Exploring the Dark Universe: The DarkSide-20k Experiment

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December 13

CNP Research Day, Virginia Tech

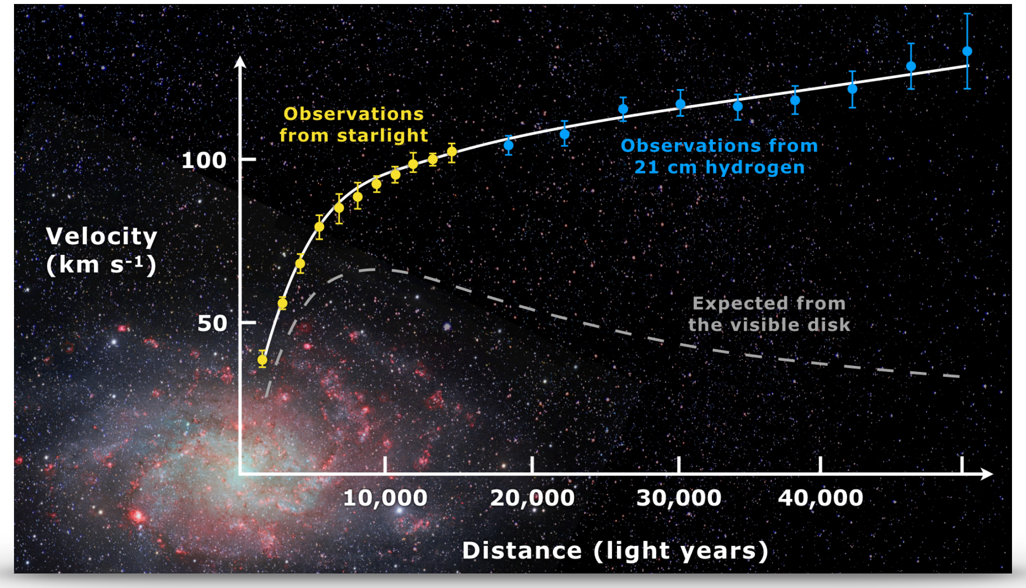
Evidences for Dark Matter

Galactic Rotation Curves:

- Rotational speeds of galaxies stay constant at different radii.
- Visible mass alone can't explain this; suggests unseen mass (dark matter).

Strong Gravitational Lensing:

- Light from distant objects bends more than visible matter accounts for.
- Indicates much more mass present, inferred to be dark matter.

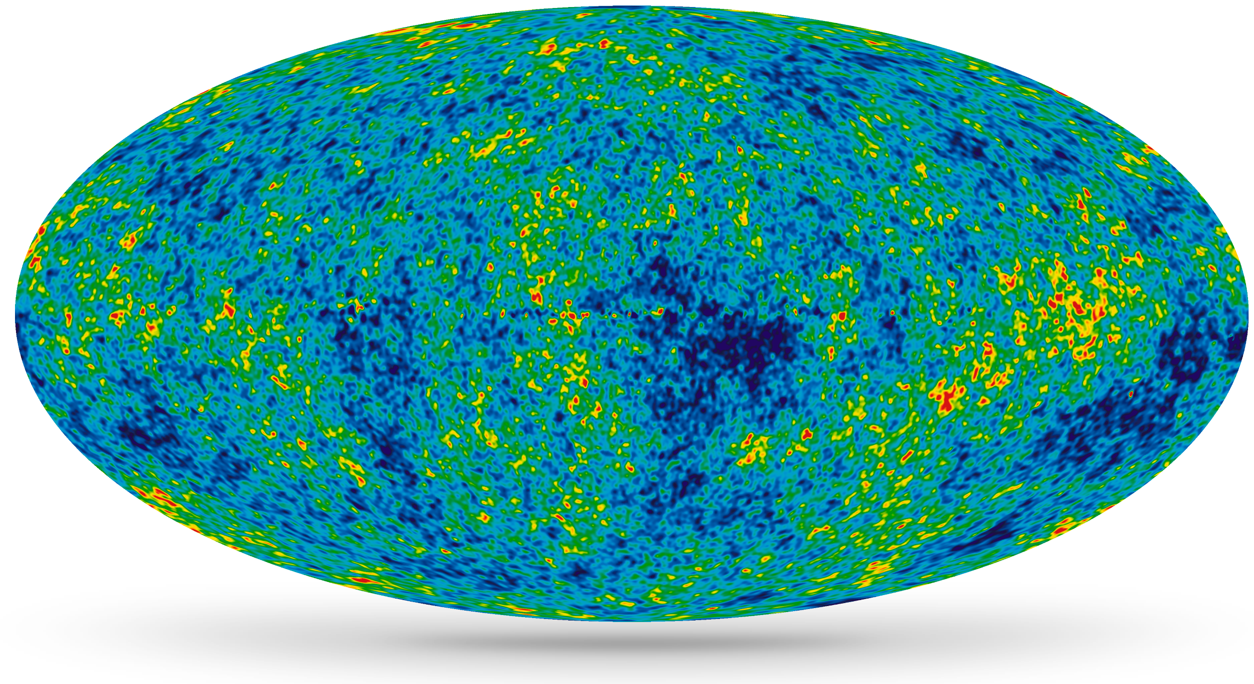


Rotation curve of spiral galaxy Messier 33

Evidences for Dark Matter

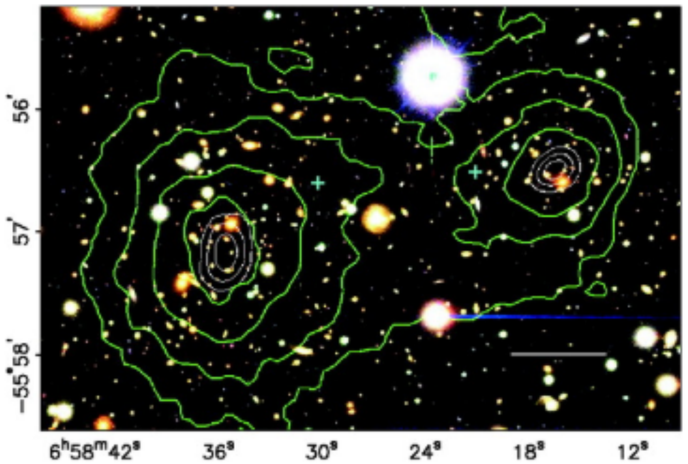
Cosmic Microwave Background (CMB) Anisotropy:

- Slight temperature fluctuations reveal early mass distribution.
- Patterns support dark matter's role in cosmic structure growth.

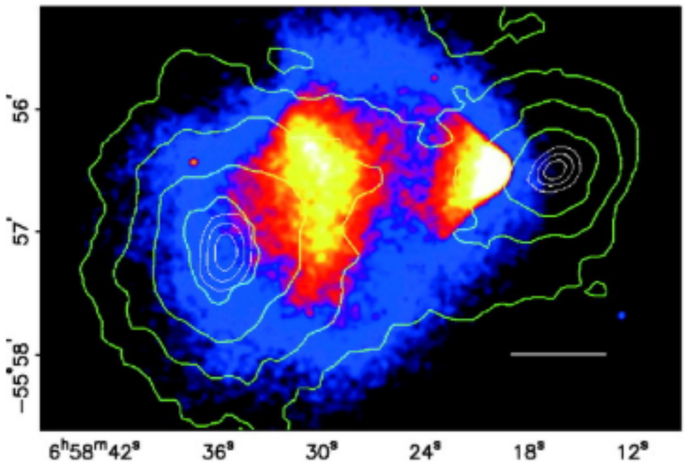


Bullet Cluster Observations:

- Colliding galaxy clusters show separation of normal matter (X-ray) and gravitational fields (lensing).
- Evidence that dark matter interacts mainly through gravity, unlike normal matter.



