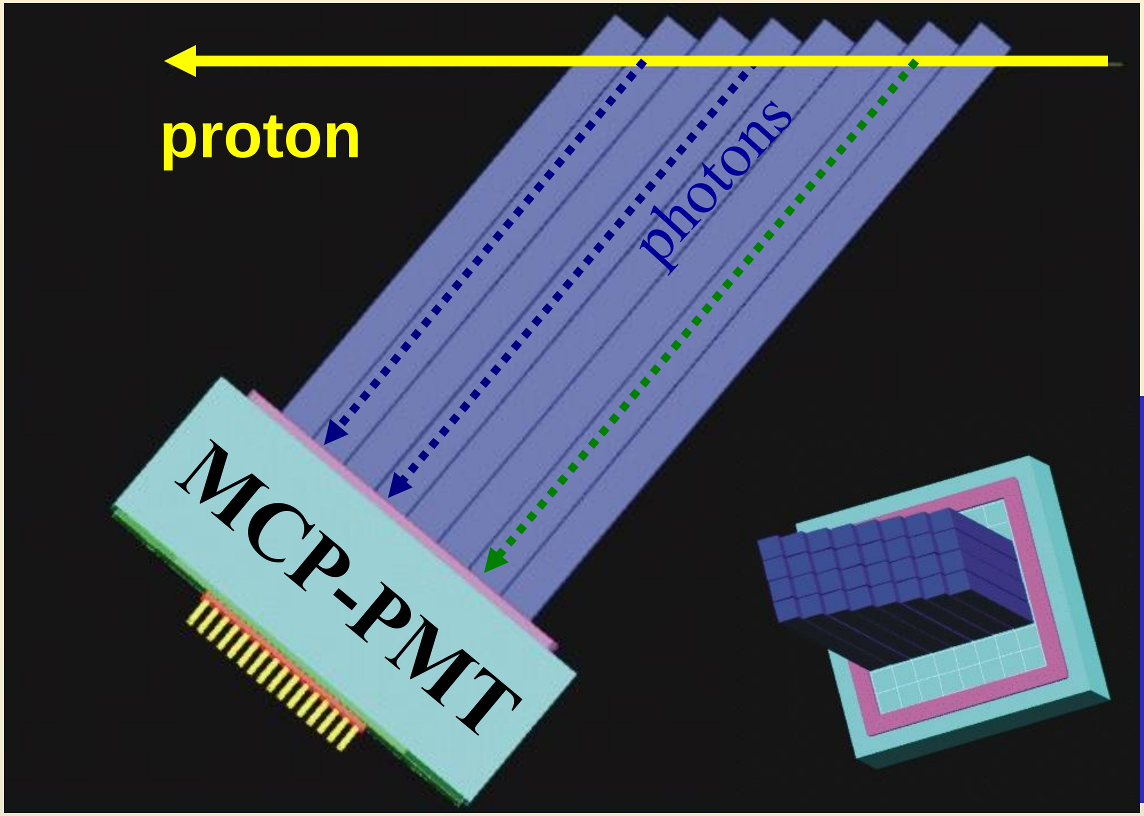
# MCP-PMTs Performance and Lifetime Studies

**Andrew Brandt, University of Texas, Arlington**

**Started looking into fast timing in 2006 as part of FP420 Collaboration, a joint ATLAS/CMS project to add proton detectors upstream and downstream of central LHC detectors to precisely measure scattered protons to complement discovery physics program (see talks by K. Piotrzkowski, me tomorrow).**

**Timing detectors useful for suppressing background from overlap events/confirming that any especially interesting events are consistent with single interaction (BUT need ~10 ps resolution to be useful at high luminosity!)**

# QUARTIC Detector




**UTA, Alberta**, Giessen, Stony Brook in ATLAS; FNAL+Louvain in CMS

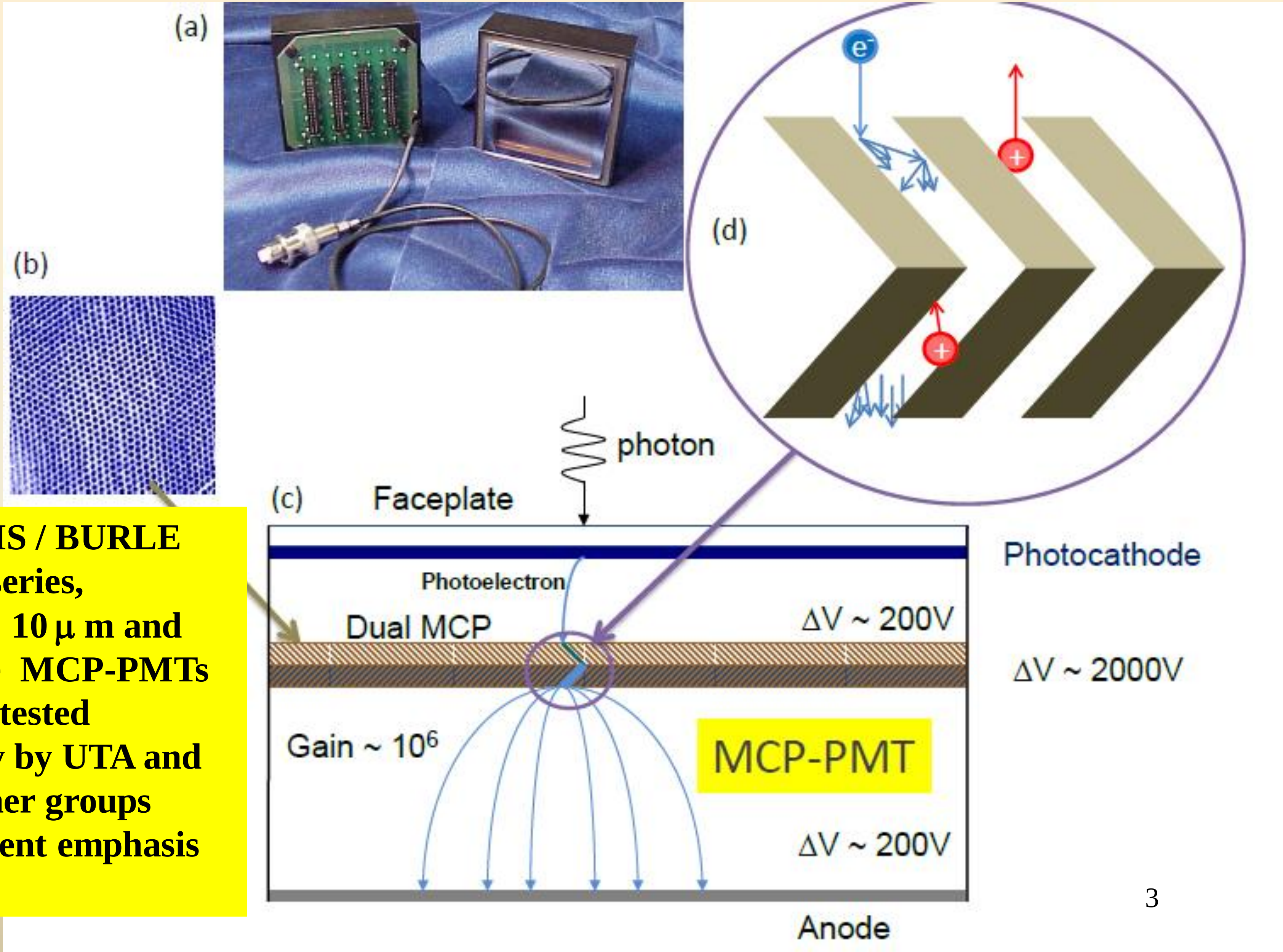
4x8 array of 5x5 mm² fused silica bars

**Only need a 40 ps measurement if you can do it 16 times: 2 detectors with 8 bars each, with about 10 PE's per bar**

**Multiple measurements with "modest" resolution simplifies requirements in all phases of system, plus we have an electronics readout solution for this option**

- **Details tomorrow, for this talk it establishes our focus: high rate multi-PE, multi-channel measurements**

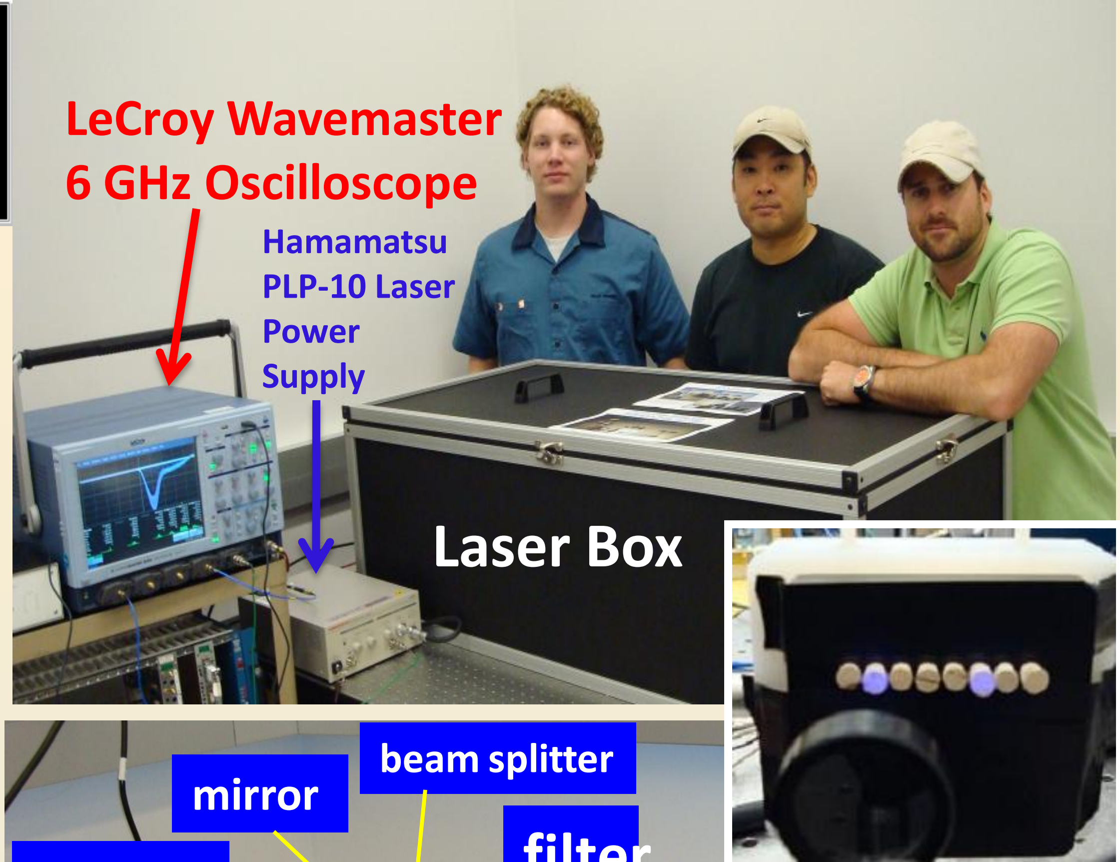
# Micro-Channel Plate Photomultiplier Tube

