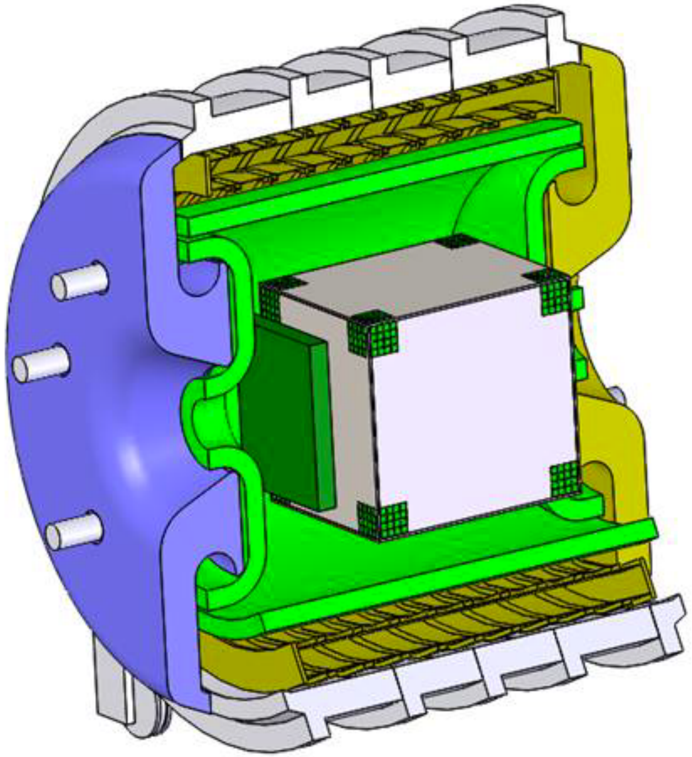
ND-SAND
(System for on-Axis Neutrino Detection)

Luca Stanco, INFN – Padova
for the SAND Collaboration

ND meeting, January 22, 2020



SAND people

SAND: a very wealthy group from merging of 3DST and KLOE groups
(about 100 people from about 20 institutions)

Bi-weekly meetings, chaired by four convenors* on a monthly basis
(Lea Di Noto, Paola Sala, Guang Yang, Davide Sgalaberna)

People very active and very kind…

Active on many fronts: event simulation, background estimation, test-beams, internal Infrastructure, and general infrastructure at FNAL near site

A couple of results will be here reported as examples,
much more at the DUNE general meeting on next week.

* Please, note: Convenors .not.equal. Coordinators
Else, it seems there has often been a missing communication between AHA and SAND

Public (to DUNE) presentations about SAND

- DUNE general meeting on September 2019, FNAL, general session:
  Sergio Bertolucci,
  https://indico.fnal.gov/event/21445/session/19/contribution/23/material/slides/0.pdf

- DUNE general meeting on September 2019, FNAL, ND session:
  Chang Kee Jung,
  https://indico.fnal.gov/event/21445/session/15/contribution/41/material/slides/0.pdf

- Near Detector Workshop for DUNE on October 2019, Hamburg:
  Davide Sgalaberna,
  https://indico.fnal.gov/event/21340/session/1/contribution/6/material/slides/0.pdf

- LBNC meeting on December 2019, CERN:
  Sergio Bertolucci,
  https://indico.cern.ch/event/857610/contributions/3654731/attachments/1957937/3252993/LBNC_Dec_6th_2019_SB.pdf

ND - CDR

- December 2019, new input from groups/studies
- January 2020, major editing push, begin internal reviews
- February 2020, revise and edit using internal review feedback
- March 2020, version ready for LBNC

Huge effort, mainly during Xmas holidays, by the SAND delegates:
Laura Patrizii, Davide Sgalaberna, Roberto Petti, Guang Yang, Sara Bolognesi

32 dense pages out of many exhaustive (and exhaust) discussions, thoughts, compromises…

Why SAND in the DUNE-ND system?

