LDMX Concept, Status, and Plans

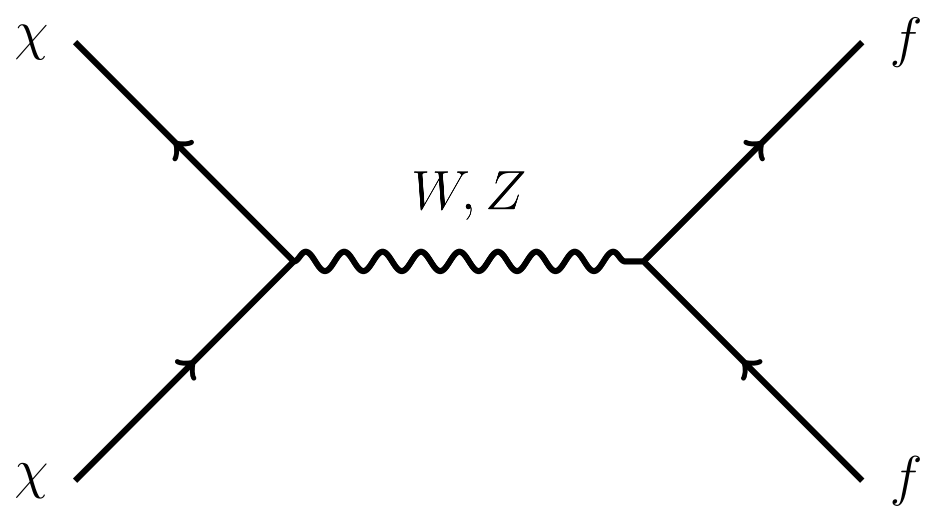
Minnesota CMS/LDMX Group Symposium

August 16, 2021

Jeremiah Mans

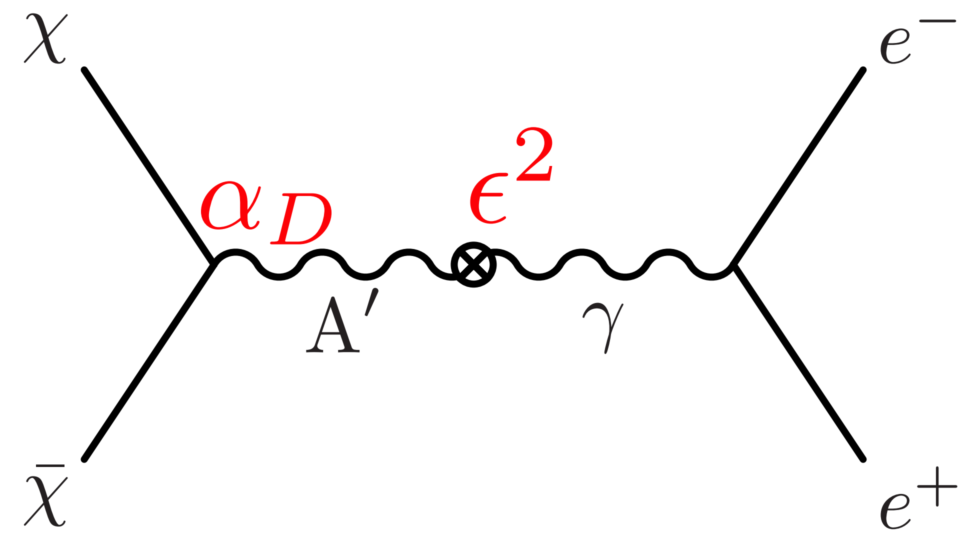
Sub-GeV Freeze-out Thermal Relics

WIMP thermal DM:
$M_\chi < 2\ \mathrm{GeV}$ results in early freeze out, too much DM



$$\sigma v \sim \frac{\alpha^2 m_\chi^2}{m_Z^4} \sim 10^{-29}\mathrm{cm}^3\mathrm{s}^{-1}\left(\frac{m_\chi}{\mathrm{GeV}}\right)^2$$

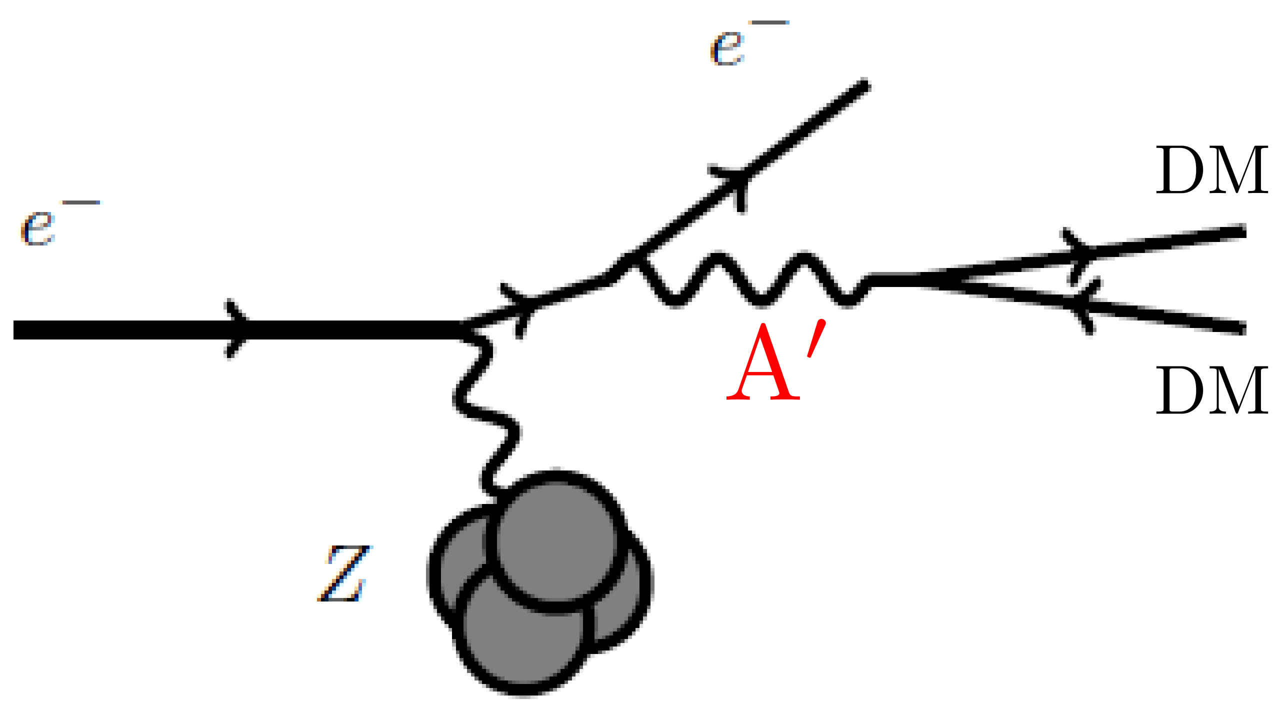
sub-GeV thermal DM:
new comparably light mediator can give correct relic abundance.
Example: dark photon mediator

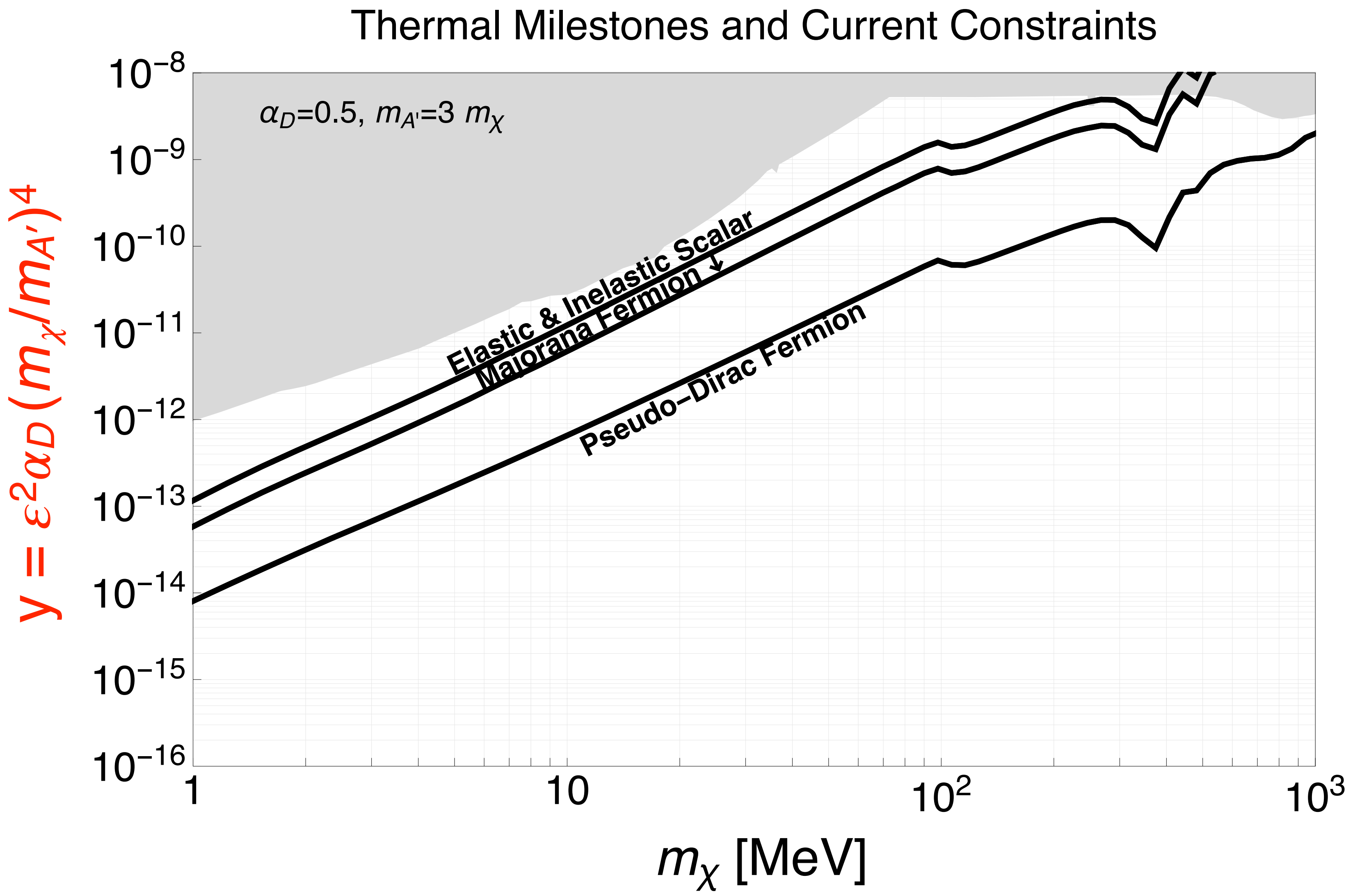


$$\sigma v \propto \epsilon^2 \alpha_D \frac{m_\chi^2}{m_{A'}^4} \equiv \frac{y}{m_\chi^2}$$

$$y \equiv \epsilon^2 \alpha_D \left(\frac{m_\chi}{m_{A'}}\right)^4$$

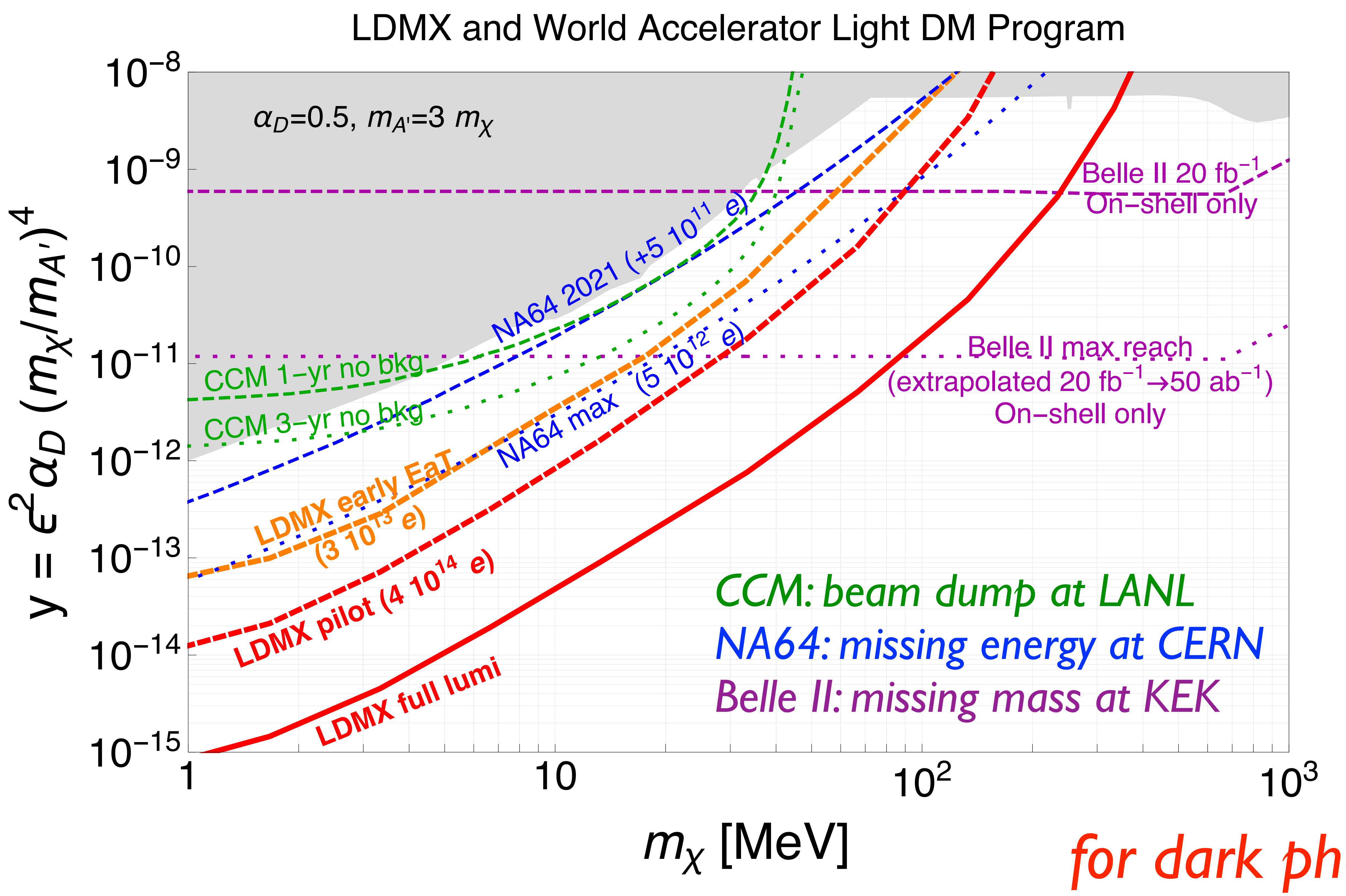
Observed DM abundance predicts (minimum) cross section at accelerators





Sensitivity: Missing Energy/Momentum, Beam Dumps, and Direct Detection

Missing momentum experiments, using modern detectors operating directly in a low-current lepton beam, identify dark matter production events based on the kinematics of visible particles recoiling from the production event. Such experiments in a continuous-wave electron beam offer a path to reach 1000-fold improvement in sensitivity over a broad mass range …



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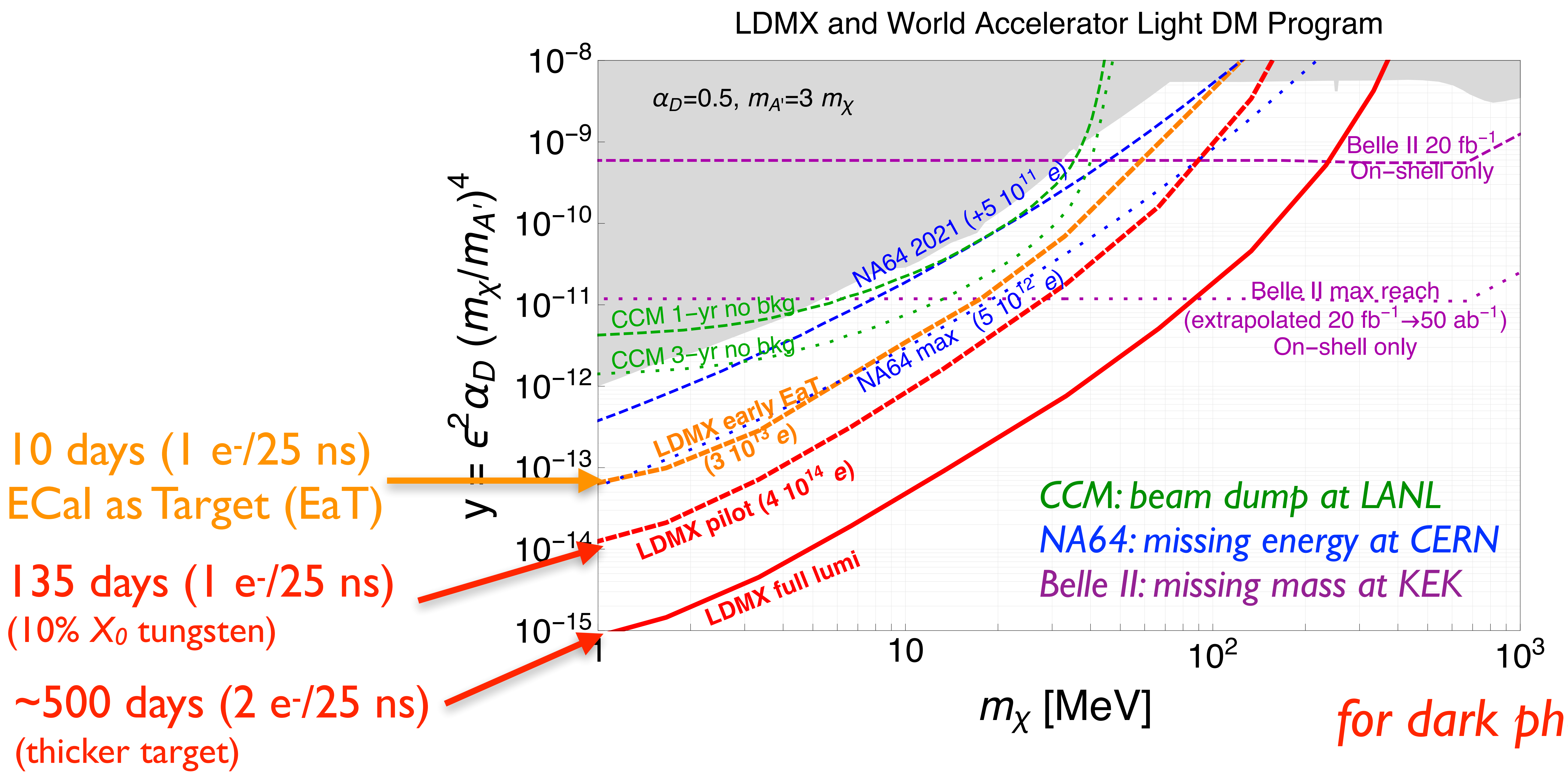

