Nonabelian Kinetic - Mixing -

At the energy and intensity frontiers

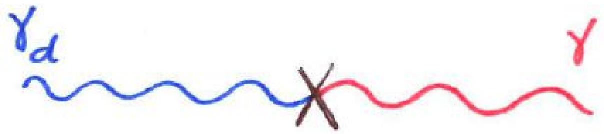
arxiv : 1511.02865

Gabriel Barello

work with Spencer Chang and Christopher Newby

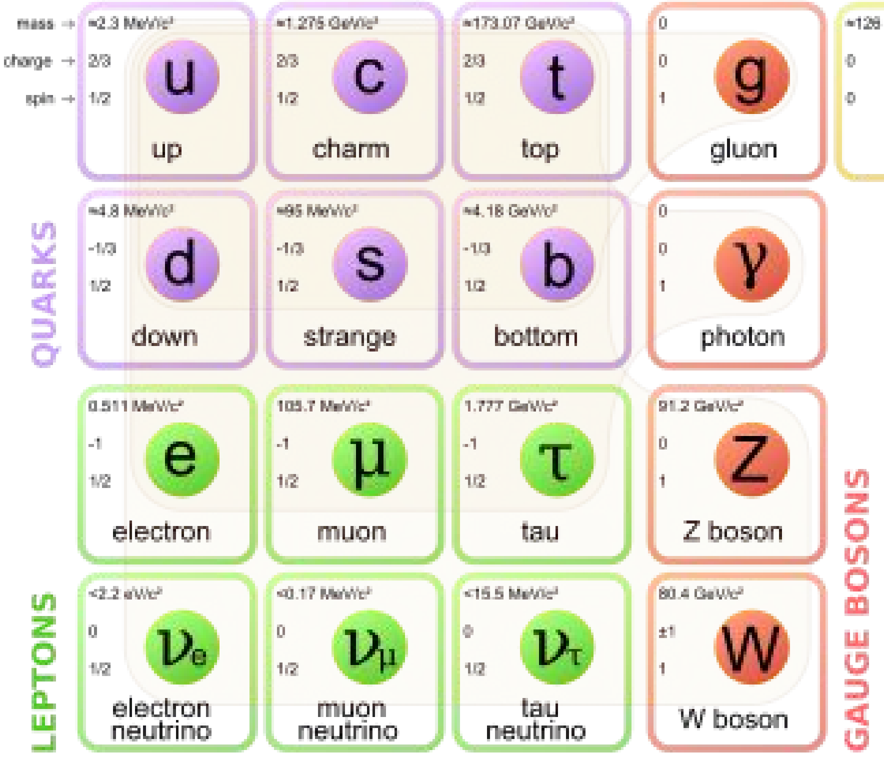
What this talk is about:

Kinetic mixing is a phenomenon in which a new gauge boson (the 'dark photon') can change back and forth into the regular photon



This talk is about <u>nonabelian</u> kinetic mixing

Dark Photons as a Simple Extension:



Strong $\quad SU(2)_L \quad Y$

$SU(3) \otimes SU(2) \otimes U(1)$

Gluons $\quad$ Electroweak

(W/Z/Photon)

