System for on-Axis Neutrino Detection as beam monitoring for the DUNE experiment

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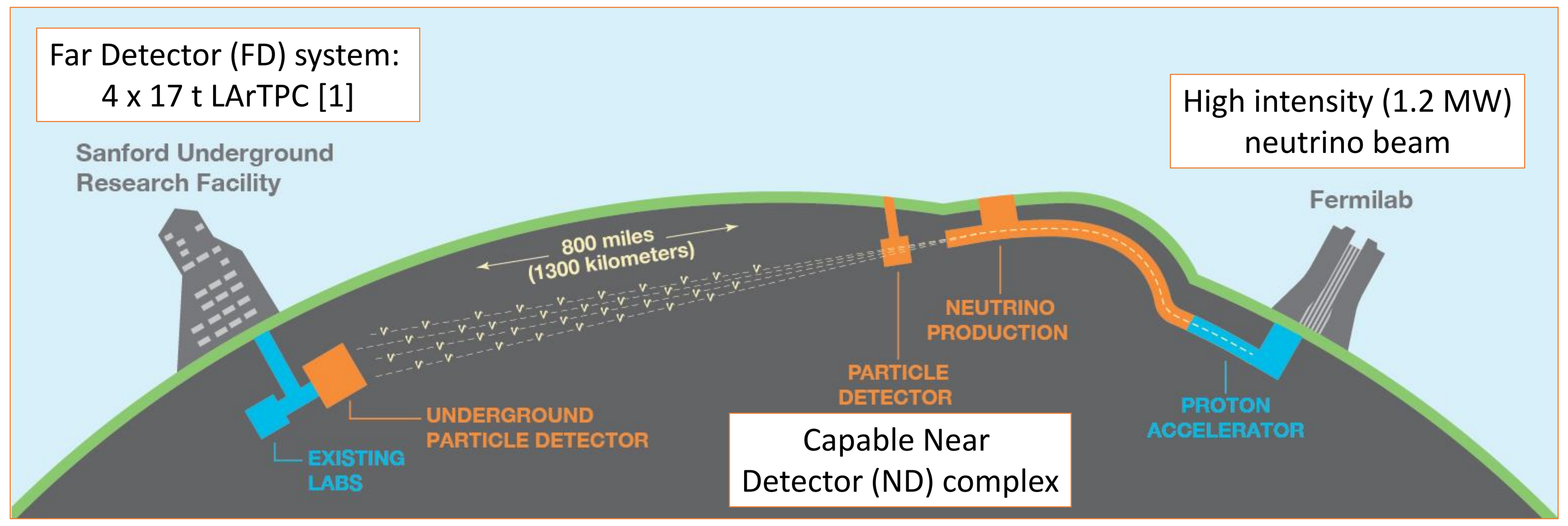
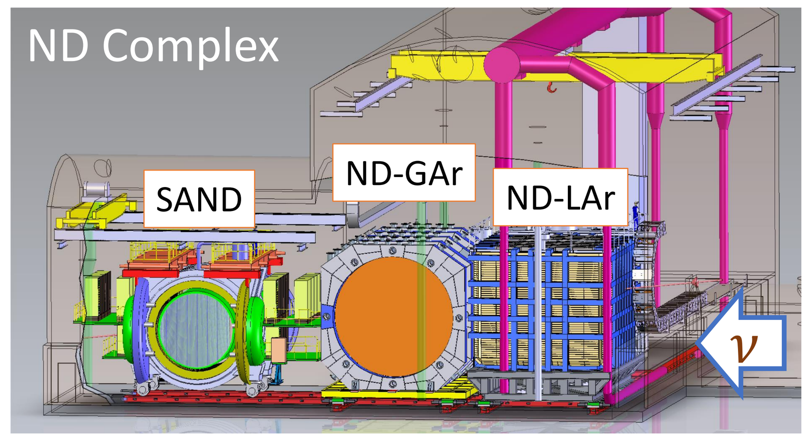
DUNE Experiment

The Deep Underground Neutrino Experiment (**DUNE**) is a long-baseline neutrino oscillation experiment. Its major aims are:

- Study of the **neutrino oscillation** phenomenon
- Search for **beyond SM processes**
- Detection of **supernova neutrinos**





ND-LAr: modular 67 t LArTPC

Multi-Purpose Detector (**ND-GAr**): magnetized (0.6 T) high pressure GArTPC surrounded by electromagnetic calorimeter

System for on-Axis Neutrino Detection (**SAND**)

