SAND2014-19717C

Detector System Component Studies for a Single-Volume Neutron Scatter Camera

Jim Brennan, **Erik Brubaker**, Aaron Nowack,
John Steele, Melinda Sweany, Eli Woods
Sandia National Laboratories, Livermore, CA

John Mattingly, Kyle Weinfurther
North Carolina State University

November 13, 2014

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND XXXX-YYYY.

Sandia National Laboratories

SNM detection/imaging

We develop systems for eventual application in a range of scenarios:

Standoff detection

Cargo screening

SNM detection applications

- Low signal rate
  - Need large area detectors!
- Low signal to background
  - Need background discrimination!

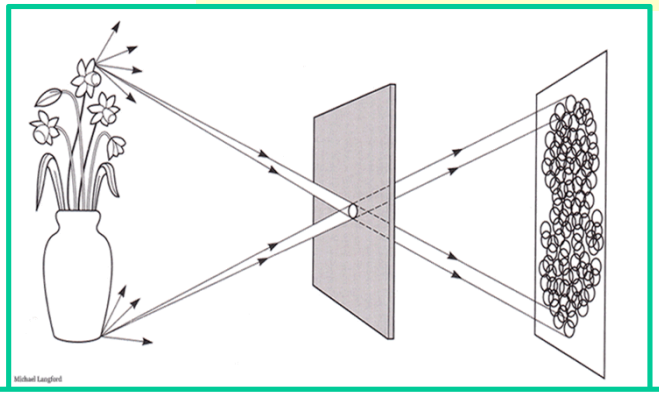
Arms control treaty verification

Emergency response

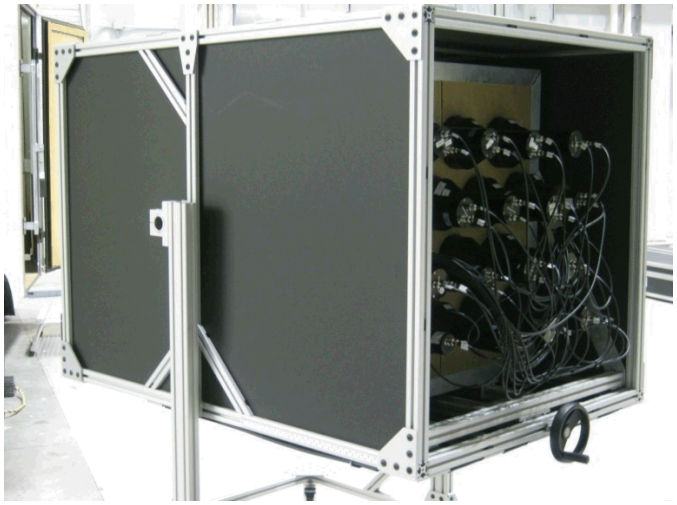
SNM imaging applications

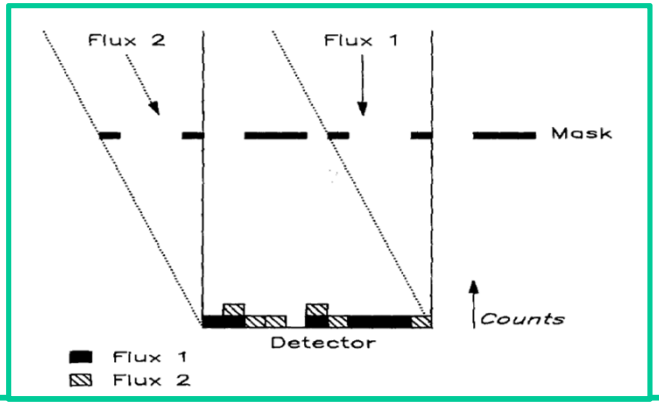
- High resolution required
  - Fine detector segmentation
- Multiple or extended sources

