Large-Area Fast Micro-channel Plate Photo-detectors

Yi Qiang

SoLID Meeting

Jan 15, 2013

Large-Area Pico-second Photo Detector (LAPPD)

- Newly funded by DOE and NSF (fall '09)
  - 4 National Labs
  - 5 Divisions at Argonne
  - 3 US small companies;
  - Electronics expertise at UofC and Hawaii
  - Photocathode expertise at Washington University, St. Louis and UIC

- Premise:
  - Apply advances in material science and nanotechnology to develop new, batch methods for producing cheap, large area photo-detectors
  - Improvement in at least one performance parameter by an order of magnitude
  - Develop path to a commercializable product

- Project currently in its third year
  - http://psec.uchicago.edu/

Large Area Picsecond Photodetector Collaboration

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Space Sciences Laboratory, University of California, Berkeley, CA

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Synkera Technologies Inc., Longmont, CO

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Department of Physics, University of Washington, Seattle, WA

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Goal: develop a family of large-area robust photo-detectors with ***good position and timing resolution*** that can be tailored for a wide variety of applications where large-area ***economical*** photon detection is needed.

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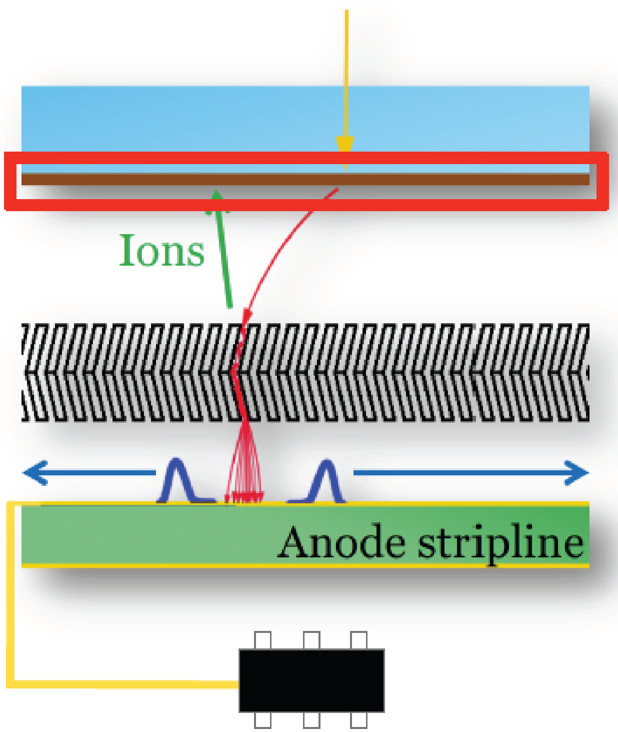
LAPPD Deconstructed

8" Square Tile



1. Photo-Cathode (PC)
   - Conversion of photons to electrons
   - Engineer III-V materials to develop robust high QE photo-cathodes
2. Micro-Channel Plates
   - Amplification of signal: two plates with tiny pores, held at high potential difference. Use Atomic Layer Deposition for emissive material on inert substrates to create avalanche
3. Electronics
   - Transmission line readout: 50Ω scalable strip line, silk-screen printed on glass ground plane
   - Readout at both ends with fast custom CMOS SCA chip with 10GHz waveform digitization
4. Hermetic Packaging
   - Maintain vacuum and provide support. No internal connections; no penetrations

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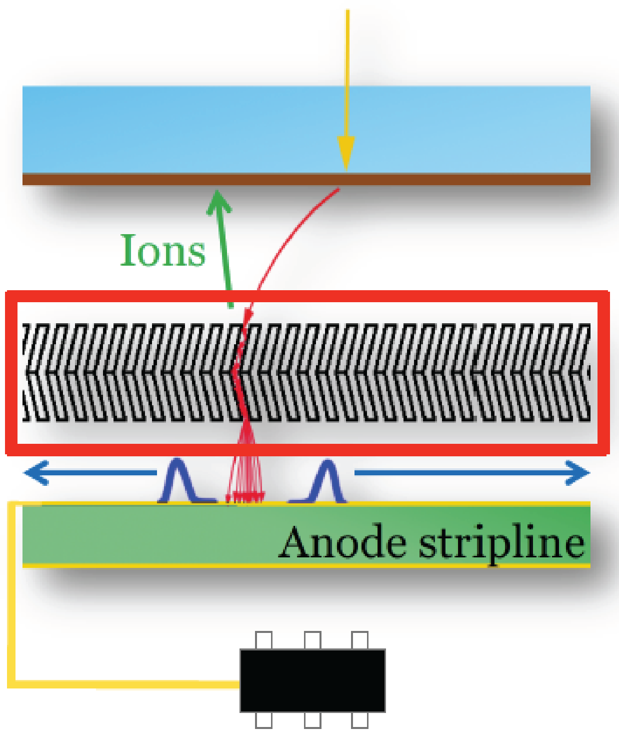

