Fast Timing R&D

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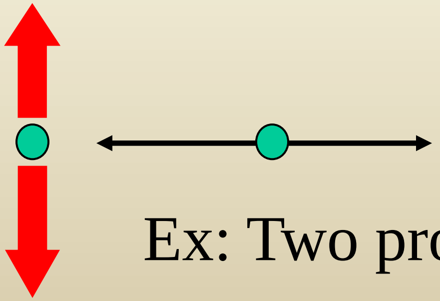
Use arrival time difference between protons to measure z-vertex compared with the central tracking primary vertex

Motivation: Pileup background rejection/signal confirmation for pp→ppΦ (Φ =jets, Higgs, Etc.)



Ex: Two protons from one interaction and two jets from another

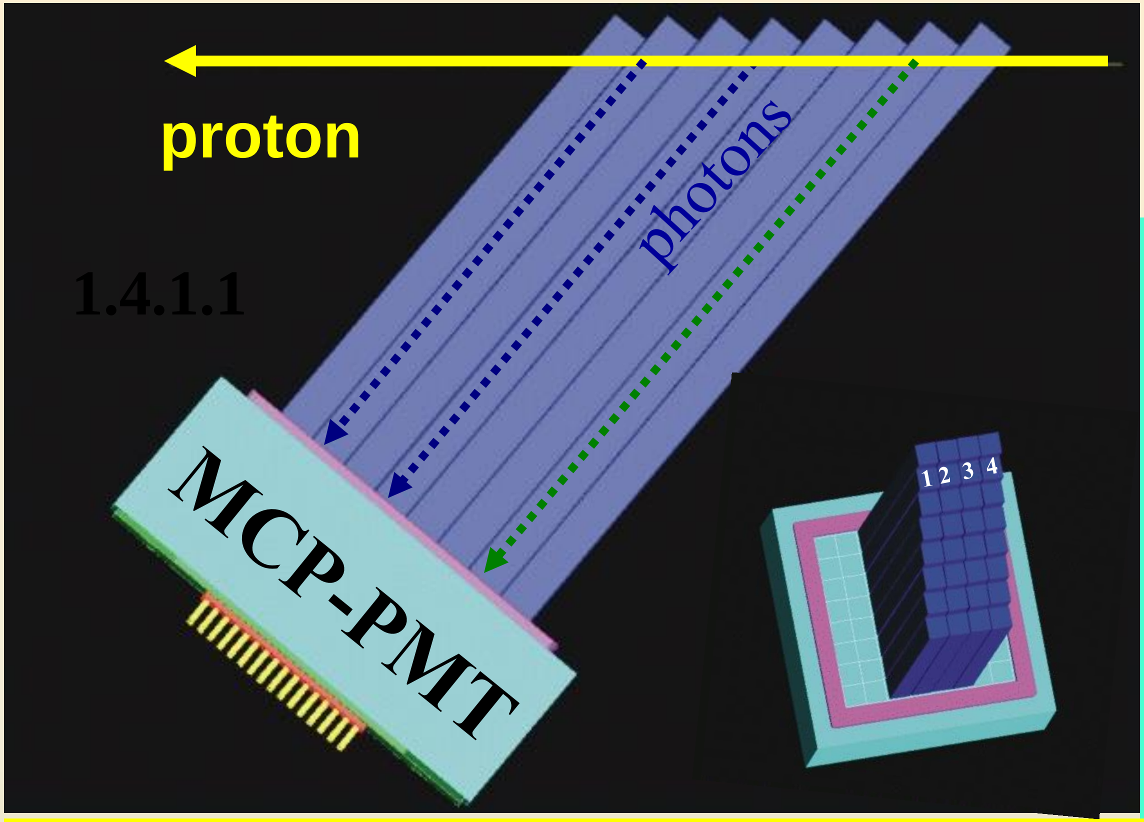
Requirements for an LHC Proton Timing System

- 10 ps or better resolution at high luminosity
- High efficiency and full acceptance
- High rate capability (proton rates up to 5 MHz/pixel)
- Segmentation for multi-proton timing
- Robust operation in high radiation environment

10 picosecond resolution is design goal (light travels 3mm in 10 psec!) gives ~x20 fake background rejection; originally considering 25 interactions per crossing, now designing for 50 interactions

QUARTID (QUARtz TIming Detector)

QUARTIC concept: Mike Albrow for FP420 (R&D effort for diffractive Higgs at LHC) 2004 based on Nagoya Detector.



Initial design: **4x8** array of 6x6 mm^2 quartz bars , 8-12 cm long

Isochronous—by mounting detector at Cherenkov angle, all light reaches tube at ~same time

Proton is deflected into one of the rows and measured by eight different bars/detector with a micro-channel plate PMT.

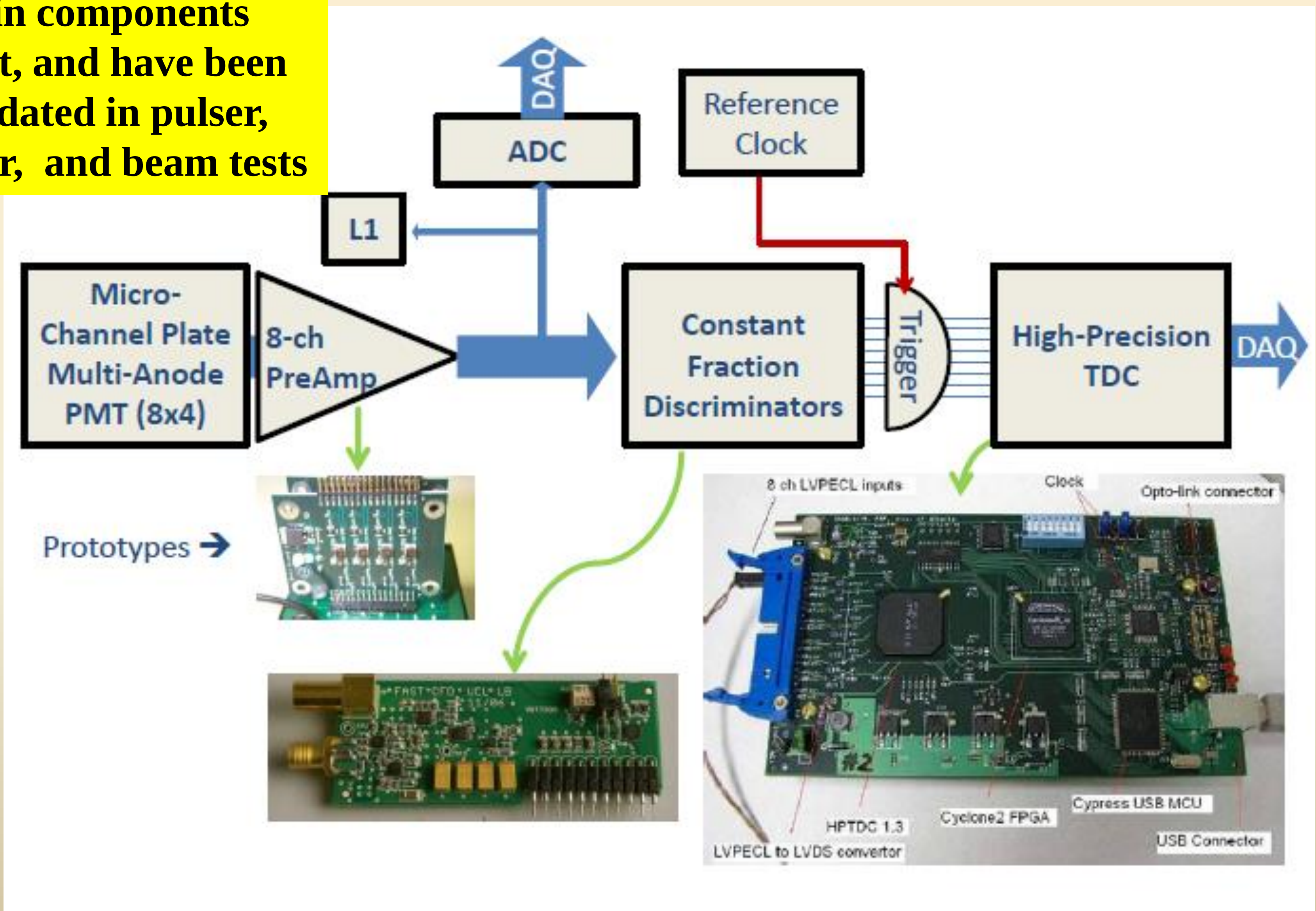
If δt= 40 ps/bar need 16 measurements /row for 10 ps

