Report on PICOSEC Beam tests

-Sub 100 Picosecond timing w. MMEGAS->(sub 50->..)

Sebastian White-CERN/Princeton September 13, 2016
RD51 Collaboration Meeting Aveiro, Portugal

representing:

CEA(Saclay),CERN GDD, Princeton, Thessaloniki, USTC(Hefei)

HL-LHC role of fast sensor development: mitigate effects of pileup
-> "Hermetic Timing Layer"

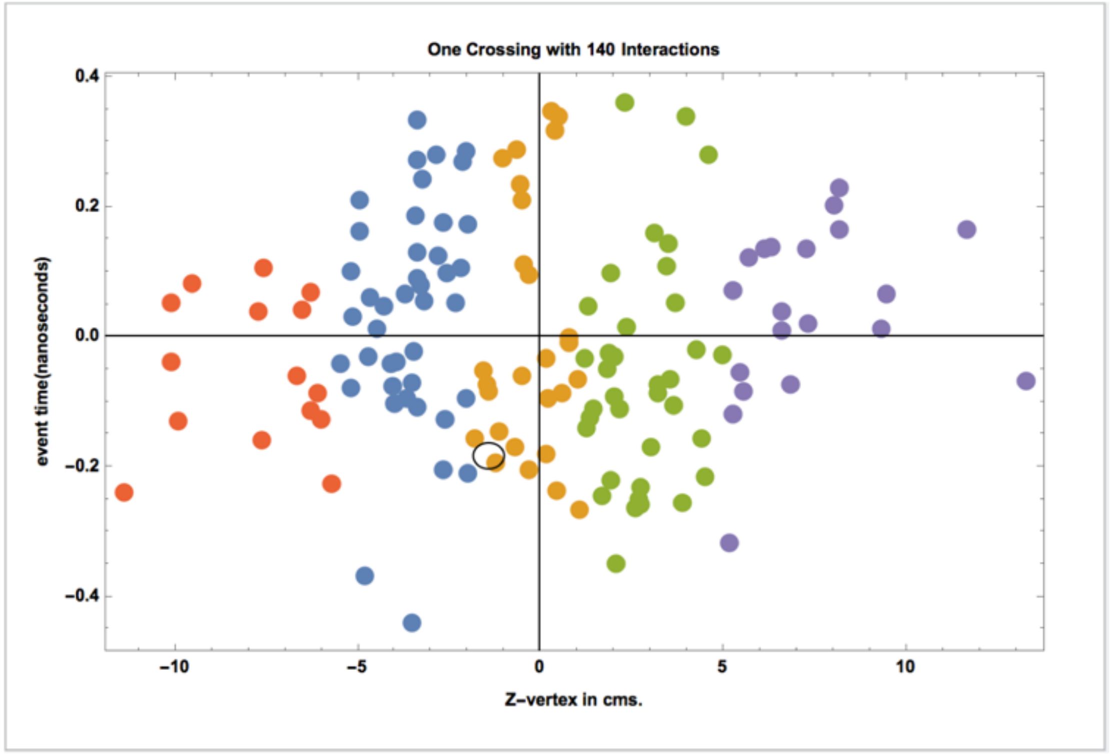
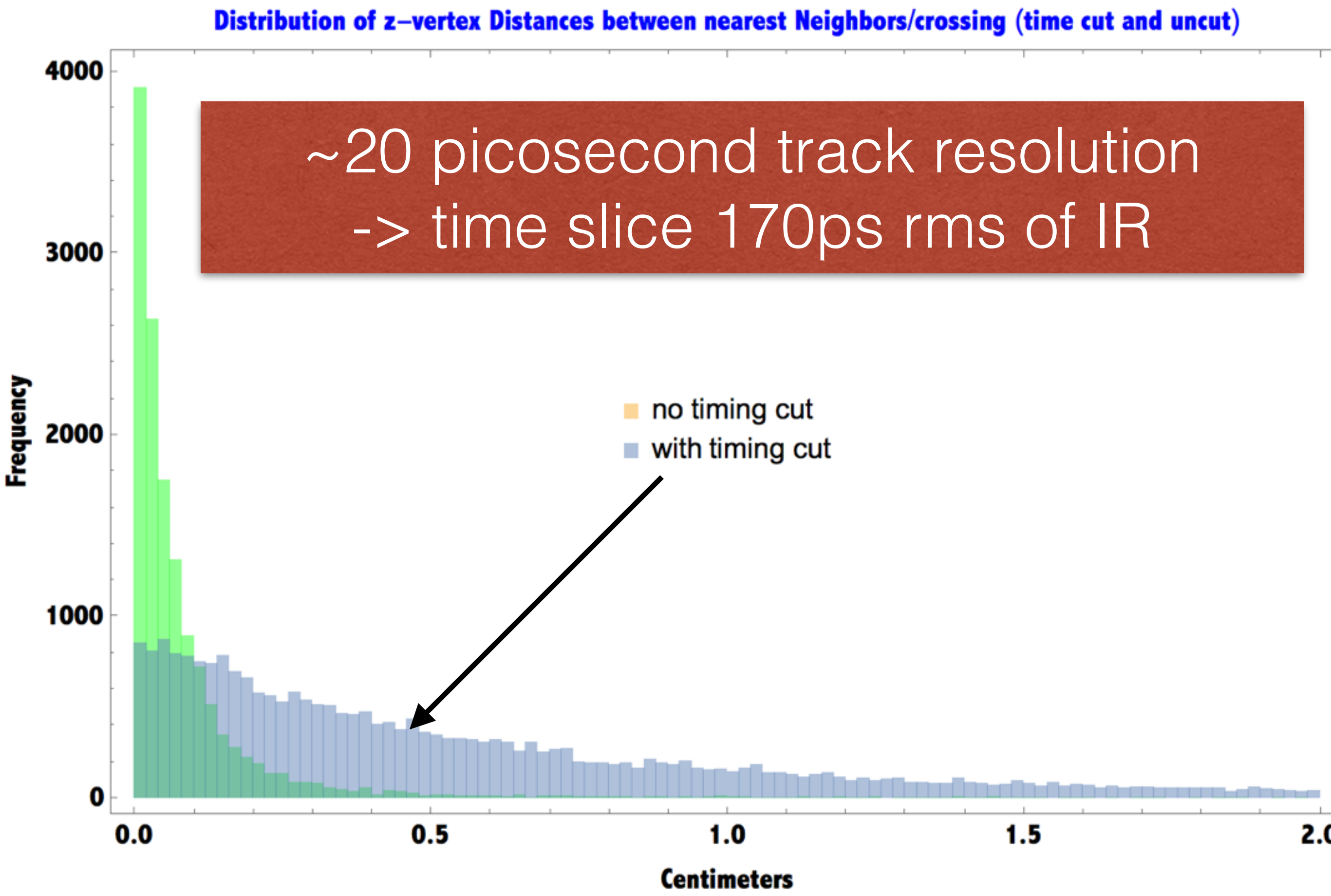


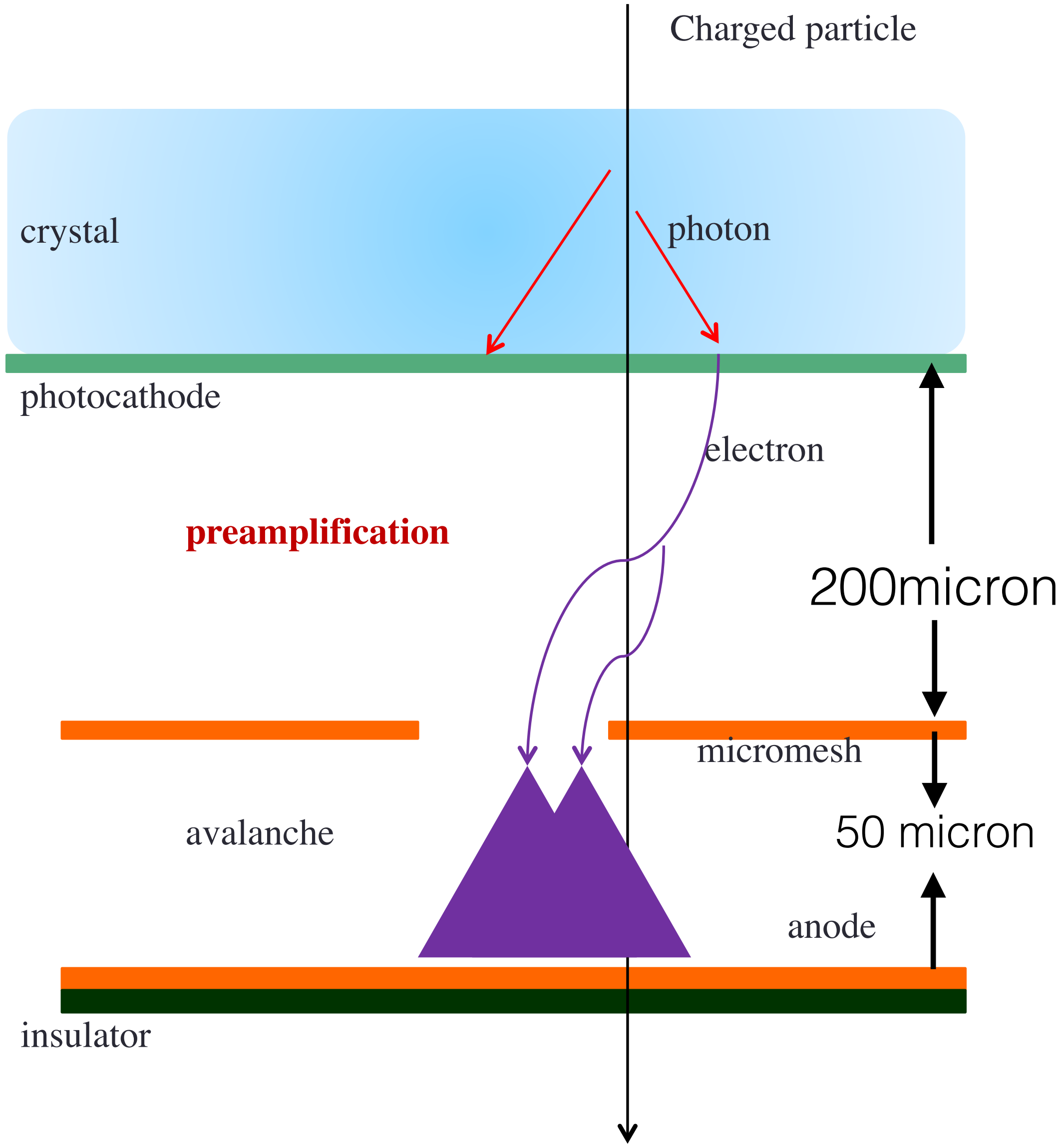
Fig. 1. Simulation of the space(z-vertex) and time distribution of interactions within a single bunch crossing in CMS at a pileup of 140 events- using LHC design book for crossing angle, emittance, etc. Typically events are distributed with an rms-in time- of 170 picoseconds, independent of vertex position.



