Progress and Status of MOLLER Main Detectors
- Simulation · Prototype

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Detector Simulation

• What we have done: single detector study, detector rings in full MOLLER simulation environment, background/interference study, optimization of detector geometry

• Basic design (1.5 cm thick quartz, 3” PMT, air-core light guide) meets our requirements, but with potential issue of background/interference.

• Most of the simulation outcomes were already discussed in smaller group meetings. Details are in a series documents: Moller-doc# 38, 39, 45, 61, 62, 63.

• The following slides will provide some supplementary updates to “geometry optimization” in order to facilitate our ongoing major work – detector prototyping for beam test.
Geometry Optimization

- **Background/interference are troublesome** (see DocDB-# 63) the major sources of the tails on #PE spectra were identified:

  - **Low-end tail**: Cerenkov light in air-core light guide
  - **High-end tail**: Cerenkov light in PMT window due to direct hit

- **Methods for reducing tails**:

  - **High-end tail**: increasing light-guide length (with side effects of less #PE), better shielding (especially, shield the beam and shower events from upstream)

  - **Low-end tail**: the idea of making **rough vacuum** in the light guide was abandoned after a group discussion with KK et. al. It was proposed to use “geometry optimization” to reduce the low-end tail.
Favorable Model

**Bottom wedge cut:**
- Allowing the Cerenkov light to escape easily from quartz with specific direction, and to reduce the loss due to bouncing in quartz

**Tilting light guide towards beam:**
- Matching the angle of escaping Cerenkov light from quartz *(green)*, so as to minimize the loss due to bouncing on light guide inner surface
- Directing the Cerenkov light in air *(blue)* to the opposite side of PMT, so that these interferences can be reduced by bouncing in light guide

![Diagram](image-url)
Spectrum of Detected Photons

**Detection efficiency** of optical photons is mainly affected by the reflectivity of light guide material and the quantum efficiency of PMT.

The number of Cerenkov photons emitted per cm is

\[ \frac{dN}{d\lambda} = \frac{2\pi z^2 \alpha}{\lambda^2} \left( 1 - \frac{1}{\beta^2 n(\lambda)^2} \right) \]

Cerenkov photons are mostly generated in deep UV

detected photon energy spectrum from simulation

Peak at ~280 - 300 nm

detected photon wavelength spectrum from simulation
Optimization of Acceptance Angle

Acceptance angle: the angle between light guide and quartz

<table>
<thead>
<tr>
<th>Wavelength [nm]</th>
<th>Refractive index n</th>
<th>Cerenkov angle $\Theta_c$ [degree]</th>
<th>$\Theta_{in}$ [degree]</th>
<th>$\Theta_{out}$ [degree]</th>
<th>Acceptance angle $\Theta_A$ [degree]</th>
</tr>
</thead>
<tbody>
<tr>
<td>180</td>
<td>1.575</td>
<td>50.6</td>
<td>5.6</td>
<td>8.3</td>
<td>36.7</td>
</tr>
<tr>
<td>250</td>
<td>1.507</td>
<td>48.4</td>
<td>3.4</td>
<td>5.2</td>
<td>39.8</td>
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<tr>
<td>300</td>
<td>1.485</td>
<td>47.7</td>
<td>2.7</td>
<td>4.0</td>
<td>41.0</td>
</tr>
<tr>
<td>700</td>
<td>1.455</td>
<td>46.5</td>
<td>1.5</td>
<td>2.4</td>
<td>42.6</td>
</tr>
</tbody>
</table>

Best acceptance angle:

From simulation, #PE yield is maximized at an acceptance angle of $\sim41$ deg, with a small tolerance ($\sim1$ deg).

Reasoning:

Optical photons at peak wavelength (300 nm) have the minimized number of bounces on the light guide surface.
Quartz Tilt Angle

In order to maximize #pe yield:

- Keep acceptance angle (41 deg) unchanged
- Tilt quartz so that quartz tilt angle = scattered beam angle
- Tilting quartz properly could produce 10 – 20% more #PE
- It is worth the effort to put more strict precision requirement on detector construction and installation.

Definition:

Scattered beam angle – the angle between the scattered electrons and z-axis
Quartz tilt angle – the angle between quartz and z-plane
Implementation

Implemented in the independent detector simulation package:

**Configuration:**
- Quartz thickness: 1.5 cm
- Length of e-e ring light guide: 34 cm
- Light guide material: Anolux-UVS
- PMT: 3” round quartz window

**#PE yield of e-e ring detector:**
- \(~37\) PE
- rms: 8.7

To see the background/interference, an implementation in the full MOLLER simulation environment is needed (not done yet)
Light Guide Material

- Light guide material should have excellent reflectivity in UV.

- Polished aluminium has super good reflectivity in deep UV.

- Concern: possible damage to interior finish of light guide due to: NOx + humidity + oxidation, etc.

- Polished Al needs dielectric protection coating, which usually degrade the reflectivity in deep UV.

- In addition, commercial products (low cost) are preferable.

