A System for on-Axis Neutrino Detection in the DUNE experiment

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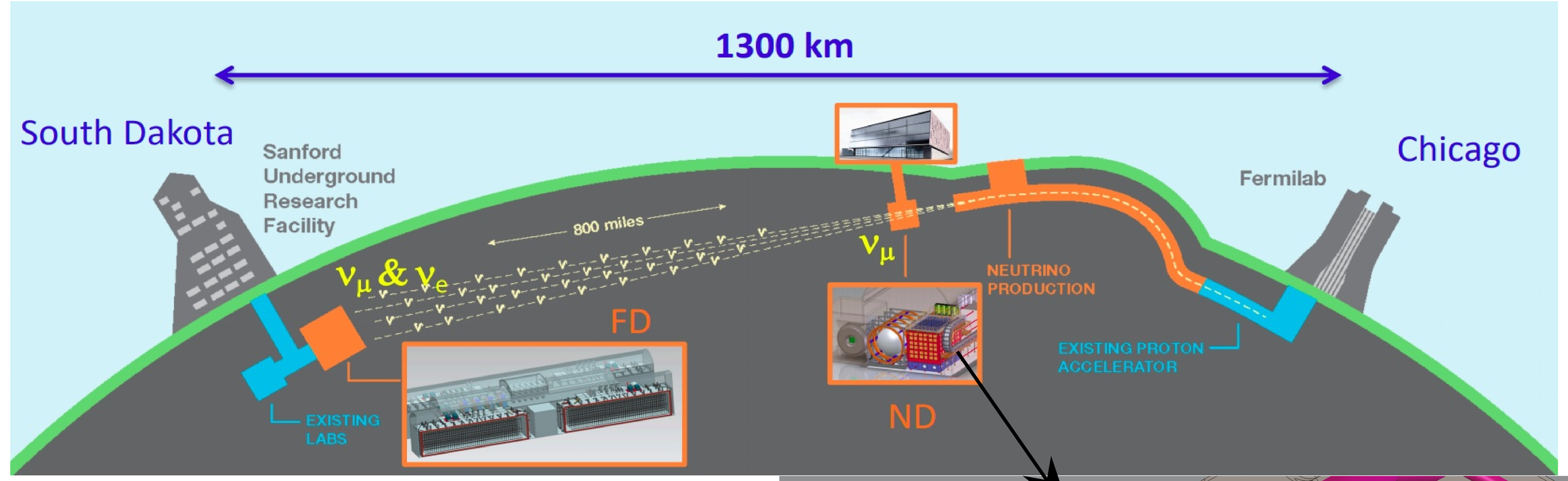
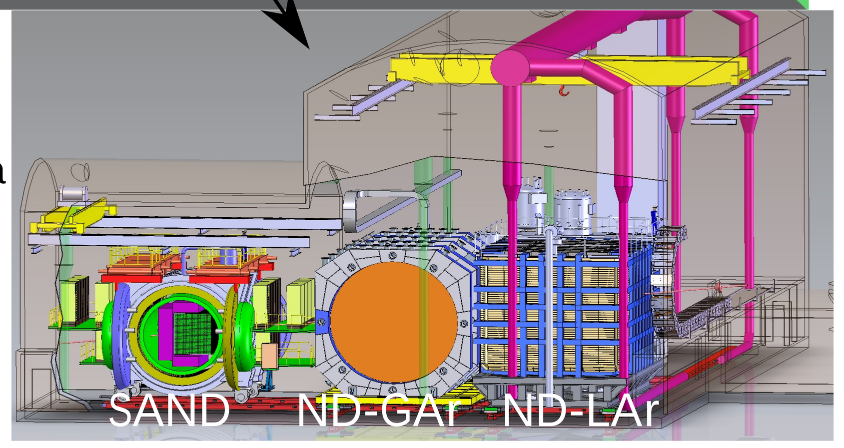
Near Detector in DUNE



