Sensor/IC Integration Using Oxide Bonding

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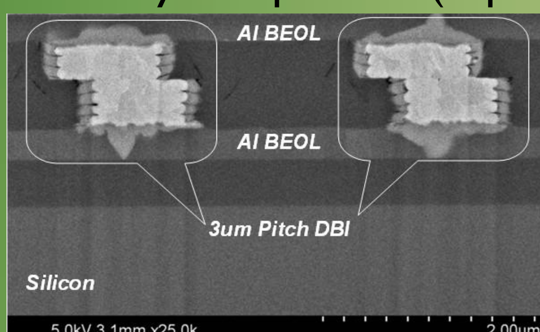
Introduction

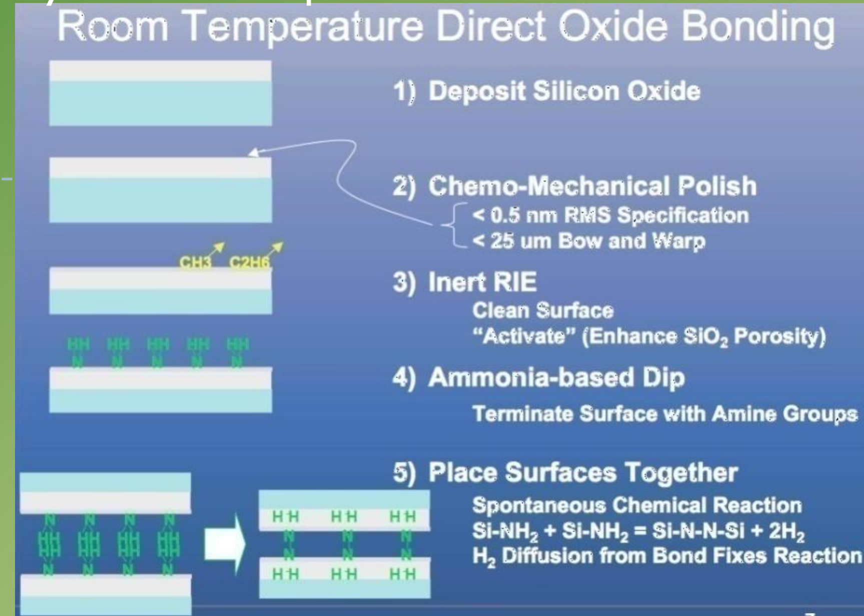
- Vendors with commercially available 3D processes:
  - Tezzaron – Cu-Cu thermo-compression for bonding;
  - Ziptronix- Direct Bond Interconnect;
  - Zycube – Adhesive and In-Au bump for bonding.
- Fermilab is working with Tezzaron to fabricate 3D ROIC (talk by Ronald Lipton).
- Fermilab is working with Ziptronix to demonstrate the DBI technology for particle physics sensor/ROIC integration:
  - ultimate goal – fine pitch (<25 μm) pixel arrays with a sensor tier integrated with one or more tiers of electronics with total thickness of less than 100 μm.

By Dr. Paul Enquist

DBI Technology

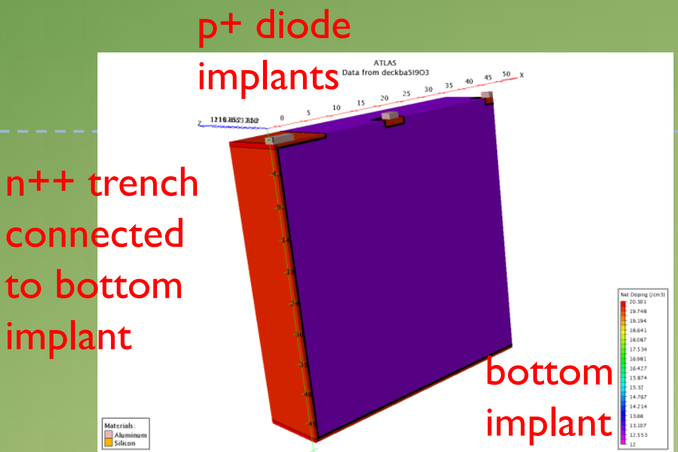
- Oxide bonding at room temperature.
- Metal connection by thermo-compression.
- Robust mechanical connection – sensor/IC can be ground and thinned after bonding.
- 3 μm pitch achieved.
- Die to wafer, wafer to wafer.
- ROICs can be placed onto sensor wafers with 10 μm gaps – pave the way towards thinned full coverage detector planes.
- Could be fairly inexpensive (esp. w2w).



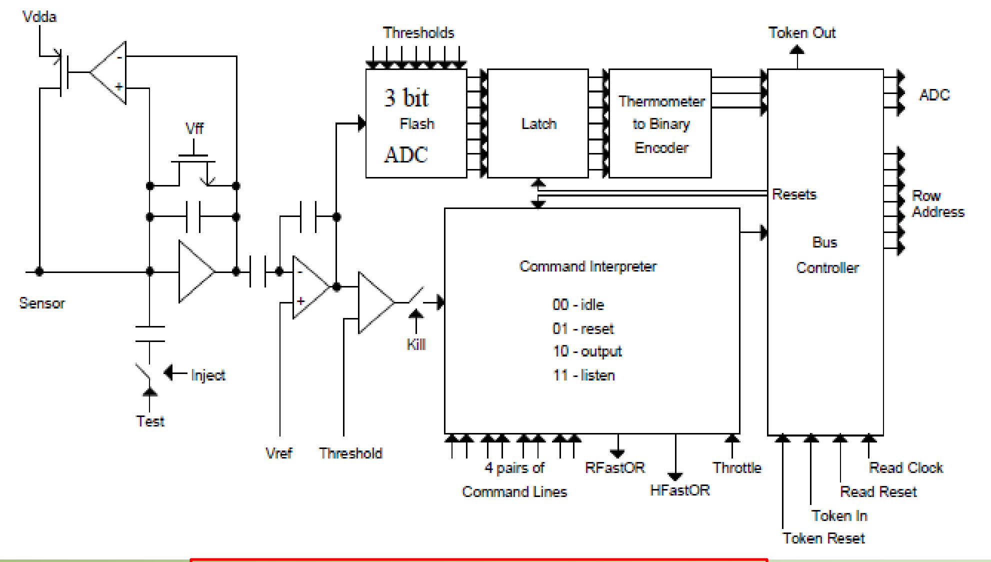


DBI Prototypes

- Edgeless trenched pixel sensors:
  - p+ diodes on n- bulk (ρ=5kΩ·cm);
  - 50 μm deep n++ trench at the edge:
    - can use it as a high quality detector edge;
    - can use it as an electrode – eliminating edge losses in tiling reticle-sized detectors.
  - masks designed at Fermilab;
  - fabricated by MIT-Lincoln Lab.
- BTeV FPIX2.1 readout chips:
  - 22x128 (C*R) pixel cells of 50x400 μm;
  - designed for e- signals (3 bits ADC), can work with small hole signals but Y/N only;
  - can inject test pulse to capacitor(~3.5fF);
  - debugging pads available for analog and digital output of the pixels in the last row.

