The Development of Large-Area Pico-second Photodetectors

Henry Frisch, Enrico Fermi Institute, Univ. of Chicago

For the LAPPD Collaboration

Acknowledgements - LAPPD collaborators, Howard Nicholson and the DOE HEP, ANL Management, and the NSF.
Using New Technologies to Exploit Fundamentally Simple Ideas To probe new things
Motivation(s)

SRI’s “NABC” approach
A methodology to develop a quantitative value proposition — the first step in value creation

Apologies if it seems obvious or didactic- it turns out to be powerful
Colliders:

Need: 1) identify the quark content of charged particles
2) vertex photons

Theme: extract all the information in each event (4-vectors)

Approach: measure the difference in arrival times of photons and charged particles which arrive a few psec later. Light source is Cherenkov light in the window/radiator.

Benefit: Discoveries in signatures not possible now (Note: conventional TOF resolution is 100 psec - factor of 100 worse than our goal = 1” is 100 psec, so need a small scale-length).
The bizarre structure of basic matter

Distinguishable only by mass (and possibly lifetime)—hence measure velocity (v) and momentum (gmv) of the parent particle to find out m and thus the quark content.

Charge +\(\frac{2}{3}e\)
- Up
- Charm
- Top

Charge -\(\frac{1}{3}e\)
- Down
- Strange
- Bottom
Need, e.g. - Higgs to gamma-gamma at the LHC - tie the photons to the correct vertex, and more precisely reconstruct the mass of the pair.
Why has 100 psec been the # for 60 yrs?

Typical path lengths for light and electrons are set by physical dimensions of the light collection and amplifying device.

These are on the order of an inch. One inch is 100 psec. That’s what we measure - no surprise! (pictures from T. Credo)
Time resolution on 2 ends of 8”-anode strip vs \((S/N)^{-1}\) in psec (pair of 8” MCP’s)

N = RMS of the noise; S = signal amplitude

< 6 psec

Laser spot size

M. Wetstein, B. Adams, A. Elagin, R. Obaid, A. Vostrikov, ...
Neutrino Physics

**Need:** lower the cost and extend the reach of large neutrino detectors

**Approach:** measure the arrival times and positions of photons and reconstruct tracks in water

**Benefit:** Factor of 5 less volume needed, cost.

**Competition:** large PMT’s, Liquid Argon
Can we build a photon TPC?

Work of Matt Wetstein (Argonne,&Chicago) in his spare time (sic)
Daniel Boone

• Proposal (LDRD) to build a little proto-type to test photon-TPC ideas and as a simulation testbed
• `Book-on-end’ geometry-long, higher than wide
• Close to 100% coverage so bigger Fid/Tot volume
• $\Delta x, \Delta y << 1 \text{ cm}$
• $\Delta t < 100 \text{ psec}$
• Magnetic field in volume
• Idea: to reconstruct vertices, tracks, events as in a TPC (or, as in LiA).
Medical Imaging (PET)

Need: 1) much lower dose rate
     2) faster through-put
     3) real-time feedback (therapy as well as diagnosis)

Approach: precise Time-of-Flight, sampling, real-time adaptive algorithms in local distributed computing, use much larger fraction of events and information

Benefit: higher resolution, lower dose to patient, less tracer production and distribution, new hadron therapy capabilities

Competition: Silicon PMT’s
Sampling Calorimetry in PET?

Can we solve the depth-of-interaction problem and also use cheaper faster radiators?

Simulations by Heejong Kim (Chicago)

Alternating radiator and cheap 30-50 psec planar mcp-pmt’s on each side.

Heejong Kim

Depth in crystal by time-difference

Depth in crystal by energy-asymmetry
Reconstructing the vertex space point:
Simplest case- 2 hits \((x,y)\) at wall

E.g. for KOTO (Prof. Wah’s expt at JPARC)

Vertex (e.g. \(\pi^0\to\gamma\gamma\))

\[
T_v, \ X_v, \ Y_v, \ Z_v
\]

One can reconstruct the vertex from the times and positions-
3D reconstruction
Cerenkov-sensitive Sampling Quasi-Digital Calorimeters

A picture of an em shower in a cloud-chamber with ½” Pb plates (Rossi, p215- from CY Chao).