- SAND detector is the only component within the near detector (ND) complex that will be permanently located on-axis along the neutrino beam
- ArgonCube and the MPD systems will move off-axis for about 50% of the time
- Crucial to have an on-axis beam monitoring to detect time-dependent spectral changes intrinsic to the beam, on a weekly basis
- The SAND system will continuously monitor the rate, spectrum and profile of the neutrino beam by measuring the event topology (energy+momentum) of the neutrino interactions on event-by-event basis.
- Precision in-situ flux measurements of νμ , a-νμ , νe , a-νe (absolute and relative rates)

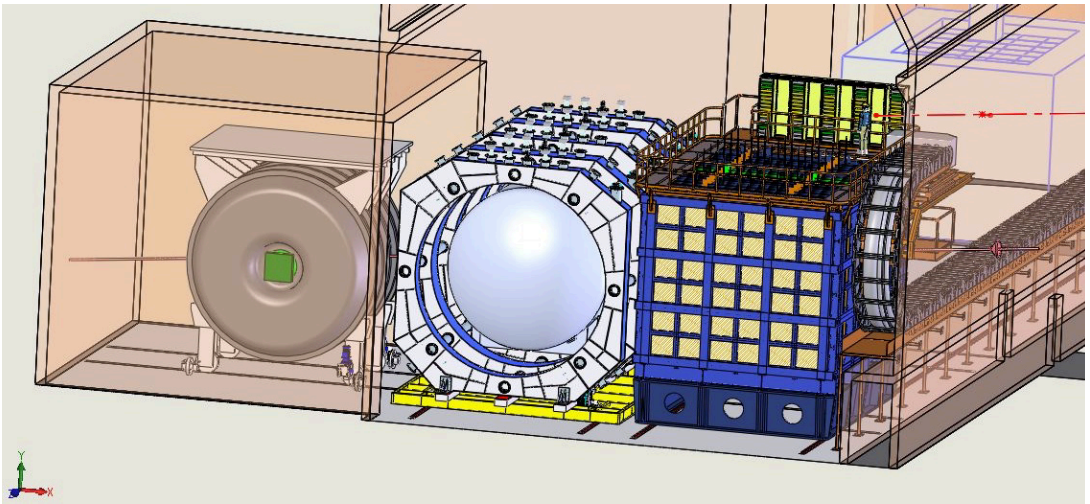
Provide the necessary redundancy and resolution to achieve a ND complex to improve the extrapolation of the ν and a-ν fluxes to the far detector, to constrain systematics from nuclear effects, and to be very robust against unknown unknowns

SAND in the ND hall

SAND will be permanently on-axis in a dedicated alcove

A possible schematic configuration is:

- a superconducting solenoid magnet
- an Electromagnetic Calorimeter (ECAL)
- a 3D scintillator tracker (3DST) as active neutrino target
- a low-density tracker to precisely measure particles escaping from the scintillator
- a thin active Lar target



SAND in blocks

1.2 The Superconducting Magnet . . . 3
1.3 The Lead-Scintillating Fiber Calorimeter . . . 4
1.3.1 Detector Description . . . 4
1.3.2 Reconstruction of Time, Position and Energy . . . 5
1.3.3 Calibration and Performance . . . 7

What already exists

1.4 Three-Dimensional Projection Scintillator Tracker . . . 8
1.4.1 Characterization of the 3D plastic scintillator concept with beam tests . . . 10
1.4.2 The mechanical box . . . 10
1.4.3 The light readout system . . . 11
1.4.4 The front-end electronics . . . 12
1.4.5 The light readout calibration system . . . 12
1.4.6 Current prototypes and future R&D . . . 12
1.5 Time Projection Chambers . . . 14
1.5.1 TPC general design . . . 14
1.5.2 TPC performances and specifications . . . 15
1.5.3 TPC Micromegas modules and electronics . . . 16
1.6 The Straw Tube Tracker . . . 17
1.6.1 A Compact Modular Design . . . 17
1.6.2 “Solid" Hydrogen Target . . . 19
1.6.3 Prototyping and Tests . . . 19
1.6.4 3DST+STT Configuration . . . 20