~20 picosecond track resolution
-> time slice 170ps rms of IR

technologies tested in H4 this summer

MPGD:”PICOSEC”-topic today

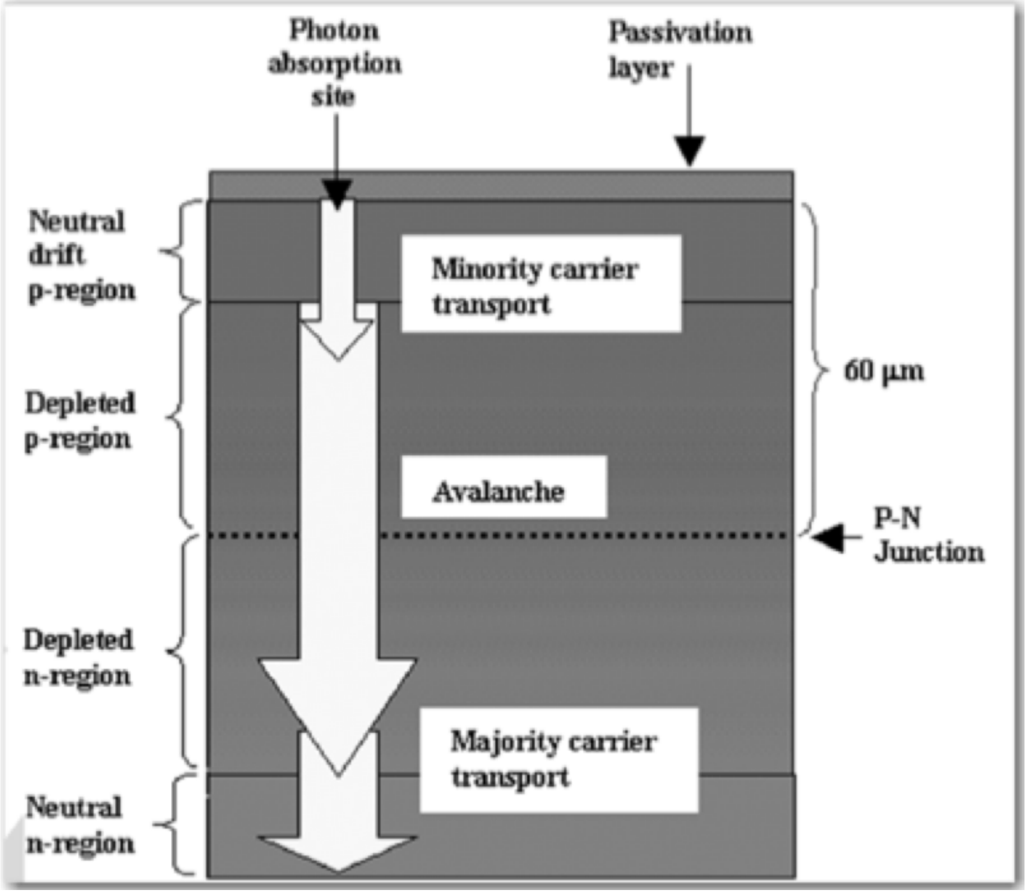


eliminates effect of stochastic energy deposition(Landau)

diffusion limit to time jitter (Gas choice)

robustness of photocathode (or secondary emitter)

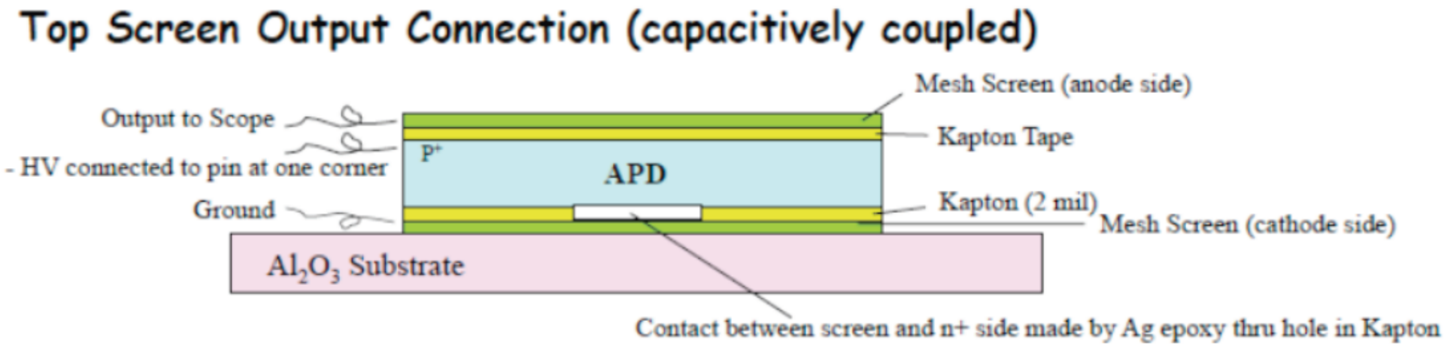
DD-AD(HyperFastSilicon)



front end and interconnects

rad hardness (so far $0.9\ 10^{14}$p)

optimize structure/bias/algorithm for Landau



“fast timing Landscape”

- see recent review by Jerry Va’vra

https://indico.cern.ch/event/393078/contributions/2241767/attachments/1333660/2005259/2-Vavra_invited_talk_Bled_2016.pdf

- very few technologies for hi rate, large area, < 50 picosecond, MIP sensitive layer
- much “enabling” progress related to this objective
  - new (hi BW, low noise, R_{input}<50 Ohm) FEE->ie our ASIC development w. Mitch Newcomer of Si-Ge transimpedence amp in IBM technology->mitigate large C_{Det} from large Area
  - Development of fast Waveform digitizers &TDCs (PSI- DRS4, Saclay/Orsay “SAMPIC”, Chicago/ Hawaii.., CERN HPTDC)
- many shortcuts to above objective-> get low δt by multiple sampling
  - TOTEM Diamond sensors (50 picosecond w. 4 layers)
  - AFP Quartz rods +SiPM (4 layer proposal)
  - CMS W-Si (multiple layers in shower, conventional sensors)+ other CMS shower demo
  - ATLAS HGTC w. 3 layer low gain Si…………

landscape (continued)

- IMHO these shortcuts evade issue of costly effective clock distribution, proliferation of hi cost/channel in a high channel count solution

- IMHO it is high time for our field to develop sensors for hi-rate MIP timing w. MCP-like performance, low cost, rugged, production at scale

- very hard to find an org in HEP w. sufficient imagination to support this objective

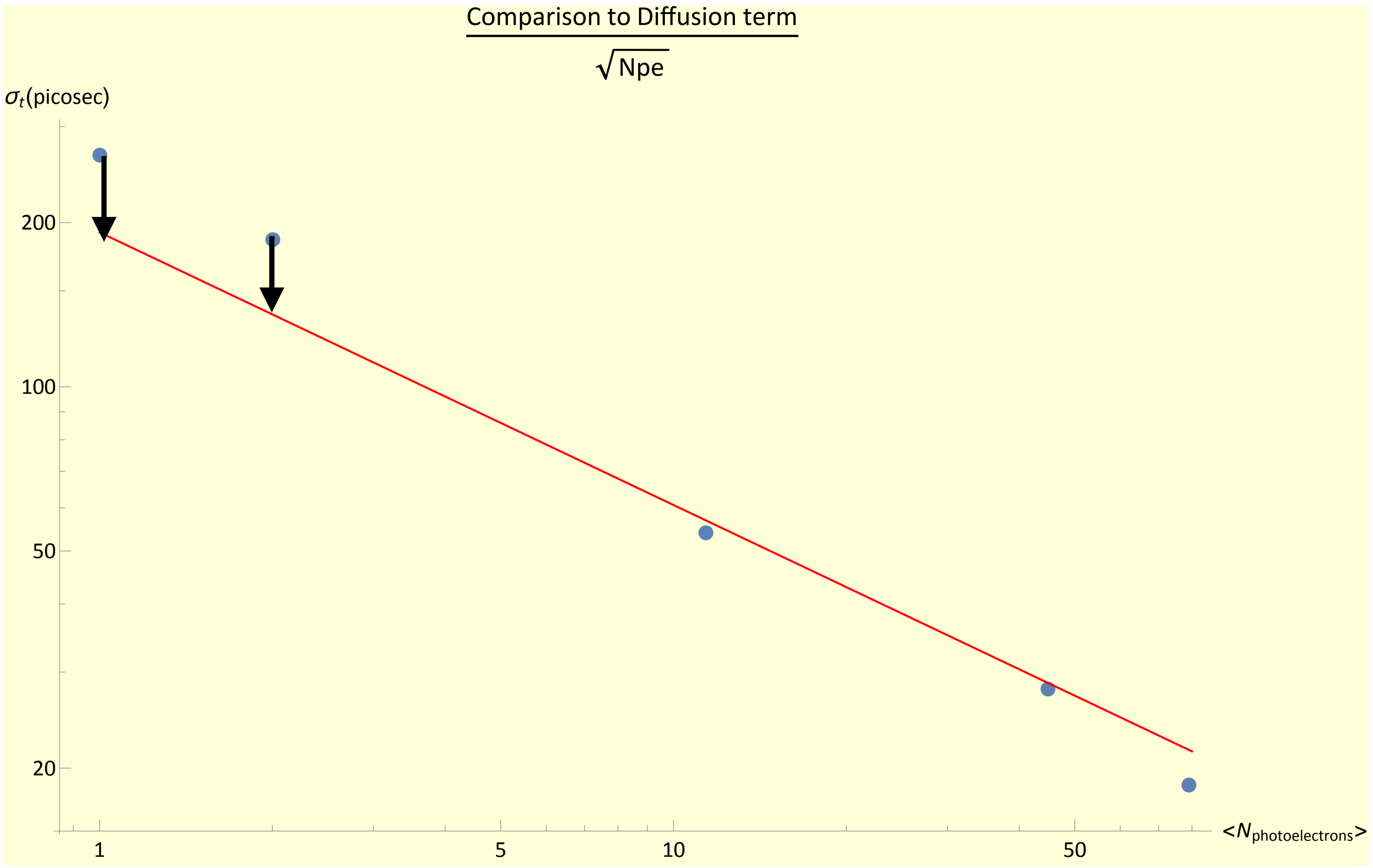
- RD51 took up the challenge w. PICOSEC

  - =>"common fund" project approved in 2015

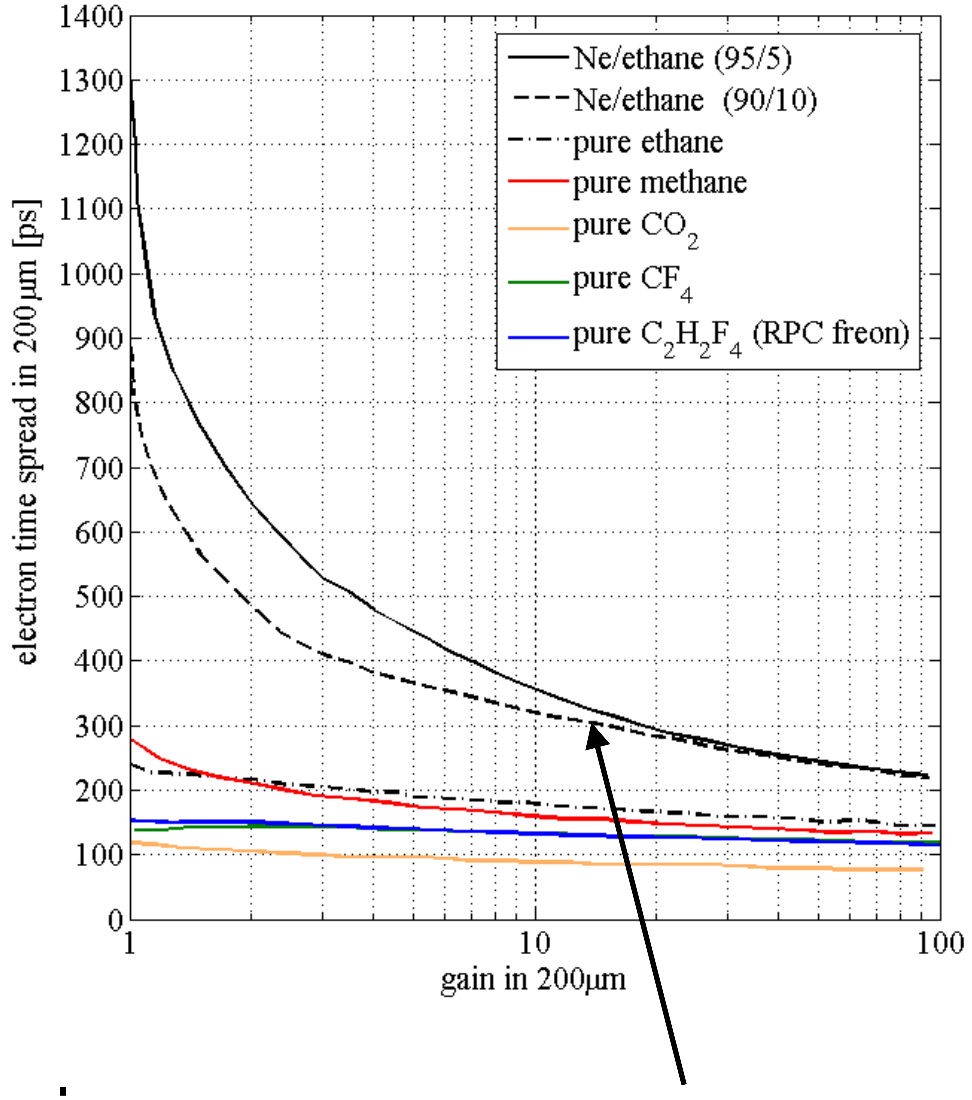
  - similar interest for optimal fast timing/rad hard Si w. internal gain in CERN SSD

