Light Guides for Future Long/Short Baseline Experiments

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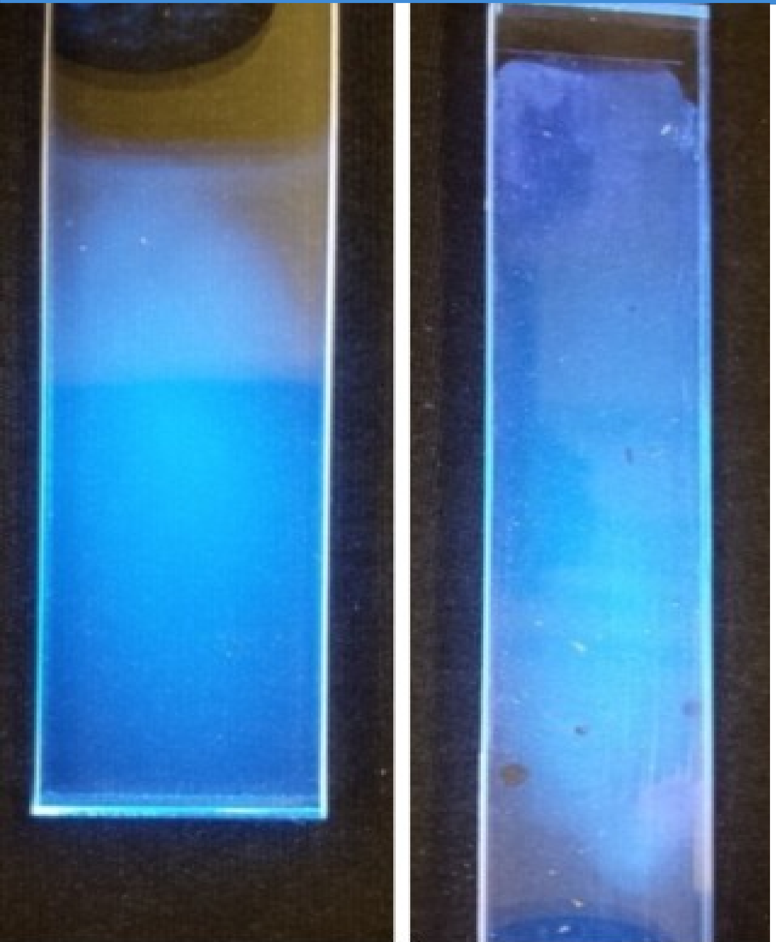
LIDINE 2015



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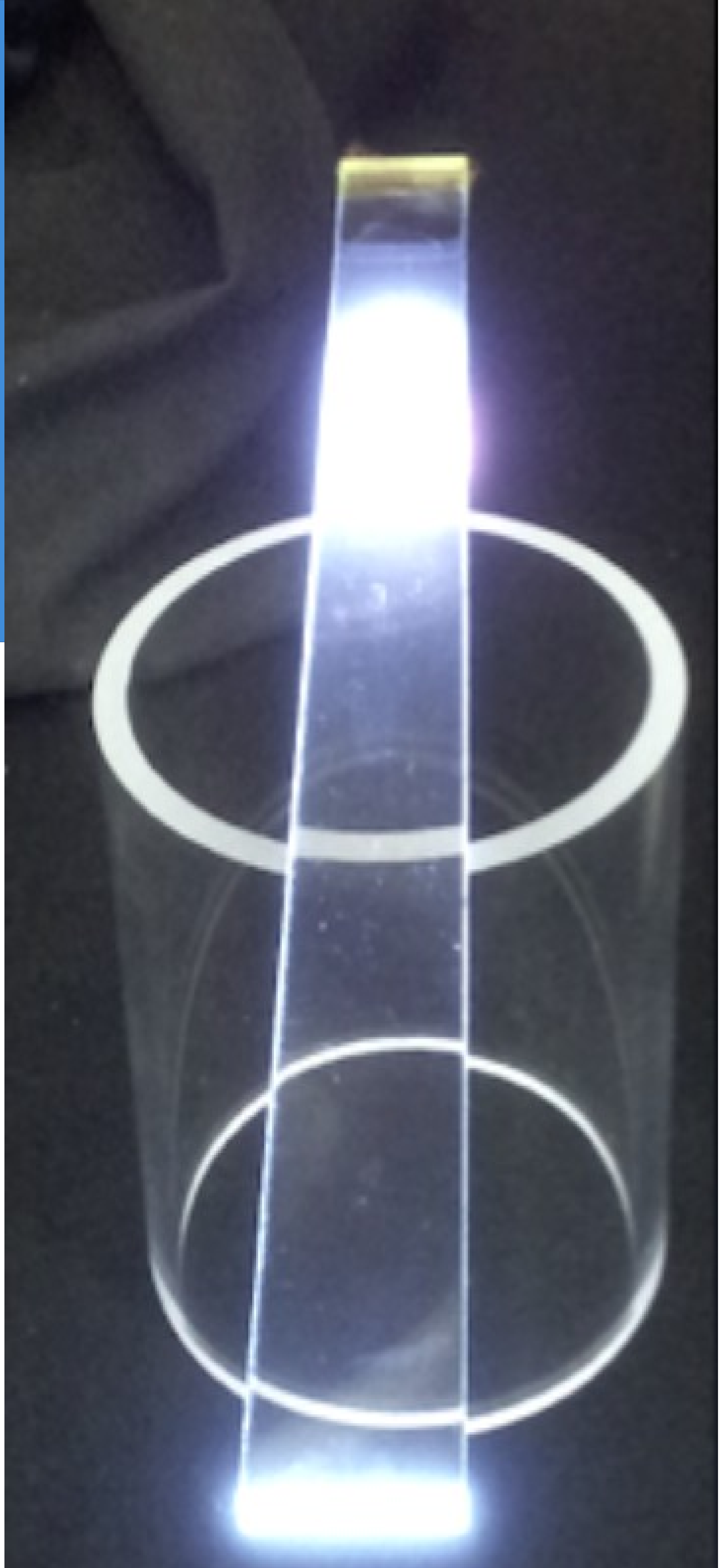