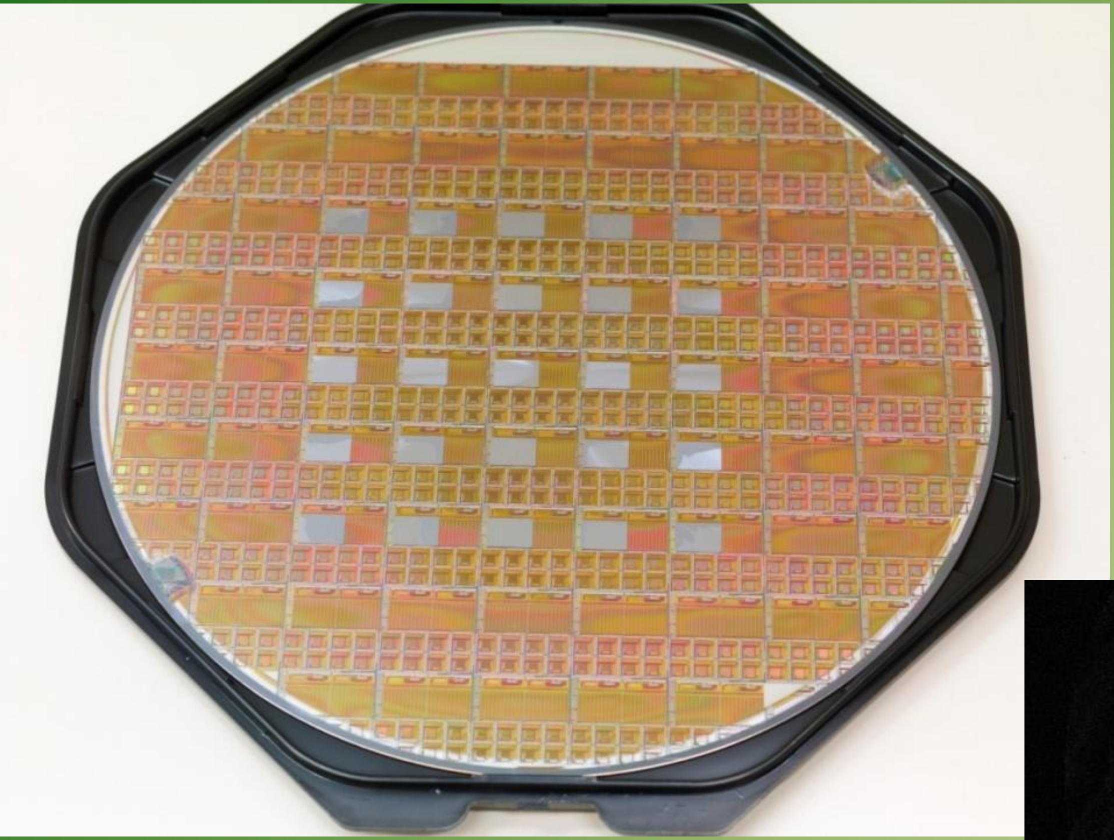


Sensor cross section near the edge



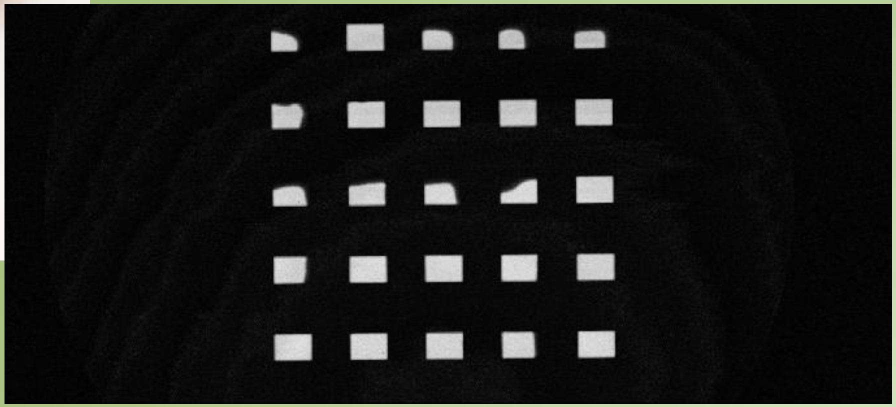
A FPIX2 Pixel Unit Cell

DBI Prototypes



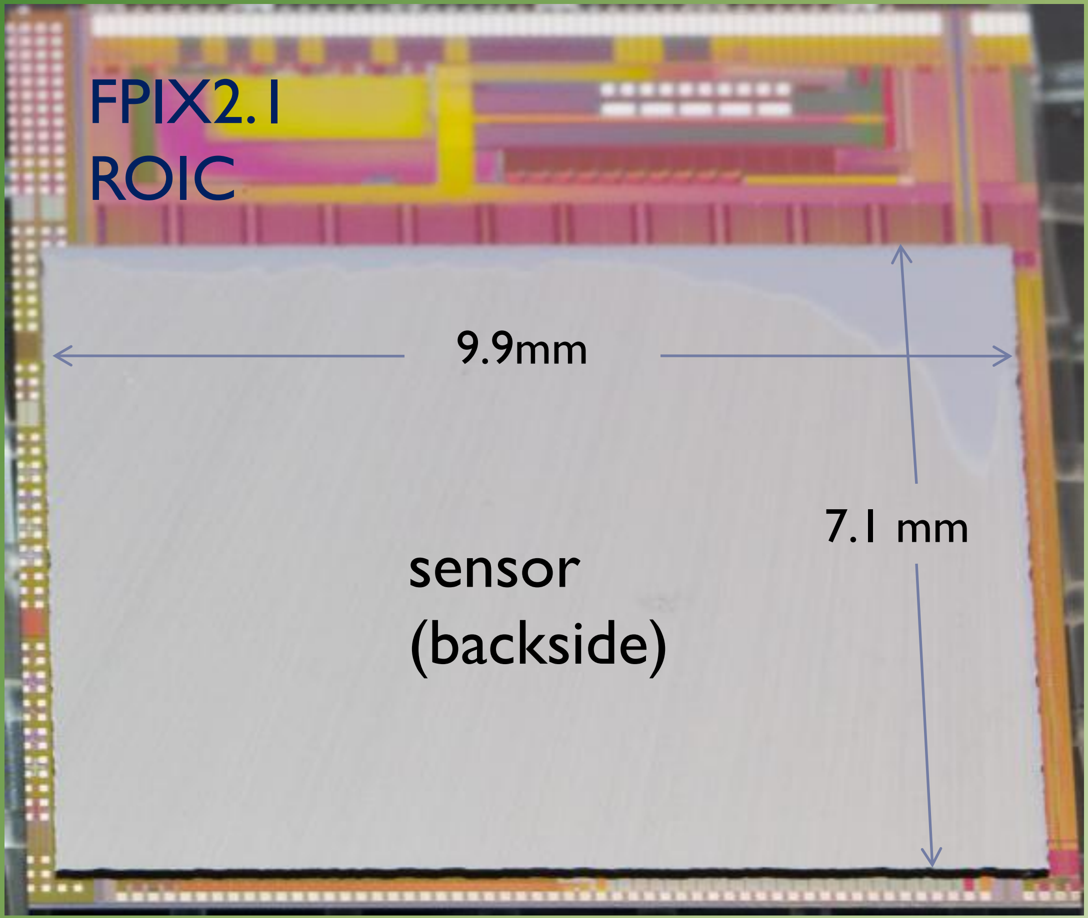
A DBI bonded FPIX wafer by Ziptronix

- 50 MIT_LL sensors DBI bonded to two FPIX wafers by Ziptronix.
- Sensors thinned to 100 μm after bonding, backside not implanted.
- 30 good devices in the end (16 with bond voids indicated by SAM. Normal yield is 80-90% if not dealing with a small number of wafers as us).



