DEEP UNDERGROUND NEUTRINO EXPERIMENT

https://lbnf-dune.fnal.gov/

The straw tube tracker for the SAND near detector of DUNE experiment.

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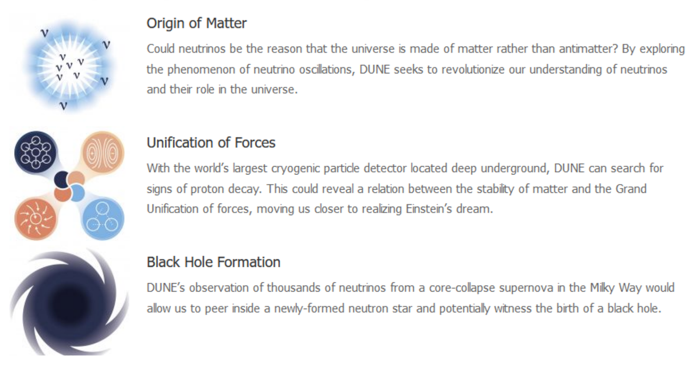
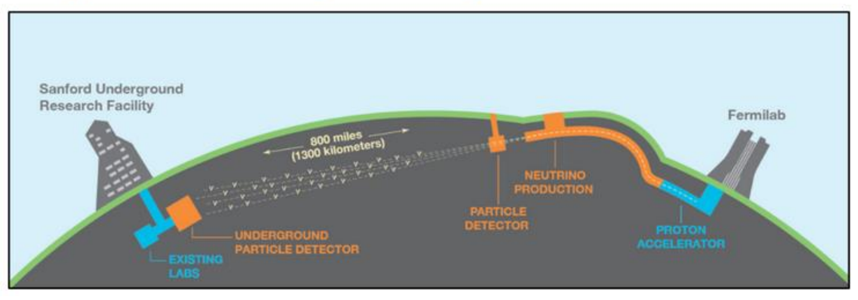
1. An International Experiment for Neutrino Science

DUNE will consist of two neutrino detectors placed in the world's most intense neutrino beam. One detector will record particle interactions near the source of the beam, at the Fermi National Accelerator Laboratory in Batavia, Illinois. A second, much larger, detector will be installed more than a kilometer underground at the Sanford Underground Research Laboratory in Lead, South Dakota — 1,300 kilometers downstream of the source. These detectors will enable scientists to search for new subatomic phenomena and potentially transform our understanding of neutrinos and their role in the universe.

Aiming for groundbreaking discoveries



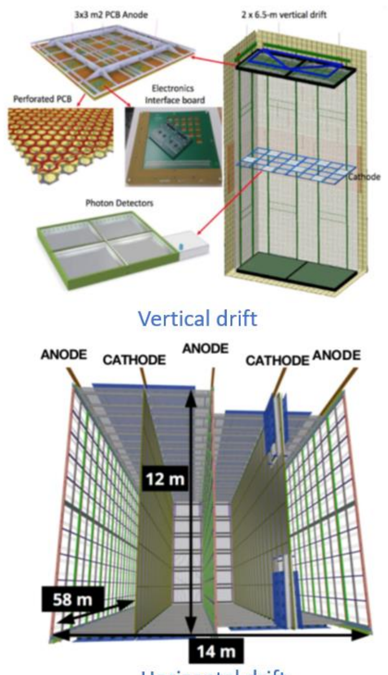
Deep Underground Neutrino Experiment (DUNE)



Far detector.

The far detector will consist of almost 70000 tons of liquid argon, housed in two gigantic caverns.

The far detector will comprise four LArTPC detector modules, each employing two distinct technologies: the horizontal and vertical drift of the electrical charges produced by neutrino interactions. In both cases, ionization charges move in the liquid argon under the influence of an electric field towards the anode, where they are detected and read out. No signal amplifications are present inside the cryostat, making the process sensitive to electronic noise. In liquid argon, in addition to the charge produced by ionization, we also observe the scintillation light which, thanks to the speed of the signal, manages to separate the traces coming from different interaction vertices in time.

