Design and Characterization of a Micro-Strip RF Anode for Large-Area based Photodetectors

Orsay- *Friday, June 15. 2012*

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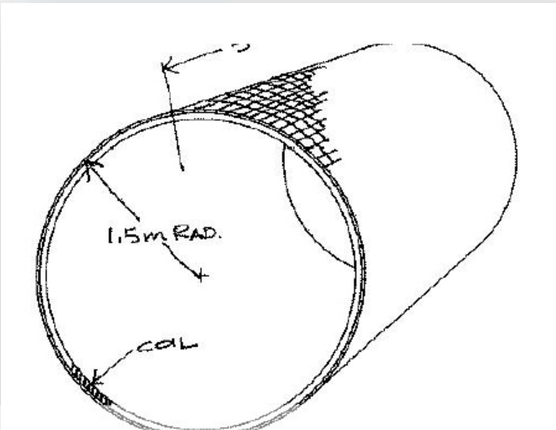
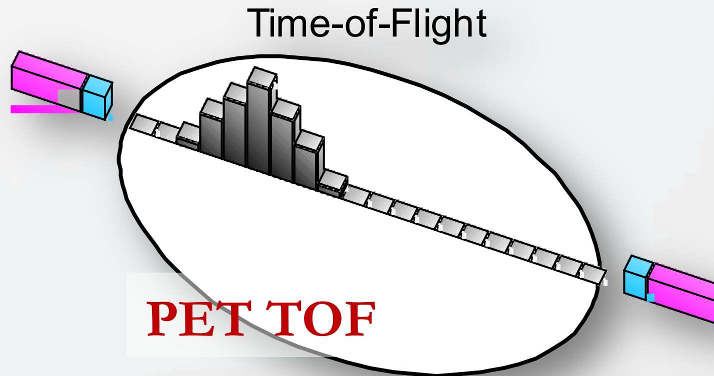
Outline

- Introduction
  - Precise timing in physics experiments.
  - MCP as a fast timing detector
  - Large Area Picosecond Photo-Detector
  - The role of transmission line readout
- Modeling RF transmission lines
  - The stripline excitation
  - Techniques and measurement tools
- The key parameters for RF anodes design
  - Impedance
  - Bandwidth
  - Attenuation and crosstalk
  - Geometry matching
- Conclusion

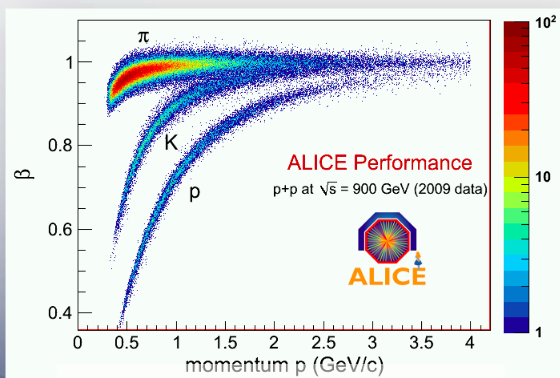
Precise timing applications in physics experiments



