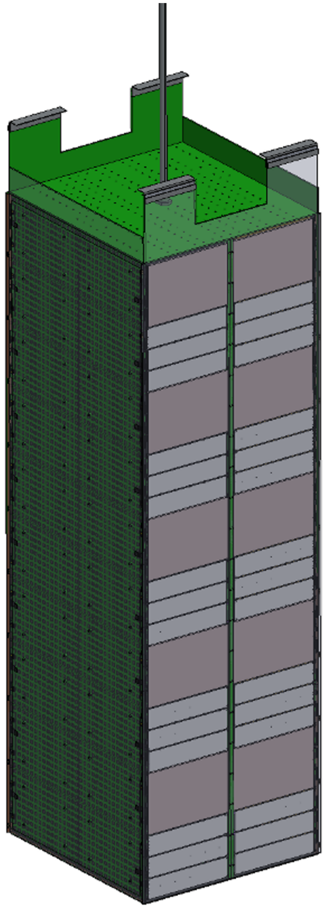
ND-LAr in DUNE Phase II

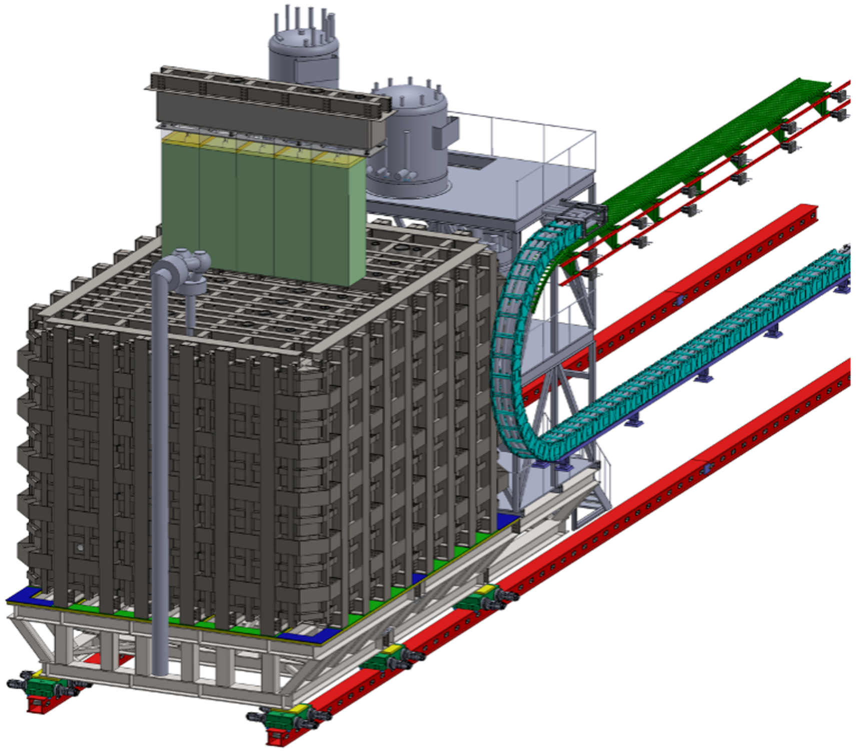
Saba Parsa, University of Bern, *on behalf of ND-LAr Consortium*

DUNE ND Phase II workshop, London, 20-22 June 2023

ND-LAr detector for phase I

- 3m x 7m x 5 m liquid Argon TPC
  - Large event sample with same nucleus and technology as far detector
  - Dimension defined by containment, event topology comparison to FD, not rate
  - Mass allows v-e scattering flux measurement, 8300 events per year, QCD free flux measurement
- Modular design with contained light and pixelated charge readout
  - Suitable for high-rate environment
  - Allows localization of light signals





CDR document

https://doi.org/10.3390/instruments5040031

ND-LAr requirement

ND Requirements		
ND-M1	Classify interactions and measure outgoing particles in a LArTPC with performance comparable to or exceeding the FD	LArTPC
ND-M2	*Measure outgoing particles in ν-Ar interactions with uniform acceptance, lower thresholds than a LArTPC, and with minimal secondary interactions*	
ND-M3	Measure the neutrino flux using neutrino electron scattering	LArTPC
ND-M4	Measure the neutrino flux spectrum using the "low-ν" method	LArTPC
ND-M5	Measure the wrong-sign component	LArTPC
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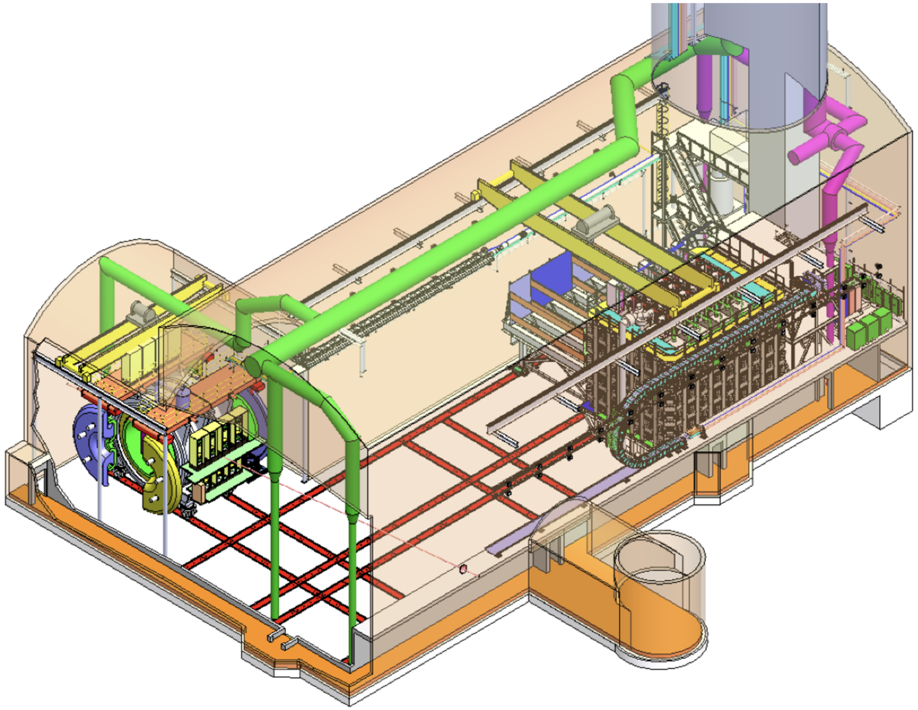
ND-M8	Monitor the rate of neutrino interactions on-axis	SAND
ND-M9	Monitor the beam spectrum and interaction distribution on-axis	SAND
ND-M10	Assess External Backgrounds	All



ND-LAr is capable to cope with phase II beam upgrade

- Phase II environment
  - Increased # of nu interactions and rock muons
- Without adding scope, ND-LAr satisfies the general requirements of DUNE for phase II
  - ND-LAr with current design will be sufficient and well performing with doubling of the beam intensity in phase II
  - Lifetime of detector components

Do Nothing <----> Major modification of the detector

0 cost <---> Prohibitive cost?

