A Demonstration of Light guides in Liquid Argon TPCs

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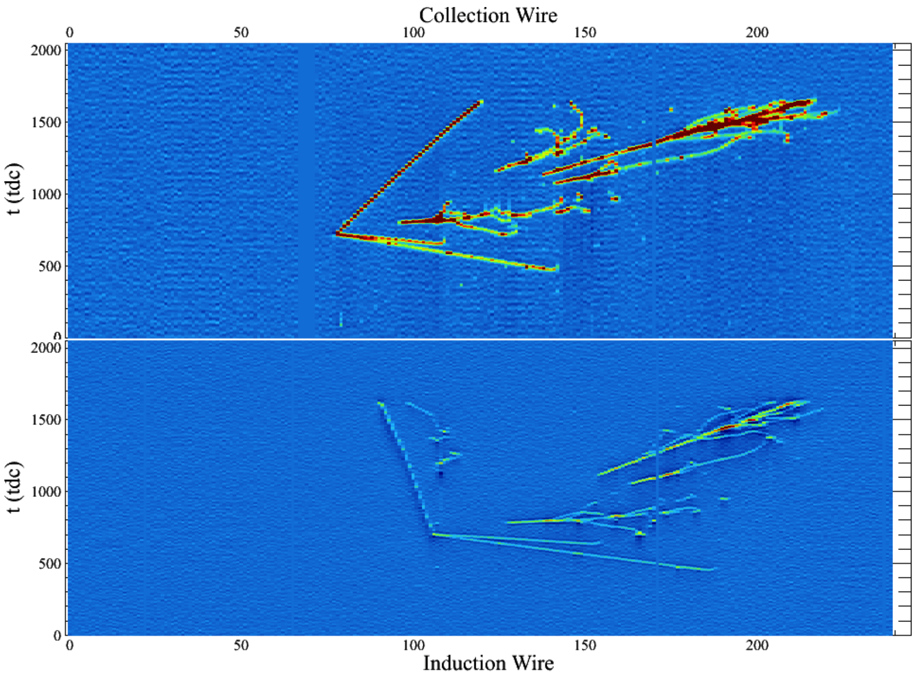
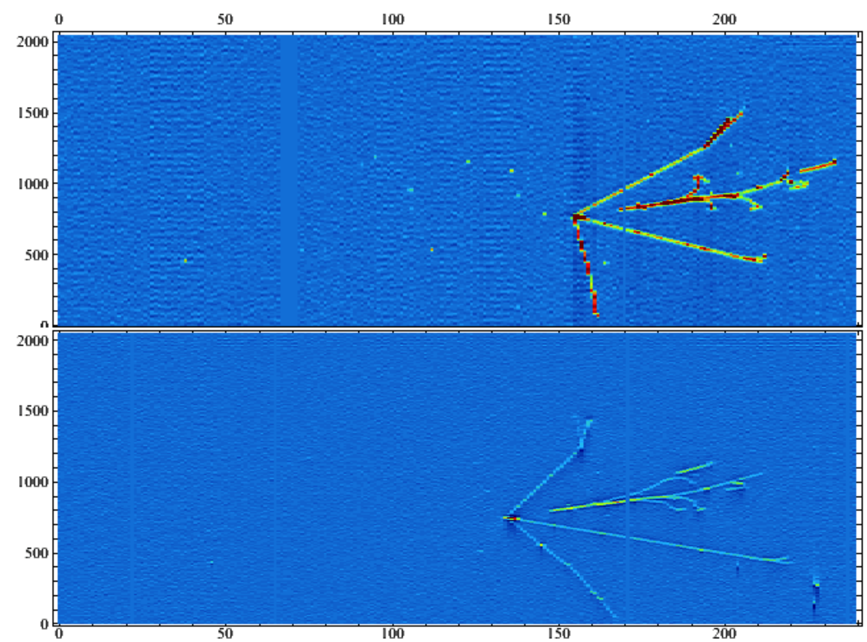
Liquid Argon Time Projection Chambers (LArTPCs)

- Developing detector technology useful for neutrino experiments
- Measures deposited energy of particles
- High signal efficiency, low background



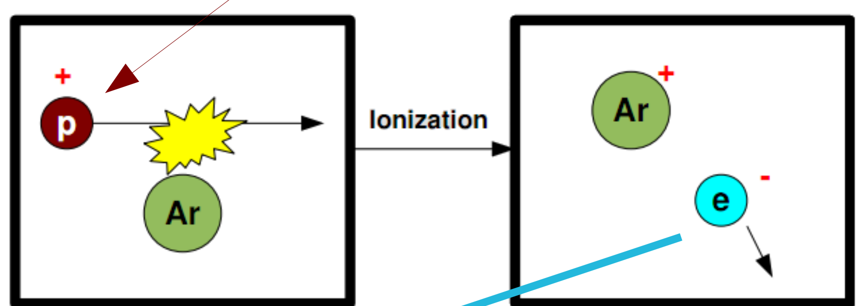


LArTPCs

Charged particles are created in neutrino interactions, ex:

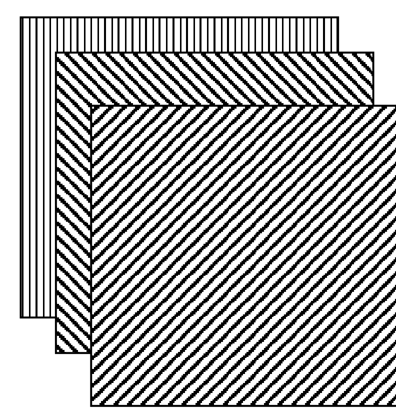
$$\nu_e + n \rightarrow p + e^-$$

As these charged particles pass through the LAr, they ionize the Argon atoms:



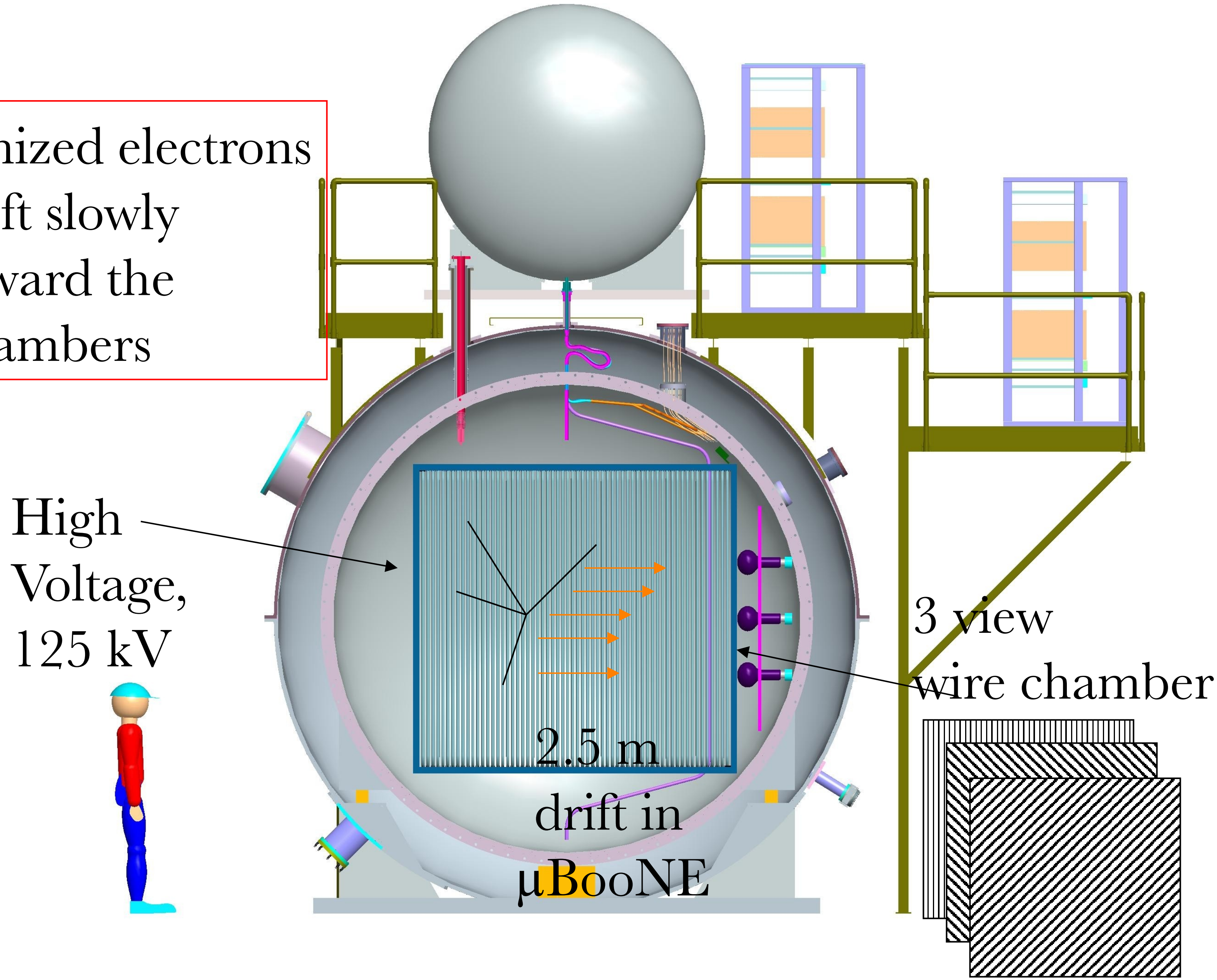
Resulting "ionization electrons" drift due to an applied electric field into a wire chamber

wire chamber



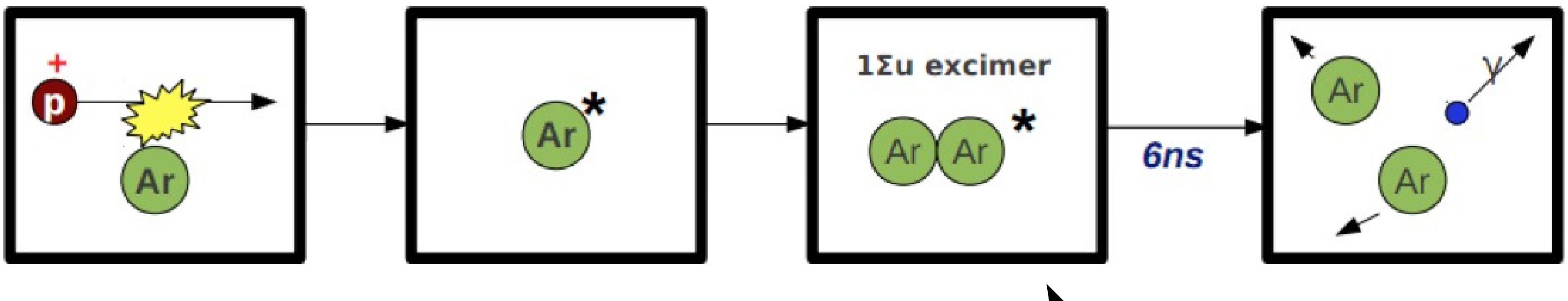
Example: MicroBooNE

Ionized electrons drift slowly toward the chambers

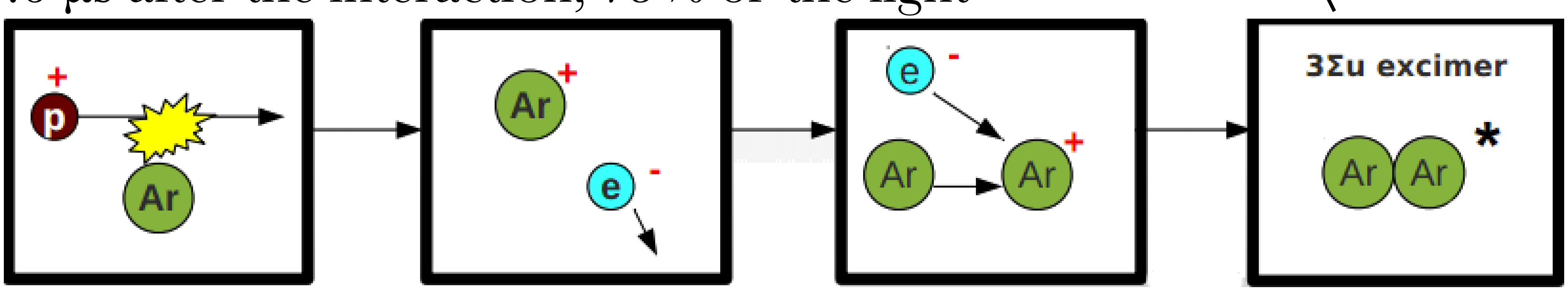


Light in LAr

Fast scintillation path
~6ns after the interaction, 25% of the scintillation light



Slow scintillation path
~1.6 μs after the interaction, 75% of the light



In both cases, this light is emitted at 128 nm, which our phototubes cannot see since it can not get through the glass

128 nm is in the "vacuum UV" so it doesn't even propagate through air!

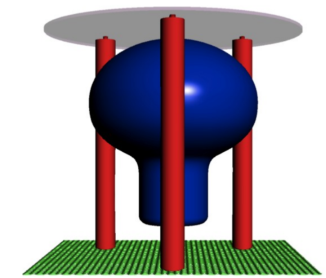
Why light detection in LAr is important

- Rejection of background by comparing interaction time with beam time structure
- Triggering on interesting non-beam events
- Correcting for charge losses and diffusion as a function of drift distance for a more accurate measurement of the energy deposits
- Reduce noise by comparing optical and TPC data