Neutron camera approaches

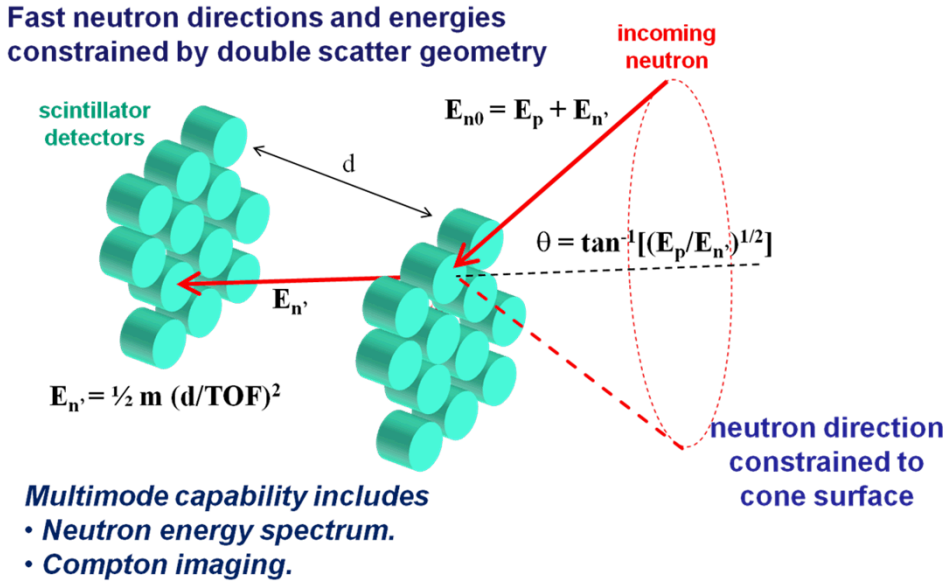


Pinhole: High Resolution, Low Throughput

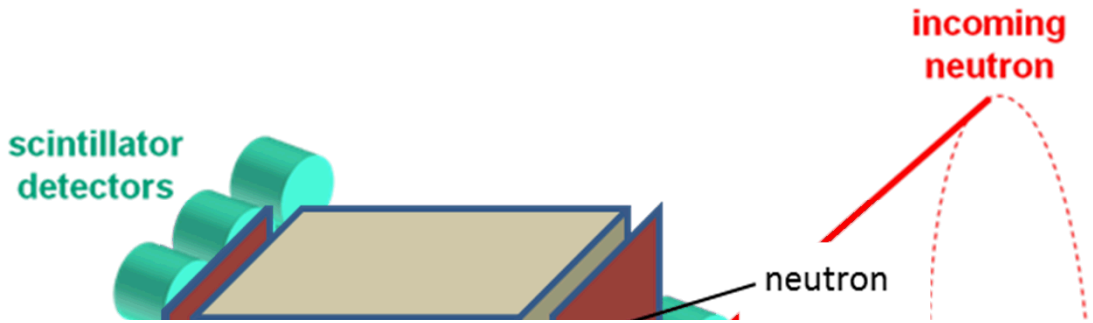


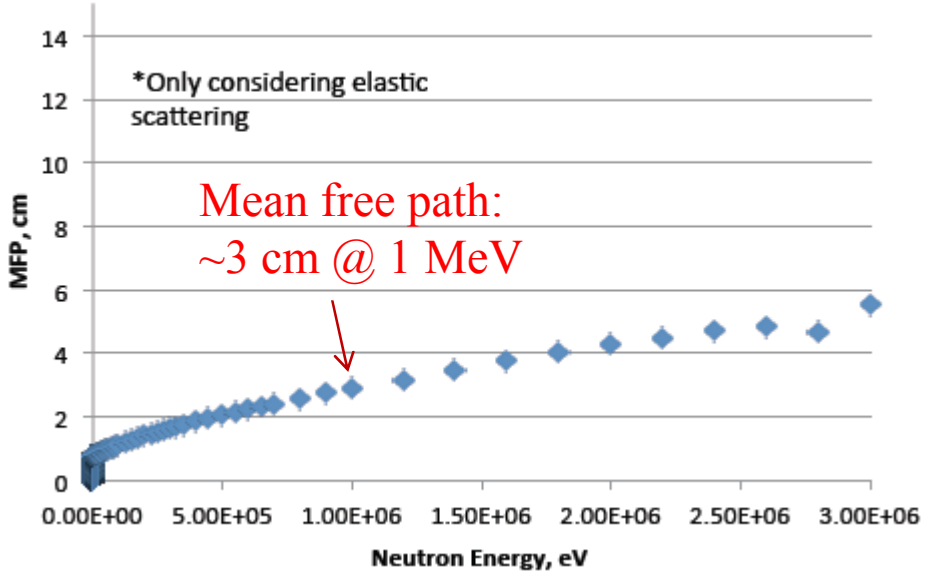


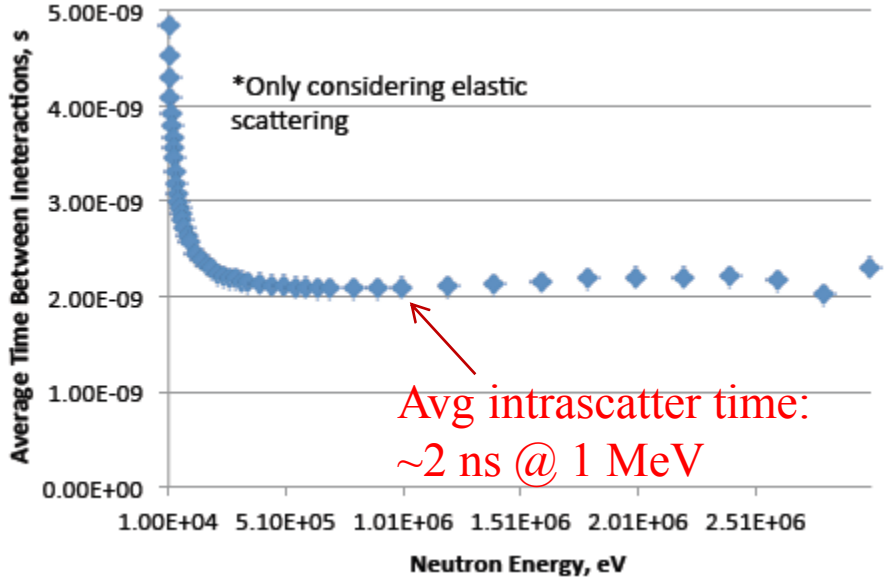
Coded aperture: High Resolution, High Throughput



Single-Volume Neutron Scatter Camera

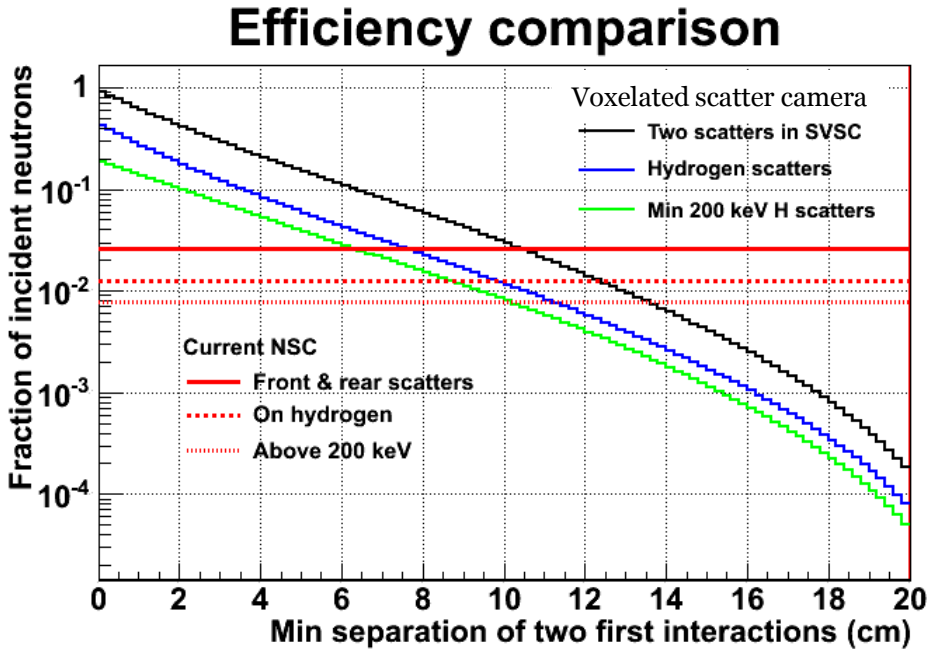


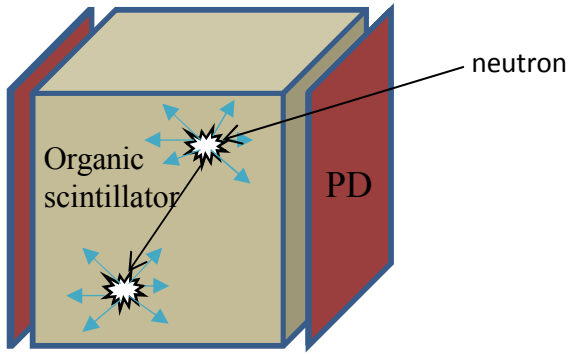




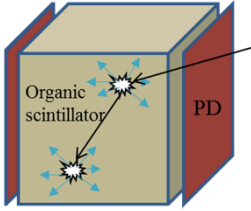
Single-Volume Neutron Scatter Camera

- A scatter camera built from a highly voxelated volume can recover more than an order of magnitude of efficiency if nearby interactions can be resolved.
- Resolving multiple interactions of a neutron separated by O(cm) and O(ns) in a bulk scintillator is difficult!
- Excellent spatial and temporal resolution of photodetectors based on microchannel plates is the key enabling technology.

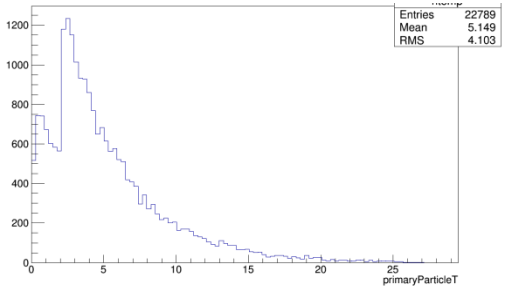




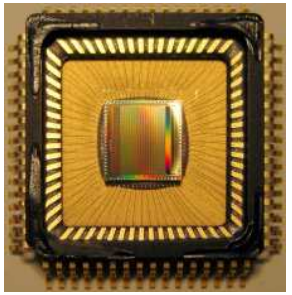
System Components



- Active material
  - Fast organic scintillator
  - Plastic vs crystalline
- Photodetector
  - MCP-PMT, e.g. Planacon
  - Position resolution depends on anode structure
  - 35 ps transit time spread
    - Equals 8 mm photon travel
- Electronic readout
  - Switched capacitor array
    - e.g. DRS4 (5 GS/s, 950 MHz, 11.5 enob)
  - Need careful board design—bandwidth, noise
  - Long reset time



