HFS:Performance Scans in Runs 291-292

Sebastian White, representing HFS-CERN/Princeton/BNL/Delhi/RMD

RD51 Precision Timing Workshop, Feb. 21, 2017

In these PICOSEC runs no MMEGAS chambers but full tracking system readout (as in previous talks).

1) 8x8 mm^2 HFS detector, 1800 V bias
2) w. Aug. 2016 version of TIA (see M. Newcomer talk)
3) R3809U Microchannel Plate PMT(see M. Vignali talk)
4) Full tracking (~40micron rms projected to HFS)
5) MCP & HFS waveforms digitized @ 20GSa/s, 2.5 GHz BW

Here we emphasize detailed mapping of detector performance additional data with various Vbias &

Lecroy scope-> SAMPIC (later)

Silicon with Gain

- NA62 Gigatracker Project explored limits of Silicon w/o Gain-> likely ~90-100 picosec
  - limiting factors not SNR but detector physics (Landau, Weighting Uniformity, charge collection)
- likely true of any SSD (see Beretti, TOTEM Diamonds)
- what technologies are available with gain? what are relative advantages for timing, robustness?
- recognize “right” pixel size for timing ~ 1 cm^2
  - uniformity over large areas, FEE matched to larger capacitance
- HFS started in ~2007 to address these issues (RMD, BNL, Princeton, Yale..)- SNW et al. https://arxiv.org/pdf/0901.2530.pdf

State of the art in Si w. Gain in 2007 (and still today)

- 1994 paper on MIP timing with Avalanche Diodes by McIntyre et al. (wrote the book on AD- and patents):Andrew Hauger et al., “A Time of Flight detector based on Silicon avalanche diodes”, Nuclear Instruments and Methods A 337 (1994) 362-369.

- mostly the same detector parameters as MPGD- (electron/hole drift velocities, impact ionization-Townsend…)

Table 1
Time resolution, gain and breakdown voltage of the diode modules

Diode module	σ_{time} (ps)	Gain ($V_{BD} - V_{bias} = 10$ V)	V_{BD} (V)
1	65	47	425
2	66	31	409
3	78	32	348
4	87	49	404

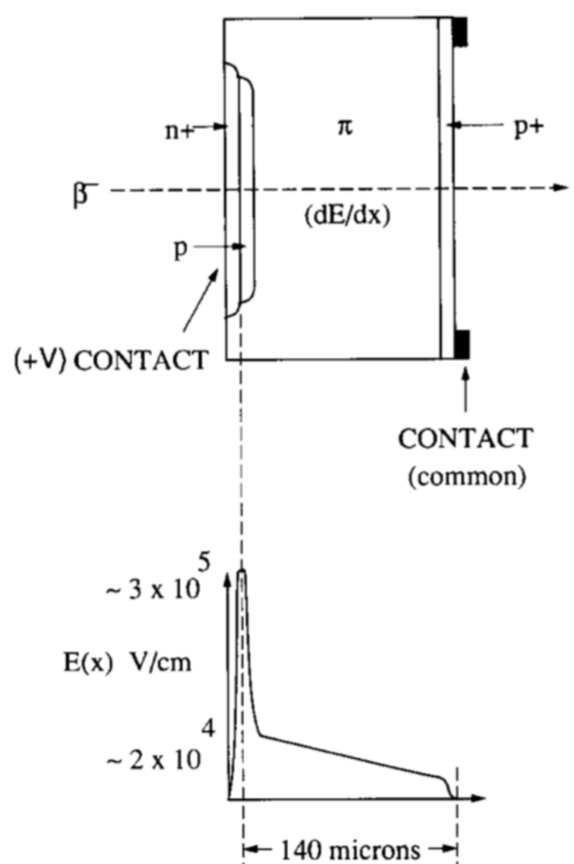


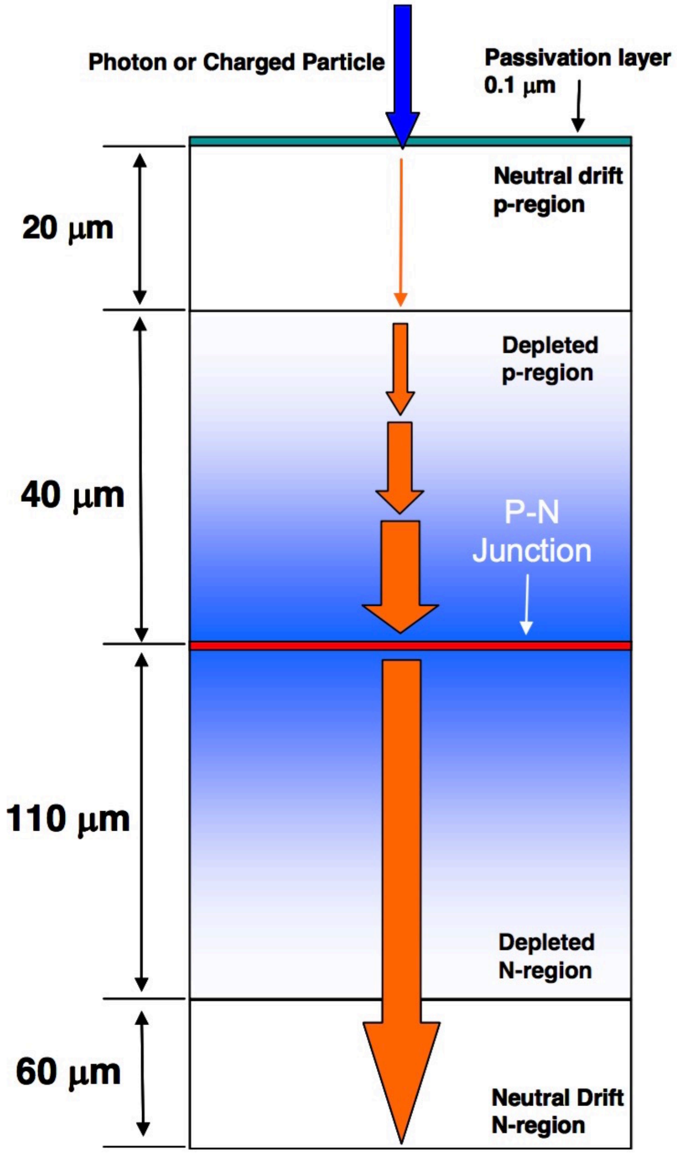
Fig. 2. Schematic AVD profile and resulting electric field distribution. The peak field corresponds to the multiplication region.

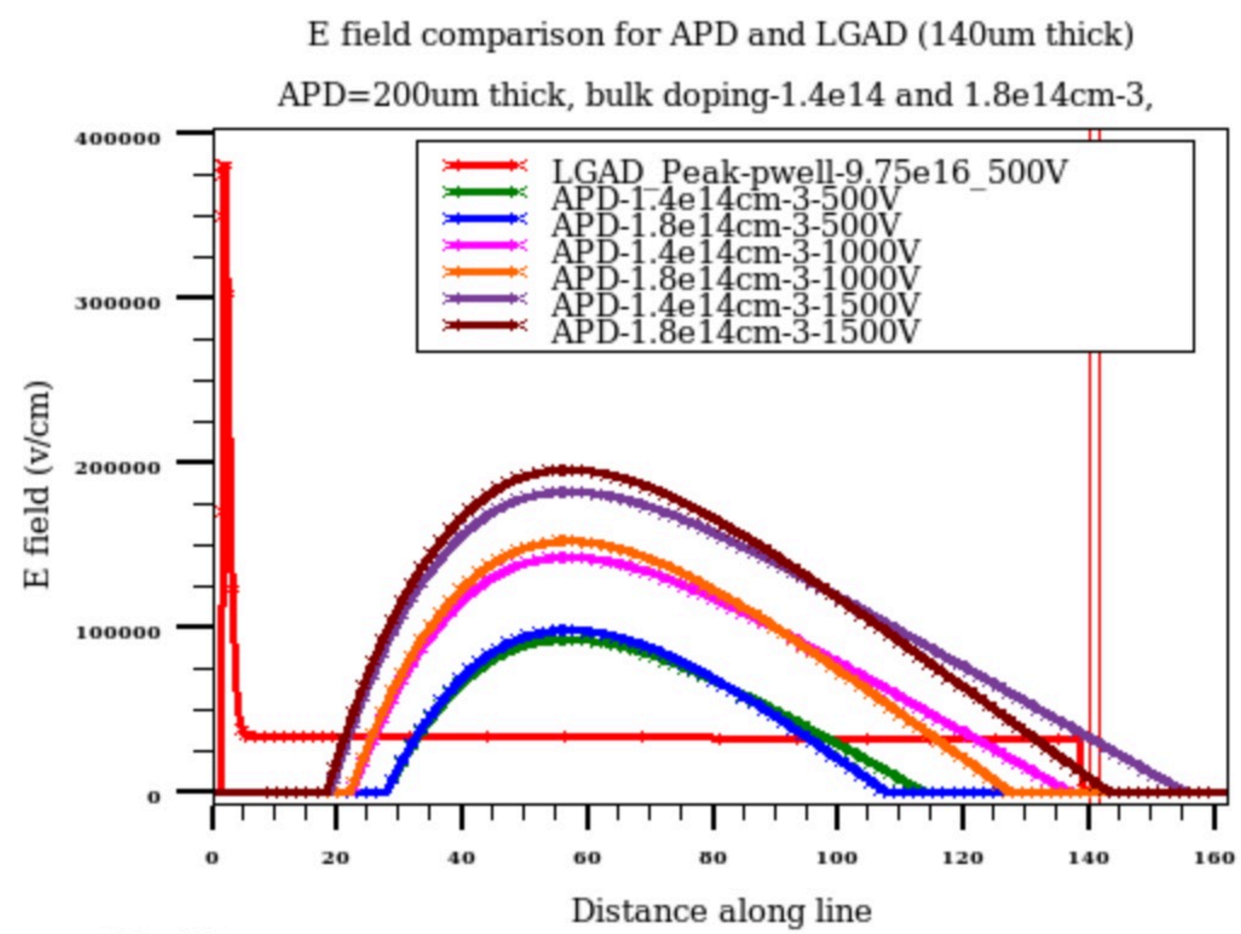
not bad for 23 years ago!
aka Low Gain Avalanche Diode
see Fabian’s talk