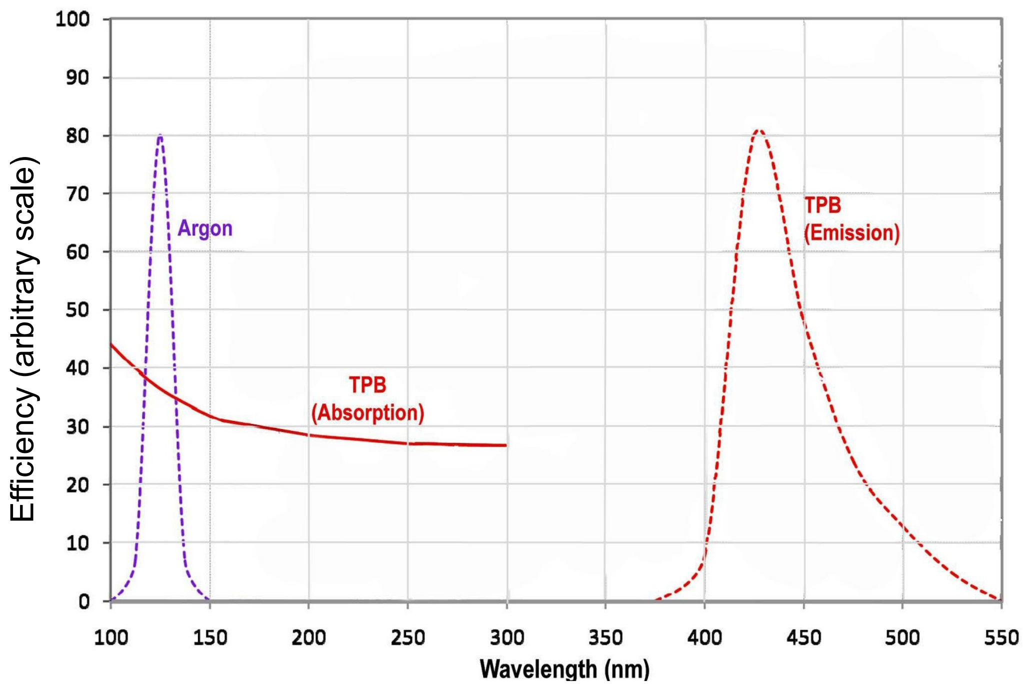
TPB

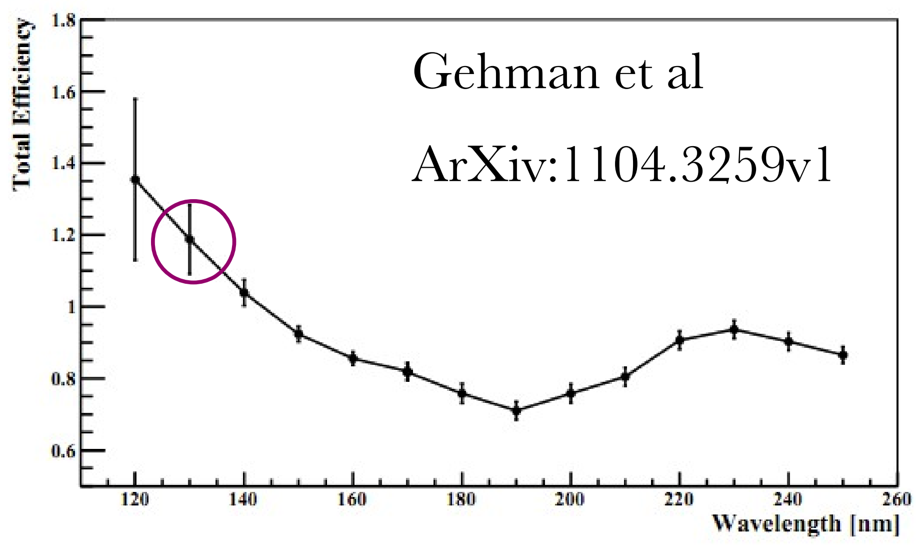
- We detect the UV light using a wavelength shifting material, Tetraphenyl Butadiene (TPB)

- Currently, many experiments are coating PMTs or plates in front of PMTs with evaporative coatings of TPB or a mixture of TPB and Polystyrene to detect the light produced in LAr



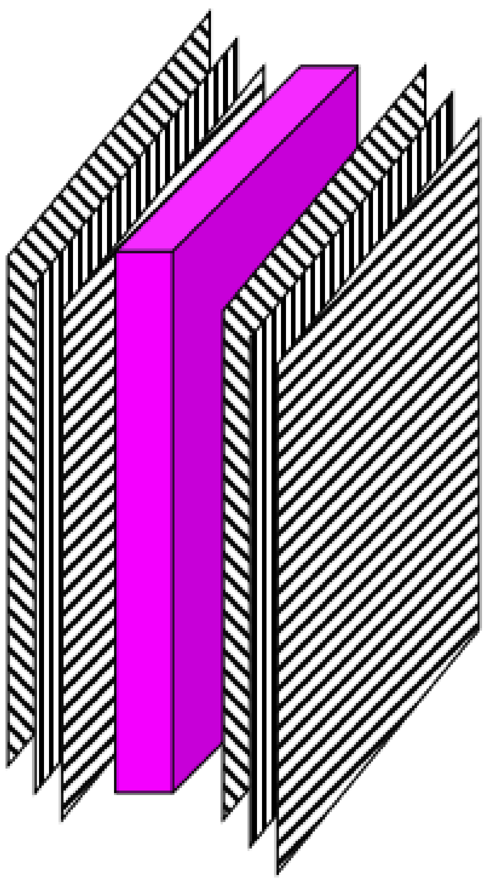
Model of PMT mount with TPB coated plate in MicroBooNE





Scaling up to multi kton detectors

Light detection along the outside edge of detector unlikely to work.
Rayleigh scattering leads to a high chance that interior light will hit wires and be absorbed.
Needs a flat system that can be inserted in interior, w/i wire planes



Solution: lightguides that slide between the wireplanes

Why Light Guides?

- Can go places that phototubes can not such as in electric fields and tighter spaces
- More coverage so possibly less phototubes needed
- Takes up less space, so more fiducial volume for your detector

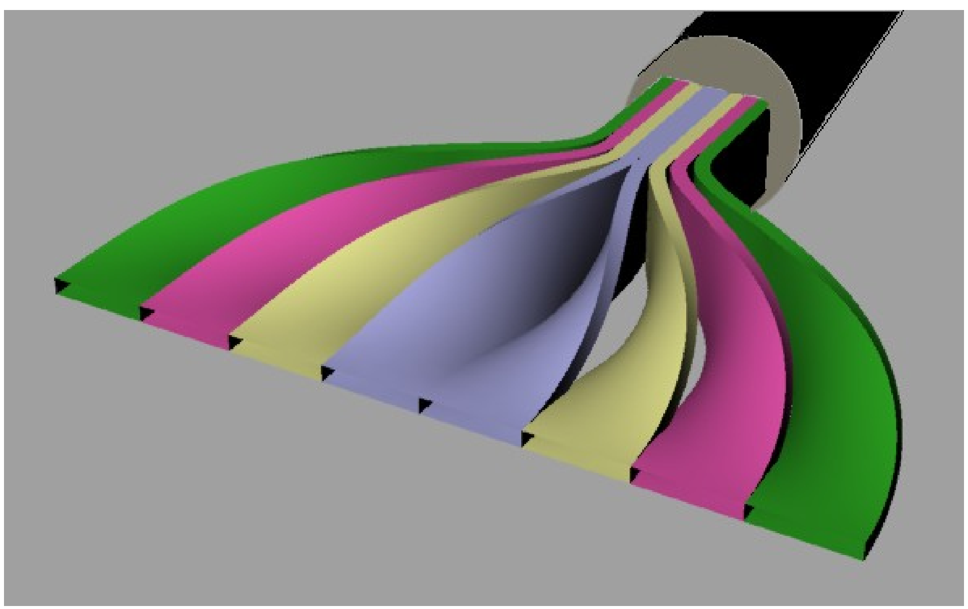
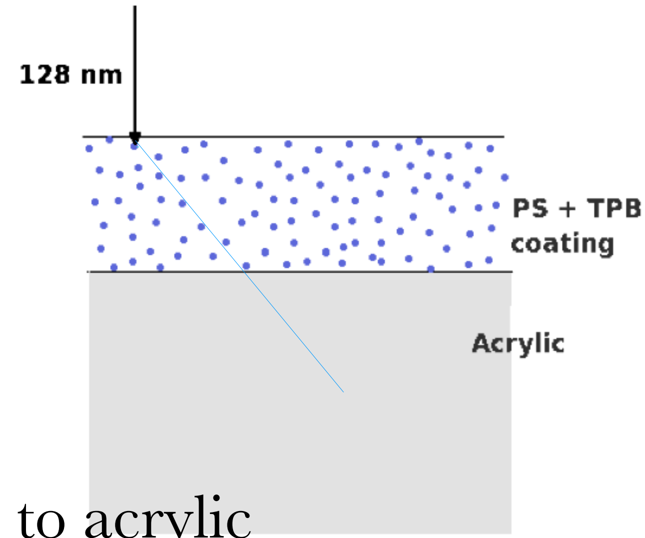


