DARK SHOWERS FROM SNEAKY DARK MATTER

Pedro Schwaller
Mainz University

In collaboration with:
Adrian Carmona
Fatemeh Elahi
Christiane Scherb
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Cluster of Excellence
PRISMA+

Dark Showers Workshop

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Overview

Dark QCD with dark flavour symmetry

- Some stable dark pions, degenerate with decaying dark pions
- Relic abundance from co-scattering
- Degenerate spectrum evades indirect detection → Sneaky DM

Sneaky DM at colliders

- Dark showers with mixture of long lived and stable dark pions
- Semi-visible + emerging!
- Existing limits, and new parameter space to explore

Exploring the landscape of dark QCD models

Dark QCD with n_f dark quarks Q_α

$$\mathcal{L}_D = -\frac{1}{4}(G_D^{\mu\nu,a})^2 + \bar{Q}_\alpha i \not{D} Q_\alpha - m_{Q,\alpha\beta}\bar{Q}_\alpha Q_\beta$$

Global $SU(n_f) \times SU(n_f)$ symmetry in dark sector

$$m_{Q,\alpha\beta} = m_Q \delta_{\alpha\beta}$$

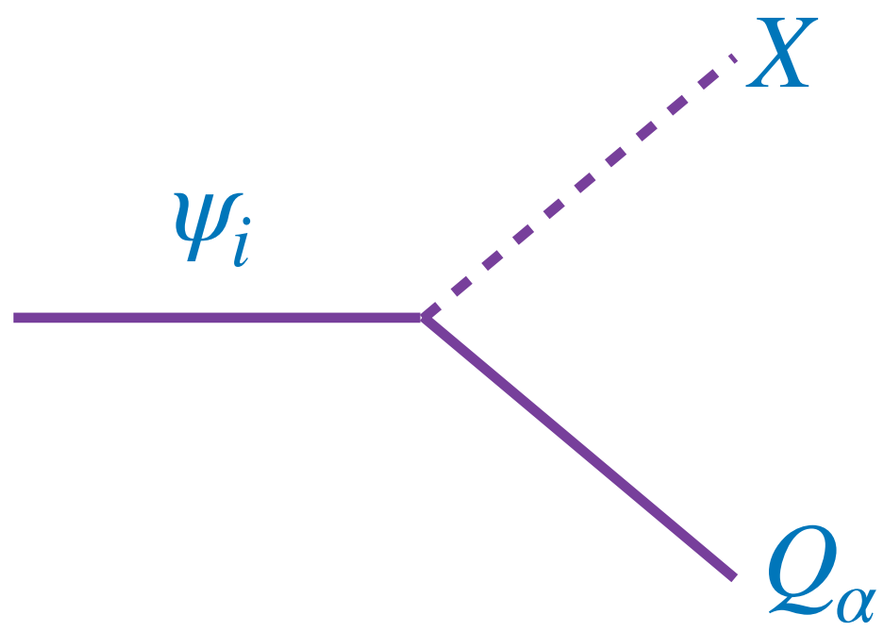
Spontaneously broken to $SU(n_f)_V$ after confinement

Today: Assume $SU(n_f)_V$ exact in dark sector, only broken by interactions with SM

Stable dark pions π_{DM}

T-channel mediator:

$$\mathcal{L}_{\text{portal}} = -\kappa_{\alpha i}\bar{\psi}_i Q_\alpha X + \text{h.c.}$$



SM fermion $\psi_i = u_i, d_i, q_i$ today

For $n_f \geq 4$, this results in stable dark pions π_{DM} if $SU(n_f)_V$ is unbroken:

$$\kappa = V\, D\, U$$

Unitary $n_f \times n_f$

Diagonal

Unitary 3×3

V absorbed by $SU(n_f)_V$ rotation!

$$\Longrightarrow \kappa = \begin{pmatrix} \cdot & \cdot & \cdot & 0 \\ \cdot & \cdot & \cdot & 0 \\ \cdot & \cdot & \cdot & 0 \end{pmatrix}$$

Stable dark pions π_{DM}

Symmetry argument: κ breaks $SU(n_f)_V$ to

$$SU(n_f)_V \to SU(n_f - 3) \times U(1) = G_{DM}$$

$n_f^2 - 1$ dark pions, some of which transform non-trivially under G_{DM} → stable

Focus on $n_f = 4$! Dark pions $\pi_{\alpha\beta} \sim Q_\alpha \bar{Q}_\beta$ are stable if $\alpha \in 1,2,3$ and $\beta = 4$, or vice versa

π_{DM} (6 states, stable), π_{tran} (9 states, decaying)

DM phenomenology

Rapid interactions $\pi_{DM}\pi_{DM} \leftrightarrow \pi_{\text{tran}}\pi_{\text{tran}}$

