UCSC FNAL Beam Test Analysis

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Overview

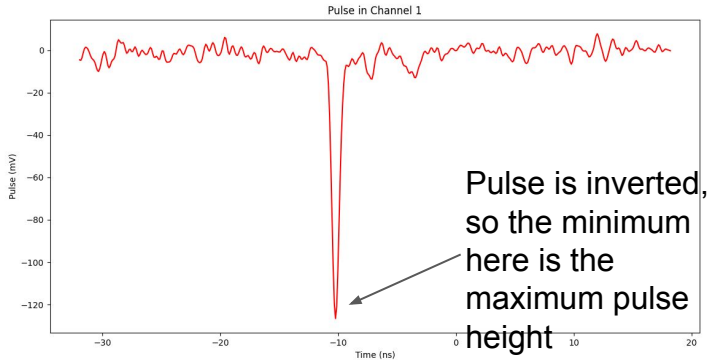
- Talk consists of two types of studies: pulse sharing and position resolution
- Studies on pulse sharing are done using pmax histograms with respect to the horizontal location
- Position resolution is calculated by fitting a function to a plot of the position vs pmax fraction (more on what the pmax fraction is in a bit).

Introduction to Pulse Sharing Studies

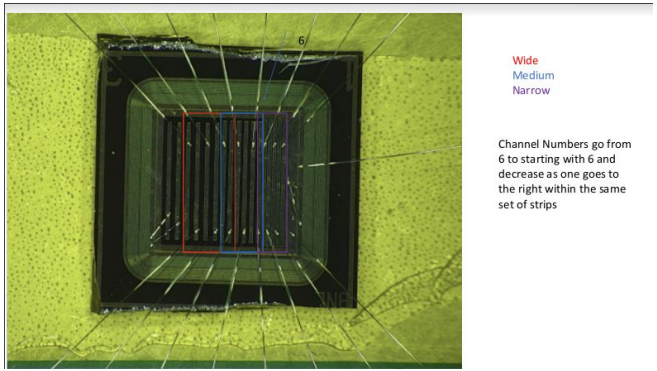
AC-LGAD strips depend on the sharing of pulses between neighboring strips for good position resolution. On the other hand, shared pulses can generate a background for Physics processes. The shared pulse tends to weaken with long distance, and at one point it reaches the level of the noise. We have investigated this distance with beam test data taken in the FNAL 120 GeV proton beam using as a sensor a BNL 2021 AC-LGAD. By requiring a fairly large pulse in one strip we can follow the shared pulse by reading out pulses appearing contemporaneously in neighboring strips. The noise on each strip can be determined from out of time data, and we compare the pulse height (Pmax) spectrum of in-time and out-of-time data.

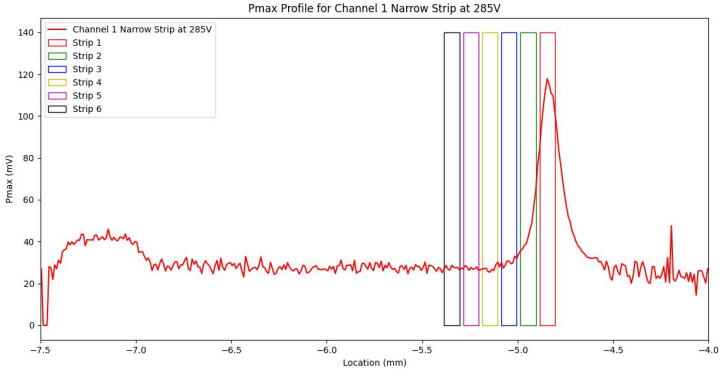
Overview of Shared Pulses

- Pmax is the max value of a pulse for an event read out by a strip. The average pmax across the sensor can be calculated and plotted in a pmax profile

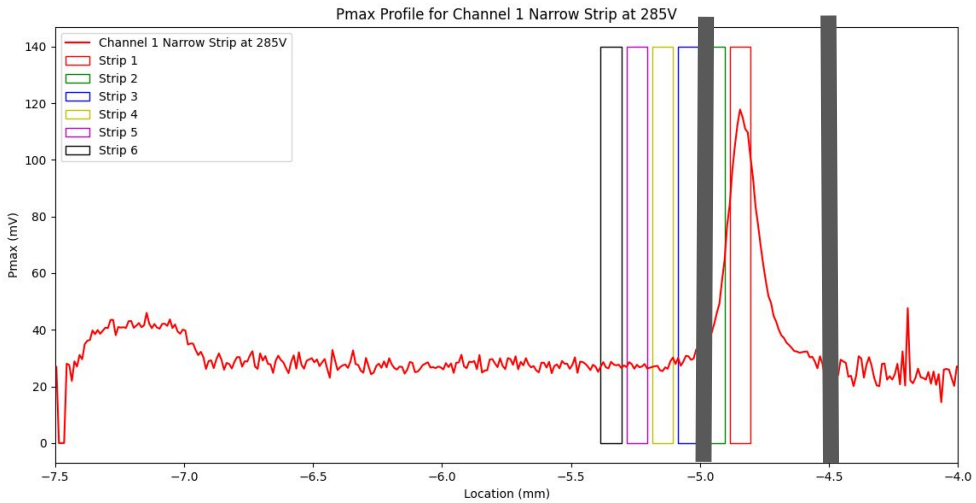


Wide: 200 um pitch, 80 um metal
Medium: 150 um pitch, 80 um metal
Narrow: 100 um pitch, 80 um metal