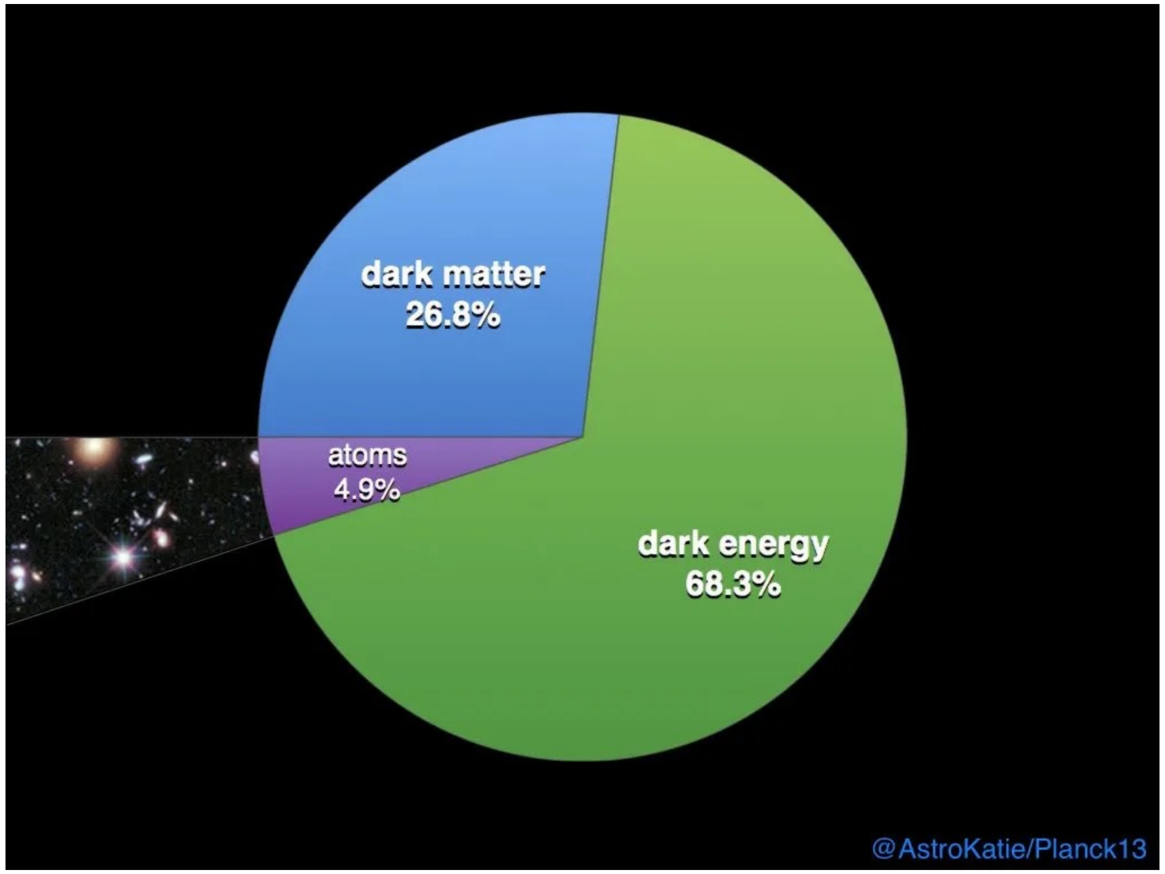
map of gravitational lensing



X-ray emission

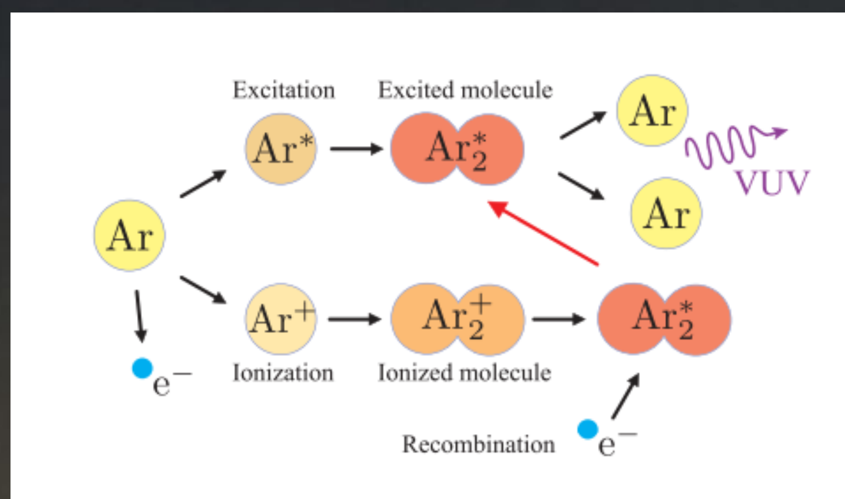
Dark Matter Candidates

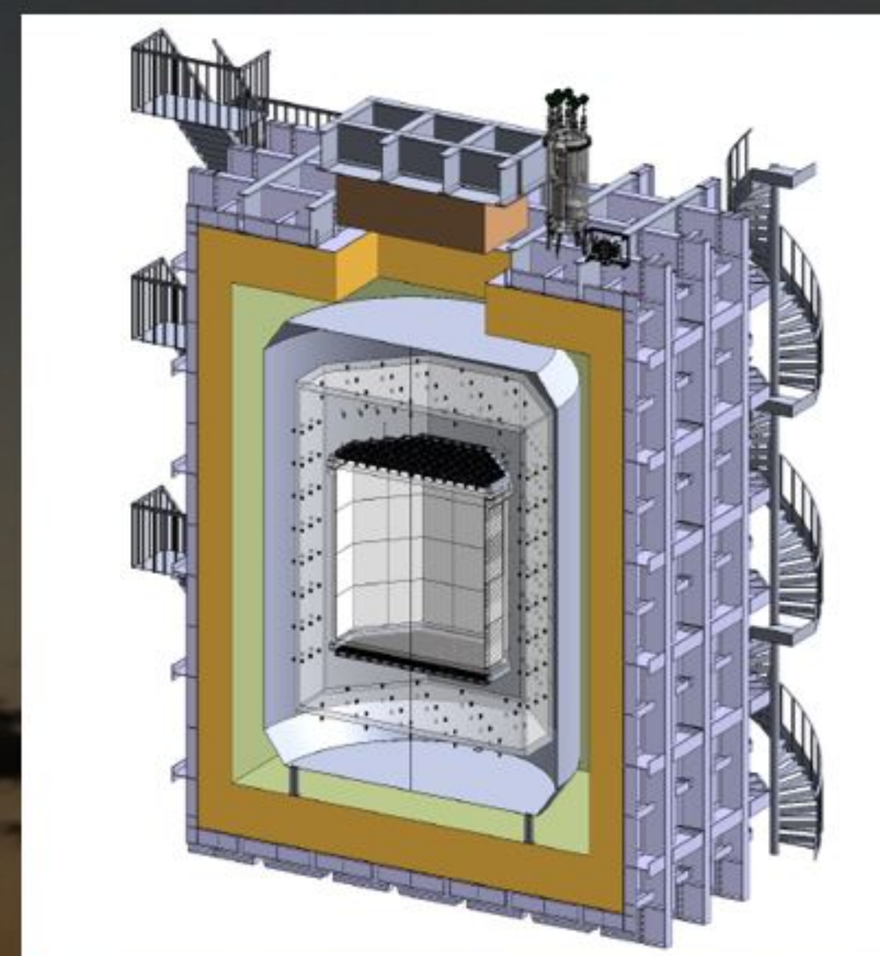
- ***A form of matter that does not emit, absorb, or reflect light, making it invisible to electromagnetic observations.***
- Dark matter estimated to make up about 27% of the universe's total mass and energy content.
- Hypothesized to consist of exotic particles such as **WIMPs (Weakly Interacting Massive Particles) or axions.**
- WIMPs interact through the weak nuclear force and gravity.



Purpose-Built for WIMP Detection

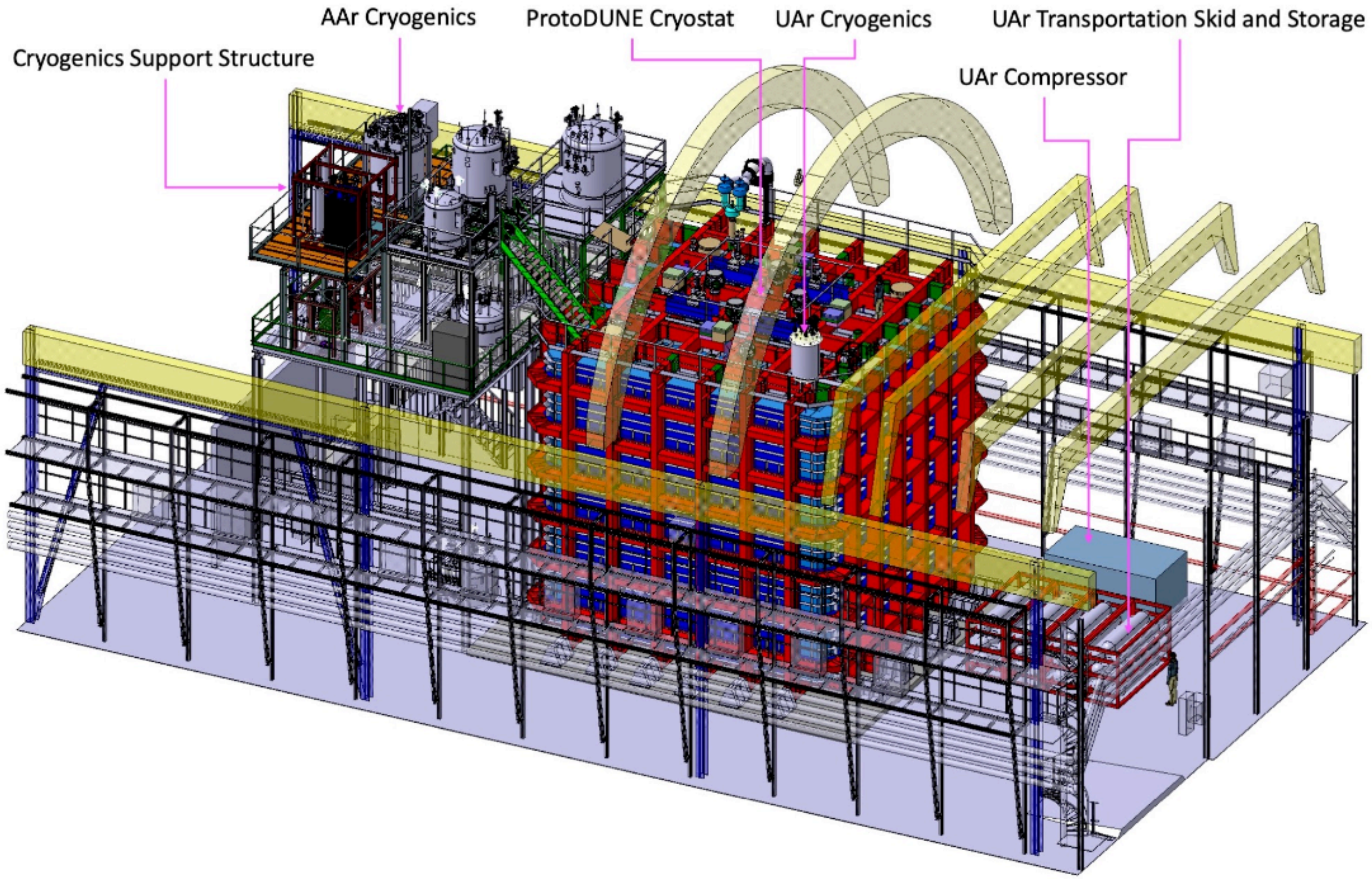
- **DarkSide-20k is a purpose built detector for WIMP detection with 20 ton liquid Argon detector.**
- Aiming to observe the nuclear recoils caused by WIMPs scattering off argon nuclei.





DarkSide-20k Experiment

- DS-20k experiment in HallC of LNGS, Italy showing the red ProtoDUNE like cryostat housing the detector and the cryogenics system and its support structure.



DarkSide-20k Detector

- **^{39}Ar activity in atmosphere:** 1Bq/kg – represents large background for Dark Matter Experiments.
- Cosmic rays in the atmosphere interact with ^{40}Ar:

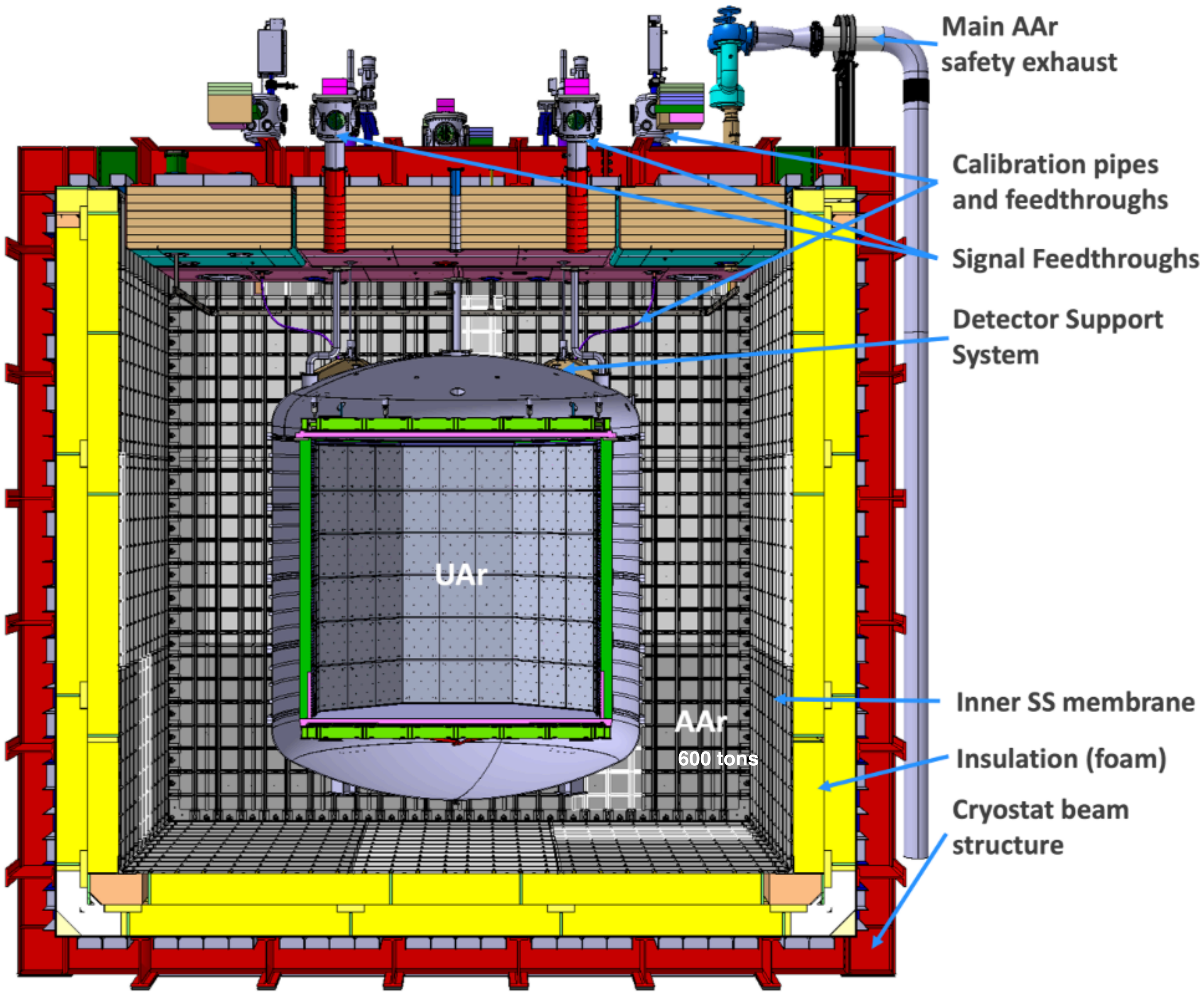
$$^{40}\mathrm{Ar} + n \rightarrow ^{39}\mathrm{Ar} + 2n$$

and undergoes beta (β) decay:

$$^{39}\mathrm{Ar} \rightarrow ^{39}\mathrm{K} + e^{-} + \bar{\nu}_e$$

(half life: ~269 years)

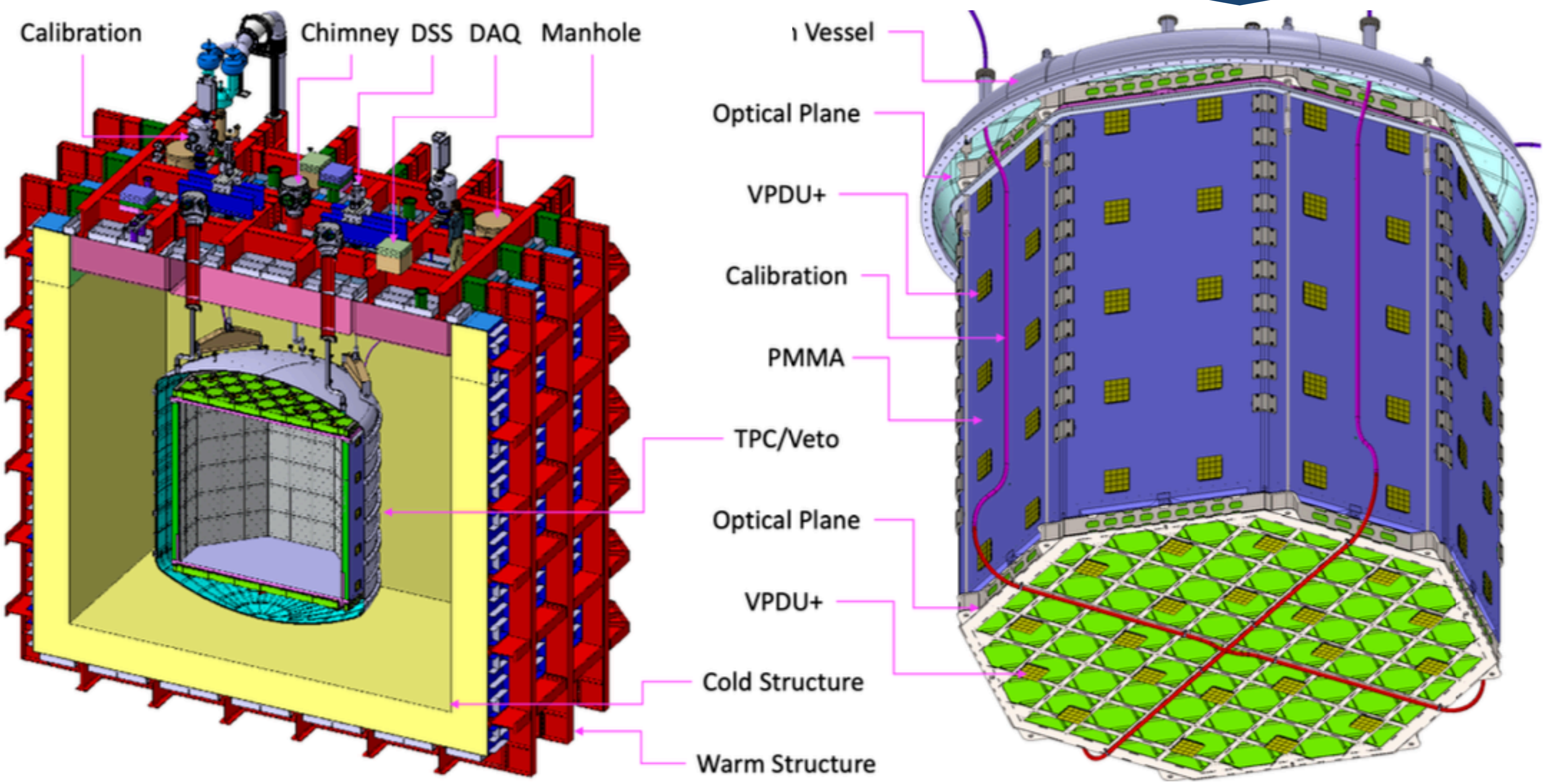
- The concentration of ^{39}Ar in underground argon (UAr) greatly reduced (an activity 1400 times lower) due to shielding from cosmic rays.