Pile up with beam upgrades

Beam nu pileup at ND-LAr:

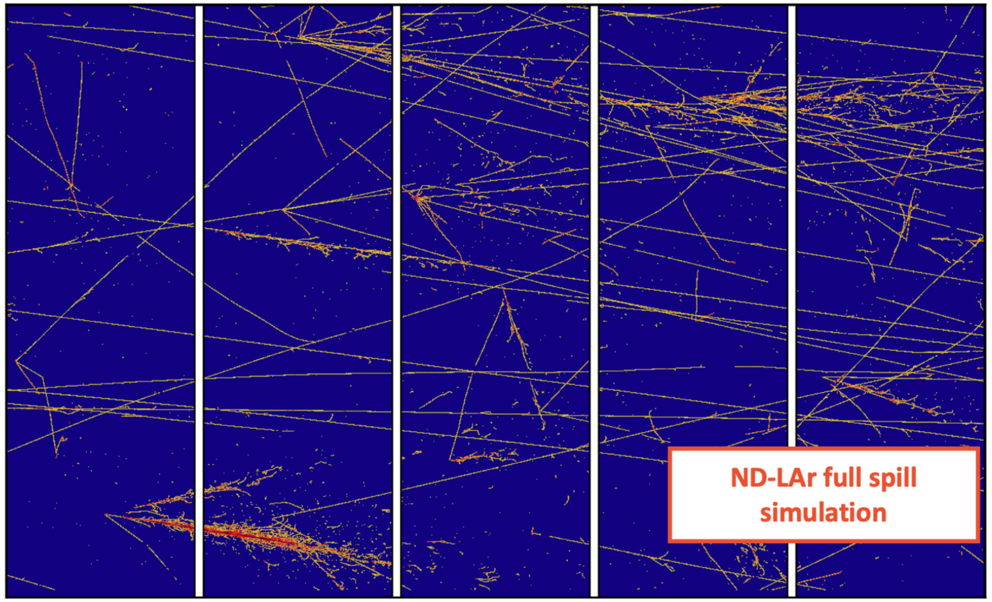
~ 50 ν interactions per spill @ 1.2 MW

~ 100 ν interactions per spill @2.4 MW

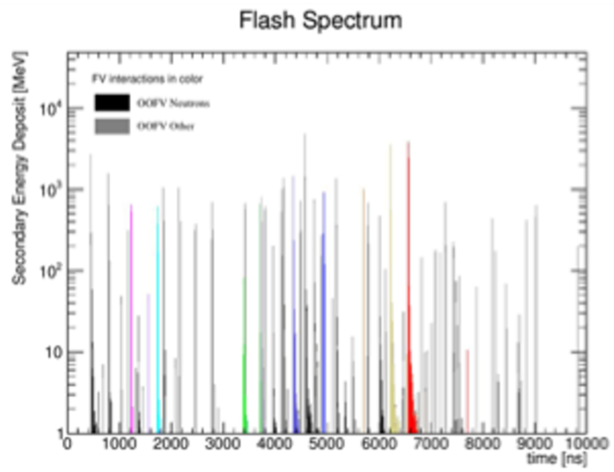
ND-LAr detector design is capable of correct assignment of detached final state particles with high fidelity

Optical segmentation (i.e. modularization) enables assignment light and charge deposits by drastically reducing the combinatorics of:

