Work during the past year on pileup mitigation through fast timing in CMS: Results and Plans

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Forward Detector Concepts WG, Oct. 3, 2012

Outline

- brief recap of earlier talks in CMS over past year
- earlier work on pileup simulation in CMS, FP420 specific application, generic work on electron test beam for picosecond timing studies and development of
  - 11 picosec SPTR (single photon time response) photodector with >240 C lifetime (Hamamatsu HAPD pre-production prototype)
  - deep-depleted APD for direct charged particle timing

CMS talks

- presentations at PISA, Saclay irfu.**cea**.fr/Pho**cea**/file.php?file.../2796/**White**.
  and Turing Centennial Symposium/ UCL
- series of talks in Task Force meetings and also to FSQ working group
- Task Force presentations set up as an on-going series with upcoming presentations also by Frisch, Giomataris, HADES(GSI),Hamamatsu,etc

- this work started within context of FP420. Mike Zeller, Thomas Tsang and I designed <5 picosec clock distribution system for CMS, described in FP420 report see: http://www.fp420.com

- generic simulation of pileup mitigation via timing in: On the Correlation of **Subevents** in the ATLAS and **CMS**/Totem ...hep-ex arXiv:0707.1500v3 -von SN White - 2007 (see also full Higgs analysis by Brian and Andy in Andy Pilkington's thesis)

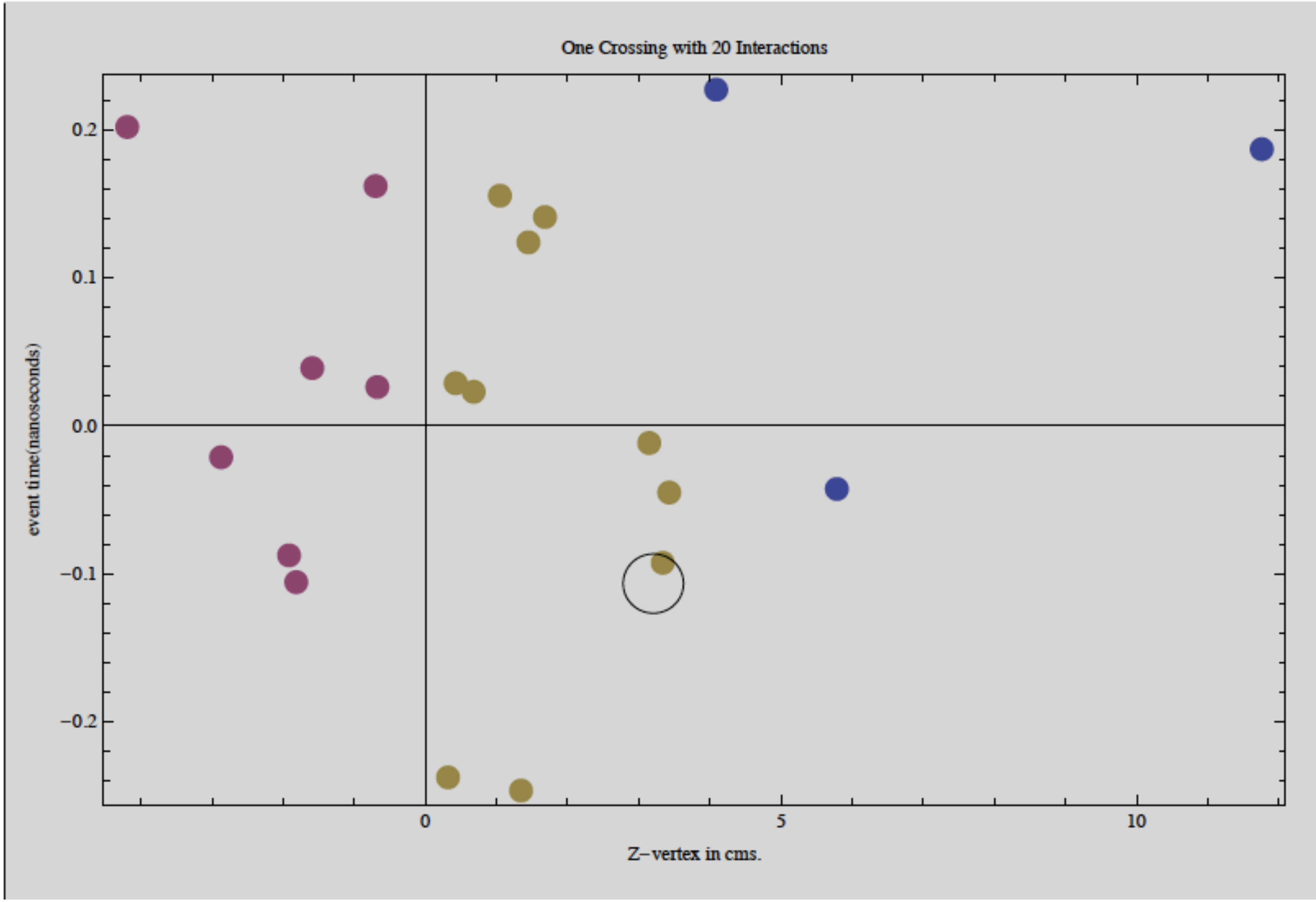
- In late 2009, Brian defined a separate activity, within ATLAS, to look into a fast timing solution for full (10^{34})luminosity

"At maximum luminosity the proposed detectors will have rates in the 10 MHz range and **see an integrated charge of a few tens** of coulombs per year depending on the exact details of the detectors and the gain at which the phototubes are operated The current commercially available MCP-PMT's will not sustain such high rates and will not have an adequate lifetime. **"-from FP420 R&D report**

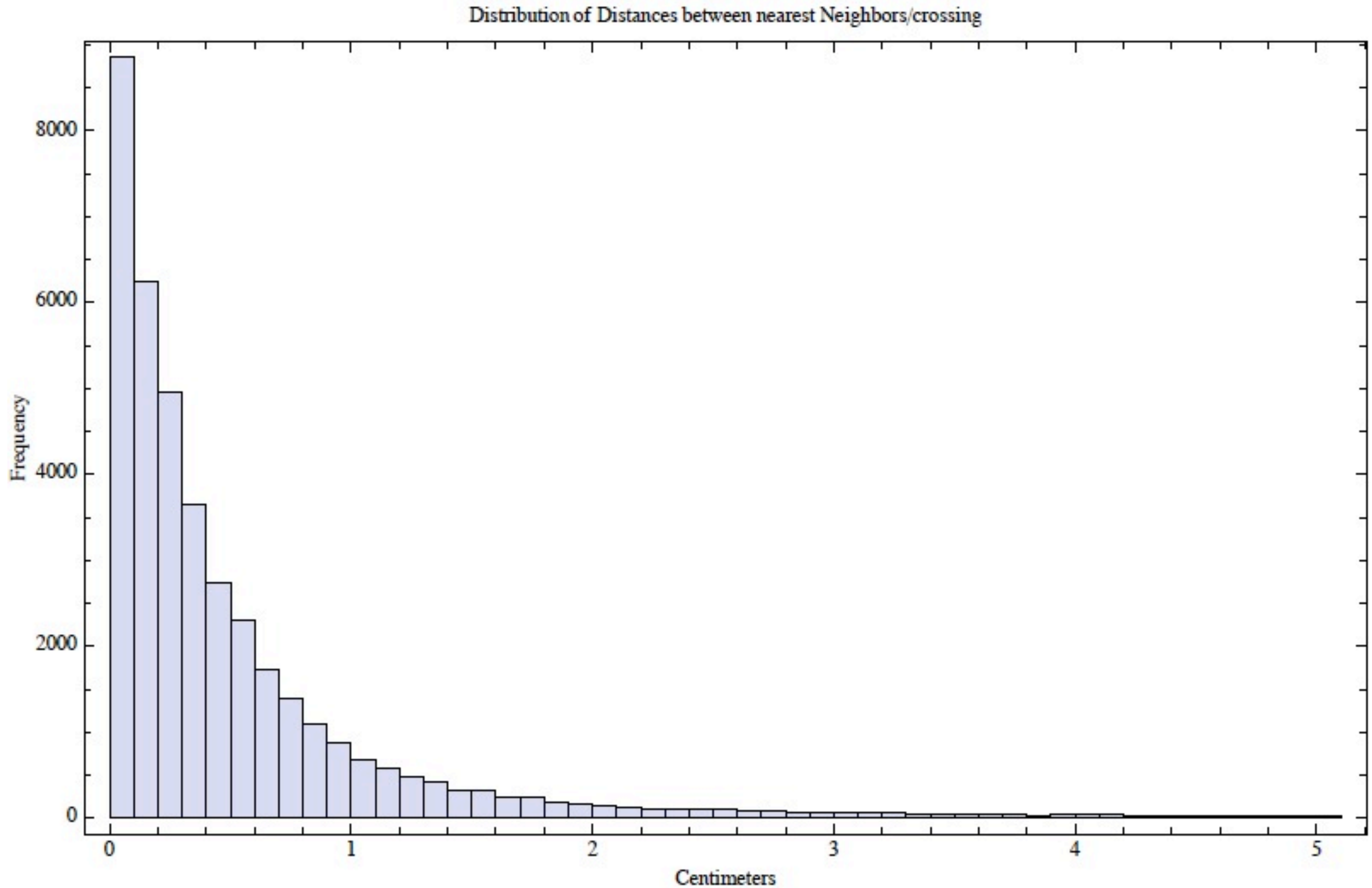
- This work started from Brian's mandate to find a timing solution at 10^{34} but, on Mike's retirement, became a generic, high rate fast timing project with Princeton/Rockefeller as lead Institutions

resolving association with leading protons:

SNW, http://adsabs.harvard.edu/abs/2007arXiv0707.1500W



this is really a generic problem! If forced to use time diff rather than vertex msmt on forward jets/or tracks



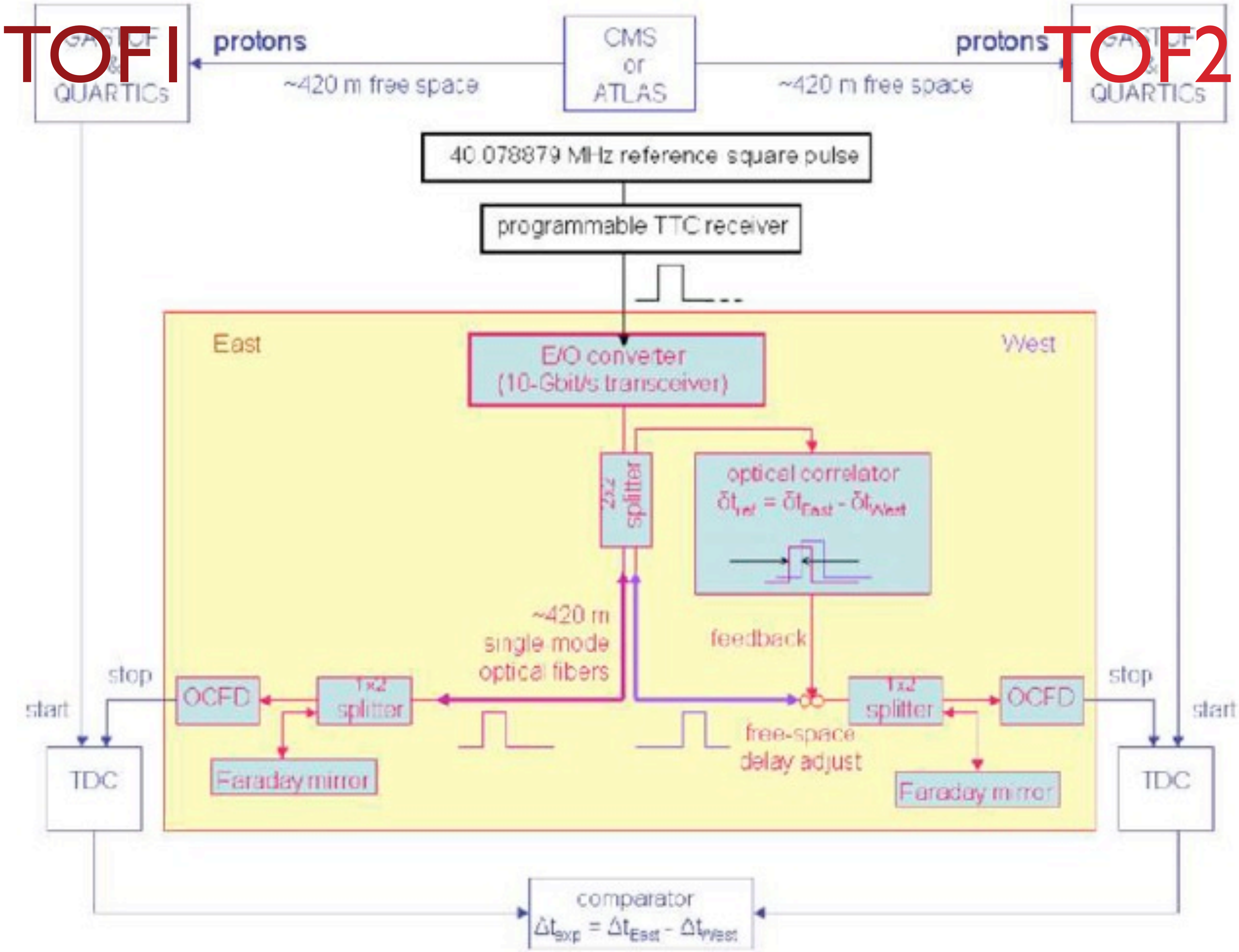
Exponential due to Poisson distributed population

see eg. p 362 Papoulis: Probability, random variables and stochastic processes (1991 ed)

Synchronization of detectors 1km apart to <5 psec is not expensive.

