Characterization of HFS response to MIP equivalent laser pulse.
-S.White, 10/2/2018

This work is a repeat of earlier work I did with Eric Delagnes that was reported at the 2015
PISA meeting and also similar studies by T. Tsang and C. Lu using earlier variants of
mesh readout Deep Depleted APDs (aka HFS). In the current work we use ~2016 version
of HFS- namely electroformed Ni mesh/ 2 mil Kapton dielectric wire bonded to "Penn1"
version of the fast Si-Ge trans impedance amplifier of Mitch.

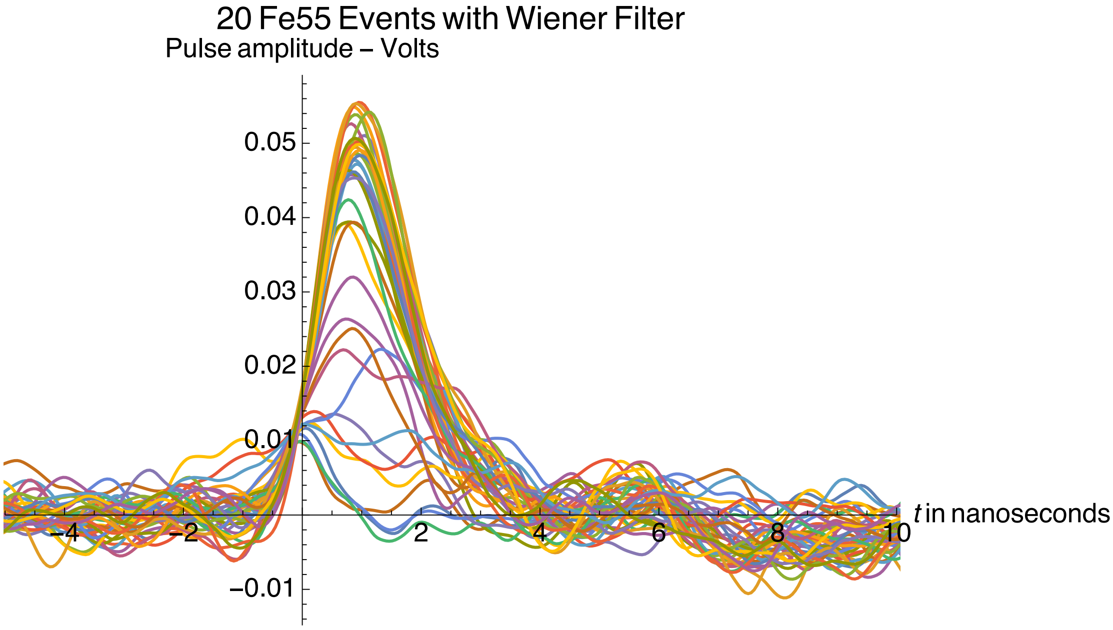
I use as a MIP equivalent touchstone the Fe55 line at 5.9 keV, but the absolute
calibration relies on F. Resnati's pulsed x-ray source with which I took some data
under identical conditions as in the 2016 testbeam around the same
time (also using Penn1). This finesses the ambiguity that arises in calculating the total
number of e-h pairs in the MIP peak.

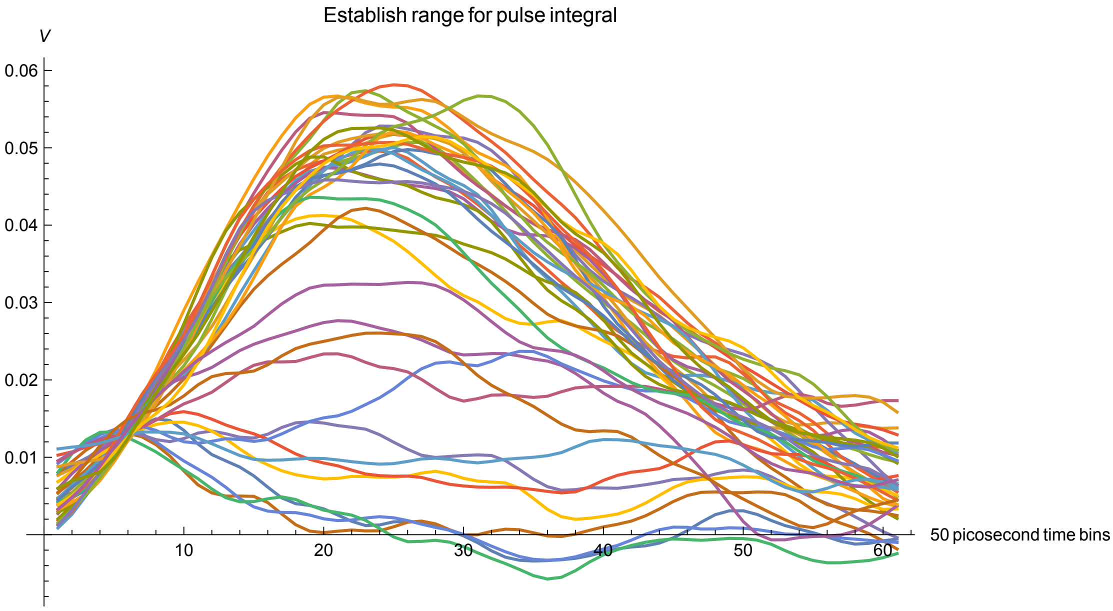
Unless stated the Si bias is 1776V and I~600 nAmp- so there is a few Volt
reduction due to voltage drop in 10MOhm protection resistor

```
SetDirectory["~bastian/Desktop/bldg28feb18/sebtestfeb18fe55"];
Namelist = FileNames[]; nevents = Dimensions[Namelist][[1]];
scopedata = Import[ Namelist[[1]], "csv"];
wave = Drop[scopedata, 5]; npts = Dimensions[wave][[1]]
waveforms = ConstantArray[0, {nevents, npts, 2}];
vwaves = ConstantArray[0, {nevents, npts, 2}];
twaves = ConstantArray[0, {nevents, npts, 2}];
```

```
1002
```

