Large Area Picosecond Photo-Detectors and their Applications

Jonathan Eisch
Iowa State University

CPAD 2016: Caltech
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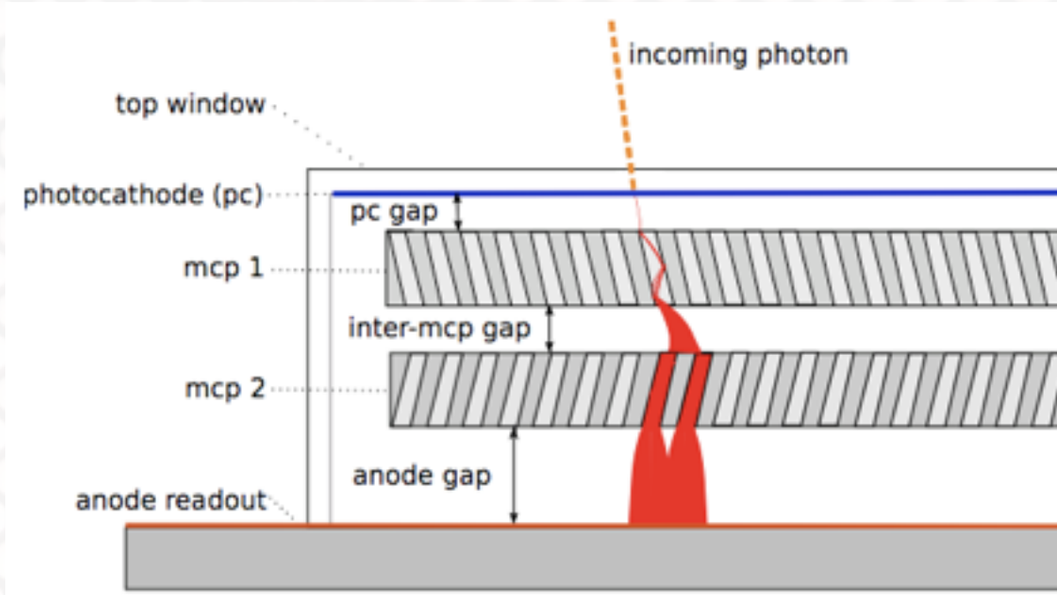
Overview

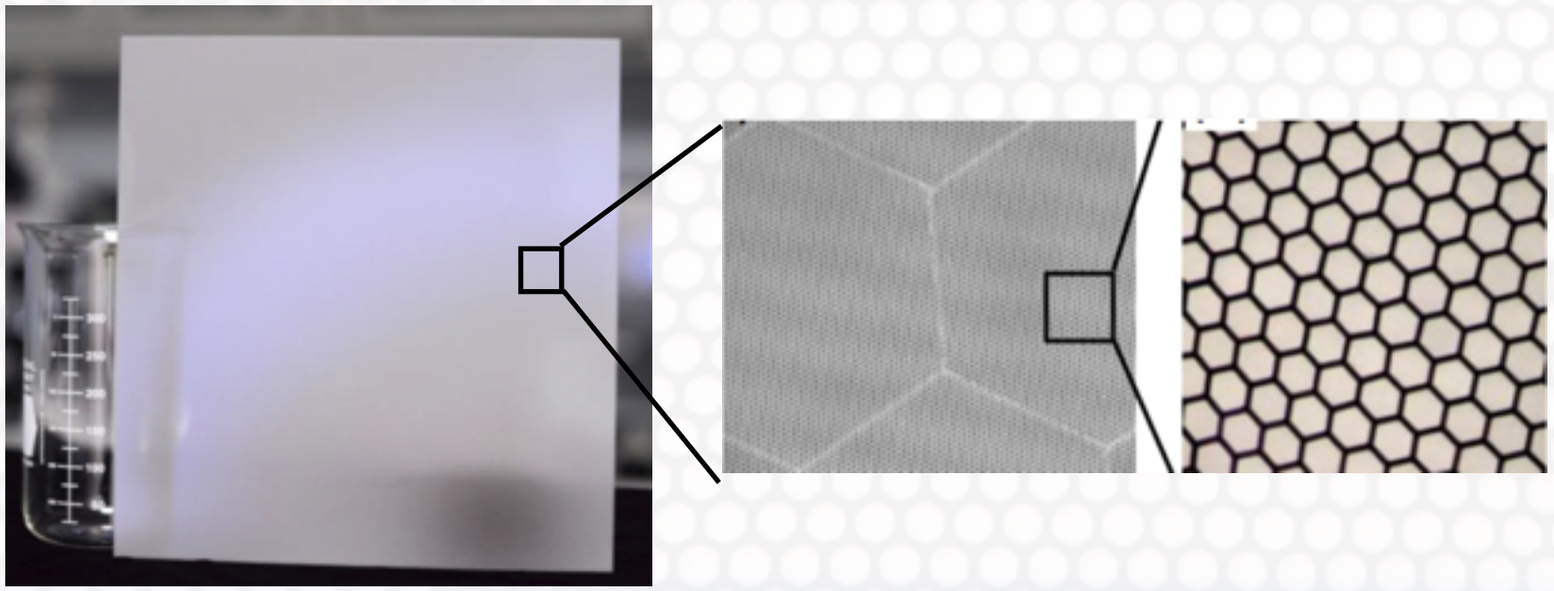
- LAPPDs: Functional description and comparison to existing detector technologies
- Current development status
- The ANNIE detector, a case study for LAPPD deployment
- Around the corner for LAPPDs
- Conclusions

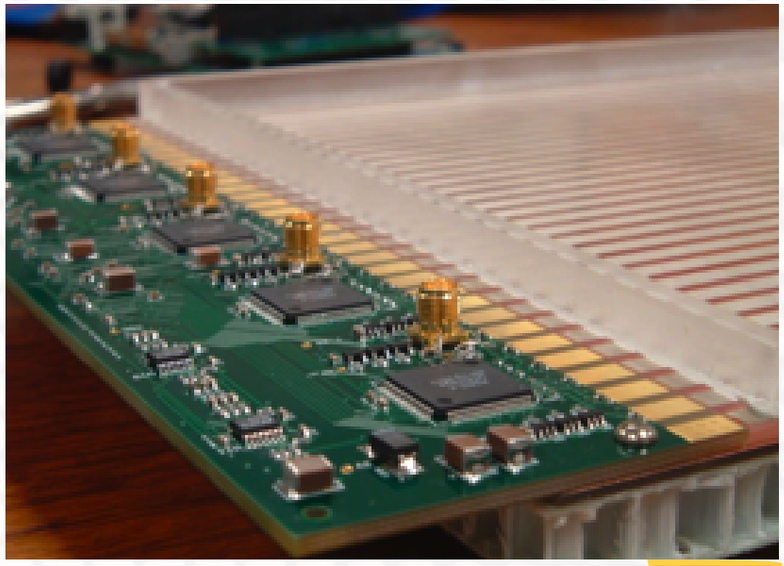
What is an LAPPD?

8” square MicroChannel Plate based photodetector:

- Multi-Alkali photocathode
- *Next-generation* 20cm MCP
- 30 strip-line anodes







What makes LAPPDs unique?

- Fast response
- Great spatial resolution
- Large 20cm-square MCP
- Tunable resistive and emissive layers
- High gain uniformity

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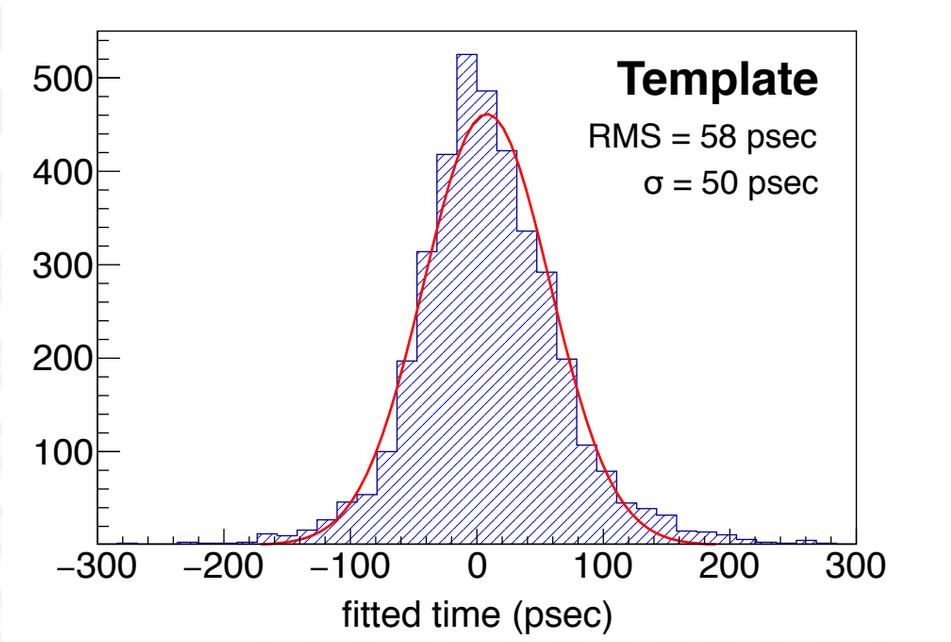
- Very short amplification path
- Fast response
- Low jitter
- <60ps single photo-electron time resolution.



