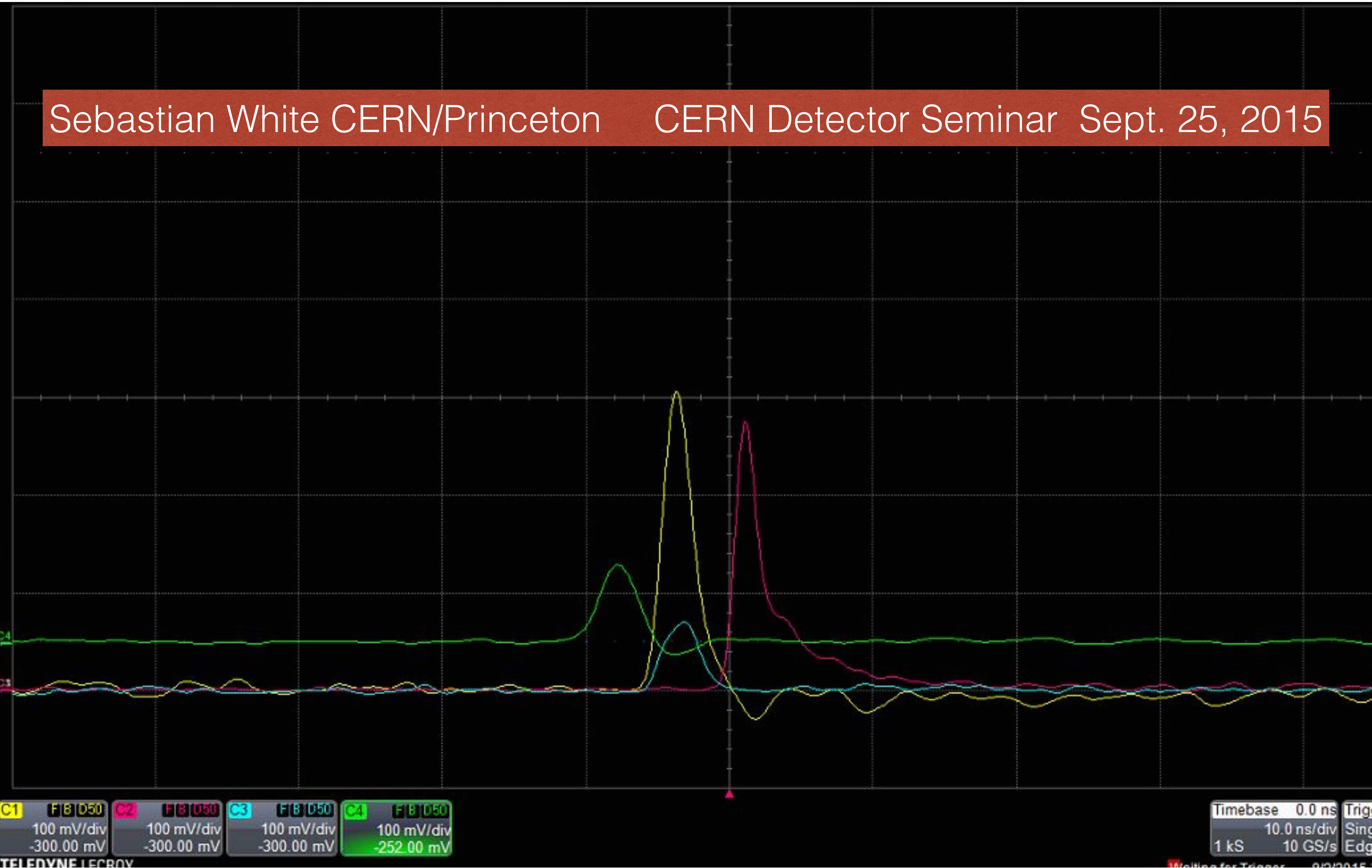
Fast Timing R&D for the HL-LHC Era



Sebastian White CERN/Princeton CERN Detector Seminar Sept. 25, 2015

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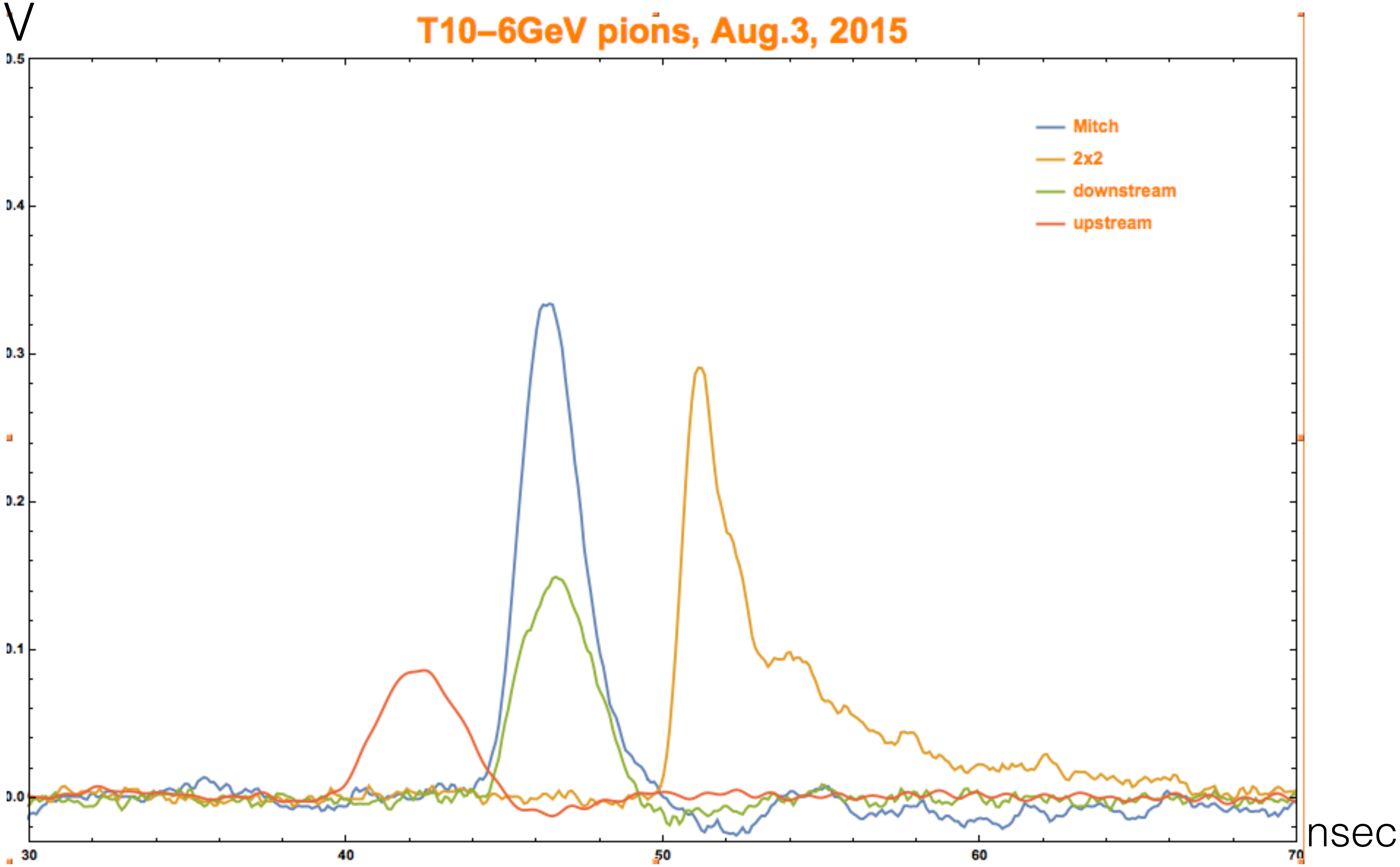
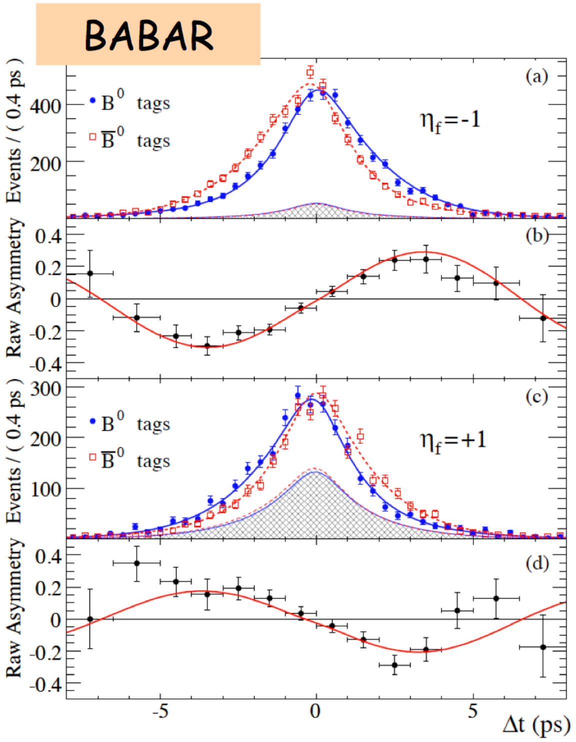


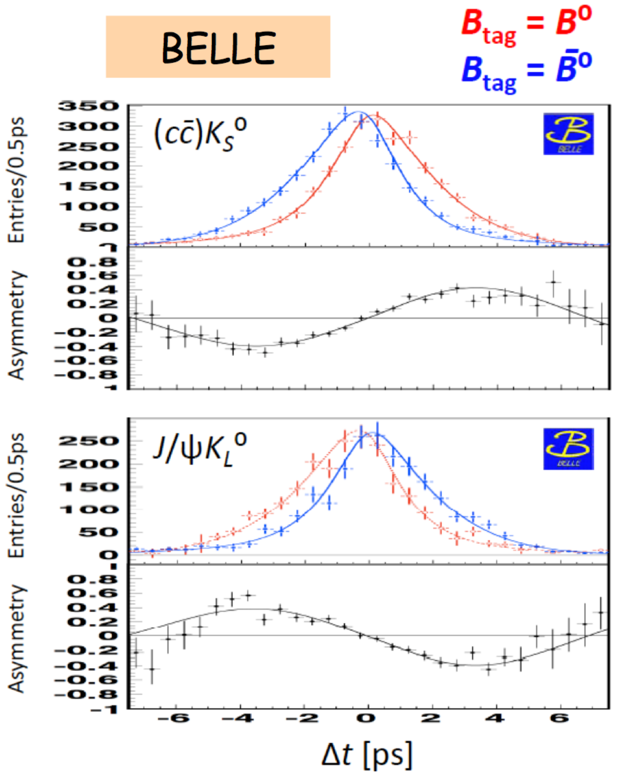
Outline

- In this talk I will focus on our MIP timing sensor development for HL-LHC environment
- Started from Problem (FP420) of 10-20 picosecond timing at sustained rates of ~10^6-10^7Hz/cm^2 in 2007-> Princeton ADR&D DOE Grant ~2011-2012
- J. Incandela encouraged applying this to CMS Phase II Upgrades-USCMS supported this for FY'14-15
- RD51 common Project Application (I. Giomataris&SNW)-awarded March 2015
- CERN support to carry this out in RD50(Moll&co.)&RD51 groups (Leszek &co.) in 2015
- 7 year Productive Collaboration w. RMD/Dynasil on "Hyperfast Si"
- CERN has been great environment for push on fast timing (Crispin, Lecoq, Fritz Caspers, Farthouat……….
- HL-LHC provides the challenge.
- This talk all about Micropattern Detectors

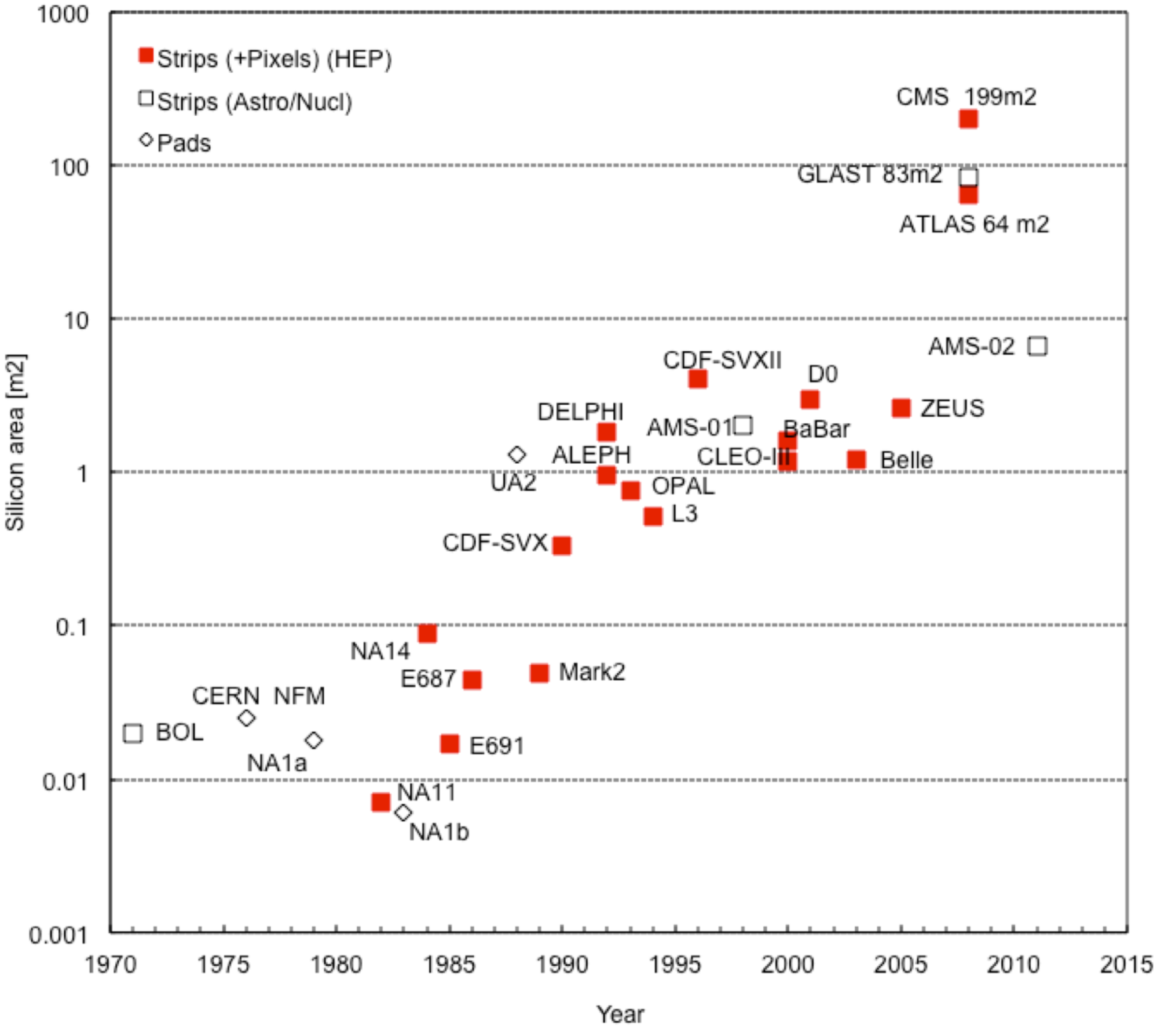
Micropattern detectors enable Precision Tracking and Speed

“Neutrino Flux Monitor”,Heijne, Jarron et al.,1976
November Revolution, c-quark, 1974
Upsilon, b-quark, 1979
A.B.Carter&A.I.Sanda, CP violation in b decay, 1981





file by Nobu Unno, KEK, updated June-August 2015 by Erik Heijne, CERN



but we accessed picoseconds with
precision tracking

Does HL-LHC Provide an “unmet need” for Fast Timing?

we are in a transition Period

CDF/Tevatron

“up to pileup of 6”

*www2.pv.infn.it/~ifae2006/talks/ModelloStandard/**Vallecorsa**.ppt*

LHC

Burt Richter

http://arxiv.org/pdf/1409.1196.pdf

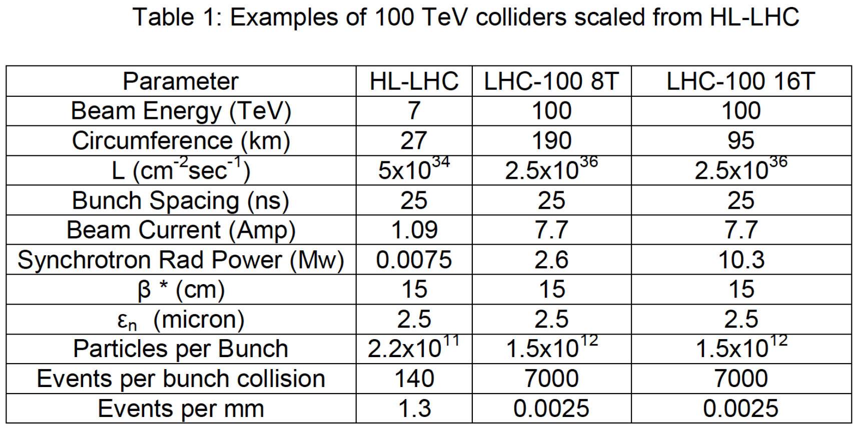


Table 1: Examples of 100 TeV colliders scaled from HL-LHC

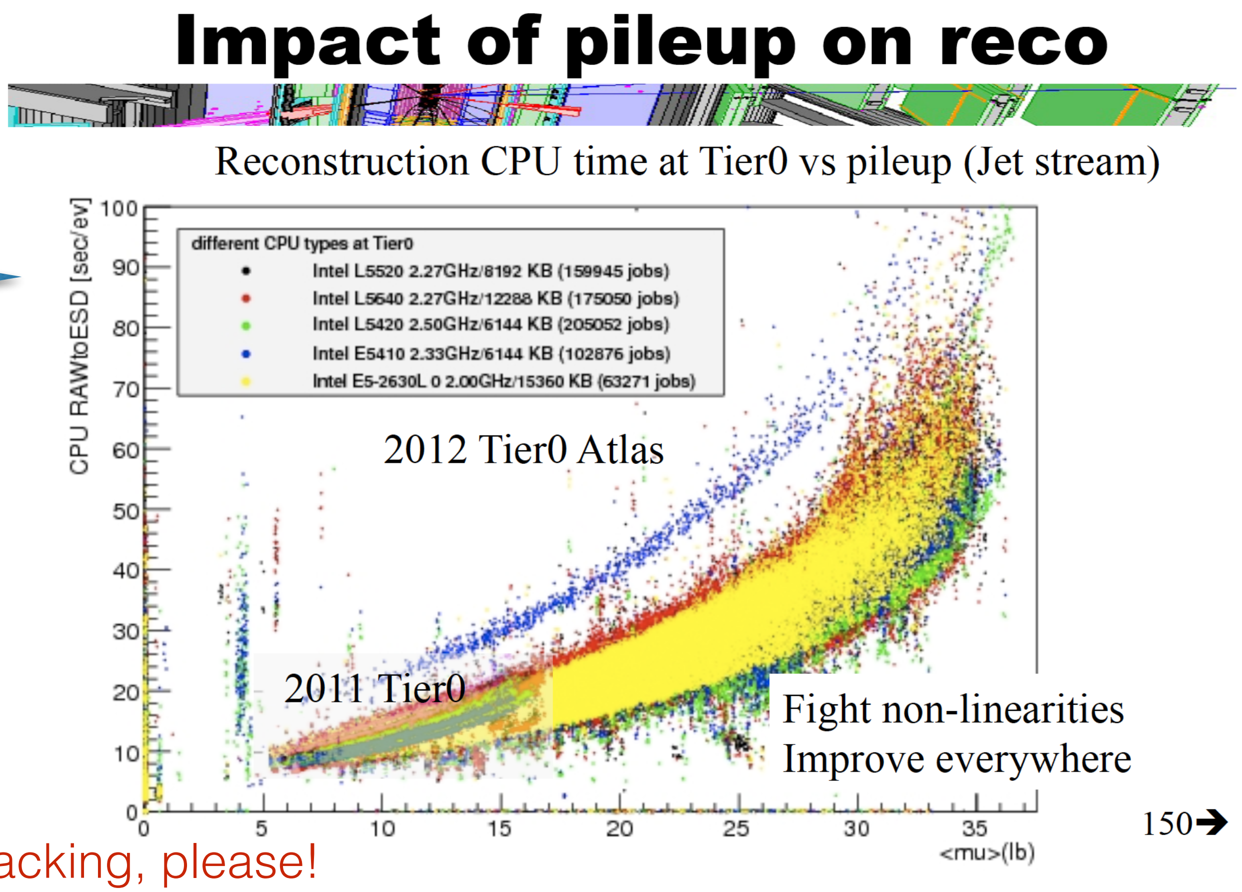
Parameter	HL-LHC	LHC-100 8T	LHC-100 16T
Beam Energy (TeV)	7	100	100
Circumference (km)	27	190	95
L ($cm^{-2}sec^{-1}$)	$5x10^{34}$	$2.5x10^{36}$	$2.5x10^{36}$
Bunch Spacing (ns)	25	25	25
Beam Current (Amp)	1.09	7.7	7.7
Synchrotron Rad Power (Mw)	0.0075	2.6	10.3
β * (cm)	15	15	15
ε_n (micron)	2.5	2.5	2.5
Particles per Bunch	$2.2x10^{11}$	$1.5x10^{12}$	$1.5x10^{12}$
Events per bunch collision	140	7000	7000
Events per mm	1.3	0.0025	0.0025

(@LHC ALICE used ~10^5 channel 80 picosec TOF to enable precision matter/antimatter symmetry test. R&D of C. Williams et al->16 picosec but @low rates.)

Is there a limit to all this?

see eg. :R.**Huson**, L.M.**Lederman** and R. **Schwitters**, "A Primer on Detectors in High Luminosity Environments", in Snowmass 1982, Proceedings

D. Rousseau, ATLAS
ECFA 2013



Impact of pileup on reco

Reconstruction CPU time at Tier0 vs pileup (Jet stream)

- when will this plot go North?
- general feeling that better algorithms will be found. Are there tradeoffs?
- could "hit time" aid reconstruction?

SNW, http://arxiv.org/pdf/0707.1500.pdf, 2007

No crab-smacking, please!
dt is useful.

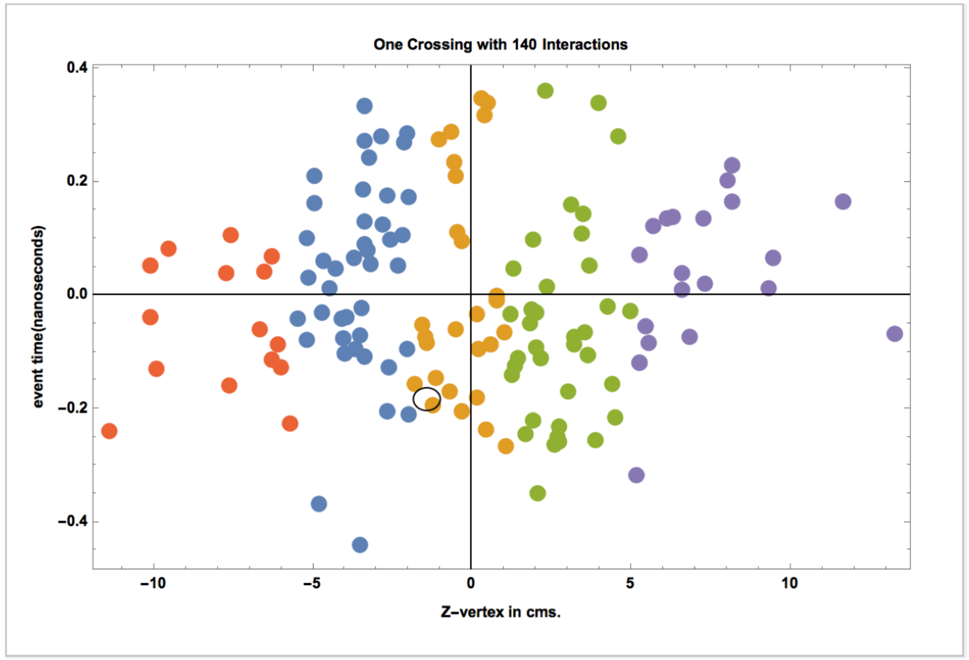
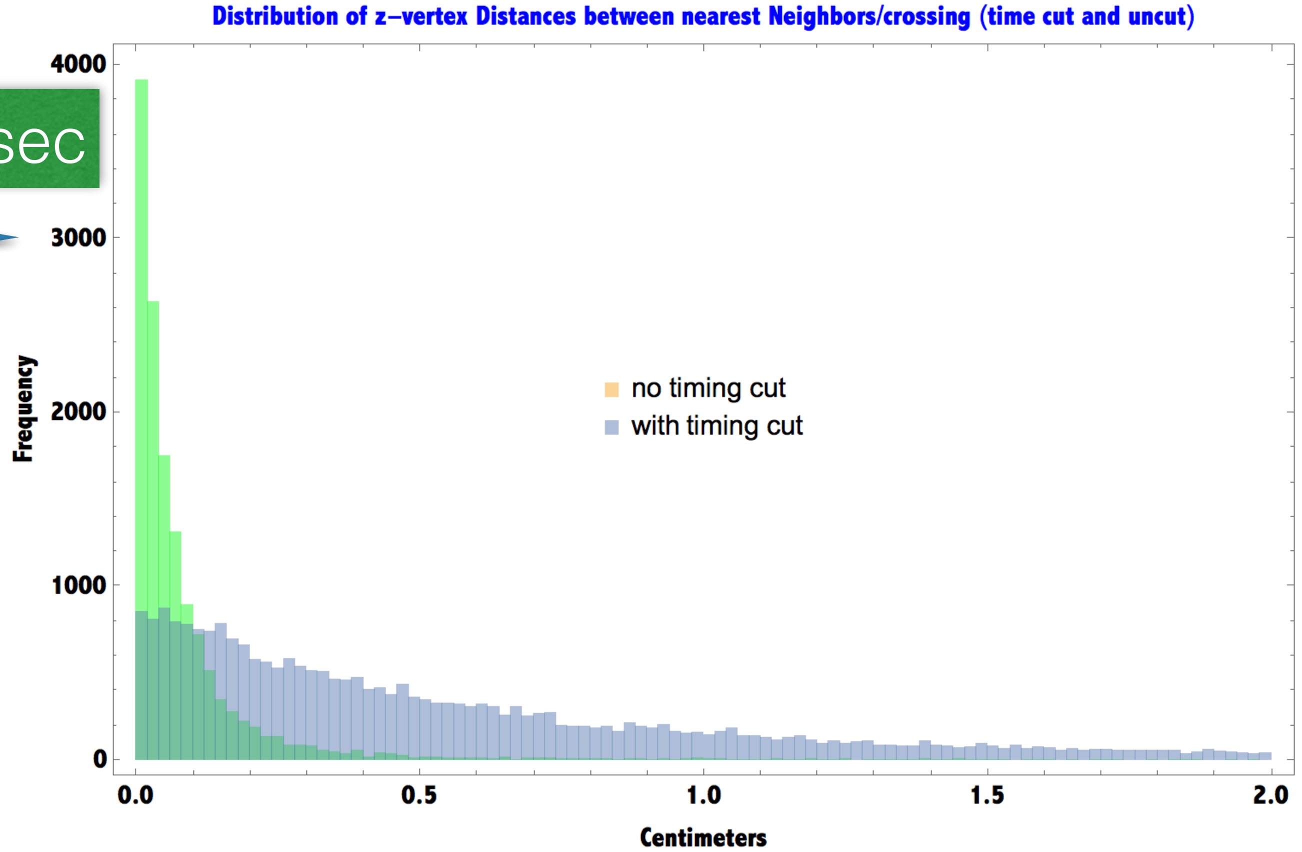


Fig. 1. Simulation of the space(z-vertex) and time distribution of interactions within a single bunch crossing in CMS at a pileup of 140 events- using LHC design book for crossing angle, emittance, etc. Typically events are distributed with an rms-in time- of 170 picoseconds, independent of vertex position.

dt~20psec



Sub-100 picosecond charged particle timing with MicroMegas a proof of concept

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)

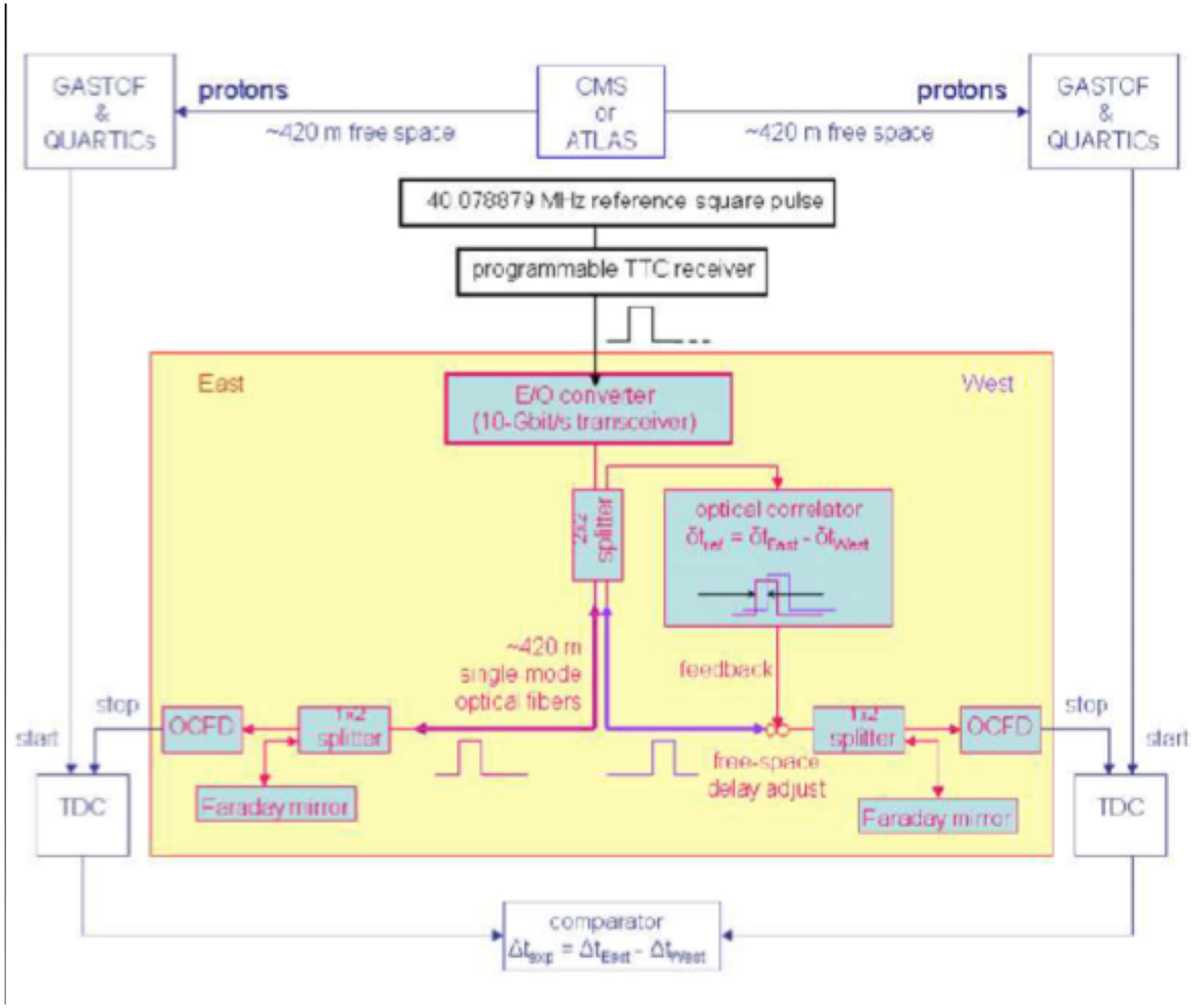
for RD51 common fund project: “Fast Timing for High Rate Environments: a MicroMegas Solution”- awarded 3/2015

Tools: Clock Distribution

clock distribution with few pico sec jitter not common in HEP but wide use in FEL.. accel. world

Point-to-Point

we (SNW&T.Tsang) designed an inexpensive demonstrator for FP420



Within a crate:

Hello Sebastian,

Trigger and clock distribution inside a crate can indeed be done with accuracies and precisions in the order of a few picoseconds. Typically, modern standard platforms such as PXIe and MTCA.4 provide a timing distribution infrastructure in the form of a star in the backplane, i.e. there is a slot from where copper lines (in the backplane) go to every other slot in the crate.