Deep Depleted Avalanche Diodes

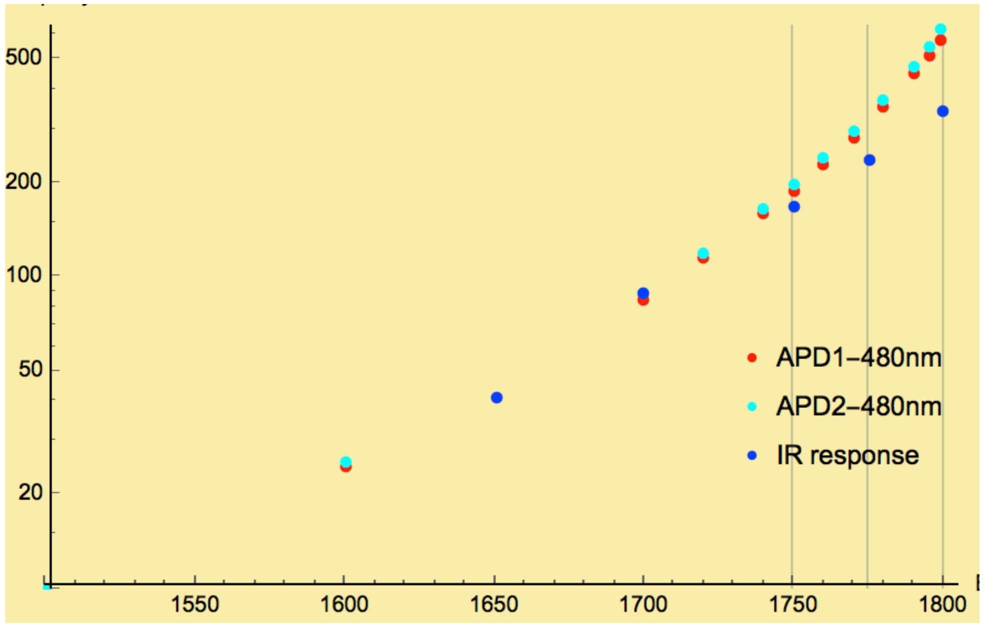
- also in the 1990's 3 companies in the US invested heavily in developing an alternative to vacuum PMTs(large area, high gain Si)
- we worked closely with Radiation Monitoring Devices (Boston Area)
- higher maximum Gain (~500 vs. ~45 of McIntyre et al)- potentially more headroom to address uniformity and other issues
- up to 1.3x1.3 cm^2 vs. 0.5x0.5 of McIntyre
- needed high BW transimpedence FEE to deal w. larger C_D (Mitch)
- HFS somewhat merger of 2 (fiscal) cultures: financed by 2 separate DOE generic detector awards (explicitly not LHC) and large fraction of activity in CERN SSD (explicitly for LHC environment). This has slowed down developing packages suitable for rad and beam testing
- we are finally out of the woods on latter (see summary)

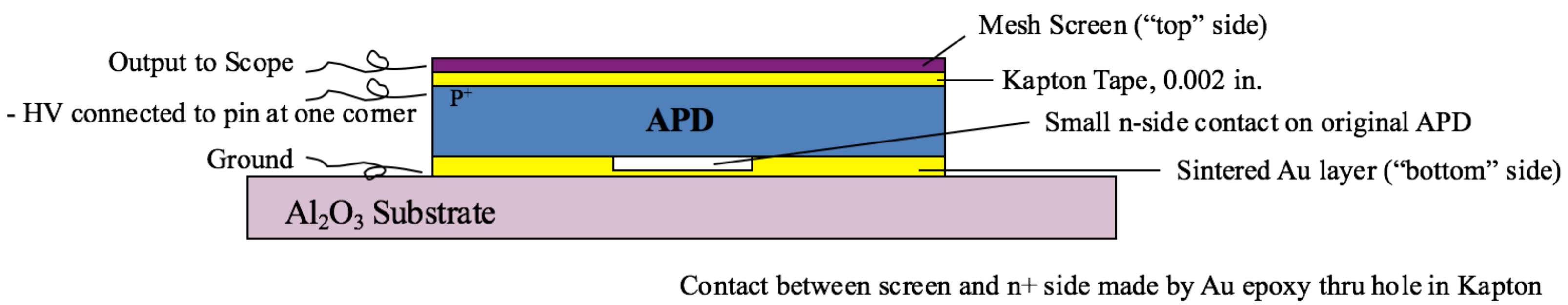
HyperFastSilicon(HFS) structure





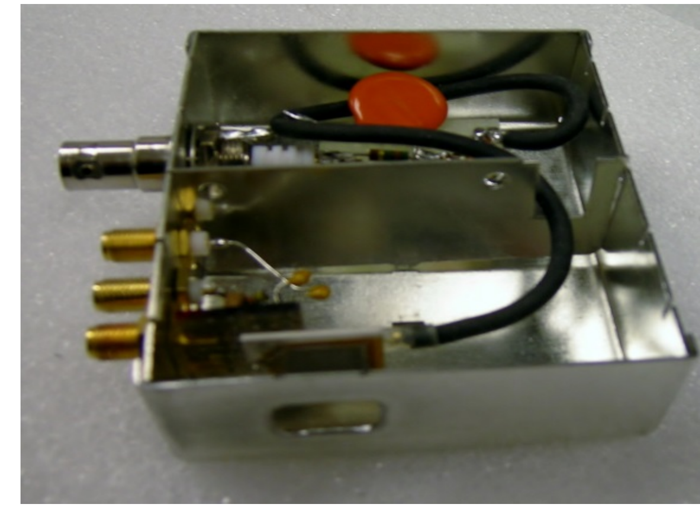
Sketch by Thomas Tsang





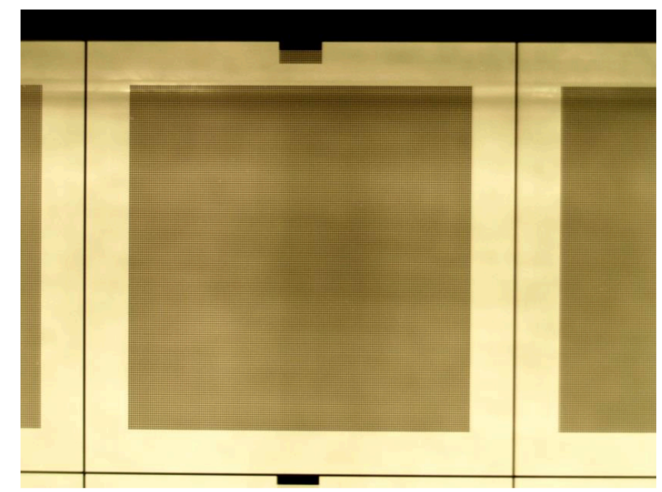
packaging, packaging,…

much of characterization was done with
with low tech packaging like this——>
bad for stray inductance, uniformity…



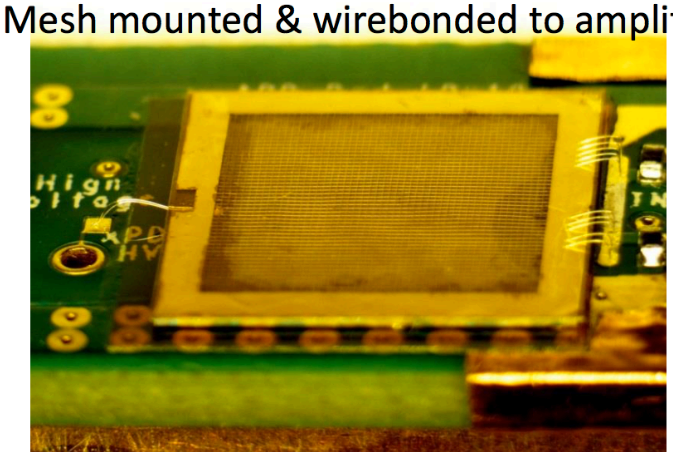
in past 2 months concerted effort to
come up with large volume of detectors
(~24 now in hand) for modern packaging,
integration suitable for SSD measurement
infrastructure, rad exposure, beam tests

