Thoughts on Future Silicon Detectors

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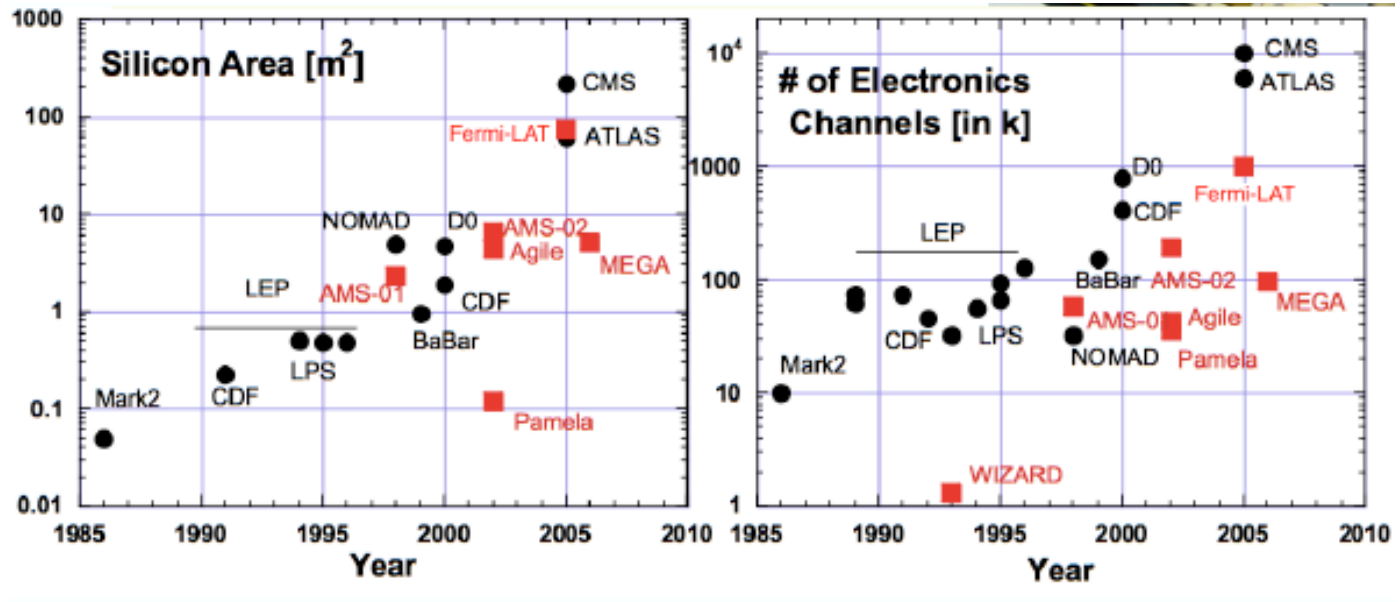
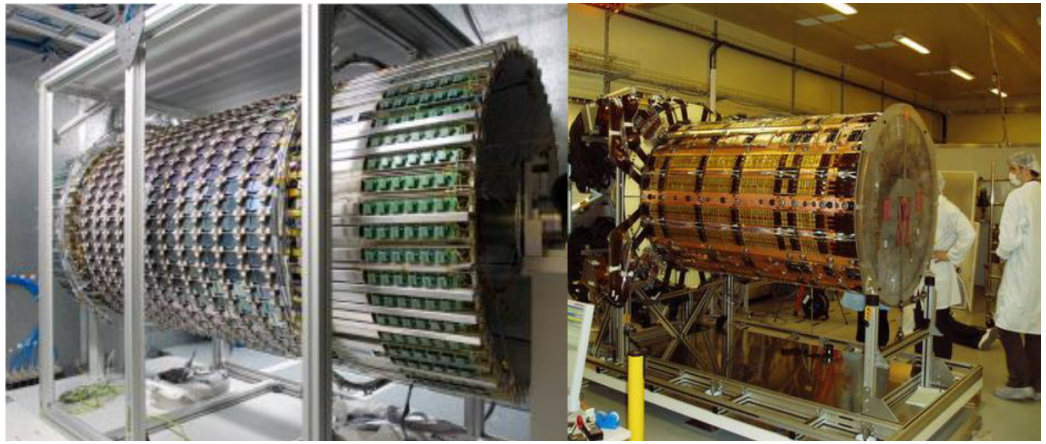
Motivation