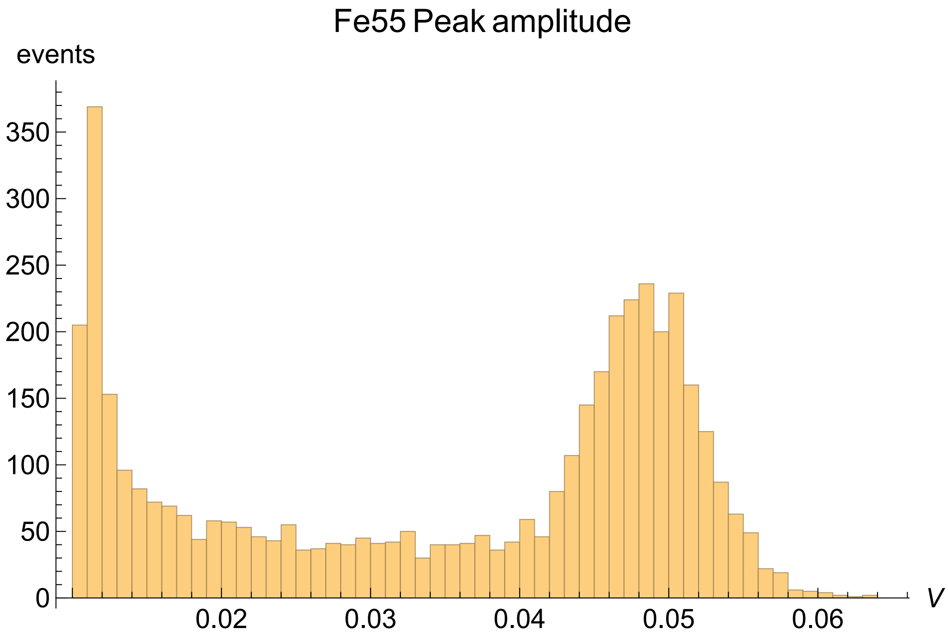
```
Do[
  wave = Drop[Import[Namelist[[i]], "csv"], 5];
  nbins = Dimensions[wave][[1]]; t0 = wave[[1, 1]] * 10^9; dt = 0.05;
  time = t0 + Range[0, (nbins - 1)] * dt; ampl = -wave[[All, 2]];
  vwaves[[i]] = ampl; twaves[[i]] = time;
  waveforms[[i]] = Transpose[{time, ampl}];
  , {i, nevents}];
```