Overview

Light Collection in Liquid Argon

Building Our Light Guides

Attenuation Measurements

Argon/Air Behavior Modeling

The “Wunderbars”

Costs and Final Analysis

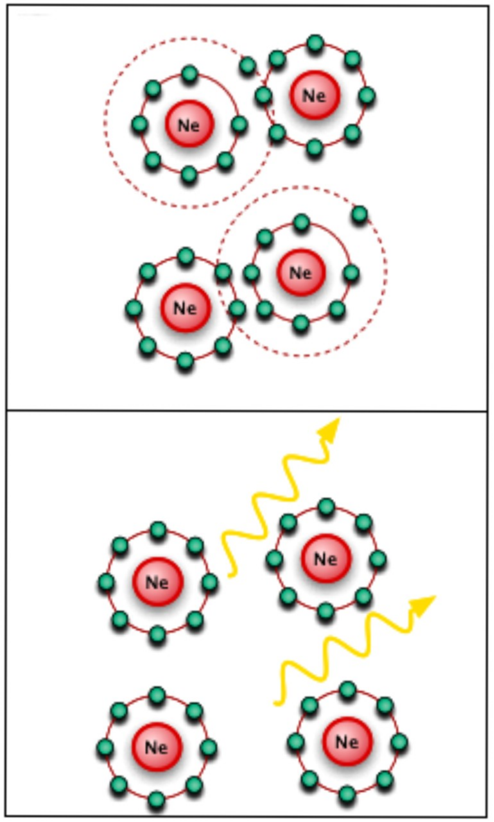
Conclusions

Liquid Argon Scintillation

- Ionized Argon forms metastable dimers

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

- Liquid Argon is highly transparent to its own scintillation light
- It is a very good scintillator ~10^4 γ/MeV



Using Scintillation in LArTPCs

- Liquid Argon time projection chambers provide spectacular resolution
- Scintillation light further helps by providing
  - Background rejection
  - Nanosecond resolution t_0 information
- We get lots of photons, we need not collect them all
- Because of the size of LArTPCs it becomes an issue of developing a light collection system with maximal coverage

Checklist...

In addition to collecting lots of light there are several other practical attributes a system needs to have

- Collects lots of light
- Robust Design
- Space Efficient
- Economical

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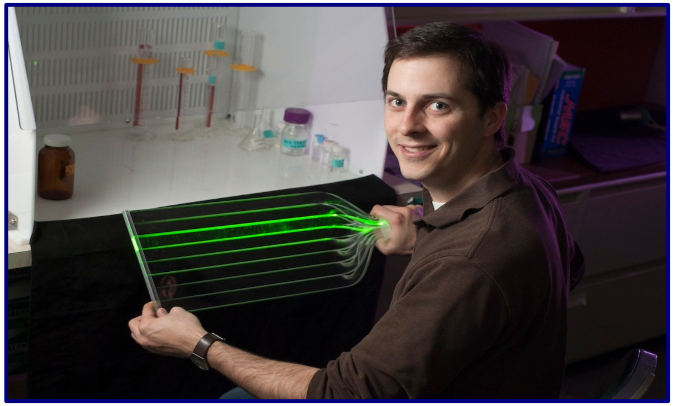
Light Guides

