Hannah Herde, on behalf of Swedish Collaborators in LDMX

LDMX

LunDMX

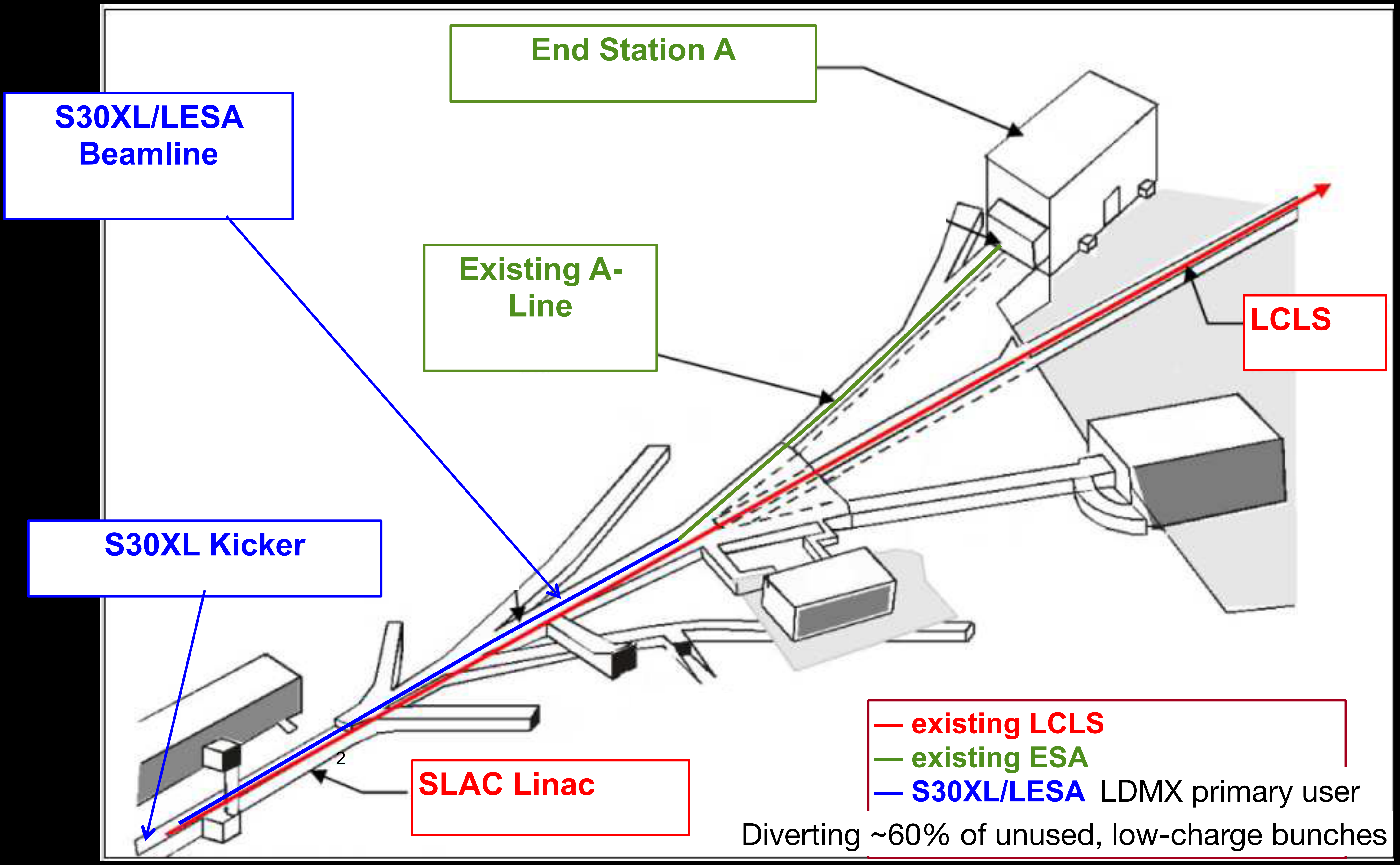
SLAC on flickr, https://www.flickr.com/photos/slaclab/35539015616

Sweden in LDMX

Status as of Partikeldagarna 2024

Making Light Dark Matter

LDMX: Fixed-target detector at SLAC



Parasitic beam harvesting electrons *between* bunches delivered for ɣ physics at SLAC's LCLS-II

8 GeV electrons

Linac to End Station A (LESA): 8 GeV

Low current

- Measure each incoming <u>and</u> outgoing electron

High repetition rate

- 37 MHz bucket frequency → ~10^{14} electrons on target in a year within 1-2 years

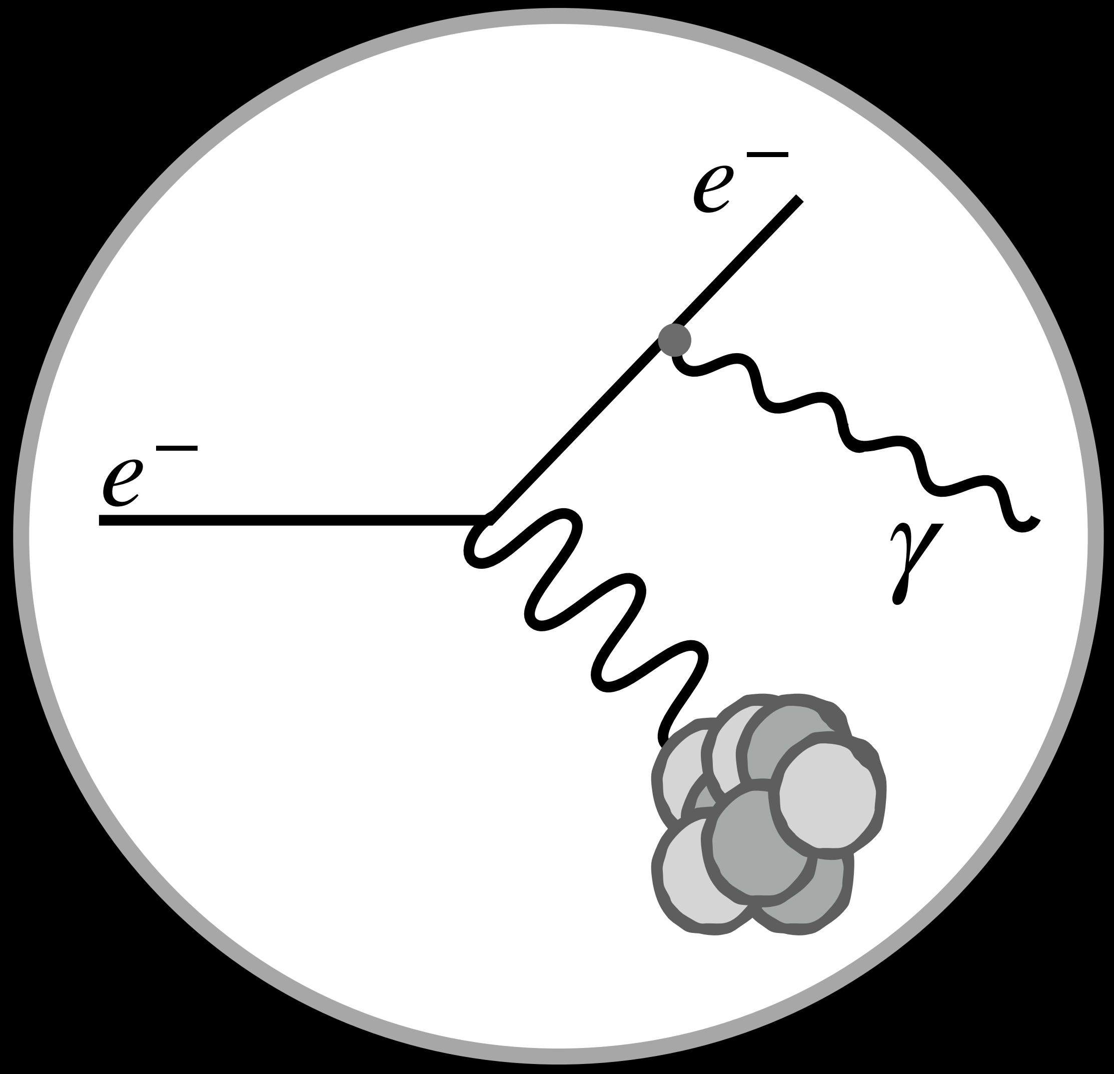
Under construction right now

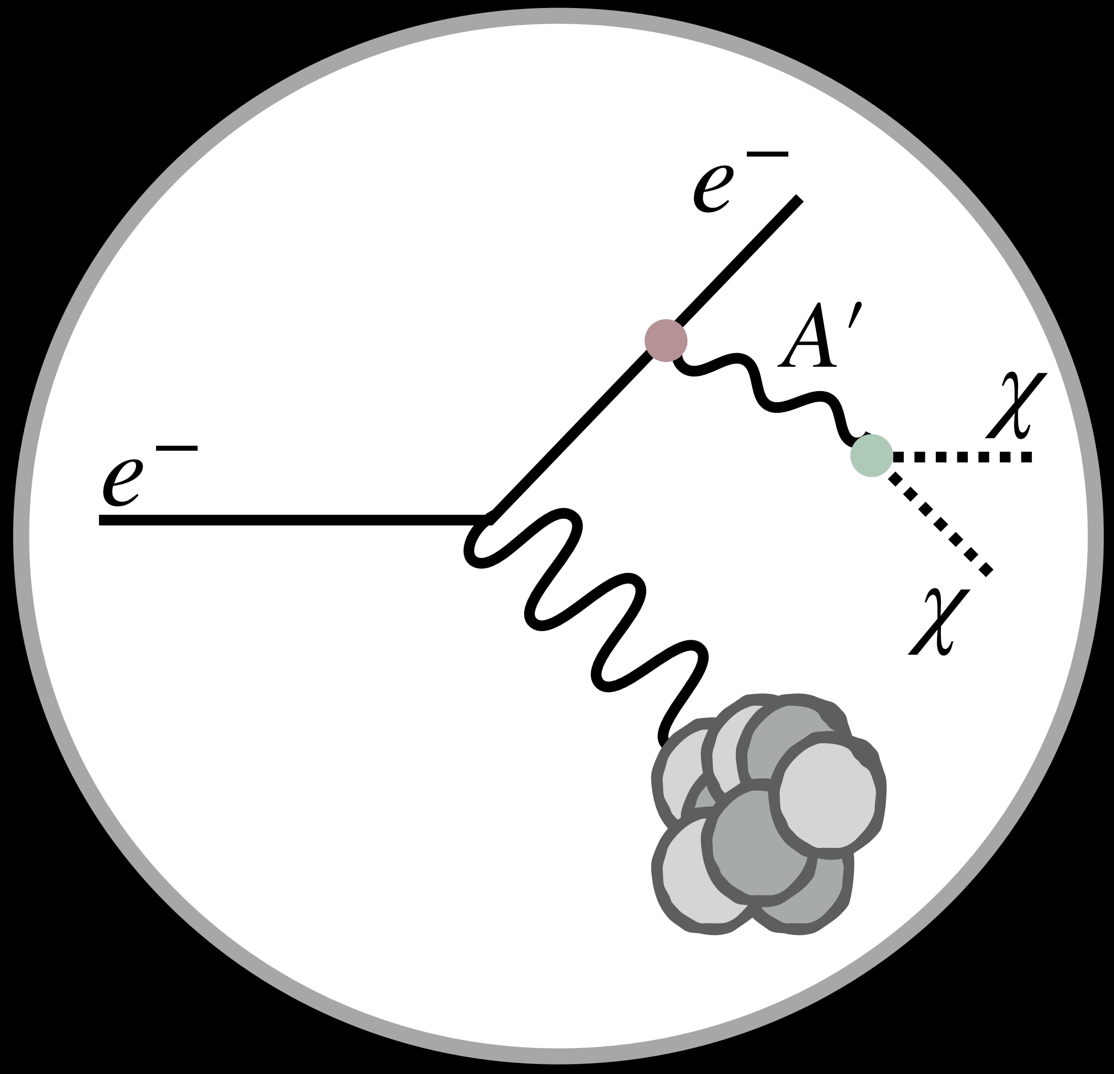
arXiv:2205.13215

Wide physics potential

Measure momentum before/after target & energy

SM (QED) Bremsstrahlung





Dark photon Bremsstrahlung
(short lifetime)

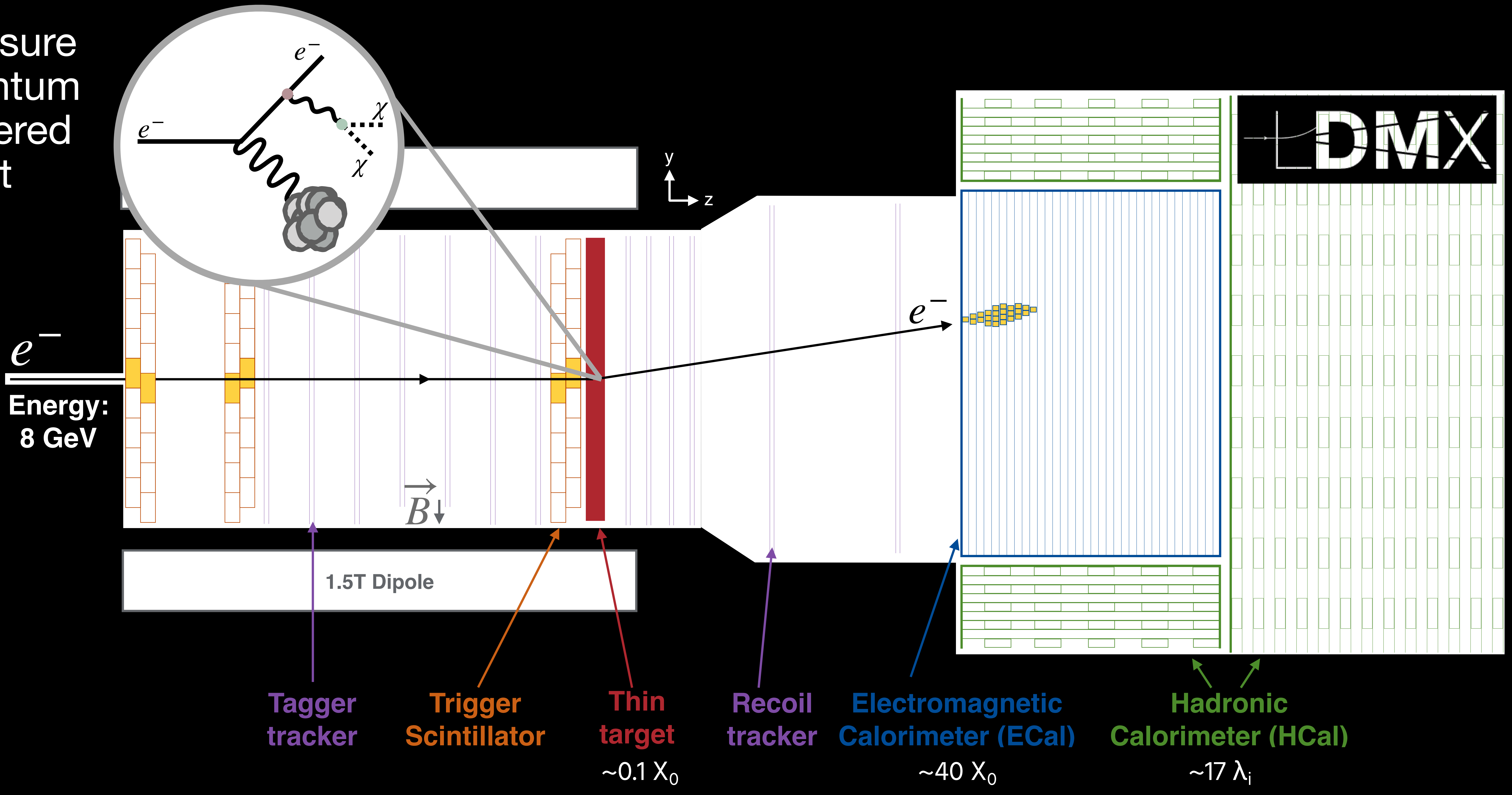
- Other mediators to Dark Sector
- Millicharged particles
- Inelastic DM
- SIMPs
- Freeze-in DM
- ALPs
- Photo-production of vector mesons mixing with A'
- Long-lived particles (visible & invisible signatures)
- Electro-nucleon cross section measurements
    - Key for neutrino program

arXiv:2112.02104; arXiv:2203.08192; Phys. Rev. D 99, 075001 (arXiv:1807.01730) ; Phys. Rev. D 101, 053004 (arXiv:1912.06140)