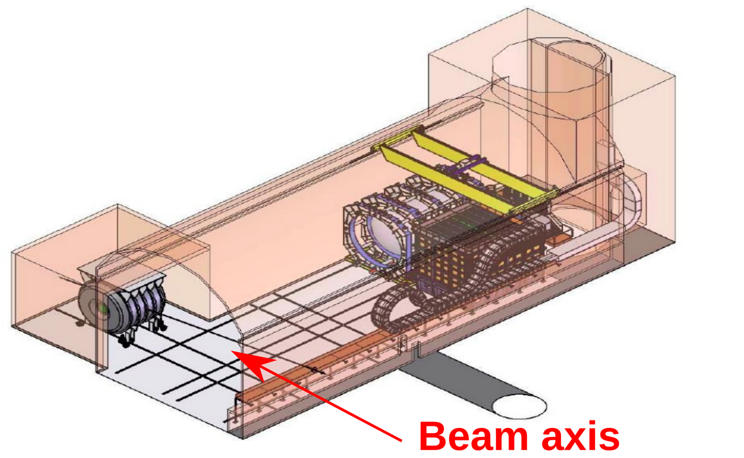


The **D**eep **U**nderground **N**eutrino **E**xperiment is a neutrino experiment with a Far Detector complex in South Dakota (underground) and a Near Detector complex located at Fermilab (underground).

The reference design of the **Near Detector** :

- **ND-LAr :** Liquid Argon Time Projection Chamber.
- **ND-GAr :** Magnetized Gaseous Argon Time Projection Chamber.
- **SAND :** System of on-Axis Neutrino Detector, the only component on axis along the neutrino beam.

DUNE-PRISM ND concept (DUNE Precision Reaction-Independent Spectrum): the **ND-LAr** and **ND-GAr** can move at off-axis positions.



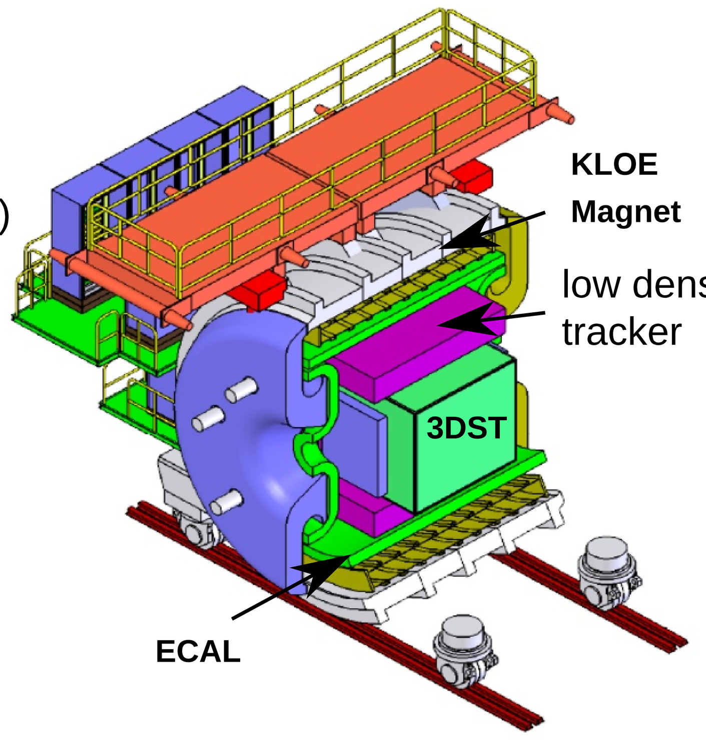
SAND

The reference design for SAND consists of :