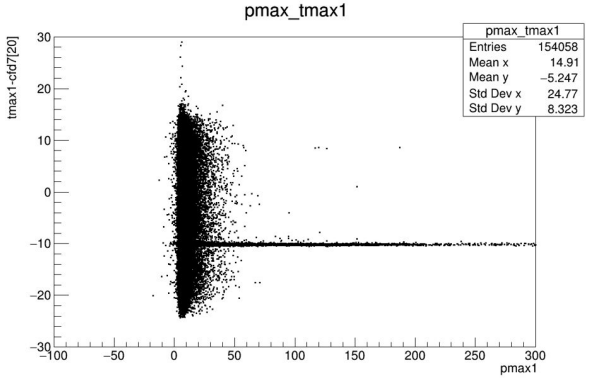
Overview of Shared pulses



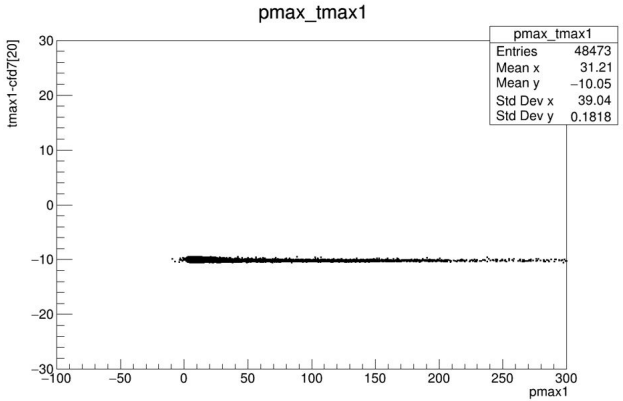
- Created pmax histograms using events between x = -5.0 to -4.5 mm for the narrow and medium strips and between x = -5.2 to -4.7 mm for the wide strips to study sharing between channel 1 and the other channels and to compare it to noise
  - Picking these events approximately picks out the events that occurred around strip 1
- Made two types of histograms: in-time and out-of-time
  - In-time histograms were made using in-time events, which had a tmax between -10.5 ns and -9.5 ns and pmax_ch1 > 100 mV.
  - Out-of-time histograms were made using out-of-time events, which had a tmax between -16 ns and 10 ns (except for the events that were in-time between -10.5 ns and -9.0 ns)

Tmax vs Pmax Plots (Medium Strips)

All Events

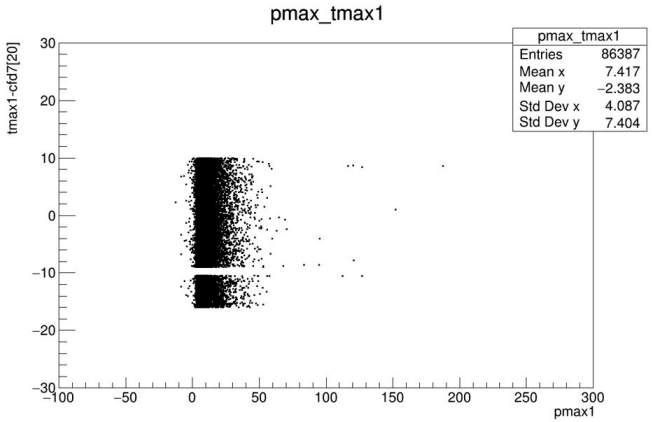


In-Time Events

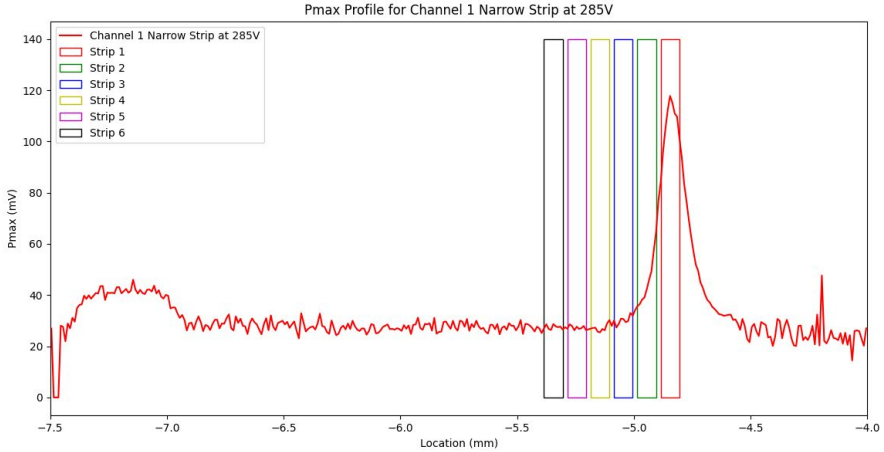


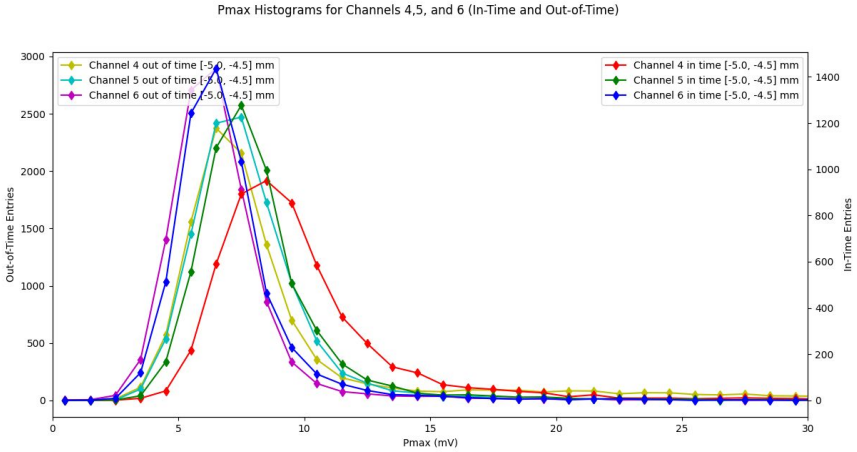
In Tmax vs Pmax scatter plots, Tmax corresponds to the time that the pulse reached its maximum value, and pmax corresponds to the maximum value of the pulse.

