HighGainAPDs developed as a Hyperfast Charged Particle Sensors: Radiation Damage Issues

Sebastian White, Rockefeller U.

Oct. 10, 2014

Arcetri

- 7 year development of tools for pileup Mitigation by timing
- control of E field uniformity,effect of Landau/Vavilov
- testbeam results
- Common FEE development
- past and upcoming work on rad damage
- a hedge against rad damage and cost:RD51 project

addressing the HL-LHC experimental challenges

- 20 year history of R&D on consequences of integrated luminosity/dose
- only emerging focus on consequences of high instantaneous rate-pileup
- nice summary of ATLAS/CMS by Takubo at FNAL FCC workshop
- here focus on new tools based on timing: Started 2007 in FP420, 2010 DOE ADR&D and ATF AE55(McDonald and White), in 2014 USCMS&RD51 (see also http://arxiv.org/abs/1409.1165)

ATLAS FP420 R&D, 2007-2010. Yale, BNL Rockefeller- Zeller, White et al.- developed 5 picosecond clock distribution

DOE Advanced Detector R&D:"Fast Timing for High Rate Environments", McDonald&White 2011-2013 (BNL, Rockefeller,Princeton)

2013 USCMS charge: "build a community beyond CMS"

Development of Precision Timing Pileup Mitigation Tools within the Context of a Dual Readout Calorimeter for CMS: *Proposal Submitted to US-CMS*

Crispin Williams[a], Andrea Vacchi[b], Paul Lecoq[c], Rob Veenhof[c], Eric Delagnes[d], Ioannis Giomataris[d], Changuo Lu[e], Kirk McDonald[e], Chris Tully[e], Jim Olsen[e], Richard Wigmans[f], Yuri Gershtein[g], Vladimir Rekovic[g], Umesh Joshi[h], Marcos Fernandez Garcia[i], Thomas Tsang[j], Sebastian White[k,]*

Request for Project Funding from the RD51 Common Fund

- Date: *20-05-2014*

Title of project: Fast Timing for High-Rate Environments: A Micromegas Solution

Contact persons: *Sebastian White (co-PI),CERN/ Rockefeller sebastian.white@cern.ch*
Ioannis Giomataris (co-PI), Saclay ioa@hep.saclay.cea.fr

RD51 Institutes:

1. *IRFU-Saclay, contact person Ioannis Giomataris*
ioa@hep.saclay.cea.fr
+ Alan Peyaud, Eric Delagnes

2. *NCSR Demokritos, contact person George Fanourakis*
gfan@inp.demokritos.gr

3. *CERN, contact Leszek Ropelewsky Leszek.Ropelewski@cern.ch*
+SEBASTIAN WHITE swhite@rockefeller.edu
+ Eraldo Oliveri and Filippo Resnati
+RD51&Uludag University, Rob Veenhof veenhof@mail.cern.ch

4. *Universidad deZaragoza, Diego González Díaz*
diegogon@unizar.es

Ext. Collaborators: **1**. *Rockefeller/FNAL, contact person Sebastian White*
swhite@rockefeller.edu

2. *Princeton University, contact person K.T. McDonald,*

Sensor Technology

- better to understand whether anything available/affordable/ survivable if physics demands timing
- good first start is to talk to commercial manufacturers. We have been working directly with Hamamatsu responsible for MCP/ PMTs for past 7 years, so had easy access to info

Some MCP/PMT facts-Hamamatsu perspective

- nice SPTR (~15 picosec)
- pricey(>$10k/$cm^2$)
- nice work by Belle people 8 yrs ago. No one has come close.
- notoriously unsuited for high rates (Q_{anode}^{max}~0.1C)
- a small area PC alternative now available for high rates (HAPD)

What else is out there?

good place to start is "Picosecond Workshop" series started by Henry Frisch (ie Clermont meeting last March)

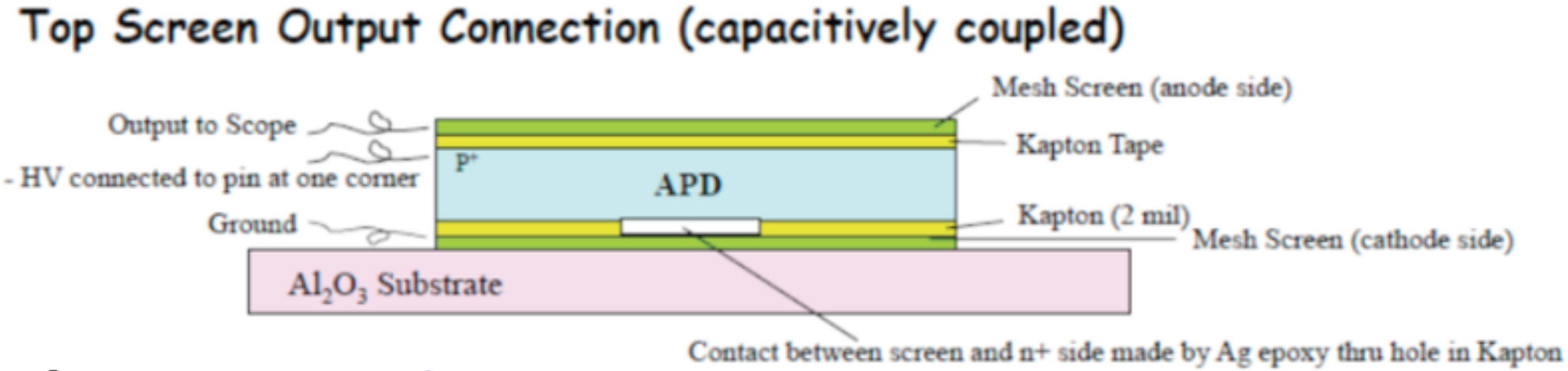
- traditionally PET and low rate HEP-ie Henry's LAPPD project primarily for neutrino expts.(see his TIPP 14 talk)
- we have been only project to report on CMS PhaseII
- some related generic-ie Sta Cruz "LGAD" and diamond det.- in context of forward protons
- we reported on long running development of Si option +GasPMT starting up+electronics development
- good progress on WFDs reported by Delagnes, Ritt, Breton (note different approach by CERN HPTDC and new paper from China in recent arxiv)-> required precision ok, need work on architecture within CMS

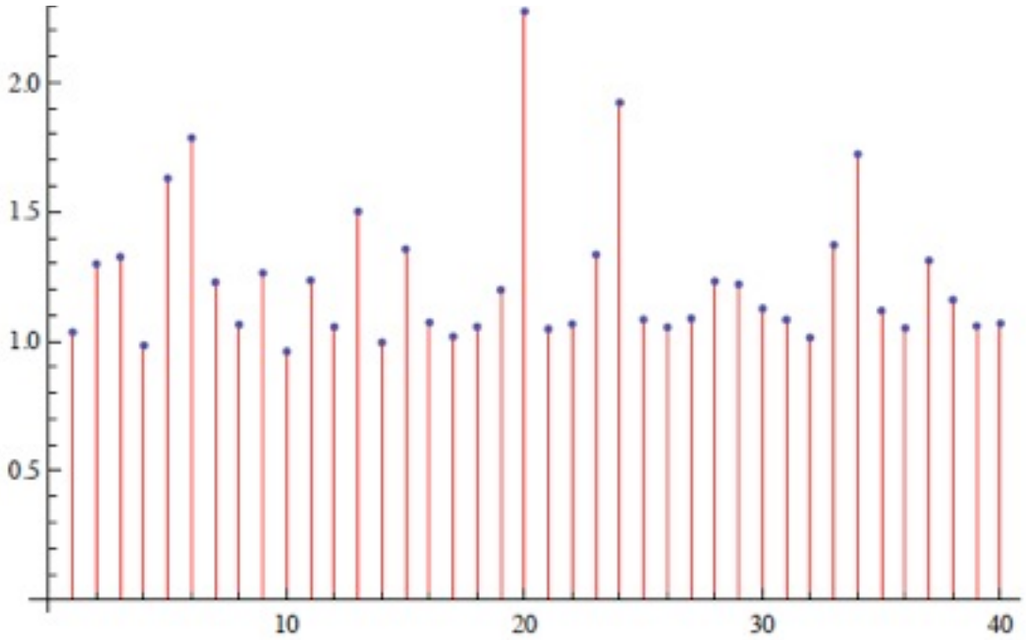
we reported on 2 technologies

(we started work on 2nd option a year ago as a hedge against concerns about cost and rad hardness -particularly if eta>3)

