Inelastic Dark Matter and a Dark Higgs

Camilo A. Garcia Cely

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DESY.

New trends in dark matter

ICTP SAIFR Brazil

December 7,2020

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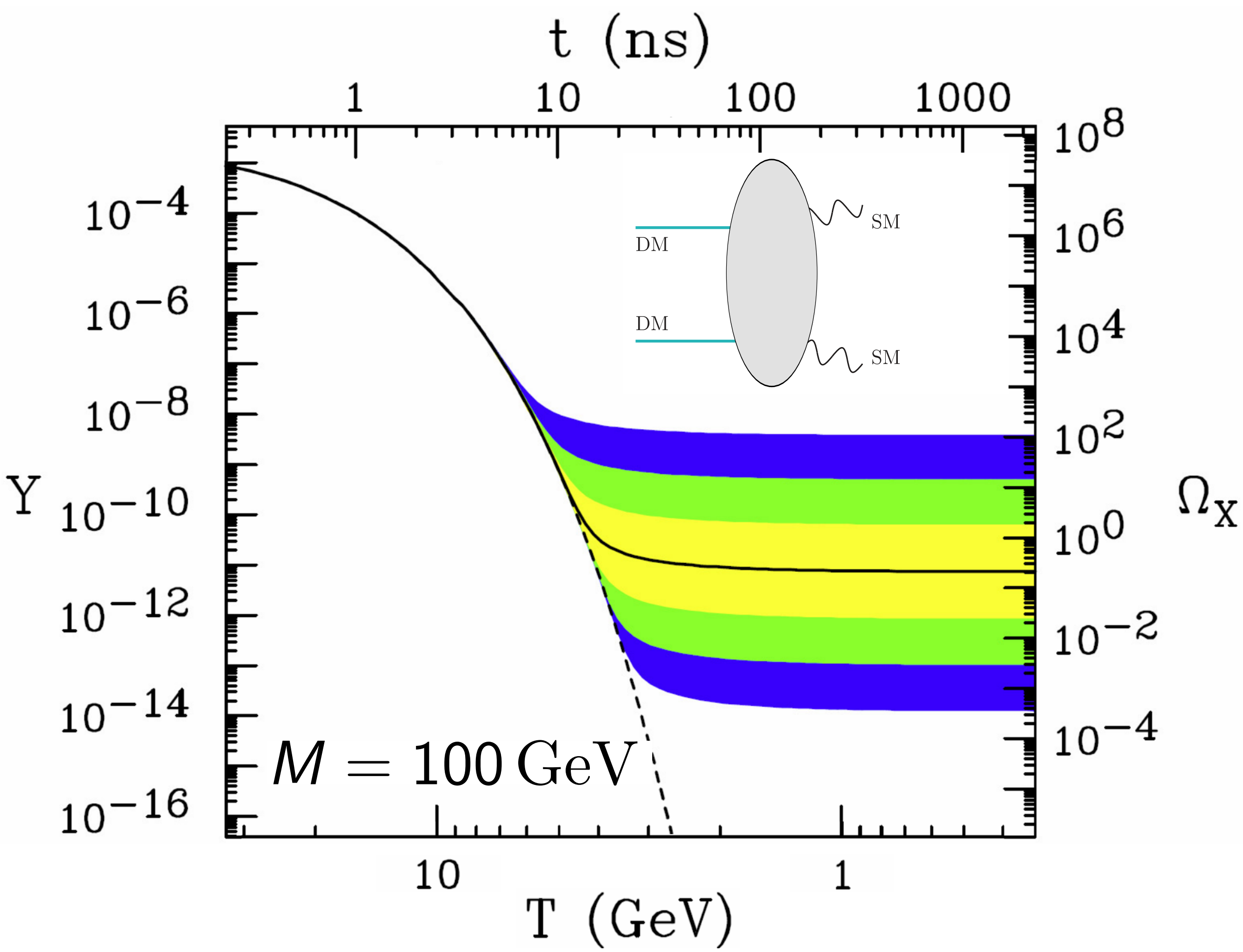
Preliminary

Duerr, Ferber, Garcia-Cely, Hearty, Schmidt-Hoberg

Thermal Dark Matter Paradigm

Zel'dovich (1966)
Lee Weinberg (1977)
Dicus, Kolb, Teplitz (1977)



Feng et al. (2010)

Thermal dark matter is a well motivated and predictive scenario which can be probed with direct and indirect searches as well as with collider experiments