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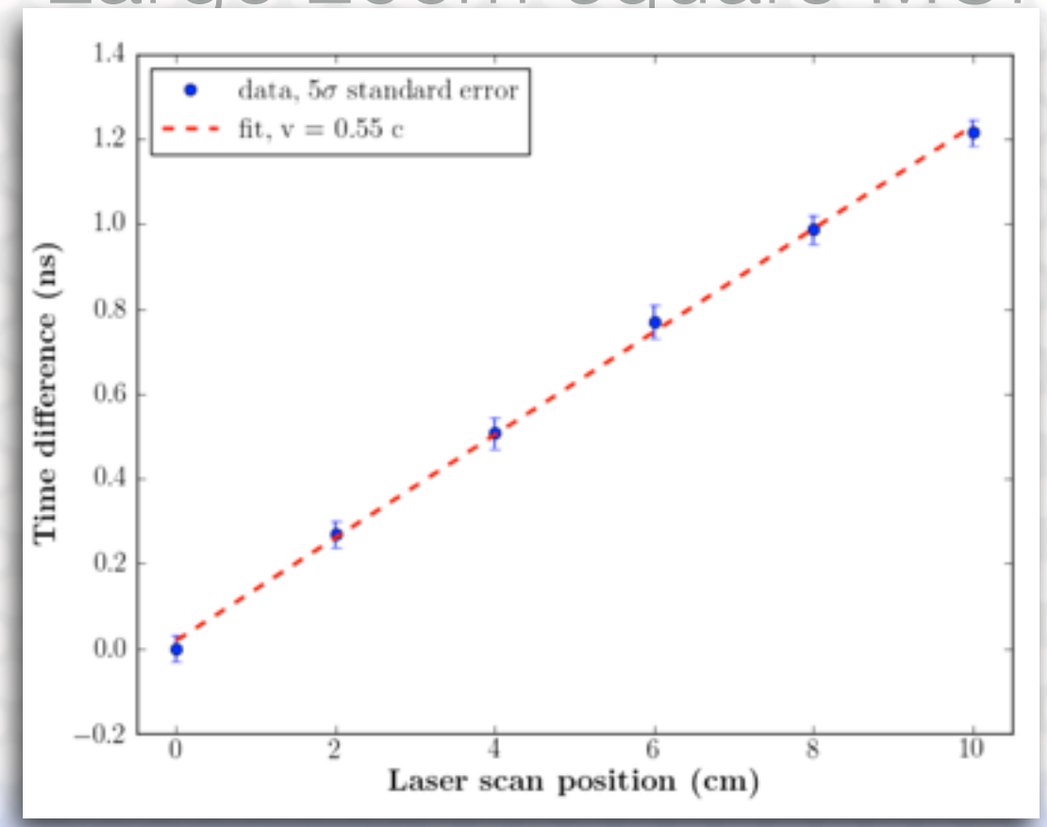
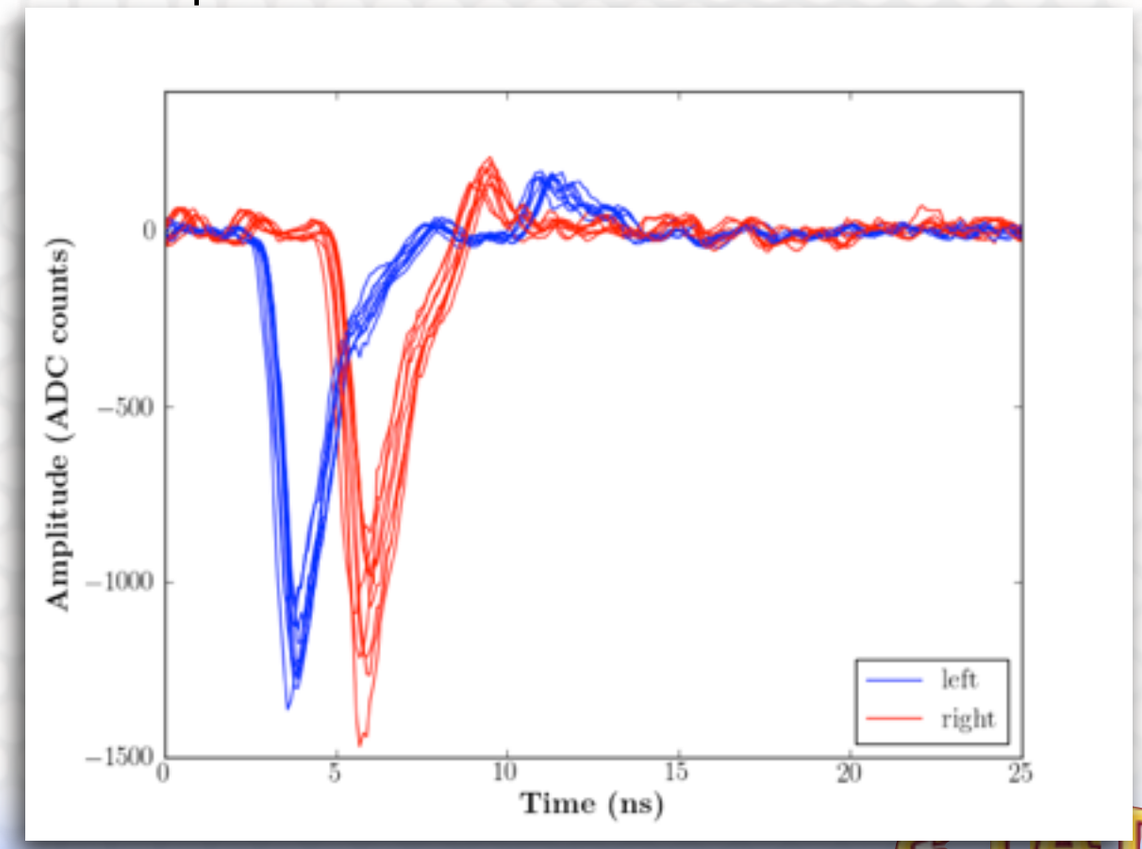


- Horizontal position from relative signal delay between sides of the strip line.
- Vertical position from relative signal size between adjacent strip lines.



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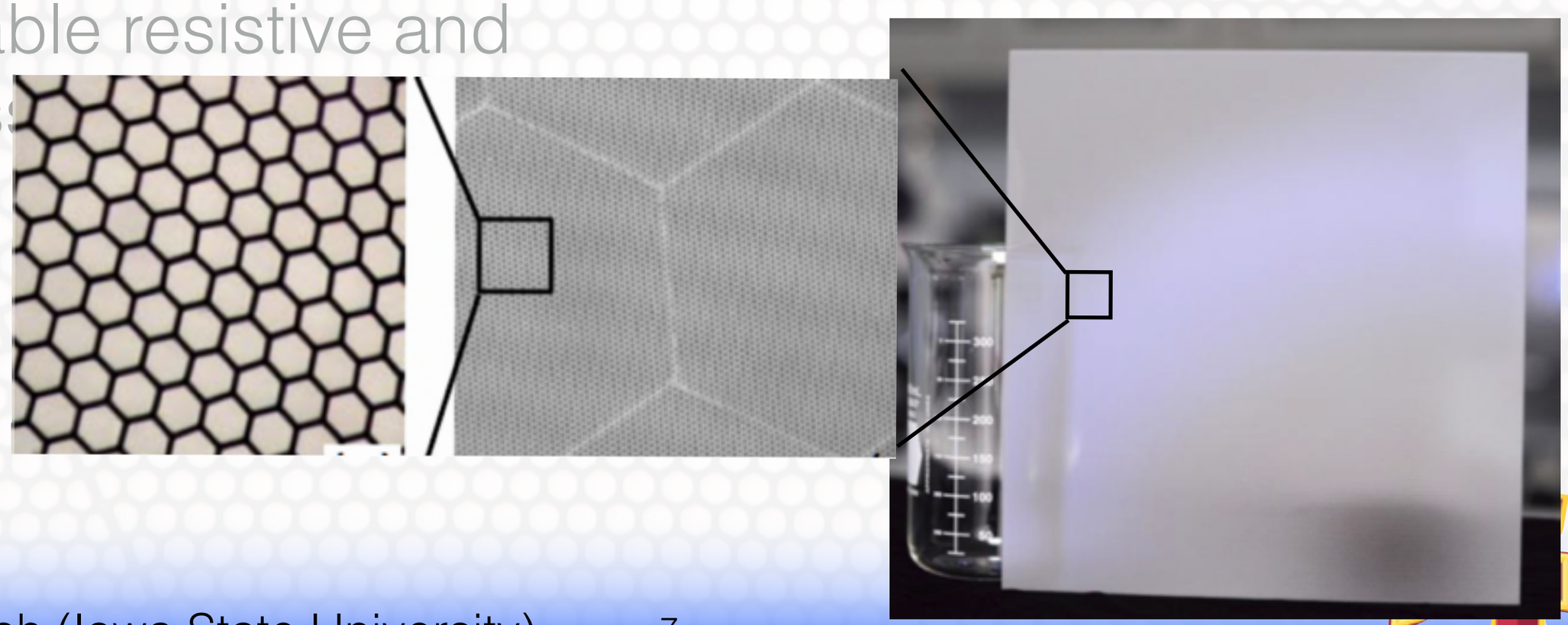
- High

- Incom glass capillary array substrates: an enabling technology.
- Large collection area
- Uniform pore geometry



What makes LAPPDs unique?

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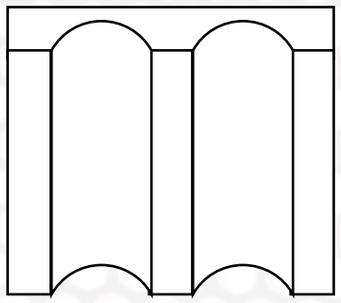
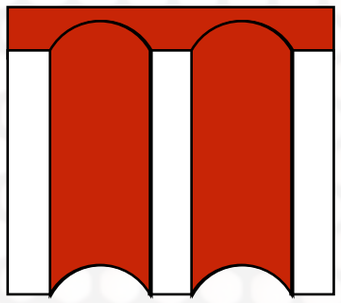
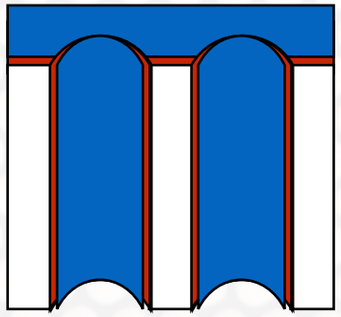
- Atomic Layer Deposition (ALD): another enabling technology
- Tunable coating thickness to match application
- Ability to choose low activity glass



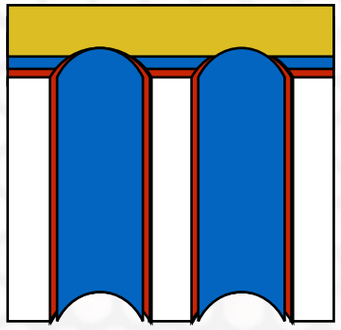
Raw borosilicate capillary glass array



ALD resistive coating



ALD emissive coating



Thermal evaporation conductive coating

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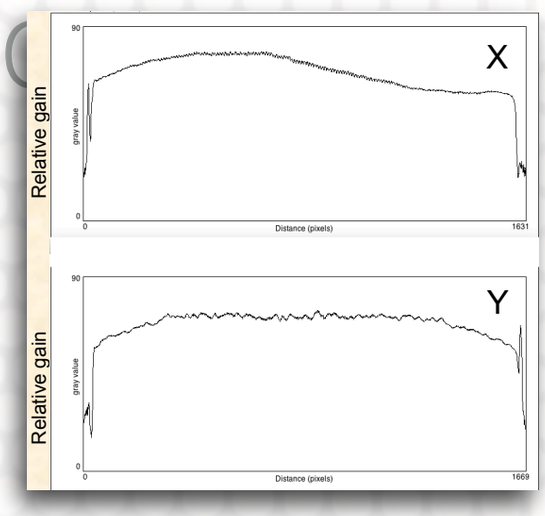
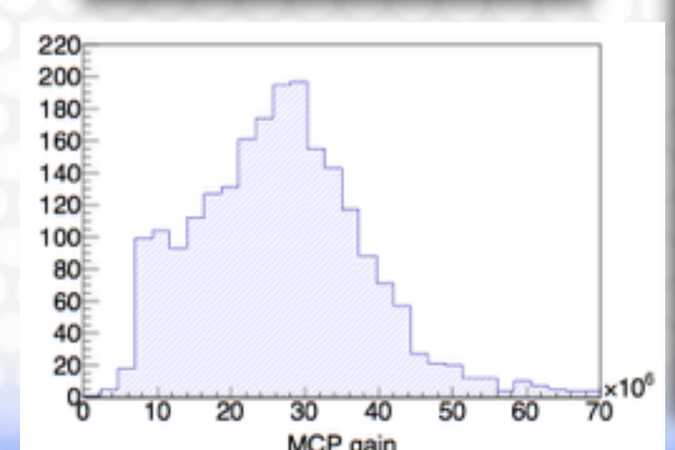
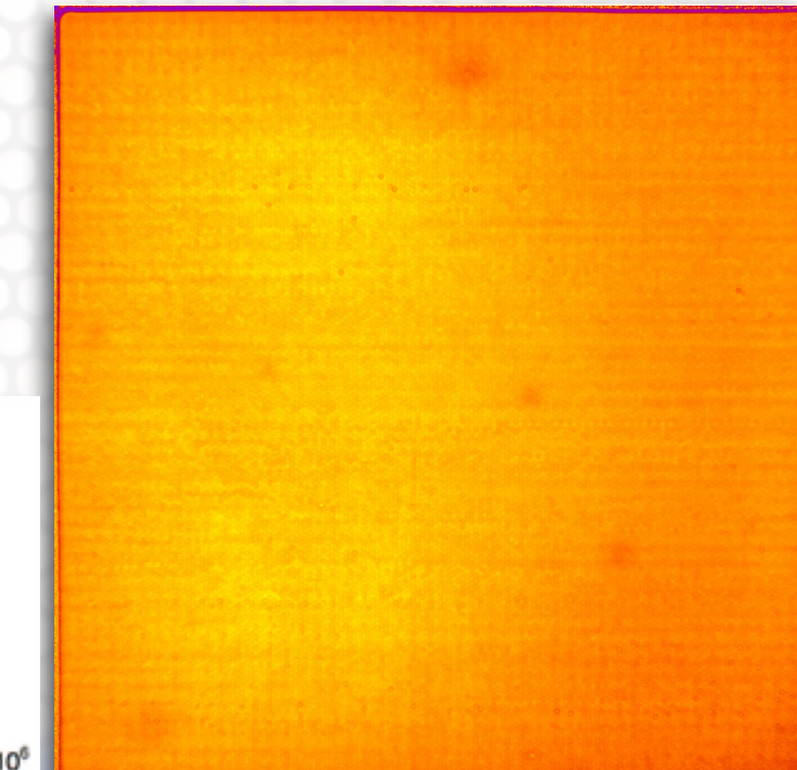




