The Light Dark Matter Experiment

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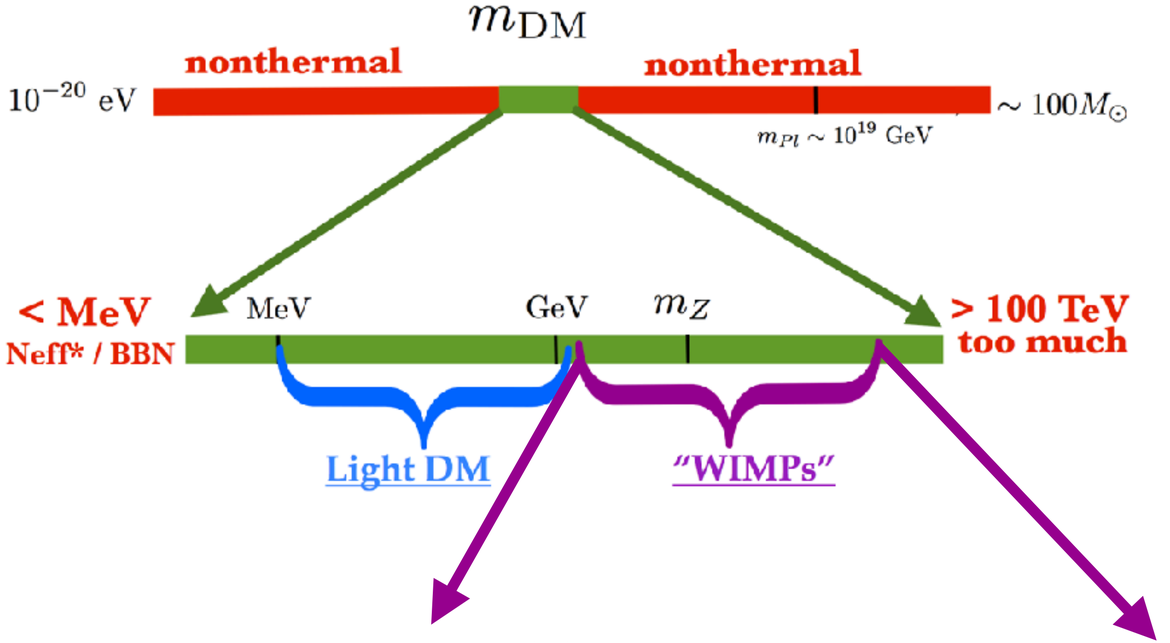
DPF, Fermilab — July 31, 2017

LDMX

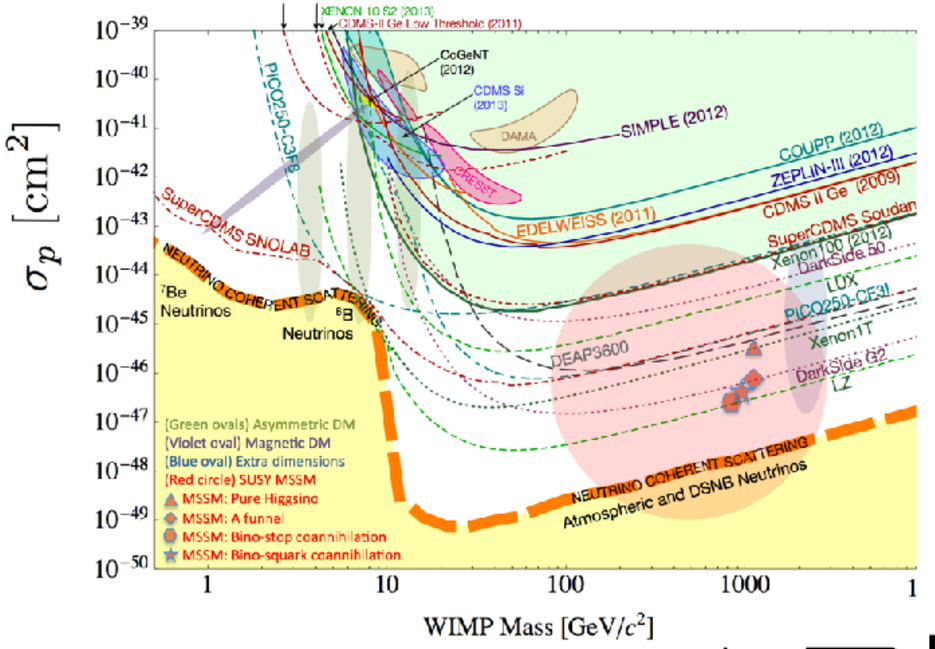
The hunt for dark matter

- Broad and impressive program has built up to understand non-gravitational interactions of WIMPs



- Still a large region of thermal DM parameter space < 1 GeV where thermal targets are largely unexplored
  - *highlighted in Cosmic visions white paper (arXiv:1707.04591)*

US Cosmic Visions: New Ideas in Dark Matter 2017 : Community Report



Light dark matter searches

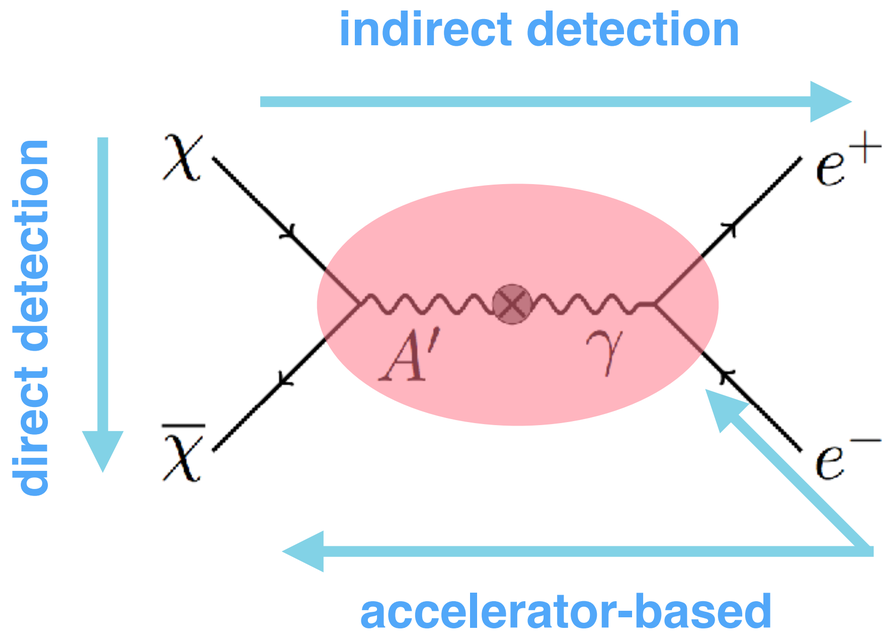
Light dark matter parameter space is a natural evolution of WIMP search program

Electrons play a central role in dark matter & light mediator searches over most of this parameter space

electron accelerators can play a major role in testing these models

Requires new light mediators

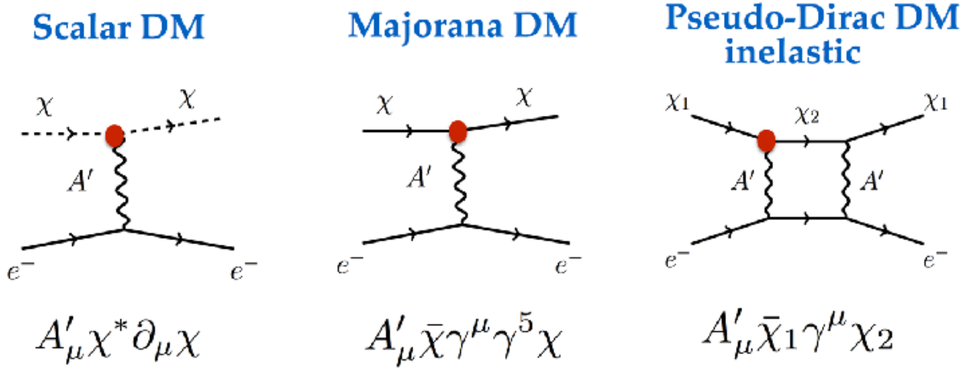
simplest, predictive model: vector mediator which weakly mixes with photon

