Progress and Status of MOLLER Main Detectors

- Simulation · Prototype

Peiqing Wang & Michael Gericke
University of Manitoba

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Detector Simulation

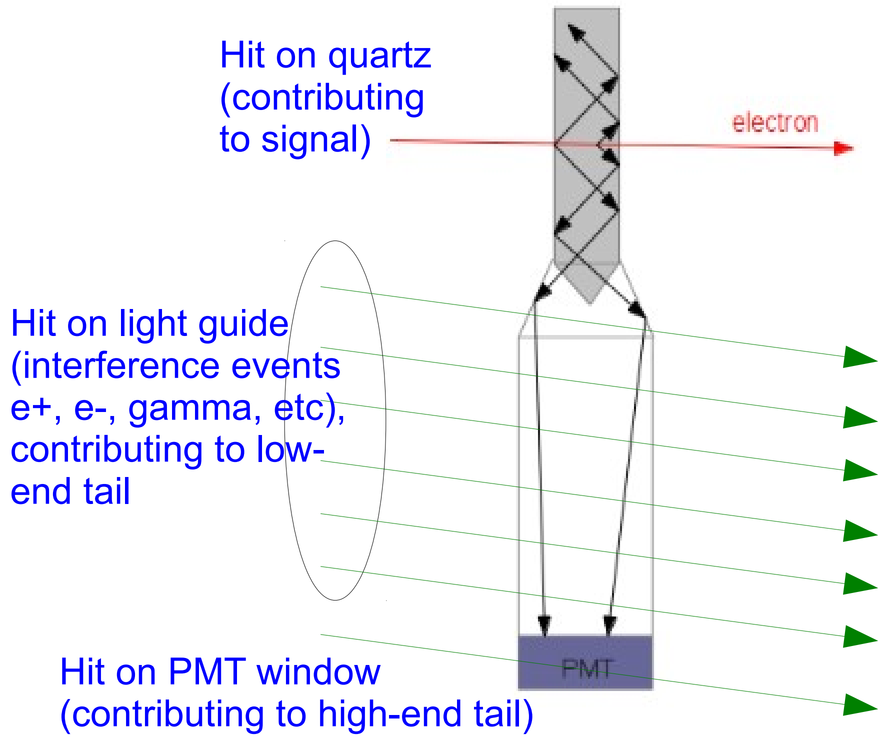
- What we have done:
  single detector study, detector rings in full MOLLER simulation environment, background/interference study, optimization of detector geometry

- 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 facilicate 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:

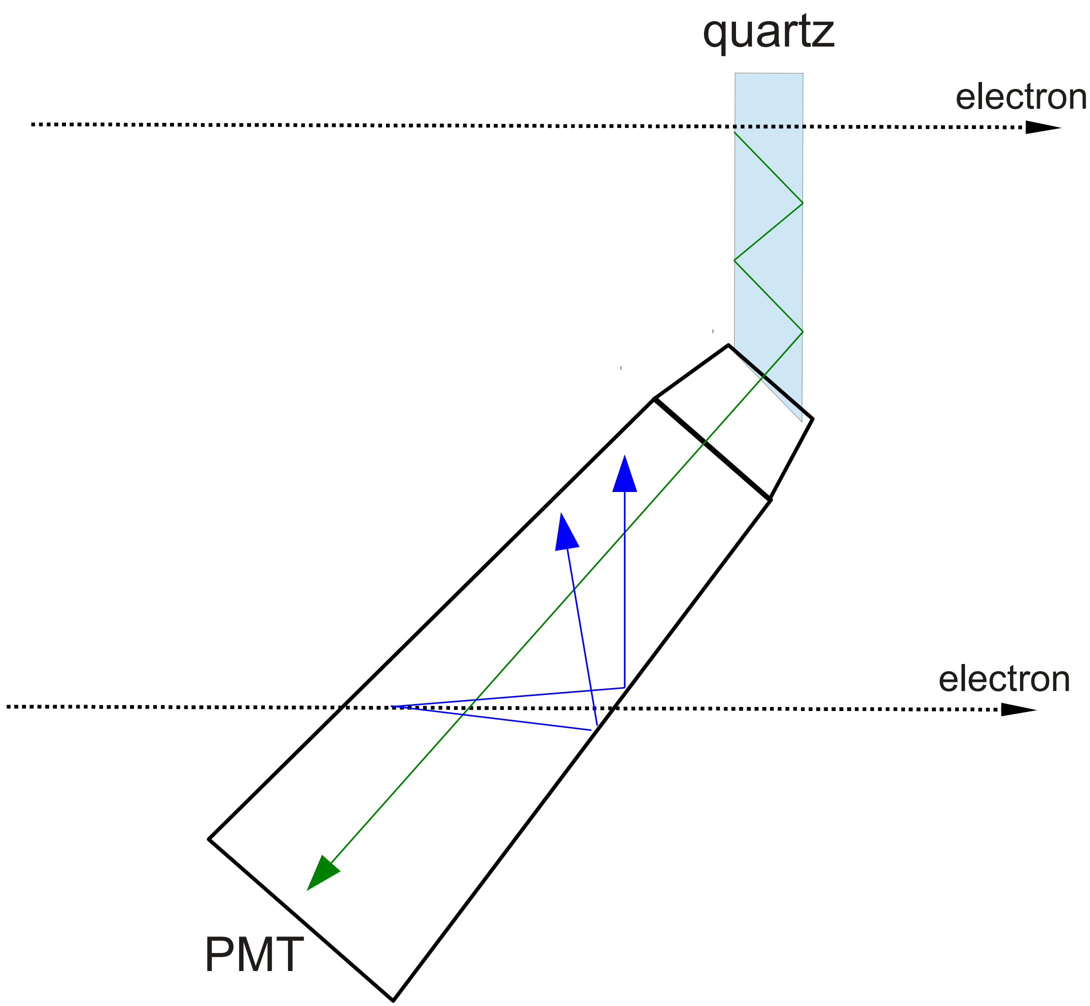
  Low-end tail: Cerenkov light in air-core light guide
  High-end tail: Cerenkov light in PMT window due to direct hit

- **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 obandoned 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

