STT: Indian Interest in SAND

Bipul Bhuyan
Indian Institute of Technology Guwahati

DUNE Near Detector Discussion Meeting
TIFR, Mumbai

February 29, 2020

Interest of the Indian Group on DUNE-Near Detector

- The Indian group on DUNE has shown interest in the Near Detector since LBNE era.
  - Interest has been on a high resolution fine grained tracker with STT as the tracking volume, surrounded by an plastic scintillator based ECAL, and a RPC based muon detector inserted in a dipole magnet.
  - Some of these earlier interest in the ND project resulted in the current involvement of the BARC group in the magnet design for the MPD.
  - The signing of the Annex-II of the agreement between DAE (India) and DOE (USA) is also the result of hard work by many physicists from India during 2008 – 2015.

LBNE-INDIA

Proposal of Indian Institutions and Fermilab Collaboration for Participation in

the Long-Baseline Neutrino Experiment at Fermilab

(A Proposal to Design and Build a High-Resolution Near Detector

and to Contribute to the Liquid Argon Far Detector)

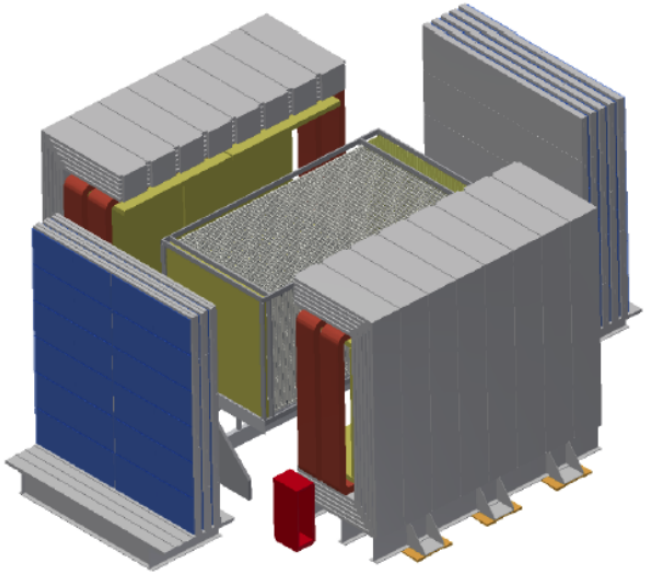
Dated December 12, 2012

to

Department of Atomic Energy and

Department of Science and Technology

Government of India



188 pages document with full detector design supported by detail physics studies

Interest of the Indian Group on DUNE-Near Detector

- The STT based tracker remained the reference baseline design for DUNE-ND till July 2018. **[DUNE CDR Volume 4]**
  - Successfully passed the technical and DOE CD1 reviews.
    - DUNE ND Design Review, May 28-29, 2015,

      https://web.fnal.gov/project/LBNF/ReviewsAndAssessments/DUNE%20ND%20Design%20Review/SitePages/Home.aspx
    - Director's CD-1 Refresh Review of LBNF-DUNE, June 2-4, 2015,

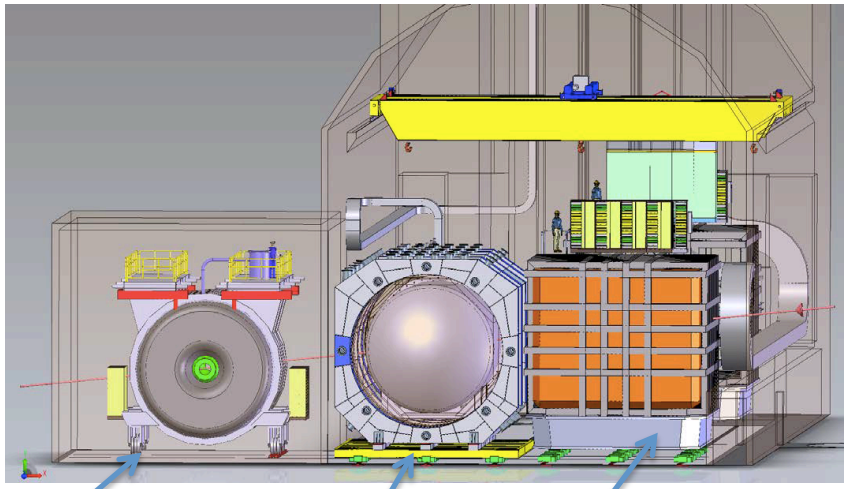
      https://web.fnal.gov/organization/OPSS/Projects/LBNFDUNE/SitePages/Director%27s%20CD-1%20Refresh%20Review%20of%20LBNF-DUNE,%20June%202-4,%202015.aspx
    - DOE CD-1 Refresh Review of LBNF-DUNE, July 14-16, 2015,

      https://web.fnal.gov/organization/OPSS/Projects/LBNFDUNE/SitePages/DOE%20CD-1%20Refresh%20Review%20of%20LBNF-DUNE,%20July%2014-16,%202015.aspx

Institutions involved: IIT Guwahati, IIT Hyderabad, University of Hyderabad, Delhi University, Panjab University, BHU, Jammu University, BARC, VECC, HRI

DUNE-Near Detector (post 2015)

STT will allow the possibility of having different nuclear targets such as Fe, C, Ca, H etc which will significantly enhance the physics potential of the DUNE-ND complex.