- 10^7 gain typical
- Uniform gain across window (~15%)



For More Info…

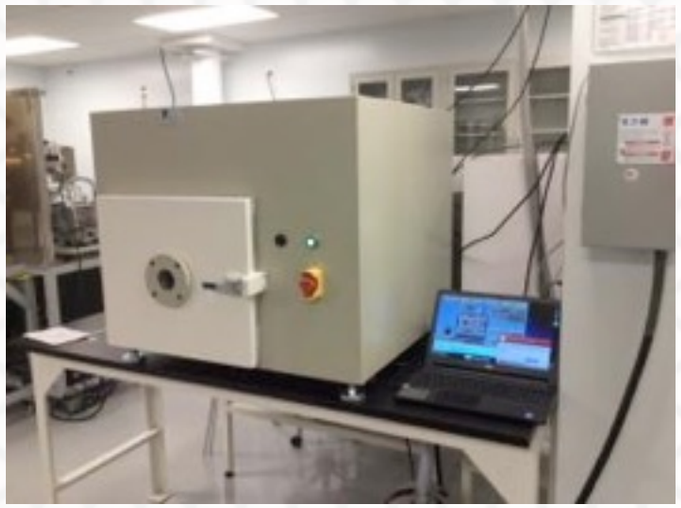
psec.uchicago.edu

A Brief Technical History of the Large-Area Picosecond Photodetector (LAPPD) Collaboration

arXiv:1603.01843

Current Commercialization Status at Incom

Plasma cleaner



Vacuum oven

LAPPD integration and sealing tank

Beneq ALD coater with load-lock

Thermal evaporator

Measurement & test station,

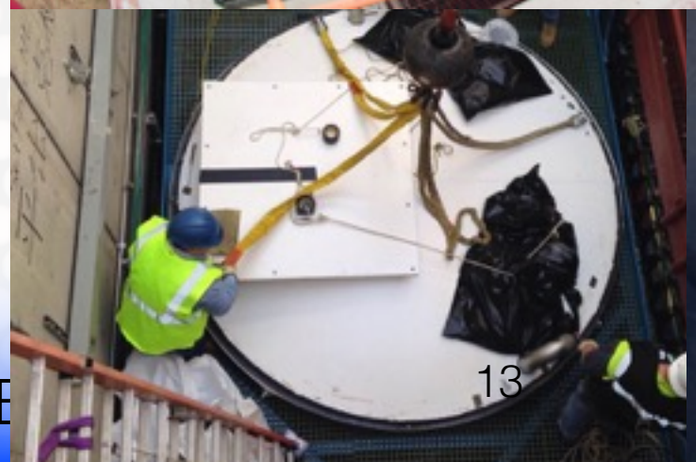
Current Commercialization Status at Incom

- Pilot LAPPD production program ongoing
- Infrastructure complete in January 2016
- MCP performance and production procedures well-established. Now sold as a standalone product.
- Making incremental process and design improvements towards routine LAPPD tile production.
- Most recent trial, #9, resulted in a sealed working LAPPD with an aluminum photocathode.
- Trial #10 in progress, will use a bi-alkali photocathode.

Minot, Proc. of SPIE Vol. 9968 99680X-1

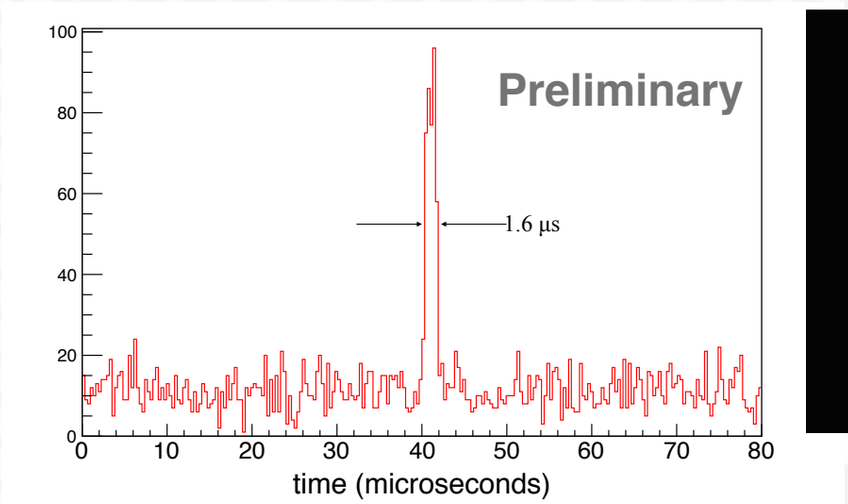
ANNIE: An Early Adopter

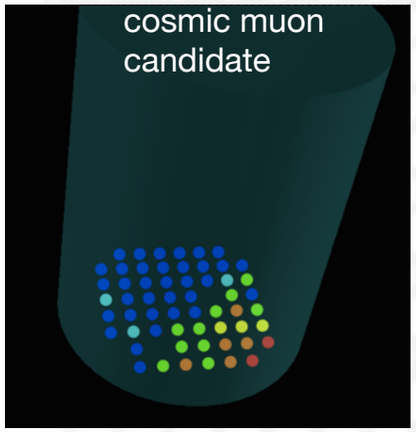
- First Water Cherenkov detector deployed at Fermilab
- An ideal platform for:
  - First implementation of LAPPDs (and fast electronics) in a water Cherenkov detector
  - First detector to use Gd-loaded water on a neutrino beam.

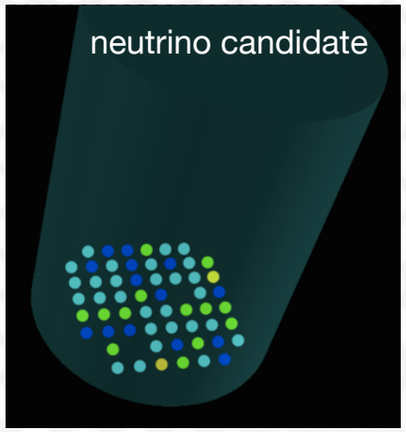


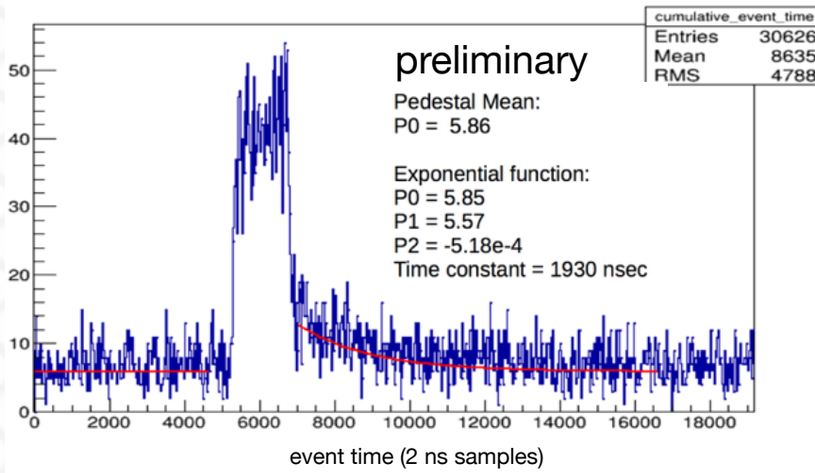
ANNIE: An Early Adopter

- Phase I built and executed
- Phase IB (approved through Intermediate Neutrino Program) and ongoing - will integrate LAPPD system with the detector
- Phase II proposal to be submitted in winter







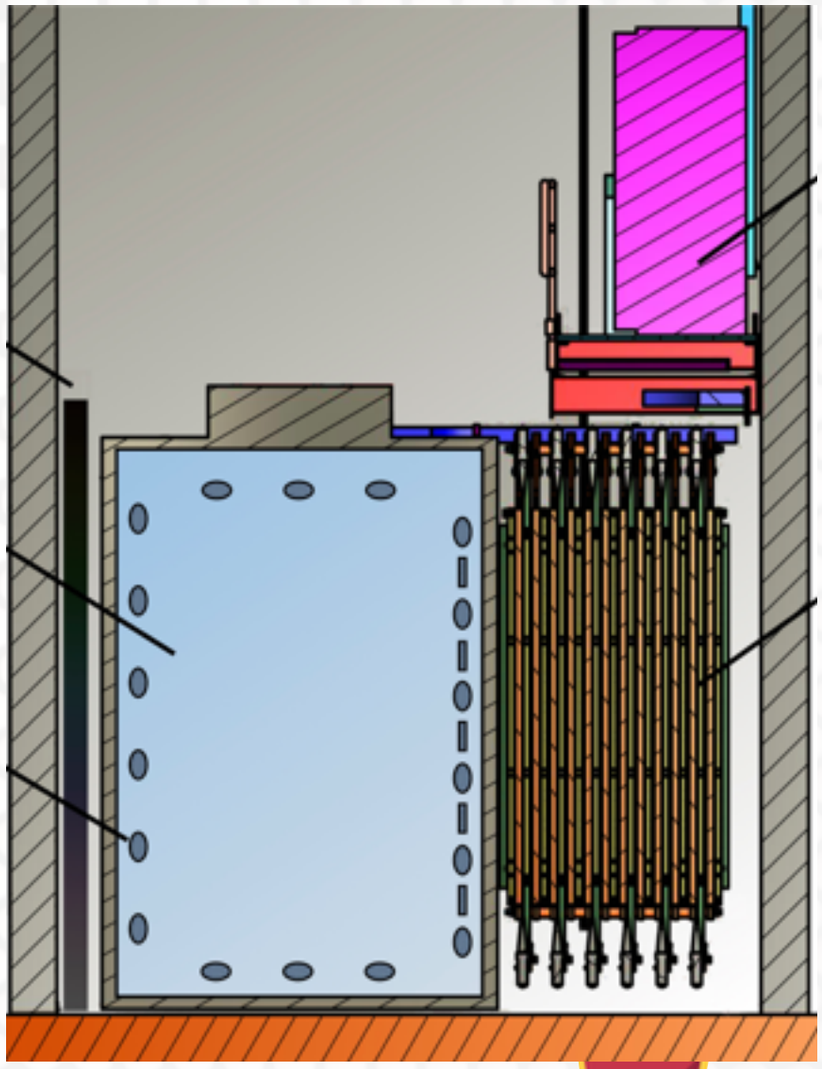


- The detector is built - all we have to do is add the LAPPDs

The ANNIE Detector

- ANNIE is the **A**ccelerator **N**eutrino **N**eutron **I**nteraction **E**xperiment

- 26 ton water-Cherenkov detector
- Located at Fermilab on axis with the BNB beamline.
- 10 foot diameter, 13 feet tall steel tank with a plastic liner
- Filled with ultra-pure water doped with Gadolinium sulfate.
- Detection volume instrumented with conventional PMTs with 500 MHz full waveform digitization and newly developed high-speed photo-detectors.
- Also includes an upstream muon veto detector and the SciBooNE Muon Range Detector (muon tracker) installed downstream.