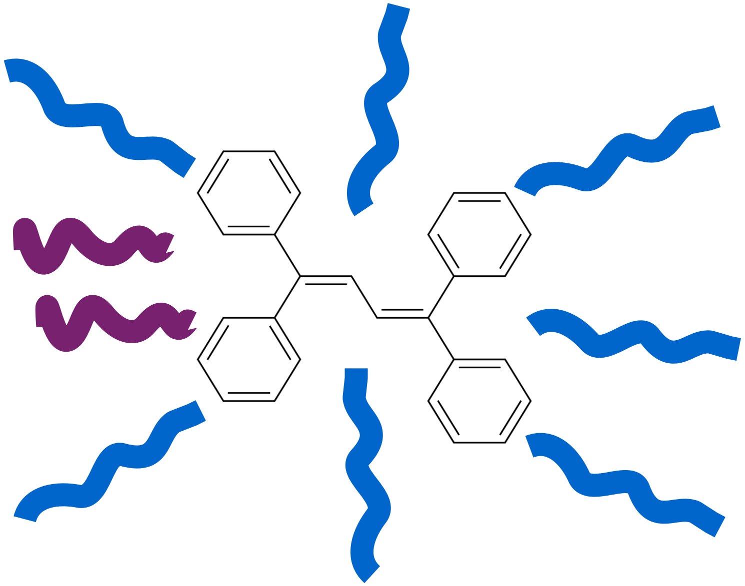
- Try covering the region inside of the APA with flat profile light guides
- Instrument the ends of the guides with SiPMs
- Two major problems
  - We may lose lots of light to attenuation
  - PMTs can't see 128 nm light

Matt Toups chilling with a light guide



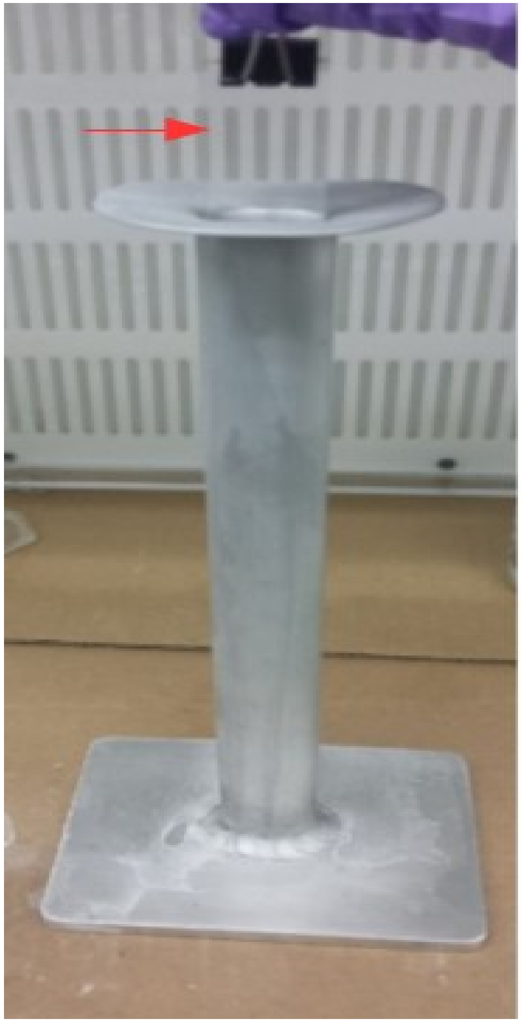
Wavelength Shifting With TPB

- Thankfully, there is a well known solution to the 128 nm insensitivity problem
- Use Tetraphenyl Butadiene to shift the VUV light to visible
  - Absorbs VUV and isotropically re-emits at 425 nm



A TPB coated guide illuminated by a UV flashlight

Light Guide Construction



An acrylic bar being dip coated in TPB solution

- Bars made of 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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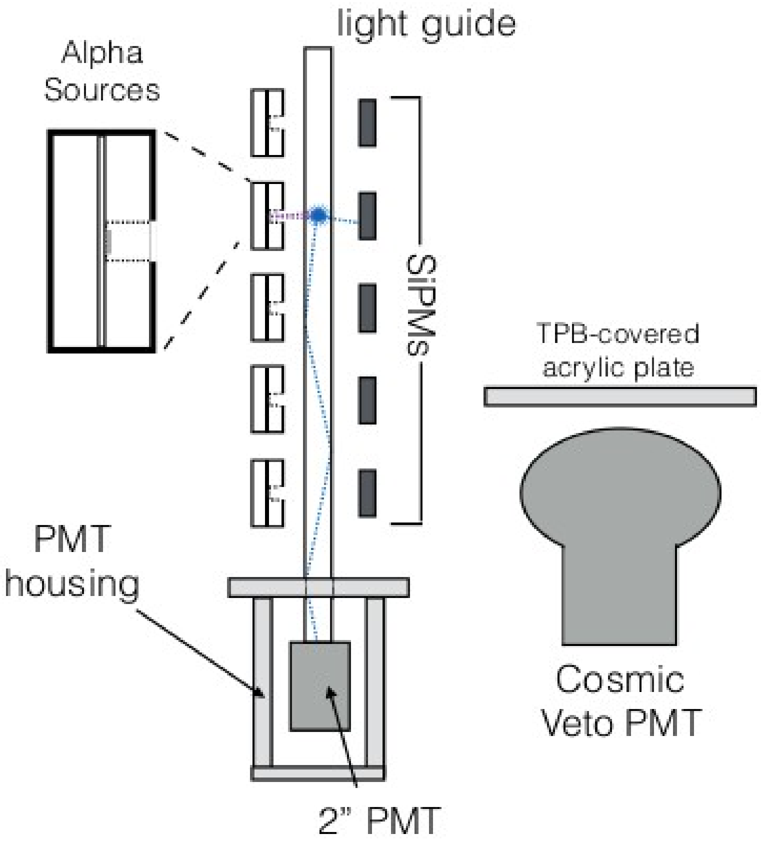
Measurement in LAr