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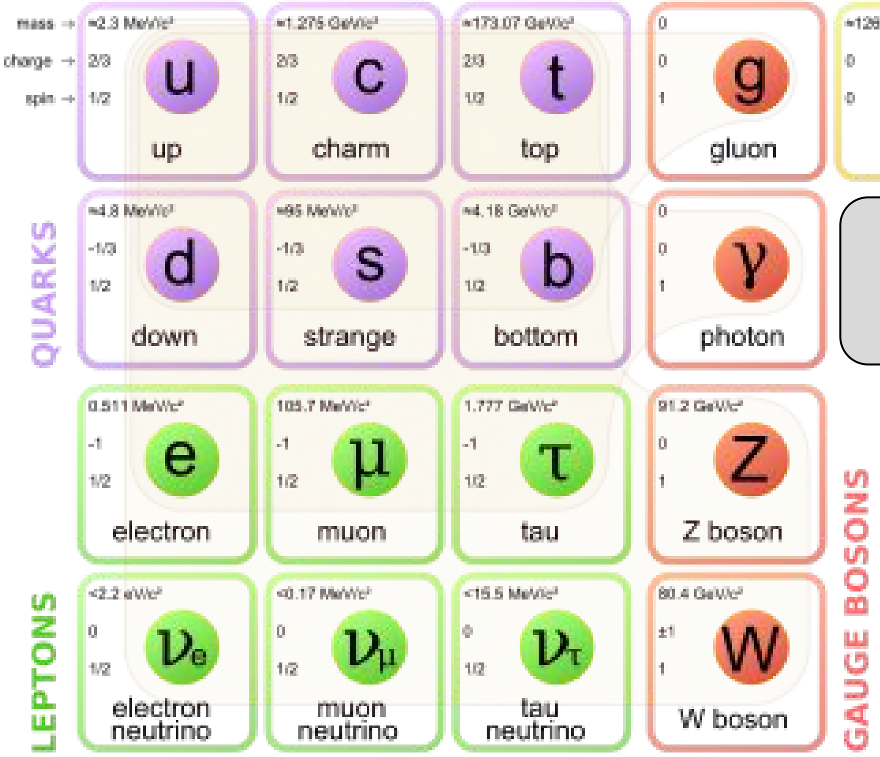

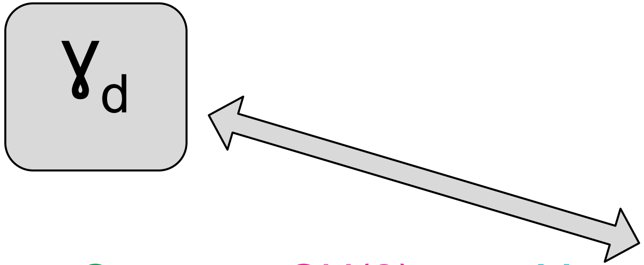

Strong	$SU(2)_L$	Y	Dark Photon
$SU(3) \otimes$	$SU(2) \otimes$	$U(1) \otimes$	$U(1)$
Gluons	Electroweak (W/Z/Photon)		

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The simplest extension:

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}(\not{D} - m)\psi$$

$$F^{\mu\nu} = \partial^{\mu}A^{\nu} - \partial^{\nu}A^{\mu}$$

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$$-\frac{1}{4}\tilde{F}_{\mu\nu}\tilde{F}^{\mu\nu}$$

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$$\tilde{F}^{\mu\nu} = \partial^{\mu}\tilde{A}^{\nu} - \partial^{\nu}\tilde{A}^{\mu}$$

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$$-\frac{1}{4}\tilde{F}_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{\epsilon}{2}\tilde{F}_{\mu\nu}F^{\mu\nu}$$

B. Holdom (1986)

$$F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$$

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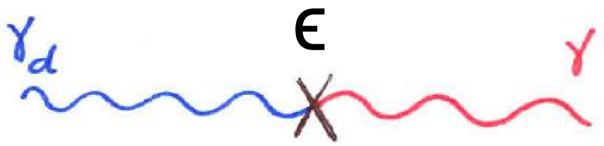

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$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}(\not{D} - m)\psi$$

field redefinition

$$-\frac{1}{4}\tilde{F}_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{\epsilon}{2}\tilde{F}_{\mu\nu}F^{\mu\nu} + i\epsilon q\tilde{A}\bar{\psi}\psi$$

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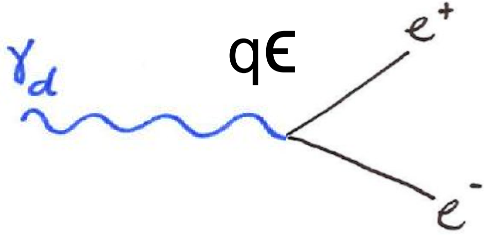