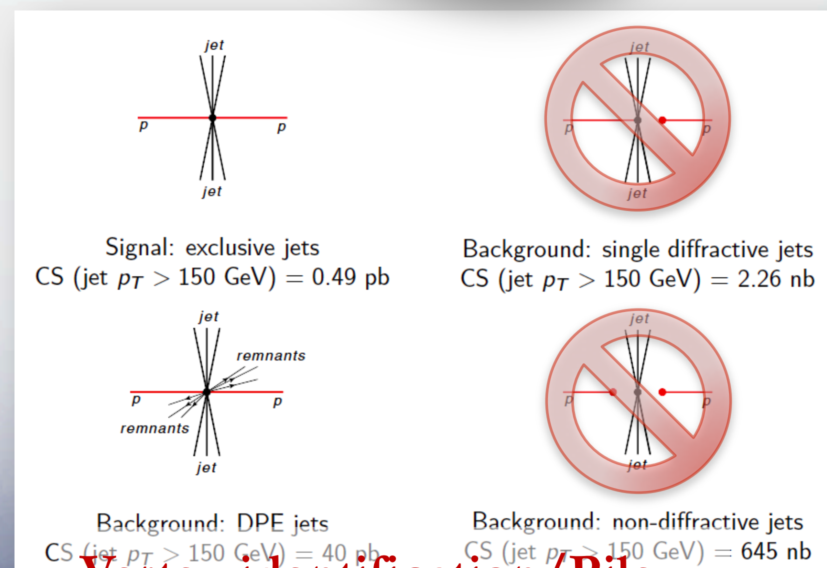
Time of Flight calorimeter



PET TOF



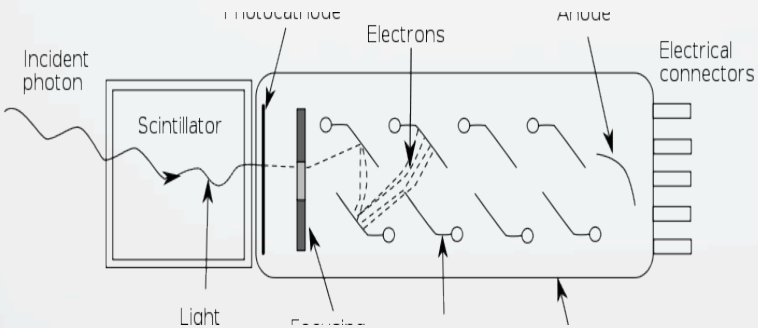
π / κ separation



Vertex identification/Pile-up suppression

Getting fast timing

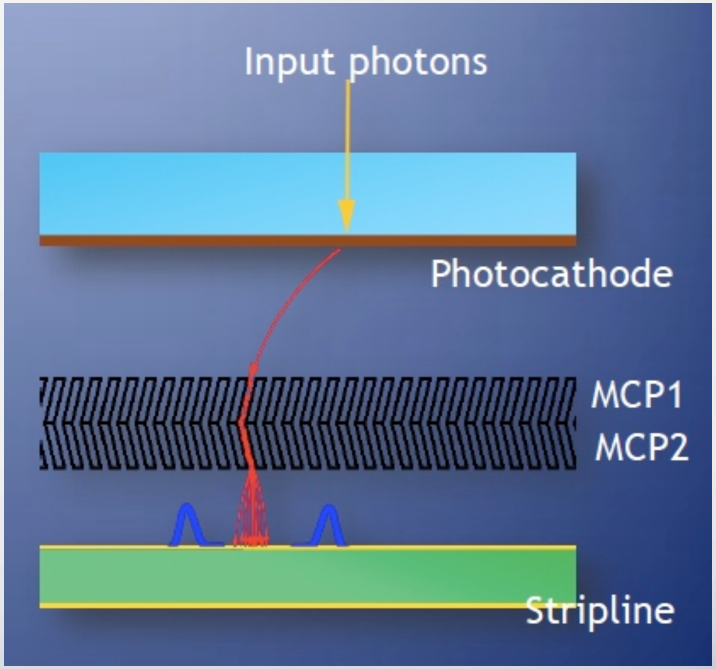
- Photomultiplier



~10cm

- Microchannel plate

<1cm

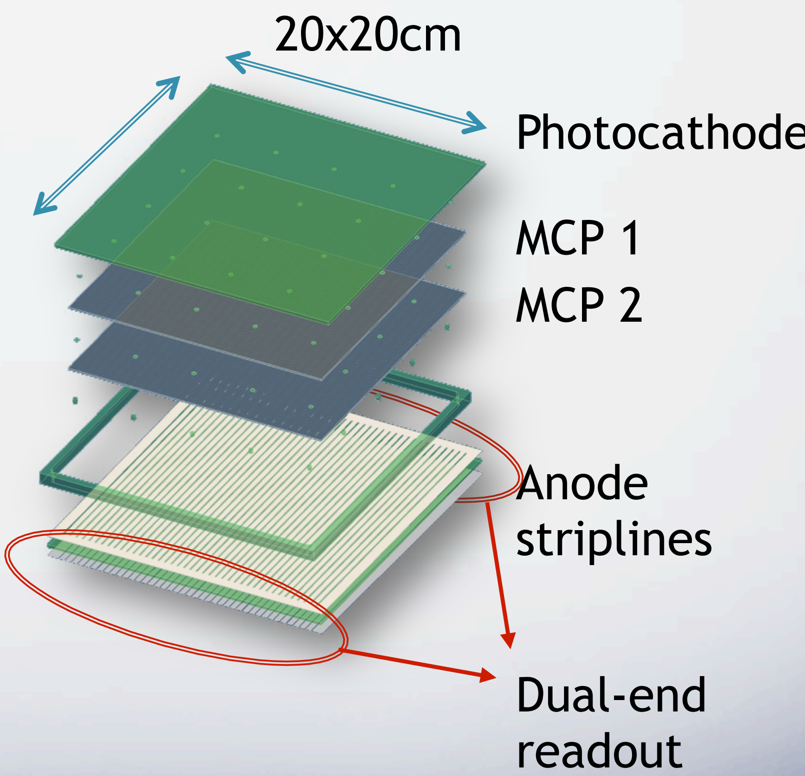


The key towards fast timing detector:

Reducing the size of the electron path in the Photo-detector reduces the jitter and increases the rise time of the signal.

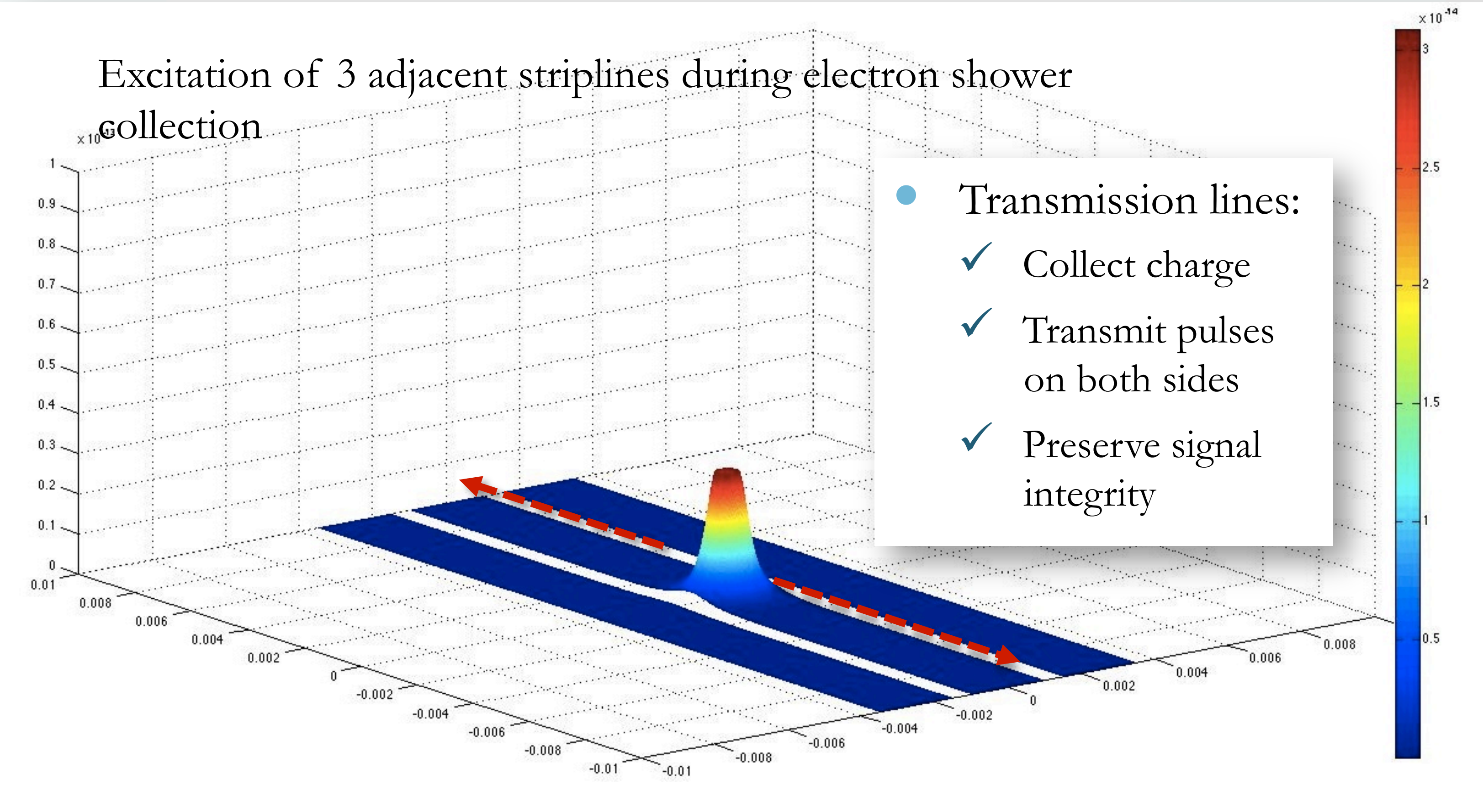
The Large Area Picosecond Photo-detector

- Create Large Area Fast and Low Cost photomultiplier. See LAPPD project at the Univeristy of Chicago.
- Stripline readout:
  - ✓ Reduce the number of pins
  - ✓ Avoid pins through the glass
  - ✓ Reduce the cost



The role of the transmission line anodes.

