Quartz TIR Cerenkov Detectors in Hall C

D.J. Mack, TJNAF

Hall C Collaboration Meeting, January 6, 2006

Introduction

Prototype tests

The specifications that matter

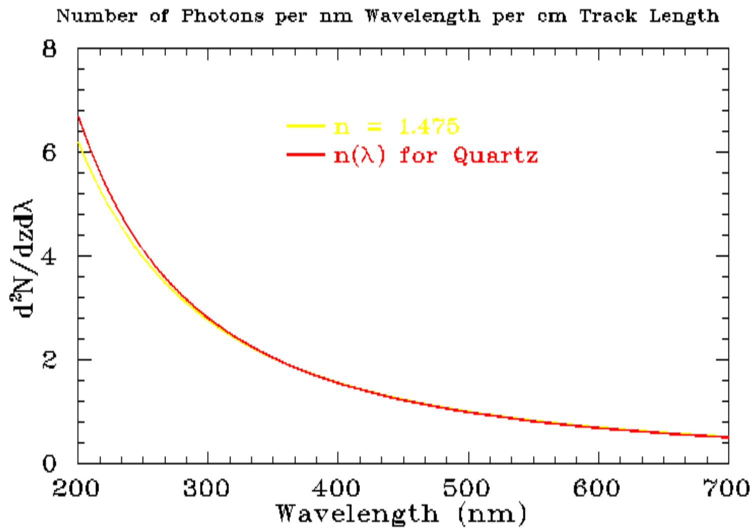
Potential vendors and brands

Upcoming Hall C applications

Cerenkov Radiation in Solids

The number of Cerenkov photons emitted per cm is

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



Material	Index of Refraction[1] n (nominal)
Calcium Fluoride	1.43
Quartz (SiO_2)	1.47
Pyrex	1.474
Lucite	1.49
Crown Glass	1.50-1.62
Flint Glass	1.57-1.88
Sapphire (Al_2O_3)	1.81

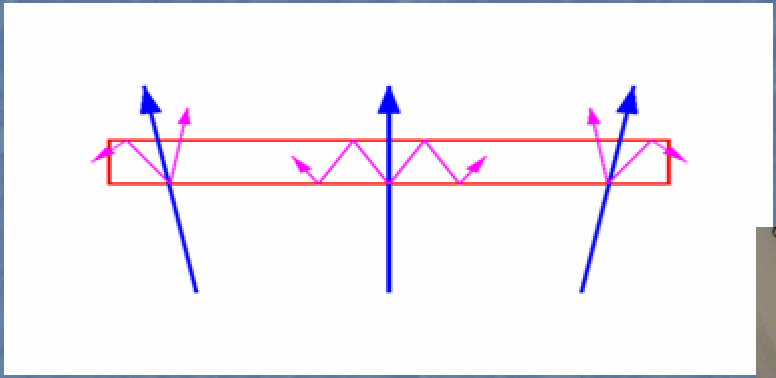
Solids have much higher refractive indices than gases, so can produce much more light per cm.

But few transparent solids transmit efficiently below 300 nm.

Most of the potential photons are UV.

Among the few UV transmitting solids, Quartz is most practical for detectors because of price and availability in large sizes.