Ni/Au Electroplated mesh ---- 5um/20nm respectively



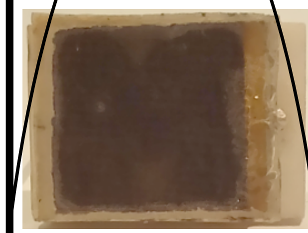
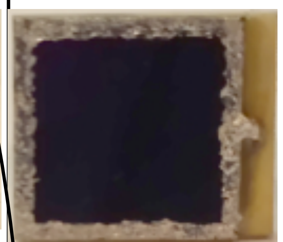
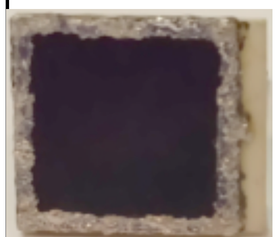
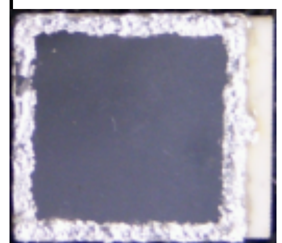
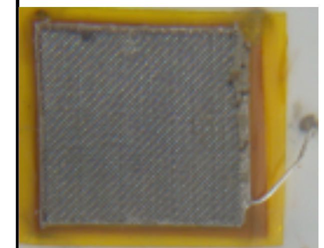
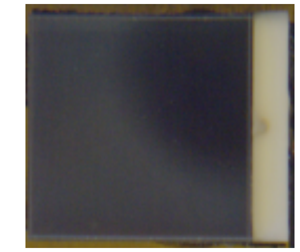
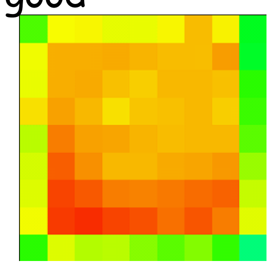
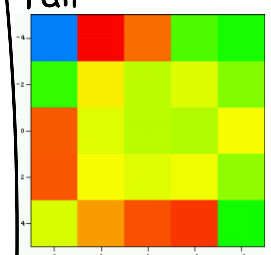
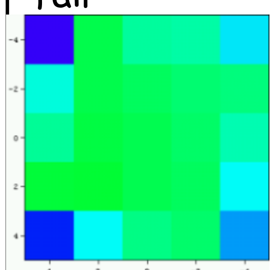
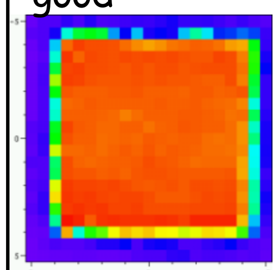
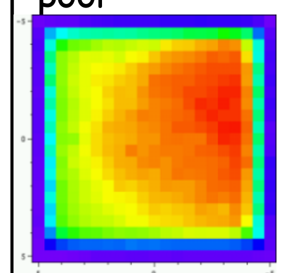
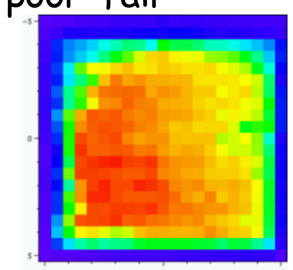
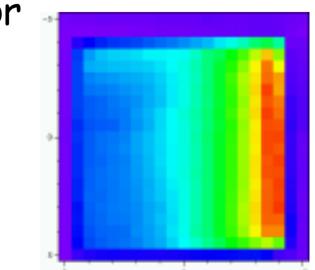
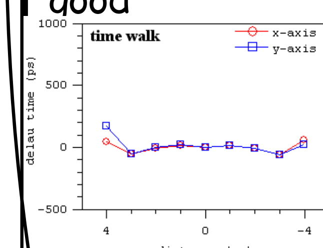
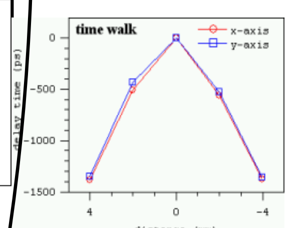
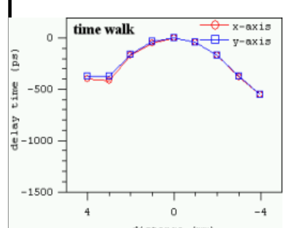
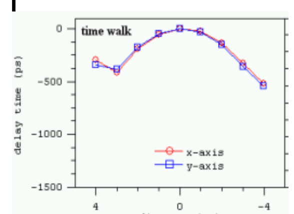
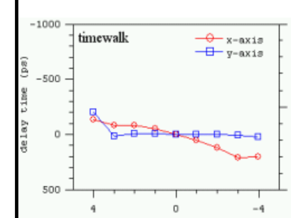
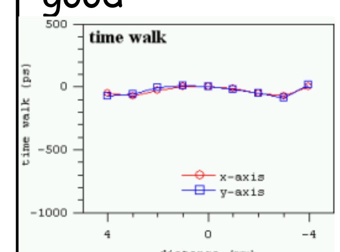
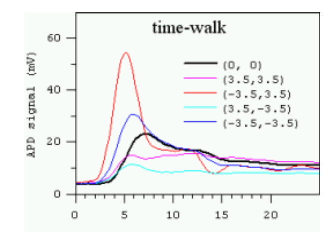
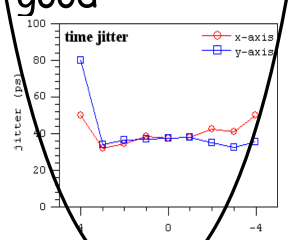
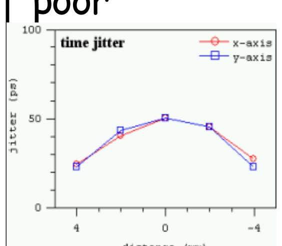
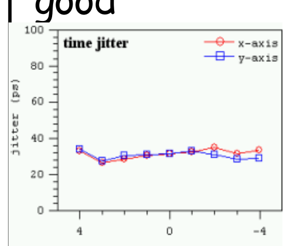
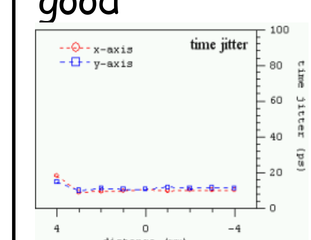
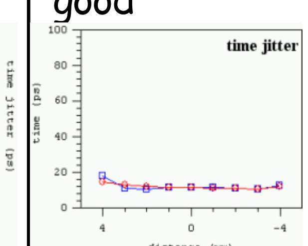
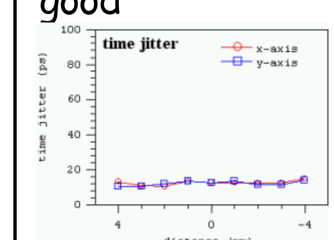
caveat: measurements reported here
still mostly with old packaging

Mesh mounted & wirebonded to amplifier



Summary of RMD 8x8 mm^2 APDs

T. Tsang, *BNL*, 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

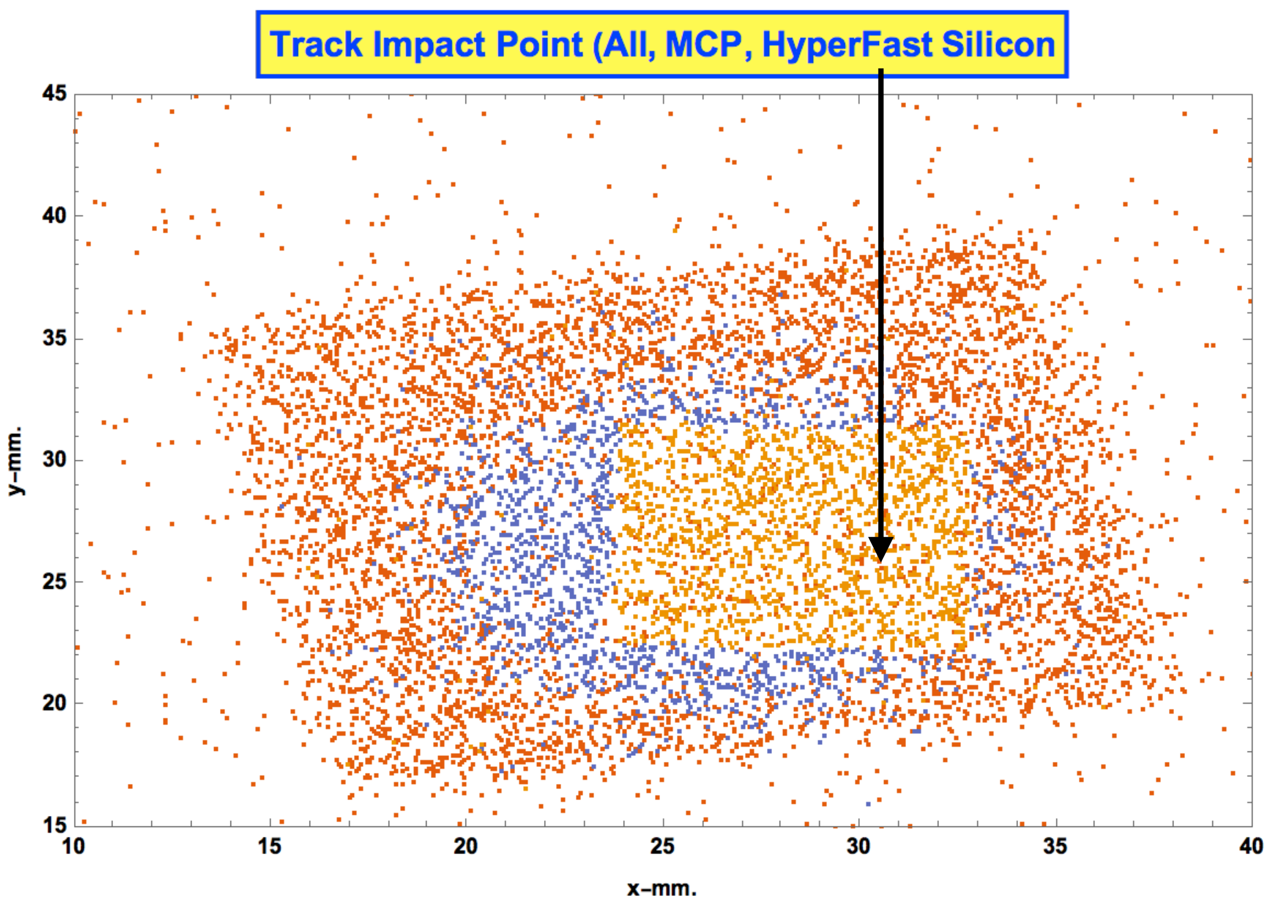
Conclusion: metallic mesh with gold sintered device is the best of all.

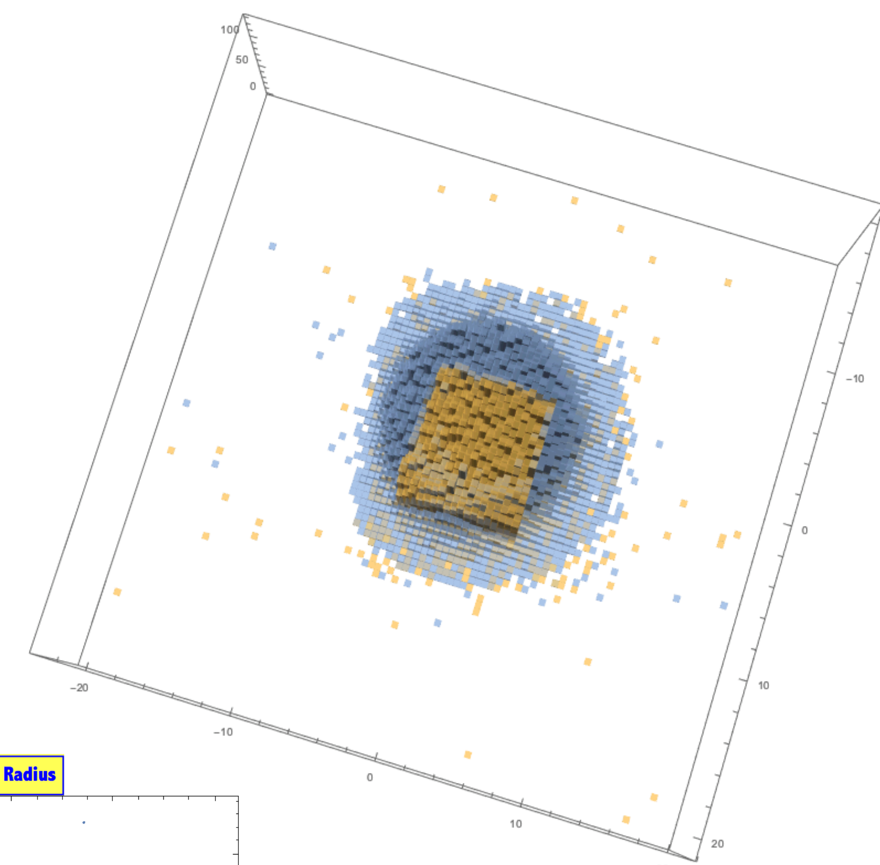
We need only a <u>simple parallel plate capacitor geometry</u> to maintain the field lines throughout the entire ADP surface

it's taken ~3 years to reach point where laser summary->Testbeam
much learned from DESY,PSI,LNF,FNAL, PS, SPS tests but……

