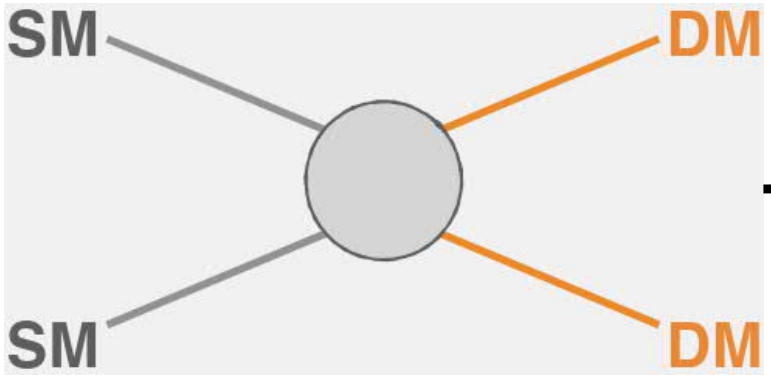
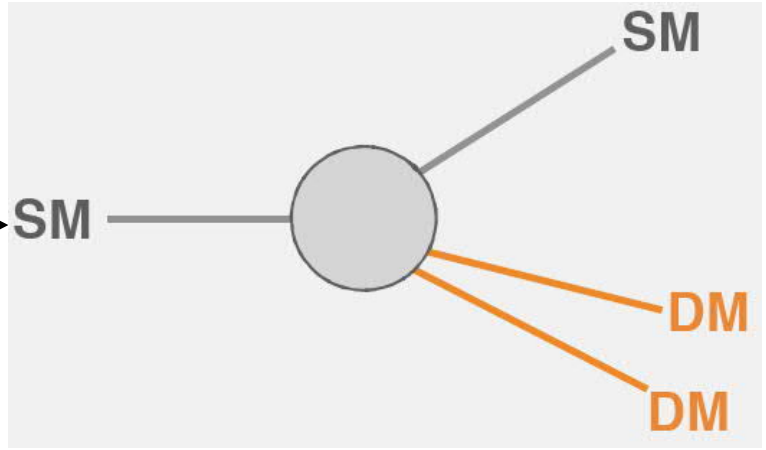
Light dark matter; production in a laboratory



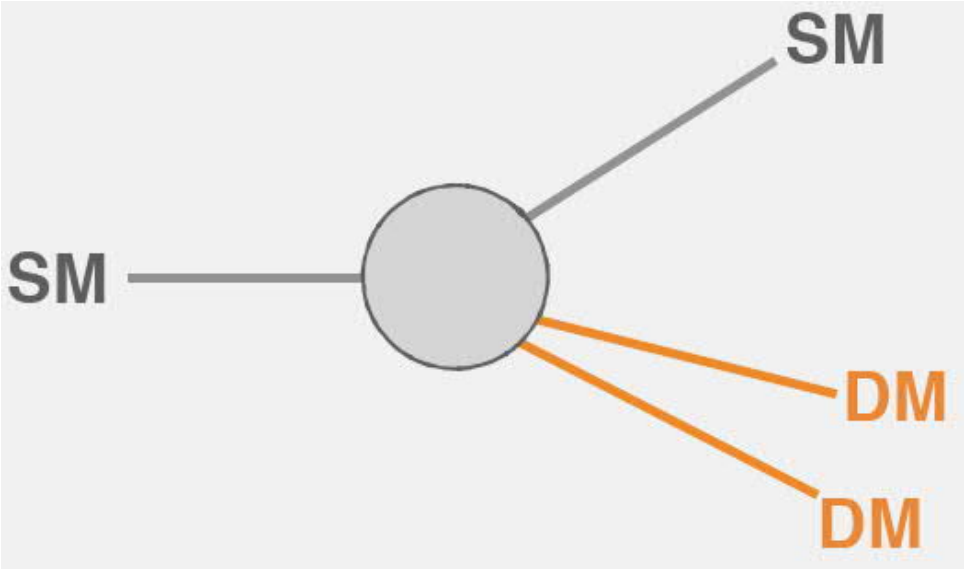
By necessity



Thermal equilibrium between known and dark matter requires an interaction between them

Dark matter will be produced in an accelerator-based experiment, with a rate determined by the strength of that interaction

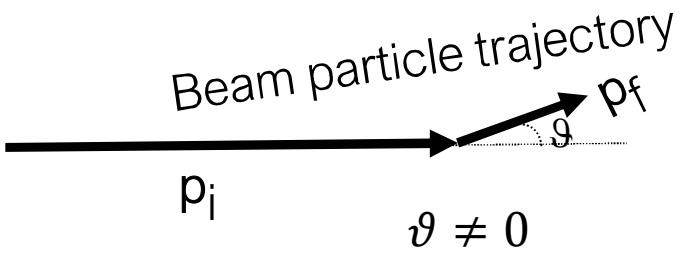
Light dark matter; kinematics in production in a laboratory