Inner trackers

1.7 The Internal LAr Target 20

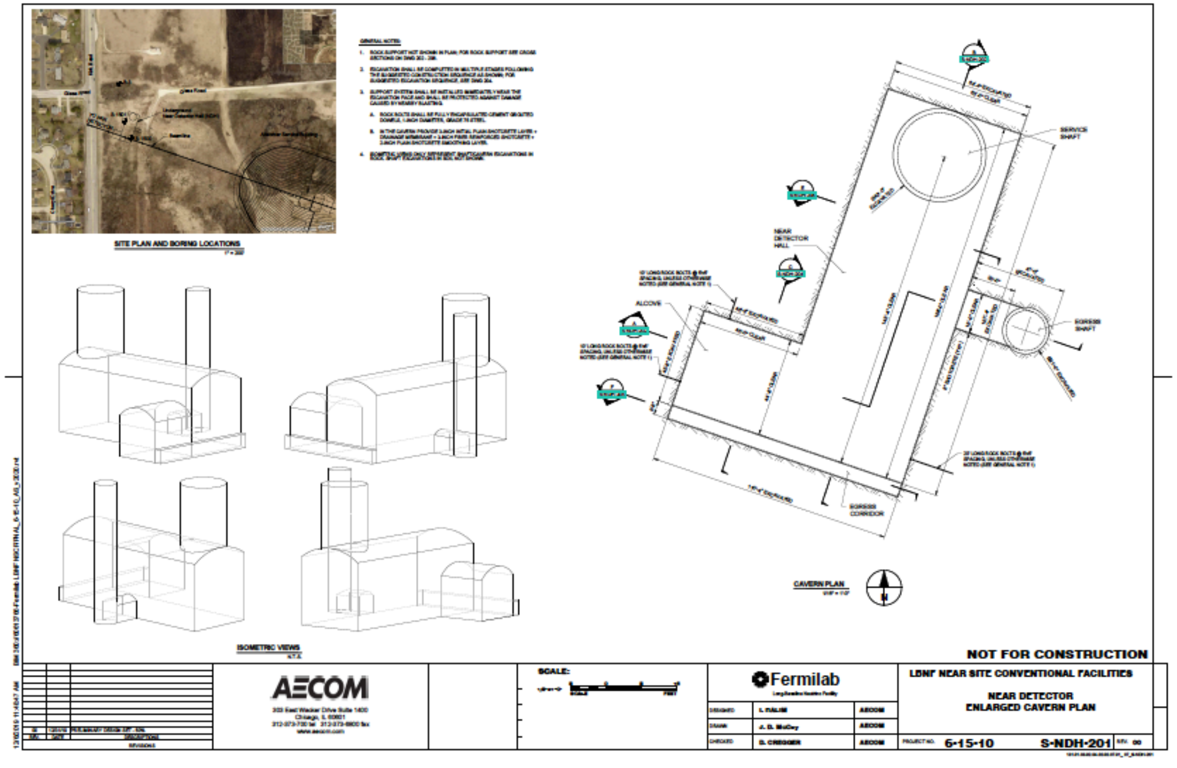
PLUS PHYSICS PERFORMANCES

1.8 Detector and Physics Performances 20
1.8.1 On-axis Beam Monitoring 21
1.8.2 Neutron Detection 22
1.8.3 Measurement of $\nu(\bar{\nu})$-Hydrogen Interactions 24
1.8.4 Flux Measurements 26
1.8.5 Constraining $\nu(\bar{\nu})$-Nucleus Cross-sections and Nuclear Effects 27
1.8.6 External Background 28