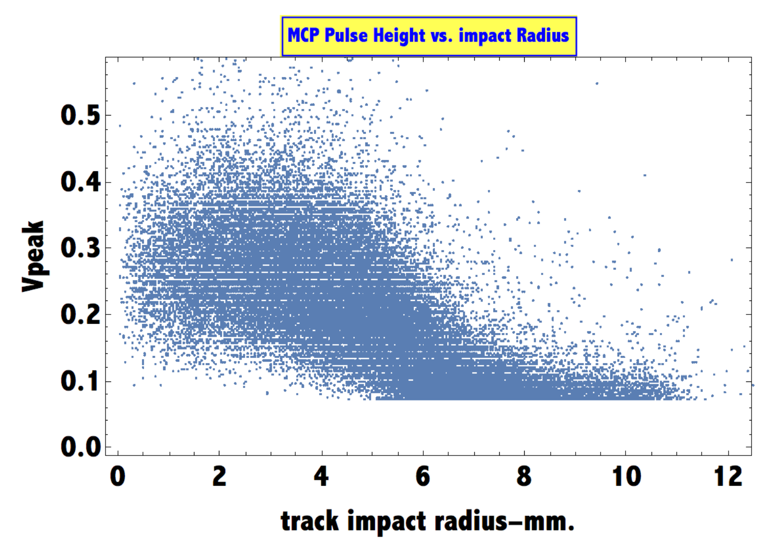
"Tracking and MCP (time ref.) coverage"

- special run with large area trigger
(2x2 vs usual PICOSEC 0.5x0.5 cm^2)
- good for detailed map of HFS silicon, good for understanding MCP time resolution vs. position



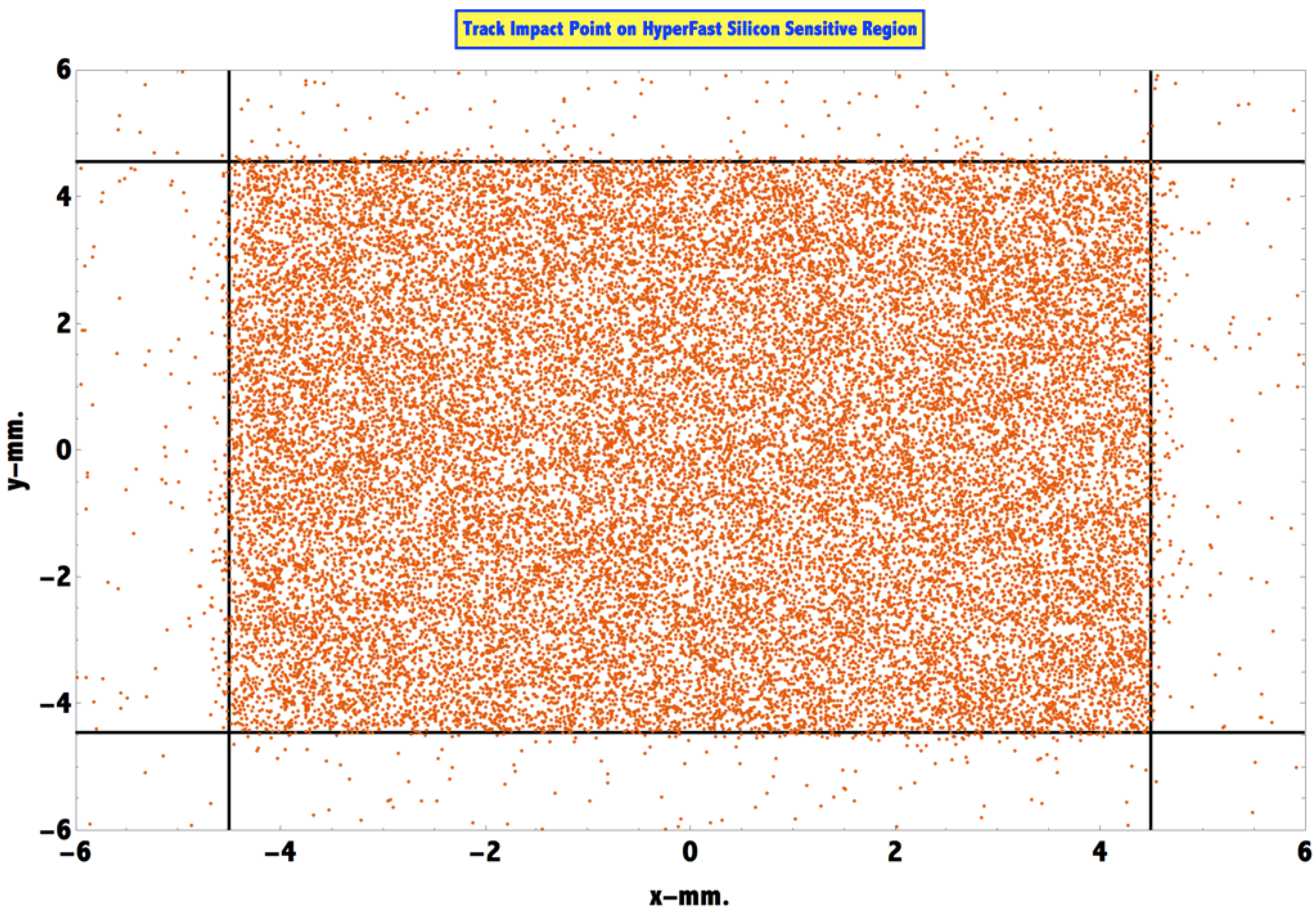


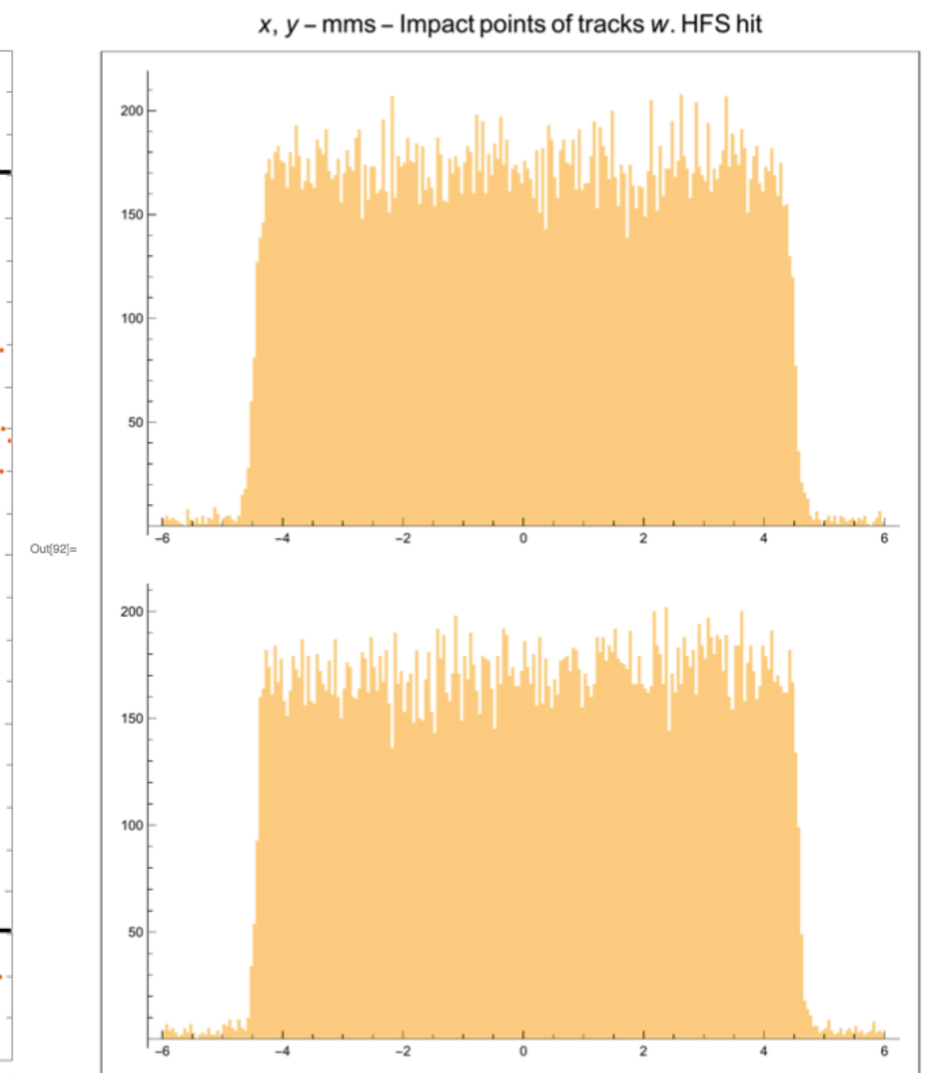
since goal is to map both
HFS Ampl. &time response
tracks at edge of MCP dropped



“Efficiency Map w. 150 GeV muons”

