Large Area Picosecond Photodetectors (LAPPD)

Kurtis Nishimura
on behalf of the LAPPD Collaboration
PHENIX PID Workshop
December 16, 2010
Much here is borrowed from other collaborators!
Lots of other good talks, for example:

- Matt Wetstein, RICH2010 [link]
- Herve Grabas, Timing Workshop, Cracow, 2010 [link]
- Jean-Francois Genat, Timing Workshop, Cracow, 2010 [link]
- ...and more, at [http://psec.uchicago.edu](http://psec.uchicago.edu)
Who needs large area fast photodetectors?

- Lots of applications! A couple (very) recent examples with only modest area requirements:
  - **Belle II TOP** – roughly $\sim 0.4 \text{ m}^2$, $\sigma_t \sim 50$ ps
  - **SuperB fDIRC** – roughly $\sim 1.6 \text{ m}^2$, $\sigma_t \sim 100$-200 ps
Photon detector options

- **HAPD**
  - Good result from test bench with ASIC readout
  - Need experience with batch production

- **MCP-PMT**
  - Good TTS for TOF information
    - $<20\text{ps}$ TOF resolution
    - Good ability for low momentum PID
  - Improved lifetime – sufficient?

- **SiPM/MPPC**
  - Good stability, Enough gain but only $100\text{ps}$ TTS
  - Need large effective area or light guide to make $\sim5\times5\text{mm}^2$ anode
  - High dark count ($<\text{MHz}$)
  - Radiation hardness $\Rightarrow$ thus far not good enough
LAPPD Collaboration:
Pushing the limit on multiple frontiers: timing, volume, & cost.

Microchannel Plates are an existing photo-multiplier technology known for:

- Picosecond-level time resolution
- Micron-level spatial resolution
- Excellent photon-counting capabilities
- Being expensive

What if we could exploit advances in material science and electronics to develop new methods for fabricating:

- Large area (8”x8”), flat panel MCP-PMTs (BIG)
- Preserving that excellent time resolution (FAST)
- At competitive costs for particle physics scales (CHEAP)

How could that change the next-generation particle Detectors?
The LAPPD Collaboration

Roughly ~100 members from:
• National laboratories
• Universities
• Private companies

Funded by DOE:
• Currently at the end of year 1 (of 3)

More information at:
http://psec.uchicago.edu
Elements of an MCP-PMT

- Photocathode
- Micro-channel plates
- Collection anode
- Readout electronics
- Mechanical design / tile assembly.

⇒ Active research is ongoing for all elements... I will mention the most about the electronics.
Elements of an MCP-PMT

- Photocathode
- Micro-channel plates
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Photocathodes

- Multi-Alkali seems to have perfect cathode properties
  - But
    - Little understanding
    - Small community
    - No developed Industry
    - Problems with mass-production

- Existing III-V cathode have not the right properties
  - But
    - Excellent understanding
    - Large community
    - Excellent developed Industry
    - Easy mass-production

⇒ Move forward on multiple fronts...
Active area of R&D with multiple parallel approaches:

- Work to scale conventional bi/multi-alkali technology to large sizes.
- At the same time, investigate novel photocathode concepts (III-V).
- ...and simultaneously keeping in mind how to integrate & move to mass production.
Elements of an MCP-PMT

- Photocathode
- **Micro-channel plates**
- Collection anode
- Readout electronics
- Mechanical design / tile assembly.
Micro-channel Plates

• Conventional MCPs:
  – Drawn/sliced lead-glass fiber bundles.
  – Chemical etching & heating in hydrogen to improve emissivity.
  – Expensive!

• LAPPD approach:
  – Use atomic layer deposition (ALD) on low-cost substrates.
    • Allows precision control over thicknesses, down to single atomic layers.
    • Can be used with a large variety of materials.
    • Potentially significant cost savings.
ALD Activation of Glass Capillaries

1) Begin with insulating glass capillaries

2) Use ALD to apply a resistive coating.
3) Use ALD to apply an emissive coating.
Performance of ALD MCPs

• Successful functionalization of glass capillaries:

  Average pulse shape

  Gain characterization

⇒ Significant progress after 1 year... and improving constantly.
Elements of an MCP-PMT

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Stripline Anodes (Prototype)

• Photonis-Planacon on transmission line PCB:

• Striplines allow coverage of a large area with a manageable number of channels.
Stripline Anodes (Prototype)

- Difference in timing along strip gives position.

Transmission line readout using fast timing
Resolution < 200 μm with 50 PEs

8” x 8” plates are investigated
Stripline Anodes (Prototype)

- Average timing along strip gives arrival time.

\[ \sigma_t \text{ of order \( ps \) feasible for large } N_{pe} \]
• As part of the understanding work done on the MCP-PMTs detector in the LAPPD we are looking at:

  ✓ How is the signal created in the last MCP gap (between MCP and anodes).
  ✓ How is the signal (E-field) is coupling into the micro-stripline.
  ✓ How is the signal propagating along the striplines.
Detector simulation

Simulation of the signal generation and propagation in the stripline
- In progress
- Challenging

Simulation difficulties
- Near field
- Particle in cell
- Time dependent

Objectives
- Validate experimental results
- Improve detector efficiency (by better coupling the electron energy in the striplines)

Surface charge induced on the strip as a function of time and position
Elements of an MCP-PMT

- Photocathode
- Micro-channel plates
- Collection anode
- **Readout electronics**
- Mechanical design / tile assembly.