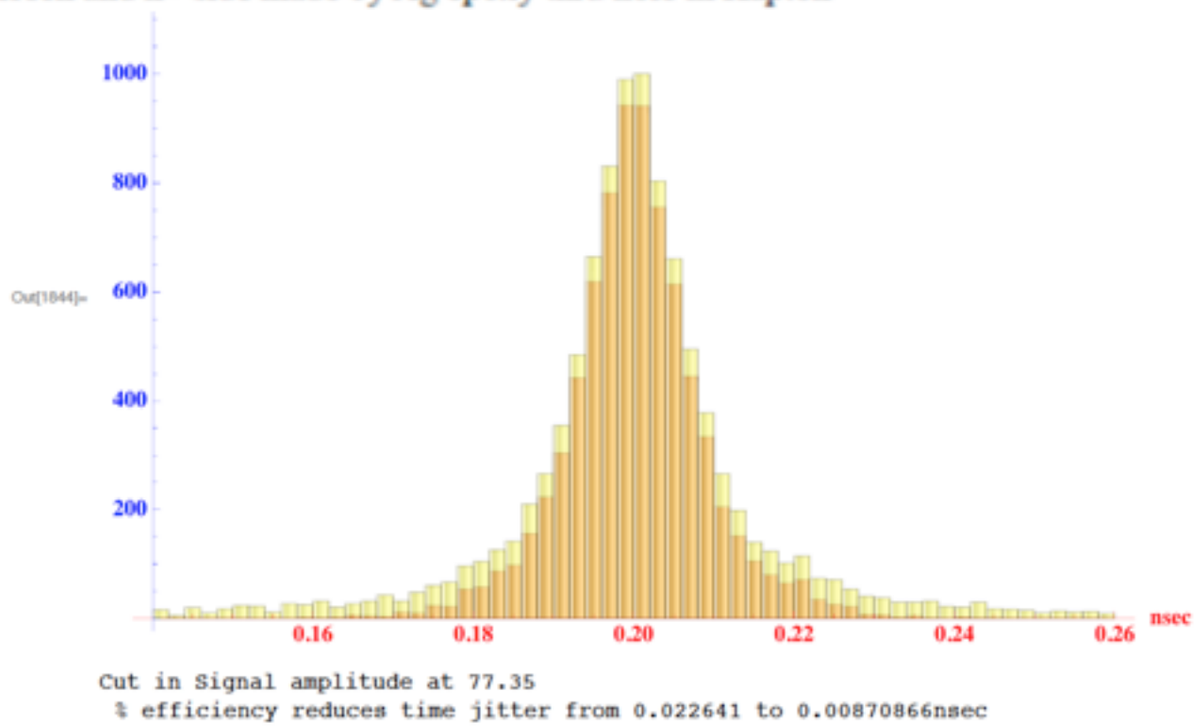
Si option:(many presentations to FCWG over past 2 years)

- useful object lessons from NA62 GTK project
- 1) Landau/Vavilov contribution to time jitter

