4D/5D technology for future trackers – Simone Mazza (UCSC)

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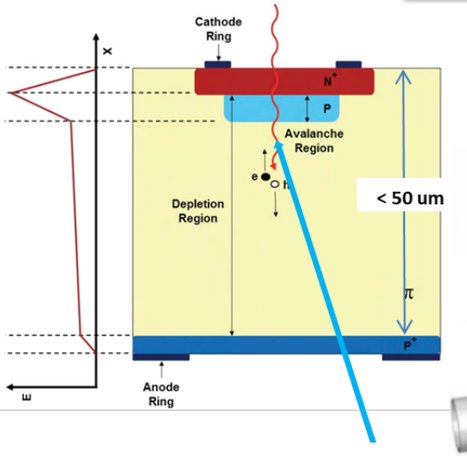
Need very small pixels: (e.g. 50k pixels/cm^2)

Thin sensors are required for very good time resolution
Thin sensors need gain!

- **Basic research need (BRN) requirements for future trackers**
- Spatial resolution ~ 5 um
- Temporal resolution ~ 10 ps
- Very low material budget (sensor + elect. < 100 mm of silicon)
- Very low power consumption (air cooling < 0.2 W/cm2)

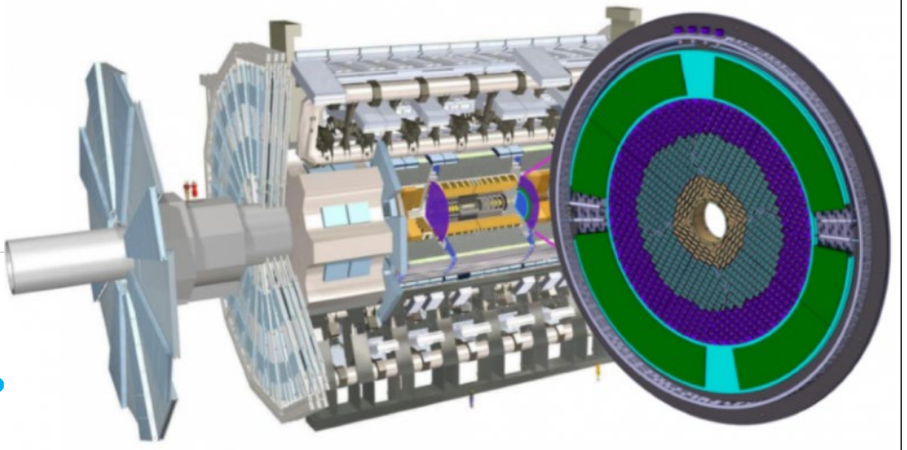
Good temporal resolution requires a lot of power per pixel: minimize # of channels!

- Low-Gain avalanche detectors **(LGADs)**
  - **Example of blue-sky R&D** within RD50, AIDA, supported by the US DoE (UCSC), now also within US-Japan collaboration
- **Started in 2012**
  - In 2019/2020 **ATLAS and CMS** submitted TDRs for **large-scale timing upgrades** to suppress backgrounds **using LGADs** with area of ~10 m^2
  - Now produced by >10 companies/labs
- **Issues:** granularity, radiation hardness, power dissipation



