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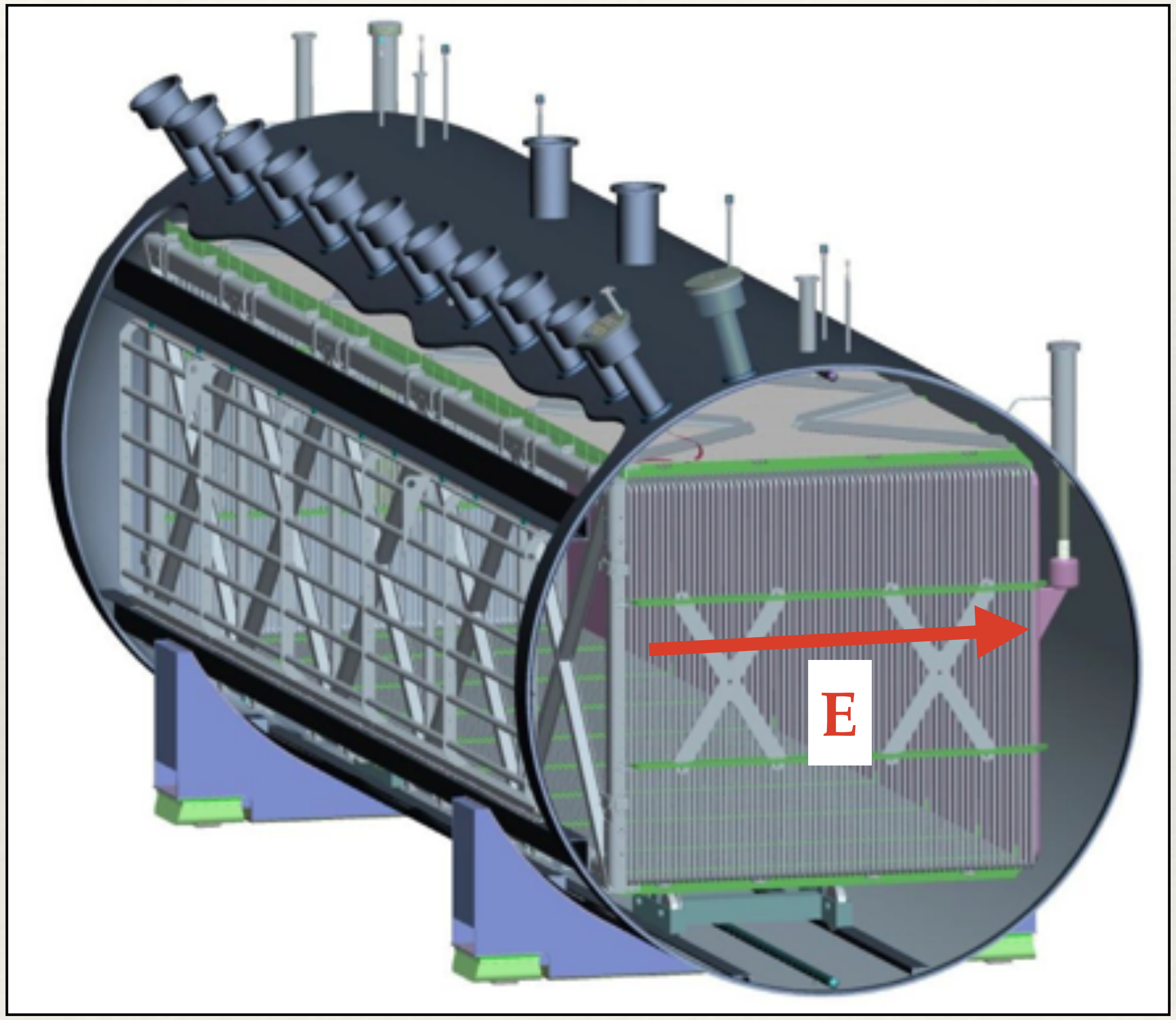
A Capacitively Coupled Wire-plane Diagnostic System

Gabriel Collin,
Massachusetts Institute of Technology

Motivation

- Liquid Argon Time Projection Chambers (LAr TPC) are a leading technology for neutrino detection.
- Neutrino interactions ionize electrons in the Argon.
- Electrons drift in a uniform electric field toward the wire plane.