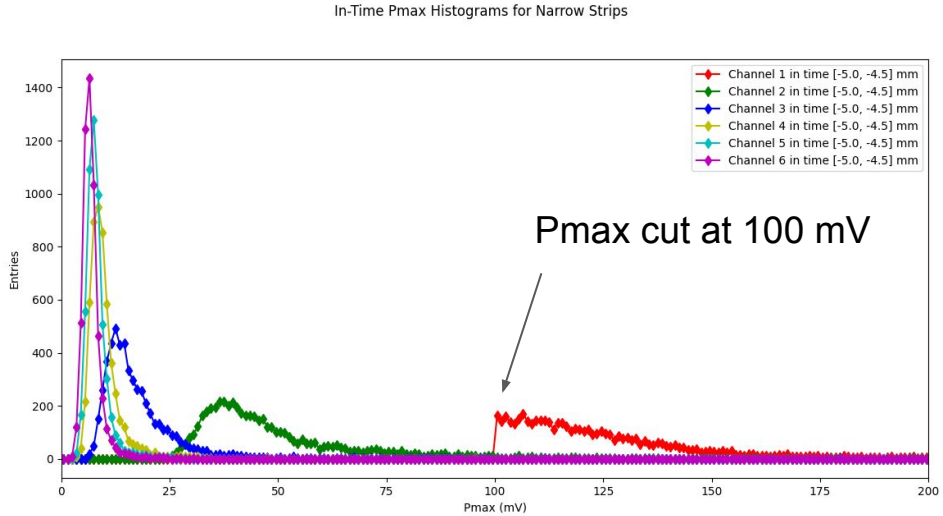
Out-of-Time Events



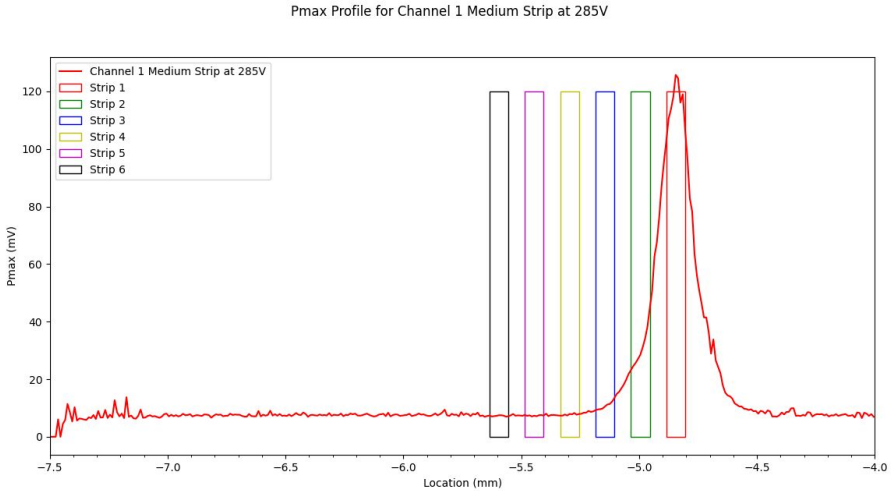
Narrow Strips (100um Pitch)