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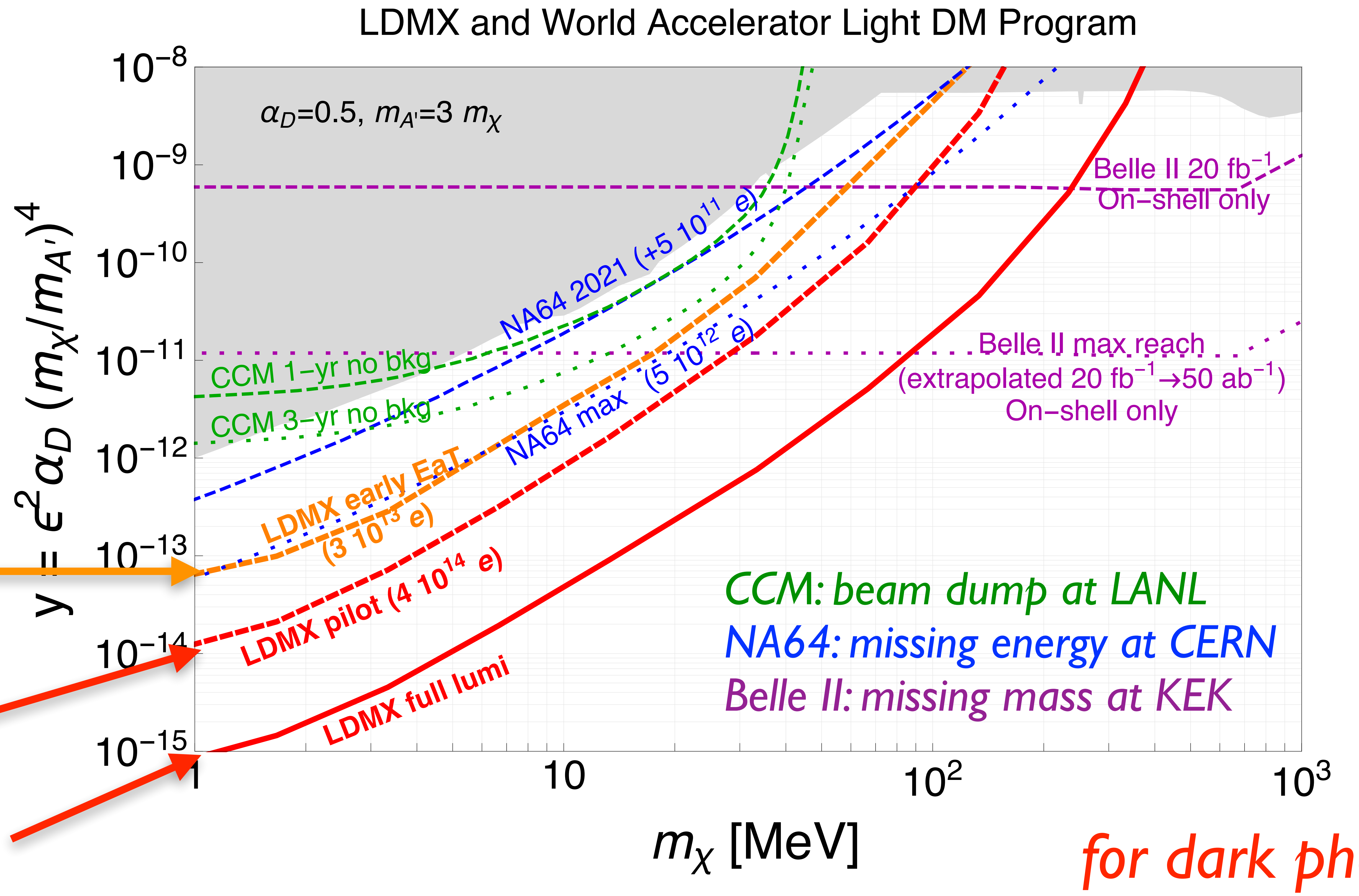
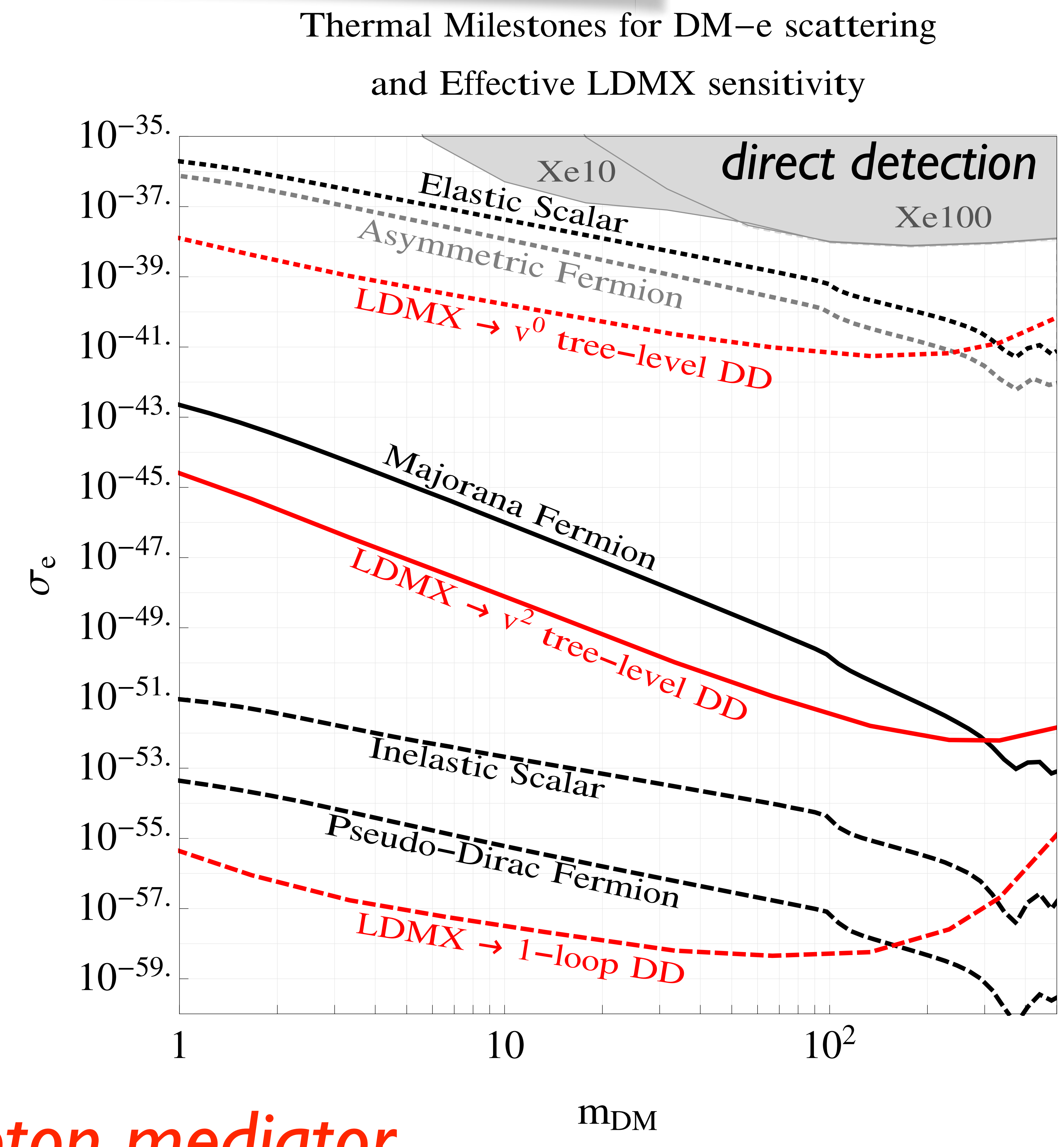
10 days (1 e-/25 ns)
ECal as Target (EaT)

135 days (1 e-/25 ns)
(10% X_0 tungsten)

~500 days (2 e-/25 ns)
(thicker target)





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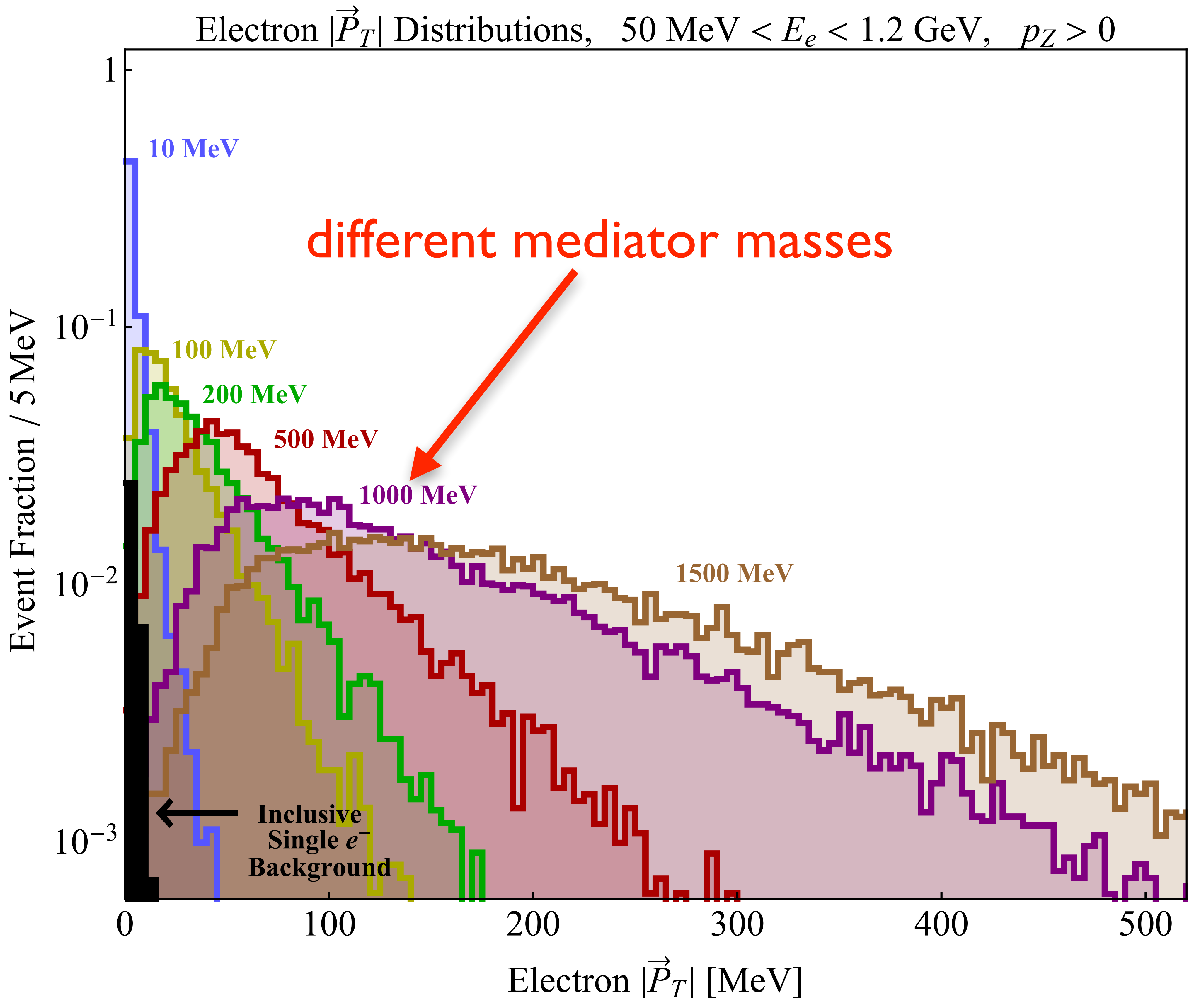
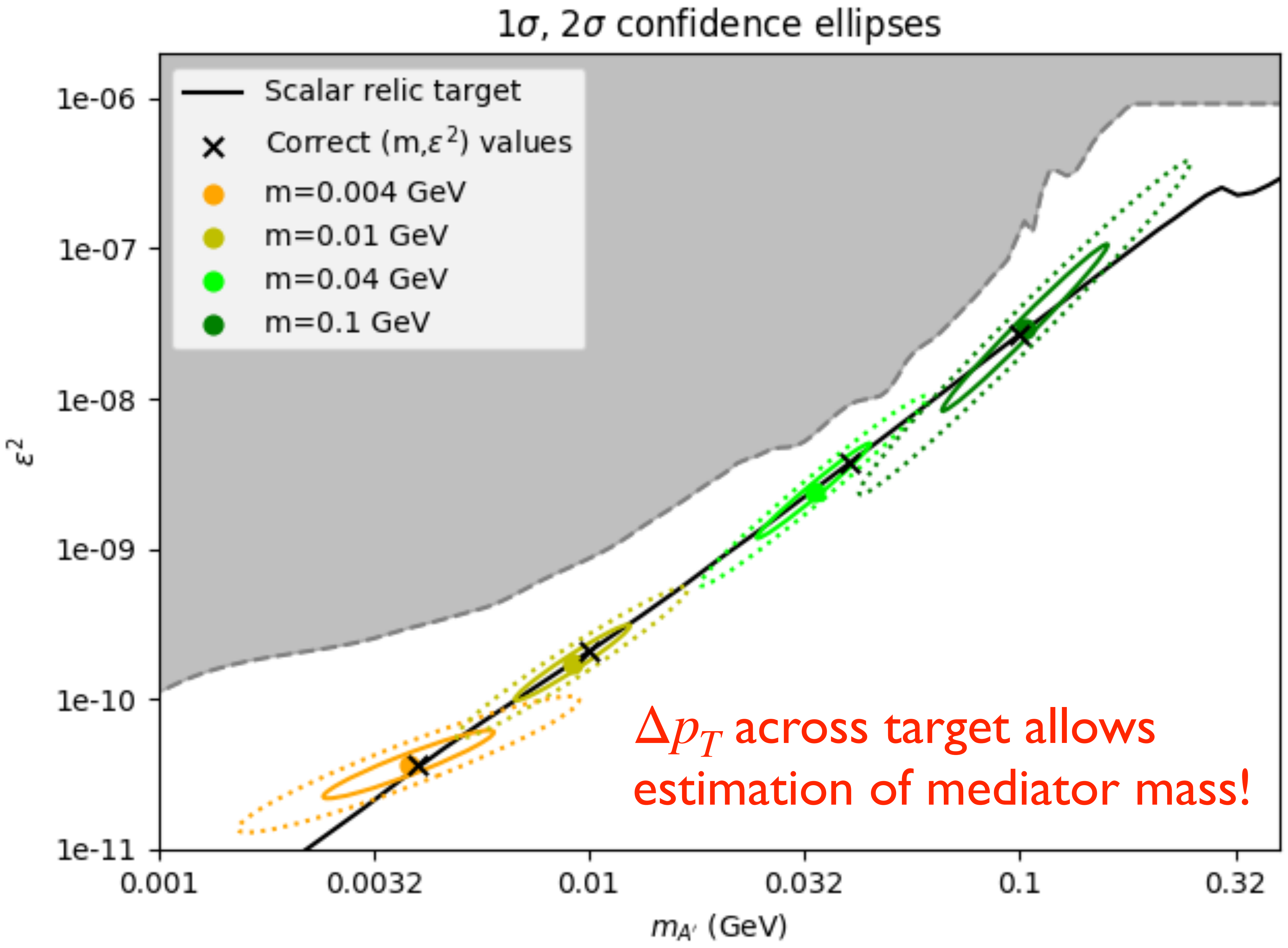
LDMX measures the kinematics of dark matter production, enabling detailed study of the dark sector!





for dark photon mediator

LDMX: The Broader Physics Case

Invisible Signatures

- other mediators
- millicharged particles:
  arise from ~massless dark photons and
  thrust into spotlight by EDGES anomaly
- inelastic Dark Matter (iDM):
  large mass-splittings in dark states
- Strongly Interacting Massive Particles (SIMPs):
  a confining interaction in the dark sector
  (both visible and invisible signatures)
- freeze-in DM

Visible Signatures (DMNI PRD 1, Thrust 2)

- Dark Photons
- Axion-like particles (ALPs)

arXiv:1807.01730 [hep-ph]

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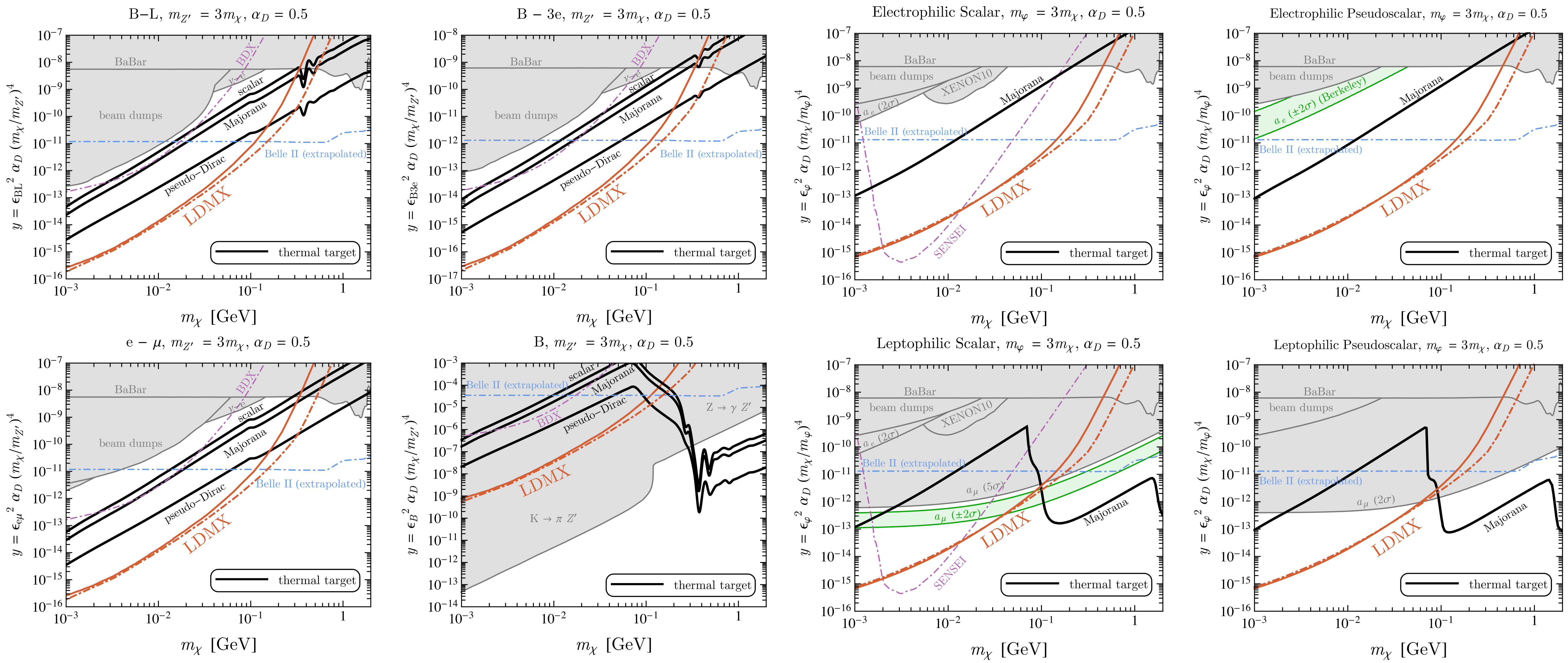

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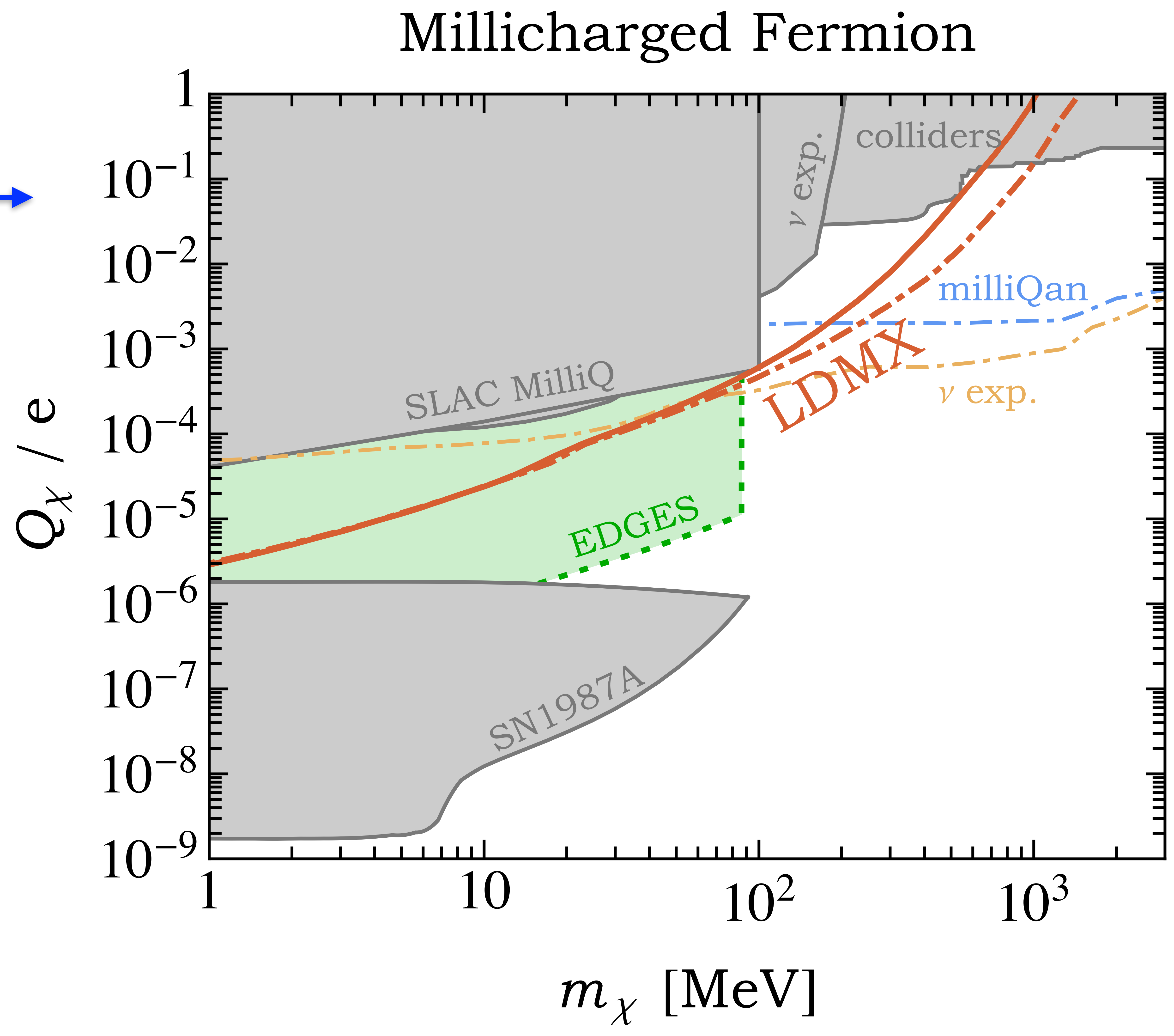

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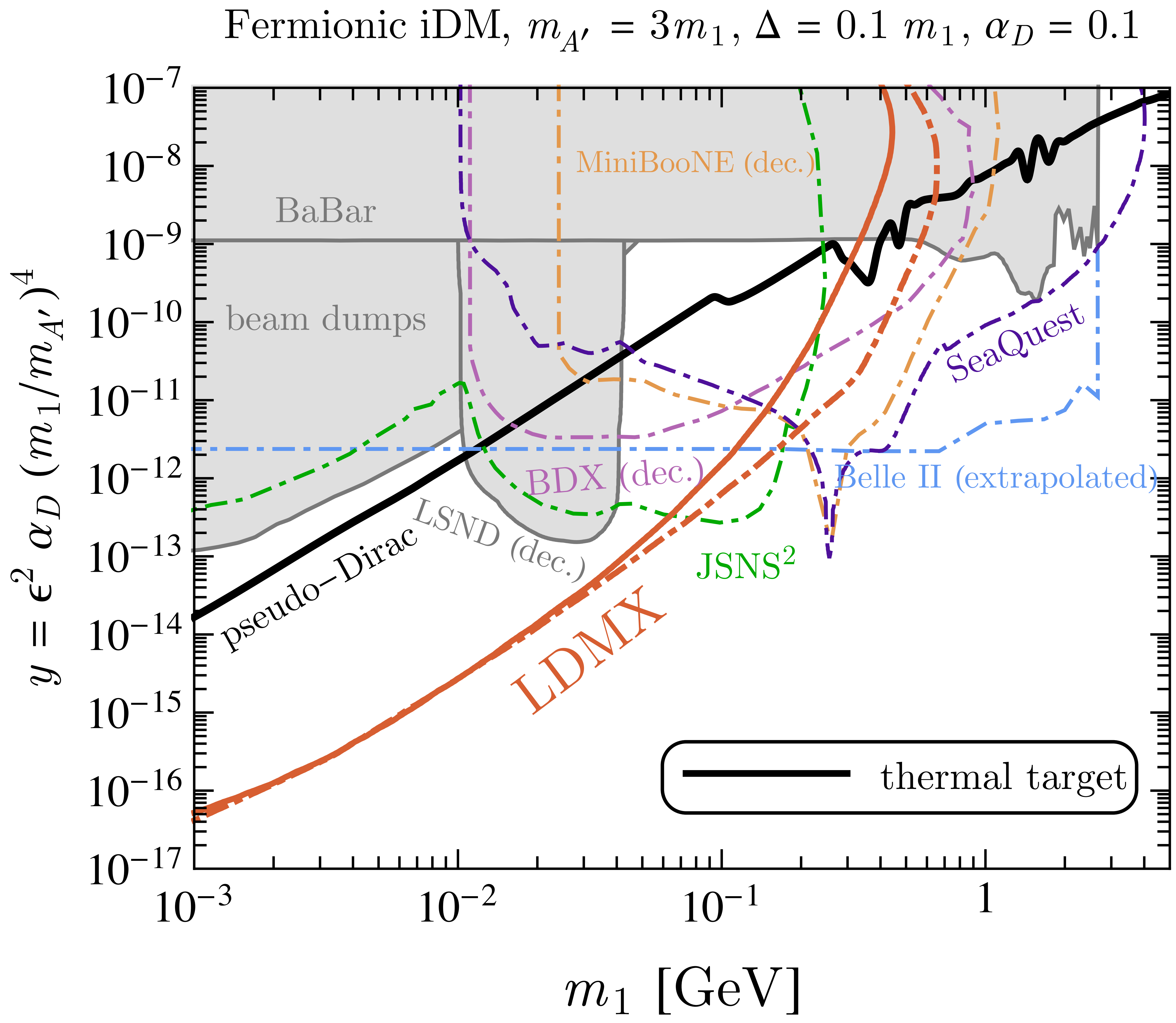