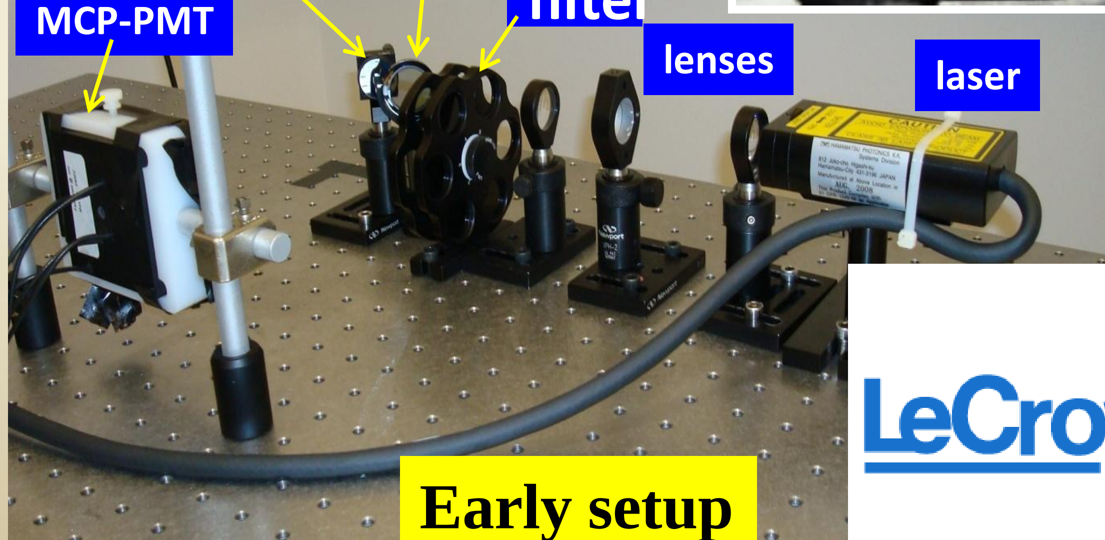



**PHOTONIS / BURLE Planacon series, 64 channel 10 µ m and 25µm pore MCP-PMTs have been tested extensively by UTA and several other groups with different emphasis on tests**

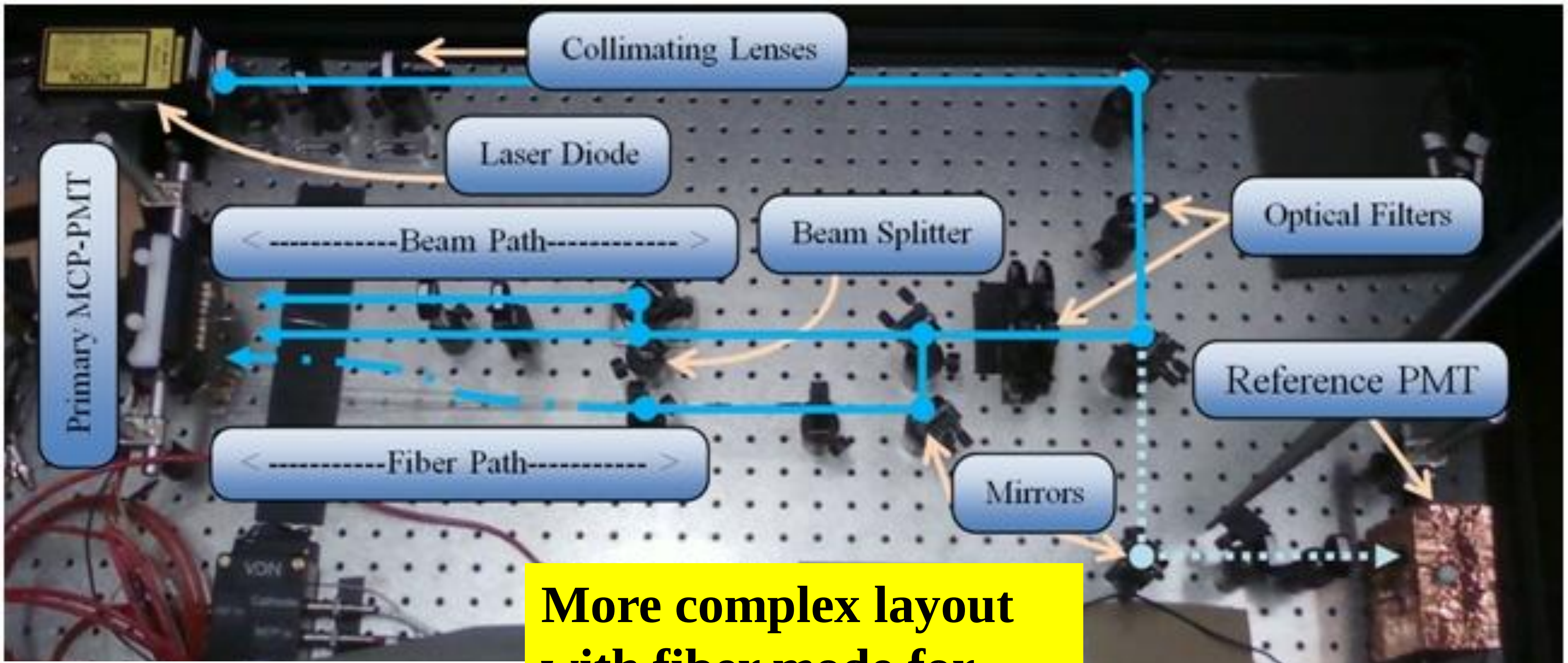
# PICOSECOND TEST FACILITY

**Established with Dept. of Energy Advanced Detector Research, Texas ARP funds. It relies heavily on the use of undergraduates, supported by various sources including local grants, NSF SBIR funds (and even volunteers).**

