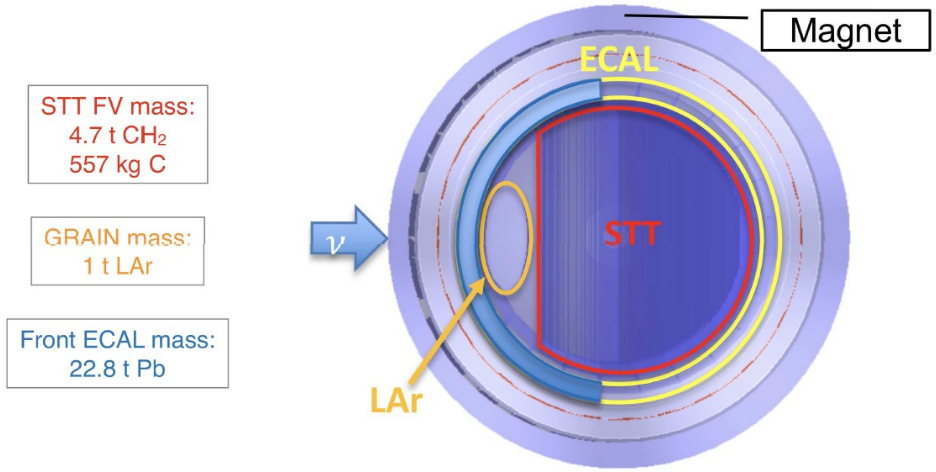
DUNE ND-SAND *(Luca Stanco)*

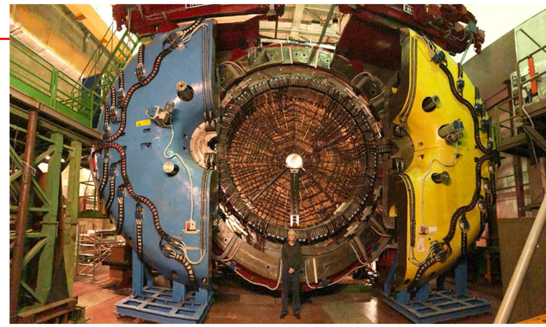
- Introduction

- ECAL/Magnet
- STT
- GRAIN
- Physics & Software

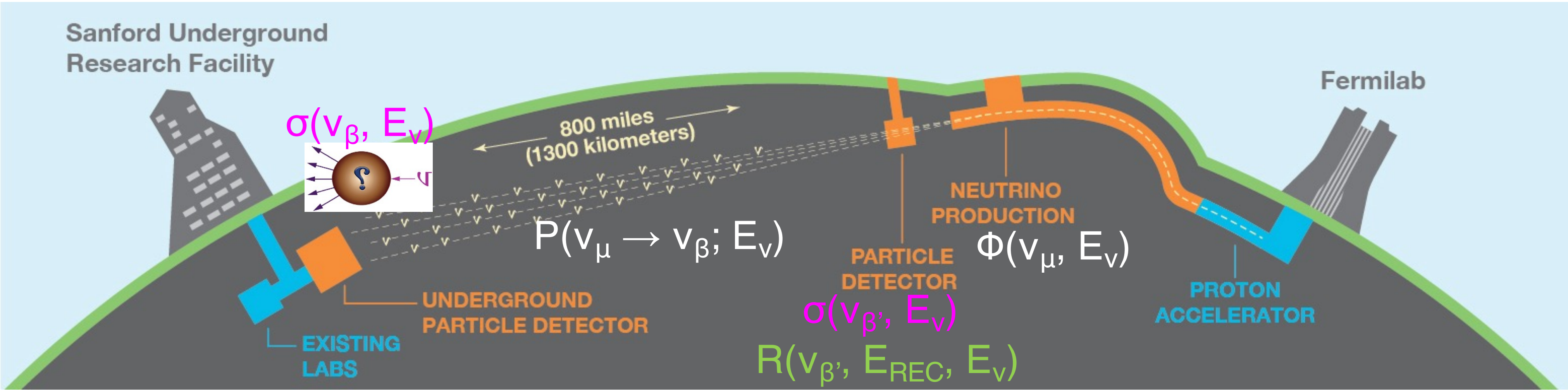
- Conclusions

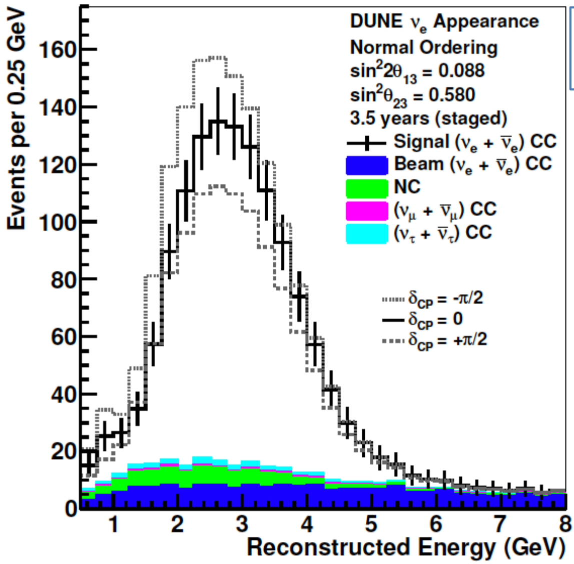


SAND, a multipurpose detector with an high-performant ECAL, light-targeted tracker, LAr target, all of them in a magnetic field



Dune at work

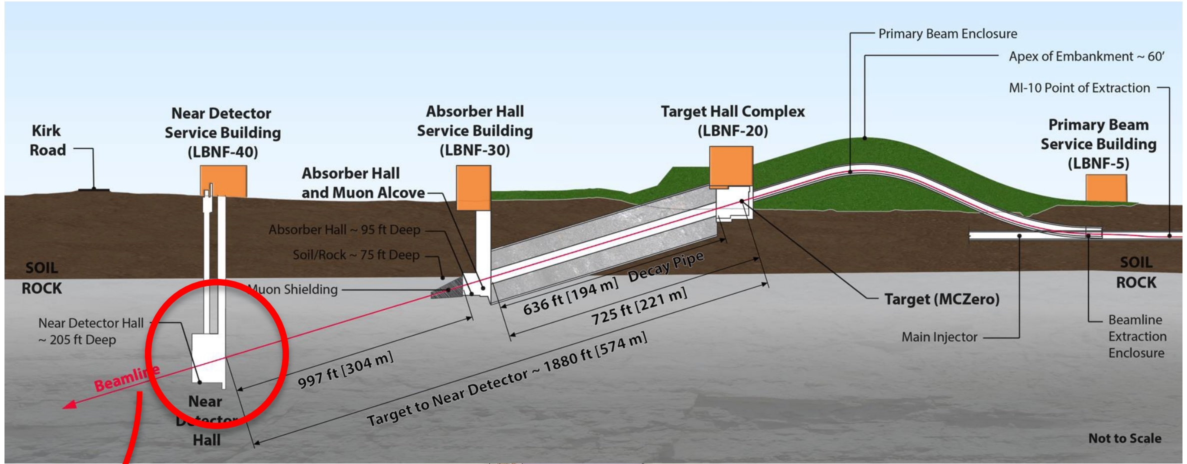




ν_e appearance from ν_μ beam after 3.5 years (staged)

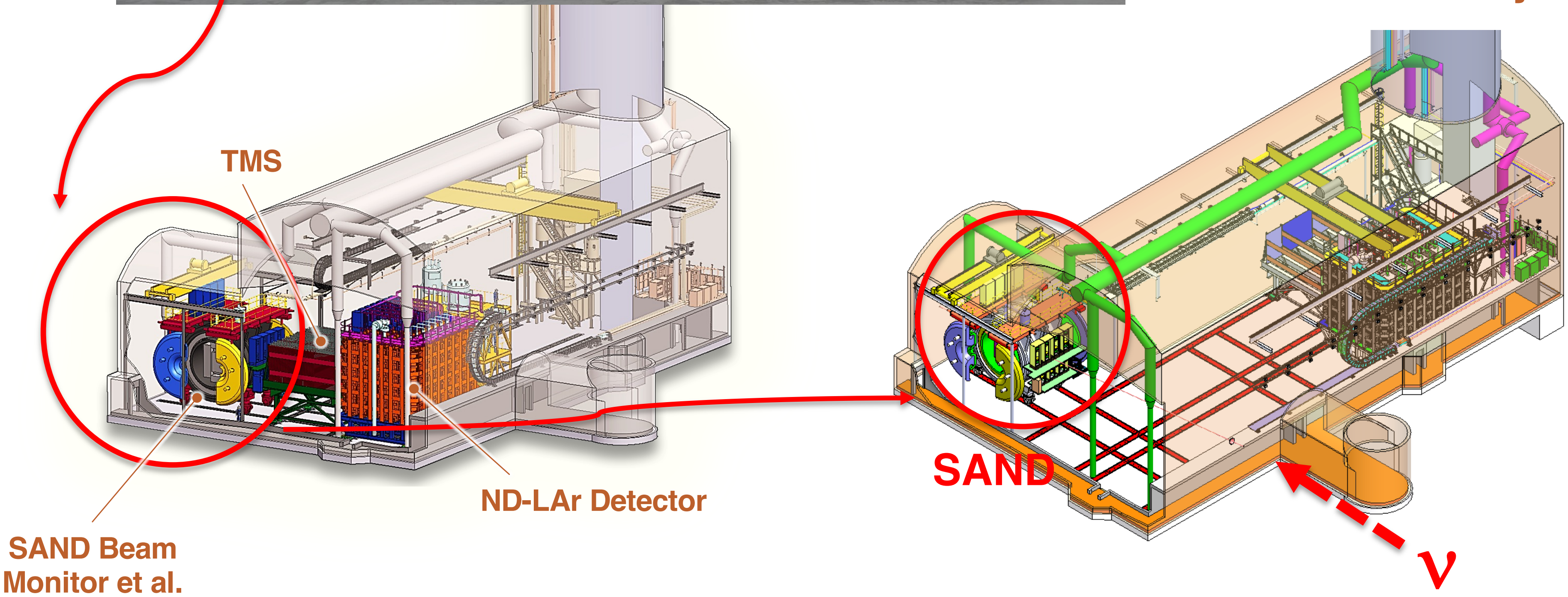
Need maximal control of prediction under PMNS parameters:
fluxes, cross-sections, detector responses

To maximize deconvolution of intrinsic degeneracies perform single measurements for as many as possible sources of systematics effects ☞ Near Detector complex



High statistics constrains cross section and neutrino flux.