Photonis

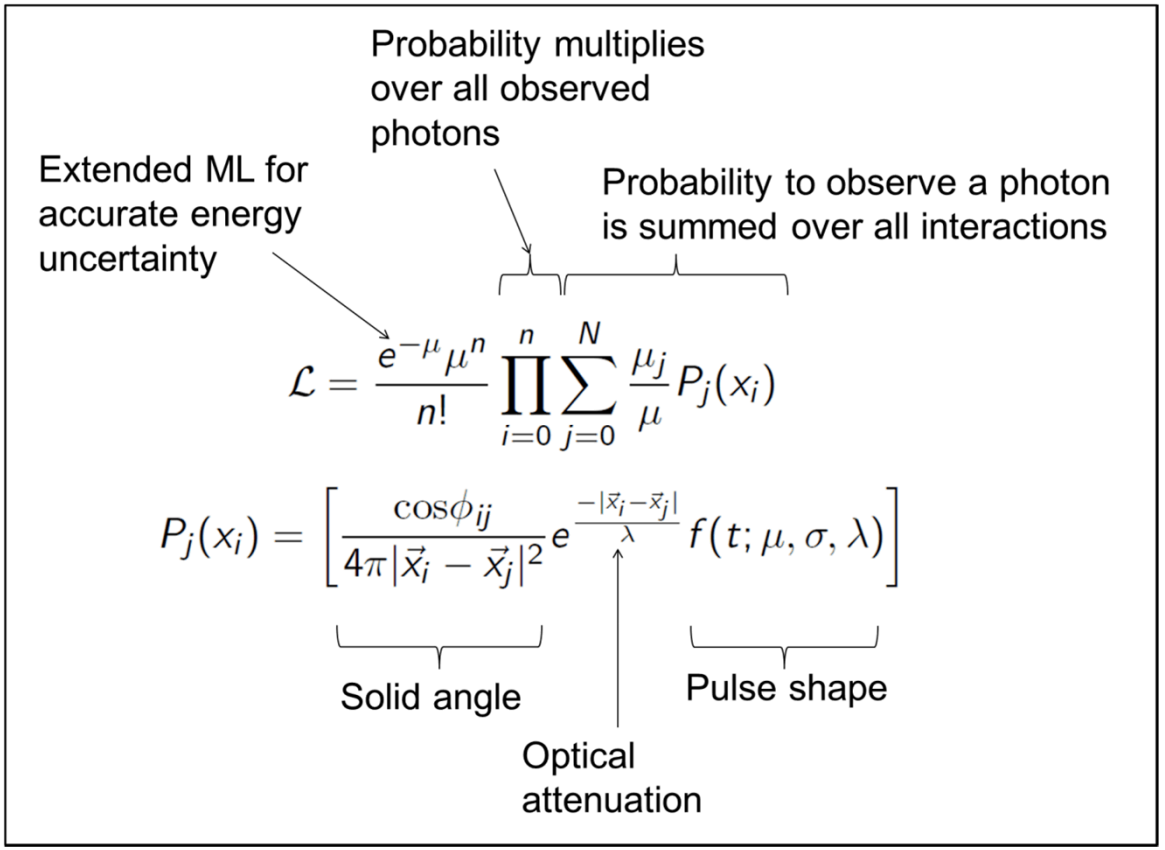


PSI

+ Simulation
+ Event reconstruction algorithm
+ Image reconstruction algorithm

Simulation/Reconstruction

- GEANT4 simulation incl optical photons
- $(10\ \text{cm})^3$ detector, PD on all six sides
- Fixed event, 3 cm/2 ns separation, ~1 MeVee each recoil
- Stilbene pulse shape (0.1 ns rise, 4.5 ns decay)

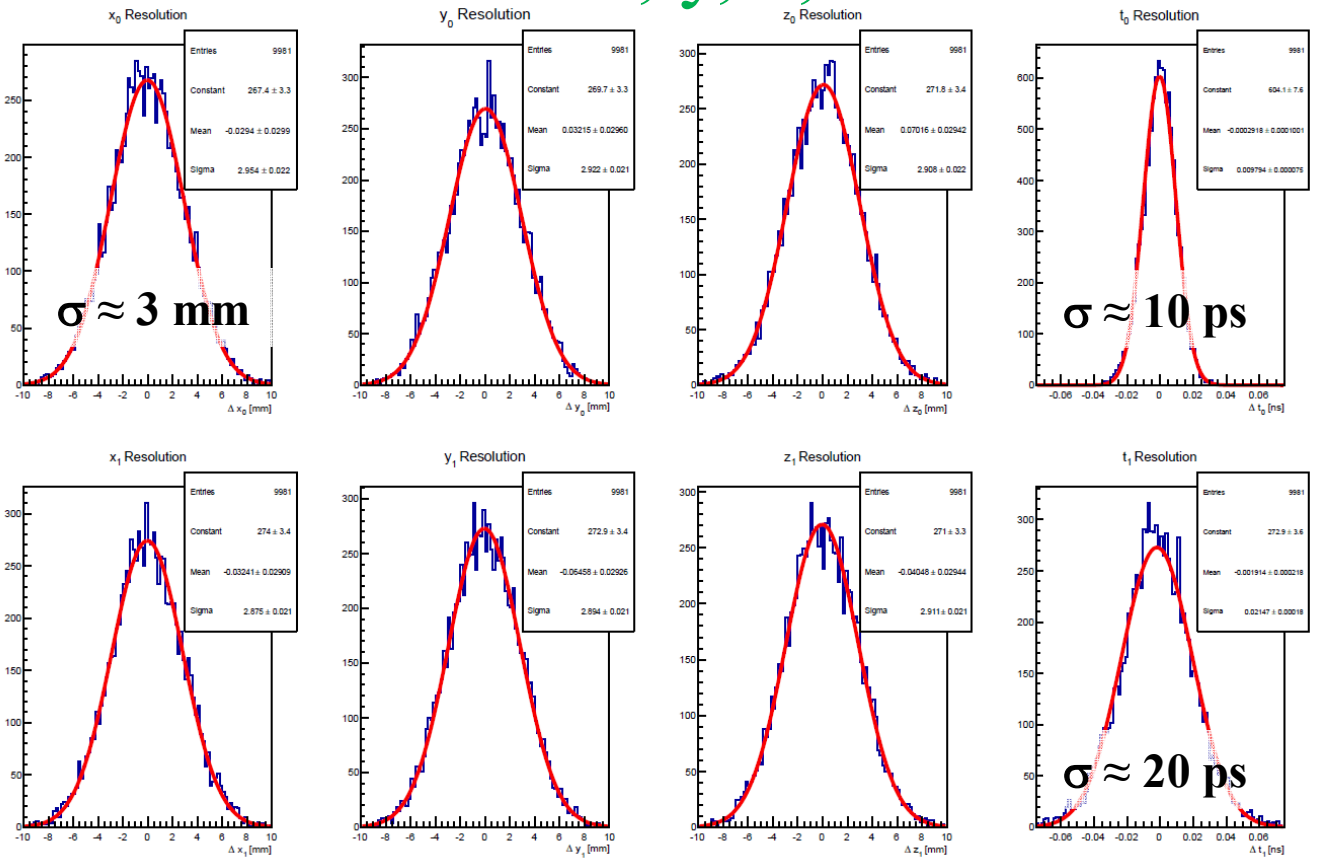


Event reconstruction via likelihood maximization. Input is a list of photon arrival positions and times.

Simulation/Reconstruction

- GEANT4 simulation incl optical photons
- $(10\ \text{cm})^3$ detector, PD on all six sides
- Fixed event, 3 cm/2 ns separation, ~1 MeVee each recoil
- Stilbene pulse shape (0.1 ns rise, 4.5 ns decay)

