Elementary target experiments and DUNE

Alan Bross

INT Workshop INT-18-2a, *From nucleons to nuclei: enabling discovery for neutrinos, dark matter*

28 June, 2018

Introduction

- The theoretical challenges to understanding ν nucleus interactions are daunting (as you have been discussing).
  - Limited progress has been made over the last decade (ν)
  - Although Nuclear Physics has witnessed tremendous progress in the theoretical and computational tools that produce our understanding of light nuclei and their interactions with electroweak probes (e γ)
- The DUNE science program will likely have to address this issue at some point, if not initially

Introduction II

- However, currently there is not a consensus within the DUNE collaboration as to the usefulness of taking data on targets other than Ar for the core DUNE oscillation physics program
- On one side:
  - Powerful Ar near detector: Pixelated LAr + HP gas Ar TPCs (Integrated Ar detector)
    - >50M ν_μCC evts/yr. in the liquid
    - Flux normalization from ν + electron elastic scattering in the liquid
    - Very-high resolution sample (1.6M ν_μCC evts/yr.) in HPgTPC
      - Utilizing the TPC + powerful ECAL (electromagnetic + neutrons)
  - Extrapolations from ν+p to Ar problematic at best
    - Currently. The subject of this meeting
- On the other side:
  - Data on Ar alone not sufficient ➛ multiple targets needed
  - Data on protons (composite of H & C) essential

Assuming data on Ar alone is not sufficient

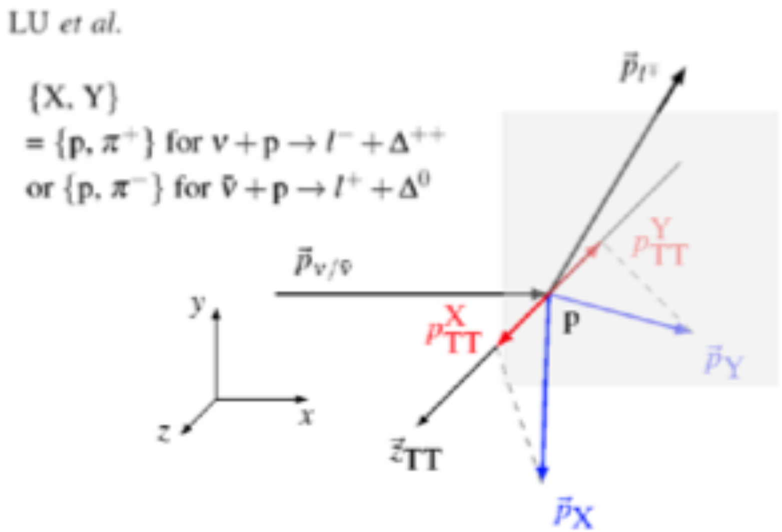
- Can the necessary high-quality data come from ν interactions on composites?
  - C_3H_6
  - CH
  - CH_4 & CD_4
- If Yes, then that is certainly the way to go. This has been discussed in detail within the DUNE near detector WG.
  - STT (~ 1t H)
  - 3DST (≥ 1t H)
  - CH_4 and CD_4 in Ar (HPgTPC) (.2t with almost 100 % CH_4)