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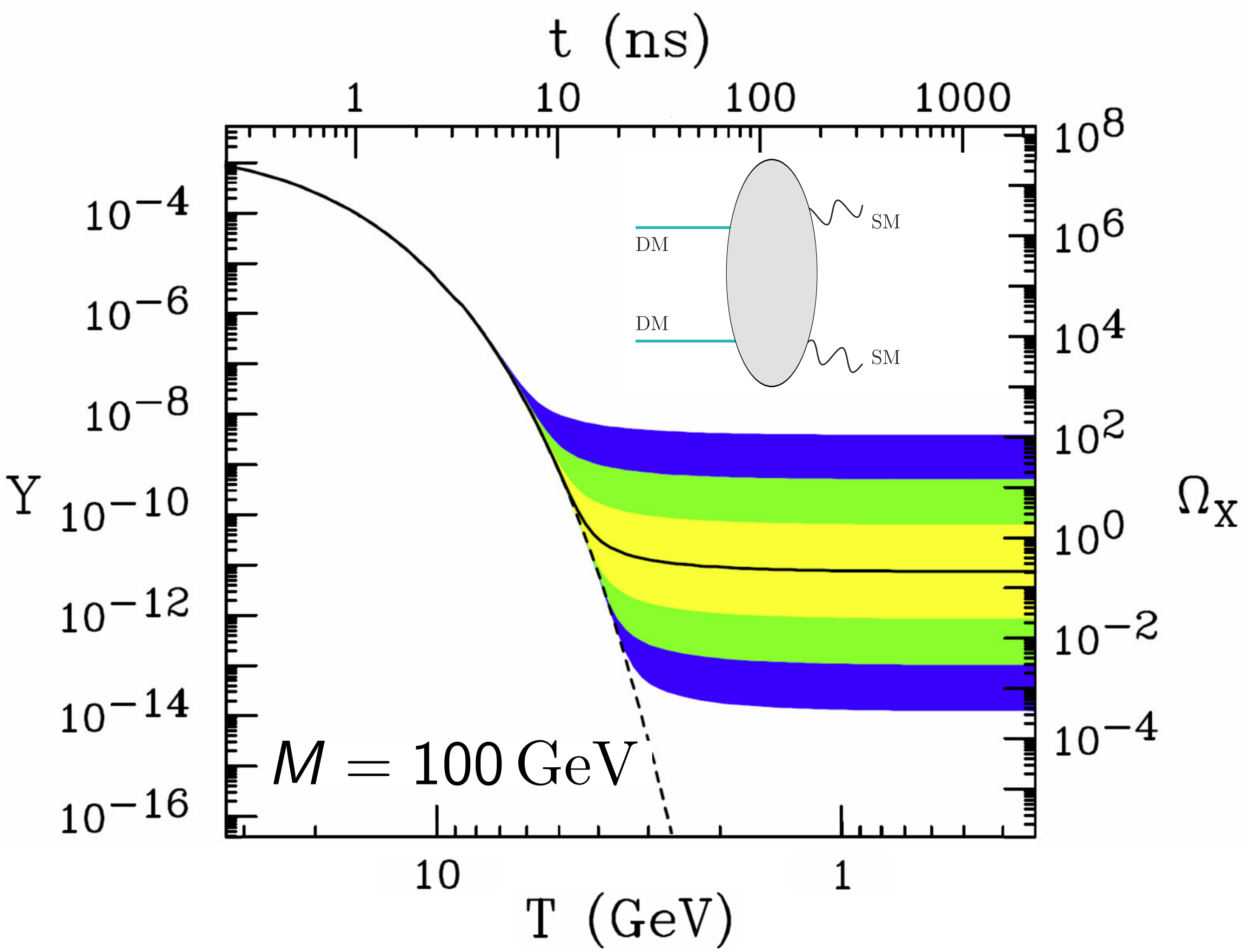


Feng et al. (2010)

$\sigma v \sim 10^{-26}$cm$^3/s$

$\sigma \sim 1$pb

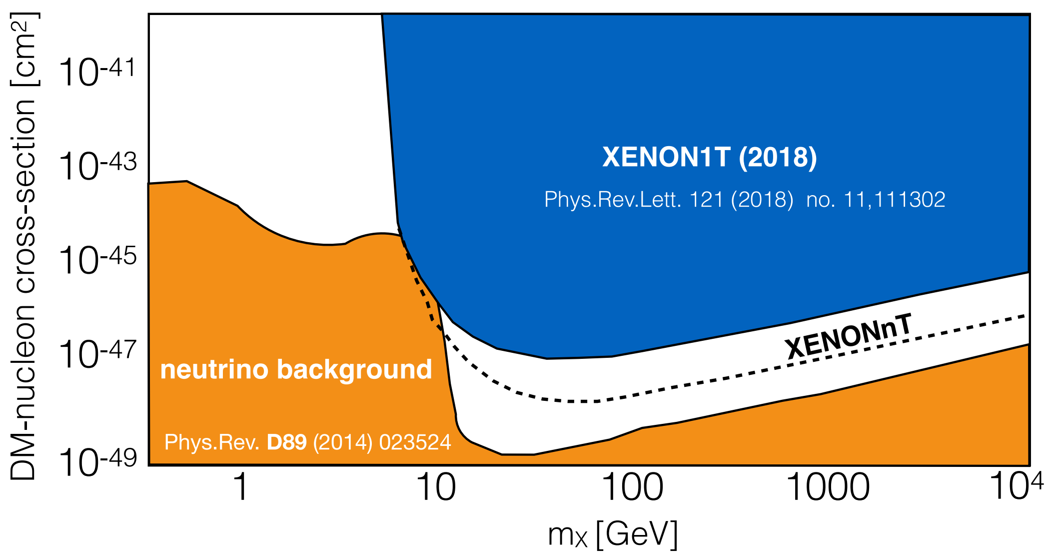
m from subGeV to 100TeV

Griest and Kamionkowski (1990).

Thermal dark matter is a well motivated and predictive scenario which can be probed with direct and indirect searches as well as with collider experiments

Thermal Dark Matter Paradigm

Direct searches

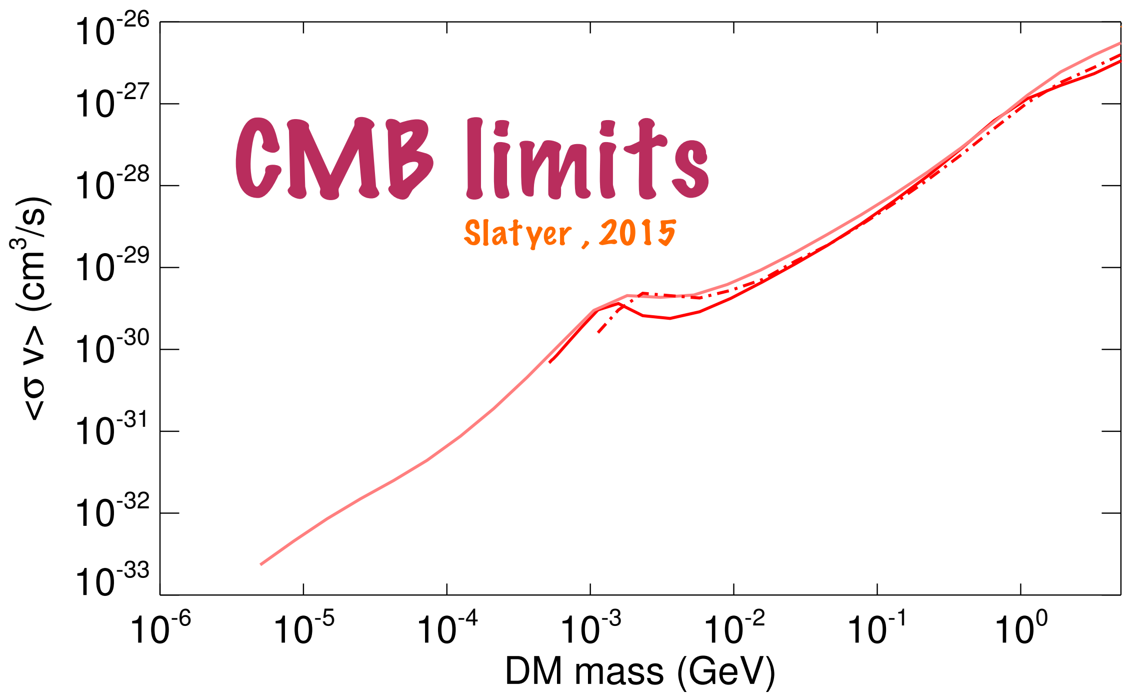


Borrowed from Tien-Tien Yu

Light dark matter does not have enough momentum to kick heavy nuclei

Loss of sensitivity mass for SubGeV masses.