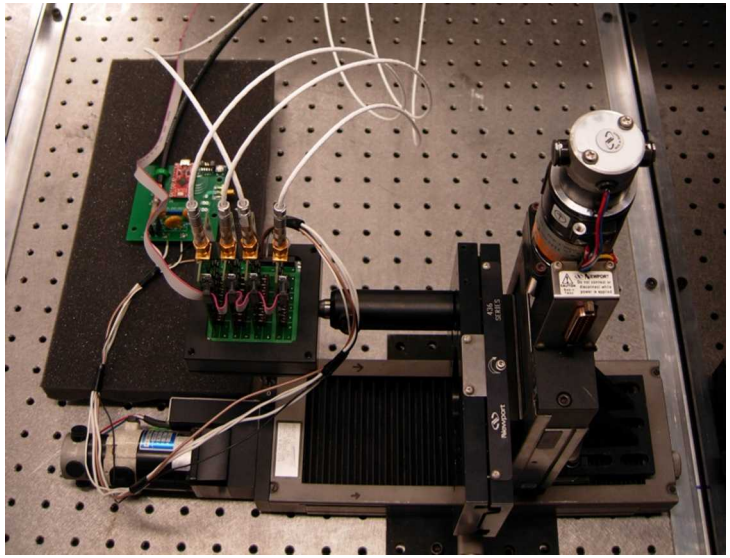
First Interaction x, y, z, t

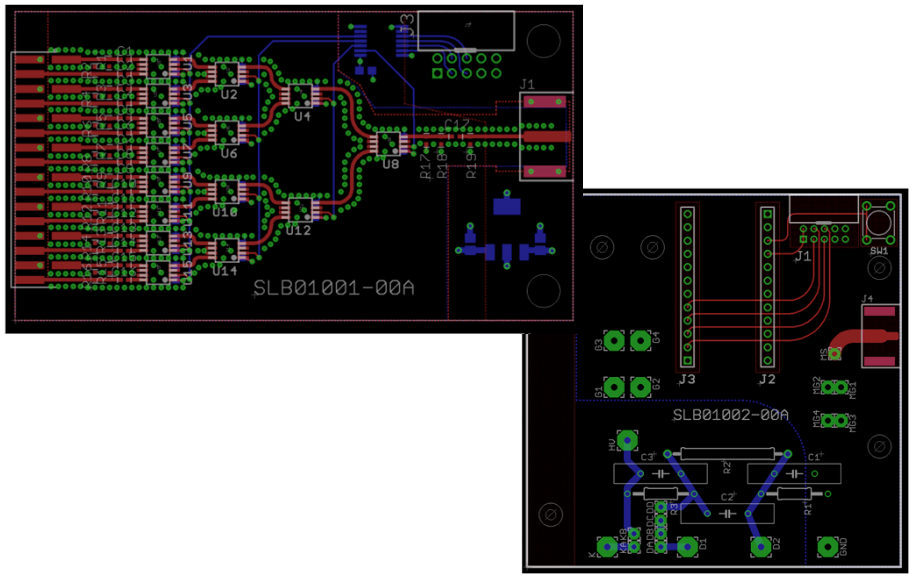


Second Interaction x, y, z, t

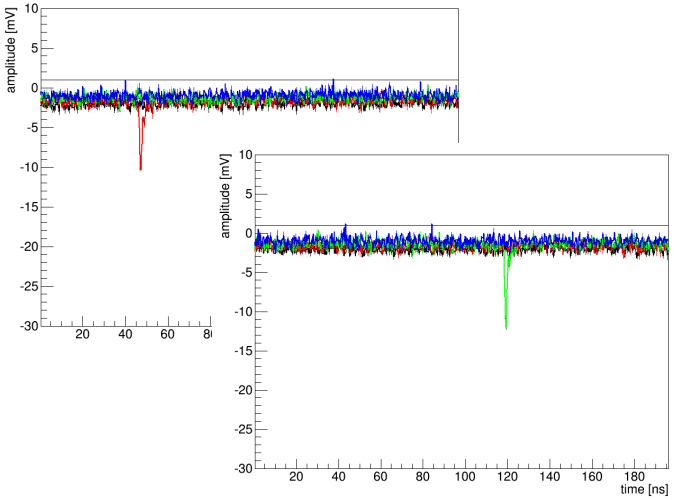
Ideal case, **NOT** predictions of experimental resolutions!

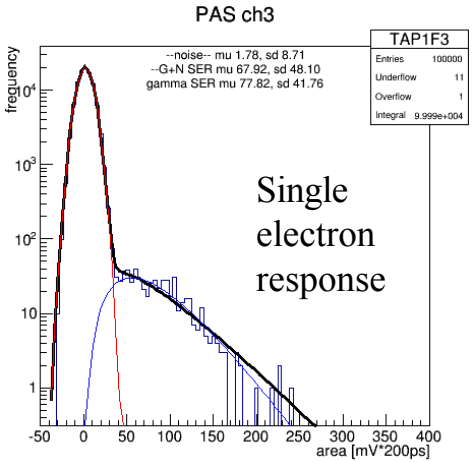
Experimental Status





Pulsed LED
Planacon XP85012
Multiplexer
DRS4 eval board (4 ch)
C++ DAQ

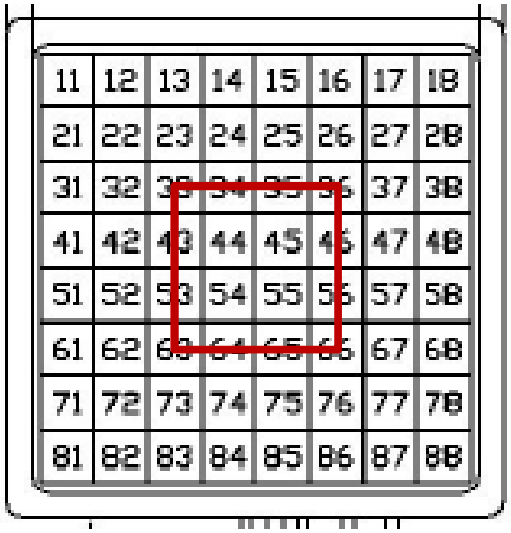




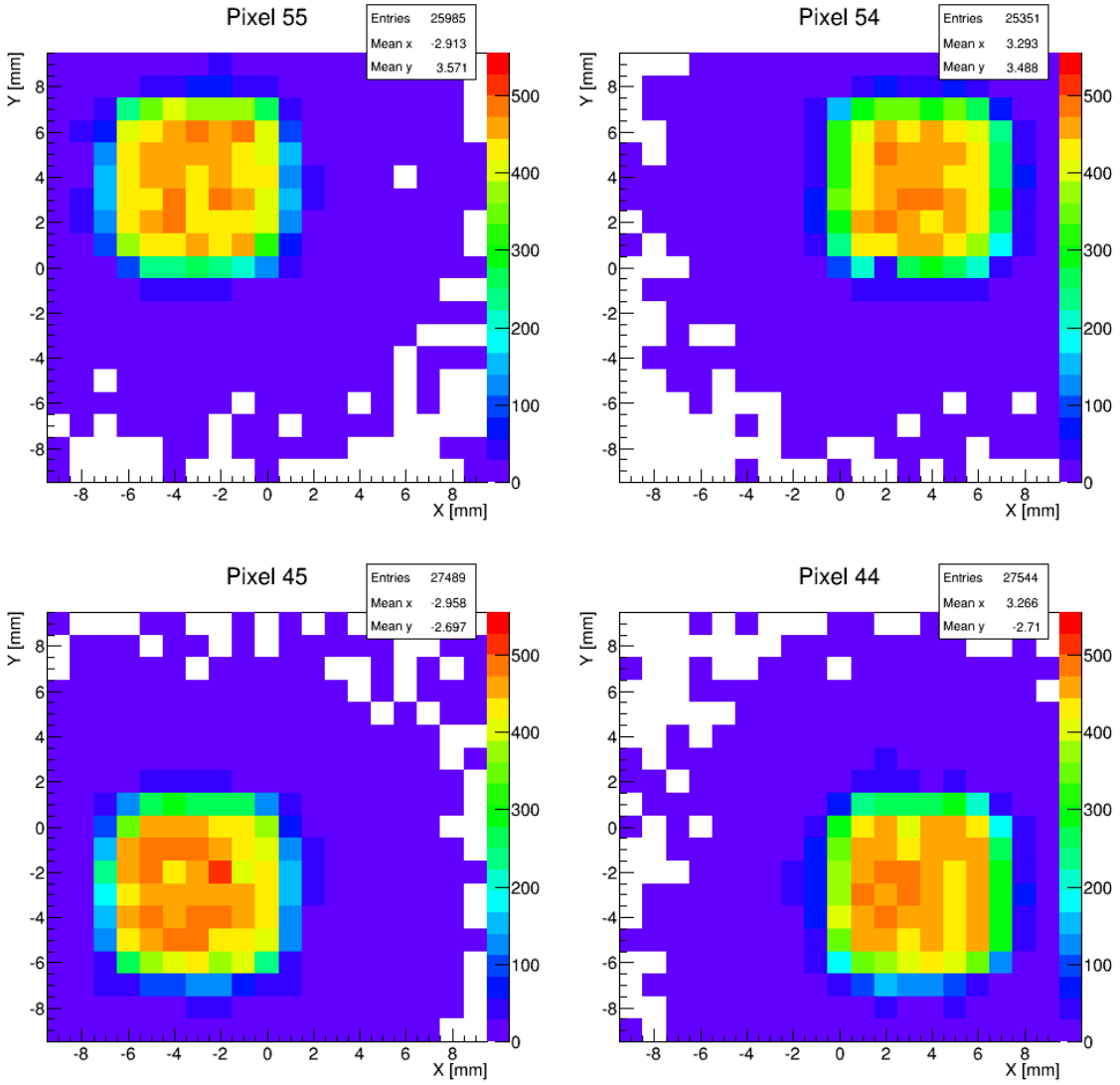
Photodetector characterization

- Complex PD/electronics requires significant effort to **characterize and calibrate**.
- Use LED with 1 mm pinhole aperture; scan Planacon in x,y
- Determine position response of Planacon
  - $N_{pe} \propto QE$
  - Pulse height $\propto$ gain
  - Also see anode response, charge sharing
- Ultimately feed back to simulation for increased realism & systematic studies.