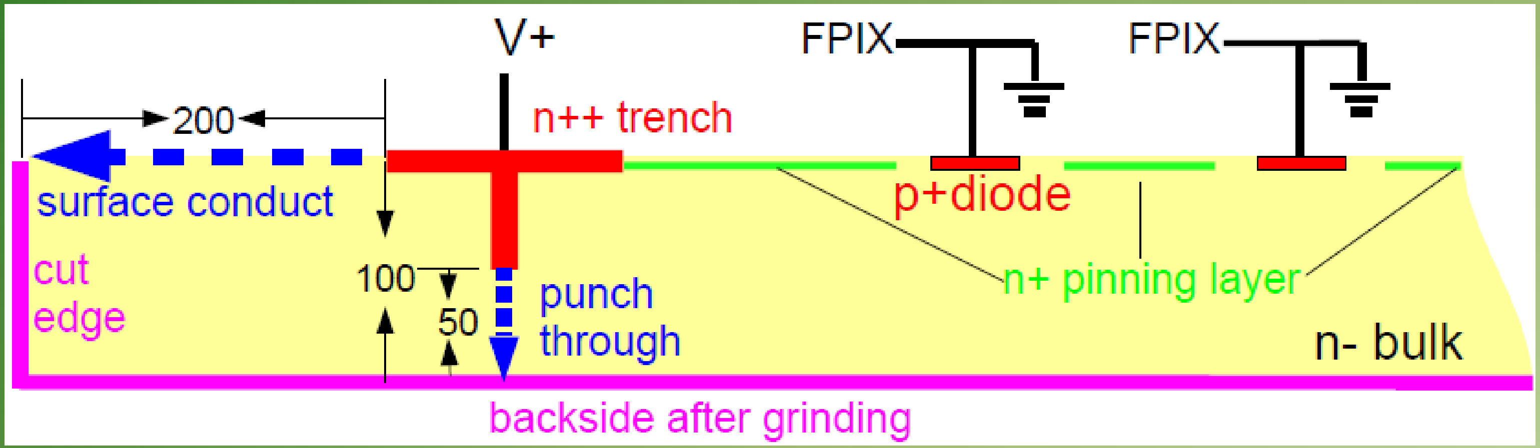
Scanning Acoustic Microscopy

DBI Prototypes



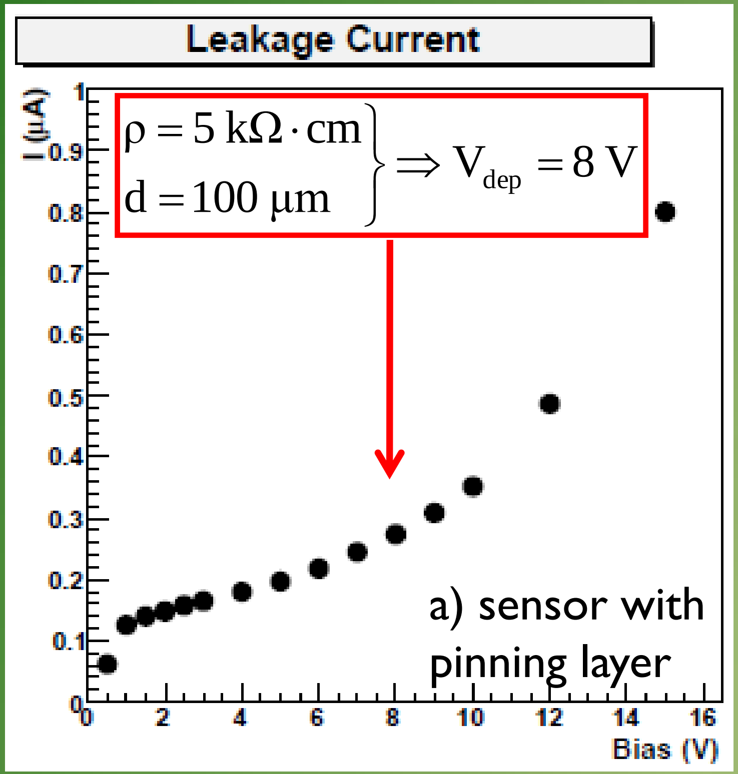
A integrated device after dicing

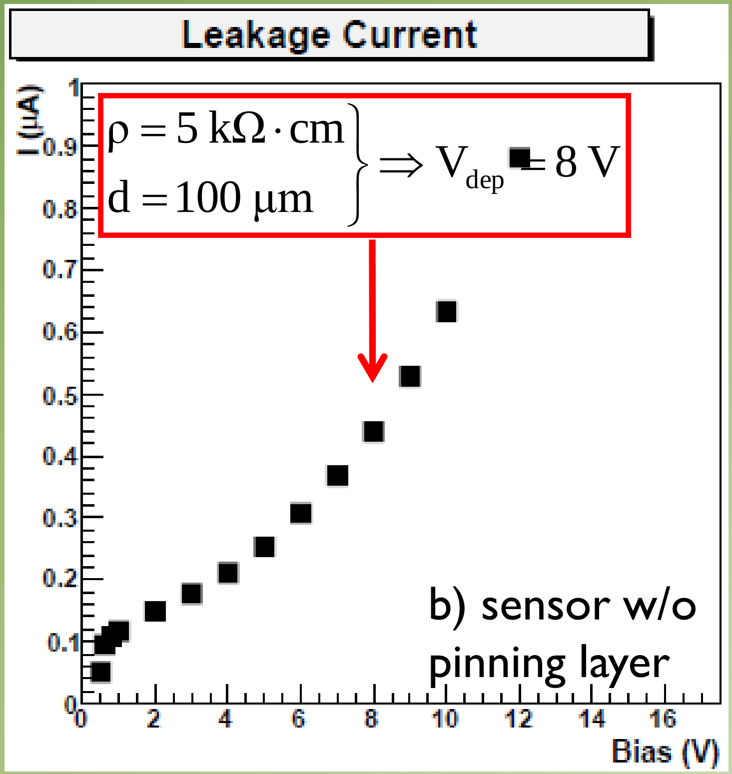
Sensor Bias Scheme



- Sensor bias scheme:
  - p+ diodes (DBI) connected to FPIX input at ground potential;
  - n++ trench (DBI) connected to positive potential through FPIX.
- The electrical connection from the trench to the ground surface of the backside might be either (a) along the surface and cut edge or (b) by punch-through 50 μm bulk.
- (optional) n+ pinning layer surrounding p+ diodes and entended to trench:
  - commonly used in optical devices to passivate the detector surface;
  - could act as a shield between the detector and ROIC.