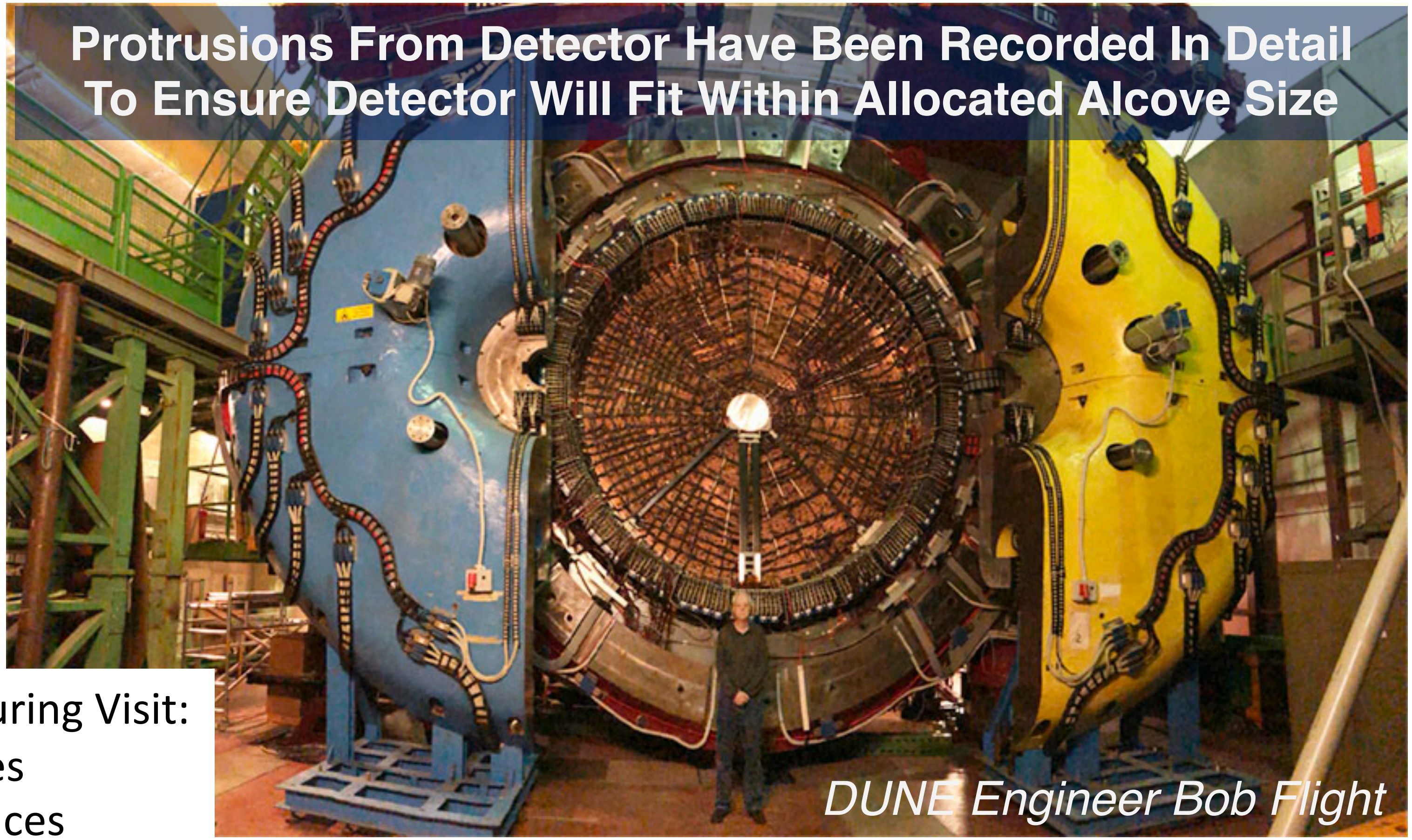
ND hall infrastructure

Many (very positive) interactions with Matthaeus Leitner
(in December 2019 he came to Frascati with Robert Flight)

Optimzed size
(within safety requirements)
of the ALCOVE



SAND: what exists



Topics Covered During Visit:
- Cavern Interfaces
- Electrical Interfaces
- Cryogenic Interfaces
- Handling Procedures
- Detector Assembly

Why SAND needs a 50 ton crane

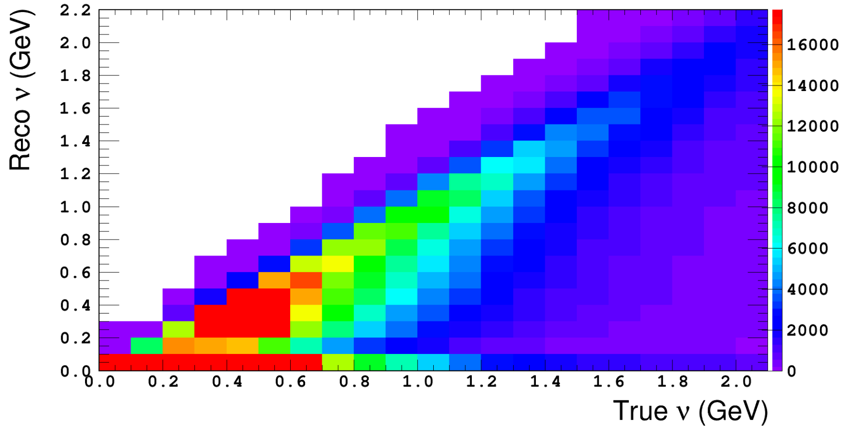
Physics performances

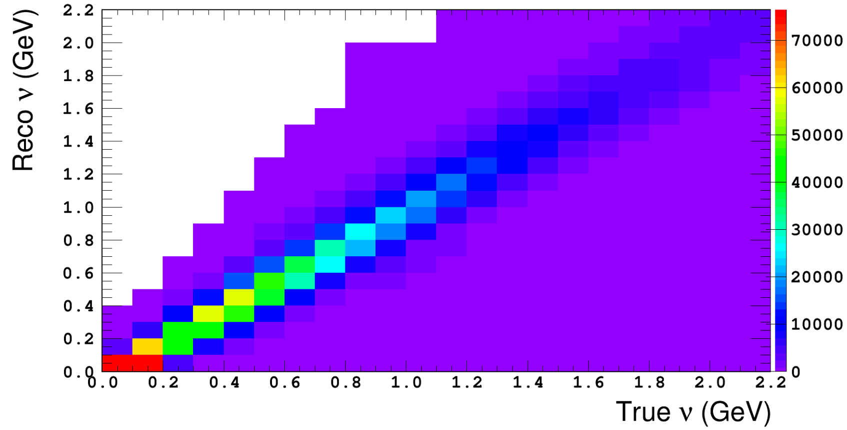
Channel	ν mode	$\bar{\nu}$ mode
ν_μ charged current (CC) inclusive	15.3×10^6	6.1×10^6
CCQE	3.9×10^6	2.4×10^6
CC π° inclusive	5.0×10^6	1.4×10^6
neutral current (NC) total	5.2×10^6	3.3×10^6
ν_μ-e$^-$ scattering	349	190
ν_μ CC coherent	$7.49\ \times10^5$	$4.6\ \times10^5$
ν_μ CC low-ν (ν <250 MeV)	1.74×10^6	$1.4\ \times10^6$
ν_e CC coherent	7.3×10^3	4.3×10^3
ν_e CC low-ν (ν <250 MeV)	1.9×10^4	$1.5\ \times10^4$
ν_e CC inclusive	2.4×10^5	8.7×10^4