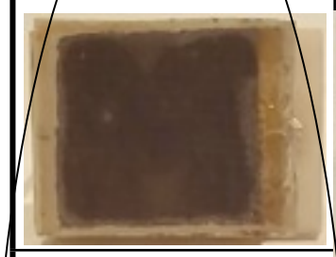
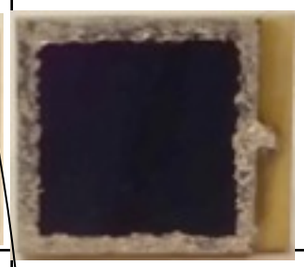
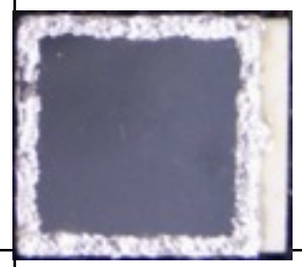
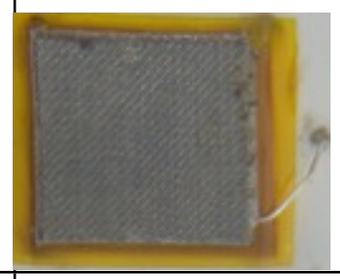
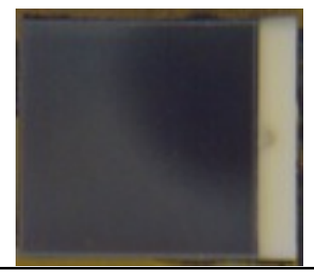
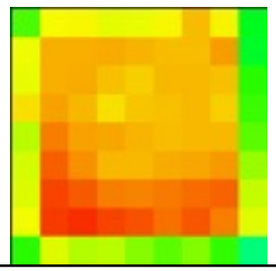
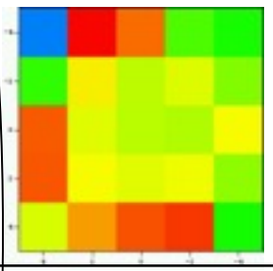
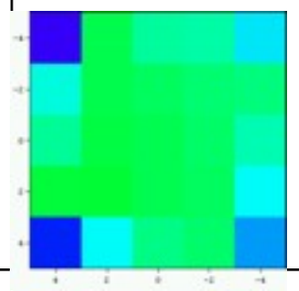
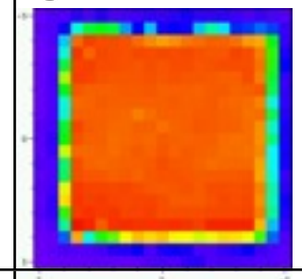
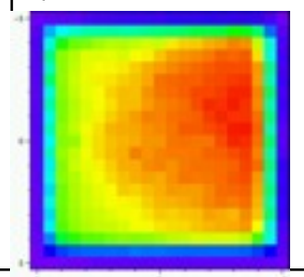
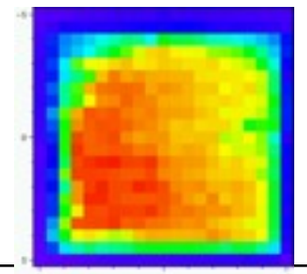
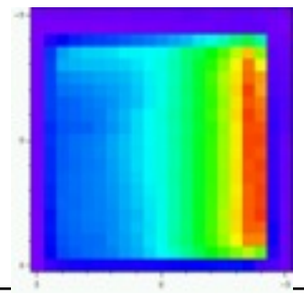
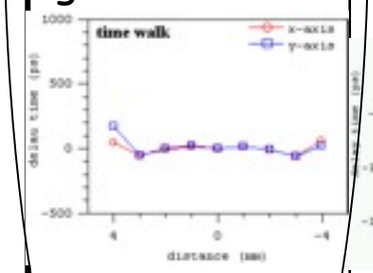
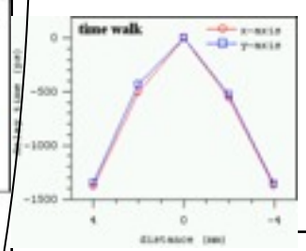
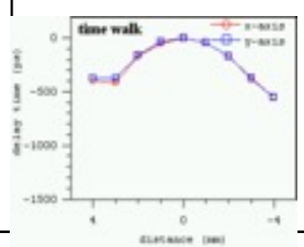
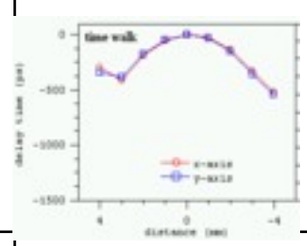
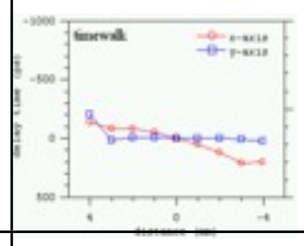
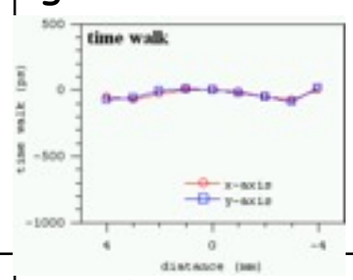
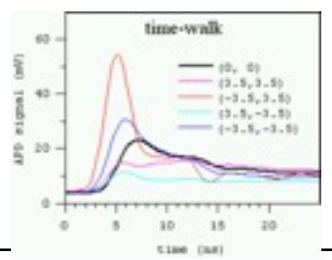
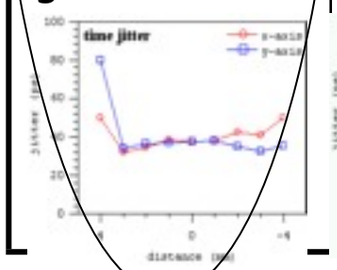
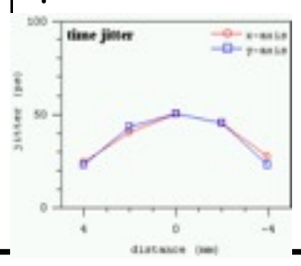
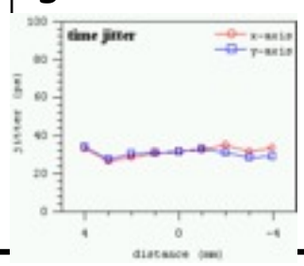
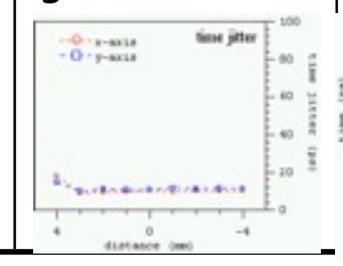
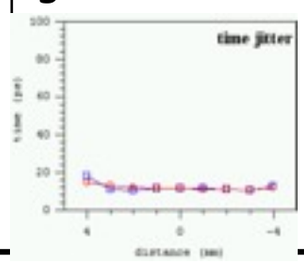
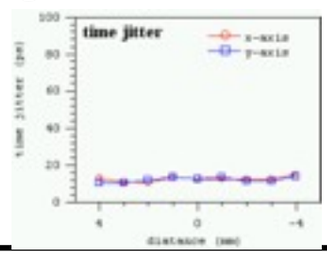




Simulated energy deposit/per each of 40 1 micron layers-typical event



Summary of RMD 8x8 mm^2 APDs Dec. 13, 2013

	Dec.13, 2013 432-6 Mesh	Nov.14, 2013 4 (previously graphene)	Nov.14, 2013 432-6-In	Oct.22, 2012 193A-6-In	Oct.22, 2012 420-3-4	Nov. 20, 2012 432-5	Sept. 26, 2012 unknown
	Al-mesh Au sintered	In-edged No Au	In-edged Au sintered	In-edged Au sintered	Al-coated No Au	Al-mesh No Au	standard n+ diffusion No Au
							
spatial uniformity	good 	fair 	fair 	good 	poor 	poor-fair 	poor 
time walk	good 	poor 	fair 	fair 	good 	good 	poor 
time jitter	good 	poor 	good 	good 	good 	good 	poor data not available

2) weighting field uniformity (and internal series resistance elimination)