- Fast O(ns) light signal
- Slow O(ms) charge signal

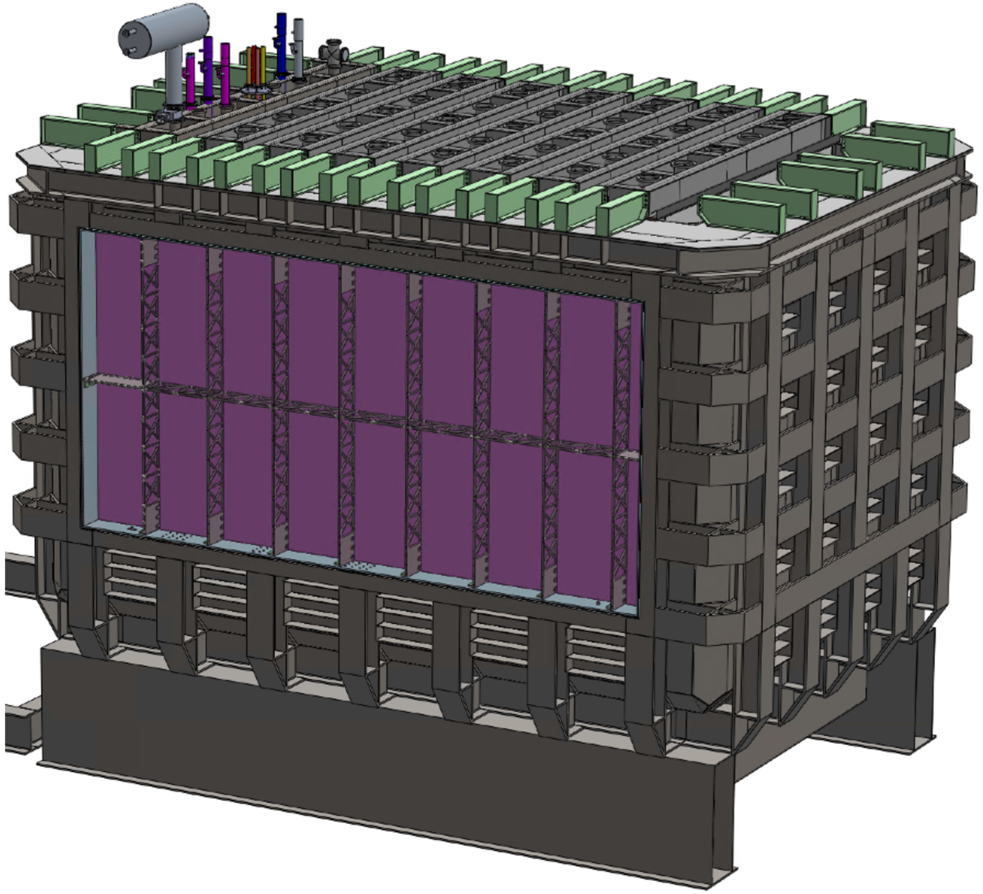


ND-LAr full spill simulation



Upgrade ideas for ND-LAr

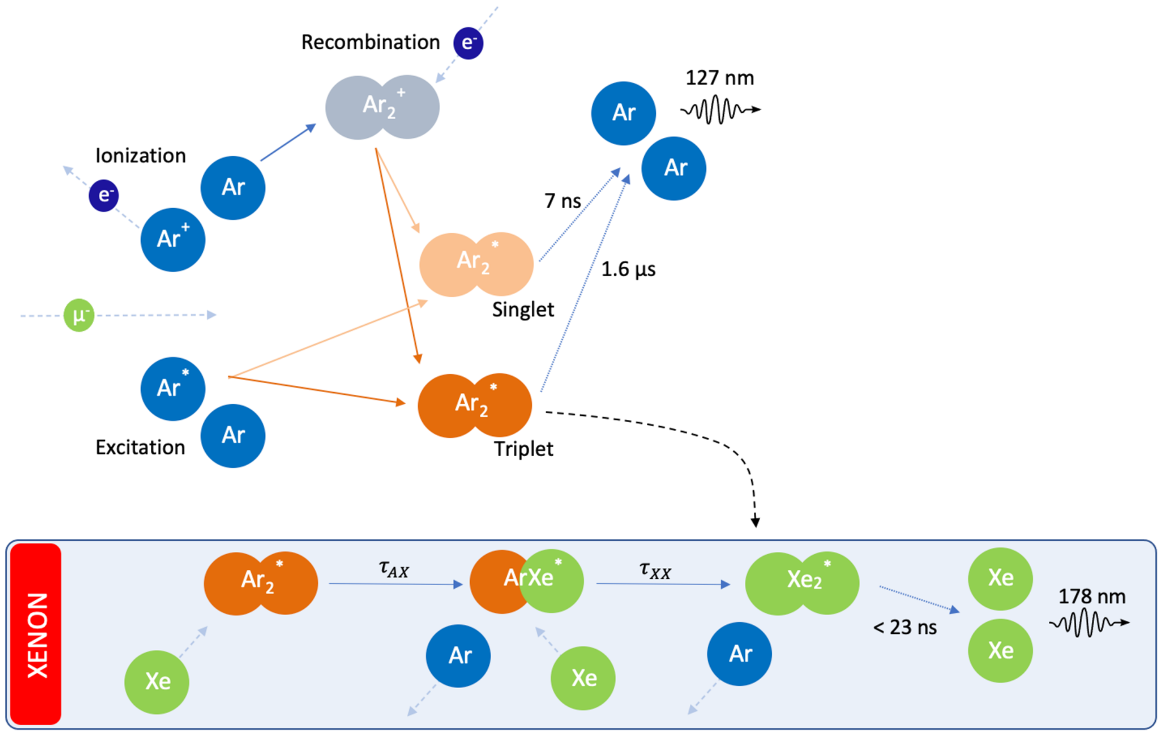
Aim is to suggest additional potential modifications to ND-LAr that might enhance its capabilities



- **Upgrades without touching the inner detector hardware or emptying LAr**
  - Xenon doping
  - Upgrade of the Off-detector electronics
  - Adding a Rock muon tracker in front of ND-LAr
  - Better Calibration with 220-Rn injection
- **Some hardware modifications (empty LAr)**
  - Improve neutron detection methods by upgrading optical detectors (Li-Glass)
  - Replace charge tiles of a module with smaller pixels and lower thresholds
  - Photosensitive dopants
  - Use Radio-Pure Underground Ar
- **Significant Modification**
  - Magnetize ND-LAr
    - All detector volume magnetized with two superconductive coils
      - LTS -> outside the cryostat (up to 1 T)
      - HTS -> inside the cryostat (~ 0.1 T)
    - Magnetized Iron plates in between module rows

Xenon doping of Liquid Ar

- Xenon atoms interact with Ar2* triplet dimers via non radiative collisions, creating ArXe* and then Xe2* dimers
- Scintillation light is partially shifted to 178 nm (instead of the characteristic LAr 127 nm -> higher detection efficiency
- Xe light decay times are of ~4 and 22 ns, i.e., the pulses are shorter and the probability of pile-up is reduced
- Furthermore, Xe interactions are competitive with quenching induced by N2 contamination, therefore the presence of Xe can mitigate light losses due to accidental pollution of LAr



- **Higher quantum efficiency**
- **Faster timing**
- **N2 mitigation**

ProtoDUNE-SP

https://indico.fnal.gov/event/57487/contributions/267464/attachments/167386/223329/DUNE_CMmay2023_zani_1.pdf

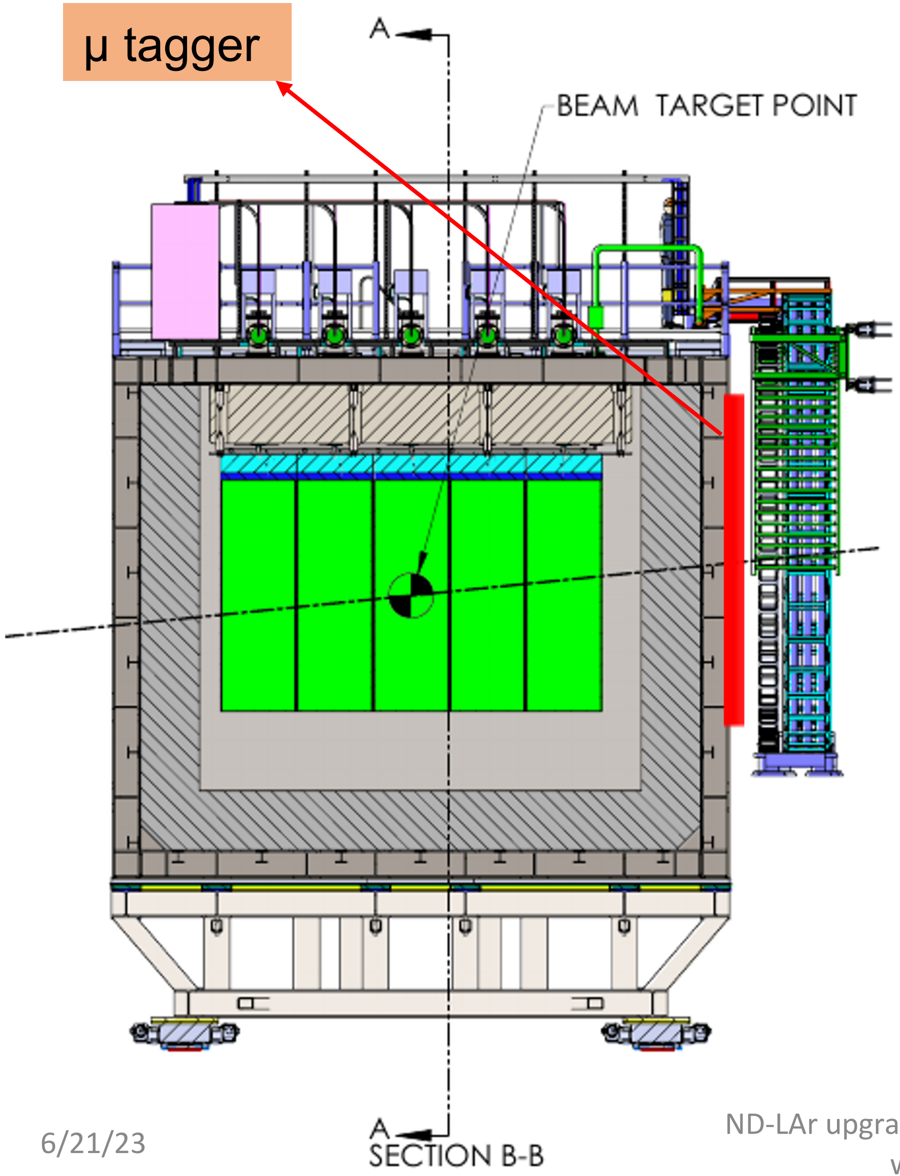
Upgrade of the off-detector electronics

Online event builder and trigger logic for saving data stream

- FPGA based online processing
- Light and Charge matching
- Trigger logic for interesting low energy physics
- Trigger logic on late events