TIR Cerenkov Prototype

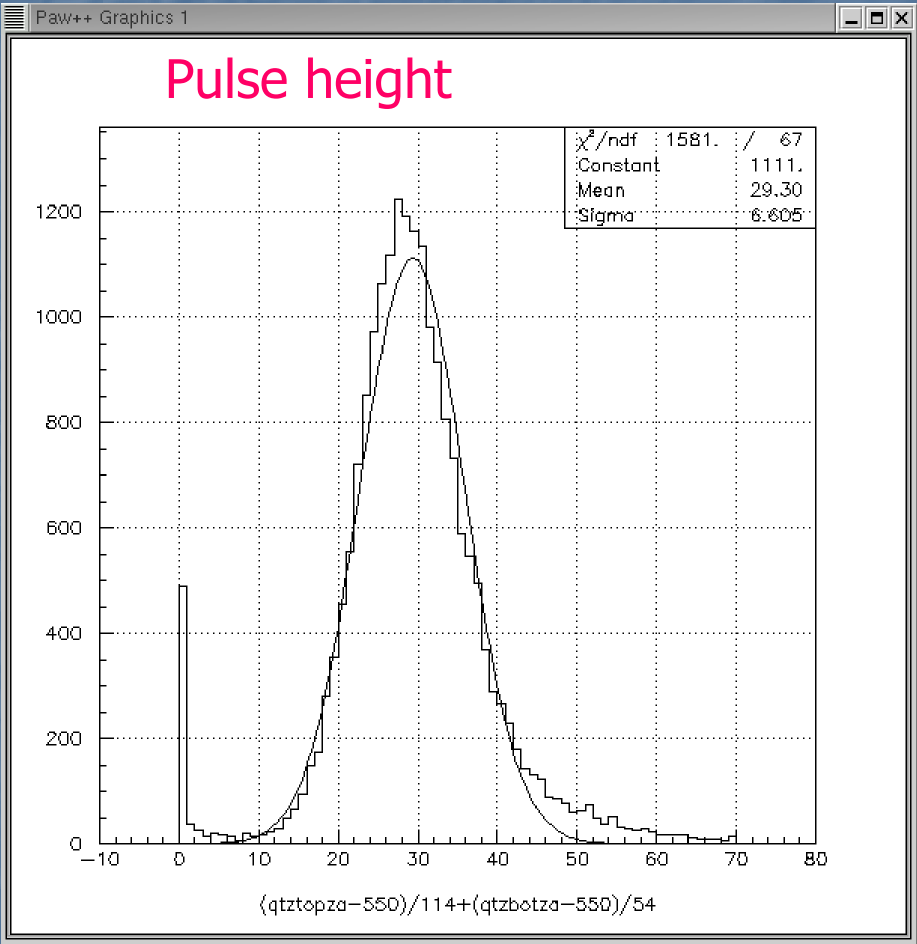


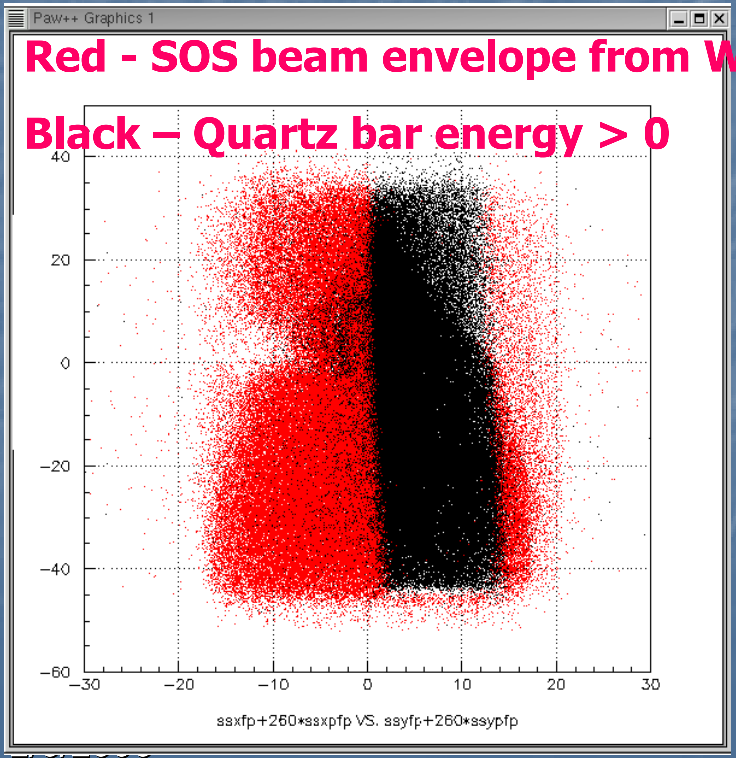
- Naïve 2-D picture suggests that most hits are single-ended.
- Full 3-D simulation shows that all hits are double-ended for electrons even at rather steep angles.

- Spectrosil 2000 fused silica
- Dimensions 100cm x 2.5cm x 12.5 cm
- XP4572B 5" pmt's, lime glass windows, >300 nm

Prototype Beam Test

- Inserted between SOS S2X and S2Y
- Tracking by WC's
- 1 and 1.5 GeV/c
- Mixed pi- and e- beam
- 80 cm of 100cm length illuminated
- Two tilt angles: 0 and 5 degrees





Photoelectron Yields: Importance of the Bevels

Simulations agreed well with test results once the unpolished, 1.5 mm bevels were included. These reduced the pe yield by almost half.