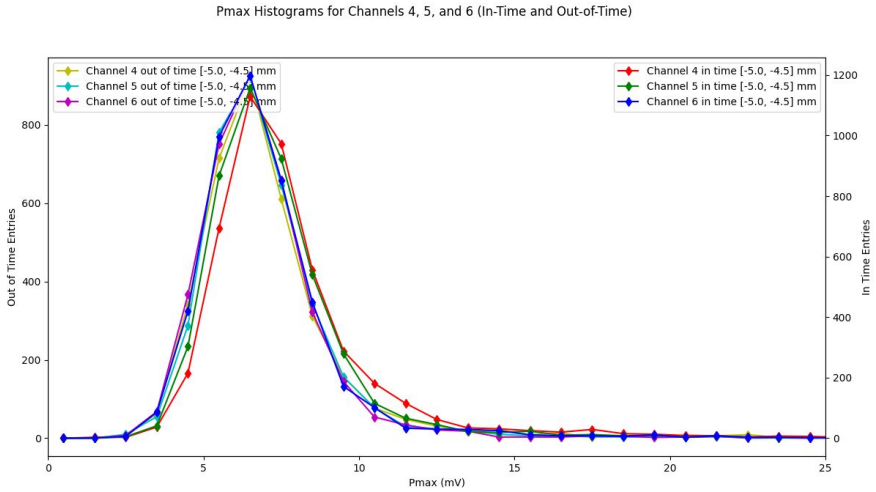


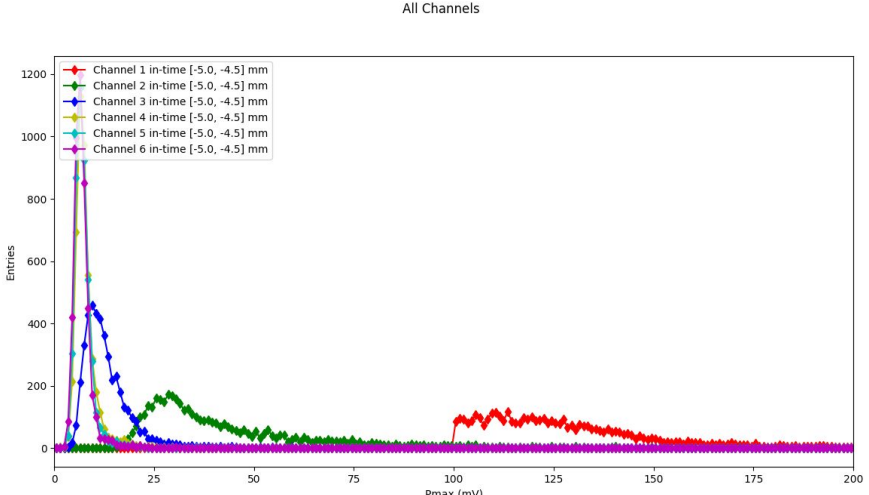




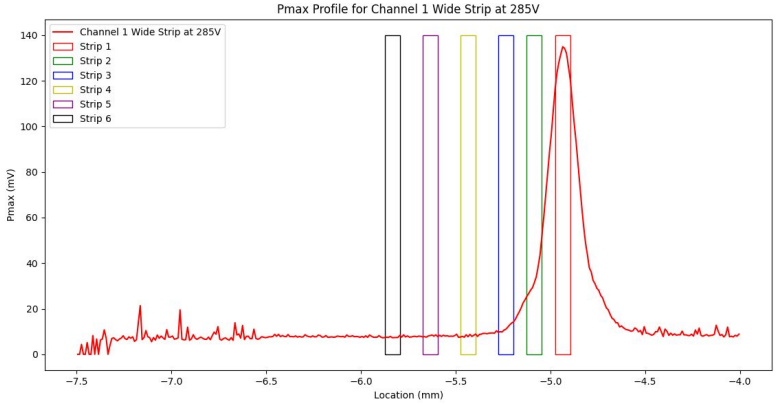
Medium Strip (150 um pitch)

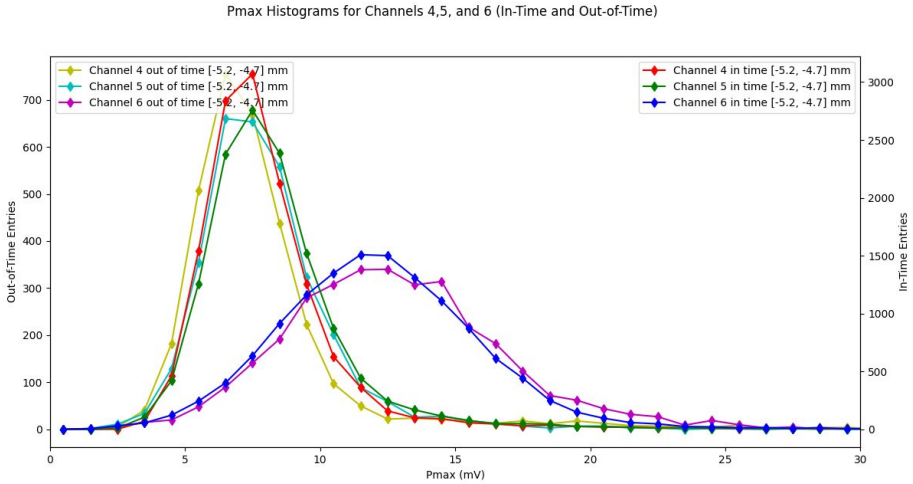


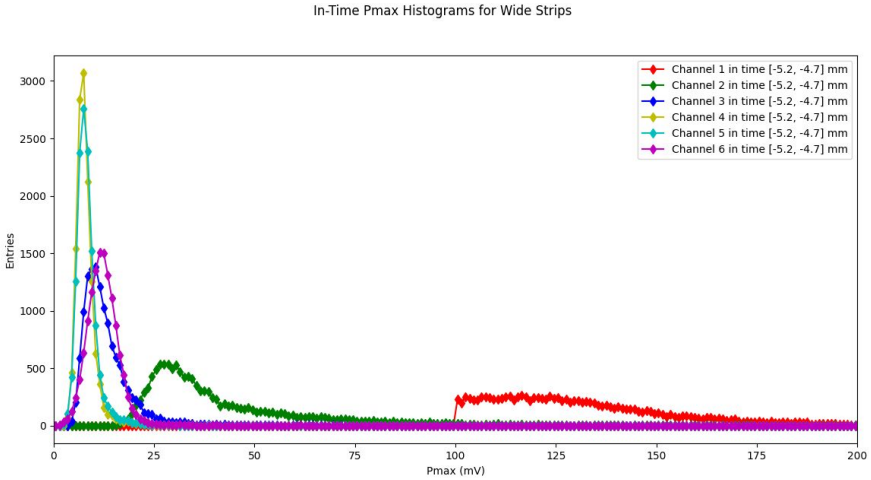




Wide Strips (200 um pitch)

