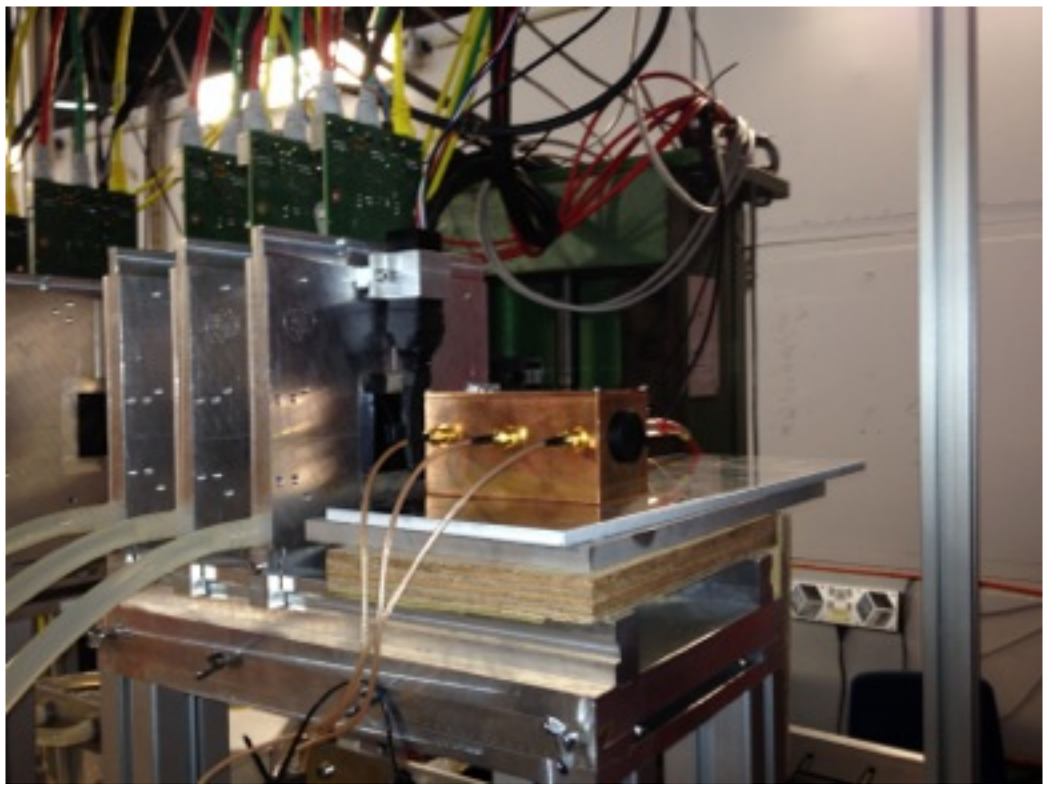
R&D on pileup Mitigation through Fast Timing

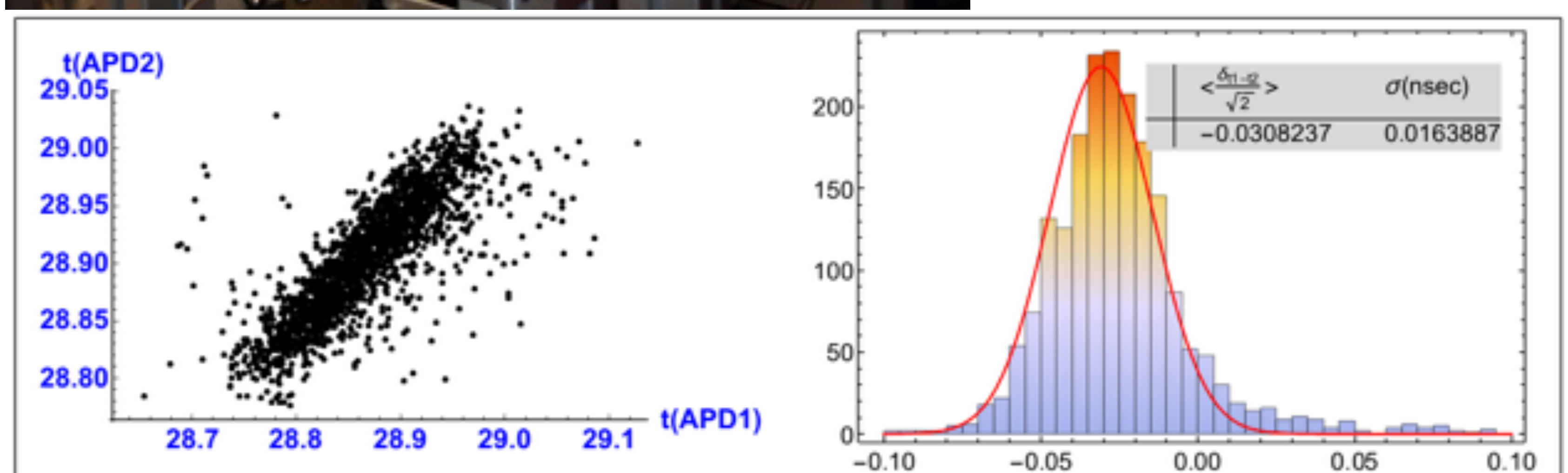
PPS timing mtg. CERN, Nov. 19, 2014

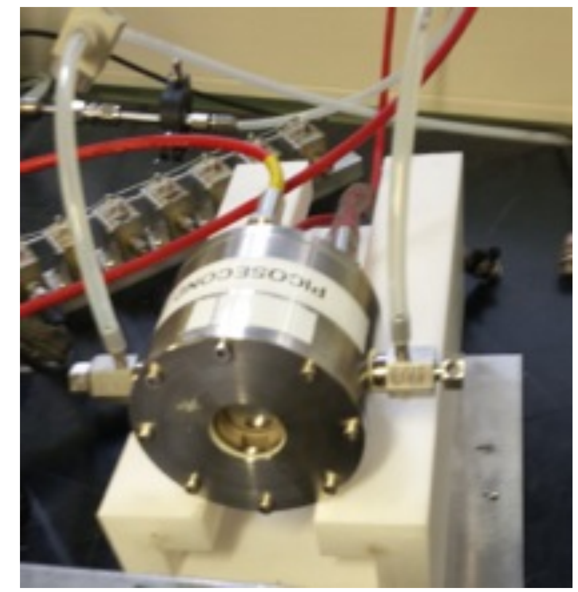
Sebastian White, Rockefeller U.

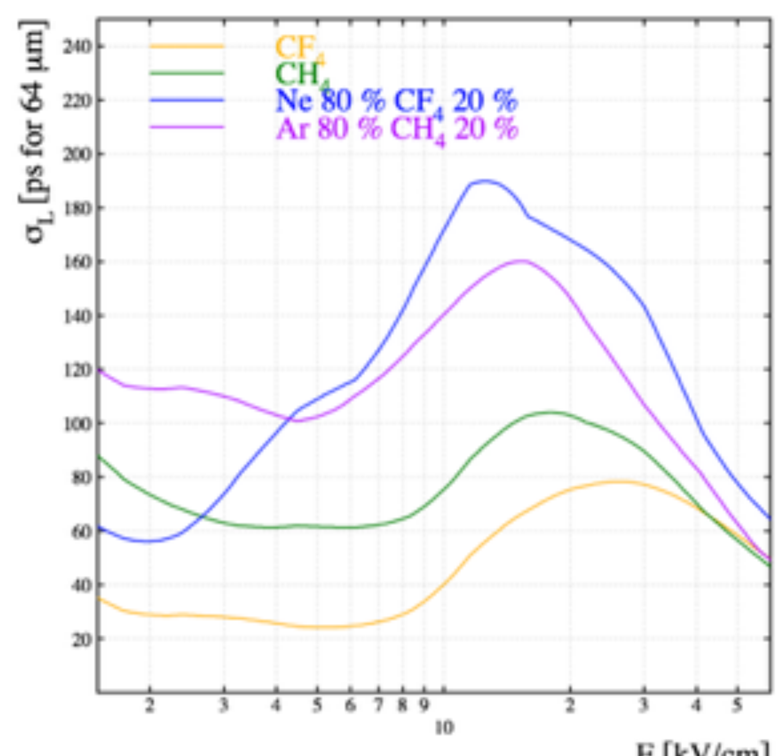
Si technology

MPGD technology









Collaborators:

- new tools for pileup mitigation based on timing: Started 2007 in FP420, 2010 DOE ADR&D and ATF AE55(McDonald and White,co-PIs), in 2014 USCMS&RD51

US-CMS PhaseII R&D

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

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RMD/DYNASIL:

Richard Farrell, Mickel McClish

FEE development:

Mitch Newcomer, Susan Fowler, Brig Williams (U. Penn.)

Hamamatsu Photonics:

Motohiro Suyama

Photocathode Development:

Anatoly Ronzhin (FNAL)

DAQ techniques:

Eric Delagnes, Dominique Breton, Herve Grabas, Stefan Ritt, LRS/Teledyne, Roman Zuyeuski

RD51

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

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Ext. Collaborators:

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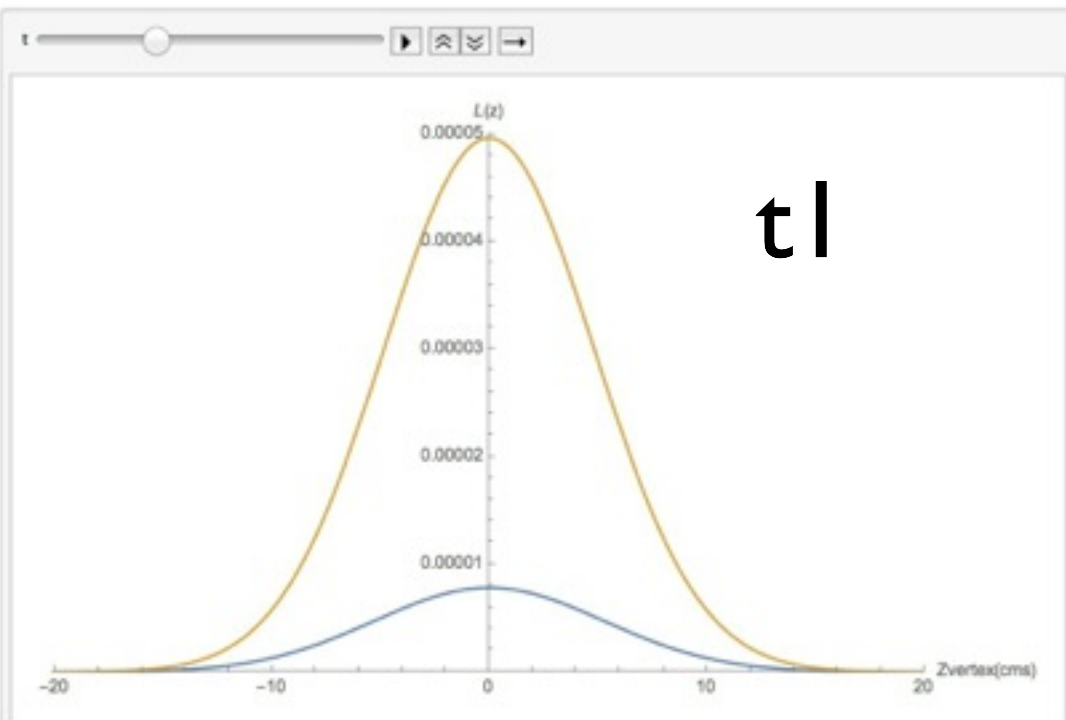
2. *Princeton University, contact person K.T. McDonald,*

LHC bunch xing sim.

(Sunanda has included a precision timing layer in CMSSW phase-2 but still awaiting results from physics performance simulation. Below some general things to anticipate these results, using LHC design book params.)



