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

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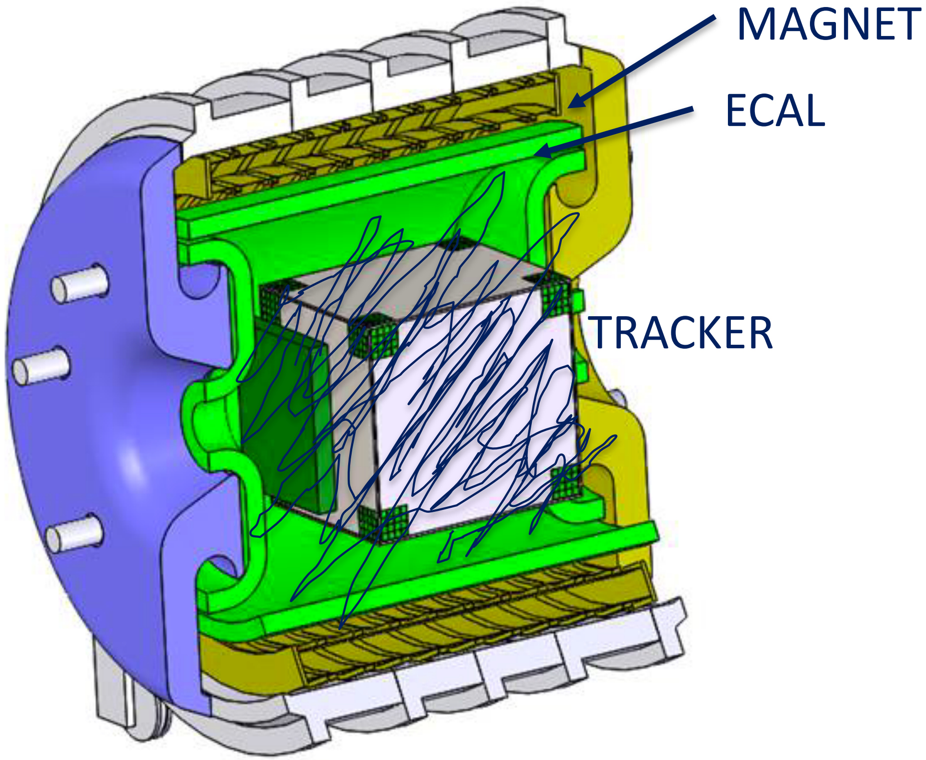
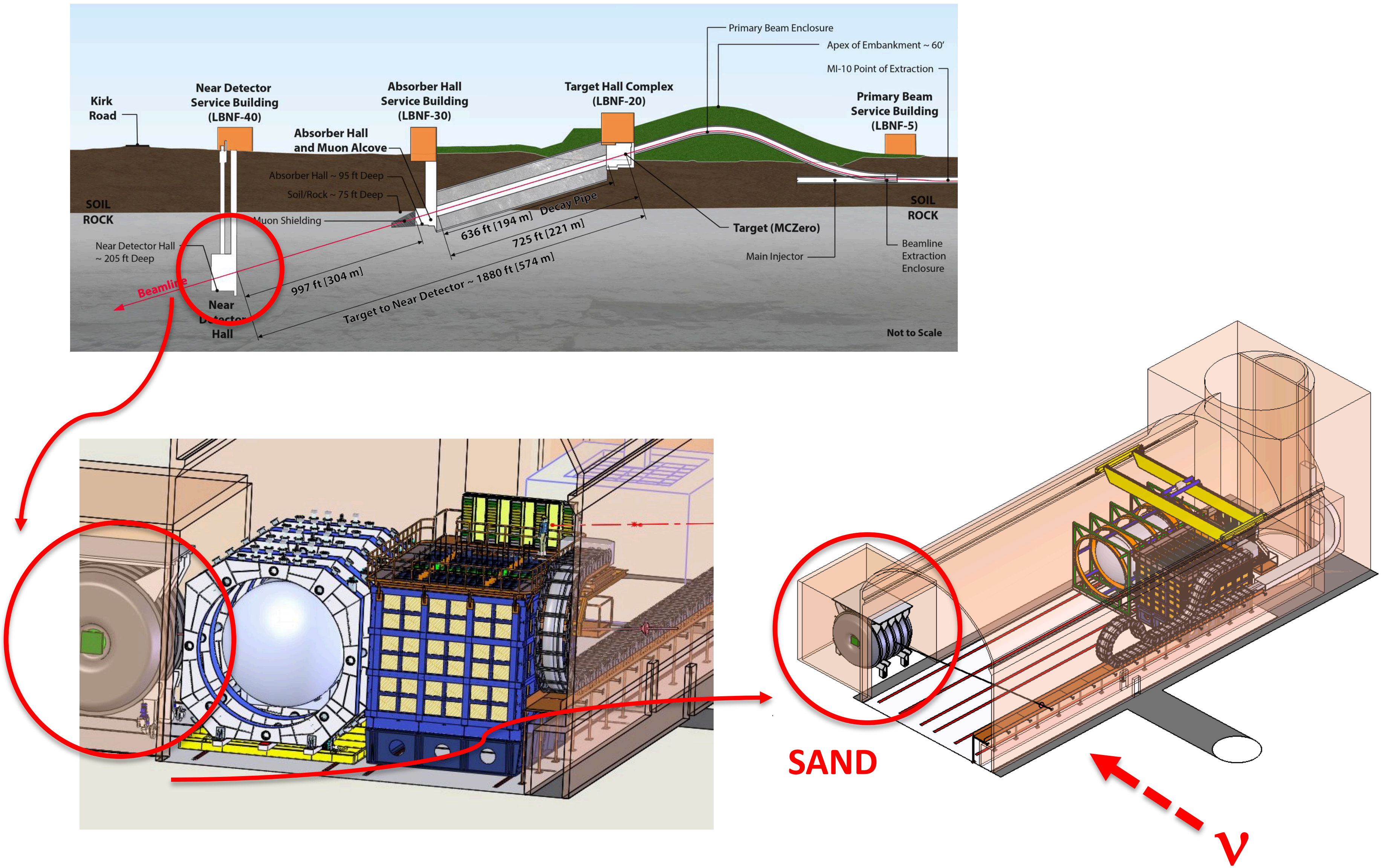
for the SAND Collaboration

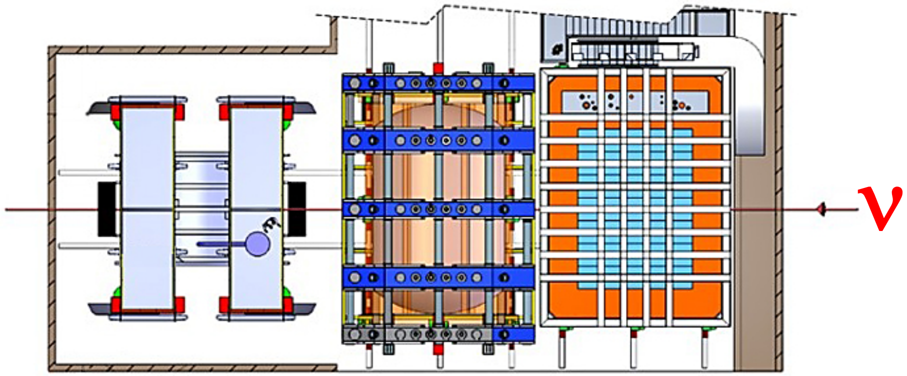


India ND workshop,
February 29, 2020

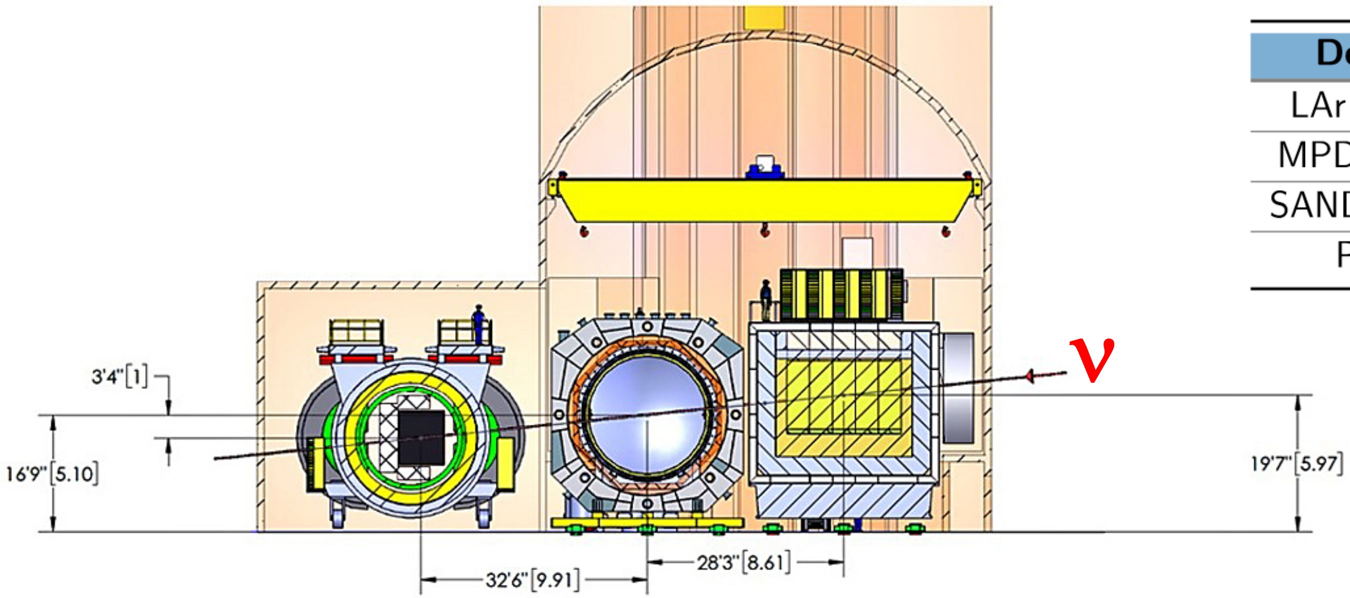
The Near detector System



DUNE Neutrino Beamline And Near Detector Locations



Cavern Parameter	Dimension
Main Cavern Length	166 ft
Main Cavern Width	63 ft
Main Cavern Height	50 ft
Alcove Width	40 ft - 2 in
Alcove Depth	50 ft - 6 in
Alcove Height	37 ft
Access Shaft Clear Diameter	38 ft



Detector	Approx. Weight
LAr Detector	880 metric ton
MPD Detector	710 metric ton
SAND Detector	900 metric ton
PRISM	incl. in detectors

A bit of history

- The final layout of the ND detectors' system took a long time to be optimized (years, not months)
- The PRISM concept (Precision Reaction Independent Spectrum Measurement) driven the necessity of TWO «multipurpose detectors», one moving across the beam, the other on-axis
- The « mpd» concept is needed, first, for an accurate deconvolution of systematics, resolutions, cross-sections, fluxes…
- The in-kind KLOE magnet and electromagnetic-calorimeter was a great opportunity (in terms of performances, redundancy, robustness, reliability and availability)
- **In-kind system has to be completed by an excellent tracker** (43 m^3)

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 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