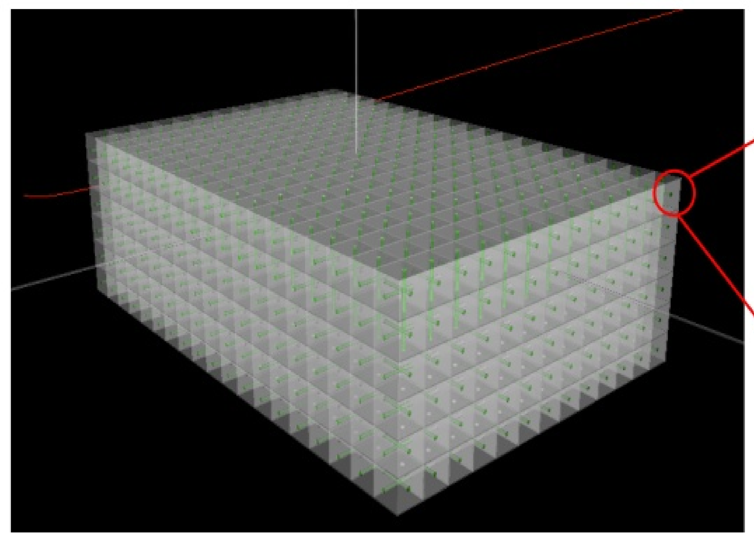
- **3DST** : 3 Dimensional Projection Scintillator Tracker.
- A low density tracker **: STT** (Straw Tube Tracker) or **TPC** (Time Projection Chamber).
- A LAr target can be considered.
- ECAL : Electromagnetic Calorimeter.
- KLOE Magnet : superconducting magnet.

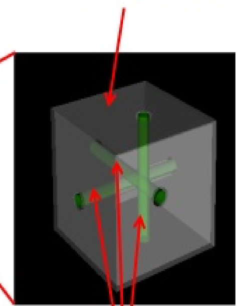
Others options including STT and LAr can being considered.

The reference KLOE magnet dimension is 4m in diameter and 4.3 m long.



3DST : SAND's active target





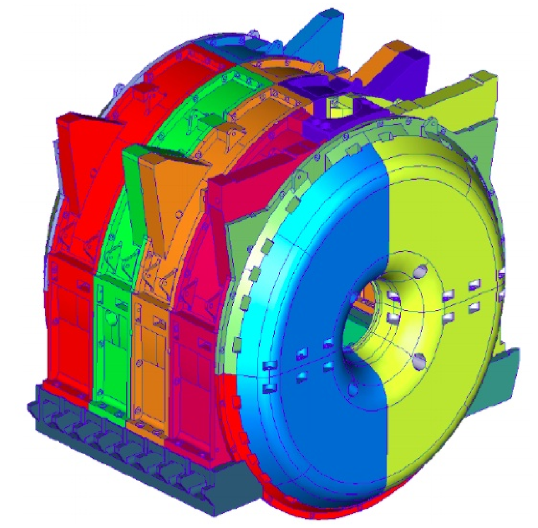
Reference size : 2.4 x 2.4 x 2 m^3.

Made of 1 x 1 x 1cm^3 plastic scintillator cubes.

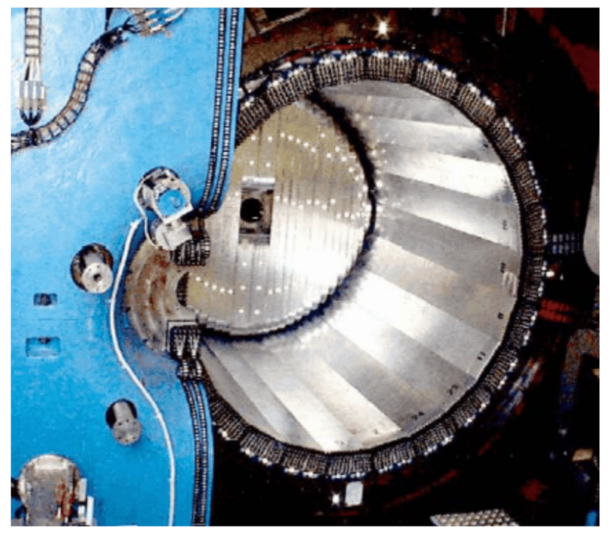
Read out by 3 orthogonal **WLS** (Wavelength-Shifting) fibers.