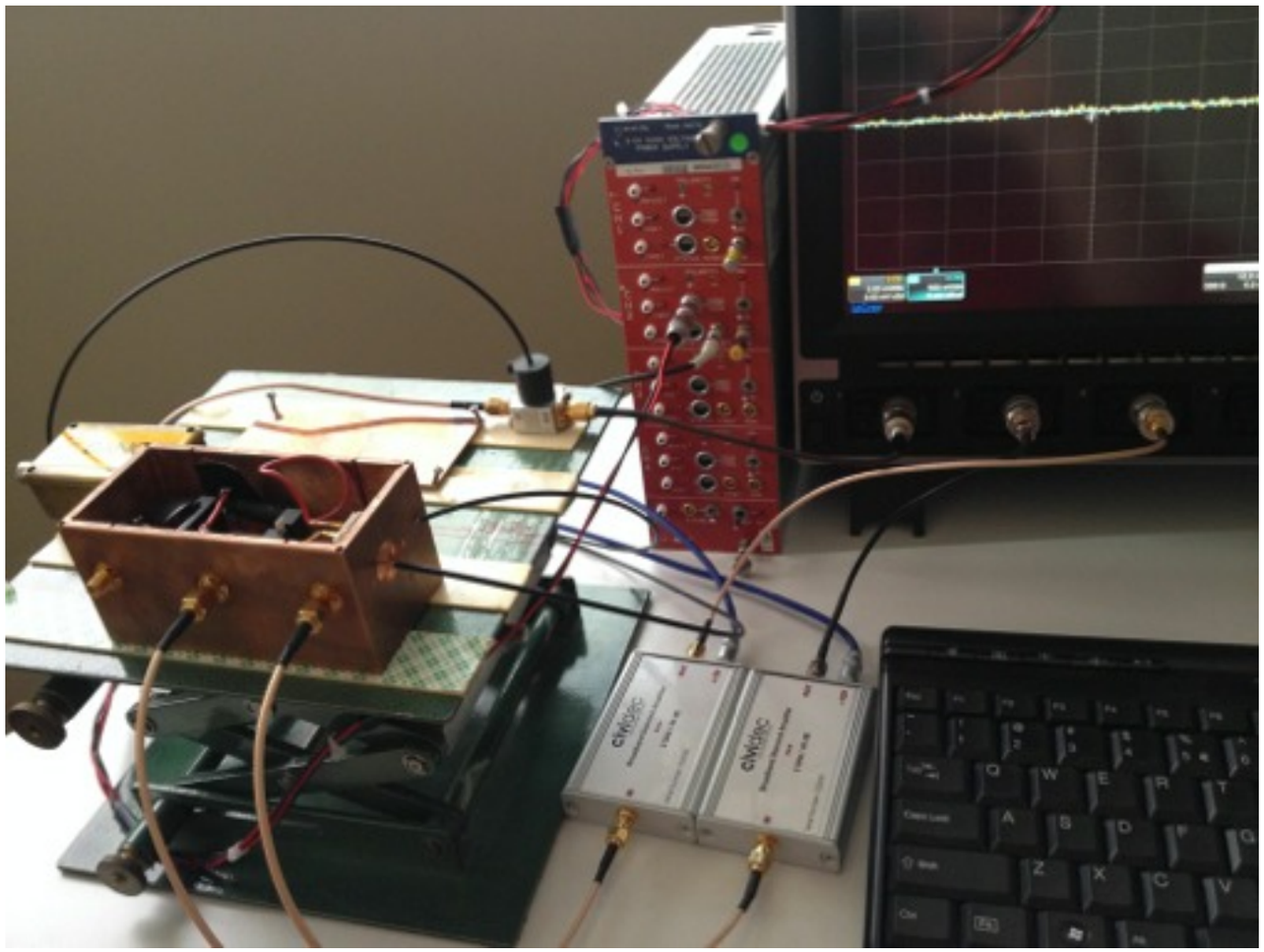
Fabrication costs

- currently sold at ~$1k/cm^2 in small quantities (ie 10% of MCP-PMT cost)
- production cost in quantity ~$1/mm^2 (ie 1% of MCP-PMT cost)
- SBIR proposal to study cost at large scale for specific charged particle app.

Lifetime/rad dose

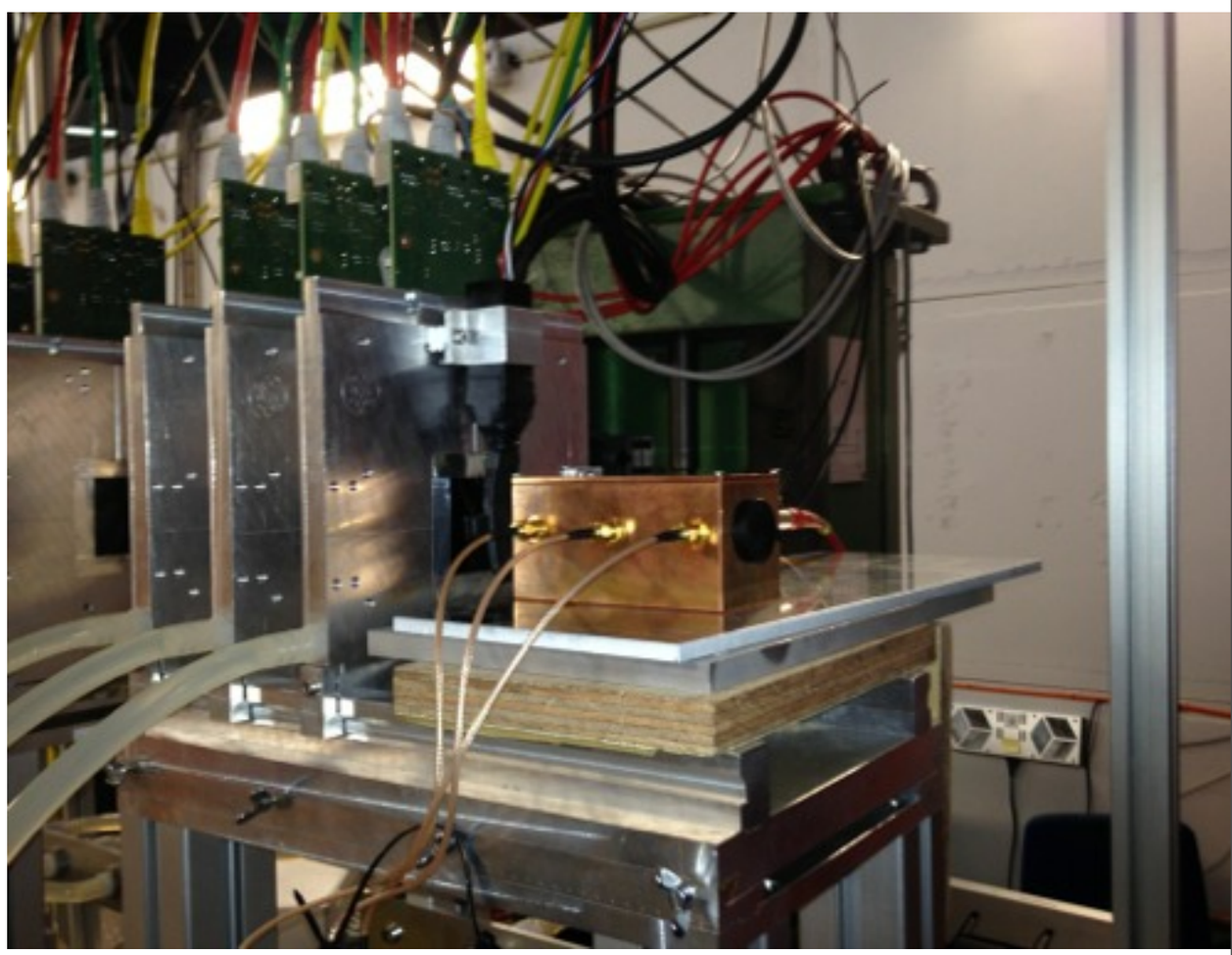
- beam tests by RMD(and by us) show that cooled detector would have identical (noise) performance to ones we test warm up to now @10^{13}n/cm^2.
- Also calculation using CMS scaling rules (see our 2009 paper).
- We are comfortable to ~10^{14} but concern about higher.
- starting next round of rad exposures this month-FNAL, CERN

Timing results



office/workbench

(we developed cheap, CERN made picosec pulsers to drive 980nm Vcsel)



DESY

(also PSI, SPS, LNF,ATF)

- testbeam data very useful to understand
  - effective depletion depth (~40 micron)
  - effect of R_S & C_D on risetime, peak

Preamp in voltage mode

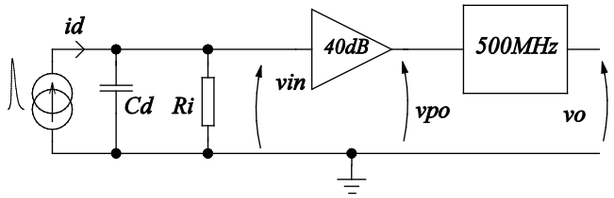


Fig1. Preamplifier working in voltage mode.

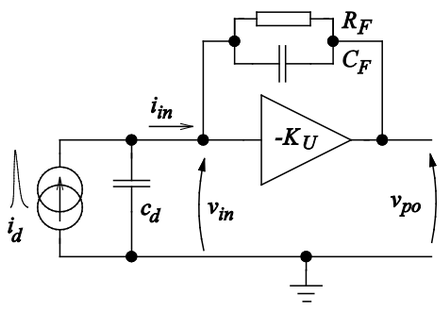
Response (vo(t)) can be found solving following equations.

