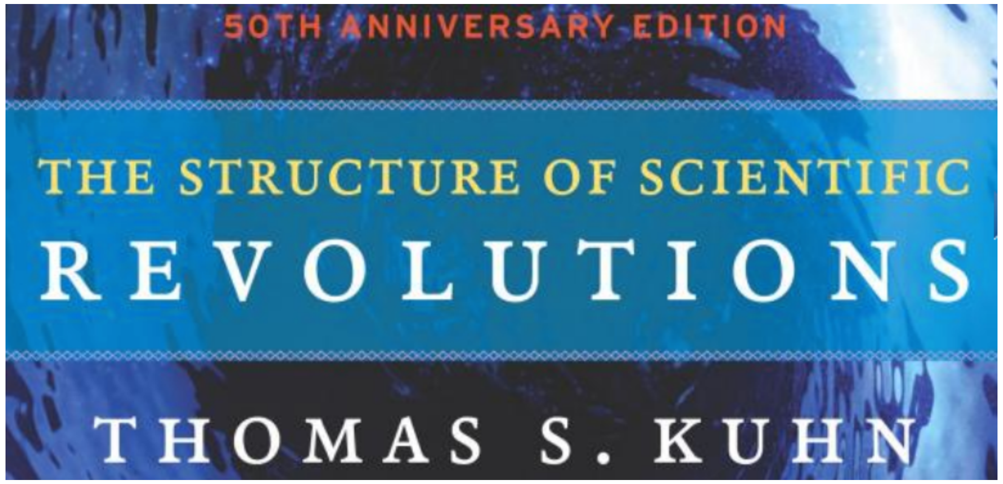
Experimental Challenges in Future..(mostly HL-LHC)

Sebastian White, Rockefeller Spalato,HR 4/10/2104

Outline:

- some background: the tension between going industrial in Collider detector construction and the need for novelty
- The European, US and regional strategy process
- The urgency of addressing needs for HL-LHC
- an example: Development of Pileup Mitigation tools based on timing-RD51 project+ some USCMS funding.
- possible lessons for FCC

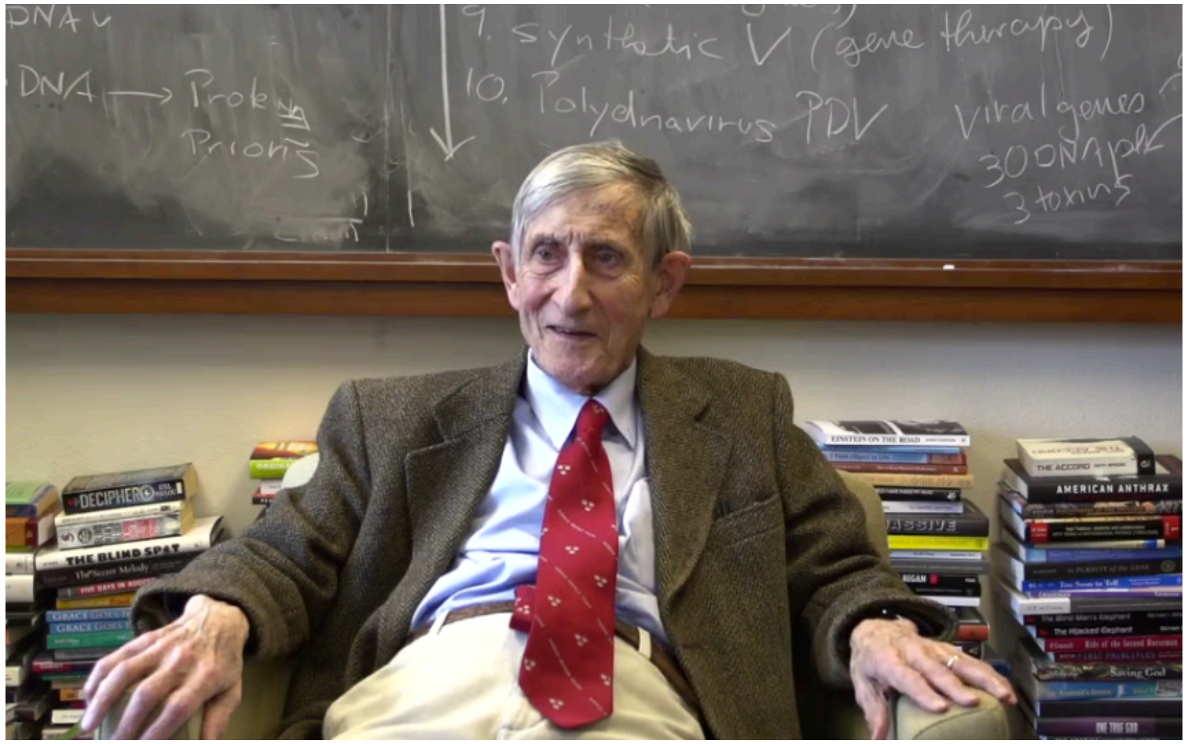
Ideas and Tools



HISTORY OF SCIENCE

Is Science Mostly Driven by Ideas or by Tools?

1. Freeman J. Dyson



"In almost every branch of science, and especially in biology and astronomy, there has been a preponderance of tool-driven revolutions…"

Freeman Dyson, "Imagined Worlds", 1997

Quoted by W. Riegler in 2008 CERN Academic Lectures. It became popular with managers arguing for Instrumentation funding (ie Snowmass). I recently corresponded with Dyson to get an update:

...2012 article in Science:``Is Science Mostly Driven by Ideas or by Tools?'' As you will see, the answer to the question is that both are important. Sometimes ideas are dominant and sometimes tools.

You can quote me on both sides of many questions. I am glad to hear that Tolstoy is alive in Lausanne. Yours, Freeman.

Dyson, private communication, May 2013

Donald Glaser:

“After winning the Nobel Prize, Glaser began to think about switching from physics into a new field. He wanted to concentrate on science, and found that as the experiments and equipment grew larger in scale and cost, he was doing more administrative work.”

moved to Molecular Biology ~1960

founded Cetus Corp.-the first Biotech company ~1971

Donald A. Glaser

Luis Alvarez:

Alvarez industrialized bubble chamber physics, which led to a golden age of physics at Berkeley.
Later in life he developed techniques to map the pyramids and worked on dinosaur extinction.

Luis Alvarez

Georges Charpak:

“When I came to CERN I found myself in a milieu which was like a reserve in Africa. Big game hunters -and the prey was some big physics discovery. I thought I would be poaching on their territory. I found that it was easier to make a fortune by selling them weapons. In other fields people have found this to be the best way to become rich.”

Burton Richter:

”High Energy Colliding Beams: What is their Future?”

“ I see too little effort going into long range accelerator R&D, and too little interaction of the three communities needed to choose the next step, the theorists, the experimenters, and the accelerator people. Without some transformational developments to reduce the cost of the machines of the future, there is a danger that we will price ourselves out of the market”

“The events per beam crossing and per unit length along the collision region are going to make serious problems for the detectors. Having 50 times the events per beam crossing **[mu=7,000]** will require something new in detectors. Having the mean spacing between vertices go from 1.3 mm to 2.5 microns will probably also require something new in detector technology. Getting the experimenters involved in setting parameters is necessary in building something that can really do the physics.
I understand that CERN is setting up such a group. It is about time”

The Planning Process

- EU strategy for particle physics was released about a year ago.
- P5 process presented this summer. Many of us also wrote support letters for the findings.
- consensus that highest priority of HE frontier is to "exploit the full potential of the LHC" to ~10x original integrated luminosity
- P5 stopped short of recommending specific effort in technology. HEPAP addressed accelerator aspect.
- Experimental challenges fall to collaborations. Perhaps only a year remains to sort out design. This is very short.
- Much attention to the cost drivers and clear need for refurbishment (next talks).
- Our group works in an area where there isn't yet a full demonstration of benefit to CMS- pileup mitigation tools. We have been given a year to demonstrate physics benefit and ensure that there is a technical solution. Both cost drivers and potential enablers need support.
- there is a risk to this strategy (as SB has also pointed out):
  - we don't yet know what the next 2 years will bring
  - for the health of the field important that upgrades are perceived as adding new capabilities

addressing the HL-LHC experimental challenges

- 20 year history of R&D on consequences of <u>integrated</u> luminosity/dose
- only emerging focus on consequences of high <u>instantaneous</u> rate-pileup
- nice summary of ATLAS/CMS by Takubo at FNAL FCC workshop(see next talks)
- 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

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*

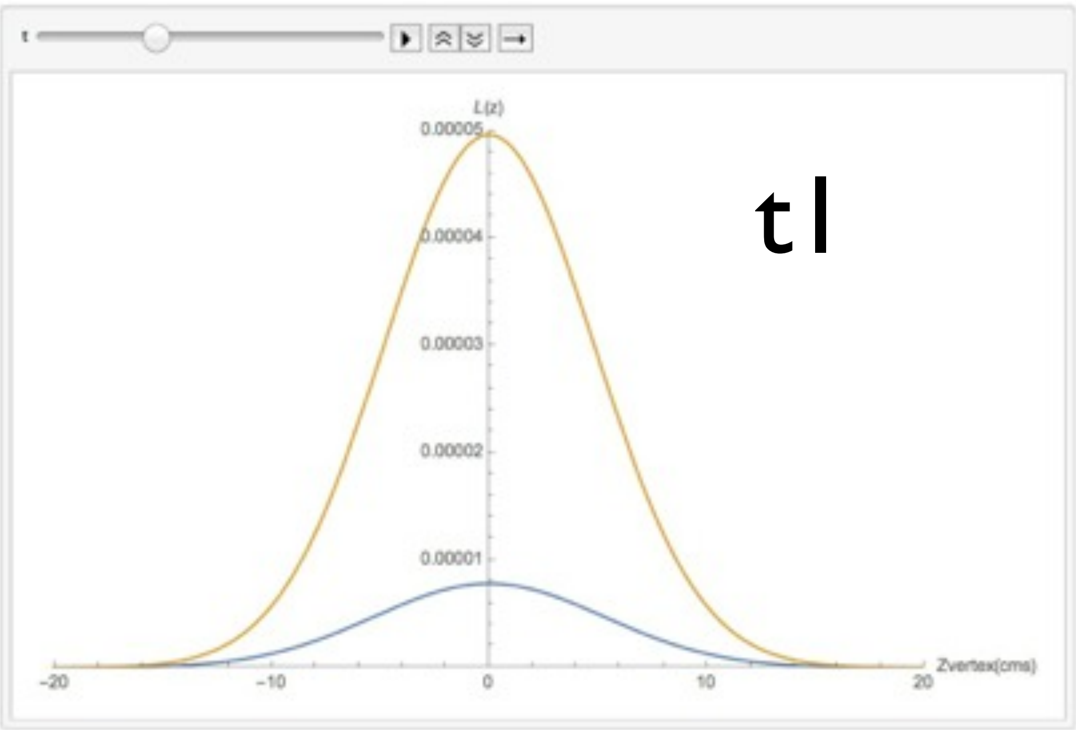
Ext. Collaborators:

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

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

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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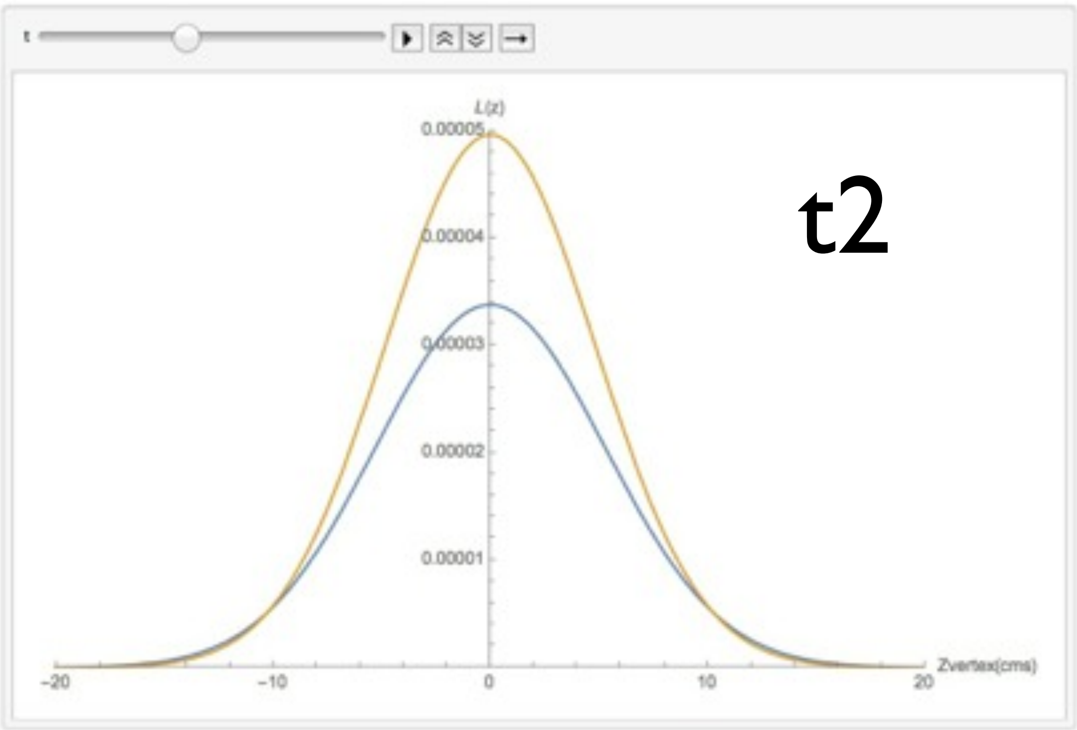
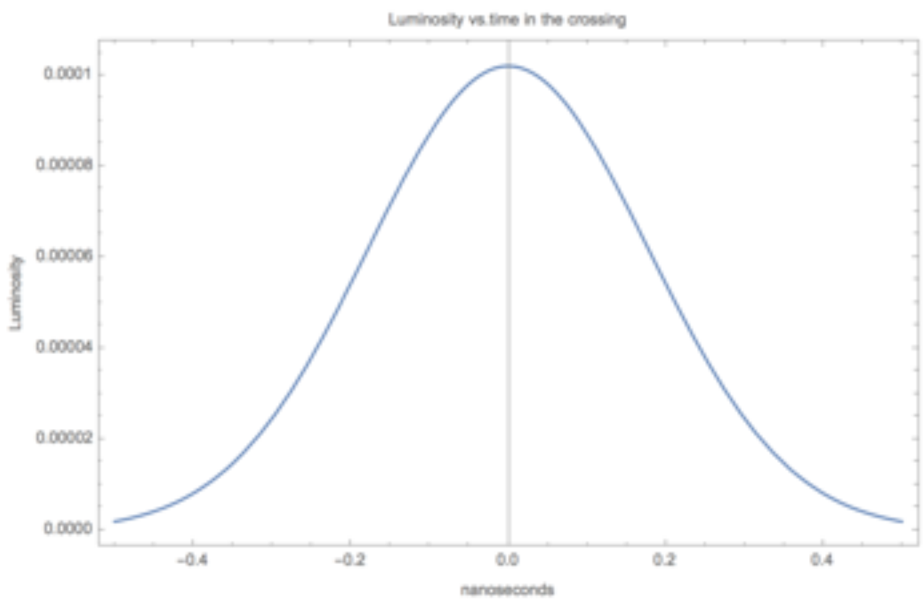
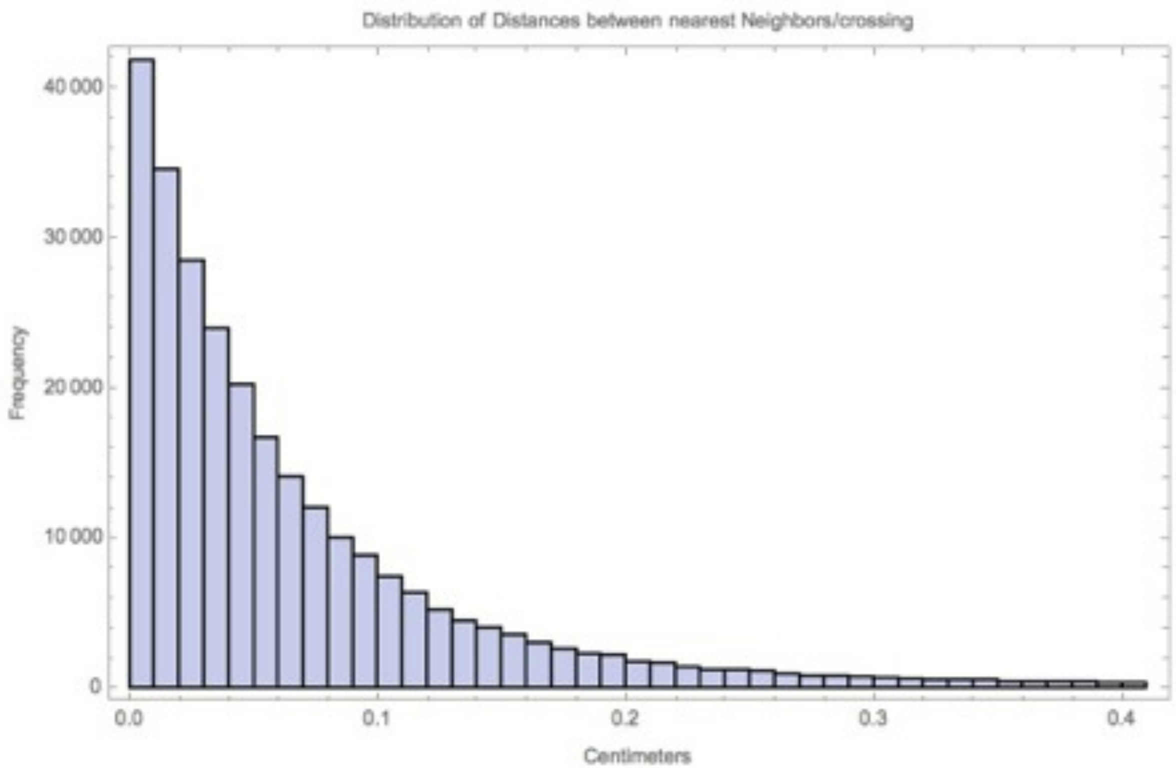


Zvertex distribution in z invariant wrt time during xing, rms= 4.8cms.