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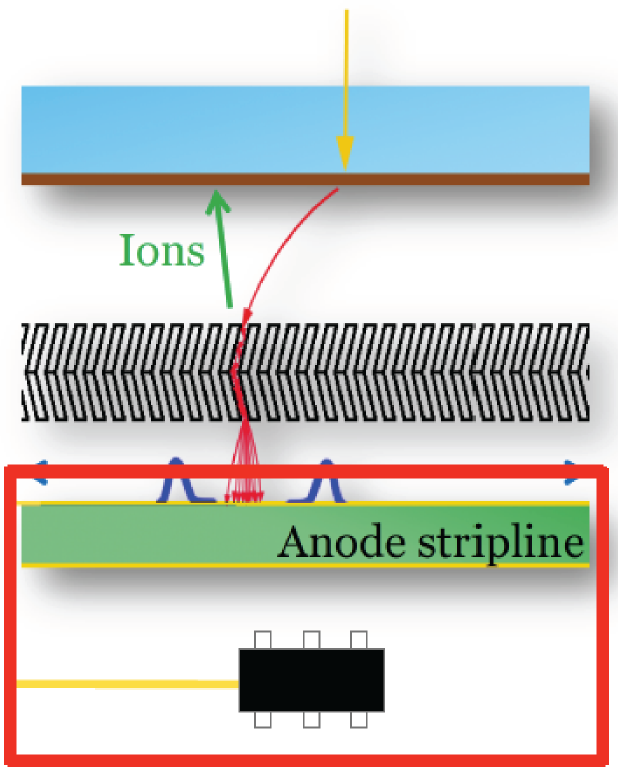

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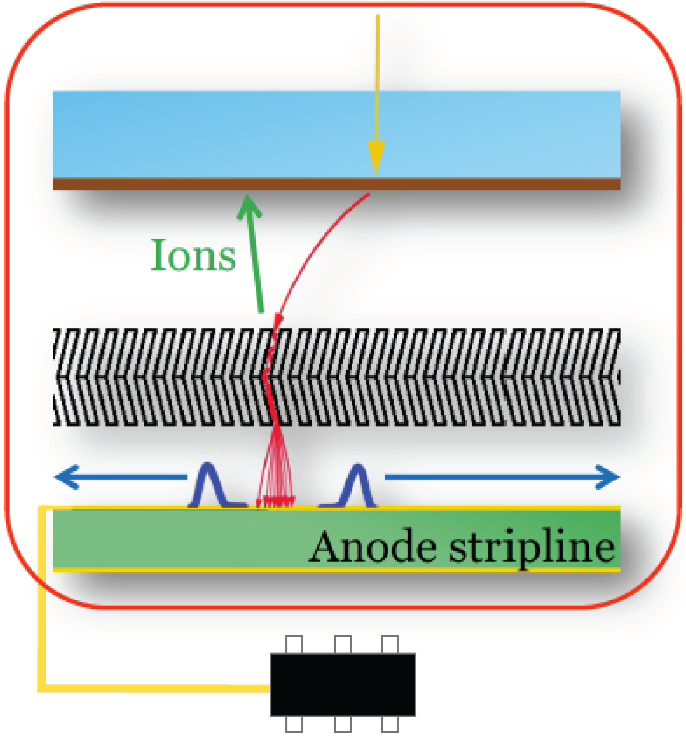