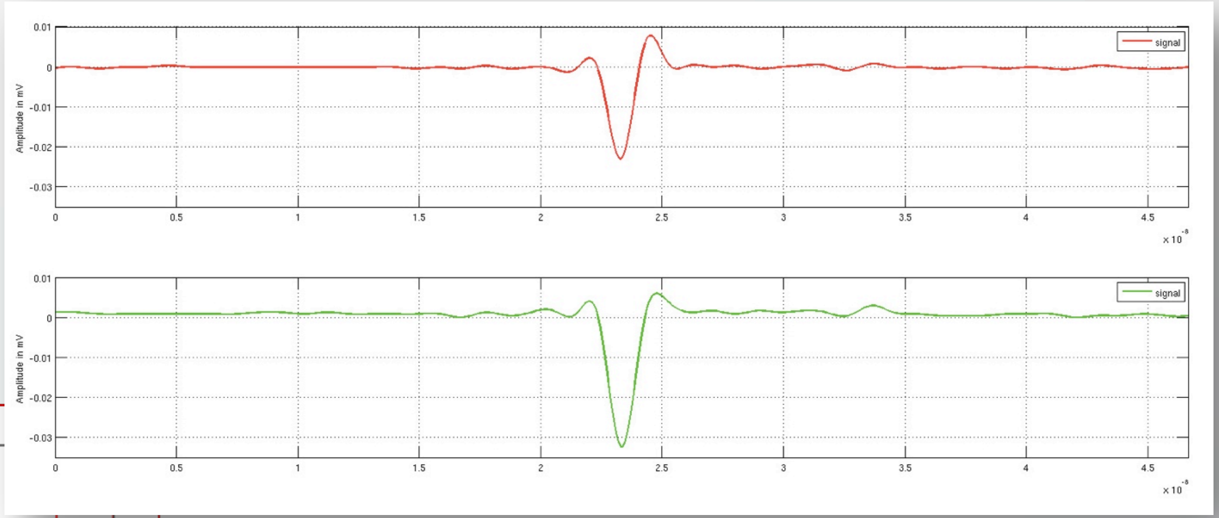
Excitation of 3 adjacent striplines during electron shower collection

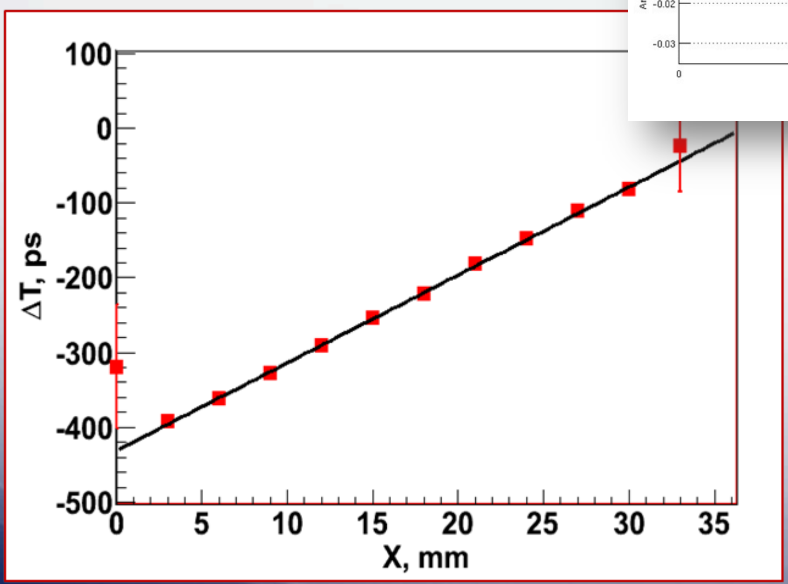


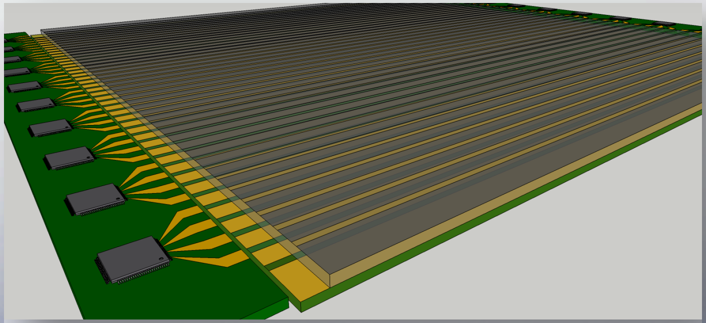
- Transmission lines:
  - ✓ Collect charge
  - ✓ Transmit pulses on both sides
  - ✓ Preserve signal integrity

Spatial resolution with RF anodes

- Fast timing is required (see E. Oberla talk).
- ~10's psec resolution.







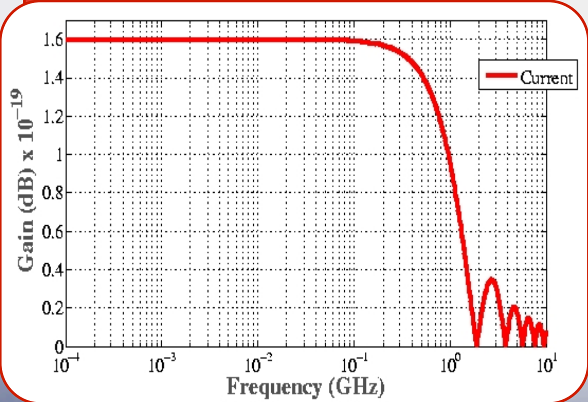
Time of Arrival on both side

Modeling and designing the stripline anodes

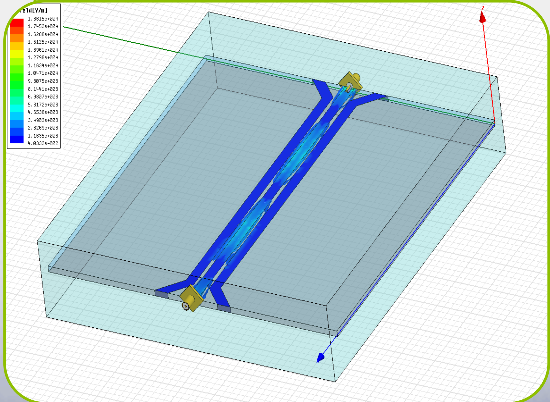
✗ **Full time domain simulation of transmission line readout**

