Theory overview on dark showers

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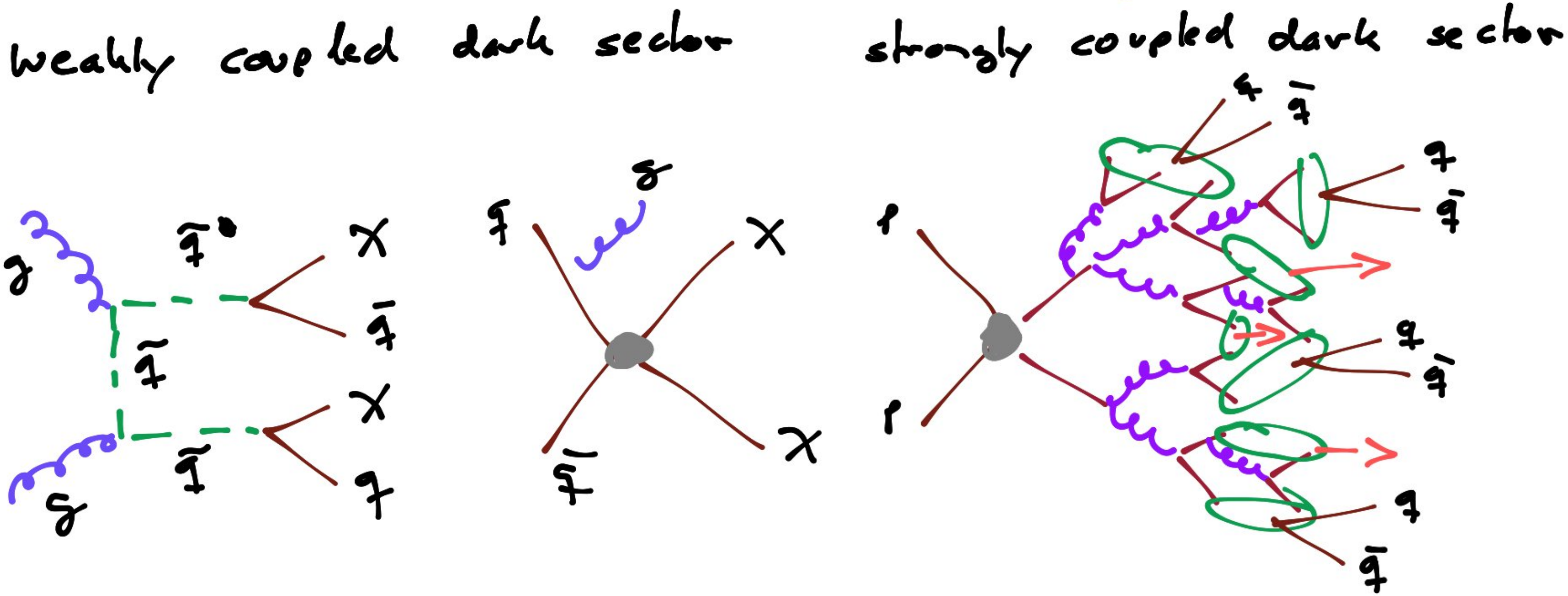
Why dark showers?

dark showers are a feature/signature of confining dark sectors



Why dark showers?

dark showers are a feature/signature of confining dark sectors

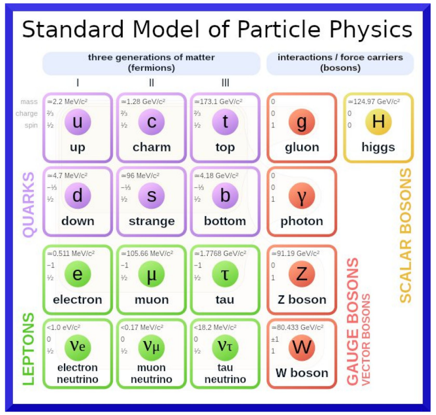
Strassler, Zurek '06

Hidden Valley models/QCD-like dark sectors

$\longrightarrow$ sector of SM neutral particles connected via a portal

- produced in SM collision
- include states that decay within 1 s lifetime
- have self interactions
- unusual collider pheno

Hidden Valley models



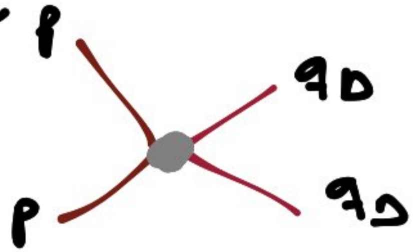
QCD-like Dark Sector

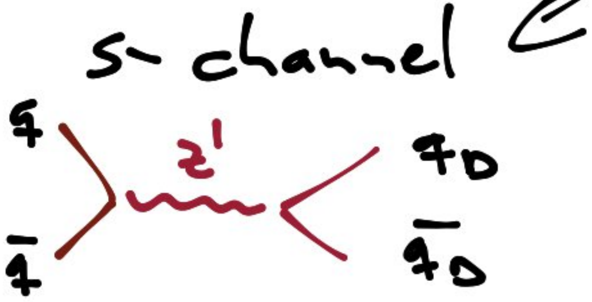
$\mathcal{G}_{SM} \times SU(N_D)_D$

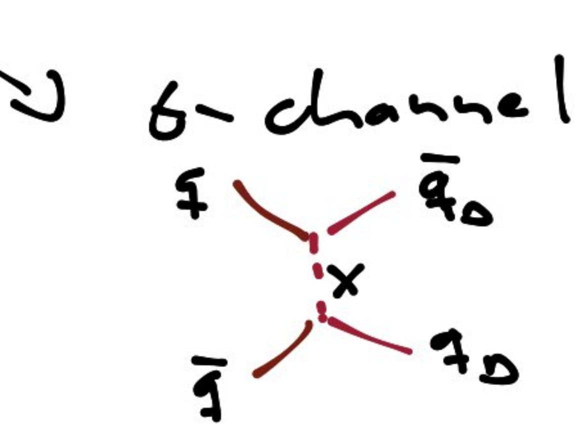
n_D dark quarks Q_D

N_D dark colours

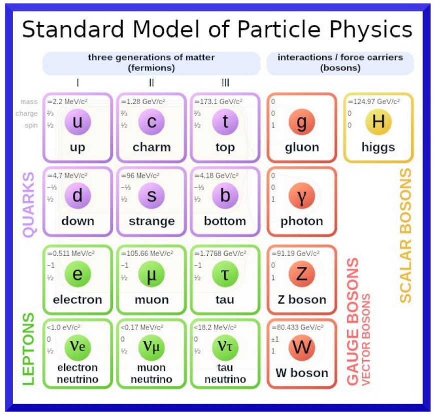
Portal







Hidden Valley models



QCD-like Dark Sector

$\mathcal{G}_{SM} \times SU(N_D)_D$

n_D dark quarks Q_D

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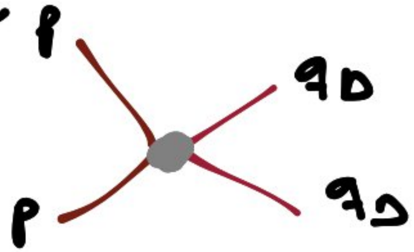
Portal

s-channel



t-channel

→ connection to flavor

- neutral meson mixing
- $B \to K \pi_D$, $B \to \pi \pi_D$
  $K \to \pi \pi_D$, $D \to \pi \pi_D$

