LDMX -- Light Dark Matter eXperiment

Owen Colegrove, Josh Hildbrand, Joe Incandela, Eder Izaguirre, Gordan Krnjaic, Jeremiah Mans, Takashi Maruyama, Tim Nelson, Philip Schuster, Natalia Toro
**Cartoon Guide to LDMX**

- **Signal definition is a low energy, moderate $p_T$ electron and an otherwise empty calorimeter**
  - Recoil $p_T$ between $\sim 80$ MeV and 800 MeV
  - Goal of $10^{15} - 10^{16}$ EOT
Potential Sensitivity

$y = \varepsilon^2 \alpha_D (m_\chi/m_A)^4$

$LHC@CERN$

$10^{-4}$

$10^{-5}$

$10^{-6}$

$10^{-7}$

$10^{-8}$

$10^{-9}$

$10^{-10}$

$10^{-11}$

$10^{-12}$

$m_\chi$ (MeV)

$10^1$ to $10^3$

$3 \times 10^{16}$ electrons on 10% $X_0$ target

Adapted from PRL 115, 251301 by E. Izaguirre and G. Krijiac
“Easy” Backgrounds

• **~Non-interacting beam**
  - Straight high-momentum track, full-energy cluster colinear* with incoming electron

• **Hard-brem**
  - Low momentum track, could be scattered at high angle
  - Fate of the photon
    - EM-shower: energetic cluster in calorimeter colinear with incoming electron
    - Hadronic interaction: often multiple charged particles (p,K,π,μ), sometimes nastier...
Hard Backgrounds/Signals

- **Neutron (and $K_L$) backgrounds**
  - $\gamma p \rightarrow \pi^+ n$
    - $\sim 10^{-9}/\text{EOT}$ with forward $\pi^+$
    - $\sim 10^{-11}/\text{EOT}$ with forward $n$
  - $\gamma n \rightarrow n\bar{n}n$
    - $\sim 10^{-9}/\text{EOT}$

- **Pileup**
  - Background: “Medium” brems overlapping with 4 GeV electron shower
  - Signal: For $\sim 1$ GeV recoil electrons, overlap with 4 GeV primary electron
Requirements

- Dense, fast calorimeter able to separate multiple showers to allow high-intensity beam
  - Must also be radiation-hard
- Incoming (tagger) tracking to pinpoint photon impact position, reject off-momentum incoming particles
- Outgoing (recoil) tracking to measure recoil electron, identify closely-spaced charged particles
- MIP-sensitivity in calorimeter to identify photonuclear processes
Experiment Concept

- Low mass trackers in dipole field and fringe field: leverage experience/technology from HPS and NA62
- Silicon/tungsten calorimeter for good shower separation and high rate capability: based on developments for CMS HL-LHC endcap calorimeter
Tagging Tracker

- **Identify beam-energy electrons with extraordinary purity**
  - many layers over large lever arm in 1.5T field
  - low-mass construction in vacuum to minimize multiple scattering and production of secondaries
  - high S/N to minimize noise occupancy
  - fast readout, good time resolution to reduce physics occupancy

- **For low intensities, silicon microstrips may work (~HPS)**
  - 0.7% X0/layer
  - 2 ns time resolution/hit

- **Highest intensities motivate pixels similar to NA62**
  - \( \lessapprox 0.5\% \) X0/layer
  - microchannel CO\(_2\) cooling
  - 100\(\mu\)m \(\times\) 100\(\mu\)m pixels
  - \( \lessapprox 1\) ns time resolution
Recoil Tracker

• Measure E, pT of recoils, secondaries over large range in momentum and production angle in compact space
  - many layers over small lever arm in fringe field
  - low-mass construction in vacuum to minimize multiple scattering and production of secondaries
  - high S/N to minimizes noise occupancy
  - fast readout, good time resolution to reduce physics occupancy
  - readout must enable simple tracking in trigger, certainly for high intensities

• For low intensities, silicon microstrips may work
  - 0.7% X0/layer
  - 2 ns time resolution/hit

• Highest intensities and acceptance motivate pixels similar to NA62 for small layers closest to target
  - ≤0.5% X0/layer
  - microchannel CO2 cooling
  - 100μm × 100μm pixels
  - ≤1 ns time resolution
The CMS HL-LHC Endcap Calorimeter

- Modules consist of one or two hexagonal sensors with a copper/tungsten baseplate.
- Readout PCBs with integral readout ASICs glued on top and wirebonded down through holes in the PCB
- Copper cooling plates + CO$_2$ for heat removal
Performance of default design

- Default design
  - 10 layers with 0.65 $X_0$ spacing
  - 10 layers with 0.88 $X_0$ spacing
  - 8 layers with 1.25 $X_0$ spacing

- For low-energy electrons, using 0.65 $X_0$ for more layers may be appropriate

- MIP sensitivity, S/N starts at 14, should stay above 7 for $10^{16}$ EOT
Cluster Separation

- High-granularity in longitudinal shower development allows separation of closely-spaced showers by matching large amplitude signals at shower max with narrow signatures in the early layers.
Studies of Cluster Separation for LDMX

- **Study of separating a single 4 GeV electron from a 2-3 GeV bremsstrahlung photon plus a beam electron**
  - Hit counting and shower-shape variables are effective.

![Diagram showing 2000 MeV Photon with hit counting and shower-shape variables](image1)

![Geant4 Simulation showing normalized distribution of hits and containment radius](image2)
Potential of Timing

Simulation, backed by testbeam results, indicates that O(80 ps) timing should be possible for EM showers in the 2-4 GeV range.

- Provides additional handle to separate clusters at higher beam current, correct effects of.
- Depending on beam configuration (e.g., deterministic RF dilution), can use for associating clusters with incoming beam particles.

P. Meridiani et al, under preparation
DAQ and Trigger

- CMS FE-ASIC to produce 2x2 merged-cell trigger primitives (no TDC) at 40 MHz, full readout with TDC at 750 kHz
  - Total 5 Gbps link count < 600 for full detector
  - Operational mode for 5ns bunch spacing with ASIC designed for 25ns requires study

- Trigger algorithm required to drop rate to ~750 kHz
  - $10^{16}$ EOT in a year implies ~1 GHz
  - At low intensities, trigger may be possible by looking for events with less than 2 GeV in the calorimeter
  - At higher intensities, trigger will likely require input from either tagging tracker or recoil tracker
Status of the CMS HL-LHC Endcap R&D

- **Testbeam studies at FNAL in March and May 2016**
  - Production-candidate sensors with CALICE-type readout chip (low rate)
  - Results (preliminary!) are good for S/N and absence of anomalous signals

- **First full-scale FE-ASIC expected in 2017, much of readout chain technology already demonstrated**
Conclusion

- Physics potential for LDMX is very exciting
  - Target large range of thermal relic phase phase, possibility for study of characteristics of dark matter in the case of discovery

- Experiment is realistic based on technologies in use or under development for HL-LHC experiments

- More collaborators are welcome!