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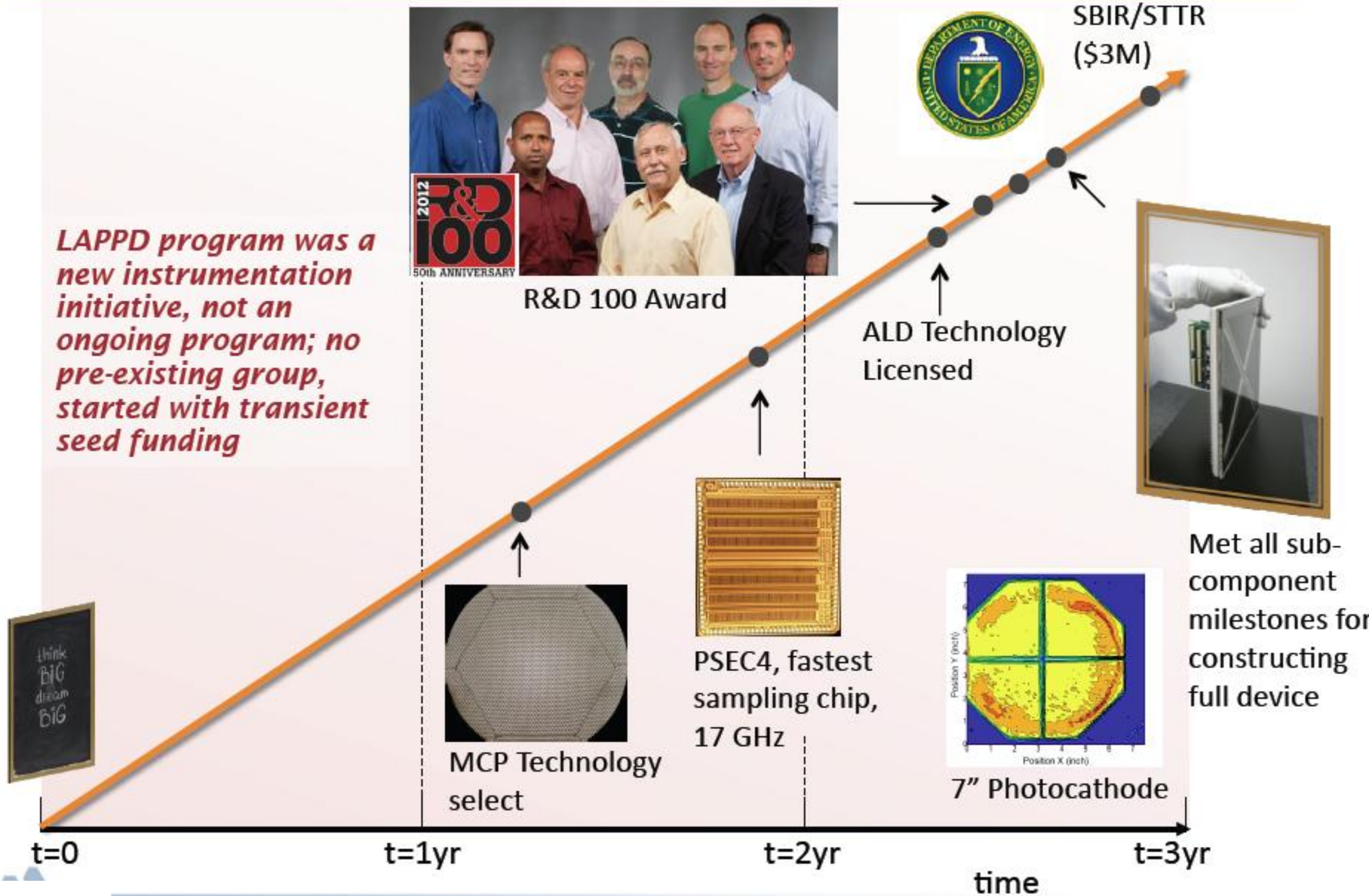
The Previous Three Years



Argonne

Argonne 8" PhotoCathode Progress Summary

- Large area (7"X7") flat photocathode with average QE (~16%) was produced,
- Highest QE value was 22% QE of the photocathode is directly related to base Sb layer thickness.
- The optimized Sb thickness for KCs-Sb photocathode is around 78% transmission (@400nm).
- In related studies we used the BNL Synchrotron light source experiment and successfully saw the K diffusion process and K_2CsSb crystalline growth with X ray reflection/diffraction.

Next Steps

- More Reflection data on Sb films to calibrate the transmission
- Optimize the cathode recipe for higher QE cathode based on parameter studies & X ray reflection/diffraction data.
- Input findings into LAPPD sealed tube fabrication program

UCB 8" PhotoCathode Progress Summary

8" PC/Seal Test Chamber

- $<10^{-9}$ Torr base vacuum, RGA operational, fully baked
- 5mm thick, 8.7" polished B33 windows, NiCr border with "X"
- Successfully hot/vacuum sealed window to tube indium well.
- Deposited Na_2KSb photocathodes on 8" windows
  - *~25% QE with good uniformity (±15%) and stability (>5 Mo)*
  - *Can repeat successful process in different vacuum tanks*
  - *RGA/pressure/temp/response record for entire process*