Design driver: Missing momentum signatures

LDMX sub-detectors overlaid with an invisible DM signature

Individually measure energy & momentum for 10^{16} e^- scattered off thin target

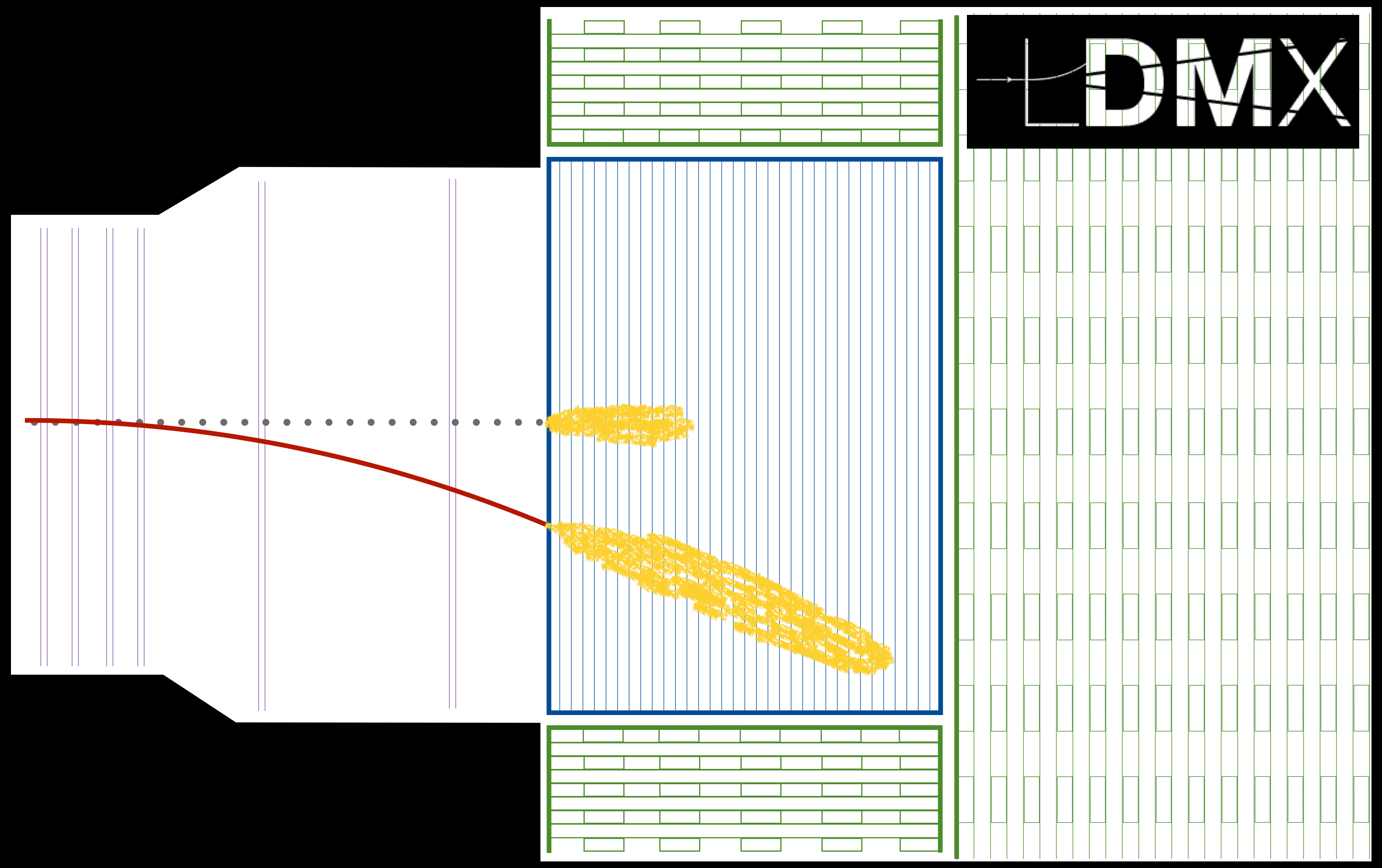


Eliminate neutral backgrounds
(SM ɣ Bremsstrahlung;
Photo-nuclear reactions)

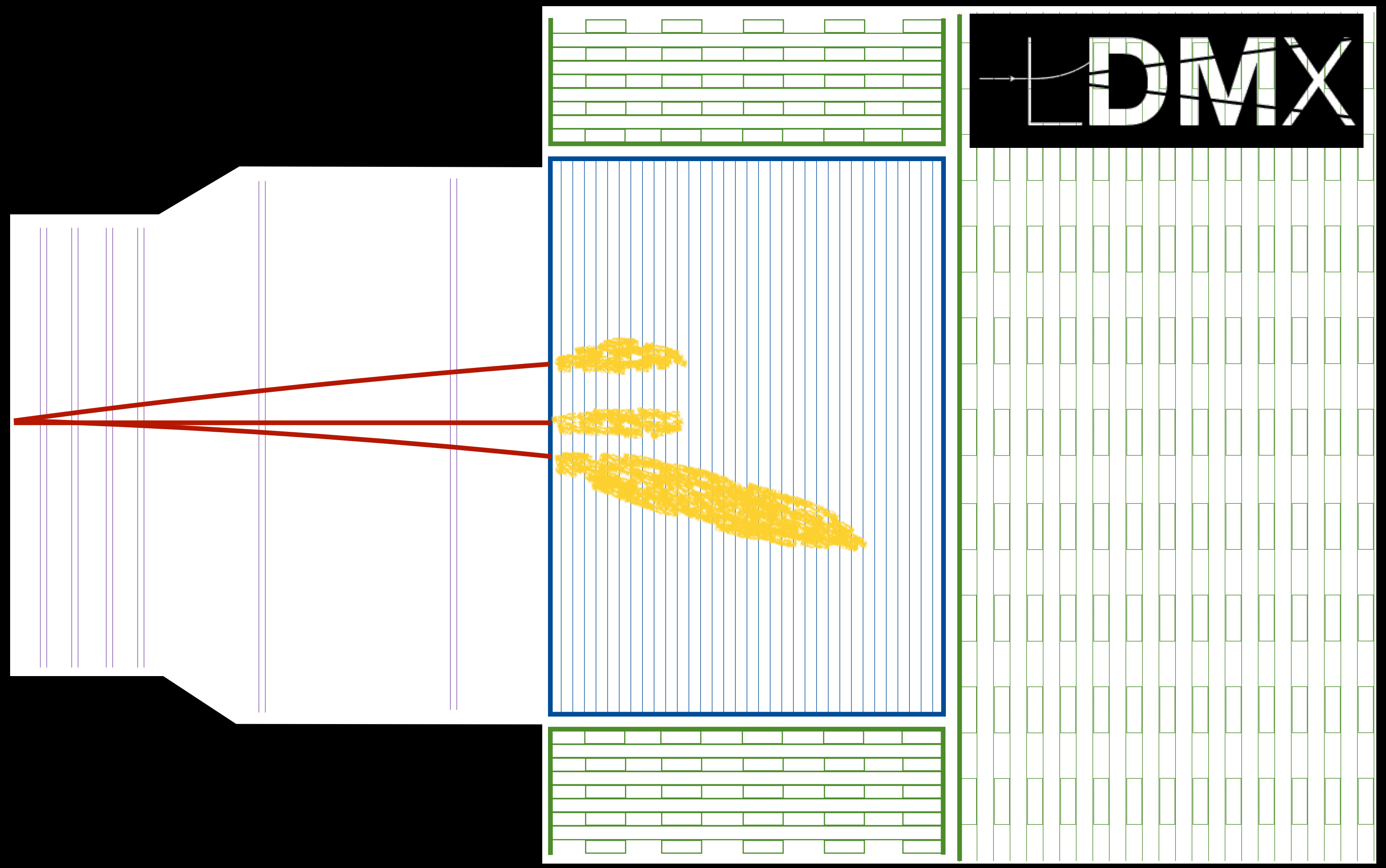
Modified from Snowmass 2021 LDMX status and prospects, fig 1, https://arxiv.org/abs/2203.08192