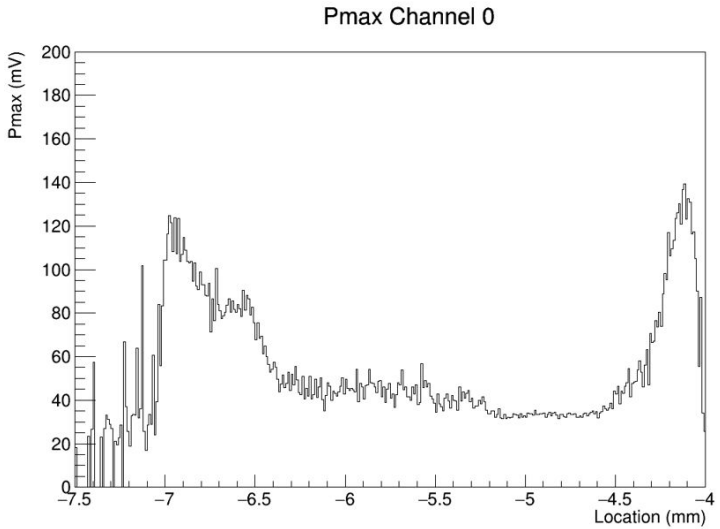






Channel 0 Pmax Profile

- Plot of the average maximum pulse height along the x-axis
- Around -5.0 to -4.5 mm, the average maximum pulse height is around 40 mV



Dependence on Pitch

- Sharing is clearly present in channels 2 and 3
- At the present with an S/N of 80, this limits the investigation of sharing in AC-LGAD strip detectors to a distance of about 500 um
- The Pmax distributions for the channels 2,3 move to lower values with wider pitch (sharing depends on the distance)
- Channels 4,5,6 are essentially at the noise floor
- Channels “Wide” 6 and “Narrow” 1 have larger noise since they are close to the N+ contact which exhibits large noise

Position Resolution

Procedure:

- Our goal is to calculate the position resolution according to:

$$\textbf{Position Resolution } \sigma(\textbf{Pos}) = \sqrt{2}\,\frac{d(\textbf{Position})}{d(\textbf{Fraction})}/\left(\frac{S}{N}\right)$$

- Create a 1D profile for two adjacent pads/strips with the average pmax at a particular x-location on the y-axis. Then, add the two pads'/strips' curves to obtain the **Pmax Sum** curve.

- Calculate **Pmax Fraction** as a function of position between the two pads/strips:

$$\textbf{Pmax Fraction Ch1} = \frac{\textbf{Pmax Ch1}}{\textbf{Pmax Sum}} \qquad \textbf{Pmax Fraction Ch2} = \frac{\textbf{Pmax Ch2}}{\textbf{Pmax Sum}}$$

- Create a plot of "Position vs Pmax Fraction" and fit the data to get an equation for **Position(Fraction)**.

Procedure:

- Take the derivative, **d(Position)/d(Fraction)**, of the “Position vs Pmax Fraction” fit.

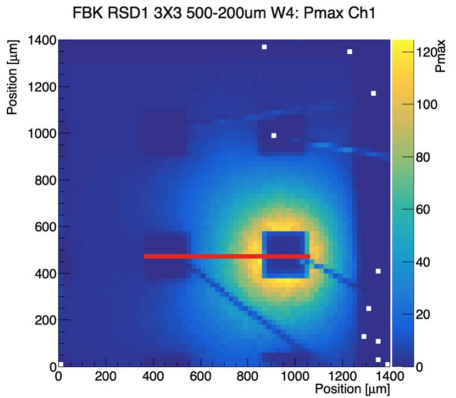
- Calculate the signal to noise ratio for each channel, where **S** is the value of **Pmax Sum** between the two pads being analyzed, and **N** is the RMS noise of each channel.

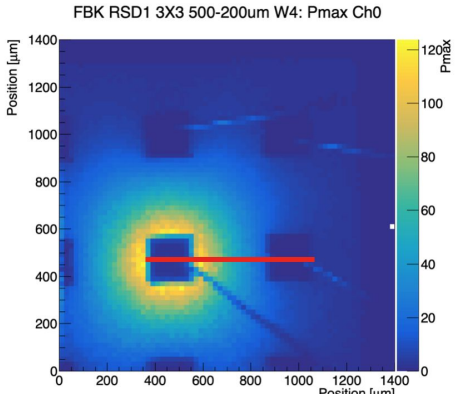
- Plug **d(Position)/d(Fraction)** and **S/N** into the position resolution formula and plot as a function of position

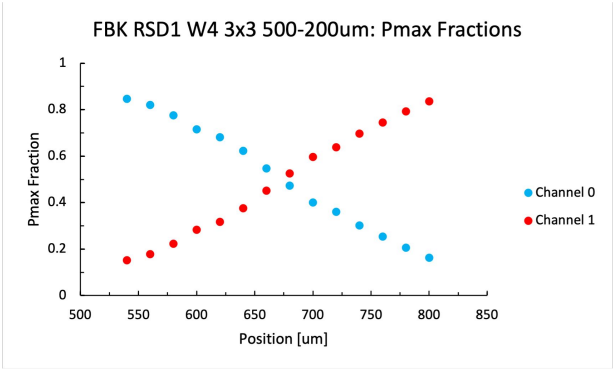
$$\textbf{Position Resolution } \sigma(\text{Pos}) = \sqrt{2}\,\frac{d(\text{Position})}{d(\text{Fraction})}\Big/\left(\frac{S}{N}\right)$$