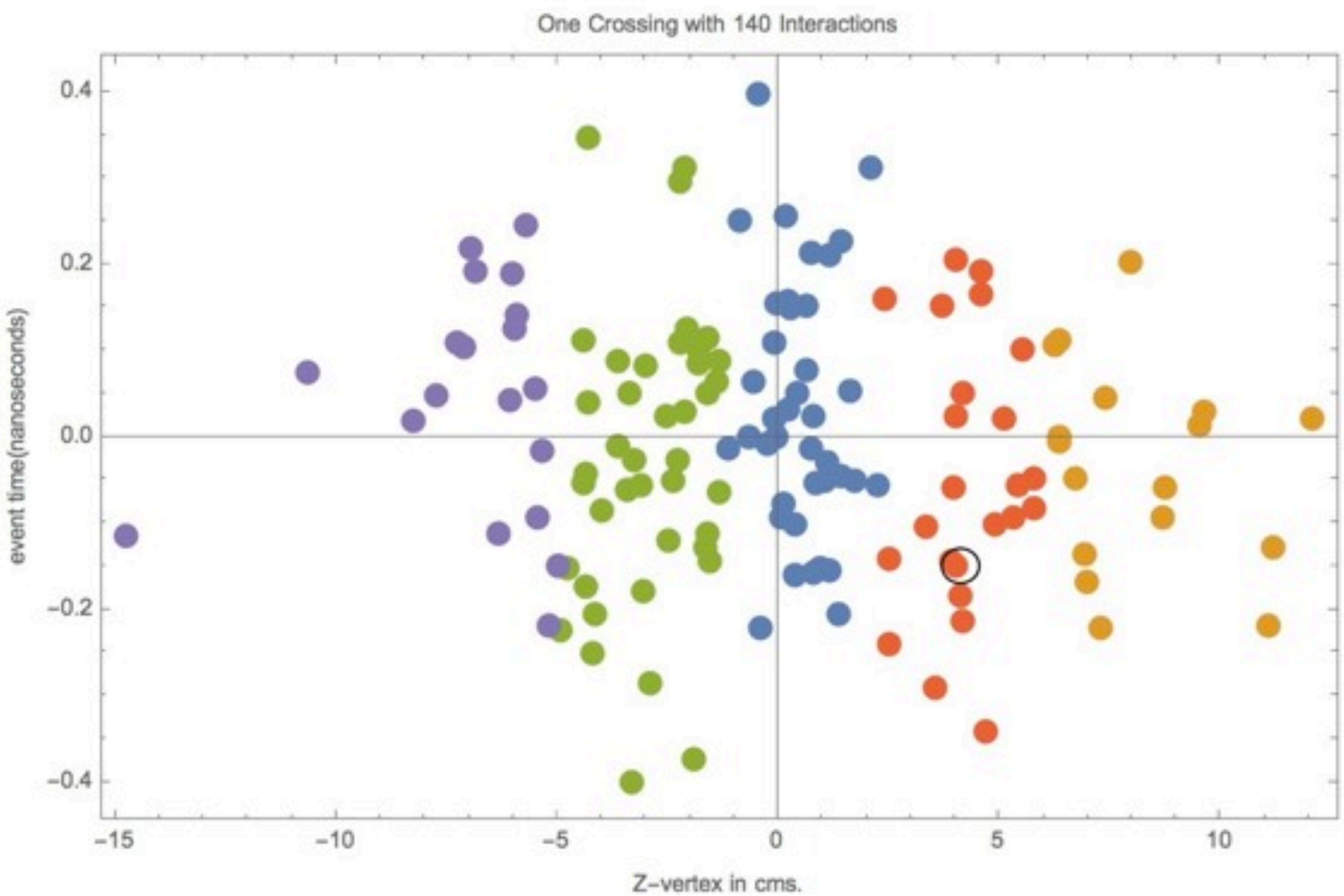


rms in time domain=170 picosec

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

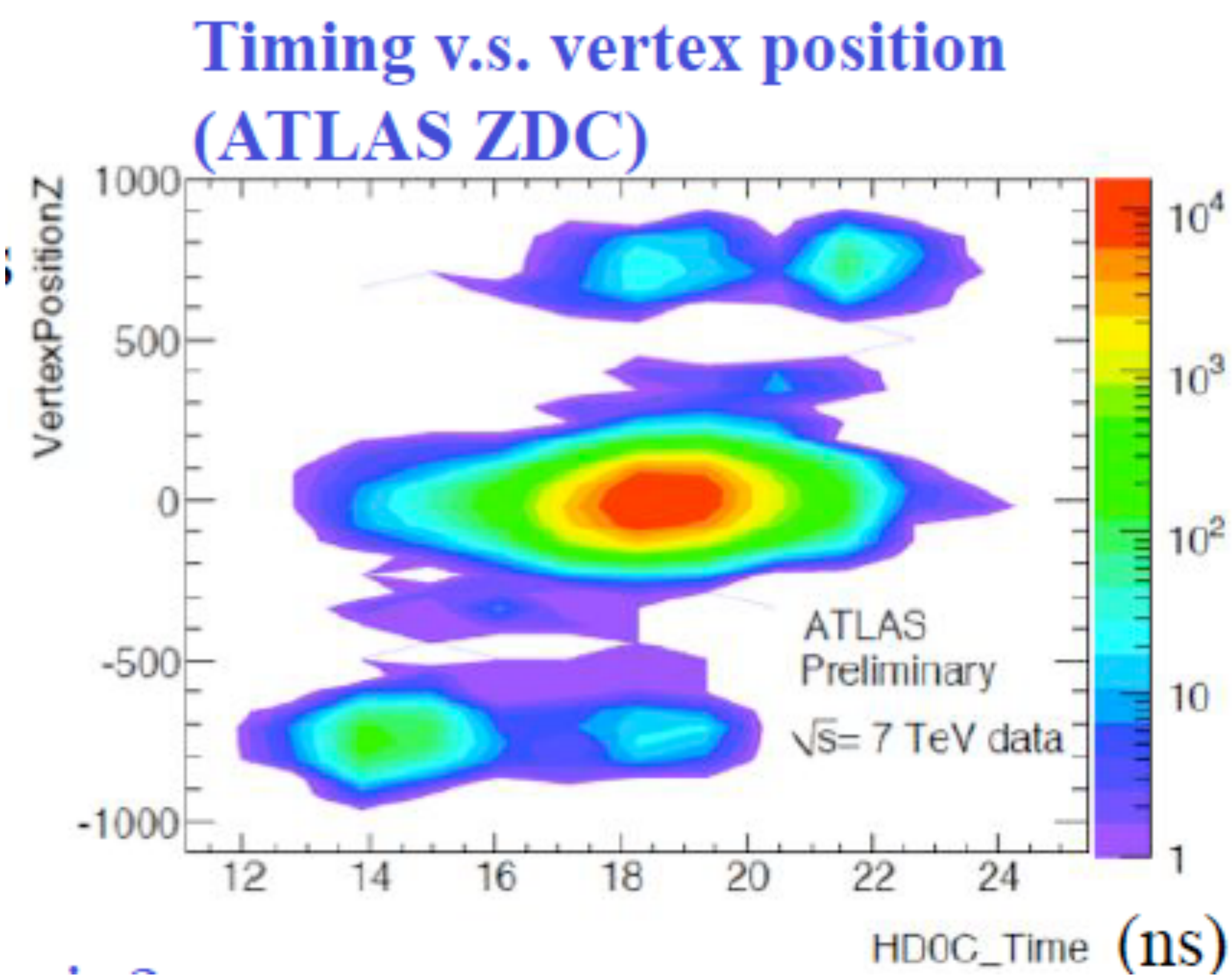
talks about precision timing usually start from assumption that vertex time is known (??)

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

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

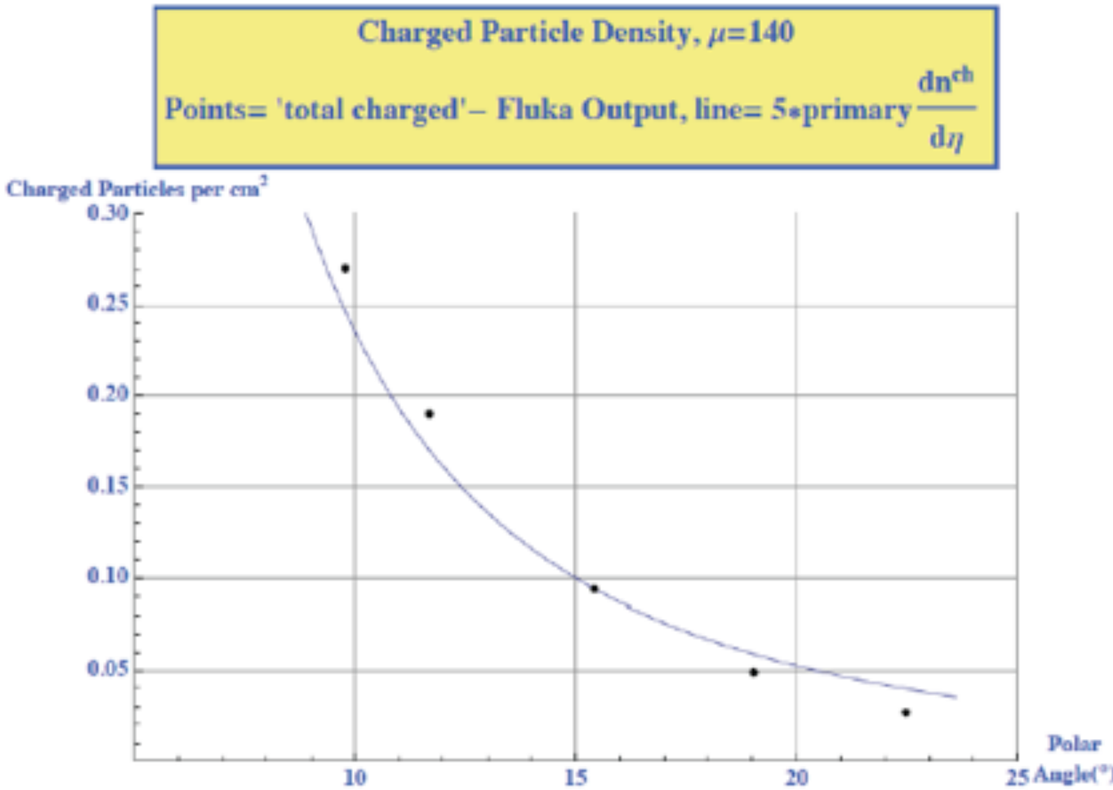
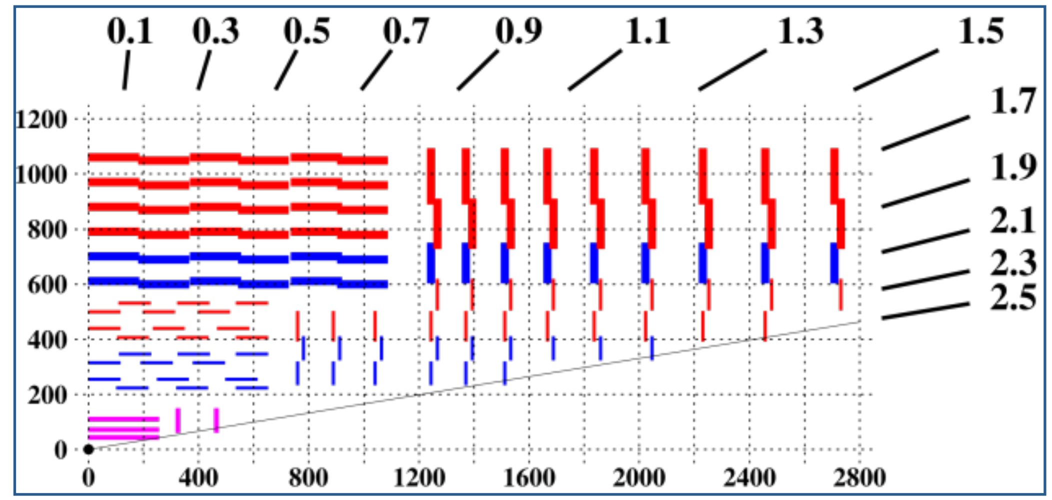
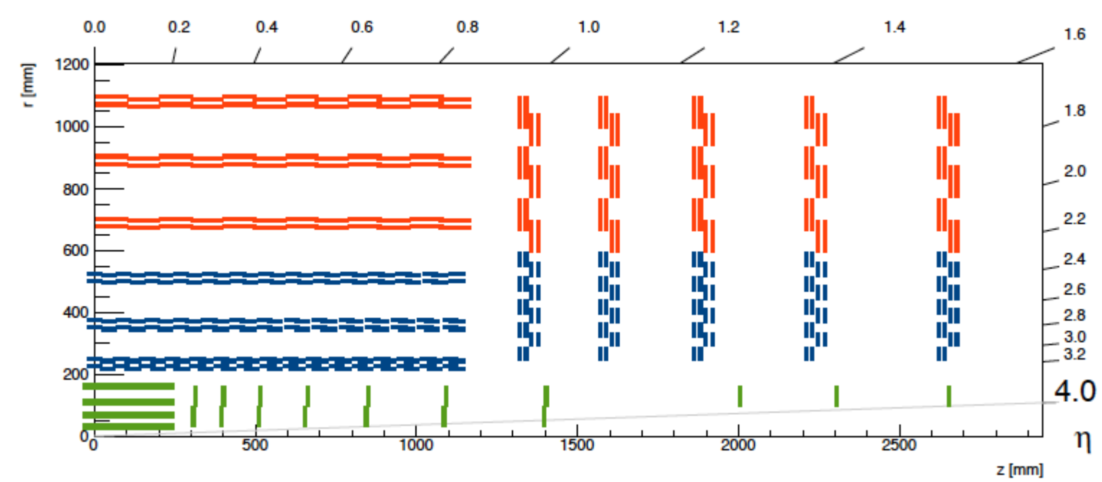


Figure 2: The charged particle density in the region of the dedicated timing detector. The points are FLUKA output for "total charged". The line is calculated from estimates of primary charged particle density-dn/deta- scaled up by a factor of 5. FLUKA output is roughly consistent with a constant factor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

current model in CMSSW matched to:

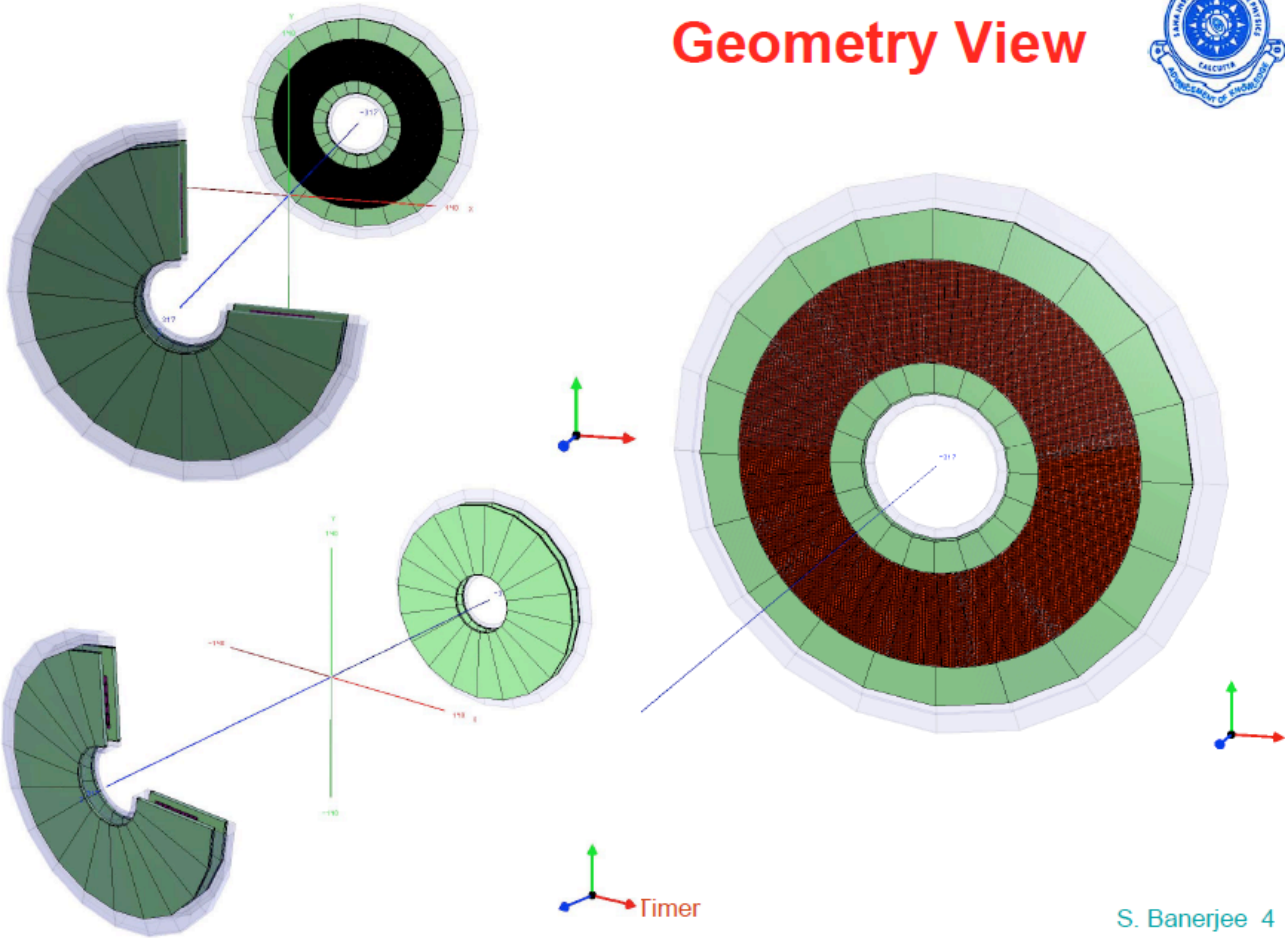


if tracker extended in Phase2, complementary role?