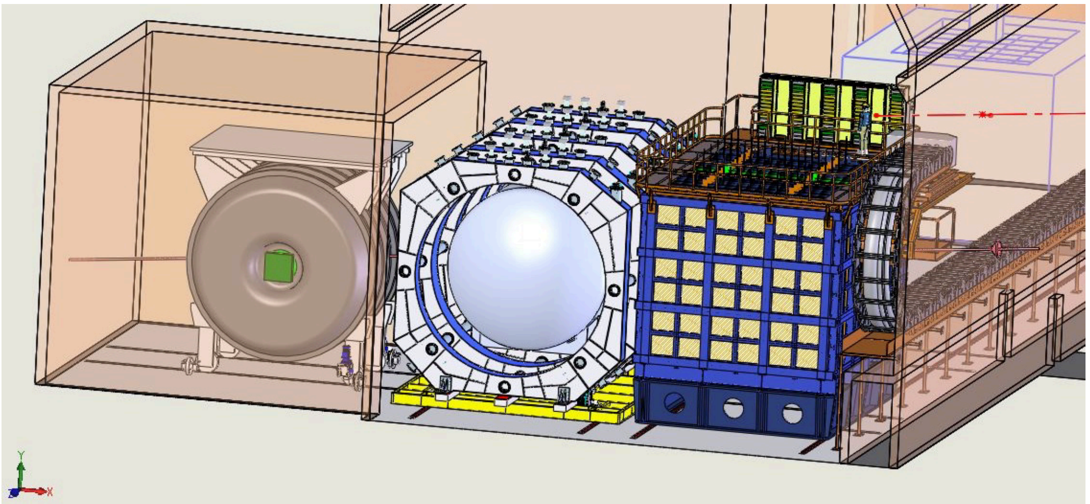
SAND in the ND hall

SAND will be permanently on-axis in a dedicated alcove

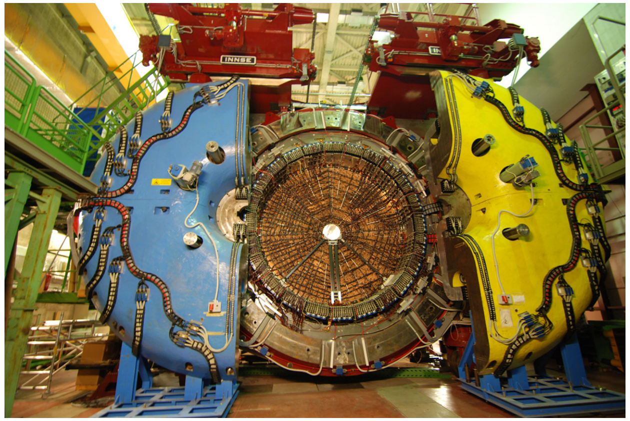
A *possible* schematic configuration is:

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

(the 3DST and the low-density tracker together: *TRACKER*)



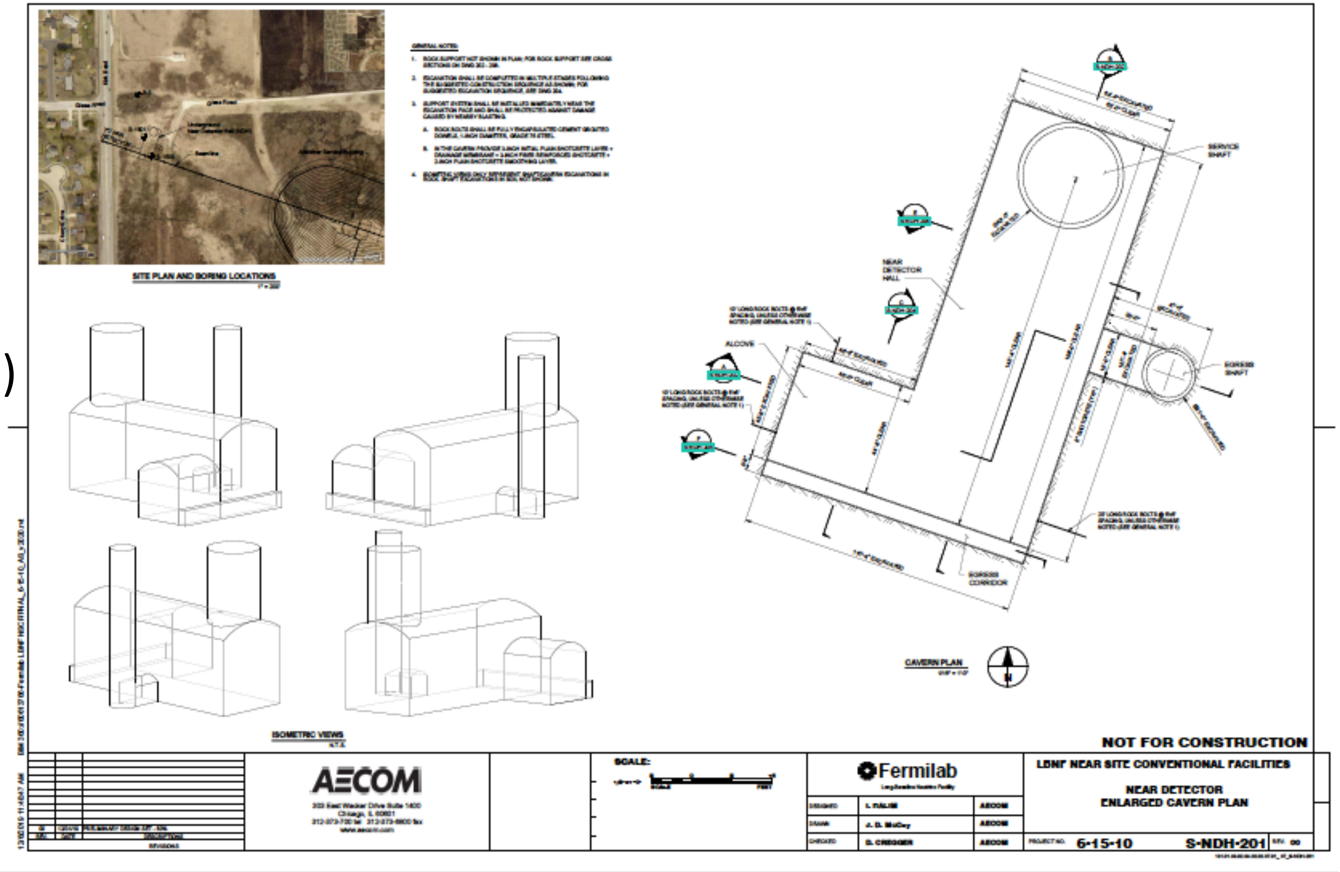
November 2019: Two DUNE Near Detector Engineers Visited INFN Frascati To Collect Cavern Design Requirements For SAND Detector



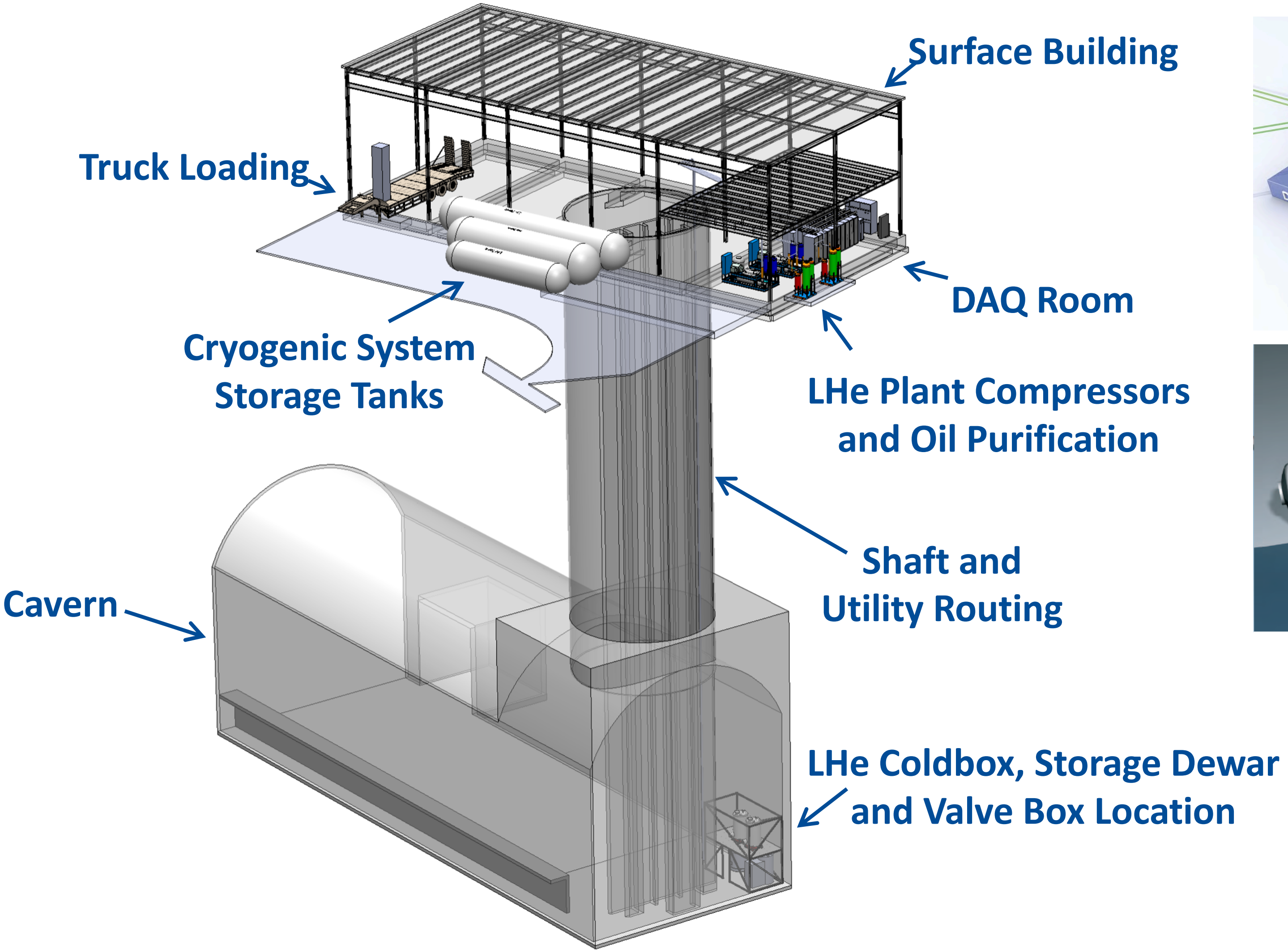
Topics Covered During Visit:
- Cavern Interfaces
- Electrical Interfaces
- Cryogenic Interfaces
- Handling Procedures
- Detector Assembly

