UNIVERSITY OF CALIFORNIA SANTA CRUZ

International Linear Collider

Highlights From ILC R&D at SCIPP

LCWS 2010

Friendship Hotel, Beijing, PRC

March 26-30 2010

Bruce Schumm

Santa Cruz Institute for Particle Physics

The SCIPP/UCSC SiLC/SiD GROUP (R&D Participants)

Faculty/Senior	Students	More Students
Vitaliy Fadeyev	Alex Bogert	Dale Owens
Alex Grillo	Jerome Carman	Sheena Schier
Bruce Schumm	Kelsey Collier	Dustin Stolp
	Spencer Key	Aaron Taylor
	Jared Newmiller	Capella Yee

Lead Engineer: Ned Spencer

Technical Staff: Max Wilder, Forest Martinez-McKinney

All participants are mostly working on other things (BaBar, ATLAS, biophysics…)

Students: undergrad physics and/or engineering majors at UCSC

Current Areas of Inquiry

ILC-Specific Instrumentation

- SiD sensor testing
- Performance of KPIX as a tracking chip
- LSTFE front-end chip development

Generic Instrumentation

- Charge division and longitudinal resolution
- Noise sources in high-resolution limit

Red = topics covered in this talk

Current Areas of Inquiry Cont'd

Simulation

- Tracking performance
- Non-prompt track reconstruciton
- Meta-stable stau signatures

Red = topics covered in this talk

Charge Division for Silicon Strip Sensors

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.

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

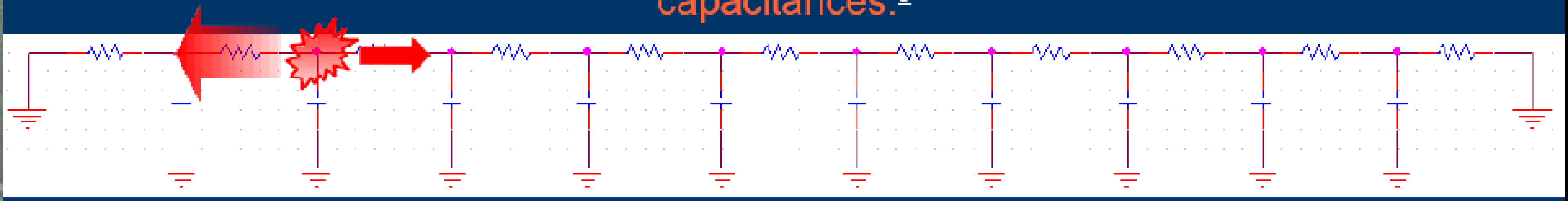
χ = coefficient which depends on the shaping function

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]



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

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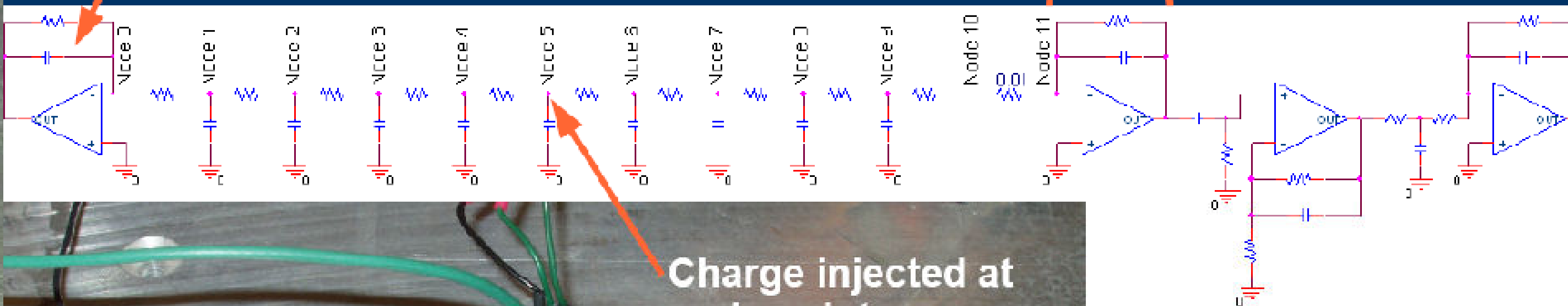
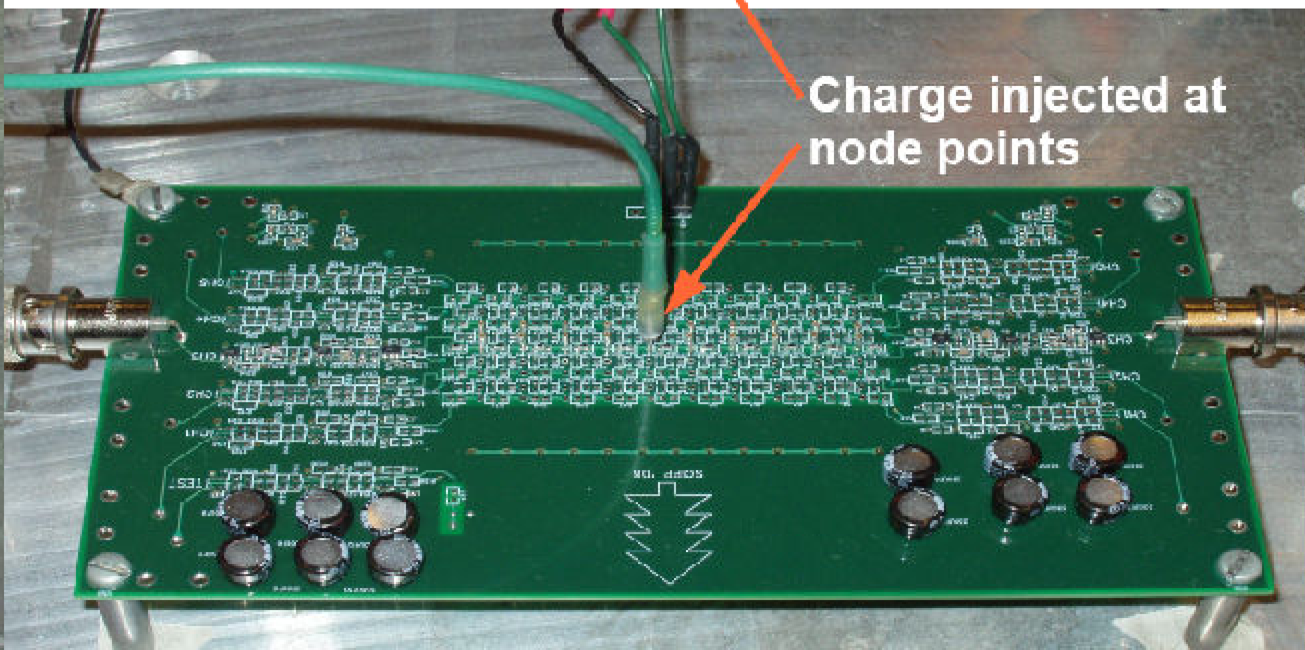
Left side amplifier design is identical to the right side, but not shown

Preamp is a high GBP charge sensitive integrator.