✓ **Go to the frequency domain**

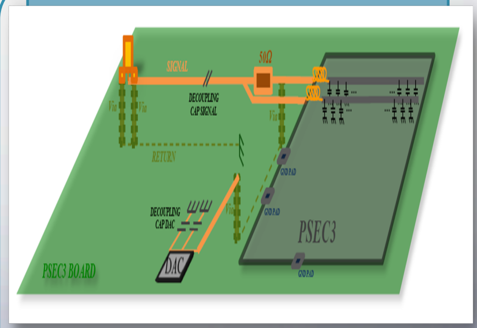
Strip excitation



Signal propagation

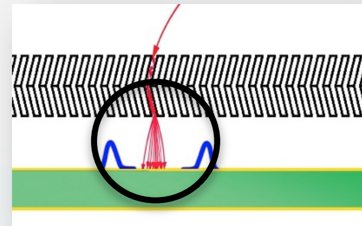


Signal acquisition



In the frequency domain

Modeling the stripline excitation



- Create equivalent model in the frequency domain of the electron showering.
  - ✓ Model the electron distribution:

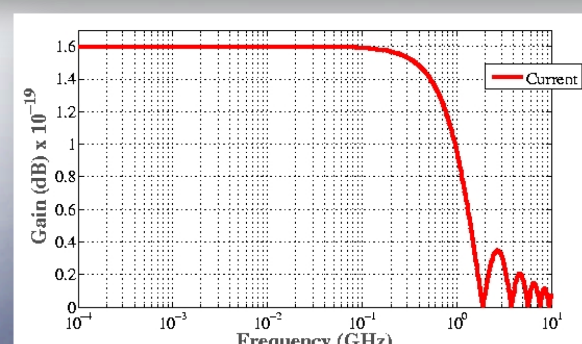
$$\rho(x,y,z,t) = \frac{Q}{s^3} \times \mathrm{rect}\left(\frac{x - x_D(t)}{s}\right) \mathrm{rect}\left(\frac{y - y_D(t)}{s}\right) \mathrm{rect}\left(\frac{z - z_D(t)}{s}\right)$$

  - ✓ Fourier transform:

$$\begin{aligned}\hat{i}(f) &= \iint_S \int_{-\infty}^{\infty} \frac{Q}{s^3} \times \mathrm{rect}\left(\frac{x}{s}\right) \mathrm{rect}\left(\frac{y}{s}\right) \mathrm{rect}\left(\frac{z - z_D(t)}{s}\right) \times v_0 \times e^{-2i\pi f t} \,\mathrm{d}t \,\mathrm{d}S \\ &= Q \times \mathrm{sinc}\left(\frac{\pi f s}{v_0}\right) \times e^{\frac{-2i\pi f z}{v_0}}\end{aligned}$$

  - ✓ Extract the bandwidth:

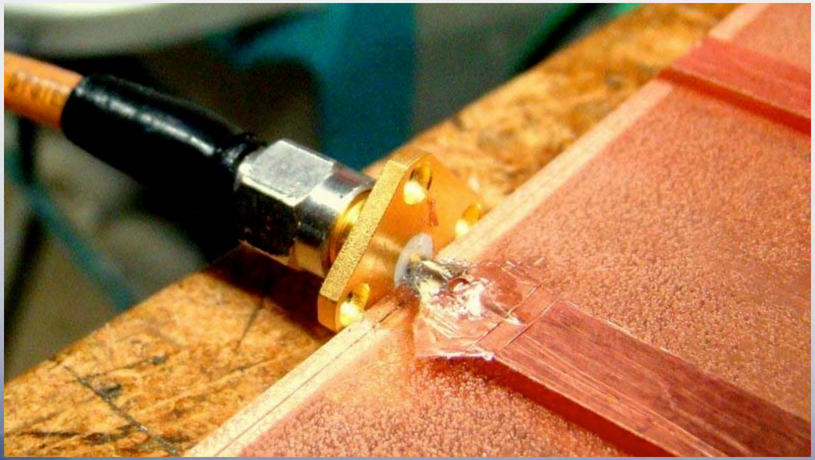
For typical MCP:
Bandwidth of signal ~ GHz

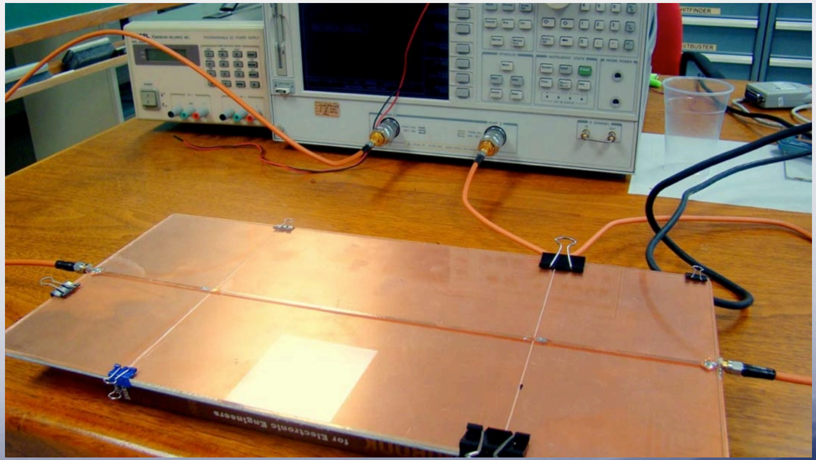


Tools and techniques used for RF anode design

- Launcher
  - ✓ Couple SMA cable & connector to stripline geometry.
  - ✓ 10dB gain over the whole bandwidth with good launcher.
  - ✓ RF field solver doesn't work use copper tape.