KLOE Magnet and ECAL

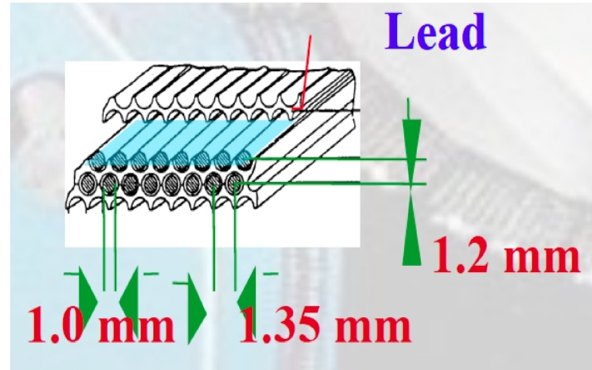
- The Superconducting Magnet in conjunction with its iron yoke can produce 0.6T over a 4.3m long and 4.8m diameter volume. The mass of the KLOE return yoke is 475 tons. [3]



- KLOE Superconducting Magnet



- KLOE Electromagnetic Calorimeter



- Lead, Fiber and Glue = 42, 48, 10 (by volume).

- The KLOE ECAL is a lead-scintillating fiber sampling calorimeter and offer a good light transmission.
- Inherited from the KLOE detector operated at DAΦNE (LNF).
- About 15 X_0 ECAL (5 bars 4.4cm granularity, 4880 channels).

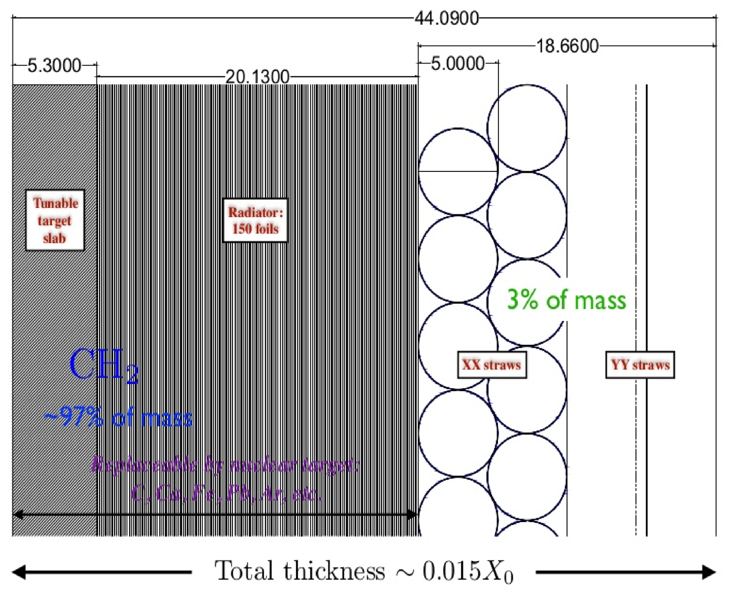
$\sigma_t = 54 \text{ ps} / \sqrt{E_{dep}(GeV)}$ [4]

$\sigma_E = 5.7\,\% / \sqrt{E_{dep}(GeV)}$ [5]

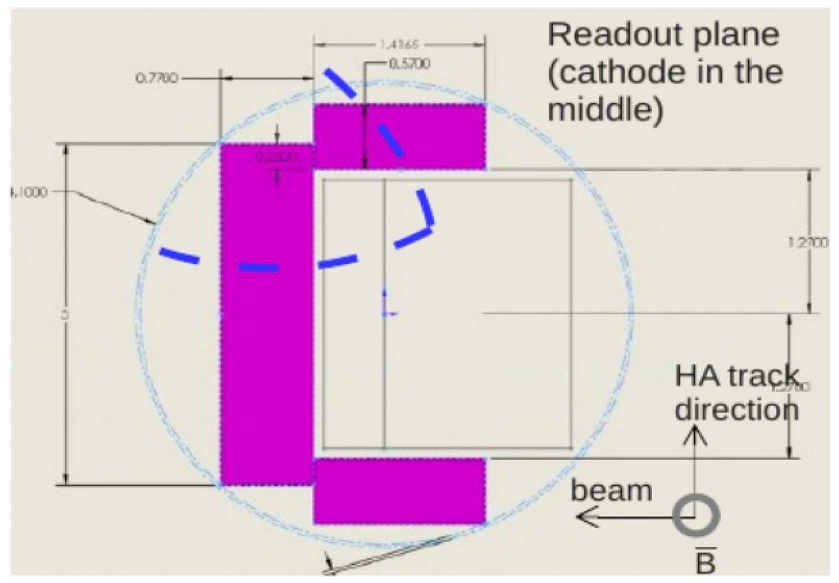
Resolution of Time and Energy.