If δt= 28 ps/bar need 8 measurements/row for 10 ps

Increase #rows to minimize multi-proton and rate effects (pixelation)

Components of AFP Fast Timing

Main components exist, and have been validated in pulser, laser, and beam tests



Lifetime Issues

•Historically MCP-PMT's have **not** been extremely robust, and are typically capable of operating only for a few hundred mC/cm^2 before their performance (QE) degrades, presumably due to positive ions damaging the photocathode.

•If operated at high gain without sensible pixelation, this amount of charge would be accumulated too quickly for the device to be useful

• For low gain (5E4) and modest pixelation (4 equal rate bins), the lifetime presents a challenge: **μ=23** implies R=4 MHz/pixel and I=0.8 $\mu A/cm^2$ resulting in an annual charge of **8 C/cm^2/yr** (with LHC year $=1x10^7$s). This corresponds to $\int Ldt=[23 \cdot (40 \times 0.8)\ MHz] \cdot t/100\ mb=80$ fb^{-1}. In other words, **for every 10 fb^{-1} or so 1 C/cm^2** is accumulated.

•Formed a collaboration between UTA, Arradiance, and Photonis to address these issues, partially funded by NSF SBIR

Brandt's Ideal MCP-PMT

Improved lifetime by x10-20 (3 main options)

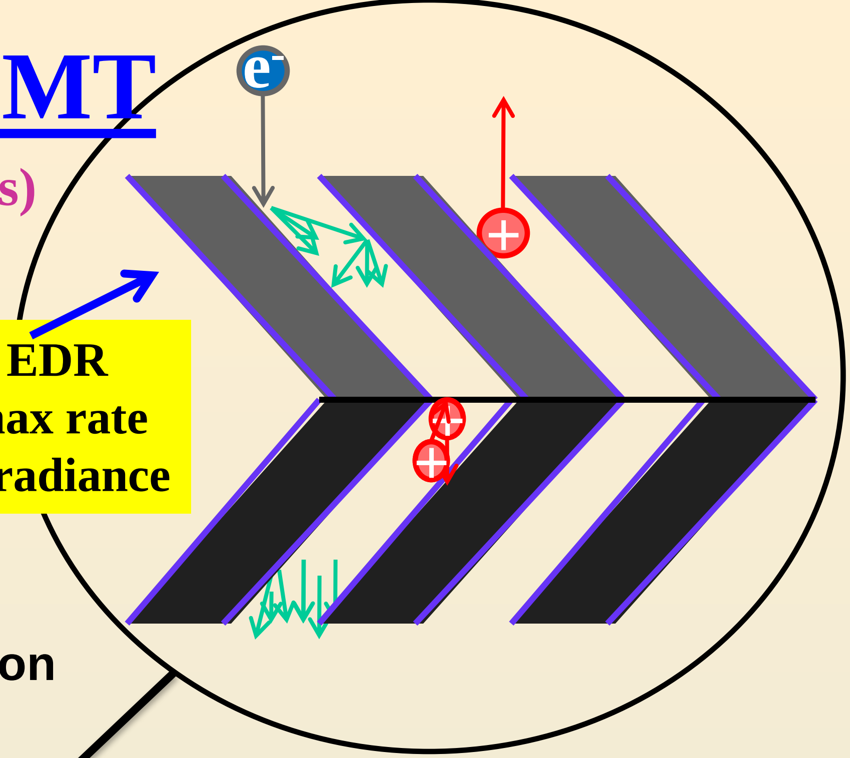
1) Suppressed positive ion creation (Arradiance)

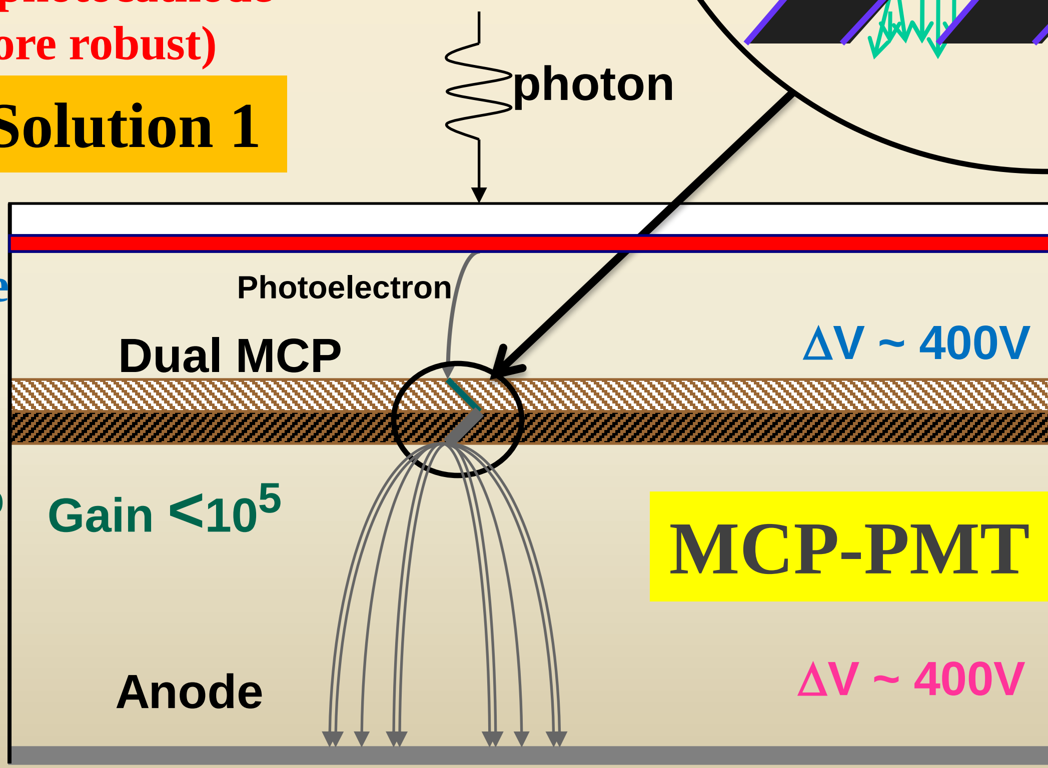
2) Ion Barrier keeps positive ions from reaching photocathode (Nagoya/Hamamatsu)