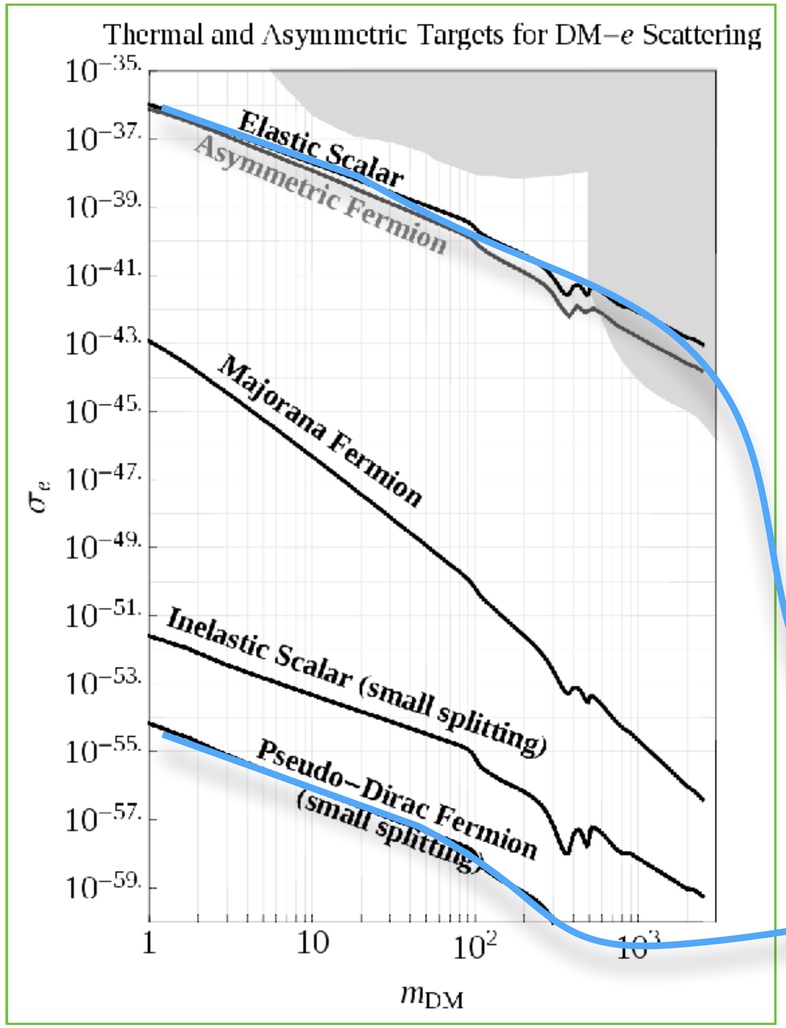


$$\epsilon F'_{\mu\nu} F^{\mu\nu}$$

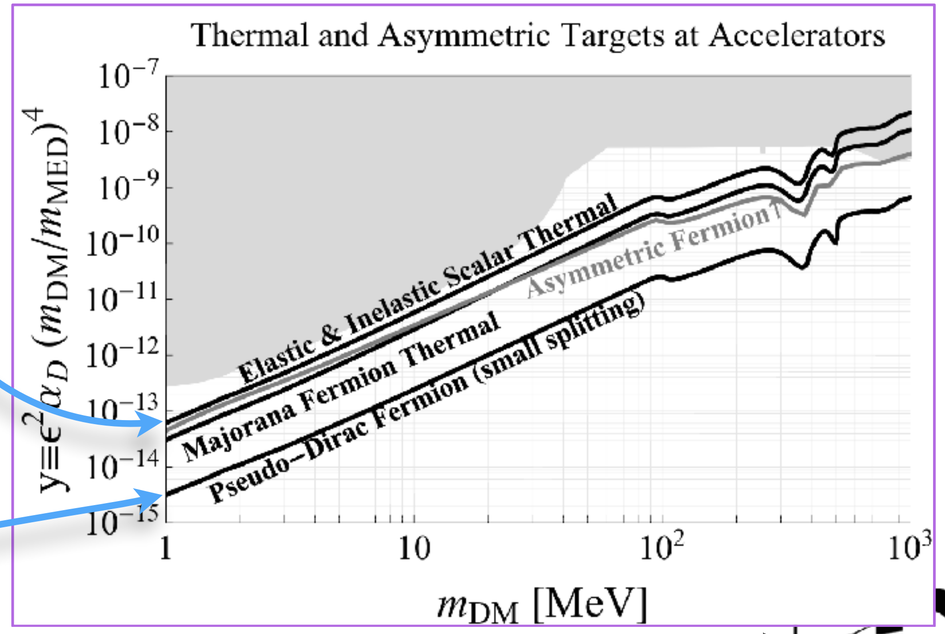
Light dark matter targets

Thermal targets in non-relativistic direct detection scattering is highly sensitive to Lorentz structure of interactions

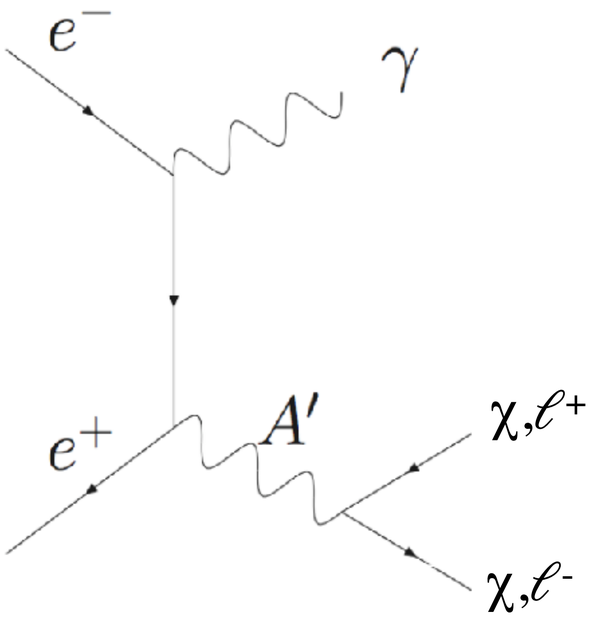




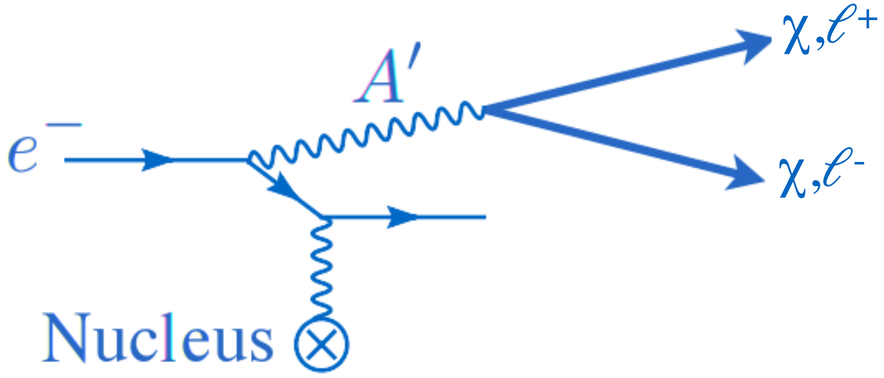
Accelerators produce dark matter relativistically, minimizing effect of different Lorentz structures.



Accelerator searches

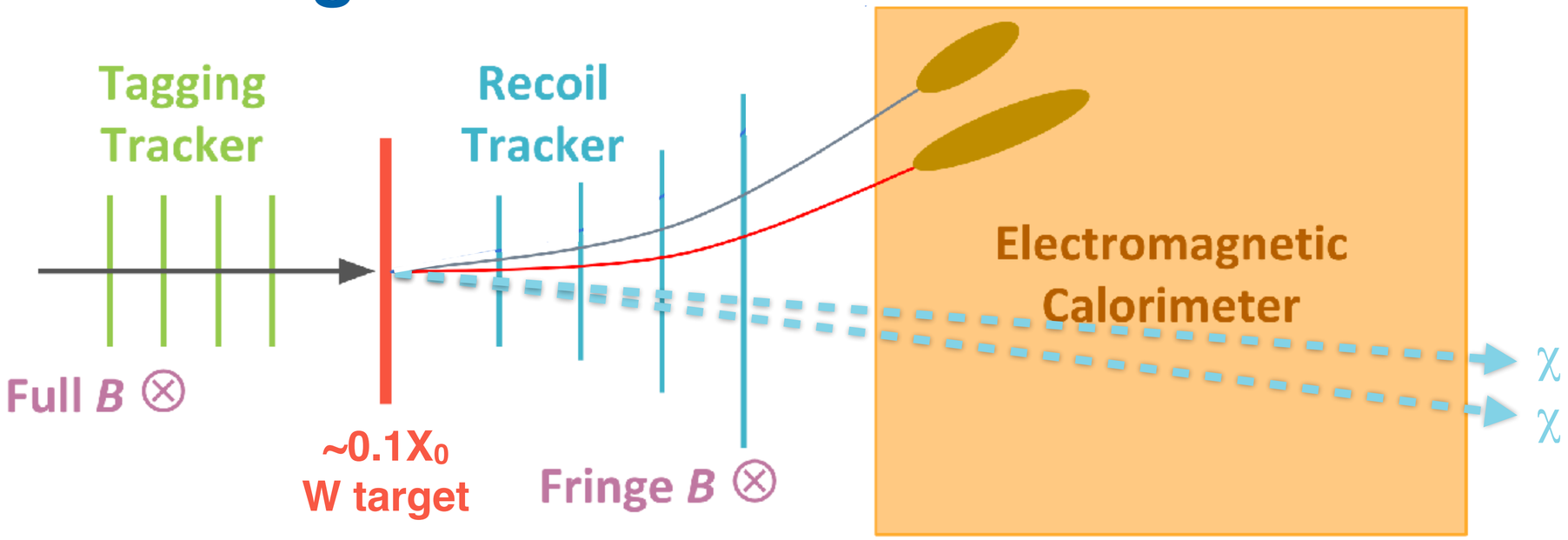


- Collider experiments:
  - mono-X searches
    - (BaBar, Belle II, LHC)



- Fixed target experiments:
  - missing energy/momentum (invisible)
    - e.g. LDMX, NA64
  - beam dump experiments (visible)
    - e.g. BDX, miniboone (protons)

Experimental design



Beam which enables $\mathcal{O}(10^{16})$ electrons to be individually identified & reconstructed

low-current, high repetition rate beam (10^{16}/year~1e^- / 3 ns)