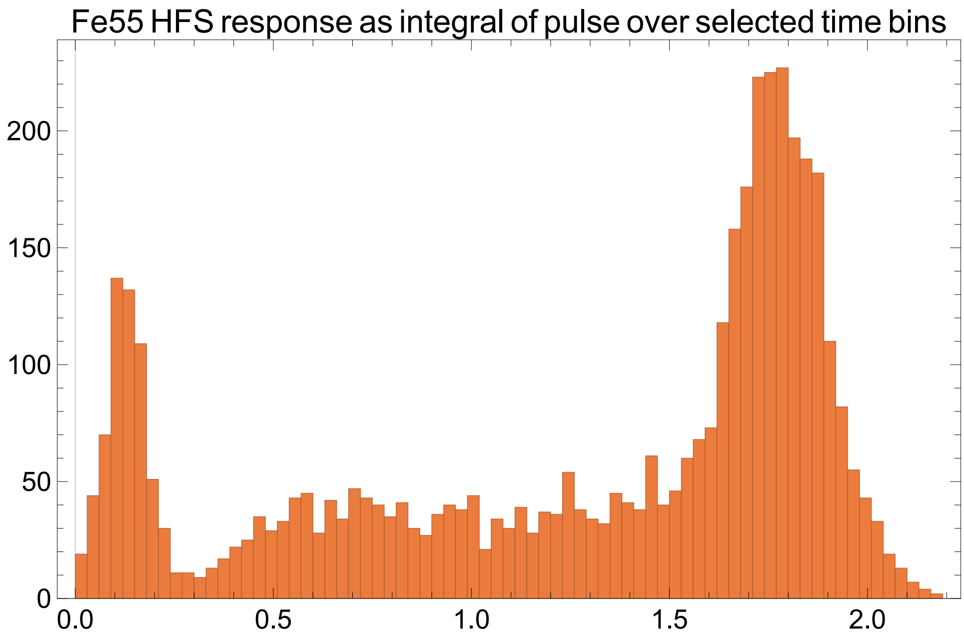


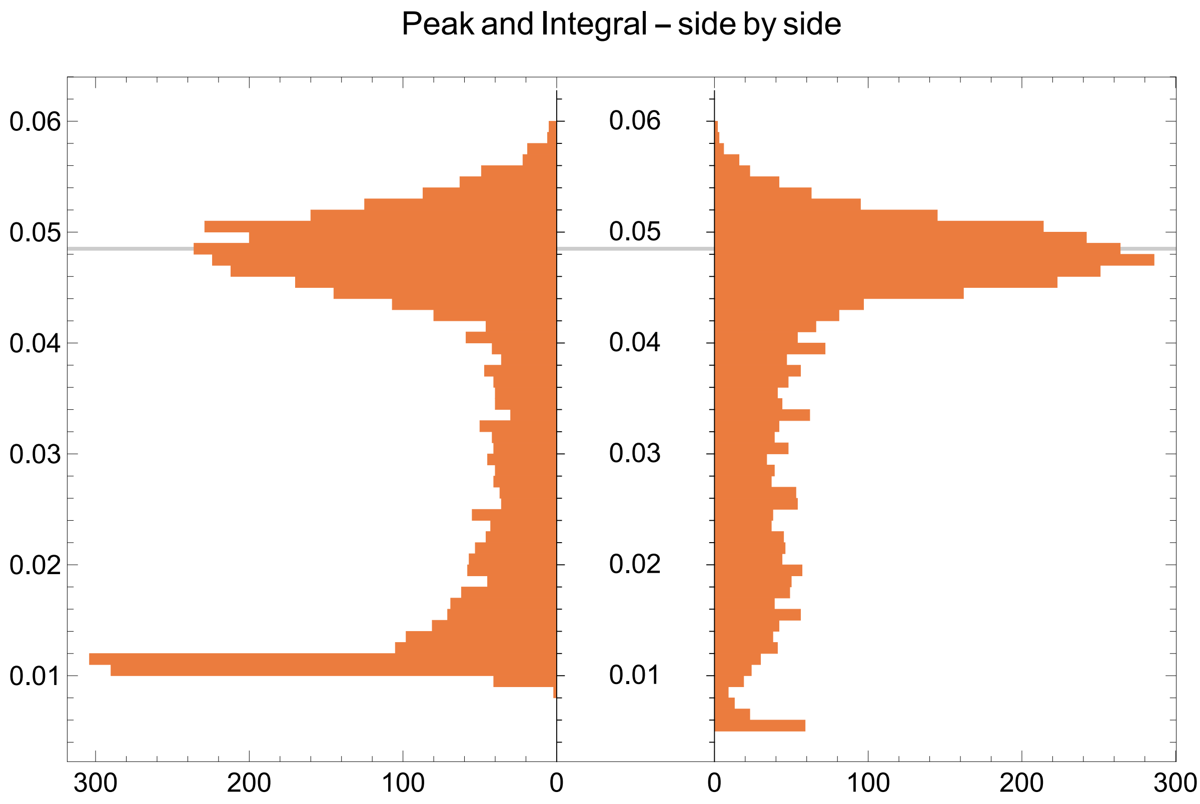


Using Either the peak distribution or the integral, the Fe55 peak is clearly established and we even have FWHM~15 % in the integral, which seems pretty good for an Si timing/tracking detector.

```
GraphicsColumn[
 {Histogram[Table[Max[Take[WienerFilter[vwaves[[i]], 6, 0.05], {380, 440}]],
    {i, nevents}], PlotRange → {{10, 20}, Full},
   AxesLabel → {HoldForm[V], HoldForm[Events]},
   PlotLabel → HoldForm[Fe55 Peak Amplitude], LabelStyle →
    {FontFamily → "Abadi MT Condensed Extra Bold", 14, GrayLevel[0]}],
  Histogram[Table[Total[Take[vwaves[[i]], {380, 440}]], {i, nevents}],
   {0, 2.2, .03}, PlotTheme → "Scientific", AxesLabel →
    {HoldForm[Sum of Amp in selected time bins], HoldForm[Events]}, PlotLabel →
    HoldForm[Fe55 HFS response as integral of pulse over selected time bins],
   LabelStyle → {14, GrayLevel[0]}]}, ImageSize → Large]
```


Fe55 Peak amplitude
events
350
300
250
200
150
100
50
0
0.02
0.03
0.04
0.05
0.06
V


Fe55 HFS response as integral of pulse over selected time bins
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0



The number of eh pairs (3.6 eV / pair) for the Fe^{55} line at 5.9 KeV is 1638. So, based on this result, we could derive the expected amplitude for the Minimum Ionizing Peak(MIP), assuming a given effective thickness of the depletion layer. Take, for example, 60 micron - which we have often used. Then we would find the expectation for the MIP peak is ~135mV, or ~3 times the Fe^{55} peak.