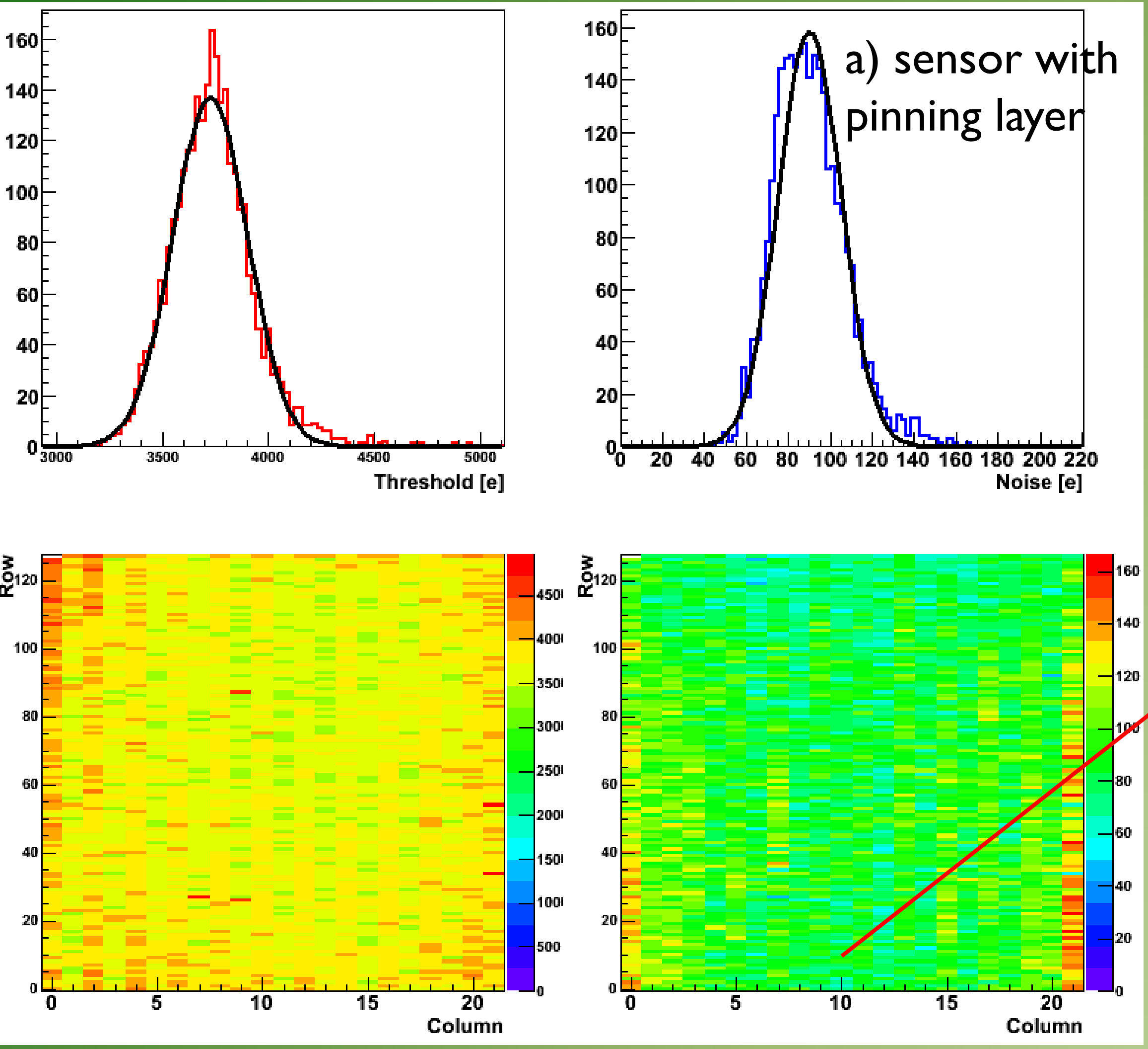
Leakage Current per Chip



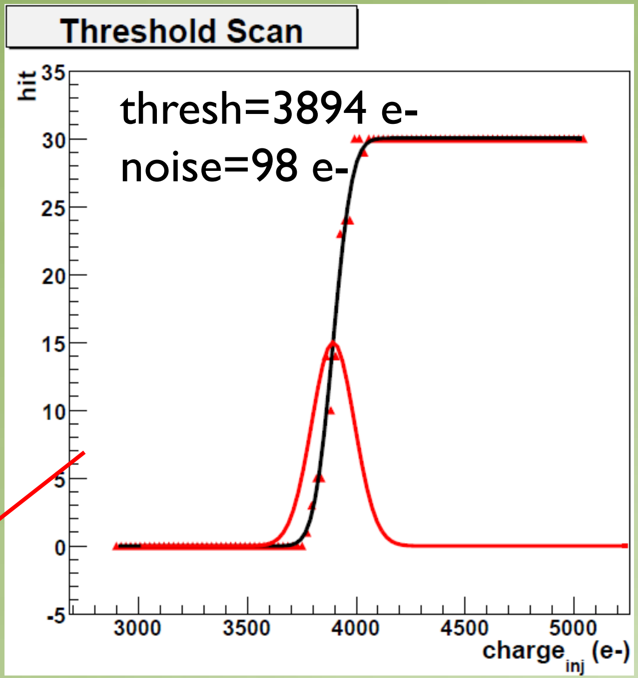


- The rapid increase of the leakage current beyond the full depletion voltage is due to the bare ground backside surface and the associated crystal damages.
- Have sent chips to Cornell to further thin the sensors down to 50 μm (include a fine grind process "near-CMP" quality), then backside implant and laser anneal.

Threshold Scan – (e-) Charge Injection

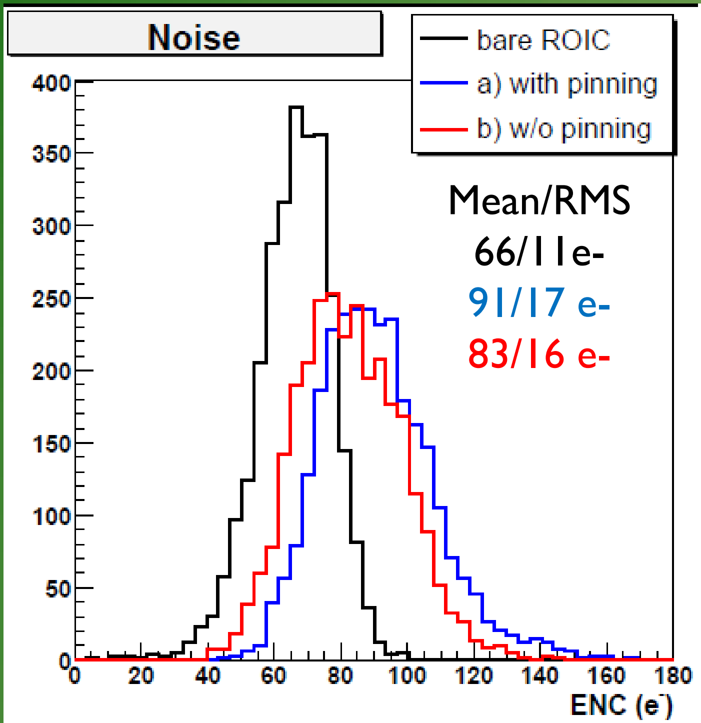


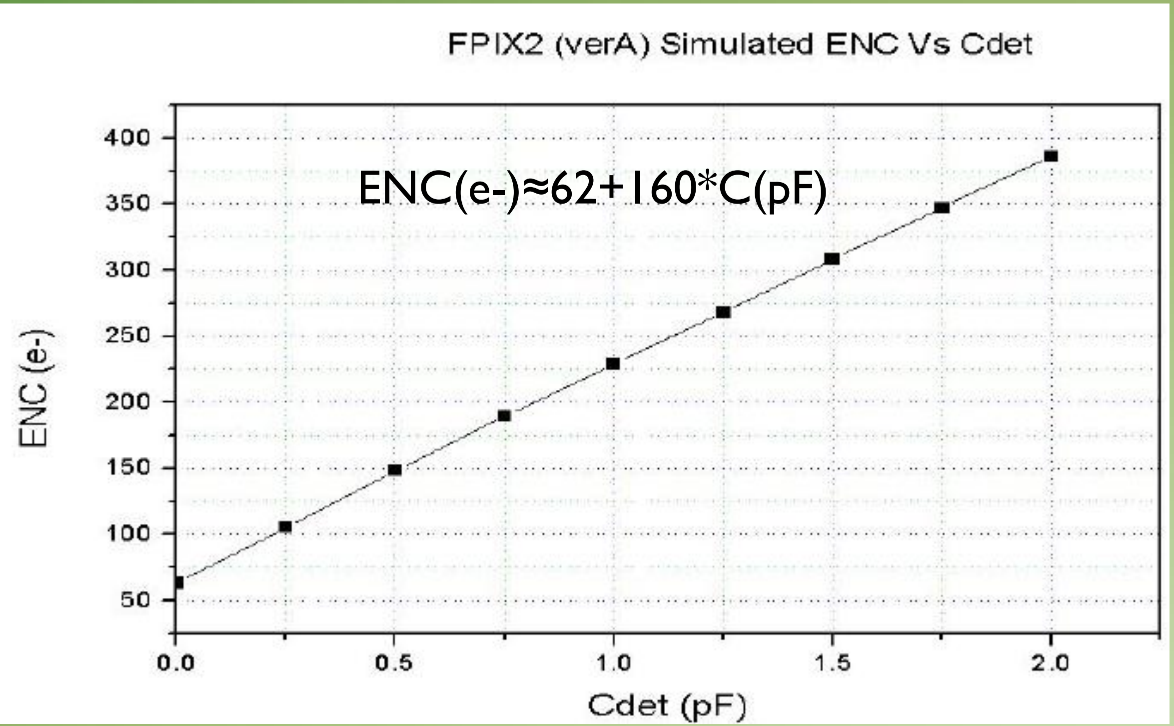
S-curve for pixel (10,10)



Conversion from the test pulse size to the number of electrons done assuming 3.5fF injection capacitors.