Motivation

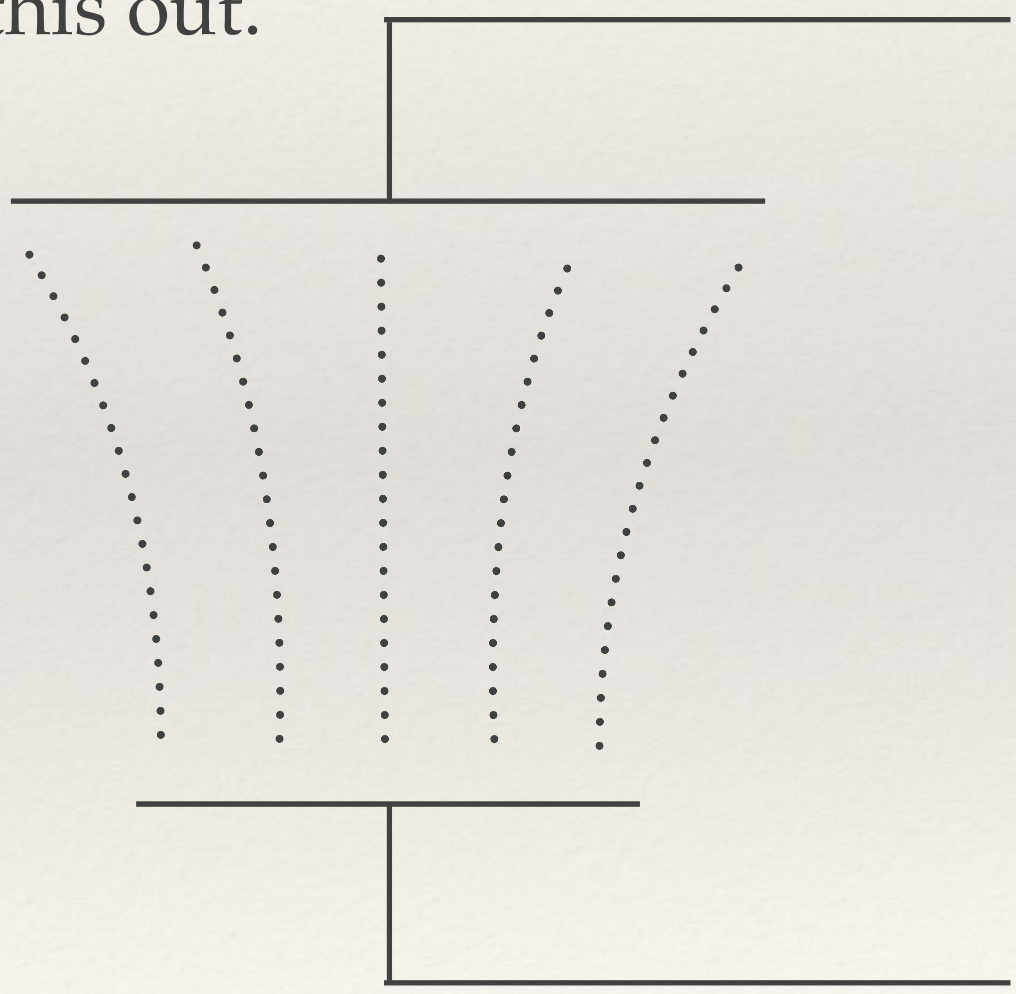
- Large detectors require O(>10^4) sense wires.
- These wires are usually strung over many meters, requiring high tension.
- High strain presents a risk to the integrity of the wire plane.
- An unidentified broken wire could bias any subsequent analysis.

Diagnostic

- Ideally, any broken wires would be identified by injecting free charge into the free end of the wire.
    - This requires electronics to address each wire.
- A more efficient design would passively deliver a signal to the entire set of wires.
- Charge can be simultaneously put on many wires using an electromagnetic radiator.

Capacitive Coupling

- Far-field transmission requires RF frequencies (~300 MHz for a typical experiment).
  - Shaping electronics would average this out.



- A capacitively coupled radiator can efficiently deliver signal at low frequencies.
- Magnetic coupling not possible, due to lack of loops.