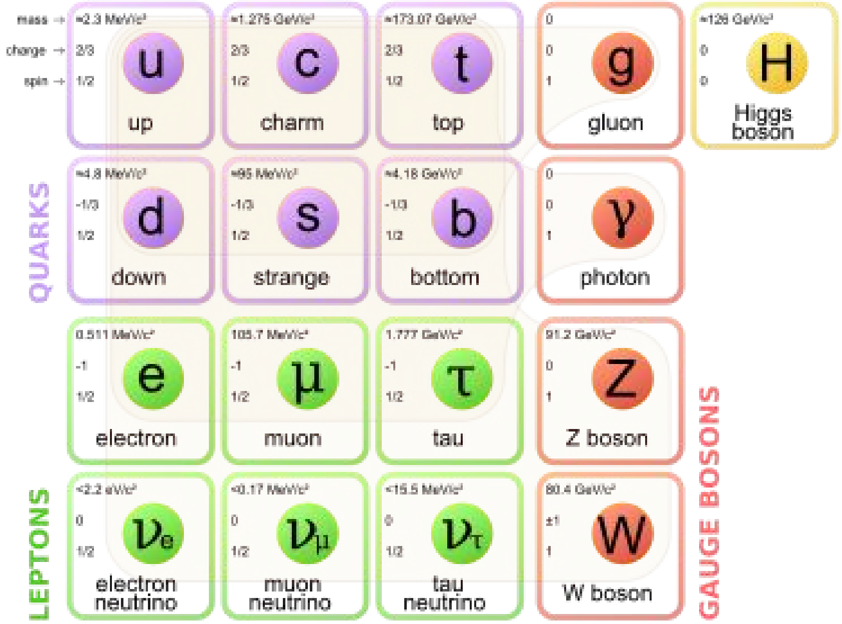
Nonabelian Kinetic Mixing

-“Regular” Kinetic Mixing-

The Dark U(1) and hypercharge mix

Strong	$SU(2)_L$	Y	Dark Photon
$SU(3)$	$\otimes\ SU(2)$	$\otimes\ U(1)$	$\otimes\ U(1)$

“Matter” “Force Carriers”



γ_d

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Nonabelian Kinetic Mixing

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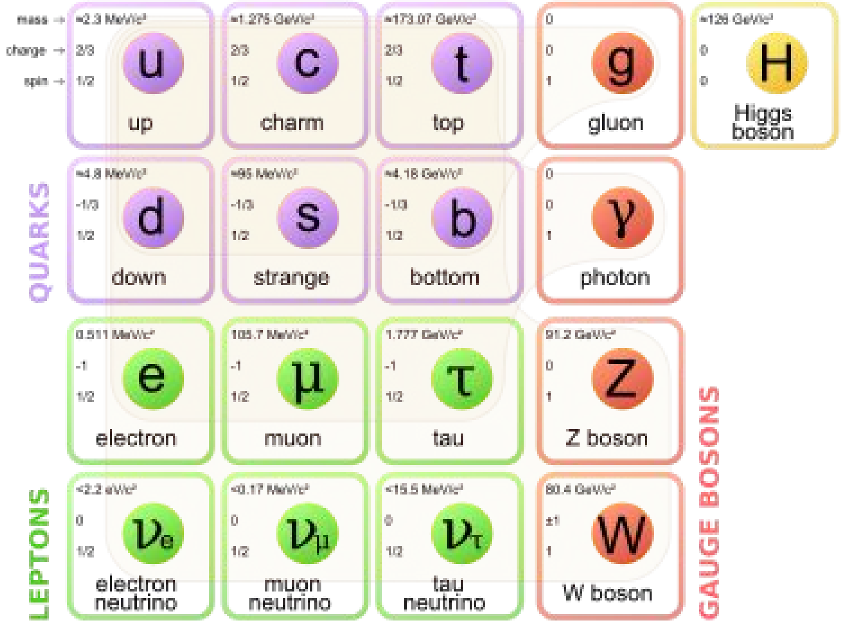

γ_d

- Nonabelian Kinetic Mixing-

The Dark U(1) and $SU(2)_L$ mix

Strong	$SU(2)_L$	Y	Dark Photon
$SU(3)$	$\otimes$ $SU(2)$	$\otimes$ $U(1)$	$\otimes$ $U(1)$

Originally Arkani-Hamed & Weiner proposed the other way around, dark nonabelian group mixing with SM - arxiv: 0810.0714

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Nonabelian Kinetic Mixing - How can it happen?

$$\mathcal{L}_{\rm NAKM} \supset \frac{\epsilon}{2}\tilde{F}_{\mu\nu}W_a^{\mu\nu}$$

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Epsilon is a field that transforms under $SU(2)_L$

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The Higgs!