Benefiting from LHC online triggering expertise

Adding a Muon tagger upstream



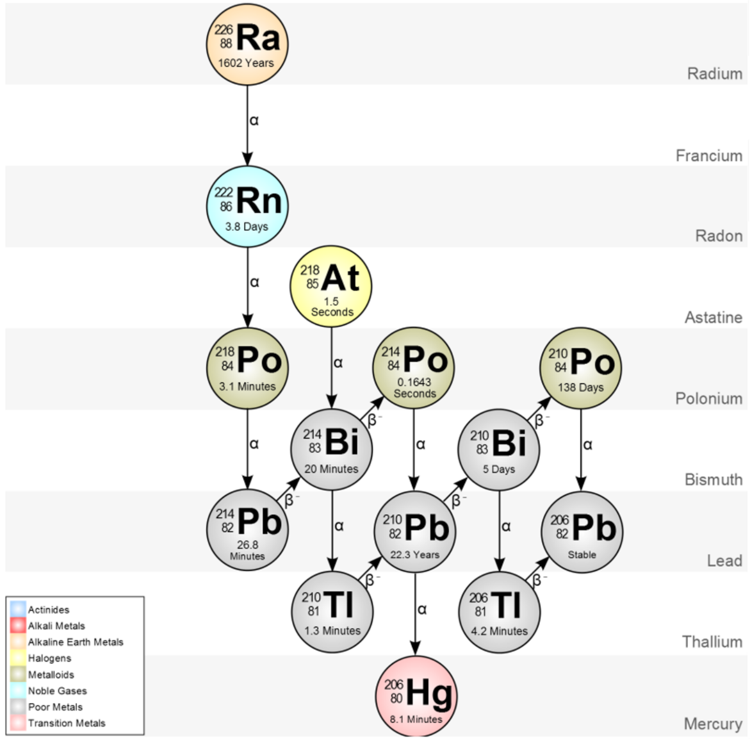
- Two 1cm scintillator planes, with 3.85cm-wide strips in 90° stereo for 3D position
- Cover ~ 9m x 4.5m area on upstream face of ND-LAr
- Use TMS scintillator design, fiber extrusion, readout electronics
- Piggy-back on existing TMS design and prototyping effort to reduce new costs

https://indico.fnal.gov/event/48392/contributions/211337/attachments/141423/178067/chris_NDLArIB_muontagger.pdf

Improve Calibration with 220Rn injection

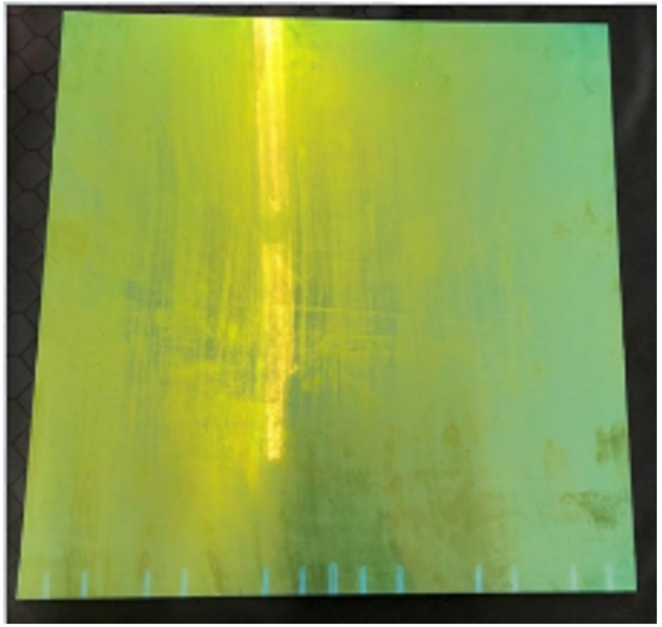
- Fluid Flow mapping
- Electron lifetime calibration

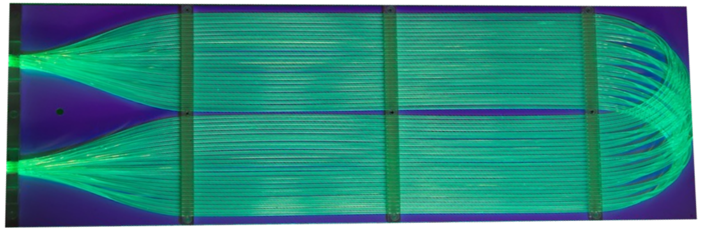
This has been done in XENON100



https://indico.fnal.gov/event/17677/contributions/44390/attachments/27527/34070/DUNE_CalibrationTaskForceMeeting_18_07_31.pdf

Improve neutron capture capabilities





^{6}Li-glass scintillator (GS20) Ce-doped

at O(mm) thickness ~ O(10%) detection efficiency for thermal neutrons

n + ^{6}Li → α + 3H + 4.78 MeV

^{6}Li has a large capture cross-section (940 barn) for thermal neutrons and their capture in ^{6}Li produces energetic particles, with short ranges

GS20 «sand» in polystyrene matrix
(backplane of LCM, back surface of ArCLight)

https://scintacor.com/technologies/neutrons/

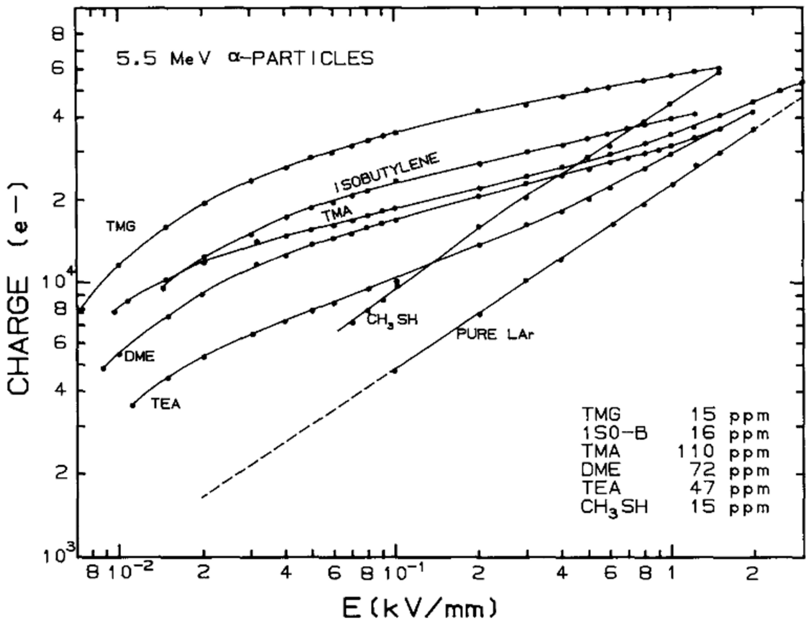
Upgrade LArPix tiles for a Single module with smaller pixels and lower thresholds

- Reducing Pixel pitch from 4mm -> 1mm
- Sensitive to Lower energy protons
- Similar statistics as ND-GAr with only a single module upgraded with new tiles
- Could Improve neutron tagging and Michel electron efficiencies

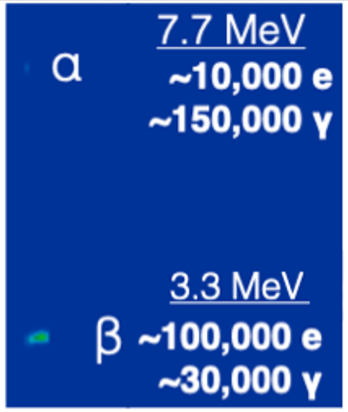
Exact thresholds and effect on physics program to be studied

Photosensitive Dopants

- Dopants that convert light to charge (Photosensitive dopants) might help expand the reach of DUNE phase- II at low energies.
- Improvements to energy resolution at low energies will also impact Phase-II precision measurement era.