SAND

Multi Purpose Detector

Liquid Argon Detector

A detector such as SAND with STT as the tracking volume remains attractive to re-activate Indian interest in the DUNE Near Detector program.

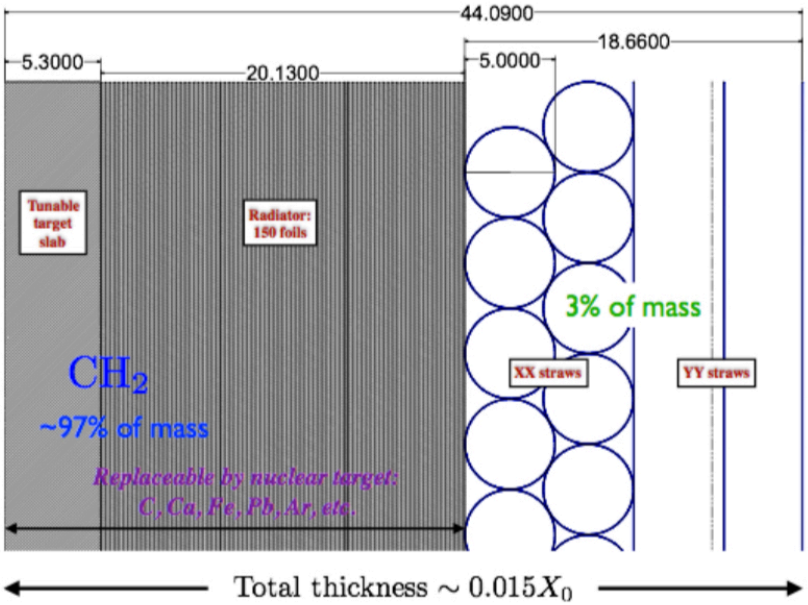
- ✓ Driven by the strong physics program in addition to the neutrino oscillation physics.

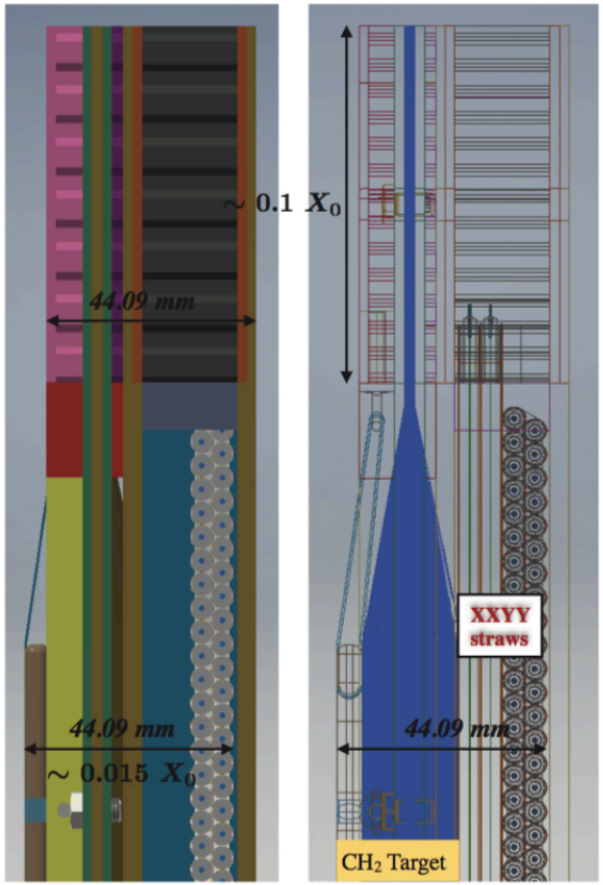
SAND:

- ✓ Option 1: put STT as the tracking detector in the KLOE magnetic volume.
  (reference for performance studies: see Sergio Bertolucci's LBNC talk, December 6, 2019)
  (For details, see DUNE-DOC- 13262: https://docs.dunescience.org/cgi-bin/private/RetrieveFile?docid=13262&filename=A_Near_Detector_for_DUNE.pdf&version=4)
- ✓ Option 2: 3DST + a low density tracker (TPC or STT) : Require detail comparison studies.

Straw Tube Tracker (STT) for SAND

- Thin passive targets (100% purity) physically separated from active tracker (straws ~3% of total mass)
- Tunable target mass & density by varying thin targets (~97% of total mass) with average density 0.005<= rho <=0.18 g/cm^3
- A variety of thin (<0.1 X_0) nuclear targets can be installed & replaced during data taking: C, Ca, Fe, Pb,etc