Small, polished bevels (< 0.5 mm) are a reasonable compromise between performance and cost.

Assuming 2.5 cm thickness:

SHMS

Qweak

Simulations by N. Simicevic (LaTech)

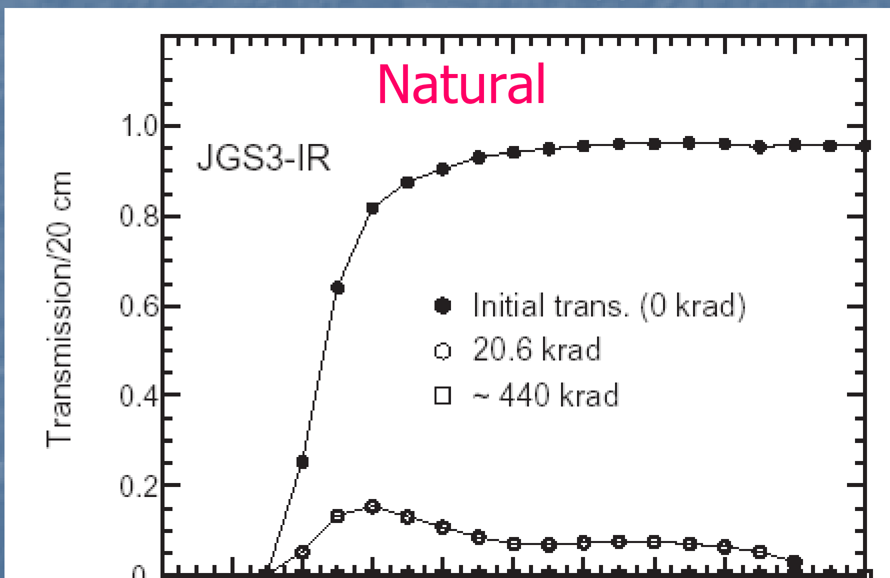
Bevel Type	Lime Glass/bialkali (JLab config.)	UV Glass/bialkali (LANL config.)	UV Glass/S20 (Qweak Config.)
no bevel	70	133	89
polished 1 mm	57	108	72
unpolished 1.5mm	40 (vs 38 in JLab test)	76 (vs 87 in LANL test)	51

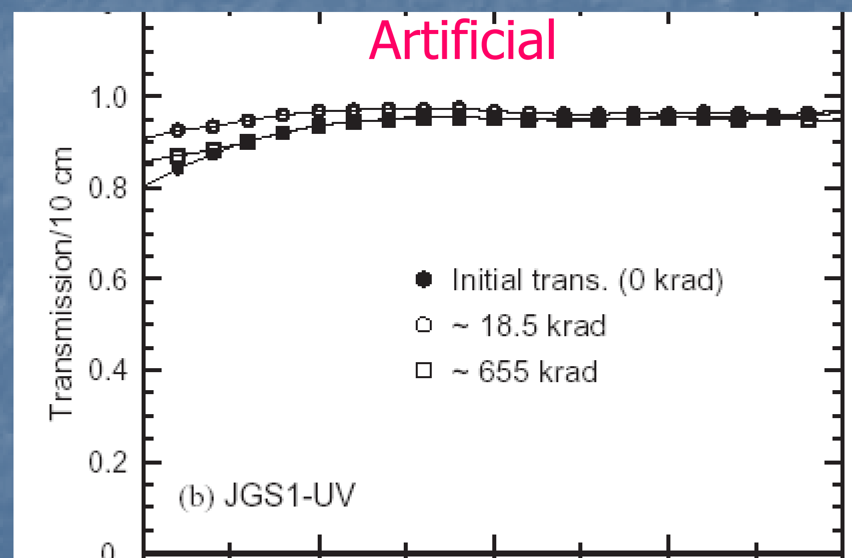
Radiation Hardness of Fused Silica

Chemical formula is SiO_2. Artificial quartz is glassy (virtreous) rather than crystalline.

Mine feedstocks have contaminants which result in product which may radiation damage severely by 20 kRad. (Cohen-Tanugi et al, NIM A 515 (2003) 680-700.)
Some brands are better, but next year's quartz may be different.

Artificial feedstocks have fewer contaminants, are more rad-hard and presumably more consistent from year to year.
There is no such thing as perfect radiation hardness below 300 nm, but the modest loss in transmission appears to saturate by 1 MRad.