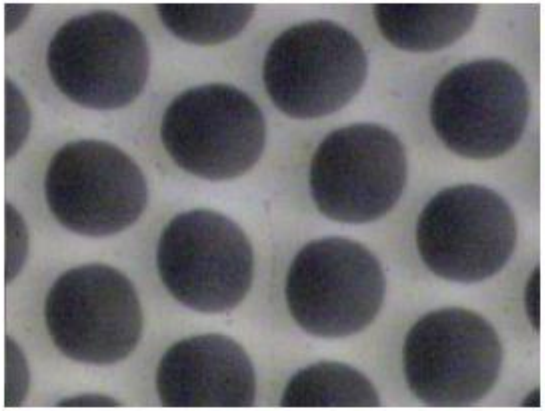
8" Sealed Tube Process Tank

- *$<10^{-9}$ Torr base vacuum, RGA operational, fully baked*
- *Deposited 1st cathode, optimization process underway*

Next Steps

- *Optimize cathode process in 8" Sealed Tube Tank*
- *Seal Na_2KSb photocathodes onto LAPPD devices*

MCP Development: Simplifying Construction



Conventional Pb-glass MCP

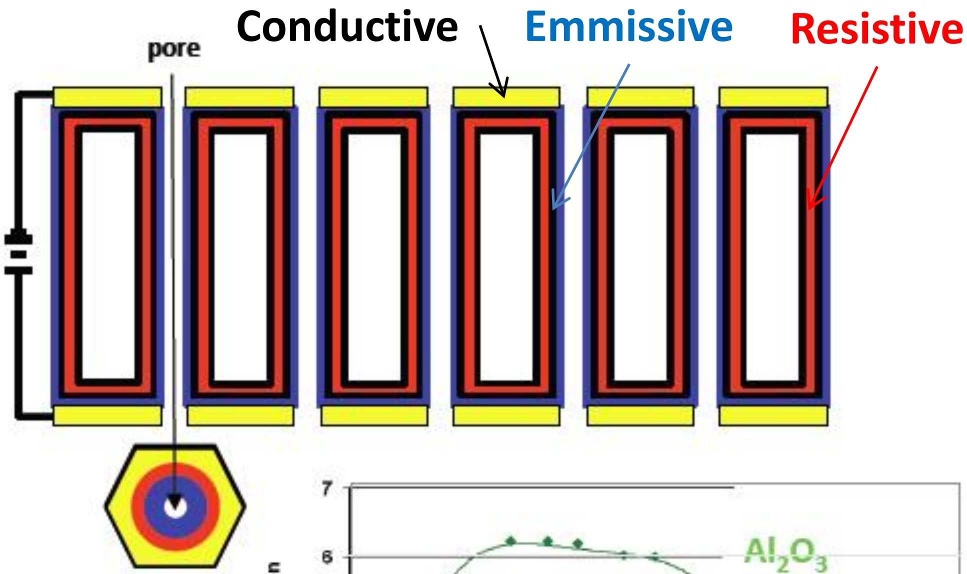
Incom Glass Substrate

- Chemically produced and treated
- Pb-glass provides 3 functions:
  - Provides pores
  - Resistive layer supplies electric field in the pore
  - Pb-oxide layer provides secondary electron emission

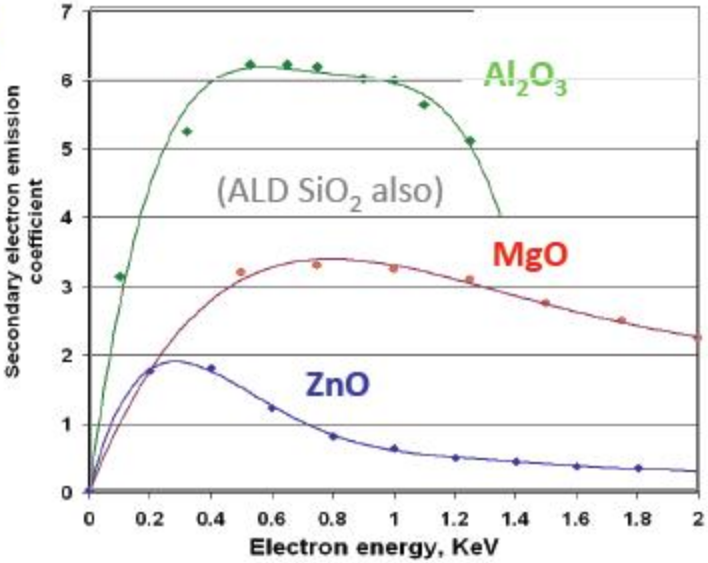
- Separate the three functions:
  - Hard glass substrate provides pores
  - Separate Resistive and Emissive layer functions
  - Produce Tuned Resistive Layer (Atomic Layer Deposition, ALD) provides current for electric field
  - Specific Emitting layer provides secondary electron emission

