GPD (Geiger Photodiode) Modules for Scintillating Fiber Readouts

S. Vasile

svasile@apeakinc.com

APEAK’s mission

- Our mission is the development of single-phonon photodetector arrays and photon detection technologies for biomedical, defense, HEP/nuclear physics, and space applications
- So far we have developed GPD arrays with pixel size ranging from 13 to 150 microns diameter
- We are capable of designing and manufacturing custom GPD arrays and modules with very short turnover time and in any quantities using high-volume CMOS manufacturing

Outline

- Geiger avalanche advantages
- Performance goals
- GPD array and module design
- Timing performance
- Detection efficiency
- Reliability evaluation
- Summary

GPD performance parameters

- A Geiger photon detection is a breakdown event that may be initiated by a SINGLE-photoelectron

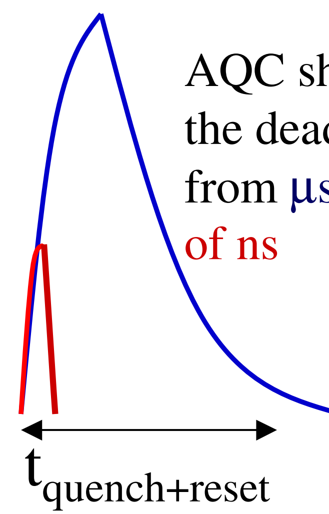
$$D = [1 - EXP(-P_b \cdot n_{carriers} / event)] \cdot n_{events} / \sec$$

DE

$$DER = [1 - EXP(-P_b \cdot QE \cdot n_{photons} / photon\_event)] \cdot n_{photon}$$

DCR

$$DCR = [1 - EXP(-P_b \cdot 1_{carrier} / event)] \cdot n_{carriers\_events} / \sec$$



AQC shortens the dead time from μs to tens of ns

Advantages of Geiger avalanche

- Single-photon detection capability
- No integration time for single-photon events!
- Gain > $10^8 \Rightarrow$ No low-noise PA are needed!
- Binary output, compatibility with digital CMOS
- Compact, low power
- Superior intrinsic timing resolution (timing jitter)
- No shielding in high-magnetic field is needed

Overall goals

- Our goal is to develop silicon-based GPD structures with integrated AQC and buffer electronics, fabricated in high-volume CMOS, at low-cost, with superior process repeatability, verifiable high-reliability, as well as enhanced design flexibility to meet both detector research and detector prototyping needs in HEP and medical physics

Performance goals

- Room temperature operation
- Output on 50 ohm load > 500 mV
- Detection efficiency 100% *
- DCR low enough to detect events <1Hz in gated mode
- $t_{qr} < 1\mu s$

* @ WLS Y11 photon output = 140-180 photons/event x mm^2. A MINOS style setup containing Y11 fibers is used to assess the detection efficiency performance.

Statement of the problem

- Main challenge to the development of large area GPDs matching the diameter of scintillating fibers currently used in HEP experiments (typically 1mm diameter):
  - large area GPDs result in large DCR and require AQCs to decrease t_{qr} and increase the effective detection efficiency