Collimated LED scan



- QE flat (over small region)
- Sharp anode pixel boundaries
  - 1 mm collimation
- Some PE scatter

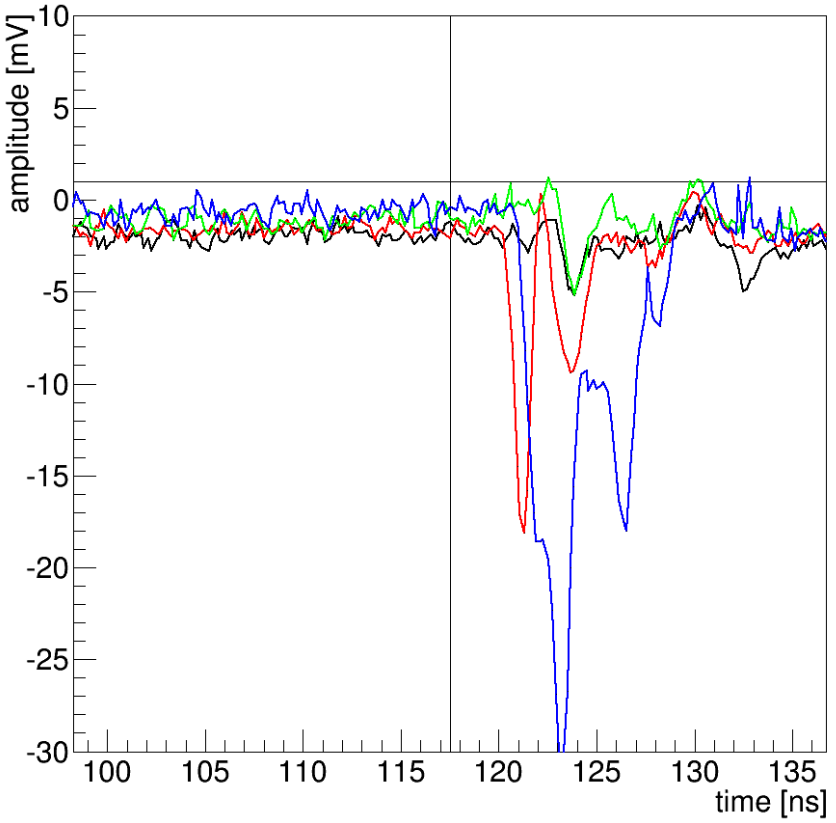


Photodetector concerns

- MCP-PMT lifetime
  - Limited by back-propagating ion bombardment of photocathode.
  - Lifetime expressed in terms of integrated charge through MCP.
  - We want single-photon sensitivity → run at high gain → reduce lifetime.
  - Using atomic layer deposition to coat pores increases lifetime by more than an order of magnitude! (Reported elsewhere in this conference.)
- Tradeoff between anode segmentation, system cost/complexity.

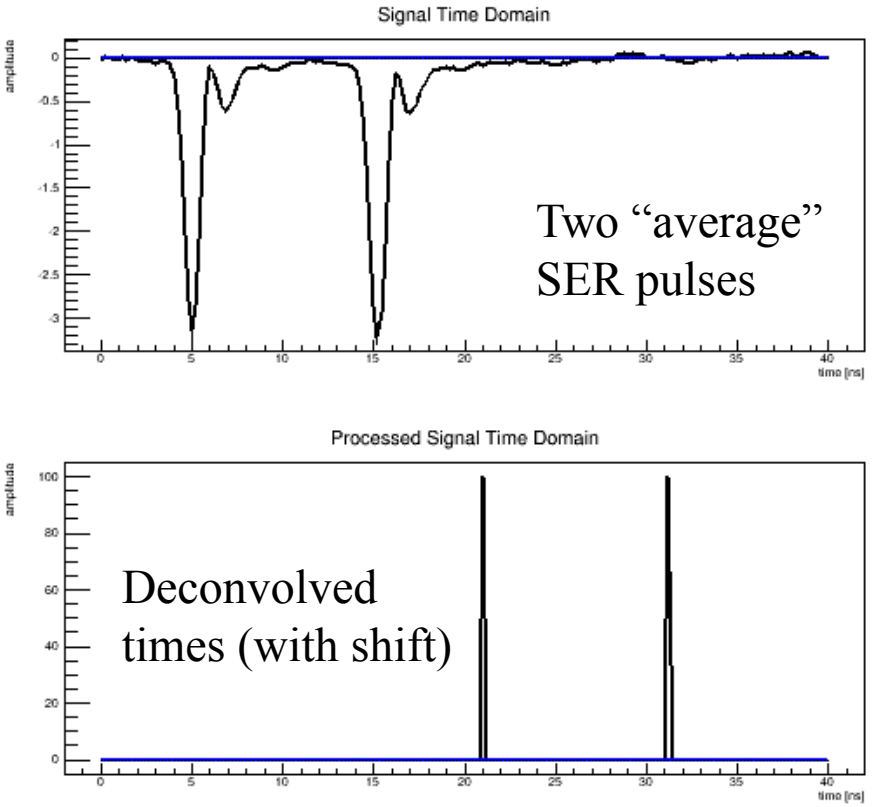
Signal readout/processing

- Not all pixels see well separated single photons.
- Reconstruction algorithm assumes it is handed a list of photon arrival positions & times.
- How to analyze signal trace?



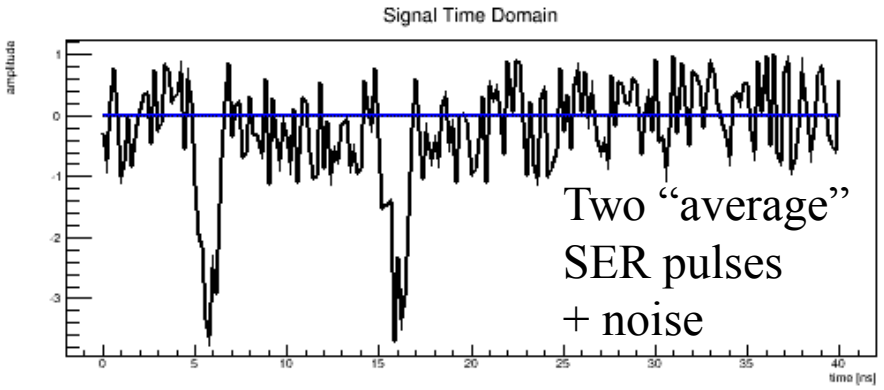
Signal readout/processing

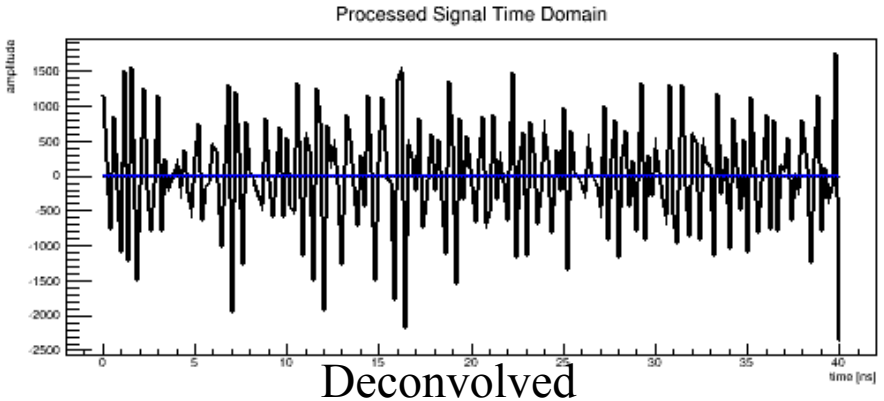
- Not all pixels see well separated single photons.
- Reconstruction algorithm assumes it is handed a list of photon arrival positions & times.
- How to analyze signal trace?
- Use deconvolution with average pulse shape?
- Works great with no noise!



Signal readout/processing

- Not all pixels see well separated single photons.
- Reconstruction algorithm assumes it is handed a list of photon arrival positions & times.
- How to analyze signal trace?
- Use deconvolution with average pulse shape?
- Broken with noise!