Here is one example of a timing distribution module in PXIe format:

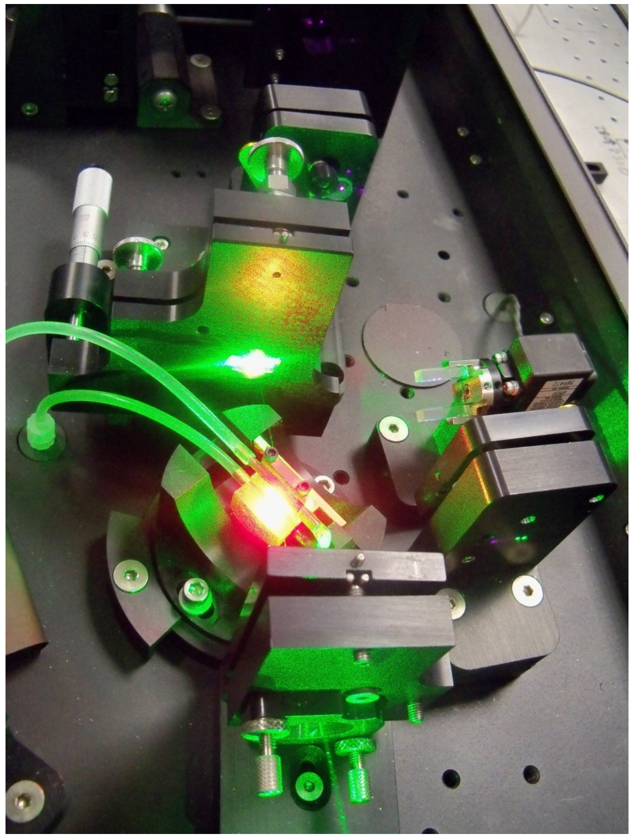
—-Javier Serrano

see also “White Rabbit”

MPGD &Si Characterization with picosecond Lasers Key Throughout

1) The Ti:Sa wavelength is tunable from 700 to 1000 nm
2) The fundamental laser pulse length at 800 nm is 120 femtoseconds. The Ti:Sa oscillator runs at 76 MHz repetition rate
3) We used an OPO to obtain ~550 nm radiation, which were passed through a pulse-picker in order to decrease the repetition rate from 76 MHz to 11 kHz
4) We then frequency doubled the ~550 nm radiation in a 5 mm BBO crystal, obtaining ~275 nm radiation.
5) There are important losses in the pulse-picker so we had only about 0.15 pJ / pulse at 11 kHz (275 nm = 4.5 eV => 1.75x10^7 photons / pulse)
6) We use the residual 550 nm radiation leaking through a dichroic UV mirror in order to trig the electronics.

(Generation of ultrashort pulses by “magic“ mode-locking was discovered in 1990.)

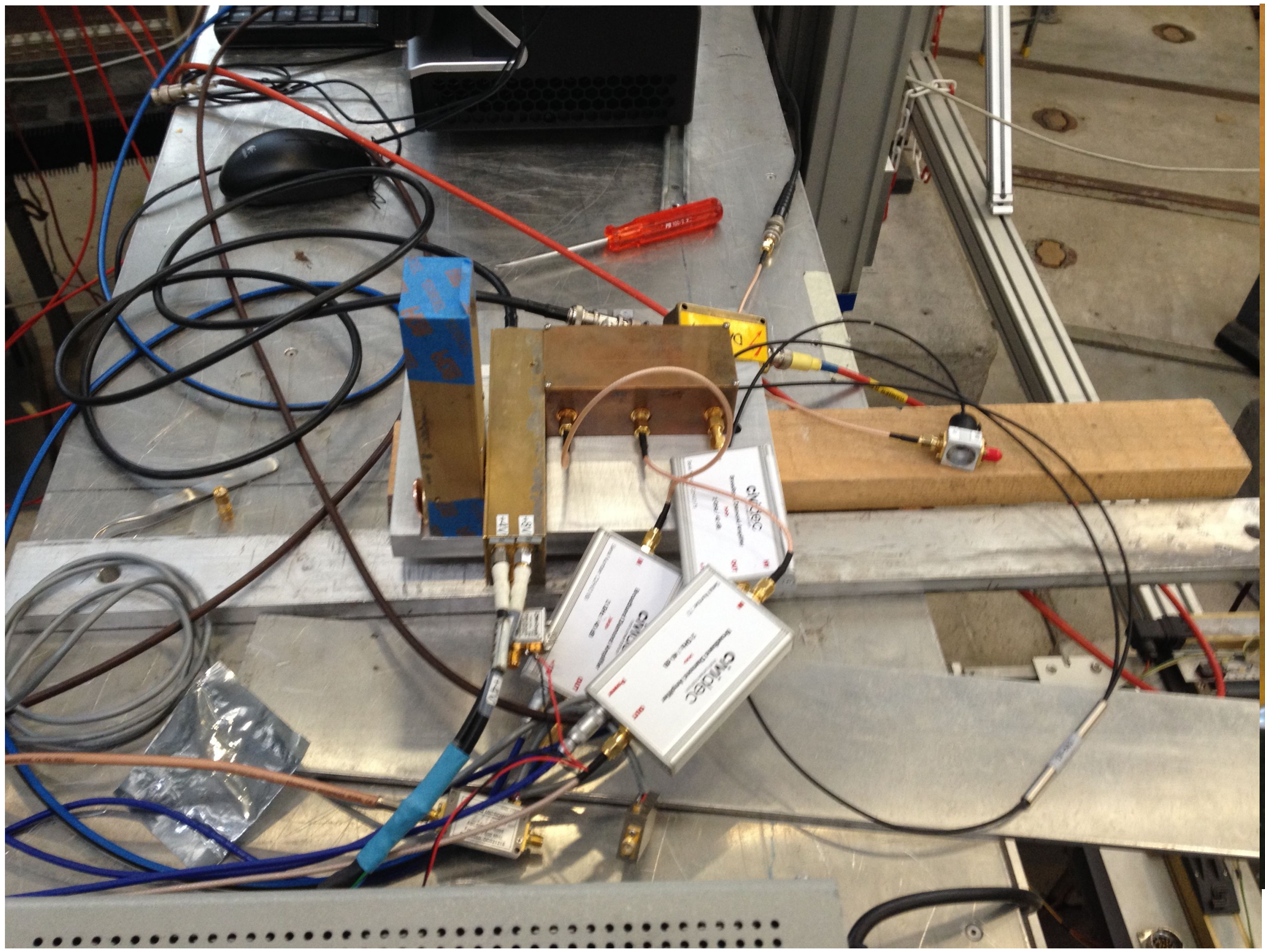


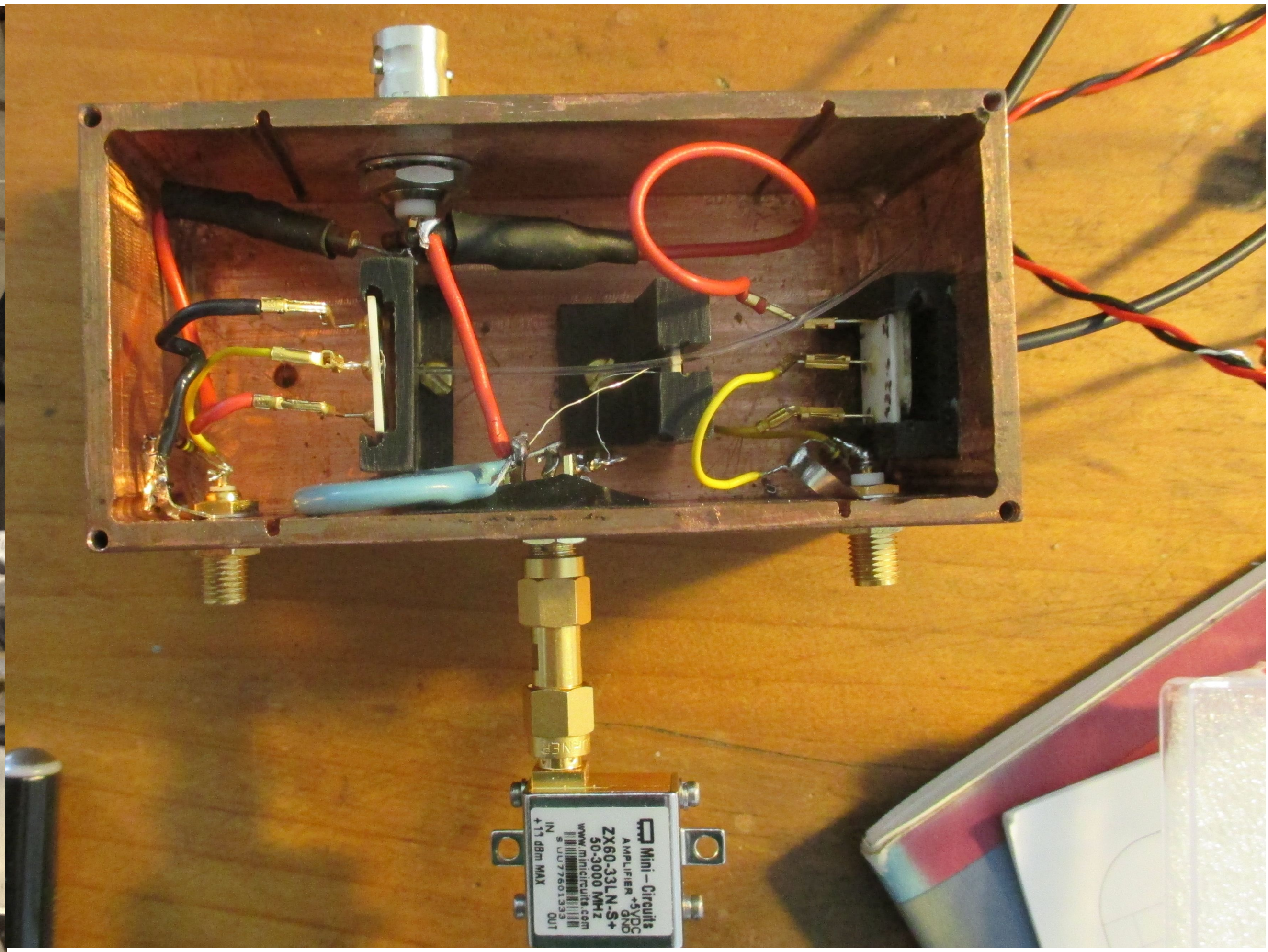
(Details from Thomas Gustavsson, IRAMIS)

We used ~1000nm for Si (Thomas Tsang, Instrumentation Division)
-model for MIP deposition through Si detector
and 275 nm for MPGD (low qe Al photocathode)

MIP Testing in Particle Beams

- High Brightness Electron Linacs->$\mathrm{RMS}_{\mathrm{bunch}}$~ 3 picosec
- ->ATF Expt Be44 (K.McDonald&SNW+V. Yakimenko, 2010)
- ~1 scattered 80MeV electron from 10^8 e bunch
- great for single device testing (in back yard)- also LAL?
- But abundant available beams @few GeV->~dozen Si telescope tests at DESY, PSI, LNF,FNAL, PS&SPS in last 3 years



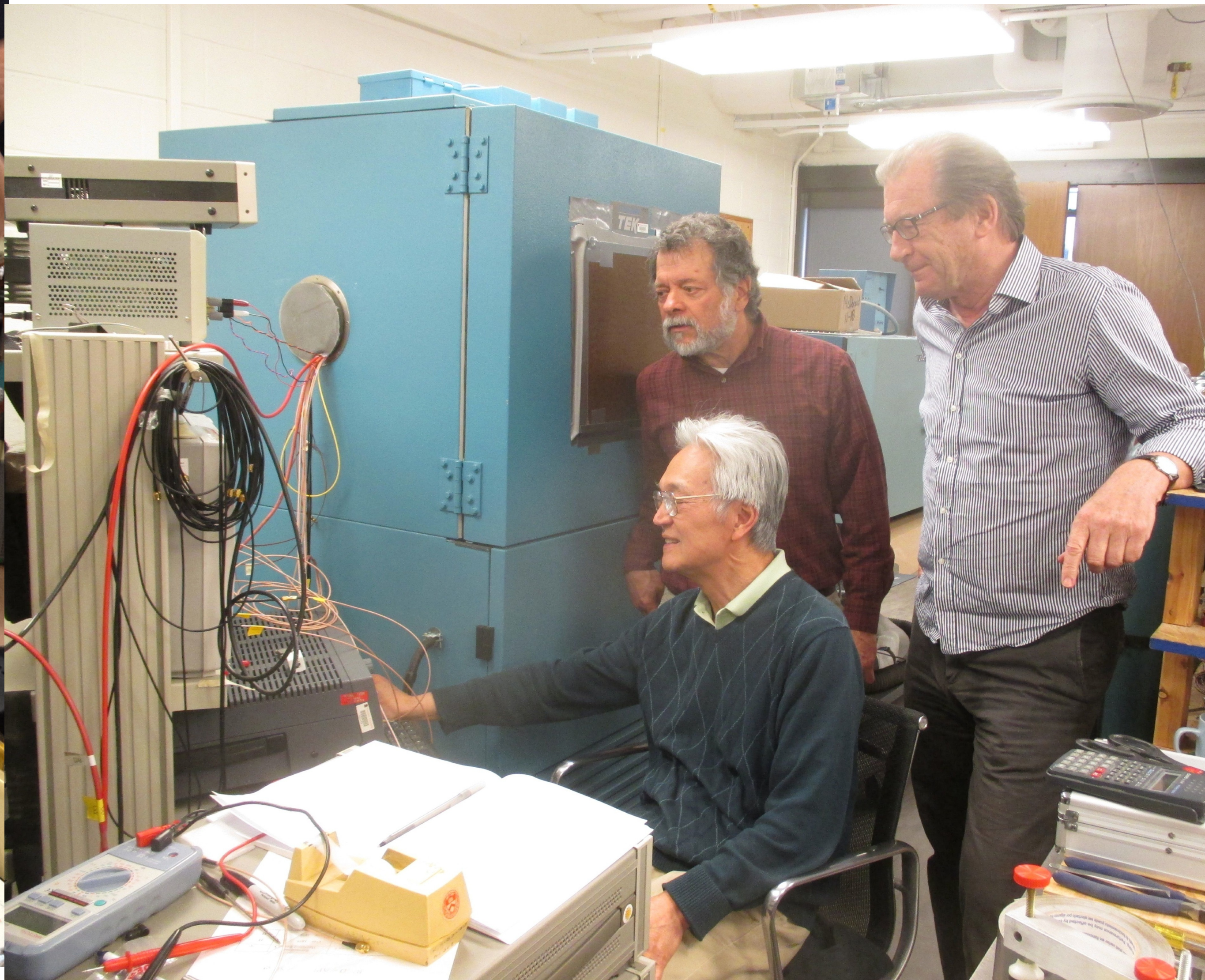


Tools:FEE

- many low noise >1 GHz voltage amplifiers (50 Ohm) on market:Minicircuits,Wenteq, Miteq…..mostly for aerospace/communications
- high end Amp from Cividec developed for Diamonds, great input protection!
- within our project we developed a hi-BW low noise Si-Ge transimpedance amp (Mitch Newcomer) which does better for higher C_{det}
- help in modelling from Jan Kaplon, Erich, Fritz Caspers and others.

Erich

Mitch



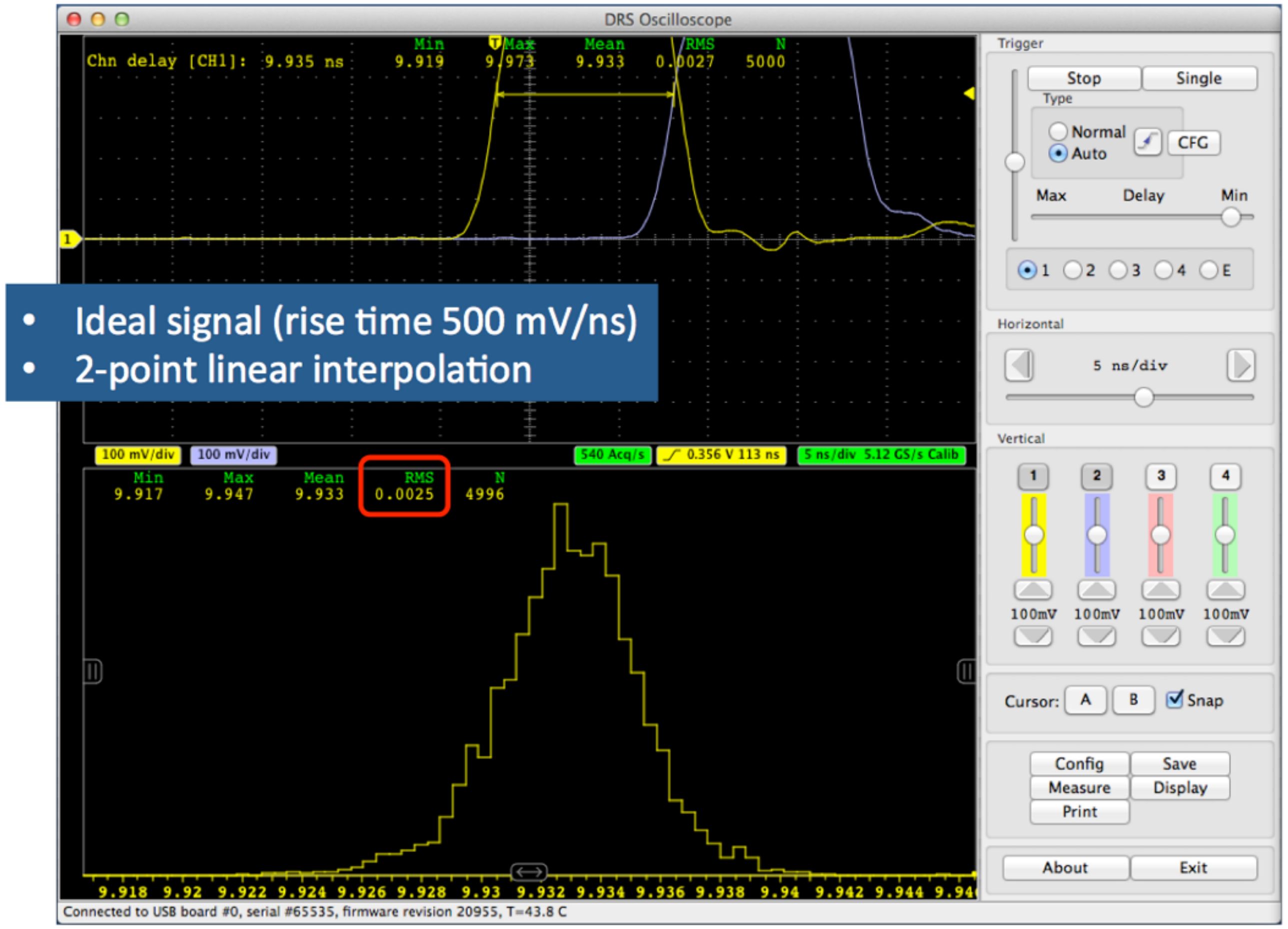
Tools:Digitization

Xavier

preferred daq tool-lot's of
Lecroy scopes
w. R. Zuyeuski's Labview software

Stefan Ritt- Dec 2013

First inter-channel 2.5 ps measurement



DRS Oscilloscope

```
Chn delay [CH1]: 9.935 ns   Min    Max    Mean   RMS     N
                            9.919  9.973  9.933  0.0027  5000
```

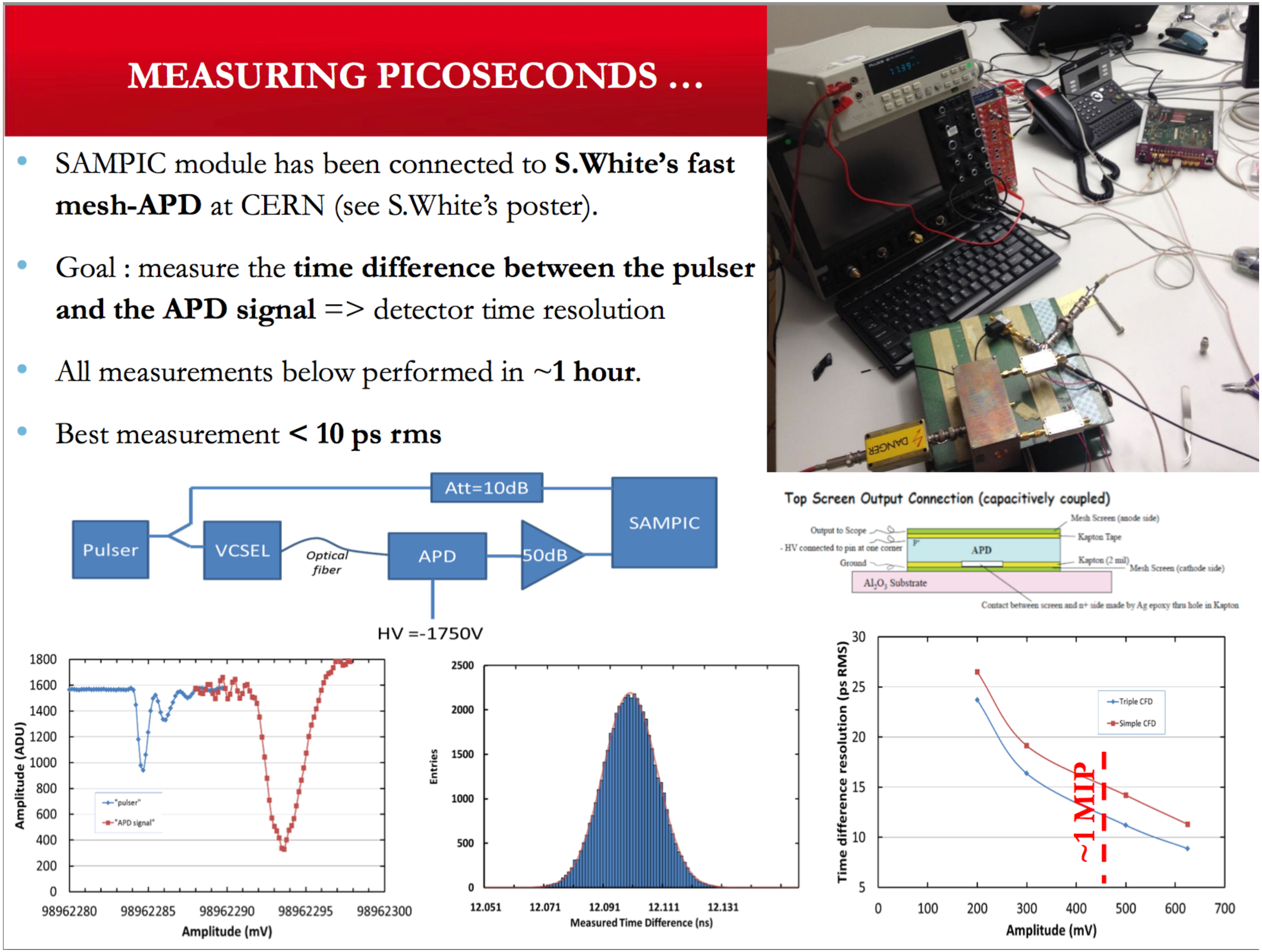
- Ideal signal (rise time 500 mV/ns)
- 2-point linear interpolation

```
Min    Max    Mean   RMS     N
9.917  9.947  9.933  0.0025  4996
```

Connected to USB board #0, serial #65535, firmware revision 20955, T=43.8 C

also alternate to WFD: High Performance TDC-J. Christiansen et al.