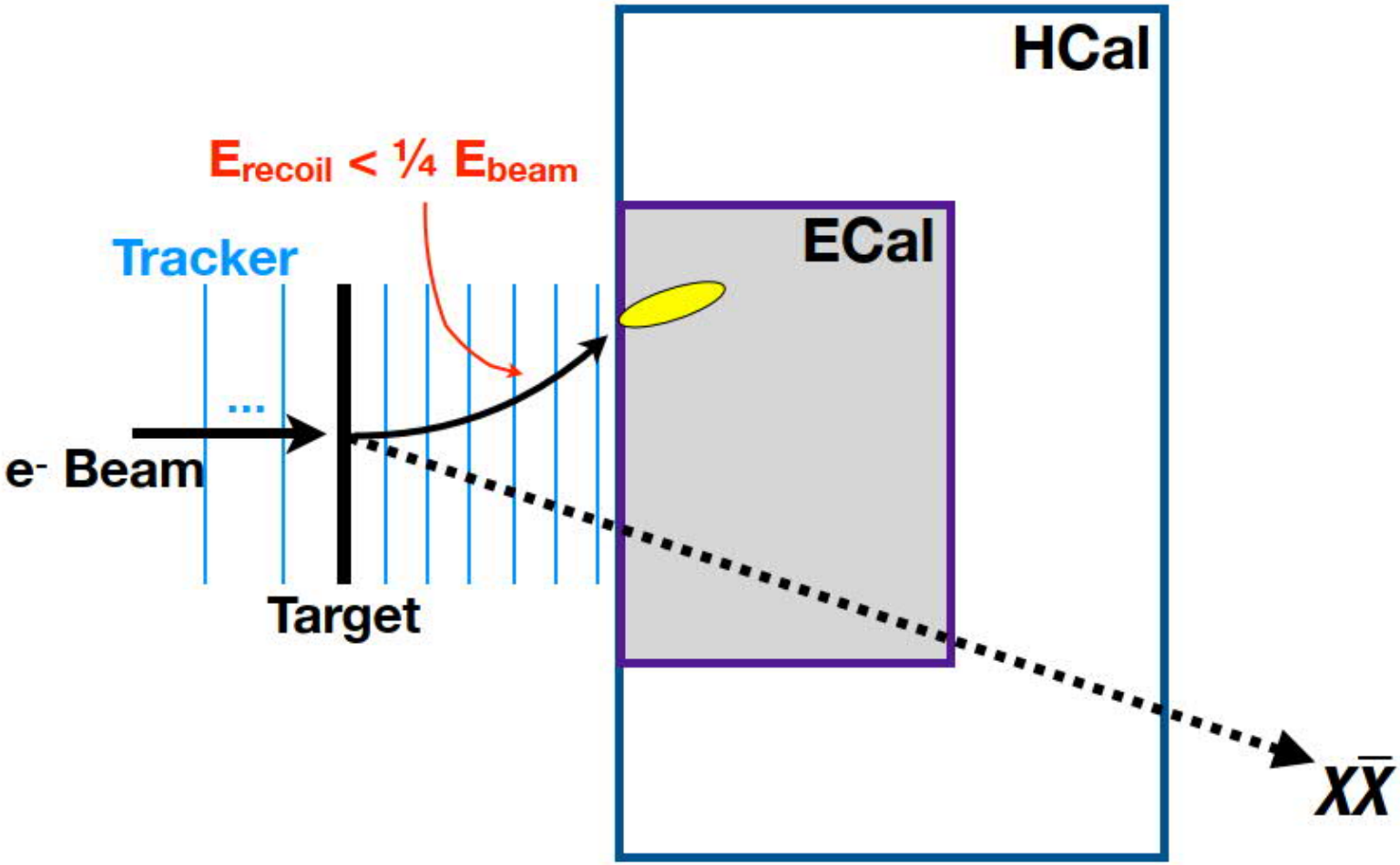
If mass is produced

(1) the beam particle gets a p_T and exits with a deflection angle,
(2) the beam particle loose energy

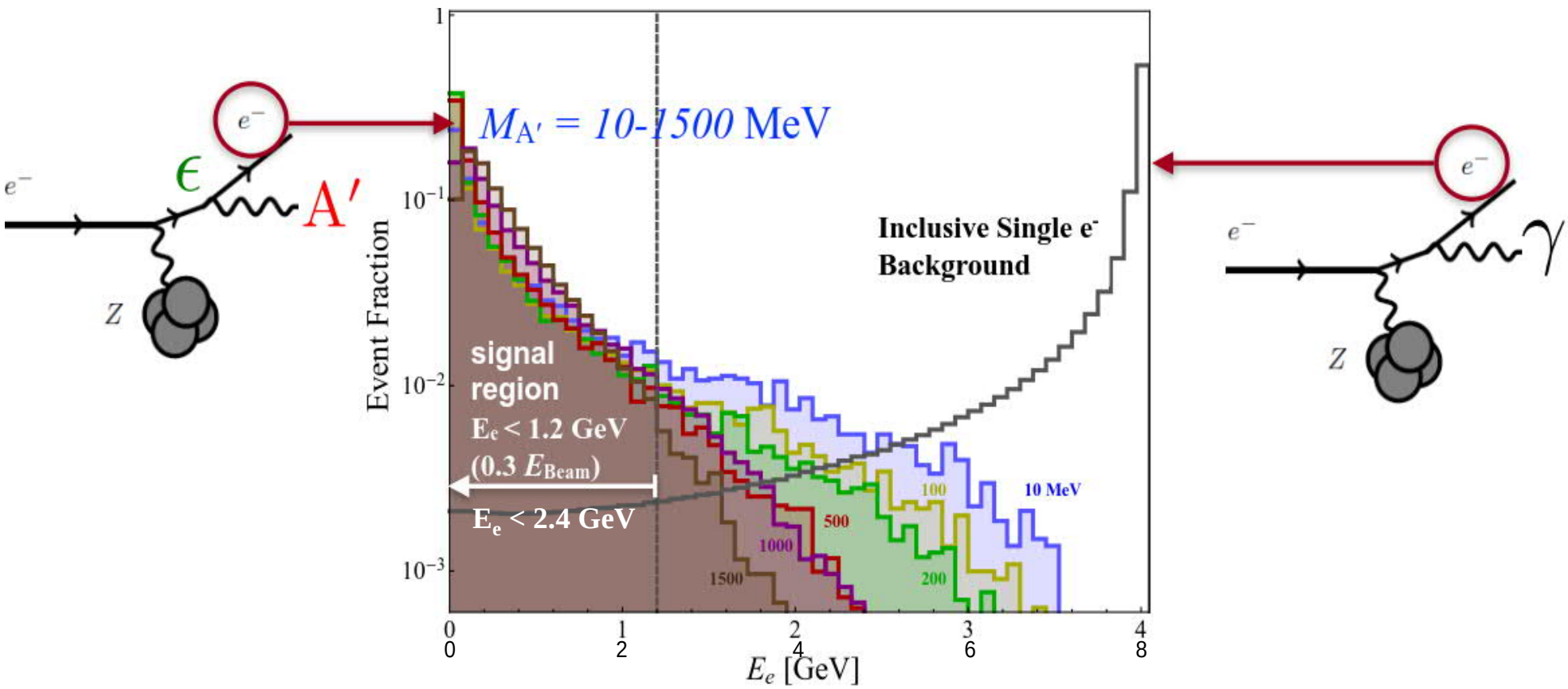
The lower mass the beam particle has, the bigger the effect → electron beam