Indirect searches



S-wave thermal cross sections are excluded by CMB observations

Camilo A. Garcia Cely, DESY

Inelastic Dark Matter

A simple scenario for light thermal dark matter which evades the strong CMB bounds is the case where DM couples inelastically to Standard Model.

Here a sufficiently large mass splitting between the DM particle $\chi 1$ and its heavier twin $\chi 2$ ensures that:

(i) direct detection limits are basically absent Smith, Weiner (2001)

(ii) residual DM annihilations are no longer efficient during the time of the CMB.

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start with ψ a Dirac fermion charged under a $U(1)$ symmetry .

After $U(1)$ symmetry breaking $$\chi_1 = \frac{\psi - \psi^c}{\sqrt{2}}\,, \qquad \text{and} \qquad \chi_2 = \frac{\psi + \psi^c}{\sqrt{2}}\,.$$

Portals to the Standard Model

Wilczek (2006)

$B_{\mu\nu} V_{\mu\nu}$	"Kinetic mixing" with additional U(1)' group
$H^+H\,(\lambda S^2 + A S)$	Higgs-singlet scalar interactions (scalar portal)
$LH\,N$	neutrino Yukawa coupling, N – RH neutrino

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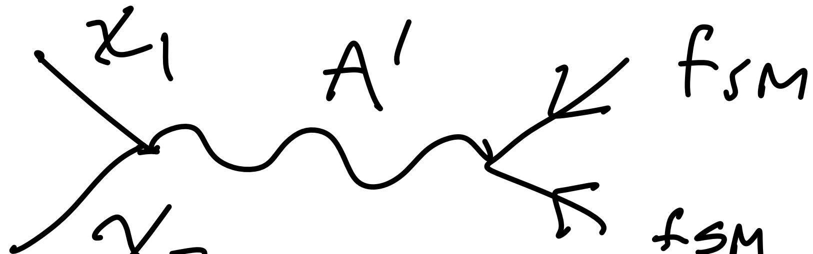
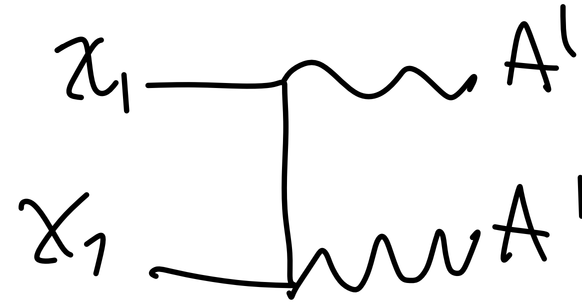
$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4}\hat{X}_{\mu\nu}\hat{X}^{\mu\nu} - \frac{\epsilon}{2c_{\rm W}}\hat{X}_{\mu\nu}\hat{B}^{\mu\nu}$$

A' inherits the coupling structure of the photon to the SM fermions where the electric charge is multiplied by a common factor ε.

Inelastic Dark Matter



Thermal process



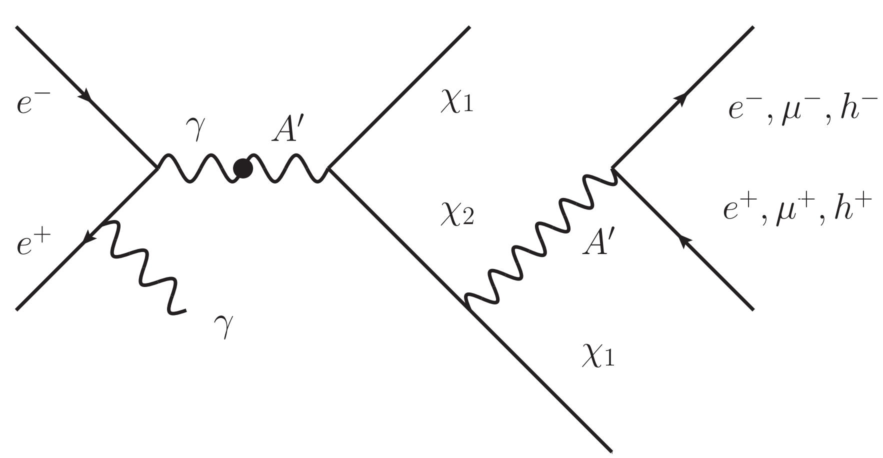
Take $m_{A'} > m_{\chi_1}$ to avoid CMB constraints

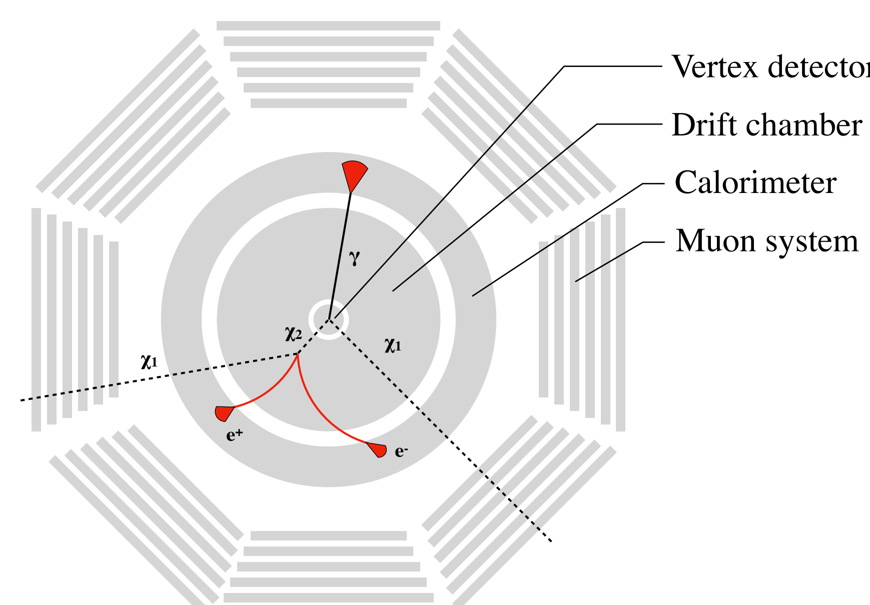
Collider signatures

Izaguirre, Krnjaic, Shuve (2016)
Izaguirre, Kahn, Krnjaic, Moschella (2017)

displaced vertices

Duerr, Ferber, Hearty, Kahlhoefer, Schmidt-Hoberg (2019)





Open questions

This talk

Duerr, Ferber, Garcia-Cely, Hearty, Schmidt-Hoberg

Preliminary

What process generates the dark photon mass?