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**

Top Screen Output Connection (capacitively coupled)

Model for Timing Layer Cell

1/2-1 cm^2 cell size
down to ~8^o
ie well into "endcap"

we identified a chamber from "for fire"
(an earlier Saclay MMegas project)
special chamber also completing @CERN

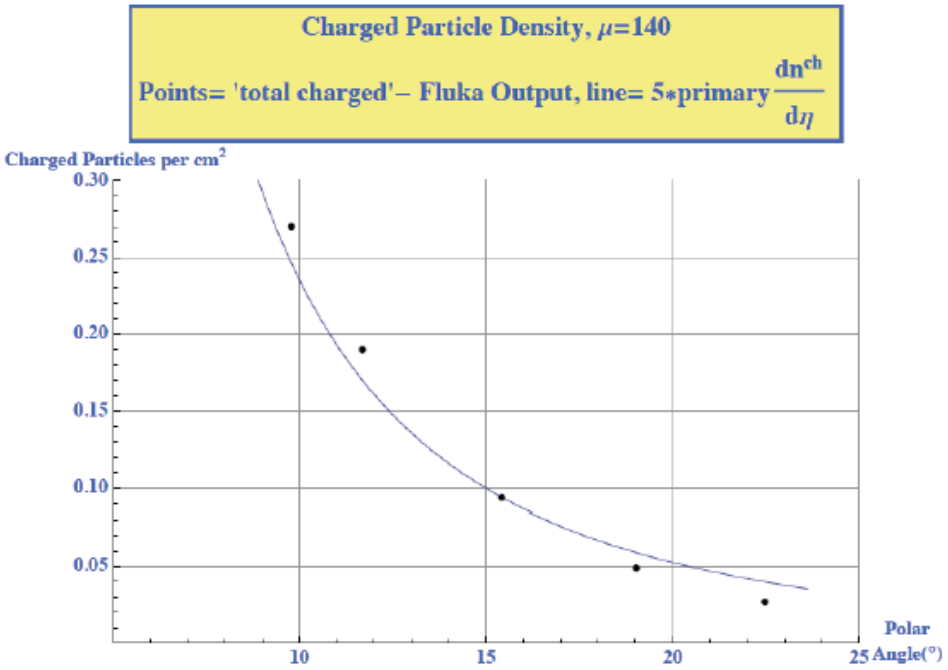
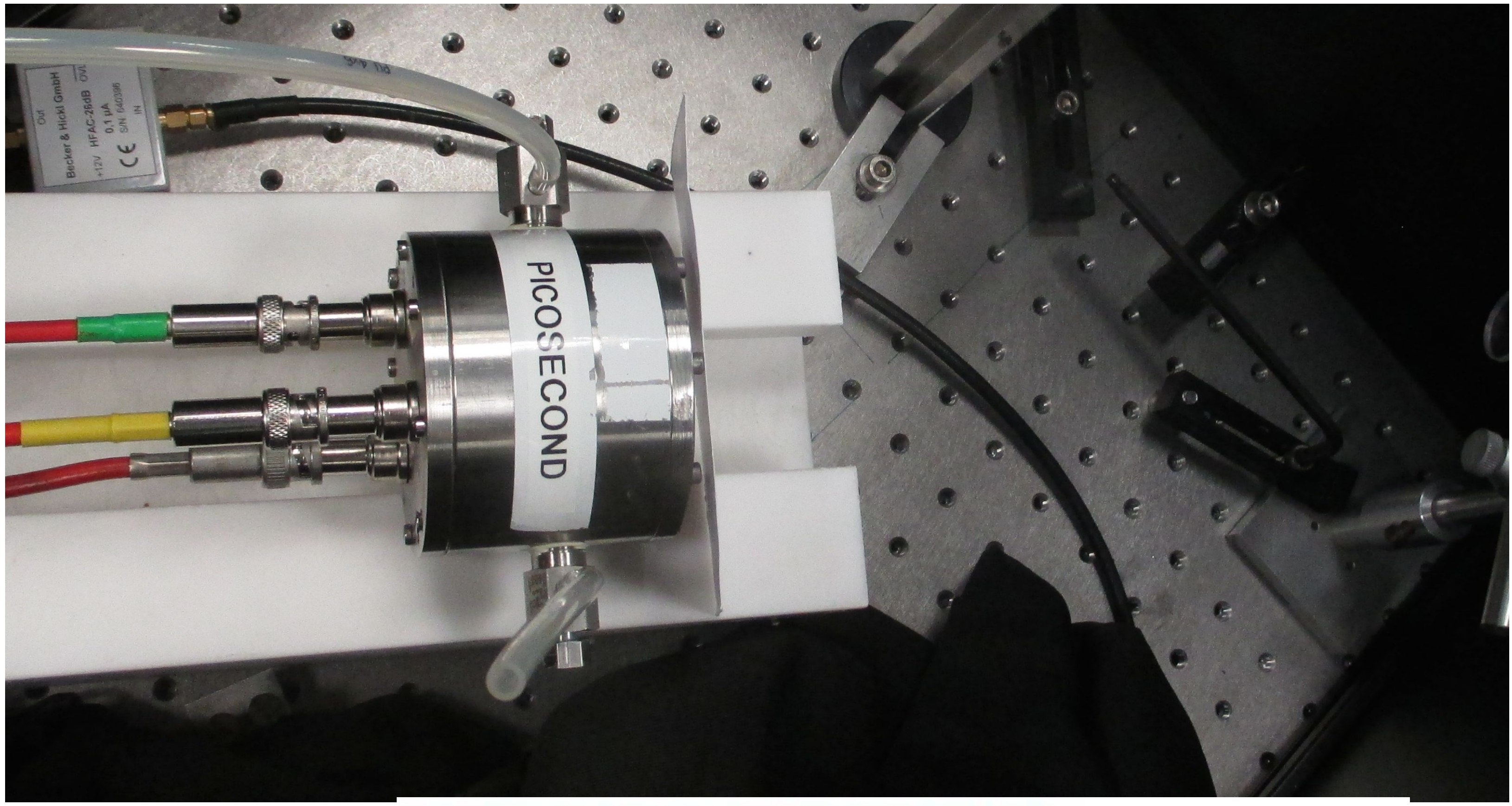


Figure 2: The charged particle density in the region of the dedicated timing detector. The points are FLUKA output for "total charged". The line is calculated from estimates of primary charged particle density-dn/deta- scaled up by a factor of 5. FLUKA output is roughly consistent with a constant factor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



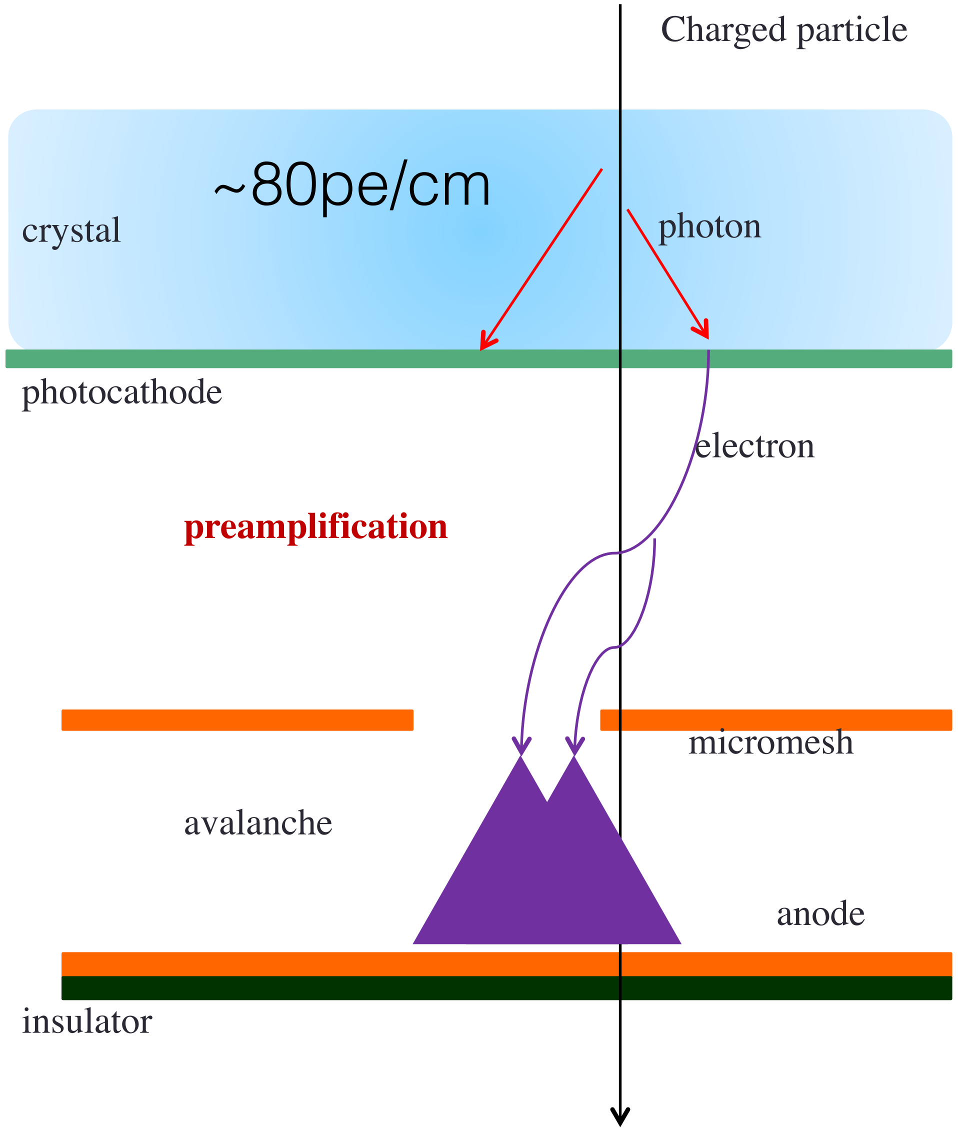
chamber consists of
1)quartz window w. Al pc
2) 0.2mm drift
3) "Bulk 128" MMegas

The bulk-micromegas technique uses PCB production tools and methods
The mesh is placed at a well controlled distance on top of a PCB, what opens the door to industrial fabrication

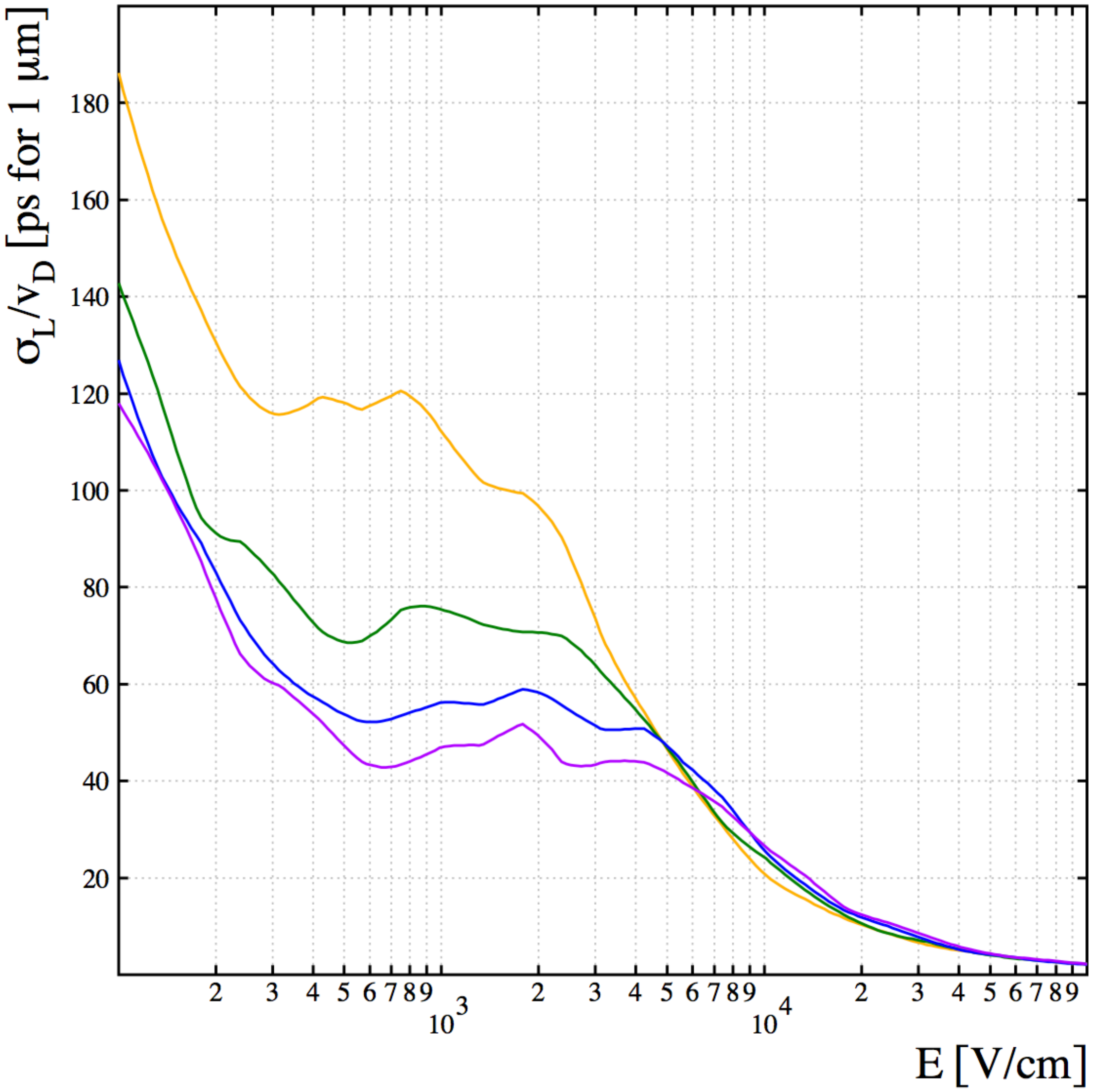
Standard configuration

- Pillars every 5 (or 10) mm
- Pillar diameter ≈350 µm
- Dead area ≈1.5 (0.4)%
- Amplification gap 128 µm
- Mesh: 325 lines/inch

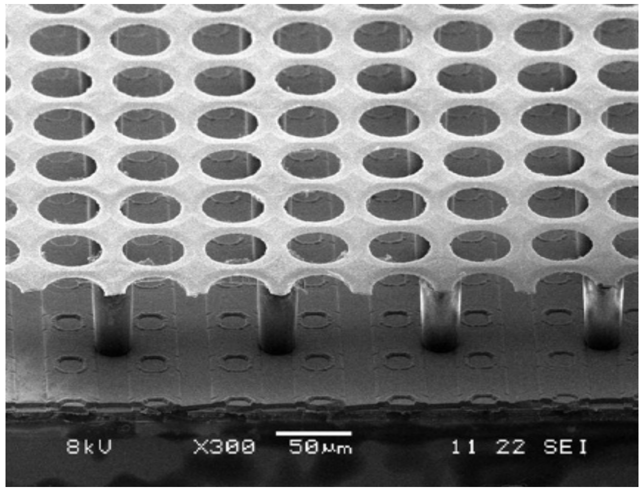
Detector Concept:Diffusion limited time jitter



Ne-C_2H_6 (10%)-green, +other fractions



reflective pc
also attractive:

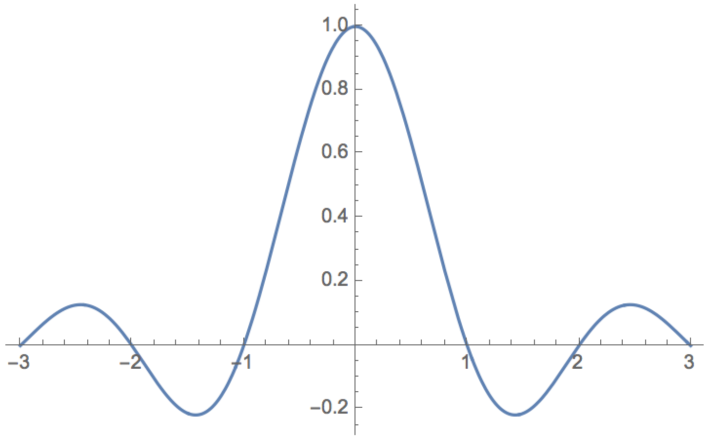


so far, tests in high drift field->10kV/cm,200 micron gap
->200-300 pico sec per photoelectron

Now try for a fit function that will better scale with amplitude using the Sinc (wavelet) treatment. This yields stable fits for the amplitude (ie Npe) but the earlier method using normalized waveforms gives more stable fits for the phase, so I combine these methods.

```
In[145]:= Plot[Sinc[Pi * x], {x, -3, 3}]
```

Out[145]=

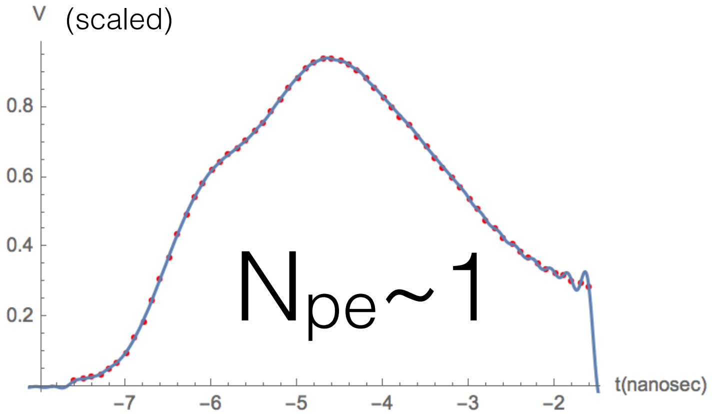


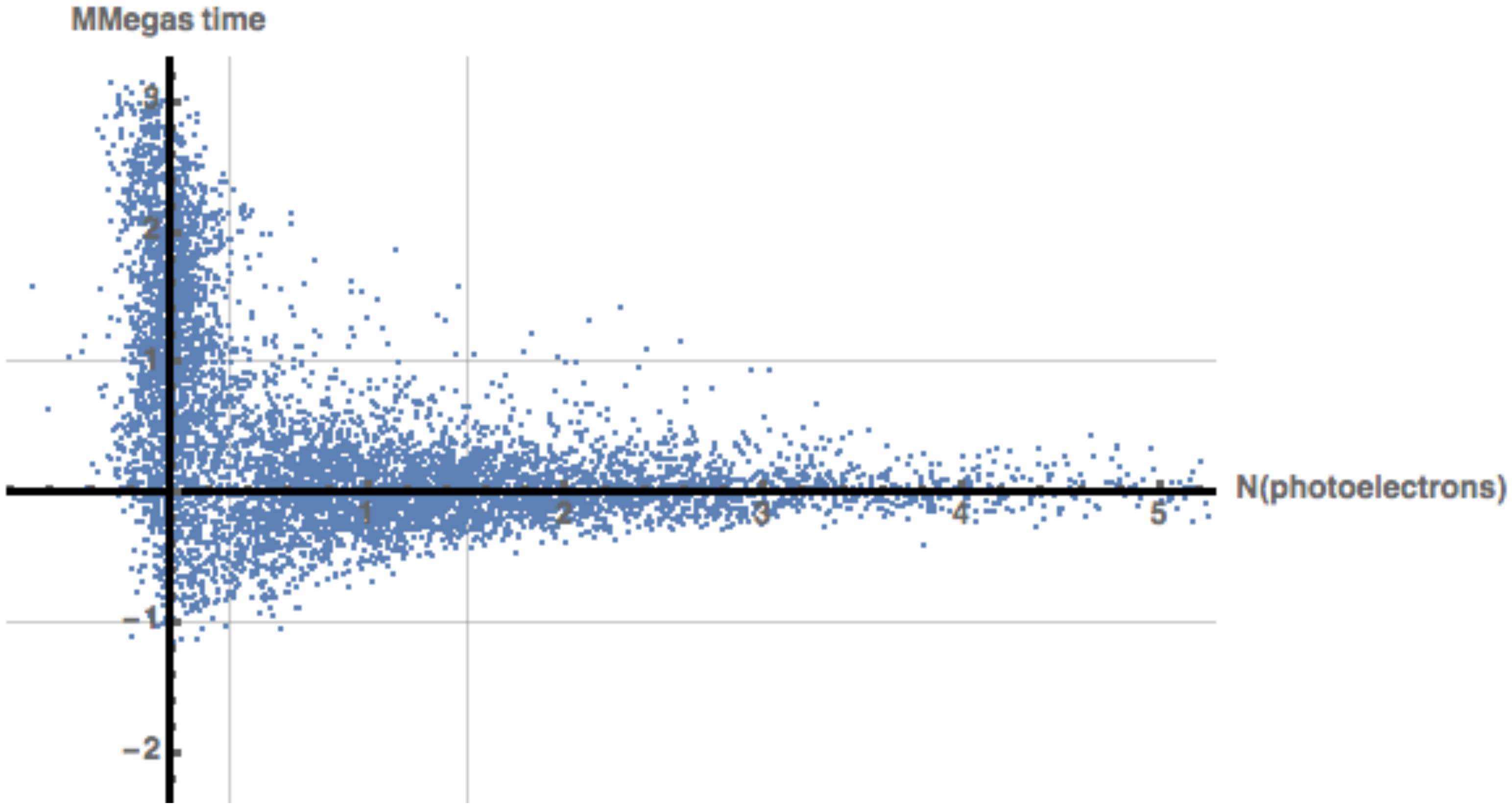
$$\text{avewave} = \frac{1}{2}\,(\text{v01}[\![5]\!] + \text{v01}[\![7]\!]);$$

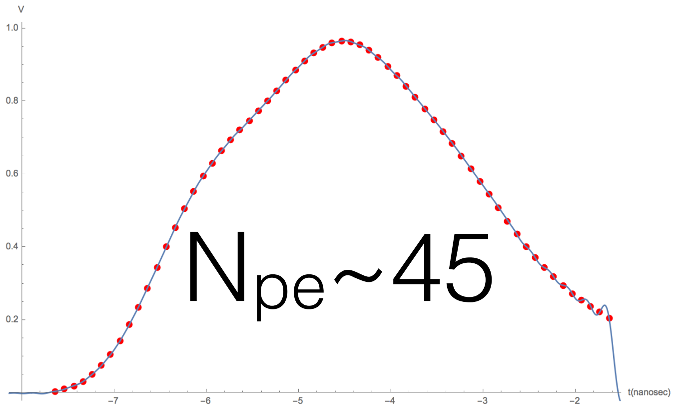
$$\text{templatefit}(\text{x\_}) := \sum_{i}^{61} \text{avewave}[\![i]\!]\ \text{sinc}\left(\frac{\pi\,(x - \text{ttt}[\![i]\!])}{0.1}\right)$$

Sinc expansion fit to Template Single pe waveform

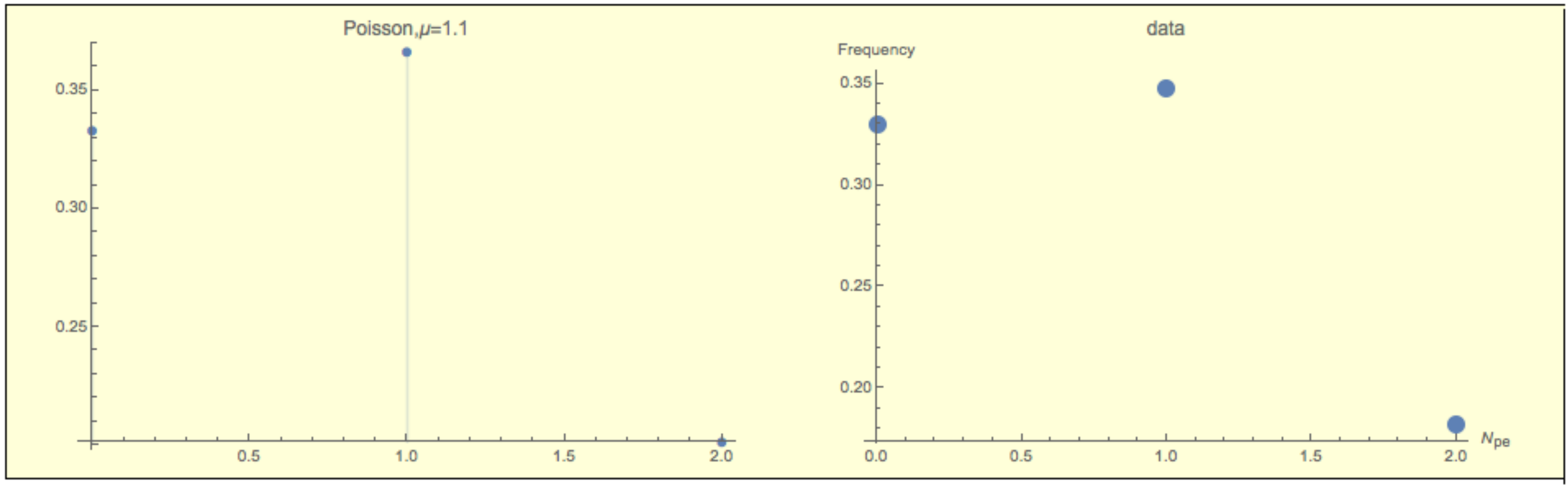
Out[148]=



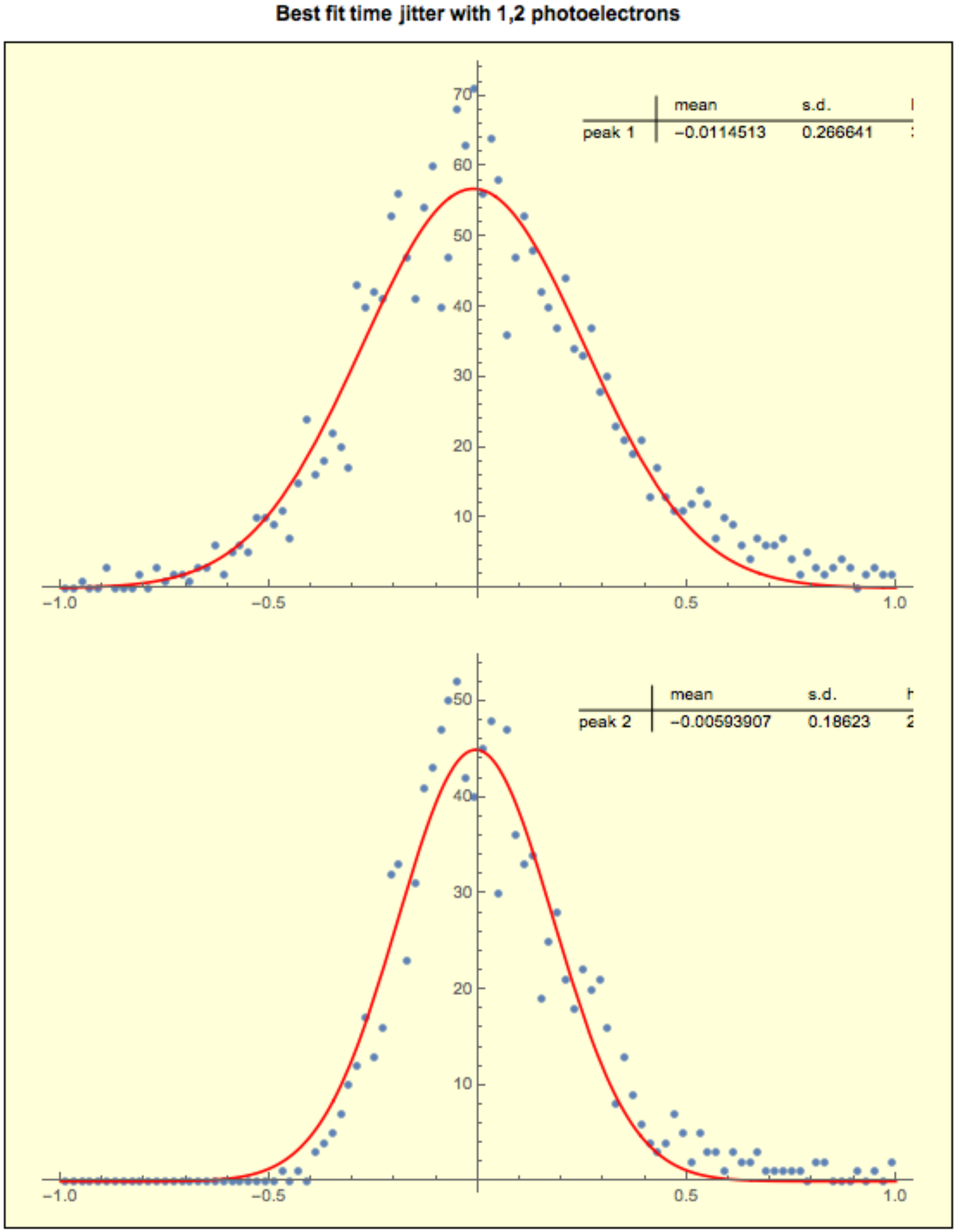




Best fit to N_{pe} Distribution,μ=1.1±0.1



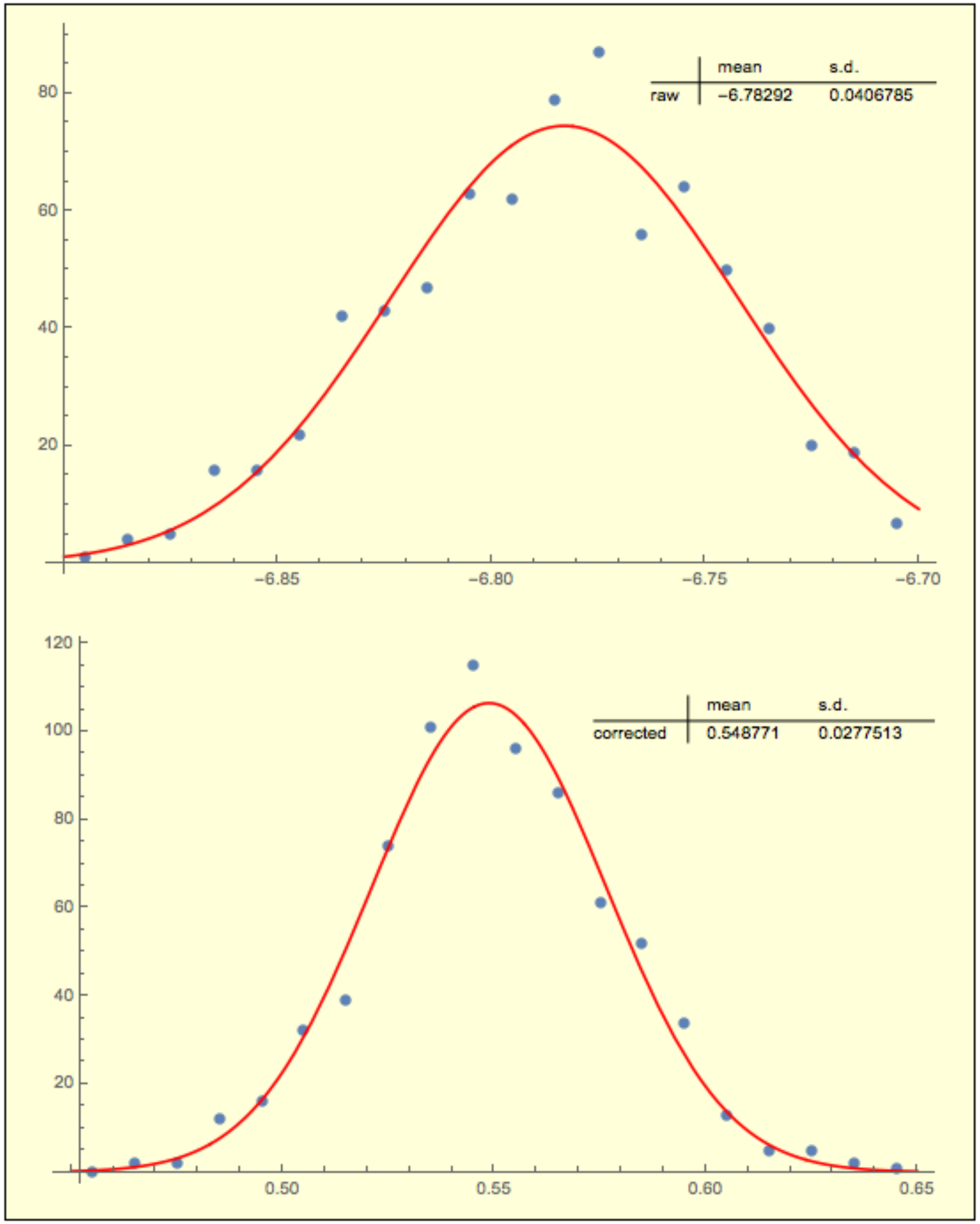
Time jitter for 1,2 pe

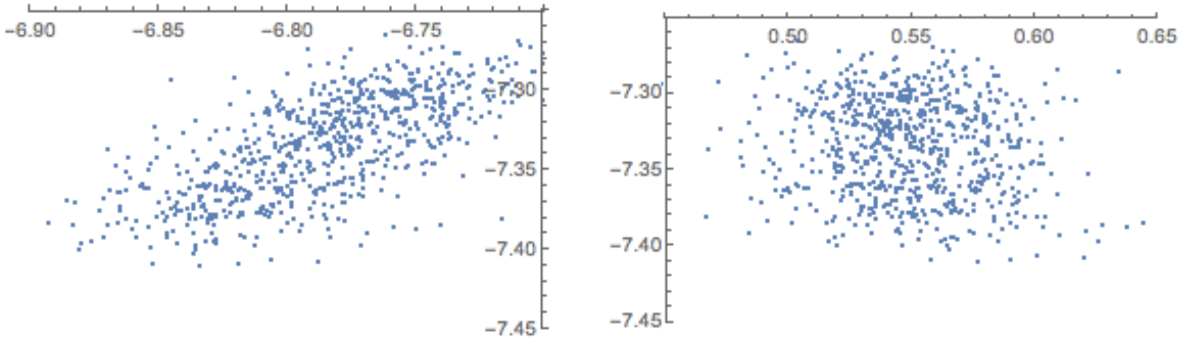

Best fit time jitter with 1,2 photoelectrons

Caveats:
1)robust method for 1,2 photoelectrons is template fit
2) for higher Npe find that CF method better
3) also some overlap of 1,2