PICOSEC test beam data and limits to *d*t -> fundamental limit from detector physics

2015 proof of Principle
laser, NeEthane



but clearly there could be
better choices:

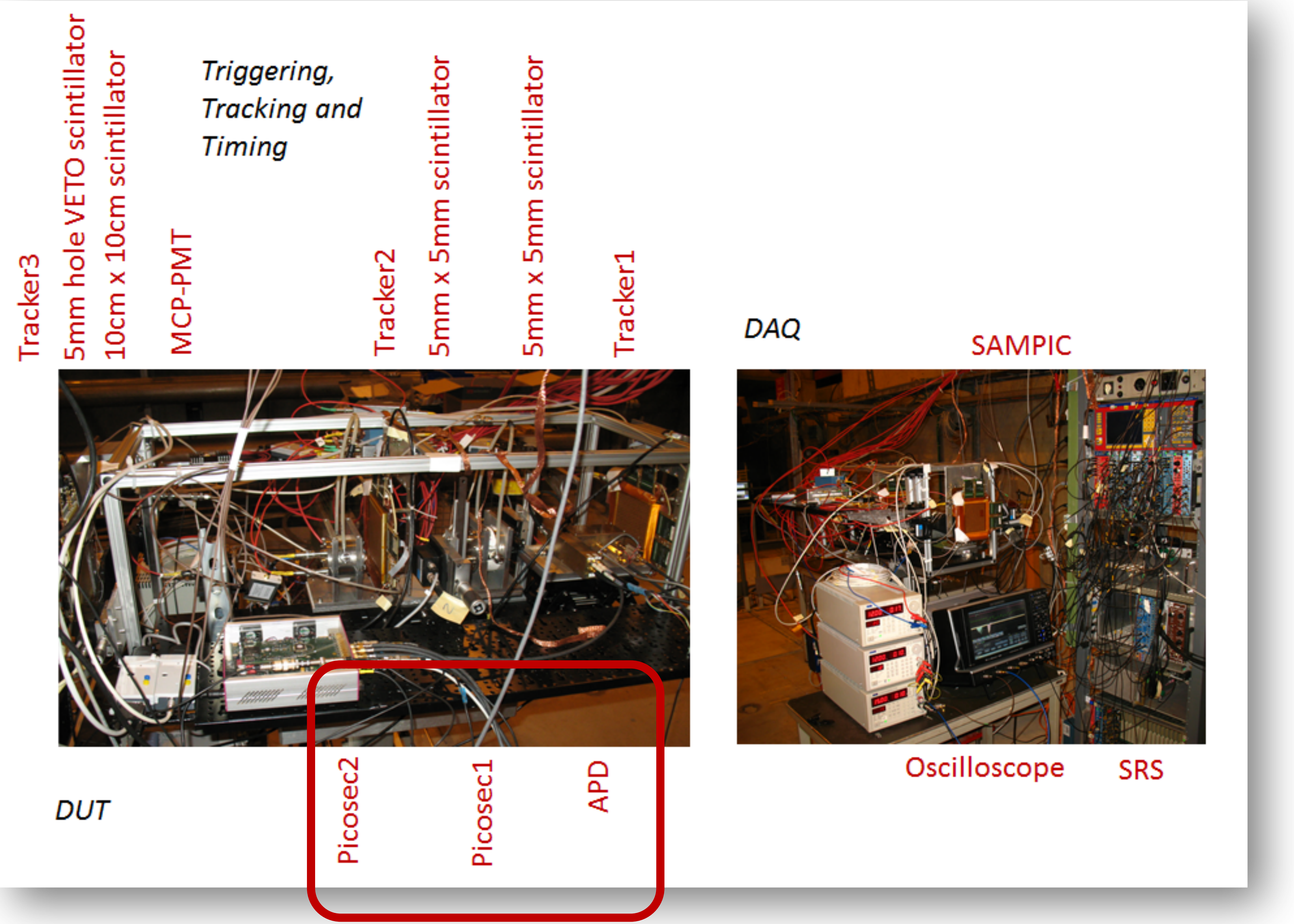


2015 operating point

A factor of 3 in Single electron
time spread=> few photoelectron regime

=>more photoelectrons, less longitudinal diffusion/v_D

PICOSEC(+HFS+MCP) tested in RD51 testbeam(H4)

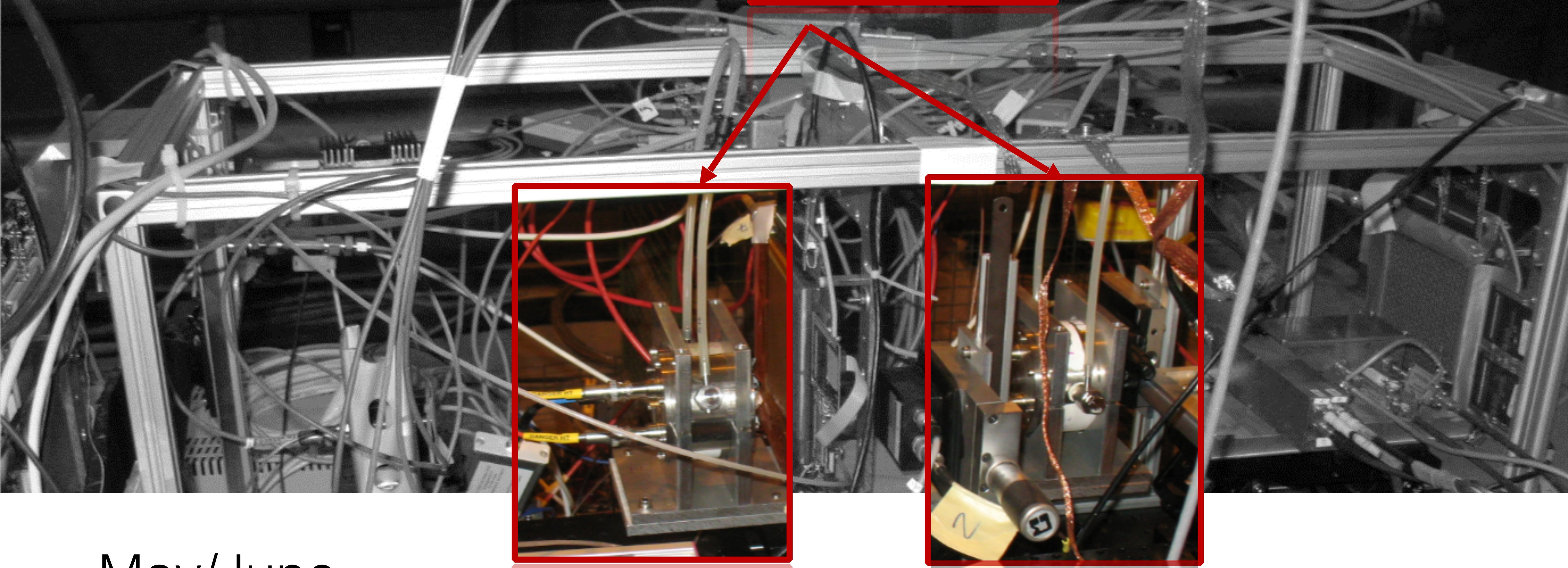


Photocathodes (from Saclay):

1. CsI
2. Al

Radiator: MgF2 (3mm for CsI, 5m for Al)

Remarkable work done in Saclay for the photocathodes evaporation (Mariam Kebbiri)



May/June

Measurements Performed:

1. CsI and Ne-CF4-C2H6 80-10-10 (Sealed)
2. CsI and Al in Ne-CH4 95-5 (Sealed)
3. CsI in Pure CO2 (Sealed)
4. Al in Pure CO2 (Flushed)

Thanks to the Saclay colleagues Philippe Legou and Olivier Maillard that made a great job on improving the internal cabling, signal routing and grounding

Thanks to the COMPASS colleagues (Yann Bedfer et al.) for providing us some help with the gas

- very professional setup with months of preparation
- several other RD51 technologies (besides PICOSEC) tested

limits to δt (continued)

- <u>traditionally</u> limit to dt has form:

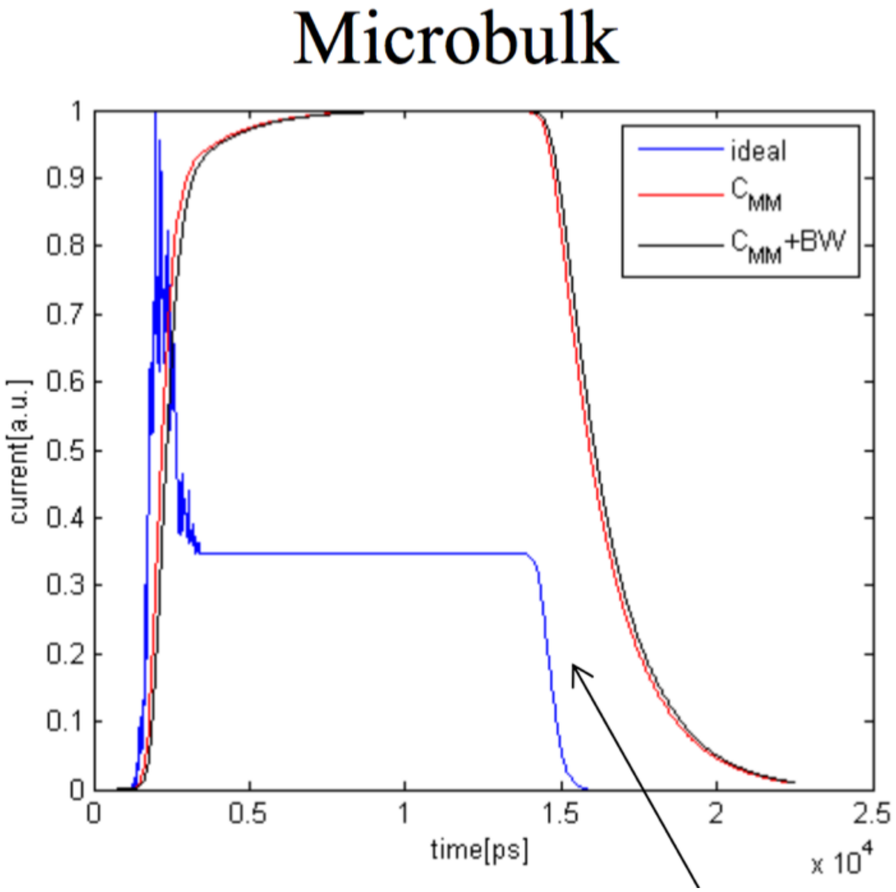
$\delta t \sim t_{Rise}/SNR$

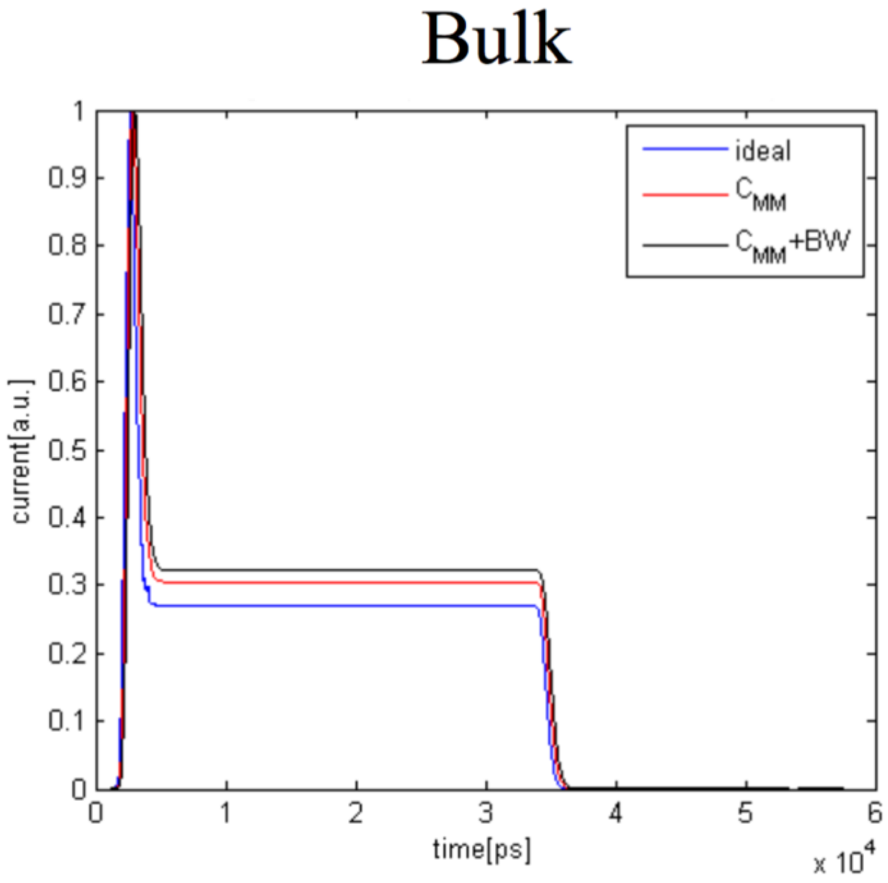
in bad old days limited by:

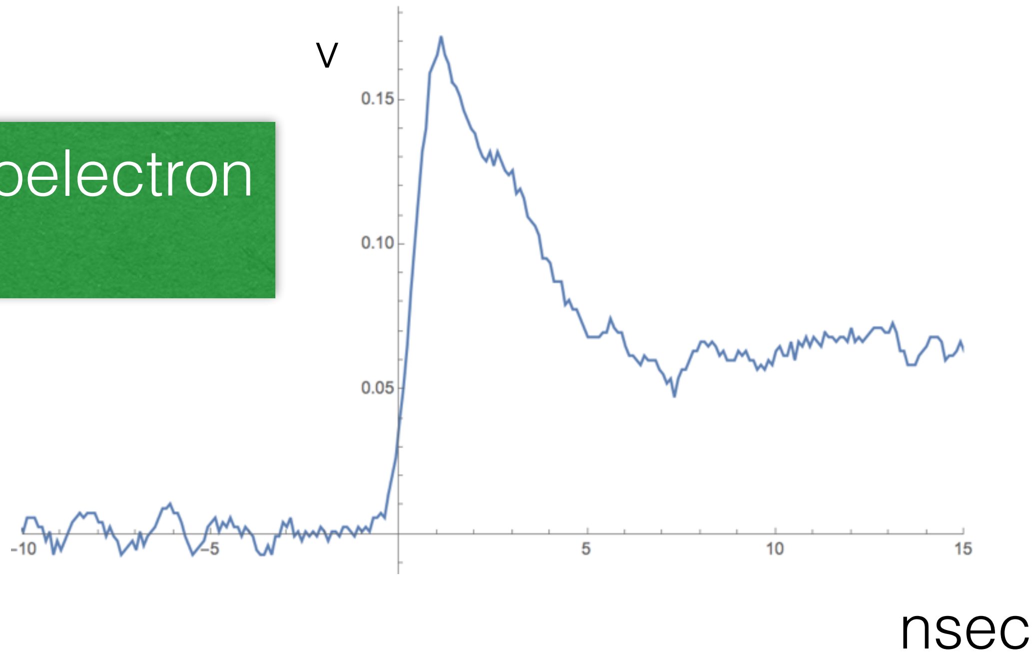
- eg. Scintillator decay time or electronics slew rate
- input noise of FEE and C_{Det}
- <u>now:</u> using Hi-BW(>500 MHz) and fast micro pattern detectors->reach ultimate limit from detector physics (diffusion in PICOSEC and Landau/Vavilov in HFSi)

but first address traditional issues..

- in August in H4 we used 50 micron “Bulk” mesh and fine mesh amplification structures-> lower capacitance







actual single photoelectron response

- Cividec C-4 Amplifier
- nevertheless SNR (ie sufficient G)

is limiting our gas choice

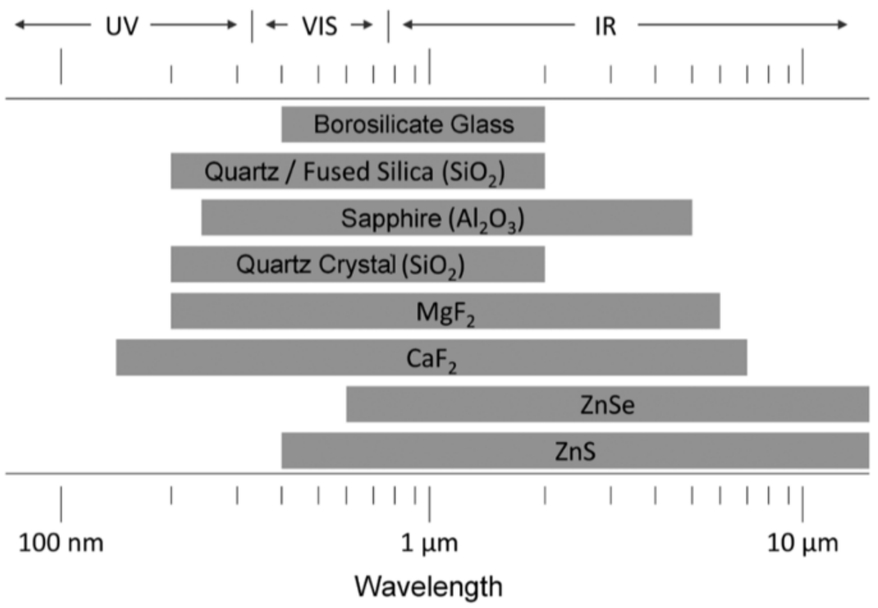
comparison of technologies tested in August

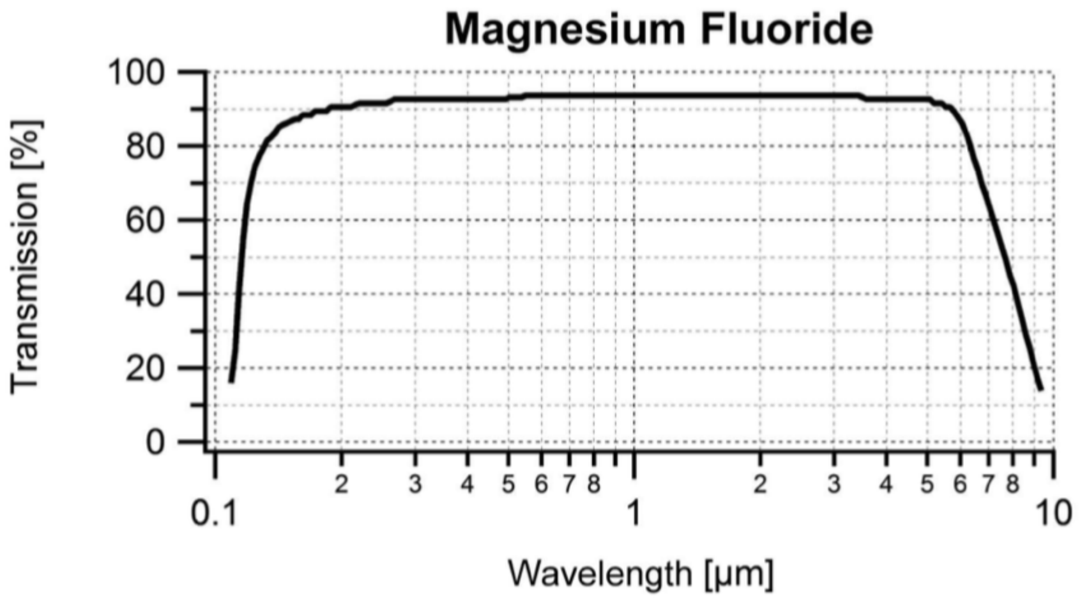
	Picosec	**HyperFast Silicon**	**MicroChannel Plate PMT R3809U-50/52**
t_{Rise}(nsec)	~1.0	~1.2	0.2
SNR	~45	~60	200

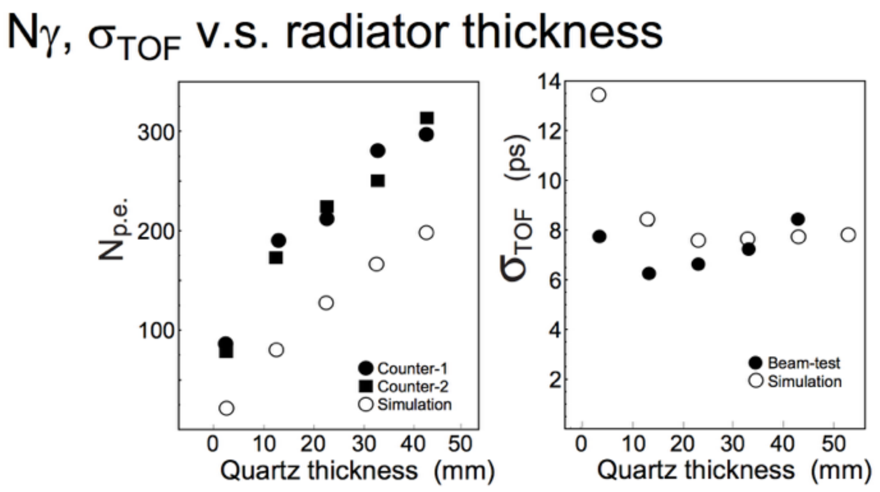
nb: SNR ~100 implies care w. 8 bit scopes, digital noise
-> advantage of i.e. SAMPIC 11 bit digitizer

Photoelectron yield: radiator

- we tested MgF2 windows (2,3,5 mm)