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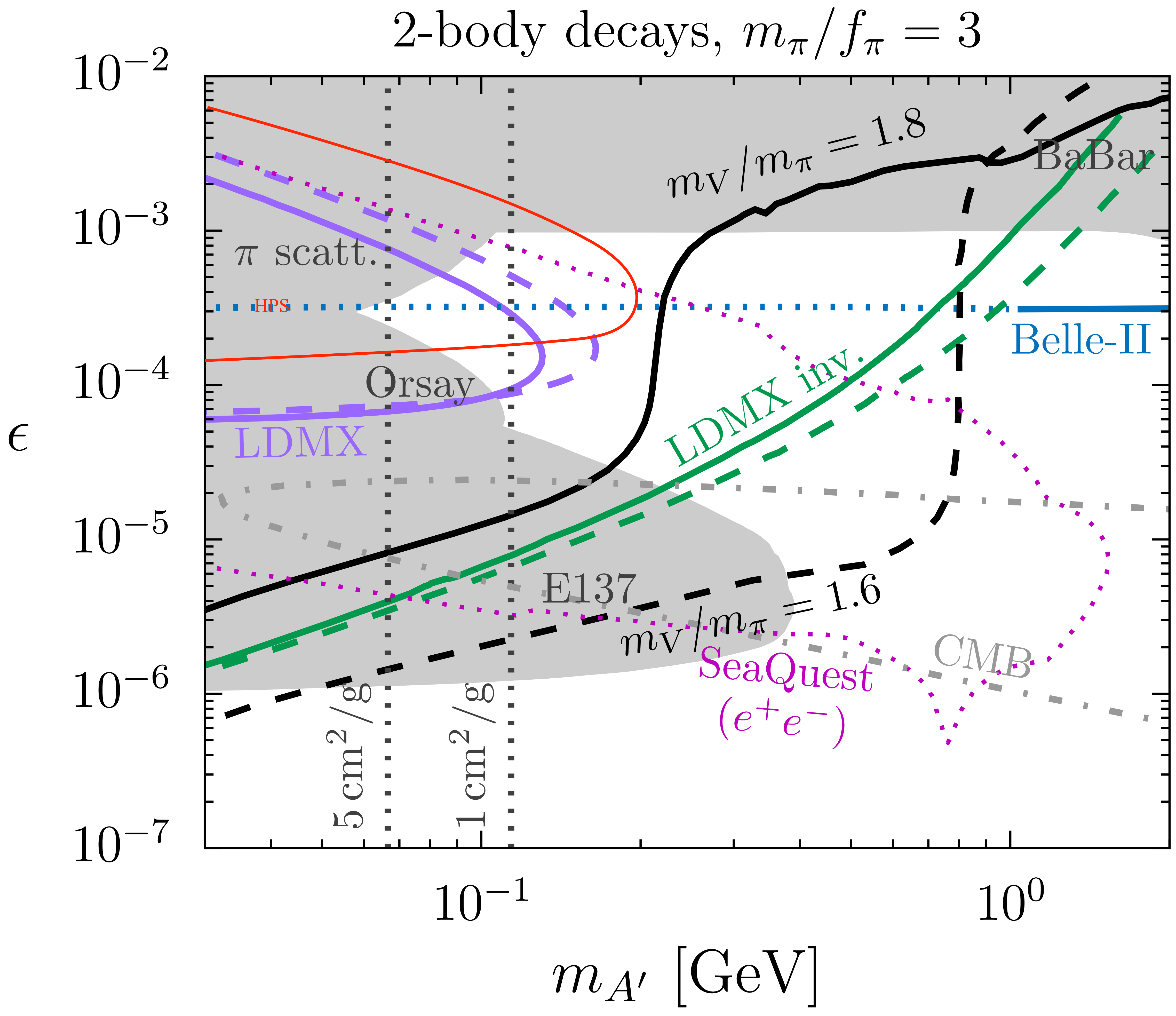

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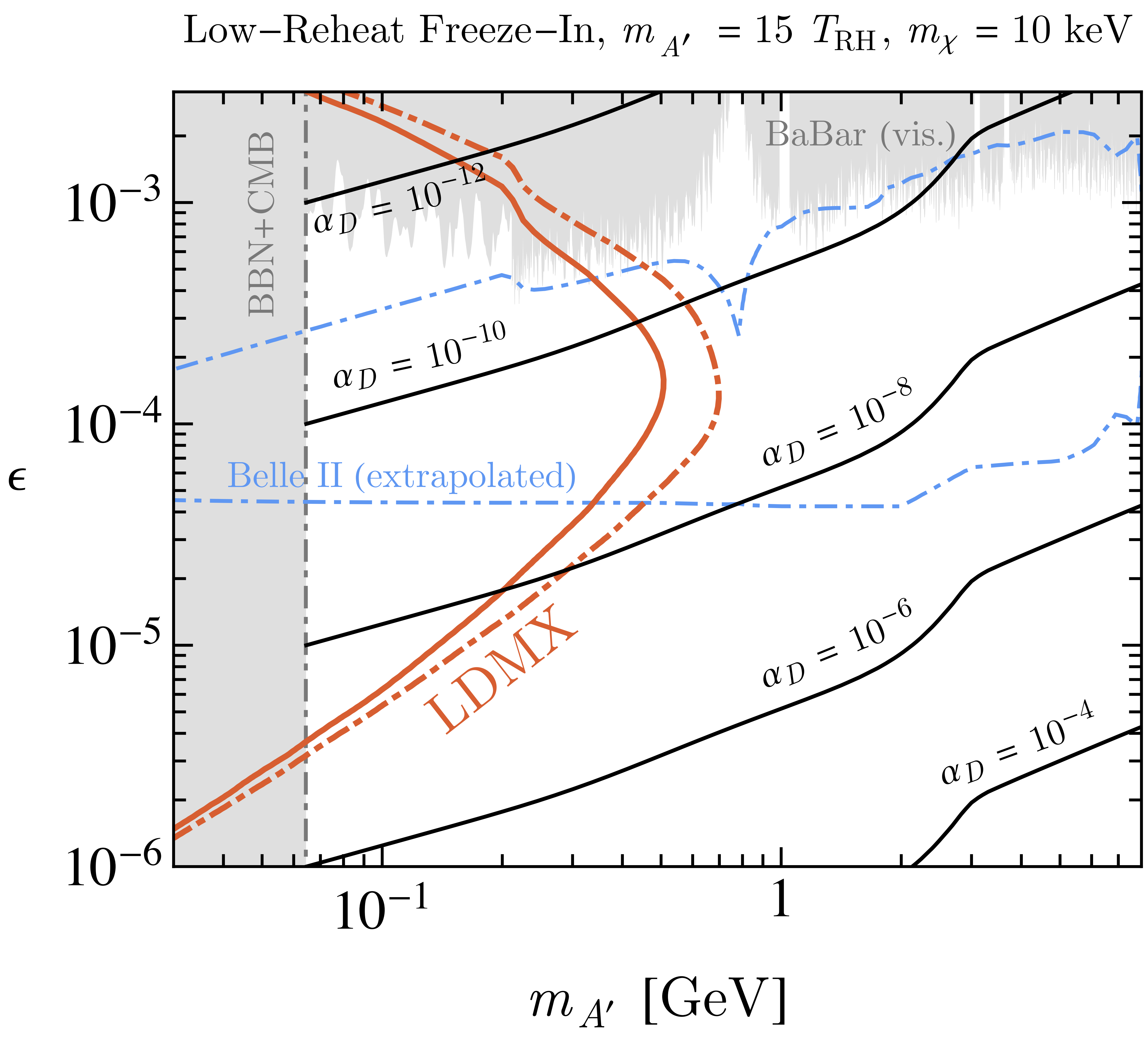

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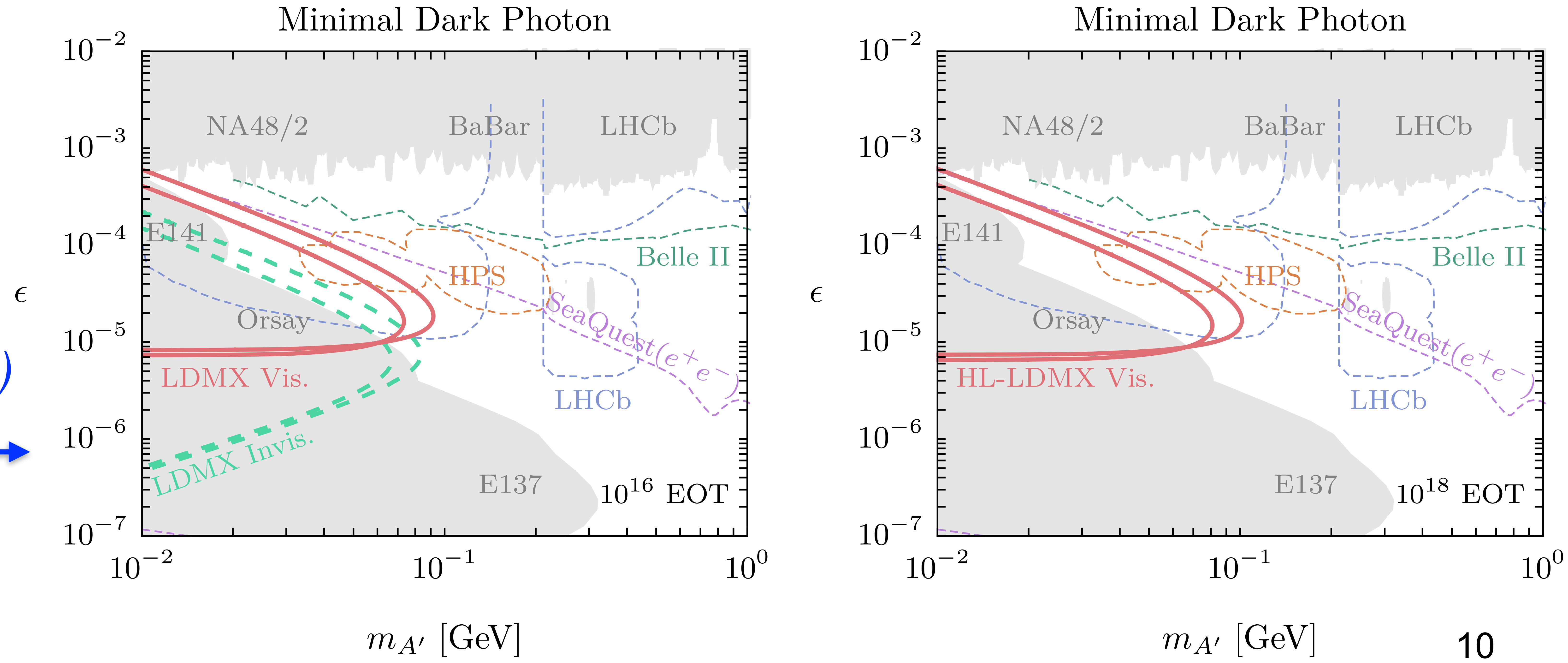

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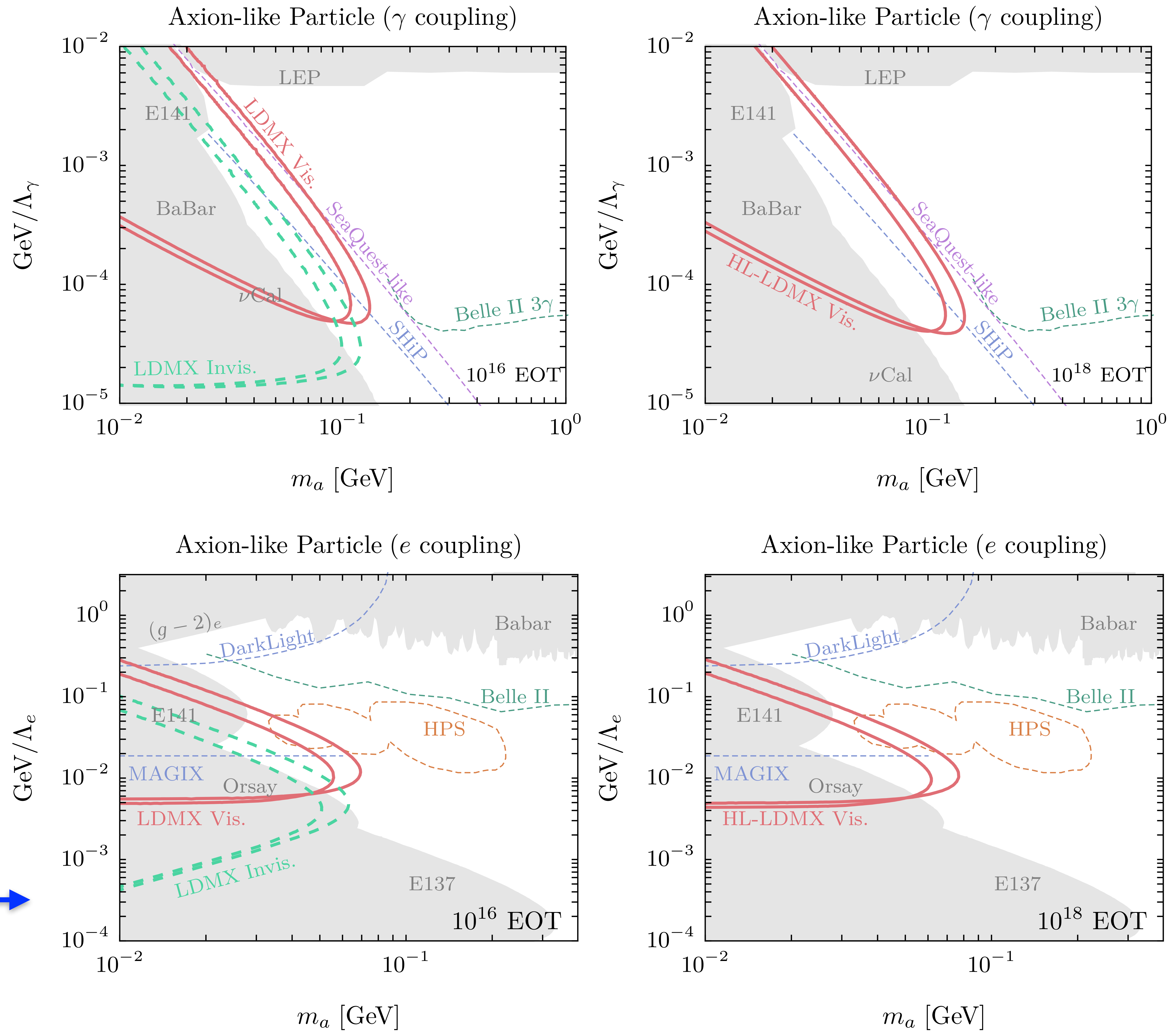

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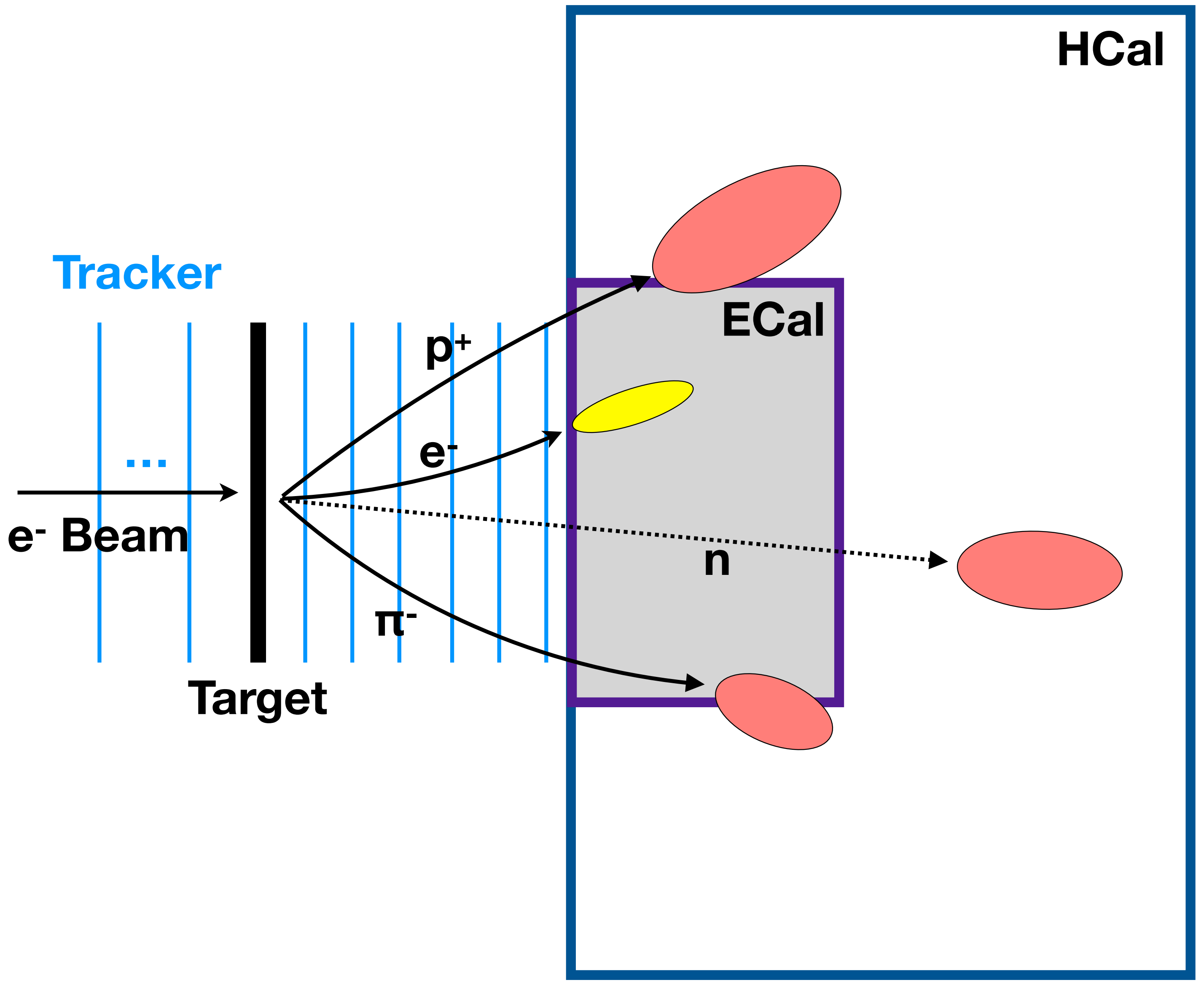
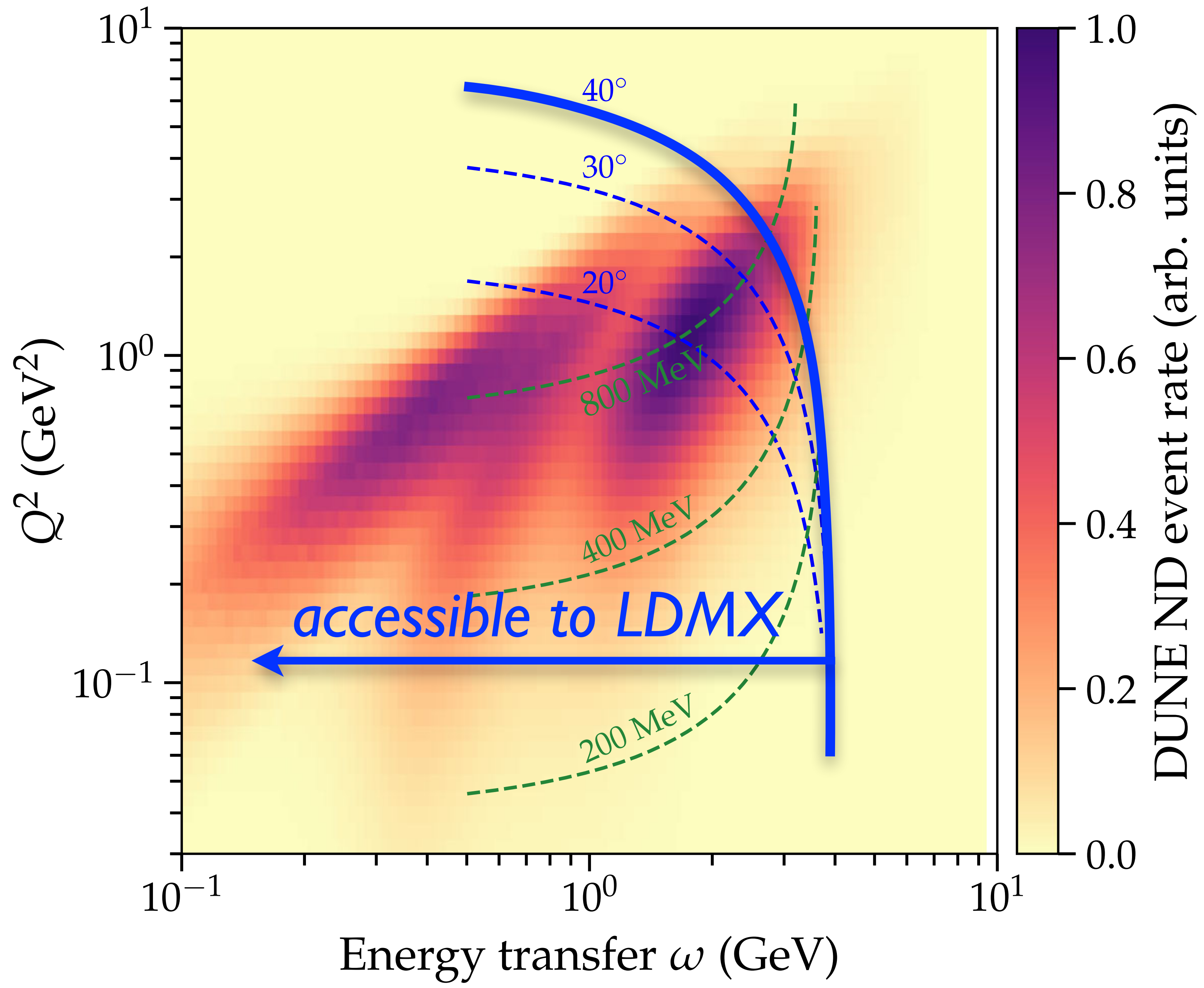
LDMX also enables measurements of electron-nucleon cross-sections that would be critical to the neutrino program