MCP Fabrication with ALD

- Apply conductive coating for HV, using thermal evaporation or sputtering

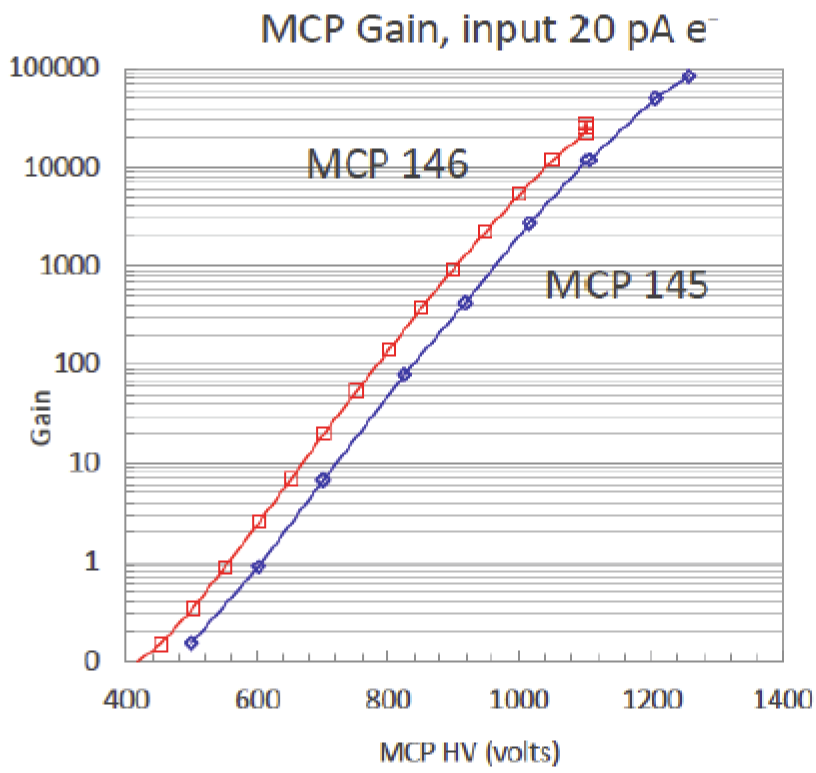


- First time applying new technology, a factor >5 improvement obtained in gain of ALD treated MCPs compared to commercial MCPs; area will be substantially increased



MCP Performance

- Single MCP, 33mm diameter, 20µm pore borosilicate MCP substrate, L:d = 60:1, 8 degree pore bias
- MCP disks functionalized with identical "Chemistry 2" resistive coating and Al_2O_3 SEE layer
- Single MCP tests in DC amplification mo[…] imaging and gain very similar to conventional MCPs.
- MCP pair gain of > 10^7 with > 10^5 in a single plate
  - Attractive for cost/simplicity



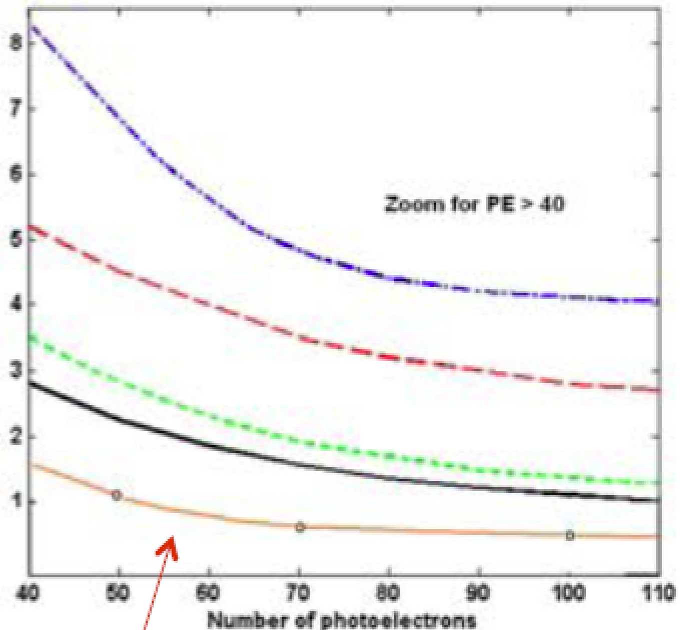
DAQ

- The DAQ system is targeted towards a module, which is six tiles (large area applications)