A ‘cartoon’ of a fixed target geometry such as for JPARC’s KL-> pizero nunubar (at UC, Yao Wah) or LHCb.
How Does it Work?

Requires large-area, gain > $10^7$, low noise, low-power, long life, $\sigma(t)<10$ psec, $\sigma(x) < 1$mm, and low large-area system cost

Realized that an MCP-PMT has all these but large-area, low-cost:
(since intrinsic time and space scales are set by the pore sizes- 2-20µ)

window

Incoming charged particle

Photocathode on inside of window

Radiated Cherenkov photon

Pair of micro-channel plates

Photo-electron from cathode

RF strip-line anode

Output pulse of $10^7$ electrons
Collaboration with SSL/UCB

• Two parallel but intertwined efforts:
  – SSL/Hawaii (Siegmund) - ceramic package based on Planacon experience, NaKSn cathode, higher cost, smaller area, lower throughput;
  – ANL/UC (Wagner, Byrum, Frisch) - glass package, KCsSb cathode, lower cost, larger area, higher throughput;
  – Reduce risk and enhance reward by diversification onto the 2 paths. Has proved very beneficial to both efforts (much cross-fertilization, and shared MCP development). Not a competition, but a shared collegial effort that has worked, and is working, very well.
So what are the new technologies?

- Glass capillary substrates (Incom)
- Atomic Layer Deposition (Arradiance, ANL)
- RF transmission line anodes (Tang, UC..)
- Waveform Sampling (Hawaii, MPI, Orsay, Saclay, UC)
- Cheap plate glass, frit seals, silk-screened anodes, home-brew indium seals, ...

However- there are areas where we have only old technologies and need new ones-

Challenges and opportunities (have some fun while you’re mostly typing in deathless C++)
Simplifying MCP Construction

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

Conventional Pb-glass MCP

Separate the three functions:
1. Hard glass substrate provides pores;
2. Tuned Resistive Layer (ALD) provides current for electric field (possible NTC?);
3. Specific Emitting layer provides SEE

Incom Glass Substrate
Latest Incom Micropore Substrate

INCOM glass substrate

.075”
~150 20μ pores

80 million 20-micron pores in an 8”-sq plate
65% open-area ratio; 1.2mm thick (L/D=60)
New MCP Structure (not to scale)

1. resistive coating (ALD)
2. emissive coating (ALD)
3. conductive coating (thermal evaporation or sputtering)

Jeff Elam
Atomic Layer Deposition (ALD) Thin Film Coating Technology

- Atomic level thickness control
- Deposit nearly any material
- Precise coatings on 3-D objects

Lots of possible materials => much room for higher performance

Jeff Elam pictures
ALD & Integration tests at ANL
Argonne Atomic Layer Deposition and Test Facilities

- In situ measurements of R (Anil)
- Femto-second laser time/position measurements (Matt, Bernhard, Andrey, Razib, Sasha, Bob, Eric)
- 33 mm development program
- 8” anode injection measurements

The Test Stand
- Ultra-fast (femto-second pulses, few thousand Hz) Ti-Sapphire laser, 800 nm, frequency triple to 266 nm
- Small UV LED
- Modular breadboards with laser/LED optics

Anil Mani and Bob Wagner
Razib Obaid and Matt Wetstein

RealTime 2012 Berkeley CA
SSL (Berkeley) Test/Fab Facilities

Ossy Siegmund, Jason McPhate, Sharon Jelenski, and Anton Tremsin-
Decades of experience
(some of us have decades of inexperience?)