LGAD, Silicon sensor with thin gain layer to boost S/N

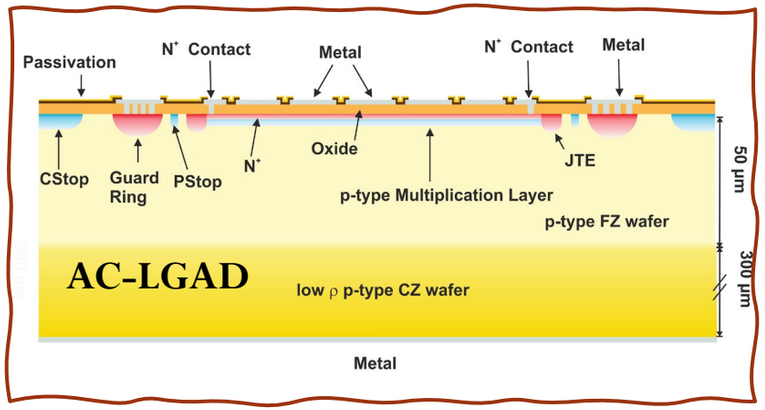
ATLAS HGTD CMS ETL

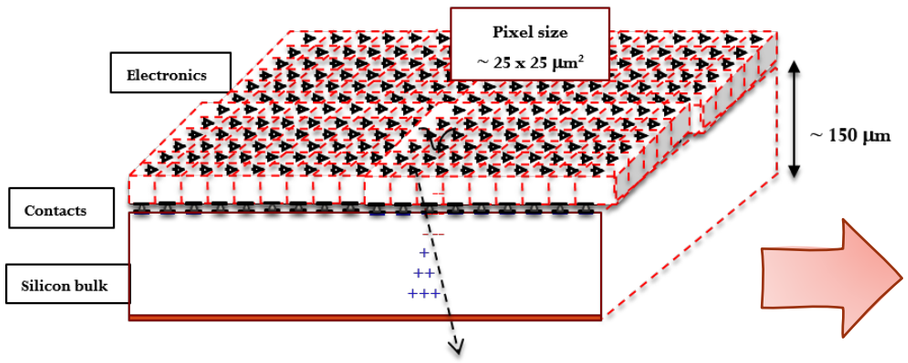


Snowmass papers: 4D tracking paper, CMOS, Electronics, SiC, 3D integr.

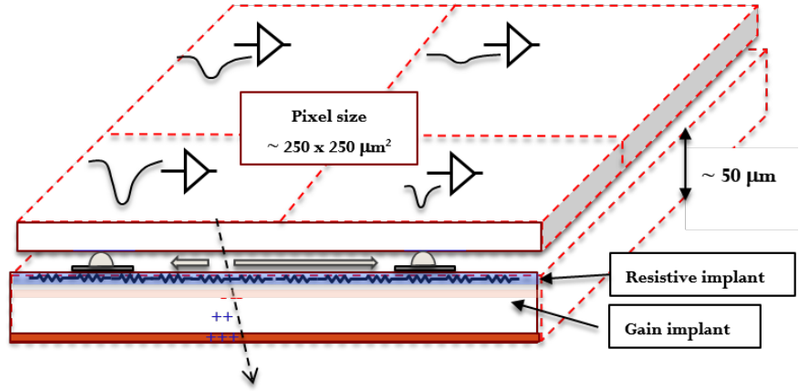
4D devices – AC Low-gain avalanche detectors (AC-LGADs)

- Issues to solve: **low granularity** of traditional LGADs and **power dissipation**
  - Solution for both: **AC-coupled LGADs (AC-LGADs)**
- Continuous sheets of multiplication layer and resistive N+ layer, **AC-coupled readout**
  - **Collected charge is shared** between electrodes **(position resolution << pitch)**
- New concept: **sparse readout, high precision and low power**
  - Great time resolution from thin LGADs
  - Works in low occupancy environment, good for lepton colliders
- Upcoming AC-LGAD applications: the ePIC (@ EIC) and PIONEER (small-scale) experiments
  - **Next: Higgs factories**, technology optimization needed!





