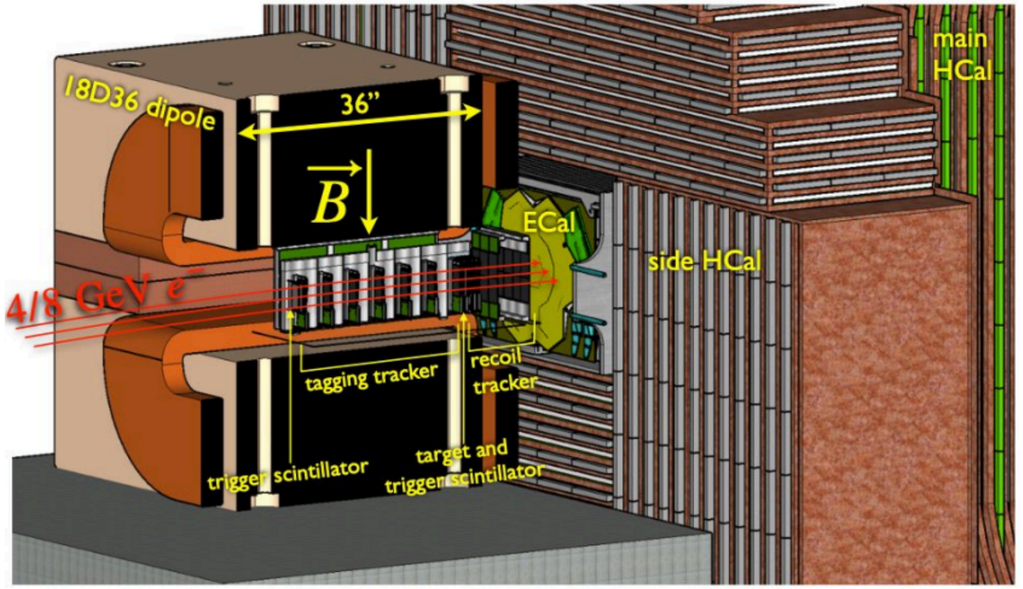
ACTS in LDMX

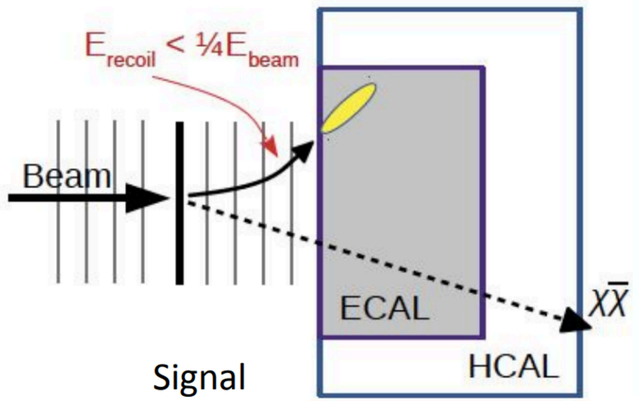
ACTS Workshop, Nov. 18 2024

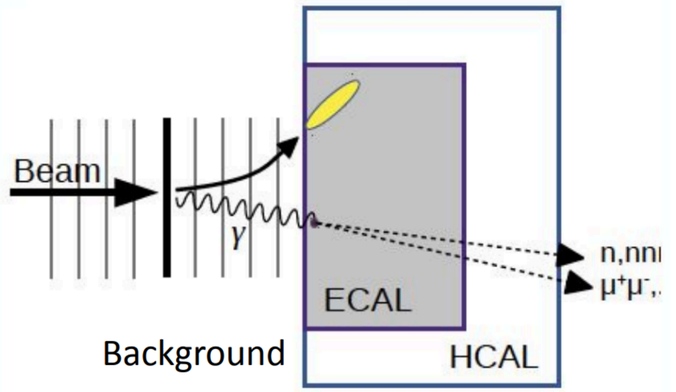
Elizabeth Berzin (Stanford University)

LDMX Overview

- Missing momentum search for thermal relic light DM
  - Broader physics impact: eN scattering, involves more complex final states
- Signal characteristics:
  - Typical benchmark: dark photon (A') kinetically mixing with SM photon
  - Dark matter production through dark bremsstrahlung (invisible decay)
  - A's carry most of the beam energy; only visible final state particle is a soft recoil electron
- Requires individual reconstruction of incident electrons, achieved with low-intensity beam (~1-4 electrons on target per event)
- Plan to accumulate 1e16 electrons on target at a beam energy of 8 GeV, using the LCLS II beam at SLAC.