MCP Specific Test Facilities

- Double chamber UHV test station for single/double MCP detectors
- Multiple port UHV lifetest station for single/double MCP detectors
- Both have support electronics
Performance:

Noise (bkgd rate). \( \leq 0.1 \text{ counts/cm}^2\text{/sec; factors of few > cosmics} \)
Microchannel Plates-4d

Performance: burn-in (aka `scrub’)

Measurements by Ossy Siegmund, Jason McPhate, Sharon Jelinsky, SSL/UCB

(Measurements by Ossy Siegmund, Jason McPhate, Sharon Jelinsky, SSL/UCB)

Big deal commercially?)

Gain drop <5% over 16 hours and 0.01 C cm\(^{-2}\), quite stable since the

[Graph showing gain drop and extracted charge with annotations]

Measured ANL ALD-MCP behavior (ALD by Anil Mane, Jeff Elam, ANL)

Typical MCP behavior-long scrub-times

1μA scrub @ 3 x 10\(^5\) gain, 700v per MCP
Signal- want large for S/N

We see gains $> 10^7$ in a chevron-pair

Ossy Siegmund, Jason McPhate, Sharon Jelinsky, SSL/UCB

ALD by Anil Mane and Jeff Elam, ANL
Tile-Tray Integrated Design

Because this is an RF-based readout system, the geometry and packaging are an integral part of the electronic design.

The design is modular, with 8”-square MCP sealed vacuum tubes (‘tiles’) with internal strip-lines capacitively coupled to a ground plane (tray) that also holds the electronics.
A `tile’ is a sealed vacuum-tube with cathode, 2 MCP’s, RF-strip anode, and internal voltage divider. HV string is made with ALD.

A `tray’ holds 12 tiles in 3 tile-rows. 15 waveform sampling ASICS on each end of the tray digitize 90 strips. 2 layers of local processing (Altera) measure, extract charge, time, position, goodness-of-fit.
SuperModule Mockup: $\frac{1}{2} - m^2$ of cathode

- Real 8” glass tile package parts- anode, side-wall, window (sic)
- `Innards’ stack of 2 MCP’s +3 spacers+anode+window under test
- Have read out through from AC card through full DAQ chain to PC
Extract time, position of pulse using time from both ends

DAQ system

- Backside of Super Module:

Data + System Clock + Ctrl

Gigabit Ethernet

FPGA

Center Card
- System control
- Clock distribution
- Feature extraction
- CPU interface

Eric Oberla slide from ANT11
Demonstration of the Internal ALD HV Divider in the Demountable Tile

Demountable at APS

Average pulse shape vs HV

Scanning the laser: t vs x

IV Curve (expected 32 Megs)
Developing and Testing the Electronics, Anodes, and DAQ

Eric Oberla (grad student) and Craig Harabedian (engineer) working on the Tray layout and cabling

6/9/2012
Analog Card to Digital Card

Can be direct connection (shown) or cable
Digital Cards and Central Card

Present readout to PC and Nvidia GPU is via USB; Ethernet hardware is on boards- later
Anode Testing for ABW, Crosstalk,..

Herve’ Grabas, Razib Obaid, Dave McGinnis

Network Analyzer

Tile Anode
Anode Testing for ABW, Crosstalk,..

Razib Obaid
Brown line: 10 Gs/sec (we’ve done >15); 1.5 GHz abw (we’ve done 1.6); S/N 120 (N=0.75mv, S is app specific)
The PSEC4 Waveform Sampling ASIC

PSEC4: Eric Oberla and Herve Grabas; and friends...