Sensor Input Capacitance to FPIX2.1



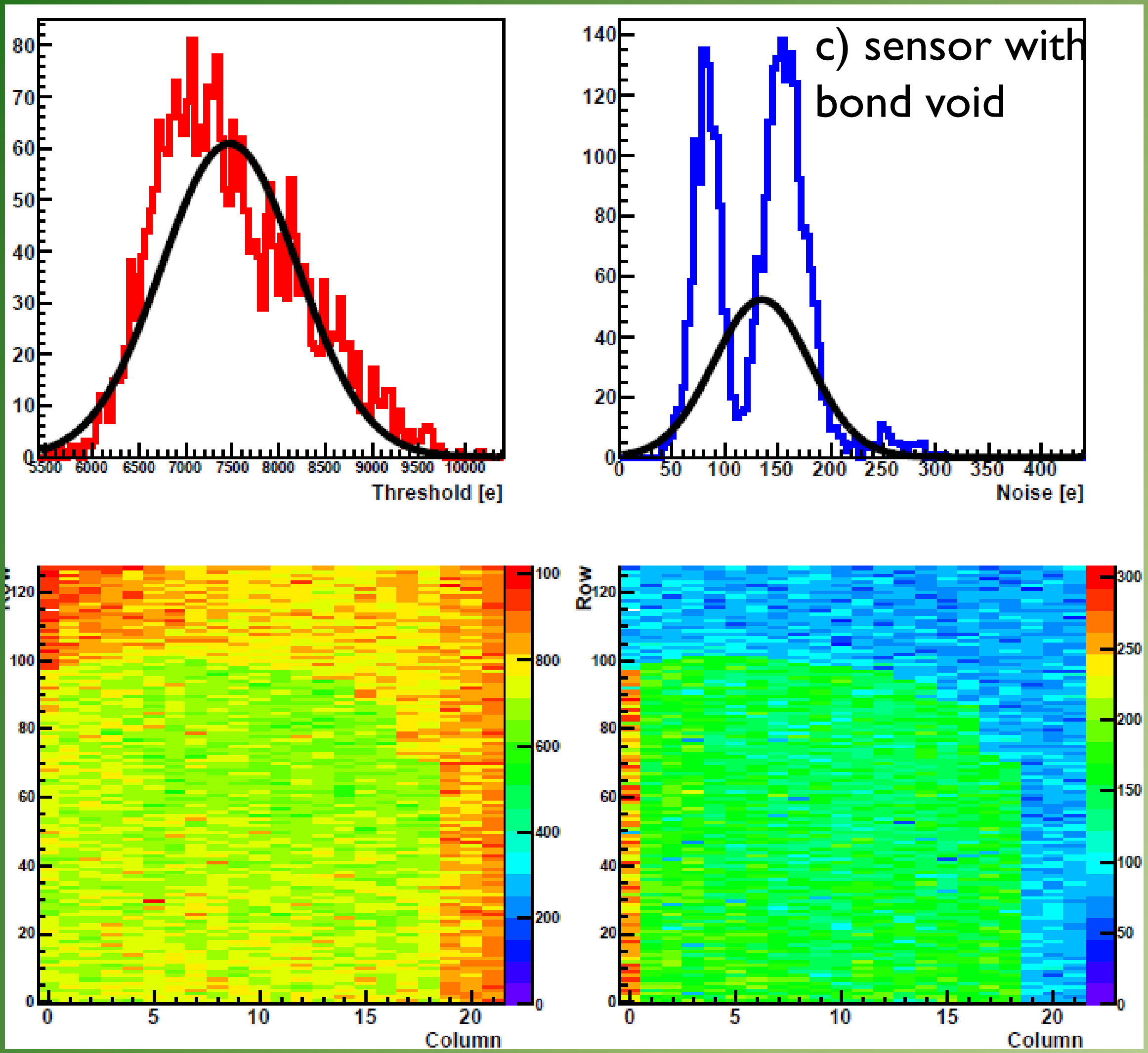


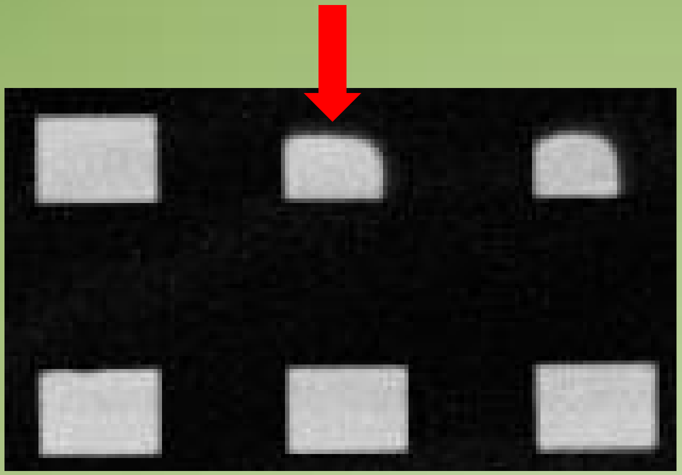
Conversion from the test pulse size to the number of electrons done assuming 3.5fF injection capacitors. Absolute calibration underway.