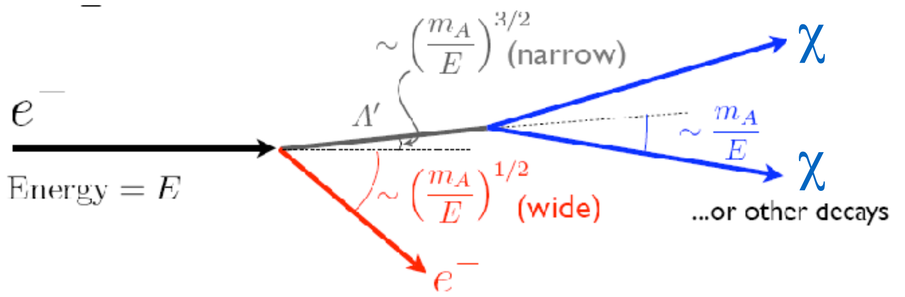
possibilities include DASEL @ SLAC (4/8 GeV) or CEBAF @ JLAB (< 11 GeV)

Detector technology with fast readout and high radiation tolerance

high momentum resolution, low mass tagger/recoil tracker

high energy resolution EM calorimeters (ECal)

Signal production & kinematics

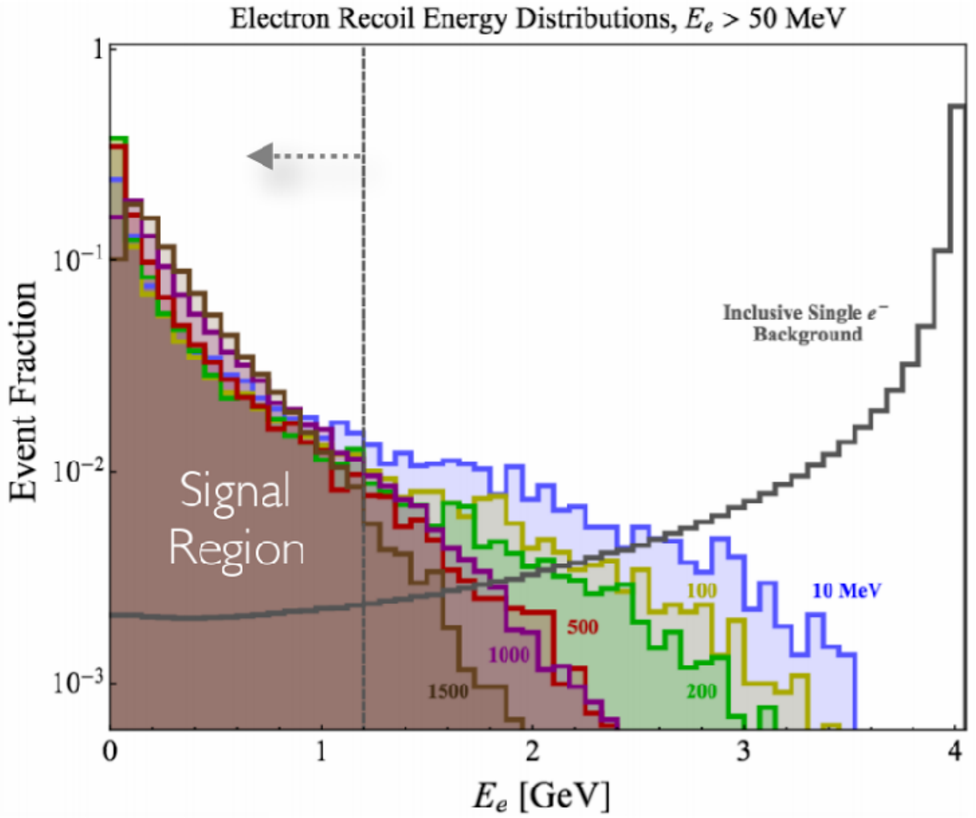


- For $m_{A'} \gg m_e$, $\sigma \propto \frac{Z^2\epsilon^2}{m_{A'}^2}$

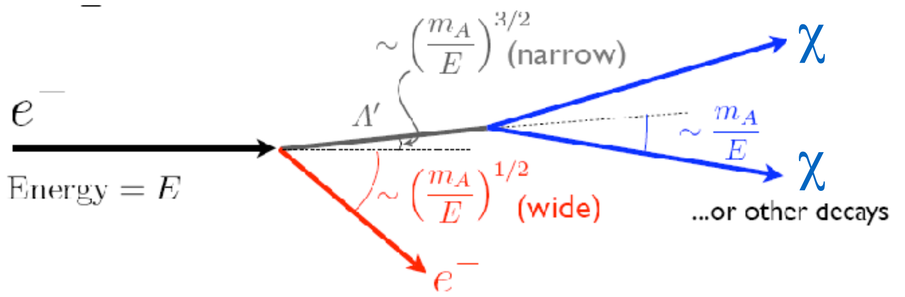
- A' carries away mostly of the beam energy and converts it to invisible particles

$$E_A \sim E - m_{A'}$$
$$E_e \sim m_{A'}$$

- p_T spectrum of signal depends on $m_{A'}$ and is an important experimental handle
  - both for background discrimination and signal characterization