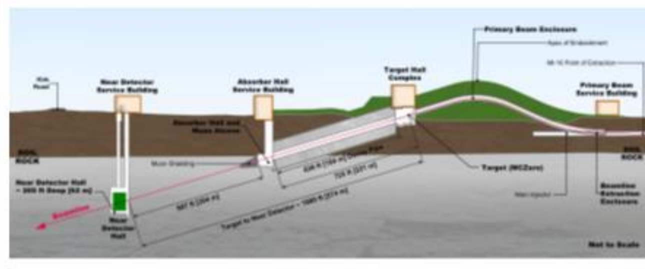


Vertical drift

Horizontal drift

Near detector complex

The near detector is a crucial component of the DUNE experiment. It will be placed 62m underground, 574m from the neutrino source. It is designed to study the neutrino beam characteristics and composition at production before they undergo oscillations during their propagation to the far detector. It is designed to study the neutrino beam characteristics and composition at production before they undergo oscillations during their propagation to the far detector.

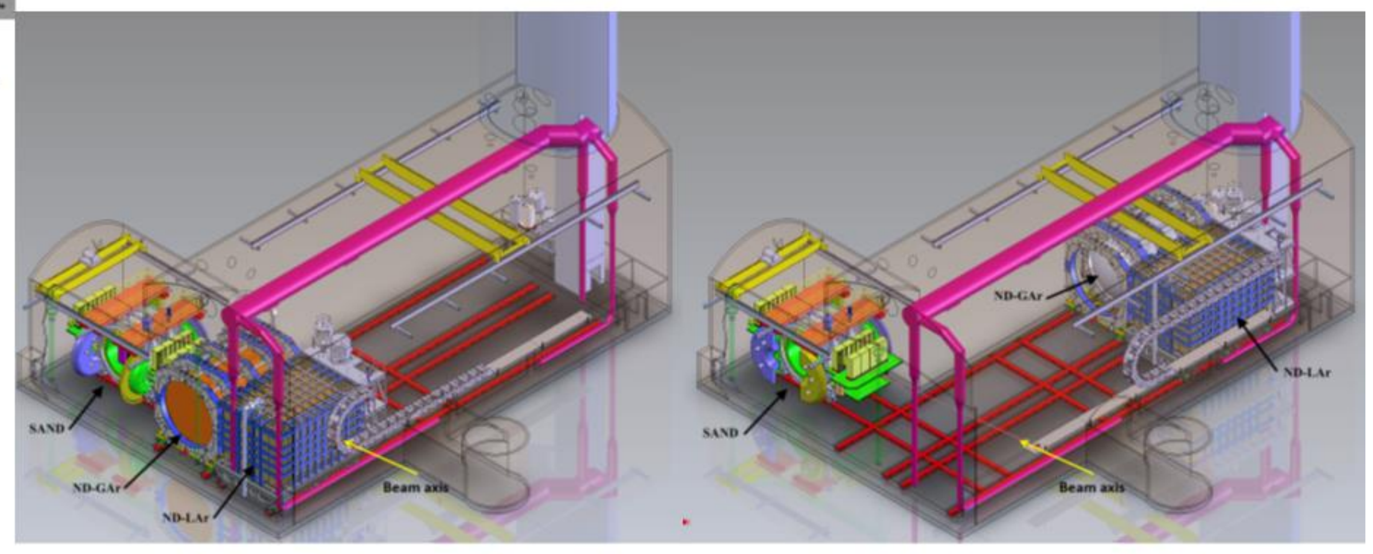


View of the near site neutrino beamline. Source

In the first phase of running the near detector will consist of three different components: a highly modular liquid argon time projection chamber (ND-LAr), a magnetized muon tracker (TMS), and a magnetized beam monitor (SAND).

In a second phase the muon tracker will be replaced by a magnetized gaseous argon time projection chamber (ND-GAr).

The near detector can partially be moved off the neutrino beam axis to change the incoming neutrino spectrum and study the differential interaction cross section as function of the neutrino energy.