Design

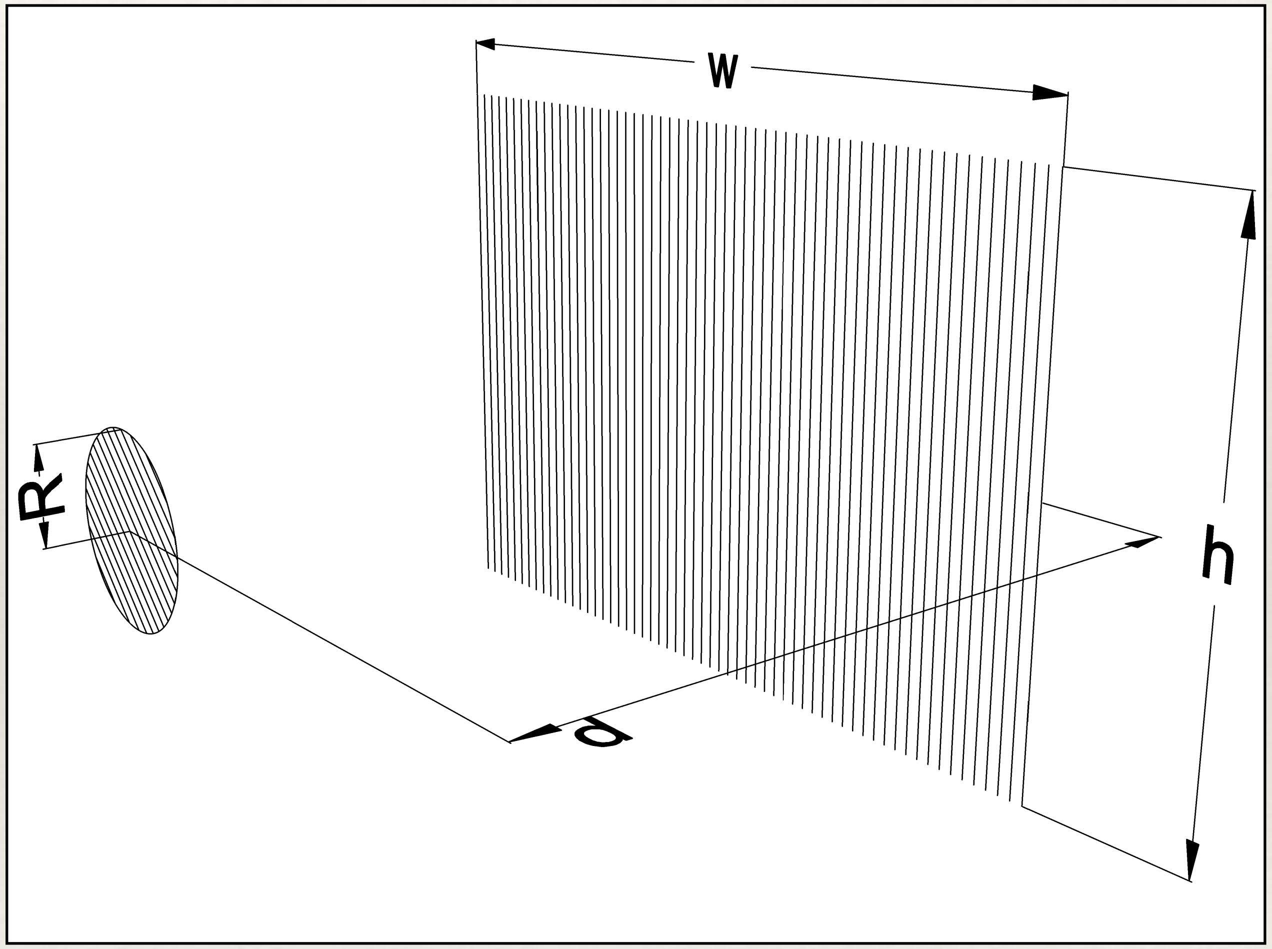
- When $\frac{\omega d}{c} \ll 1$, an electrostatic approximation can be used.
- When $R \ll d$, the antenna can be taken as a point charge.
- Linear charge density induced on wires:

$$\lambda = \frac{q}{4\pi} \frac{ds}{(d^2 + x^2 + y^2)^{3/2}}$$

- Total charge on a wire:

$$Q = \frac{q}{4\pi} \frac{2dsh}{(d^2 + x^2)\sqrt{4d^2 + h^2 + 4x^2}}$$

s = vertical distance between wires

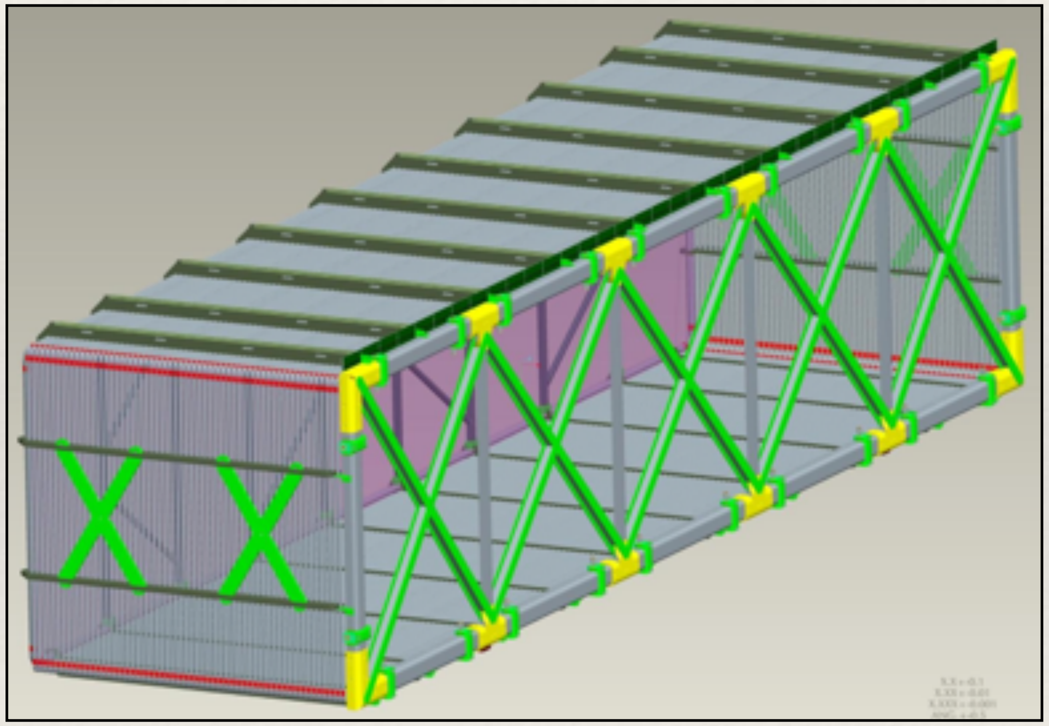


Design

- Ideally, the read-out electronics should be placed at the bottom of the wire plane.
- The wires are most likely to break in one of two places:
  - Bottom: The wire is disconnected from the read-out, and no induced signal is observed.
  - Top: The wire falls to the bottom of the field-cage, drastically changing the amount of induced charge.

