LBNL LDRD Proposal: Future Instrumentation for Future Colliders

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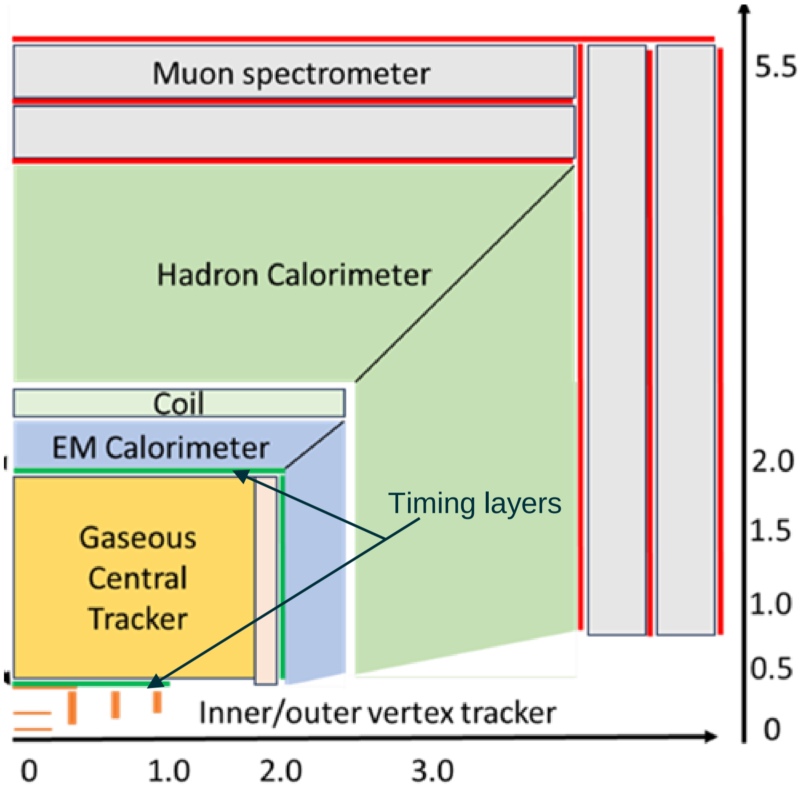
1. **co-PI's**

Future Colliders for HEP and Berkeley Lab

- LDRD is a discretionary process within the national labs to seed new developments in areas which are not yet programmatic
- Based upon a %$ tax on grants
- Competitive, can be thematic at management’s perogative
- FY funded, proposals in Feb-April, decisions in Summer
- Up to 3 years but often 2
- **Propose an R&D effort aimed at precision tracking/timing at a future Higgs Factory**

Tracking Requirements for Higgs Factory Collider Detector

- Inner vertex with high spatial resolution
  - MAPS (monolithic active pixel sensor)
- Extremely low mass
  - Thinned sensors and readout
  - Minimal cooling mass
  - Gaseous central tracker
- Moderate rate
  - Drift or straw tubes (not TPC)
- Particle identification
  - dE/dx over a wide momentum range using custom FE ASIC
  - Time of Flight (TOF) at low pT ~ 1 GeV/c, using Low Gain Avalanche Detectors (LGADs)