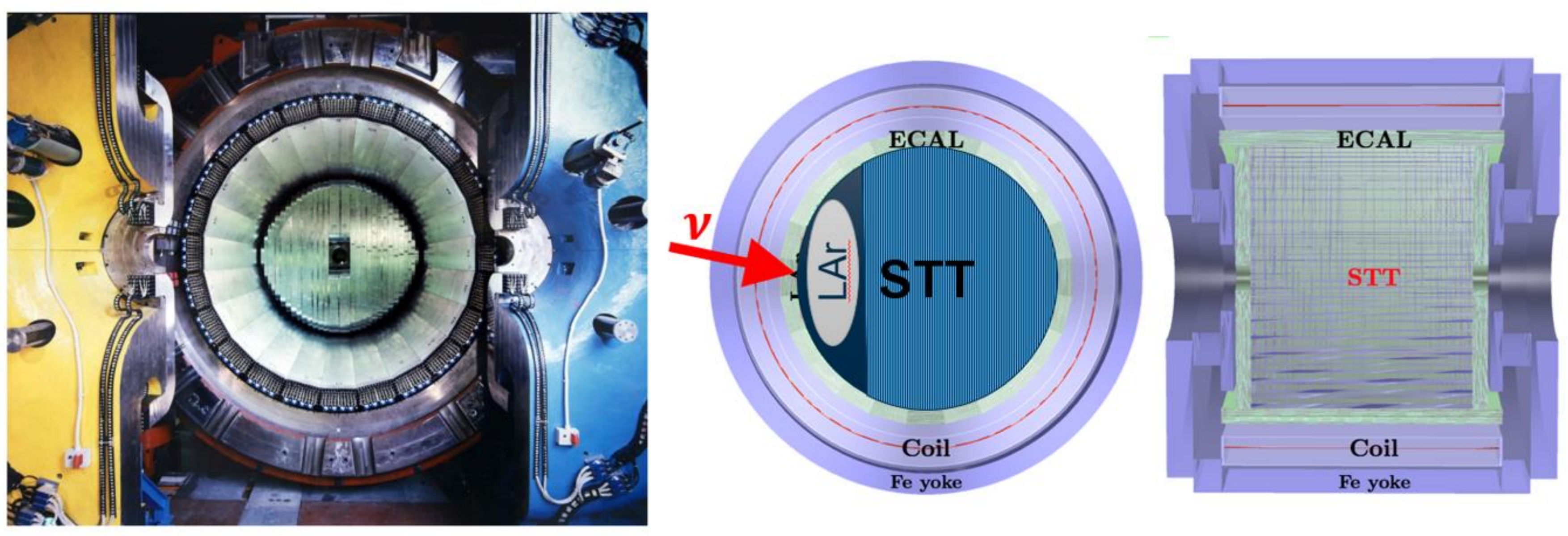


On-axis configuration

Off-axis configuration

2. Sand of Dune Experiment

The final component of the near detector is a magnetized beam monitor called the System for on-Axis Neutrino Detection (SAND). SAND, with its high sensitivity, specifically monitors the changes in the beam. It offers an independent measurement of the flux, assesses the flavor composition of the neutrino beam, and enhances the robustness of the near detector complex to manage systematics effectively. SAND is largely based on a reuse of the magnet and calorimeter from the KLOE experiment. The inner volume of the magnet will be instrumented with a target/tracking system and a small liquid argon detector.



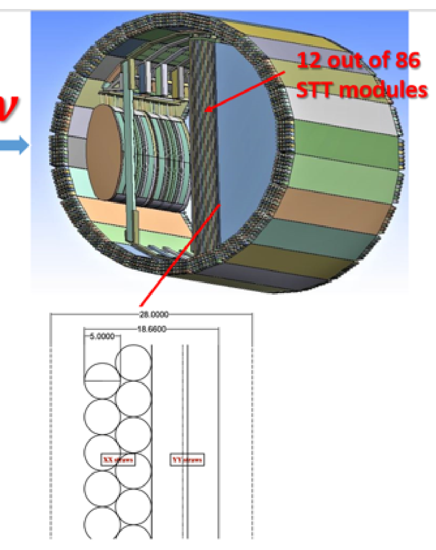
3. STT tracker overview.