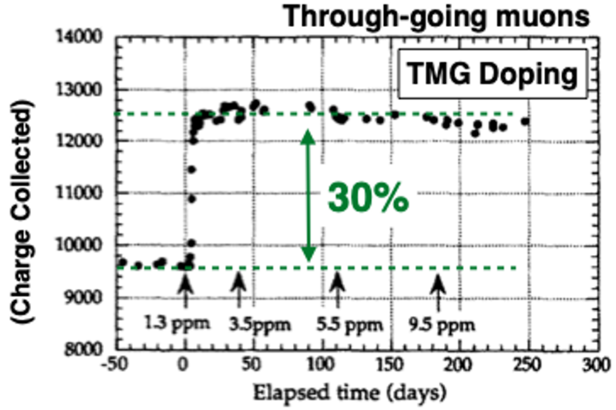
Simulated Event in Pure LAr



Courtesy of Ivan Lepetic

Nucl. Instrum. Methods. Phys. Res. B 355, 660 (1995).

ICARUS Collaboration



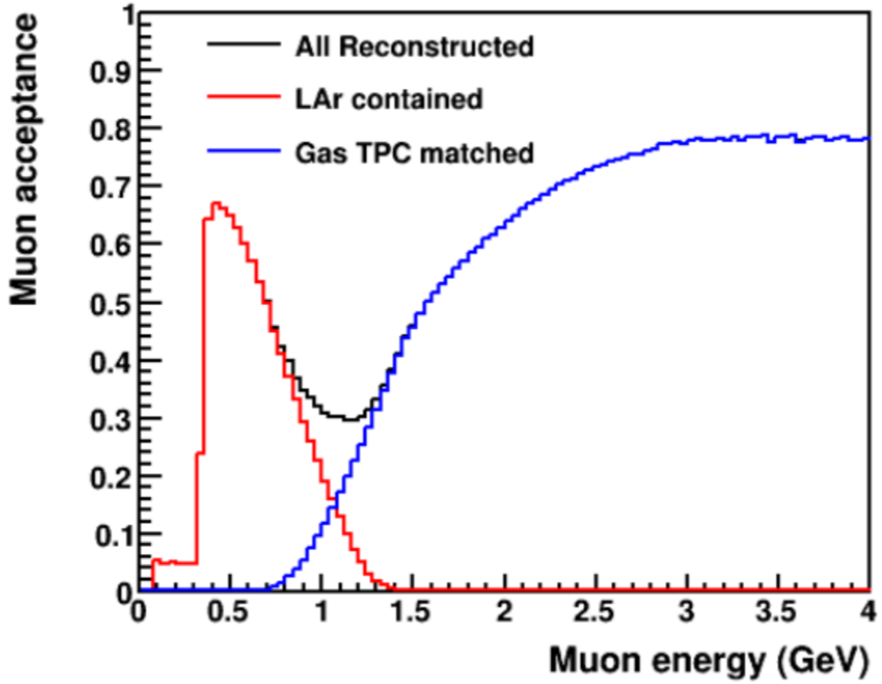
https://indico.fnal.gov/event/22303/contributions/244945/attachments/157602/206252/Psihas_2022_DopingLAr_Snowmass.pdf

Magnetization of ND-LAr

Muons around 1 GeV typically do not go through TMS/GAr
With a B-field we can reconstruct muon momentum in this range.

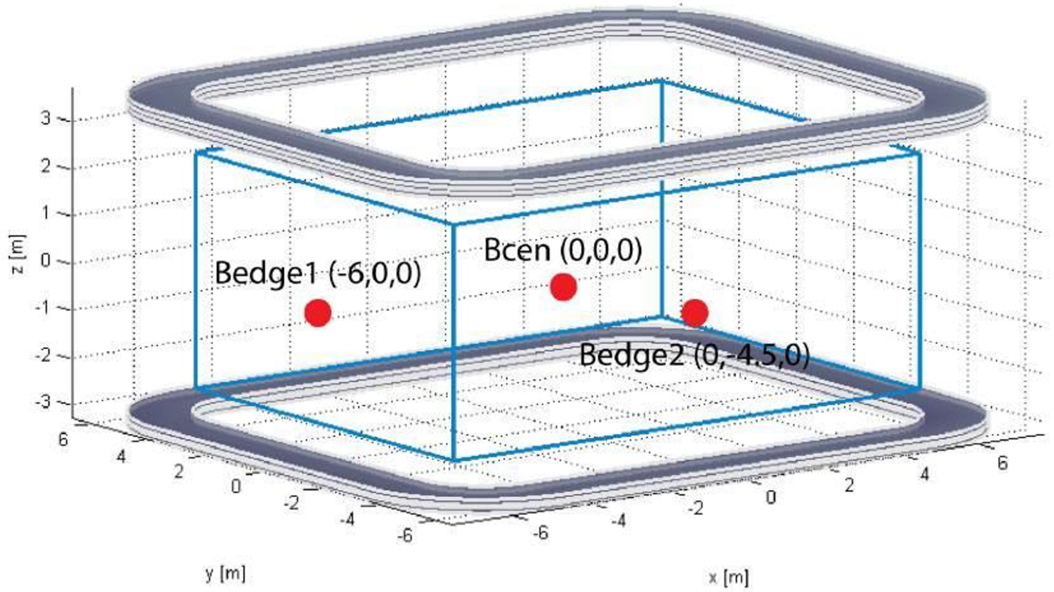
Two possible magnetization schemes:

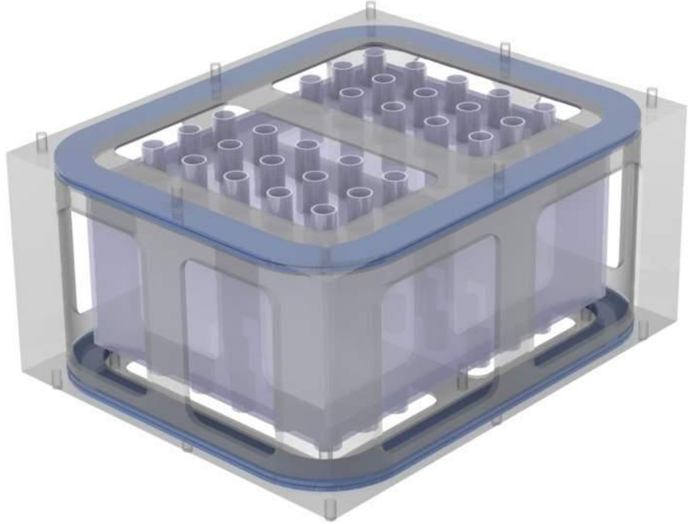
- Large coils around the whole detector. All LAr volume is magnetized → LTS or HTS → Very high cost
- Magnetized Iron plates between the rows → exp: 3 cm thick Iron plates, 18 cm total → Low cost

