# Flavorful news from the dark side of the Universe

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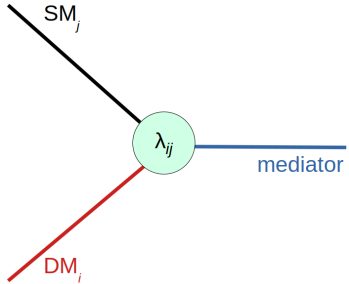
Collaborative Research Center TRR 257
Particle Physics Phenomenology after the Higgs Discovery

Exploring new physics with flavour
Karlsruhe – July 2, 2026

# What is flavored dark matter?

**Basic assumptions**

- dark matter comes in multiple generations
- dark flavor multiplet couples to SM flavor triplet via new mediator field
- new flavor-violating coupling matrix $\lambda$



# Benefits of flavored dark matter

## Rich phenomenology

- variety of signatures in collider, flavor & dark matter experiments Kile, Soni (2011); Agrawal et al. (2011) Agrawal, MB, Gemmler (2014); Chen et al. (2015); ...
- dark matter freeze-out beyond the canonical WIMP

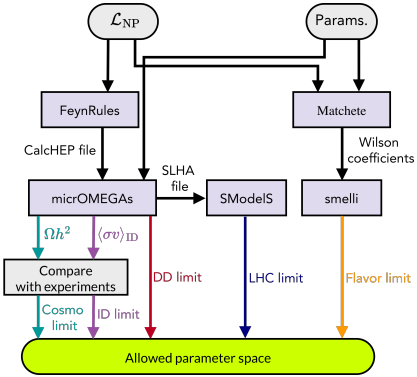
  Acaroglu, MB, Heisig, Krämer, Rathmann (2023)
- possible connection to baryon asymmetry

  Belfatto, MB, Heisig, Rathmann, Wilsch (soon)

## Toolchain

➢ connects publicly available tools for efficient study

Belfatto, MB, Heisig, Krämer, Rathmann, Wilsch (2025)



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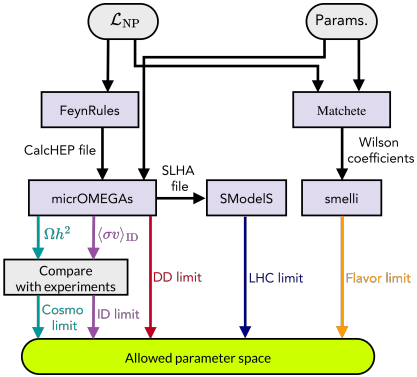
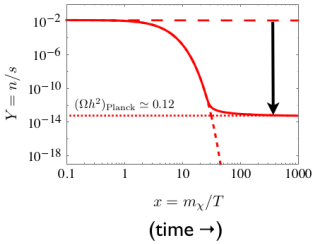
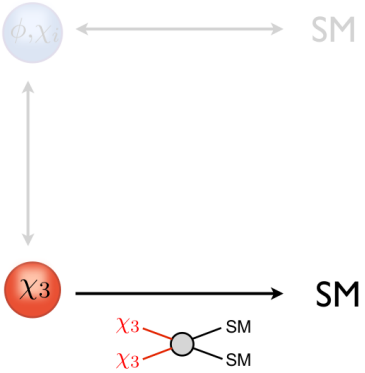


# Dark matter freeze-out

## Canonical WIMP freeze-out



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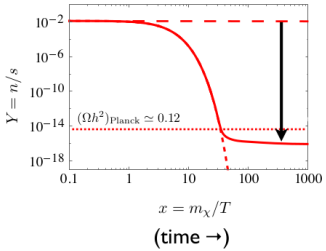


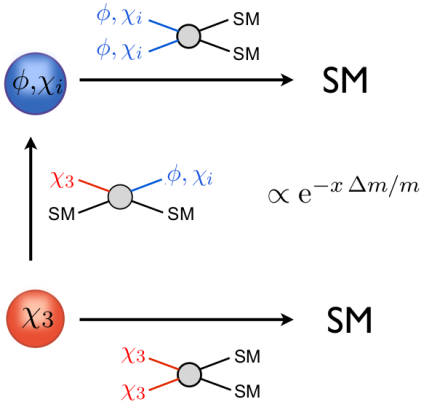


Griest, Seckel (1991); Bell, Cai, Medina (2013)

