(Progress Towards the) Demonstration of a Water Cherenkov Optical Time Projection Chamber

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HIGH ENERGY PHYSICS

THE UNIVERSITY OF CHICAGO

Overview

- Large Area Picosecond Photodetectors
- Electronics Readout
- Optical TPC
- Simulation/detector status



400 cm² LAPPD MCP glass package: Microstrip Anode



- Location of event (x,y) determined by the time difference of signal on two ends (x) and the charge-centroid of adjacent strips (y).
- Efficient use of electronics channels.

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X, mm

33mm MCP position scan:

V_{prop} ~ 2/3c along stripline

LAPPD -- results

The 'Demountable': reconstructing laser spot position and time

Amplitude (ADC counts)



Fast waveform sampling readout: PSEC4 0.13 µm CMOS

'oscilloscope-on-a-chip'



- 10-15 GSa/s Switched Capacitor Array (SCA) sampling
- Up-convert low frequency (~10's MHz) clock to multi-GHz using tapped voltage-controlled delay line (VCDL):



Sampling Rate

- Sampling rate locked on-chip
- ~Small recording window [25 ns when sampling at 10.24 GSa/s]



0.15 **PSEC4** architecture 0.1 0.05 Serial operation: (1) sample; (2) trigger; 0 -0.05 (3) A/D conversion; (4) readout -0.1 Default operation is 10.24 GSa/s == 25 ns snapshot per triggered waveform 15 20 Write clock 10-15 GSa/s VCDL [40MHz] [6 channels x DLL 256 samples Charge Phase per chip] Pump Internal Trigger Discriminator Signal Self_trigger SCA Trigger_threshold 50Ω Ext. Trigger ADC Clock ADC 12-bit ADC start/stop +1.2 V registers ADC Ramp V_ped Data[12..1] **Readout Control** Address Logic Data_address Read clock LADDD DOF review

Analog Bandwidth

 Preserve the rise-times of fast (photo)detectors on chip: maximize analog bandwidth



Timing calibration

- Overall PSEC4 time-base locked on-chip
- Individual time-steps are not uniform due to process variations
- Employ a 'brute force' method for calibrating PSEC4's 256 sample time steps:
 - -1) Record ~100K sine waves with period T_{input}
 - 2) Measure average # of zero crossings per cell
 - 3) With enough statistics, can extract Δt for each timestep:

$$\langle \Delta t \rangle = T_{input *} \langle N_{zero} \rangle / (2*N_{events})$$

Also, a novel method that didn't quite work for PSEC4:

K. Nishimura, A. Romero-Wolf, "A Correlation-Based Timing Calibration & Diagnostic Technique for Fast Digitization ASICs", Physics Procedia 37 (2012) 1707-1714.

Timing calibration : verification

- measure 2-channel timing
- Generate ~2 ns FWHM Gaussian pulse, split, and inject into 2 channels of PSEC4
- Apply voltage and time calibrations. Fit pulse rising edge (~10 points) and extract time difference. No other data processing



Building systems



Central Card

- Controls 4 front-end boards
- USB 2.0 or gigabit Ethernet PC connection
- Daisy chain or tree configurations to extend system channel count
- Clock fan-out

Front-end PSEC4 Card ("AC/DC Card")

- 30 channels PSEC4 waveform recording
- At 10GS/s, captures a 25 ns snapshot per waveform
- USB 2.0 standalone readout or 8x LVDS lines communication to Central Card

LVDS system interface

- Up to 800 Mbps data rate per line
- Clock, trigger, configuration

System syncing and timing

- Crucial system parameter: chip and system time resolution require precision clock
- ~7-8 ps clock jitter between boards 'out-of-box'
- Still much room to improve performance of jitter cleaner chip (TI CDCE62005)



Optical TPC (OTPC) idea

- One application of LAPPDs is to build an optical tracking detector, by tagging photons at the ~mm spatial and ~10's picosecond time-scales.
- Fast timing = ability to use 'drifted' optical light (v = c/n) generated from Cherenkov process (analog to electrons in a liquid noble TPC)
- Opens up possibility to reconstruct relativistic charged particle tracks in a (non-cryogenic) water-based TPC.
- LAPPD's: large photo-active area and economical. Enabling technology to build 'large' size water-based TPC. (i.e. neutrino detector)

The OTPC:

Enabling technology: MCPs + **100's of channels of high bandwidth waveform recording**



Light 'drift time' in water: 225,000 mm/s ~20 photons/mm





- A muon is produced and detected in the MRD.
- LAPPDs used to reconstruct vertex position based on arrival of Cherenkov light.



ANNIE proposal (M. Wetstein)

Scaling down...

- LAPPD's in commercialization phase, not available quite yet.
- Build prototype water detector with 2x2 sq. inch commercial (\$\$\$) MCPs:



Planacon 32-microstrip anode PCB card –

same basic readout configuration as LAPPD: readout using PSEC4 ASIC (next slides)

Optical TPC prototype in **Chroma**, importing 3D CAD models

~40 kg cylindrical water detector. 6 Planacon MCPs + 6 mirrors

 $\Phi = 60^{\circ}$

Φ = 0°
Stereo configuration of MCPs and mirrors allows for 3D track reconstruction

Chroma :: a high performance optical photon simulation for particle physics detectors [*With the assistance of a CUDA-enabled GPU*]

Time projection of Cherenkov light

Simulated down-going 1 GeV muon with all detector resolutions included



6/4/14

Time projection of Cherenkov light



Detector construction/progress

- Water + light tight
- Cosmic ray test stand + PiLas Laser pulsing
- 120 (out of 160) channels PSEC4 electronics + 4 (out of 6) MCPs installed

MCP mounts





mirrors

Transmission line single-ended readout



Summary

- Full systems of PSEC4 10 GSa/s waveform sampling electronics developed and in use: both commercial and LAPPD MCP readout
 - System time resolution ~10 ps level
- New type of neutrino/water Cherenkov detector: the OTPC is up-and-running data taking
 - Beam test this summer?
 - Building likelihood analysis for generic track fitting



Backup

Timing calibration : example



Timing calibration : verification

- (1) fitting for frequency
- Apply Δt values to another 240 MHz data set, fitting sine waves
- Good fit qualities and stable over events



A prototype OTPC:: 40 kg water detector



A prototype OTPC:: 40 kg water detector



Watertight, inside surface painted matte spray paint as cheap light absorber 3/3/2014

Chroma :: a high performance optical photon simulation for particle physics detectors [*With the assistance of a CUDA-enabled GPU*]



"MiniLBNE" with 12" PMTs in Chroma *Credit*: Stan Seibert

Optical TPC prototype in Chroma:





Time projection along azimuth

Straight





Photon Time histograms at each MCP



Angle





200

170

170

180

reconstructed R [mm]³²

190

200

180

190

Fitting the Reflected Light

Straight

Angle