Input photons

Photocathode

MCP1

MCP2

Anode

Readout Electronics
Readout Electronics

- Building on experience from existing devices & readouts.
  - Readouts based on waveform sampling.
  - Requirements of the readout vary significantly by application.
    - Testing of existing devices can help guide design choices...
Single Photon Timing Studies

- Studies performed at Hawai‘i using laser on Hamamatsu SL10.
  - (Synergistic development with TOP R&D)
  - Laser attenuated to get single $\gamma$, data logged with a 20 GSa/s, 8 GHz analog bandwidth scope.
  - Timing extracted with constant-fraction algorithm:

$\sigma \sim 38.37$

=> Excellent single photon timing... what happens at lower sampling rates / bandwidths?
Single Photon Timing Studies

• Studies performed at Hawai’i using laser on Hamamatsu SL10.
  – (Synergistic development with TOP R&D)
  – Laser attenuated to get single $\gamma$, data logged with a 20 GSa/s, 8 GHz analog bandwidth scope.
  – Timing extracted with constant-fraction algorithm:

  ➔ Lower sampling rate (4 GSa/s) and lower bandwidth (~350-400 MHz) could be adequate for Belle II TOP.

  ➔ Each application is different! These types of studies help determine the electronics needs.

  ➔ We also study different algorithms...
Timing Extraction Methods

**Single threshold**

The single threshold is the least precise time extraction measurement. It has the advantage of simplicity.

**Multiple threshold**

The multiple threshold method takes into account the finite slope of the signals. It is still easy to implement.

**Constant fraction**

The constant fraction algorithm is very often used due to its relatively good performance and its simplicity.

**Waveform sampling**

The waveform sampling above the Nyquist frequency is the best algorithm since it preserves the signal integrity.

In principle, sampling above the Nyquist-Shannon frequency and fully reconstructing the signal preserves the best timing information.
Examples of Timing Algorithm Studies...

Comparison of two algorithms*:
1. “Reference” (~template fitting)
2. Constant fraction
   • Performance demonstrated on two different waveform sampling ASICs.

Reference method: CFD method:

- On both ASICs, the reference method performed slightly better than CFD.
- The difference was small... for many applications CFD may be enough.

N_{pe} \approx 30-50 for these tests.

*for details, see SLAC-PUB-14048 (also to appear in NIM A)
Timing Extraction Simulations

How to get to picosecond timing

- The four algorithm models have been simulated.
- In principle, pulse sampling gives the best results.
- To realize this performance, sampling frequency is taken to be $2 \times$ the fastest harmonic in the signal: 10Gs/s.


From Jean-François Genat
Components of a Waveform Sampling ASIC

- Single storage Channel
- Sample timing Control
- Readout Control
- Few mm x Few mm in size
- On or off-chip ADC

G. Varner -- Deeper Fast Waveform Sampling -- picoSecond WS in Krakow
LAPPD: Development of a 10Gs/s sampling chip

<table>
<thead>
<tr>
<th>Chip characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>IBM CMOS 0.13µm</td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>&gt;10Gs/s</td>
</tr>
<tr>
<td>Number of channels</td>
<td>4</td>
</tr>
<tr>
<td>Number of sampling cells</td>
<td>256</td>
</tr>
<tr>
<td>Input bandwidth</td>
<td>&gt;2GHz</td>
</tr>
<tr>
<td>Dead time</td>
<td>2µs</td>
</tr>
<tr>
<td>Number of bits</td>
<td>8</td>
</tr>
<tr>
<td>Power consumption</td>
<td>To be measured</td>
</tr>
</tbody>
</table>

No results to present yet.
Chip (basic) internal architecture

Timing Generator

Input

Sampling cell #1
Sampling cell #2
Sampling cell #3
...
Sampling cell #n-1
Sampling cell #n

ADC
ADC
ADC
...
ADC
ADC

Output bus

Token
Chip (basic) internal architecture

Third revision (PSEC3) just received, testing beginning.
Hawai’i Waveform Sampling Development

- Potential alternative ASICs for waveform sampling:
  - Ice Radio Sampler (IRS) Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>32768 samples/chan</td>
<td>(16-32us trig latency)</td>
</tr>
<tr>
<td>8 channels/IRS ASIC</td>
<td></td>
</tr>
<tr>
<td>8 Trigger channels</td>
<td></td>
</tr>
<tr>
<td>~9 bits resolution (12-bits logging)</td>
<td></td>
</tr>
<tr>
<td>64 samples convert window (~32-64ns)</td>
<td></td>
</tr>
<tr>
<td>1-2 GSa/s</td>
<td></td>
</tr>
<tr>
<td>1 word (RAM) chan, sample readout</td>
<td></td>
</tr>
<tr>
<td>16 us to read all samples</td>
<td></td>
</tr>
<tr>
<td>100’s Hz sustained readout (multibuffer)</td>
<td></td>
</tr>
</tbody>
</table>