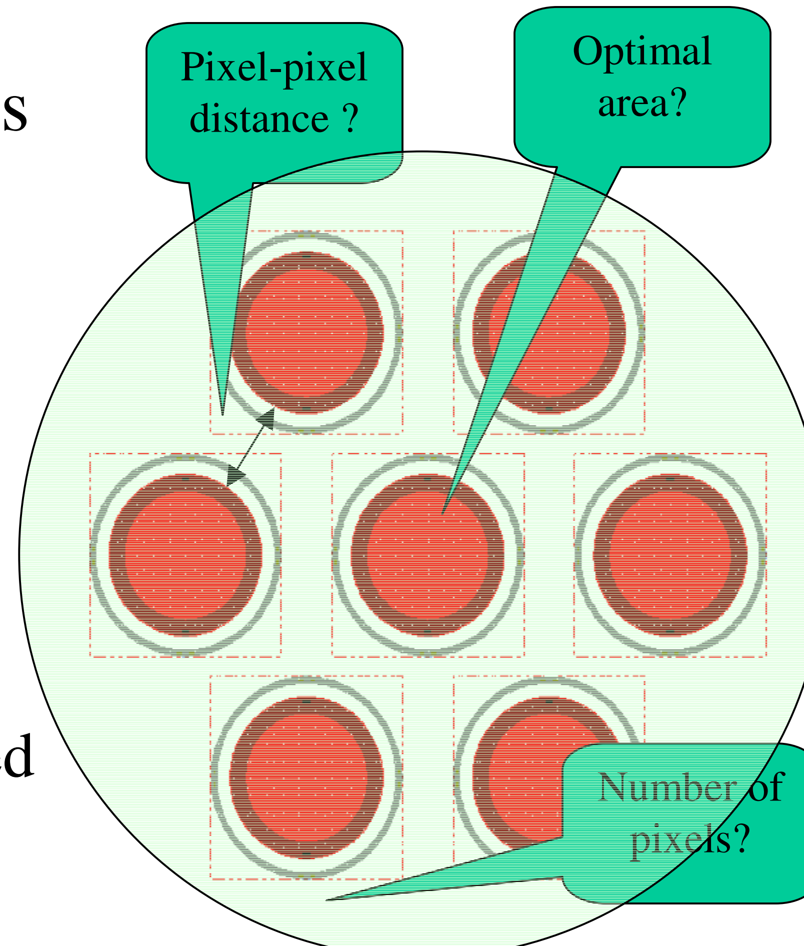
$$DE_{eff} = DE * (1 - t_{qr} * DCR)$$

Detection efficiency limitations

- For example, in order to avoid dead time induced degradation of the detection efficiency for 800-micron diameter GPDs, the avalanche should be quenched and reset within 15 ns!
- This requires low triggering threshold on AQC's comparator, which results in poor immunity to noise and does not recommend using large area GPDs as readouts for 1mm diameter scintillating fibers
- APEAK's solution – Use GPD arrays with smaller pixel size instead of a single, large area GPD detector

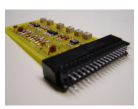
Solution implementation

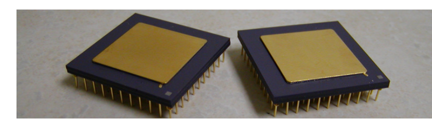
- GPD modules = arrays of {small sized GPDs + AQCs + output drivers} MUXed on 50 ohm loads
- Evaluation GPD array layout for 1mm Y11 WLS in a reference muon setup:
  - Seven, 150-micron GPD cluster in a close-packed hexagonal structure inscribed in a 800 micron diameter circular footprint

