Hyperfast Sensor Development for the HL-LHC era

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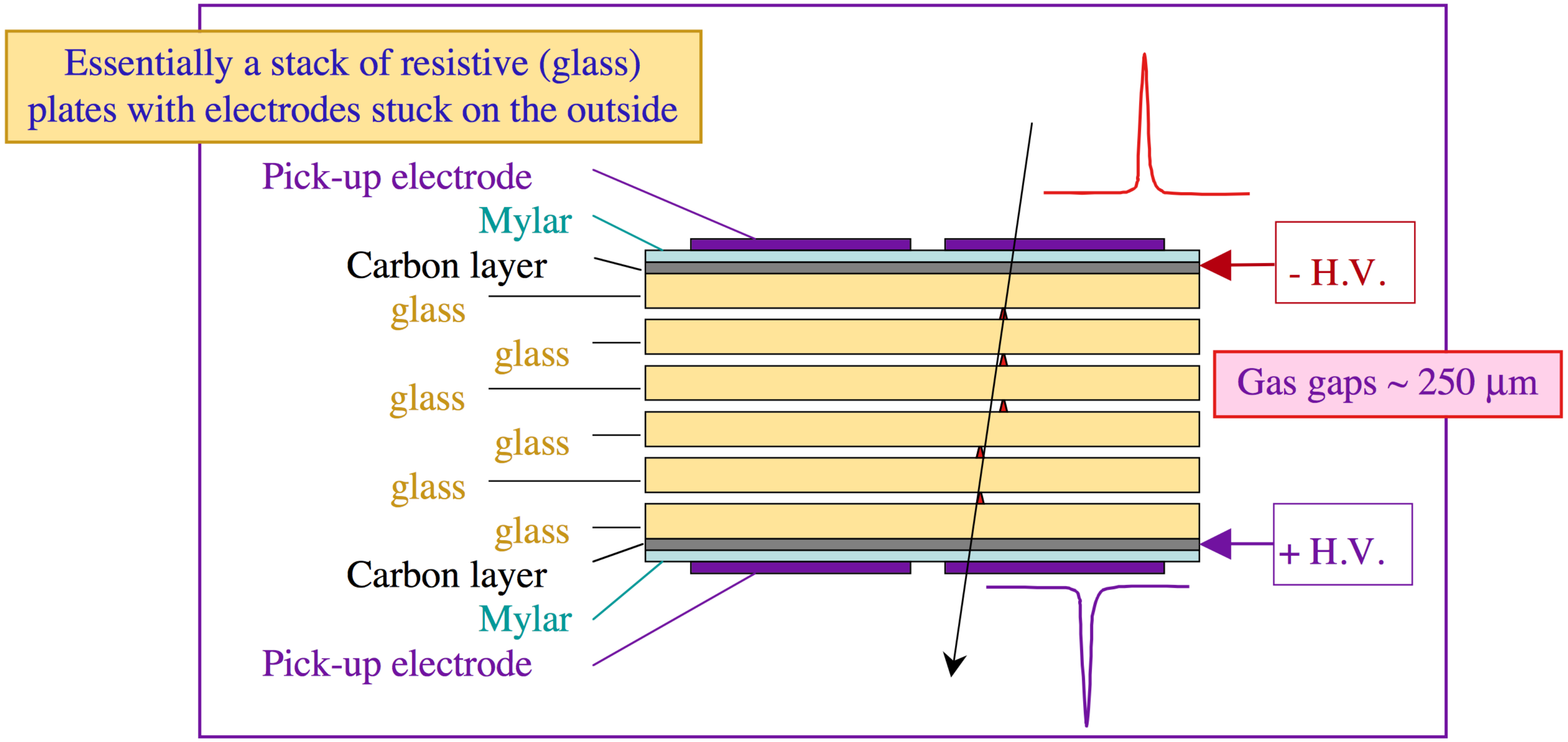
DESY/Hamburg Joint Instrumentation Seminar Hamburg June 12, 2015

- Sensors for charged particle timing
- We (Rockefeller/Princeton) started ~5 years ago under DOE ADR&D grant
- State of the art then(and now) not suited for high rate timing

1) Multigap RPC -ALICE TOF

C.Williams et al.-This is the big existing system. ~10^5 channels, ~80 pico sec time jitter -> hadron id.

His current R&D -> ~16 pico sec in test beam. Rate capability limited by material resistivity



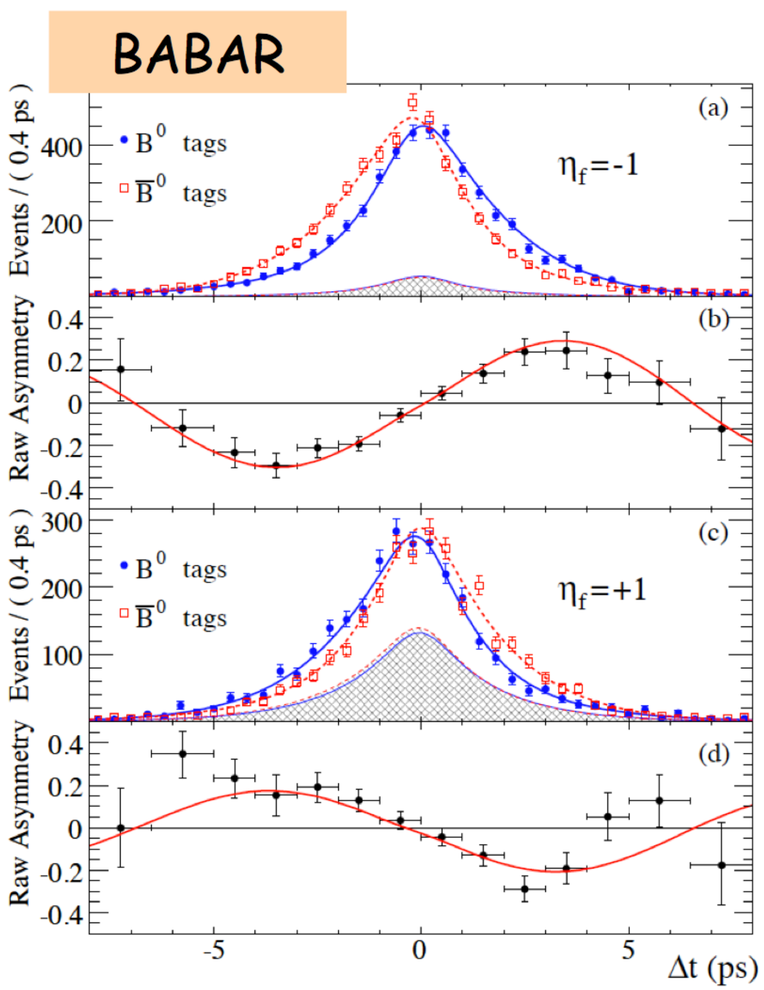
2)

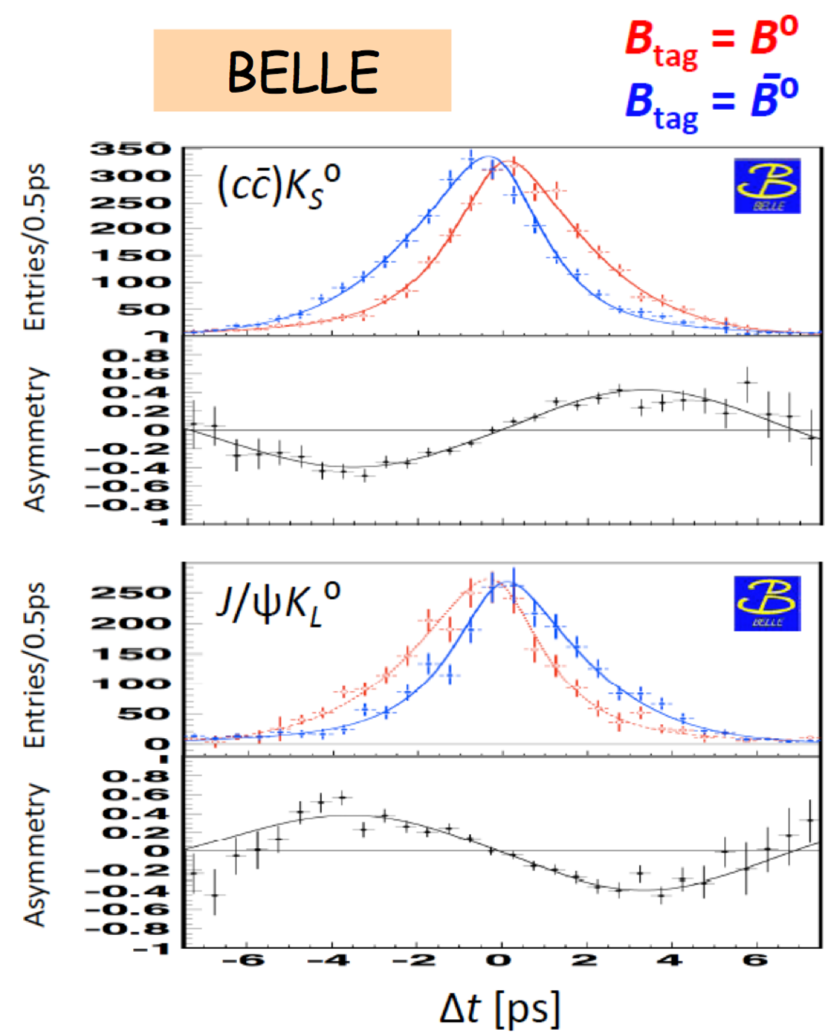
MCP.and MCP-PMT

- Nagoya Group (Belle) got ~6 picosec particle timing using radiator and proximity focus PMT in 2006
- many copy cat projects since but none as good.
- but MCPs have been around forever (~1950)-> Cost and Lifetime (Q_{Anode}<1 Coulomb) have always been an issue
    - many applications where not suited for other reasons
    - massive US project (LAPPD) trying to address 2 issues
    - nevertheless good reason to explore alternatives
- => in many respects MCP has become a “MacGuffin” for timing

“unmet need”

- Clearly room for new ideas in timing sensors.
- what is the physics driver?
- ironically, with the discovery of b-quark picoseconds got interesting but =>field moved to path length





Outline

- this talk framed by our interest in mitigating “pileup” for HL-LHC
- first our most recent results from Micro-pattern Gas Detector-> 36 picosecond time jitter
- then update on our development of mesh readout avalanche diodes “Hyperfast Silicon”->currently ~12-16 pico sec
- as we will see, Micromegas mesh is a key element of both.

Sub-100 picosecond charged particle timing with MicroMegas

representing:

L. Ropelewski, E. Oliveri, F. Resnati,SNW, R. Veenhof (CERN)

I.Giomataris, T. Papaevangelu, T. Gustavsson, E. Delagnes, E. Ferrer, A. Peyaud (CEA/Saclay)

D. Gonzalez-Diaz(Zaragoza)

G. Fanourakis (Demokritos)

K. McDonald, C. Lu &SNW(Princeton)

for RD51 common fund project: “Fast Timing for High Rate Environments: a MicroMegas Solution”- awarded 3/2015