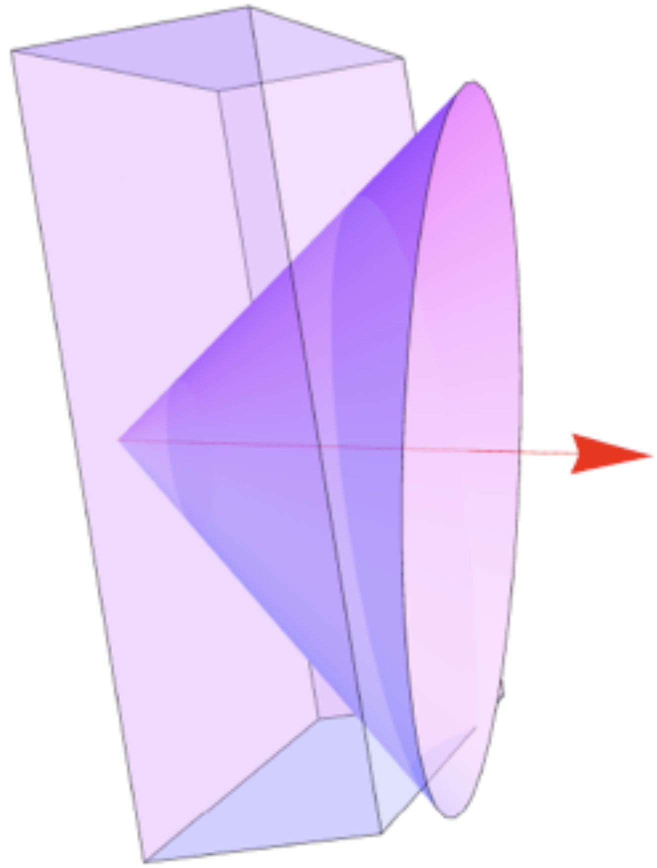
T.Tsang, SNW (and MZ): design for FP420 (cost ~$60k)

State of the art is ~10 femtoseconds using interferometrically stabilized optical fiber -see ILC design or National Ignition Facility



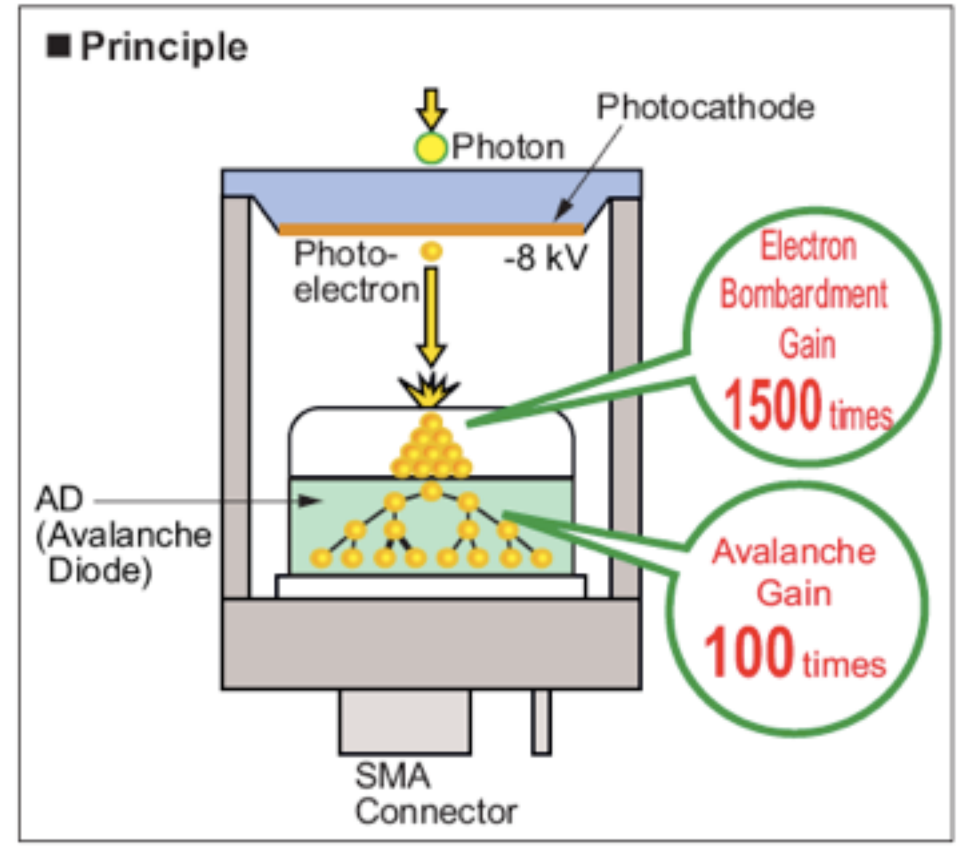
an alternative photosensor for high rates (HAPD)

- we found one (see below) but my personal opinion is that this is a non-starter because hard to deal with pileup in a Cerenkov based timing detector. Also, design of isochronous photon collection with high photostatistics difficult.
- achieved 11 psec single photon response with 300 psec risetime



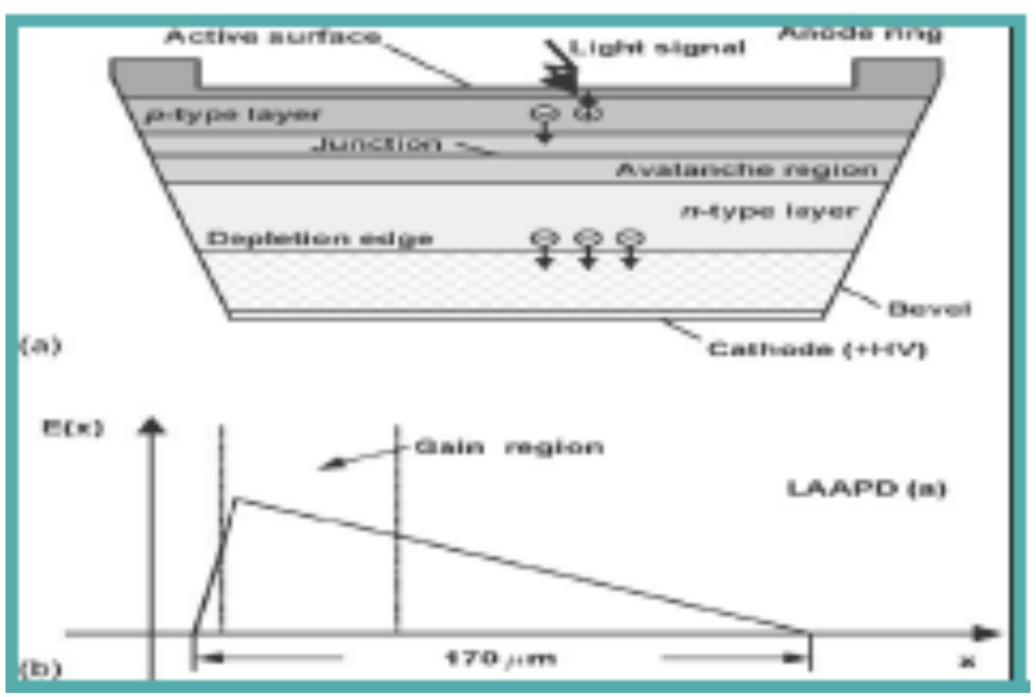
Cerenkov Radiation cone

Cerenkov
or
APD
option

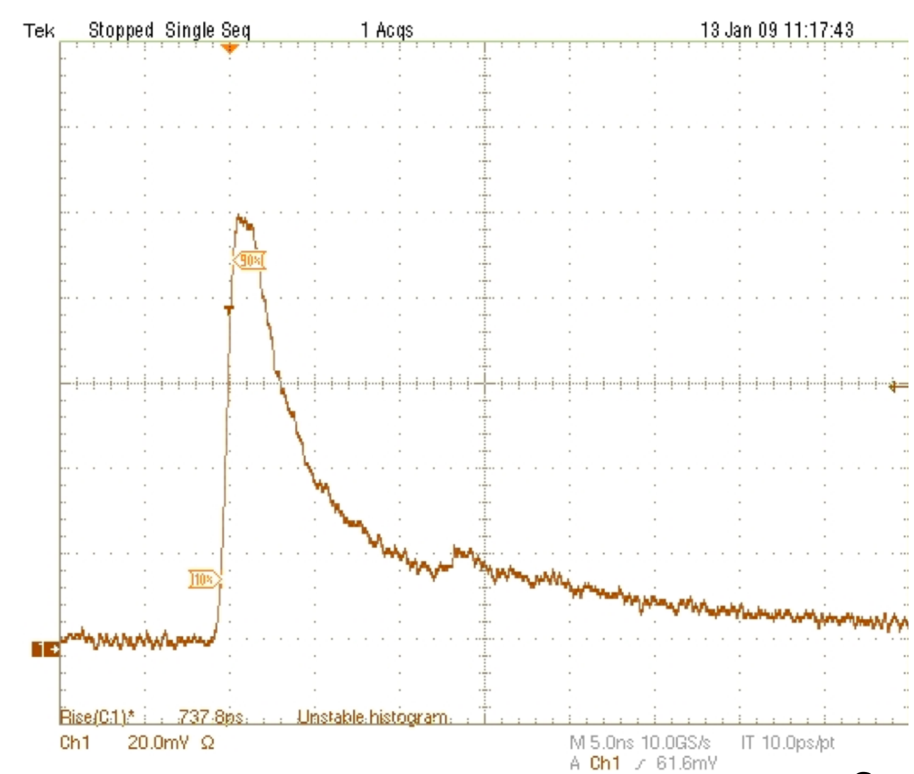


Pre-production Hybrid photodetector

"A 10 picosecond time of flight detector using APD's", SNW et al.

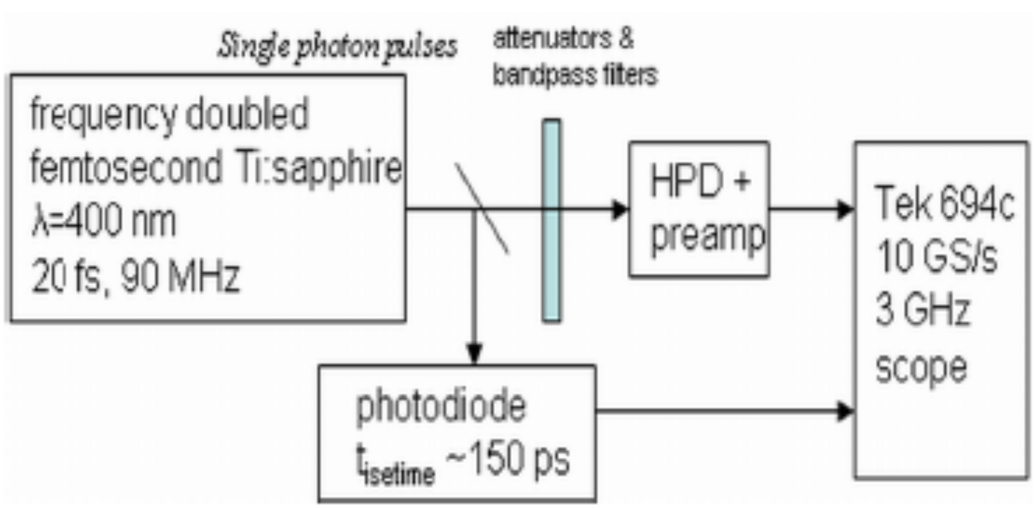


Deep diffused avalanche photodiode

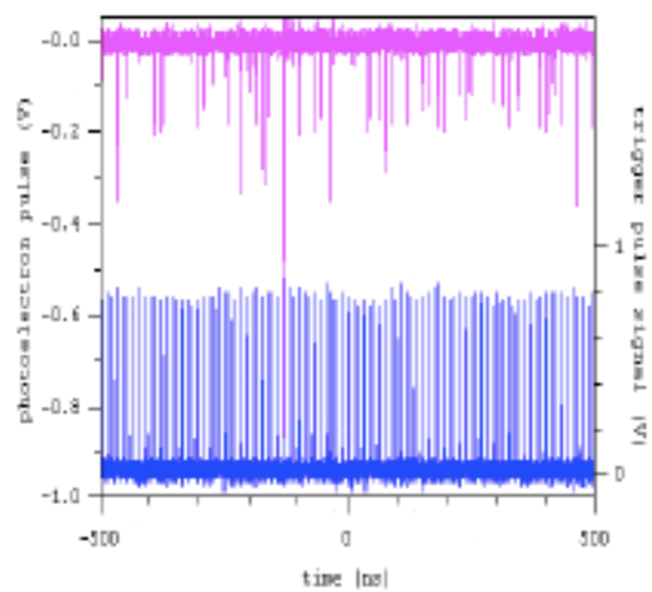


650 picosecond risetime (β's)