$N_{ehFe55} = 5900 / 3.6$

1638.89

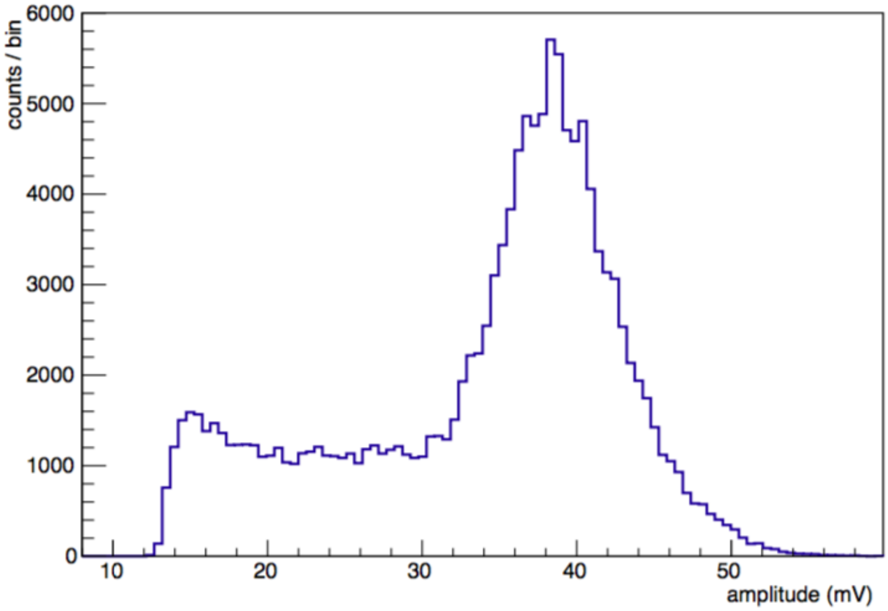
$N_{ehMIP} = 60 * 74$

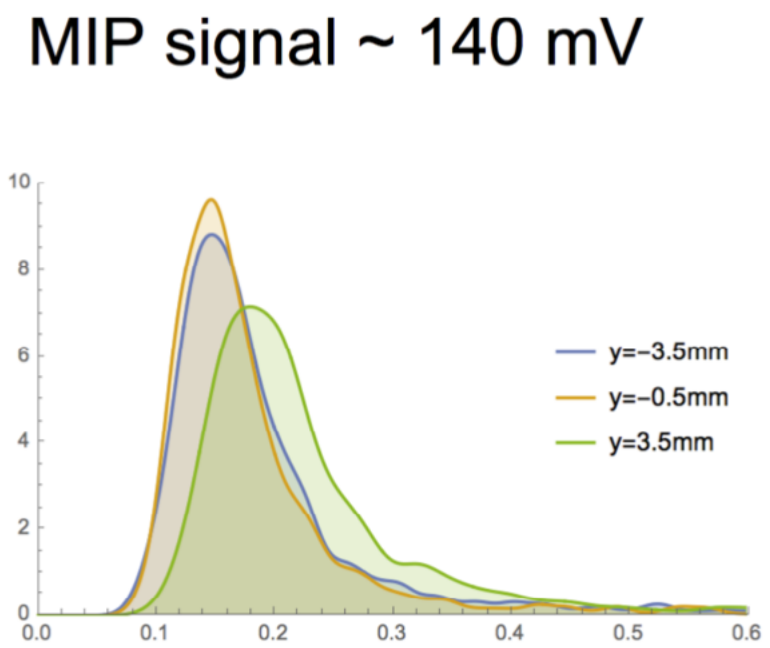
4440

$peak_{MIP} = N_{ehMIP} / N_{ehFe55} * 0.05$

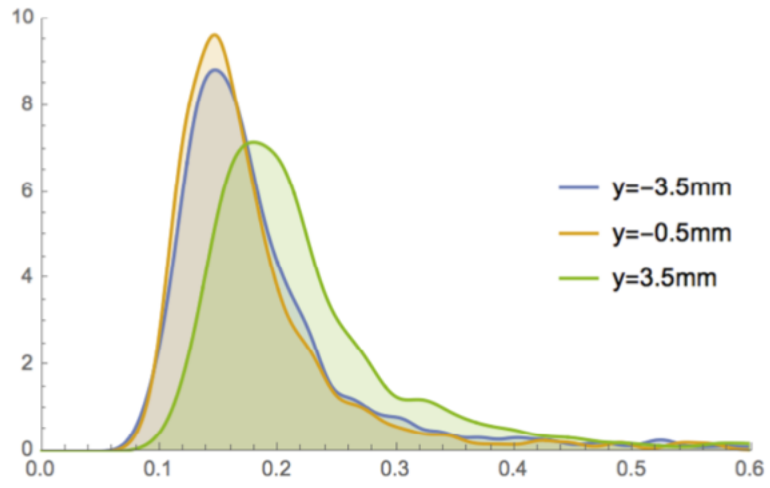
0.135458

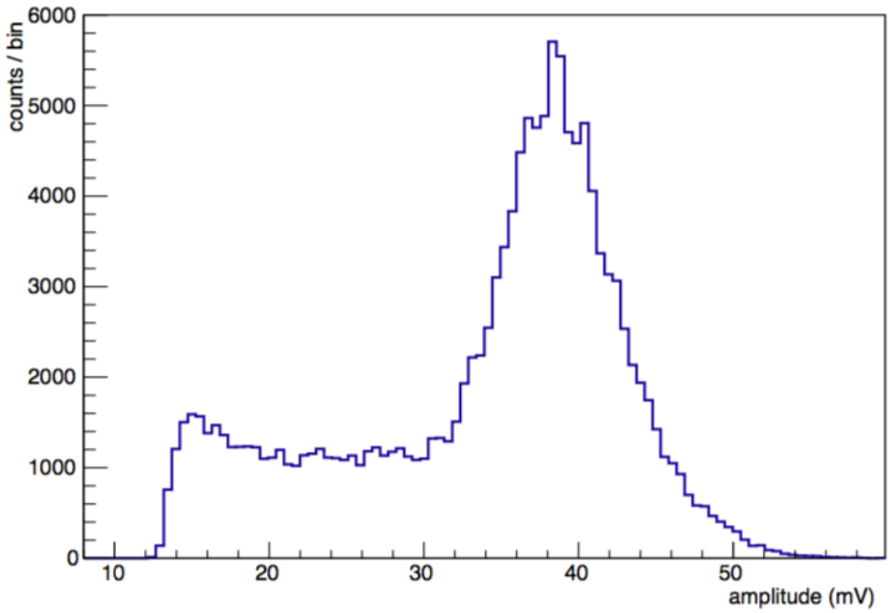
There is a bit of a puzzle in that Filippo Resnati' s pulsed X - ray source (5.4 keV - from Cr cathode), when compared with the MIP peak data taken under the same conditions (Penn1, 1.8 kV bias), results in a different e - h pairs/MIP estimate. Here below are the peak pulse height distributions from 5.4 keV X - rays and the beam.





MIP signal ~ 140 mV





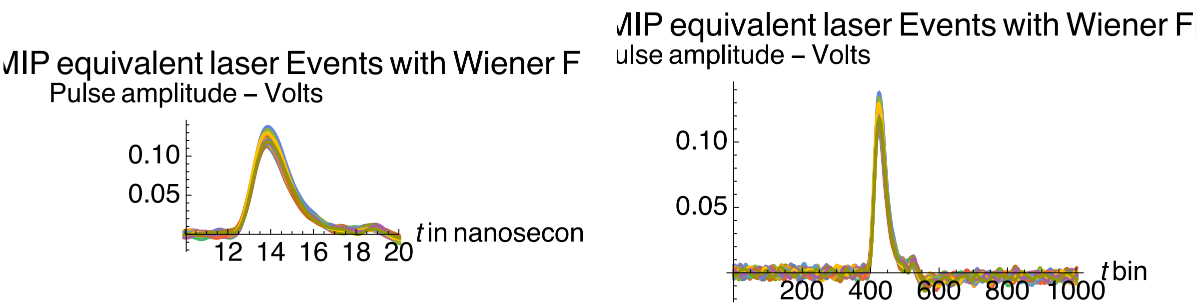

```
NehCr = 5400 / 3.6
NehMIP = % * 140 / 39
1500.
5384.62
```

This discrepancy (5384/4440~ 20 %) runs counter to our intuition from SILVACO TCT edge scans, since we would expect that the fast signal comes from a shallower region than 60 microns. It may be that the 5.4 keV X - rays, which have about 20 micron mfp in Silicon, have reduced signal compared to fully penetrating MIPs. In any case our best estimate for the MIP peak under

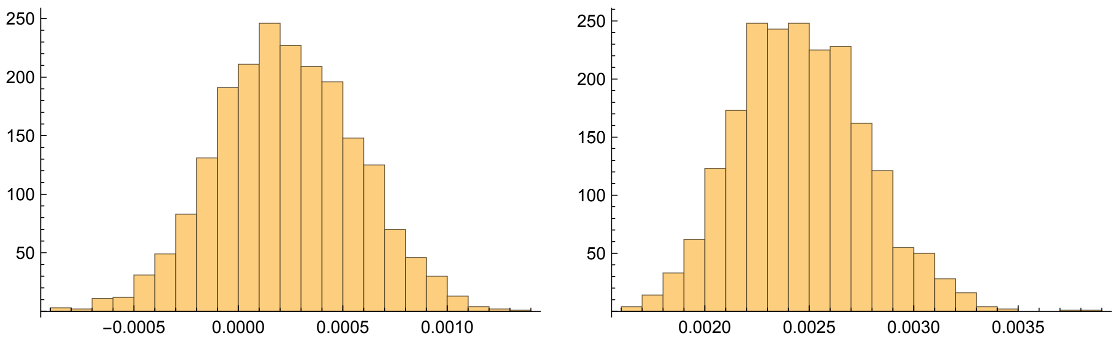
the 1776V test conditions below is MIP peak-> 164mV.

```
SetDirectory["~bastian/Desktop/bldg28feb18/sebtestfeb18vcse/c2"];
Namelist = FileNames[]; nevents = Dimensions[Namelist][[1]]
scopedata = Import[ Namelist[[1]], "csv"];
wave = Drop[scopedata, 5]; npts = Dimensions[wave][[1]]
waveforms = ConstantArray[0, {nevents, npts, 2}];
vwaves = ConstantArray[0, {nevents, npts, 2}];
twaves = ConstantArray[0, {nevents, npts, 2}];
```