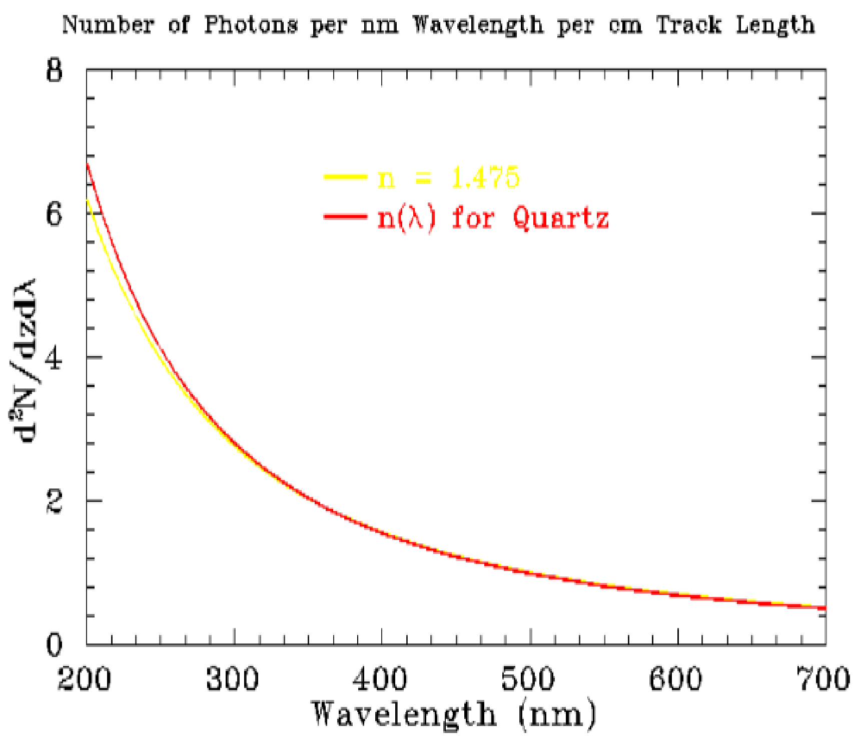
- Directing the Cerenkov light in air (**blue**) to the opposite side of PMT, so that these interferences can be reduced by bouncing in light guide

Spectrum of Detected Photons

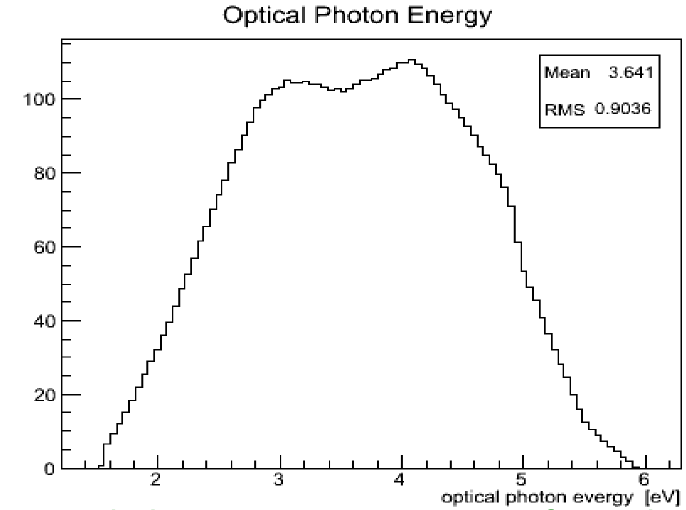
Detection efficiency of optical photons is mainly affected by the reflectivity of light guide material and the quantum efficiency of PMT

The number of Cerenkov photons emitted per cm is

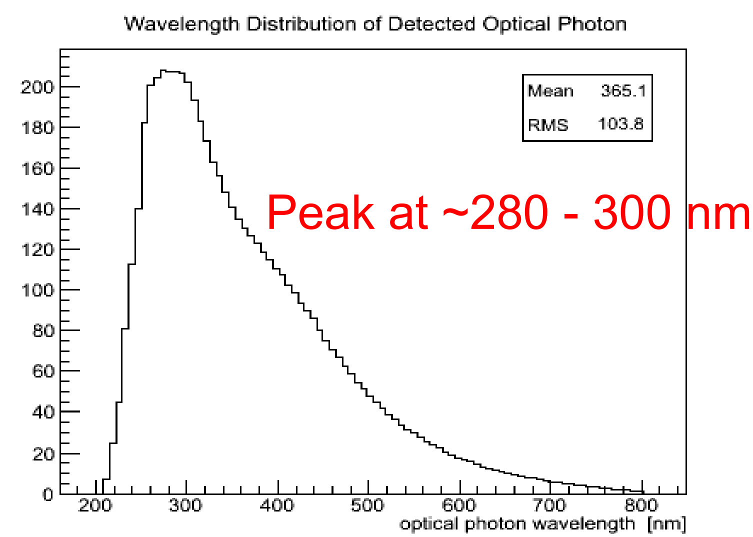
$$\frac{dN}{d\lambda} = \frac{2\pi z^2 \alpha}{\lambda^2}\left(1 - \frac{1}{\beta^2 n(\lambda)^2}\right)$$



