Composite Inelastic Dark Matter

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arXiv:0903.3945
With
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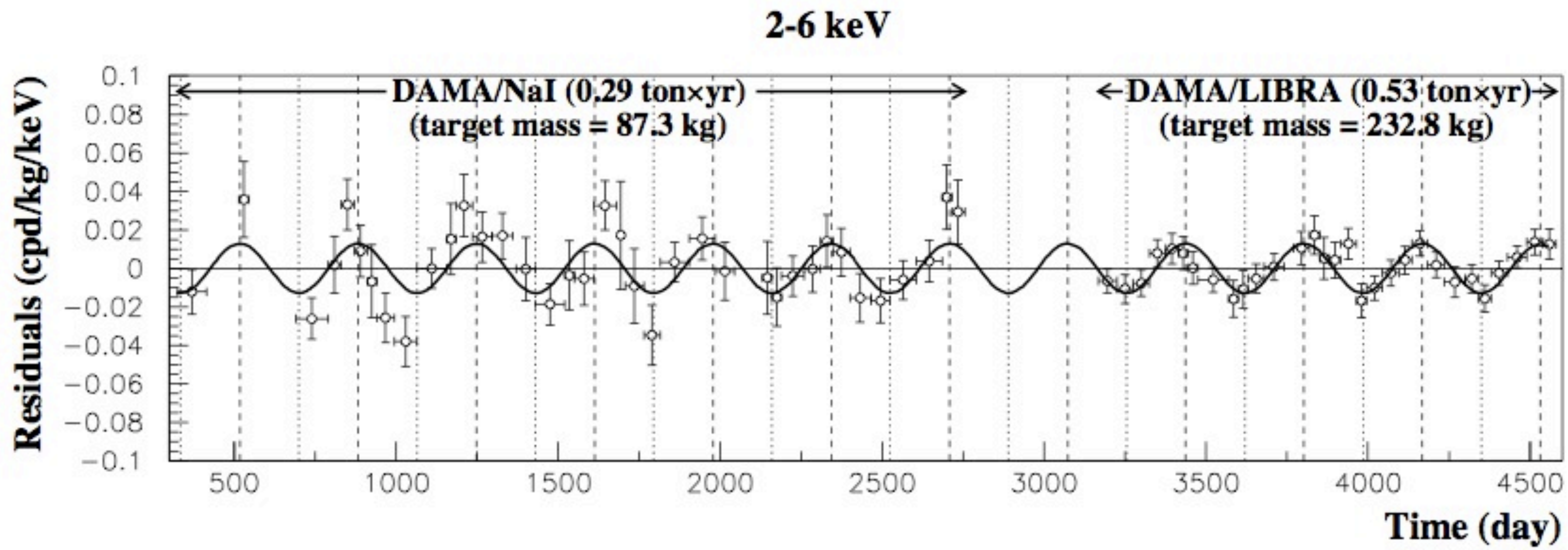
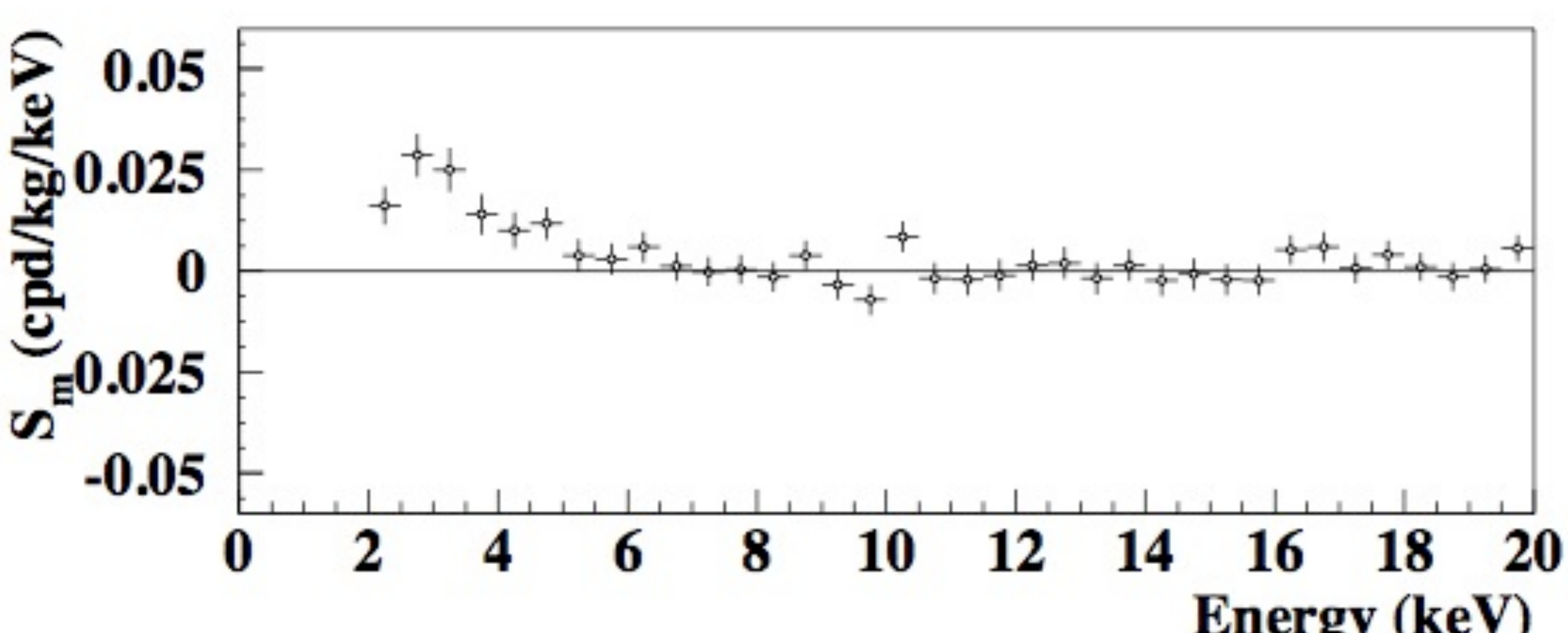
11 Years of Oscillation