The importance of the neutron detection…

Projected event rates per year for a 2.4 x 2.4 x 2.0 m^3 3DST detector.
A 10 cm veto region at each side was required.

Reconstructed versus true ν transfer energy in 3DST





In general, neutron measurement provides an event-by-event reconstruction of neutrino interaction, allowing for the selection of dedicated samples

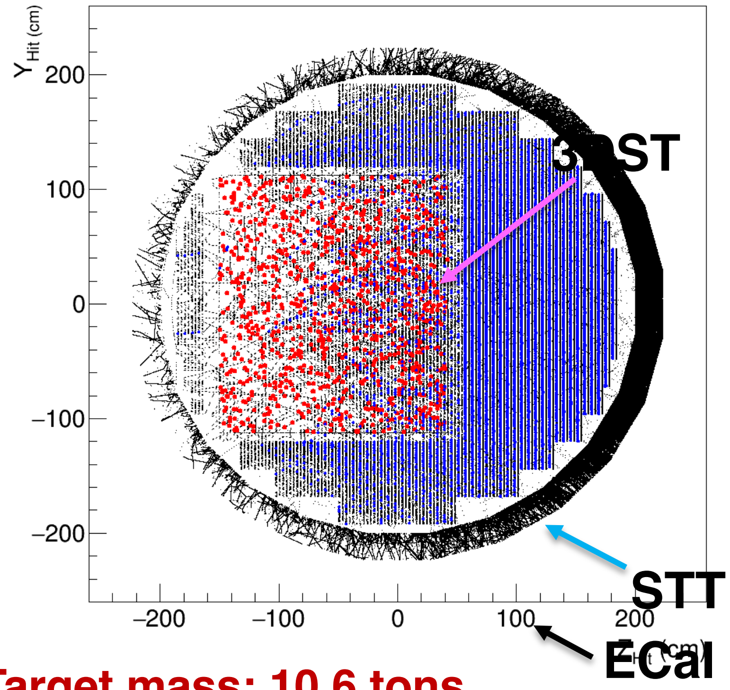
Physics performances

Background from induced external interactions

Active volume: 2.24x2.24x2m³

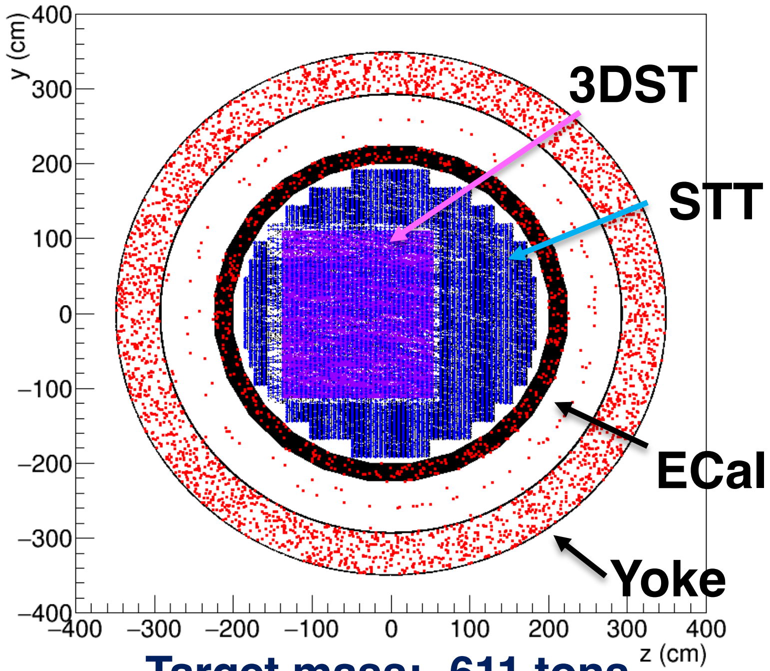
MC samples by FLUKA

"Internal" events: ν_μ (CC) interactions inside 3DST



Target mass: 10.6 tons

External" events: ν_μ (CC+NC) interactions inside SAND magnet+Calorimeter (ECal)