DarkSide-20k Detector

Cross section showing the inner detector with the PMMA in green, the vessel in gray

External view of the TPC and Veto showing the full assembly features including VPDU+, Calibration, Optical planes and the PMMA wall structure.



- Tetraphenyl Butadiene (TPB) evaporated on Enhanced Specular Reflector (ESR) for the inner lateral walls of the TPC.

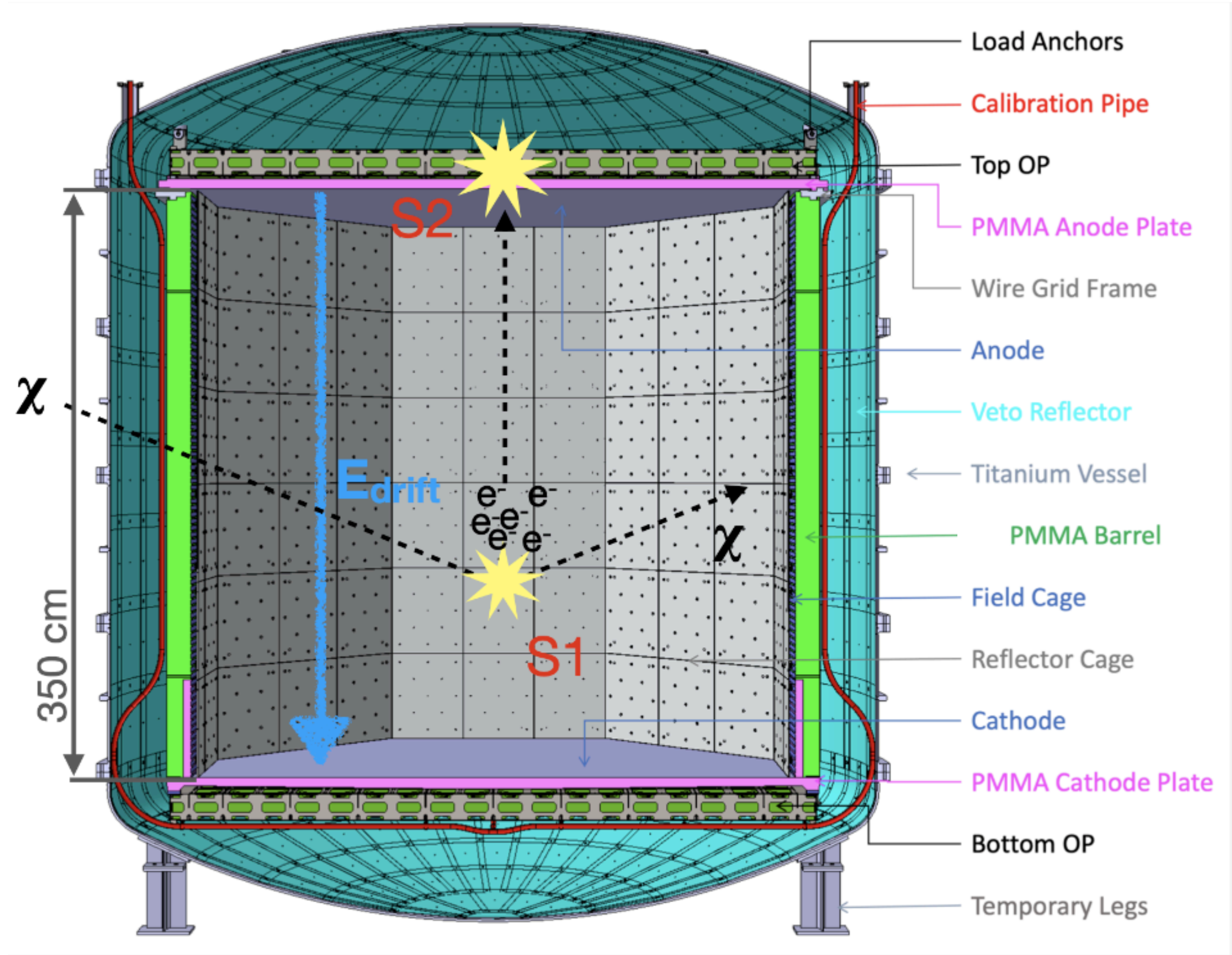
Inner Detector

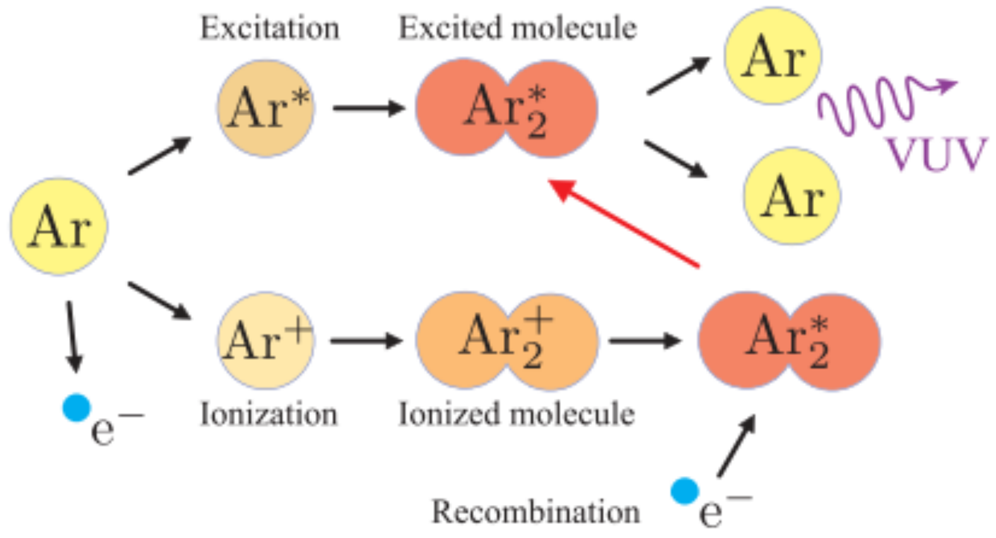
2 Phase DS-20K detector operate using both liquid and gas phases of argon to detect potential dark matter interactions.

Basic Setup

- **Two-Phase System**: The detector consists of a container filled with liquid argon, above which a small region of gaseous argon (7 mm).

- **Field Cage**: A strong electric field is maintained across the liquid and into the gaseous argon.

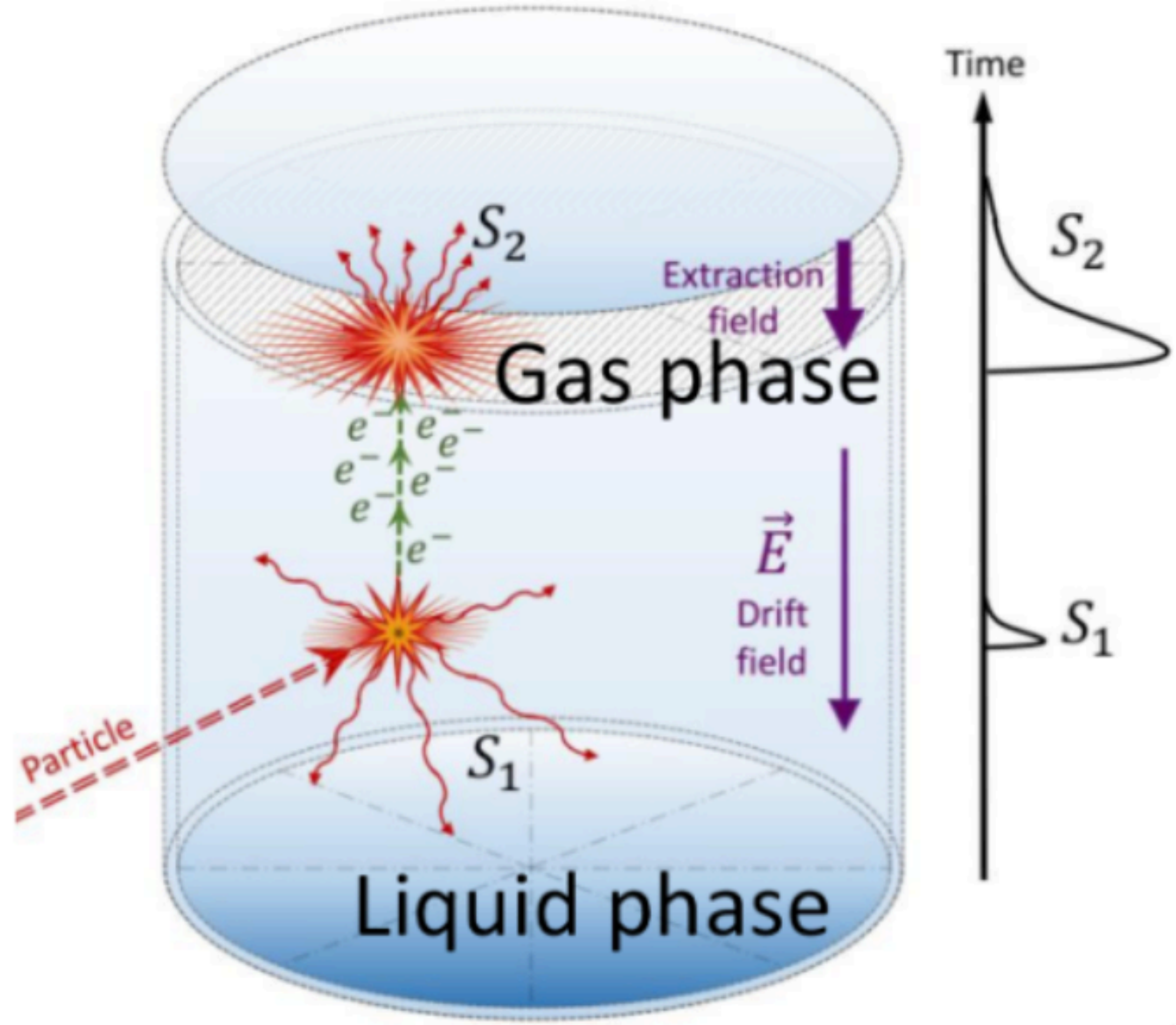




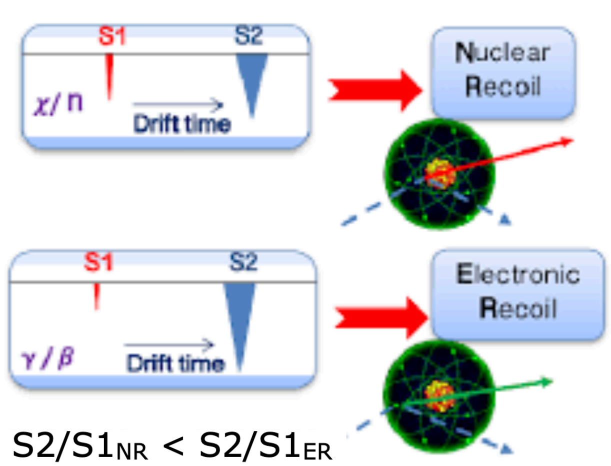
Experimental Signatures in LAr

Liquid argon detector observe WIMP-nucleus interactions through:

- **S1 Signal:** UV light from primary scintillation as excited electrons return to their ground state.
- **S2 Signal (Electroluminescence):**
  - Ionization electrons drift toward the liquid-gas interface under an electric field.
  - A stronger field extracts them into the gas phase, where they accelerate and excite argon atoms, which then emit UV light as they de-excite.