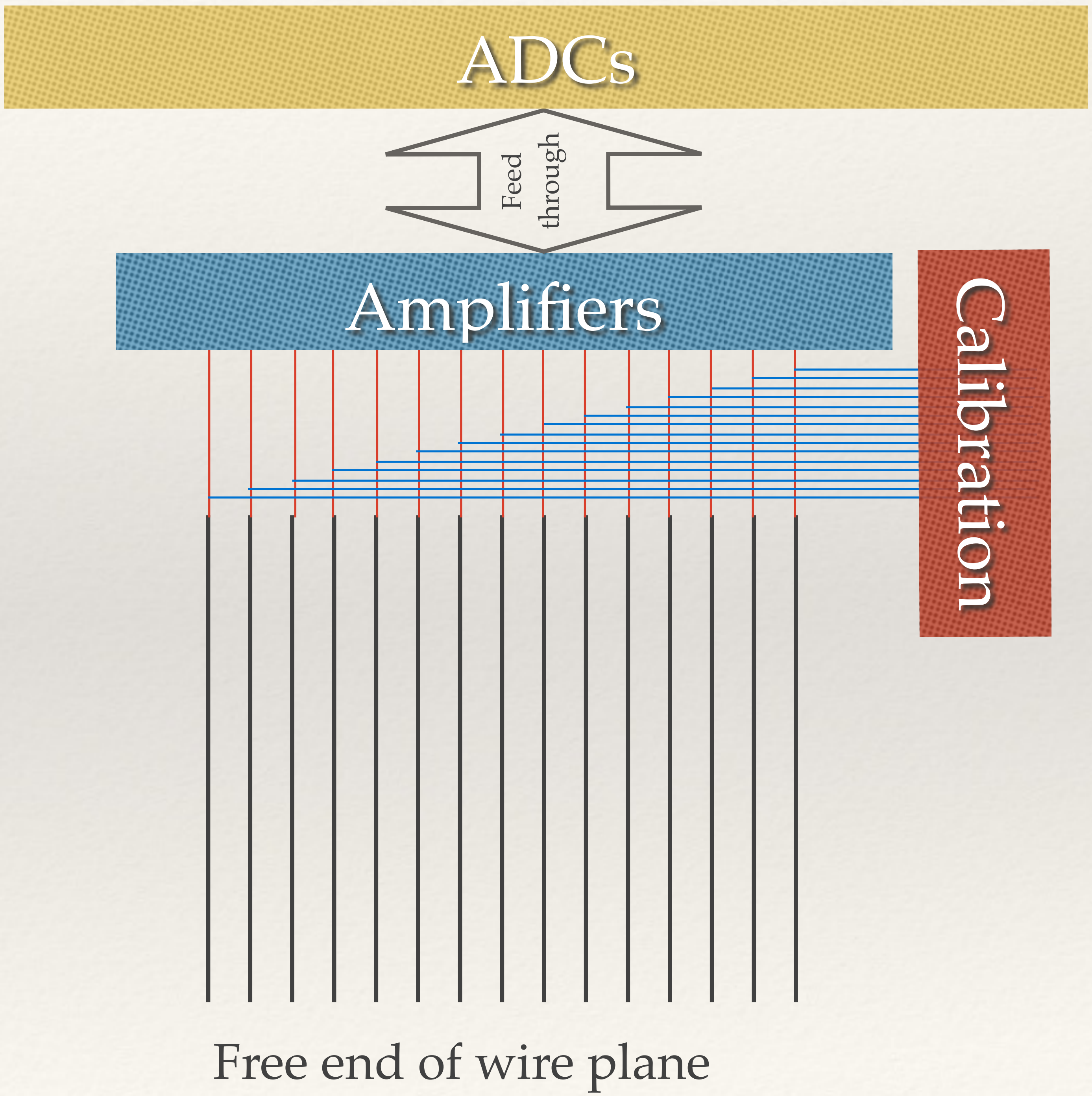
MicroBooNE

- MicroBooNE is an LAr TPC experiment at Fermilab, currently under construction.
- Data taken using production MicroBooNE wire planes.
  - TPC was located outside the EM shielding cryostat.
- Signal modulation, and trigger provided by function generator.



MicroBooNE Electronics

- Read out electronics are placed at the top of the wire plane.
- ADCs integrate over 500 ns.
- Amplifiers shape the signal.
- Averaged over 10,000 events to eliminate effect of high noise environment.
- Charge injection calibration system injects directly into the amplifiers.
- Modular design.
  - Many modules make up the whole wire plane.