Signal event in the detector

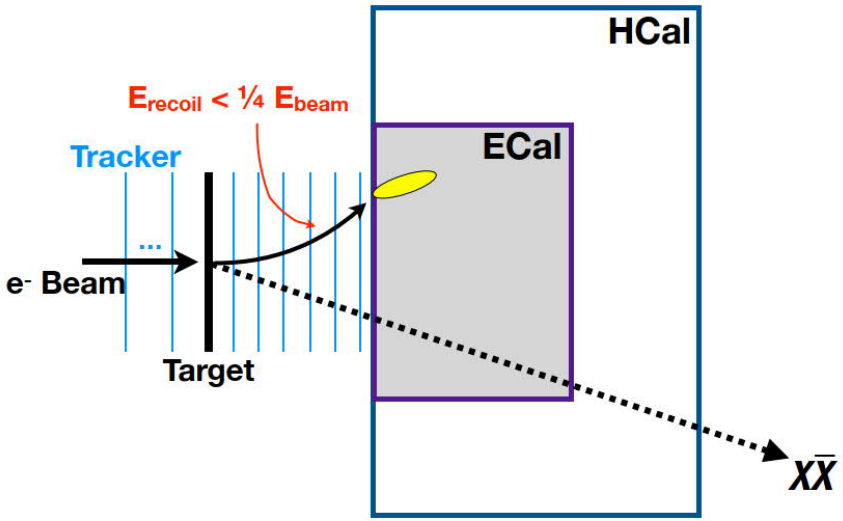


Kinematics: electron energy

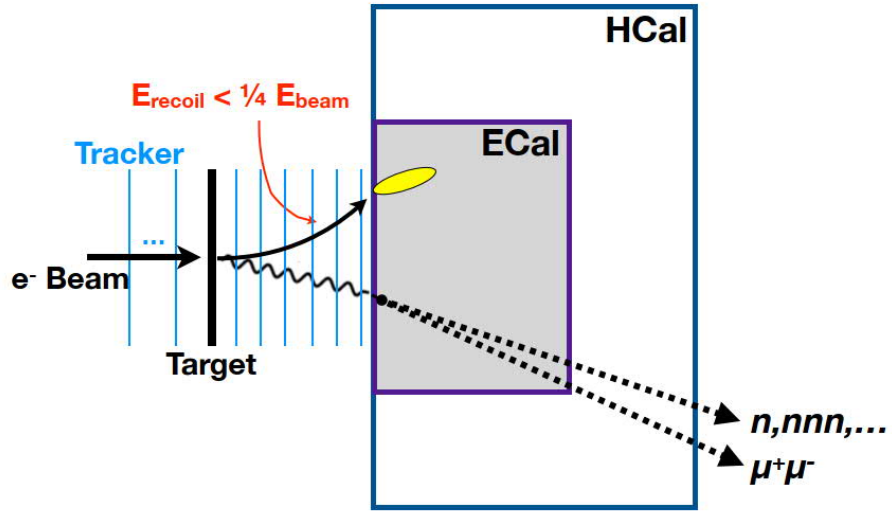


A' created close to threshold in the em-field around the target nucleus, since the A's, heavier that the electrons, take most of the incoming electron energy —> soft recoil electron, large missing energy

