Fermilab

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Texas Tech University
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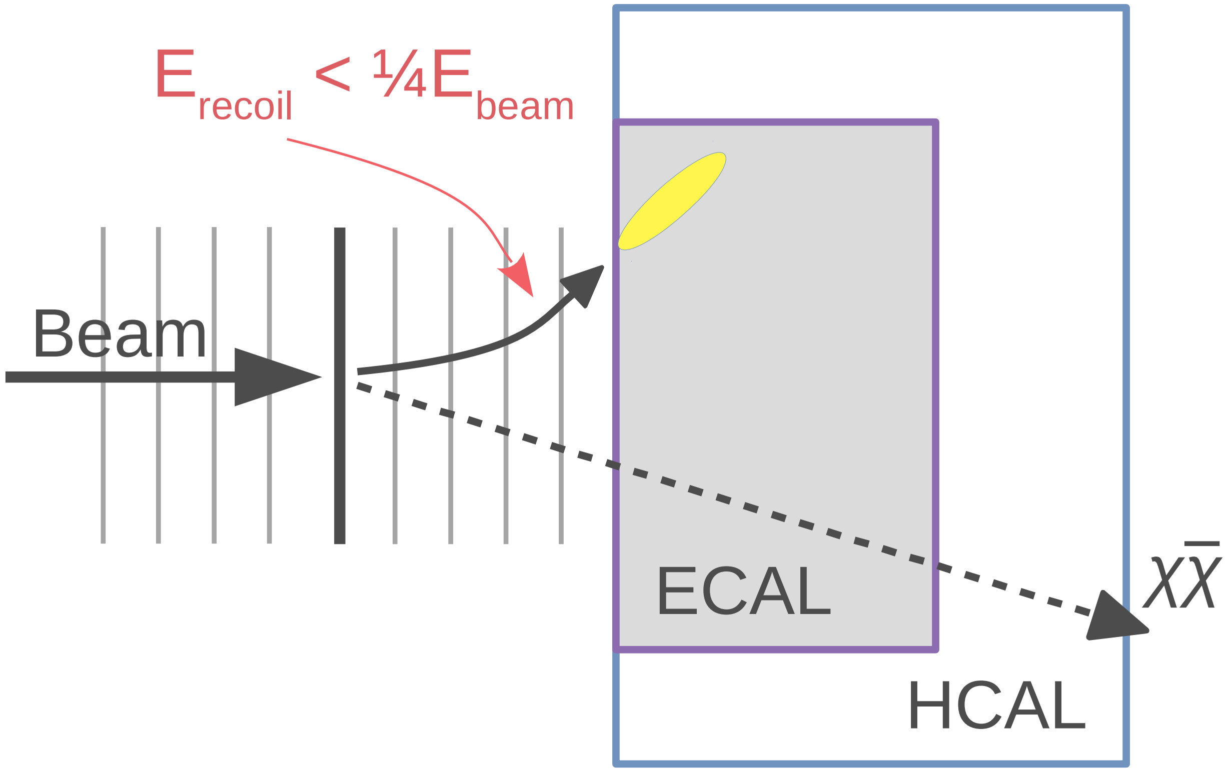
LDMX

Light Dark Matter Experiment

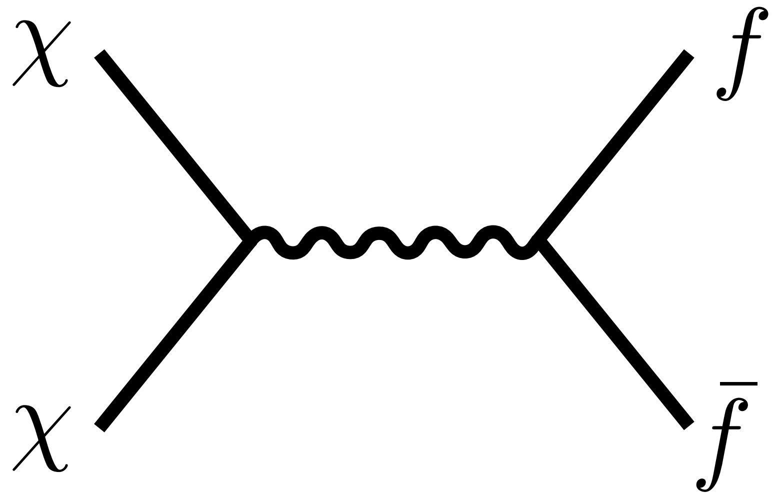
Christian Herwig (Fermilab)
for the LDMX Collaboration
Pheno21 // May 24, 2021



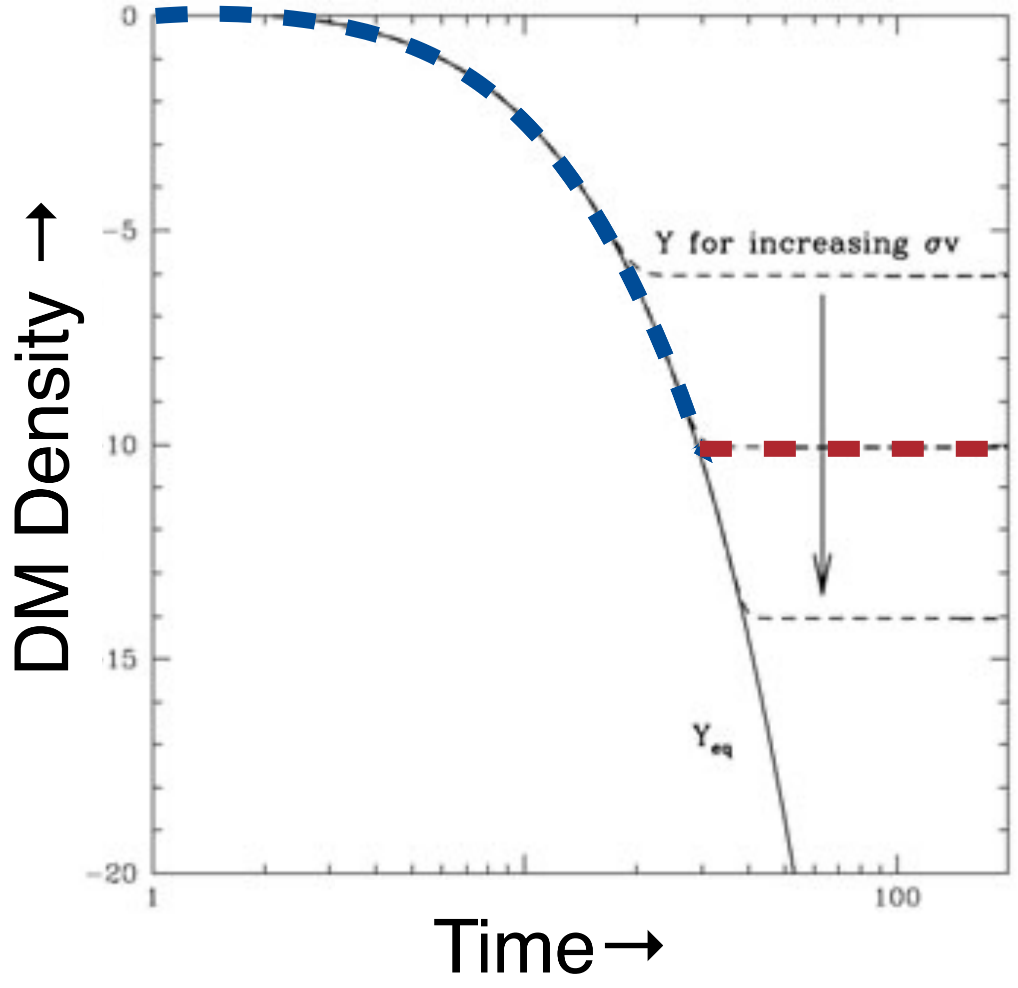
Thermal dark matter

Non-gravitational interactions lead to SM-DM chemical equilibrium in the early universe.

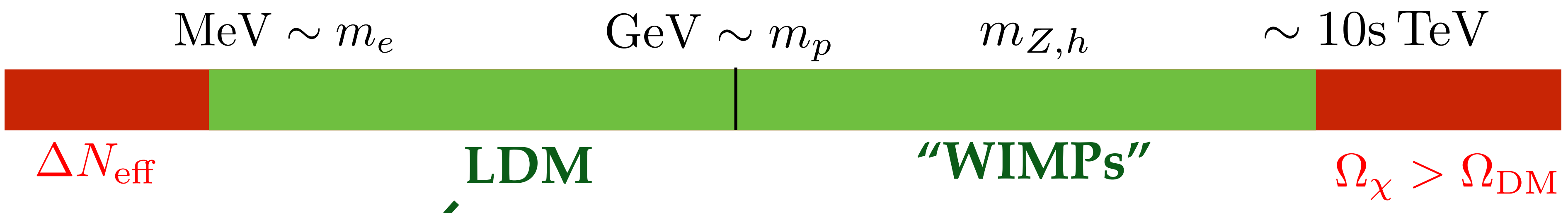
DM relic abundance observed today can be related to scattering cross sections.



$$\leftrightarrow \quad \underline{\langle \sigma v \rangle}$$



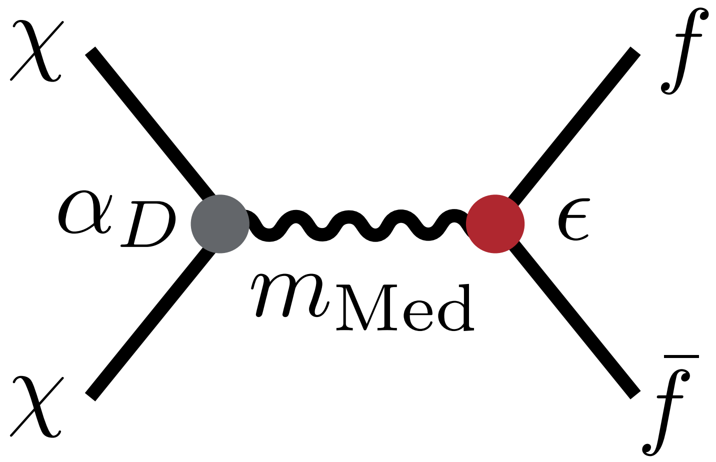
"Narrow" range of DM masses viable:

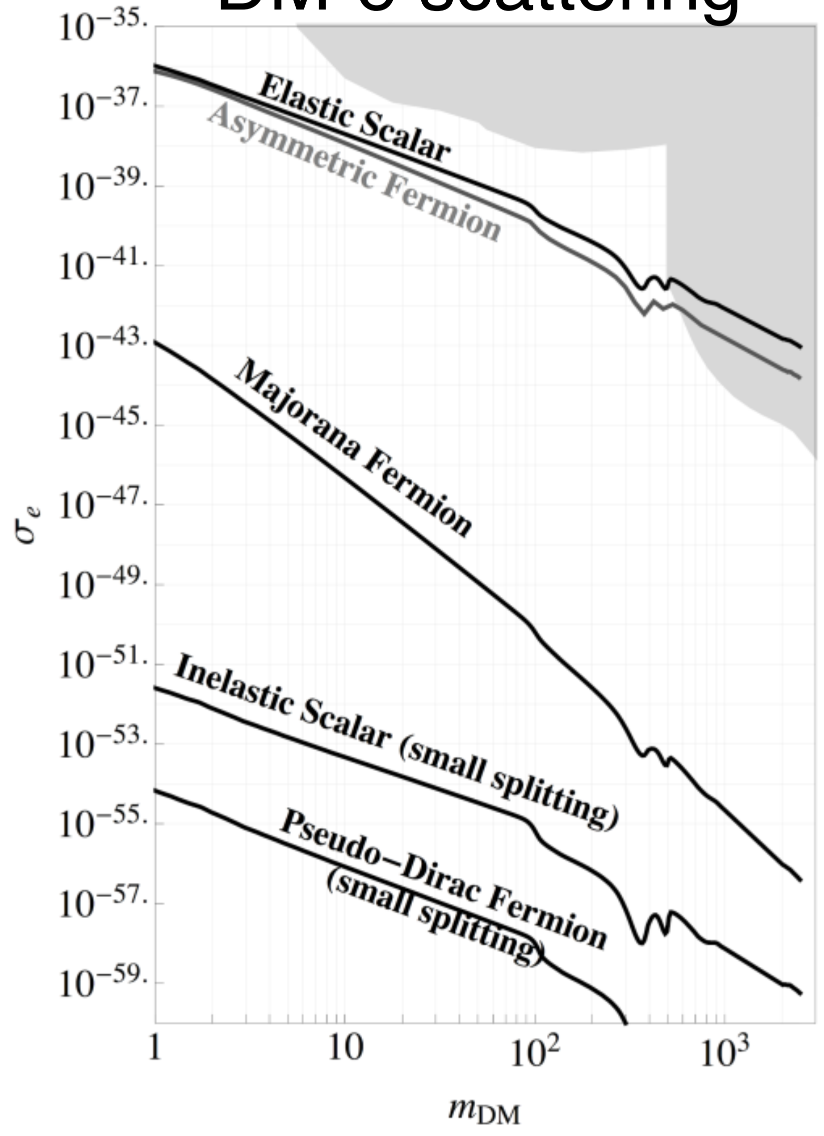


DM must be a SM singlet.
Implies a new light mediator.

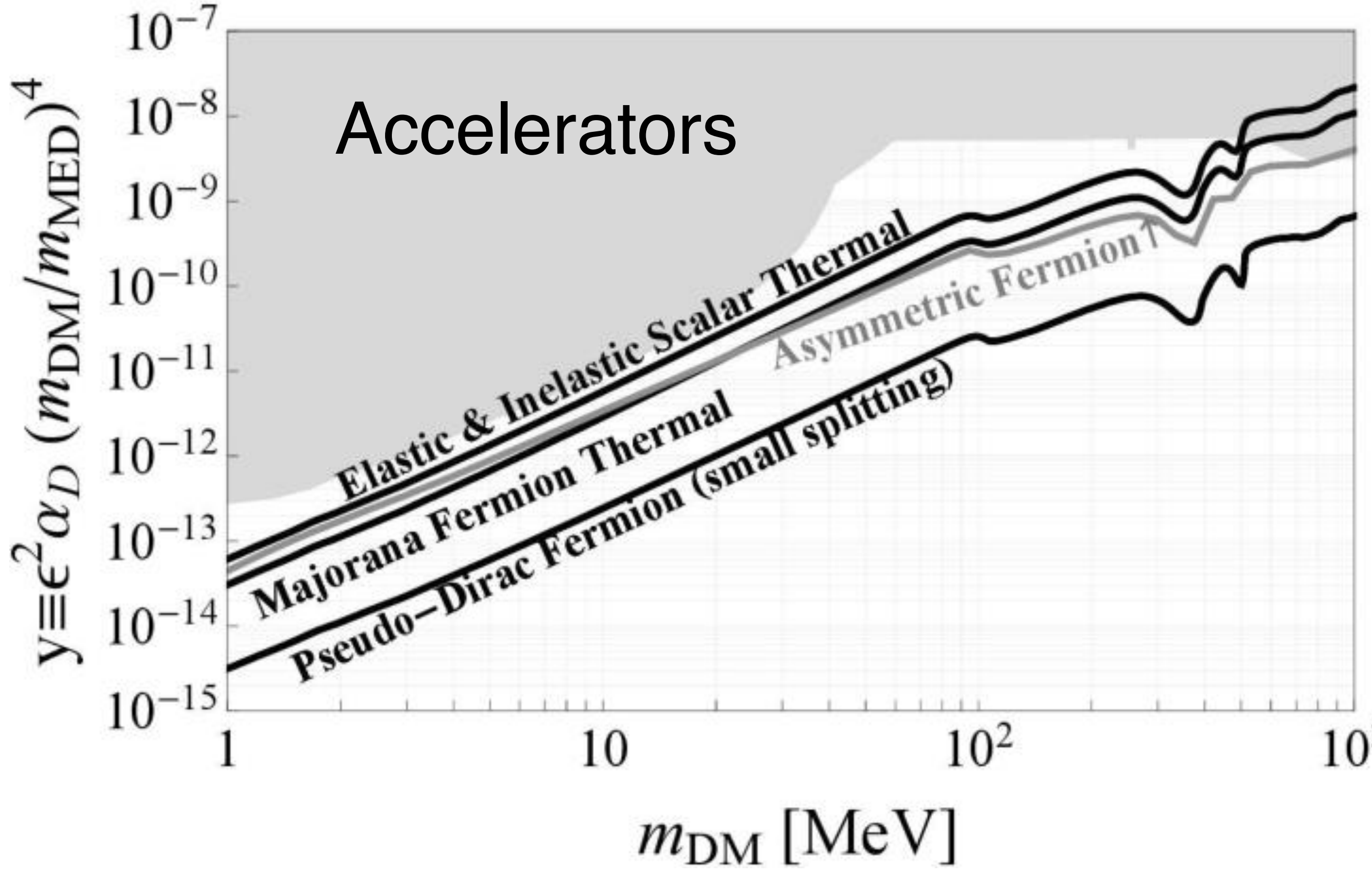
Light DM at accelerators

For $m_{DM} < m_{Mediator}$, relic abundance gives clear experimental targets.




DM-e scattering

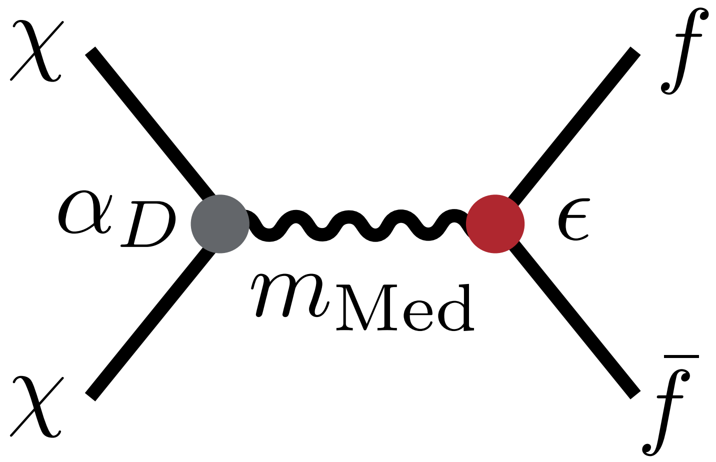
Relativistic production at accelerators leads to narrower band of target cross-sections.



Targets for dark photon mediators

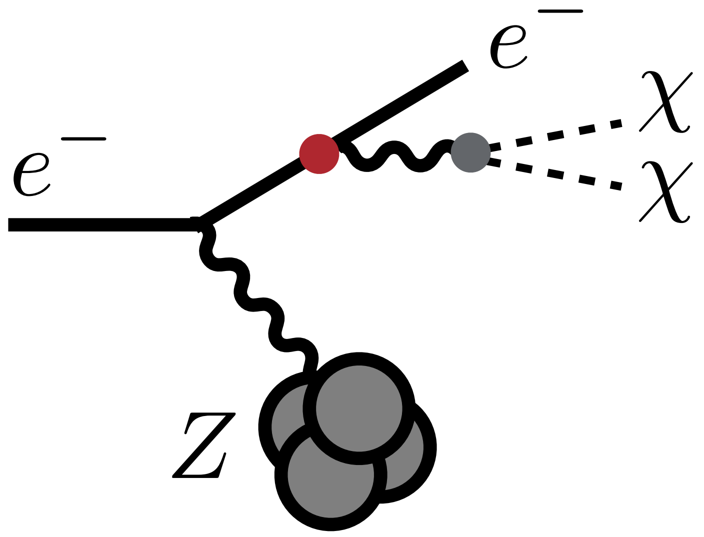
Light DM at accelerators

For $m_{DM} < m_{Mediator}$, relic abundance gives clear experimental targets.