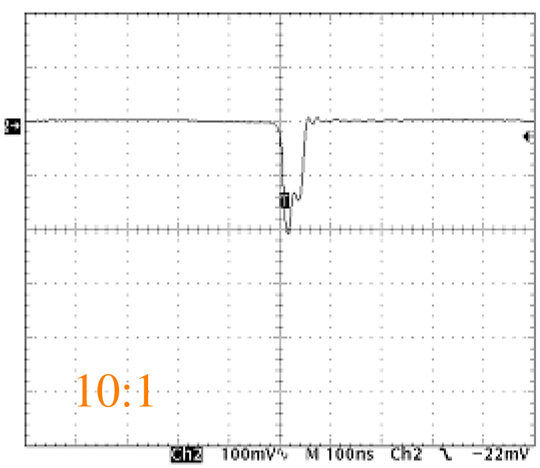


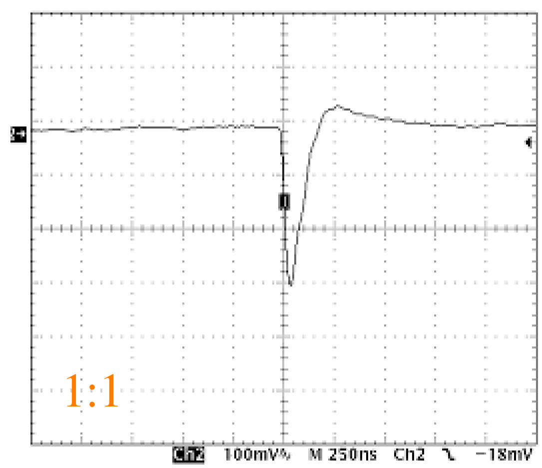
AQC Performance

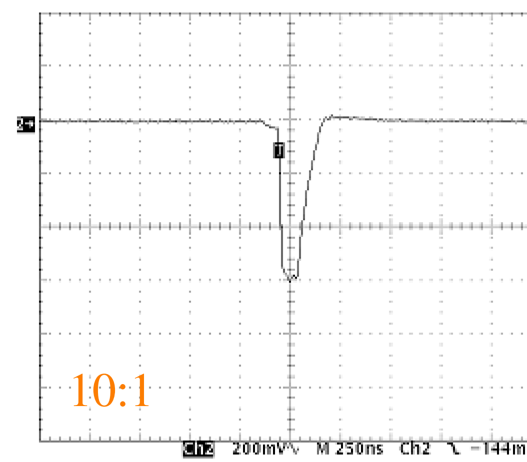
1st generation high speed AQC2x	2nd generation low cost AQC7x	3rd generation high speed, low cost AQC4x-m





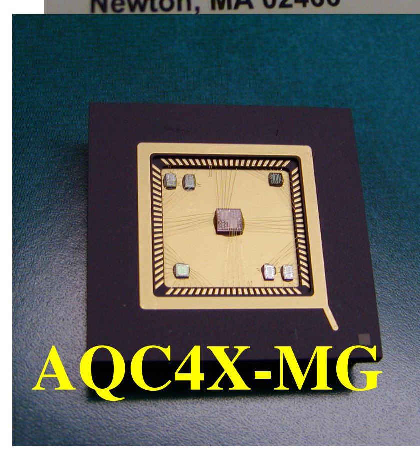






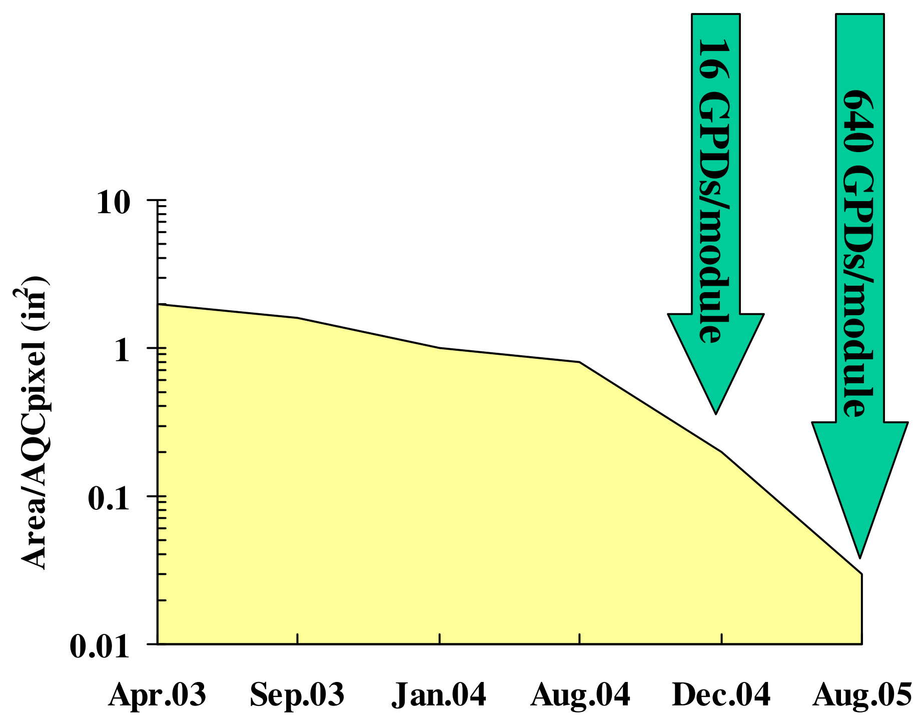
Multi-chip module AQC array

- Currently 4AQC pixels/module (AQC4X-M)
- AQC4X-MG packaged (AQC4X-M + GPD)
- End of 2004 APEAK will integrate up to 14 pixels/module (AQC14X-M)