Basic task for the experiment

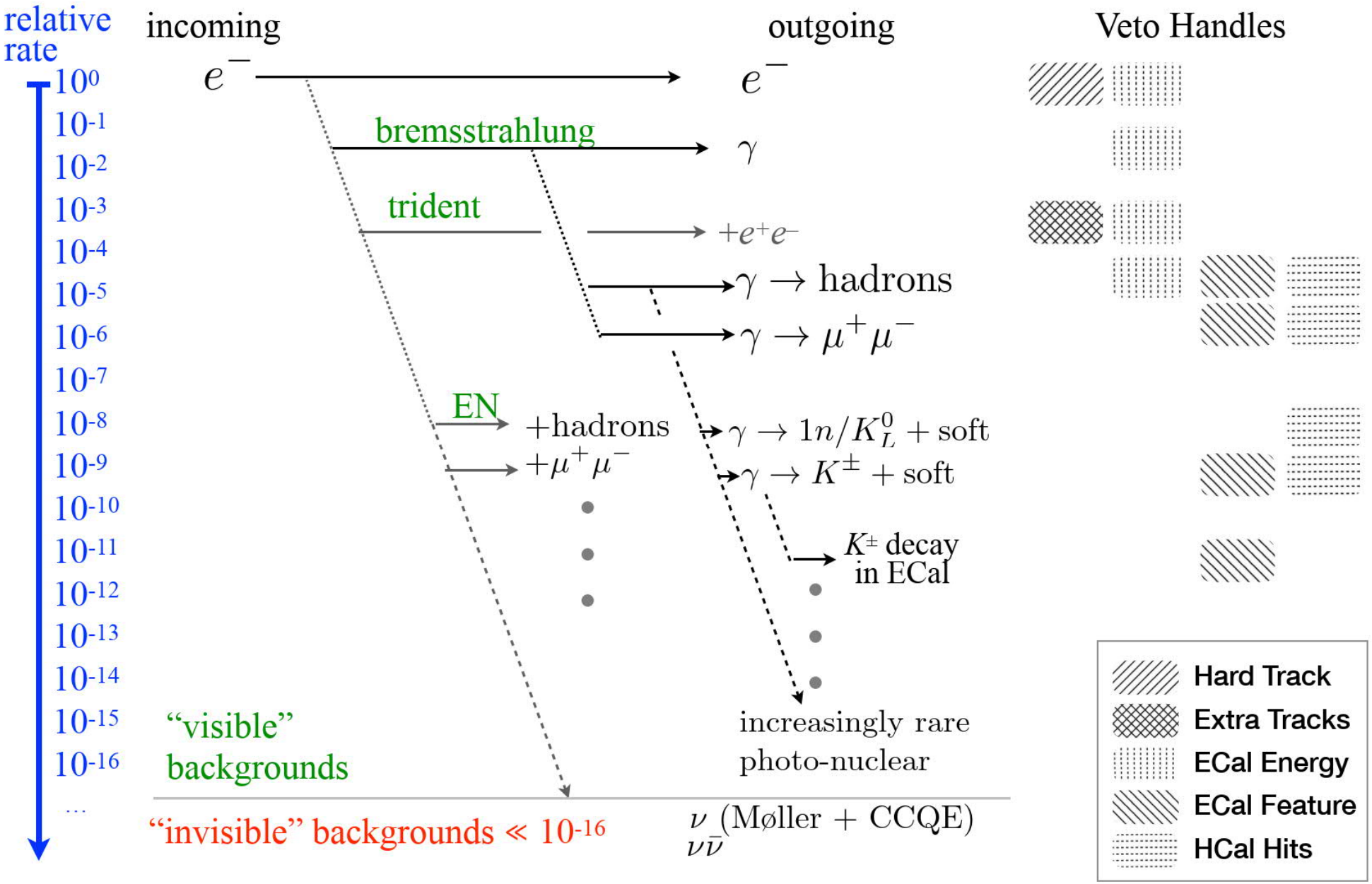


Select these

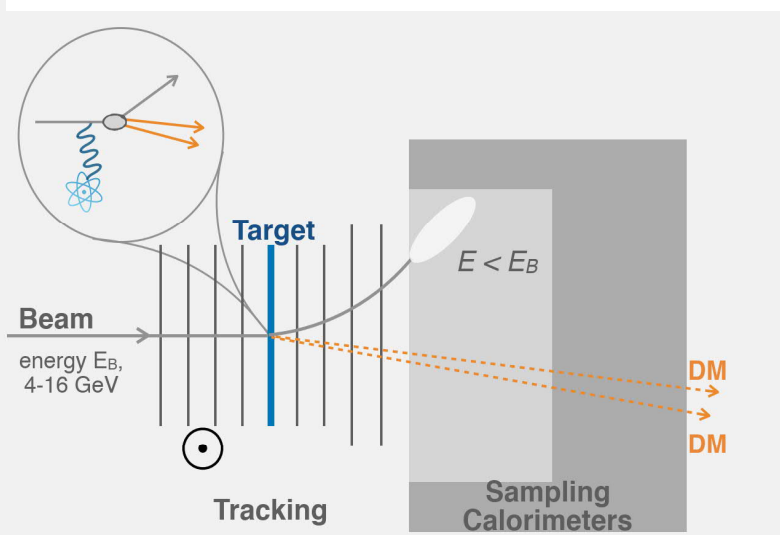


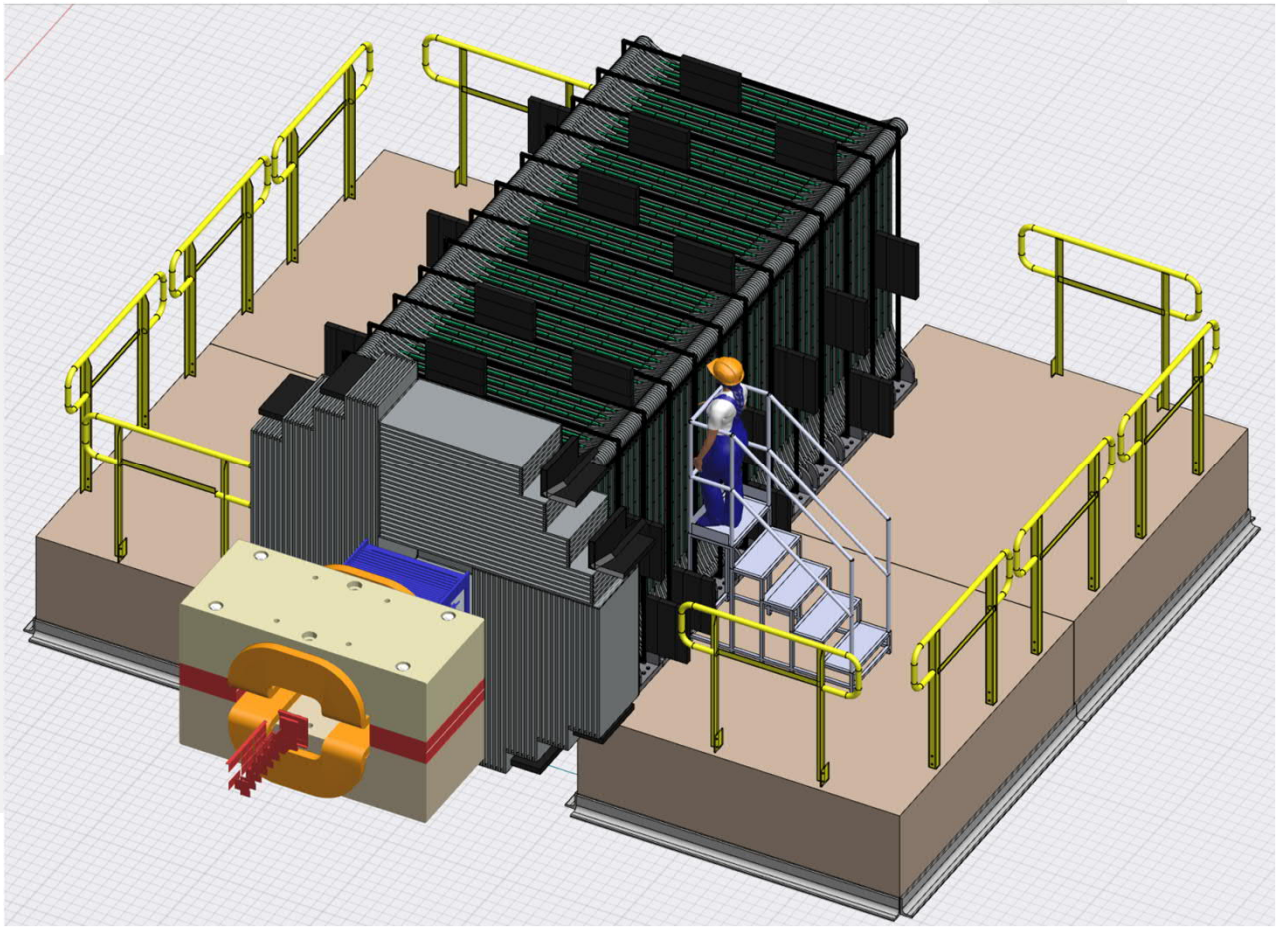