Prototype

- Two antenna types made to test coupling hypothesis.
  - 4:1 balun dipole antenna.
    - No pickup seen at RF frequency modulation.
    - Pickup seen at quasi static frequencies (T > 1 us).
  - 6″ x 6″ copper plate.
    - Pickup seen at quasi static frequencies.
    - Gain of twice the dipole antenna.

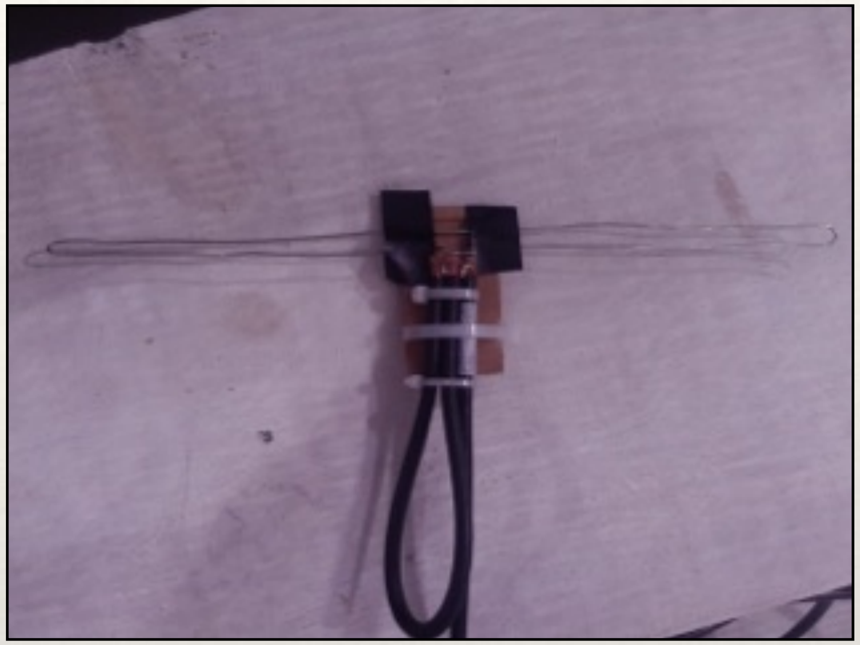
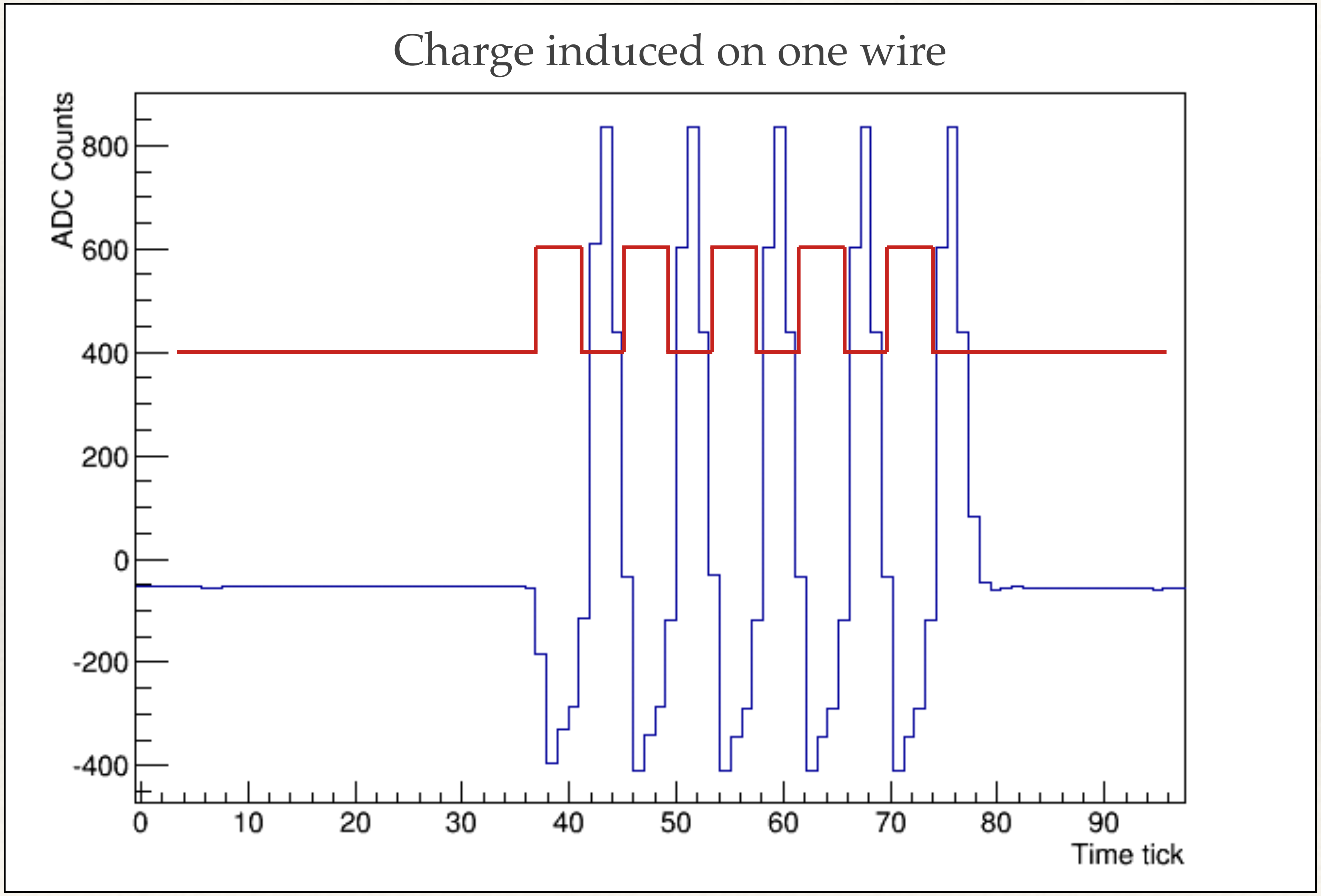


