Light Guides for Light Collection in Liquid Argon

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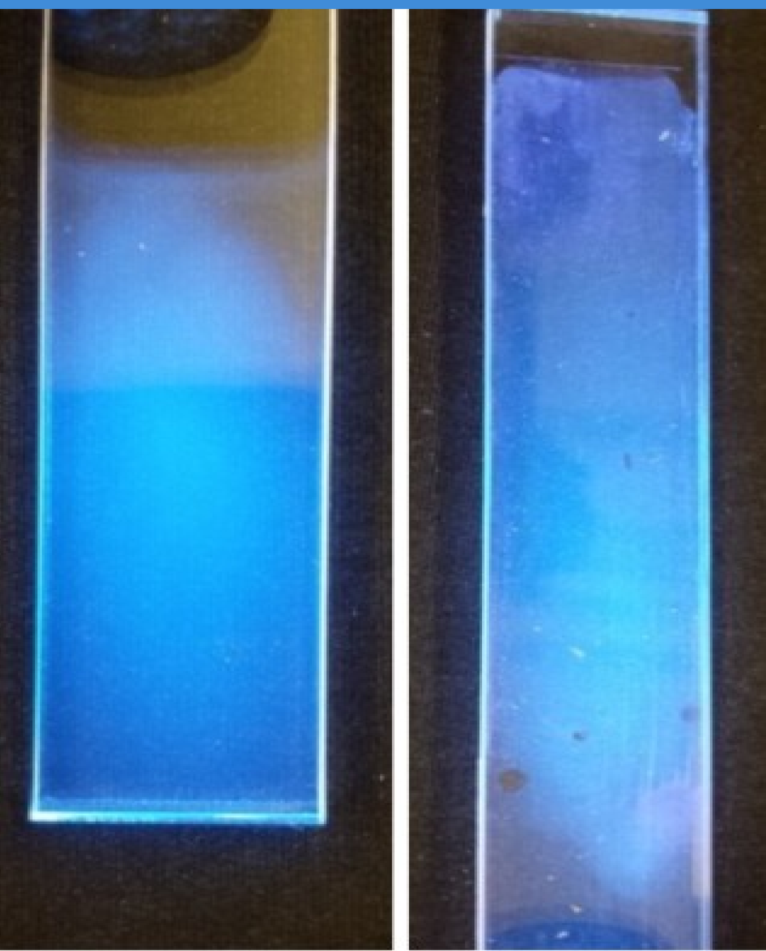
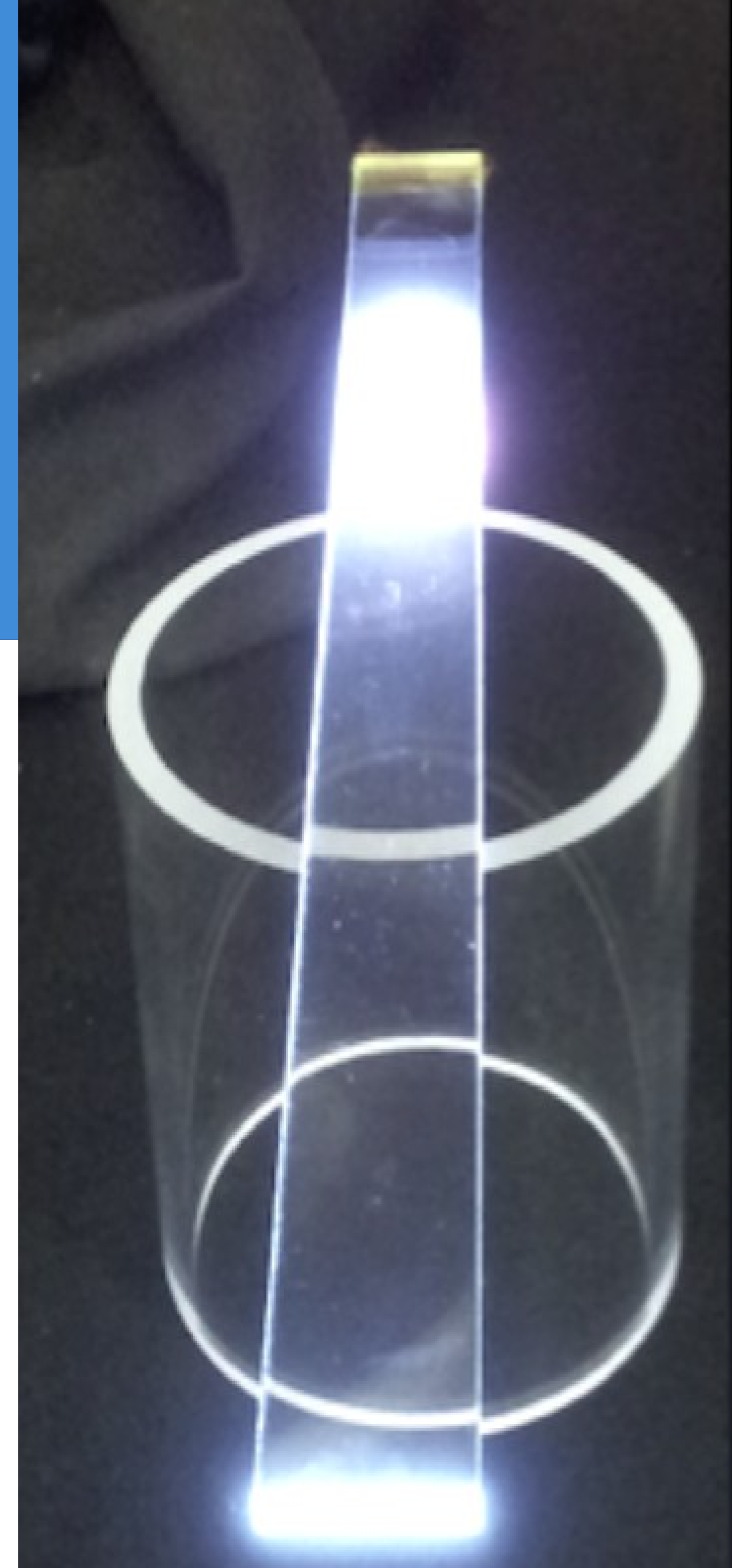
8/4/2015 APS DPF Meeting