Systematics' control for neutrino oscillation analysis.



DUNE Phase-1 Near Detector Layout

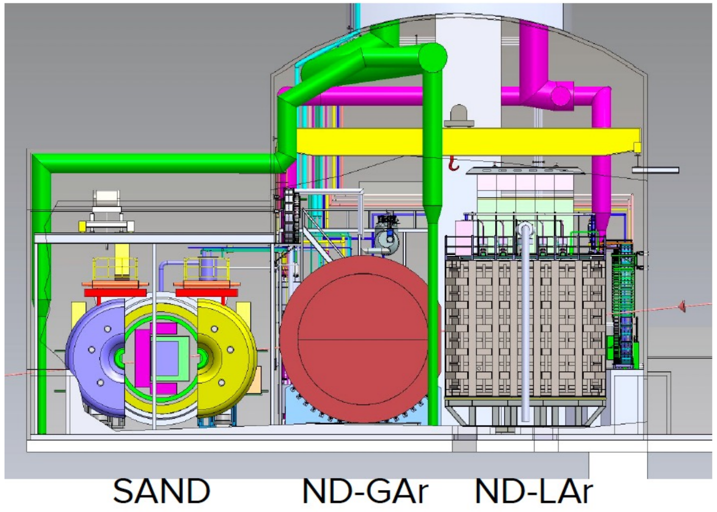
Near Detector Complex (asymptotic)

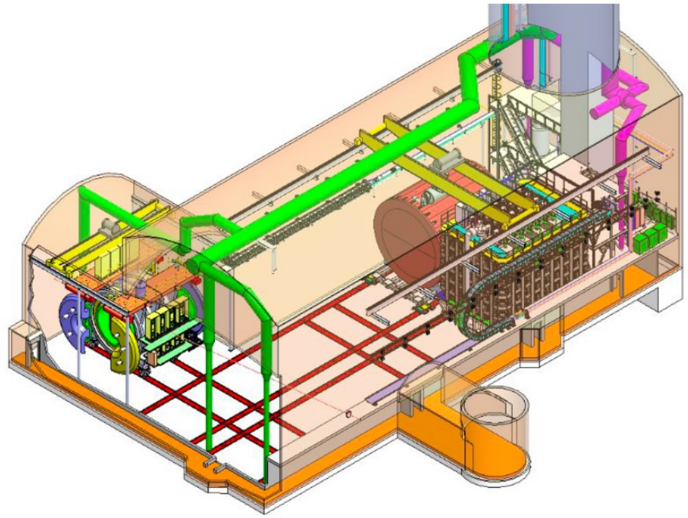
Four main components

1. Liquid argon detector (ND-LAr)
2. Downstream tracker with gaseous argon target (ND-Gar/MCND), in magnetic field
3. ND-LAr and MCND systems can move to off-axis fluxes (PRISM concept)
4. System for on-Axis Neutrino Detection (SAND), in magnetic field

High statistics constrains cross section and neutrino flux.

Systematic control for neutrino oscillation analysis.





SAND's requirements & interplays

1. It **must** monitor the (relevant) beam changes on a **weekly basis** with sufficient sensitivity
2. It **must** provide an independent measurement of the **flux** and measure the **flavor** content of the neutrino beam on event-by-event basis.
3. It **should** contribute to remove **degeneracies** when the other components are off-axis (50% of the time)
4. It **would** add robustness to the ND complex to keep **systematics** and **background** under control
5. and while delivering all of the above, it **could** contribute to **oscillation analysis** and enjoy the high statistics to perform a plethora of **other physics** measurements.

As a matter of fact SAND needs to be a multipurpose detector

(with challenging compromises between mass, ID and tracking)

SAND configuration

SAND will be permanently on-axis in a dedicated alcove

The schematic configuration is:

- a Superconducting Solenoid Magnet
- an Electromagnetic Calorimeter (ECAL)

} in-kind from KLOE experiment (LNF-Italy)

- an Inner Tracker, including a thin active LAr target

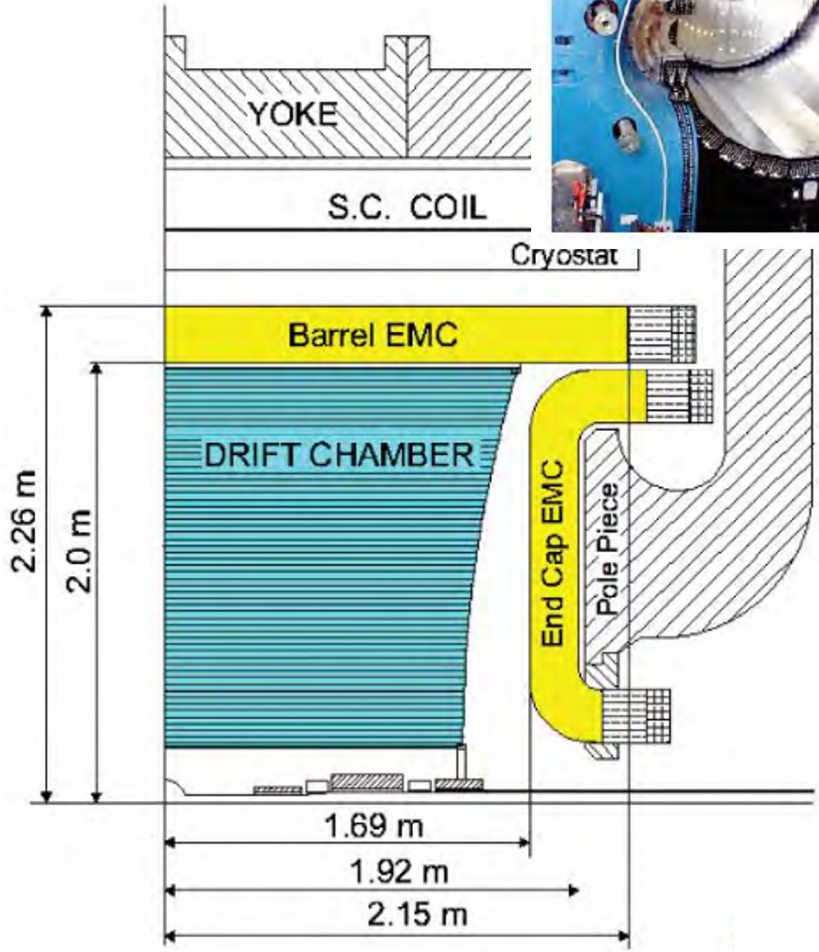
Inner Tracker

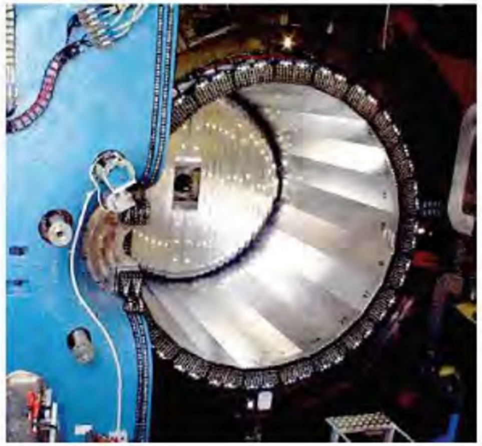
- **Why SAND needs a dedicated tracker system inside the magnet?**
  Separation of neutrino and anti-neutrino fluxes (charge ID),
  event-by-event reconstruction,
  neutron identification,
  subtraction analysis to isolate free proton interactions.