Silicon detectors are a cornerstone of High Energy Physics

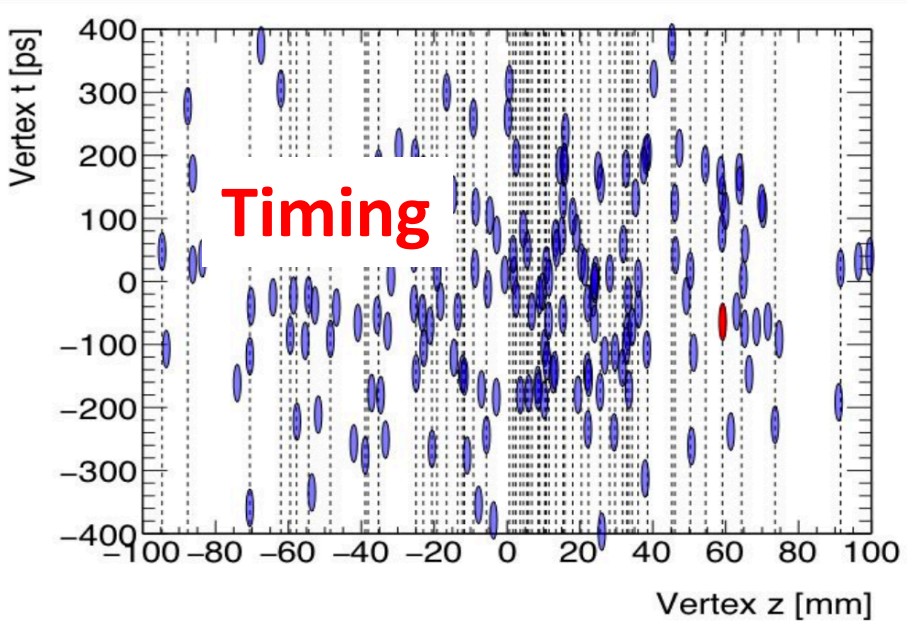
Larger fractions of detectors are made with silicon

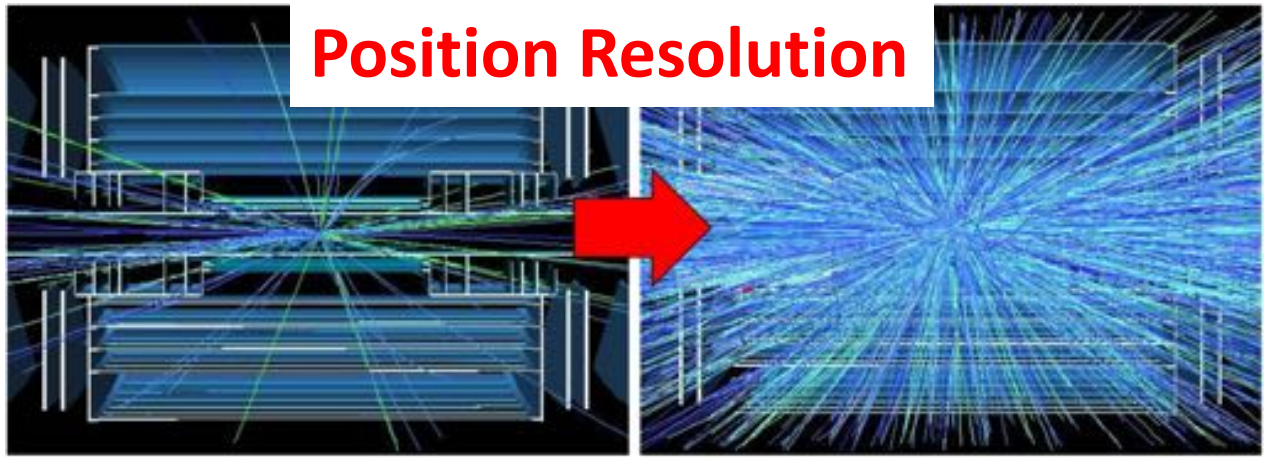
- Limiting factor is often the cost
- More layers for precise tracking
- shift toward high precision silicon calorimeters
- no reason not to make the entire detector out of silicon other than cost