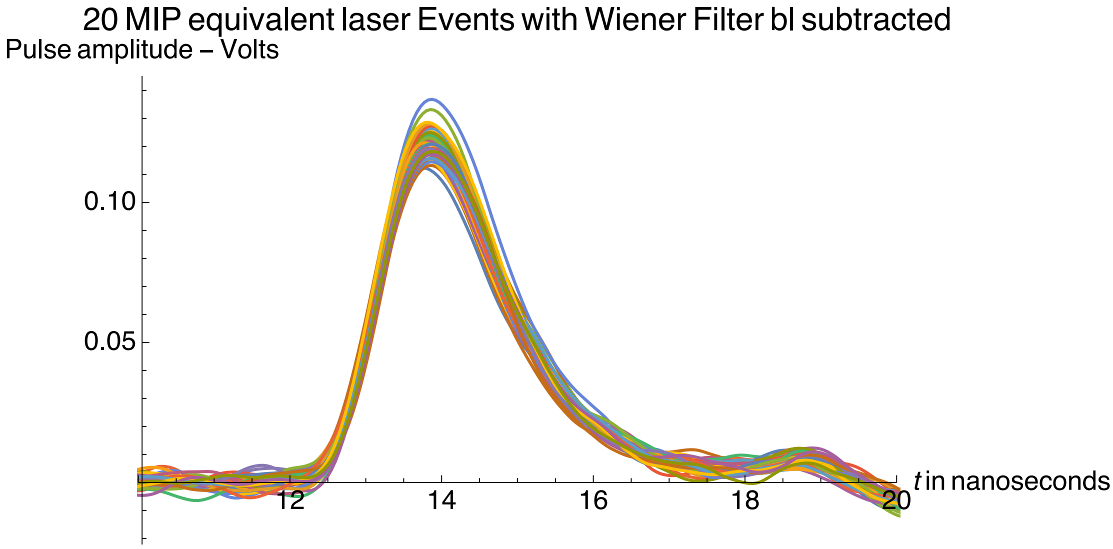
```
Do[
  wave = Drop[Import[Namelist[[i]], "csv"], 5];
  nbins = Dimensions[wave][[1]]; t0 = wave[[1, 1]] * 10^9; dt = 0.05;
  time = t0 + Range[0, (nbins - 1)] * dt; ampl = -wave[[All, 2]];
  vwaves[[i]] = ampl; twaves[[i]] = time;
  waveforms[[i]] = Transpose[{time, ampl}];
  , {i, nevents}];
```




```
bllaser = Table[Mean[Take[vwaves[[i]], {1, 380}]], {i, nevents}];
noiselaser = Table[
   RootMeanSquare[Take[(vwaves[[i]] - bllaser[[i]]), {1, 380}]], {i, nevents}];
GraphicsRow[{Histogram[bllaser], Histogram[noiselaser]}, ImageSize → Large]
```

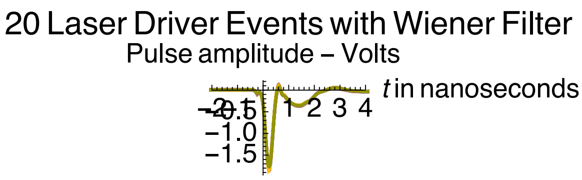


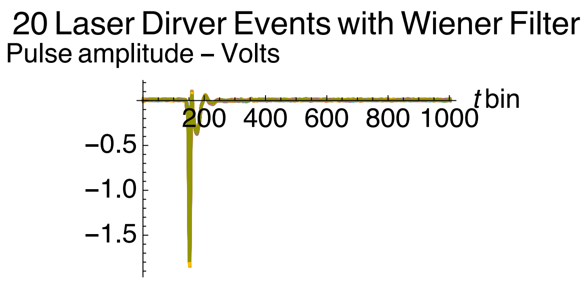

```
vwaves = Table[(vwaves[[i]] - bllaser[[i]]), {i, nevents}];
blc = Table[Mean[Take[vwaves[[i]], {1, 380}]], {i, nevents}];
```



So baseline drift is negligible and the noise (only slightly reduced by Wiener Filter used to cleanup peak measurement) is 2.5 mV.

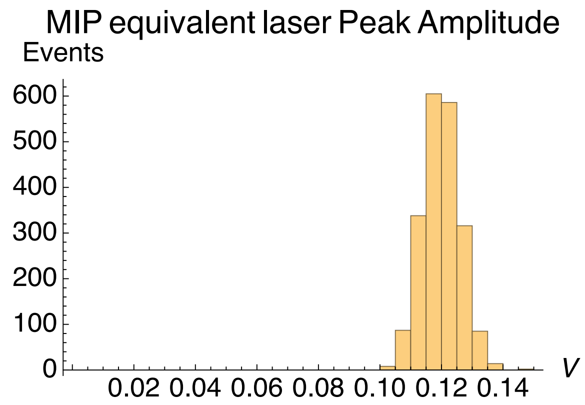
Under these conditions we can expect a noise dominated time jitter of dt~tRise/SNR~15 picoseconds. To quote something comparable to the earlier result with Delagnes we would use the slightly higher laser amplitude (ie the MIP equivalent discussion above) and operate at a higher HFS bias voltage - we get a gain increase of about a factor of 2 at 1800 V bias so comfortably below 10 picoseconds jitter. In the mean time we proceed with this data set and see what we get. First read laser driver data.