Introduces a new scale Lambda

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EWSB generates KM

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$$\mathcal{L}_{\rm NAKM} \supset \frac{v^2}{\Lambda^2}\tilde{F}_{\mu\nu}W_3^{\mu\nu}$$

The origin of weak scales:

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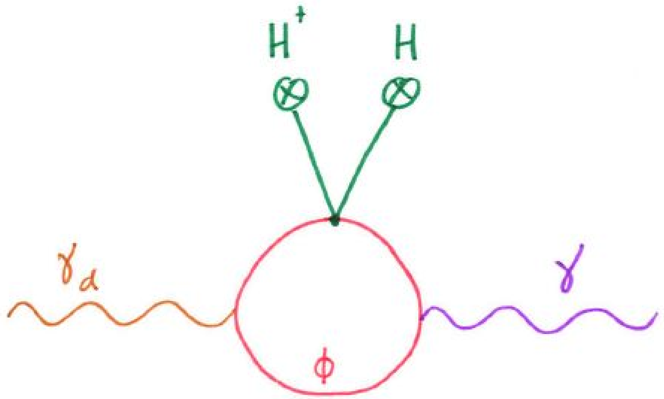


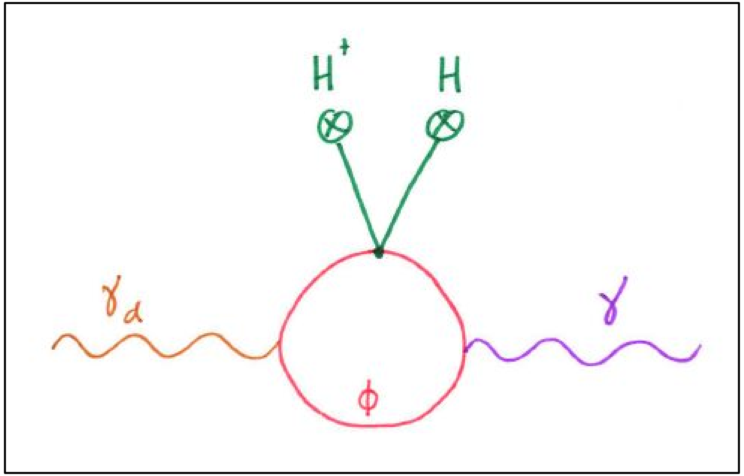
$$\Lambda^2 \sim 16\pi^2 m_\phi^2$$

G.B. Chris Newby, Spencer Chang: arxiv 1511.02865

The origin of weak scales:

The Photon Field Strength

$$\mathcal{L}_{\text{NAKM}} \supset \frac{H_i^\dagger \tau_{ij}^a H_j}{\Lambda^2} \tilde{F}_{\mu\nu} W_a^{\mu\nu} \longrightarrow \frac{\epsilon}{2} \tilde{F}_{\mu\nu} F^{\mu\nu}$$



$$\epsilon = \frac{c v^2 s_W}{2\Lambda^2} \qquad \Lambda^2 \sim 16\pi^2 m_\phi^2$$

$$m_\phi = \sqrt{\frac{c v^2 s_W}{32\pi^2 \epsilon}} \sim 1\text{TeV} \times \sqrt{\frac{c}{\epsilon/10^{-4}}}$$