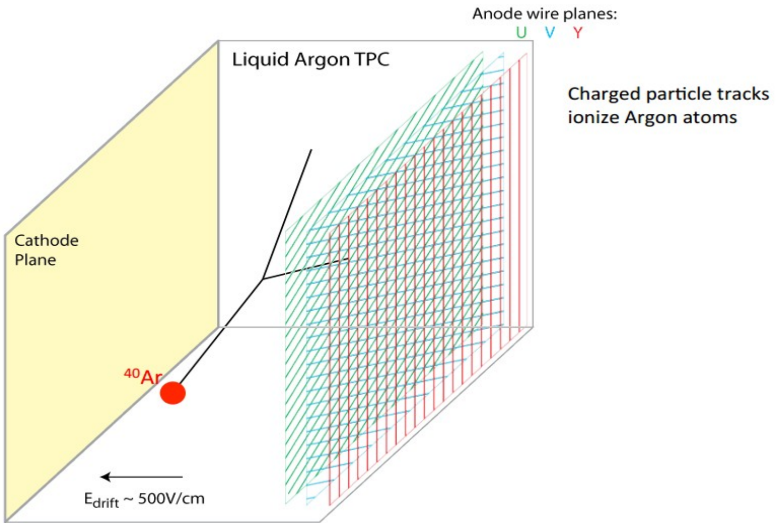


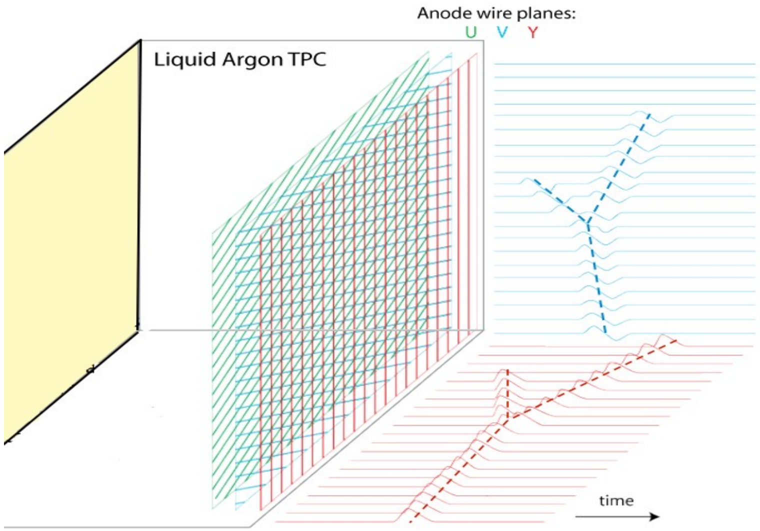
Outline

- Light Collection in Liquid Argon
- Building Our Light Guides
- Attenuation Measurements in LAr
- Attenuation Measurements in Air
- Model Connecting LAr and Air Measurements
- Future Work
  - Improved TPB coating
  - Xenon Doping
- Conclusions

Liquid Argon TPCs

- Liquid Argon time projection chambers detect electrons stripped from Argon atoms
- An electric field drifts these electrons past a wire plane



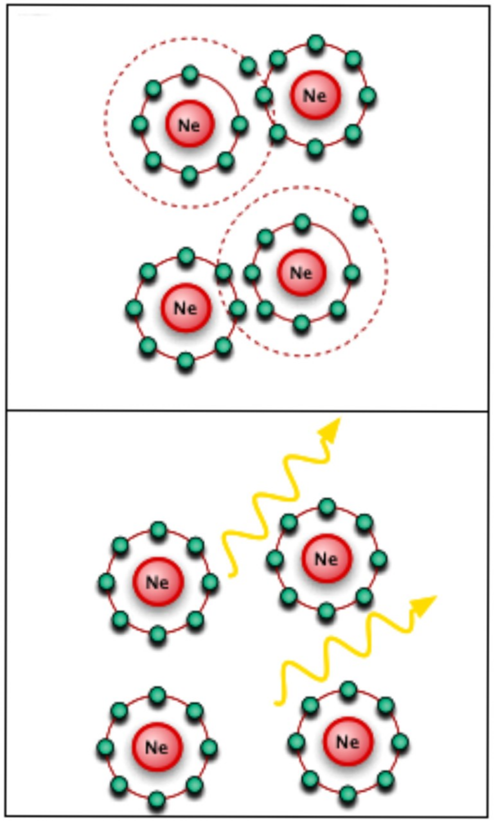


- You get lots of data this way, but using drift electrons alone neglects another major source of data

Scintillation in Liquid Argon

- Several noble gases, including Argon, scintillate
- After ionization, the atoms form metastable dimers which release light when they decay