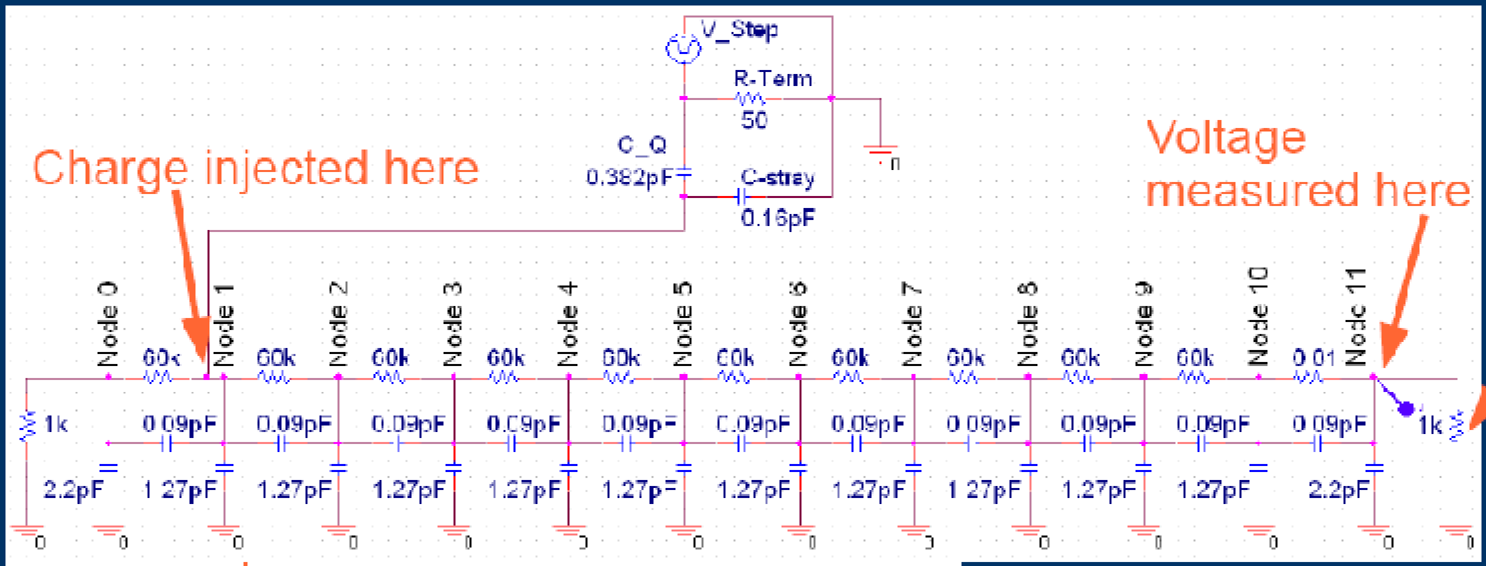
Schematic of one of five channels.



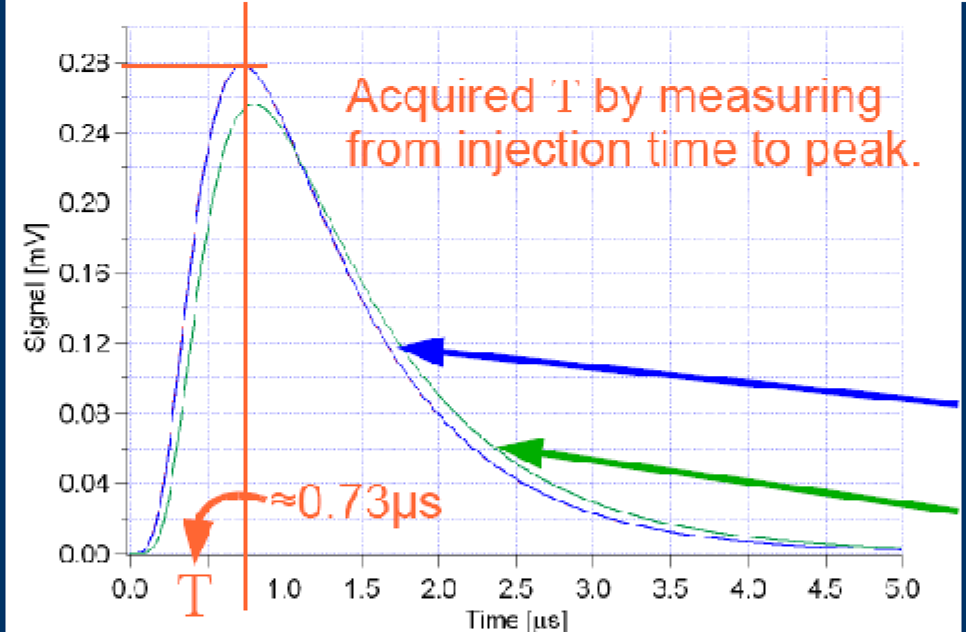


- Three stage integration, with the shaping time of each stage ≈⅓ total shaping time
- AC coupled to preamp via differentiation with long shaping time to minimize undershoot