Reject these

Background Challenges

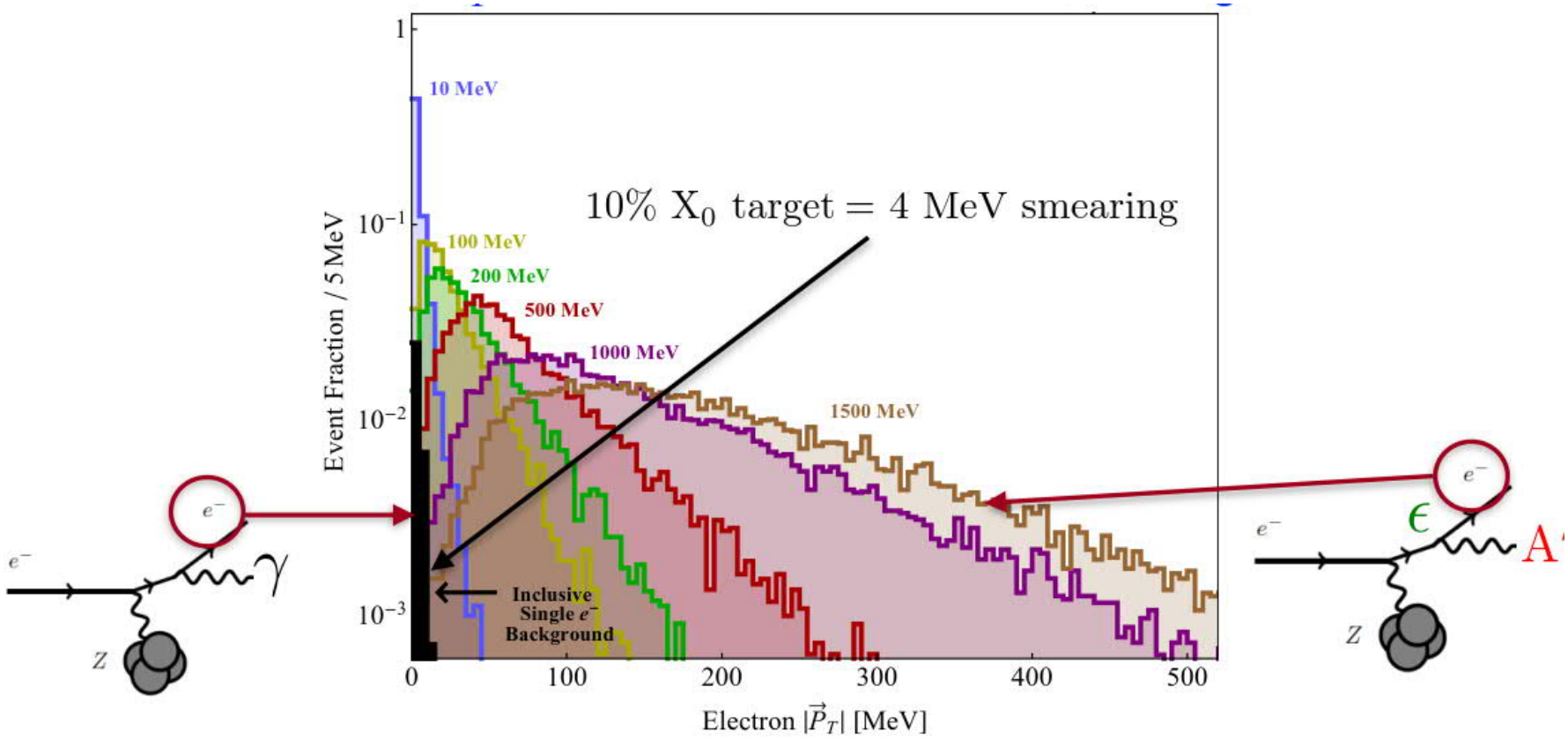


The Light Dark Matter eXperiment – LDMX