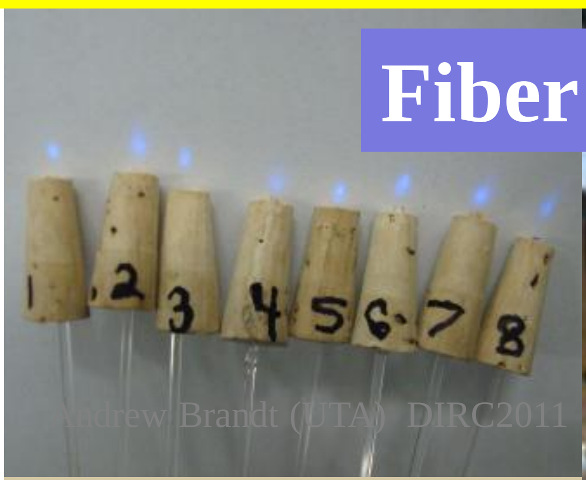



LeCroy




**More complex layout with fiber mode for multi-channel studies**

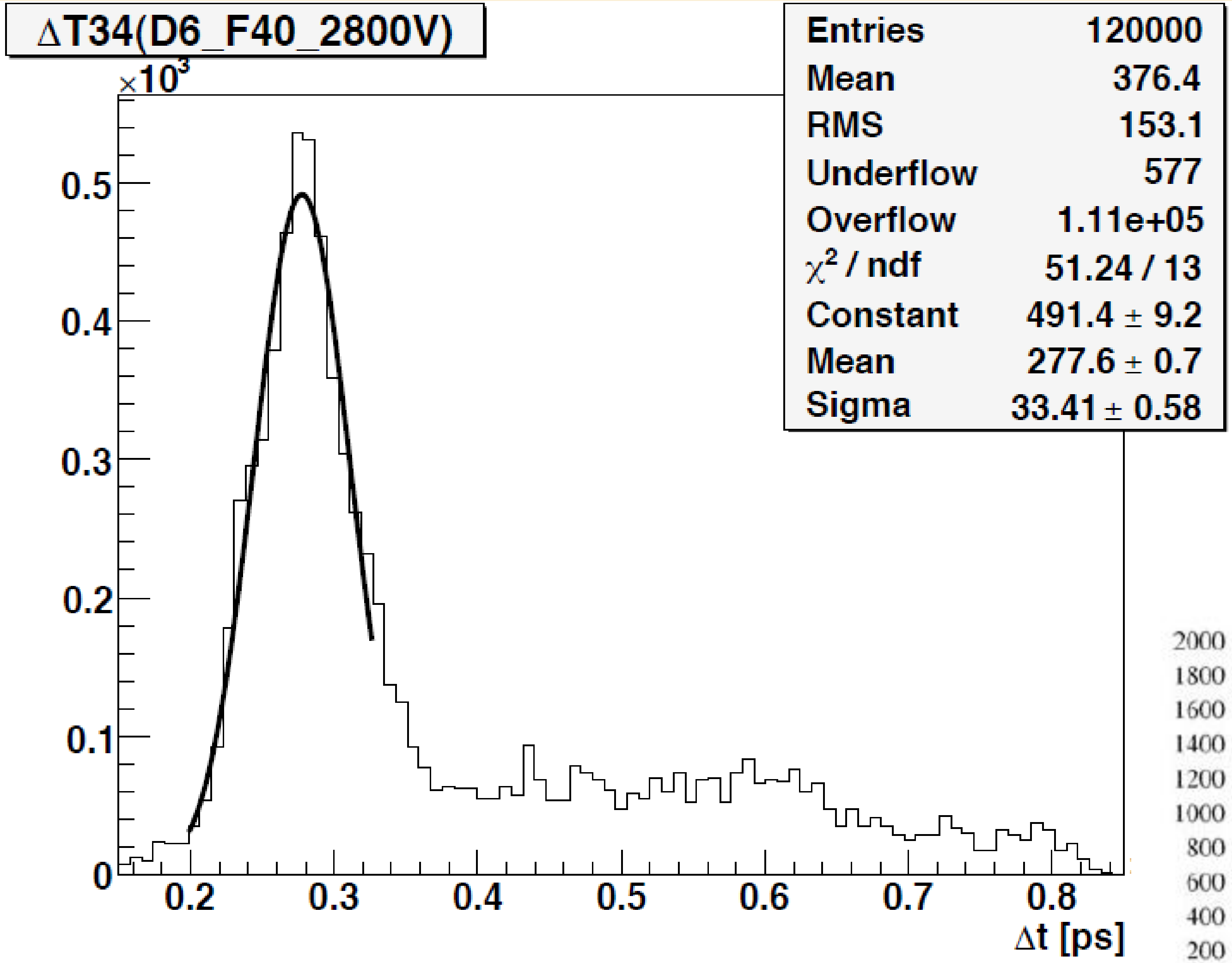




**Fiber Mode**

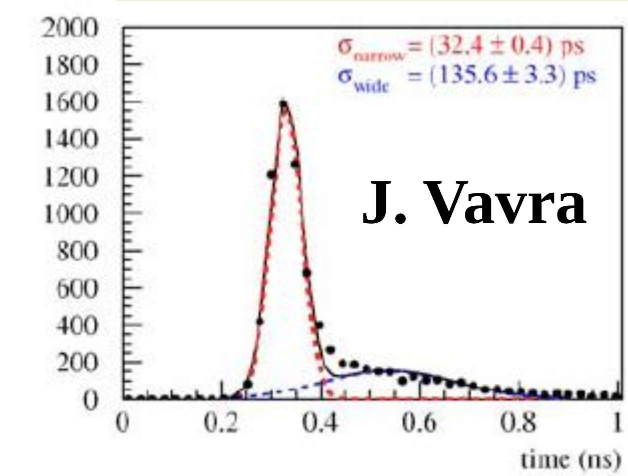
# Our Time Measurements

- Light source is PLP-10 405 nm laser typically at 1 kHz rep rate
- Generally use a pair of Minicircuits ZX60-4016E amps (4 GHz x 10) with SMA cables and attenuators as needed
- Main time measurement done with ALCFD (a constant fraction discriminator designed by Louvain, modified by Alberta) readout by LeCroy 8620a scope (6 GHz, 20 GS/s) . We measure time relative to laser trigger (used to use time difference of two channels or w/respect to high light reference tube, but more accurate to use laser trigger –of course can't do this in test beam)
- Residual time walk after CFD is only a few ps for signals in 200 mV-1V range, but can become large for small signals, so we tune amplification for mean of about 0.5 V to avoid time walk contamination of measurements
- Offline fit leading edge of CFD Nim pulse (rise time 130 ps). We do not generally correct for our system measurement uncertainty which is a complicated function of CFD, fitting, scope, and laser, but it does not contribute more than a couple ps to the resolution total of any measurement we make

# UTA Transit Time Spread for Burle 64 Channel Planacon (10 μm pores)




**Shows basic system functionality**




J. Vavra

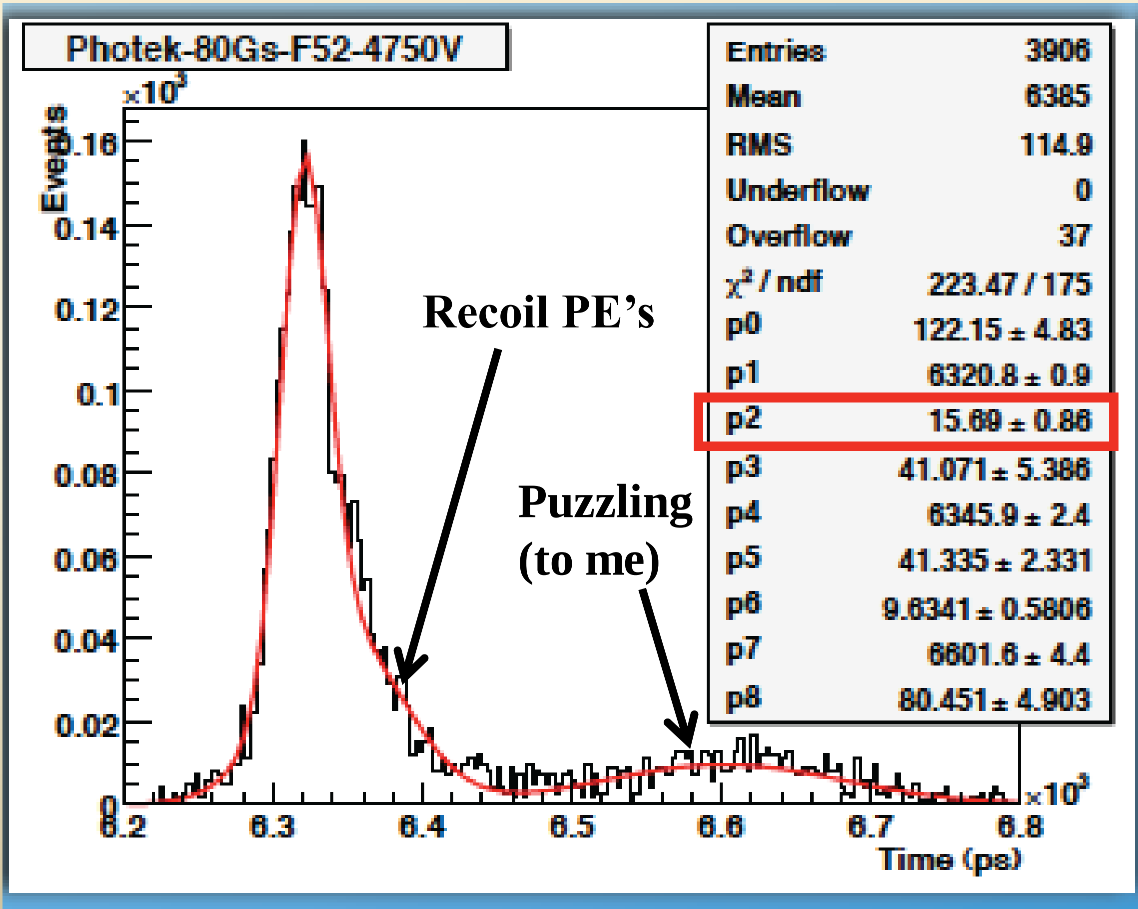
# FAQ's (Maybe not as frequently asked as they should be!)

- Is it true that low bandwidth amps are as good or better than high bandwidth ones?
- Is PLP-10 good enough (small enough jitter?)
- What kind of scope should I buy?
- Do I need high gain to do fast timing?
- How can you do a single PE measurement with the long recoil tail?
- Is 10 µ Planacon better than 25 µ one?

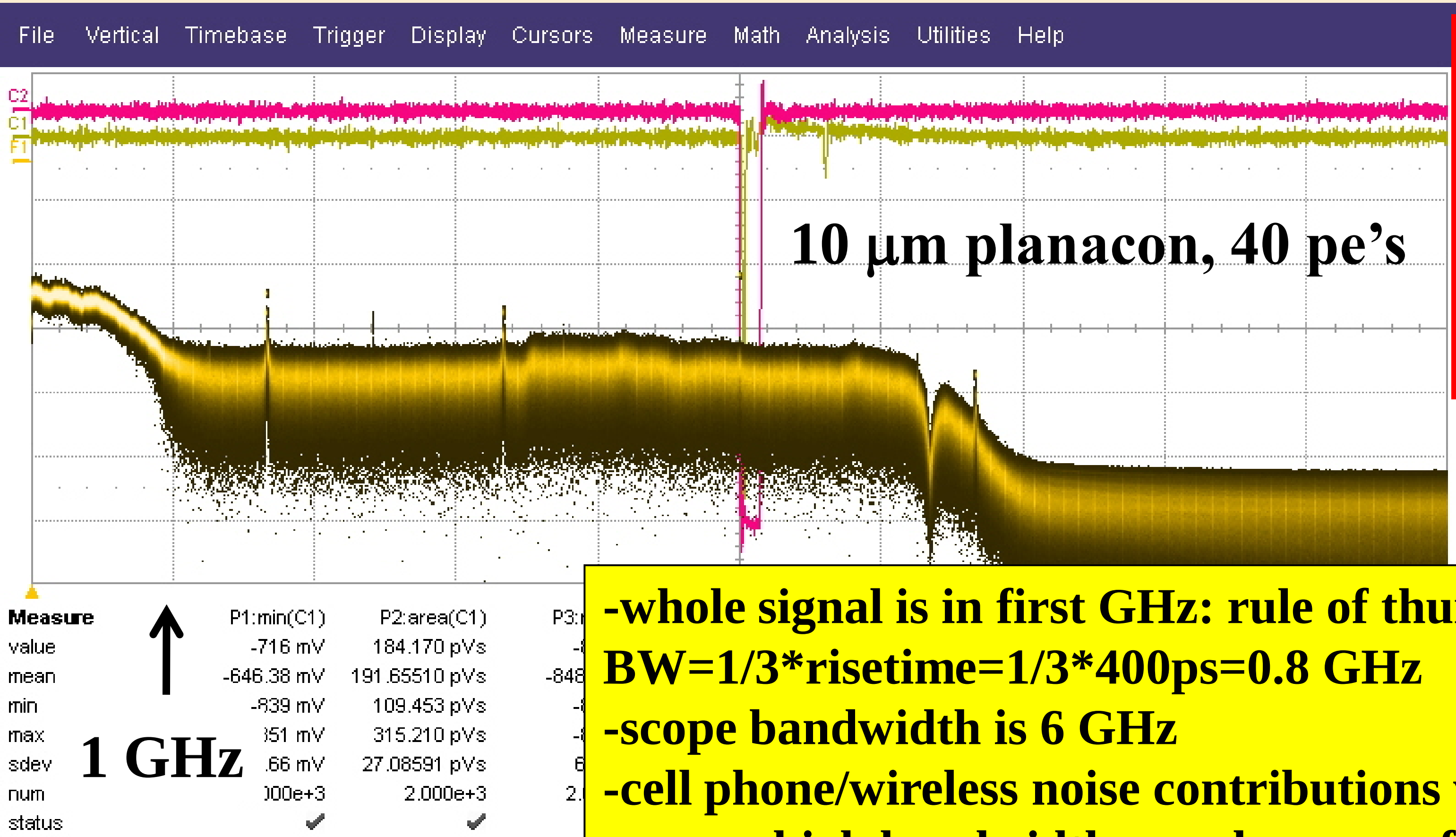
[My answers to follow]