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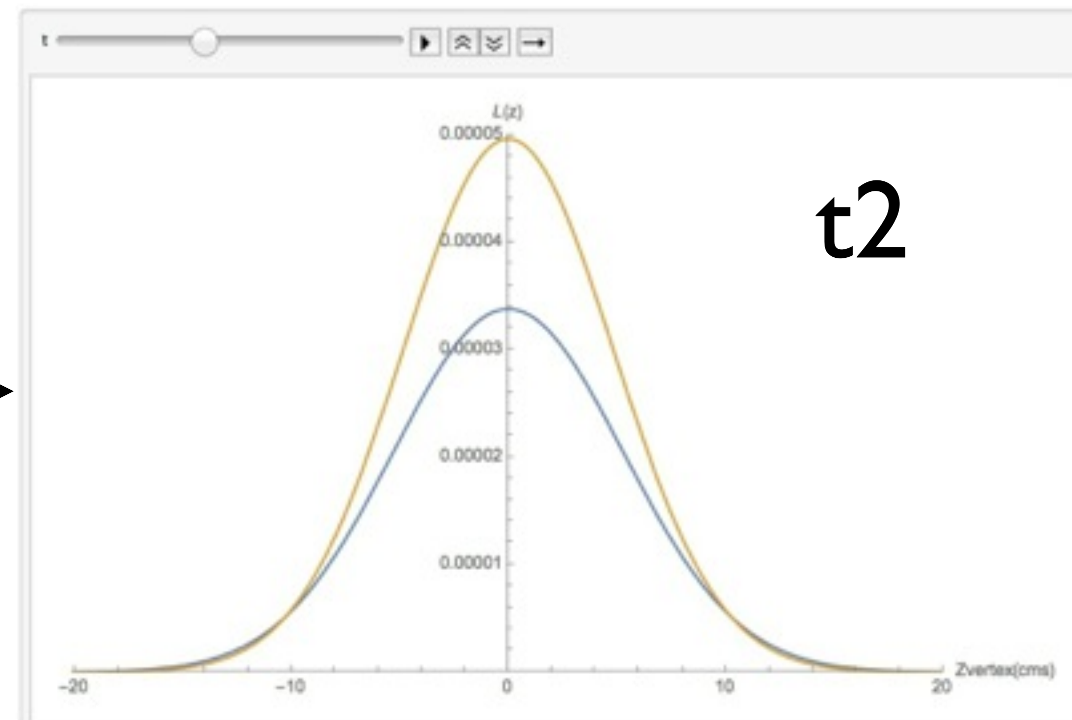
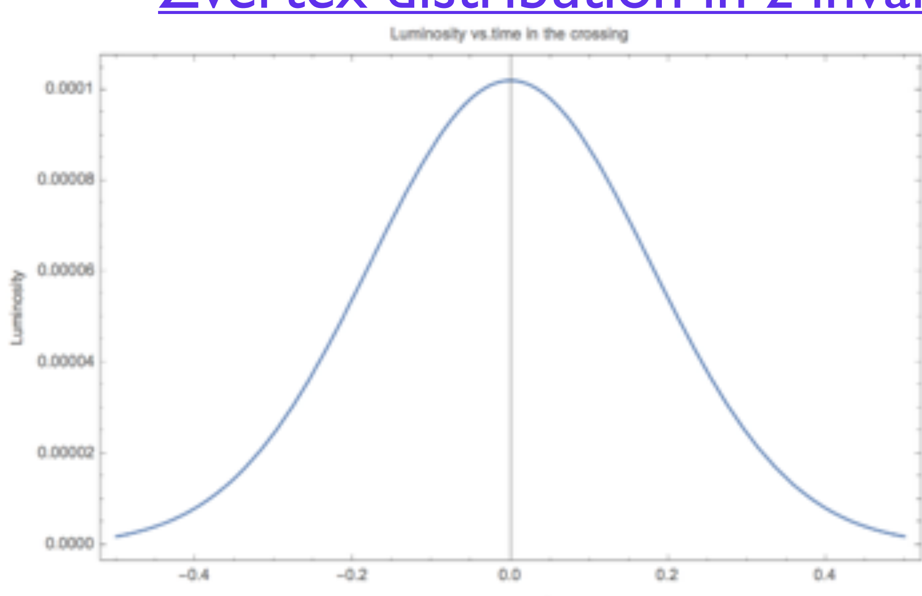
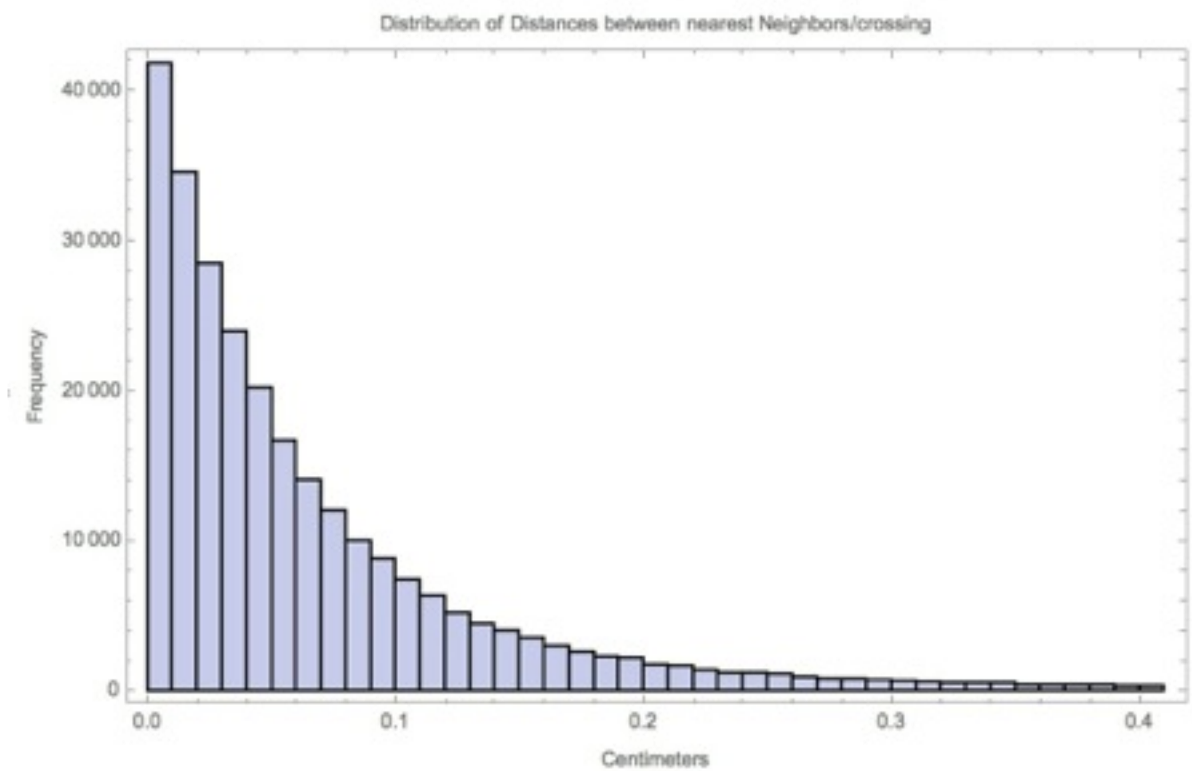


Zvertex distribution in z invariant wrt time during xing, rms= 4.8cms.

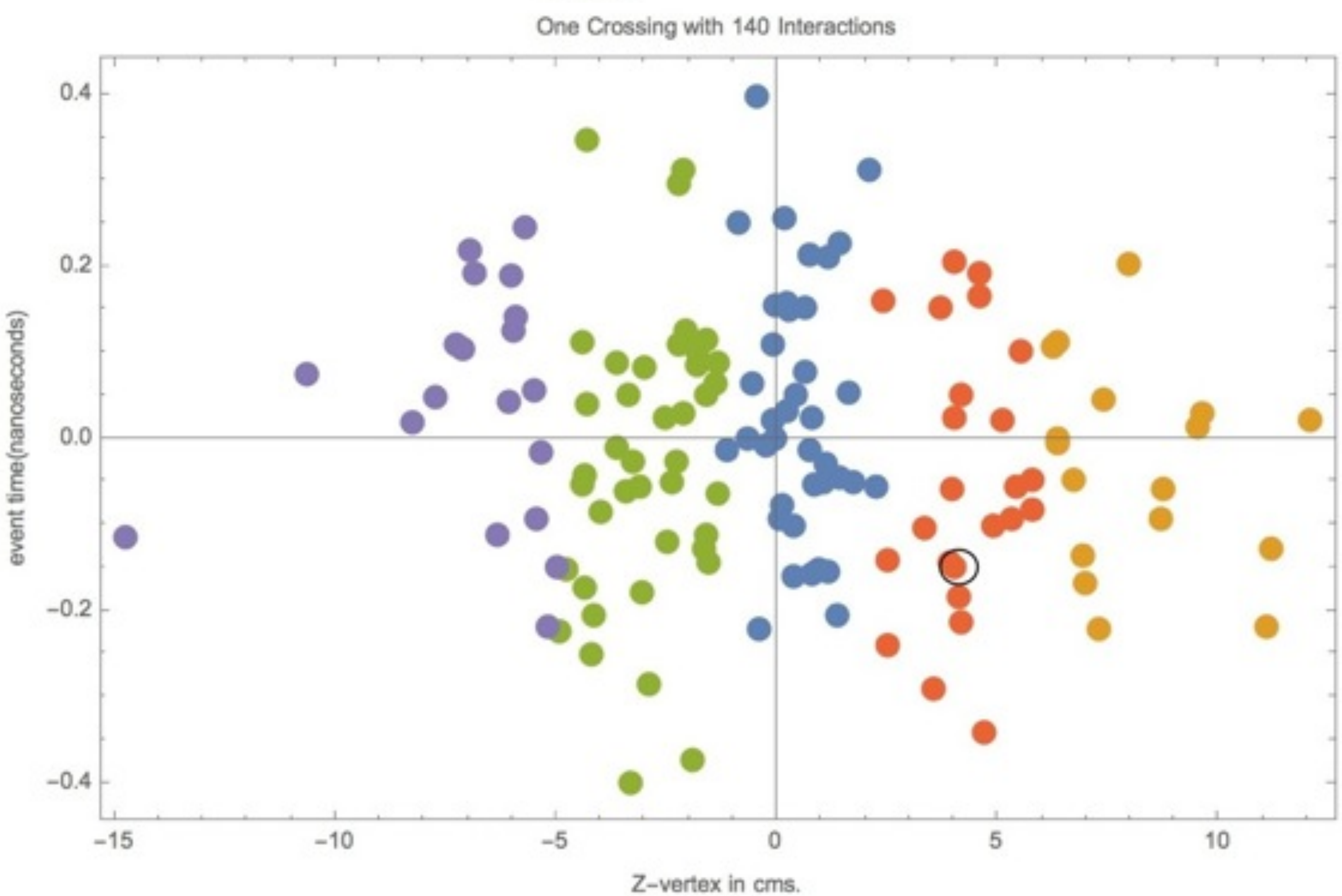


rms in time domain=170 picosec

sim (continued)



distance to nearest neighbor vertex
@pu=140, a challenge for forward tracking,
jets and EM showers



sorting vertices in a time vs. z plane
is a potential way to reduce background.

How could one make such a plot?

ie turn
this
1-d plot into a 2-d plot

above plot starts from the work-horse for vertex finding-the CMS inner tracker

talks about precision timing usually start from assumption that vertex time is known (??)

though I am an enthusiast for precision timing, I don't believe CMS can afford to build 2 systems!

should calorimeter drive timing?

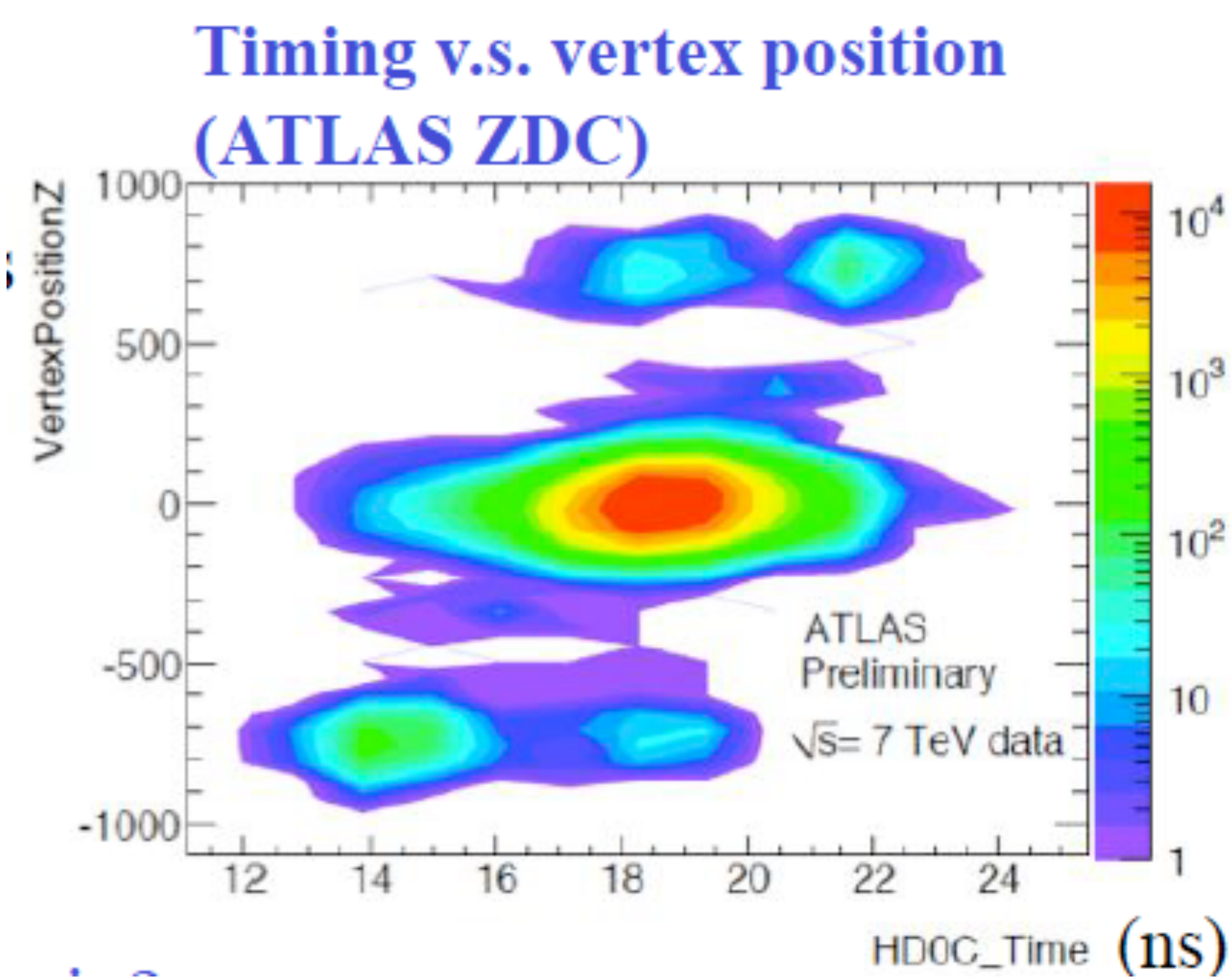
simple considerations make it attractive:

- projective emcal or dual readout intrinsically fast
- combined with high photostatistics->good performance (eg SPACCAL, DRC)

however DRC was down-selected. Initial talk of a fast wave-shifter on the shashlik calibration fiber inconclusive?

->We focus instead on a dedicated timing layer.<-

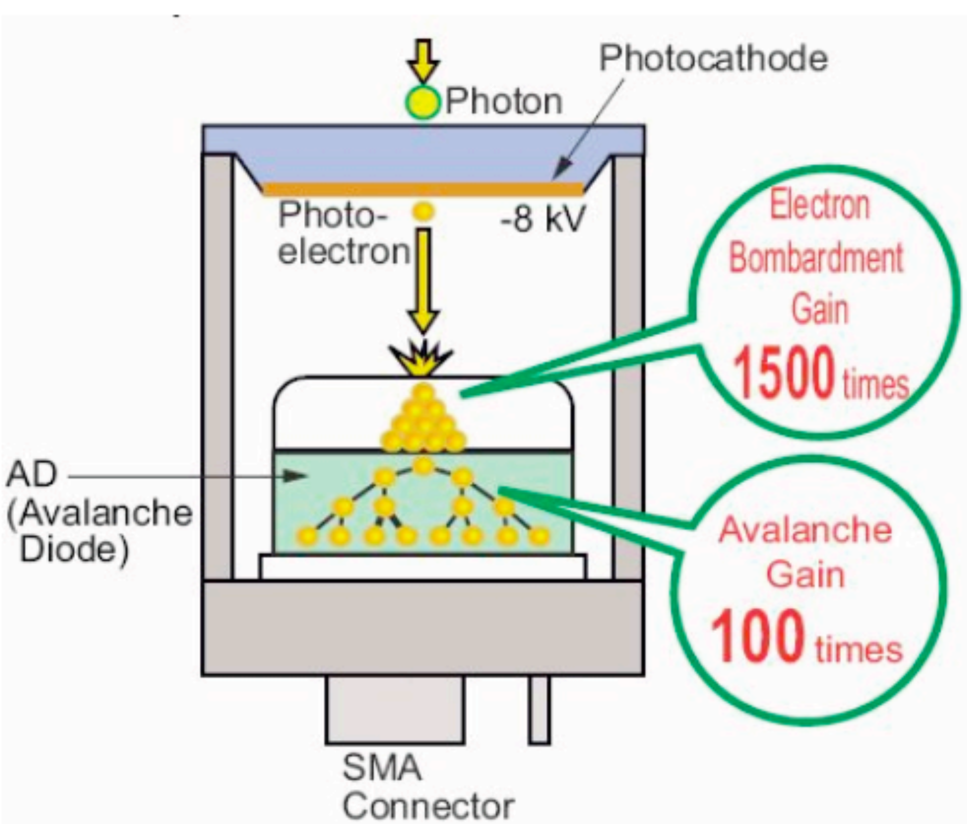
- realistic 10-20picosecond timing at high rates @radiation environment hard enough without combined function (see eg NA62 lessons).



in 2010 we showed ZDC calorimeter timing could resolve micro-bunches from SPS Rf
http://xxx.tau.ac.il/abs/1101.2889
still ~an order of magnitude needed to resolve in-time pileup

some comments on Calo timing(aside)

- the jury is still out on whether charged particle timing should be a key component in CMS(or ATLAS) EC upgrade strategy
- with ATLAS ZDC (Quartz/Tungsten Shashlik) we obtained <100picosec resolution (not "few 100's")- that is what enabled ATLAS plot on previous page
- it used conventional PMT's
- we worked also with Hamamatsu on evaluating their high rate alternative to MCP->found 11 picosec SPTR, >*1000 improvement in lifetime. These excellent results motivated our development of APD charged particle timing.



why
1)produce light in a scintillator/Cerenkov radiator,
2)convert it into photoelectrons,
3)detect them in an APD with 11 picosecond time resolution,
when APD itself gives excellent timing resolution?
->direct APD charged particle timing

We focus on timing layer for EndCap region of Phase-2

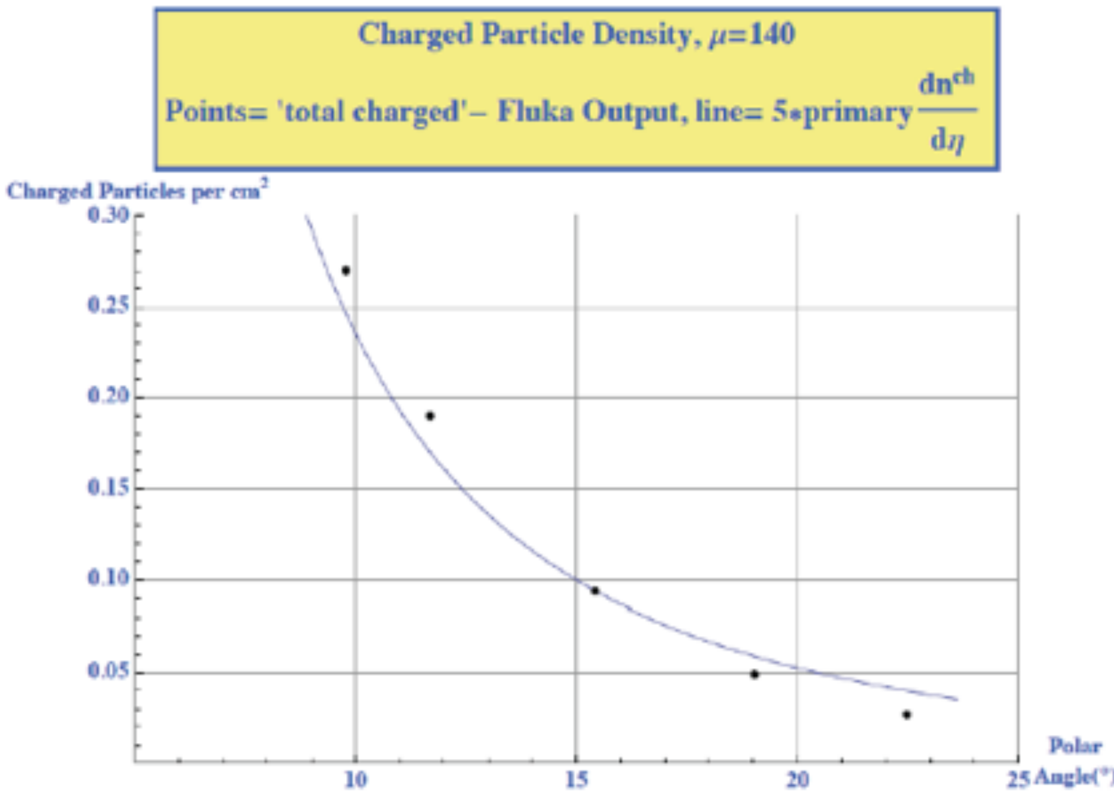
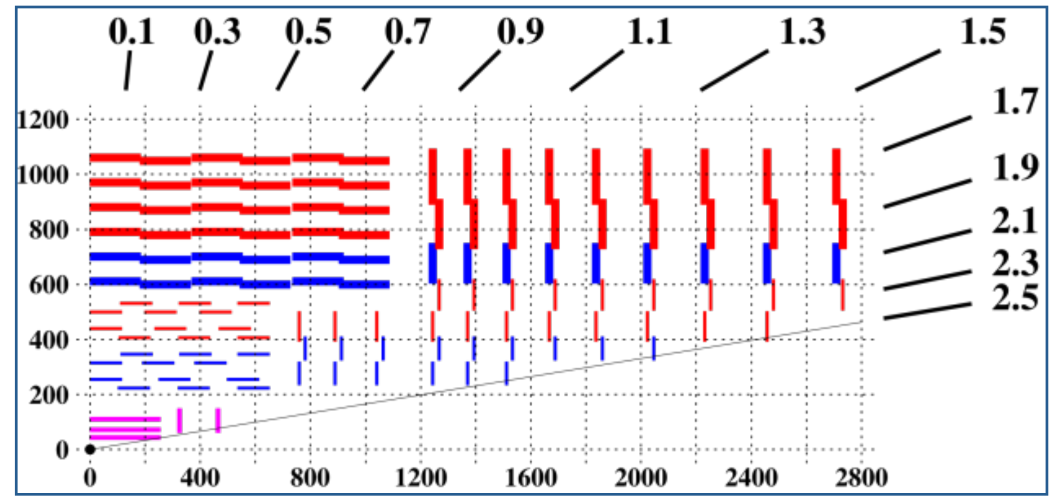
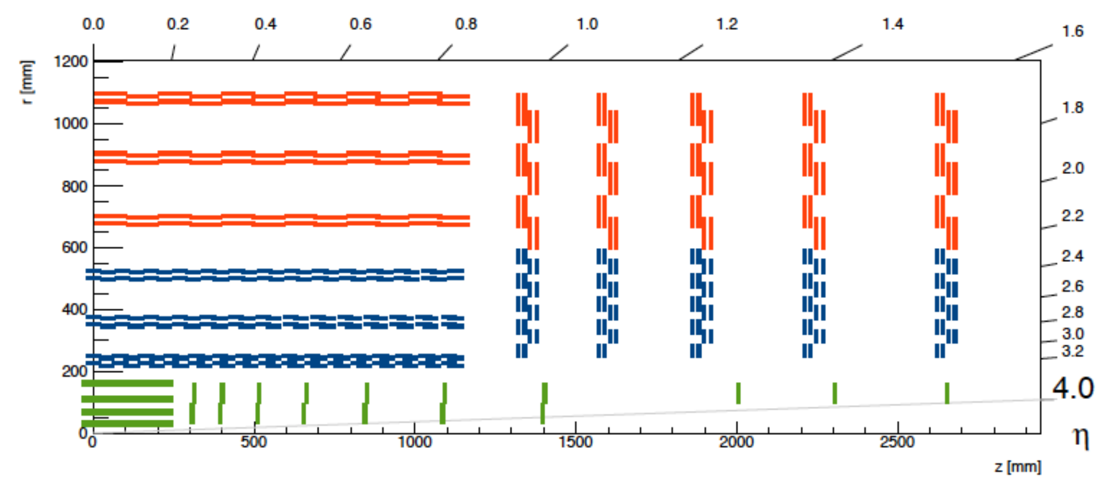


Figure 2: The charged particle density in the region of the dedicated timing detector. The points are FLUKA output for "total charged". The line is calculated from estimates of primary charged particle density-dn/deta- scaled up by a factor of 5. FLUKA output is roughly consistent with a constant factor over this angular range.

current model in CMSSW matched to:



if tracker extended in Phase2, complementary role?