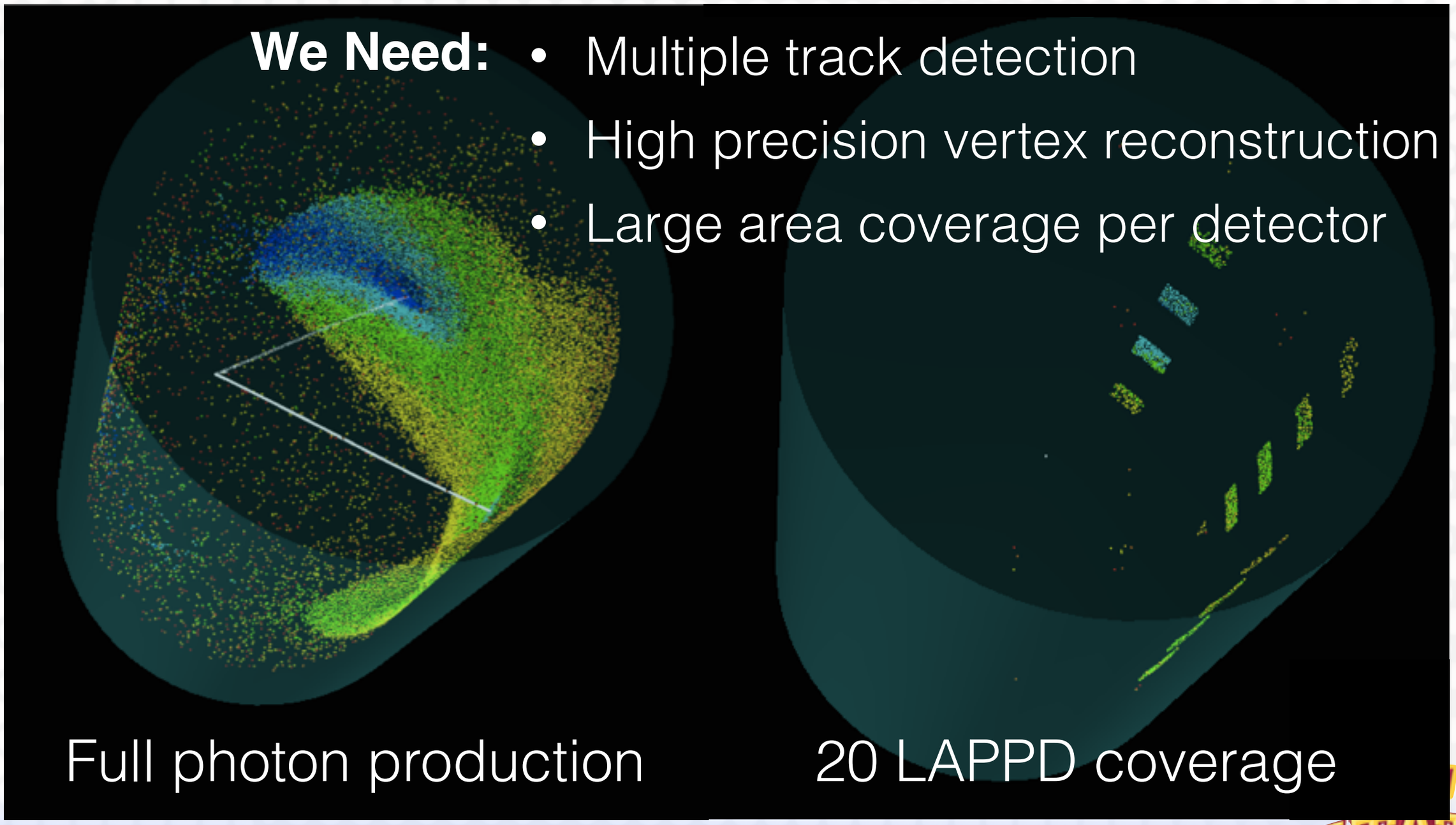
The Physics of ANNIE

- Primary science goal: Measure the abundance of final state neutrons from neutrino interactions in water as a function of energy.
  - Understanding neutrino-nucleus interactions to improve energy resolution of neutrino oscillation experiments
- Tag charge-current quasi-elastic like events by the presence of neutrons and additional charged particles.

A two-prong (μ+π) event in ANNIE

We Need:

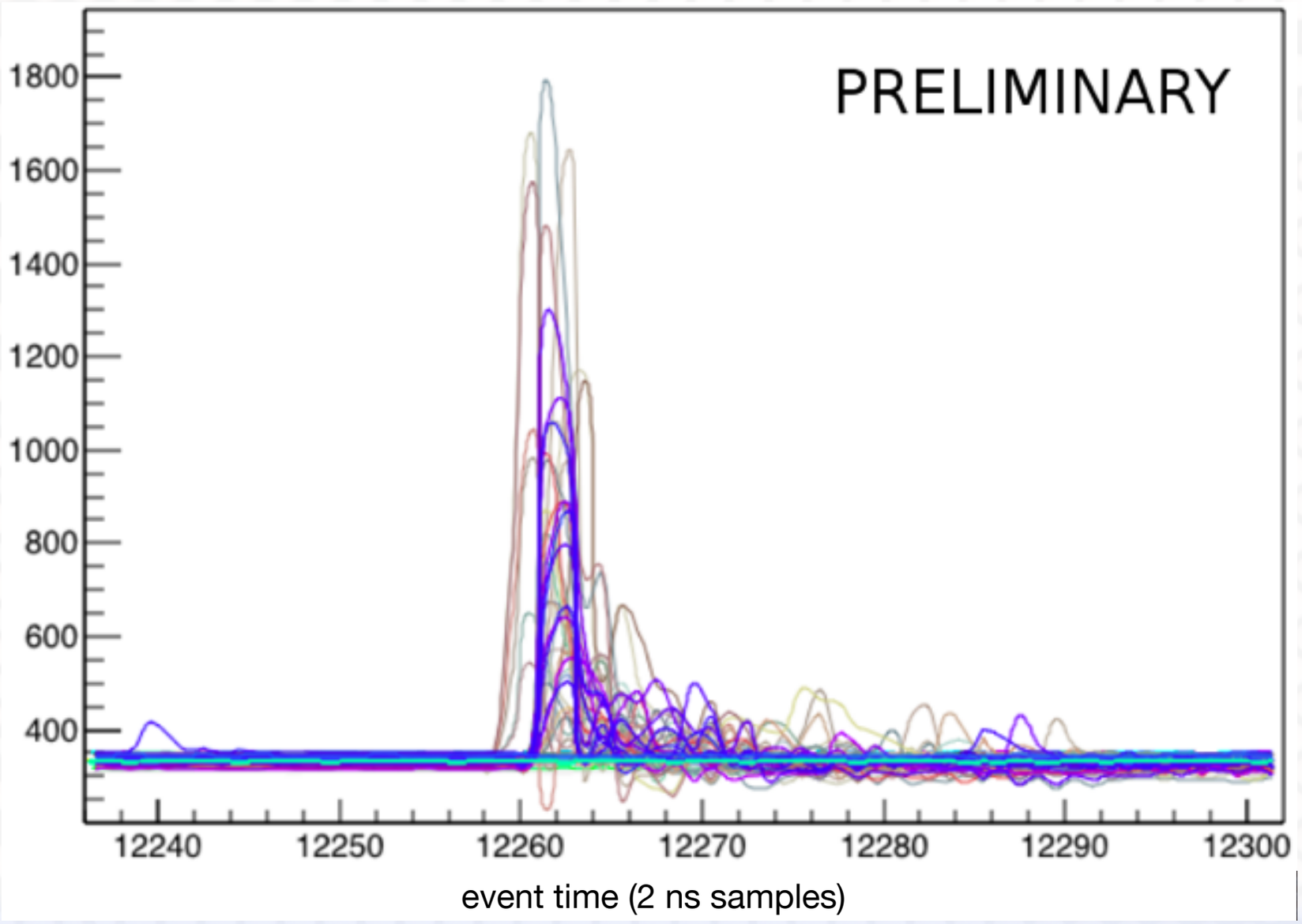
- Multiple track detection
- High precision vertex reconstruction
- Large area coverage per detector



Full photon production

20 LAPPD coverage

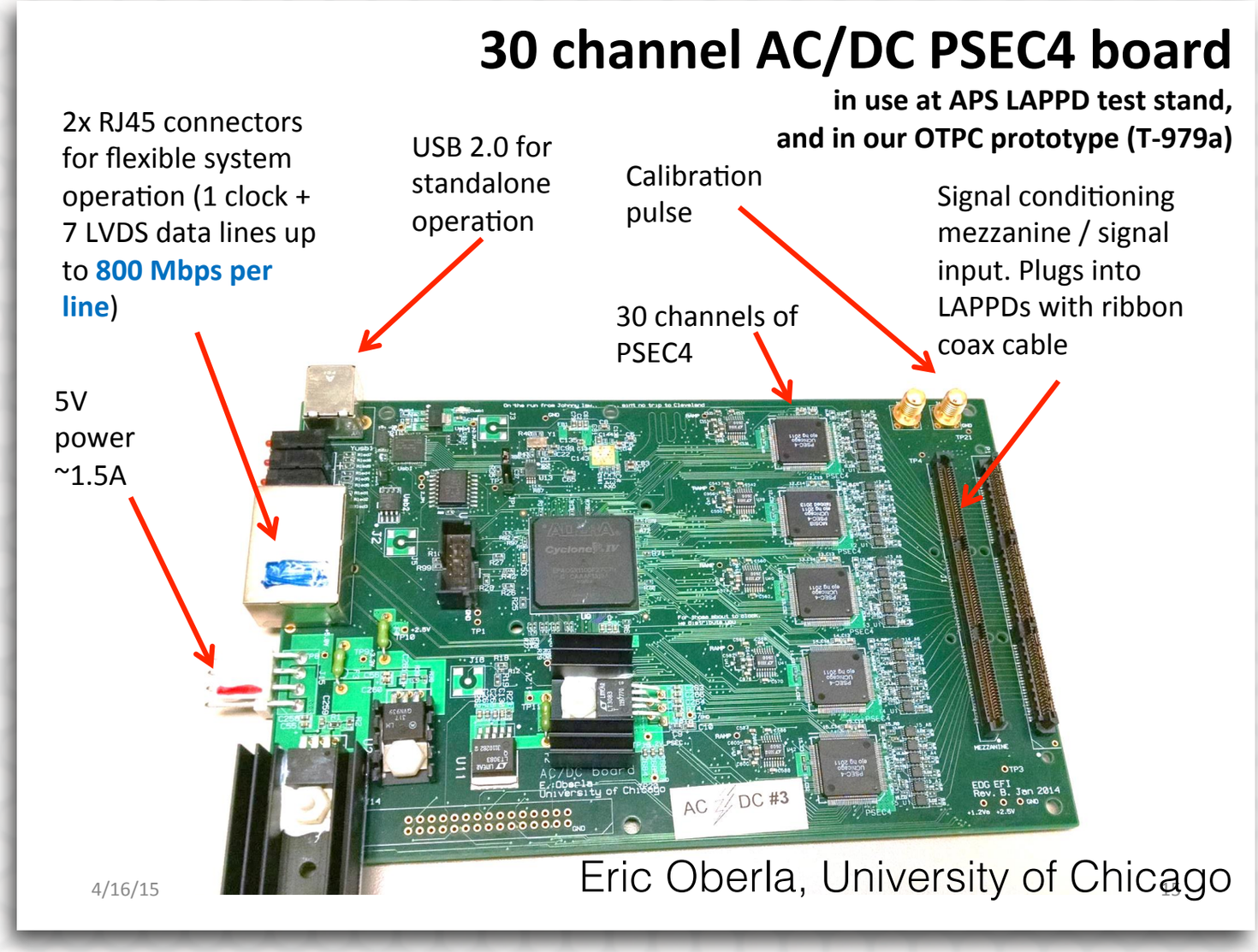
Waveform Sampling in a water Cherenkov detector



