PPPL U.S. DEPARTMENT OF ENERGY

Wendelstein 7-X IPP Max-Planck-Institut für Plasmaphysik

F.C. FILD Prototype Testing

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HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

EUROfusion

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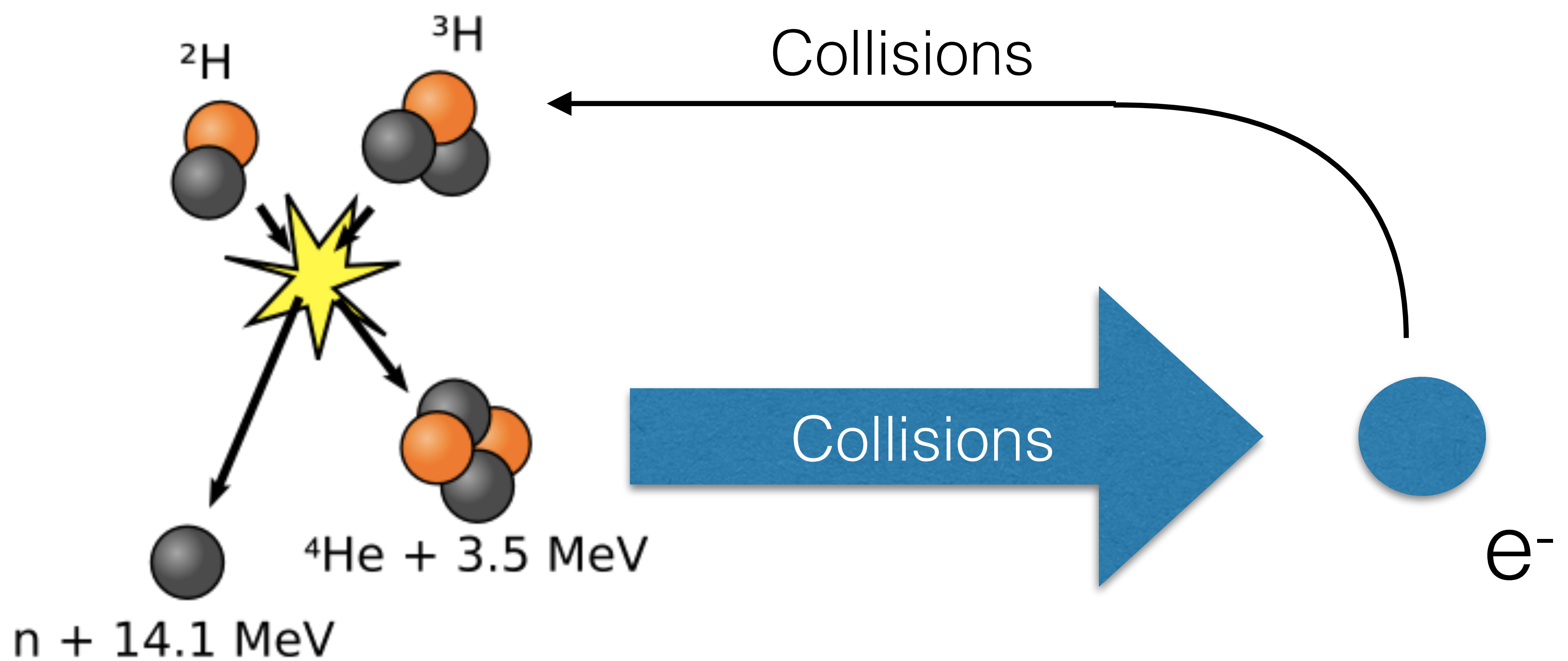
Why do we care about fast-ions losses?

- Deuterium-Tritium fusion produces 3.5 MeV He particles.
- These particles must slow down on the background plasma, thus heating it.
- If the particles aren't confined long enough to heat the plasma we cannot reach a burning plasma scenario.



Losses to the first wall provide a proxy for the level of energetic particle confinement.

Why develop a new type of detector?

- Given the three-dimensional nature of stellarators we'd like to measure losses at multiple toroidal positions
- Scintillating detectors tend to be bulky and expensive given the necessity of CCD's and PMT's
- Often pitch angle is less of a concern than energy discrimination

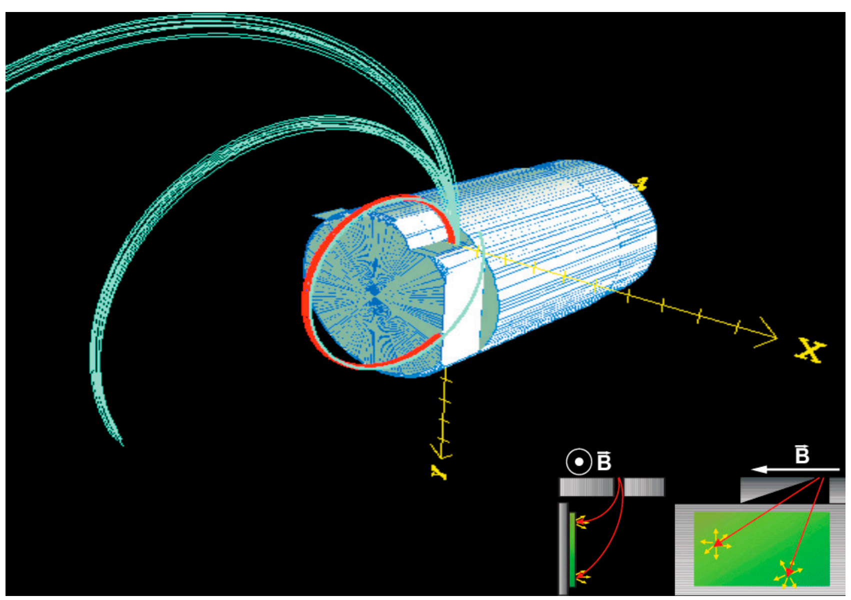


FIG. 1. Schematic of the FILD: CAD view of some escaping ion trajectories hitting the detector head. In blue particle trajectories which enter into the scintillator chamber and in red particle trajectories blocked by the graphite protection. The inset on the right-bottom part of the figure shows the collimating process.

Published in: M. García-Muñoz; H.-U. Fahrbach; H. Zohm; *Review of Scientific Instruments* **80,** 053503 (2009)
DOI: 10.1063/1.3121543

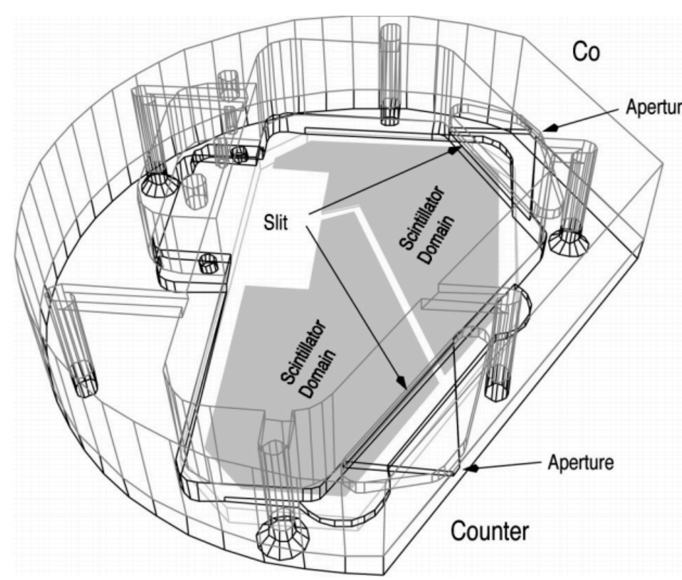


FIG. 5. An isometric line diagram of W7-AS probe head, including the scintillator, metal film domains for charge collection, apertures, and supporting structures. The aperture "cones" are at the right hand side in this view.

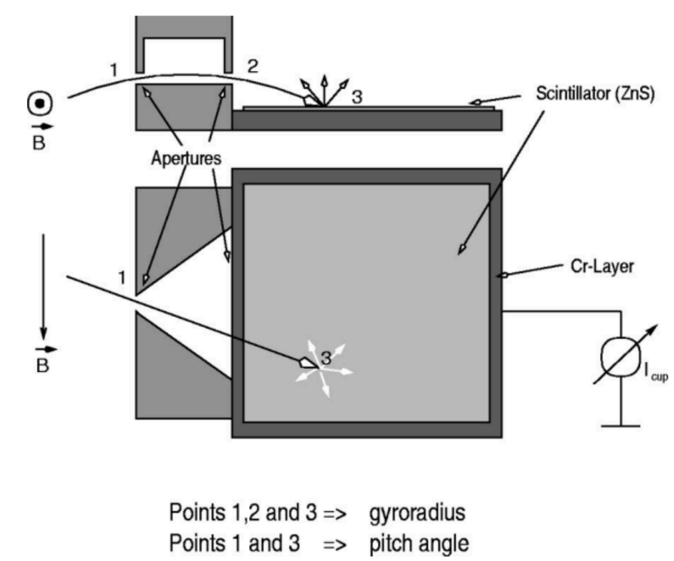
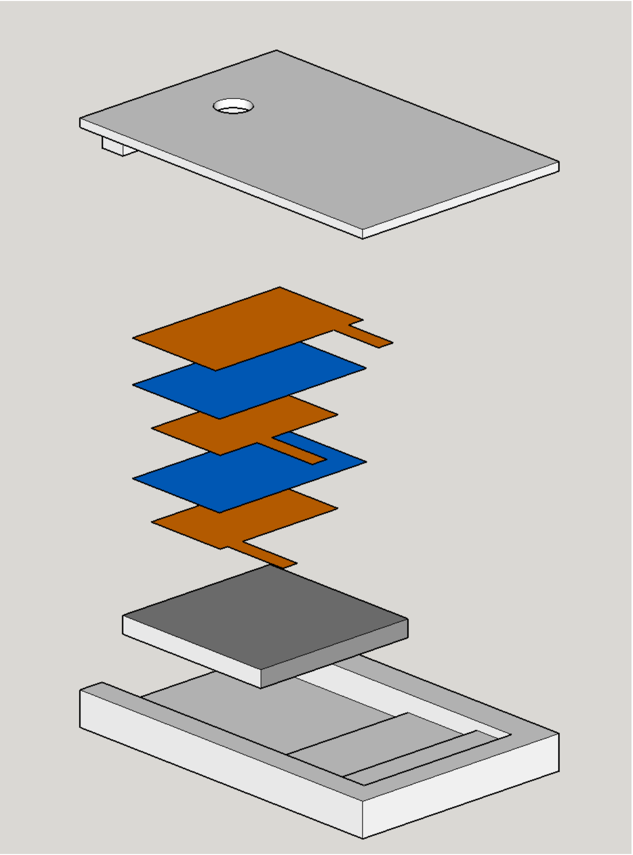