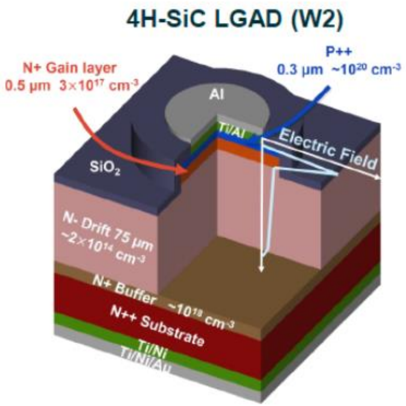
LBNL Leverage

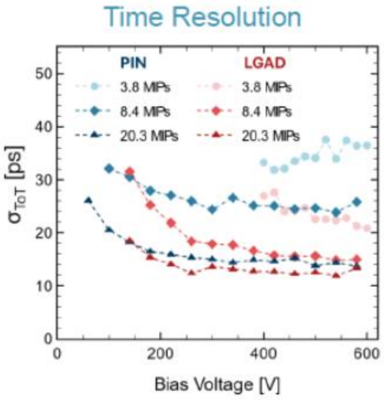
- Strong Engineering Division capabilities in low mass composite mechanics and ASIC design
  - **B77a Composites Facility**
  - **ASIC design group**
- Several past Physical Science Area LDRDs, which all yielded new funding, are directly relevant
  - Multi-modular structures 2009-10
  - Precision low mass mechanics 2014-15
  - Optical metrology 2016-17
  - **Silicon Carbide LGADs (SiC-LGAD) 2021-22**
- **SiC LGADs are a promising approach to fast timing with minimal cooling mass**
- Ongoing collaboration with North Carolina State University (leading wide band gap expertise) and BNL, on the development of wide band gap LGADs for fast timing
  - **Physics Division LGAD testing lab**

Target of Opportunity

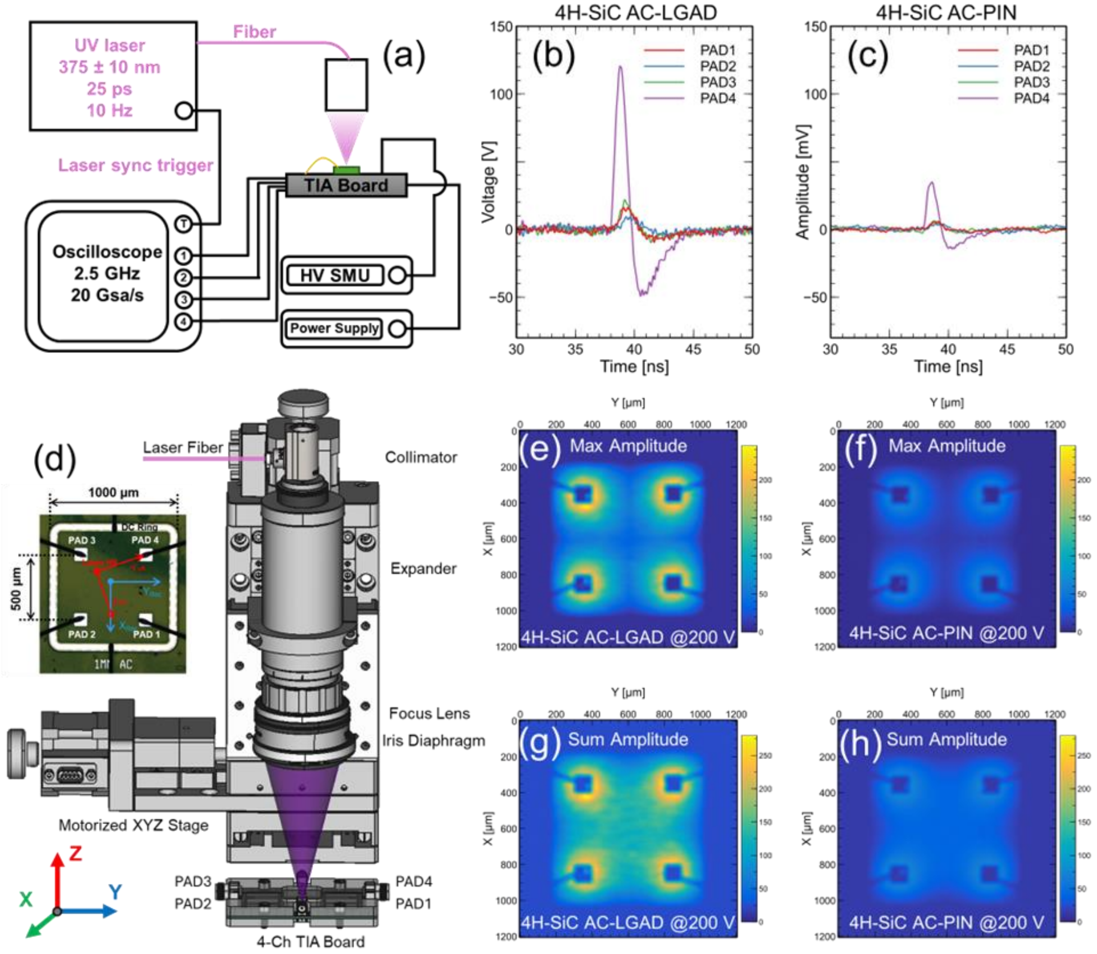
- Baseline detector designs call of a fast timing “wrapper” layer at R= 2m to catch ~1 GeV particles which are not well measured by dE/dx (ionization loss gap), t_res ~100 ps
- But for high resolution tracking the B field may result in a cutoff > 1 GeV at 2m
- **Solution is a low mass inner timing layer at R=0.5 m but t_res ~20 ps**