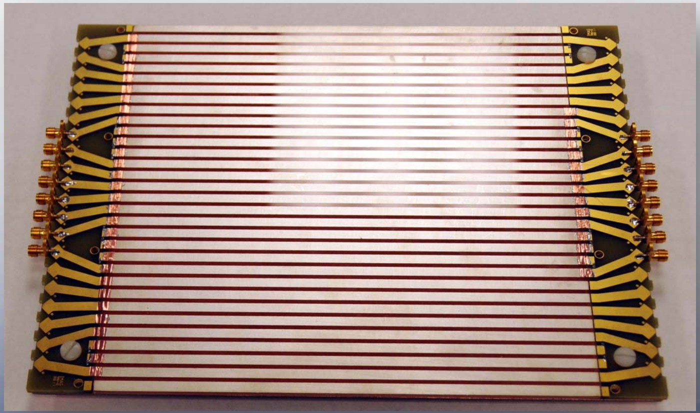
- Frequency measurement
  - ✓ Use network analyzer.
  - ✓ Direct measure of bandwidth.
  - ✓ Identify resonance and absorption in the spectrum
  - ✓ With TDR option identify bottleneck location in your design





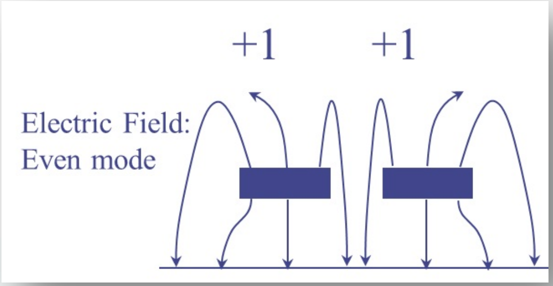
Designing the anode: the key parameters

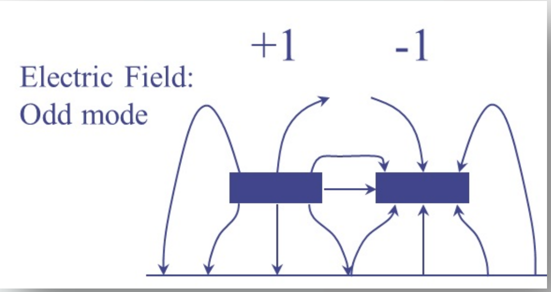
- Impedance
  - ✓ Match the input impedance of the electronics (50Ohms)
- Bandwidth
  - ✓ Match the bandwidth of the signal.
- Cross-talk
  - ✓ Reduce cross-talk as much as possible between strips.

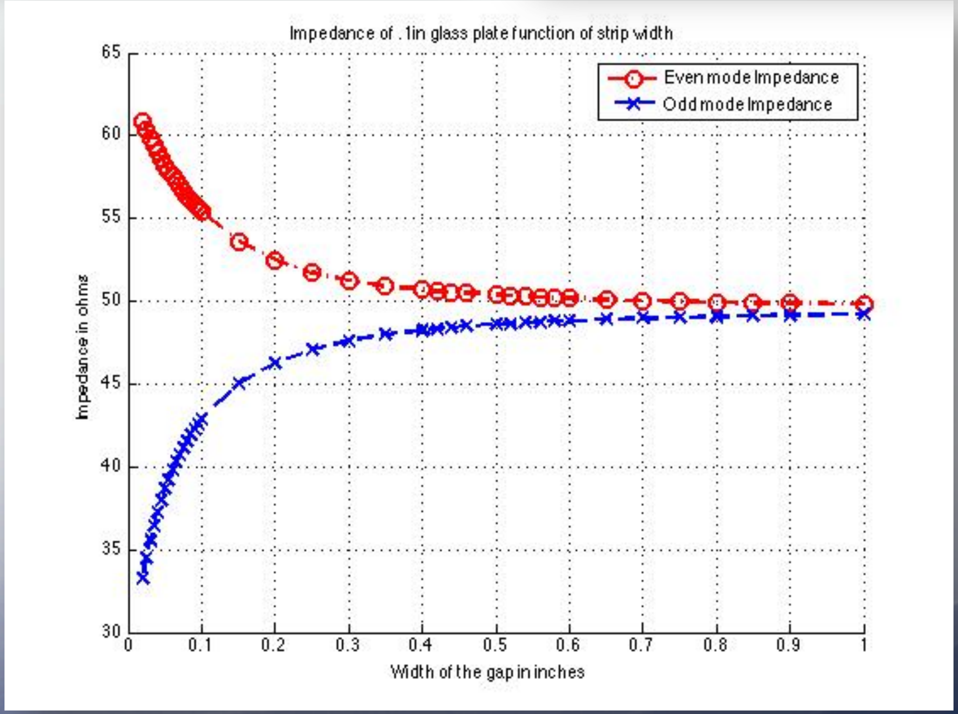


RF strip impedance

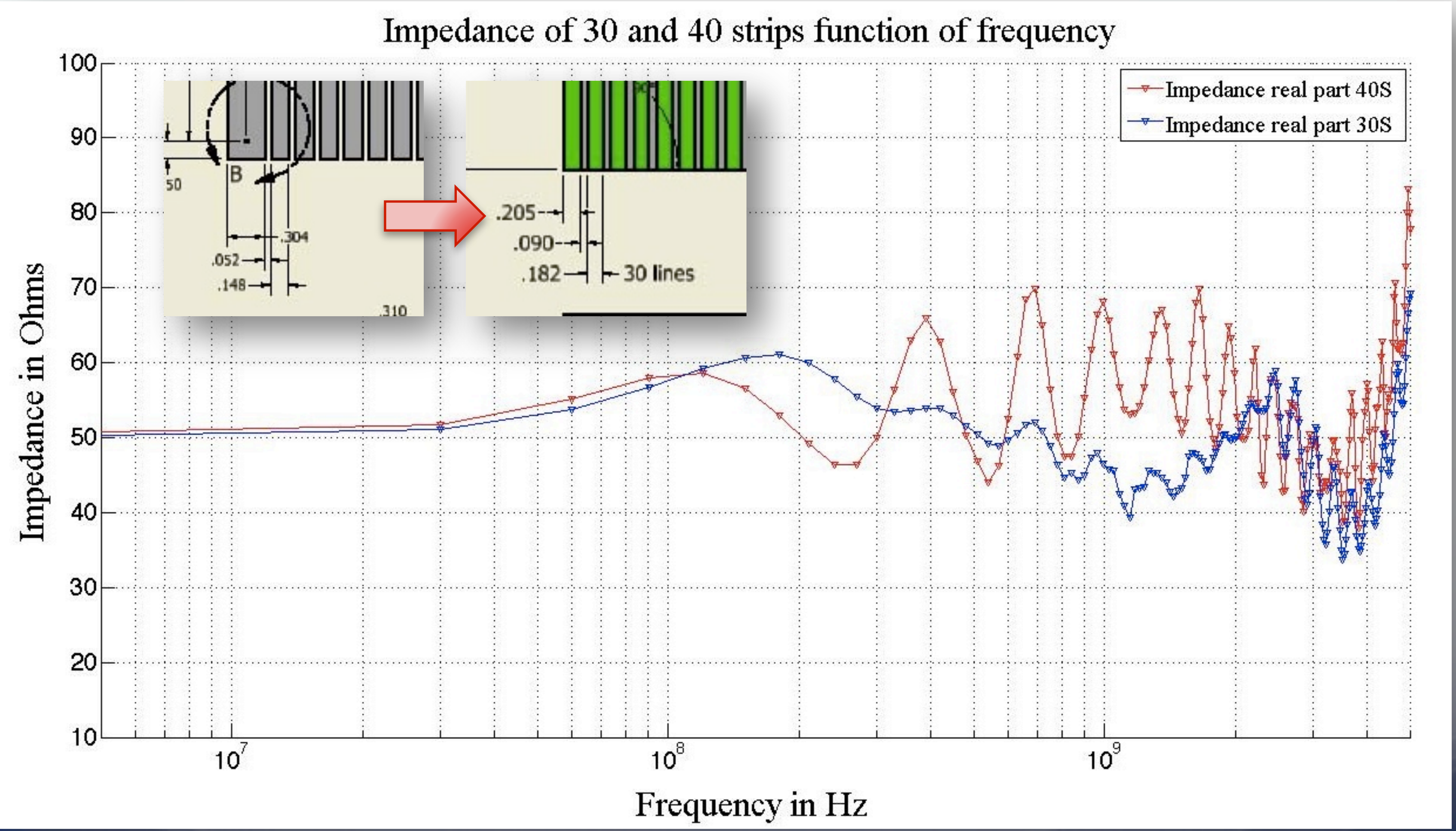
- For an array of striplines: odd and even mode impedance.
- Even mode: crosstalk
- Increase pitch between strip (but reduce the covered area)
- Thinner strips