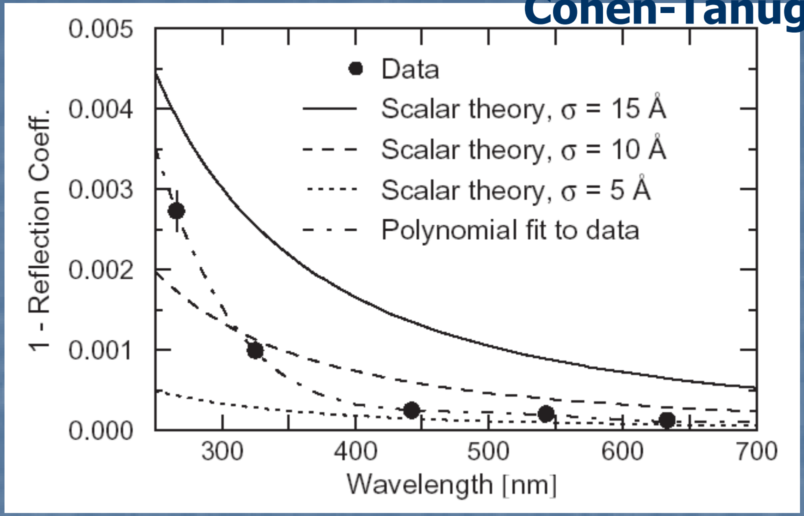




200 nm 300 nm 400 nm 200 nm 300 nm 400 nm

Critical Mechanical Specifications

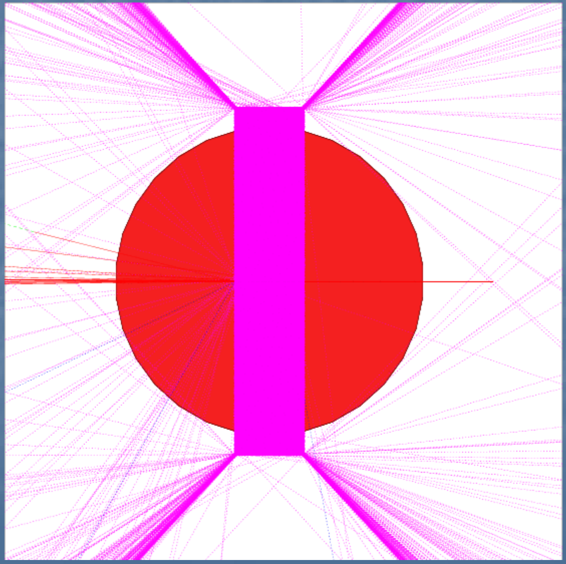
Cohen-Tanugi et al



Manufacturers strongly prefer to bevel delicate edges to hide small chips and make them easier to handle/ship without further damage.

Their preference is to our cost advantage.

Bevel dimensions must be controlled to limit light losses!
(In our case <0.5 mm.)



Neven Simicevic (LaTech)

Our requirement was for an optical grade polish with TIR coefficient > 0.997% or 25 Angstroms (rms).

St. Gobain subcontractor uses a pitch lap polishing technique, same method used for small telescope mirrors.

This time-consuming process yields superior surfaces, nominally 5 Angstroms (rms), which should meet our reflectivity specification even in the UV assuming clean surfaces.

Big cost driver. About 2/3 final cost in our case.

Vendors and Brands: the Right Stuff

Small periodic variations in index of refraction are acceptable. We don't require higher grades of material such as Spectrosil 2001 such as might be used for UV lithography.

BABAR DIRC tests found Spectrosil 2000 and JGS1-UV, both derived from artificial sources, to have desired properties of UV transparency, rad-hardness, and low luminescence.