Signal production & kinematics



- For $m_{A'} >> m_e$, $\sigma \propto \frac{Z^2\epsilon^2}{m_{A'}^2}$

- A' carries away mostly of the beam energy and converts it to invisible energy

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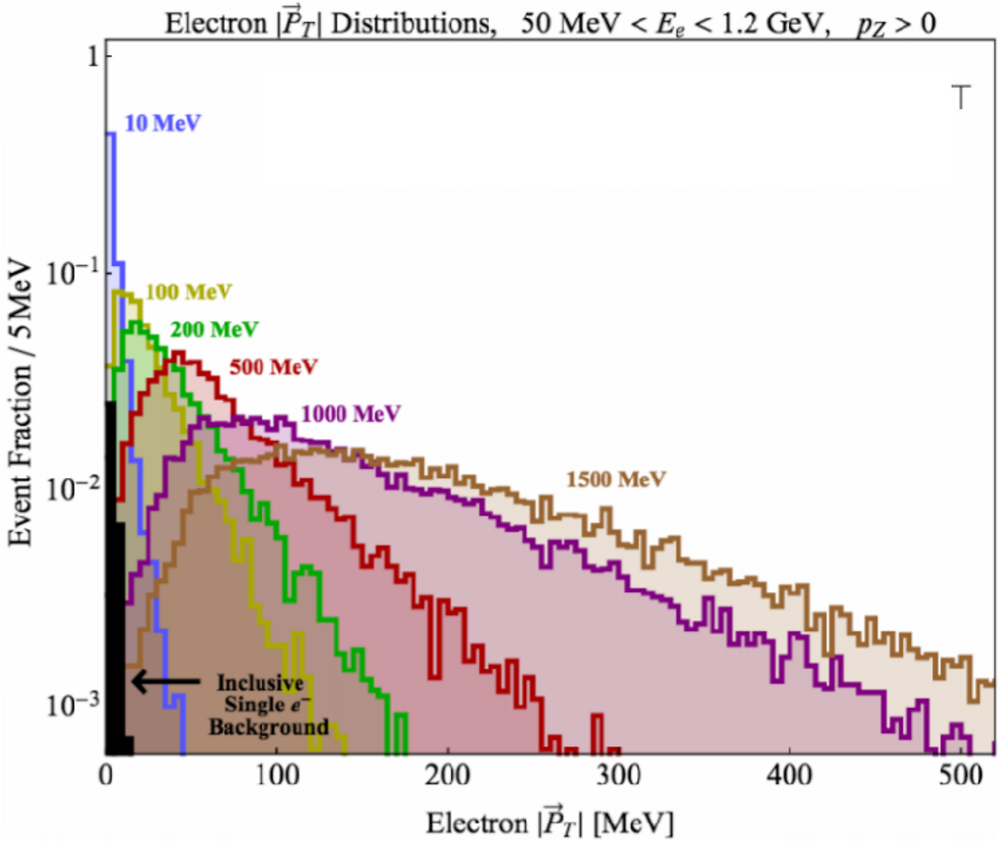
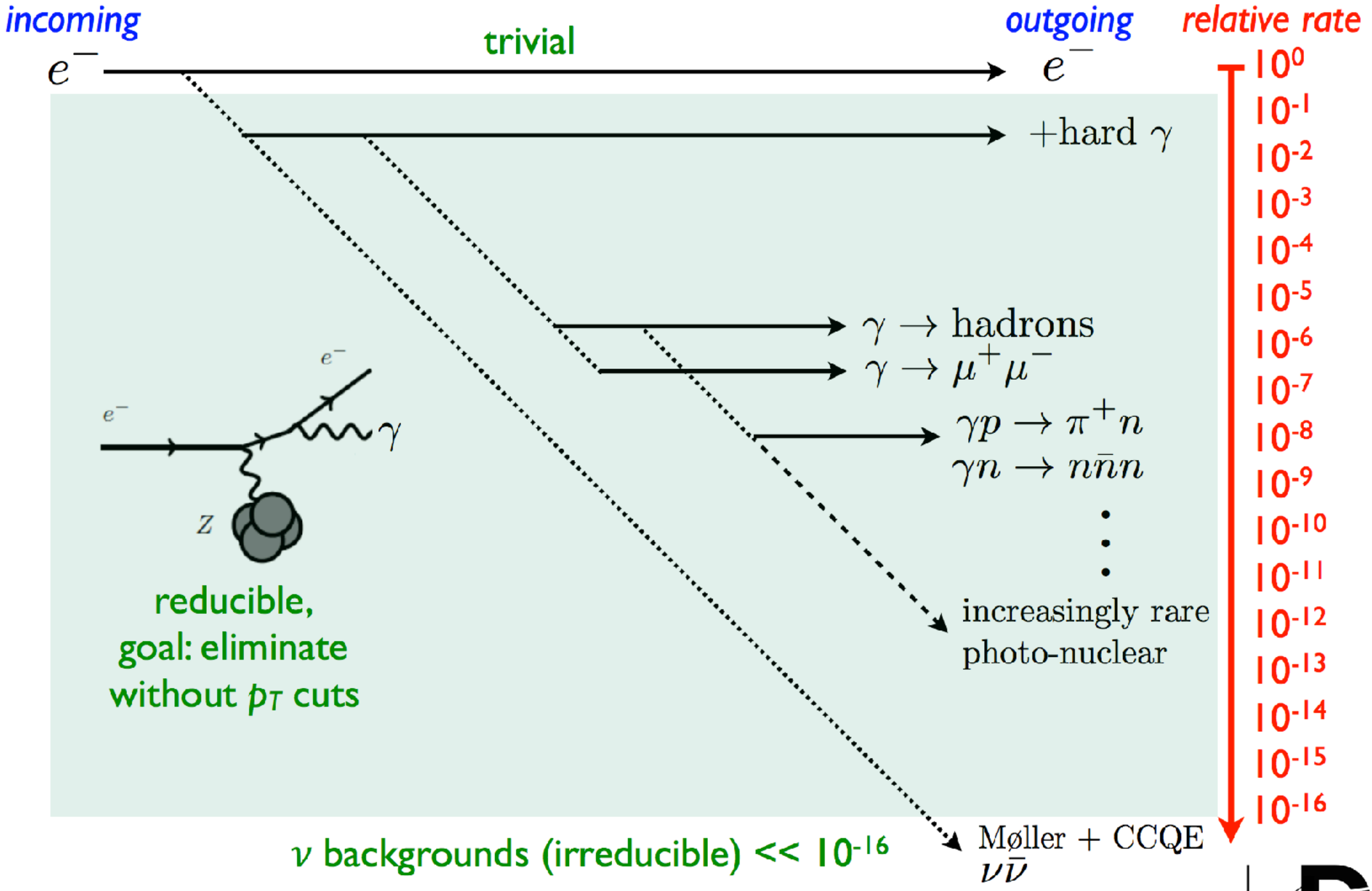
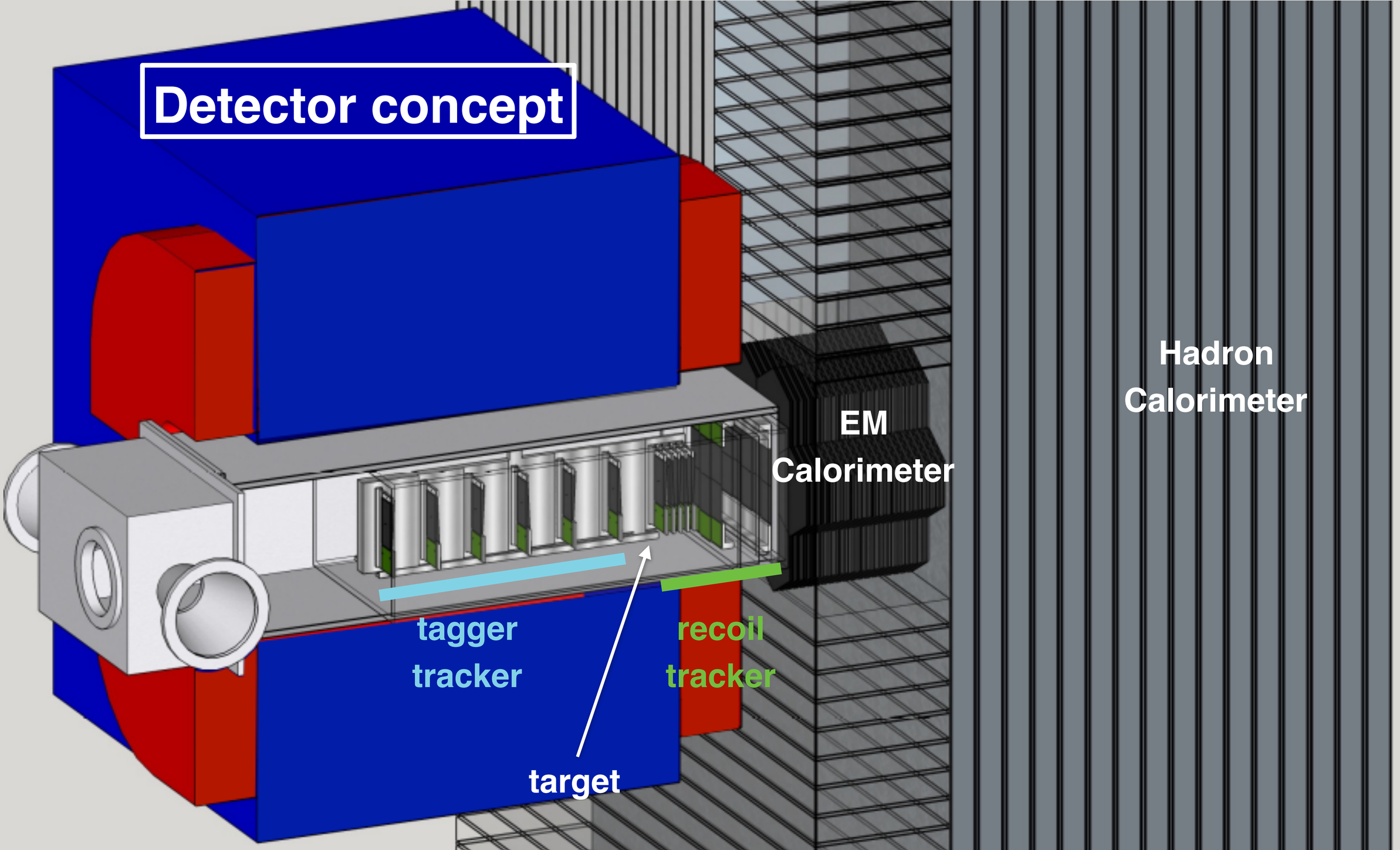
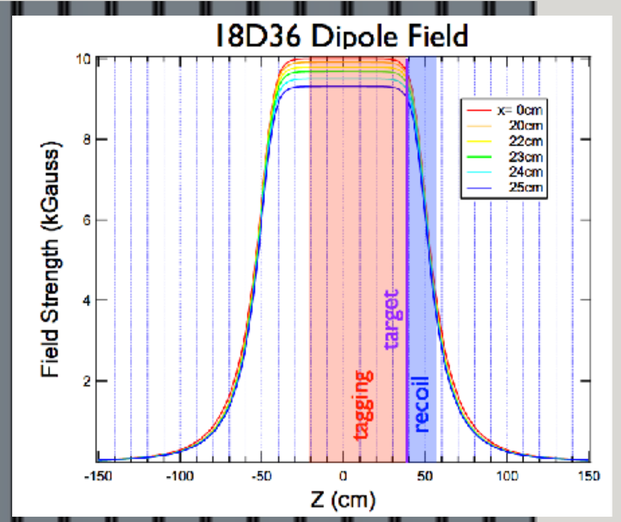



incoming
outgoing
relative rate
trivial
e^-
e^-
+hard γ
$\gamma \to$ hadrons
$\gamma \to \mu^+\mu^-$
$\gamma p \to \pi^+ n$
$\gamma n \to n\bar{n}n$
increasingly rare
photo-nuclear
Møller + CCQE
$\nu\bar{\nu}$
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
e^-
e^-
γ
Z
reducible,
goal: eliminate
without p_T cuts
ν backgrounds (irreducible) << 10^{-16}