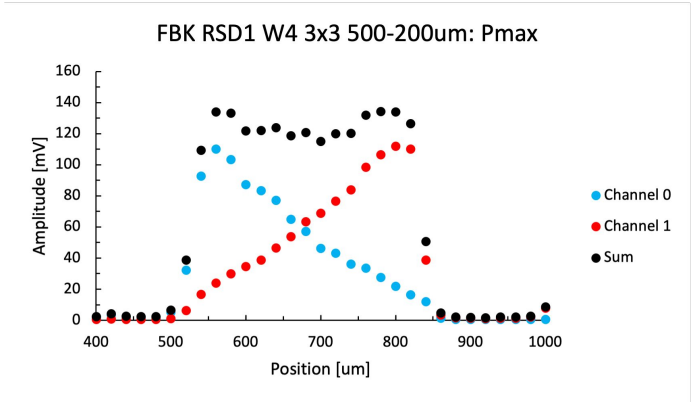
W4 - Pmax and Pmax Fractions

FBK Sensors: 500um pitch, 200um pad size, and are 3x3 arrays of square pads



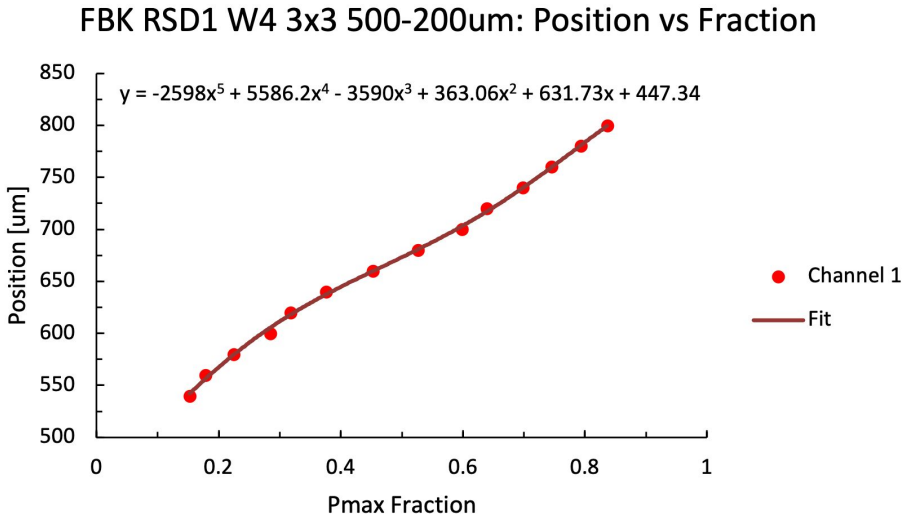


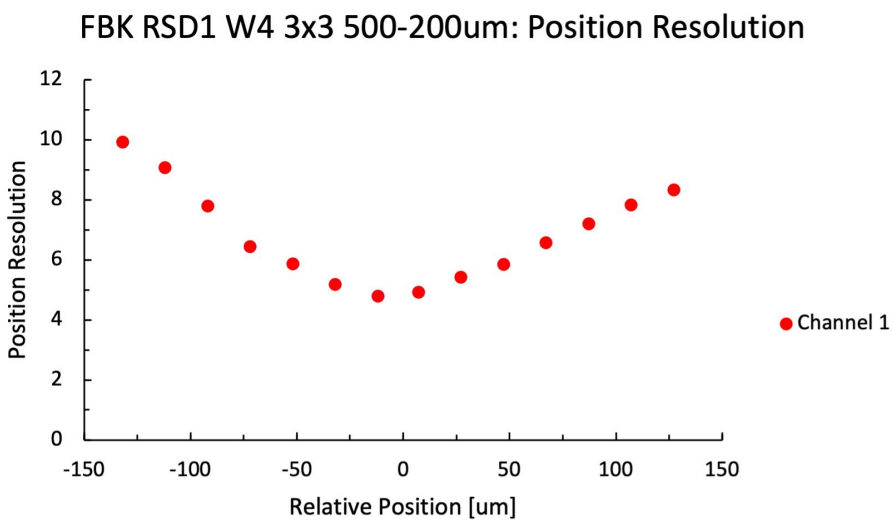




Here the pmax fractions only extend to the edge of the metal pad

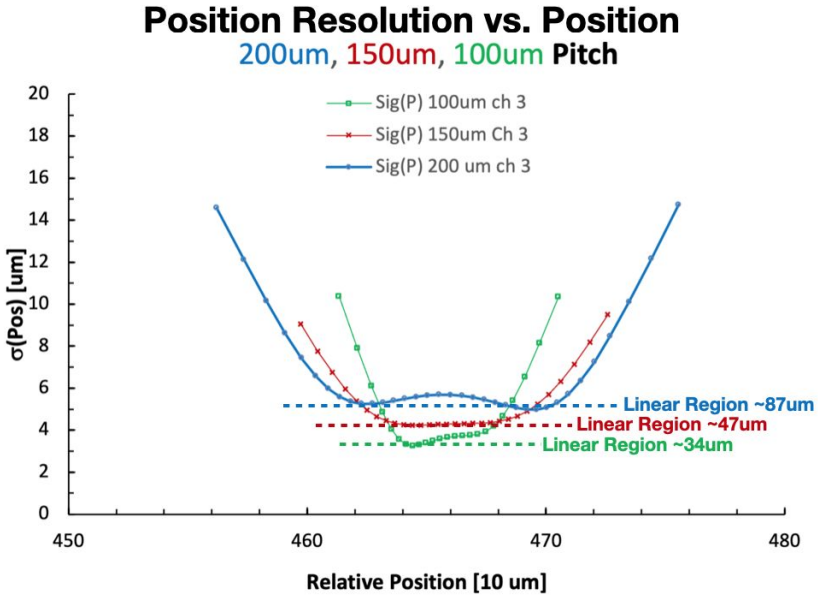
W4 - Position vs Fraction





$$\text{Position Resolution } \sigma(\text{Pos}) = \sqrt{2}\,\frac{d(\text{Position})}{d(\text{Fraction})}/\left(\frac{S}{N}\right)$$

Position Resolution-BNL Strips



This plot is the position resolution plot for the BNL strips based on data taken by the FNAL beam test.