PSEC-4 ASIC

- Designed to sample & digitize fast pulses (MCPs):
  - Sampling rate capability > 10GSa/s
  - Analog bandwidth > 1 GHz (challenge!)
  - Relatively short buffer size
  - Medium event-rate capability (up to 100 KHz)

→ 130 nm CMOS

<table>
<thead>
<tr>
<th>SPECIFICATION</th>
<th>2.5-15 GSa/s</th>
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<tbody>
<tr>
<td>Sampling Rate</td>
<td>6 (or 2)</td>
</tr>
<tr>
<td># Channels</td>
<td>256 (or 768) points</td>
</tr>
<tr>
<td>Sampling Depth</td>
<td>Depth*(Sampling Rate)^1</td>
</tr>
<tr>
<td>Sampling Window</td>
<td>&lt;1 mV RMS</td>
</tr>
<tr>
<td>Input Noise</td>
<td>1.5 GHz</td>
</tr>
<tr>
<td>Analog Bandwidth</td>
<td>Up to 12 bit @ 2GHz</td>
</tr>
<tr>
<td>ADC conversion</td>
<td>0.1-1.1 V</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>2 µs (min) – 16 µs (max)</td>
</tr>
<tr>
<td>Latency</td>
<td>yes</td>
</tr>
</tbody>
</table>

Eric Oberla, ANT11
PSEC-4 ASIC

• 6-channel “oscilloscope on a chip” (1.6 GHz, 10-15 GS/s)
• Evaluation board uses USB 2.0 interface + PC data acquisition software
6-channel `Scope-on-a-chip’

Designed by Eric Oberla (UC grad student) working in EDG with EDG tools and zeitgeist

Real digitized traces from anode

20 GS/scope 4-channels (142K$)

17 GS/PSEC-4 chip 6-channels ($130 ?!)

6/9/2012 RealTime 2012 Berkeley CA
PSEC-4 Performance

Digitized Waveforms

Input: 800MHz, 300 mV_{pp} sine

- Only simple pedestal correction to data
- As the sampling rate-to-input frequency ratio decreases, the need for time-base calibration becomes more apparent (depending on necessary timing resolution)
Digitization Analog Bandwith

Eric Oberla, ANT11

PSEC4: Eric Oberla and Herve Grabas+ friends...

\[ \text{Amplitude [dB]} \]

\[ \text{Frequency [MHz]} \]

ABW~1.6GHz

3 db loss
Noise (unshielded)

PSEC4: Eric Oberla and Herve Grabas+ friends...

Channel 3

RMS=755 microvolts

Entries: 51200
Mean: 0.2038
RMS: 0.7781
Integral: 5.12e+04
$\chi^2$/ndf: 276.5 / 29
Constant: 8445 ± 47.7
Mean: 0.06695 ± 0.00335
Sigma: 0.7547 ± 0.0026

Full-Scale ~1.2 volts (expect S/N>=100, conservatively)

Eric Oberla, ANT11

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Status of PhotoCathodes

Have made >20% 8”PC at SSL; 25% small PC’s at ANL, 18% 4” (larger underway)

SSL 8” SbNaK cathode

QE of SSL 8” SbNaK cathode

QE of ANL small SbKCs cathodes

4” cathode: Chalice in Burle oven

ANL
Opportunities: Can we go deep sub-picosec?: the Ritt Parameterization

(agrees with JF MC)

Stefan Ritt slide, doctored

S/N, $f_z$: DONE

abw: NOT YET

How is timing resolution affected?

\[ \Delta t = \frac{\Delta u}{U} \cdot \frac{1}{\sqrt{3} f_s \cdot f_{3db}} \]

<table>
<thead>
<tr>
<th></th>
<th>$\Delta u$</th>
<th>$f_s$</th>
<th>$f_{3db}$</th>
<th>$\Delta t$</th>
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<tr>
<td>today:</td>
<td>100 mV</td>
<td>1 mV</td>
<td>2 GSPS</td>
<td>300 MHz</td>
</tr>
<tr>
<td>optimized SNR:</td>
<td>1 V</td>
<td>1 mV</td>
<td>2 GSPS</td>
<td>300 MHz</td>
</tr>
<tr>
<td>next generation:</td>
<td>100 mV</td>
<td>1 mV</td>
<td>20 GSPS</td>
<td>3 GHz</td>
</tr>
<tr>
<td>next generation * optimized SNR:</td>
<td>1 V</td>
<td>1 mV</td>
<td>10 GSPS</td>
<td>3 GHz</td>
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</table>

*Includes detector noise in the frequency region of the rise time, *and aperture jitter

Stefan Ritt slide
UC workshop 4/11

100 femtosec
What’s the limit? (2009 cartoon)

Funnel pore with reflection cathode, dynode rings, ceramic anode,...