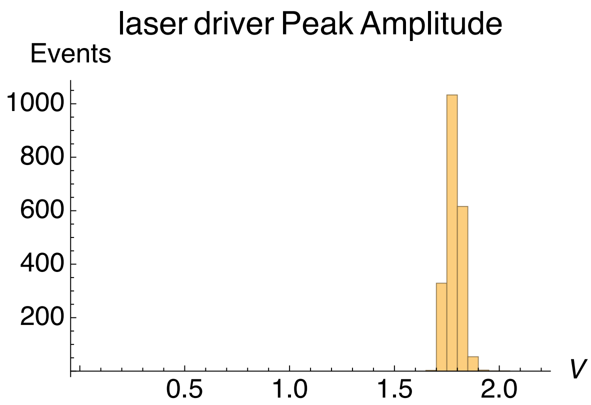


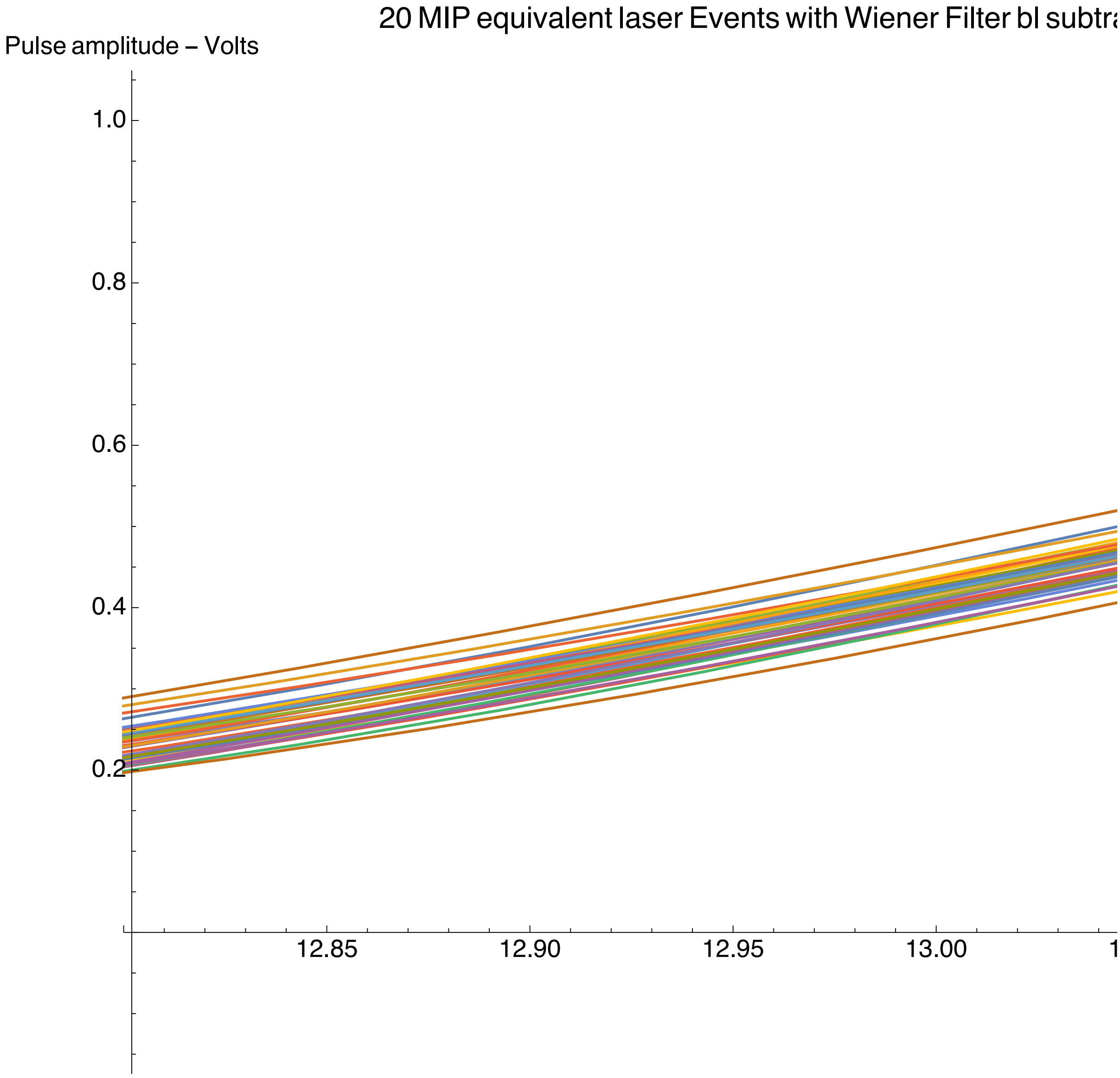


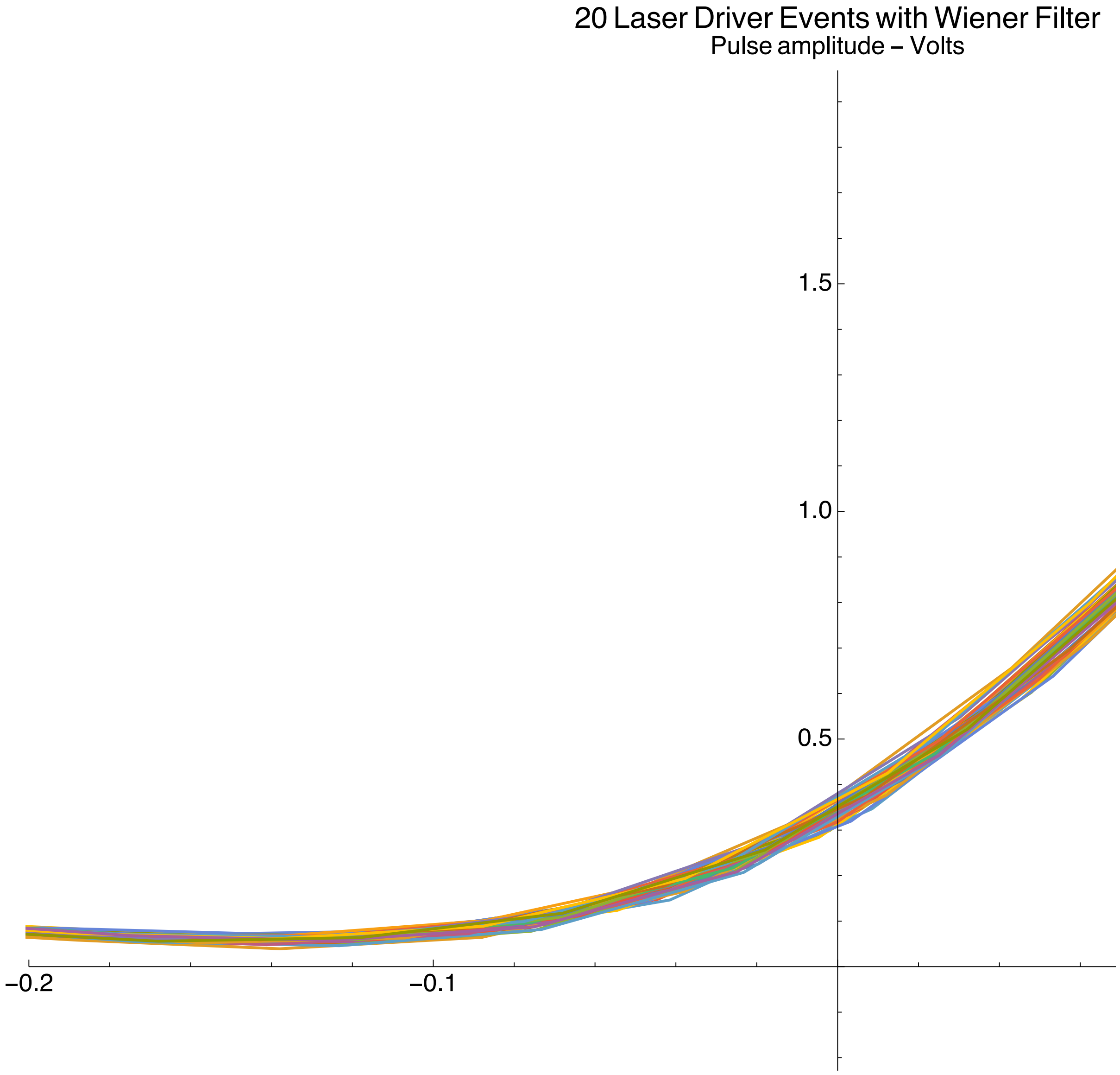
It seems unlikely that you can improve on the trigger time itself since the laser driver signlas look so identical. In particular, the amplitude of the driver has much less variation than the HFS signal, which has contributions from both laser and Si Gain fluctuations.

```
mippeak =
  Table[Max[Take[WienerFilter[vwaves[[i]], 6, 0.05], {380, 440}]], {i, nevents}];
```