Straw tube tracker (STT)

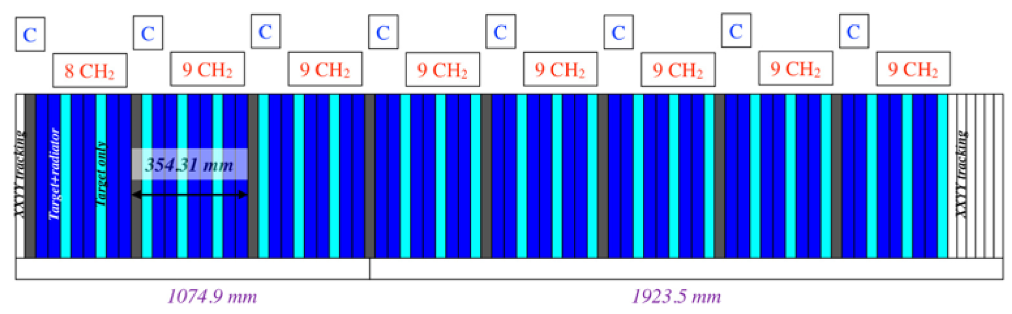
The internal magnetized volume of SAND will be instrumented with an Inner Tracker to:

- separate neutrino and antineutrino events (**charge ID**),
- identify primary leptons (**beam flavor composition**),
- Measure the energy of all charged particles and with the help of calorimeter, of all neutral particle(π^0, n) coming from the neutrino interaction vertex.

86 modules with planes of 5 mm diameter straw tubes filled with Xe/CO_2 gas at 2 absolute pressure arranged in X and Y layers, optimized for the "solid" hydrogen target obtained from a subtraction between CH2 and C layers which are alternated to guarantee the same acceptance.



Straw module size



Number of straws	219,334
Total straw length (km)	700
Straw outer diameter (mm)	5
Average straw length (m)	3.19
Maximal straw length (m)	3.75
Total straw film area (m^2)	10,990
Total straw internal volume (m^3)	14
Total detector length (mm)	2,998
Total number of modules	86
Number of modules with CH_2 target & radiator	48
Number of modules with CH_2 target only	23
Number of modules with graphite target	8
Number of tracking modules (no target)	7
Number of straw planes	344
Number of modules per super-module	10
Number of super-modules	8+1
Number of FE boards	3,427
Modularity of FE boards (channels)	64
Number of HV channels	172
Number of LV channels	188
Number of DAQ/DTS distribution boards	16
Number of LV distribution boards	16

Summary of key numbers for the default STT configuration

Test beam performance

- Position resolution hit 200 µm Y.
- Time resolution hit 2 ns

4. Components of straw tube detectors.

Straw tube are made starting from 19 µm with double side Aluminum of 70 nm Hostaphan® RNK* An inner wire of gold tungsten-rhenium of 20 µm is inserted inside stretched at 50gr. Straws are filled with a mixture of argon/CO_2 (70/30) and Xe/CO_2 (70/30) at 2 bar absolute pressure.

-600 um ID crimping pins to fix the wire + extra spacers for wire centering

-self centering of wires with glued spacers insensitive to end plug/pin misalignments

-end plug and spacers produced with injection molding'

* is a highly transparent, biaxially oriented coextruded film made of polyethylene terephthalate (PET).

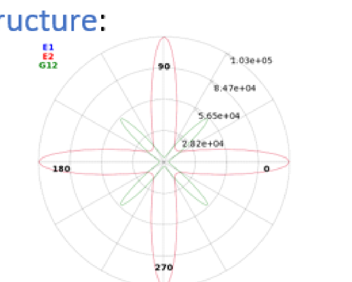
5. Straw supporting structure.