# Answering Questions

- Borrowed Photek 210 with 3 µm pores and 80 ps rise time
- Borrowed Lecroy 16 GHz 8Zi scope 40 Gs, 80 Gs with doublers (Very sad to give it back)
- With 20 Gs (50 ps/pt) and no CFD measured 25 ps RMS (main peak)
- With 80 Gs (12.5 ps/pt measured16 ps with CFD, marginally worse without (the more GS the better!)
- **Laser good enough to make a 16ps single PE measurement!**



# Fourier Transform of Signal




Lecroy 8620A Wavemaster 6 GHz 20 Gs/s

-whole signal is in first GHz: rule of thumb BW=1/3*risetime=1/3*400ps=0.8 GHz

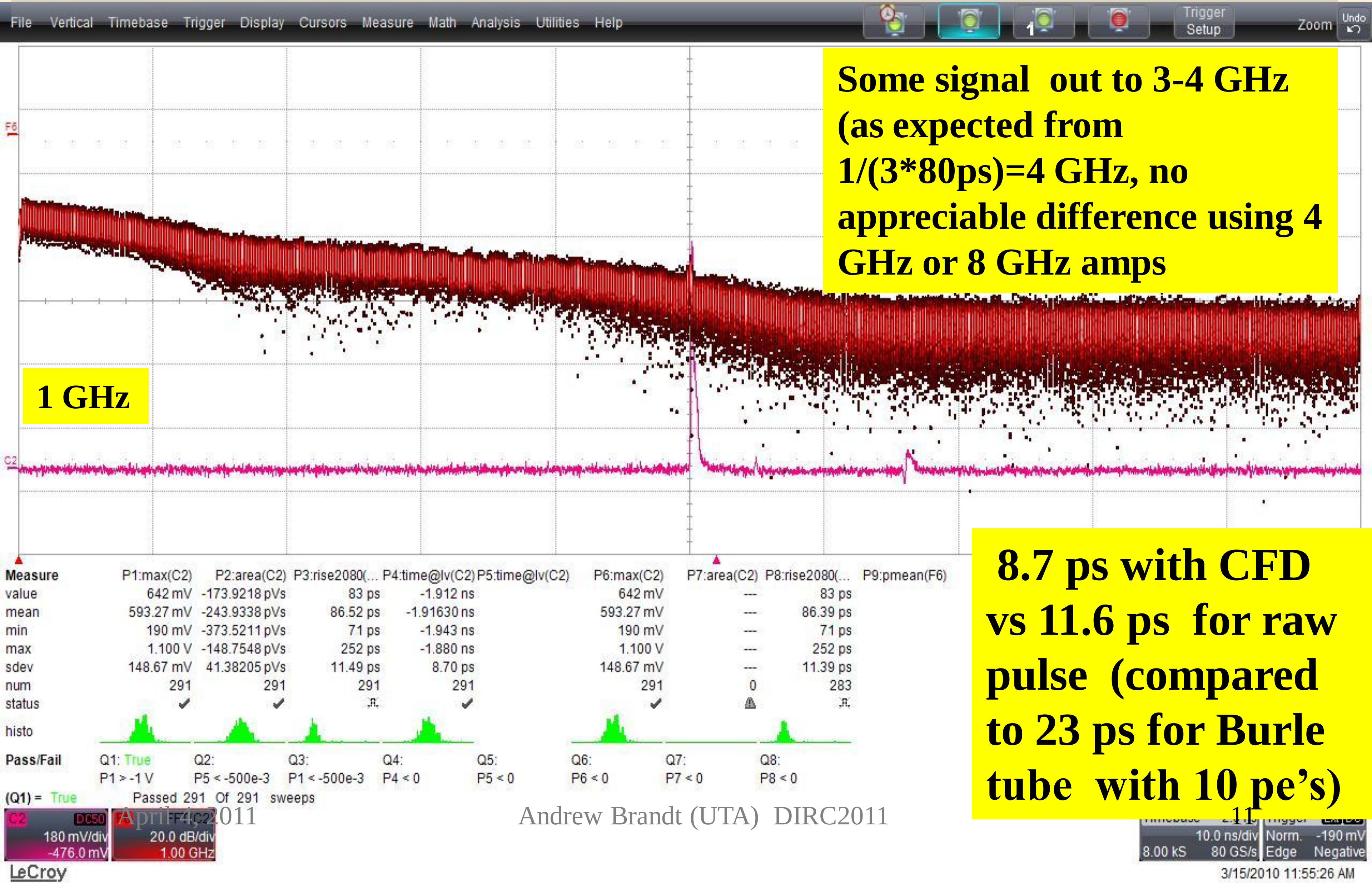
-scope bandwidth is 6 GHz

-cell phone/wireless noise contributions visible

-we use high bandwidth amp because of low noise and then add filter (or not). A 1 GHz low noise amplifier would likely be preferable, but we couldn't find one in our price range (1.5 GHz filter helps a little, 1 GHz starts to cut into signal degrade performance)

Gary Varner said do a Fourier transform, so we did!

# Photek 210 with 8 GHz amp (10 PE's)

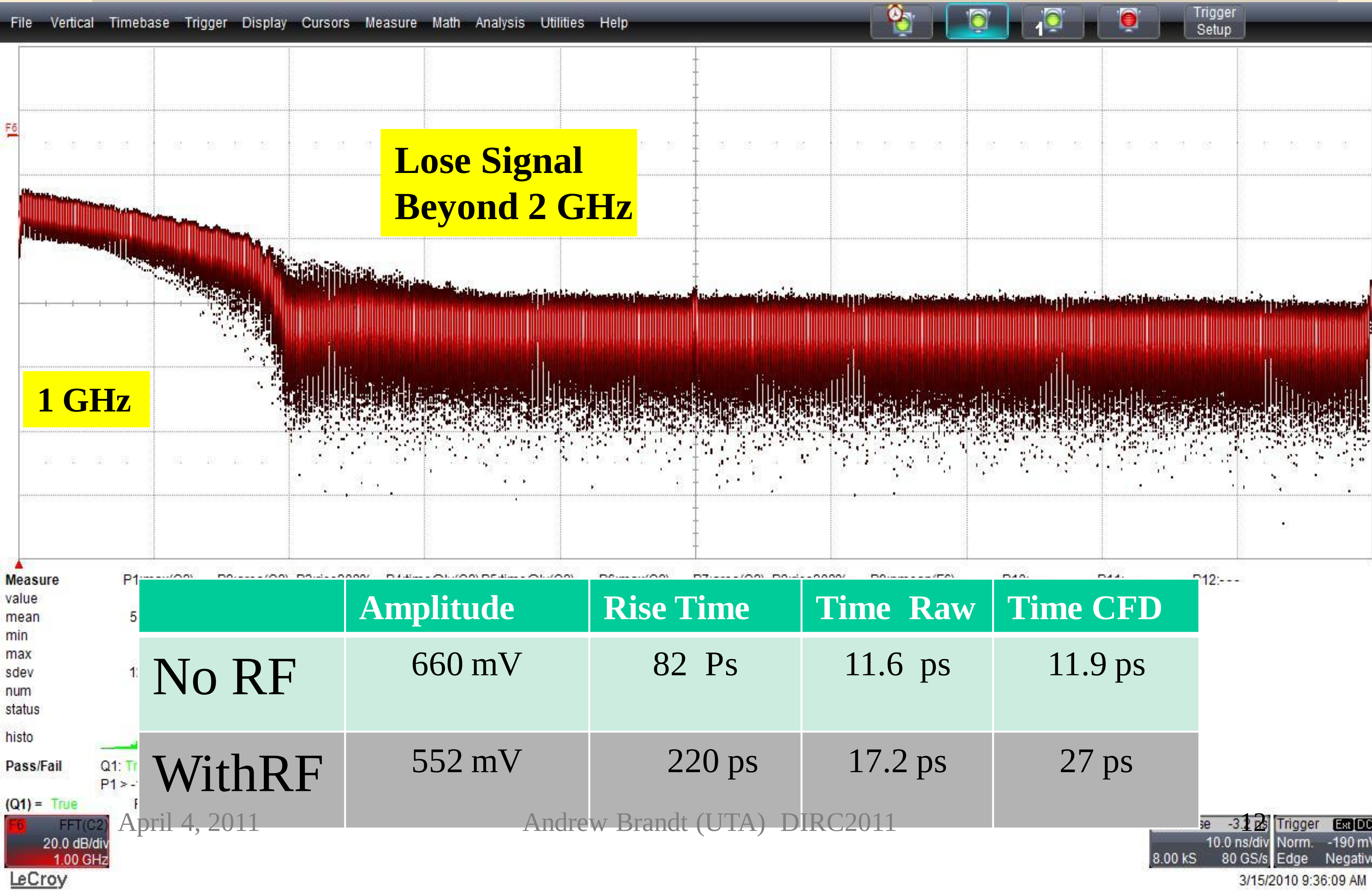



Some signal out to 3-4 GHz (as expected from 1/(3*80ps)=4 GHz, no appreciable difference using 4 GHz or 8 GHz amps

1 GHz

8.7 ps with CFD vs 11.6 ps for raw pulse (compared to 23 ps for Burle tube with 10 pe's)