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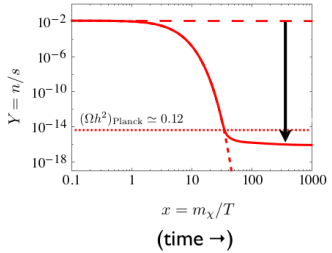


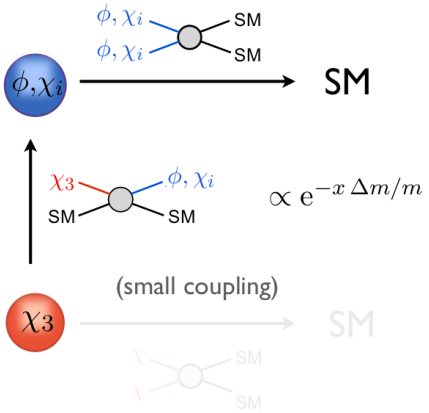


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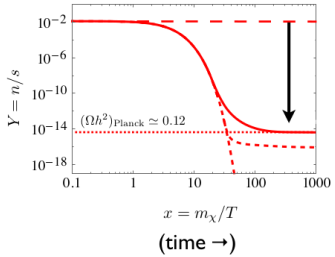
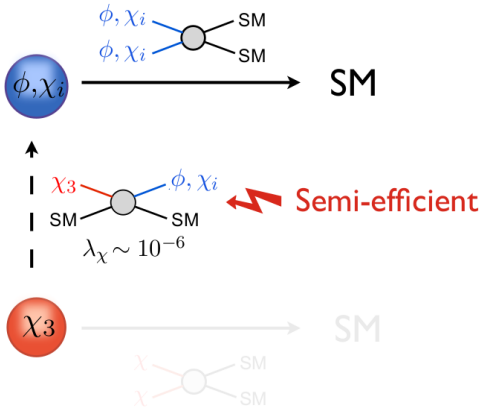
## Conversion-driven freeze-out




Garny, Heisig, Lülf, Vogl (2017); D'Agnolo, Pappadopulo, Ruderman (2017)

# Conversion-driven freeze-out

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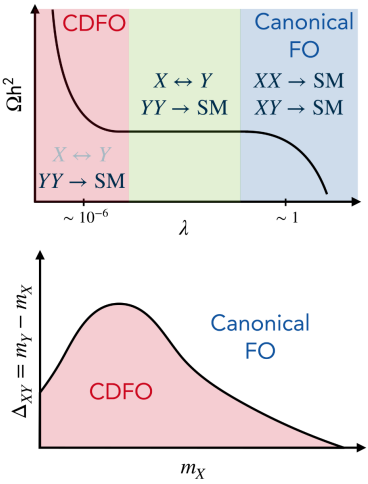
**CDFO in a nutshell**

- departure from chemical equilibrium:
  DM conversion rate $\sim$ Hubble expansion rate
  ➢ set of coupled Boltzmann equations needs to be solved for all contributing particles
- enhanced relic abundance for small mass splitting and very small DM couplings $\mathcal{O}(10^{-6})$
  ➢ enlarged viable parameter space
- flavored DM models:
  different scenarios with semi-efficient conversions between DM and heavier flavors and/or mediator

Acaroglu, MB, Heisig, Krämer, Rathmann (2023)



# Towards the baryon asymmetry

**Sakharov conditions**

1. departure from chemical equilibrium
   ➢ realized in CDFO regime
2. baryon number violation
   ➢ sphaleron processes[a] violate $B + L$ in SM sector (but conserve $B - L$)
3. C- and CP-symmetry violation
   ➢ from conversion process with CP-violating coupling

[a] non-perturbative transitions in the electroweak theory between topologically distinct vacua, active at high temperatures $T \gtrsim 130\,\text{GeV}$

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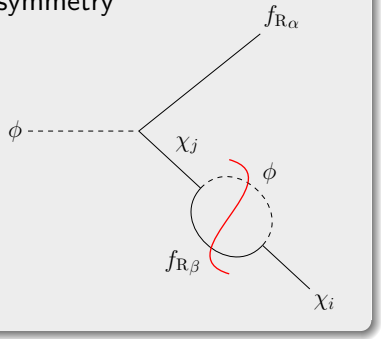
**Flavored DM**

leading contribution to CP asymmetry




➢ initial study: conversion-driven leptogenesis in lepton-flavoured DM model HEISIG (2024)