for large Npe correlated jitter from scope trigger easily corrected e-by-e

Fit to MMegas time jitter and including laser PD correction, $\langle N_{\text{photoelectron}} \rangle$=45

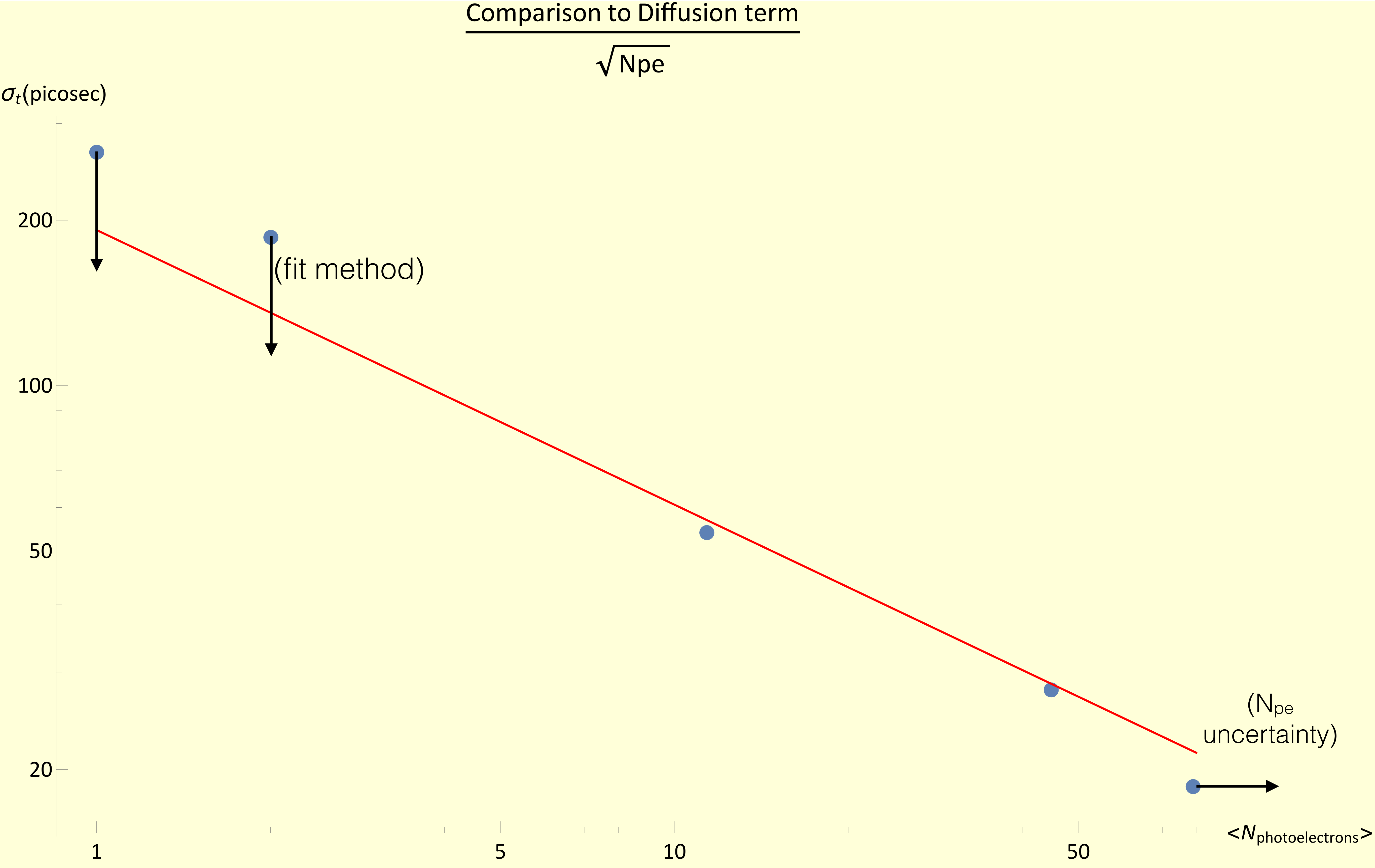




many internal checks on
Npe vs. run

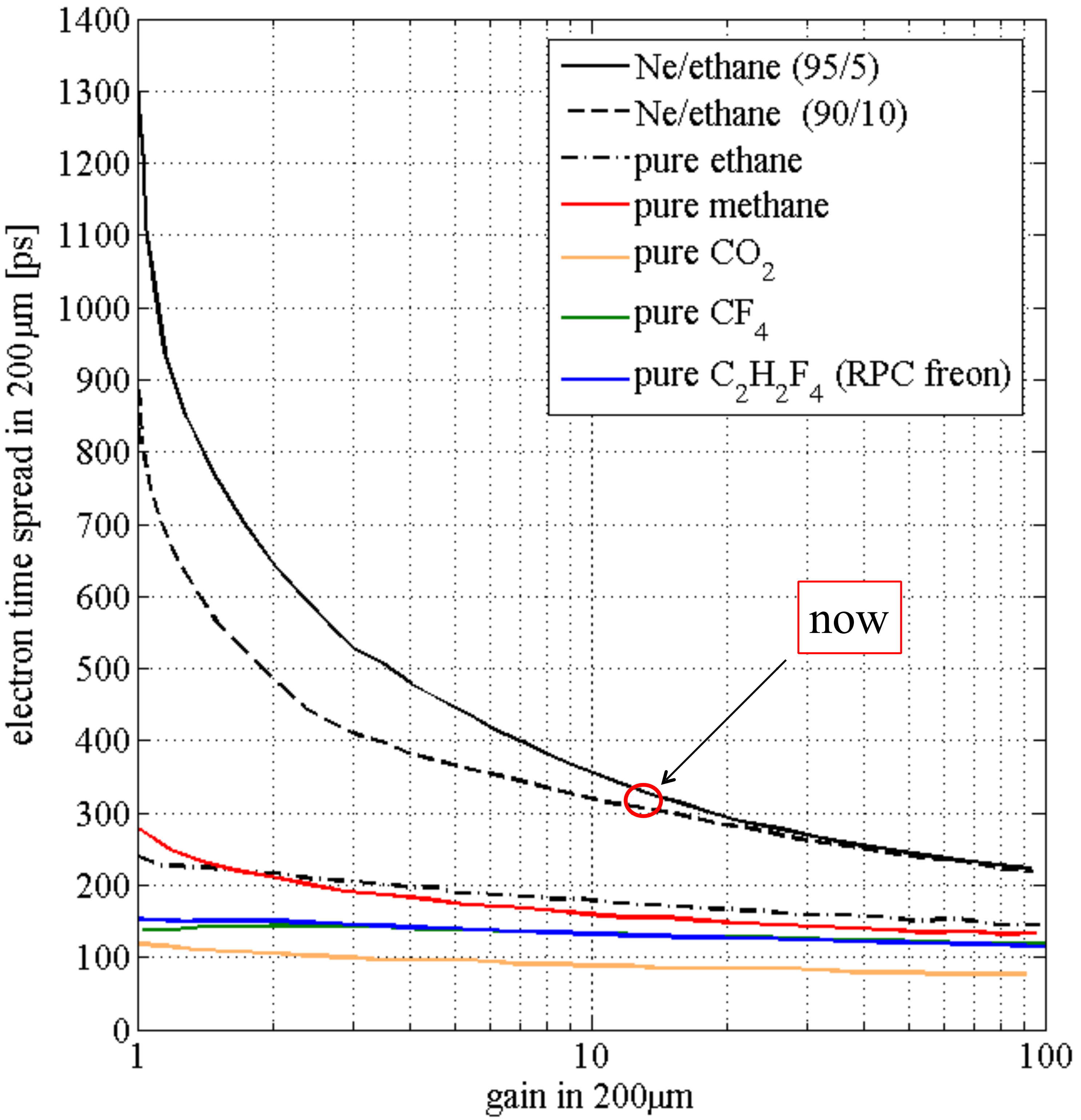
1) recalibrated optical filters
2) line width ~1/Sqrt[Npe]
3) amplitude

Summary of Ne-Ethane(10%): Efield=10kV/cm; Drift Gap =0.2 mm
1,2 pe data points consistent with 40% worse template method
fitted curve->~2xbetter than Sigma(diffusion)



Optimum gas mixtures in timing Micromegas? (D. Gonzalez&R. Veenhof)

Look for the minimum time spread ('fastest mixture') at any given gain



now

Simulations from Rob Veenhof
($C_2H_2F_4$ from data)

There's still room
at the bottom!

Notes:

- Working fields in the MM for pure quenchers need to be about x2 higher. May limit the gain in case of defects.
- Drift fields for pure quenchers need to be about x3 higher.
- Dissociative attachment for CO_2 and freons expected to be compensated by gain. Needs to be verified.

Could we eliminate need for radiator?
->Secondary emission
->Proposals by Princeton, Saclay

Plans(MPGD)

- continue tests w. Saclay chamber- laser and bench-> 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 in fall
- many interesting issues to follow proof of concept: gas & field configuration optimization, rate effects, photocathode development , possible benefits of reflective photocathode, etc.

really 2 collaborations w. overlapping interests

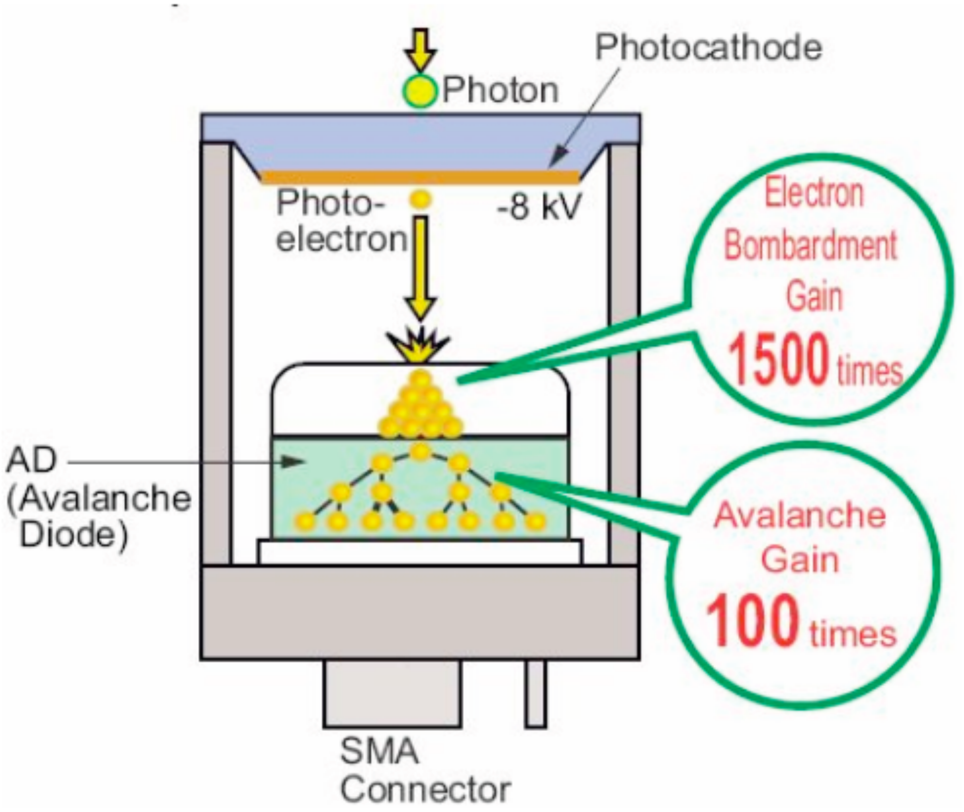
1) HFS=Mesh Readout Si

representing:

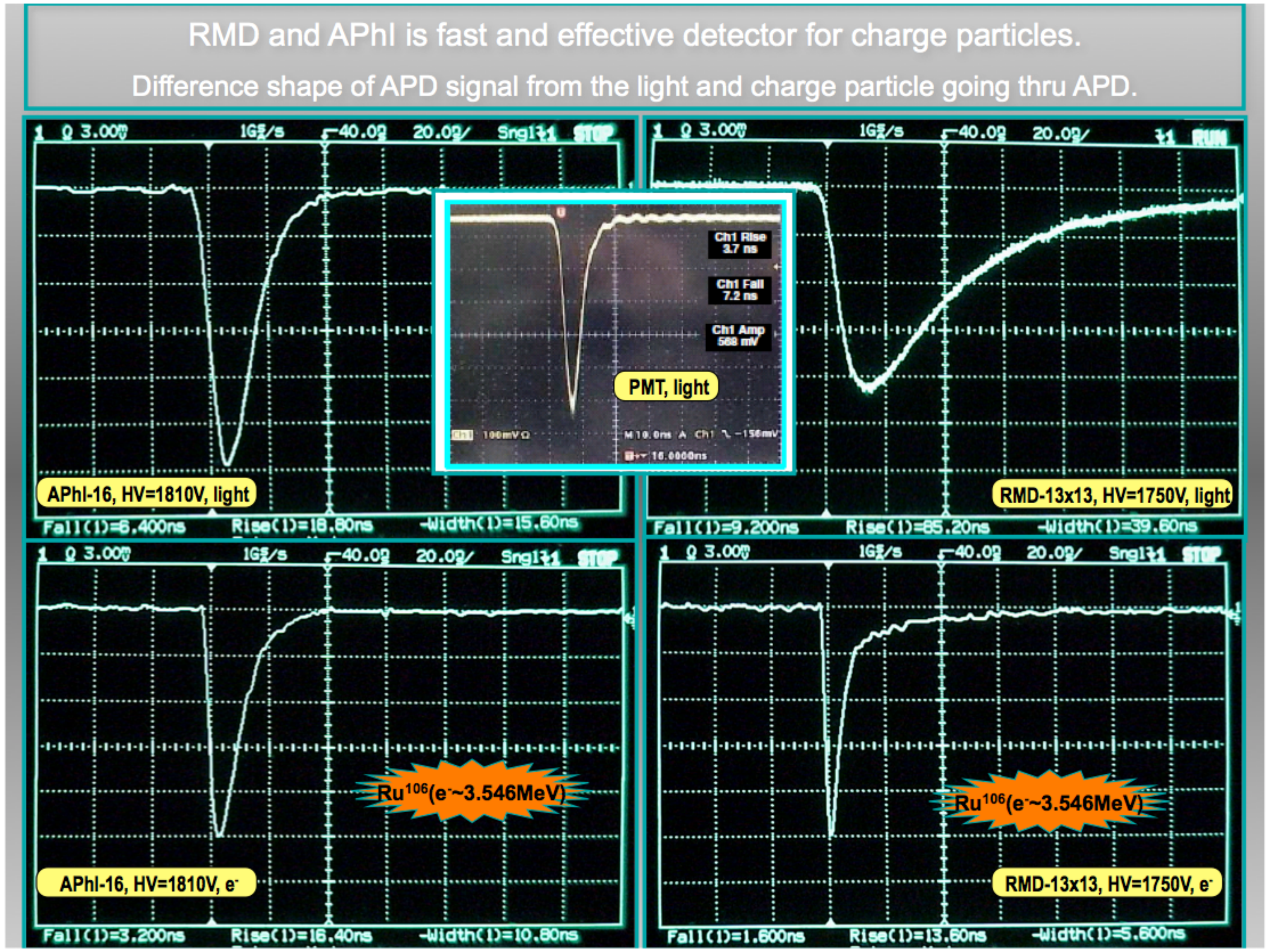
C. Williams*, P.Lecoq*, SNW -*in collaboration w. M. Moll, C. Gallrapp, M. Fernandez-Garcia*(CERN)
E. Delagnes (CEA/Saclay)
K. McDonald, C. Lu,K.Mei, C. Tully & SNW (Princeton)
M. Newcomer (U. Penn)
for USCMS Phase II Upgrade R&D

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

How we got into Avalanche Diodes



Koei Yamamoto, Motohiro Suyama, HPK
In 2009 we evaluated their pre-production alternative to MCP
we found 11 pico sec SPTR
Clear indication that Avalanche diode intrinsically a fast charged particle detector!

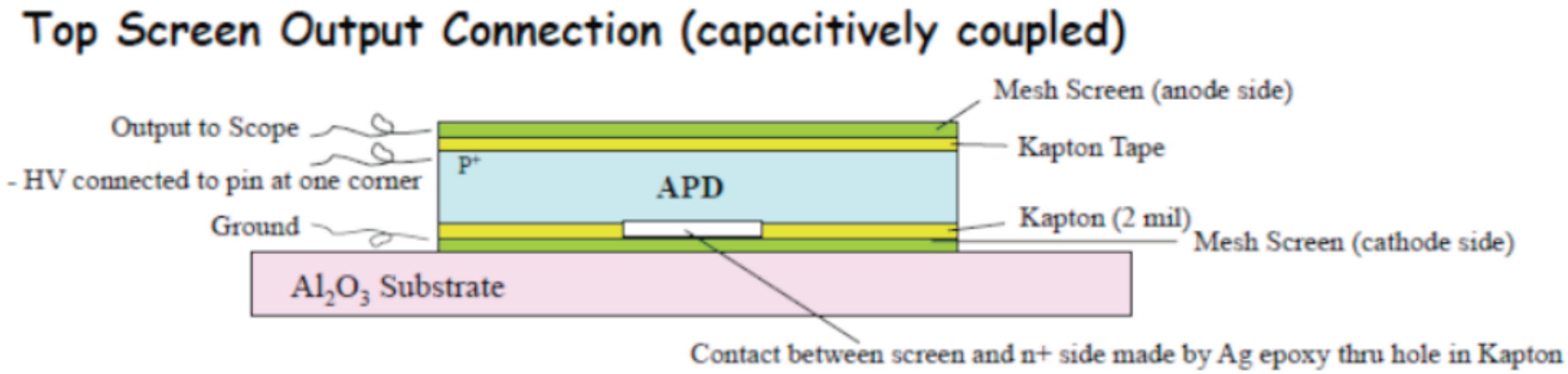


RMD and APhI is fast and effective detector for charge particles.

Difference shape of APD signal from the light and charge particle going thru APD.

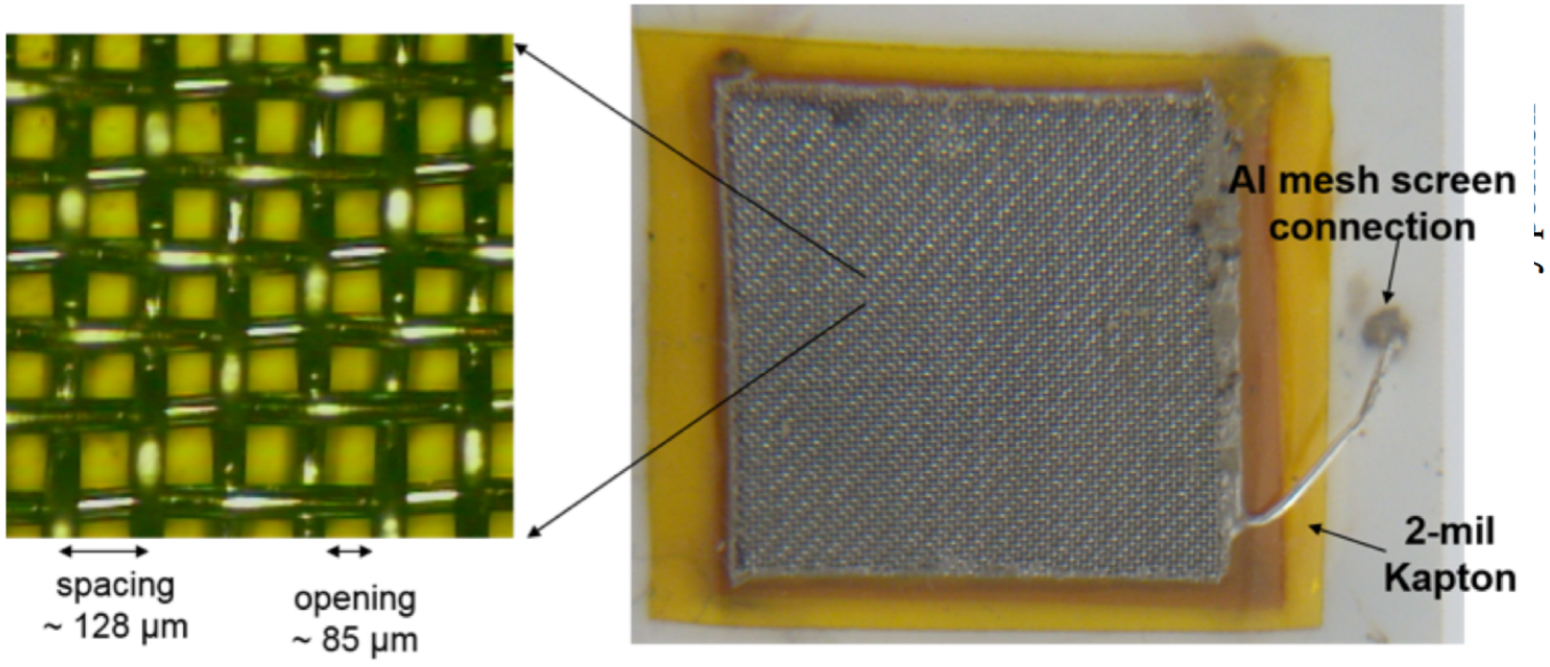
Could such an intrinsically fast device with very large MIP signal be exploited for timing?