The alignment and stability of the straw tubes is ensured by a rigid frame where the straws are glued. Detailed simulations, and insights gained from previous experiments, have been used to establish the key requirements for this structure:

- must ensure precise alignment of straws with an accuracy of 100 μm;
- should possess the capacity to withstand a pressure of 2 bar absolute while ensuring an appropriate safety factor;
- gas tightness must be lower than or comparable to the straw leak rate;
- must prevent straw compression throughout all phases, including construction, handling, and transportation;
- ensuring the minimum required stress on the electric wire is a crucial aspect of the frame functionality;

Property	Value	Unit	Test method
Tensile strength	4.21	GPa	TY-030B-01
Tensile Modulus	436	GPa	TY-030B-01
Maximum strain	1.0	%	TY-030B-01
Density	1840	kg/m^3	TY-030B-02
Filament diameter	5	μm	

Fiber M46J properties



Laminate stiffness properties

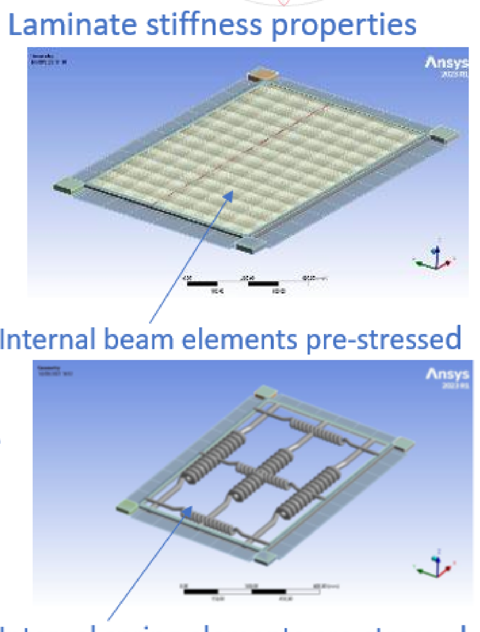
The frame elements are made by 18 plies 0/90 of fabric pre-preg. (55/45)

Analytical, FEM analysis of the straw and wires, confirmed by mechanical test have been used to model as spring, in the mechanical description of the frame.

During the assembly procedure straws pressurized at 3 bar absolute pressure are glue to the frame, then their extremities are cut to insert the wires and the tension due to their pressurization is released to the frame. The minimum tension on the tungsten-rhenium wire (3%) wire is 50 gr.

Mechanical analysis shows that the stiffness of the frame is such that the straw are never compressed. In addition after wire crimping the tension of the wire is not affected by the deformation of the frame. The frame must also withstand to 2 bar absolute pressure of gas.

Experimental test has confirmed the mechanical data used for the mechanical simulation.