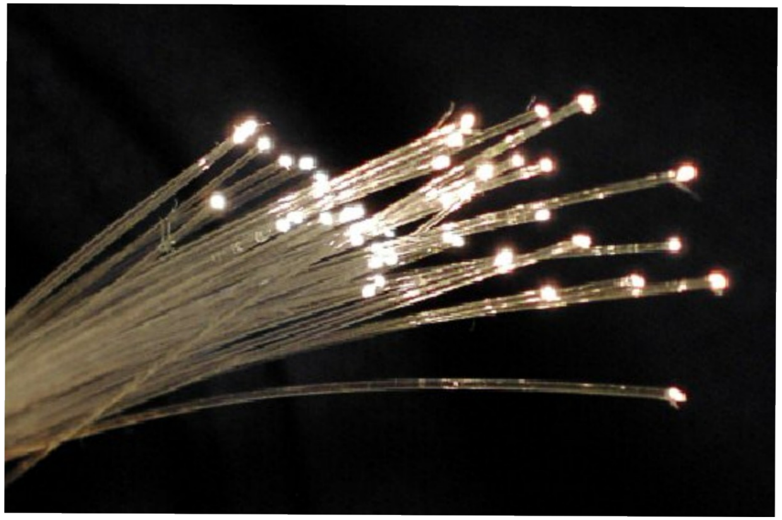
$$Ar_2^* \rightarrow 2Ar + 128 \text{ nm light}$$

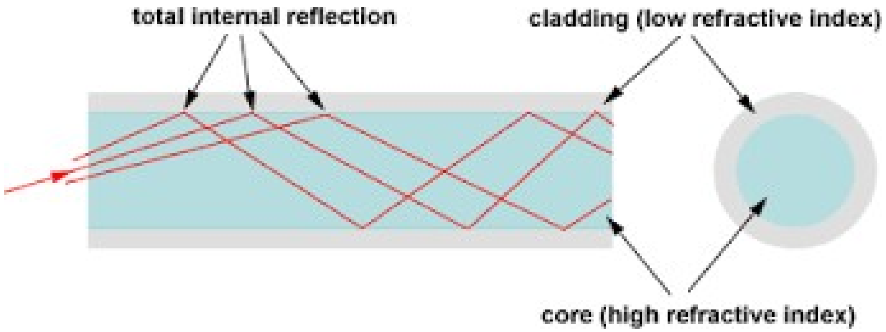


- This scintillation light is useful for
  - Triggering
  - Background rejection
  - Track reconstruction
- The more light we collect the better

Light Guides 101

- Light guides are simply an object which takes in light and channels it where we want it to go using total (or nearly total) internal reflection
- A common example is optical cabling





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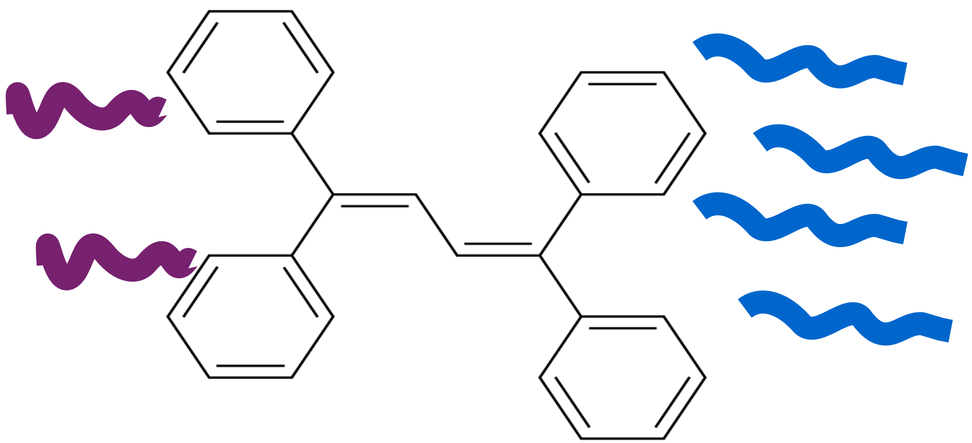
Wavelength Shifting With TPB

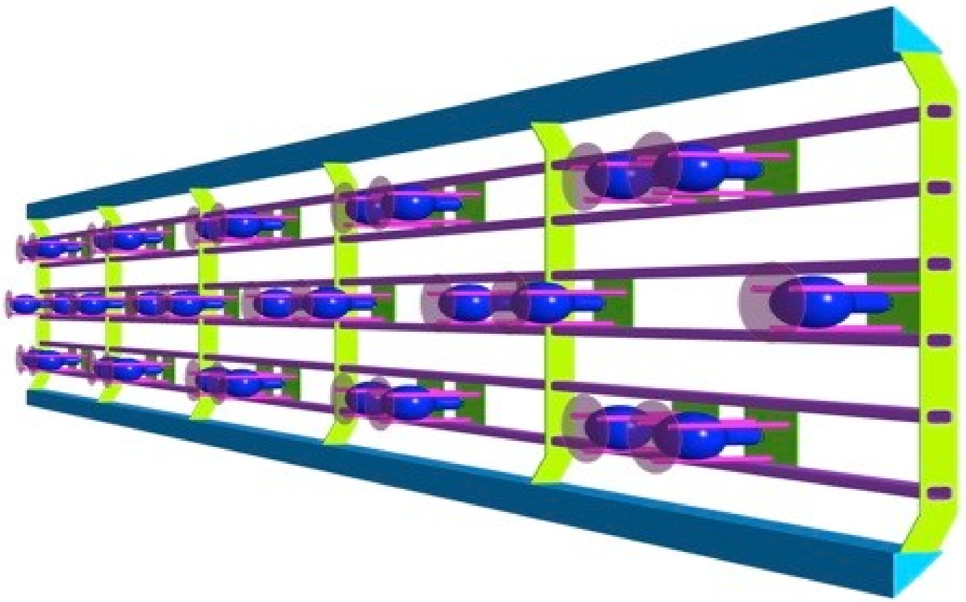
- Most photodetectors are not sensitive to 128 nm light
- The scintillation light must be shifted to the visible for detection
- Tetraphenyl Butadiene (TPB) is employed
  - Absorbs VUV and re-emits at 425 nm