ND provides input for the neutrino interaction model, measures and monitors the beam, and constrains systematic uncertainties

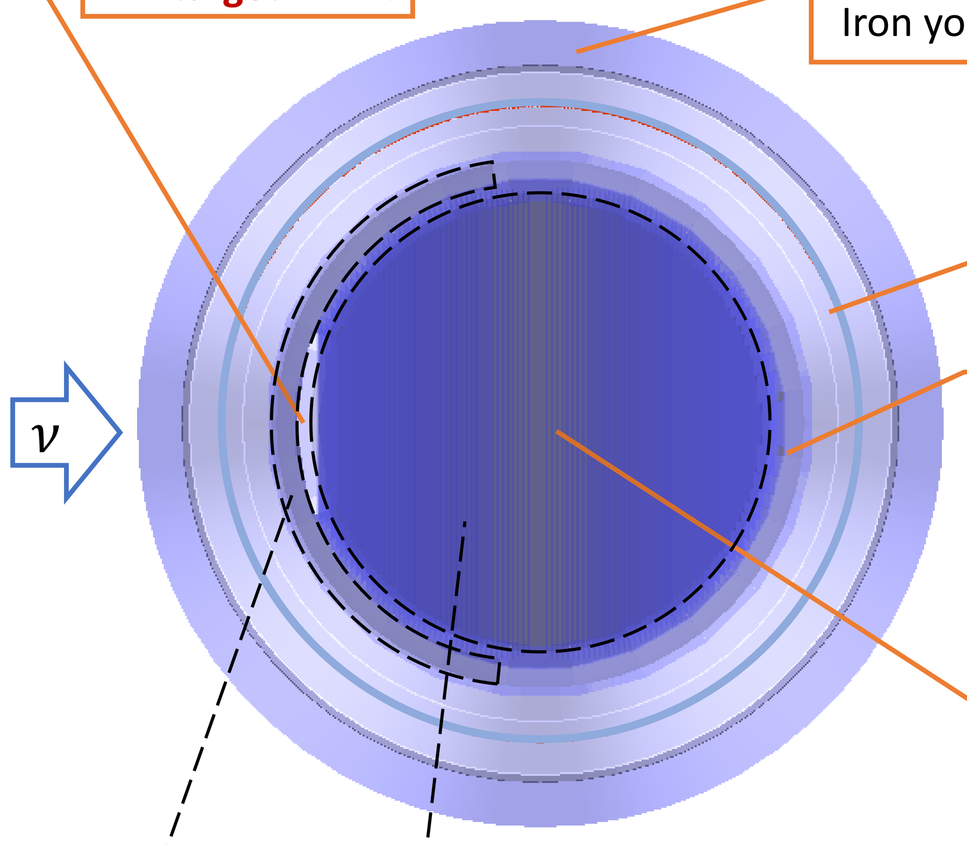
A SAND design*

LAr target: ~ 1 t

Iron yoke

Side view of the **solenoidal superconducting iron magnet** (B = 0.6 T)

Cryostat and coil



Lead/scintillating fiber 4π-coverage e.m. calorimeter (ECAL): 24 barrel modules and 2 endcaps. Total mass: 90.6 t

See F. Ferraro's poster for details

Straw Tube Tracker (STT): modules of CH2 or C targets interleaved with horizontal and vertical planes of straw tube. Total mass: 7.4 t

See B. Guo's poster for details

STT fiducial mass: 6.7 t

ECAL fiducial mass: 22.8 t

** This is one of the alternative designs currently being studied*

Beam Monitoring

Continuous monitoring of the neutrino beam is mandatory to detect both deliberate and unanticipated changes in the beam parameters which could directly affect the FD oscillation analysis.

SAND being the only ND detector permanently located on-axis will have the **capability to monitor** the neutrino beam.

The stability of the beam is checked monitoring the **rate, neutrino energy spectrum, and spatial distribution** of the ν_μ charged current (CC) interactions on a week basis corresponding to 3.78×10^{19} protons on target (p.o.t.).

This study focuses on the sensitivity to

- the **main parameter variations** recommended to be studied by the beam working group. They result in 1σ of the corresponding systematic uncertainties on the (anti)neutrino fluxes and are below the sensitivity of the beam instrumentation
- variation in **beam direction**

Event selection and reconstruction

Monte Carlo Sample: $\sim 1.5 \times 10^6$ ν_μ CC interactions in ECAL, STT and LAr target (corresponding to a week of data taking) in FHC nominal beam configuration were simulated using GENIE [2] and GEANT4 [3] software.