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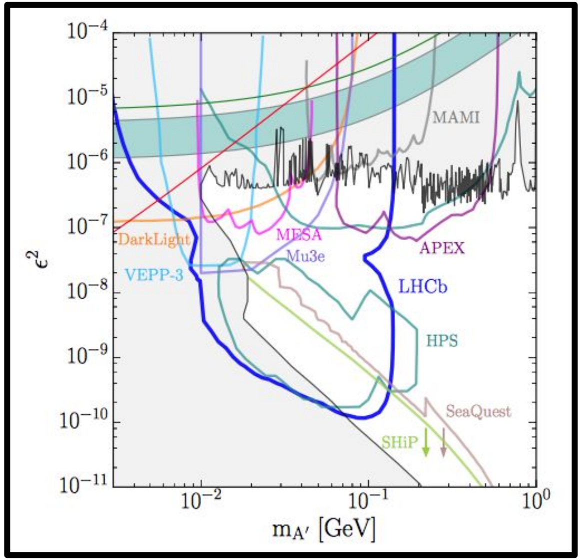
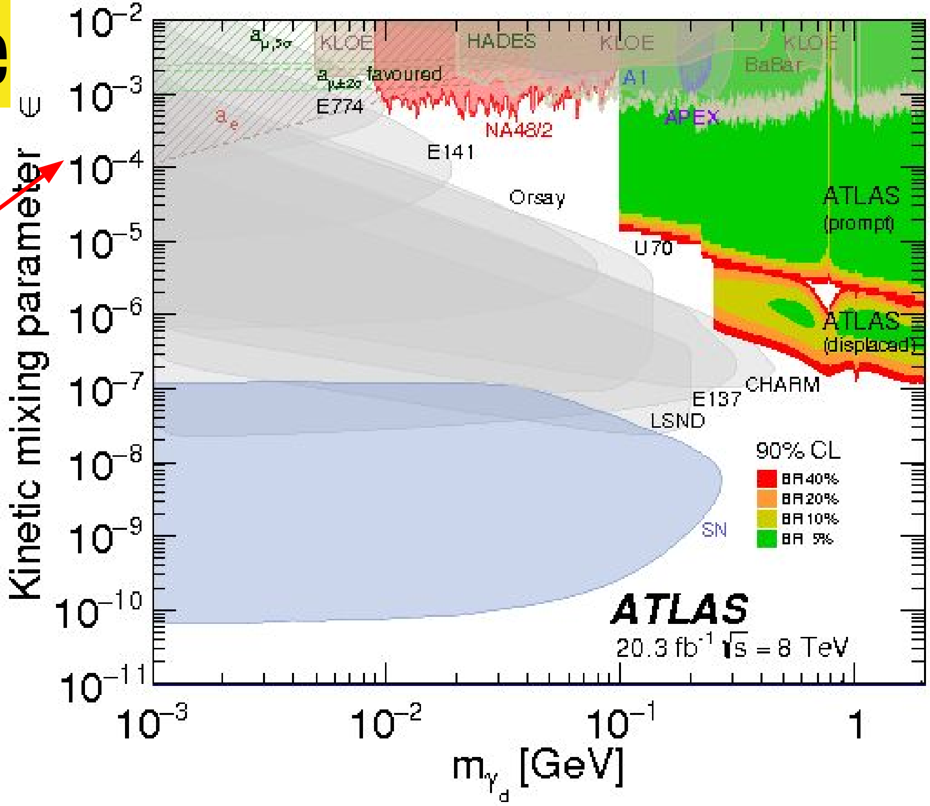
A compelling coincidence

$$m_\phi \sim 1\text{TeV} \times \sqrt{\frac{c}{\epsilon/10^{-4}}}$$

Ilten, Thaler, Williams, Xue: arxiv 1509.06765





ATLAS Collaboration: arXiv: 1511.05542

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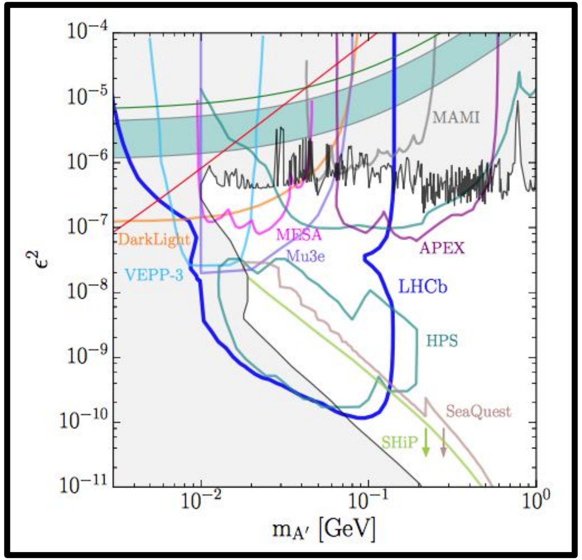