Front Window and Radiator

Photocathode

Pump Gap

High Emissivity Material

Low Emissivity Material

Gold Anode

Low Emissivity Material

‘Normal’ MCP pore material

Rogers

PC Card

50 Ohm Transmission Line

Capacitive Pickup to Sampling Readout

N.B.- this is a ‘cartoon’- working on workable designs-join us...
Opportunities

- Sub psec timing - e.g. Ritt 100 fsec extrp.
- Tight pulse height (high SEY 1st strike)
- Photocathode- QE’s >45%
- Non-vacuum transfer assembly
- Simpler top seal- (incl. metal for neutrons)
- Commercialization (SBIR/STTR)
Truth in Advertising - Current Problems
(remember we’re only in 3\textsuperscript{rd} yr)

- Uniformity of ALD (parallel efforts at ANL, Arradiance)- will be solved...

- Vacuum transfer assembly- ceramic in progress (SSL); several years for glass package most likely...

- `Frugal’ top seal for glass package (progress)

- Optimization for specific applications (e.g. Collider, KOTO, HE and LE neutrinos, PET)

- Lack of simulation for applications (help?)
More Information on LAPPD:

- **Main Page**: [http://psec.uchicago.edu](http://psec.uchicago.edu) (has the links to the Library and Blogs)

- **Library**: Workshops, Godparent Reviews, Image Library, Document Library, Links to MCP, Photocathode, Materials Literature, etc.;

- **Blog**: Our log-book- open to all (say yes to certificate Cerberus, etc.)- can keep track of us (at least several companies do);
The End
BACKUP SLIDES
Parallel Efforts on Specific Applications

Explicit strategy for staying on task - Multiple parallel cooperative efforts

LAPD Detector Development
ANL, Arradiance, Chicago, Fermilab, Hawaii, Muons, Inc, SLAC, SSL/UCB, UIUC, Wash. U
Drawing Not To Scale (!)

PET
(UC/BSD, UCB, Lyon)

Collider
(UC, ANL, Saclay)

Muon Cooling
Muons, Inc (SBIR)

K-\(\rightarrow\pi\nu\nu\)
JPARC

Neutrinos
(Matt, Mayly, Bob, John, ..; Zelimir)

Non-proliferation
LLNL, ANL, UC

Mass Spec
Andy Davis, Mike Pellin, Eric Oberla

All these need work - naturally tend to lag the reality of the detector development
MCP and Photocathode Testing

Testing Group: Bernhard Adams, Matthieu Cholet, and Matt Wetstein at the APS, Ossy Siegmund’s group at SSL

First measurements of gain in an ALD SEE layer at the APS laser test setup

(Bernhard Adams, Matthieu Cholet, and Matt Wetstein)

N. B.!

Comparison of MCP Amplification
Before and After ALD Coating

LAPPD Preliminary
(very)
$K_L$ to pizero nu-nubar
The Large-Area Psec Photo-Detector Collaboration

Organization Chart

R&D Program for the Development of Large-Area Fast Photodetectors
Photocathodes

Subject of next talk by Klaus - touch on here only briefly

LAPPD goal - 20-25% QE, 8”-square

2 parallel efforts: SSL (knows how), and ANL (learning)

ANL Optical stand

First cathodes made at ANL

PMT13, 18: Dosing without O₂
PMT12: Dosing with O₂
PMT19: Dosing with O₂ and Thicker Sb layer