overall goal of this R&D

is to go from 1-d to 2D vertex identification

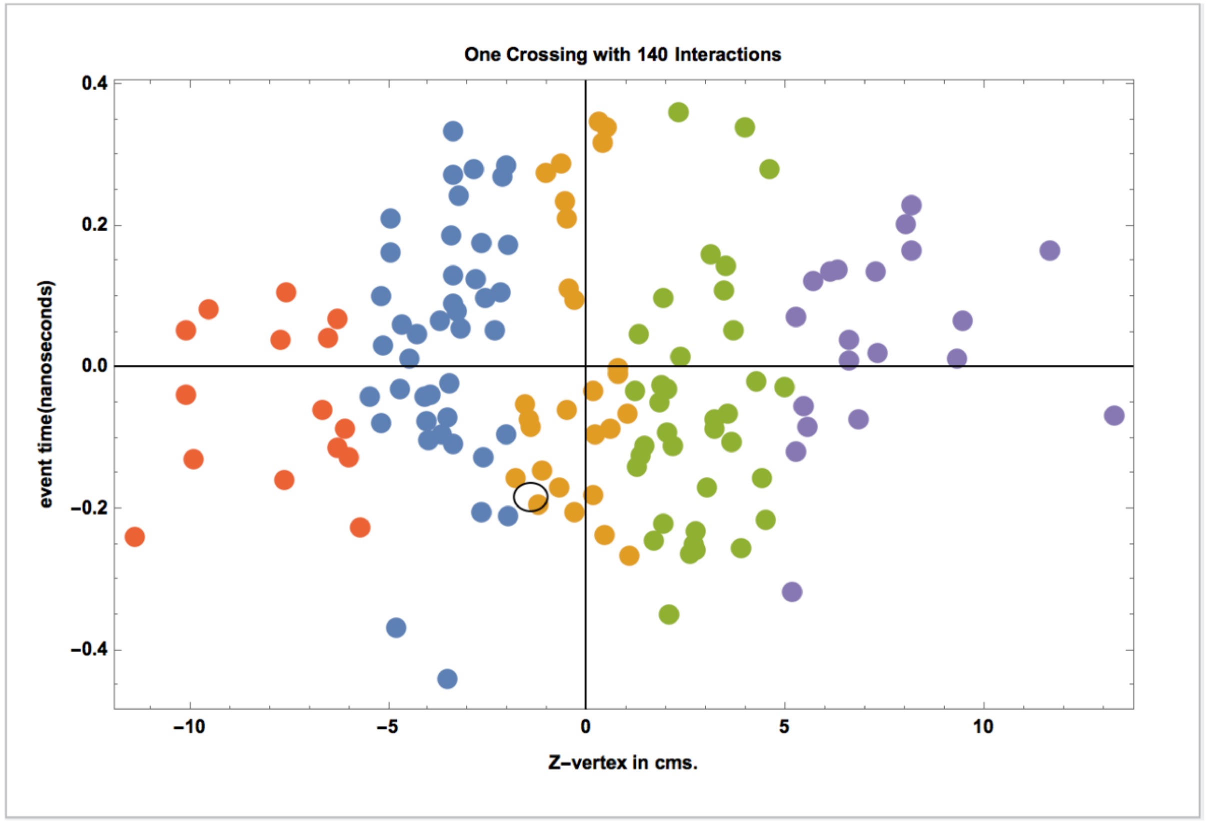
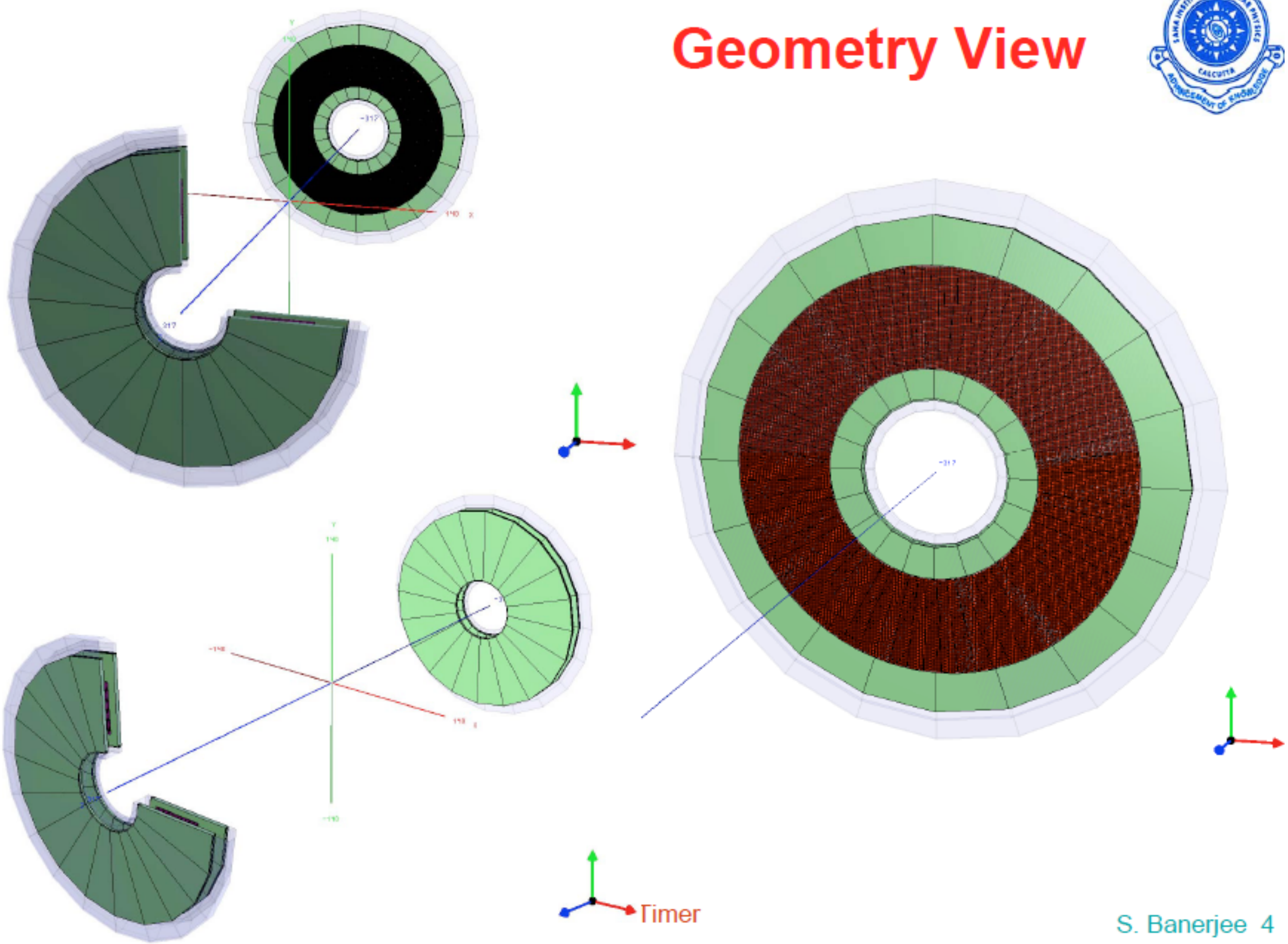


Fig. 1. Simulation of the space(z-vertex) and time distribution of interactions within a single bunch crossing in CMS at a pileup of 140 events- using LHC design book for crossing angle, emittance, etc. Typically events are distributed with an rms-in time- of 170 picoseconds, independent of vertex position.

Efforts in CMS and ATLAS to evaluate usefulness for mitigation of vertex merging, Jet-misassociation, etc. in HL-LHC environment

Our group has been developing a dedicated fast timing solution with Si or MPGD options for end cap



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

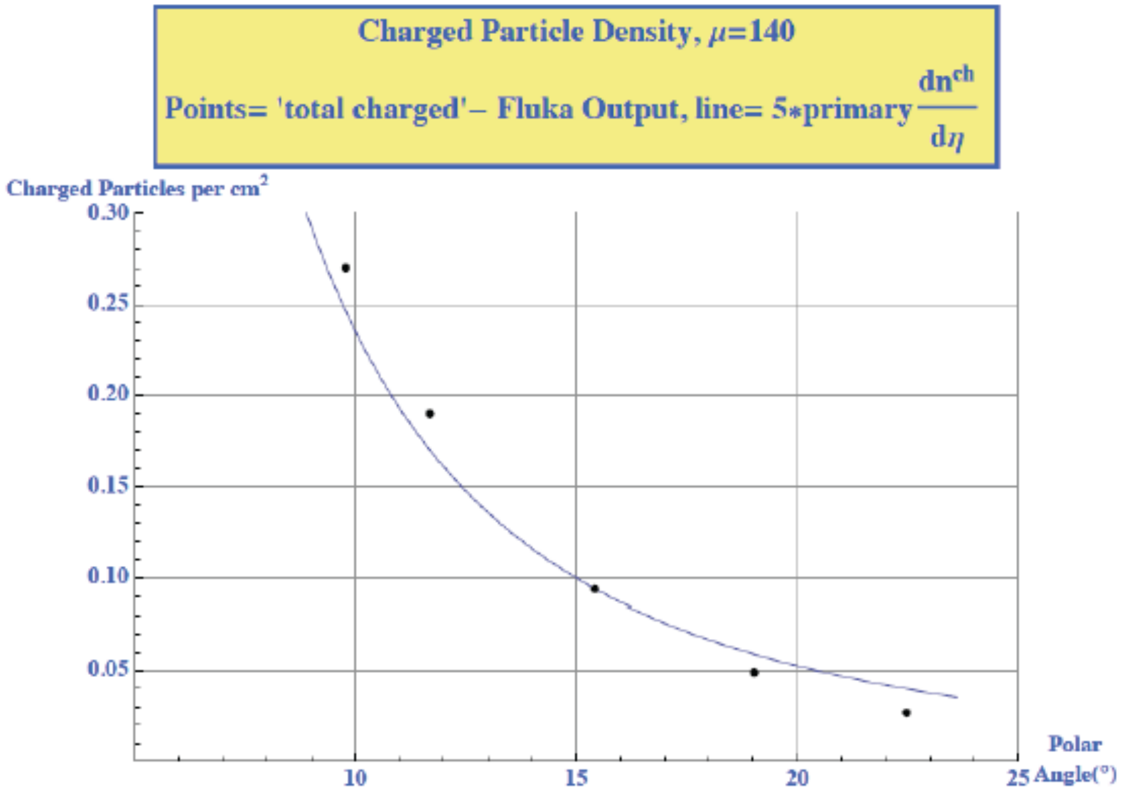
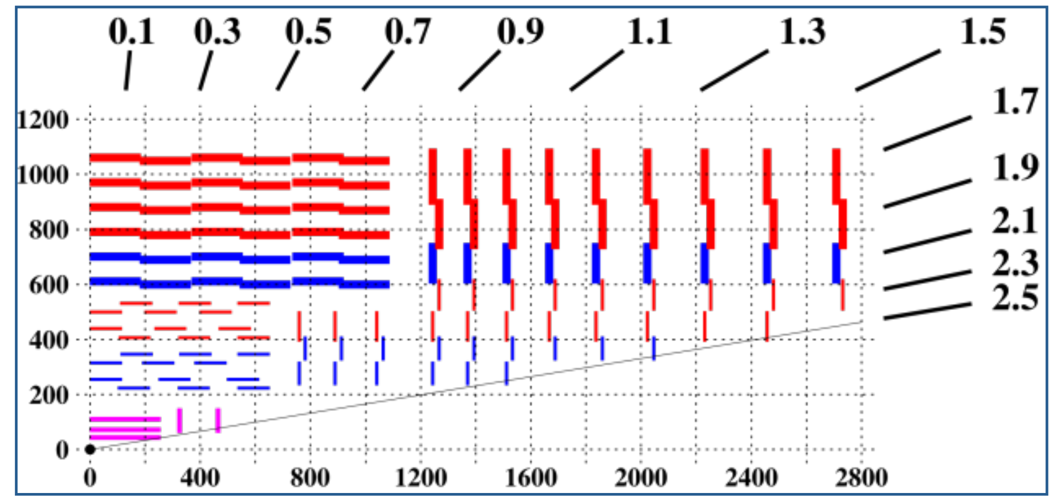
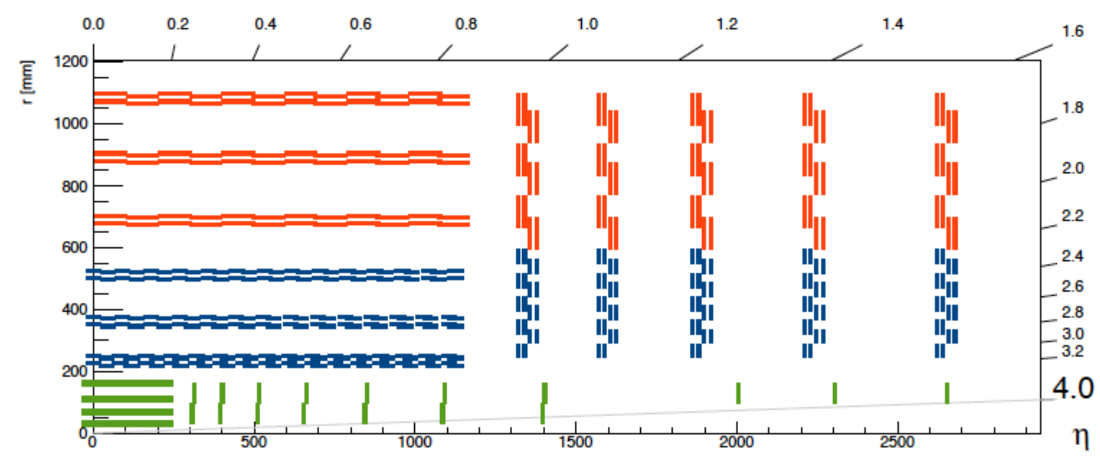


Figure 2: The charged particle density in the region of the dedicated timing detector. The points are FLUKA output for "total charged". The line is calculated from estimates of primary charged particle density-dn/deta- scaled up by a factor of 5. FLUKA output is roughly consistent with a constant factor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

current model in CMSSW matched to:



if tracker extended in Phase2, complementary role?

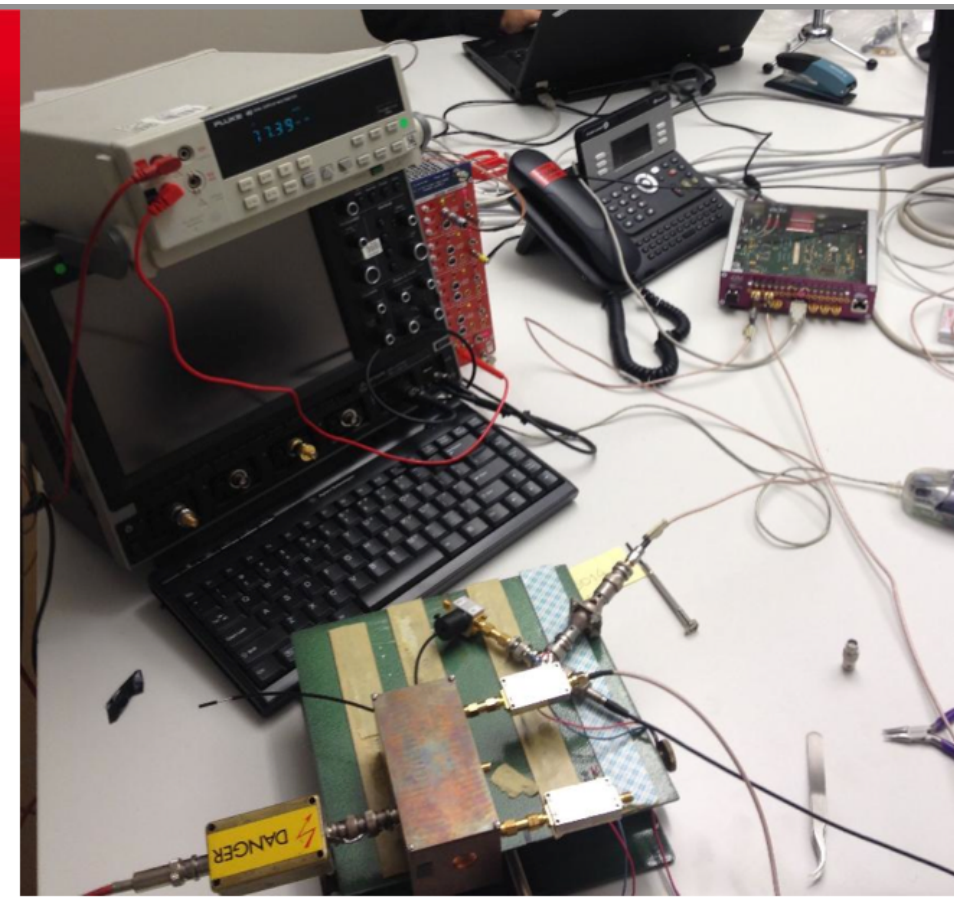


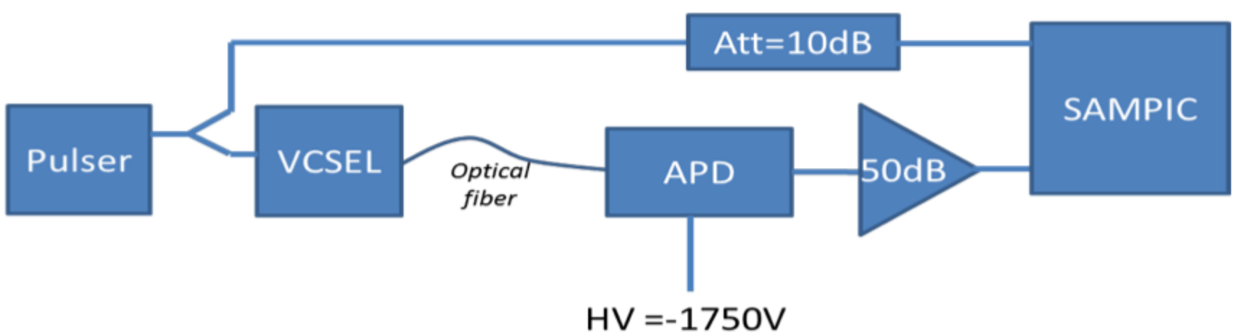
physics justification for timing layer likely stronger if we can extend timing well beyond eta=2.6