Investigation Of Optimum Shaping Time



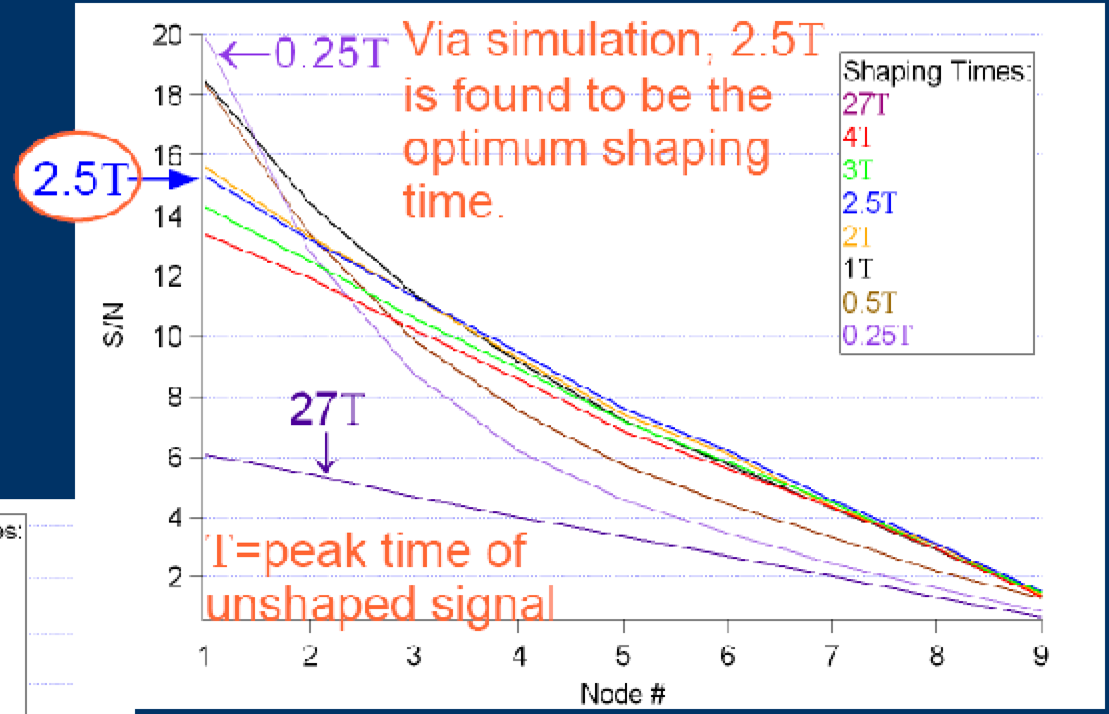
Input impedance of preamp is 1kΩ



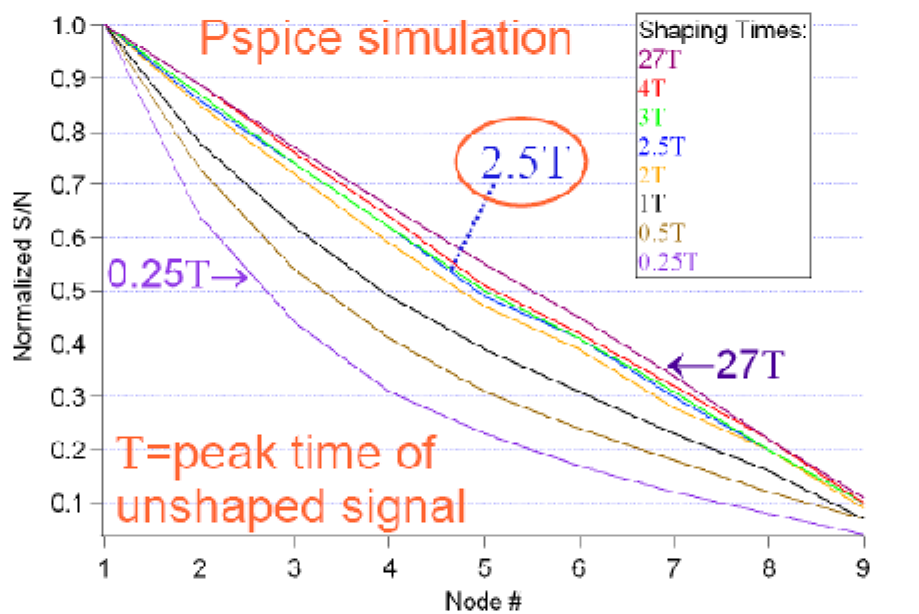
- I define T as the time constant from node 1 to node 11 (or node 9 to node 0).
- $T = (1/10) R_D C_D$
  - R_D = total strip resistance
  - C_D = total strip capacitance
- Blue signal is the 600k 12.7pF diffusive line shown above.
- Green signal is a 600k 12.7pF diffusive line with 0.09pF and 2.2pF strays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

Investigation Of Optimum Shaping Time

- Using the Pspice simulations shown here, we find that the optimum S/N occurs for a shaping time of $\tau \approx 2.5T \approx 0.23R_DC_D$
  - 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 $\tau \approx 3T \approx 0.27R_DC_D$
  - shown as the **green line**.

Benchmarking Simulation With The PC Board

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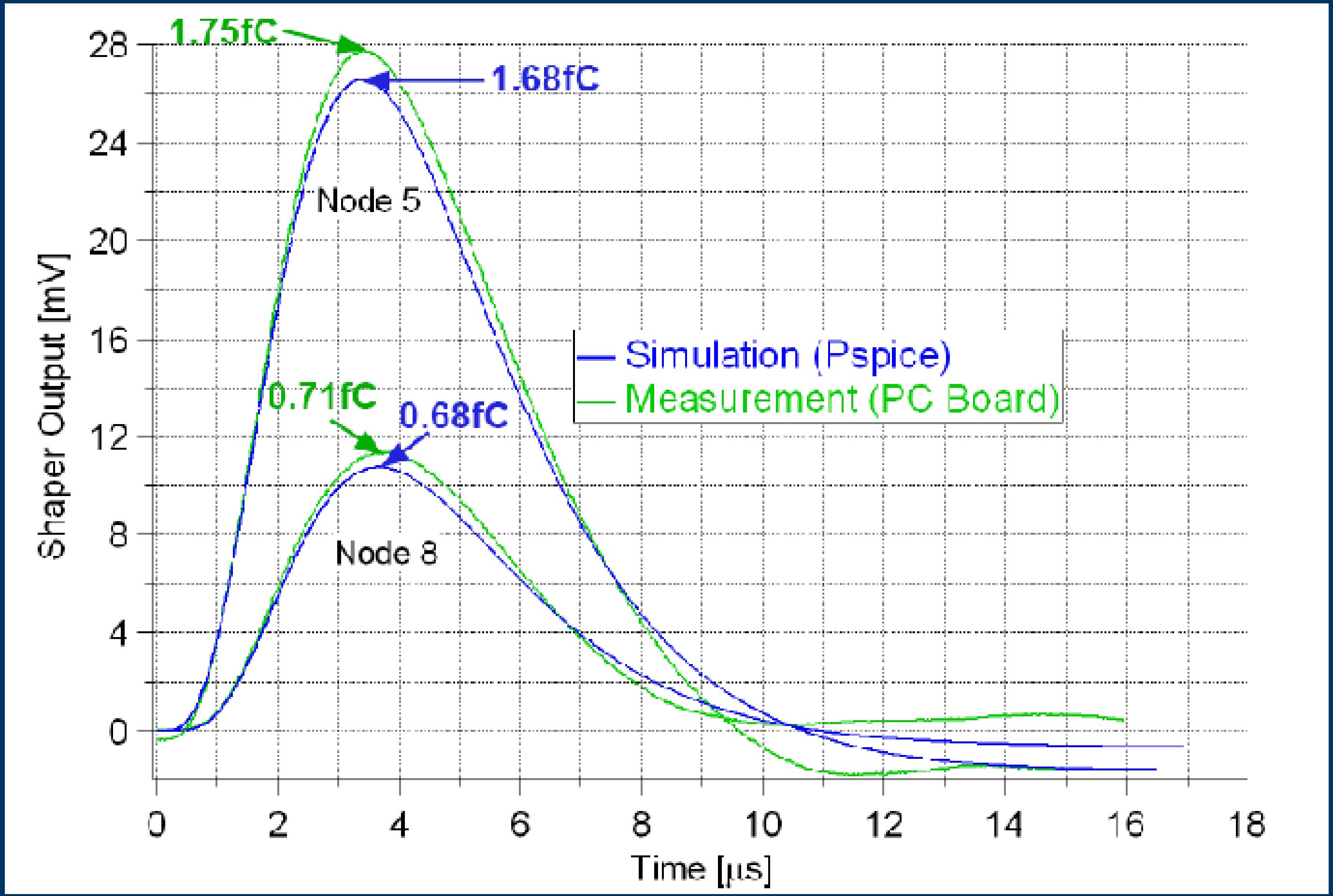
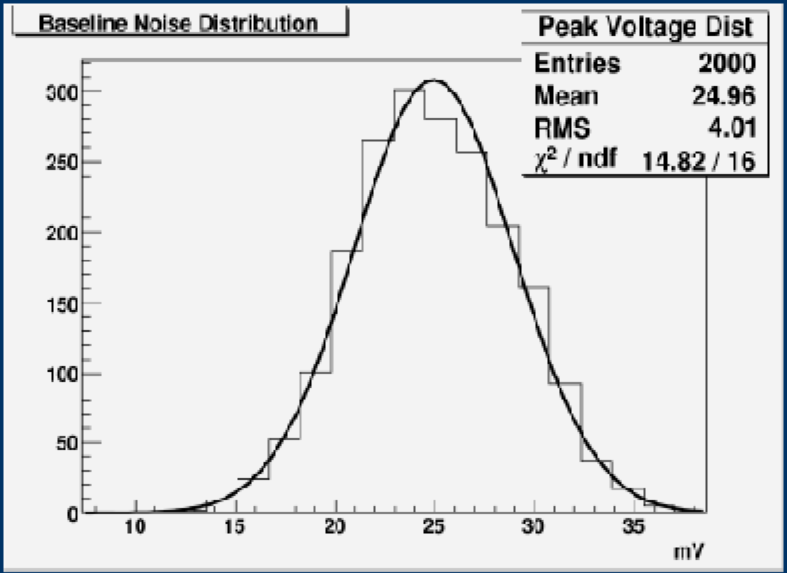
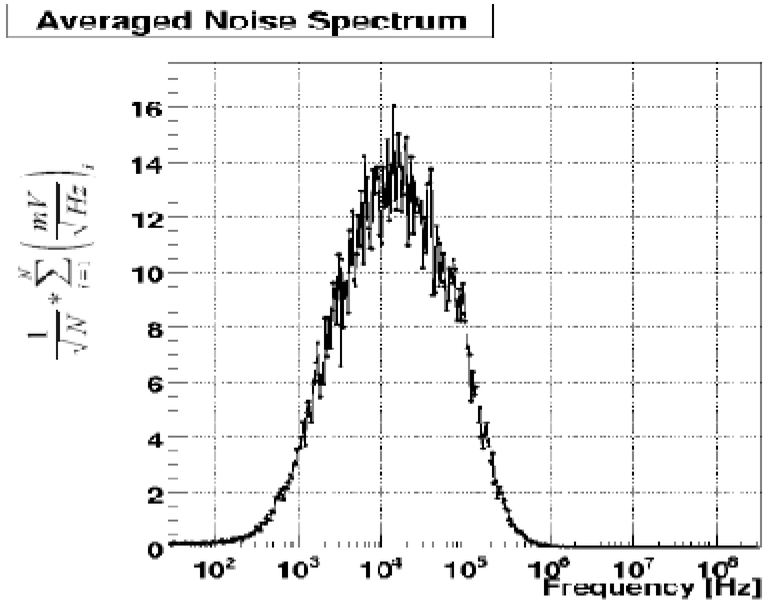