What induces the mass splitting $\Delta = m_{\chi_2} - m_{\chi_1}$?

Does it affect the phenomenology?

Invoke the dark Higgs mechanism:

$$V(\phi, H) = \lambda_H \left(H^\dagger H - \frac{v_H^2}{2} \right)^2 + \lambda_\phi \left(\phi^* \phi - \frac{v_\phi^2}{2} \right)^2 + \lambda_{\phi H} \left(H^\dagger H - \frac{v_H^2}{2} \right) \left(\phi^* \phi - \frac{v_\phi^2}{2} \right)$$

$$\phi = \frac{v_\phi + \hat{h}'}{\sqrt{2}}, \qquad H = \left(0 \ \ (v_H + \hat{h})/\sqrt{2} \right)^T$$

ϕ has two units of charge

Portals to the Standard Model

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two portal model

$$\mathcal{L}_\psi = \frac{1}{2}\left(i\overline{\chi_1}\partial\!\!\!/\chi_1 + i\overline{\chi_2}\partial\!\!\!/\chi_2 - m_{\chi_1}\overline{\chi_1}\chi_1 - m_{\chi_2}\overline{\chi_2}\chi_2\right) + \frac{i}{2}g_X\hat{X}_\mu(\overline{\chi_2}\gamma^\mu\chi_1 - \overline{\chi_1}\gamma^\mu\chi_2) + \frac{f}{2}\hat{h}'(\overline{\chi_1}\chi_1 - \overline{\chi_2}\chi_2)\,,$$

Portals to the Standard Model

Wilczek (2006)

ε → $B_{\mu\nu} V_{\mu\nu}$ "Kinetic mixing" with additional U(1)' group

θ → $H^{+}H\,(\lambda S^2 + A\, S)$ Higgs-singlet scalar interactions (scalar portal)

$LH\,N$ neutrino Yukawa coupling, N – RH neutrino

scalar mixing angle

two portal model

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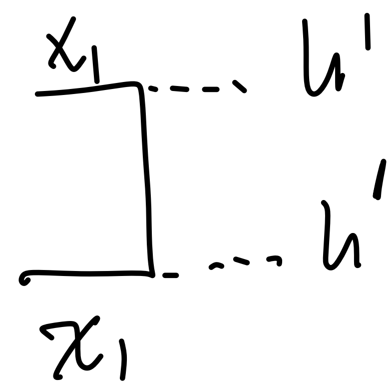
Inelastic interactions | Elastic interactions