Burle commercial equipment

6/9/2012
Hermetic Packaging

• Top Seal and Photocathode - this year’s priority

3 parallel paths

Tile Development Facility at ANL
Production Facility at SSL/UCB
Commercial RFI for 100 tiles (Have had one proposal for 7K-21K tiles/yr)
Works on GEANT events too
Sampling calorimeters based on thin cheap photodetectors with correlated time and space waveform sampling

Proposal: Alternating radiator and cheap 30-50 psec thin planar mcp-pmt's on each side (needs simulation work)
A `Quasi-digital’ MCP-based Calorimeter

Idea: can one saturate pores in the MCP plate s.t. output is proportional to number of pores. Transmission line readout gives a cheap way to sample the whole lane with pulse height and time - get energy flow.

Electron pattern (not a picture of the plate!) - SSL test, Incom substrate, Arradiance ALD. Note you can see the multi’s in both plates => ~50 micron resolution

Oswald Siegmund, Jason McPhate, Sharon Jelinsky, SSL (UCB)
II STATE OF THE ART

Several circuits have already been designed in the HEP community for fast pulse sampling, mainly to record photo-multipliers pulse shapes. As detailed in section I, fast timing requires higher sampling rates, but smaller dynamics ranges.

<table>
<thead>
<tr>
<th></th>
<th>Hawaii</th>
<th>Orsay/Caché</th>
<th>PSI</th>
<th>PSAC</th>
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<tr>
<td><strong>Lab 3</strong></td>
<td>Planned Labs</td>
<td>Sam</td>
<td>Planned</td>
<td>This proposal</td>
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<td></td>
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<td>400 MHz</td>
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<td>&gt;= 1 GHz</td>
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<td></td>
<td></td>
<td></td>
<td>1.1 mW</td>
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<td><strong>Dynamic range</strong></td>
<td>1 mV/µV</td>
<td>0.5 mV/µV</td>
<td>0.3 mV/µV</td>
<td>0.3 V/µV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.35 V/µV</td>
</tr>
<tr>
<td><strong>X-talk</strong></td>
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<td>&lt;= 0.1%</td>
<td>0.3%</td>
<td>&lt;= 0.5%</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td>&lt;= 0.5%</td>
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<tr>
<td><strong>Sampling filter</strong></td>
<td>T/E D</td>
<td>40 ps</td>
<td>200 ps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>EntPLL</td>
</tr>
<tr>
<td><strong>Power supplies</strong></td>
<td>2.5 V</td>
<td>2.5 V</td>
<td>2.5 V</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.5 V</td>
<td></td>
</tr>
<tr>
<td><strong>Process</strong></td>
<td>TSMC 0.25</td>
<td>TSMC 0.25</td>
<td>AMI 0.35</td>
<td>AMI 0.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UMC 0.25</td>
</tr>
<tr>
<td><strong>Chip area</strong></td>
<td>2.5 mm x 2 mm</td>
<td>12 mm x 12 mm</td>
<td>10 mm x 2 mm</td>
<td>25 mm x 2 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25 mm x 2 mm</td>
</tr>
<tr>
<td><strong>Cost/channel</strong></td>
<td>500$±40</td>
<td>10$±12k</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table I. State of the art, this proposal. The yellow column is from Gary Warner’s group at the University of Hawaii (USA) [12], the light blue from Dominique Breton from the University of Paris-Sud (Orsay) [10] and Eric Delannes from CEA (Saclay), (France) [11]. The orange column from Stefan Bitt at PSI (Switzerland), [13]. The dark blue is this proposal.
MCP+Transmission Lines Sampled at Both Ends Provide Time and 2D Space

Field Programmable Gate Arrays (not as shown- PC cards will be folded behind the panel- not this ugly...)