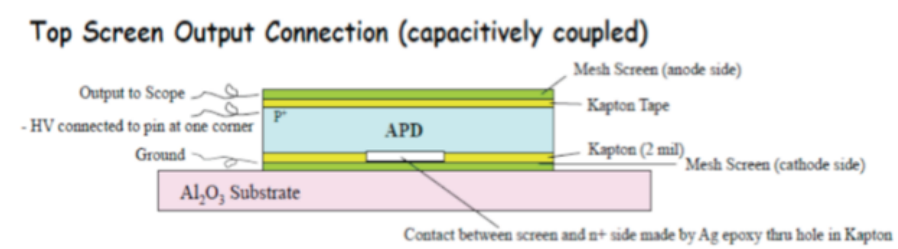
{in fact, ATLAS opportunity only starts at eta~2.6} pre-existing collaboration with Orsay/Saclay on timing- see D. Breton's Elba talk:

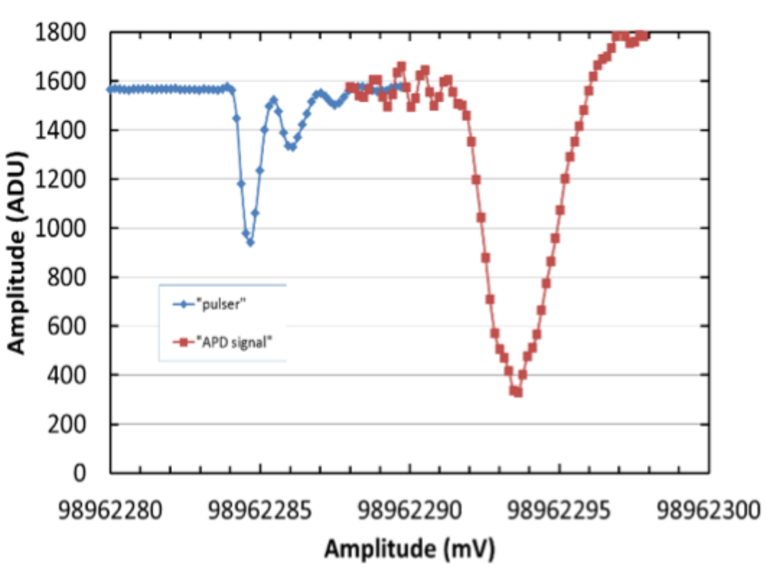
MEASURING PICOSECONDS …

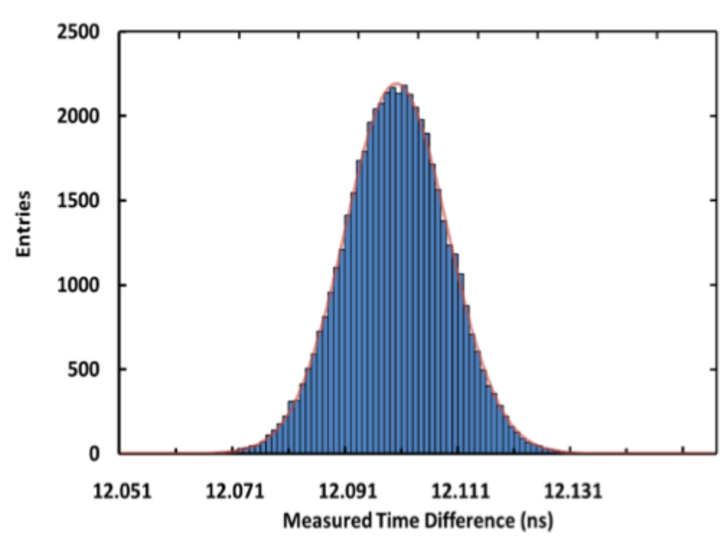
- SAMPIC module has been connected to **S.White's fast mesh-APD** at CERN (see S.White's poster).
- Goal : measure the **time difference between the pulser and the APD signal** => detector time resolution
- All measurements below performed in ~**1 hour.**
- Best measurement **< 10 ps rms**

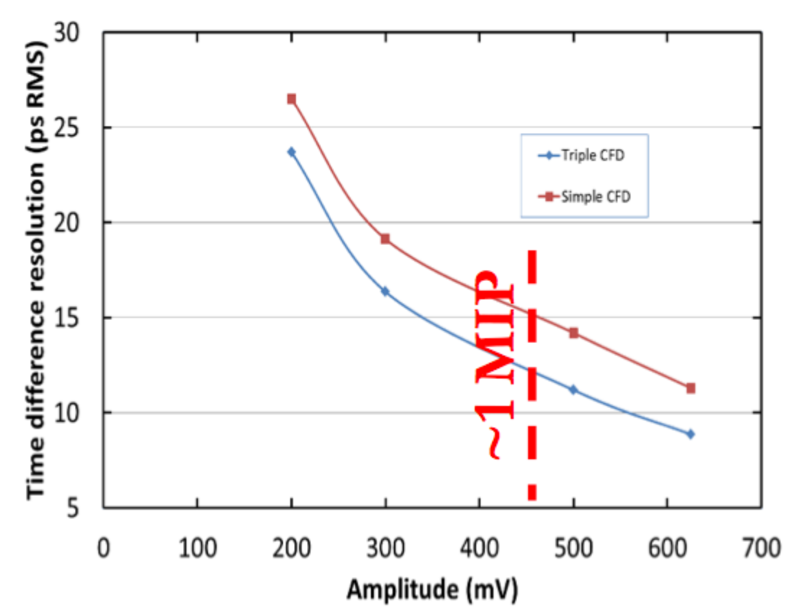












Our RD51 Project undertaken as a hedge against cost/ raddam issues w. solid sensors.

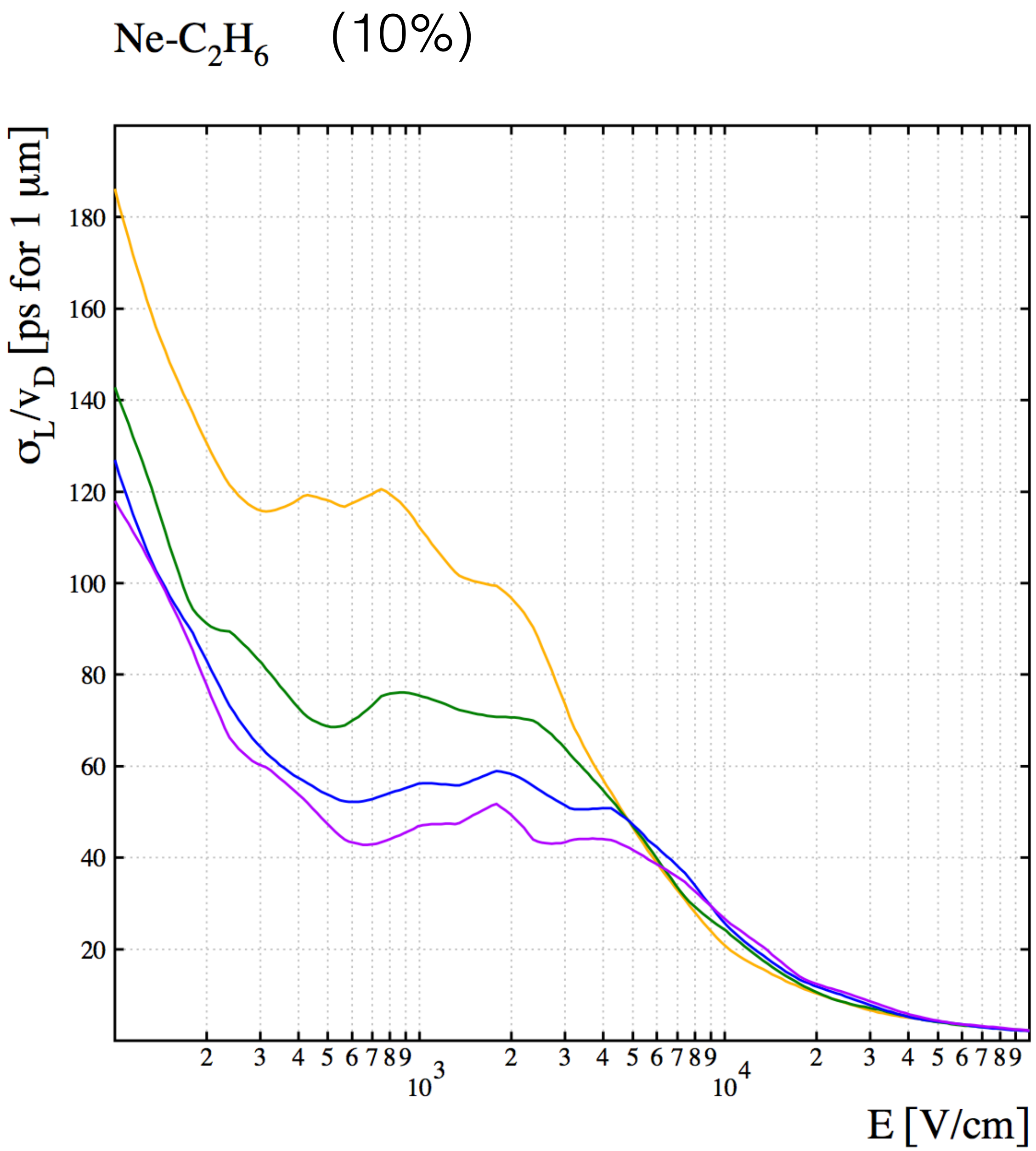
very little out there as options:

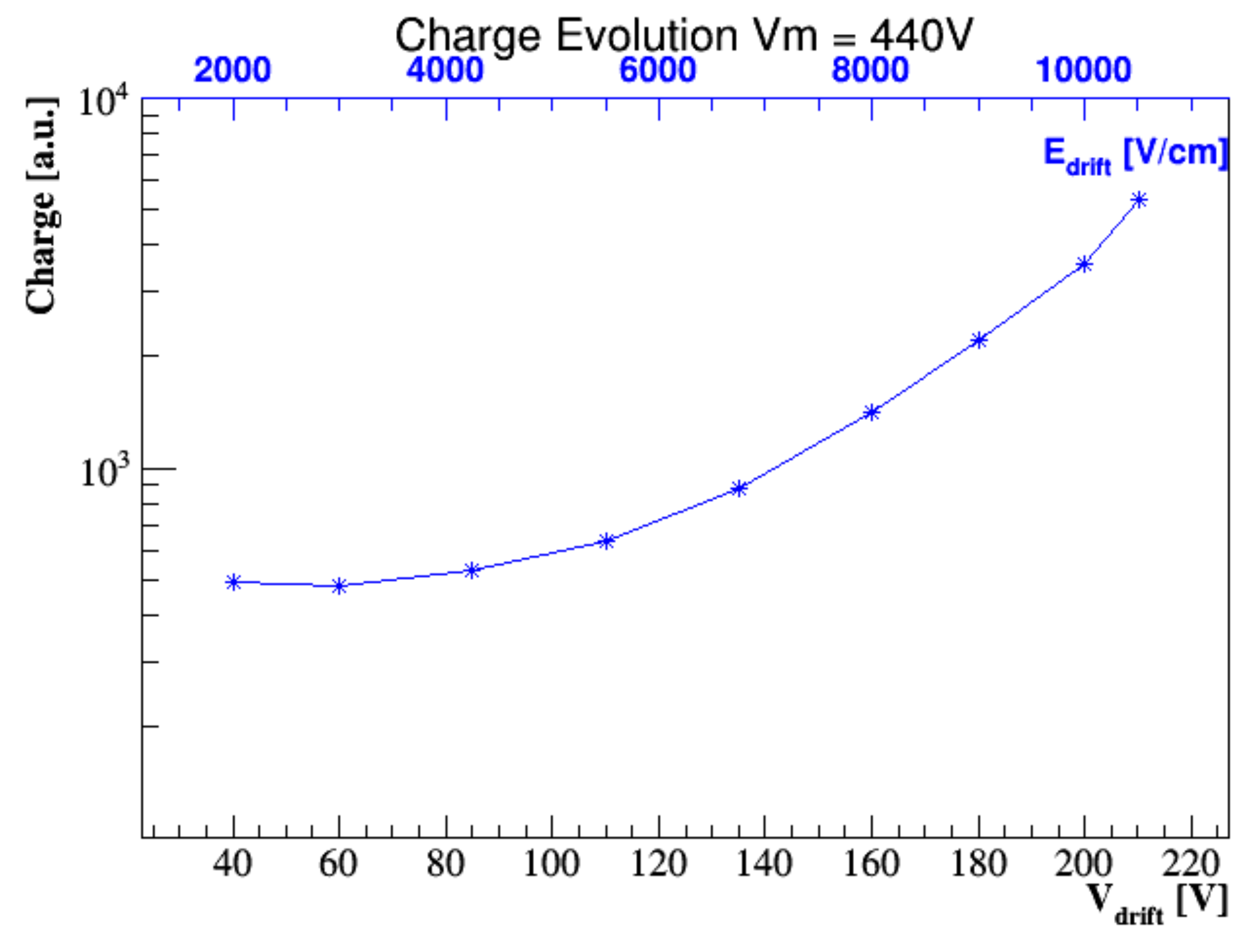
- CVD diamond-> ~95 picosecond
- GTK silicon->150-200 picosecond
- "LGAD" (similar t-resolution but rad issues at ~10^{14} neq/cm^2)
- Our Hyperfast, mesh readout, Si APDs still to be evaluated @>10^{14} neq/cm^2

what precedent for fast timing with Micromegas?

- at the 2001 Vienna Wire Chamber Conference Charpak, Ioannis, et al. demonstrated 680 pico sec rms (single pe) {NIM A 478 p.26 (2002)}
- Could this be developed into a charged particle detector w. MgF2 radiator and proper choice of gas/field configuration?