Sub-detectors work together for zero-background

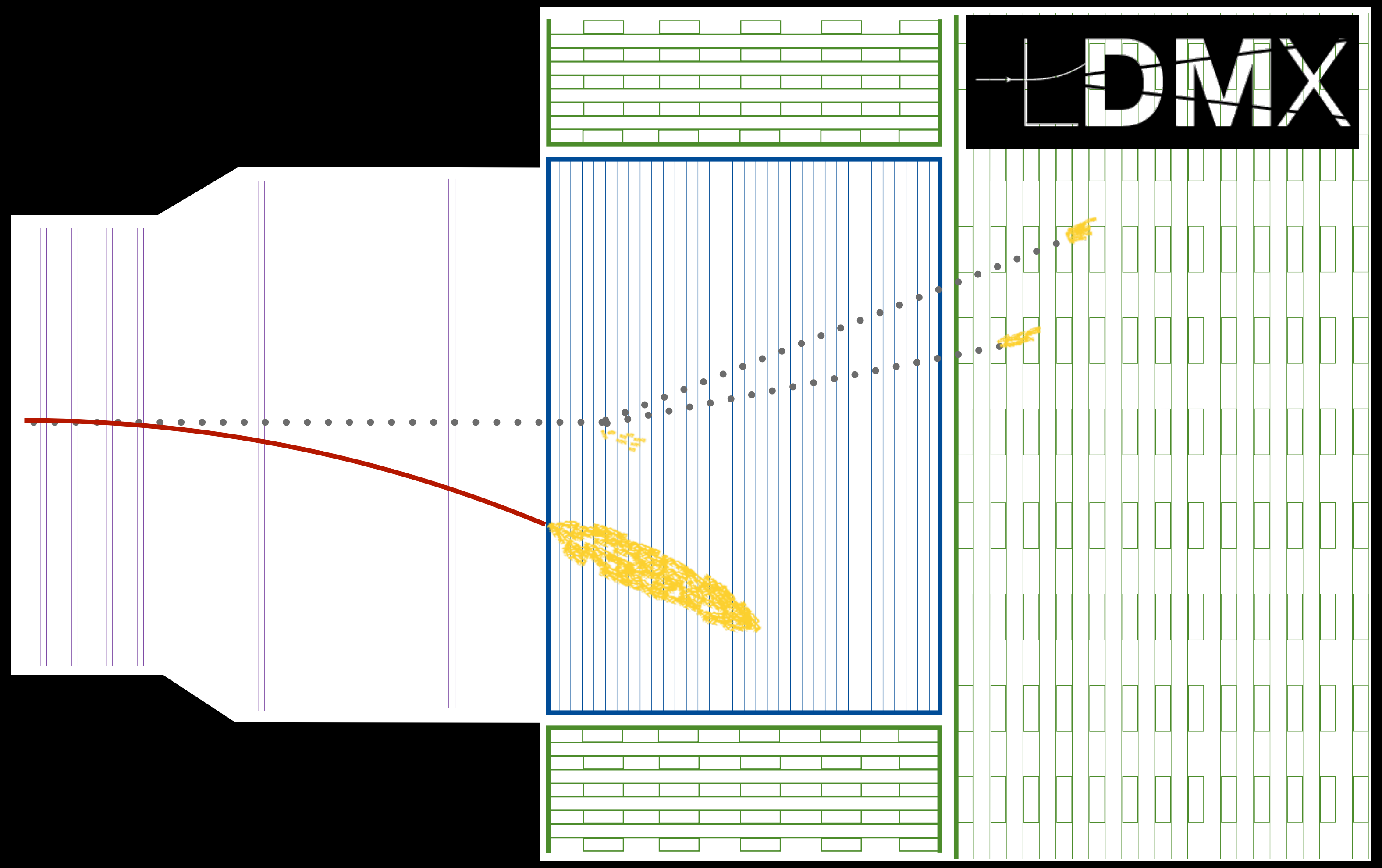
SM Bremsstrahlung



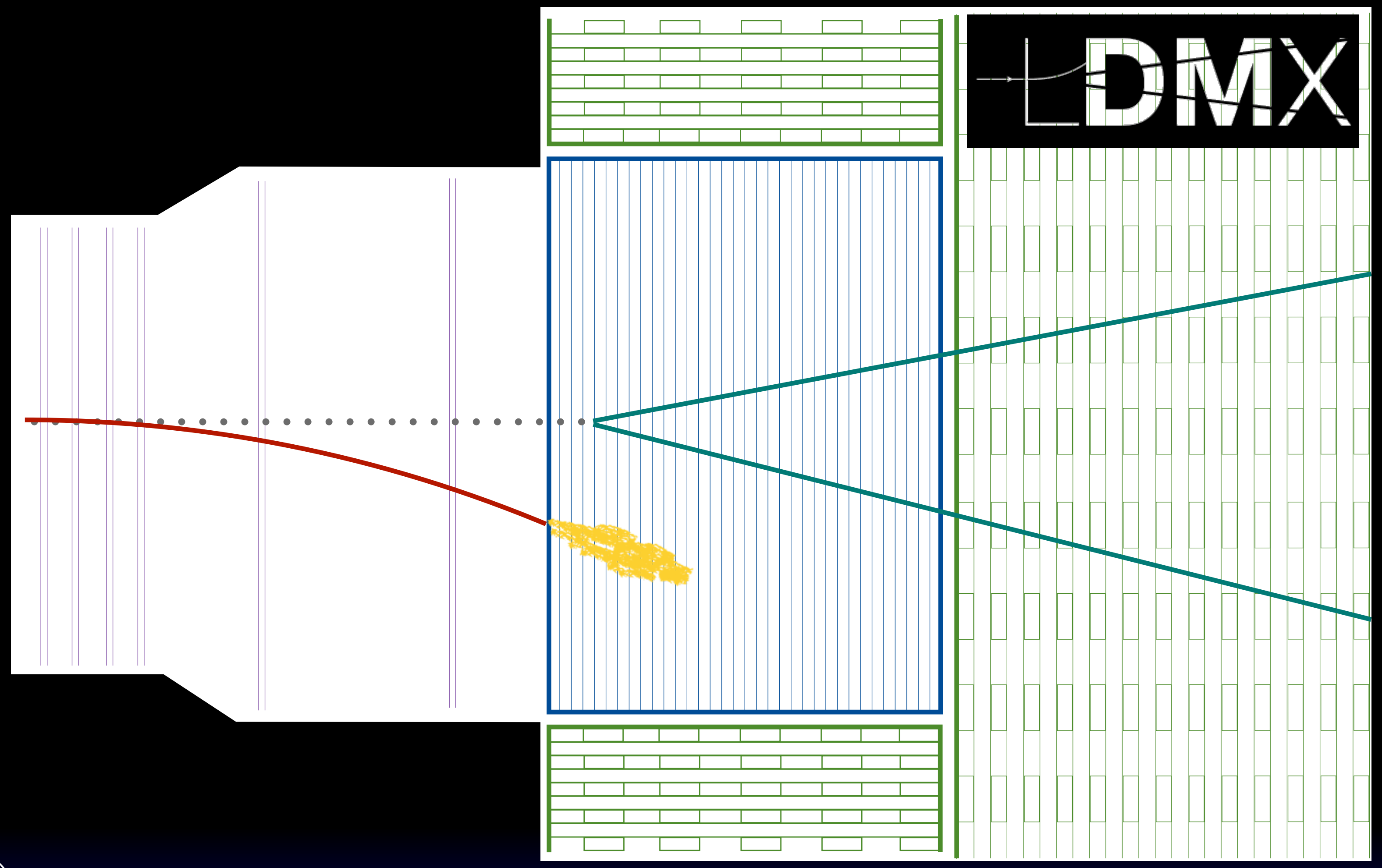
Trident



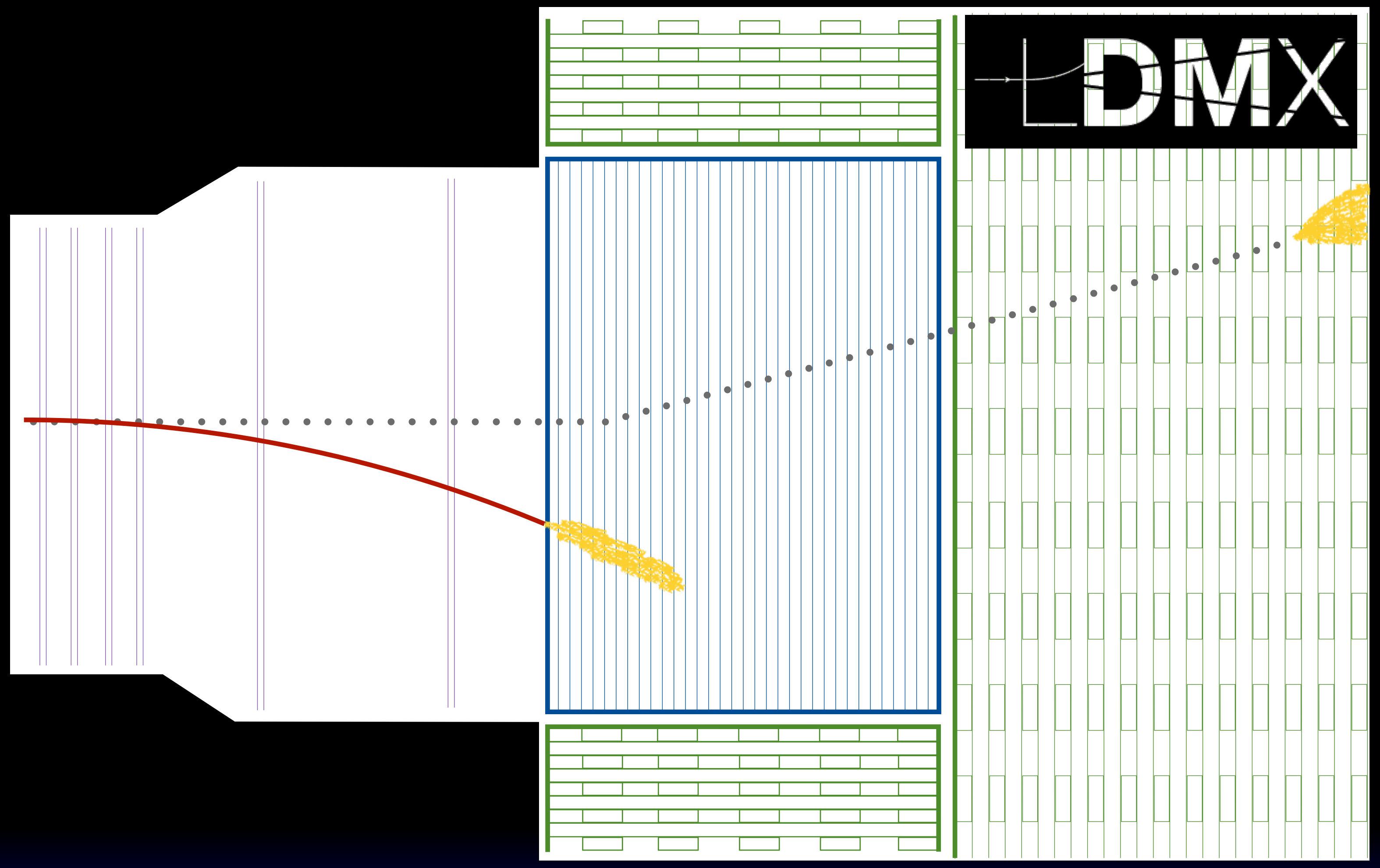
Hadronic production in the ECal



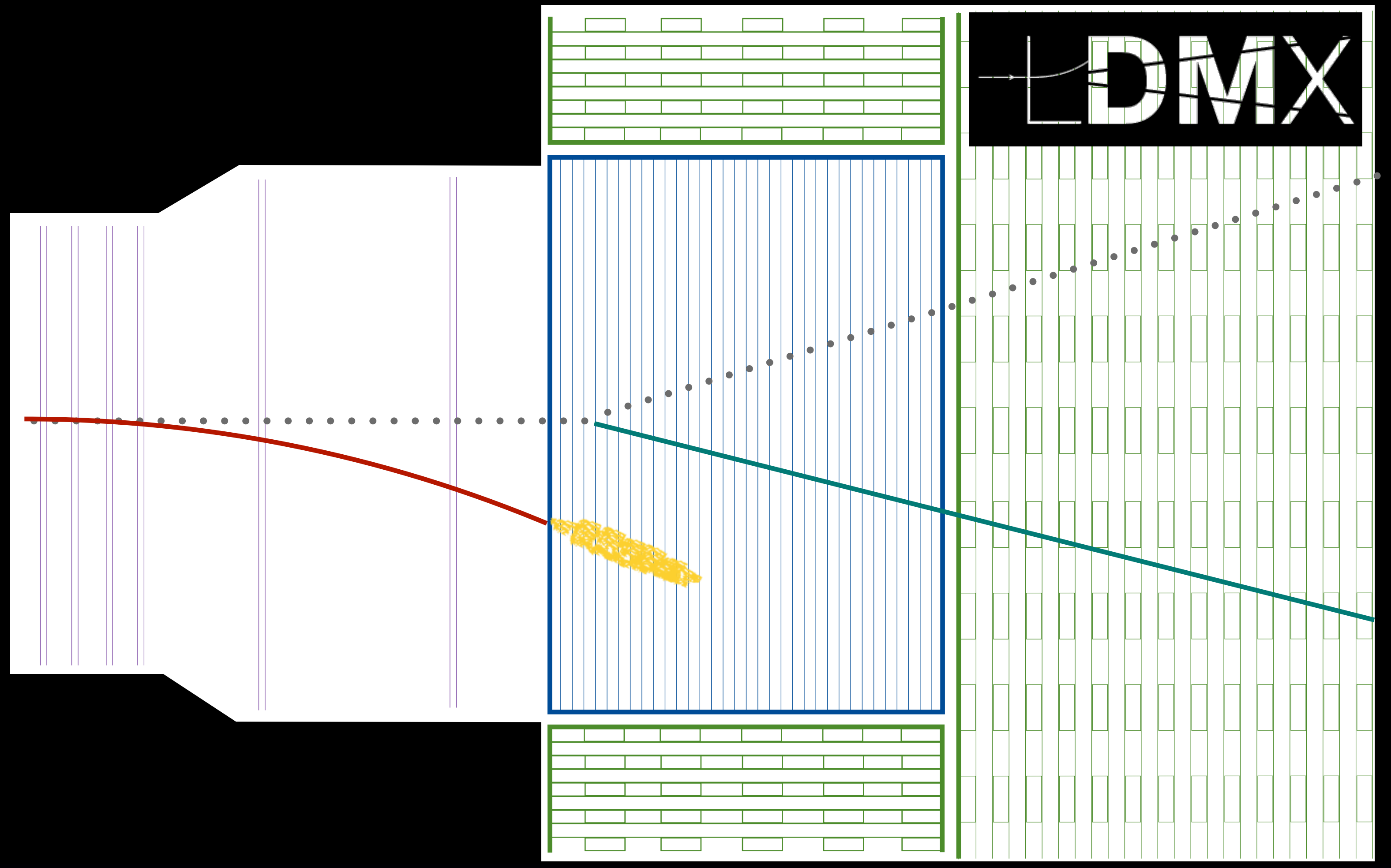
Photon conversions to muon pairs



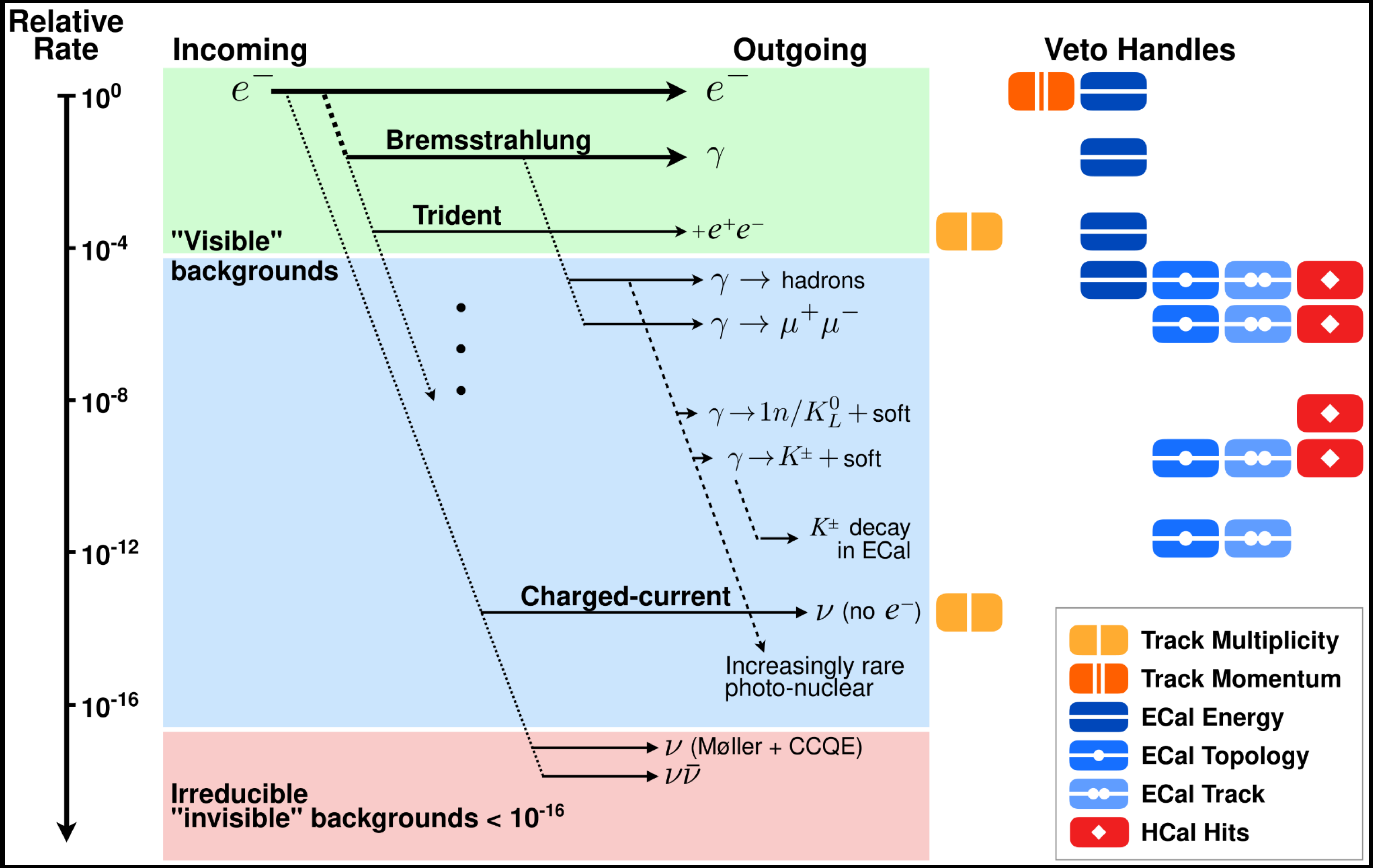
Neutral hadron production



Kaon production (example)



Sub-detectors work together for zero-background



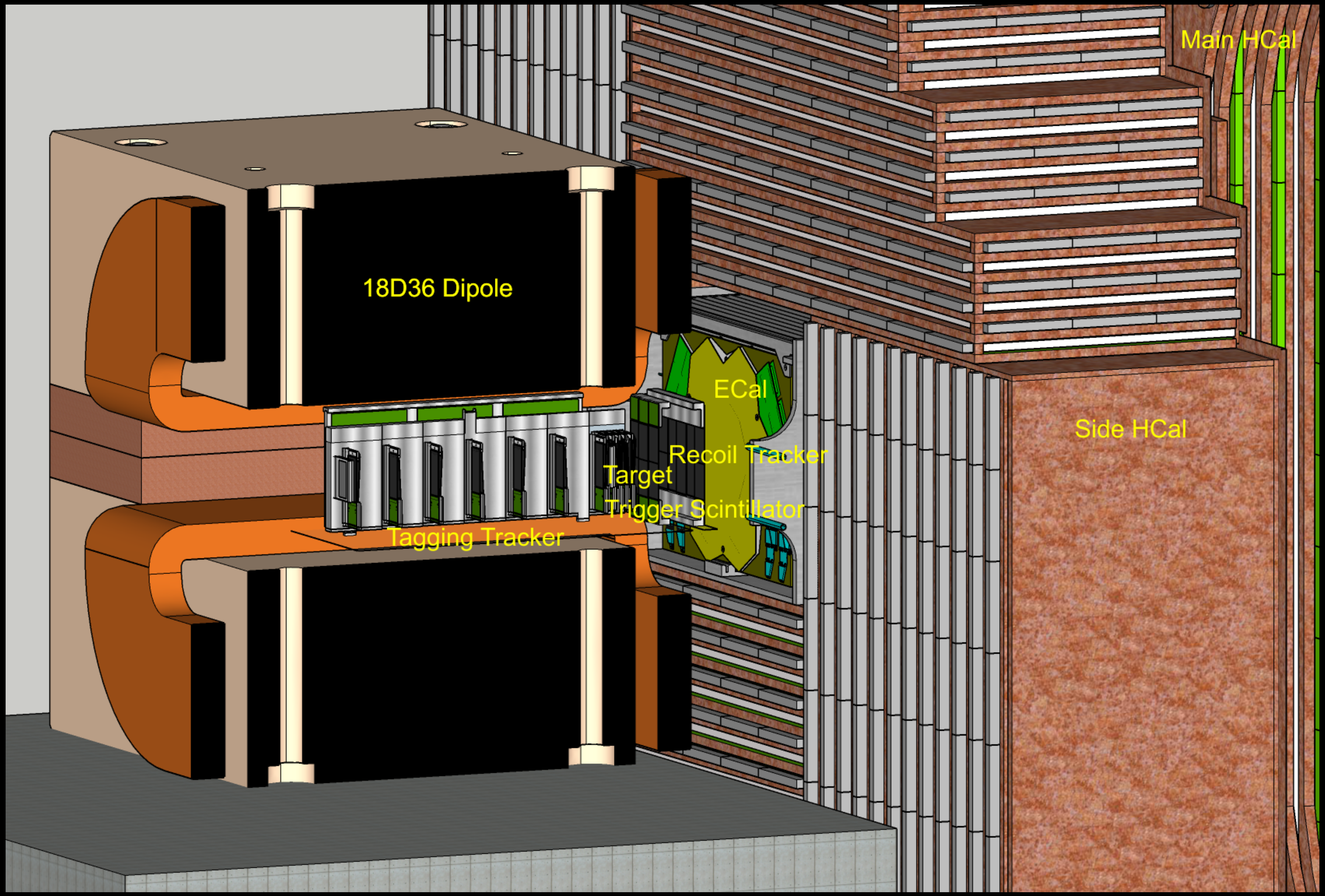
Zero background remaining:

→ at 4 GeV with ~10^{14} electrons on target
A High Efficiency Photon Veto for the Light Dark Matter eXperiment, JHEP 04, 003 (2020).

→ at 8 GeV with ~10^{14} electrons on target
Photon-rejection power of the Light Dark Matter eXperiment in an 8 GeV beam, JHEP 12, 092 (2023).
(🇸🇪 LunDMX: E. Wallin, R. Pöttgen)

LDMX detector

Combine technologies from other operational/planned detectors



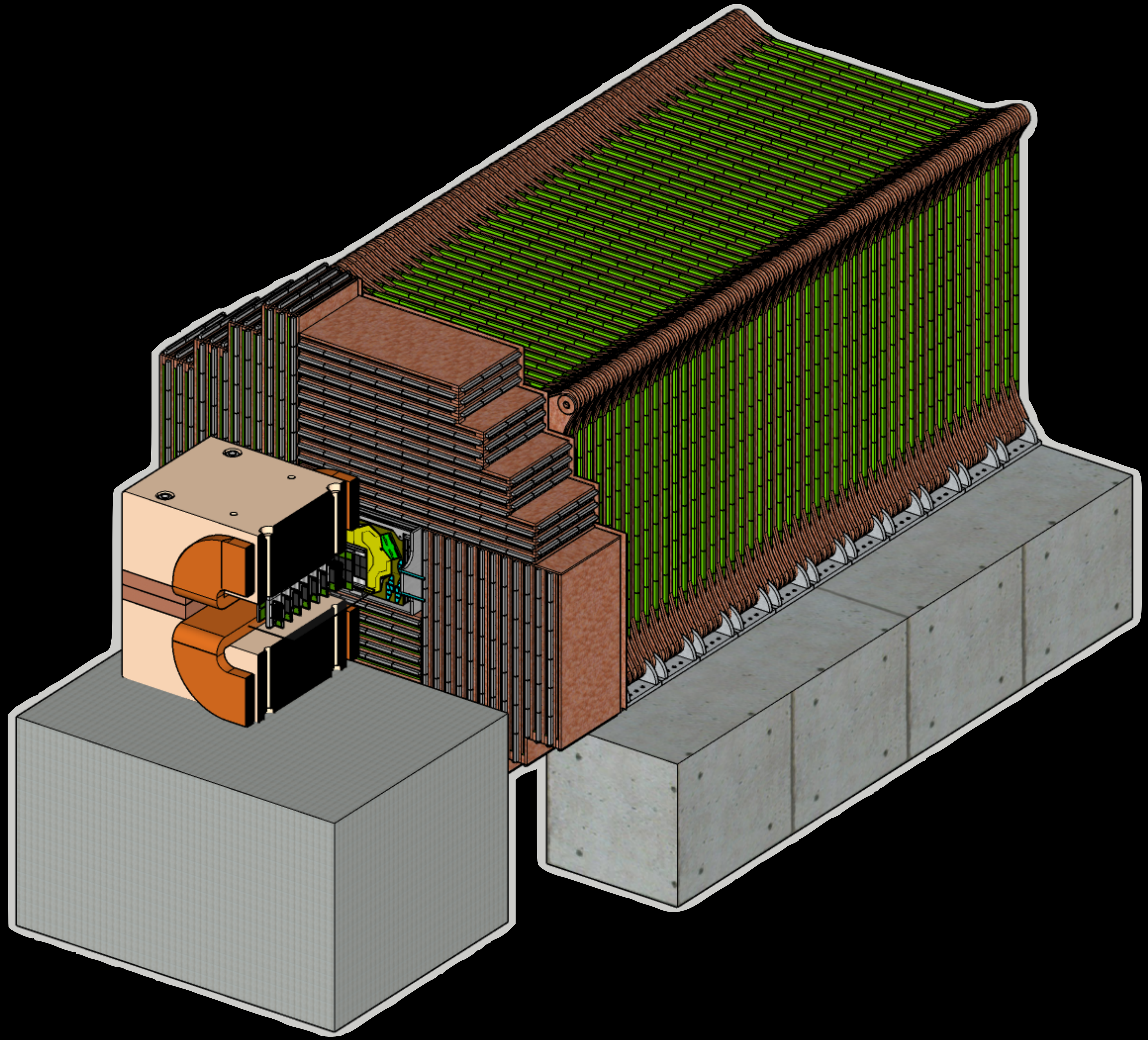
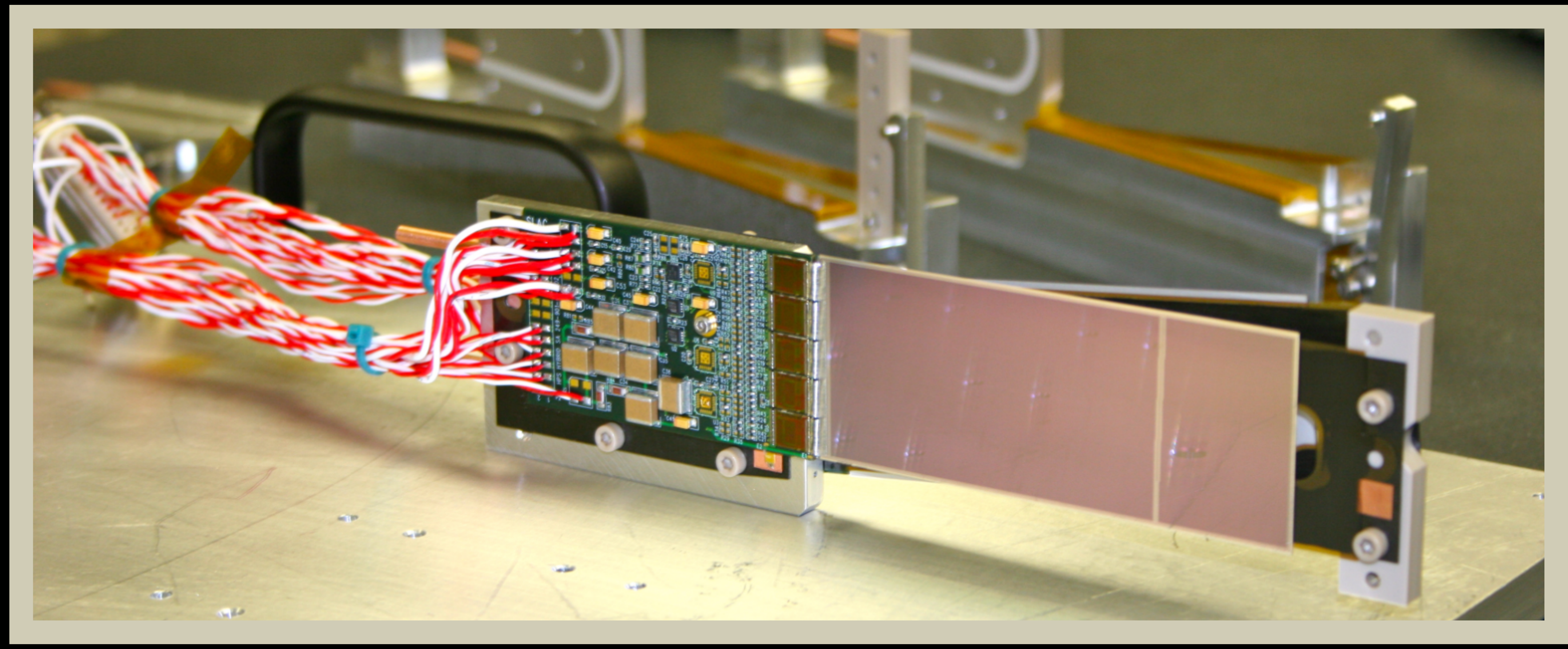
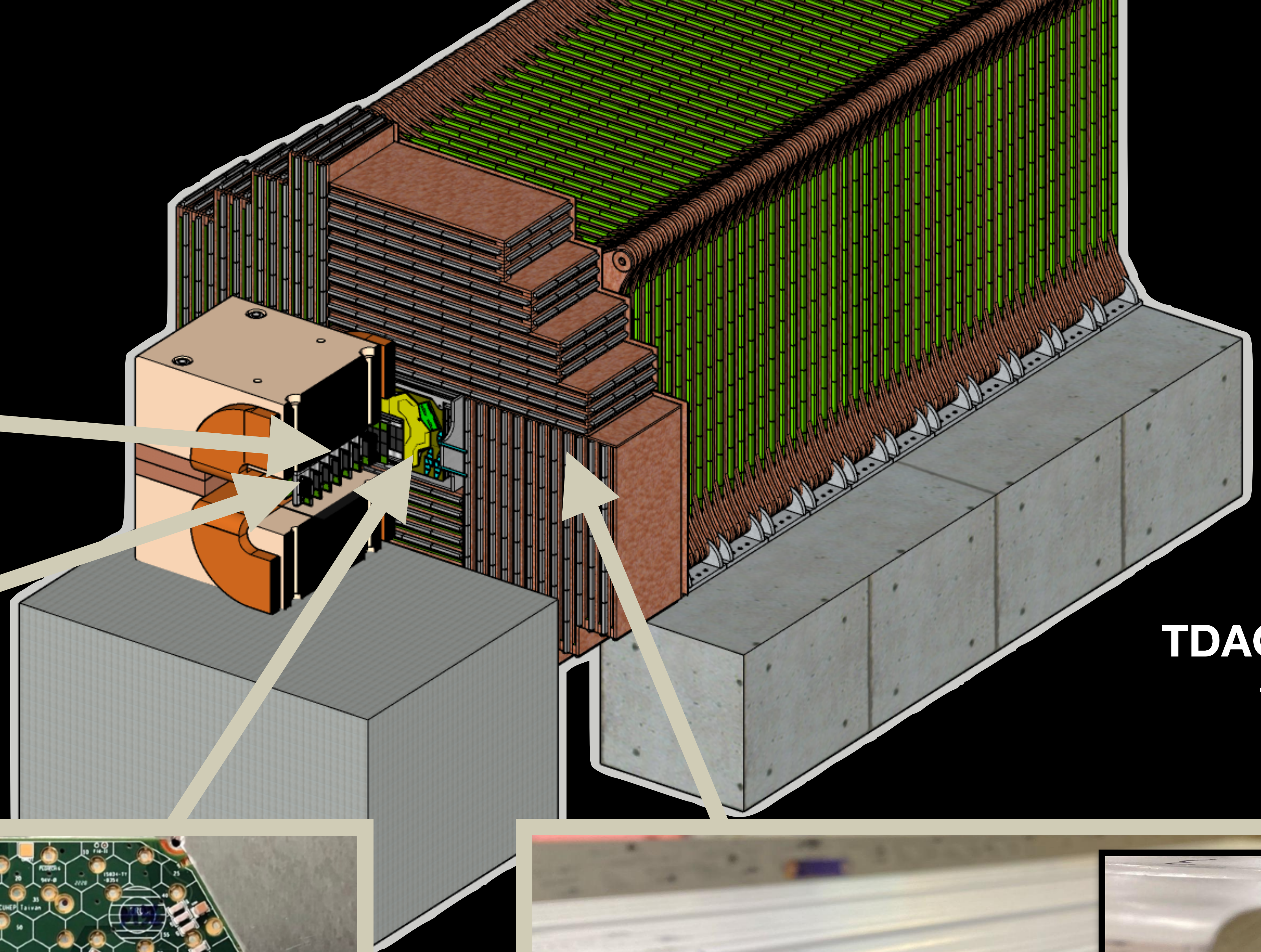