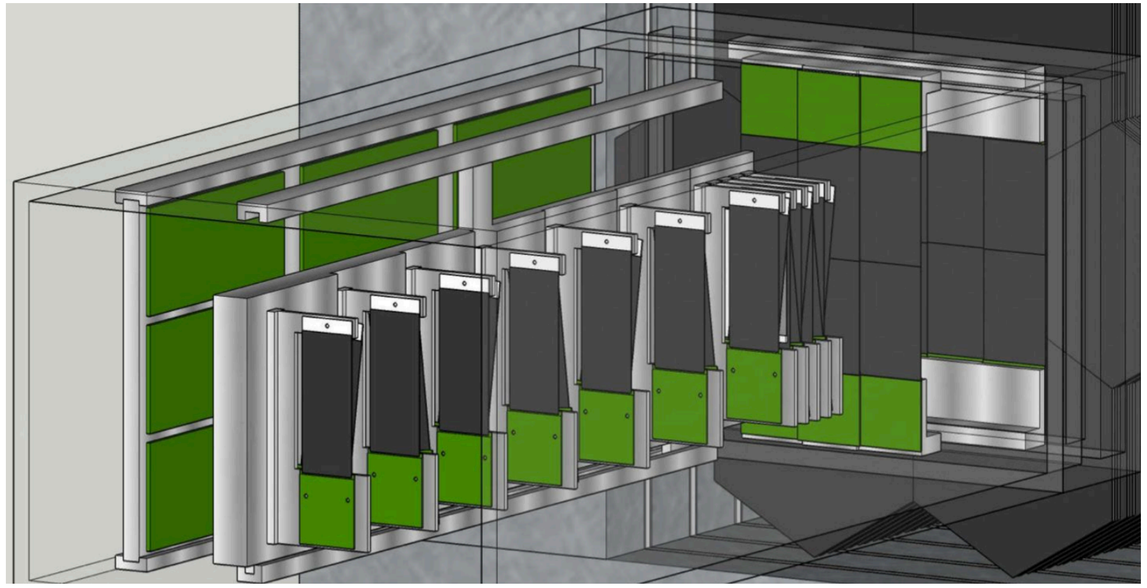


Tracker Geometries

- **Tagger tracker:** reconstructs incoming electron momentum, and rejects off-energy electrons (low acceptance, high momentum resolution at the beam energy)
  - Consists of 7 double-strip layers, 46.02 mm x 94 mm active area, in large uniform B-field.

TABLE I: The layout and resolution of the tagging tracker.

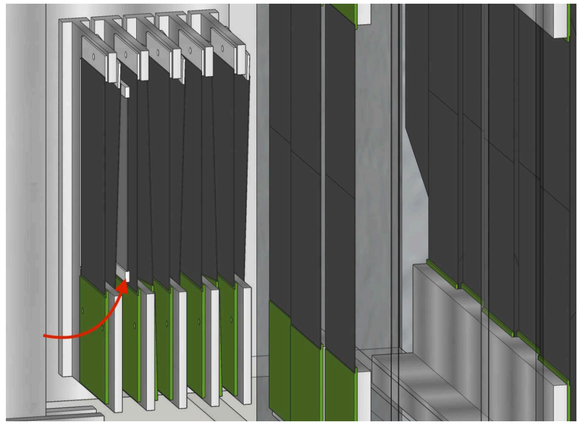
Layer	1	2	3	4	5	6	7
z-position, relative to target (mm)	-607.5	-507.5	-407.5	-307.5	-207.5	-107.5	-7.5
Stereo Angle (mrad)	-100	100	-100	100	-100	100	-100
Bend plane (horizontal) resolution (μm)	$\sim$6	$\sim$6	$\sim$6	$\sim$6	$\sim$6	$\sim$6	$\sim$6
Non-bend (vertical) resolution (μm)	$\sim$60	$\sim$60	$\sim$60	$\sim$60	$\sim$60	$\sim$60	$\sim$60

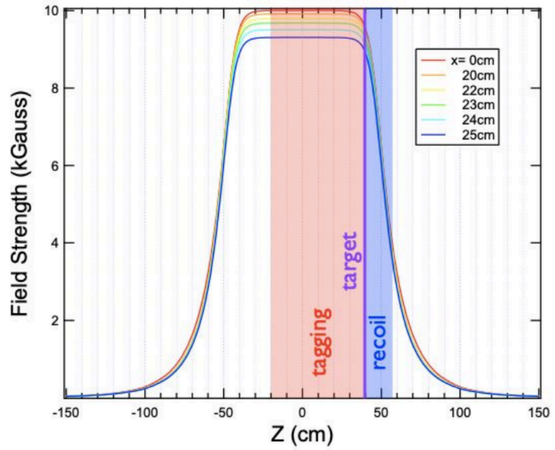


- **Recoil tracker:** reconstructs recoil electron (high acceptance, good resolution at low momentum)
  - Consists of 4 double-strip layers + 2 axial-only layers for increased acceptance, in downstream fringe field.

TABLE II: The layout and resolution of the recoil tracker.

Layer	1	2	3	4	5	6
z-position, relative to target (mm)	+7.5	+22.5	+37.5	+52.5	+90	+180
Stereo Angle (mrad)	100	-100	100	-100	-	-
Bend plane (horizontal) resolution (μm)	$\approx$6	$\approx$6	$\approx$6	$\approx$6	$\approx$6	$\approx$6
Non-bend (vertical) resolution (μm)	$\approx$60	$\approx$60	$\approx$60	$\approx$60	-	-



