Dark QCD search at collider

Snowmass-EF10

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Based on: 1712.07279 Myeonghun Park & MZ

Outline

1. Model

2. Dark QCD search at hadron collider

3. Dark QCD search at ep collider

Motivation

$$\Omega_{\mathrm{DM}} : \Omega_{\mathrm{B}} \sim 5 : 1$$

We need a asymmetry between baryon and anti-baryon:
1)C and CP violation
2)B-number broken
3)deviation from equilibrium

Baryon mass comes from QCD confinement

WIMP:
Heavy Majorana particle freeze out

WIMP mass is given by hand (soft term in SUSY)

Motivation

$$\Omega_{\mathrm{DM}} : \Omega_{\mathrm{B}} \sim 5 : 1$$

So maybe the story is more like:

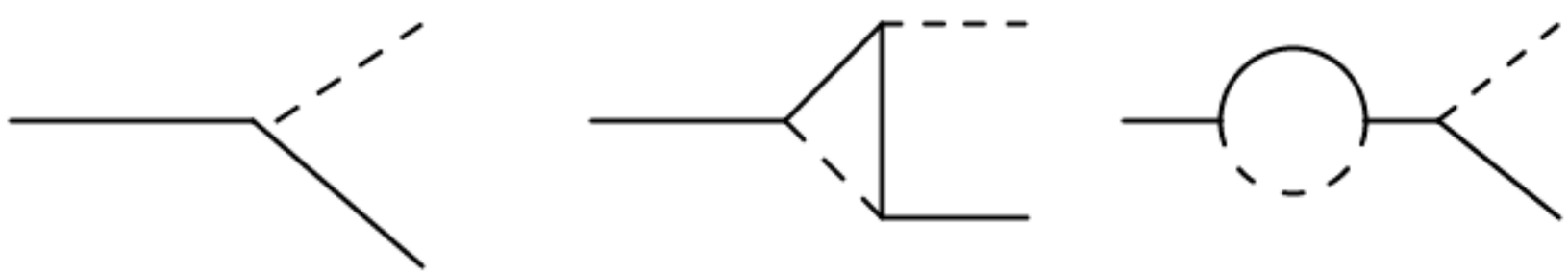
B-number and D-number are produced at early universe, through some related process.

Baryon mass and DM (dark baryon) mass comes from QCD and Dark-QCD respectively.

An Example: 1306.4676 Y. Bai & P. Schwaller

Out of equilibrium decay of heavy Mojarana fermion:

$$\mathcal{L} \supset k_i \bar{Y}_1 \Phi N_i + \text{h.c.}$$



if $\text{Im}[k_1 k_2^*]^2 \neq 0$, then $\dfrac{\Gamma(N_1 \to Y_1 \Phi^\dagger) - \Gamma(N_1 \to \bar{Y}_1 \Phi)}{\Gamma(N_1 \to Y_1 \Phi^\dagger) + \Gamma(N_1 \to \bar{Y}_1 \Phi)} \neq 0$

$SU(3)\times$dark $SU(3) \times U(1)_Y$:

Y_1: $(\bar{3}, 3)_{1/3}$ Φ: $(\bar{3}, 3)_{1/3}$

An Example: 1306.4676 Y. Bai & P. Schwaller

Then we need to break B and D:

$$\mathcal{L} \supset \kappa_1 \, \Phi \, \bar{Y}_1^c \, Y_2 + \kappa_2 \, \Phi \, \bar{Y}_2 \, e_R + \kappa_3 \, \Phi \, \bar{X}_L \, d_R + \text{h.c.}$$

This term break B and D

Y_2: $(\bar{3}, 3)_{-2/3}$

e_R: right-hand lepton

d_R: right-hand quark

X_L: left-hand dark quark

For collider search, only important term is $\kappa \Phi \bar{X} q$

Collider search

There can be two portals, quark portal or lepton portal:

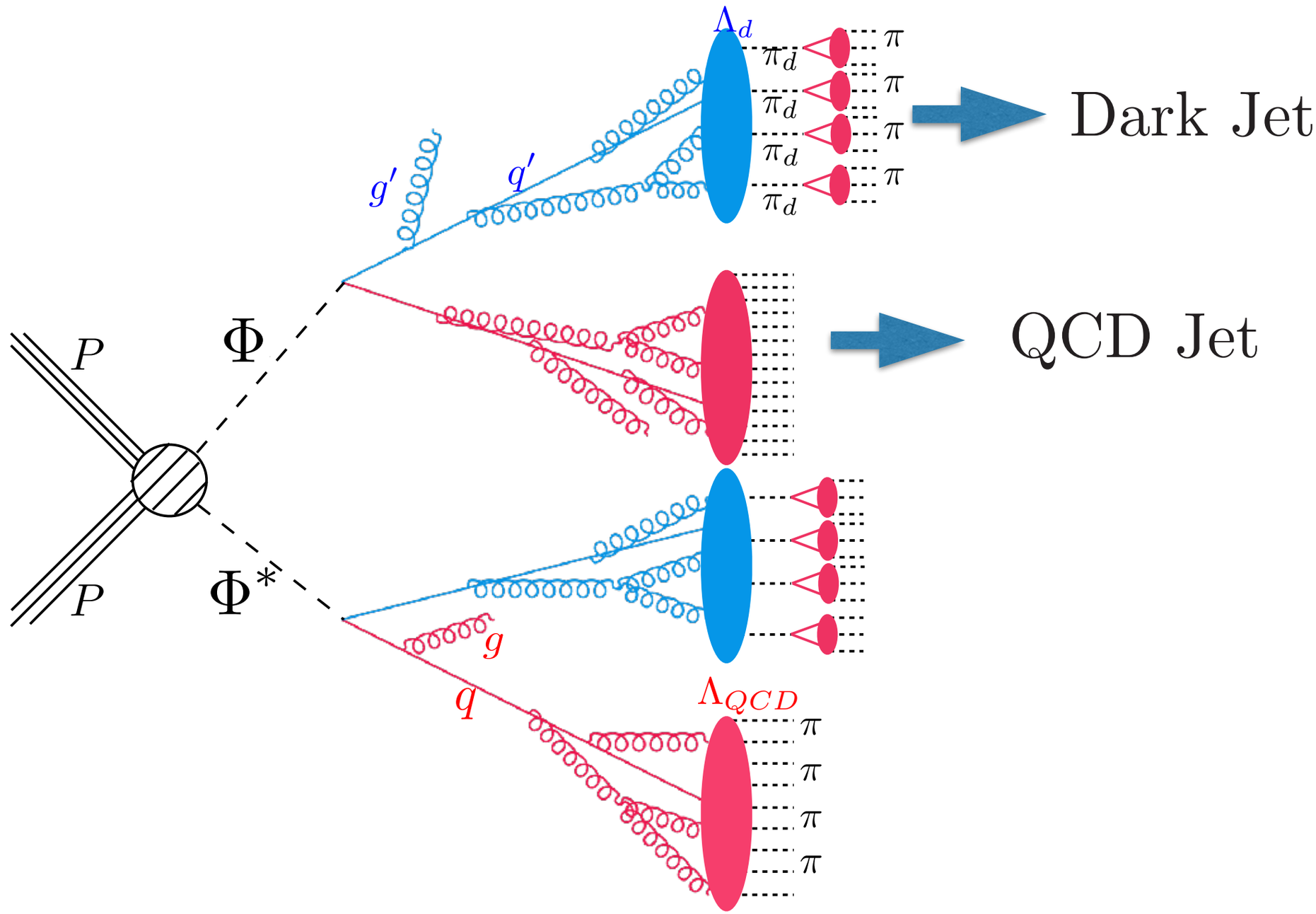
$\kappa \Phi \bar{X} q$ hadron collider

$\kappa \Phi \bar{X} e$ ep collider

$\bar{X}, q, e$ are very light,Φ is around TeV scale.