LAPPD Readout electronics

PSEC4 chip

- Custom CMOS switched capacitor array digitizer
- 17 Giga-samples/sec
- 1 mV noise
- 6 channels/chip



AC/DC Board

- Triggering
- PSEC4 digitization
- Clock cleaning
- Control and communication

ANNIE Central Card

- For example: ANNIE instrumented with 20 LAPPDs
- 60 channels/LAPPD (two-sided)
- 2100 Channel digitization
- ANNIE Central Card supports 8 front-end AC/DC cards, 240 channels/card
- 4800 channels/VME crate
- Many communication options

arXiv:1607.02395

2x multi-gigabit optical

LVDS clock+sync

16x LVDS over twisted pair to AC/DC front end (Control, Data, Clock)

Gigabit Ethernet

USB

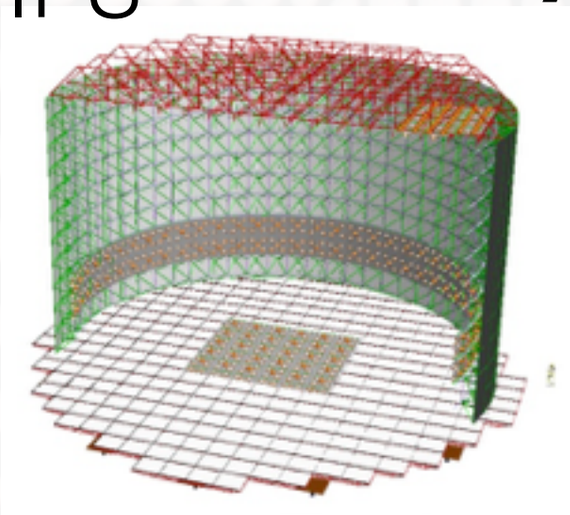
VME power & communication

Stratix V FPGA

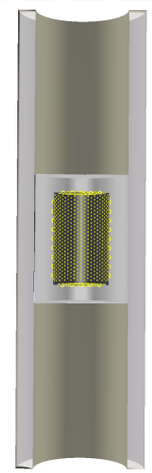
Potential future applications of LAPPDs

And Many More…

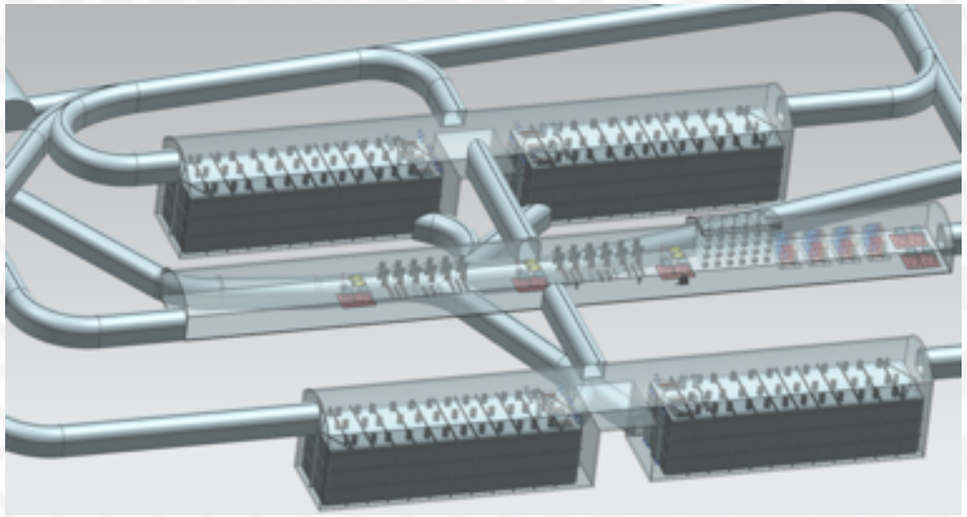
CHIPS



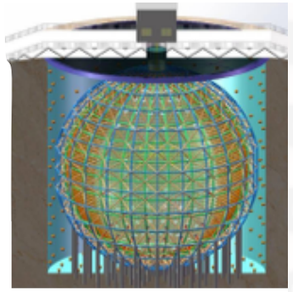
NuPRISM



DUNE

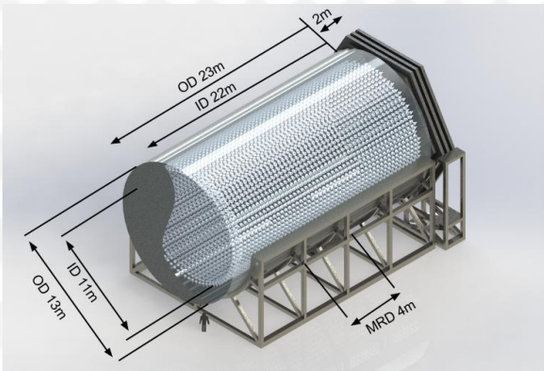


JUNO

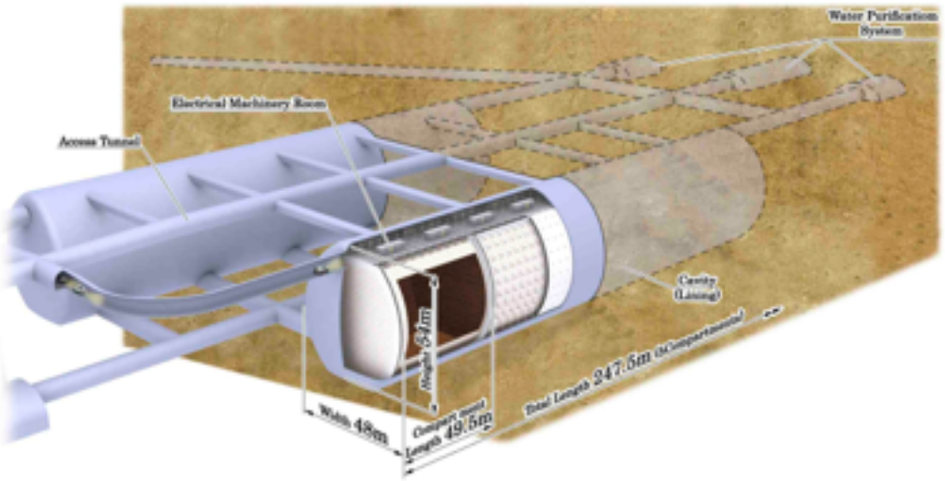


LENA

TITUS



Hyper-K



See also A. Elagin's work on NuDot and double beta decay

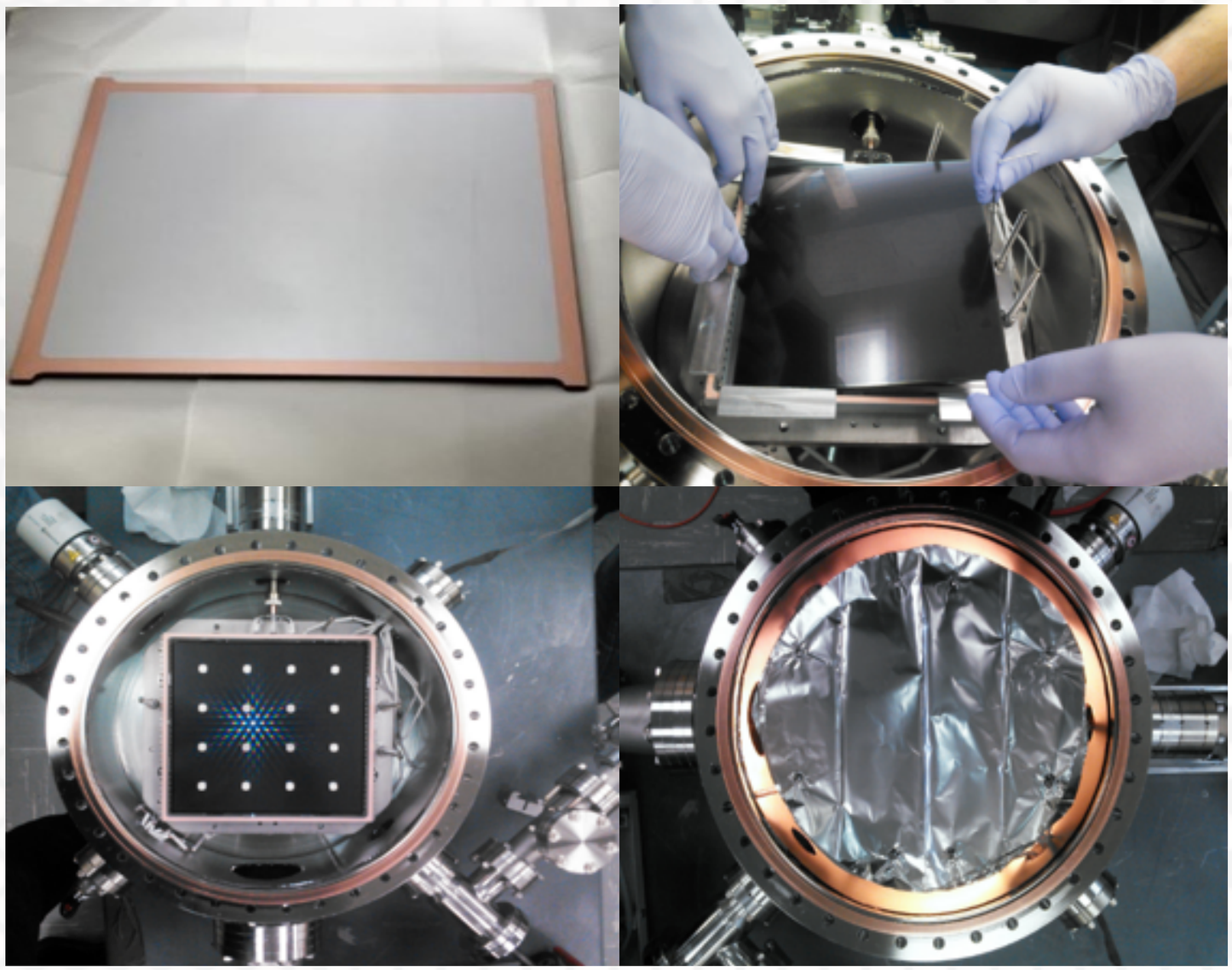
Continued LAPPD R&D

- Argonne National Laboratory
  - (see the next talk)
- University of Chicago group, in collaboration with Incom, is testing methods for high-volume mass-production
  - In-situ stack assembly
  - photocathode deposition after assembly
  - Ceramic body, capacitive readout

