

# Inelastic Dipole Dark Matter at FASER

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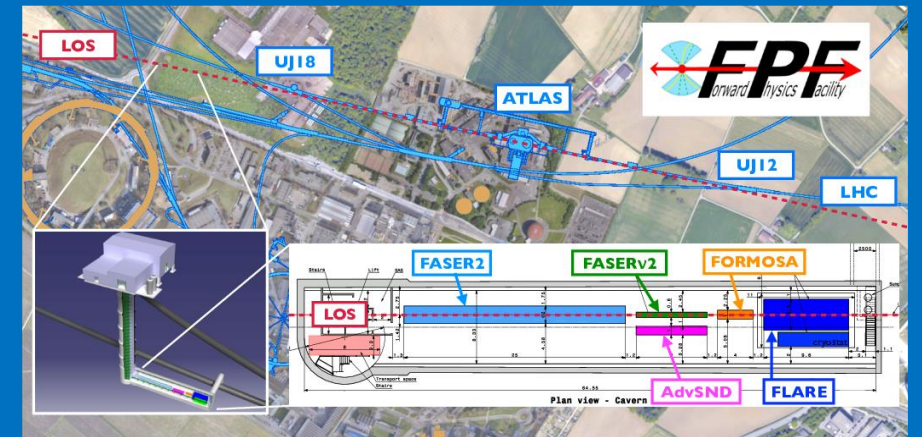


**PHENO**

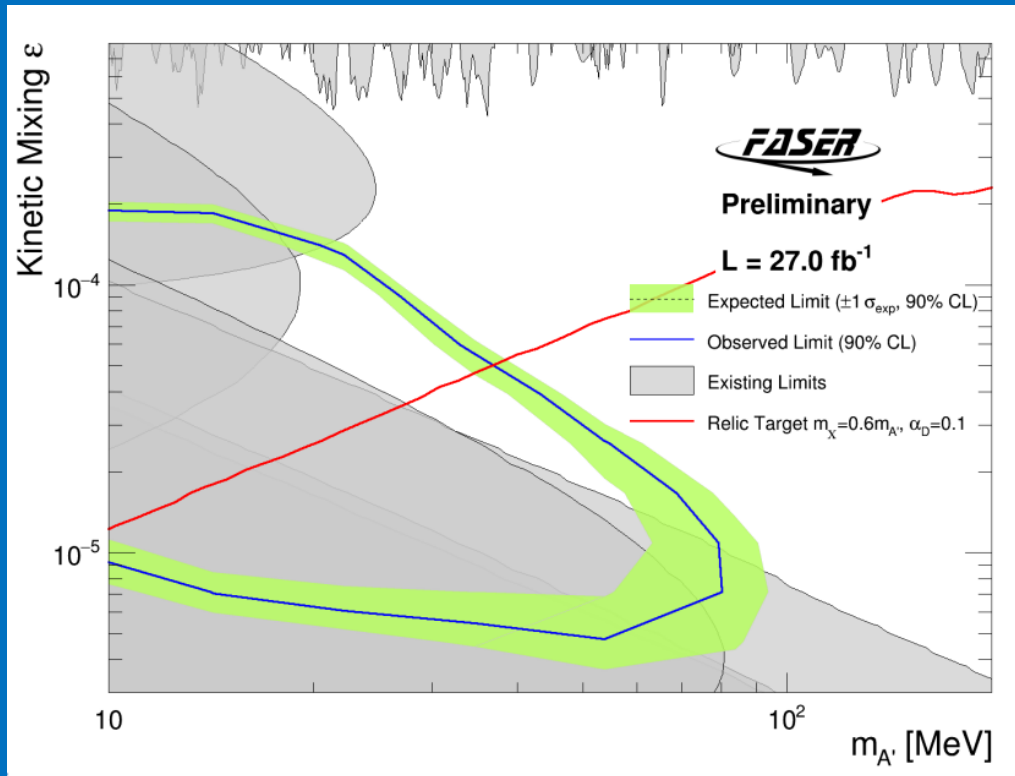


# ForwArd Search ExpeRiment (FASER)

- 500m from ATLAS IP
- large flux of particles produced in the forward direction:  
 $\nu, \pi^0, K, D^0, \rho, J/\psi \dots, A'? \chi? a?$
- Very low backgrounds:  $\mu, \nu$
- Proposed upgrade, FASER2, along with the rest of the Forward Physics Facility



# Recent FASER Results



## Dark Photon Analysis

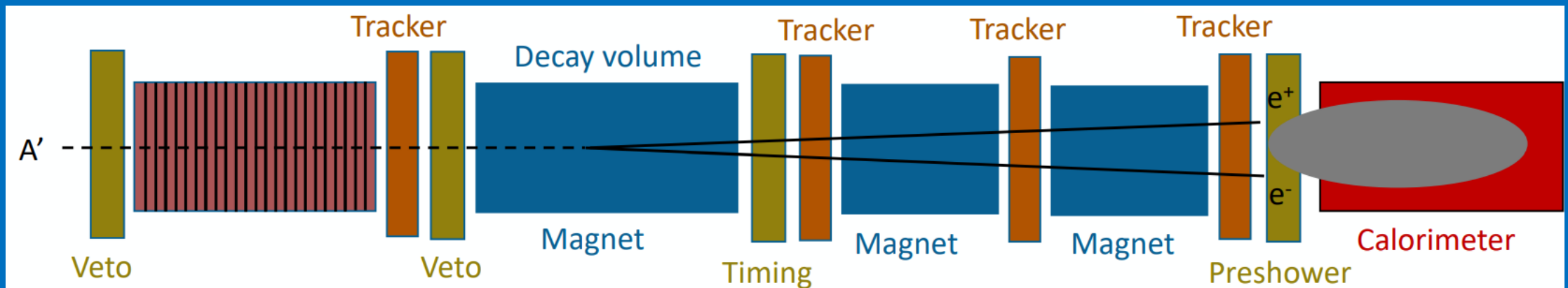
$$\pi^0, \eta, \eta' \rightarrow A' \gamma, A' \rightarrow e^+ e^-$$

$$N_{bgd} \approx 10^{-3}$$

$$N_{sig} = 0 \text{ ☹}$$

No signal events, resulting in exclusion.

What other models / signatures can we look for?



# What models make motivated targets for FASER?

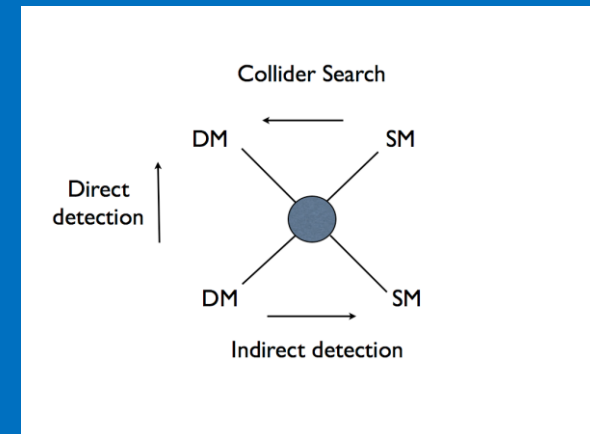
Need an LLP

Novel SM signature

Uniquely suited for FASER (ideally)

$\tau$  ——— Low  $B_{jd}$  ~ Large Boosts

Bonus: can describe DM?



# Magnetic Inelastic Dipole (Dark Matter)

- We look at the minimal model

$$\mathcal{L} \supset \frac{1}{\Lambda_m} \bar{\chi}_1 \sigma^{\mu\nu} \chi_0 F_{\mu\nu} + h.c.$$

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[2203.05090](#)  
[2207.05100](#)  
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Exploit LHC boost

$$E_\gamma \approx 100 \text{ MeV} \frac{E_{\chi_1}}{100 \text{ GeV}} \frac{\Delta}{0.001}$$

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Can also describe dark matter!

- Abundance through freezeout
- Direct detection evaded with sufficient  $\Delta$

# ~~Magnetic~~ Inelastic Dipole (Dark Matter)

Electric

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$\gamma$

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LLP

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Monophoton



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# How to produce it?