Image sources

Image sources

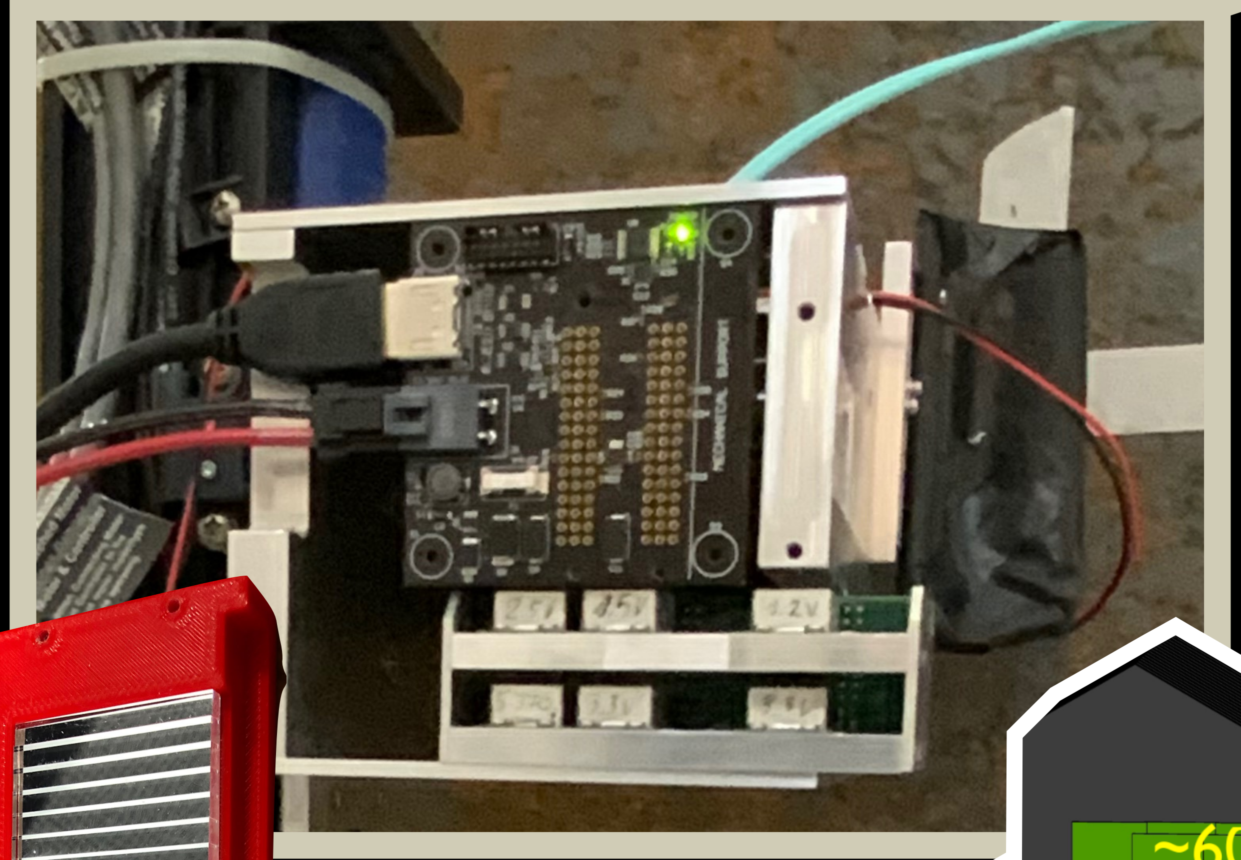
HPS Silicon Vertex Tracker modules

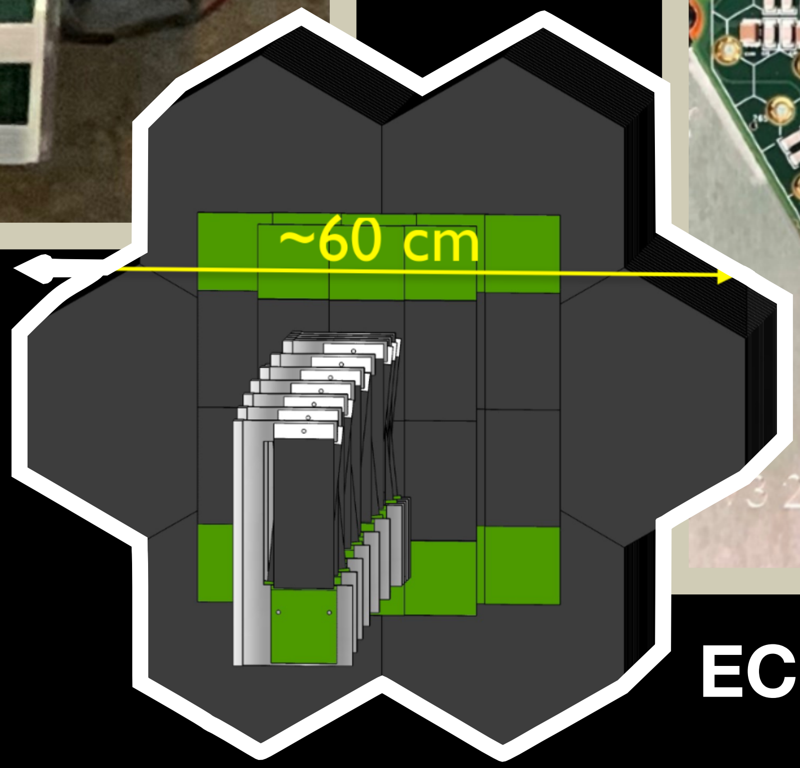


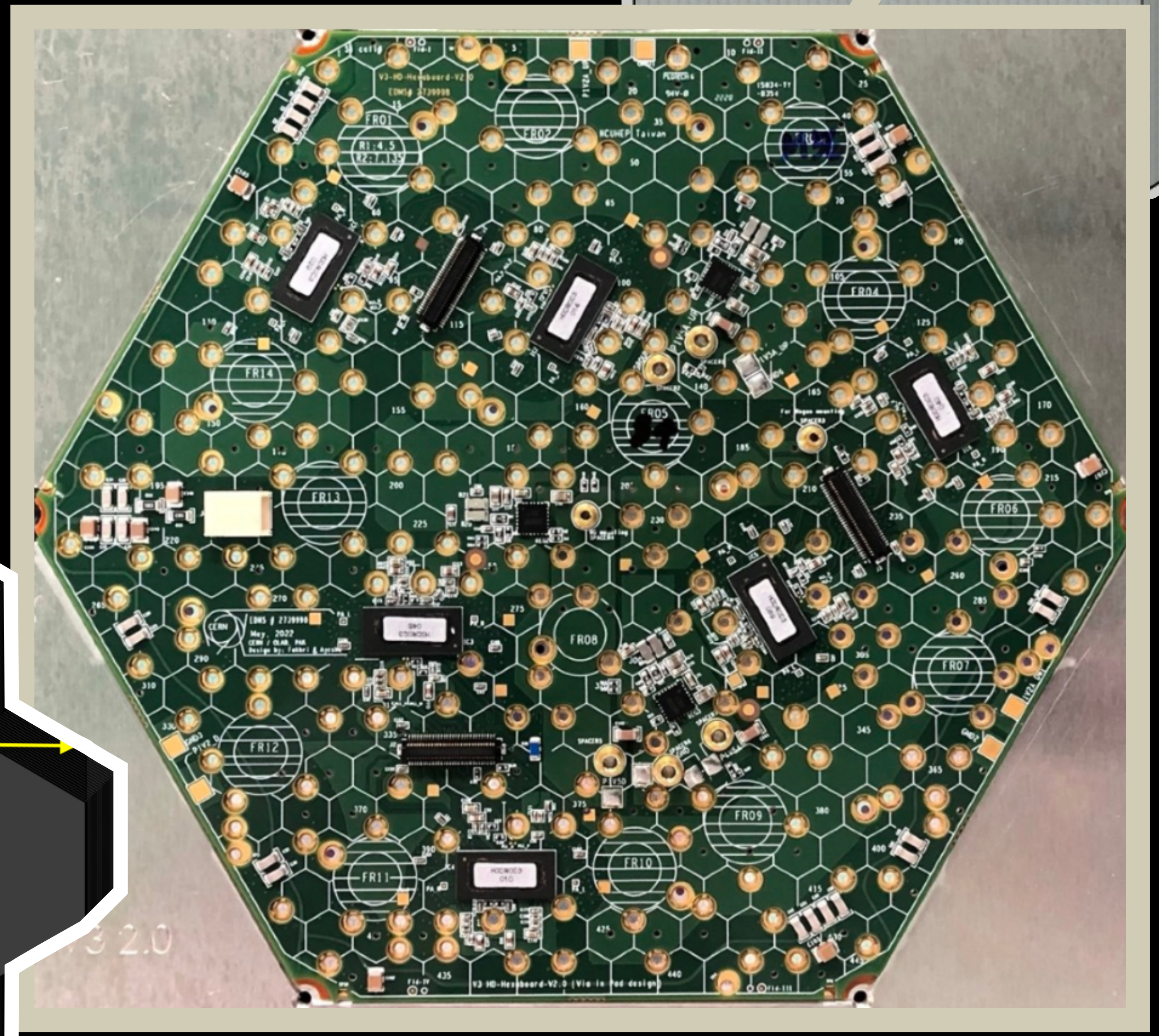


TDAQ: SLAC/Fermilab technologies

Trigger Scintillator from CMS HCal







ECal modules based on CMS' Si-W High Granularity Calorimeter

TDAQ: SLAC/Fermilab technologies

🇸🇪 LunDMX

LUND UNIVERSITY

LunDMX as part of KAW Light Dark Matter project

🇸🇪 Partnership with Chalmers University of Technology: R. Catena, T. Gray

LDMX	Simulation: PYTHIA-GEANT4 integration
Statistical inference	Detector material evaluation for direct detection

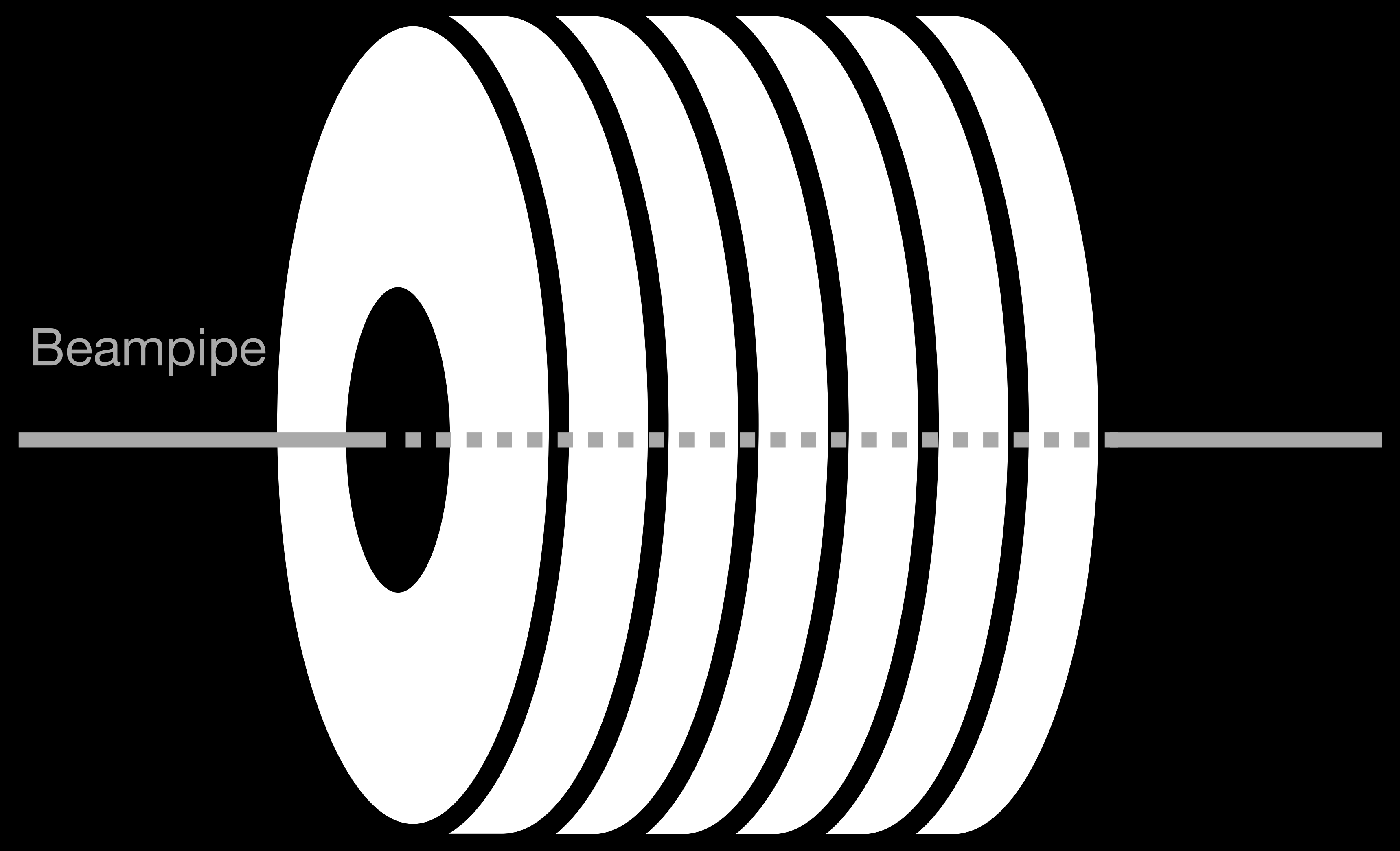
- Model building for current & future fixed-target experiments
- GAMBIT: Global and Modular BSM Inference Tool
- Live at Partikeldagarna:
  - Michał Iglicki, Theoretical upper bounds on detector's response to DM-e interactions in direct searches for sub-GeV dark matter
  - Andreas Lund, On the dark matter origin of a LDMX signal
  - Taylor Gray, Resonant or asymmetric: The status of sub-GeV dark matter
- KAW-LDM bibliography