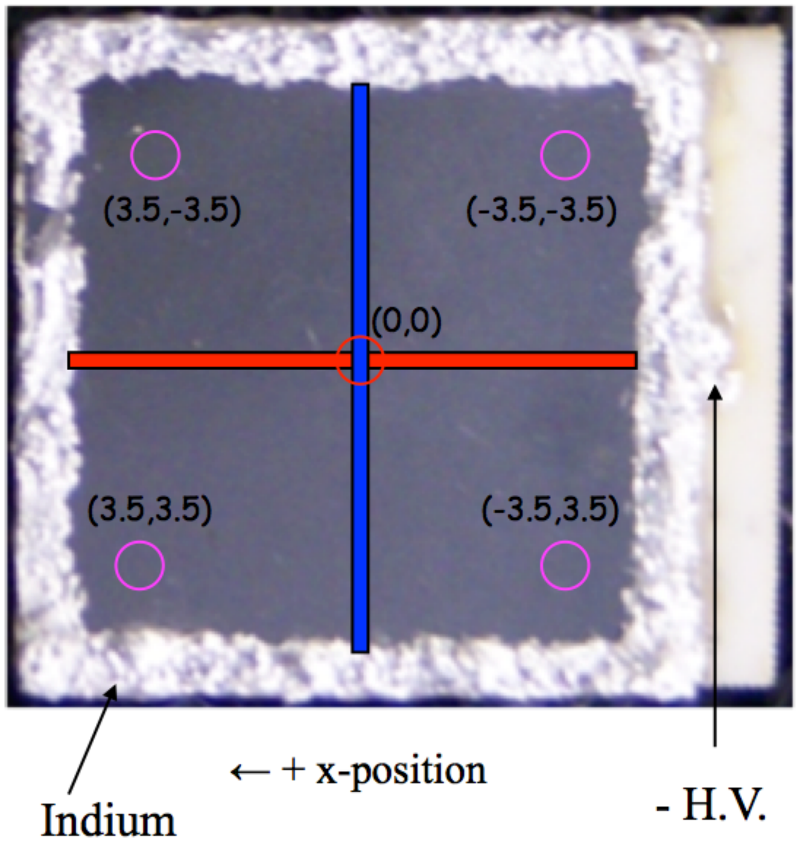
Detector Concept


Top Screen Output Connection (capacitively coupled)

top view

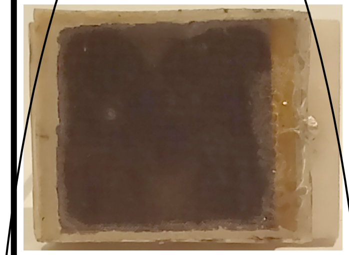
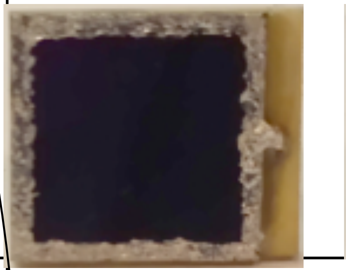
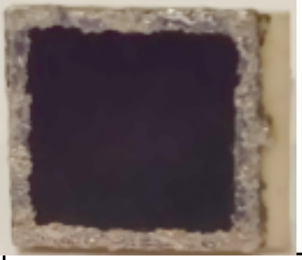
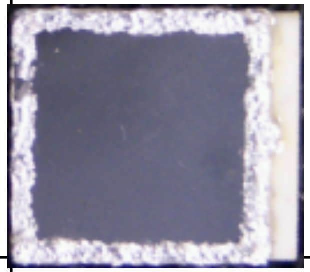
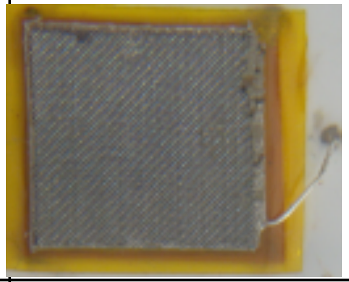
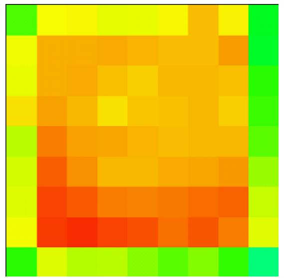
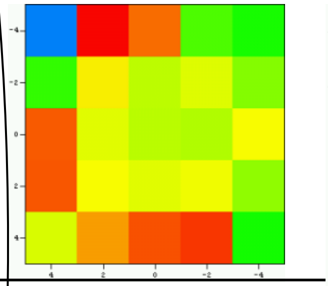
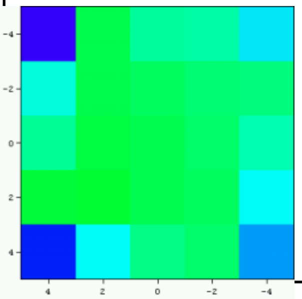
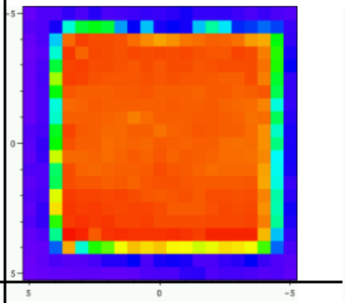
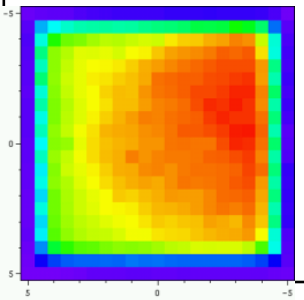
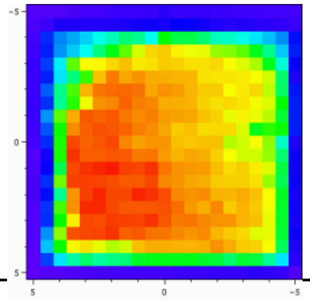
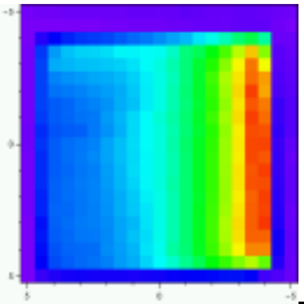
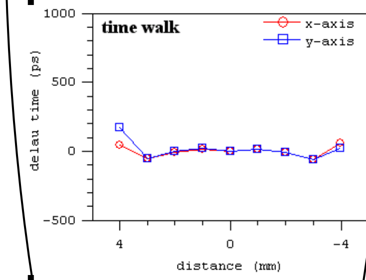
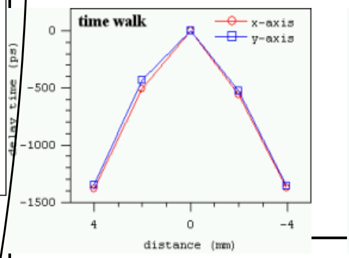
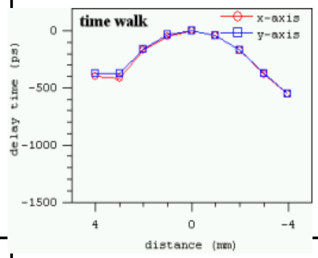
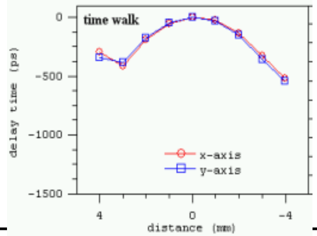
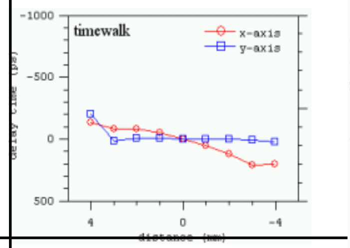
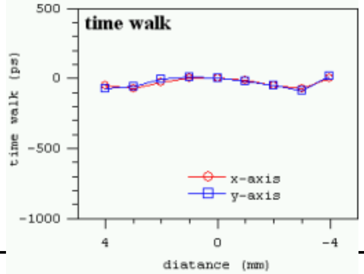
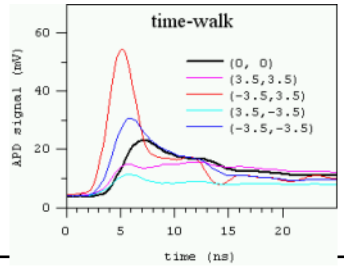
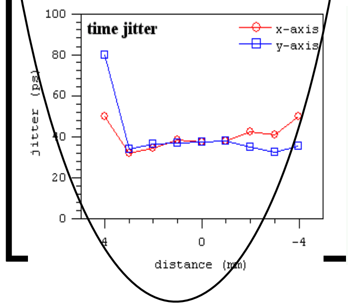
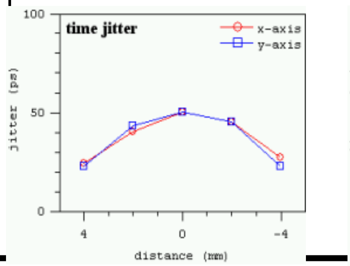
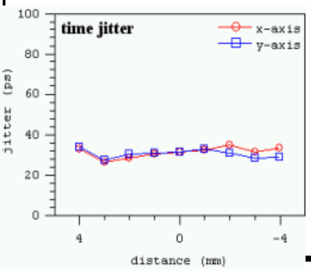
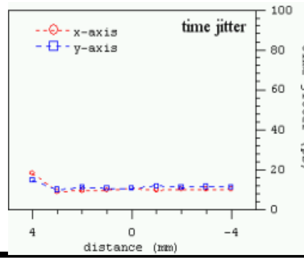
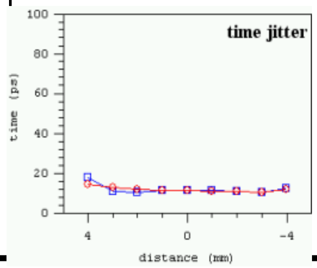
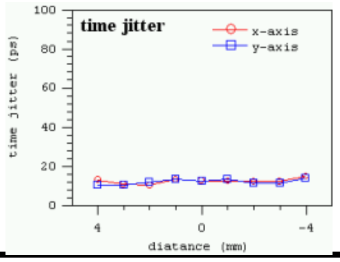
early variant





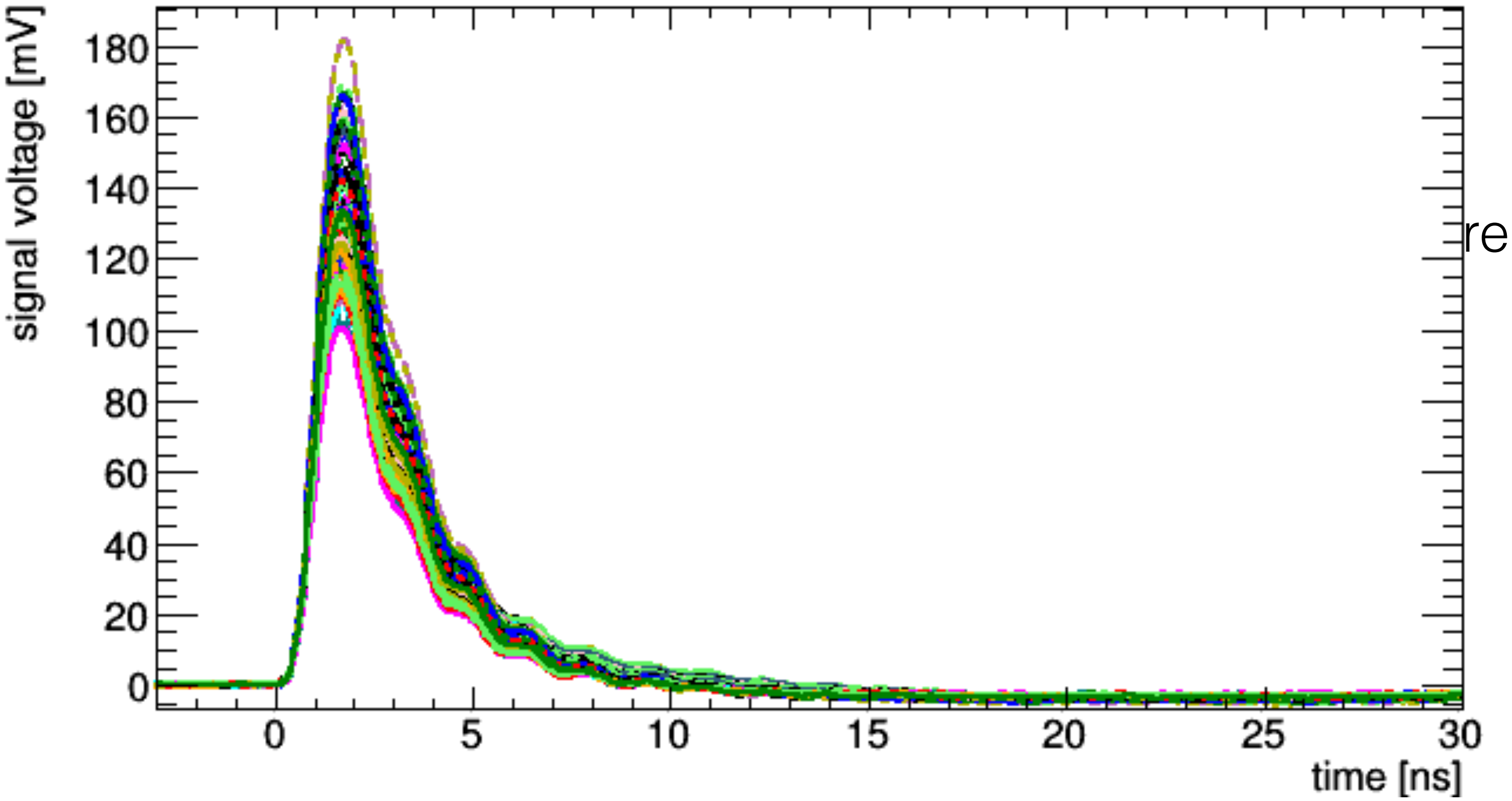
- emphasis of our development has been to deal with weighting field uniformity for fast signals
- essential outcome is that detectors look like a good capacitor at high frequencies
- relevance in the NA62 Gigatracker development where it was found that dominant jitter from:
- weighting field
- Landau 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)-recent scan data->~3 pico sec time walk in 8mm

2015- M. Moll Lab

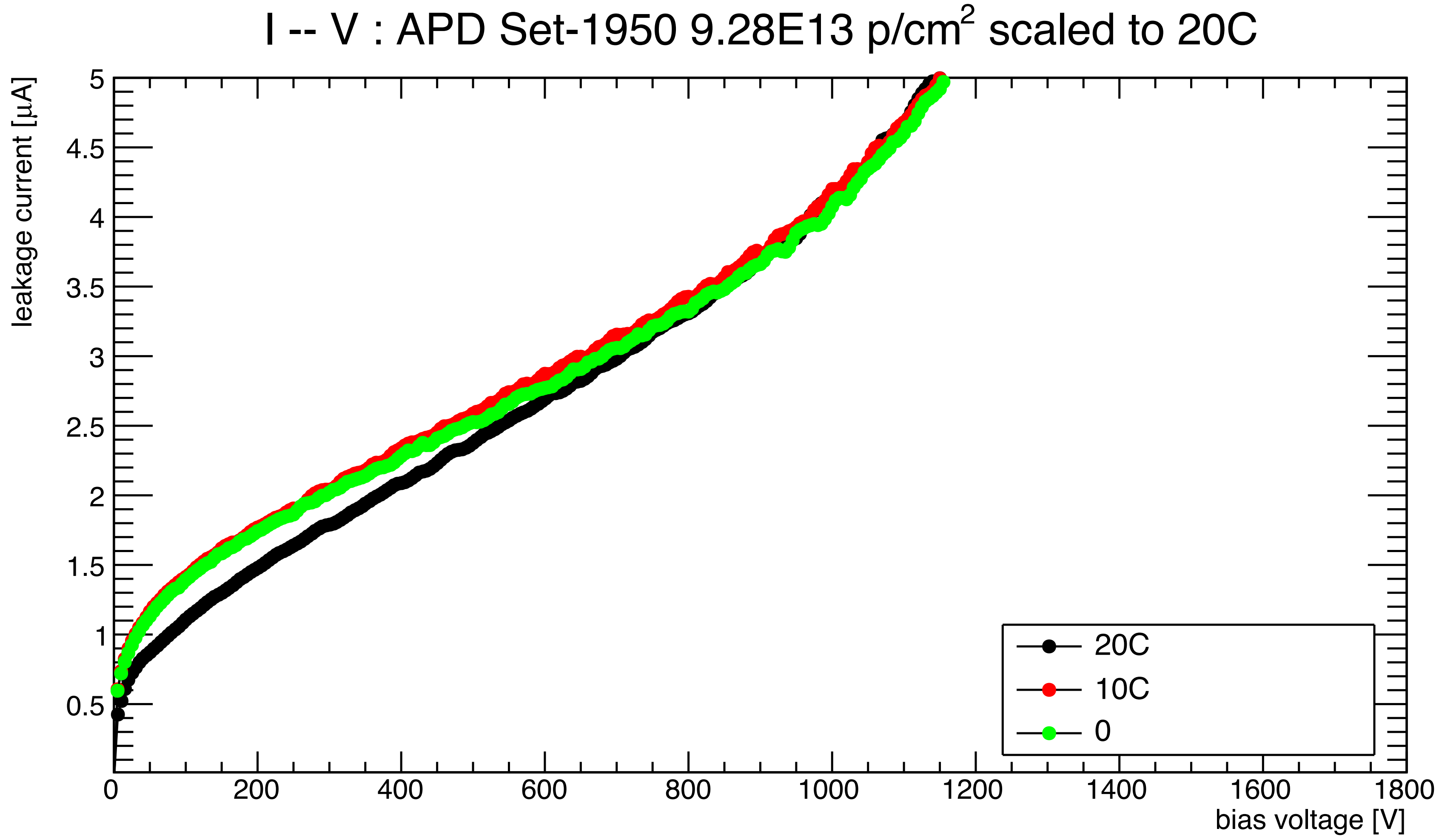


IR-surface scan of 2x2mm^2
detector wo. screen
reasonable time walk but worse amplitude
uniformity- C. Gallrapp

RD50 infrastructure enabling us to address open questions which can aid modeling

1) relative importance of top-side screen and bottom sintered Au
2) have we also created a faster photodetector?
3) how critical is metallization at smaller pixel size?
4) Is there an optimum gain for intrinsic time jitter?
5) what is optimum dielectric thickness (lowering C_{det})?
6) rad dam issues- leakage current and Gain stability- So far to 10^{14} p/cm^2

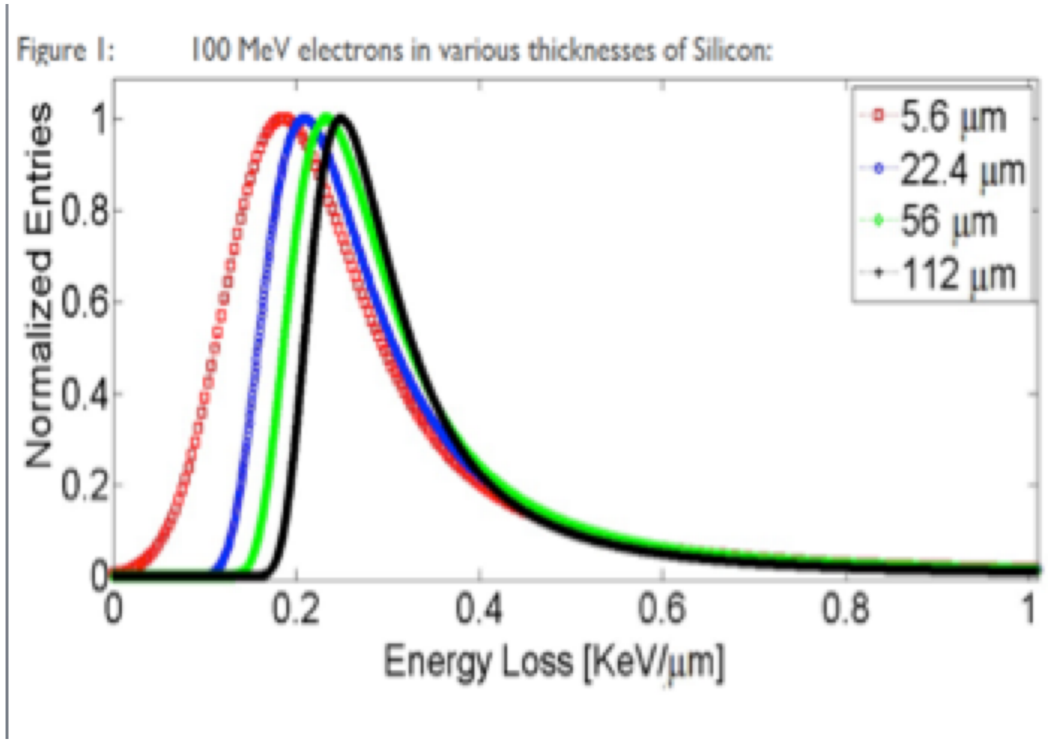
Radiation Exposures

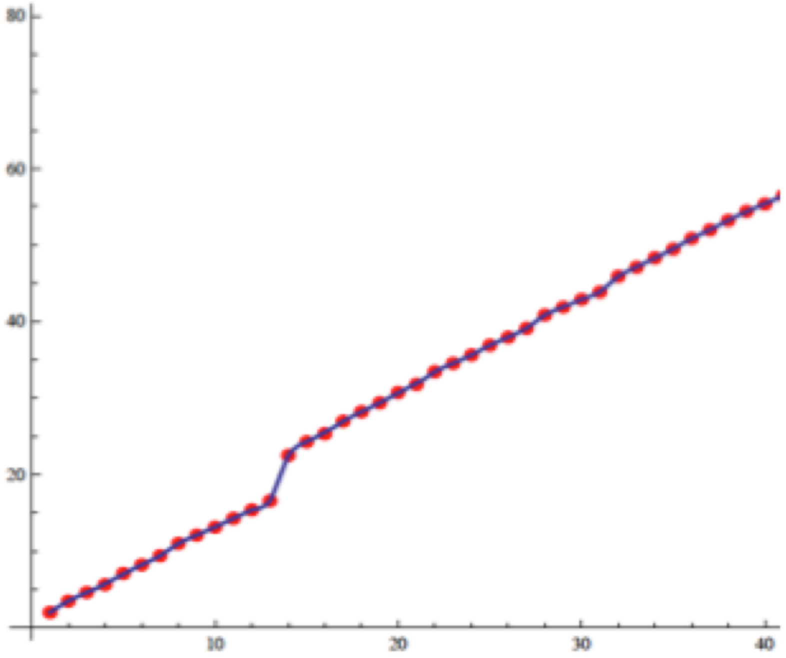


Initial Exposure this year to $9.3x10^{13}$
growth in bulk leakage from displacement damage as predicted.(SNW et al. http://arxiv.org/abs/0901.2530)
Further tests on Gain stability after more complete baseline measurements.
Relevant for another RD50 project (LGAD) since we use heavier element doping-ie not Boron.

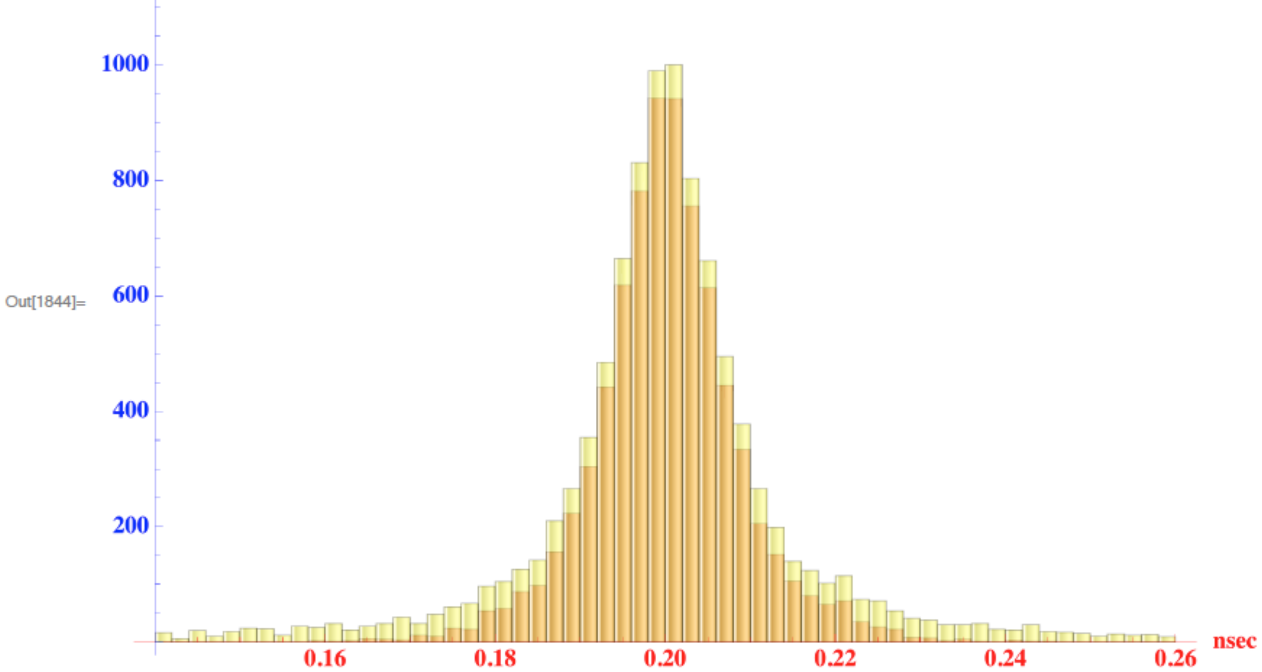
Landau/Vavilov contribution

(original model)

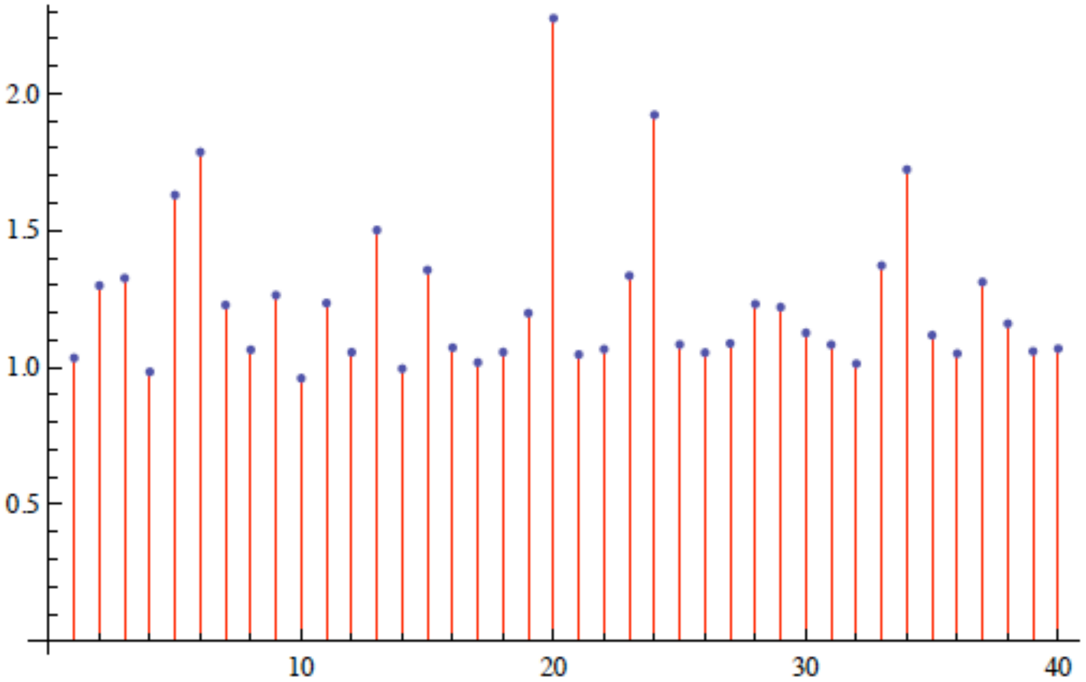




Mean Signal Arrival Time



```
Cut in Signal amplitude at 77.35
 % efficiency reduces time jitter from 0.022641 to 0.00870866nsec
```



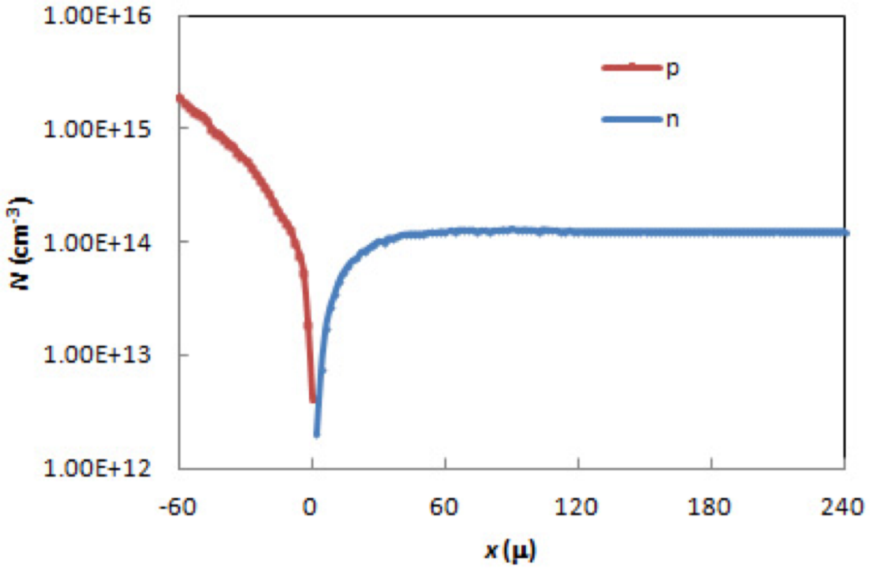
Simulated energy deposit/per each of 40
1 micron layers-typical event