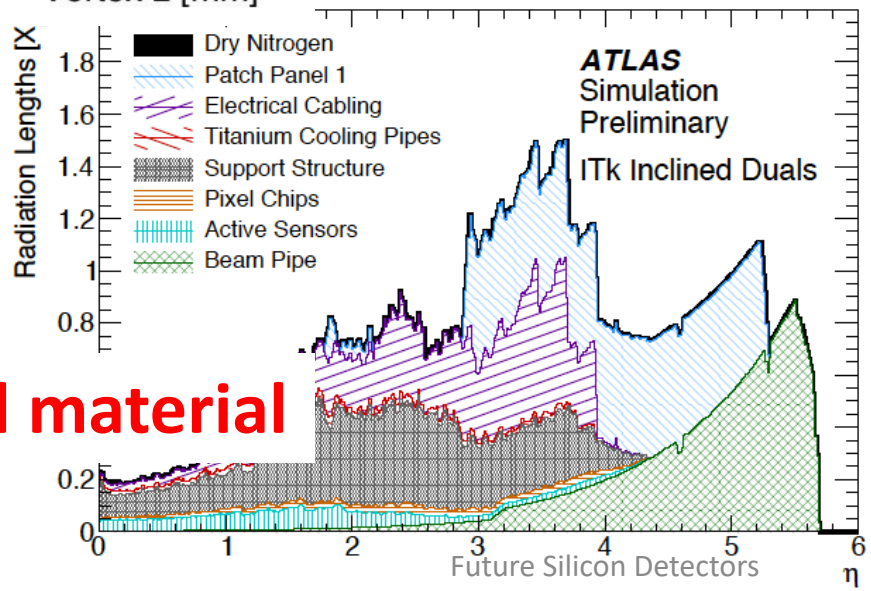


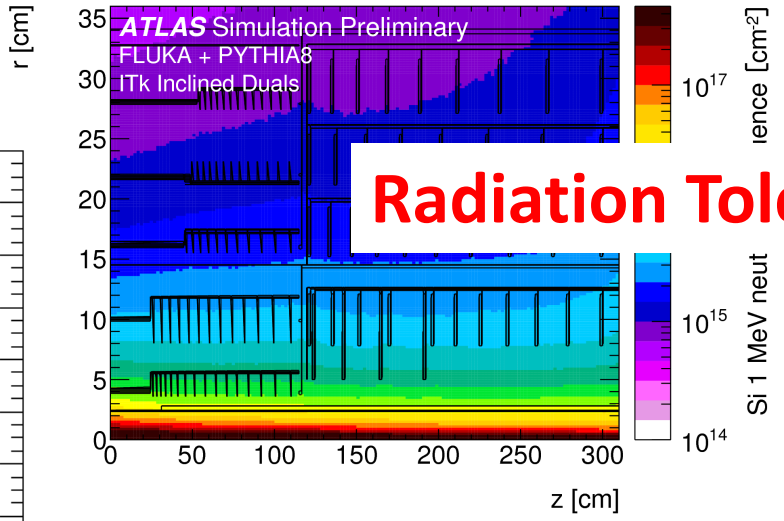


Challenges







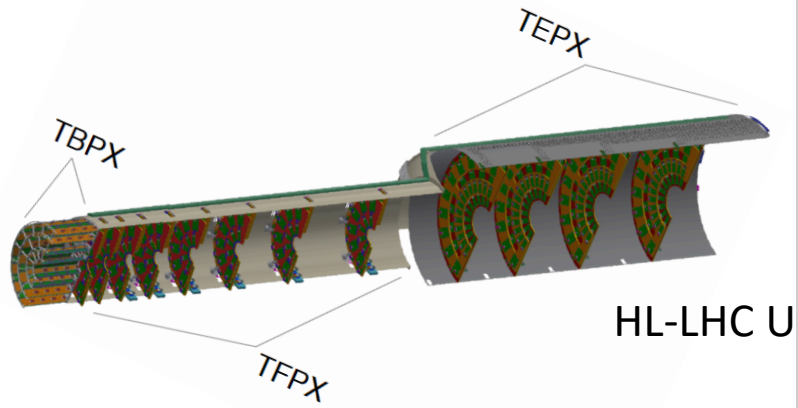


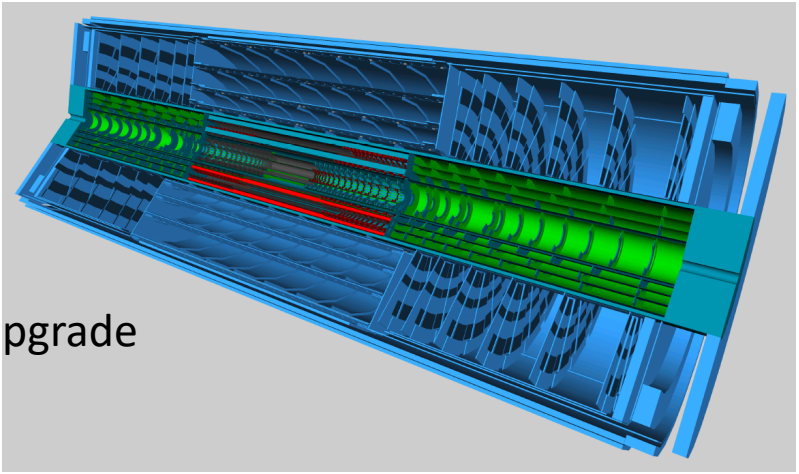
…Typical of large accelerator experiments

Synergies

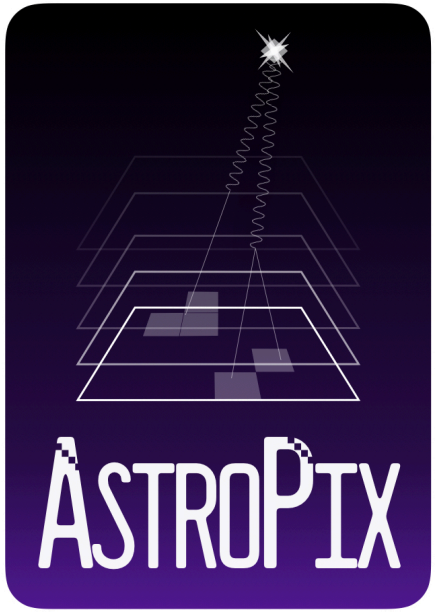
Work with other upcoming experiments

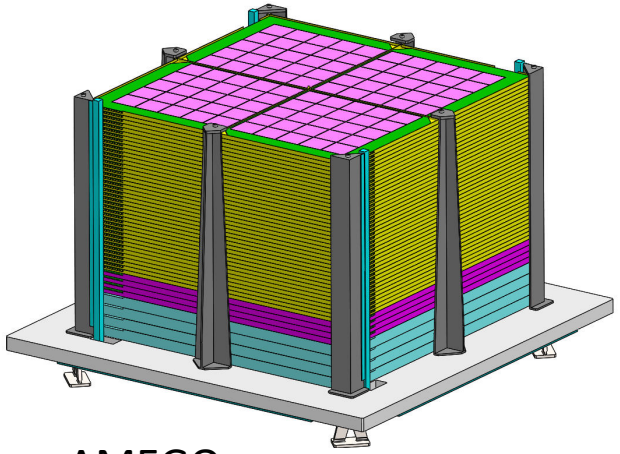
- Electron ion collider
- Neutrinoless double beta decay
- Gamma-ray telescopes in space
- ….





HL-LHC Upgrade