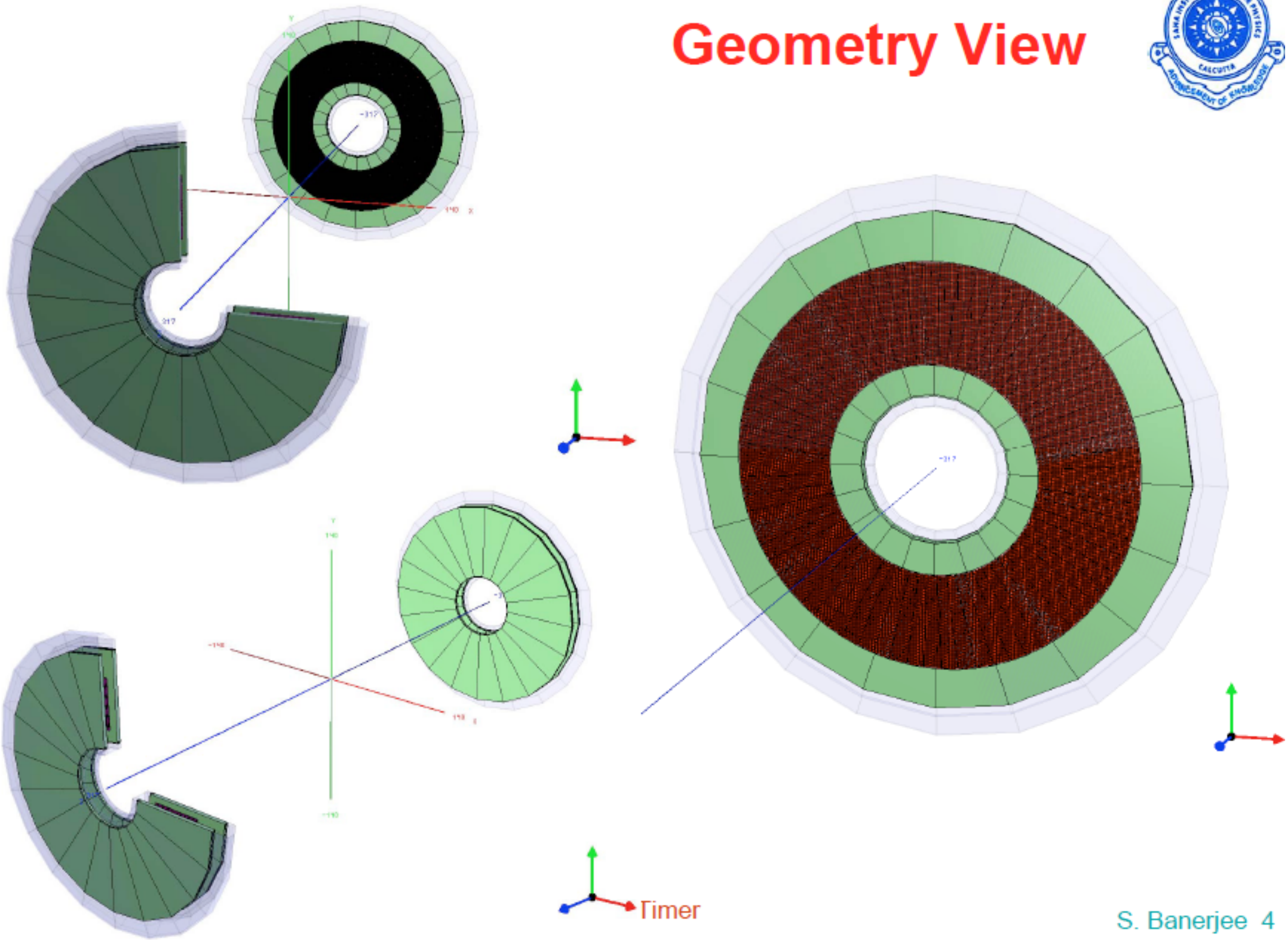


physics justification for timing layer likely stronger if we can extend timing well beyond eta=2.6

=>our RD51 MicroMegas development could enable this

(continued)

Geometry View



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)

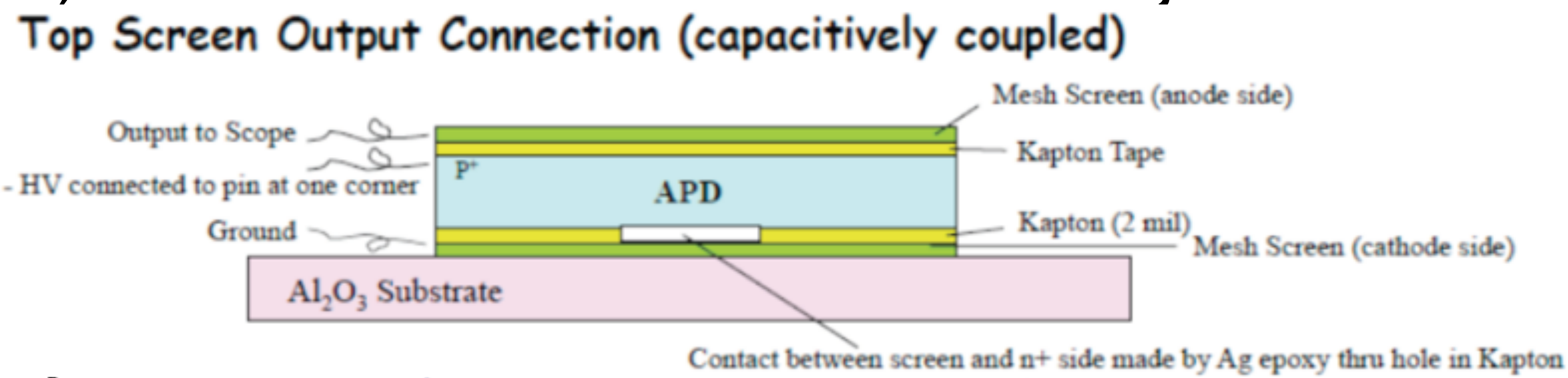
- traditionally PET and low rate HEP-ie Henry’s LAPPD project primarily for neutrino expts.(see his TIPP 14 talk)
- we have been only project to report on CMS PhaseII
- some related generic-ie Sta Cruz “LGAD” and diamond det- in context of forward protons
- we reported on long running development of 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

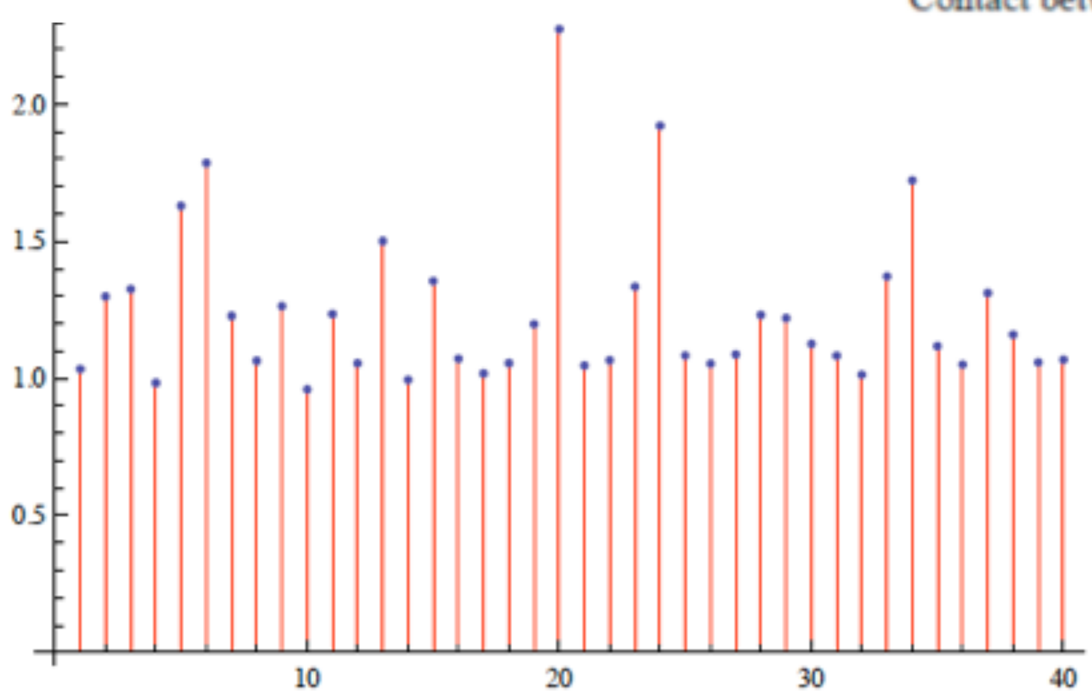
we reported on 2 technologies

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

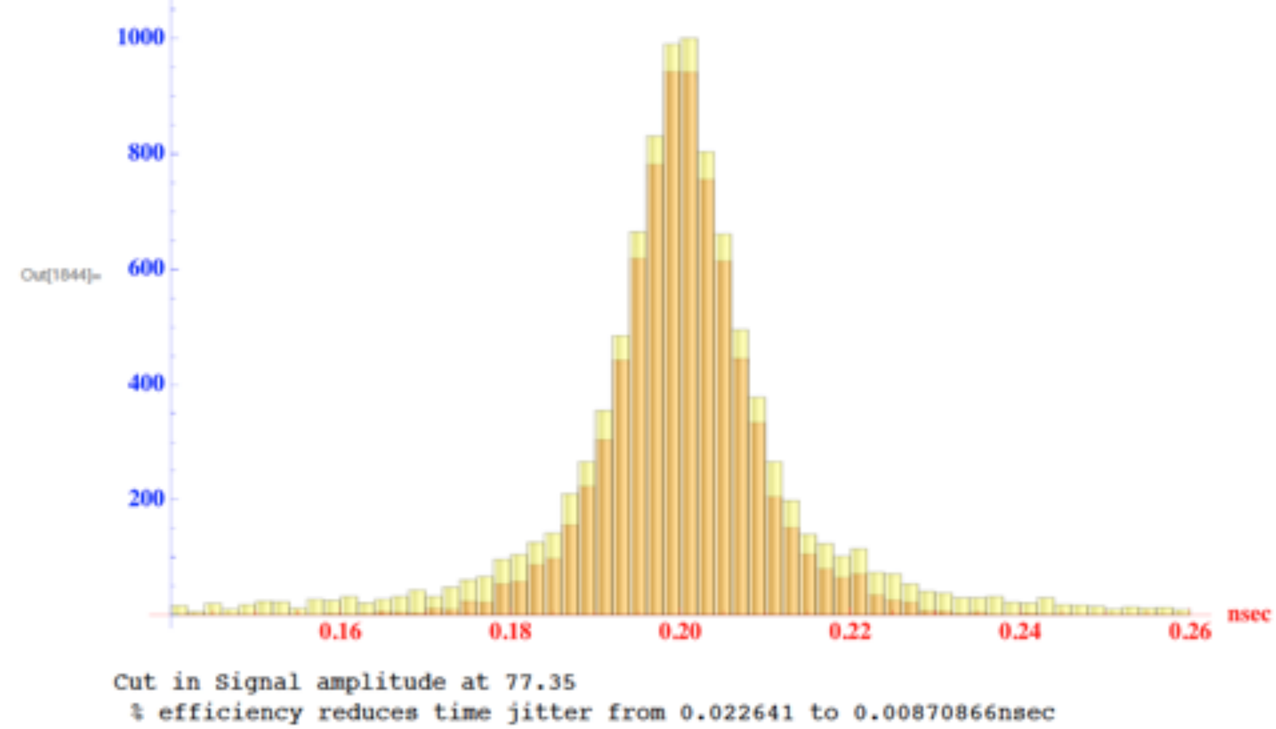
Si option:(many presentations to FCWG over past 2 years)