- a StrawTubeTracker (STT) providing a low density tracker with integrated thin targets (final choice in September 2021)

SAND ECAL

- 24 barrel modules
  - 60 cells (5 layers)
  - 4.3m total length
- 2 x 32 endcaps modules
- Operated from 1999 till March 2018 with good performances and high efficiency

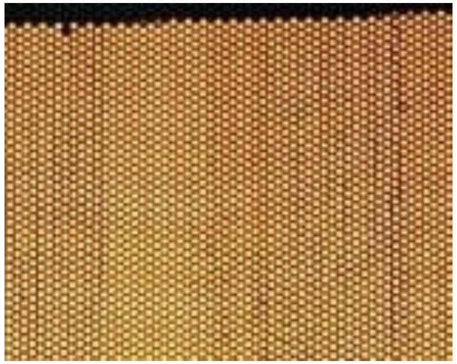




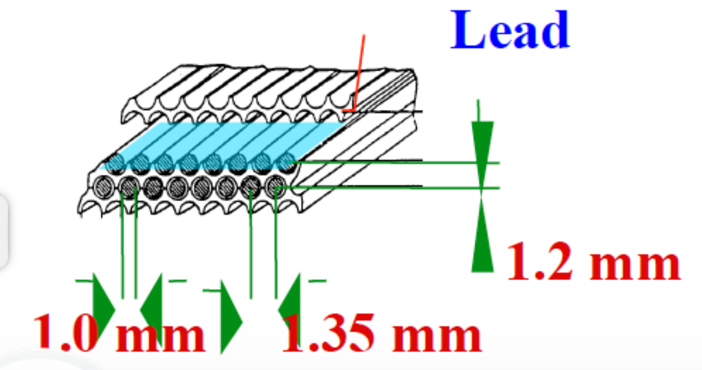
Electromagnetic Calorimeter

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



The KLOE calorimeter

Operated from 1999 till 2018 with excellent performances for electron and photons and good capabilities for p/μ/e separation

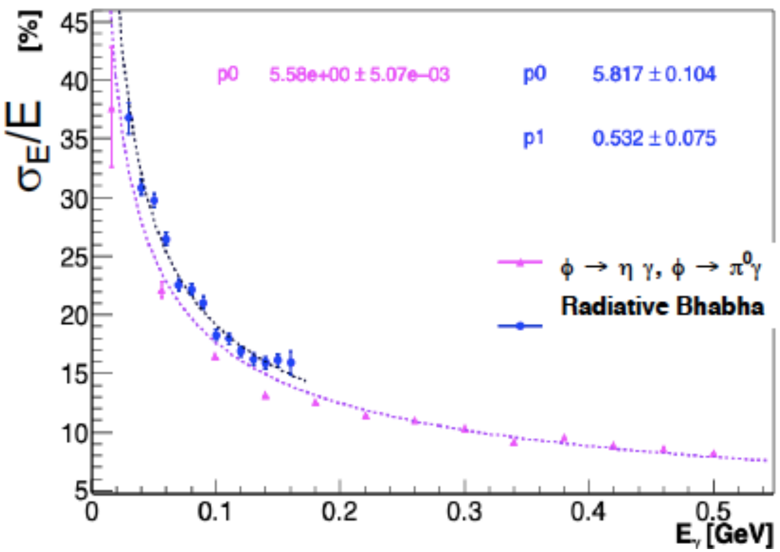
Also: good neutron detection efficiency due to the small sampling fraction and the high frequency sampling.

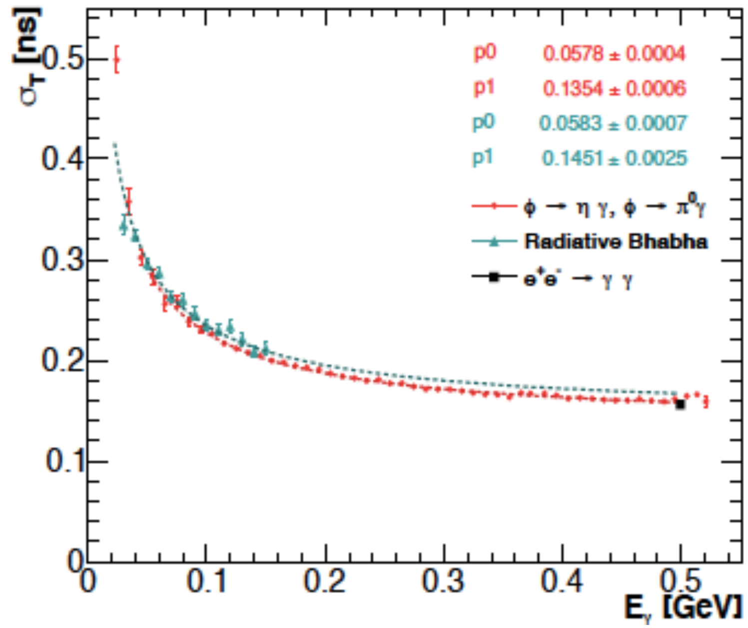
$\sigma_E/E \cong 5.6\% / \sqrt{E(GeV)}$

$\sigma_t \cong 58\ ps / \sqrt{E(GeV)} \oplus 135\ ps$

Check e.m. calorimeter performance

during KLOE-2 data taking (2015-2018): compatible with known performance.





SAND will probably be one of the best detector ever placed in a near site of a neutrino beam.

Is it worth for DUNE? A three-fold yes:

1. Plenty of neutrino measurements (xs, fluxes, systematics)
2. Beam monitoring
3. In-kind international contribution

Building it from scratch would not be reasonable due to the corresponding needs in terms of money and personnel.

It has a two-fold added value for DUNE:

1. Complementarities to the other specialized detector(s)
2. Bit the unknown unknowns that could (much probably) be encountered.

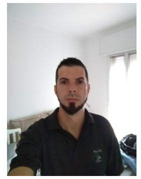
For an extensive view : DUNE DocDB:13262-v7

DUNE-SAND Consortium

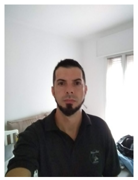
SAND Consortium setup in May 2020: 25 Institutions (Italy, US, India,…) and it is growing up

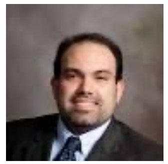
Appointed **Consortium Leader**: Luca Stanco
Appointed **Technical Leader**: Claudio Montanari

Boards: **Advisory** (Sergio Bertolucci, Milind Diwan, Bipul Bhuyan, Marco Pallavicini, Laura Patrizii, Roberto Petti)
Steering and Physics (Claudio Montanari, Lea Di Noto, Paola Sala, Matteo Tenti)



Software Coordinators: Matteo Tenti





DAQ/SC coordinators: Michele Pozzato and Matteo Tenti (deputy), Camillo Mariani

SAND commitments and interplay

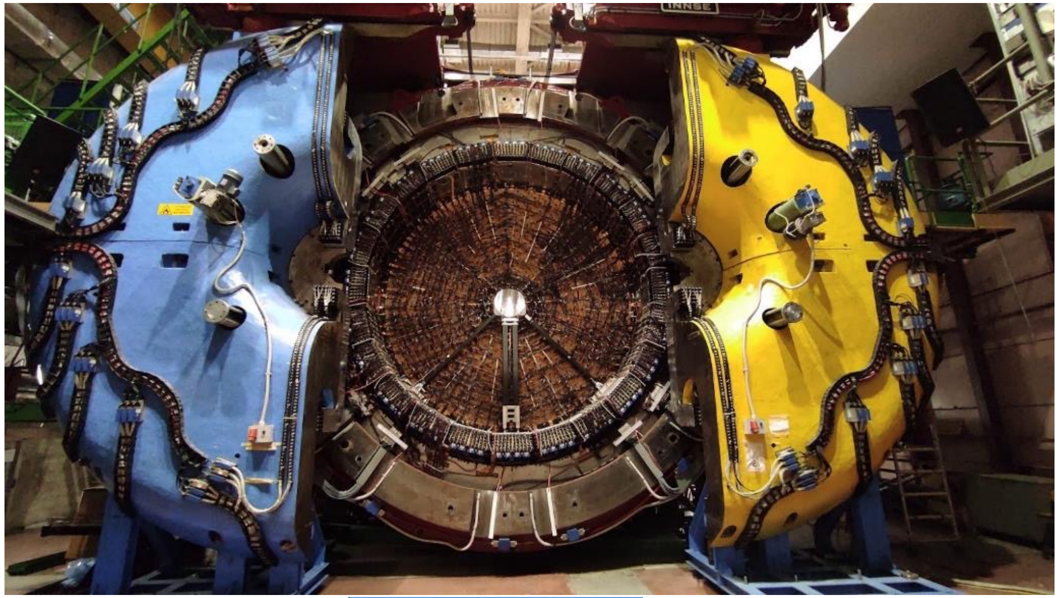
- SAND Consortium provides the detector components, expertise and resources for testing, assembling, installation, commissioning
- DUNE-US/Fermilab is proposed to provide logistics, technical support and engineering for the pre-assembly activities, pre-shipping and post-shipping acceptance tests, occurring outside the DUNE-ND complex prior to installation
- DUNE-US/Fermilab is proposed to provide cryogenics for detector operation, logistic, technical support and engineering oversight for the installation activities in the DUNE-ND complex

Technical Working Groups

Activities / Sub-systems	Initial chair(s)
1) Magnet and Yoke	*G. Delle Monache*
2) ECAL	*D. Domenici, A. Di Domenico*
3) STT	*G. Sirri, S. Di Falco, R. Petti*
4) GRAIN	*A. Montanari, L. Di Noto*
5) DAQ/Trigger & Timing/Slow Controls	*M. Pozzato, S. Di Domizio, C. Mariani*