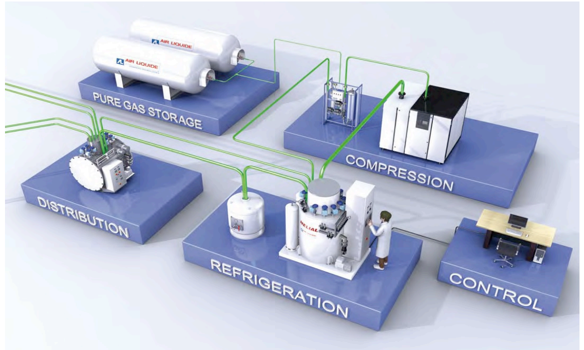
ND hall infrastructure

Optimized size
(within safety requirements)
of the ALCOVE



SAND Liquid-He Coldbox Will Be Located In Underground Cavern





Commercial LHe
Cryosystems

Near Detector Liquid Nitrogen System Will Be Shared Between SAND And LAr-TPC

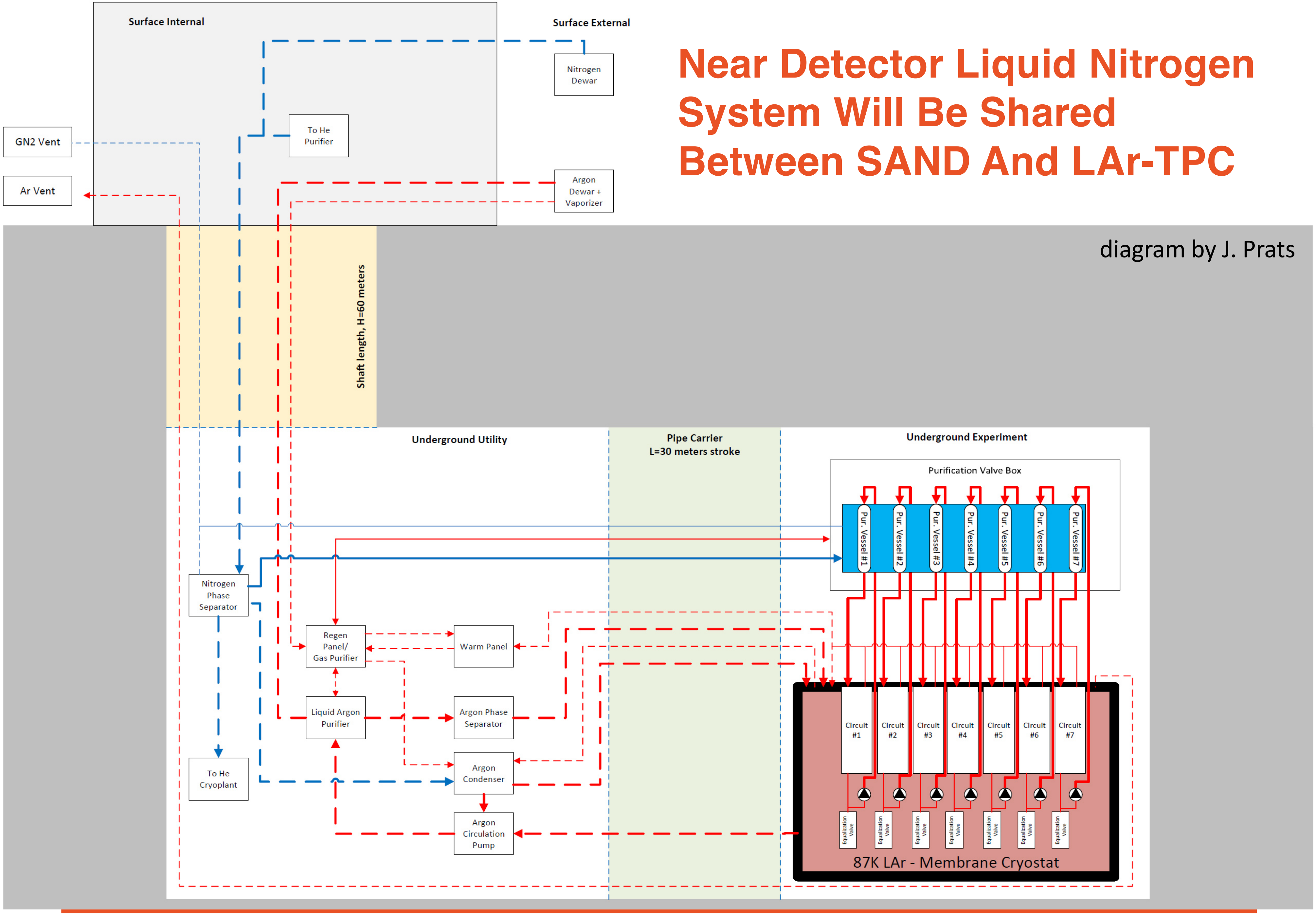
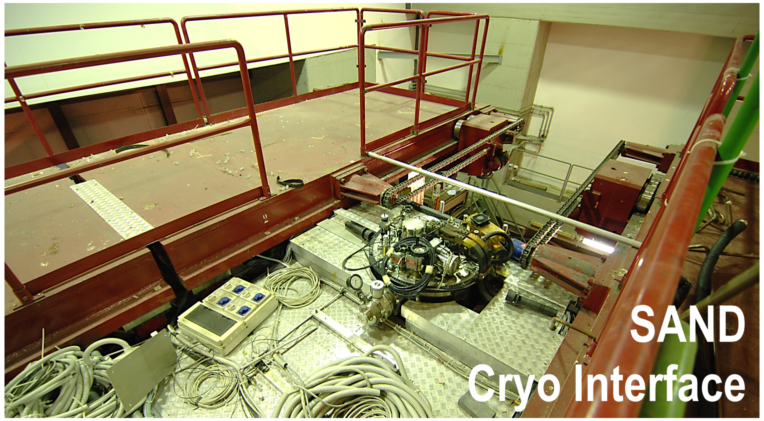


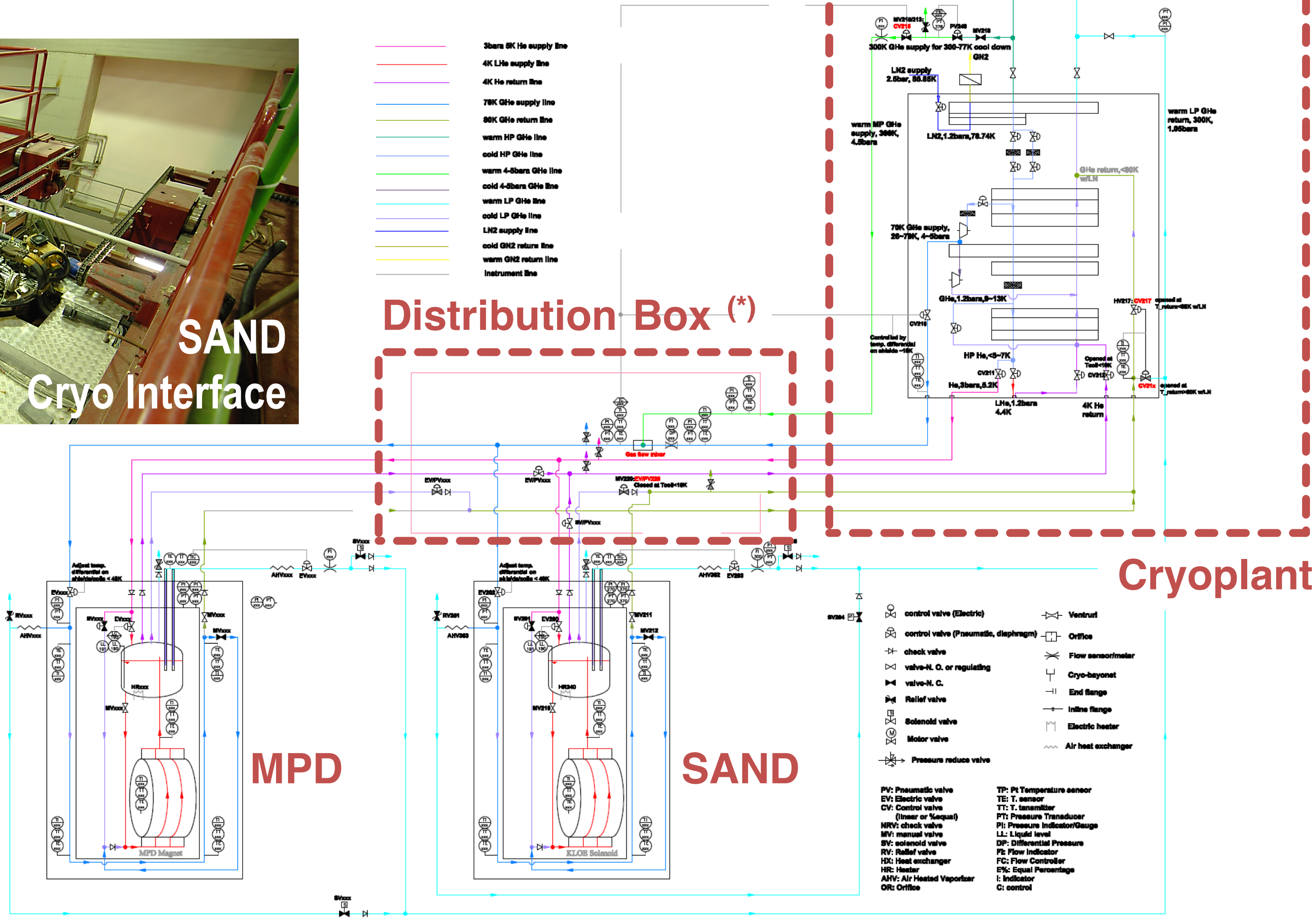
diagram by J. Prats

SAND / DUNE Cavern Cryoplant PID Established: Currently Developing Hardware Specifications

- Near Detector LHe Plant Could Also Cool MPD Detector Coils

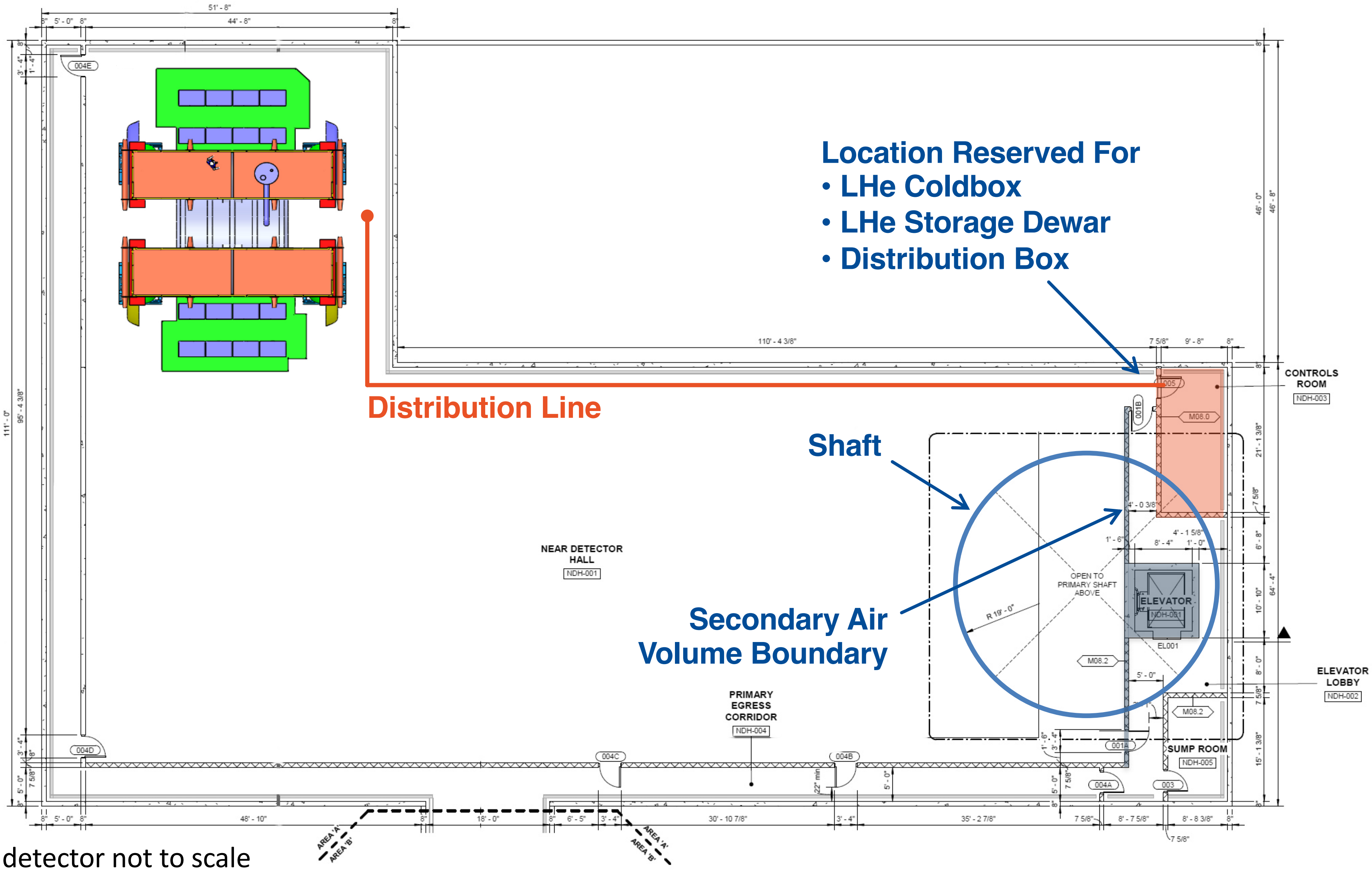


PID by L. Wang



(*) New distribution system will incl. simplified SAND mixing valve connections.