Comparison of shaper output between simulation and measurement for 600kΩ, 12.7pF, 2.5T shaping time.

- Target rise time is 1.83µs (2.5T) 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





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

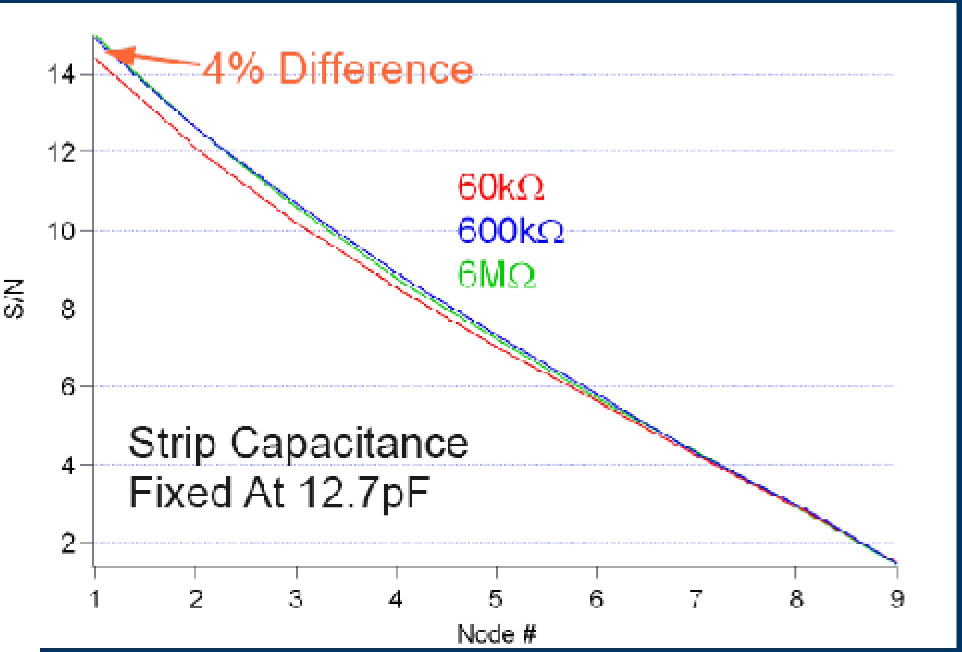
PSpice Prediction	3.69	0.23

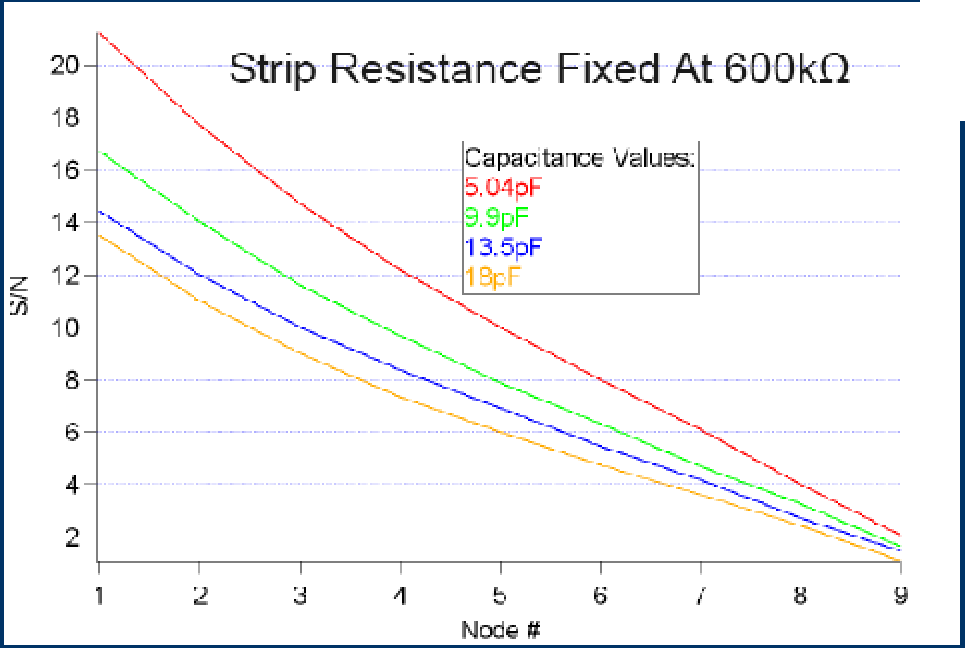
- Noise measurement agrees amazingly well with Pspice prediction!!
- We have confidence in the Pspice model.
- Pspice shows opamp noise contribution is less than 1% confirming that the noise is dominated by the RC network

