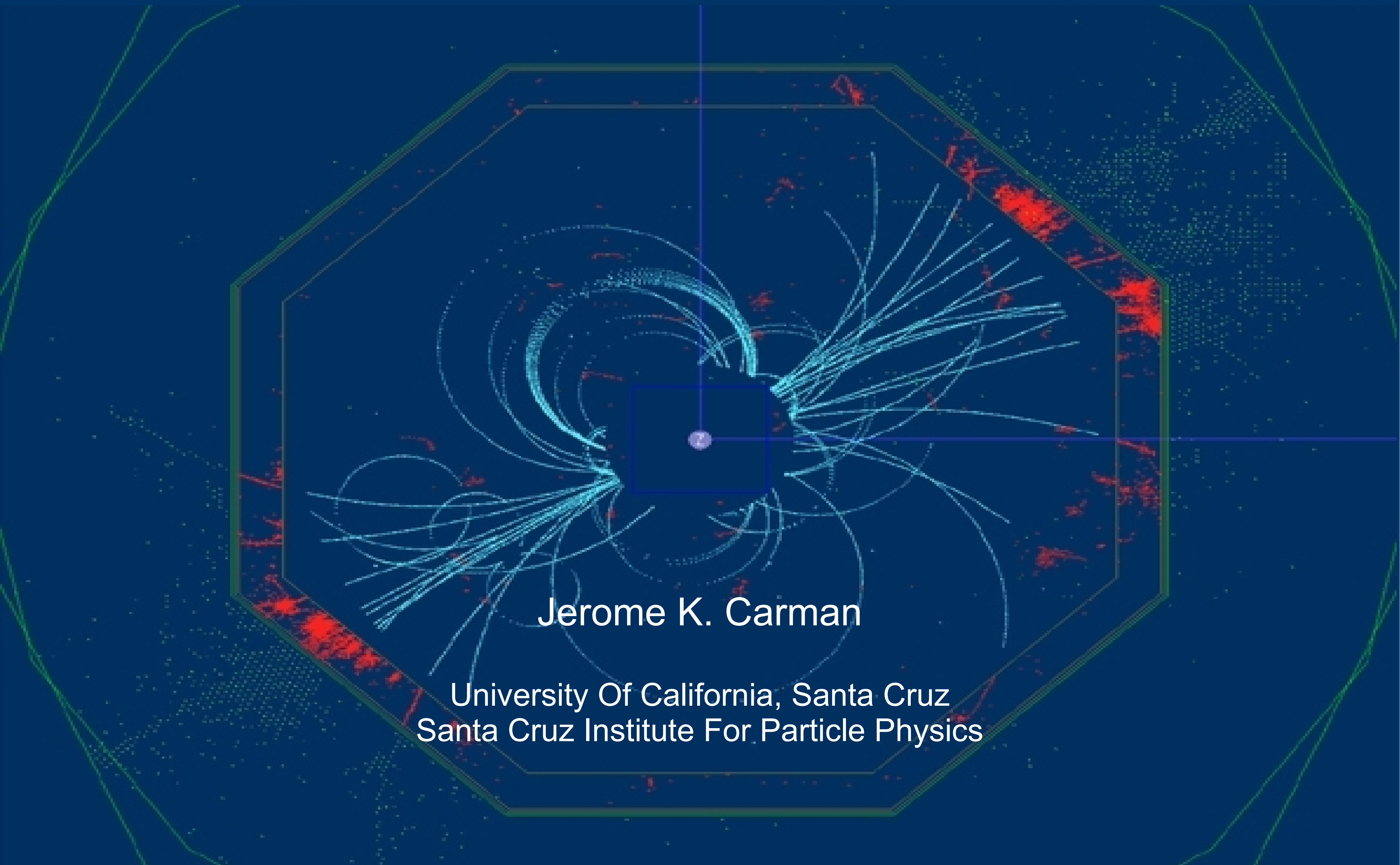
Measurement Of Longitudinal Position For Silicon Strip Detectors Via Charge Division



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Why Charge Division?

What methods exist for longitudinal position measurements?[1,2]

- Diffusive RC Line (noise dominated by the RC line)
  - Charge Division Method
    - Inherently linear for optimum shaping
    - Resolution is independent of resistance (both total as well as variations along the length of the diffusive line)
  - Rise Time Method
    - Not inherently linear
    - Sensitive to variations in both resistance and capacitance
- Delay Line (noise dominated by external sources (i.e. amplifiers))
  - Not efficient use of material
  - Requires significant line inductance to work

Why Charge Division?

Motivated specifically by a paper written by V. Radeka in 1974 entitled "Signal, Noise And Resolution In Position-Sensitive Detectors".[1]

- Most interesting is the claim that position resolution is independent of resistance for a diffusive line for relevant shaping times.

- $$\frac{\Delta L}{L} \approx \chi \left(\frac{\sqrt{kTC}}{Q_s} \right)$$

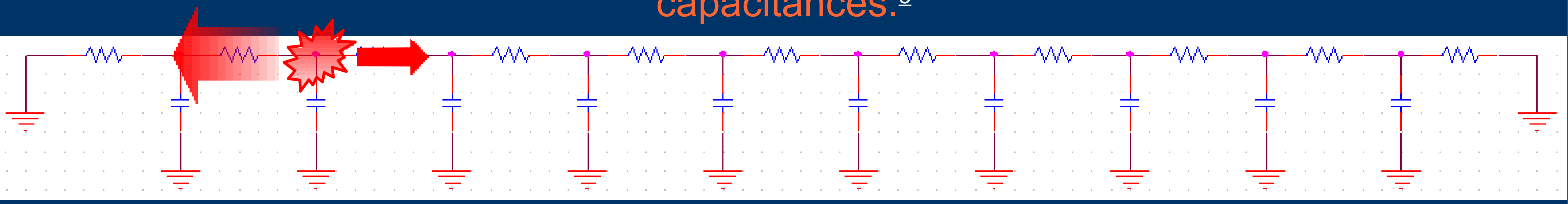
χ = coefficient which depends on the shaping function

kT = from parallel Johnson noise contribution

C = total detector capacitance

Q_s = total signal charge

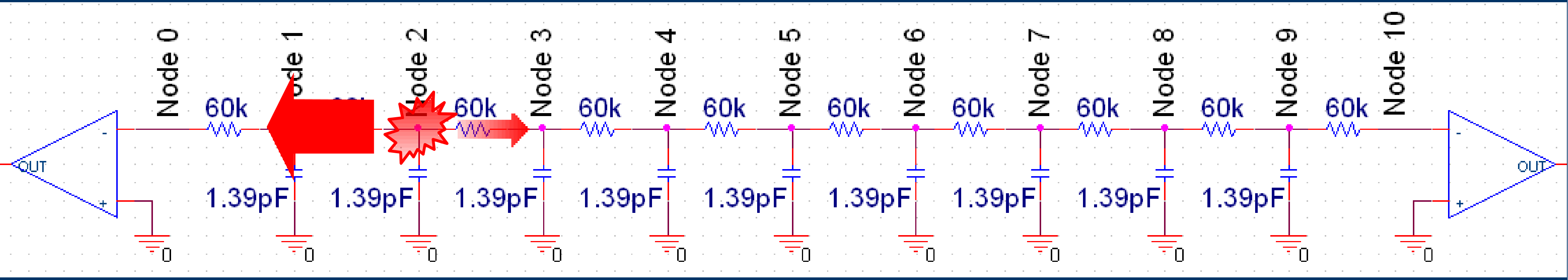
The diffusive line property of a silicon strip detector is modeled as a simple one dimensional RC line with a homogeneous distribution of discrete resistances and capacitances.[3]