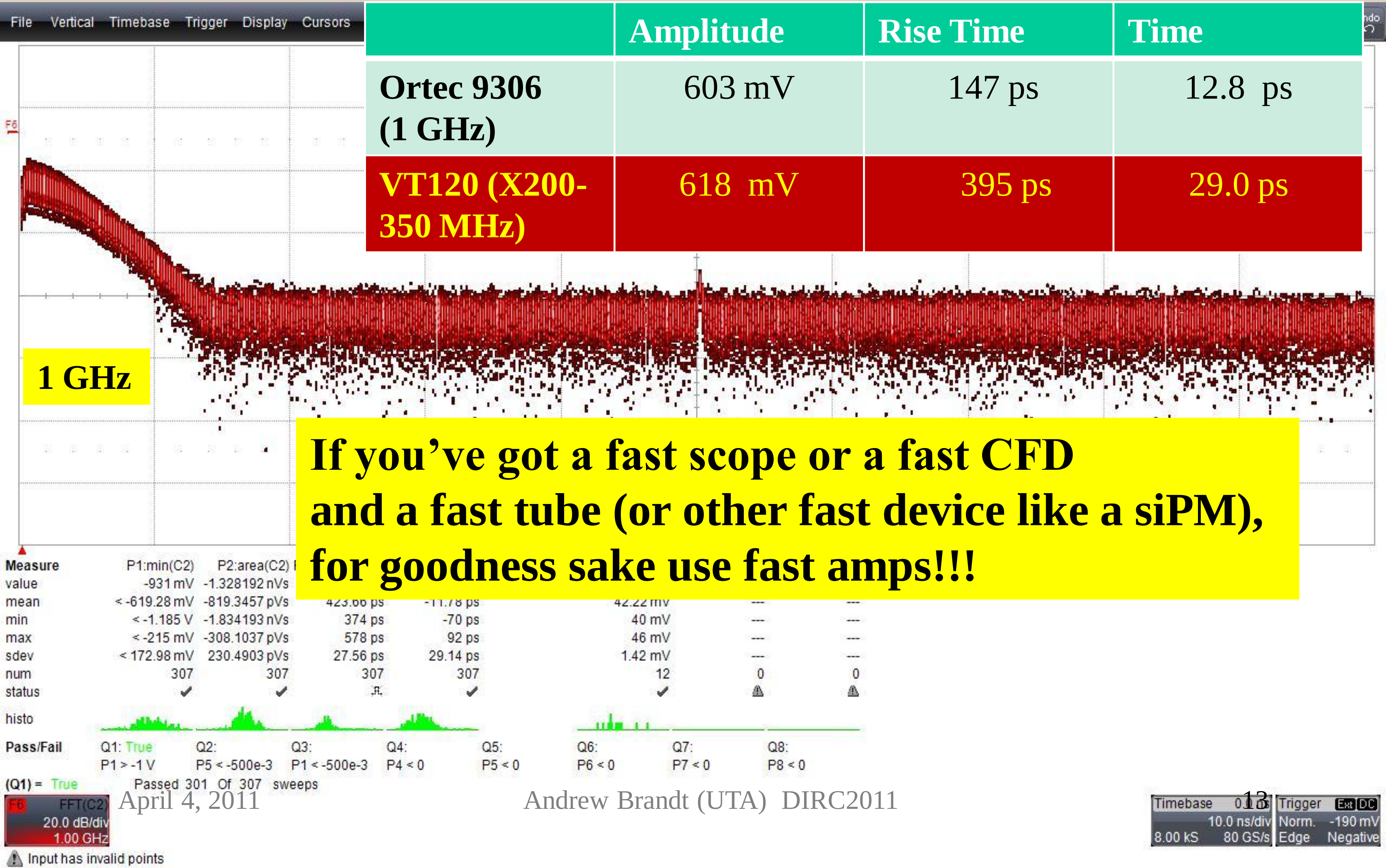
# Add 1.5 GHz RF Filter (10 PE's)




| | Amplitude | Rise Time | Time Raw | Time CFD |
|---|---|---|---|---|
| No RF | 660 mV | 82 Ps | 11.6 ps | 11.9 ps |
| WithRF | 552 mV | 220 ps | 17.2 ps | 27 ps |

# Ortec VT120 Amp Instead of ZX60 (10 PE's)

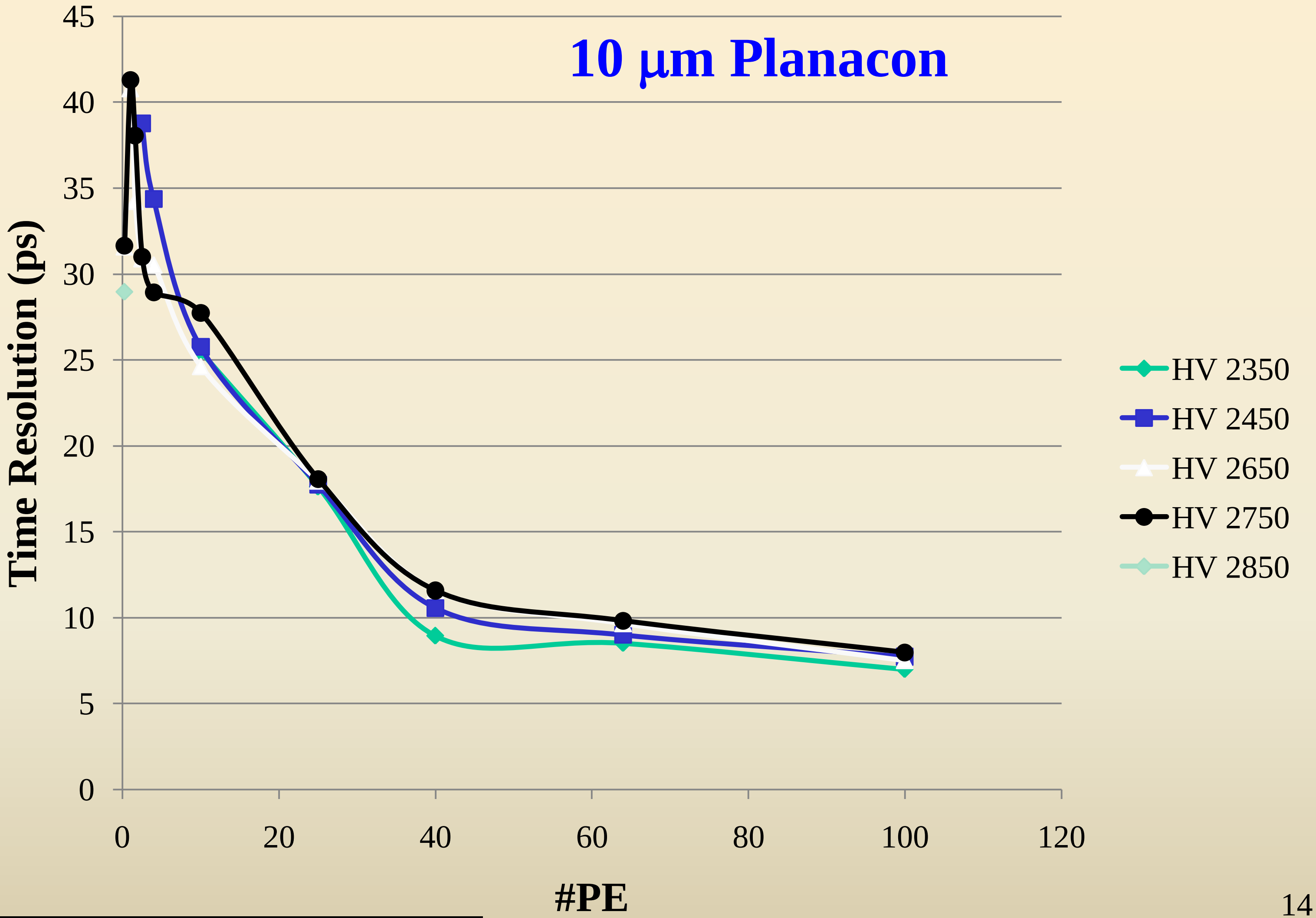
| | Amplitude | Rise Time | Time |
|---|---|---|---|
| **Ortec 9306 (1 GHz)** | 603 mV | 147 ps | 12.8 ps |
| **VT120 (X200-350 MHz)** | 618 mV | 395 ps | 29.0 ps |




**1 GHz**

**If you've got a fast scope or a fast CFD and a fast tube (or other fast device like a siPM), for goodness sake use fast amps!!!**

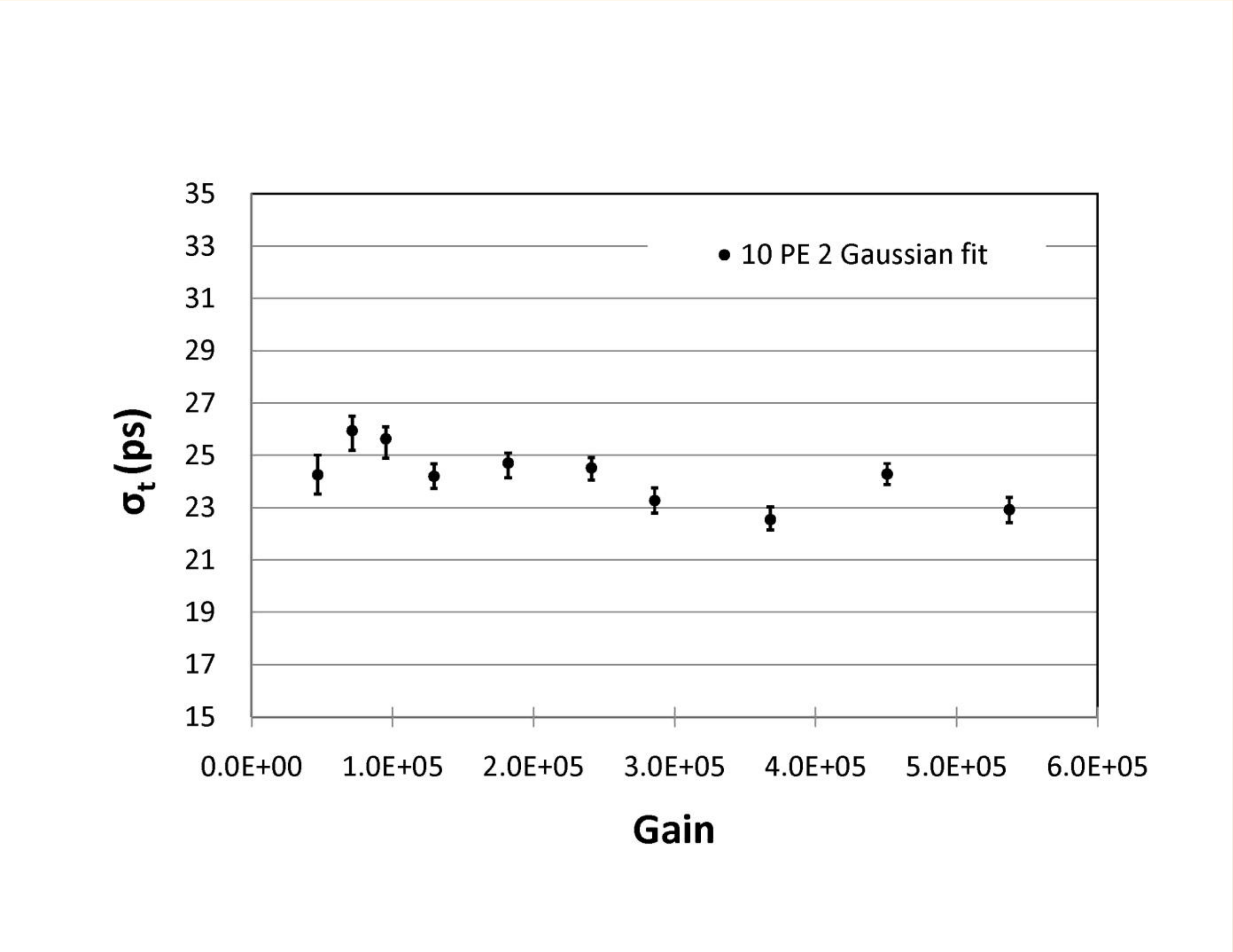
# Timing vs. Number of PE's






**If** $N_{pe} \times G \geq 5 \times 10^5$ **then timing independent of HV/gain**

# 10 pe Time Resolution from Laser Tests




**Laser tests of Photonis 10 µm tube show that with sufficient amplification there is no dependence of timing on gain (low gain operation extends lifetime of tube)**