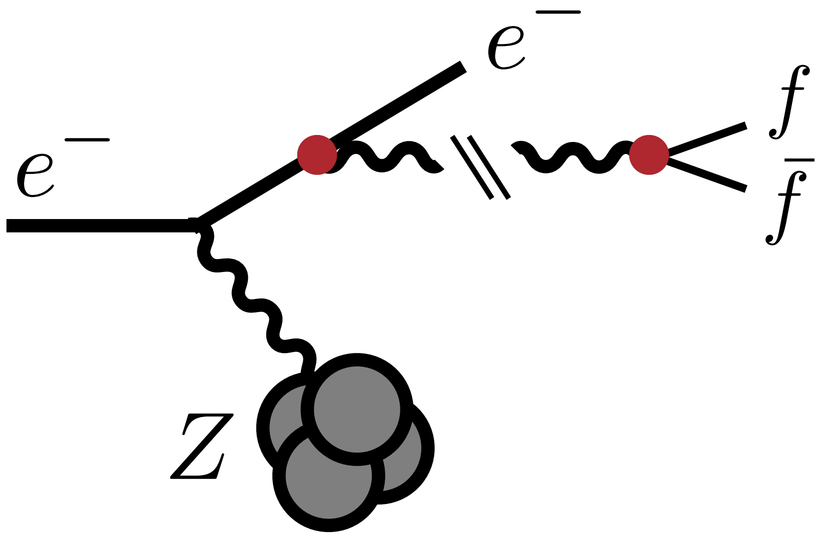
Complementarity accelerator strategies:

Missing momentum



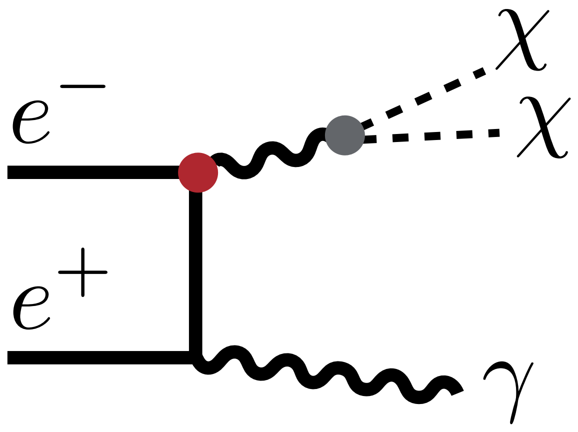
$$\sigma \sim Z^2\epsilon^2/M^2_{\mathrm{Med}}$$

Beam dump



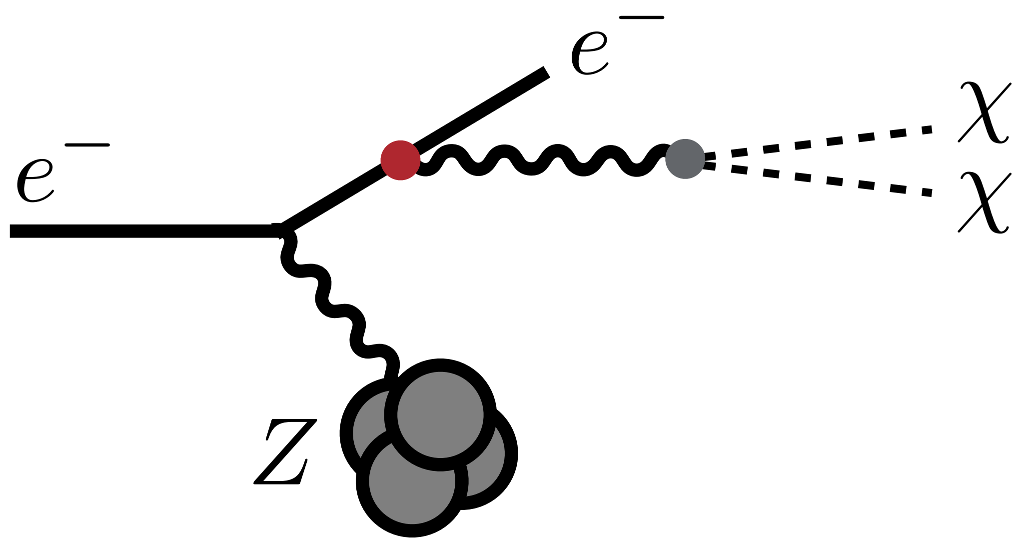
$$\sigma \sim \epsilon^4$$

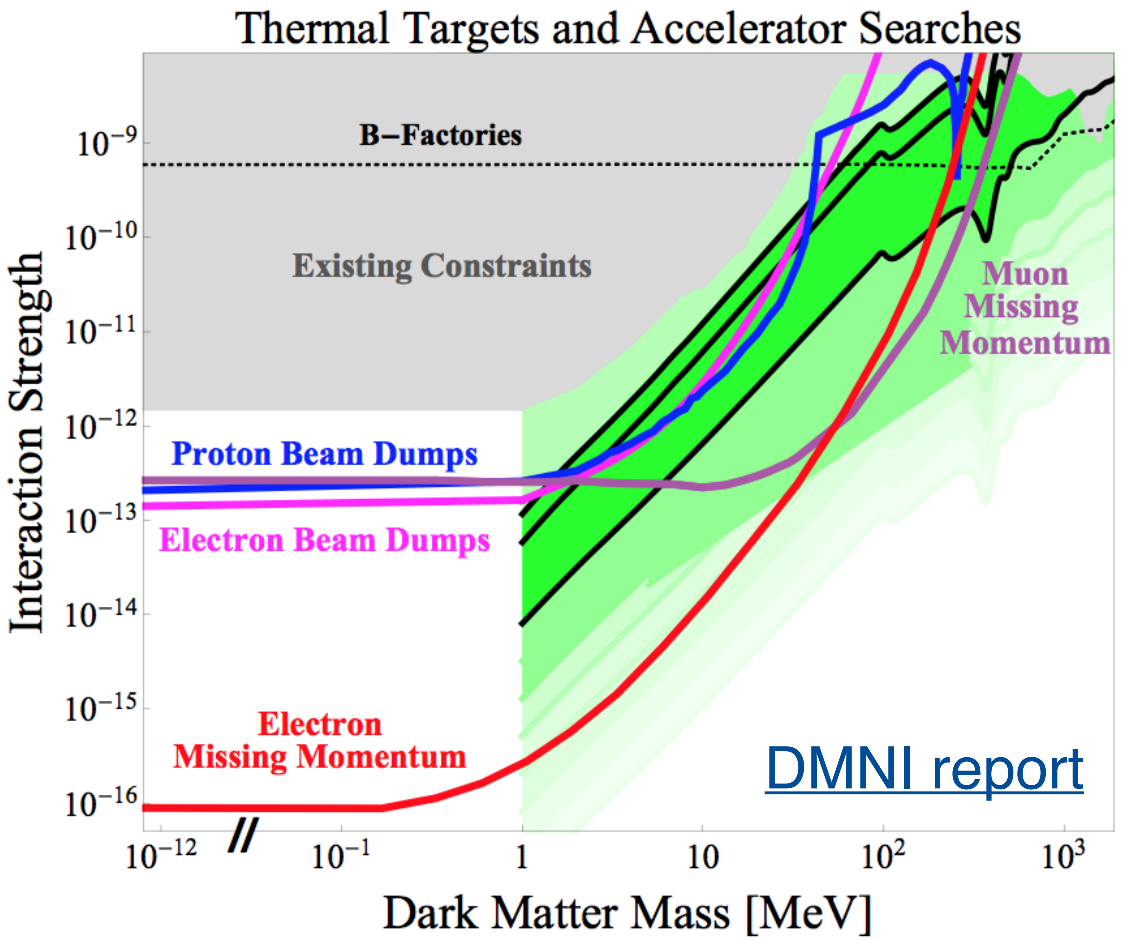
Missing mass



$$\sigma \sim \epsilon^2/(s - M^2_{\mathrm{Med}})$$

Missing momentum technique





DMNI report

Requires precisely-controlled electron beam

Minimal E spread, high rate, and low current.

Near-hermetic detector to rule out difficult SM backgrounds

Invisible signatures require full event reconstruction.

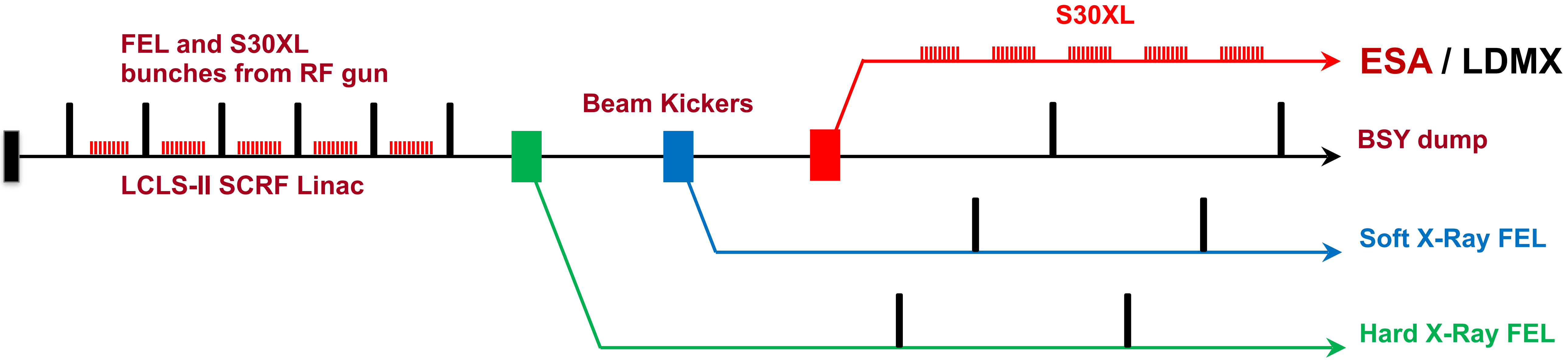
Fast readout electronics

Must trigger only events with large missing energy

High-precision electron source

LCLS-II SRF (SLAC) will provide electrons to End Station A delivering ~27 ns bunches w/ ⟨n_e⟩ ~ 1, via parasitic dark current between FEL pulses.

