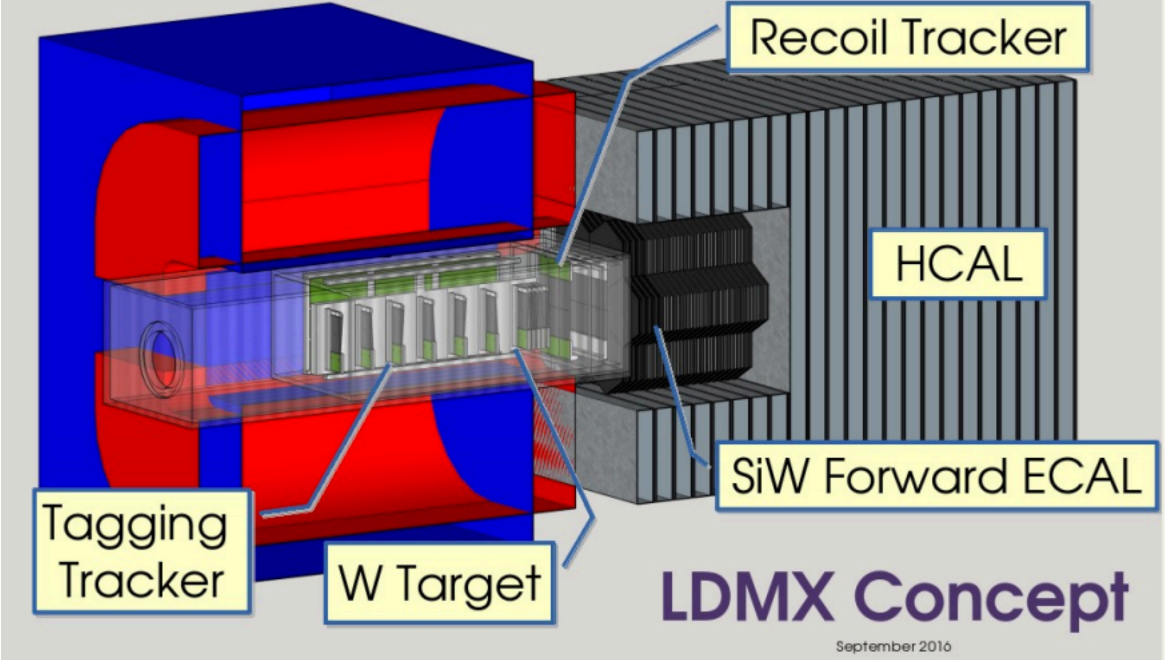
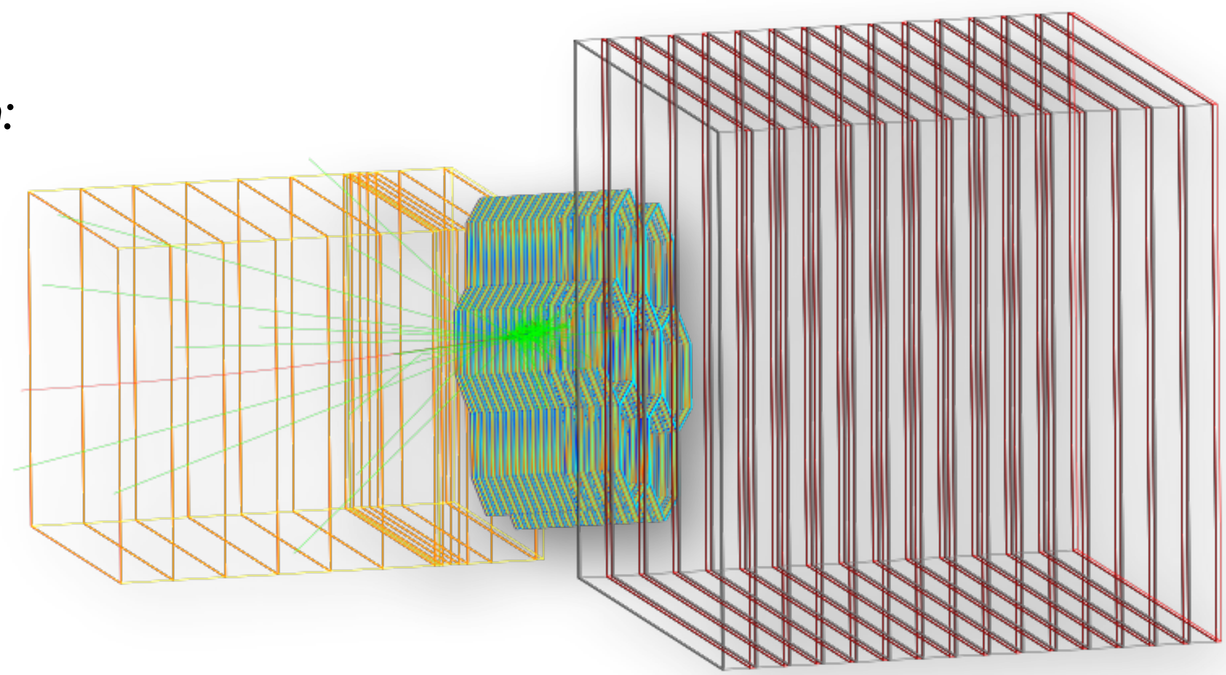
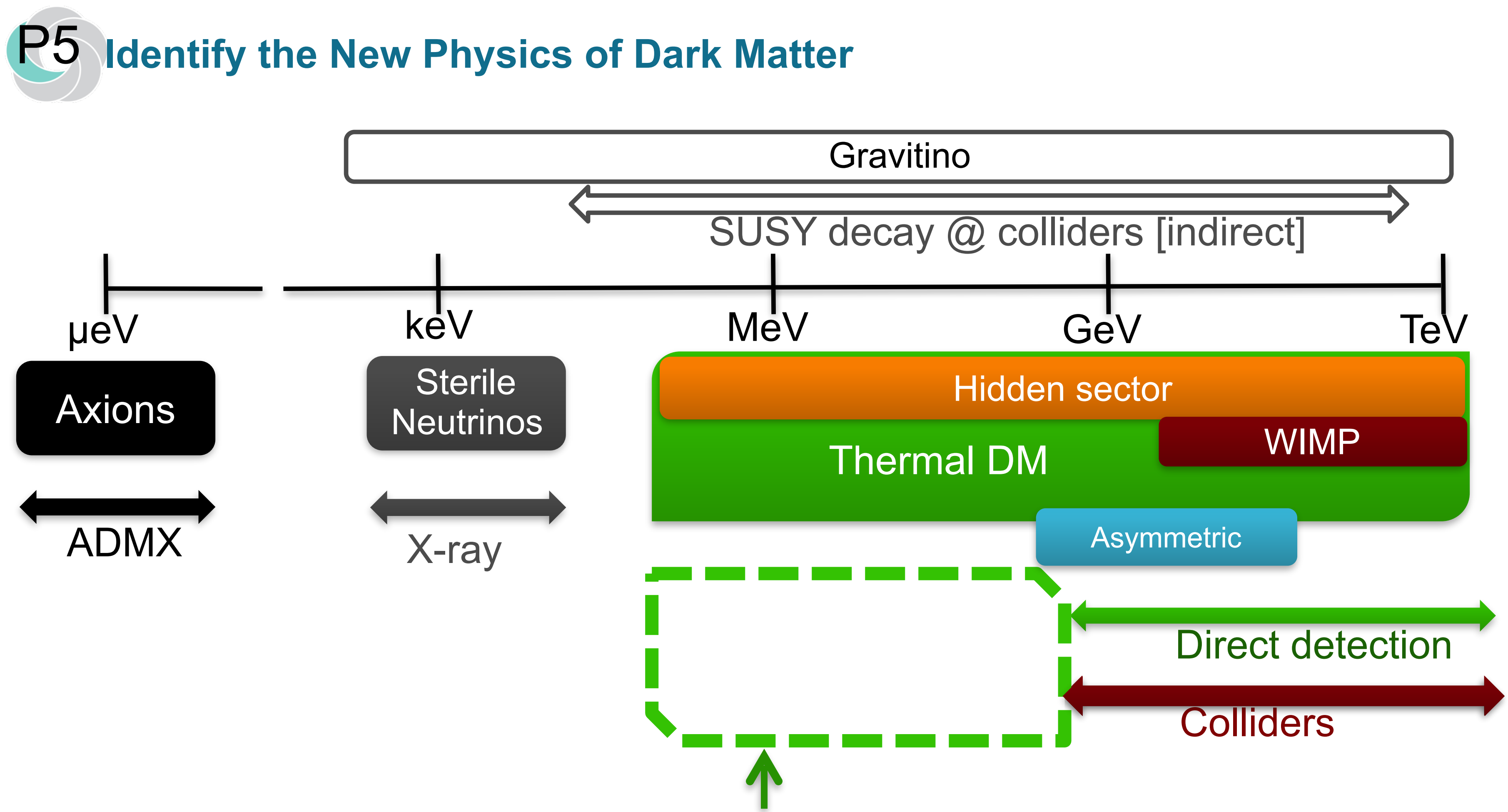


Light Dark Matter eXperiment (LDMX)