Working principle of the time projection chamber (TPC) detector

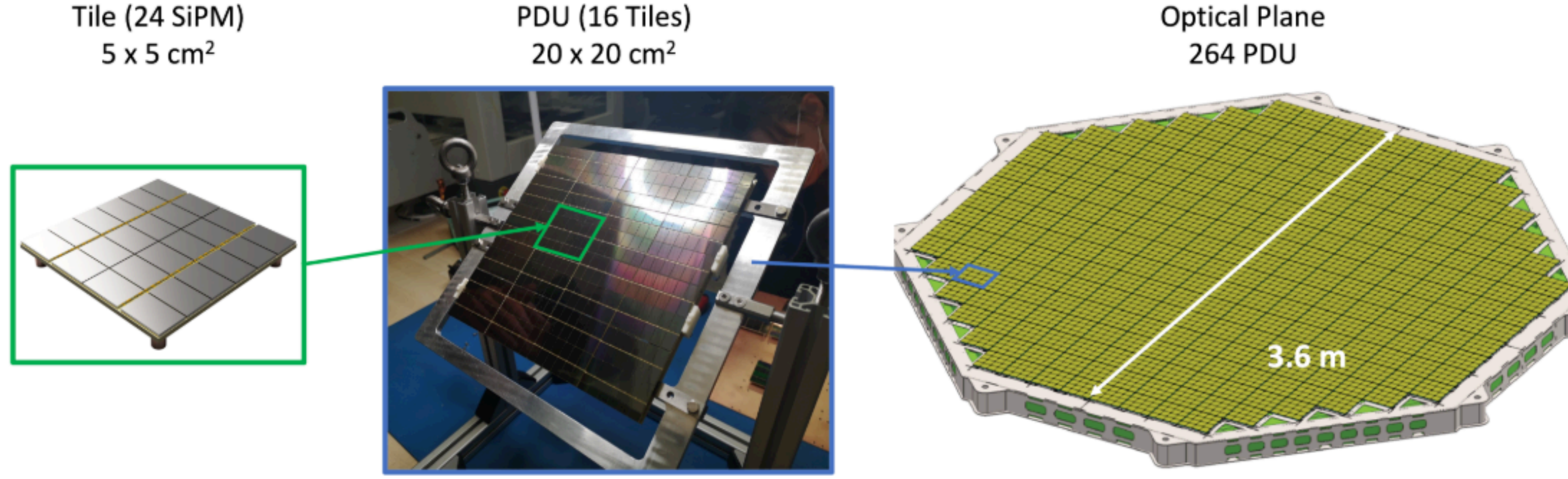


$S2/S1_{NR} < S2/S1_{ER}$

Signal Detection

Photon Detection:

- UV light from electroluminescence is detected by sensitive light detectors.
- Detectors are silicon photomultipliers (SiPMs) located at the top of the gas phase.



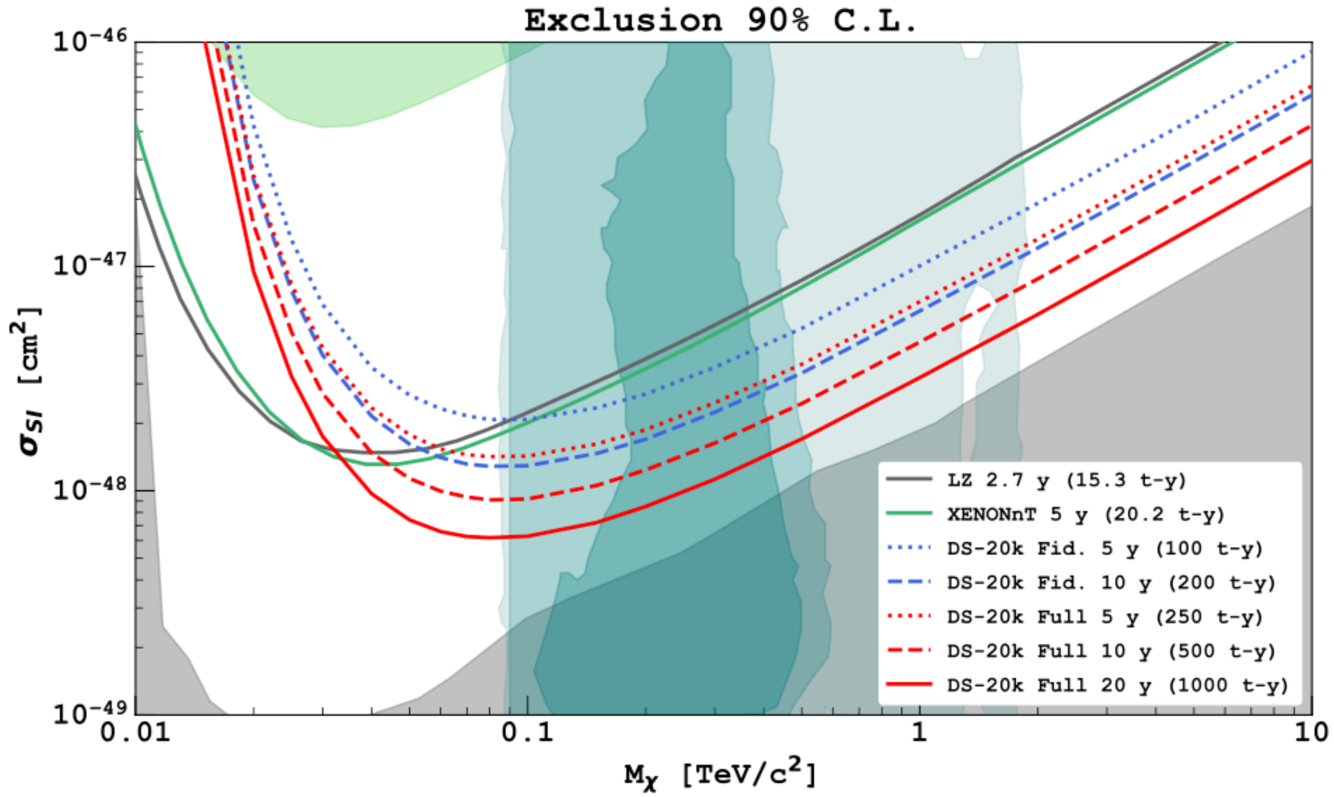
Signal Processing:

- Detected light is converted into an electrical signal.
- Signal is amplified and analyzed to identify interaction characteristics, potentially indicating a WIMP event.

The Sensitivity

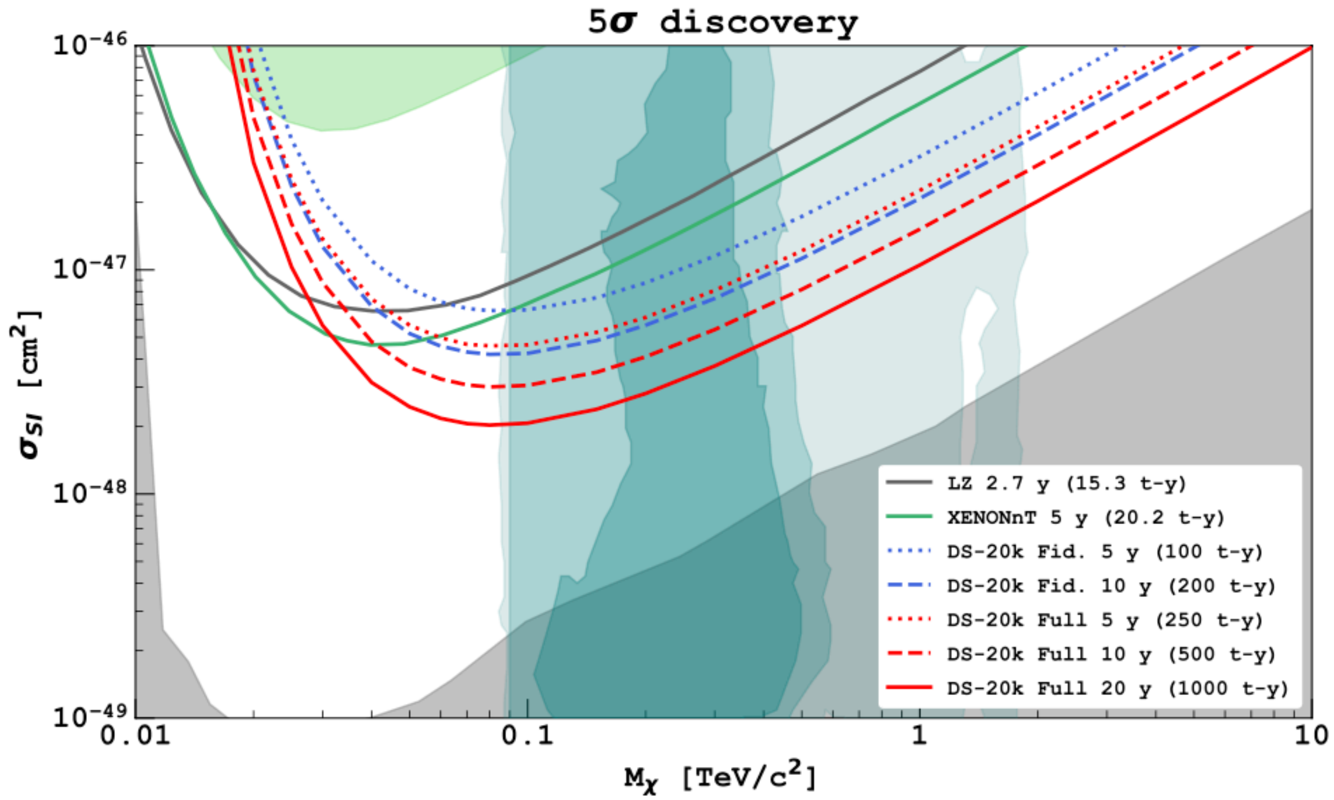
- Foreseen to begin operations in 2027 and will either detect WIMP dark matter or exclude a large fraction of favored WIMP parameter space.

90 % C. L. Exclusion



- The nominal run time of DS-20k is 10yr, corresponding to a fiducial volume exposure of 200tyr