3) Use Solar Blind photocathode (UV response to more robust)

Funding for Solution 1

10 µm pore EDR MCP for max rate ALD by Arradiance





Increase cathode voltage to improve collection efficiency (UTA)

Photocathode

ΔV <3000V

Run at low gain to reduce integrated charge (UTA)

Increase anode voltage to reduce crosstalk (UTA)

Reduce anode gap to reduce cross talk

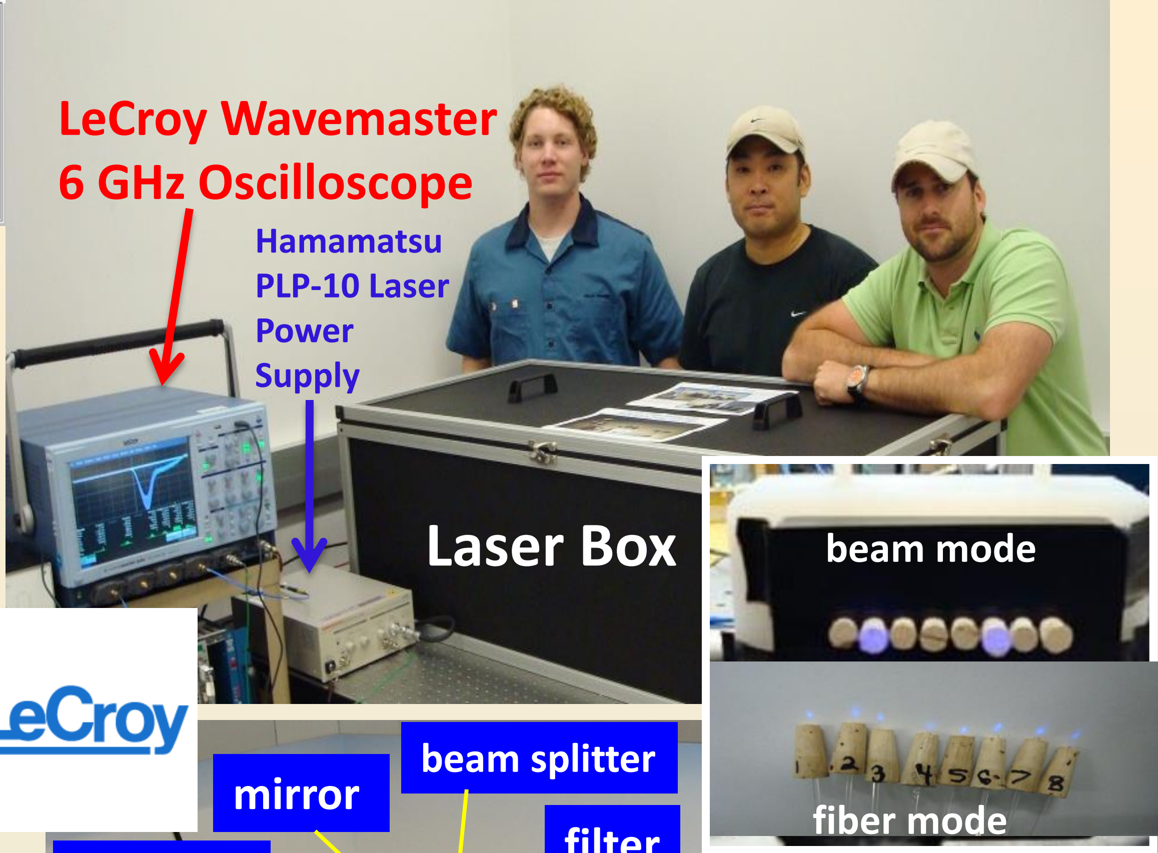
PICOSECOND TEST FACILITY

•Established in 2009 at UTA with DOE Advanced Detector Research,+Texas ARP funds, primarily to evaluate MCP-PMT's for use in fast timing.

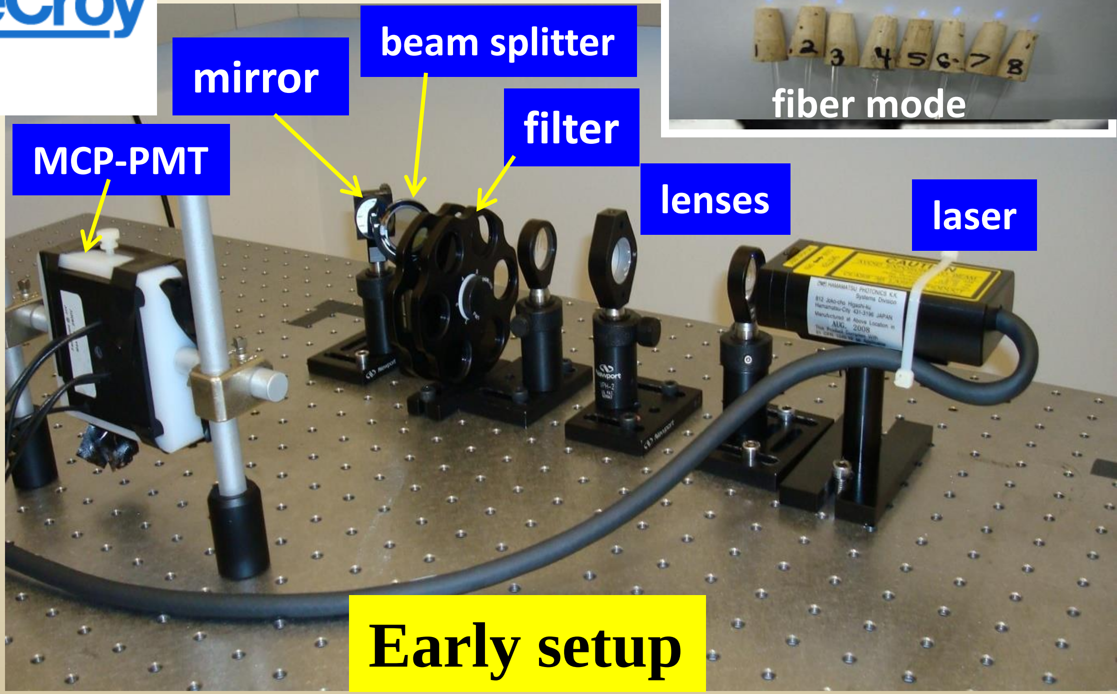
•Relies heavily on the use of undergraduates

•The PTL serves as a permanent test bed to study a myriad of subtle effects associated with picosecond timing

1)Evaluate MCP-PMT and electronics with laser tests
2) Evaluate detector/full chain with test beam



LeCroy



MCP-PMT Rate and Current

- Anode Current = proton Rate × Number of photo-electrons generated by each proton × Gain × charge