Cerenkov photons are mostly generated in deep UV



detected photon energy spectrum from simulation

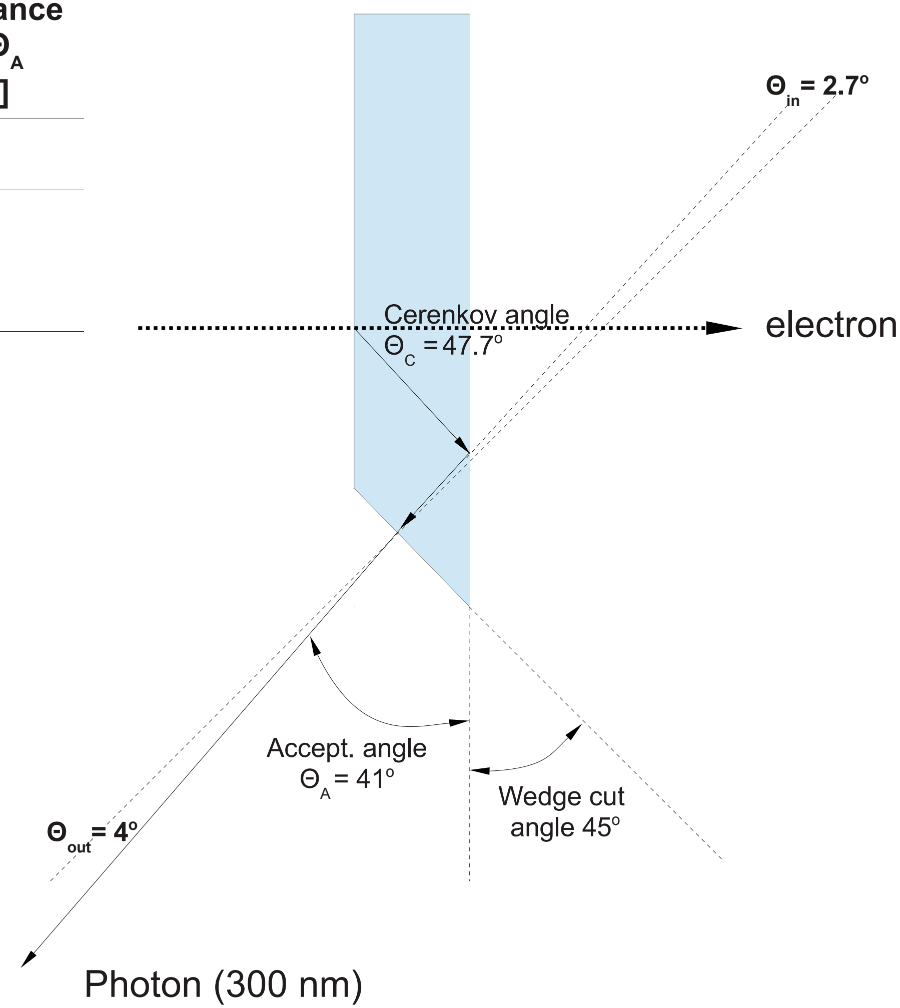


detected photon wavelength spectrum from simulation

Optimization of Acceptance Angle

Acceptance angle: the angle between light guide and quartz

Wavelength [nm]	Refractive index n	Cerenkov angle Θ_C [degree]	Θ_{in} [degree]	Θ_{out} [degree]	Acceptance angle Θ_A [degree]
180	1.575	50.6	5.6	8.3	36.7
250	1.507	48.4	3.4	5.2	39.8
300	1.485	47.7	2.7	4.0	41.0
700	1.455	46.5	1.5	2.4	42.6



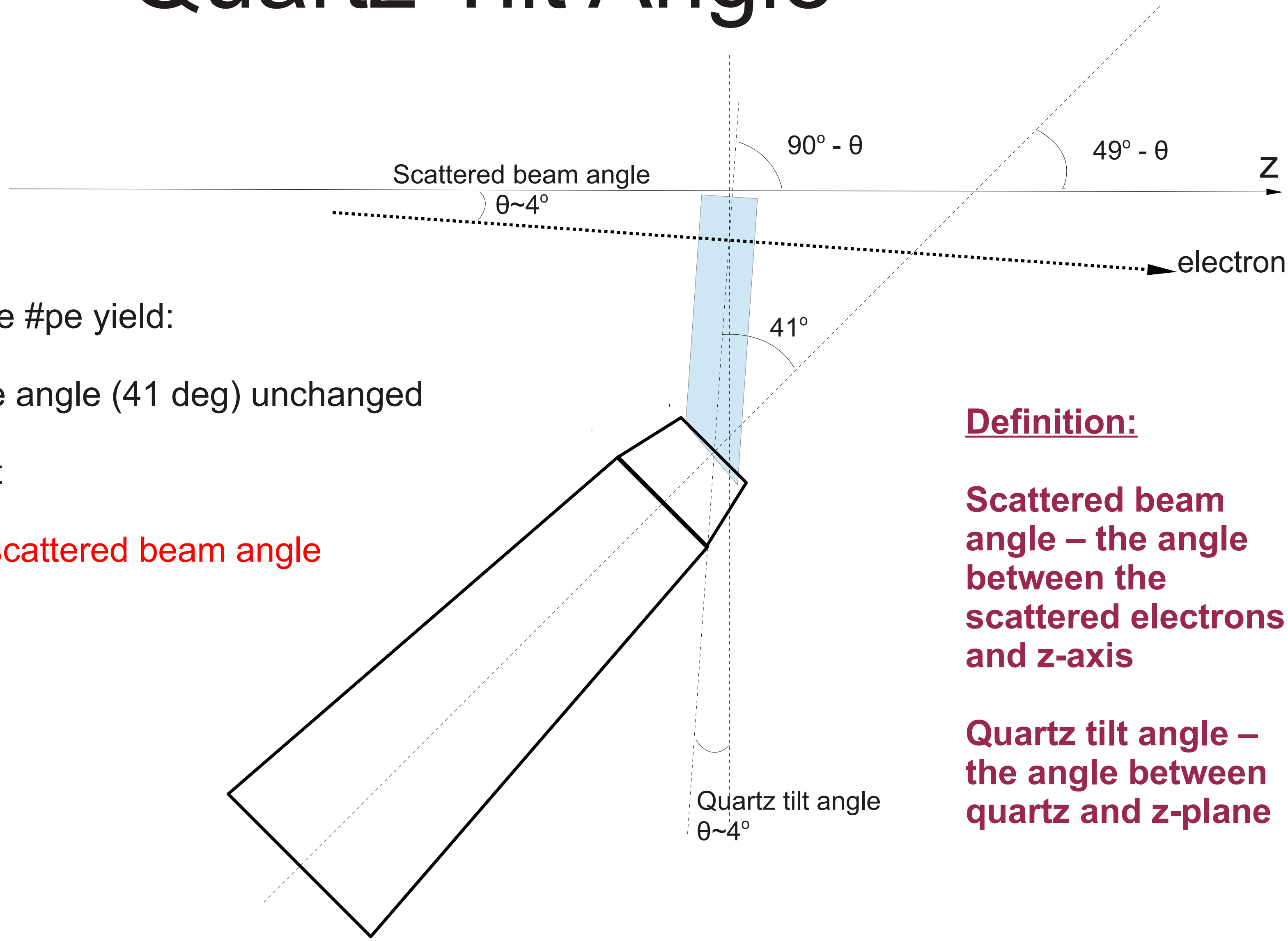
Best acceptance angle:

From simulation, #PE yield is maximized at an acceptance angle of ~41 deg, with a small tolerance (~1 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

Definition:

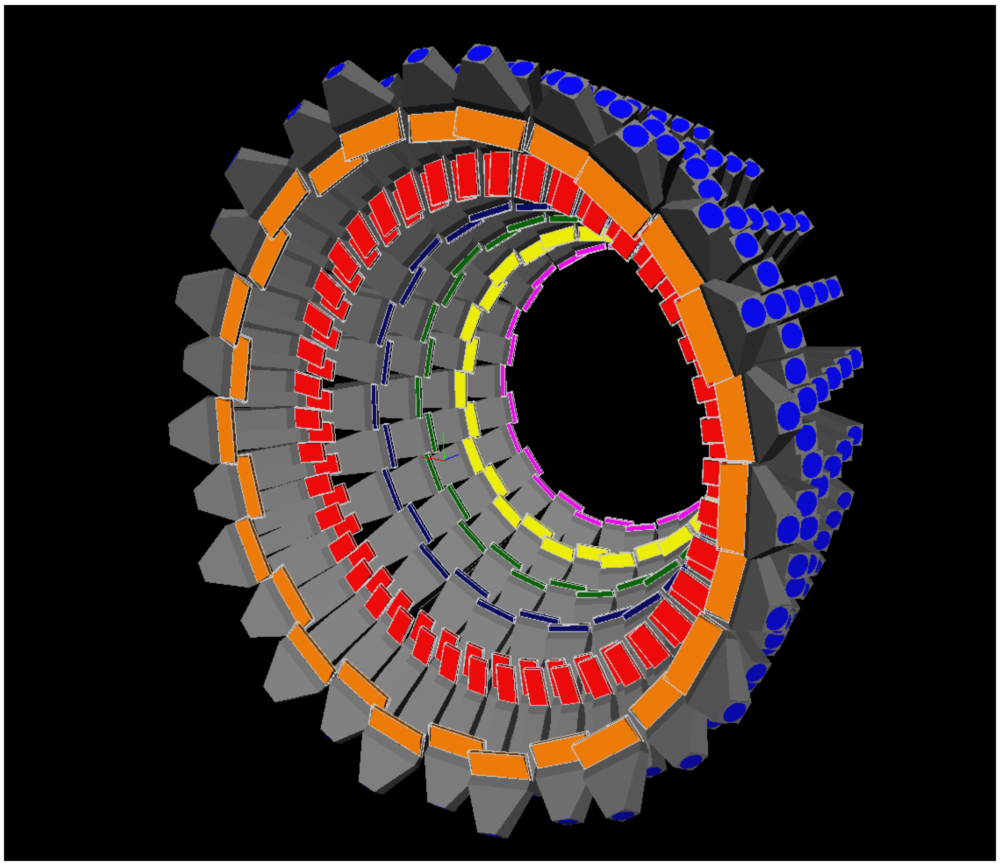
Scattered beam angle – the angle between the scattered electrons and z-axis

Quartz tilt angle – the angle between quartz and z-plane

- 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.

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 mateial: Anolux-UVS
- PMT: 3” round quartz window

#PE yield of e-e ring detector:

- ~37 PE
- rms: 8.7

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

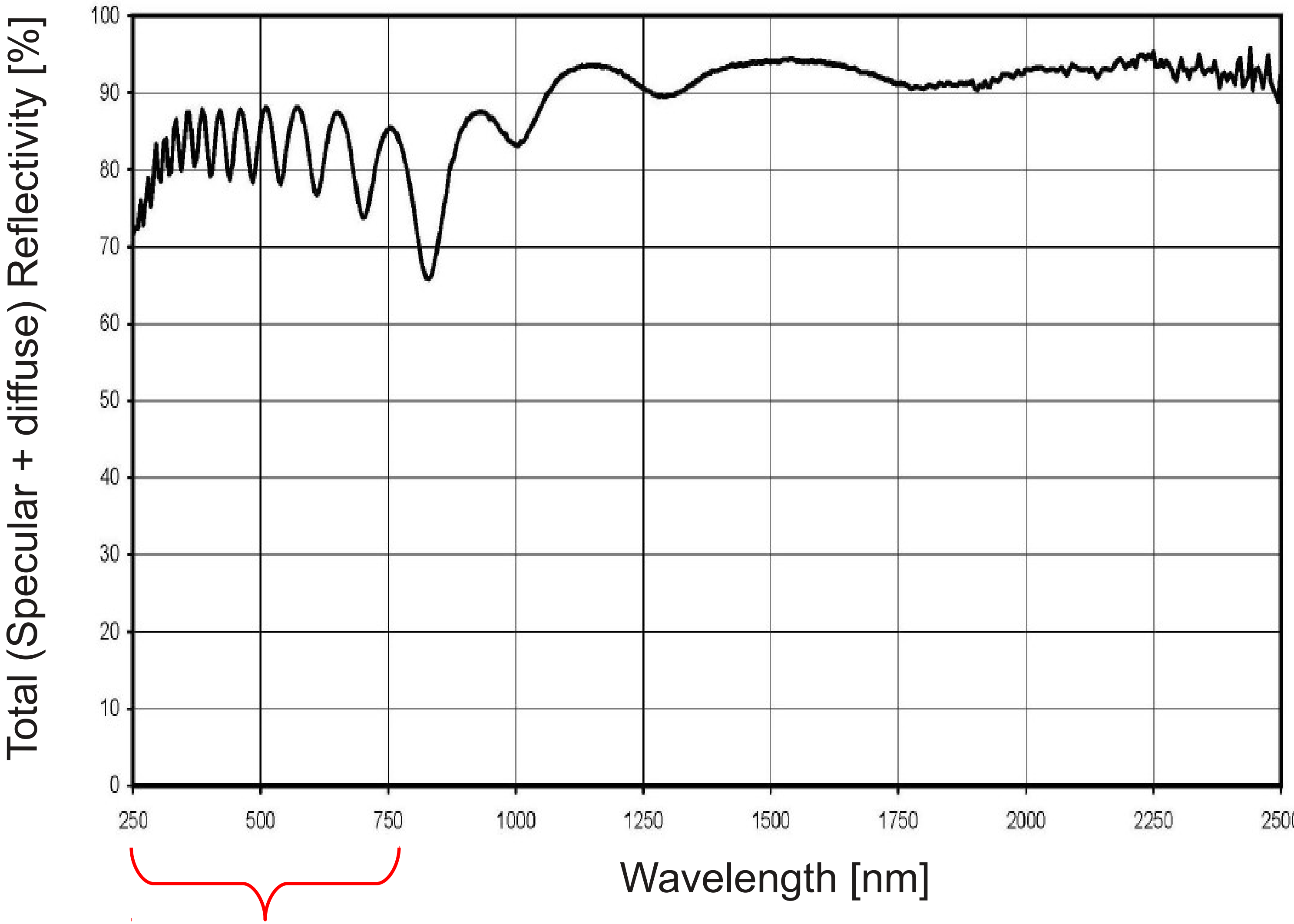
Light Guide Material

- 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



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

Simulation Study:

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

Order Information

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Quick Ship Products

Product Name	Minimum % Total Reflectivity	Image Clarity DI	% Diffuse Reflection	Specular Reflectivity (Min.)	Sheet Size (inches)		Price per sheet
Anolux® UVS Specular Mirror Finish	**86**	92	15-22	72 %	.020 X 48" X 24" .040 X 48" X 24"		**$ 45.00** **$ 63.50**

- 25-Year Limited Warranty*: Anolux Miro® & Anolux®
- 10-Year Limited Warranty*: Whitelite® 92 & WhiteOptics™
- We accept: Visa, MasterCard & American Express
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- Accepting order of single sheet or multiple sheets
- Low unit price
- Local vendors in US & Canada
- Quick ship available

Prototyping

Material & Compenent:

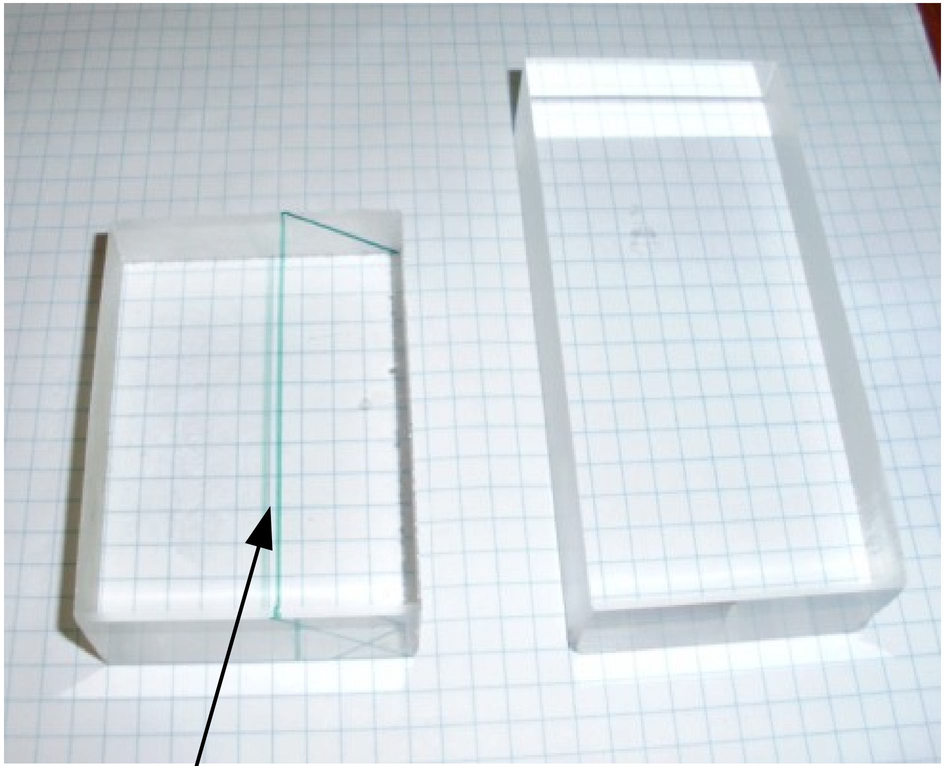
	Required	On-hand
Quartz	18 cm x 8 cm x 1.5 cm (optical grade polish)	8 cm x 6 cm x 2.5 cm (need cut and polish)
PMT	3” quartz window	Hamamatsu H1949-51, 2” Borosilicate glass window (available soon: Photonics XP2268, 2” quartz window)
Light guide	Anolux-UVS (~80% in UV 250 – 400 nm)	Alazk Miro-4 (cut-off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

Variation:

- Using on-hand materials and compenents 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