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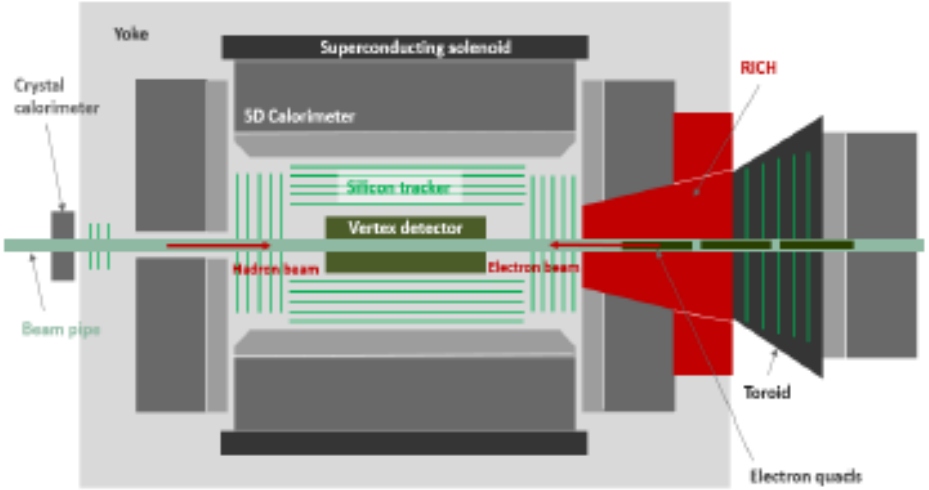


Goals

- Low Mass
- Low power
- High position resolution
- Fast timing resolution
- Monolithic
- Radiation Tolerance

- Energy resolution
- Energy range: signal/noise
  - Low electron energies

- Low cost

- Reduce services
- Reduce cooling needs

- All-in-one?
  - Fewer ‘sub-systems’
    - Reduce cost
    - Optimize resources

- Faster development cycle

How many features can we combine into one detector technology?