Hidden Valley Models: dark pions

$$\mathcal{L}_{dQCD} = \bar{Q}_\alpha \left(i\not{D} - m_{Q_D}\delta_{\alpha,\beta} \right) Q_\beta - \frac{1}{4} G^A_{D_{\mu\nu}} \tilde{G}^{\mu\nu A}_D$$

for small m_Q: approximate $SU(3)_{d_L} \times SU(3)_{d_R}$

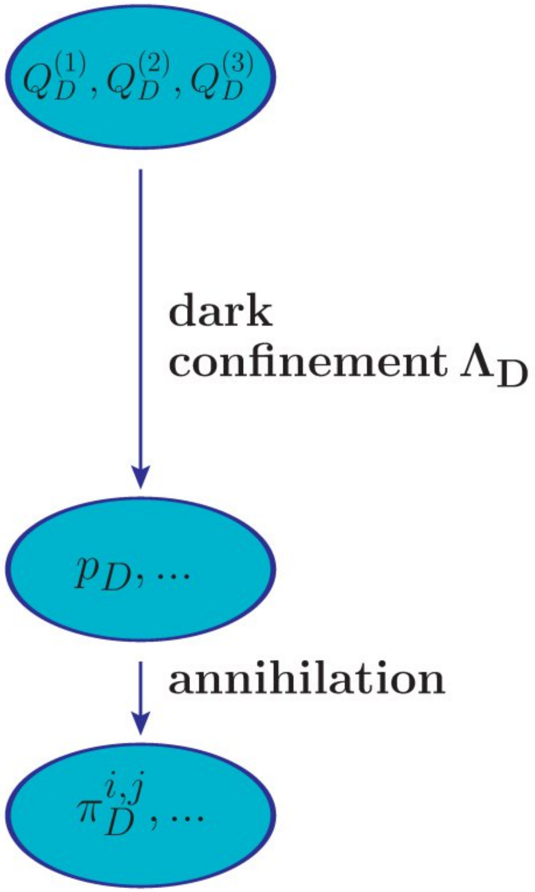
$\downarrow$

broken by dark quark condensate to $SU(3)_V$

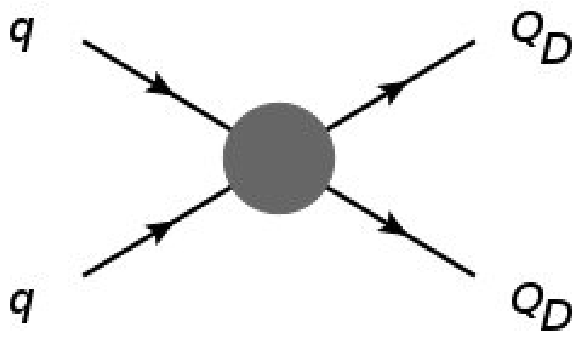
$\downarrow$

8 pseudo-Nambu-Goldstone bosons

Dark Pion	Dark Quark Content
$\pi_D^{(1,2)}$	$\bar{Q}_{D2} Q_{D1}$
$\pi_D^{(1,3)}$	$\bar{Q}_{D3} Q_{D1}$
$\pi_D^{(2,3)}$	$\bar{Q}_{D3} Q_{D2}$
π_D^3	$\frac{1}{\sqrt{2}} \left[\bar{Q}_{D1} Q_{D1} - \bar{Q}_{D2} Q_{D2} \right]$
π_D^8	$\frac{1}{\sqrt{6}} \left[\bar{Q}_{D1} Q_{D1} + \bar{Q}_{D2} Q_{D2} - 2\bar{Q}_{D3} Q_{D3} \right]$



Dark jets



dark sector shower

↓

dark sector hadronization

↓

dark hadron decay

↓

SM shower

↓

SM hadronization

Dark jets

QCD-like: SU(N) with $F \ll 3N$

- $m \lesssim \Lambda$ $\longrightarrow$ understood, pythia fine
- $m \gtrsim \Lambda$ $\longrightarrow$ somewhat

understood, not in pythia e.g. Curtin et al

less QCD-like: SU(N) with $F \gg 3N$

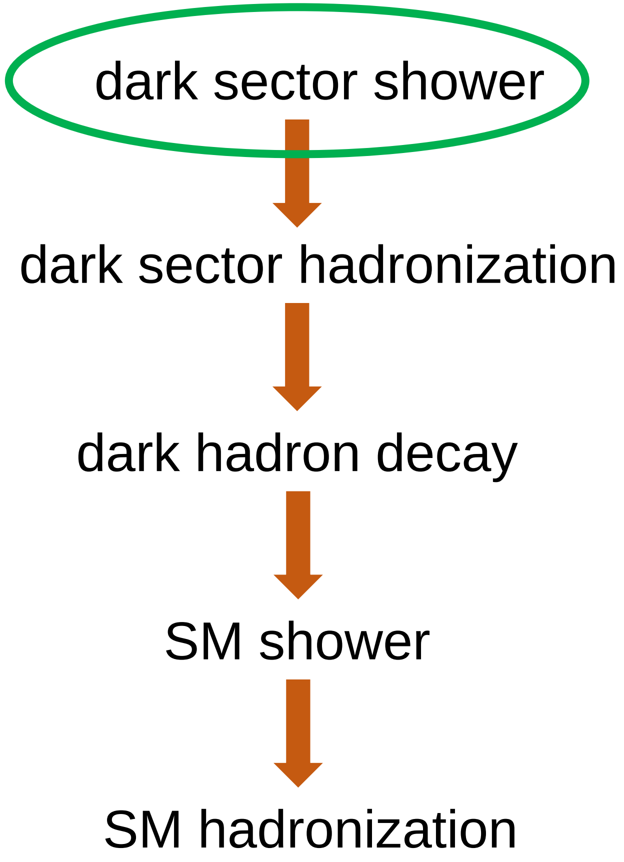
- equal m $\longrightarrow$ somewhat understood,

not in pythia

unequal m (many large some small)