Low Density Tracker option : TPC or STT

- The Low Density Tracker has to provide a high resolution measurement of the muon momentum and useful PID (Particle ID) information.
- The options for the Low Density Tracker are : the STT and the TPC.
  - STT: The base tracker the STT is provided by low-mass straws. The image in the left below shows one design of the STT with straw layers, series of thin, polypropylene foils, tunable target layer. (from the right to the left).
  - TPC: 3 rectangular chambers in the downstream, upper and lower side of the 3DST. The reference size of the downstream chamber is 57 x 147 cm^2 and for the upper/lower chambers it's 300 x 77 cm^2.



- Straw Tube Tracker



- Time Projection Chambers

On-Axis Beam Monitoring

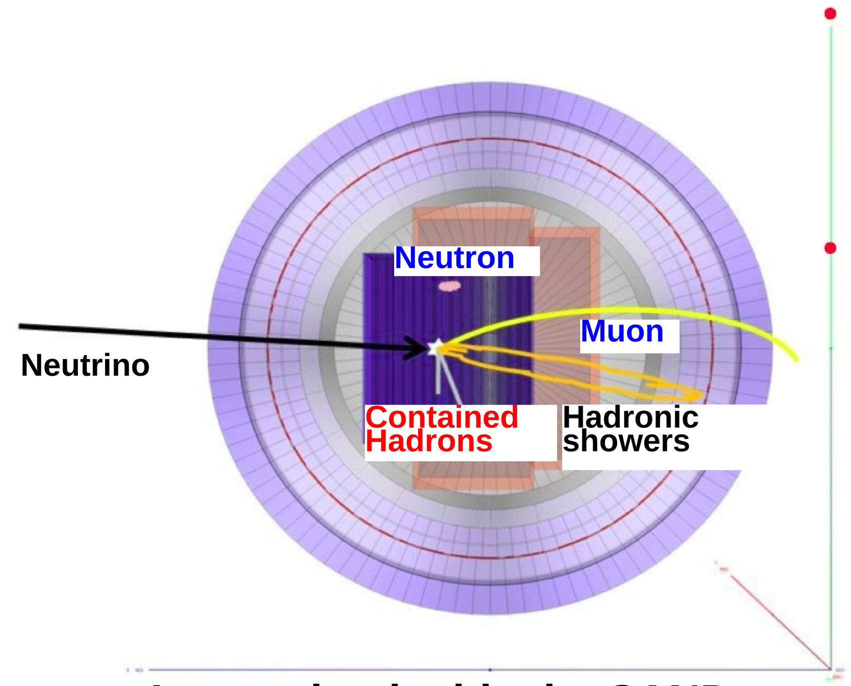
- SAND will be the only detector permanently on-axis along the neutrino beam.
- SAND will allow to monitor the neutrino beam continuously, and the number of CC events per week can be 1.1E6 for ECAL+3DST.
- SAND will be able to monitor the neutrino beam profile within the precision required by DUNE physics programme (precision on the beam direction should be about 0.2 mrad).