- Plenty of mesons produced in the forward direction during Run3 and HL-LHC

$10^{16} \pi^0, 10^{15} \eta, 10^{12} \rho, 10^{11} J/\psi \dots$

Meson mass



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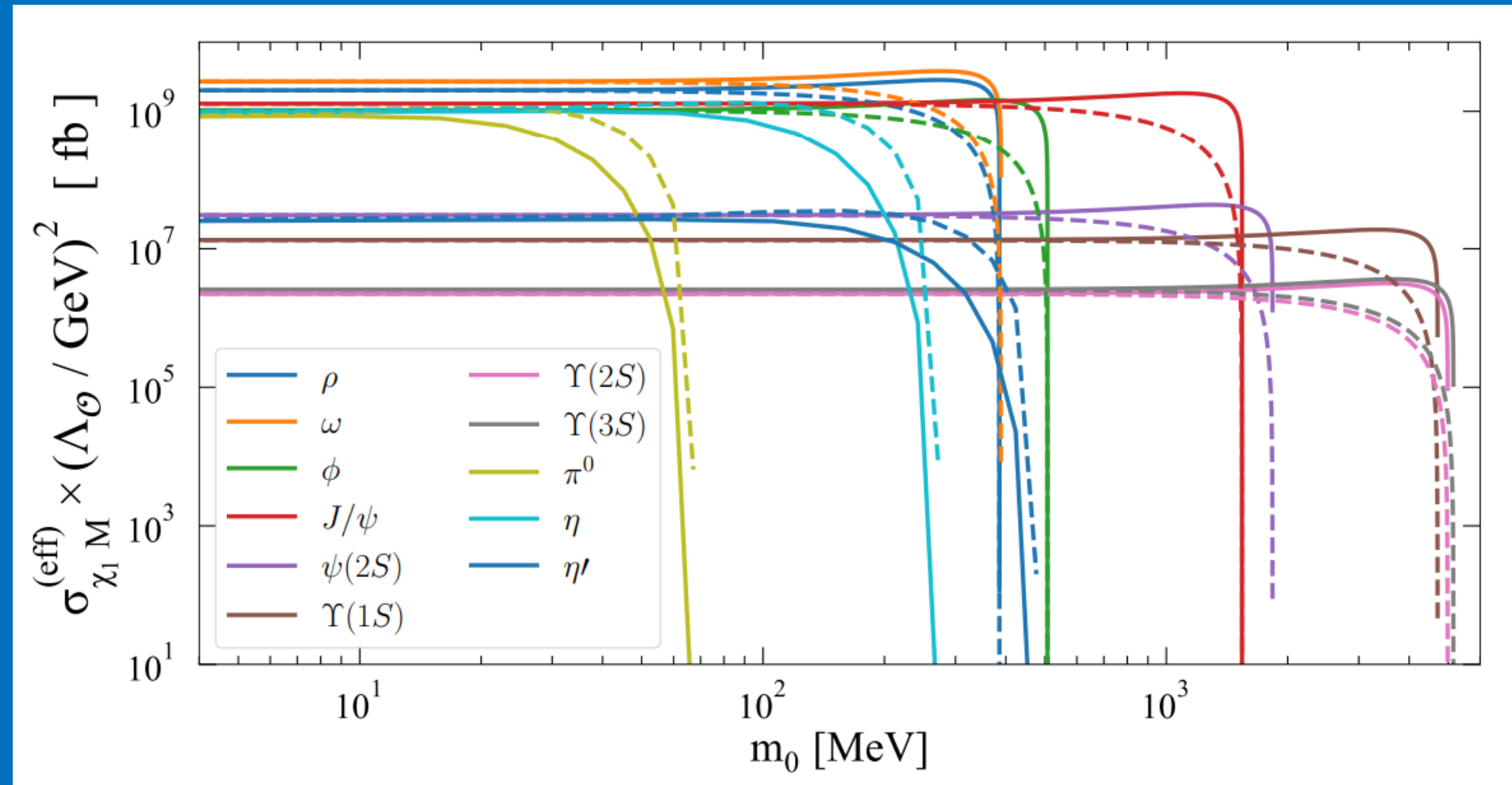
$$\text{BF}(M \rightarrow \chi_1 \chi_0) \sim \frac{m_M^2}{\Lambda^2}$$

Heavier mesons impart larger  $p_T$ , so larger FASER2 will better exploit these

$$R_{FASER} = 10 \text{ cm}, R_{FASER2} = 1 \text{ m}$$

# $\chi$ Production

- Normalized production:  $pp \rightarrow M \rightarrow \chi_0 \chi_1 (\gamma)$  in FASER ROI for magnetic (solid) and electric (dashed) dipole operators



Can reach O(1) GeV

EDM case shows p-wave suppression

What is the signal and background?

# What is the signal?

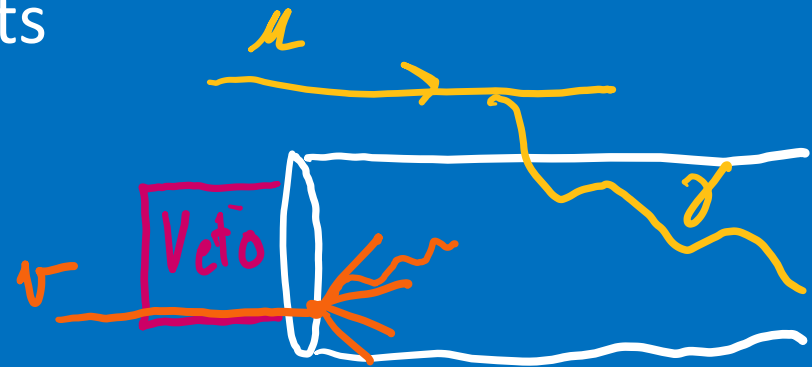
- Photon hits in the calorimeter with  $E_\gamma \approx 10 \text{ GeV} \times \frac{\Delta}{0.01}$
- Photon ID with pre-shower detector

## Backgrounds?

$\mu$ : Either vetoed or produce  $O(10)$  MeV deposits

We take  $E_\gamma > 300 \text{ MeV}$

$\nu$ : Vetoed by preshower and trackers



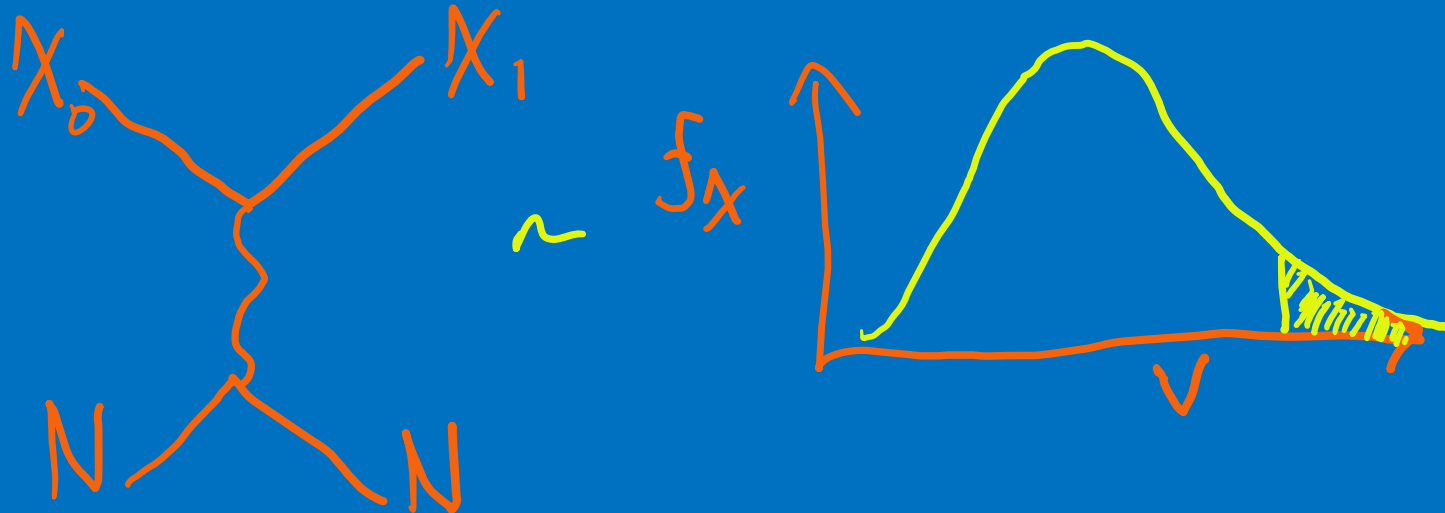
What about dark matter?