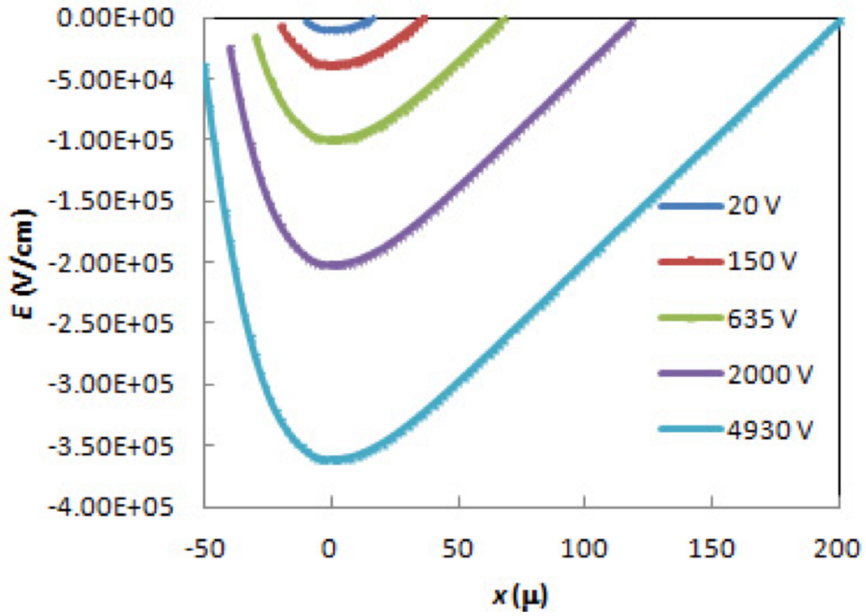
Develop Model for signal source

see eg.K.T. McDonald, Electric Field Distribution in a

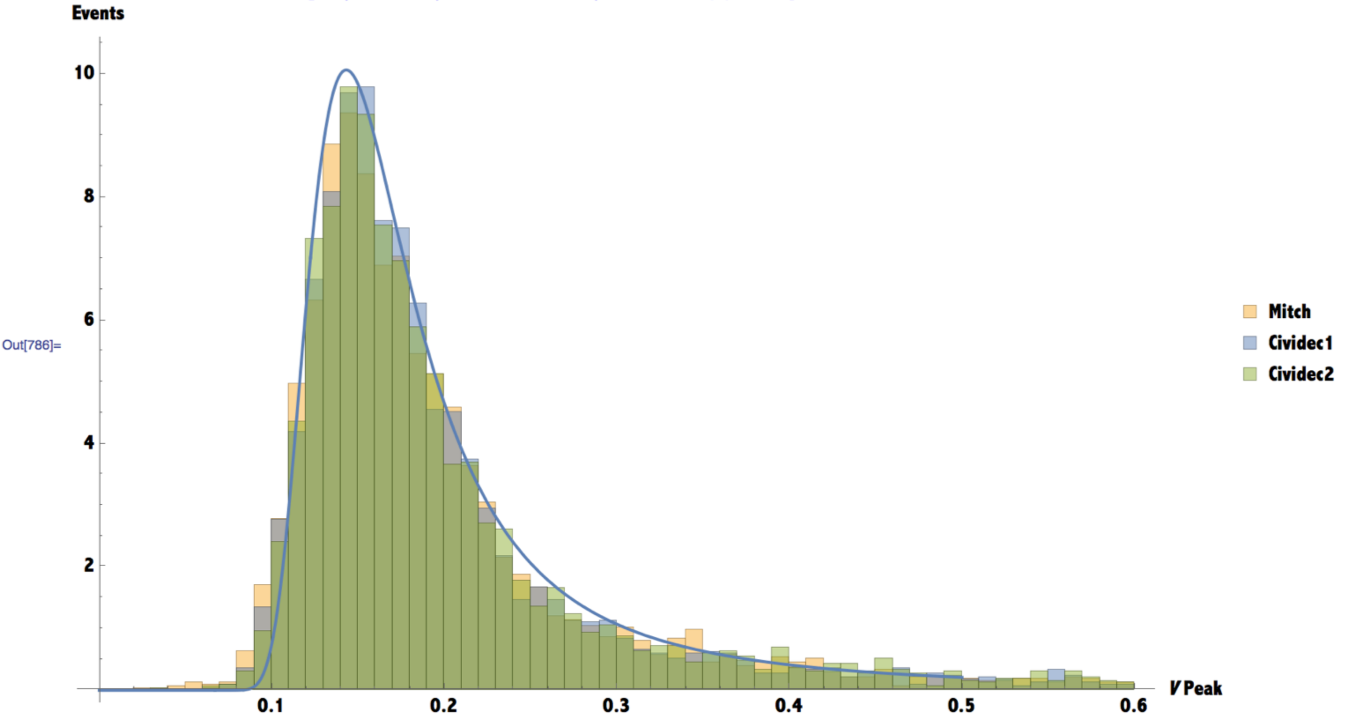
Reverse-Biased p-n Junction (Sept. 13, 2015),

http://physics.princeton.edu/~mcdonald/examples/diode.pdf

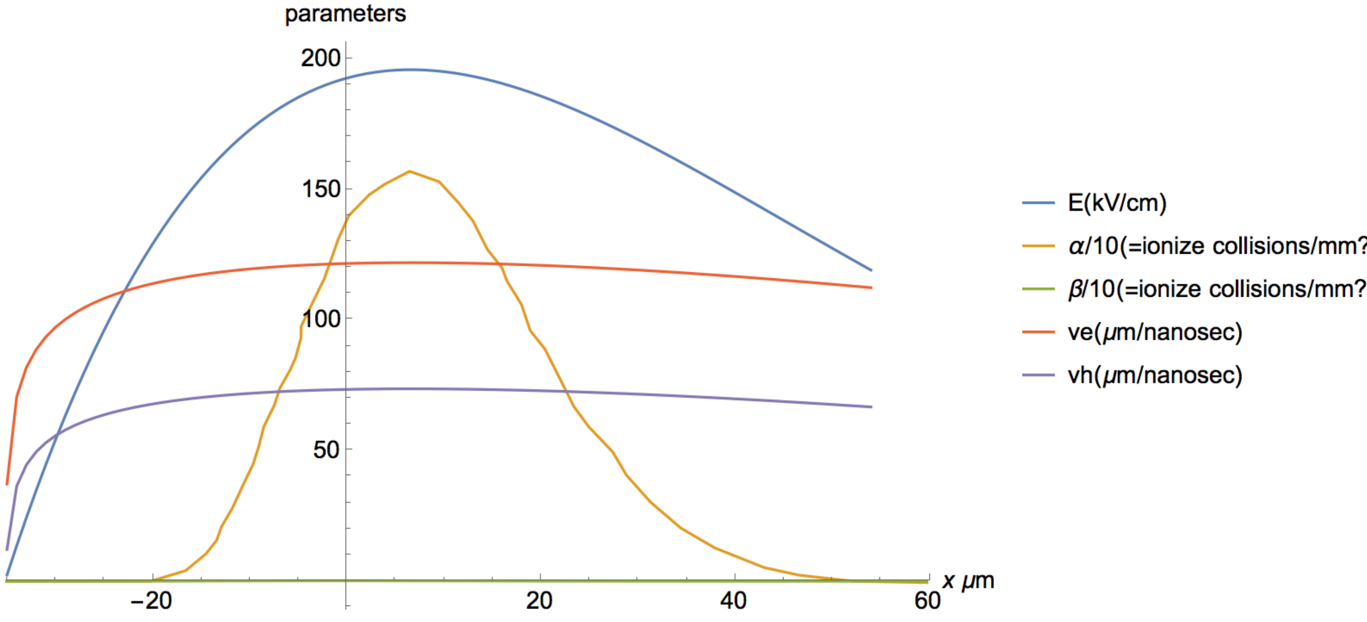




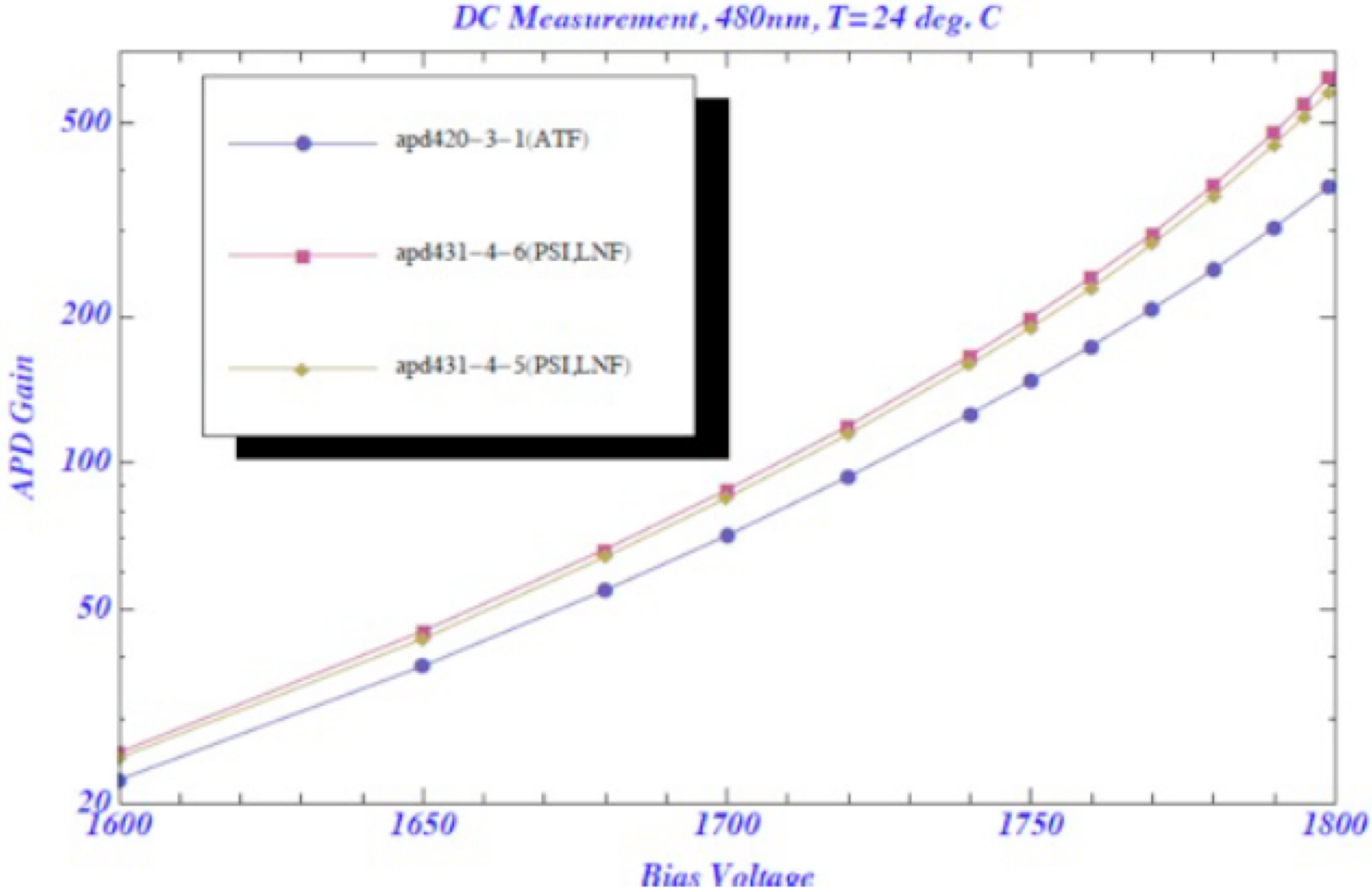
data


Aug. 3, 2015 PS, 3 HFS detectors, Peak value(V)– compare Meroli et al.

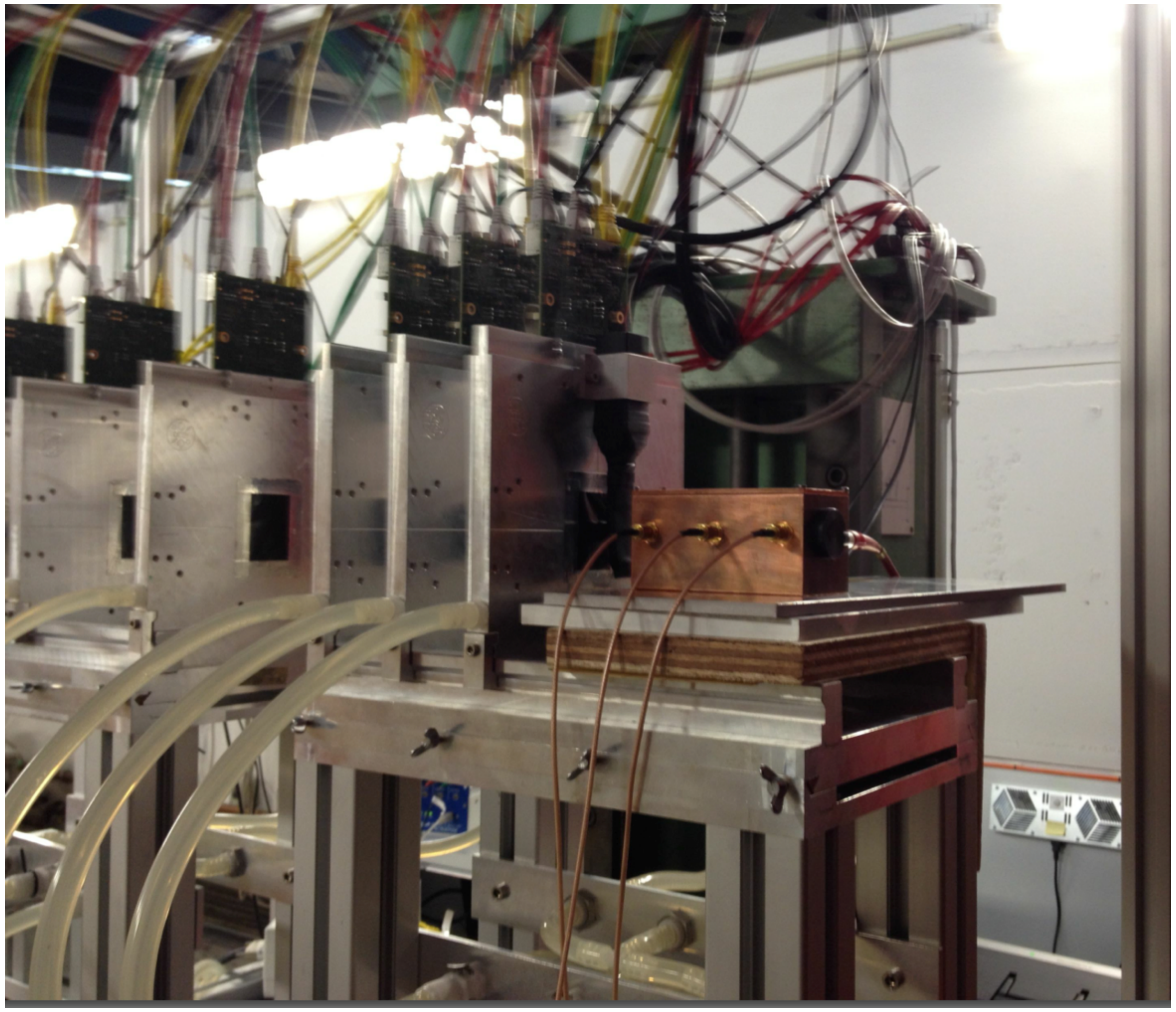
Snapshot of Field Profile, α, β, ve, vh

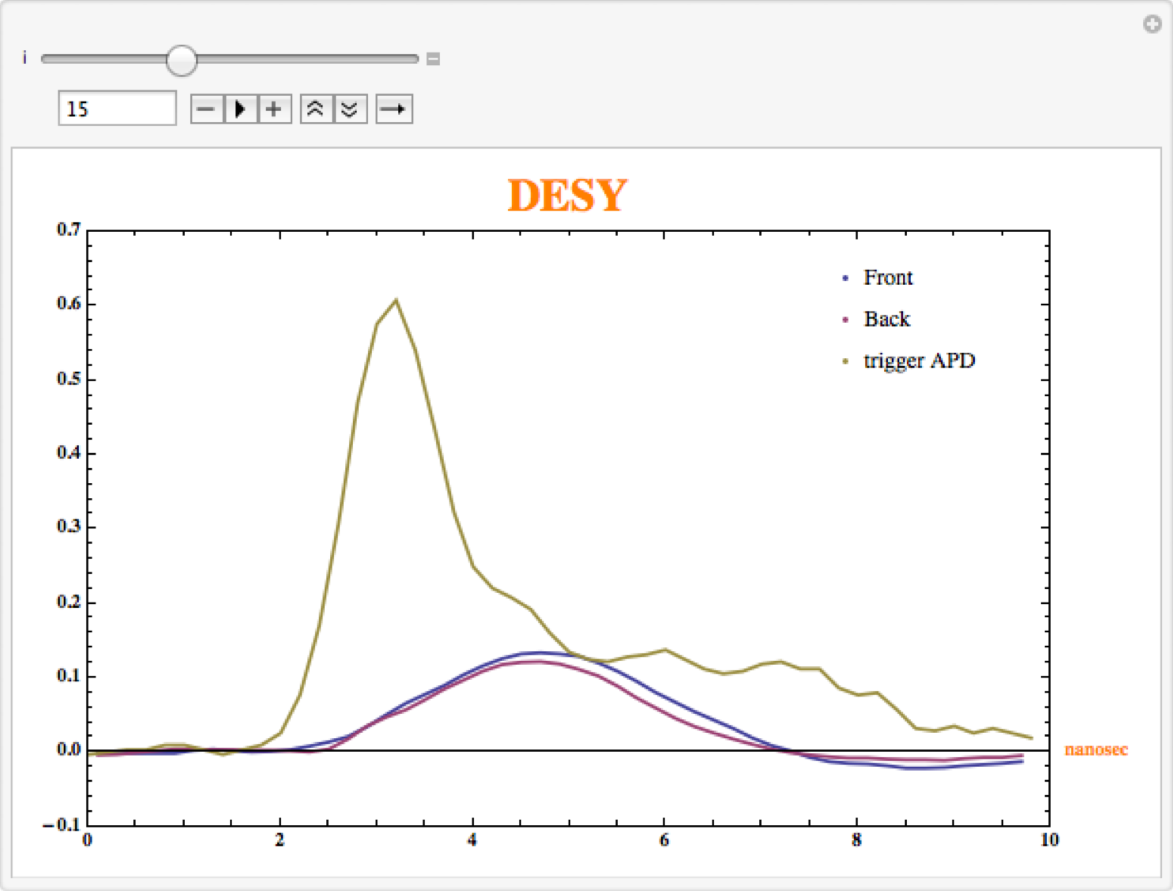


testbeam data taken at SPS, DESY, PSI, FNAL typically at detector bias ~1770-1800V



DESY 2014

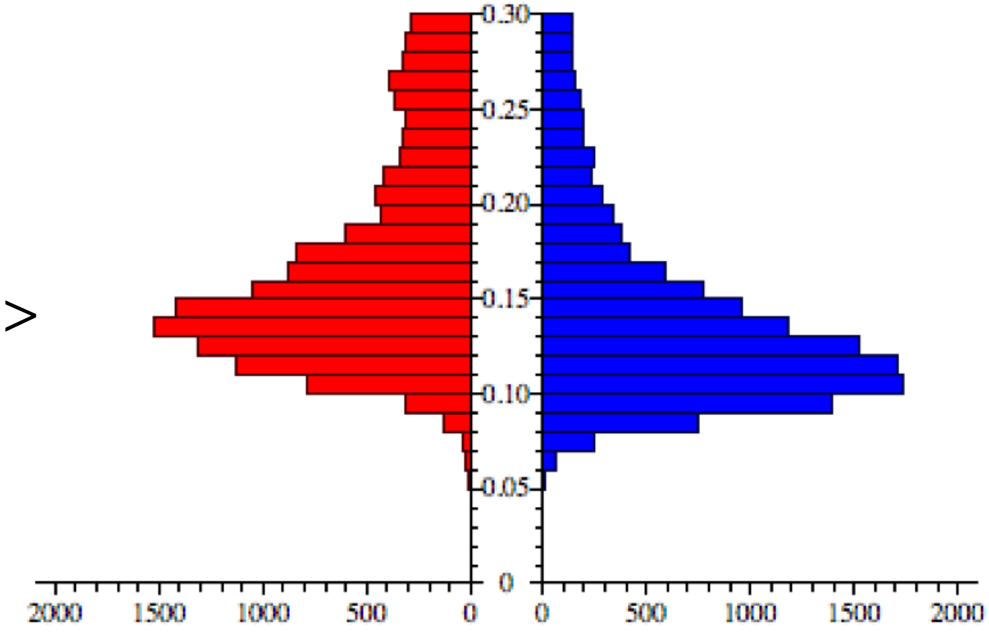




Peak amplitude 1/5 that of 4 pF detector
in large area 60 pF detector

Sim and DESY data

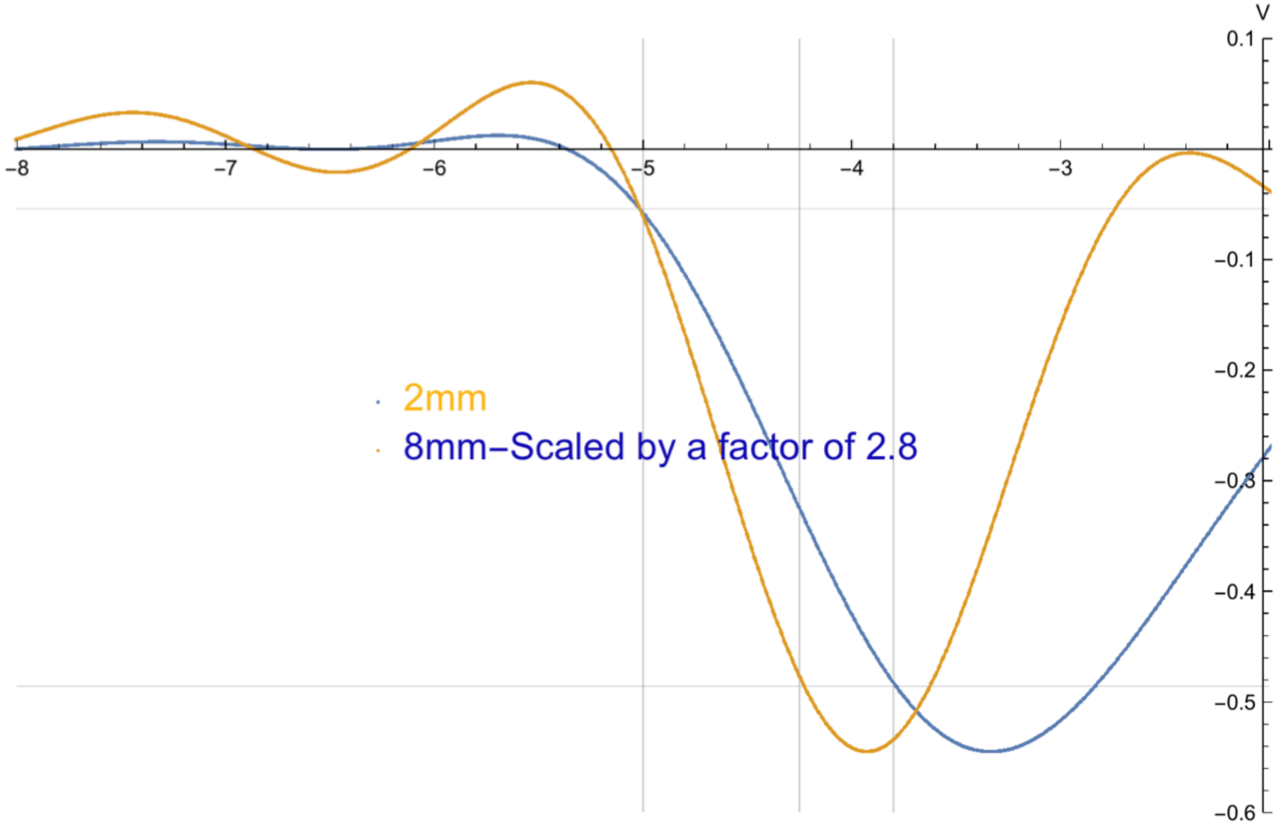
front, back detector ph distribution->



back to electronics:

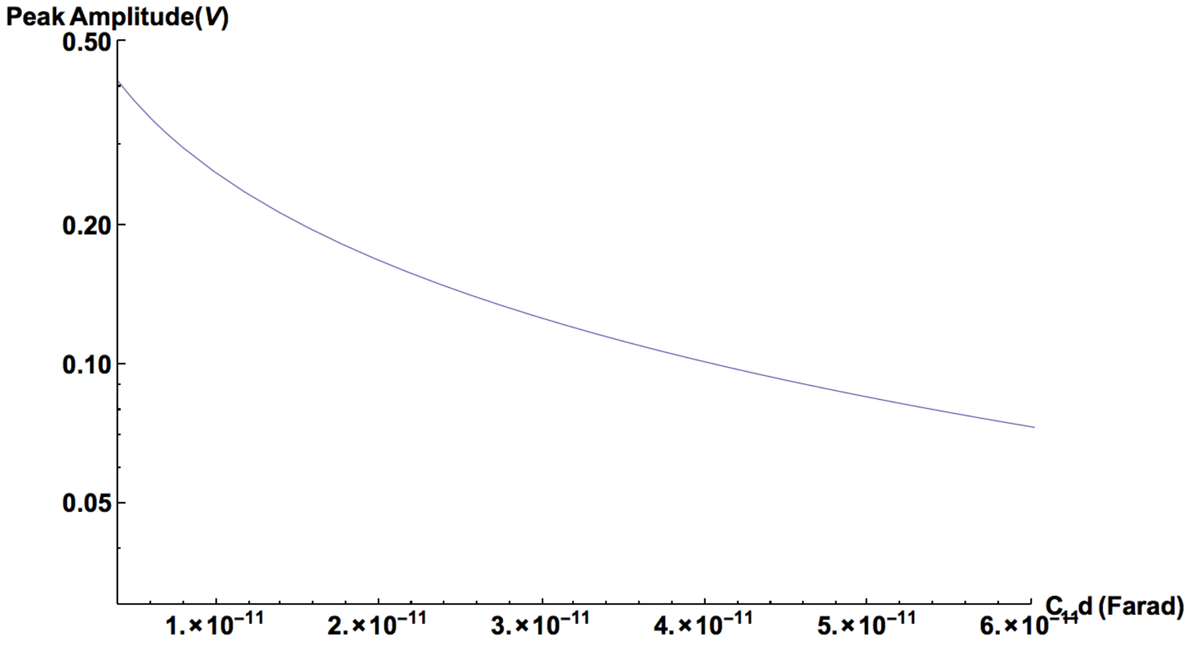
- following these developments, electronics is now our limit to timing. Why do we get 10 rather than 4 picoseconds?
- primarily due to our choice of pixel size.
- C_det for diamond typically<2 pF.
- currently ours is ~25 pF

measurement



```
LogPlot[maxresp , {cd, 4 * 10^-12, 100 × 10^-12}, AxesLabel → {  C_d[Farad], Peak Amplitude[V]},
 PlotRange → {{4 × 10^-12, 60 × 10^-12}, {.03, .5}}, LabelStyle → Directive[Bold, Larger]]
```

$$\mathrm{ku}\,\mathrm{Qi}\,\mathrm{ri}\left(-\frac{\left(\frac{\mathrm{cd}\,\mathrm{ri}}{\mathrm{taup0}}\right)^{-\frac{\mathrm{cd}\,\mathrm{ri}}{\mathrm{cd}\,\mathrm{ri}-\mathrm{taup0}}}}{\mathrm{cd}\,\mathrm{ri}-\mathrm{taup0}}+\frac{\left(\frac{\mathrm{cd}\,\mathrm{ri}}{\mathrm{taup0}}\right)^{-\frac{\mathrm{taup0}}{\mathrm{cd}\,\mathrm{ri}-\mathrm{taup0}}}}{\mathrm{cd}\,\mathrm{ri}-\mathrm{taup0}}\right)$$



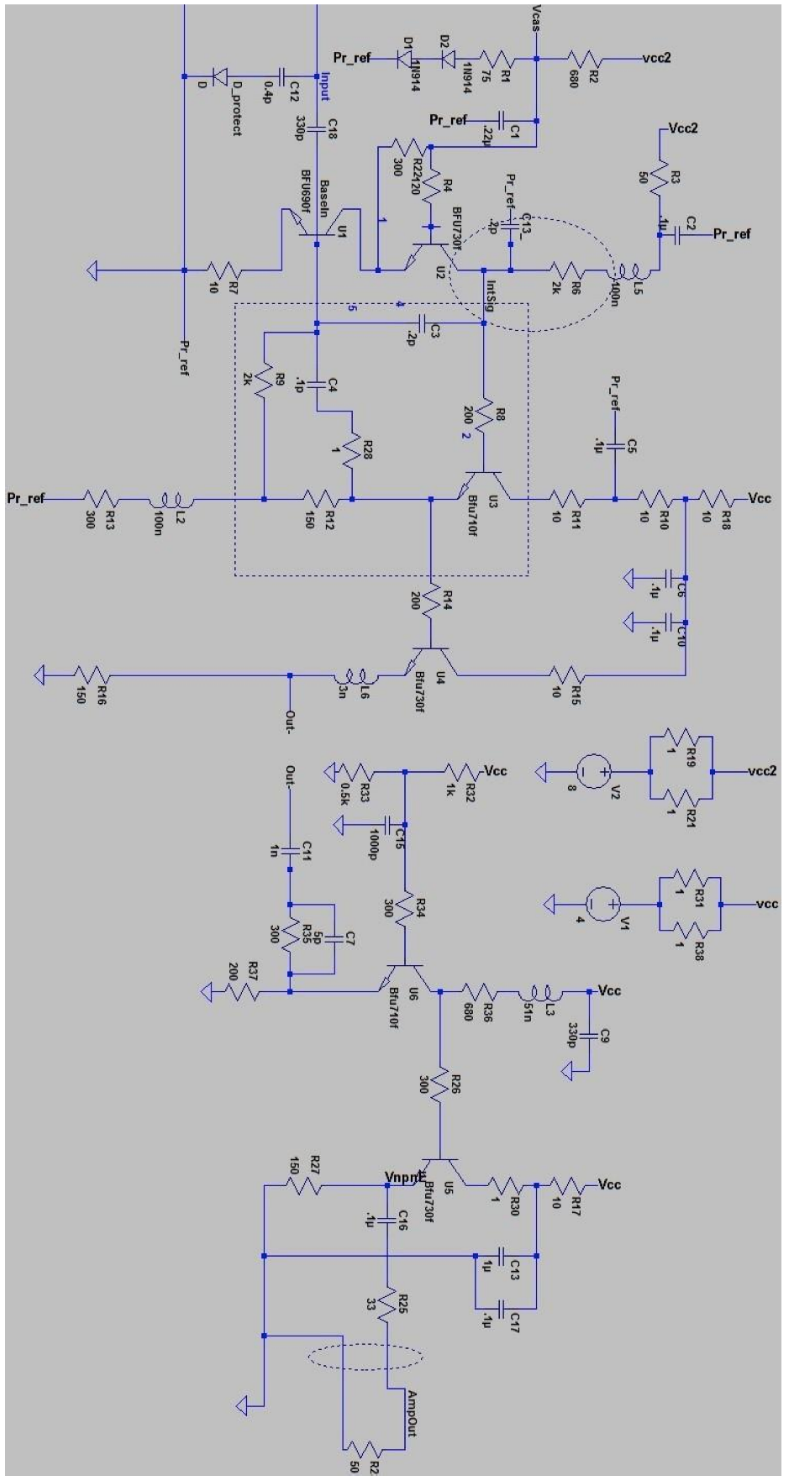
circuit model

can we optimize amp
for timing w. 25 pF detector?
ASIC development at Penn is
part of this project

Amp Development at Penn

(Mitch Newcomer,Emmanuel Morales,Susan Fowler)

The following LTspice schematic shows all the connections and values on the board.