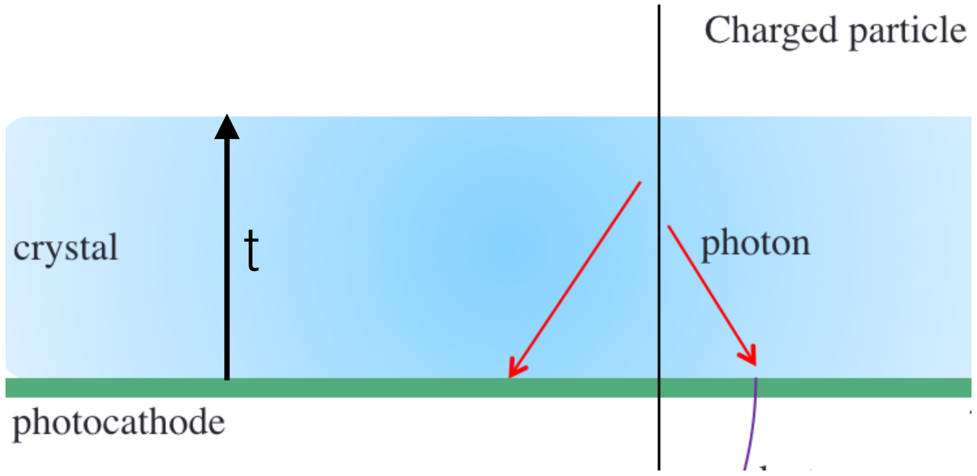






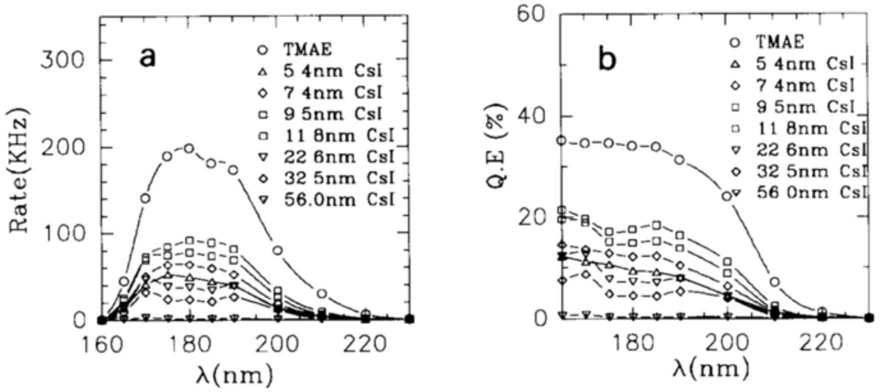
-> minimal time jitter at 10-20mm.
pileup considerations->thinner window

Inami et al,Quartz/MCP

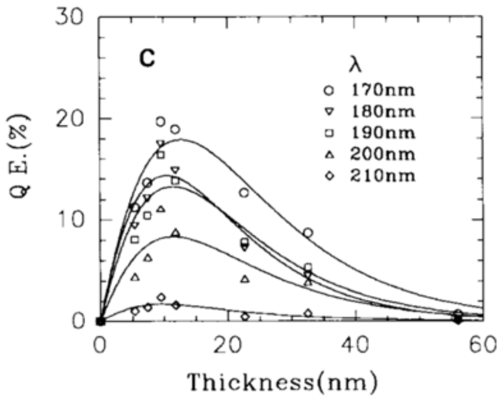


Cherenkov cone Diameter~2t

photoelectron yield: transparent photocathode



Lu, McDonald (Princeton NIM '94)

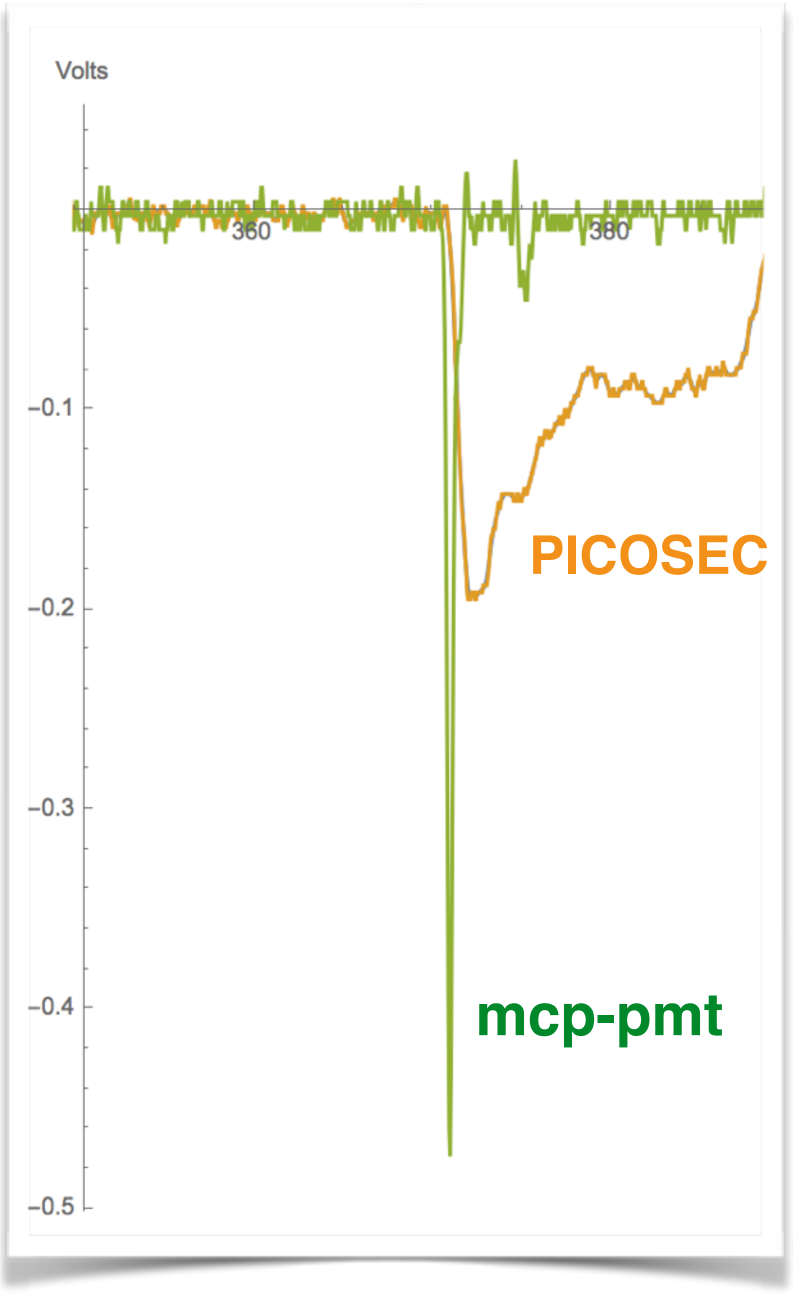


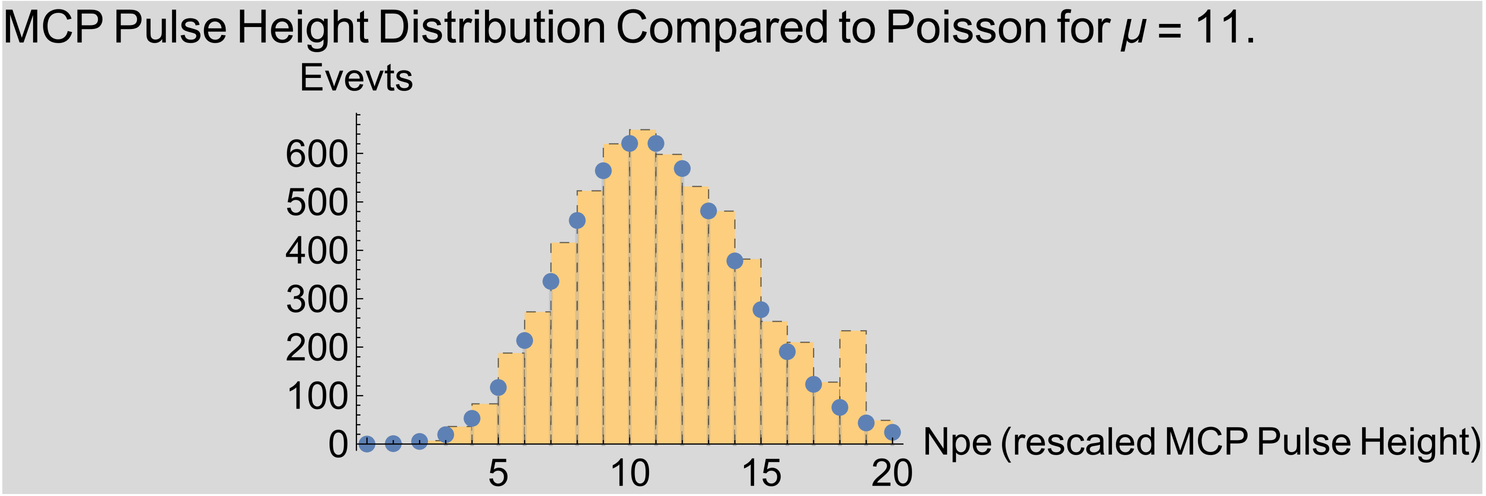
- issues are CsI thickness,substrate
- also search for more rugged than CsI
- ->metallic, Diamond…..

<u>pc's prepared for August TB run:</u>

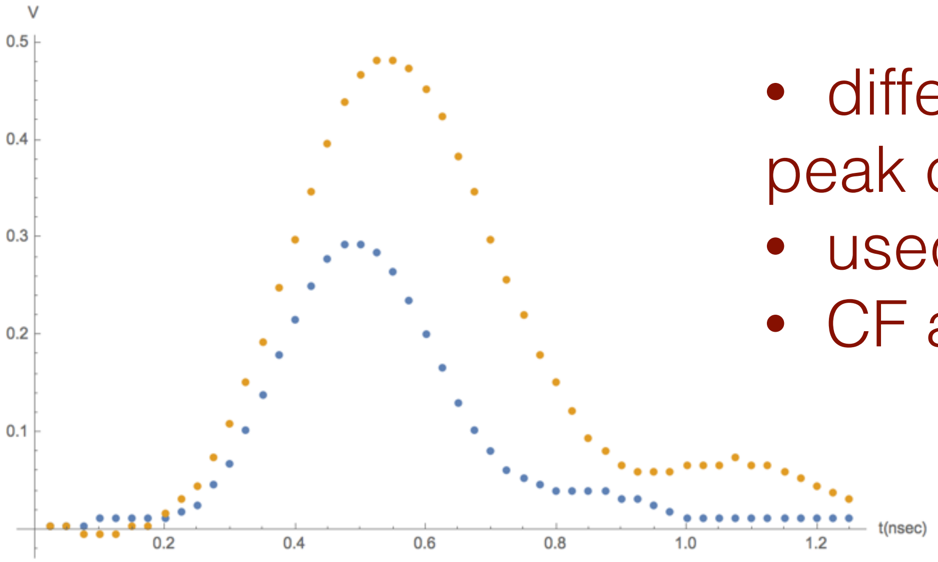
1)from Saclay(IRFU)- 18nm CsI,Al substrate
2)from Saclay (Pomorski et al) 2 Diamond windows (w,w/o Cr substrate) on 5 mm MgF2
3) from CERN EP (Miranda van Stenis et al) various CsI (11,18,25 nm) on Cr substrate
4)from Hamamatsu 2 CsI on 3 mm MgF2 -in Sept
5) not tested in August- various metallic options other than Cr (Al..)

first look at the data:MCP-PMT(t0)





good pe yield from PMT window Cherenkov photons (cp Inami et al simulation)