Illustration by Tess Smidt

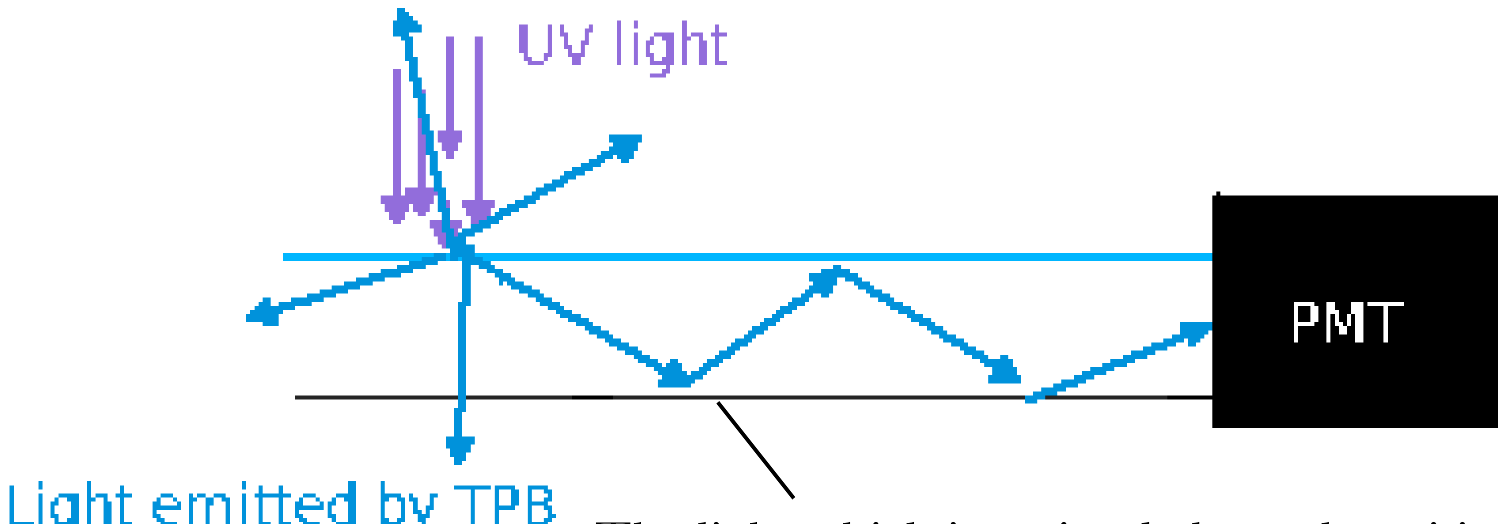
Adiabatic bending still allows light to be transmitted down the rod

Acrylic Rods as Light Guides

- TPB embedded in polystyrene (PS)



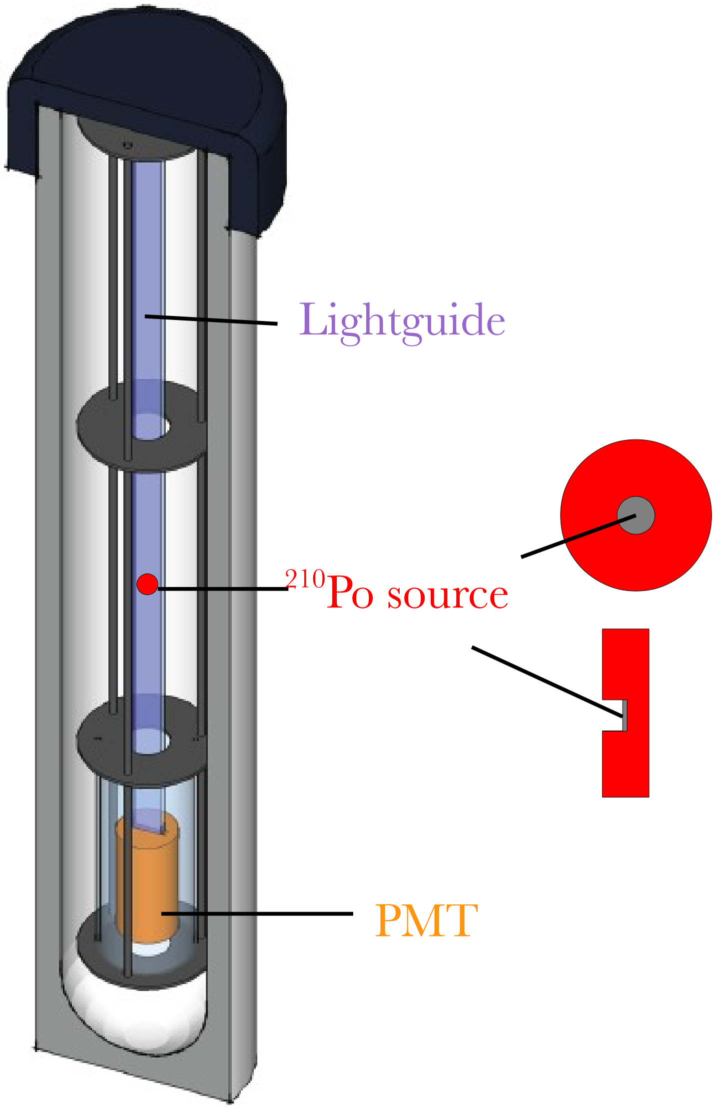
- PS is a good index of refraction match to acrylic
- Light emitted by the TPB coating is essentially produced inside the rod (needed for total internal reflection)