A distinctive recoil spectrum

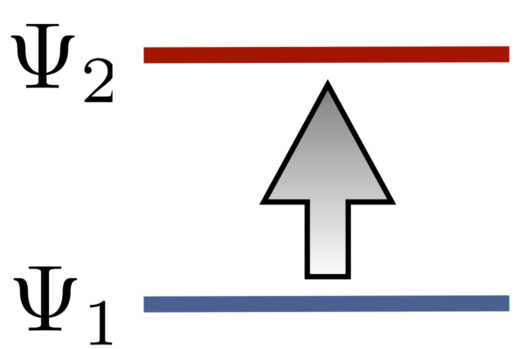


Inelastic Dark Matter

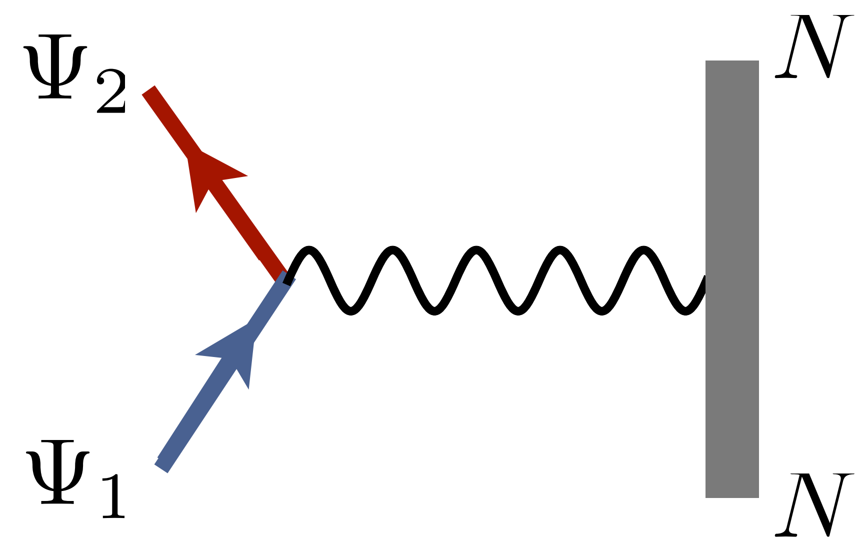
Tucker-Smith & Weiner (2001)