Current Snapshot

Existing Sensor Technologies

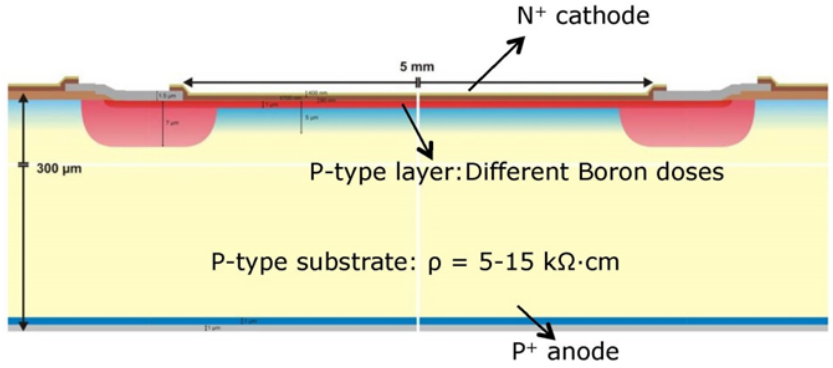
- LGAD's (presented last time) –pad sizes: mm, cm
  - AC LGAD's ~10 um pixels
- Monolithic detectors
  - MAPS (diffusion), slow
  - Monolithic CMOS (SiGe) (drift)
  - ns collection times HL-LHC
  - Low power/low mass (low occupancy)
- Diamond detectors
- 3D sensors

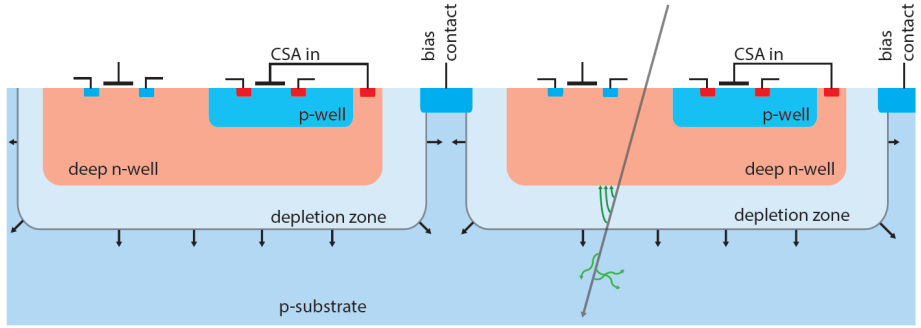
New technologies that could combine multiple features

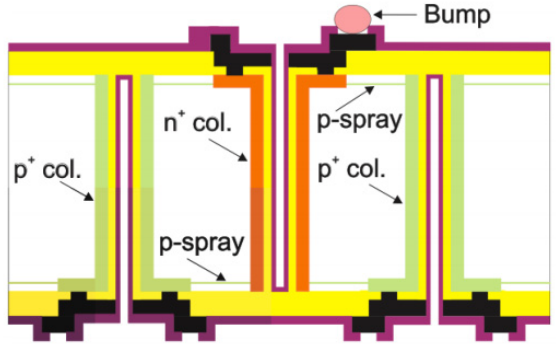
- => monolithic LGAD's?
- Thin Film Detectors?
- Low power electronics