O. Colegrove (UCSB)
For the LDMX Collaboration:
SLAC, UCSB, UMN,
UCSC, CIT, and FNAL



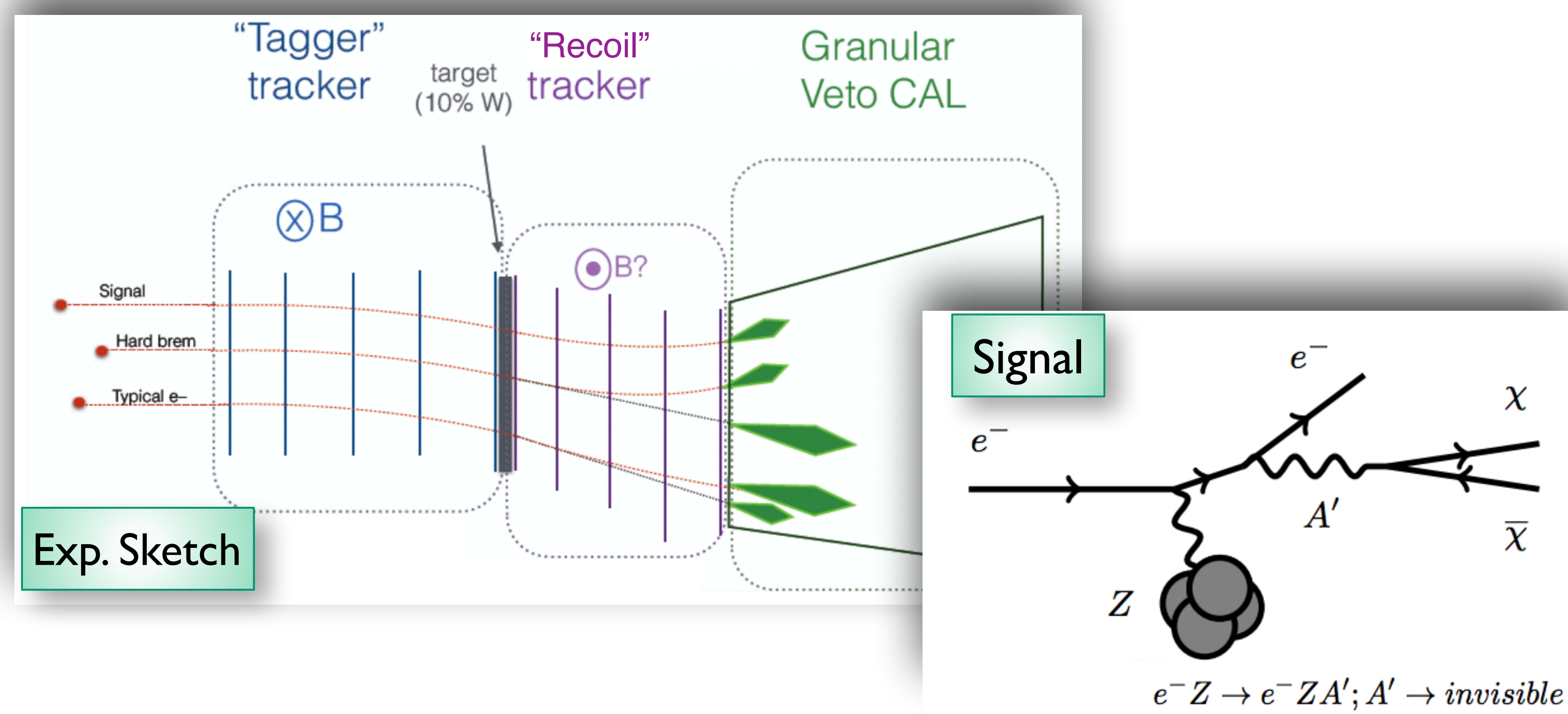
Motivation for Sub-GeV Dark Matter



- Next frontier for Dark Matter science
  - Logical place to focus given LHC and Direct Detection null results
  - Unique opportunity for high impact from small experiment!

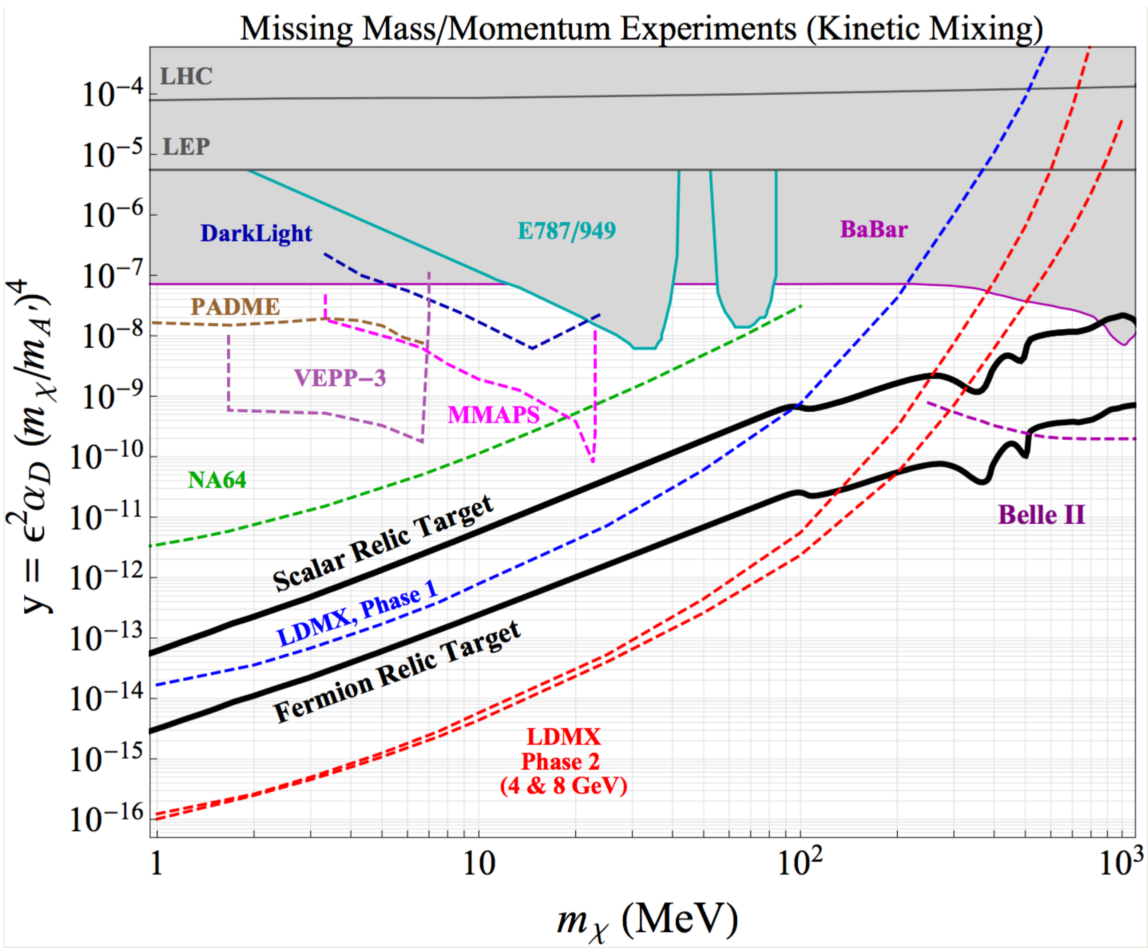
The Missing Momentum Approach

- Considered by many to be the most robust technique for discovering Sub-GeV thermal dark matter
- LDMX employs this technique via fixed target electron scattering
  - Dark photon A' produced via Brem. in 10% X_0 target
  - Distinctive signal kinematics ($M_e << M_{A'} << E_{beam}$) yields a final state with radiated A' (invisible) and a soft recoil electron

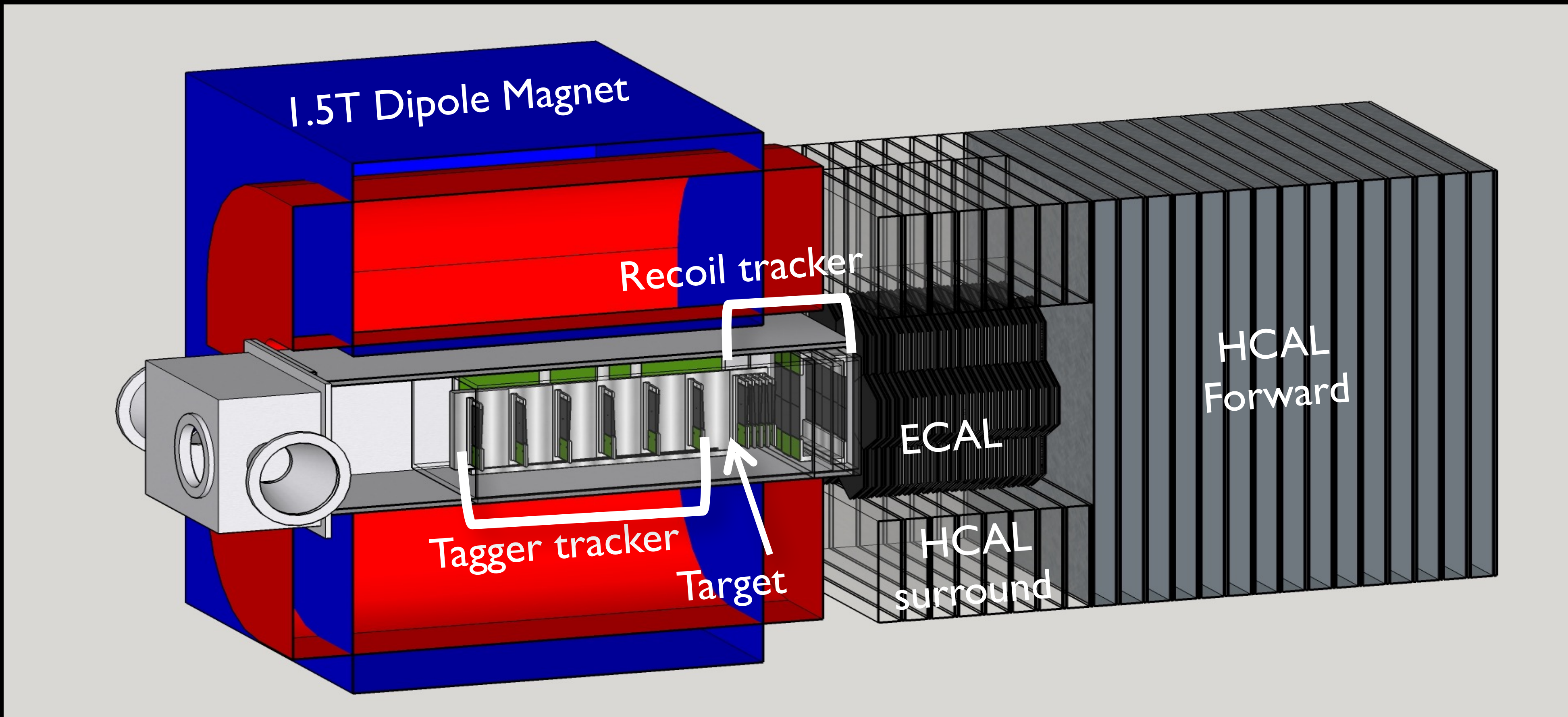


Projected Sensitivity

- Phase I — 4•10^{14} electrons delivered over 1-2 years of running time
  - LCLS-II at SLAC can provide 4 (8) GeV electrons to LDMX at 25 nhz
  - LDMX aims to exclude sub-GeV DM at/beyond the Scalar Relic Density