With $\pi_{\text{tran}} \rightarrow \text{SM}$ decays in equilibrium

- Co-decaying/impeded dark matter[1]

$$\langle \sigma v \rangle \approx \frac{m_{DM}^2}{f_D^4} v$$

See e.g.
Dror et al, 1607.03110
Kopp et al, 1609.02147

- Good relic abundance for $m_{DM} = \text{GeV} - 10\ \text{TeV}$, independent of mediator

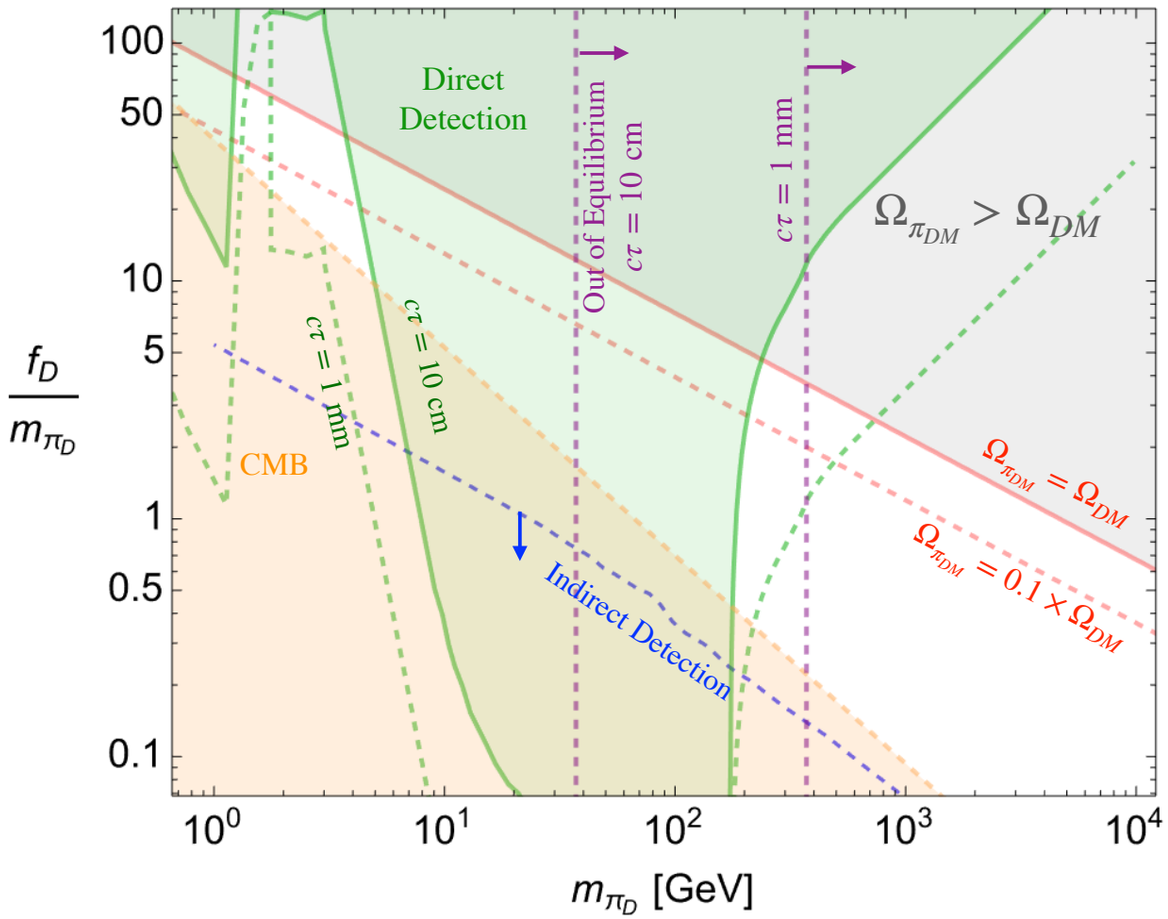
Velocity dependence suppresses indirect detection (sneaky!)