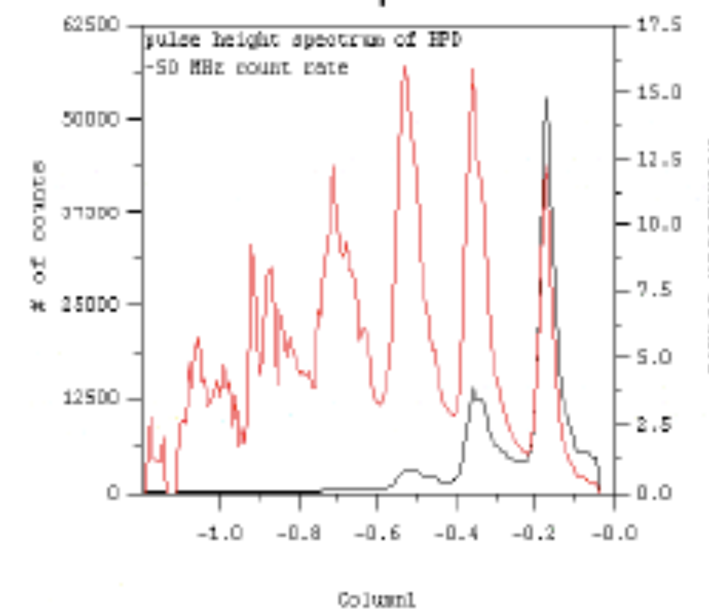
Applications in eg fluorescence spectroscopy
T.Tsang, S.White



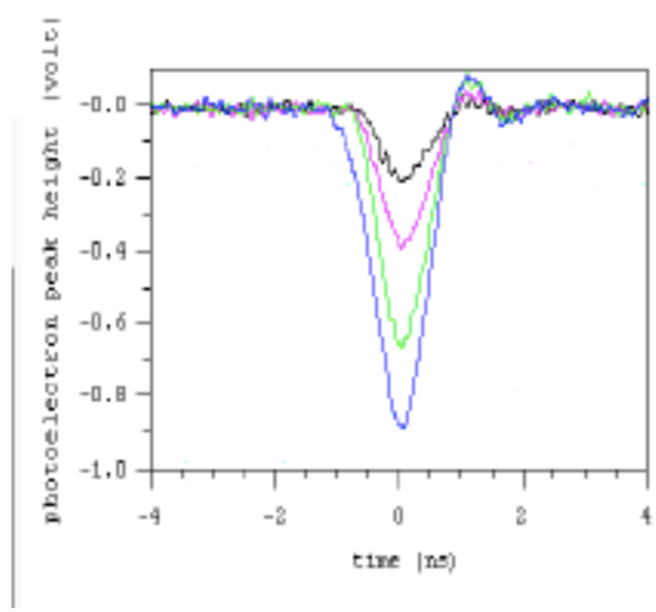
Temporal response



N_{pe}



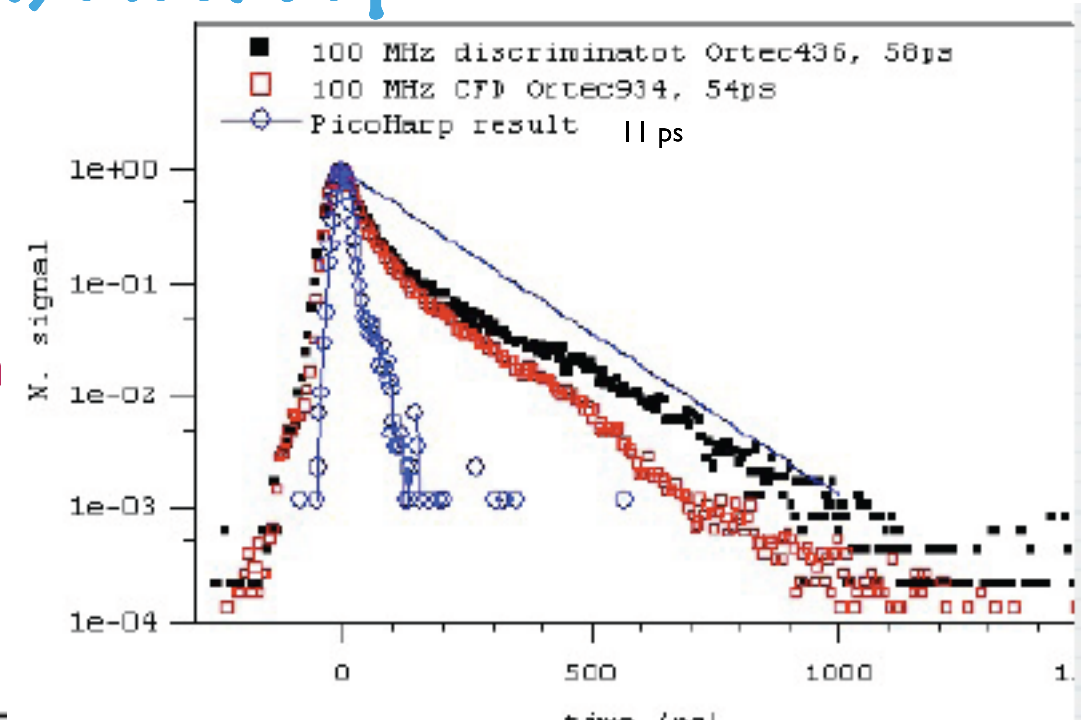
risetime=300 psec

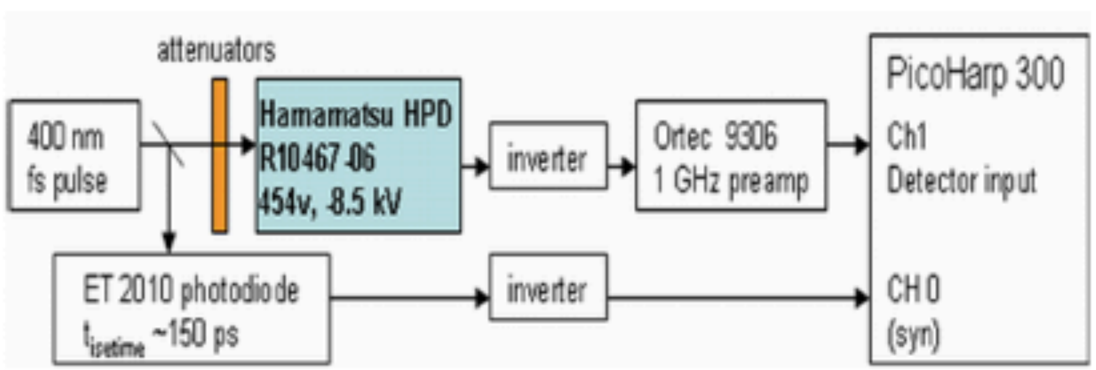


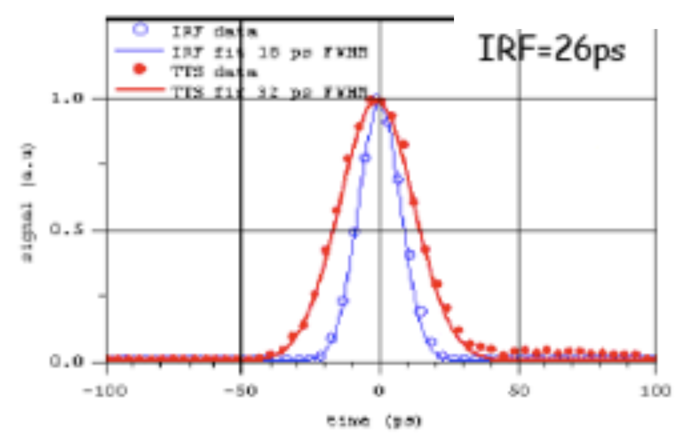
N_{pe}	pulse height after preamp (Volt)	pulse height before preamp (mV)	normalized count rate
1	0.176	2.2	1
2	0.36	4.5	0.26
3	0.528	6.6	0.061
4	0.71	8.9	0.009
5			~0.0014
6			~0.0002

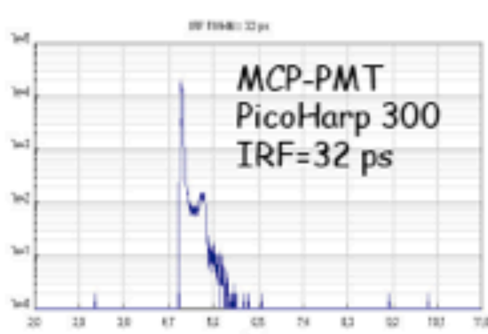
11 psec single photon response is not common! Below studies comparing LE, CFD, PicoHarp

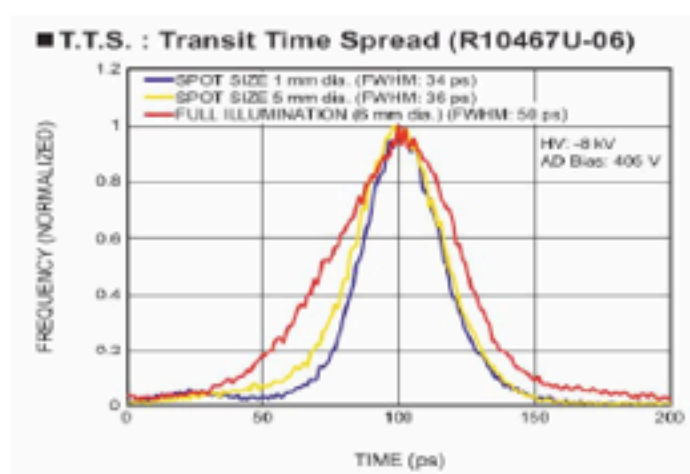
similar exercises in literature comparing methods
(see eg. Breton, Delanges, Va'vra, et al.)
now developing formalism for calculating expected resolution
-potentially useful for electronics development











Clearly a great substitute
for MCP-PMT
with 10^2-10^3 times
the lifetime!

$$\sigma_{TOF} = \sqrt{\sigma^2_{HPD} + \sigma^2_{radiator} + \sigma^2_{electronics}}$$

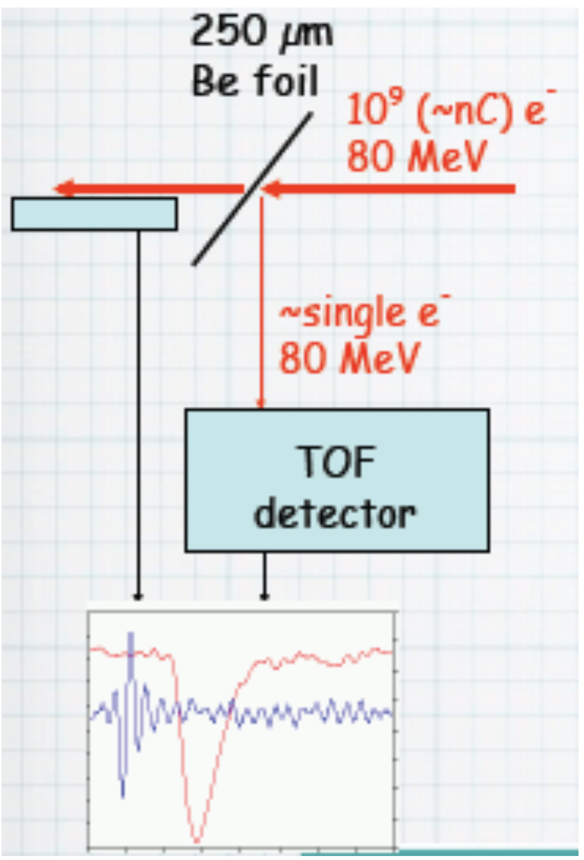
$$\sigma_{HPD} = \frac{\sigma_{TTS}}{\sqrt{N_{pe^-}}} = \frac{11\,ps}{\sqrt{N_{pe^-}}}$$