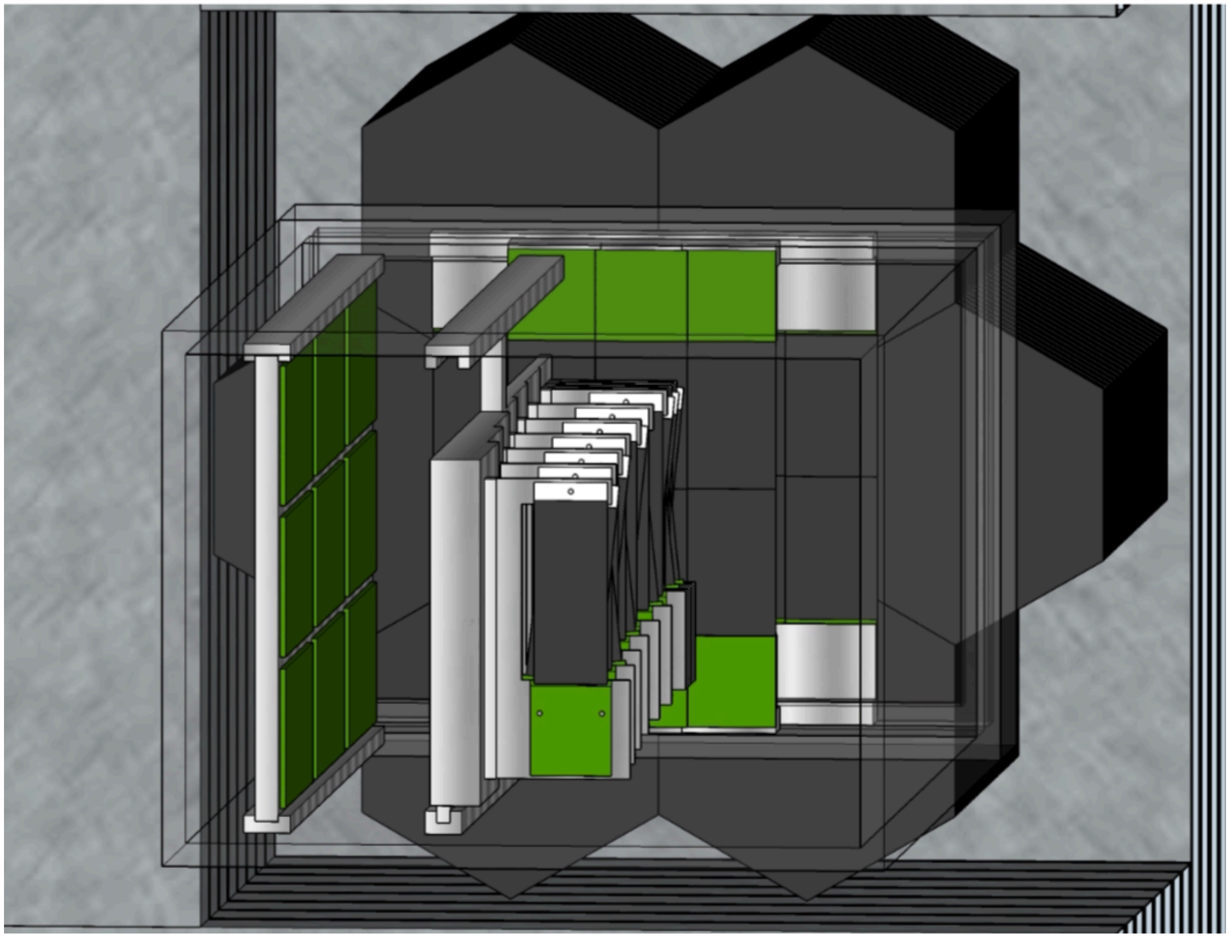


LDMX Detector Concept



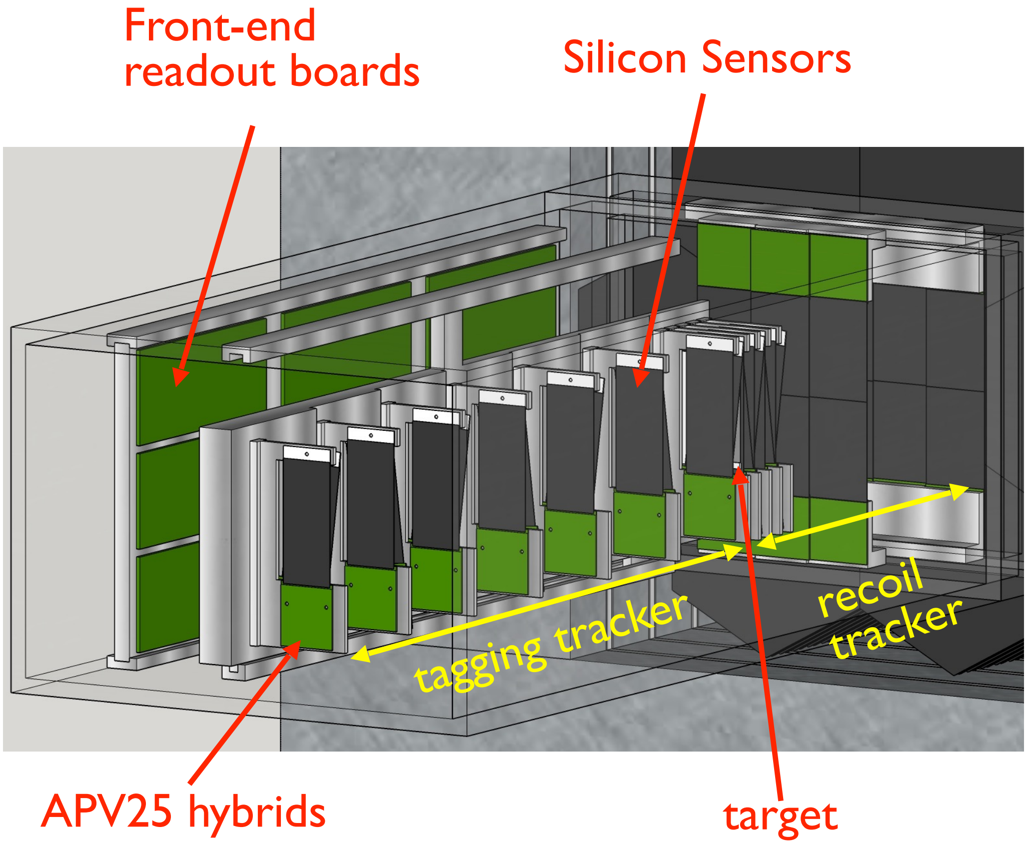
- Magnet and Tracking
  - Collimated precision tagger tracker in full field → 10% X_O target → compact and precision recoil tracker in fringe field
- Si-W sampling calorimeter (ECAL)
  - 40 X_O, 1.5 λ, 30 Layers, 7 modules per layer of high efficiency, high granularity calorimetry
- Scintillator-Steel sampling calorimeter (HCAL)
  - HCAL Forward — Up to 50 layers (15 λ), un-segmented for simplicity, veto boosted hadrons
  - HCAL Surround — Up to 20 Layers, 6 λ, veto wide-angled hadrons

Tagger and Recoil Tracker



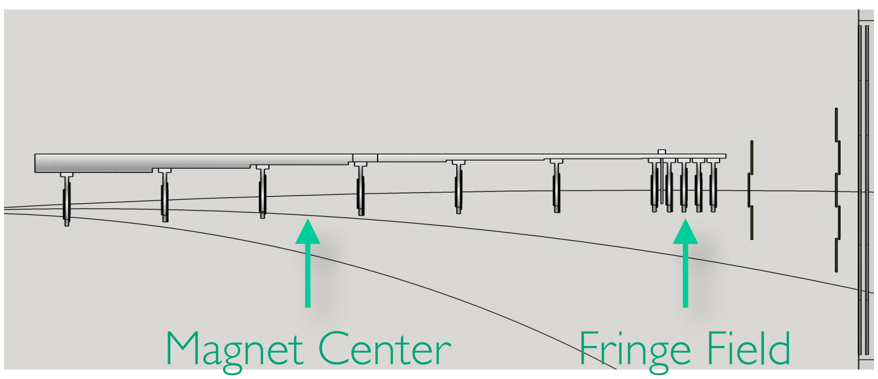
- A beam's eye view of the tagging and recoil trackers

