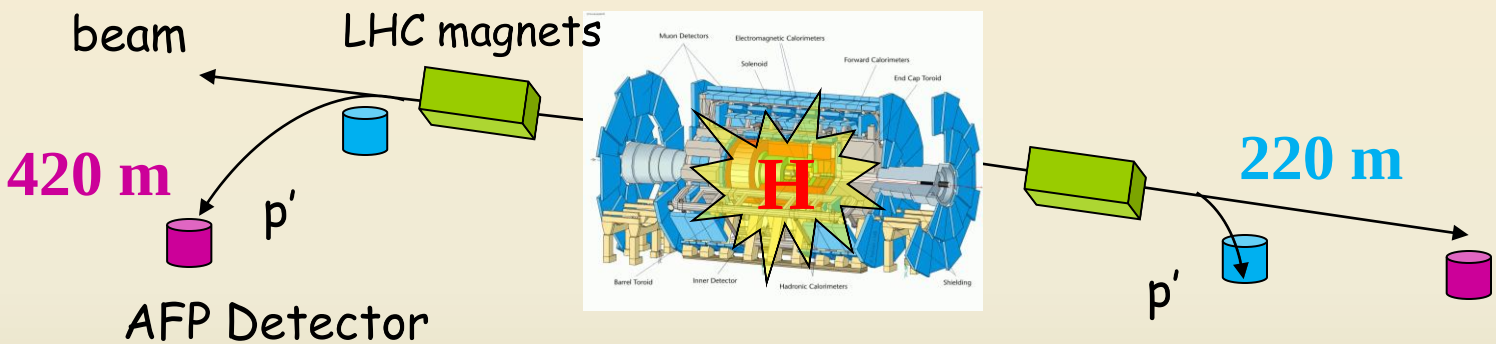
ATLAS Forward Proton Upgrade

Andrew Brandt, University of Texas, Arlington

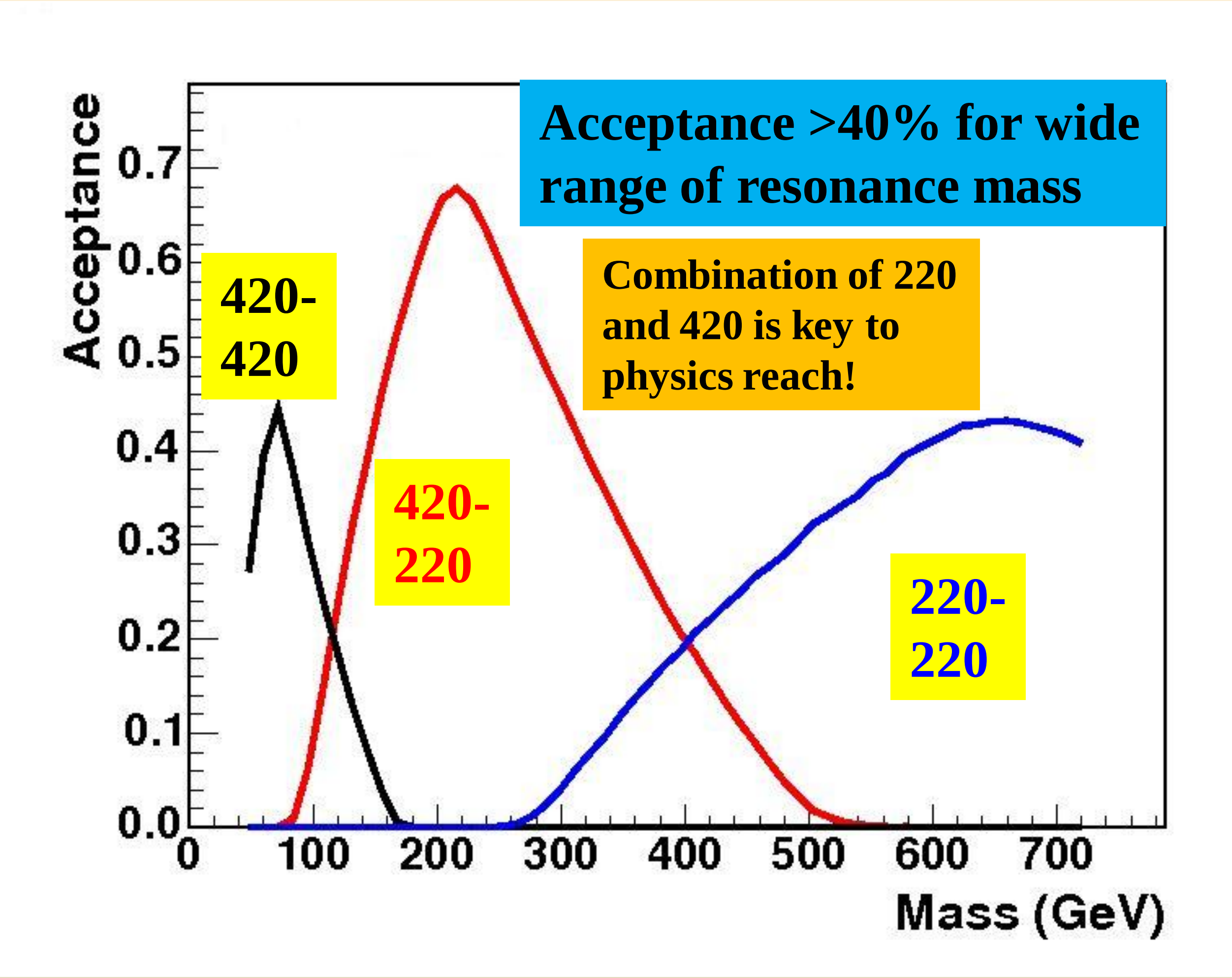
AFP concept: adds new ATLAS sub-detectors at 220 and 420 m upstream and downstream of central detector to precisely measure the scattered protons to complement ATLAS discovery program.
These detectors are designed to run at a luminosity of 10^{34} cm^{-2}s^{-1} and operate with standard optics (need high luminosity for discovery physics)



AFP Components

1) Rad-hard edgeless 3D silicon detectors with resolution ~10 μm, 1μrad
2) Timing detectors to reject overlap background (SD+JJ+SD)
3) New Connection Cryostat at 420m
4) “Hamburg Beam Pipe” instead of Roman Pots

What does AFP Provide?



- Mass and rapidity of central system, assuming central exclusive production (CEP) process, where momentum lost by protons goes into central system
- Mass resolution

  of 3-5 GeV ***per event***

Allows ATLAS to use LHC as a tunable √s glu-glu or γγ collider while simultaneously pursuing standard ATLAS physics program

P is for Proton

P is for Proton, that's good enough for me

Forward Proton, Central Physics!

AFP is designed to add to the core physics program of ATLAS: Higgs, SUSY etc.: measure quantum numbers and mass of any resonance, cross section enhanced for MSSM Higgs, most sensitive anomalous coupling measurements (important for Higgsless models). + SM physics, too

http://www.youtube.com/watch?v=dhUFxaauNTE

AFP Evolution

- **2000 Khoze, Martin, Ryskin (KMR): Exclusive Higgs prediction**
  Eur.Phys.J.C14:525-534,2000, hep-ph/0002072
- 2003-2004 Joint CMS/ATLAS FP420 R&D collaboration forms
- 2005 FP420 LOI presented to LHCC CERN-LHCC-2005-0254
  "LHCC acknowledges the scientific merit of the FP420 physics programme and the interest in exploring its feasibility"
- 2006-7 Some R&D funding, major technical progress, RP220 formed
- 2008 AFP formed, cryostat design finished, LOI submitted to ATLAS
- 2009 "AFP year in review", FP420 R&D document published

"The FP420 R&D Project: Higgs and New Physics with Forward Protons at the LHC," FP420 Collaboration, arXiv:0806.0302v2, published in J. Inst.: 2009_JINST_4_T10001,
http://www.iop.org/EJ/abstract/1748-0221/4/10/T10001.