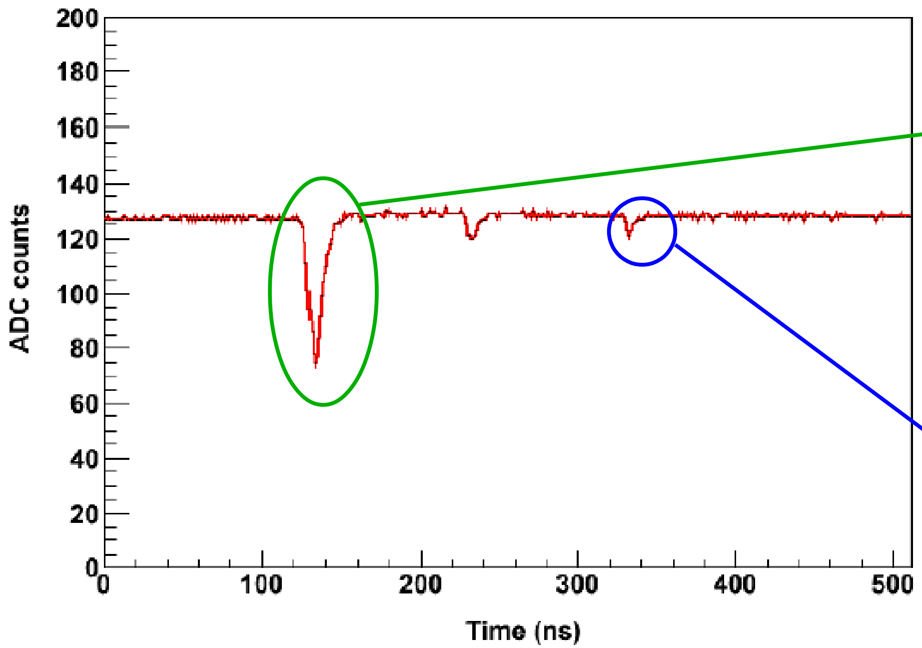
The light which is emitted above the critical angle is totally internally reflected down the lightguide

Testing

- The lightguides are tested using a ^{210}Po source which produces 5.3 MeV α particles
- The α particles travel 50 μm in Argon and produce photons along this path, some of which hit the lightguide and are transmitted to the PMT
- Source is located ~5 mm from the rod



PMT Response



Pulse of light from an alpha particle. Quantized by number of photoelectrons

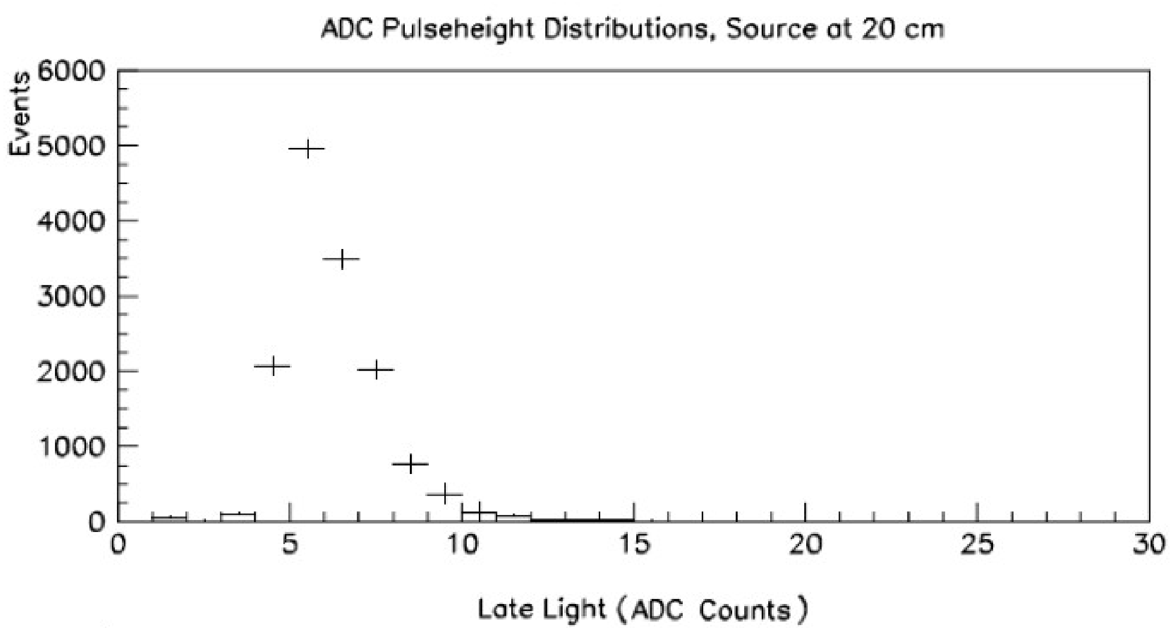
We would like to know how many photoelectrons!