Fiducial mass: 22.8 t (ECAL) + 6.7 t (STT + LAr target)

Momentum reconstruction: A minimum number of STT digits in the YZ bending plane is required to reconstruct particle momentum

- For interactions in ECAL and LAr target: ≥ 6 digits
- For interactions in STT: ≥ 4 digits

Reconstructed momentum is obtained using a fast reconstruction based on the Gluckstern's formula [4] supplemented by multiple scattering contribution.

Neutrino energy:

$$E_\nu^{rec} = E^{ECAL} + E^{LAr} + \sum_{tracks} K^{STT}$$

E^{ECAL} and E^{LAr} being the visible energy in ECAL and LAr target and K^{STT} kinetic energy associated to reconstructed tracks.

Analysis and Results

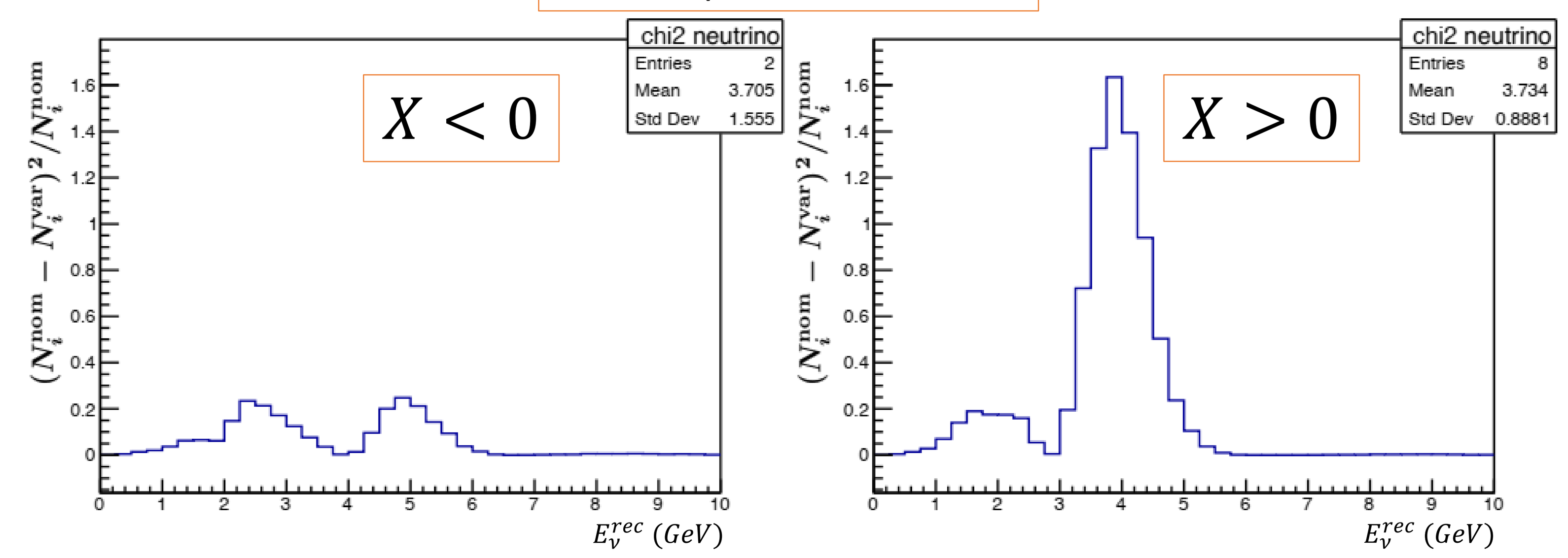
Expected sensitivity are evaluated comparing the distribution of E_ν^{rec} expected from ***nominal*** (N_i^{nom}) and ***varied*** (N_i^{var}) beam, using the **test statistic T**:

$$T = \sum_{i=1}^{n} \frac{(N_i^{nom} - N_i^{var})^2}{N_i^{nom}} \sim \Delta\chi^2$$

The nominal distribution is evaluated using a full Monte Carlo (MC) simulation, while the varied one is derived from the former using **re-weighting technique**. The weights as a function of neutrino energy and off-axis position were obtained from MC simulation.