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)



S. Banerjee 4

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)

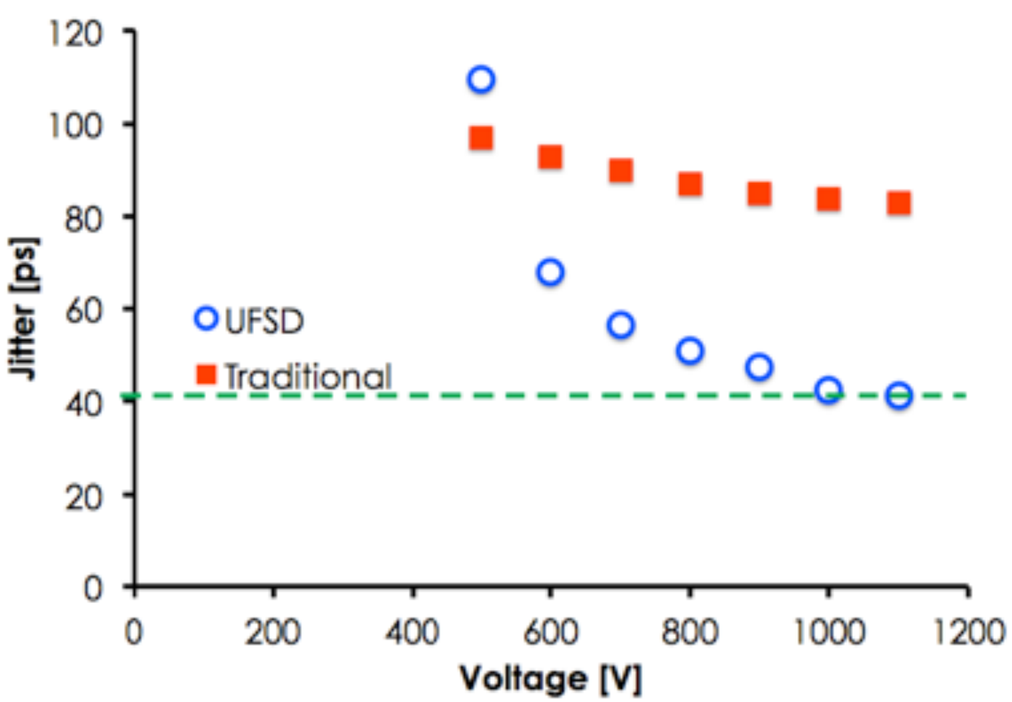
What else is out there?

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. (next slide)
- 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

Other Solid state devices (Diamond, LGAD)

- Diamond sensors attractive for rad hardness
  - fast but low SNR->~90 psec/layer
  - AFP considering for forward protons
- LGAD-H. Sadrozinski et al. ("4-D Si","UFSD", etc.)
  - RD50 discovered that gain is a "feature" of Si damage at high doses
  - recent timing measurement by M. Moll@CERN
  - recent rad testing->Gain unstable at ~10^14 neq->now considering alternate processing similar to HGAD used in our project(below)



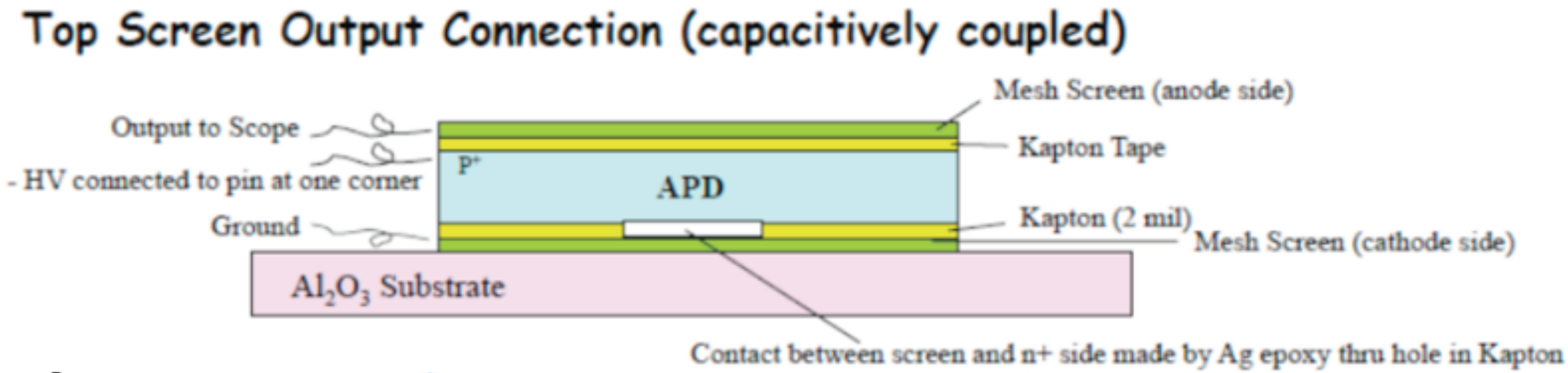
<-recent laser test@CERN, M. Moll
pretty fast but cornered the market on catchy names

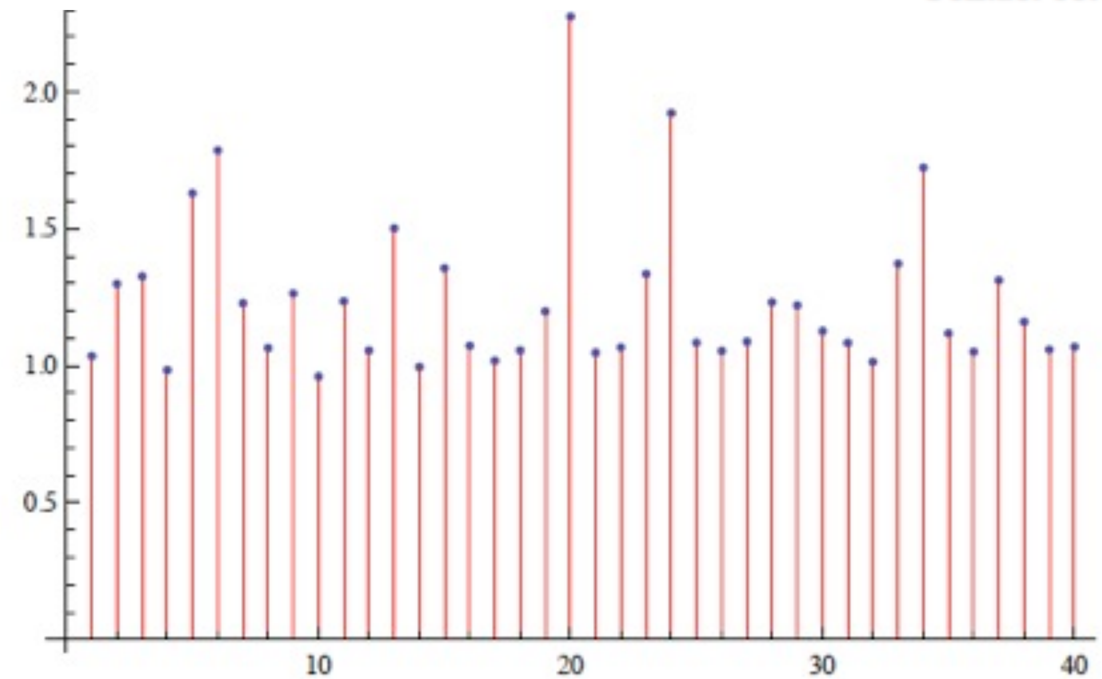
we reported on 2 technologies

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

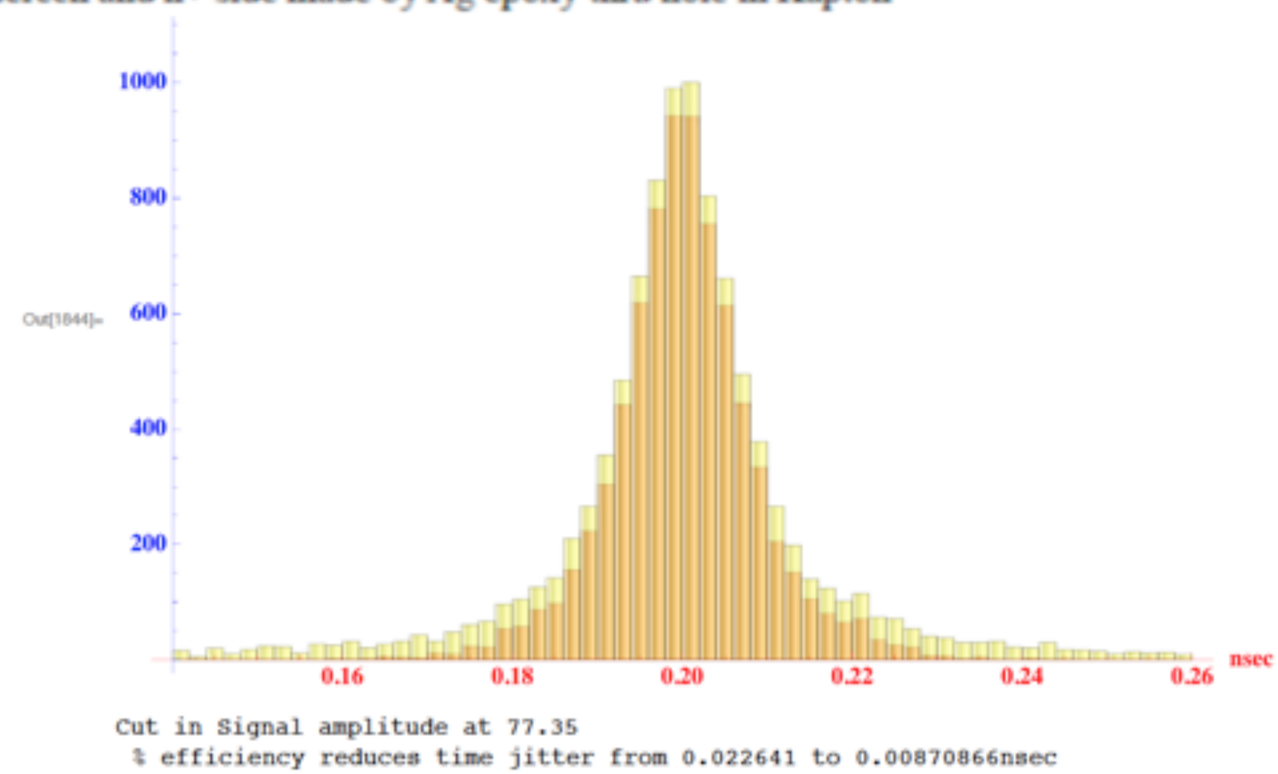
Si option:(many presentations to FCWG over past 2 years)