A one photoelectron pulse

We use an AlazarTech ATS9870 digitizer for data acquisition

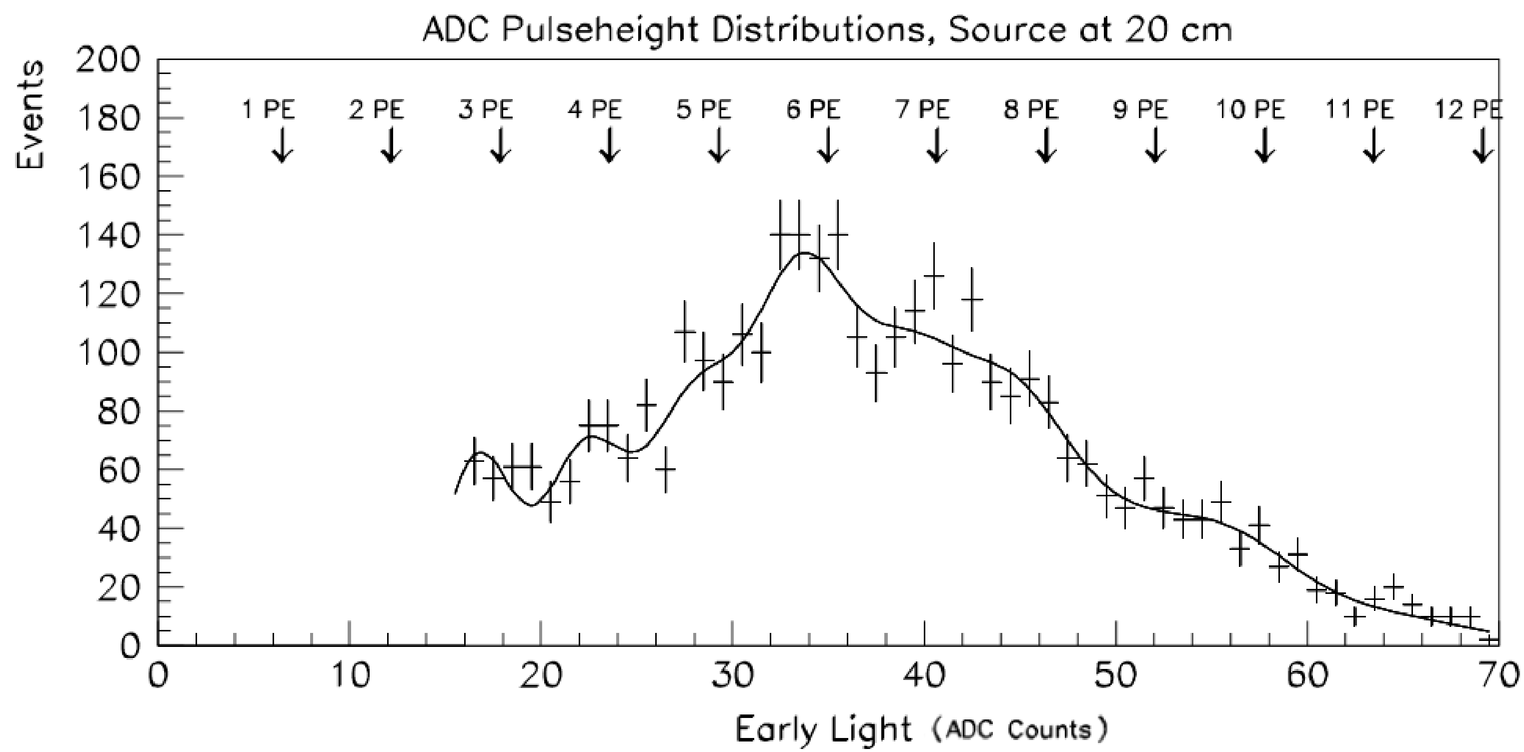
Calibration

- Define one photoelectron (p.e.) so we know how many ADC counts it corresponds to
- We can use this information to find out how many p.e. are in an early light pulse
- The resulting fit gives 5.7 ADC counts per p.e.



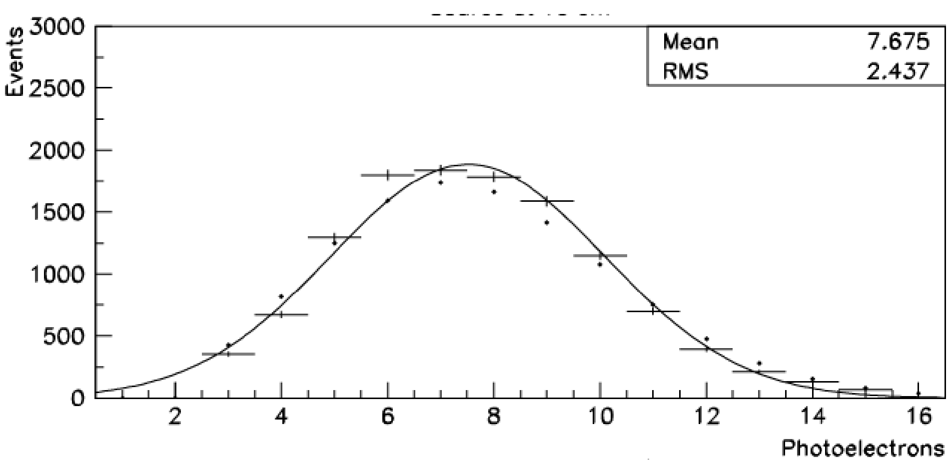
Example early light distribution

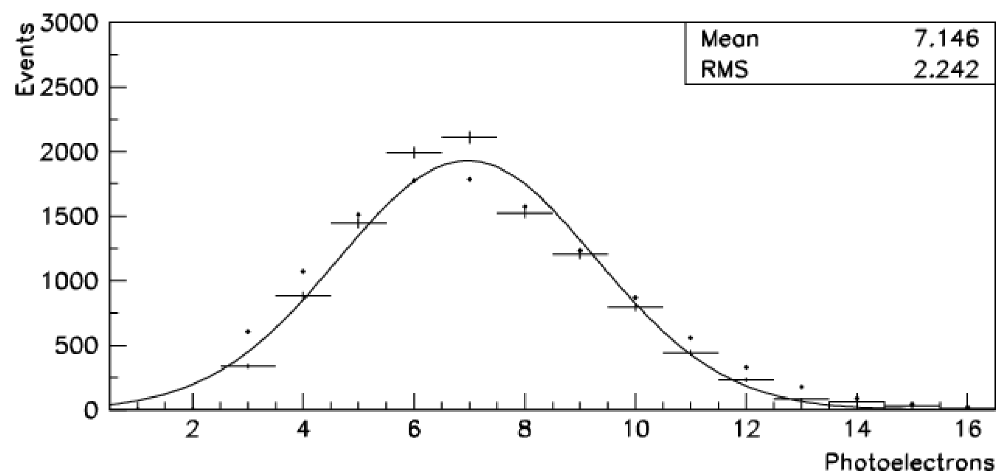
- Data forms peaks, representative of a Poisson distribution around each number of p.e. that a pulse can have
- Fit is to 10 equally spaced Gaussians, with spacing allowed to float
- Resulting fit yields 5.7 ADC count spacing, which is in agreement with previous slide
- Peaks formed by overlapping Gaussians



Variations in coating - Repeatability

We find that our coating is pretty uneven, and are currently investigating new coating methods

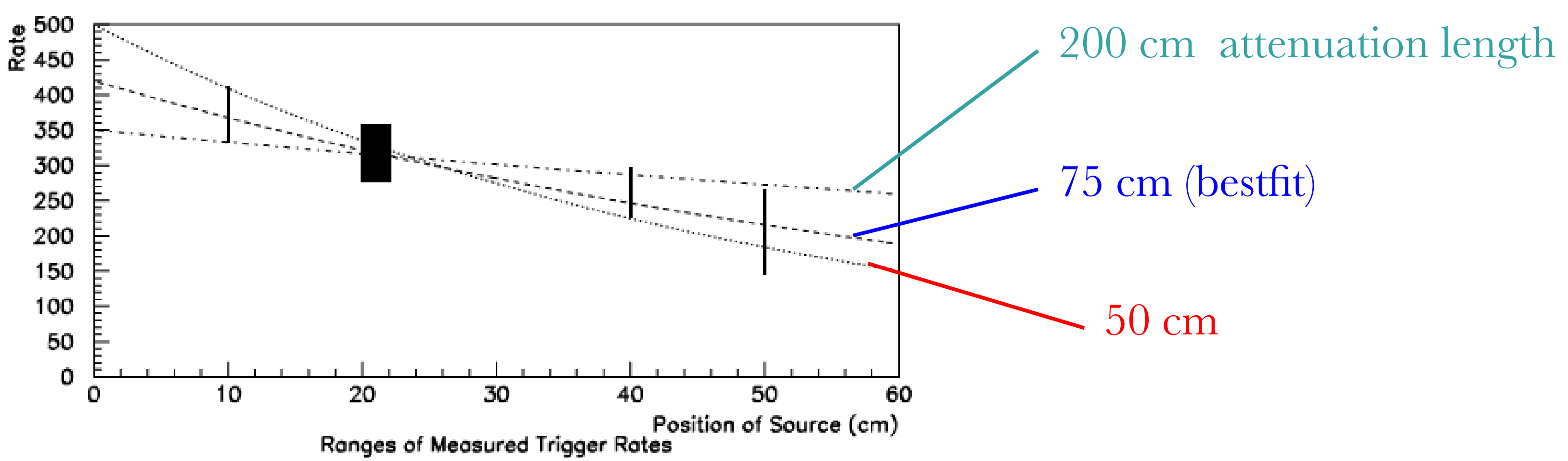




Example of two measurements done at the "same" place on the lightguide, 10 cm away from the PMT

Attenuation lengths

- Measure attenuation length by comparing trigger rates at multiple points along the bar (subtracting cosmic ray background)
- Large error in attenuation length measurement due to variations in coating along the bar
- Very conservative: 50cm attenuation length (but we think we can do better!)



