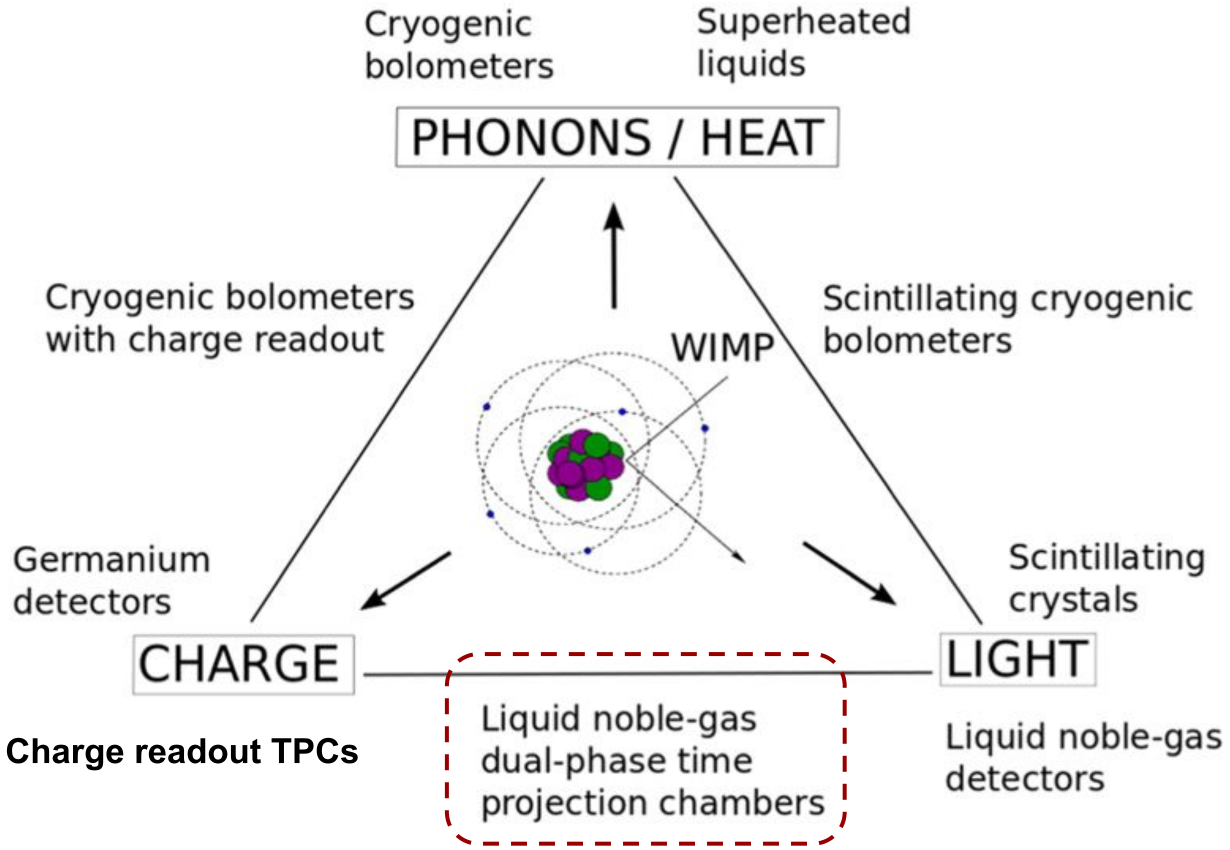


Fig (2): Possible signals in direct detection experiments depending on the technology in use.