Diffusion limited time jitter



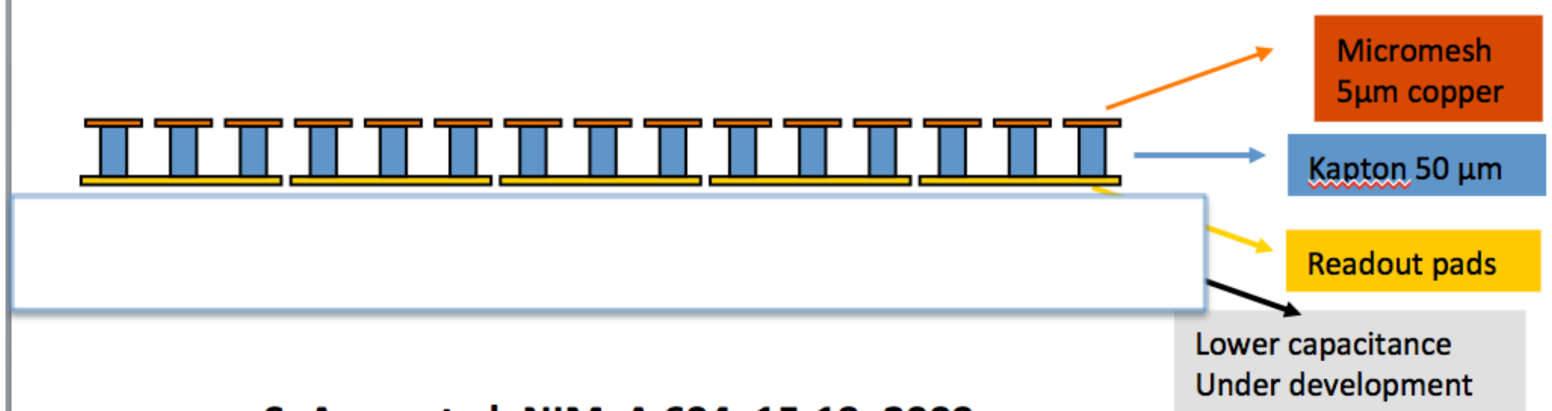


so far, tests in high drift field->10kV/cm,200 micron gap
->~350 pico sec per photoelectron

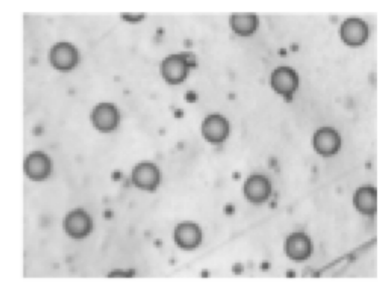
<u>however</u>, at these high drift fields we also have preamplification gain
-> effective ~factor 2 reduction in diffusion limit
->need ~50-60 pe/MIP
MgF2/CsI->~80pe/cm

This initial test used Microbulk technology for amplification structure.
Potential time jitter reduction with higher pitch.
Used Ne-Ethane (10%). CF_4 possibly will yield lower jitter.
210 V in 200 micron “drift region” led to limited pre amplification gain.
440V across micro bulk in run shown below.
initial test with 10nm Al used as “pc” with very low (~10^-6) qe
n-photon ~ Cerenkov photon yield in final design

Microbulk technology



Pitch 100 µm,
Holes 30 µm



S. Aune et al. NIM A 604: 15-19, 2009
S. Andriamonje et al. JINST, 2010

✓Energy resolution (<13% FWHM @ 6 keV)
✓Low intrinsic background & better particle recognition
✓Low mass detector
✓Very flexible structure

×Higher capacity
×Fabrication process still improving
×Fragility / mesh can not be replaced

Detector design

First tests with UV lamp / laser ➔ quartz windows

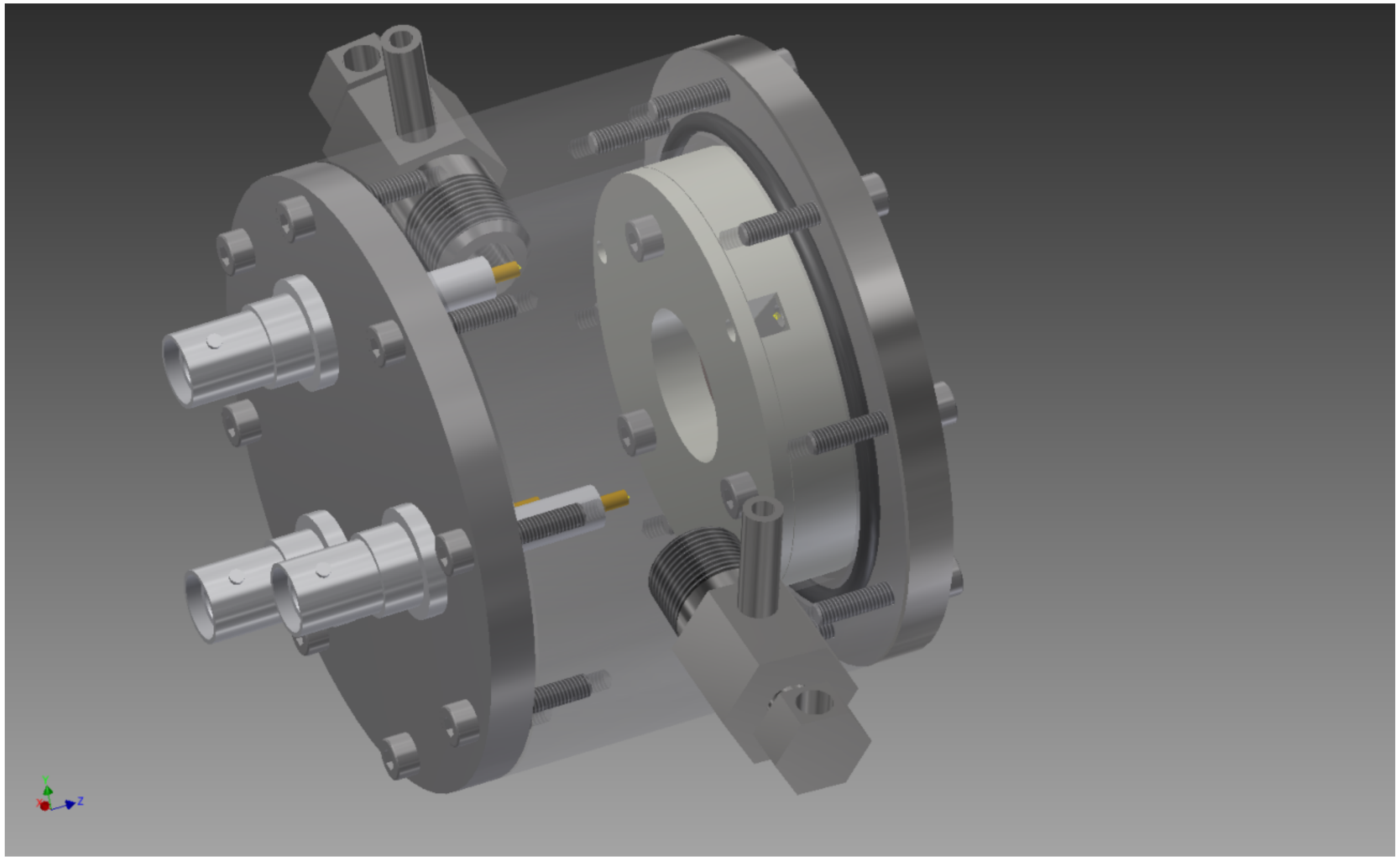
Microbulk Micromegas ø 1cm

➢ Possibility to deposit CsI on the mesh surface

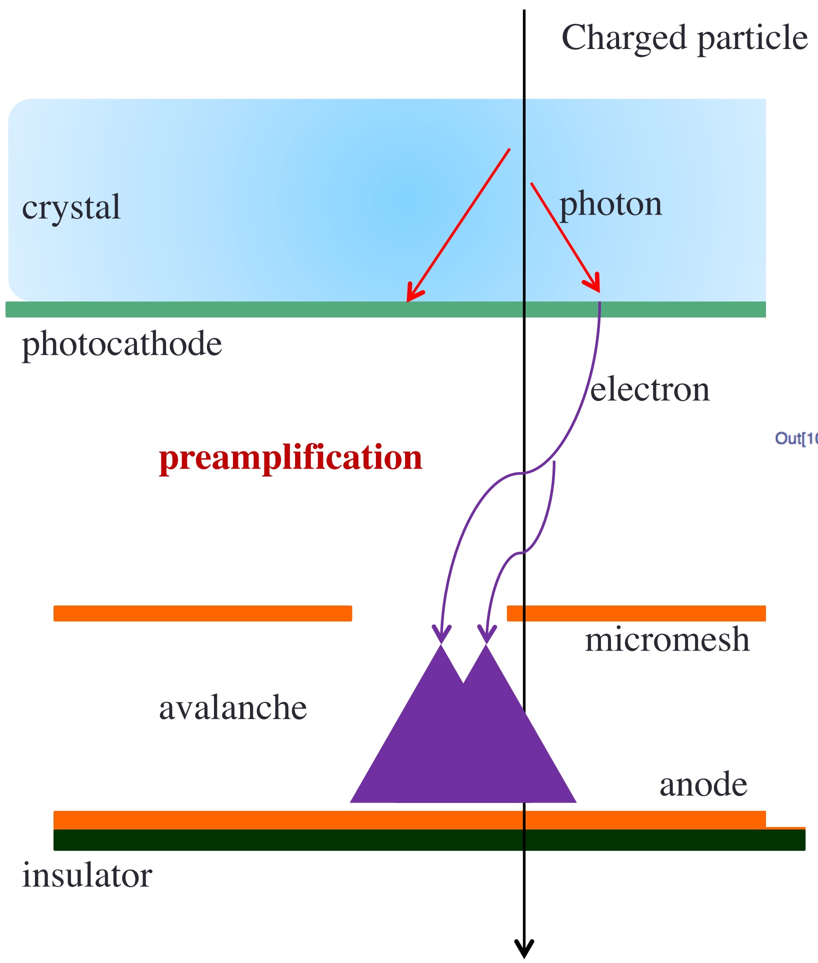
➢ Capacity ~ 35 pF

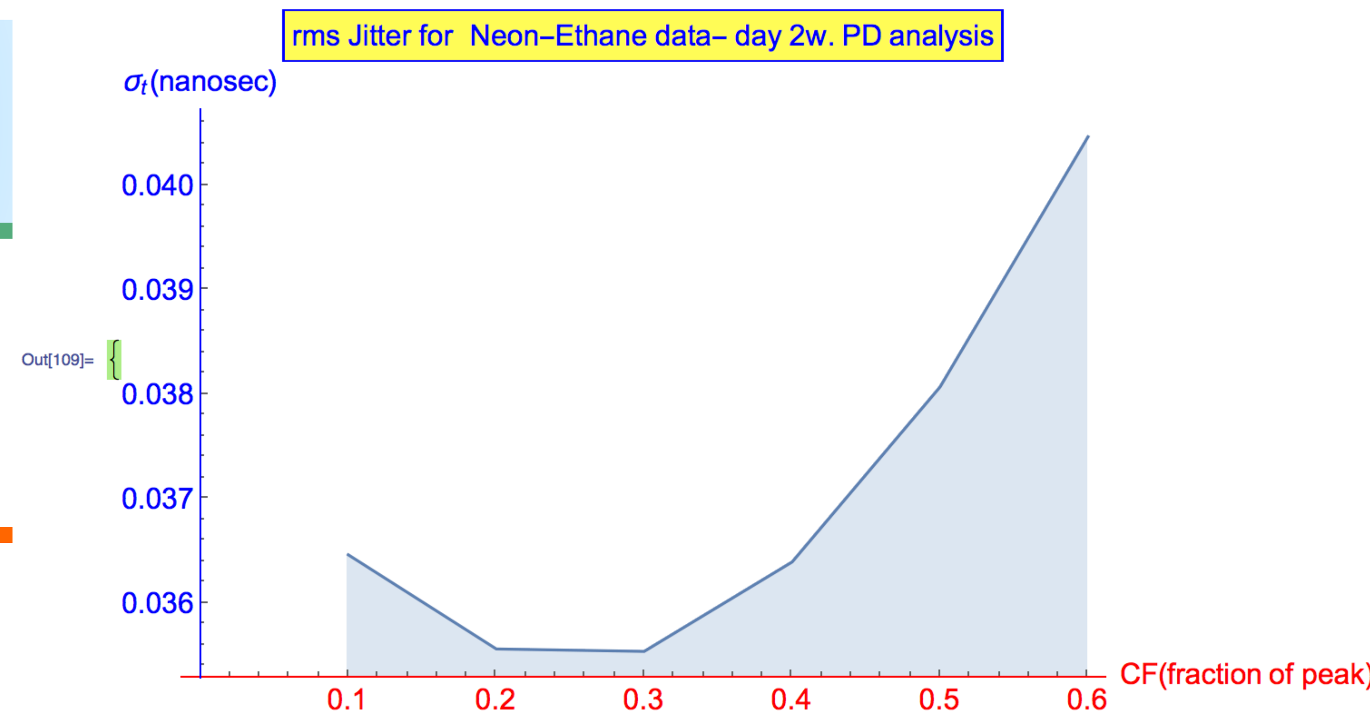
Ensure homogeneous small drift gap + contacts

Stainless steel chamber for sealed mode operation



Started with semi-transparent pc concept so far, 3 test runs at IRAMIS, Saclay





0.1	0.0364597
0.2	0.0355588
0.3	0.0355354
0.4	0.0363913
0.5	0.0380673
0.6	0.0404614

Several potential benefits:

cost @ scale
elimination of Landau jitter

Calibration of N_photoelectrons

good collaboration with Thomas Gustavsson of IRAMIS
improvements in noise environment around TiSa laser
end of April runs with single pe sensitivity

Method 1 from bench calibration:

Estimation of number of photo-electrons:

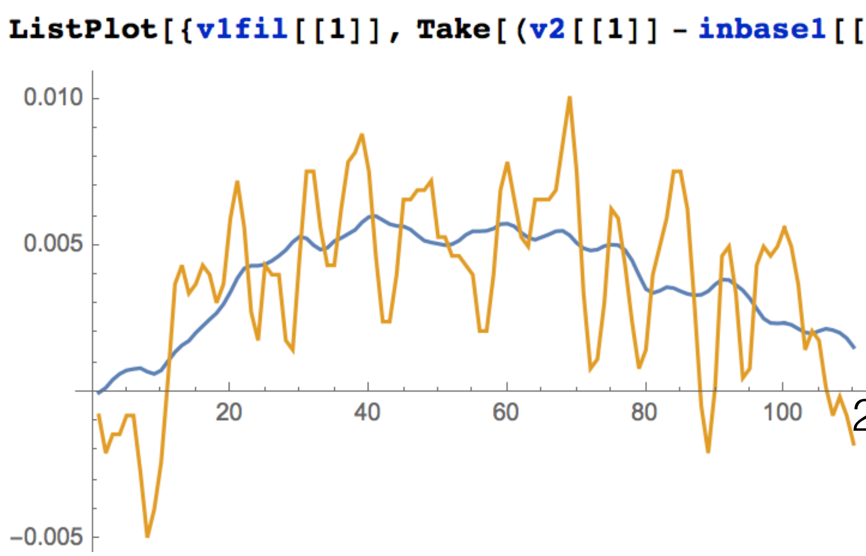
Measurement @ IRAMIS: signal ~1300 mV

Measurement with pulsed lamp @ SEDI: signal ~600 mV
Measurement with candle @ SEDI: <signal> ~30 mV