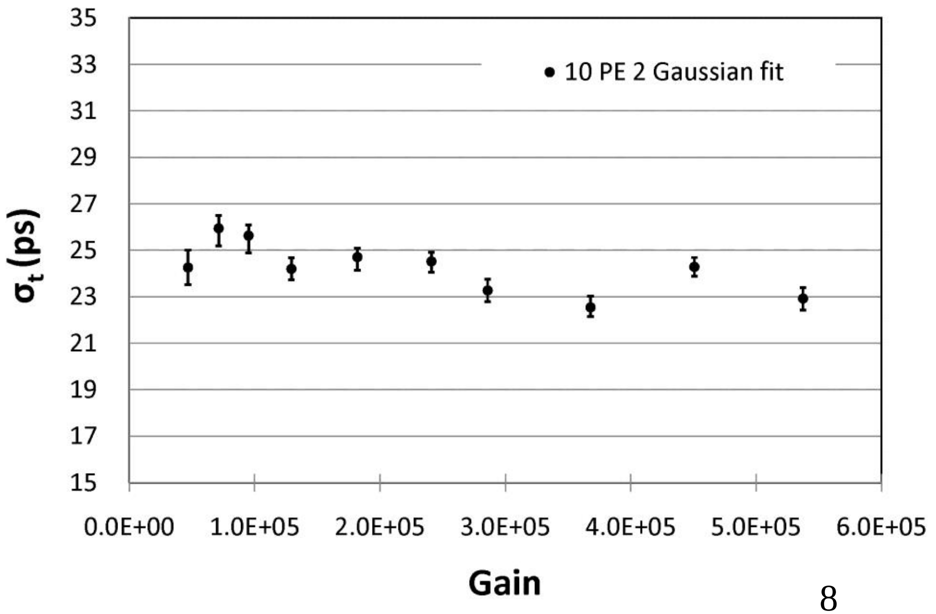
$$I = R \times N_{pe} \times G \times e$$

- 4 MHz proton rate with 10 pe's at 10^6 gain gives 6.4 µA in a 0.4 cm^2 pixel or about 16 µA/ cm^2, several times what is possible!

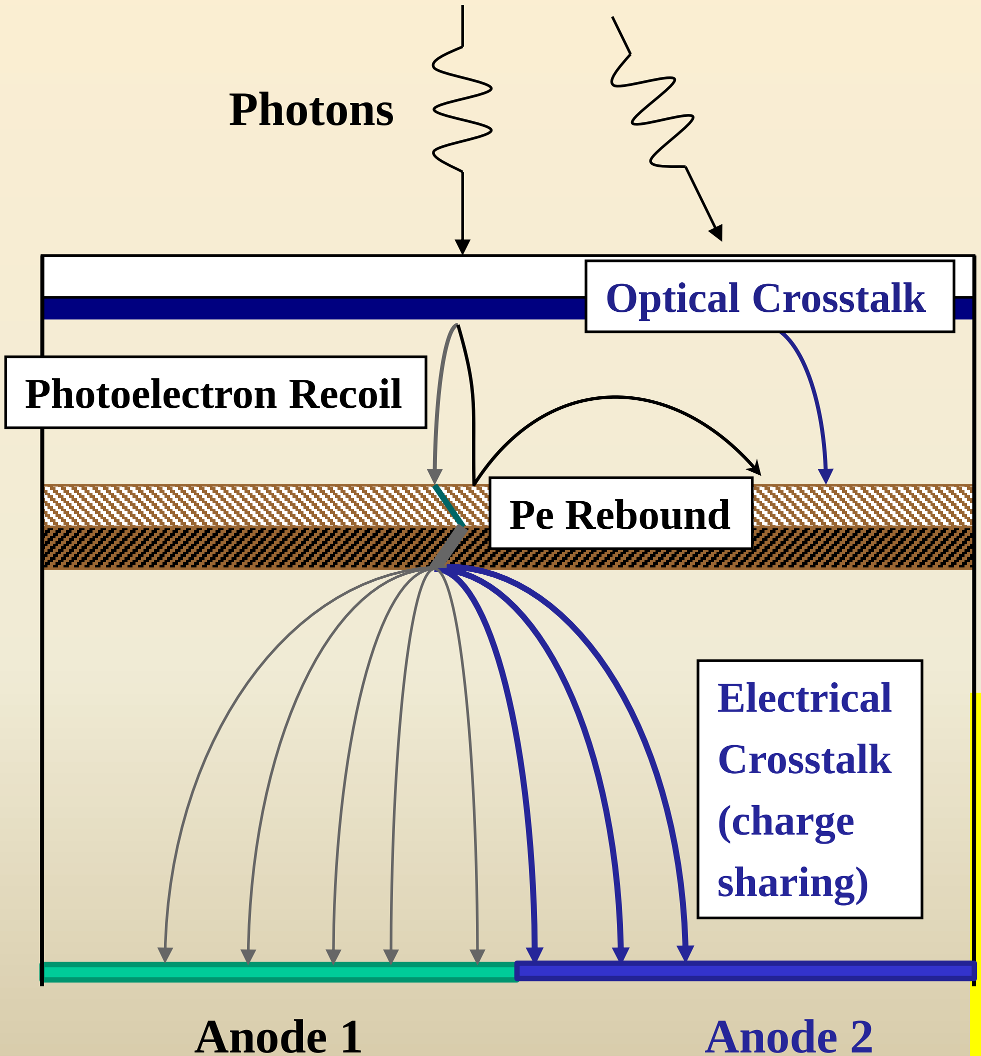
Conventional wisdom: need high gain for fast timing (but CW is based on single pe experience). From UTA laser tests timing is ~ independent of gain as long as

$$N_{pe} \times G \geq 5 \times 10^5$$

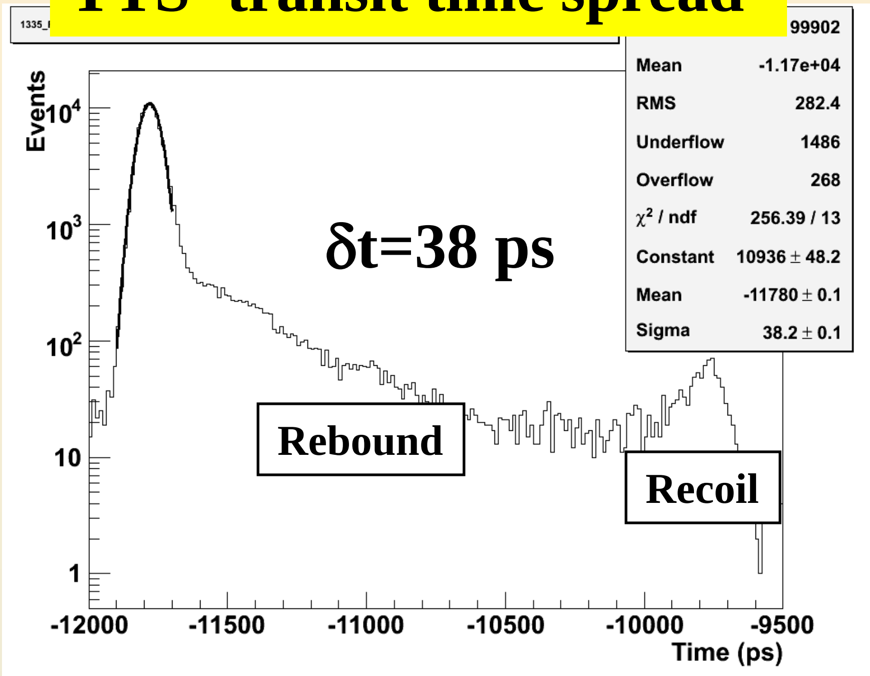
Reduces current requirement by x10 to 20