- Regular weekly or bi-weekly meetings of the WG's

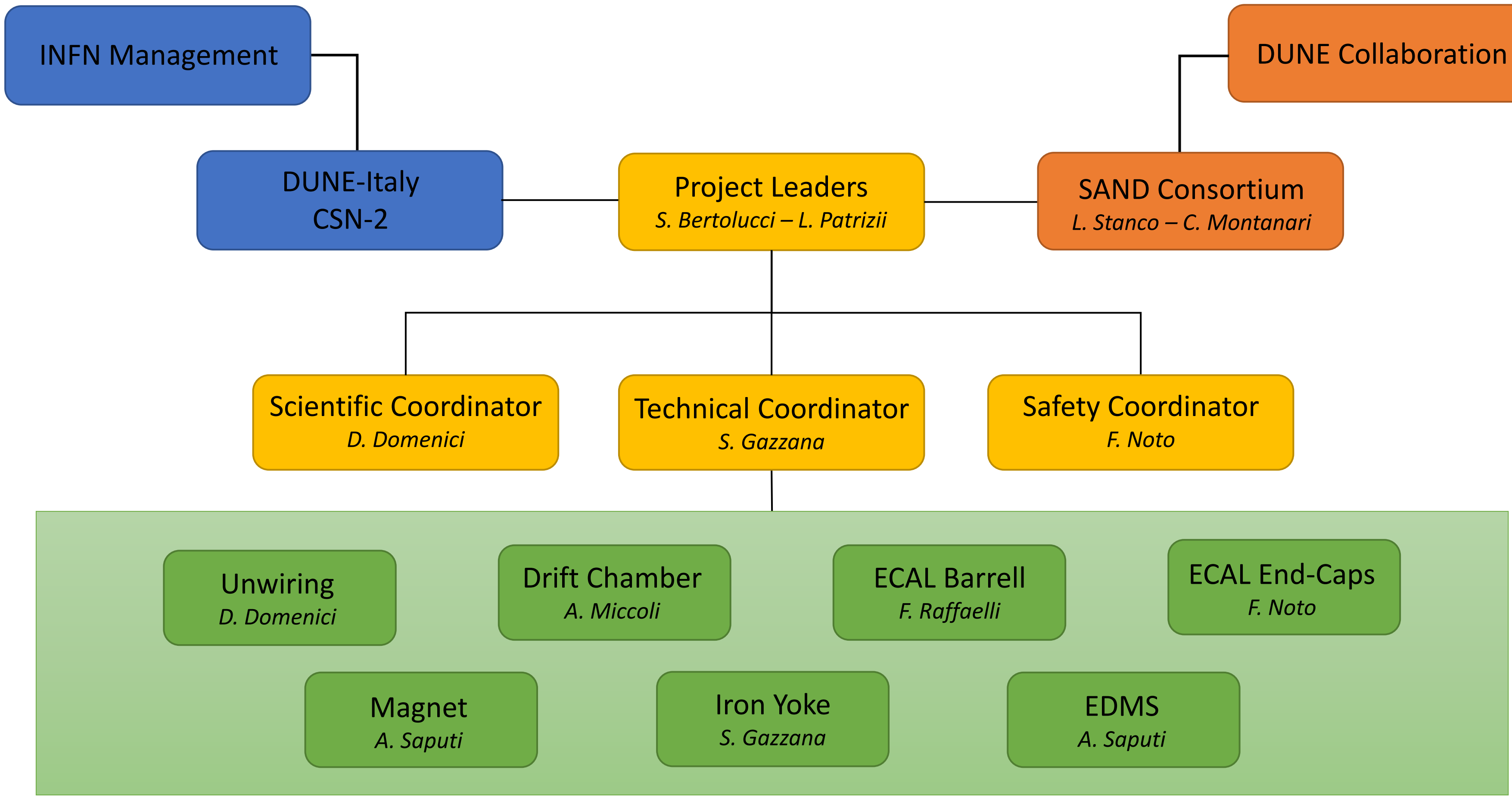
ECAL and Magnet status: from KLOE to SAND



List of operations:
1. Survey, revision and design of mechanical tools
2. Unplugging and cables removal
3. Extraction of KLOE drift chamber
4. Extraction of ECAL barrel modules
5. Dismounting of ECAL endcaps
6. Extraction of coil
7. Dismounting of iron yoke

KLOE-to-SAND

KLOE-TO SAND Project OBS



KLOE-to-SAND project

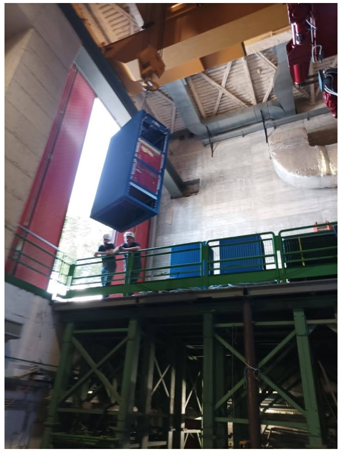
Foreseen schedule (slight update from May)

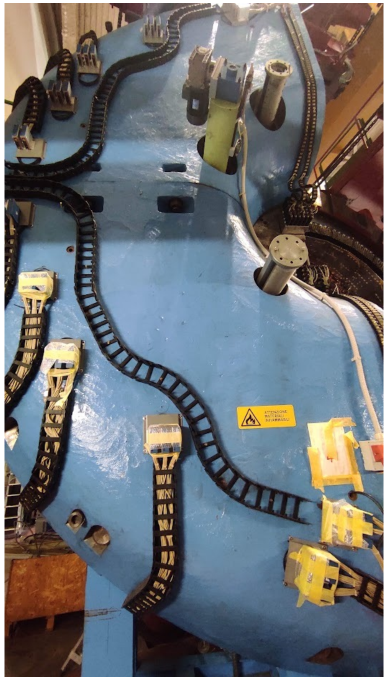
Regular activities as foreseen:
>=2 technicians per shift from several INFN sites
2 engineers supervising
1 physicist supervision

More details on the Danilo Domenici talk at SAND parallel session

Operations begun

administratively in February, workable way in May 2022



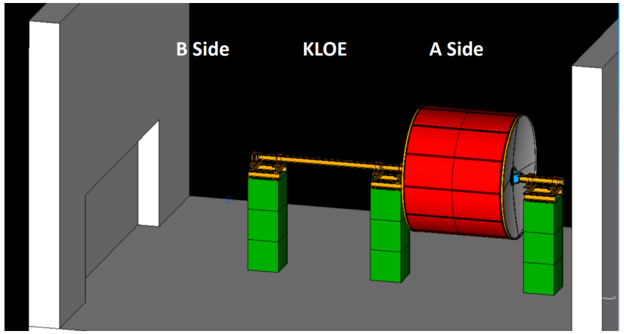


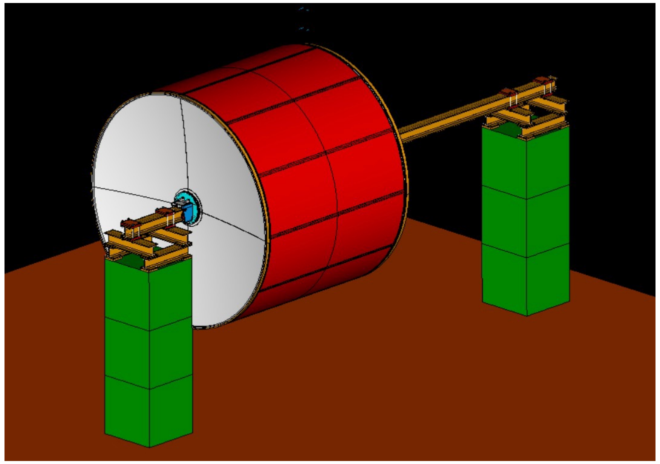
10 boxes full of ECAL cables (to be reused)

- Cable removal: completed end of September
- Almost ready for Drift Chamber extraction

Removal of the Drift Chamber

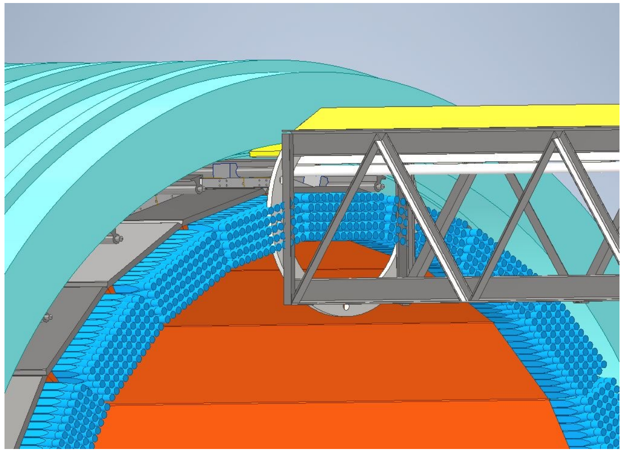
New tool





ECAL extraction: Barrell

Old tool



New (refurbished for extraction)

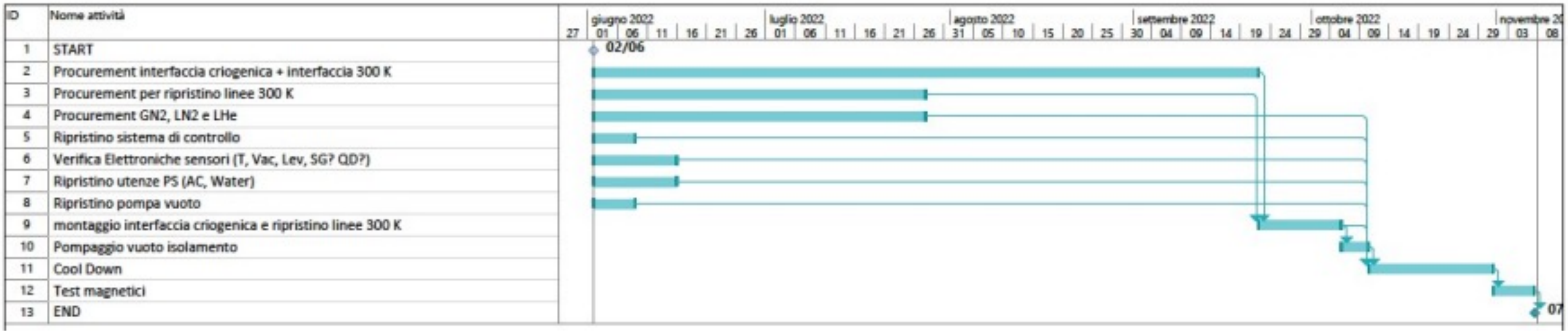
End-caps

Design for SC-coil testing at LNF

An operational test is foreseen before extraction using the new power supply
Magnet is no more connected to LNF cryo line: must fill it by external tank