SAND LHe Coldbox Will Be Located In Underground Cavern Interface With Egress Space Remains To Be Defined



detector not to scale

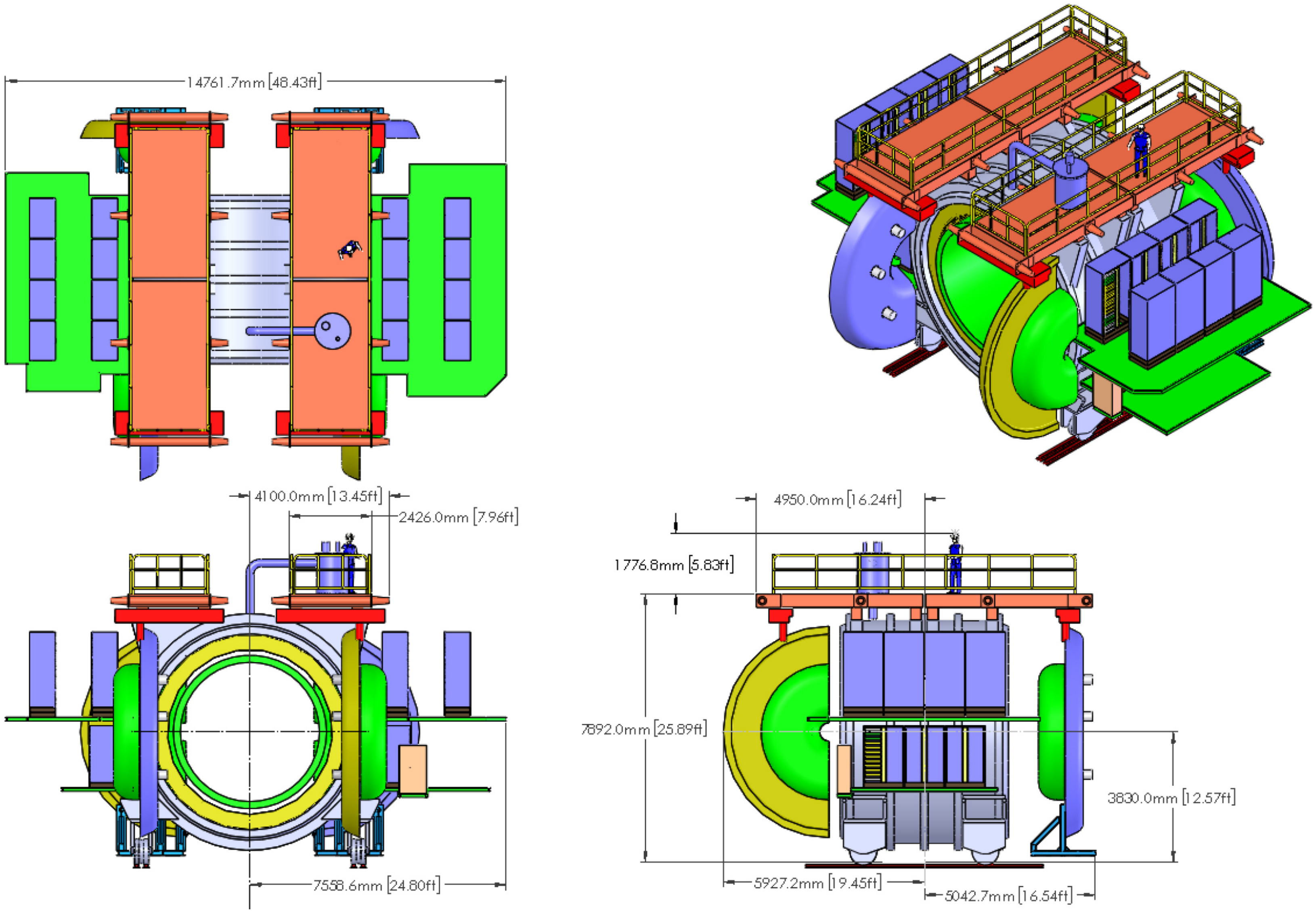
SAND Detector Installation
Will Require 50-ton Crane With Two Hooks

	Volume [m³]	Weight [tonne]
Coil incl. Cryostat	-	42
Yoke[2]	65.2	510
KLOE Existing EmC	21.5	108
Aux. Steel Structures	20	156
New Outside End EmCs	0.4	2
New Inside End EMCs	1.2	6
Low-Density Detector[4]	-	3
3DST Structure	-	15
Racks	-	20
Prism Rollers		10
KLOE-3DST TOTAL WEIGHT		**~900**

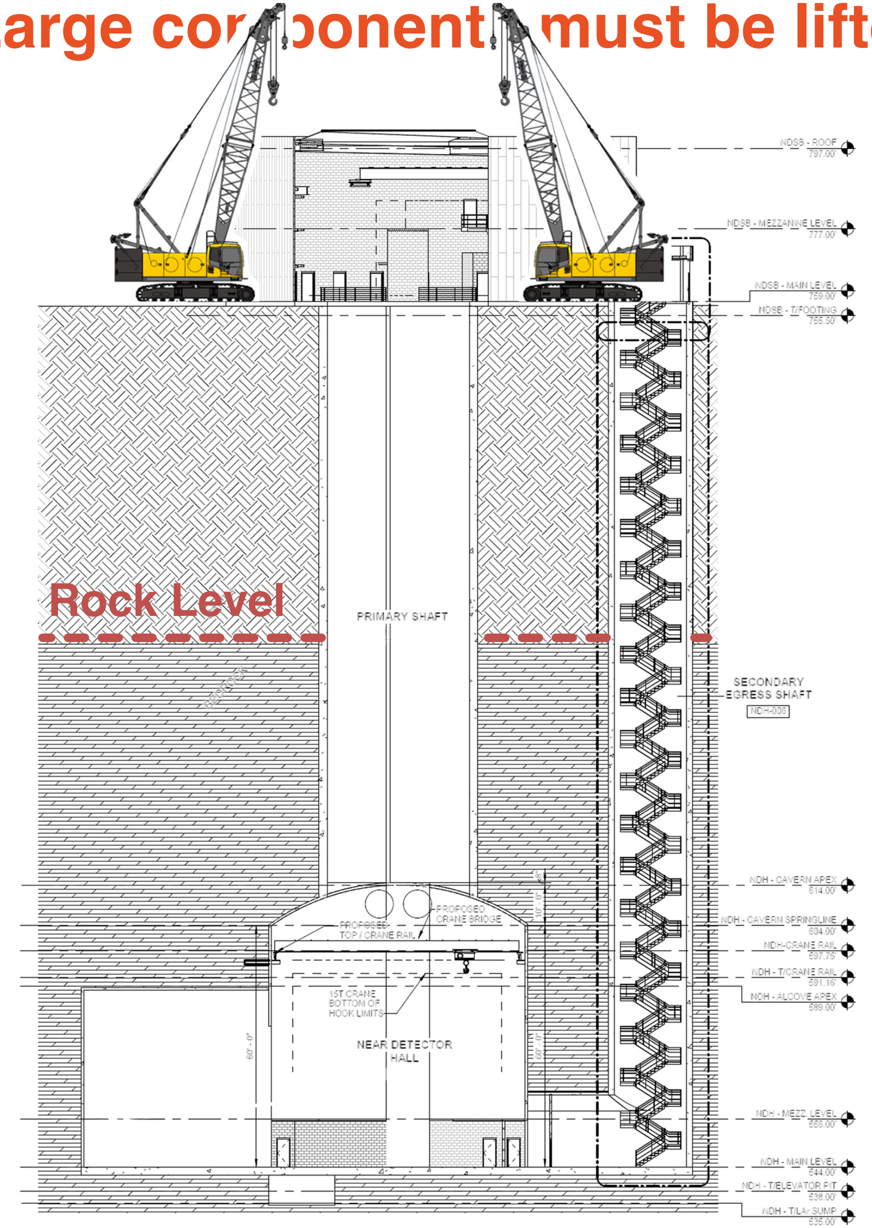
Yoke:
Length = 6 m
Diameter = 7 m

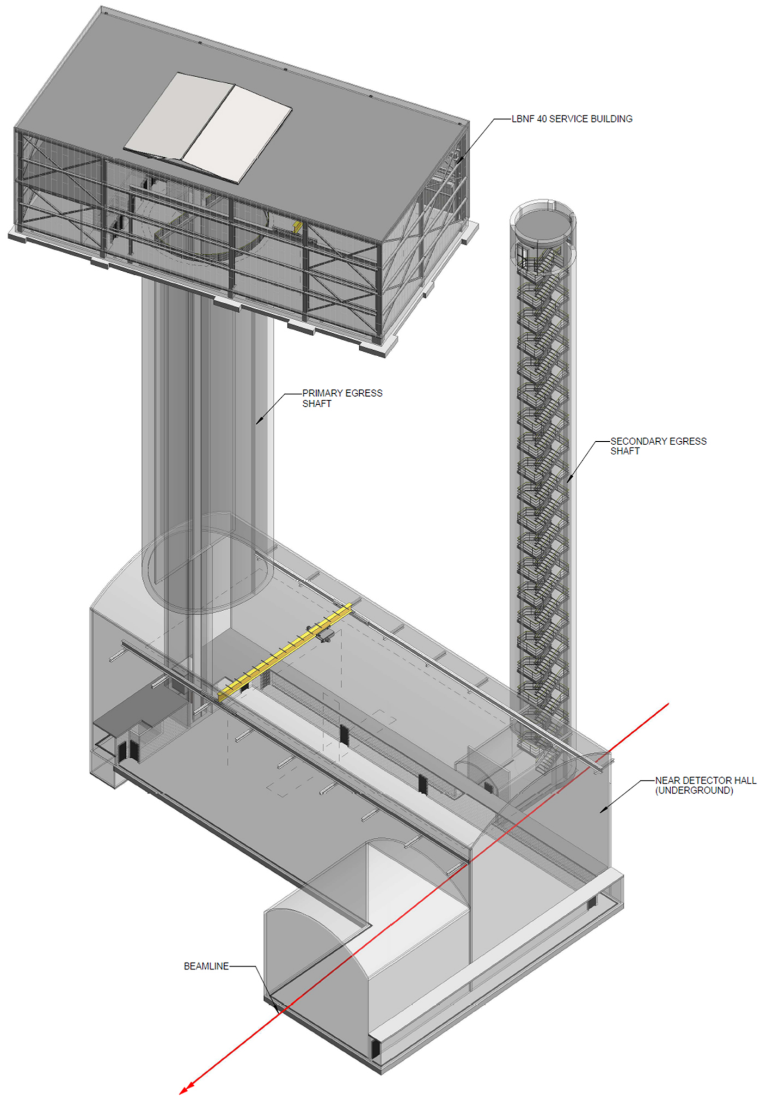
Full Detector Size:
Length ≈ 10 m
Height ≈ 11 m

SAND Magnet assembly consists of several approx. 30 Ton heavy yoke segments and a 42 ton Solenoid Cryostat

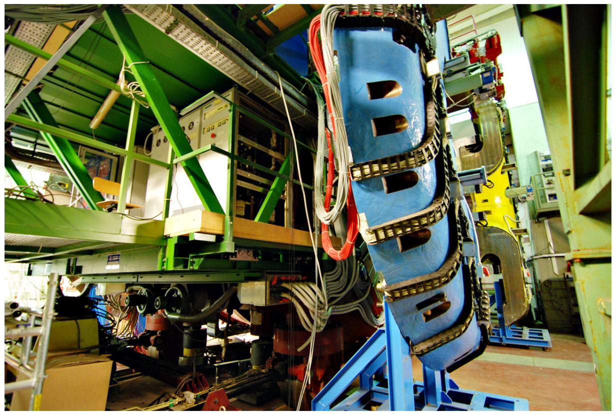


Near Detector Surface Building: Large component must be lifted through the roof



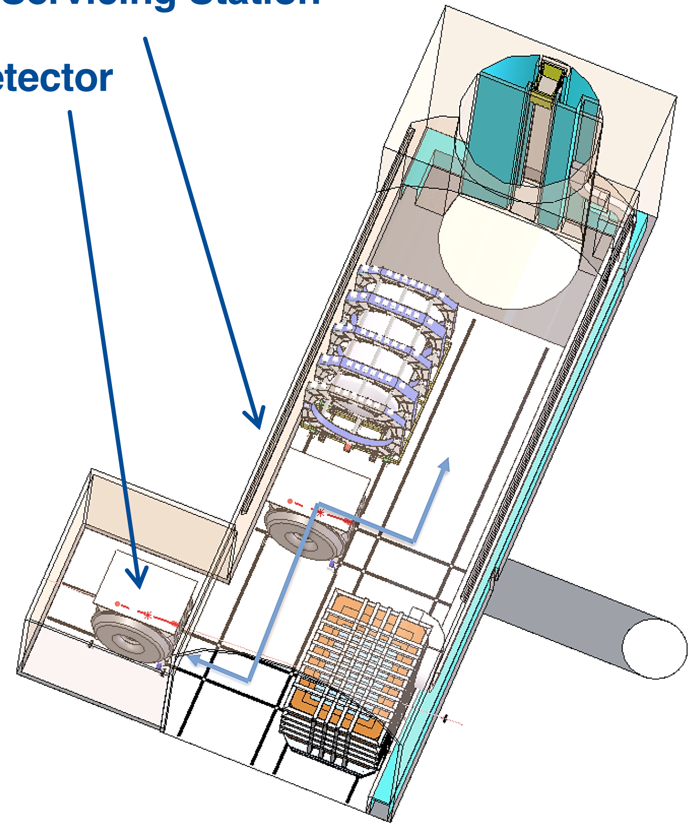


KLOE Detector will serve as stationary Beam Monitor, but movement during installation and servicing must be planned