A TPB coated guide illuminated by a UV flashlight

Light Collection in MicroBooNE

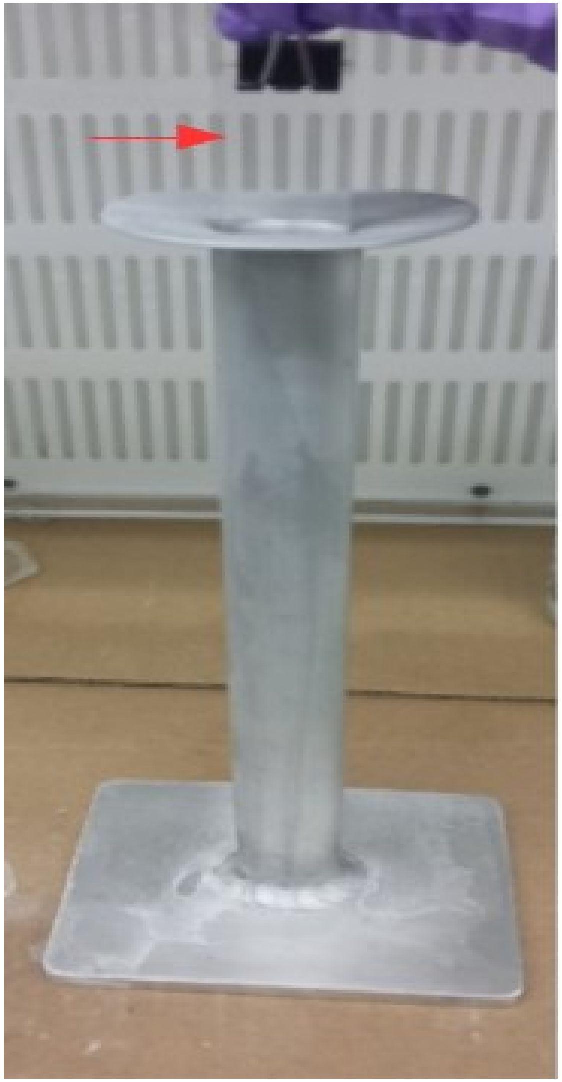
- An example of a current light collection system is that implemented in MicroBooNE at FNAL
- You can see each PMT has a plate in front which is coated with the wavelength shifting TPB



Can We Do Better?

- Improved coverage
  - Current systems see a relatively small portion of the total scintillation light
- Space efficient
  - We cannot have a bulky system, an ideal system will collect a large fraction of the light without taking up much space

Light Guide Construction



An acrylic bar being dip coated in TPB solution

- Bars constructed from diamond polished UVT acrylic
- The bars are annealed to prevent crazing
- The wavelength shifting coating is applied
  - TPB (shifter)
  - Toluene (solvent)
  - Ethanol (surfactant)
  - Dissolved acrylic
- We now coat using a dip method as opposed to prior painting methods

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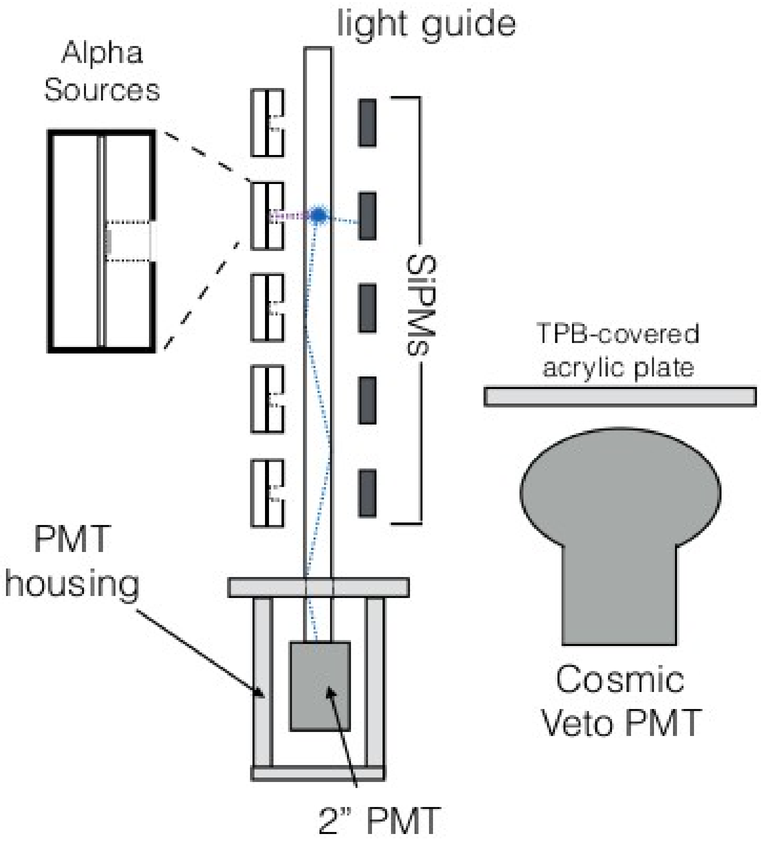
Measurement in LAr

- Measurements done in the TallBo test stand at the Proton Assembly Building at Fermilab
- Scintillation light is produced by five Po-210 sources
- Five adjacent SiPMs act as a trigger
- Waveforms from each SiPM, a PMT at the base of the bar, and a cosmic veto PMT were recorded
- Light output vs distance to triggering source gives attenuation