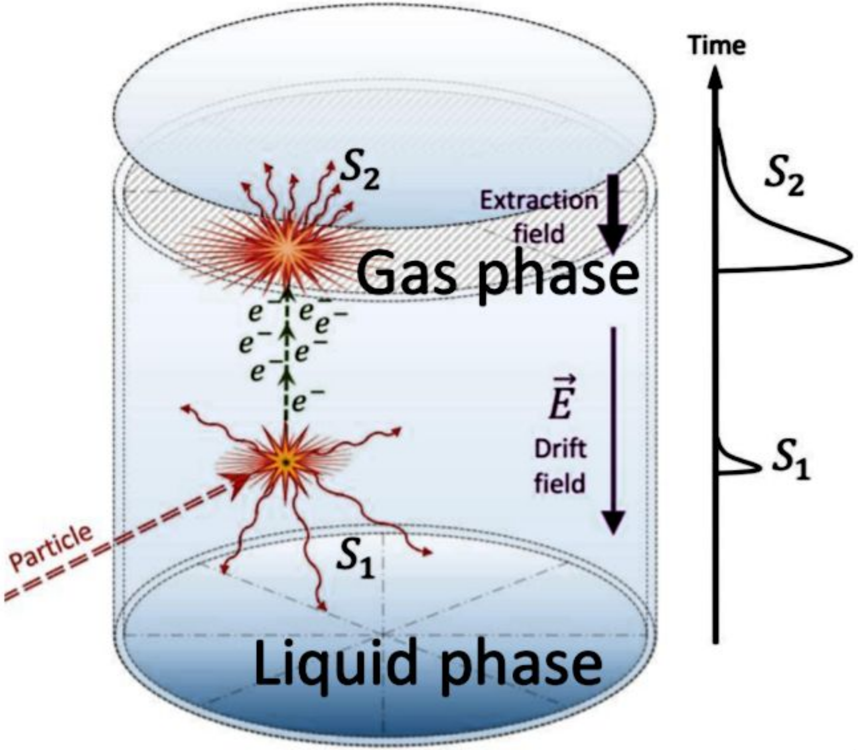
Dual phase Time Projection Chambers (TPCs)

A liquified noble gas (Ar, Xe, Ne) used as detector medium.

Particle interaction in the medium emits primary scintillation light pulse (S1)

Electrons generated are drifted towards a gas pocket on the top, where they produce a second scintillation light pulse (S2)

Emitted S1 and S2 photons are detected by a set of photodetectors at the top and at the bottom of the detector.



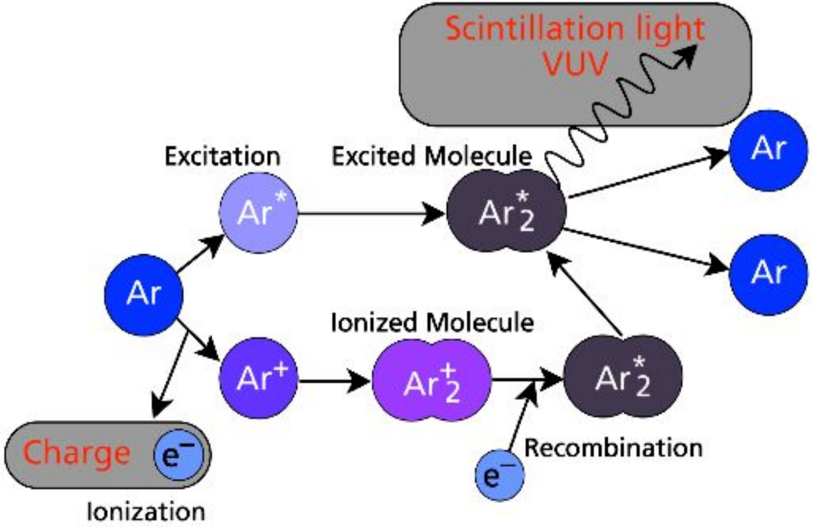
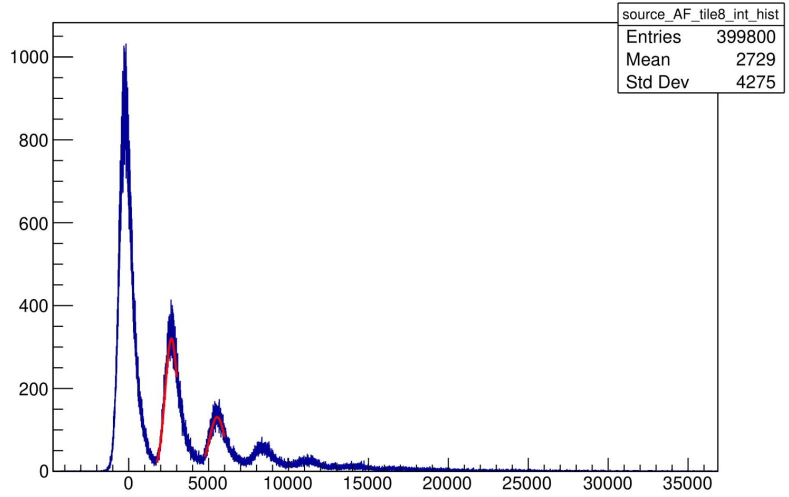


Fig: Mechanisms of Scintillation in LAr

SiPM gain Calibration

Tile 8 charge spectra (6.5 VoV)



Tile 8 amplitude spectra (8.5VoV)