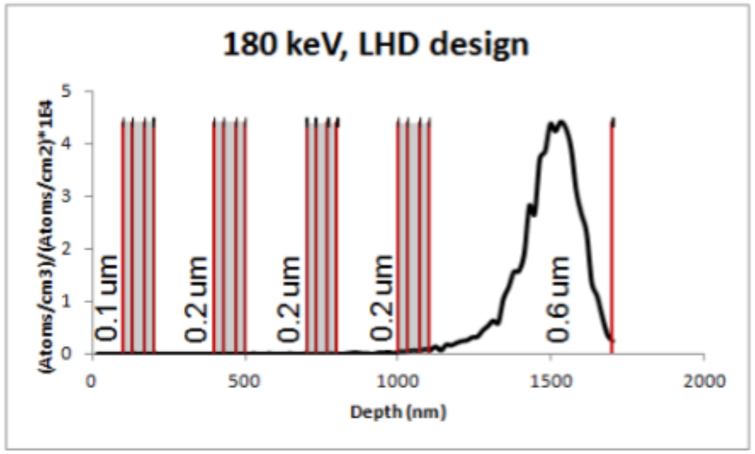
FIG. 3. A schematic of top and side view of probe operation, including a fast ion orbit. The gyroradius (energy) of the particle determines how far from the apertures it will strike the scintillator. The pitch angle determines where the ion will strike along the orthogonal dimension of the scintillator.

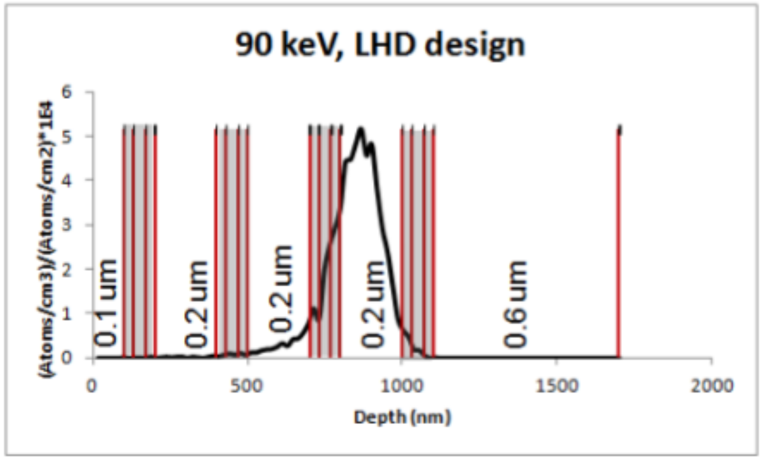
Published in D. Darrow; A. Werner; A. Weller; *Review of Scientific Instruments* **72**, 2936 (2001)
DOI: https://doi.org/10.1063/1.1379602

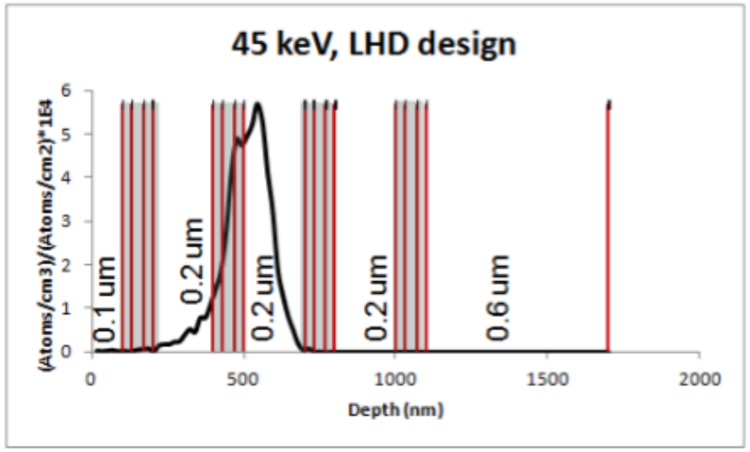
A Faraday Cup Fast Ion Loss Detector (F.C. FILD)

- Stacked conductive layers to bin particles
  - JET detectors use foils (>1 μm thickness)
  - Foils limit detectors to MeV range particles
- Thin film deposition allow for much thinner layers
  - Layer thicknesses of <1000 Å possible.
  - Allows for sub 100 keV particle discrimination
    - W7-X uses 55 keV beams