# Dark Matter

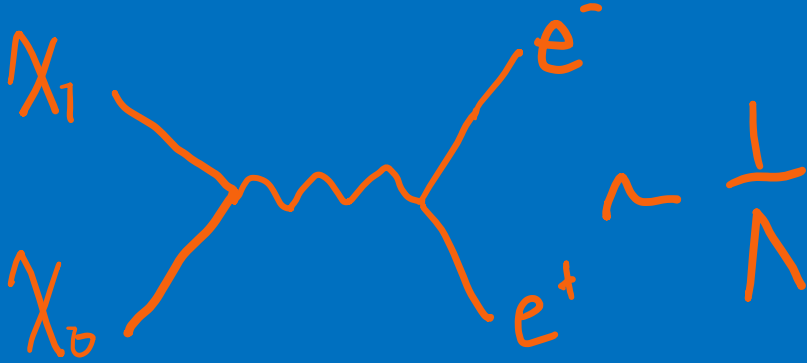
- Splitting well-above direct detection reach

$$\frac{E_{\text{kinetic}}}{m_1 - m_0} \sim \frac{10^{-6}}{\Delta} \ll 1$$

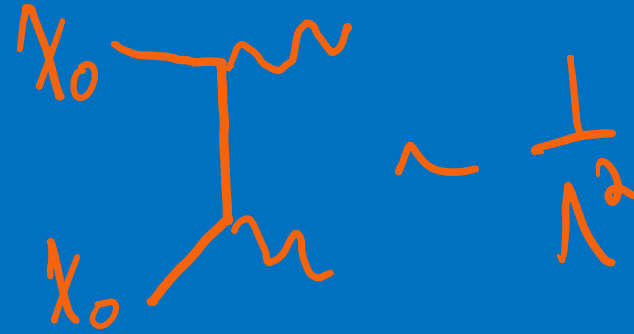


# Dark Matter

- Freezeout process governed by (co-)annihilation processes



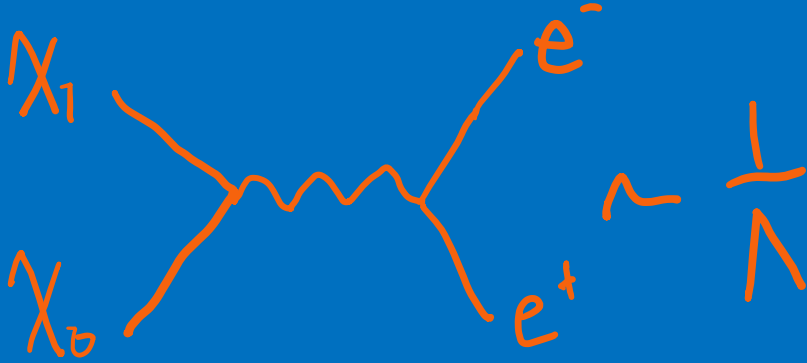
Less  $\Lambda$  suppression in s-channel  
but Boltzmann suppressed



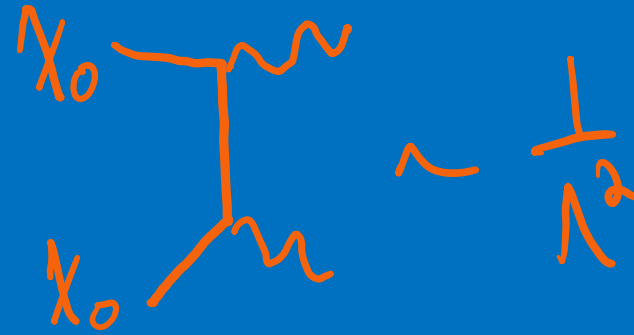
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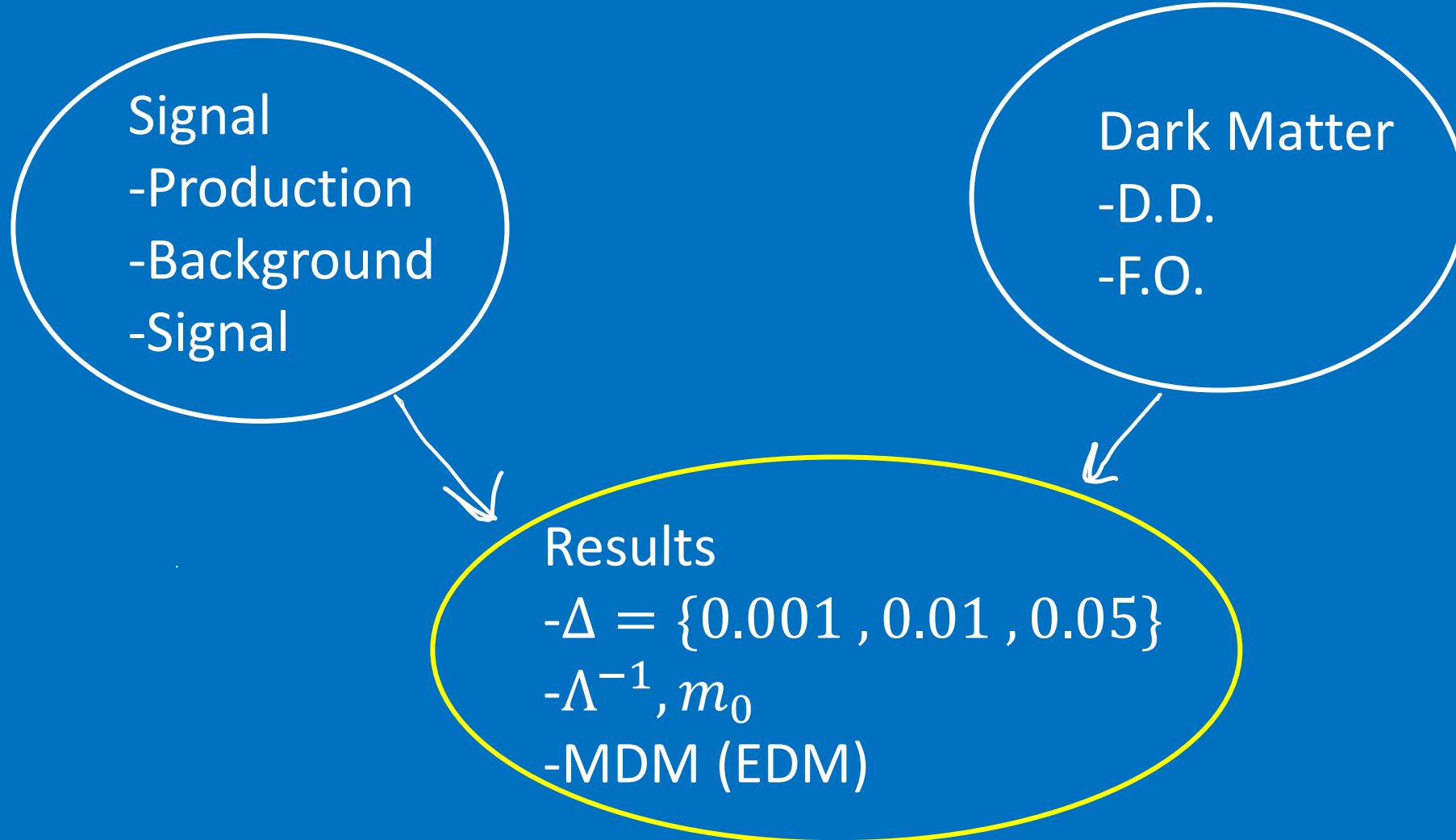


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Bottom line:

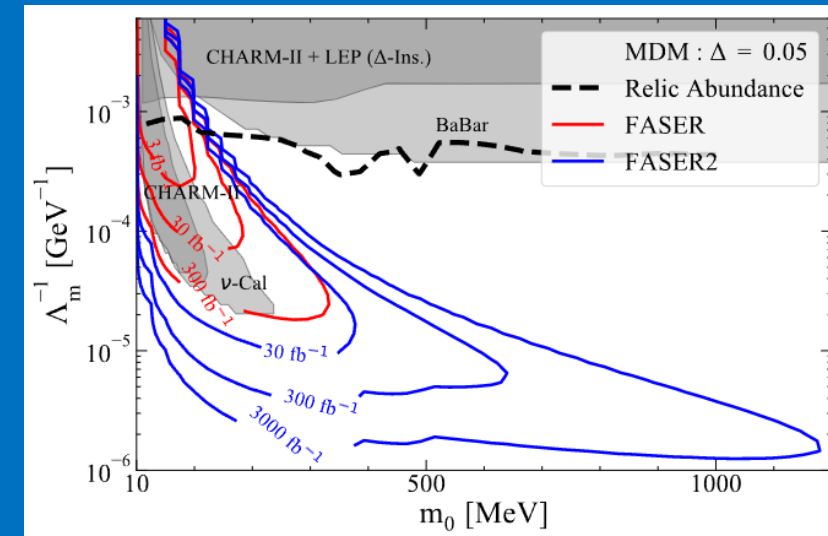
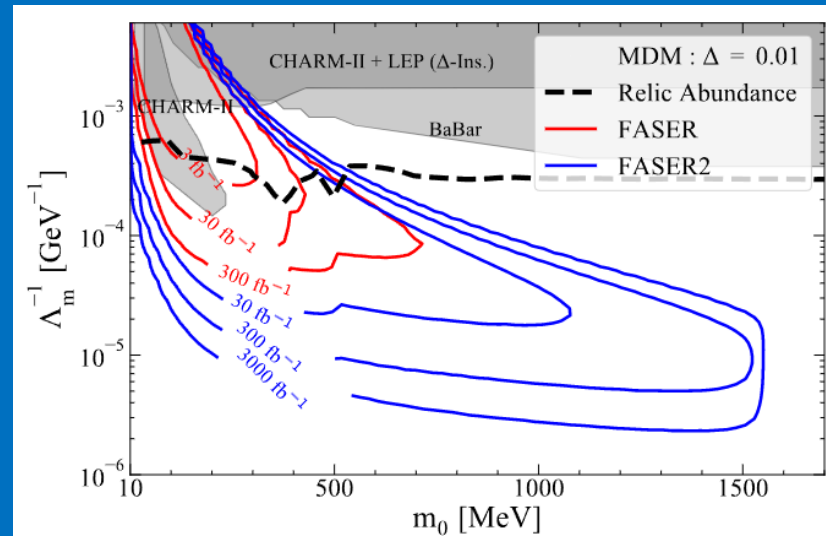
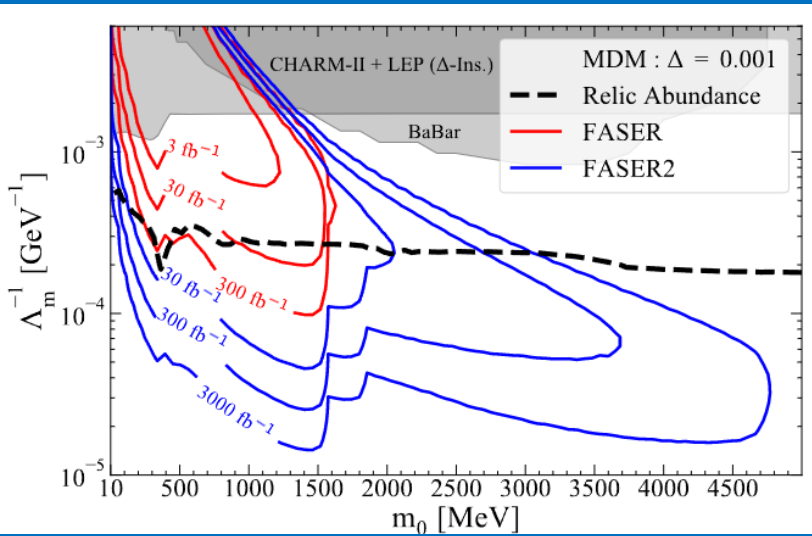
- for  $\Delta \ll 1\%$  : s-channel dominates, but have direct detection constraints
- for  $\Delta \sim 1$  : t-channel dominates - need large couplings for F.O. that are excluded
- for  $\Delta \sim 1\%$  : **unprobed masses and couplings that give right relic abundance**

# Results

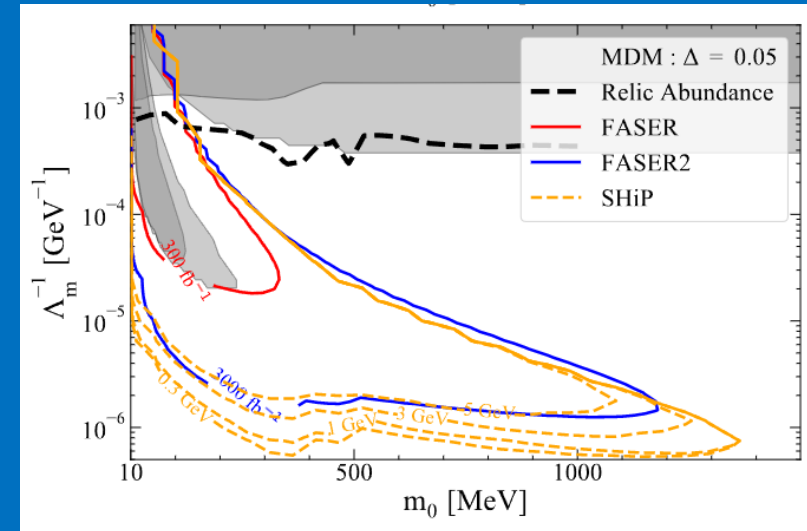
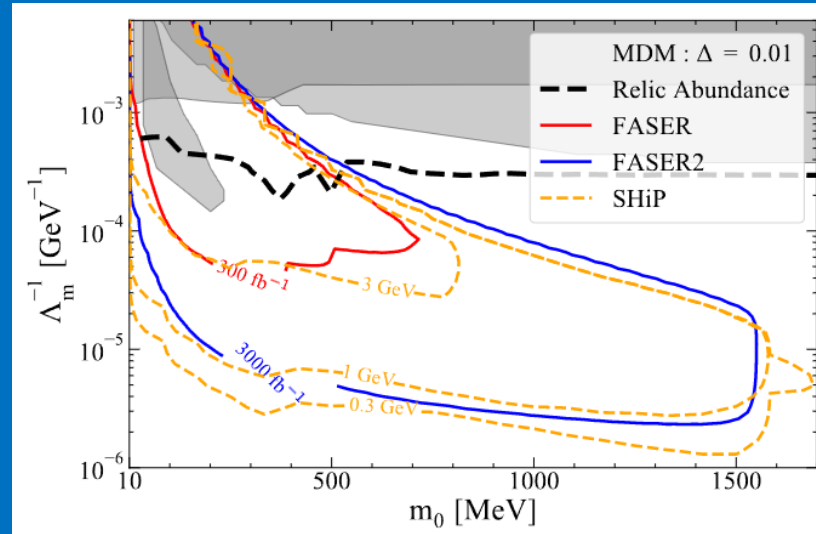
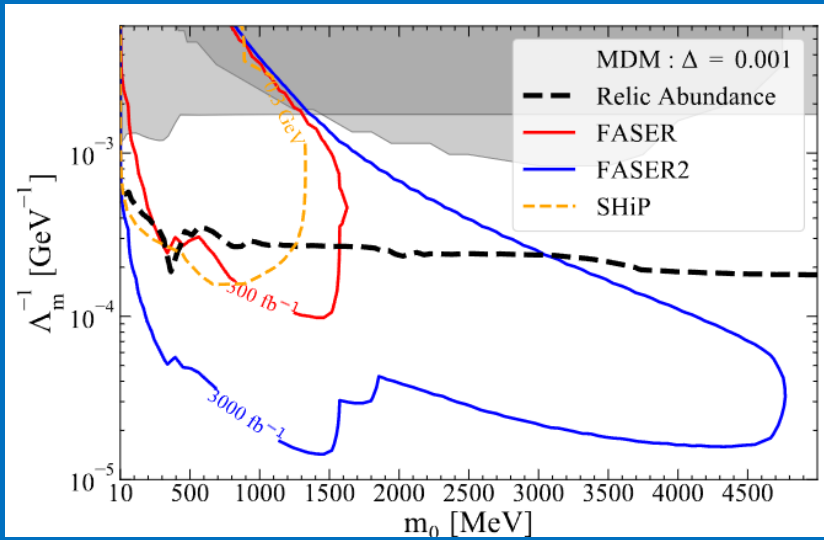