Detector concept



Detector concept



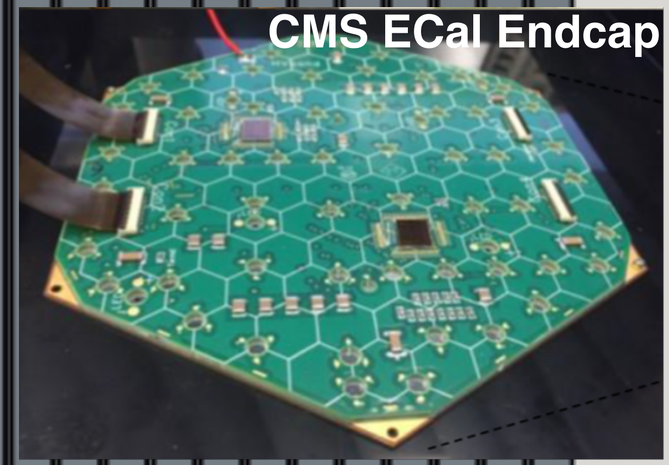
EM Calorimeter

Hadron Calorimeter

tagger tracker

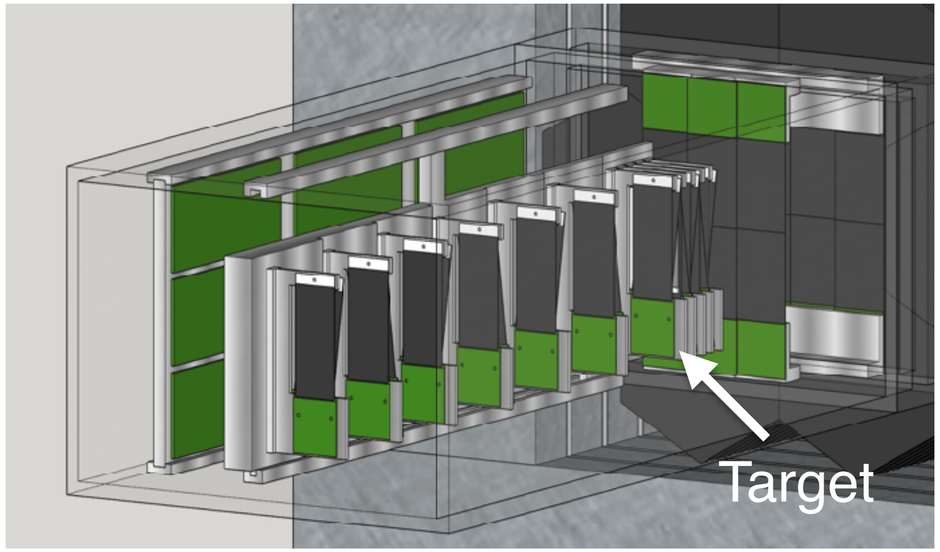
recoil tracker

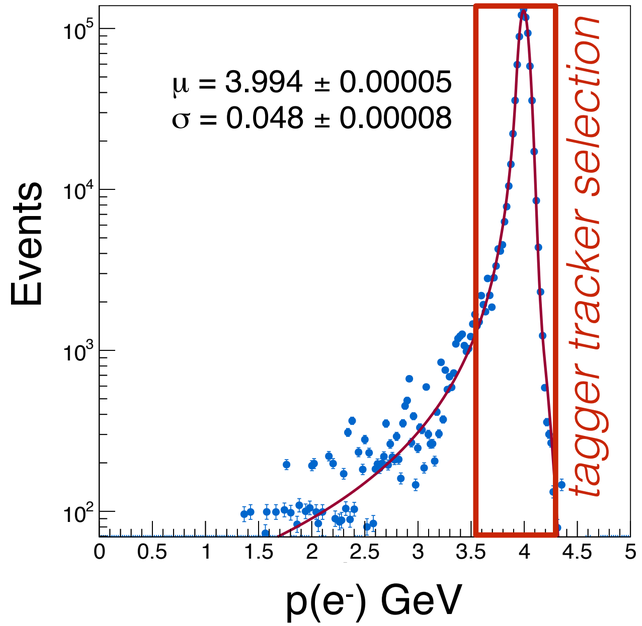
target

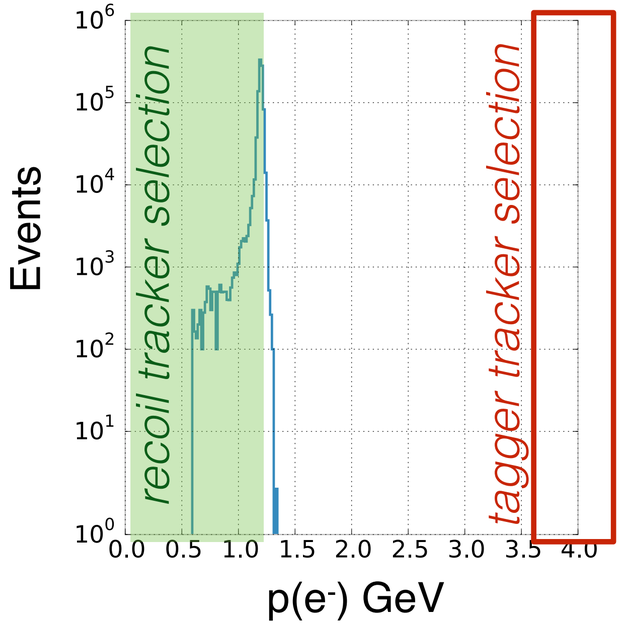


Tracking

- **Silicon strip spectrometers:**
  - single 1.5T dipole magnet with 2 field regions
  - tagger tracker: located in magnet bore
    - measure incoming momentum
    - efficiently identify off-energy beam components
  - recoil tracker: located in fringe field
    - measure outgoing momentum
    - good recoil momentum resolution (1-2 GeV)

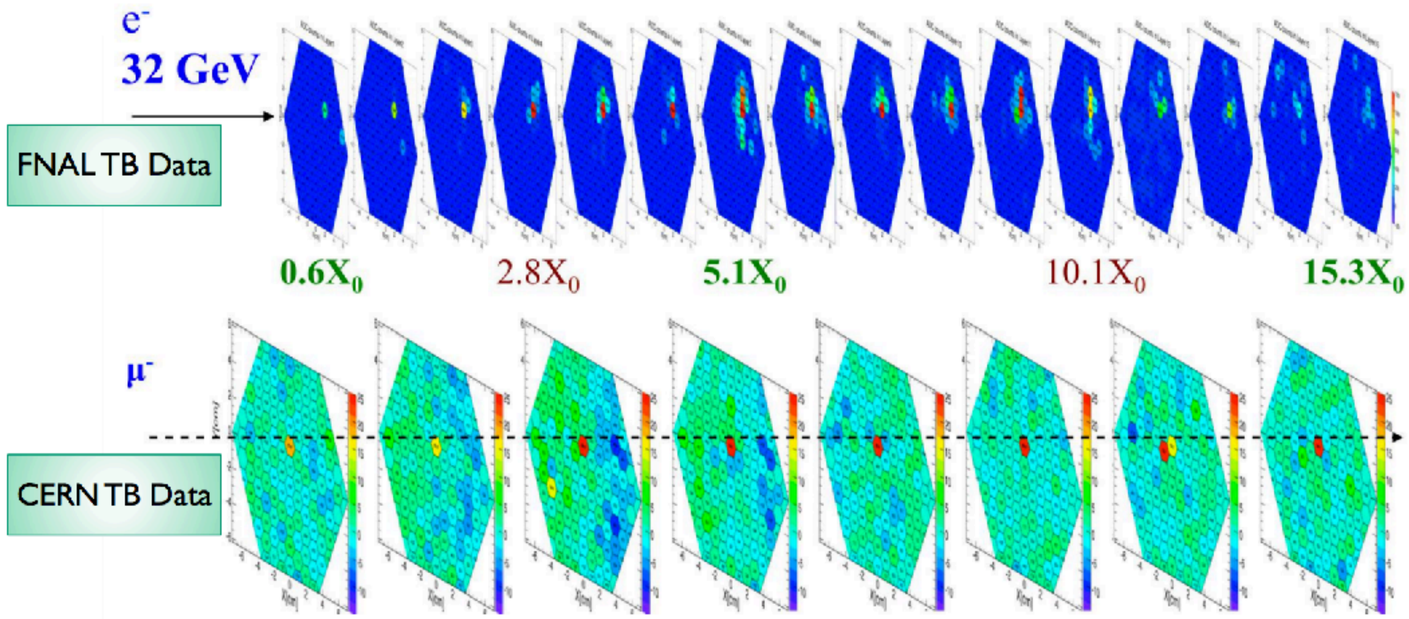


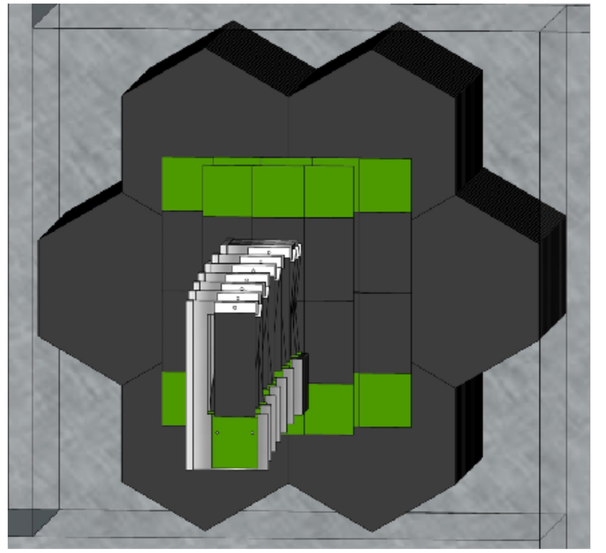




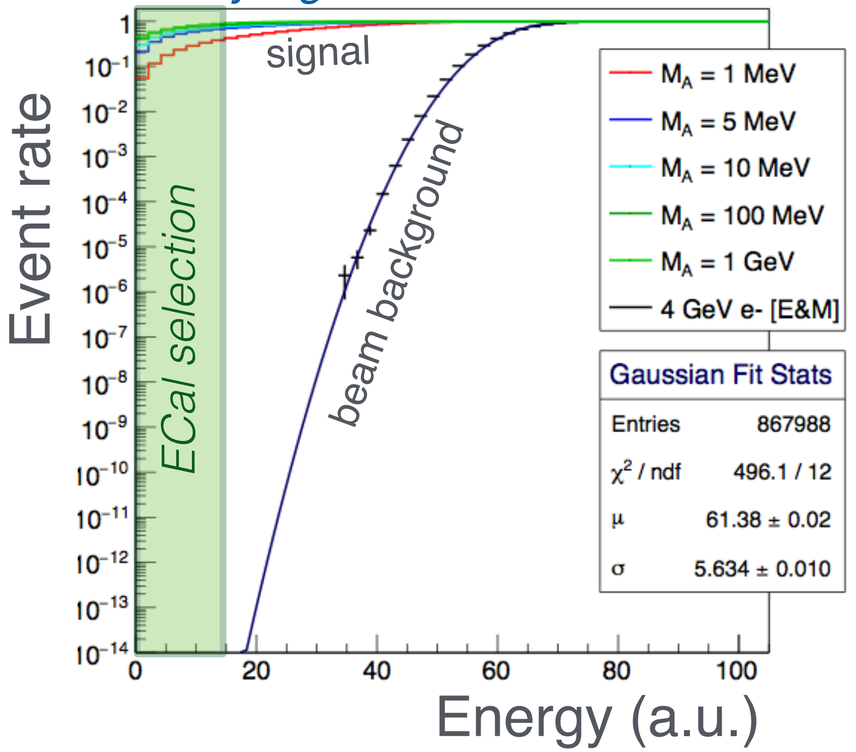
EM Calorimeter

- 40 X_0 tungsten-silicon imaging calorimeter
  - fast readout and radiation tolerant
  - great energy resolution
  - MIP sensitivity (S/N=10-15)
  - high granularity: can exploit both transverse & longitudinal shower shapes to reject PN events