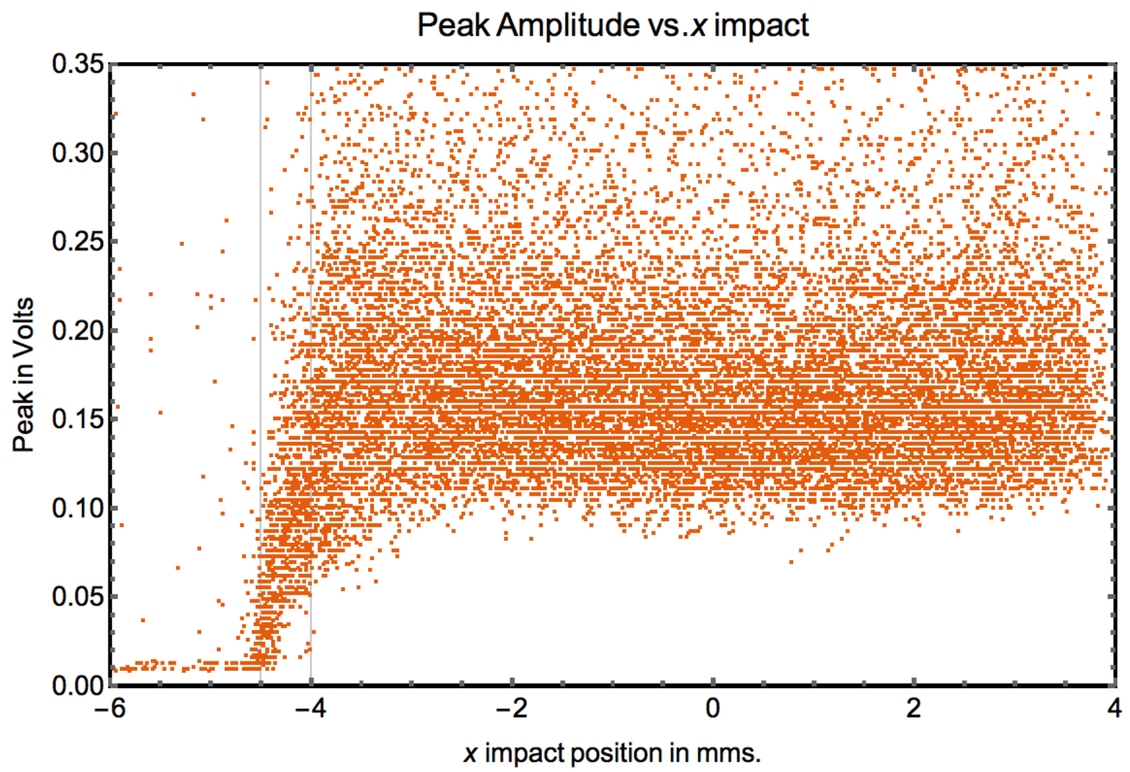
tracks for which HFS peak>7*noise



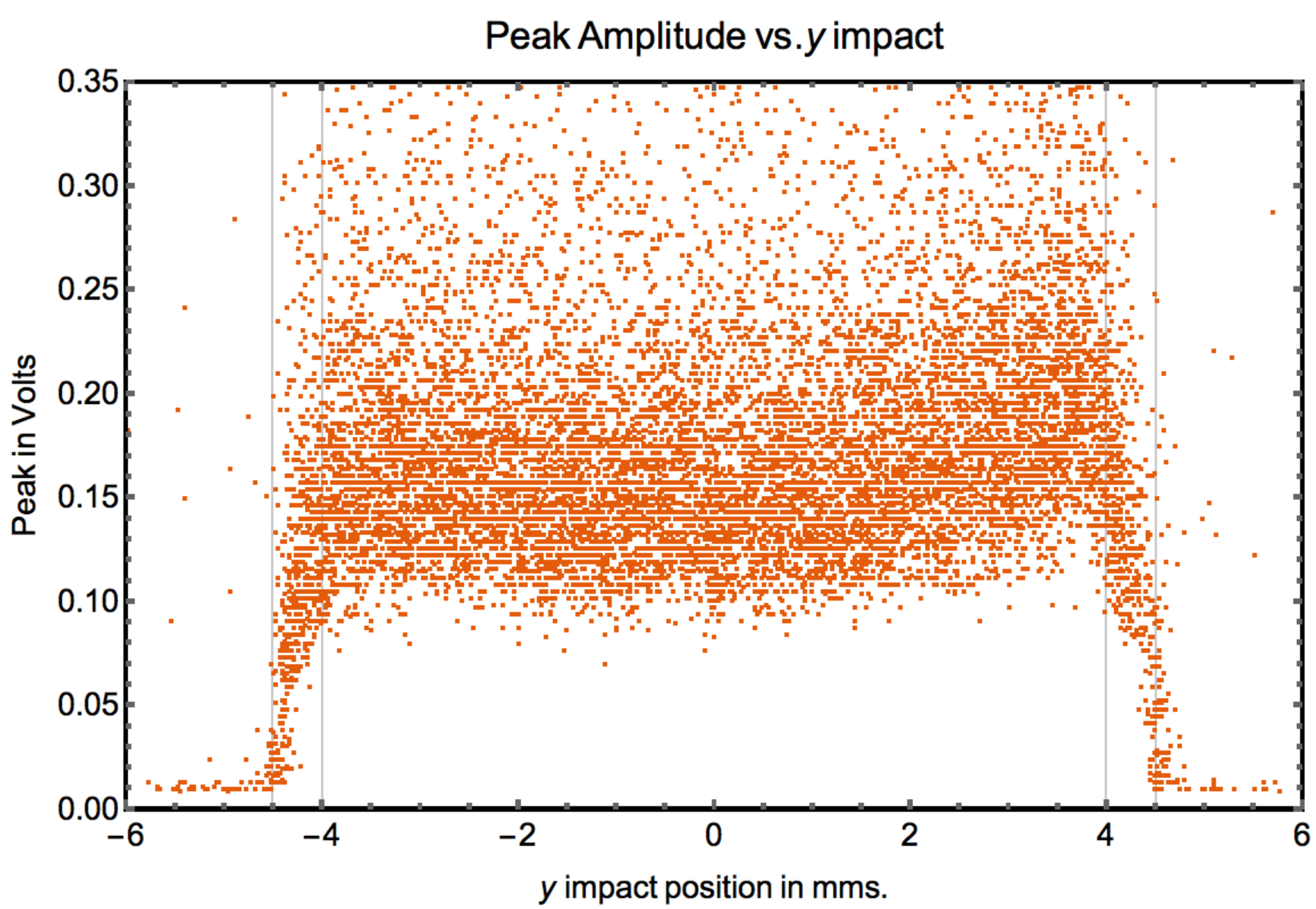


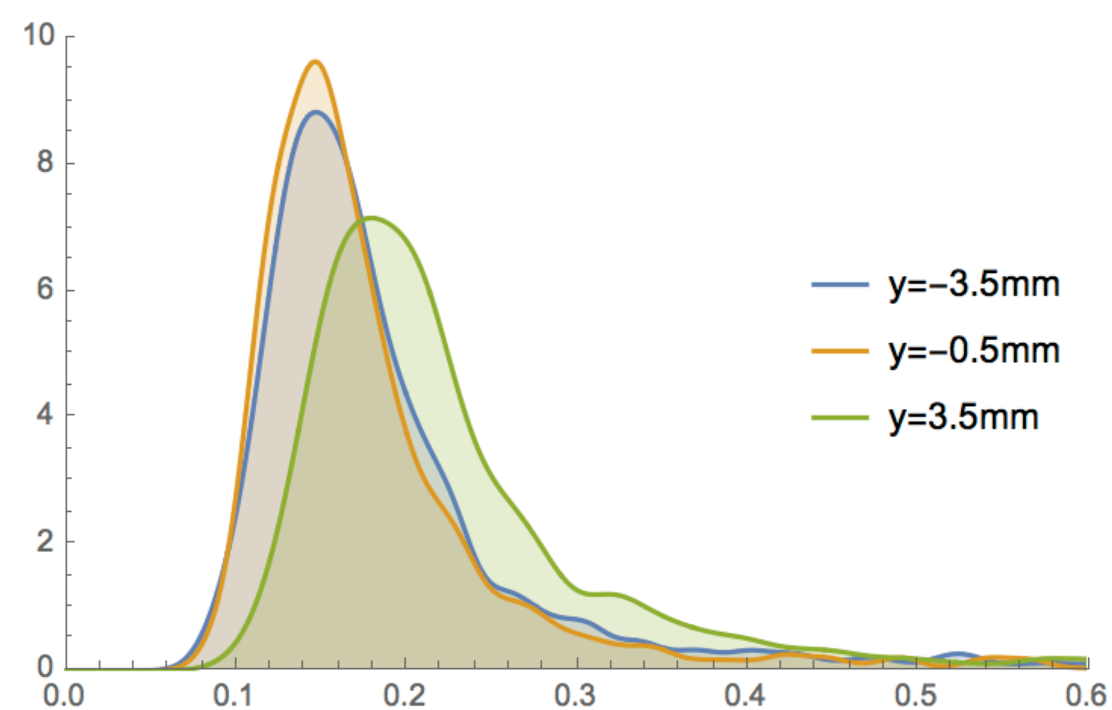
looks good! efficient to physical edge.

Now Look Deeper!



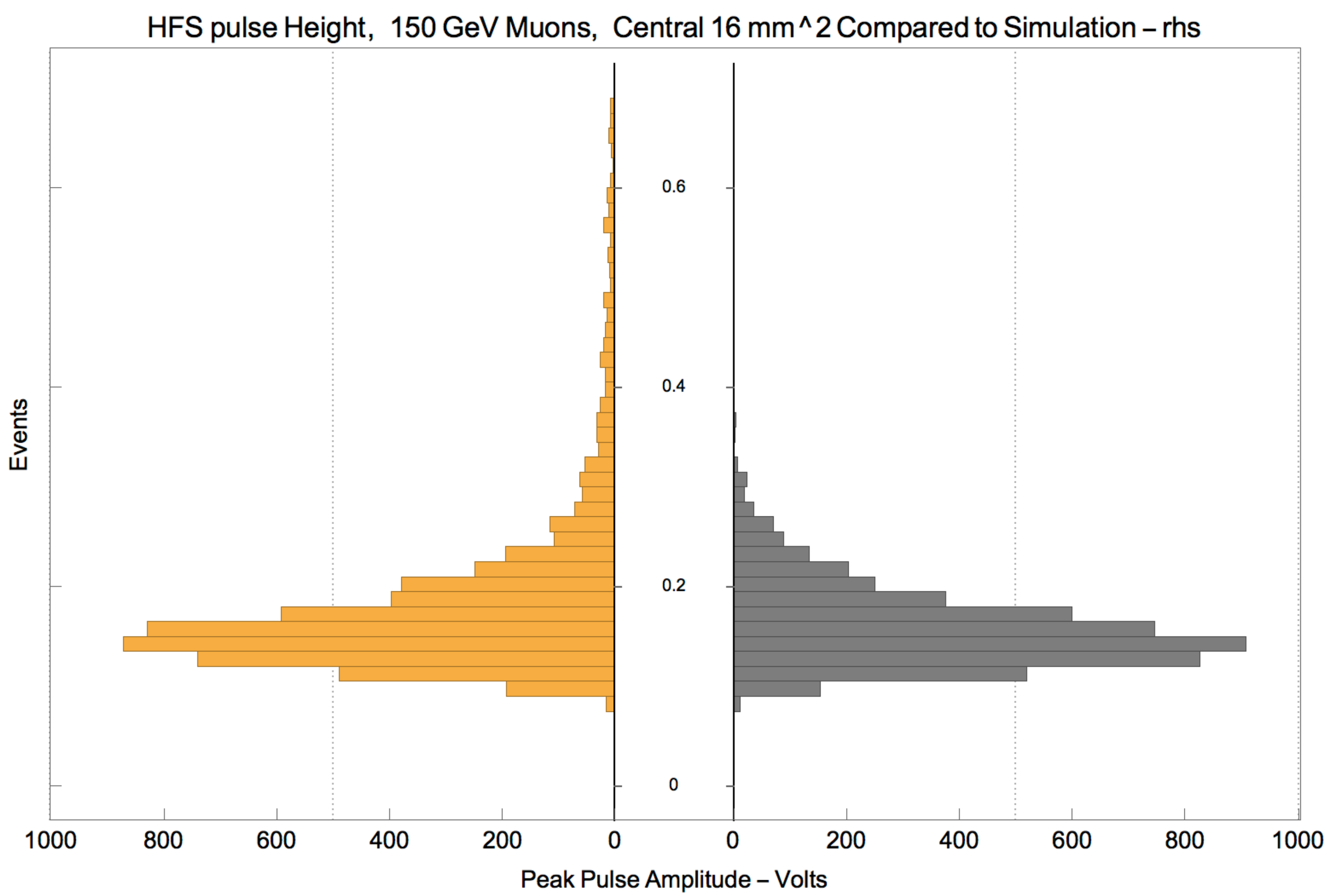
- x-scan cut by MCP fiducial
- at each pos'n->Landau
- y-scan shows small variation