Knut and Alice Wallenberg Foundation
LUND UNIVERSITY
CHALMERS UNIVERSITY OF TECHNOLOGY
Stockholm University

Simulation: Integrating PYTHIA and GEANT4

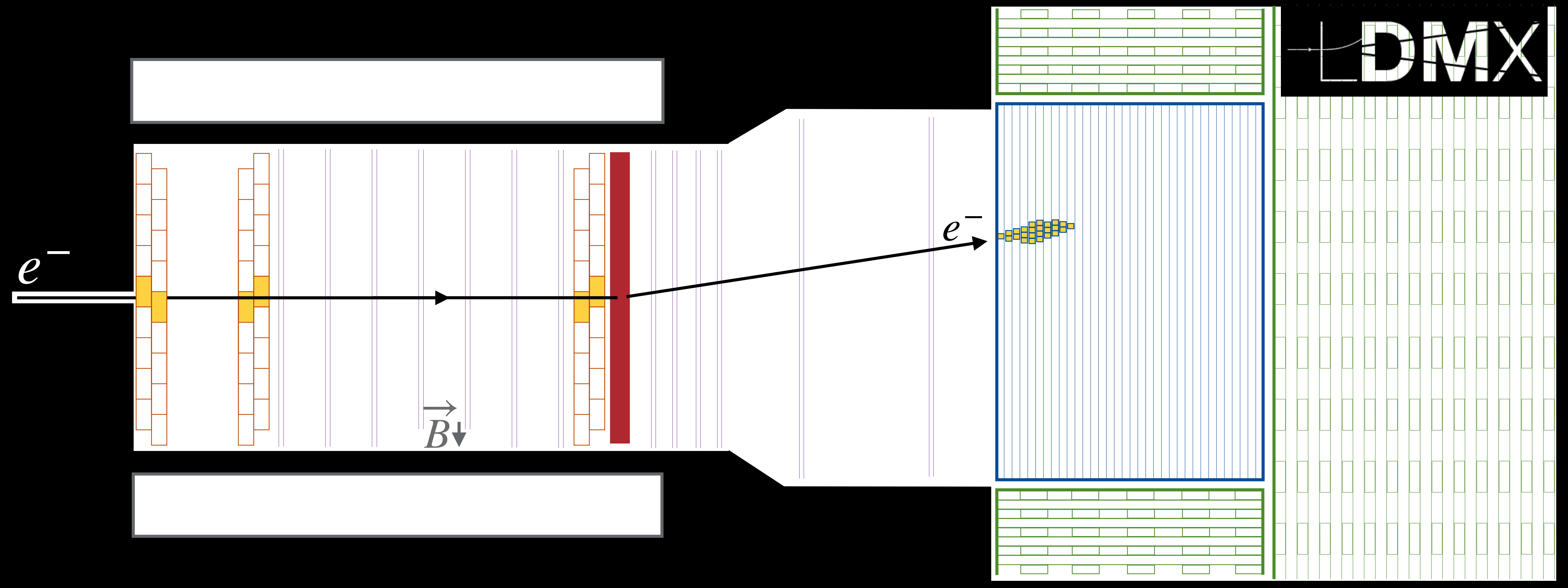
🇸🇪 LunDMX: E. Elén, L. S. Pico

Collider experiment with Beamline



Collisions isolated from detector

Fixed target experiment like LDMX

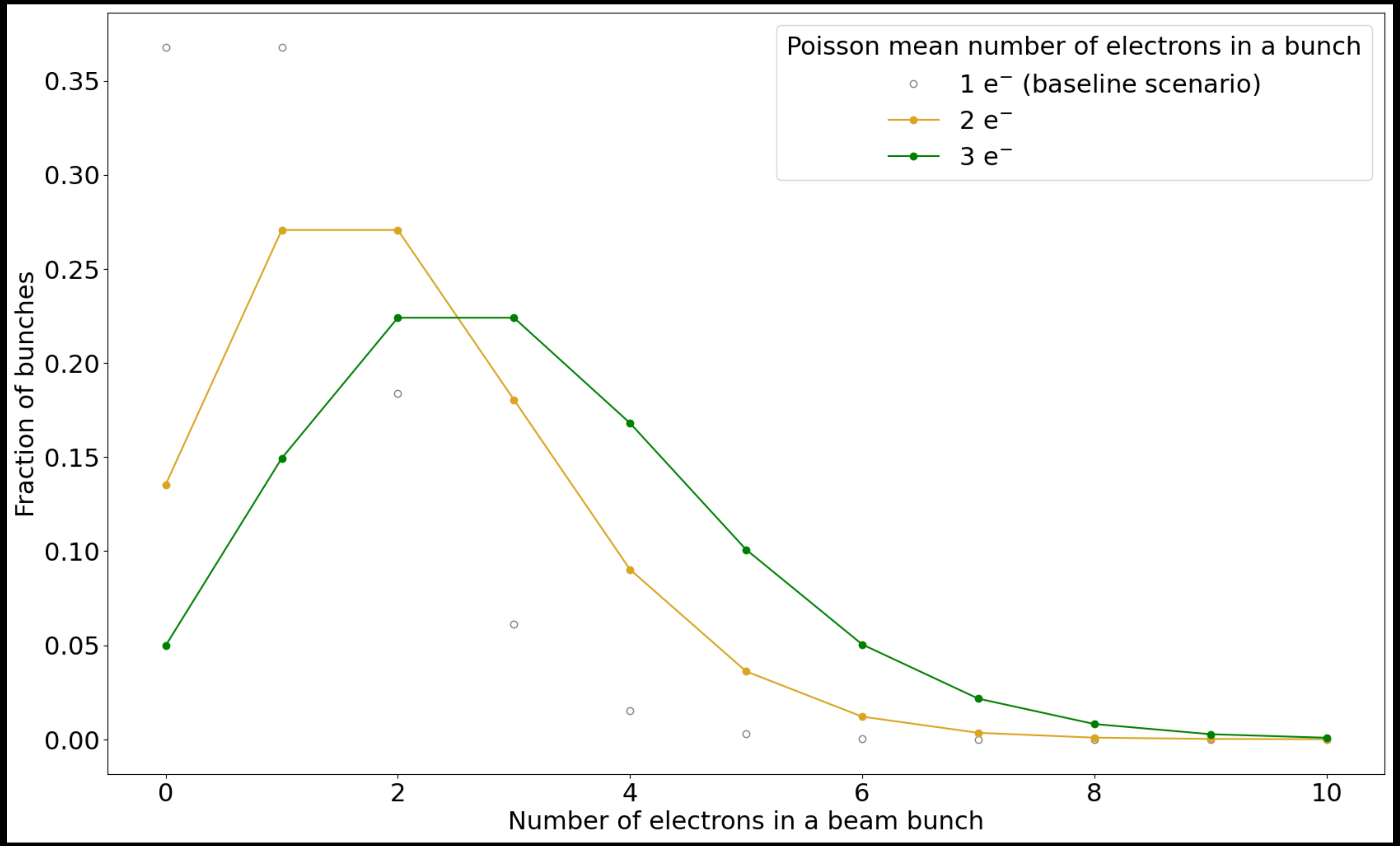


Target *inside* detector structure → Beam sees material *before* target

- Aiming for model flexibility within GEANT4 itself
  - Example: Embed dark photon collisions *inside* simulated detector volume

Handling multiple electrons-on-target simultaneously

🇸🇪 LunDMX: L. K. Bryngemark



Poisson distributions of electrons in LESA beam bunches

- Default LDMX run plan: Trigger only when 1 electron-on-target at a time
  - $\mu_{Poisson}$ = 1: ~37% beamtime usable
- Studying how to distinguish multiple simultaneous electrons-on-target
  - Enable significantly faster data-taking
    - Example: $\mu_{Poisson}$ = 2
      - Up to 5e per bunch
      - Runtime ⬇️ x 5
  - Less runtime → Reduced environmental footprint (R. Pöttgen's talk) 🌍

HCal development

🇸🇪 **LunDMX: L. Österman, E. Wallin, G. Gajdán, A. Helgstrand, H. Herde, T. Åkesson**

LDMX HCal scintillator readout based on Mu2e Cosmic Ray Veto

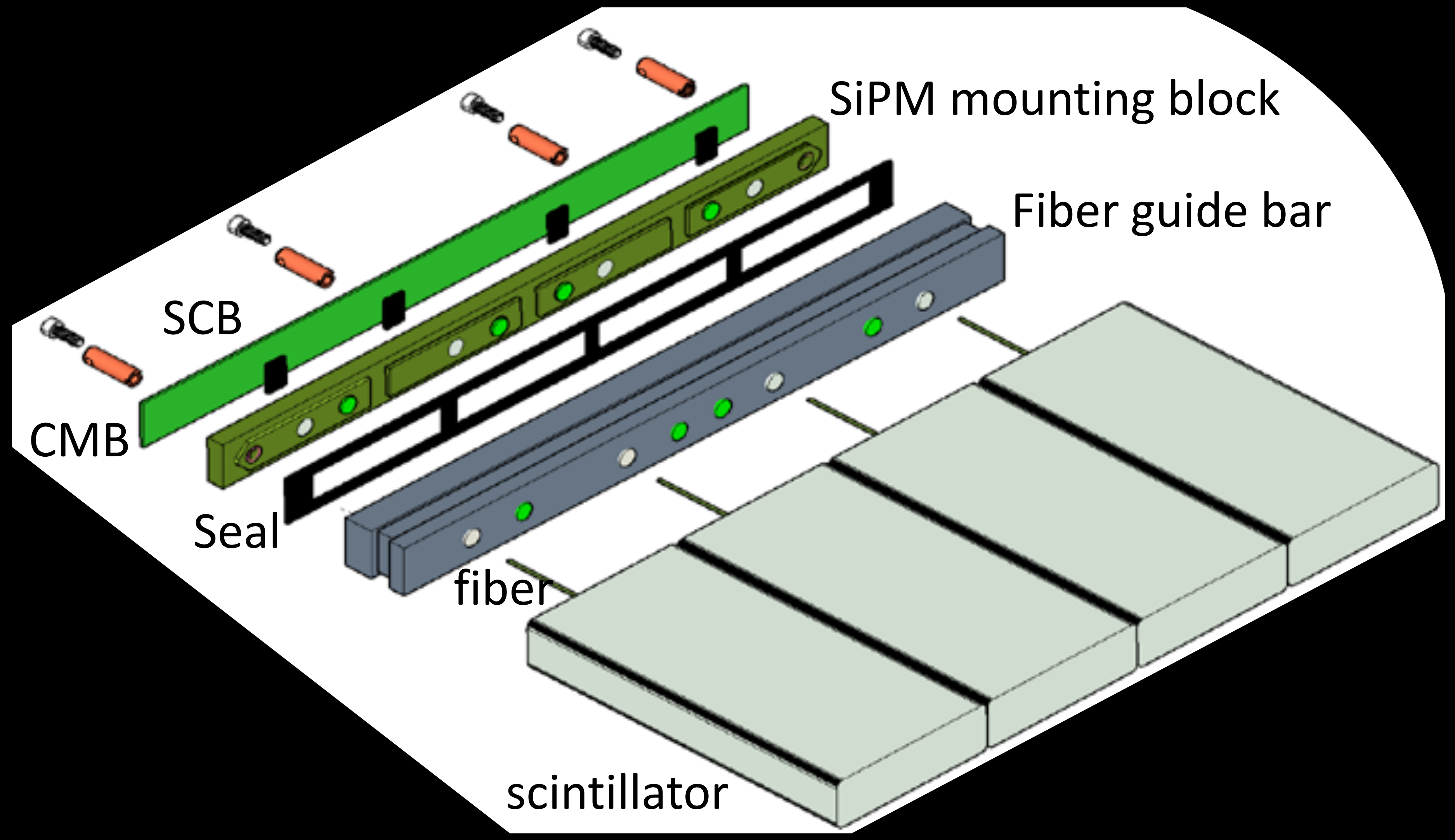
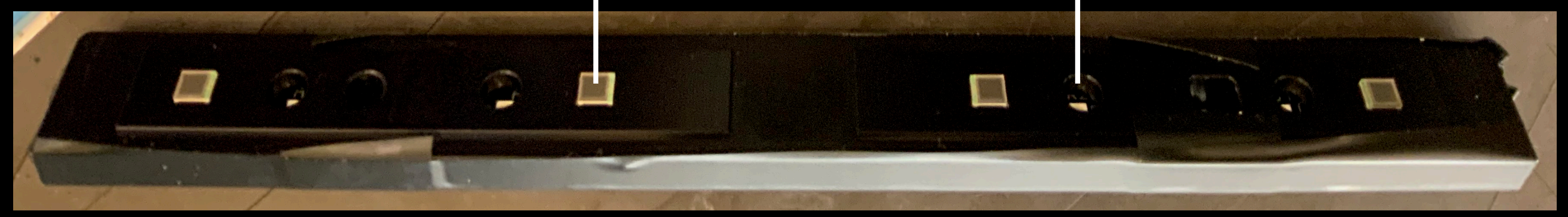
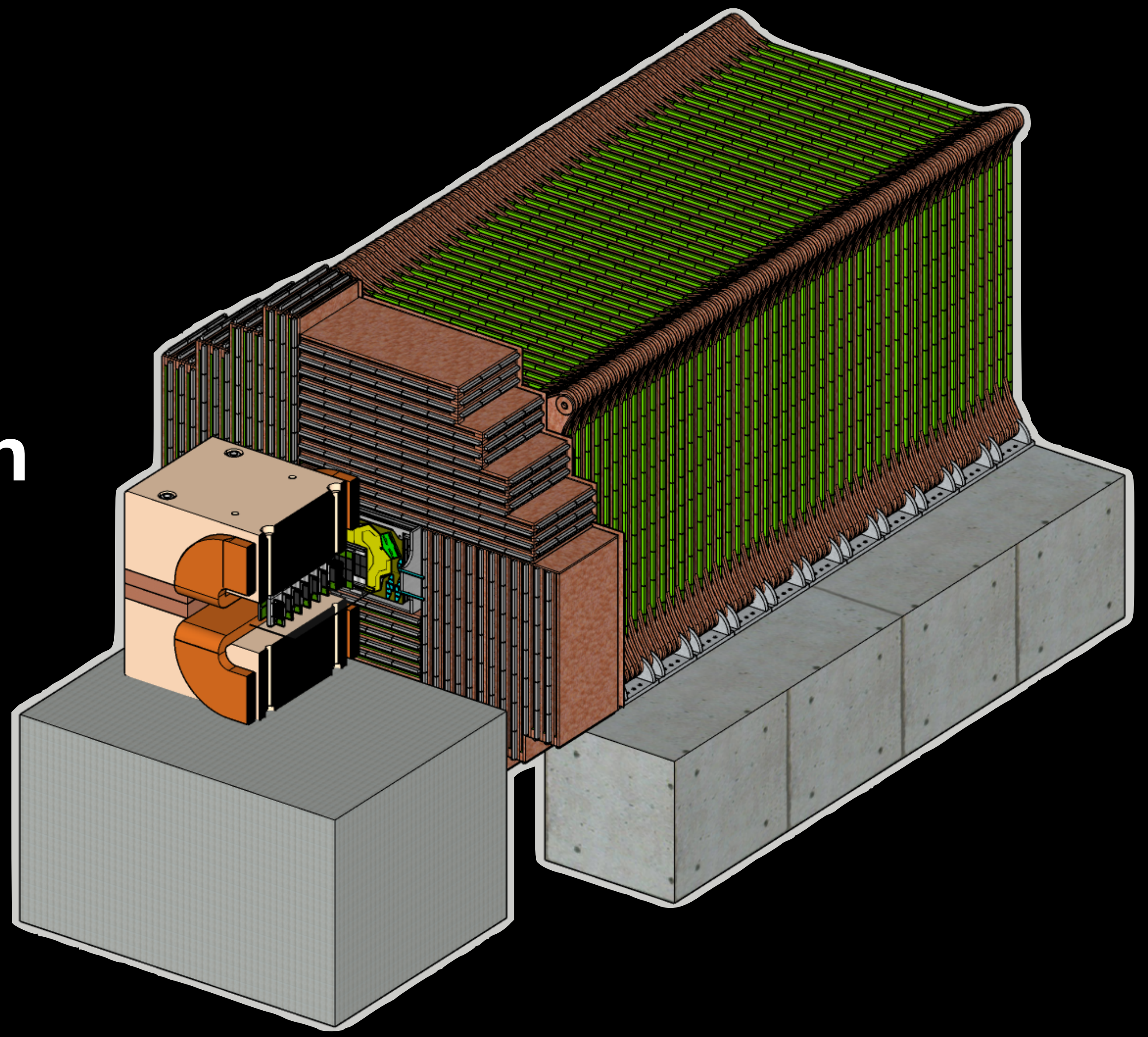


Image source



Front panel with SiPMs visible

Backside of control board, showing HDMI port & SiPM probe points



HGCROC board connected via an adapter card to ZCU development board

- Designing HCal front-end boards
  - HGCROC: front-end developed for CMS High Granularity Calorimeter
- Testbench work to characterise signal (charge injection, LED flashing)
- Testbeam design, operation, and analysis

🇸🇪 LunDMX

Contribution summary

- HCal design and performance
- HCal readout electronics design, test stand
- HCal and trigger scintillator testbeam design, operation, and analysis
- Generator integration
- Multi-electron triggering and analysis
- Lund e-science (arc developers) designed and now maintain LDMX's distributed computing system
- Leadership: co-spokesperson (T. Åkesson), physics co-coordinator (R. Pöttgen), Computing and software co-coordinator (L. K. Bryngemark), Testbeam co-coordinator (H. Herde)
- 18 BSc/MSc student theses since 2019