Inelastic Dark Matter and a Dark Higgs

Relic density via thermal processes

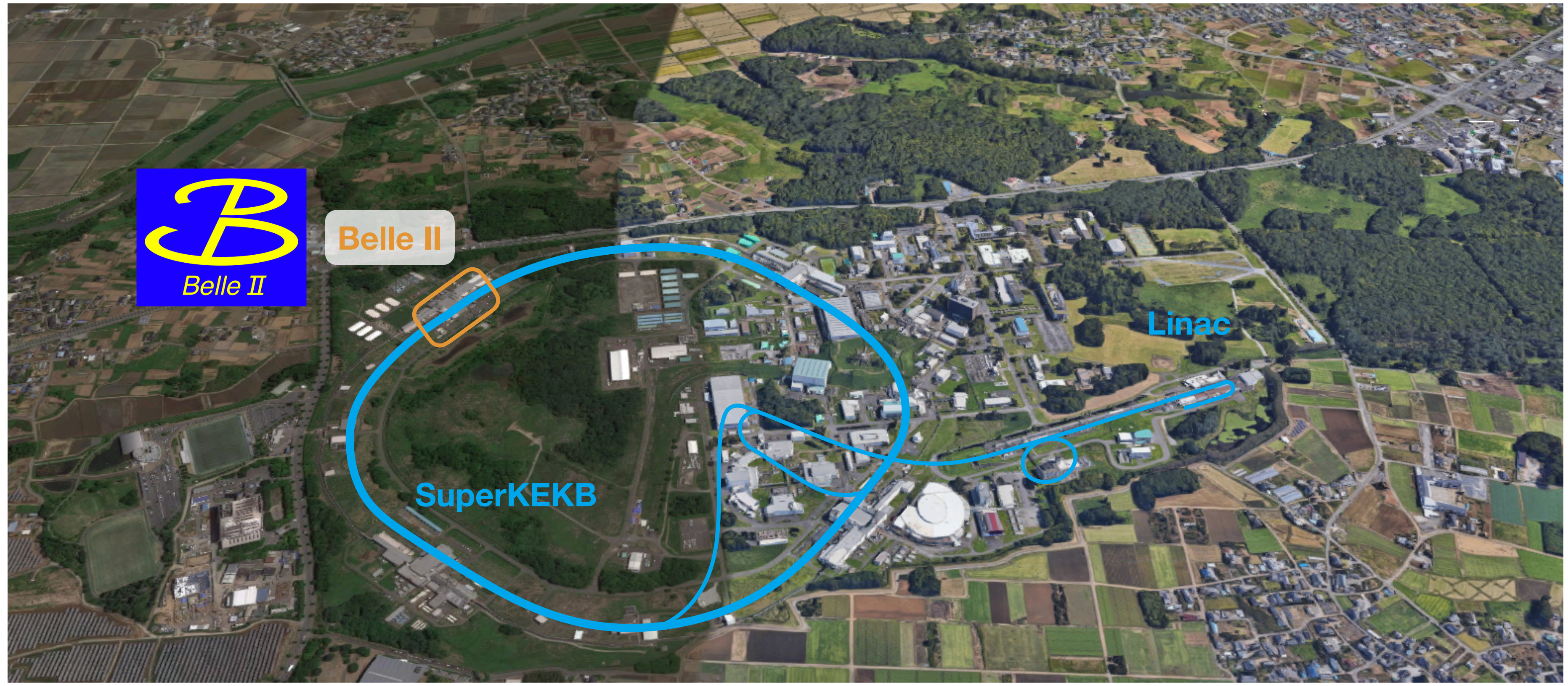


p-wave

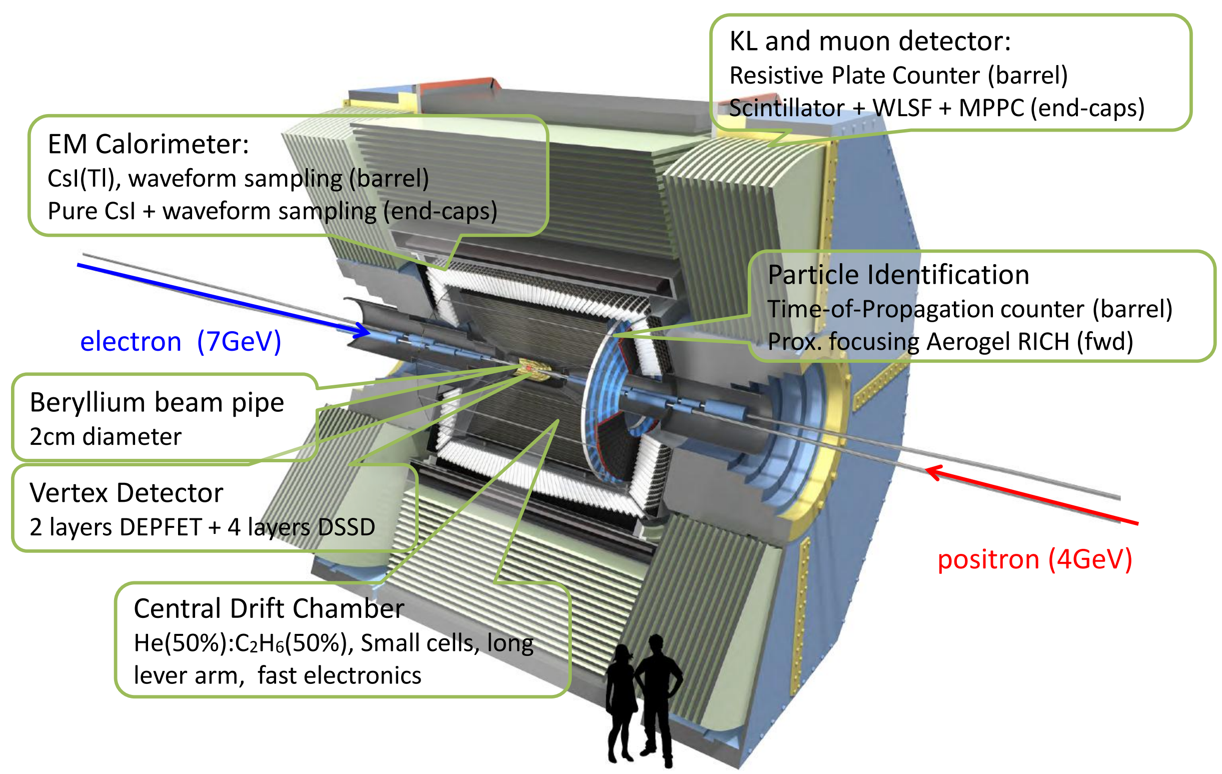
Belle II

B factory

KEK in Tsukuba (Japan)



Belle II Detector



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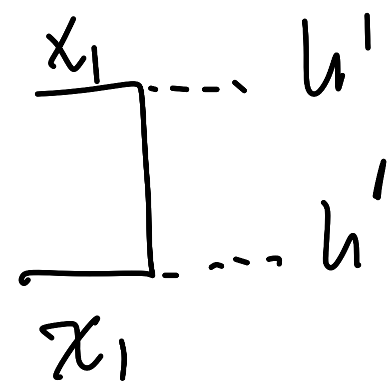
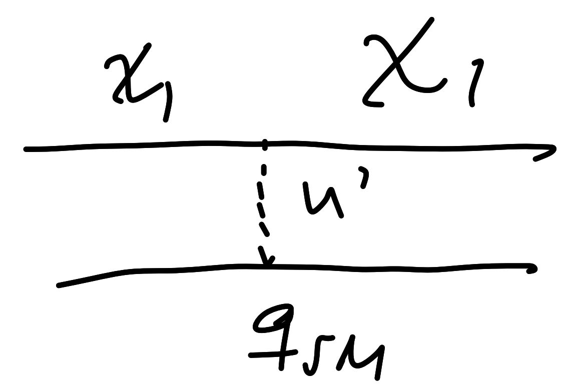


p-wave

Elastic Scattering



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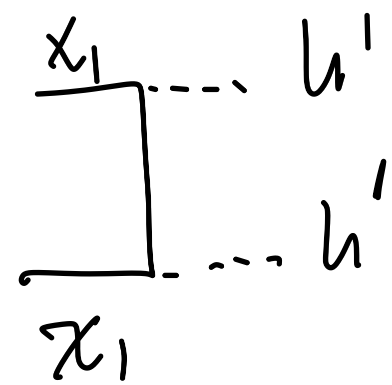

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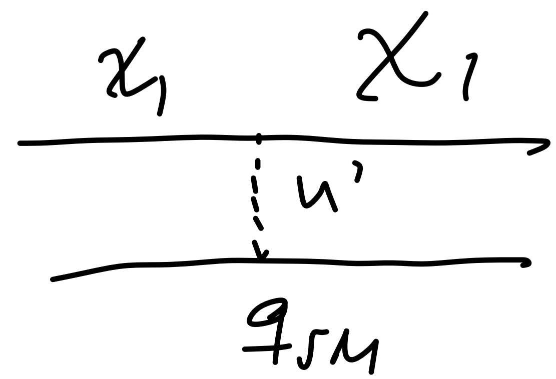