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

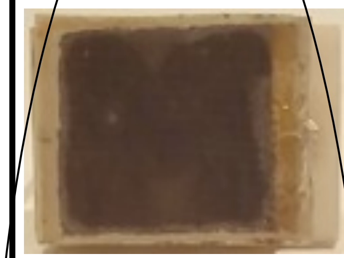
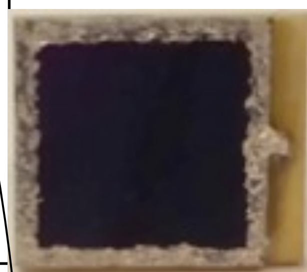
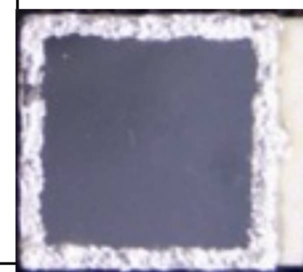
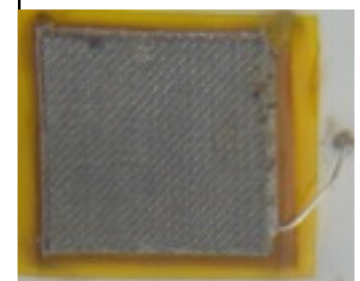
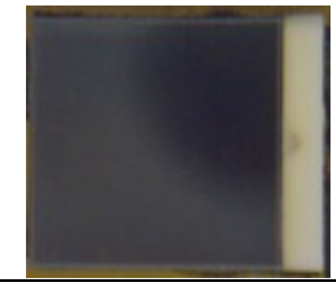
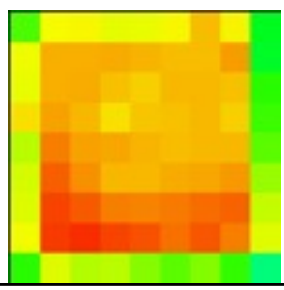
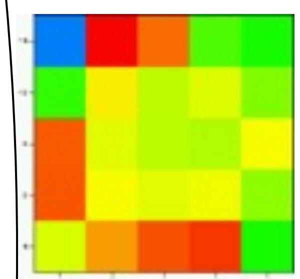
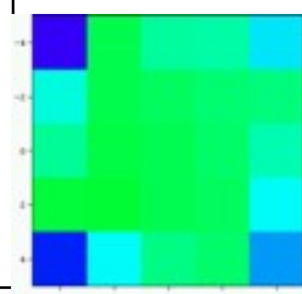
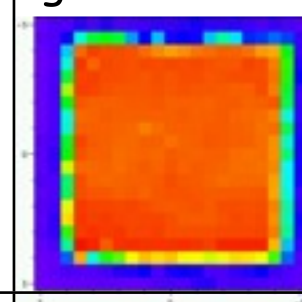
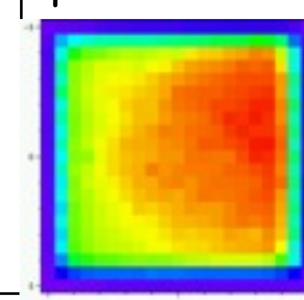
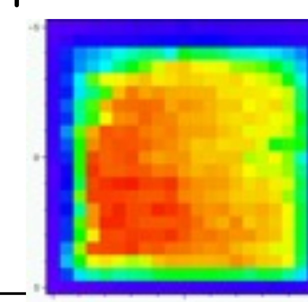
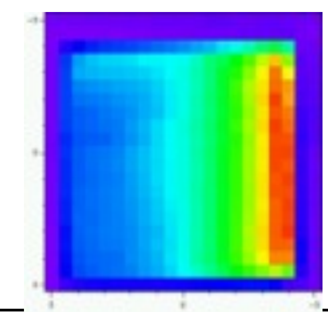
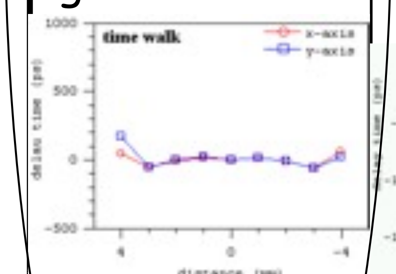
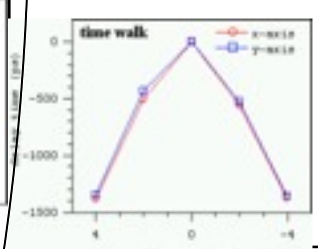
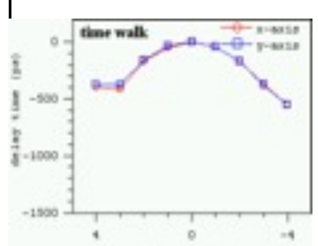
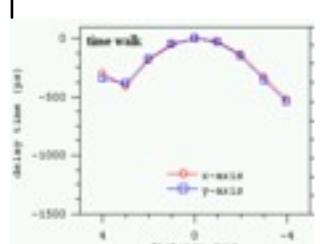
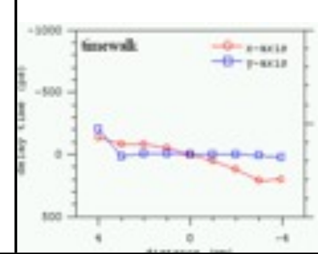
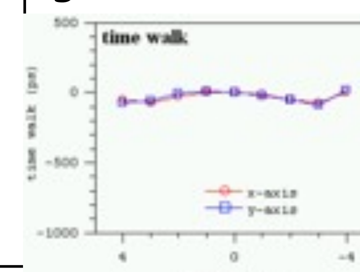
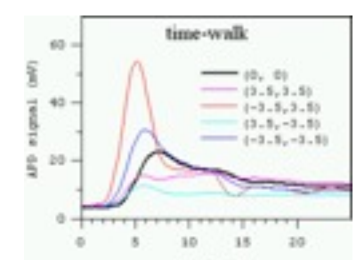
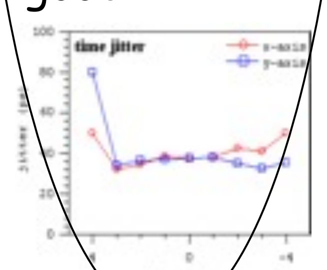
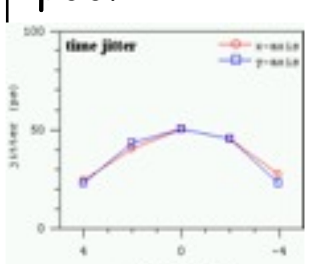
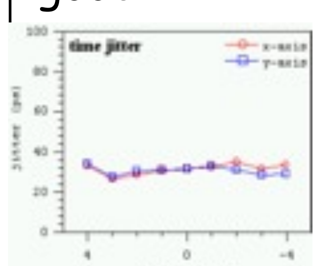
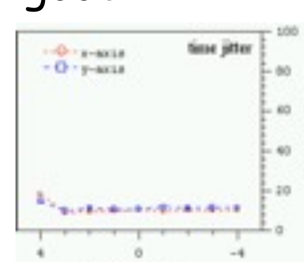
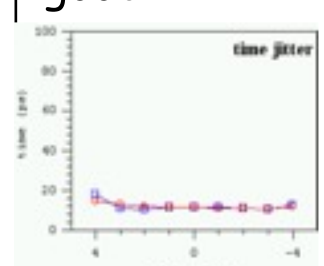
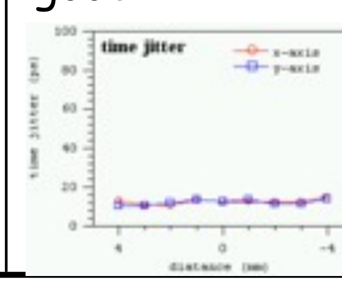




Simulated energy deposit/per each of 40 1 micron layers-typical event



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

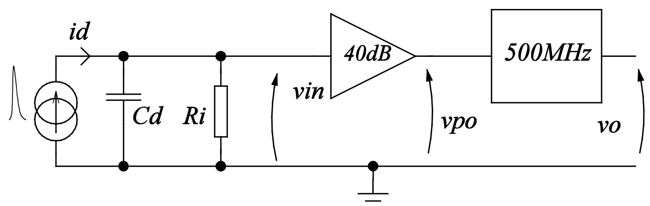


Fig1. Preamplifier working in voltage mode.

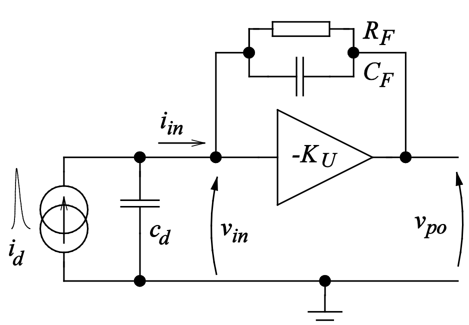
Response (vo(t)) can be found solving following equations.

Voltages:

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

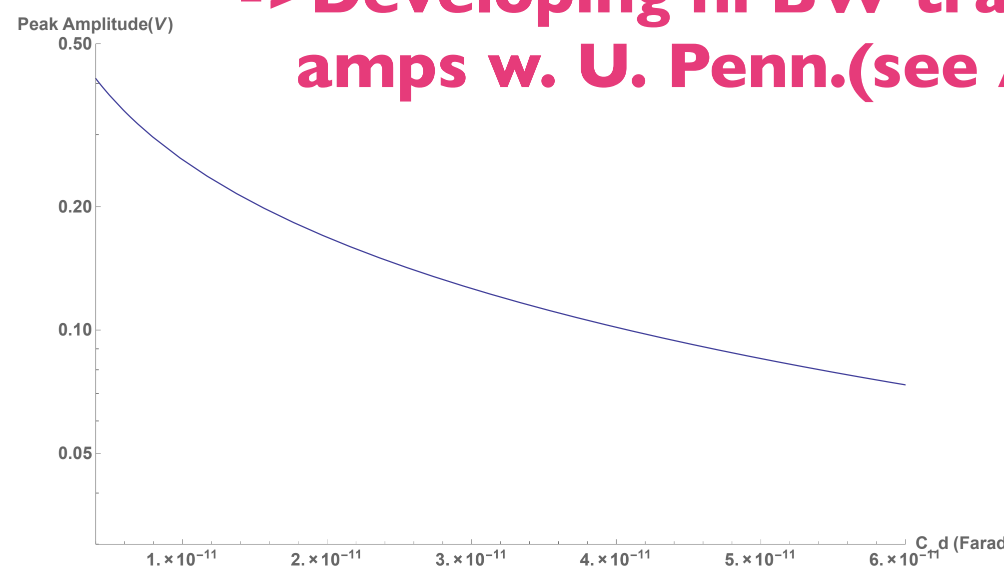
Where τ_{Po} defines bandwidth of the amplifier (for 500MHz 3dB bandwidth τ_{Po} =0.32ns)