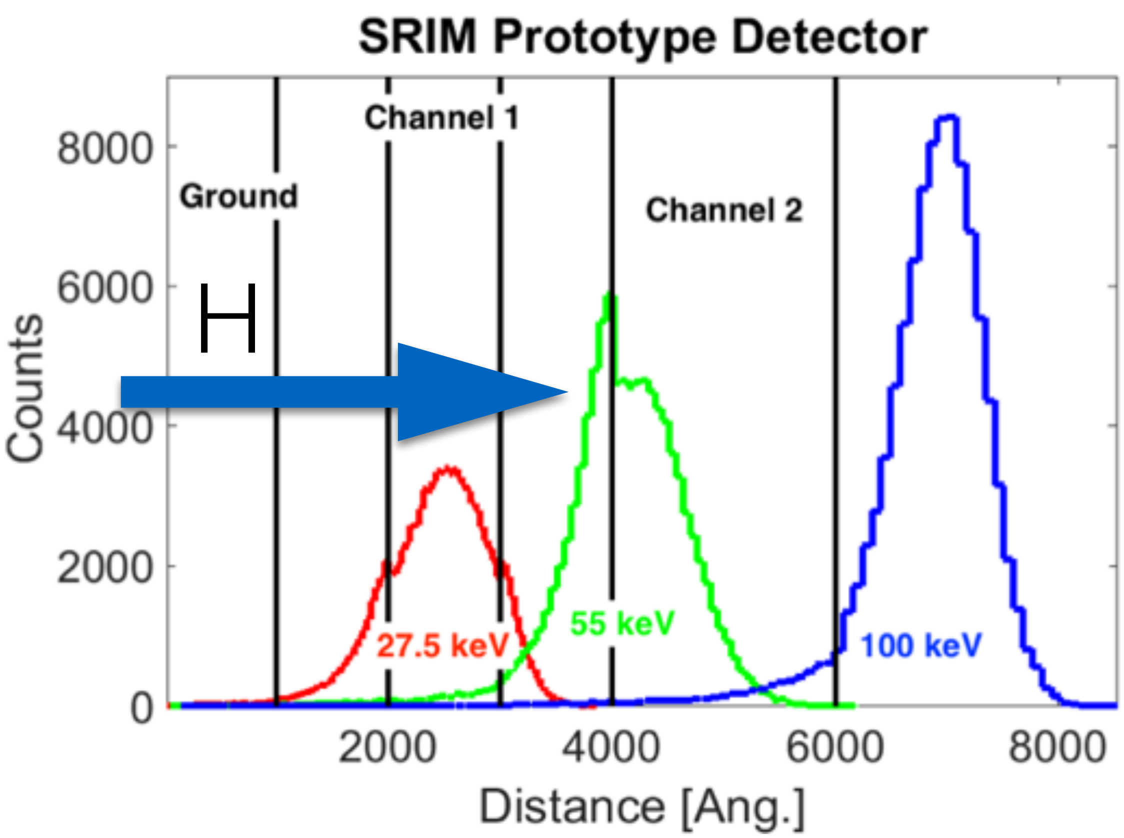


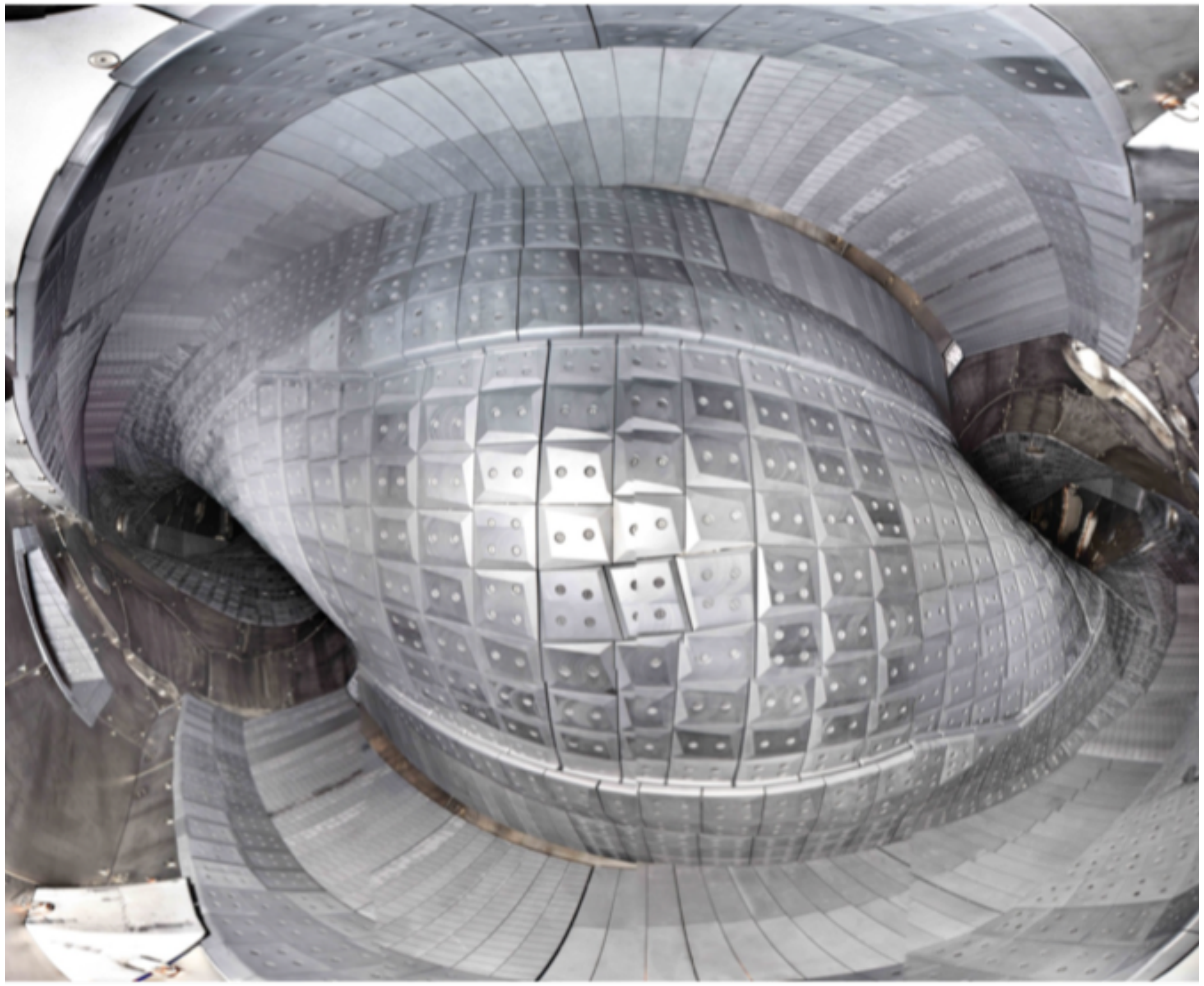




W7-X provides a facility to test FC-FILD

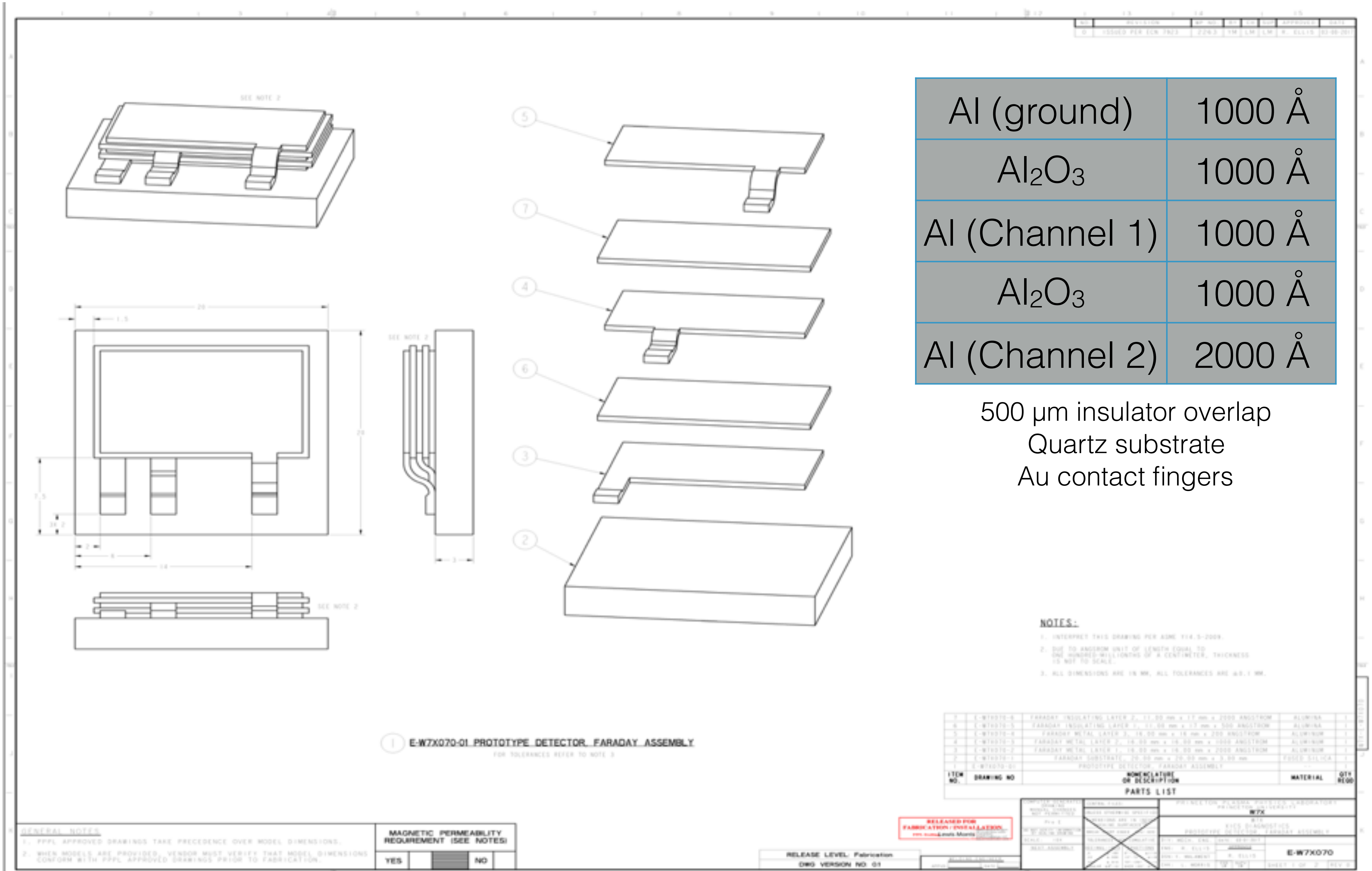
- 55 keV H injection from NBI
- Three dimensional losses go to carbon tiles
- Low energies push limits of manufacturing (sub 1000 Å)





Picture courtesy of G. Wurden (LANL)