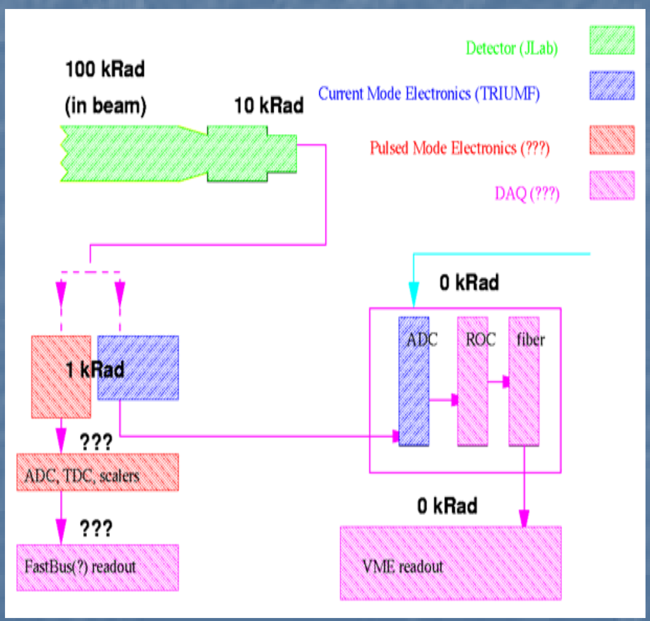
Potential sources of finished detector-grade quartz products (in which the manufacturer performs or subcontracts all work from material procurement to machining to polishing):

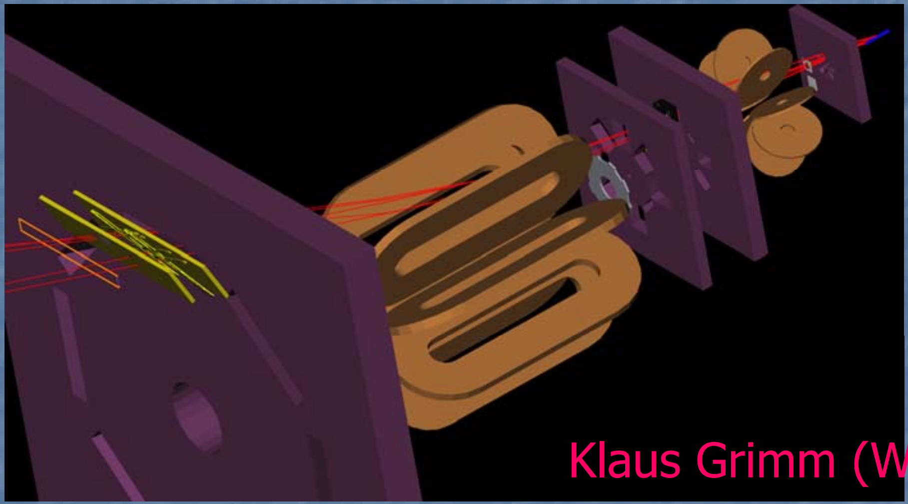
- **St. Gobain Quartz - Spectrosil 2000**
- **Scionix - JGS1-UV (Beijing Institute)**

The latter source is less known to us. They have produced some beautiful small pieces for JLab and SLAC, but I'm not aware of any meter-scale production and can't locate catalog specifications for JGS1-UV.

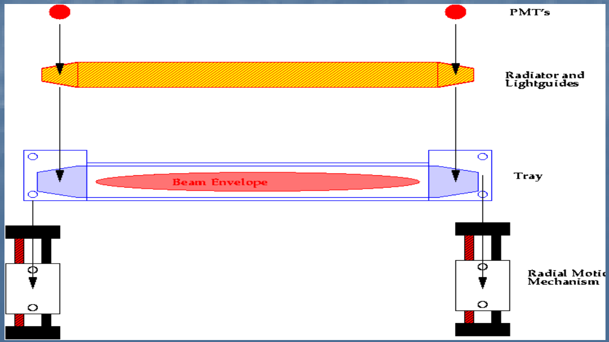
Current Mode Application: Q_{weak} Main Detector

Qweak required a rad-hard, low background detector that could be used in current mode. As pointed out by N. Simicevic (LaTech), a natural solution was to adapt BABAR DIRC R&D on artificial, fused silica.