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

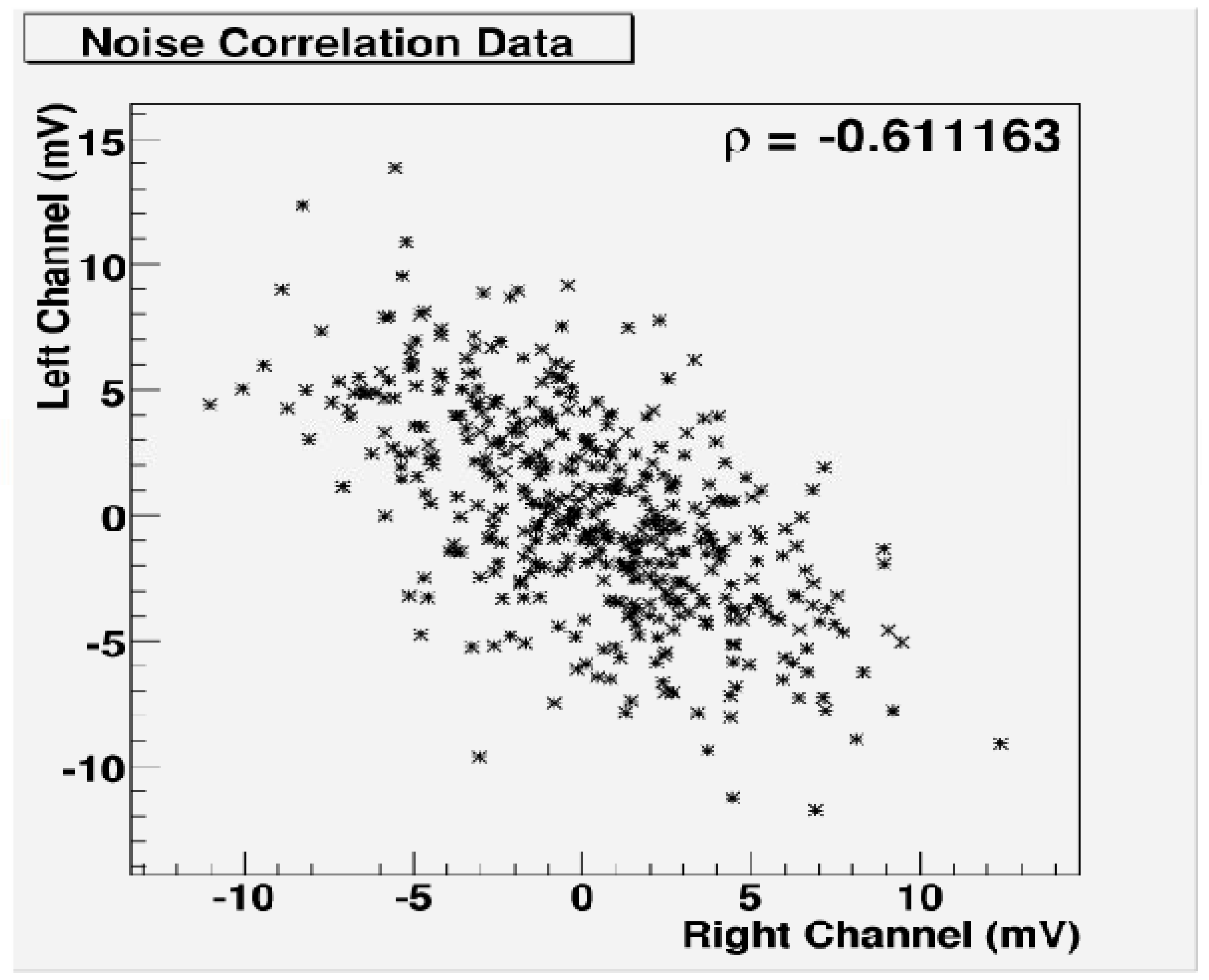
2.5T shaping time for all measurements

- 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.



- 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

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

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

Anti-correlation factors in here

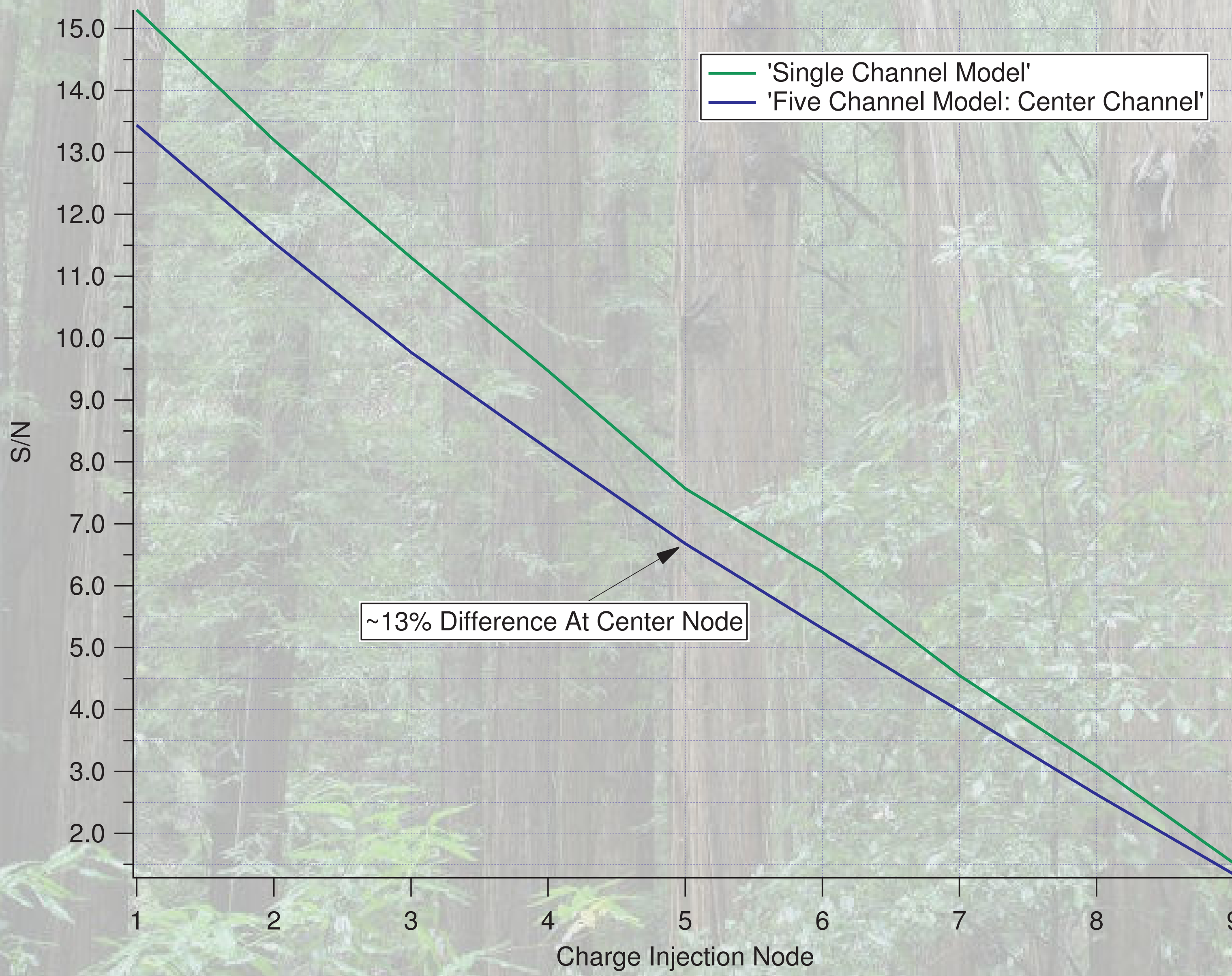
$$\sigma_\alpha = (\alpha)\left\{\left(\frac{\sigma_R}{Q_R}\right)^2 + \left(\frac{\sigma_L}{Q_L}\right)^2 - 2\rho\left(\frac{\sigma_R}{Q_R}\right)\left(\frac{\sigma_L}{Q_L}\right)\right\}^{\frac{1}{2}}$$