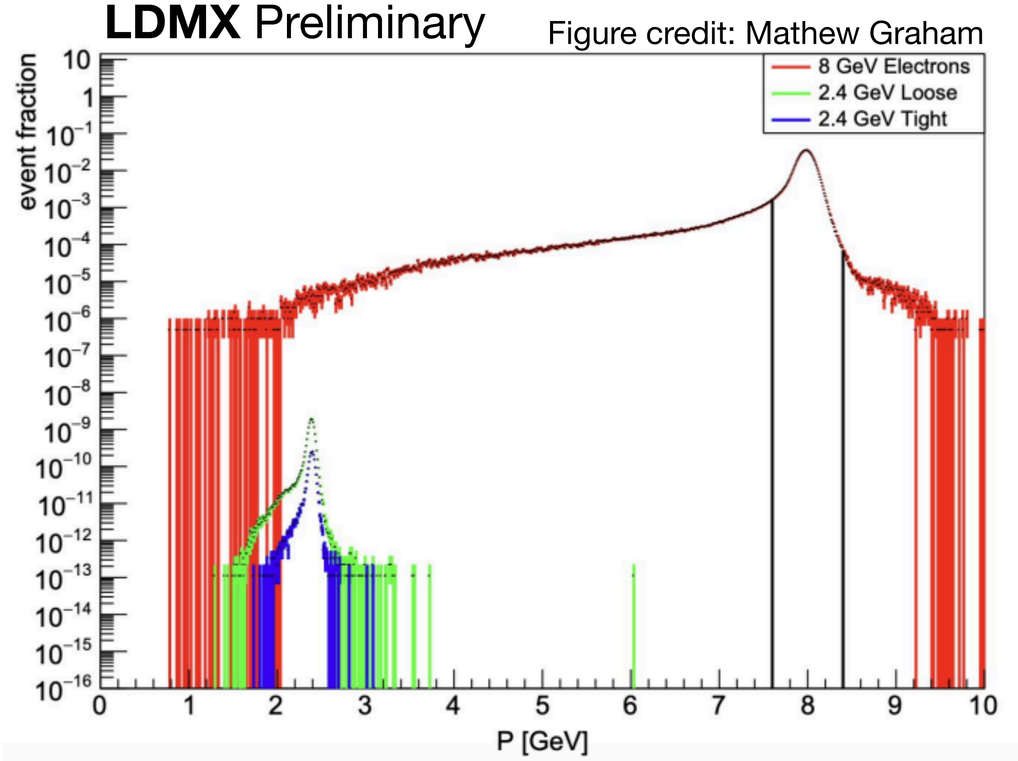


Overview of Tracking Approach

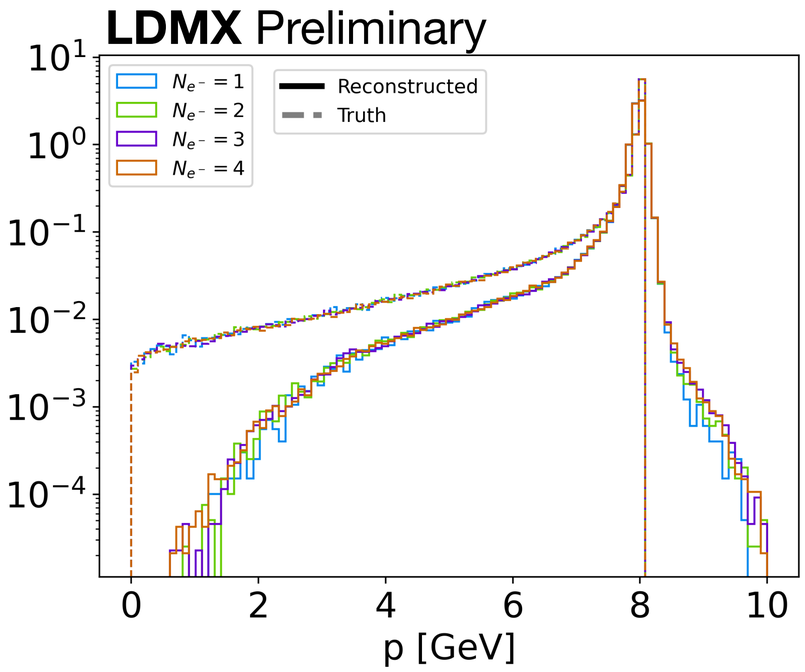
- **Seeding:** Initial track parameters estimated used a parabolic fit to sets of five hits.
- **Tracking:** CKF, GSF refitting with ACTS.
- **Ambiguity Resolution:** Greedy and score-based solvers adapted from ACTS.
- **Performance Requirements:**
  - 2.4 GeV fake rate < 1e-13 in tagger tracker
    - Most important benchmark for tagger: full rejection of off-energy beam electrons assuming worst-case beam contamination of 1e-3 with electrons < 2.4 GeV
  - Fake rate for 8 GeV electrons < 1e-2 in recoil tracker
    - Recoil tracker assists ECal in identification of non-interacting electrons
  - Tagger-recoil Δp_T resolution < 4 MeV
    - p_T (momentum transverse to beam direction) limited by multiple scattering in the target