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

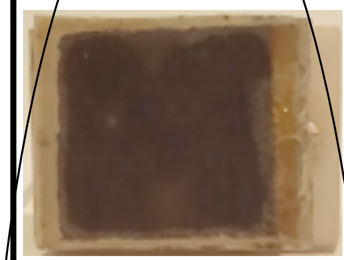
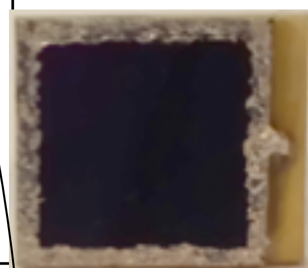
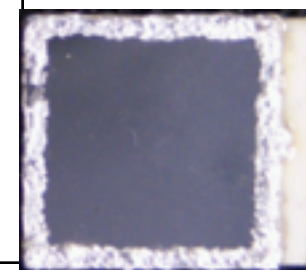
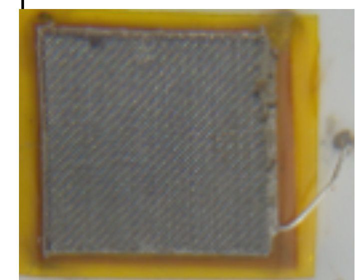
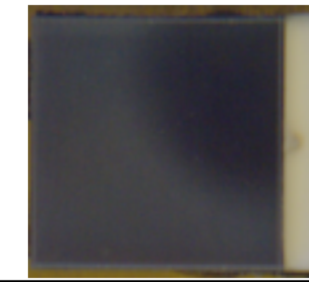
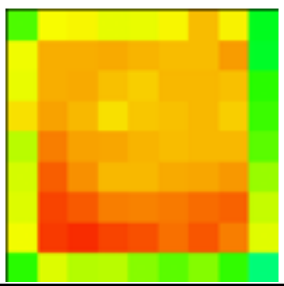
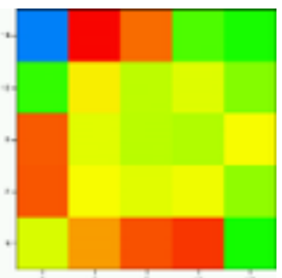
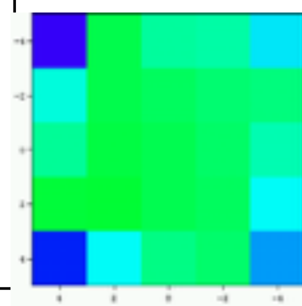
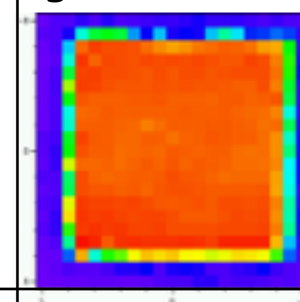
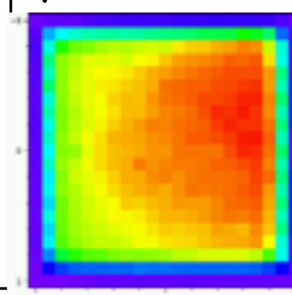
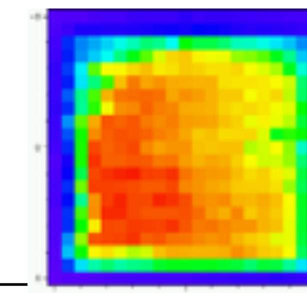
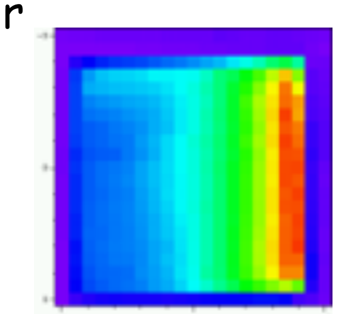
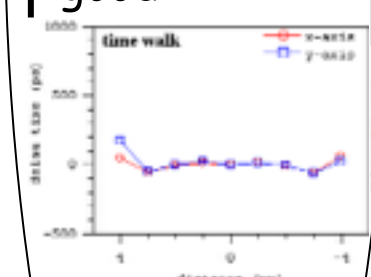
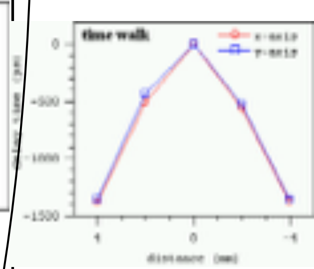
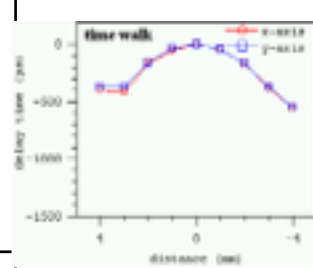
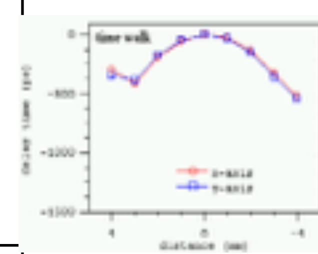
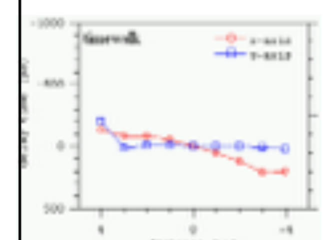
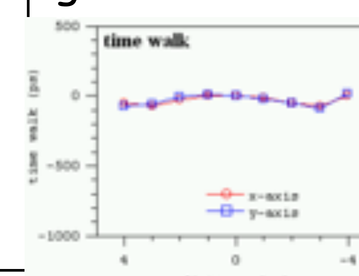
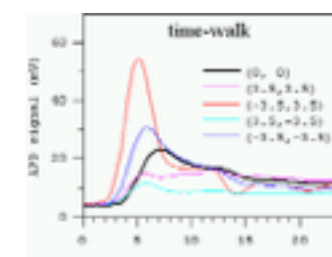
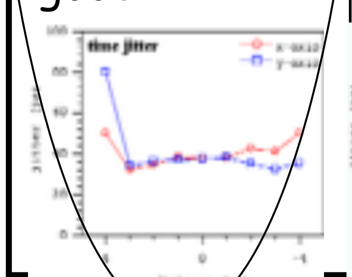
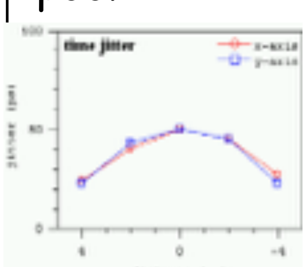
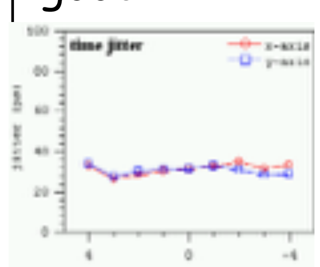
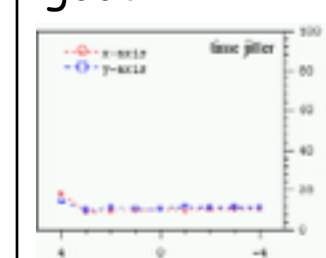
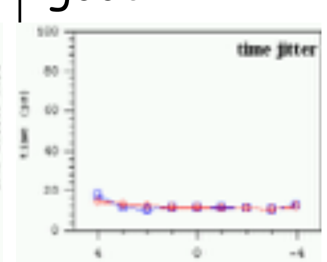
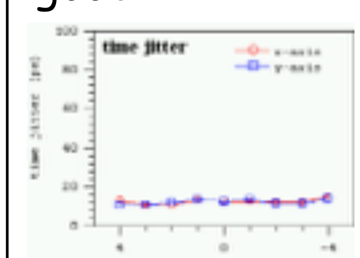




Simulated energy deposit/per each of 40 1 micron layers-typical event



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)

Modelling effect of large C_D

(with J. Kaplon)

Preamp in voltage mode

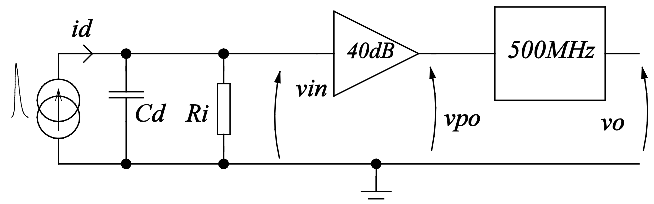


Fig1. Preamplifier working in voltage mode.

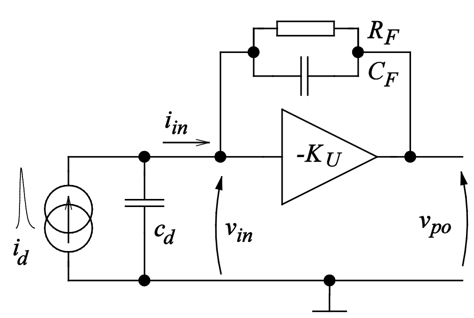
Response (vo(t)) can be found solving following equations.

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)

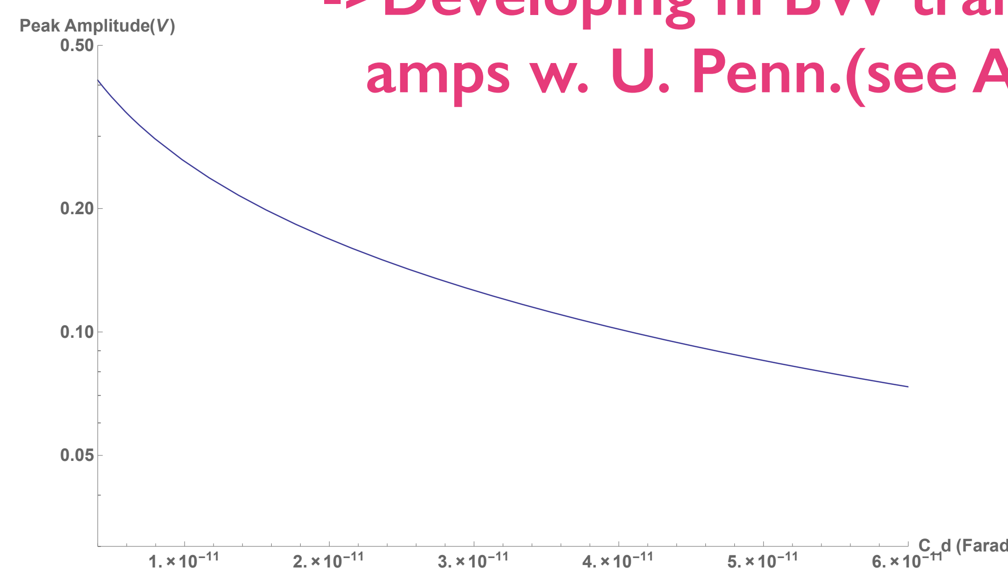
Preamp in charge/transimpedance mode

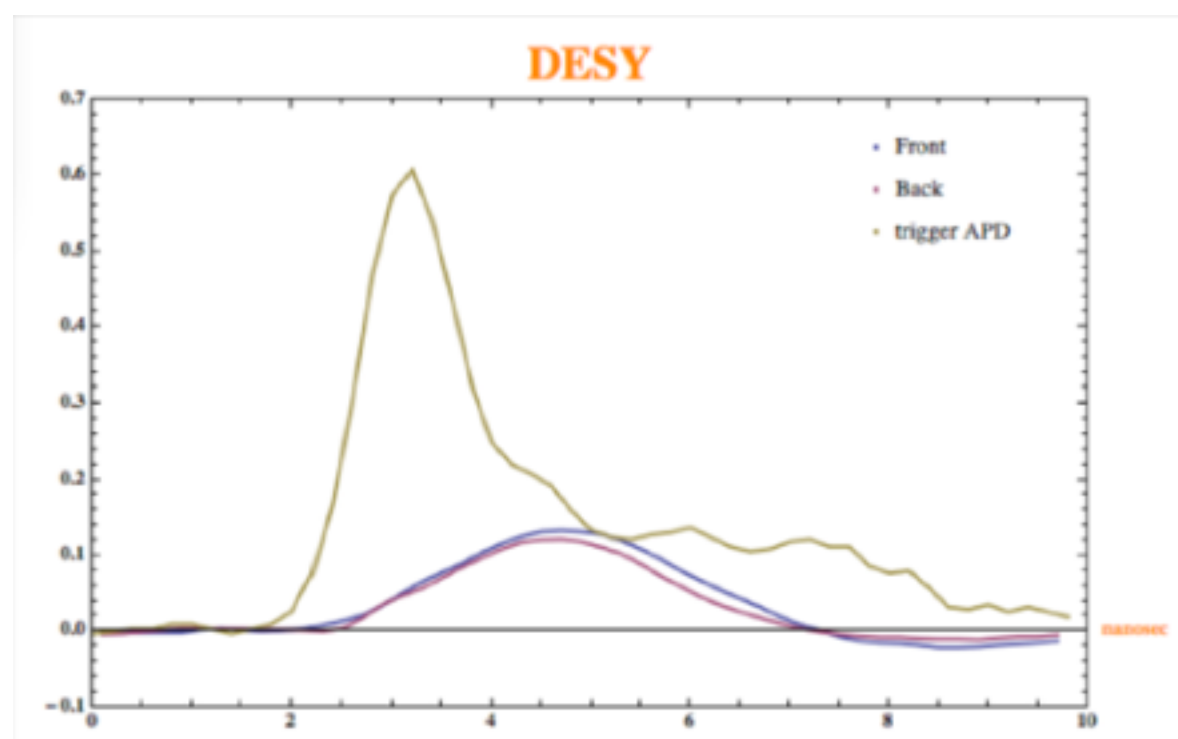


Assuming high Ku the amplitude response does not depends in first order on c_d.