8” Tiles

10-15 GS/sec Waveform Sampling ASICS

Single serial Gbit connection will come out of panel with time and positions from center of back of panel
## Applications

### LAPPD Markets: Need. Applications. Benefit. and Competition

<table>
<thead>
<tr>
<th>Application</th>
<th>Market Need</th>
<th>Approach</th>
<th>Benefit</th>
<th>Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-cryogenic Tracking Neutrino Detectors</td>
<td>HEP-Fermilab</td>
<td>Very-large-area, bialkali-cathode</td>
<td>Bkgd rejection, Cost, Readiness</td>
<td>Liquid Argon</td>
</tr>
<tr>
<td>LE Neutron Detection</td>
<td>Neutron Diffraction</td>
<td>B or Gd Glass, no cathode</td>
<td>Time and Position resolution, pulse shape γ/ν differentiation, Large area</td>
<td>He3, B tubes</td>
</tr>
<tr>
<td>LE Neutron Detection</td>
<td>Transportation Security</td>
<td>B or Gd Glass, no cathode</td>
<td>Large area pulse shape γ/ν differentiation, Large area</td>
<td>He3, B tubes</td>
</tr>
<tr>
<td>LE Anti-Neutrino Detection</td>
<td>Reactor Monitoring</td>
<td>Large-area, bialkali-cathode</td>
<td>Efficiency, Cost</td>
<td>PMT’s, SiPMs</td>
</tr>
<tr>
<td>HE Collider Vertex Separation</td>
<td>CERN</td>
<td>Psec TOF</td>
<td>Resolution, Radiation-Hard</td>
<td>Silicon Vertex</td>
</tr>
<tr>
<td>HE Collider Particle ID</td>
<td>CERN, Future Lepton Collider</td>
<td>Psec TOF</td>
<td>Resolution, Reach in Pr</td>
<td>None</td>
</tr>
<tr>
<td>π0/η Reconstruction and ID</td>
<td>Rate K Decays (JPARC), Fermilab</td>
<td>Psec TOF</td>
<td>Combinatorial Bkgd Rejection</td>
<td>Conventional TOF</td>
</tr>
<tr>
<td>Strange Quark ID</td>
<td>RHIC (BNL), ALICE (LHC) Collider</td>
<td>Psec TOF</td>
<td>Resolution, Reach in Pr</td>
<td>dE/dx</td>
</tr>
<tr>
<td>Positron-Emission Tomography</td>
<td>Clinical Medical Imaging</td>
<td>TOF, Large Area</td>
<td>Lower Dose Rate, Faster throughput</td>
<td>SiPM</td>
</tr>
</tbody>
</table>

SRI’s NABC Approach [http://www.itu.dk/~jeppeh/DIKP/NABC.pdf](http://www.itu.dk/~jeppeh/DIKP/NABC.pdf) (sic- Denmark?)
The 4 ‘Divisions’ of glass LAPPD

Hermetic Packaging
See Bob Wagner’s talk

MicroChannel Plates
See Ossy’s talk

Photocathodes
See (hear) Klaus Attenkofe’s talk

Electronics/Integration
This talk
LAPPD Performance

Fast Preconditioning

- Gain drop <5% over 16 hours an 0.01 C cm\(^{-2}\), quite stable since then
- 1µA scrub @ 3 \( \times 10^5 \) gain, 700v per MCP

Low noise

- Post-bake ~2000 sec
- ~0.1 events cm\(^{-2}\) sec\(^{-1}\)

High Gain (>10\(^7\))

- Event = 0

400 micron resolution

- (8” plate, anode, PSEC-4)

8 inch MCP x-position scan. Two ends readout.
Application 4-
Cherenkov-sensitive Sampling Calorimeters

A picture of an em shower in a cloud-
chamber with 1/2 Pb plates (Rossi, p215- from CY Chao).

Idea: planes on one side read both Cherenkov and scintillation light- on other only scintillation.

A `cartoon' of a fixed target geometry such as for JPARC's KL-> pizero nunubar (at UC, Yao Wah) or LHCb.
Detector Development - 3 Prongs

MCP development - use modern fabrication processes to control emissivities, resistivities, out-gassing

Use Atomic Layer Deposition for emissive material (amplification) on cheap inert substrates (glass capillary arrays, AAO). Scalable to large sizes; economical; pure – i.e. chemically robust and (it seems- see below) stable

Readout: Use transmission lines and modern chip technologies for high speed cheap low-power high-density readout.