2 MCP-PMTs@40GSa/s

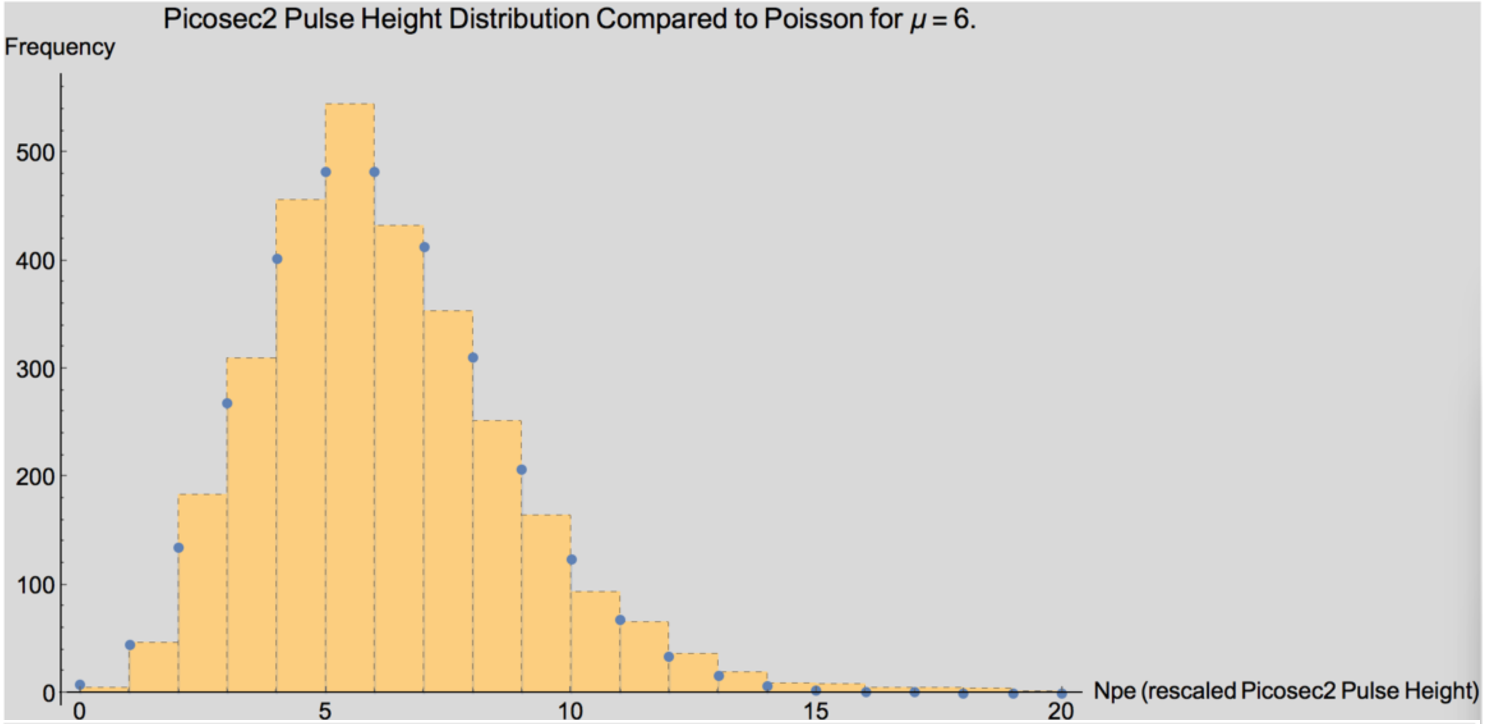
- difference time resolution from peak channel->~21 picos rms
- used in current analysis
- CF also used elsewhere

first look at the data:PICOSEC

for plots below we use “Compass gas”ie Ne-C2H6-CF4 with gas flow.
Other tests included CF4+quencher, etc.

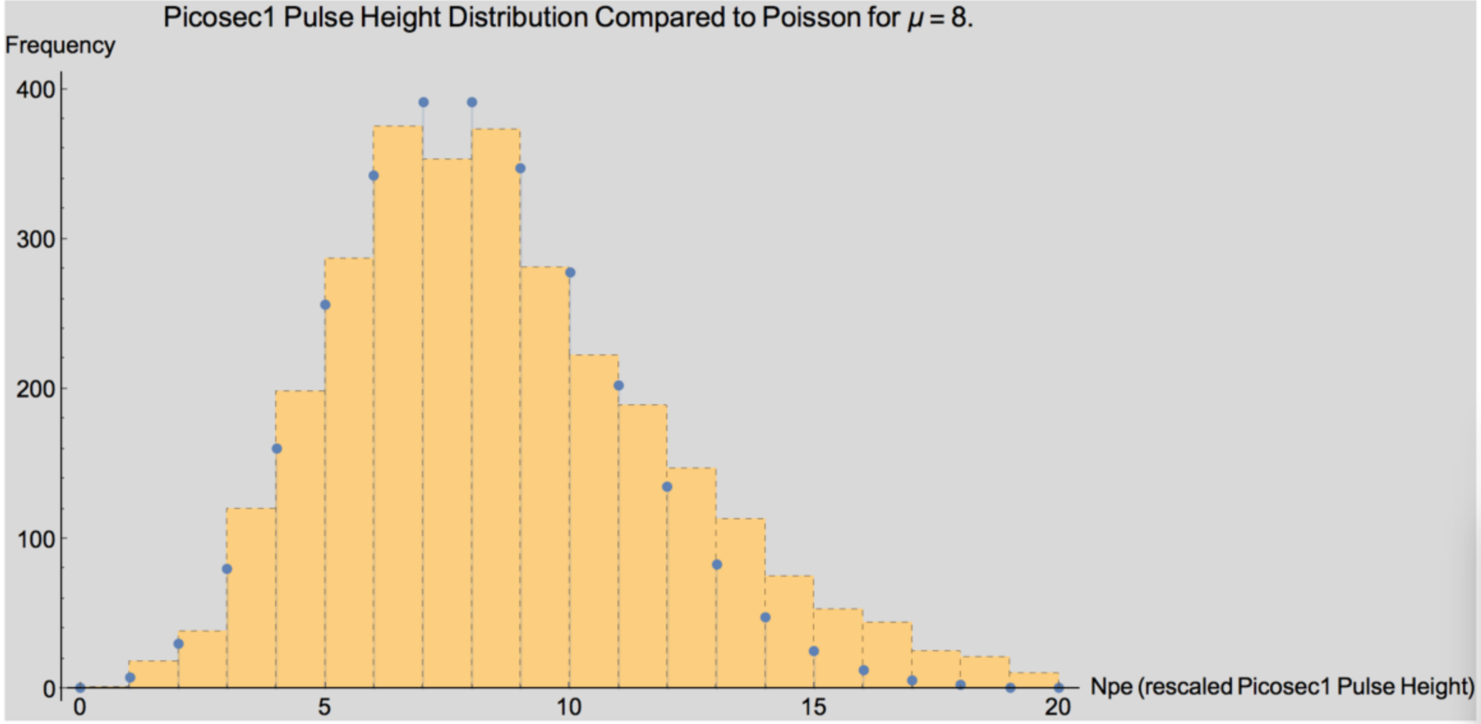
photoelectron yield to be calibrated using Single pe data from “candle”

but initial estimate from photo statistics encouraging:



Picosec2 Pulse Height Distribution Compared to Poisson for $\mu = 6$.

2mm MgF2 window,
18nm CsI

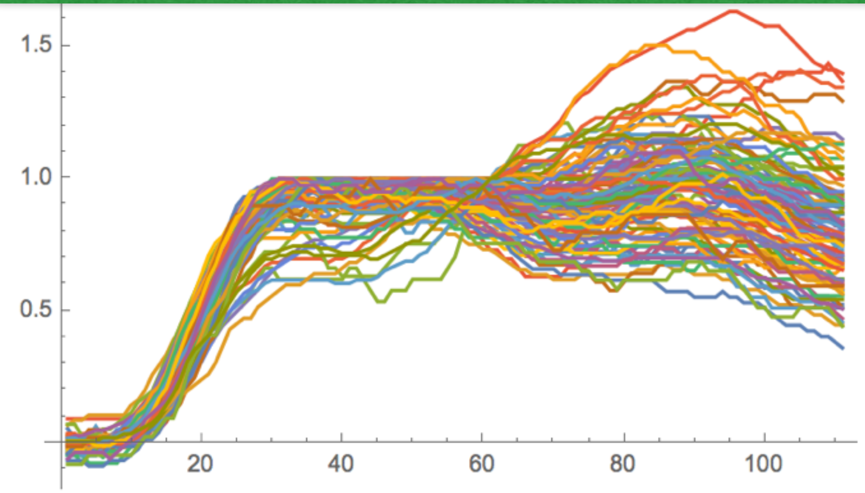


Picosec1 Pulse Height Distribution Compared to Poisson for $\mu = 8$.

3mm MgF2 window,
11nm CsI

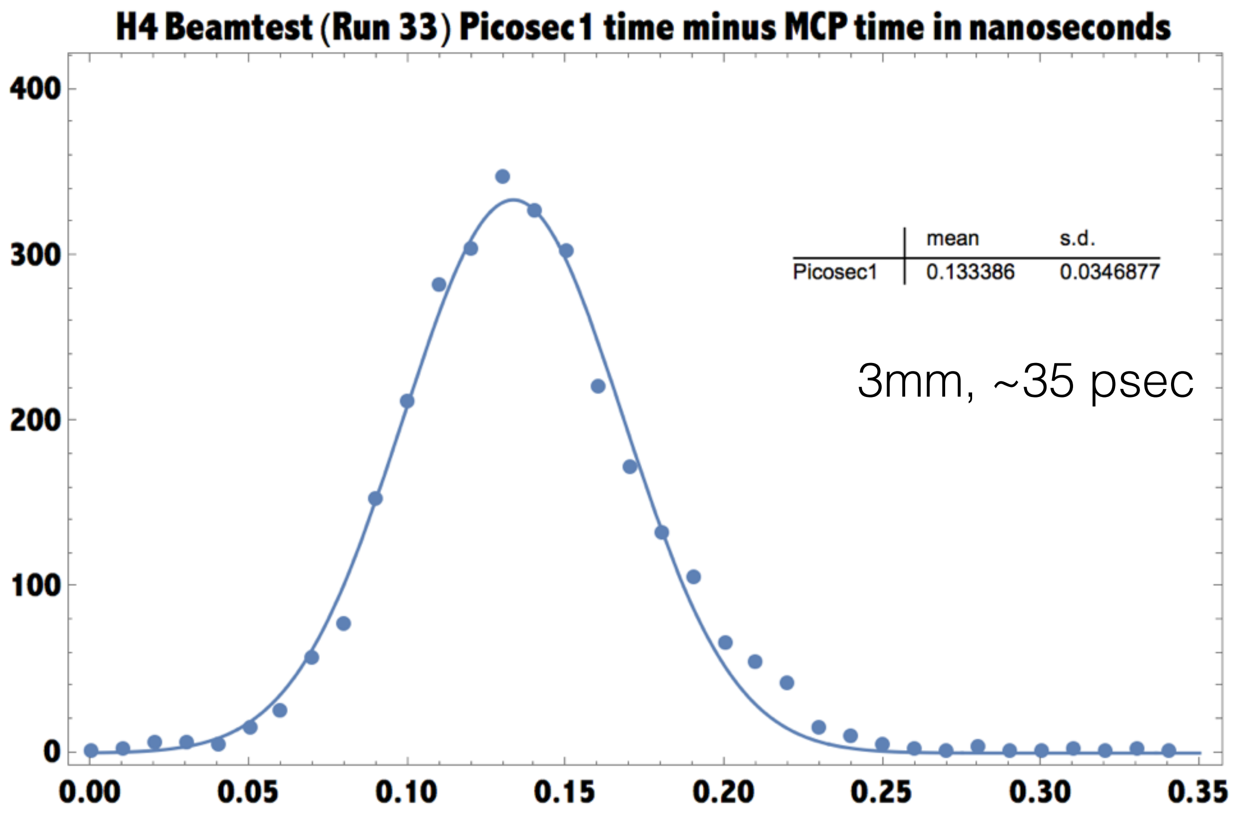
select fast component of PICOSEC for modified Constant Fraction:

use early peak to derive local slope

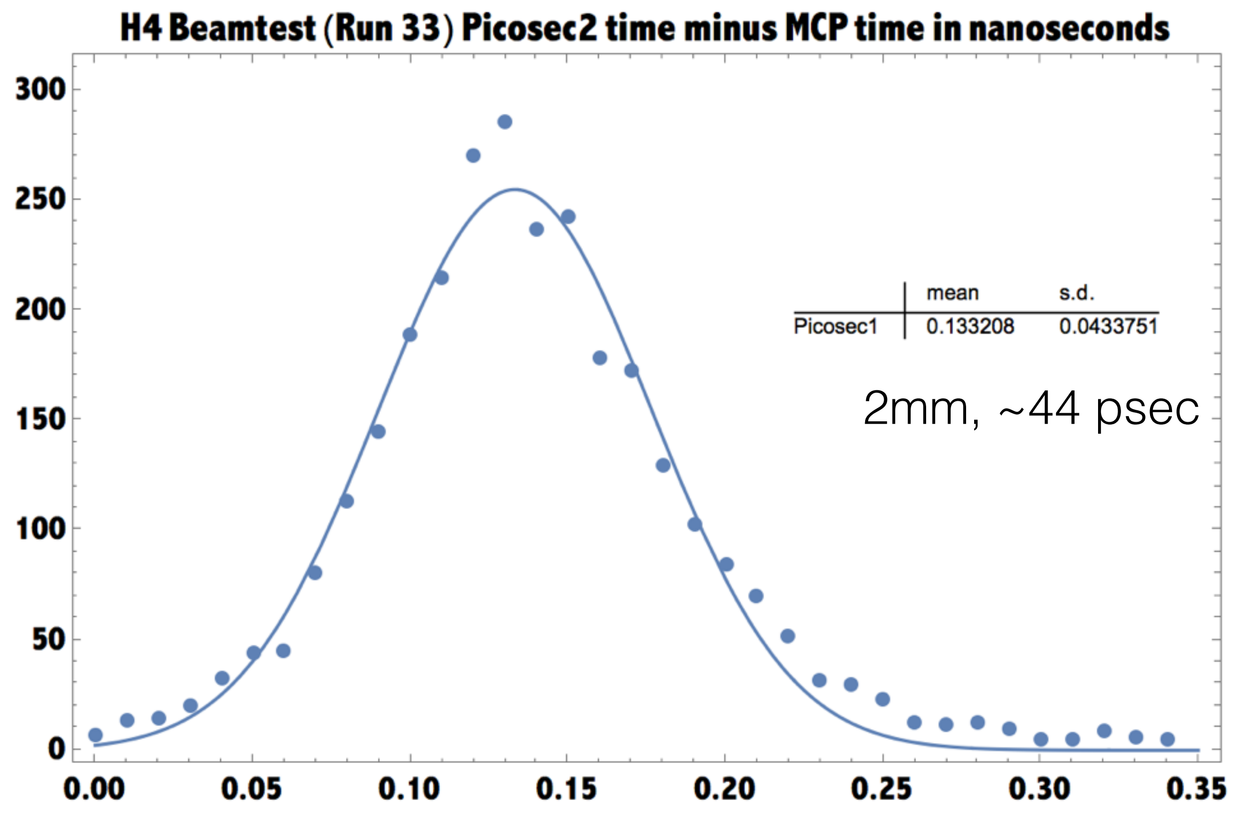


caveats:

1) still working on t0
2) this “typical result” is a good result
3) much more data to analyze
4) .....



3mm, ~35 psec



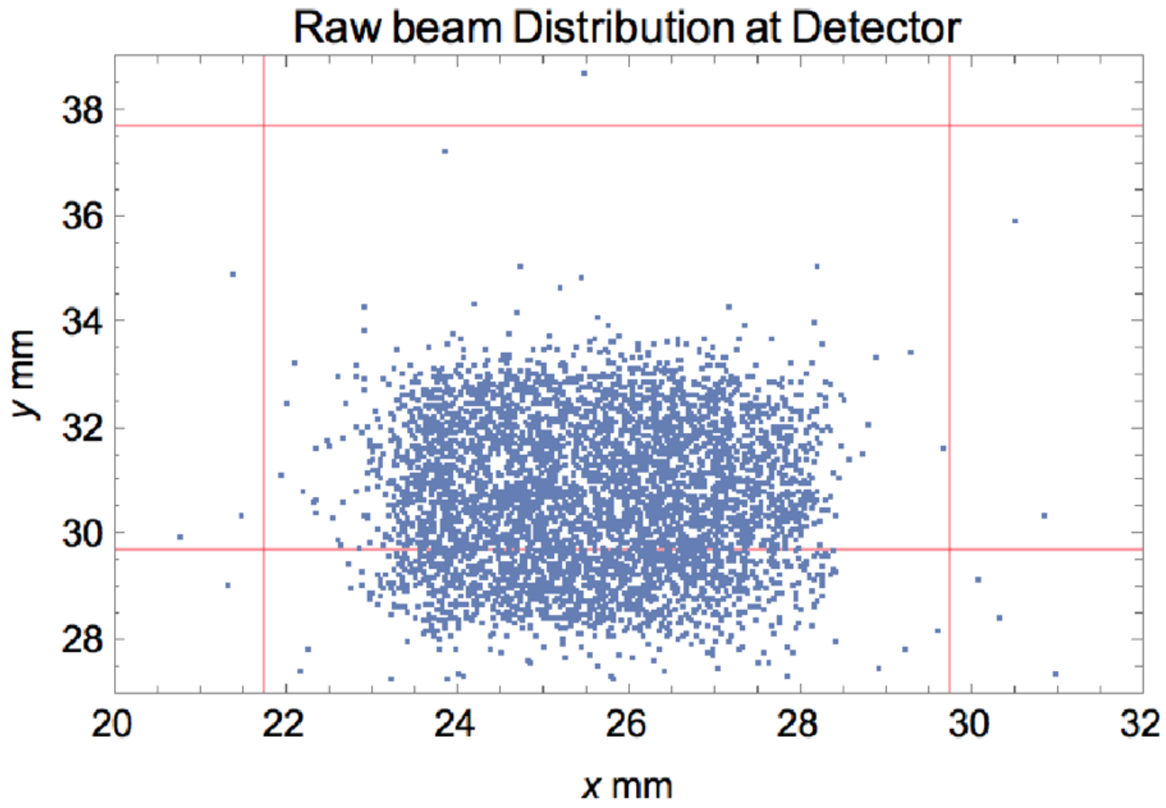
2mm, ~44 psec

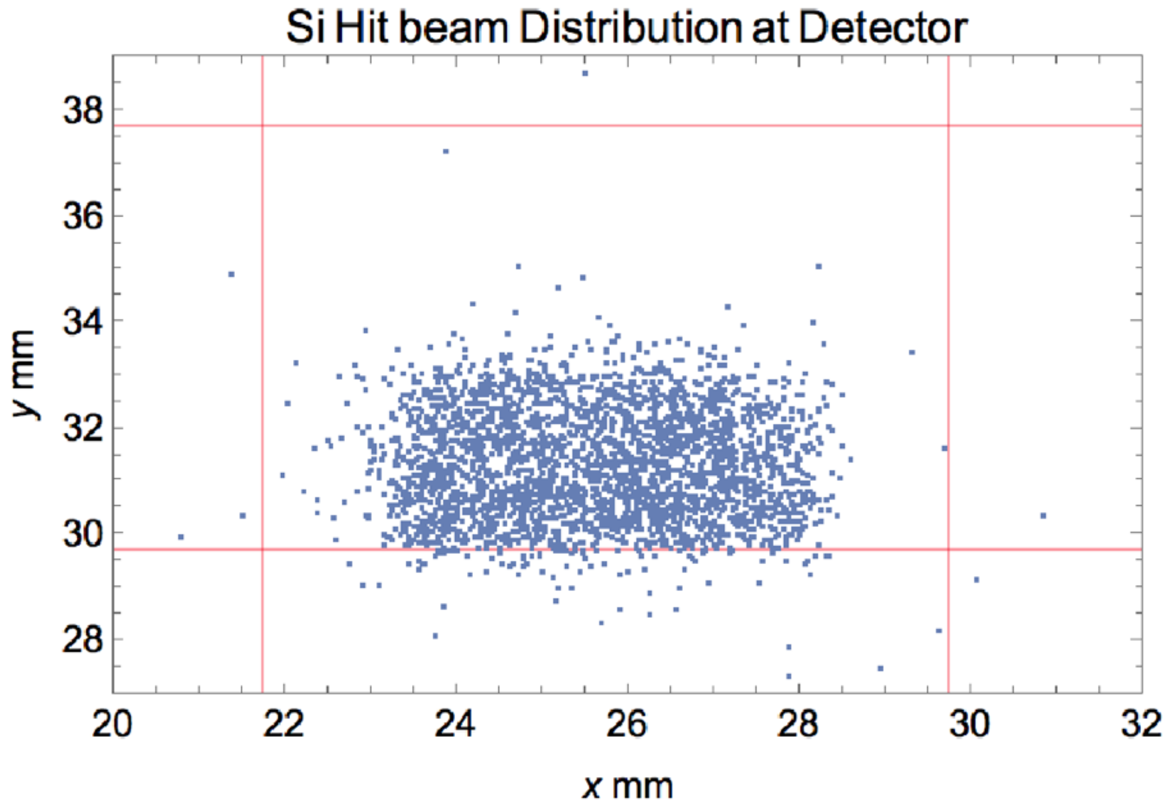
not surprisingly 3mm radiator yields better time jitter than 2mm

first look at tracking tool: Si data

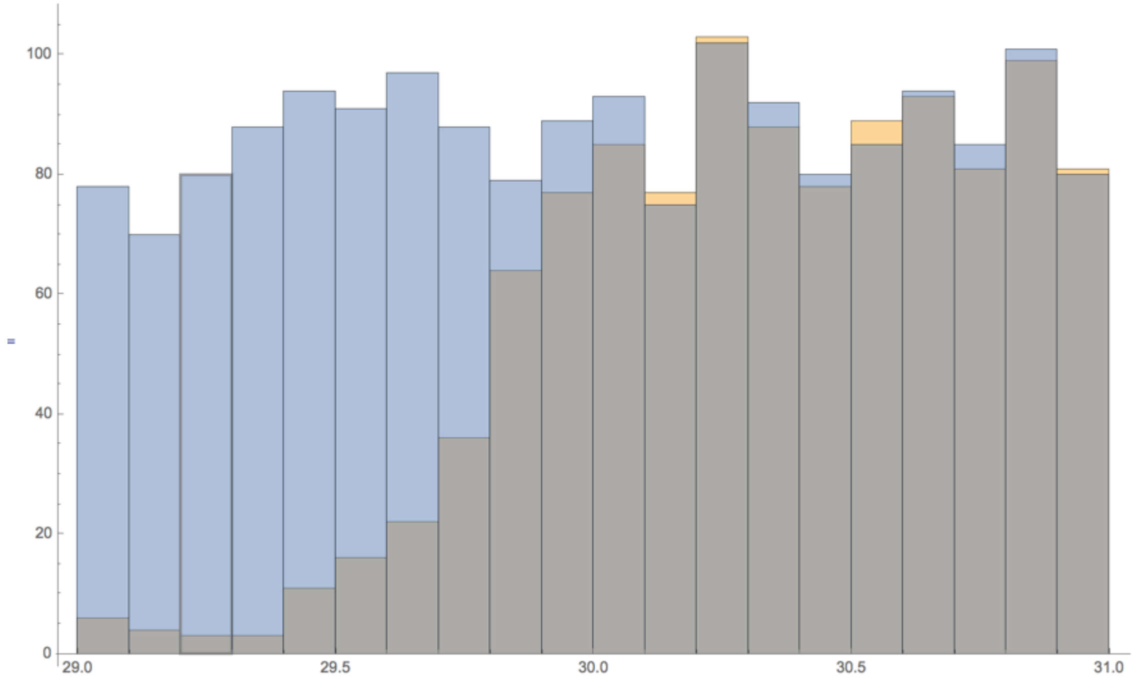
(track reconstruction by Jona Bortfeldt)

how will an array of timing detectors perform?