Slides: Andrey Elagin

In-Situ Assembly Strategy

Simplify the assembly process by avoiding vacuum transfer:
make photo-cathode after the top seal

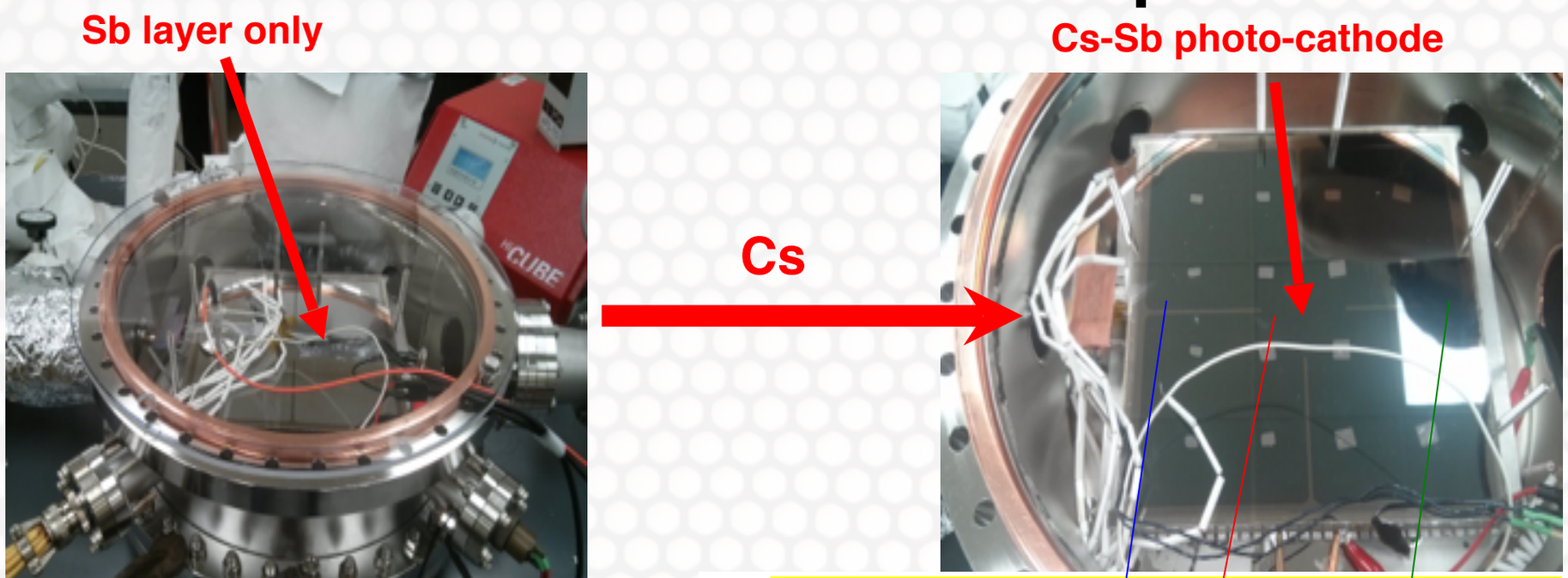


UChicago processing chamber

Step 1: pre-deposit Sb on the top window prior to assembly
Step 2: pre-assemble MCP stack in the tile-base
Step 3: do top seal and bake in the same heat cycle
Step 4: bring alkali vapors inside the tile to make photo-cathode
Step 5: flame seal the glass tube or crimp the copper tube

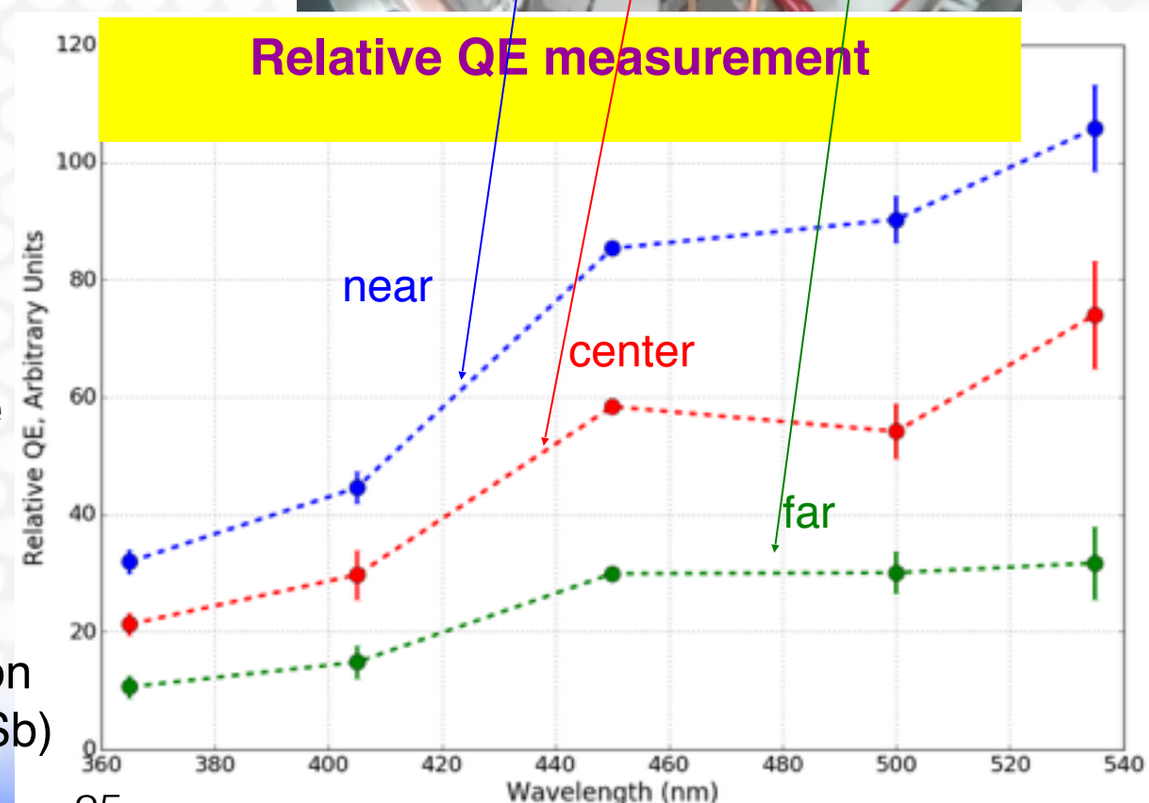
Slides: Andrey Elagin

Photocathode Deposition



First in-situ commissioning run is complete
- saw the first photo-current response
- measured relative QE

Demonstrated a “sealed tile” configuration
- The glass tube was flame sealed and the were no QE drop for 3 weeks in a stand alone sealed tile.



Note on this commissioning run:
PC is very thick for transmission mode operation
(initial 20nm of Sb translates into ~80nm of Cs-Sb)