a) with pinning layer C=0.155 pF

b) w/o pinning layer C=0.106 pF

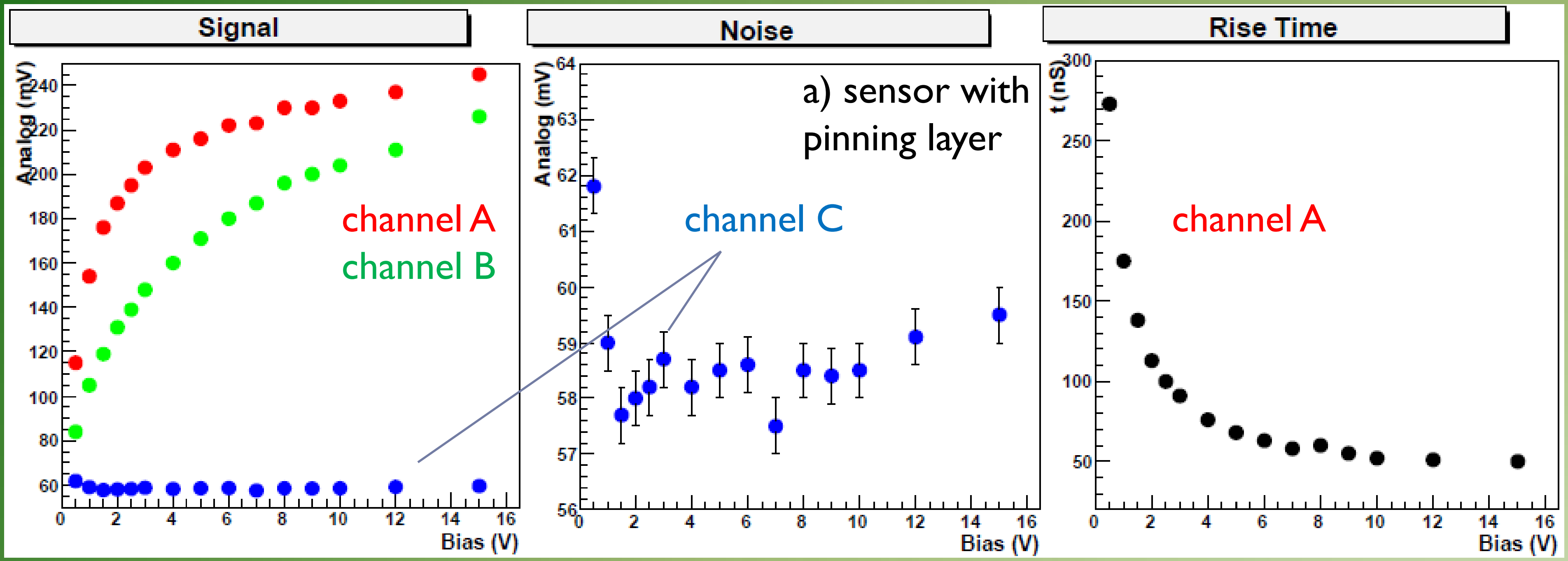
Threshold Scan – Sensor with Bond Void





Scanning Acoustic Microscopy

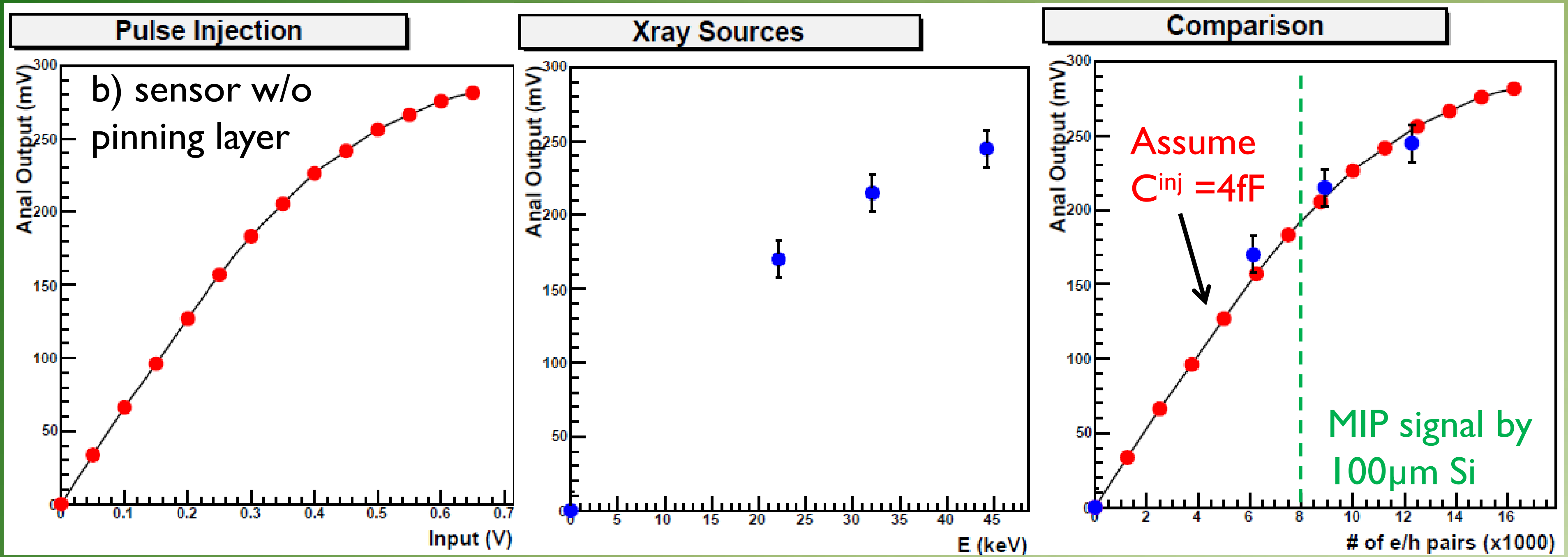
Analog Outputs Due to Laser (E=1.13eV)



Spot a laser on the sensor backside. Measure the analog outputs of two FPIX channels (A, B) close to the laser, and that of a channel (C) far way from the laser.

- ❑ Amplitude of Anal_Out of A and B increase versus bias – depletion volume increase.
- ❑ Amplitude of Anal_Out of C (interpreted as noise) decreases versus bias – input capacitance of the sensor to the FPIX pre-amplifiler decreases versus bias.
- ❑ Rise time of A decreases versus bias – drifting starts to dominate over diffusion.

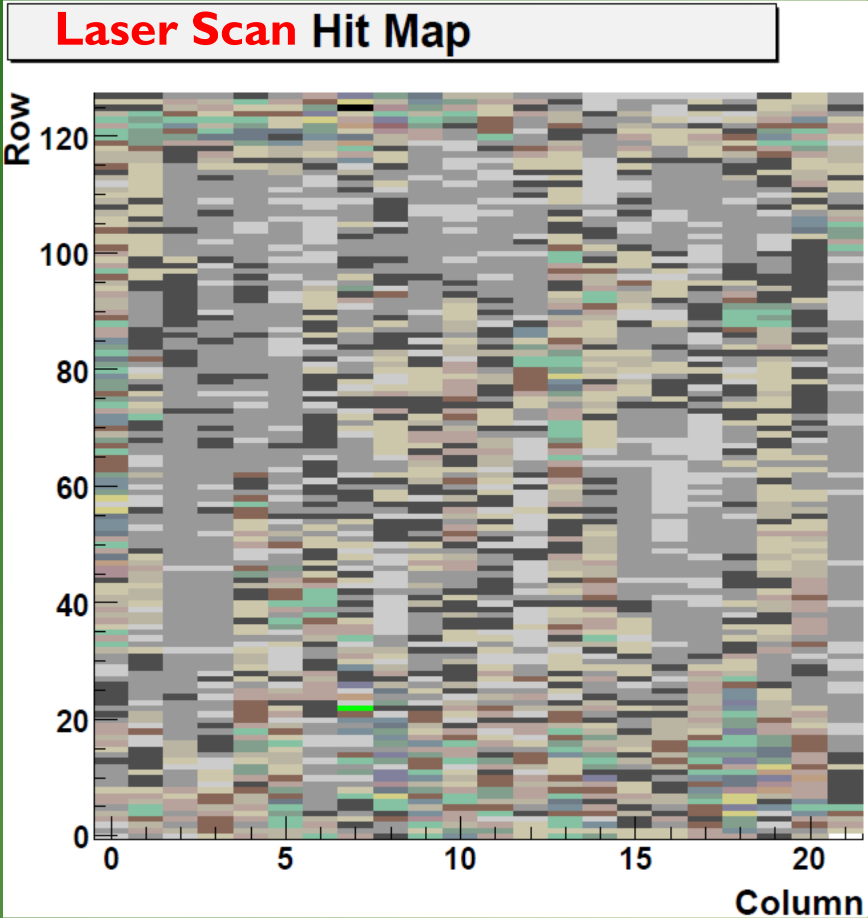
Absolute Calibration Using X-ray Sources