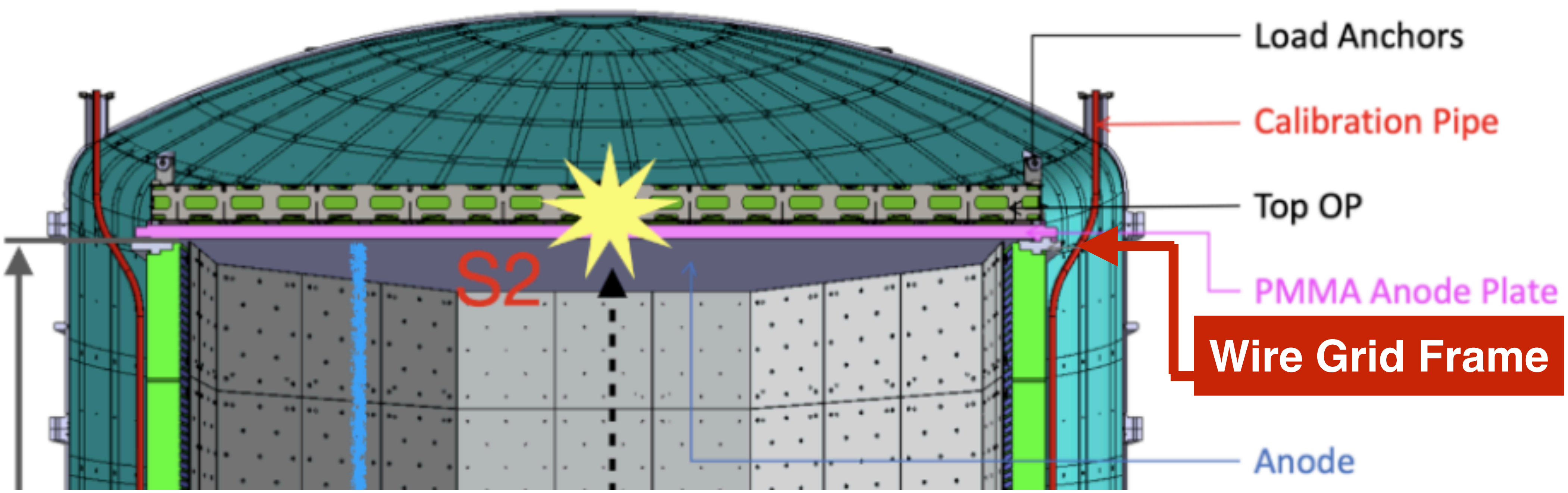
5 Sigma Discovery



Wire Grid Construction at Virginia Tech

Wire Grid for S2 Signal Generation in TPC

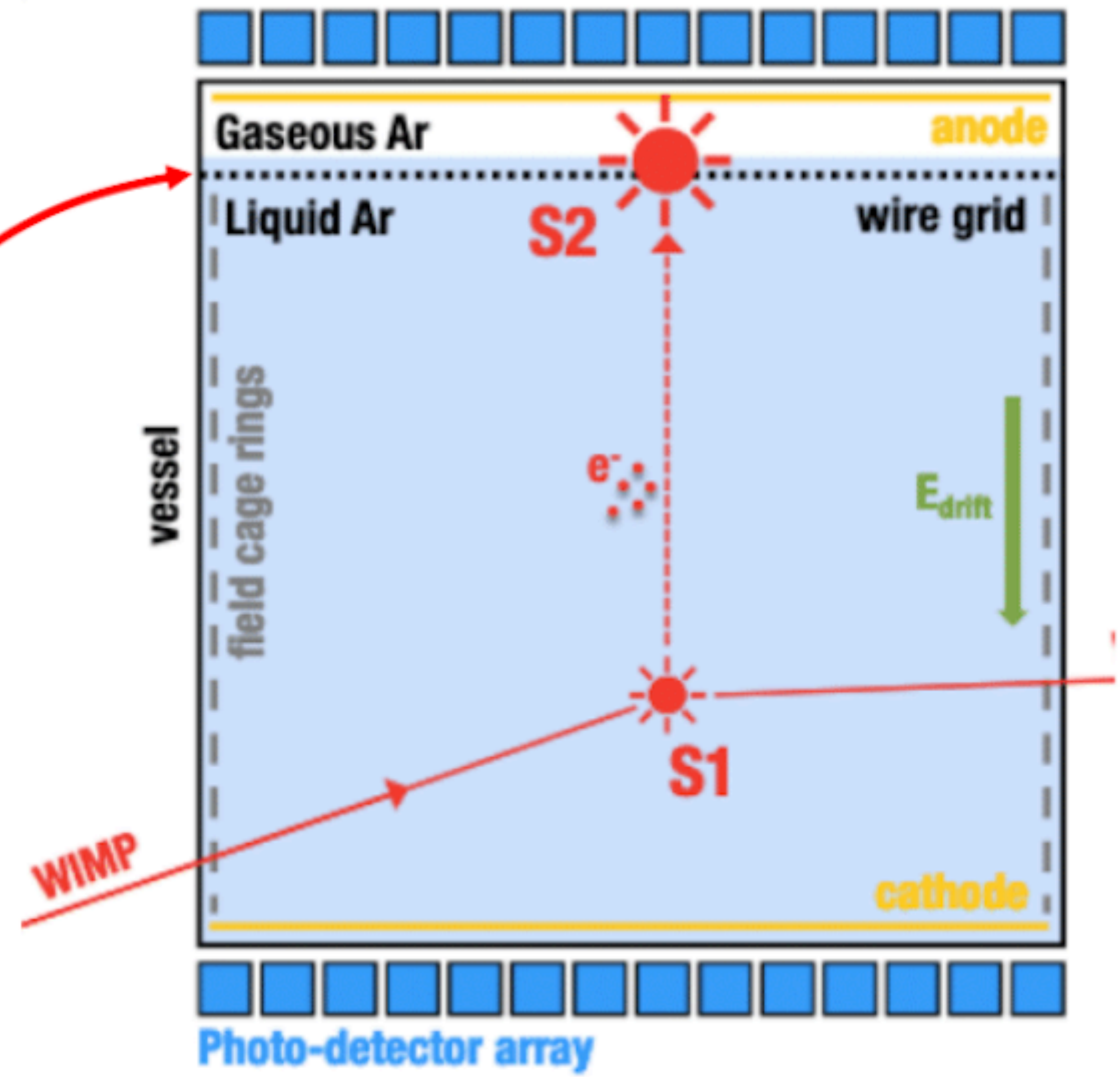
- **Purpose of Wire Grid:**
  - Creating a high electric field at the top of the TPC.
  - Enables drift electrons to rapidly enter the argon gas phase.
  - Electrons accelerated toward the anode produce electroluminescence (S2 signal).
- **Requirements:**
  - **Transparency:** Allows light passage for both S1 and S2 signals.
  - **Planarity:** Wires form a horizontal plane flat within ∼ 0.1mm for uniform S2 gain.
  - **Low Background:** Minimize radioactivity and surface electron emission.



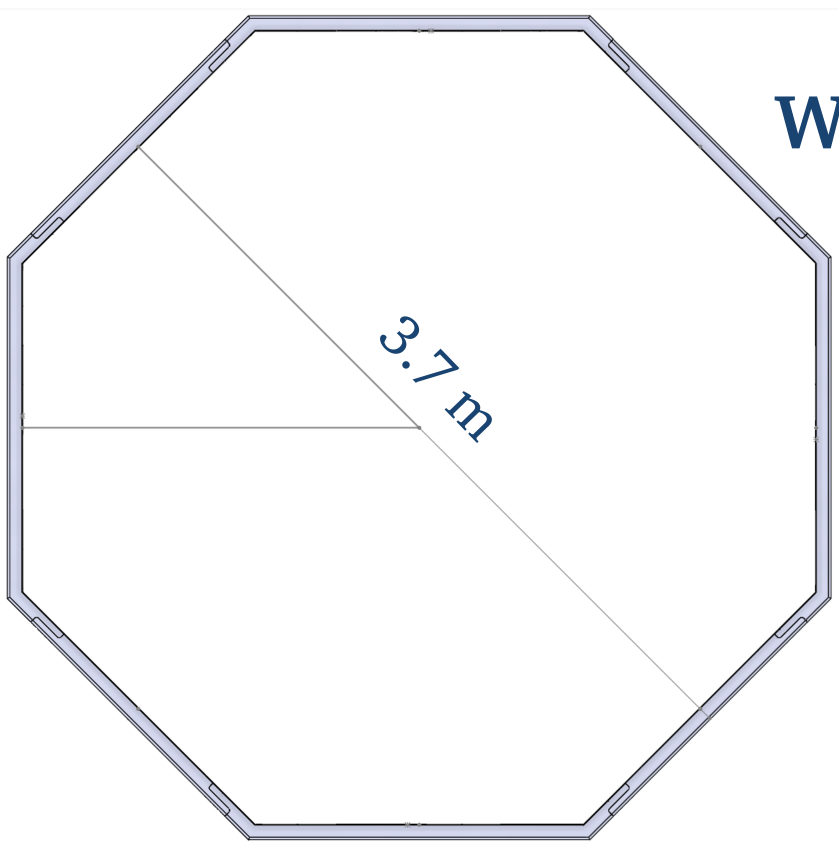
Wire Grid Technical Specifications

- **3.7 m octagon** using stainless steel.
- ~1236 parallel wires of 0.235 mm diameter with a spacing of 3 mm.
- ~ -5-6 kV with respect to anode.
- Located 10.0mm below the anode.
- 3.0 mm below the liquid argon level.

2 Phase TPC Detector



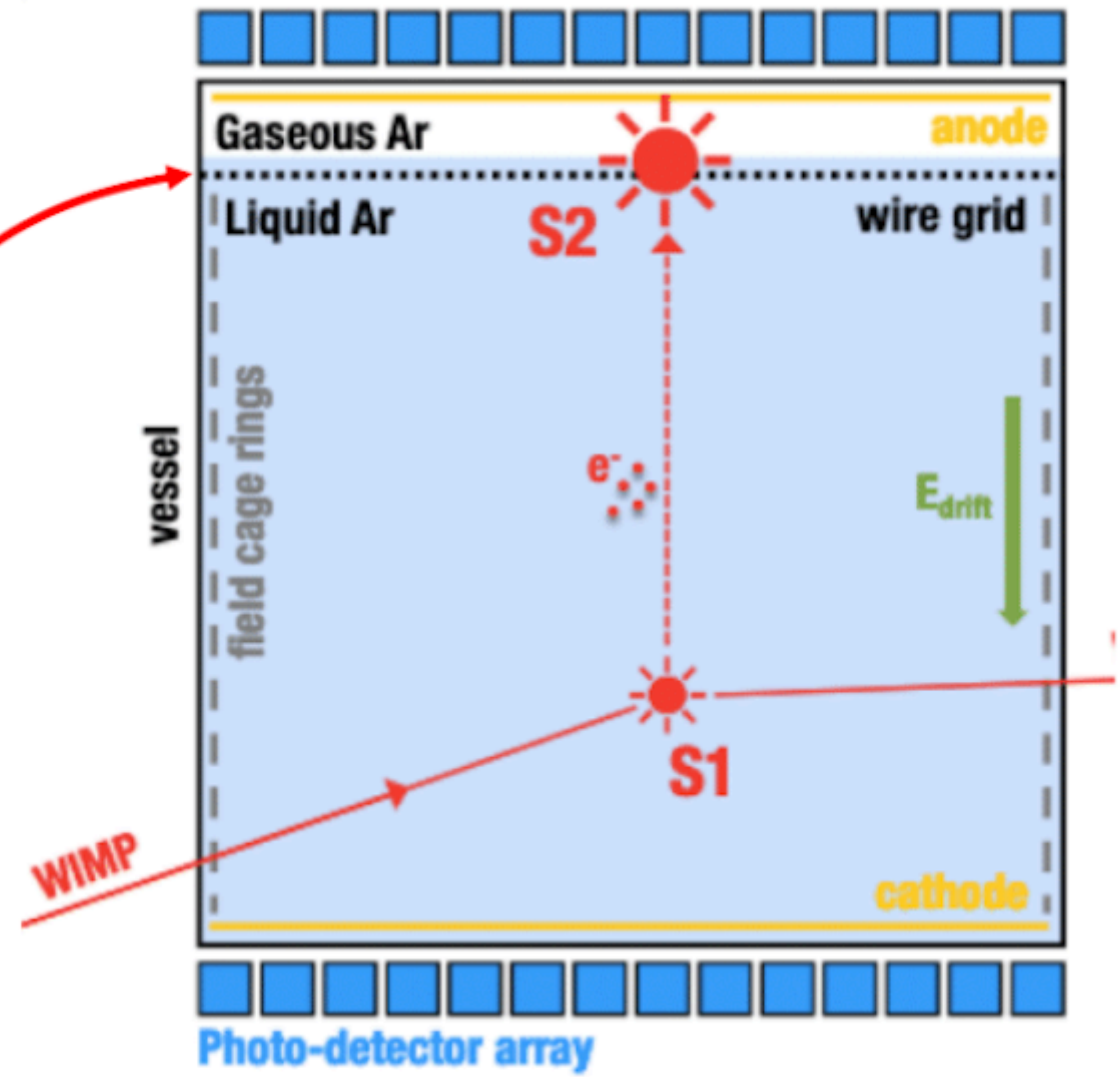
Wire Grid



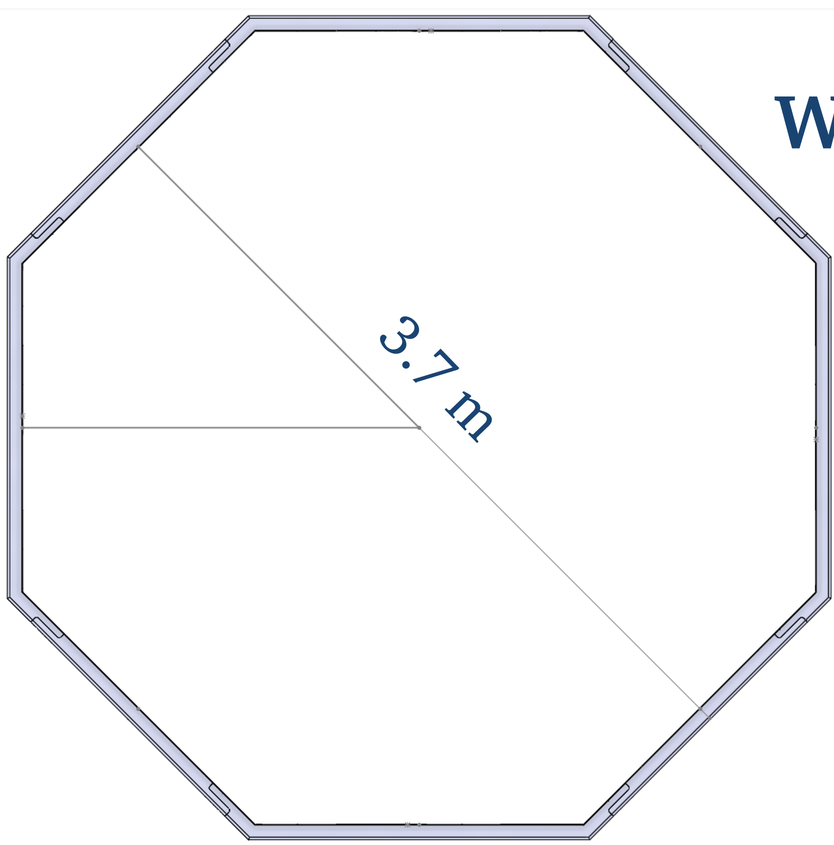
Wire Grid Vertical Precision

- Deviations in vertical precision or flatness distort the electric field.
- This distortion leads to non-uniform acceleration of electrons.
- This affects the detector's resolution by causing spatial distortions.