$\longrightarrow$ understood, not in pythia yet

poster by
Joshua Lockyer



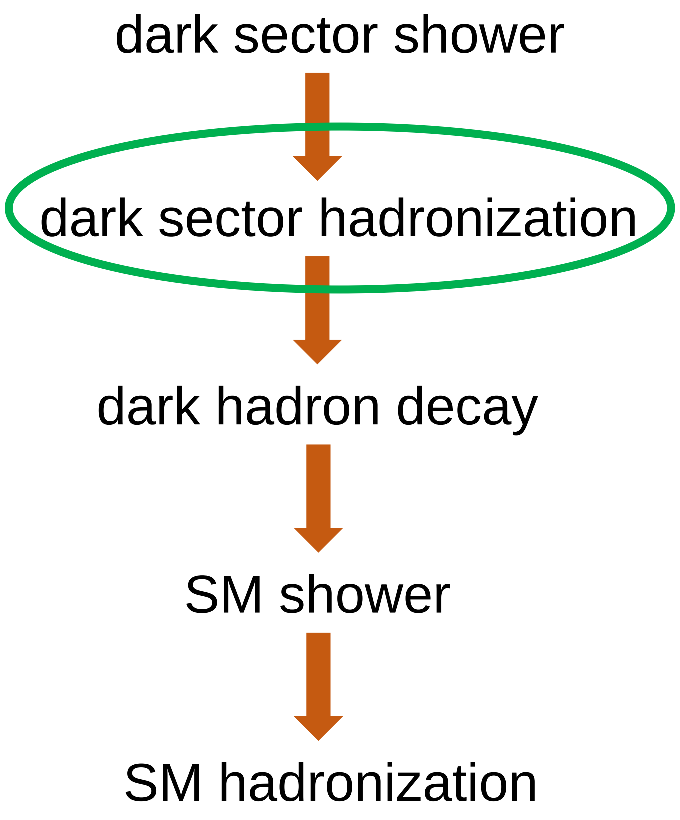
Dark jets

- non-perturbative, unknown
- Lund string fragmentation in pythia

$$f(z) = \frac{1}{z^{1+r_{Q_D} b_{m^2_{Q_D}}}} (1-z)^{a_L} \exp\left(\frac{-b^2_{m^2_{Q_D}}}{z}\right)$$

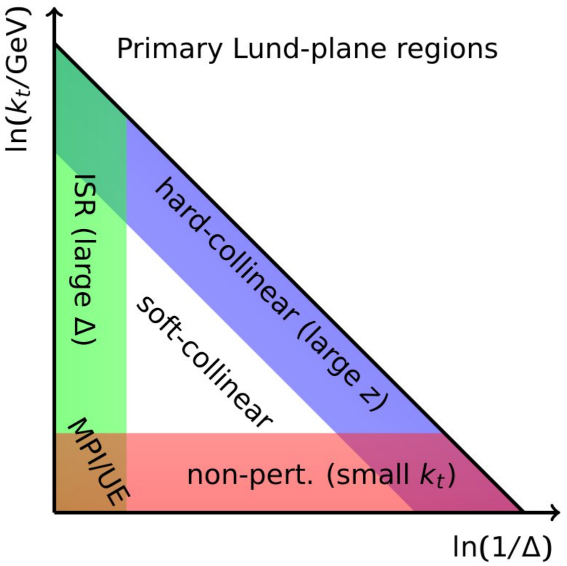
- observables can depend on hadronization parameter choice

Cohen, Roloff, CS ‘23‘

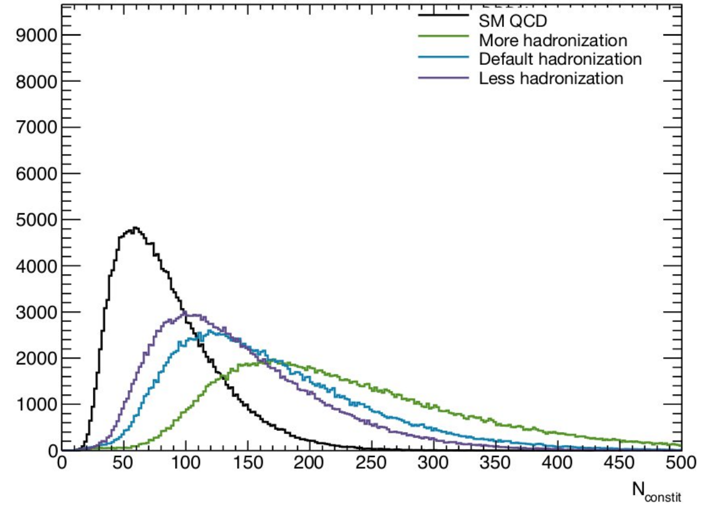


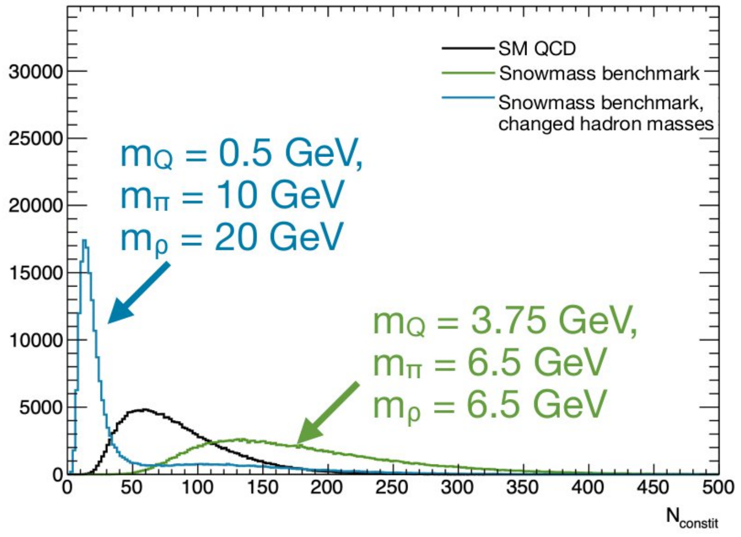
Dark hadronization

- changing hadronization parameters can change observables
- Lund jet plane useful to separate haronization dependent region