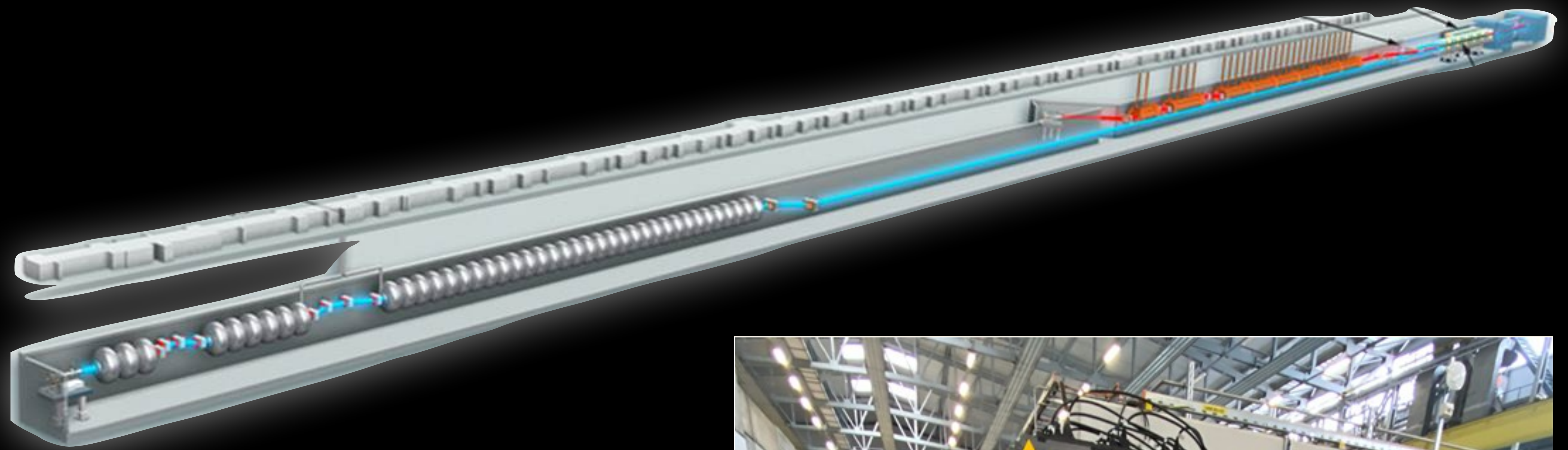
Knut and Alice Wallenberg Foundation

Stockholm University

LDMX	Simulation: PYTHIA-GEANT4 integration
Statistical inference	Detector material evaluation for direct detection

LDMX

2025 and beyond



LESA Beamline expected to open!

Planning “miniLDMX” system test & testbeam in 2025

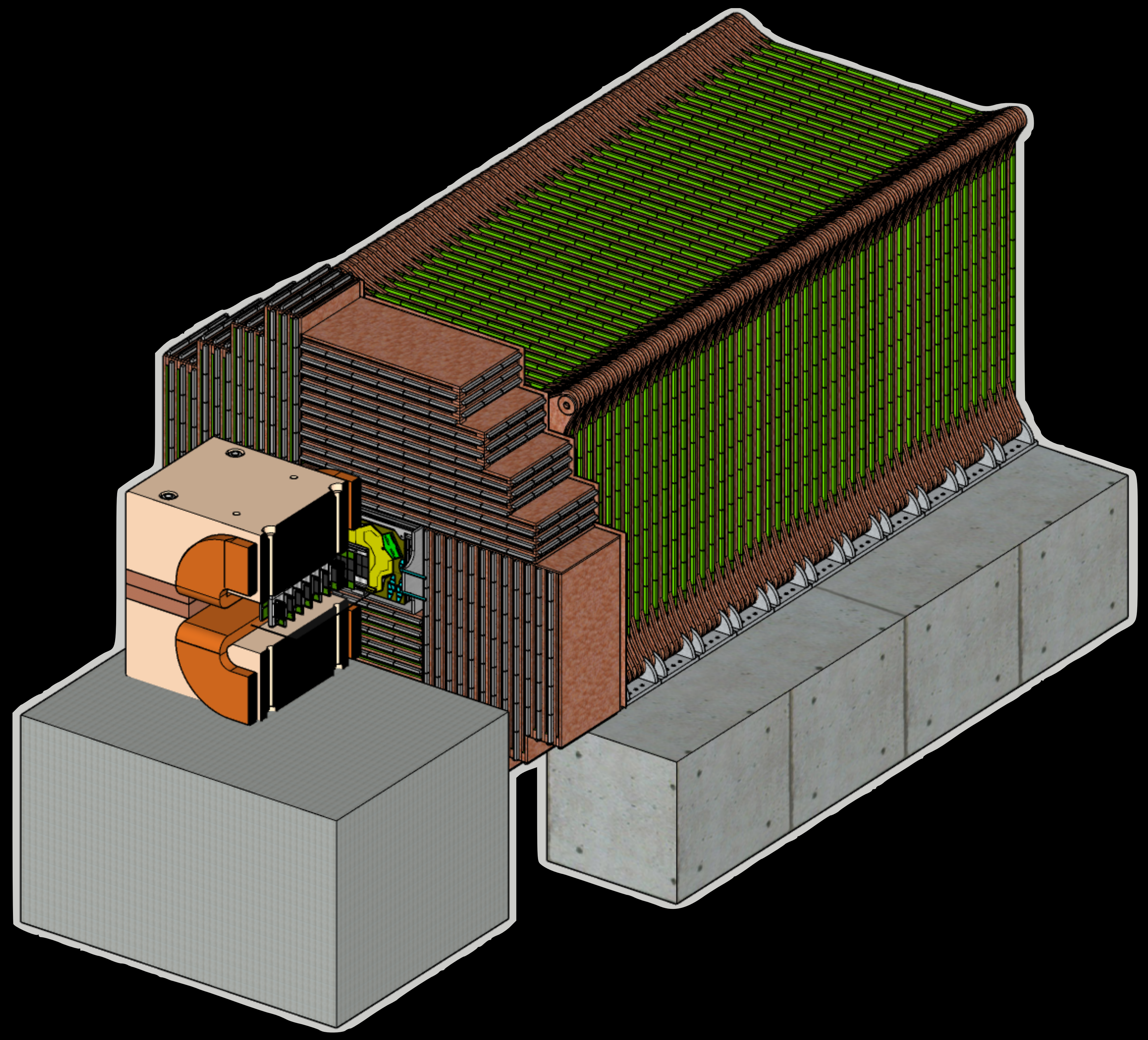
- First exposure to our eventual home beam
- Including as many sub-detector prototypes as possible
- Lessons from CERN testbeam critical →
  - G. Gadján & A. Helgstrand, Noise and shower shapes in the LDMX hadronic calorimeter prototype

HCal prototype from CERN testbeam; now at SLAC

Image sources

LDMX Collaboration

Lund University and 9 US institutions



Swedish Research Council · Crafoord foundation · Knut and Alice Wallenberg Foundation · U.S. Department of Energy · Kungl. Fysiografiska Sällskapet i Lund

Reading list:

- Åkesson, Torsten et al. 2022. "Current Status and Future Prospects for the Light Dark Matter eXperiment." arXiv. https://doi.org/10.48550/arXiv.2203.08192.
- Åkesson, Torsten et al. 2023. "Photon-Rejection Power of the Light Dark Matter eXperiment in an 8 GeV Beam." *Journal of High Energy Physics* 12 (12): 092. https://doi.org/10.1007/JHEP12(2023)092.
- Bryngemark, Lene Kristian et al. 2021. "Building a Distributed Computing System for LDMX: Challenges of Creating and Operating a Lightweight e-Infrastructure for Small-to-Medium Size Accelerator Experiments." *EPJ Web of Conferences* 251:02038. https://doi.org/10.1051/epjconf/202125102038.

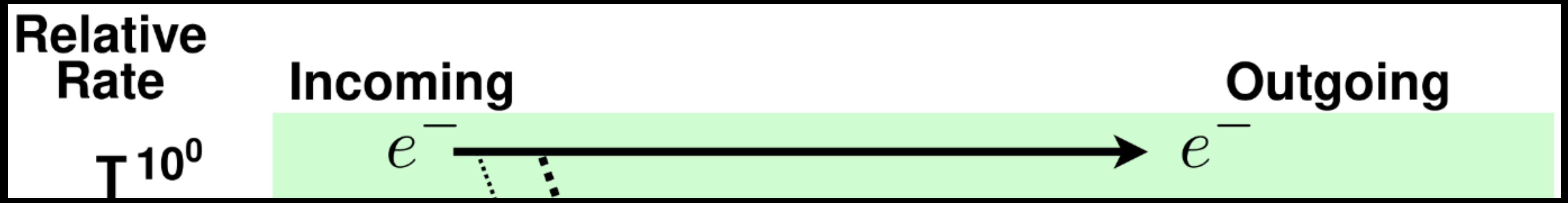
Beamline considerations

Goal: Individually measure energy & momentum for up to 1016 e- scattered off thin tungsten target

- Motivation: Generate high statistics! 1014-1016 electrons on target within few years
- Requirements
  - Beam energy: 4-16 GeV range
    - >16 GeV: Churn out neutrinos (= irreducible background)
  - Low-current (~pA), high-bunch repetition (~40 MHz) e beam
  - 108 electrons/second on target
  - Resolve individual particles
    - Low number of electrons per bunch
    - Large beam spot

A zero-background experiment

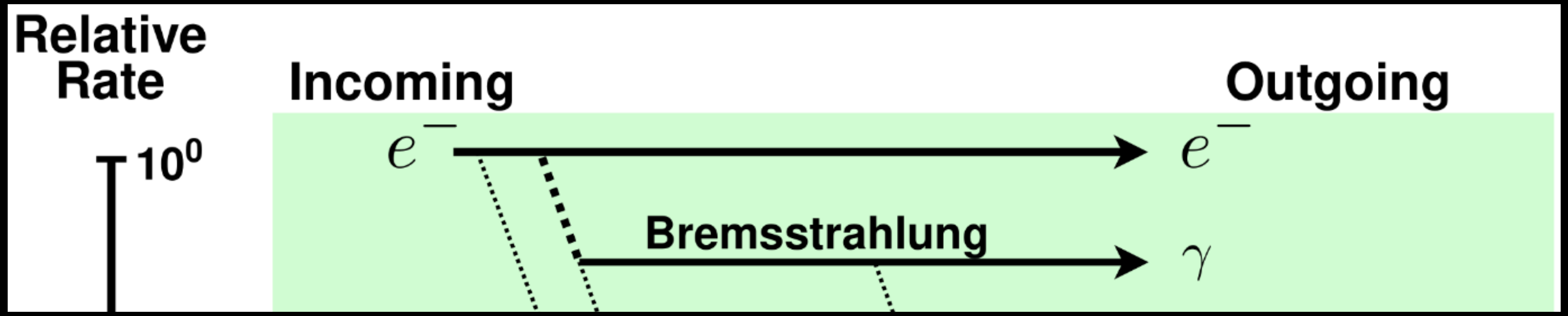
No interaction

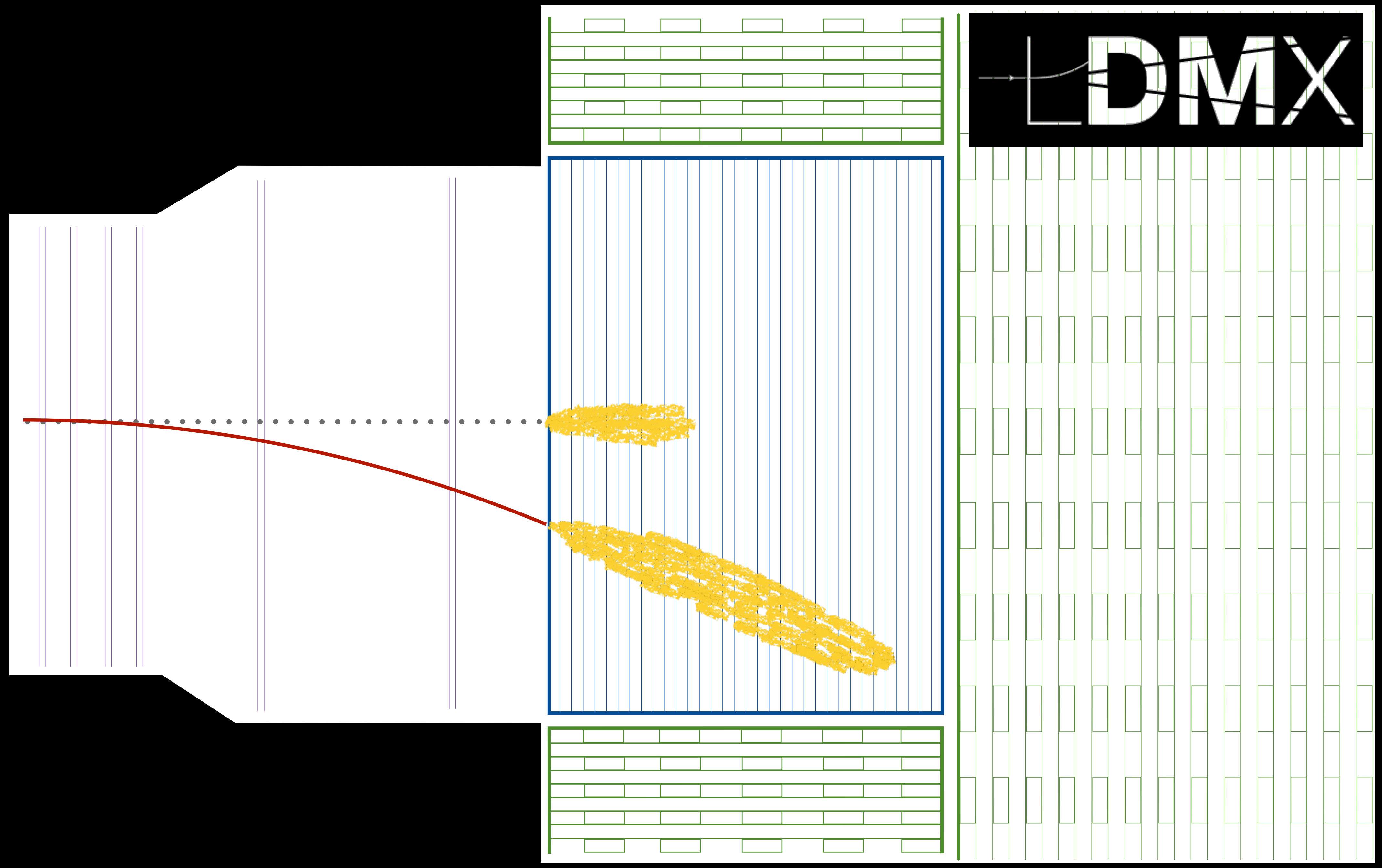


- 90% of electrons on target pass right through without interaction
  - Target’s thickness ~1X_0
- Eliminate with trigger requirements
  - Electron multiplicity
  - ECal energy