Detector FC-FILD chip design

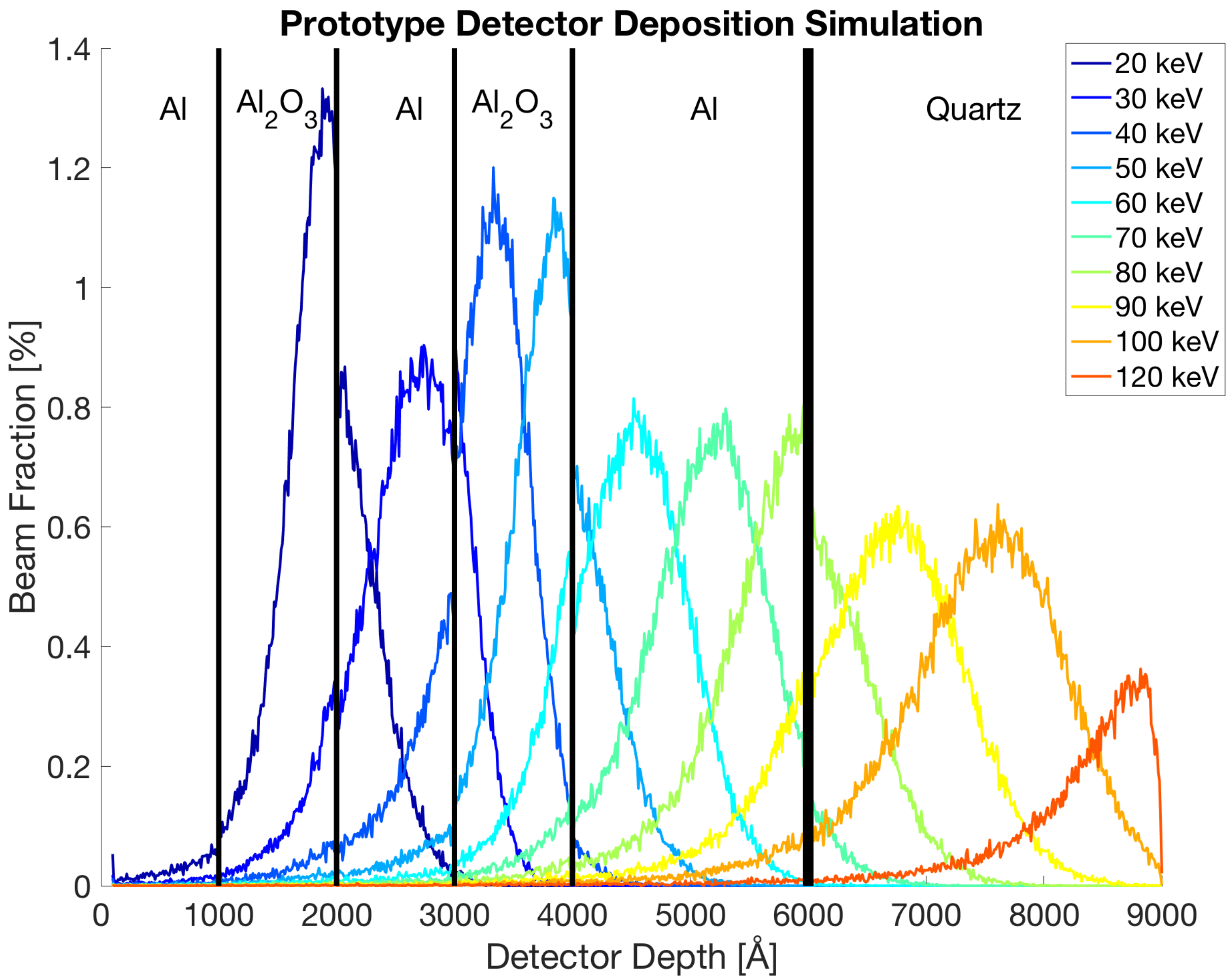


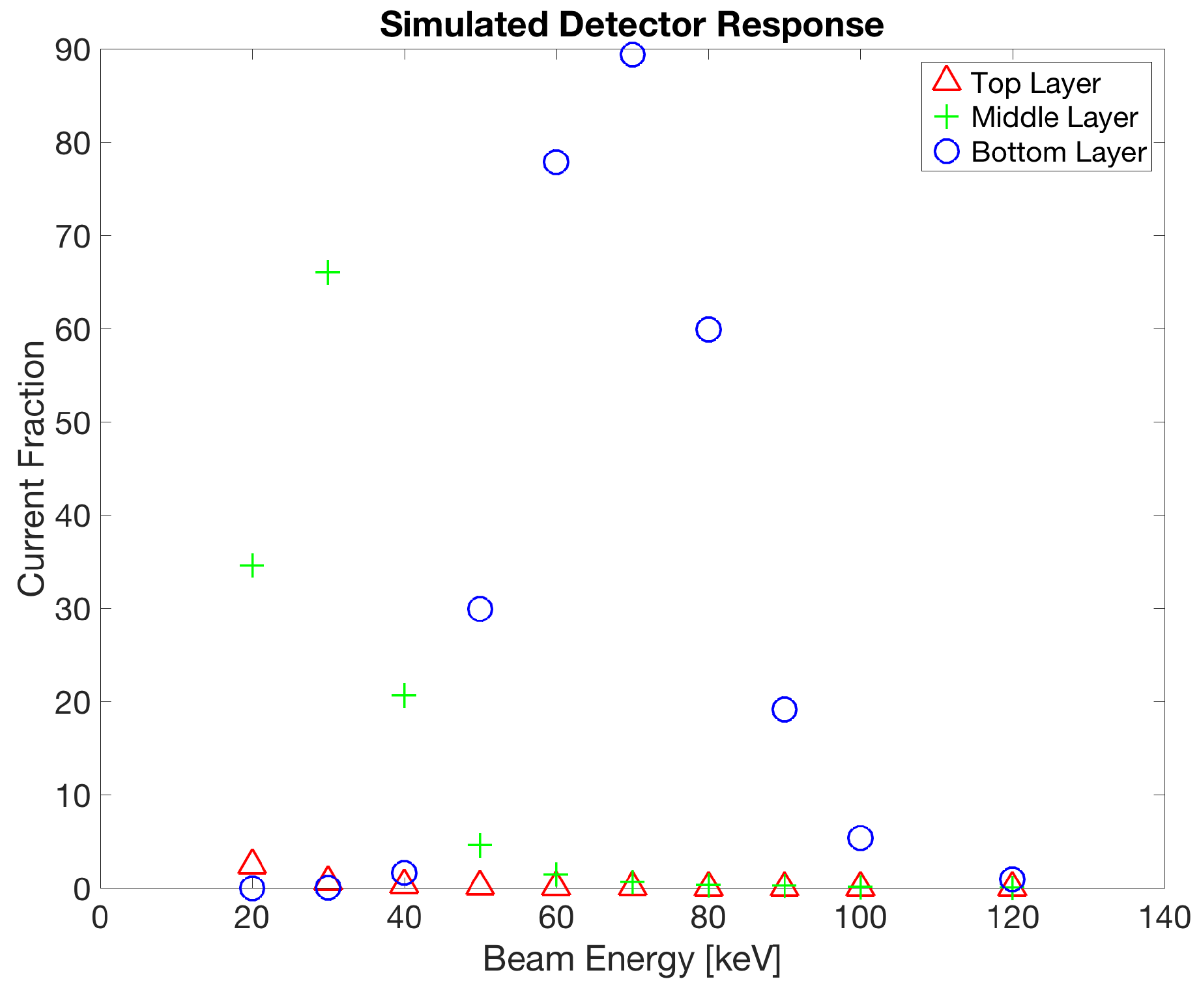
Al (ground)	1000 Å
Al_2O_3	1000 Å
Al (Channel 1)	1000 Å
Al_2O_3	1000 Å
Al (Channel 2)	2000 Å

500 µm insulator overlap
Quartz substrate
Au contact fingers

First prototype design to demonstrate energy discrimination

- Standard Ranging Into Matter (SRIM) packaged used for modeling of detector response
  - Middle layer has peak signal at 30 keV (1000 Å)
  - Bottom layer has peak signal at 70 keV (2000 Å)