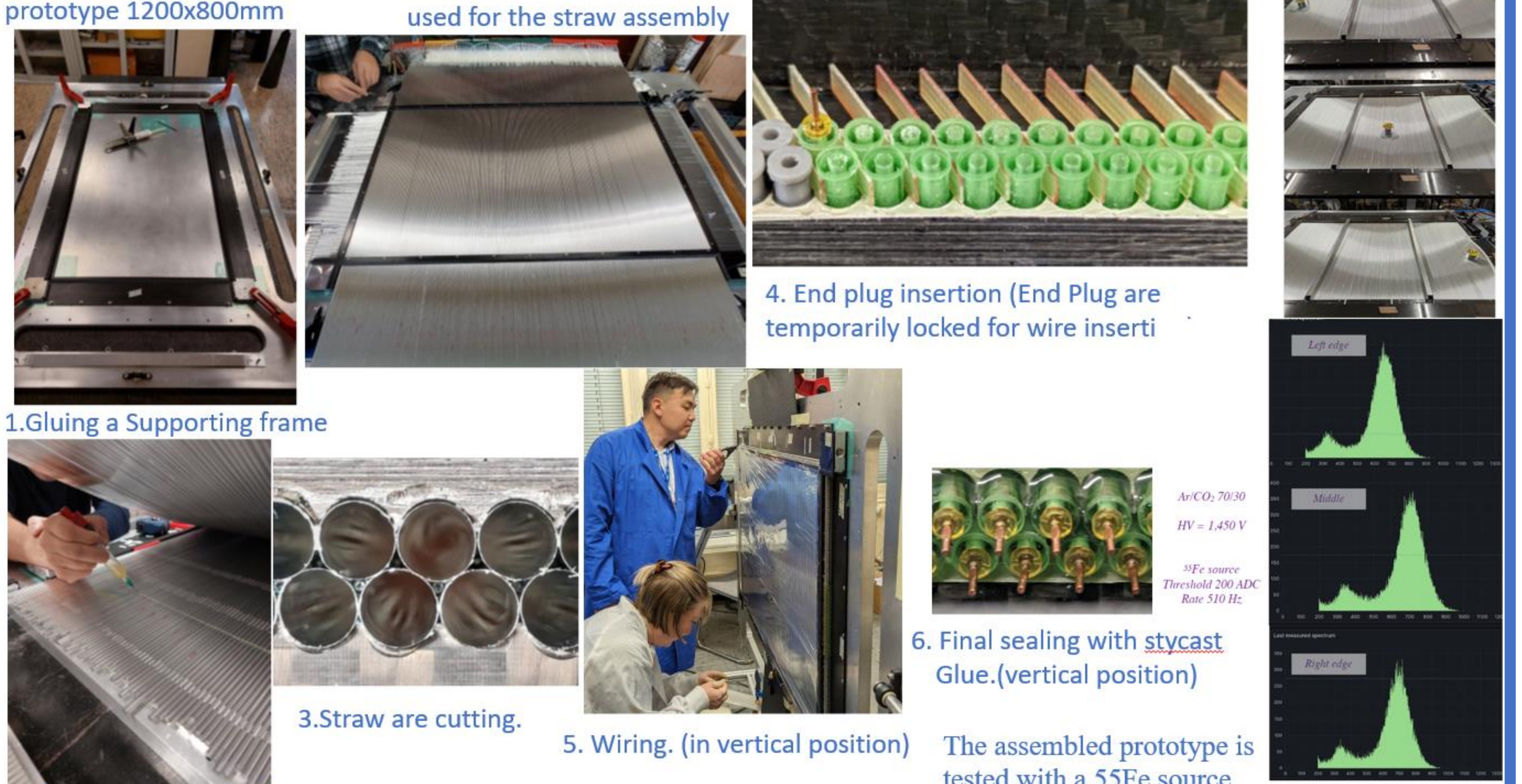


Internal beam elements pre-stressed

Internal spring elements pre-stressed

6. Construction phases of a scaled prototype 1200x800mm

3 bar pressure absolute are used for the straw assembly



1.Gluing a Supporting frame

2. Gluing straws to the frame

3.Straw are cutting.

4. End plug insertion (End Plug are temporarily locked for wire inserti

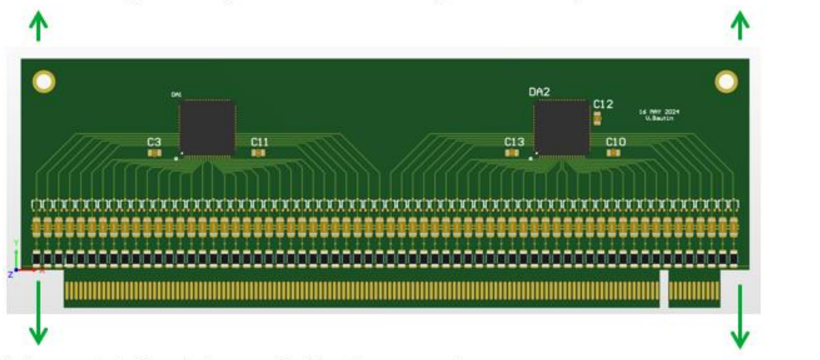
5. Wiring. (in vertical position)