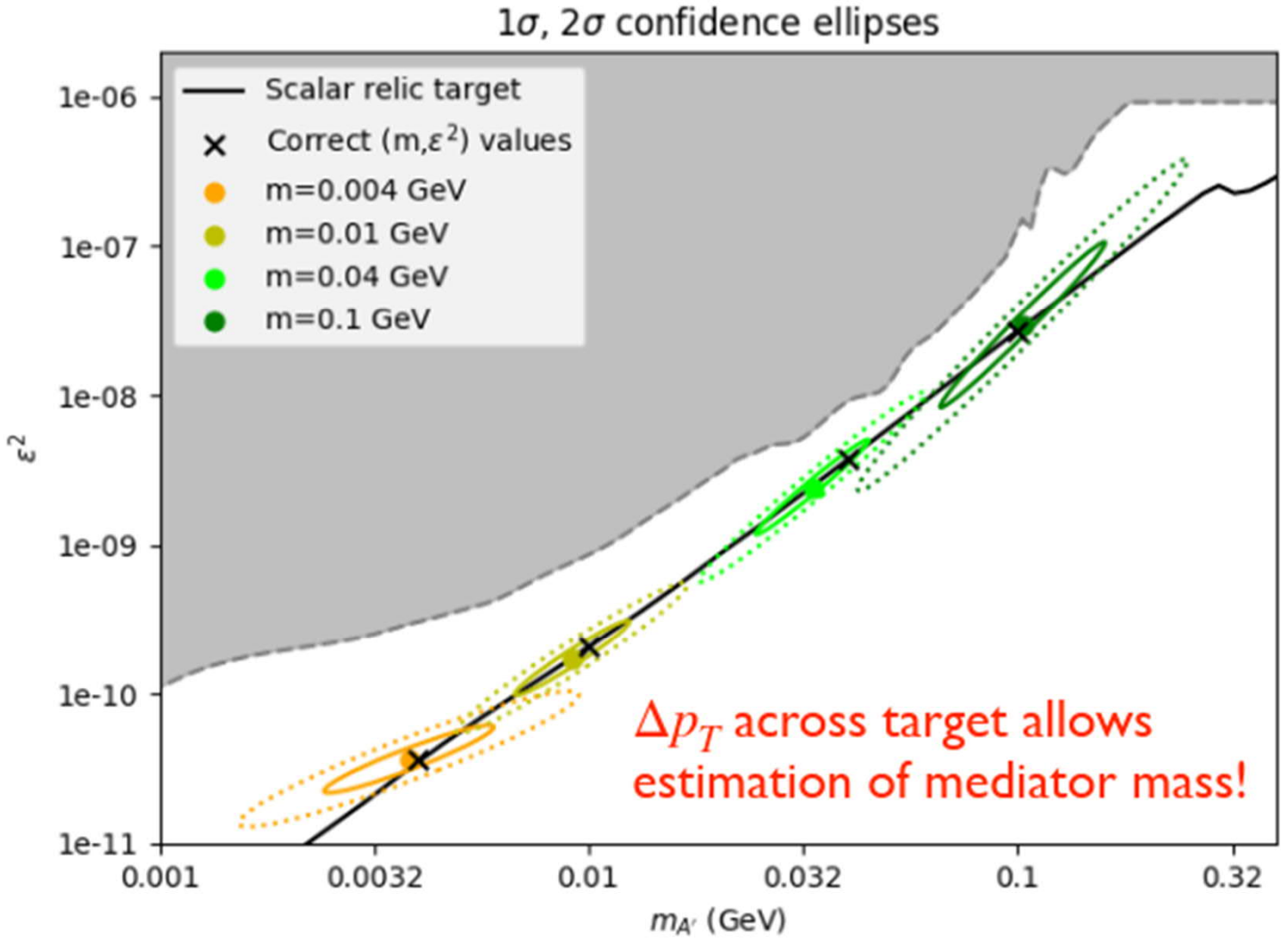


Kinematics: electron p_T



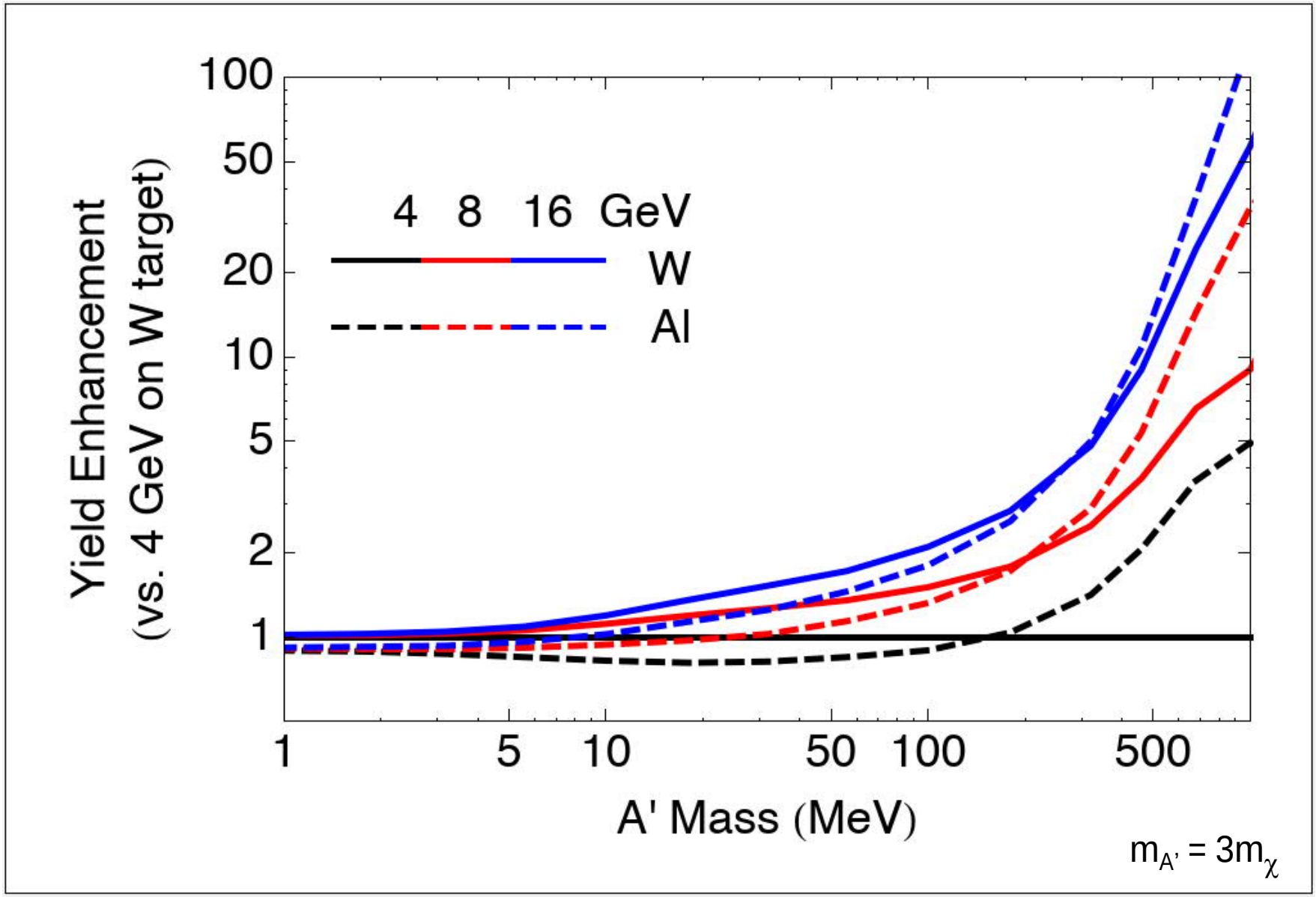
p_T of the recoil electron very different from bremsstrahlung.