MCP-PMT Cross Talk and TTS



TTS=transit time spread



- Cross talk could correlate adjacent channels within a row and reduce expected √N improvement
- Cross talk can give a false signal in channel in adjacent row which distorts/biases time measurement if there is a second proton in that row

Cross Talk and other MCP-Issues

Pedro Duarte, Masters Thesis on early test beam studies 2007
Ryan Hall UTA, Honors Thesis on cross talk 2010
Paul Pryor UG Thesis on Lifetime 2011
James Bourbeau, Honors Thesis on test beam 2013
-Currently have team of 6 undergraduates (10-20/hr/week/person)

Have studied and will continue to study many features of MCP's @PTF

- **Cross talk:** Using a series of fibers with different path lengths to simulate proton arrival time, found that ~10% of pulse is collected in adjacent pixel due to charge sharing

  -improves resolution for pixels in same row and correlates pixels since light is in time

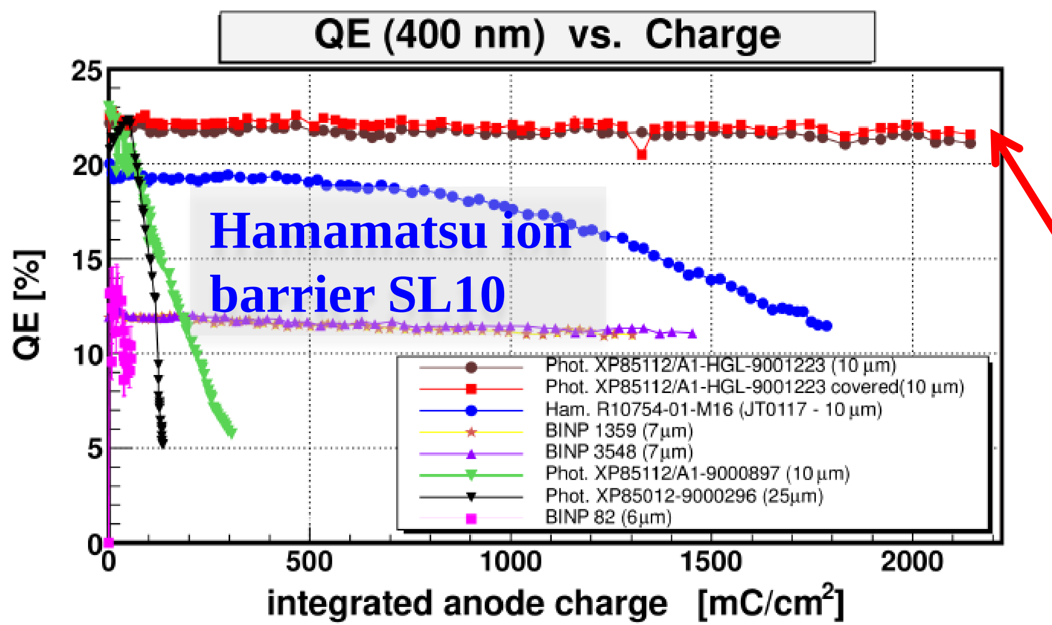
  -degrades resolution and biases time for pixels in adjacent row (on either side) for later arriving proton
- **Two protons in same pixel mixes time in complicated manner**
- After-pulsing and origins of lifetime issues
- Forming a data-based simulation of MCP response to augment GEANT capabilities
- **Tuning cathode and anode voltage to maximize performance (increase collection efficiency and reduce cross talk for example)**

Lifetime Issues

•Our first lifetime tests on ALD tube got out to 2 C/cm^2 with no loss in QE but too resource intenstive, will start major new lifetime tests this summer

Lehman et al
As of today no loss in QE with ∫Q>5 C/cm^2!!!
10-20 improvement over typical tube 1C~10 fb^{-1}; similar results reported bu Photek!

Lifetime of Different MCP-PMTs



der BINP and PHOTONIS MCP-PMTs: rapid Q.E. degradation

- new PHOTONIS XP85112: **still no Q.E. drop at >2 C/cm^2**

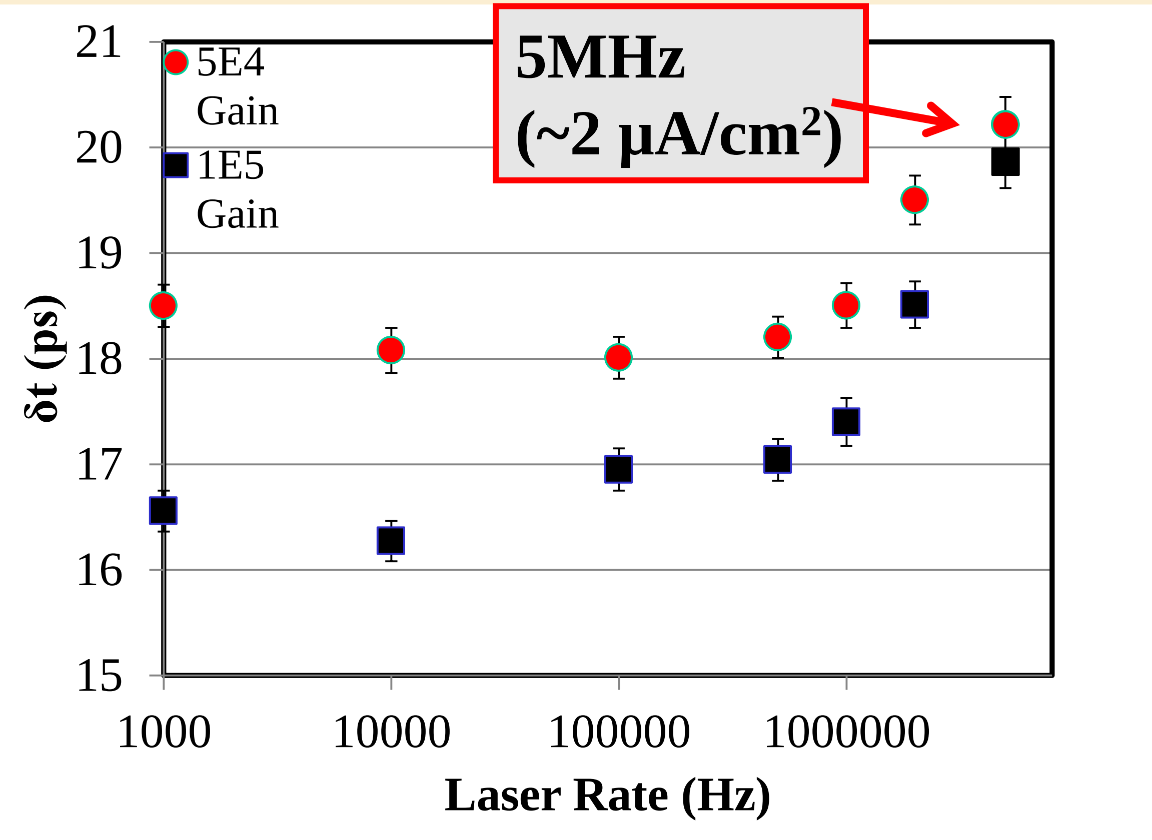
Albert Lehmann 12th Pisa Meeting on Advanced Detectors -- May 20 - 26, 2012

Wrap-up: Timing vs. Rate

*Have demonstrated desired timing capability at 5 MHz (~largest desired rate) with a long life high rate 25 µm pore PMT!