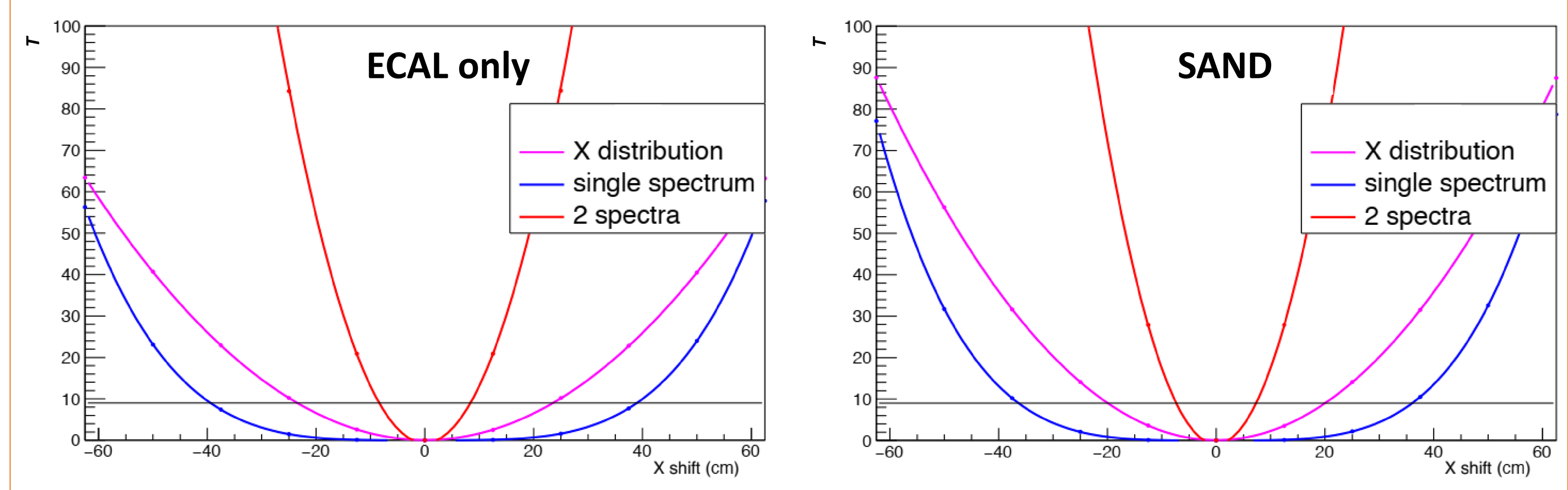
For variations breaking the cylindrical symmetry of the beam, the sensitivity is increased by grouping events according to the interaction point location w.r.t. the center of SAND (i.e. $X > 0$ and $X < 0$).

An Example: Horn 1 Shift X



Results	test statistic $T \sim \Delta\chi^2$ (1 dof)			
	ECAL only		SAND	
Beam parameter	E_ν^{true}	E_ν^{reco}	E_ν^{true}	E_ν^{reco}
proton target density	18.0	14.3	25.6	19.6
proton beam width	34.9	27.6	48.4	37.4
proton beam θ	0.7	0.2	1.1	0.3
horn current	107.6	76.1	158.2	105.6
water layer thickness	21.1	16.2	30.2	22.2
decay pipe radius	42.0	34.3	61.9	48.0
proton beam offset X	24.6	16.9	34.1	22.2
proton beam θ and ϕ	0.5	0.1	0.8	0.2
horn 1 along X	16.2	10.7	23.4	14.6
horn 1 along Y	20.6	13.6	27.9	17.7
horn 2 along X	0.4	0.2	0.6	0.3
horn 2 along Y	0.4	0.1	0.6	0.2

Exploiting a similar analysis, SAND will be able to identify with a significance > 3σ a beam shift > 8.4 cm corresponding to a beam tilt of **0.13 mrad**. It is worth noting that the intrinsic beam divergence (1.5 mrad) is an order of magnitude larger.



Conclusions and References

SAND has a sensitivity greater than 3σ in one week of data taking for the variation of most of the relevant parameters affecting the beam systematics.

A similar sensitivity is obtained for a change in the beam direction of about 0.13 mrad by combining the independent ECAL and STT samples in one week of data taking.

References:

[1] DUNE Far Detector TDR: arXiv:2002.02967; arXiv:2002.03005; arXiv:2002.03008; arXiv:2002.03010

[2] Nucl.Instrum.Meth.A614 (2010) 87-104; arXiv:1510.05494

[3] Nucl.Instrum.Meth.A506 (2003) 250-303

[4] Nucl.Instrum.Meth.24 (1963) 381-389