- **Nov. 2009 2010 AFP LOI approved, physics case acknowledged, encouraged to prepare Technical Proposal for 2011**

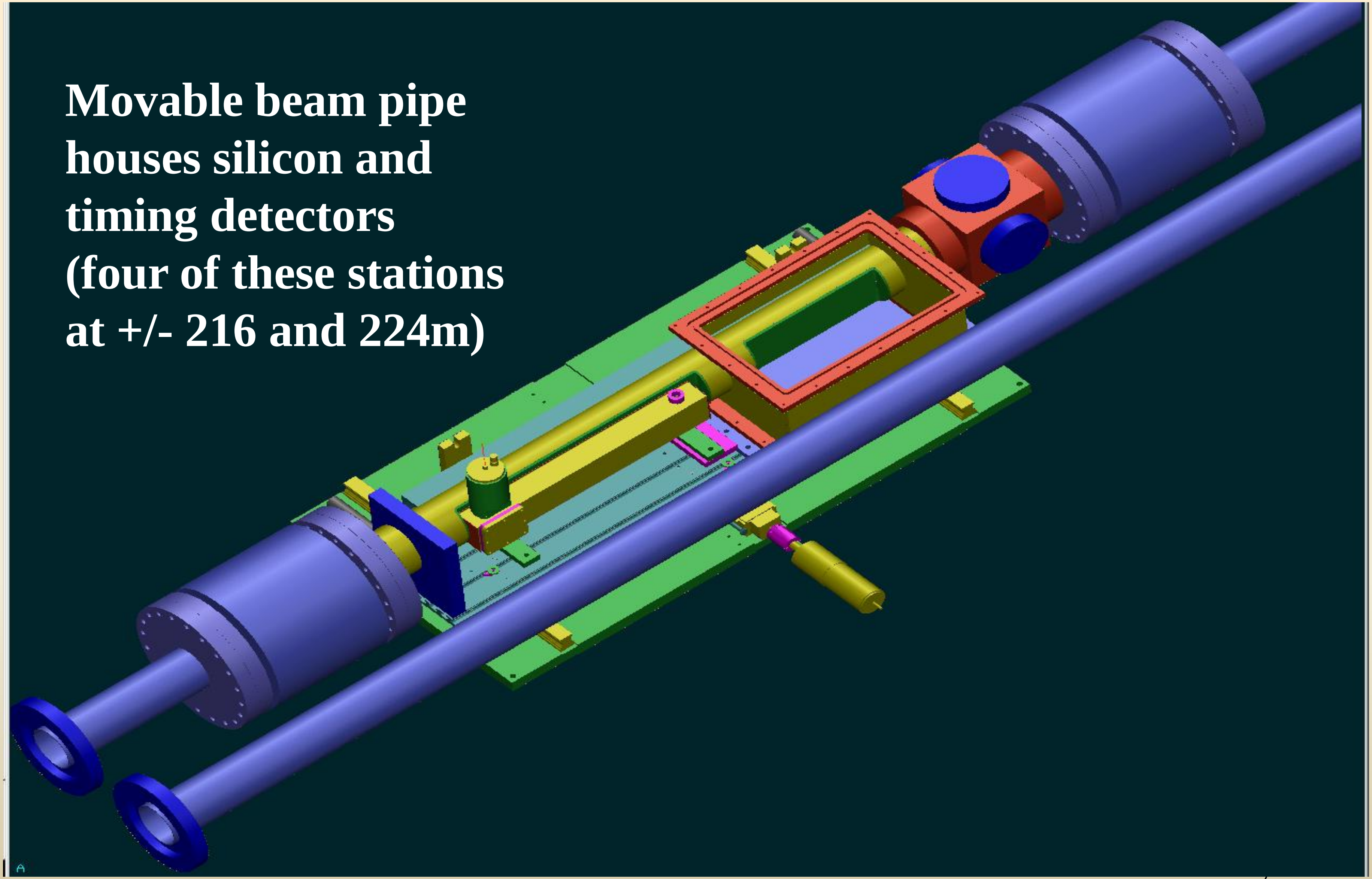
AFP Devolution

August 5, 2010 : UK funding for AFP project terminated (moment of silence). Loss of English groups is a big blow to project.

AFP Moving Forward

- Technical Proposal submitted to ATLAS Forward Detector group (review Thursday), if endorsed by FD group and ATLAS review AFP can be moved under upgrade umbrella and be prioritized with other upgrade projects – this is critical for funding and to encourage new groups to join, both of which need for a full Technical Design Report
- **Our plan: a staged approach with 220 m system (at minimum movable beam pipe +infrastructure, but ideally tracker + timing detectors) installed in 2013/2014 shutdown**
- **420 m stations to be installed in 2016 shutdown**

Stage I: 220m Detector Stations



Stage I: Advantages

1) Trigger not required

2) No "significant" accelerator modifications (modified cryostat at 420m not needed since beampipe warm at 220m)

3) PMT lifetime not as big an issue due to lower rates from lower lum

4) Less expensive

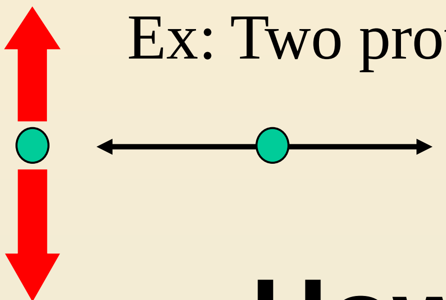
Lack of low mass acceptance motivates move to Stage II as soon as possible

Timing System Motivation

WHY?

Pileup background rejection/signal confirmation

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



How?

Use time difference between protons to measure z-vertex and compare with inner detector vertex. In 220 m phase this will provide crucial confirmation that any observed signal is legit

How Fast?

10 picoseconds is design goal
(light travels 3mm in 10 psec!)
gives ~x20 fake background rejection;
Stage I: 2014 220 m few 10^{33} $\delta t < 20$ ps
Stage II: 2016 add 420 m 10^{34} $\delta t < 10$ ps

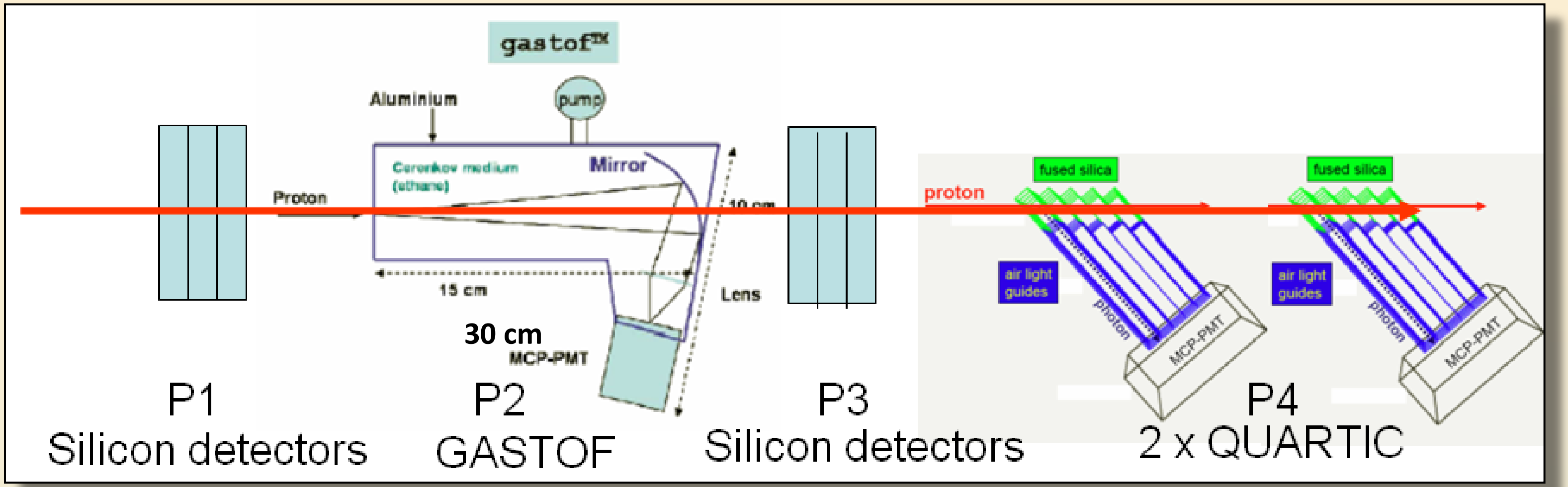
Final Timing System Requirements

- 10 ps or better resolution
- Acceptance over full range of proton x+y
- Near 100% efficiency
- High rate capability (~5 MHz/pixel proton rate!)
- Segmentation for multi-proton timing
- L1 trigger Capability
- Radiation Tolerant

Note: For 220 m at modest luminosity/multiple interactions, the requirements are not as stringent:

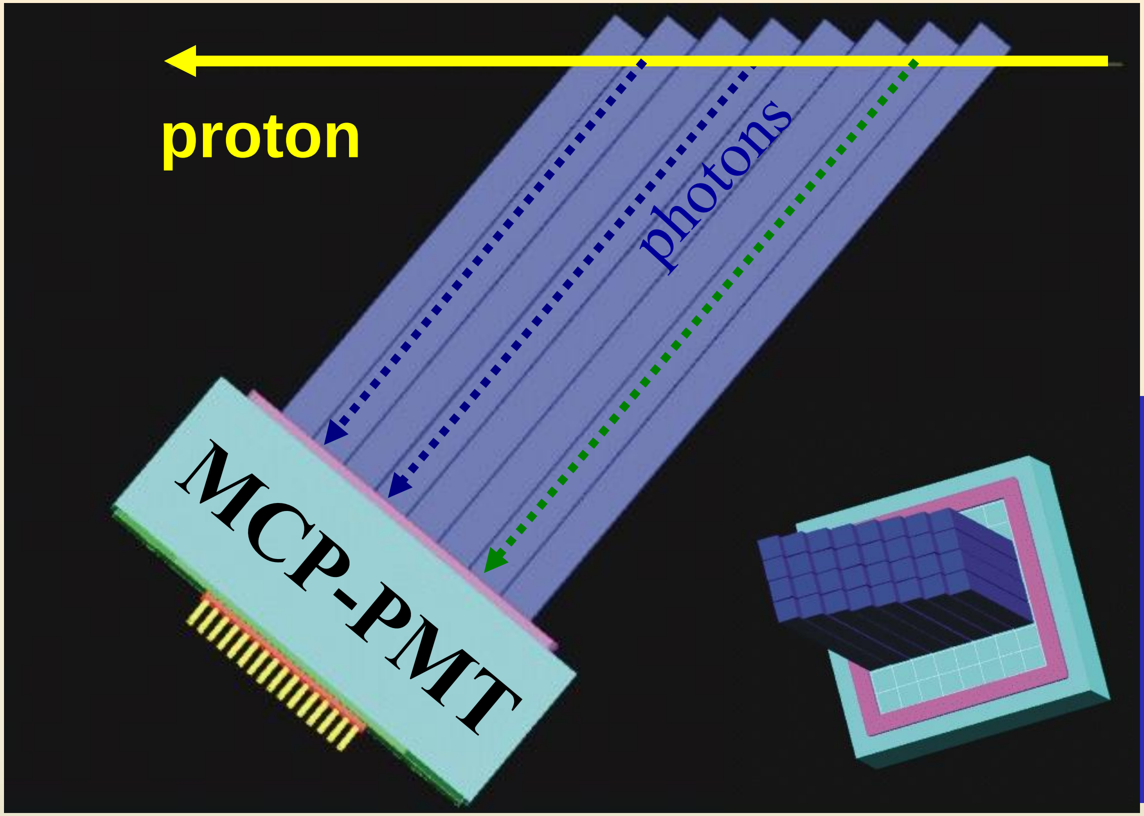
20 ps resolution, perhaps <1 MHz/pixel, multi-protons on same side not a significant problem, and the Level 1 trigger capability is not strictly necessary.

AFP Baseline Plan



- **Two types of Cerenkov detector are employed:**
  - **GASTOF – a gas Cerenkov detector that makes a single measurement (you just heard about this)**
  - **QUARTIC – two QUARTIC detectors each with 4 rows of 8 fused silica bar will be positioned after the last 3D-Si tracking station because of the multiple scattering effects in the fused silica.**
  - **Both detectors employ Microchannel Plate PMTs (MCP-PMTs)**

QUARTIC is Primary AFP Timing Detector



UTA, Alberta, Giessen, Stonybrook

4x8 array of 5x5 mm^2 fused silica bars

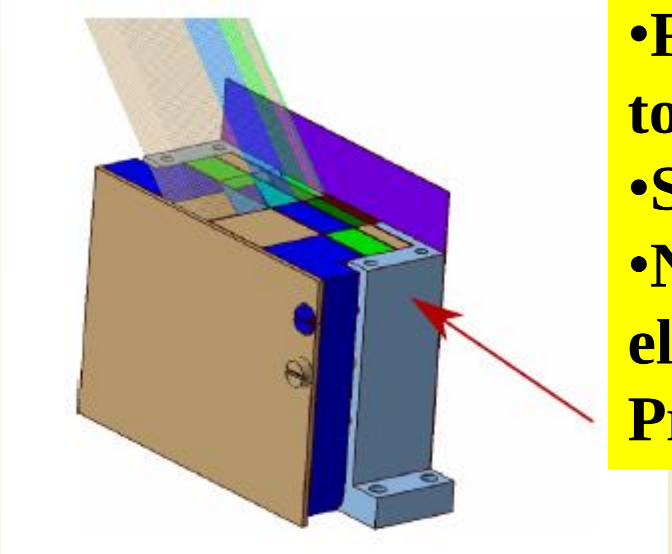
Only need a 40 ps measurement if you can do it 16 times: 2 detectors with 8 bars each, with about 10 pe's per bar

Multiple measurements with "modest" resolution simplifies requirements in all phases of system

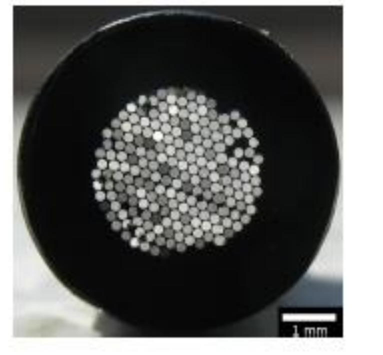
1) **We have a readout solution for this option**
2) **We can have a several meter cable run to a lower radiation area where electronics will be located**
3) **Segmentation is natural for this detector**
4) **Possible optimization with quartz fibers instead of bars**

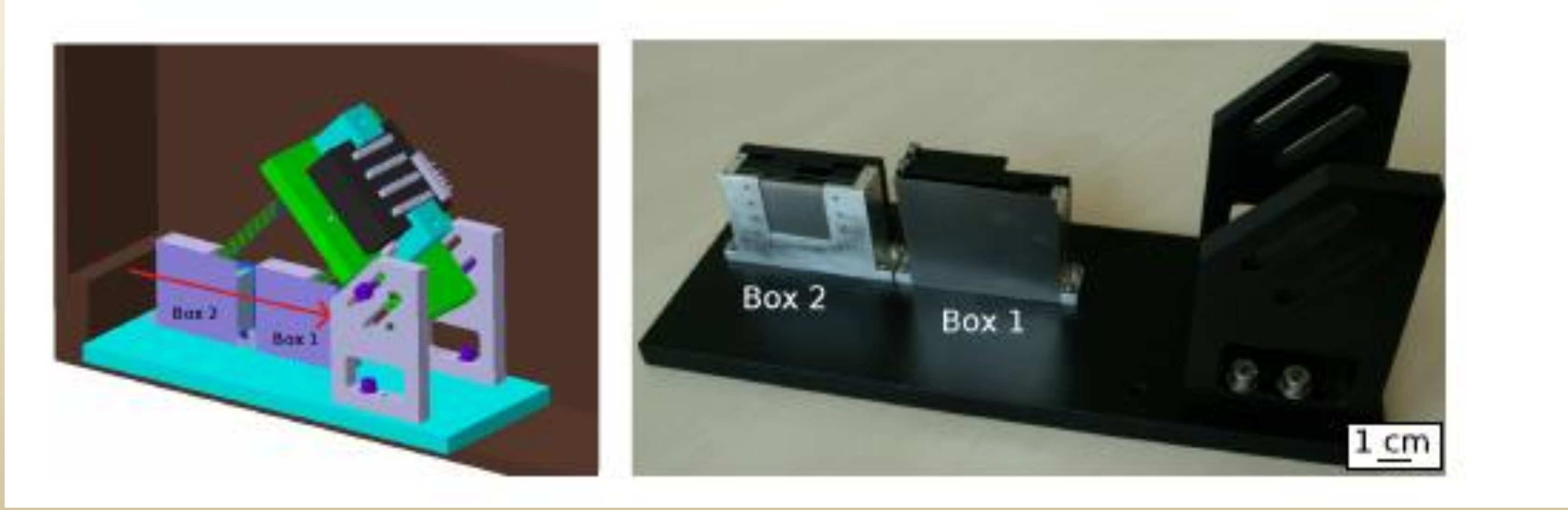
Giessen Fiber Quartic

From Sabrina Darmawi's thesis, Michael Dueren, Hasko et al



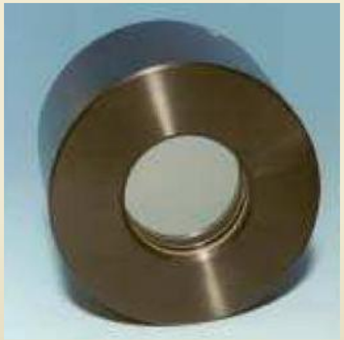
- **Facilitates variable bin size to optimize rate+lifetime**
- **Simulations promising**
- **Needs upgraded readout electronics to fully evaluate Prototype performance**





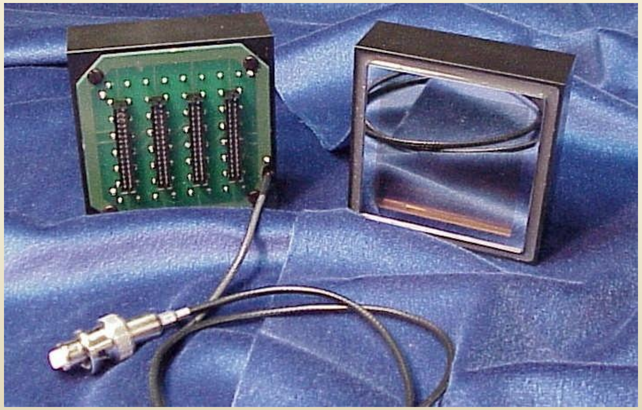
MCP-PMT Requirements

Excellent time resolution: 20-30 ps or better for 10 pe's
High rate capability: I_{max} ~ 2 μA/cm^2
Long Lifetime: Q ~ 10 to 20 C/cm^2/year at 400 nm
Multi anode: pixel size of ~6 mm x 6mm
Pore Size: 10 μm or smaller
Tube Size: 40 mm round, 1 or 2 inch square



Photek 240 (1ch)

Hamamatsu SL10 (4x4)