- At LBNL/NCSU/BNL have developed wide-band-gap Silicon Carbide LGADs
- **WBG/SiC = high temperature operation and very fast response**
- If implemented in a low mass layer with passive cooling and **appropriate high temperature electronics** this could be a great solution to **an INNER FAST TIMING LAYER**





UV-TCT Setup for SiC AC-LGAD / PIN



Technical Challenges

- The development of SiC-LGAD is funded by DOE HEP Detector R&D and ECA as a generical development
- Substantial progress to achieve higher breakdown voltages and full depletion
- AC SiC-LGADs – optimization of position reconstruction
- A system which runs at RT+ would also require high temperature tolerant front end readout electronics
- Emerging WBG (SiC or GaN) ASIC processes could be a possible solution
  - **Present process cannot provide required bandwidth – like Si 30y ago**
  - Example circuits designed at OAW/HEPHY Vienna (see presentation in last BNL tracking workshop)
- **Mount effort in the US to study these emerging processes**

Technical Challenges - continued

- How do we handle extremely thin (~50 micron) semiconductors?
- What sort of carbon support structures are appropriate?
- How can we integrate mechanical/thermal/electrical functions in the most efficient and low mass way?
- Tools to simulate stress and fracture in very thin semiconductors.
  - ATLAS ITk experience shows importance of detailed thermo-mechanical simulation of composite structures across ΔT, thin and possibly “warm” structures are a new area to understand
- Novel carbon based materials – ie, electrical conductors

LDRD Year 1 Proposal

- We propose to focus on **low mass and fast timing technologies**
- Leverages experience, facilities, and past LDRD and project investments

1. Manipulation of extremely thin semiconductors and carbon materials
2. Layout and design of a high performance inner fast timing/tracking layer
3. Emerging ASIC design using **wide band gap** WBG (SiC and GaN) processes to complement our SiC-LGAD effort
4. Simulation of extremely thin composite structures including thermal effects
5. Low mass electronic transmission lines in carbon nanotubes

A second year would extend the prototyping of mechanical structure and include a fabrication of wide band gap ASIC

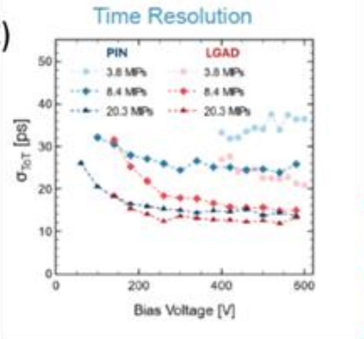
- **Eventual focus is an inner fast timing layer with only passive cooling by combining our SiC-LGADs with WBG ASICs and ultrathin supports**

Work Plan Year 1

1. Manipulation of extremely thin semiconductors and carbon materials
    a. Procure materials, design and prototype tooling for thinning, bending, and support
2. Layout and design of a high performance inner fast timing layer
    a. First pass engineering design of an inner support layer including services, consistent with full detector concept
3. Emerging ASIC design using wide band gap (SiC and GaN) processes
    a. Survey emerging processes, acquire s/w toolkit, design and layout of transimpedance amp and/or TDC
    b. In consultation with our NC State collaborators
4. Simulation of extremely thin composite structures including thermal effects
5. Low mass electronic transmission lines in carbon nanotubes
    a. Design study

Backup

C)