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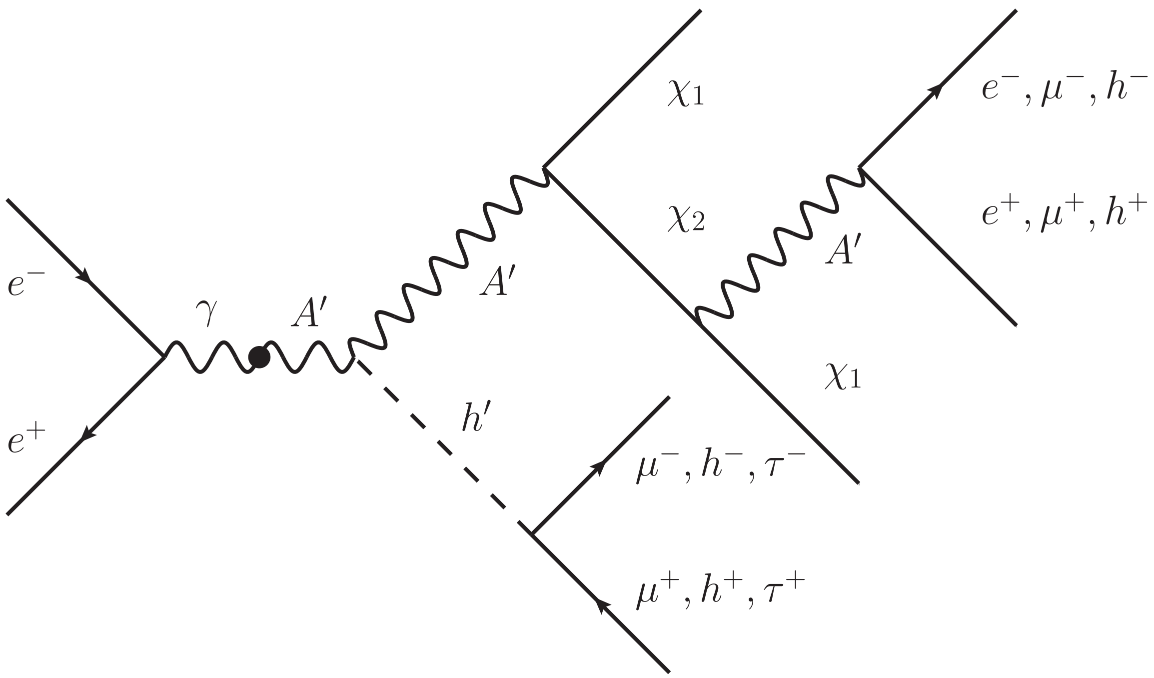
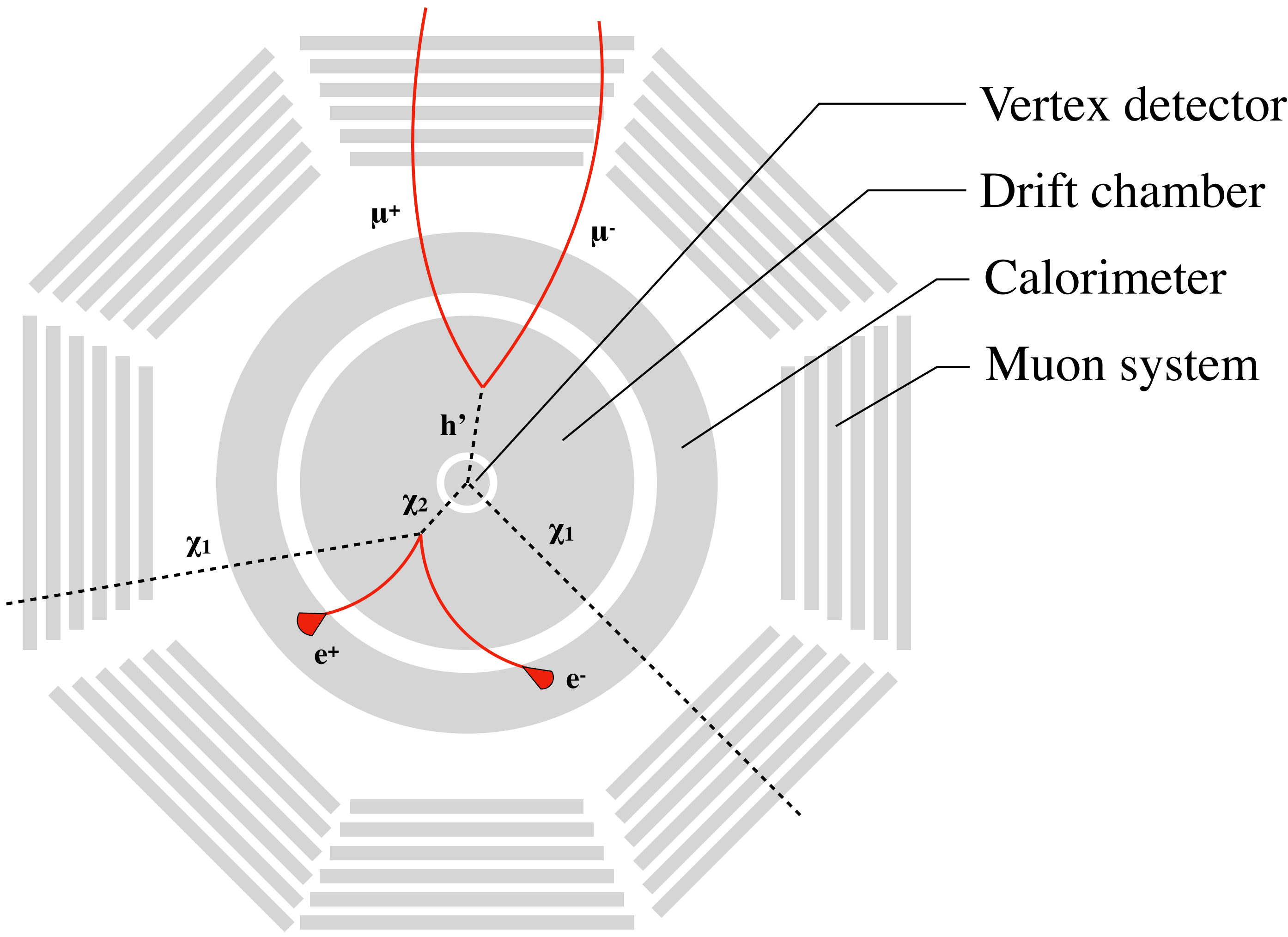
More parameter space