- Measurements done in “TallBo”, a high purity dewar 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

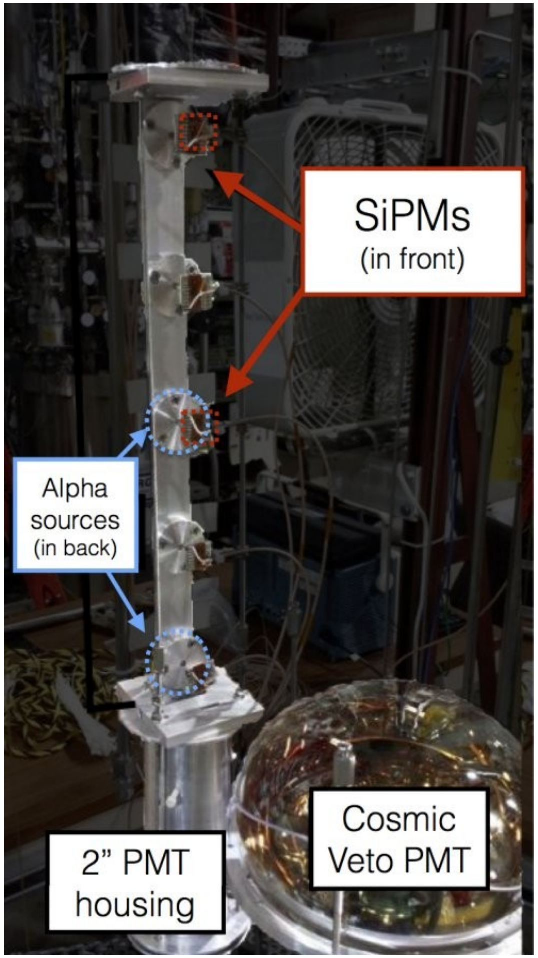
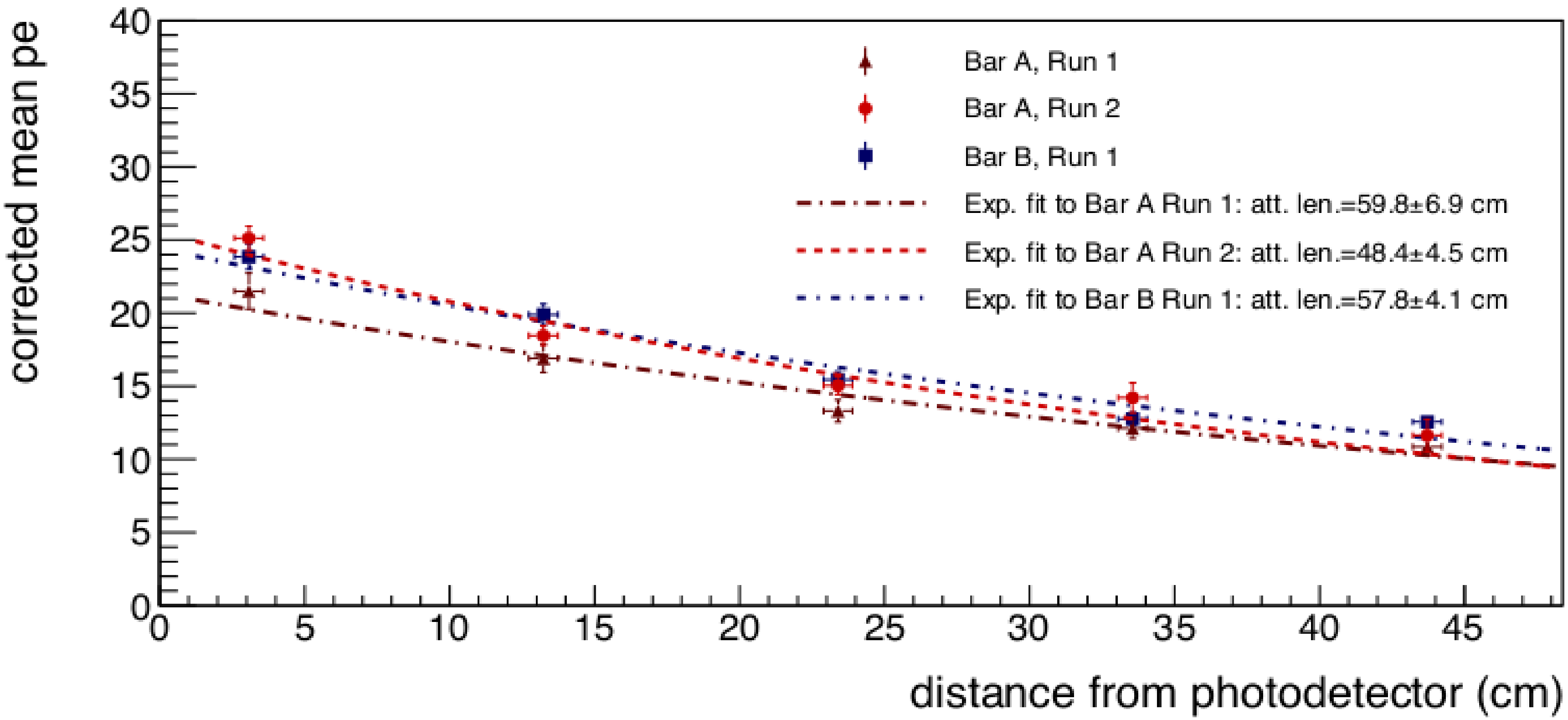