# Results

## MDM



# SHiP projections



# Summary

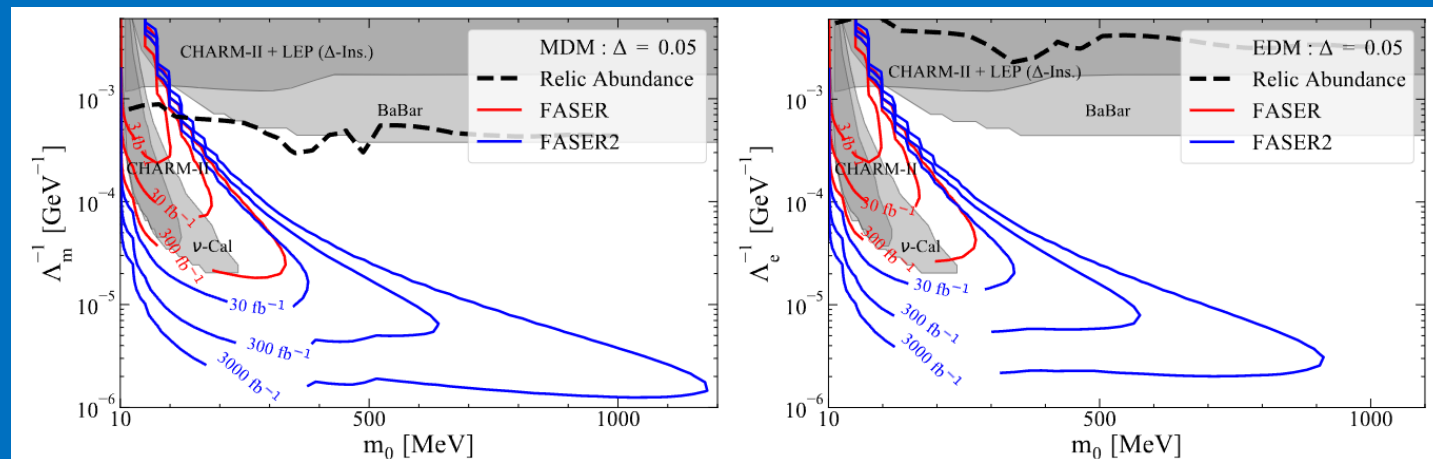
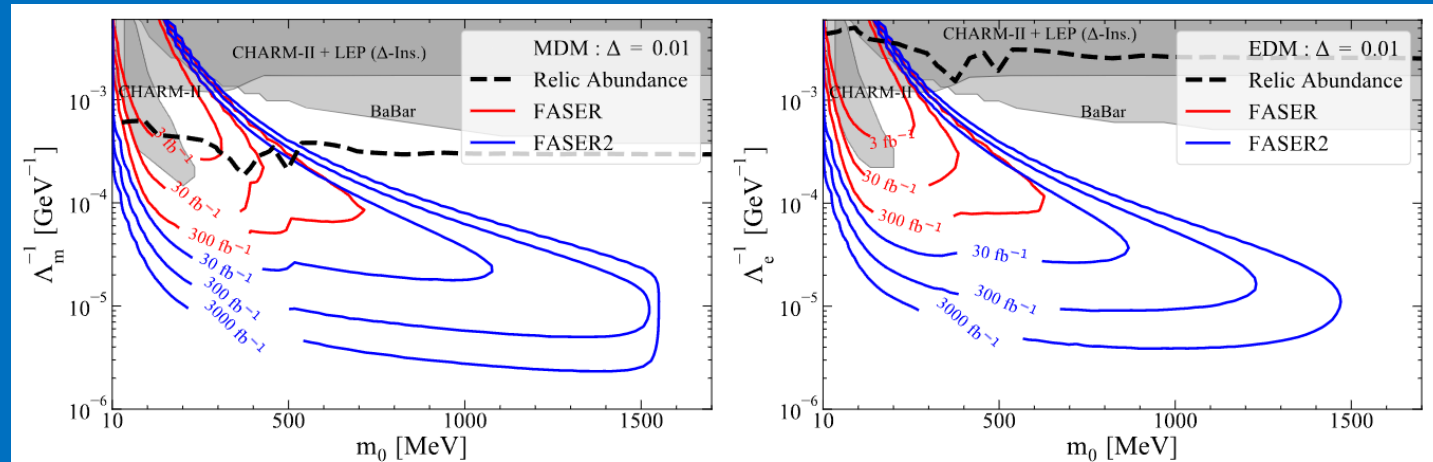
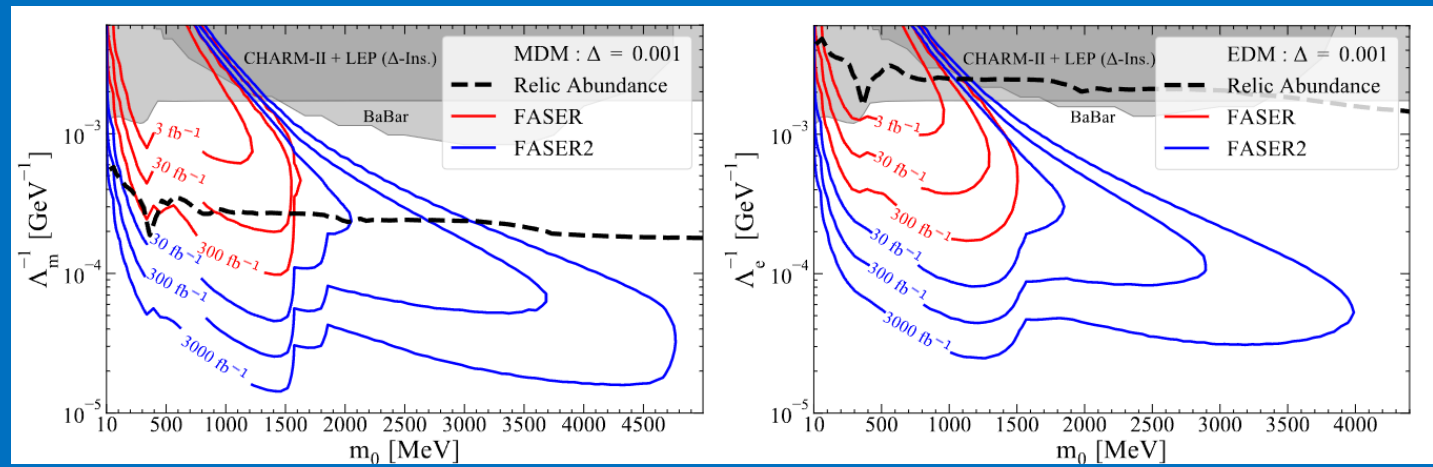
$$\Delta = \{0.001, 0.01, 0.05\}$$

- FASER can search for  $\gamma$ 's from inelastic dipole DM decay
- Best suited to explore signals that would be too soft at other experiments

If DM is thermally produced and interacts via MIDM

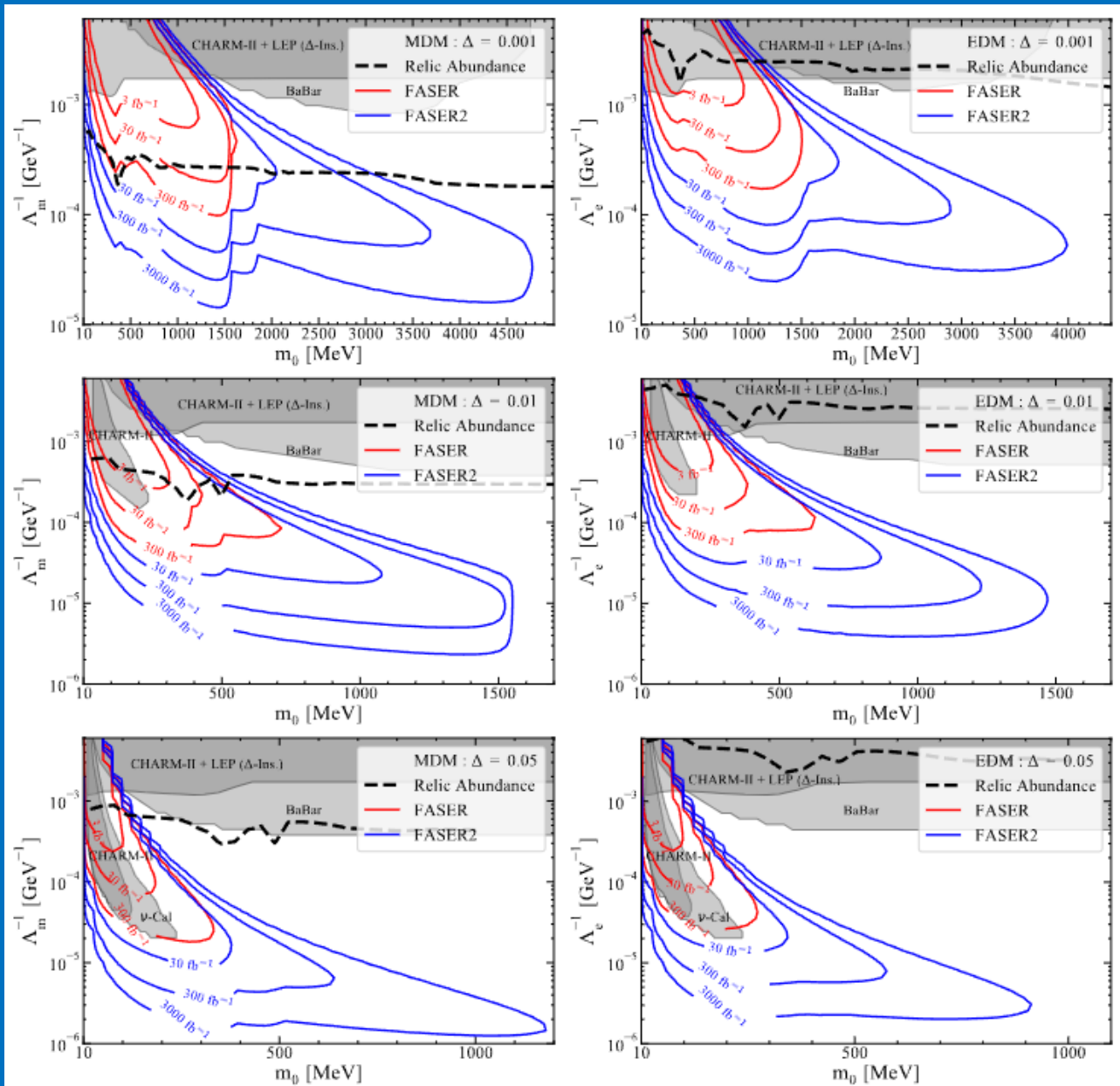
→ then only  $\Delta < 0.05$  is unexcluded for GeV masses