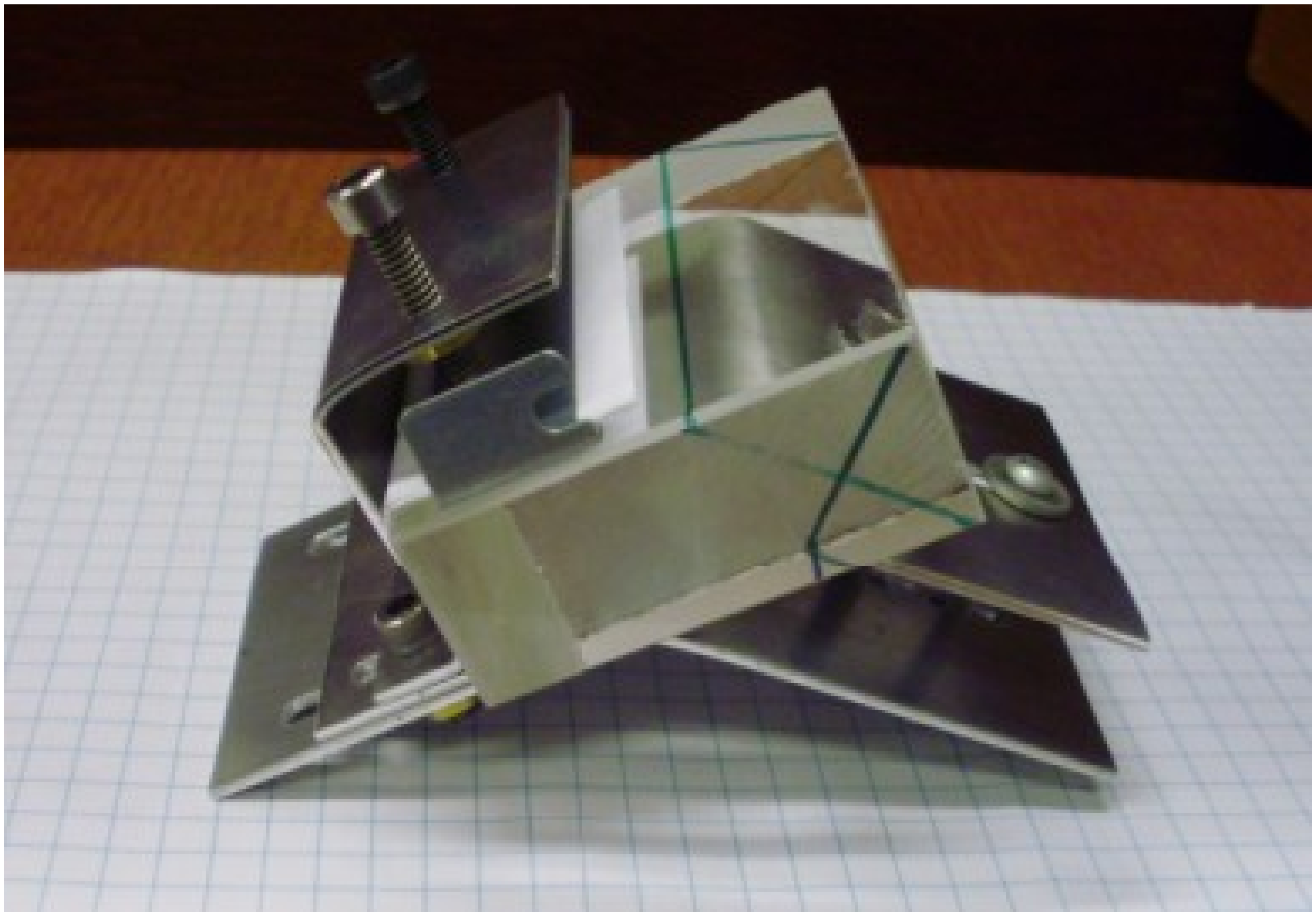


- We have 4 quartz blocks
  (Qweak's leftover, thanks to Dave Mack)
- Size: 120 x 60 x 25 mm^3
  (3 pieces)
- Size: 80 x 60 x 25 mm^3
  (1 piece)
- Required size for MOLLER prototype:
  180 x 80 mm x 15 mm^3