Ideal light yield (ref: arXiv:1101.3013)

Parameters Used in Ideal Calculations				
#	Parameter	Value in Calc.	Source	See Sec(s)
Related to UV light production				
1	Early (< 10 ns) UV γ/MeV (MIP)	7600	Ref. [14]	4 & 6
2	Light reduction factor for α	0.72	Ref. [14]	4
3	Light reduction factor for p	0.81	Ref. [15]	6
Related to Geometry of Teststand				
4	Acceptance of UV light	0.33	calculated	4
Conversion and Capture in the Bars				
5	UV/visible γs, evaporative coat	1.0	Ref. [16]	4 & 6
6	Response, bar coating to evap.	0.1	measured	4 & 6
7	Capture fraction	0.05	calculated	4 & 6
PMT response				
8	QE of 7725 PMT	0.25	Ref. [9]	4 & 6
9	Cryogenic modification factor	0.8	Ref. [10]	4 & 6

Combining Parameters to Calculate Efficiencies				
	Efficiency	Value	Combined Params.	See Sec(s)
10	Efficiency to convert and capture	0.005	$5 \times 6 \times 7$	4 & 6
	Total Ideal Efficiency	0.001	$8 \times 9 \times 10$	4 & 6

Predict 10 p.e. Per alpha particle

Additional factors when in a TPC:

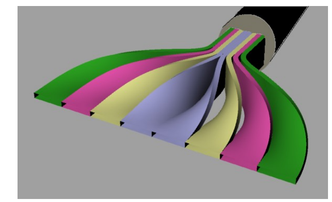
Suppression due to electric field: **66%**

Suppression due to blockage by wire planes: **~20%** (MicroBooNE simulation)

Addition from reflection of UV light: **~20%** (ICARUS)

What can be done right now?

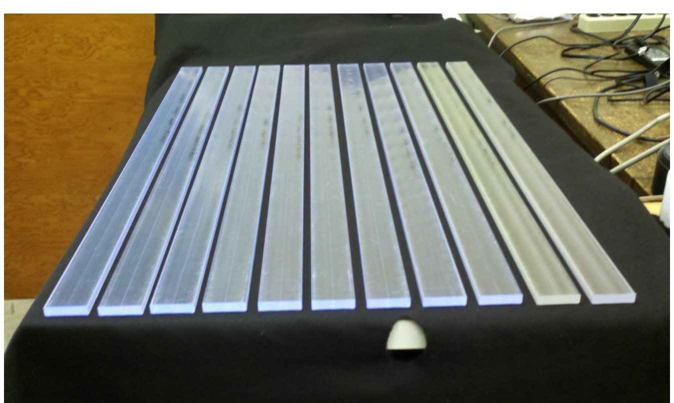
- Consider:
  - 1 m long paddles made up of 8 2.54 cm wide bars curving into a 2 in PMT (2032cm^2 collection area)

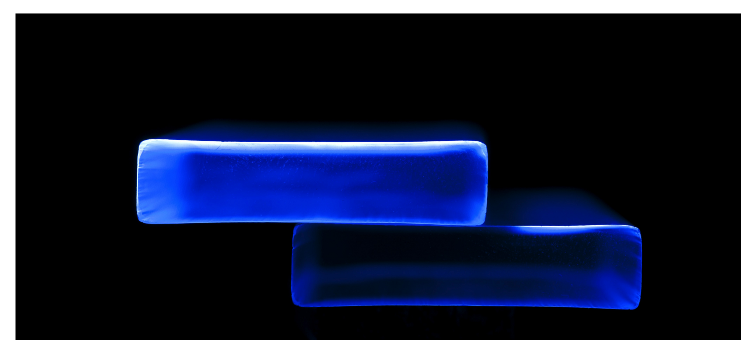


  - Collection for MicroBooNE experiment: 1.1x10^6 cm^2 surface area (~150 ton volume)
  - Reduction factor of 60% from ideal expectation (2 m attenuation length + reduction from experimental studies)
- 40 MeV proton: expect 2.5 x 10^5 UV photons
  - 27 paddles (2% coverage) needed to detect 5 p.e. (17 paddles for ideal case)
- 5 MeV electron (such as from supernovae)
  - 42% coverage needed (~650 paddles... not quite there yet)
  - 357 for ideal case, or 36 10m long paddles
- Still at beginning stages of R&D!
  - Even now, it would get better if make lightguides longer or fit more per PMT

Near Future

- Production of lightguides through co-extrusion—PS bar with PS+TPB coating
- Testing with Bis-MSB (since it was readily available)
- Investigating possibilities and cost of doing this with TPB
- Smooth and consistent coatings possible, much longer attenuation lengths might be possible.

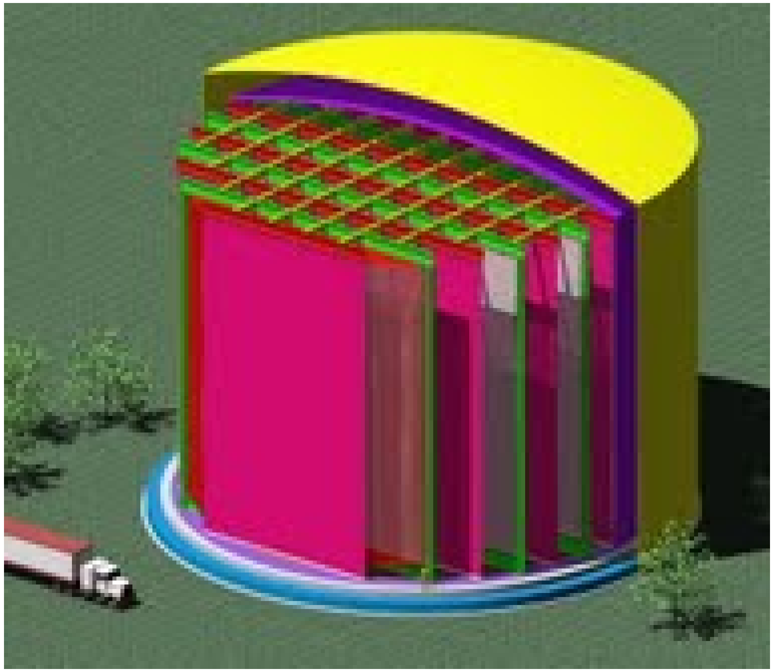




Our Demonstration Detector

- Plan to set up at MIT this summer
- Phototubes ringing top with paddles hanging down
- Only need one side of rods coated with TPB
- Goals for this year:
  - See Michel electrons
  - Address some of the things we will see in MicroBooNE and future large LAr detectors