2 Phase TPC Detector

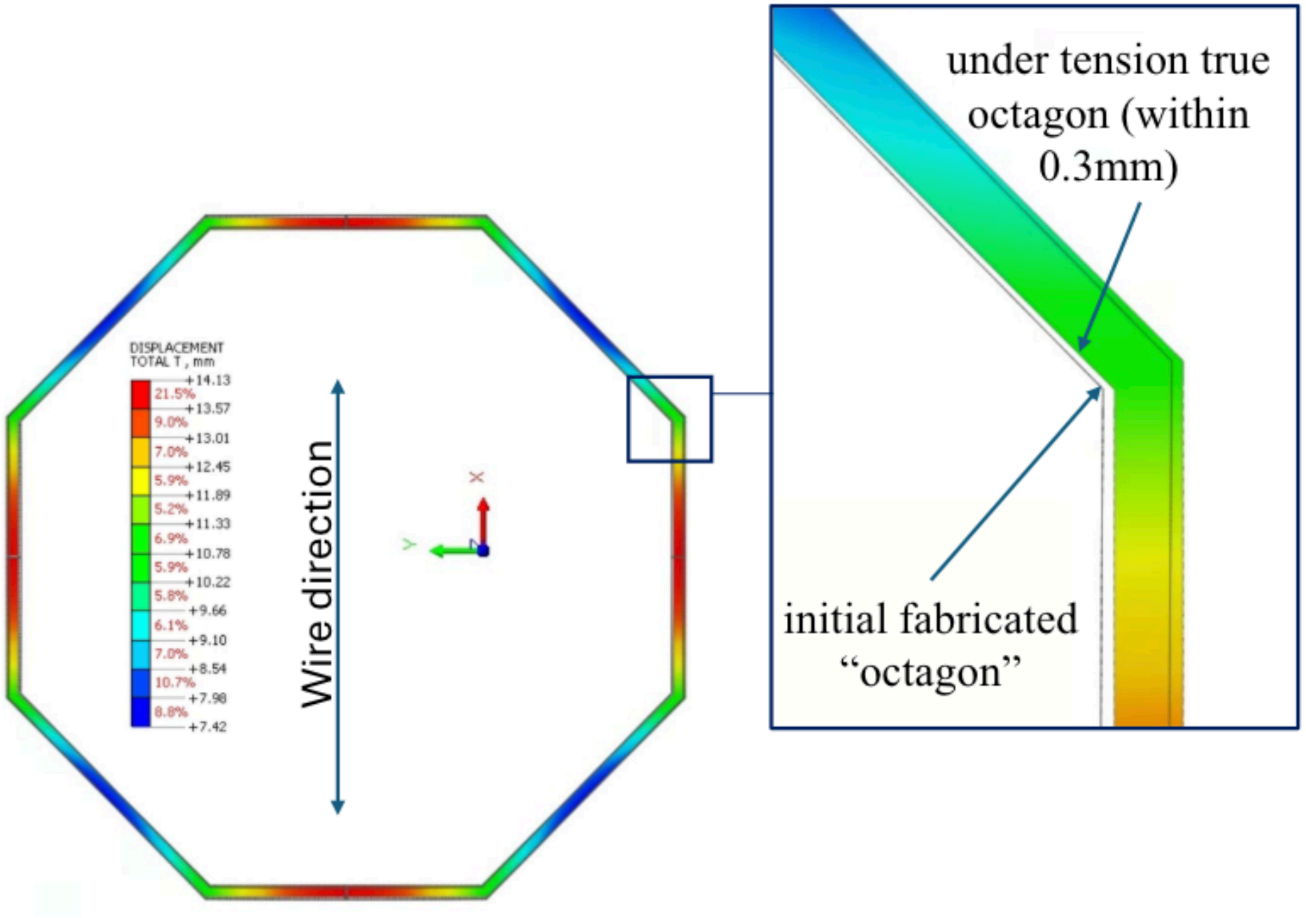


Wire Grid



Wire Grid at Cryogenic Temperatures

- **Stress Management**: Design must accommodate deformation due to the wire tension to maintain grid integrity and performance.

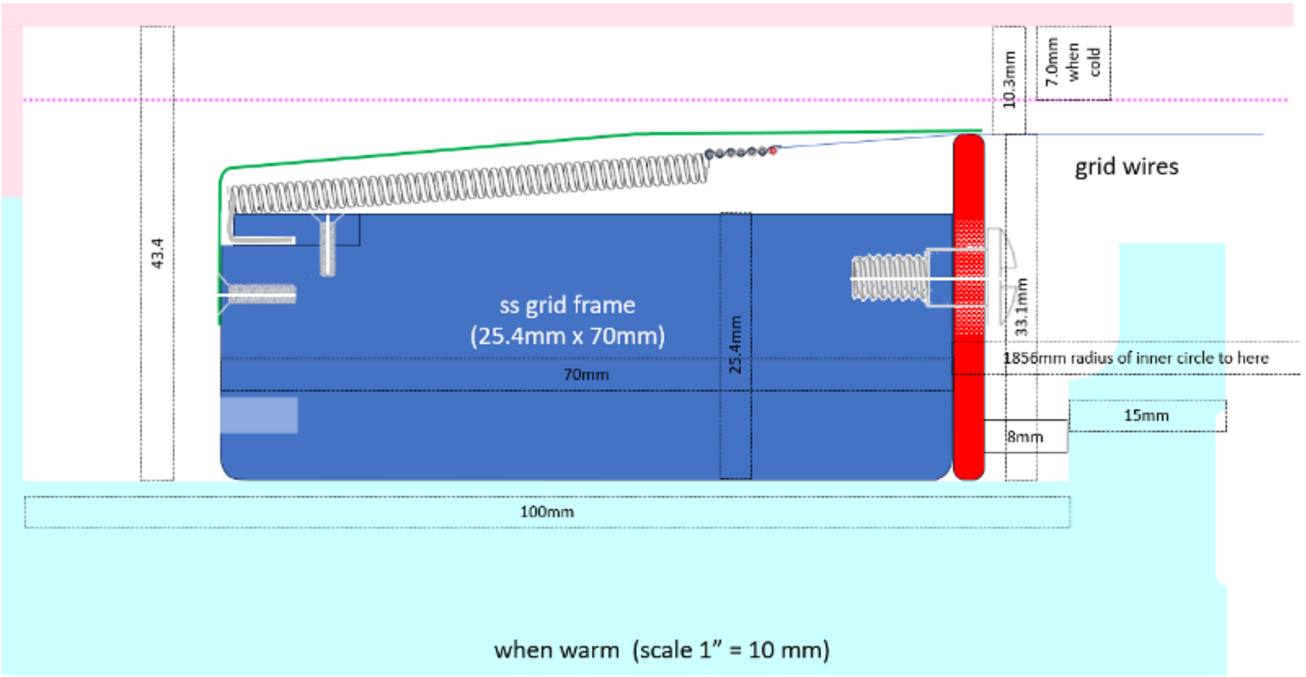


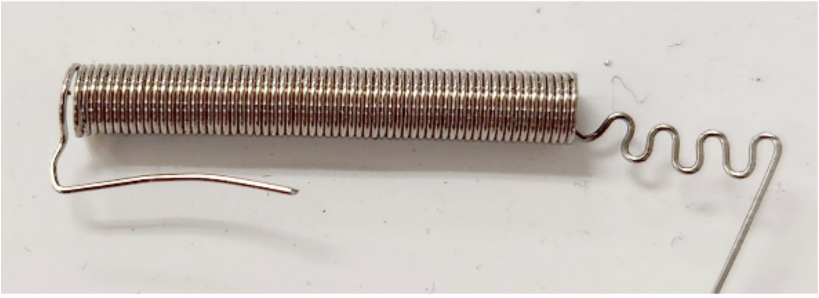
- **Faster Wire Cooling**:Wires cool and shrink faster than the grid frame due to smaller mass and higher surface area-to-volume ratio.

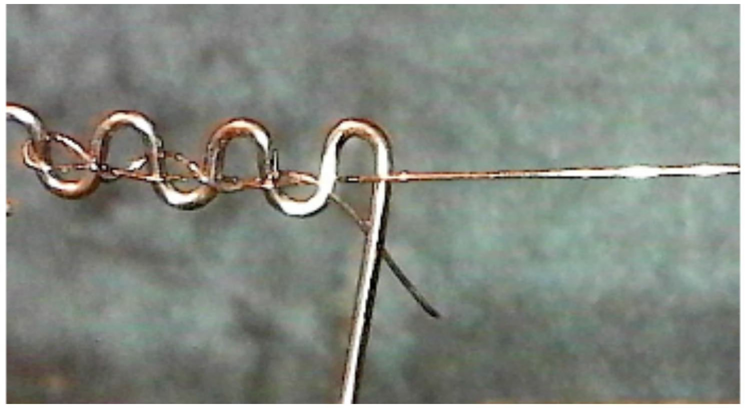
- **Thermal Mismatch**: Faster wire shrinkage creates stress and potential deformation due to contraction differences with the slower-cooling frame and even breakage of wires.

Upgraded Wire Grid Design

- **Inherited Features:**
  - 3N tension stainless steel wires from the original Technical Design Report.
  - Wires oriented in only one direction.
- **Major Changes Introduced after revisit at VT:**
  - **Frame Placement:**
    - Frame now integrated within the shelf of the barrel walls.
  - **Tension Mechanism:**
    - Wire tension provided by springs instead of fixed anchors.
    - Frame and bridge are vertically decoupled.
    - Wire height is precisely set by a bridge between the shelf and the wires.