Plate Antenna

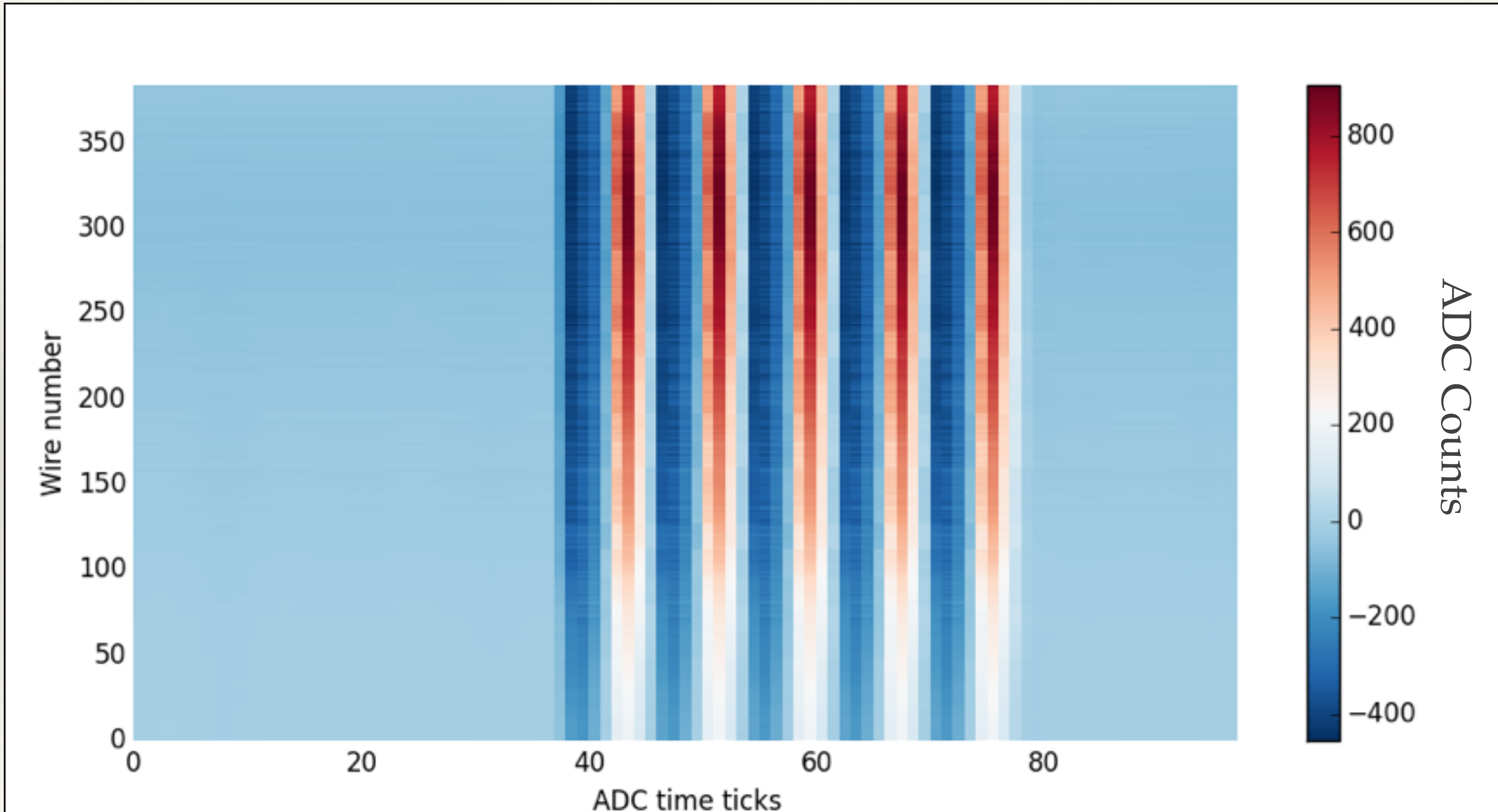


Red: Sketch of modulation.