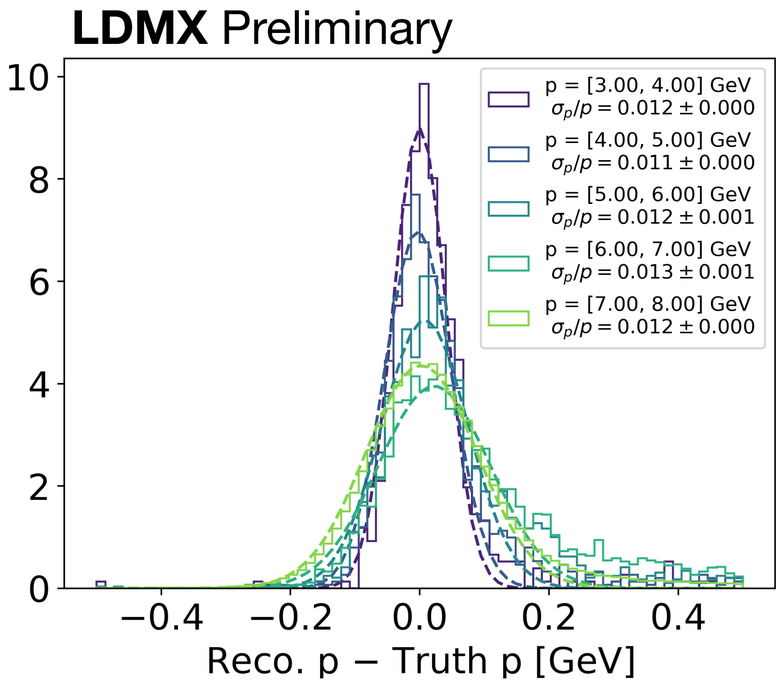
Off-Energy Beam Electrons

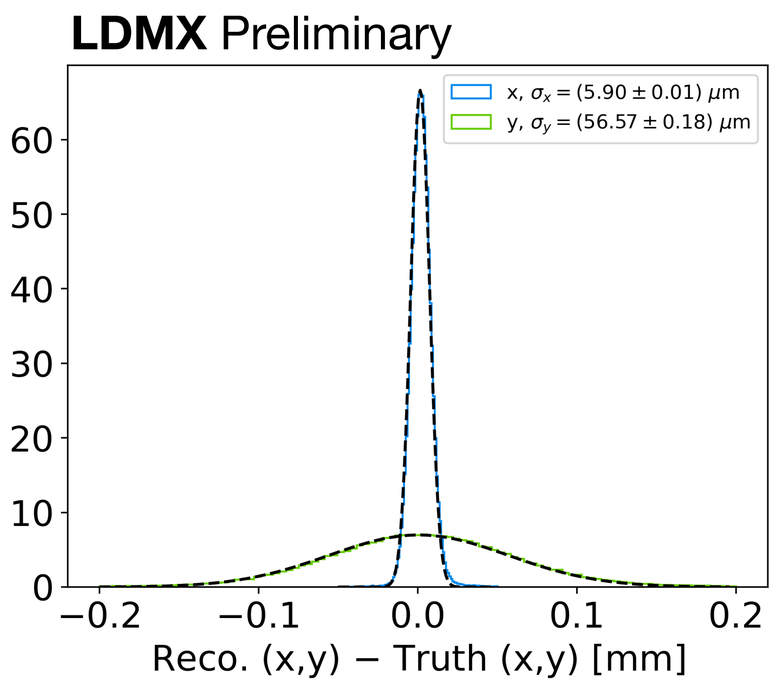
- Assuming worst-case 1e-3 beam contamination with 2.4 GeV electrons, tagger must have < 1e-13 mis-reconstruction rate.
- Most off-energy electrons will be bent out of tagger acceptance before reaching the target, but hard scatters may cause low-energy electron to mimic beam-energy electron trajectory.
- For 1e11 electron sample, no off-energy events reconstruct within 5% of beam energy.
  - Handles: electron position at the target, angle with respect to target surface.
- Work underway to demonstrate rejection power in higher statistics sample.