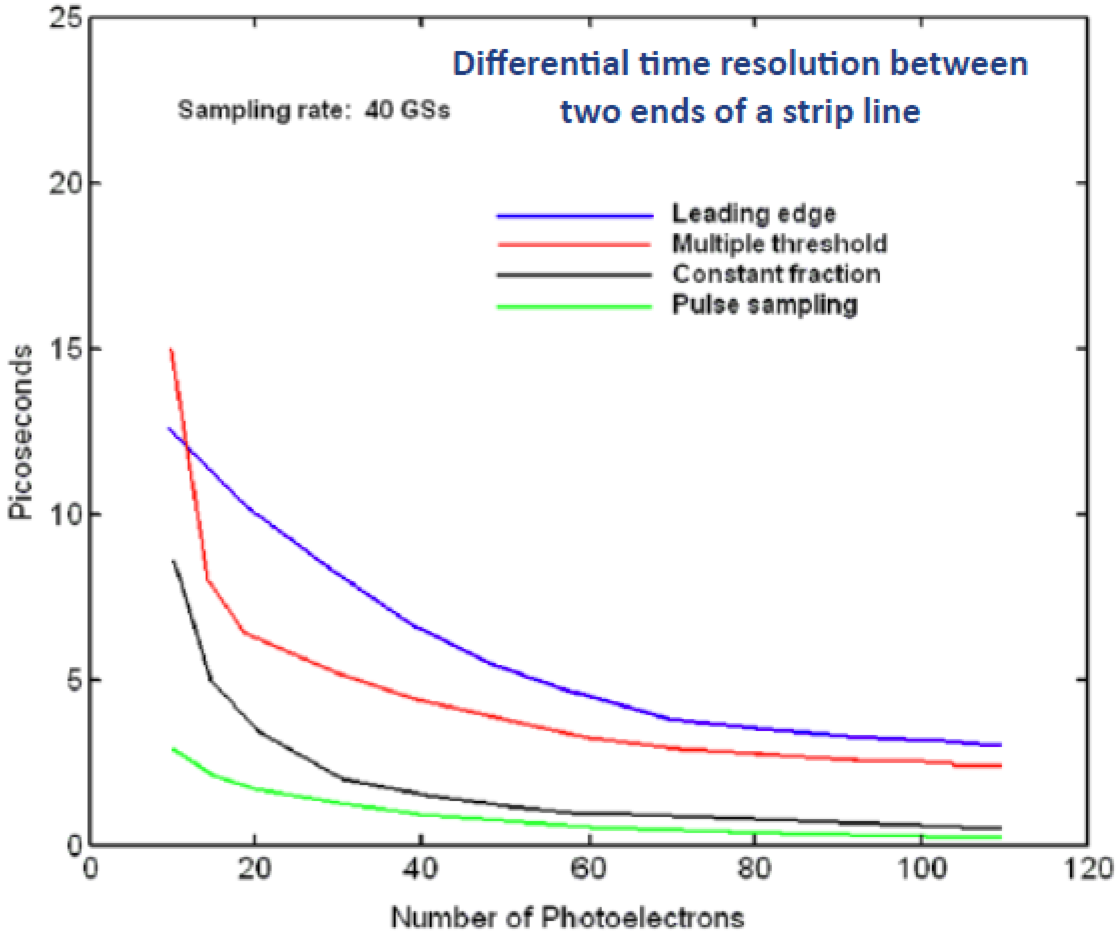
PSEC4 Waveform Sampling ASIC

- Resolution depends on # photoelectrons, analog bandwidth, and signal-to-noise.

- Simulations showed "pulse sampling" to give the best results



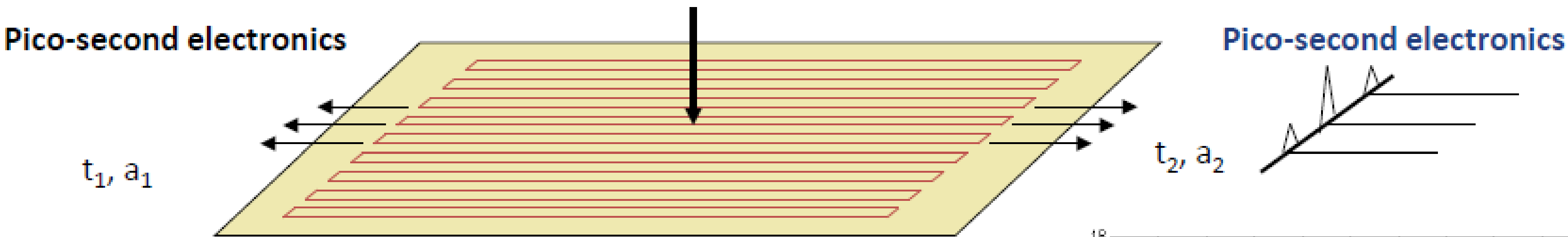
Measured!