Direct detection rate is related to lifetime of π_{tran}

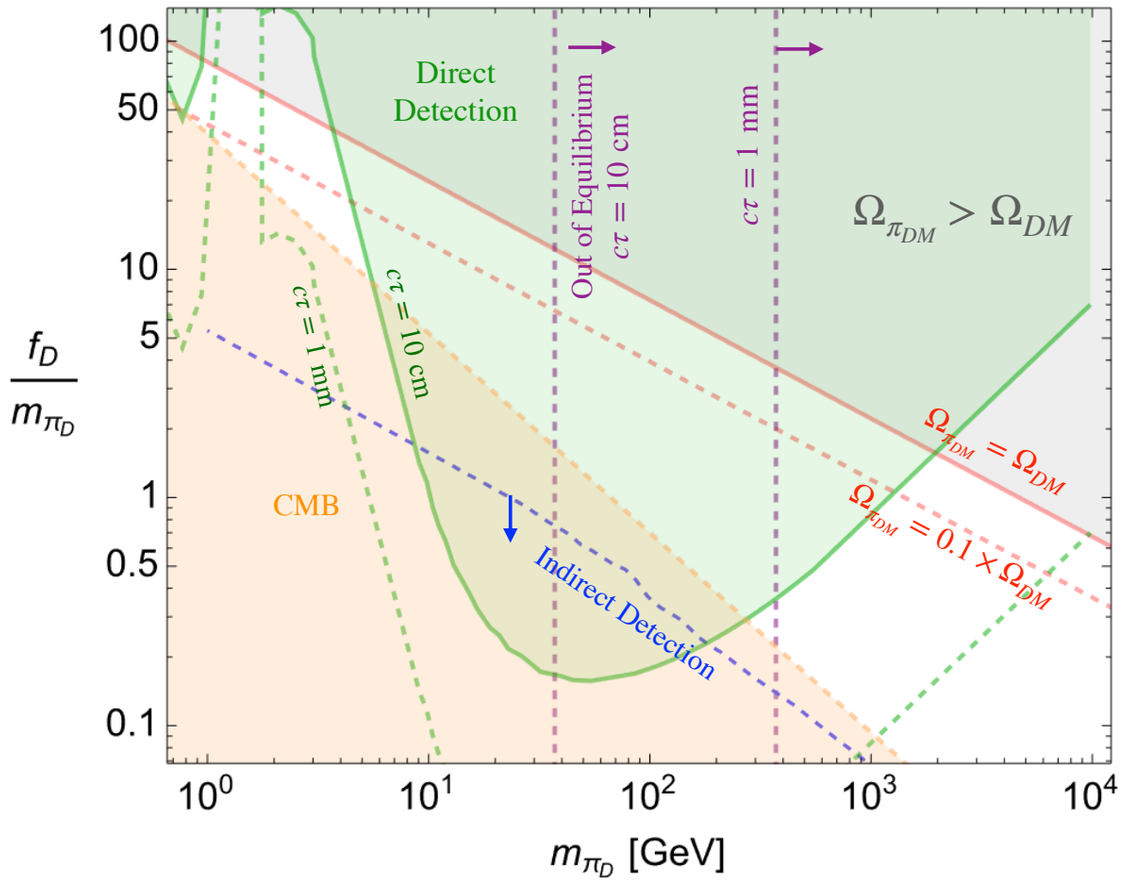
$$\sigma_{\text{SI}} \sim \frac{\kappa^4}{m_X^4}$$