Photo of test stand

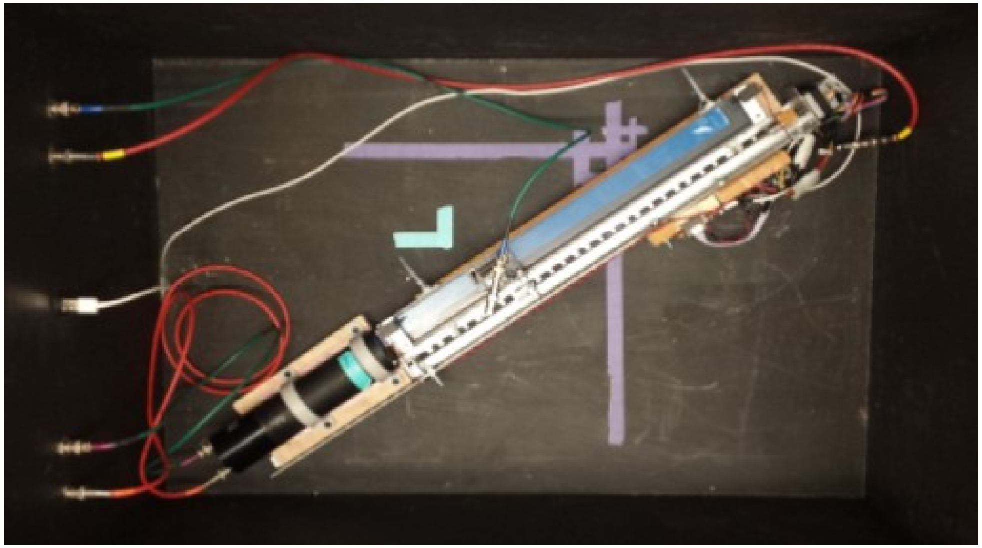
Attenuation in LAr

- The attenuation length in LAr is between 50 and 60 cm

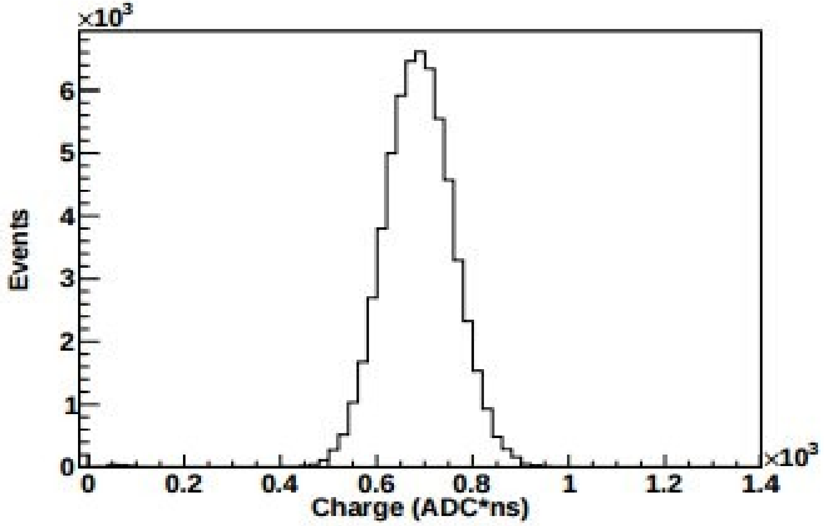


Measurement in Air

- 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



