Shadowing by Wire Planes

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Abstract

In the lbne-DocDB document # 4134, Bruce Baller showed some calculations of photon transmission through the TPC wire planes. As a reality check, we have measured light transmission through the existing 6-plane prototype in Lab 6, for normal incidence and 45 degree incidence. The results agree well with the predictions of the simple formula in Bruce's paper.

The Light Detector and the Setup Geometry

The measurement calls for a light detector with linear response and good stability.

We have found that a set of 4 Solar cells, connected in series, produces a current strictly proportional to the incident light intensity, independent of the current meter range. The cells came from an abandoned yard LED lantern, and were installed in a cardboard box to baffle ambient light:

The linearity was checked with a set of 3 lamps in a common fixture, by turning on 1, 2, or all 3 lamps in all combinations to make sure they add as expected:

Linearity check:

2000 microamp range.

Lamp lit	Current [microamp]	Expected	diff^2	Difference
ABC	165	171	36	-6
BC	110	112	4	-2
C	56	56	0	0
BC	110	112	4	-2
B	55	55.5	0.25	-0.5
AB	114	114.5	0.25	-0.5
A	59	58.5	0.25	0.5
AC	116	115	1	1
ABC	172	171	1	1
BC	113	112	1	1
C	56	56	0	0
AC	114	115	1	-1
B	57	55.5	2.25	1.5
AB	116	114.5	2.25	1.5
A	60	58.5	2.25	1.5
AC	118	115	9	3
ABC	175	171	16	4
A	60	58.5	2.25	1.5
			82.75	
Fit parameters				
Zero	-0.5			
A	59		59	
B	56		56	
C	56.5		56.5	

Testing dependence on themultimeter range:

Range[microamp]	Current
2000	180
200	180.4
20000	181
2000	181

No range dependence seen

The Setup

We set up the light source (a 1000 W Halogen lamp) and the detector (4 solar cells in their cardboard box light baffle) in Lab 6 at Fermilab at night.

Source and detectors were kept in a fixed location, while the Wire chamber was inserted and removed from the beam a couple of ties to get a good reading on stability and reproducibility. Both were excellent.

For the 45 degree measurement, the source and detectors were moved a little closer for space reasons.

Here is a picture of the setup:

Here are the results:

Setup:		
Room light + halogen lamp through the wire planes	110.7	microamp
Halogen only	105.6	microamp

Condition (All Halogen only, Room lights off)

Normal incidence:		
Through wires, normal	105.6	microamp
open	126.4	microamp
Through wires, normal	106	microamp
open	127.5	microamp
Through wires, normal	106.8	microamp
Average open	**127.0**	
Average through planes, normal	**106.1**	
Transmission factor	**0.836**	
Set up for 45 degree incidence		
Through wires, 45 degrees	183	microamp
open	227.5	microamp
Through wires, normal	183.5	microamp
open	228	microamp
open	228	microamp
Average open	**227.8**	
Average through planes, 45 degrees	**183.3**	
Transmission factor	**0.804**	
Halogen off, room light off	less than 0.1	microamp

Expectations for Normal Incidence

Using simply the open area between wires (as also shown in Bruce's paper), for normal incidence, we expect

Wire spacing	5	mm
wire diameter	0.15	mm
Wire plane angles	0, +- 60 degrees	
Normal plane transmission, no reflection	0.970	
Expected for 6 planes, normal	0.833	

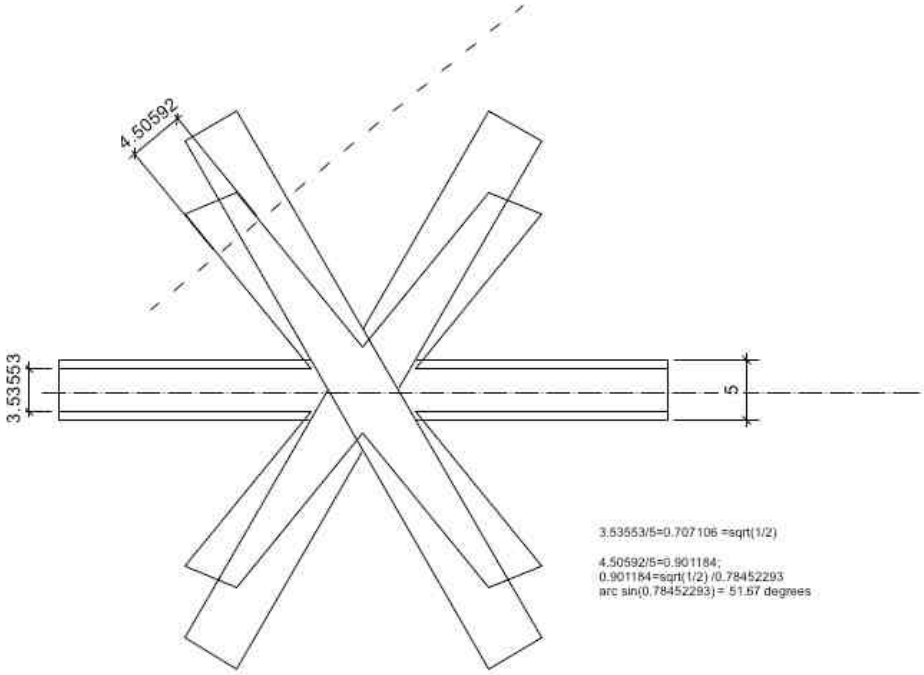
This agrees very well with the data (see above), measuring a transmission of 0.836