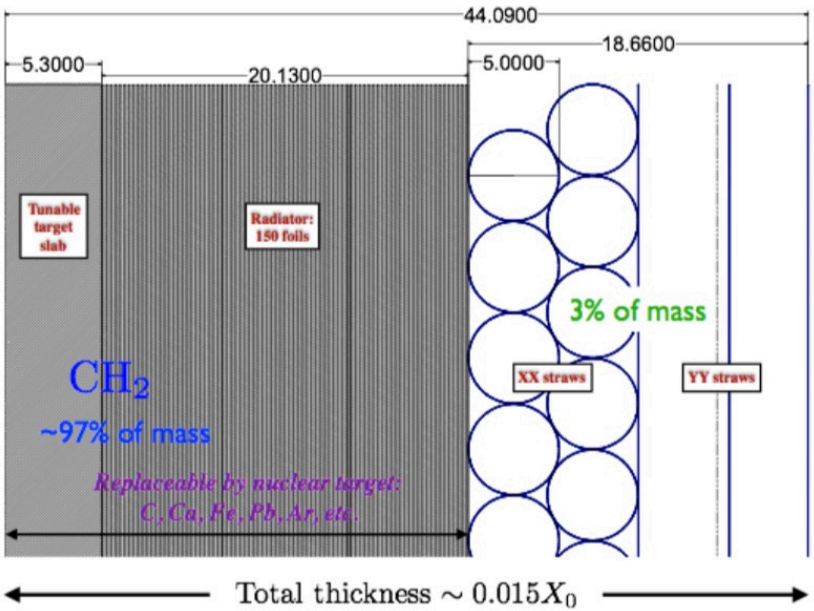


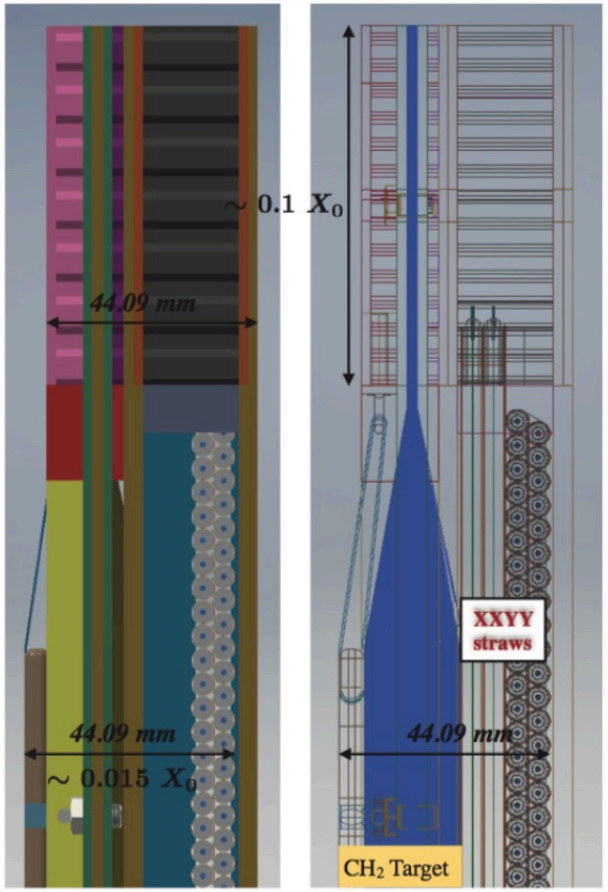
Modular design (flexible) offering a control of the configuration, chemical composition, and mass of targets comparable to e-scattering experiments

3DST + STT Options

Possible STT configurations:

- Straw Pure tracking in STT: remove most density & mass
- Physics measurements in STT: multiple nuclear targets, increase density & mass





Detailed studies and optimization are ongoing to evaluate performance: find optimal compromise between target mass (statistics) & resolution

Physics Potential of a STT based Tracker

- Determine the relative abundance and energy spectrum of the four ν species in LBNF beam: $\nu_\mu, \bar{\nu}_\mu, \nu_e$, and $\bar{\nu}_e$ through CC-interactions.
  - **Prediction of FD/ND (E_ν) fluxes to ~ 1%**
- Determination of the absolute ν_μ and $\bar{\nu}_\mu$ fluxes to ~ 3%
- Measure cross-sections and exclusive topologies
  - Event by event NC/CC separation as a fun
  - Measurement of π^0 and γ yield
  - Measurement of $\pi^\pm$ / $\mu^\pm$ decays.
  - Measure e -Ar interactions: Quasi-elastic, single π , Deep Inelast duction.

d disappearance channels.

- Cali lute energy scale in $\nu - Ar$ and $\bar{\nu} - Ar$ interactions.
- Quant vs $\bar{\nu}$ asymmetries in E_ν scale, flux and interactions cross-sections for δ_{CP}
- Precision measurement of fundamental neutrino (anti-neutrino) interactions with matter such as free nucleon (H). **See Roberto's talk.**