Not silicon but…

- Services integrated into carbon fiber structures



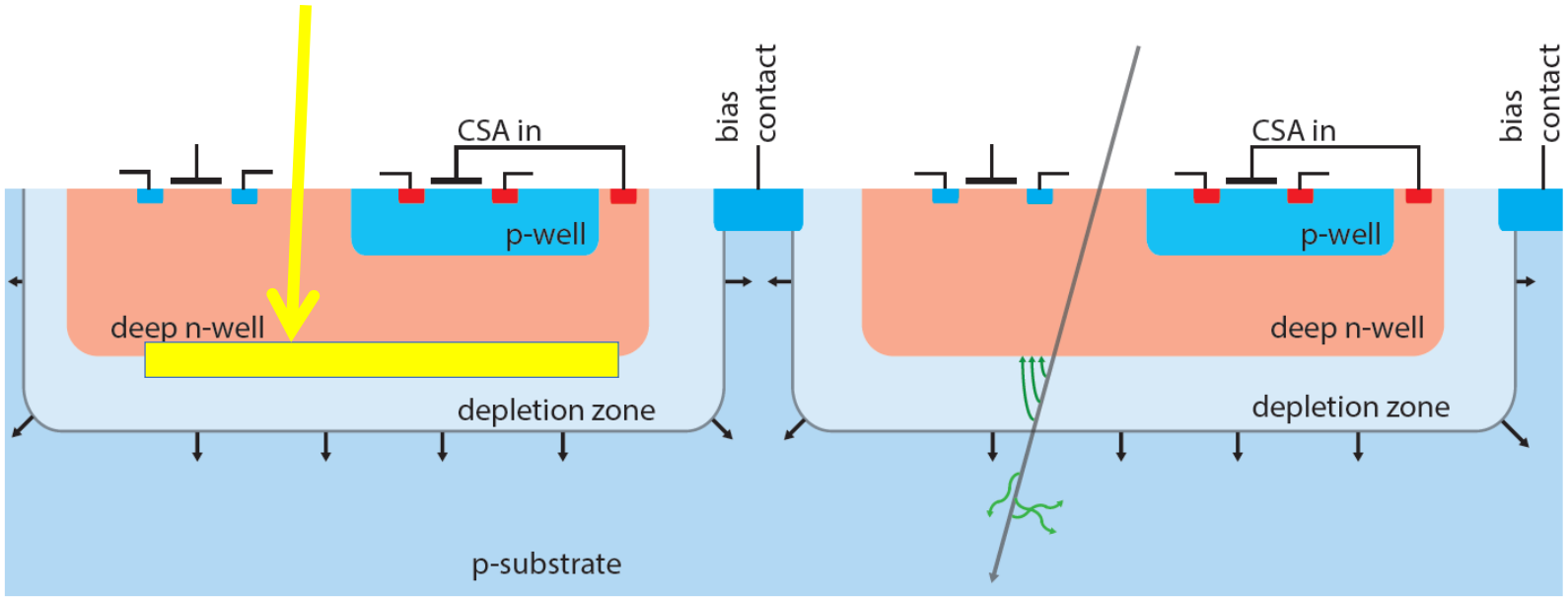




Monolithic LGAD

Modify HVCMOS/MAPS design to increase timing resolution
- incorporate amplification region characteristic of the LGAD sensors
- Manipulate geometries: thinner sensors, collection wells, applied bias, etc.
- 5 - 10 years to develop