Dark matter has 2 nearly degenerate states

$$\delta m \sim \mathcal{O}(100\ \mathrm{keV})$$



Scattering off the SM is
$\Psi_1 \longrightarrow \Psi_2$



3 Consequences:

Scatters off of heavier nuclei (CDMS ineffective)

Large recoil energy (Xenon10 didn't look)

Large modulation fraction

Inelastic Dark Matter

A new number to explain:

$$\frac{\delta m}{m} \sim 10^{-6}$$

Breaking of an approximate global symmetry

Like Yukawas

Radiatively stable

Hard to discover origin

Sign of dark sector dynamics

First of many splittings

New interactions to discover

Changes what questions are interesting

Composite Dark Matter

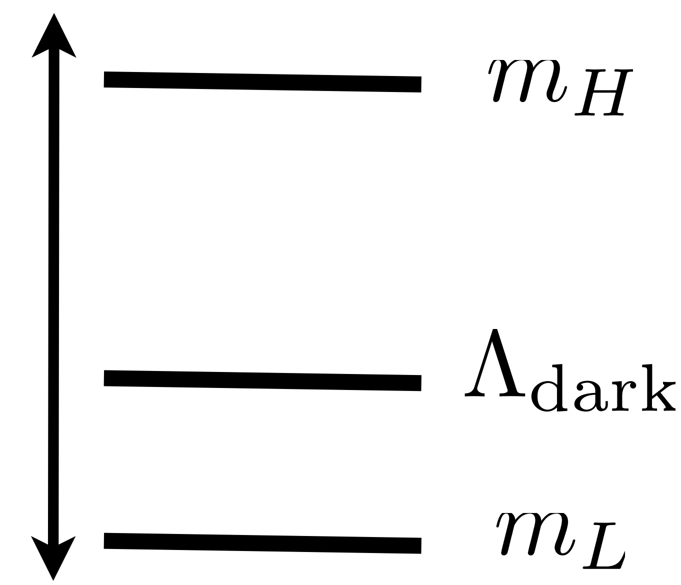
A new SU(N_c) gauge sector

Confines at Λ_{Dark}

A pair of quarks:

$q_L \quad m_L \ll \Lambda_{\text{dark}}$

$q_H \quad m_H \gg \Lambda_{\text{dark}}$



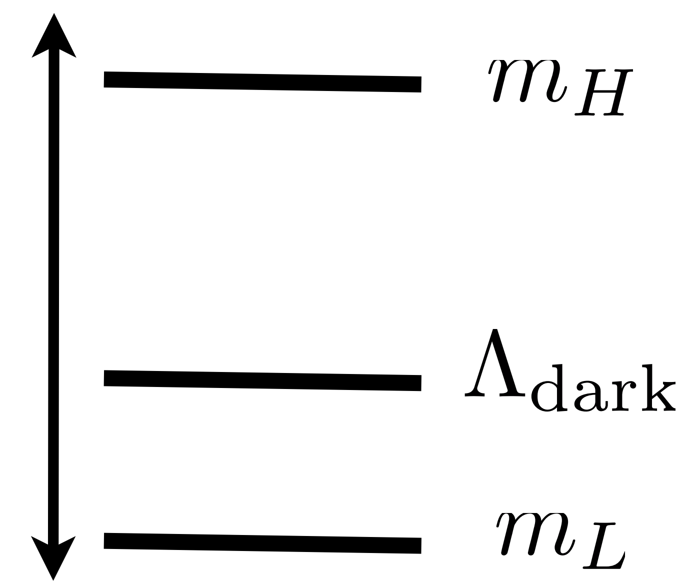
Composite Dark Matter

A new SU(N$_c$) gauge sector

Confines at Λ_{Dark}

A pair of quarks: $q_L \quad m_L \ll \Lambda_{\text{dark}}$

$q_H \quad m_H \gg \Lambda_{\text{dark}}$



A cosmological asymmetry

$$(n_H - n_{\bar{H}}) = -(n_L - n_{\bar{L}}) \neq 0$$

At $T \ll \Lambda_{\text{Dark}}$ DM is in

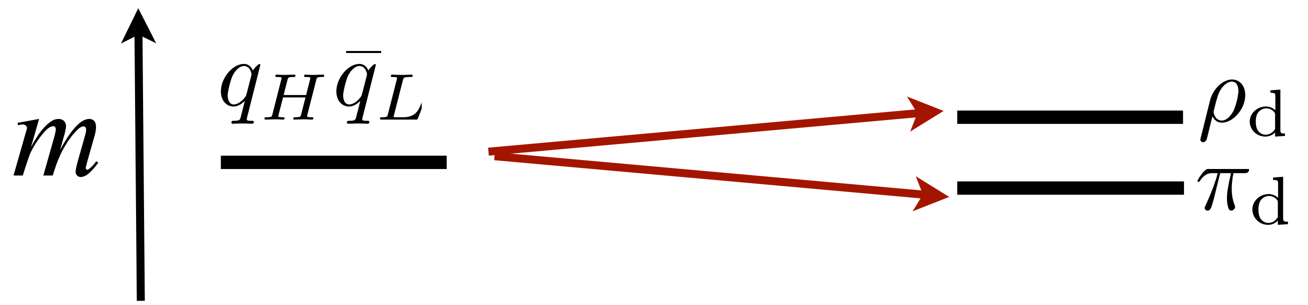
$q_H \bar{q}_L$ bound states

Dark Mesons

Degeneracy of the Ground State

Heavy quark spin preserved in electric interactions

Dark Chromomagnetic interaction breaks spin symmetry



$$\delta H \sim \frac{\vec{\sigma} \cdot \vec{B}}{m_H}$$

Spin 0 | Spin 1

Dark Pion $\pi_{\rm d}$ | Dark Rho $\rho_{\rm d}$

$$m_{\rho_{\rm d}} - m_{\pi_{\rm d}} \sim \frac{\Lambda^2_{\rm Dark}}{m_H}$$

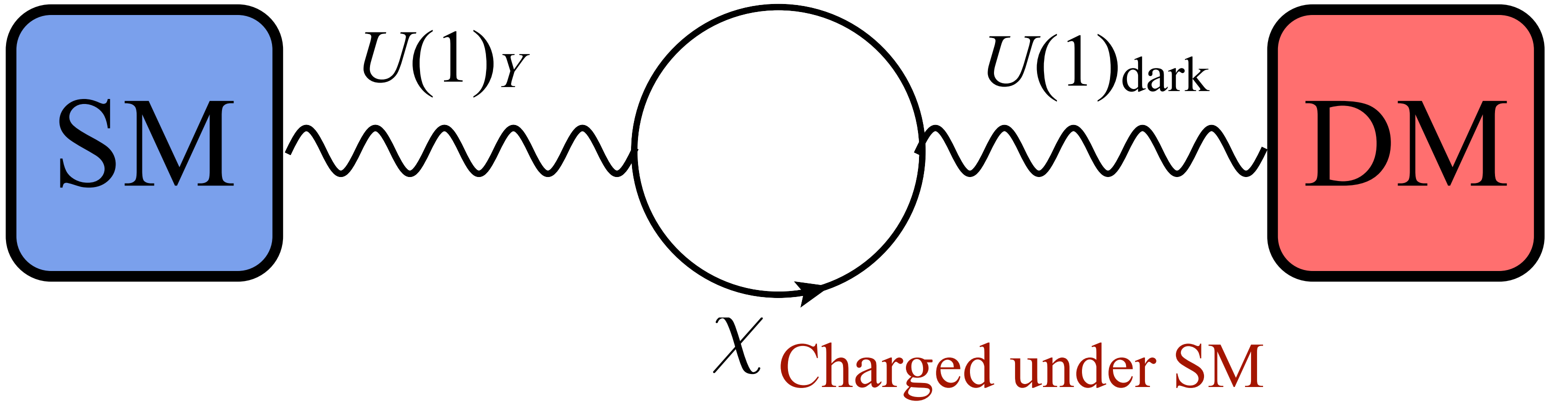
Doesn’t require adding new symmetry and breaking it

Accidental global symmetry from Lorentz Invariance

Coupling to the SM

Kinetically Mix $U(1)_Y$ with $U(1)_{\rm dark}$

$$\mathcal{L}_{\rm mix} = \epsilon\, F^{\mu\nu}_{\rm dark} F_{Y\,\mu\nu}$$



At low energy $\mathcal{L}_{\rm int} = \epsilon\, A^{\mu}_{\rm dark}\, j_{{\rm EM}\,\mu}$