- 25kl of LN_2 to cool down from 300K to 100K
- 6kl of LHe to cool down from 100K to 4.4K

we are here



Schedule summary

- ~20 weeks for preparation (cryo interface and lines, control system, electronics, procurement of GN_2, LN_2, Lhe)
- ~8 weeks for test (vacuum pump, cool down, switch on)

@Danilo.Domenici, Antonio.DiDomenico

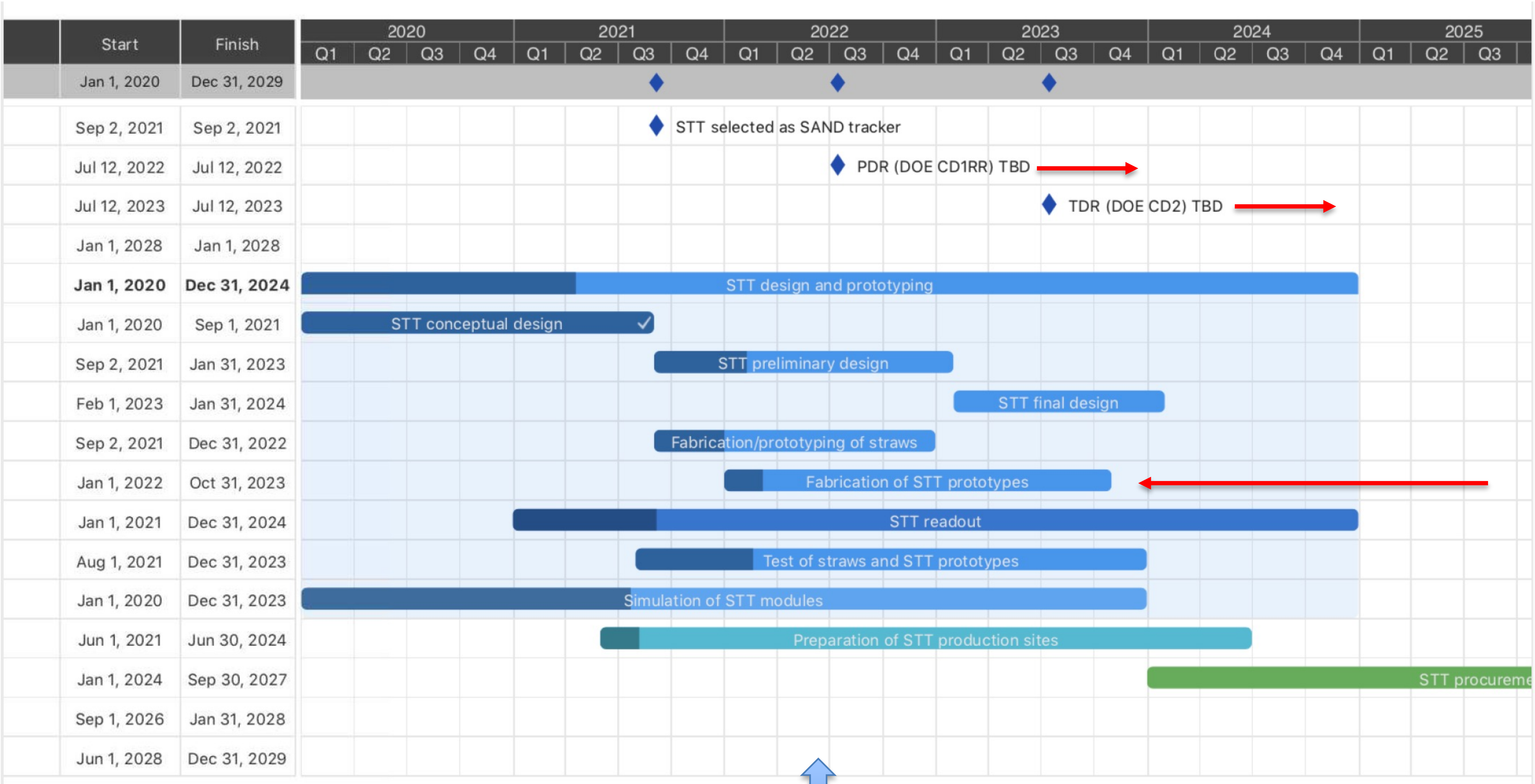
STT activities and schedule

- Defined all activities required for the completion of the design, production and installation of the STT.
- Foreseen schedule and related deliverables:
  - Identified main tasks and timeline (to be revised following inputs/developments); 3 prototypes will be arranged:
    - 35x35 cm^2, the mockup
    - 120x80 cm^2, the intermediate
    - 400x40 cm^2, the module-0
  - Uncertainties on availability of ND site and current situation (covid19, conflict, supplies, etc.).

USA: Duke University, University of South Carolina, BNL,…
Italy: INF/Univ. Bologna, Genova, Pisa; INFN/Lab. Frascati, Catania, Pavia,…
India: IIT Guwahati, NISER, Panjab University, University of Lucknow, …
Georgia: Georgian Technical University (GTU) Germany: Joint Institute for Nuclear Research (JINR), Dubna
(Germany: University of Hamburg)

Driven by the current DUNE schedule that foresees the ND beneficial occupancy in 2028

and backward



we are here

Test beam at CERN (April-July)

Initial setup:

- XX+YY STT prototype
- 3 scintillators for trigger
- 4 Micromega trackers with APV readout

XX straws + 3 scintillators + MM layer 2 read by Mu2e VMM3 board

Test beam schedule 2022:

- 25 April – 3 May H4 parasitic
- 18 May – 24 May H4 main user
- 25 May – 8 June parasitic
- 13 July - 27 July H4 main users

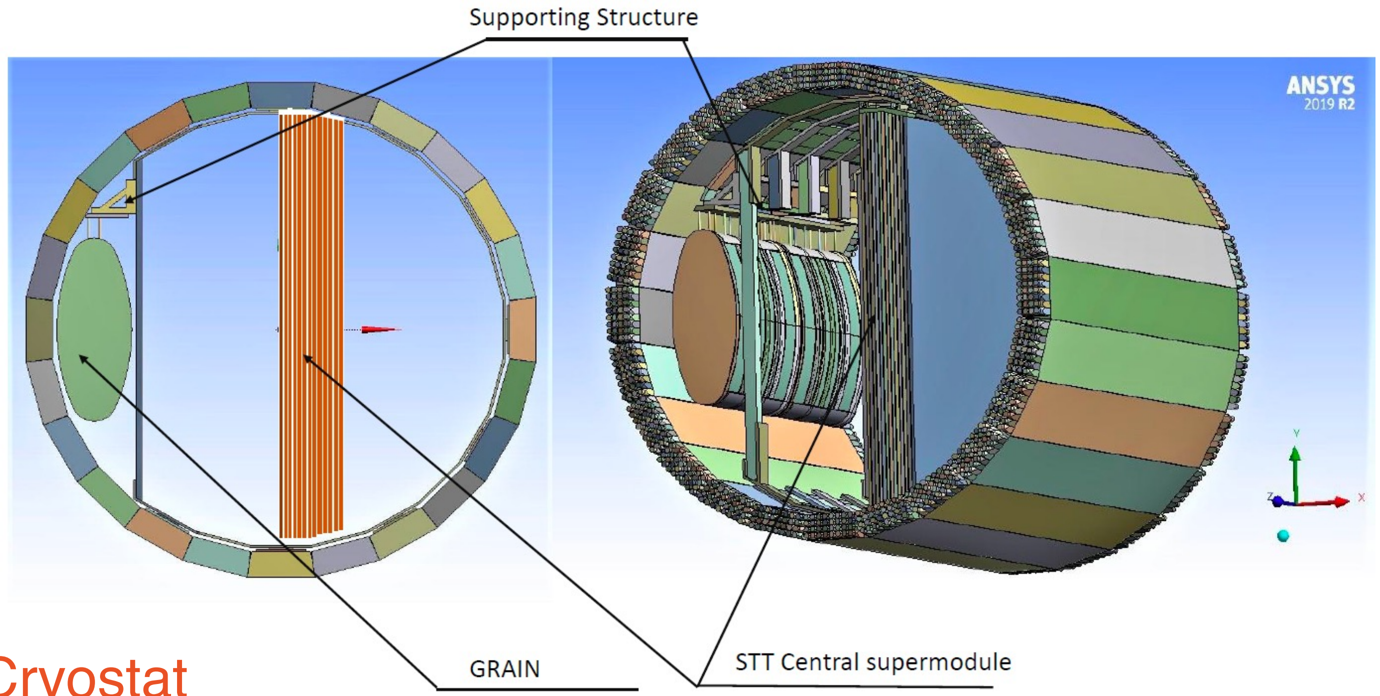
  1 August - 31 Dec. H8 parasitic

Results are promising but still under evaluation

STT setup and operation: JINR+PNPI with help from RD51 + Bologna, Pisa and UofSC

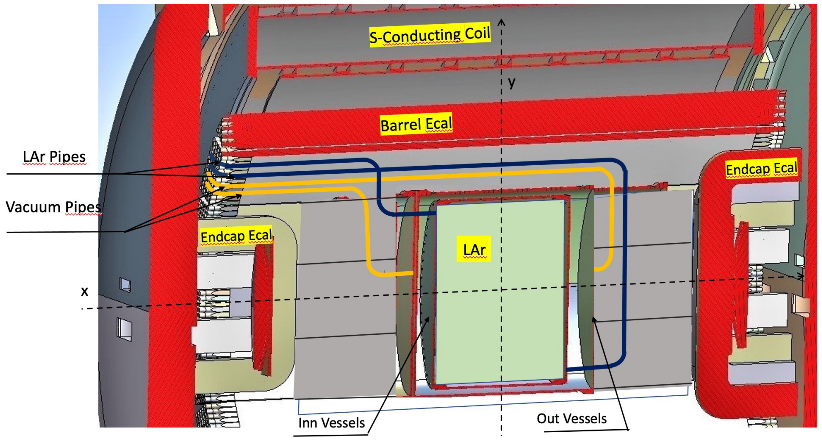
⇒ Critical for the choice of the ASIC chip & front-end readout planning