Dreyer, Salam, Soyez ‘18



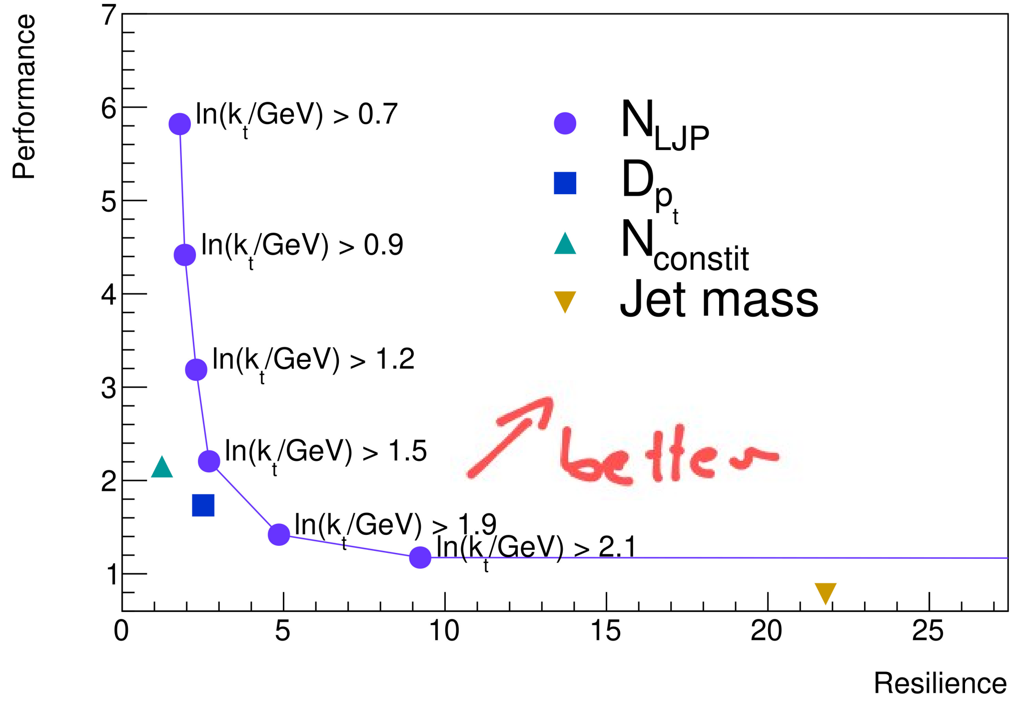


Dark hadronization

- changing hadronization parameters can change signature
- Lund jet plane useful to separate haronization dependent region