A zero-background experiment

SM Bremsstrahlung



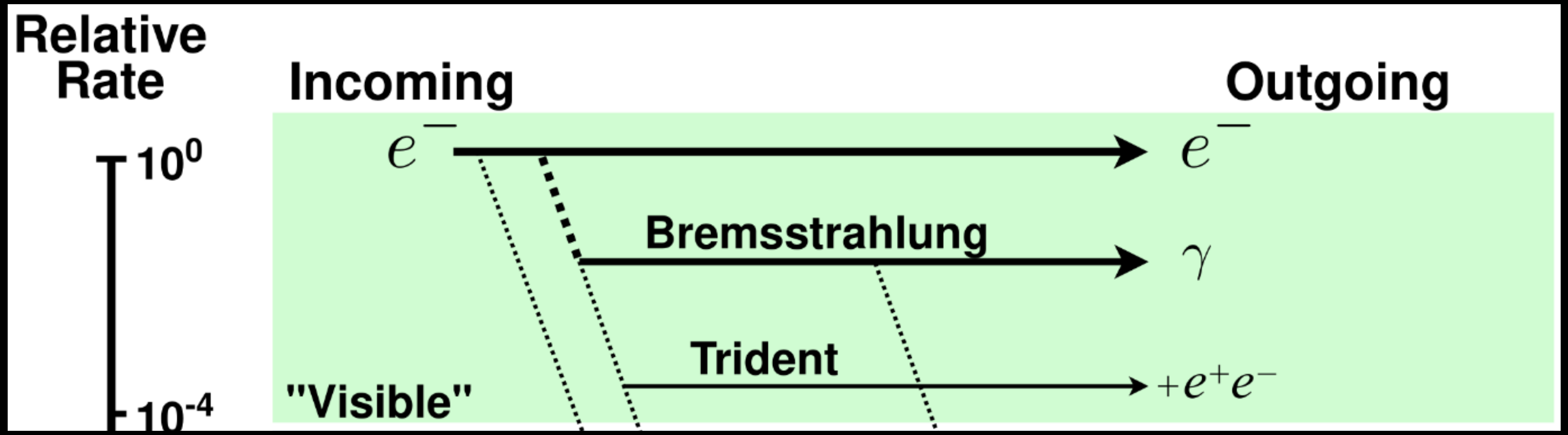


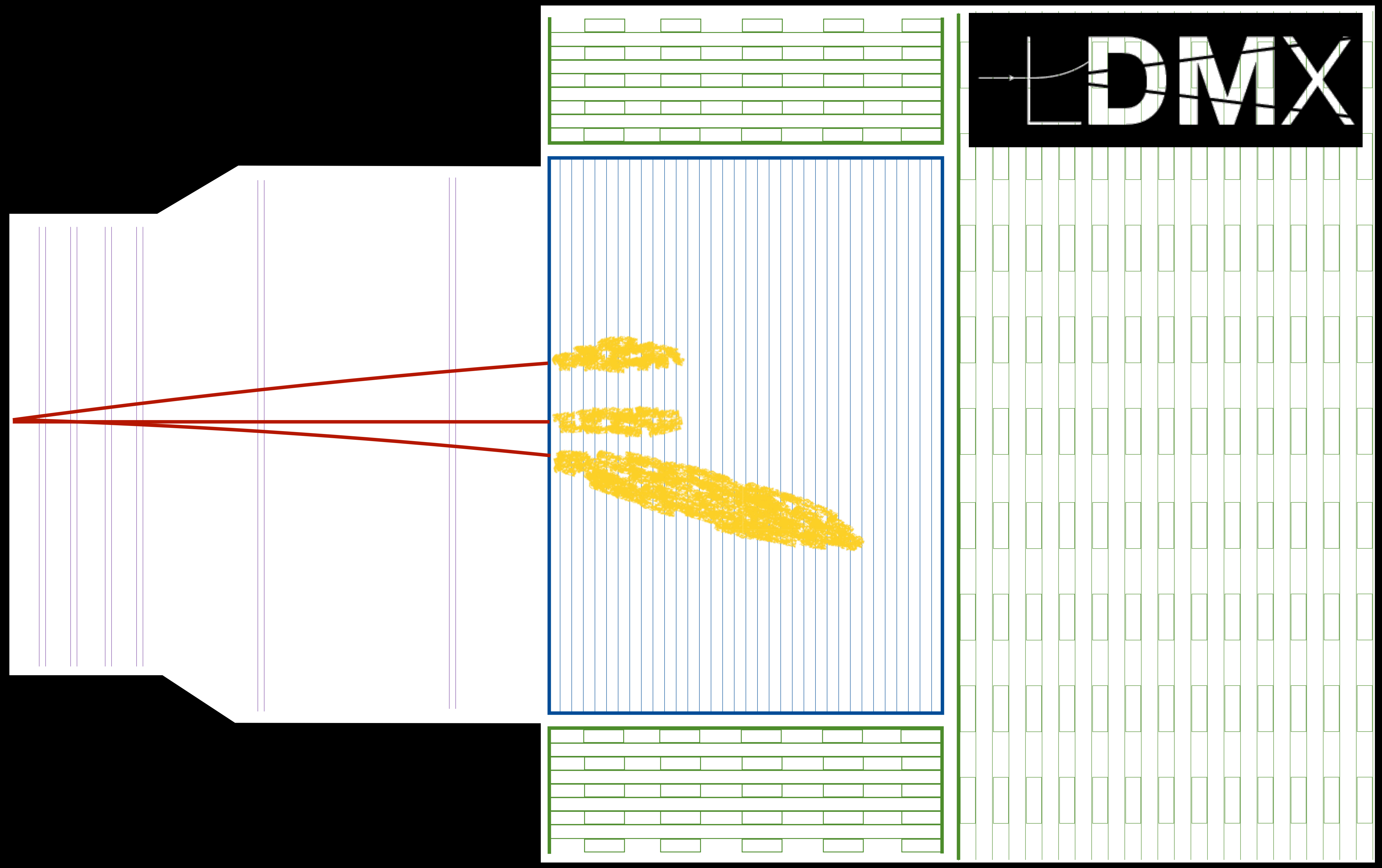
ECal signature

Cartoons inspired by L. K. Bryngemark

A zero-background experiment

Trident



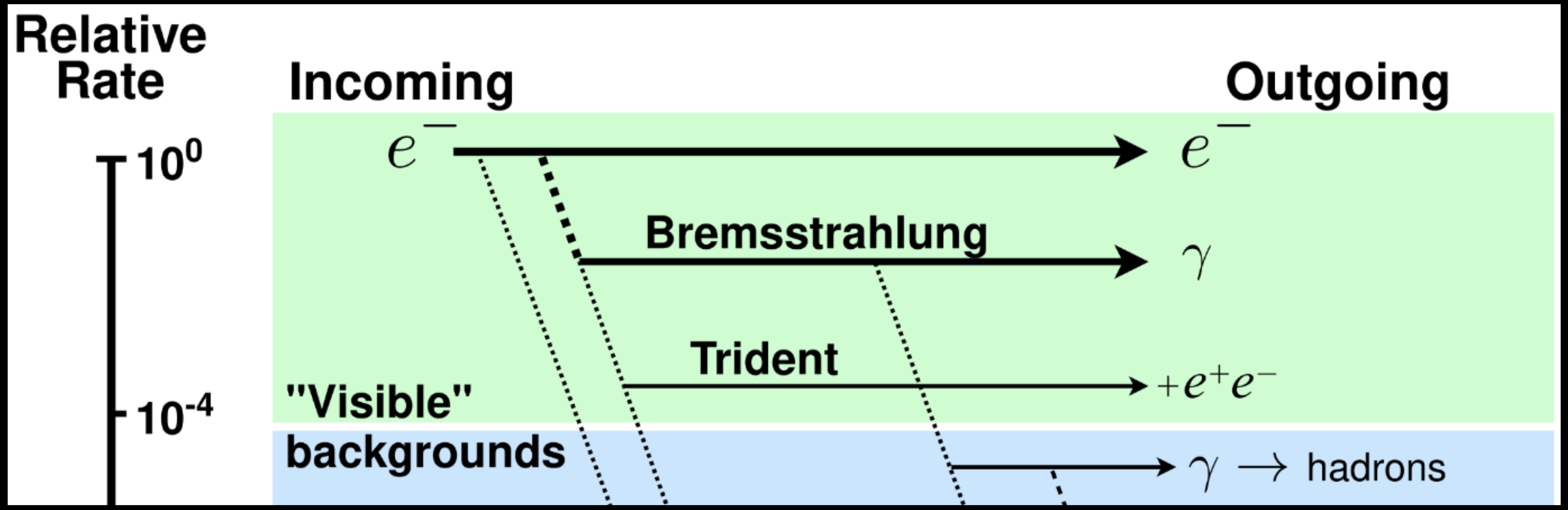


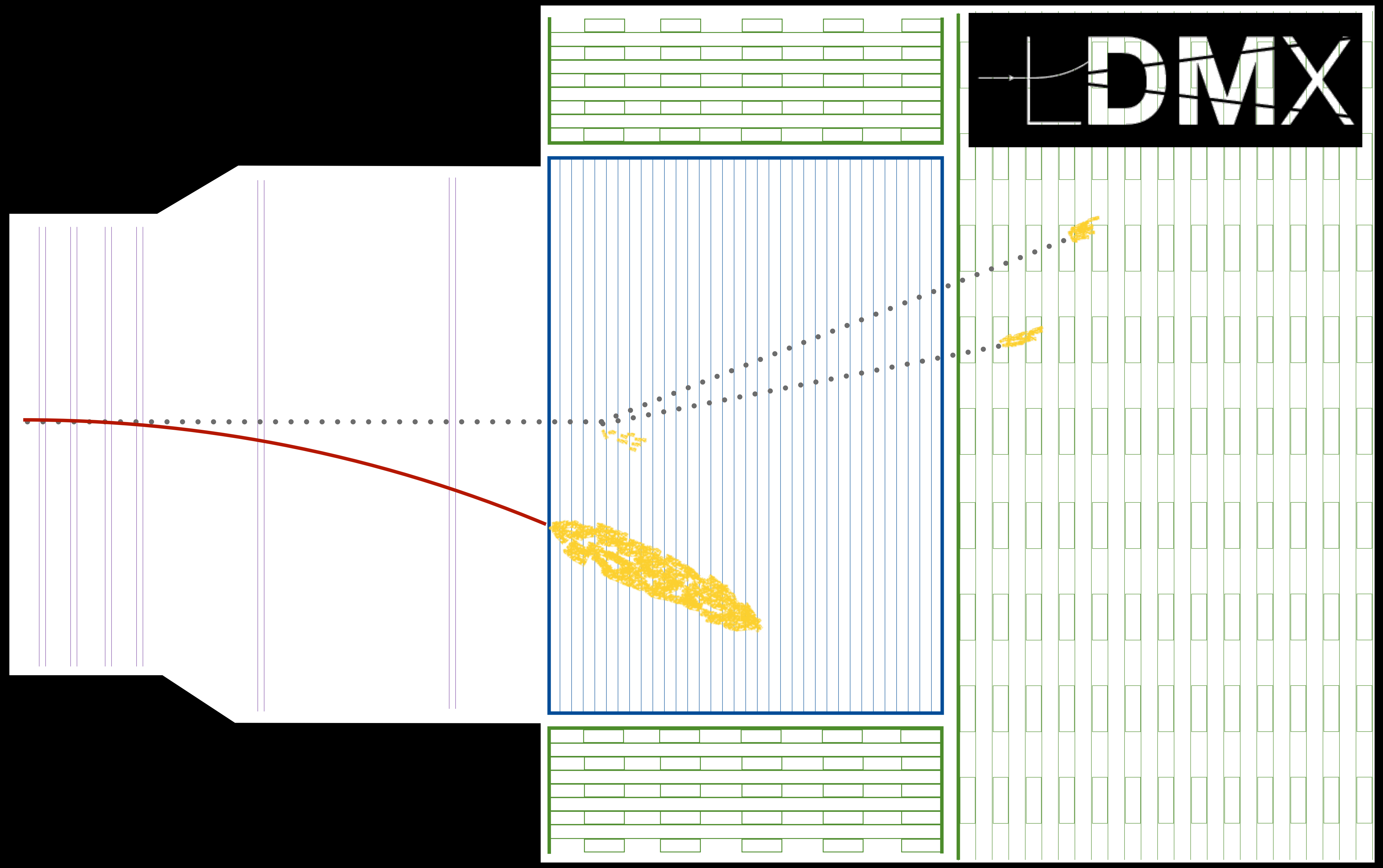
Tracker & ECal signatures

Cartoons inspired by L. K. Bryngemark

A zero-background experiment

Hadron production in the ECal volume



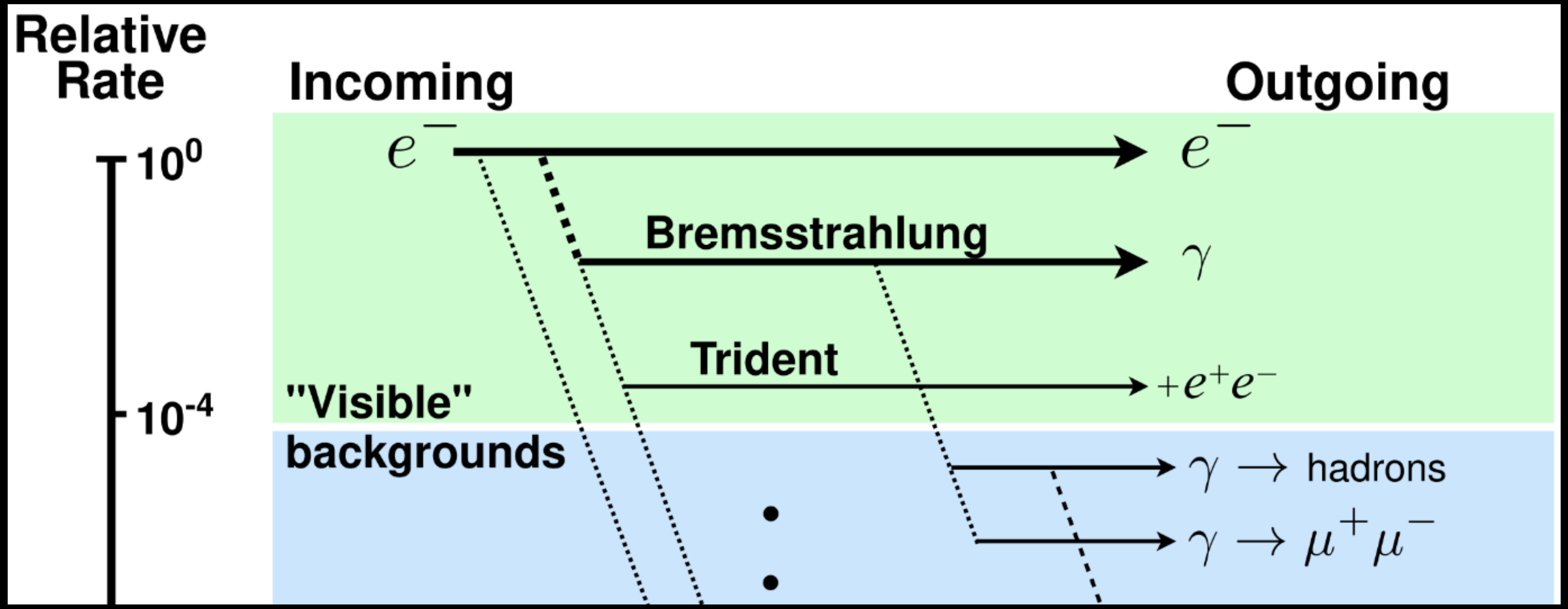


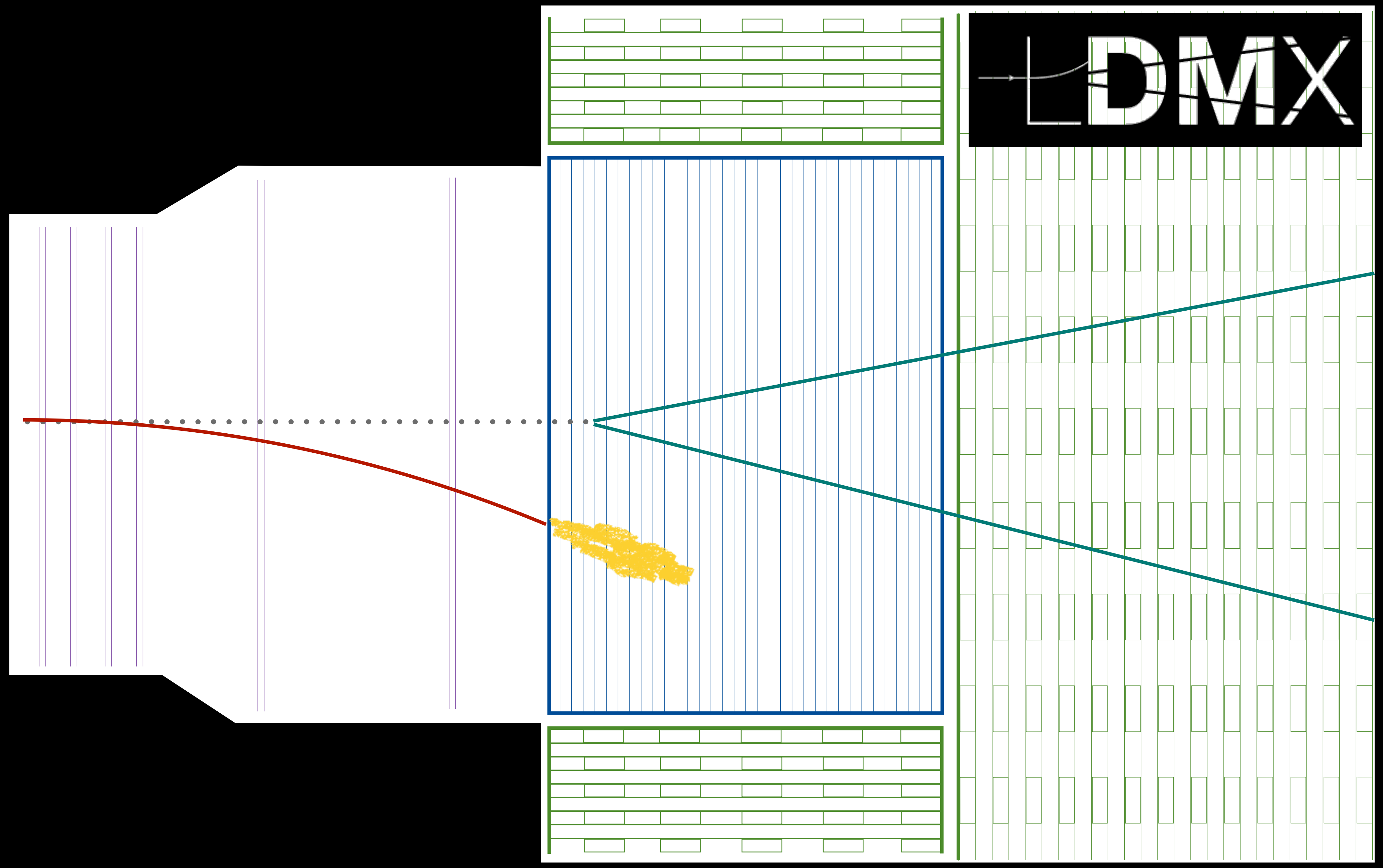
ECal & HCal signatures

Cartoons inspired by L. K. Bryngemark

A zero-background experiment

Photon conversions to muon pairs



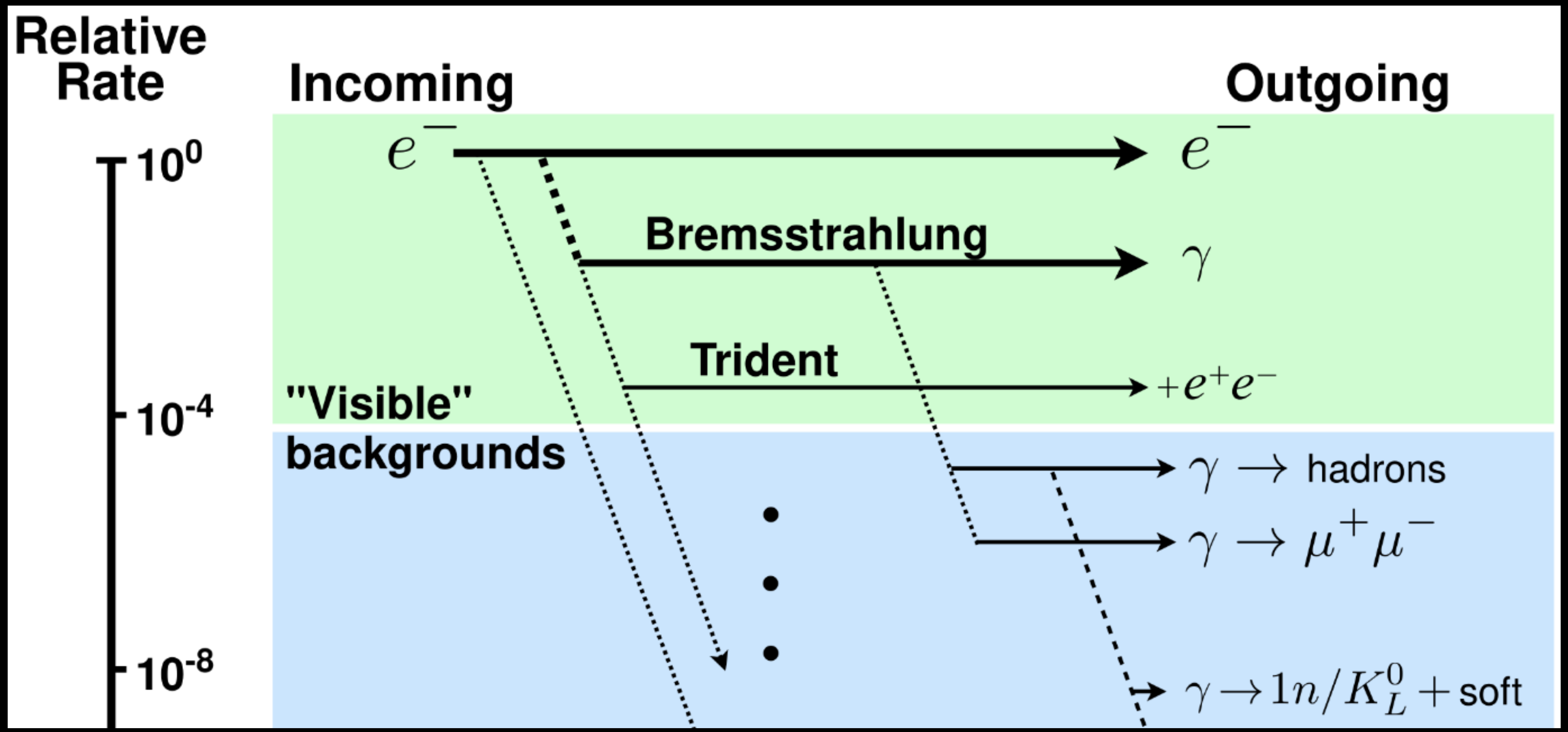