Tracker and Magnet

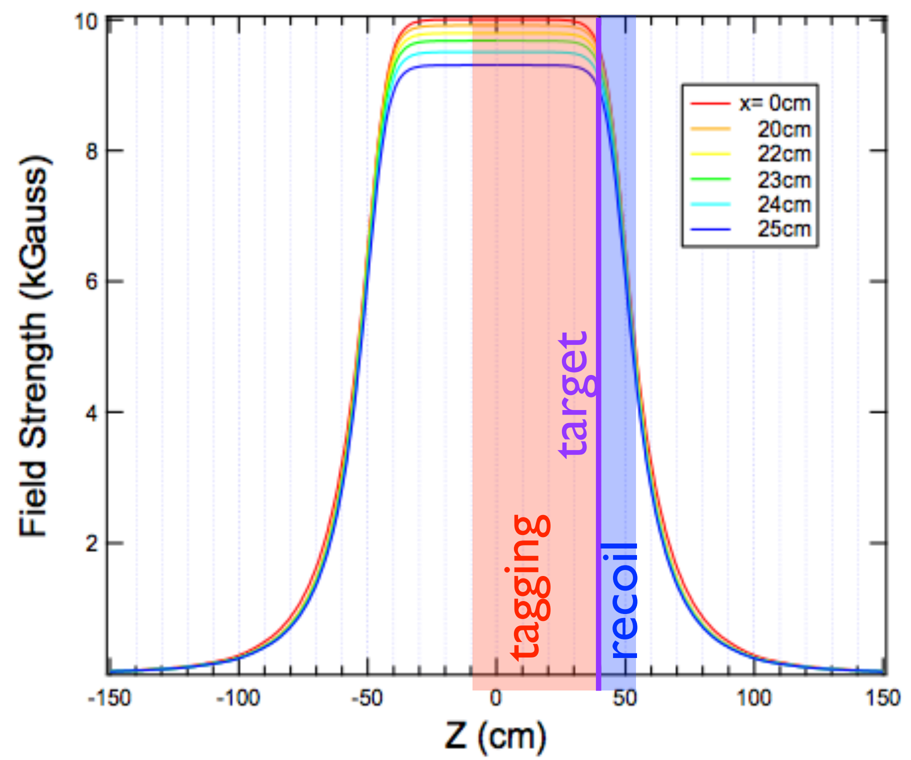


Two tracking systems, separated by a target in separate vacuum, one magnet

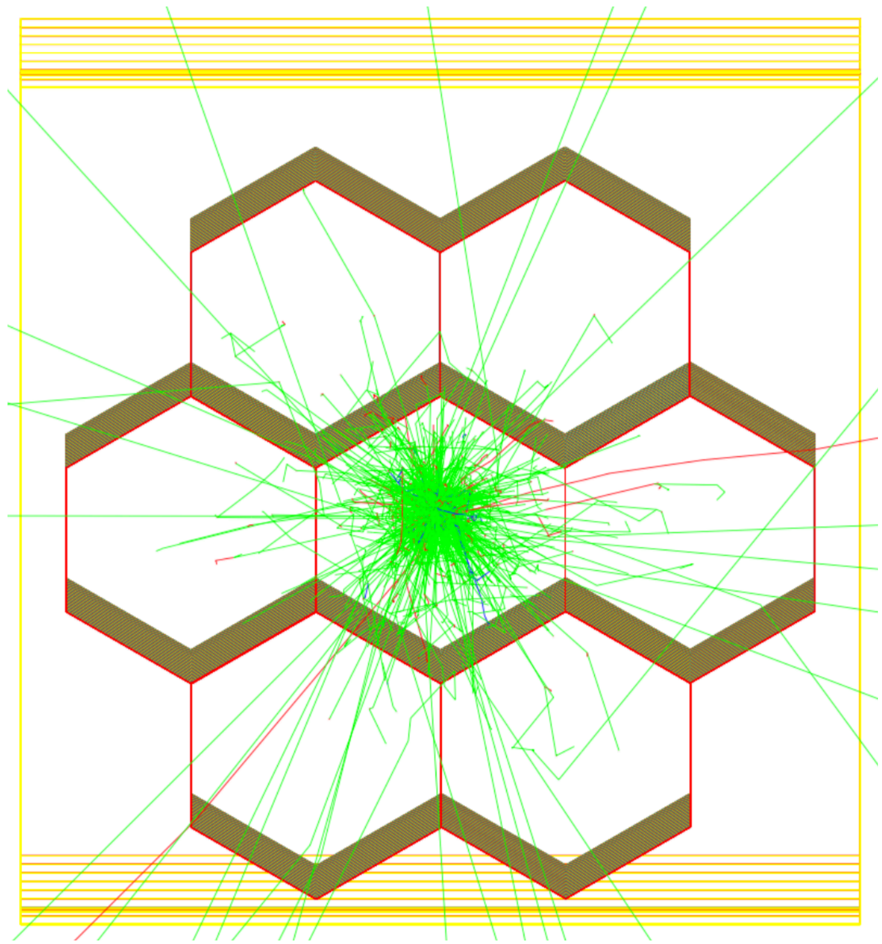
- Tagging tracker: Tag incoming e-
  - Precise p and (x,y) position at target.
  - 7 stereo Layers: Modules like HPS SVT (L1-L3)
- Recoil tracker: Associate tag to recoil
  - Matches recoil electron track to incoming tagger track.
    - Momentum measurement for e-'s with E > 50 MeV.
  - 4 Stereo Layers: Modules like HPS SVT (L1-L3)
  - 2 Axial Layers: Modules like HPS SVT (L4-L6)



- Screen out straggling (off E_{Beam}) electrons
- Measure Δp across target
  - Recoil tracker placed in fringe field



Electromagnetic Calorimeter

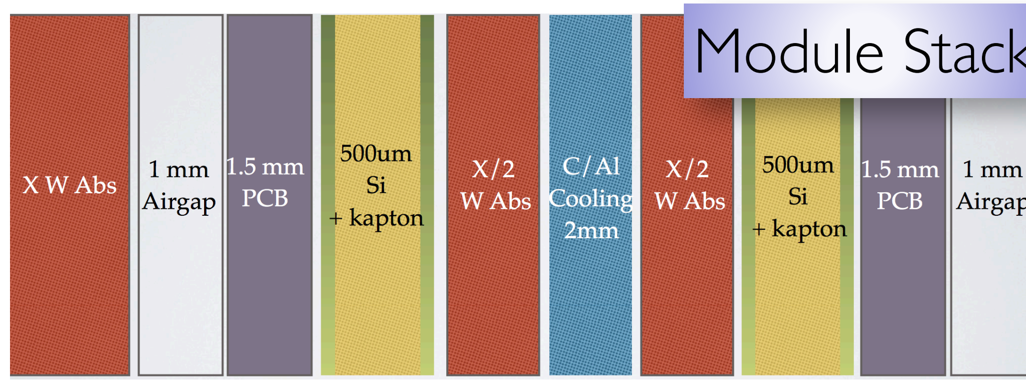


- A beam's eye view of a typical 4 GeV e-'s shower in the ECAL

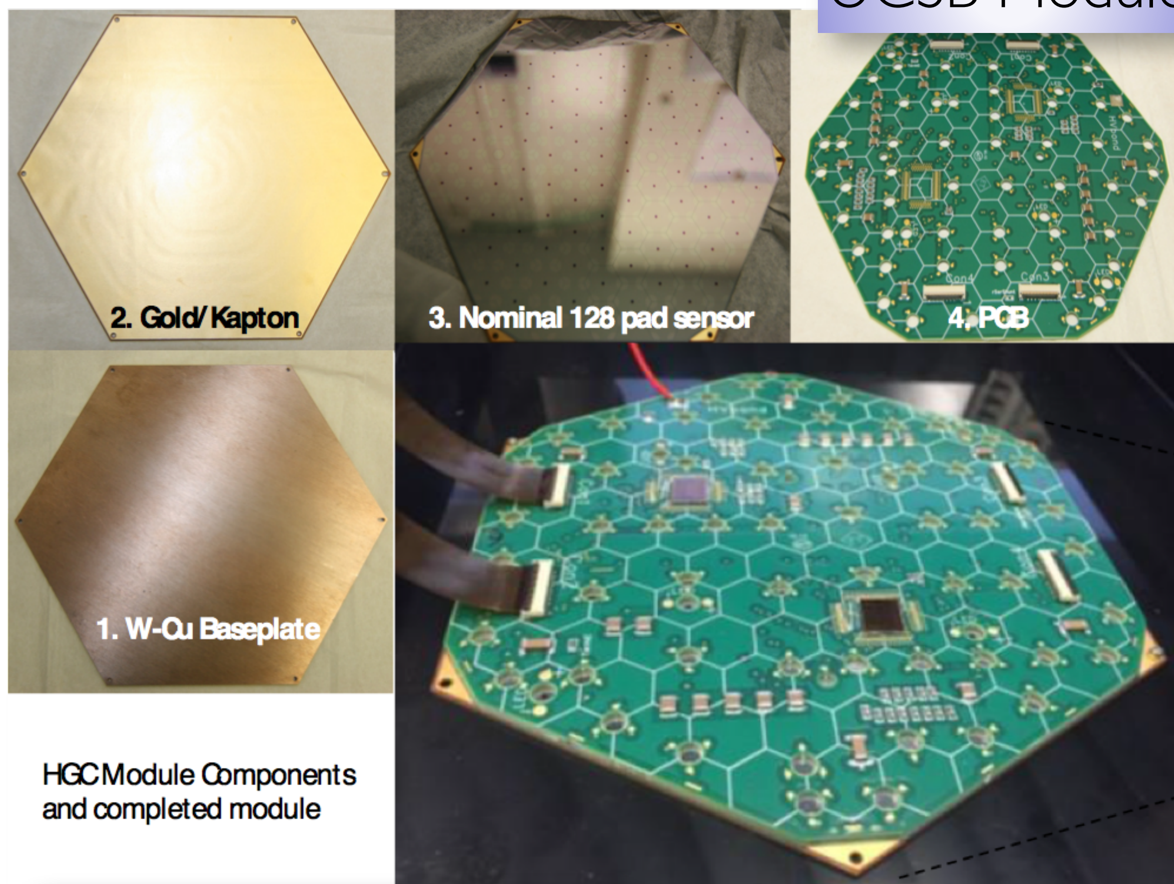
ECAL Modules

- Specifications
  - Modules to be mounted on thin C/Al cooling planes
  - 256-512 channel 8 in. hexagon sensors
  - Radiation hard design
  - Support 25 ns readout rate
- Leverage CMS HGCal technology
  - CMS HGROC front end readout chip
  - Module validation provided by CMS's extensive test beam campaign
  - 210 modules required — Production can be achieved within 2 wks at one of five CMS production facilities