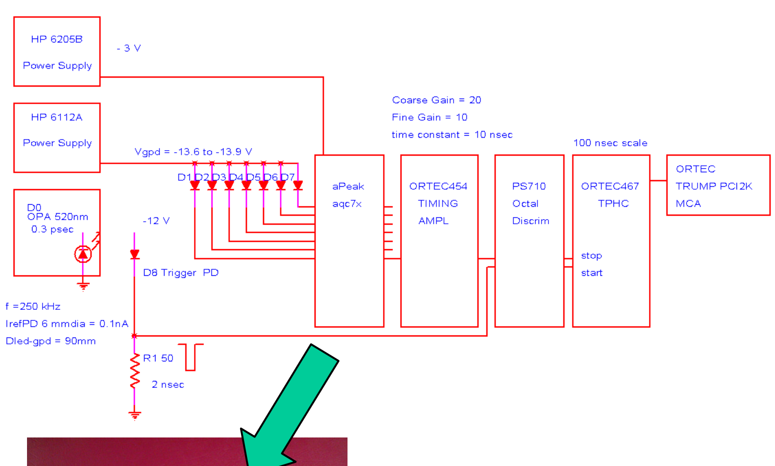
AQC scale down roadmap

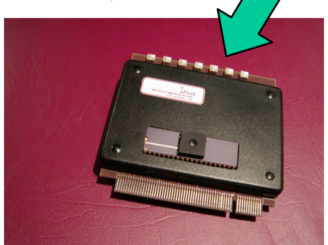
- AQC size and cost are important factors in choosing GPDs for SciFi and WLS applications

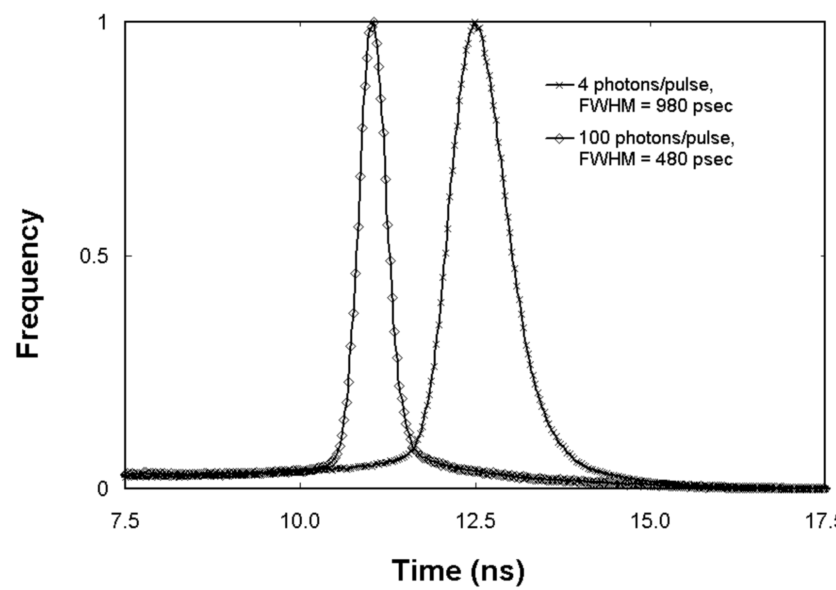


Timing resolution

- Typical setup using 300 fs Ti-sapphire laser pulses on +150 micron GPD quenched by AQC7x