→ Upgrade planned from 4→8 GeV



High-precision electron source

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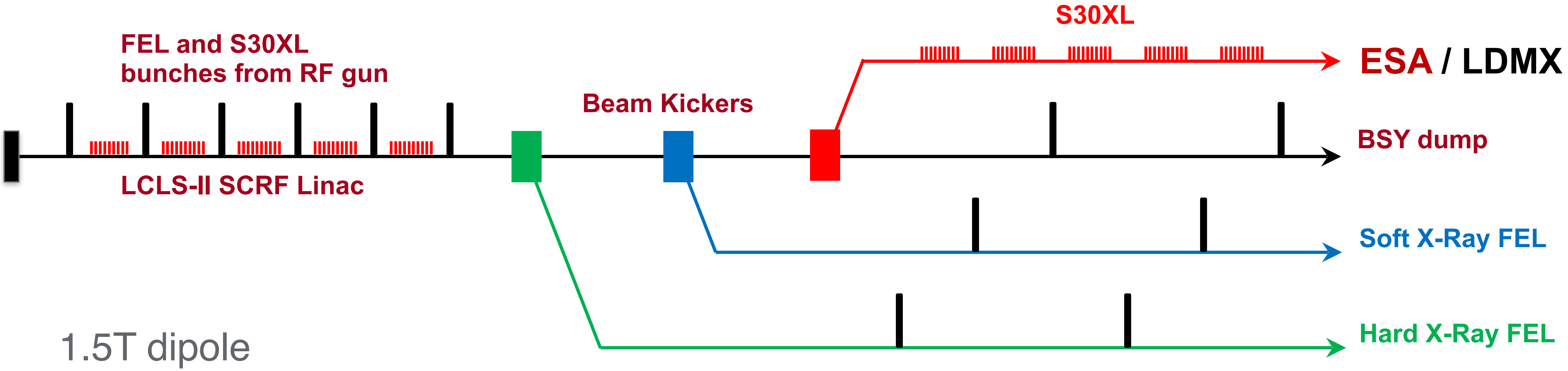
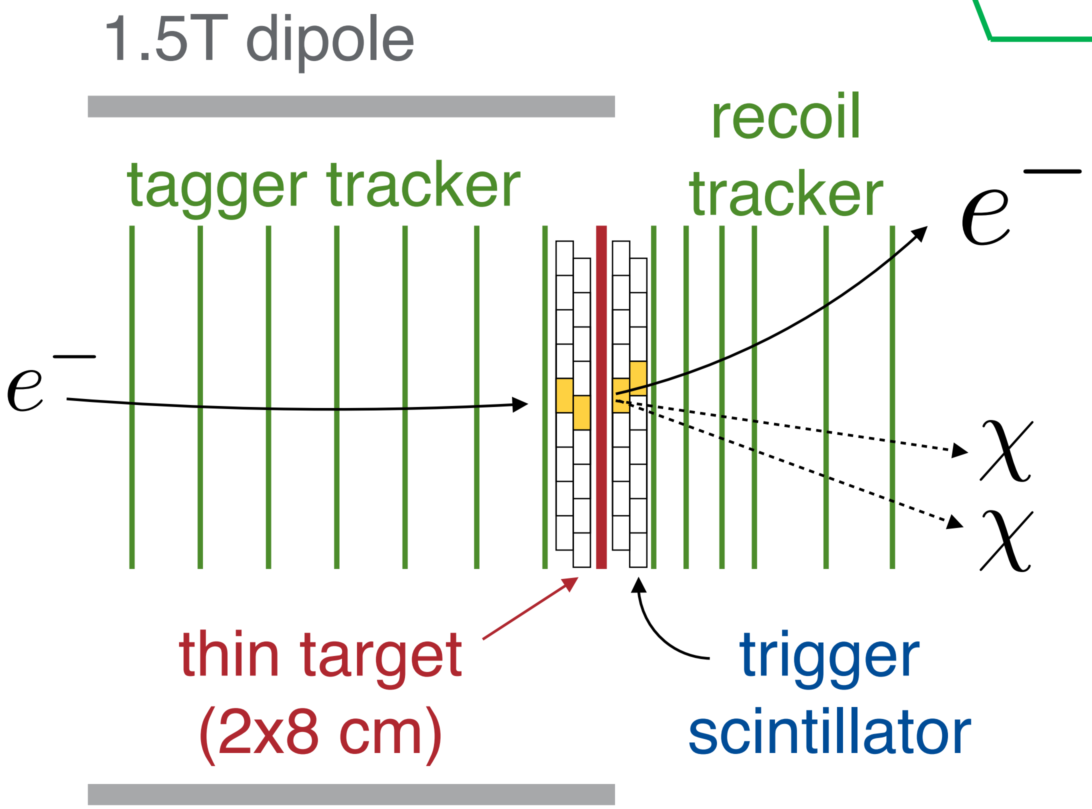




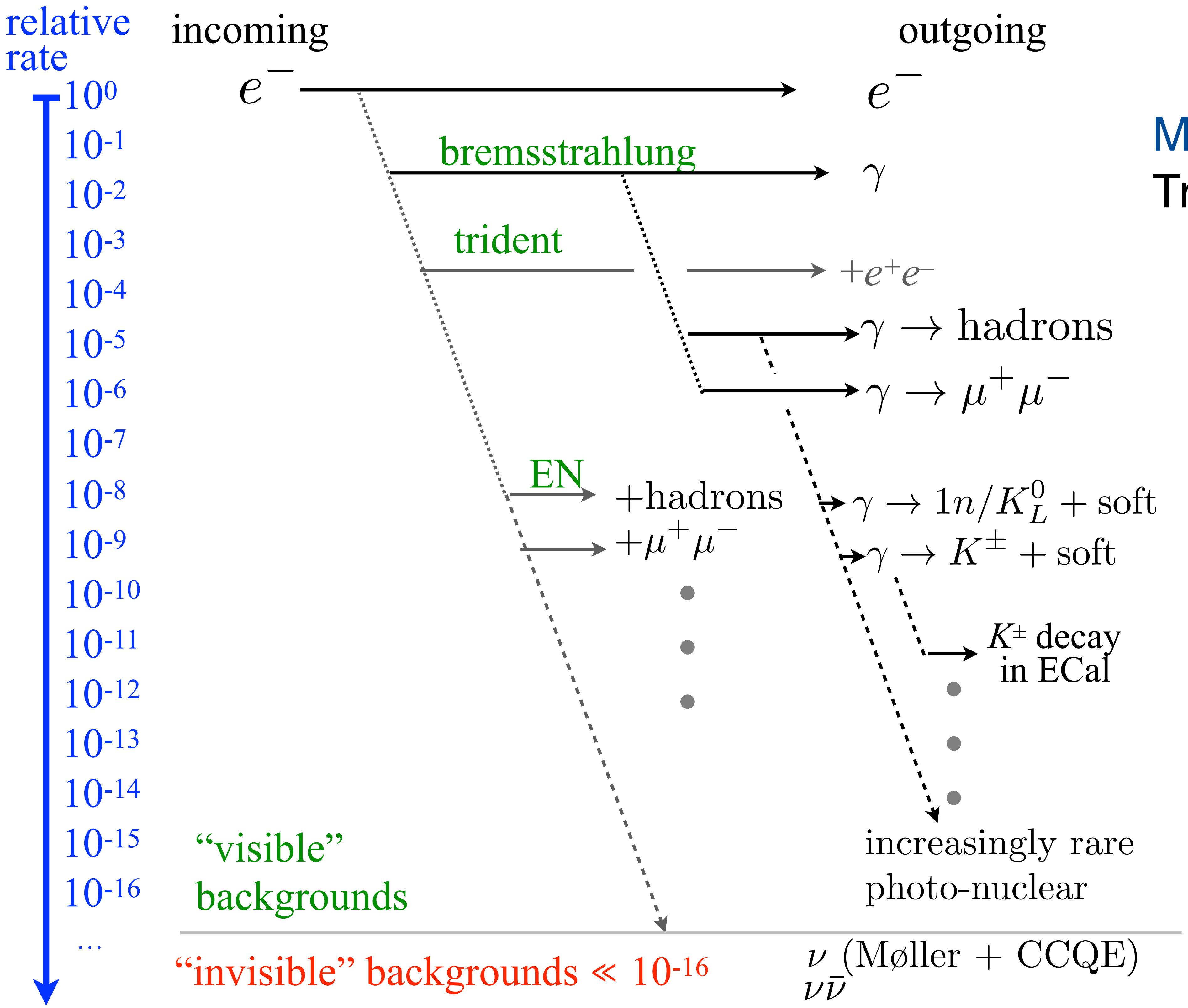
Tracking system measures $p_T(e^-)$ in B field.

e^- interacts in thin ($0.1X_0$) W/Al target.

Segmented scintillator tags filled bunches.

Ultimate target ~ 1e16 EOT

SM Background rejection



relative rate

10^{0} 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13} 10^{-14} 10^{-15} 10^{-16} …

incoming

outgoing

e^{-} → e^{-}

bremsstrahlung → γ

trident → $+e^{+}e^{-}$

$\gamma \rightarrow$ hadrons

$\gamma \rightarrow \mu^{+}\mu^{-}$

EN → +hadrons

→ $+\mu^{+}\mu^{-}$

$\gamma \rightarrow 1n/K_{L}^{0} + \text{soft}$

$\gamma \rightarrow K^{\pm} + \text{soft}$

$K^{\pm}$ decay in ECal

increasingly rare photo-nuclear

"visible" backgrounds

"invisible" backgrounds ≪ 10^{-16}

ν (Møller + CCQE)
$\nu\bar{\nu}$

Missing energy

Trigger: 40MHz→kHz

Rare shower reconstruction:

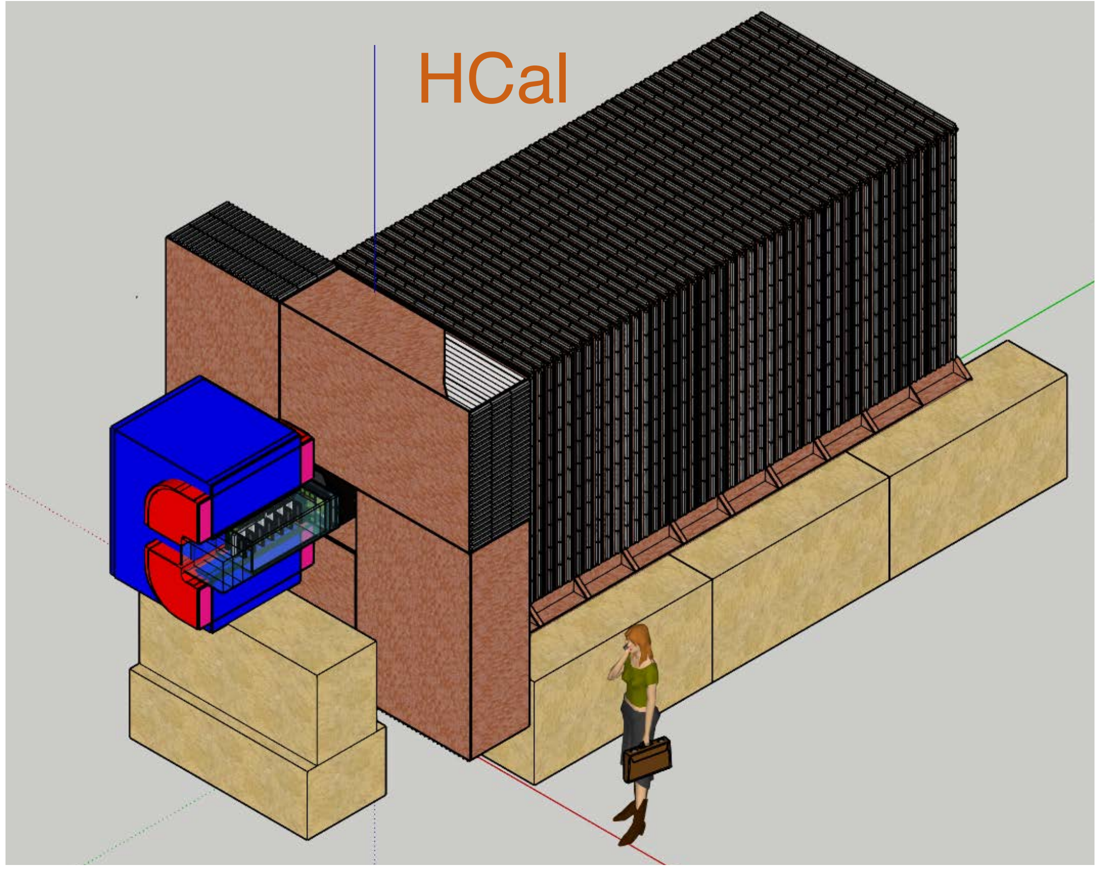
MIP tracks
Soft pions
Neutrons, Kaons, …