Floor Guides To
Assembly And Servicing Station

KLOE Stationary Detector
Inside Alcove

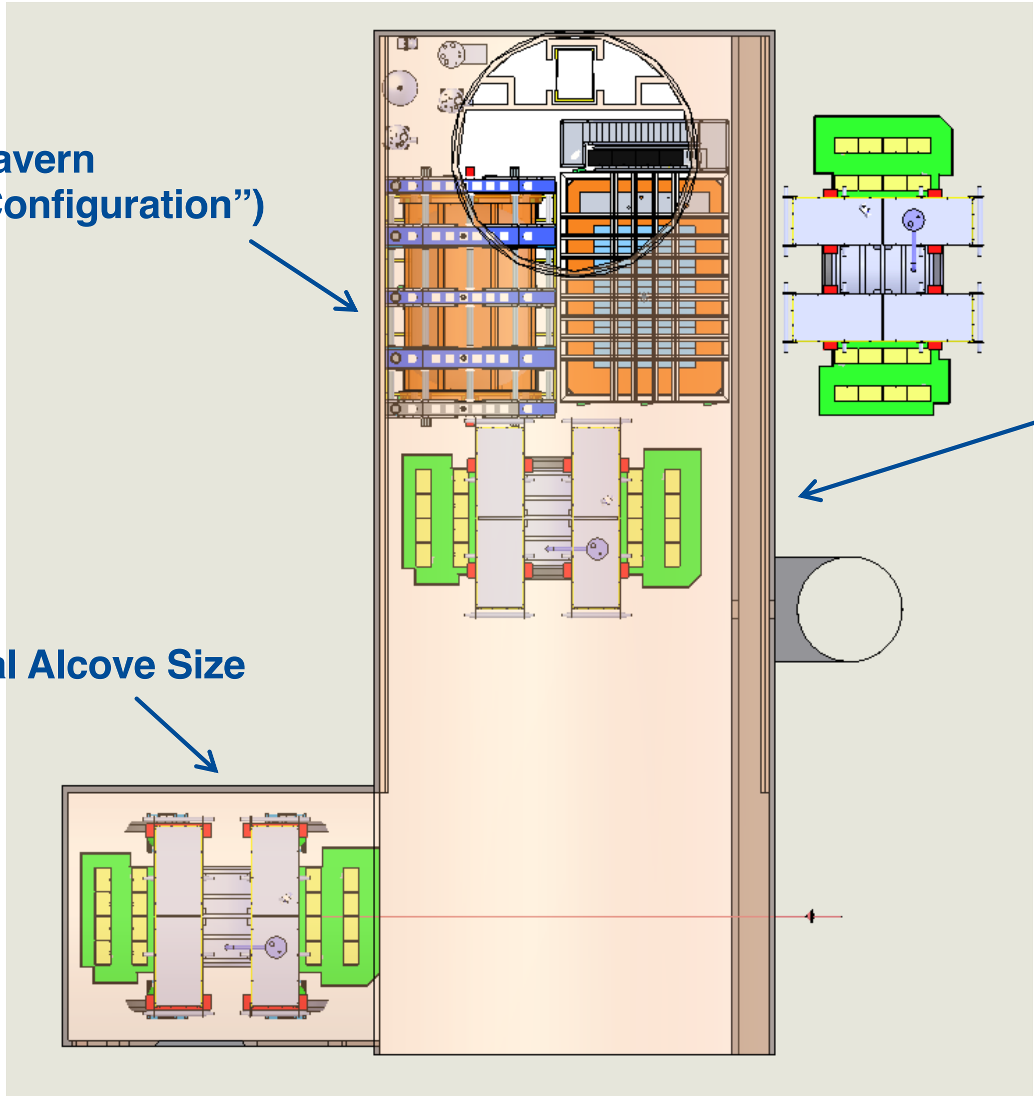


initial movement concept likely not feasible due to SAND detector size

Size of SAND necessitates careful assembly and installation Planning to sequence with assembly of other detectors

Small Cavern
("BCR Configuration")

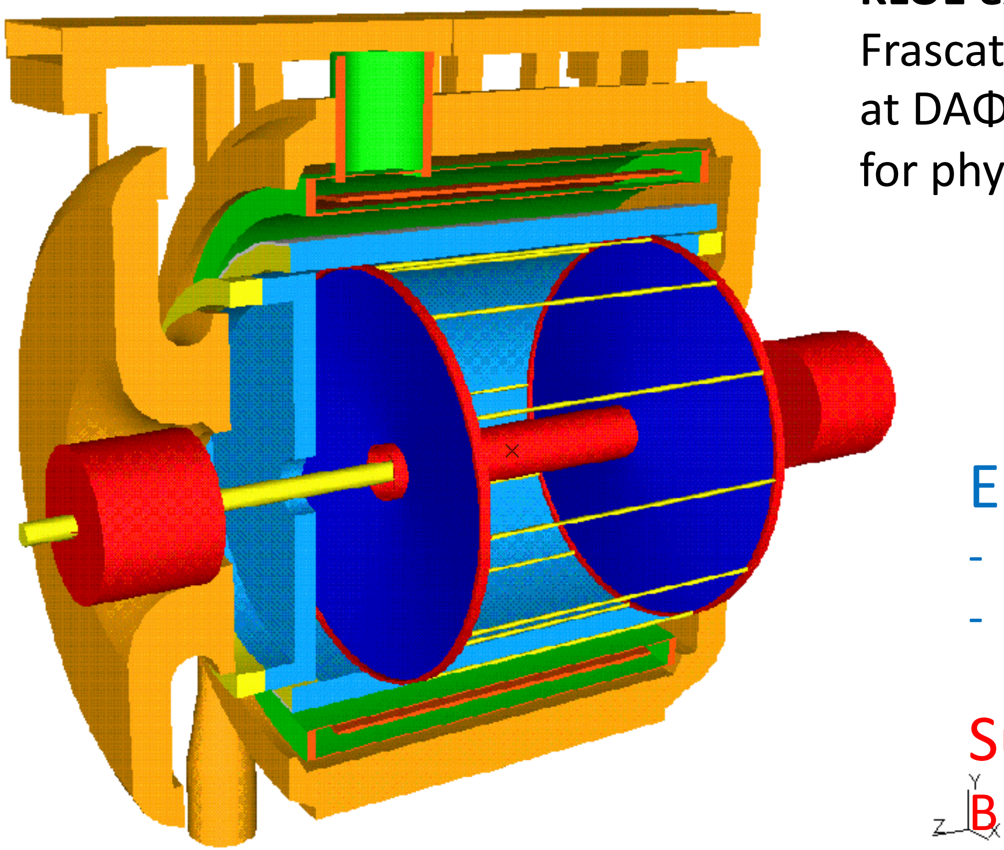
Final Alcove Size



SAND Detector Has To Be Assembled And Installed First Since Detector Size Prohibits Rearranging Once Fully Assembled (*)

(*) NDDG has asked SAND group to evaluate if detector electronics mezzanine structure size could possibly be reduced.

KLOE: magnet + ECAL + Drift chamber



KLOE experiment run at Laboratori Nazionali di Frascati(Rome) Italy from 1999 until 2018, at DAΦNE e^+e^- collider, for physics of K and Φ mesons.

Electromagnetic calorimeter

- Lead/scintillating fibers
- 4880 PMT's

Superconducting coil (5 m bore)

B = 0.6 T (∫ B dl = 2.2 T.m)

Superconducting Magnet

Coil parameters

Layers	2
Turns/layer	368
Ampere-turns	2.14 MA-T
Operating current	2902 A
Stored energy	14.3 MJ
Inductance at full field	3.4 H
Discharge voltage	250 V
Peak quench temperature	80 K

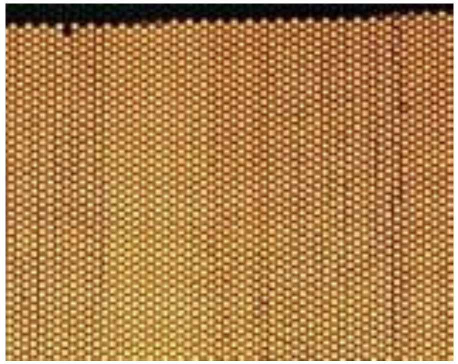
Guaranteed heat loads

Source	**Heat load**
Current leads	0.6 g/s
4 K Radiation and conduction	55 W
70 K Radiation and conduction	530 W

Electromagnetic Calorimeter

Pb - scintillating fiber sampling calorimeter of the KLOE experiment at DAΦNE (LNF):

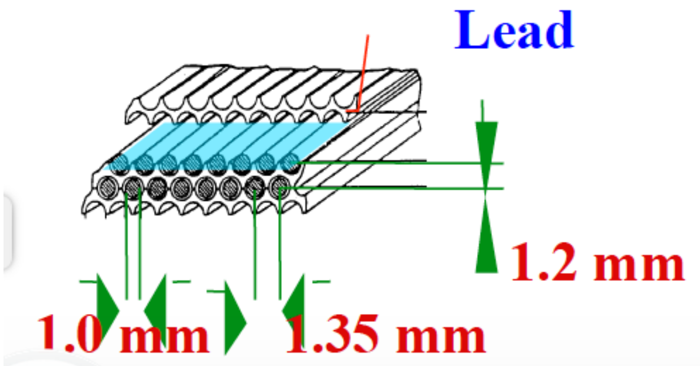
- 1 mm diameter sci.-fi. (Kuraray SCSF-81 and Pol.Hi.Tech 0046)
- Core: polystyrene, ρ =1.050 g/cm^3, n=1.6, λ_{peak} ~ 460 nm



- grooved lead foils from molding .5 mm plates

- Lead:Fiber:Glue volume ratio = 42:48:10

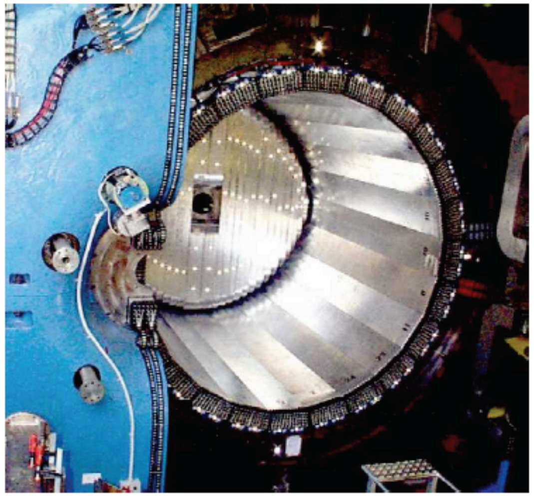
- X_0 = 1.6 cm ρ=5.3 g/cm3
- Calorimeter thickness = 23 cm
- Total scintillator thickness ~ 10 cm