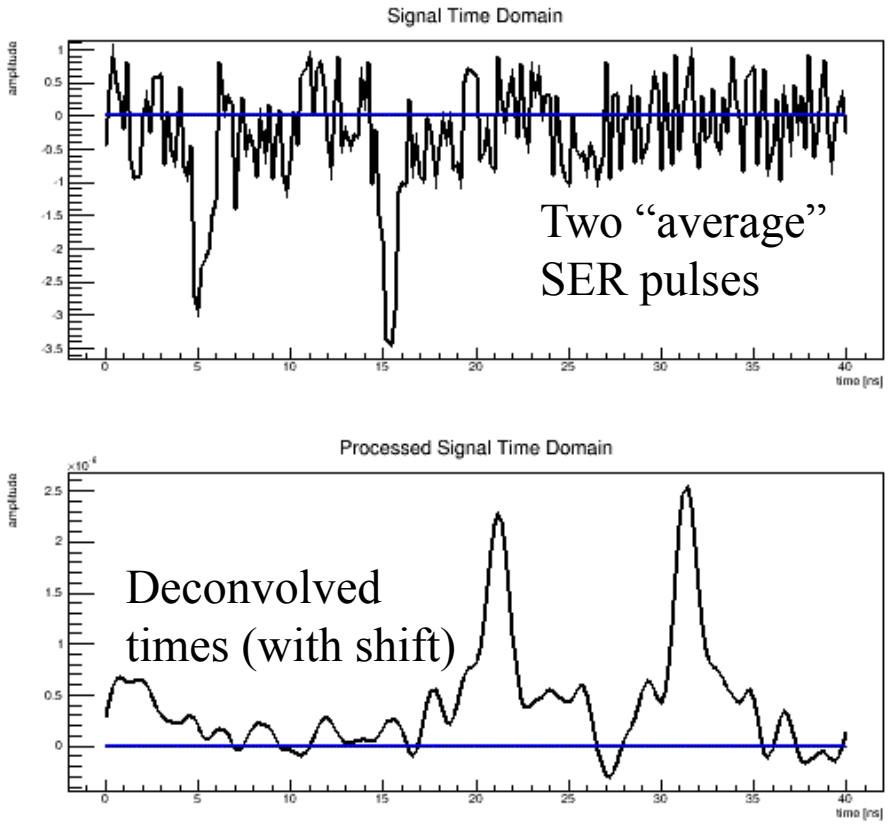




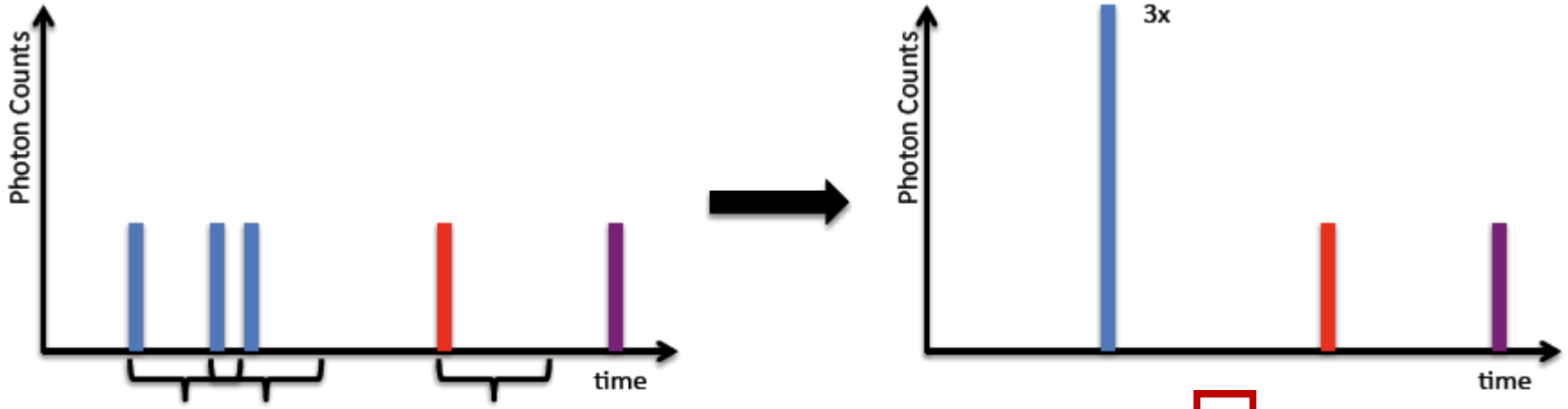
Deconvolved times (with shift)

Signal readout/processing

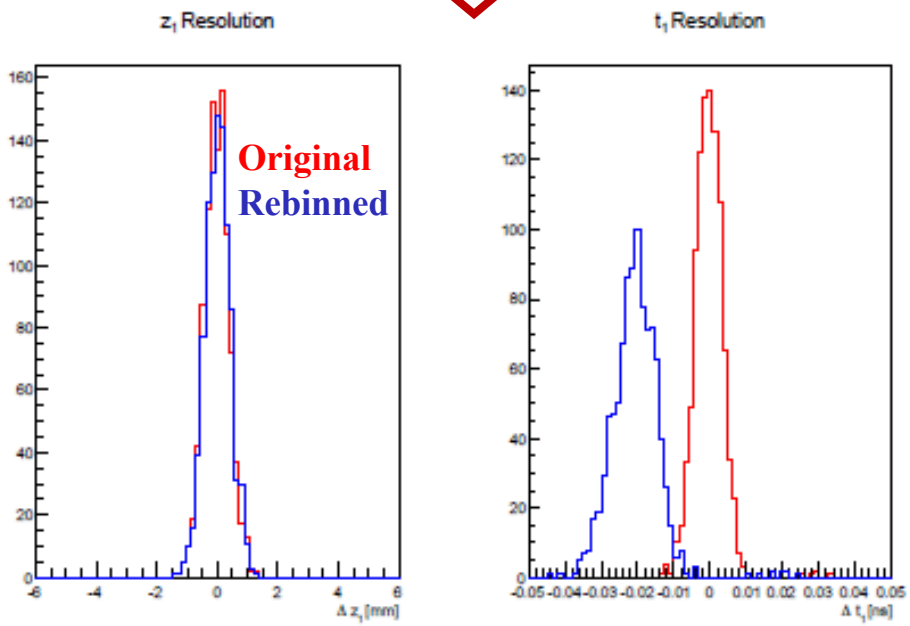
- Not all pixels see well separated single photons.
- Reconstruction algorithm assumes it is handed a list of photon arrival positions & times.
- How to analyze signal trace?
- Use Wiener deconvolution with average pulse shape?
- Better, but not great…



Signal readout/processing



- What if the best we can do for overlapping photons is count them?
- Check in simulation study.
- For t_{window} = 300 ps, time is shifted but reconstruction still reasonable.

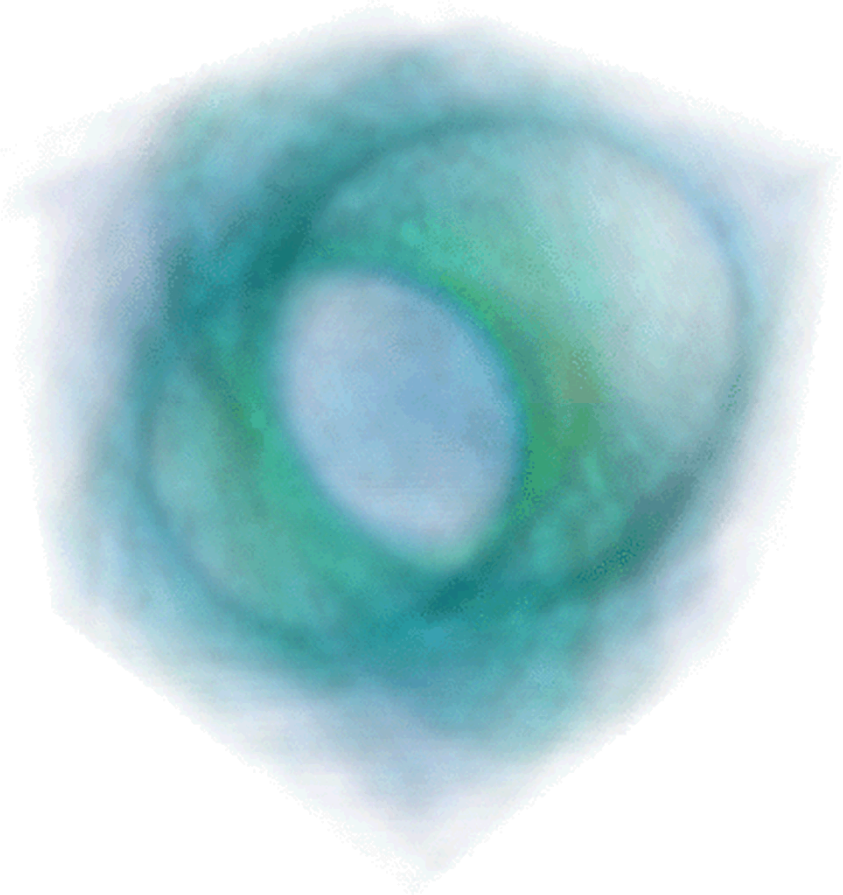


Summary & Conclusions

- Single-Volume Neutron Scatter Camera for high-efficiency double-scatter imaging
  - Enabled by high-resolution photodetectors, electronics.
- Successfully reconstructed two-interaction events in (optimistic) simulation study.
- Automated characterization of MCP-PMT spatial response via scanning collimated LED.
- Demonstrated one approach to processing MCP-PMT signal for overlapping photons.
- Converge on realistic performance
  - Add more realism to simulations.
  - Apply conclusions from simulation studies to develop design of lab prototype.