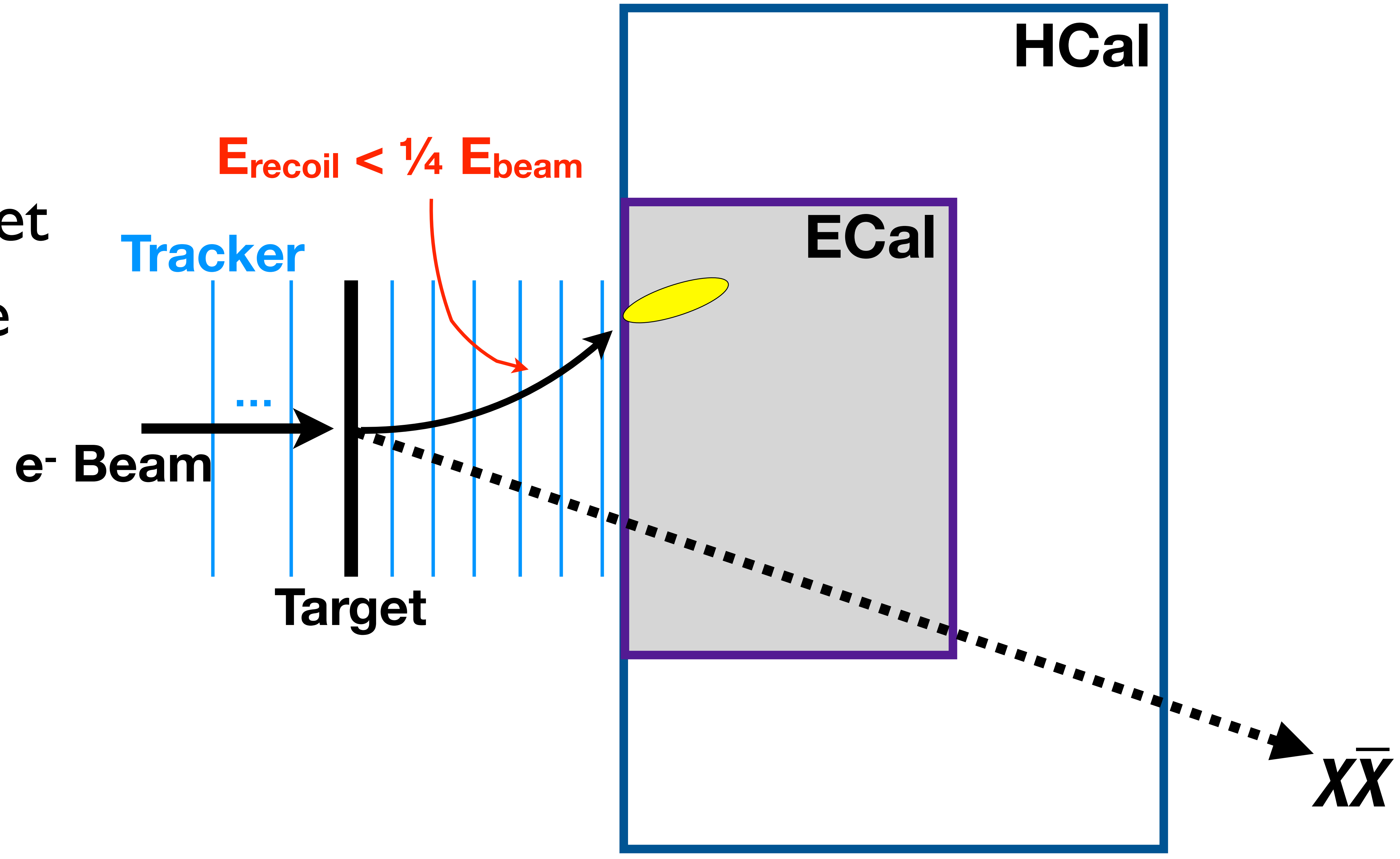


PHYSICAL REVIEW D 101, 053004 (2020)

Missing Momentum: Operational Design Drivers

Signature:

1. substantial energy loss by incoming beam electron
2. substantial transverse momentum change across target
3. no other particles with significant energy in final state



Goal: low background from ~10^{16} e^-

Operational Requirements:

- Low-intensity multi-GeV beam (10^{16} e^- = *50 pA-years*)
- Spread out beam in space/time (large beamspot ~ 20 cm², high repetition-rate ~ 40 MHz)

➡ allows individual events to be distinguished at higher rate (a few electrons/pulse) in detectors with fine granularity and resolution in both space and time

➡ spreads out peak radiation doses so radiation tolerance is less an issue for tracking and ECal

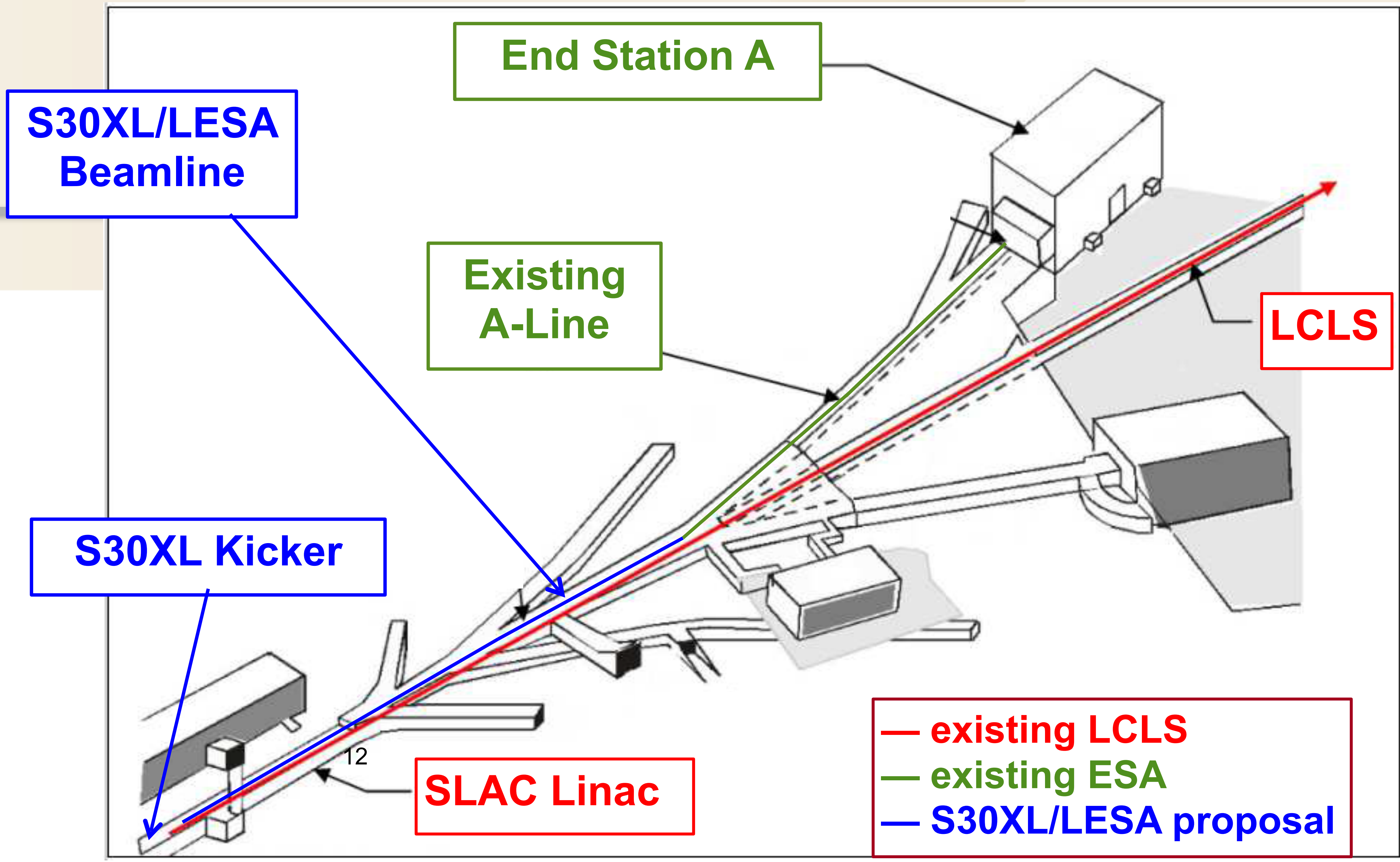
Linac to End Station A (LESA) at SLAC

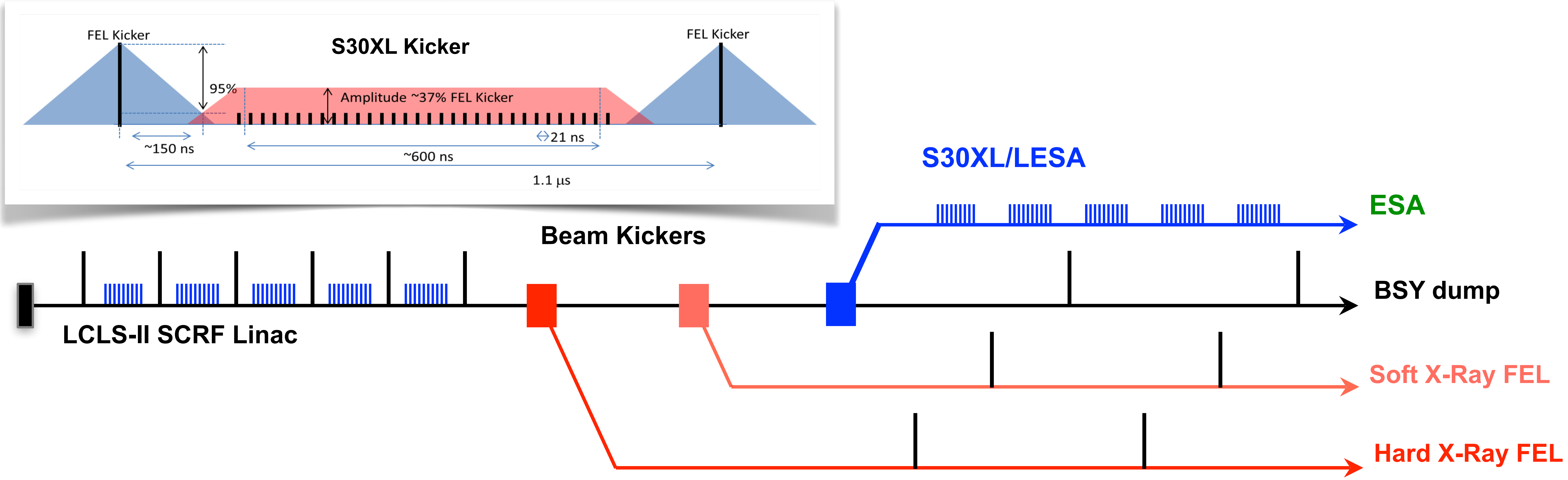
LCLS-II 4 GeV drive beam accelerates 186 MHz bunches

- ~5000 hours/year operation for photon science
- LCLS-II uses 929 kHz: >99% of bunches go to dump
- Sector 30 Transfer Line (S30XL) diverts ~60% of unused, low-charge bunches to LESA with LDMX as primary user.
- LCLS-II-HE upgrade to 8 GeV in ~2025-2027

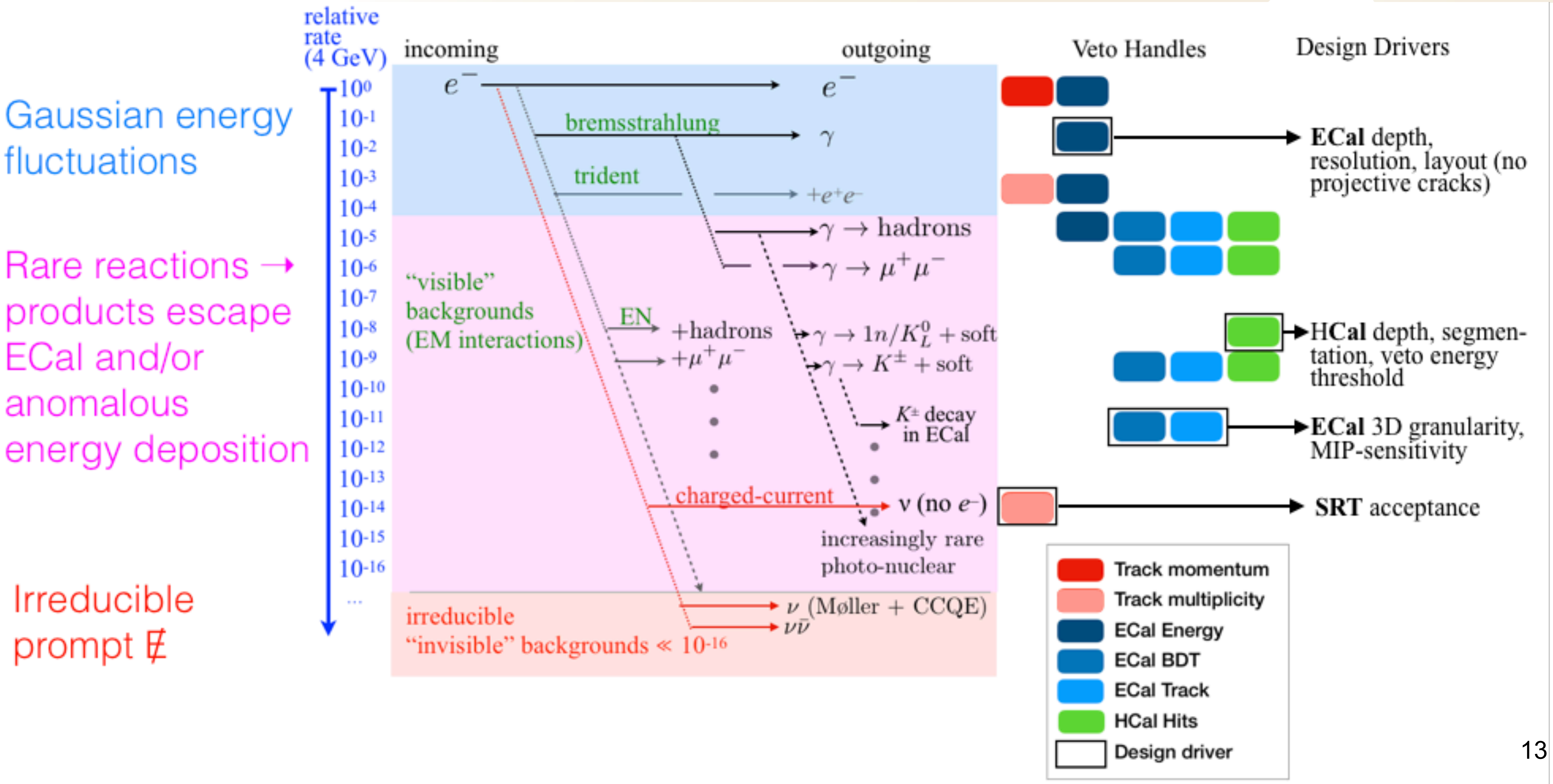
S30XL AIP is currently under construction alongside LCLS-II.

LESA is expected to deliver beam to End Station A in late FY23.





Missing Momentum: Physics Design Drivers



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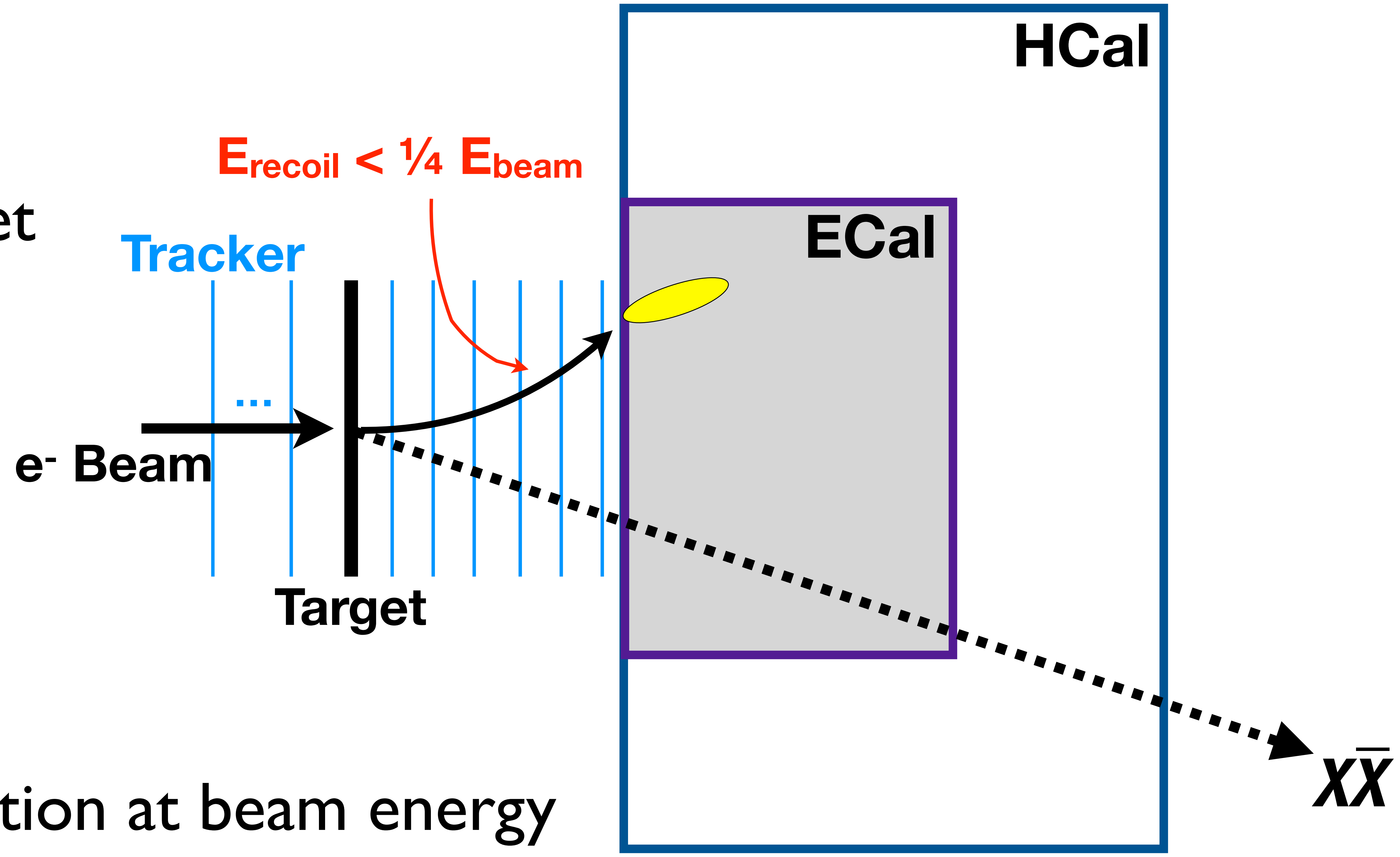
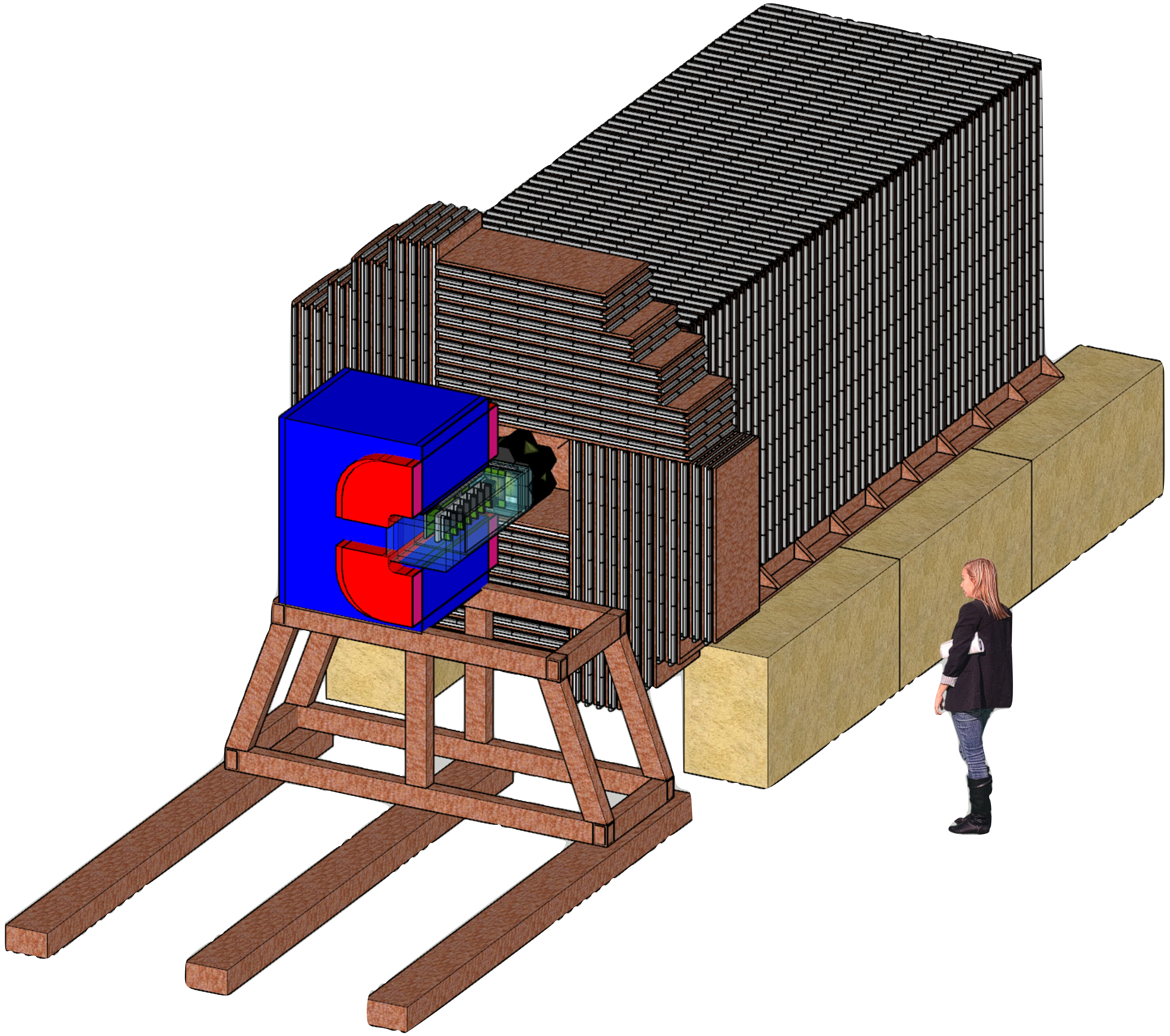
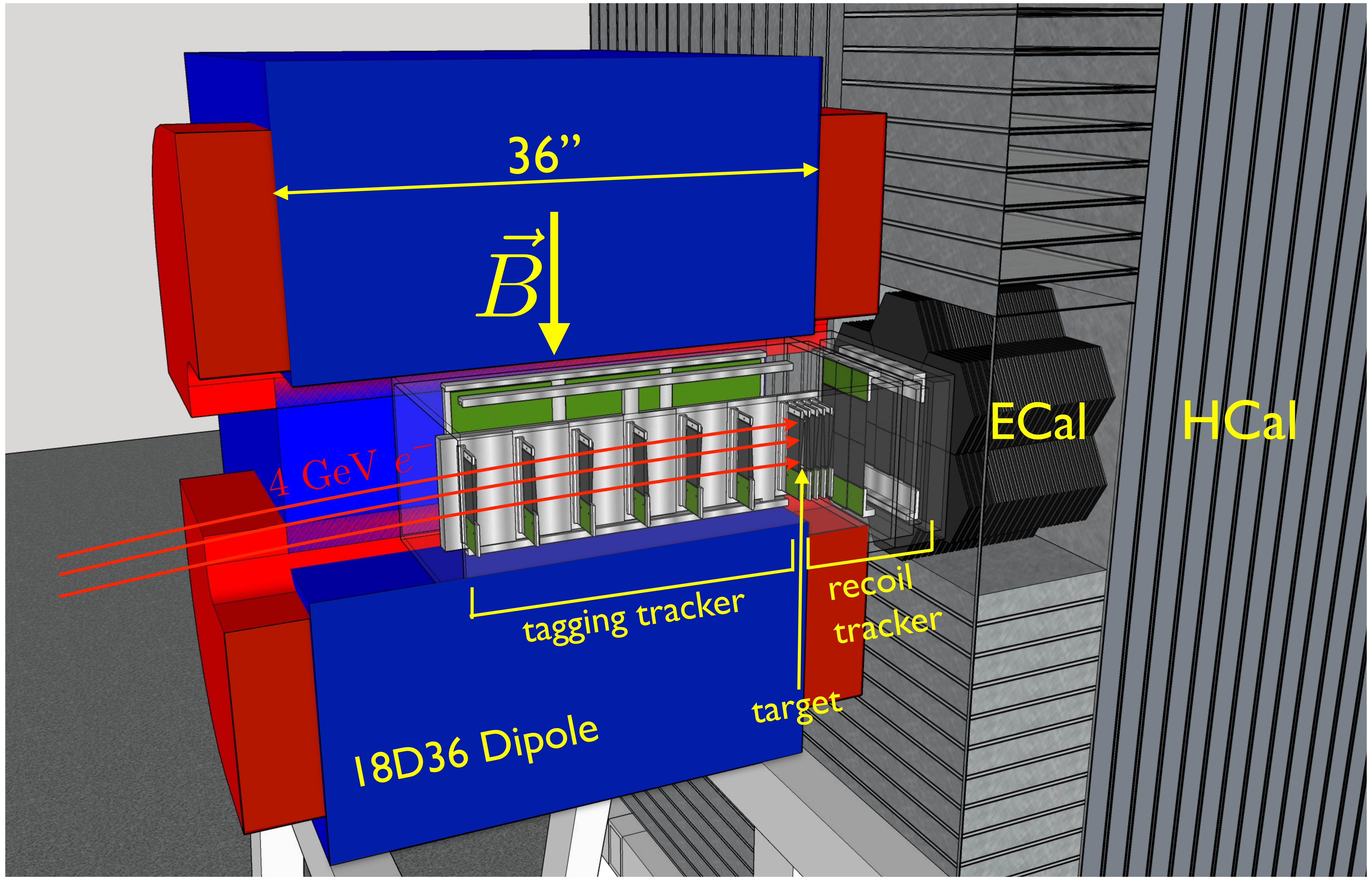