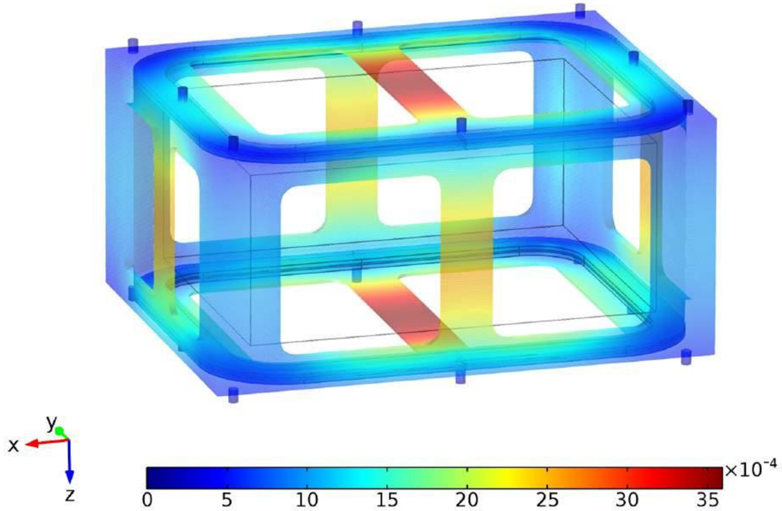


Magnetization Concept with two coils [LTS]

Thesis: L.Y. van Dijk (2014)
Title: **Design Optimization of a new Superconducting Magnet System for a LAr Neutrino Detector**







Magnetization Concept with two coils [HTS?]

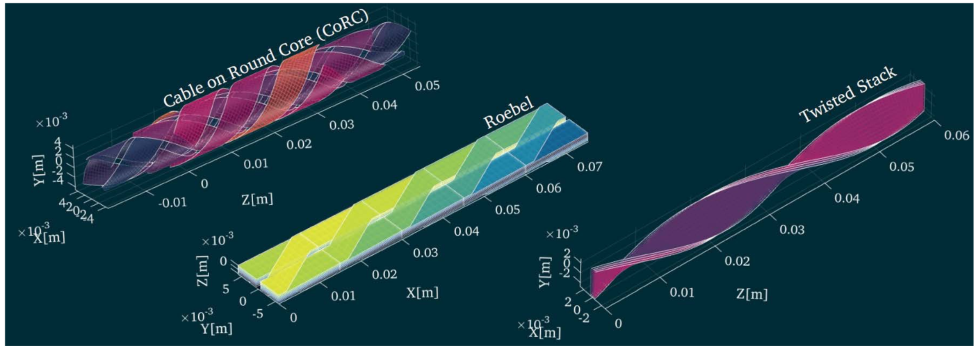
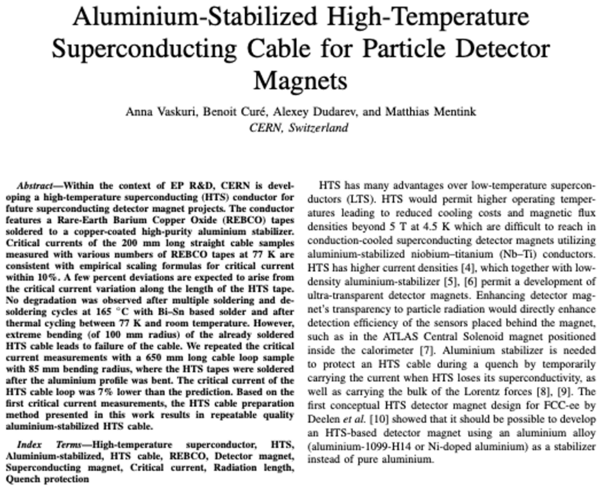


Table 1. Details of SuperOx® REBCO tape.

Characteristics	
Width	4 mm
Total thickness	∼120 µm
Substrate layer	60 µm
Silver layer	∼2 µm
Copper (×2) layer	20 µm
Deposited polyimide	10 µm
Superconducting layer	2 µm
I_c min (77 K, self-field)	120 A



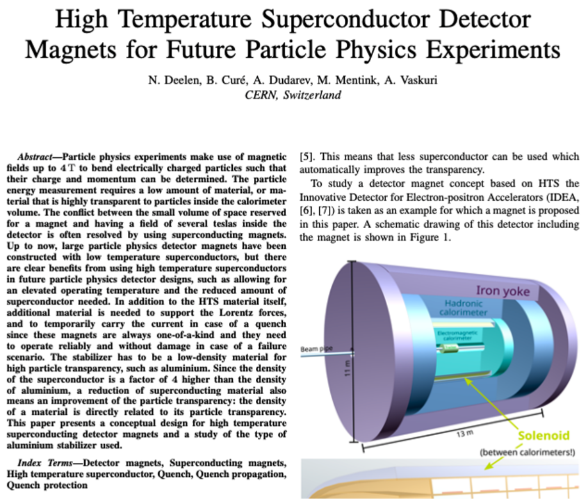
Aluminium-Stabilized High-Temperature Superconducting Cable for Particle Detector Magnets

Anna Vaskuri, Benoit Curé, Alexey Dudarev, and Matthias Mentink
CERN, Switzerland

***Abstract*—Within the context of EP R&D, CERN is developing a high-temperature superconducting (HTS) conductor for future superconducting detector magnet projects. The conductor features a Rare-Earth Barium Copper Oxide (REBCO) tapes soldered to a copper-coated high-purity aluminium stabilizer. Critical currents of the 200 mm long straight cable samples measured with various numbers of REBCO tapes at 77 K are consistent with empirical scaling formulas for critical current within 10%. A few percent deviations are expected to arise from the critical current variation along the length of the HTS tape. No degradation was observed after multiple soldering and de-soldering cycles at 165 °C with Bi–Sn based solder and after thermal cycling between 77 K and room temperature. However, extreme bending (of 100 mm radius) of the already soldered HTS cable leads to failure of the cable. We repeated the critical current measurements with a 650 mm long cable loop sample with 85 mm bending radius, where the HTS tapes were soldered after the aluminium profile was bent. The critical current of the HTS cable loop was 7% lower than the prediction. Based on the first critical current measurements, the HTS cable preparation method presented in this work results in repeatable quality aluminium-stabilized HTS cable.**

***Index Terms*—High-temperature superconductor, HTS, Aluminium-stabilized, HTS cable, REBCO, Detector magnet, Superconducting magnet, Critical current, Radiation length, Quench protection**

HTS has many advantages over low-temperature superconductors (LTS). HTS would permit higher operating temperatures leading to reduced cooling costs and magnetic flux densities beyond 5 T at 4.5 K which are difficult to reach in conduction-cooled superconducting detector magnets utilizing aluminium-stabilized niobium–titanium (Nb–Ti) conductors. HTS has higher current densities [4], which together with low-density aluminium-stabilizer [5], [6] permit a development of ultra-transparent detector magnets. Enhancing detector magnet's transparency to particle radiation would directly enhance detection efficiency of the sensors placed behind the magnet, such as in the ATLAS Central Solenoid magnet positioned inside the calorimeter [7]. Aluminium stabilizer is needed to protect an HTS cable during a quench by temporarily carrying the current when HTS loses its superconductivity, as well as carrying the bulk of the Lorentz forces [8], [9]. The first conceptual HTS detector magnet design for FCC-ee by Deelen *et al.* [10] showed that it should be possible to develop an HTS-based detector magnet using an aluminium alloy (aluminium-1099-H14 or Ni-doped aluminium) as a stabilizer instead of pure aluminium.