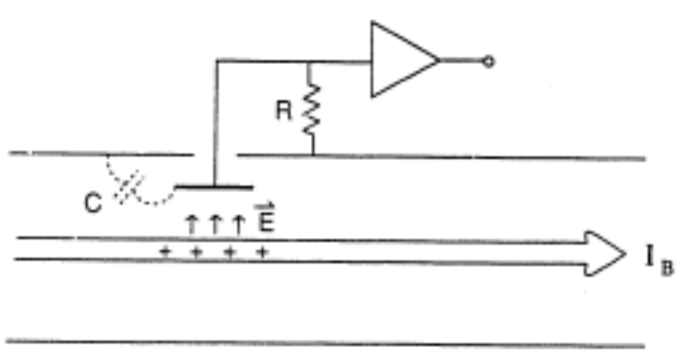
Testbeams used to characterize APD based timing detector

1. Single electron project at ATF
2. PSI (~200 MeV muons and electrons)
3. Frascati BTF <500 MeV electrons, tertiary beam from DAFNE Linac

5. **Energy Calibration of Underground Neutrino Detectors using a 100 MeV electron accelerator** / White, Sebastian ; Yakimenko, Vitaly
An electron accelerator in the 100 MeV range, similar to the one used at BNL's Accelerator test Facility, for example, would have some advantages as a calibration tool for
Argon neutrino detectors. [...]
arXiv:1004.3068. - 2010.

rates calculated based on Hofstadter's data



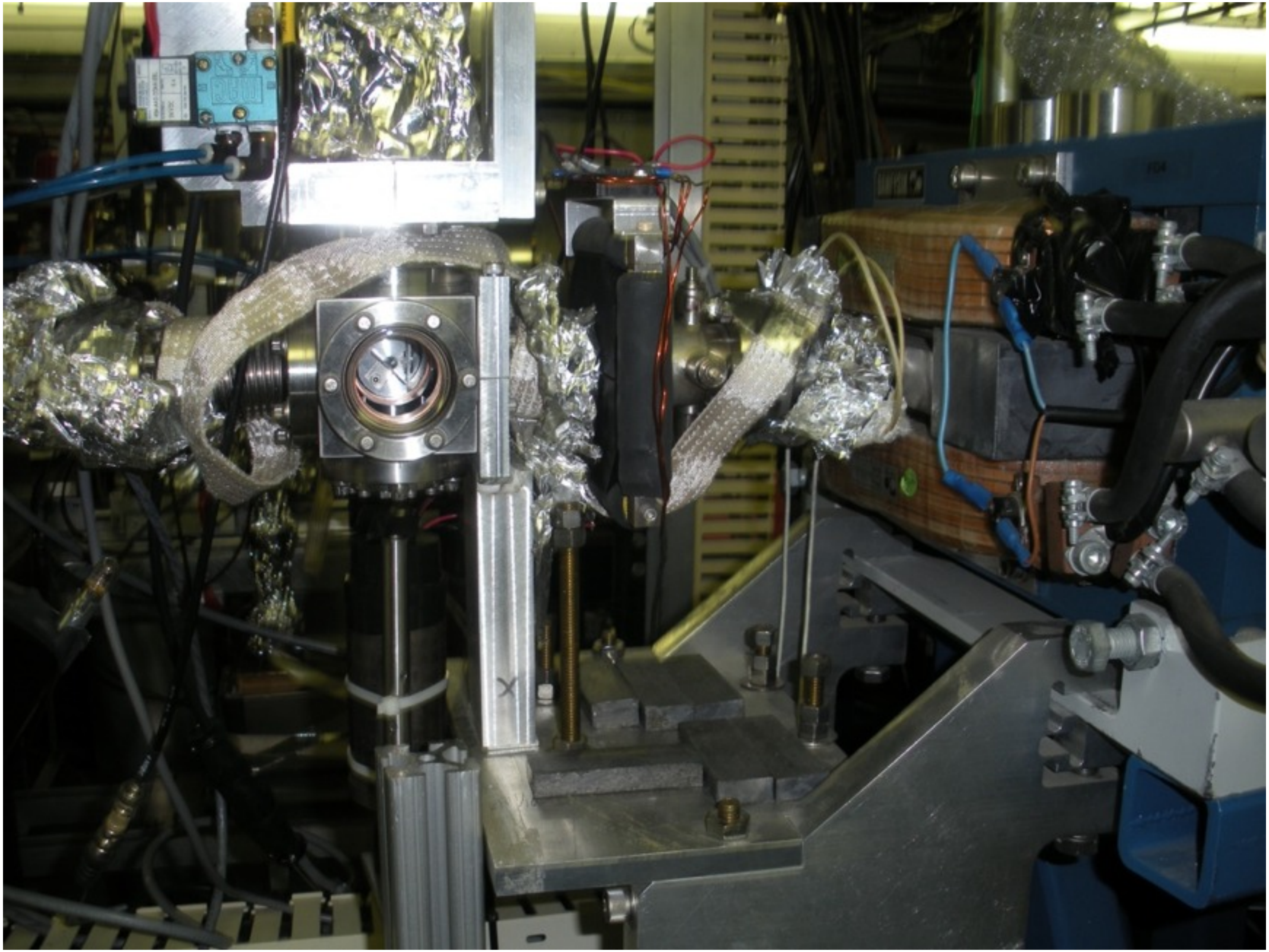


- a unique feature of ATF beam is 3 picosec bunch length(streak camera)
- could this be exploited to evaluate fast timing detectors?
- common technique for secondary beam design is successive dispersion and collimation
- this requires real estate