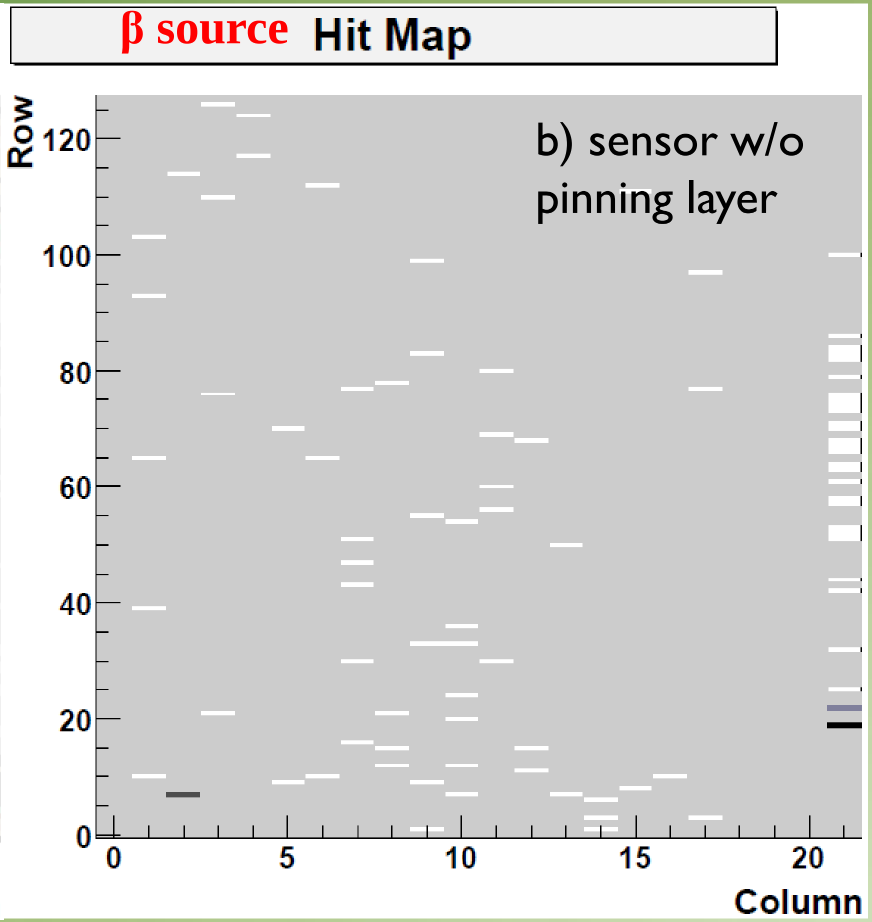


Use a variable X-ray source (metal films in front of Am-241) for absolute calibration:

- measure the (analog output) response curve by charge injection;
- measure (analog output) response to X-ray with different energies (22/32/44 keV);
- converting both of them to # of e/h pairs (to constrain injection capacitance C^{inj}).

Digital Outputs Due to Laser and β Source





We are able to see the digital outputs of most of the channels due to the laser and due to a β source (Sr-90).

Summary and Outlook

- We are trying to demonstrate the DBI technology as a replacement of bump bonding for particle physics pixel sensor/ROIC integration.
  - Low mass, fine pitch;
  - Sensor/ROIC thinning possible after bonding;
  - Available commercially, fairly inexpensive.
- First tests of DBI bonded prototypes very promising:
  - A extremely small number of interconnect failures (see most of the pixels by the laser scan):
  - Sensor input capacitances seem to be small.
- To-do
  - study the charge collection near/outside the trench,
  - study the charge collection within each pixel area

by (a well focused) laser and test beam.

Backup Slides Start Here

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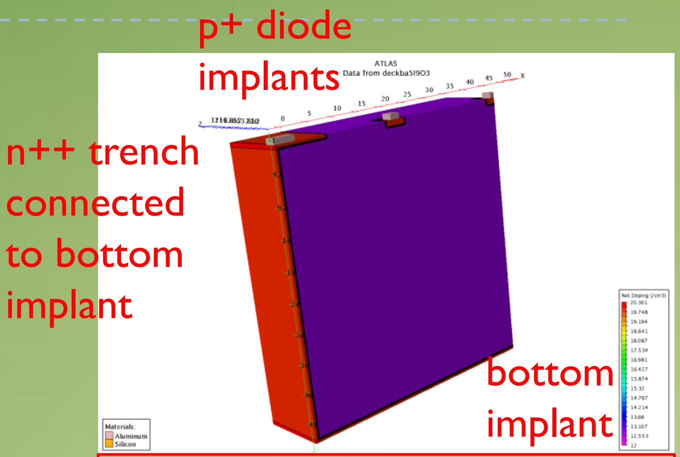