Measurement in LAr



Schematic of test stand

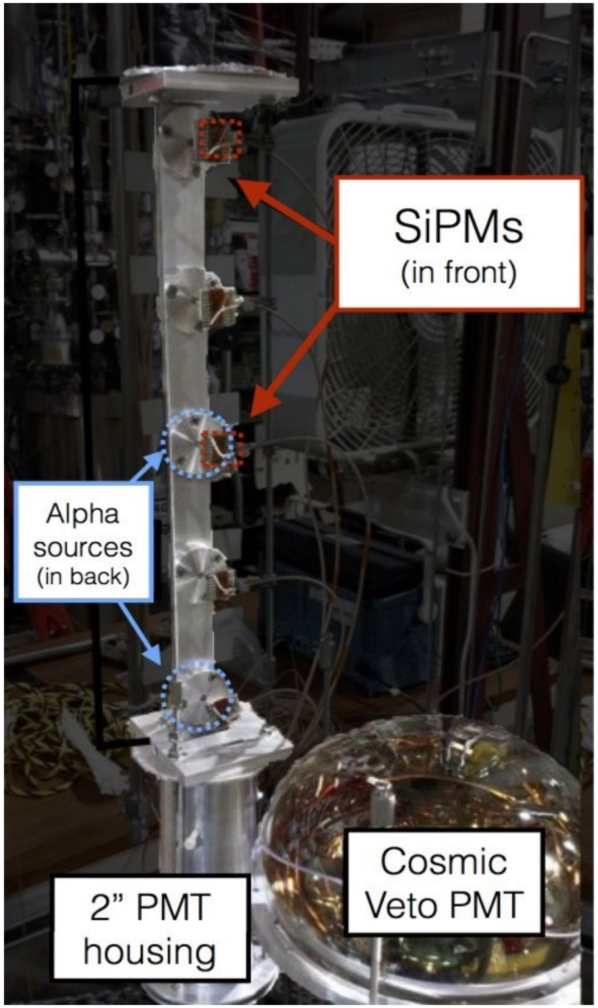
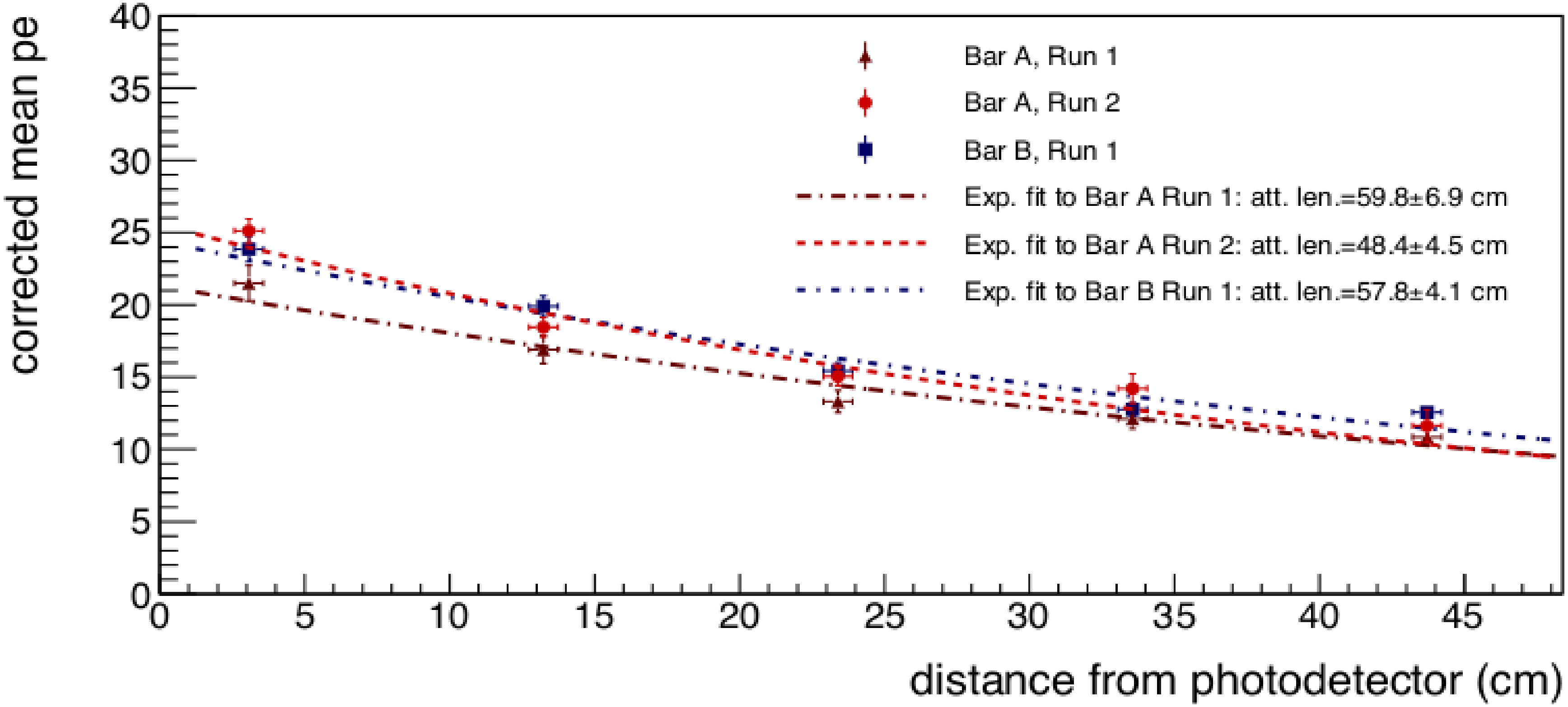


Photo of test stand

Attenuation in LAr

- The “attenuation length” in LAr is between 50 and 60 cm
- Note however that the data is poorly fit by an exponential due to a sharp upturn below 5 cm