So, we concluded that we had around 20 photo_electrons at the lab and around 50 with the laser.

method (2) from/200 optical attenuator data

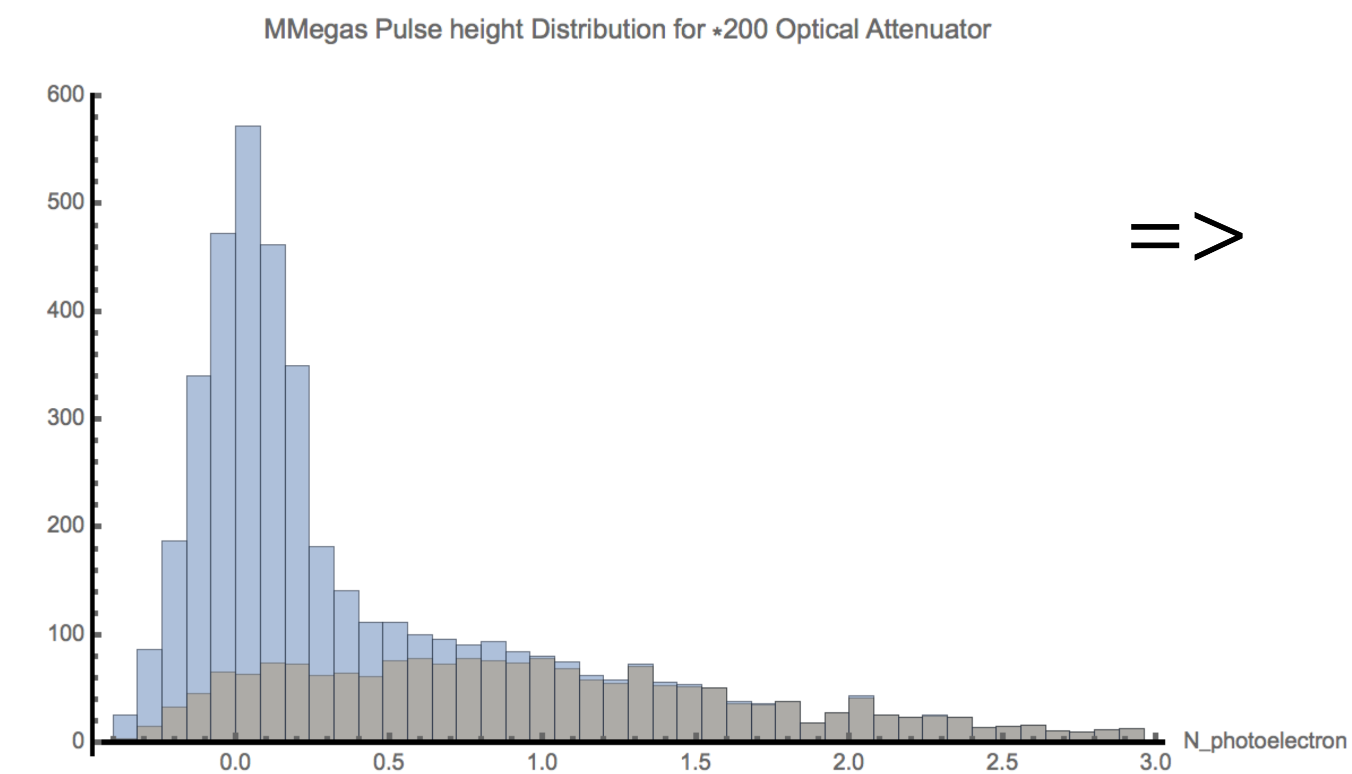
Effect of filtering on a typical waveform.



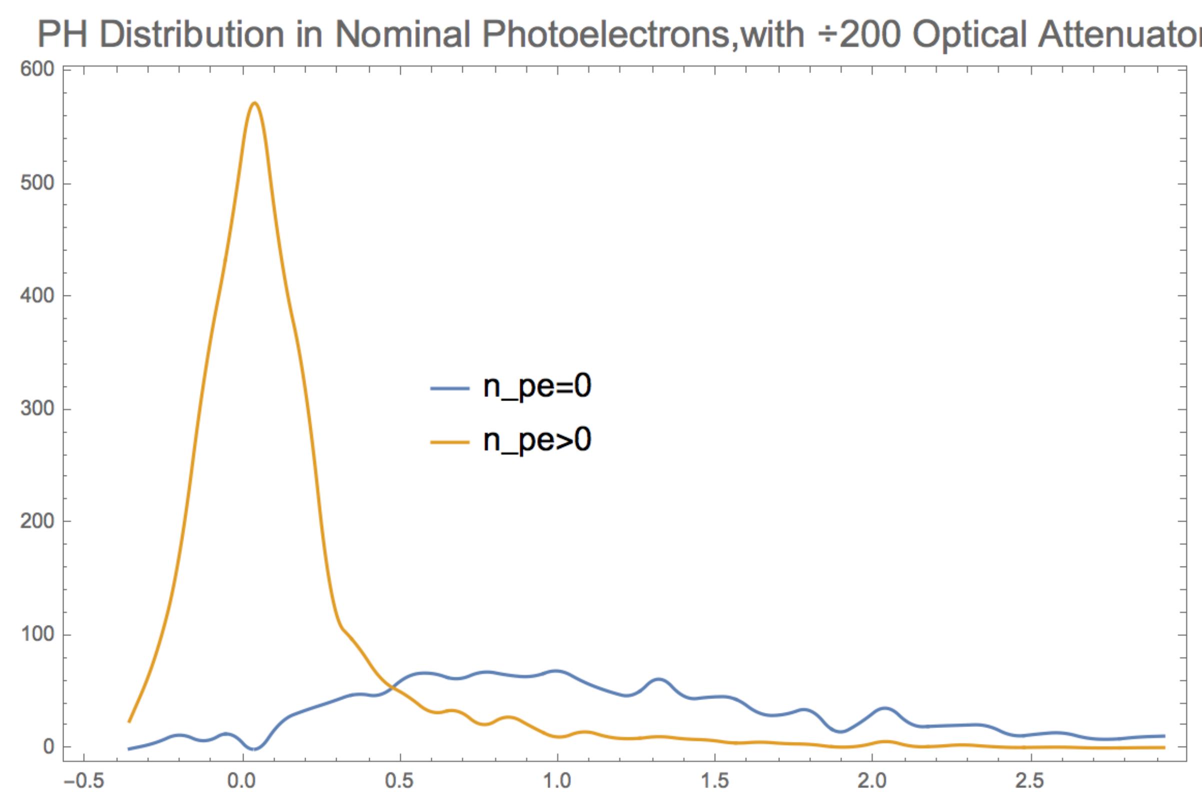
200 psec bins->

<=

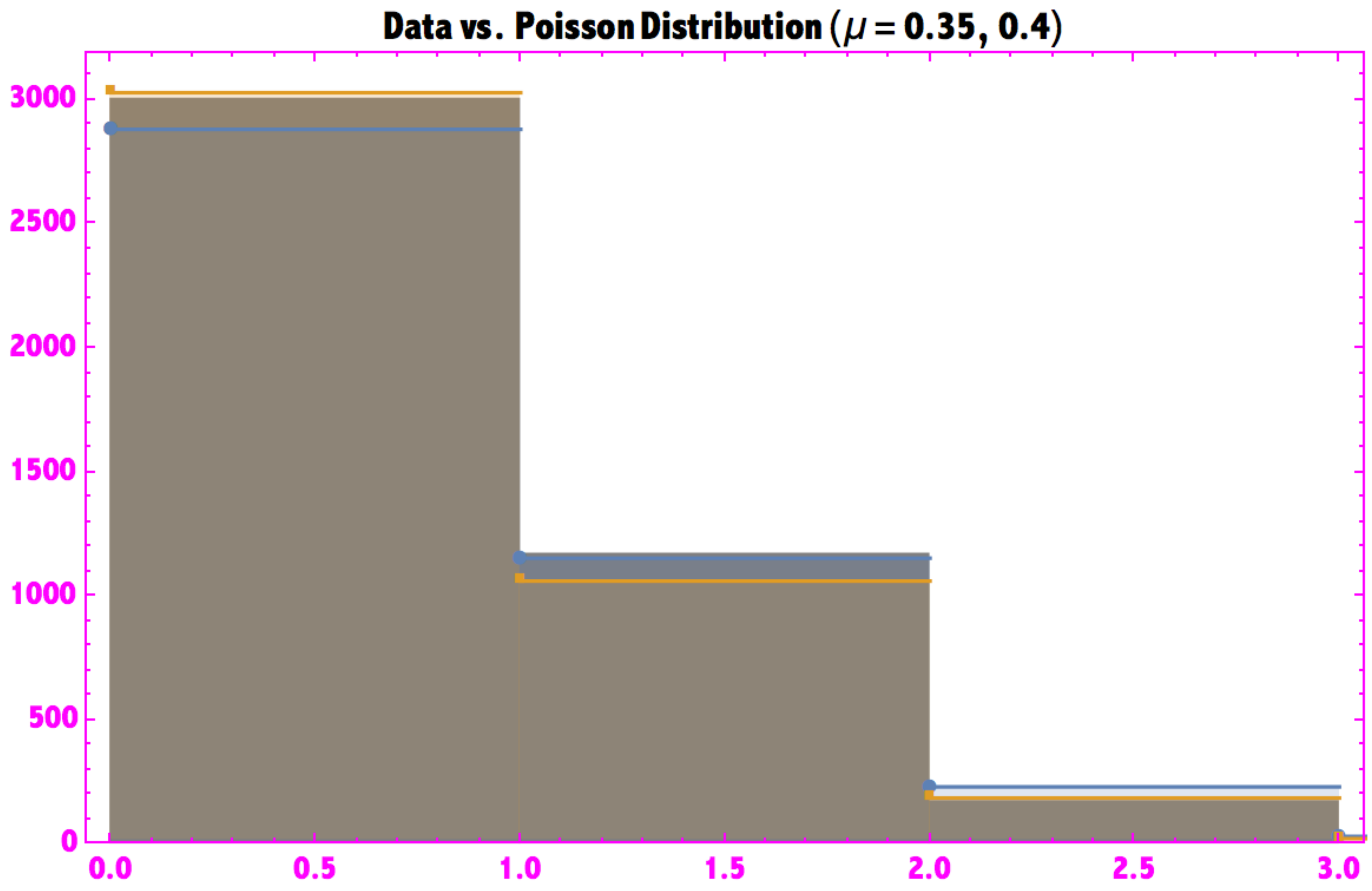
single pe data are pretty noisy
looks like digital noise dominates
next time need higher sampling
also setting scope to lower scale would have reduced this



=>



Photostatistics from attenuator data

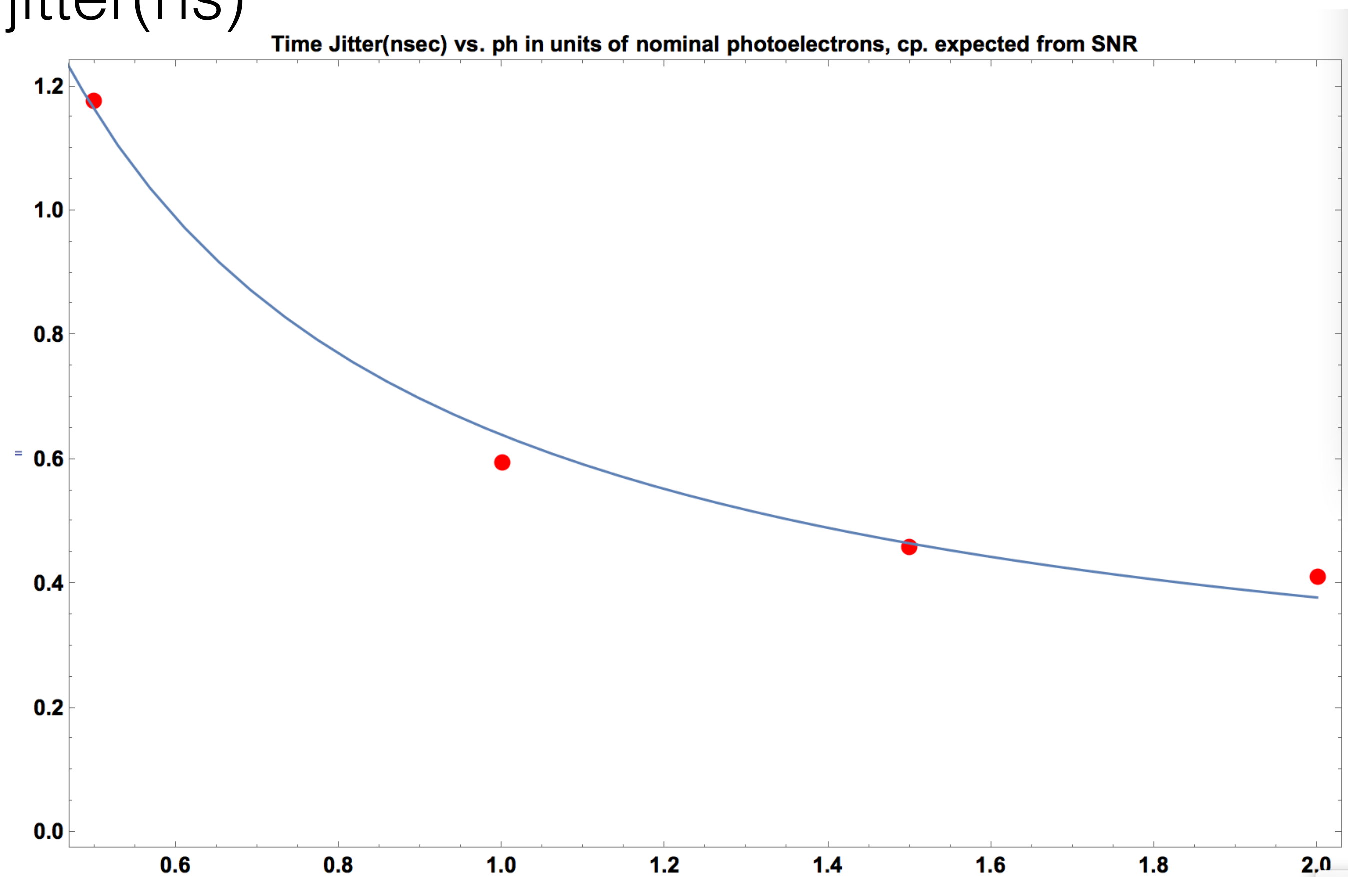


This plot shows extracted N_pe distribution
It is compared to expectation for mean of 0.35 and 0.4

correcting for the /200 attenuator we find N_pe~60 for normal running with no attenuator
We consider this to be consistent with the ~50 result obtained by Thomas