Module Stack



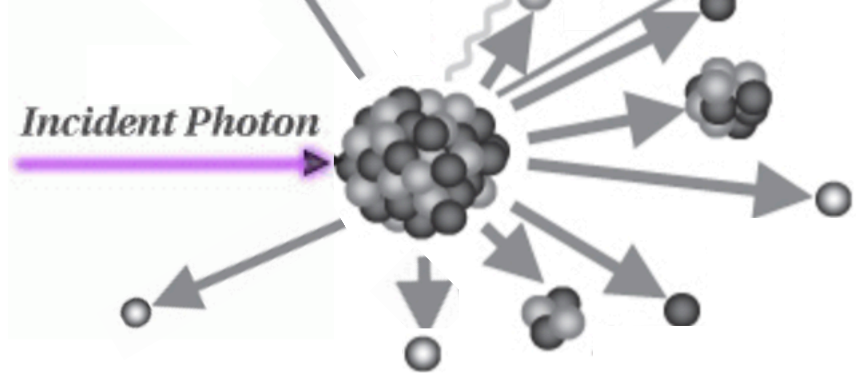
UCSB Module



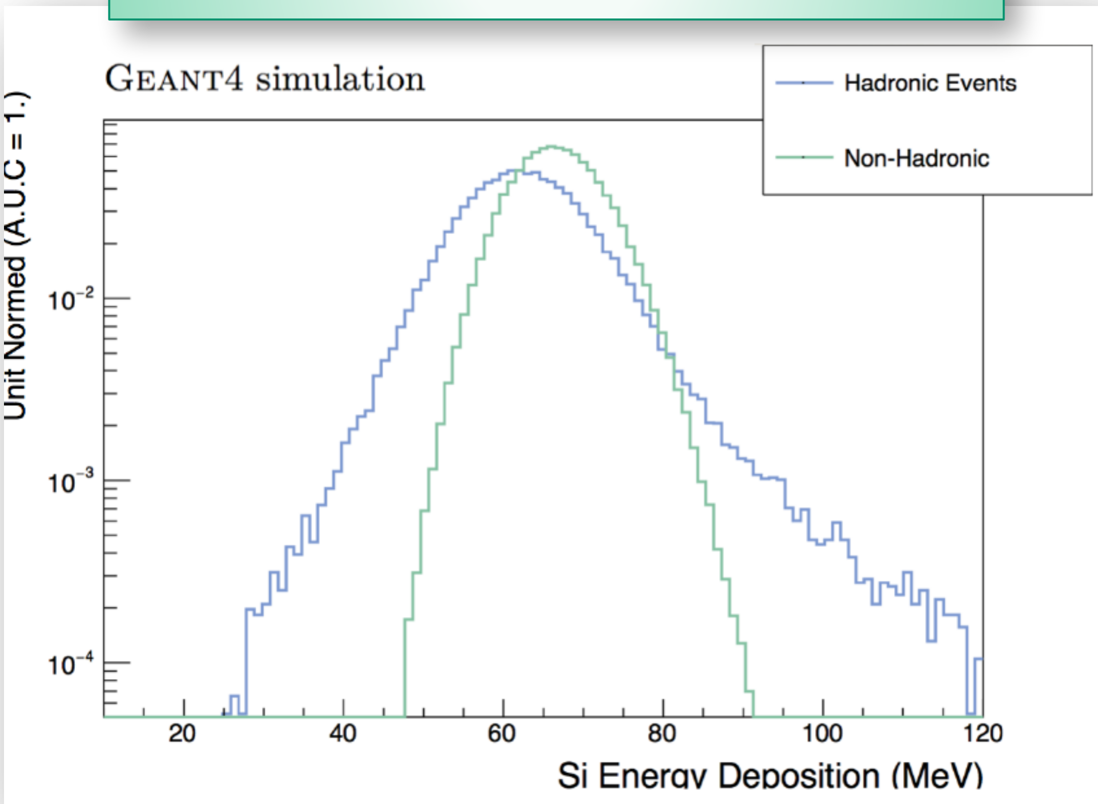
HGC Module Components and completed module

Successful test beams carried out at FNAL & CERN in 2016

Photonuclear Background



From 10^14 electrons on target we expect ~3B recoil electrons w/ hard brem that undergoes PN reaction



- LDMX's main background :
  - Initial results show that neutron dominated final states are most difficult to veto.
  - Steps are being taken to validate Bertini model in Geant4 v10.XX
- ECAL geometry has been optimized to help with detection
  - Thin absorers in earliest layers
  - Single mip tracking capability
  - HCAL still required to successfully mitigate all PN events

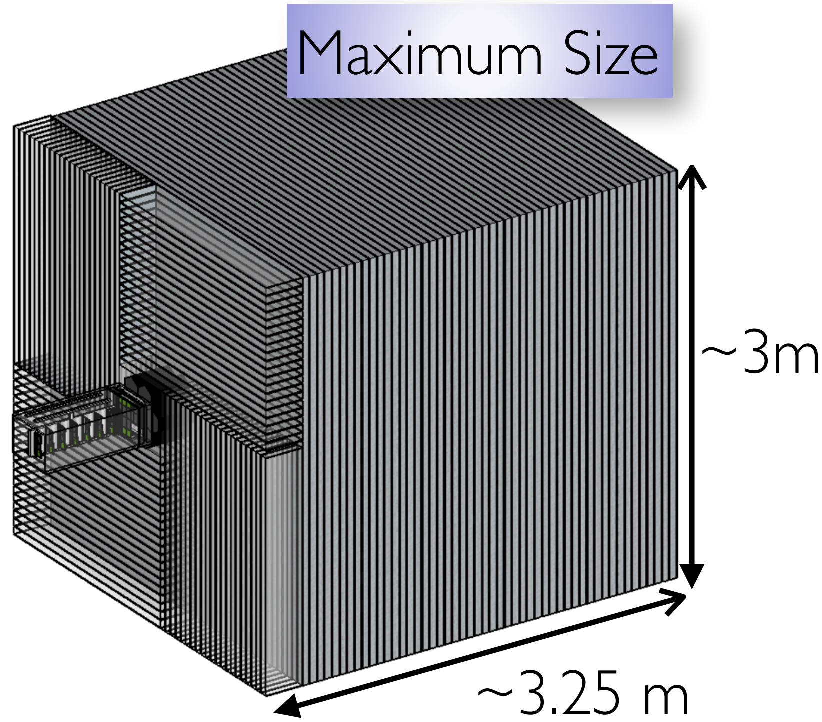
- Energy Deposition in ECAL
  - Tails from photonuclear (PN) reactions create a non-Gaussian low energy tail that composes primary background (~25M events in histogram above).

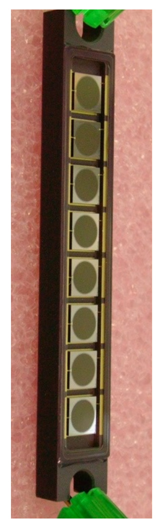
Hadron Calorimeter, Trigger & Daq

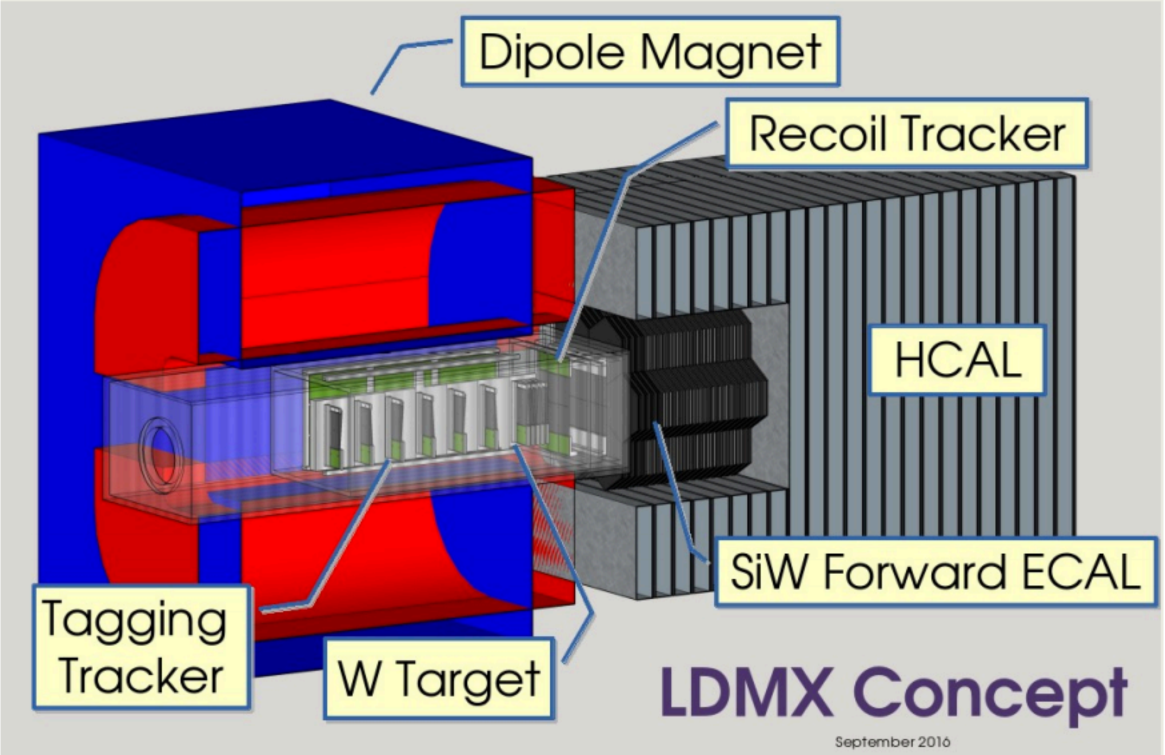
CMS/LHC upgrades and SLAC hardware

Hadron Veto Design

- HCAL Structure
  - Maximum of 3m x 3m in size allowable in detector cavern
  - Steel absorber and plastic scintillator planes read out w/ wavelength-shifting fibers
- Readout with SiPM-based electronics developed for the LHC CMS Detector Upgrade
  - Same electronics chain used for readout of trigger/target scintillator, with modified mechanics
  - Production of components for LDMX would be merged with production of last phase for the CMS Upgrade







Summary and Conclusions

- LDMX at LCLS-II provides the potential to comprehensively expand current exclusion limits of sub-GeV DM.
  - Strategically chosen location to leverage existing accelerator tech.
  - Intelligently designed detector makes use of US expertise
- Steps are being made to meet an aggressive timeline
  - DASEL beamline design is at an advanced stage
  - Project is being discussed with DOE to install beamline during LCLS-II construction stop in 2019
  - Construction schedule is focused on operation in 2020/21
- Studies are underway to understand photonuclear background.
  - Inclusive Geant4 background vetoed at $O(10^{10})$ e- on target
  - Analysis is ongoing for $O(10^{12})$ & exclusive processes