Landau Modeling

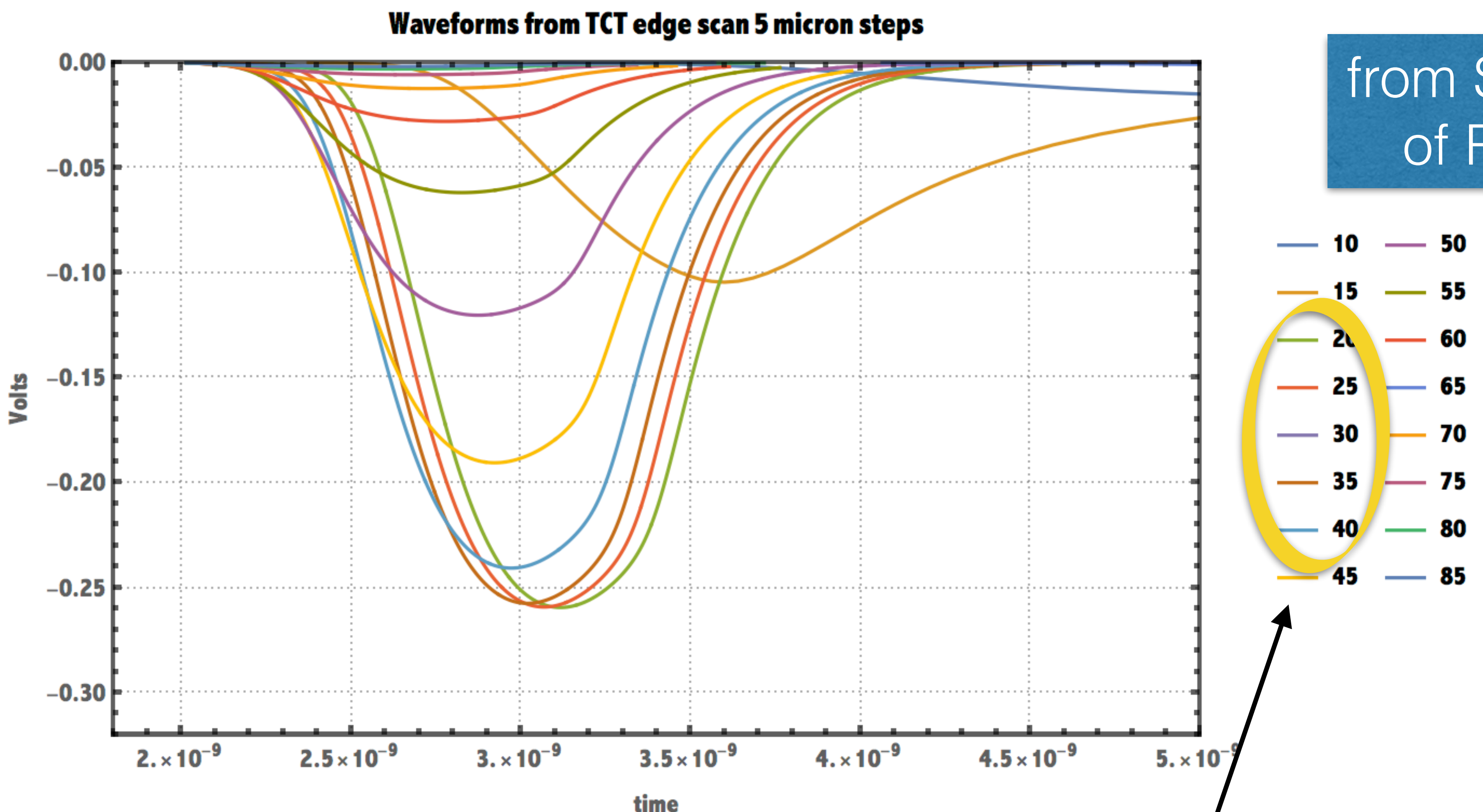
- significant activity in HFS is modeling the MIP time resolution and rad hardness using SILVACO.
- Goal (we have bi-weekly meetings of CERN SSD, manufacturer/RMD and Delhi called “Silicon sensors with Gain”) is to define optimum for both criteria- i.e. proposal for optimal doping profile
- key to the model (working with Su Dong,SLAC) is correct Landau for 5 micron slices



- simulation (rhs) built from 5 micron slices w. varying gain
- not quite there
- tail from Hofstadter - not yet in