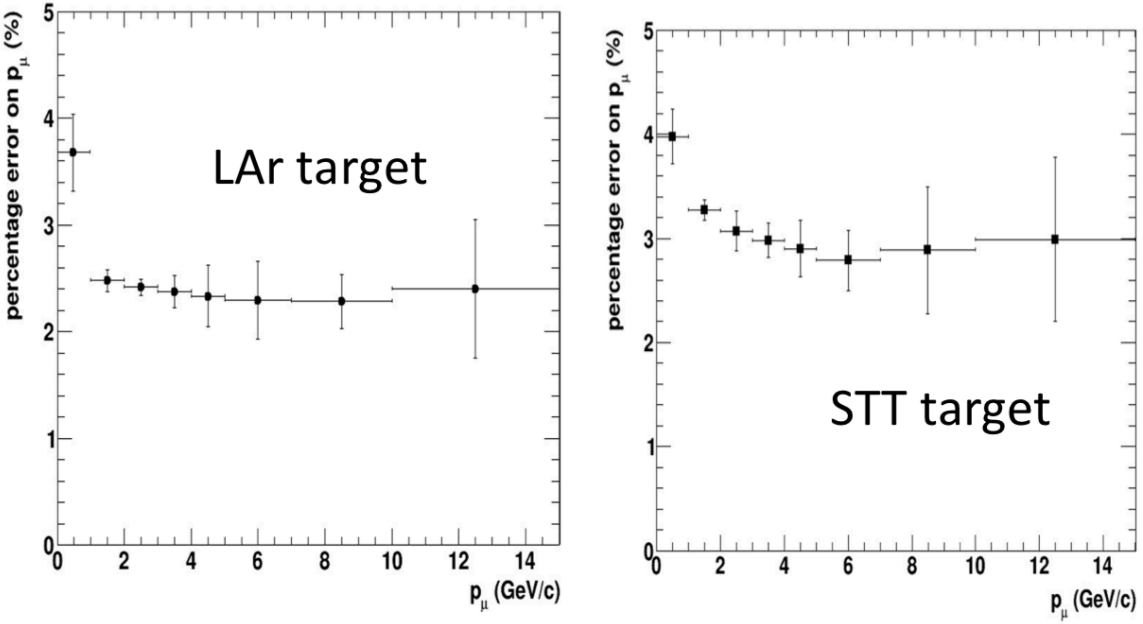
Large number of Ph.D. topics based on STT based tracker volume for students.

One of the important requirements of the Indian funding agencies.

STT Performance

- The STT provides excellent momentum (~3%) and angular resolution (~ 2 mrad).
- Excellent particle identification via both ionization signals *dE/dx* and the Transition Radiation produced by e+ and e- in the radiator foils.
- Offers ~ 10^3 pion rejection with about 90% electron efficiency.

STT results: muon



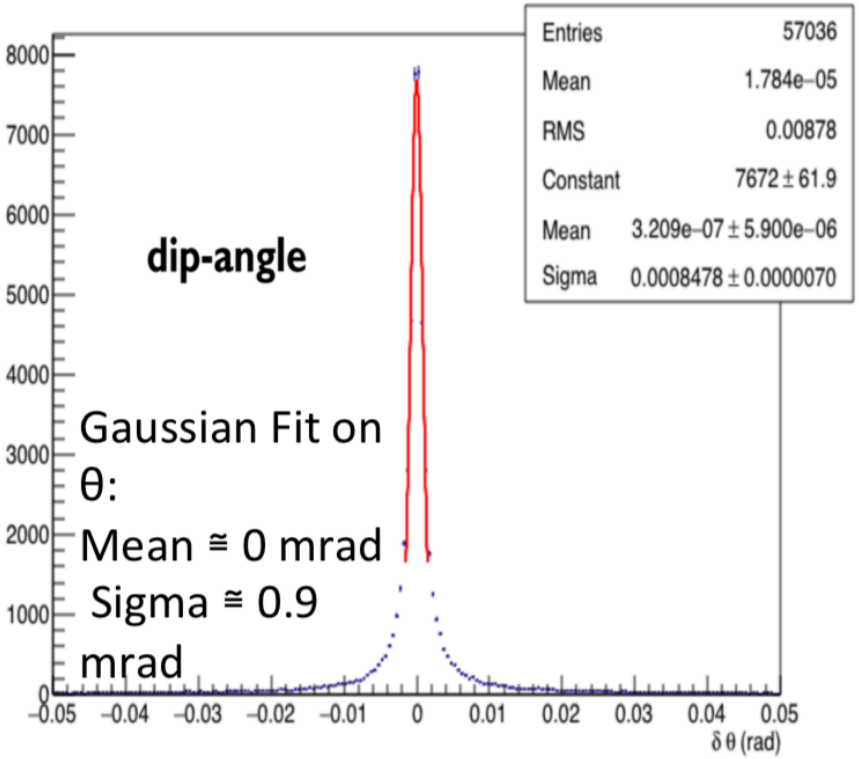
Good resolution on p (~3%) for both targets.