Tagger Resolution



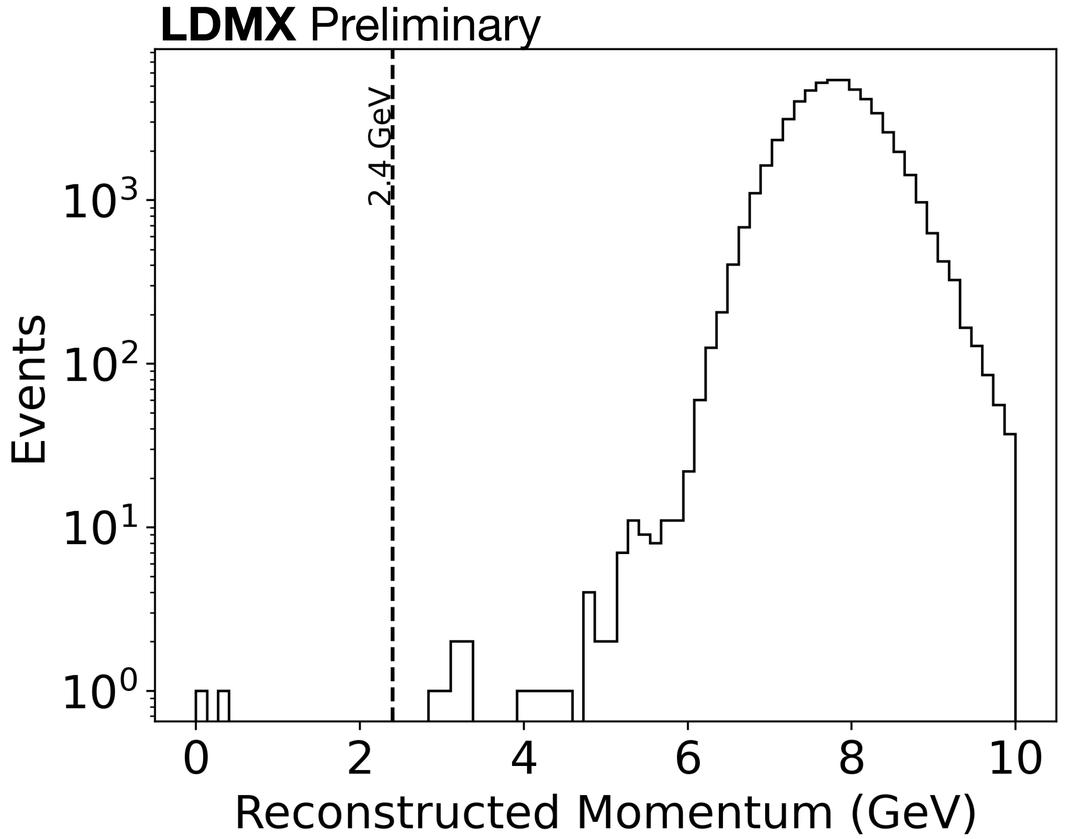




- ~1% momentum resolution near beam energy.
- Position resolution at target in x,y of ~6 um, 60 um.
- Some asymmetry in momentum residual (improvements possible with GSF).

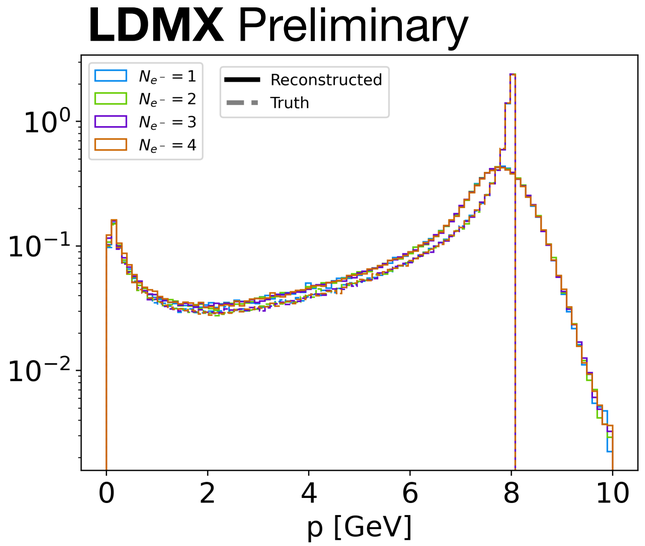
Full-Energy Beam Electrons

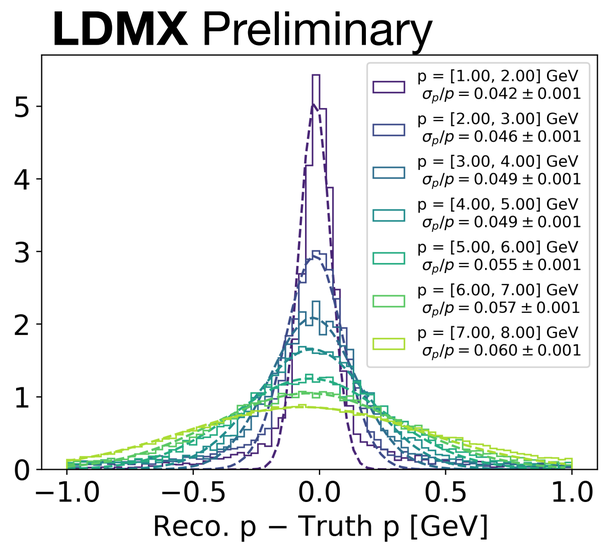
- Recoil tracker can assist with identification of non-interacting electrons.
- After selecting truth tracks with energy > 7.6 GeV at the ECal: fraction of events reconstructing < 2.4 GeV: ~1e-5