Lets Test This Theory

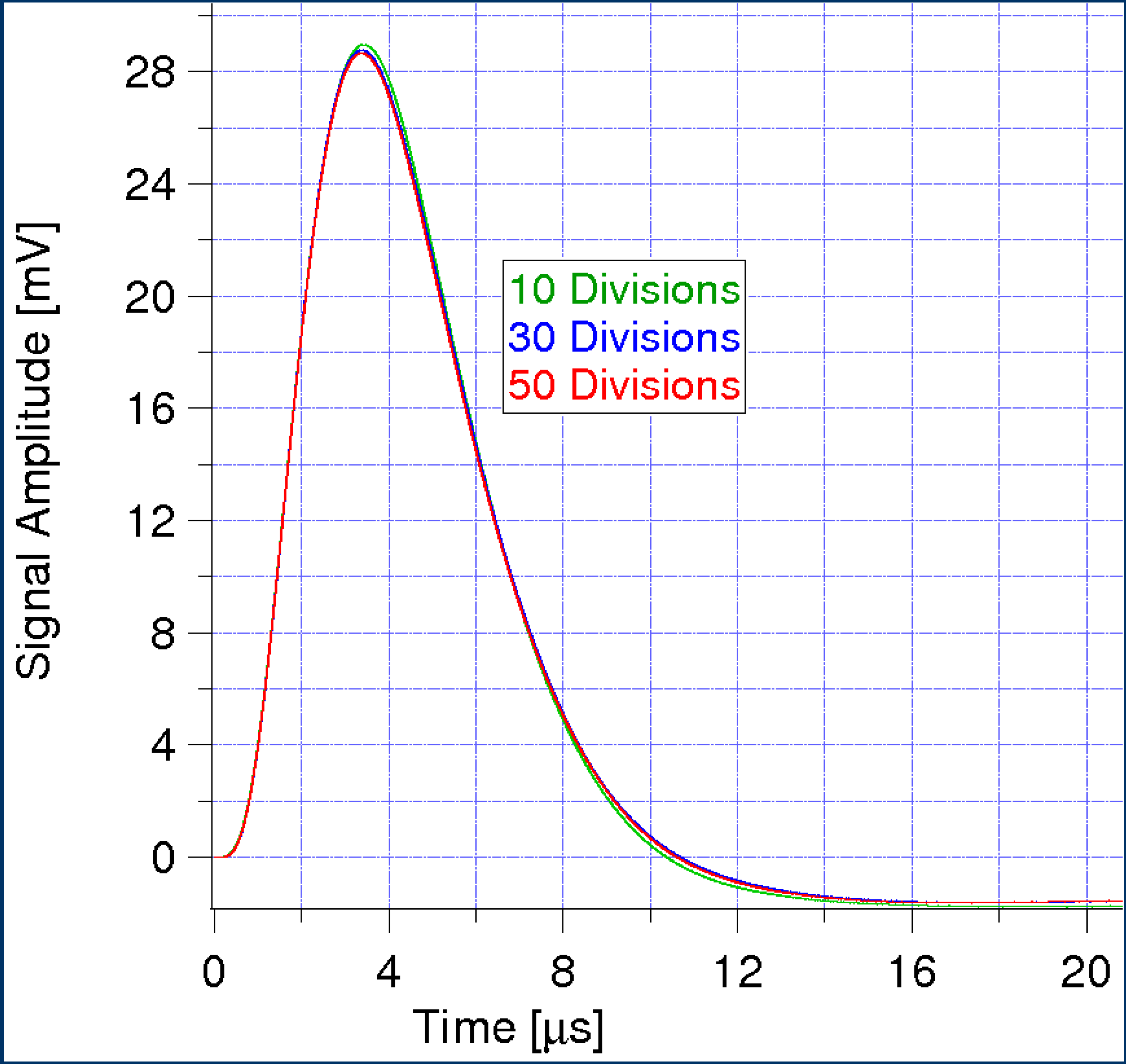
- Designed a pc board as a mock silicon strip detector with readout
- Use of a pc board was motivated by two factors.
  - Detectors designed specifically for charge division investigation were manufactured incorrectly making them unusable for this project
  - A pc board model is easier anyways!

10cm Detector Model:
- Total R = 600kΩ
- Total C = 12.5pF



Choosing The Number Of Divisions For A PC Board Detector Model

SCIPP



- Pspice Simulation
- Used 600kΩ, 12.5pF divided equally between 10, 30, 50 divisions.
- Used same shaping function for all three cases.
- Result shows that the 10 division model has sufficient granularity to approximate a continuous distribution.

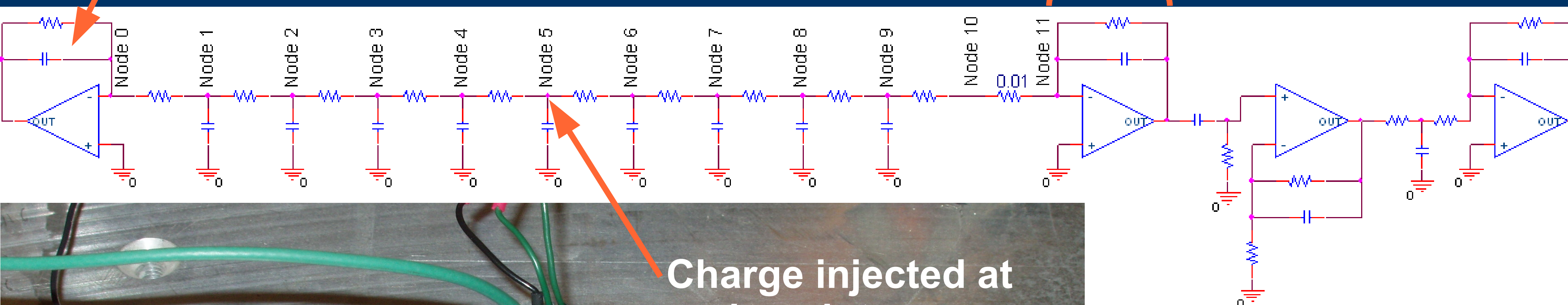
PC Board Model Of A Five Channel Silicon Strip Detector With Charge Division Readout

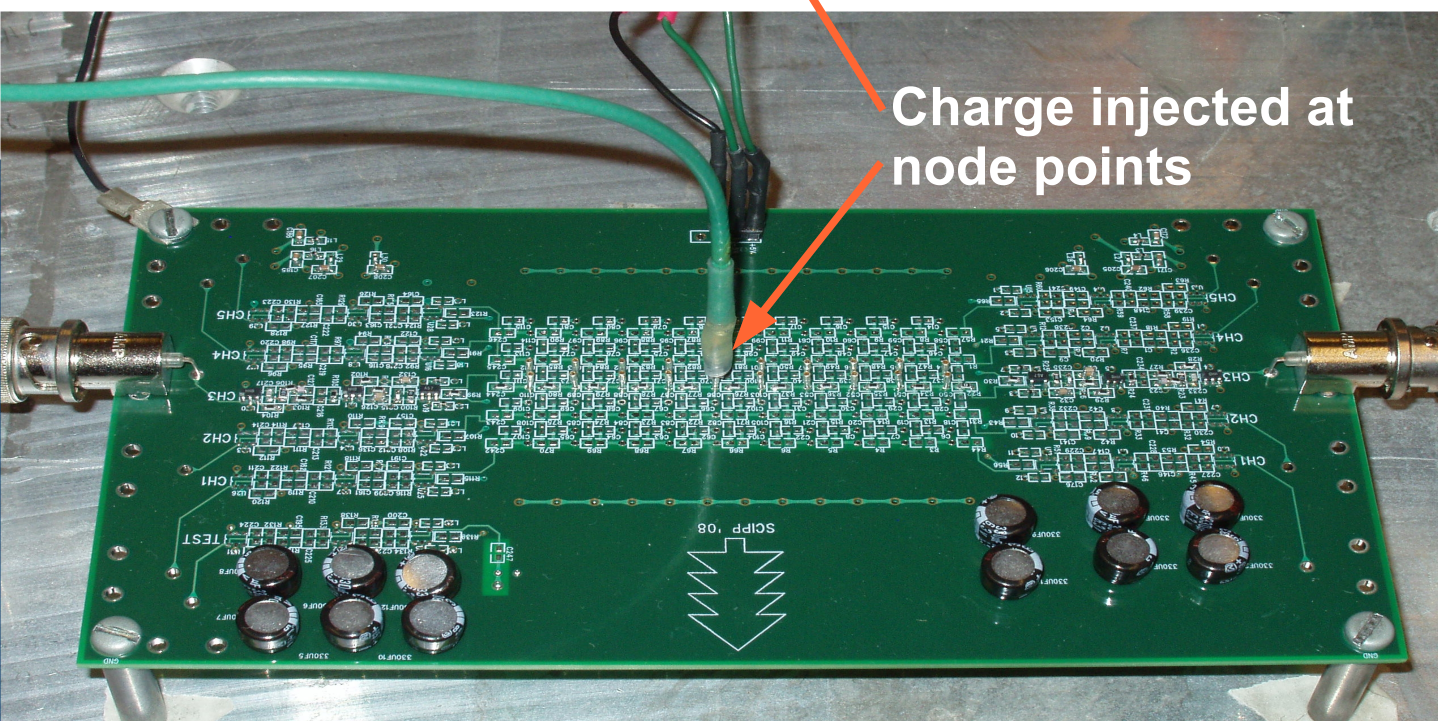
SCIPP

Left side amplifier design is identical to the right side, but not shown

Preamp is a high GBP charge sensitive integrator.

Schematic of one of five channels.