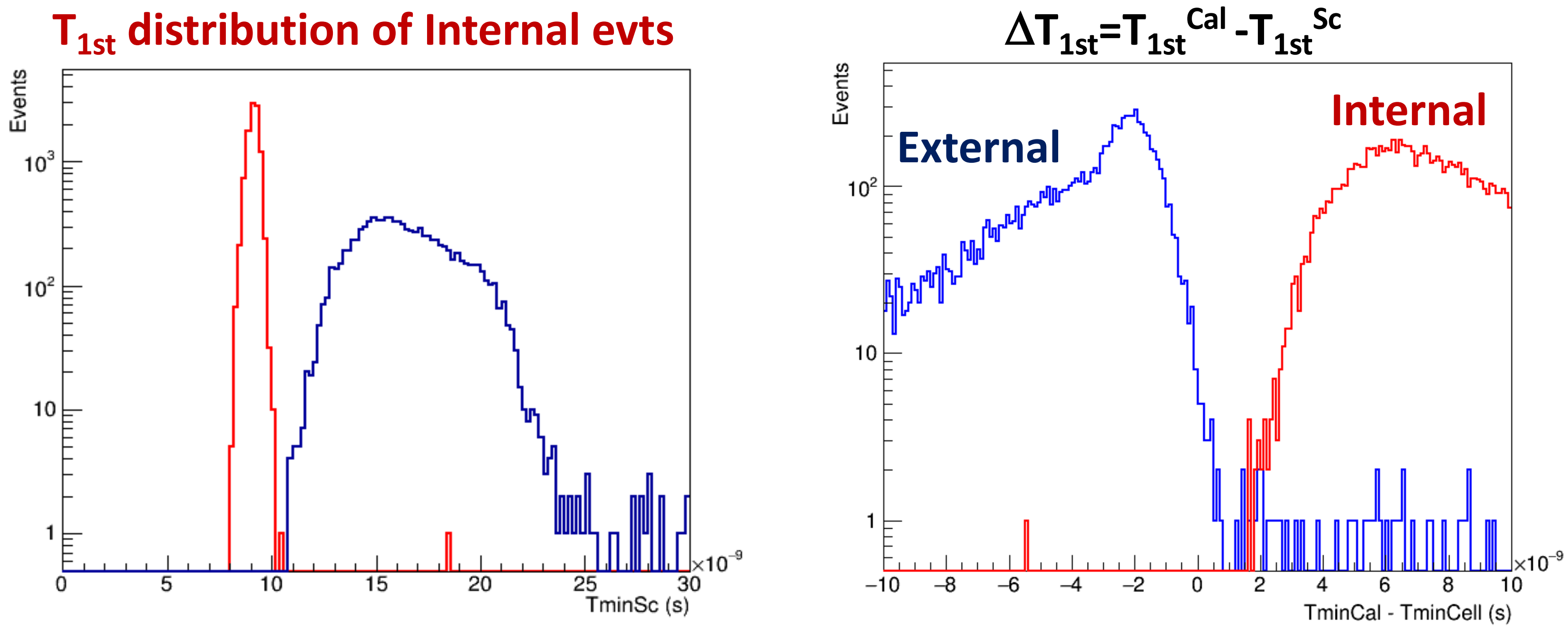


Target mass: 611 tons

• Interaction vertices

Using only the timing, Fiducial-Volume and cell counts…

T_{1st}^{Sc}, T_{1st}^{Cal} and Time difference ΔT_{1st} before any cut



Absolute Bck : ~1.2% of External events

Plus FV and N(cells)>30, extrapolated to include NC: : ➢ **Bck : ~1.8%**

(from CC+NC interactions in magnet + ECal)
based on Time difference between Ecal and 3DST

Much, much more at

SAND in the next DUNE general meeting

PRELIMINARY

Plenary:

- Introduction to SAND 15 mins

SAND Parallel:

- KLOE integration in the ND hall 20 mins
- KLOE calorimeter/tracker background study 20 mins
- KLOE ECAL neutron detection study 20 mins
- KLOE beam monitoring study 20 mins
- 3DST general study (background, beam monitoring, event rate etc.) 20 mins
- 3DST neutron background study 20 mins
- 3DST acceptance with TPC 20 mins
- LANL neutron beam test 20 mins