cutting marks

- Too much difficulties to make it thiner
- Try cross cut and angle cut only

Cutting Jig

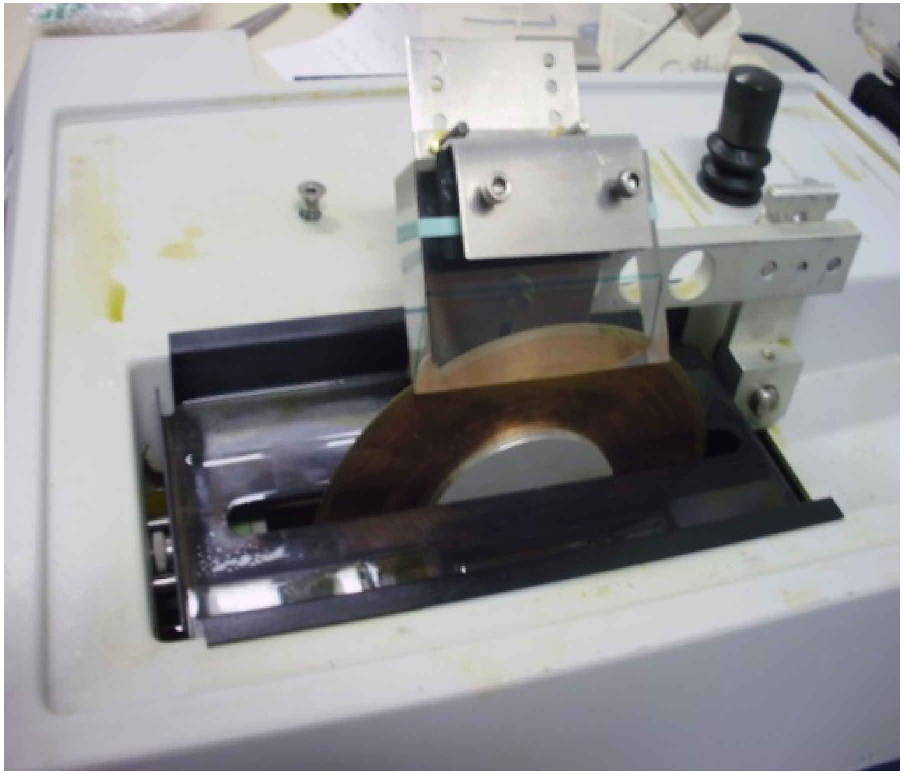


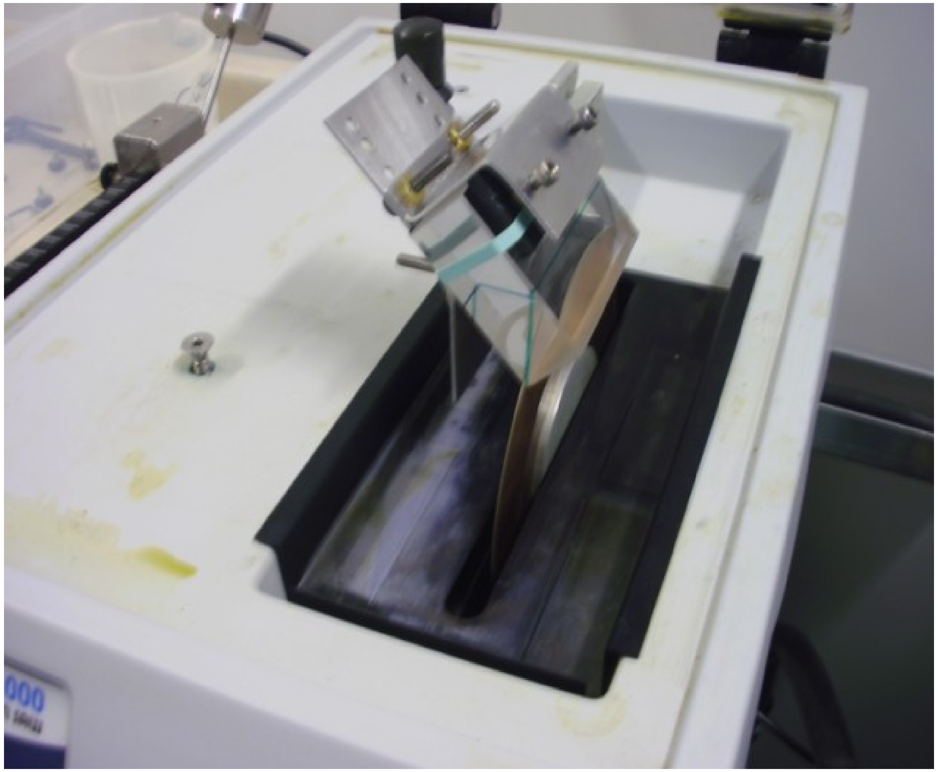
Picture of the jig for angle cut

(Another jig was made for cross cut)

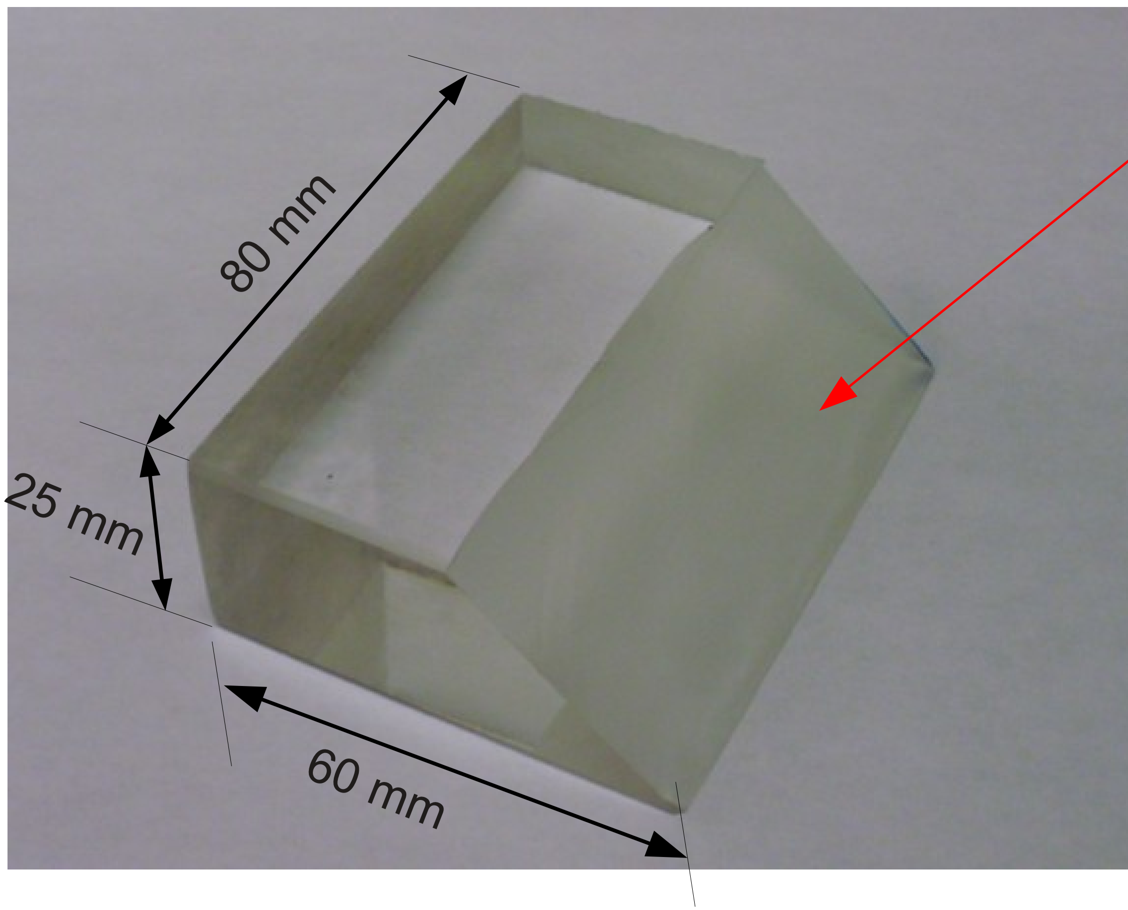
Quartz Cutting

- 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)



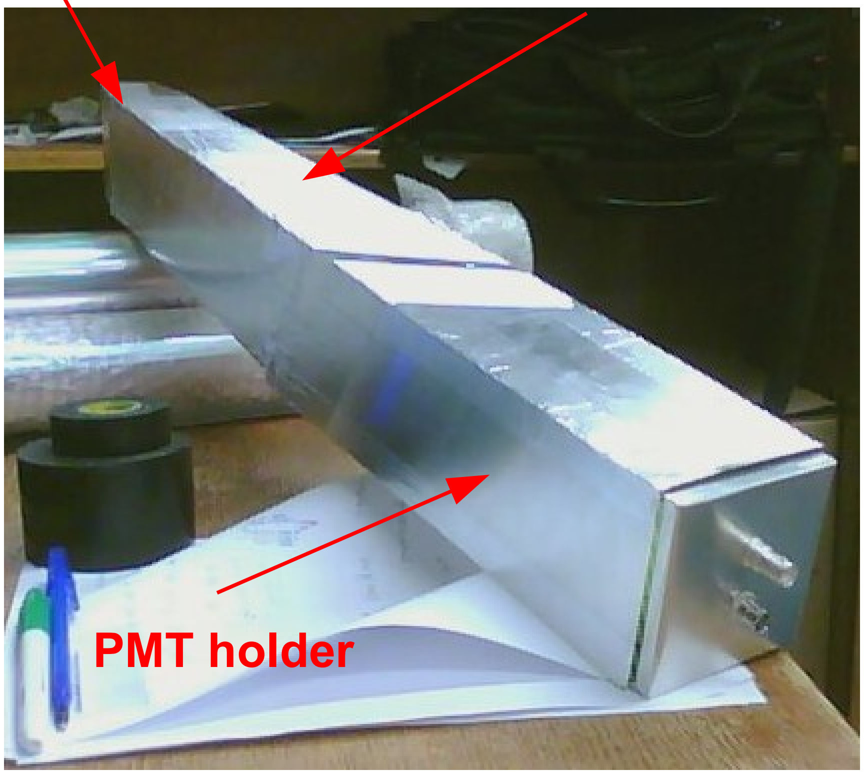


First Sample



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

First Detector Prototype



First detector prototype
(using Alazk Light guide)