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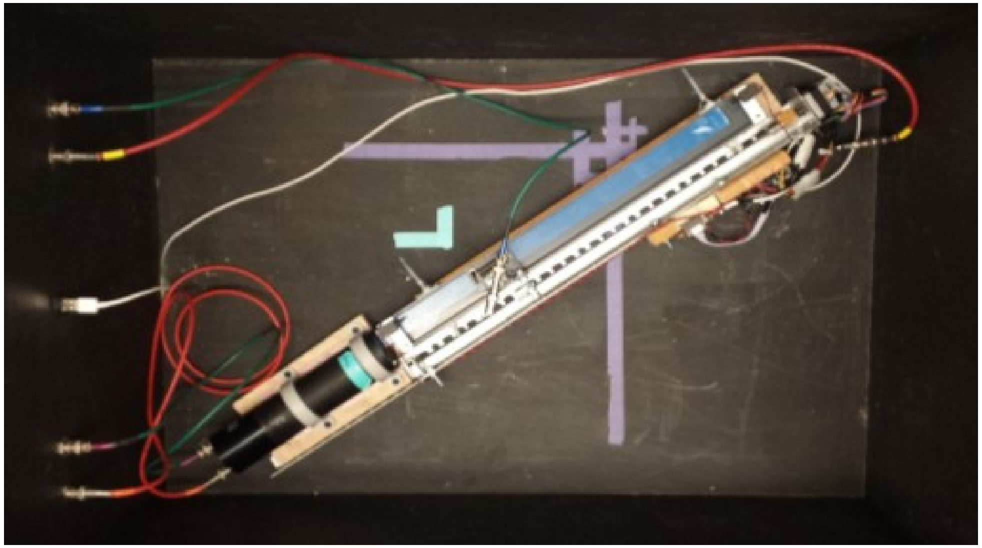
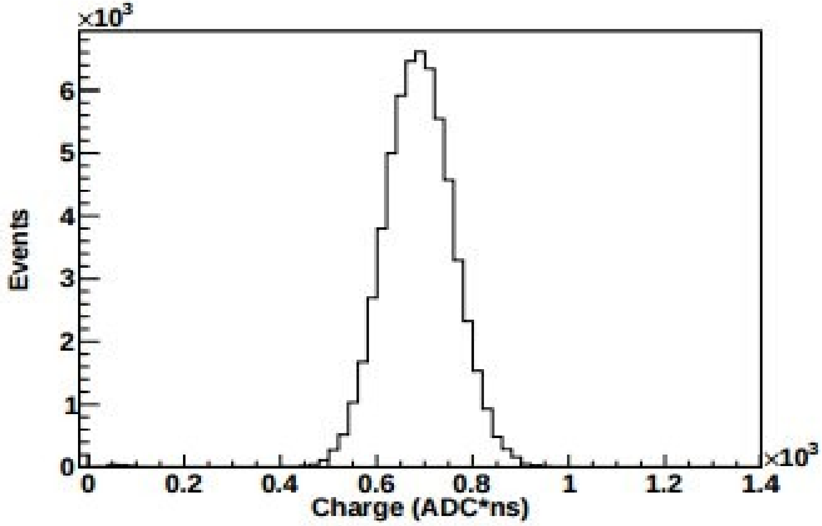
Measurement in Air

- In a dark box, a 286 nm LED flashes at 2.5 cm increments
- A PMT at the base detects the output light
- Light output vs distance yields attenuation length



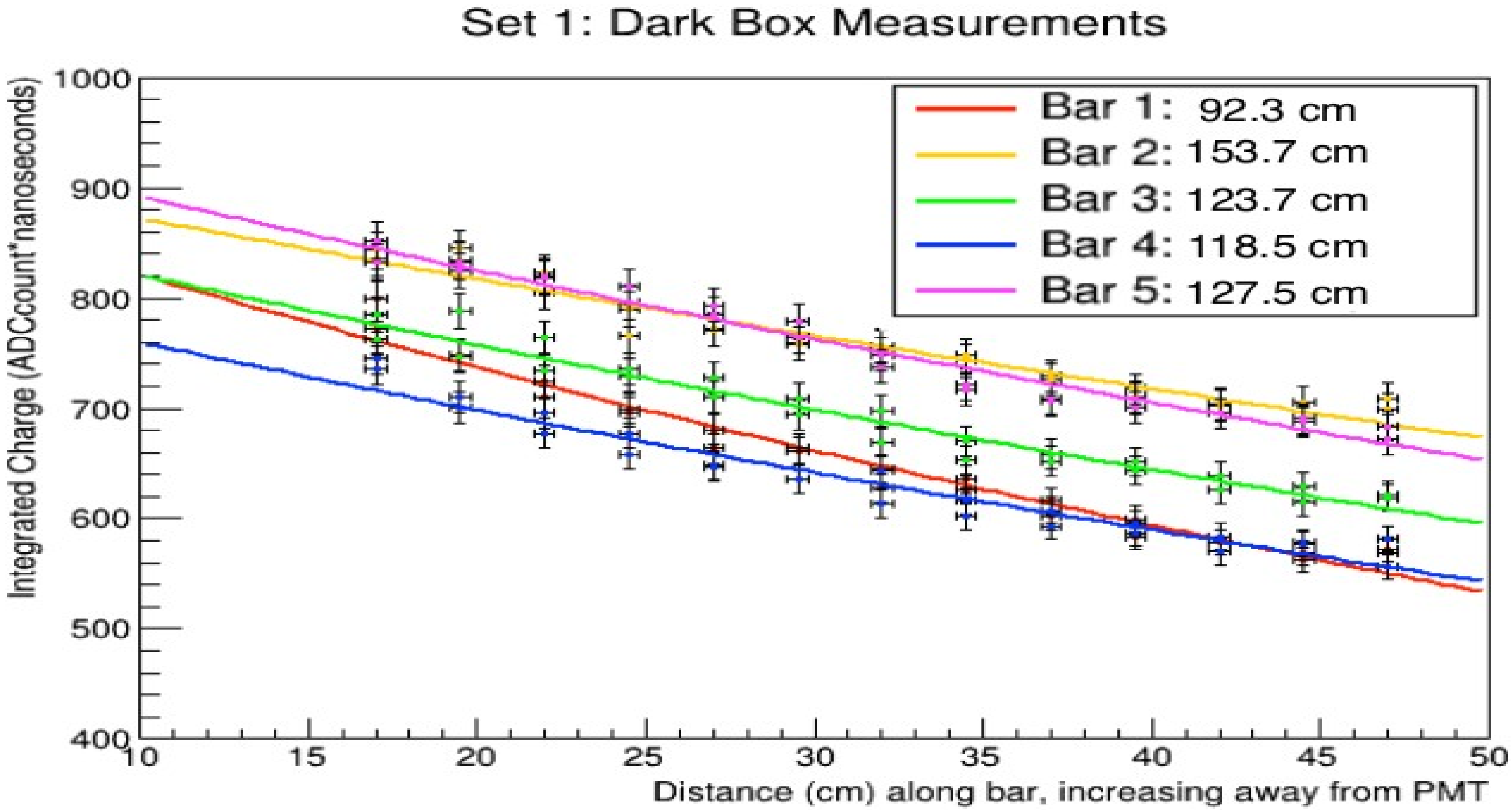
Dark box setup with PMT, bar, and stepper