Features reproduced in beam testing @SPS,LNF,PSI,DESY over last 2 years

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





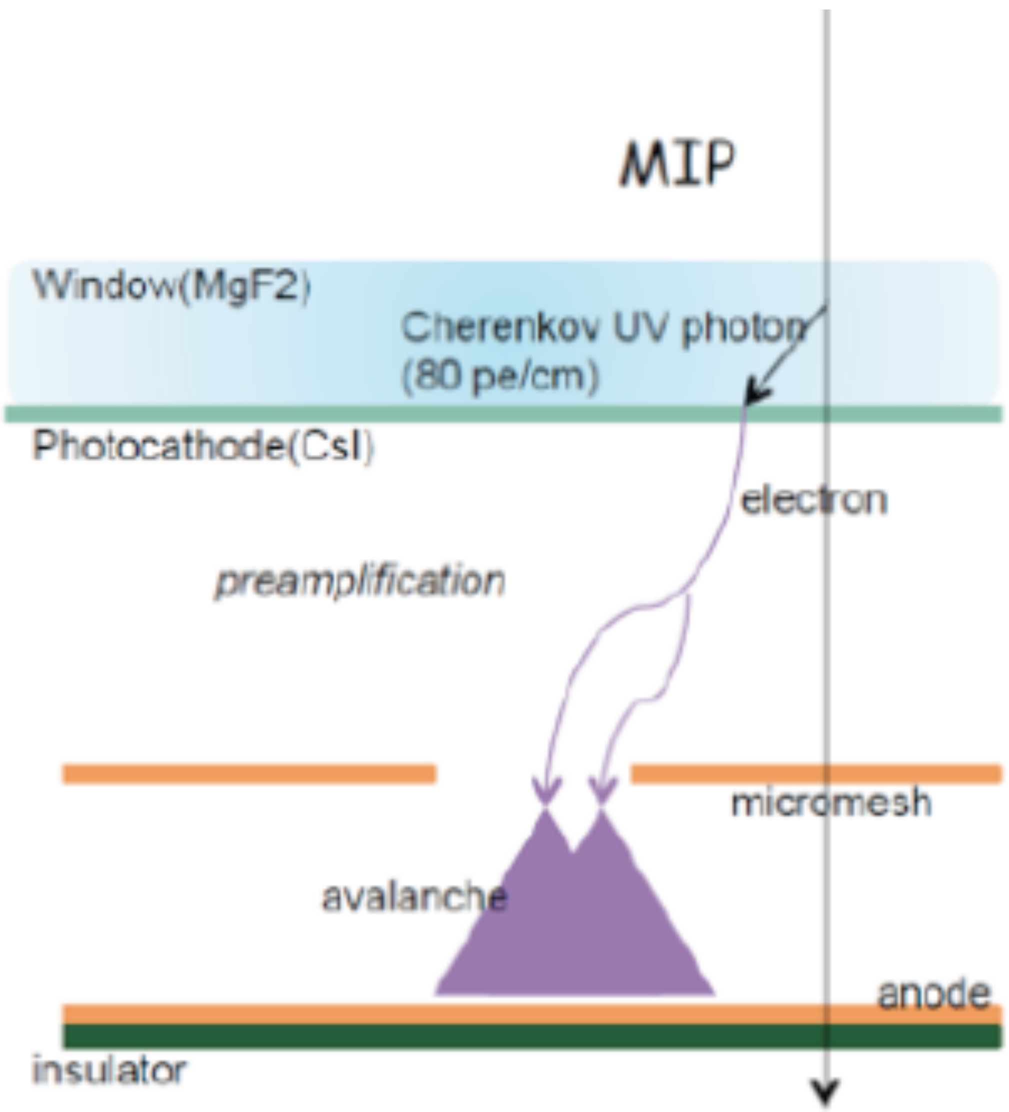
Fabrication costs

- 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.

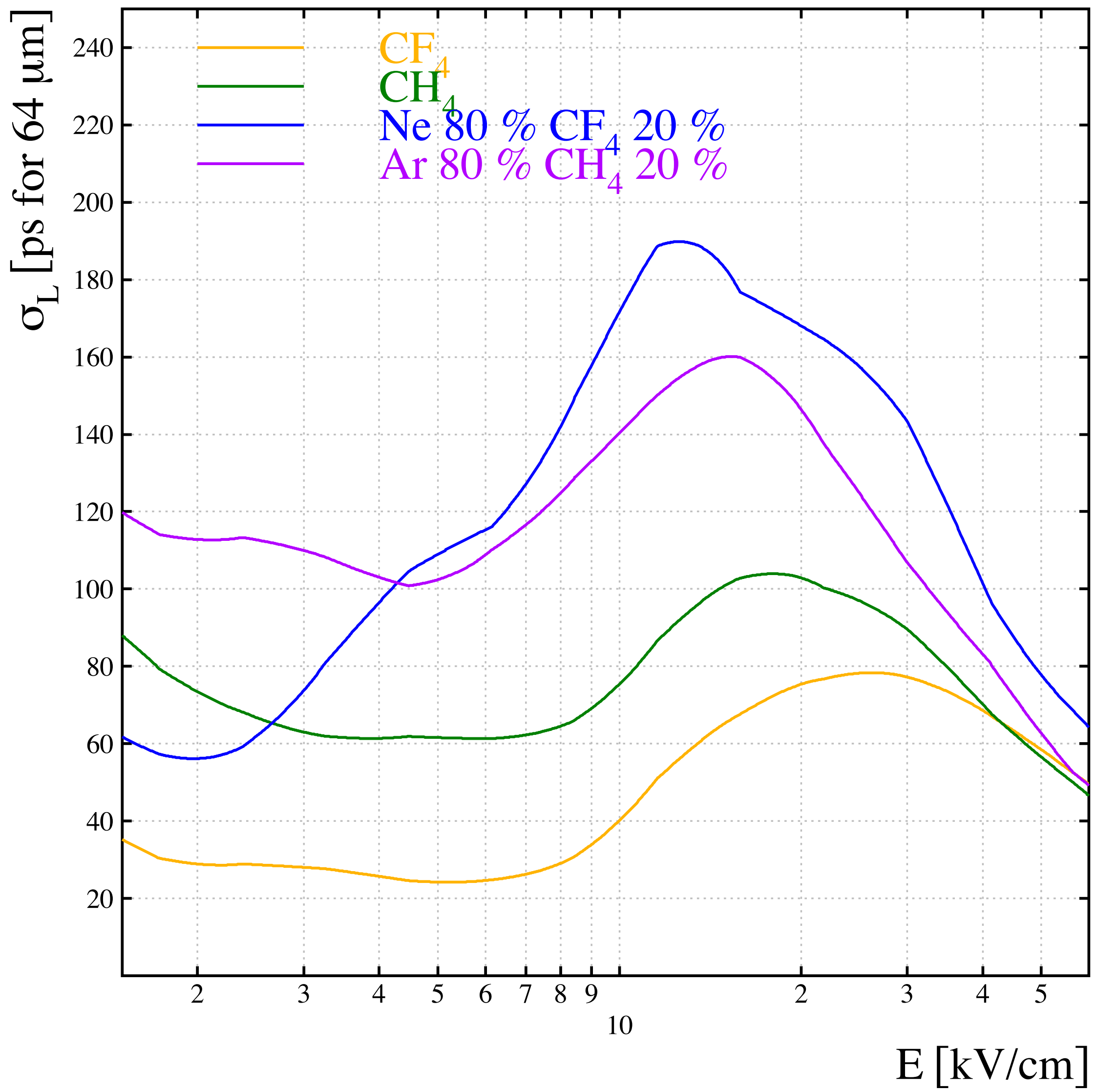
Lifetime/rad dose

•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.
•higher dose measurements starting this month at CERN (working with Michal Moll), also in parallel at FNAL

for both issues have started GasPMT parallel effort



transparent pc version



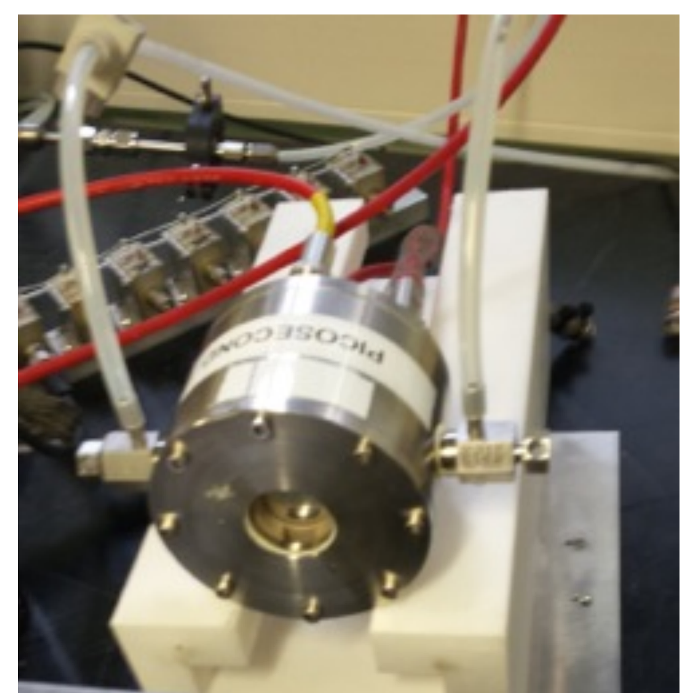
(Rob Veenhof calculation)

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.)

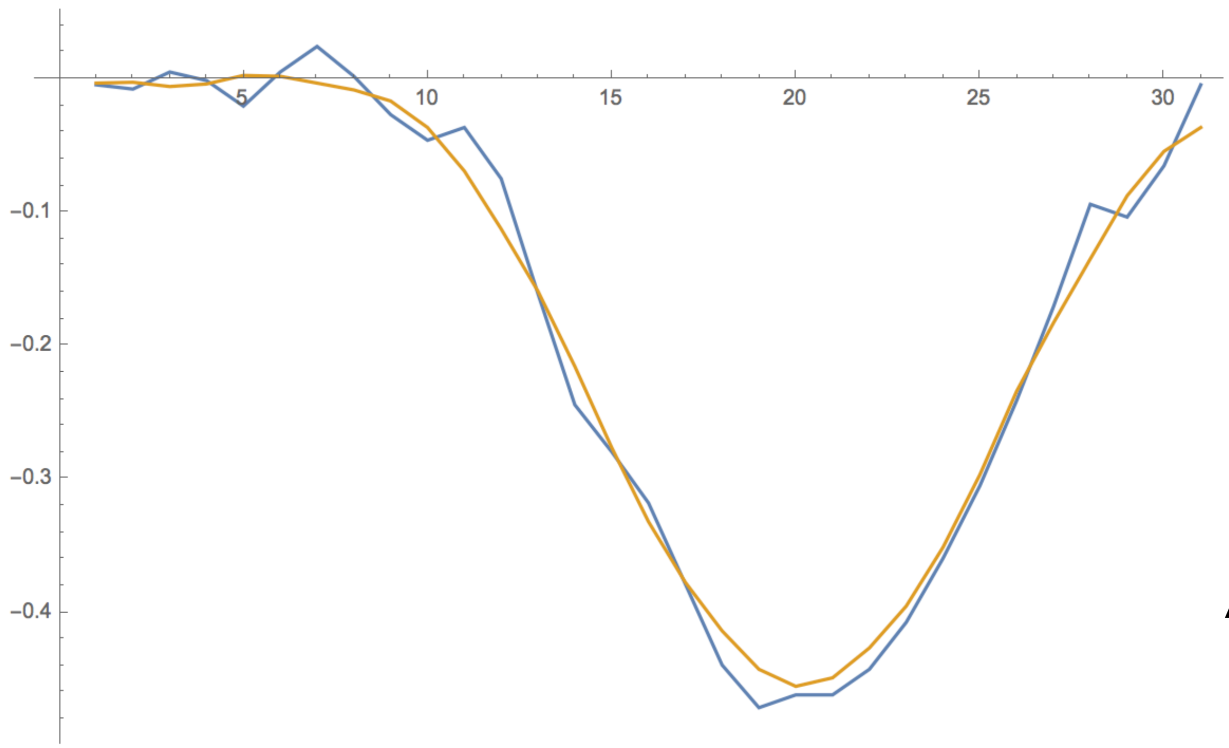
- From above calculation clear that diffusion term for single photoelectron can be as small as ~35 picosec with ~100 micron Micromegas gap.
- So we seem to have alot of head room to optimize things
- many common issues w. ie front end electronics
- chambers under construction at CERN and Saclay for tests at Saclay femtosecond laser facility to measure jitter
- first results reported at our RD51 meeting this morning-nice!
- If succesful, pc lifetime is thing to optimize but much local expertise- also at FNAL on photocathodes.
- Could be cheap!

initial measurements of
gain and time jitter using Deuterium flash lamp



Common issues on FEE and signal processing

```
ListPlot[{wave, WienerFilter[wave, 1.5, .1]}, Joined → True, ImageSize → Large]
```



<-waveform w. 30 pts@0.2ns/point
tR~2 nsec w. commercial amp

unoptimized Wiener filter seems effective.
A signal with 2 nsec t_R contains no frequencies higher than 200 MHz.