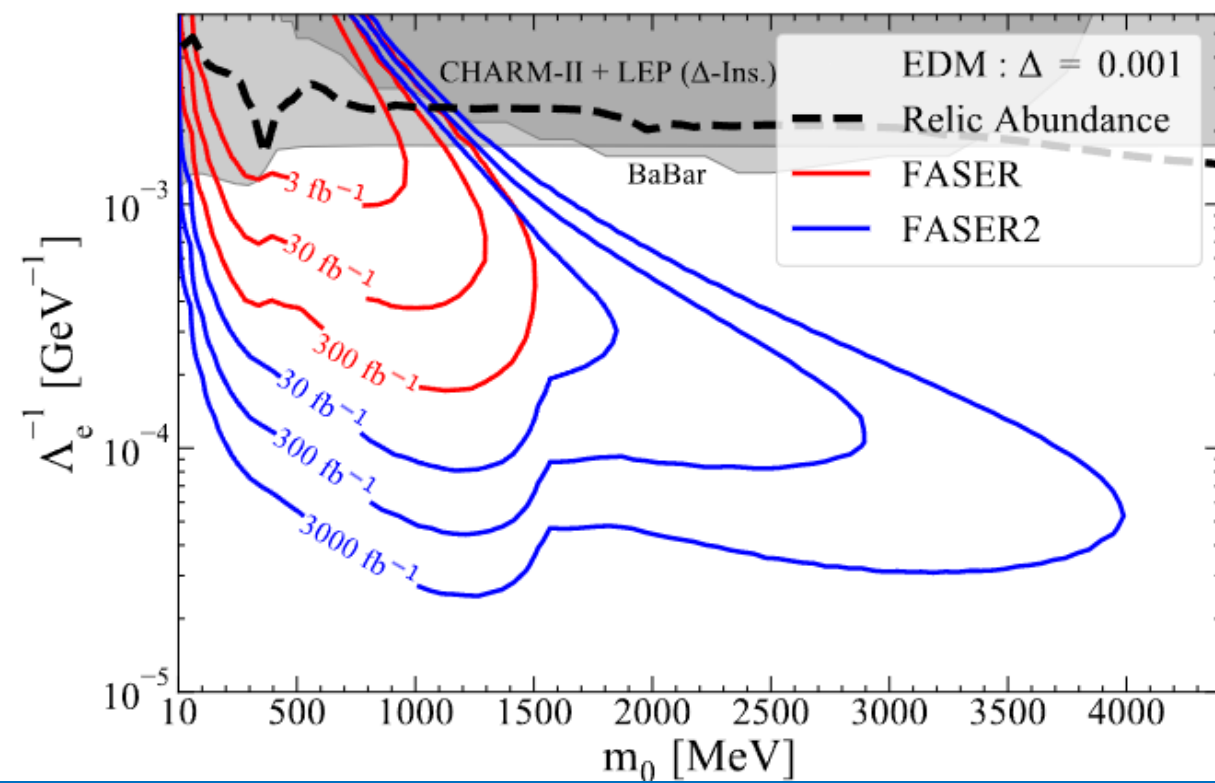
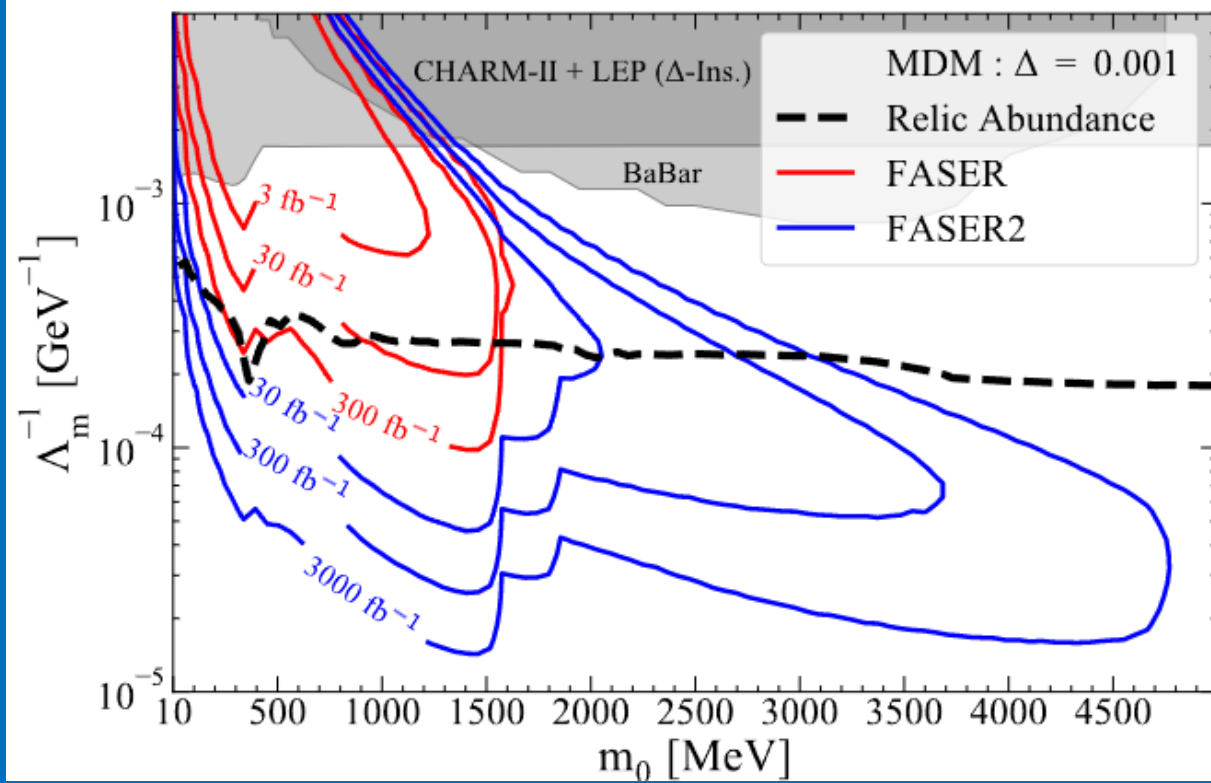
→ FASER can probe