Dreyer, Salam, Soyez

- allows to construct hadronization independent observables

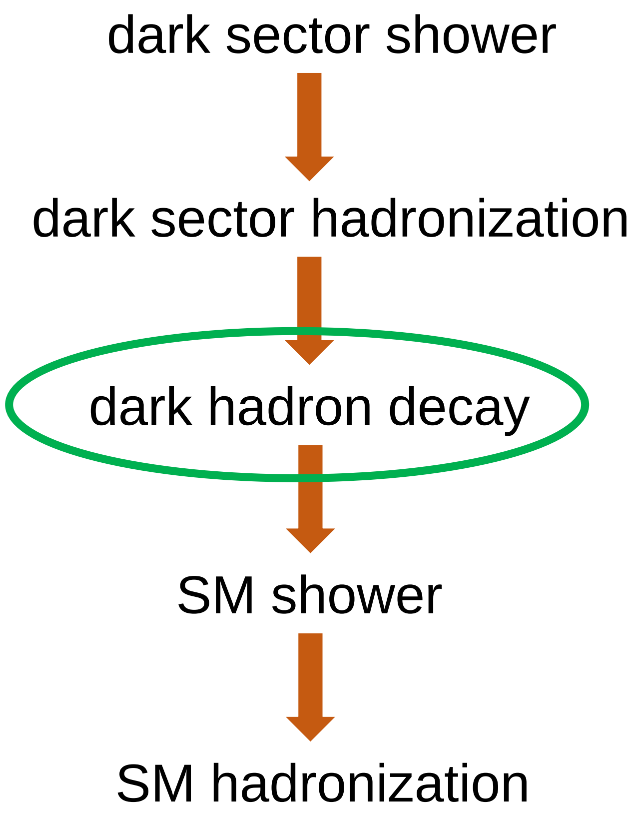


Cohen, Roloff, CS ‘23

Dark jets

- model dependent
- calculate and implement

$\longrightarrow$ pythia ok



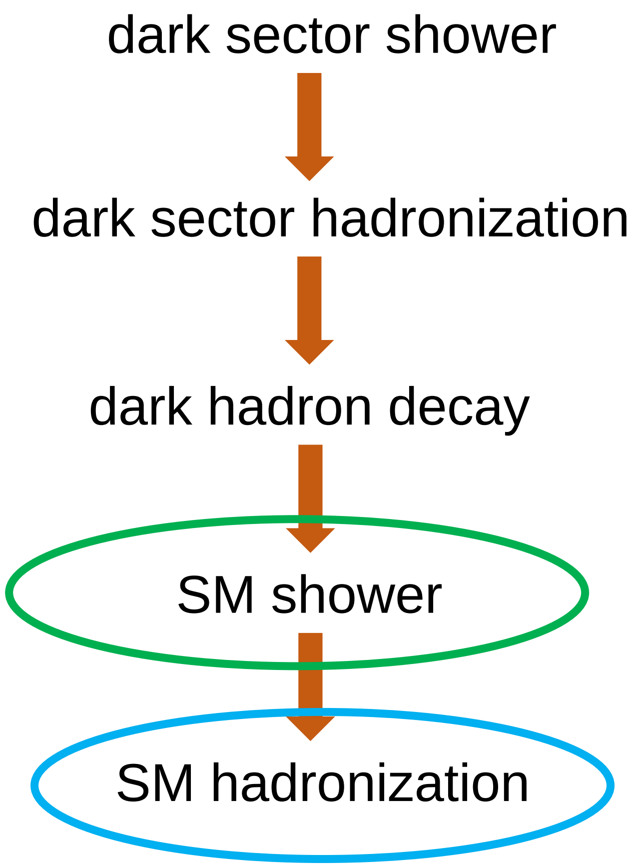
Dark jets

• SM shower understood

⟶ pythia ok

• SM hadronization non-perturbative, but (mostly) known

⟶ pythia ok

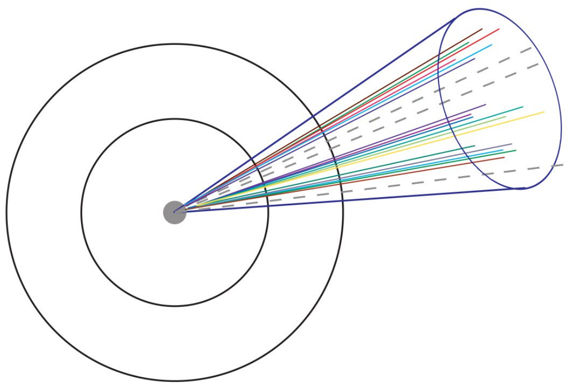


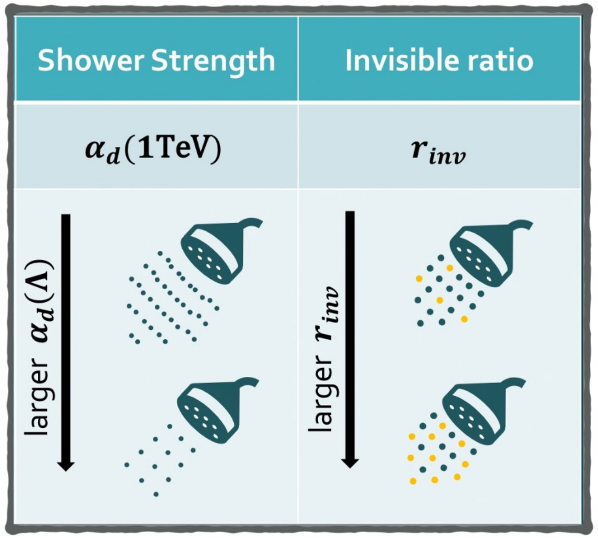
Signatures

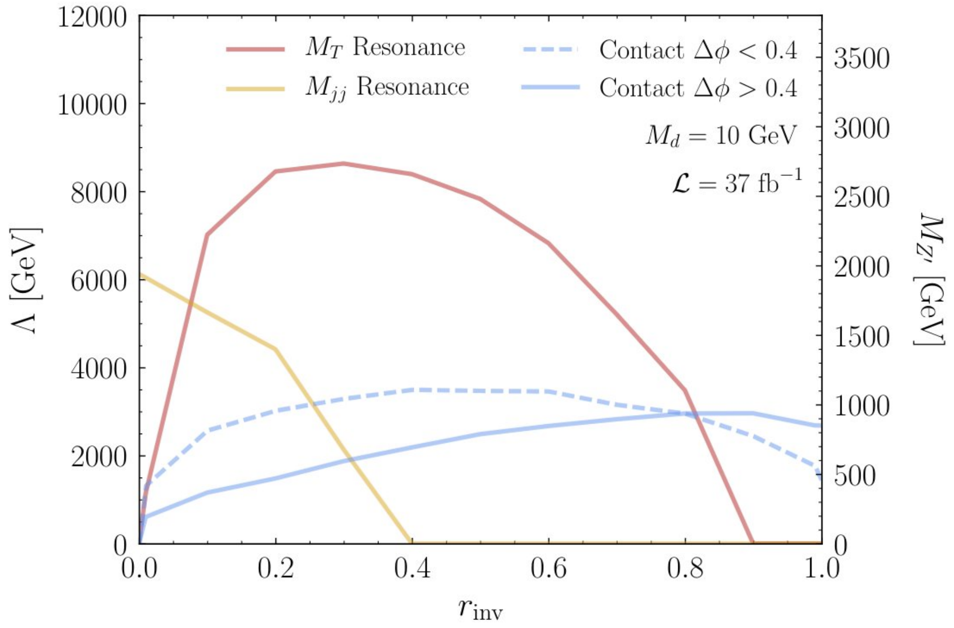
- semi-visible jets
- lepton jets
- emerging jets
- soft unclustered energy patterns (SUEPs)
- quirks
- ...

Semi-visible jets

- multiple neutral particles decaying to SM
- stable ones $\longrightarrow$ MET



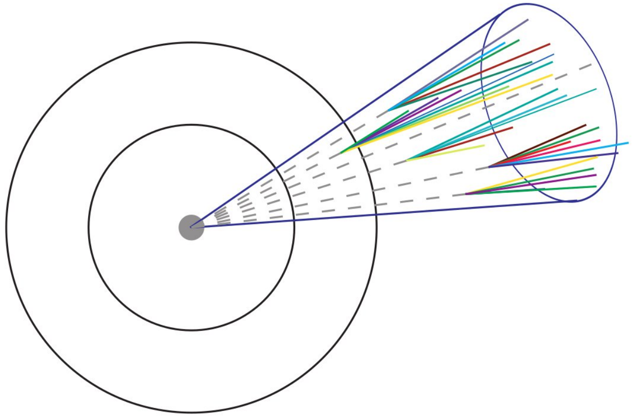


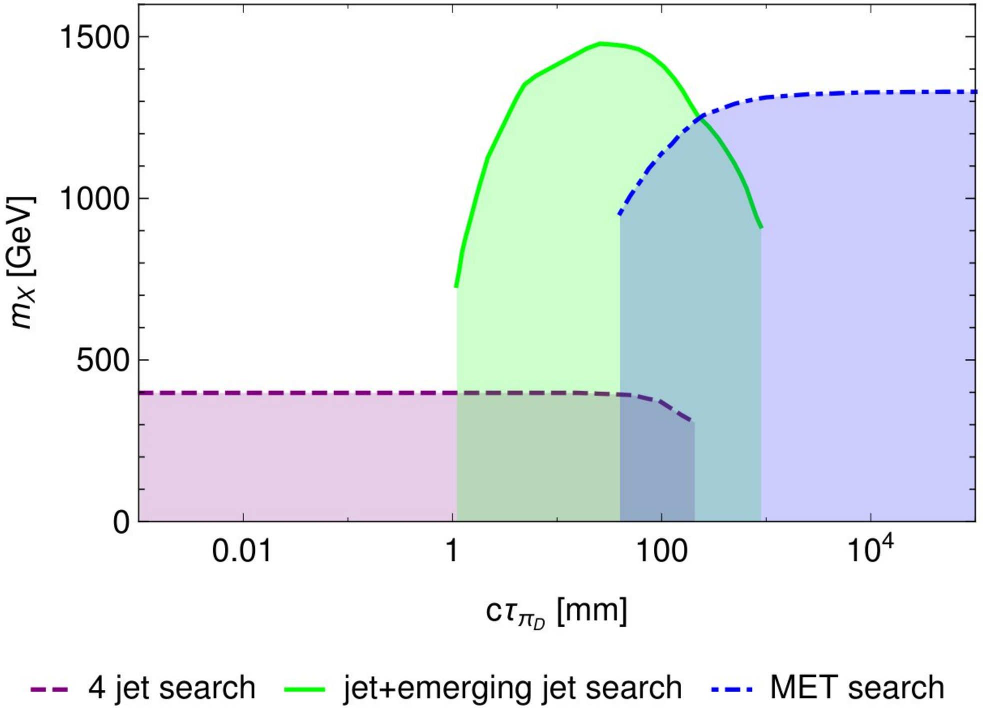


Cohen, Lisanti, Lou ‘15
Cohen et al ‘17

Emerging jets

- multiple neutral particles decaying to SM
- stable ones $\longrightarrow$ MET
- displaced vertices