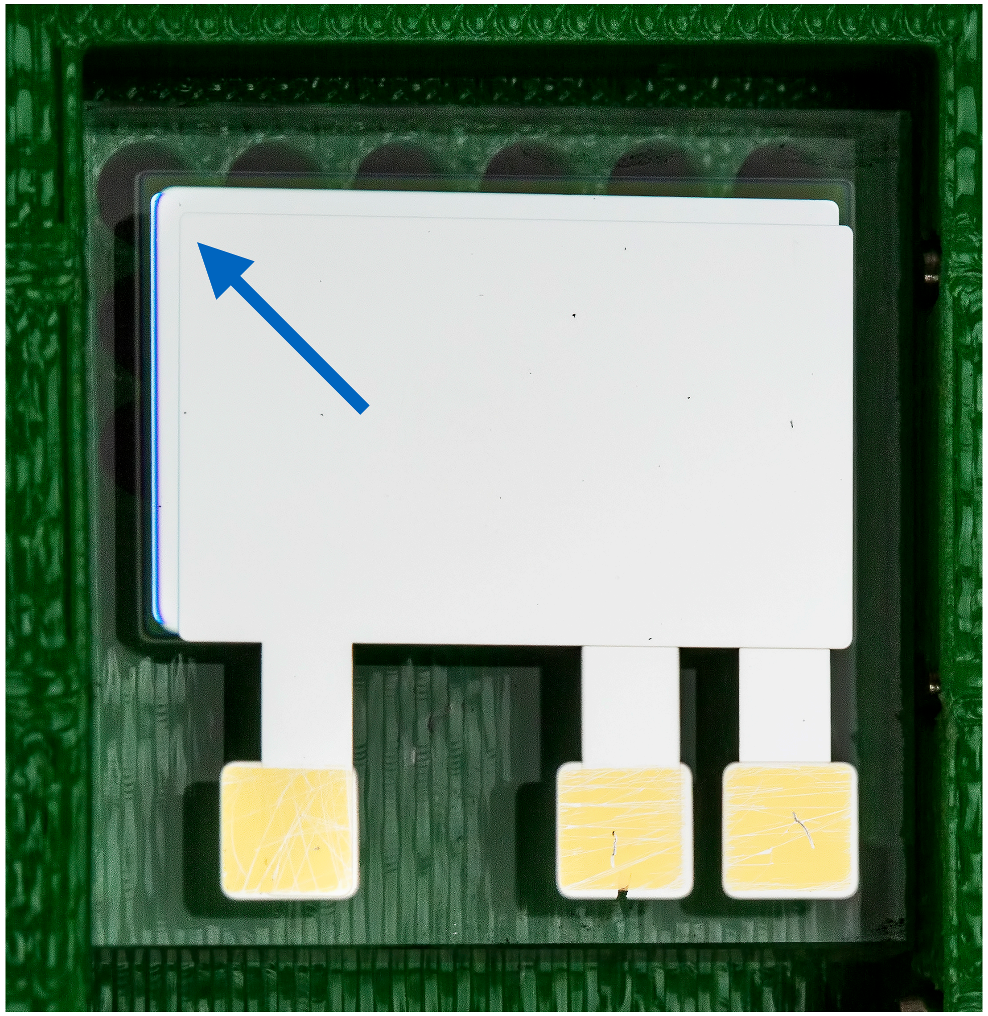


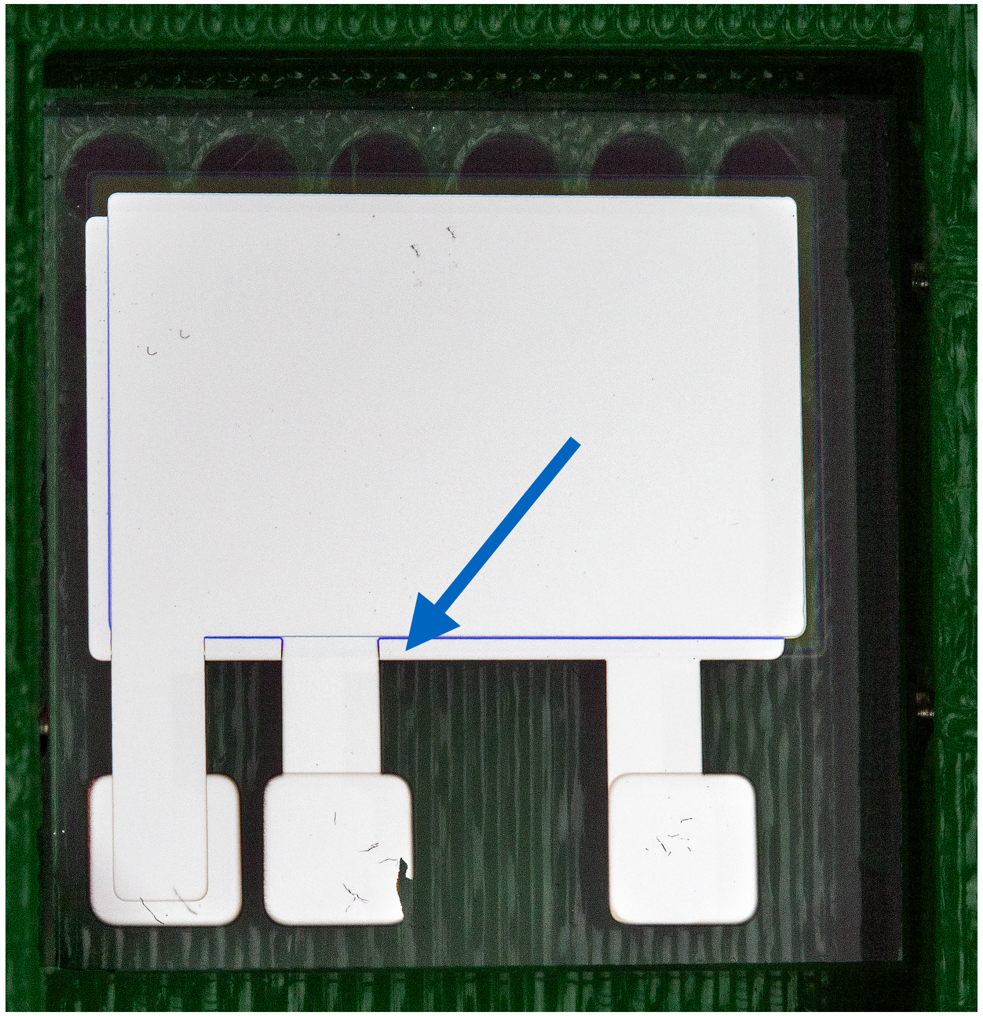
J. P. Biersack and L. Haggmark, Nucl. Instr. and Meth., vol. 174, 257, 1980

"***The Stopping and Range of Ions in Matter***", *volumes 2 - 6*, Pergamon Press, 1977-1985

First round detectors had large layer shifts

- 4 of 5 detectors show shorts between all layers
- One detector has short between Middle and Bottom layer but top layer isolated (ground layer)
    - Capacitance confirms estimates for ~1000 Å insulating layer
- Large layer shifts identified (~ 1 mm)
    - Will be mitigated by redesign of connection points in future





Pictures courtesy of E. Starkman (PPPL)

Calculation of capacitance

- Assume plate area of 10x16mm = 160 mm2
- Layer Thickness: 1000Å = 0.0001 mm
- Dielectric constant for Aluminum Oxide: K=9.34
- Breakdown voltage for 50 MV/cm

132 nF, voltage limit of ~40V

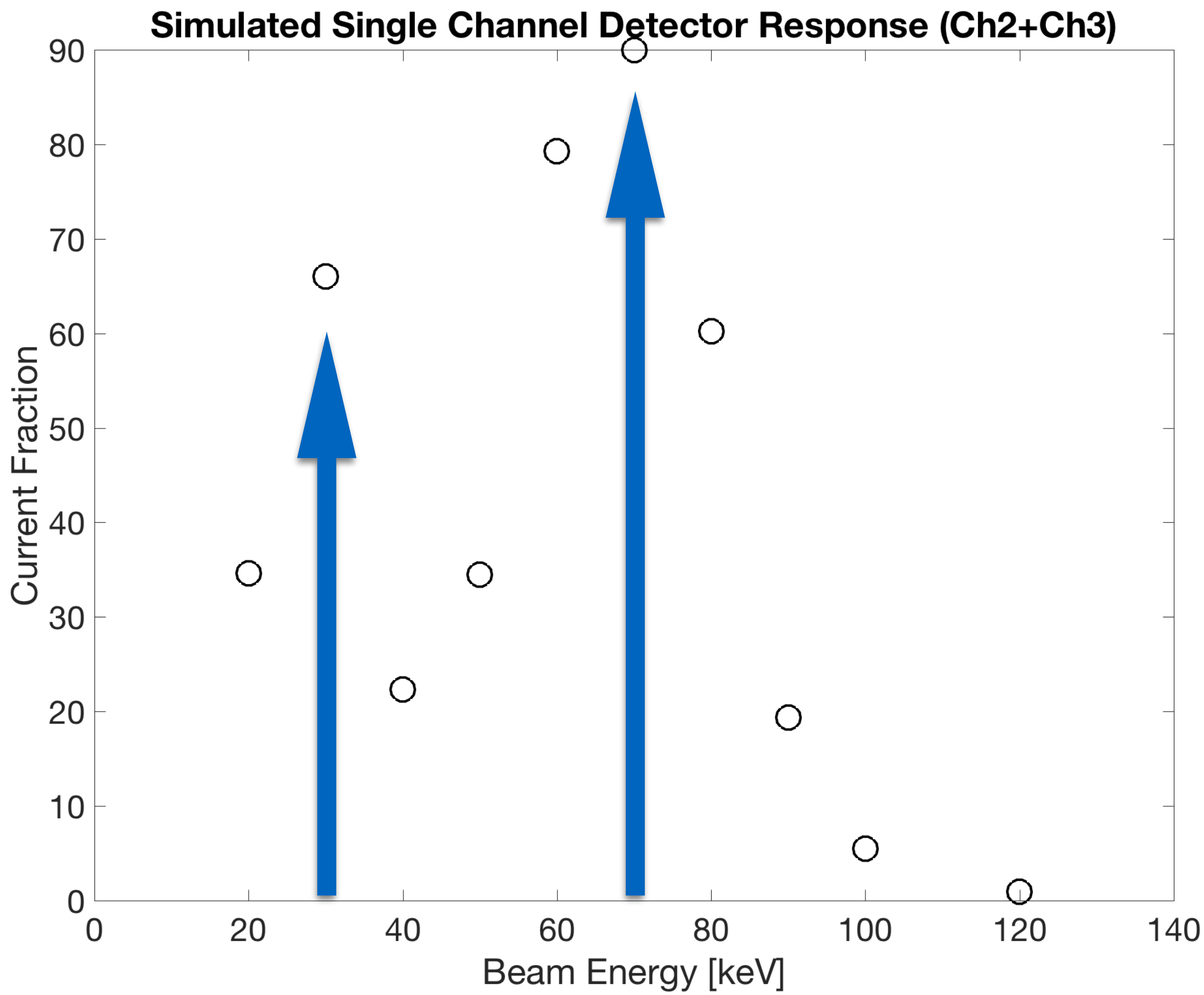
$$C = \frac{k\epsilon_0 A}{d}$$

- Measured capacitance 94.5 nF
  - 28% discrepancy
  - ~20% can be accounted for by layer shifts
  - Layer may be ~10% thinner than expected

	Capacitance 1-2	Capacitance 2-3	Capacitance 1-3
Detector 1	Short	Short	Short
Detector 2	Short	Short	Short
Detector 3	Short	Short	Short
Detector 4	95.5 nF	Short	94.5 nF
Detector 5	Short	Short	Short

Detector has a single channel-like response

Single channel should show response maximum at 30 and 70 keV with minimum at 40 keV