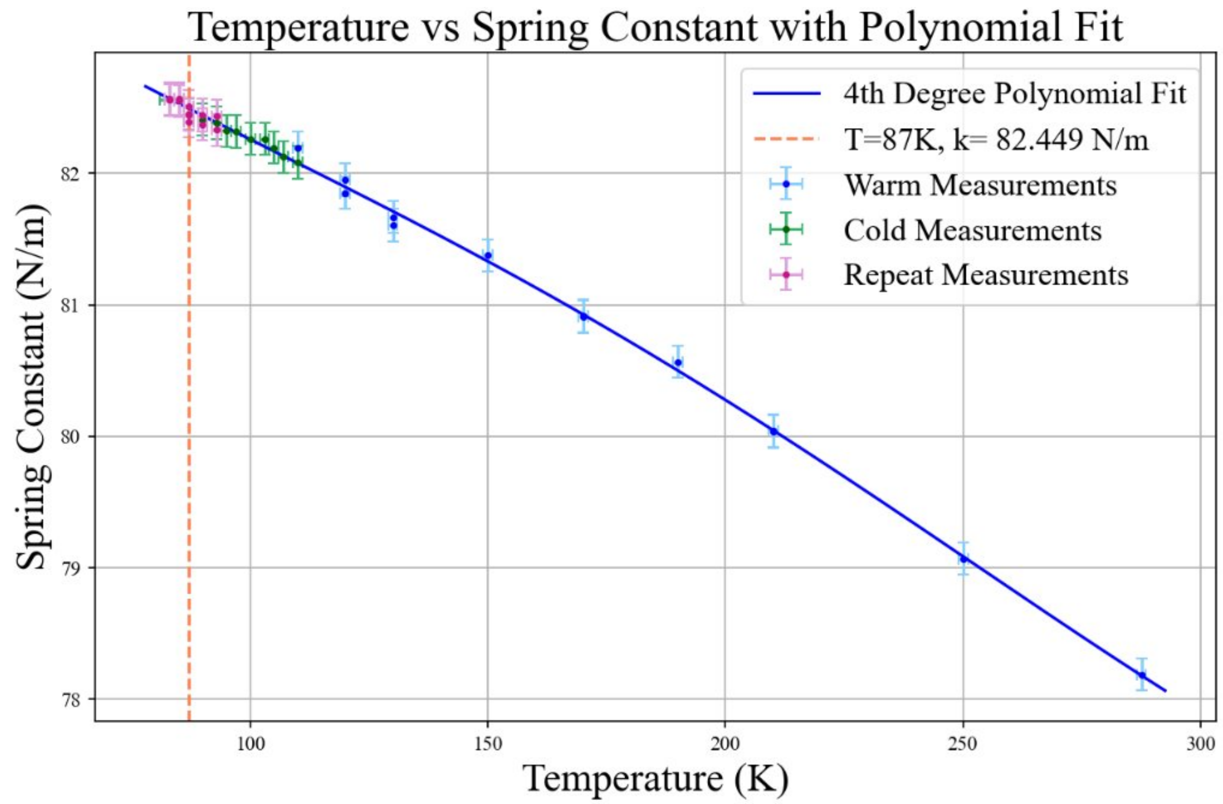


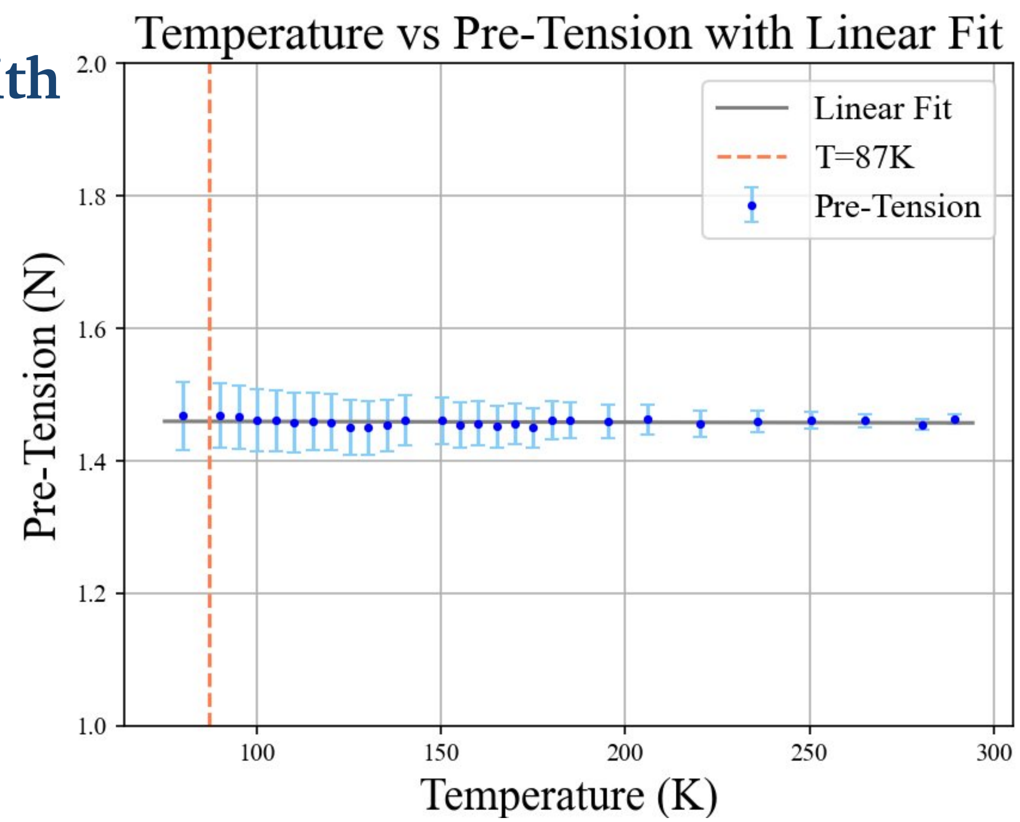




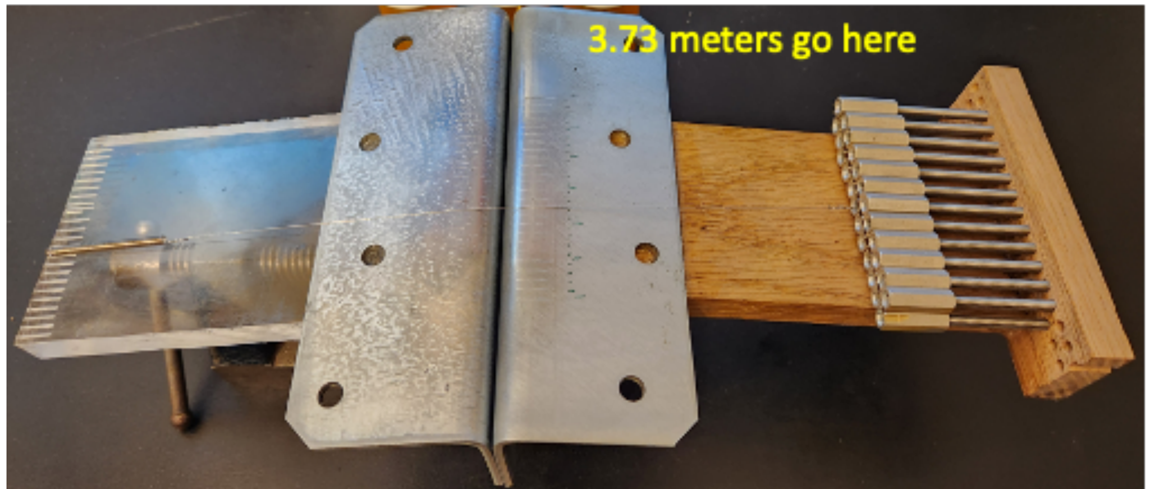
Cryogenic Tests on Springs

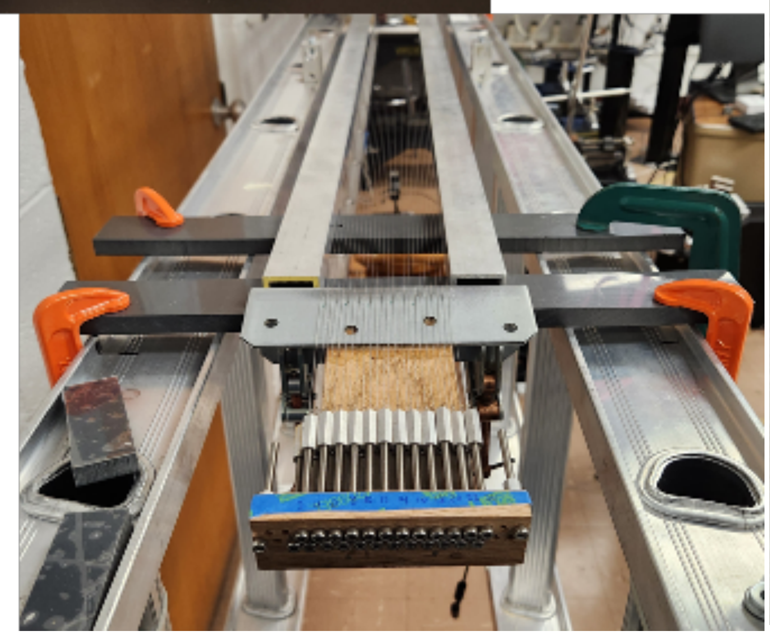
- Summer students conducted cryogenic tests with springs at VT.
- Used cold nitrogen gas to simulate extreme cold environments.
- Capable of **reaching temperatures as low as 77 Kelvin (< 87 K of LAr).**
- **Observed 5.5 ± 0.2% increase in spring constant over a ΔT = 206K**
- **In good agreement with prediction.**

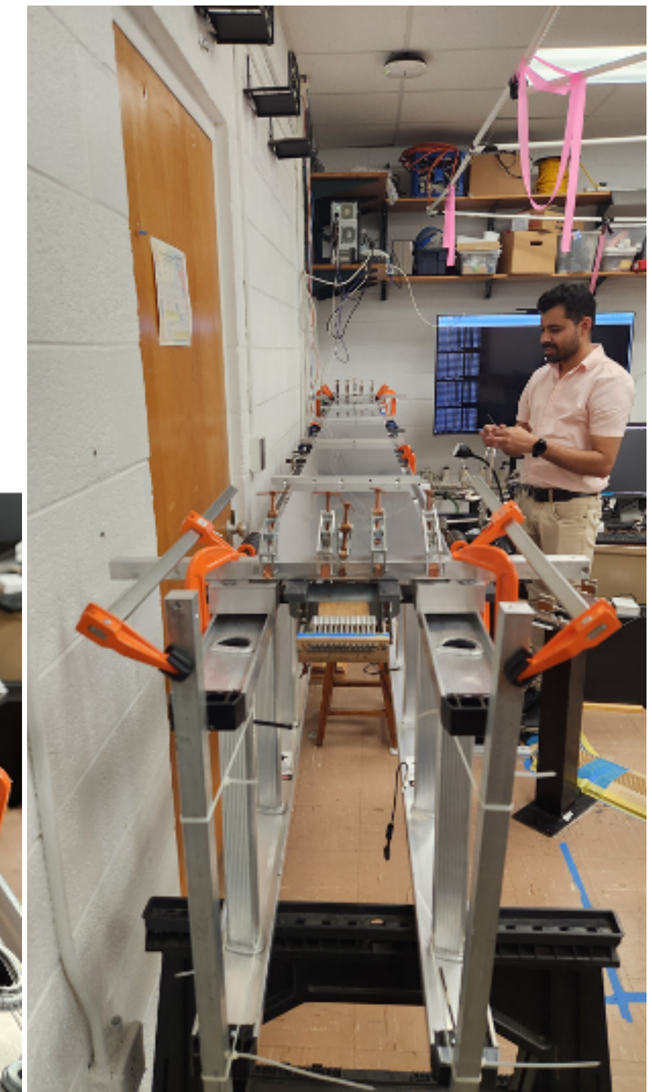




Grid Testing Station at VT





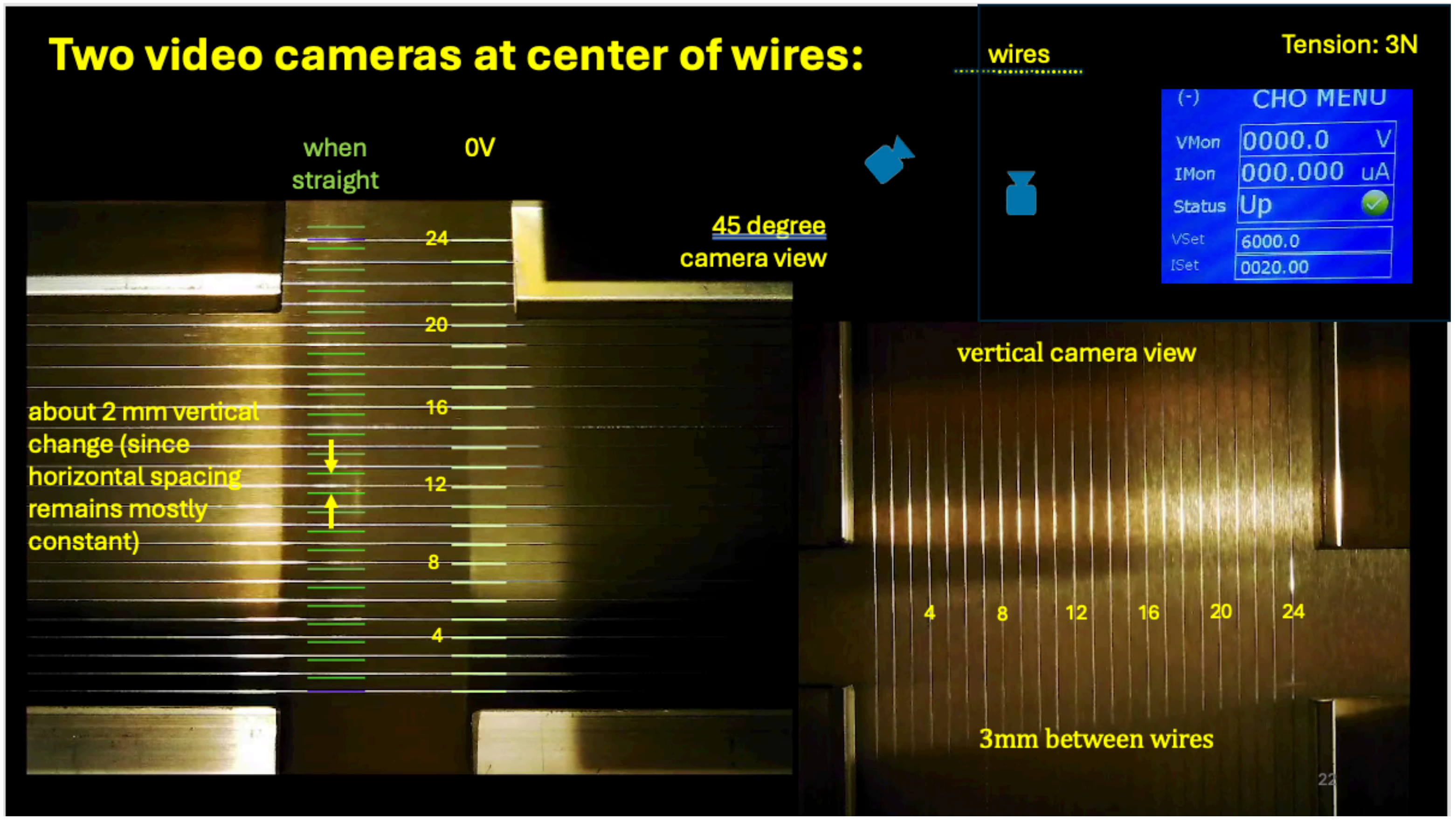


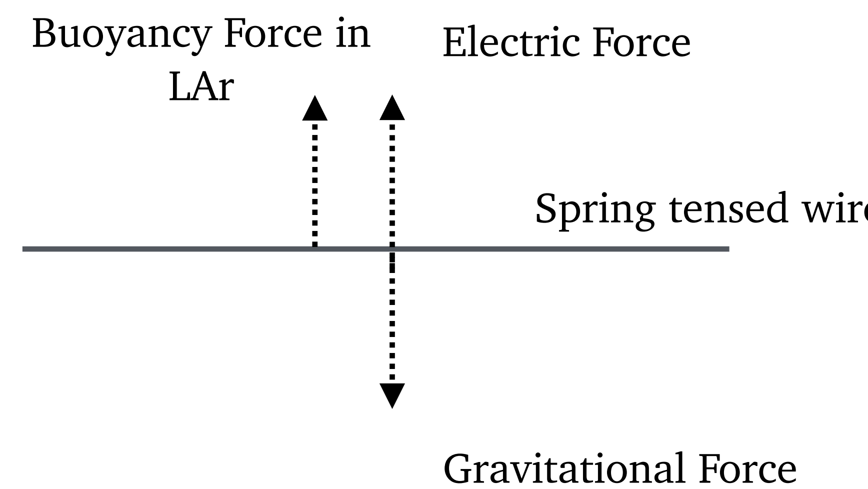
- 24 wires at settable tension (3 to 10 N).
- 3 mm spacing between wires.
- 3730 mm wire span (max in DS20k).
- side-rails to mimic local grid frame.
- Aluminum anode sheet located 10.0 mm. above center of wire plane.