Acknowledgments

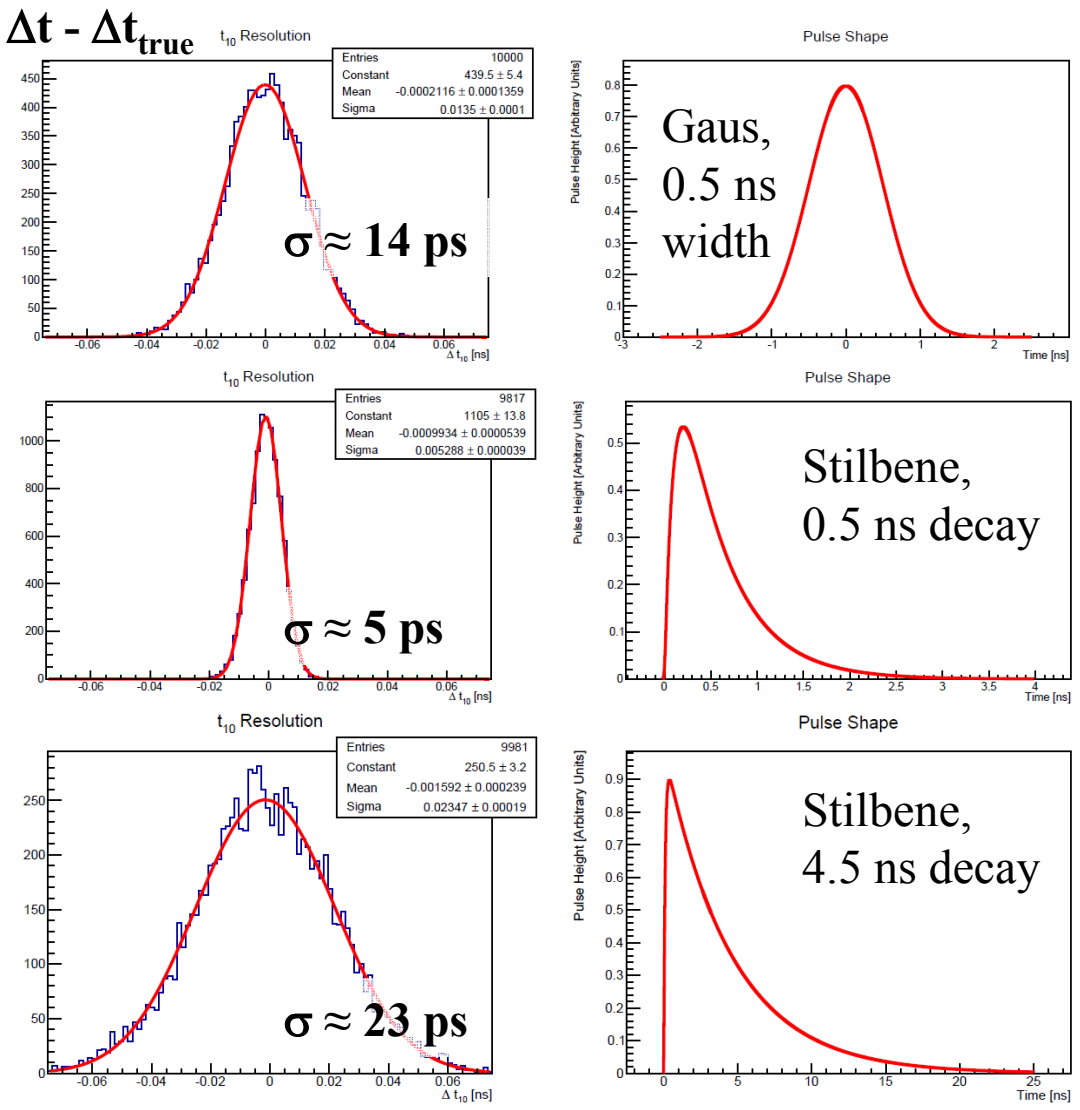
- SNL LDRD funding
- LAPPD collaboration
- mini Time Cube



Additional Slides

Active material studies

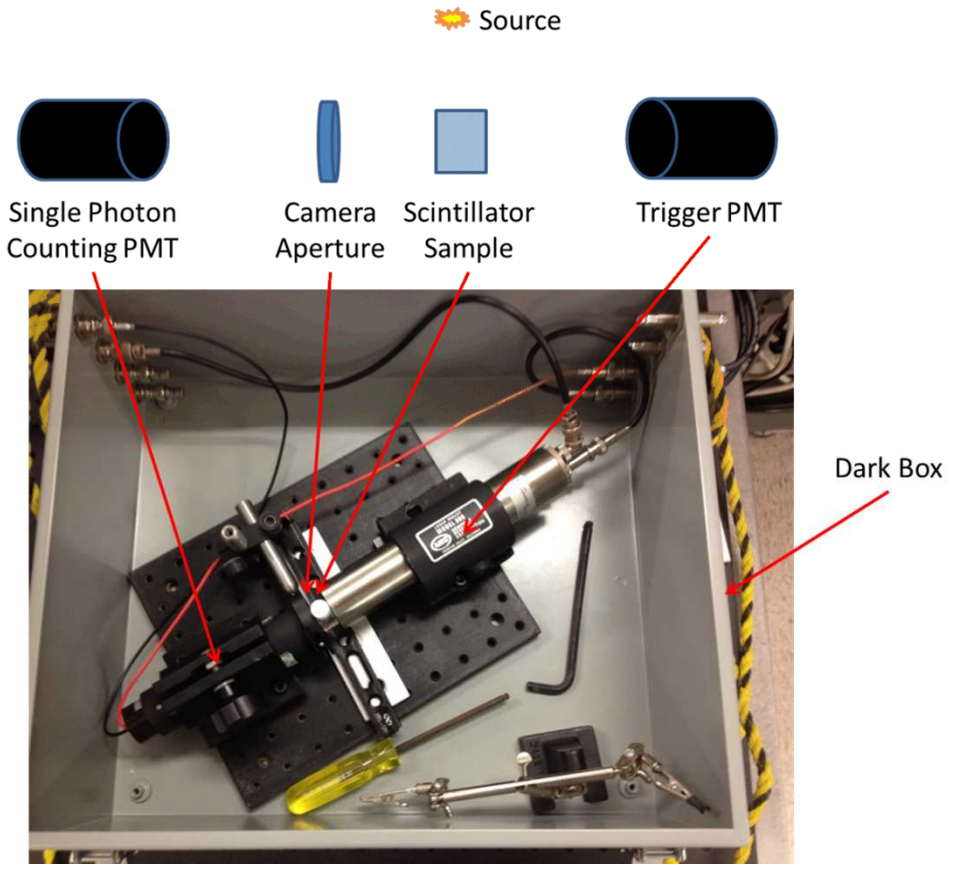
- Study effect of pulse shape on Δt resolution
- Same default event as earlier slide
- Pulse width important, especially rise time
- Quenched plastics?
  - Short decay
  - But slower rise
  - Low light output



Active material studies

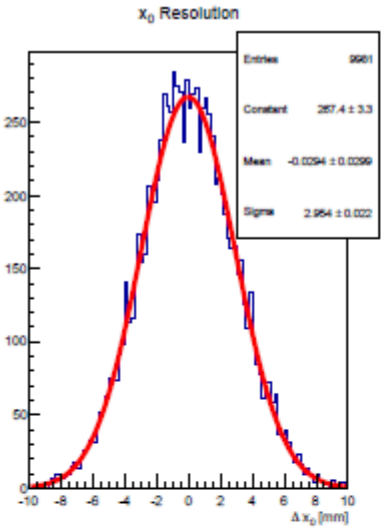
- Use single-photon time-delay method to measure pulse shape of
  - 3 quenched plastics
  - Stilbene single crystal
  - EJ-309 (reference)
- System time resolution is comparable to pulse width!