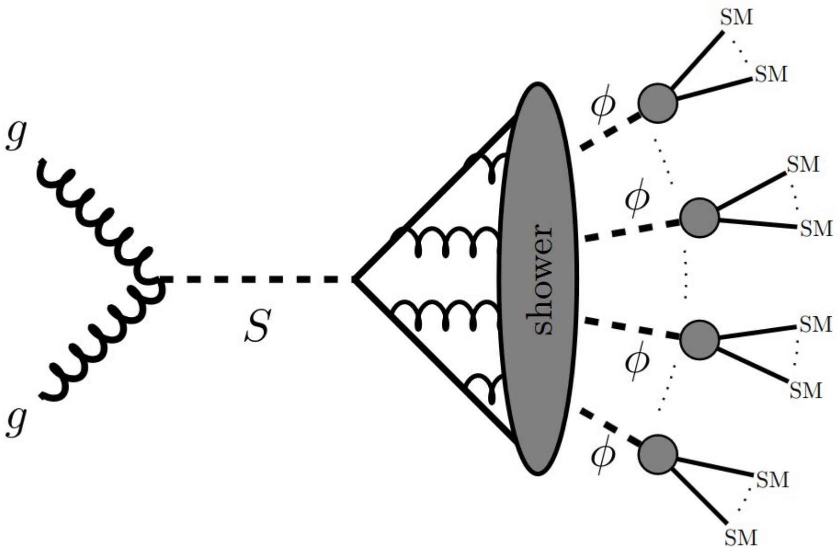


Schwaller, Stolarski, Weiler ‘15
Mies, CS, Schwaller ‘20

SUEPs

- coupling close to confinement scale

$\longrightarrow$ gluon radiation at larger angles



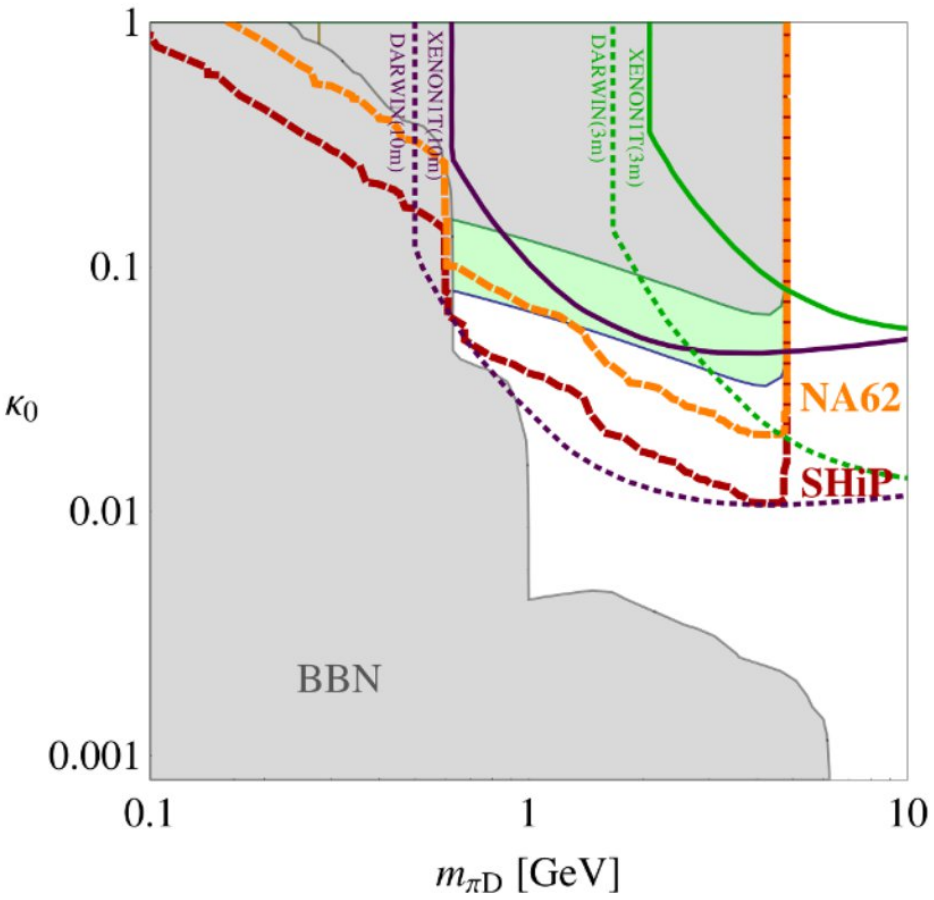
Knapen et al ‘16

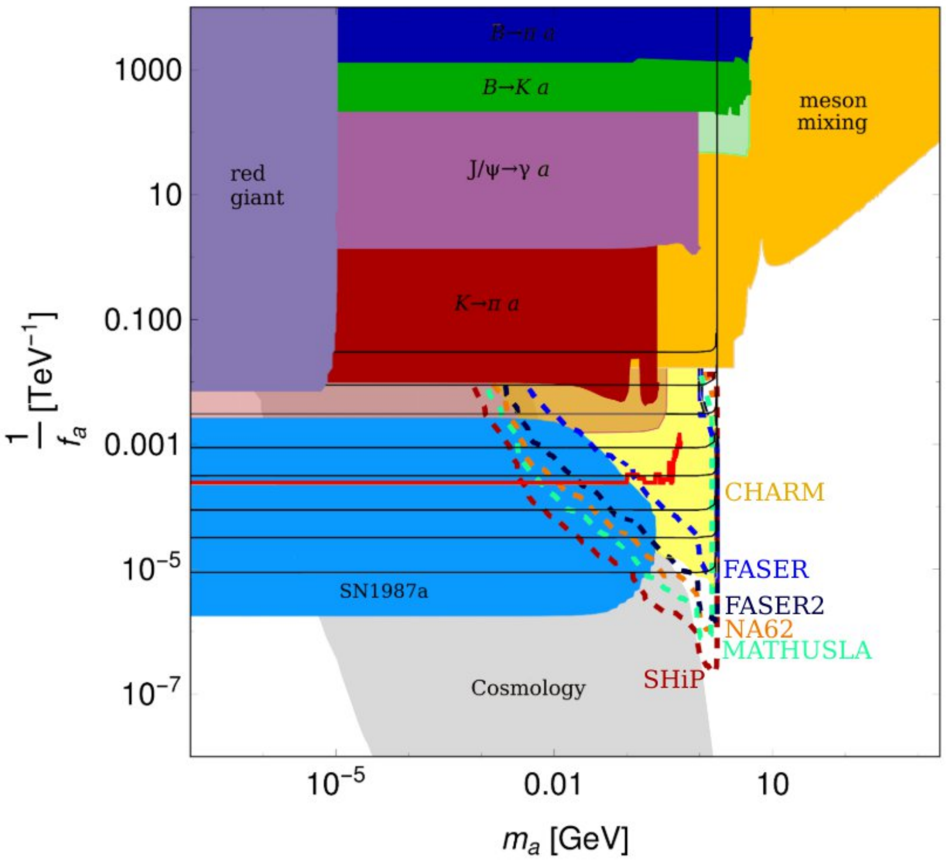
Summary

- realistic dark sectors are rich, but complicated
- collider pheno done piecewise
- difficult to capture full breadth