ND software parallel:

- SAND software 20 mins

thanks

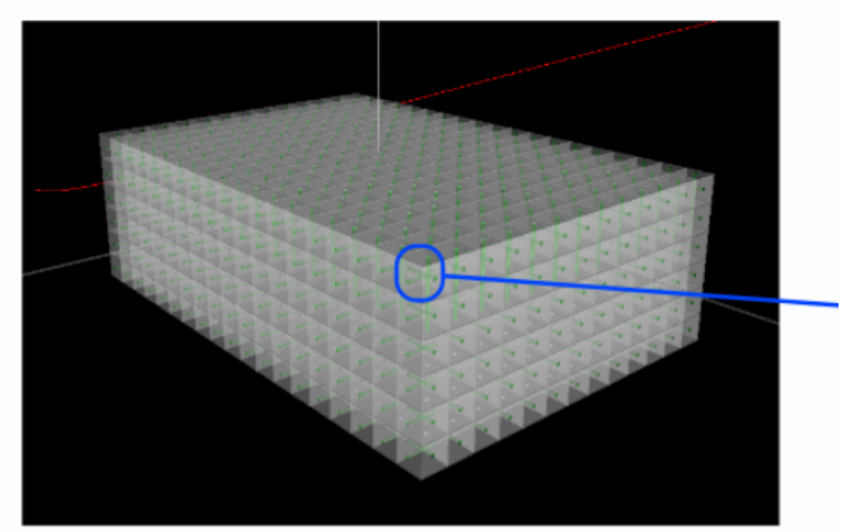
Backup slides

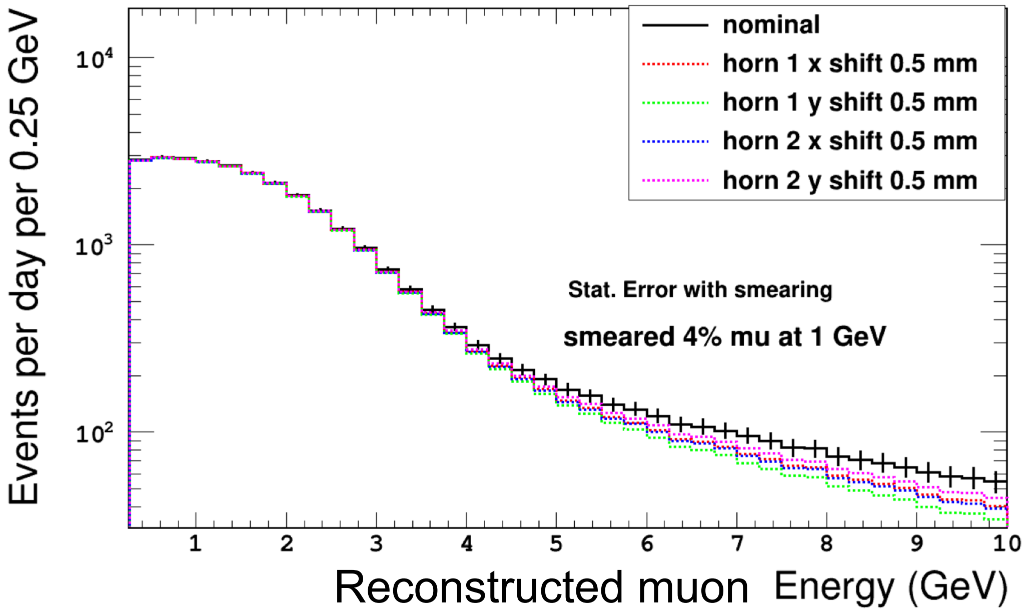
(none approved)