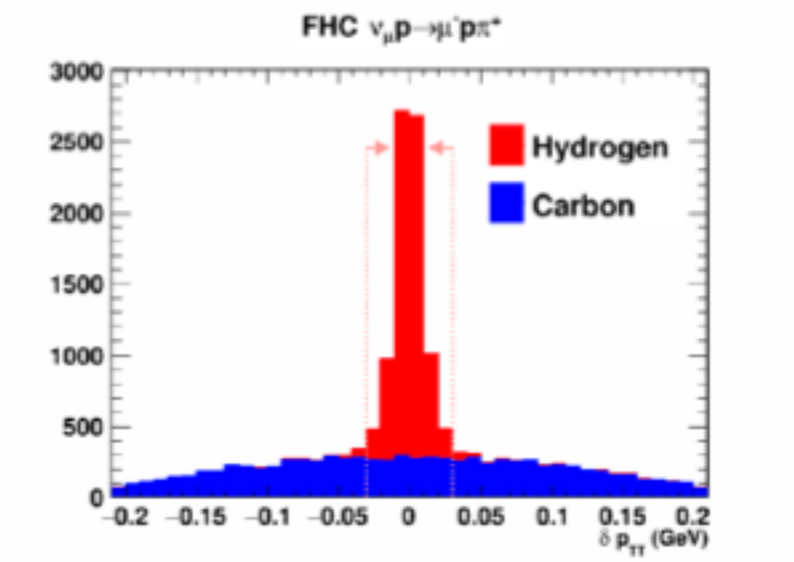
Note: ~ 1.5M ν_μCC evts/t-yr. on H

Fermilab

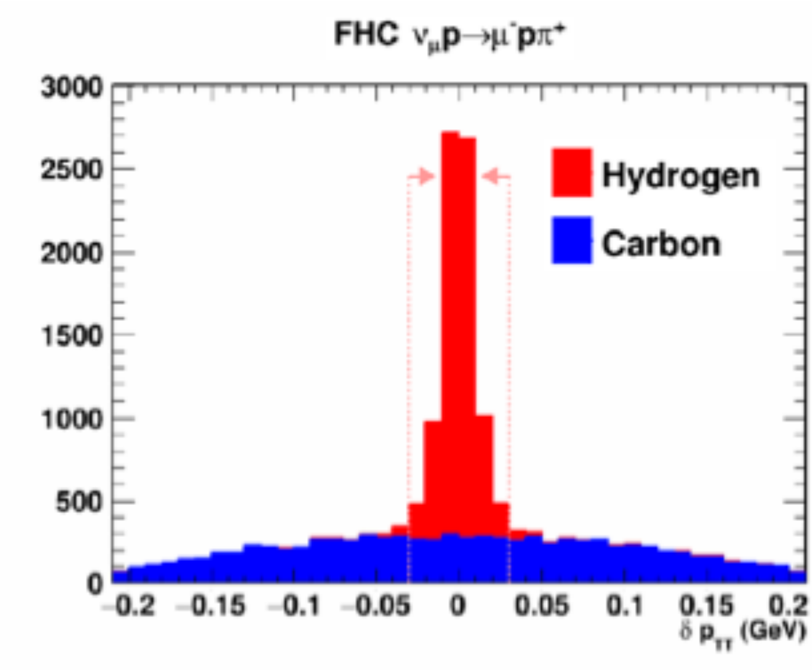
How does one go from data on composites to data on protons? Double transverse variable (δp_{TT}) analysis

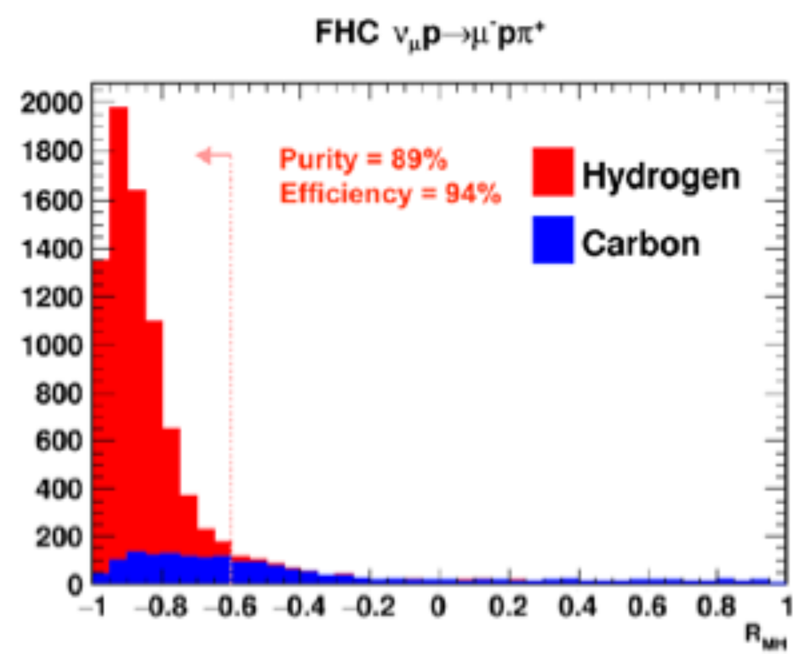
- $\nu_\mu p \longrightarrow \mu^- p \pi^+$ analysis in straw-tube tracker (STT) (from University of South Carolina group)