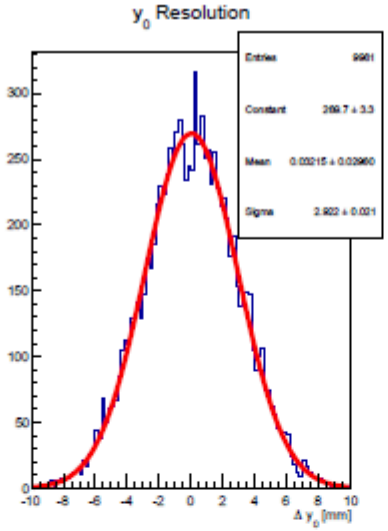
➢ Use Planacon/DRS4 in place of PMTs?

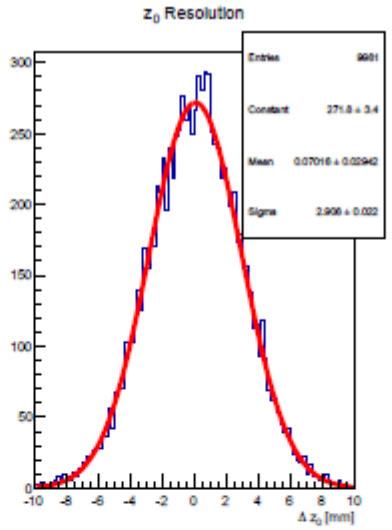


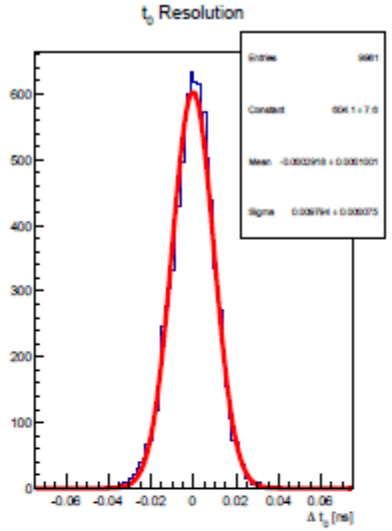
Central event

(10,0,0,0) [mm,ns]

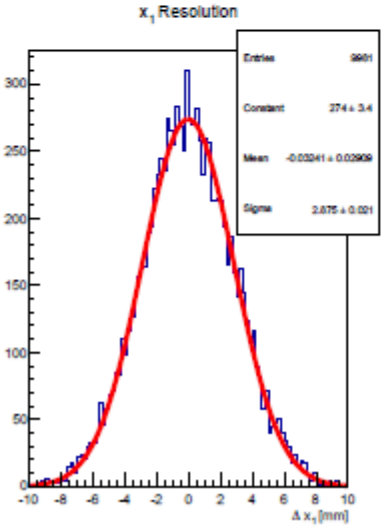


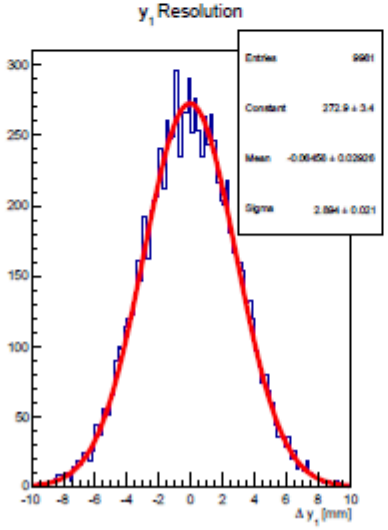


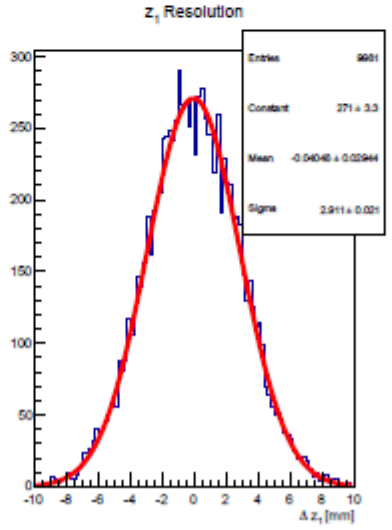


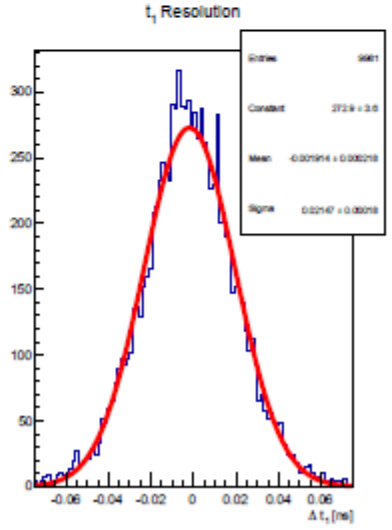


(20,20,20,2) [mm,ns]



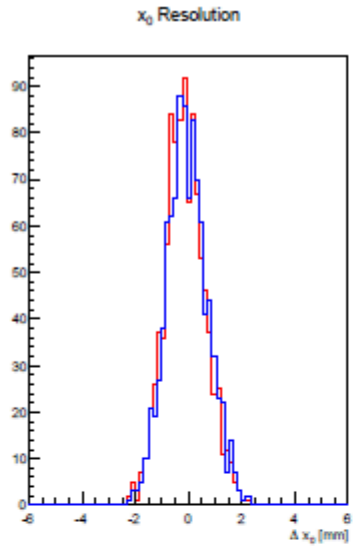


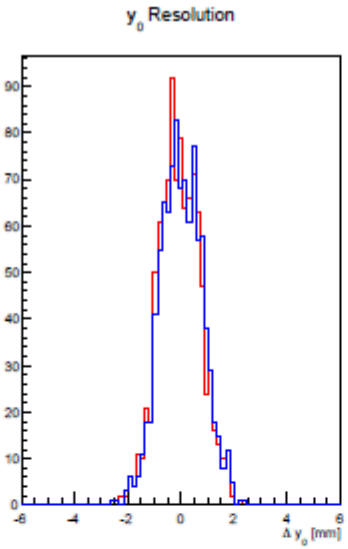


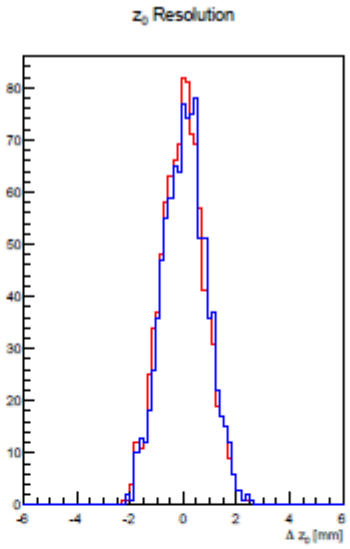


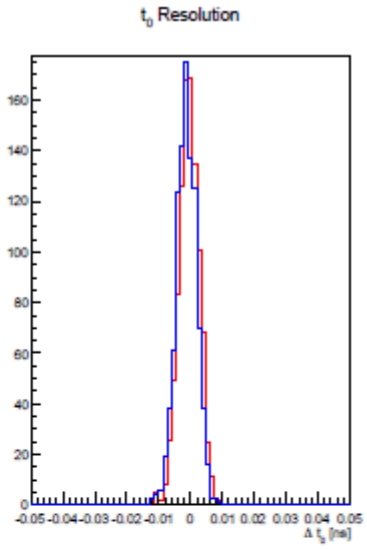
Shifted event

(80,0,0,0) [mm,ns]









(90,20,20,2) [mm,ns]