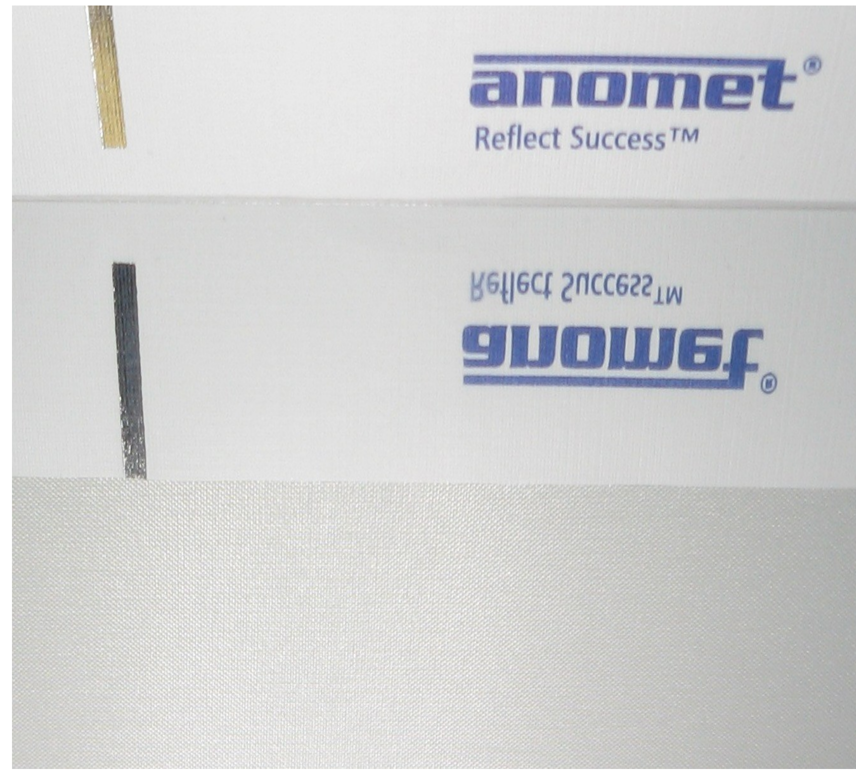


Image of Anolux-UVS
(One sheet was ordered & received)

DAQ & Cosmic Test Setup

Dark box: contining the trigger scintillators & the prototype detector

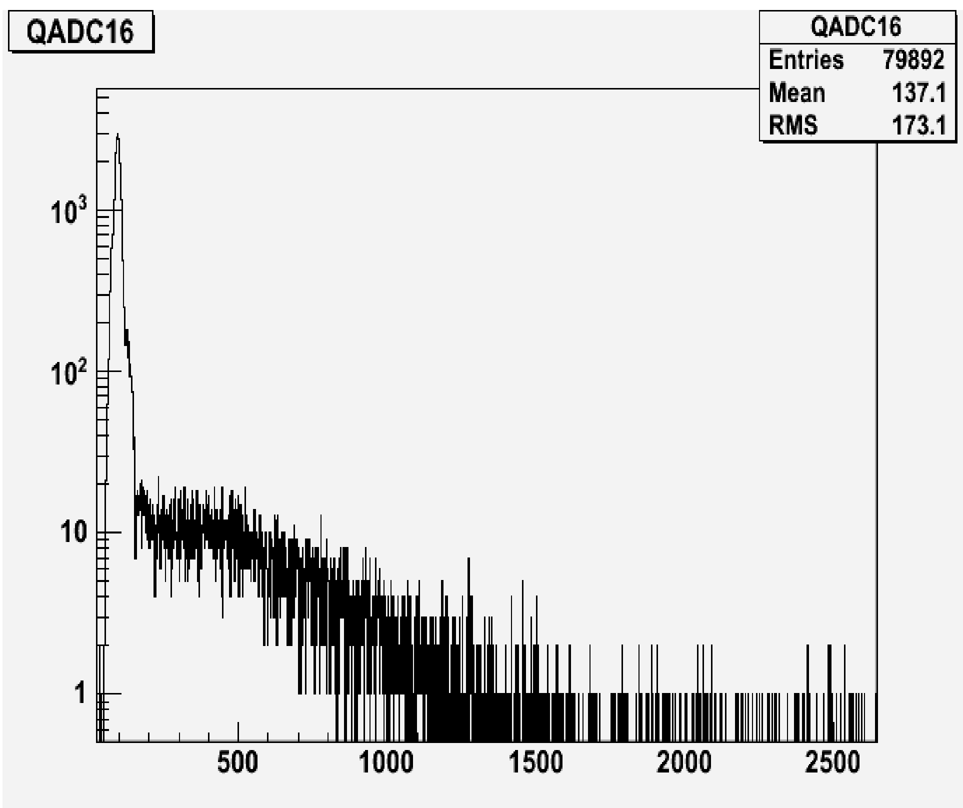
Amplifer, Discriminator, Logic Unit, Charge ADC & Flash ADC

HV power supply

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

"Preliminary" Test

Current Test Configuration	"Future" Configuration
Unpolished raw quartz block	Polished quartz with wedge cut
Alazk light guide	Anolux-UVS light guide
Non-quartz window 2" PMT	Quartz window 3" PMT



- Purpose: basic functionality test for cosmic ray test stand, DAQ etc.
- ~ 5 – 8 PE (very preliminary, not carefully calibrated)
- Low #PE and broden 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 evoluate the effects etc.

Prototyping:

- A variation of required materials and components is availale
- 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.