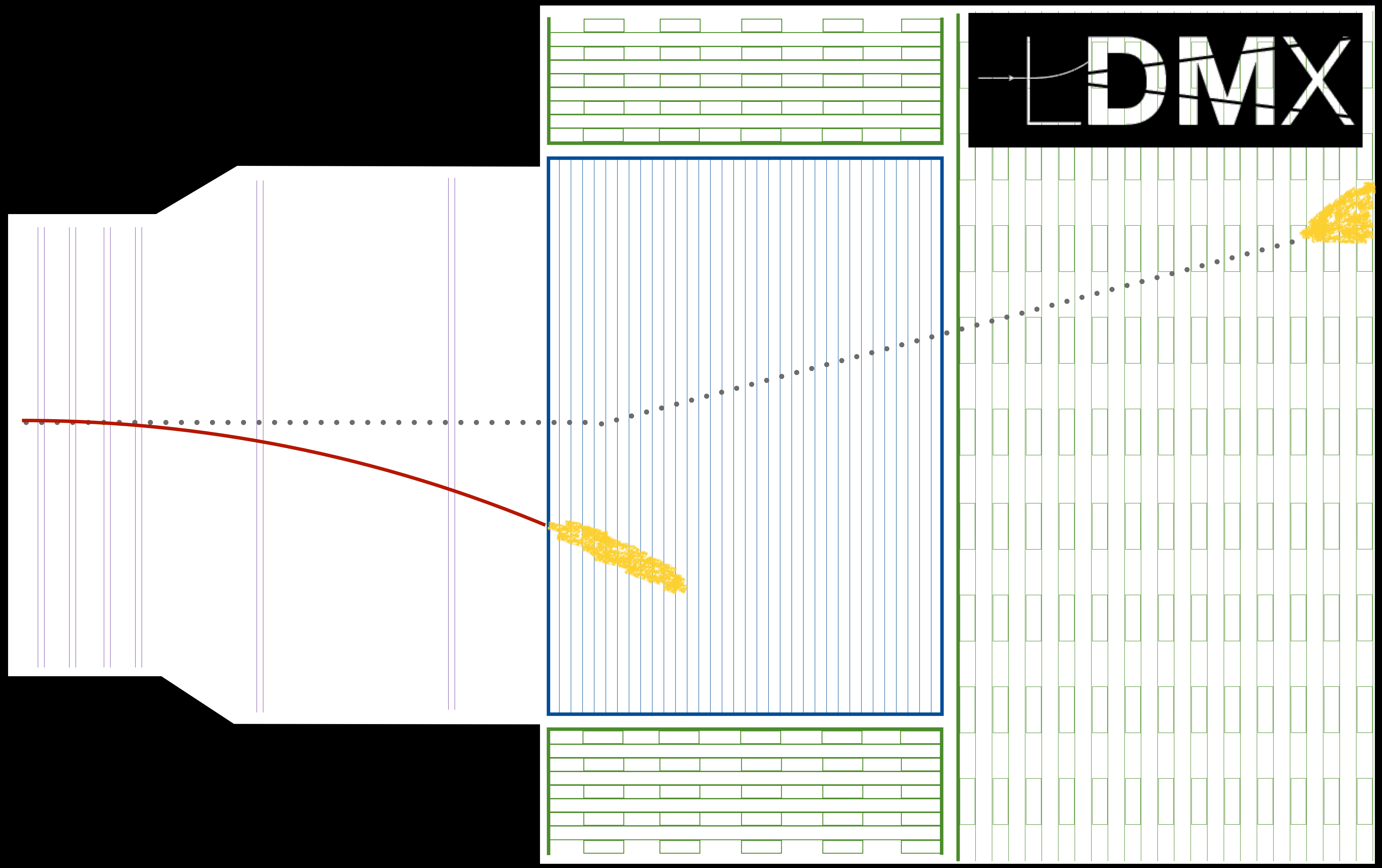
ECal & HCal signatures

Cartoons inspired by L. K. Bryngemark

A zero-background experiment

Neutral hadron production



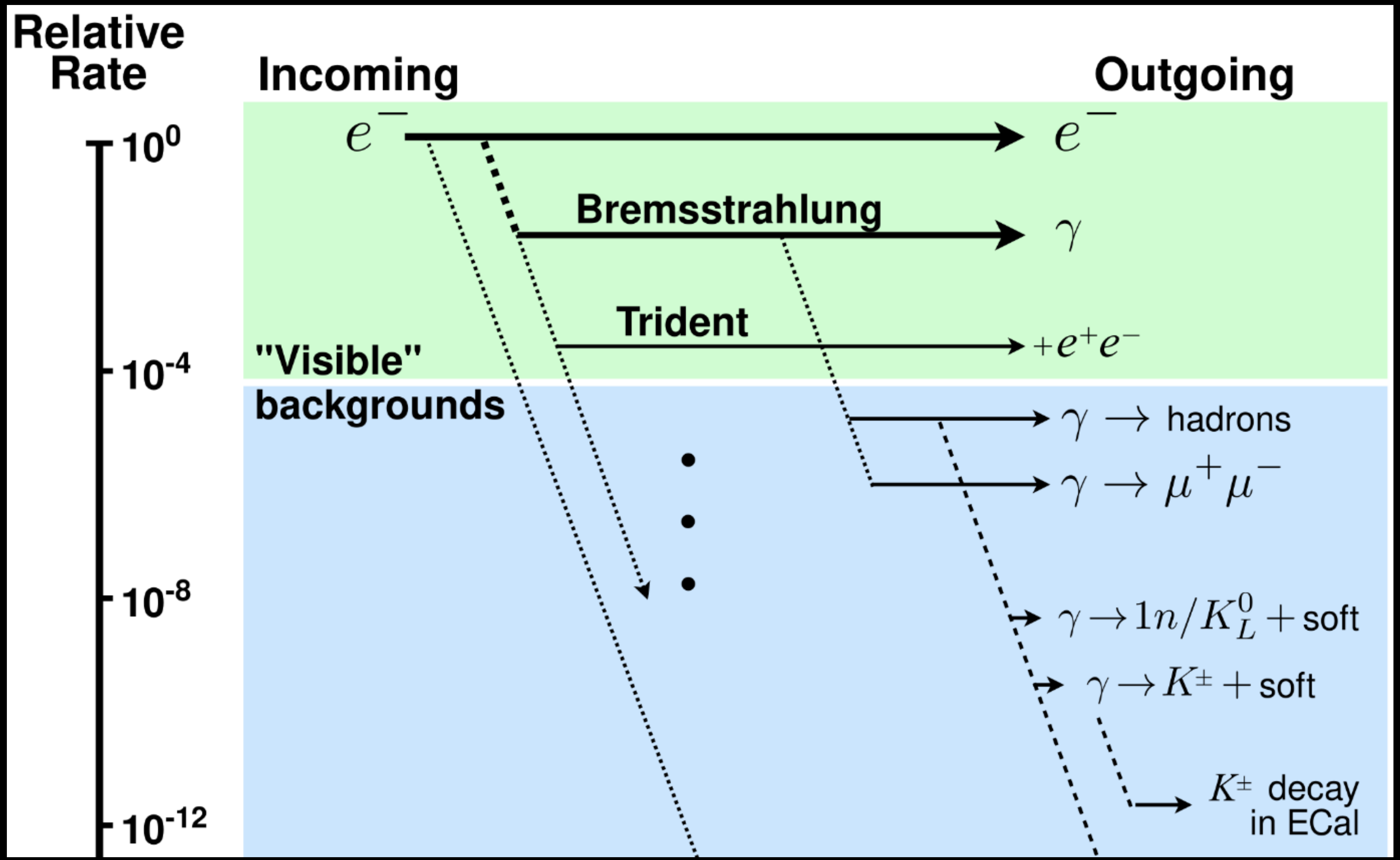


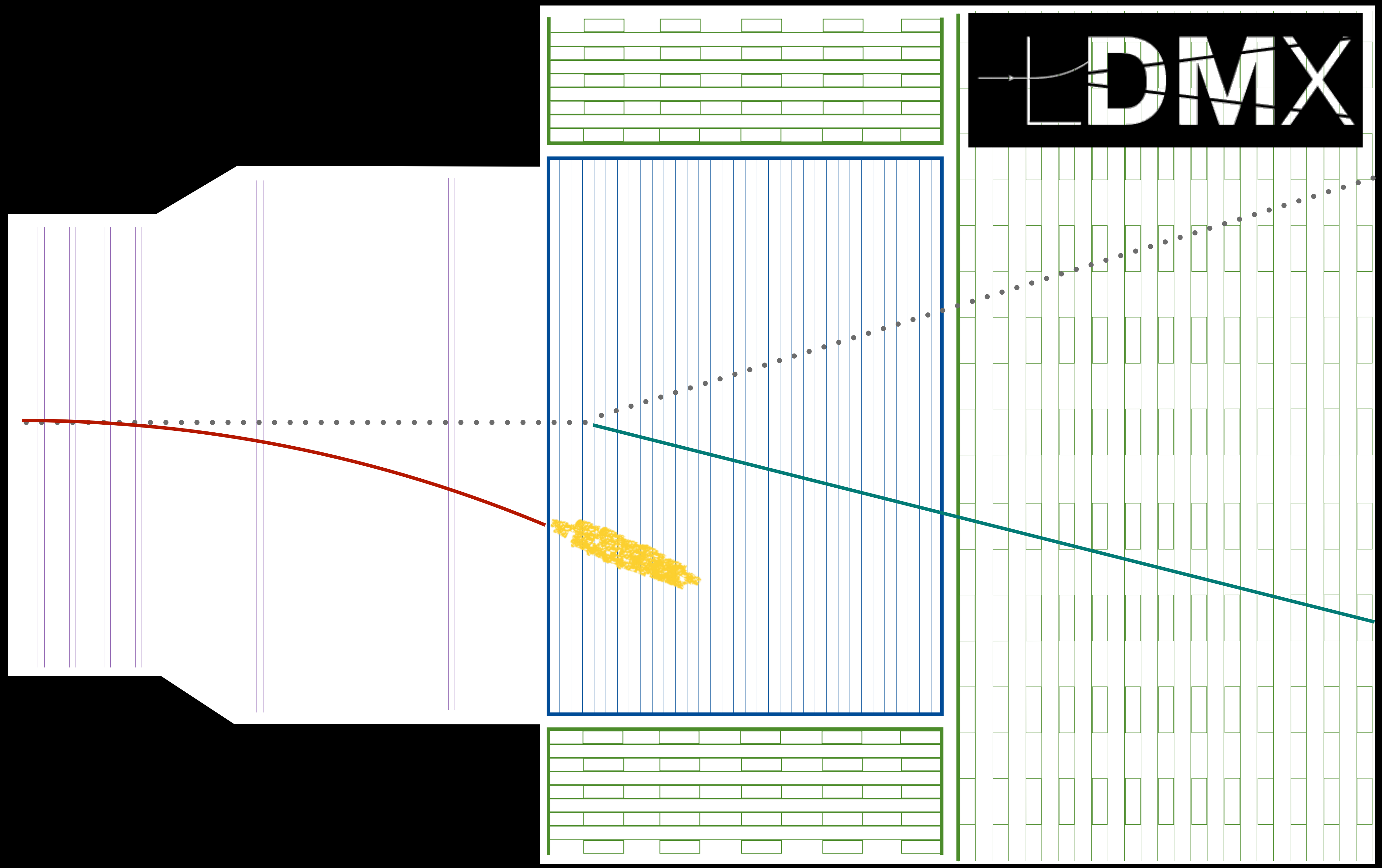
Various ECal and/or HCal signatures possible (one example here)

Cartoons inspired by L. K. Bryngemark

A zero-background experiment

Kaon production



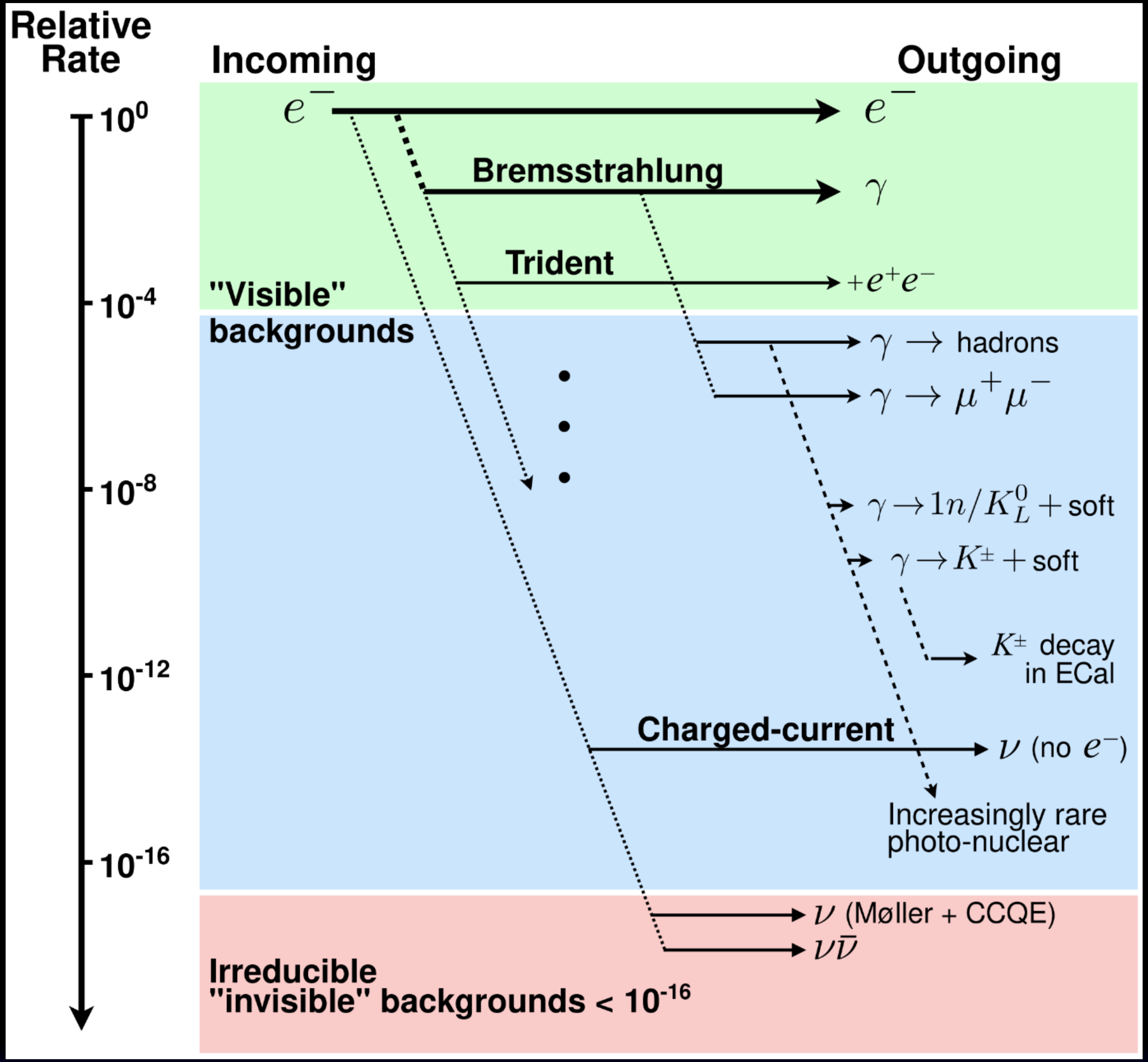


Various ECal and/or HCal signatures possible (one example here)

Cartoons inspired by L. K. Bryngemark

A zero-background experiment

Charged-current producing ν & irreducible “invisible” background



Extra tracks

Fortunately, too rare for LDMX to observe