Position Resolution Comparison:

Sensor Type	Pitch [um]	Metal [um]	Pad Distance [um]	Linear Distance [um]	Position Resolution Interpad [um]	Position Resolution Pad Center [um]
BNL Strip	200	80	120	87	5	15
BNL Strip	150	80	70	47	4	9
BNL Strip	100	80	20	34	3	10
HPK Pad C2	500	490	10	120	7	47
HPK Pad B2	500	490	10	45	14	48
FBK RSD1 W4	500	200	300	20	5	**N/A** (laser data)
FBK RSD1 W15	500	200	300	100	6	**N/A** (laser data)

Conclusion

- Pmax histograms show that sharing occurs generally for the first couple of neighbors. The exact extent of the sharing that occurs depends on the pitch of strips used.

Position Resolution of BNL 2021 AC-LGAD Strips at the FNAL Beam Test

- The sensors were designed and fabricated at BNL
G. Giacomini et al., “Fabrication and performance of AC-coupled LGADs”, 2019 JINST14 P09004
- The experiment was planned and executed by the Fermilab team, results were presented in Chris Madrid’s talk at this year’s RD50 Workshop https://indico.cern.ch/event/1029124/contributions/4411264/attachments/2268718/3852510/RD50_Jun22_2021.pdf, paper coming soon.
- Significant effort by the FNAL team to improve the position resolution of the tracker and DAQ to read out many channels with high efficiency.
- For the setup and previous results: A. Apresyan et al., JINST 15 P09038 (2020) (arXiv:2006.01999)

Contributors

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Fermi National Accelerator Laboratory FNAL

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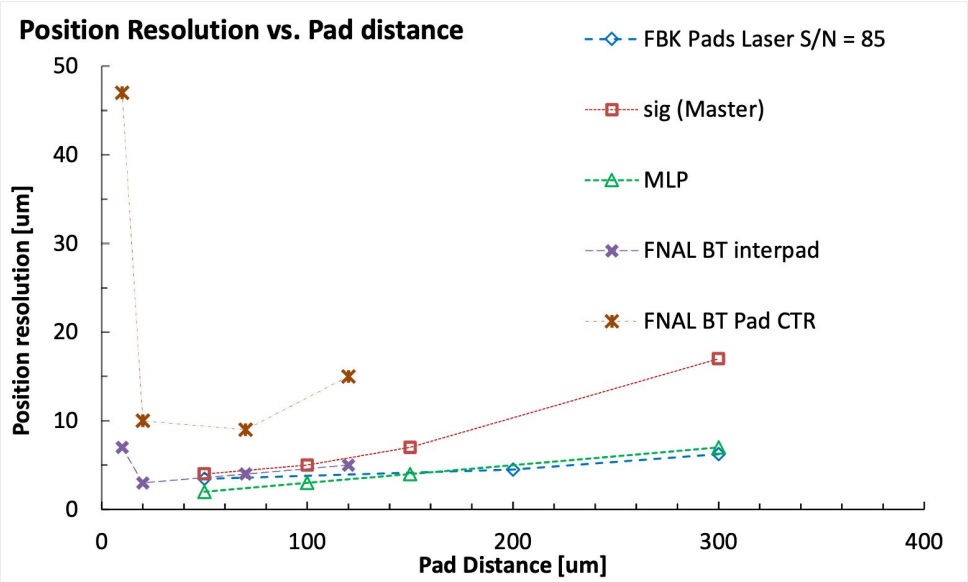
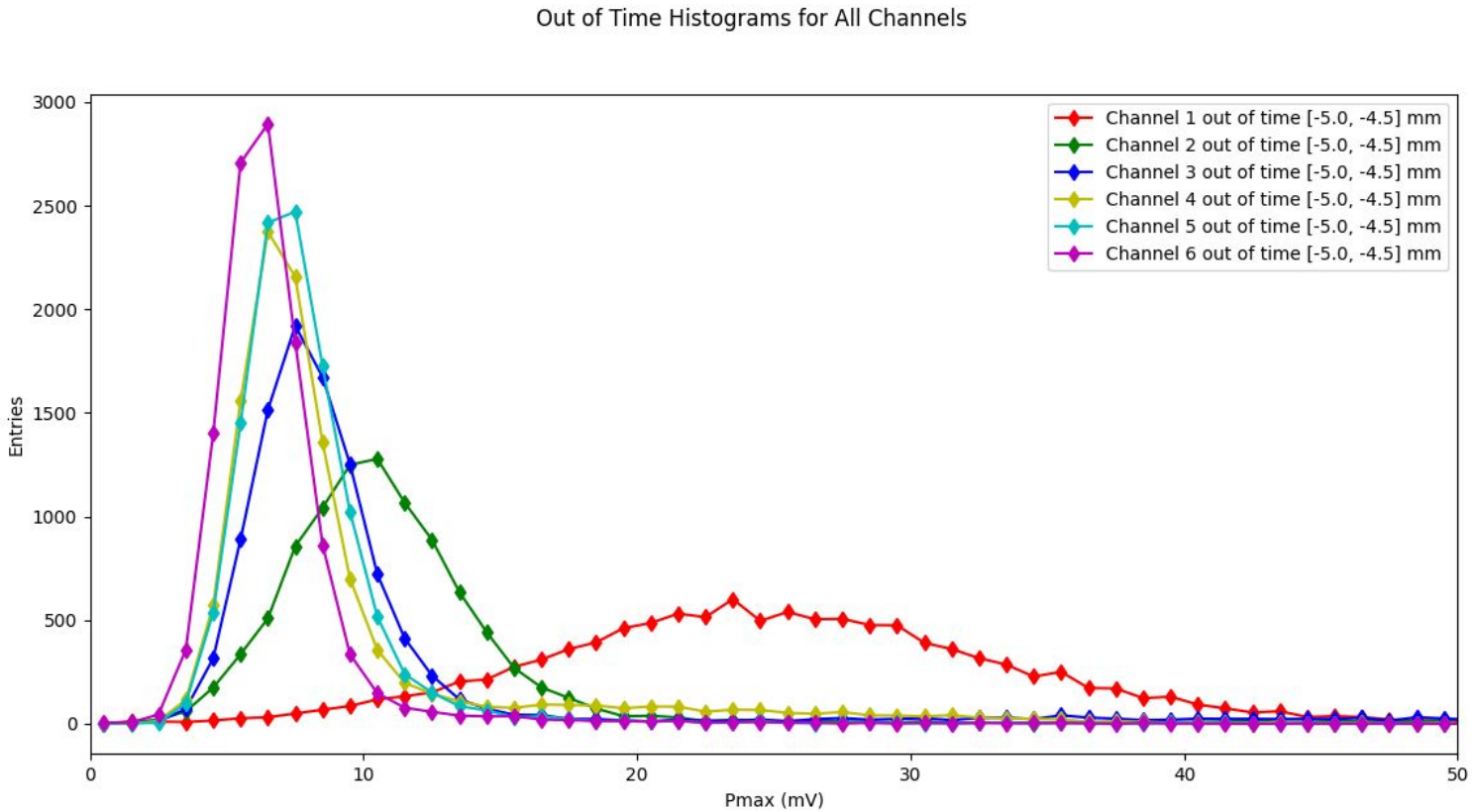
Backup Slides