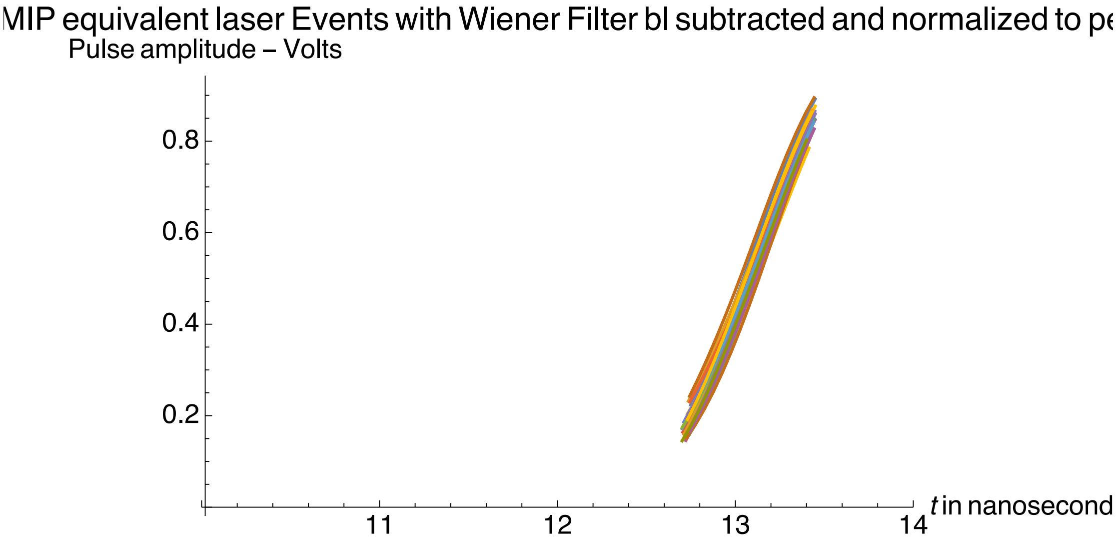



20 MIP equivalent laser Events with Wiener Filter bl subtra
Pulse amplitude – Volts
1.0
0.8
0.6
0.4
0.2
12.85
12.90
12.95
13.00
1

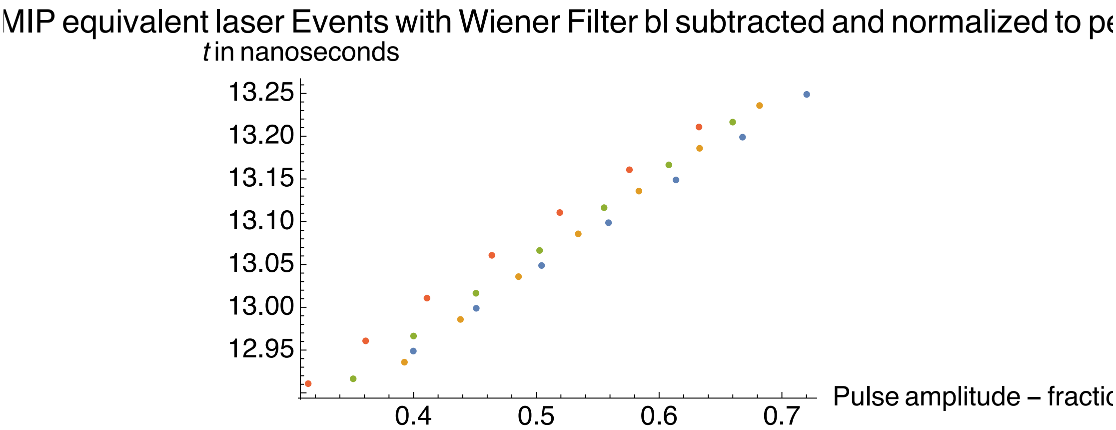


20 Laser Driver Events with Wiener Filter
Pulse amplitude – Volts
1.5
1.0
0.5
–0.2
–0.1

So do conventional 40 % Constant fraction timing on the HFS signal without trying to correct reference timing jitter.

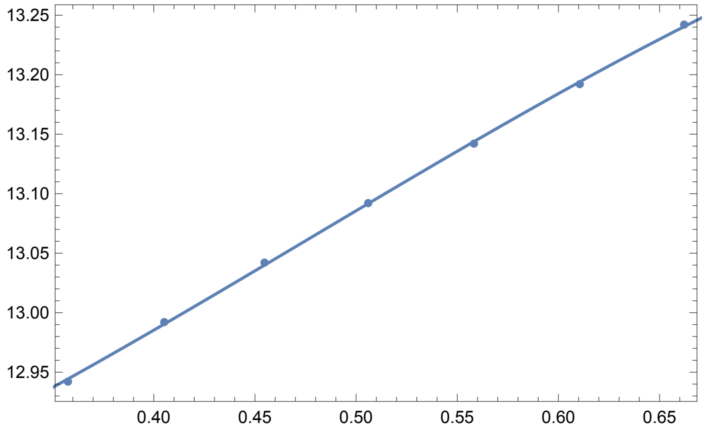



```
wavefit = Table[Take[
    Transpose[{WienerFilter[vwaves[[i]], 6, 0.05] / mippeak[[i]], twaves[[i]]}],
    {406, 412}], {i, nevents}];
```