previous analysis allows us to compare w. simulation

Contribution to time jitter from Landau/Vavilov Fluctuations

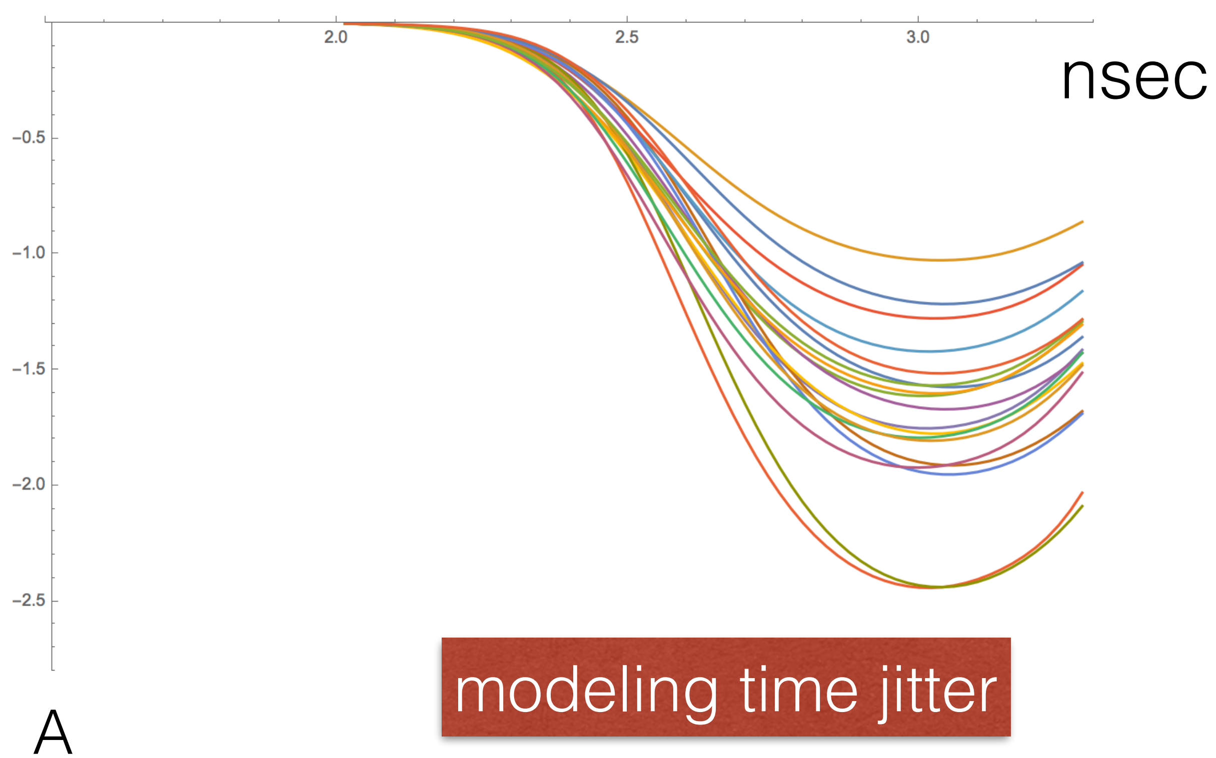


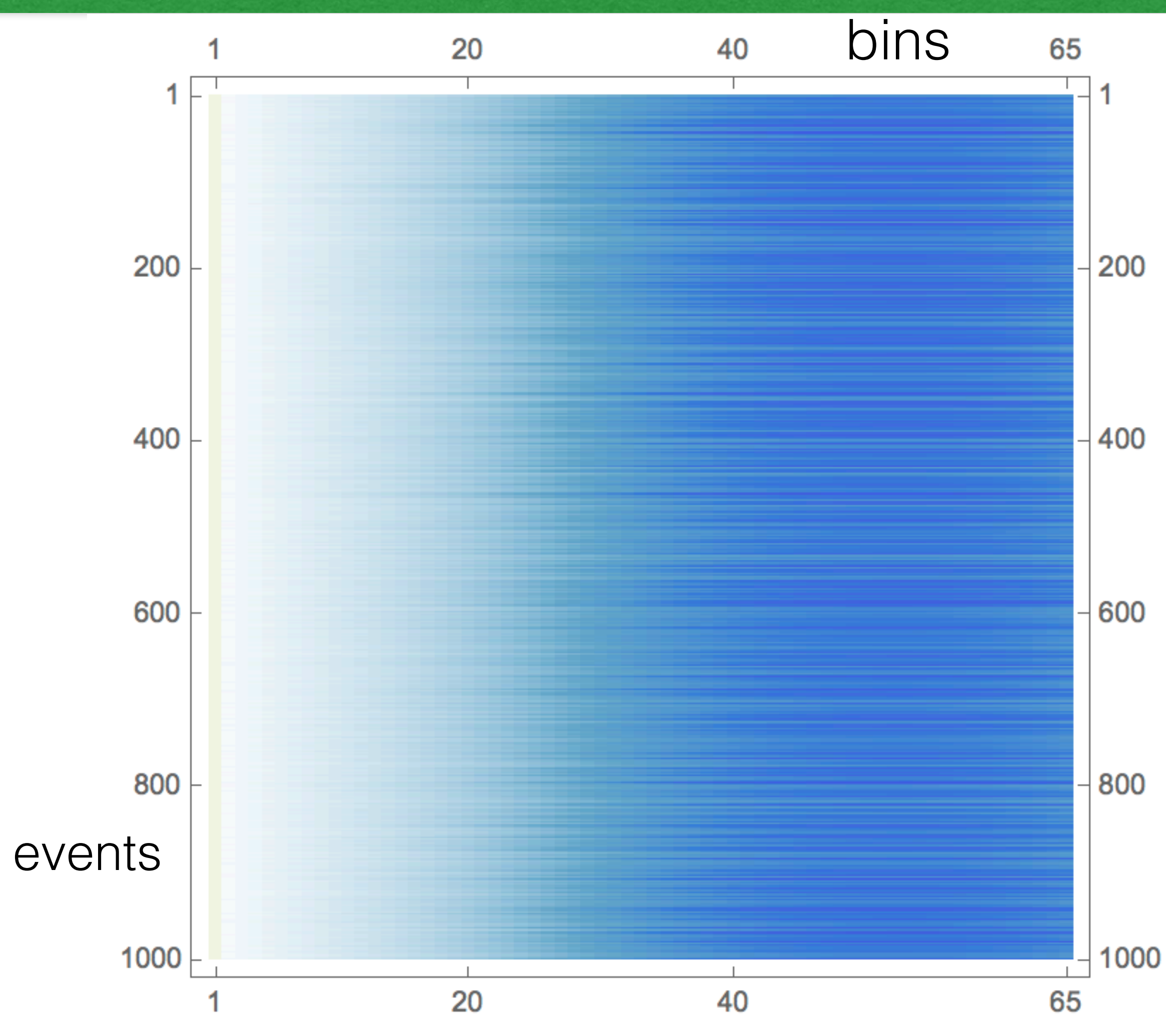
from SILVACO output of R. Dalal, Delhi

- each trace is waveform contribution from e-h pair at given depth
- note: a limited range of relevant depths(~20-40 micron) determine edge
- due to variation of Townsend multiplication (impact ionization)
- note: HFS effectively a very thin detector!
- Landau fluctuation at each depth-> MIP time jitter
- limited drift region should be an advantage over “reach-through” devices (ie LGAD)
- very similar to PICOSEC interplay between pre-amplification and diffusion
- these determine MIP ultimate time jitter

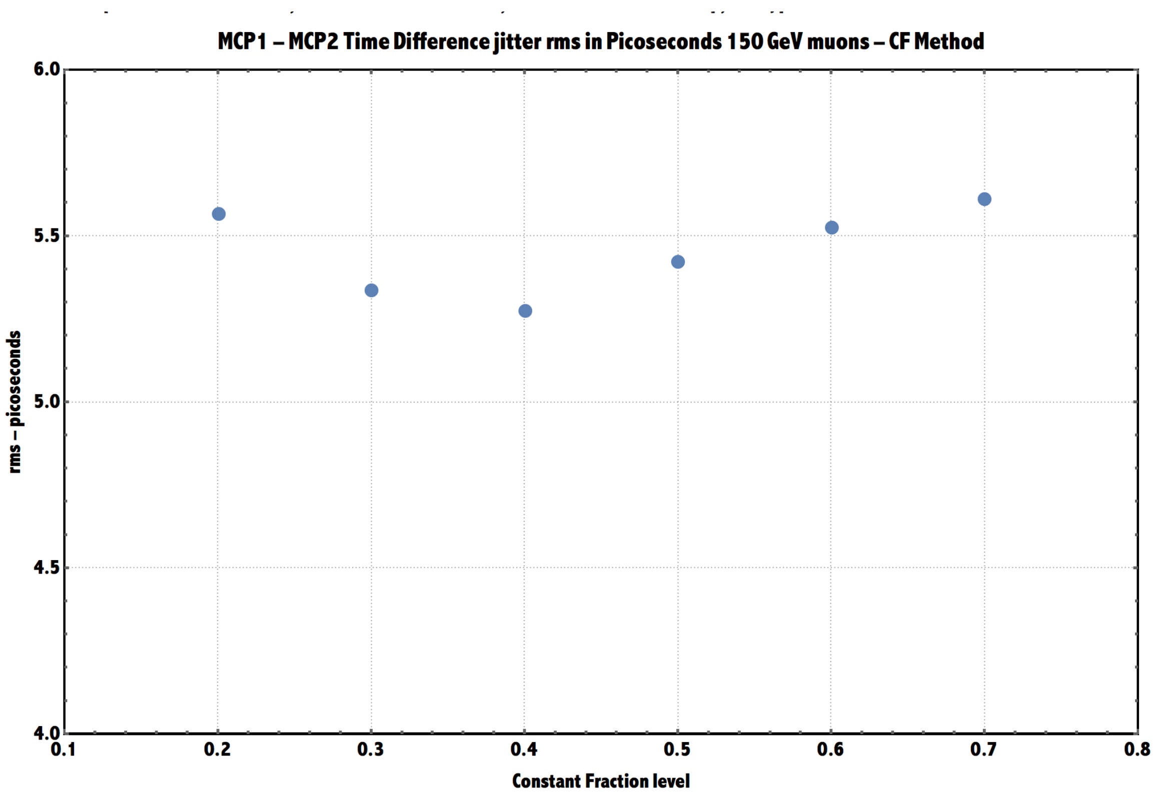
- further details of modeling time jitter in HFS see eg.M. Moll, RD50 Collab. mtg. June'16
- bottom line: depends on getting Landau correctly
- in following slides we show some first results from 2016 PICOSEC run
- caveat: still certifying data reduction/channel time jitter
- on modeling side: adding circuit/mesh to model

20 model waveforms-> Guides timing algorithm, 1000 waveforms

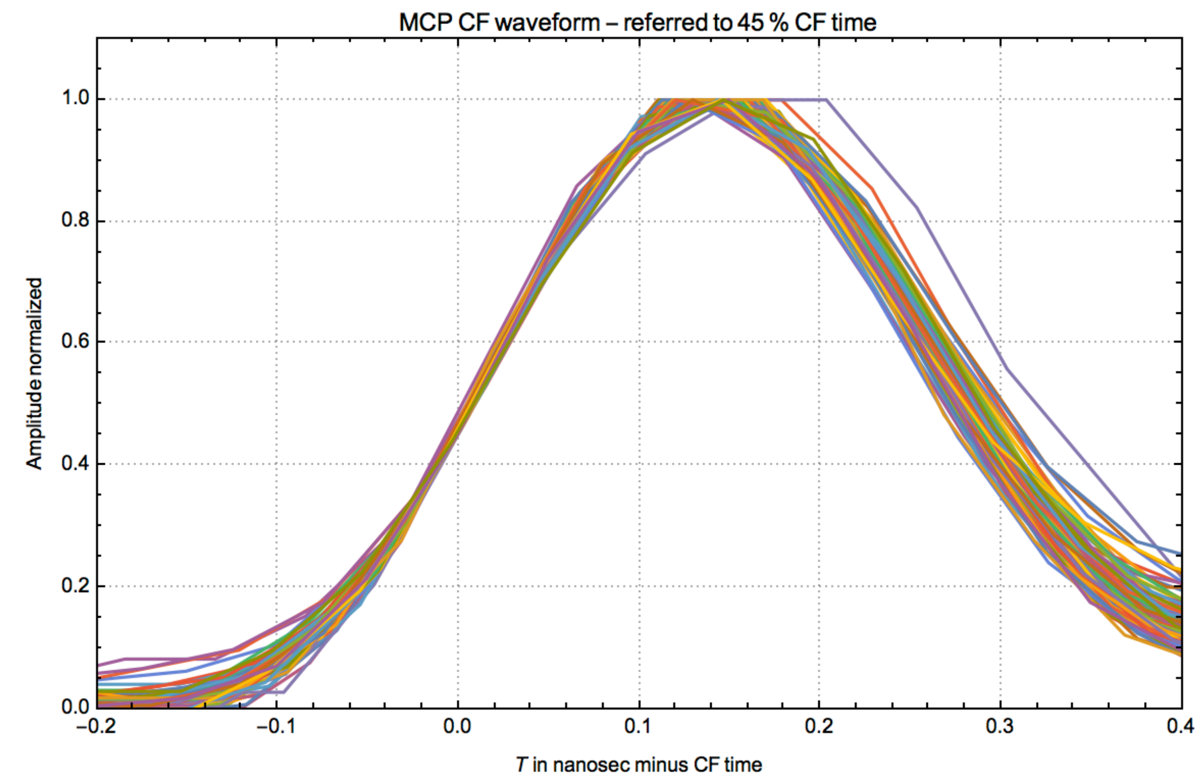




H4/PICOSEC Timing Data (t0 ref)