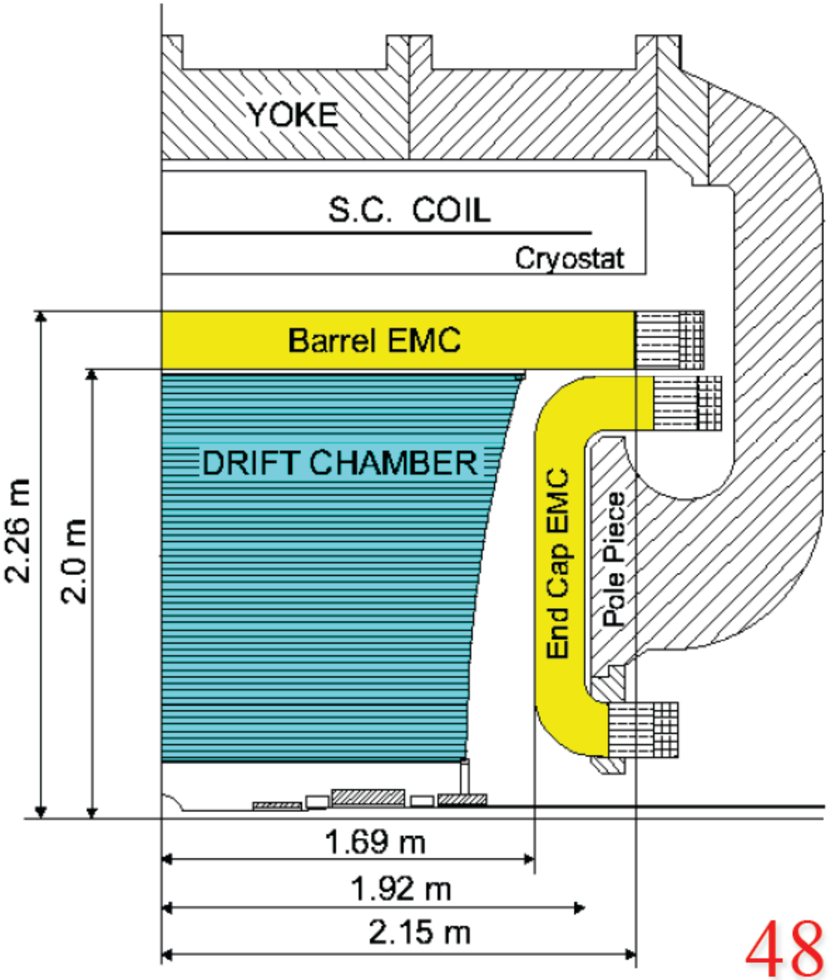


Structure

24 barrel modules
60 cells (5 layers)
4.3m length

2 × 32 endcap modules
10/15/30 cells



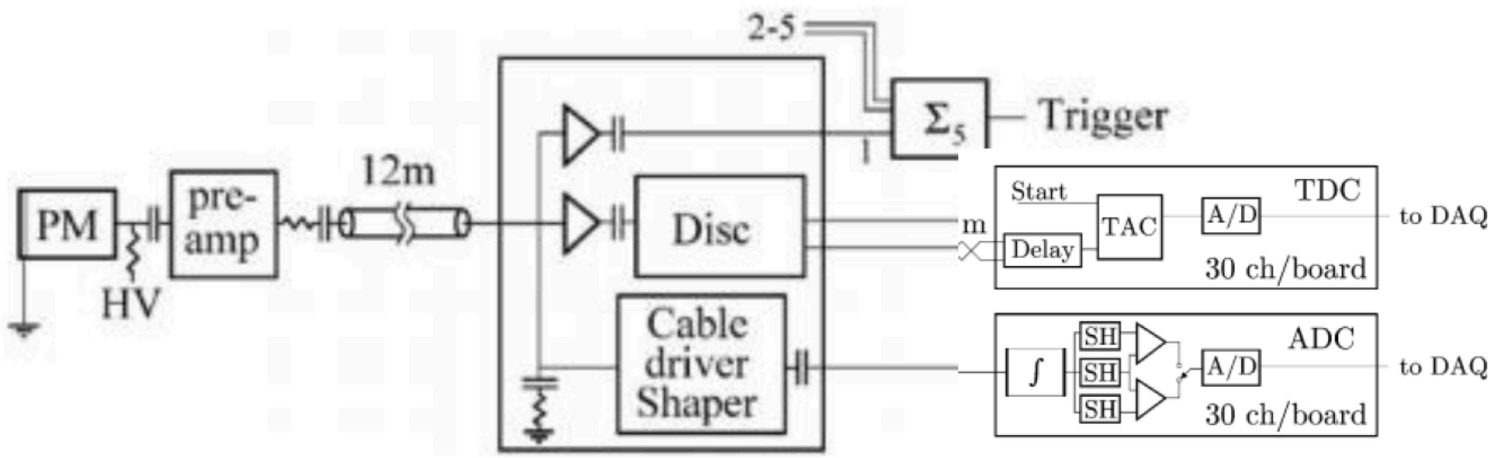


2440 cells total

4880 channels

Electronics

It should/may be improved….if it needs/if it is worth



12 bit TDC 53 ps/count
12 bit ADC 5 counts/MeV

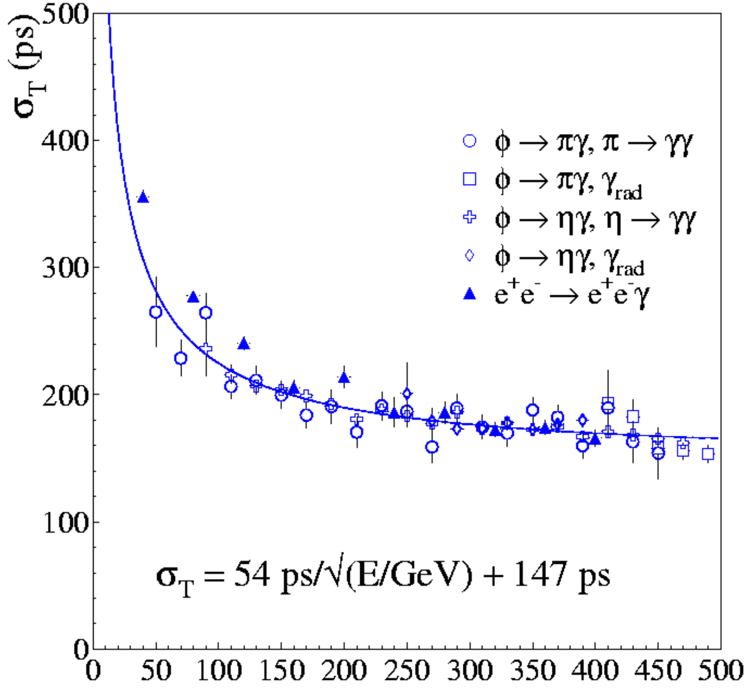
TDC threshold: 4-5 mV (3-4 p.e) → (≈100 keV)

Performances

Operated from 1999 till March 2018 with good performances and high efficiency for electron and photon detection, and also good capability of π/μ/e separation

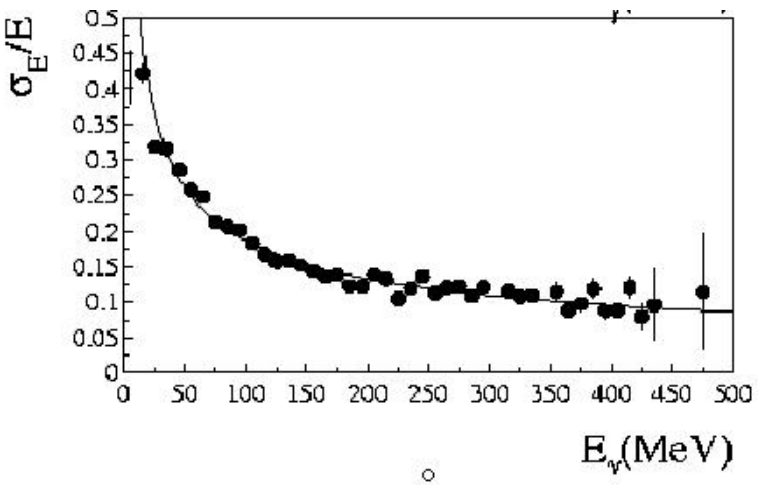
Time resolution:

σ_t=54 ps/√E(GeV)⊕50 ps



Energy resolution:

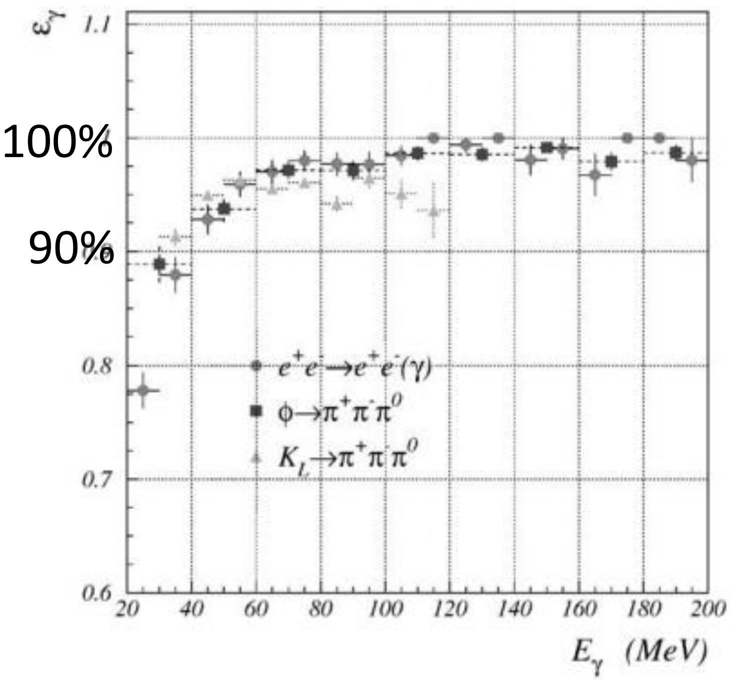
σ_E/E=5.7%/√E(GeV)



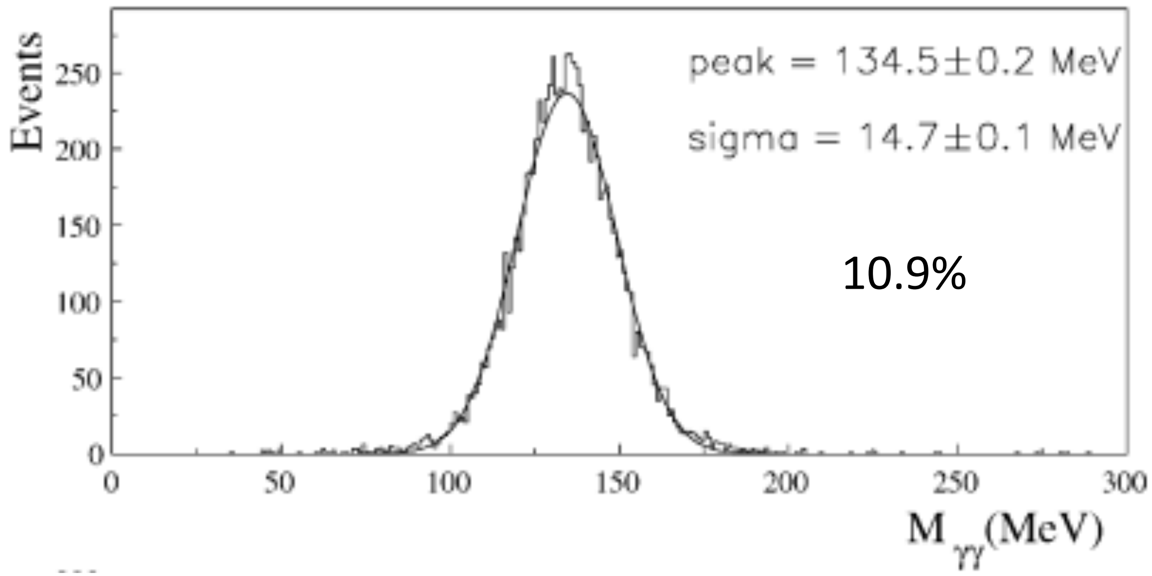
(see KLOE Collaboration, NIM A482 (2002),364)