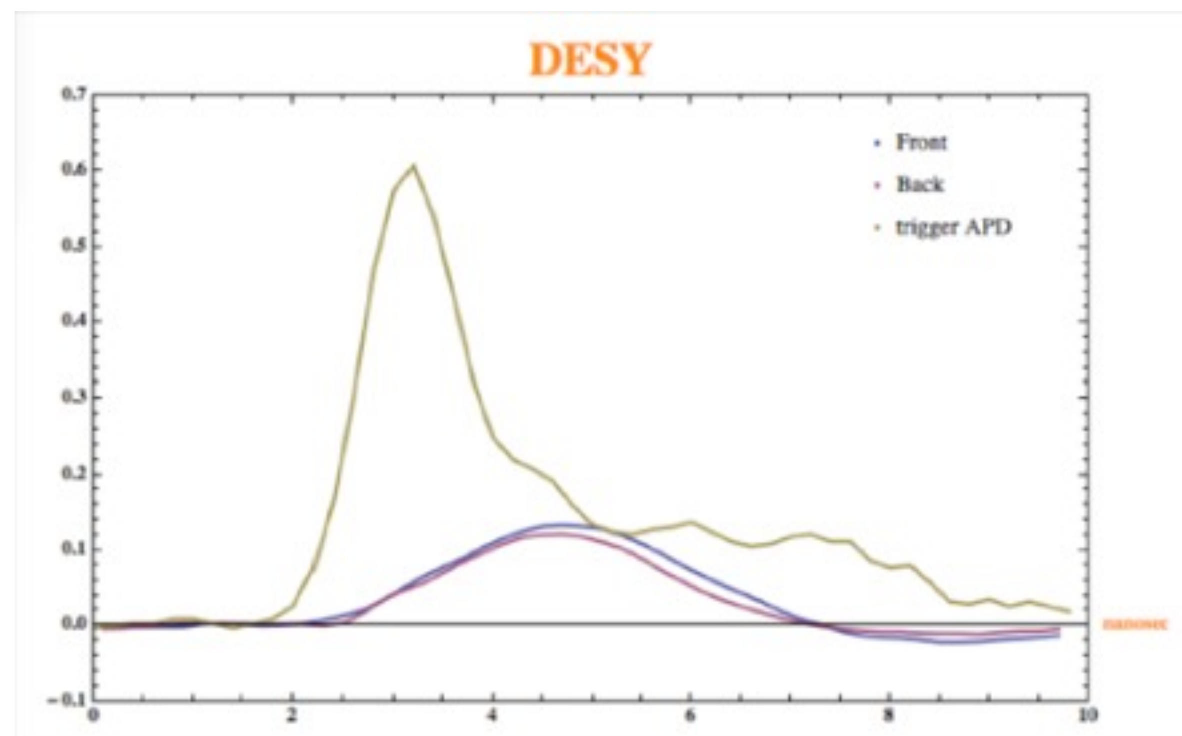
Preamp in charge/transimpedance mode



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

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





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

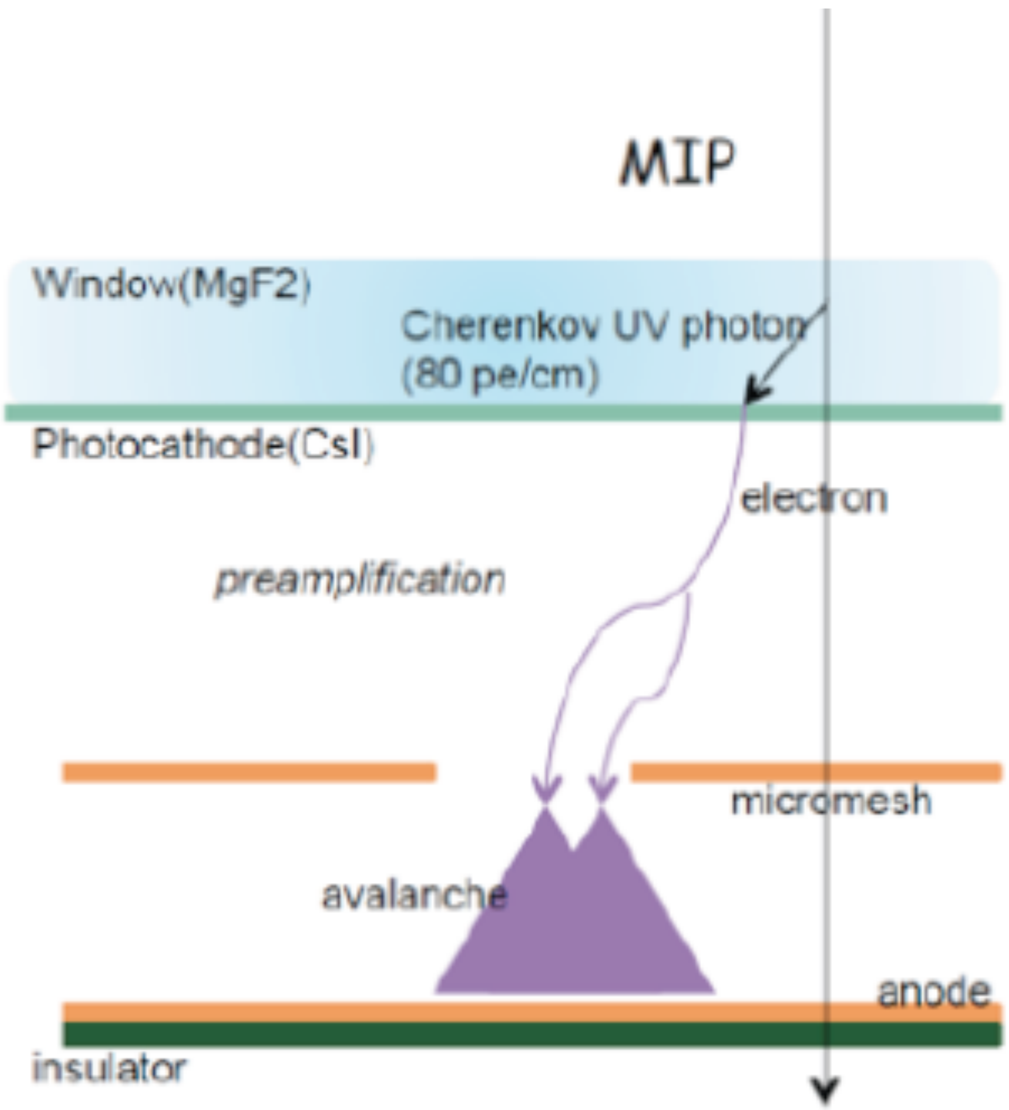
Fabrication costs

- 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.

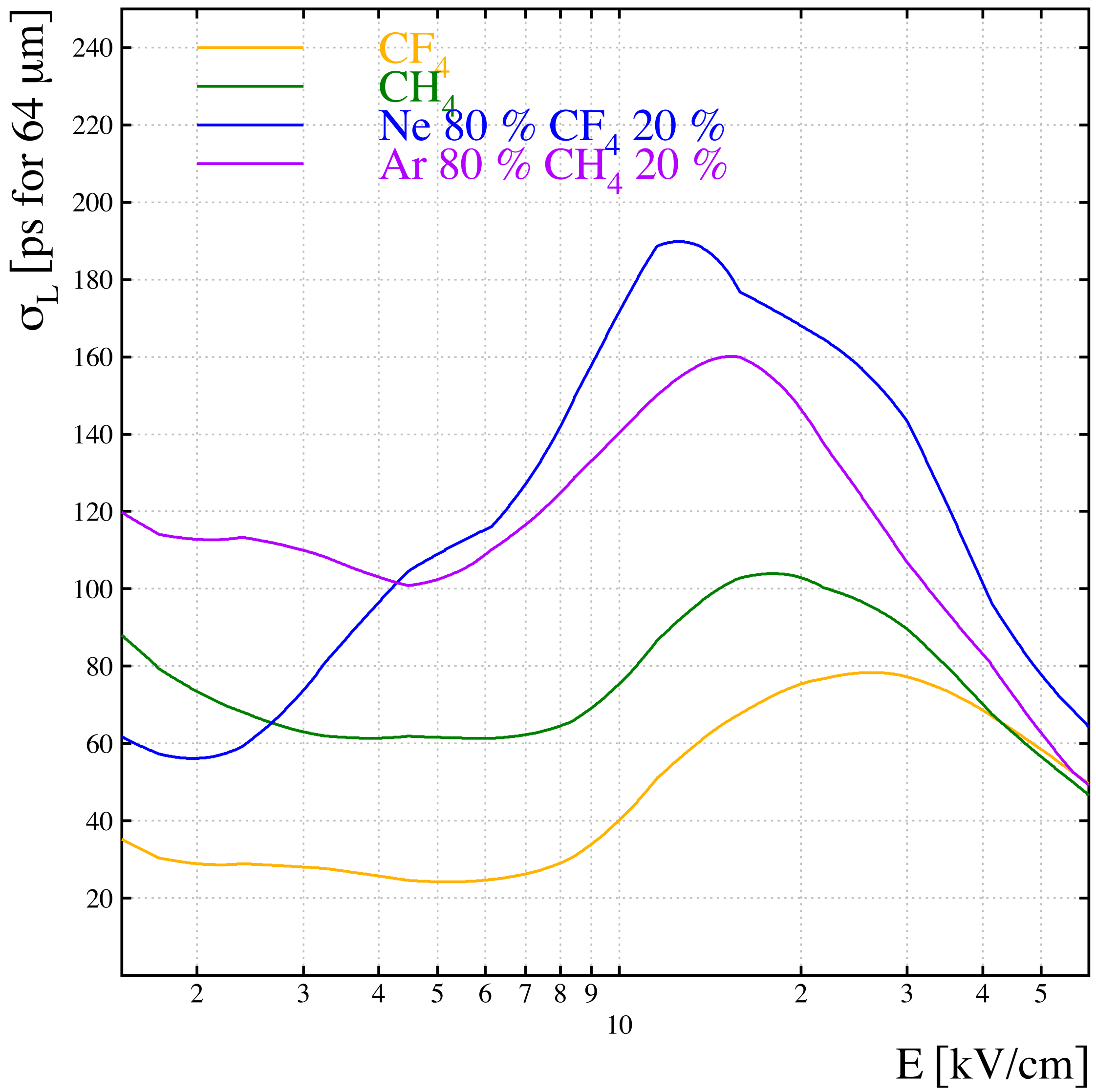
Lifetime/rad dose

- 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 (BU, Fermilab help?)

for both issues have started GasPMT parallel effort



transparent pc version



(Rob Veenhof calculation)

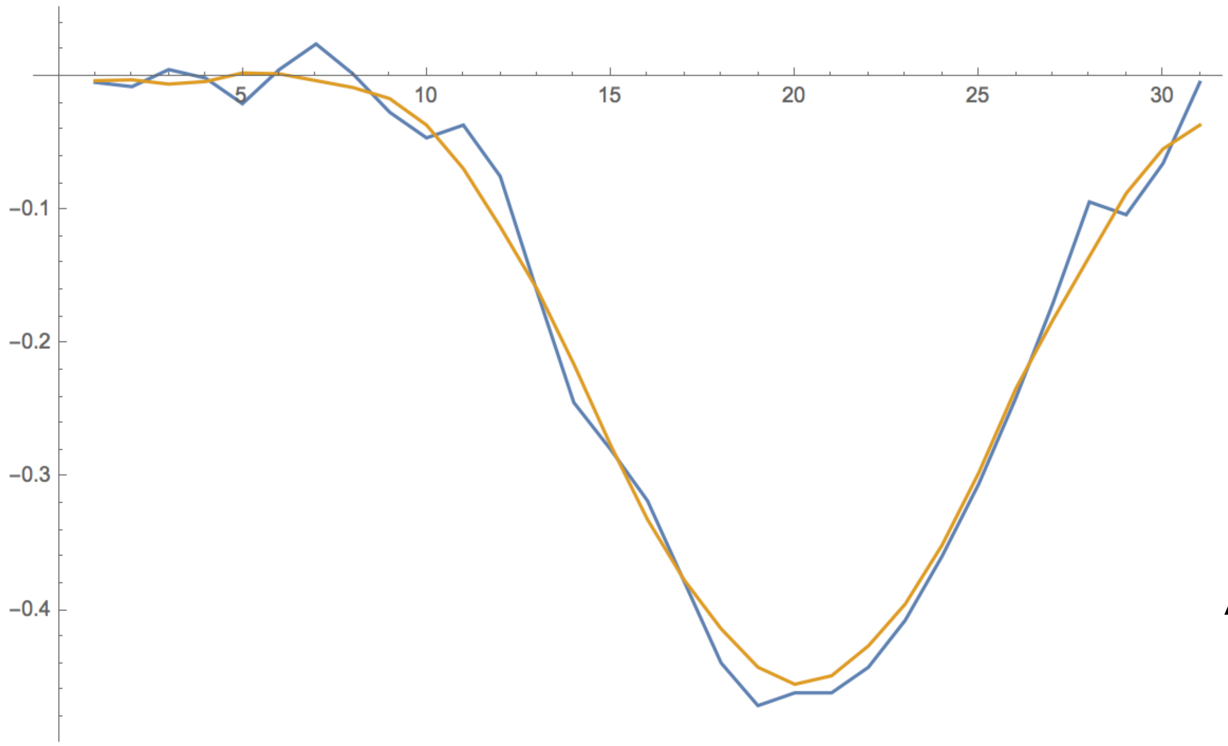
now building test chambers @Saclay and CERN
look forward to working with FNAL detector group on rad hard Photocathode development, etc.
(A. Ronzhin is an expert)

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!