Standard Tracker



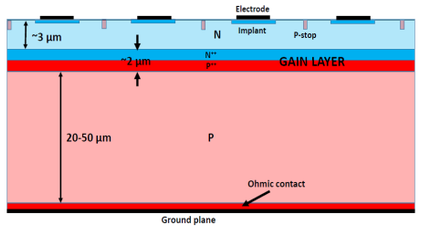
4D tracker

Long-term development of 4/5D LGAD detectors

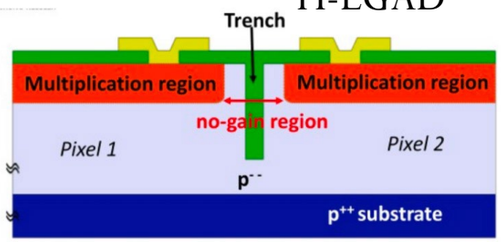
- **New technology** needs to be developed for future colliders with **high radiation hardness requirements** ($10^{16\text{-}17}$ Neq/cm^2) and **high occupancy** (e.g.: FCC-hh)
  - **x10 improvement in LGADs radiation hardness**, up to 2.5E15 Neq/cm^2, with R&D effort in ATLAS/CMS **in ~6 years**
  - Need for **order of magnitude increase in radiation hardness and higher granularity**
- **Critical need to continue developing LGAD sensor technology** for far future applications
  - Why **5D**? Think of **extra information on Angle or Energy**
- **Lower power electronics and advanced integration** needs to developed together with sensor R&D

- At the same time **pursue pure technology advancement**: blue sky R&D
  - **Applications in other fields** (X-ray detection, imaging, medical science, space, …)

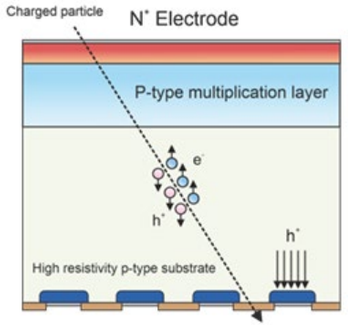
DJ-LGAD



TI-LGAD

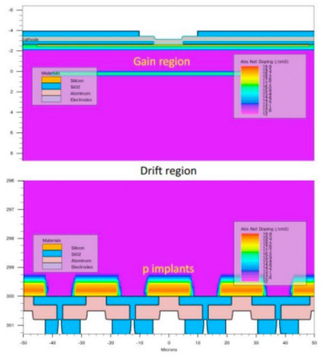


iLGAD



High granularity

DS-LGAD



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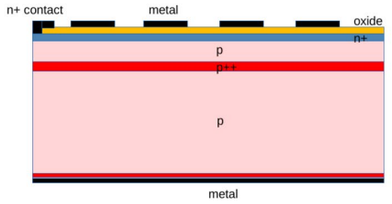
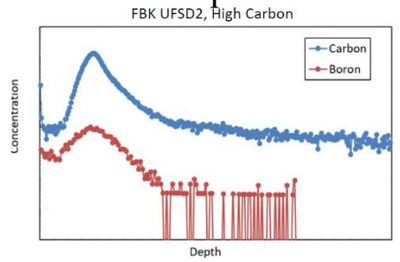
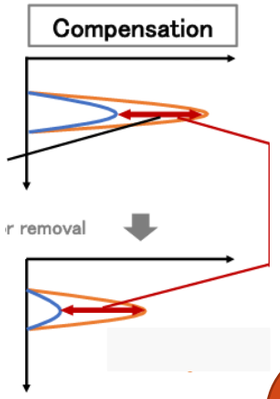
Buried-LGAD



Carbon implantation



Compensated gain layer



Inactive Boron,
Low diffusion…

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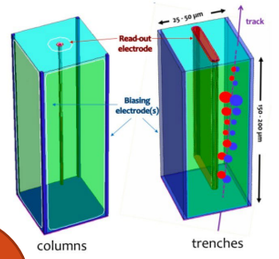
Radiation hard

3D trenches



LGAD CMOS

Snowmass papers: 4D tracking paper, CMOS, Electronics, SiC, 3D integr.

Conclusions and R&D cost profile

- For **near-future applications AC-LGADs seem to solve granularity and power issue**
  - However, **many challenges lie ahead** in terms of high radiation damage and large occupancy
- There has been **great and fast development on 4/5-D detectors based on the LGAD technology** that makes it a **viable technology for short, medium and long term** applications
  - But **to fully meet the BRN goals continuing funding for R&D is critical**
  - Cost increment: **new technologies are progressively more complicated**