- Three stage integration, with the shaping time of each stage ≈⅓ total shaping time
- AC coupled to preamp via differentiation with long shaping time to minimize undershoot

Characterizing Stray Capacitances On The PC Board And Charge Injection Probe

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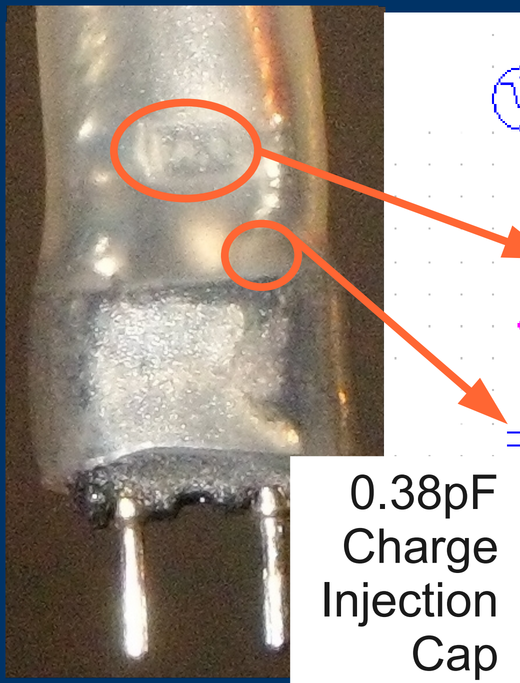
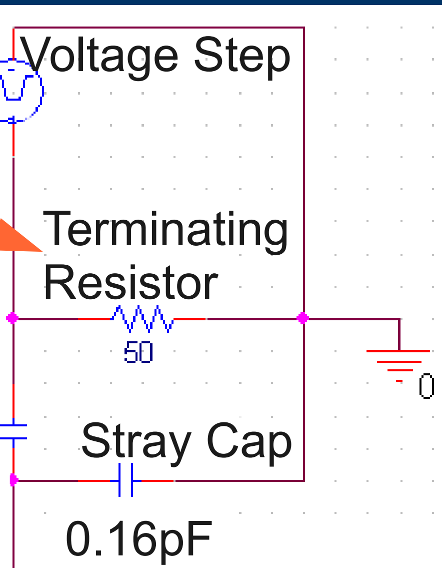




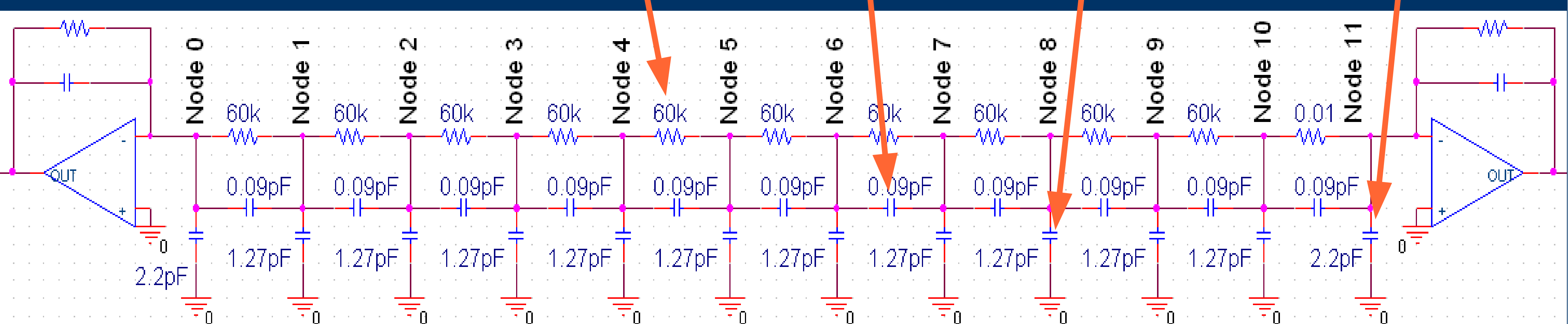
Used HP 2GHz LCR Meter With Kelvin Style Test Probe

0.09pF shunt capacitance due to both surface mount pads and part.

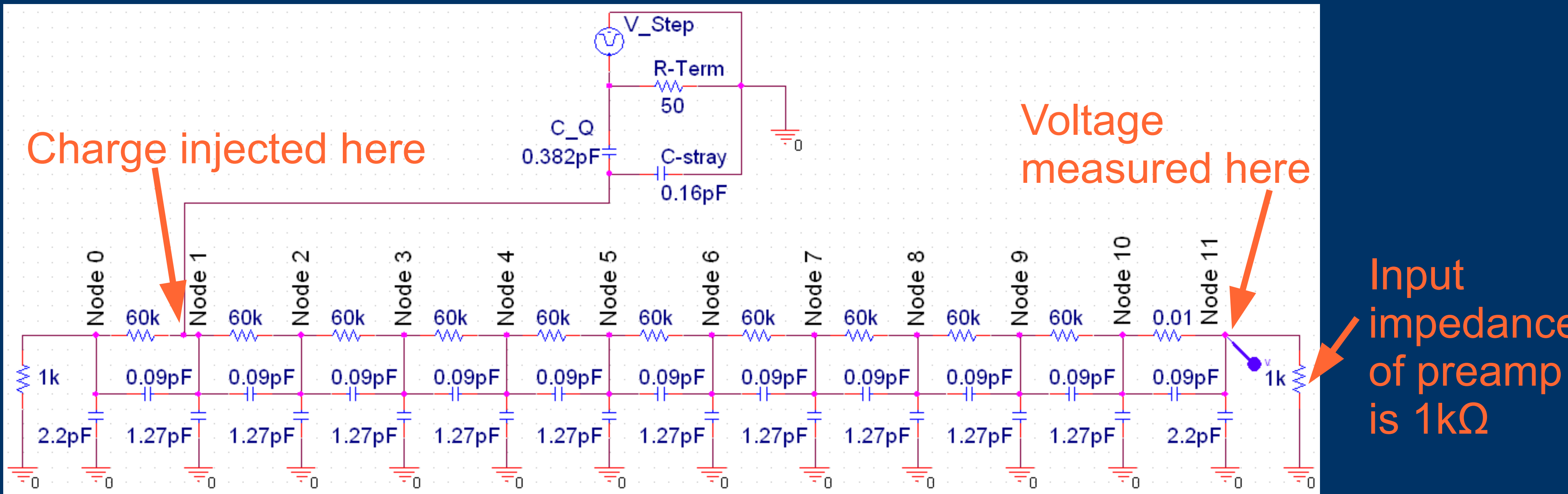
2.2pF from trace on input of preamp.

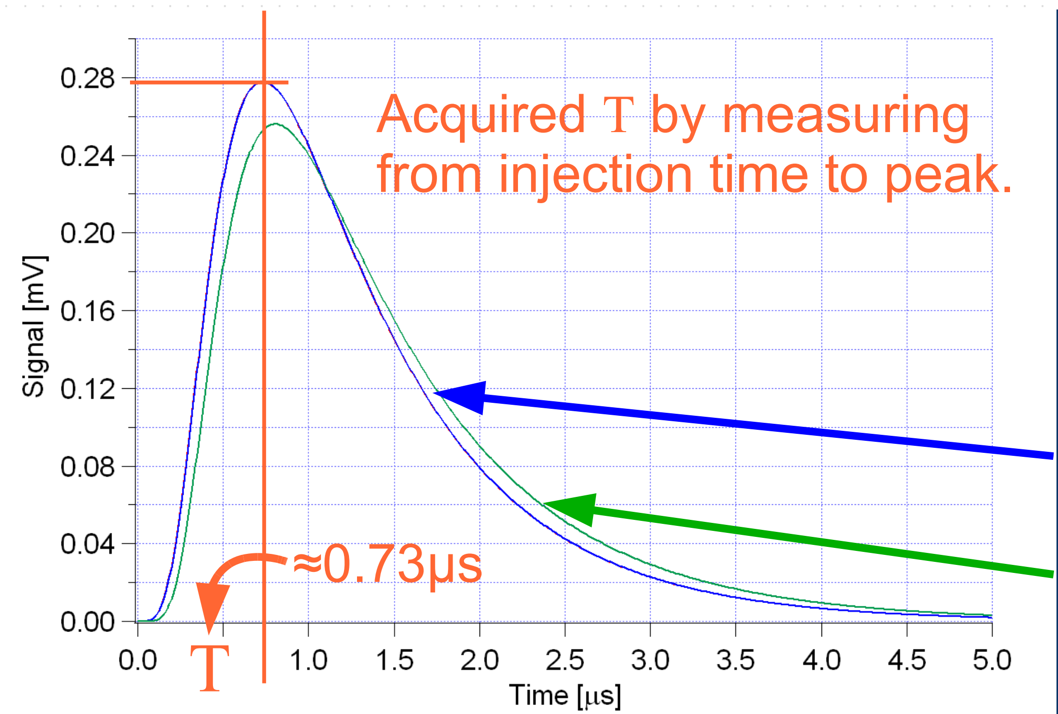
1.27pF to ground plane is all parasitic from pads and traces. No loaded capacitance.