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

- 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**

But: Add neighboring strips in simulation…



Readout Noise for Linear Collider Applications

Use of silicon strip sensors at the ILC tend towards different limits than for hadron collider or astrophysical applications:

- Long shaping time
- Resistive strips (narrow and/or long)

But must also achieve lowest possible noise to meet ILC resolution goals.

- How well do we understand Si strip readout noise, particularly for resistive networks?

- How can we minimize noise for resistive networks?

Standard Form for Readout Noise (Spieler)

Parallel Resistance

Series Resistance

$$Q^2 = F_i \tau \left(2eI_d + \frac{4kT}{R_B} + i_{na}{}^2 \right) + \frac{F_v C^2}{\tau} \left(4kTR_s + e_{na}{}^2 \right) + 4F_v A_f C^2$$

Amplifier Noise (parallel)

Amplifier Noise (series)

F_i and F_v are signal shape parameters that can be determined from average scope traces.

CDF L00 Sensor “Snake”

CDF L00 strips: 310 Ohms per 7.75cm strip (~3x GLAST)

➔Long-ladder readout noise dominated by series noise (?)

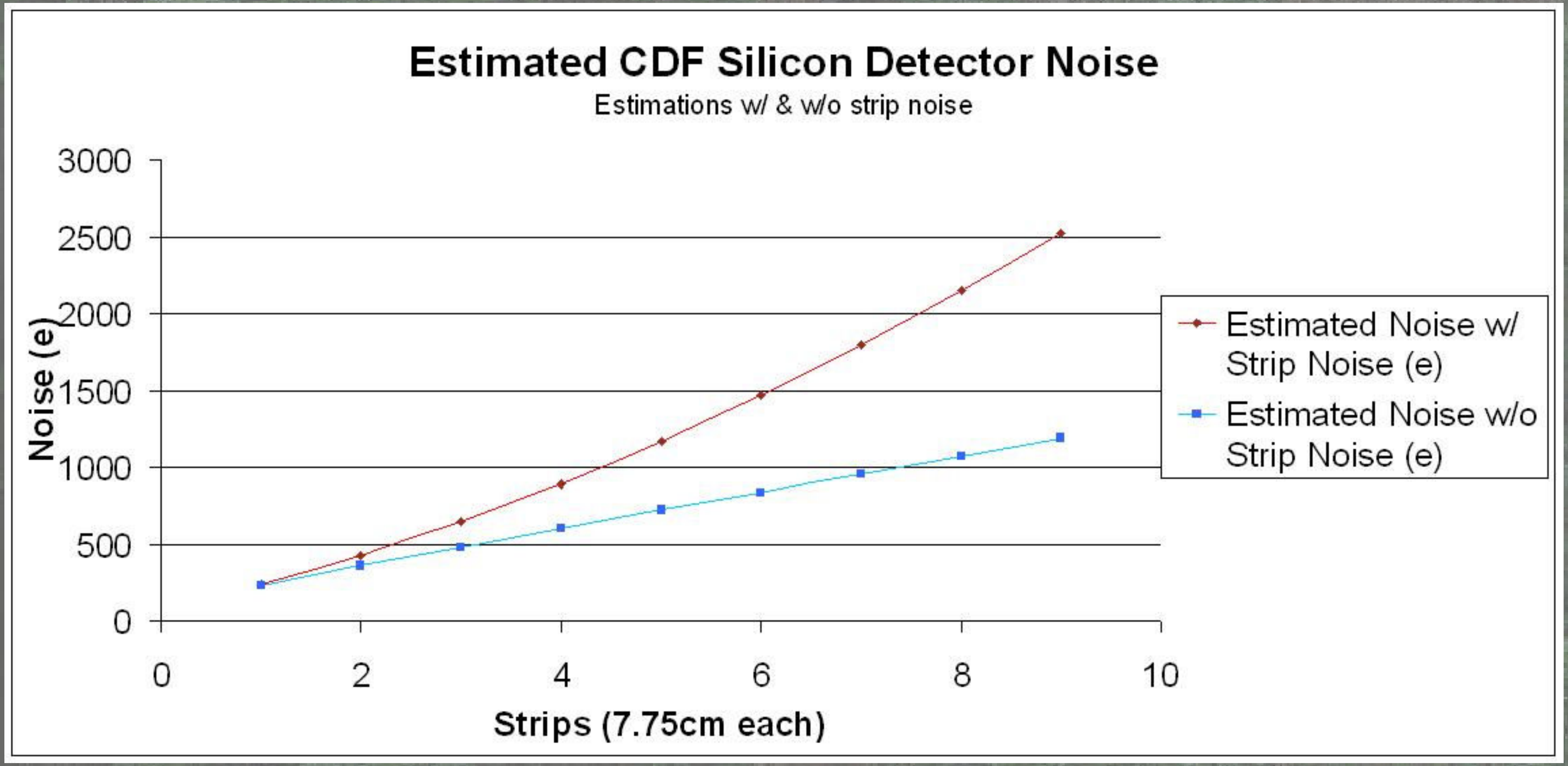
Construct ladder by bonding strips together in “snake” pattern (Sean Crosby)