Event selection - $\nu_\mu p \longrightarrow \mu^- p \pi^+$



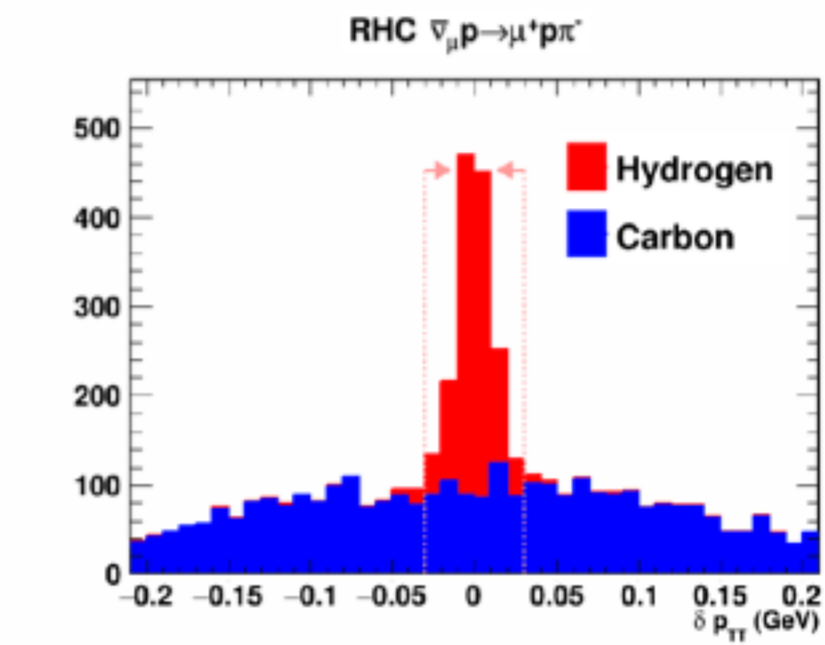


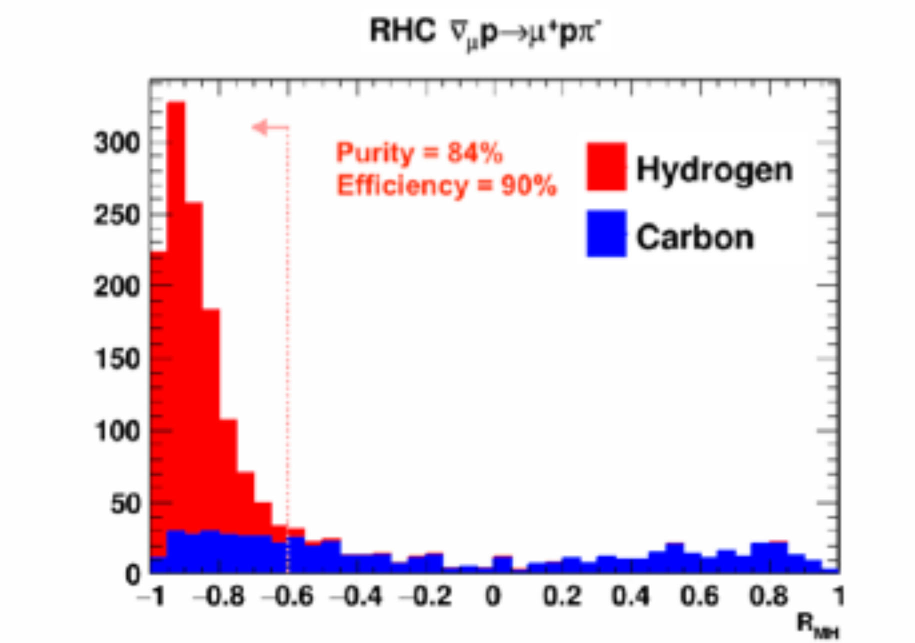
$$Where: R_{MH} = \frac{p_T{}^M - p_T{}^H}{p_T{}^M + p_T{}^H}$$

$p_T{}^M$ is the total missing p_T and $p_T{}^H$ is the hadron p_T

And for anti-neutrinos

$$\bar{\nu}_\mu p \to \mu^+ p \pi^-$$





Detailed analyses with all detector effects still need to be done.
And obtaining information beyond the total rate seems difficult.