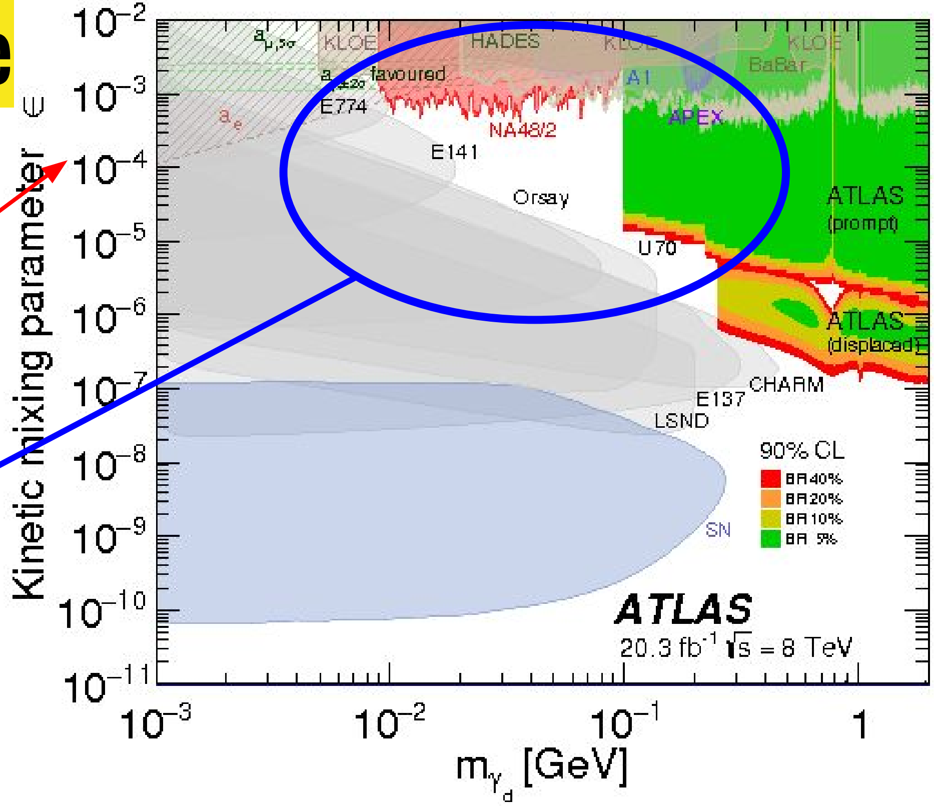

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The Connection

“If we discover a dark photon in the next few years, nonabelian kinetic mixing predicts that we’ll produce the mediating particle at the LHC!”

Next:

- Build a model
- Design search strategies
- Explore other related scenarios

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Our Model

- A dark photon γ_d: the force carrier associated with the new force
- The "dark higgs" h_d : Gives the dark photon a mass
- The mediator ϕ : Generates Nonabelian Kinetic Mixing

New Particle Quantum Numbers:					
Name	$SU(2)_L$	$U(1)_d$	$U(1)_Y$	Spin	Mass
Dark Photon (γ_d)	0	0	0	1	0.2 GeV
Dark Higgs (h_d)	0	1	0	0	0.4 GeV
Mediator (ϕ)	3	1	0	0	TBD

NOTE: No particle charged under $U(1)_Y$ means no regular KM!

The Mediator

EWSB splits the mediator into 3 sets of particles:

$\chi^{\pm}$

ϕ_R^0 / ϕ_I^0

Mediator Mass
~ 100s of GeV

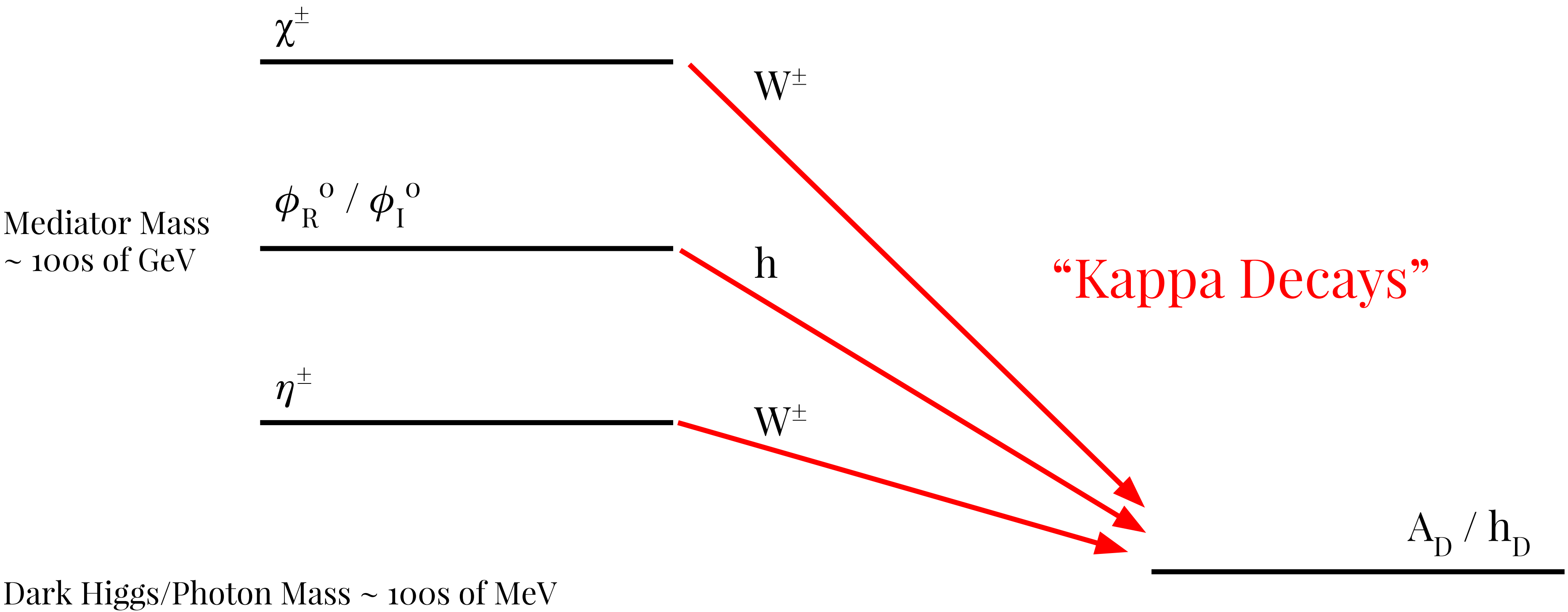
$\eta^{\pm}$

A_D / h_D

Dark Higgs/Photon Mass ~ 100s of MeV

The Mediator

EWSB splits the mediator into 3 sets of particles:



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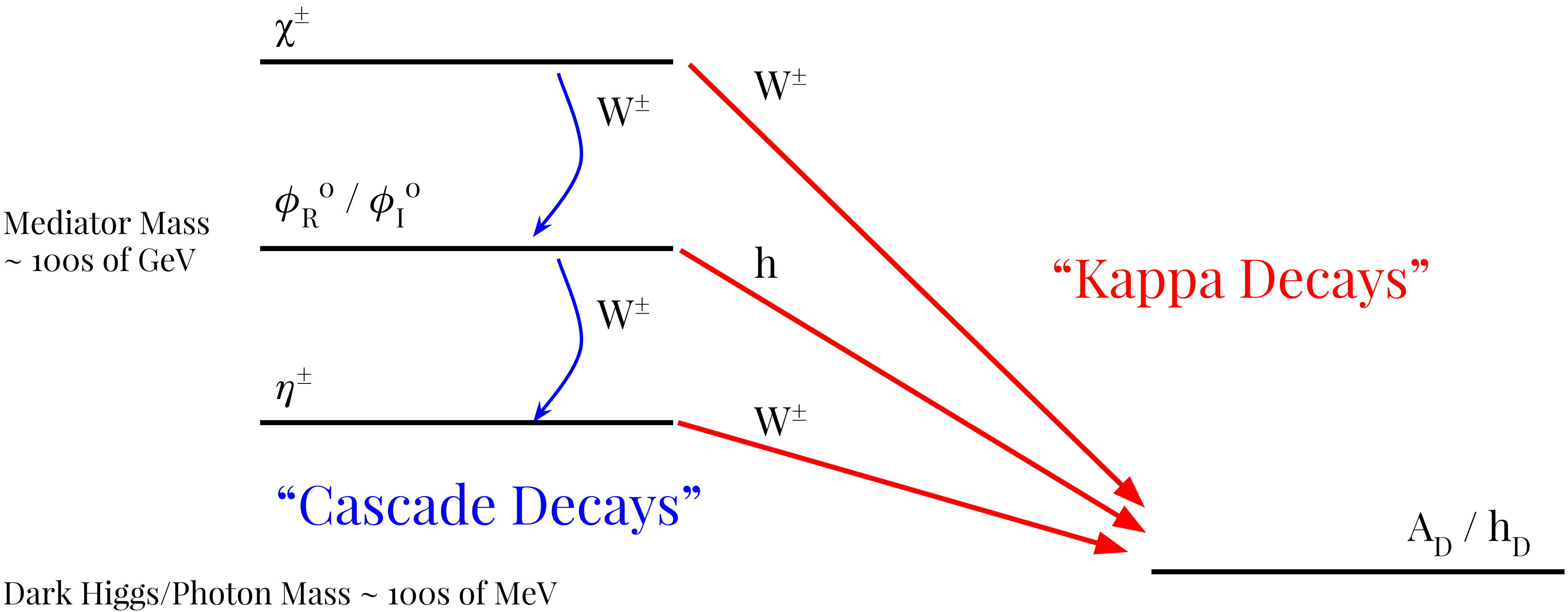
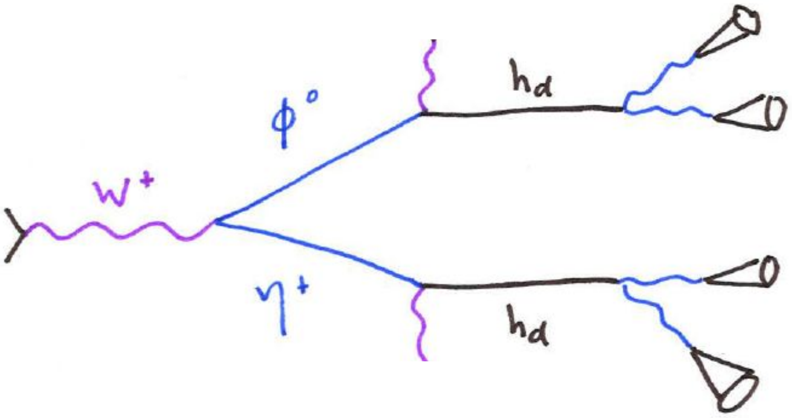