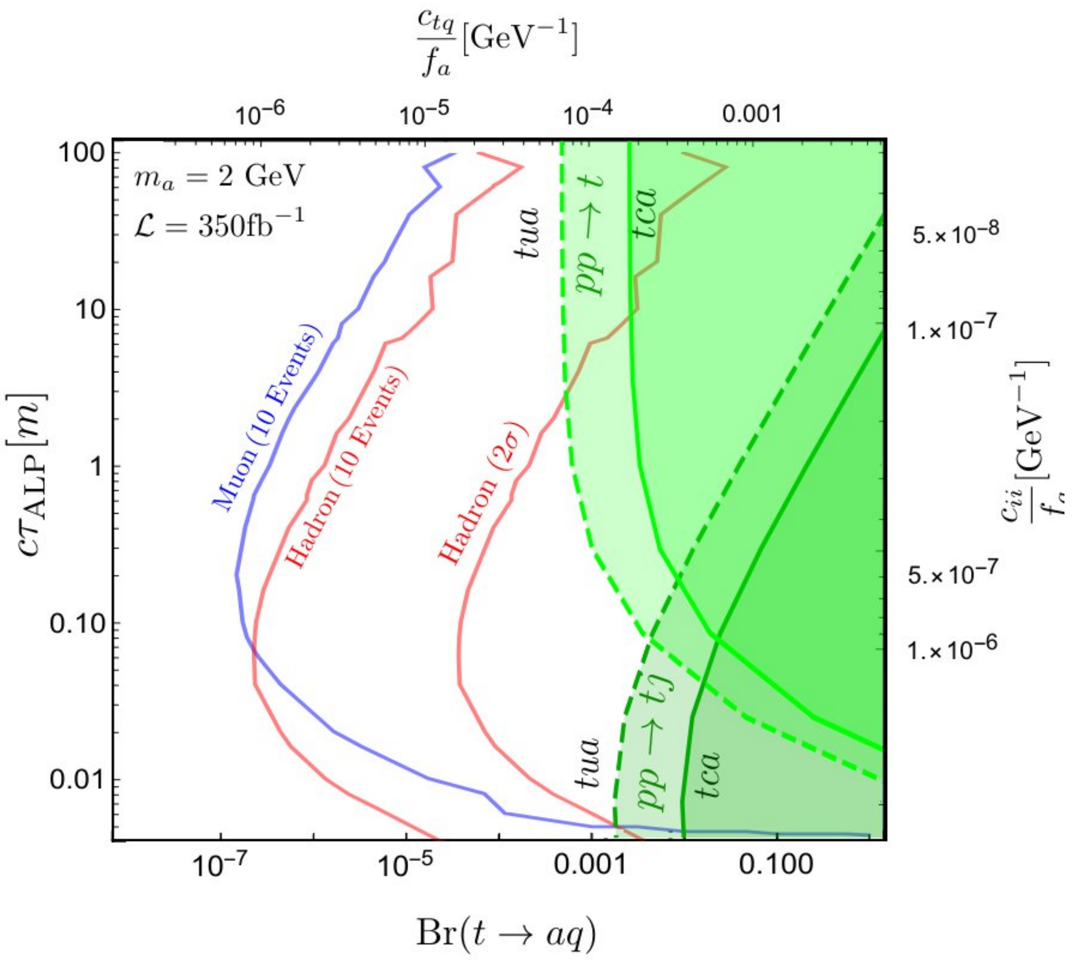
- great progress on simulation and experimental side!