Estimate of the mass created

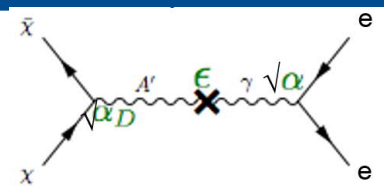


In the case of a signal, the mass can be estimated from the electron p_T and E

Form factors influence the signal rate at higher masses



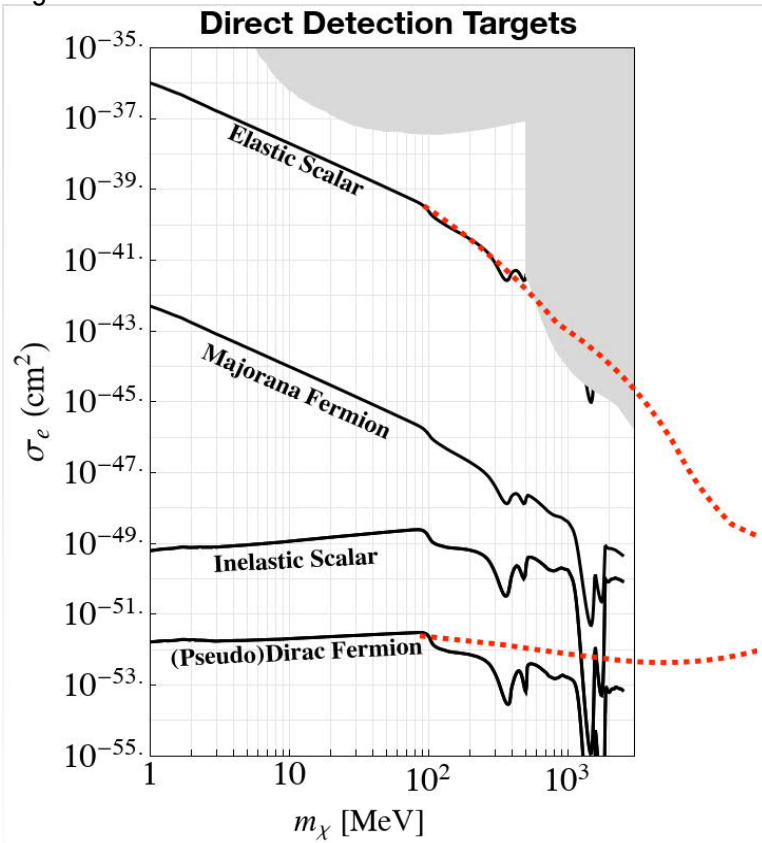
Direct Detection and Accelerator Based Production

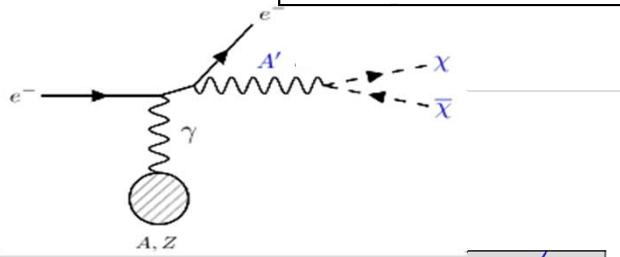


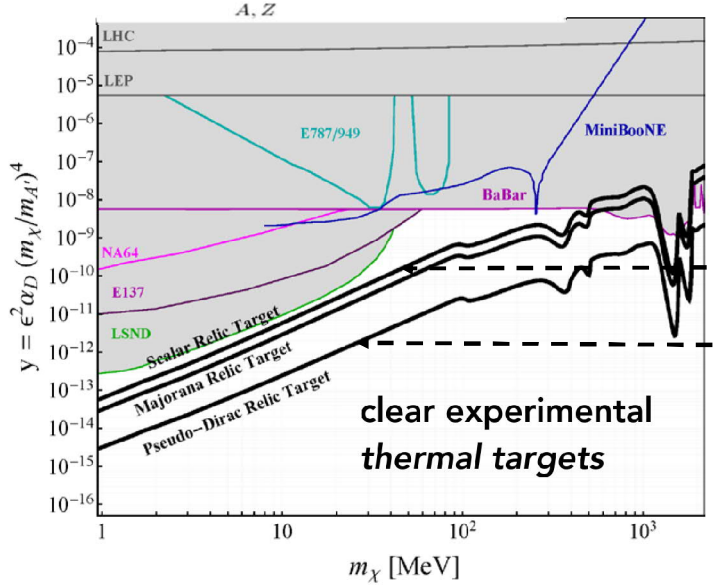
$$\sigma v \sim \varepsilon^2 \alpha_D \frac{m_\chi^2}{m_{A'}^4} = \frac{y}{m_\chi^2};\ y = \varepsilon^2 \alpha_D \left(\frac{m_\chi}{m_{A'}}\right)^4$$

$$\sigma \sim \left(\frac{m_{A'}}{m_\chi}\right)^2 \frac{yZ^2}{\alpha_D m_\chi^2} \Rightarrow \boxed{y \sim \left(\frac{m_\chi}{m_{A'}}\right)^2 \frac{m_\chi^2 \alpha_D}{Z^2} \sigma}$$

But, cross sections can be loop- or velocity- suppressed in the non-relativistic regime of direct detection:







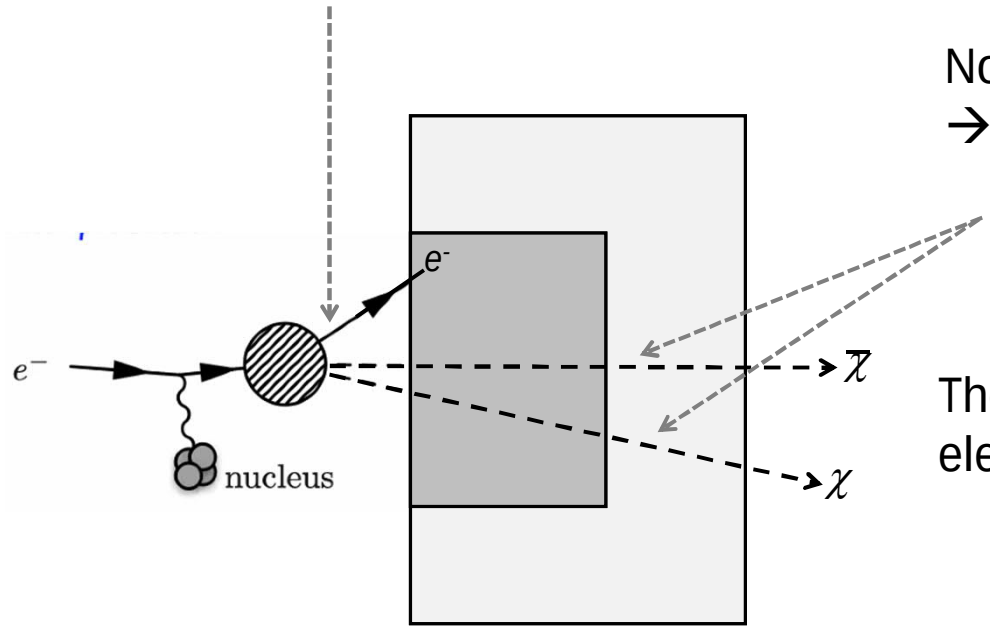
Need 10^{14} e⁻

Need 10^{16} e⁻

$\alpha_D = 0.5$ and $m_{A'} = 3m_\chi$

Signal: Direct Detection of created mass carrying no QCD or QED charges, with a production rate consistent with the Dark Matter abundance

An electron that has lost most of its energy and acquired a transverse momentum → Direct Detection of mass creation



No detector signals in the calorimeters →
→ Direct detection that the escaped mass does not carry QCD or QED charges.