60k are loaded surface mount resistors



Investigation Of Optimum Shaping Time



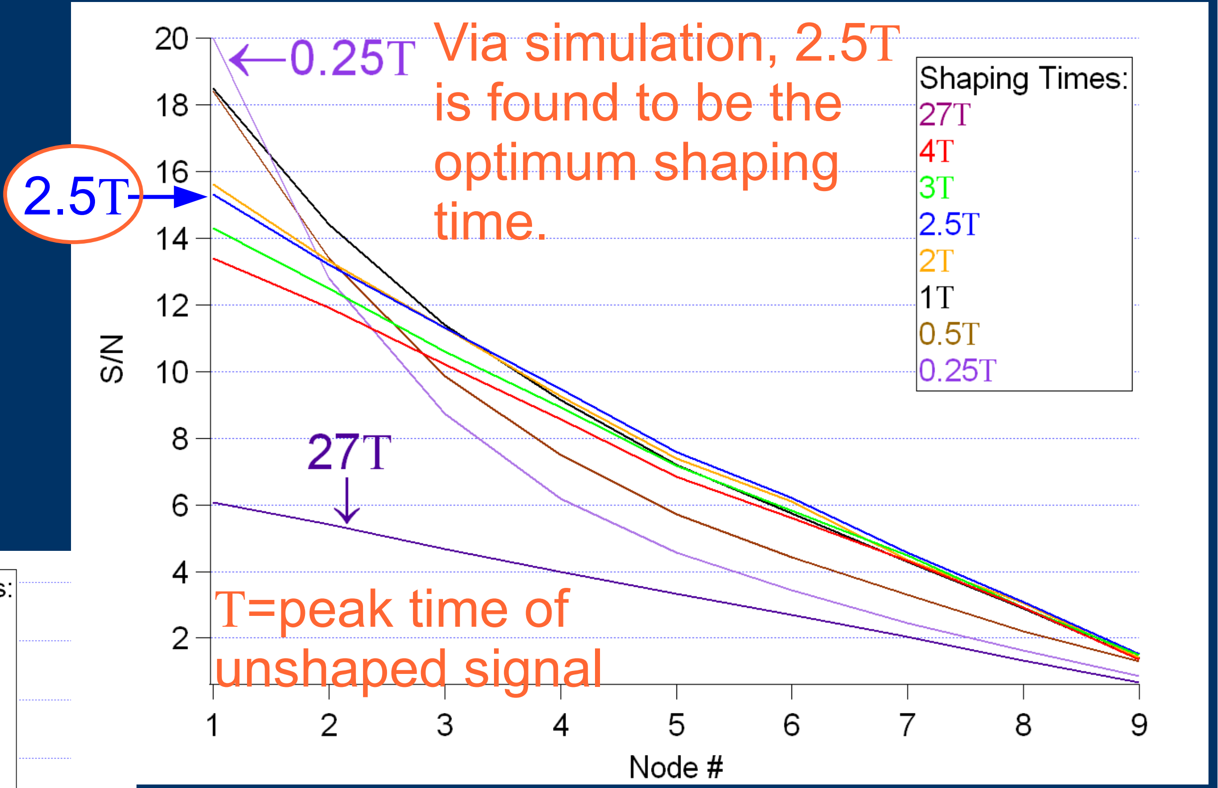


- I define T as the time constant from node 1 to node 11 (or node 9 to node 0).
- $T \approx (1/10)R_D C_D$
  - R_D = total strip resistance
  - C_D = total strip capacitance
- Blue signal is the 600k 12.7pF diffusive line shown above.
- Green signal is a 600k 12.7pF diffusive line with 0.09pF and 2.2pF strays removed.

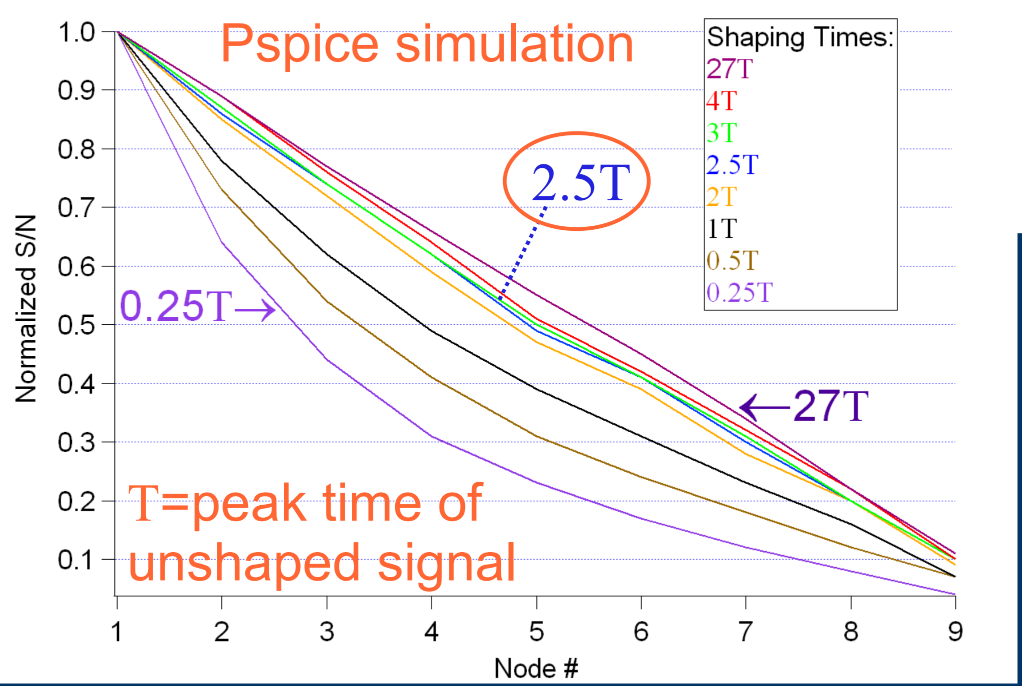
Investigation Of Optimum Shaping Time

SCIPP

- Using the Pspice simulations shown here, we find that the optimum S/N occurs for a shaping time of $\tau \approx 2.5\mathrm{T} \approx 0.23 R_D C_D$
  - shown as the **blue line**.



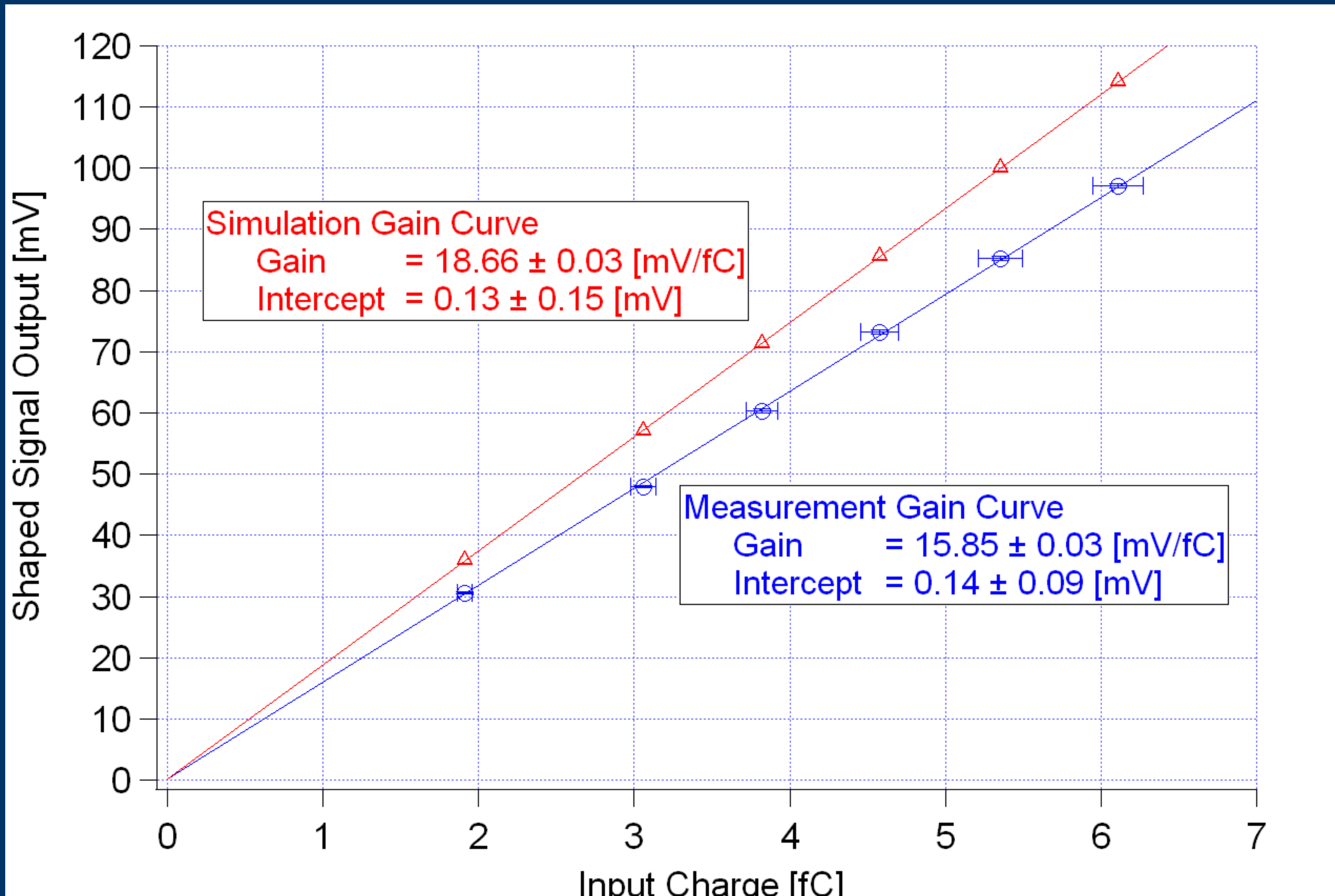
S/N vs. position



Normalized full scale S/N vs. position

- Radeka estimates that the optimum S/N occurs for a shaping time of $\tau \approx 3\mathrm{T} \approx 0.27 R_D C_D$
  - shown as the **green line**.