Higgs $U(1)_{\rm dark}$ near EW scale

$$\mathcal{L}_{\rm Higgs} = |D_\mu \phi_{\rm d}|^2 - V(\phi_{\rm d}) \longrightarrow m_{\rm d}^2 A_{\rm d}^2$$

Charging the Dark Quarks

Two Choices Anomaly-Free Charges

- Vector coupling

$$j^{\mu}_{\mathrm{dark}} = g_{\mathrm{d}}(\bar{q}_H \gamma^{\mu} q_H - \bar{q}_L \gamma^{\mu} q_L)$$

Doesn't forbid dark quark masses

Has both elastic and inelastic scattering channels

Charging the Dark Quarks

Two Choices Anomaly-Free Charges

- Vector coupling

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Doesn't forbid dark quark masses

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- Axial Vector coupling

$$j^{\mu}_{\rm dark} = g_{\rm d}(\bar{q}_H \gamma^{\mu} \gamma^5 q_H - \bar{q}_L \gamma^{\mu} \gamma^5 q_L)$$

Forbids dark quark masses until $U(1)_{\rm dark}$ Higgsing

Only inelastic scattering channels

Inelastic Axial Transitions

Must compute couplings to dark mesons

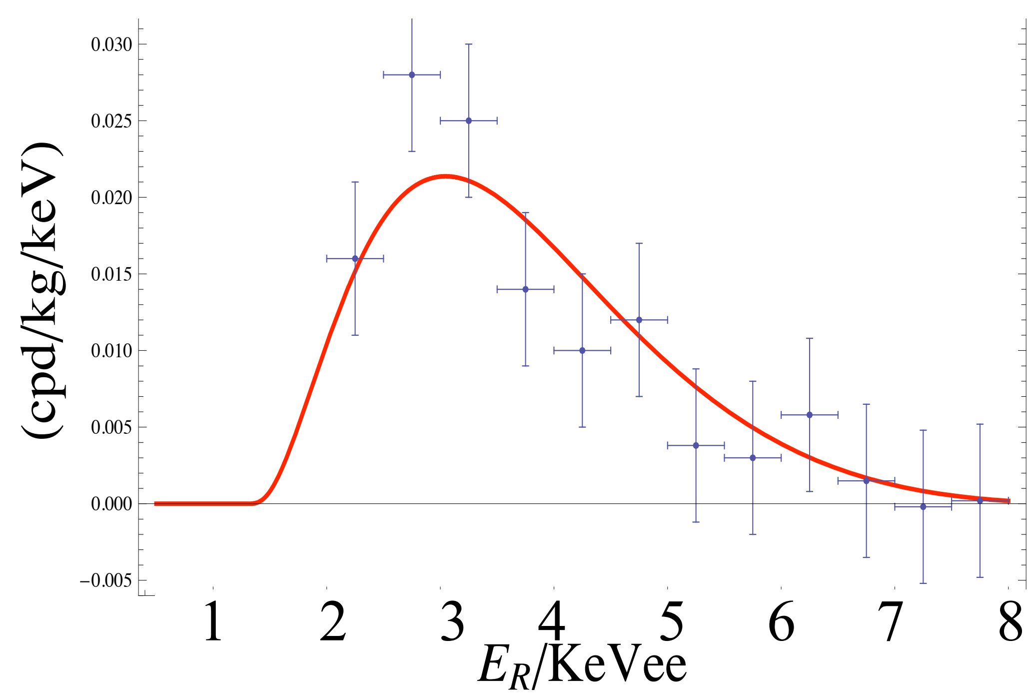
$$\mathcal{L}_{\rm int} = \frac{g_{\rm d}}{\Lambda_{\rm dark}} F^{\mu\nu}_{\rm dark}\, \rho^{\dagger}_{{\rm d}\,\nu}\, \partial_\mu \pi_{\rm d}$$