Search Scenarios:

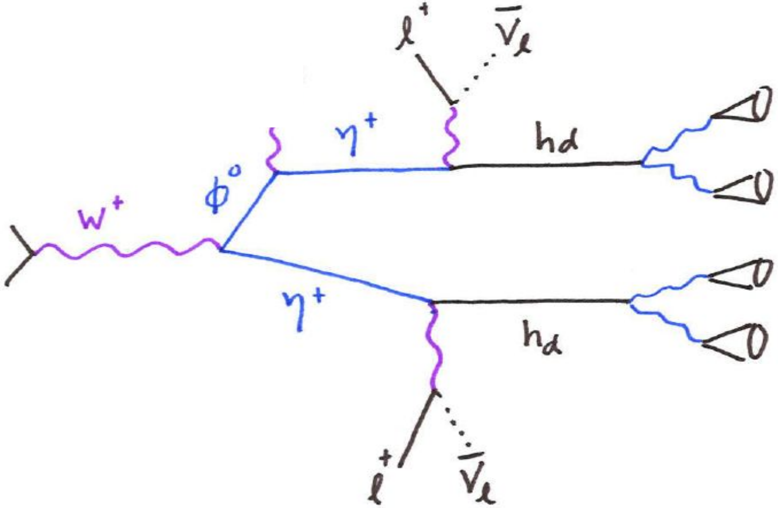


Direct Decay

- Kappa decays dominate

Cascade Decays

- Cascade decays dominate



In the Future:

- We'll finish up this collider study - keep an eye out!
- There is a large space of potential models to explore
    - Change the dark photon mass, larger mass means much different constraints
    - SU(2) of the dark sector mixing with U(1) of the standard model
    - Maybe the mediator could be dark matter?

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Questions?

The lagrangian

$$\mathcal{L} = \text{Kinetic Terms} + \text{Mass Terms}$$

$$+ \ \lambda(\phi_a^\dagger T_c^{ab} \phi_b)(H_i^\dagger \tau_{ij}^c H_j)$$

Generates KM

$$+ \ \kappa \ \phi^a (H^\dagger \tau^a H) h_d + h.c.$$

Allows the mediator to decay

$$+ \text{Other scalar coupling terms}$$

Unimportant for this talk