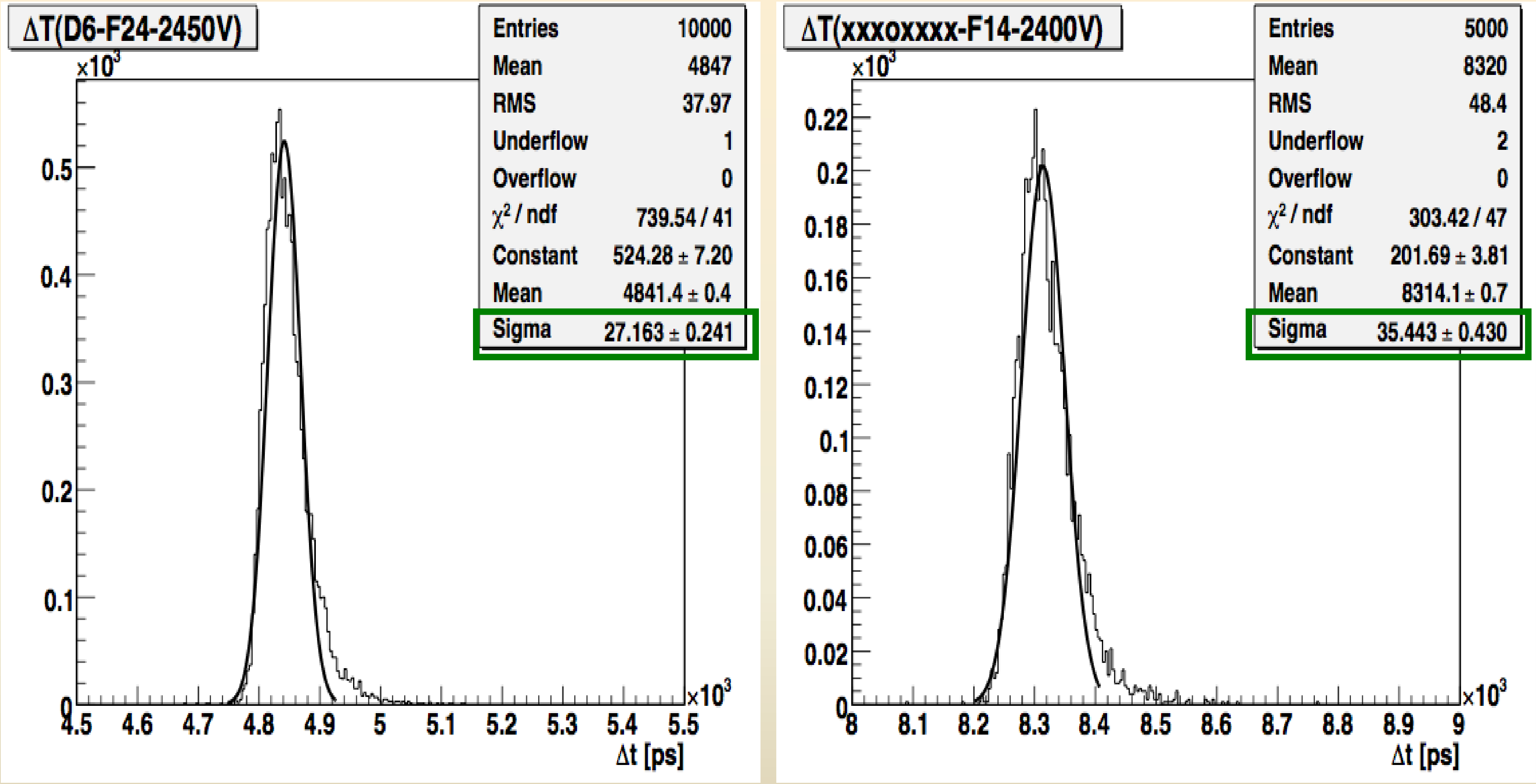
# FAQ’s Answered

- Is it true that low bandwidth amps are as good or better than high bandwidth ones? **NO (or at least not generally)**
- Is PLP-10 good enough? **YES**
- What kind of scope should I buy? **8 GHz 80 GS/s (6 GHz would do and I’m partial to LeCroy!)**
- Do I need high gain to do fast timing?

  **Not if you’ve got enough PE’s (more light always better!)**
- How can you do a single PE measurement with the long recoil tail? **I’ve got no idea and I’m glad we have >10!**
- Is 10 µ Planacon better than 25 µ one? **Seems obvious,**

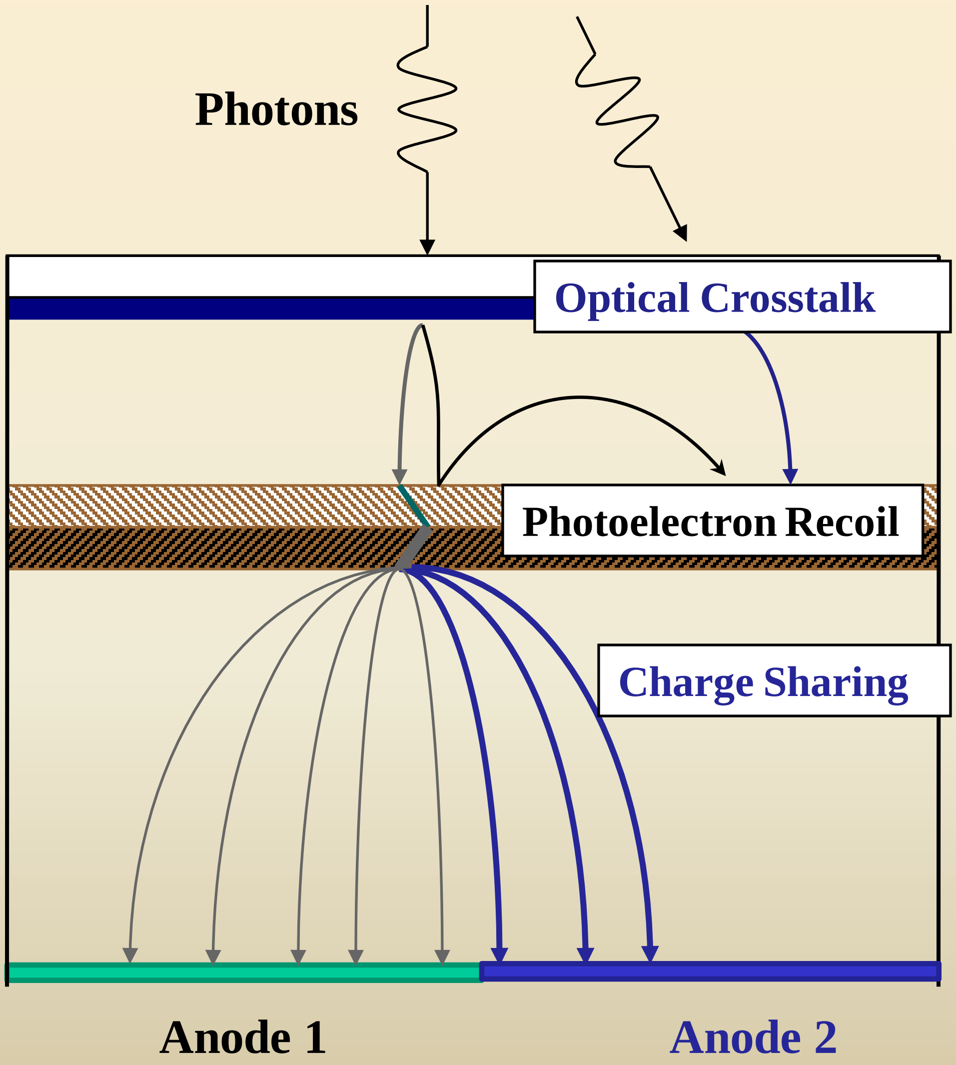
  **will answer tomorrow (or at least answer why people would ask)!**