Performances-II (energy)

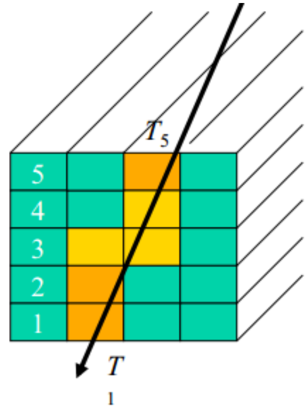
Gamma efficiency detection



π^0 invariant mass

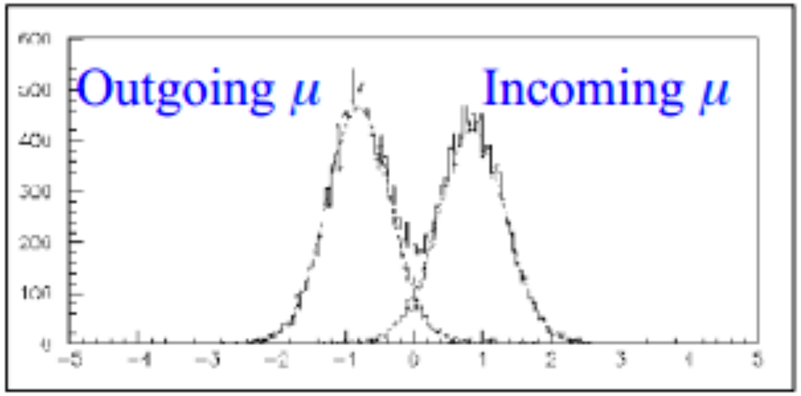


Performances-II (timing)



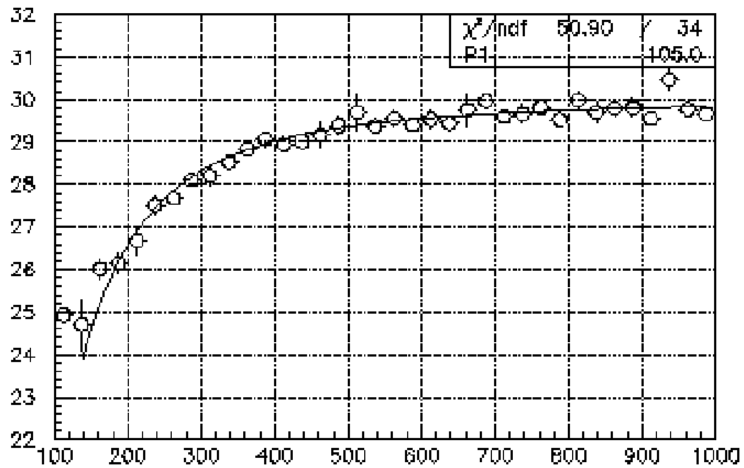
T_1-T_5 distribution can distinguish incoming/outcoming events

In combination with the TRACKER for L and T_0 : $\beta = L/\Delta T$



T_1-T_5 (ns)

βc (cm/nsec)

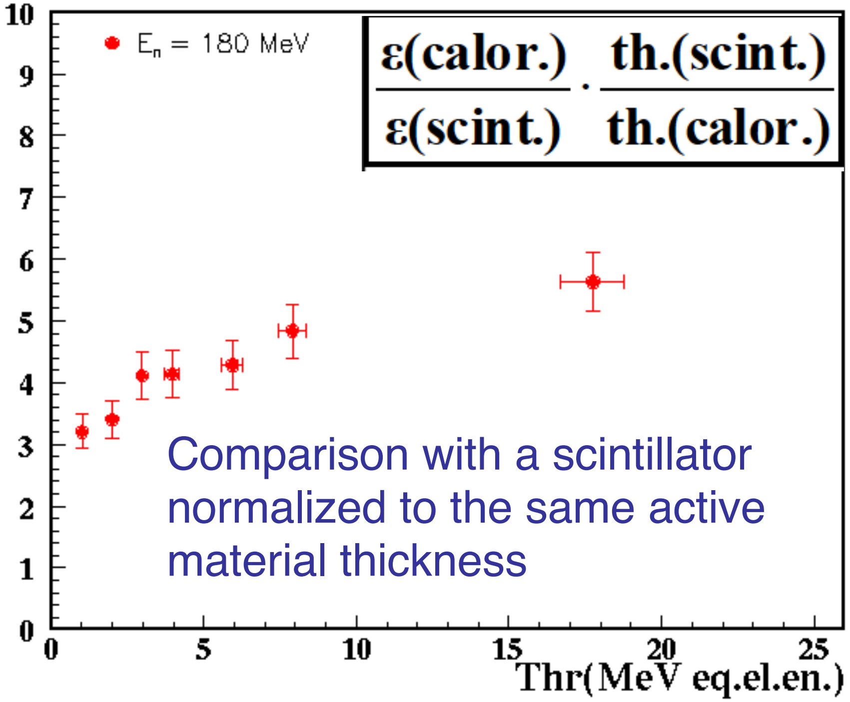


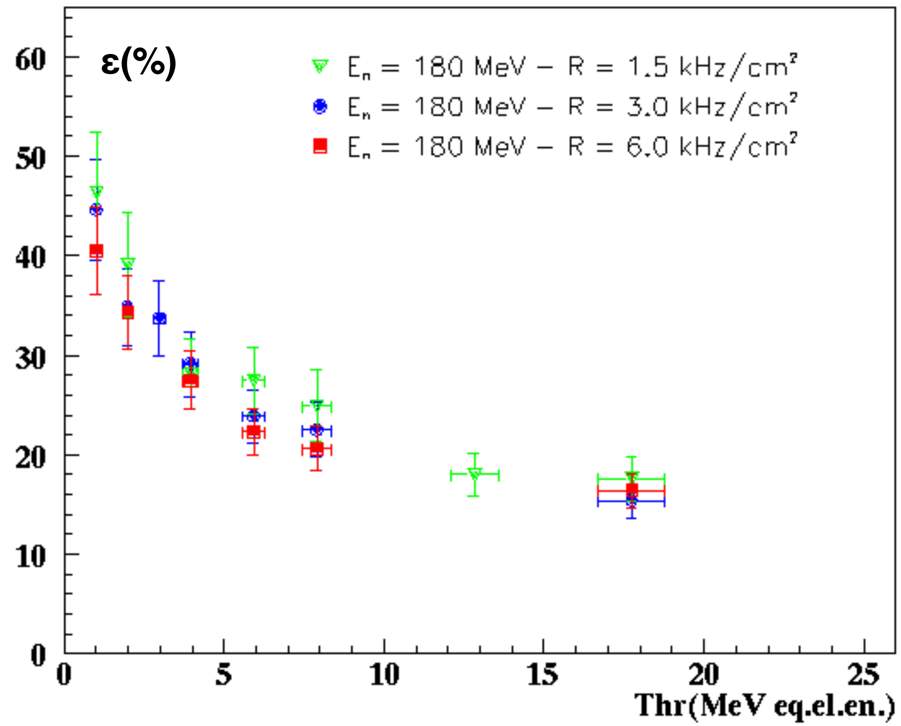
$p_{TRACKER}$ (MeV/c)

(from fit) m_μ = 105.6 MeV/c^2

Performances-III: neutrons!

NIM A 598 (2009) 244–247





Huge inelastic production of neutrons on the lead planes.
Secondary neutrons and protons and photons that contribute to the visible energy

TRACKER: see next talks

INFN and SAND:

INFN is willing to provide all the needed resources to dismount, refurbish, deliver, reassemble and commission of

- **a fully functional magnet plus**
- **a e.m. calorimeter plus**
- **a LAr active target (~1.5 t)**

within an opening large collaboration with other groups

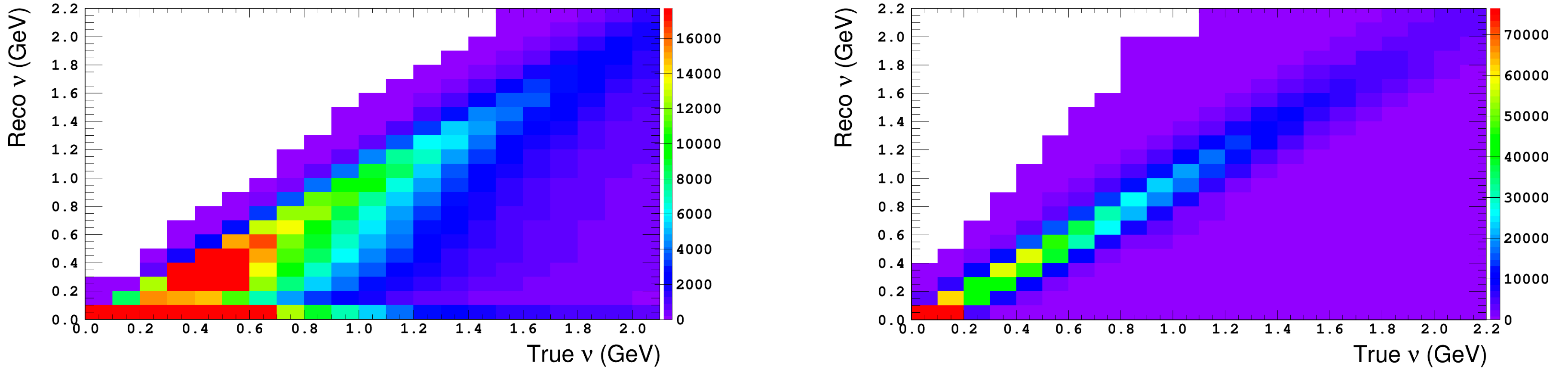
Some Physics performances (more on next talks)

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



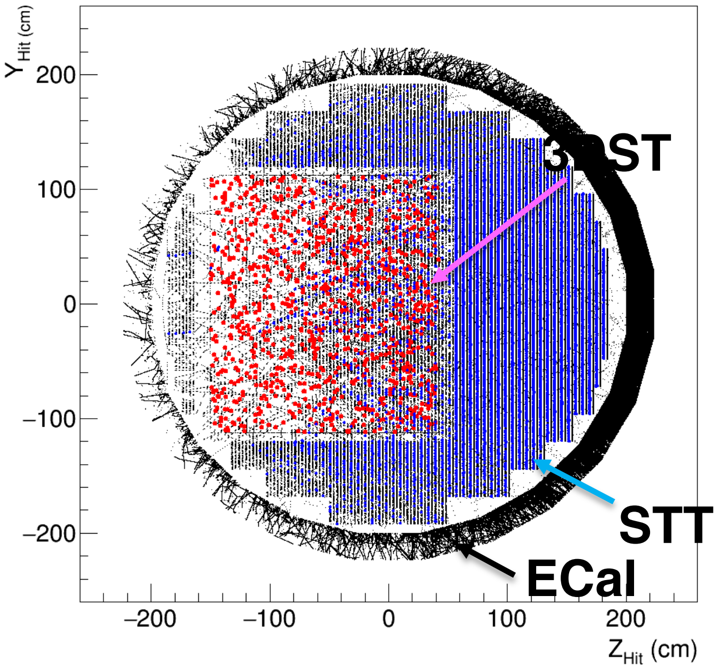
In general, neutron measurement provides an event-by-event reconstruction of neutrino interaction, allowing for the selection of dedicated samples