Signal at hadron collider

Because of color confinement in dark sector, these models will give you jet-like signal, we call it “dark jet”.

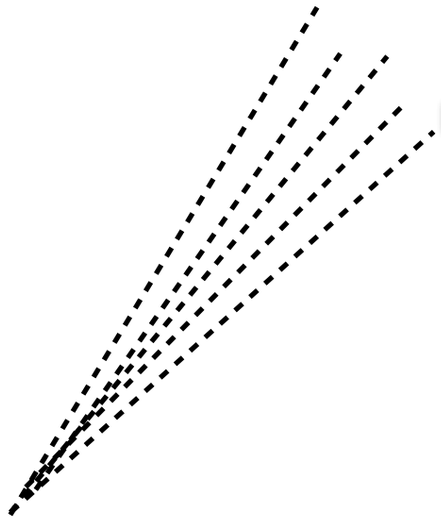


What a dark jet looks like?

It's very, very model dependent.

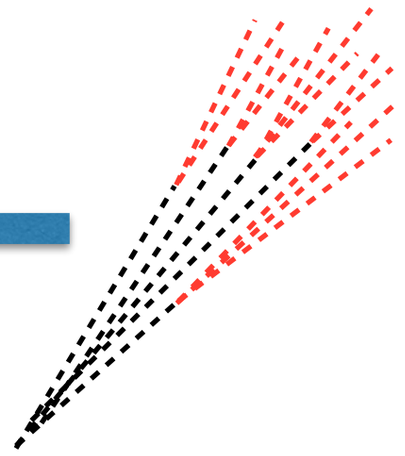
How long is lifetime of dark meson π_d, ρ_d...?

How much invisible particle inside a dark jet?



Most dark mesons are stable or stable enough.

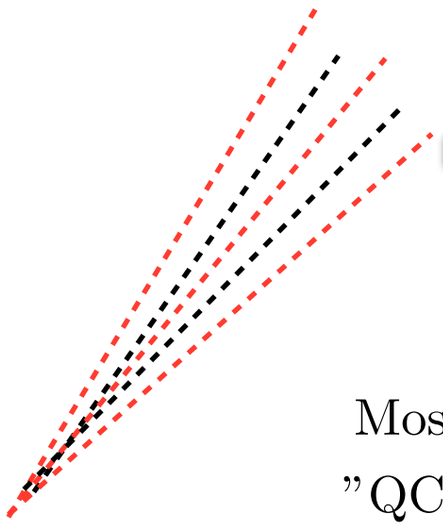
Invisible Jet (Missing Energy)



Most dark mesons are long-lived.

Emerging Jet (Displaced Track)

JHEP **1505**, 059 (2015)



A fraction of dark mesons are stable.

Semi-visible Jet (Transverse Mass)

Phys. Rev. Lett. **115**, no. 17, 171804 (2015)

Most of dark mesons decay to visible particles promptly

"QCD-like" dark jet. We can use jet sub-structure (q/g)