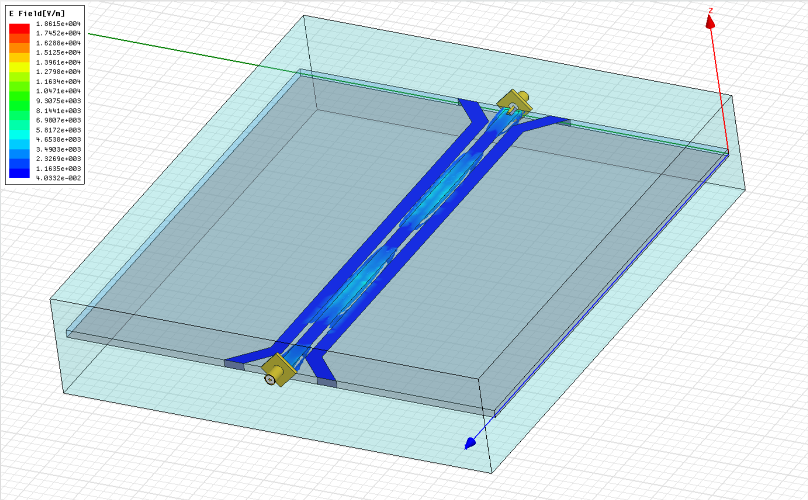


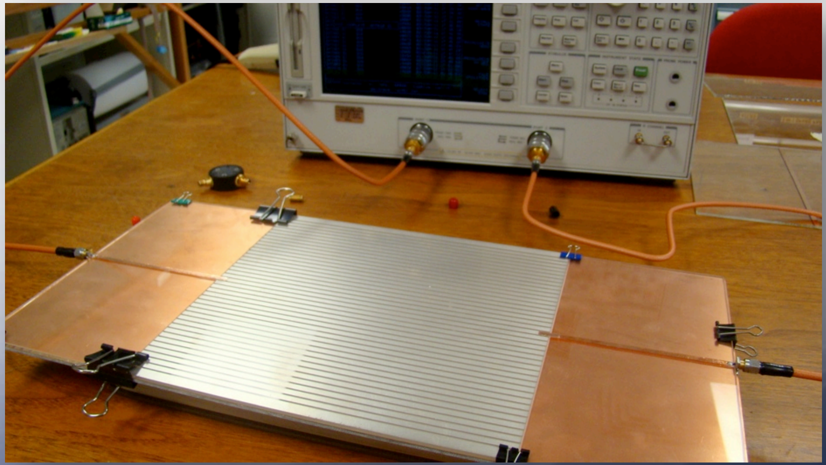
Measured impedance



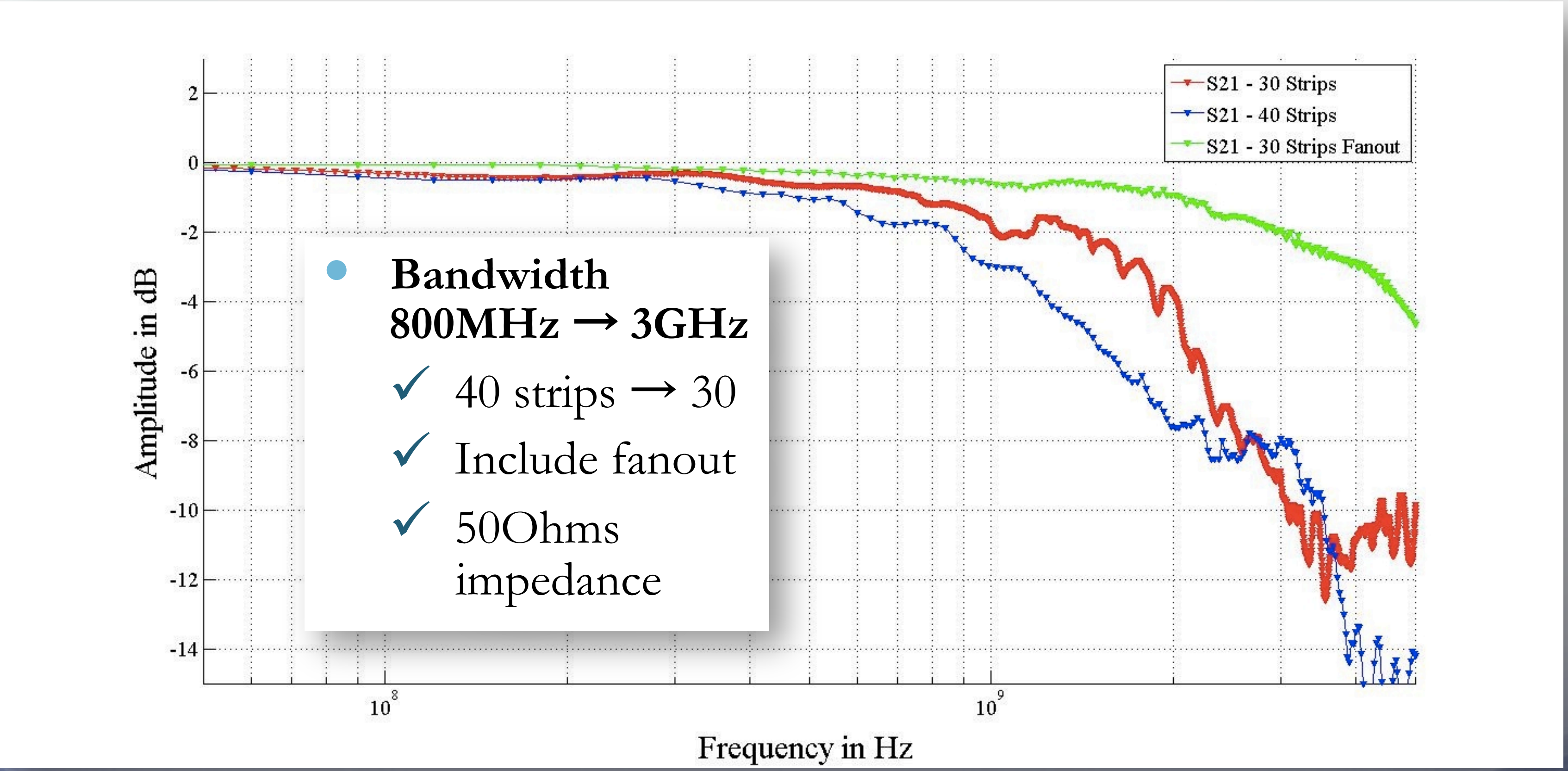
Bandwidth

- Modeling with filed simulators doesn't give usable results.
  - ✓ Complicated modeling
  - ✓ Very sensitive to model
  - ✓ Time consuming and hard to understand