GRAIN



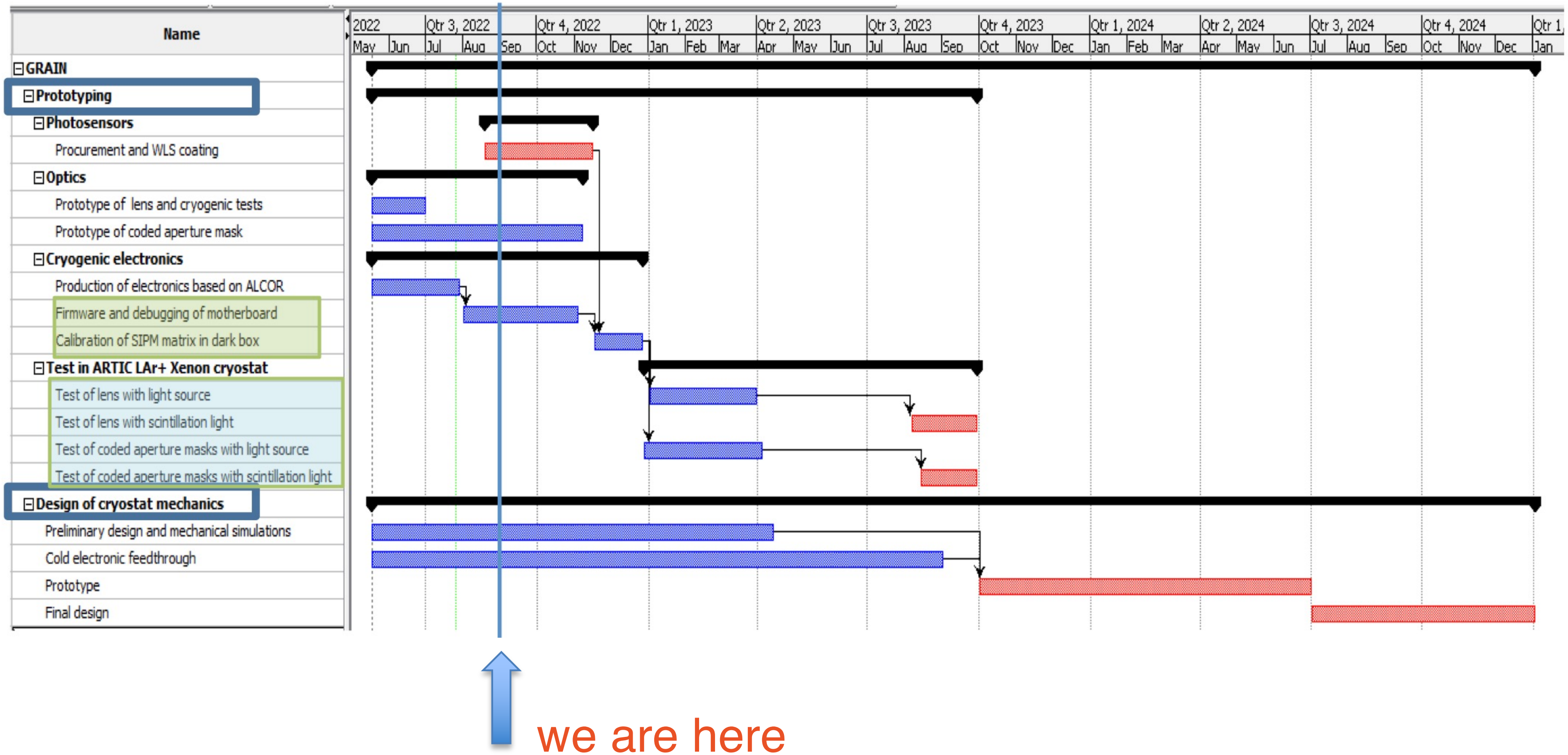
Working on:

- Mechanics of the Cryostat
- Detectors and Optics for VUV
  - Scintillation light Coded Aperture masks (Hadamard)
  - Lens for VUV
- Cryogenic readout electronics and Detector demonstrator
- Tests in Argon cryostat(Artic)



Timeline

1. **Prototyping:**
   → set up a first readout system for SiPM matrix
   → set up measurements in LAr (two phases)
2. Cryostat and sensor **design** in GRAIN



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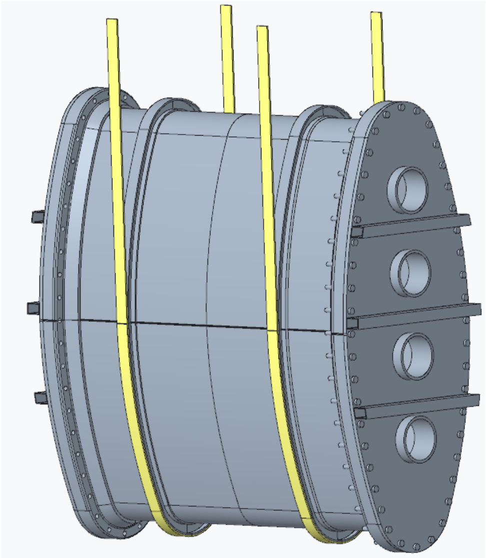
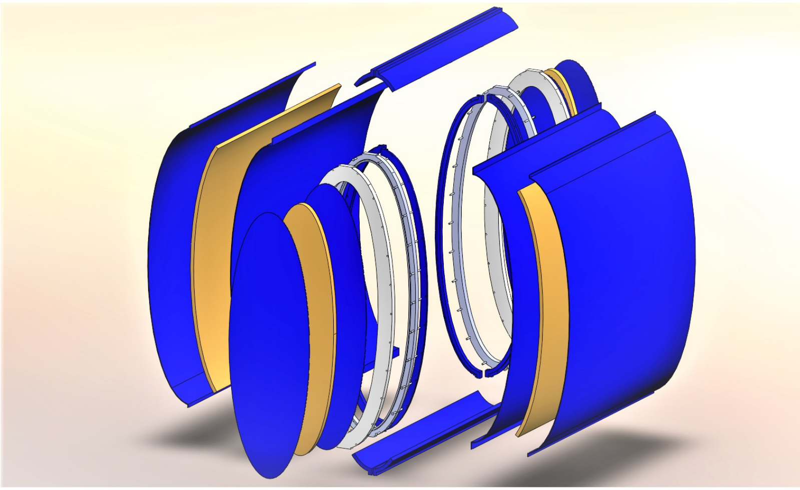


The internal vessel

Dimension and geometry fixed,
prototype 1:1 planned for next year

- All Stainless Steel
- Barrel : 6 mm thick
- End Caps: 16 mm thick + reinforce bars
- It will be certified by external qualified company



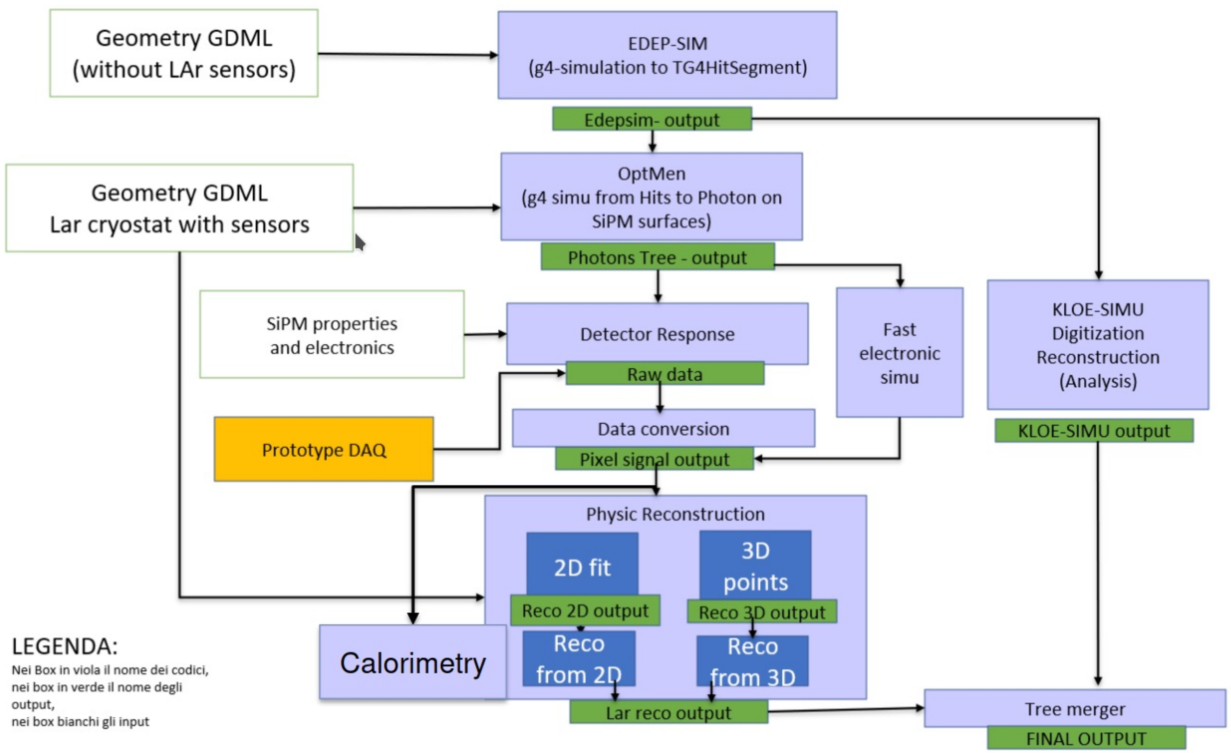
Outer vessel

(preliminary design)