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"

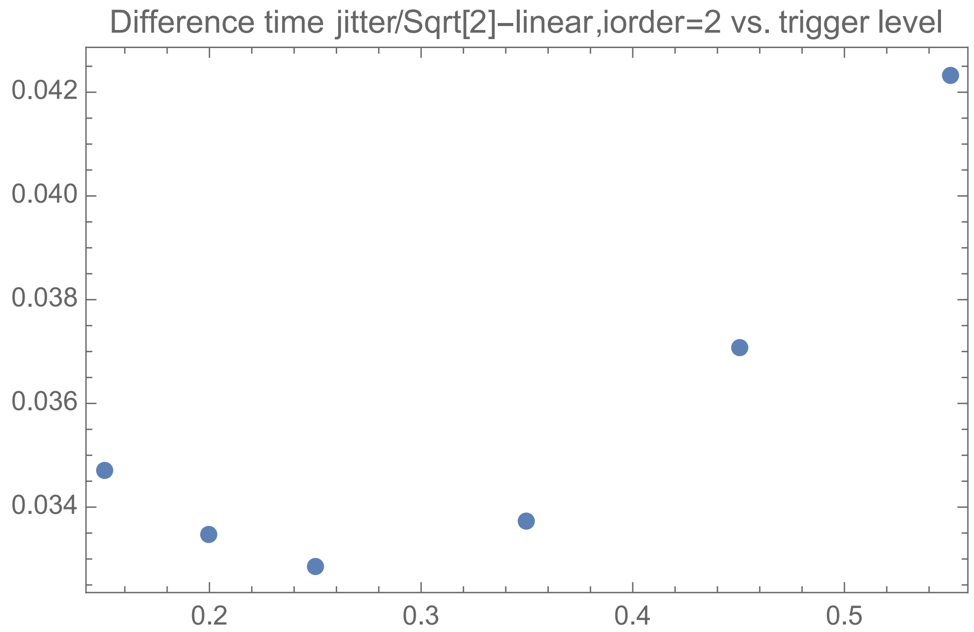
most relevant literature comes from outside our field (radar, GPS)

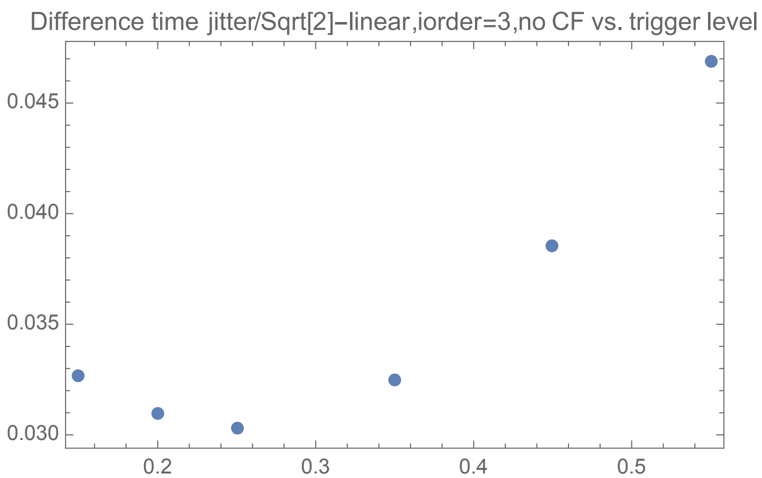
[1] N. Wiener 1949, Extrapolation, Interpolation, and Smoothing of Stationary Time Series, John Wiley & Sons, New York.

[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.


Difference time jitter/Sqrt[2]–linear,iorder=2 vs. trigger level
0.042
0.040
0.038
0.036
0.034
0.2
0.3
0.4
0.5


Difference time jitter/Sqrt[2]–linear,iorder=3,no CF vs. trigger level
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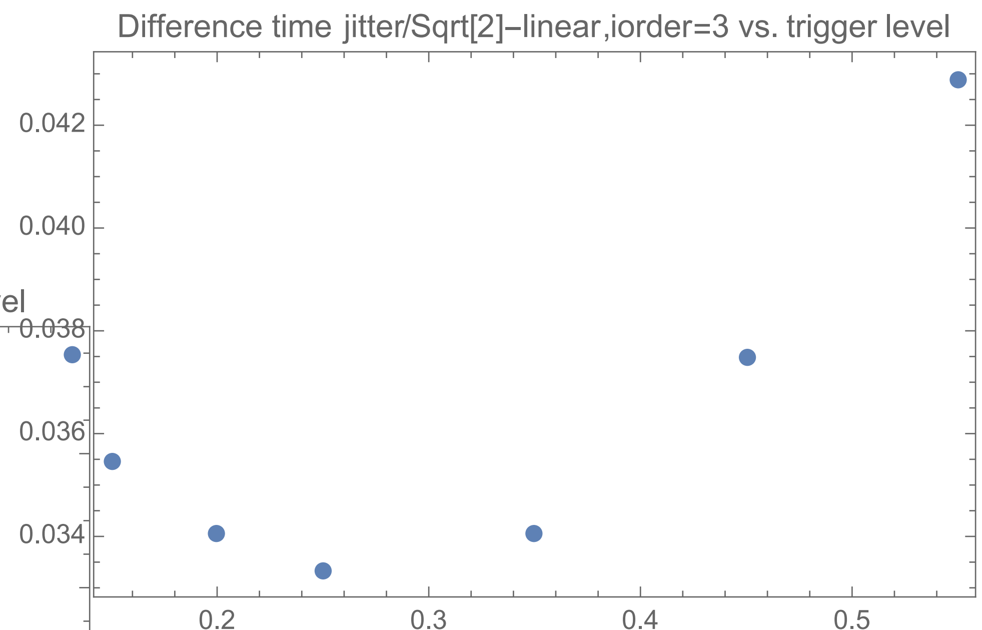
0.040
0.035
0.030
0.2
0.3
0.4
0.5


Difference time jitter/Sqrt[2]–linear,iorder=3 vs. trigger level
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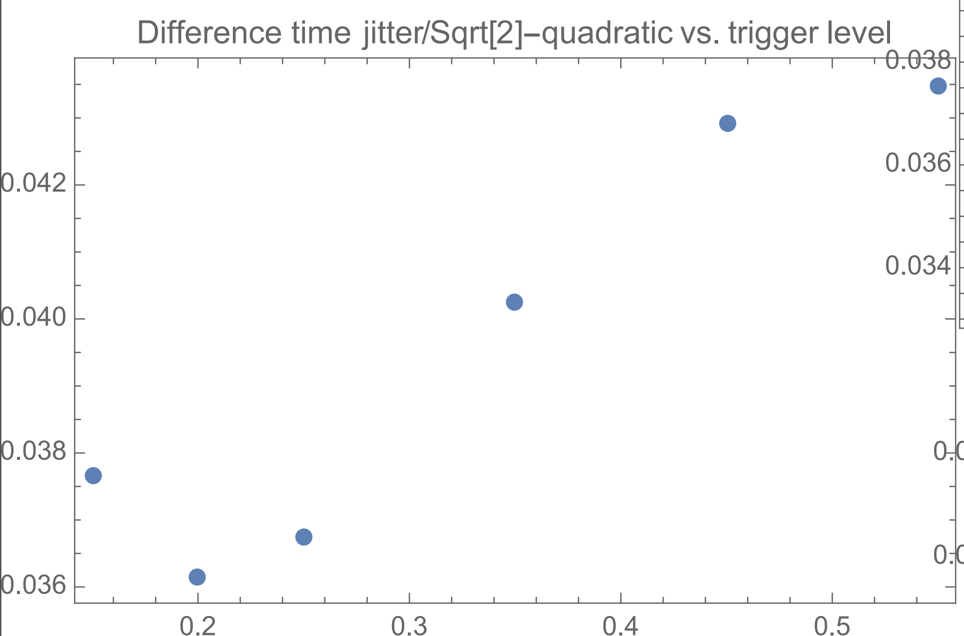
0.038
0.036
0.034
0.2
0.3
0.4
0.5