"Greg's desk"

most relevant literature comes from outside our field (radar, GPS)

[1] N. Wiener 1949, Extrapolation, Interpolation, and Smoothing of Stationary Time Series, John Wiley & Sons, New York.

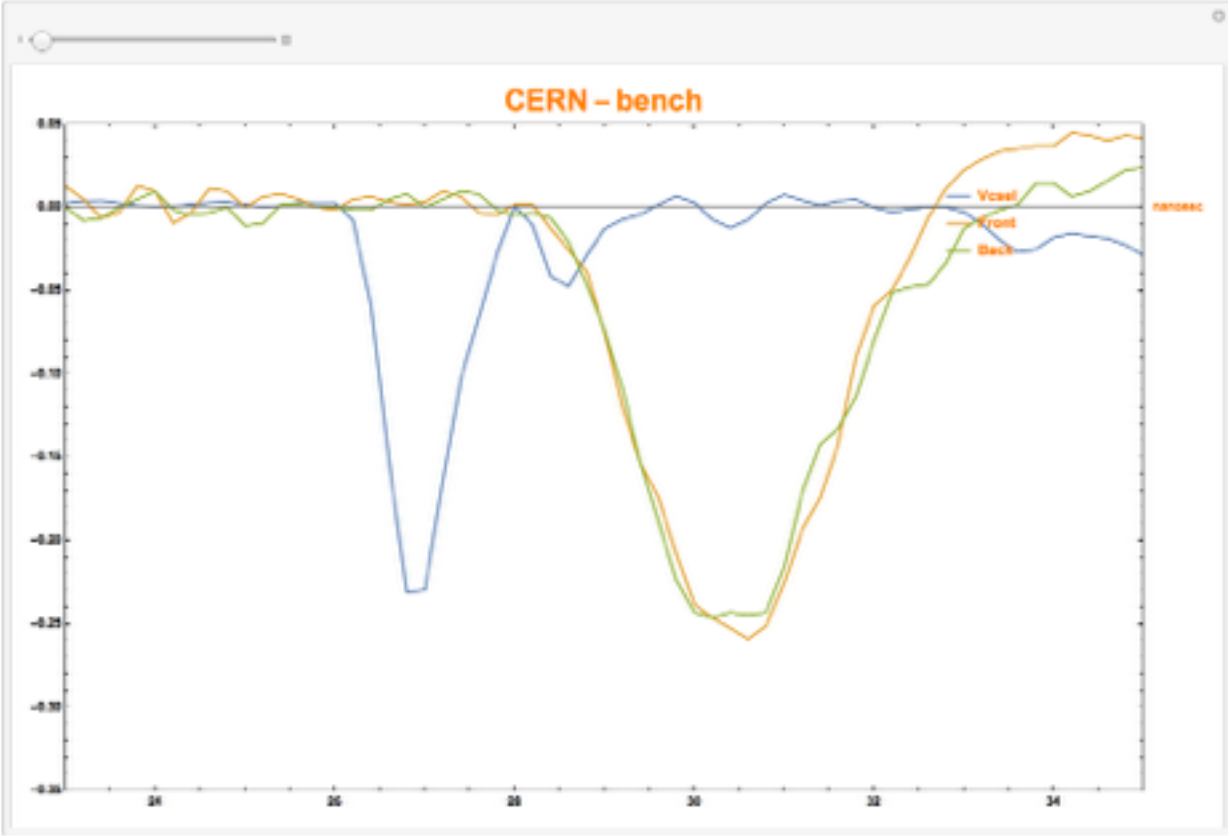
[2] R. E. Kalman 1960, *"A new approach to linear filtering and prediction problems,"* Transactions ASME, Ser. D, Journal of Basic Engineering, 82, pp. 35-45.

[3] S. K. Mitra, and J. F. Kaiser (eds.) 1993, Handbook for Digital Signal Processing, John Wiley & Sons, New York, 1268 p.

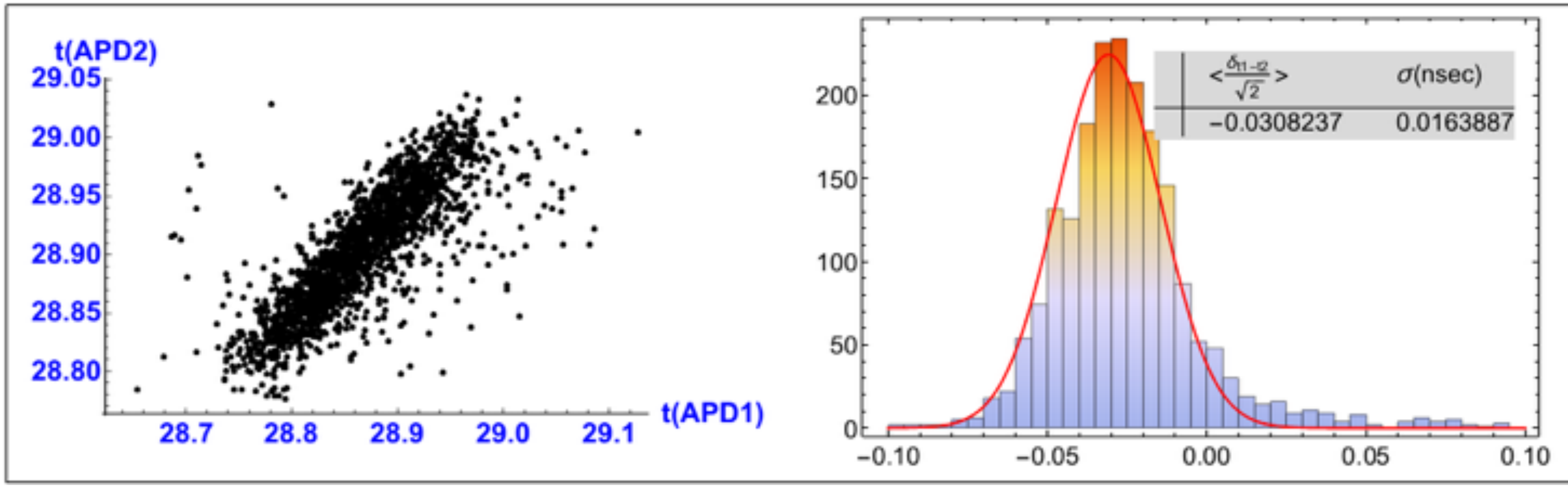
[4] Y. C. Chan, J. C. Camparo, and R. P. Frueholz 2000, *"Space-segment timekeeping for next generation satcom,"* Proceedings of the 31st Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 7-9 December 1999, Dana Point, California, USA, pp. 121-132.

Laser testing
(980 nm, #e-h pairs matched to MIP)

time jitter in presence of significant noise
(here due to noise from transistor discharge in pulser)
to test signal filtering algorithms.
These algorithms will be critical in operation after
full rad dose at LHC.



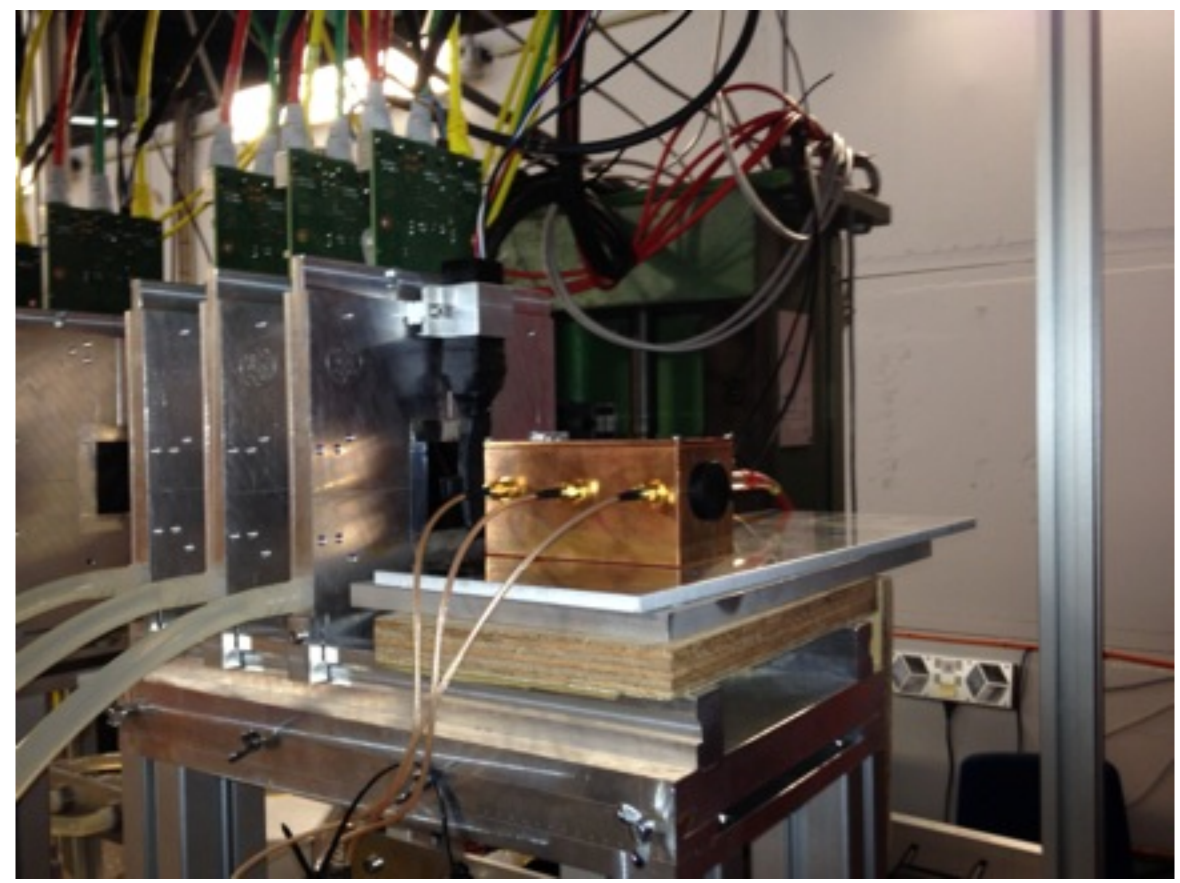
16 picoseconds time jitter
is a respectable
performance!