# Beam vs Fiber



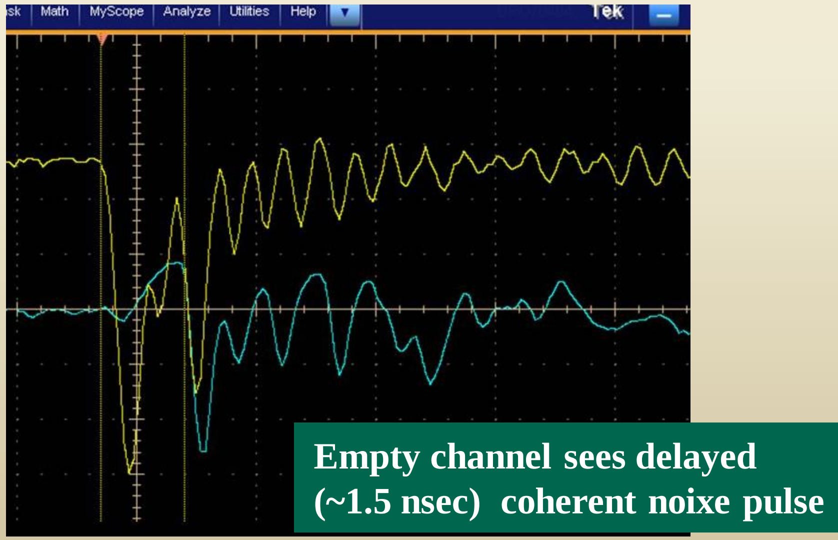

**Fiber timing not as good, but allows us flexibility for some characterization tests**

# Cross Talk



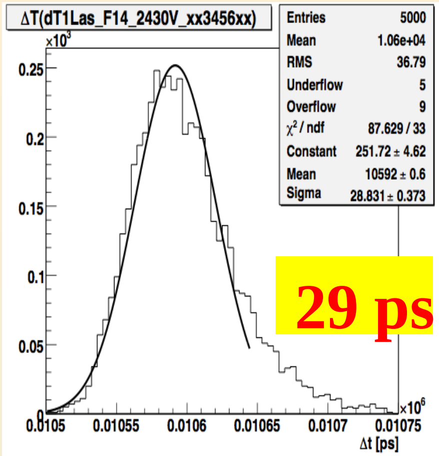

- Initial photons or PE's can end up in wrong channel (optical cross talk or recoil)
- Shower can be larger than the pixel (charge sharing)
- Ground oscillation (coherent noise)

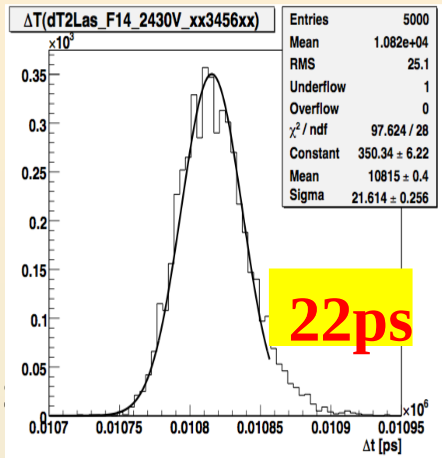
**Results is a false signal in the adjacent channel, which may distort measurements of time value**

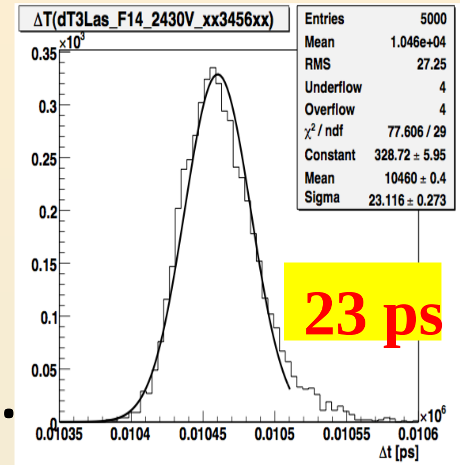


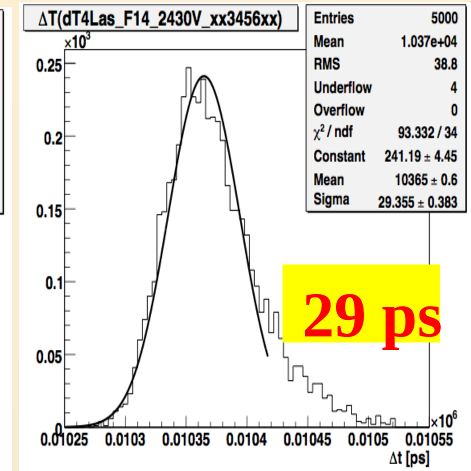

**Empty channel sees delayed (~1.5 nsec) coherent noixe pulse**

# The √N Effect-is it Comprimised by Crosstalk?



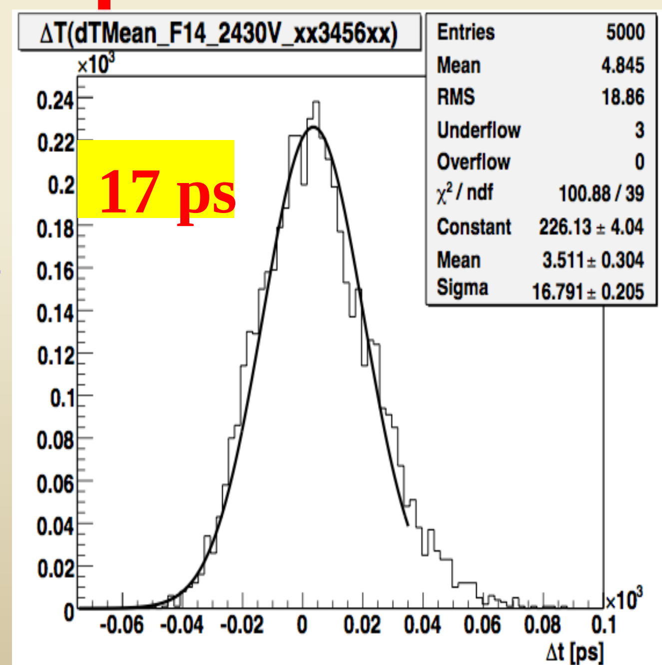




- Use fibers to put light simultaneous into 4 central channels in one row, measure time of each w/respect to laser.
- All values less than single fiber value of 35 ps; middle fibers which receive light from both fibers give 23 ps, while edge fibers give 29 ps

TB results on this tomorrow




- Correct for T0 offset, and average to get one time for each event
- Get 35/√4=17 ps!

# Cross-talk Results

- We explored the effect of cross talk on timing (other studies I've seen mostly concentrated on amplitude)
- Strobed a prototype 10 μm Planacon with variable length fibers to examine the effect of light arriving in multiple pixels at different times (this is a concern for multi-particle timing in same event)
- Examined effect of neighboring channels receiving signals 100, 250 and 500 ps before the target pulse
- About 10% of the pulse height is typically detected approximately in time with the in an adjacent pixel for this tube
- Early time pulses are not significantly affected by later light
- Later light mean time is shifted, but is not totally dominated by the early pulse, but the resolution can be degraded significantly as a f(Δt)
- Increasing the voltage across the anode helps somewhat

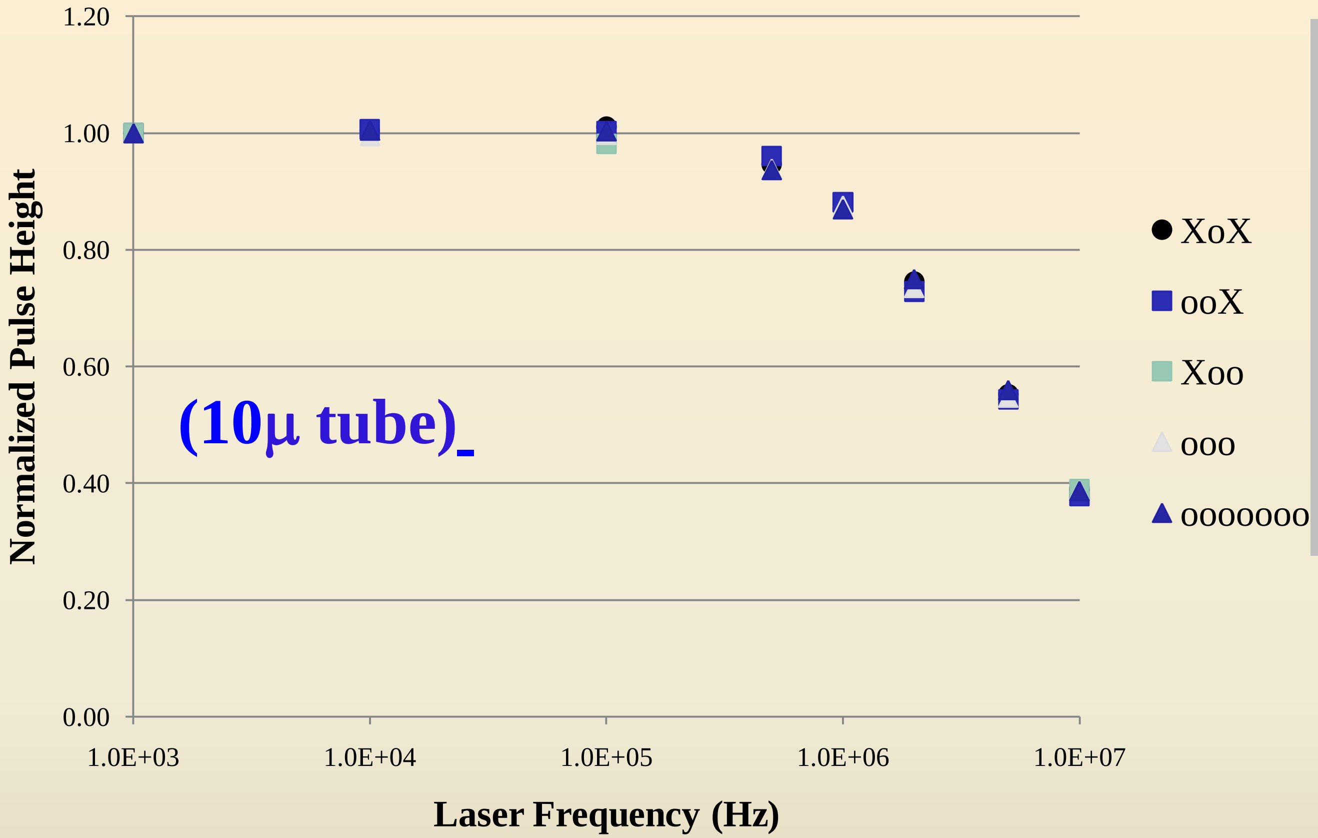
# Lifetime Issues

**Lifetime due to positive ions damaging the photocathode is believed to be proportional to extracted charge:**
**Q/year = I*$10^7$ sec/year**

**Q for <I>=2 μA/$cm^2$ is 20 C/$cm^2$/yr**

**Can reduce this requirement with fiber detector but still off by at least a factor of 20, so developed an R&D plan to pursue this**

# Saturation from Laser Tests




**Last point is 2.0 µA/cm$^2$ ~the high luminosity goal. (Note: even with saturation we still obtain the same time resolution if we amplify adequately!)**