Testing performed in a 140 kV linear accelerator

20-120 kV
80-800 nA Beam Current
3.71 Hz vertical, 0.24 Hz horizontal Raster

Source and Accelerator

Oscillator

Target Chamber

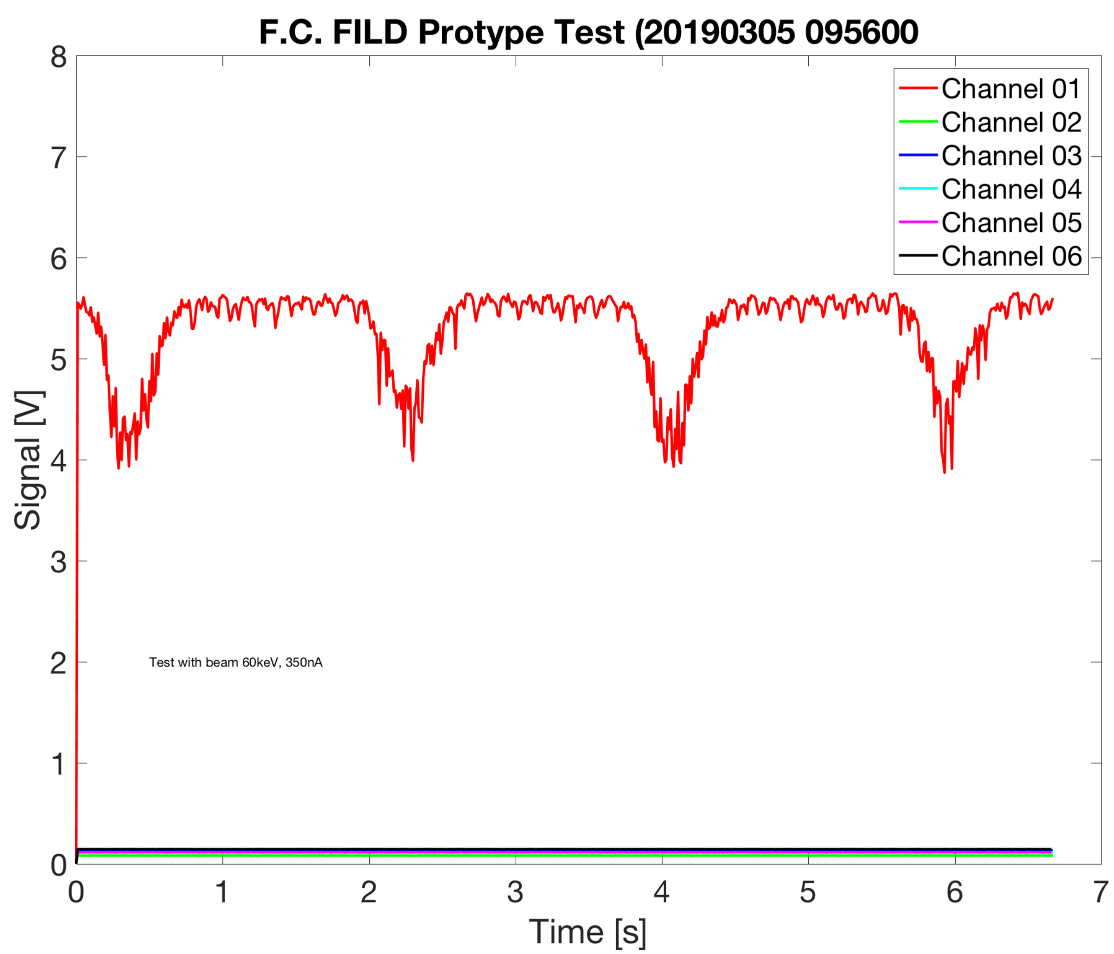
Initial Sensor Signals

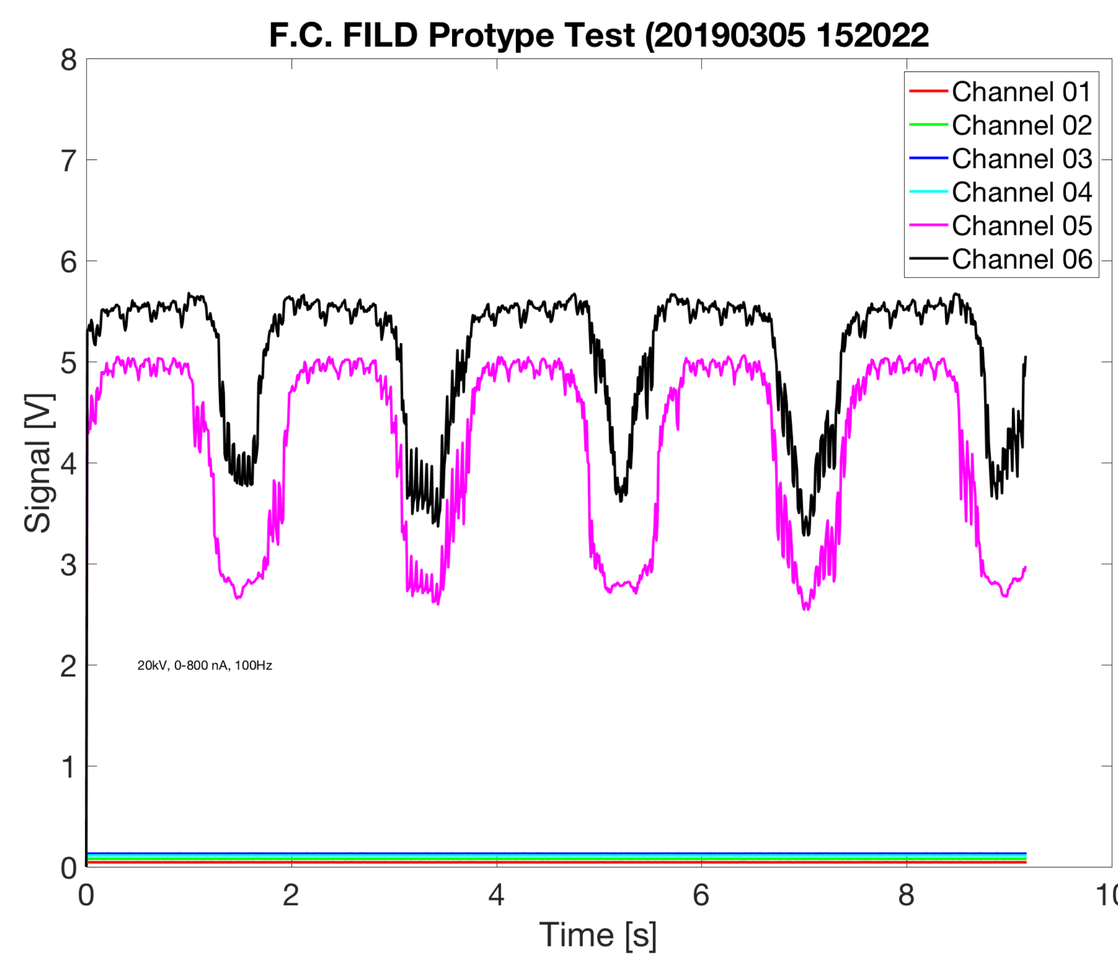
Fully shorted sensor tested

- 20-120 kV
- 80 nA current
- No damage due to beam detected

Partial shorted sensor tested

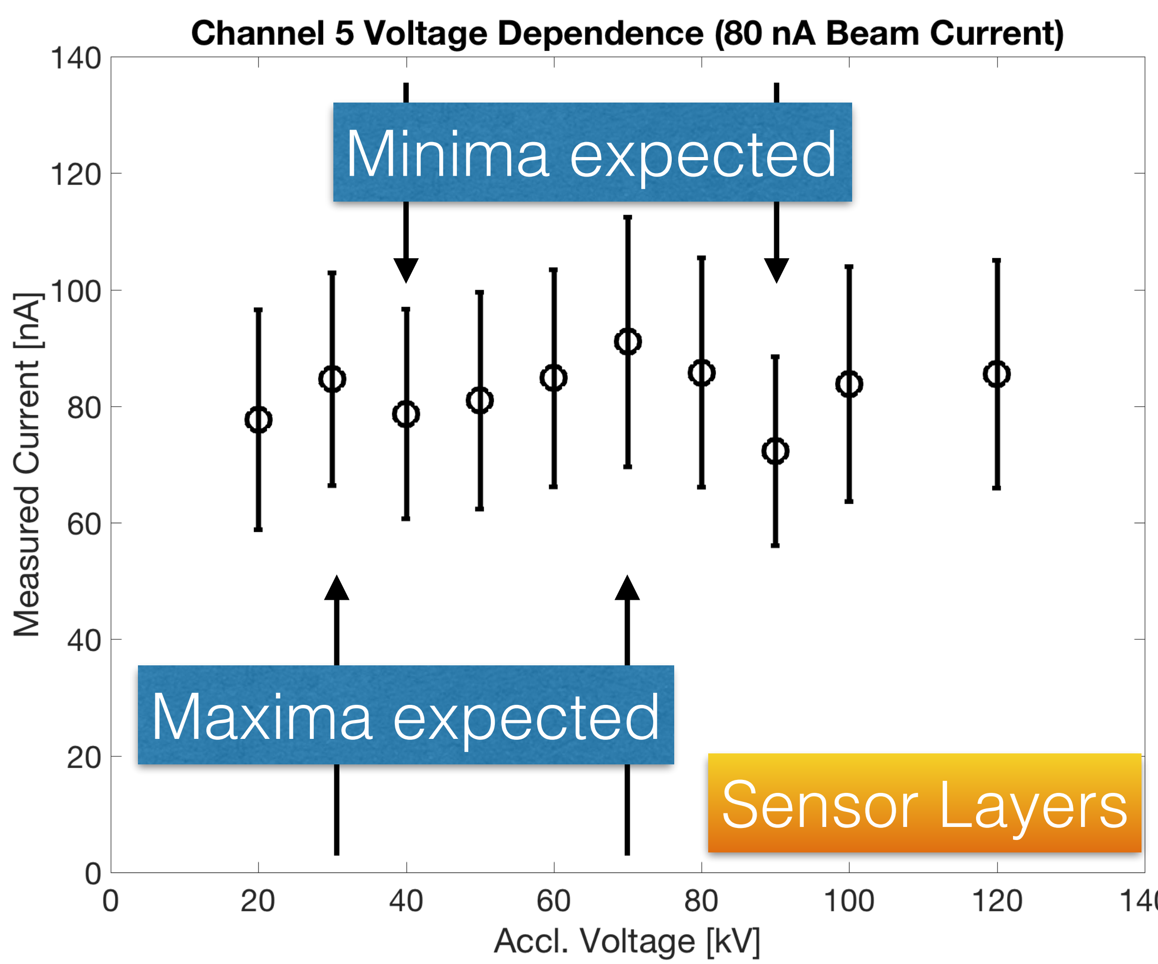
- 20-120 kV @ 80 nA
- 80-800 nA @ 60 kV

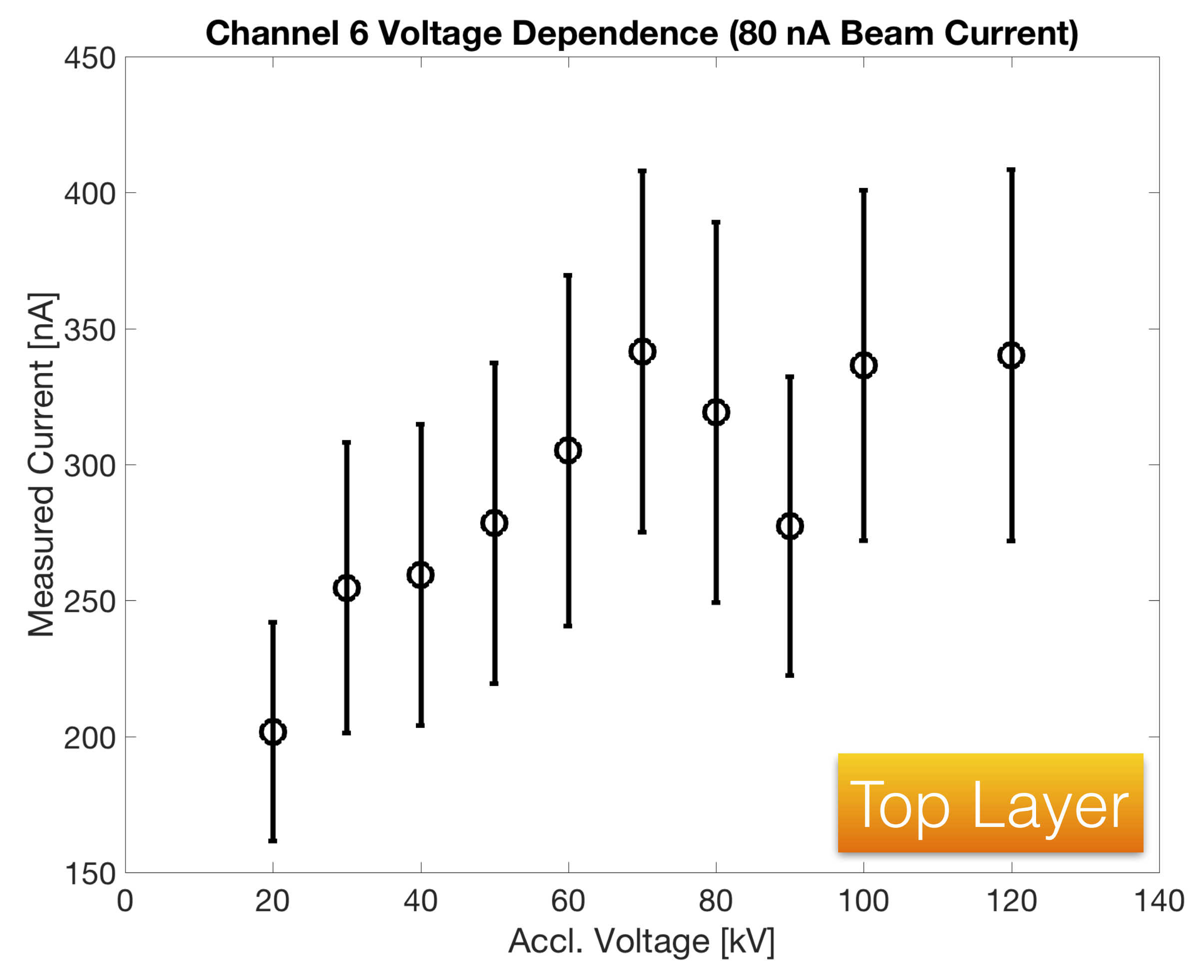