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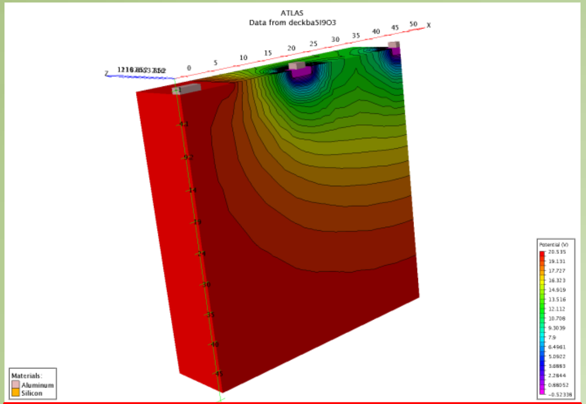
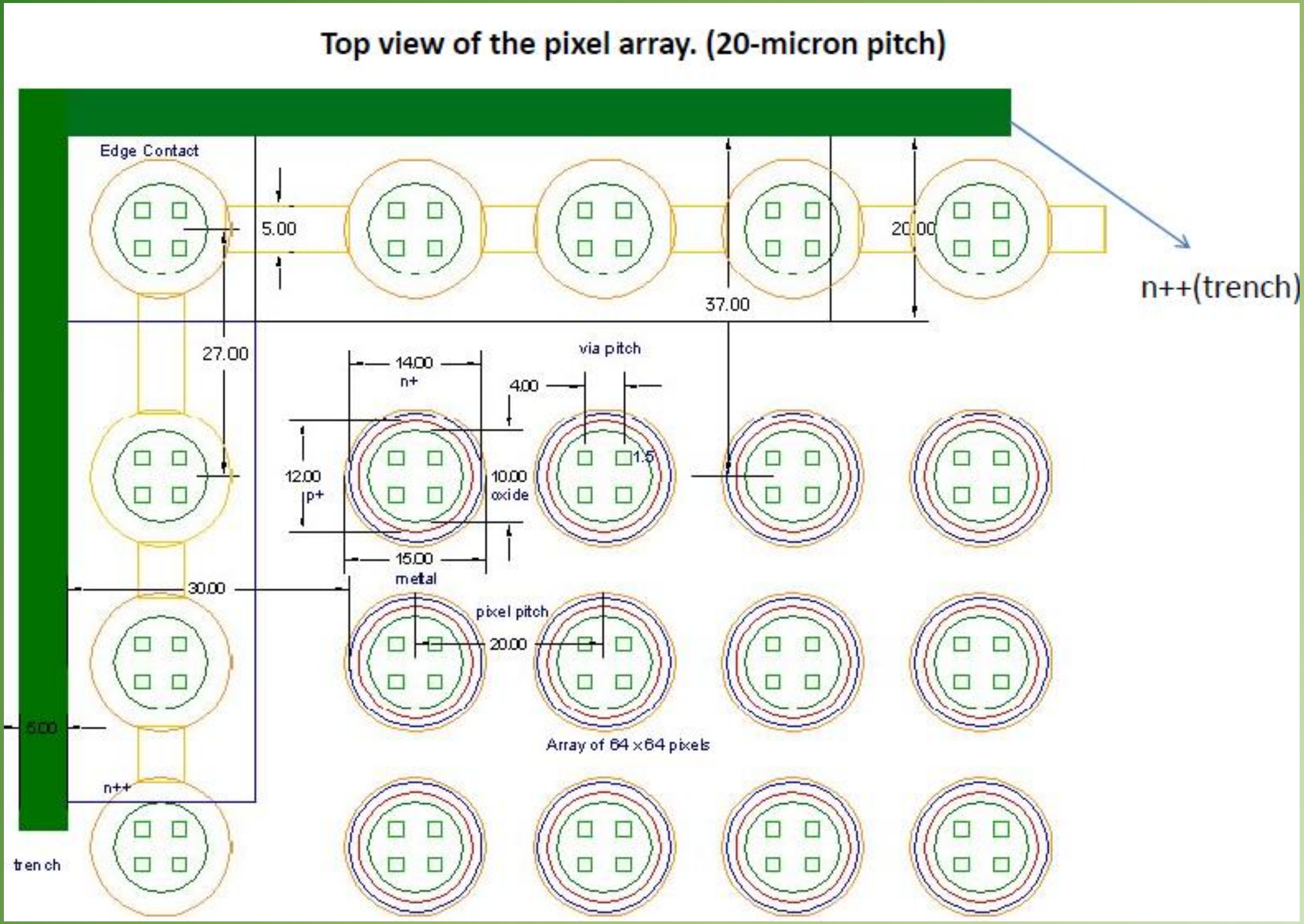
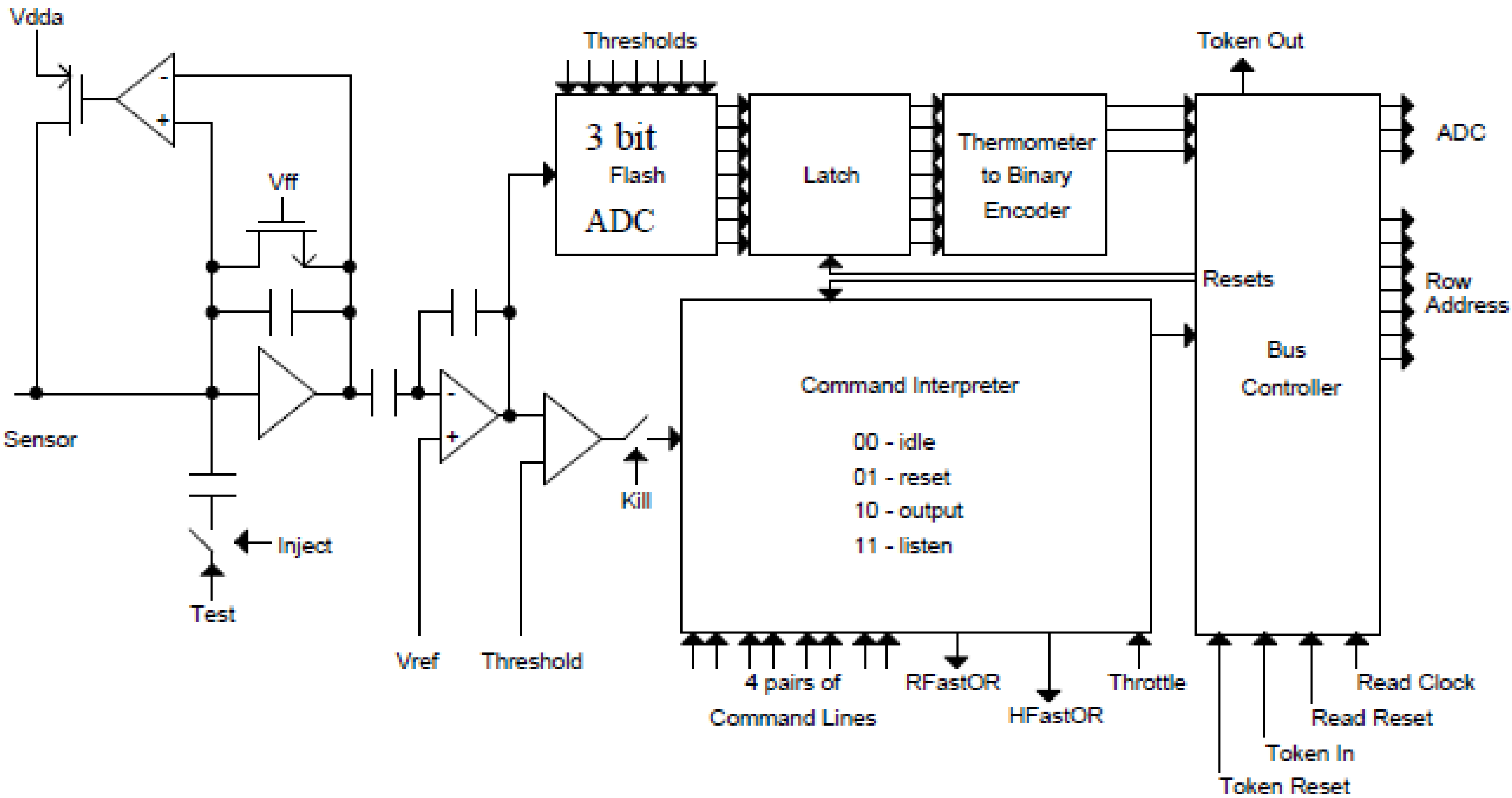


equipotential field lines

Edgeless Trenched Pixel Sensor



BTeV FPIX2.1 Readout Chips



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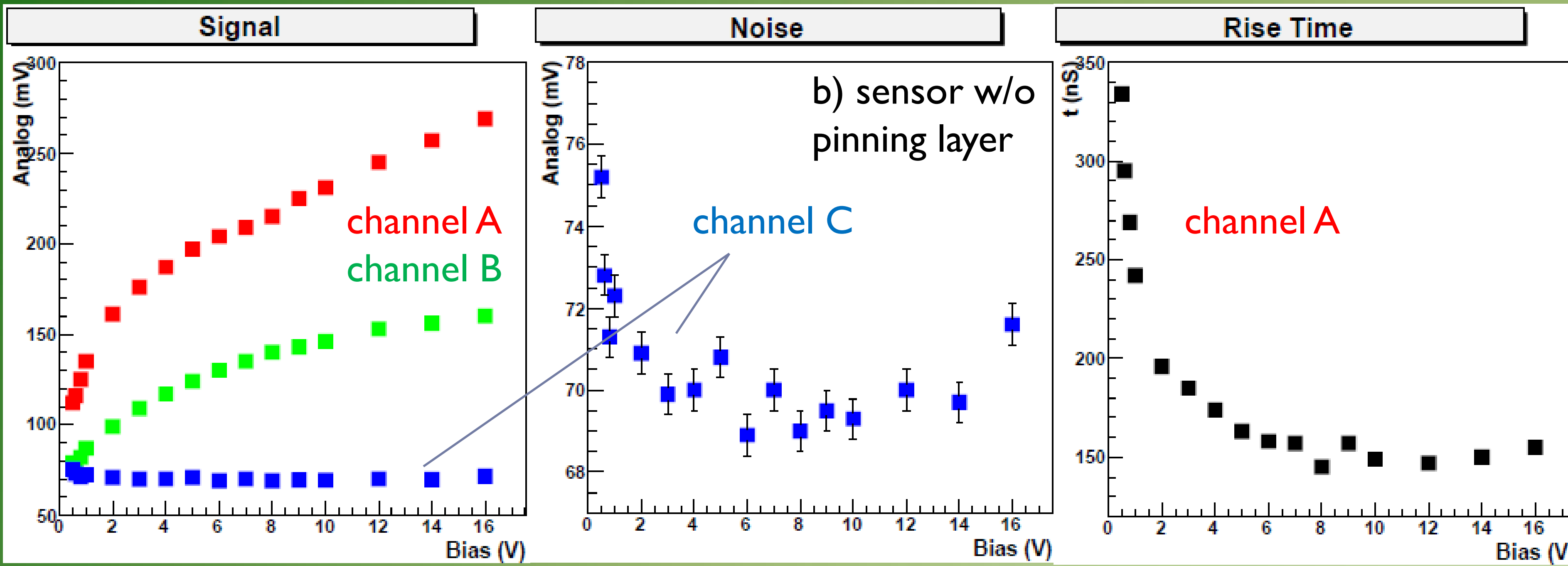

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