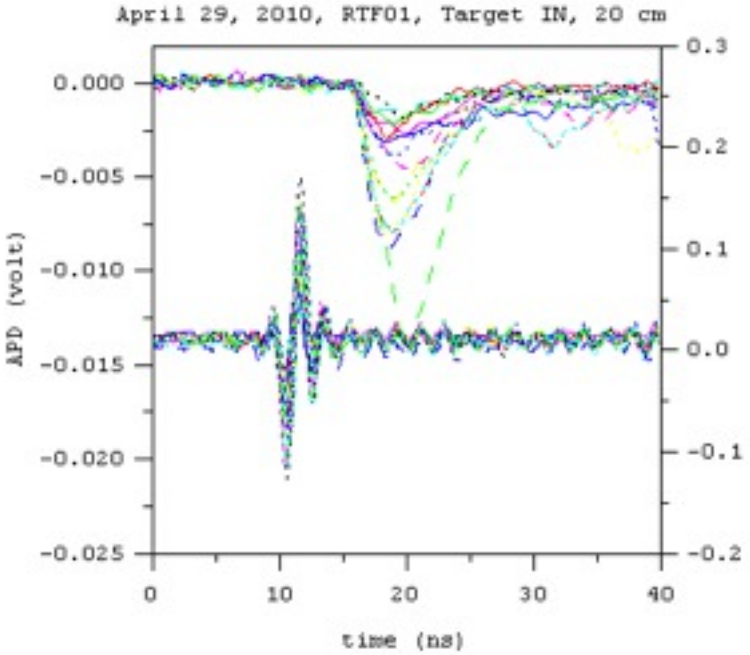
Kirk, Thomas, Misha

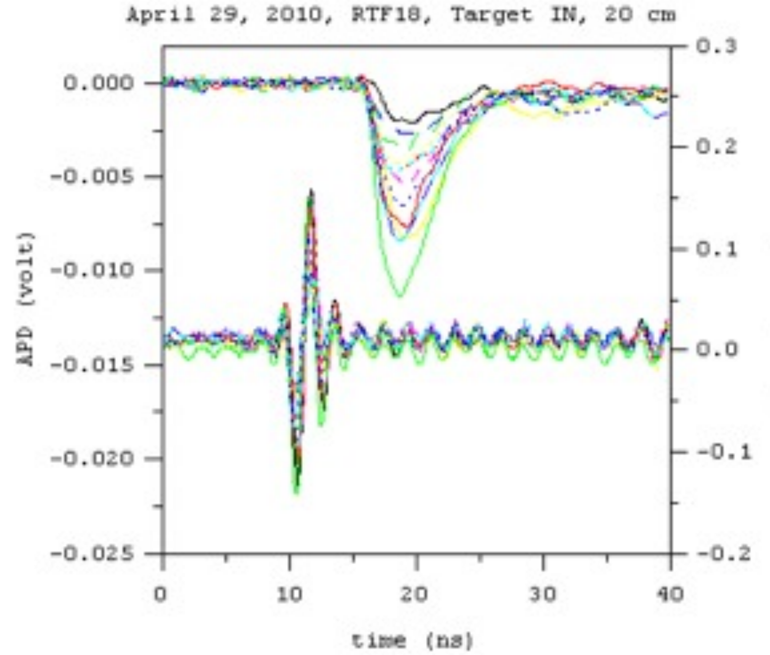
Vitaly

the beamline

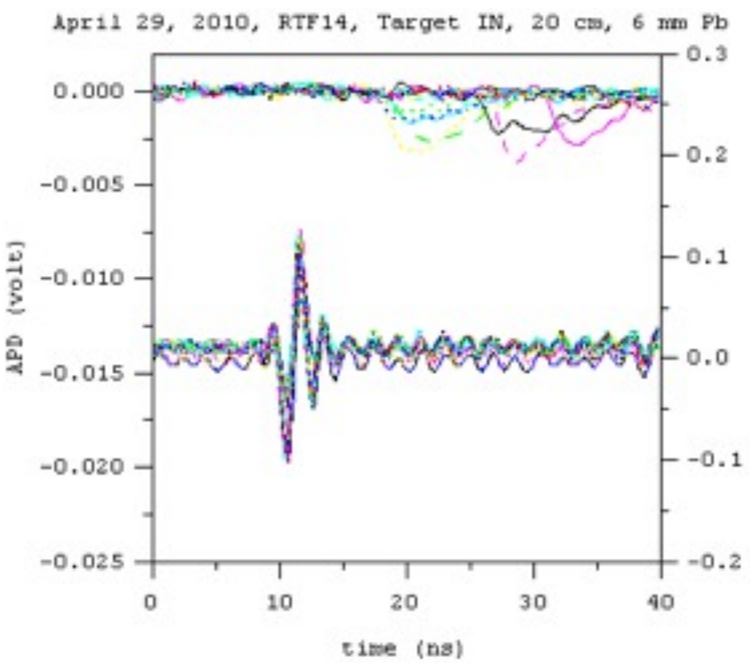


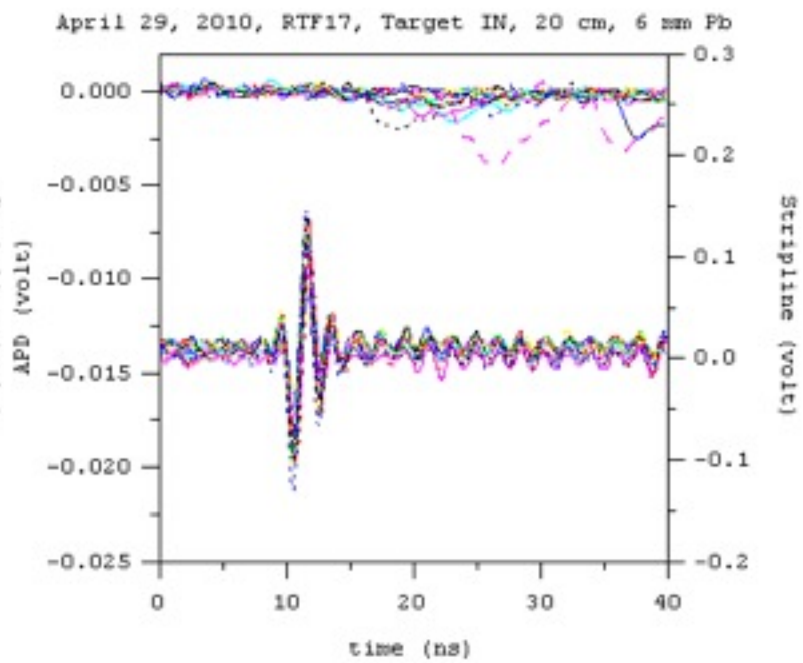
Target IN 20 cm



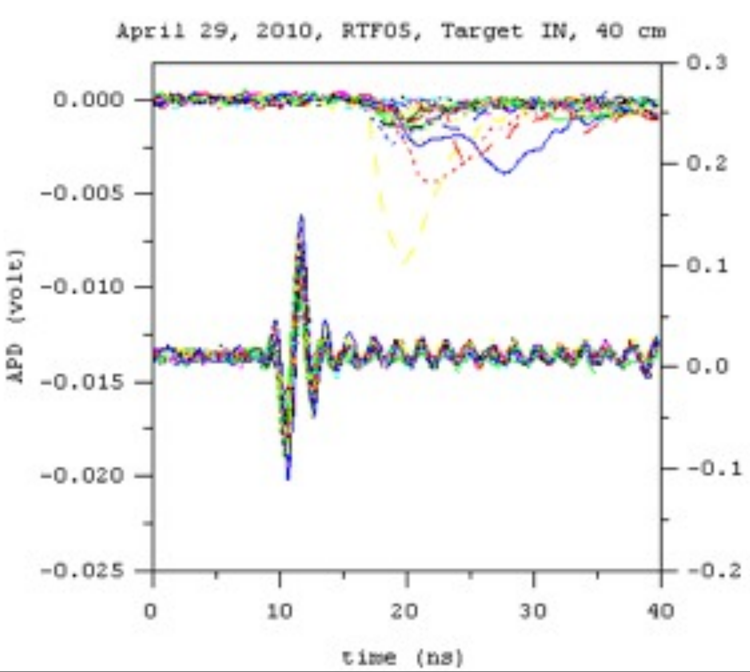


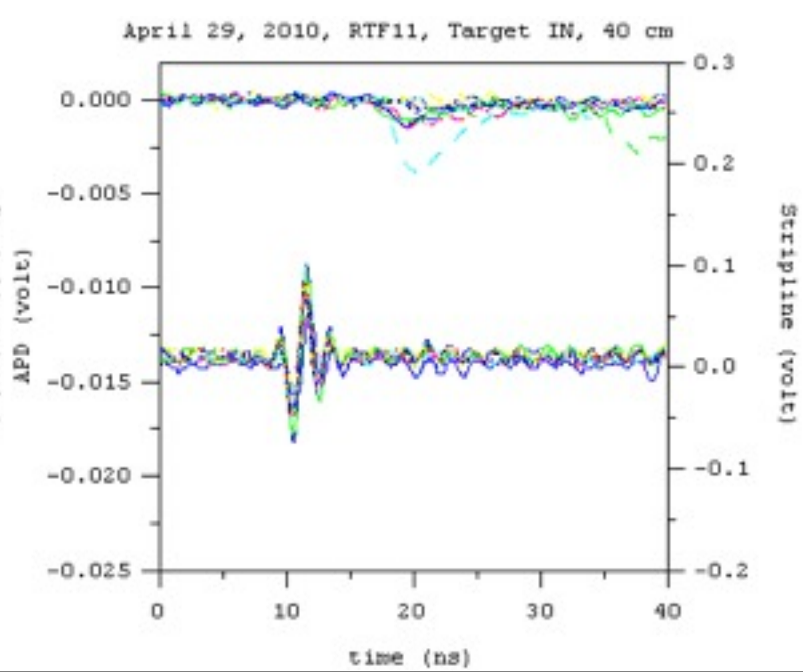
Target IN 20 cm, 6 mm Pb



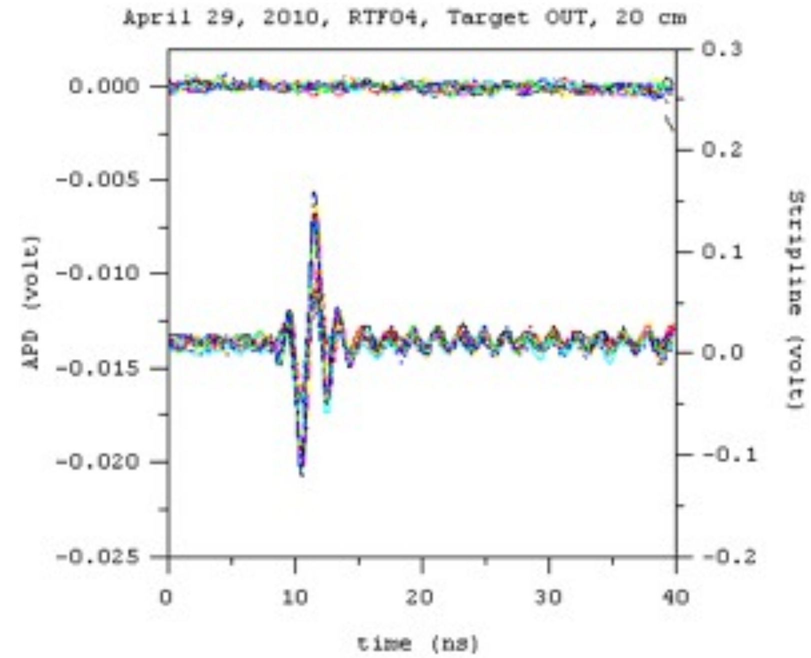


Target IN 40 cm

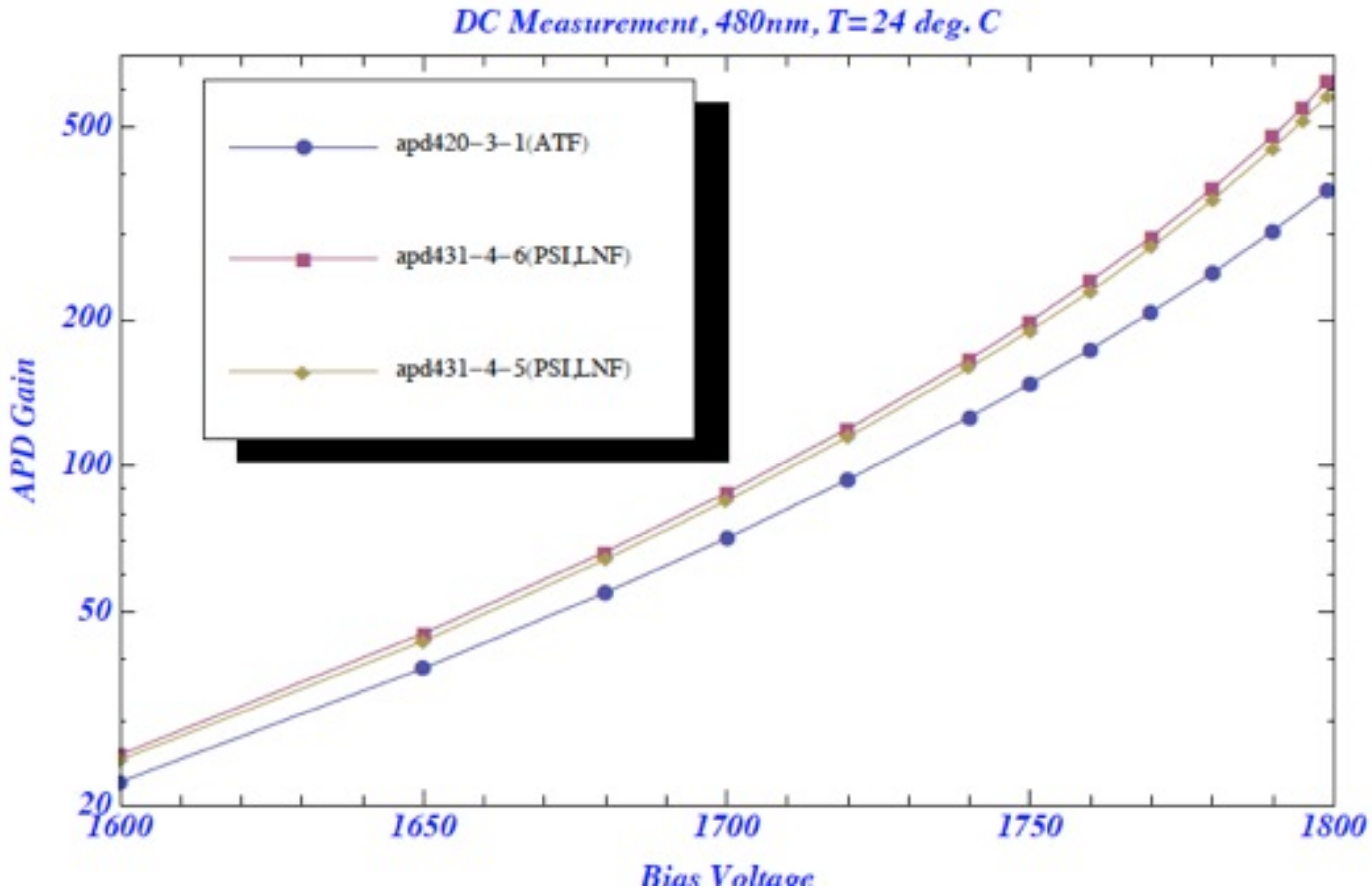


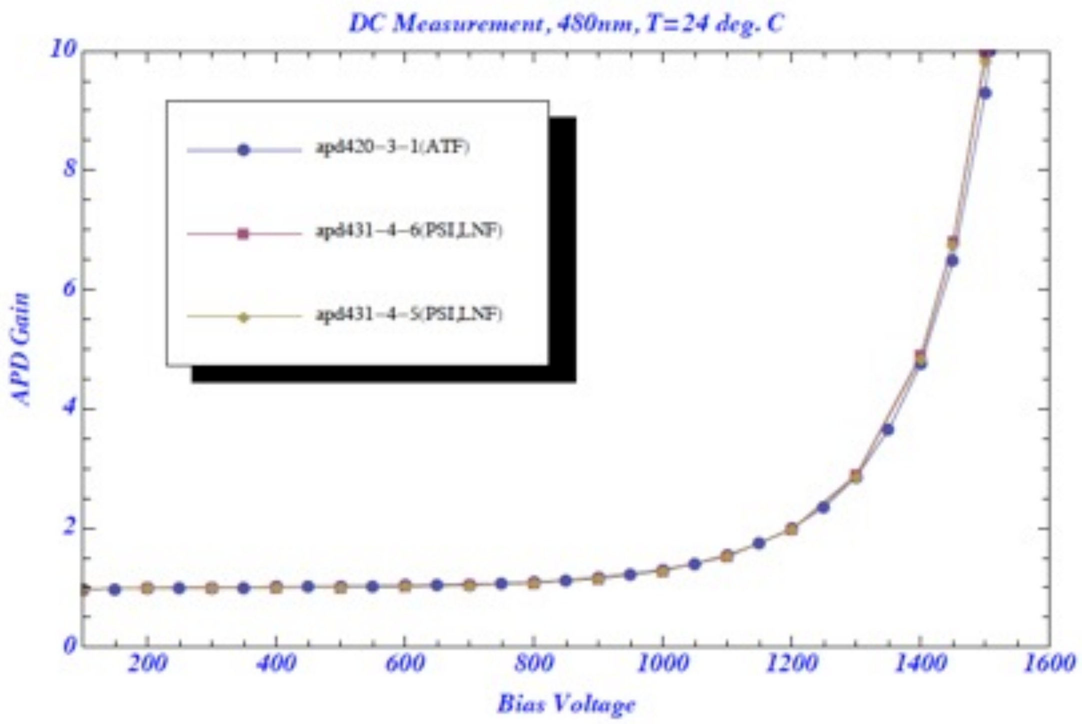


Target OUT 20 cm



Gain Curve for APDs used in Frascati/PSI





Expected APD mip signal

In[130]:=

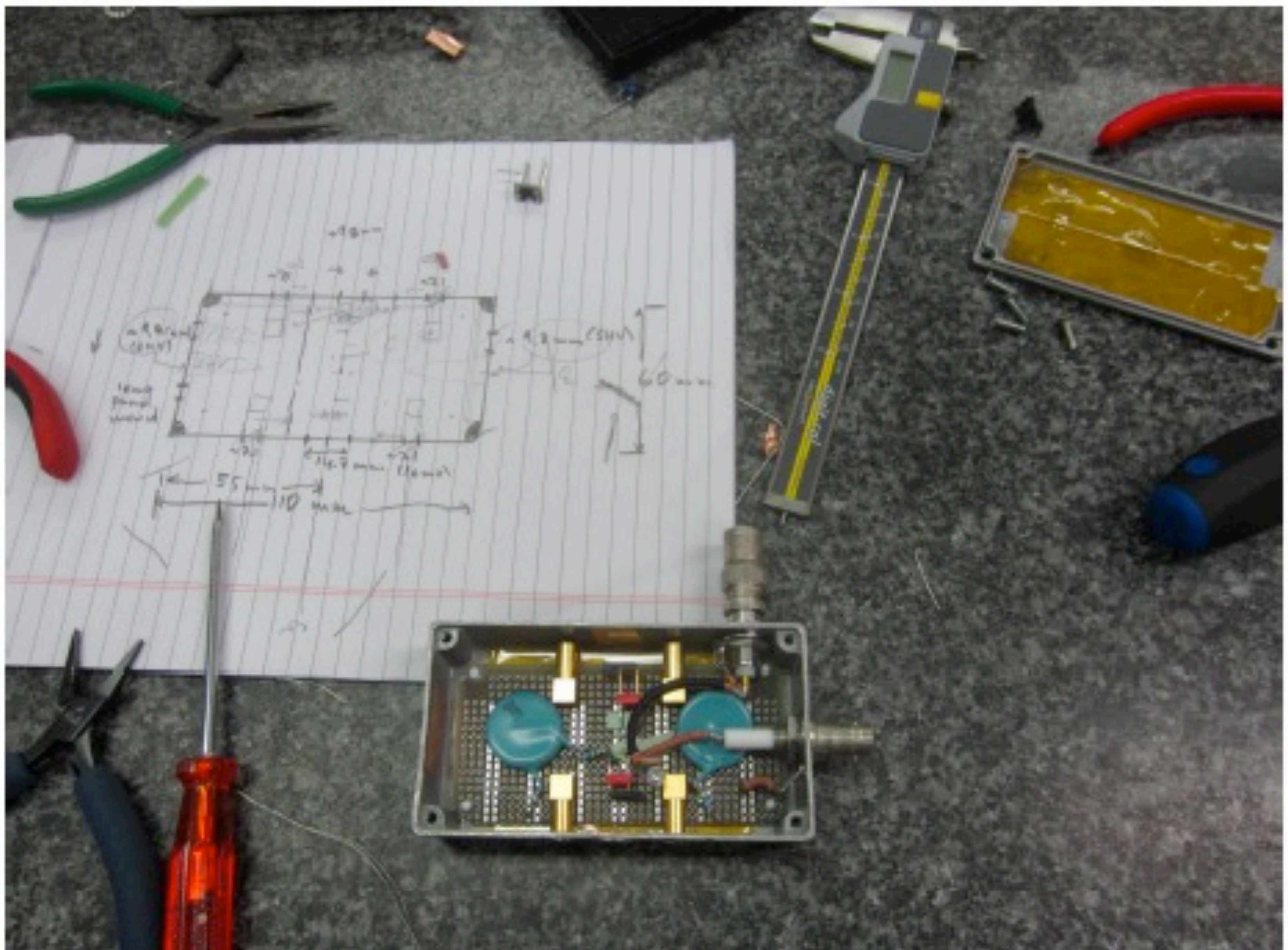
```
q = 6000 * 200 * 1.6 * 10^-19;
ampgain = 8;
t = 5 * 10^-9;
i = 2 * q / t;
mV = 1000;
e = i * 50 * mV * ampgain
```