At long shaping-time, bias resistors introduce dominant parallel noise contribution

➔Sever and replace with custom biasing structure (significant challenge…)

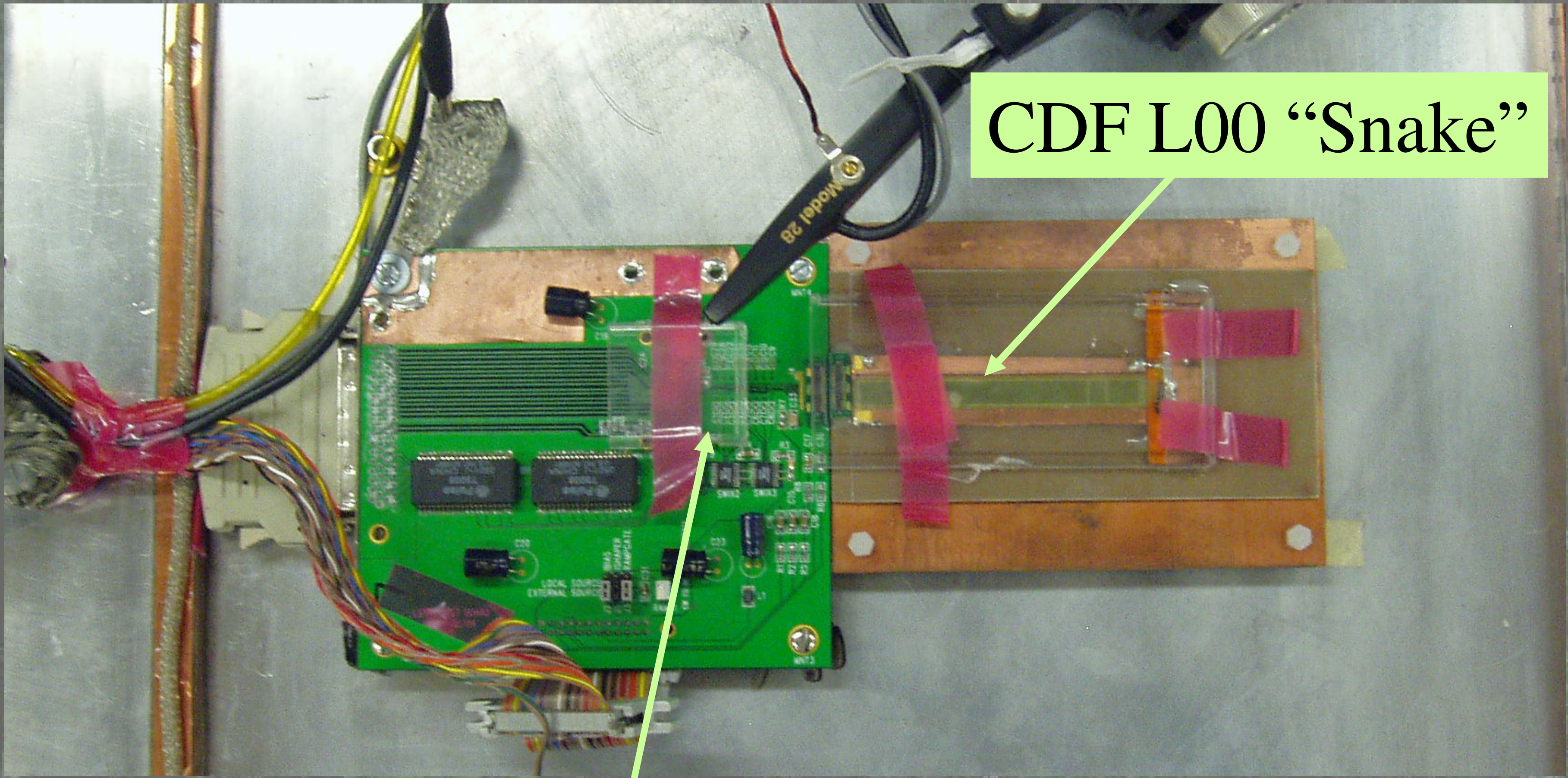
Thanks to Sean Crosby and Kelsey Collier, UCSC undergraduate thesis students

Expected Noise for Custom-Biased L00 Ladder



Spieler formula suggests that series noise should dominate for ladders of greater than 5 or so sensors.

CDF L00 Sensor "Snake"