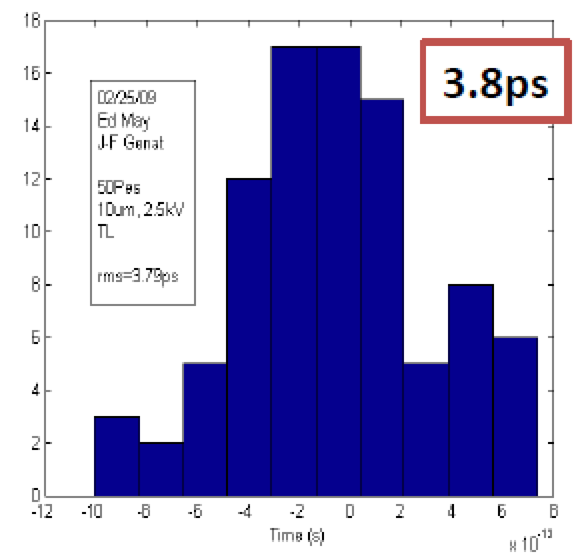
Picosecond timing and 2D position for large area detectors: delay lines and Waveform Sampling

Delay line readout and pulse sampling provide fast timing (2-10ps).
→ Delay lines should have a signal bandwidth matched to the detector

Fewer electronics channels for large area sensors



3.8 ps translates in 190 μm position resolution with 50 photo-electrons



$\frac{1}{2}(t_1 + t_2)$ = time
$v(t_1 - t_2)$ = longitudinal position
$\Sigma\, \alpha_i\, a_i \,/\, \Sigma\, \alpha_i$ = transverse position

The electronics contribution to spread is small:
3.8ps / sqrt(2) = 2.7ps,

For 50PEs, MCP is 30ps / sqrt(50) = 4.2ps, equal at 100 PEs

Facilities for MCP-PMT Fabrication

- Space Sciences Laboratory/Berkeley
  - **Large Process Tank ready for first 8" tube fabrication**
    - Ceramic or Glass body
      - Ceramic body process fully specified with most steps qualified
      - Glass body process is beginning to be qualified
    - Na_2KSb photocathode with QE > 20%
- Argonne
  - Design work for 8" vacuum transfer system is ongoing with complete design anticipated for late spring 2013 and construction through mid-2014
    - Initially Glass body production of 8"×8" pinless 30-anode strip line design with indium seal
      - Thermopressure seal; parallel backup is hot pre-tinned indium seal
    - Adaptable for fabrication of alternative formats, photocathodes, ALD materials
    - K_2CsSb photocathode
  - Existing 4" vacuum transfer system in process of modification to proof process steps on smaller 2.5" format
    - Parts handling and processing generally directly scales to 8" format. Photocathode process will likely require formulation changes

