ENHANCED LIGHT COLLECTION USING WAVELENGTH-SHIFTING PLASTIC PLATES

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# Motivation

- PMTs significant portion of WCD cost
  - PMT (+Base) cost (estimate): off the shelf cost ~$4200
  - Additional casts for cabling and mounting

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Fiducial Vol. (kT)</th>
<th>Coverage (%)</th>
<th># PMTs</th>
<th>Off shelf Cost (M$)</th>
<th>25% reduced cost (M$)</th>
<th>50% reduced cost (M$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right cylinder</td>
<td>100</td>
<td>20</td>
<td>57,129</td>
<td>239.9</td>
<td>179.9</td>
<td>120.0</td>
</tr>
<tr>
<td>Right cylinder</td>
<td>150</td>
<td>20</td>
<td>73,012</td>
<td>306.7</td>
<td>230.0</td>
<td>153.4</td>
</tr>
<tr>
<td>Right cylinder</td>
<td>200 (2 x 100)</td>
<td>20</td>
<td>114,258</td>
<td>479.9</td>
<td>359.9</td>
<td>240.0</td>
</tr>
<tr>
<td>Mailbox</td>
<td>150</td>
<td>20</td>
<td>84,466</td>
<td>354.8</td>
<td>266.1</td>
<td>177.4</td>
</tr>
</tbody>
</table>

Eg. LBNE far detector with 20% coverage. PMT numbers (not costs) taken from John Felde (UC Davis) for LBNE far detector simulation

- Even 10% less PMTs leads to significant cost reduction.
- Improved light collection efficiency is potential solution
  - Reflective cones (used in SNO)
  - WS plates (explored for IMB)
  - WS PMT coatings
  - Combination (plates or cones with WS coating)
WS Light Collector Plates

• Explored for IMB
  • Square plates were pressure fit to the PMT
  • Demonstrated improvement (doubling) in collection efficiency


• Improvements in design to be made
  • Circular geometry (20” outer radii prototypes)
  • Index matched RTV between plate and PMT
  • Tyvek with black backing on plate back.
    • Idea is to diffuse the light back into the plate and prevent escape through back
Investigating a Prototype WS Plate for LBNE Water Cerenkov Far Detector

• 1 approach being studied (others discussed at this meeting)
• Plan is to have baseline result by Oct 1, 2010
  • demonstrate increase in efficiency warrants further study
  • if potential to improve efficiency further studies undertaken
• Potential benefits of WS plate
  • Relatively cheap and easy to manufacture
  • Efficiency increase scales with plate size
  • Base plastics well understood - polyvinyl toluene (PVT)
  • Minimal blocking of PMT cathode (depends on plate backing)
• Potential issues of WS plate
  • Difficult to simulate (WS plastic absorption and re-emission)
  • Reflections back into vessel volume
  • Degradation of physics (smeared out timing)
  • Increased dark rates
  • Effect on WS plastic by backgrounds (uranium and thorium)
  • Cosmic hits in plates
Current Plan (complete by Oct 1, 2010)

• Build and Test Prototype
  • Prepare test facility ✓
  • Acquire 10” HQE PMT ✓
  • Basic characterization of PMT (dark rates, gain, etc…) ✓
  • Acrylic prototype ✓
  • WS plastic prototypes (expect delivery week of Sept 20th)
  • Measured LC efficiency, dark rates, timing degradation

• Personnel and facilities
  • Buchanan (faculty – planning and management): started @ CSU July 1, 2010
  • Warner (engineer – design, much experience with plastics, RTV, etc…)
  • Johnston (student – data collection, test setup, analysis)
  • Technicians (senior + temp – mechanical and assembly work)
  • Machine shop (+ Machinist – capable of all machining needs)

• Simulations
  • Due to short timeline no simulations before October
  • Single device and full detector simulation after empirical measurement
Dark Facility

- Needed dark "room" large enough for water tank
  - added large cabinet to small existing lab space
  - 3 separate dark spaces – allows source in different location, but close by
  - feed-throughs for electrical signals, power, and optics

3 isolated chambers

Feed-throughs
Also optical feed-through between chambers 1 and 2
Test Setup

DAQ room

SRS pulser

LED

0.5 m fiber

splitter

5.5 m fiber

Reference PMT

Chamber #1

Chamber #2

5.5 m fiber

diffuser

10” PMT

LC plate
Test Setup cont...