Blue: Charge induced on wire plane wire.

1 tick = 0.5 us

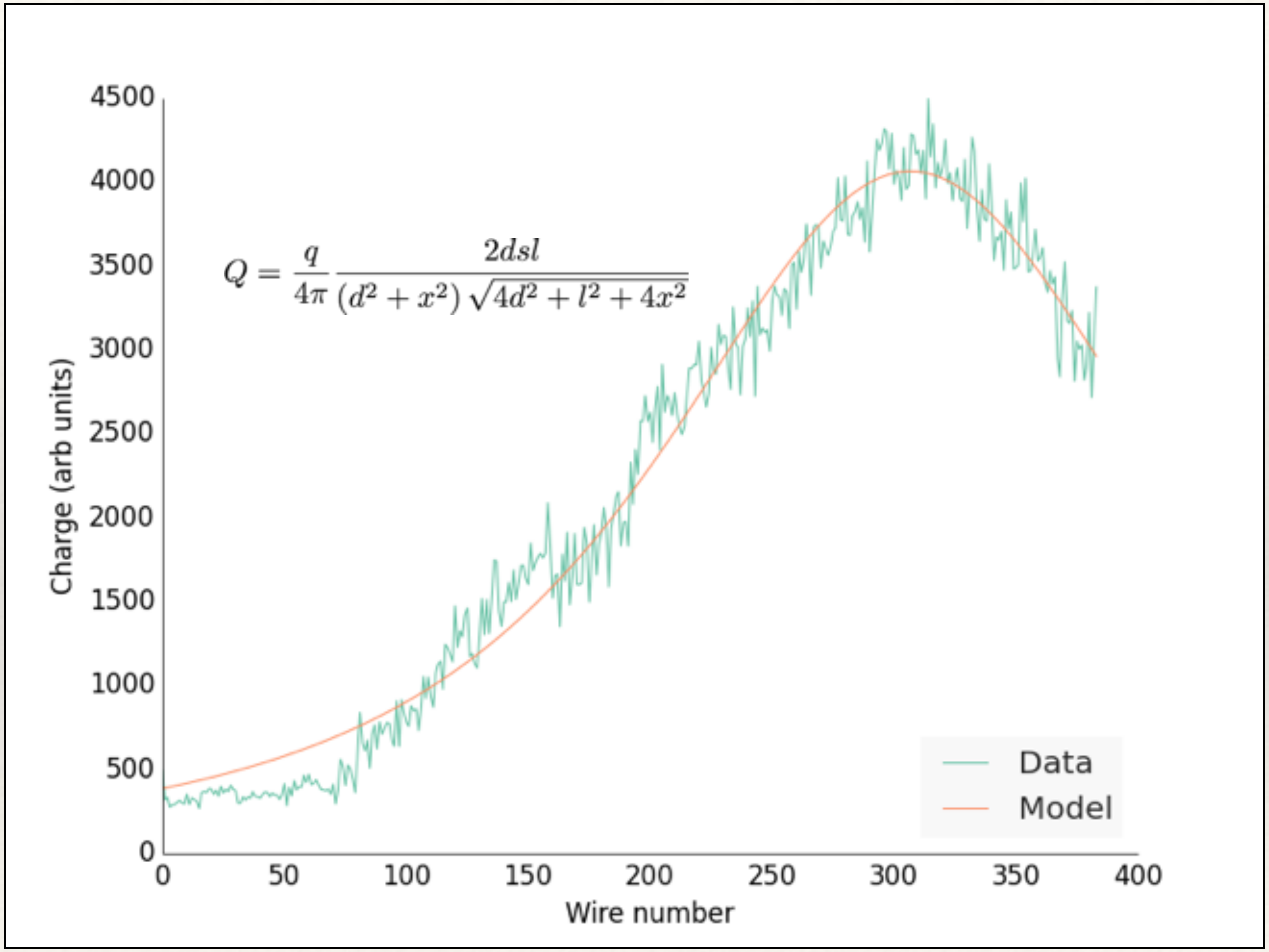
Plate Antenna



1 tick = 0.5 us

Plate Antenna

- Induced signal for each wire integrated over 16 us period.
- Fit to model derived for charge induced on a wire.
- Gives d = 18.5″ compared to actual value of 20″