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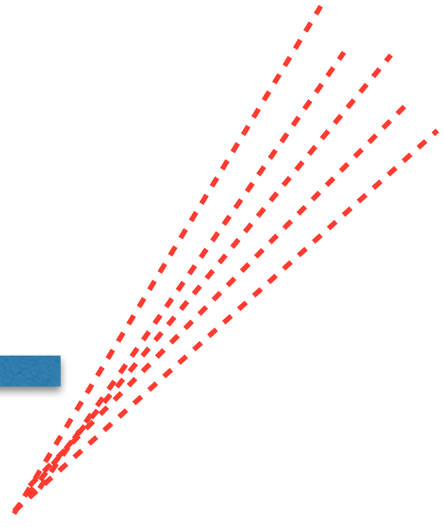
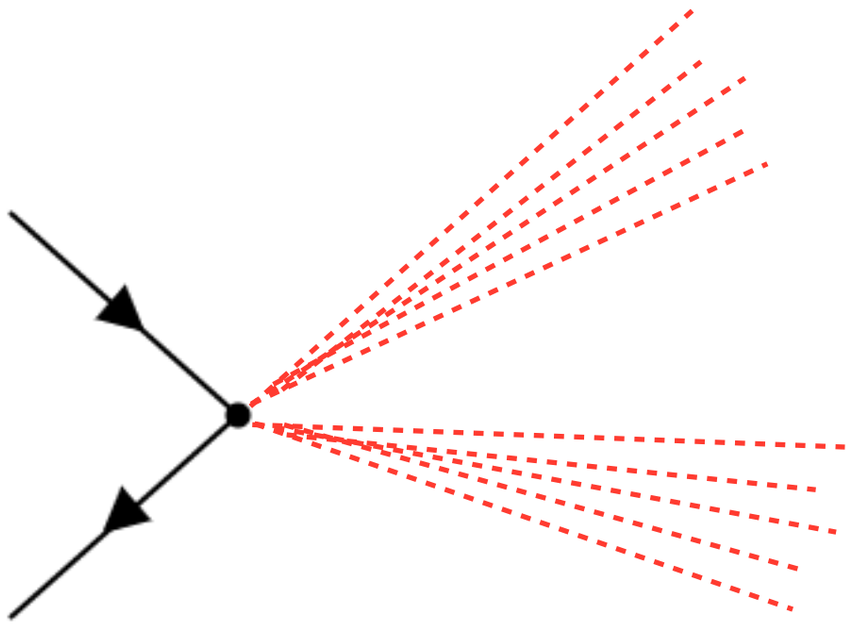


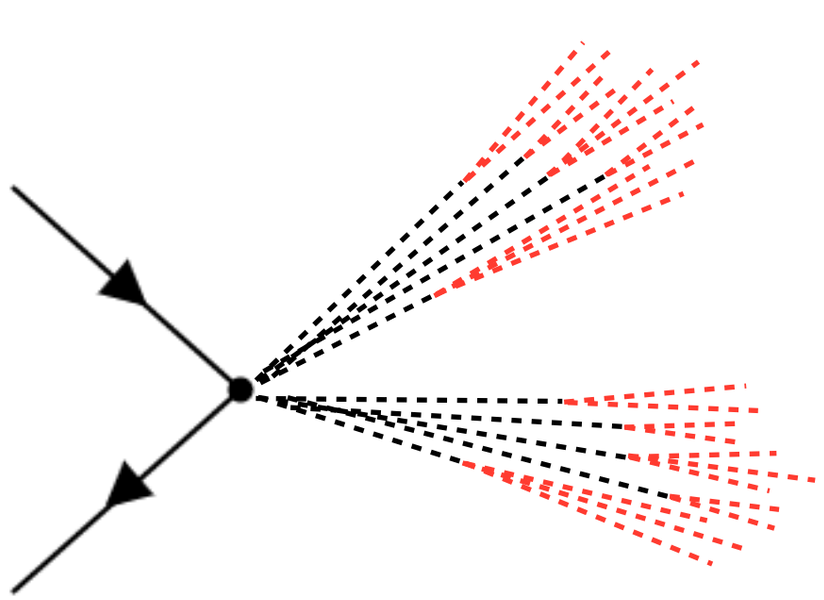
Signal at ep collider

Integrate the TeV mediator, we obtain an dim-6 operator for production and dark meson decay.

$$\kappa \Phi \bar{X} e + h.c. \quad \Rightarrow \quad \frac{\kappa^2}{\Lambda^2} \bar{e} e \bar{X} X$$



or



Lepton-jet

Displaced lepton-jet

Simulation

For event generator, we can choose Pythia8
(Hidden Valley model)

In detector simulation, we can not do electron isolation.

Electron jet seems hard to be distinguished from QCD background.

Some interesting topics:
Electron jet tagging
Study dark QCD through shower pattern (thrust)

Exclusion limit of $\frac{\kappa^2}{\Lambda^2}\bar{e}e\bar{X}X$

Thank you!