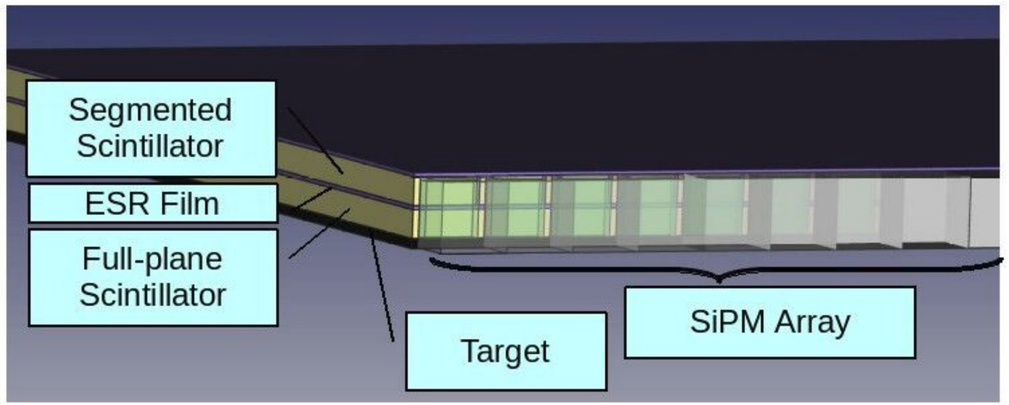


energy deposited in ECal by signal & 4 GeV electrons

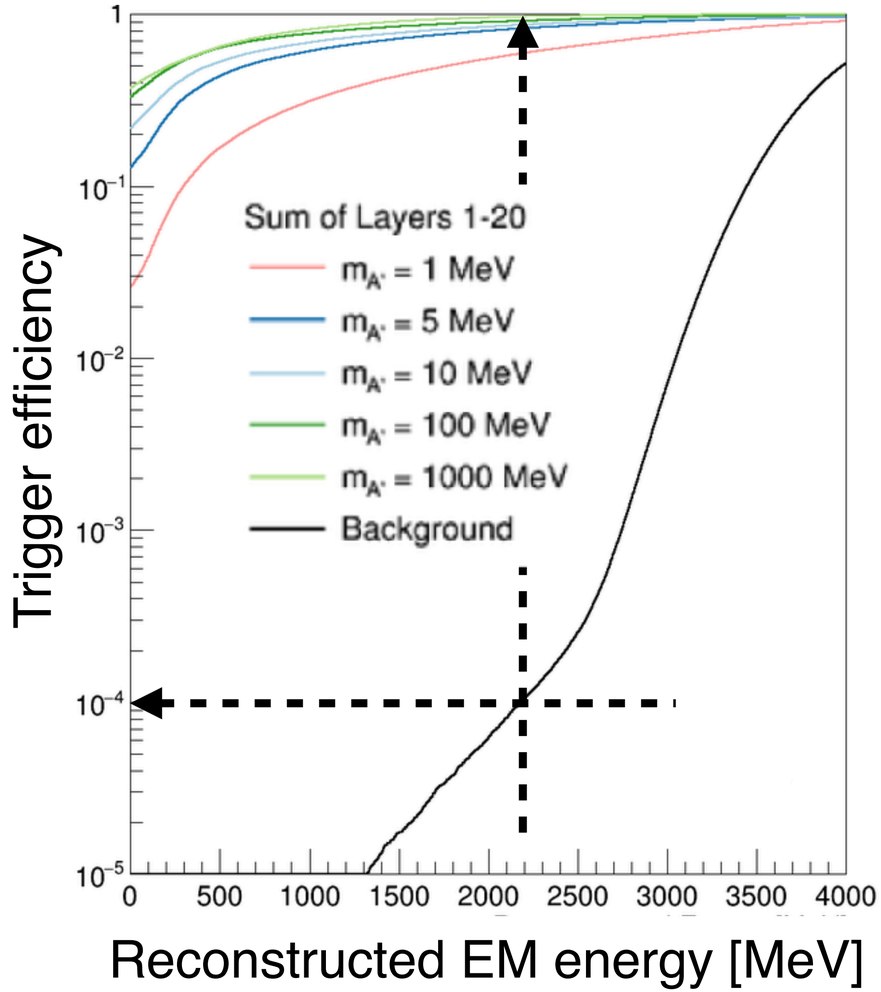


Trigger

- Trigger: based on sum of 20 layers of Ecal energy and trigger scintillator pad (just downstream of target)
  - veto events without electron
  - selection depends on electron multiplicity



- Signal efficiency 50-100% with 10^{-4} background rejection

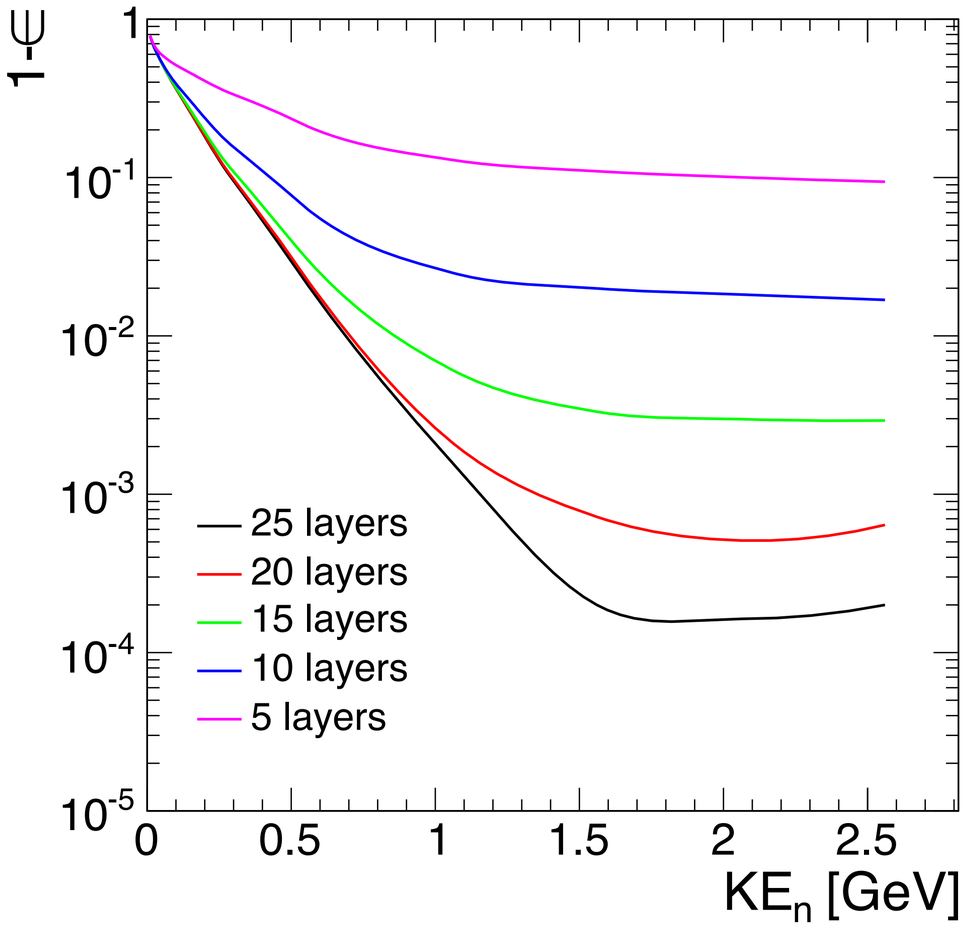


Hadron calorimeter

- Steel/plastic sampling calorimeter (up to 10λ)
  - read out with wavelength shifting fibers & SiPMs
  - enclose Ecal as much as possible to detect:
    - wide-angle brem
    - hadrons from PN events

Design studies still on going

neutron detection in-efficiency (25 layer= 9λ)