use $\mu = 0 \quad \nu = i$

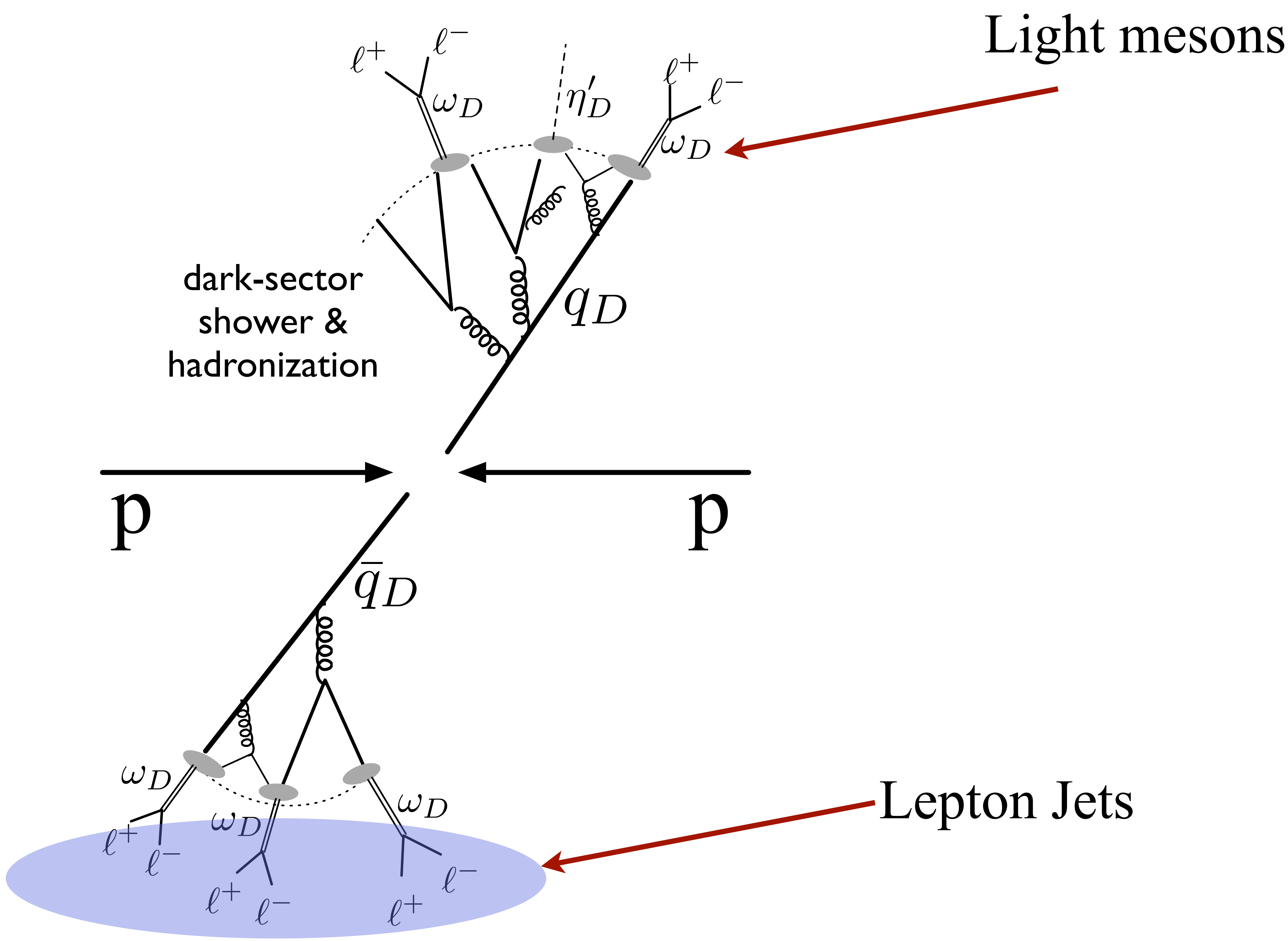
Dim 5 $\pi_{\rm d} \leftrightarrow \rho_{\rm d}$

All $\begin{matrix} \pi_{\rm d} \leftrightarrow \pi_{\rm d} \\ \rho_{\rm d} \leftrightarrow \rho_{\rm d} \end{matrix}$ transitions forbidden

Recoil Spectrum



Collider Signatures



New fixed target experiments

Bjorken, Essig, Schuster, Toro