Example readout distribution

Attenuation in Air

- Many of the bars had attenuation lengths > 1m
- Previous hand painting method had yielded attenuation lengths of ~50 cm



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LAr vs Air Results

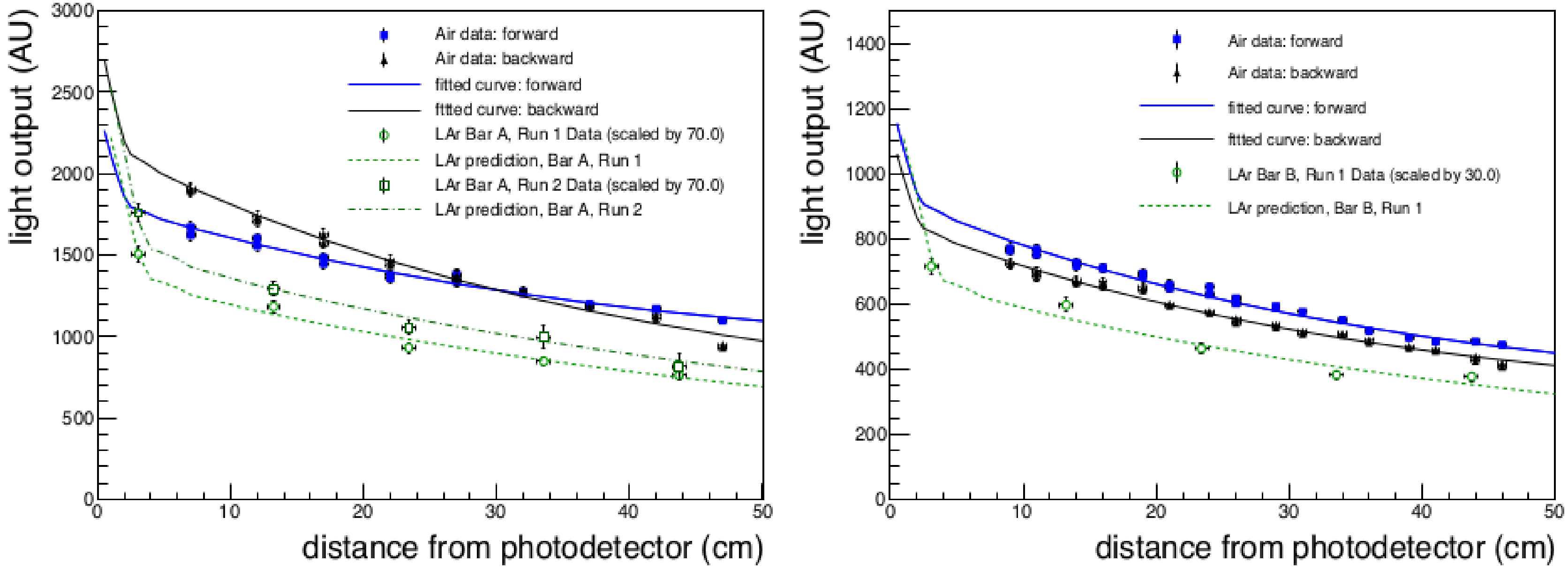
- Argon and air have different indices of refraction, so the results for attenuation were, not unexpectedly, rather different
- The performance in LAr is of ultimate interest, but measurements in LAr are comparatively time consuming, difficult, and costly
- Can we link the behavior in LAr to that in air?

Modeling LAr/Air Connection

- Try a 3 parameter model
  - Internal reflection (partial and total) depends on refractive index of the environment (Air or LAr)
  - Photon loss per reflection
  - Coating thickness gradient (to account for greater light production where thickness is greater)
- Simultaneously fit forward and backward bar runs in air to extract these parameters
- Use the loss per bounce to yield an attenuation curve for LAr
  - Assumes that the penetration of 128 nm light is less than the coating thickness

Model Results

- The model agrees well with the previously taken data, yielding a good prediction of the LAr curve based on air data
  - It correctly predicts the similarity of Bars A and B in LAr despite their difference in air
  - If you limit an exponential fit to the larger distance points, it also yields the correct attenuation length