Detector response confirms sensitivity

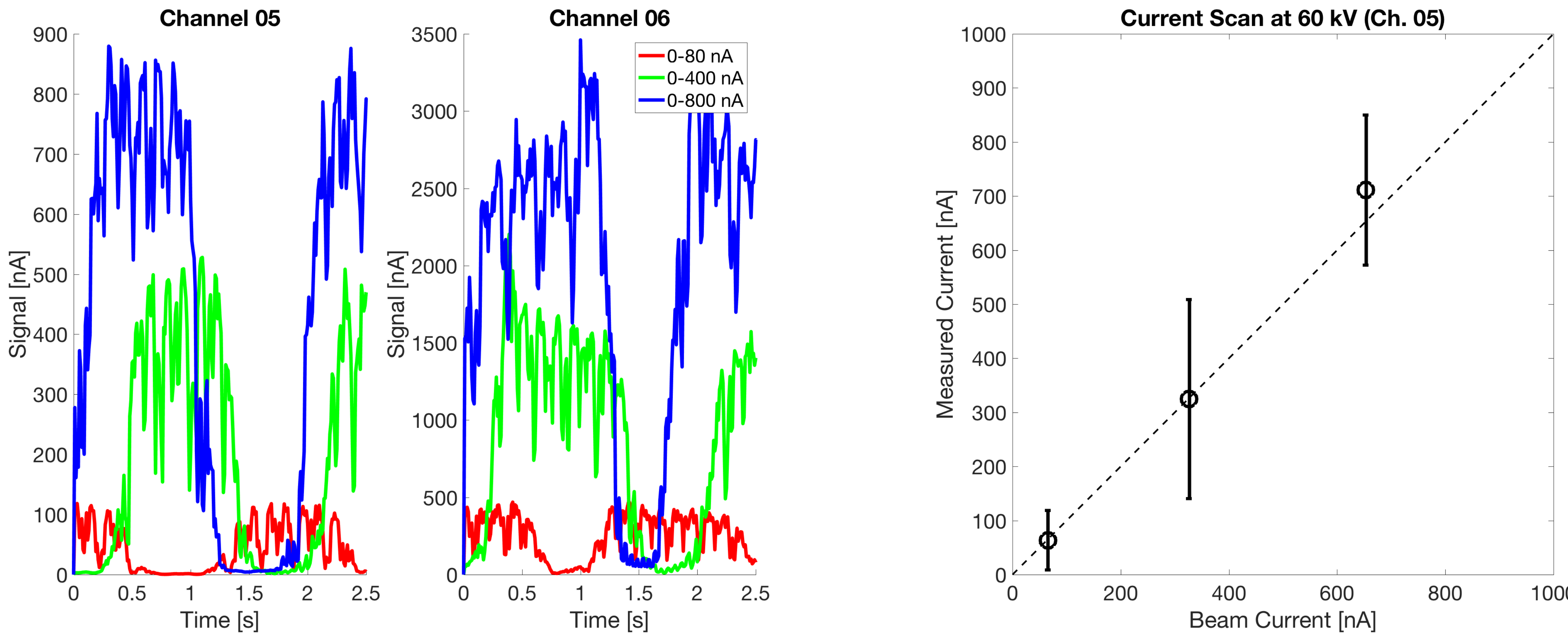
- Signal in sensor layers consistent with penetrated beam
- Signal in ground layer suggests secondary electron emission
- Maxima/minima as expected
- Cannot confirm energy discrimination at this time





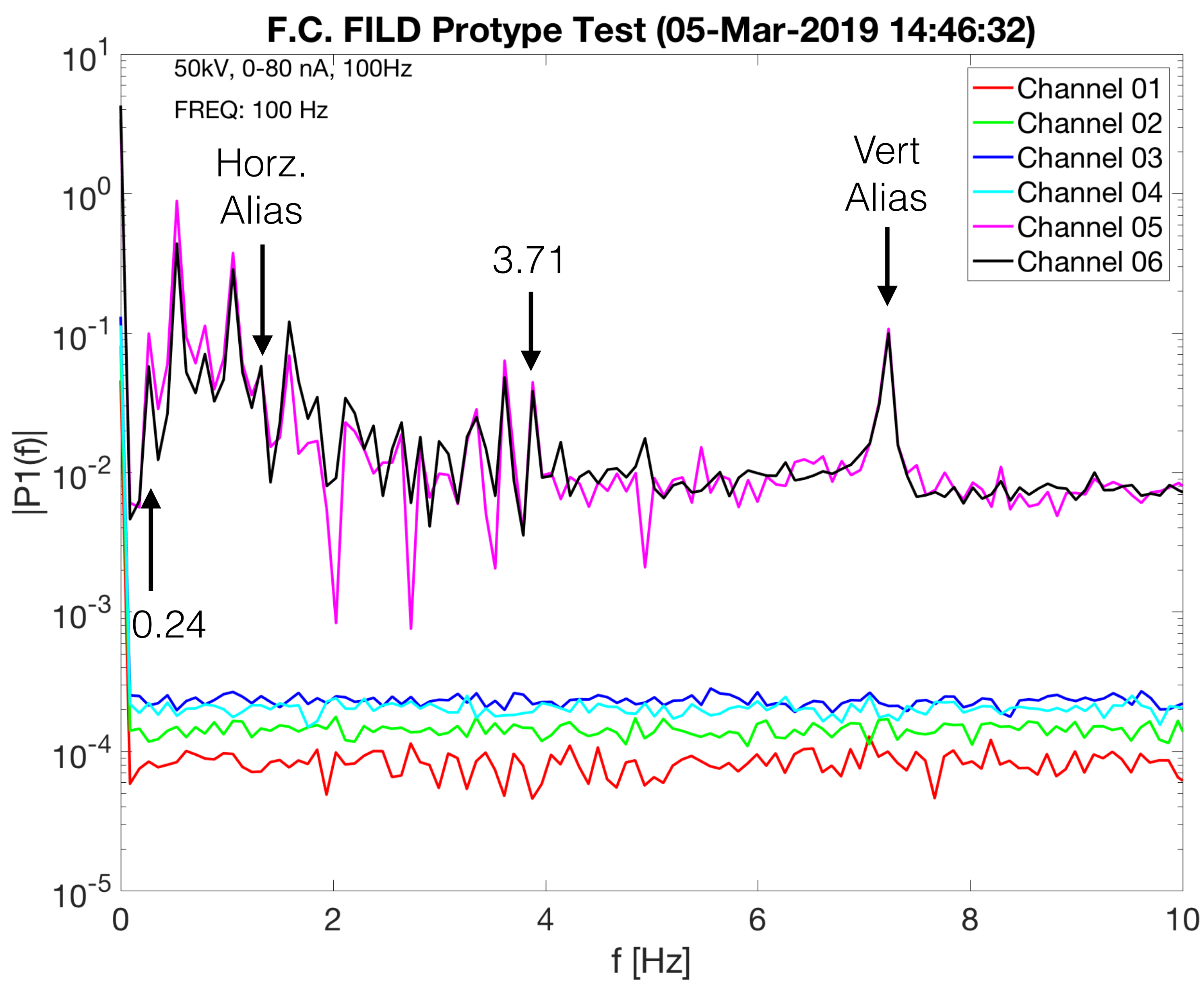
Signal scales with beam current

- Measured current agrees with RMS beam current
- Confirms calibration of amplifiers
- Confirms top layer measuring floating potential