*a 10 µm pore version has about 3 times the current capability and should maintain timing well beyond 5 MHz

*Development continues, Expect to be able to make a >10 C/cm^2 tube, which would last 100 fb^{-1} or longer



Concern: only small quantities of these special tubes have been produced, so yield is uncertain -> quote is 13 to 38 k$

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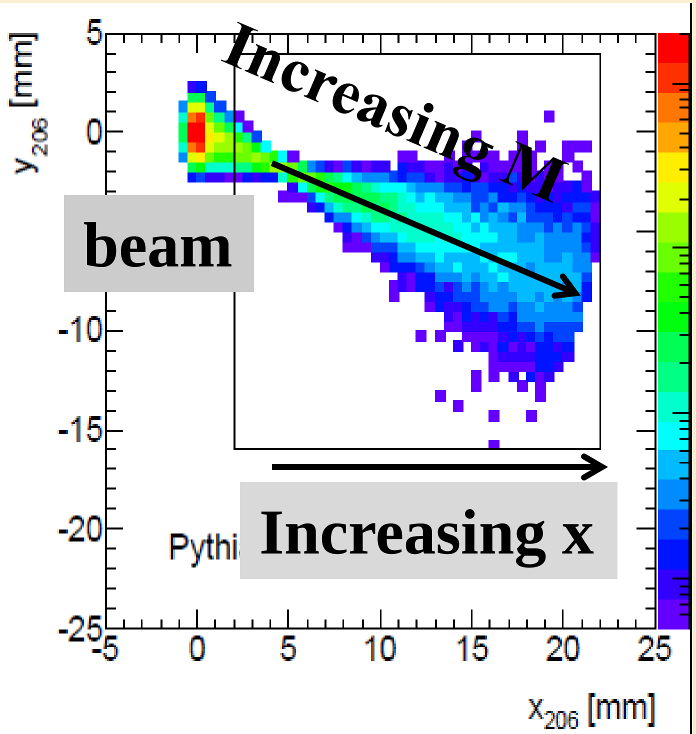
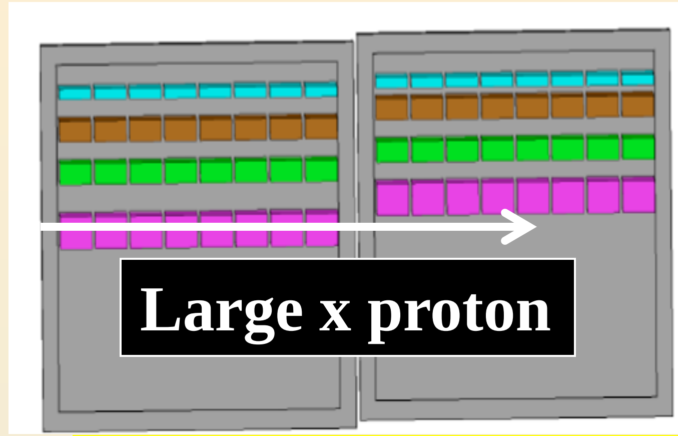
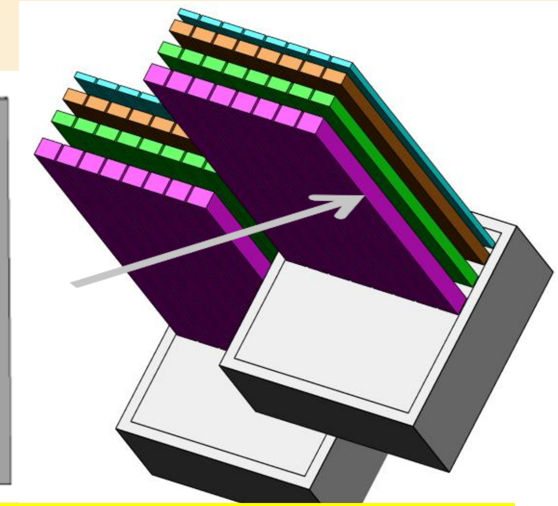
Designing a Baseline Detector

- Equal area detector bins are not in general a viable option due to rate and lifetime issues in the pixels closest the beam
- Equal rate pixels do not easily map to MCP-PMT pixels
- Smaller width pixels are better than larger ones, since if two protons are in the same pixel, neither one would be well-timed
- A full acceptance detector will suffer from cross talk, biasing neighboring rows
- To avoid this bias one needs to implement buffers between the rows
- Implies a two detector option with offset bins is a reasonable solution

A Potential Design: Two Offset QUARTIDS







In 2013 will use simulation laser tests and (August FNAL test beam) to optimize layout, test beam in Jan 2014 to validate final design and electronics

Design considerations:

1) full acceptance, efficiency, excellent timing expected ~10 ps

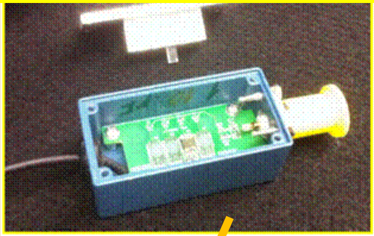
2) 8 to 10 rows with Δx =1.5 to 3 mm(x=distance of proton from beam) will avoid multi-proton effects (>90% efficient) and keep rate/pixel under 5 MHz to control current/lifetime issues (can also rotate tube 180 degrees x2 lifetime)