Based on composite structure:
Carbon Fiber – HoneyComb – CF

- Feasibility should be discussed with external firm
- Al – CF transition needs to be verified
- 10-4/10-5 bar vacuum must be guaranteed

Simulation framework

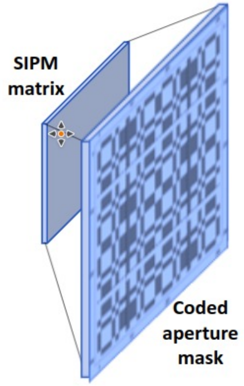


Hot items:

In order to define requirements for the readout electronics (ASIC) we need to know the arrival times of photons to the sensor during the spill, taking into account the background, scintillation properties of Lar (eventually plus Xenon doping)

- Some still unknown items of the mechanics will depend on the readout electronics: number of feedthrough, power consumption, supports for the detectors….
- We have now an accurate simulation framework, from the neutrino interaction+ background, , scintillation process, photons propagation taking into into account Rayleigh scattering, sensor response , frontend electronics.

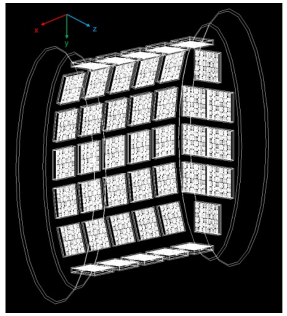
3D Reconstruction with coded aperture masks

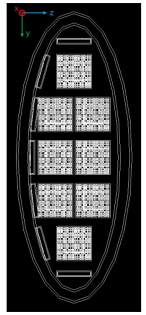


Readout system with on SiPM matrixes coupled with coded aperture masks.

The custom **reconstruction algorithm** produces a **3D map of the deposited energy**:

- measured incident photons are propagated back into the LAr volume with an appropriate weight assigned to voxels.
- This weight represents the Bayesian probability of the voxel to be a source of the detected photons.
- A score in the segmented reconstruction volume is calculated by adding these weights.



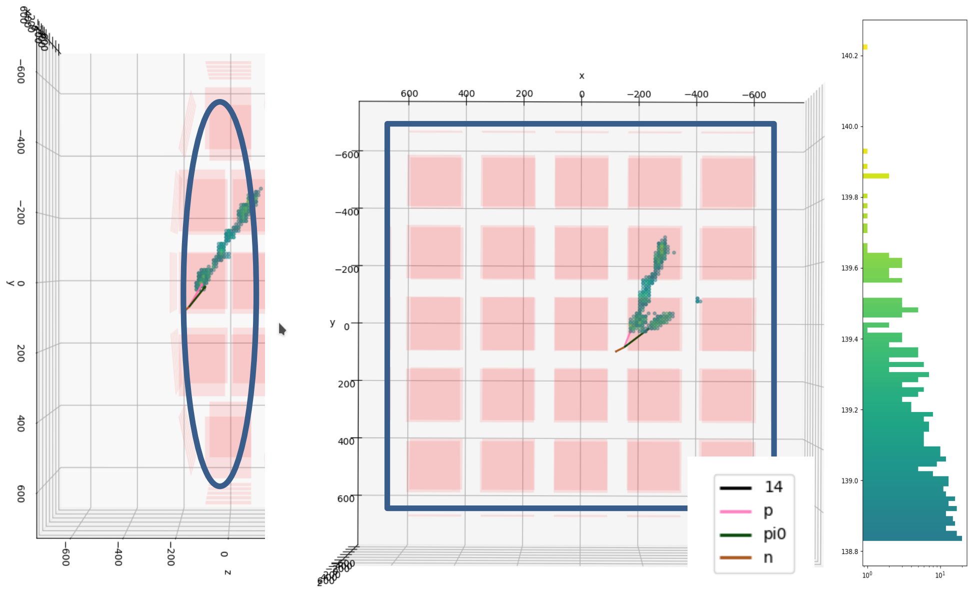


Simulations show that this algorithm is capable of reconstructing neutrino events in GRAIN with ~3 cm of resolution on vertex.

All events are reconstructed performing a **detailed simulation of the detector response** as well, considering:

- SiPM noise, crosstalk, afterpulses, PDE...
- Electronics response (ADC/TDC, time over threshold...)
- photons collected only in a short time window (200 ns) from the neutrino interaction to avoid pile-up effects in a spill

Reconstructed event

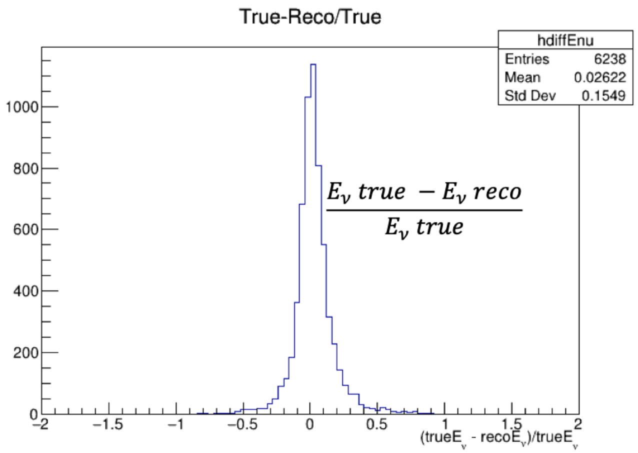


First results on CC interactions

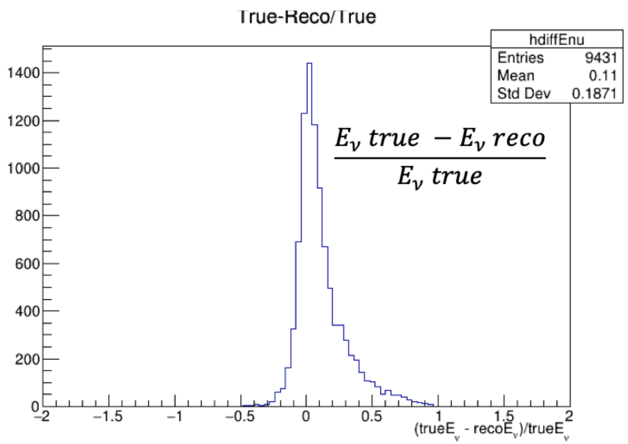
CC neutrino interactions in GRAIN achieved by combining the information of GRAIN supplied with lens based detector and the STT and ECAL signals

Neutrino energy reconstruction for different channels

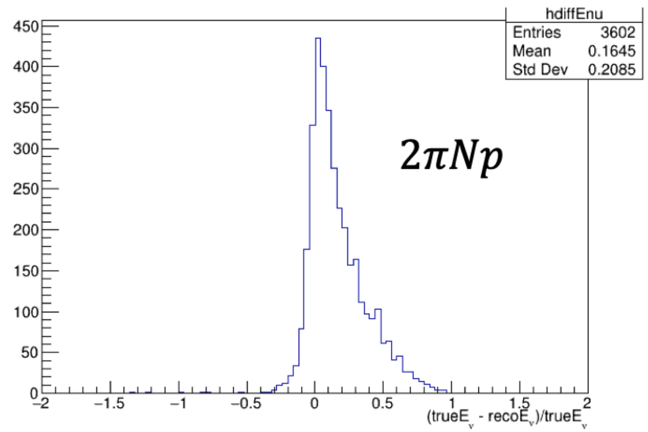
$0\pi Np$



$1\pi Np$



$2\pi Np$



In summary, SAND milestones:

- Design review of Yoke + Magnet + ECAL and of related installation procedures: April 2023

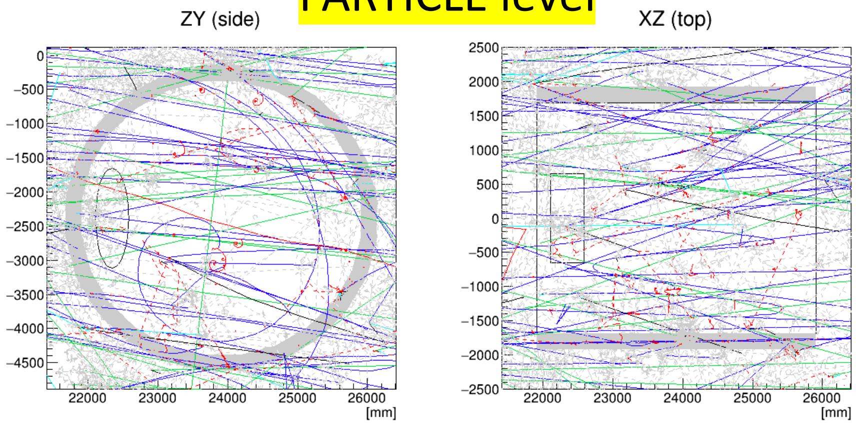
- Preliminary design review of STT: November 2023
  Prototypization up to end of 2024