Beam monitoring with 3DST

3DST-like (8.7 tons on-axis) → shape available

No ECAL information, yet

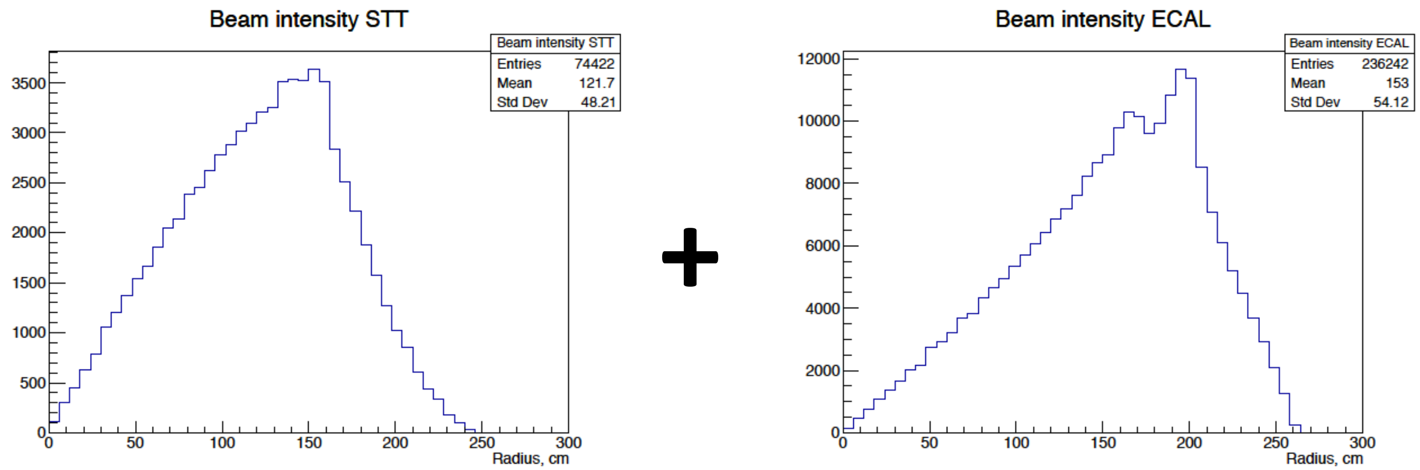




Beam monitoring with STT+ECAL

Study E_ν and E_μ spectra as a function of the distance from the beam axis using interactions in STT, front ECAL, front magnet.

- Consider sample corresponding to 7 days: 3.78 Å~ 1019 p.o.t.
- events simulated with complete chain dk2nu+GENIE+GEANT4+edep-sim

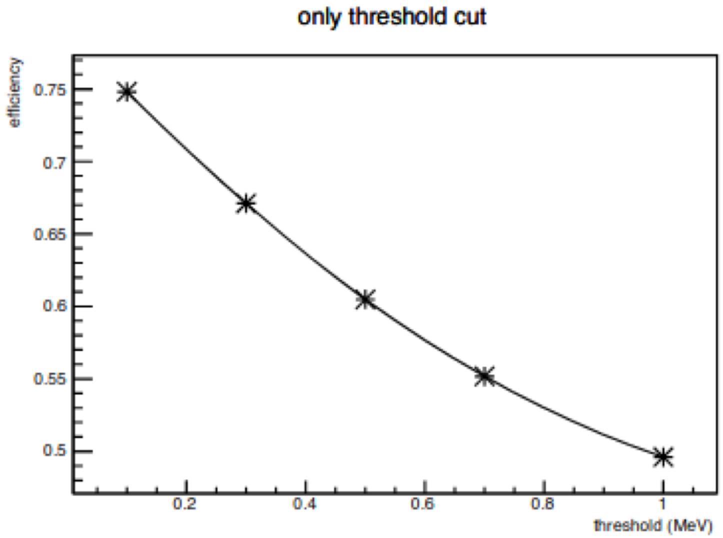


Radial bins used to monitor E_ν and E_μ (ν_μ CC):

- STT: 0-100, 100-150, 150-250 cm
- ECAL: 0-100, 100-150, 150-200, 200-250 cm

Whole range for $\bar{\nu}_\mu$ CC sample

Background cut with topology (3DST)



	cc1pi0p	cc0pi1p
efficiency	0.167	0.042

99% purity

	cc1pi0p	cc0pi1p
efficiency	0.292	0.167

98% purity

	cc1pi0p	cc0pi1p
efficiency	0.403	0.434

95% purity

	cc1pi0p	cc0pi1p
efficiency	0.790	0.891

90% purity

The inefficiency mainly comes from threshold and secondary background cut: 60% and 20%(for 1 pi sample)

«Solid» hydrogen target

Exploit high resolutions & control of chemical composition and mass of targets in STT

✦ "Solid" hydrogen concept: $\nu(\bar{\nu})$-H CC by subtracting CH_2 and C thin (1-2%X_0) targets:

- STT detector designed to provide, on average, same acceptance for CH_2 and C targets;
- Model-independent data subtraction of dedicated C (graphite) target from main CH_2 target;
- Kinematic selection provides large H samples of inclusive & exclusive CC topologies with 80-95% purity and >90% efficiency before subtraction.

⇒ Viable and realistic alternative to liquid H_2 detectors