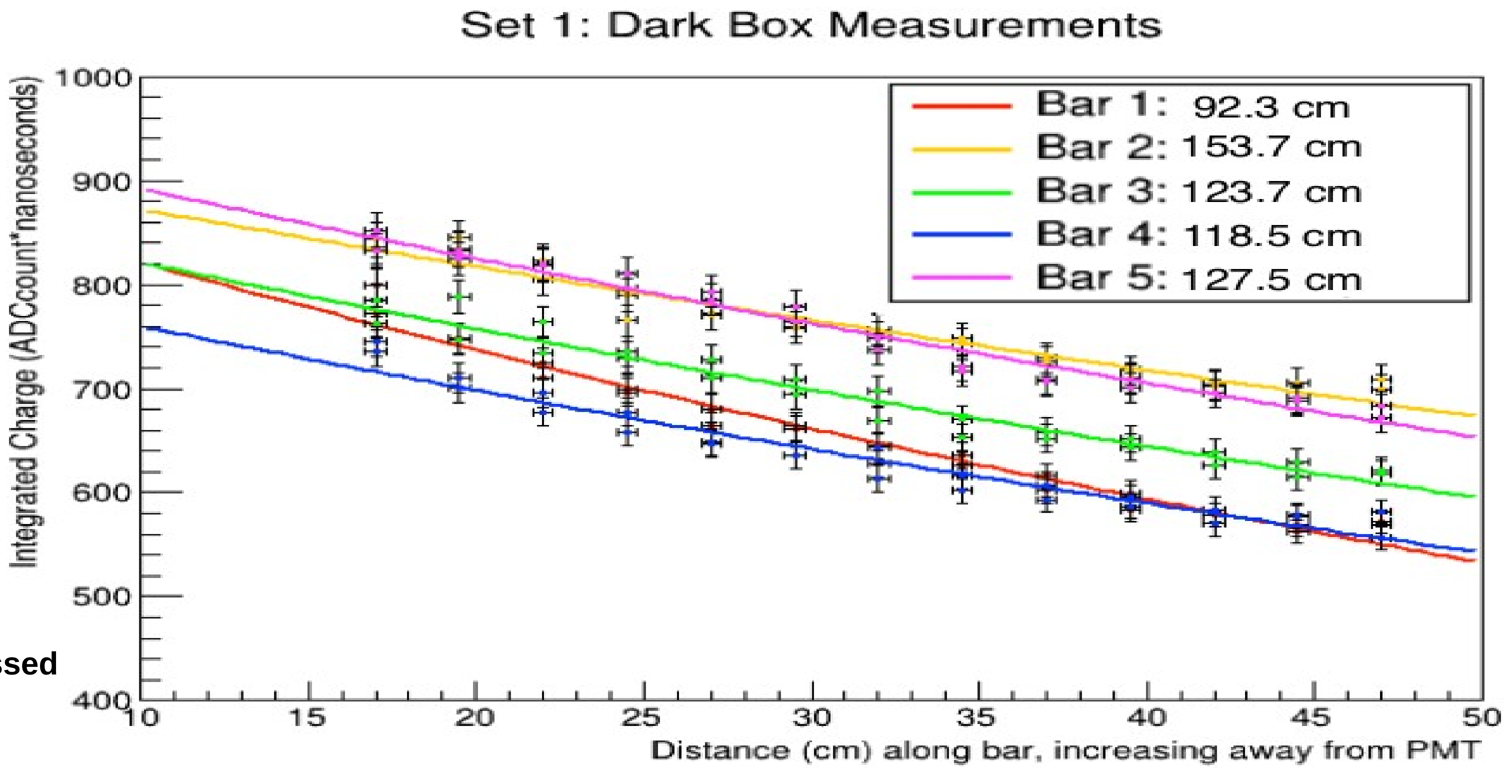
Dark box setup with PMT, bar, and stepper



Example readout distribution

Attenuation in Air

- Many of the bars had attenuation lengths > 1m
- The variation is ~10% between bars



Zero Suppressed

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?