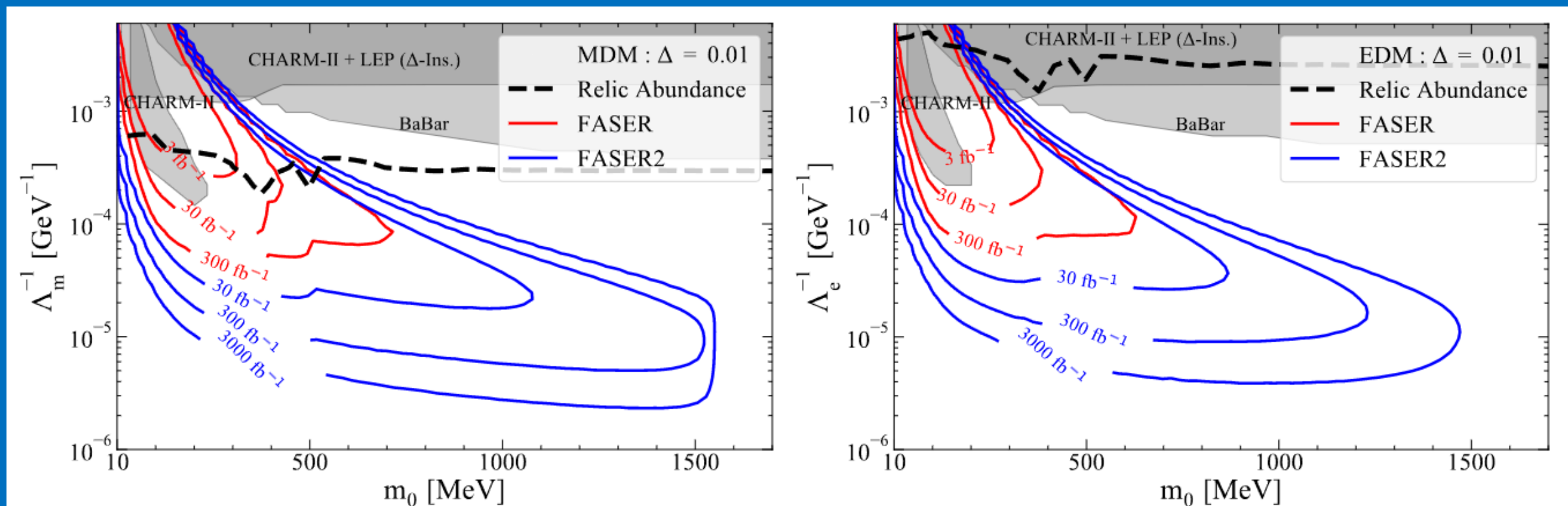


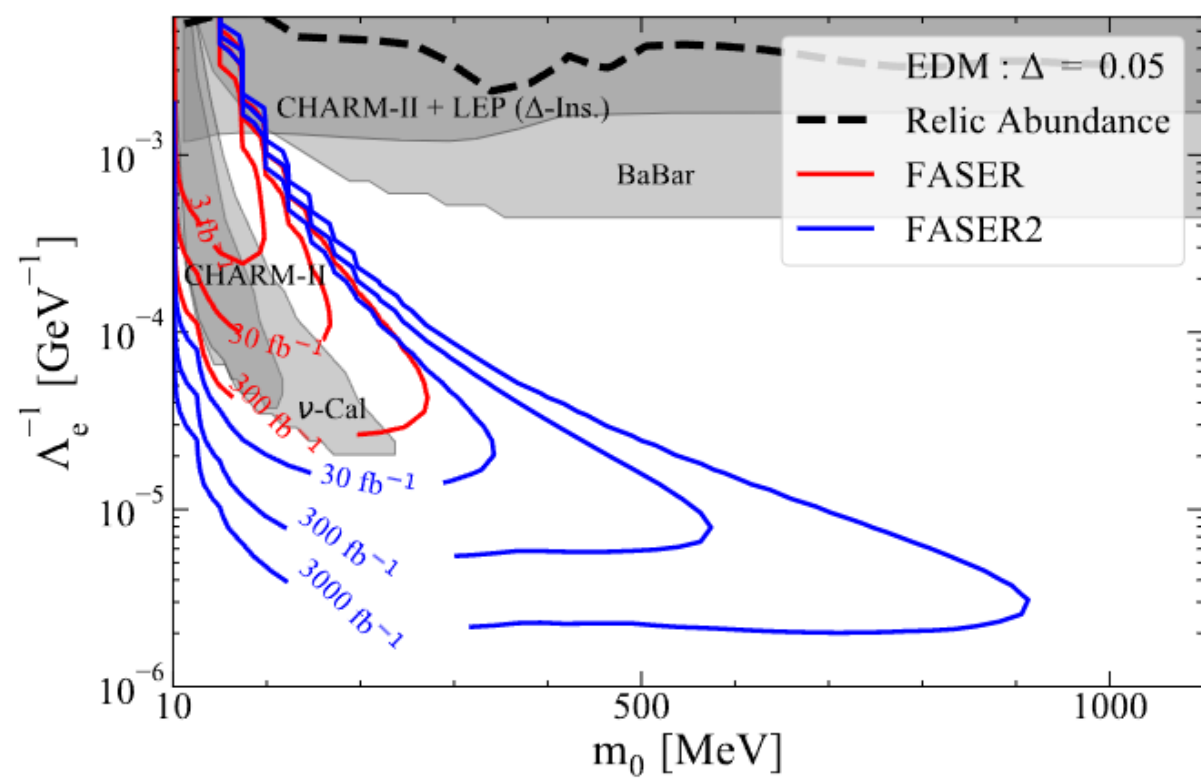
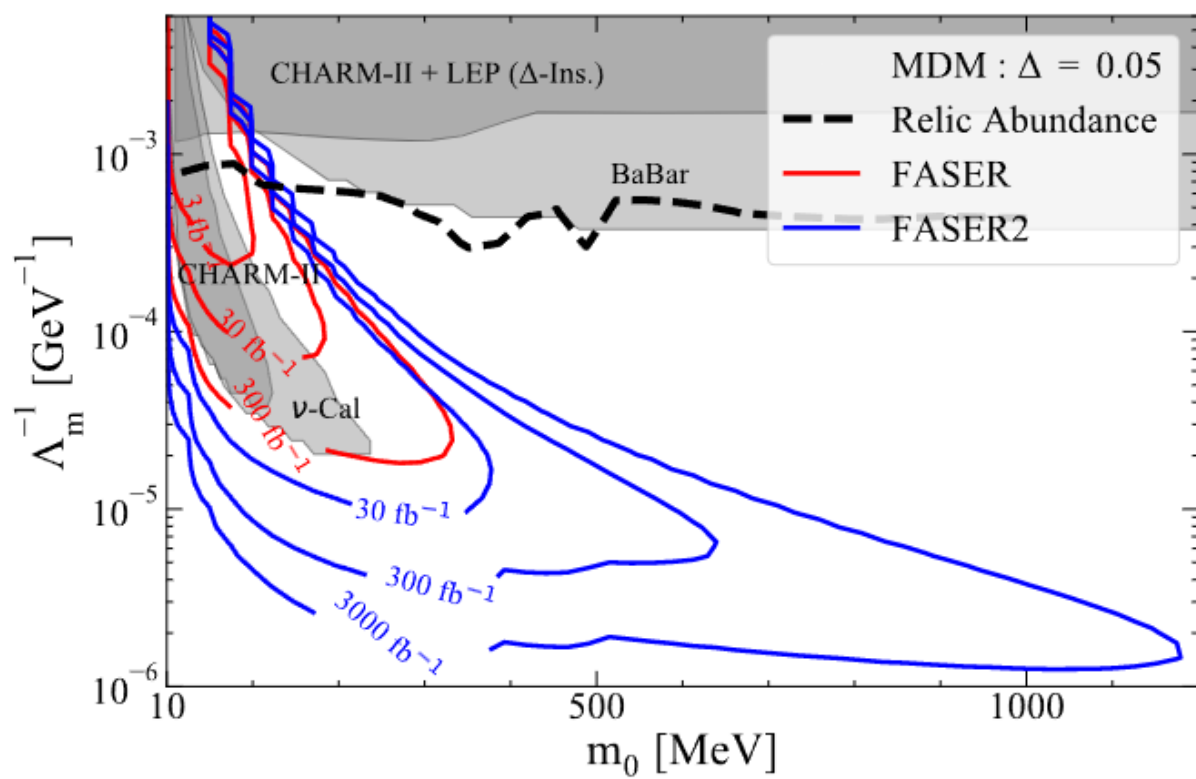
Thank you!