Out[135]= 30.72

In fall 2011 (in Crispin's lab) at CERN focused on getting fastest possible signal from apd. Low noise, fast amplifiers, LRS 6 GHz, 40 GSa/s scope, etc.

help from Crispin Williams, Fritz Caspers,Christian Joram, Iouri Musienko, Philippe Farthouat, Xavier Boissier...

Partly assembled APD telescope(the kluge board is suited for high frequency work since it has a ground plane on the underside).

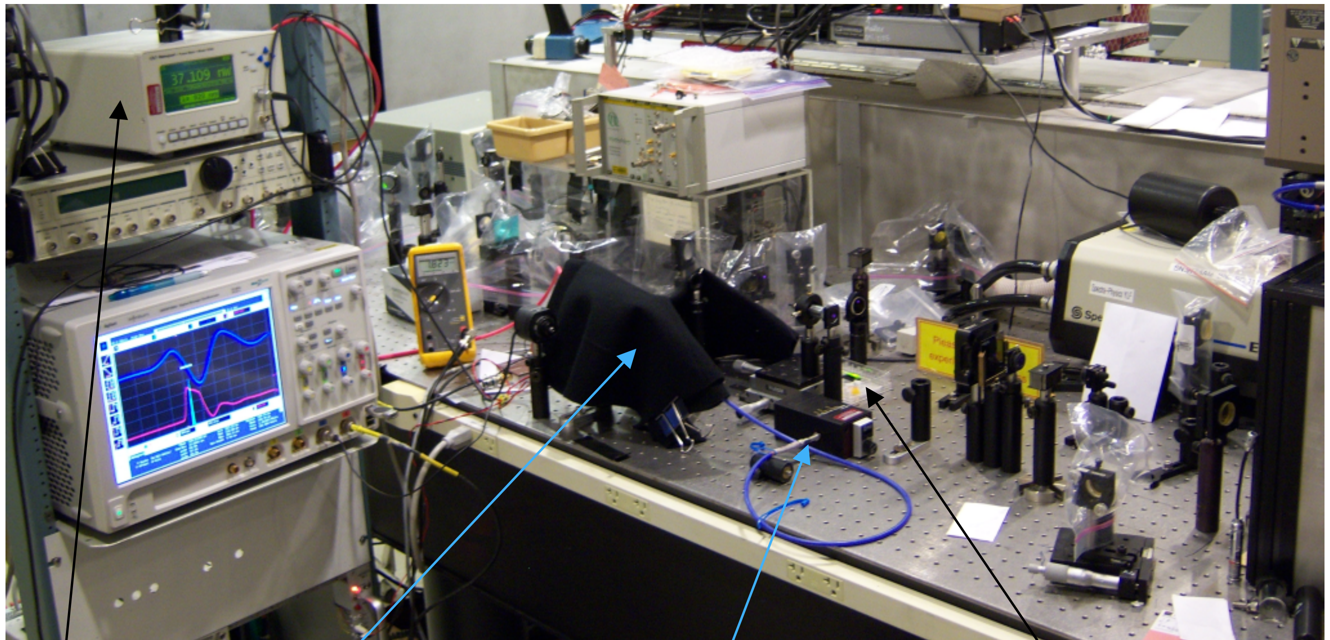


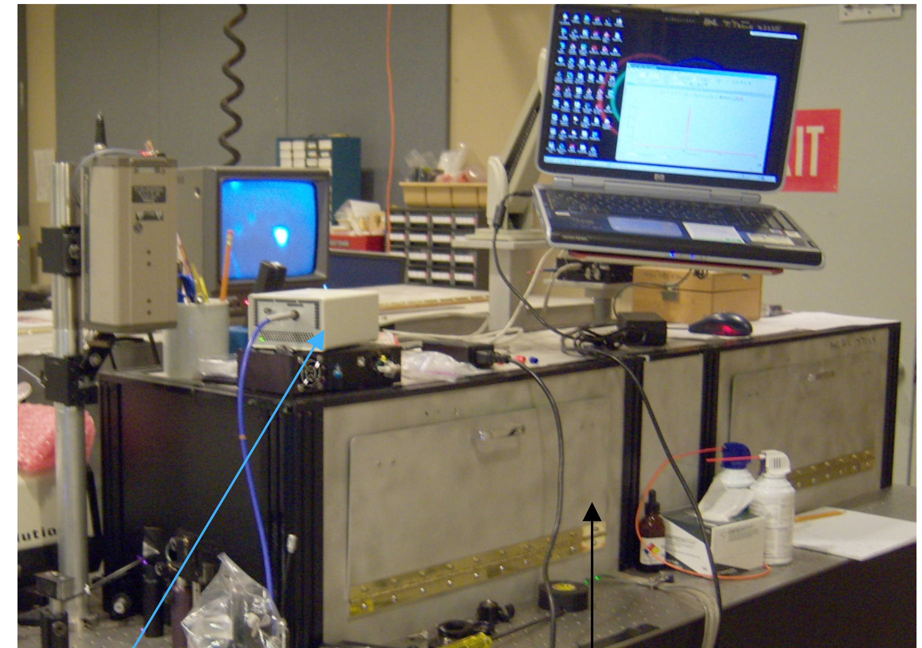
More Amplifiers with higher bandwidth just arrived from Princeton=>this will improve both risetime and SNR.

PSI testbeam team:

- testbeam results (all with 8x8mm APDs) and beta source tests (mostly using 2x2mm APDs) gave inconsistent results which we attributed to lack of tracking information and potential for position dependence of timing performance. This has held up publication of results- particularly under the DOE ADR&D project.
- In late August 2012 started tests with a femtosec laser. At ~1000nm and with proper intensity this is excellent model for MIP signal formation. Advantage of good localization (to <20 microm) and laser timing signal (to beter than 2 picosec).

Experimental set-up for femtosecond laser tests





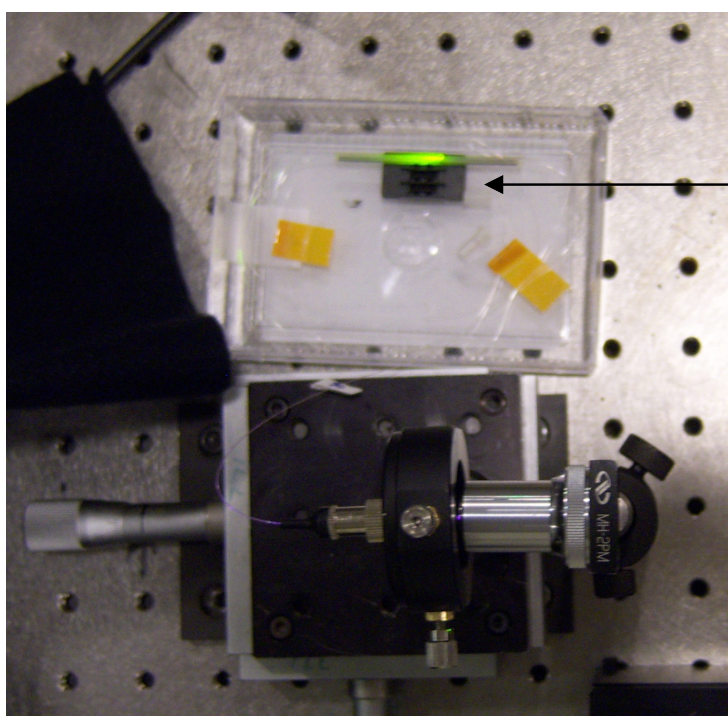
optical power meter

RMD APD

monochromator for IR wavelength selection

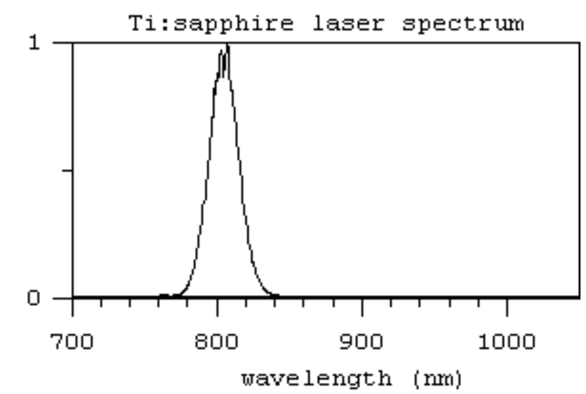
IR spectrometer

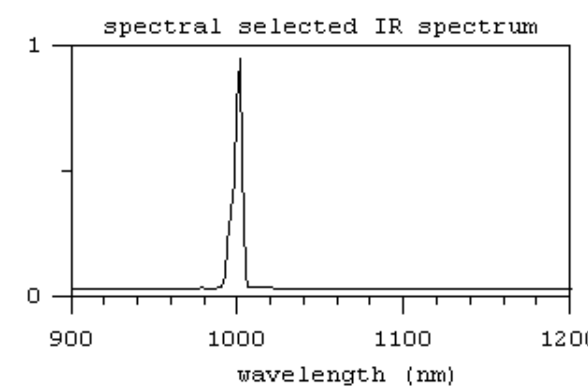
Femtosecond Ti:sapphire laser oscillator



white light supercontinuum generation from photonic crystal fiber

send IR beam directly from φ=0.6 mm optical fiber directly onto the APD both separated by <5 mm.