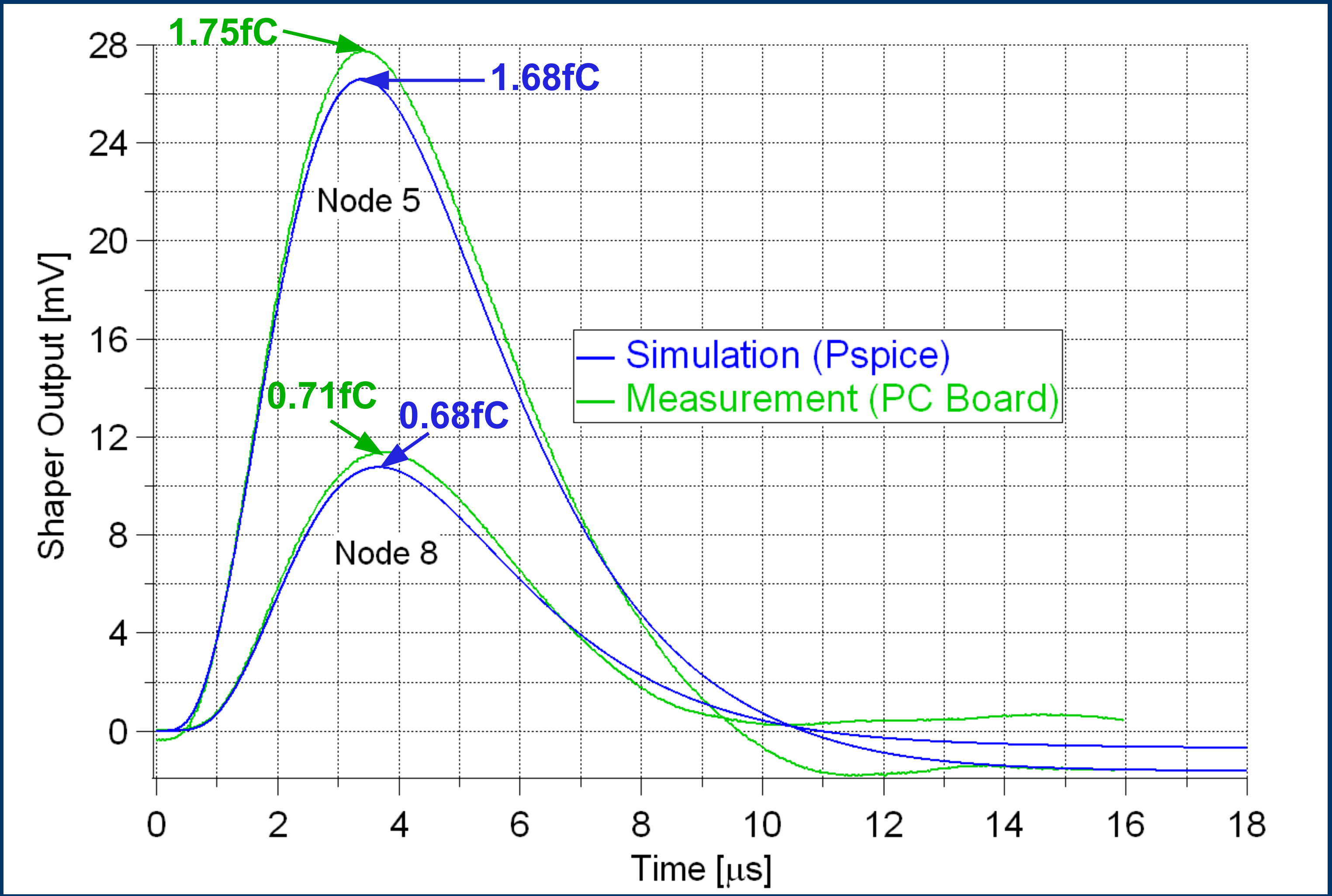
Benchmarking Simulation With The PC Board



Gain curves for simulation and pc board
for 600kΩ, 12.7pF detector model with 2.5T shaping time

- First step is to determine the gain curves for the simulation and the pc board.
- PSpice gain tends to be larger because of ideal components.

Benchmarking Simulation With The PC Board

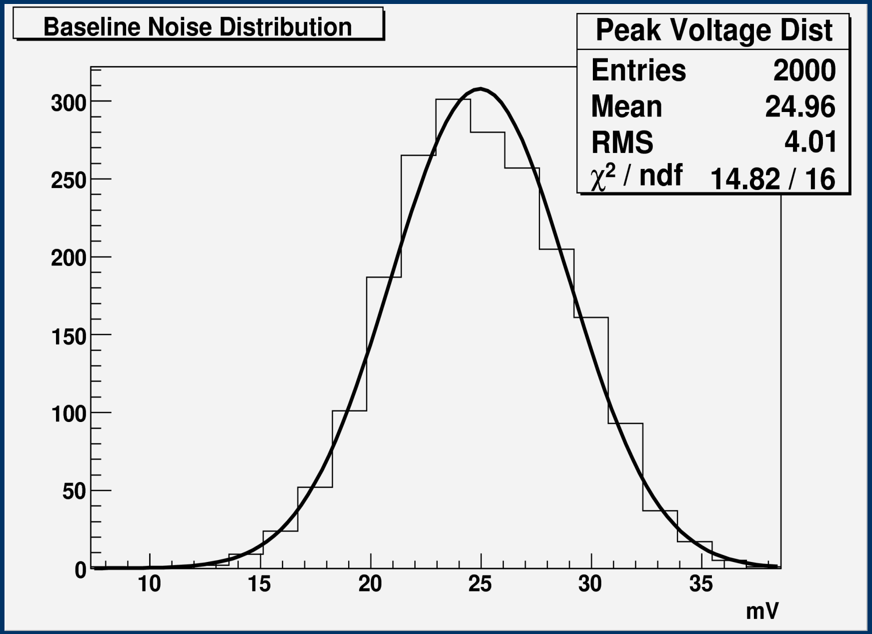


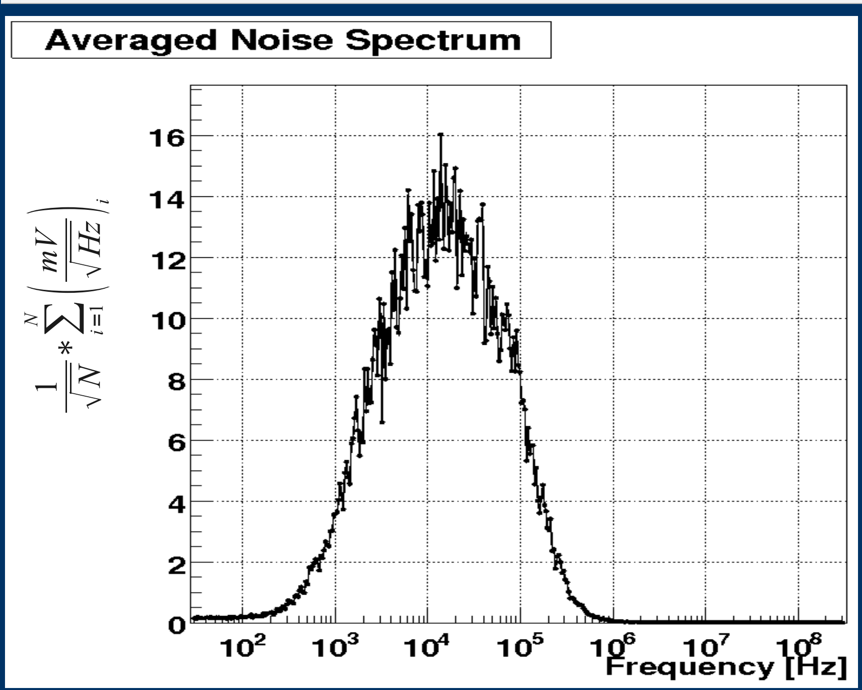
Comparison of shaper output between simulation and measurement for 600kΩ, 12.7pF, 2.5T shaping time.

- Target rise time is <u>1.83µs (2.5T)</u> from 1%→peak.
- Can see additional rise time added by diffusive line RC network which motivates the rise time method.
- Rise times differ by ≈ 5%.
- Peak charge values differ by ≈ 4%.
- e^{-1} fall times differ by ≈2.5%.