High Temperature Superconductor Detector Magnets for Future Particle Physics Experiments

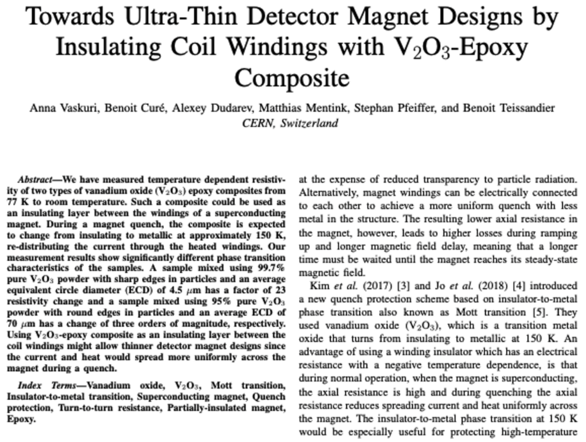
N. Deelen, B. Curé, A. Dudarev, M. Mentink, A. Vaskuri
CERN, Switzerland

***Abstract*—Particle physics experiments make use of magnetic fields up to 4 T to bend electrically charged particles such that their charge and momentum can be determined. The particle energy measurement requires a low amount of material, or material that is highly transparent to particles inside the calorimeter volume. The conflict between the small volume of space reserved for a magnet and having a field of several teslas inside the detector is often resolved by using superconducting magnets. Up to now, large particle physics detector magnets have been constructed with low temperature superconductors, but there are clear benefits from using high temperature superconductors in future particle physics detector designs, such as allowing for an elevated operating temperature and the reduced amount of superconductor needed. In addition to the HTS material itself, additional material is needed to support the Lorentz forces, and to temporarily carry the current in case of a quench since these magnets are always one-of-a-kind and they need to operate reliably and without damage in case of a failure scenario. The stabilizer has to be a low-density material for high particle transparency, such as aluminium. Since the density of the superconductor is a factor of 4 higher than the density of aluminium, a reduction of superconducting material also means an improvement of the particle transparency: the density of a material is directly related to its particle transparency. This paper presents a conceptual design for high temperature superconducting detector magnets and a study of the type of aluminium stabilizer used.**

***Index Terms*—Detector magnets, Superconducting magnets, High temperature superconductor, Quench, Quench propagation, Quench protection**

[5]. This means that less superconductor can be used which automatically improves the transparency.

To study a detector magnet concept based on HTS the Innovative Detector for Electron-positron Accelerators (IDEA, [6], [7]) is taken as an example for which a magnet is proposed in this paper. A schematic drawing of this detector including the magnet is shown in Figure 1.



Towards Ultra-Thin Detector Magnet Designs by Insulating Coil Windings with V_2O_3-Epoxy Composite

Anna Vaskuri, Benoit Curé, Alexey Dudarev, Matthias Mentink, Stephan Pfeiffer, and Benoit Teissandier
CERN, Switzerland

***Abstract*—We have measured temperature dependent resistivity of two types of vanadium oxide (V_2O_3) epoxy composites from 77 K to room temperature. Such a composite could be used as an insulating layer between the windings of a superconducting magnet. During a magnet quench, the composite is expected to change from insulating to metallic at approximately 150 K, re-distributing the current through the heated windings. Our measurement results show significantly different phase transition characteristics of the samples. A sample mixed using 99.7% pure V_2O_3 powder with sharp edges in particles and an average equivalent circle diameter (ECD) of 4.5 µm has a factor of 23 resistivity change and a sample mixed using 95% pure V_2O_3 powder with round edges in particles and an average ECD of 70 µm has a change of three orders of magnitude, respectively. Using V_2O_3-epoxy composite as an insulating layer between the coil windings might allow thinner detector magnet designs since the current and heat would spread more uniformly across the magnet during a quench.**

***Index Terms*—Vanadium oxide, V_2O_3, Mott transition, Insulator-to-metal transition, Superconducting magnet, Quench protection, Turn-to-turn resistance, Partially-insulated magnet, Epoxy.**

at the expense of reduced transparency to particle radiation. Alternatively, magnet windings can be electrically connected to each other to achieve a more uniform quench with less metal in the structure. The resulting lower axial resistance in the magnet, however, leads to higher losses during ramping up and longer magnetic field delay, meaning that a longer time must be waited until the magnet reaches its steady-state magnetic field.

Kim *et al.* (2017) [3] and Jo *et al.* (2018) [4] introduced a new quench protection scheme based on insulator-to-metal phase transition also known as Mott transition [5]. They used vanadium oxide (V_2O_3), which is a transition metal oxide that turns from insulating to metallic at 150 K. An advantage of using a winding insulator which has an electrical resistance with a negative temperature dependence, is that during normal operation, when the magnet is superconducting, the axial resistance is high and during quenching the axial resistance reduces spreading current and heat uniformly across the magnet. The insulator-to-metal phase transition at 150 K would be especially useful for protecting high-temperature

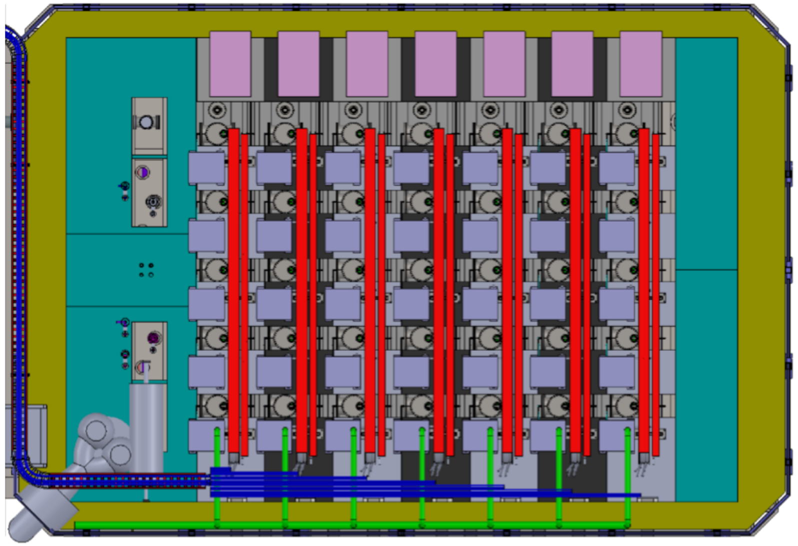
Thomas Thesis: @ 77K -> I_c = 149 A
@ 87K -> I_c = 97 A