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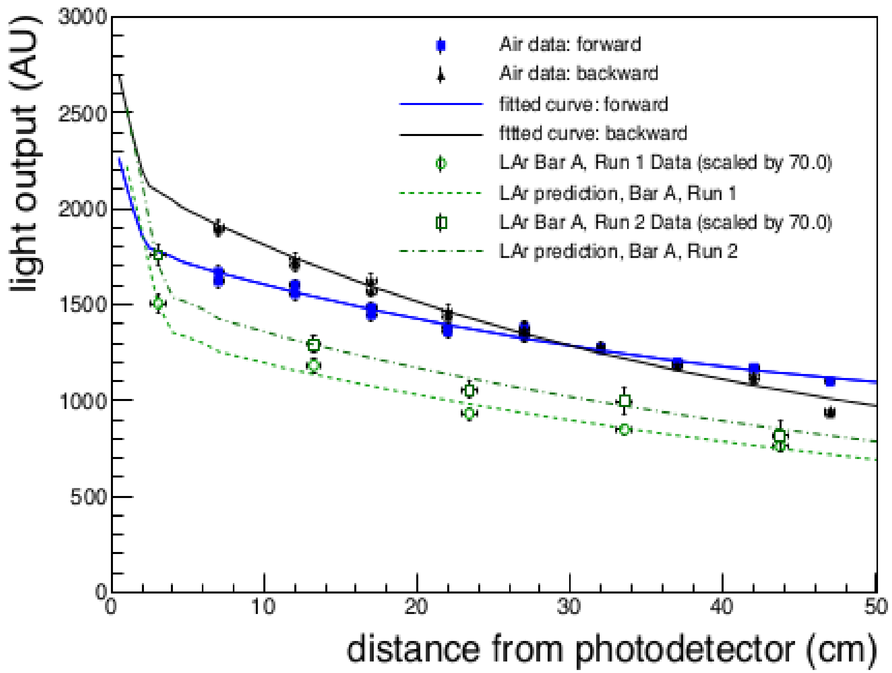
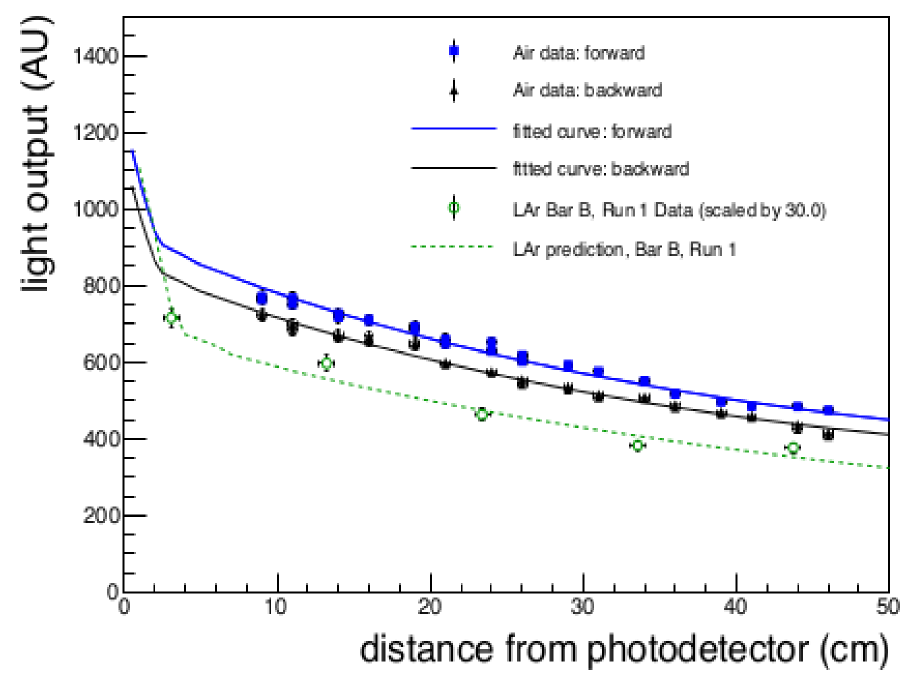
Modeling LAr/Air Connection

- Try a 3 parameter ray tracing model
  - Internal reflection depends only on n_{air} and n_{Ar}
  - Photon loss per reflection
  - Coating thickness gradient
- 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 our data, yielding a good prediction of the LAr curve based on air data
  - It correctly predicts the behavior and attenuation length in LAr based only on air data and n_{Ar}





Can We Do Even Better?

- So at this point we produce light guides of consistent quality, with attenuation length ~ 1 m
- We have the ability to do quality control on all new bars quickly and cheaply

But more would be cool!

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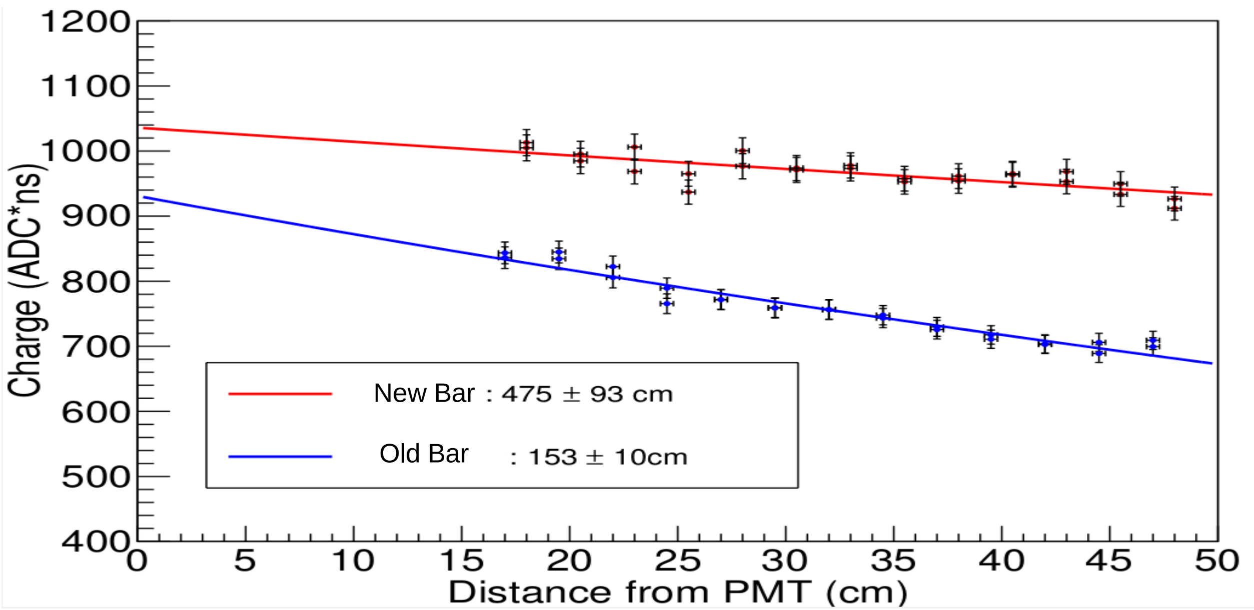
Improved TPB Coating