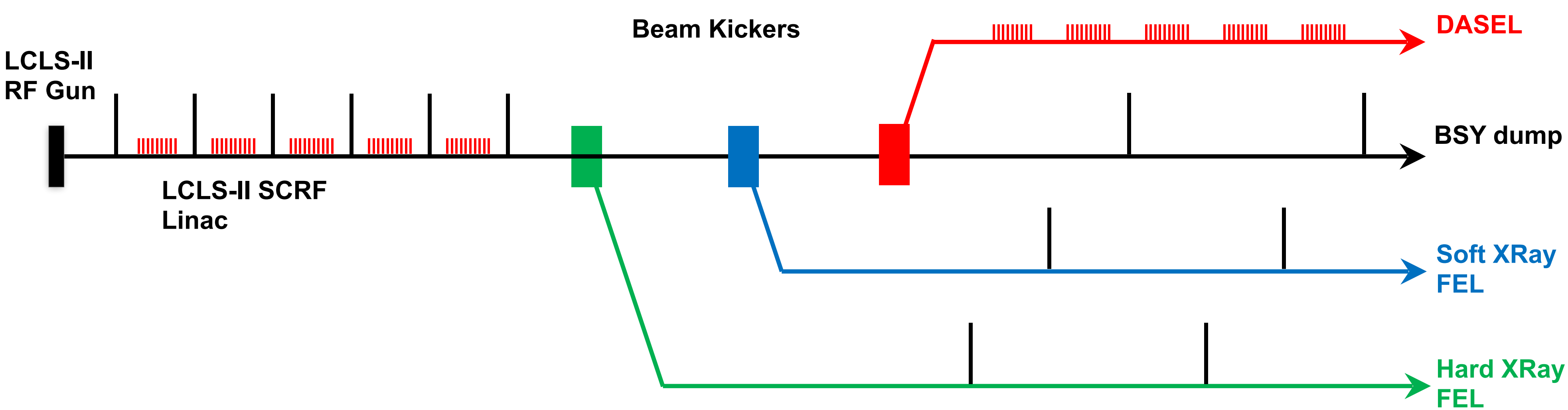
The end

DArk Sector Experiments at LCLS-II (DASEL): Concept

DASEL is a proposal to deliver low-current CW beam for Dark Matter searches parasitically from LCLSII linac.

The LCLS-II bunch rate of 0.929 MHz (1.1 us spacing) << RF frequency of the gun (186 MHz) and linac (1,300 MHz).

The SCRF linac can accelerate modest current in these “unused” buckets with minor modifications and no interference

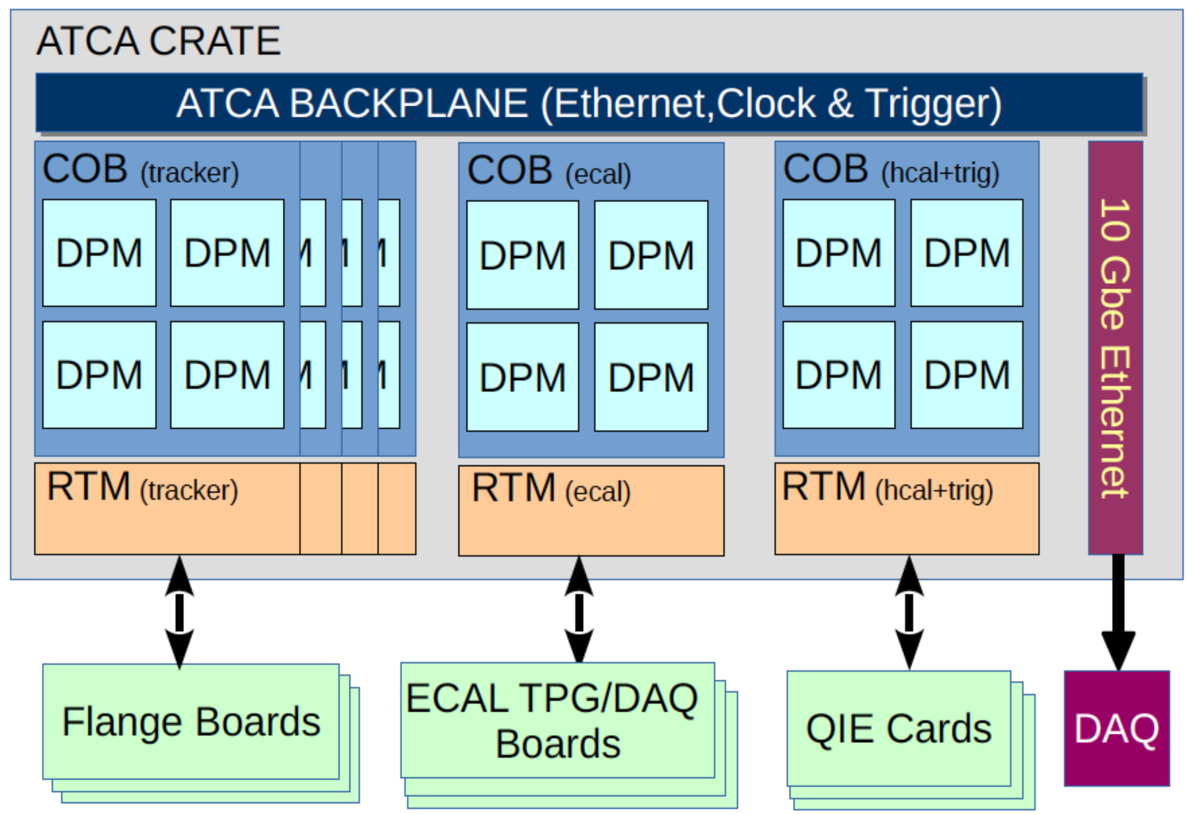


Resulting low-current CW beam can support unique & high-impact dark matter experiments

Off-detector electronics and DAQ

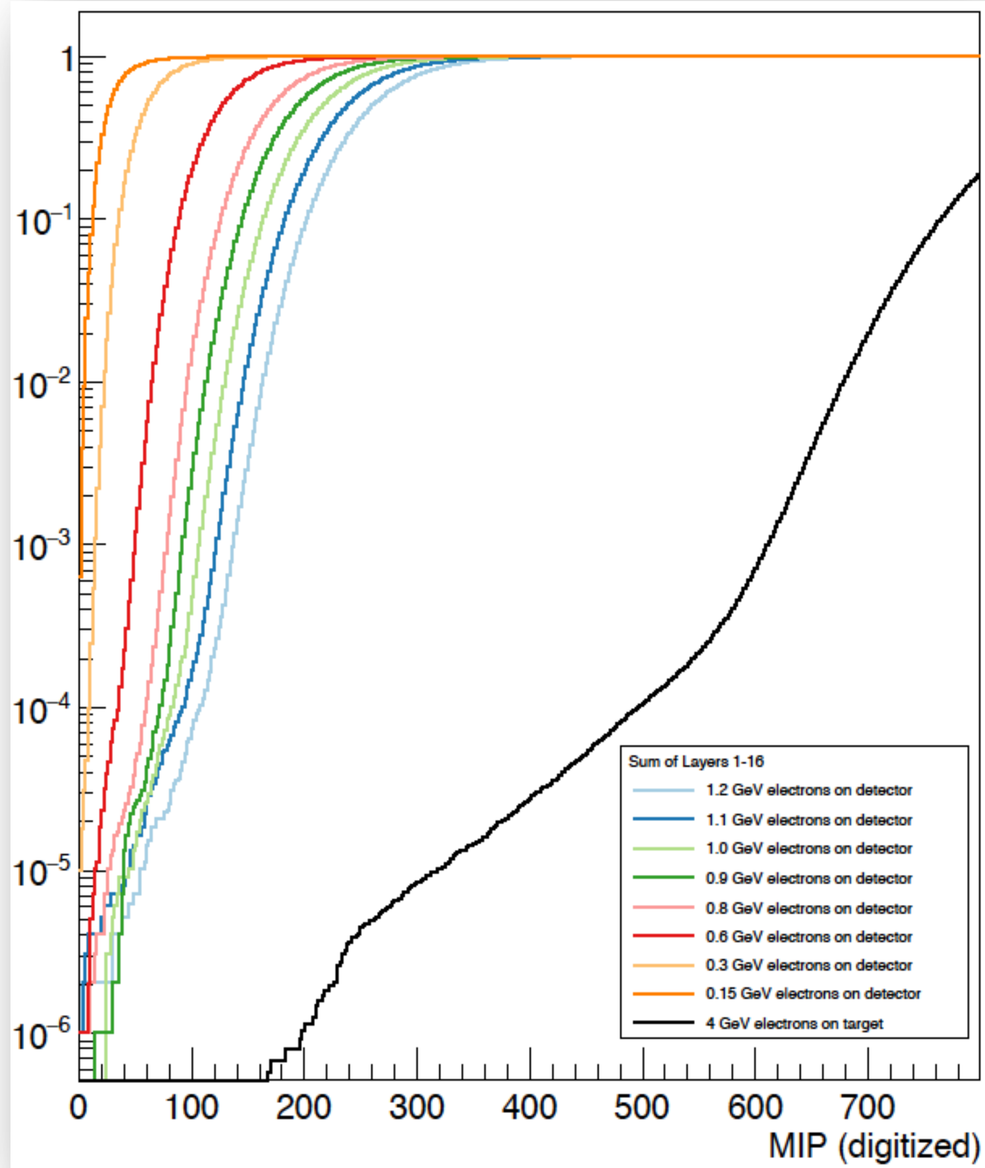
- Common off-detector electronics system based on the RCE/RPM ATCA electronics developed at SLAC
  - System is powerful enough to implement the trigger, DAQ, and controls in one ATCA crate

- DAQ
  - Est. event size 2.5 kB
  - The DAQ is capable of readout at 50 kHz, providing a factor of 10 safety on the trigger rate
  - DAQ bandwidth is additionally sufficient for a factor of five expansion in data volume, should the estimates be low