Physics Requirements:

- Tagging tracker with small acceptance and good resolution at beam energy
- Recoil tracker with large acceptance and good resolution at low momentum
- Deep ECal with good resolution and no projective cracks
- ECal with excellent granularity and sensitivity for distinguishing EM/Had showers and tracking muons
- Deep HCal with good segmentation and low veto energy threshold for neutral hadrons
- Efficient missing energy trigger and high-rate data acquisition

LDMX Detector Overview





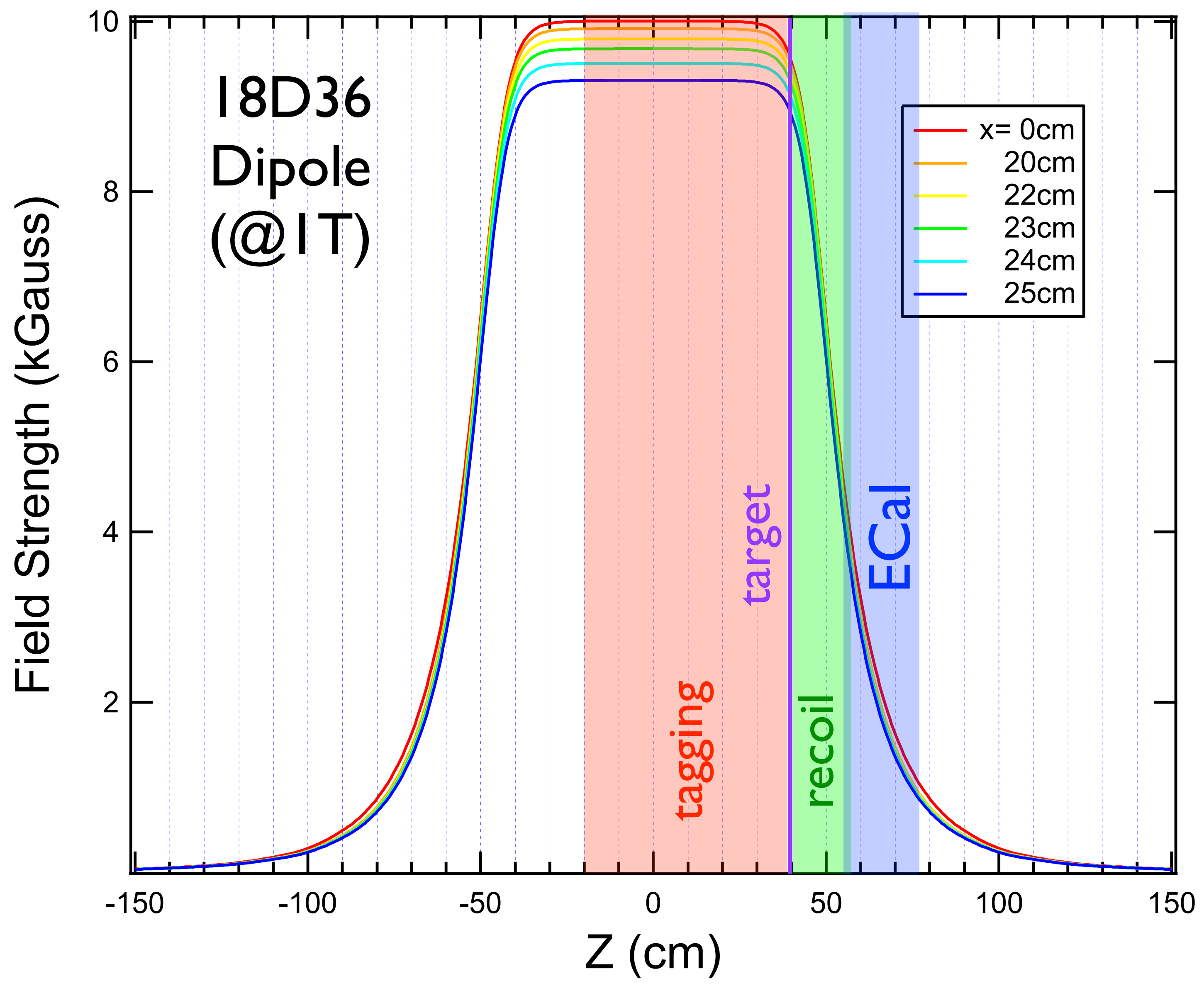
LDMX Whitepaper arXiv:1808.05219

LDMX Subsystems and Technology Choices

LDMX

WBS 1.1 – Beamline and Magnet: (strong SLAC expertise)

- final section of beam pipe with vacuum window
- common dipole magnet provides high(low) field for incoming(recoil)



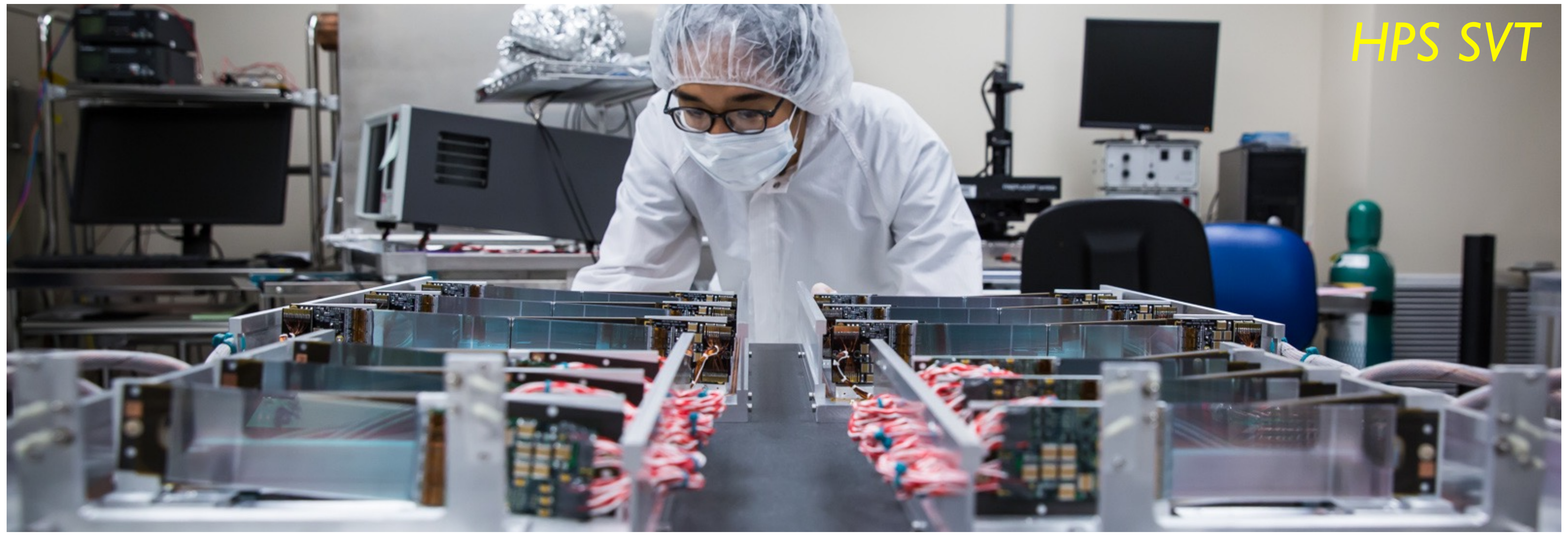
WBS 1.3 – Trackers: (from HPS Silicon Vertex Tracker built at SLAC)

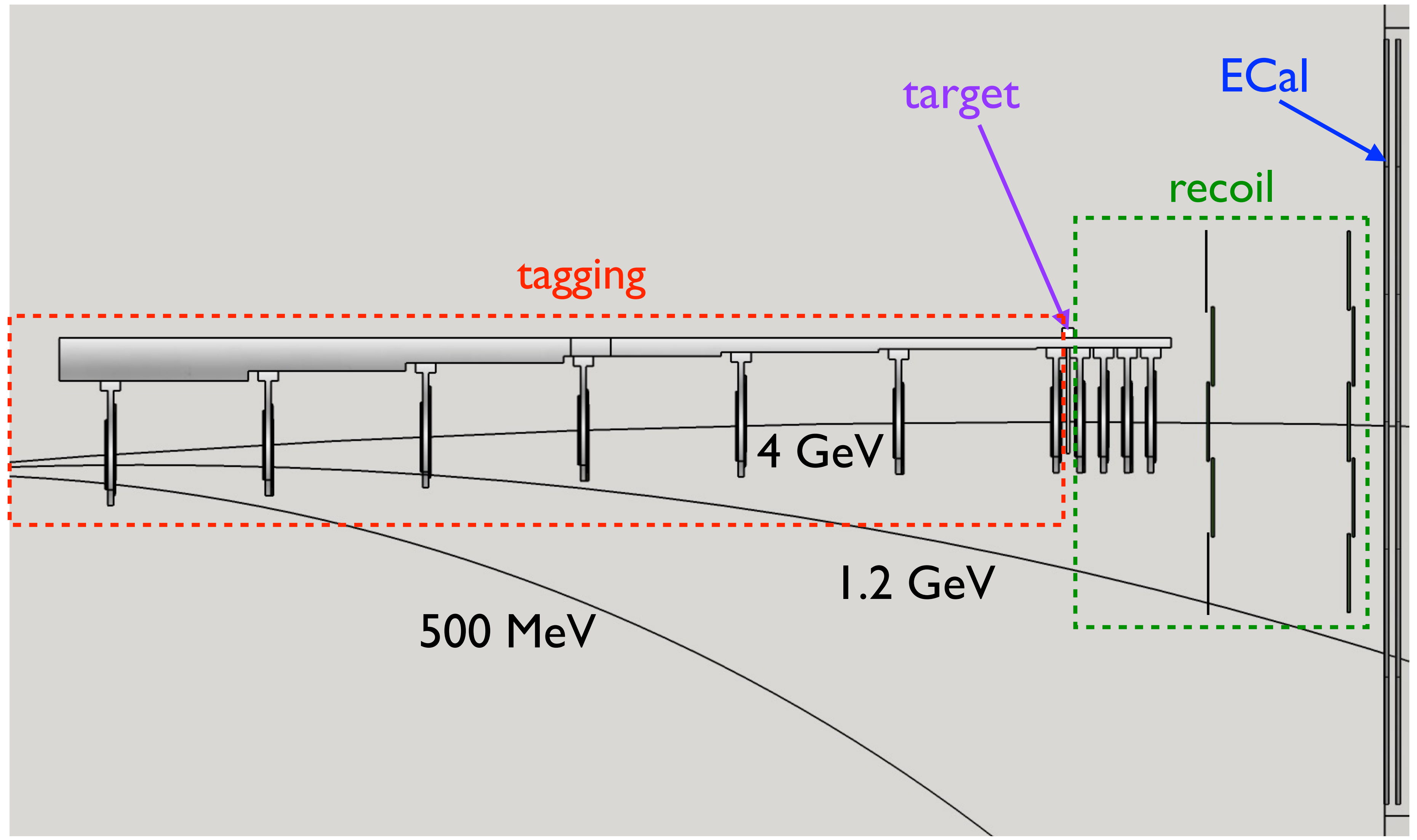
Tagging Tracker: long, narrow, in uniform 1.5 T field for p_e = 4 GeV

- 7 double-layers provide robust tag of incoming electrons

Recoil Tracker: short, wide, in fringe field for p_e = 0.05 - 1.2 GeV

- 4 double-layers + 2 axial-only layers provide good acceptance, p_T resolution limited by multiple scattering in target for recoils

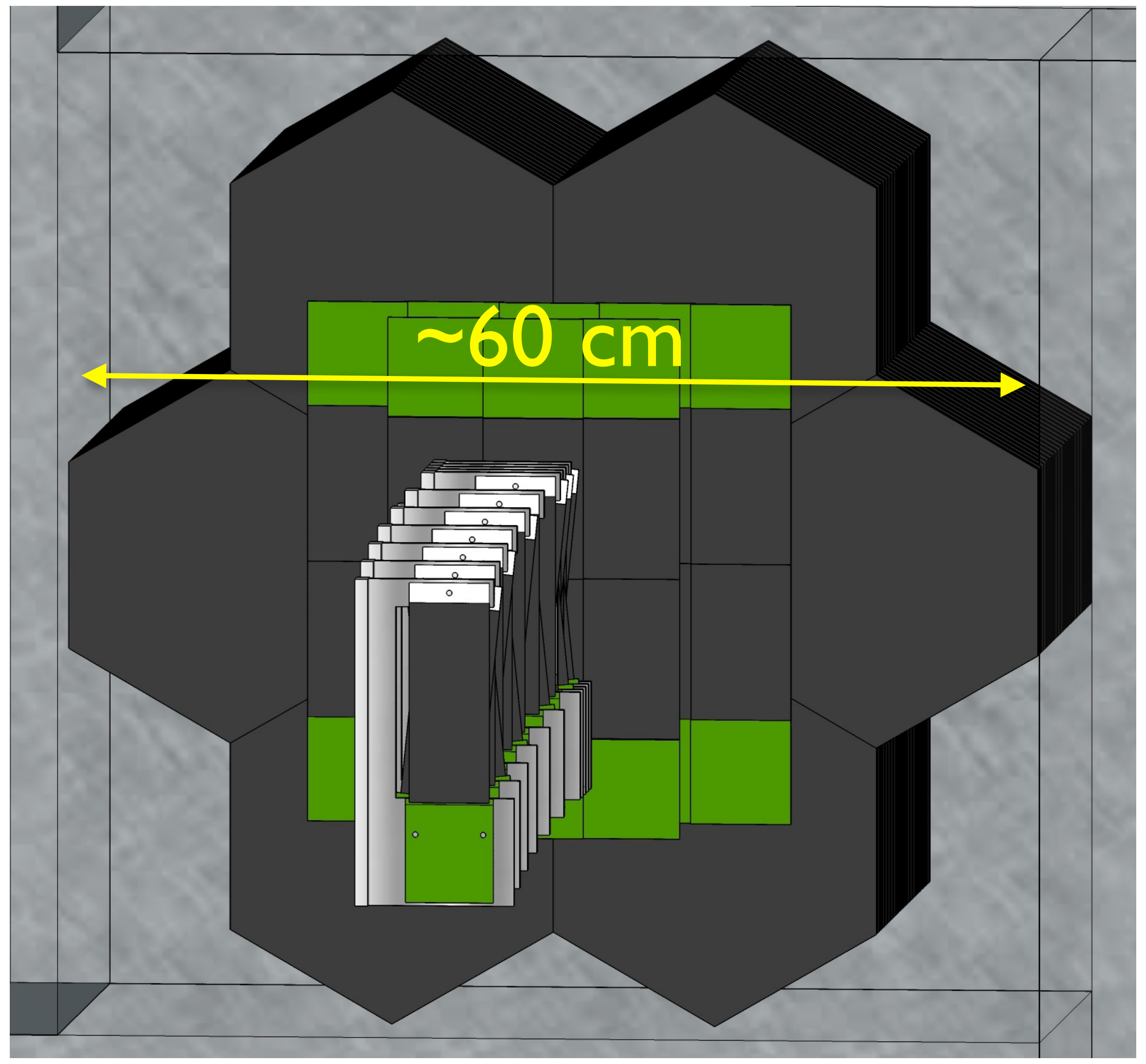


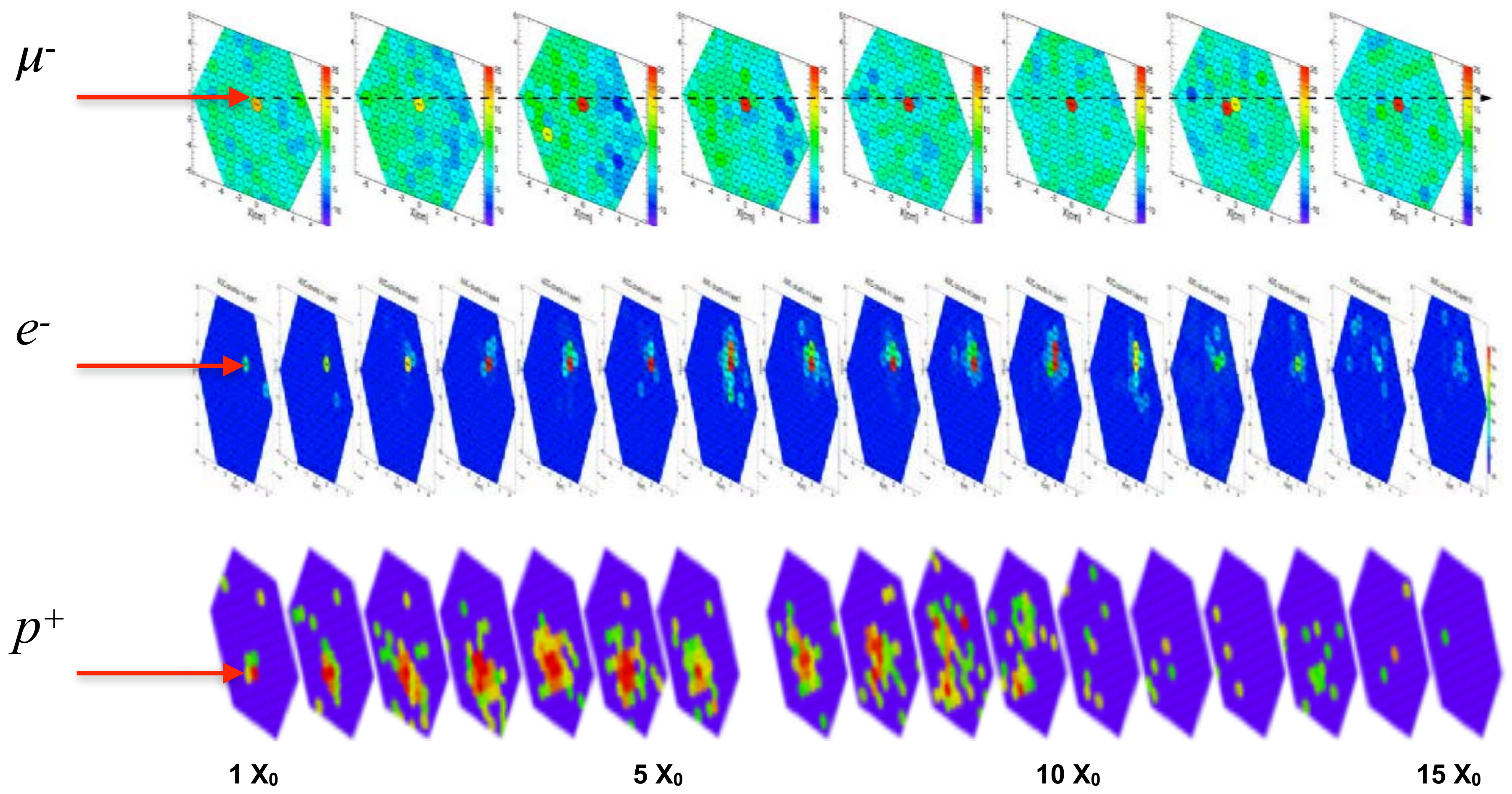


LDMX Subsystems and Technology Choices

WBS 1.4 – ECal: from CMS HGCal (UCSB – Incandela, U. Minn. – Mans)