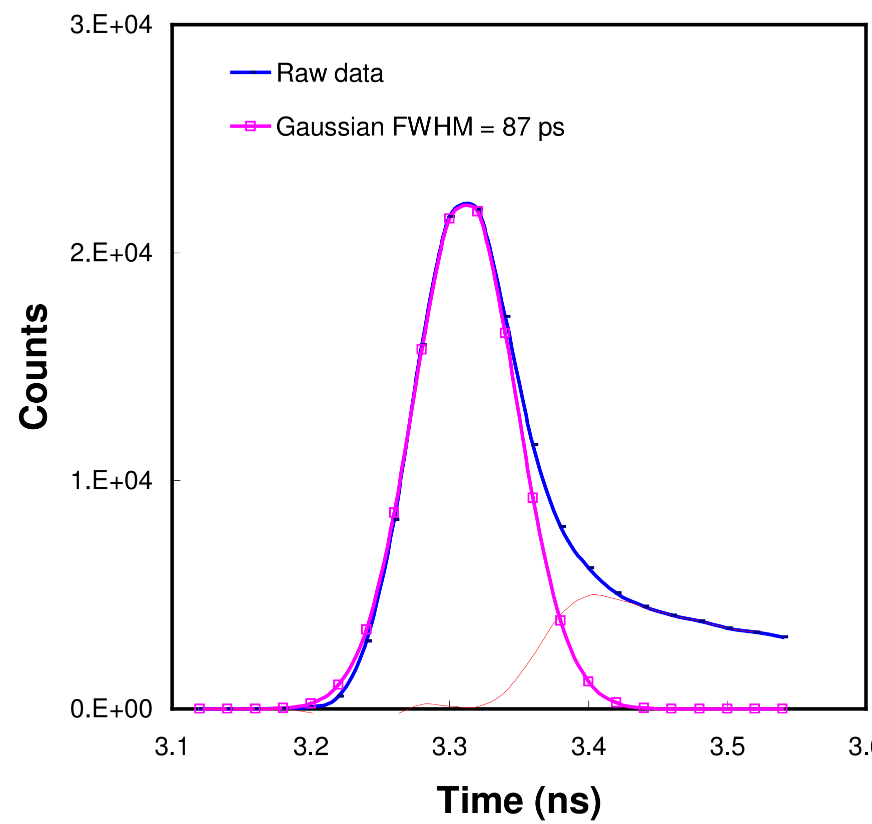




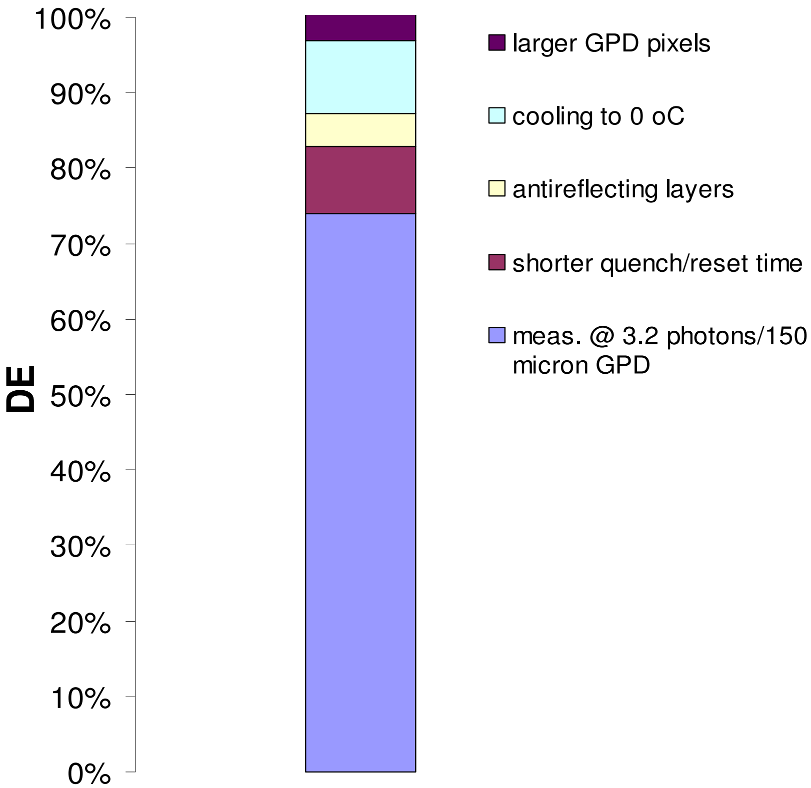


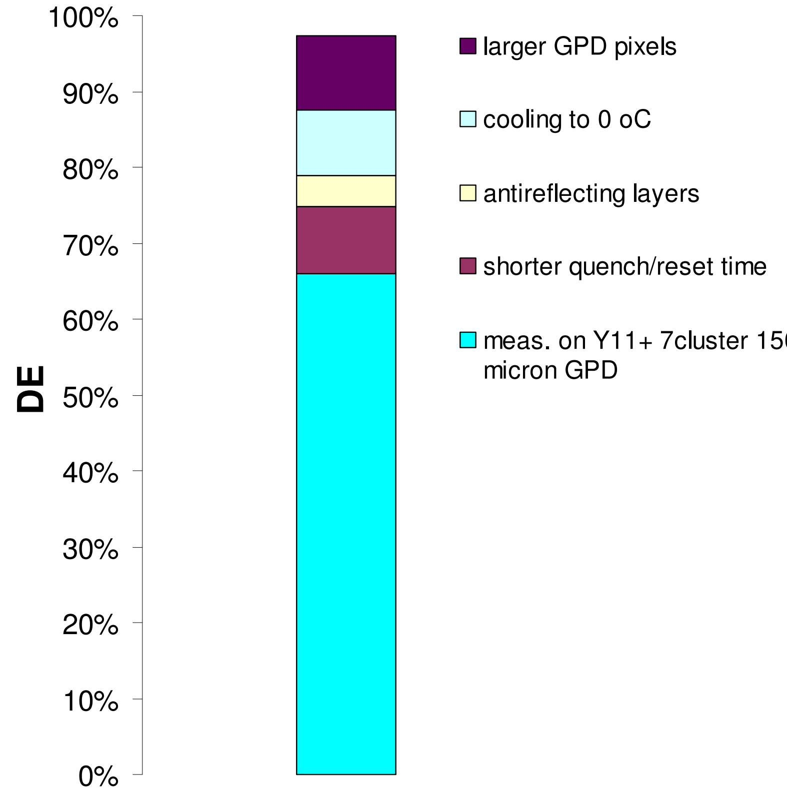
Setting the performance goal for timing resolution

- Within certain size limits, GPDs should have the same time resolution
- The timing resolution tested on 13 micron GPD + AQC2X was 87 ps



Detection efficiency





Bench test @ 10kHz

MINOS style μ setup @ 0.06 Hz

Reliability tests

- LTOL (low-temperature operation lifetime)
  - 1,000 hours JEDEC* standard
  - 14,400 hours non-standard
- HTOL (high-temperature operation lifetime)
  - Accelerated testing JEDEC standard

$$AF_{ionic} = \exp(0.75 \cdot (1/kT_{room} - 1/kT))$$
$$AF_{moisture} = \exp(0.50 \cdot (1/kT_{room} - 1/kT))$$

  - @ 92°C AF_{ionic}=370 and $AF_{moisture}$=50
  - DCR was used as degradation monitor for all reliability tests

* Joint Electron Device Engineering Council

LTOL

- LTOL 1,000 hours

Vbias = 13.6V	UM	Before LTOL	After LTOL
Average DCR	KHz	109	103
STDEV DCR	KHz	11	8
Sample size = 70			

95% CL no degradation

- LTOL 14,400 hours
  - Small sample size : no DCR degradation

HTOL

- HTOL @92 °C for 7 days is equivalent to:
  - 1 year of moisture absorption @ room T
  - more than 7 years of ionic cont. @ room T

Vbias = 13.6V	UM	Before HTOL	After HTOL
Average DCR	KHz	107	126
STDEV DCR	KHz	8	11
Sample size = 28			