- Best tools: network analyzer & copper tape.
  - ✓ Direct measurement.
  - ✓ Immediate correction with copper tape.



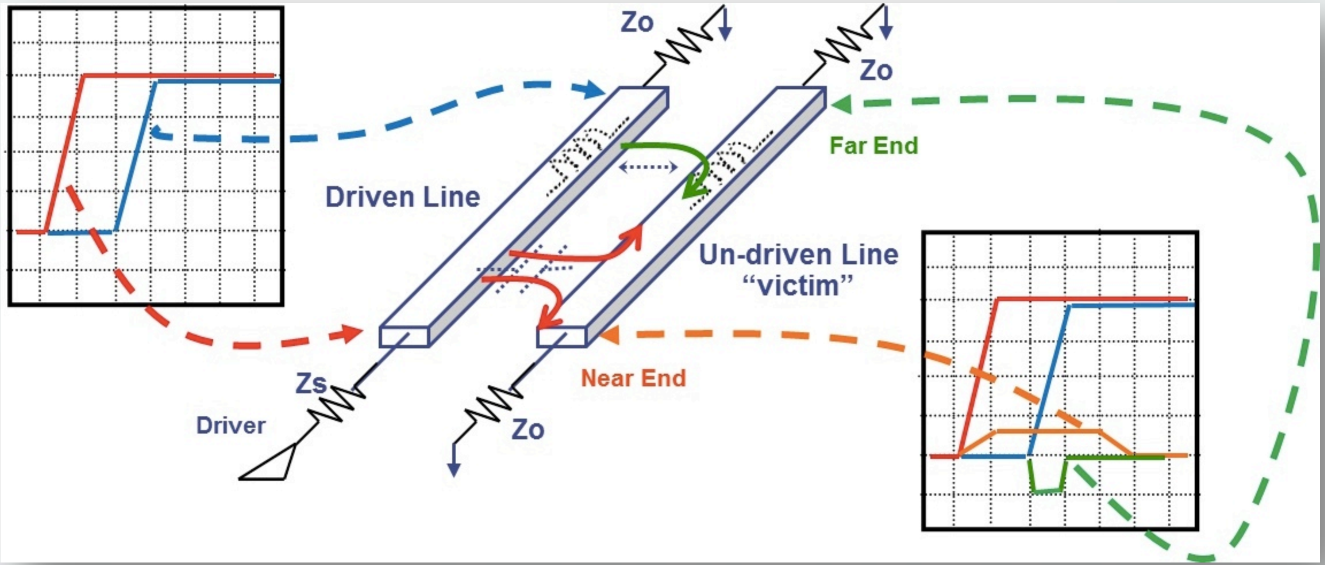


Bandwidth improvement



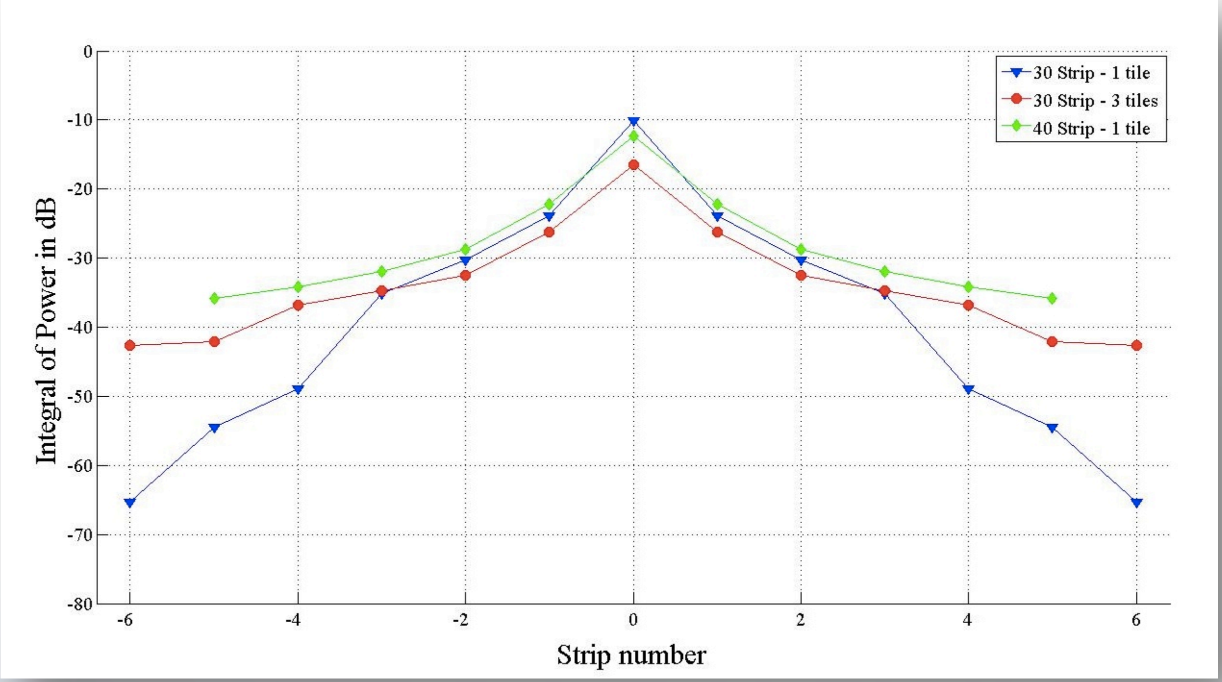
- **Bandwidth 800MHz → 3GHz**
  - ✓ 40 strips → 30
  - ✓ Include fanout
  - ✓ 50Ohms impedance