Nucleonic targets: H and D

- If there is strong motivation to obtain data on H and D
  - Life gets harder
- *Let's assume that obtaining data on H/D is crucial*

What's the problem? Not to worry?

- **No, worry - It's the beam stupid**
  - It is underground
- That means (in the US) we have to abide by the NFPA 520 Standard on Subterranean Spaces
  - Similar restrictions exist in Europe and Japan

- And here is the problem:

You can only have ~ 60L

Table 4.1.3.1(b) Maximum Quantity of High-Hazard Material in Use[a] in Closed Systems per Control Area[b]

Material	Class	Solid		Liquid		Gas	
		lb	kg	gal	L	ft^3	m^3
Combustible liquid[c,d]	II			120	454		
	III-A			330	1,249		
	III-B			13,200[f]	49,963		
Combustible fiber							
Loose		100 ft^3	2.8 m^3				
Baled		1,000 ft^3	28 m^3				
Explosives		0.25	0.114	0.25 lb	0.114 kg		
Flammable solid							
Flammable gas							
Gaseous						750[d,e]	21.2
Liquefied				15[d,e]	56.7		
Flammable liquid[c,d]	I-A			30	113.5		
	I-B			60	227		
	I-C			90	340.7		
Combination							
I-A, I-B, I-C				120	454		

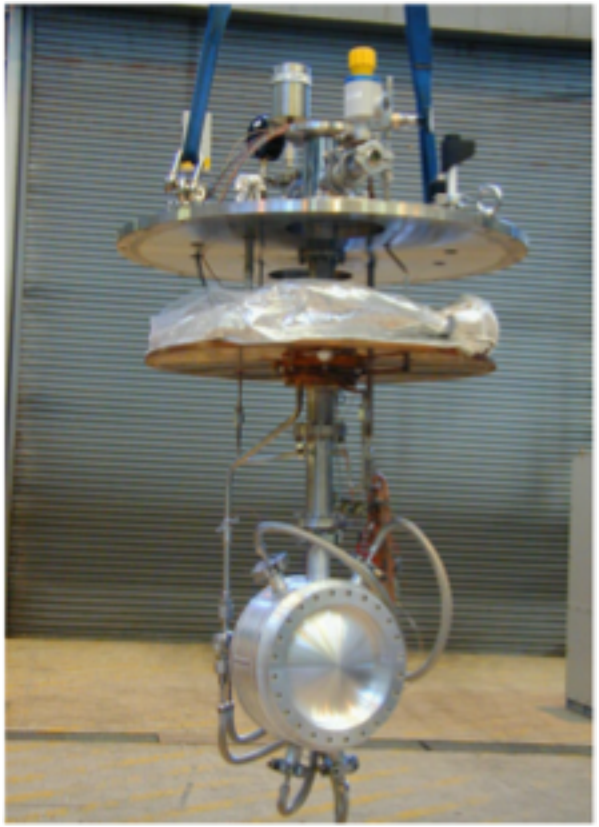
However, with sprinklers and fire wall get X4: 240L = 17kg (71g/L)
With fiducial volume cuts -> <10kg of target mass?
~ 16k ν_μCC evts/yr.

Options

- I met with a Fermilab engineer recently to discuss possibilities
  - No difference w/r to operational restrictions gas vs. liquid
  - Not concerned with having electronics in hydrogen volume
  - Believes a valid technical case can be made that safe operation underground with quantities >> than the NFPA 520 limits is possible. Ask for exception
  - This was done for Minerva (2250L)
    - Not approved to move forward with external safety analysis
  - The difficulty will be getting the Fire safety professionals at the lab to consider exceptions to NFPA 520.
  - ....
- Another subtlety:
  - Must assure that the “Hydrogen Area” is limited to just a region surrounding the detector!