Good resolution on dip angle ~ 1.7 mrad

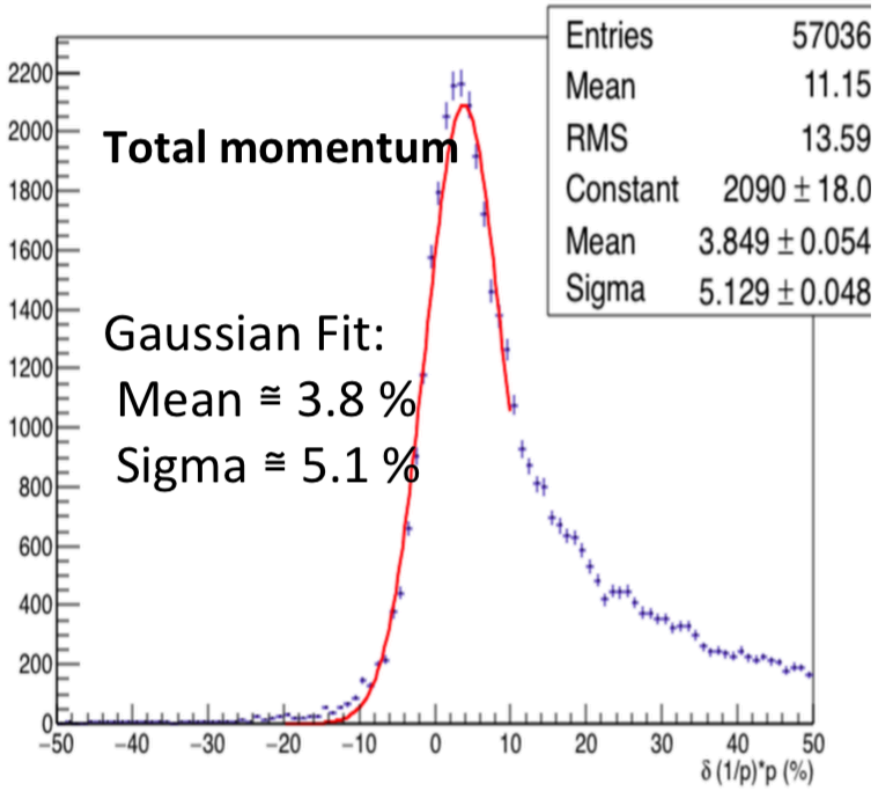
Charge mis-ID rate ~ 0.02%

STT Performance : Electrons

Generated in STT with GENIE+GEANT4. Very good resolutions, tails due to circular fit approximation to be improved i.e. with Kalman filter.



Wrong sign 1.3%



Same results with FLUKA

The Indian institutions still consider having a STT tracker in one of the detector magnetic volumes such as the KLOE is still a VERY attractive option physics wise.

Enhancing the LBNF/DUNE Physics Program

P. Bernardini[1], S. Bertolucci[2], M. Bhattacharjee[3], B. Bhuyan[3], S. Biagi[11], A. Caminata[13], A. Cervelli[6], S. Davini[13], S. Di Domizio[13], L. Di Noto[13], M. Diwan[4], C. Distefano[11], H. Duyang[5], F. Ferraro[13], A. Gabrielli[2], M. Guerzoni[6], B. Guo[5], M.A. Iliescu[12,14], G. Laurenti[6], G. Mandrioli[6], N. Mauri[2], S.R. Mishra[5], N. Moggi[2], A. Montanari[6], M. Pallavicini[13], L. Pasqualini[2], L. Patrizii[6], R. Petti[5],* M. Pozzato[6], P. Sapienza[11], F. H. Sawy[7], G. Sirri[6], L. Stanco[8], A. Surdo[9], M. Tenti[10], F. Terranova[10], G. Testera[13], M. Torti[10], N. Tosi[6], R. Travaglini[6], and S. Zucchelli[2]