[1]Note: $3 \rightarrow 2$ negligible

DM phenomenology



Coupling to up quarks



Down quarks

Nice motivation to explore cm - m lifetimes 😊

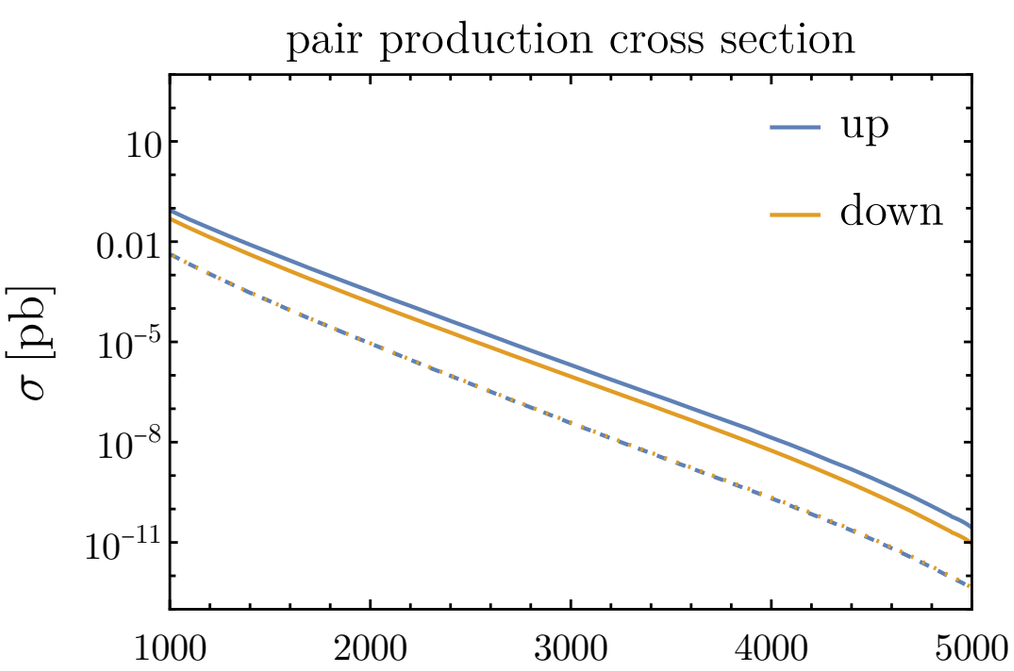
Dark showers from sneaky DM

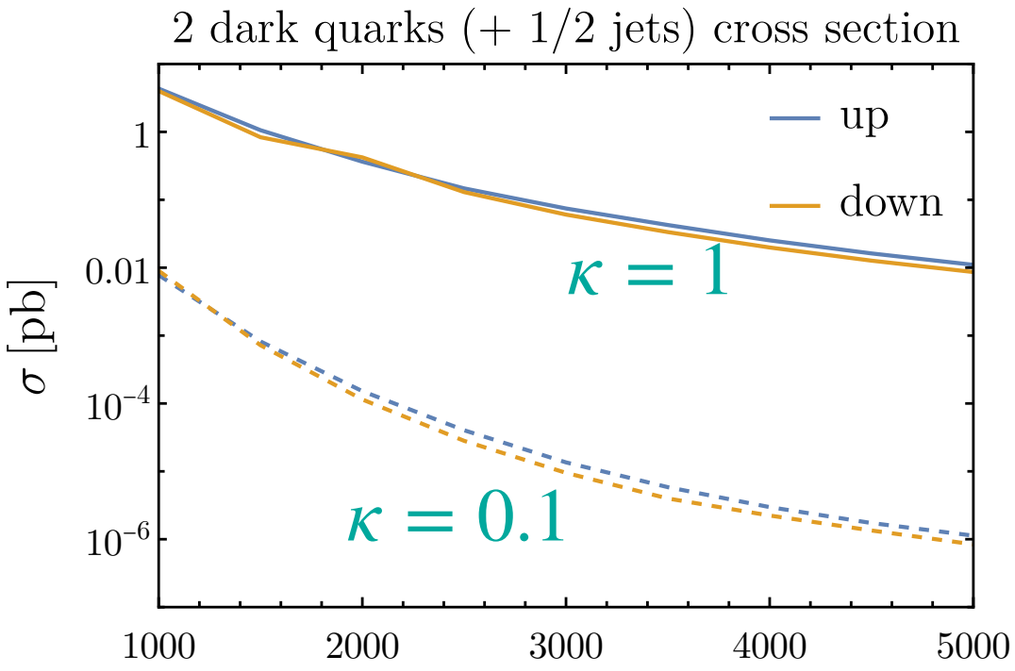
Dark showers in 2017 (LLP workshop)

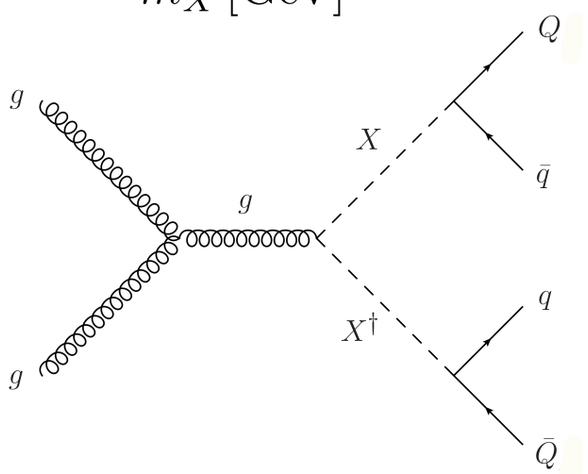
Dark showers in 2025

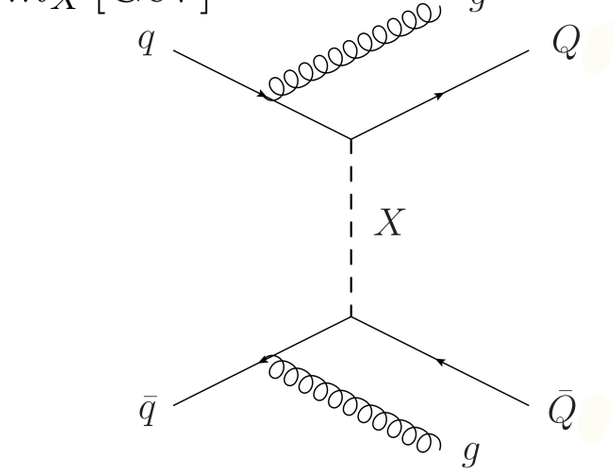
LHC signals

Pair production of X, or direct production of dark quarks









What is in the shower?