FHC Beam		RHC Beam	
Process	**Rate**	**Process**	**Rate**
All ν_μ-CC	1.5×10^7	All $\bar{\nu}_\mu$-CC	5.4×10^6
CC 0π	4.4×10^6	CC 0π	2.4×10^6
CC $1\pi^\pm$	4.3×10^6	CC $1\pi^\pm$	1.5×10^6
CC $1\pi^0$	1.3×10^6	CC $1\pi^0$	5.3×10^5
CC 2π	1.9×10^6	CC 2π	5.0×10^5
CC 3π	8.7×10^5	CC 3π	1.7×10^5
CC other	1.8×10^6	CC other	2.8×10^5
ν_μ-CC COH π^+	1.3×10^5	$\bar{\nu}_\mu$-CC COH π^-	1.0×10^5
$\bar{\nu}_\mu$-CC COH π^-	1.2×10^4*	ν_μ-CC COH π^+	1.7×10^4*
ν_μ-CC ($E_{had} < 250$ MeV)	2.4×10^6	$\bar{\nu}_\mu$-CC ($E_{had} < 250$ MeV)	1.9×10^6
All $\bar{\nu}_\mu$-CC	7.0×10^5	All ν_μ-CC	2.3×10^6
All NC	5.3×10^6	All NC	2.9×10^6
All $\nu_e + \bar{\nu}_e$-CC	2.6×10^5	All $\bar{\nu}_e + \nu_e$-CC	1.7×10^5
$\nu e \rightarrow \nu e$	1.8×10^3*	$\nu e \rightarrow \nu e$	1.5×10^3*

Event rates for one year

Neutron Detection

- Accurate reconstruction of neutron energy will improve the understanding of the neutrino interactions.
- The **ToF** (Time of Flight) method allows to reconstruct the neutron energy giving sub-nano second time resolution and fine granularity.
- The out of Fiducial Volume (FV : 2.1m x 2.1m x1.9m) background is small compared to the signal.



-- **Interaction inside the SAND**

- The secondary interaction background (coming from secondary neutrons: neutrons created by primary particles) can be rejected by a series of angle and distance cuts.
- The gamma background can be largely rejected by the beta (defined as v/c, where v is the speed of the particle either neutron or gamma).

Flux Measurements

- **SAND** can provide measurements of the absolute and relative on-axis flux for the various components of the beam.

Possible measurements with **SAND** :

- $\nu e^- \rightarrow \nu e^-$ elastic scattering : can provide an accurate measurement of the absolute neutrino flux.
- $\bar{\nu}_\mu p \rightarrow \mu^+ n$ with low transverse momentum imbalance : helps to measure the $\bar{\nu}_\mu$ flux.
- Low ν (energy transfer from neutrino to nucleus system) : allows a precise measurement of the muon (anti) neutrino flux.

Conclusion

- The SAND will be able to monitor different neutrino beam variations on a weekly basis.
- We have the potential to select the hydrogen sample in order to understand the nuclear effects.
- SAND could be able to reconstruct the neutrons energy by avoiding as much as possible background from gammas , secondary interactions or out-FV interaction by ToF technique.

SAND group posters at Neutrino 2020

- The Superconducting Magnet and Electromagnetic Calorimeter of SAND in DUNE by F. Ferraro.
- A Straw Tube Tracker for SAND in DUNE by B. Guo.
- A System for on-Axis Neutrino Detection as beam monitoring for the DUNE experiment by M. Tenti.
- Neutron detection of the System of on-Axis Neutrino Detection in the DUNE Near Detector by Sunwoo Gwon.

References

[1] DUNE Far Detector Technical Design Report , by The DUNE Collaboration, arXiv: 2002.02967.
[2] "Deep Underground Neutrino Experiment (DUNE) Near Detector Conceptual Design Report", by The DUNE Collaboration, to be published.
[3] "Progress in the design and manufacture of the KLOE solenoid for the DAPHNE ring at Frascati", by K. Smith, A. Broadbent, M. Greenslade, S. Harrison, D. Jenkins, J. Ross, A. Street, M. Townsend, J. Wiatrzyk, and J. Franzini.
[4] Nucl. Instrum. Meth. A419 (1998), 320–325.
[5] Nucl. Instrum. Meth. A482 (2002), 364.