Anode is a 50-ohm stripline. Scalable up to many feet in length; readout 2 ends; CMOS sampling onto capacitors- fast, cheap, low-power (New idea- make MCP-PMT tiles on single PC-card readout- see below)

Use computational advances - simulation as basis for design

Modern computing tools allow simulation at level of basic processes- validate with data. Use for `rational design’ (Klaus Attenkofer’s phrase).
Micro-channel Plates PMTs

Satisfies small feature size and homogeneity

Photon and electron paths are short—few mm to microns=>fast, uniform Planar geometry=>scalable to large areas
ALD for Emissive Coating

Conventional MCP’s:

ALD for Emissive Coating

Alternative ALD Coatings: (ALD SiO$_2$ also)

- Many material possibilities
- Tune SEE along pore (HF- possible discrete dynode structure (speed!))

Jeff Elam, Zeke Insepov, Slade Jokela
First have to understand signal and noise in the frequency domain.

A typical MCP signal (Planacon)

Frequency spectra of signal and noise (JF Genat)
TOF adds 3\textsuperscript{rd} dimension to Positron-Emission Tomography

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
\textbf{Hardware} & \textbf{$\Delta t$ (ps)} & \textbf{TOF Gain} \\
\hline
BGO Block Detector & 3000 & 0.8 \\
LSO Block (non-TOF) & 1400 & 1.7 \\
LSO Block (TOF) & 550 & 4.2 \\
LaBr\textsubscript{3} Block & 350 & 6.7 \\
LSO Side Coupled & 250 & 9.3 \\
LSO Small Crystal & 210 & 11.1 \\
Lu\textsubscript{3} Small Crystal & 125 & 18.7 \\
LaBr\textsubscript{3} Small Crystal & 70 & 33.3 \\
\hline
\end{tabular}
\caption{TOF (Effective Efficiency) Gain for Whole-Body PET (35 cm)}
\end{table}

\begin{itemize}
\item \textit{Incredible Gains Predicted}
\item \textit{Nothing} Else Can Give Us Gains of This Size!
\end{itemize}

Slides from Bill Moses’s talk at the Clermont Workshop
(see our library page, under workshops: hep.uchicago.edu/psec)

Clinical flat-bed scanner?
Low-density multi-layer sampling gamma detectors?
Cheap robust electronics
Real-time imaging?
Max. Gain vs. Thickness

- MgO
- Al₂O₃

Electron Gain (secondaries/primary)
Sample Thickness (Å)

6/9/2012  Berkeley CA
What sets the 1 psec goal for HEP?

Collisions at the Tevatron (e.g.) have a distribution in times with a sigma of $\approx 1.4$ nsec (1.4 thousand psec’s). Rather than measure the start time, $t_0$, at the origin, we fit the tracks from a single vertex for the $t_0$. At present we do this with the tracking chamber (COT), with a resolution on the order of a nsec.

At CDF: $t_0$ is correlated with $z_{\text{vertex}}$! (From the new TAMU EM timing system in CDF (Goncharov, Krutelyov, Toback)).

Figure 4: Contours of 1-sigma separation for pions, kaons, and protons versus the time resolution of the particle flight time over a 1.5-meter path for a detector with 1 psec resolution.

Point is that each vertex has a time—fitting the tracks can tie charged particles to vertices. Fitting photons likewise is also possible if we know $L$, as we know beta.
Electronics- Integration & Performance

Eric Oberla and Craig Harabedian cabling SuMo digital and central FPGA cards

Analog Bandwidth of strip-line anode

PSEC-4 sampling at 13.3 Gsamples/sec

This is the `money' plot

Time resolution on 2 ends of anode strip vs (S/N)^{-1} in psec