X only couples to Q_{1-3}

In dark shower and dark hadronization: Equal probability to form $Q_\alpha \bar{Q}_\alpha$ pairs for $\alpha = 1 - 4$ (or n_f)

The dark shower now contains dark matter, with a fraction determined by n_f ($\approx 1/3$ for $n_f = 4$)

R_{inv} depends in addition on $c\tau$ for the transient dark pions

Existing limits

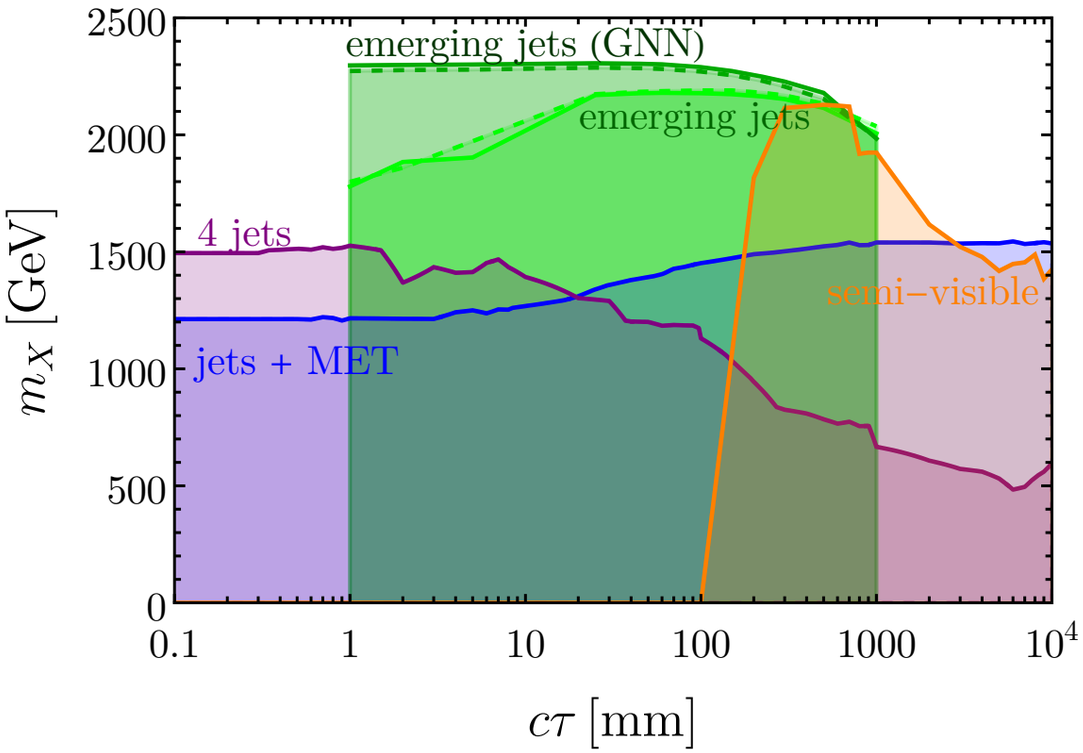
There is now always MET, even for small $c\tau$

4 jet searches are sensitive for small $c\tau$

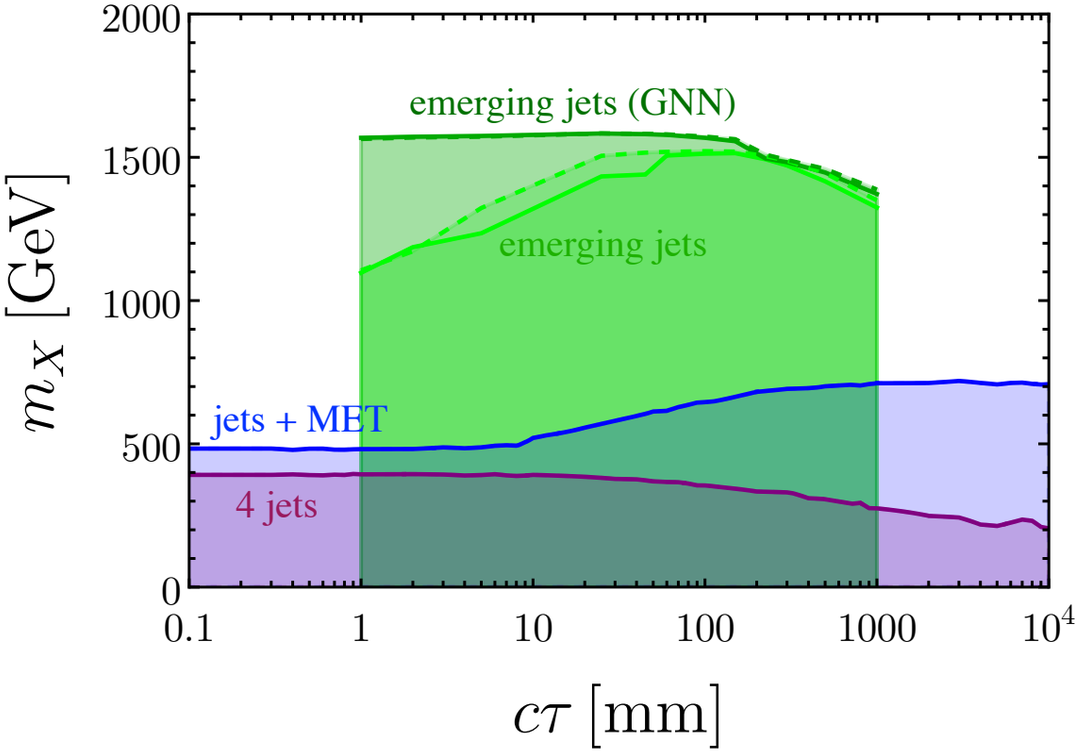
Emerging jets

Semi-visible jets

Existing limits (up quark coupling)