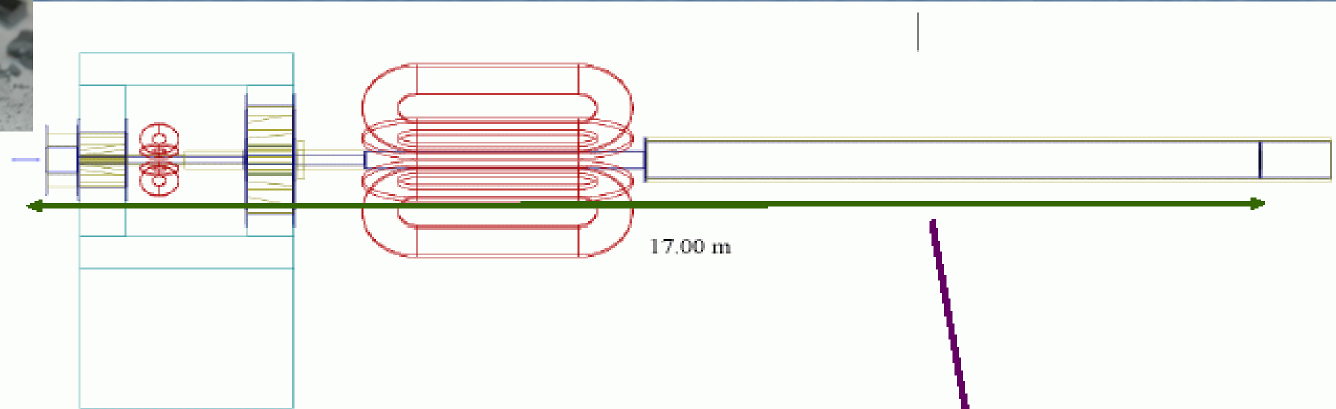
Klaus Grimm (W&M)



Current Mode Application: Q_{weak} Luminosity Monitor

G0 luminosity monitors: by the end of the forward run, glass envelopes were darkened and potted housings literally disintegrated, but artificial quartz radiators of Spectrosil 2000 looked fine.

Qweak implementation will also use Spectrosil 2000 but air lightguides.

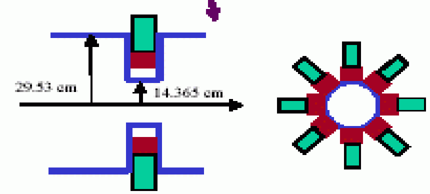


The detector cups will be deep enough to allow access to three different angle ranges

r = 15 - 18 cm .5 - .6°

r= 18 - 21 cm .6 - .7°

r = 21 - 24 cm .7 - .8°



Pulsed Mode Application: "low β" Cerenkov Hodoscope for SHMS

When event rates approach the few/shift level, and the data are a continuum with no sharp peak, experiments with heavy hadrons in the final state have been (and will be) problematical with a simple S1xS2 scintillator trigger. E.g.,

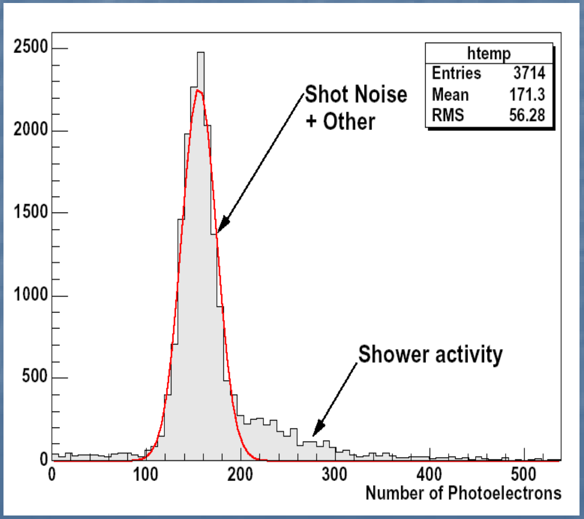
D(γ,p)n with untagged Bremsstrahlung beam

A(e,e′p)A-1 for 0 to 100 MeV missing energy

At 12 GeV, such hadrons will be relativistic, but still not generally fast enough for aerogels.

A Quartz Cerenkov hodoscope would yield 100-200 pe's, be nearly 100% efficient, and almost impervious to low energy γ or n backgrounds.

A clean S2xS2xQ trigger would also reduce tracking efficiency ambiguities for heavy hadrons.



Summary

Artificial Fused Silica is available in large sizes, is UV transparent, radiation hard, and has low luminescence. These features which make it a promising new material for TIR Cerenkov detectors.

- Procurement Experience

  we have already obtained acceptable meter-scale prototype pieces from St. Gobain and are awaiting delivery of 19 similar production bars for Qweak; also exploring other potential sources

- Prototype Experience

  cosmic tests at LANL and beam tests at JLab confirmed LaTech GEANT3 simulations, but highlighted the need to keep the bevel size < 0.5 mm.

  polish quality apparently consistent 0.997 reflectivity assumed in simulations.