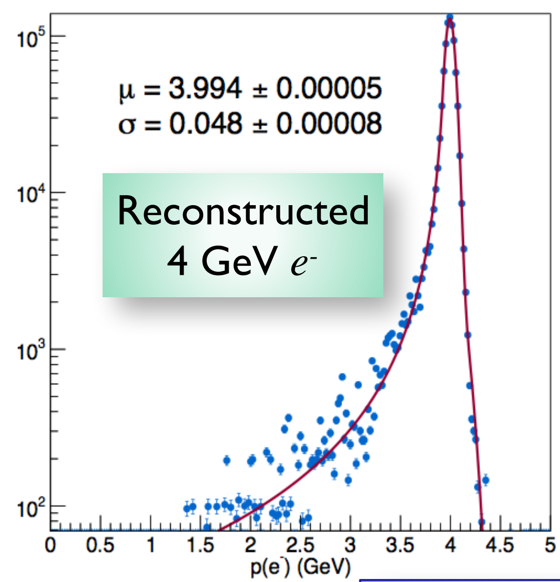
LDMX Physics Trigger

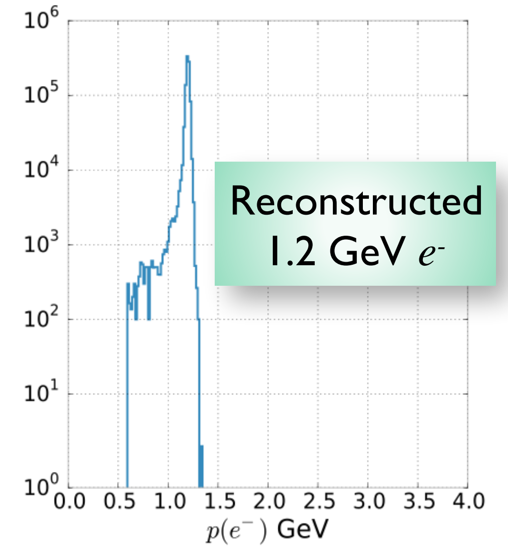
- ECAL based trigger
  - Energy sums performed using the first 16 layers of calorimeter
  - DAQ needs a reduction of ~10^{-4}
  - Simulation indicates reduction factor of 2×10^{-5} possible with no inefficiency for signal

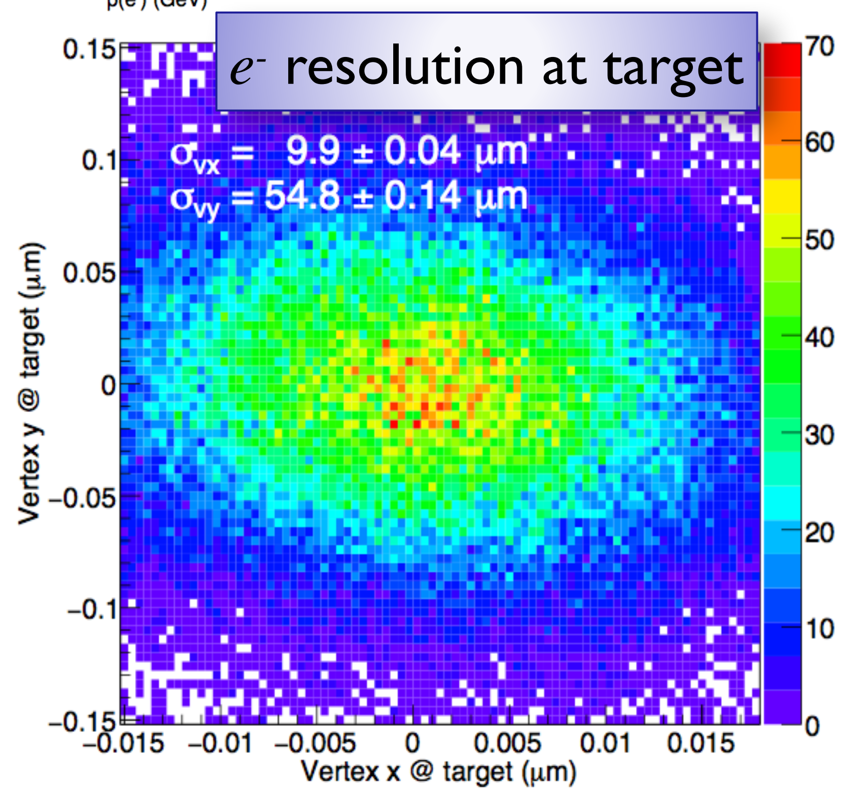


Tagging Tracker Performance

- Momentum resolution of ~1% found in simulation matches analytic calculations
  - ~Vanishing likelihood for 1.2 GeV e- to be reco. as 4 GeV e-
- Momentum Resolution (σ_{px}, σ_{py}) at target is (1.0,1.4) MeV
  - Small compared to 4 MeV smearing from multiple scattering in 10% X0 target.
- Excellent impact parameter resolution
  - Defines small "beam-spot" to match tagger and recoil tracks



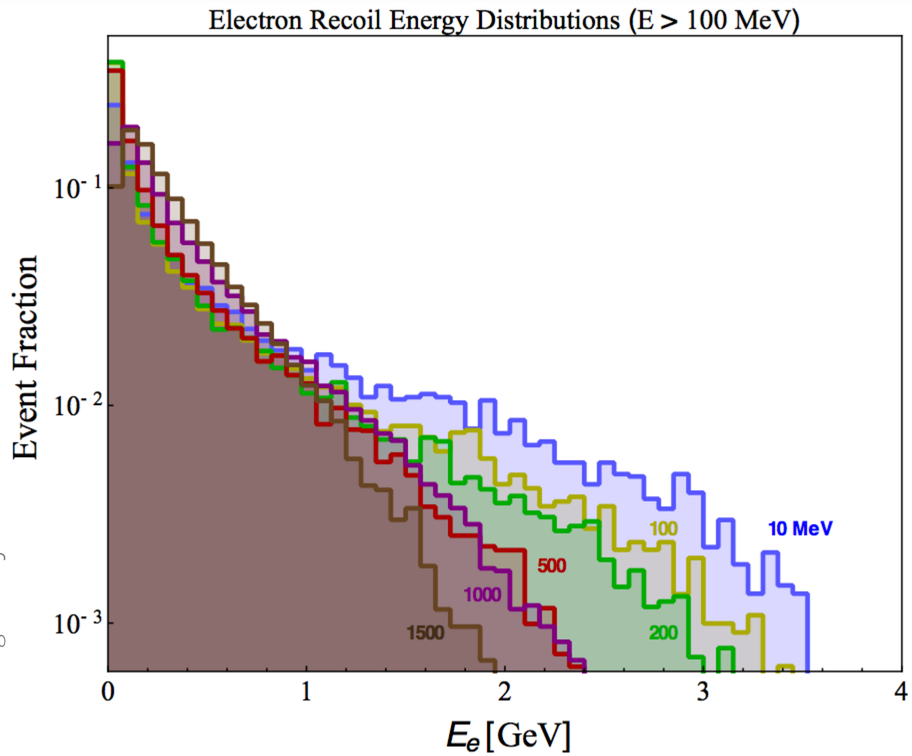


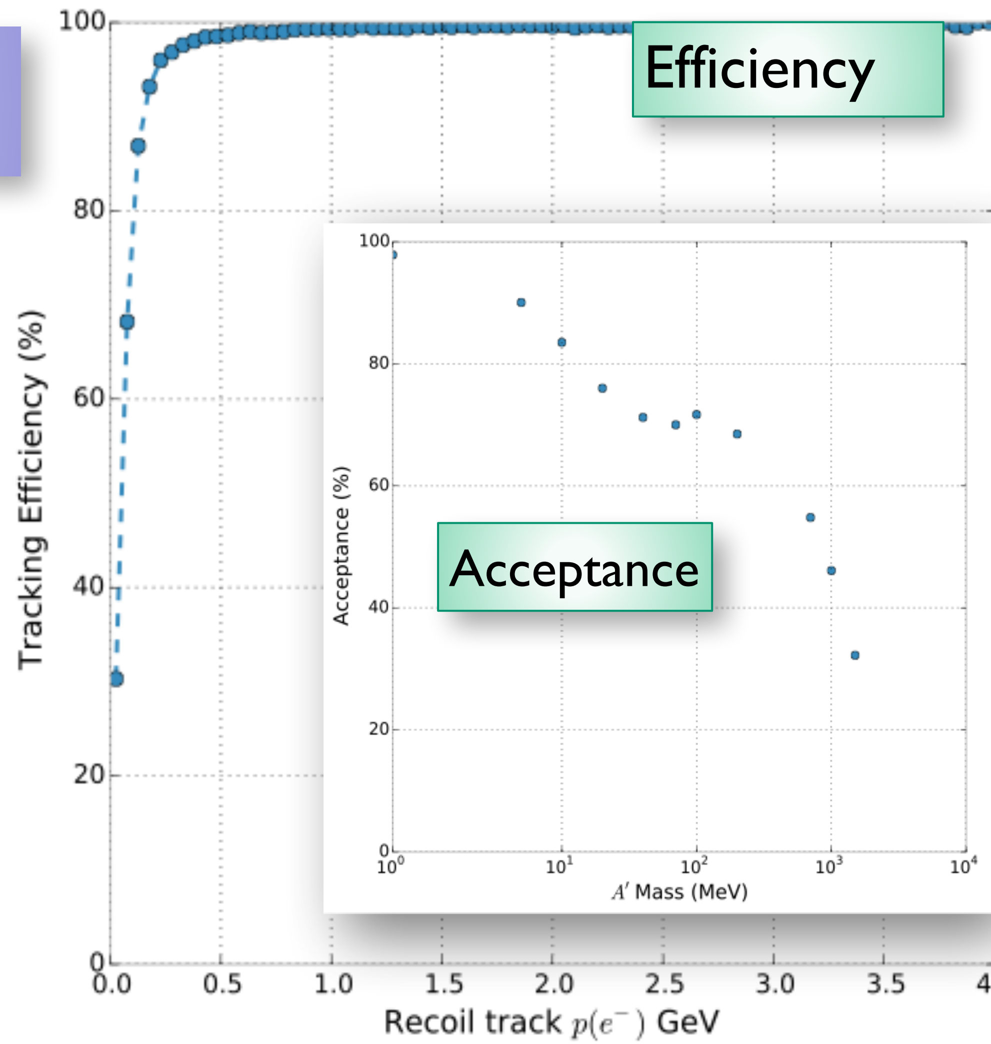


O. Colegrove (UCSB) & - LDMX - APS April Meeting - 29 Jan. 2017

Recoil Tracker Performance

Good acceptance efficiency over a wide range of A′ masses (10 to 1500 MeV shown)





Compact recoil tracker can reliably distinguish non-interacting 4 GeV electrons from low-momentum signal recoils.