Electroweak

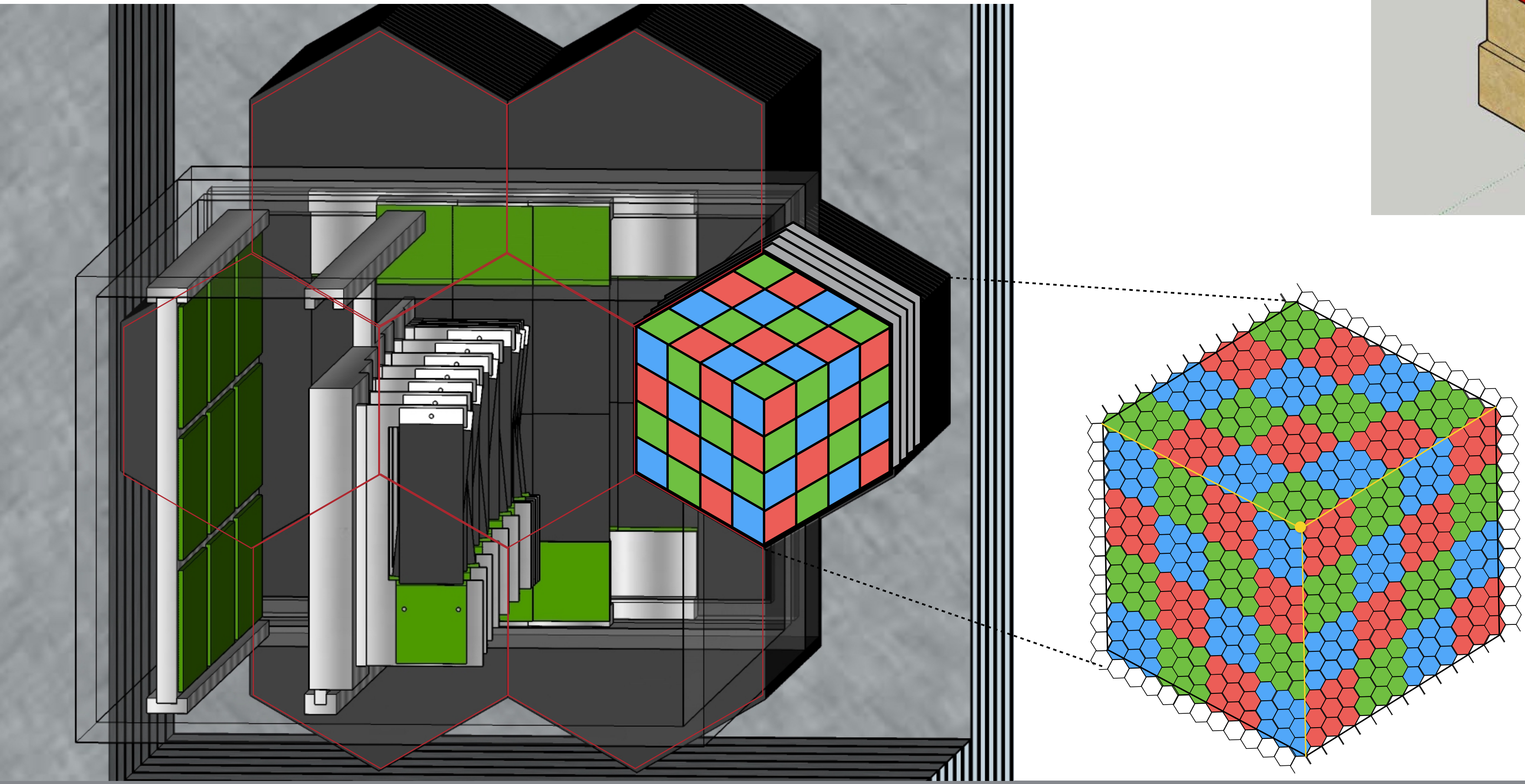
(genuine missing p)

Calorimetry

Calorimeters *must fully contain all particle showers* (EM + hadronic), including displaced decays (e.g. K_L)



Mu2e cosmic veto technology
2m x 2m steel / scintillating bars (17λ)
Side HCal for wide-angle emissions

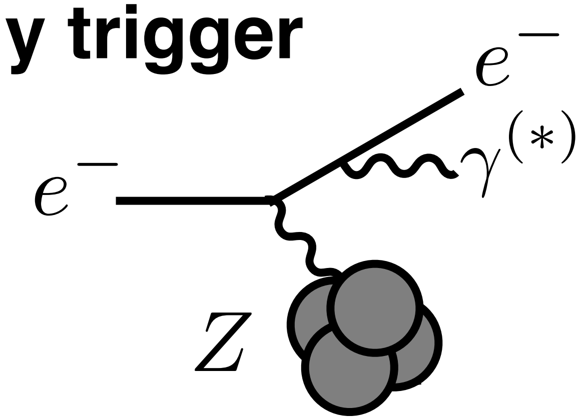


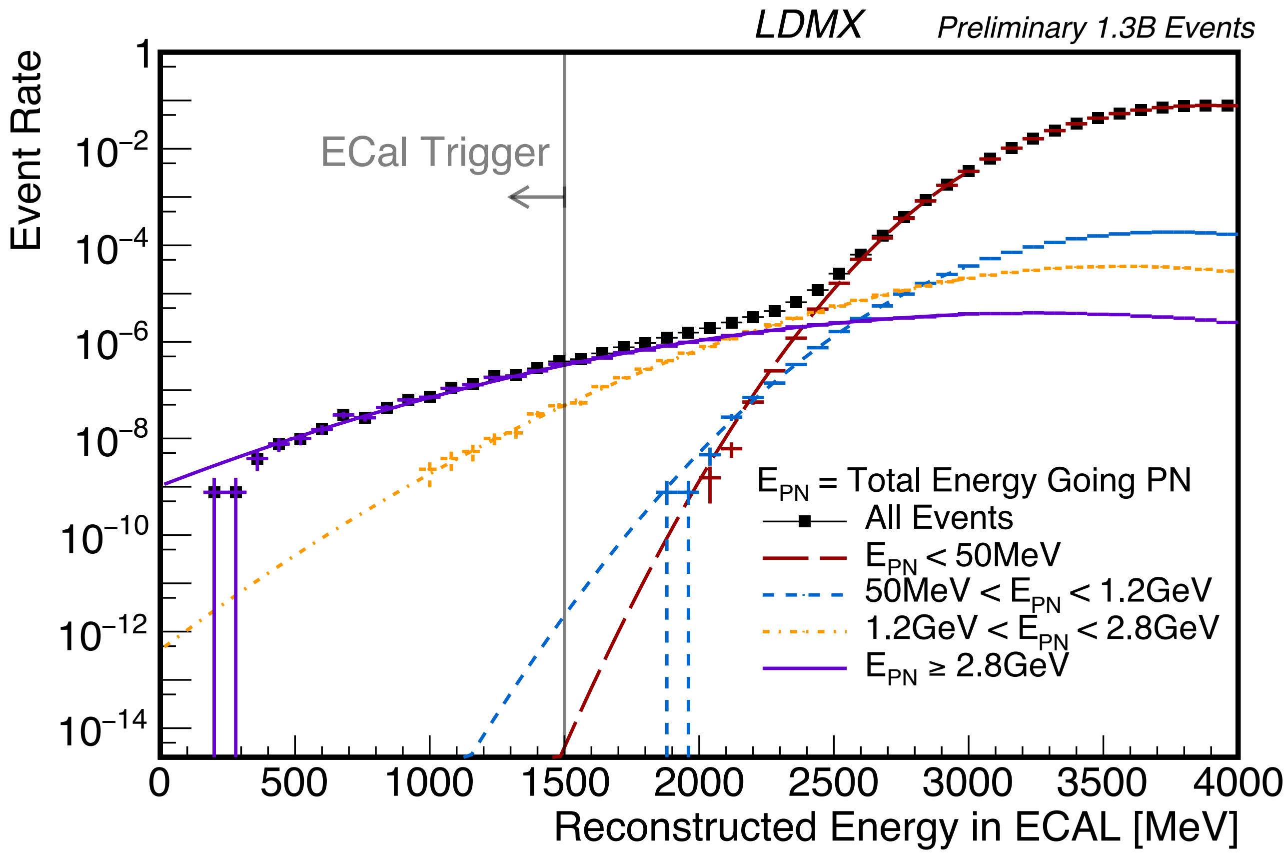
CMS HGCal technology
34 Si/W layers (40 X_0)
432 pads/module
High radiation tolerance

Background elimination strategy

1. Missing energy trigger

(majority of events are γ-nuclear)