• Use LED as light source
  • 405 nm LED provide Cerenkov-like photons
  • adjusted to give ~20 photons/integration gate

• Low tech – black plastic 55 gal. drum
  • cut top off to hang PMT/plate from
  • fiber runs to bottom and into quartz light diffuser

• 2nd PMT used as reference
  • time reference for time degradation measurements
  • allows cancellation of LED fluctuations
Test PMT

- Using a Hamamatsu HQE 10” R7081 PMT
  - On loan from UPenn – slight chance they may get a working unit back
  - Attached a collar to allow safe handling and mounting for tests

Characteristics

- Gain $\sim 10^7$ at 1585 V bias
- Dark rate: $\sim 4$kHz after 24 hours in dark
Prototype #1 – Acrylic

- WS plastic delivery delayed until around Sept 20th
  - Use acrylic as a first prototype
    - Work through mechanical details
    - Test RTV bond of Tyvek to plate
    - Dry run of full readout and analysis

RTVing Tyvek to plate
(using RTV6136 (1:1) mix – cured for >4 hrs)

PMT area: 78.5 in²
Plate area: 235.6 in²

Tyvek attached

Tyvek has black backing (used for Auger water bladders)
Prototype #1 on PMT

- Test fit (no Tyvek)
- Leveling LV plate on PMT
- Injecting RTV into air gap
- Injecting RTV into air gap
- LC prototype with Tyvek backing mounted on PMT
WS Plastic Prototypes

- 2 WS plastic prototypes
  - blue-green to couple directly to PMT
  - blue-blue to couple to WS coating on PMT (also shorter decay time)

- WS plastics same base as used in scintillator plastics
  - Polyvinyl toluene (PVT)
  - slightly softer than acrylic - requires slightly slower machining

- BC-499-76 (blue-blue) has short decay time (2.1 ns)
  - replaces BC-480
  - better match to potential WS film coatings on PMT?

- BC-482A (blue-green) slightly longer decay (12 ns)
  - better match to PMT without coating

<table>
<thead>
<tr>
<th>WS Plastic</th>
<th>Vendor</th>
<th>Type</th>
<th>Base</th>
<th>Index of Refraction</th>
<th>Decay Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC-499-76</td>
<td>Saint-Gobain</td>
<td>Blue - Blue</td>
<td>PVT</td>
<td>1.58</td>
<td>2.1 ns</td>
</tr>
<tr>
<td>BC-482A</td>
<td>Saint-Gobain</td>
<td>Blue - Green</td>
<td>PVT</td>
<td>1.58</td>
<td>12 ns</td>
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</tbody>
</table>

Some specifications of test WS plastics
Current Status

- Testing acrylic prototype in air
  - nailing down technique and analysis
  - want to minimize activity that might stress PMT
- Using 2nd PMT to monitor LED and provide $t_0$ for timing studies
  - perform event-by-event subtraction to remove LED fluctuations
- 2 DAQ settings for slow (raw) and fast (pre-histogrammed) collection

Reference PMT

ADC bin (arb units)

10” Test PMT

Pedestals for both PMTs at operating settings

Reference PMT

ADC bin (arb units)

10” Test PMT

Flashed LED for both PMTs at operating settings
Tests on Acrylic Prototype

• **Dark rate**
  - initial dark noise rate higher with disk attached
  - after 24 hours in dark box rates with and without disk were the same

<table>
<thead>
<tr>
<th>WS disk attached</th>
<th>Initial dark rate</th>
<th>Dark rate after 24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>40 kHz</td>
<td>4 kHz</td>
</tr>
<tr>
<td>Yes</td>
<td>120 kHz</td>
<td>4 kHz</td>
</tr>
</tbody>
</table>