Comments on "Hydrogen Area": My experience I

- LH_2 absorber R&D for NF & MC within the MuCool program in the MTA (MuCool Test Area)
  - ~32L of LH_2 in Al body with thin Al windows
  - Dedicated cryostat

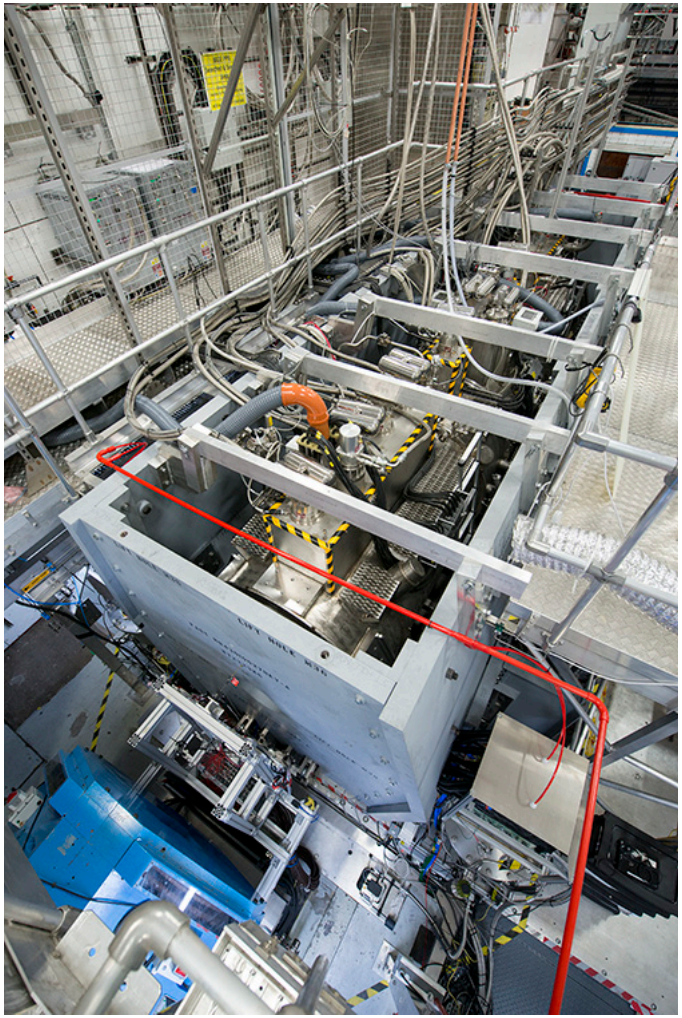


Entire MTA
Was H_2 area
➢
If absorber filled!!