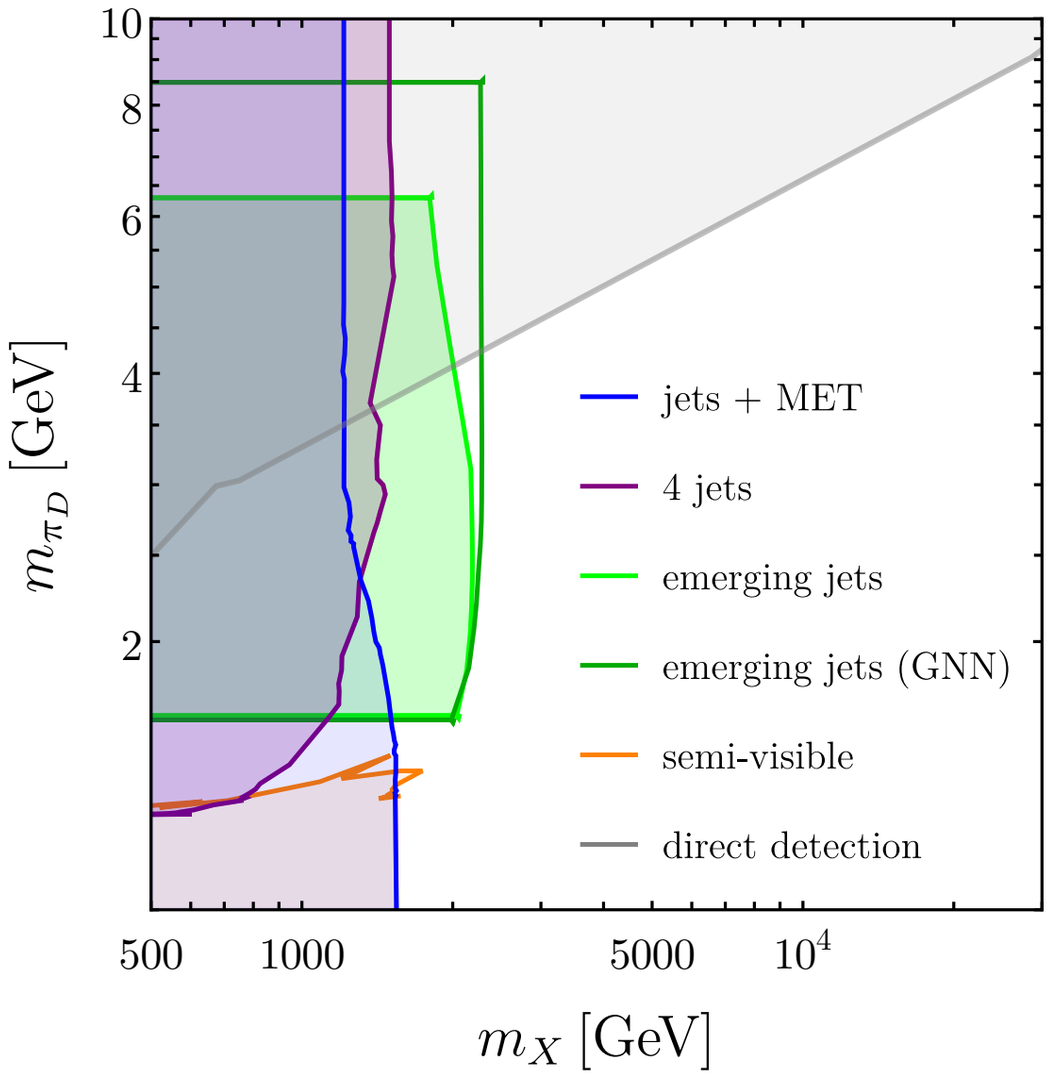


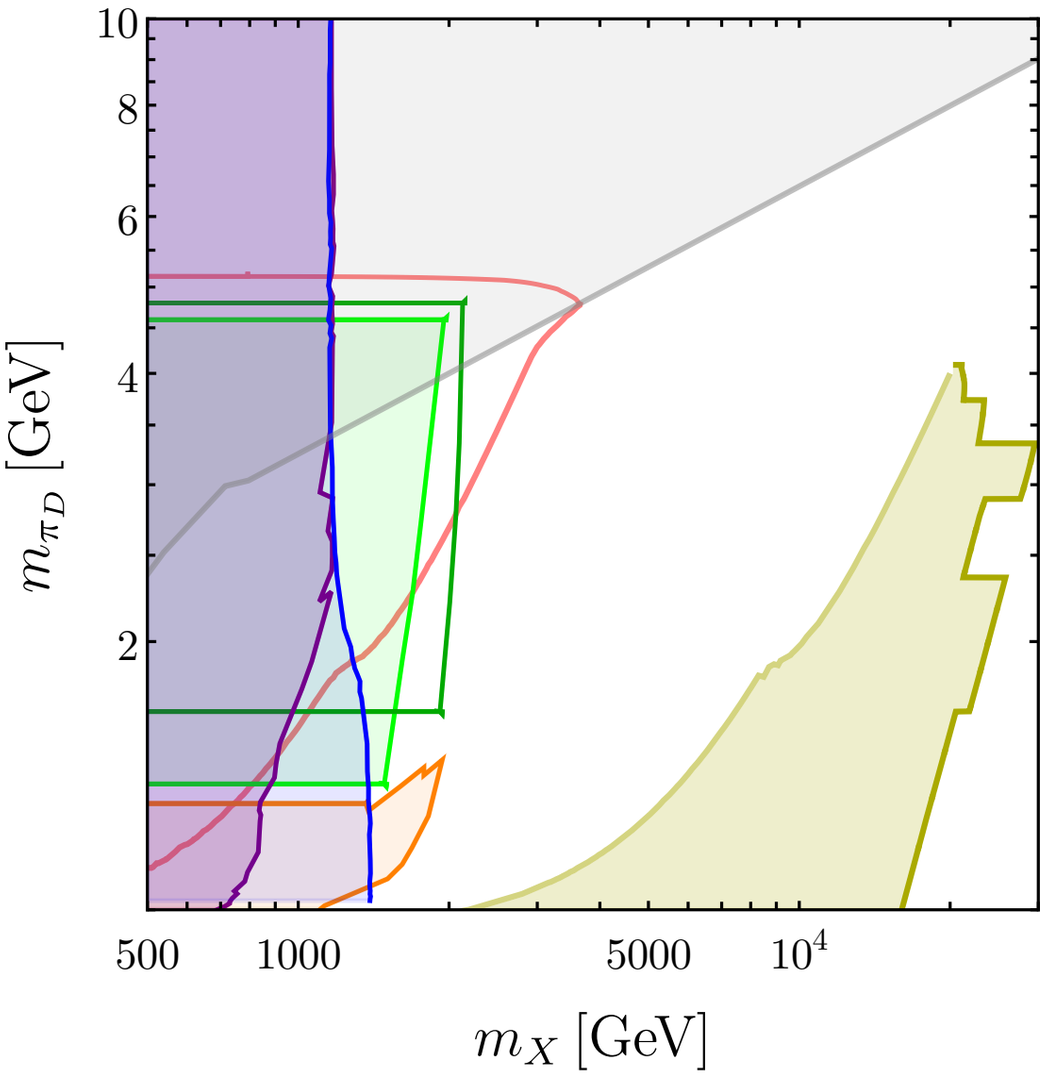
$\kappa = 1$



$\kappa = 0.1$

DM vs. Colliders vs. Flavour





Summary

Sneaky DM is a minimal scenario for DM in dark QCD theories (e.g. no asymmetry generation needed)