Submitted to European Strategy Group in 2018

https://indico.cern.ch/event/765096/contributions/3295805/

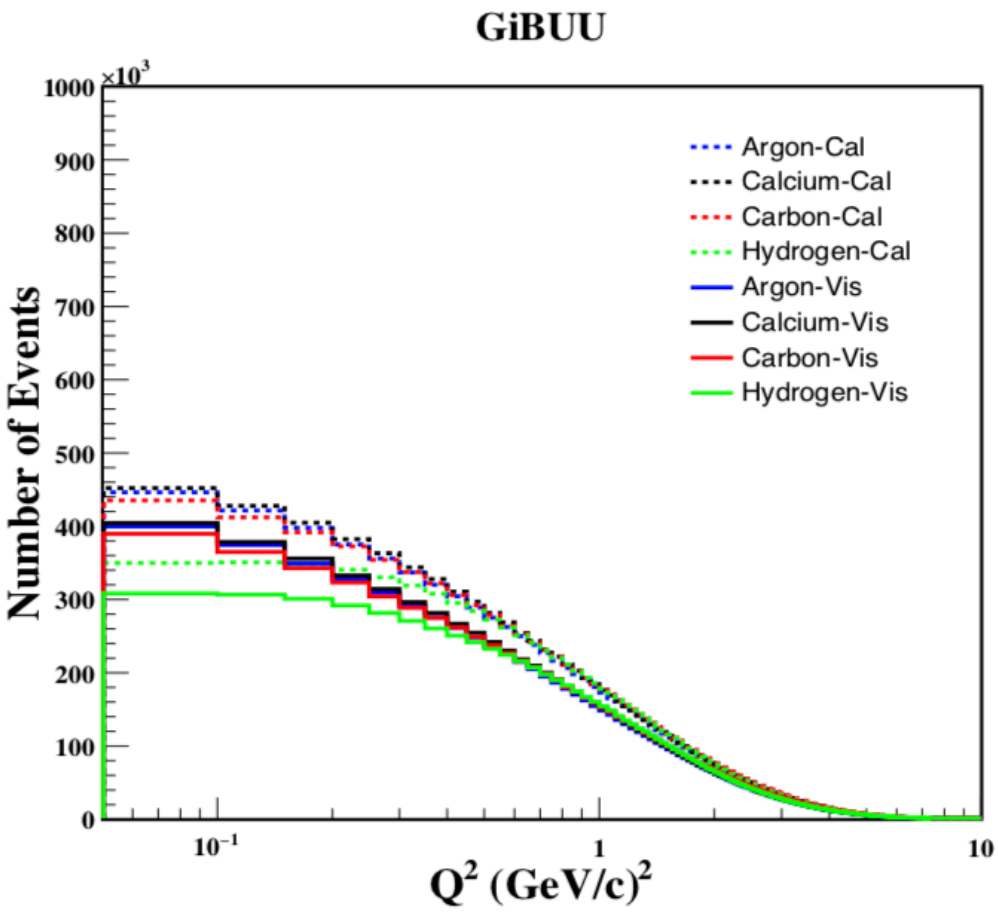
Constraining Nuclear Effects using STT

Jaydip Singh, Srishti Nagu, Dr. Jyotsna Singh
University of Lucknow

- ✓ Study neutrino nucleus interactions with different nuclear targets: Ar(A=40),Ca(A=40), C(A=12), H(A=1).

Q^2 distribution for $\nu_\mu - Ar$, Ca, C, H interaction.

Analysis is based on 1 million events generated using GIBBU.

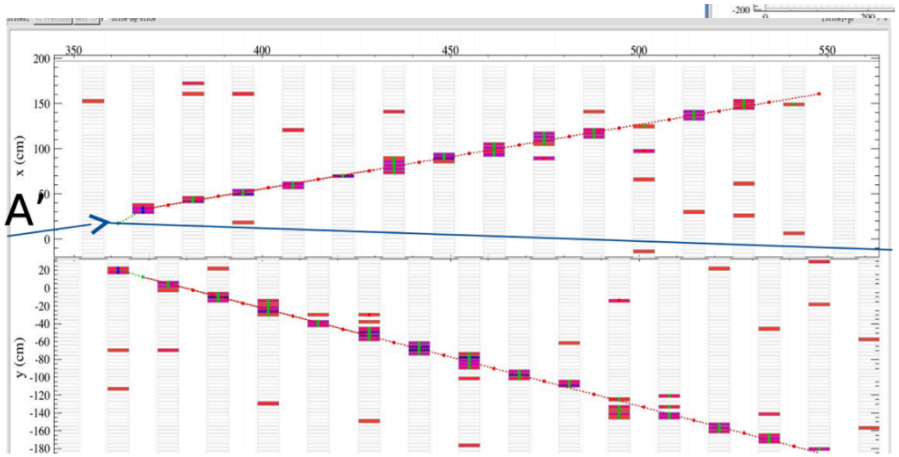


New Physics Searches using STT

Bindu Bambah, Rukmani Mohanta, Akshay Chatla, Rudra Majhi
University of Hyderabad

- ✓ Interest in Dark Sector searches at the Intensity frontier experiments.
  - ✓ May consists of new, light, weakly −coupled particles that do not interact with the known SM forces. Examples: Axions and Axions-like particles, Sterile Neutrinos, Dark photons, Dark matter (~GeV), Heavy Neutral Leptons (NHL) etc.
- ✓ Two and 3 body decays on NHL: $N \to \mu^{\mp}\pi^{\pm}$, $N \to e^{\mp}\pi^{\pm}$, $N \to e^{-}e^{+}\nu$, $N \to \mu^{-}\mu^{+}\nu$
  - ✓ Dominant backgrounds: ν_{μ} and ν_{e} interaction for the first two, neutral pion decay.
  - ✓ Require good lepton identification and neutral pion reconstruction in the detector to identify the signal.

Study is currently in progress using STT tracking volume in The KLOE magnet.



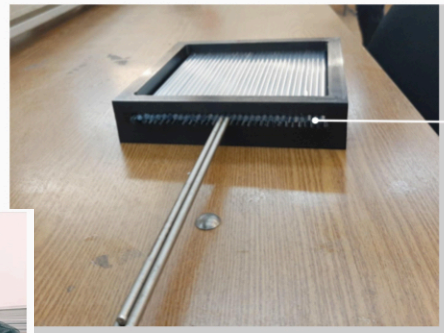
Example of a 2m long electron track from a simulated elastic scattering event with a neutral particle (A' or DM) contained inside the 14m long NOvA Near detector.

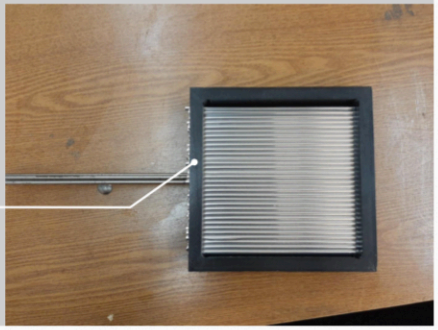
Plan for STT Production in India

Maharnab Bhattacharjee, IIT Guwahati

- Plan to set up a production site in India for the production of the Straws for the STT.
  - Will be done in collaboration with our colleagues at JINR and elsewhere. Discussion already in progress.

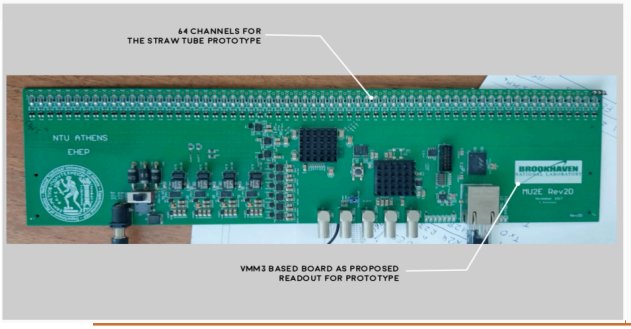
- A 160 sq. mm small prototype is already being build.
  - Maharnab is currently working with the BNL team to develop the firmware for the VMM3a chip readout board.