Tube Production Plan for Next 3 Years

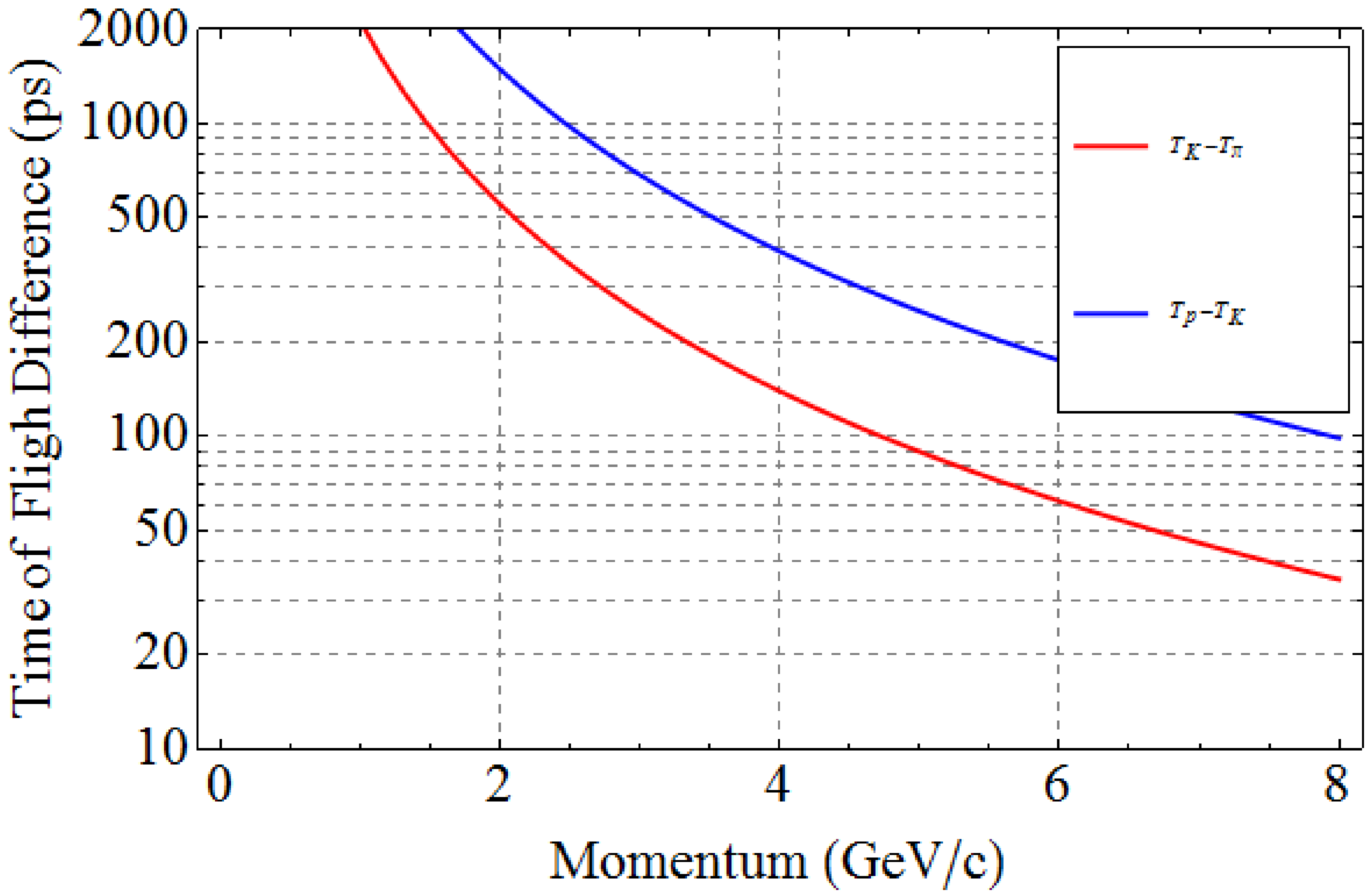
- Space Science Laboratory/Berkeley
  - Year 1
    - First sealed ceramic tube. Process Development. Continue with 1-2 more ceramic tubes
    - First glass body tube.
  - Year 2
    - Continued ceramic tube fabrication (2-3) & improvement/optimization
    - Continued glass body tube fabrication (1-2).
  - Year 3
    - Ceramic tubes and/or systems customized for early adopter; 1 per 4 week cycle
    - Glass tubes by request
- Argonne National Laboratory†
  - Year 1
    - Complete 8" Single Tile Processing System design, begin procurement and assembly
  - Year 2
    - Complete assembly of 8" STPS, demonstrate individual processing steps (sample handling, photocathode shoot, baking & scrubbing, tube sealing)
    - Fabricate first 8" glass body tube
  - Year 3
    - Establish routine production ramping up to 1 tube/2 week cycle

† need sealed-tube facility manager with phototube production experience

Potential

- Large Area photo-detectors with extended capability
- Neutrino Experiments
- TOF at collider detectors
- TOF – PID applications
  - EIC detectors
  - Glue-X
  - PANDA
- Broader impact
  - X-ray detectors
  - PET
  - Neutron detection
  - Homeland security

PID with TOF at 6 meters



Other Important Numbers

- MCP life time: >> 0.01 C/cm^2
  - 10^6 gain -> 6×10^{10} PE/cm^2 (1kHz/cm^2 -> 700 days)
- Noise Level: $<0.1/cm^2/s$
  - comparable to cosmic
- Saturation Current (from Hamamatsu): > $0.5 \sim 5 \times 10^{-7}$ A/cm^2
  - 10^6 gain -> $0.3 \sim 3 \times 10^6$ PE/s/cm^2
- Radiation Hardness: Unknown

Resources

- DOE Review Dec 9, 2011
  - https://twindico.hep.anl.gov/indico/conferenceDisplay.py?confId=740
- DOE Review Dec 18, 2012
  - https://twindico.hep.anl.gov/indico/conferenceDisplay.py?confId=1201