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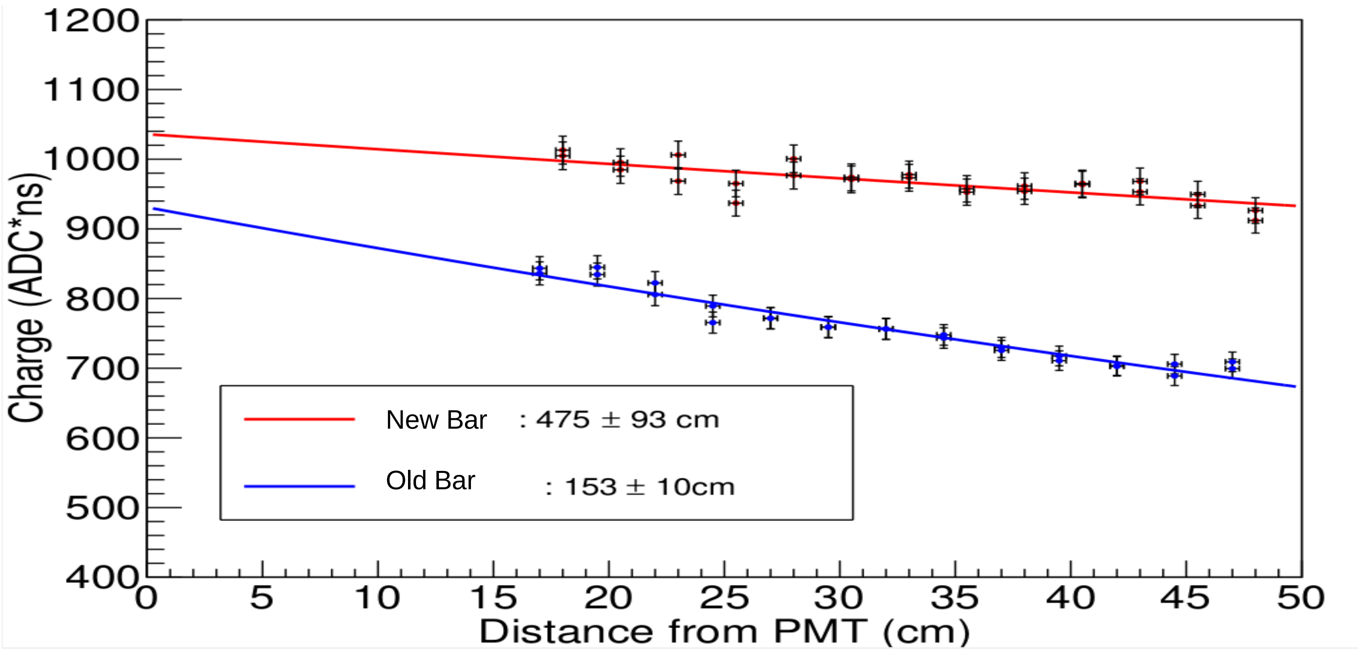
Improved TPB coating

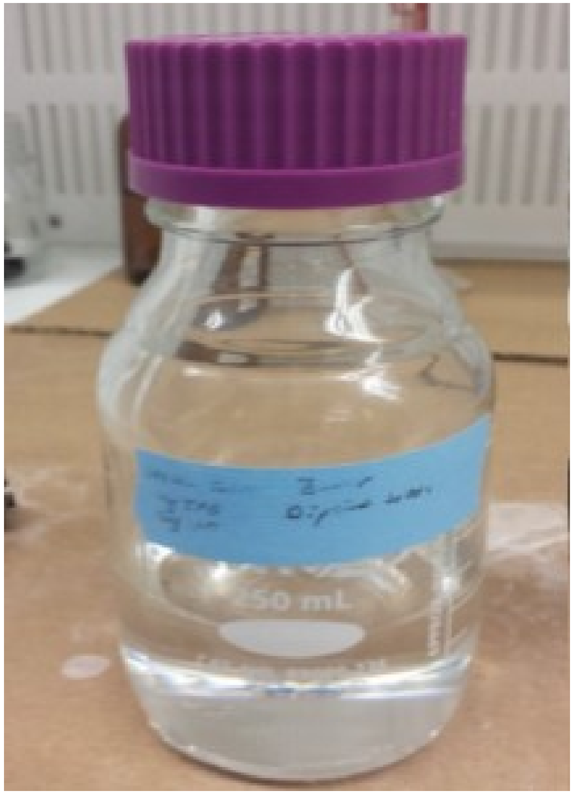
- Increase TPB/acrylic ratio in coating

0.5 g TPB	→	0.1 g TPB
50 mL toluene	→	50 mL toluene
10 mL ethanol	→	12 mL ethanol
1 g acrylic	→	0.1 g acrylic

- Not yet tested in LAr, but performance in air is *much* improved



Improved TPB coating



TPB Solution

- These results are preliminary
  - Need to do the same bar backwards
  - Use forward/backward data and feed into Lar/Air model
  - Measure in LAr, compare to model

Adding Xenon

- LAr scintillation has a fast and slow component (6 ns & 1.5 μs)
  - Ionized Argon atoms form metastable molecules in singlet and triplet states which decay with different lifetimes
- Small concentrations of Xe may have several benefits!
  - Xenon also forms metastable molecules, but with shorter decay times (4.3 ns and 22 ns)
  - Xenon de-excites at 175 nm, our coating is more efficient at this wavelength due to higher penetration, so we get more light output

Conclusions

- We have demonstrated that low enough attenuation can be obtained for our bars to be part an effective light collection system.
  - There is still much unexplored potential for improvement as well!

- Our final system will readout with SiPMs not PMTs. Their small size in conjunction with the low profile of our bars makes for a highly space efficient collection system.

- We have demonstrated the ability to do accurate modeling of Lar behavior based on less costly and easier air measurements

Acknowledgments

Special thanks to the whole light guide team!

- Janet Conrad
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Thank You!

Questions?