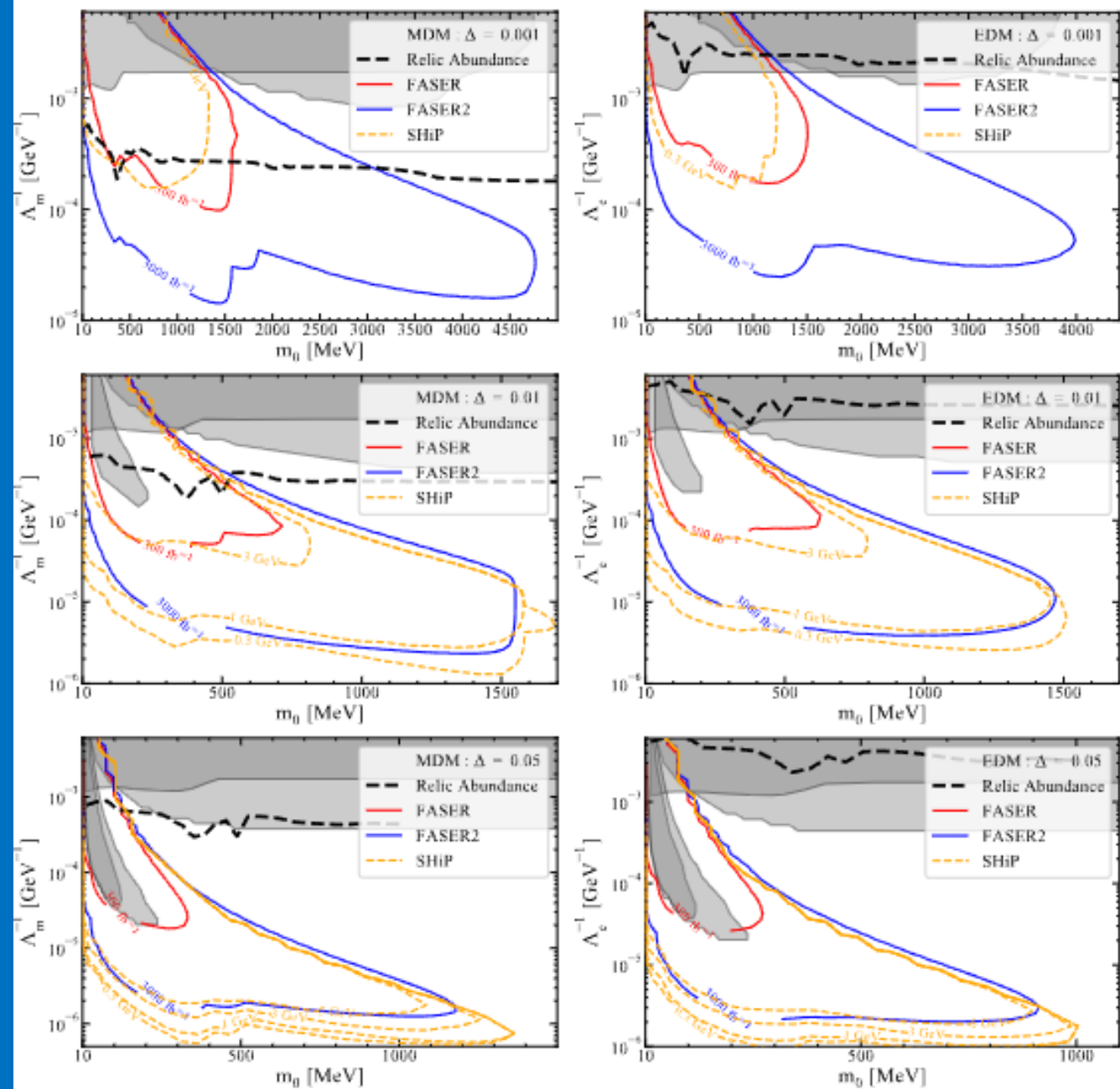






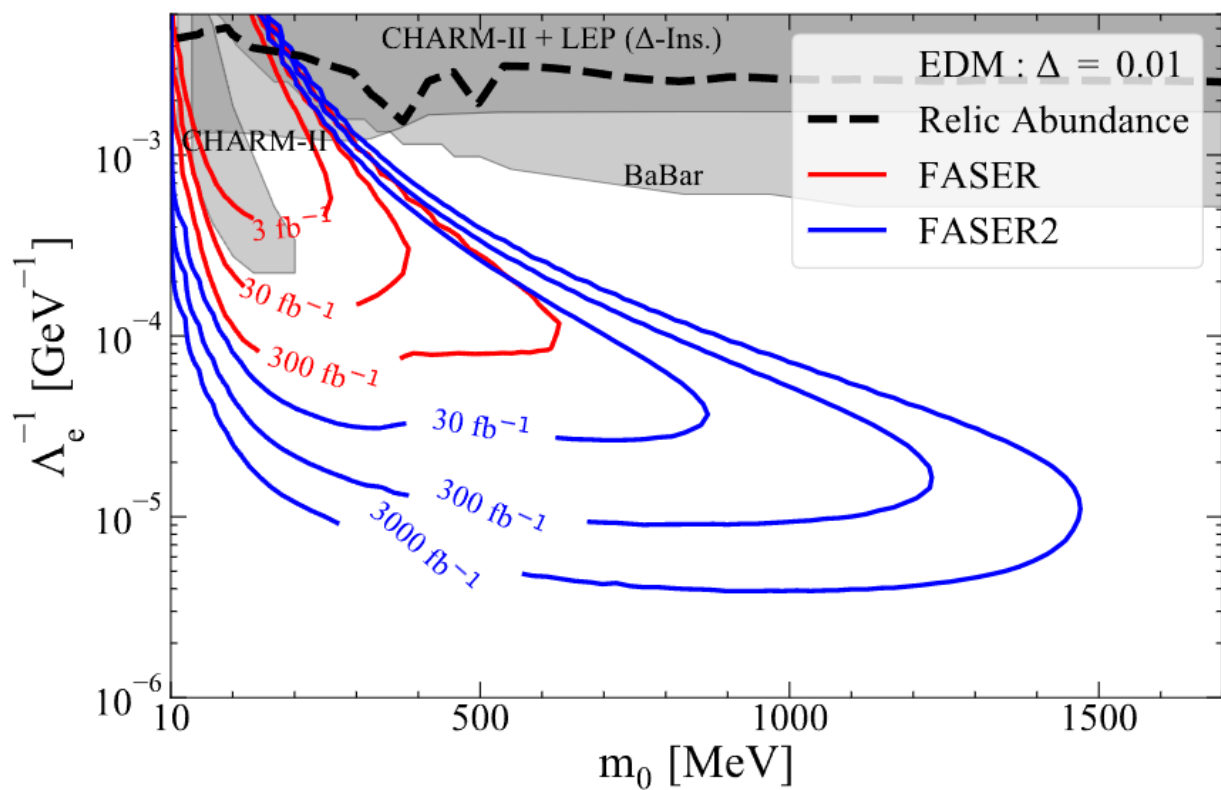
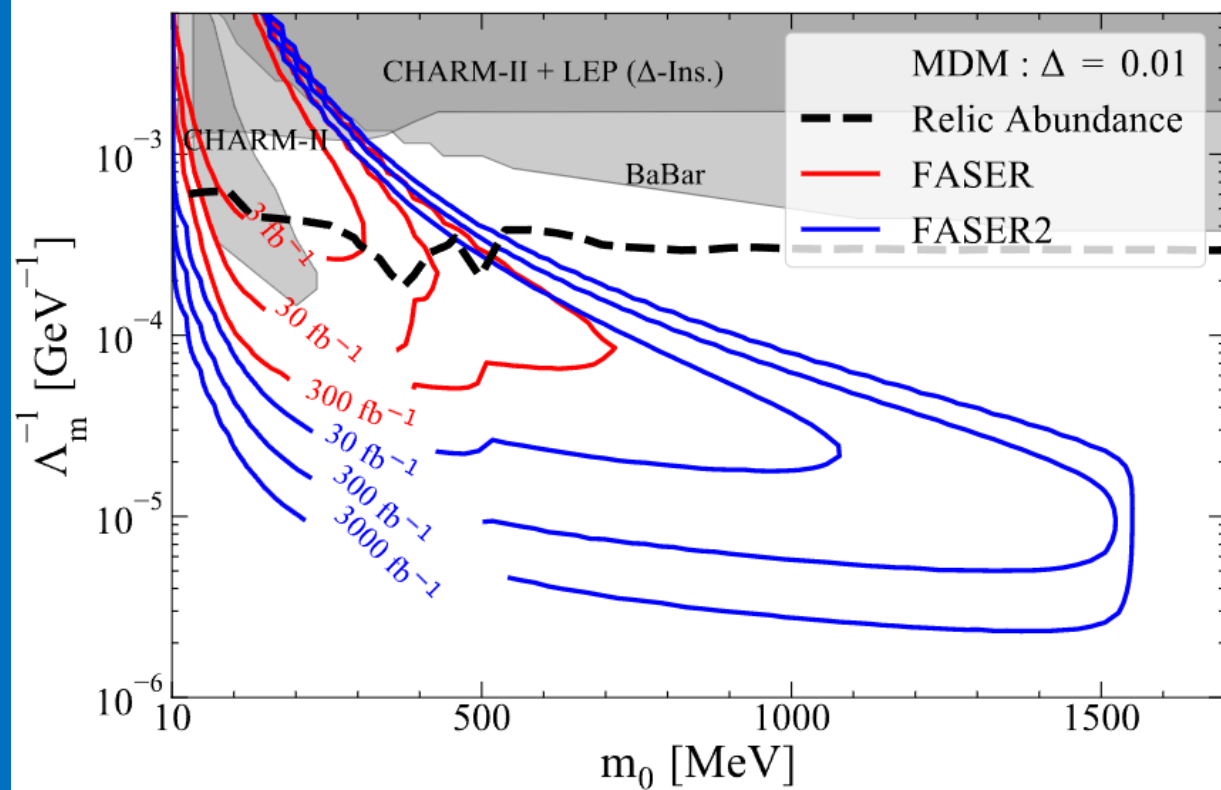






# Results

$$\Delta = 0.01$$



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