Raw beam Distribution at Detector

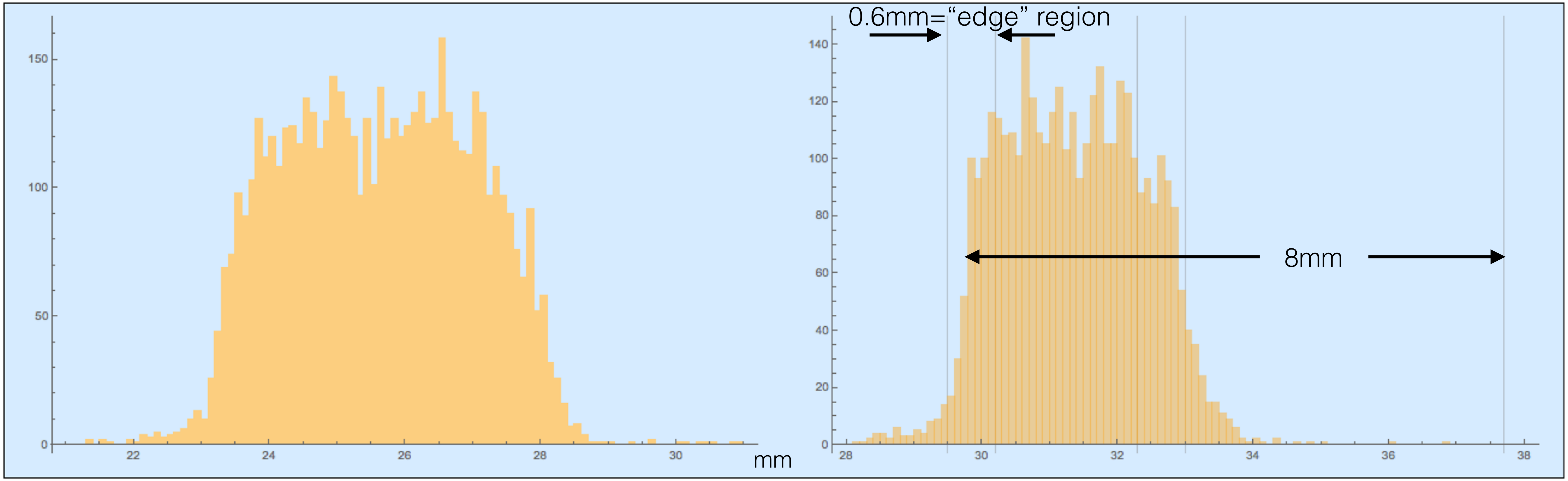

Si Hit beam Distribution at Detector

detailed y edge view->

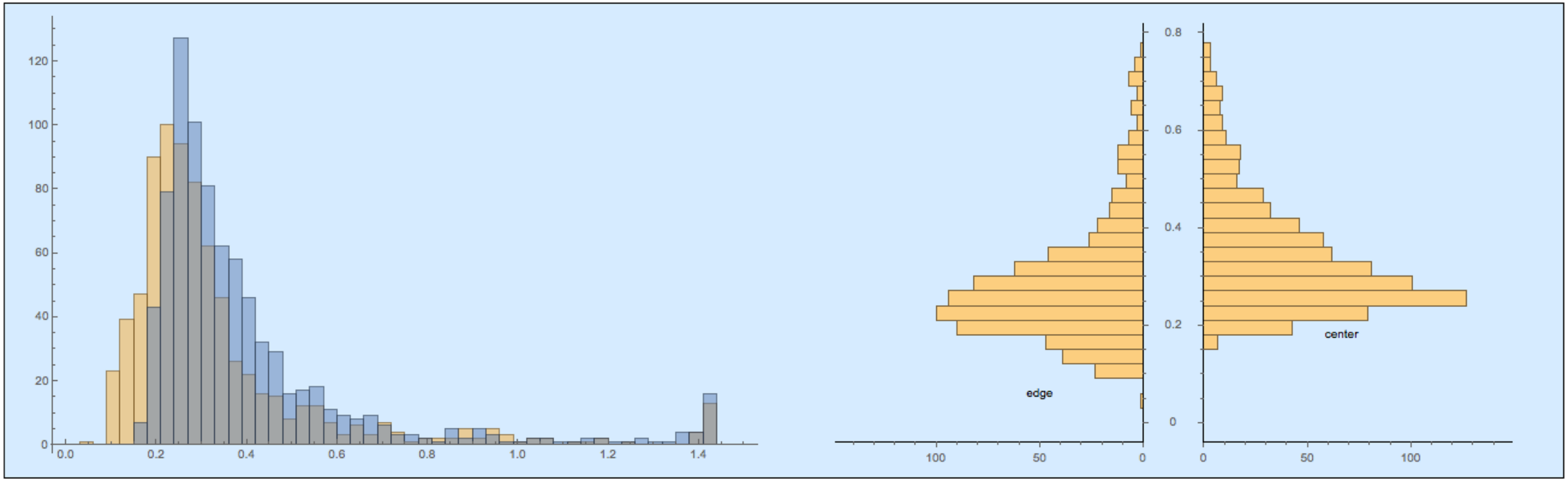


Response variation

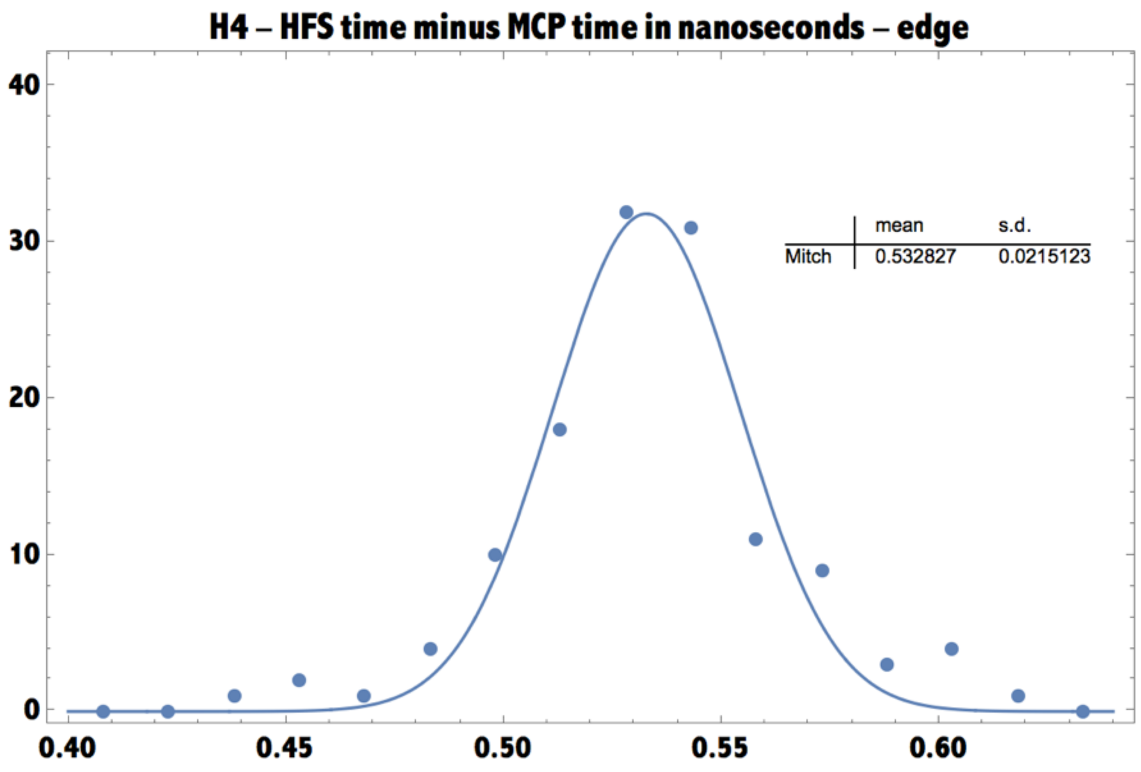
x ,y profile (in mm) of valid hits, Gridlines show selection for edge, center and top of Si

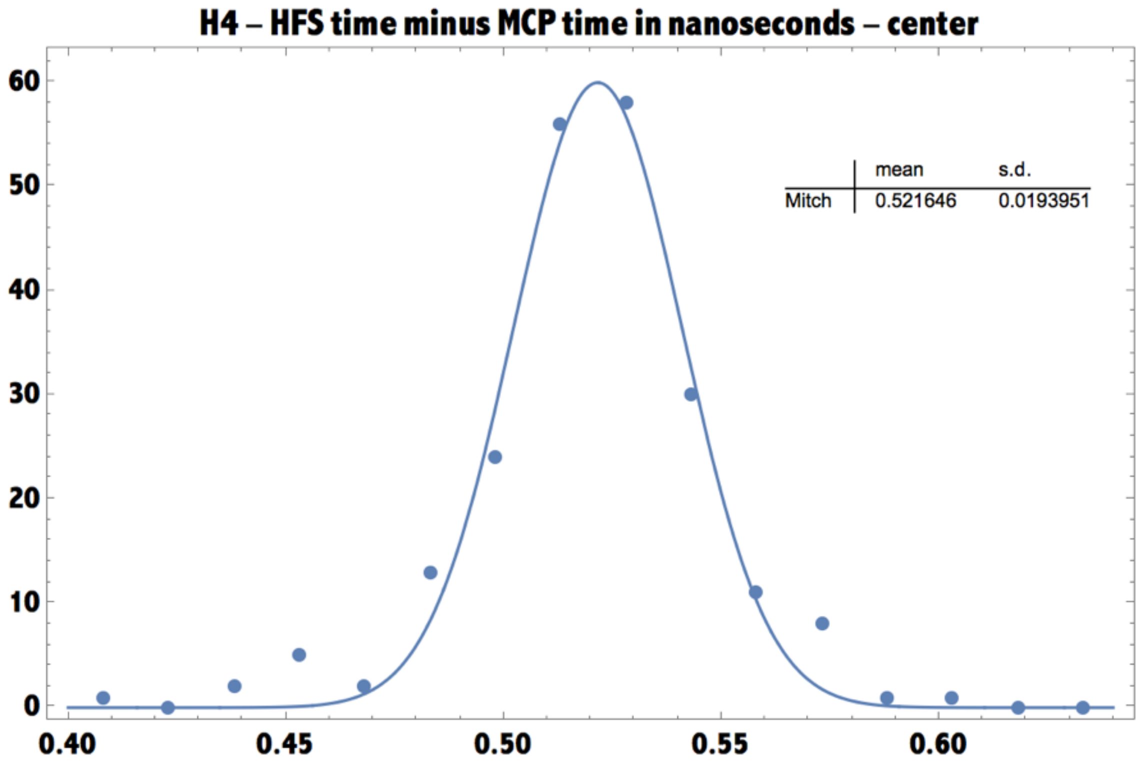


HFS Peak Amplitude in Volts, at detector edge compared w. center



very preliminary look at timing on detector edge


H4 – HFS time minus MCP time in nanoseconds – edge


H4 – HFS time minus MCP time in nanoseconds – center

edge structure of these High field Si complicated. It has been difficult to evaluate w. laser model

first look at edge behavior very encouraging!

take small difference of edge behavior from bulk with grain of salt

timing algorithm preliminary small pulse height distortion

Conclusion and Prospects:

- much additional data to analyze
- significant improvement over previous (May/June) attributable to better understanding of gas purity
- systematic data on several gas mixtures, MgF2/CsI combinations
- very important role of t0 and good tracking data

- Strong case for PICOSEC as an efficient timing technology
- continue to develop rad tolerant, rugged variant (new photocathodes or SEM..)
- informal agreement w. Hamamatsu to engineer scalable array

backup

Further Reading

Michael Moll presentation at RD50 collaboration week June 6 , 2016 (Torino)

Sebastian White, Proceedings of the 2014 Workshop on Picosecond Photon Sensors for Physics and Medical Applications, Clermont Ferrand "R&D for a dedicated Fast Timing Layer in the CMS Endcap upgrade"
https://arxiv.org/abs/1409.1165

-RMD SBIR awarded May 2016
-Princeton DOE Advance Detector R&D Grant awarded June 2016

Sebastian White and Mitch Newcomer, at ACES 2014, CERN

Thomas Papaevangelou et al.,
"Fast Timing for High-Rate Environments with Micromegas" https://arxiv.org/abs/1601.00123

Sebastian White, Proceedings of CHEF 2103 ,Paris.
"Experimental Challenges of the European Strategy for Particle Physics" https://arxiv.org/abs/1309.7985

Sebastian White et al., "Design of a 10 picosecond Time of Flight Detector using Avalanche Photodiodes"
https://arxiv.org/abs/0901.2530

Sebastian White, "On the correlation of sub-events in ATLAS and CMS/TOTEM Experiments", 2007
https://arxiv.org/abs/0707.1500