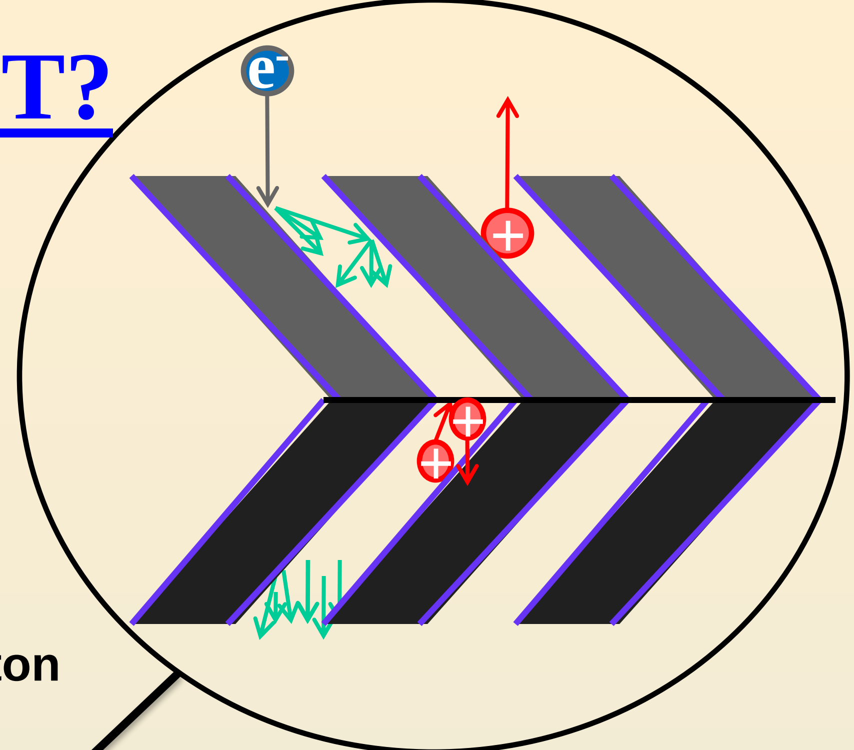


Photonis Planacon (8x8)

Need to have capability of measurements in different parts of tube between 0-2 ns apart, and in same part of the tube 25 ns apart

A.B.’s Ideal MCP-PMT?

Suppressed positive ion creation (NSF SBIR)



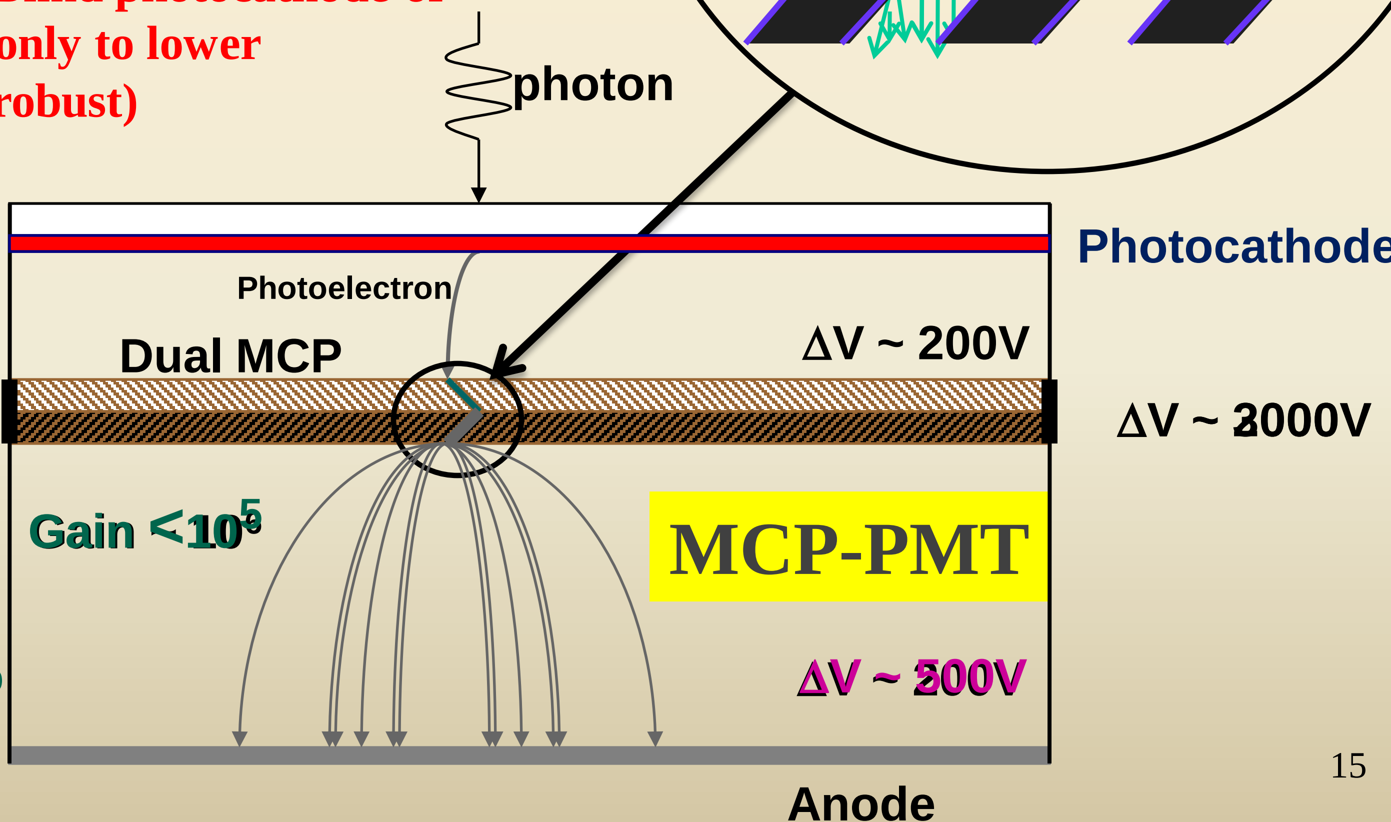
Ion Barrier keeps positive ions from reaching photocathode (developed by Nagoya with Hamamatsu)

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

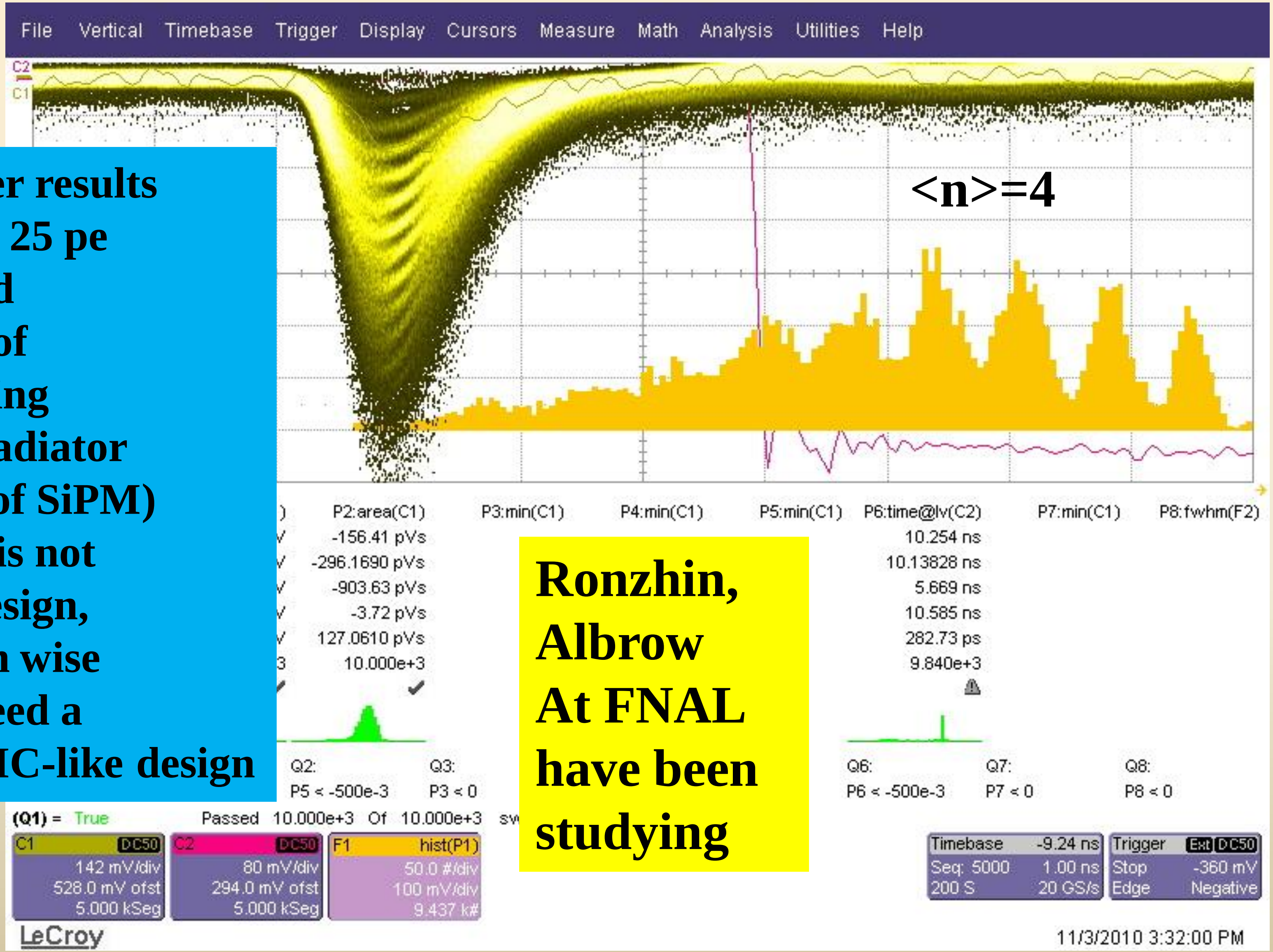
Improve vacuum Seal (Nagoya/ Hamamatsu)