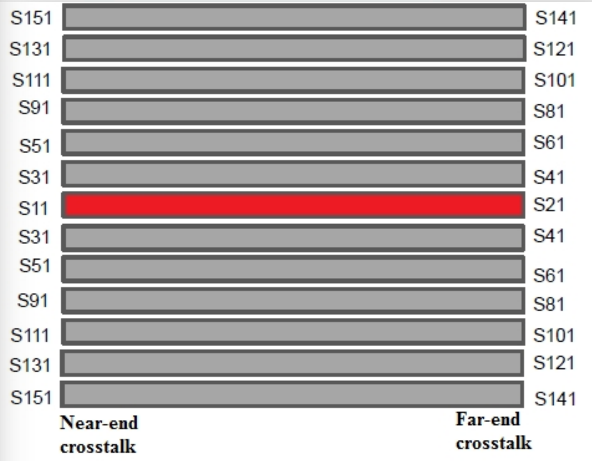
Crosstalk



- Two adjacent striplines are both capacitively and inductively coupled.
- A wave traveling down the line induces a signal on its neighbor both in the forward and reverse direction.
- The magnitude of the crosstalk depends the strip spacing, impedance and dielectric used.

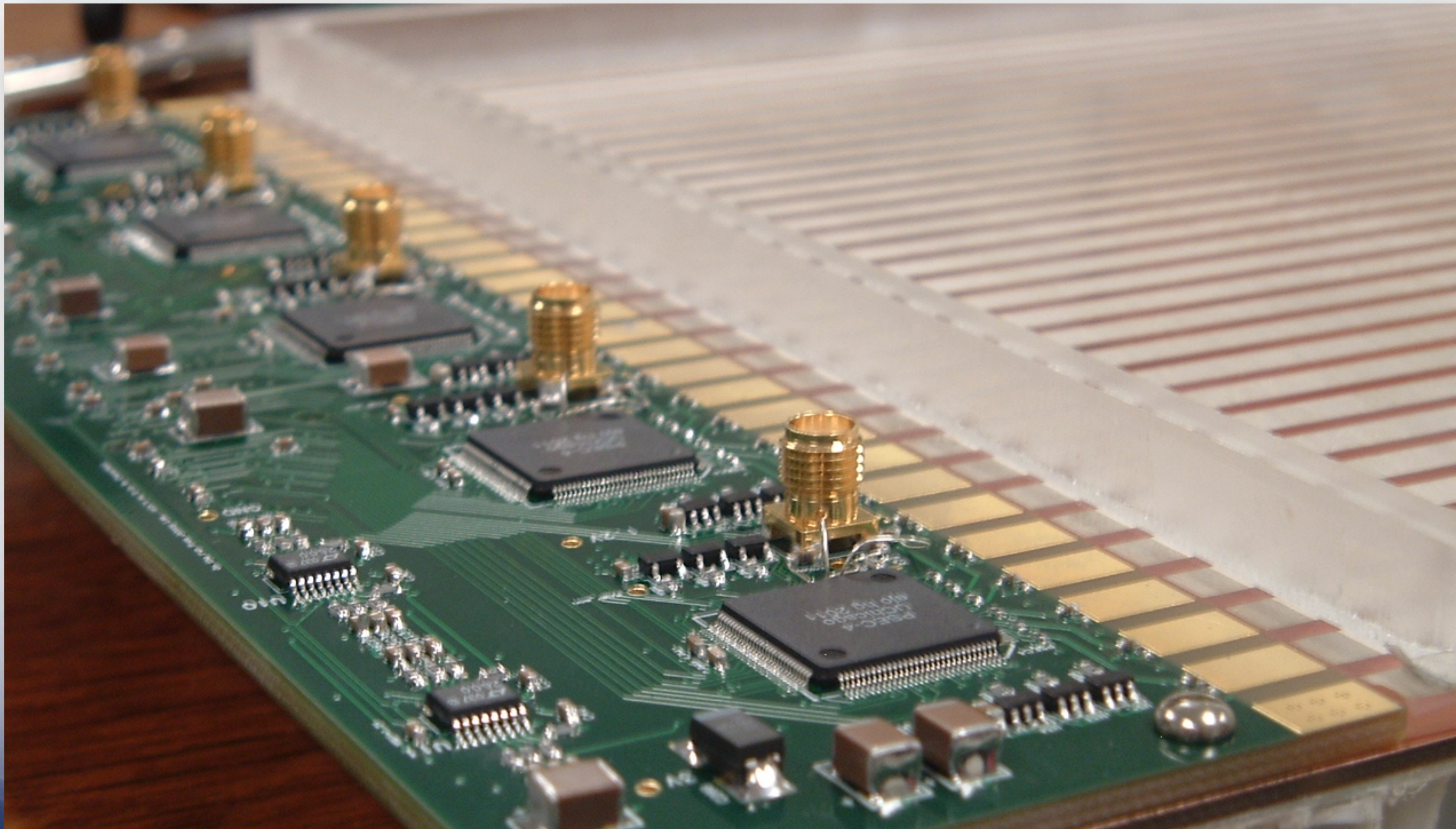
Measured crosstalk





- Measurement of the crosstalk as a function of the strip number on the anodes
- More than 12dB of attenuation over the integrated frequency span from one strip to other, while having still 68% coverage.

Anode to electronics matching



Conclusion

- Successfully build a 3GHz 30 strip transmission anodes for fast timing detectors.
- More than 10dB of attenuation between strips.
- Similar principle can probably be used for fast SiPm.