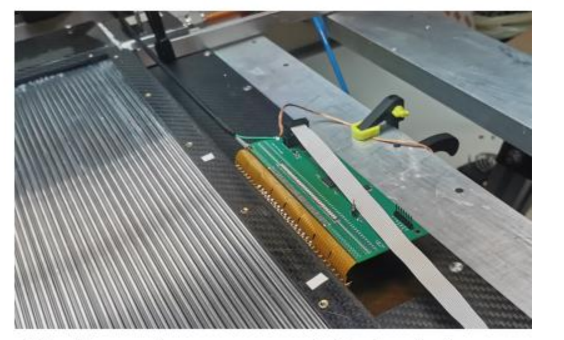
6. Final sealing with stycast Glue.(vertical position)

The assembled prototype is tested with a 55Fe source

7. Electronics

Small boards reading up to 64 straws each with ASIC + micro-controller (MCU);
Connection with straw pins via flexible kapton PCBs with PCIe connector;
Installation in gas volume is minimizing signal path, noise level and x-talk;
Off-the-shelf analog ASIC (G. De Geronimo) can be replaced with custom ASIC;

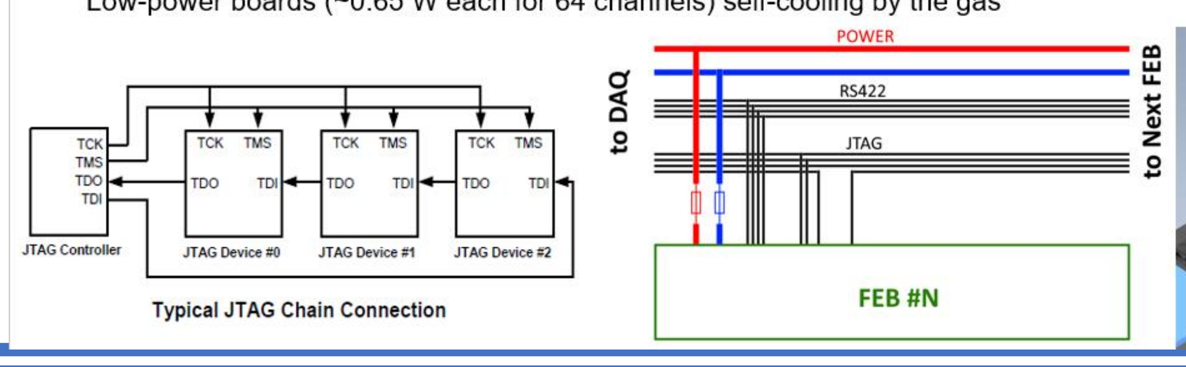


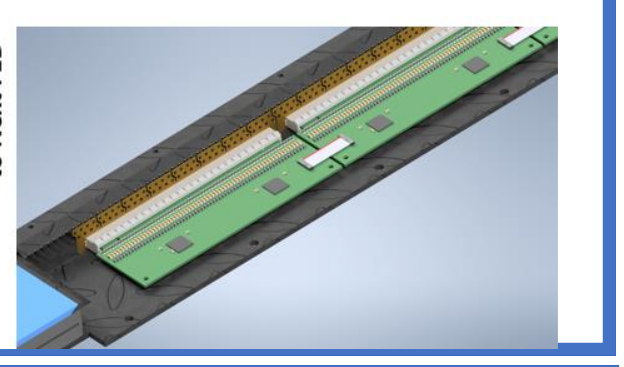


First version successfully tested, revised version (v2) in preparation

Can be fully maintained through the frame edge;
Surge protections, LV fuses, and Solid State Relay (SSR) for HV connect/disconnect
JTAG chain for on-detector firmware upload and telemetry
Low-power boards (~0.65 W each for 64 channels) self-cooling by the gas

Daisy chain for easy mount and maintaince, very compact cabling





8. Conclusions.

The Sand STT tracker has achieved a good level of maturity in term of mechanics, gas flow and thermal studies, electrical read-out (not shown here). Few steps are still needed to launch the mass production. A new prototype 1200x800mm will be produced in next couple of months to validate the wiring procedure with the new spacer, pin, end plug and the new electronic read-out board. For this prototype we have already the carbon fiber frame and the straw are in production now. A full scale prototype 3900x3200mm will be constructed for the final validation of the assembly procedure for the production modules.

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