Increase anode voltage to reduce crosstalk (UTA)

Run at low gain to reduce integrated charge (UTA)



Possible MCP-PMT Alterntive: SiPM

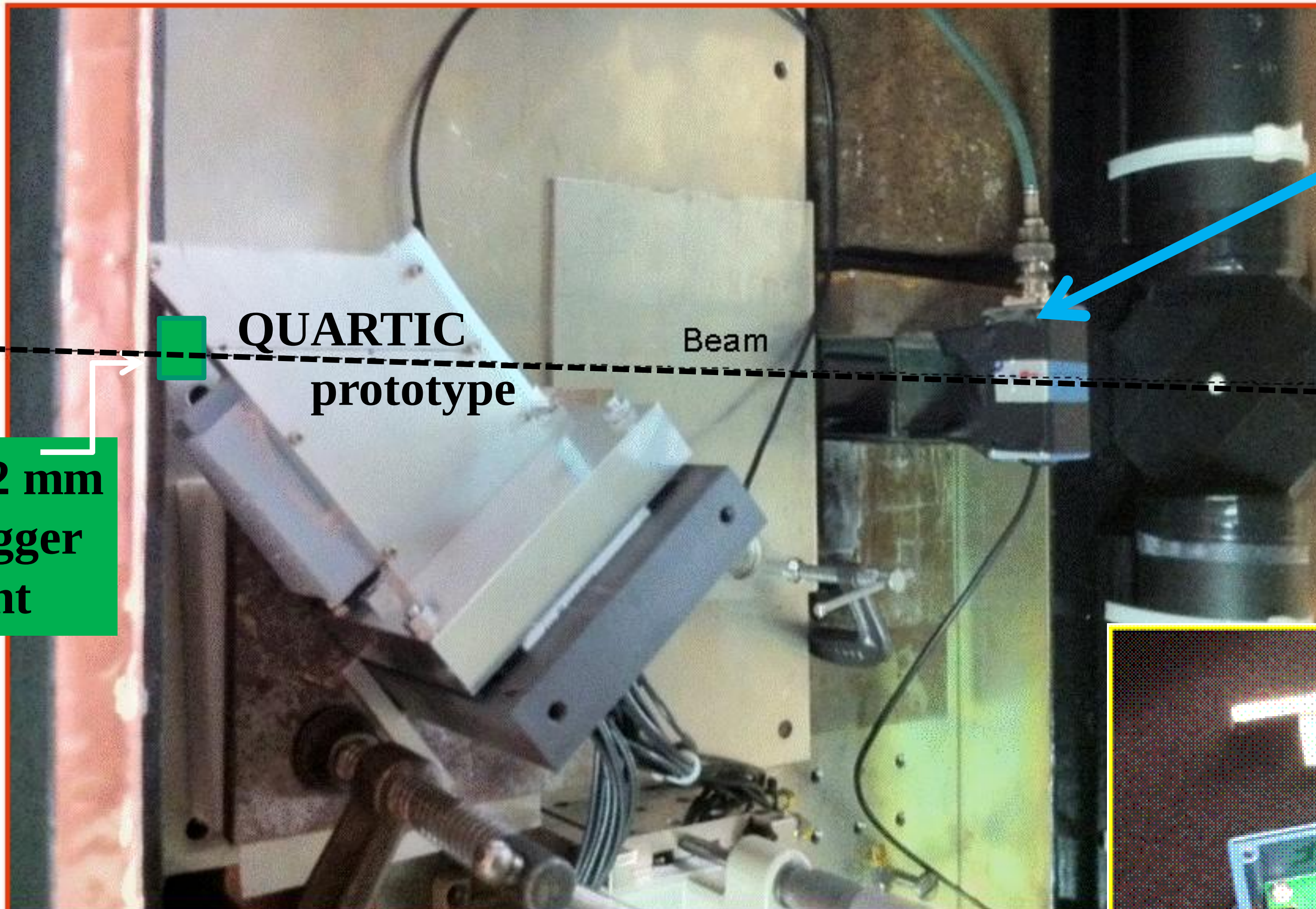


UTA laser results
16 ps for 25 pe
(expected amount of Light using quartz radiator in front of SiPM)
But this is not viable design, radiation wise would need a QUARTIC-like design