3) Buffers (space between rows) to avoid cross talk between rows

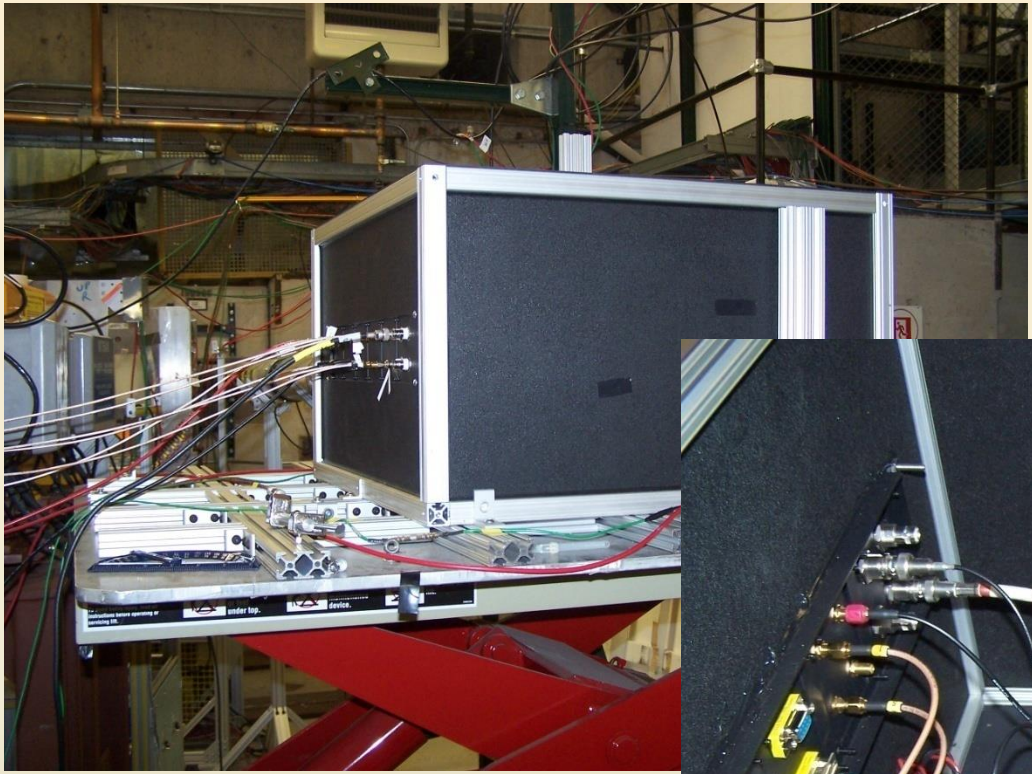
4) Rows probably should have partial overlap for alignment

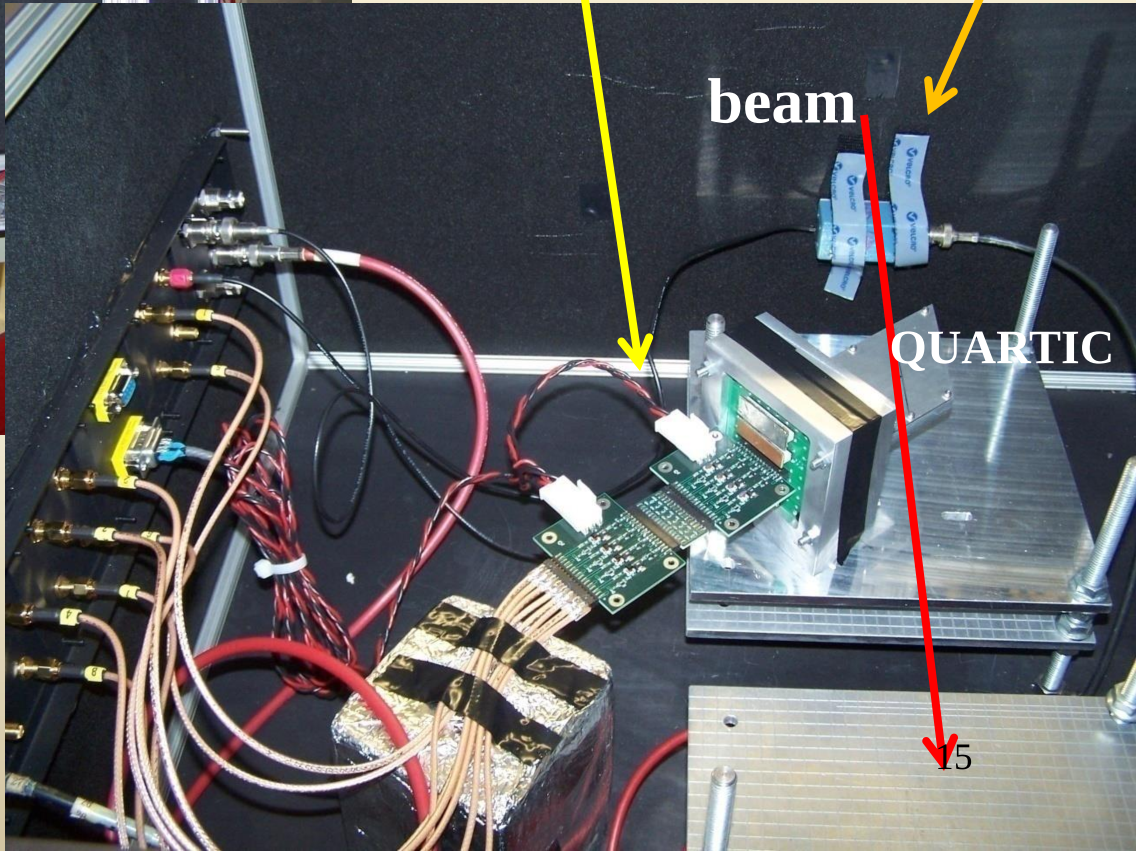
New Test Beam Setup Jan 2012 @FNAL

FNAL SiPM used in trigger and as reference counter (15 ps resolution when used in beam with quartz bar)