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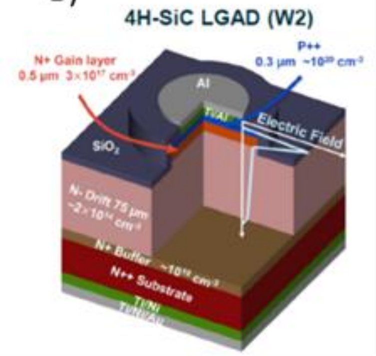
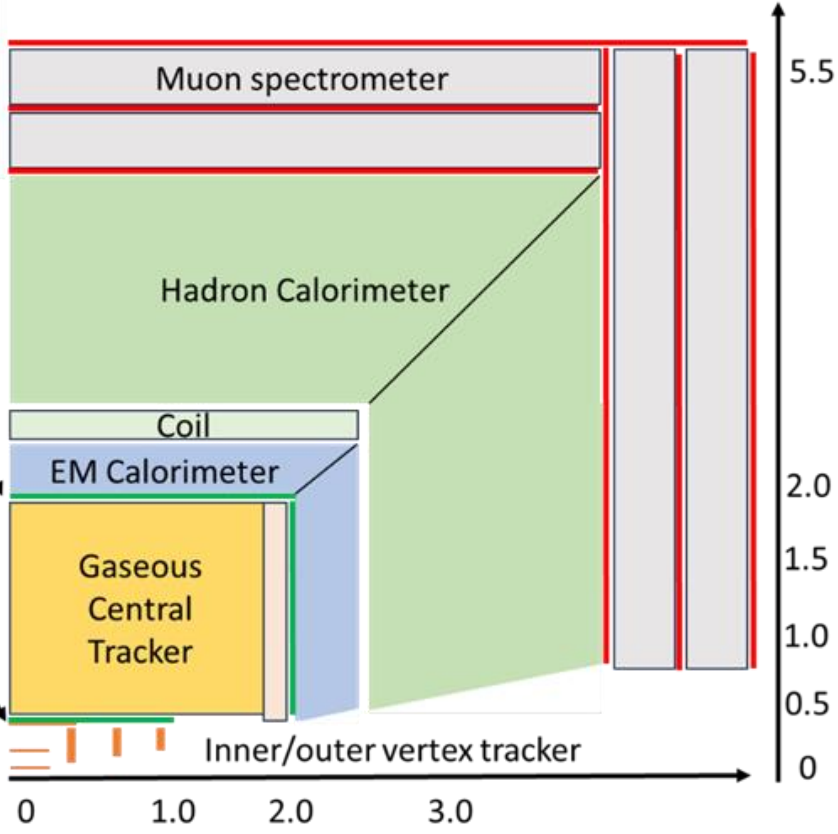




Muon spectrometer

Hadron Calorimeter

Coil

EM Calorimeter

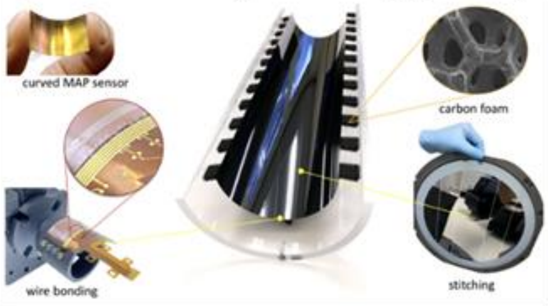
Gaseous Central Tracker

Inner/outer vertex tracker

Outer Si Wrapper Timing layer

Inner timing layer

A) Wafer bending technology (ALICE)



Why These Choices?

1. Manipulation of extremely thin semiconductors and carbon materials
    a. State-of-the-Art is 50 um silicon bent into a circular profile, we need to gain experience with these materials and methods
    b. Thinning of non-silicon materials
2. Layout and design of a high performance inner fast timing layer
    a. Baseline designs call of a timing layer at R= 2m, but B field makes this inefficient for ~1 GeV tracks. Can we design a very low mass inner timing layer (R~<0.5 m), with higher timing resolution?
3. Emerging ASIC design using wide band gap (WBG) (SiC and GaN) processes
    a. WBG devices can run hot - no cooling?, can we develop readout electronics for SiC-LGADs in an emerging WBG process?

Why These Choices - continued

4. Simulation of extremely thin composite structures including thermal effects
    a. ATLAS ITk experience shows importance of detailed thermo-mechanical simulation of composite structures across ΔT, thin and possibly “warm” structures are a new area to understand
5. Low mass electronic carbon nanotube transmission lines
    a. A new approach to low mass data transmission, may also contribute to mechanical support, no one is doing this yet…