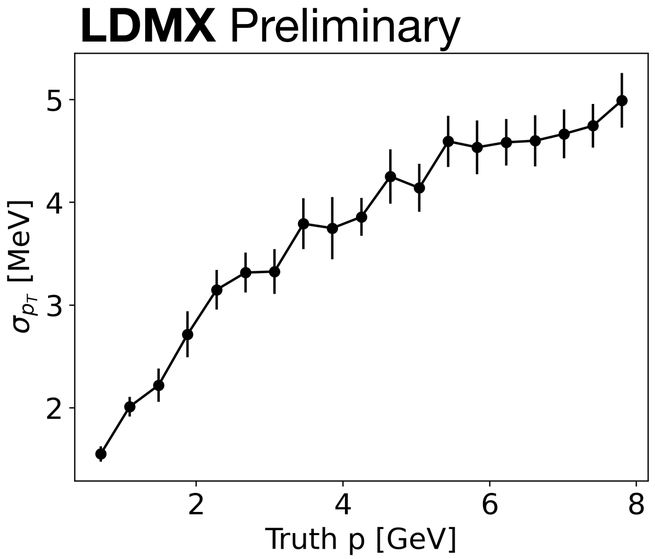


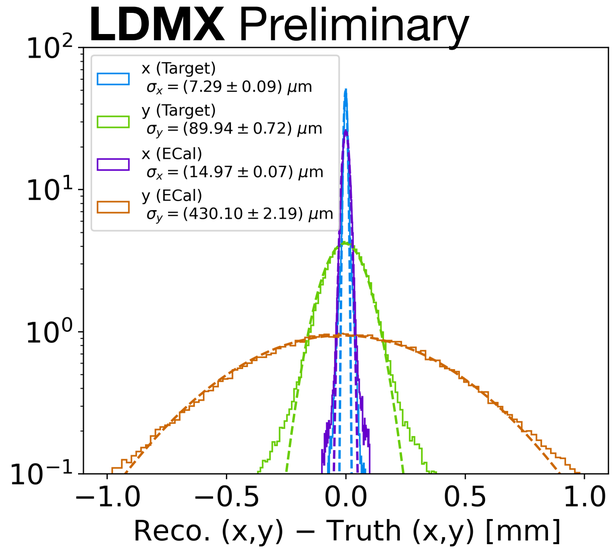
Recoil Resolution

- Recoil electron p_T resolution < 5 MeV.
  - Able to reconstruct p within ~5%.
- Position resolution at target in x,y of ~7 um, 90 um.
- Position resolution at ECal in x,y of ~15 um, 430 um.