Voltages:

$$vin = id\ \frac{1}{s\,Cd+\frac{1}{Ri}} = id\ \frac{Ri}{1+s\,Cd\,Ri} \qquad vo = vin\ Ku(s) = vin\ \frac{Ku}{1+s\,\tau_{Po}}$$

Where τ_{Po} defines bandwidth of the amplifier (for 500MHz 3dB bandwidth τ_{Po} =0.32ns)

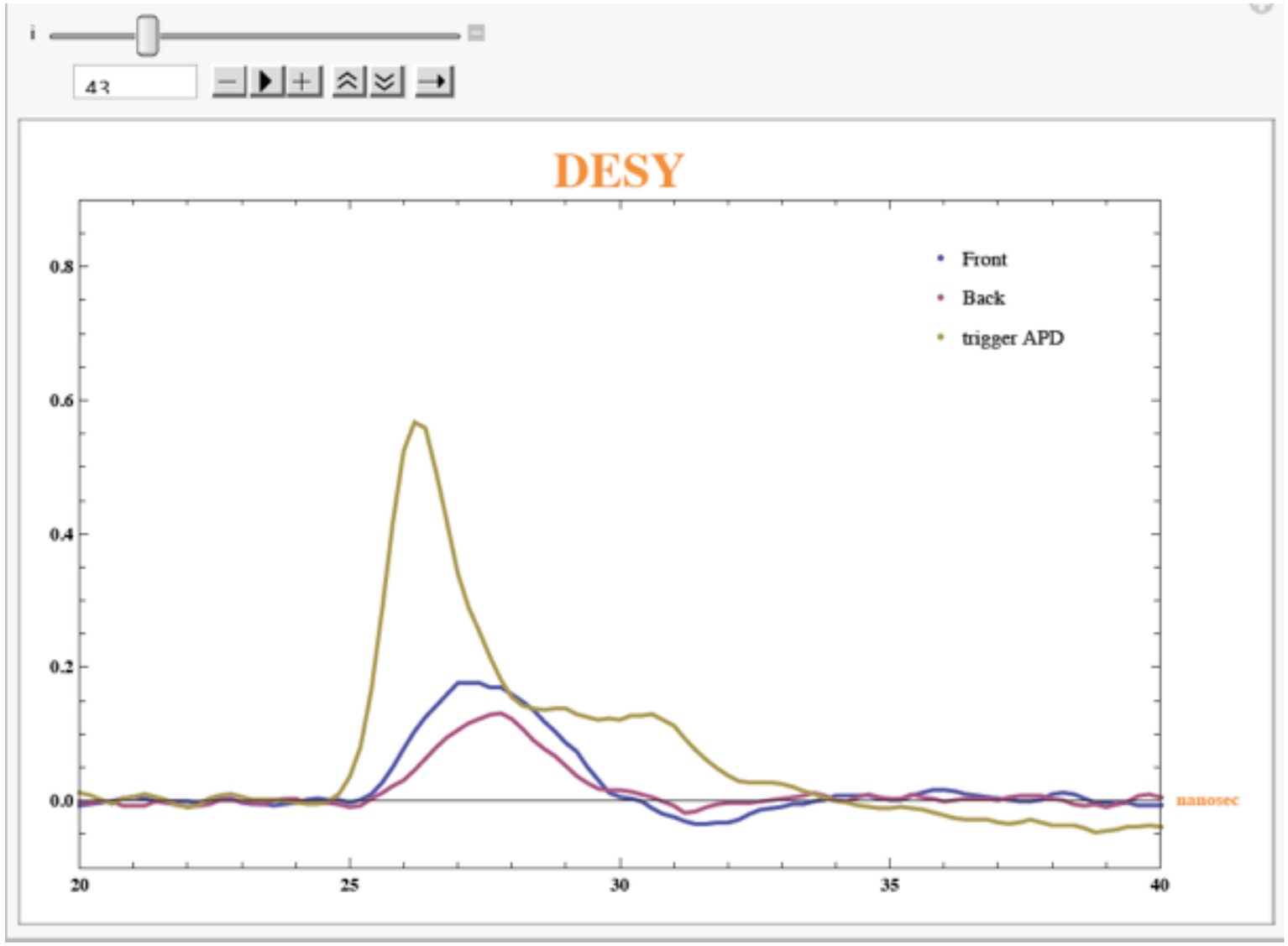
Preamp in charge/transimpedance mode



Assuming high Ku the amplitude response does not depends in first order on c_d.

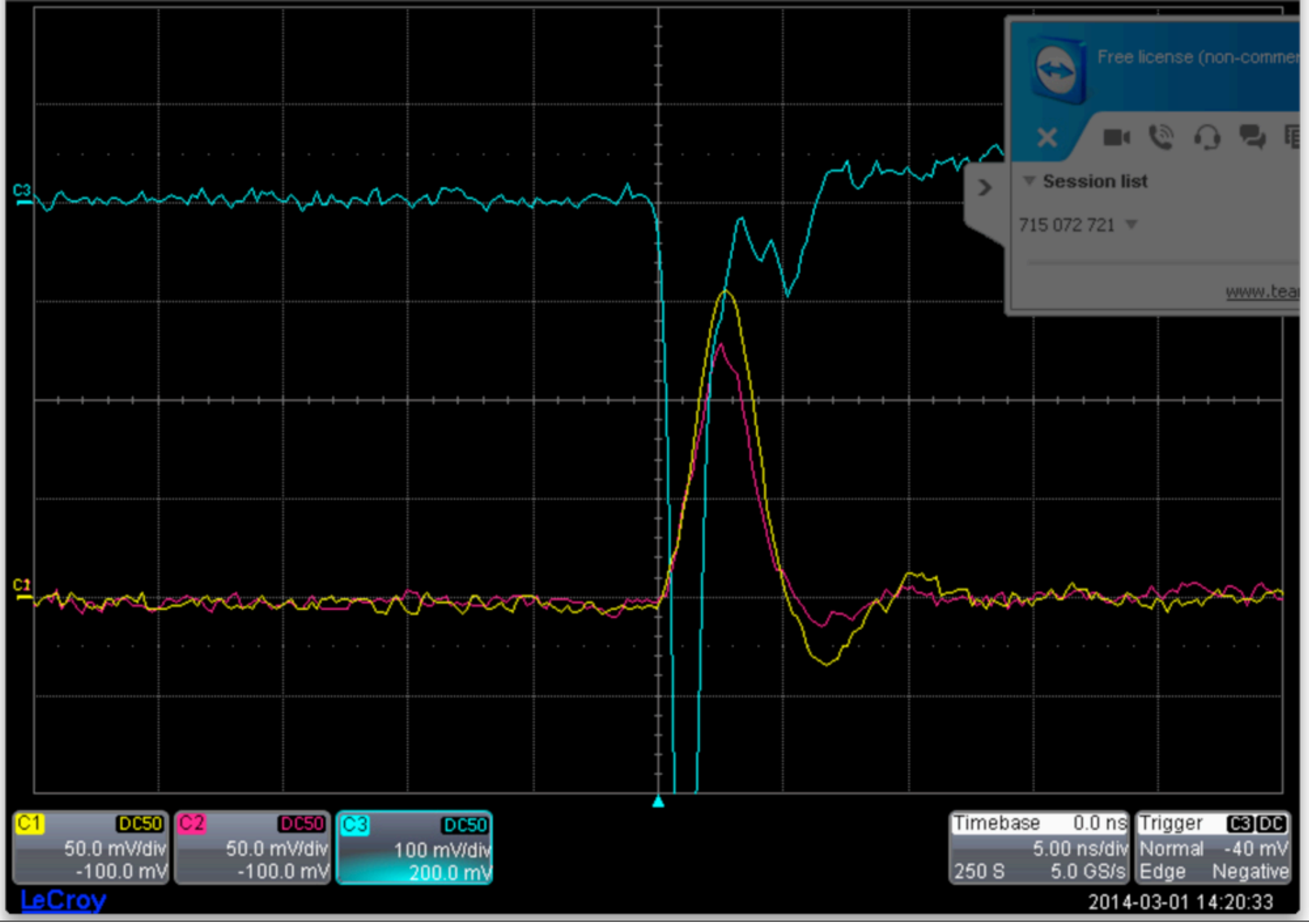
->Developing hi BW transimpedance amps w. U. Penn.(see ACES 2014)