Grid Testing: Wire Tension Control

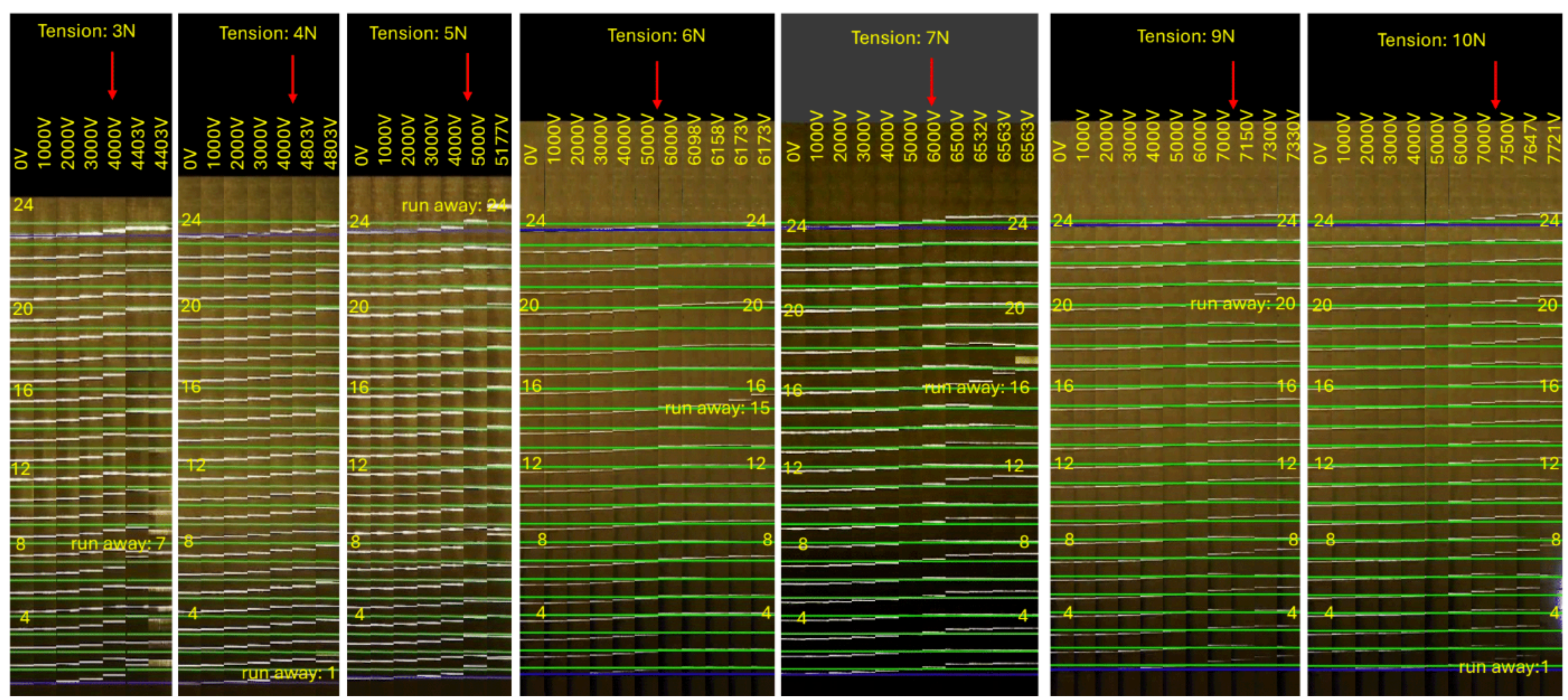
- Dialed in 3N tension (checked using central wire deflection with weight – to about 2%)
- 0.012” nominal spring-temper 304 ss.   (gave 0.055N/turn, or 0.07N/mm)

Grid Testing: Wire Monitoring Using Cameras



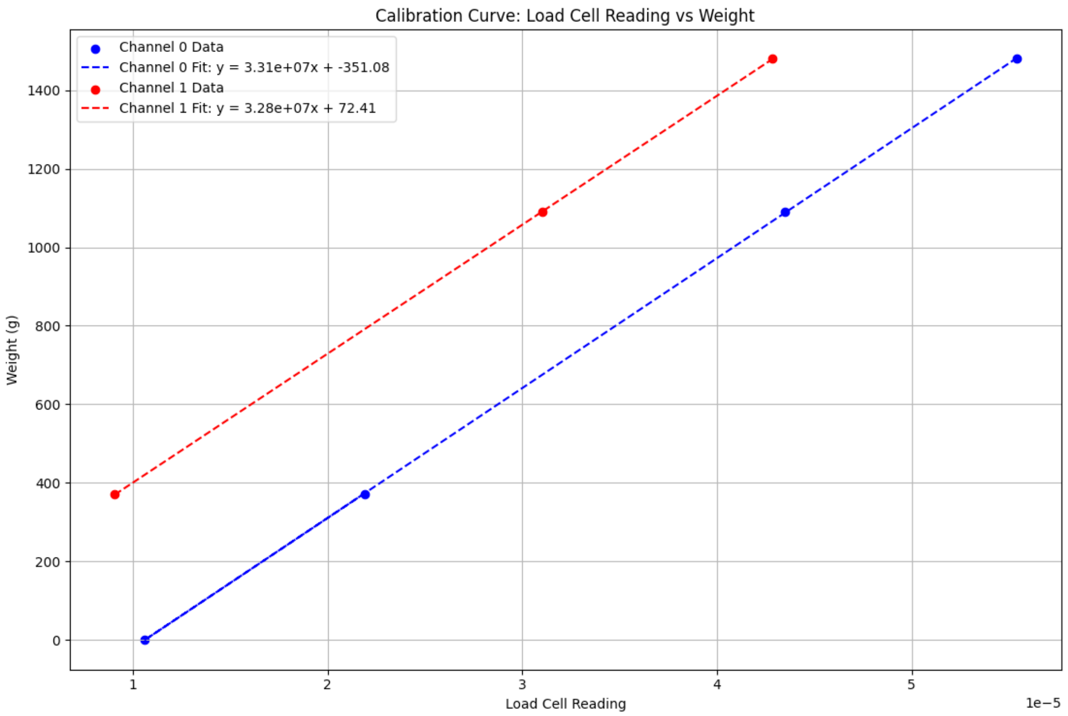


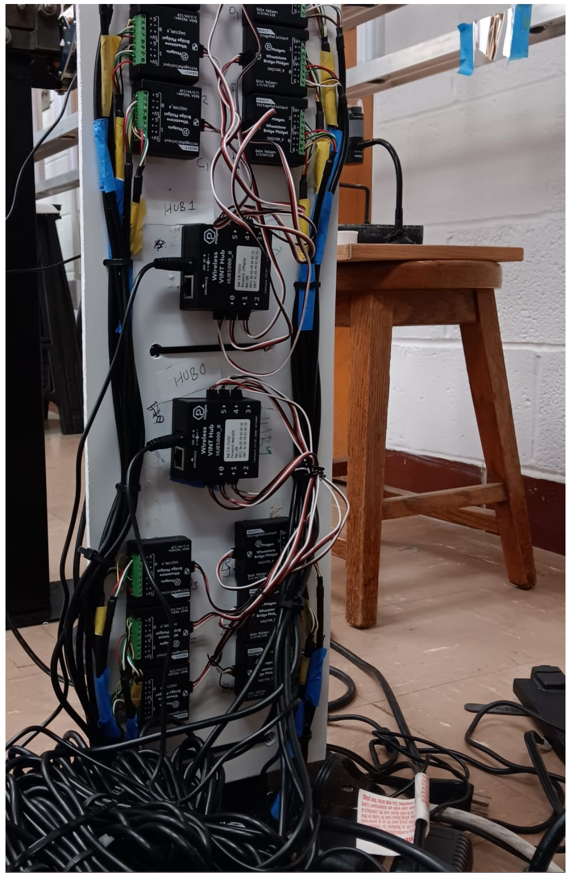
High Voltage Application at Different Wire Tensions

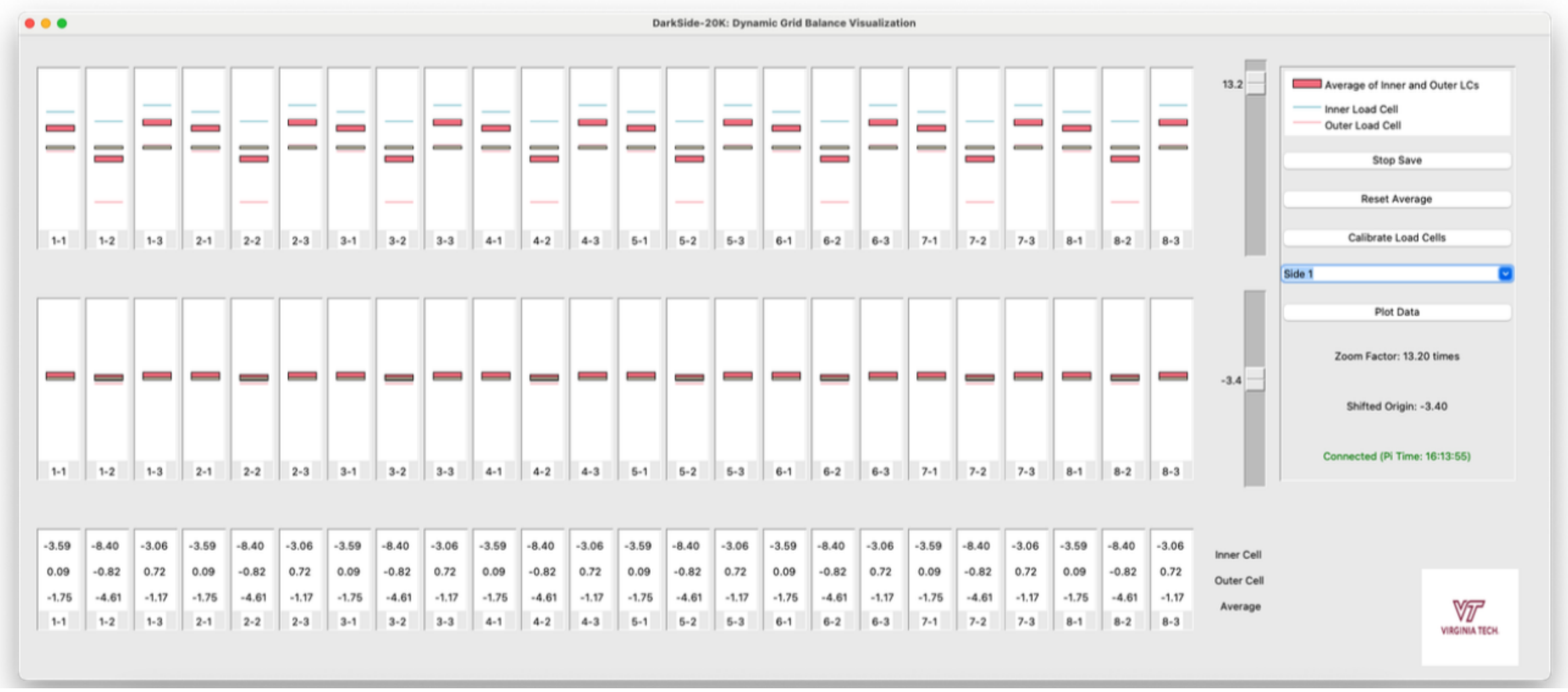


Grid Frame Fabrication Table

- 48 Load cells are connected to DAQ and readout using 4 wifi hubs.
- Calibrated all these load cells.
- A fully developed GUI is ready for monitoring the weight on each post.
- Leveling of the posts with the help of theodolite is going-on.







Summary and Future Plans

- DarkSide-20k is an advanced liquid argon TPC detector, designed to detect WIMP interactions with exceptional sensitivity.
- A key component of its inner detector is the wire grid, which generates a strong electric field to drift electrons and produce secondary scintillation (S2) signals.
- At Virginia Tech, the DarkSide team is actively developing the wire grid in Room 1 of Robeson Hall.
- Current efforts focus on optimizing grid parameters using a dedicated test setup.
- The future plans involve finalizing the grid design and construct the grid at Virginia Tech.
- Subsequently, the grid will be reassembled in a cleanroom facility in U- Alberta, Canada before being shipped to the LNGS, Italy for integration into the DarkSide-20k.

Virginia Tech DarkSide Group

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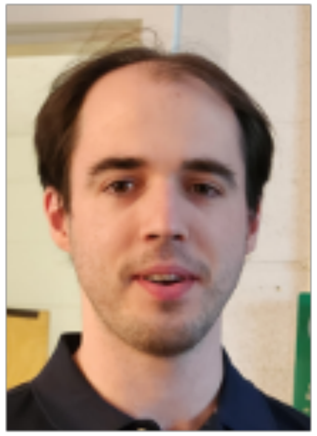

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Backup

Any deformation in the frame from the needed precision will be corrected before the full assembly of the grid

Twist remover

Hydraulic pipe bender to unbend the frame along the length

Dual load-cells with support bar on a post for monitoring the weight balance

Backup: Theoretical Context

- **Supersymmetry (SUSY):** In SUSY theories, the lightest supersymmetric particle (LSP), often the neutralino, is a stable WIMP candidate due to R-parity conservation.
- **Freeze-Out Mechanism:** WIMPs are produced in the early universe in thermal equilibrium. As the universe expands and cools, their interaction rate drops below the Hubble expansion rate, leaving a relic density that matches observed dark matter abundance.
- **Interactions:** WIMPs interact via weak force mediators such as the Z boson or Higgs boson. They may also annihilate into Standard Model particles.