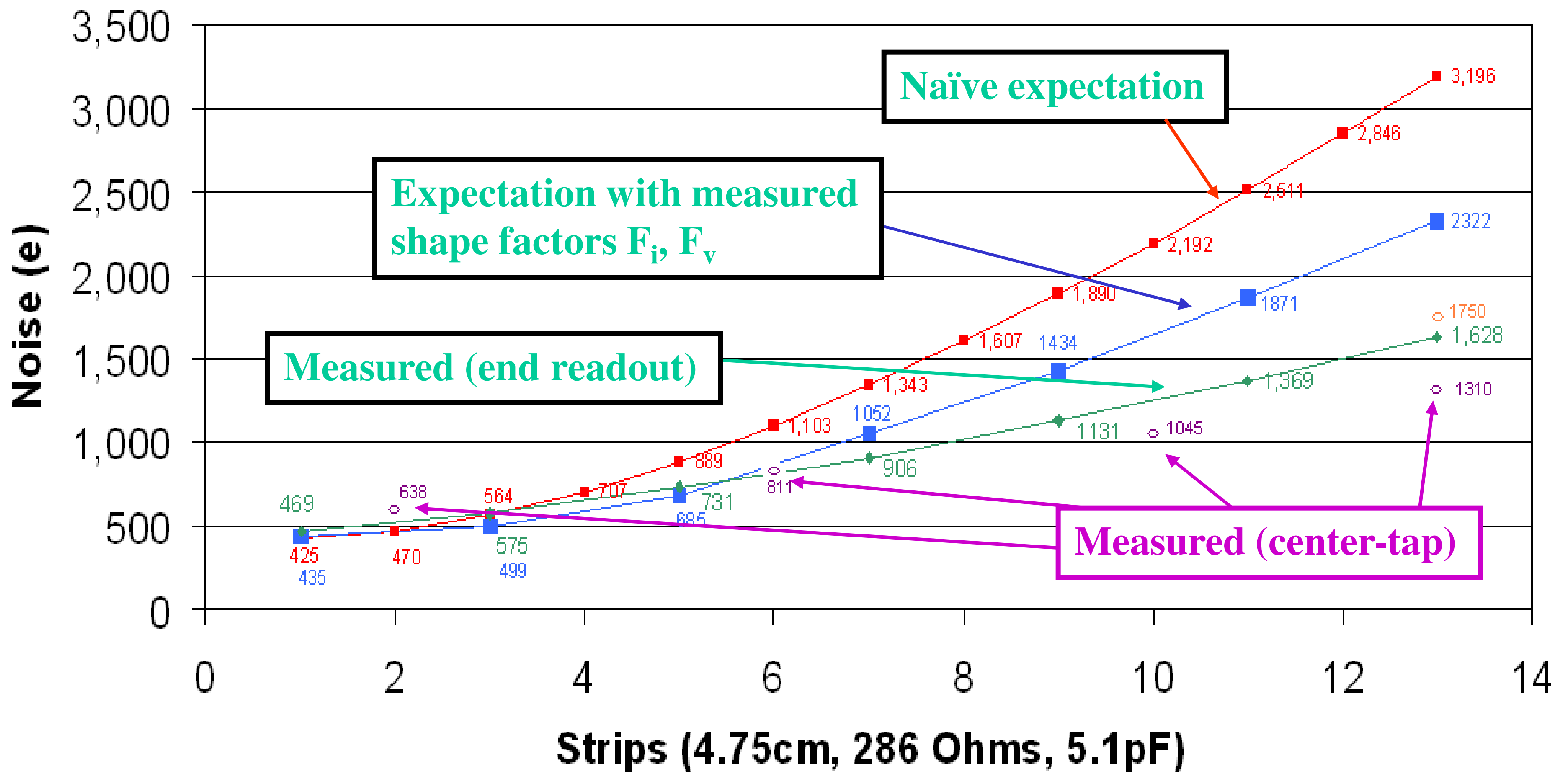


CDF L00 "Snake"

LSTFE1 chip on Readout Board

Readout Noise Results

Relative to prior results, have explored "center-tapping" (reading out from center of chain rather than end.



Summary of Findings

Reading out from ladder from end:

Significantly less noise observed than expected (network effects ignored in formulation of expectation?)

Reading out from middle ("center tap"):

Noise seems further reduced (~20%) for lengths for which series noise dominates

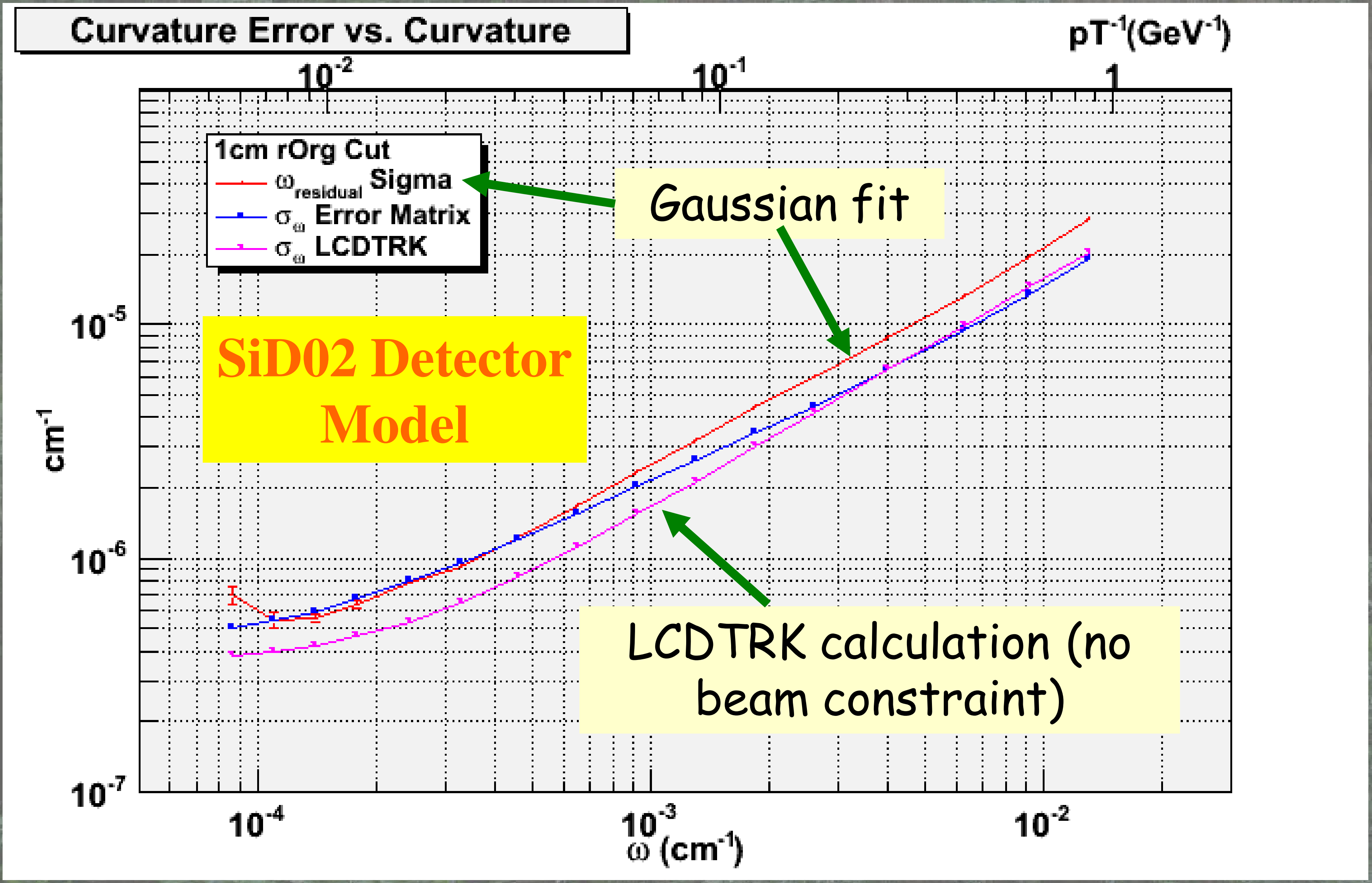
Will explore with P-SPICE simulation…

CURVATURE RECONSTRUCTION PERFORMANCE

1. Compare width of Gaussian fit to residuals with two different estimates:
   - Error from square root of appropriate diagonal error matrix element
   - Error from Billior calculation (**LCDTRK** program)
2. Only tracks with all DOF (5 VTX and 5 CT layers) are considered.
3. Require $|\cos\theta| < 0.5$

Mixture of q/qbar at 500 and 1000 GeV, tau samples at 500 GeV; also use single muons

CURVATURE ERROR vs. CURVATURE



Results for Stiff, Central Tracks

In terms of σ_p/p, comparing μ,π with p=100 GeV and $|\cos\theta| < 0.5$ we find

	μ	π
LCDTRK	0.28%	0.28%
Residuals	0.37%	0.39%
LOI Result	0.33%	----

➔ Delhi group (Kirti Ranjan et al.) looking into developing Kalman Filter fitter

SCIPP ILC DETECTOR R&D SUMMARY

- Charge division resolution ~6mm (for 10cm ladder)
- Resolution somewhat degraded by inter-strip coupling
- Network effects may mitigate series noise for ILC μ-strip applications
- Center readout may further reduce noise
- Full-simulation curvature resolution may not yet be optimized ➔ improvement with Kalman filter?