Benchmarking Simulation With The PC Board

SCIPP





R=600kΩ C=12.7pF

Measurement Method	Noise [mV]	Noise [fC]
Trace Merging	3.67	0.23
Spectrum Analyzer	3.80	0.24
Oscilloscope RMS	4.01	0.25

PSpice Prediction	3.69	0.23

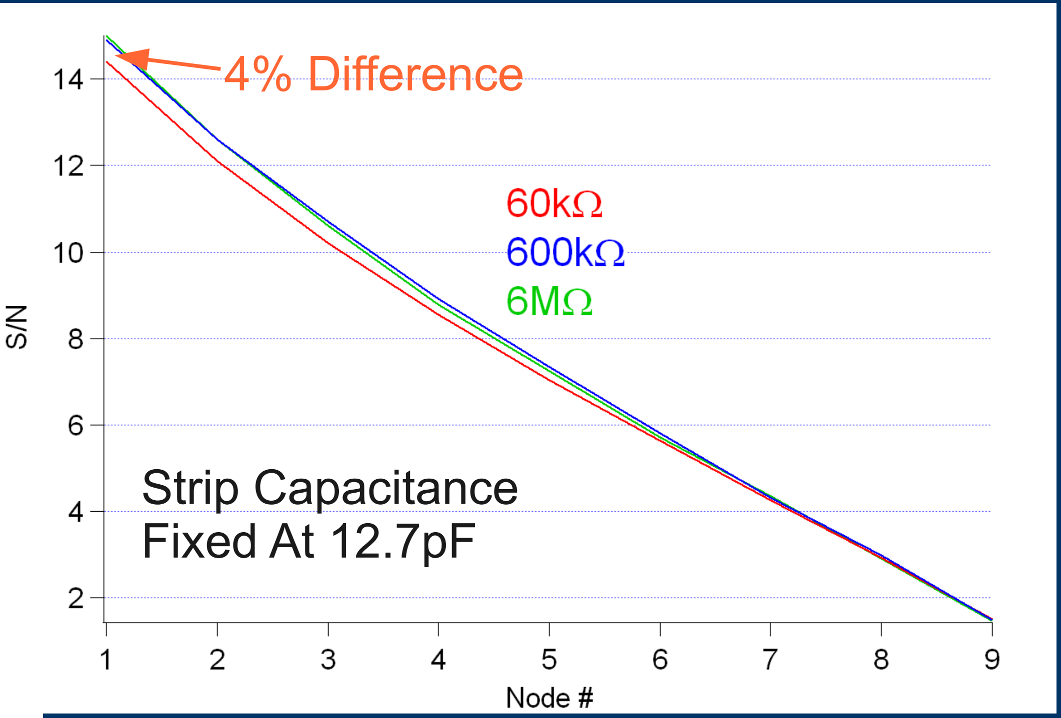
- Noise measurement agrees amazingly well with Pspice prediction!!
- We have confidence in the Pspice model.
- Pspice shows opamp noise contribution is less than 1% confirming that the noise is dominated by the RC network

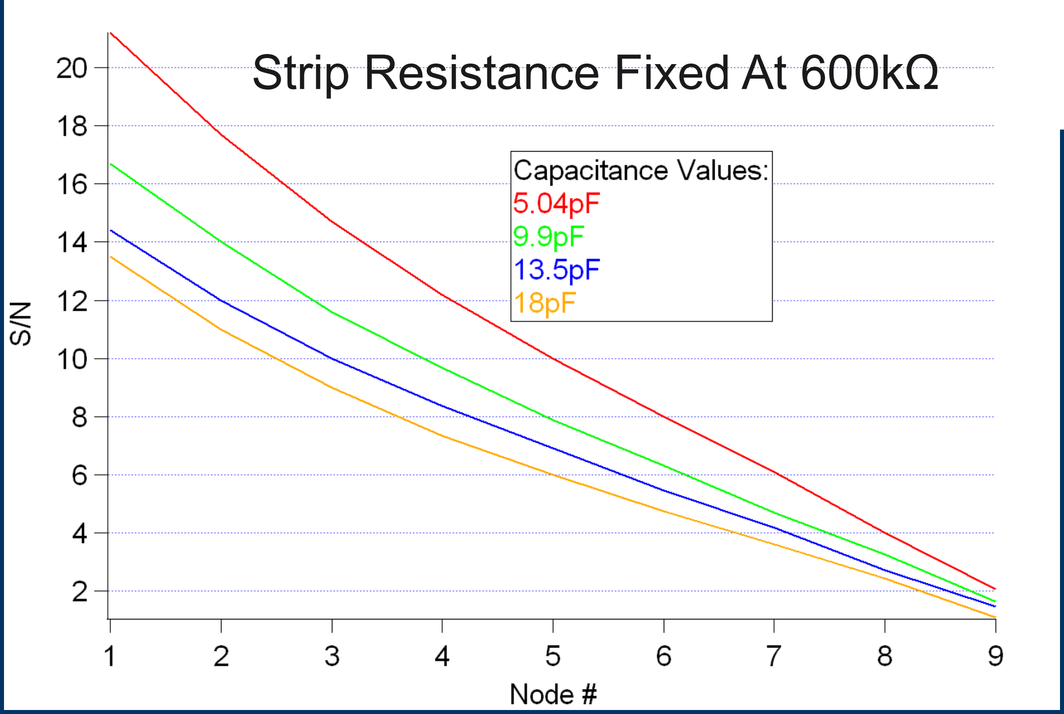
Looking At The Dependence Of S/N On RC Line Resistance And Capacitance

SCIPP

2.5T shaping time for all measurements

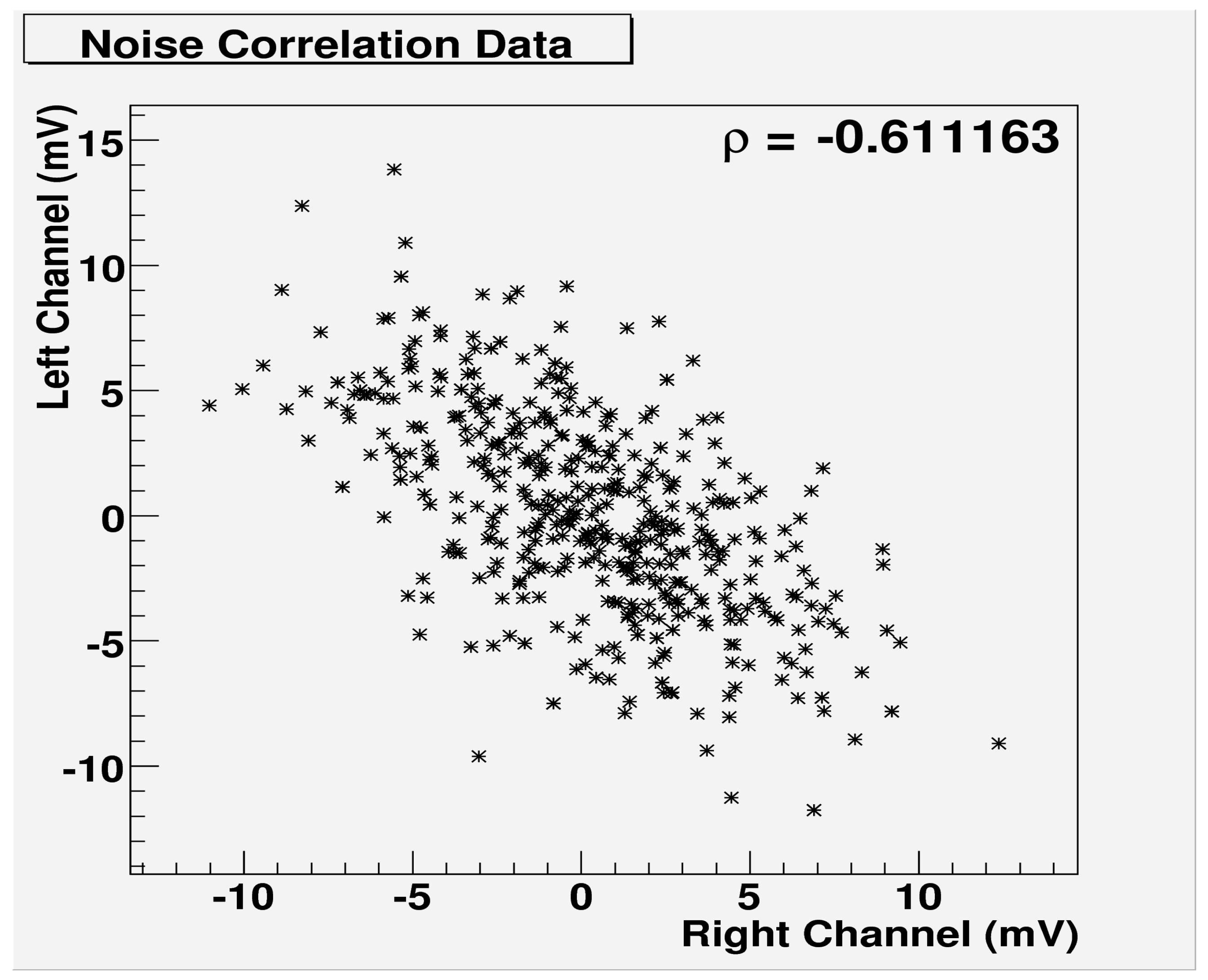
- Pspice simulation confirms the claim that S/N is independent of strip resistance.