Jitter on Single pe

jitter(ns)

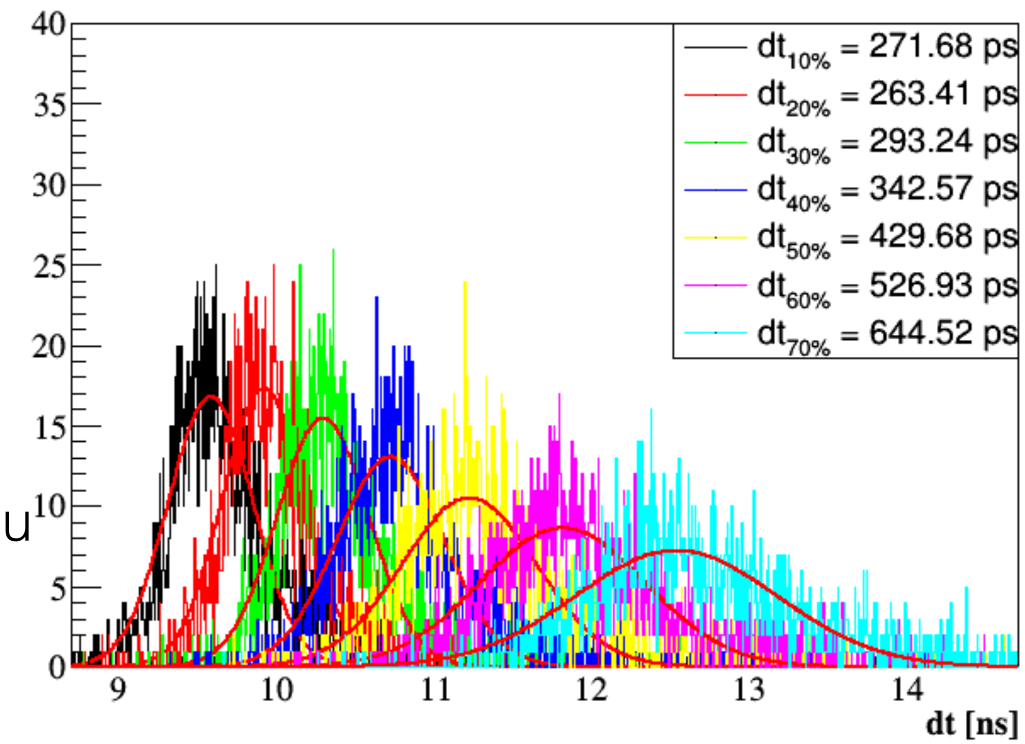


pulse height (nominal pe)->

using the same timing algorithm
as I used for jitter at ~50 pe
we are noise dominated as shown
here.

more aggressive fitting/filtering
is giving closer to expected diffusion
dominated jitter @1pe
ie ca.~260 psec

Thomas Papaevangelu
->



Plans(MPGD)

- possibly another 1-2 runs w. Saclay chamber for cosmetic purposes-> write up proof of concept
- parallel development here at CERN of other test structures
- expect to have full, charged particle detector assemblies for beam tests at end of summer
- many interesting issues to follow proof of concept: gas & field configuration optimization, rate effects, photocathode development , possible benefits of reflective photocathode, etc.

Mesh Readout Si

representing:

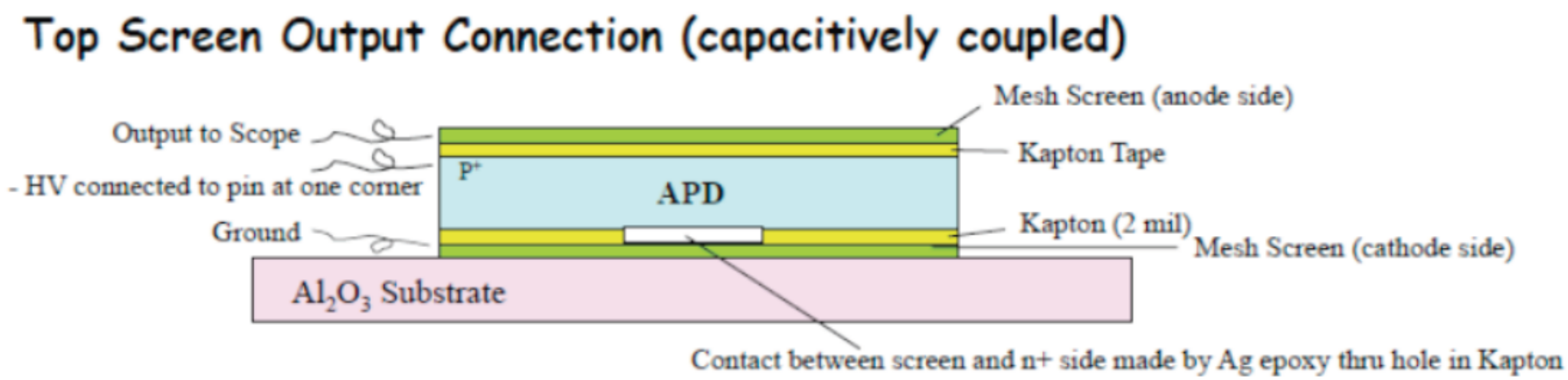
C. Williams, P.Lecoq, SNW -*in collaboration w. M. Moll, C. Gallrapp, M. Fernandez-Garcia*(CERN)
E. Delagnes (CEA/Saclay)
K. McDonald, C. Lu, C. Tully & SNW (Princeton)
M. Newcomer (U. Penn)
for USCMS Phase II Upgrade R&D

industrial partner RMD/DYNASIL: M. McClish, R. Farrell
outside collaborators T. Tsang (BNL Instrumentation)

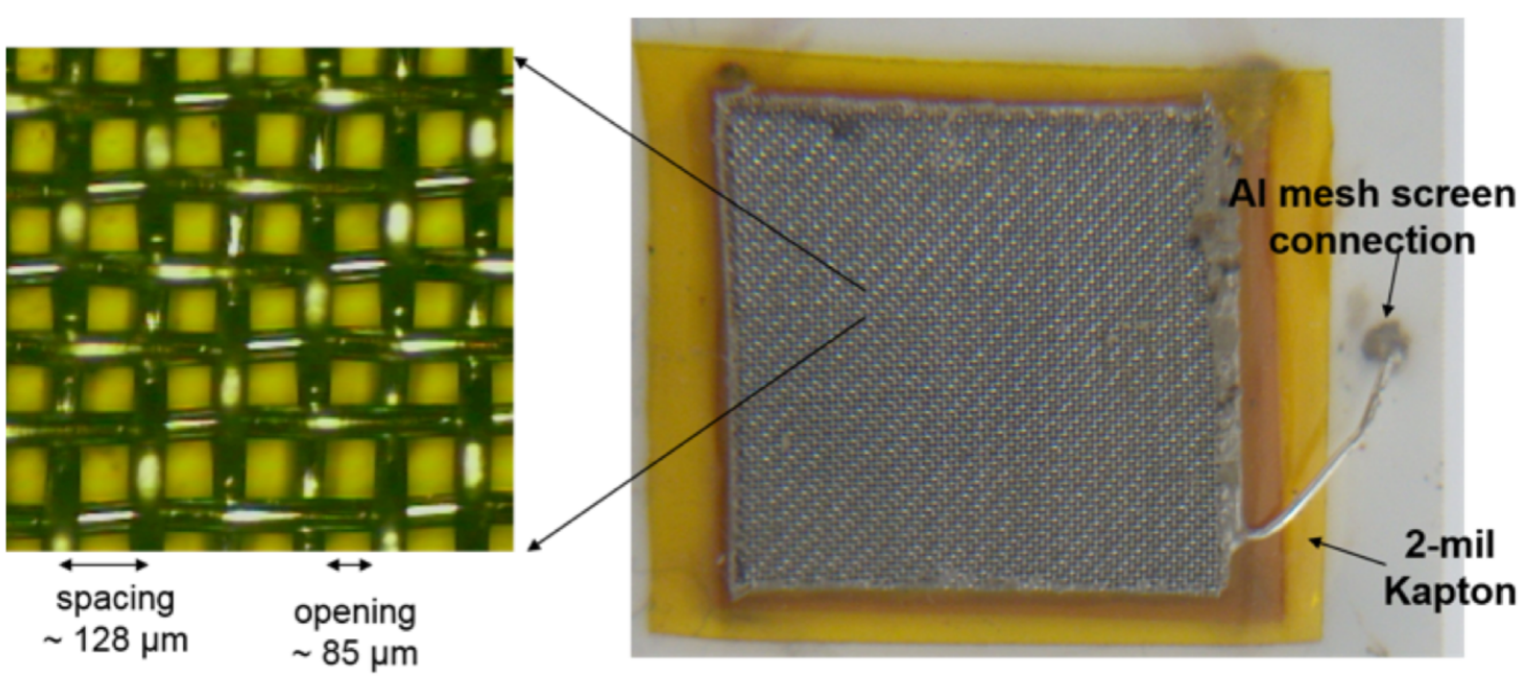
current status:
this sensor is meeting our timing goals of 10-15 picosec/MIP
in 2015 supported by CERN to work in RD50/51 to address LHC specific issues:

- *Rad tolerance @>1014 neq/cm2*
- *packaging/cost issues*
- *systems issues-i.e. FEE, DAQ architecture, clock distribution*