Rich phenomenology

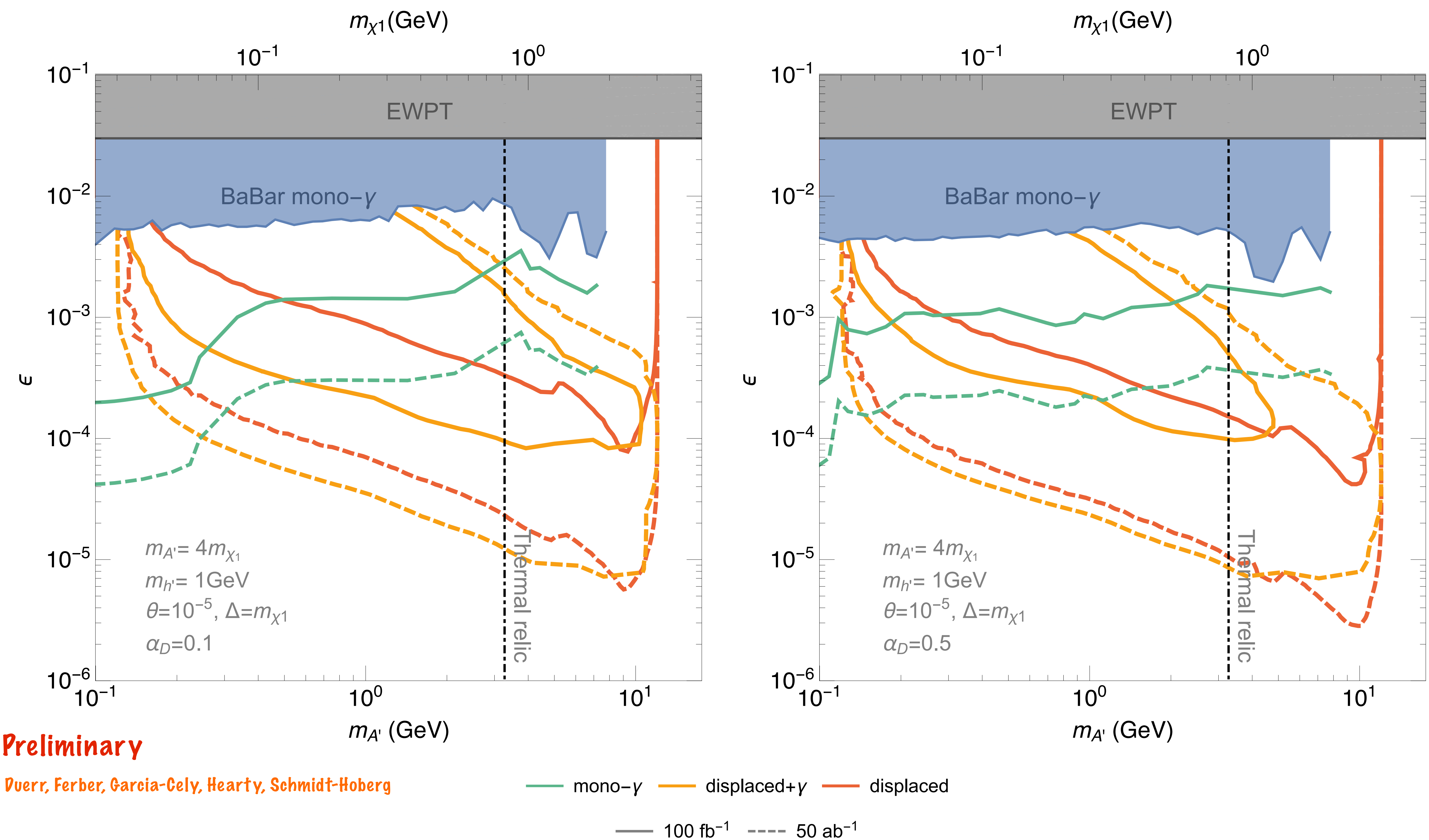
Displaced Vertices involving the Higgs





Duerr, Ferber, Garcia-Cely, Hearty, Schmidt-Hoberg

Dark Photon Plane



Preliminary

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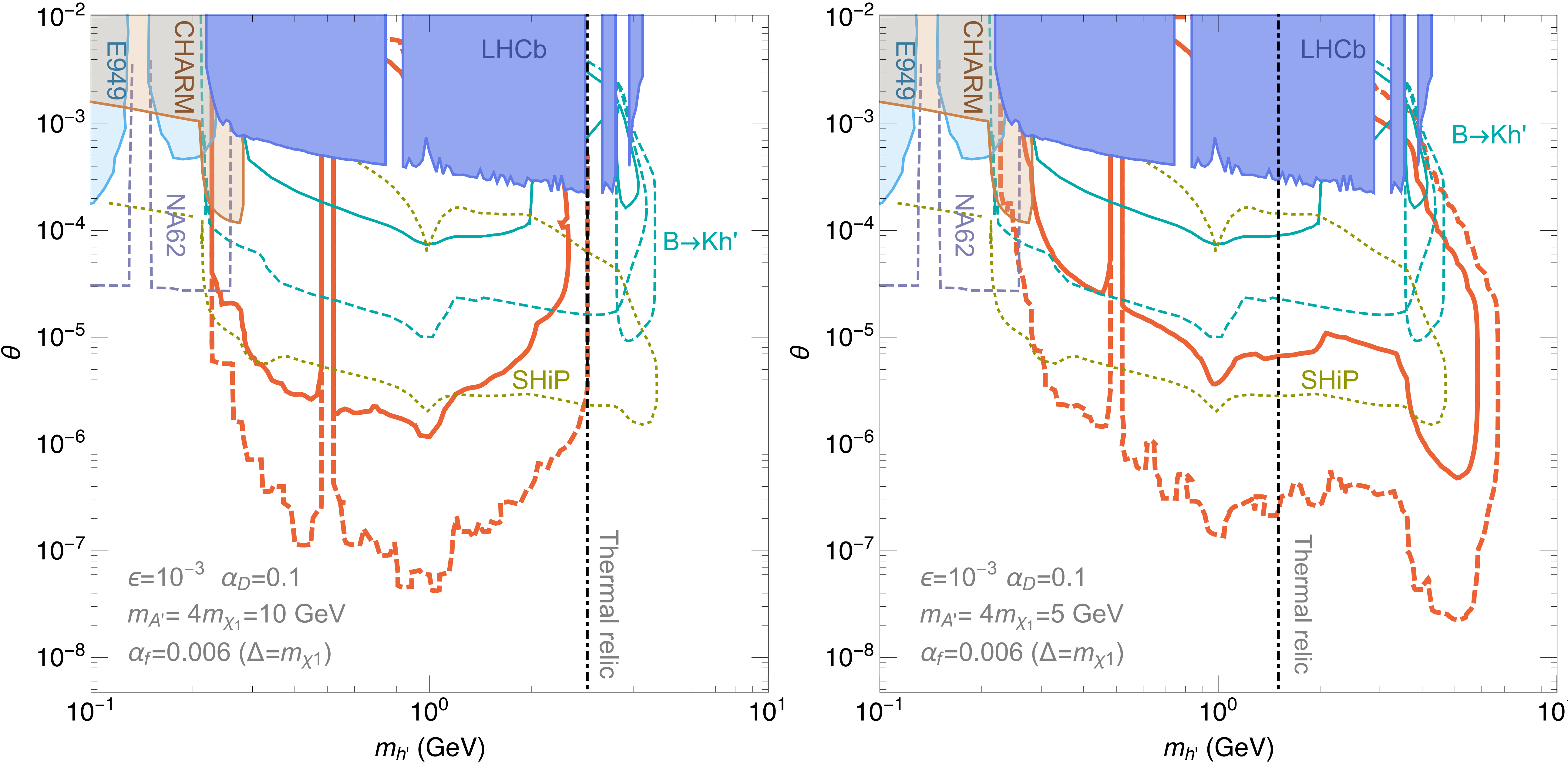