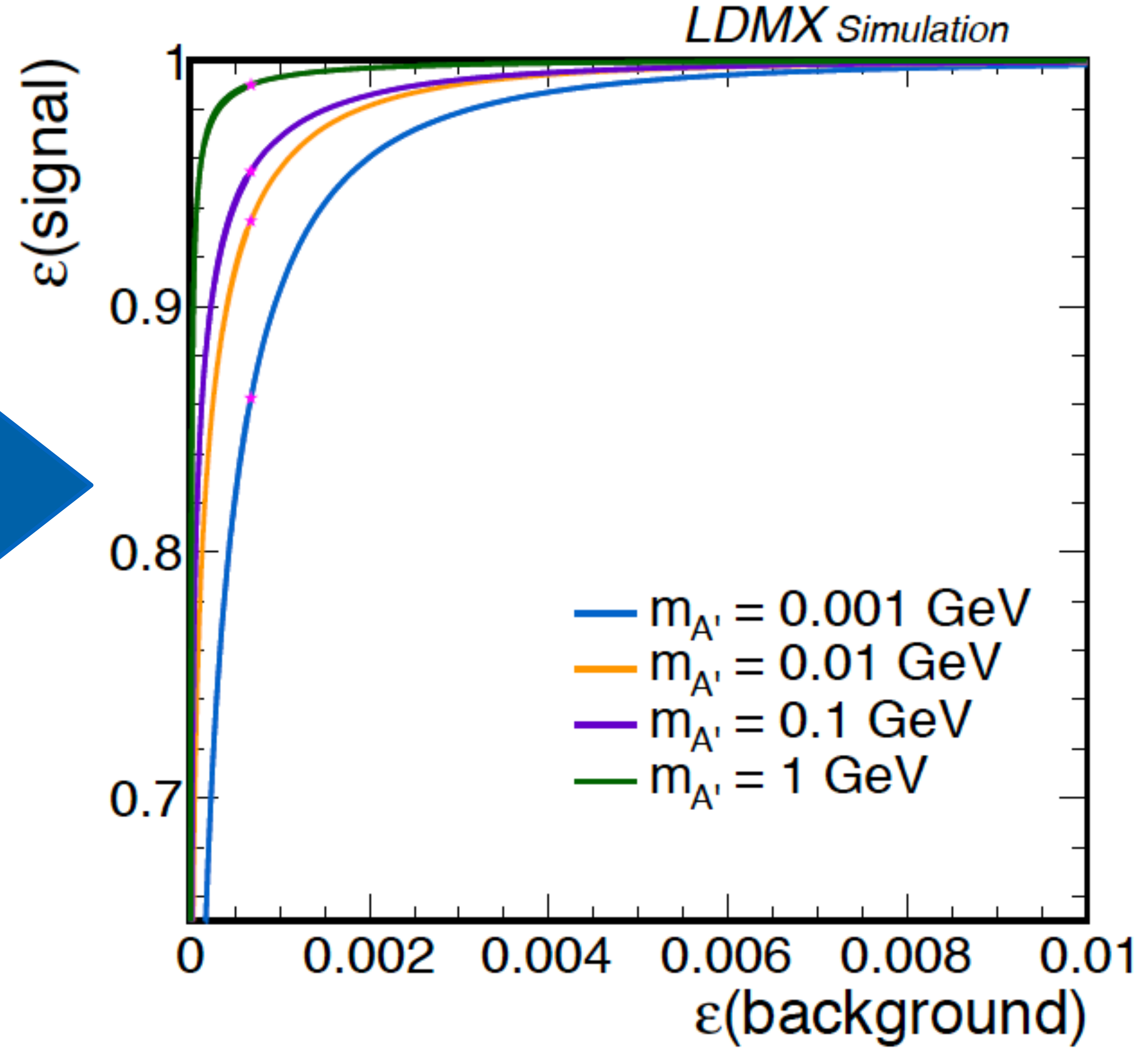
- Si-W sampling calorimeter: fast, dense, high radiation tolerance
- 40 X_0 deep: excellent containment of EM showers
- Granularity and MIP sensitivity: imaging and MIP tracking are powerful for rejecting rare backgrounds (e.g. photonuclear reactions and $\gamma \rightarrow \mu\mu$)
- designed to provide fast trigger (here using ECal energy < 0.3 E_{beam})

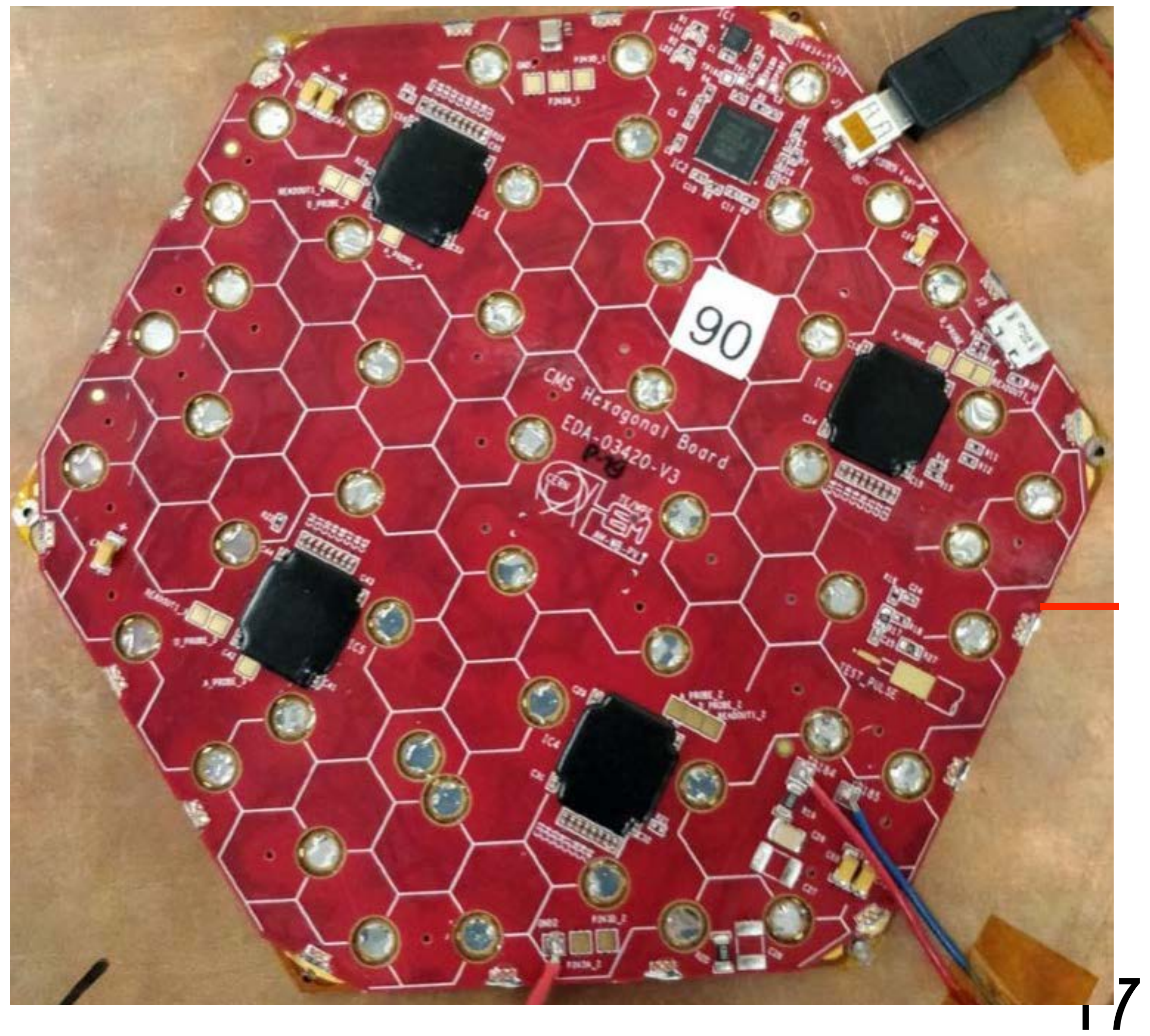




CERN Test Beam Data

Boosted Decision Tree

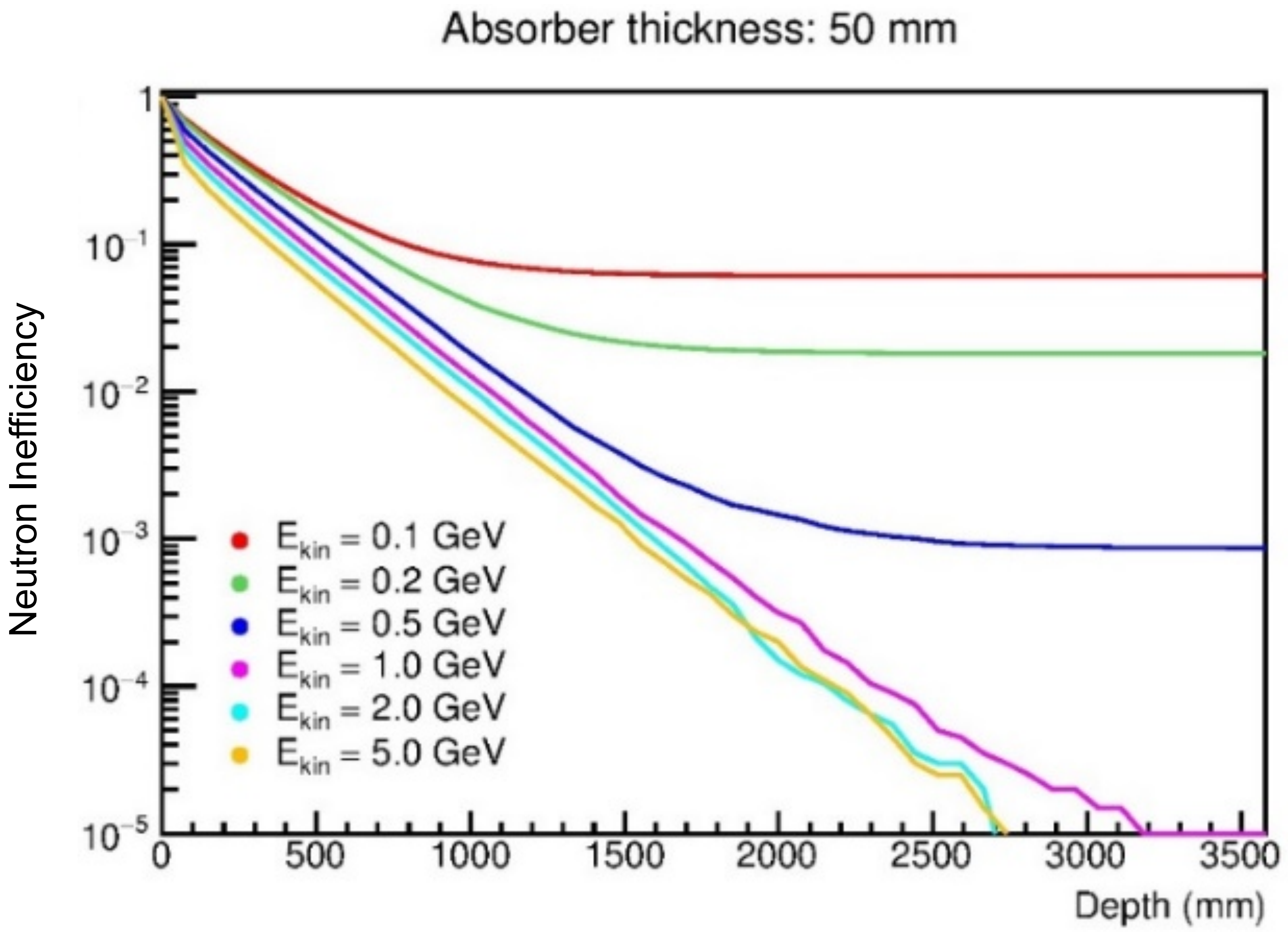


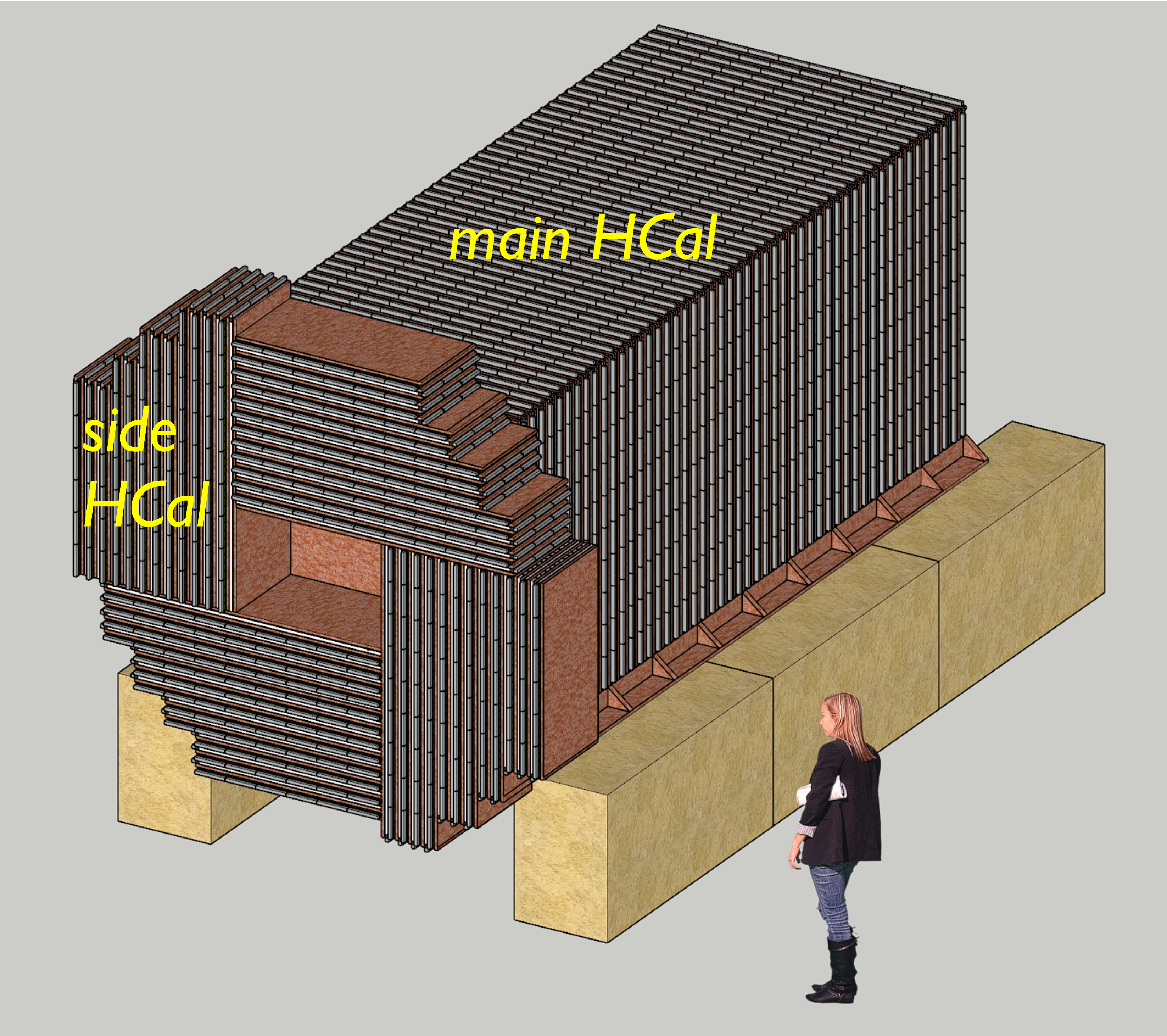


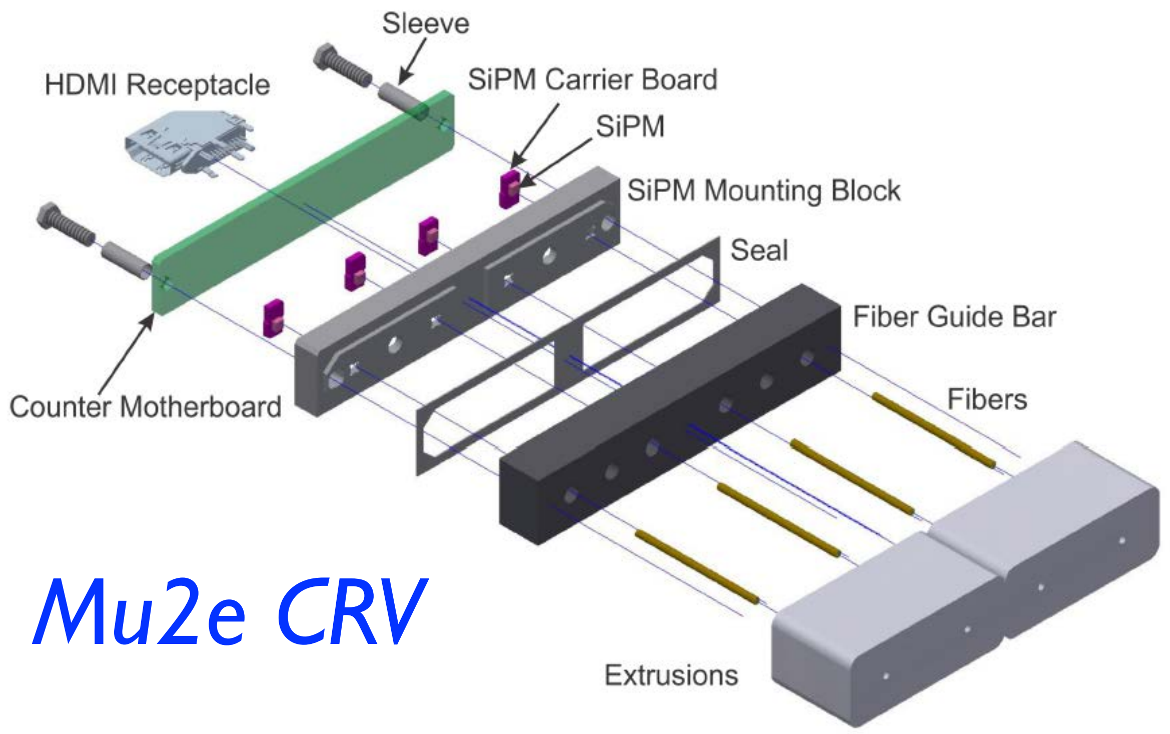
LDMX Subsystems and Technology Choices

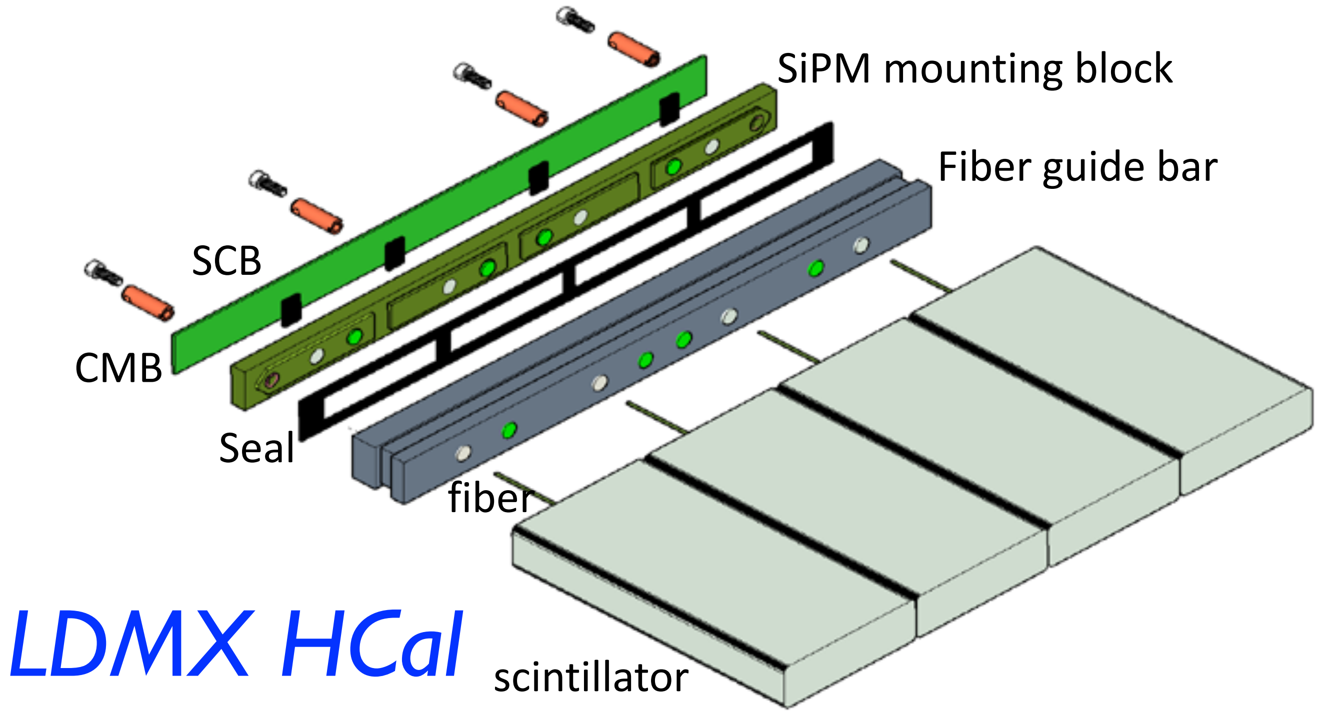
WBS 1.5 – HCal: from Mu2e Cosmic Ray Veto (UVA – Group)