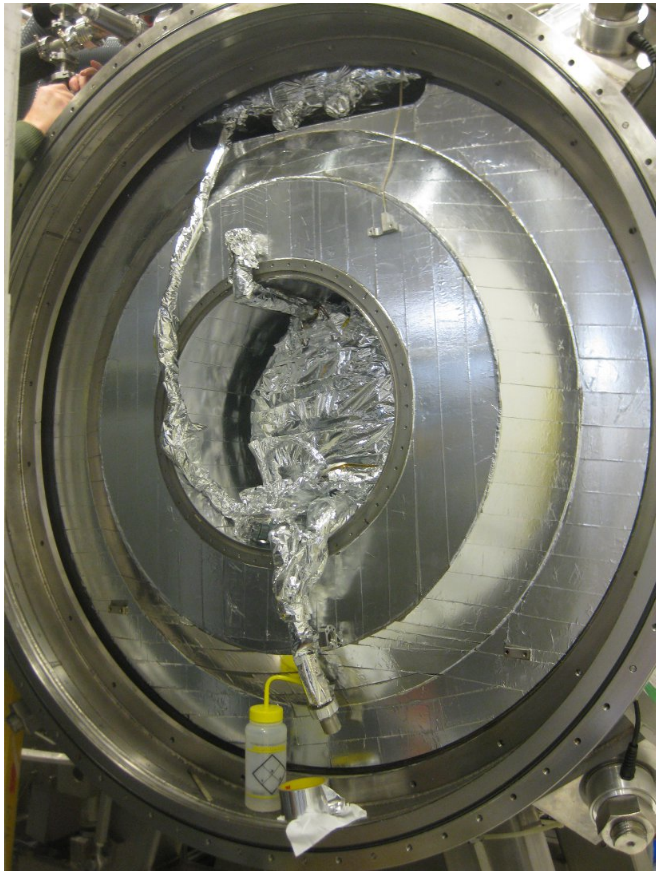
Fermilab

My experience II: MICE

MICE cooling channel



Same absorber in MICE magnet



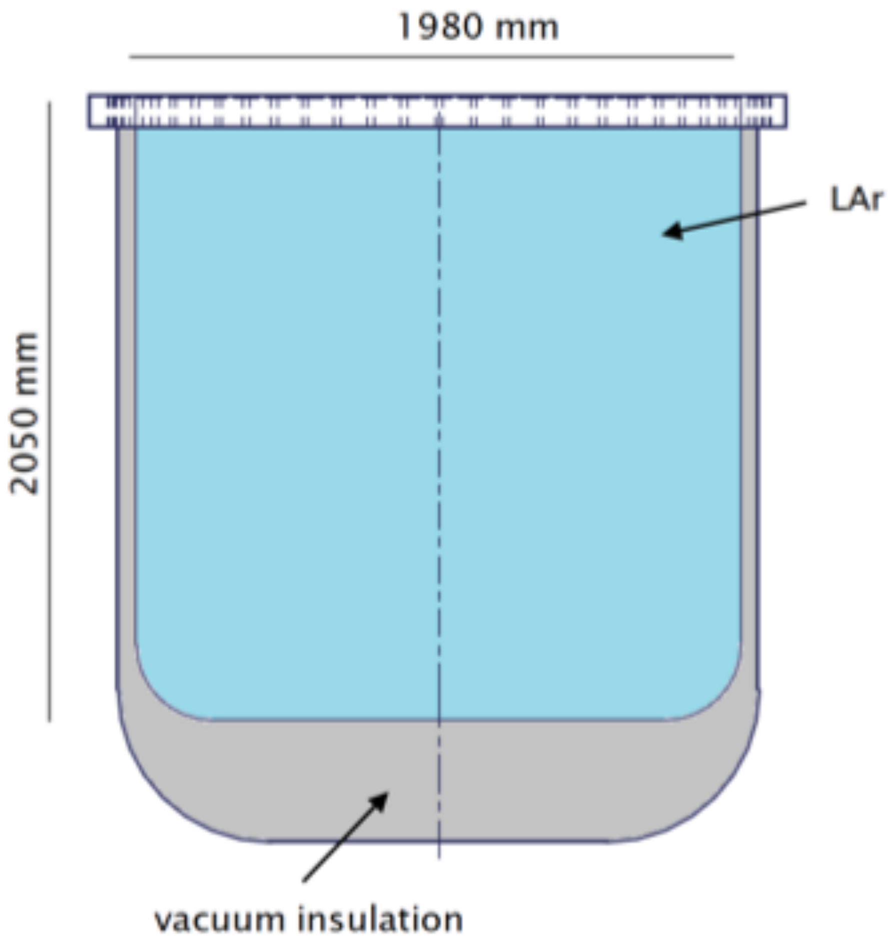
The MICE Hall was not deemed a H_2 area when the absorber was full

Fermilab

So let's assume we can get past NFPA 520

- There is a rather large body of data on Hydrogen gas TPCs
  - Numerous applications in nuclear physics
- Also, has been done at Fermilab:
- In the 1980's a 15 bar H_2 TPC was built for diffraction dissociation of photons on hydrogen, $\gamma p \rightarrow Xp$
  - Active target + tracking
  - 1.5kg of H_2
  - Note: If we fill the HPgTPC with 10 bar of H_2, we will have ~ 45kg fiducial target mass. 90kg total
    - **~68k ν_μCC events/yr.**
- So using the HPgTPC with H_2 fill is an option, but since the volume is so large, inerting or purging the volume would be complicated.
- A denser detector is an advantage in this regard.