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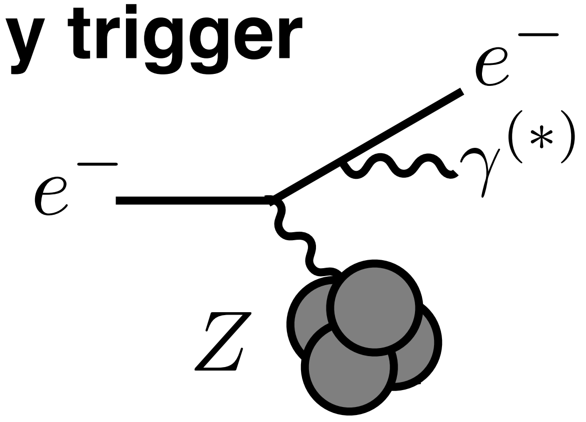
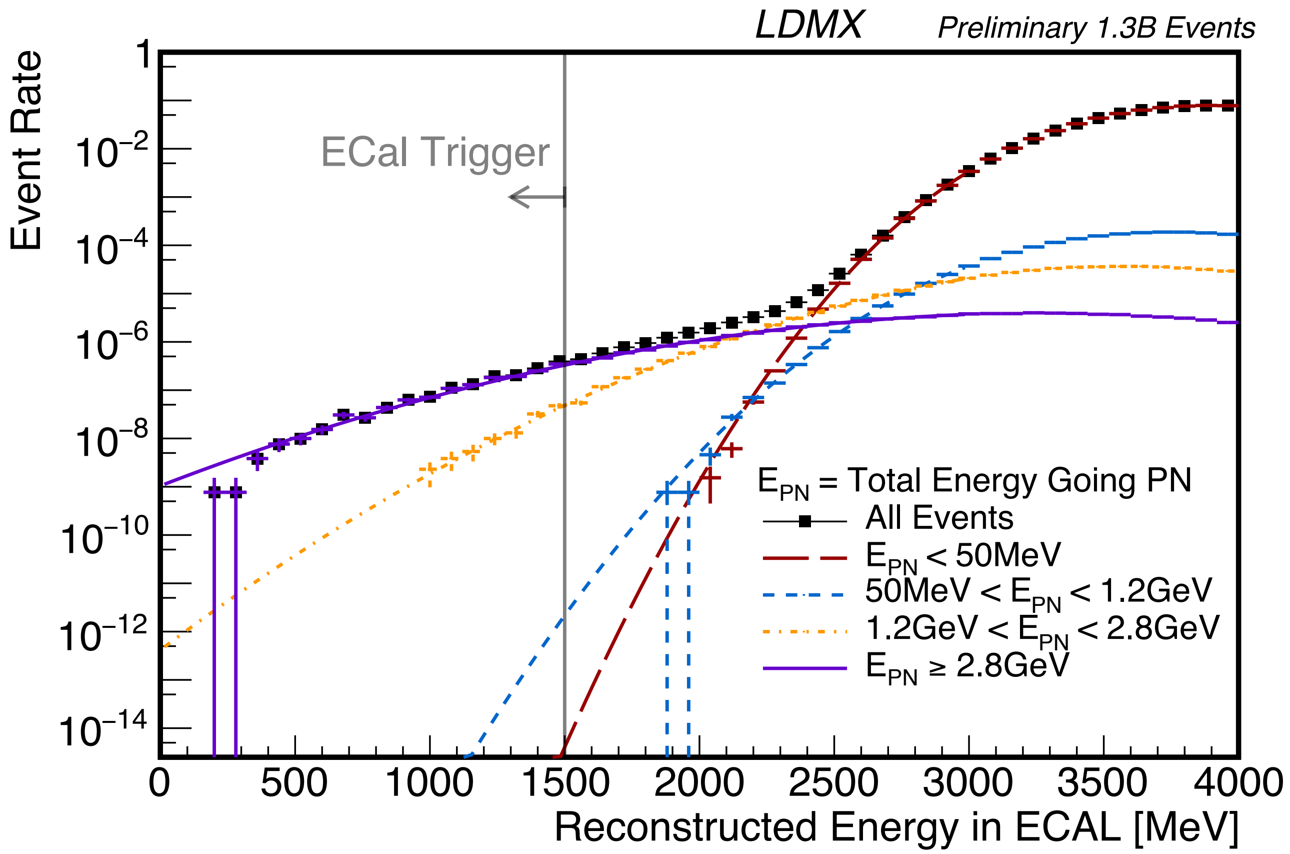
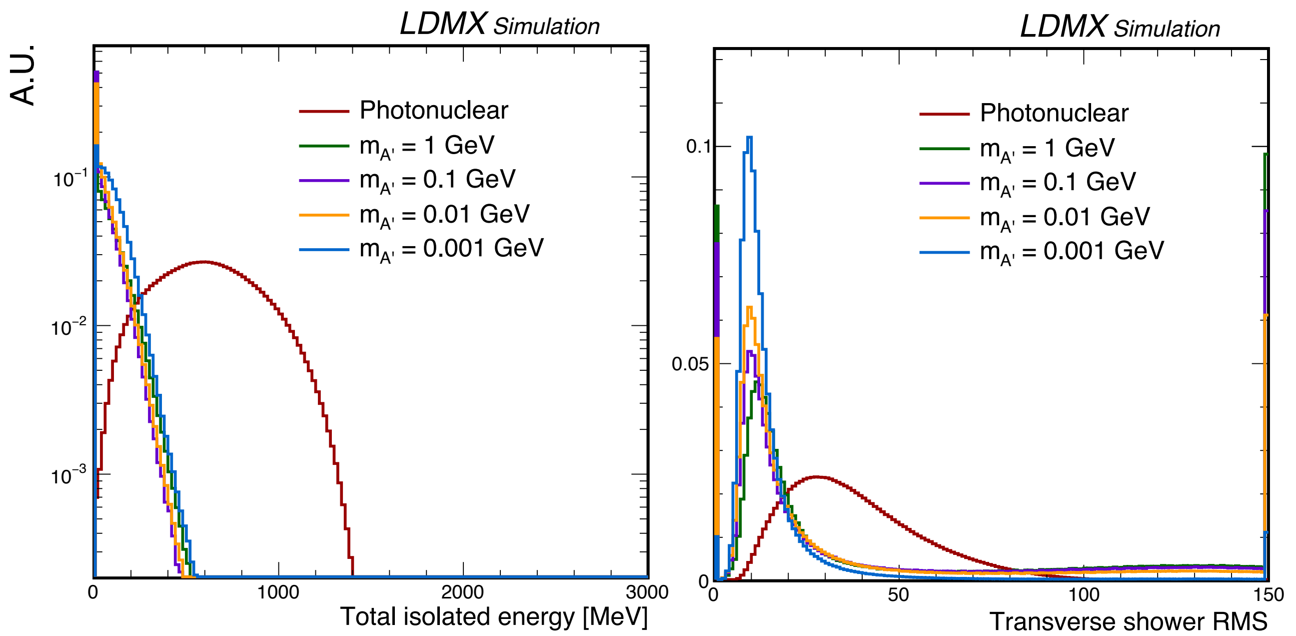




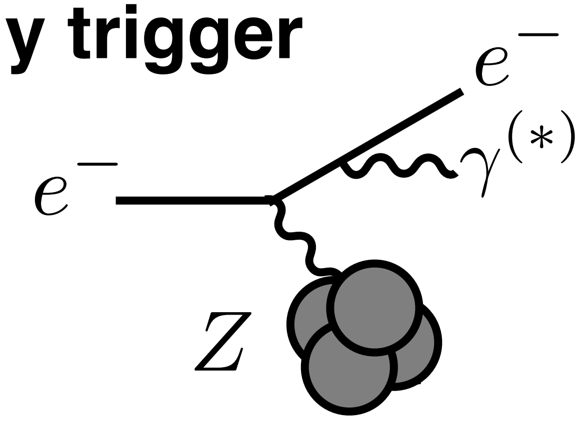


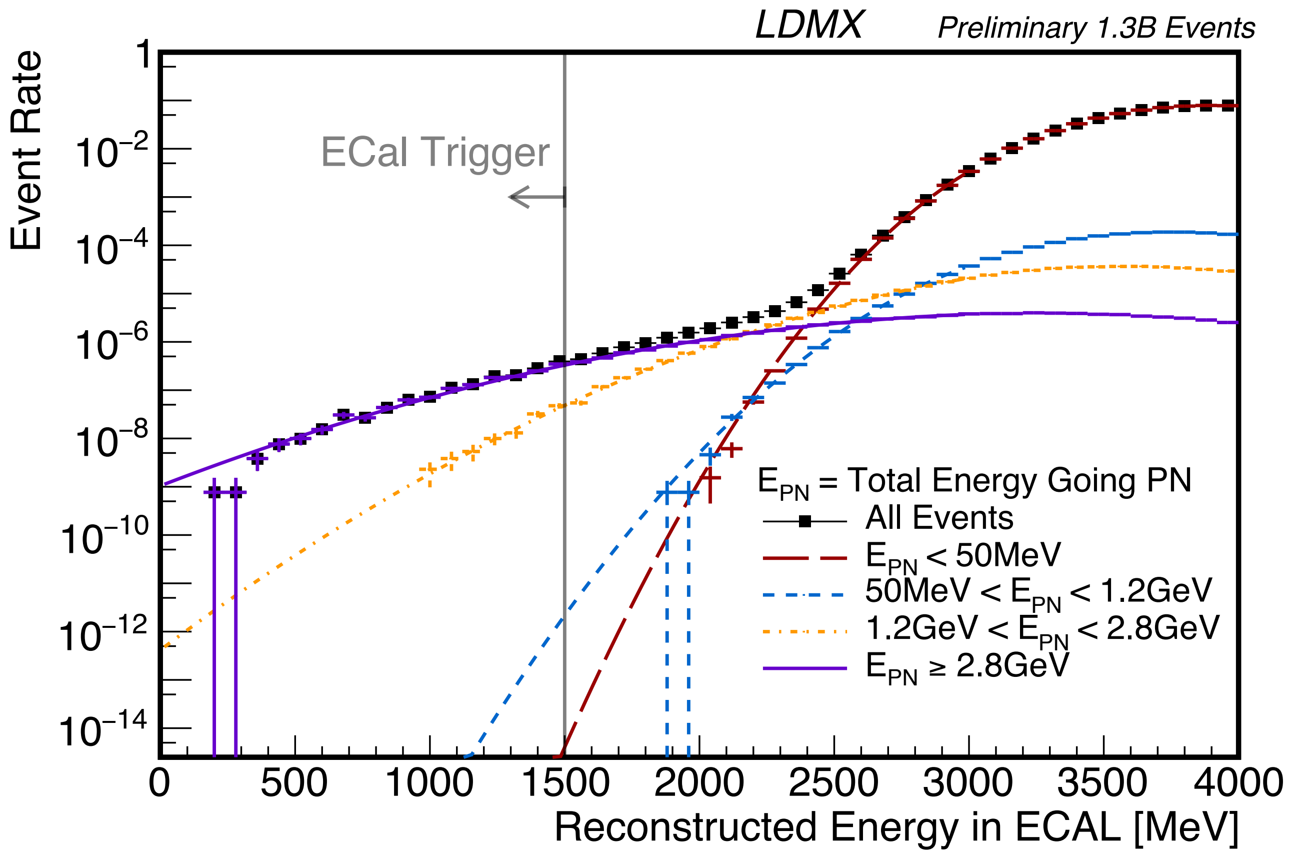
2. ECal shower discriminants → BDT

Background elimination strategy

1. **Missing energy trigger**

(majority of events are γ-nuclear)