Contact with ALANOD Aluminium- Veredlung GmbH & Co. KG (the major vendor):

Anolux-UVS could be a suitable choice.
Anolux-UVS from Anomet

Simulation Study:
- Implemented the spectrum in detector simulation
- OK if the actual products have the claimed responses

Average reflectivity at our band of interests (250 nm – 700 nm): ~83%
Order Information

Quick Ship Products

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Minimum % Total Reflectivity</th>
<th>Image Clarity DI</th>
<th>% Diffuse Reflection</th>
<th>Specular Reflectivity (Min.)</th>
<th>Sheet Size (inches)</th>
<th>Price per sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anolux® UVS Specular Mirror Finish</td>
<td>86</td>
<td>92</td>
<td>15-22</td>
<td>72%</td>
<td>0.020 x 48&quot; x 24&quot;</td>
<td>$45.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.040 x 48&quot; x 24&quot;</td>
<td>$63.50</td>
</tr>
</tbody>
</table>

- 25-Year Limited Warranty*: Anolux Miro® & Anolux®
- 10-Year Limited Warranty*: WhiteLite® 92 & WhiteOptics™
- We accept: Visa, MasterCard & American Express
- Prices are subject to change
- Overnight Delivery to most major North American Cities
- Choose from Standard and Expedited Shipping Services

18 Regan Road, Unit 25, Brampton, Ontario L7A 1C2

Toll Free: 1-877-813-8300

- Accepting order of single sheet or multiple sheets
- Low unit price
- Local vendors in US & Canada
- Quick ship available
# Prototyping

## Material & Component:

<table>
<thead>
<tr>
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<th>Required</th>
<th>On-hand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>18 cm x 8 cm x 1.5 cm (optical grade polish)</td>
<td>8 cm x 6 cm x 2.5 cm (need cut and polish)</td>
</tr>
<tr>
<td>PMT</td>
<td>3” quartz window</td>
<td>Hamamatsu H1949-51, 2” Borosilicate glass window (available soon: Photonics XP2268, 2” quartz window)</td>
</tr>
<tr>
<td>Light guide</td>
<td>Anolux-UVS (~80% in UV 250 – 400 nm)</td>
<td>Alazk Miro-4 (cut-off at 380 nm) &amp; Anolux-UVS</td>
</tr>
</tbody>
</table>

## Variation:

- Using on-hand materials and components to build the prototype
  (Hard to cut the 2.5 cm thick quartz to 1.5 cm thin, No 3” PMT available)

- Will do benchmark simulation against this variation
Quartz Blocks

- We have 4 quartz blocks (Qweak's leftover, thanks to Dave Mack)
- Size: $120 \times 60 \times 25 \text{ mm}^3$ (3 pieces)
- Size: $80 \times 60 \times 25 \text{ mm}^3$ (1 piece)
- Required size for MOLLER prototype: $180 \times 80 \text{ mm} \times 15 \text{ mm}^3$

- Too much difficulties to make it thinner
- Try cross cut and angle cut only
Cutting Jig

Picture of the jig for angle cut

(Another jig was made for cross cut)
Quartz Cutting

- Quartz cutting at U. of Manitoba Nano-fabrication Lab
- Using precision diamond saw (ISOMET 1000)
- Cutting loss due to blade thickness: ~1 mm
- Cutting time: 5 – 8 hours for a 45 degree cut (excluding set-up time, etc)
First Sample

- First sample was cut
- Polishing is in progress
- Second sample will be cut this week
First Detector Prototype

Reflector section

Light guide section

PMT holder

First detector prototype (using Alazk Light guide)

Image of Anolux-UVS (One sheet was ordered & received)
DAQ & Cosmic Test Setup

- Dark box: containing the trigger scintillators & the prototype detector
- Amplifier, Discriminator, Logic Unit, Charge ADC & Flash ADC
- HV power supply

- Software: TRIUMF MIDAS framework, online(realtime) & offline analysis
- Able to do charge integration analysis and single event waveform analysis
“Preliminary” Test

<table>
<thead>
<tr>
<th>Current Test Configuration</th>
<th>“Future” Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unpolished raw quartz block</td>
<td>Polished quartz with wedge cut</td>
</tr>
<tr>
<td>Alazk light guide</td>
<td>Anolux-UVS light guide</td>
</tr>
<tr>
<td>Non-quartz window 2” PMT</td>
<td>Quartz window 3” PMT</td>
</tr>
</tbody>
</table>

- Purpose: basic functionality test for cosmic ray test stand, DAQ etc.

- ~ 5 – 8 PE (very preliminary, not carefully calibrated)

- Low #PE and broadened distribution due to “non-ideal” configuration, but the signals could be clearly seen.
Summary

Simulation:

- Detector geometry was studied
- An favorable detector model was selected
- Full simulation in MOLLER simulation environment is need to quantify the Bkg-to-signal ratio, and to evaluate the effects etc.

Prototyping:

- A variation of required materials and components is available
- The first prototype is nearly completed
- Cosmic ray test stand is set up and fully functioning
- We are in rapid progress on the construction of several prototypes for the cosmic ray test and upcoming beam test.