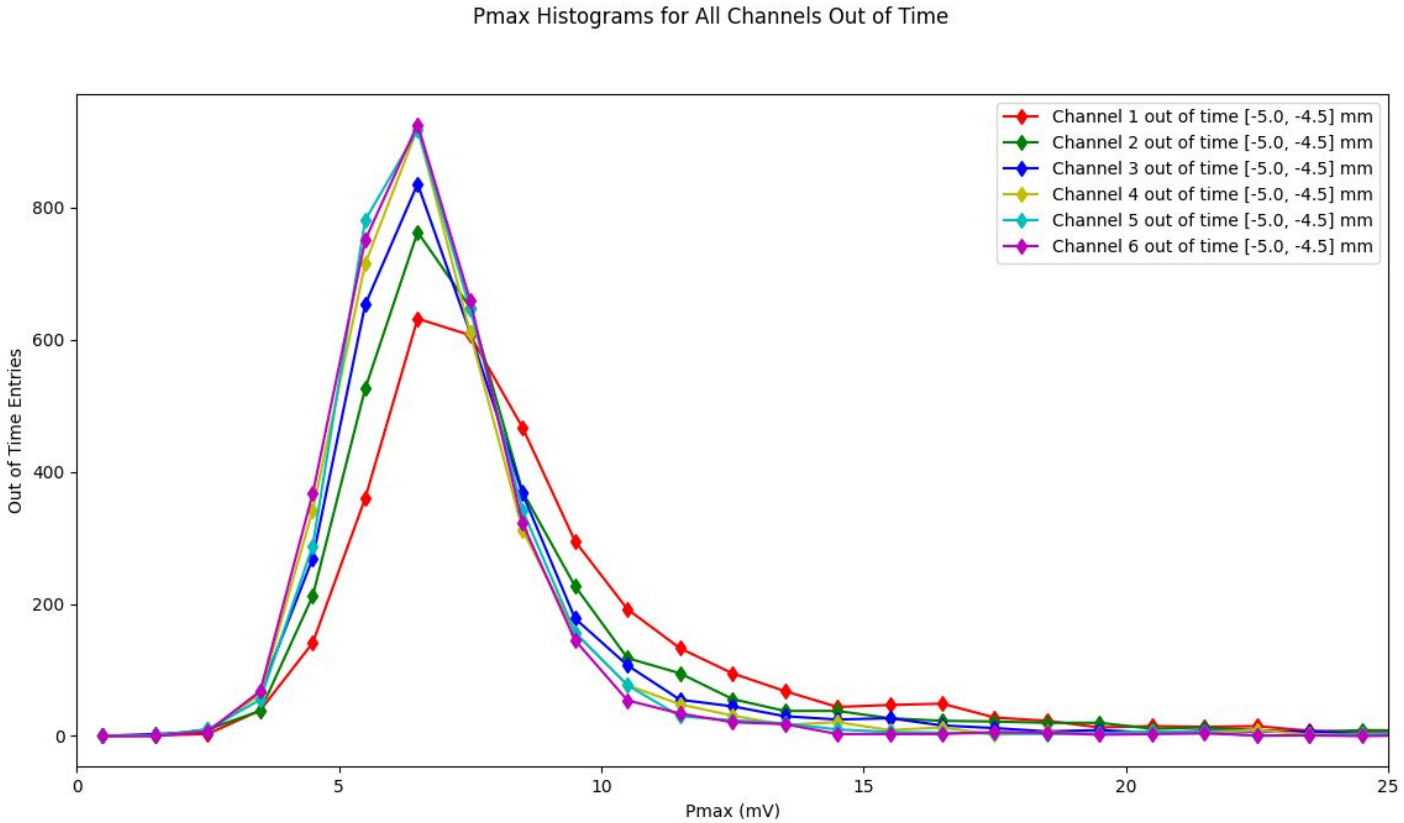
Position Resolution vs Pad Distance



Narrow Strips: Out of Time Histograms



Medium Strip: Out of Time Histograms



Wide Strips: Out of Time Histograms