August 24, 2012   APD timimg jitter on Agilent DSO91304A 13 GHz oscilloscope

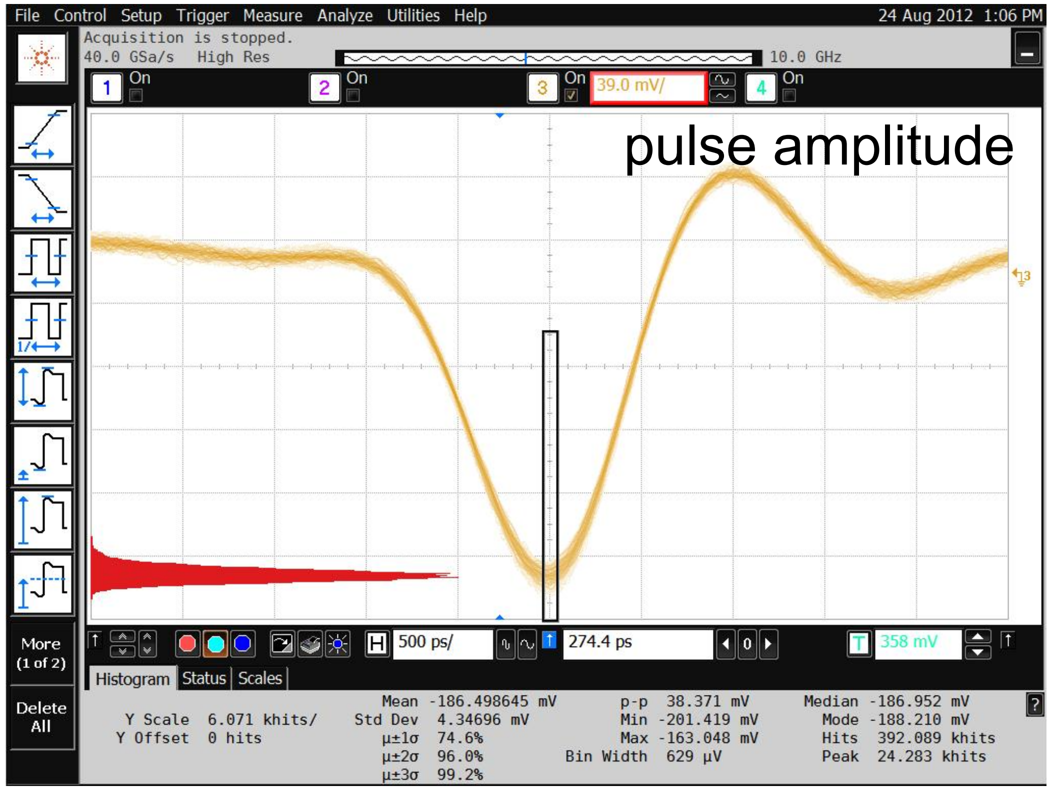
Laser wavelength: **1000 nm, ~ 2 μW**

Trigger: ET2010 photodiode, t_r=120 ps

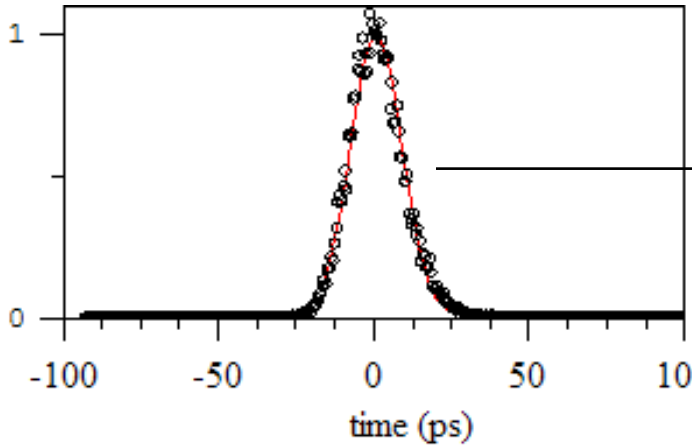
Signal: RMD APD + Ortec 9306 preamp

HV bias on APD -1.85 kV

(this is a relatively high bias- near Top of range. At lower bias (1.75 kV) Jitter is 9.8 psec.)
Nb: these are raw distributions from LE timing, no signal processing, baseline Restoration or post-analysis.



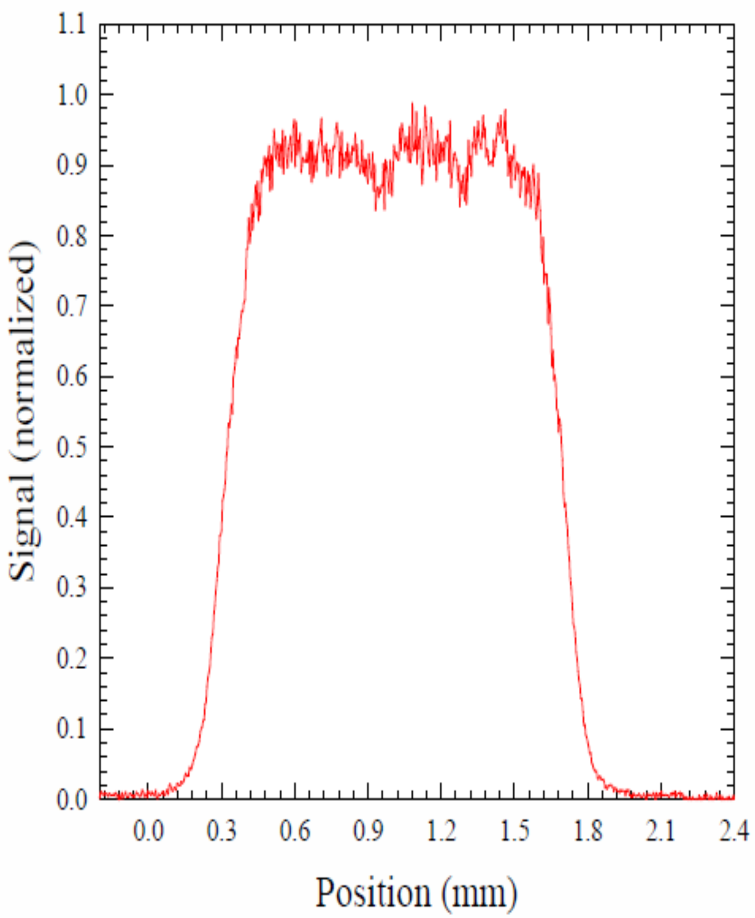
timing jitter
t_{rms}=8.28 ps



Spatial response map of RMD APD

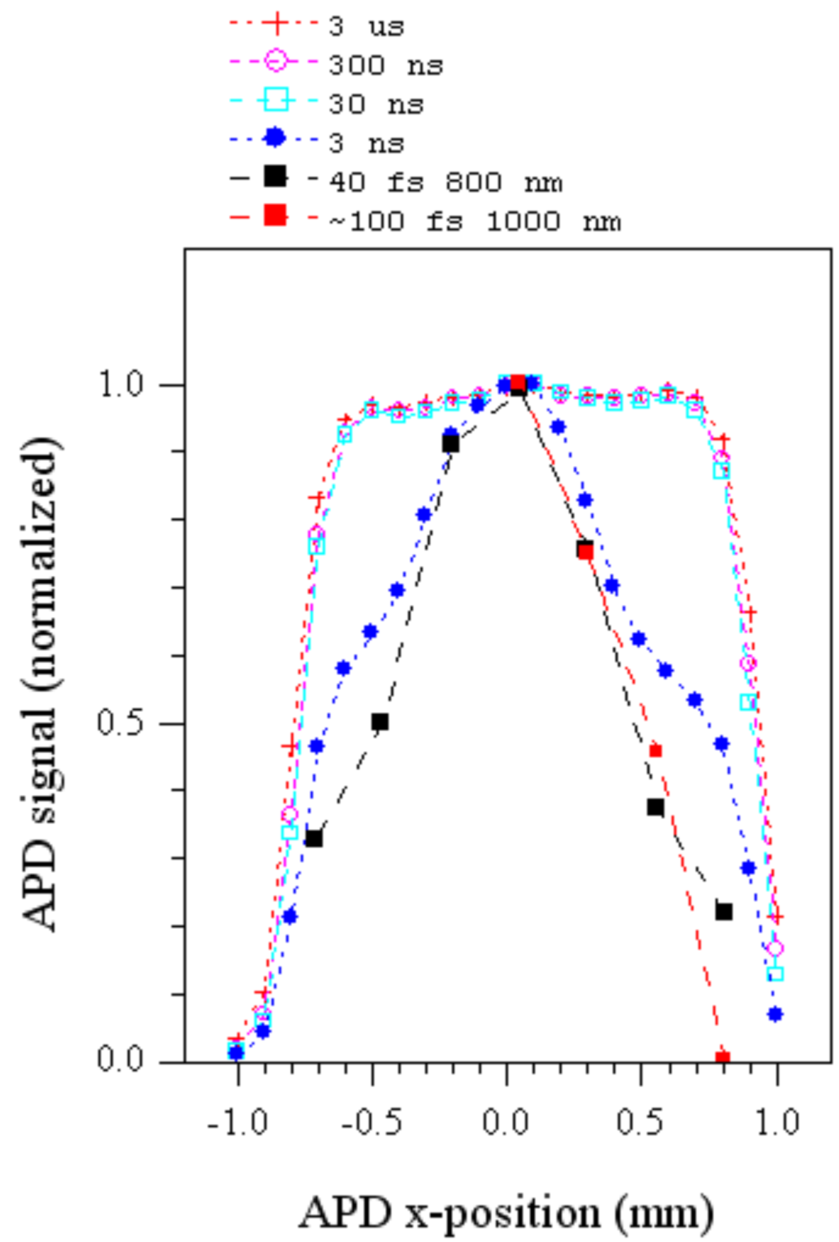
RMD data

Data from 1/12/10
Standard ~ 4 mm2
APD biased near breakdown (Gain > 500)
980 nm laser pulse, 2 μs, no averaging
laser focal spot size ~ 10 μm