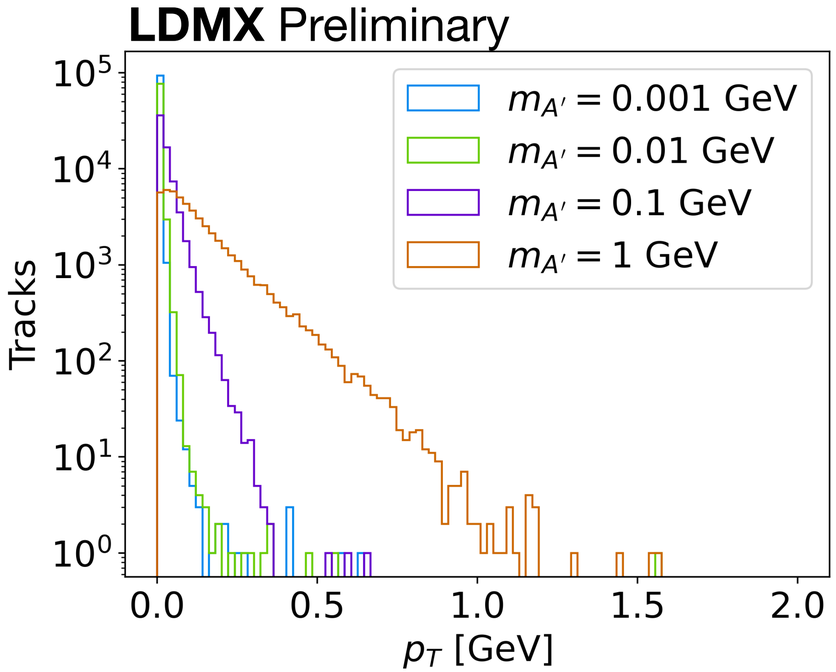


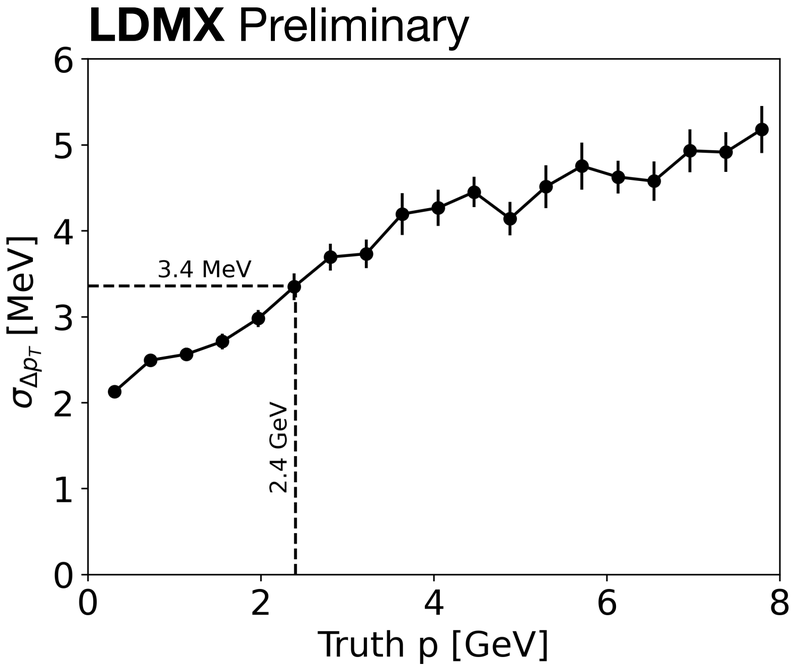






p_T change across target

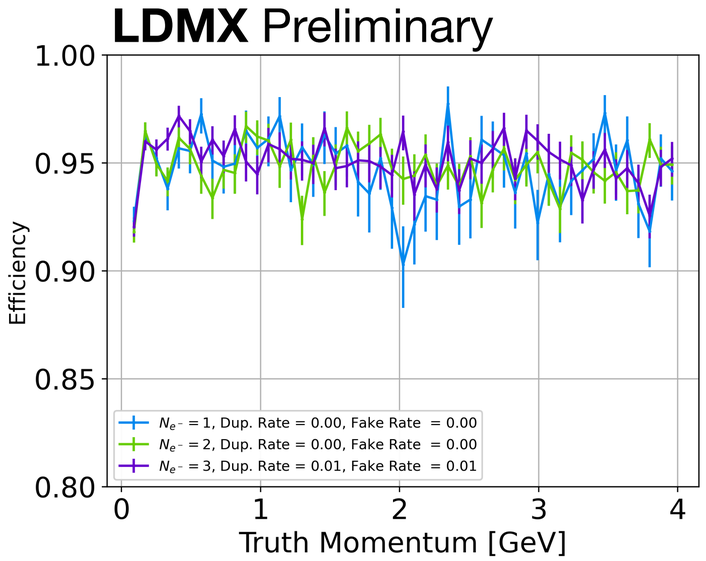


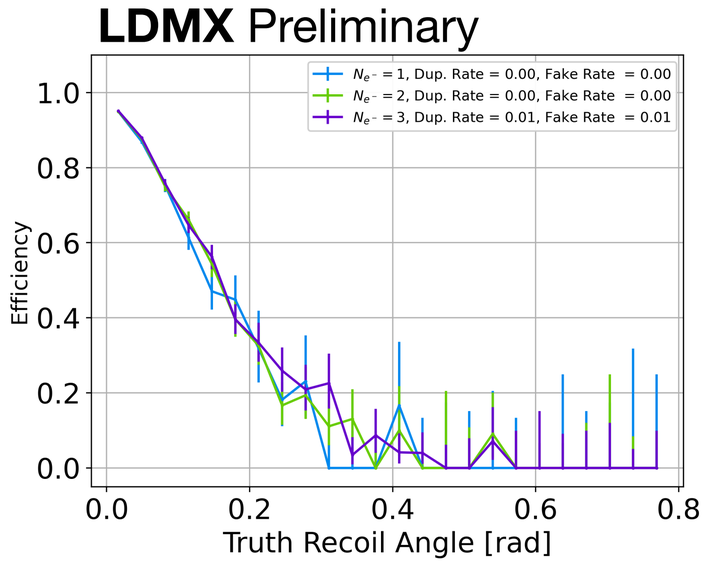


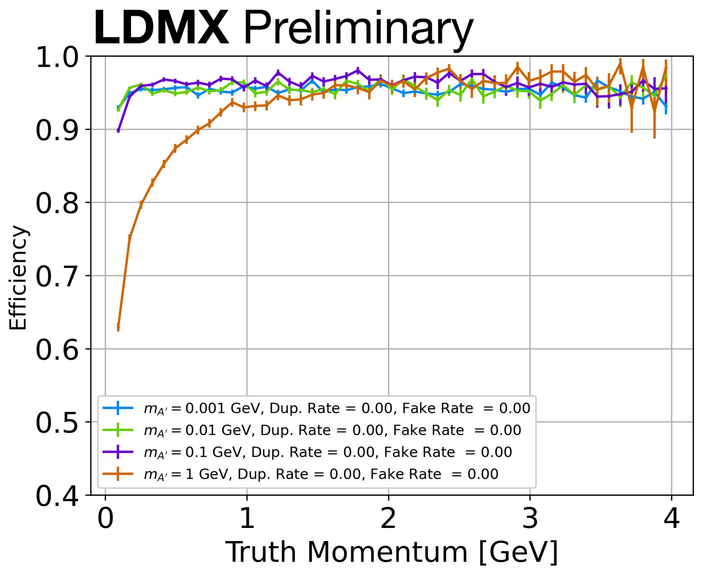
- Require p_T resolution across the target be limited by multiple scattering in target (4 MeV)
- Track p_T provides signal discrimination handle.

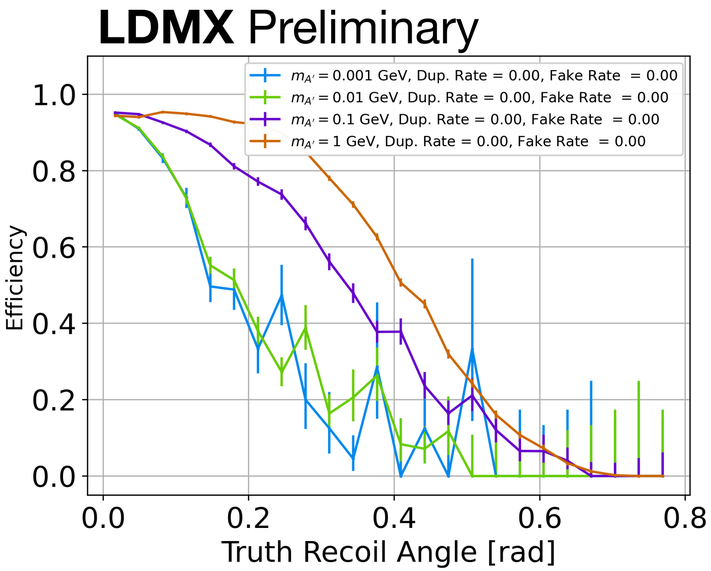
Recoil Tracking Efficiency

- Efficiency: Fraction of reconstructed tracks with truth hit fraction > 0.5, relative to all findable tracks
  - Findable track: > 7 hits
- > 90% efficiency for inclusive events and signal events with $m_{A'} \leq 0.1$GeV, down to recoil electron energies of 50 MeV.
- Drop in efficiency at highest signal mass point, due to angular distribution.