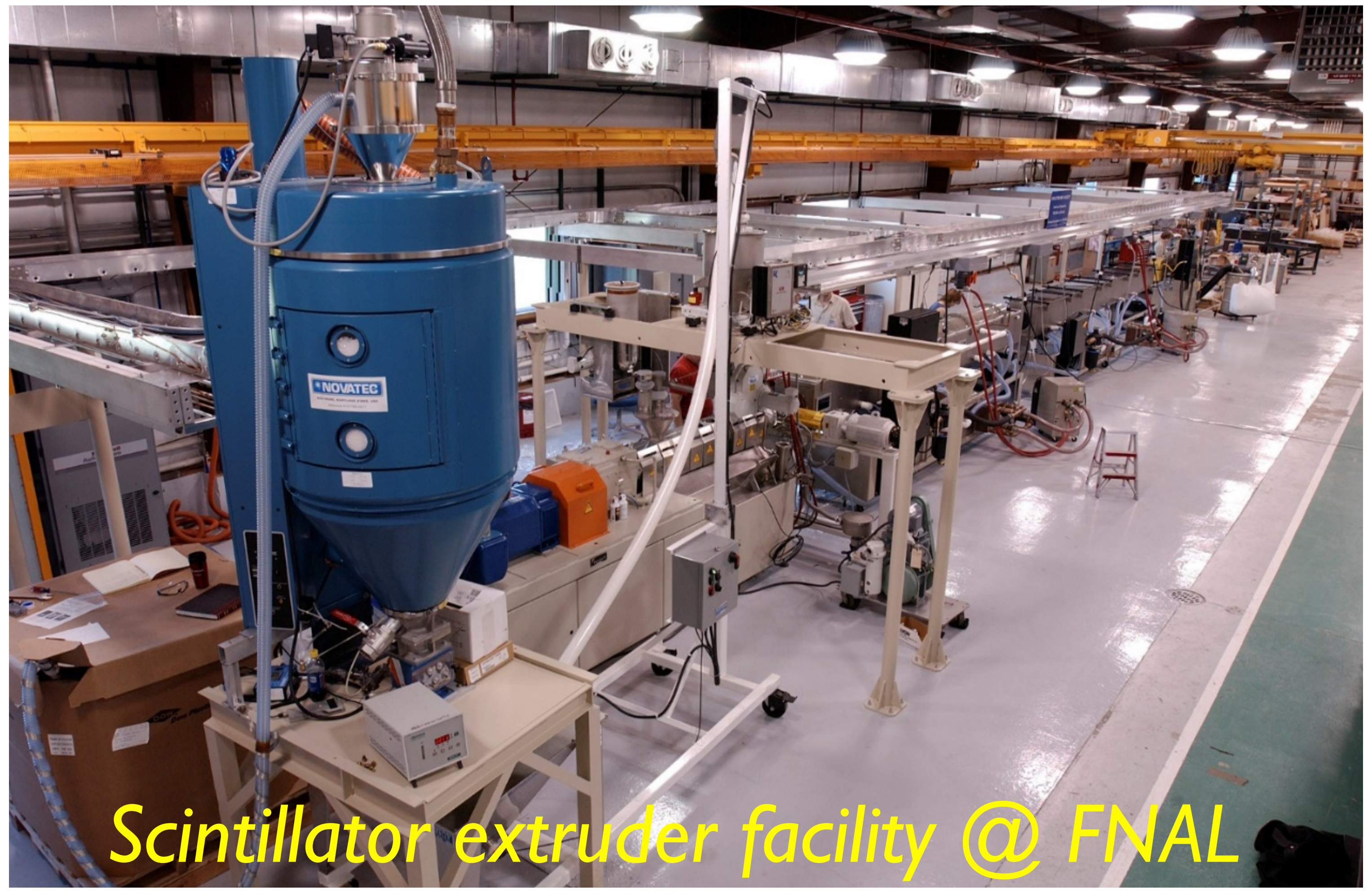
- extruded polystyrene scintillator with WLS fibers and SiPM readout
- main HCal: sufficient depth for rare events with very hard neutrons ($E_n \sim E_\gamma$)
- side HCal: important for high-multiplicity final states and wide-angle brems







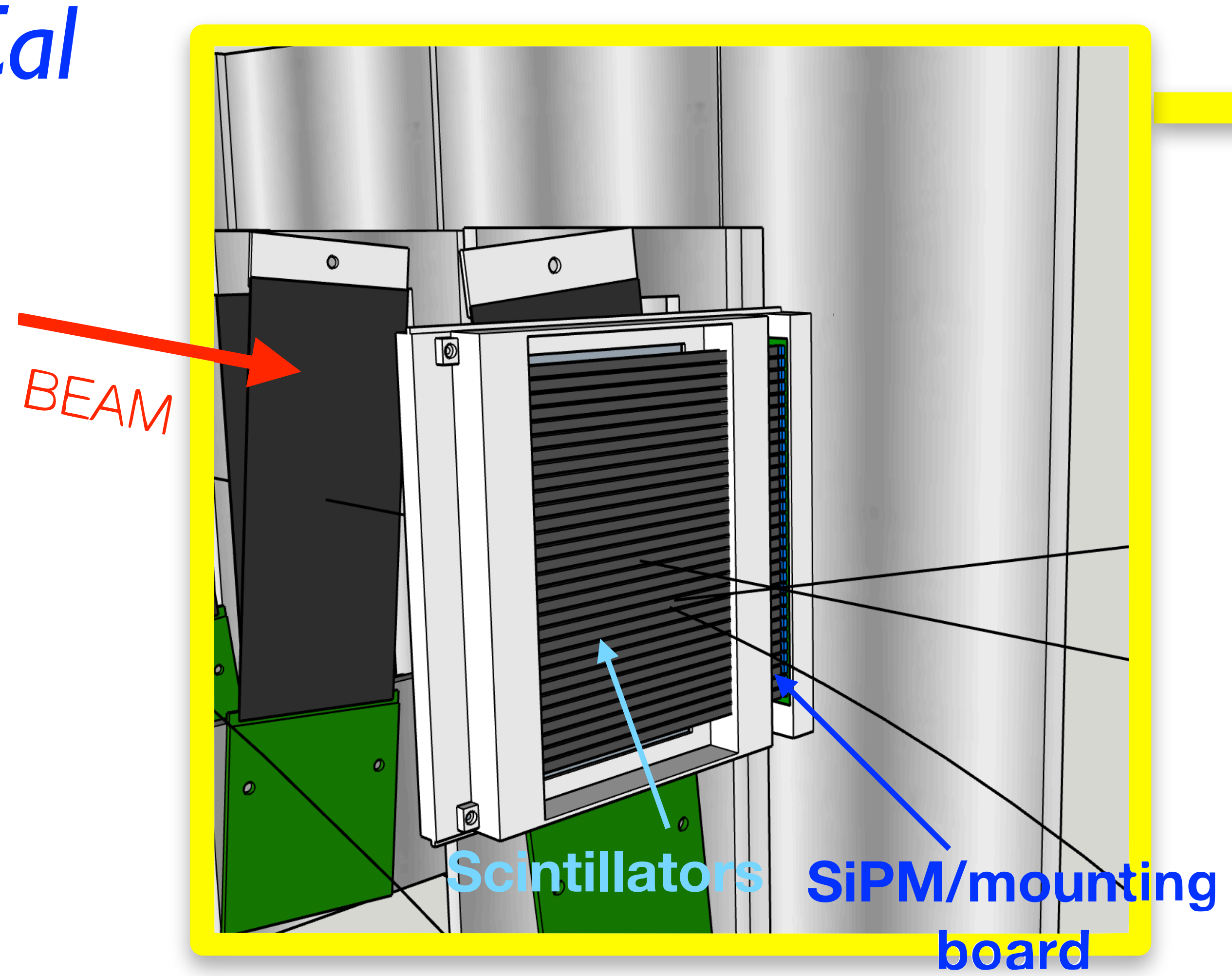


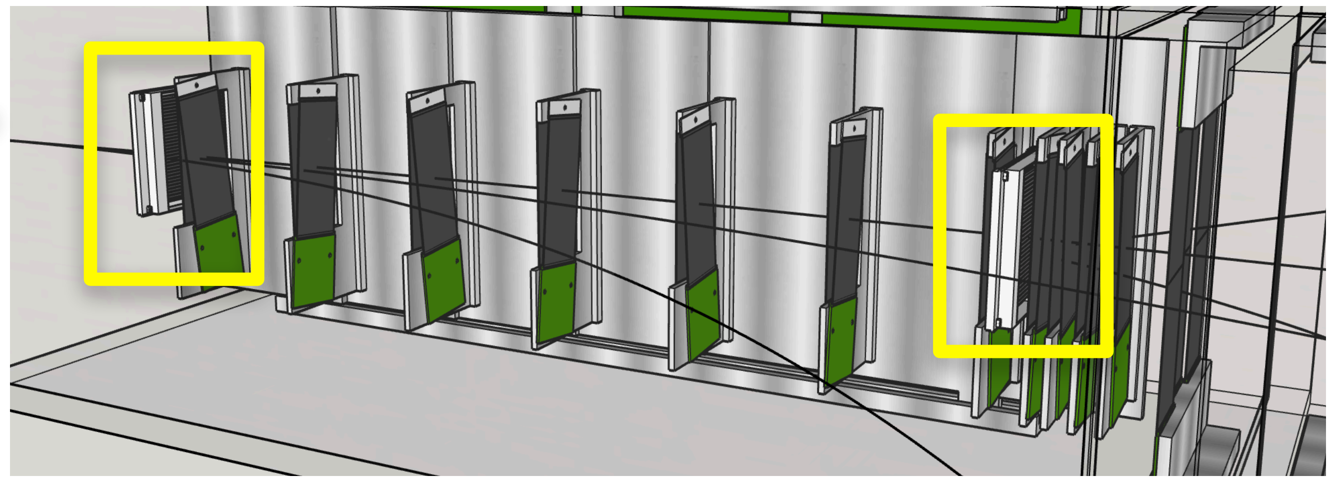


LDMX Subsystems and Technology Choices

WBS 1.2 – Trigger Scintillator: from CMS HCal

- Low-energy ECal trigger requires knowledge of n_e/pulse
- layers of segmented scintillators provides fast estimate of n_e
- also considering segmented LYSO active target: provides additional information about hard interactions in the target



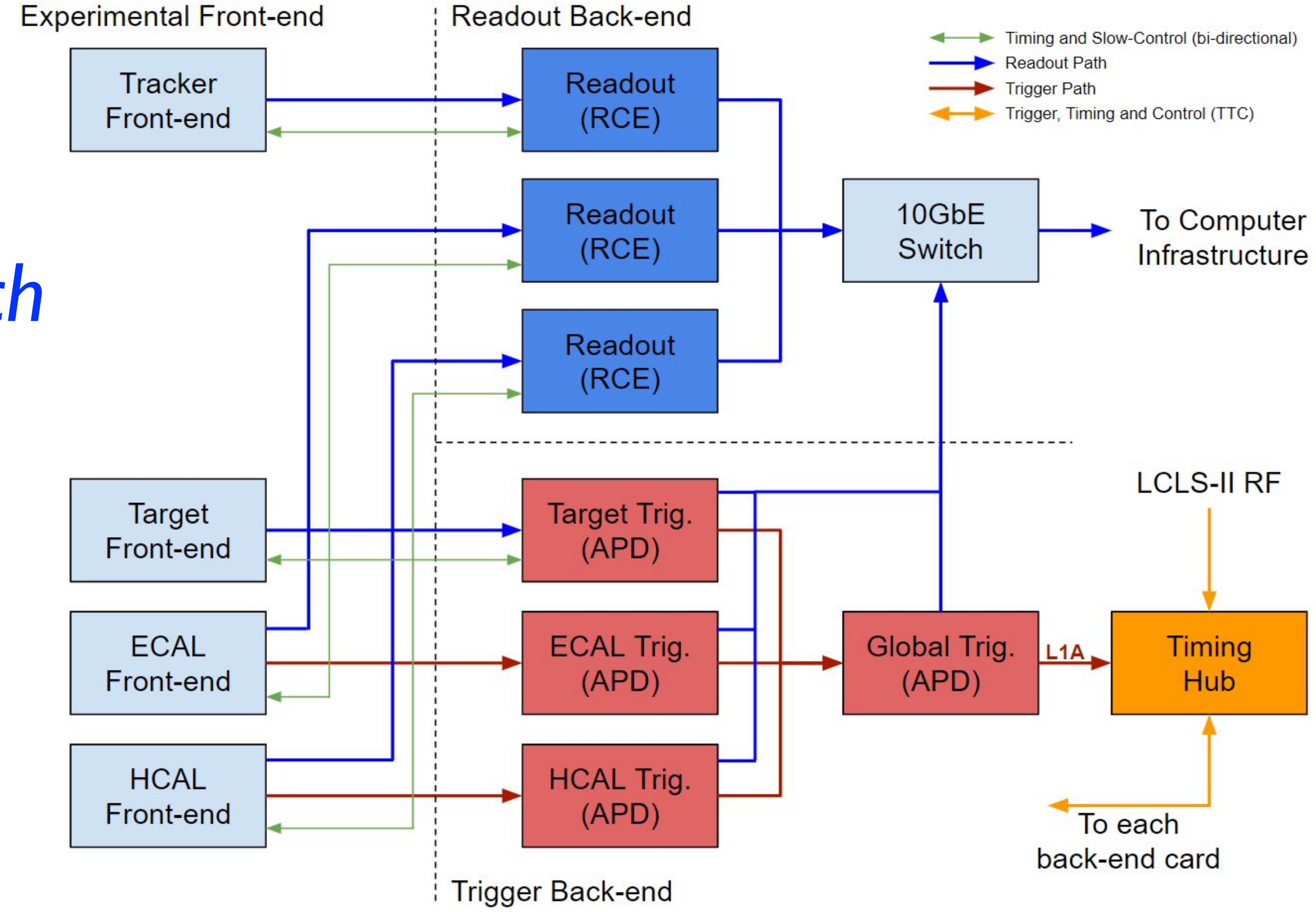


4 GeV trigger summary

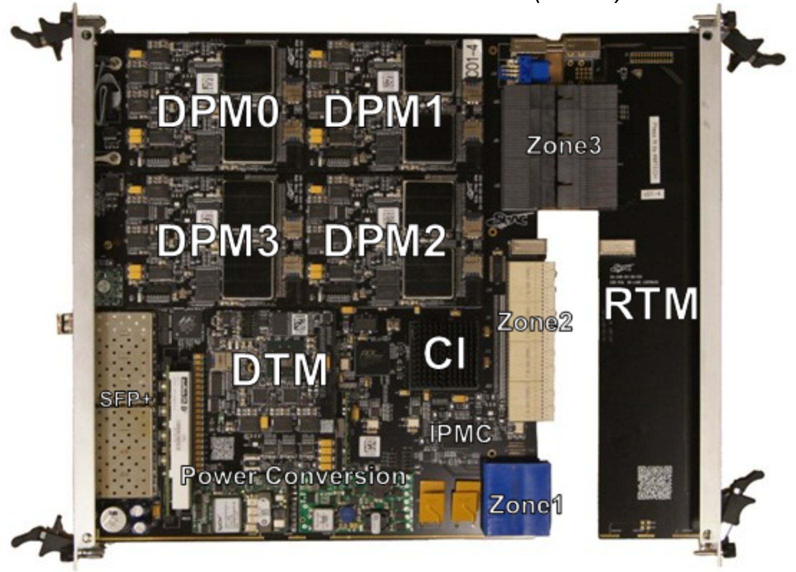
n_{beam}	Fraction of Bunches (Signal)	Trigger Scintillator Efficiency	Missing Energy Threshold [GeV]	Calorimeter Trigger Efficiency	Rate [Hz]	Signal Inefficiency
1	36.8% (36.8%)	100%	2.50	99.2%	588	0.3%
2	18.4% (36.8%)	97.4%	2.35	98.0%	1937	1.7%
3	6.1% (18.4%)	92.4%	2.70	91.6%	1238	2.8%
4	1.5% (6.1%)	84.3%	3.20	77.2%	268	1.6%
Total					4000	8.8%

WBS 1.6 – Trigger and DAQ: from SLAC/FNAL tech

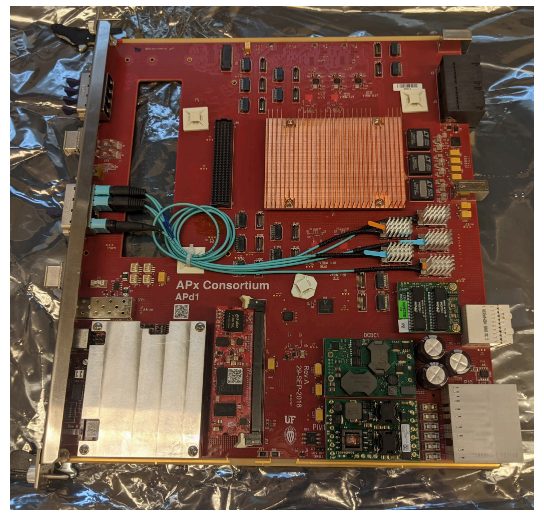
- back end DAQ based on RCE DAQ used for HPS, ATLAS, LSST, LCLS, …
- trigger DAQ based on APx DAQ developed for CMS



RCE Cluster On Board (COB)



Advanced Processor demonstrator (APd)

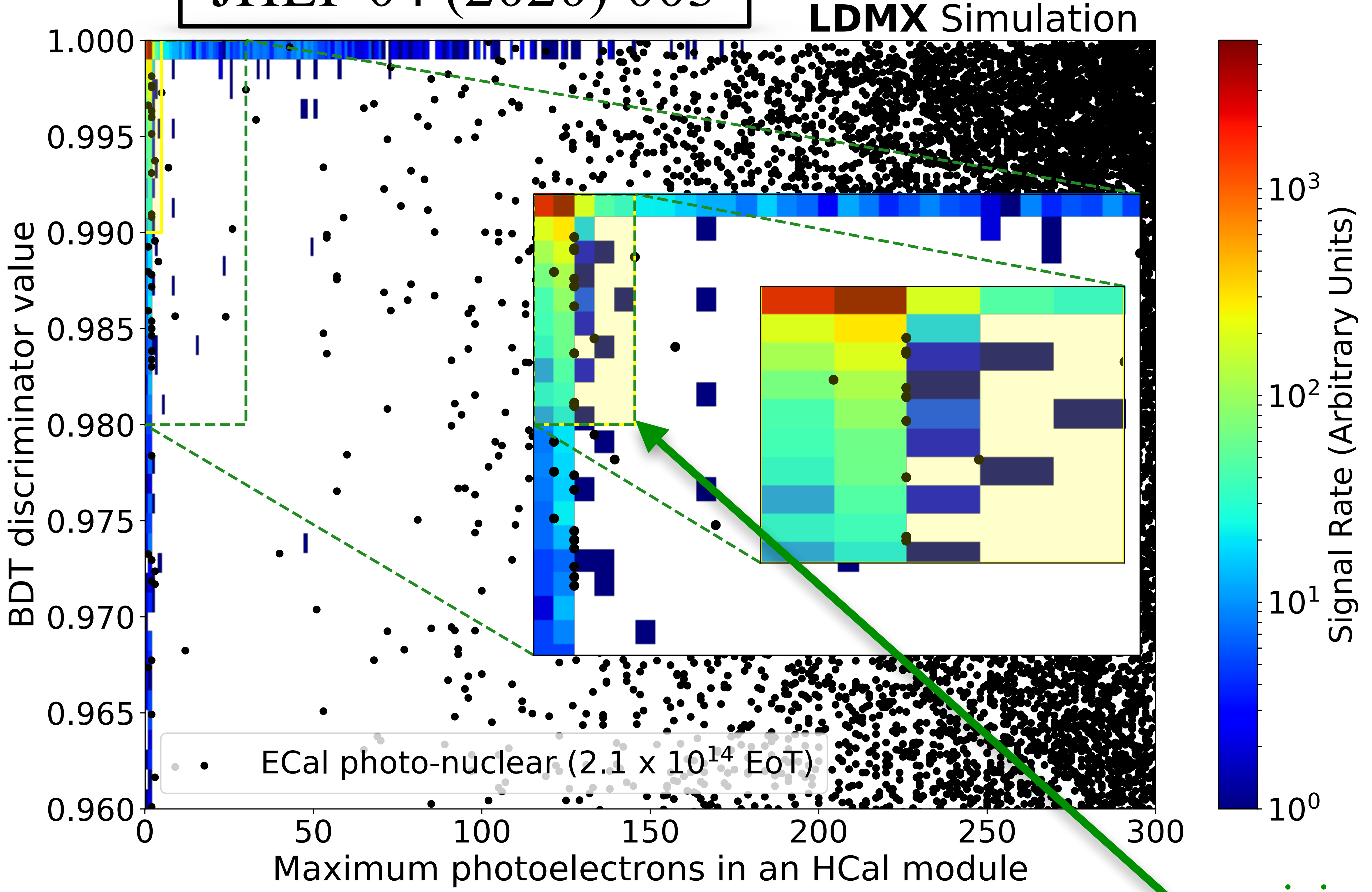


LDMX Physics Studies

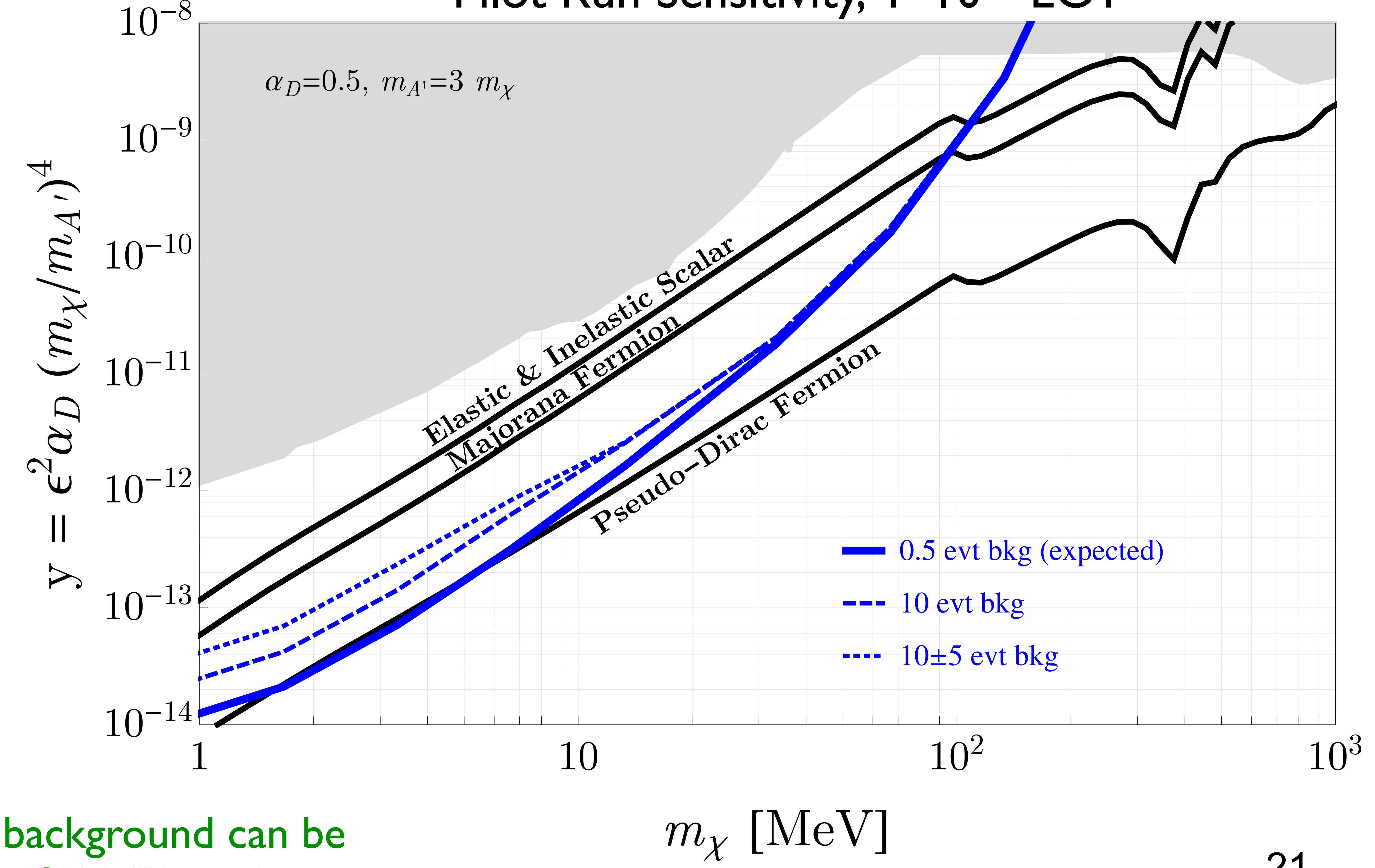
Robust software and computing infrastructure have enable detailed, high-statistics performance studies, largely driven by an active team of Ph.D. students and postdocs.