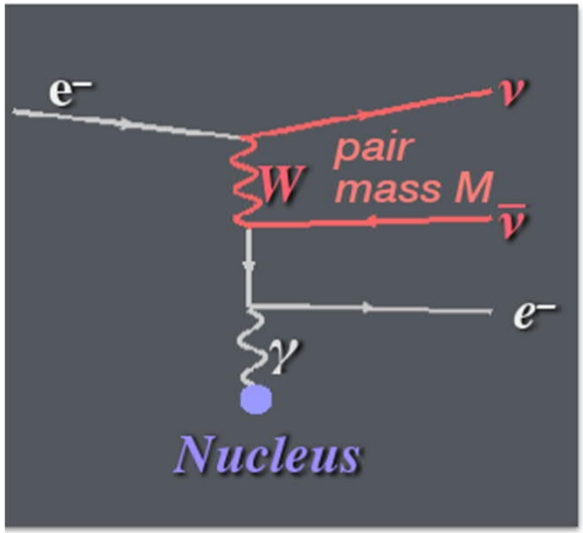
The created mass is estimated from the electron lost energy and its acquired p_T

If this signal is not interpreted as DM, then we need an explanation for what happened to this matter in the early Universe and to find another process responsible for DM.

Therefore, if this production rate is in the ballpark predicted from DM abundance, then the simplest interpretation is that we observed the process responsible for Dark Matter.

Neutrino background

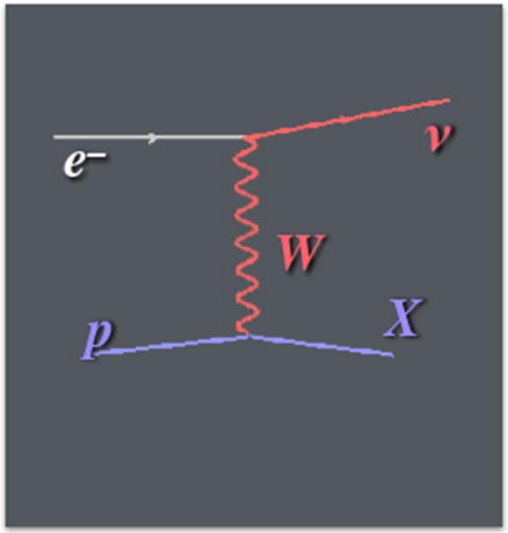
Neutrino Tridents



$N_{\nu\nu}/N_e$
$\sim 10^{-19}$ (E/4GeV)

irreducible

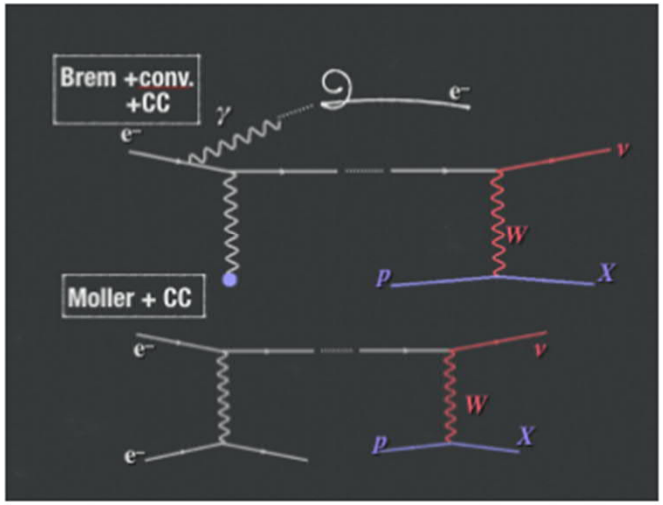
Charged Current



$N_{\nu\nu}/N_e$
$\sim 10^{-14}$ (E/4GeV)

no recoil electron
(bkg missing energy search, not for us)

CCQE+…



$N_{\nu+Brem+conv.}/N_e$
$\sim 10^{-16}$ (E/4GeV)
x $(T_{target}/0.1\ X_0)^3$
a bit reducible
curler track veto, cut out Moller kinematics

Signal modelling

A LDM model must have the properties:

Light forces: Comparably light force carrier to mediate an efficient annihilation rate for thermal freeze-out

Neutrality: Both the DM and the mediator must be singlets under the full SM gauge group

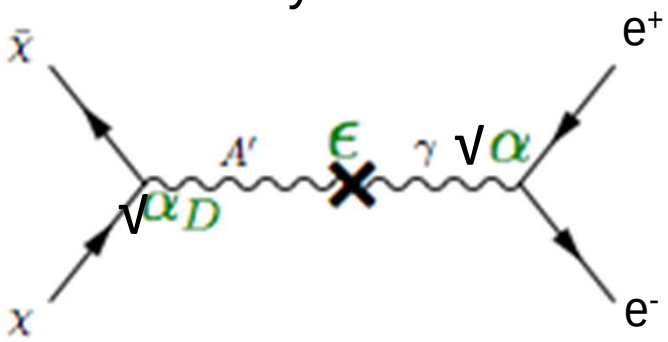
Simplest: A hidden sector QED

- Fine structure constant α_D
- Dark photon A'
- Dark matter particles χ

This hidden sector QED connects to the known physics by the A' mixing with the photon (γ) with a small mixing strength ε

Conservative choice: $\alpha_D = 0.5$ and $m_{A'} = 3m_\chi$

Thermal equilibrium in the early universe



Reaction in the laboratory