Tests are underway to determine the possibility including an active target to reject hard brem. photons which promptly undergo a photonuclear reaction.

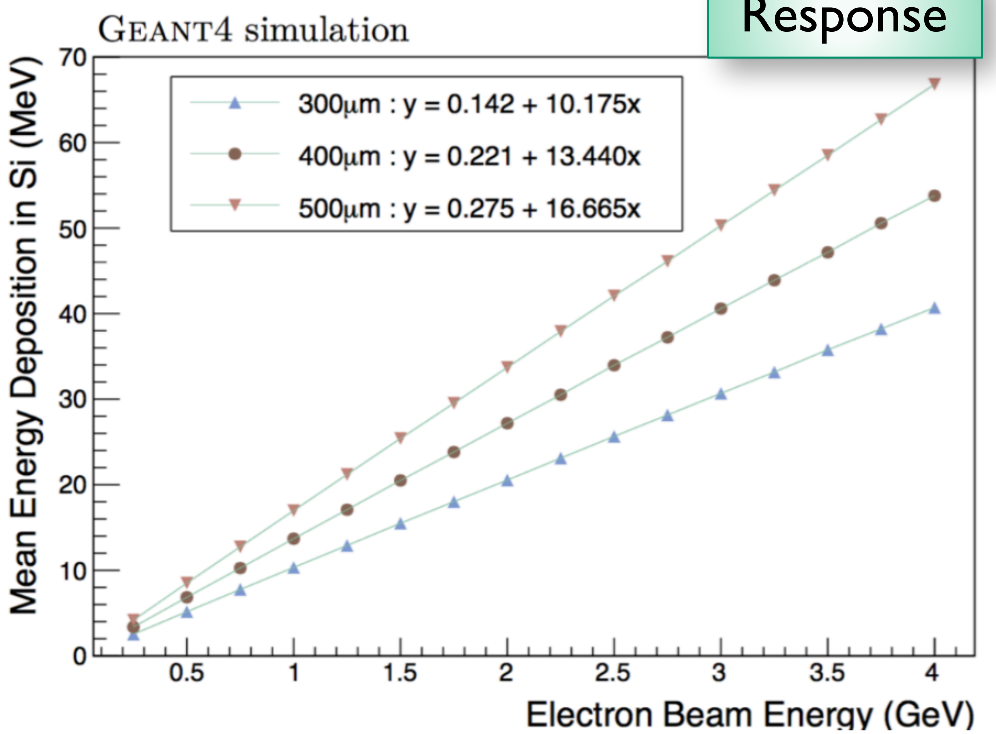
ECAL Performance

E&M Response and Resolution

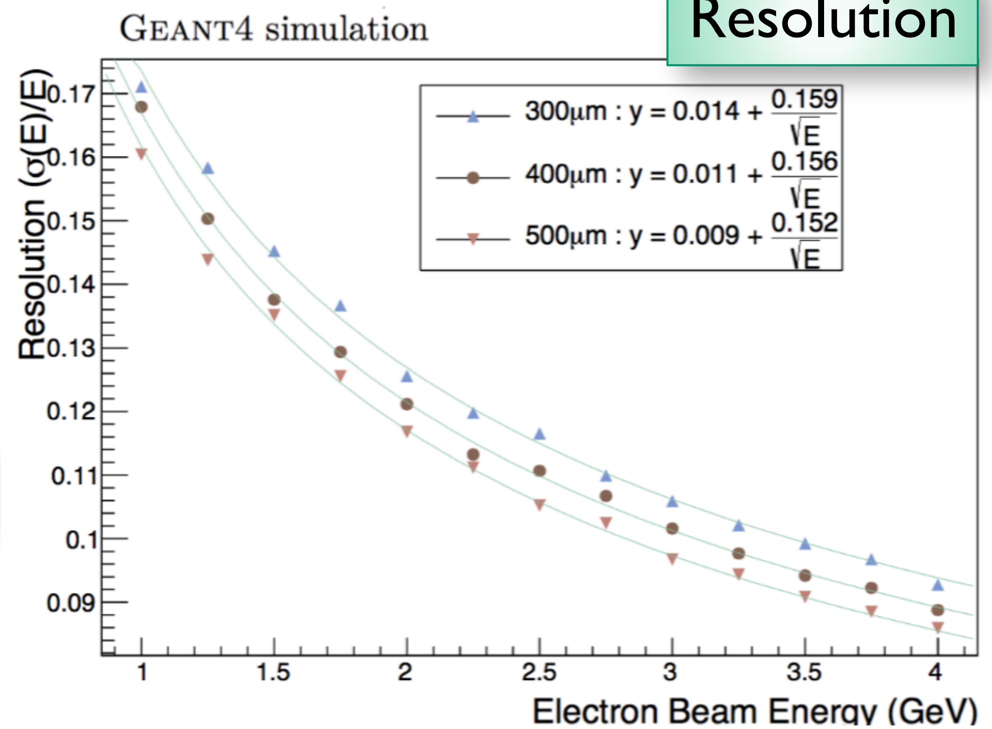
More than 7σ fluctuation is required for a 4 GeV E&M shower to be measured as a 1.2 GeV e-.

Granularity also allows one to track reasonably well-isolated charged hadrons

Response



Resolution



Other Considerations

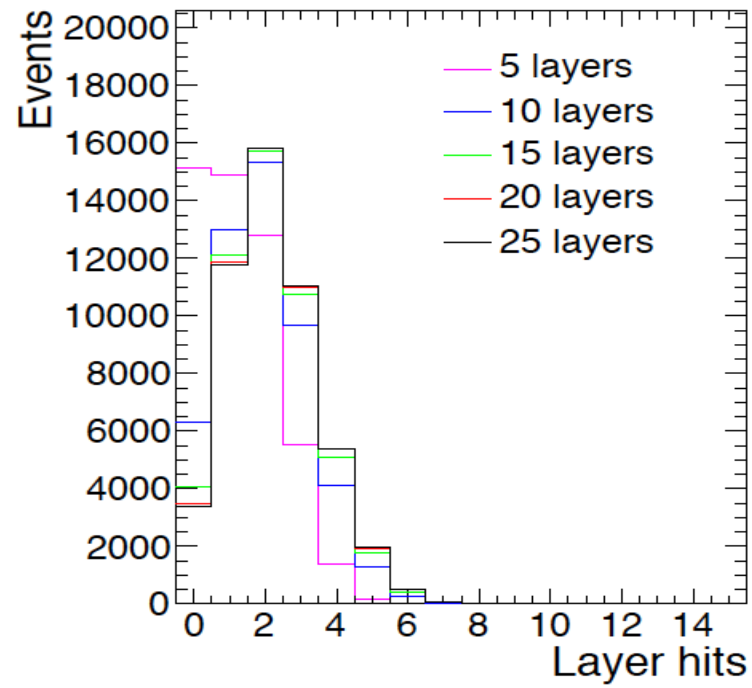
Fluka studies show that 10^{14} e-'s on target results in an effective fluence of 10^{13} n/cm^2

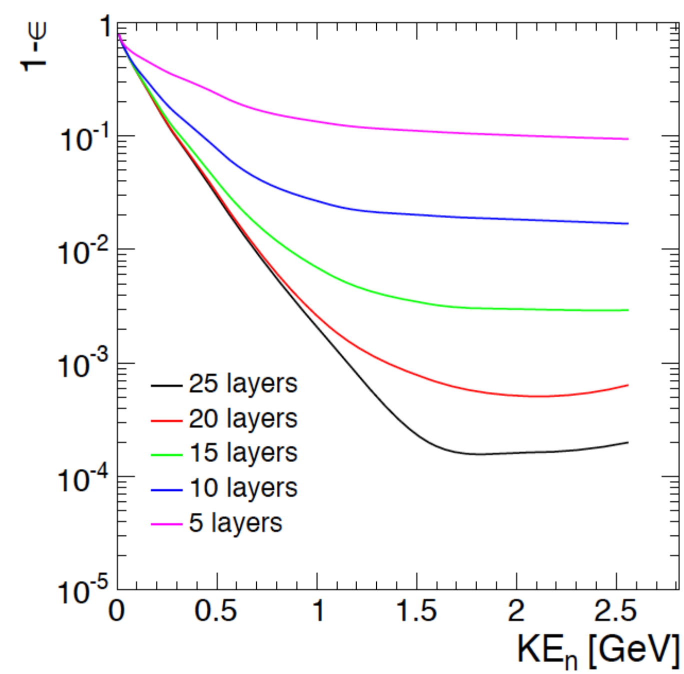
500 um Si is preferred for best resolution

It appears liquid cooling will be sufficient for this environment

Hadron Veto Performance

- Primary role
  - Identification of energetic (1-2.5 GeV KE) neutral hadrons produced in photonuclear interactions in the target or early layers of the ECAL
  - Extension surrounding ECAL will also be useful for wide-angle bremsstrahlung from target and recoil tracker
- Initial optimization
  - Studied benefit of additional layers to improve the efficiency for tagging energetic neutrons
  - Further work is ongoing to tune detector layout, but cost is not likely to change





Experiment Summary

1. Beamline
   - Delivers single 4-GeV electrons in 25 ns buckets ($4 \cdot 10^{14}$ e- in total)
2. Tagger tracker
   - Measures the position and momentum for incoming beam electrons
3. Recoil tracker
   - Measures the position and momentum of primary recoiling electron
4. Electromagnetic Calorimeter
   - Measures total E&M energy and is responsible for primary event trigger
   - High granularity Si/W design allows for the tracking of single MIPs
5. Hadronic Calorimeter
   - Detects hadronic activity resulting from photonuclear interactions
6. Detector Functionality
   - Select events with 4 GeV incoming e- and soft recoil e-.
   - Use calorimetry to reject hard Brem. PN (O(.0003%)) background events.
   - System must perform to reject background with high efficiency

99.999999999%