features of MIP data well modeled by simulation w. J. Kaplon



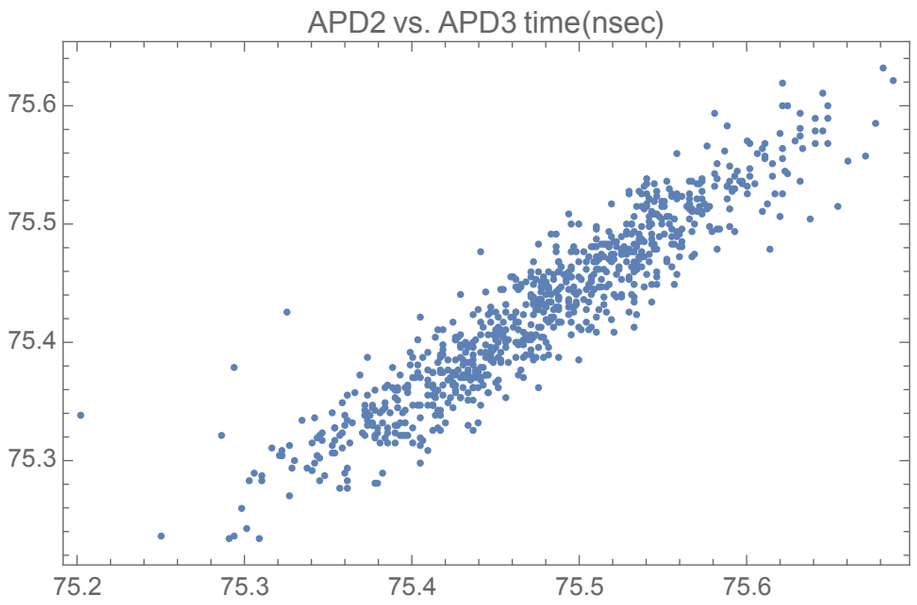
LCRY0614N49612 (835 987 661) - TeamViewer - Free license (non-commercial use only)

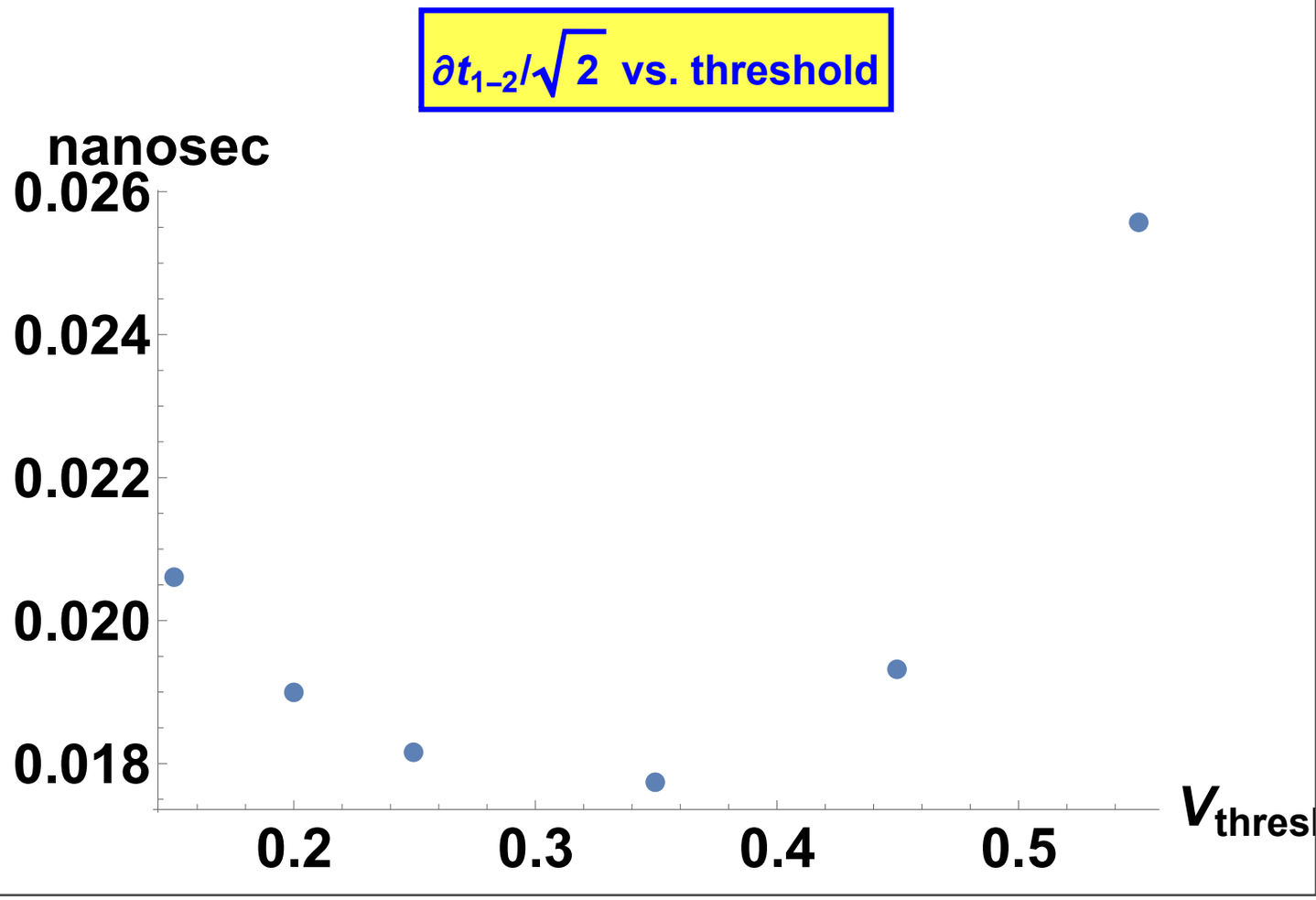
File Vertical Timebase Trigger Display Cursors Measure Math Analysis Utilities Help



SNR, t_R, Optimal filtering

- goal of hi BW SiGe transimpedance amp @Penn
- =>reduce R_i, boost signal, improve t_R
- Clear from ie DESY data that this could give much reduced time jitter (3x5)
- Mitch's amp in 3rd round of prototyping, results soon
- what are we getting now w. large C_D detectors? Not bad!