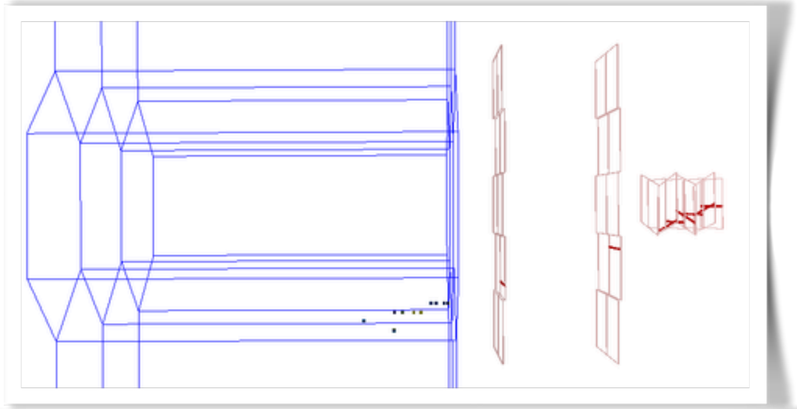


Background processes

Signal:

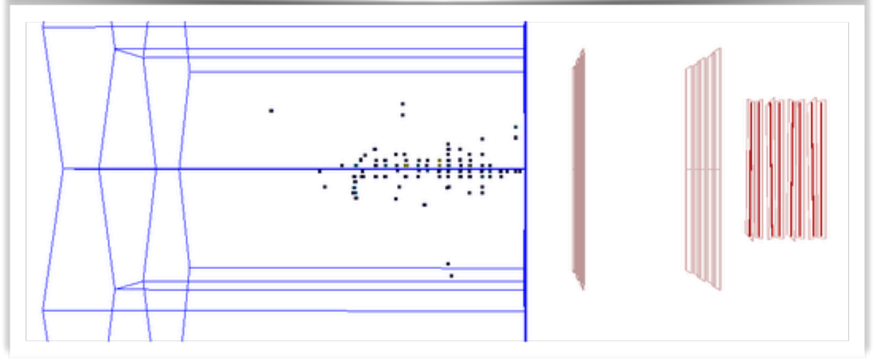
($m_{A'}$ = 1 GeV)

E_{EM} = 1056 MeV



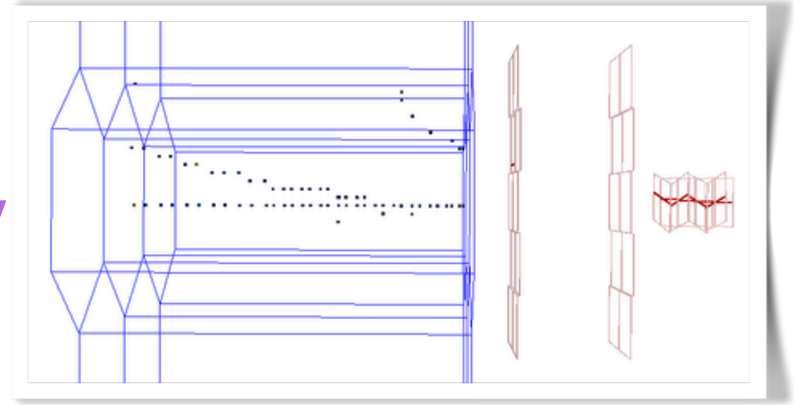
Hard Brem:

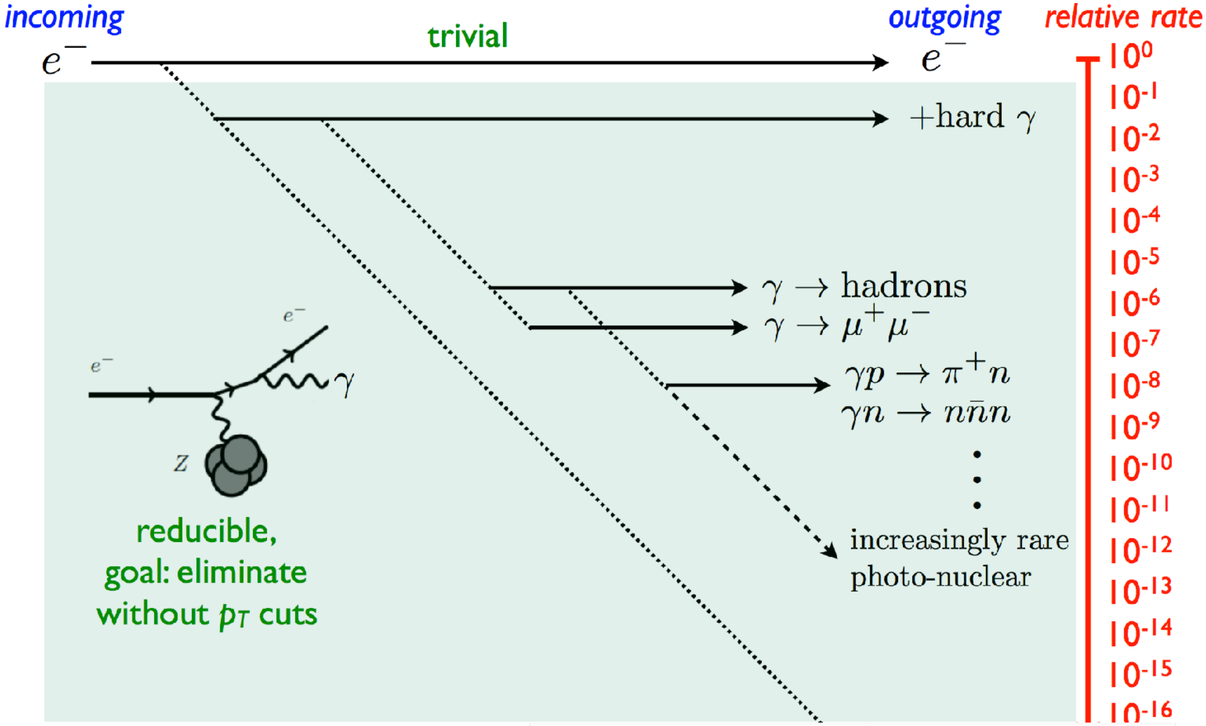
E_{EM}= ~4 GeV



γ(μμ):