New Stony Brook amp cards plug directly onto PMT

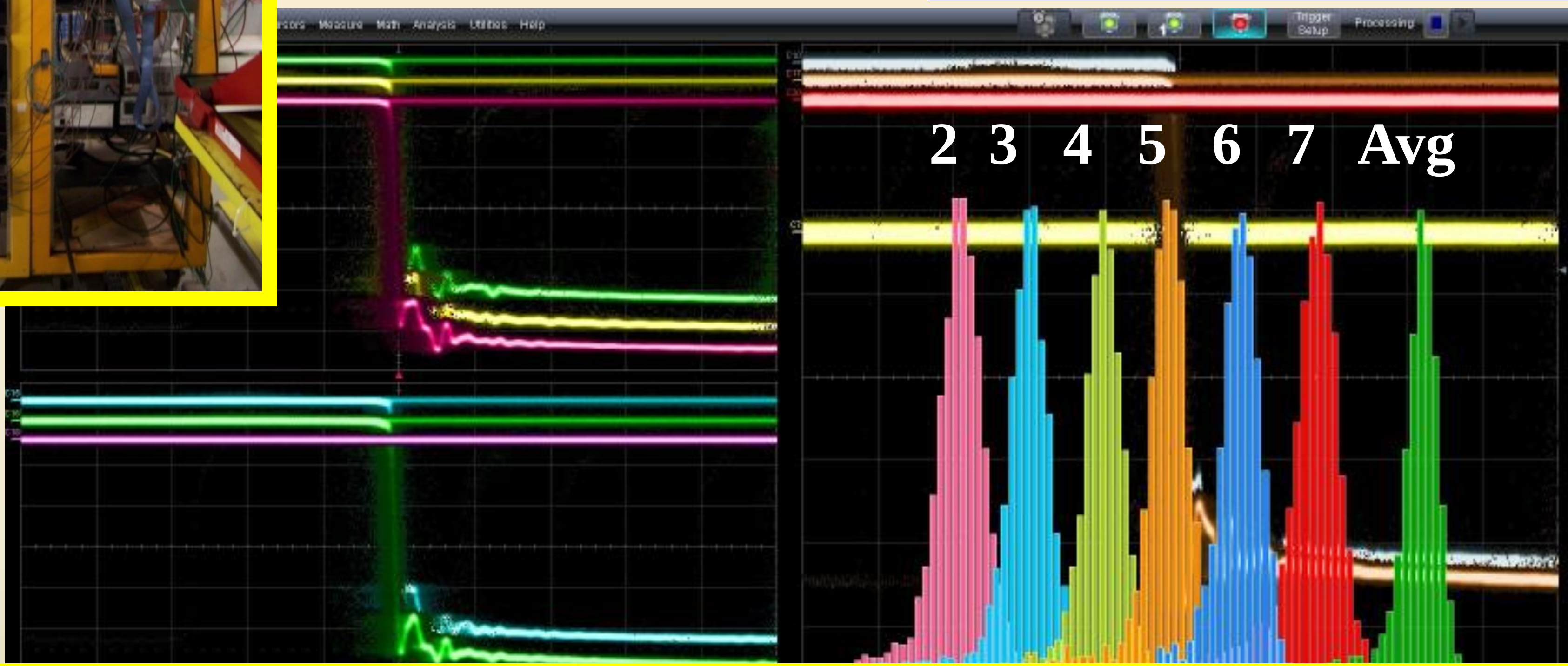




Prepared @UTA for easy alignment and versatility

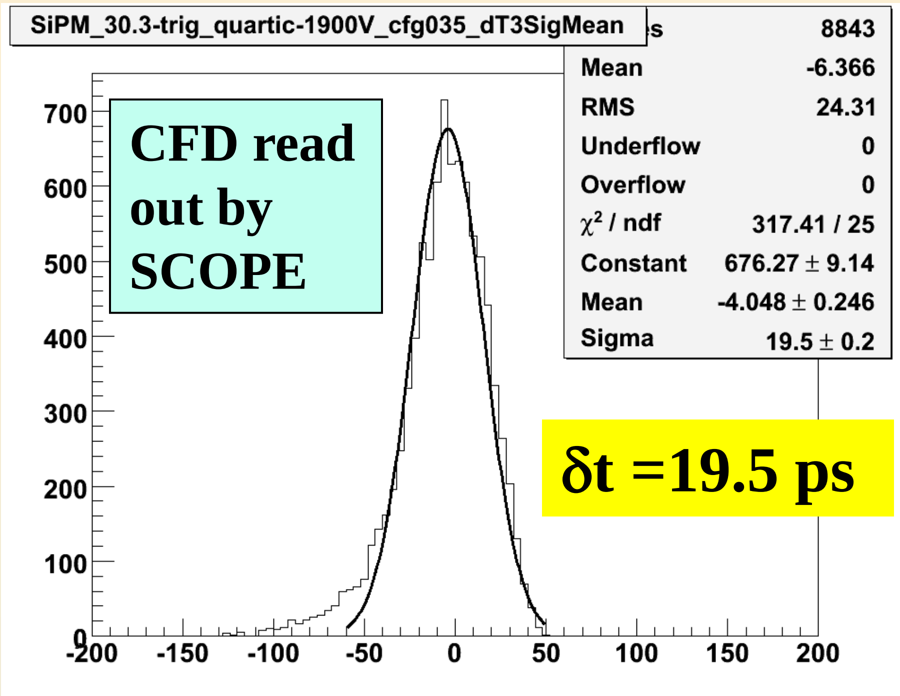
T958 DAQ

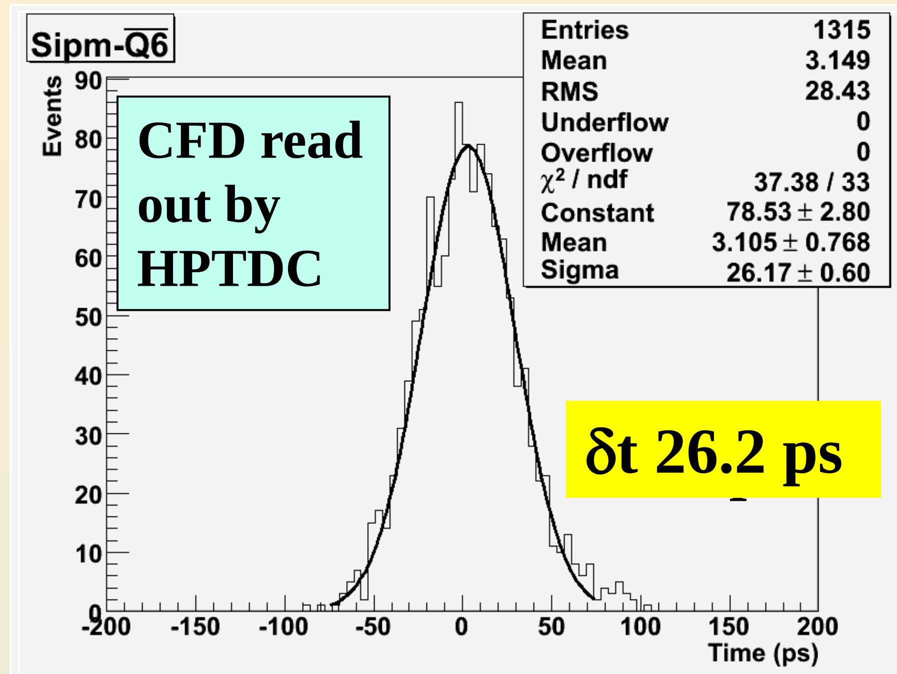
Time difference between SiPM and 6 –bar Quartic average gives FWHM=47 ps (σ=20 ps) better than design goal!



Just your garden variety 20 channel, 20 GHz/ch, 40 Gs/s ch (point every 25ps) 500k$ LeCroy 9Zi scope! "Thanks for the loaner LeCroy!"

SiPM- Quartic 6-Bar Average





QUARTIC and SiPM signals amplified, sent to CFD, then to scope, calculate Δt(SiPM-Qi) and average over 6 bars. Repeat for HPTDC readout. Difference between the measurements is dominated by 16 to 18 ps resolution of SiPM HPTDC

Extract QUARTIC resolution (6 bar) 14 to 15 ps including Q-HPTDC (Note: edge channels had different gain, not useful for this run)

Ultimate Timing System Resolution

Component	δt(ps) Current	δt(ps) Projected	Action
Radiator/MCP-PMT (~10 pe's with 10 μ pores)	19	17	Optimize radiator
CFD	5	5	-
HPTDC	18	9?	New HPTDC chip?
Reference Clock	8	5	-
Total/bar	28	20	
Total/ detector (6 ch)	12	8	-

Currently at 12 ps (Fall 2012 Test beam) with only 6 bars, and that ultimate performance of this system is probably about 8 ps

Highlights of R&D

- **In umpteen test beams (7?) we have shown steady improvement, obtaining single quartz bar/PMT resolution of 20 ps in last one (for 2x6x140 mm and 5x6x140 mm)**
- **This corresponds to a 6 bar resolution *including prototype readout electronics* of 12 ps!**
- **We have developed with Arradiance+Photonis a phototube capable of >5 MHz proton rate/pixel that has been demonstrated to have lifetime > 5 C/cm^2 expected to be good for >100 fb-1, including x2 from rotating tube, with further improvements likely**
- **Have successfully modified SLAC PLL Clock circuit that had sub-ps jitter for AFP's circumstances**