Ronzhin, Albrow At FNAL have been studying

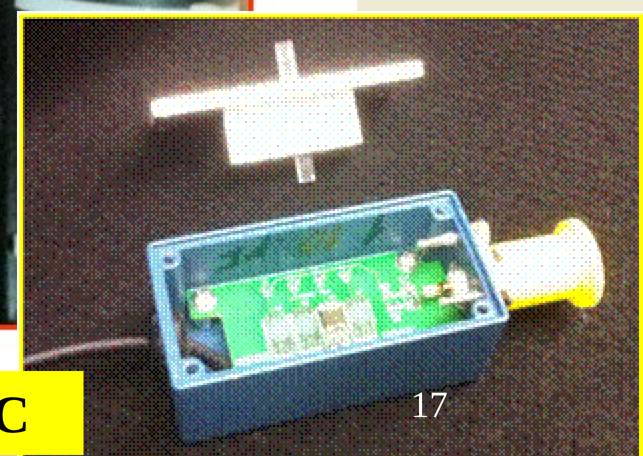
2010 CMS/ATLAS Fermilab Test Beam

siPM courtesy of Ronzhin, Albrow



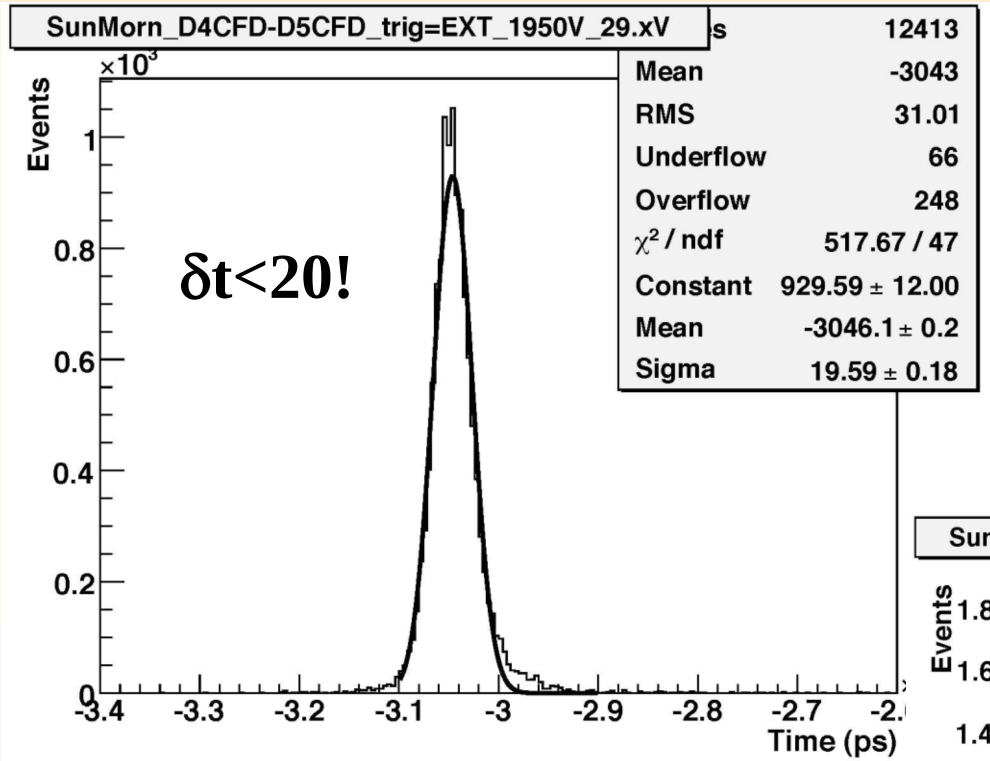
QUARTIC prototype

2 x2 mm Trigger Scint



Use siPM in beam as reference for evaluating QUARTIC

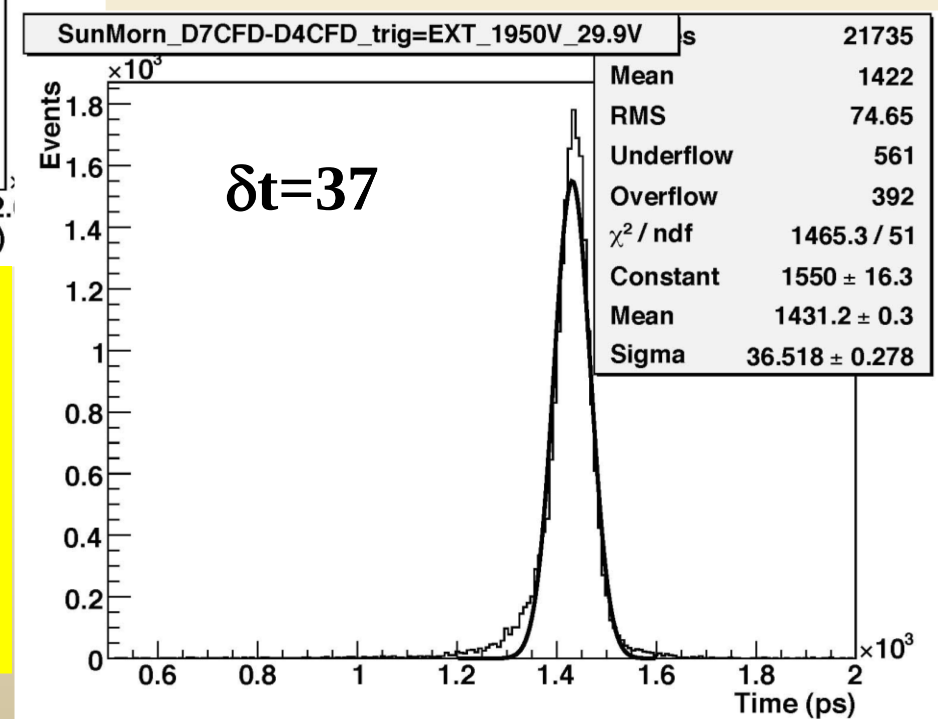
2010 QUARTIC Test Beam Results



Old (2006) Burle 25 µm pore MCP-PMT

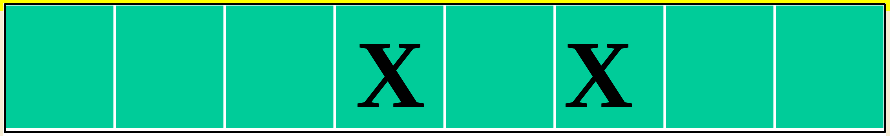
Time Difference between "distant bars" 4 and 7 is 37 ps, implies 25 ps/bar including extra light sharing from neighbors

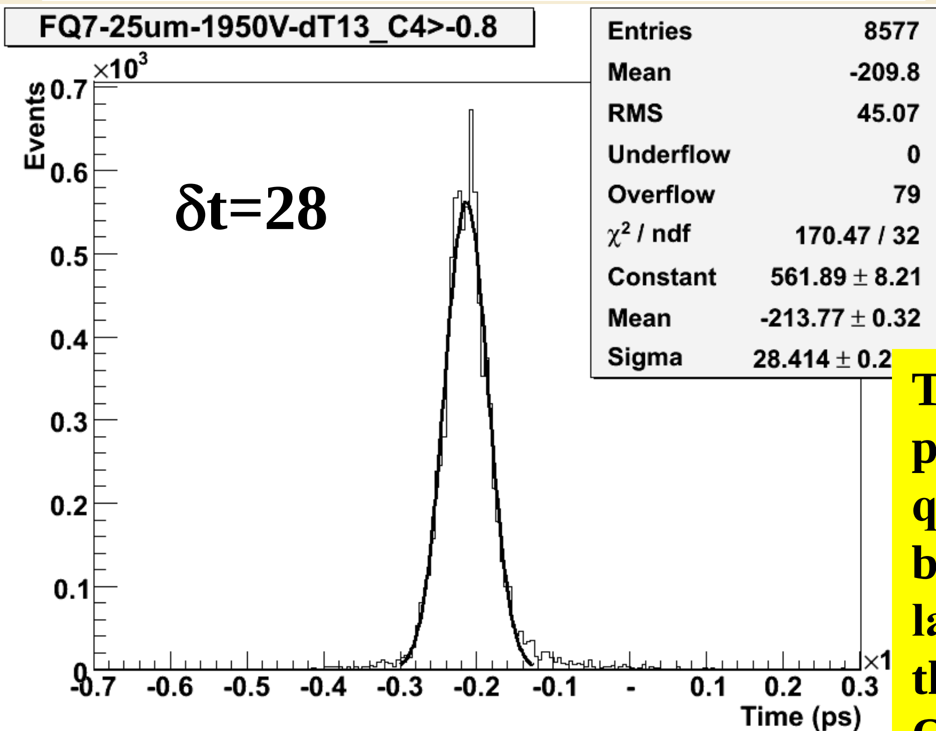
Time Difference between adjacent bars is <20 ps, implies <14 ps/bar including bar, PMT, CFD! *Too good to be true*: due to charge sharing and light sharing, bars are strongly correlated.

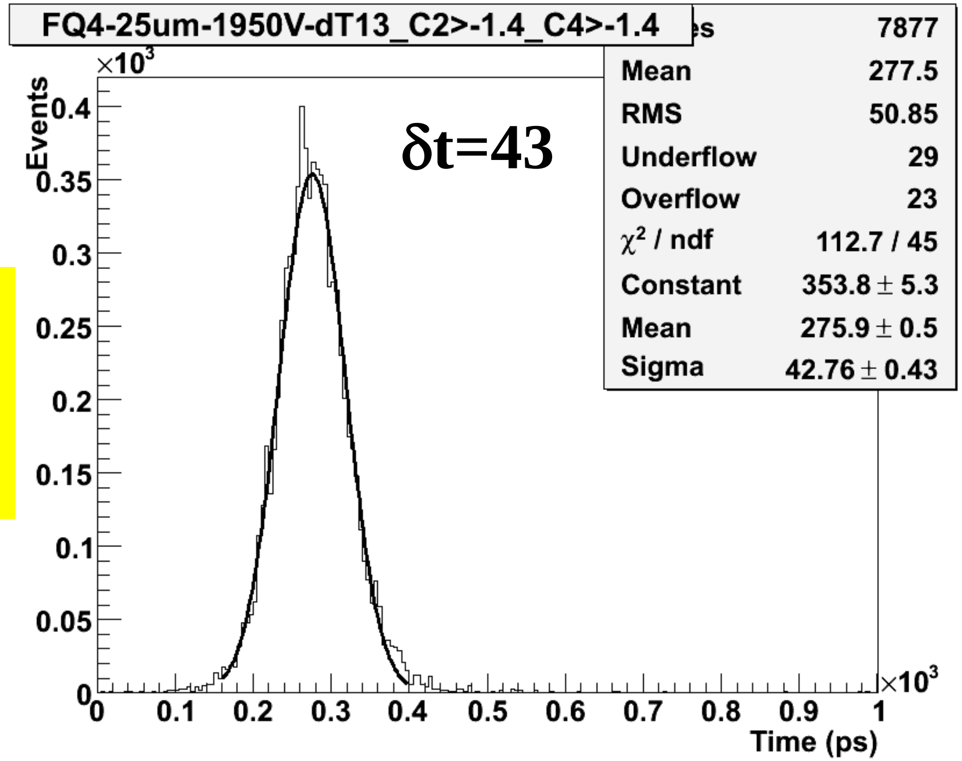


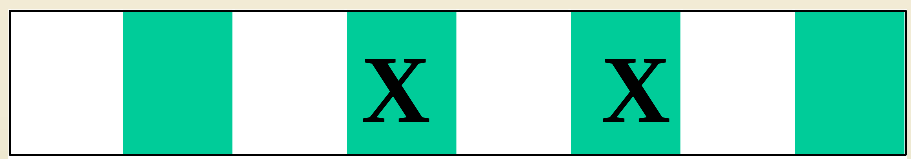
Charge Sharing Effects in TB

δt(4-6)is 28 ps [20 ps/channel] when all channels have a quartz bar, this is still correlated since some light from channel 5 goes into each bar