# Conversion-driven baryogenesis with quark-flavored dark matter

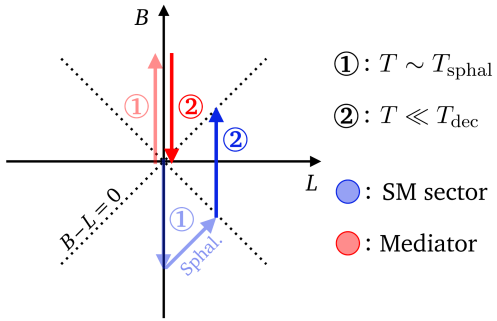
## Setup

- consider flavored Majorana DM model coupling to right-handed down-type quarks with two dark flavors $\tilde{\chi}_{1,2}$

$$\mathcal{L}_{\text{int}} = -\lambda_{ij}\bar{d}_{Ri}\tilde{\chi}_j\phi + h.c.$$

- include Sommerfeld enhancement and bound state formation effects for mediator pair-annihilation Binder et al. (2025)
- study impact of thermal effects by fully including thermal masses
  ➢ *see paper for details!*

Belfatto, MB, Heisig, Rathmann, Wilsch (soon)




PRELIMINARY

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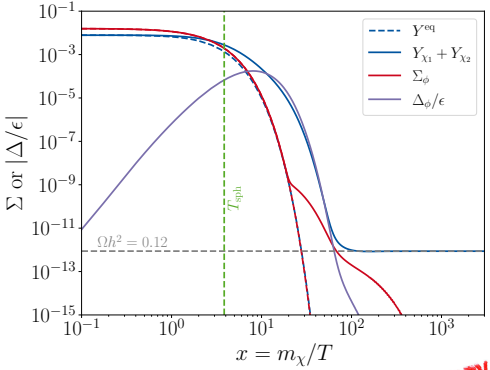
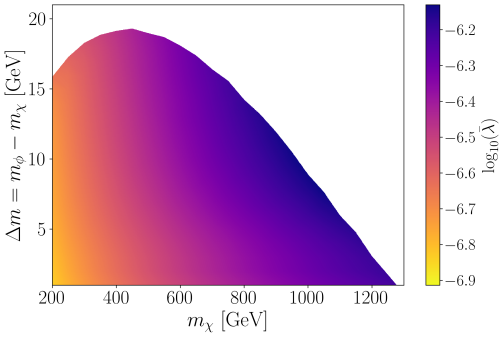


# Viable parameter space

## DM coupling strength

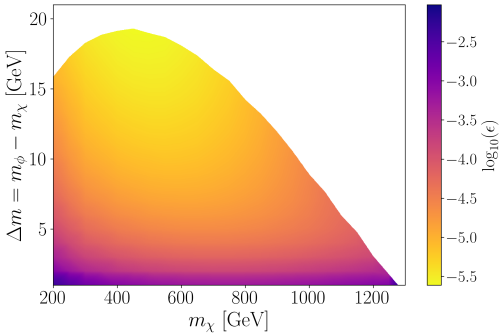
➢ drives DM relic abundance




PRELIMINARY

## CP asymmetry in mediator decay

➢ determines baryon asymmetry

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# Long-lived particle signatures

**Flavored cogenesis at the LHC** Belfatto, MB, Heisig, Rathmann, Wilsch (soon)

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- long-lived due to $\lesssim \mathcal{O}(10^{-6})$ coupling to DM

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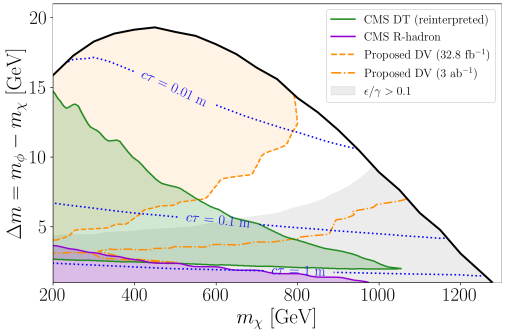
**Relevant LLP signatures**
(reinterpretation of Heisig et al. (2024))

- stable $R$-hadrons for $c\tau_\phi \gtrsim 1\,\text{m}$
- disappearing tracks for intermediate $c\tau_\phi$
- proposed displaced vertex search:
  existing ATLAS search adapted to smaller $m_{\text{DV}}$

CERN-EP-2017-202

Belfatto, MB, Heisig, Rathmann, Wilsch (soon)




PRELIMINARY

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**Milestones in a great scientist's career**

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Happy birthday Uli!