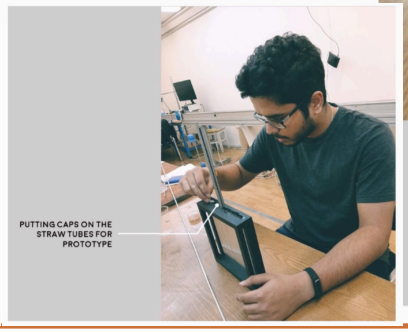




SMALL PROTOTYPE (160 X 160 SQ. MM) USING STRAWS WITH DIAMETER OF 5 MM

2.0 m and 5.0 m Straws





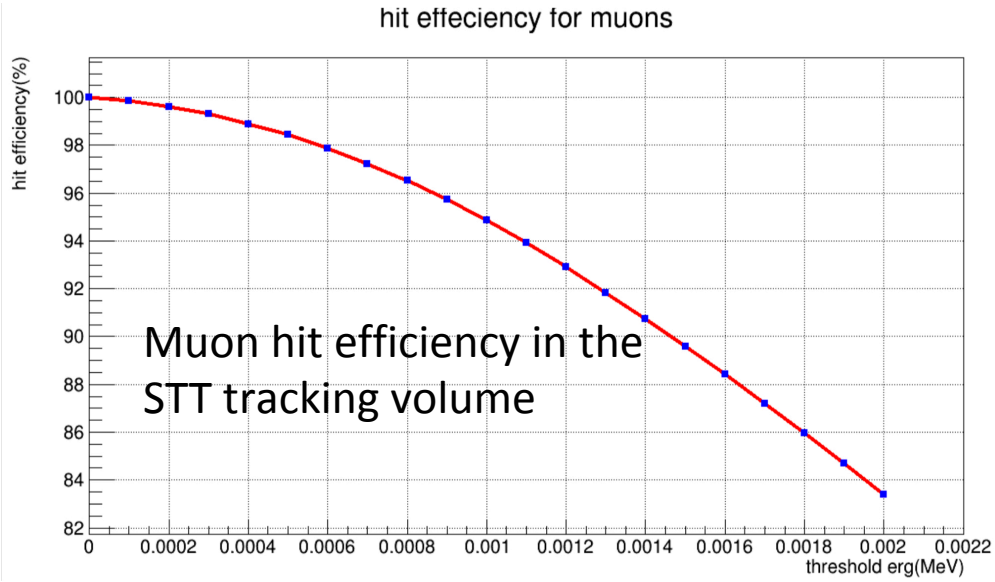
STT Simulation

Nibir Talukdar, IIT Guwahati

- Two simulation packages are currently in use: based on Geant 4 and FLUKA

Common Features:

- Flux: Optimized 3-Horn Design: https://home.fnal.gov/~ljf26/DUNEFluxes/
- KLOE Iron/coils/magnetic field from drawings. B=0.6 T in the inner volume + Ecal, 1.5T in the yoke.
- KLOE ECAL: Layered in G4. In FLUKA, exact barrel description, endcap with homogeneus material, segmented readout



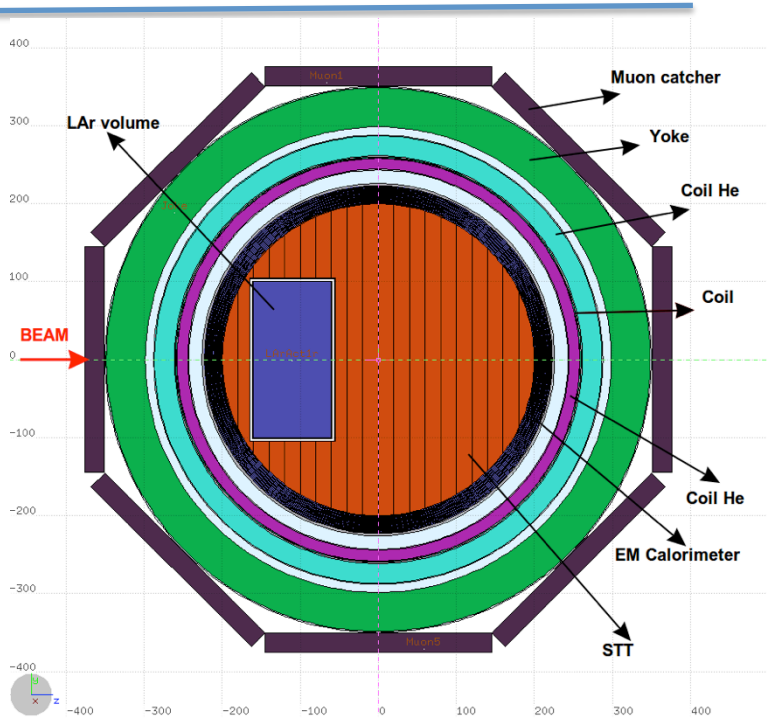
Ingredients:

- Geometry: based on https://github.com/gyang9/dunendggd
- Neutrino Event Generator: GENIE
- Energy Deposition: Edep-sim https://github.com/ClarkMcGrew/edep-sim
- Digitization, Reconstruction and Analysis: independent tools: (https://baltig.infn.it/dune/kloe-simu)

SAND Muon Detector

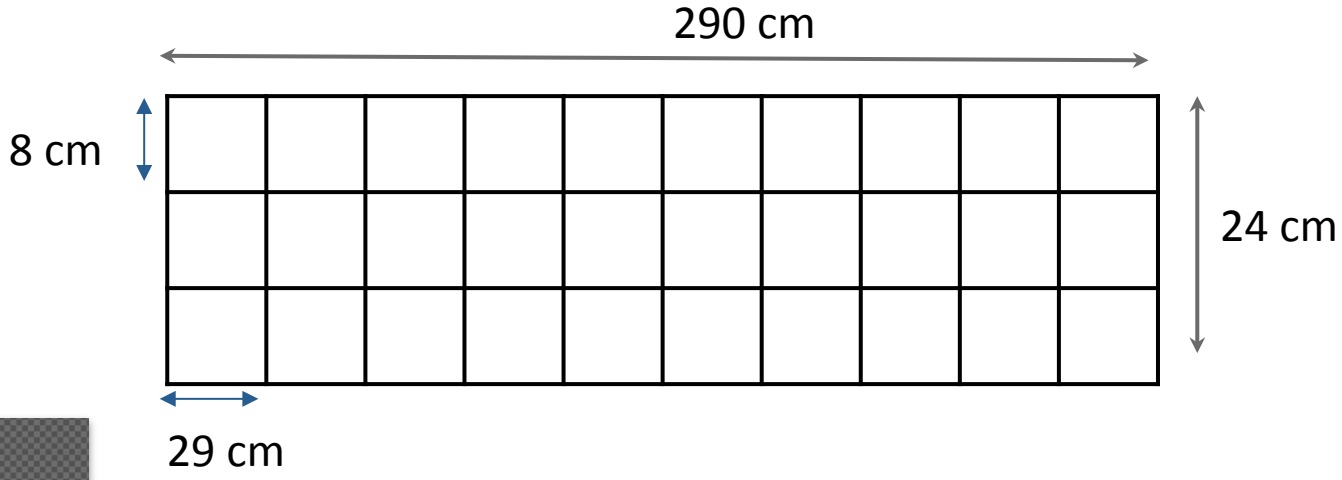
A. Nandi, IIT Guwahati

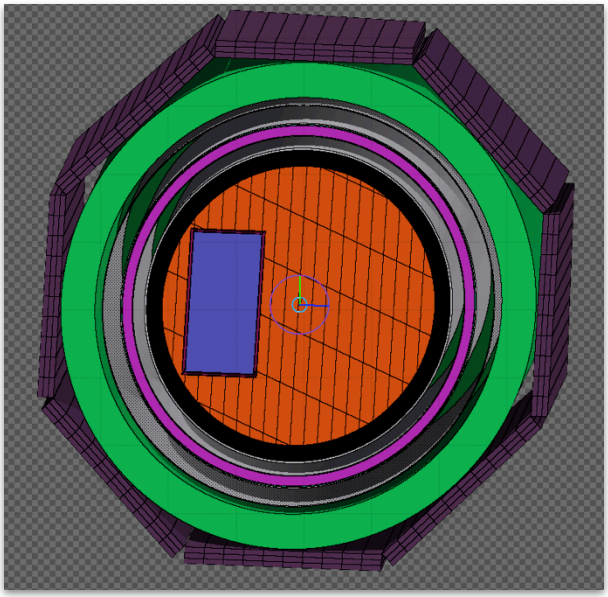
- Plastic scintillator based muon catcher for SAND implemented in FLUKA.
- 8 rectangular slabs: 524 cm long, 290 cm wide, 24 cm thick (dark purple).
- Just outside the return yoke (green).
- Gaps between consecutive slabs < 1 cm.
- Plastic scintillator: low maintenance, limited readout channels, fairly immune to ambient conditions.
- Material: BC-408, suitable for large area detectors and sensitive to muons, protons, fast neutrons etc.



Side view of the SAND

SAND Muon Detector: Segmentation





30 per slab x 8 slabs = 240 tot. segments

Work in progress for implementing the geometry using GGD[1] in gdml format to take advantage of the existing simulation and reconstruction code

1: https://github.com/brettviren/gegede

Summary

✧ The STT based tracker volume will significantly enhance the physics capability of the DUNE-ND complex.

- ✧ Very good charged particle tracking via the STT, good charged separation.
- ✧ Good momentum/energy resolution via STT/ECAL. Sufficient for SAND to act as the beam monitoring detector.
- ✧ Good hadron discrimination, muon-ID via RPC or plastic scintillator based muon detector.

✧ **SAND with STT Tracker option**

- ✧Since SAND will remain on-axis through out, it is important to ensure that we place a detector that can do physics beyond the oscillation physics.
- ✧A STT based tracker volume will yield more than 100 PhD thesis topics for training the next generation of physicists. One of the original mandate of DAE.
- ✧Possibility of using Fe as the target material in STT which will be extremely important for INO.