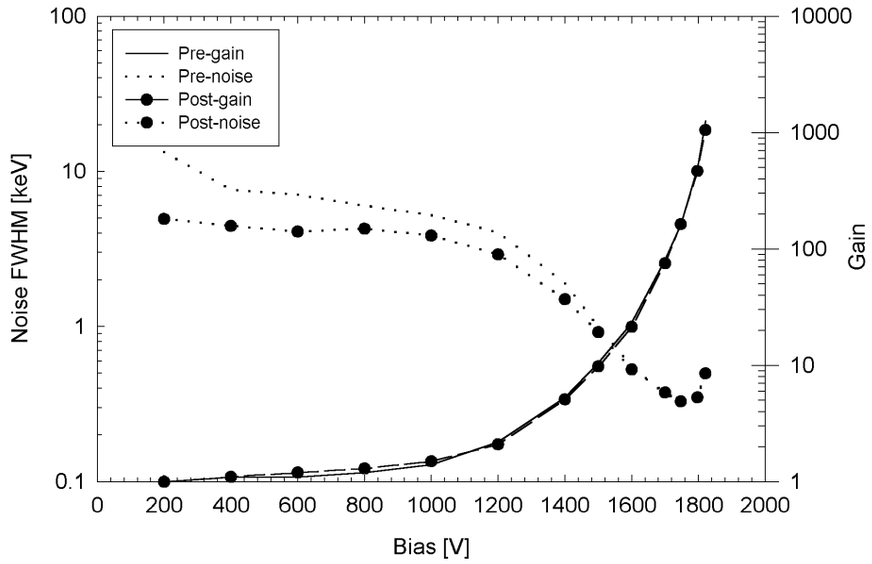
Effect of bulk displacement Damage

- ~10 years ago RMD studied effects w. 72 MeV proton beam at PSI
- up to ~0.5x10^{13} n_{eq}/cm^2 mostly photosensitivity affected
- since this was their main market, they stopped there
- we started rad program @PS this year but not significantly higher doses
- now preparing FNAL and PS exposures of 2x2 mm^2 APDs
- perhaps new results by RD50 mtg. (Nov)
- below review RMD, consequences for timing
- also note: we use special processing (Gallium vs. Boron)

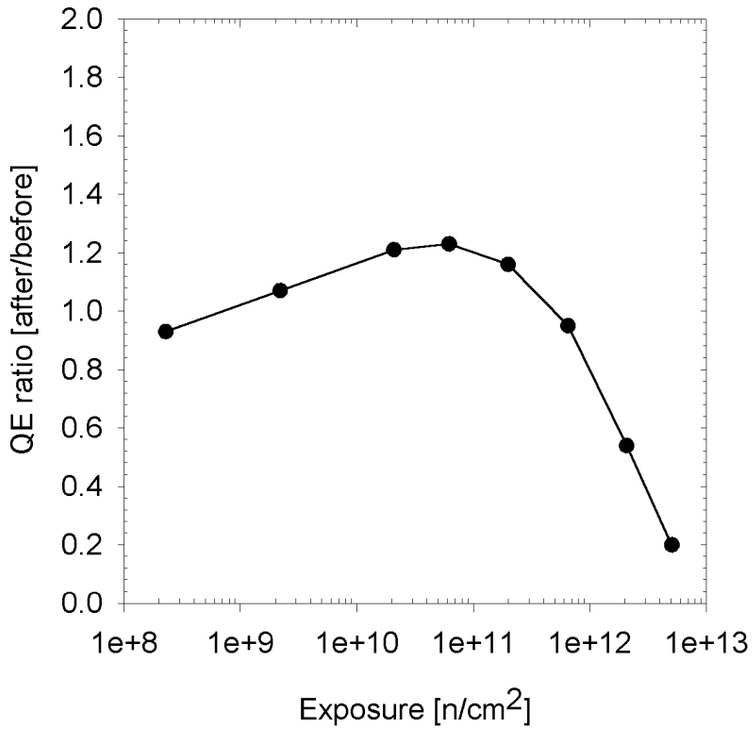
RMD paper:

APD #	Proton fluence [p/cm^2]	Equivalent neutron fluence [n/cm^2]
1	1.09x 10^8	2.29x 10^8
2	1.05x 10^9	2.20x 10^9
3	9.92x 10^9	2.08x 10^{10}
4	2.95x 10^{10}	6.20x 10^{10}
5	9.45x 10^{10}	1.99x 10^{11}
6	3.10x 10^{11}	6.51x 10^{11}
7	9.85x 10^{11}	2.07x 10^{12}
8	2.42x 10^{12}	5.08x 10^{12}

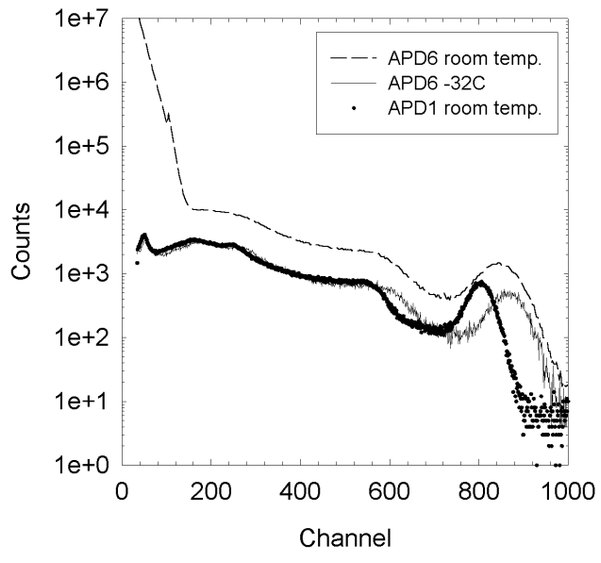
"absence of evidence is not evidence of absence"
now moving quickly for higher doses

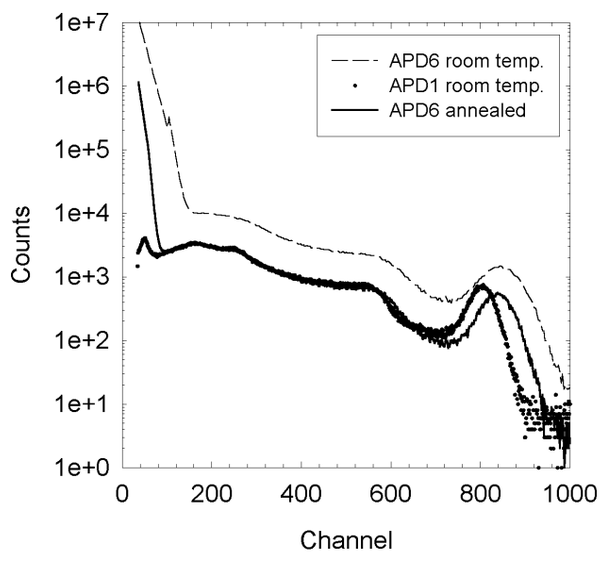


no evidence for gain instability
predicted growth of noise from leakage current



early demise of QE





annealing (100 deg. C for 3 days) or
cooling to eliminate noise

- Interesting discussions in RMD paper on damage field on/off
- we expect time resolution to be degraded at ~10^{14} n_{eq}/cm^2 due to noise (if cooled) see http://arxiv.org/pdf/0901.2530v1.pdf