- Increase TPB/acrylic ratio

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

- Initial test done in air, and showed *drastic* improvement

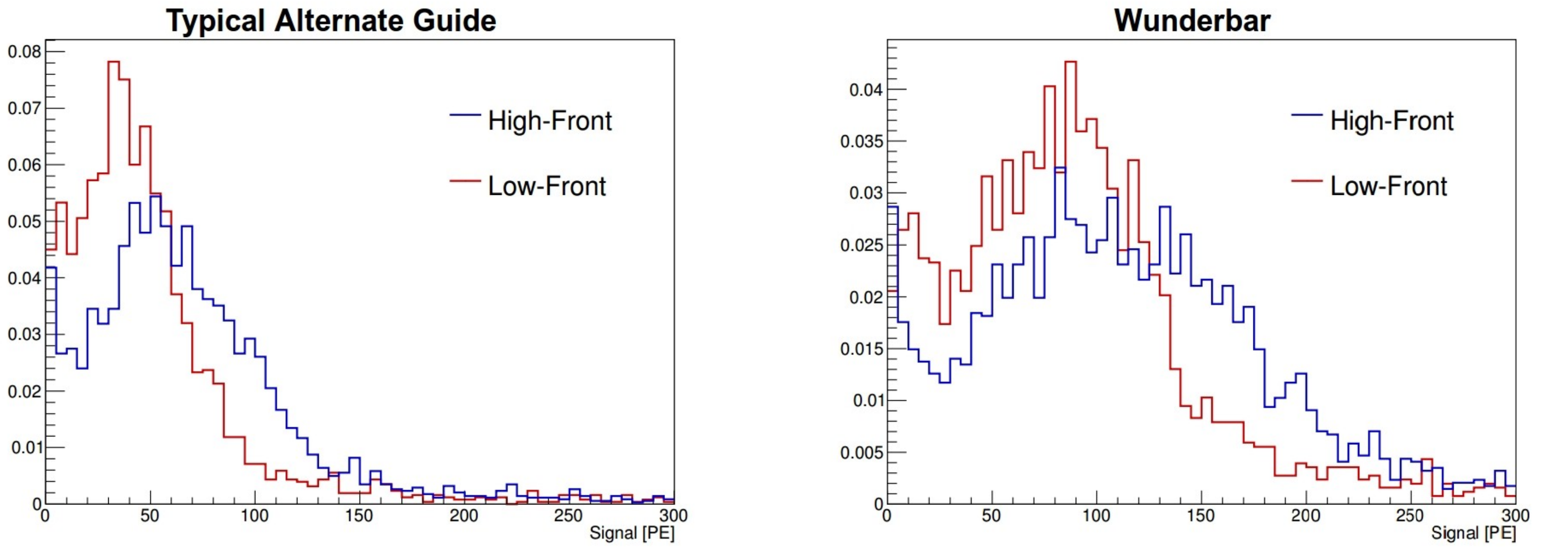


But for such a seemingly drastic improvement, the proof is in the pudding

(pudding = LAr)

The Wunderbar in Liquid Argon

- Several bars, including our latest “wunderbar” tested in liquid argon at Fermilab in summer 2015



- The wunderbar yielded an attenuation length of 230 cm compared to other guides, the best of which performed at 155 cm

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Checklist...

- We have a large attenuation length with potentially more improvement. As a bonus, quality control can be done in air
- Flat bars with SiPMs takes up very little space
- Minimal number of parts, all of which are known to be stable under cryogenic conditions

- [x] Collects lots of light
- [x] Robust Design
- [x] Space Efficient
- [ ] Economical
- [x] Easy Quality Control

What Does it Cost?

Item	Cost/ 1m bar
UVT Acrylic, polished	$ 7.74
Coating	$ 0.11
3 SiPM (bulk order)	$ 75.00 (getting cheaper)
Dedicated readout	$ ~ 250 (eg uBoone)
Total	$ 332.85

- If we implement anode coupled readout then we can construct for *well* under $100/bar
- Production costs will be low. The process is simple, and well documented in several publications.
- Production and quality control is well suited to being performed at universities by students (aka educational and cheap labor, eg me)

Checklist...

- The final cost of our system turns out to be quite reasonable, and can easily be performed at many different universities

Collects lots of light ☑

Robust Design ☑

Space Efficient ☑

Economical ☑

Easy Quality Control ☑

Conclusions

- Attenuation is low enough for this to be an effective light collection system, with ongoing improvement
- It has a well established production and quality control protocol with several associated peer-reviewed papers
- It is both spatially and economically efficient
- Production can be done at universities, resulting in greater collaboration and educational opportunities as well as low overhead

Acknowledgments

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Thank You!

Questions?