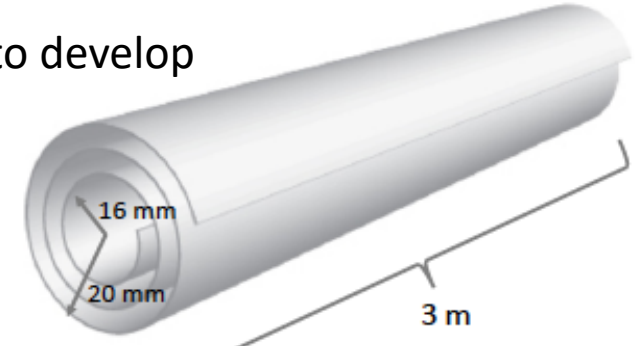
Add a gain layer similar to LGAD

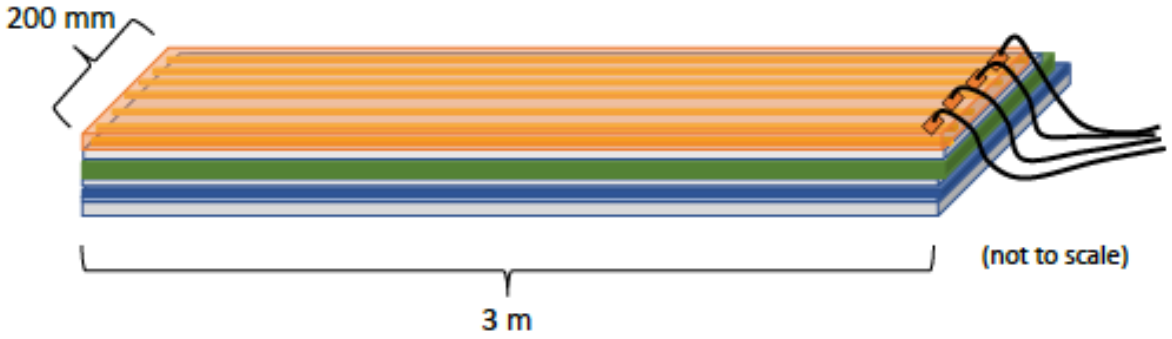


Potential Pro's:
- Low Mass
- Low power
- High position resolution
- Fast timing resolution
- Monolithic
- Radiation Tolerance
- Energy resolution
- Energy range: signal/noise
  - Low electron energies
- Low cost
- ~3 month fabrication
- Reduced cost?

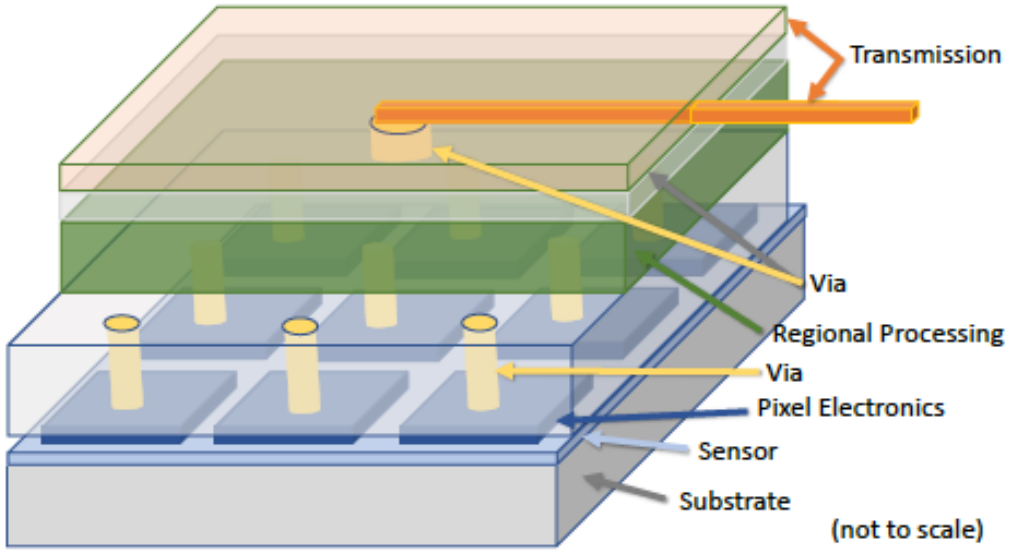
Thin Film Detectors

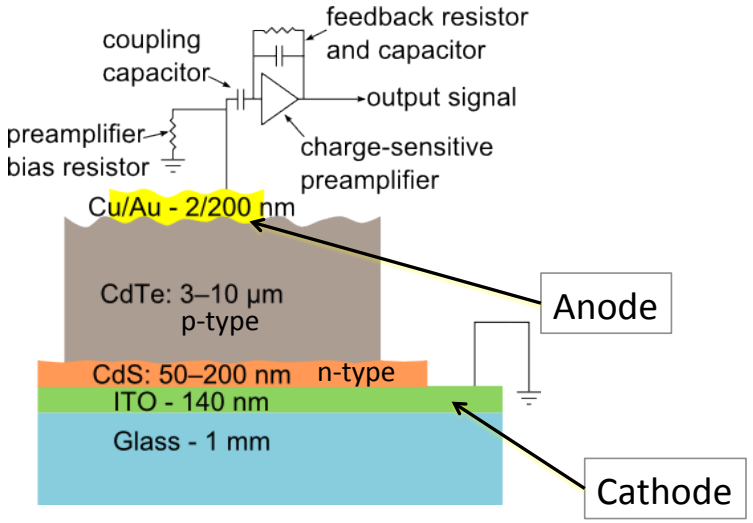
- Consider thin film deposition techniques
  - Potential to be large area low cost like LCD screens
- Options for many different semi-conductor materials
- Potential for monolithic integration of sensor + electronics
- Possible flexible substrates
- < 1% X/X_0
- 10 – 20 years to develop