- 95% CL DCR degradation (25% increase) no dead GPD pixels

Summary

what we have achieved using 7-cluster GPD layouts

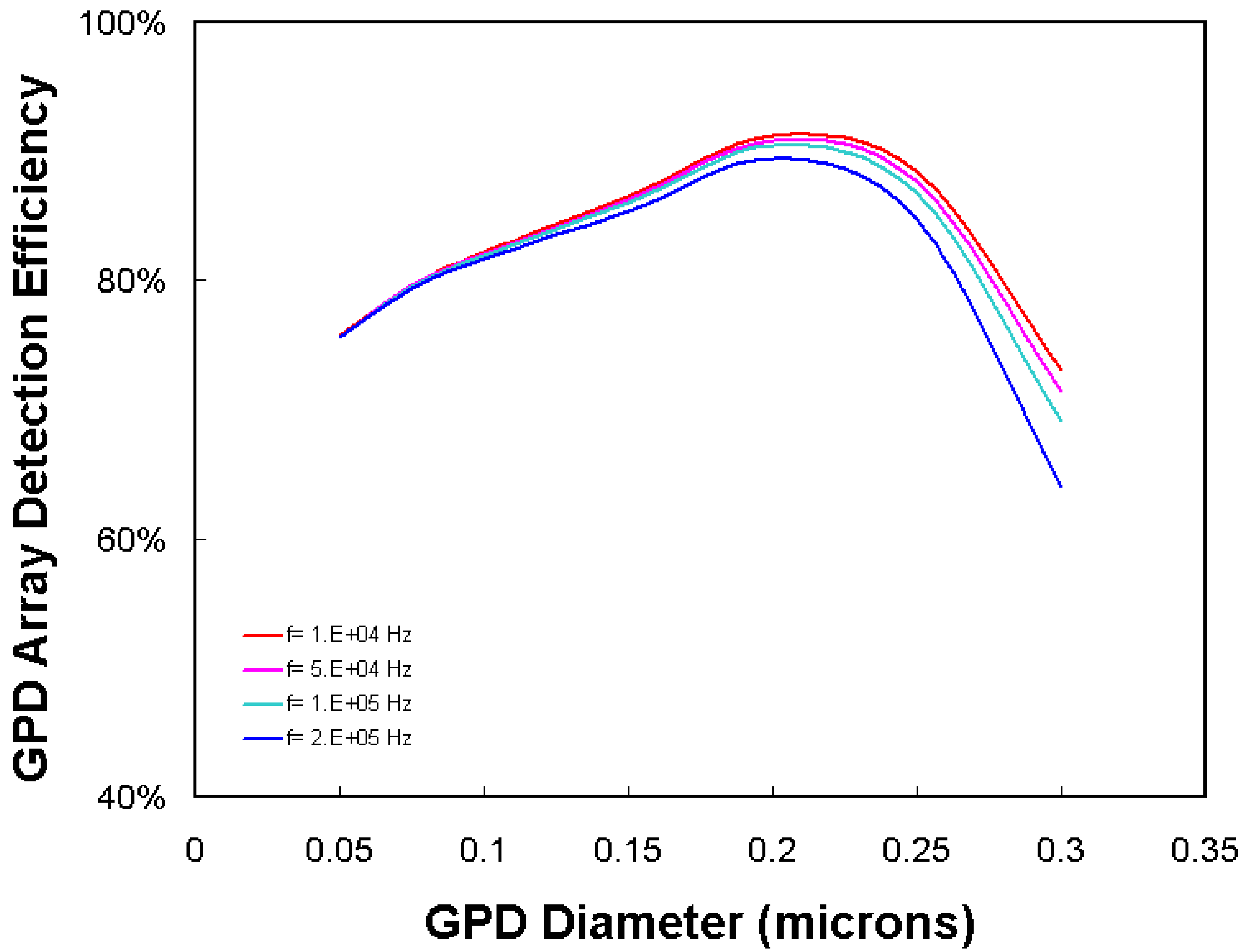
- DE=74% test bench, 62 % on muon setup
- Established AQC design tradeoffs *time vs. $$*
- AQC with buffer outputs > 500mV on 50 Ω
- Timing resolution: 1 ns, target 100 ps
- Muon detection @ 1muon/min event rate
- Verified reliability over 7 years of operation

Acknowledgements

- U.S. Department of Energy SBIR grant
- Colorado State University, Ft. Collins., Department of Physics for GPD measurements on the muon setup
- Massachusetts Institute of Technology , Spectroscopy Laboratory for support with timing resolution measurements

Backup slides

DE vs. GPD diameter



GPD fall time issues