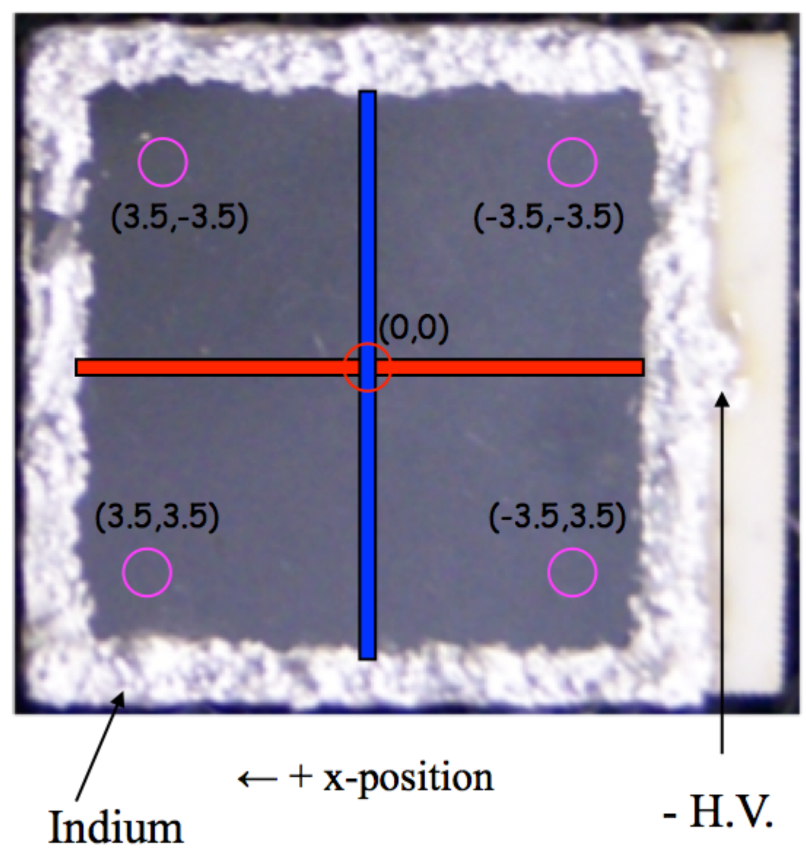
Detector Concept



top view

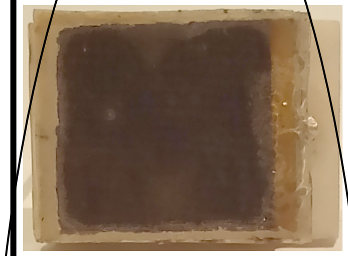
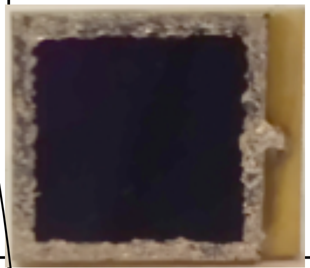
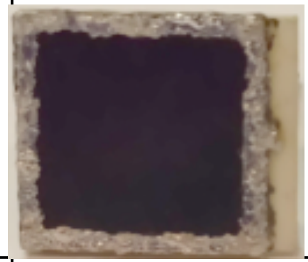
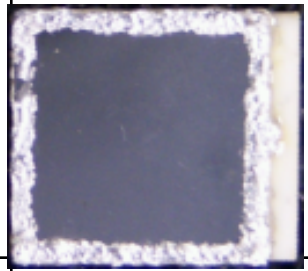
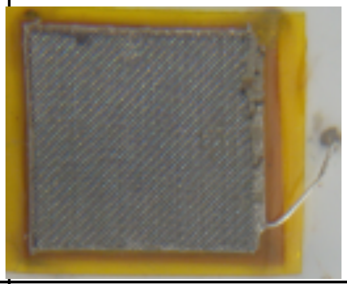
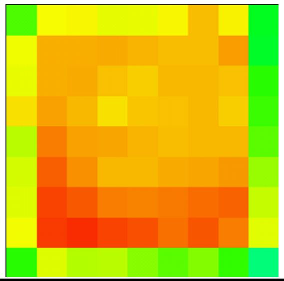
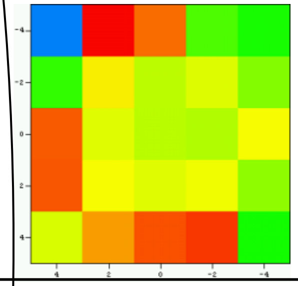
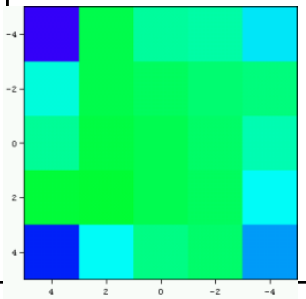
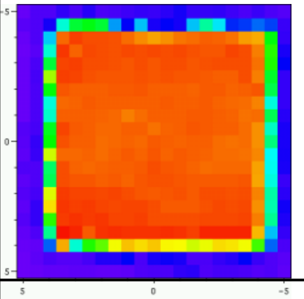
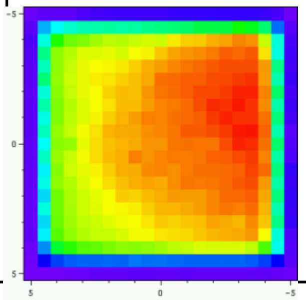
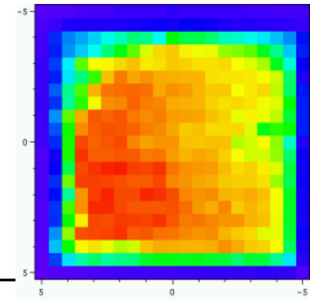
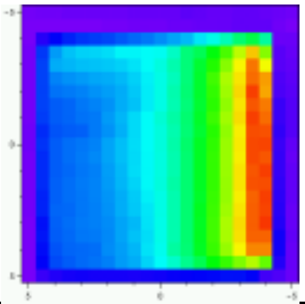
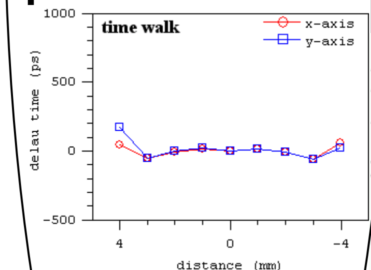
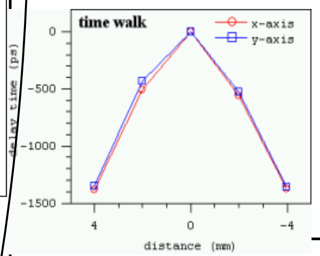
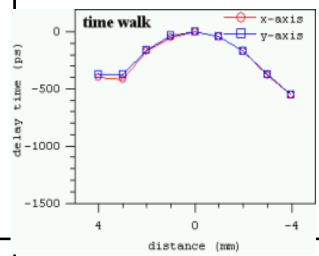
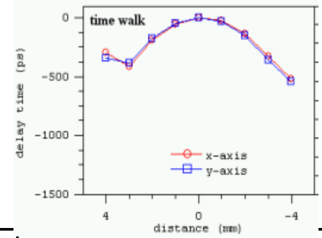
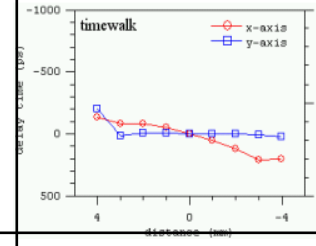
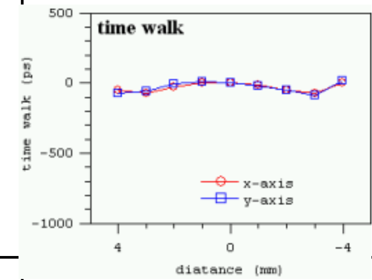
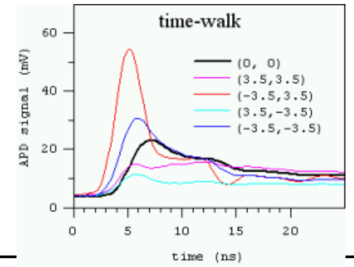
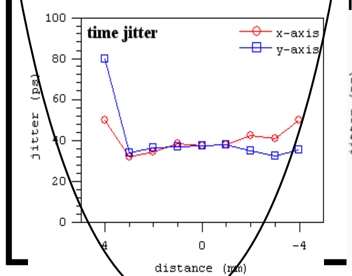
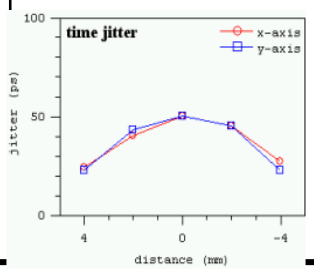
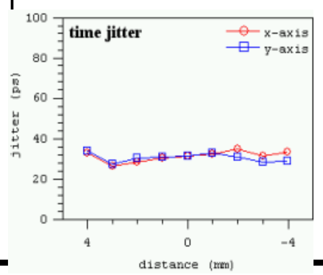
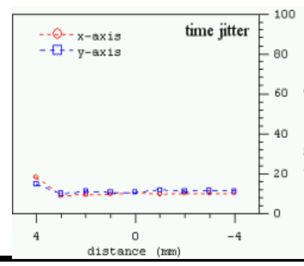
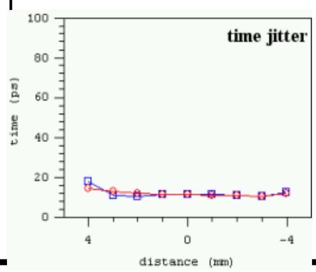
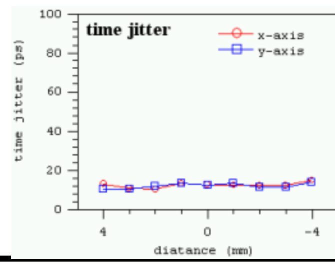


early variant



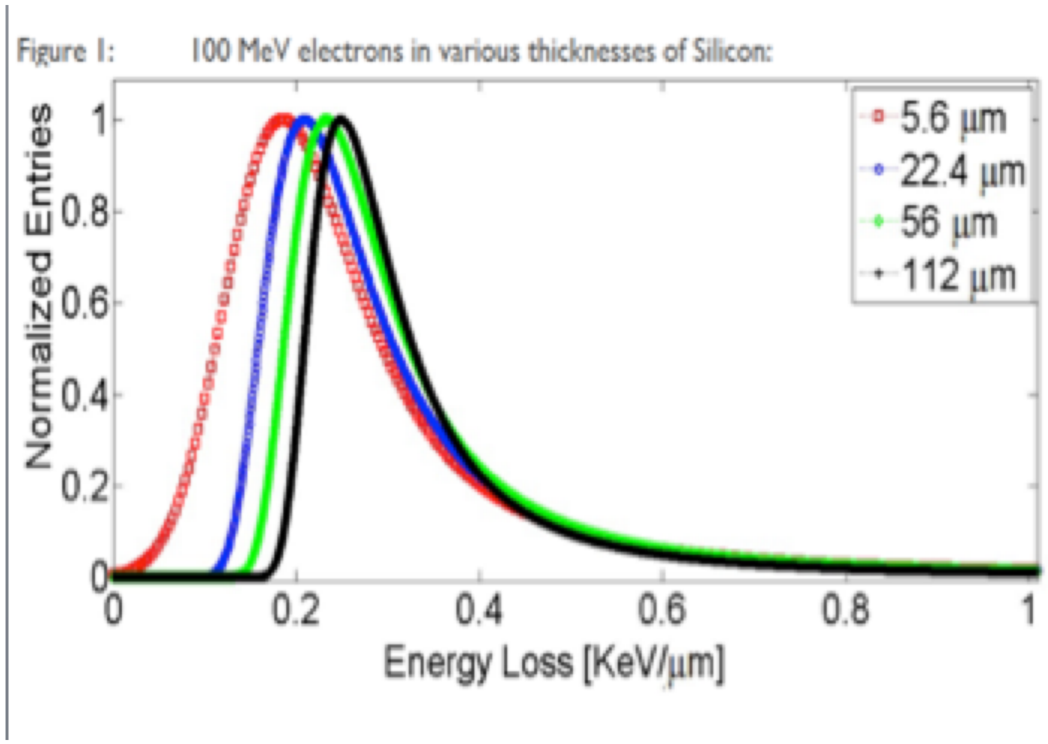
- emphasis of our development has been to deal with weighting field uniformity for fast signals
- essential outcome is that detectors look like a good capacitor at high frequencies
- relevance in the NA62 Gigatracker development where it was fond that dominant jitter from:
- weighting field
- Landau fluctuations
- developments in signal processing/filtering, timing algorithms for LHC application to address
    - Landau/Vavilov
    - radiation induced bulk leakage-> shot noise induced time jitter

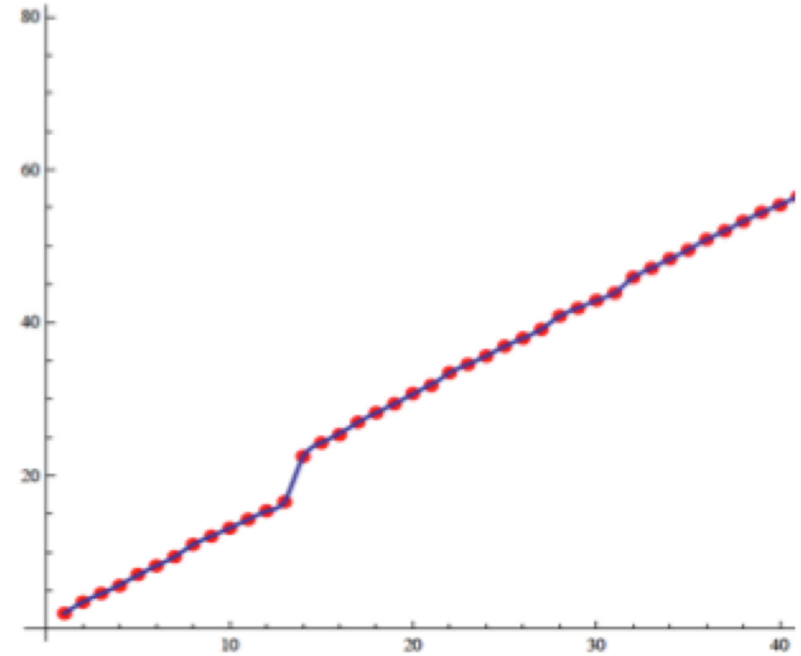
Summary of RMD 8x8 mm^2 APDs Dec. 13, 2013

	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

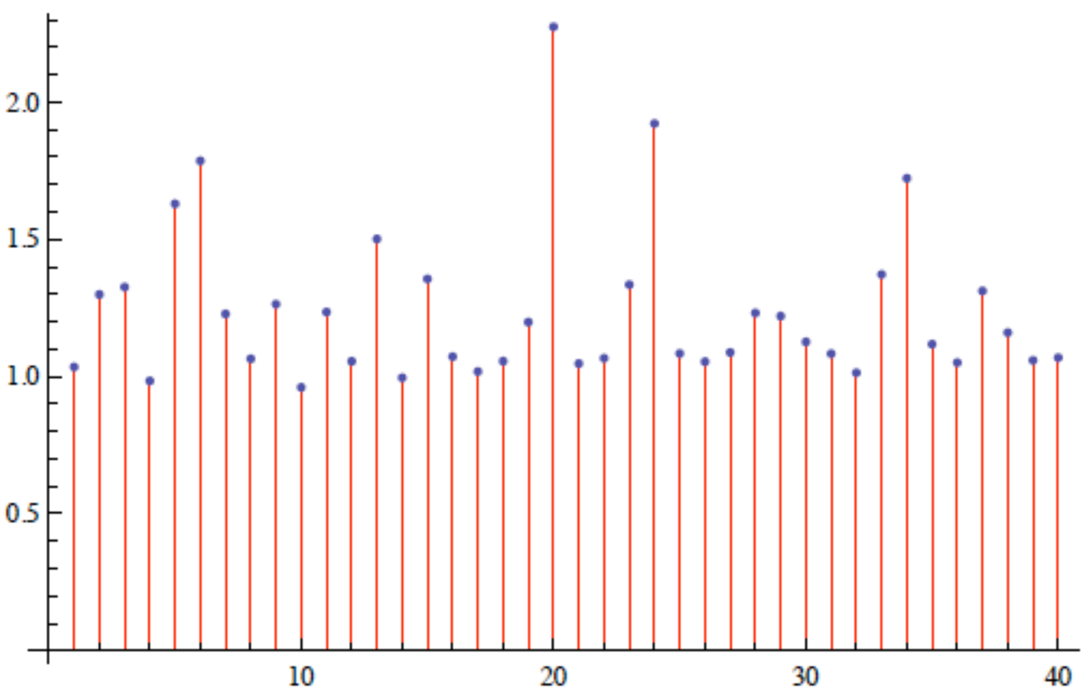
2) weighting field uniformity (and internal series resistance elimination)