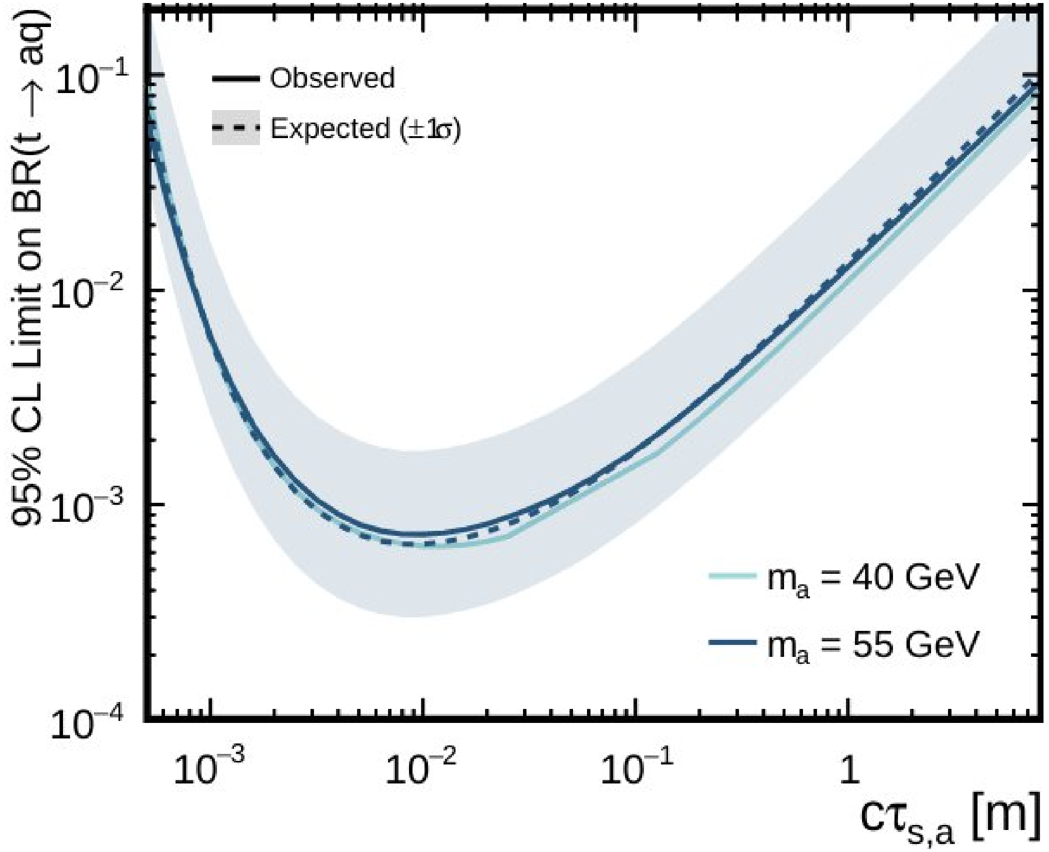
Flavor pheno





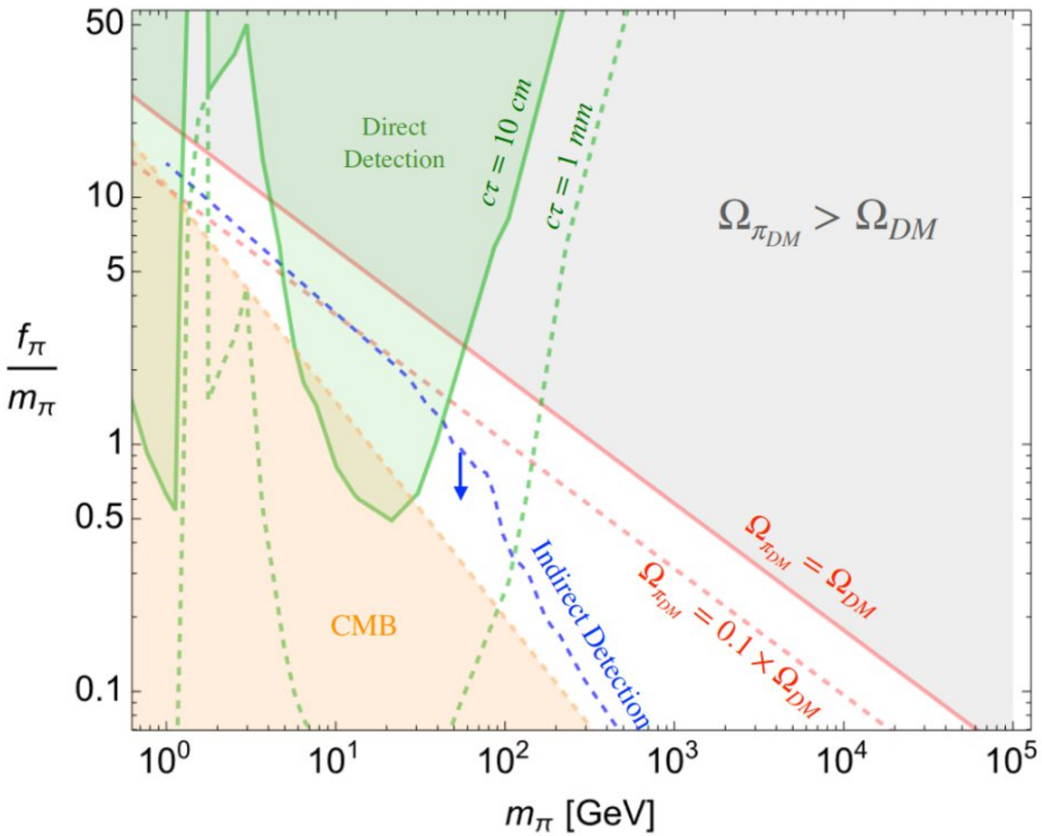
Dark pions from top decays



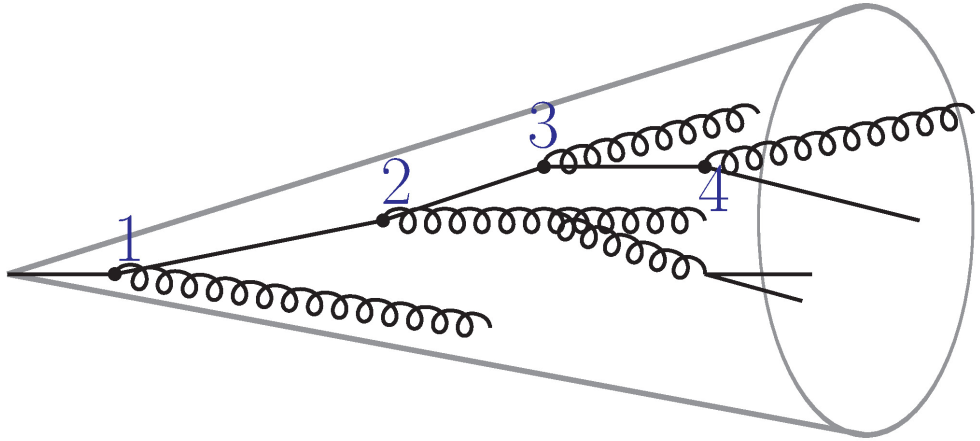


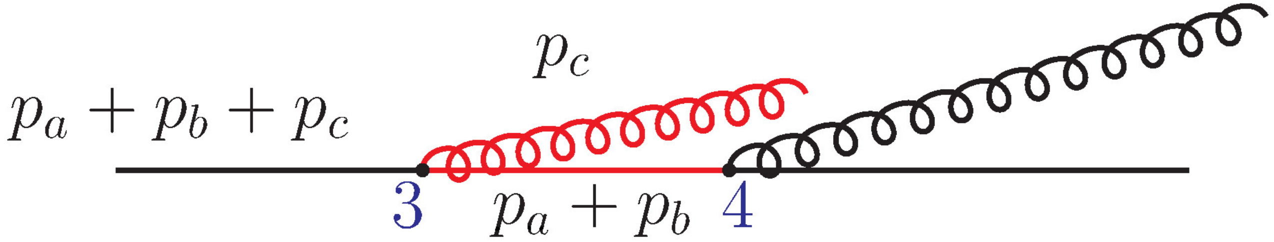
Dark pion dark matter

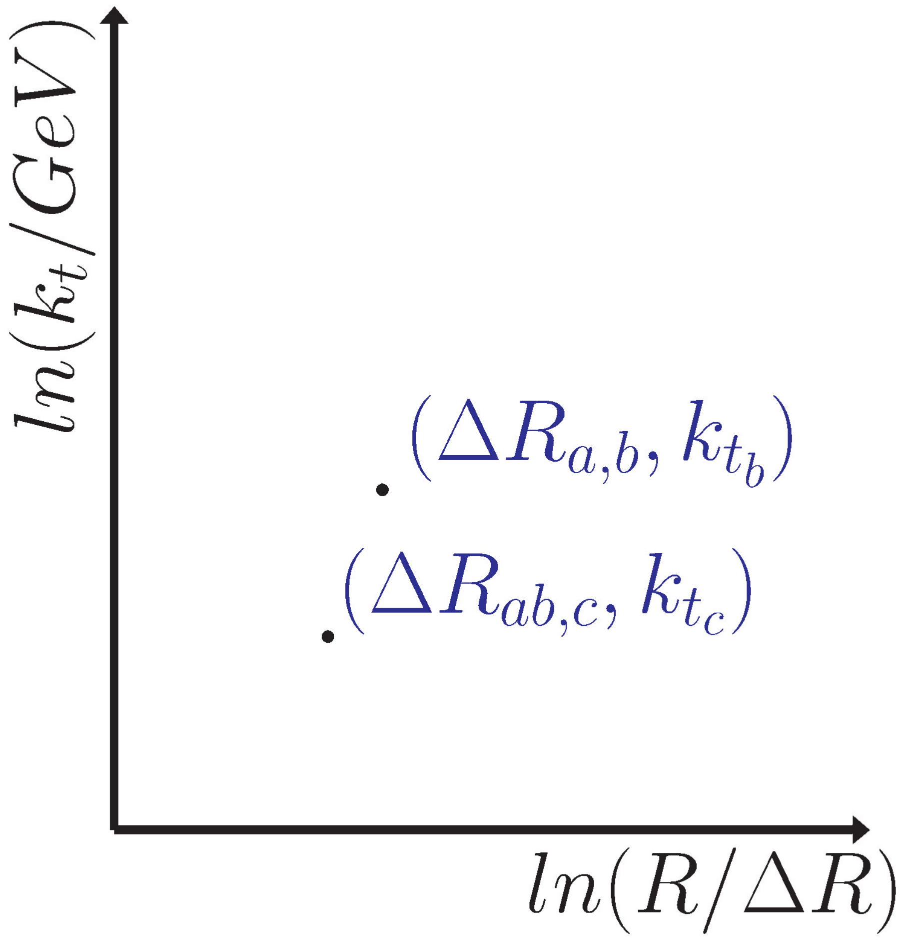
F = 4 ⟶ stable dark pions in t-channel models



Lund Jet Plane







Using Lund Jet Plane for searches

different hadronization parameter choices give very different Lund Jet Planes

⟶ can translate into large differences in variables, e.g. number of tracks