Study of dominant photo-nuclear backgrounds:
1.5M CPU hours, 1.3 PB data (unskimmed)

JHEP 04 (2020) 003



remaining background can be vetoed by ECal MIP tracking



LDMX Physics Studies

Robust software and computing infrastructure have enable detailed, high-statistics performance studies, largely driven by an active team of Ph.D. students and postdocs.

Study of dominant photo-nuclear backgrounds:
1.5M CPU hours, 1.3 PB data (unskimmed)

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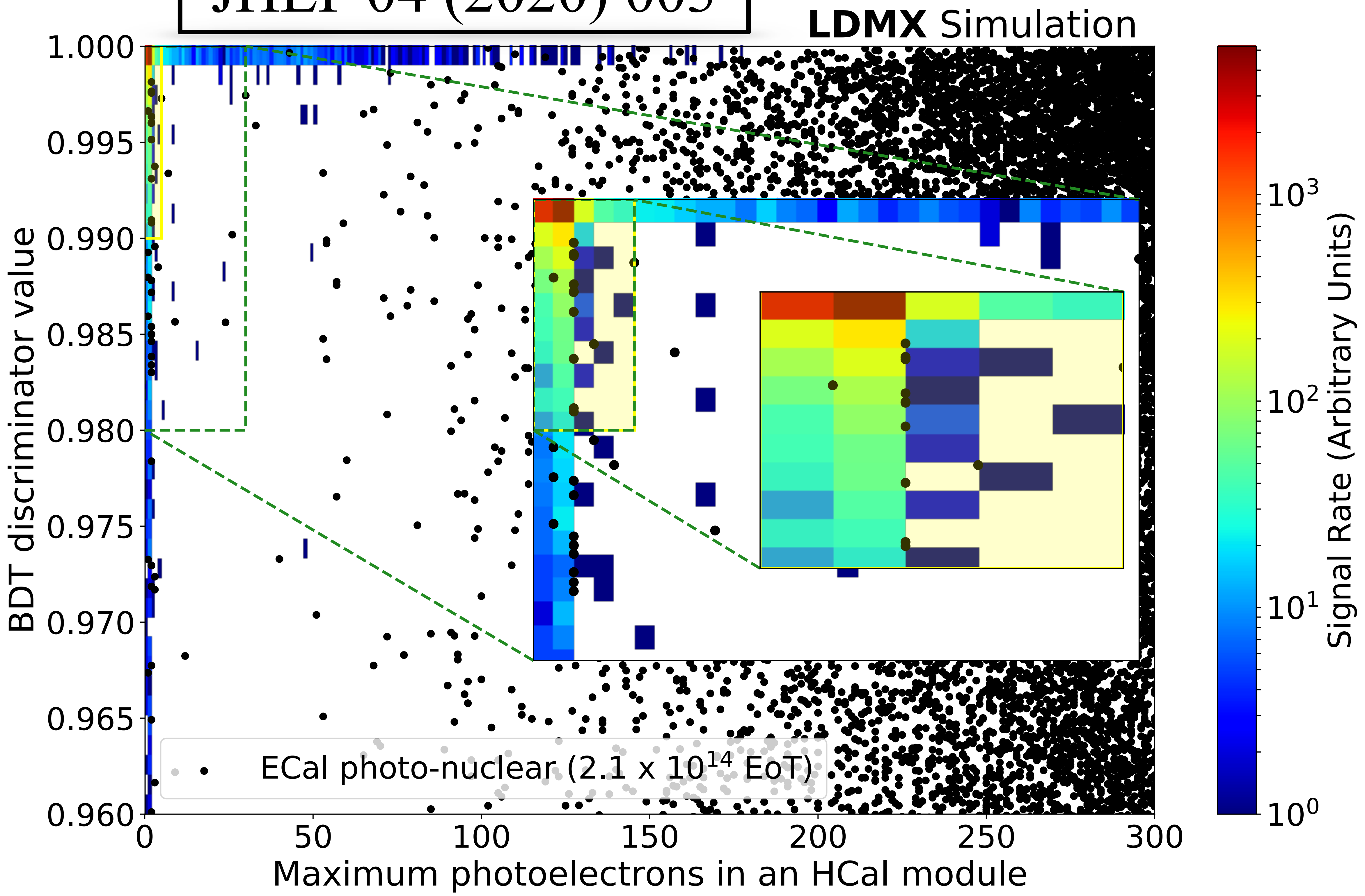
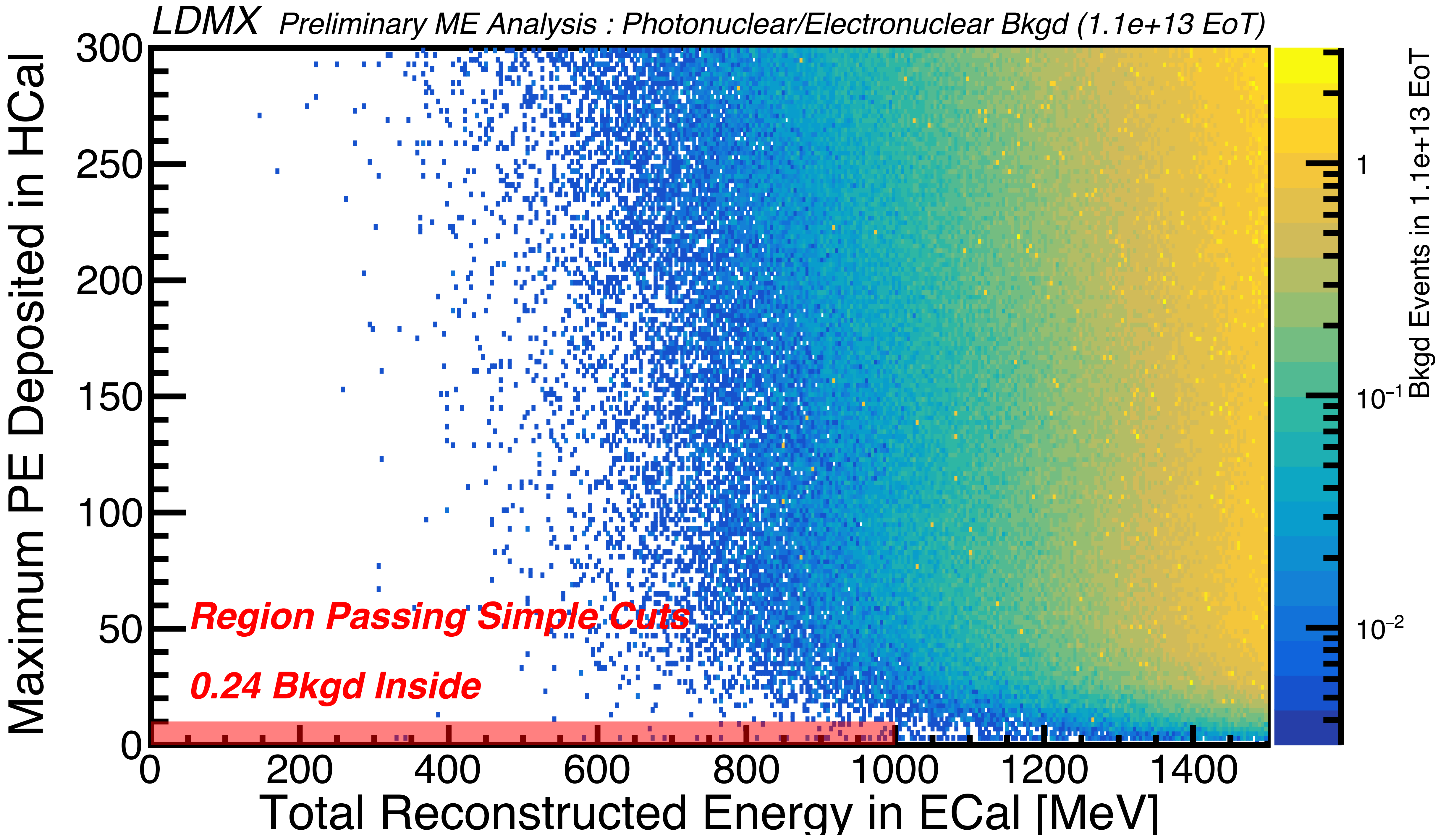
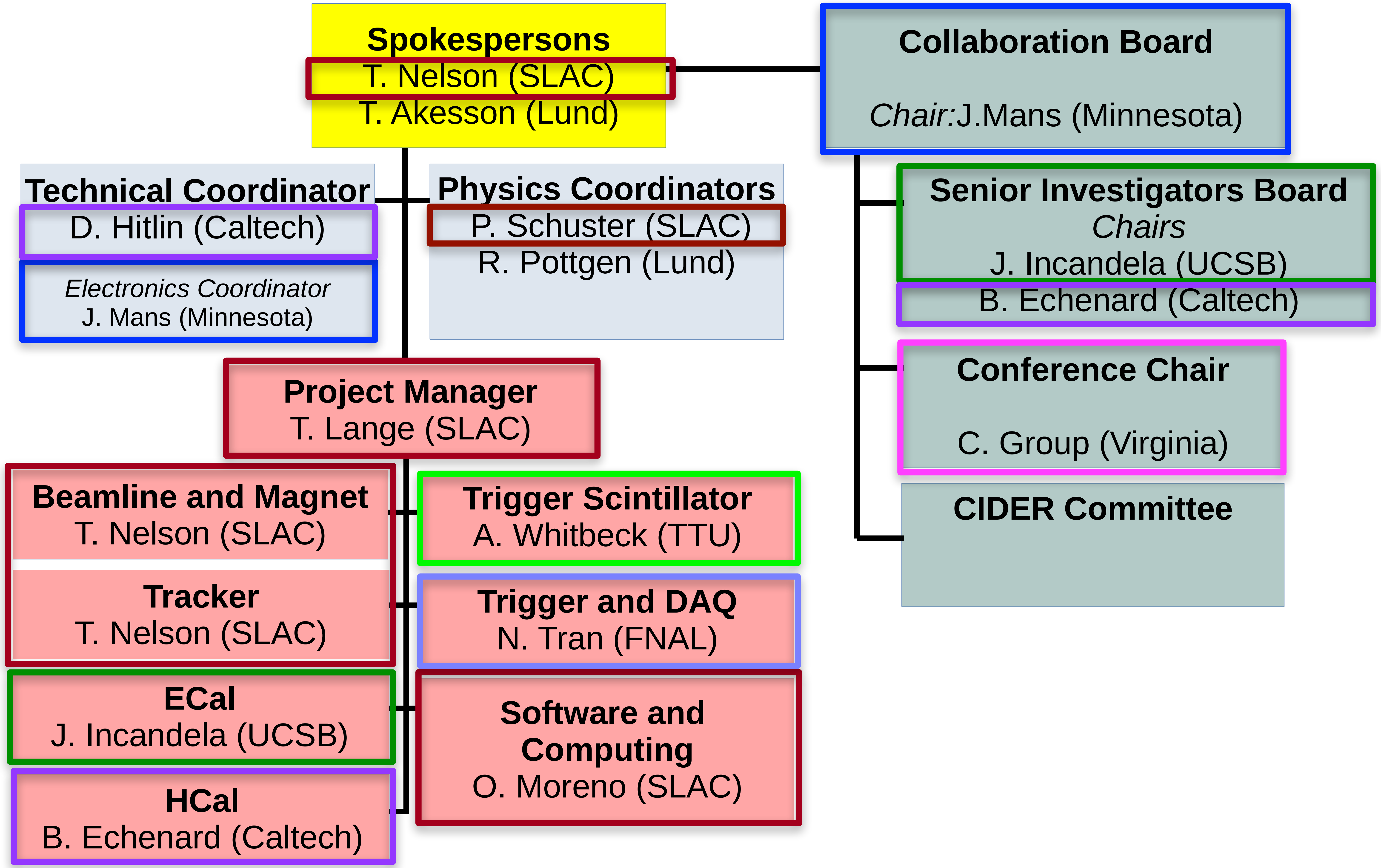


Preliminary ECal as Target missing energy study:
4.1M CPU hours, 1.1 PB data (unskimmed)



LDMX Collaboration and DMNI Consortium

Collaboration, formed in Spring 2019…



…maps onto DMNI Consortium

SLAC: PI Nelson *(HPS SVT)*
- Beamline/Magnet, Tracking, Computing, Project Management

UCSB: PI Incandela *(CMS HGCal modules)*
- ECal

U. Minn: PI Mans *(CMS HGCal electronics)*
- ECal

Caltech: PI Echenard
- HCal and Trigger Scintillator

U.VA: PI Group *(Mu2e CRV)*
- HCal

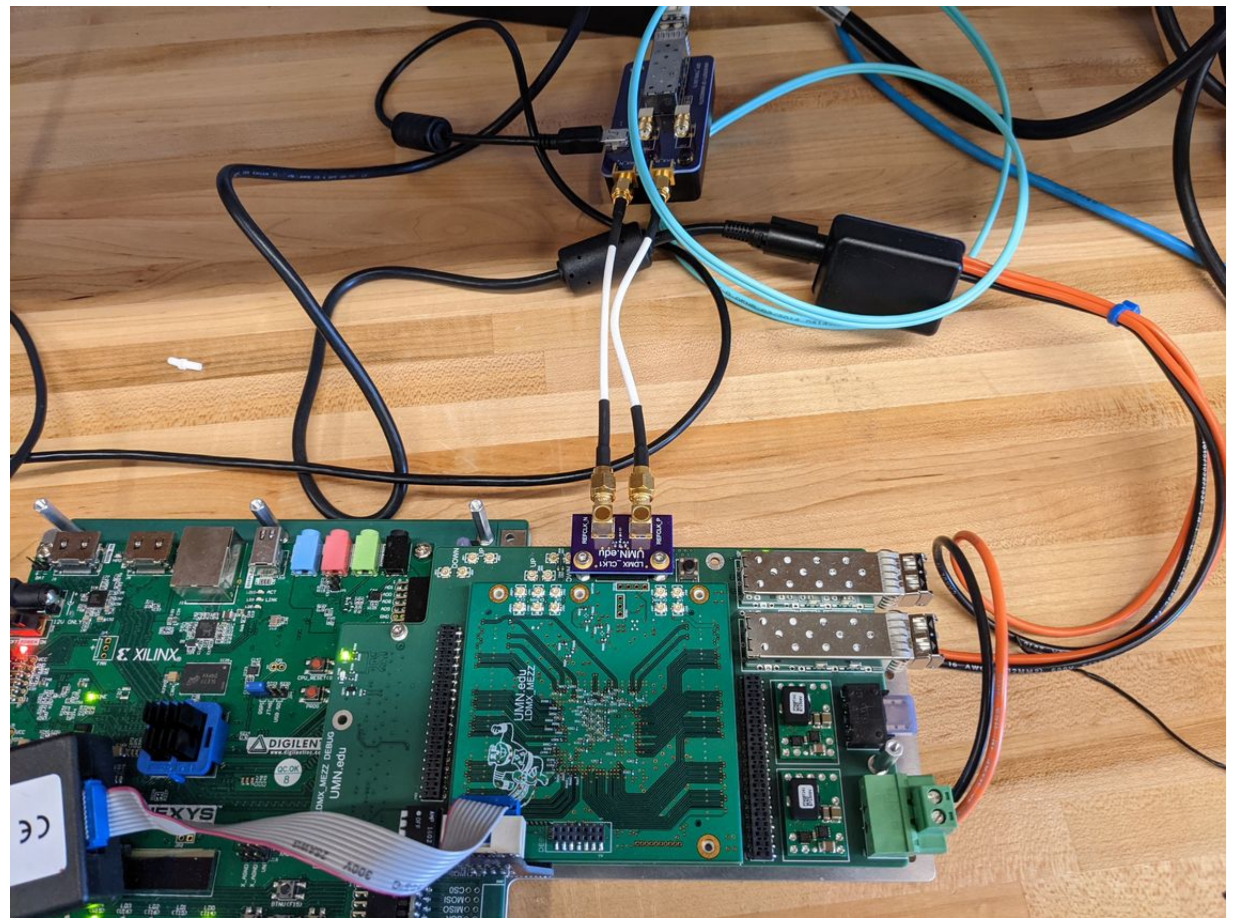
FNAL: PI Tran
- TDAQ

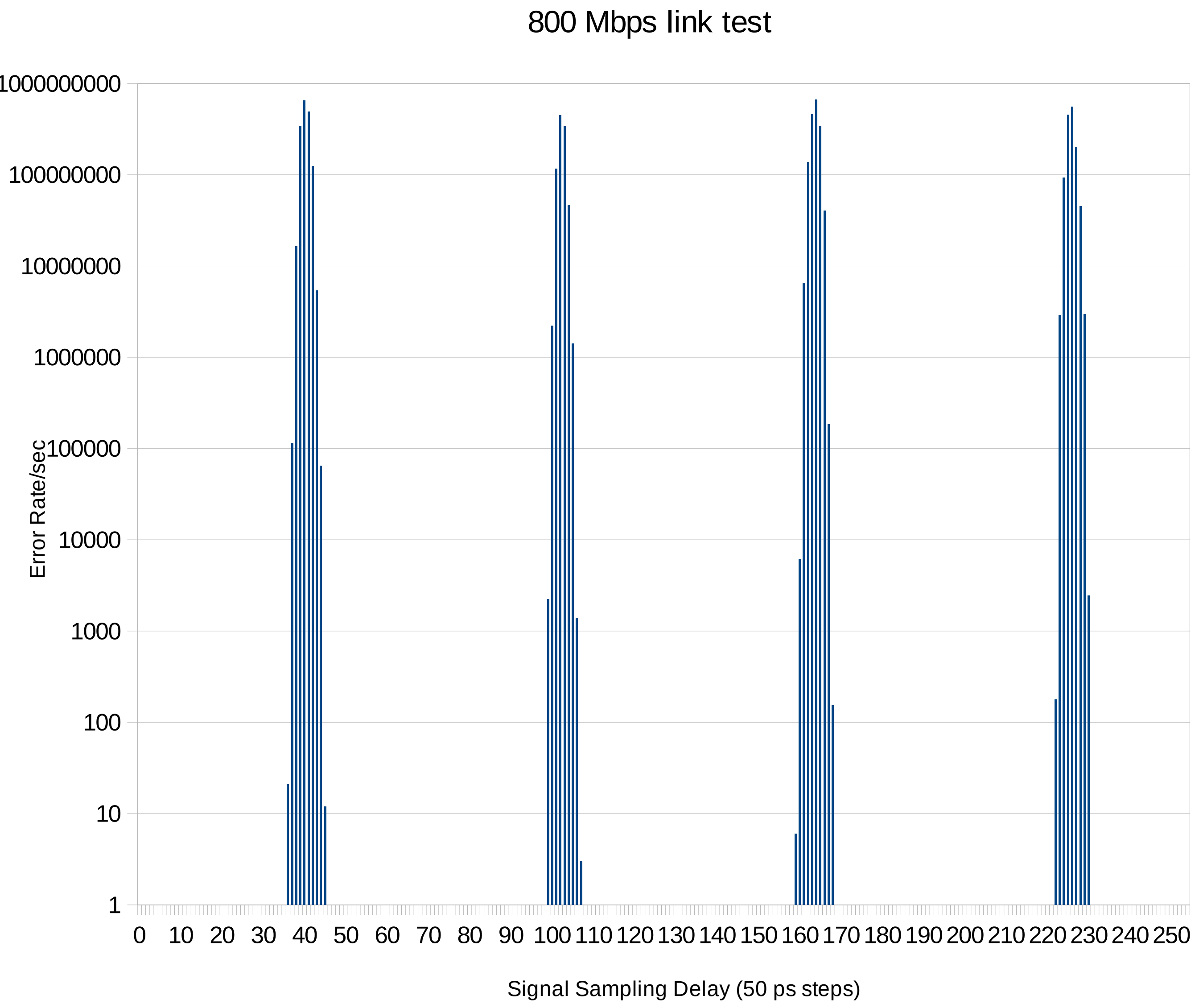
Texas Tech: PI Whitbeck
- Trigger Scintillator

Additional collaborators:
Lund: Åkesson, Pöttgen – (HCal, Computing)
Stanford: Tompkins – (TDAQ)

Polarfire Mezzanine Progress

- **Polarfire mezzanine intended for use in both ECAL and HCAL**
  - Common firmware and software base should reduce overall requirements during operations
- **Minnesota efforts have been focused on commissioning mezzanine for use in the 2021 testbeam**
  - Development of an ECAL-specific readout (motherboard) will be based on what we learn from the HCAL system and will require funding in FY22
- **Current progress:**
  - **Optical data links working both directions (July 30) from a CMS Phase 1 test card**
  - Capture of 800 Mbps data using internal deserializers working properly (limit of test setup), expect proper scaling to O(1250) Gbps to HGCROC
  - Already previously-demonstrated functionalities
    - I2C controller, required to configure the HGCROCs
    - Transport of slow signals (resets, error bits, etc)





CERN Testbeam in October 2021

LDMX

- Planning to test trigger scintillator and small Hcal section in the East Area
  - Minnesota on-site team: Revering and Mans (~1 week), offsite: Eichlersmith
  - Quite a lot of remaining work to commission system before October, as much of the readout/control electronics is being delivered only (~now) in August
  - Beam run is ~two weeks, aim to use electrons, hadrons, muons in ~500 MeV to 4 GeV range

DOE Reviews and Funding

- Detector development funding for O($1.8M) over 2.25 years announced in 2020
  - Received FY20 tranche (~$200k) on schedule, did not receive FY21 funding on schedule
- DOE Review of progress and design in June 2021
  - Went very well, impressed new program manager
  - Receiving about 10% of planned FY21 funding during FY21
  - Potentially receiving balance in FY22 (drought then flood?)
- Beamline construction continues to make progress and has received planned funding to date (very important)

Construction/Operation

- Goal to begin two-year detector construction process in ~January 2023
  - Reasonably well-aligned with CMS HGCAL schedule, which is important as the effort relies on the CMS hexaboards and module-construction technologies for the ECAL, as well as the HGCROC-SiPM for the HCAL
- Minnesota responsibility for the motherboards and ECAL readout, local trigger, and control