• **Light Collection Efficiency**
  - No measureable increase (or change) in ADC spectrum when plate attached
  - Not unexpected as acrylic not “active” …but see below

• **Cross-checks to be performed**
  - Use photo-sensor (Hamamatsu MPPC) to map photon distribution at tank top
  - Remove RTV between plate and Tyvek
    - RTV at interface might be changing Tyvek diffusion properties
Cost Estimates and Production Feasibility for WS Plates

<table>
<thead>
<tr>
<th>BC-499-76</th>
<th>Tyvek+RTV</th>
<th>Misc costs (setup, mounting, etc...)</th>
<th>Total unit cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>$225/unit</td>
<td>$2/unit</td>
<td>~$70/unit</td>
<td>~$300</td>
</tr>
</tbody>
</table>

- **Estimate for plastic based on 25 sheet run (2’ x 4’)**
  - presumably we could negotiate lower cost for much larger run

- **Technical support contact at S-G claims large production OK**
  - can produce 700 kg to 1000 kg per week (~250 – 350 plates/week or 3 years production)
  - can produce sheets 32” x 100” sheets – >1 cast in parallel
  - production has to be worked in with existing orders
  - have not talked with other vendors (eg. Eljen Tech.)
Longer Term Plans

• Simulations
  • need significant simulation at device and detector level
  • will aid in paring down my crazy ideas
  • use Geant4 with visible photon package
  • need 50% of student for this work over next year

• Improve test facility to use cosmics
  • Would like to use actual Cerenkov light
  • Bigger test tank?

• Reflection measurements (need large tank)
  • 3m x 3m x 1m tank at UC Davis
  • build something local?

• More sophisticated prototypes
  • Light guiding (graded index planes or air bubble injection)
  • WS layer on acrylic substrate (potentially significant cost reduction)
  • Plate shaping (assumes good light guiding properties)
  • Backing materials (Tyvek, other diffusers – ground surface)

• Fabrication and mounting
And now for the half-baked ideas...
Keeping Light In the Plate

• Want to get light in the collector to the PMT
  • reflections from either surface of the plate can impact physics
  • getting as much light as possible to the PMT improves efficiency
• Playing games with diffusers on back of plate may help
  • allow some light back into plate while minimizing reflections
• Graded index laminate on the plate

- use like light guide – graded index prevents reflection boundaries
- need to be careful of increasing front face reflections
WS Plastic Layer on Acrylic Base

• Potential to reduce costs with less WS plastic
  • use thinner WS plastic layer bonded to acrylic substrate
  • increase plate area, adjust fluorescent dopant
    • need to determine change in light absorption
    • can a WS film be effective on an acrylic plate?

• Collection of light from WS layer critical
  • might need to employ light guiding techniques
    • graded index plates on front side of WS layer
    • diffuser on back side of acrylic
Some General Considerations

• Contamination
  • ultra-pure water requires hard limits on contaminants
  • all proposed materials will be heavily scrutinized
  • WS plastic bases well known – glues/RTVs will be challenging

• Pressure and Implosion Cascades
  • shockwave from implosion can be in the MPa range
  • care must be taken when planning attachment of plate to PMT
  • can plate come into ANY contact with PMT glass?

• Impact on Physics
  • this cannot be emphasized enough
  • Gain in LC efficiency wasted if physics capabilities degraded!
  • Much work to be done to make sure this isn’t the case (for all approaches to improving light collection efficiency)
Summary

- Improving light collection for PMTs can lead to significant cost savings
- Currently studying WS LC plates for potential use in LBNE
  - Results from acrylic show no measureable enhancement
  - On track to have results for WS prototypes by end of Sept.
- Motivation to look into additional enhancements to WS plates
  - Light guiding with graded index layers on front face of LC
  - Explore use of thin WS plastics on acrylic substrates
- Need to ensure physics potential of detector not significantly impacted