E_{EM}=1760 MeV

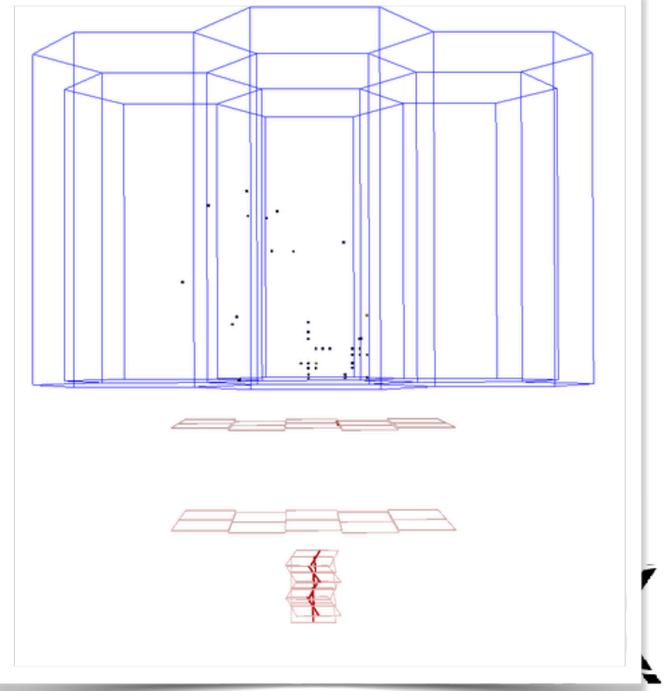




ν backgrounds (irr

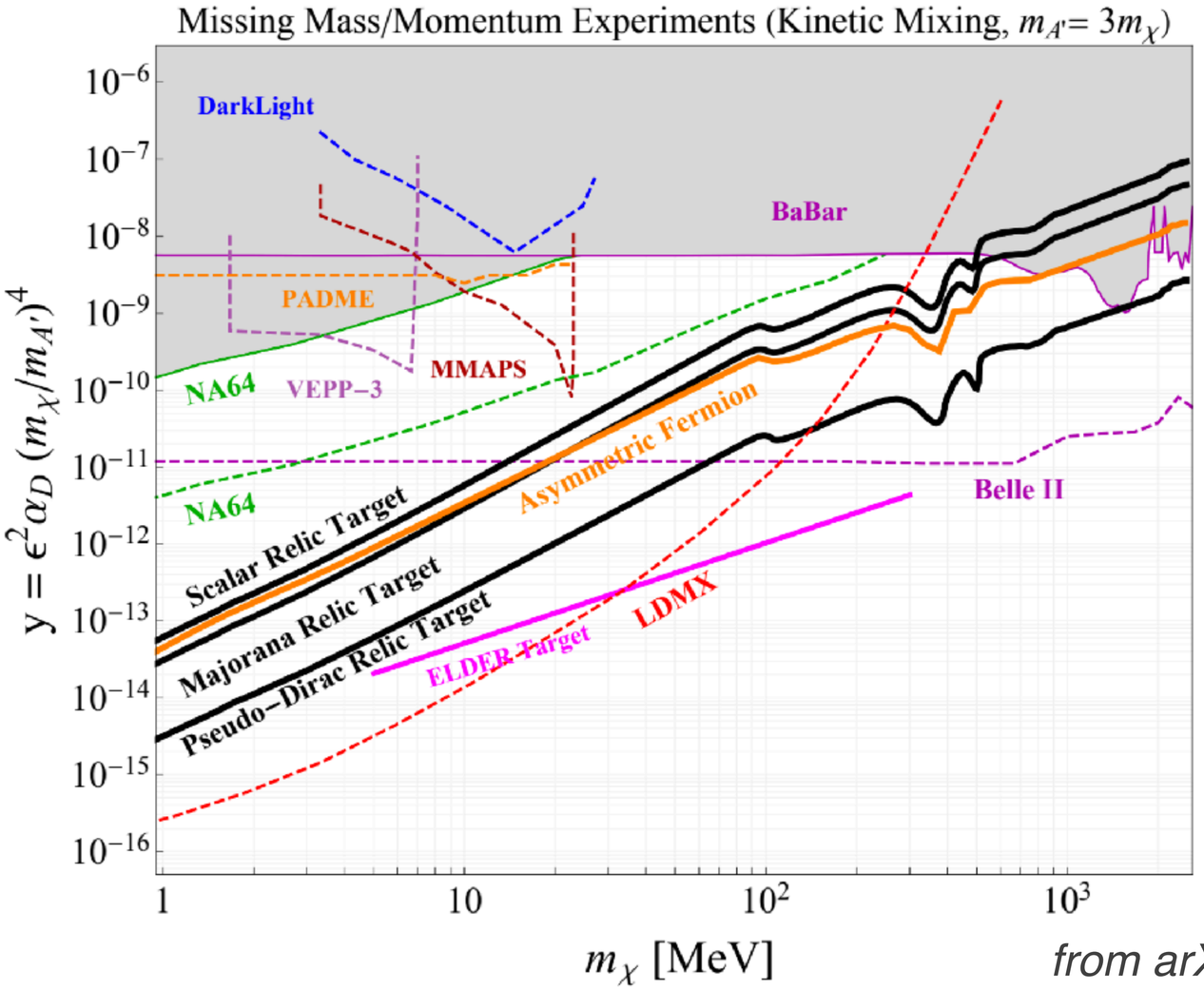
Photonuclear:

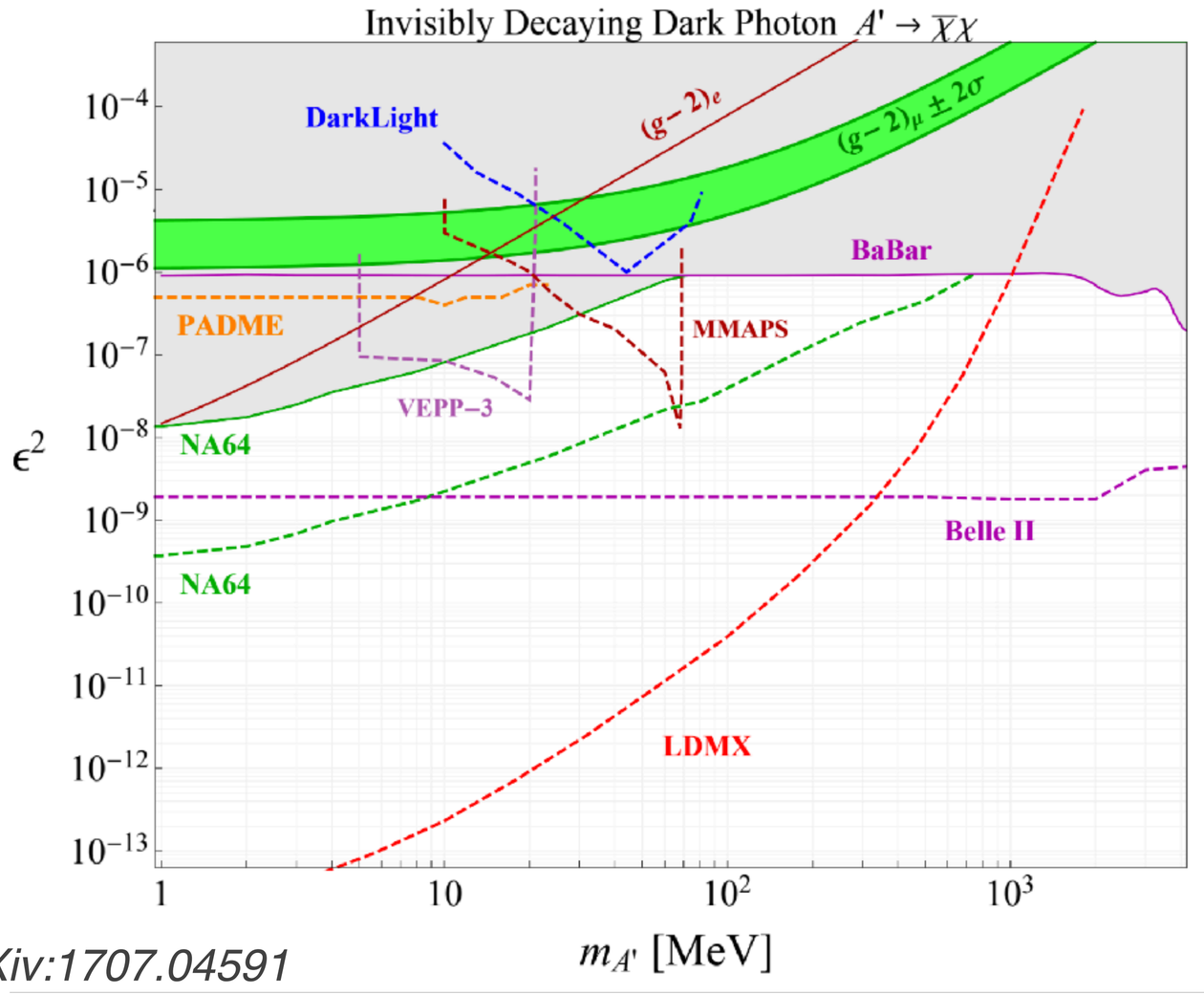
E_{EM}=569 MeV



Projected sensitivity

LDMX: 10^{16} EoT @ 8 GeV





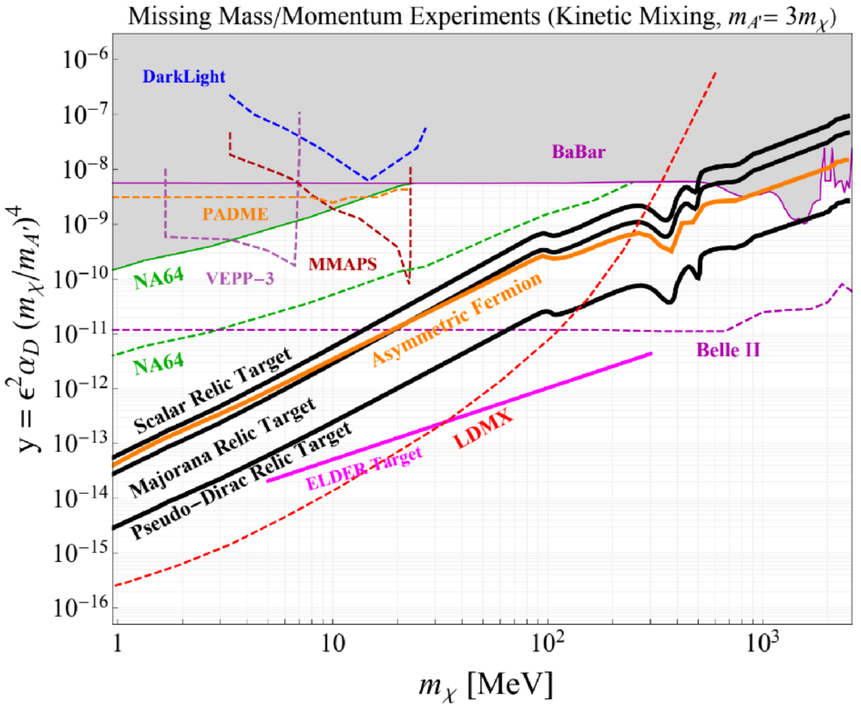
from arXiv:1707.04591

Note: $m_{A'} = 3m_\chi$ is conservative assumptions

Summary

- Accelerator-based DM searches will play a pivotal role testing the sub-GeV range
  - missing energy/momentum is a uniquely powerful and widely applicable search signature

- LDMX is an electron beam experiment that aims to fully exploit missing energy/momentum
  - Unrivaled breadth of sensitivity to asymmetric, thermal scalar elastic, Majorana, and inelastic/Pseudo-Dirac scenarios
  - Sensitivity beyond dark matter to include other light degrees of freedom that couple to electrons
- Other searches & measurements LDMX can target
  - Sub-GeV invisibly decaying mediators, including neutrino final states
  - Displaced vertex signatures from visibly decaying mediators
  - Displaced electron-positron showers from 'DM co-annihilation' models
  - Photonuclear & electronuclear measurements for neutrino physics
    - reduce nuclear initial/final state interaction uncertainties
    - measure nuclear form factors



Backup

The fate of photons

- Photons can either convert to muons or undergo photon-nuclear interactions
  - can exploit information from trigger pad, recoil tracker, ECal, & HCal

- Photonuclear reactions:
  - initial studies show promising results, rejecting all but a few events per 10^{13} EoT
  - remaining events have large momentum transfer
    - evidence that these are over predicted by Geant4

- Photon conversions (muons/pions):
  - many handles, similar to PN events
  - can reject all but a few events per 10^{14} EoT
    - studying applicability of form factor used in Geant4