- Preliminary design review of GRAIN: April 2024

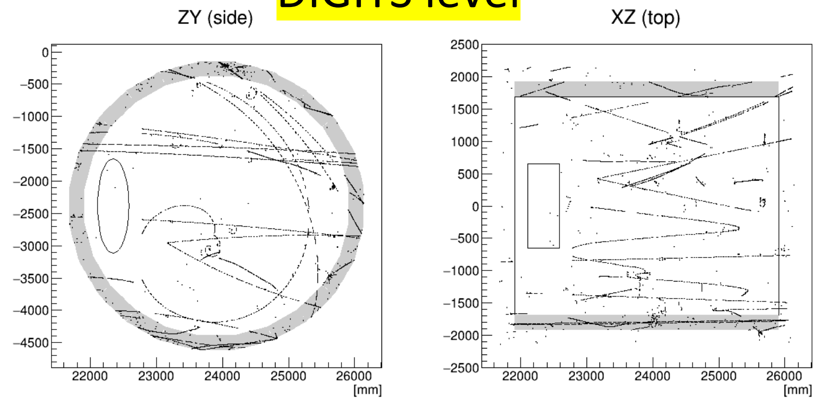
Events in an entire spill

PARTICLE level

(not time-gated)

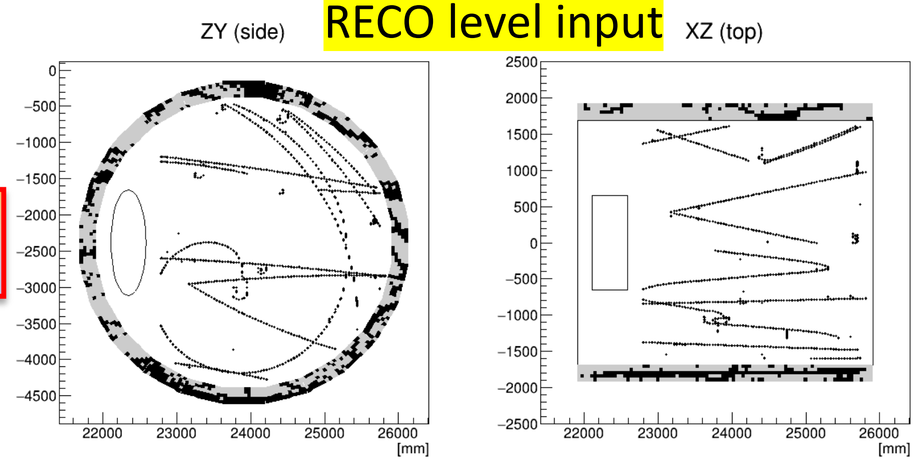


DIGITS level

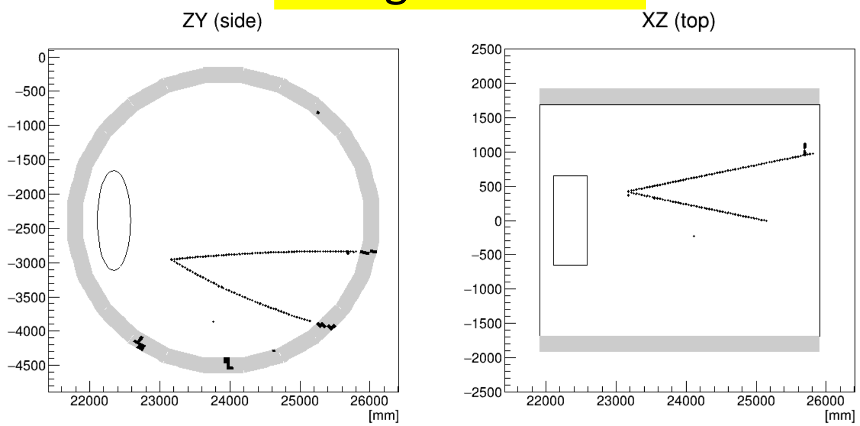


SAND + TMS + NDLAR (no rock-muon)

RECO level input



time-gated 100 ns



Event identified

STT+ECAL performances

Momentum scale uncertainty: Δp < 0.2%

calibration from $K_s^0 \rightarrow \pi^+\pi^-$ in STT volume (340 000 in FHC in 5 years)

Reconstruction efficiency:

- Protons: ~ **65%** for C interactions ~ **94%** for H interactions

  calibration from $\Lambda^0 \rightarrow p\pi^-$ in STT volume (500,000 in FHC in 5 years)

- Neutrons: ~**74%** for C interactions ~ **82%** for H interactions
- π^0 from γ conversions (at least one) (~ **49%**)

  within the STT volume + ECAL clusters

- wrong charge identification: muons **0.8%**, electrons **1.2%** (from circular fit)

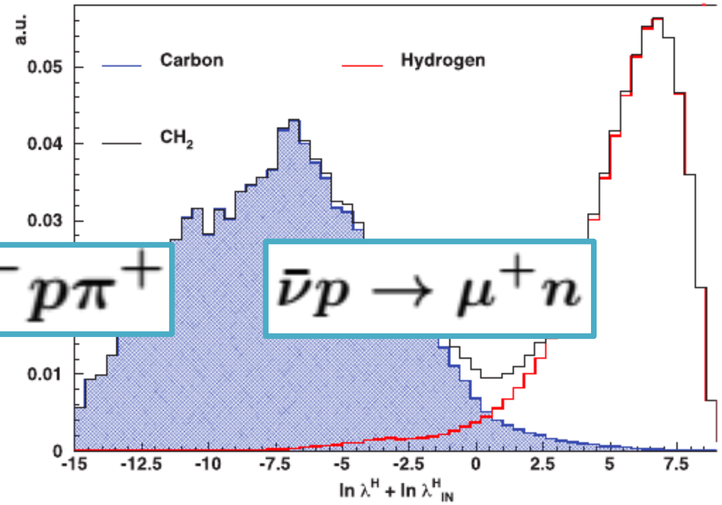
Particle identification:

- p/π/K with dE/dx, range, time-of-flight with ECAL, and ECAL energy depositions
- Electron with Transition Radiation and dE/dx in STT + ECAL energy and topology

SAND potentials

- **Interactions on CH_2 :**
  - for low-nu analysis,
  - for $\nu + e$ on-axis flux measurement $< 2\%$ **← ND-LAr+ TMS**
  - Ratio ν_e / ν_μ and $\overline{\nu_e}$ /$\overline{\nu_\mu}$ vs E
  - Ratio ν_e / ν_μ vs E from coherent π^-/π^+

- **Interactions on H (after selection):**
  - for neutrino flux measurement
  - for cross section measurement on H (model tuning)



$$\nu p \rightarrow \mu^- p \pi^+$$

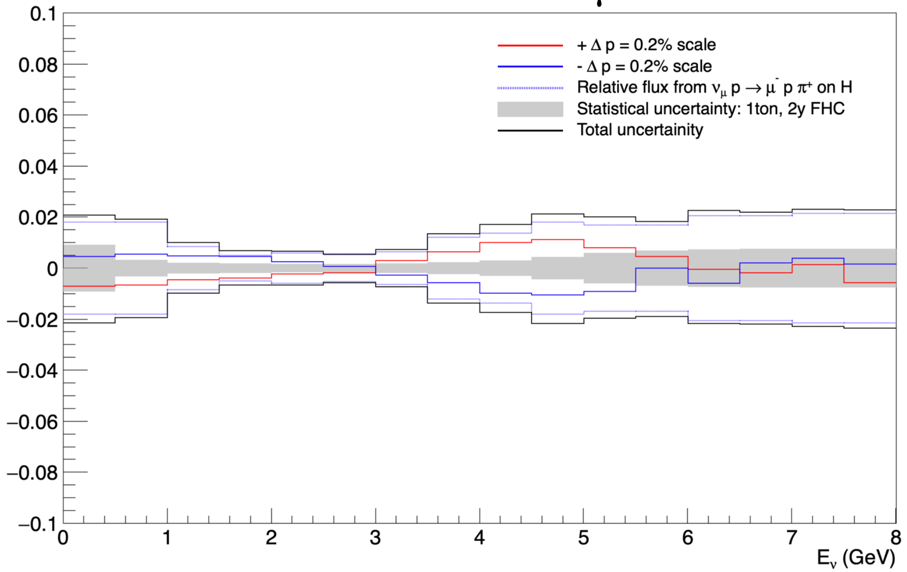
$$\bar{\nu} p \rightarrow \mu^+ n$$

- **Interactions on Ar**
  - for inclusive/exclusive CC sample with a magnetic spectrometer **← ND-LAr+ TMS**
  - for cross-section constraints / tuning nuclear model
  - by a comparison with hydrogen interactions

Example of SAND systematics using GRAIN+STT

|Δp|=0.2%, 1 ton LAr

Relative flux from μ CC on H



With a 2y FHC 1.2 MW exposure uncertainties dominated by systematics even for relatively small Ar target in SAND (~1 ton)

SAND in LBL analysis

People from SAND participated to the kick-off meeting at CERN on August 15^{th}.

Positive and constructive discussions at the workshop regarding SAND

- include SAND into next LBL analysis.
- identified “hydrogen” SAND sample as “priority”
  (use the CH_2/C analysis to constrain directly cross-section parameters and interaction modeling)
- afterwards, wrong sign muon-ID samples

Software integration: steps made towards having CAFs for SAND.

Conclusions

- ✓ The SAND detector is a key element of the ND-complex
- ✓ Disassembly of KLOE in Italy is actively going on
- ✓ Robust R&D program underway for STT**!** and GRAIN
- ✓ Our plan is compatible with the first day of ND-hall allowance to start installation
- ✓ The physics potentials and complementarities are huge **!**
- ✓ The SAND configuration allows for a full integration into DUNE-ND complex and ND hall

BACKUP