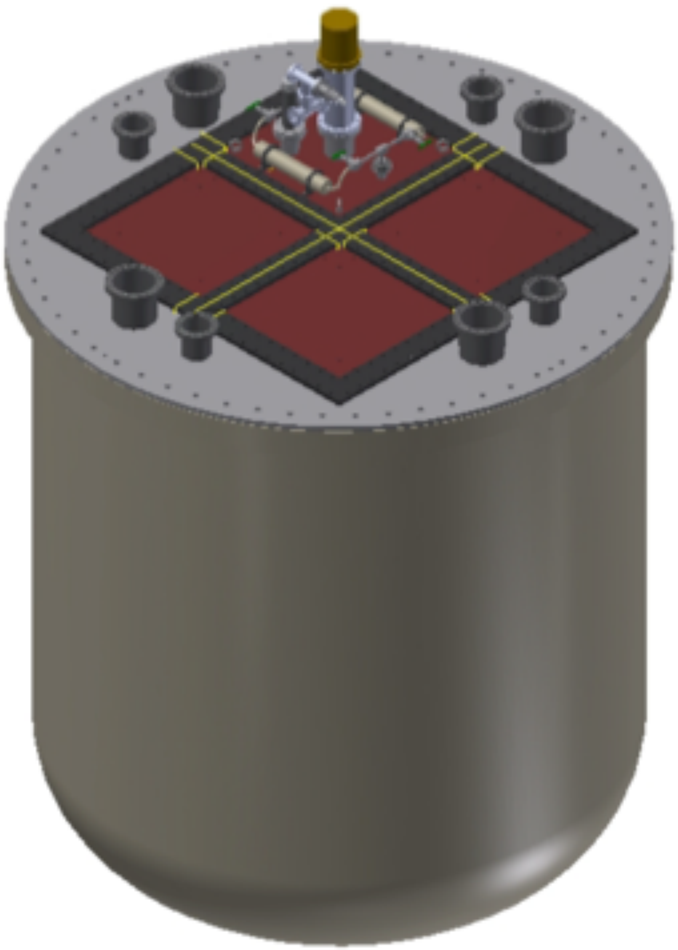
ArgonCube 2X2 demonstrator (Pixalated LAr)



- 4 modules
- Can reasonably achieve a fiducial target volume of ~ $1m^3$
  - 71kg **(~107k ν_μCC events/yr.)**
    - Potentially obtain somewhat larger fiducial target mass
  - Total volume ~ 6000L
- To my knowledge, this would be the first application of a liquid H_2 TPC.
- Quite a few cryogenic issues to work out also
  - 20K operating temperature vs. 80K
- **Electronic Bubble Chamber**