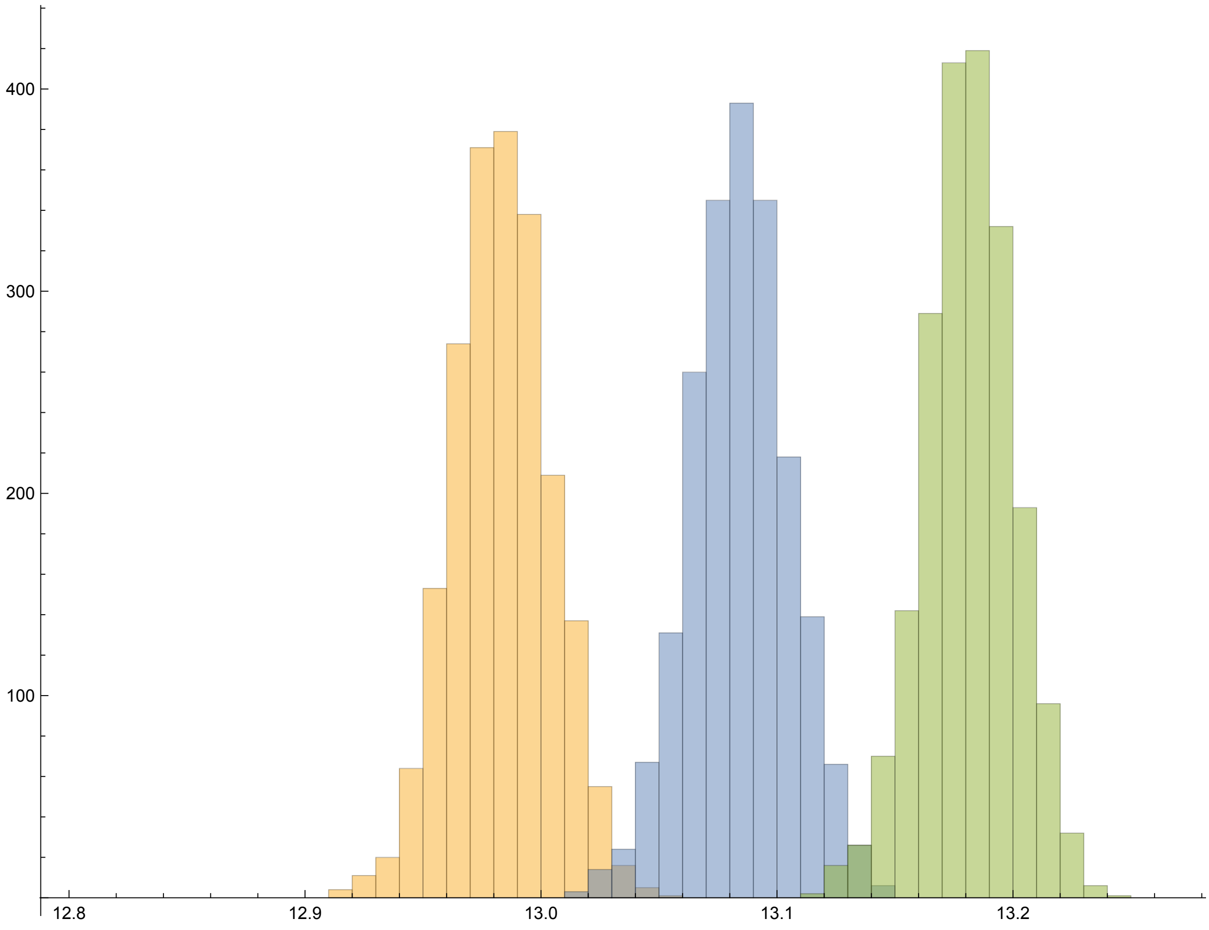



```
fitpt = ConstantArray[0, {nevents, 3}];
Do[
 data = wavefit[[i]];
 nlm = NonlinearModelFit[data, a + b x^2 + c x^3, {a, b, c}, x];
 fitpt[[i, 1]] = nlm[0.4];
 fitpt[[i, 2]] = nlm[0.5];
 fitpt[[i, 3]] = nlm[0.6];
 , {i, nevents}]
```

```
Show[ListPlot[data], Plot[nlm[x], {x, 0.2, 0.9}], Frame → True]
```




```
Histogram[{fitpt[[All, 1]], fitpt[[All, 2]], fitpt[[All, 3]]}, {12.8, 13.4, 0.01}]
```

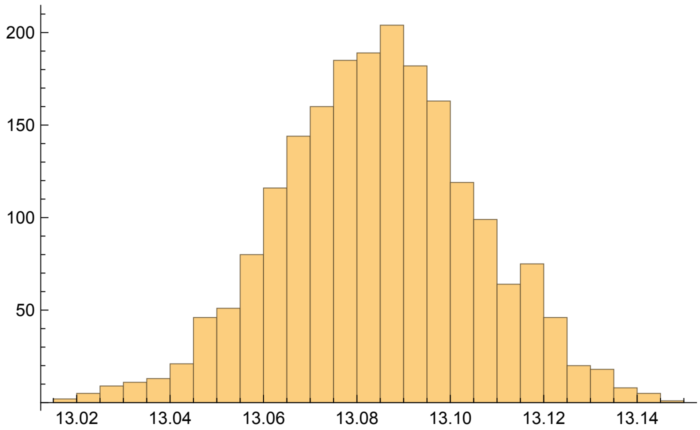



```
cleaned = ConstantArray[0, nevents - 5];
```

```
m = 0;
Do[
  If[Abs[(fitpt[[i, 2]] - 13.085)] > 0.07, Goto[Clean]];
  m++;
  cleaned[[m]] = fitpt[[i, 2]];
  Label[Clean];
  , {i, nevents}];
m
```

2036

```
Histogram[cleaned]
```




```
m = Mean[cleaned];
rm = RootMeanSquare[cleaned - m]
```

0.0210493

So the rough rms from CF timing using local cubic fit (commonly used in our PICOSEC work, for example) is 21 picoseconds rather than 15 picosec estimated from noise. But as stated above we are operating a bit below MIP equivalent and we are also a factor of 2 lower in gain (and therefore factor of 2 worse in noise limit to timing) than the 1800 V bias we commonly used.

So I conclude that we have consistency with the earlier work I did with Delagnes.

This report will be followed by another in which we use more advanced fitting and also some of the signal modeling tools.

Stay posted.