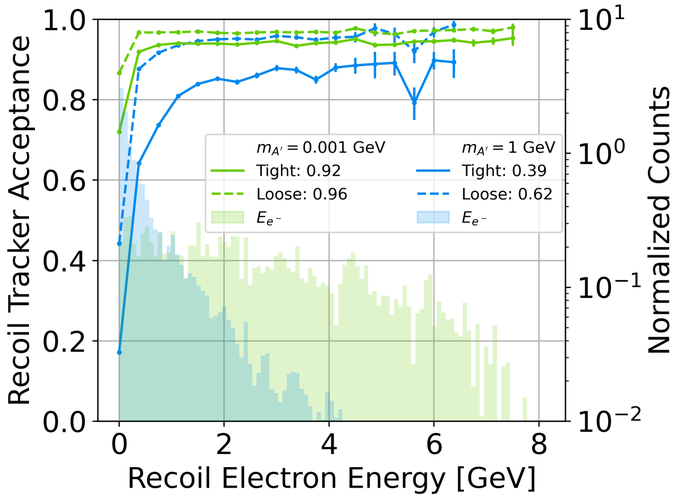
Conclusions

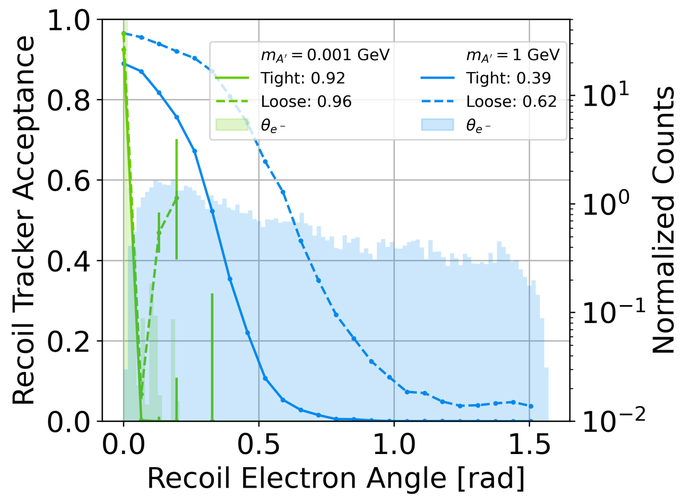
- Usage of ACTS in LDMX has been successful in reaching key performance requirements:
  - Off-energy beam electron rejection in tagger.
  - Full-energy electron rejection in recoil.
  - Tagger/recoil momentum and position resolution.
  - Tagger/recoil efficiencies.
- Ongoing work:
  - Extension of off-energy beam electron rejection studies to 1e13 sample.
  - Improvements to momentum resolution through GSF implementation.
  - Interested in implementing more sophisticated ambiguity solving.

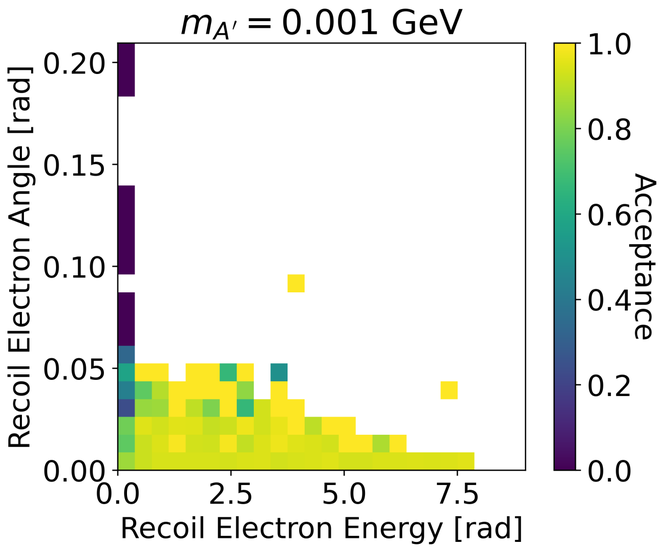
Backup

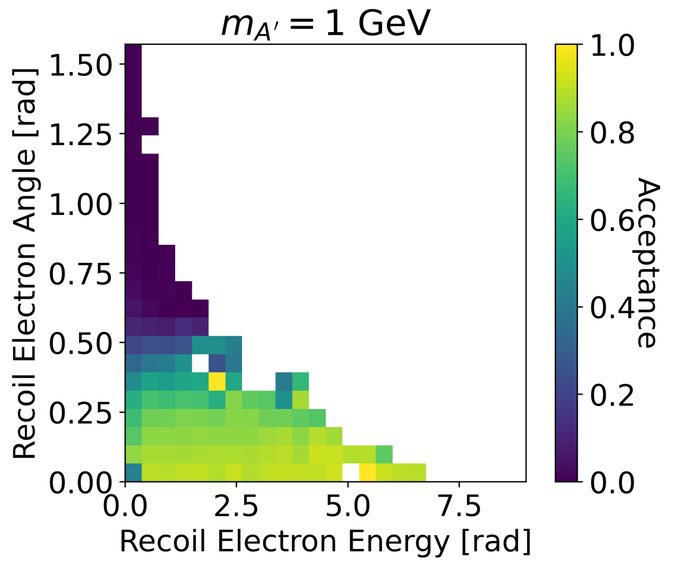
Recoil Tracker Acceptance

- Acceptance shown for two selections:
  - Tight: hits in all layers
  - Loose: hits in first two layers and >= 5 hits overall









GSF Refitting