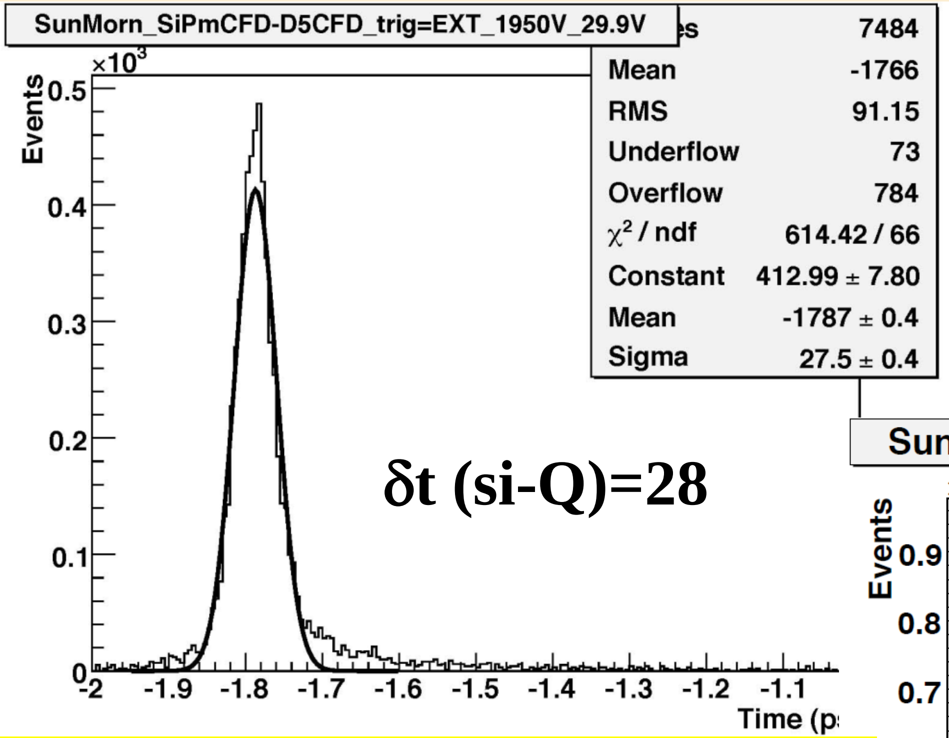




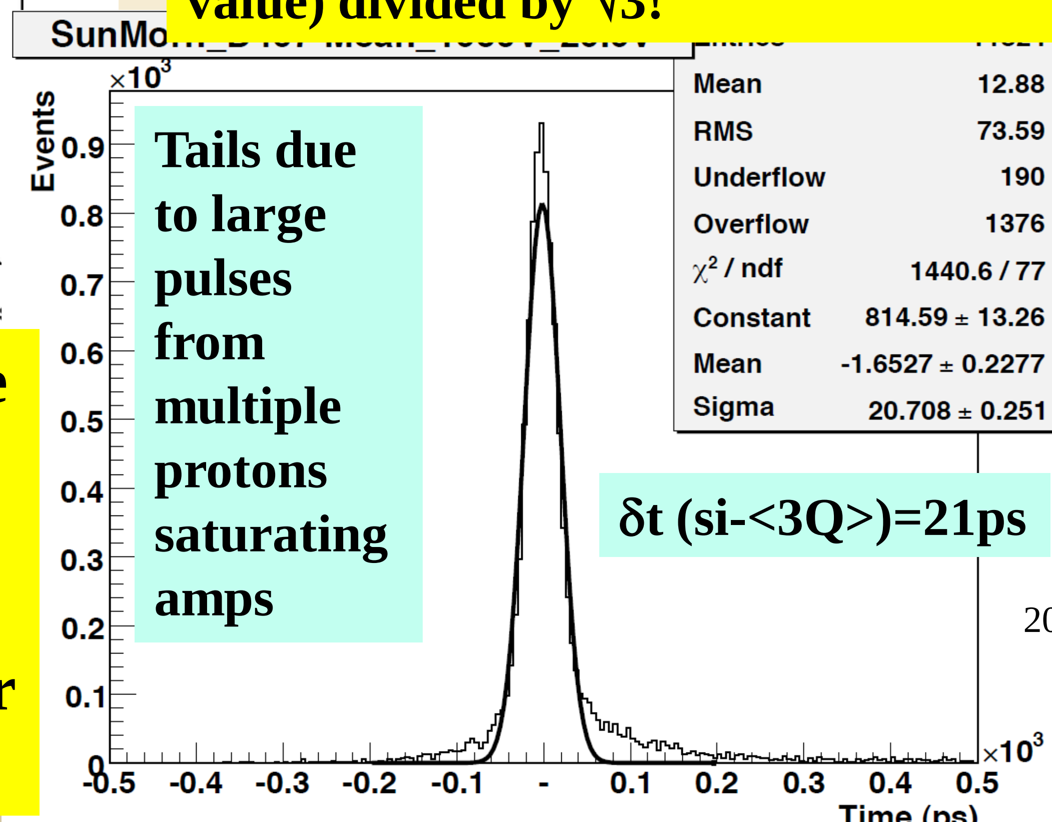


Time difference rms between ch 4 and ch 6 is 43 ps when only even number channels have a quartz bar, implying that an "independent" bar without extra light has δt~30 ps. From laser studies it is the "independent" bar value that scales with √N implying δt~10 ps in 8-bar QUARTIC with a 25 μm tube!

δt(siPM – Quartic Bar(s))

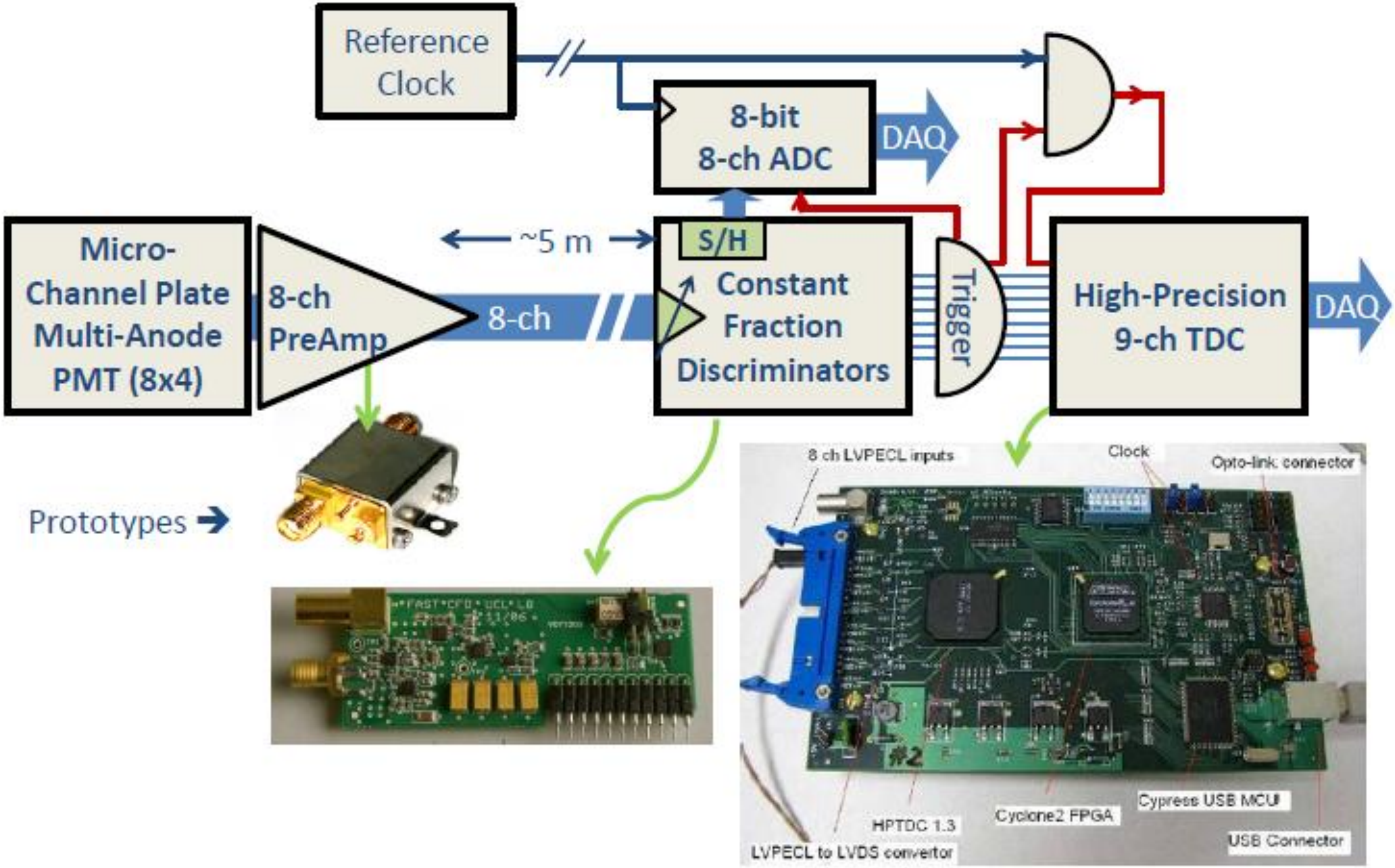


Using 21 ps and subtracting off the 13 ps SiPM leaves 17ps, which happens to be equal to 30 ps (independent bar value) divided by √3!