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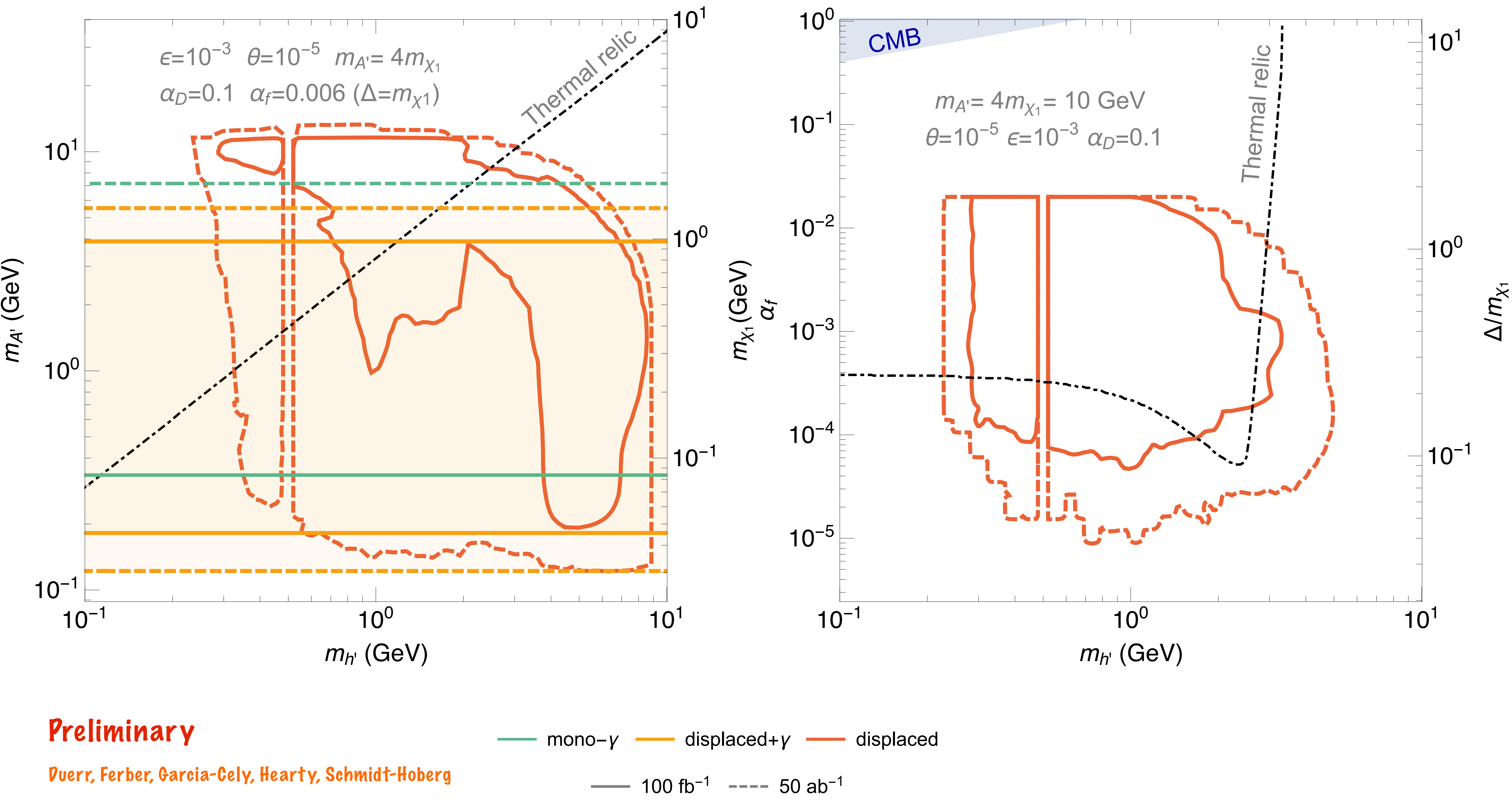

Preliminary

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Conclusions

Inelastic DM is a well-motivated thermal DM candidate at the subGeV scale, in which a mass splitting between dark matter and its excited state allows to evade stringent CMB bounds and direct detection limits.

I discussed the phenomenological impact of including a dark Higgs to generate the mass splitting and the dark photon mass.

I have investigated the sensitivity of Belle II for the key signature of this model: a lepton pair originating from a displaced vertex in association with a single photon as well as with a dark Higgs.

Preliminary Duerr, Ferber, Garcia-Cely, Hearty, Schmidt-Hoberg