Slides: Andrey Elagin

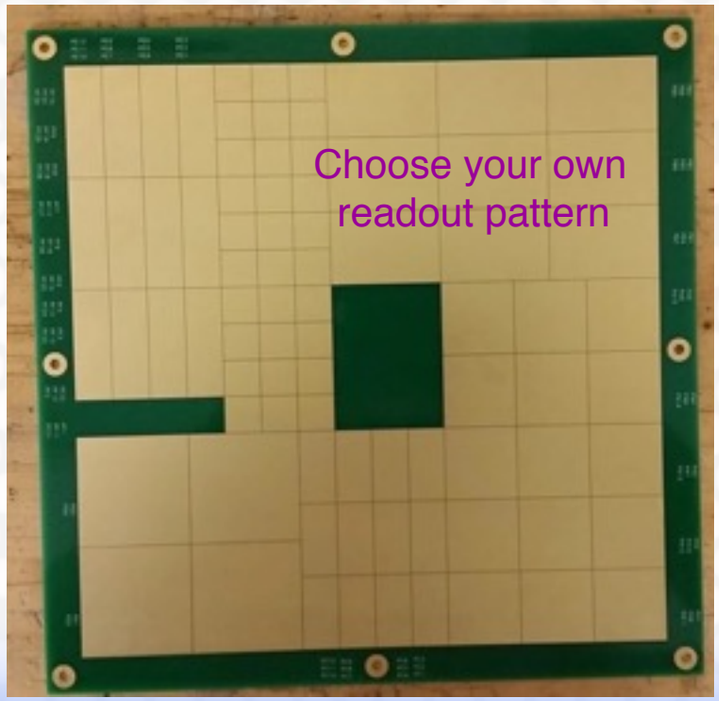
Gen-II Design: Ceramic body

Custom anode is outside

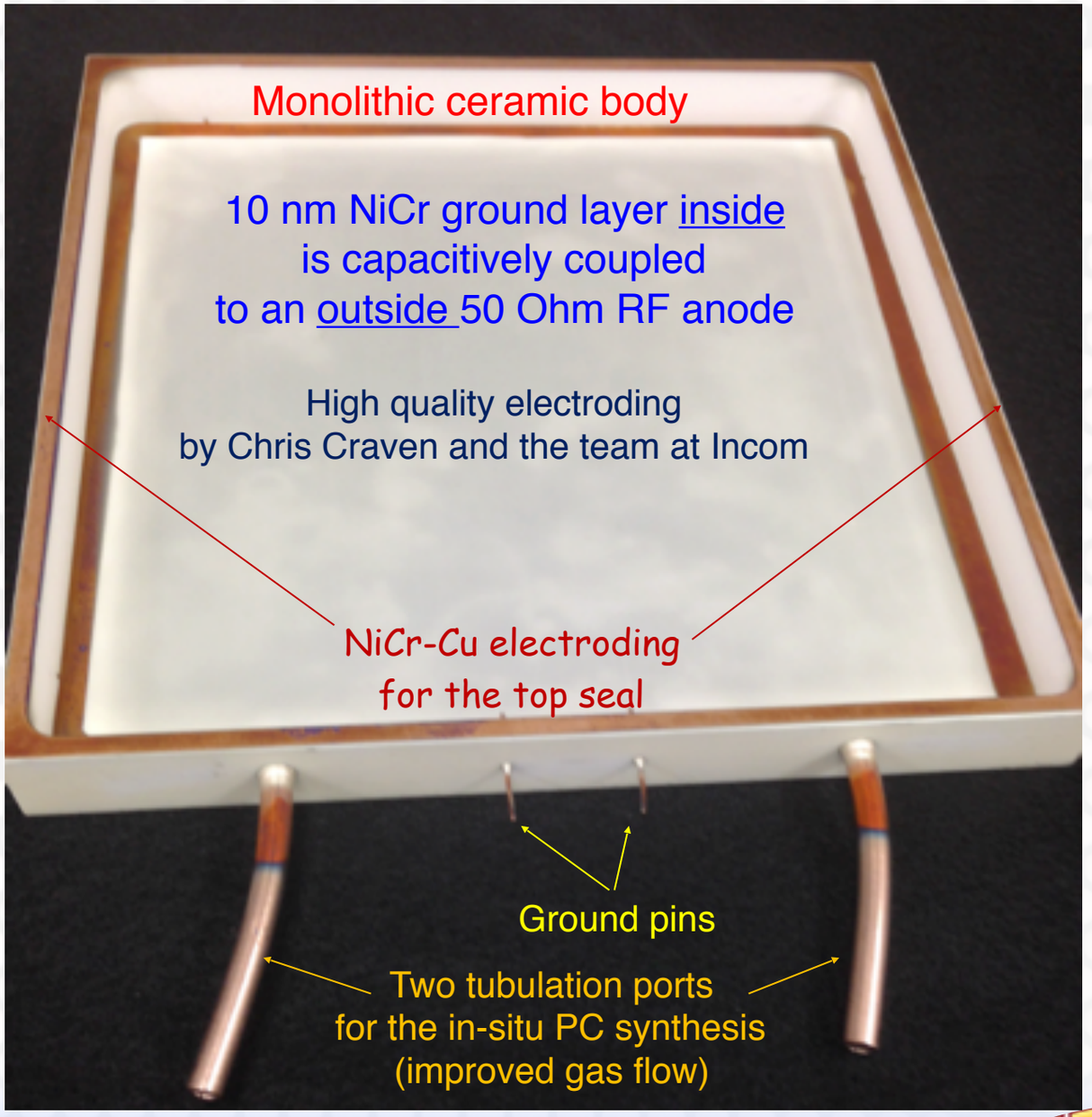
Compatible with high rate applications

Supports large-area super-module panels

Anode is not a part of the vacuum package



arXiv:1610.01434

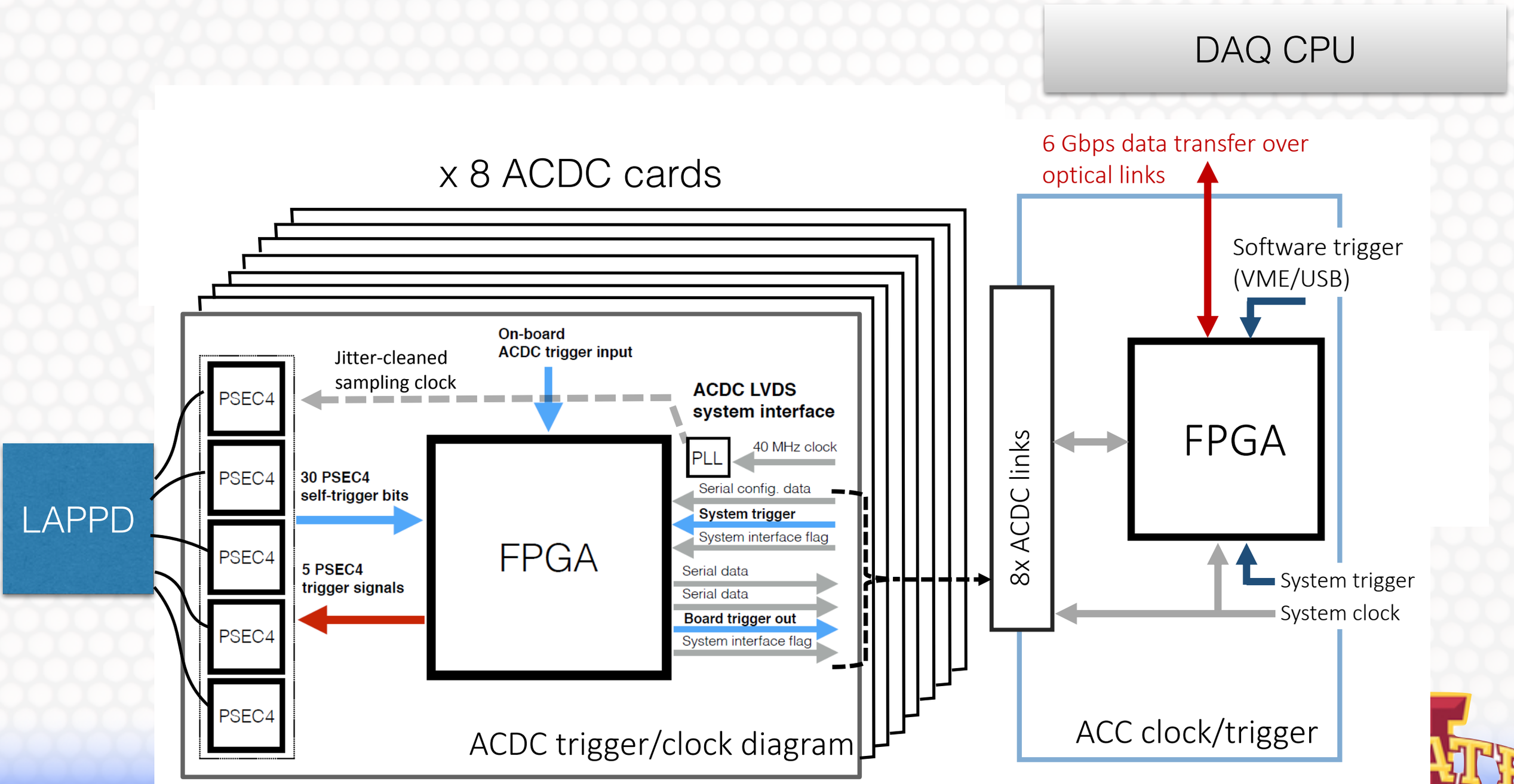


Summary

- LAPPDs are a promising successor to conventional phototubes for HEP applications and bring new capabilities
- LAPPD commercialization at Incom Inc is well underway - new developments weekly
- Early adopters are critical to proving out new technologies
  - The ANNIE experiment is well under way to do this
- Many other future applications could benefit from LAPPDs
- Continued R&D efforts can continue to advance the technology, improve performance, and lower cost.

Backup slides

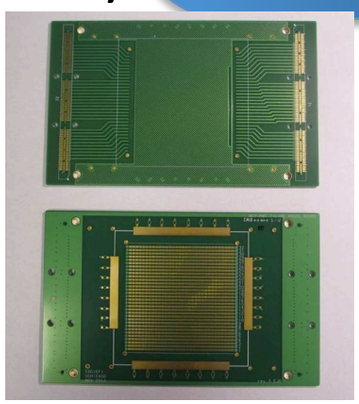
PSEC4 DAQ architecture schematic

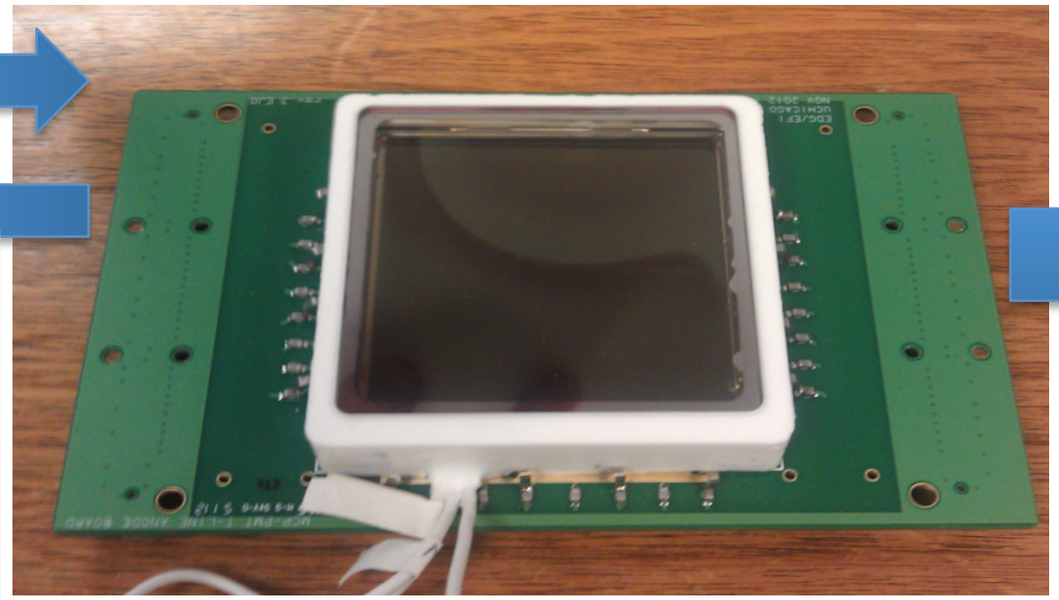


30 channel AC/DC PSEC4 board

- **Integration**: readout both ends of LAPPD anode, or install only one end – in the case of 25 cmXcm Planacon MCP:

50 ohm cable delay

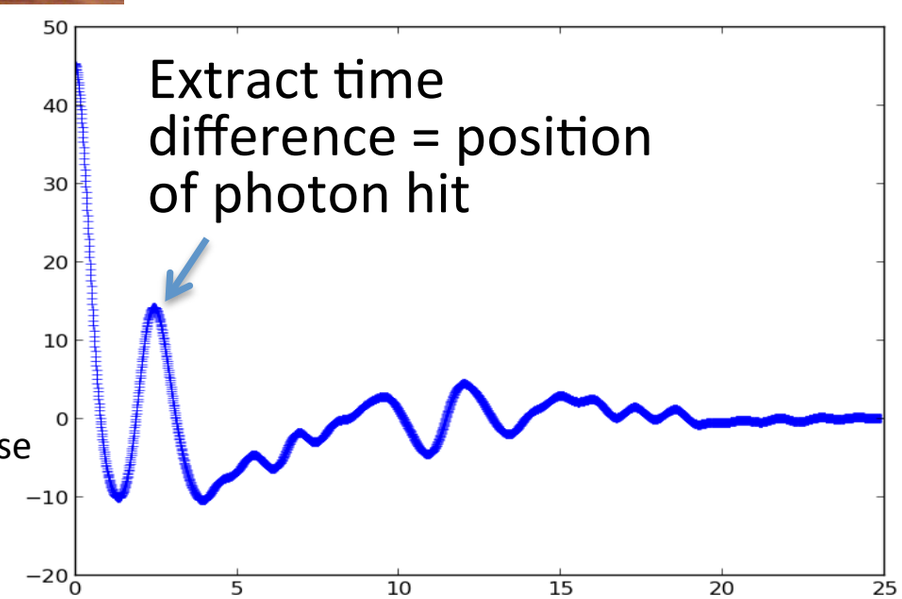




30 channels PSEC4 readout

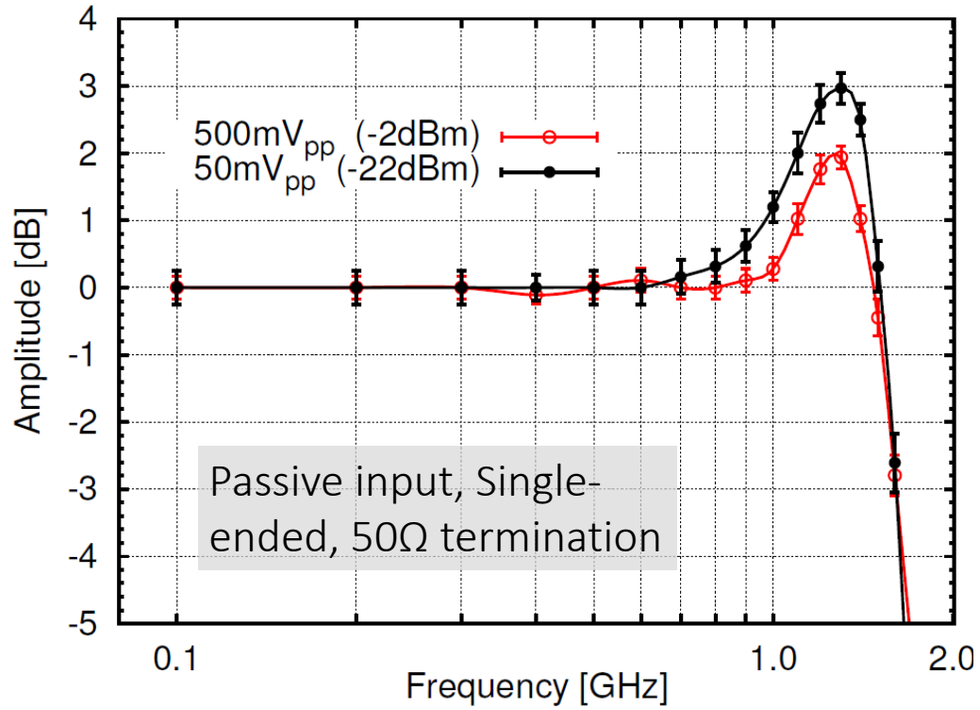
Record pulse and reflection on open end:

1)Interpolate
2)Resample timebase
3)**Autocorrelate**

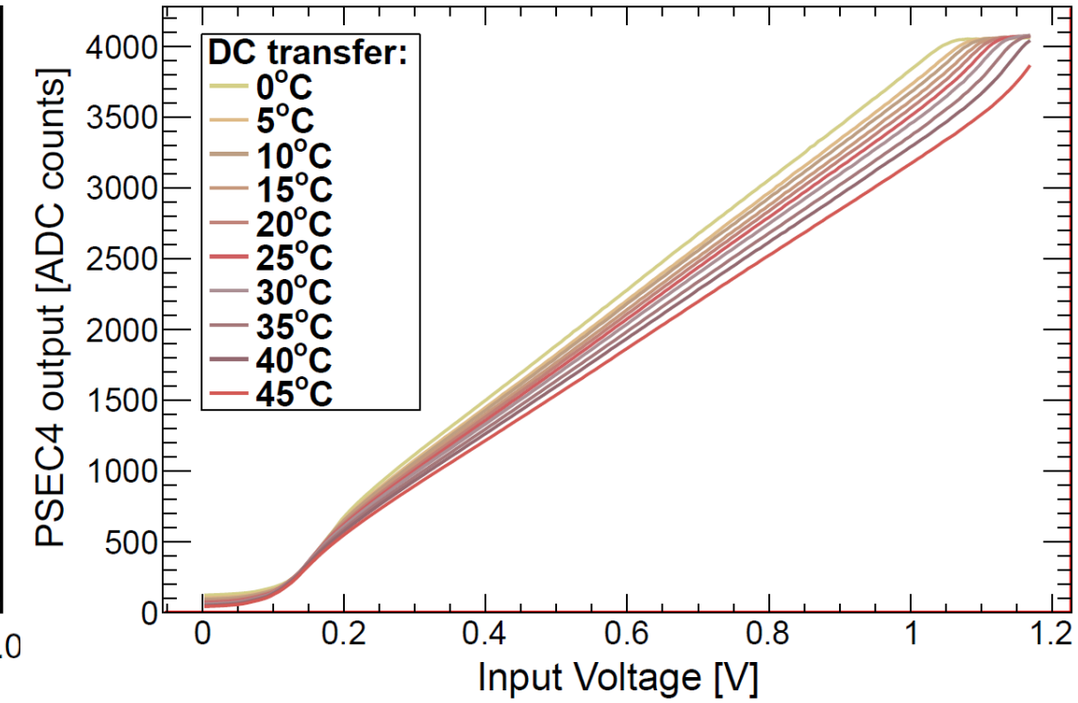


Performance

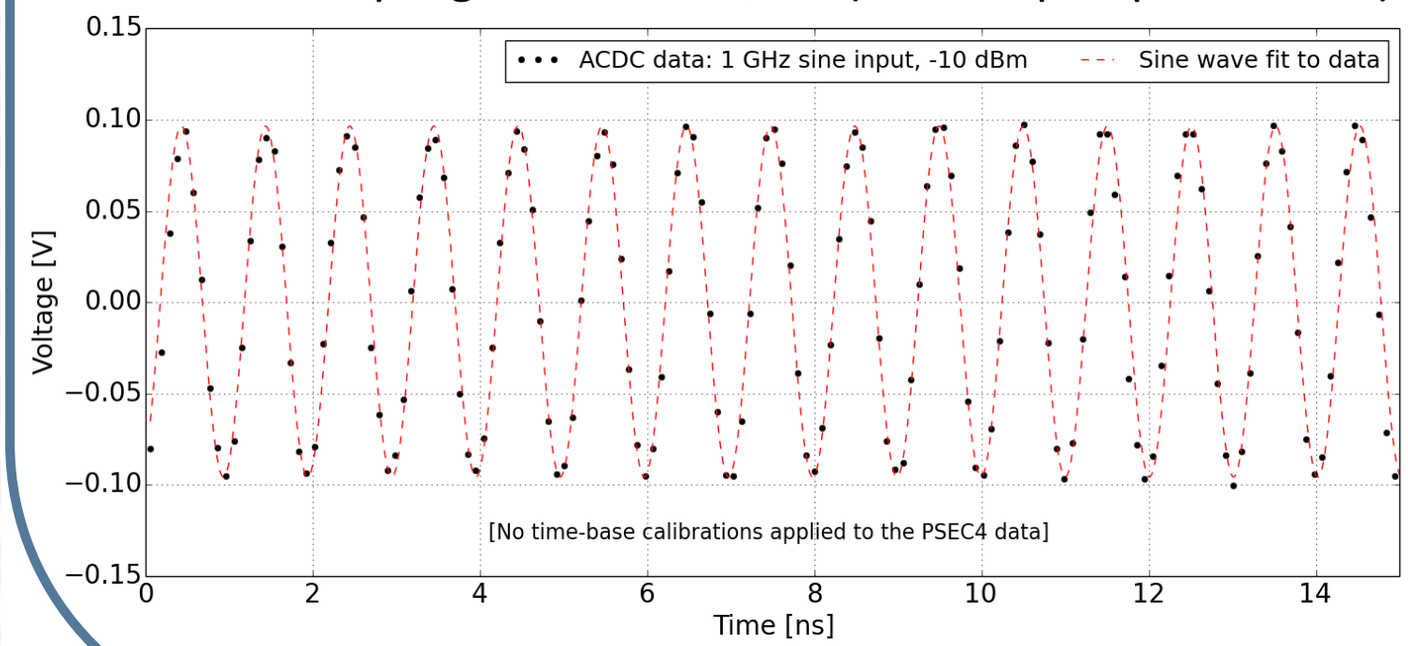
Front-end analog bandwidth[1] > 1 GHz

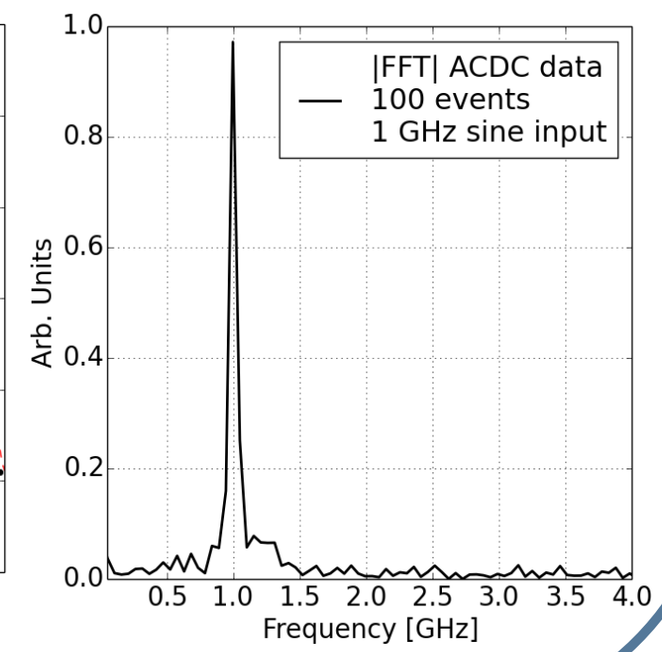


1 V_{pk2pk} signal voltage range[1]

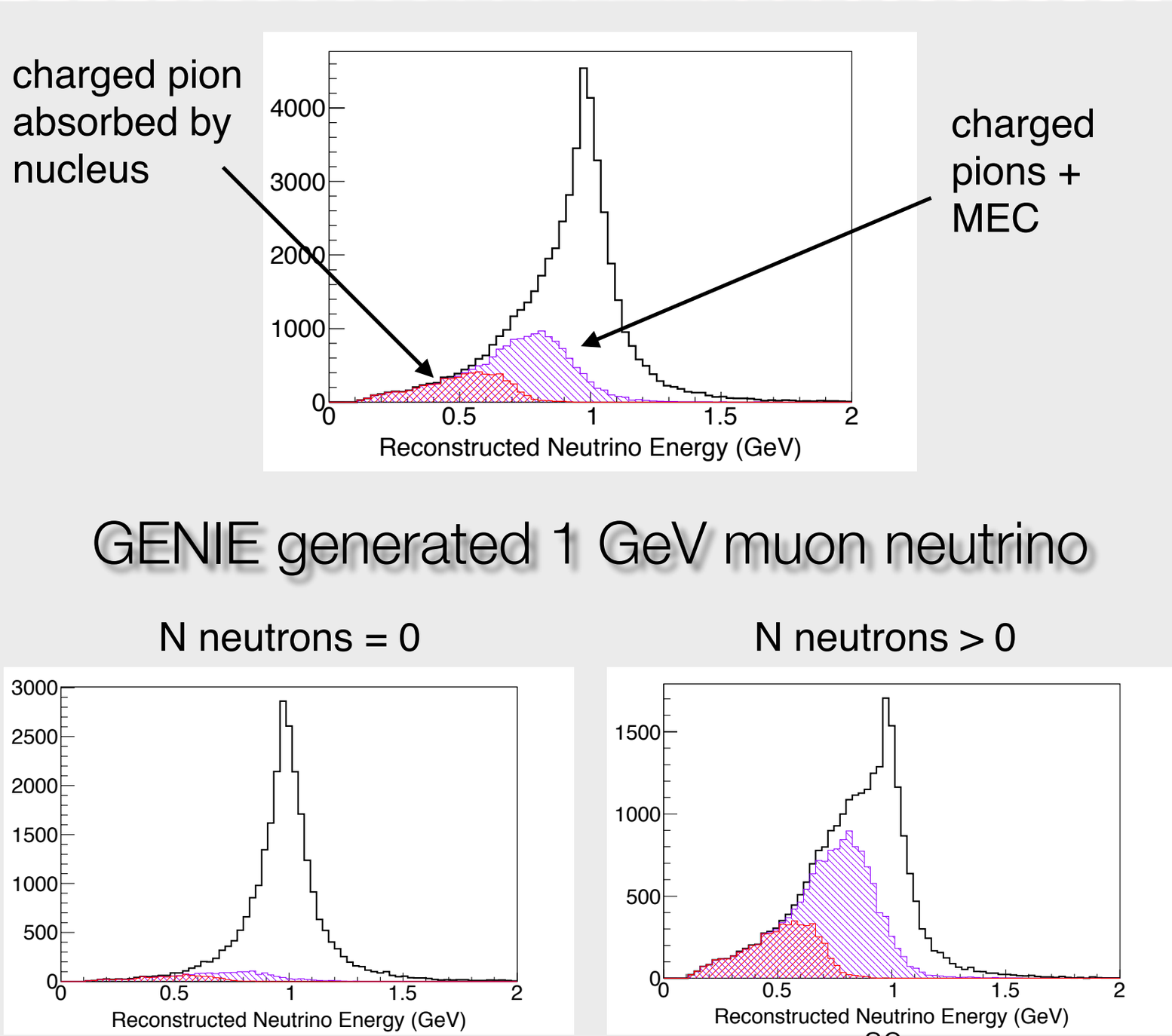


PSEC4 sampling at 10.24 GSa/sec (256 samples per channel):





Neutrino energy reconstruction



- Final state muons end up close to the interaction vertex.
- Vertex reconstruction and neutron localization are crucial to reduce background.