Qweak Quartz Cerenkov Detector

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The $Q_{WEAK}$ Experiment
A search for new physics at the TeV scale by measurement of the Proton's weak charge

- $Q_{weak}$ scatters longitudinally polarized electrons from liquid hydrogen
- We flip the electron spin and see how much the scattered fraction changes
- The difference is proportional to the weak charge of the proton

Longitudinally polarized electron beam (85%)

1.165 GeV, 180 $\mu$A

- we are slightly more likely to “hit a proton” if the electron is spinning to the left (parity violation)
- expect $A_z = (\sigma^+ - \sigma^-)/(\sigma^+ + \sigma^-) \approx -0.3$ ppm
- $\pm 5 \times 10^{-9}$ statistics in 2200 hours
- use eight detectors at 800 MHz each and run in current mode
The Qweak Apparatus

Tracking (red) detectors will be used in calibration mode only.
Critical Subsystems

- Main Detector
  - (8 Quartz Cerenkov detector)

- Collimation and Shielding

- Toroidal Spectrometer

- Target
**Synthetic Quartz Čerenkov Detectors**

Focal plane detectors:

- 200 cm x 18 cm x 1.25 cm synthetic quartz bars
- Radiation hardness (expect > 300 kRad).
- Insensitivity to background $\gamma$, n, $\pi$.
- 5'' PMT's
- Operation at counting statistics. Current mode readout $I_a = 6 \, \mu A$

![Diagram of Synthetic Quartz Čerenkov Detectors with PMTs, Elastic Events, Inelastics, and Magnet Coils]
Geant4 Simulation: Detector Geometry

Detector geometry implemented with:
- 3 glue joints between light guides (LG) and bars, bevels, imperfect edge matches, grease between LG and PMT, PMT windows, cathode volume, mirrored sides, and wrapping
- Difference in optical properties for each material taken into account
- Bars and light guide bevels vary to simulate possible light loss at the edges

For an unwrapped detector, light escapes through the bevels and at interfaces between the light guide and the PMTs
Geant4 Simulation: Photo-electron Count

PDG formula predicts ~900 photons above 250 nm cutoff:

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

Simulation gives ~1000 photons on average for arbitrary path lengths.

~250 photons get to the cathode the rest is lost.

The photon is counted only if it makes a volume transition from the PMT window to the cathode.

The mean number of photoelectrons per event:

- No Wrapping: ~40 Pes
- Millipore: ~50 Pes
- Real World: ~20 Pes
- Original design criteria: > 10 Pes
Geant4 Simulation: Optimize Detector Design

- Light yield in the quartz bar directly relates to the asymmetry measurement
- Geant4 simulation for light production and collection optimized the detector design

For example: a thicker quartz bar produces more light, but shower effects in the thicker quartz bar will generate excess noise, leading to a longer experimental time to reach the required statistics.

The optimized detector thickness is 1.25 cm
Light Yield Measurement

- Cosmic ray test for the light yield
- Test setup mainly included a 1 m long quartz bar (with light guide & PMT) and two trigger scintillators
- Result: > 10 p.e. (Qweak design criteria requirement - 10 p.e.)
- Tests also included measuring the light yield for detector partially wrapped with reflective material, the light yield uniformity along the quartz bar and effects of the incident angle.
Background

Background, such as elastic/inelastic events from target & window, soft photon/neutron from beam line, collimator, shieldings, affect the light production (PMT output) in the bar through Cerenkov, scintillation, neutron capture (Xsec goes as $1/v$), pair production, etc., hence affect the $Q^2$ determination and asymmetry measurement.

For example:
10 keV to 1 MeV photon rate is as high as the elastic electron rate!
Soft photons produce a $\sim 1\%$ background of the Cerenkov light.

Measurements and simulations used to determine the dilution factors for the background.
Low noise I-to-V or trans-impedance amplifiers, with a nominal gain of 1 Mohm (hence 1 μA ->1 Volt)
Anticipated DAQ pattern and Signal Size

- Integrates for 4 ms
- Stored as four 1 ms integrals
- $T_{\text{settle}}$ as short as 50 $\mu$s allowed

Time:
- One spin state – (1/250) second
- Next spin state

Approximately 200 $\mu$s settling time (not to scale)

Current:
- 6 $\mu$A
- 3.6 pA (0.6 ppm p-p)
- $A \sim -0.3$ ppm

On letter-sized paper
Origin 6 km off bottom

Helicity:
- Trigger
- Time
Status of Qweak Quartz Cerenkov Detector

- All preliminary tests (radiation hardness, magnetic field sensitivity, transparence, optical glue properties, scintillation and neutron background, light yield ... ) are done
- Custom designed main preamplifiers, VME integrator (ADC's) and PMT bases were built and tested
- All fused silica (quartz) bars and PMT's arrived at Jlab
- Full 3D CAD model for the quartz bar installation in the Qweak is done
- Detector housing were just fabricated, will be shipped to JLab this week

- Assemble and integrate all the detectors at Jlab
- More detector performance measurements and tests with the full detector assembly
- Install and commission the detectors in the Qweak experiment at the end of this year