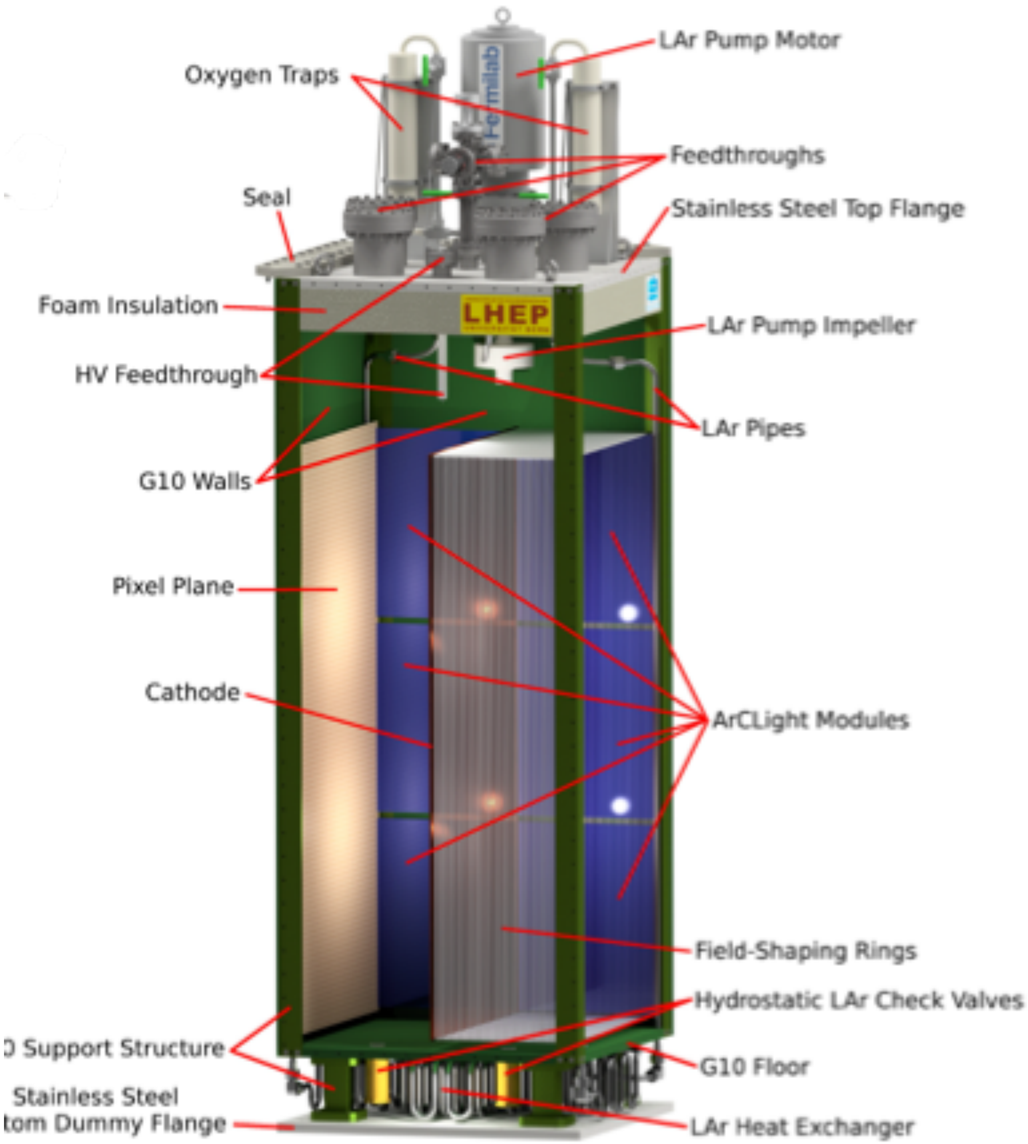
Note: Because of all the seals and the compression and expansion cycles – Making the case for a LH_2 BC in the DUNE ND Hall would be **Most challenging!**

LH_2 active target



- Likely will need a dome over the top plate to facilitate inerting with N_2 and then provide proper (sealed) feedthroughs for all cable/hose penetrations.
- Then put the 2 X 2 in a 2hr fire-rated enclosure and again inert with N_2
  - It is an ODH area obviously
  - Can be thin in X_0 : Drywall
- ArgonCube just downstream and acts as the catcher

ArgonCube LAr Module



Fermilab

LH_2 TPC

- To my knowledge, this has never been attempted
- Some data on electron transport in H_2 at 77K

ELECTRON TRANSPORT COEFFICIENTS IN HYDROGEN AND DEUTERIUM

By R. W. Crompton,* M. T. Elford,* and A. I. McIntosh*†

[*Manuscript received August* 31, 1967]

- I have not done an exhaustive search, but this is all that I found. These data indicate that the drift velocity and diffusion under these conditions are acceptable.
- R&D on electron transport in LH_2 would need to be done.

In Conclusion: In order to enable a νH/D experimental program in the DUNE near detector hall

- Need very strong statement from neutrino interaction community.
  - One from this WS?
- Discussions with LBNF need to start soon regarding special needs for ND hall
  - Dedicated vent lines to surface and supply lines to hall at the very least
- Engaging Fermilab fire safety personnel is also crucial.
- If it looks like the safety issues might be approachable, then R&D on electron transport in LH_2 would need to begin, if that route is preferred.