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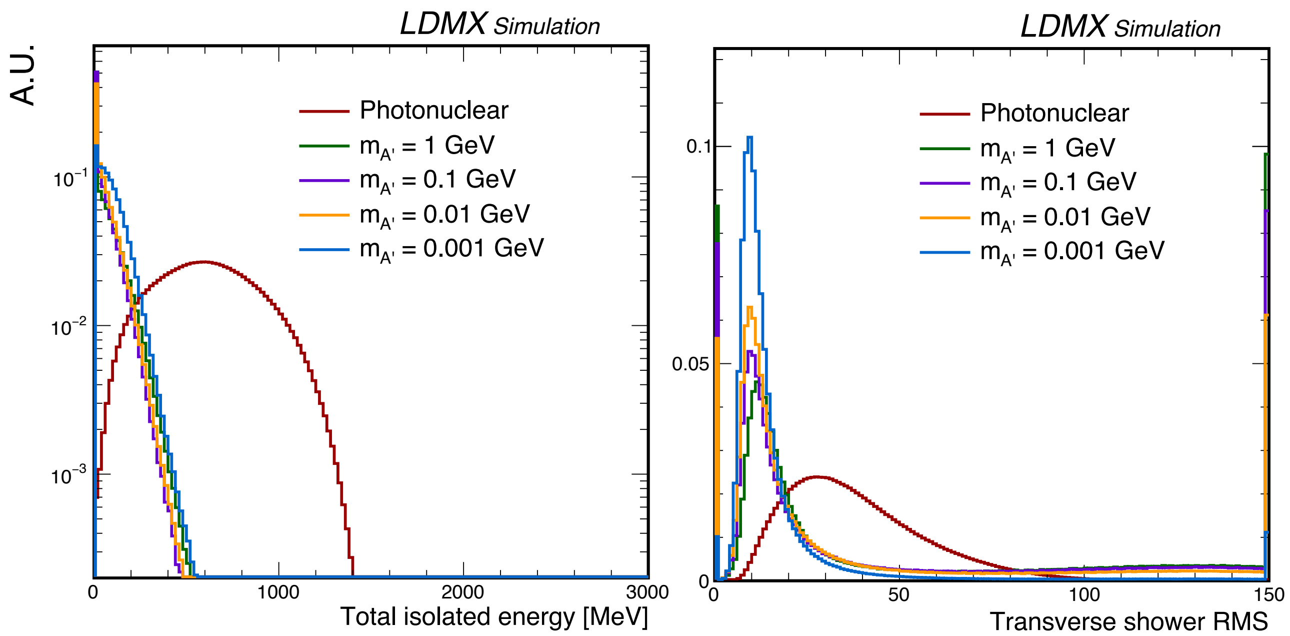
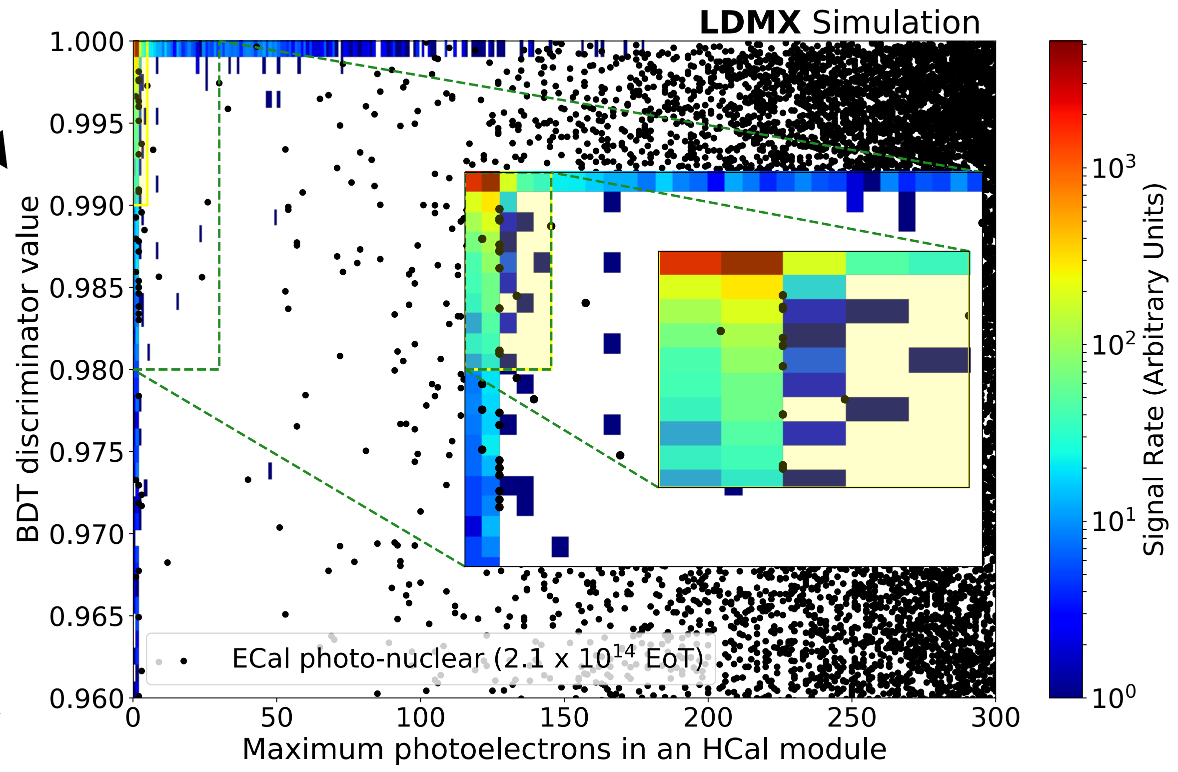
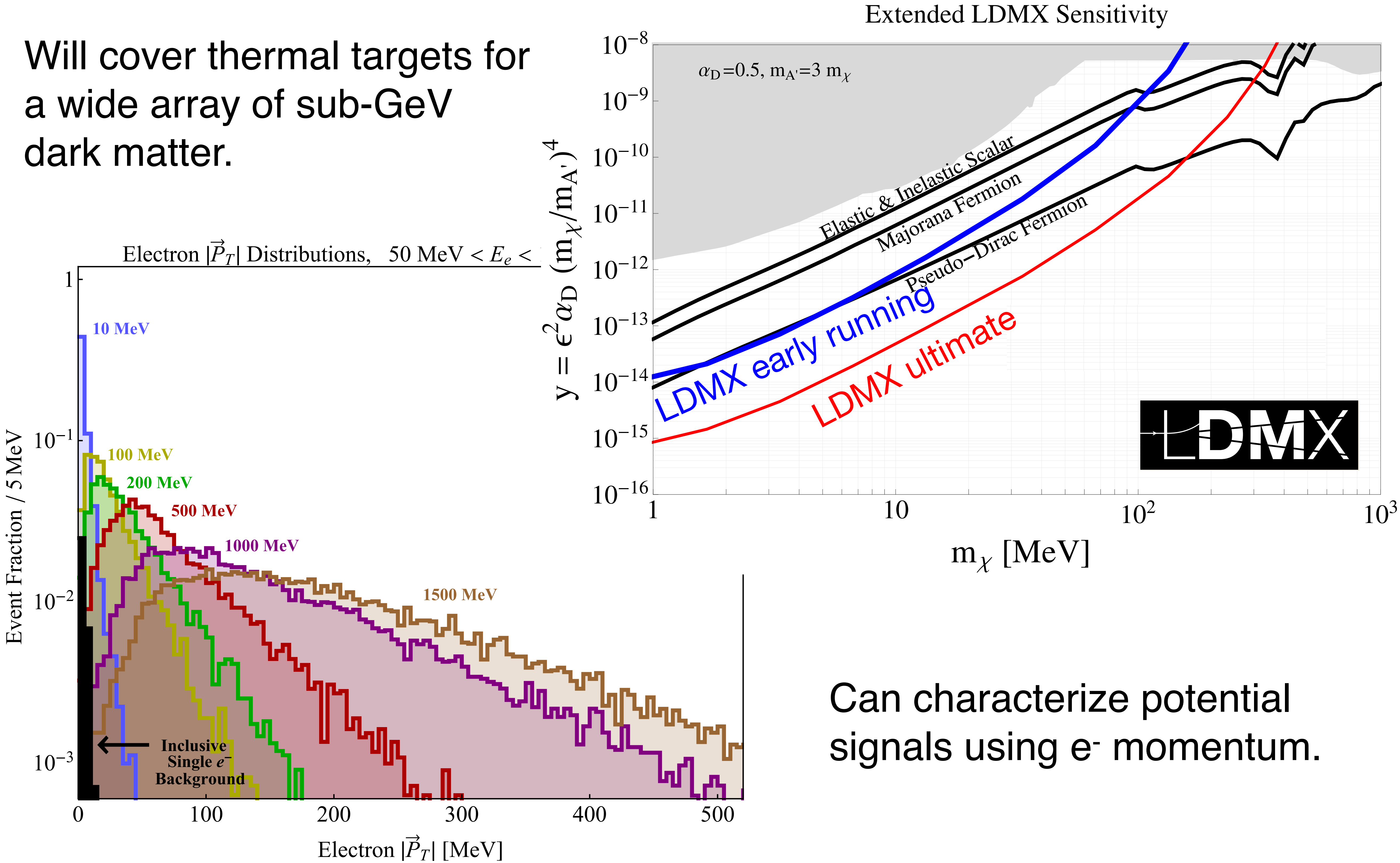




3. **Veto HCal activity + extra tracks →**

Projected sensitivity

Will cover thermal targets for a wide array of sub-GeV dark matter.