ⓐ 160.00ps −34.48mV
ⓑ −1.0200ns −3.487mV
Δ1.1800ns Δ31.00mV

2 5.00mVΩ

	Value	Mean	Min	Max	Std Dev
M Rise Time	----.s	No source wfm			

Edge Search events found: 31

2.00ns
T 44.40 %

5.00GS/s
10k points

2 ⤵ −31.0mV

15 Jul 2015
15:00:06

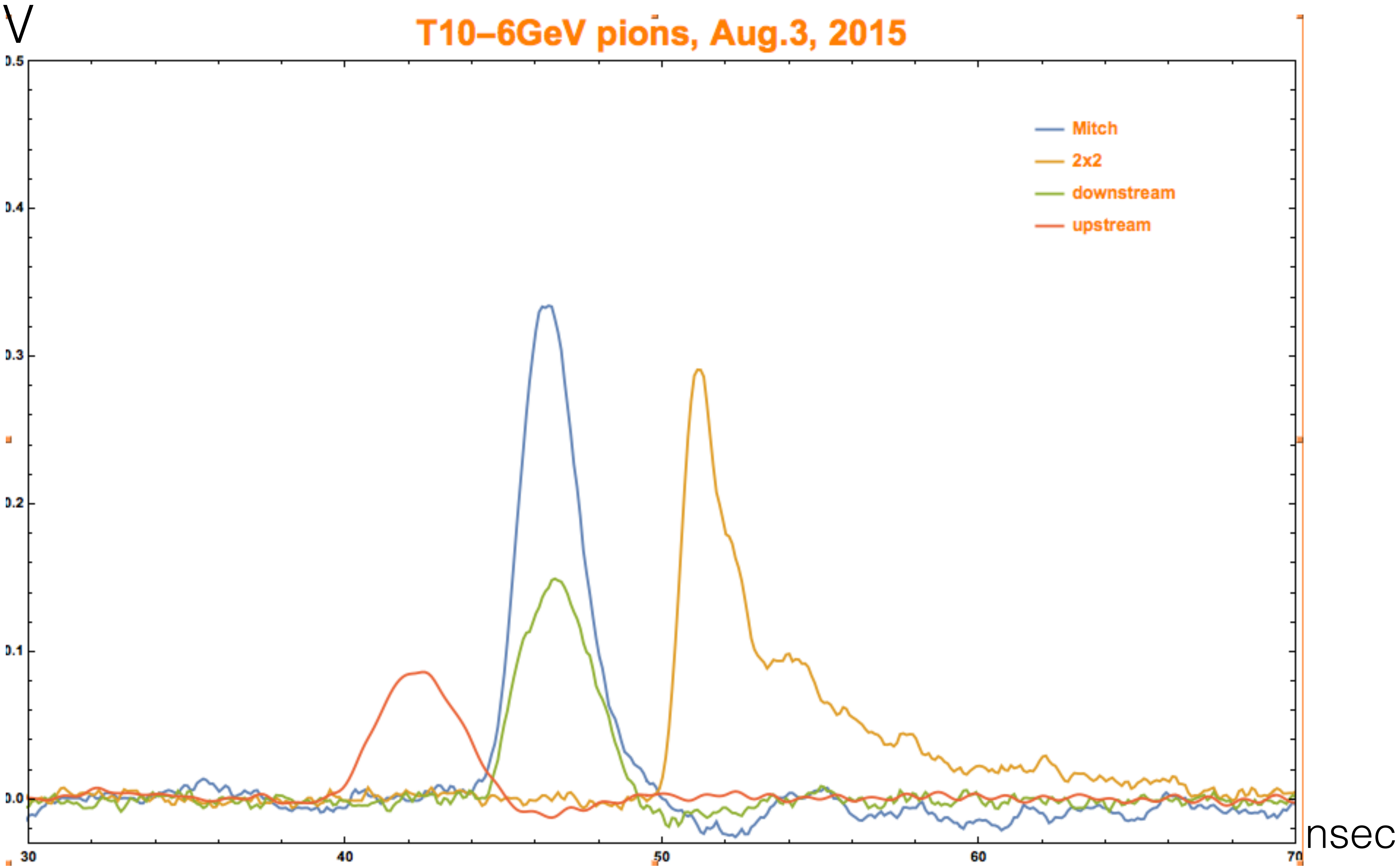
extensive testing w. Fe^{55}
ready for the Aug. ’15 T10 test

Si-Ge IBM process

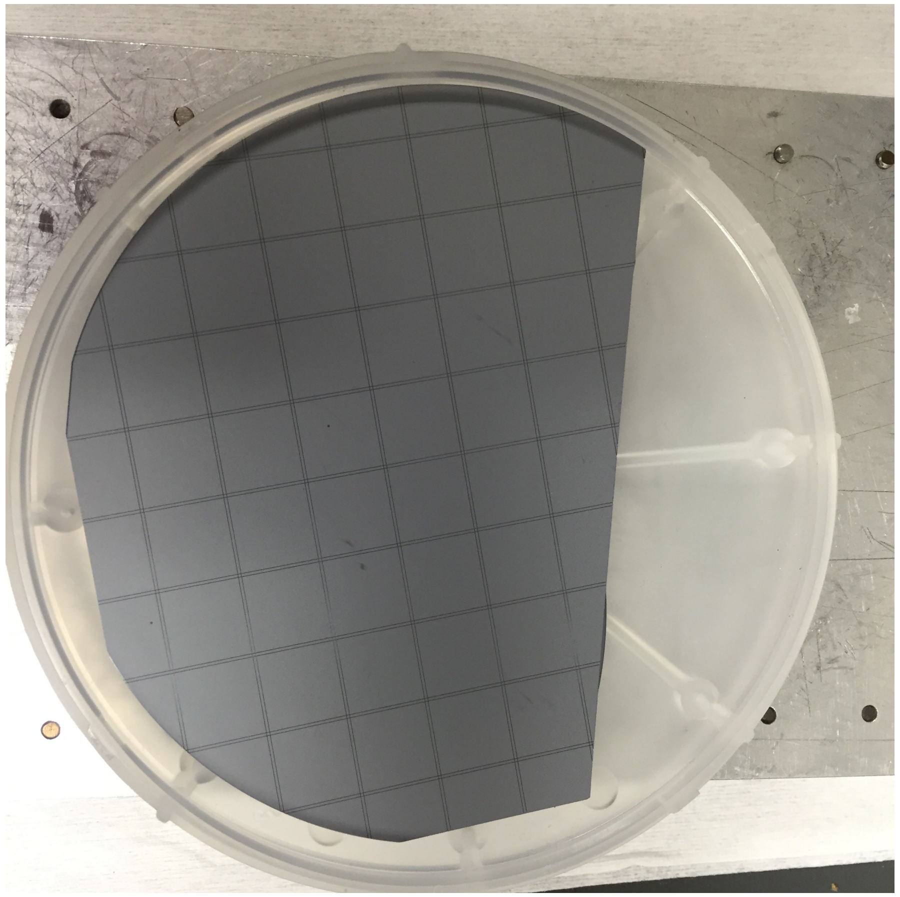
Fast Timing R&D for the HL-LHC Era

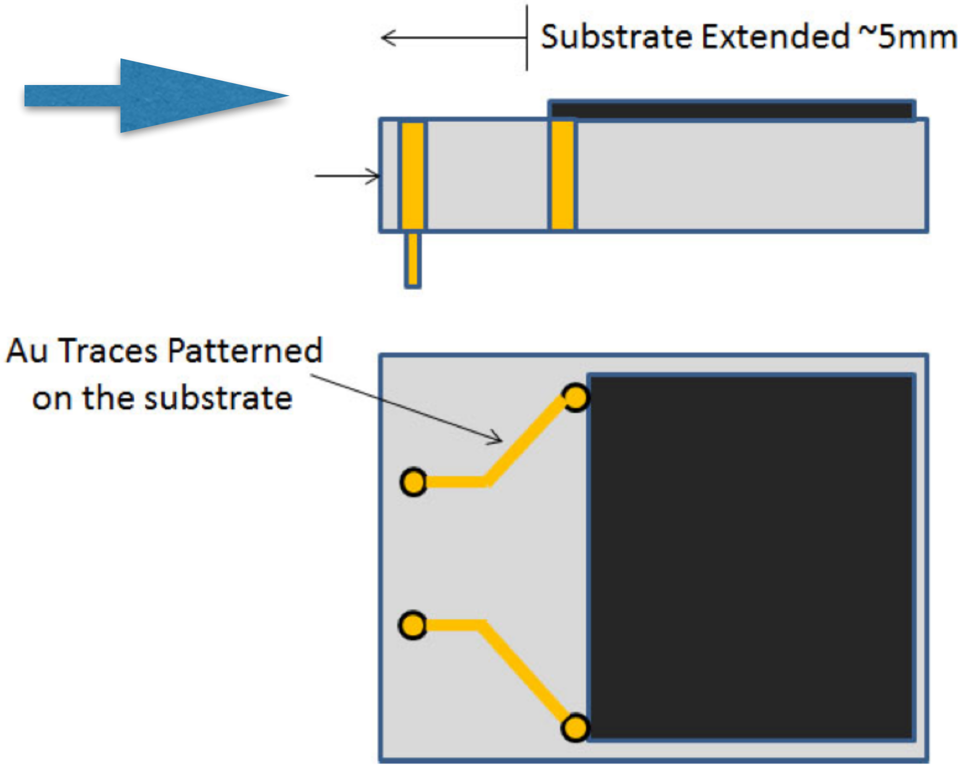
Sebastian White CERN/Princeton CERN Detector Seminar

Sept. 25, 2015



Collaborative work w. RMD on New Packaging at Princeton (B. Harrop)





develop alternatives to screen, etc for production at scale

->current projection for chip costs

-> ~\$8/cm^2

-> <0.5M\$/6m^2

Outlook for Si

- much high quality data form PS-T10 TB run
- just getting into with new algorithms for time (K.Mei)
- completing a telescope with all Penn amps
- at Princeton now doing packaging (in collaboration with RMD and U. Penn.)
- further systematic measurements in RD50 lab in parallel w. developing a 1d model for signal source (MIP deposition, ampl&drift, Ramo weighting, FEE)

Last Points

- this field often close to PET community. For PET emphasis on scintillating crystals where small signal (0.5MeV) a challenge. See P.Lecoq in backup slides(below).

- first look at Penn amp very encouraging. See Mitch in backup slides.

- much new data for MPGD and Si in July-Aug. Here emphasized MPGD and Papaevangelou will present in Trieste

- for Si we enter a new phase where electronics no longer a limitation and detector physics (as in MPGD) will be main focus.

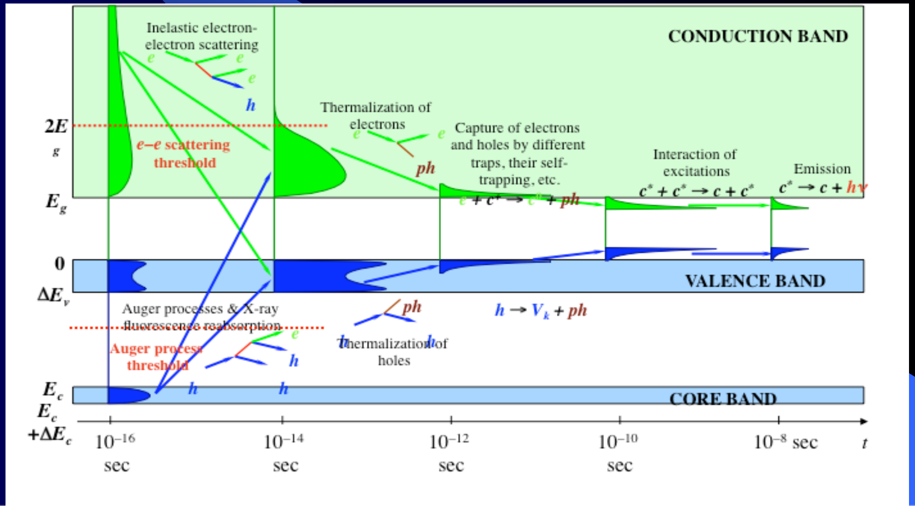
Backup

Factors influencing scintillator time resolution

P. Lecoq et al, IEEE Trans. Nucl. Sci. 57 (2010) 2411-2416

Besides all factors related to photodetection and readout electronics the scintillator contributes to the time resolution through:

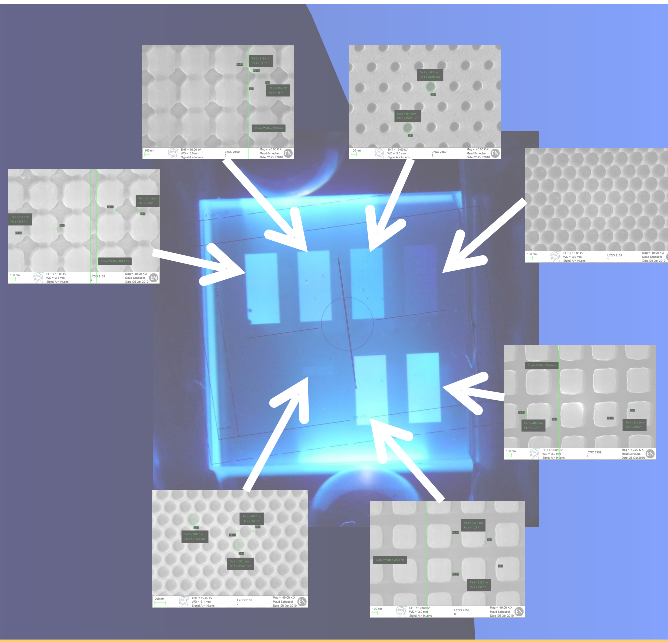
1. The scintillation mechanism
   - Light yield,
   - Rise time,
   - Decay time



A. Vasil'ev, SCINT2001 proceedings, NIMA 486 (2002) 367

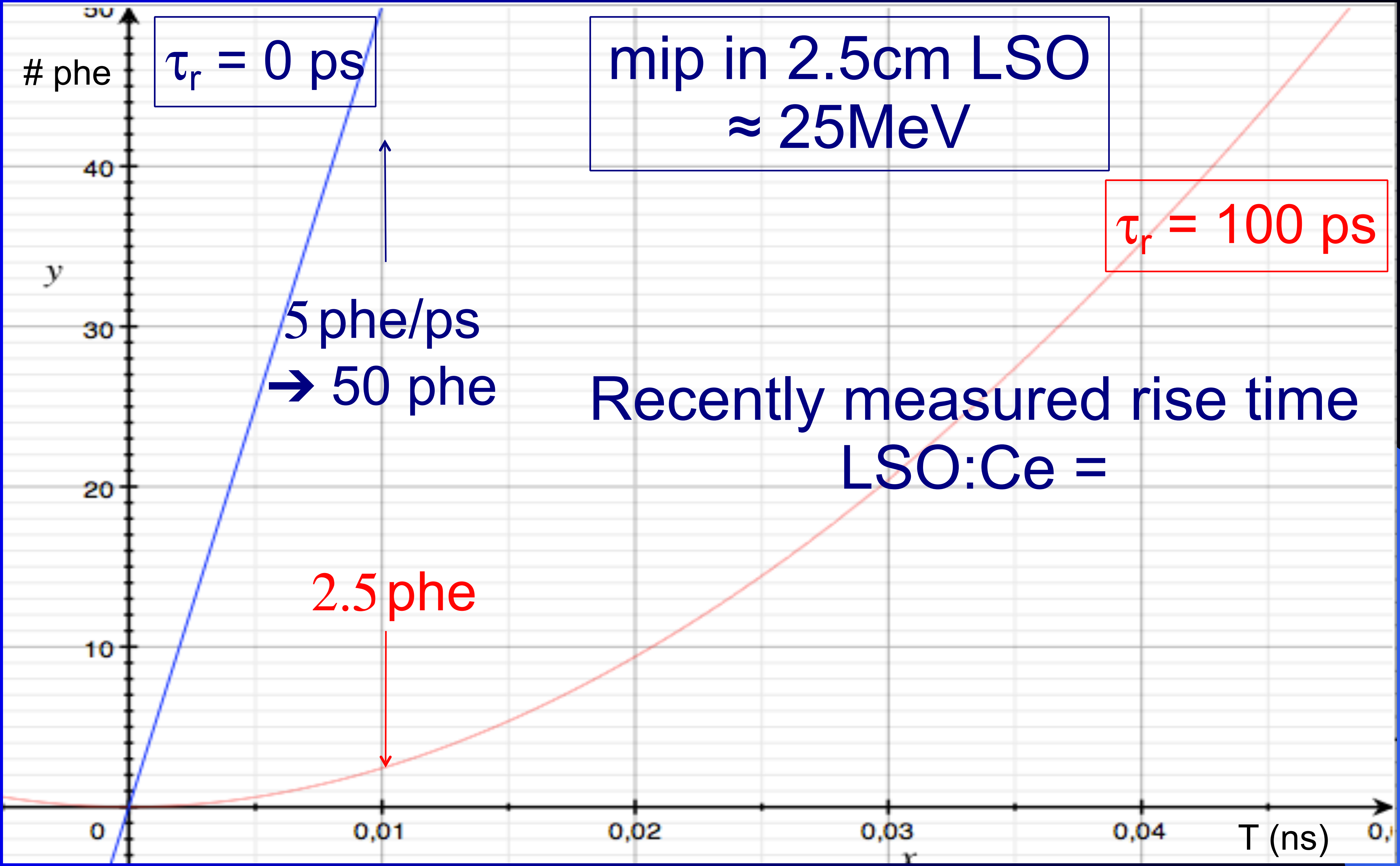
2. The light transport in the crystal
   - Time spread relat … les

… ght propagation modes



Review on photonic crystal coatings for scintillators
A. Knapitsch, P. Lecoq
International Journal of Modern Physics A
Vol. 29 (2014) 1430070 (31 pages)

Effect of rise time



τ_r = 0 ps

mip in 2.5cm LSO
≈ 25MeV

τ_r = 100 ps

5 phe/ps
→ 50 phe

2.5 phe

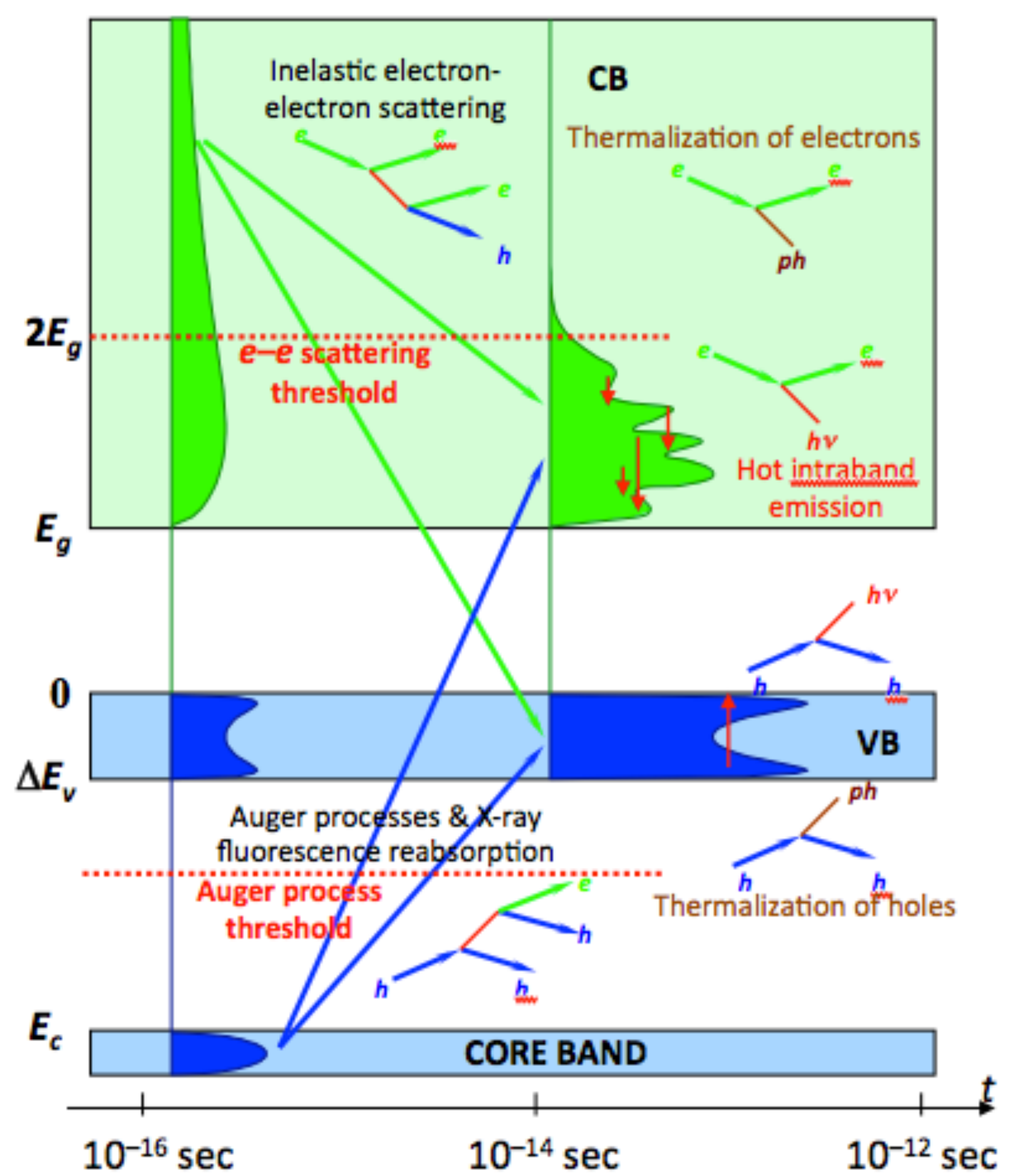
Recently measured rise time
LSO:Ce =

Avenues investigated for a faster rise time

Rise time is to a large extent related to fluctuations in the migration & capture time of thermalized e-h pairs

- More studies ongoing on self activated scintillators
  - Probability for direct low energy transfer from ionizing radiation to luminescent center (PWO, BGO, CeF3)
- Co-doping for defect-assisted carrier capture (LSO:Ce, Ca)
  - Decreases rise time from 70ps to 20ps
    - S. Gundacker, P. Lecoq, SCINT2015 conf. Berkeley (subm. to IEEE Trans. Nucl. Sc.)
- Cross luminescence: Core-Valence luminescence
  - Sub ns rise time and decay time
  - But UV-VUV emission (not maching SiPM QE)
- High donor band: ZnO, CuI, PbI2…
  - Derenzo, *NIMA 486 (2002) 214-219*
- Cerenkov
- Hot Intraband luminescence
- Quantum confinement

Hot intraband luminescence



- Wide emission spectrum UV to IR
- Ultrafast emission in the ps range
- Independant of temperature
- Independant of defects
- Absolute Quantum Yield (confirmed by recent measurements (P.lecoq, S. Omelkov)

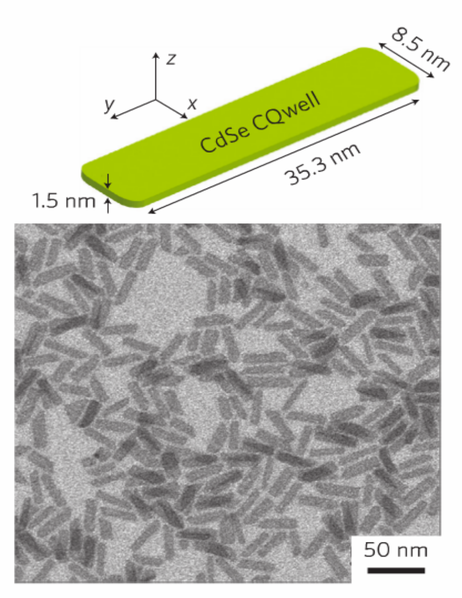
  $$W_{h\nu}/W_{phonon} = 10^{-8}/(10^{-11}-10^{-12})$$

  $\approx 10^{-3}$ to 10^{-4} ph/eh pair
- Higher yield if structures or dips in CB? Interesting to look at CeF3

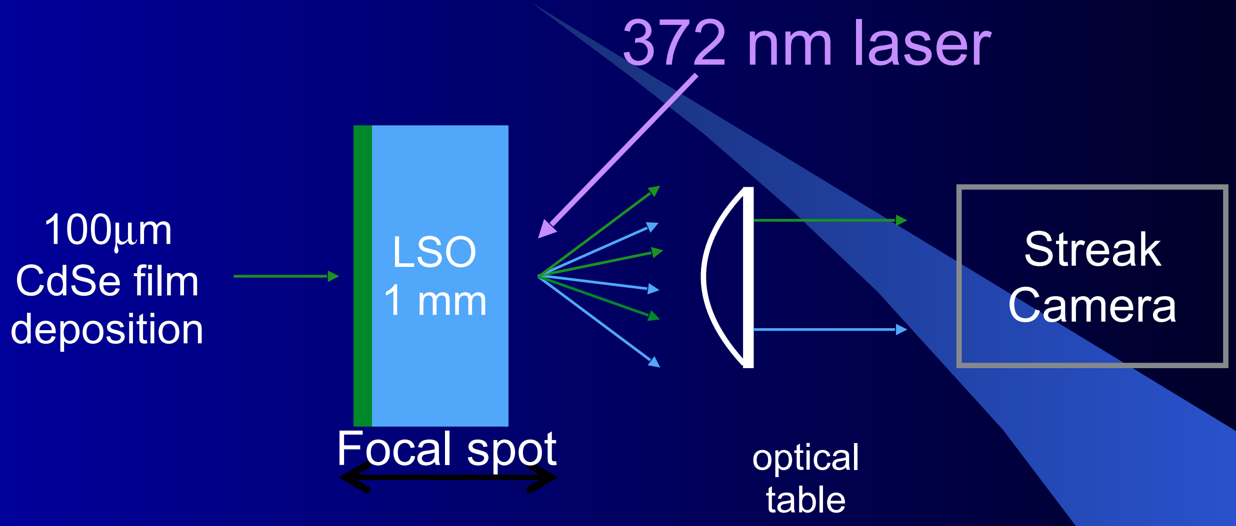
M. Korzhik, P. Lecoq, A. Vasil'ev, SCINT2013 paper
TNS-00194-2013