- We do see a dependence on strip capacitance.
  - Recall that Radeka predicted a $\sqrt{C}$ dependence of the longitudinal resolution.

Calculating Longitudinal Position Resolution



- Measured an anti-correlation in noise between the left and right sides of ρ=-0.61
- Anti-correlation is predicted qualitatively by Radeka for shaping times in the linear regime.

Calculating Longitudinal Position Resolution

SCIPP

$$P = \frac{Q_R}{Q_L + Q_R} = \frac{\alpha}{1+\alpha} = \text{fractional position}$$

$$\alpha = \frac{Q_R}{Q_L}$$

Anti-correlation factors in here

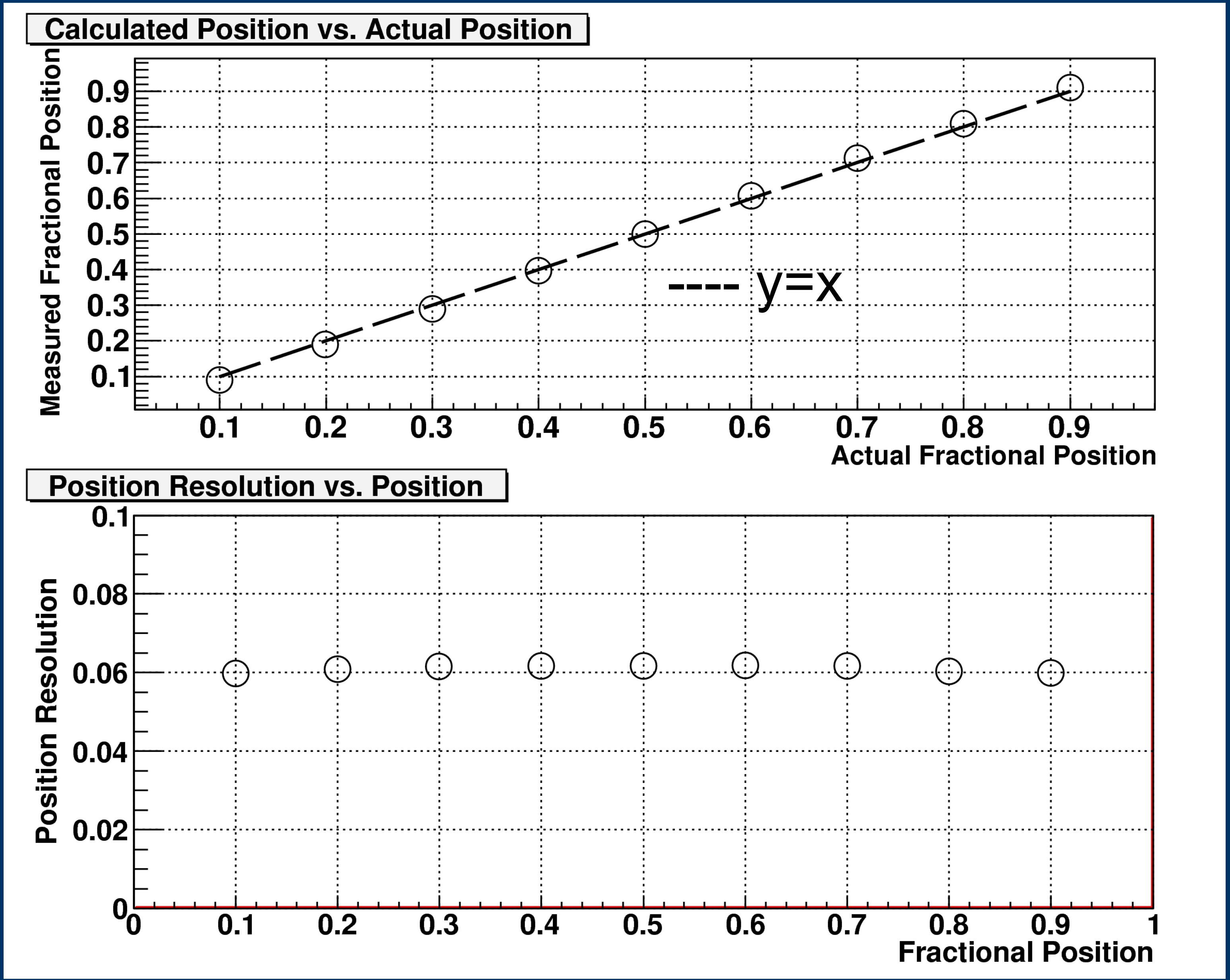
$$\sigma_\alpha = (\alpha)\left\{\left(\frac{\sigma_R}{Q_R}\right)^2 + \left(\frac{\sigma_L}{Q_L}\right)^2 - 2\rho\left(\frac{\sigma_R}{Q_R}\right)\left(\frac{\sigma_L}{Q_L}\right)\right\}^{\frac{1}{2}}$$

$$\sigma_P = \left|\frac{dP}{d\alpha}\right|\sigma_\alpha = \left(\frac{1}{(1+\alpha)^2}\right)\sigma_\alpha$$

- We measure σ_P to be **≈6.1mm** for a 10cm, 600kΩ, 12.7pF silicon strip detector
- Radeka predicts σ_P to be ≈6.5mm for a 10cm, 600kΩ, 12.7pF silicon strip detector.
- Asymmetry in σ_P due to slight non-linearity in 2.5T shaping time choice as well as measurement uncertainty.

	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7	Node 8	Node 9
Q_R [fC]	0.32	0.64	0.95	1.28	1.60	1.95	2.33	2.77	3.23
Q_L [fC]	3.24	2.75	2.33	1.94	1.60	1.26	0.94	0.65	0.32
P	0.090	0.189	0.290	0.400	0.500	0.607	0.713	0.810	0.910
$\sigma_R=\sigma_L$ [fC]	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
σ_P	**0.0598**	**0.0609**	**0.0615**	**0.0616**	**0.0617**	**0.0618**	**0.0617**	**0.0603**	**0.0600**

Calculating Longitudinal Position Resolution



- Measured position correlates very well with actual charge injection position.
- Longitudinal position resolution is independent of position

Implications of these results

- Predictions appear to be correct, even for very large resistances.
- Useful for pattern recognition without the use of a second layer.
- S/N results are the limiting factor in the accuracy of this charge division technique
- These results assume the information is read out in order to make these position measurements
- Because S/N is independent of strip resistance, improvement in resolution would come from a reduction in detector capacitance

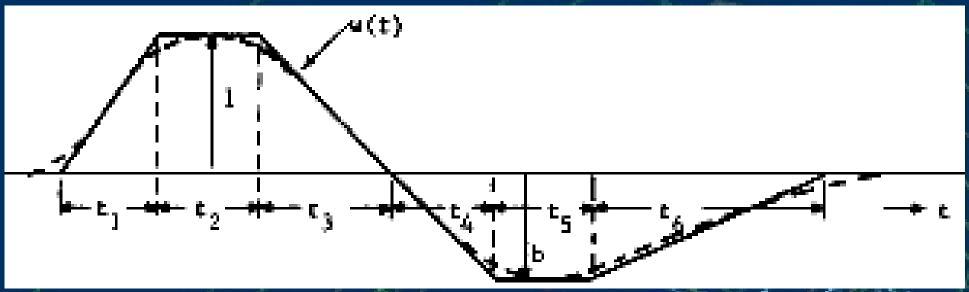
Where To Go From Here

- Address capacitive coupling between channels of a silicon strip detector through the Pspice simulation developed here.
- Continue modification, by a fellow student, of a C++ pulse development simulation to do charge division in a silicon sensor
  - Investigate the impact by the charge division method on transverse resolution measurements
  - Explore the effect of signal sharing between neighboring strips on the longitudinal position resolution
- Think about viable methods that compensate for the low S/N
  - For example, communication between left and right side readout.