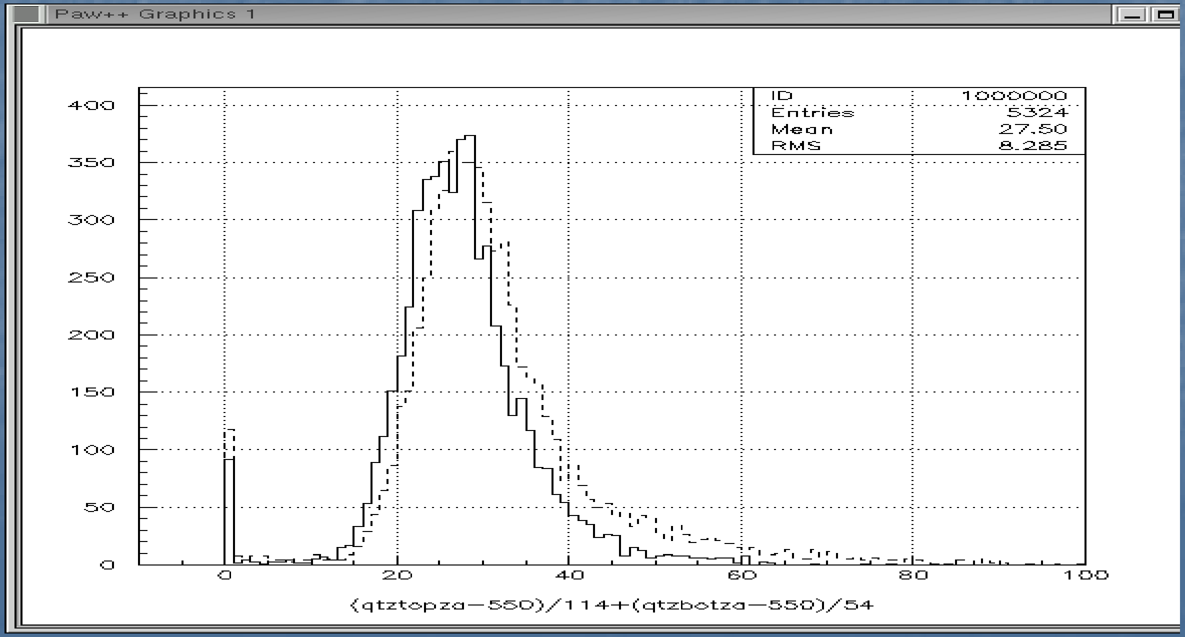
- JLab Applications

  Qweak main detector and luminosity monitor, as well as a potential "low beta" Cerenkov hodoscope for the SHMS

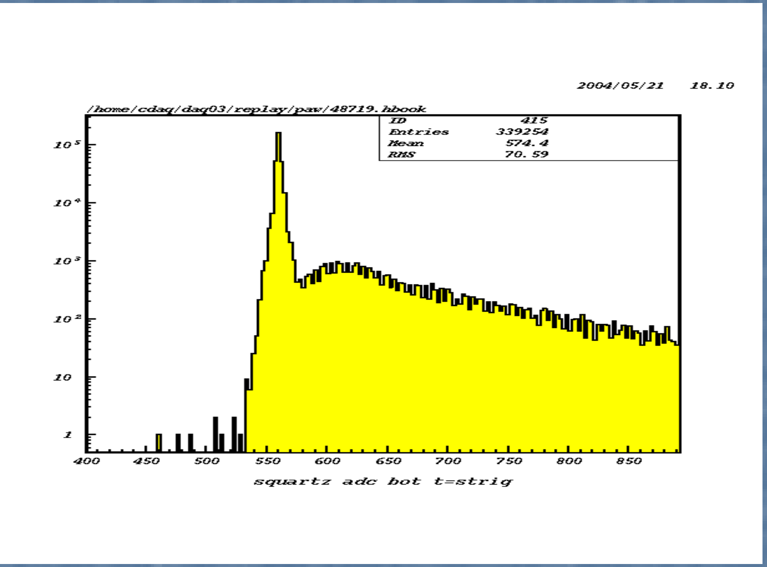
Miscellaneous

Detector Performance: Pions versus Electrons

- As expected at these momenta, pi- and e- give similar response.
- Closer examination reveals the electron response is somewhat larger and broader due to showering.



Single PE Calibration



- Couldn't do calibration reliably with beam on:
  1. single PE resolution of XP4572B is poor
  2. mean PE number was too high (~15)
- Used beam off, random trigger, and tube noise