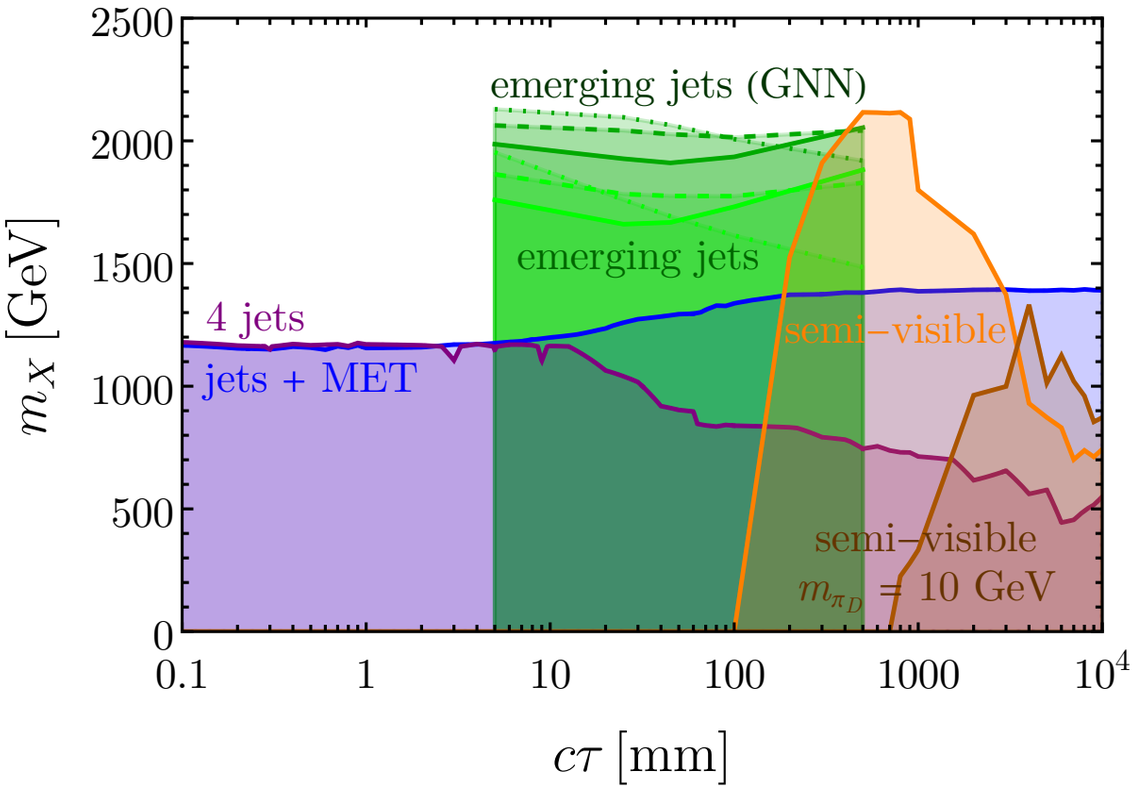
Existing constraints motivate few GeV mass window and macroscopic dark pion lifetimes

Emerging jets and semi-visible jets searches cover regions of parameter space

Benchmarks (parameter ranges) for further searches -> see paper

Combination of EJ and SVJ strategies could be powerful!

Existing limits (down quark coupling)



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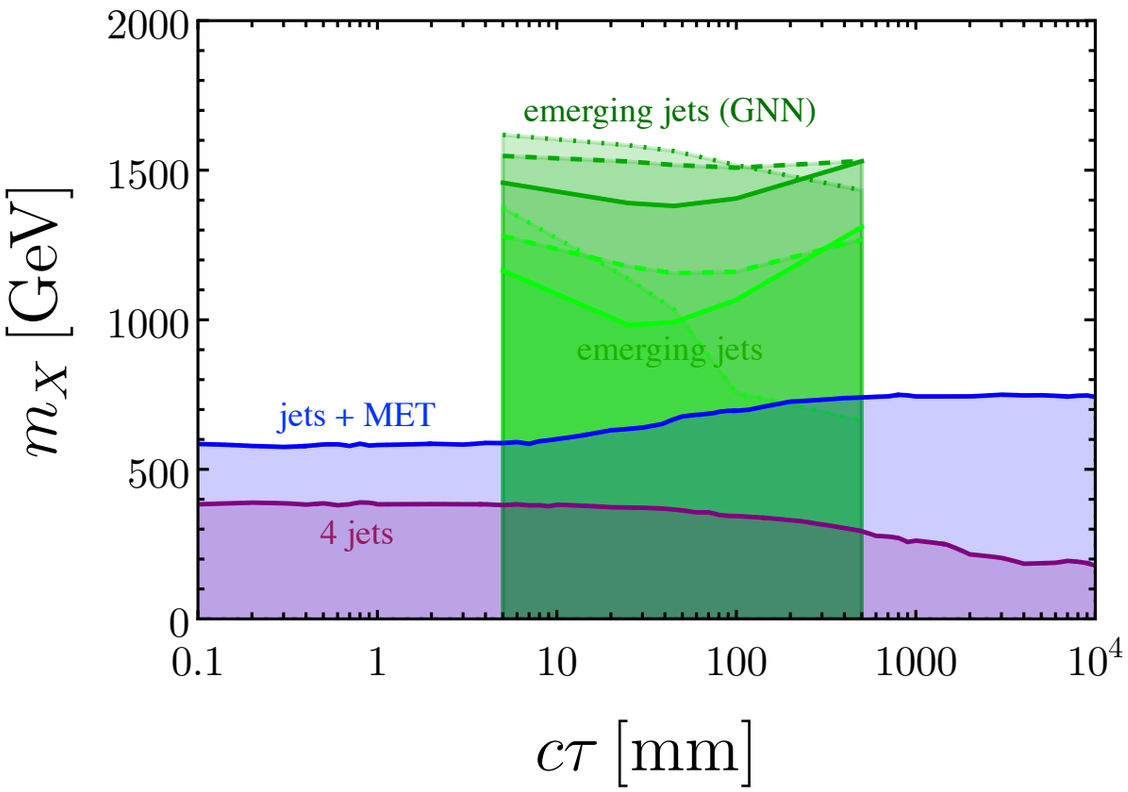

$\kappa = 0.1$