Physics performances

Background from induced external interactions

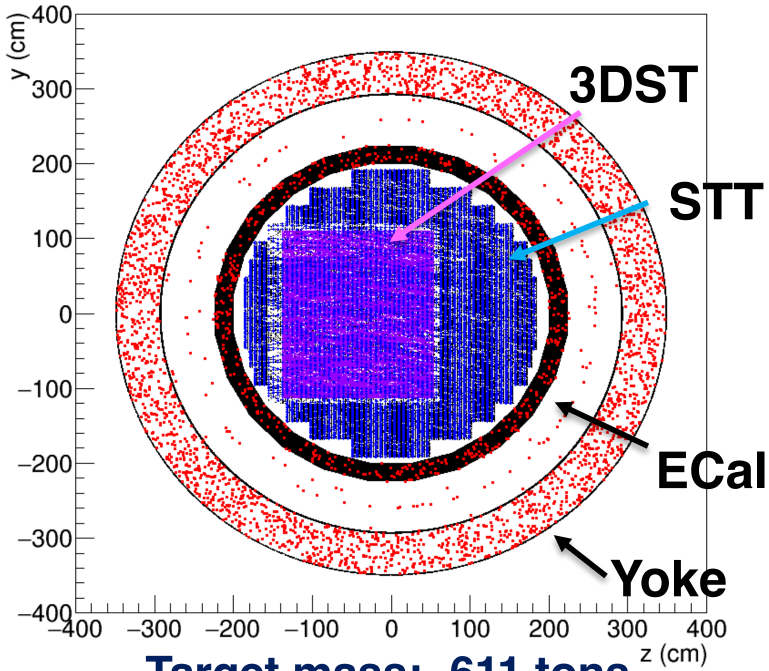
Active volume: 2.24x2.24x2m³	MC samples by FLUKA

"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)



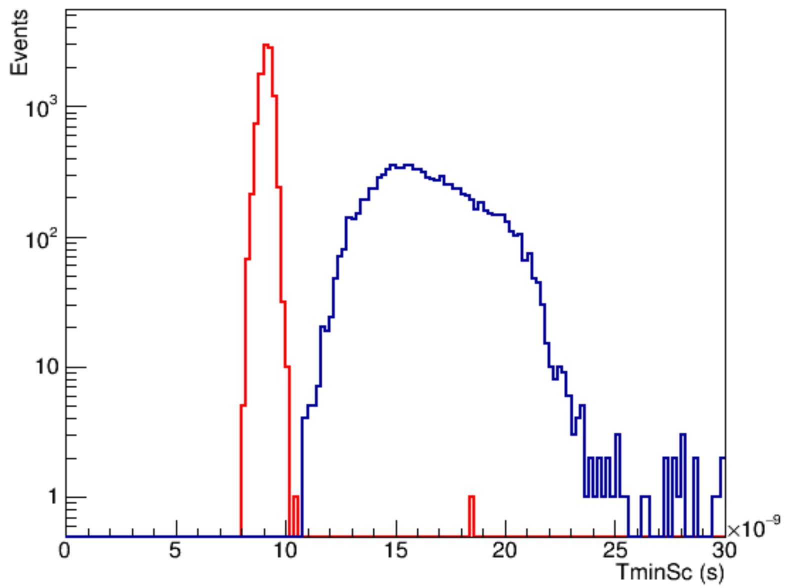
Target mass: 611 tons

• *Interaction vertices*

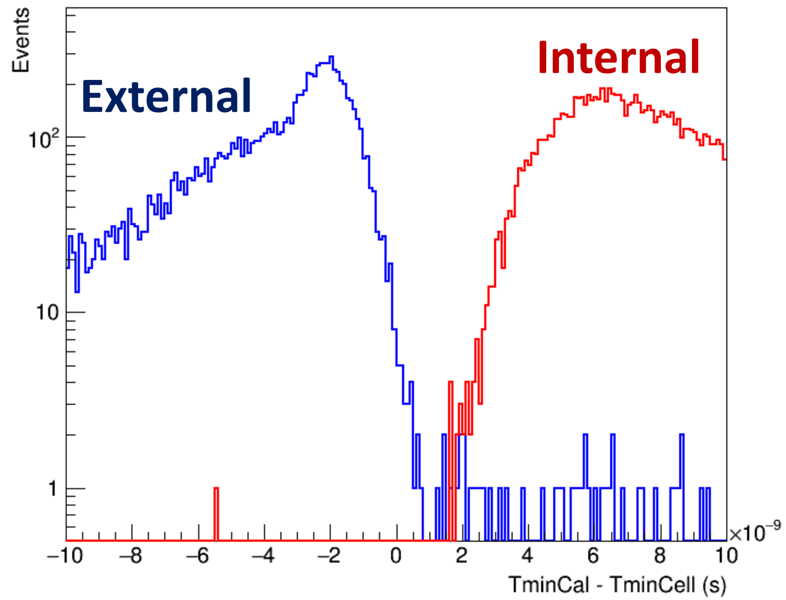
Using only the timing, Fiducial-Volume and cell counts…

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

T_{1st} distribution of Internal evts



$\Delta T_{1st} = T_{1st}^{Cal} - T_{1st}^{Sc}$



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

Conclusion

1) SAND detector is a well-advanced project for the DUNE-ND

2) A more than excellent ”beam monitoring” system to detect time-dependent beam parameters

3) A performant tracker has to be finalized

4) Its multipurpose concept will allow very extensive studies on neutrino interactions

5) SAND ND-detector is well in-line for starting of data taking at the DUNE-FAR at t_0

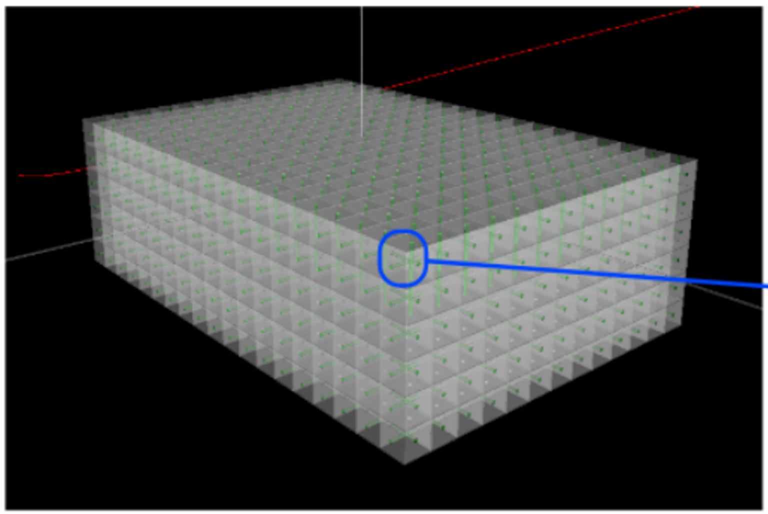
thanks

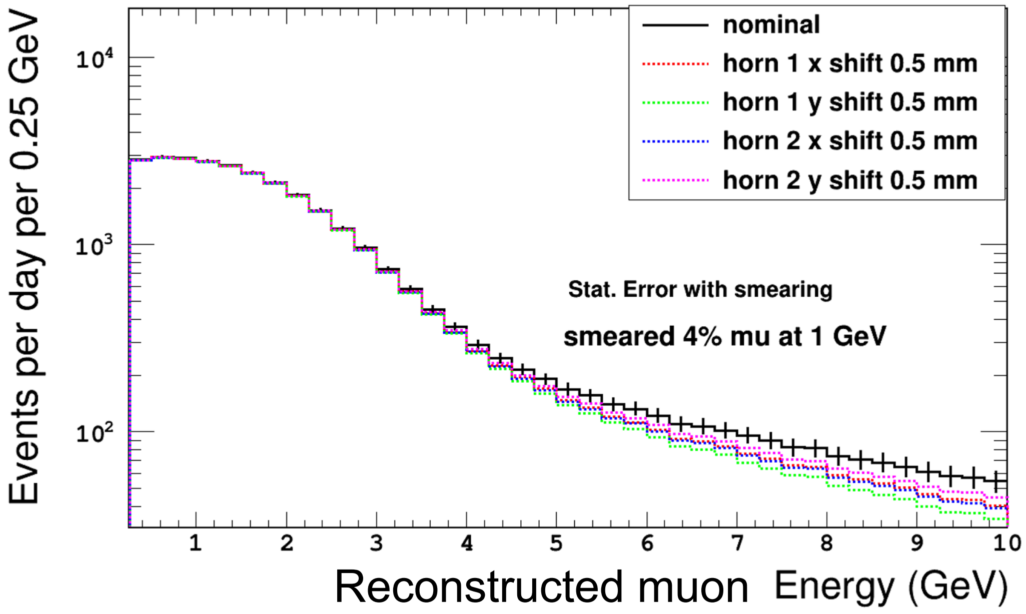
Backup slides

Beam monitoring with 3DST

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

No ECAL information, yet

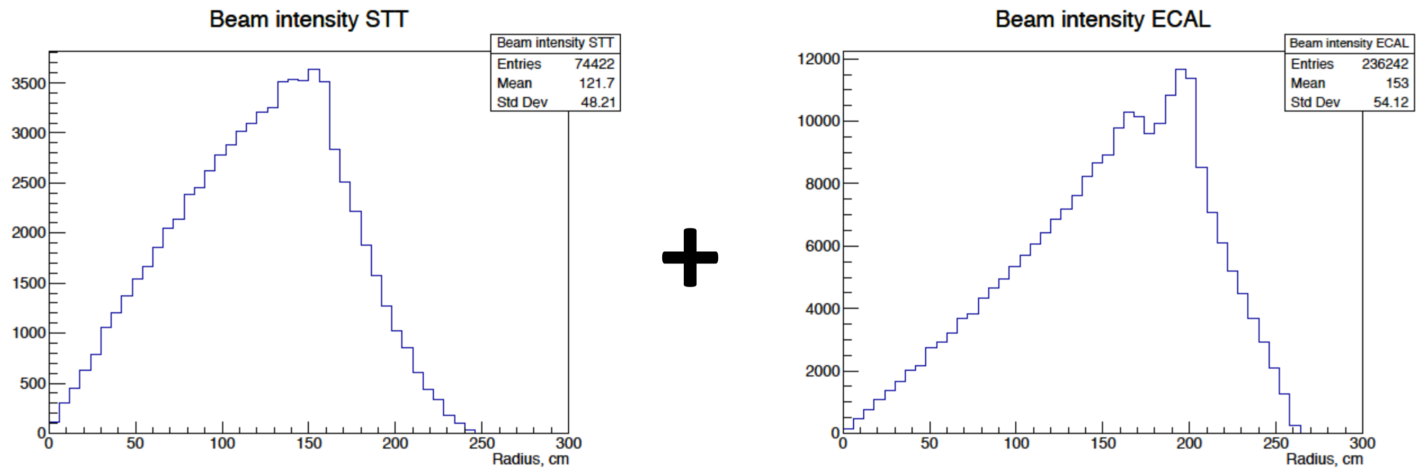




Beam monitoring with STT+ECAL

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

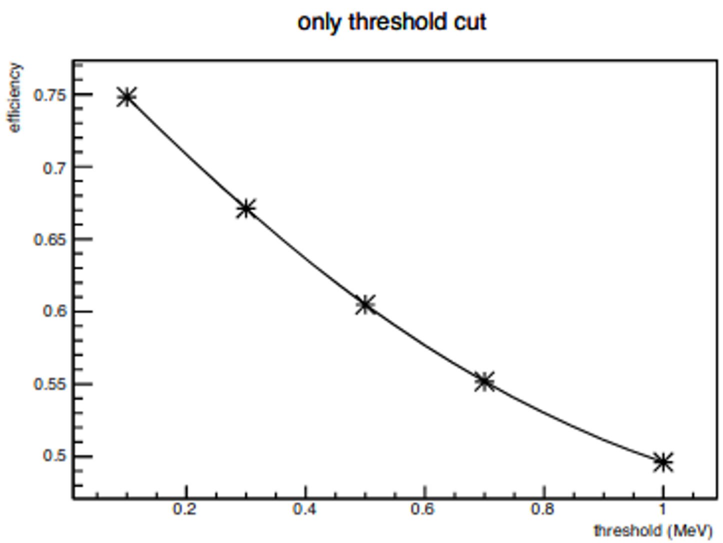


Radial bins used to monitor E_ν and E_μ (ν_μ CC):

- 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 CH2 and C thin (1-2%X0) targets:
- STT detector designed to provide, on average, same acceptance for CH2 and C targets;
- Model-independent data subtraction of dedicated C (graphite) target from main CH2 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 H2 detectors