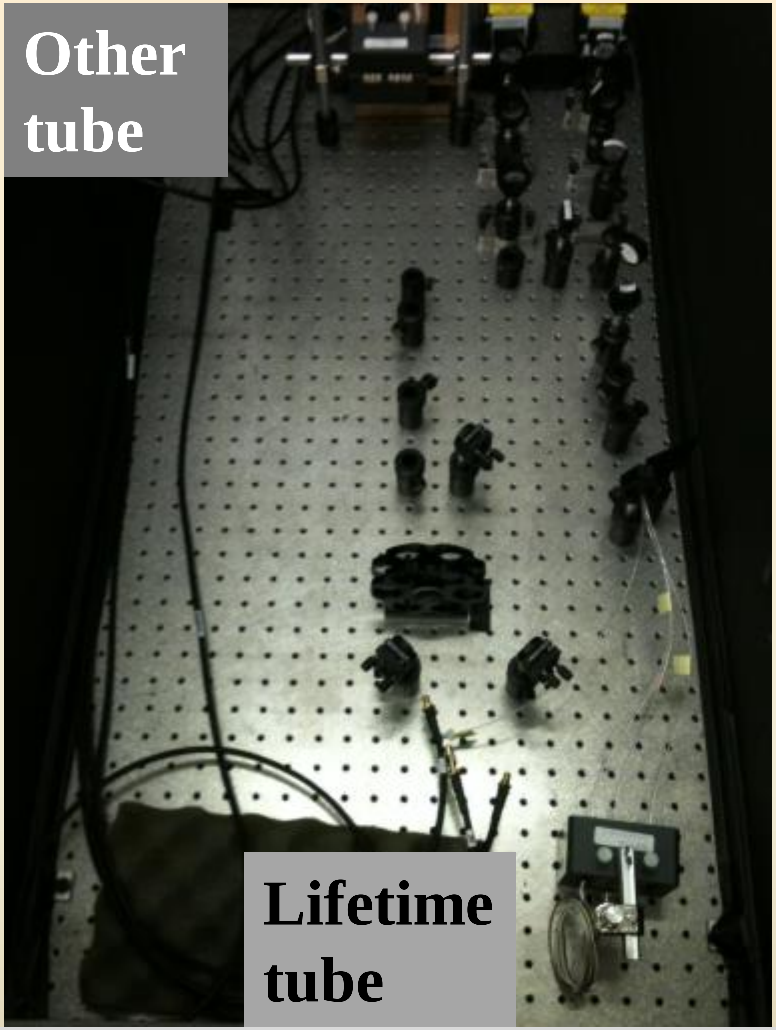
**Saturation refers to the reduction in amplitude of the output signal due to the pores becoming busy at the rate increases (typically 1 msec recovery time/pore). This plot shows that saturation is a local phenomena, and is unaffected by multiple channels being on at the same time.**

# Options for Improved Lifetime MCP-PMT

- **Inhibit positive ions from reaching photocathode:**
- **Ion barrier T. Jinno et al (Nagoya Collab) NIM A 629 (2010) 111.**
  **SL10 4x4 1 in$^2$ tube with up to 3 C/cm$^2$**!
- Z-stack A.Yu. Barnyakov, et al., NIM A 598 (2009) 160 [lifetime? effect on timing?]
- **Minimize creation of positive ions:**
- **Improved MCP & Processing (NSF funded project)**
- LAPPD use borosilicate w/ALD instead of lead glass [lifetime/ effect on timing?]
- **More Robust photocathode, such as Photek Solar blind** [ditto?]

**Various combinations of these factors are possible and should give multiplicative improvement factors**

# UTA Dual Laser Lifetime Setup





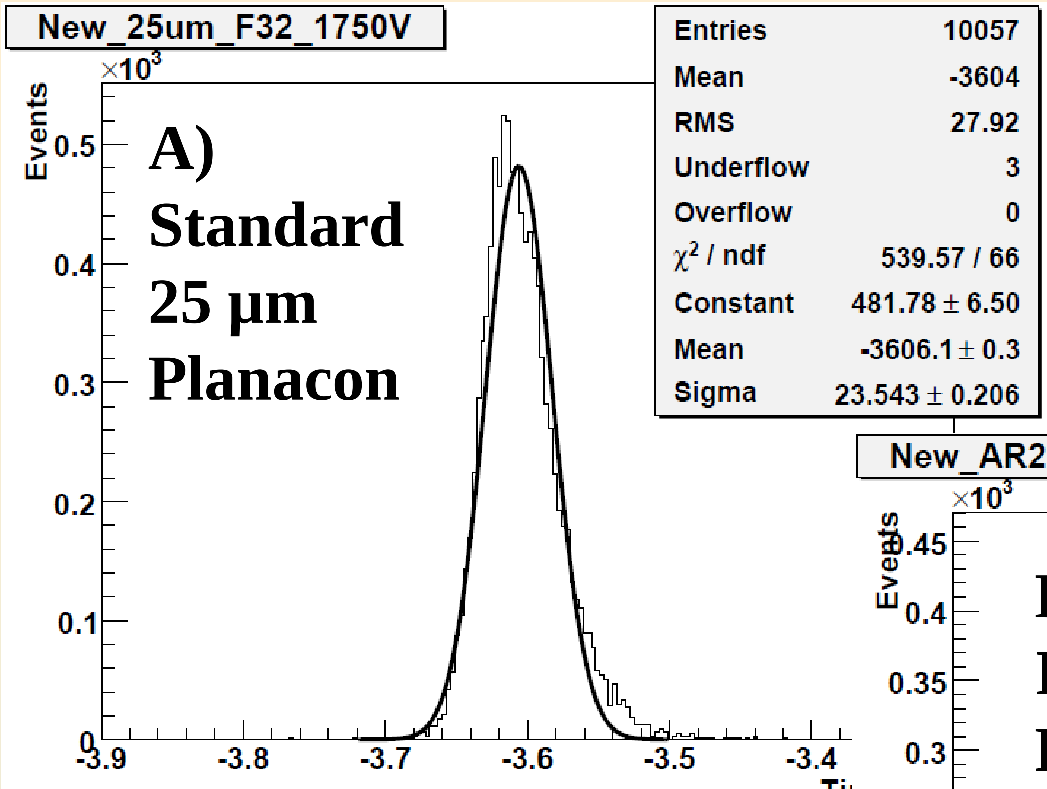
**Use red laser (632 nm) to damage selected pixels on tube and monitor response using automated scope scripts. When a change is observed, can toggle a mirror to strobe tube with blue laser. Plug in an extra fiber to check Edge channels. Should allow multiple lifetime tests with one tube**

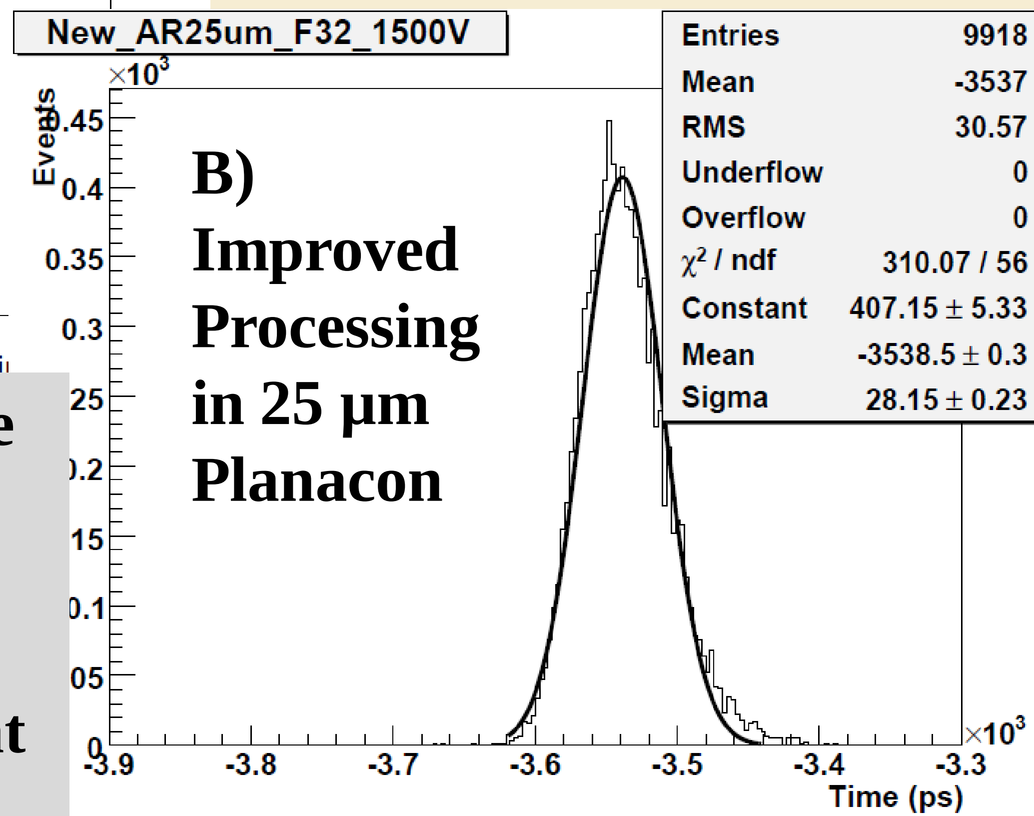
**Use characterization mode 15-20 hours/week, lifetime mode for remainder. Plan to run at ~200 nA/cm$^2$ for 1 month (or less) using both tubes (gives 0.5 C/cm$^2$) for second month one pixel at same rate and the 2$^{nd}$ at 4x (combining gain and rep rate increase, and compensating with an 0.6 filter)**

# First Look at Timing of Improved Planacon

~15 PE's

Very Preliminary




B) Timing within 10-15% (tube timing may be a little worse, appears to have more PE's, needs more study).

HV ~250V lower for equivalent gain.

# A. B.'s Ideal MCP-PMT

Suppressed positive ion creation (NSF SBIR)

Ion Barrier keeps positive ions from reaching photocathode (developed by Nagoya with Hamamatsu)

Use Photek Solar Blind photocathode or similar (responds only to lower wavelength/more robust)

Improve vacuum Seal (Nagoya/ Hamamatsu)

Increase anode voltage to reduce crosstalk (UTA)

Run at low gain to reduce integrated charge (UTA)