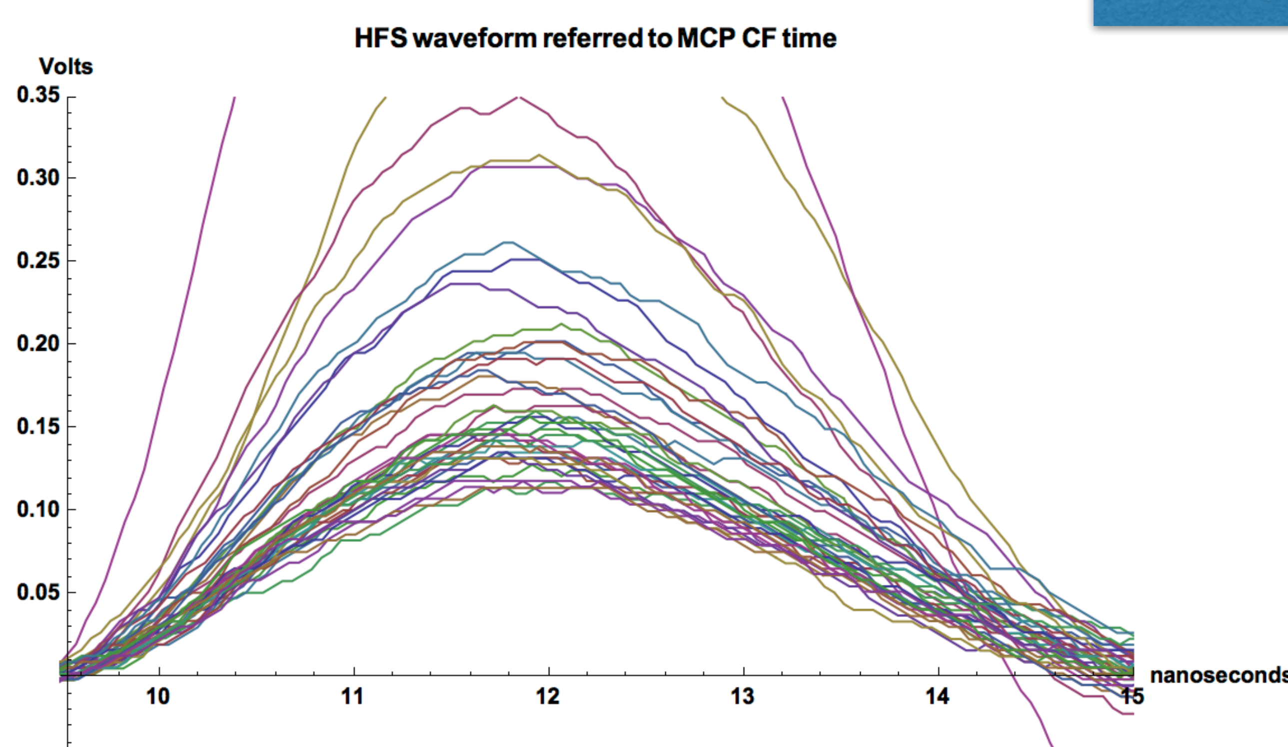
MCP t0

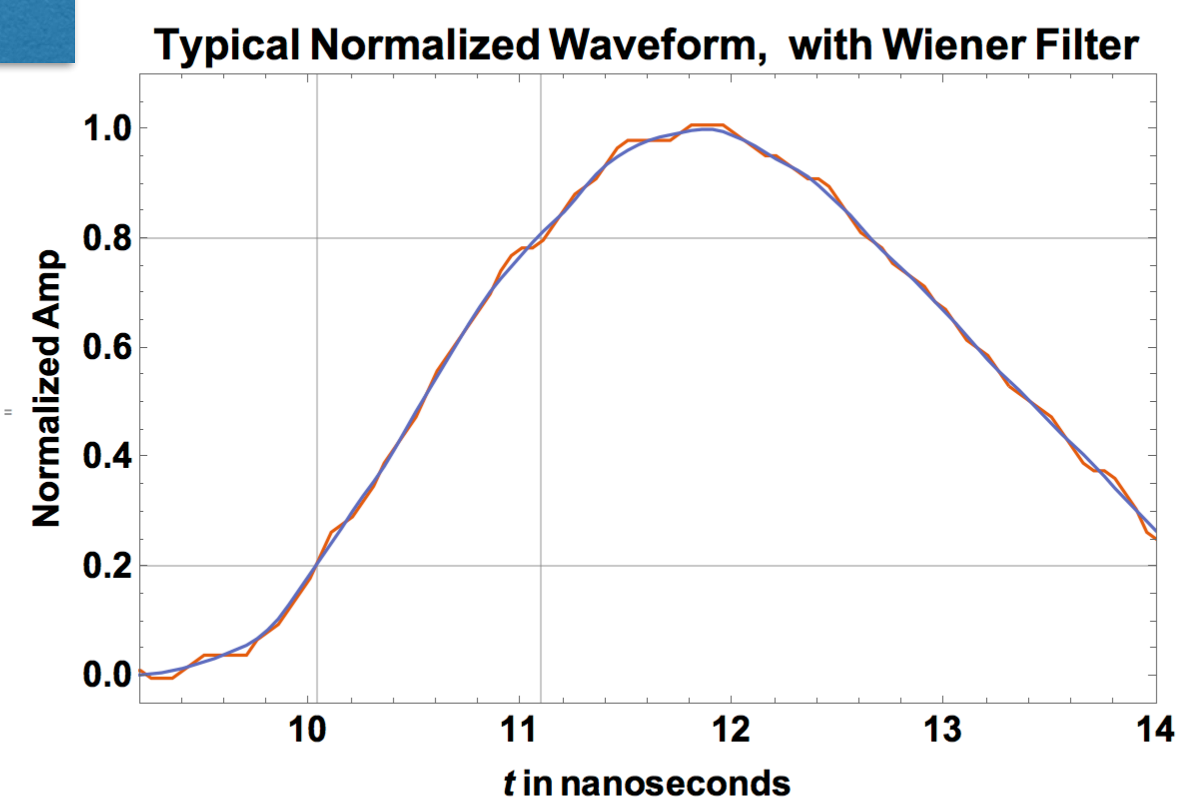


Intrinsic t0 jitter from Run 269(more tomorrow)

HFSilicon +filter

here use polynomial fit to leading edge

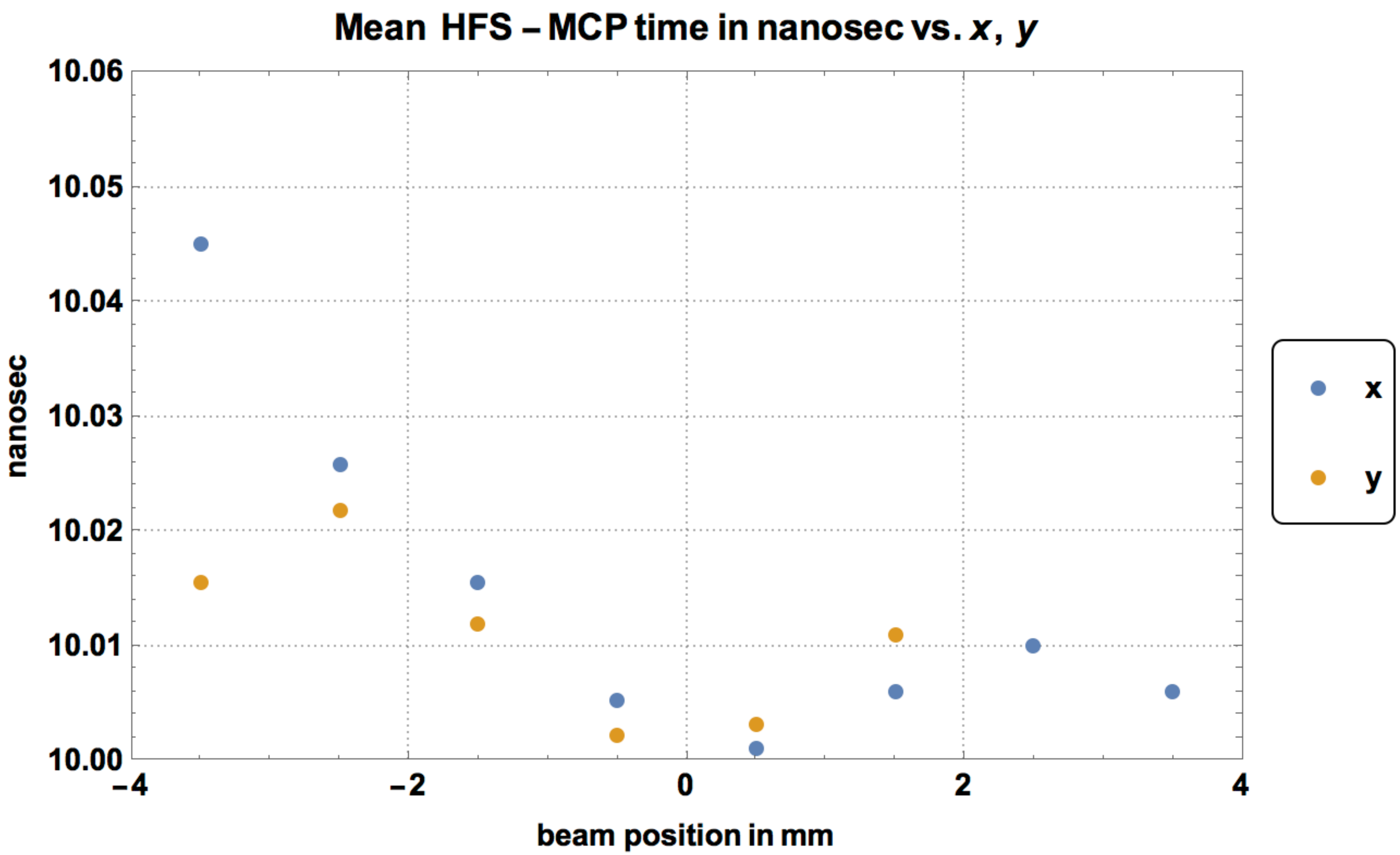




Expected time Jitter, Algorithms

- in previous figure Wiener Filter applied assuming ~3% noise level.
- T_{Rise}(20-80%)~1-1.2 nsec
- with noise(before filtering) @ <3%, clearly signals clean enough for <30 picosec time jitter
- what about jitter due to amplitude fluctuations?
  - from Landau model, not clear that CF algorithm optimal
- We try variants on Constant Fraction guided by the Landau model and our experience with MCP data

Mapping time-of-arrival over 8x8mm^2 sensor



- mostly consistent w. laser picture of <+/- 10 picosec time walk over area
- edge excursion artifact of current packaging?
- final tuning totally controlled by mesh design?
- any intrinsic non-uniformity due Si structure?

next steps

- in current climate @ CERN hard not to address relevance to HL-LHC

- we are focusing on an aggressive program to produce ~several dozen packaged sensors over next ~2 months which will allow:

    - complete characterization (including beam study as above) of pre/post irradiated sensors to ~$3*10^{15}neq/cm^2$

    - share sensors for evaluation in the wider community

HFS has benefitted in many ways from productive collaboration w. RD51 . Thanks!!