If Q~25 ps (expected for single bar with neighboring bars plugged in) SiPM =13 ps (~consistent with laser tests). Note MCP-PMT w/Quartz bar in beam can give δt=5 ps

Electronics Layout



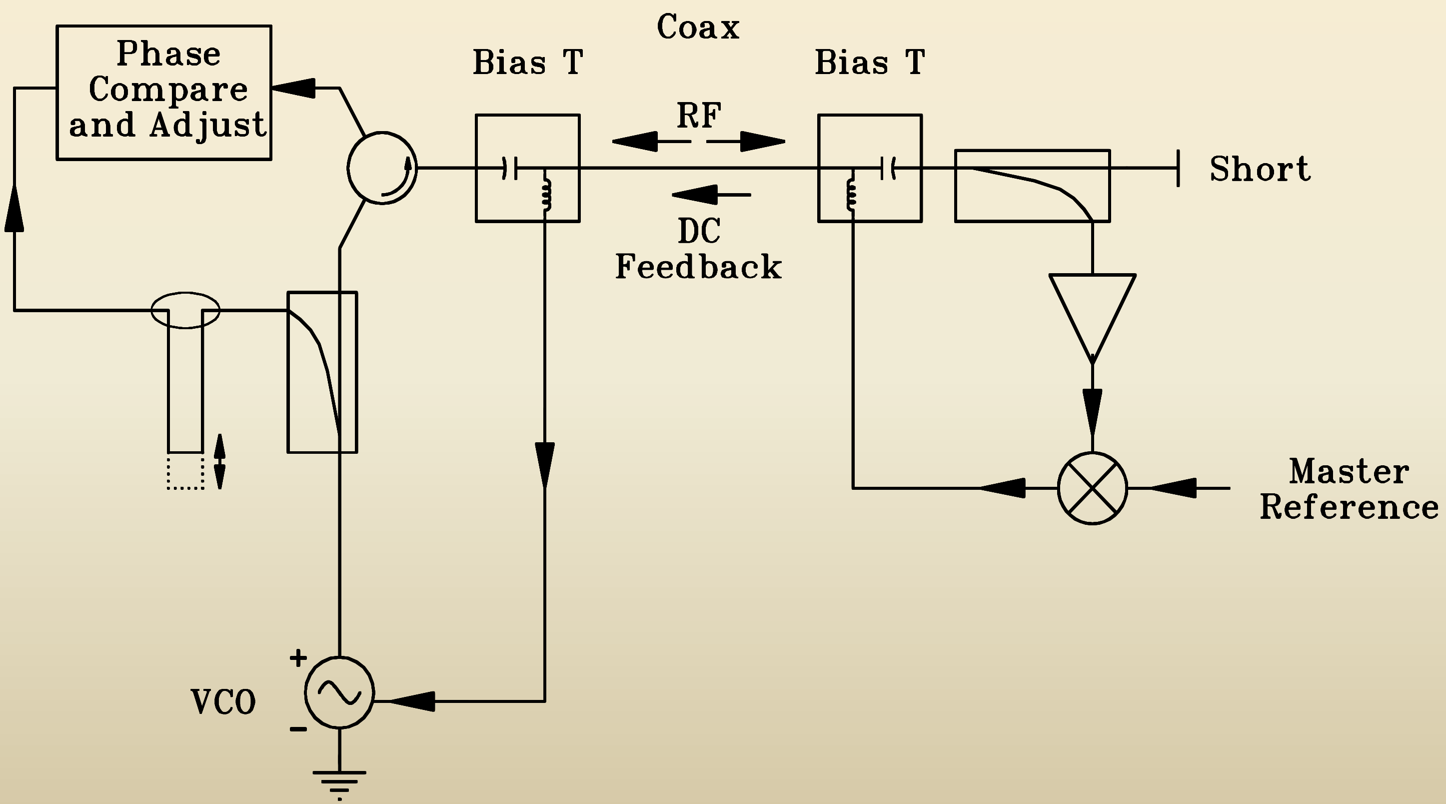
Amp-CFD-HPTDC chain built and tested <20 ps resolution

Electronics Work in Progress

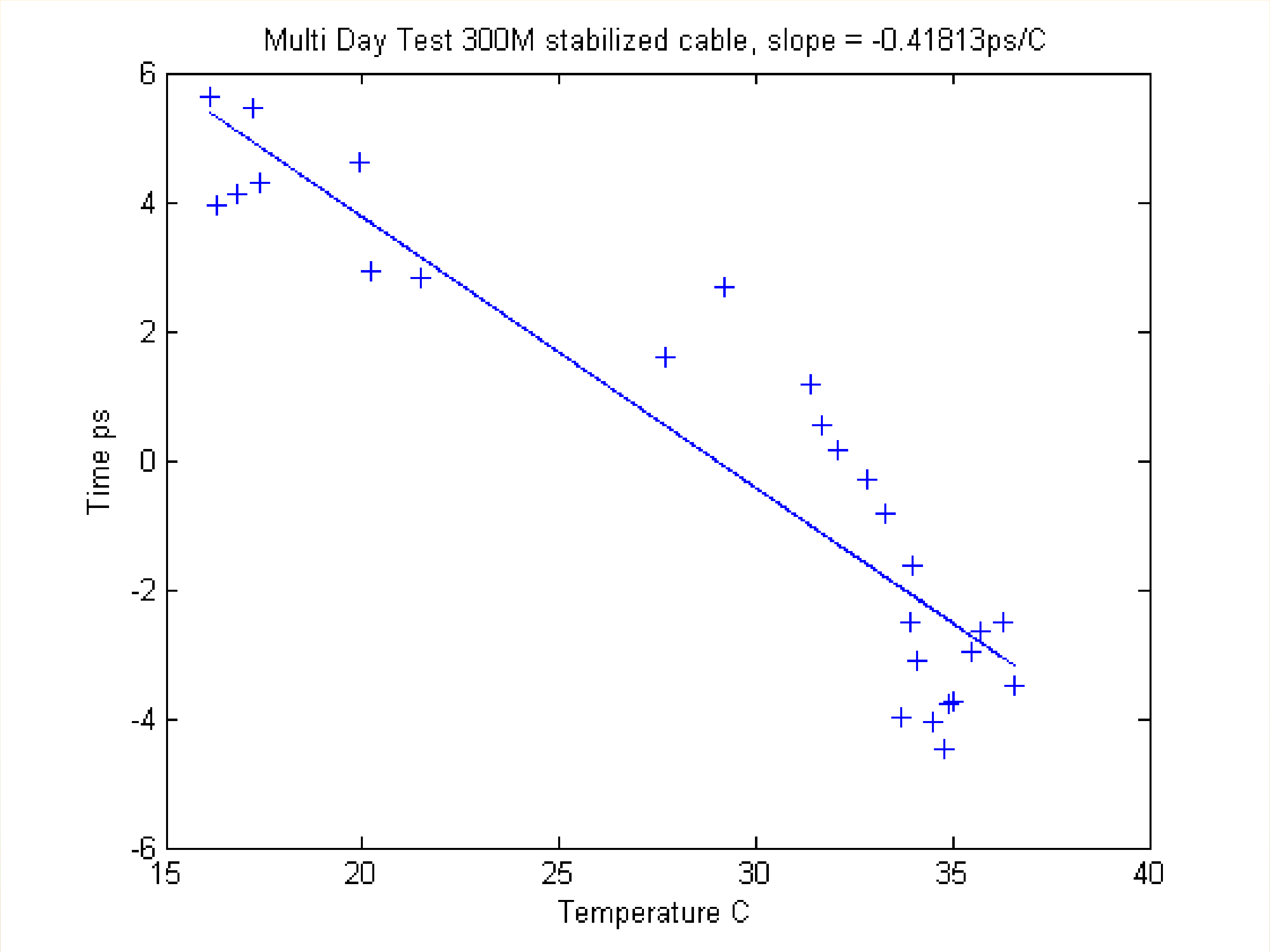
- Constructing 8 channel amplifier board including protection diode, to fit onto MCP
- Adding sample/hold to CFD mini-module to use with simple ADC for monitoring gain
- Building trigger circuit (discussed below)
- Have tested reference clock, minor upgrades needed (below)
- Upgrading HPTDC board

Reference Timing Overview

Reference timing is needed to connect two arms ~ 0.5 km apart; what we want is T_L-T_R, what we measure is (T_L-T_{ref})-(T_R-T_{ref}), so need small jitter in T_{ref}
Solution has been developed by SLAC/LLNL involving phase lock loop. We need only minor modifications to use 400 MHz RF instead of 476 MHz, and circuit to convert 400 MHz to 40 MHz and multiplex clock for use in HPTDC board



Reference Timing: SLAC Test Results



SLAC test show only 10 ps total variation over 20 C! Adding a correction for residual temperature variation, or controlling temperature of electronics (not cable) will reduce the jitter to a couple ps!

Conclusions

- **AFP upgrade provides new physics capabilities, still proceeding through the many-staged ATLAS review process**
- **Substantial progress in all phases of fast timing, including integrating trigger capabilities into fast timing detector/electronics**
- **We have a prototype fast timing system for AFP that seems to be capable of ~10 ps resolution, validated with beam and laser tests**
- **Significant improvements in lifetime by Nagoya/Hamamatsu ; also through UTA/Photonis collaborations. Solution exists for modest integrated charge (few C/cm^2), 10-20 C/cm^2 seems achievable on a few year timescale.**
- **In progress: final optimization and layout of detector, electronics, PMT; evaluating radiation tolerance/needs of all components**
- **Timing detector not on critical path assuming ATLAS approves AFP in a timely manner and R&D, production funding obtained**