Landau/Vavilov contribution

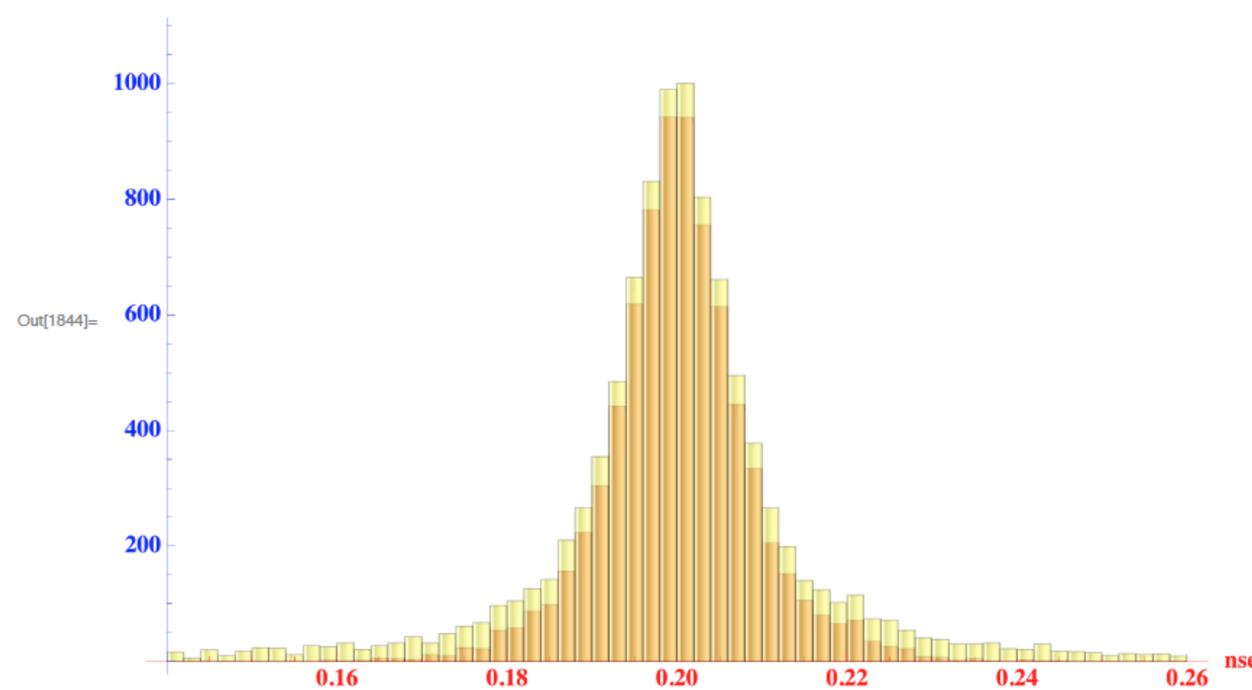




Mean Signal Arrival Time



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




```
Cut in Signal amplitude at 77.35
 % efficiency reduces time jitter from 0.022641 to 0.00870866nsec
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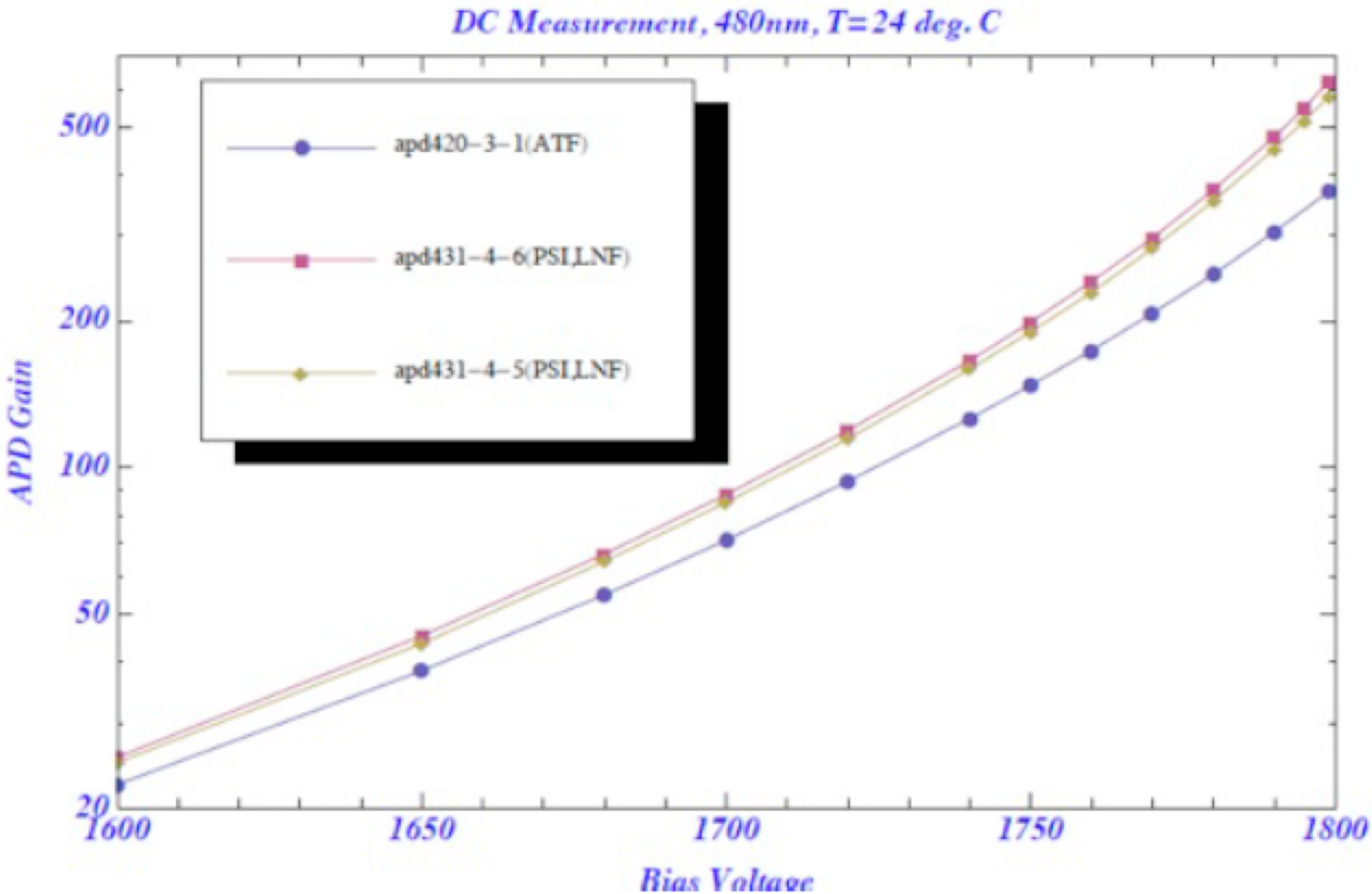
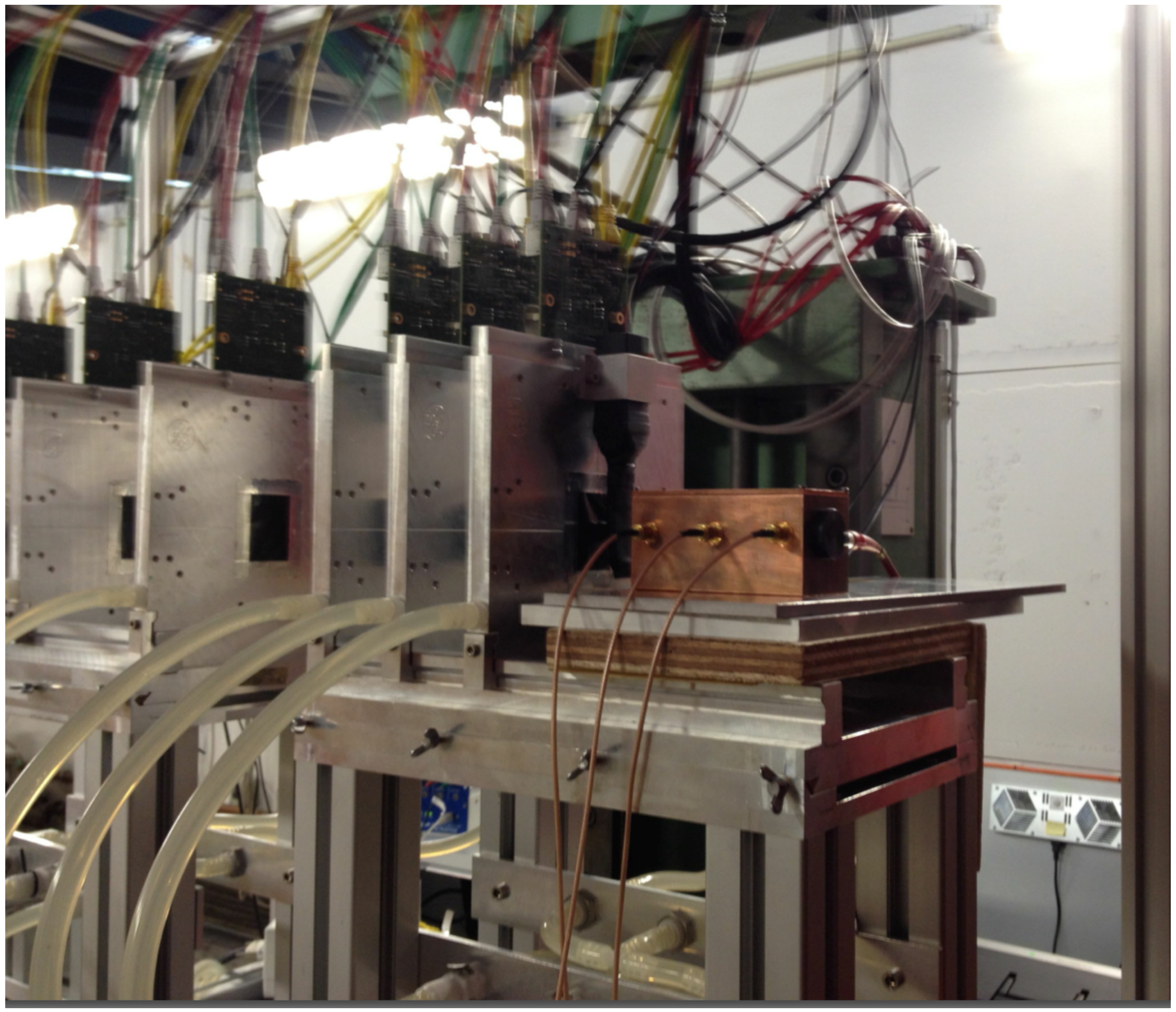
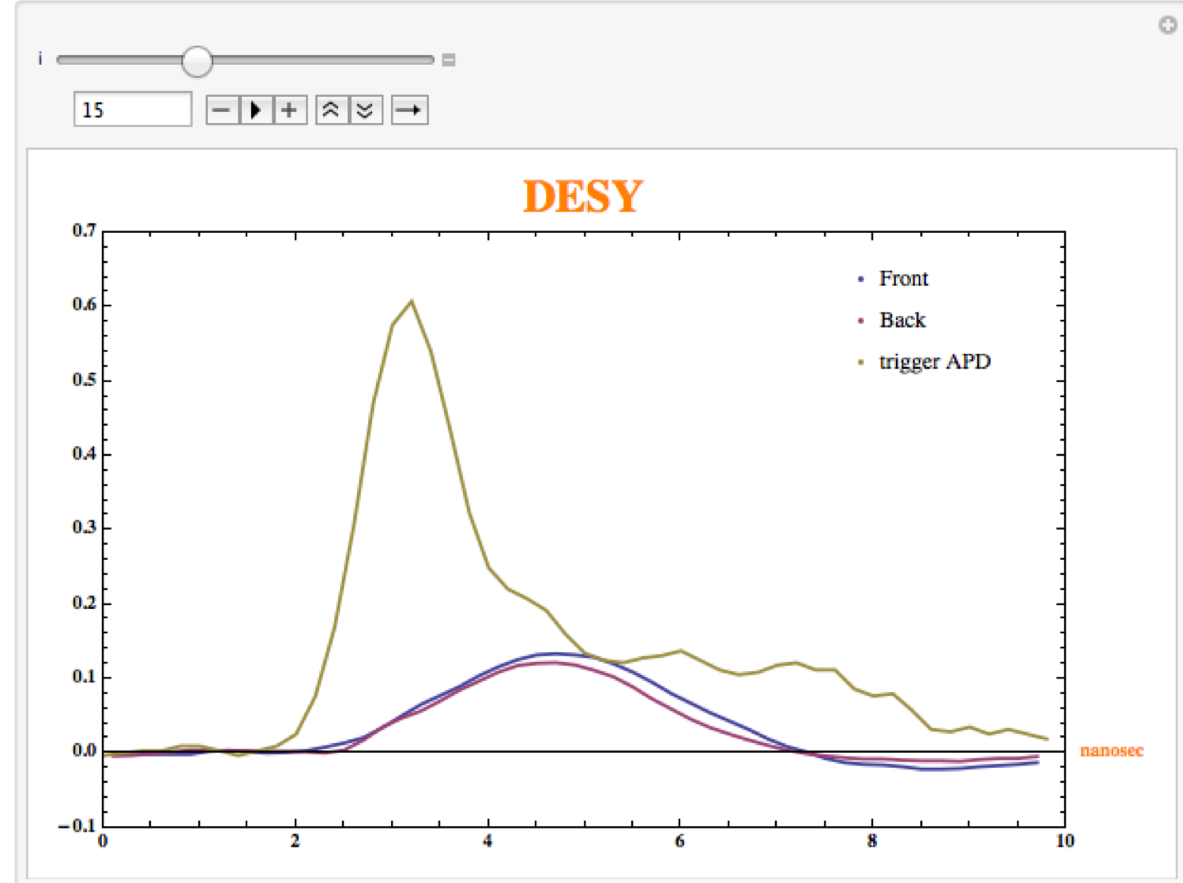
testbeam data taken at SPS, DESY, PSI, FNAL typically at detector bias ~1770-1800V



DESY 2014

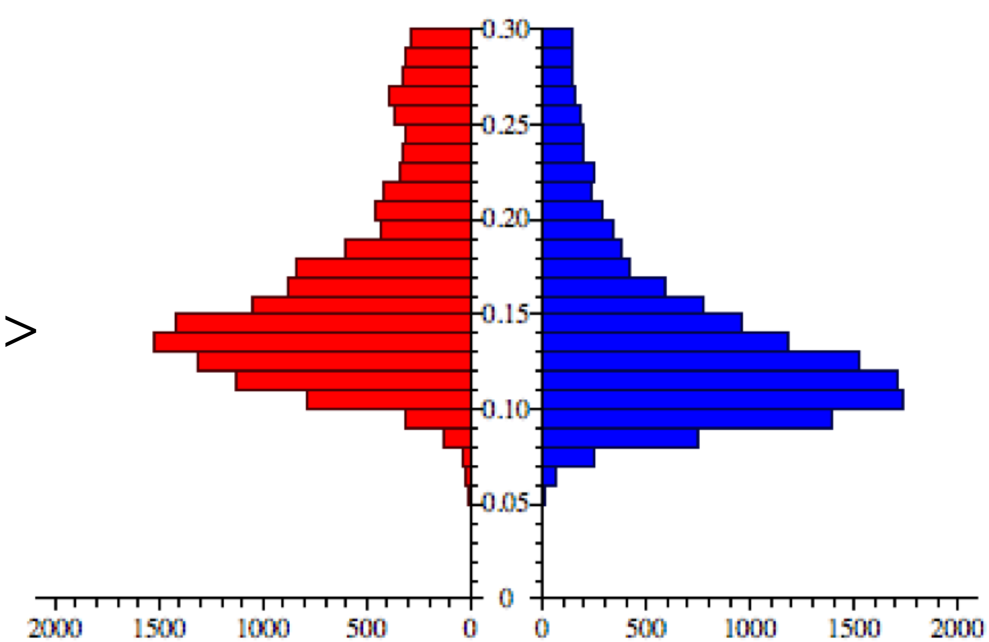




Peak amplitude 1/5 that of 4 pF detector in large area 60 pF detector

Sim and DESY data

front, back detector ph distribution->



Outlook for Si

- DESY results motivated us to develop fast Si-Ge transimpedance amplifiers (ready this week)
- working with Moll/RD50 on device modeling- very good collaboration on topic of mutual interest
- at Princeton now doing packaging (in collaboration with RMD and U. Penn.)
- in DESY beam this weekend, then SPS July 6th
- further rad damage measurements this summer (so far we reached 0.8 10^{14} p/cm^2