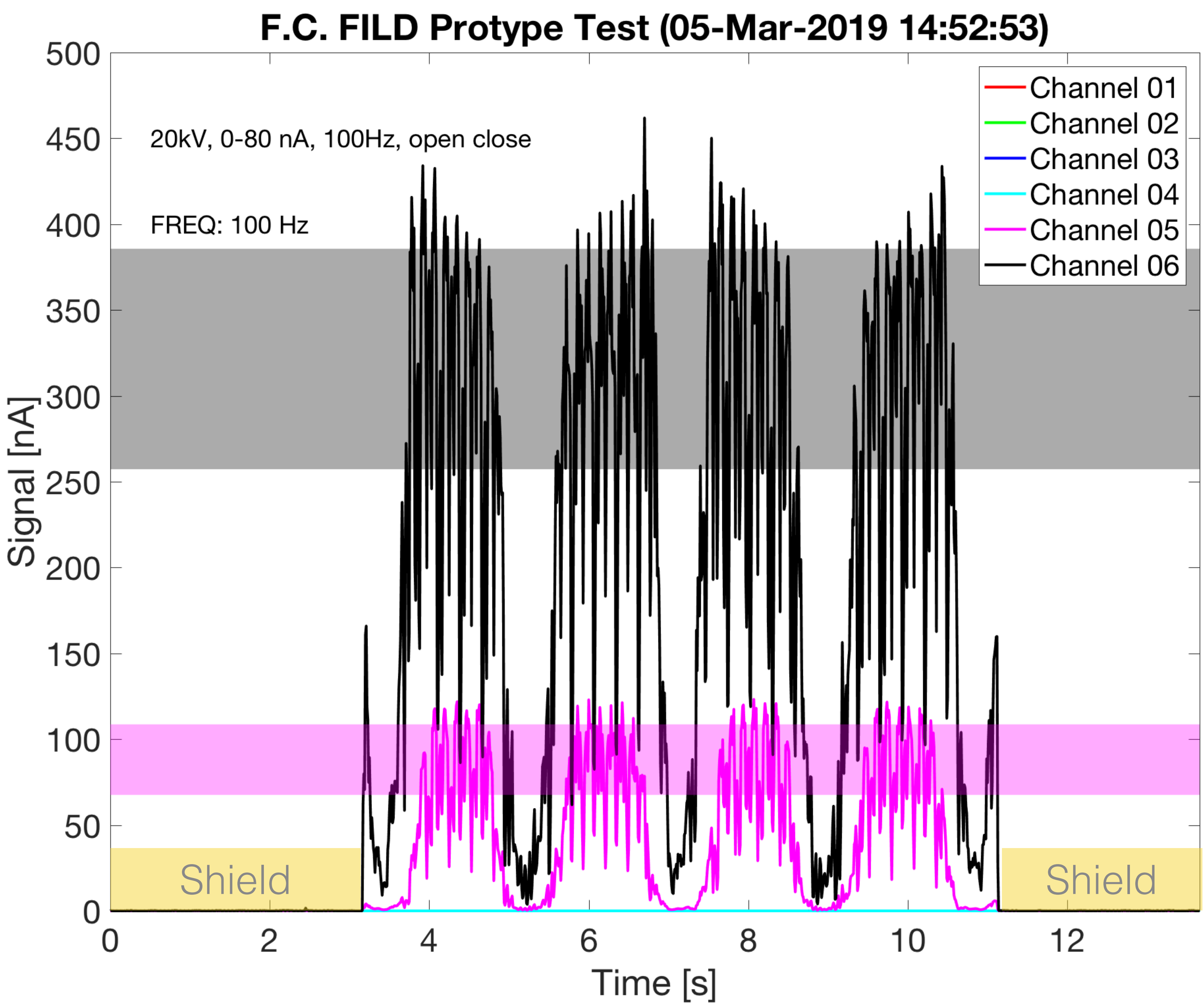


Frequency response clear

- Vertical raster: 3.71 Hz, Horizontal raster: 0.24 Hz
- Vertical Holes: 3, horizontal holes: 5
- Signals consistent with raster scan

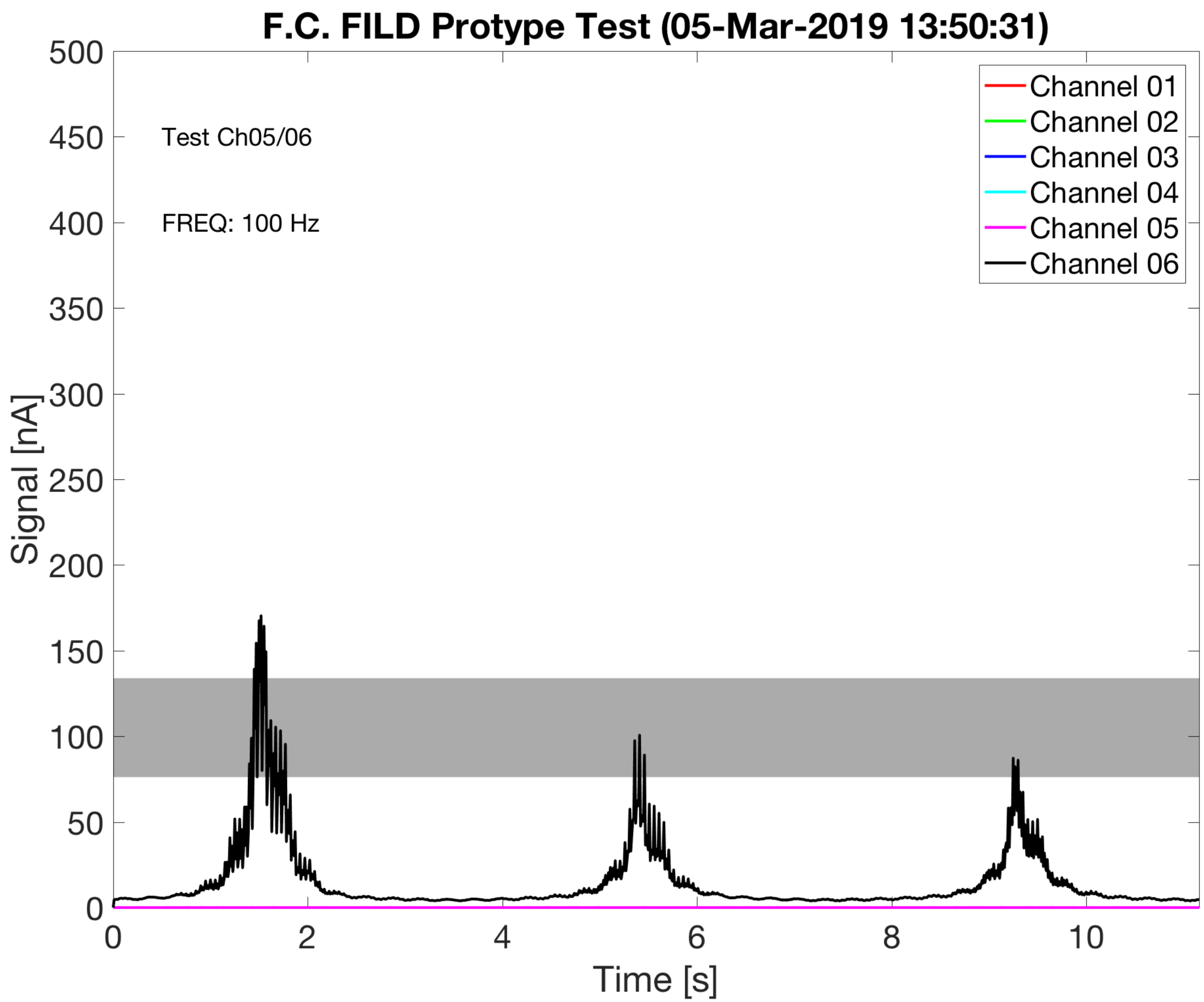


Shield used to chop signal



Surface channel measures non-beam parameters

Test data taken during setup of the beam with faraday shield in place (no beam)



The plan moving forward

- Partial sensor performs as expected
  - Signal levels consistent with beam current
  - Signal levels consistent with beam energy
  - Channel behavior consistent with expectations
- Future work
  - Development of new packaging for sensors
  - Packaging concept for OP2 prototype installation
  - Determination of locations for arrays