Expectations for 45 Degree Incidence

Here the situation is a little messier.

The projected wire plane opacity depends only on the azimuth angle around the wire direction, not the dip angle.

I used my CAD program to sidestep the 3D angle issues:



The 'Star" has been rotated 45 degrees
out of the base plane,
to measure the projected wire spacing.

The three rectangles represent 2 wires each, strung at 60 degrees, as shown in the undistorted “star”.

The same “star” has been rotated about a horizontal axis to get the distorted star with the projected wire spacings as marked.

For the vertical wires the projected spacing is now 3.53553 mm , which is smaller than the actual spacing by sqrt(2), as expected.

For the 60 degree rotated planes we find a projected wire spacing of 4.50592, which means it is reduced by the same sqrt(2), but augmented by 1/0.78452. The arc sin of this factor is 51.7 degrees, not the 60 degrees that5 I had naively expected.

From this we can calculate the expected transmission of the six planes:

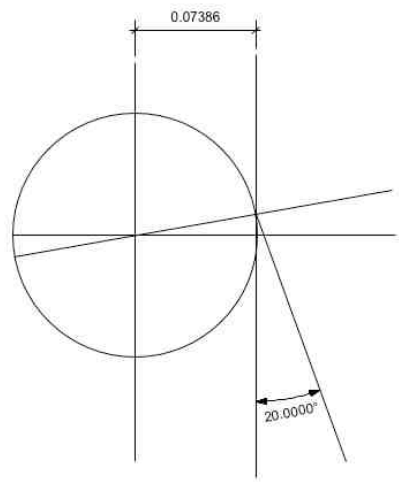
60 degree planes:

Projected spacing of vertical wires	3.536	mm
Projected transmission for one plane	0.958	
Projected spacing of 60 degree wires	4.506	mm
Projected transmission for one plane	0.967	
Expected Transmission through the 6 planes	0.801	
Measured Transmission through the 6 planes	0.804	

There is excellent agreement between the simple calculation and the measured data.

Effects of Reflection

The setup included reflected light only from about a 10 degree cone. Assuming perfect reflectivity, we can calculate the wire diameter and transmission factor assuming all reflected light within the maximum cone angle is included in the detected light.



The ray which gets deflected by 20 degrees
strikes the wire at a distance of 0.07386 mm from the wire center.
The wire size appears to shrink from 0.15 mm to 1.4772 mm,
a reduction by 1.52%

This effect is small, even for perfect reflectivity and large light acceptance cone angles:

Light deviation angle [degrees]	Diameter factor	effective wire diameter [mm]	1-plane Transmission	6-plane transmission
0	1	0.15	0.970	0.833
5	0.99905	0.149857233	0.970	0.833
10	0.99619	0.149429205	0.970	0.834
15	0.99144	0.148716729	0.970	0.834
20	0.98481	0.147721163	0.970	0.835
25	0.97630	0.146444401	0.971	0.837
30	0.96593	0.144888874	0.971	0.838
35	0.95372	0.143057543	0.971	0.840
40	0.93969	0.140953893	0.972	0.842
45	0.92388	0.13858193	0.972	0.845
50	0.90631	0.135946168	0.973	0.848

We see that the effect of reflections off the wires is quite small.

Notes on the Real Life of Light Inside a TPC

a. light generated near the photon detector (i.e. near the TPC wires) is bountiful, and we need not worry about complicated details

b. Light made further from the TPC wire planes needs a Monte Carlo calculation which includes Rayleigh scattering.