~ 1 meter

Cathode pulsing

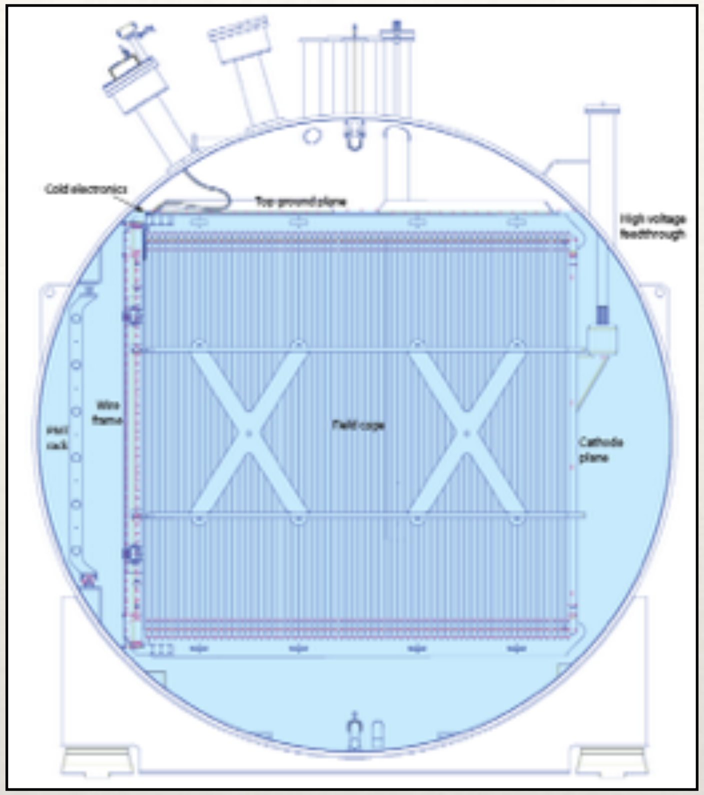
- In all drift chambers there is a cathode plane.
- This is essentially a huge antenna.
- Cathode can be pulsed to induce charge on all wires.
- Efficiency depends on the specific configuration of the field cage tubes and resistor chain.

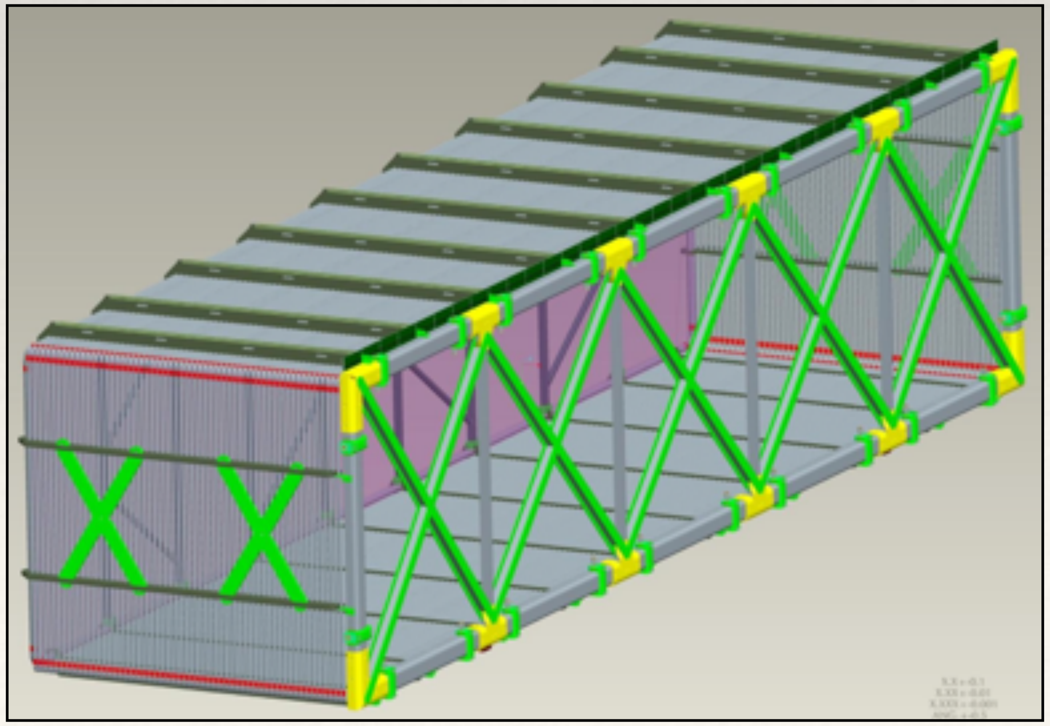
Conclusion

- Next generation of large LAr TPC detectors need cost effective wire plane diagnostic systems.

- A capacitively coupled antenna meets these goals.

- A prototype antenna has been shown to induce clear signals on the MicroBooNE wire plane.





Backup

$$\vec{E}(r) = \frac{1}{4\pi\epsilon_0} \int \frac{1}{R^2} \left[\rho(\vec{r'}, t_r) + \frac{R}{c}\dot{\rho}(\vec{r'}, t_r) - \frac{R}{c^2}\dot{J}(\vec{r'}, t_r)\right] d^3\vec{r'}$$

$$V(\rho, \phi, z) = \frac{\sigma}{4\pi\epsilon_0} \int_0^R \int_0^{2\pi} \frac{r dr d\theta}{\sqrt{(d+z)^2 + R^2 + r^2 - 2rR\cos(\theta - \phi)}}$$