Preliminary CERN tests results

J.Grim, ITT, Italy



LSO plate 1mm thick
+ CdSe nanoplate film 100µm thick


372 nm laser

100µm
CdSe film
deposition

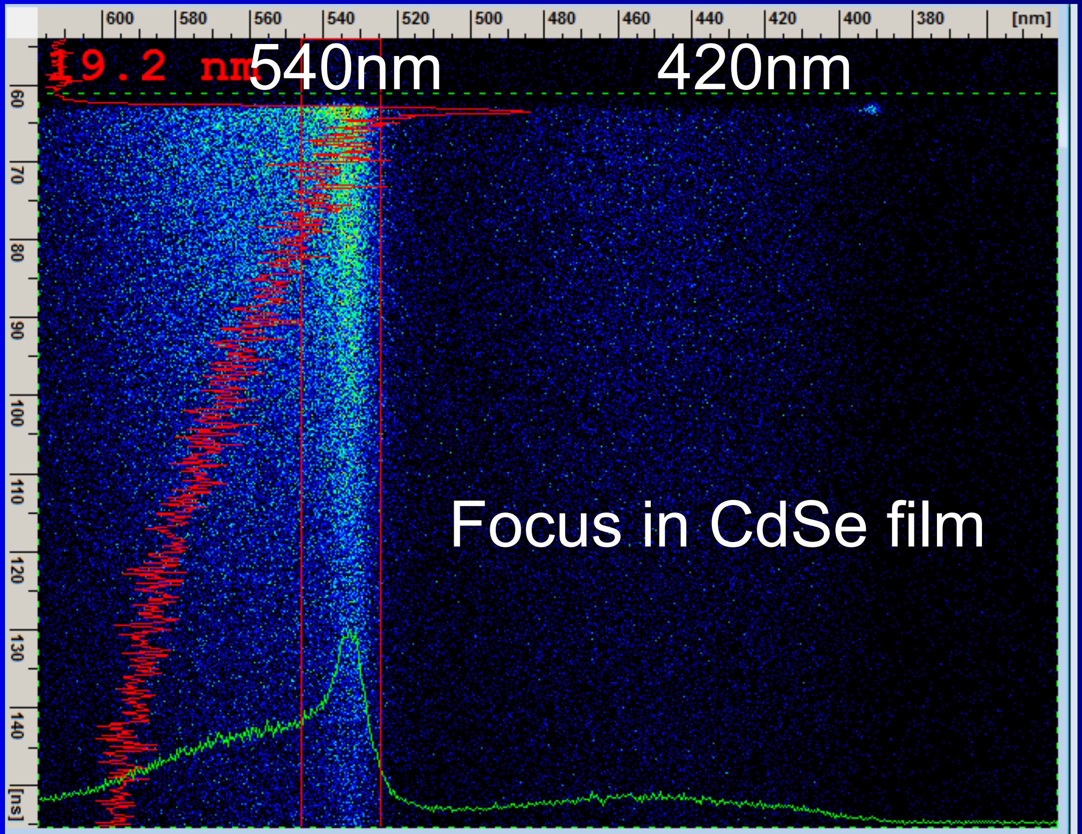
LSO
1 mm

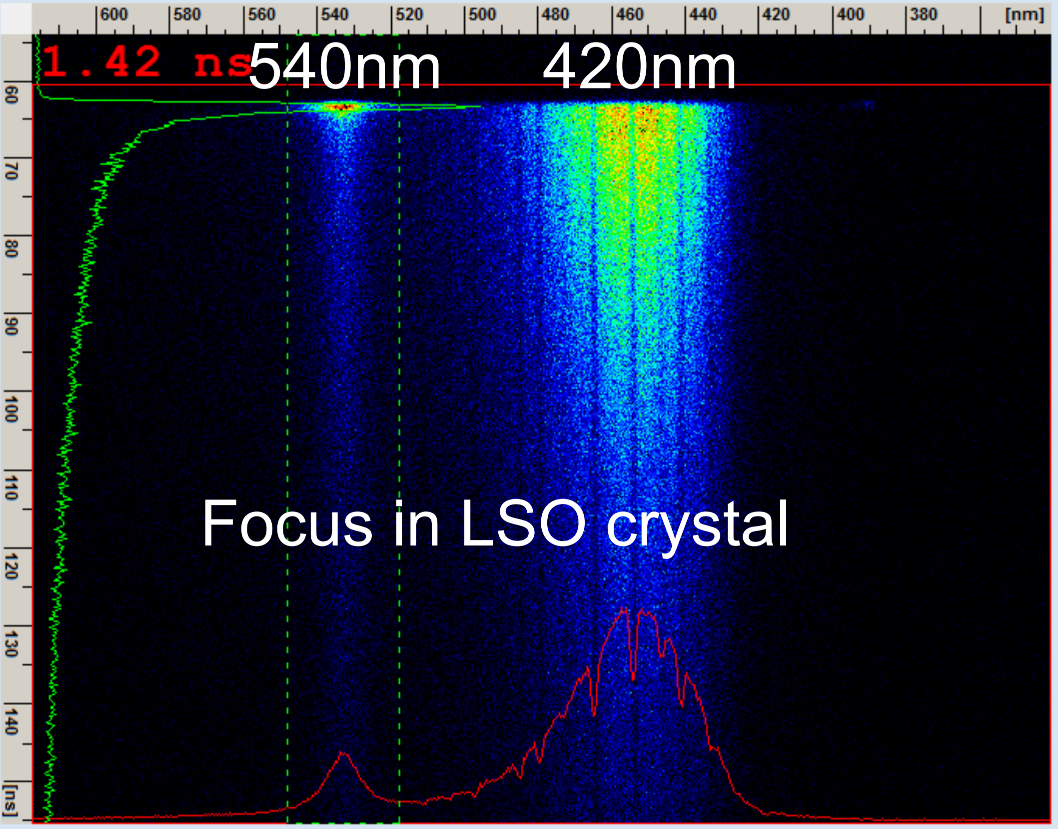
Focal spot

optical
table

Streak
Camera

R. Martinez Turtos, CERN





Conclusions

- Standard scintillation mechanisms are unlikely to give access to the 10ps range because of low photostatistics in this time range, limited by scintillation rise time

- A number of transient and quantum confinement phenomena can generate sub-ns measurable signals

- Photonic crystals improve scintillator timing resolution by two means:
  - By increasing the light output and therefore decreasing the photostatistics jitter
  - By redistributing the light in the fastest propagation modes in the crystal

First Look at Newly Designed PCB for Fast AMP

Emmanuel Morales

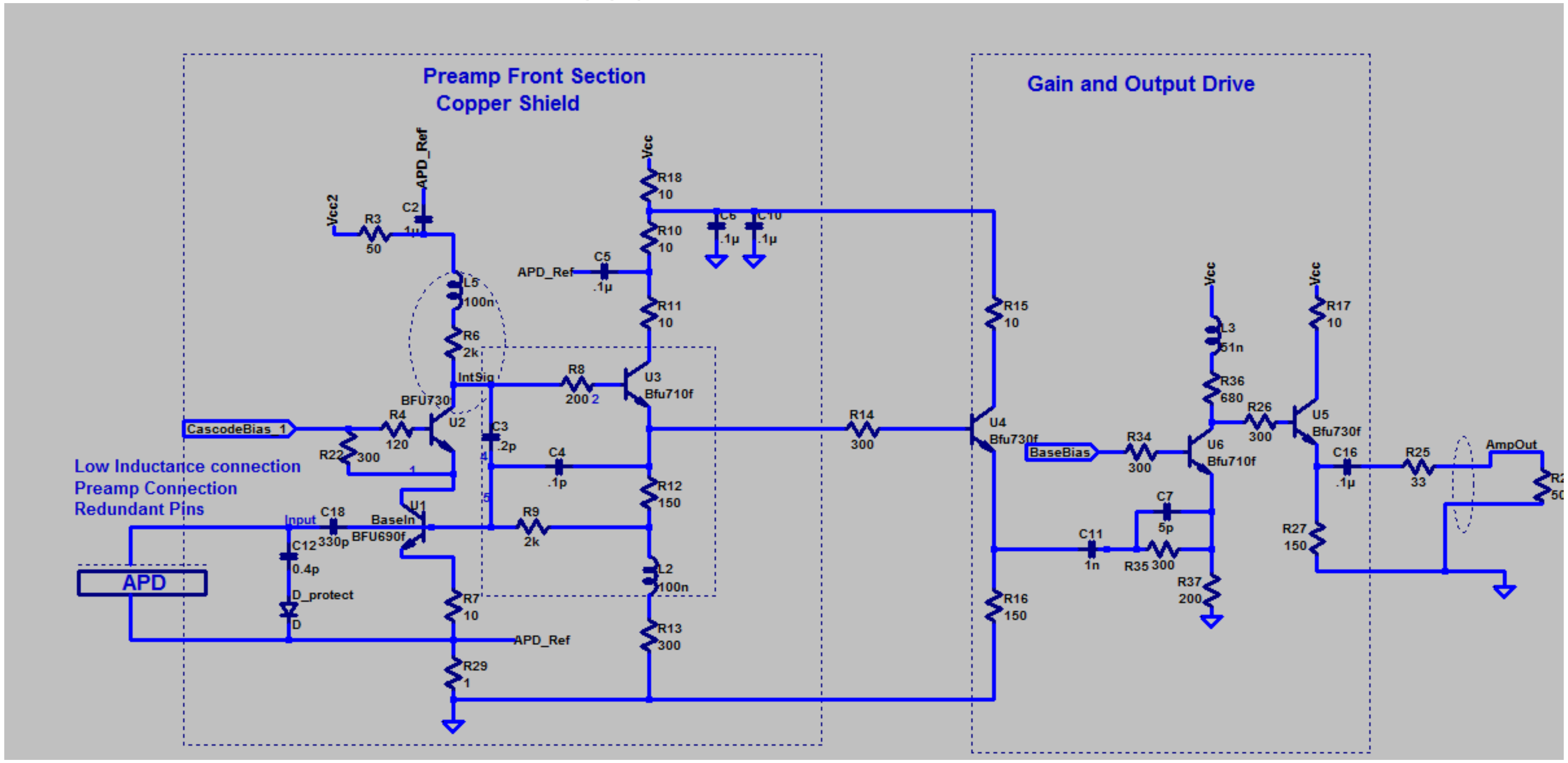
Mitch Newcomer

APD Fast Amp

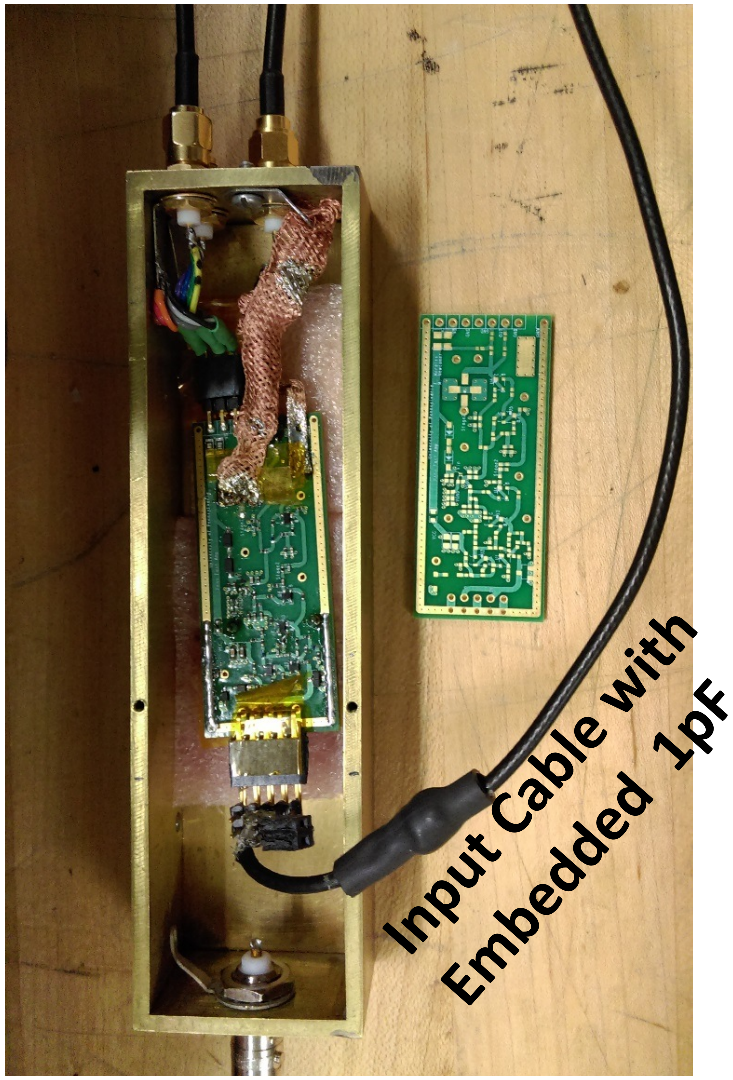
SiGe Transistors

BFU690
BFU710
BFU730

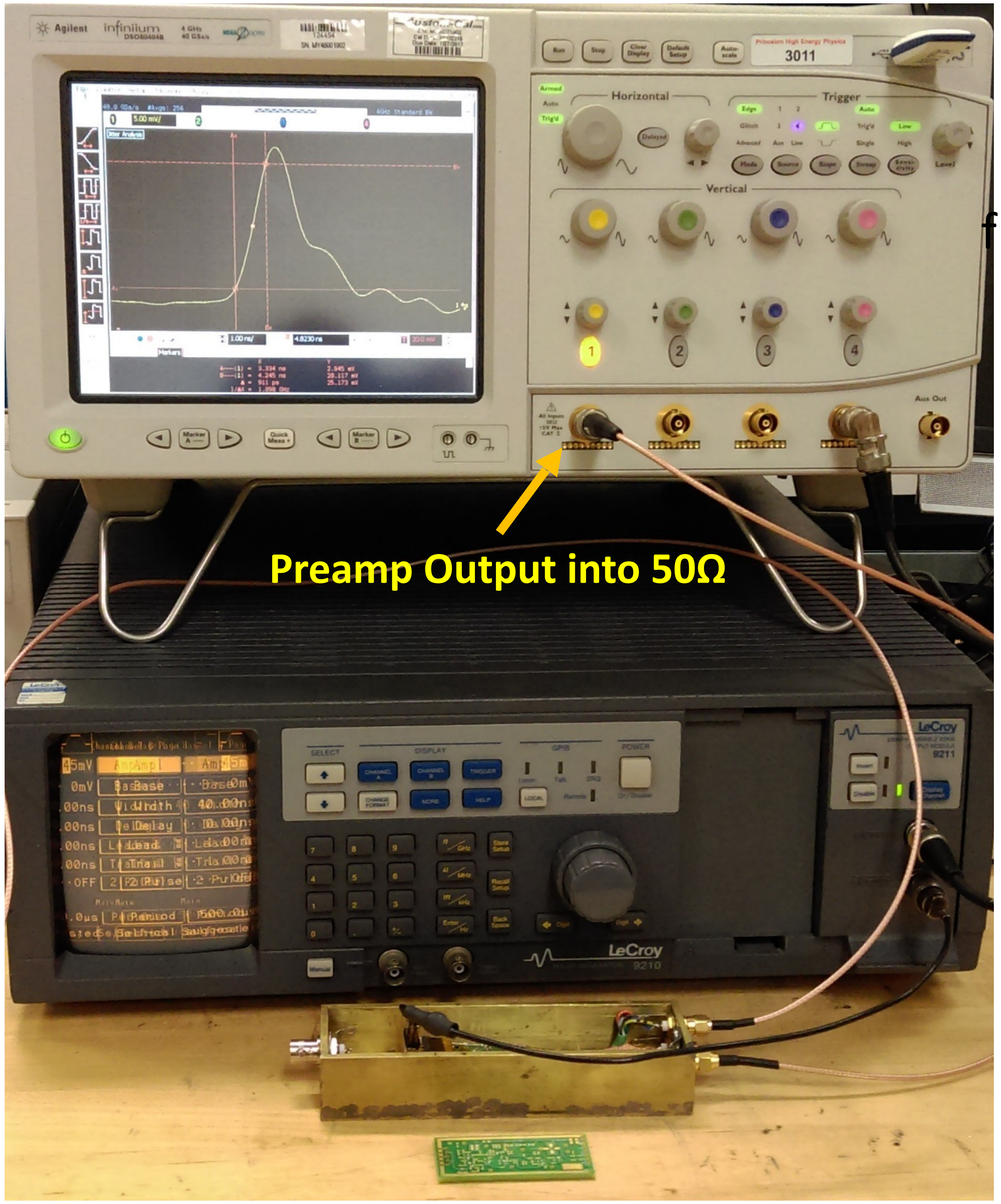
350 mW



AMP and APD Housing



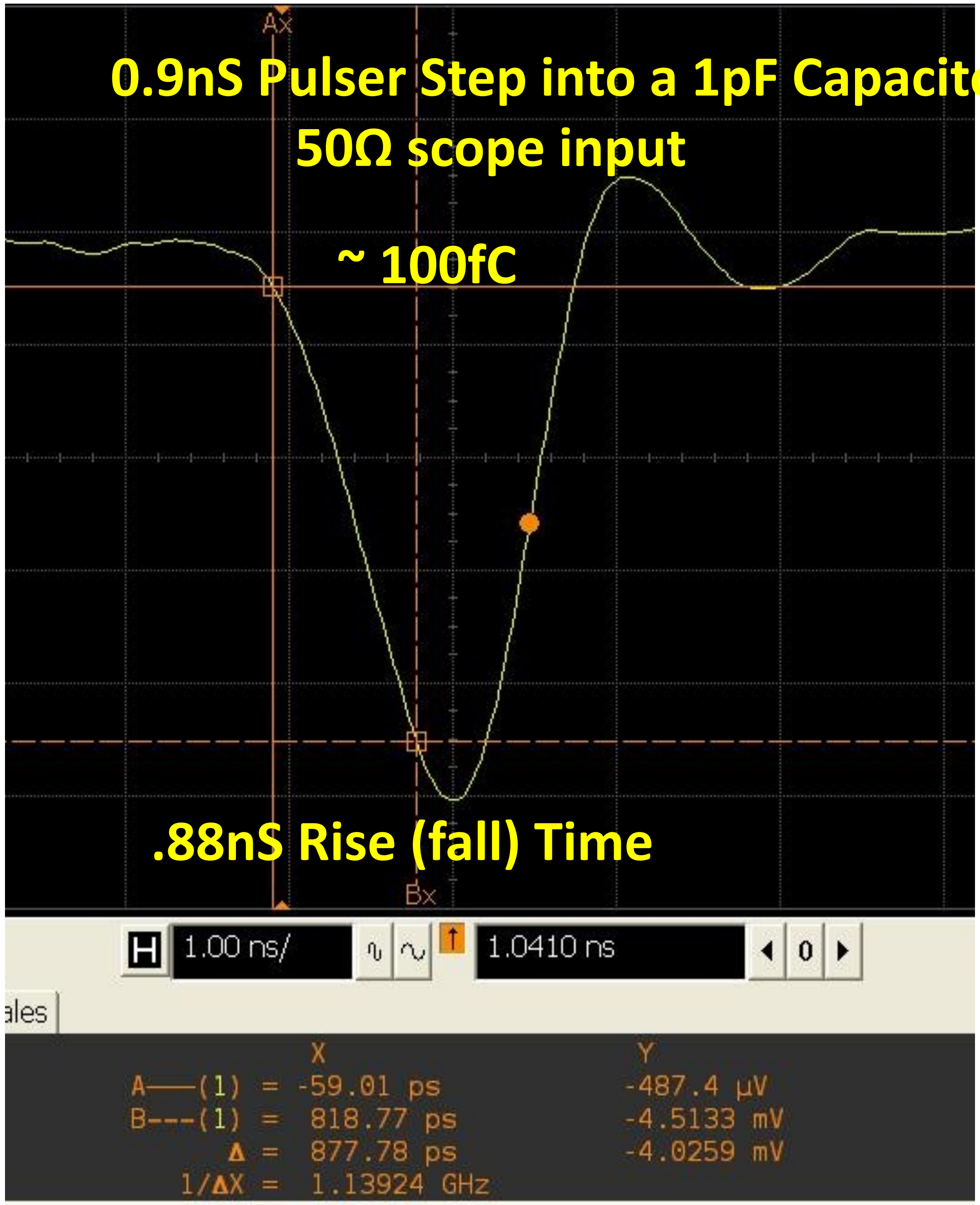
Input Cable with Embedded 1pF cap



Preamp Output into 50Ω

4GHz Scope
on Loan
from Princeton

Input Pulse



0.9nS Pulser Step into a 1pF Capacitor

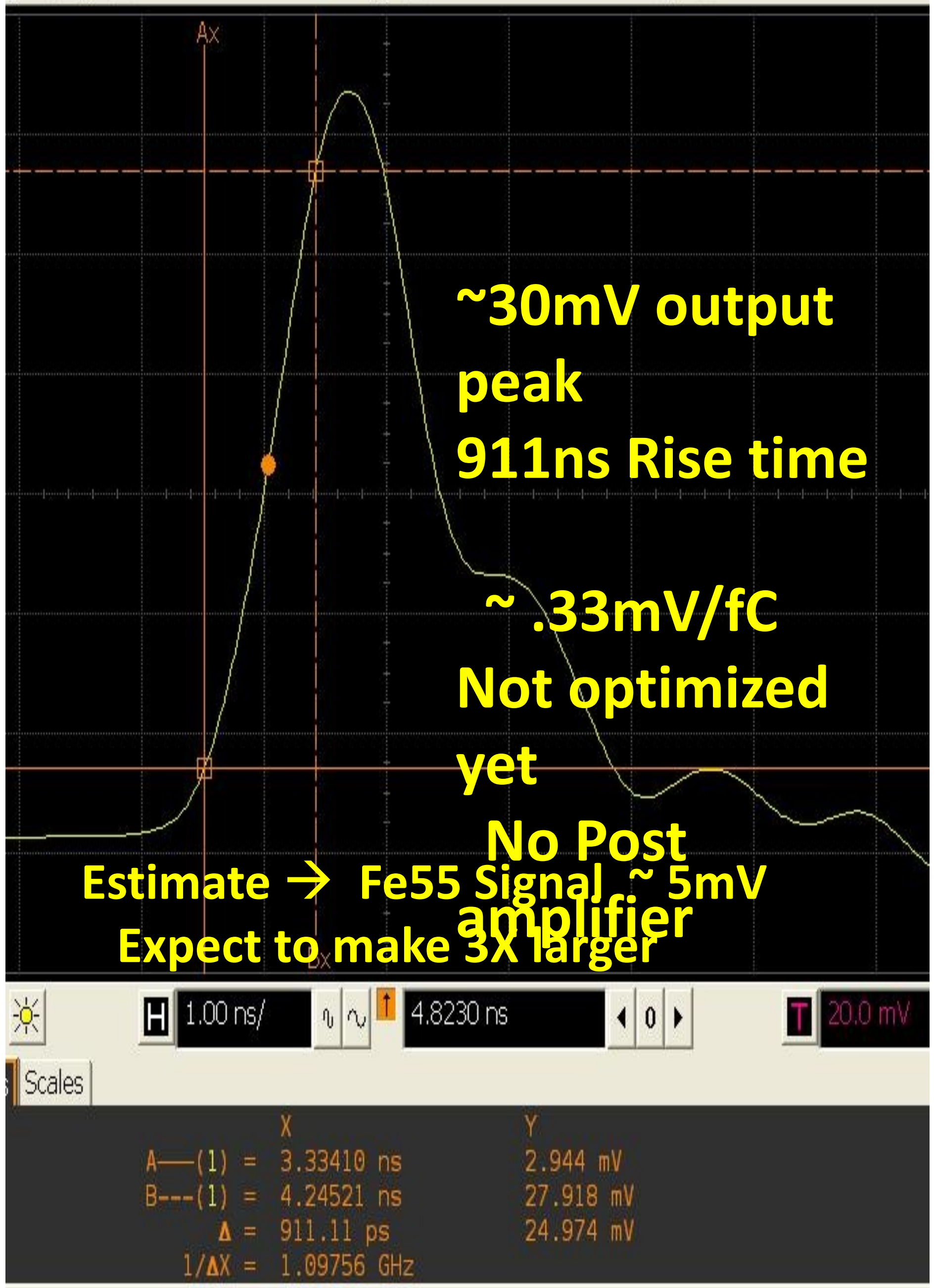
50Ω scope input

~ 100fC

.88nS Rise (fall) Time

```
              X                  Y
A——(1) = -59.01 ps          -487.4 µV
B---(1) =  818.77 ps        -4.5133 mV
     Δ =  877.78 ps         -4.0259 mV
  1/ΔX =  1.13924 GHz
```

Output Signal



~30mV output peak

911ns Rise time

~ .33mV/fC

Not optimized yet

No Post amplifier

Estimate → Fe55 Signal ~ 5mV

Expect to make 3X larger

```
              X                Y
A——(1) =  3.33410 ns      2.944 mV
B---(1) =  4.24521 ns     27.918 mV
     Δ =  911.11 ps       24.974 mV
  1/ΔX =  1.09756 GHz
```

Status of Discrete Preamp Amp

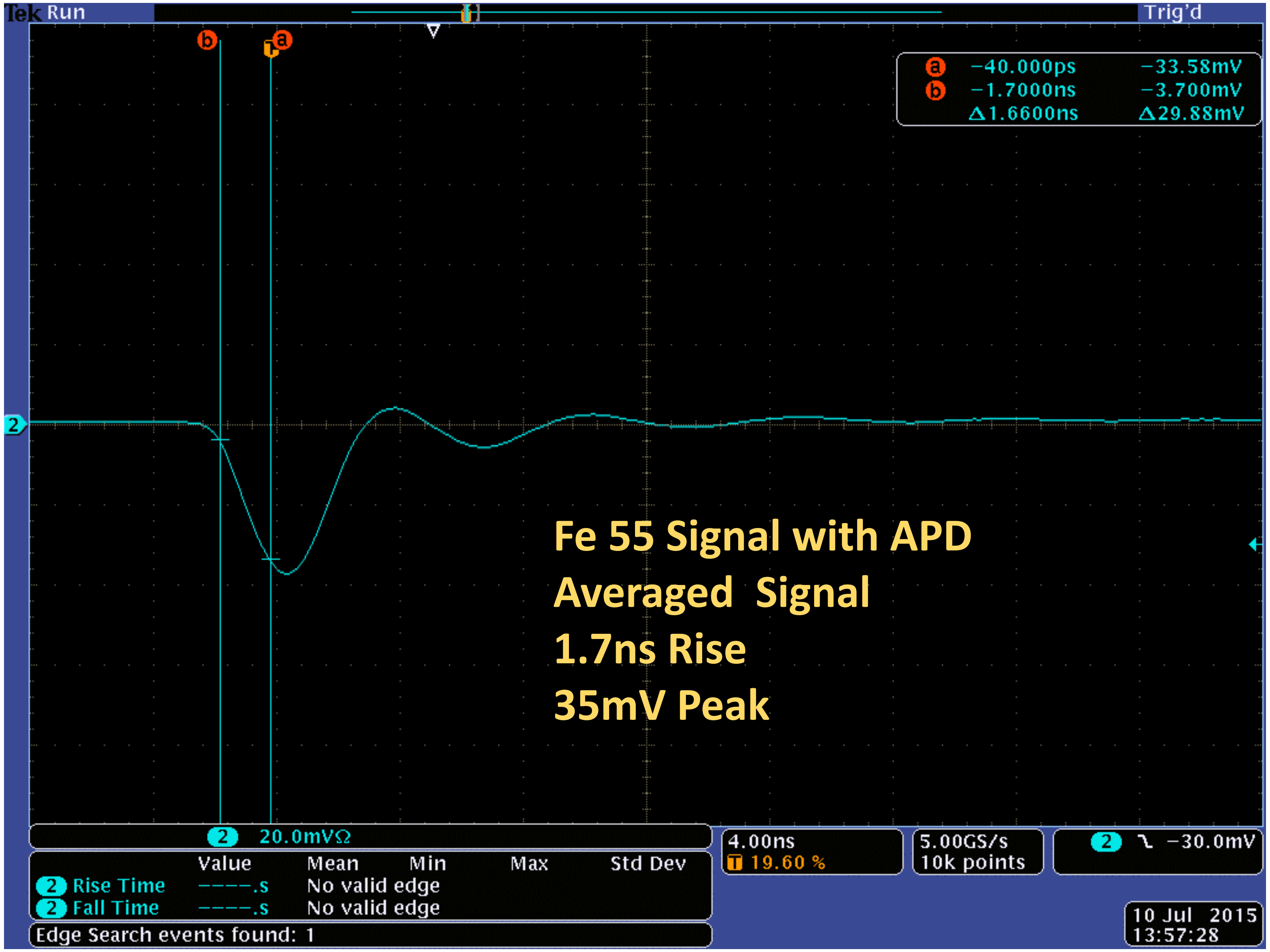
- **Optimize Signal rise time and amplitude.**
- **Study Pickup Issues.**
- **Optimize Power and Supply Voltages.**

Next

- **Add Post 10X amp Inside? / Outside APD Enclosure**
- **Test Beam Studies**
- **Plan / begin ASIC design.**

……

First Version of Circuit July 10, 201



```
Tek Run                                                   Trig'd

ⓐ  −40.000ps     −33.58mV
ⓑ  −1.7000ns     −3.700mV
   Δ1.6600ns     Δ29.88mV

②  20.0mVΩ               4.00ns        5.00GS/s       ②  ↘  −30.0mV
                         T 19.60 %     10k points
              Value    Mean        Min     Max     Std Dev
② Rise Time   ----.s   No valid edge
② Fall Time   ----.s   No valid edge
Edge Search events found: 1
                                                      10 Jul  2015
                                                      13:57:28
```

Fe 55 Signal with APD

Averaged Signal

1.7ns Rise

35mV Peak