Difference time jitter/Sqrt[2]–quadratic vs. trigger level
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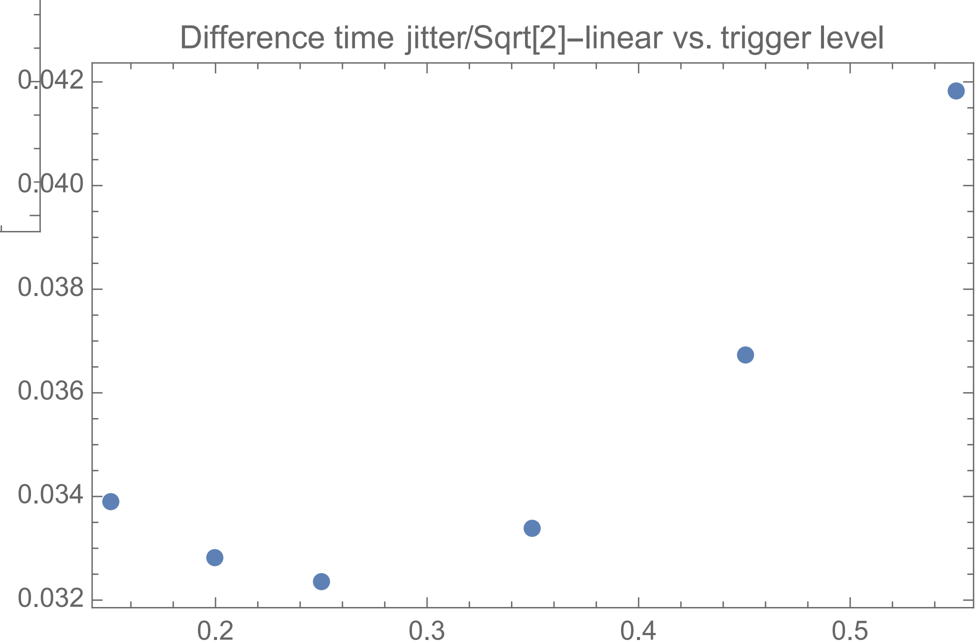
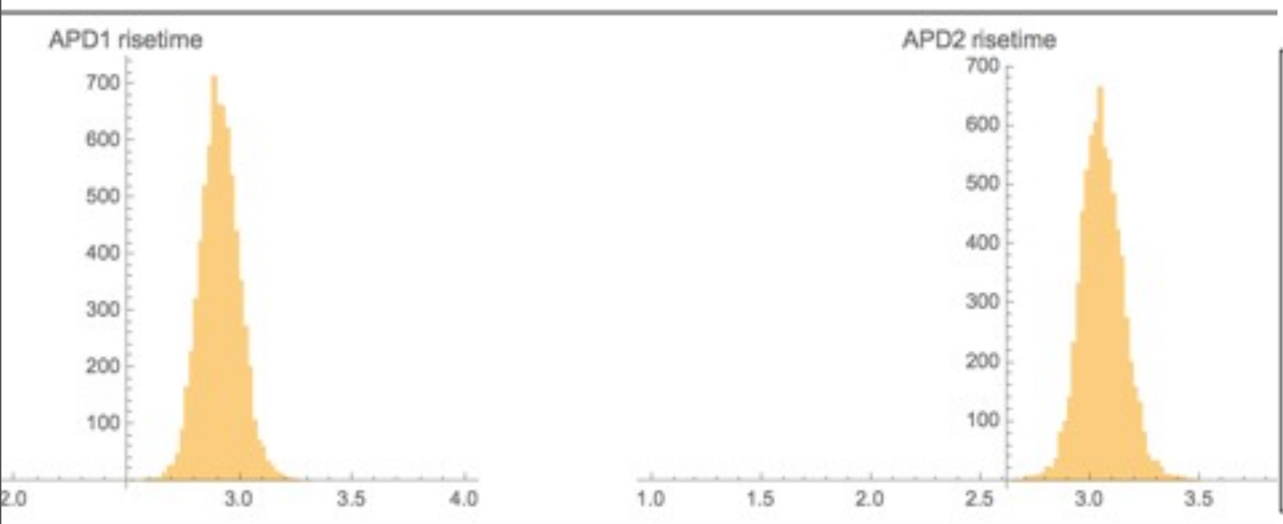
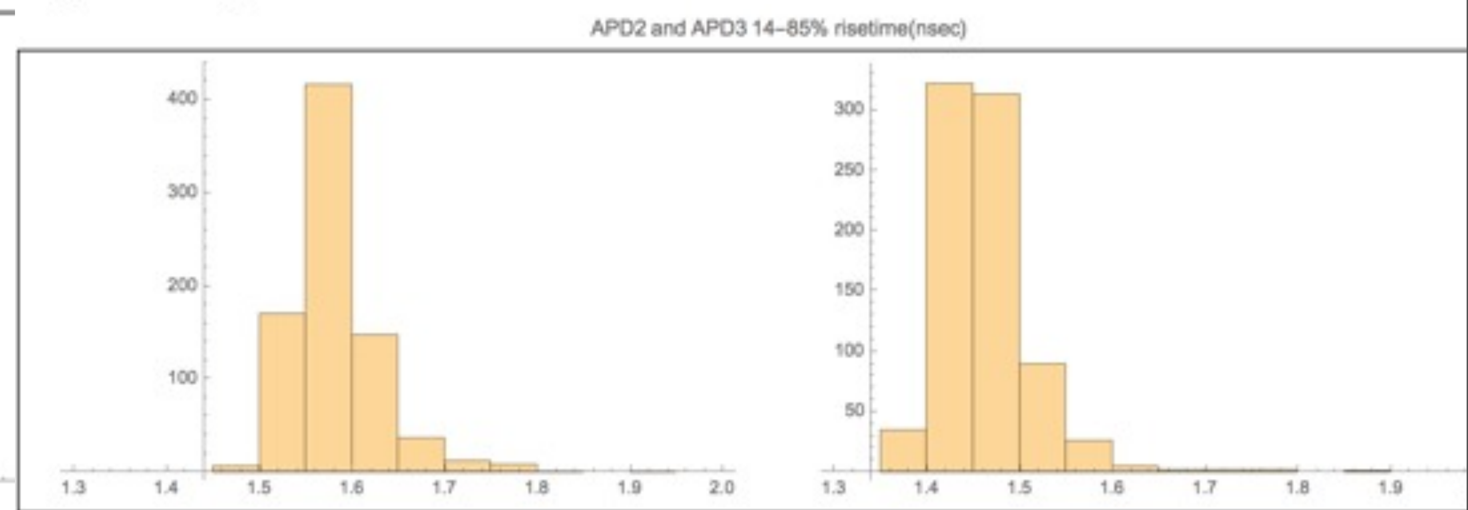
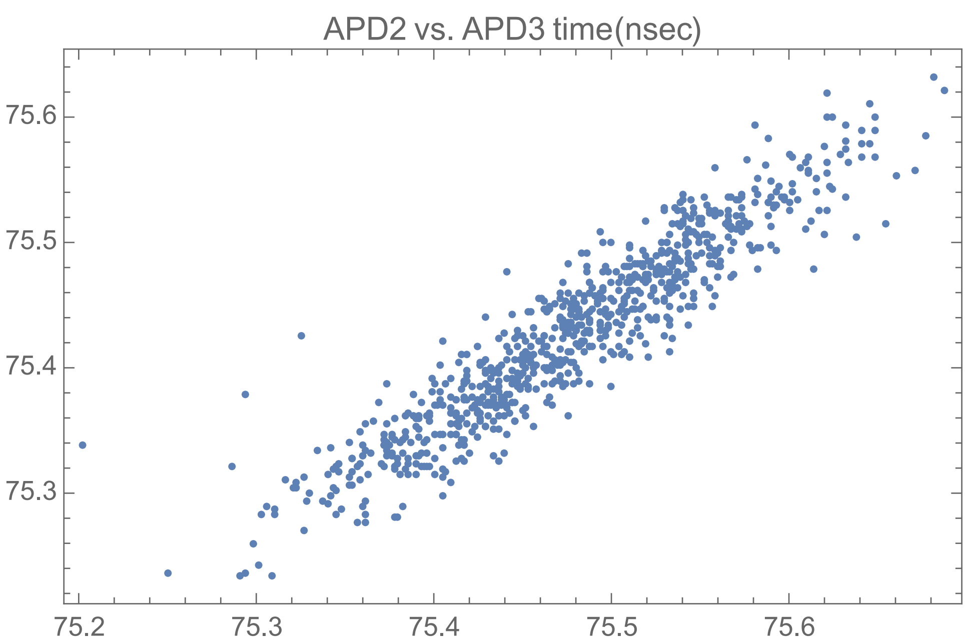
0.038
0.036
0.2
0.3
0.4
0.5

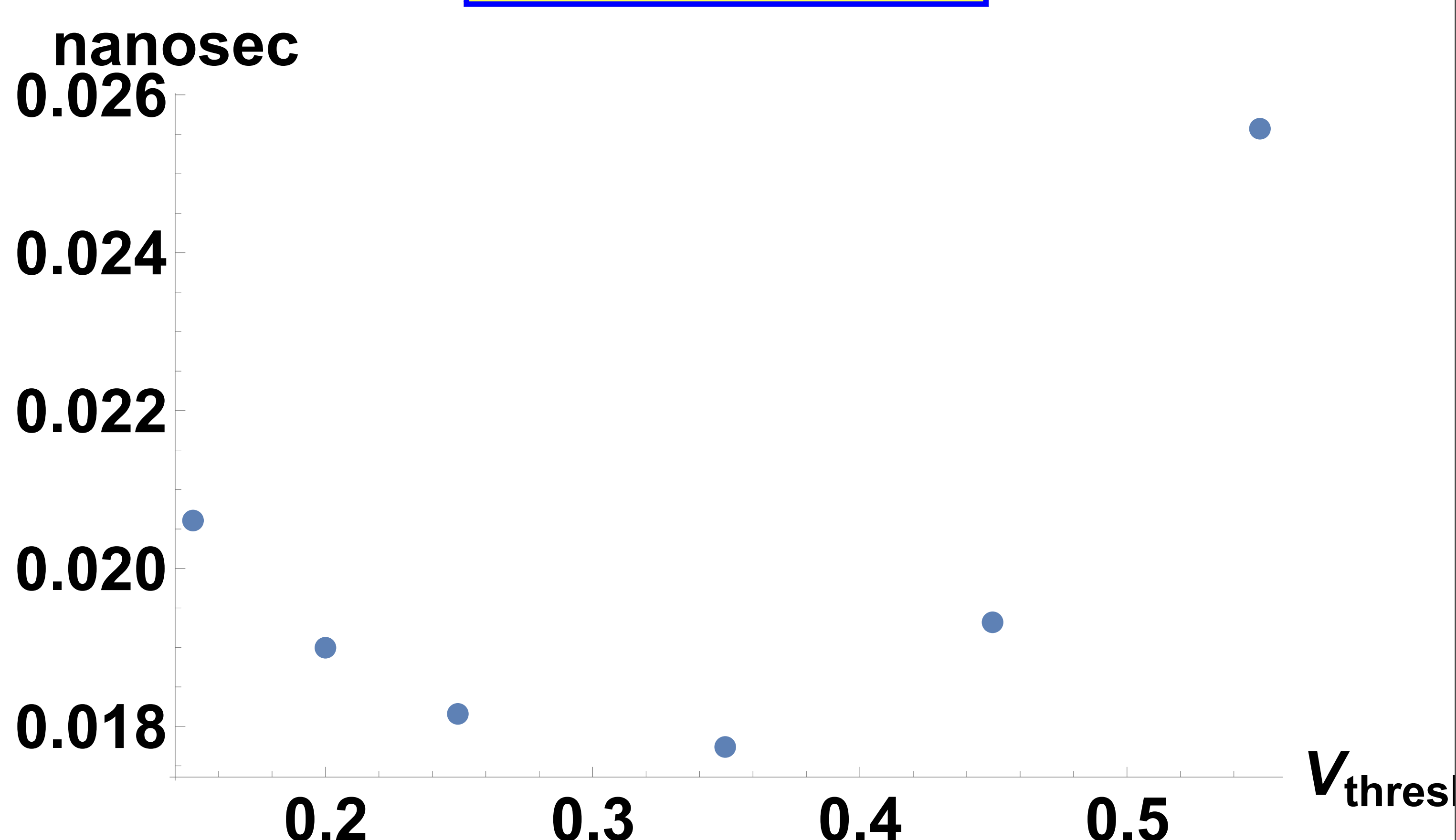

Difference time jitter/Sqrt[2]–linear vs. trigger level
0.042
0.040
0.038
0.036
0.034
0.032
0.2
0.3
0.4
0.5







$\partial t_{1-2}/\sqrt{2}$ vs. threshold



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

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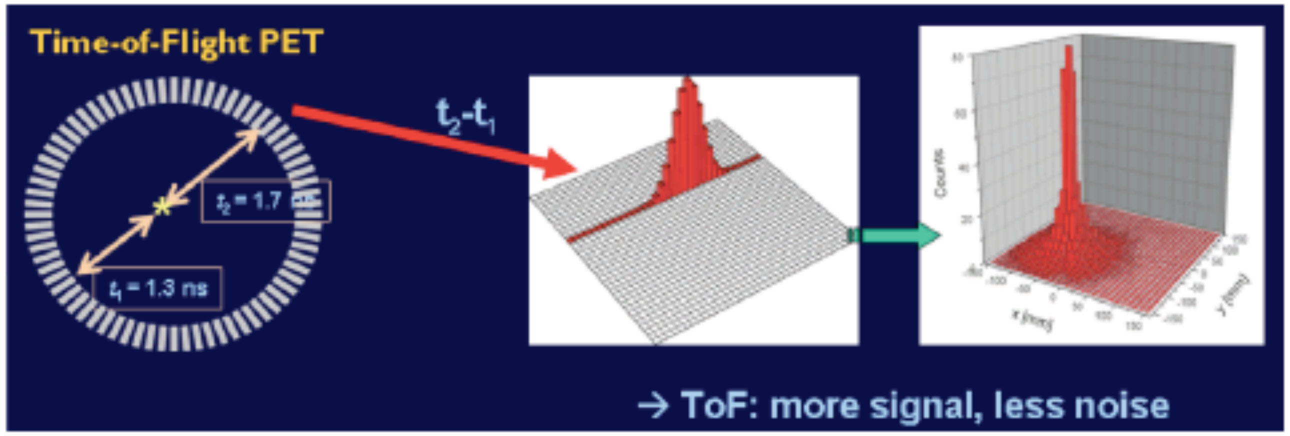

Neuroscientist Objective

- 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.

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