CMS [12] also measured damage coefficients for several types of APDs and found $\alpha \sim 1.2*10^{-16}$ A/(n-cm), where

$$I^{APD}_{dark} = \alpha * L_{eff} * Area * Dose$$

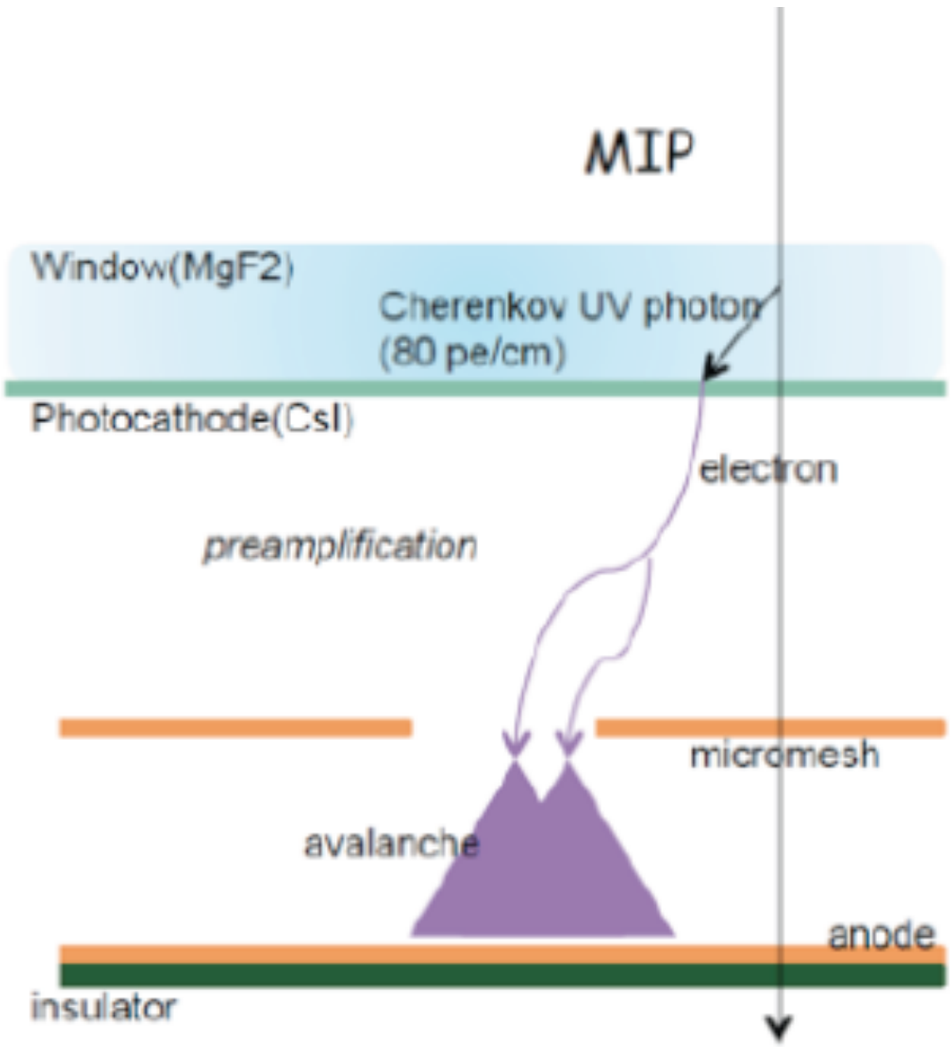
so with $L_{eff} \sim 60\mu m$ (i.e. 6000e/(100e/μm)) we find

$I = 1.2*10^{-16}*(60*10^{-4})*0.3*8.5*10^{12} = 1.9\mu A$

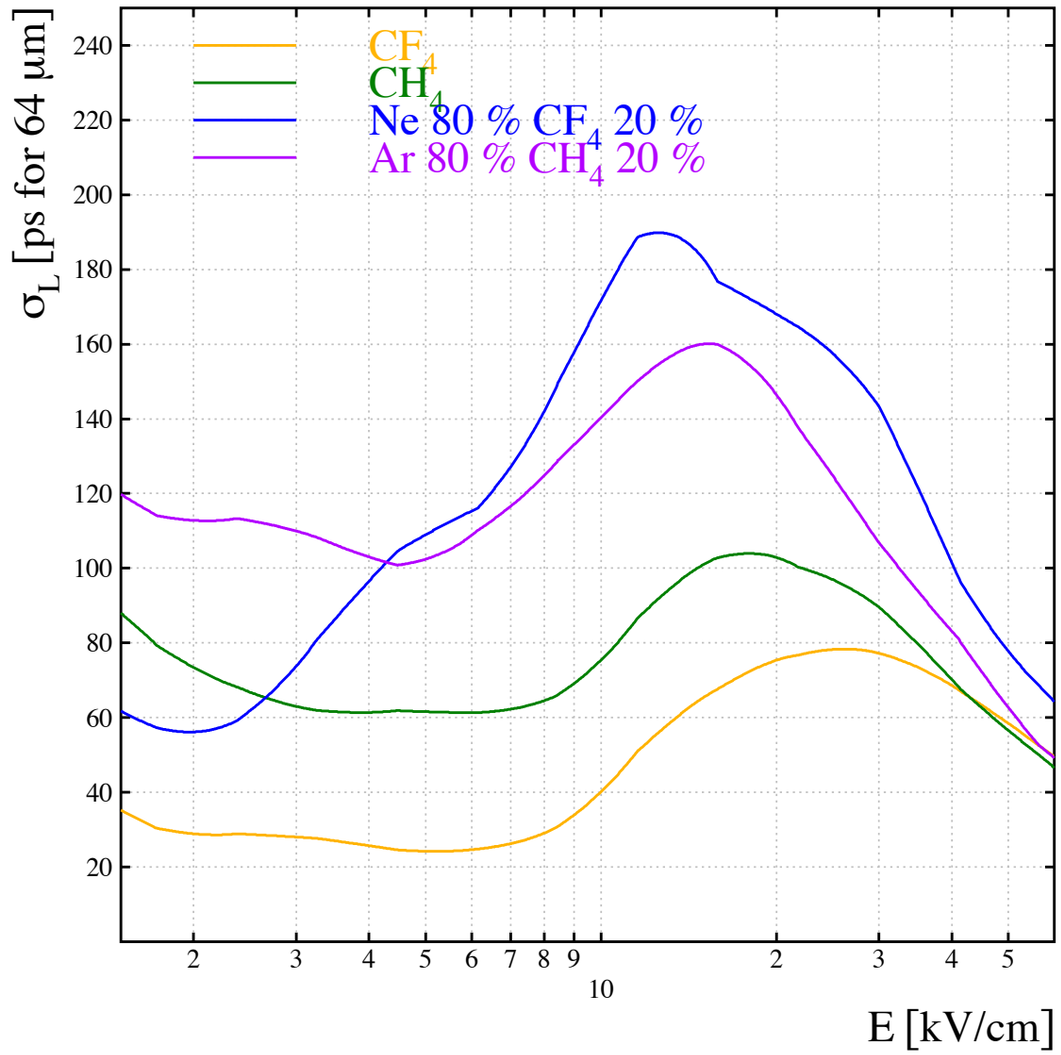
or 10 nA at –30°C

we will see what useful limit we find.
Meanwhile.....

for both issues have started GasPMT parallel effort



transparent pc version



(Rob Veenhof calculation)

now building test chambers @Saclay and CERN
look forward to working with FNAL detector group
on rad hard Photocathode development, etc.
(A. Ronzhin is an expert)

GasPMT (cont.)

- From above calculation clear that diffusion term for single photoelectron can be as small as ~35 picosec with ~100 micron Micromegas gap.
- So we seem to have alot of head room to optimize things
- many common issues w. ie front end electronics
- We are now building test chambers and working with Saclay laser facility to measure jitter
- If succesful, pc lifetime is thing to optimize but much local experience.
- Could be cheap!

Summary

- at CERN we are finding overlapping interests in RD51 and RD50
- good discussion of common interests could lead to some joint development
- CMS experiment will spend next months determining if such technology could enable physics at HL-LHC