B field in center: 0.2 T -> I = 45000

Thesis: Thomas Strauss (2006)
Title: **Test of a high temperature superconductor coil in liquid nitrogen and liquid argon**
https://s3.cern.ch/inspire-prod-files-4/4247cc9731c0b6b2b27ea8de749e79ac

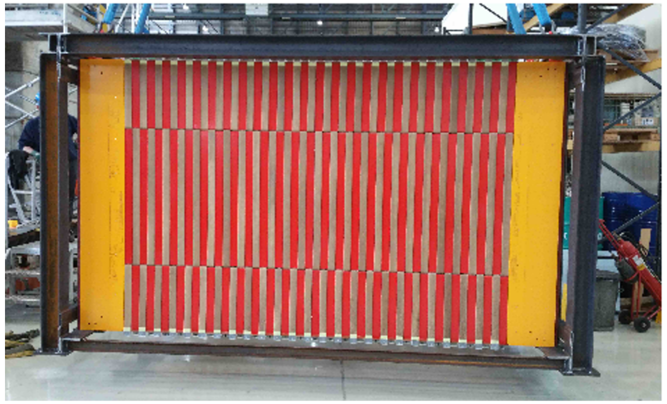
Magnetized Iron plates between ND rows

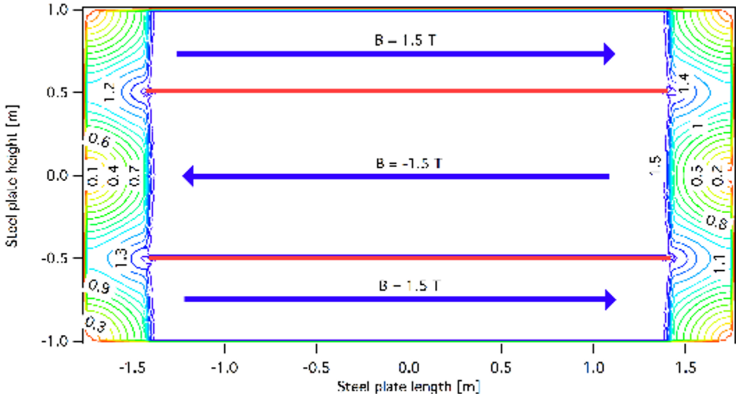
- Coils winded around individual Iron plates -> HTS would be possible
- Magnetic kick to the tracks at each row crossing. LAr Volume is not magnetized

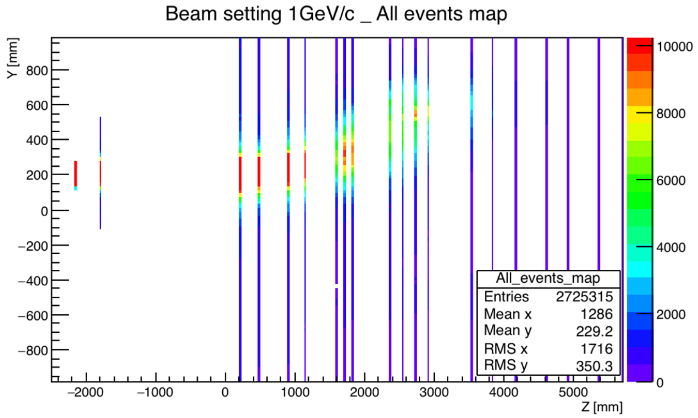


Example: 3 cm Iron in each plate, 6 magnetized plates → 18 cm total Fe

- Muon momentum reconstruction for ~ 1 GeV
- 10 % more neutrino vertices in Iron
- 10% E-loss for stopping pions, etc in Iron







Example: 1.5 T with normal conducting coil [140 A]– Baby MIND magnet modules

Summary

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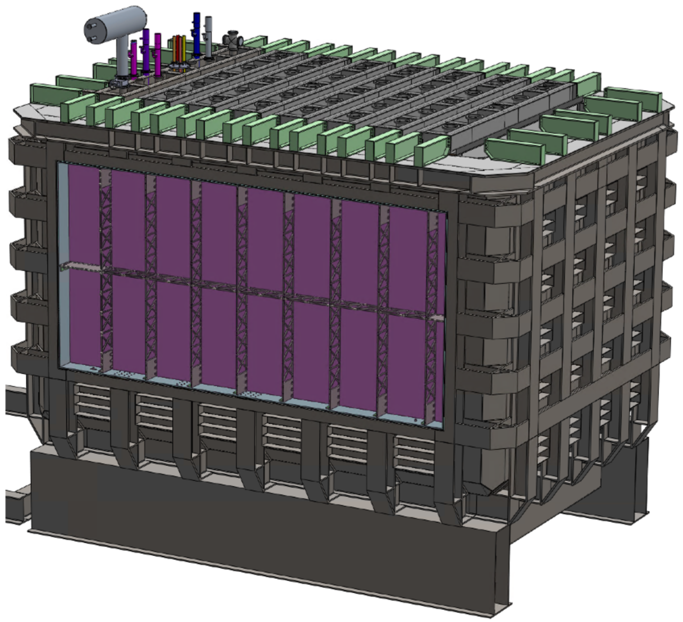

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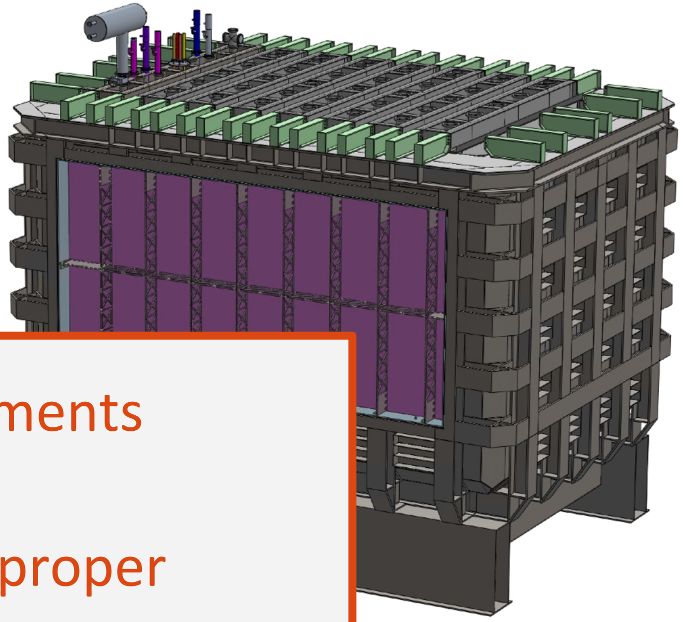
- This is a non exhaustive list of potential improvements
- ND-LAr has some will to be involved
- Refining the requirements for phase II will allow proper performance studies and cost-benefit consideration



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