Our Demo detector



100 kTon Next Generation LAr detector

Conclusion

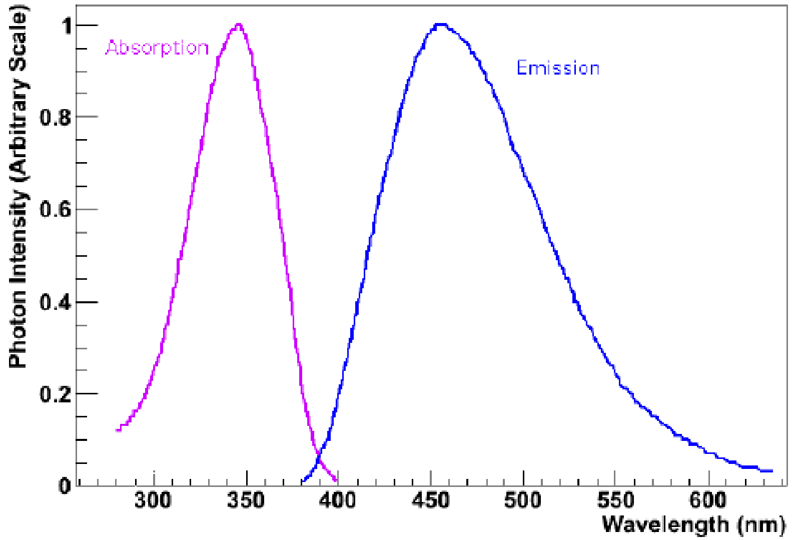
- Currently, 30 1-m long paddles would be good enough for triggering on a 40 MeV proton in MicroBooNE
- Seems likely we will get better attenuation lengths by investigating coating methods
- Beginning of R&D studies... lots of room for improvement!

Backup

TPB Self Absorption

Berlman: “Handbook of fluorescence spectra of Aromatic molecules”

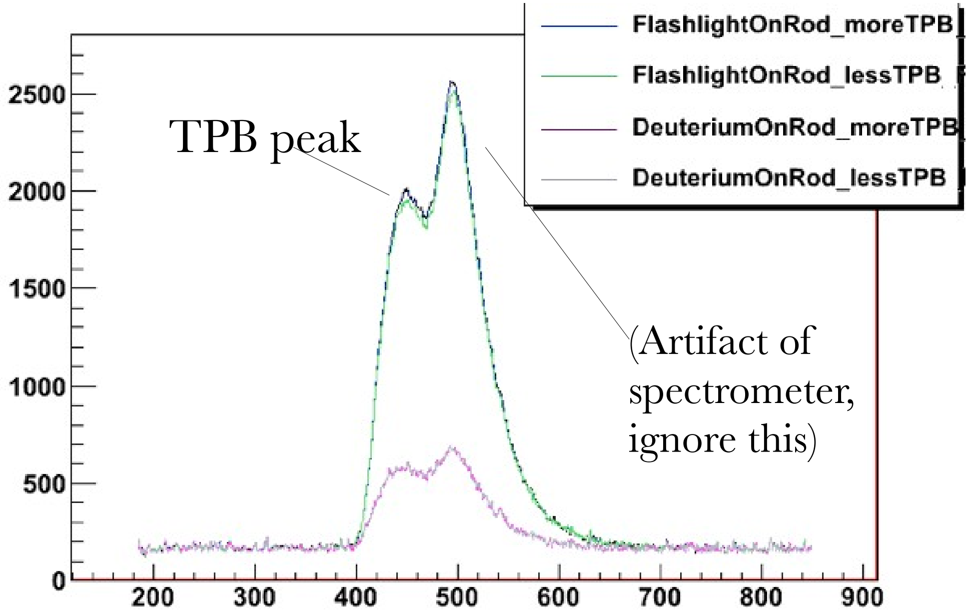
Little overlap between curves



Preliminary TPB self-absorption study:

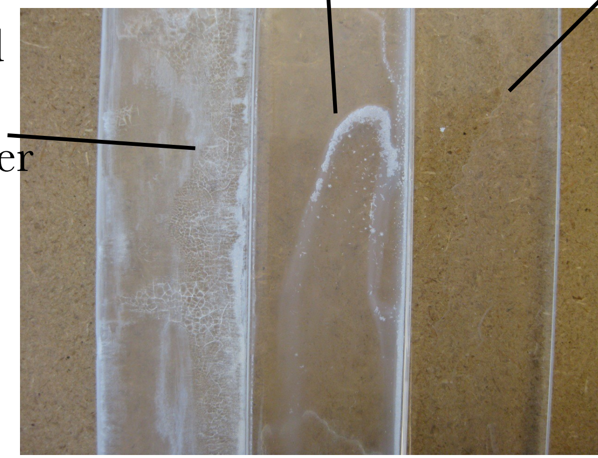
High concentration of tpb in cuvette looking at light output from a lightguide (so only light from TPB emission)

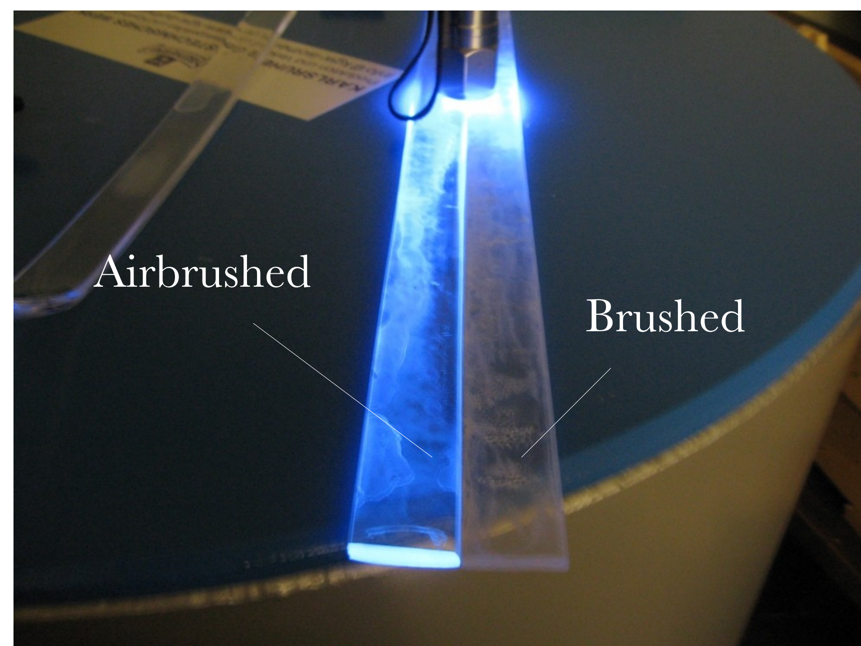
The two sets of curves overlap pretty exactly... Looks like no self absorption



Switch from Brushing to Airbrushing

- Attenuation length of ~60 cm from our first airbrushed rod (10cm from brushed rod)
- The smoother the coating, the longer the attenuation length
- Polishing after coating rubs off TPB
- Rods for the study in this talk were coated by an auto body shop using a high volume low pressure (HVLP) gravity feed spray gun
    - This gives similar attenuation lengths but a more uniform coating





Comparison of coating methods (TPB coated plates)

Normalized to evaporatively coated plate