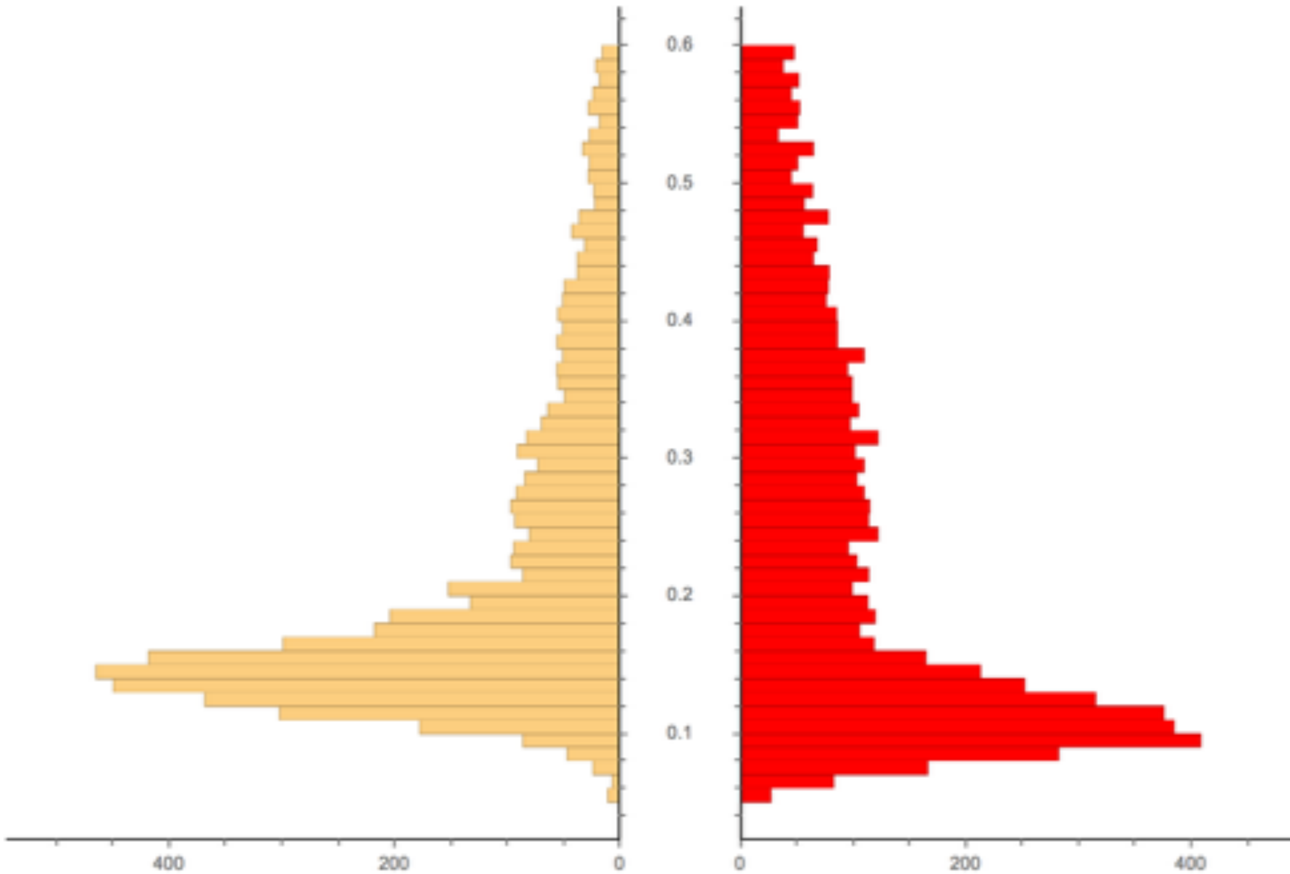
DESY electron beam

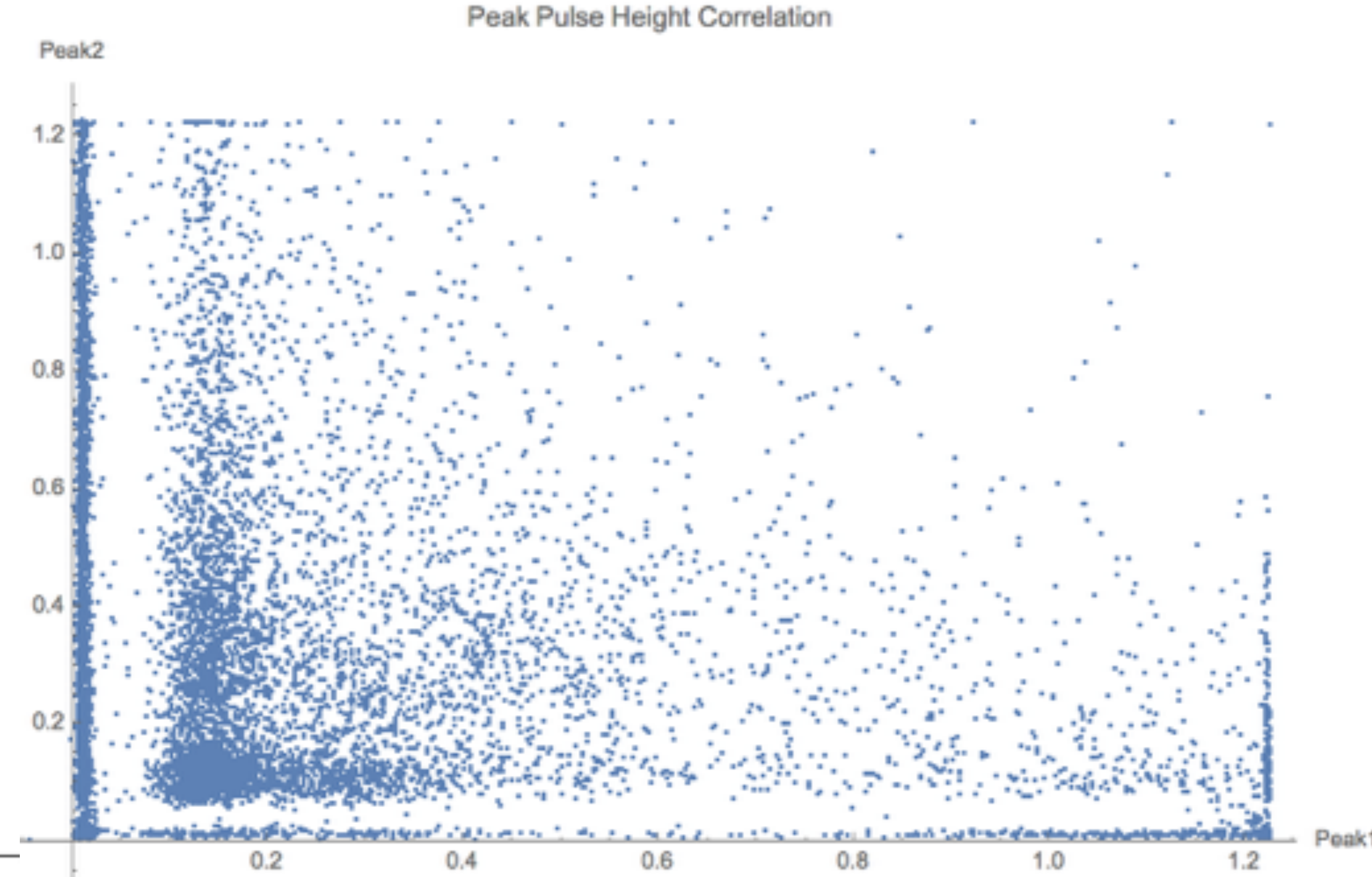
what is optimal signal processing for MIPS?

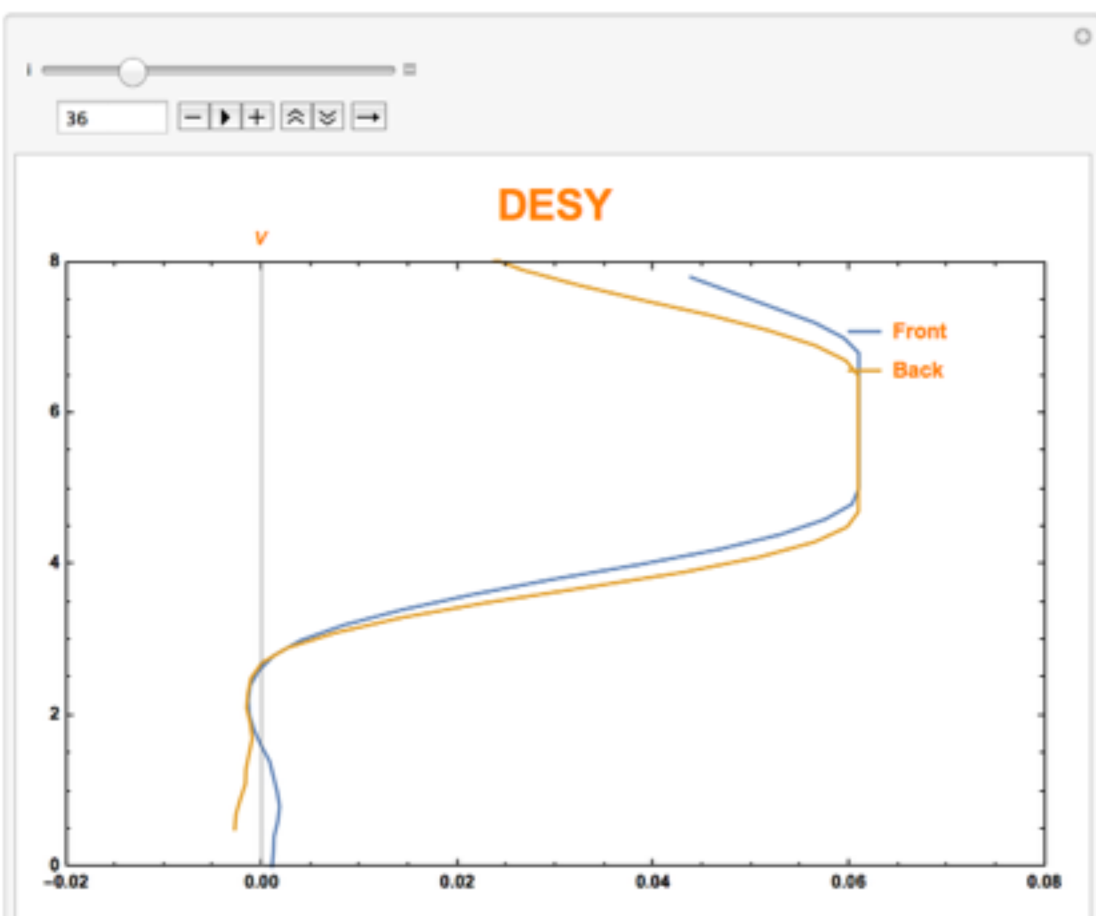
-large dynamic range and stochastic contribution from Landau/ Vavilov fluctuations



>100k events using 5 GSa/s 1 GHz , 8-bitscope DAQ. Also DRS4 v5 and SAMPIC testing on the same trip in March 2014


0.6
0.5
0.4
0.3
0.2
0.1
400
200
0
0
200
400


Peak Pulse Height Correlation
Peak2
Peak1
1.2
1.0
0.8
0.6
0.4
0.2
0.2
0.4
0.6
0.8
1.0
1.2


36
DESY
v
Front
Back
8
6
4
2
0
-0.02
0.00
0.02
0.04
0.06
0.08

Summary

- we have a year to demonstrate this for CMS
- in 2014 participation ramped up significantly- CERN,RD51(RD50),Saclay,FNAL,Trieste,Athens....a dded to core of Rockefeller/Princeton/RMD/ Newcomer/Tsang
- but the process has been very slow and mostly financed by individual's enthusiasm ($50k DOE ADR&D-2010-2013,USCMS supplied $10k for contract to U.Penn, $12k for RMD, CERN/CMS provided 1k CHf to develop a subnanosecond pulser)
- not sure I agree with Charpak in today's world

Postscript:

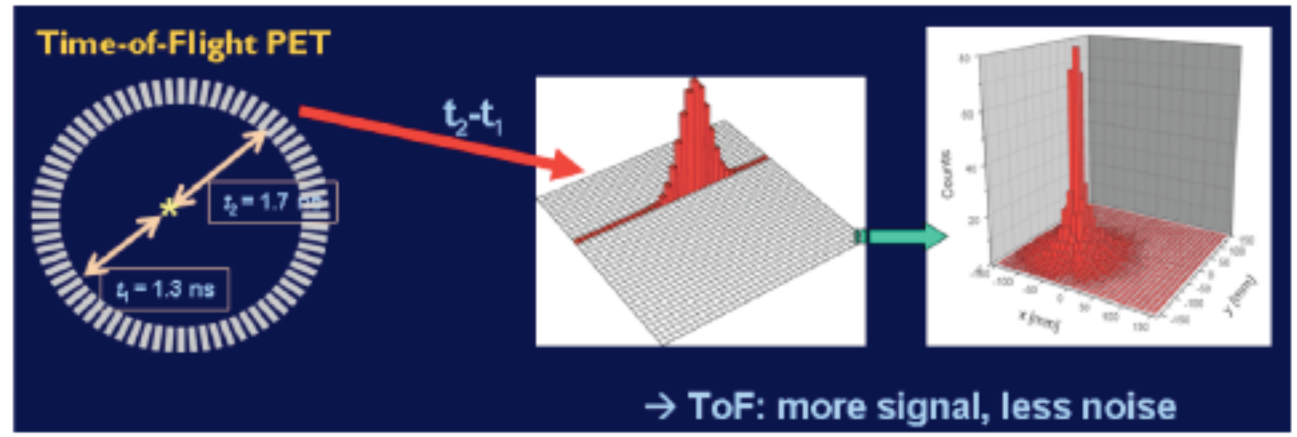
Fast Timing in Brain Imaging

“detector-centric” objective

->EU “Picosec” initiative but

- PET images the level of Sugar-uptake in the brain.
- Sugar is not the main energy source.
- The level of activity not necessary indicator of Cognitive Function

=>



Neuroscientist Objective

- MagnetoEncephalography is the only non-invasive technique to image the brain on the time scale of neuronal activity.
- Delayed response to external stimulus and its dependence on complexity of the pathway is potentially a powerful bio-marker for Alzheimer’s and other diseases.
- It could be used to provide early detection and guide therapies, etc.

=>

E. Pekkonen et al. / Clinical Neurophysiology 110 (1999) 1942–1947