Deep sampling ASICs developed in Hawai’i:
- IRS: deep sampling w/ ~1 GHz bandwidth.
- BLAB3: deep sampling w/ on-chip amplification.
Elements of an MCP-PMT

- Photocathode
- Micro-channel plates
- Collection anode
- Readout electronics
- **Mechanical design / tile assembly.**
Device Assembly

Device construction must maintain:
- a vacuum-tight seal
- mechanical integrity under high pressure and stress
- high bandwidth of the read-outs through vacuum seal
- low cost design goals

Pursuing two main directions:
- Ceramic assemblies, similar to those used in conventional MCP designs (Berkeley, SSL)
- Flat-panel sealed glass technologies (ANL, Chicago)

R. Northrop, H. Frisch, S. Asare (UC), M. Minot (Minotech Eng.), G. Sellberg (Fermilab), J. McPhate, O. Siegmund (SSL), A. Tremsin (SSL/Arradiance), R. Banwhani (UCB), D. Walters (NE/ANL), R. Wagner (HEP/ANL), J. Greggor (ANL)
Summary

• The LAPPD Collaboration, after one year:
  – Lots to do before we have 8”x8” MCP-PMTs...
  – …but significant progress has been made in all elements.

• Success could mean fast photodetection over large areas becomes affordable.

• Looking forward to continued progress…
BACKUP
Detector presentation

Specification
- Large area: 20×20cm²
- Cheap: less than 10$ incremental cost per in²
- Fast: ~1psec resolution at 100 PE
- Efficient: Study of high QE photocathode (>50%)

Parts
- Photocathode (2 options Ga-X or Multi-Alkali)
- MCP 1 & 2 (ALD coated)
- Anodes striplines (silkscreen)
- Glass enclosure (Borofloat 33)
- Readout electronics

Connectivity
- No internal connections (HV via R divider network)
- No pins (stripline read-out)

Goal: detector ready in 2 years from now. Status end of year 1.
Signal development theory

Signal creation
• The field radiated by the electrons as they are accelerated in the gap induces surface current on the top stripline that are the signal sources for stripline.
• The rise time is given by the traveling time of the electrons in the gap. Under simulation.
• The fall time is given by the ground return loop (to be verified). Under simulation.

Signal propagation
• After creation, signals propagate in a microstripline mode to both ends of the detector.

Signal limitation
• Bandwidth simulated and tested at 2.5GHz
• Field losses when coupling into microstrip lines.
Electron signal from the MCPs

Signal characteristics
- Nb of output electrons: up to $10^{10}$ per pore.
- Cloud size: 20µm (size of the MCP pore). The x-y cloud expansion is negligible in a small gap (1mm):
  \[
  \text{electrons gap speed} / \text{electron drift speed} = 10^5.
  \]

Signal development
- Electron travelling in the gap induces signal on the stripline.
- The electron time of travel and speed determines the rise-time of the signal. Under simulation.

Signal limitation
- Time resolution: Cloud elongation in z-direction creates timing degradation. Under simulation.
- Spatial resolution: Pores create a shift in the direction of their bias angle for the electron clouds (~200µm @800V).
- Noise: Photocathode thermal-emitted electrons (1PE equiv. noise).
- Saturation: each pore has a limited output current (depending on the MCP resistivity).

Best to work at:
- Balanced number of PE
  - Insensibility to noise
  - Avoiding saturation
- High last-stage bias voltage
  - Fast rise time

Superimposed pinhole mask for two voltage value in the last gap. O Siegmund (Berkeley)
Signal development results

Propagation in the stripline

Micro-stripline array typical bandwidth:
- Measured (red)
- Simulated (blue)

Micro-stripline simulated in HFSS @ 1Ghz.

2.5Ghz = 140ps rise time
Timing generator

- Generates a sampling frequency at:
  \[ \frac{1}{\text{Delay}} \]
  - The min delay is smaller for smaller process
  - Locking the DLL improves temp. dependency, jitter, ...
  - Current sampling speed : 11Gs/s

- Digitization: count until the comparator reaches the threshold.
  - Slow process (2µs)
  - Good linearity (given by the ramp)
  - Question: number of counter to use (so far: 1 counter per cell) ?
Chip evolution

• Issues faced during development
  ✓ Lack of support from IBM (new kit).
  ✓ Wrong ESD protections.
  ✓ Leakages.
  ✓ Digital part (flip-flop, counters).

• Strengths of the design
  ✓ The relative simplicity.
  ✓ Has already be fully proven working (Delagnes, Breton, Ritt, Varner).
  ✓ Support from G. Varner, E. Delagnes and D. Breton

• Future plans
  ✓ More testing in the upcoming month (boards and chips coming).

Analog outputs from Psec2 before correction showing cell-to-cell offset (and scope noise).