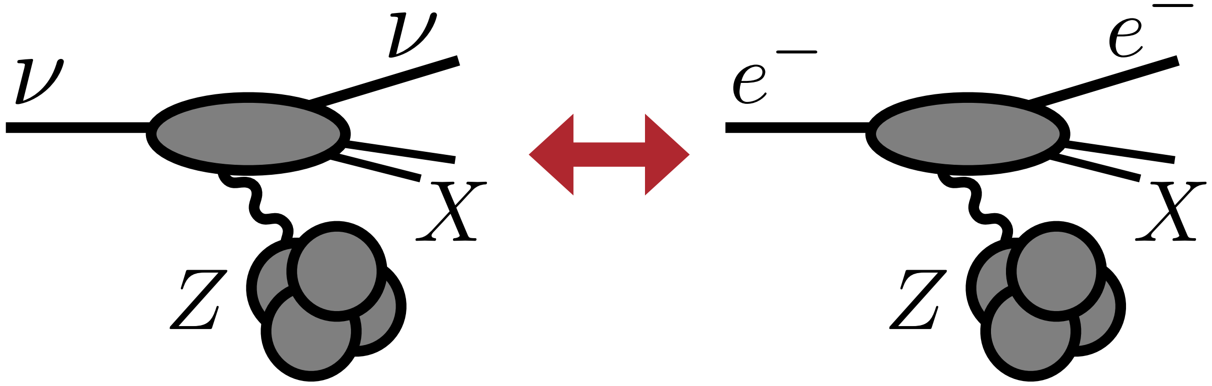


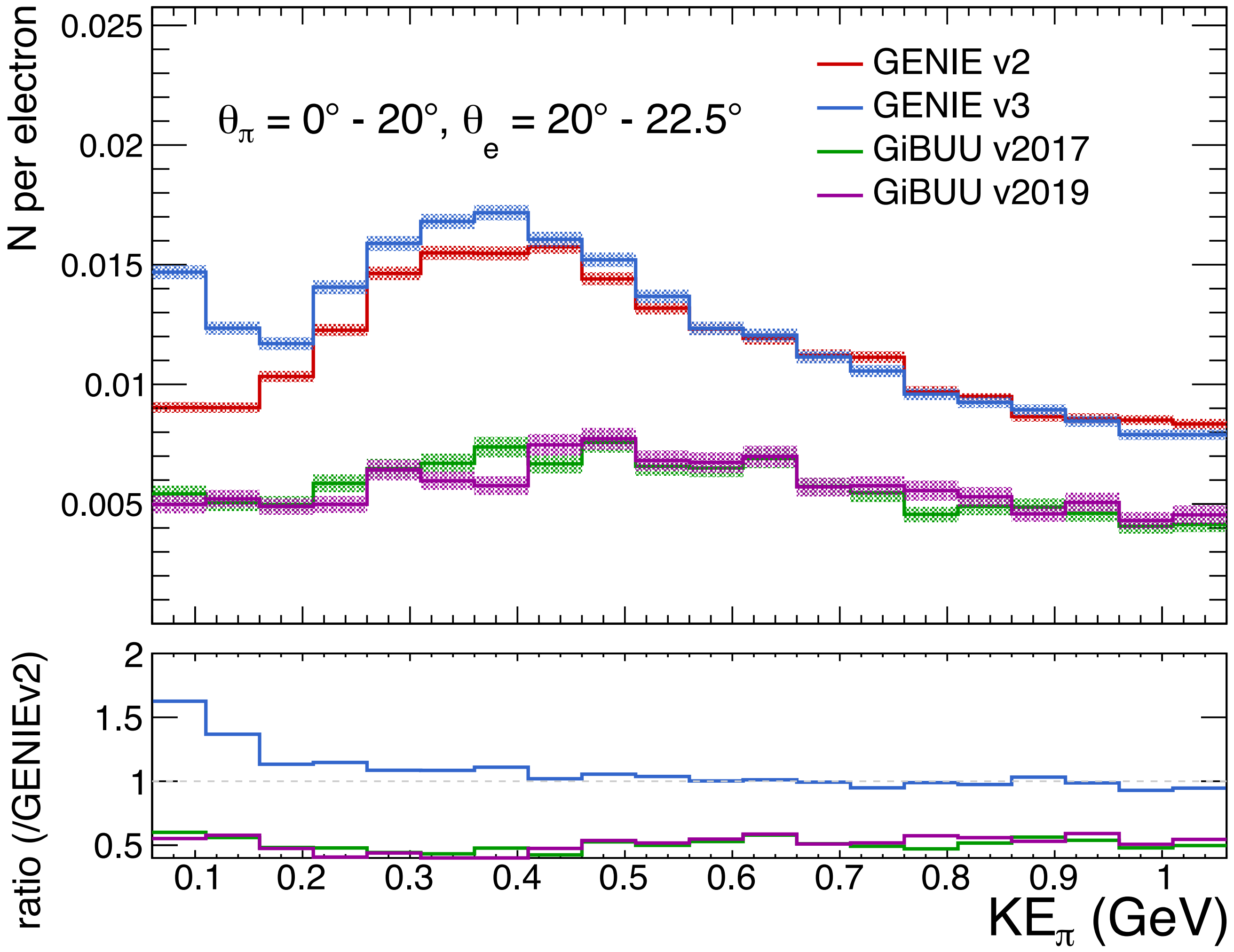
Can characterize potential signals using e$^-$ momentum.

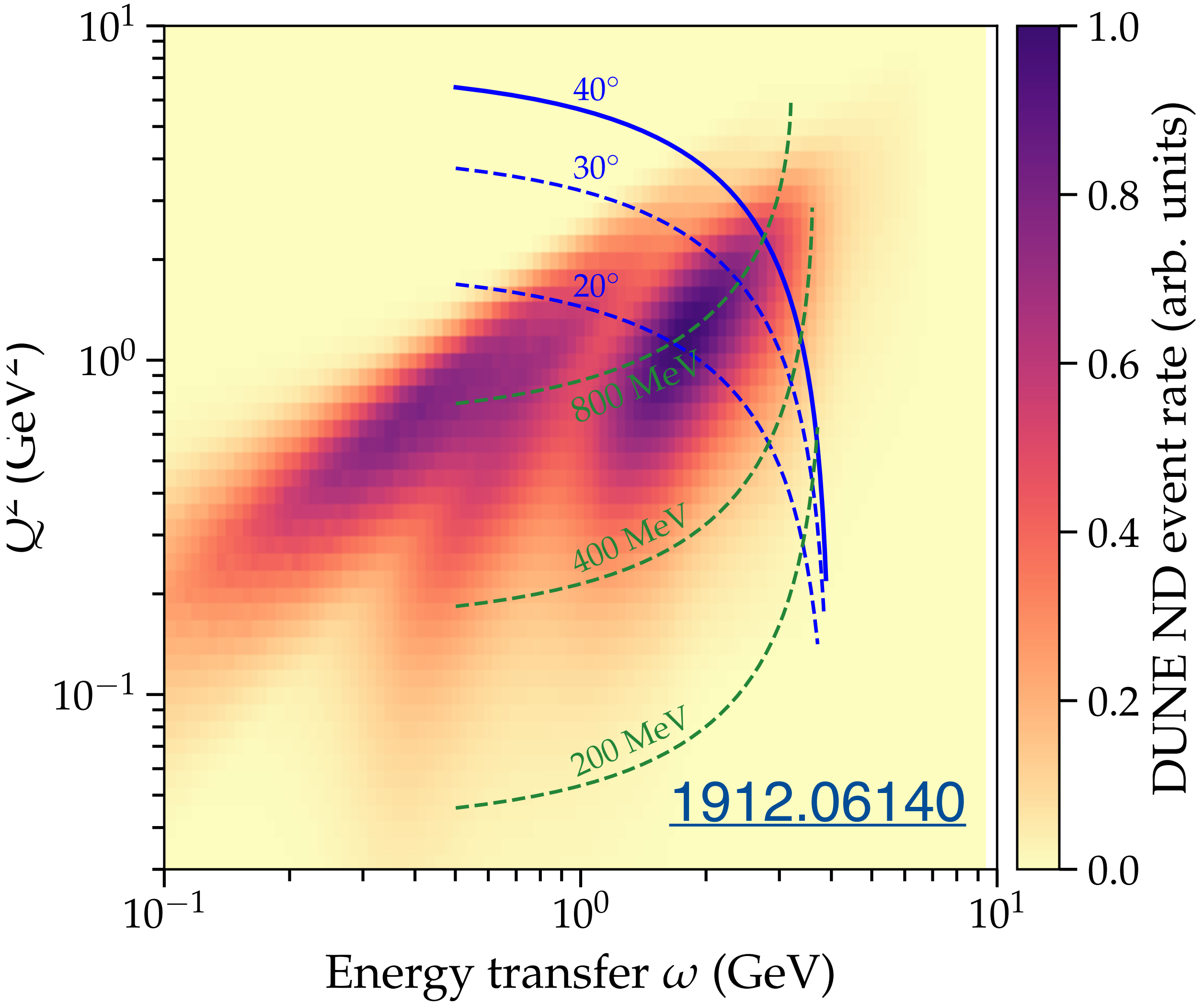
Physics beyond dark matter

Constrain *neutrino-nucleon* interaction via *electron-nucleon measurements.*

Probe DUNE phase space with *precisely-known beam energy*.







1912.06140

Conclusions

Thermal dark matter motivates a broad search program for $m_e < m_{DM} < m_p$.

The missing momentum technique is a powerful accelerator probe.

LDMX will explore vast new territory, robustly *reaching thermal relic targets across most of the MeV-GeV mass range*.

However, sensitivity to Dark Matter models extends far beyond this, including visible signatures as well (LDMX as a beam-dump).

Interesting models include: strongly interacting massive particles (SIMPs), milli-charged particles (MCPs), inelastic dark matter (iDM), axion-like particles (ALPs) … and more!

Will also provide powerful new constraints on *lepton-nucleon interaction* models critical to the neutrino program.

LDMX offers a broad physics program, in light dark matter and beyond.

We look forward to realizing this potential on a short timescale!

Additional information

Light Dark Matter eXperiment (LDMX) (1808.05219)

A High Efficiency Photon Veto for the Light Dark Matter eXperiment (1912.05535)

Characterizing Dark Matter Signals with Missing Momentum Experiments (2010.03577)

Dark Matter, Millicharges, Axion and Scalar Particles, Gauge Bosons, and Other New Physics with LDMX (1807.01730)

Lepton-Nucleus Cross Section Measurements for DUNE with the LDMX Detector (1912.06140)

M^3: A New Muon Missing Momentum Experiment to Probe $(g - 2)_\mu$ and Dark Matter at Fermilab (1804.03144)