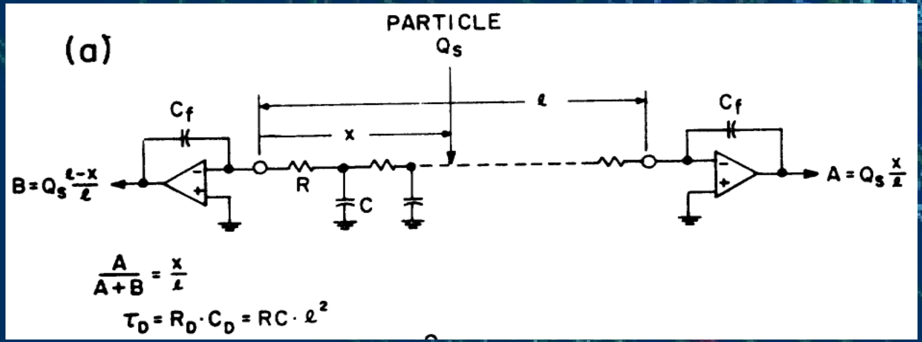
References And Footnotes

1. Radeka, V. "Signal, Noise, And Resolution In Position-Sensitive Detectors".
2. Alberi, J. L. and Radeka, V. "Position Sensing By Charge Division".
3. Kalbitzer, S. and Melzer, W. "On The Charge Dividing Mechanism In Position Sensitive Detectors".
4. A similar result for the propagation time is found by Kalbitzer and Melzer. They found a time equal to RC/π^2.
5. Owen, R. B. and Awcock, M. L. "One And Two Dimensional Position Sensing Semiconductor Detectors".

Radeka's results and methods



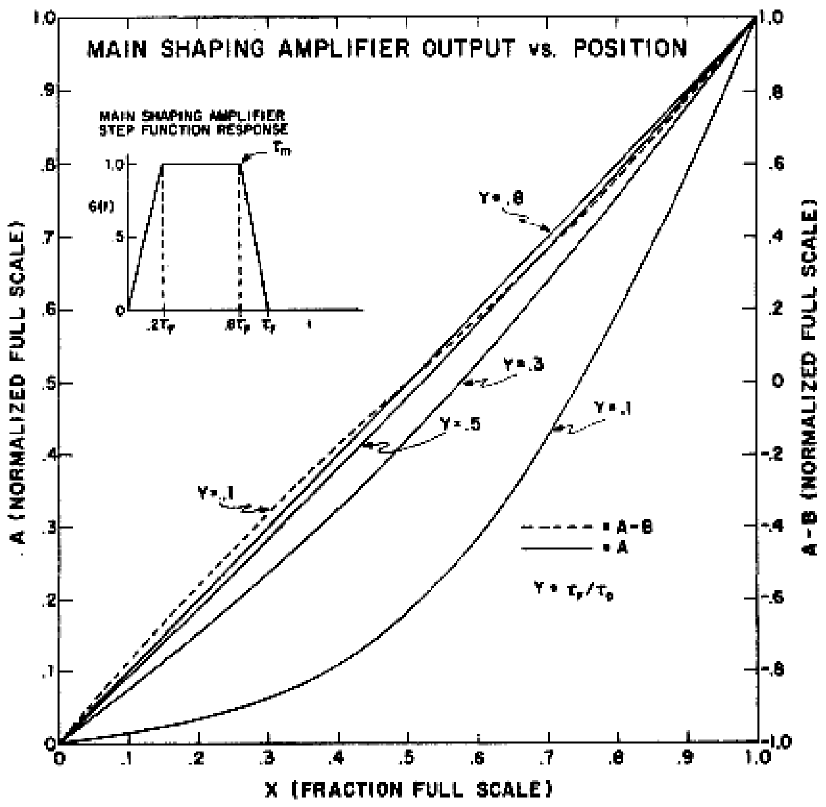
Trapezoidal fit method of signal analysis[1]



Charge division schematic.[1]

$$\sigma_P = 2.54 \left(\frac{\sqrt{kTC}}{Q_R + Q_L} \right) \quad (FWHM)$$

Radeka's position resolution prediction.[1]



Plot showing measured position for various shaping times[2]

Owen and Awcock results and methods

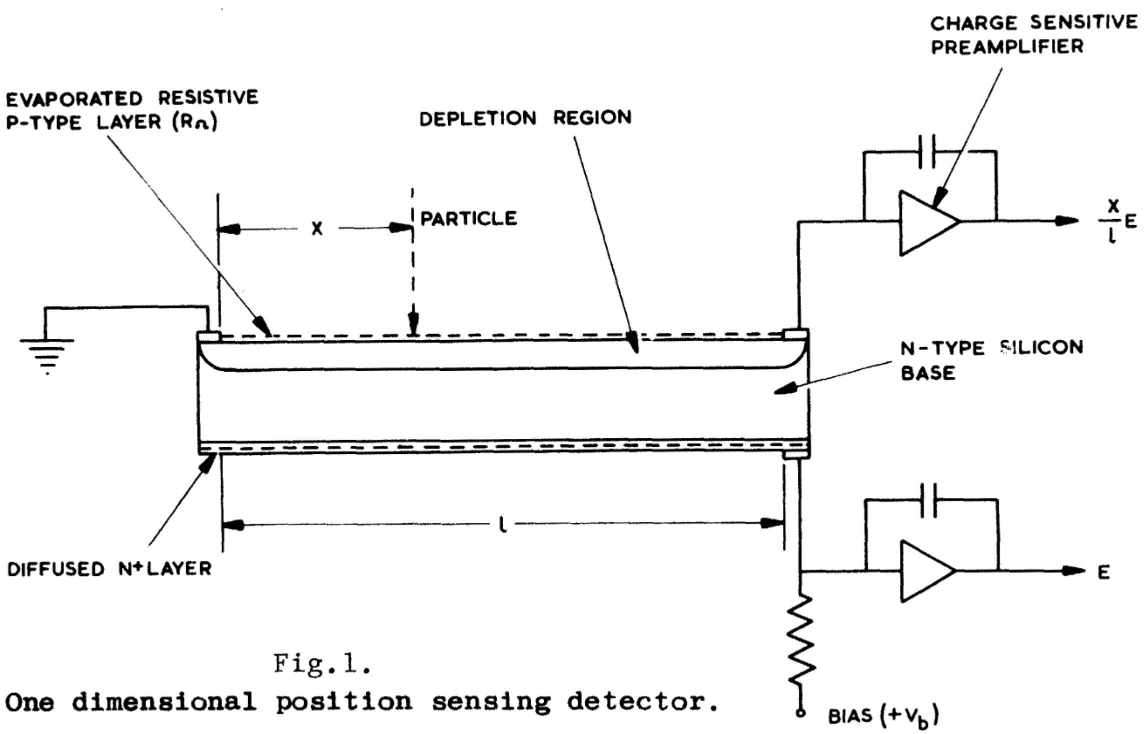


Fig.1.
One dimensional position sensing detector.

Alternative charge division readout design.[5]

Table I

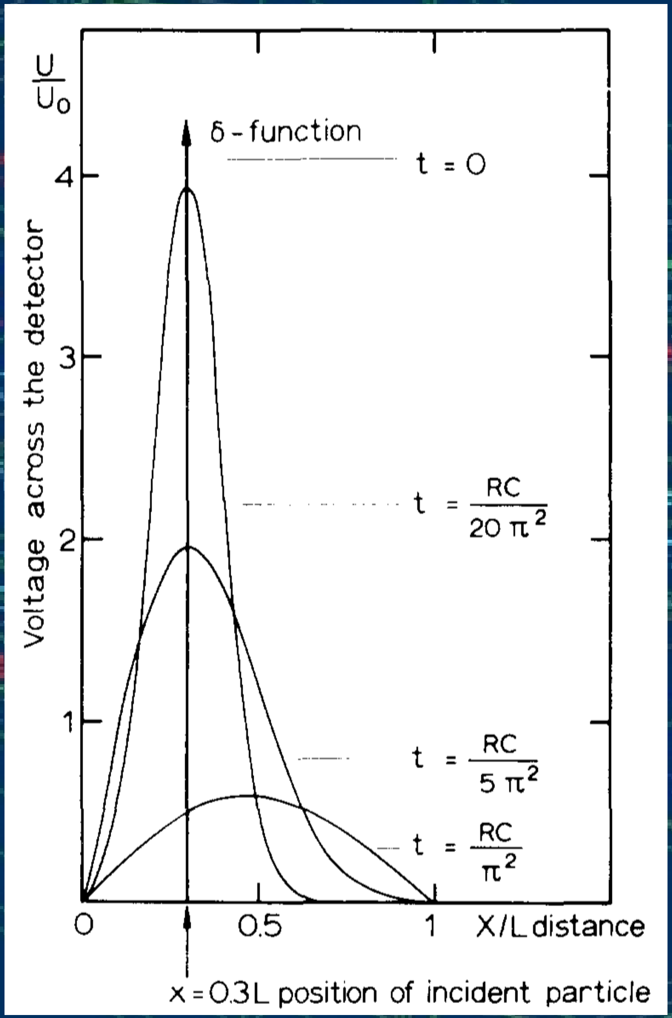
p/l	0	.1	.3	.5	.7	.9
τ_R	0	.28	.69	.84	.90	.90

From this it can be seen that there is little variation in rise time with position at the end distant from the amplifier.

This behavior is observed as well by the experiment presented here.[5]

Reference Plots And Images

Kalbitzer and Melzer results and methods



Simulating
signal propagation time.[3]