J. Metcalfe et al. Potential of Thin Films for use in Charged Particle Tracking Detectors. arXiv1411.1794, 2014.



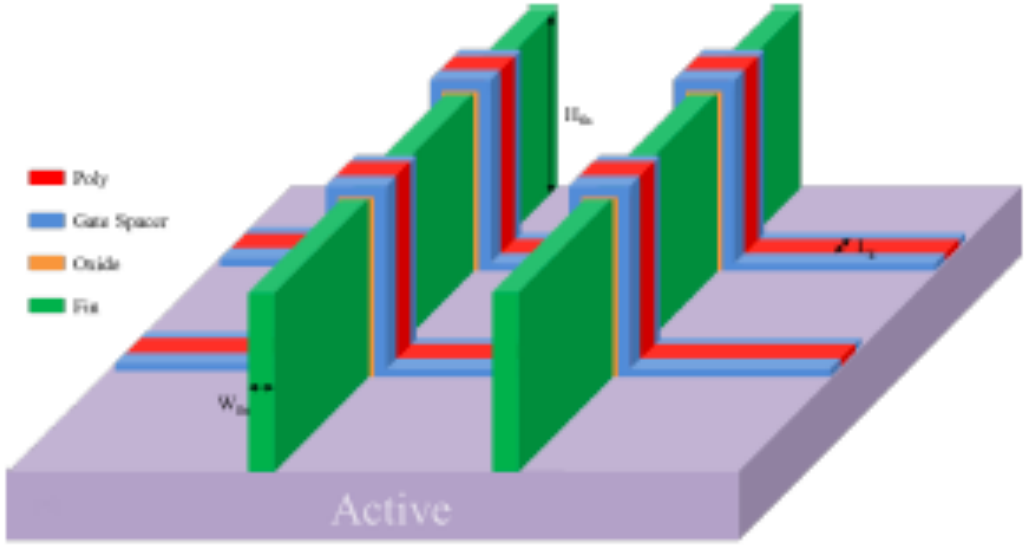


Low Power Electronics

- FinFETs
  - ~30% less power than CMOS
  - Faster switching times
  - Energy harvesting interfaces
    - ‘self-powering’
    - Can we take advantage?

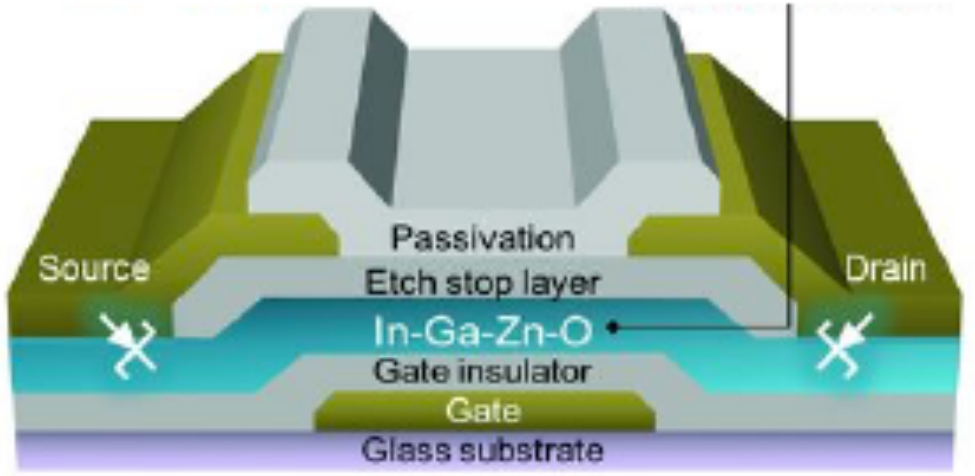
- TFTs
  - High gains > 400
  - Low power < 1 nW
  - Potential integration in thin film detector

FinFETs



Katrine Lundager, Behzad Zeinali, Mohammad Tohidi, Jens K. Madsen, and Farshad Moradi. Low Power Design for Future Wearable and Implantable Devices. *J. Low Power Electron. Appl*, 6(64):20, 2016.

Thin Film Transistors (TFTs)



Sungsik Lee and Arokia Nathan. Subthreshold Schottky-barrier thin-film transistors with ultralow power and high intrinsic gain. *Science*, 354(6310):302–304, 2016.

Summary

- Trend toward larger area, more channels, fast timing, etc.
- Indication that we can combine many of the best features into one technology
- Cost should also be considered
- My favorite blue sky technologies:
  - Monolithic LGAD
  - Thin Film Detector
  - Extreme low power electronics