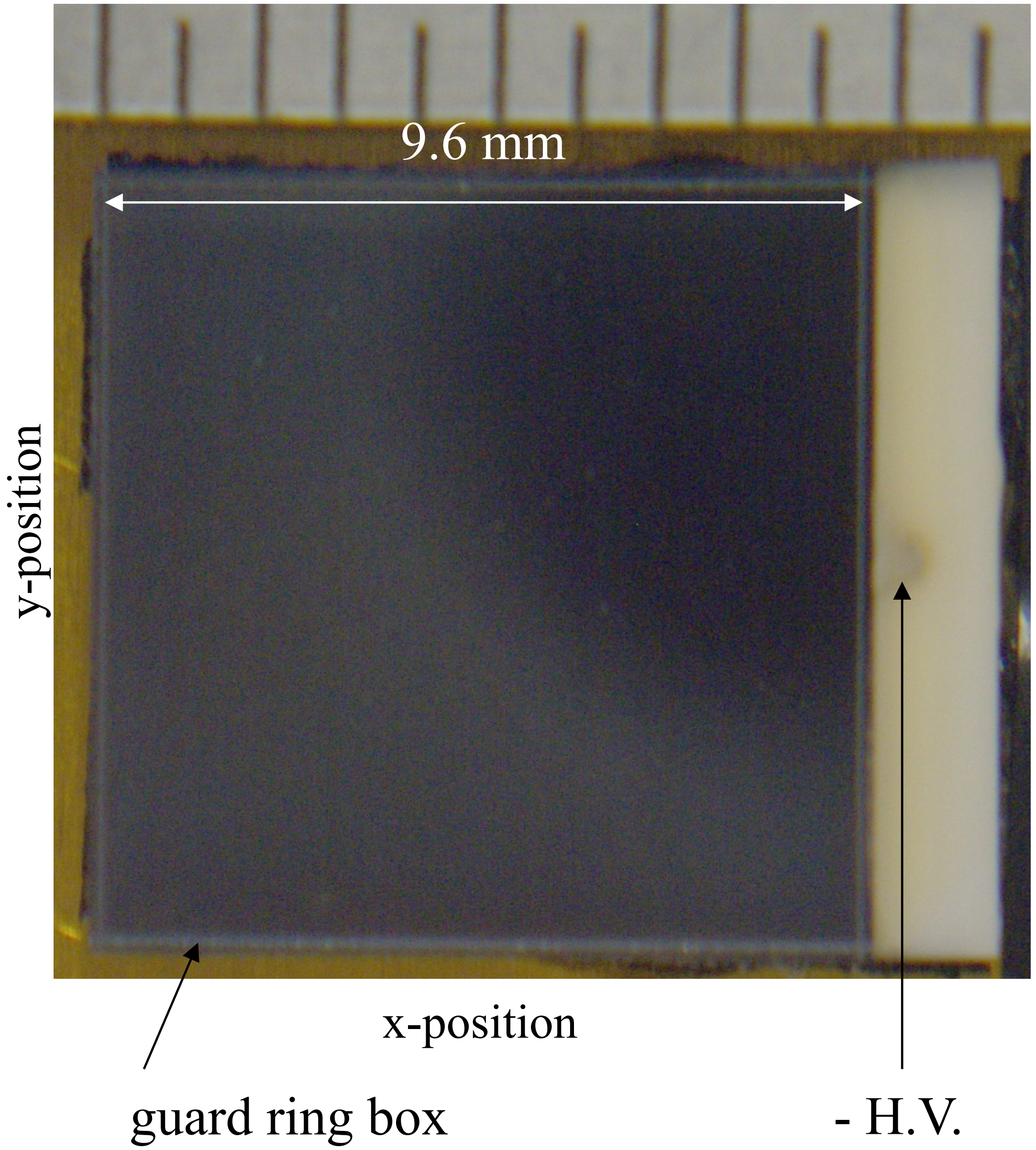


T. Tsang data, Inst. Div.

Sept. 12, 2012
Laser pulse width 3 μs to ~fs

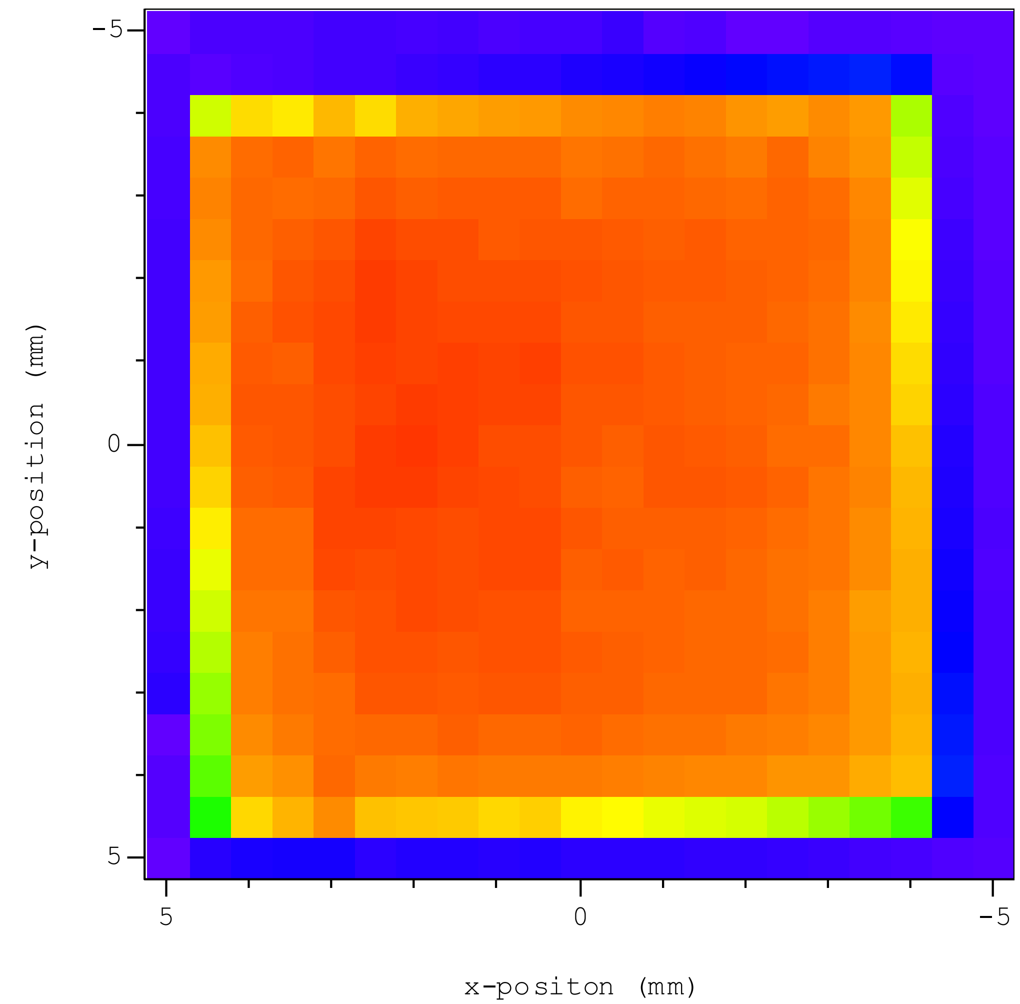


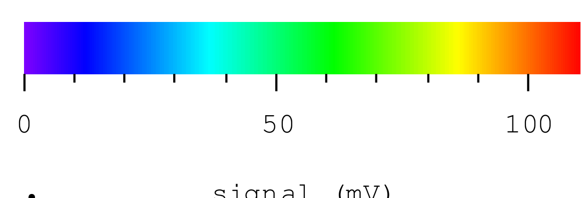
Sept 26, 2012   RMD APD 8x8 mm^2



Spatial response map

APD bias at -1750 volt, 850 nm laser
laser focus spot size <100 μm
~3 μs pulse, 1 kHz, 8.5x10^7 photons/pulse

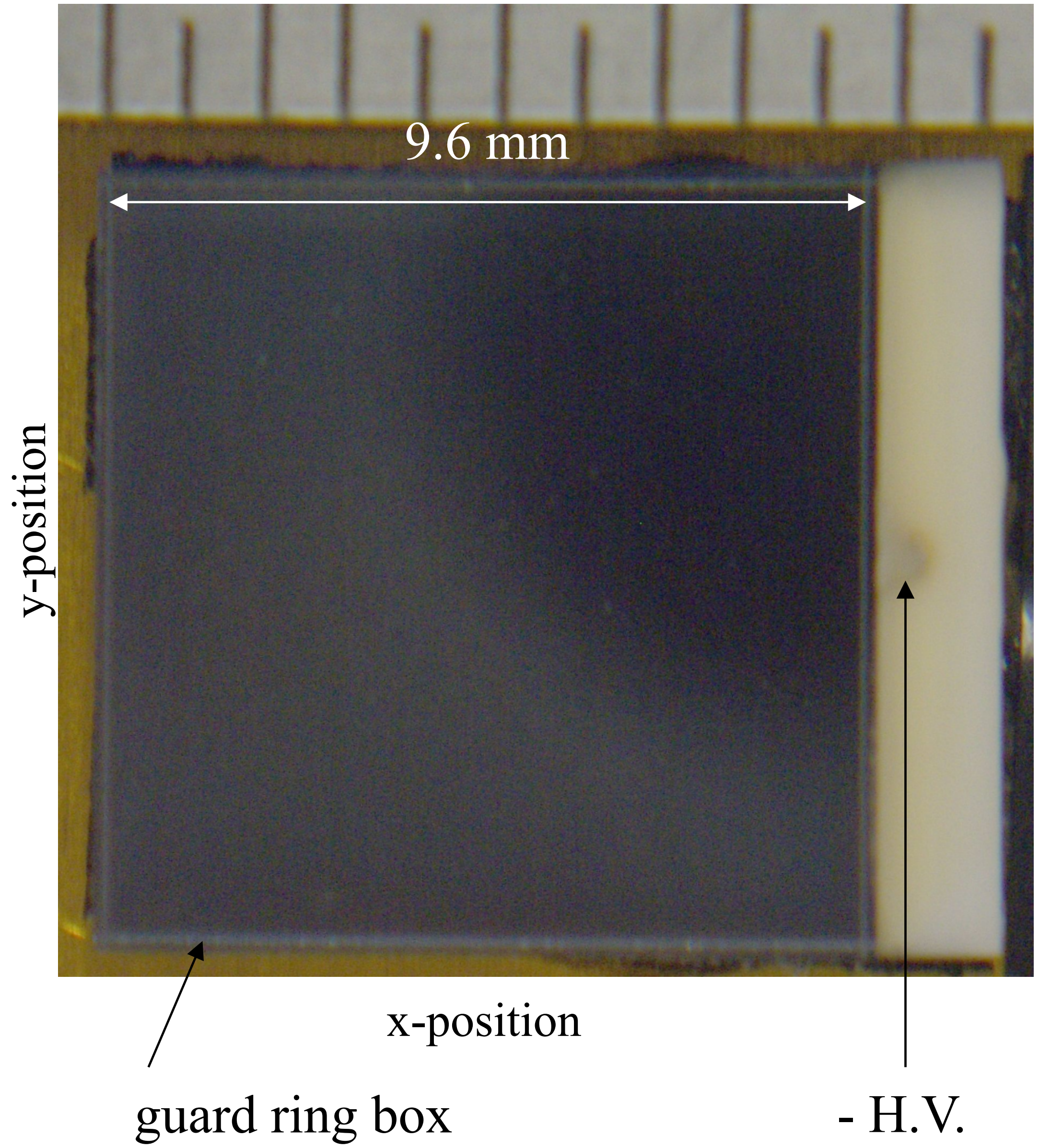




APD active area is larger than 8x8 mm^2 ?

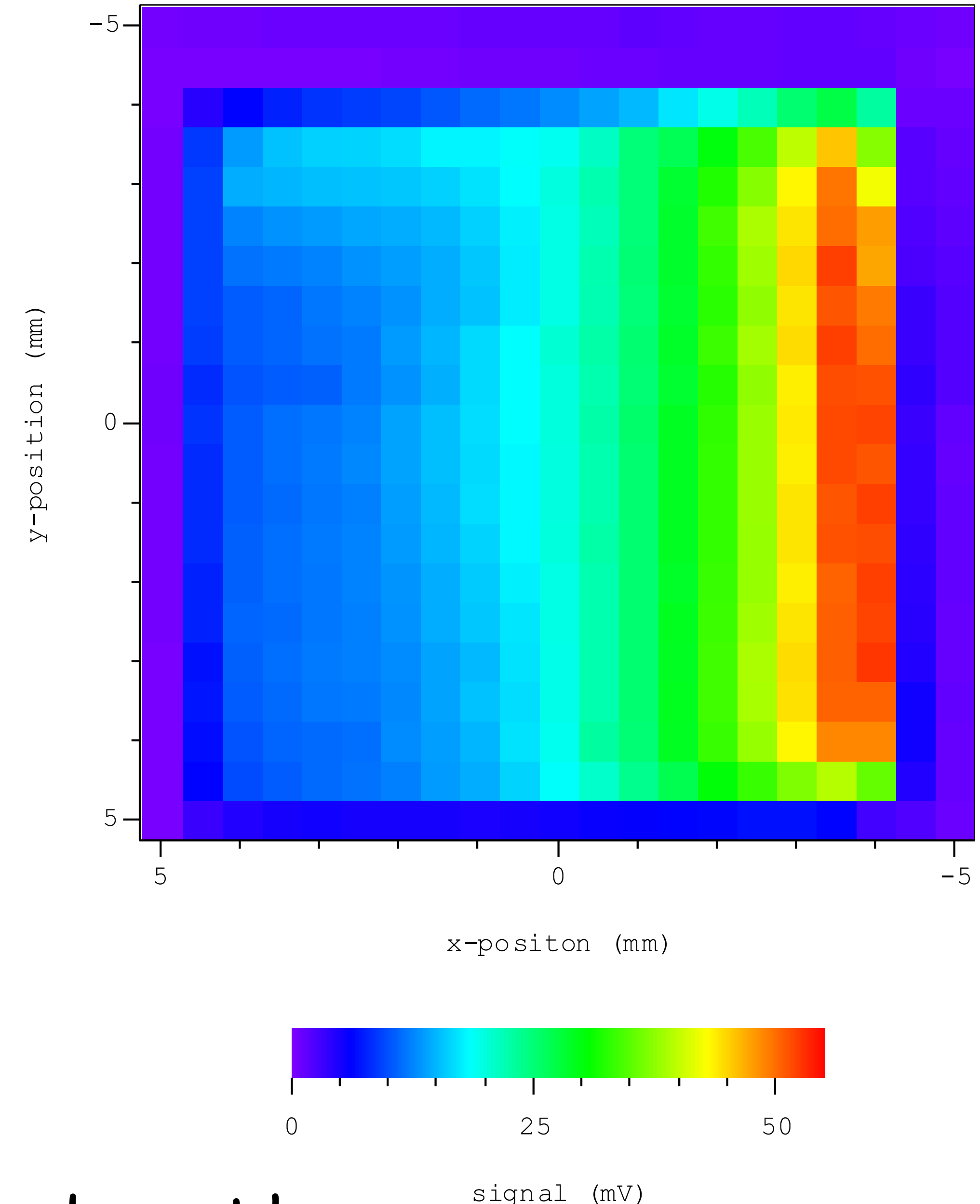
APD signal amplitude has good spatial uniformity with long duration light pulses

Sept 26, 2012 RMD APD 8x8 mm^2



Spatial response map

APD bias at -1750 volt, 850 nm laser
laser focus spot size <100 µm
~3 ns pulse, 1 kHz, 2.5x10^5 photons/pulse
(1-σ noise ~7.7x10^3 photons)



APD signal amplitude does not has good spatial uniformity with ns short light pulses

Here too there is clearly an issue with metalization!

Yesterday's message from Dick Farrell, Director of APD Research at RMD, Dynasil:

"Hello All,

I promised Sebastian that I would let him know if we saw anything interesting. We don't yet have the APD coated with 50 Angstrom Al , but yesterday I applied a band of Indium around the top edge of an '8X8mm' device. This device had previously had Indium applied to its 7X7mm n+ back contact, but when tested it showed the same nonuniform response to short laser pulses as had shown up in Thomas' data. When re-tested after the Indium band was applied around the top surface, however, there was a marked improvement in the uniformity of response across the exposed area using 2ns pulses from a 980nm laser. Looking at the scope, we could discern no variation in pulse amplitude across the APD area.
My best guess, based on this result, is that......."

=>Very realistic expectation that we will have in hand 8x8 mm APDs which do not show position variation and will be fully characterized with femtosecond laser tests.
=>This greatly simplifies upcoming beam tests at T10, since tracking will be unnecessary.

Plans for coming months concerning APD (charged particle)timing R&D

- we are in productive close contact with RMD APD development activities and are jointly submitting a related SBIR
- for completeness, also in close contact with Hamamatsu concerning limits of their (thin) APD technology
- have applied for testbeam scheduling in Oct-Nov at PS
- longstanding discussion with TOTEM technical coordination about an LHC exposure in Jan-Feb 2013

*partial list of collaborators can be found in Kirk's web area- ie: http://puhep1.princeton.edu/~mcdonald/LHC/White/ATF_proposal_final_k.pdf