PARTICLE PHYSICS IN THE DARK

Flip Tanedo

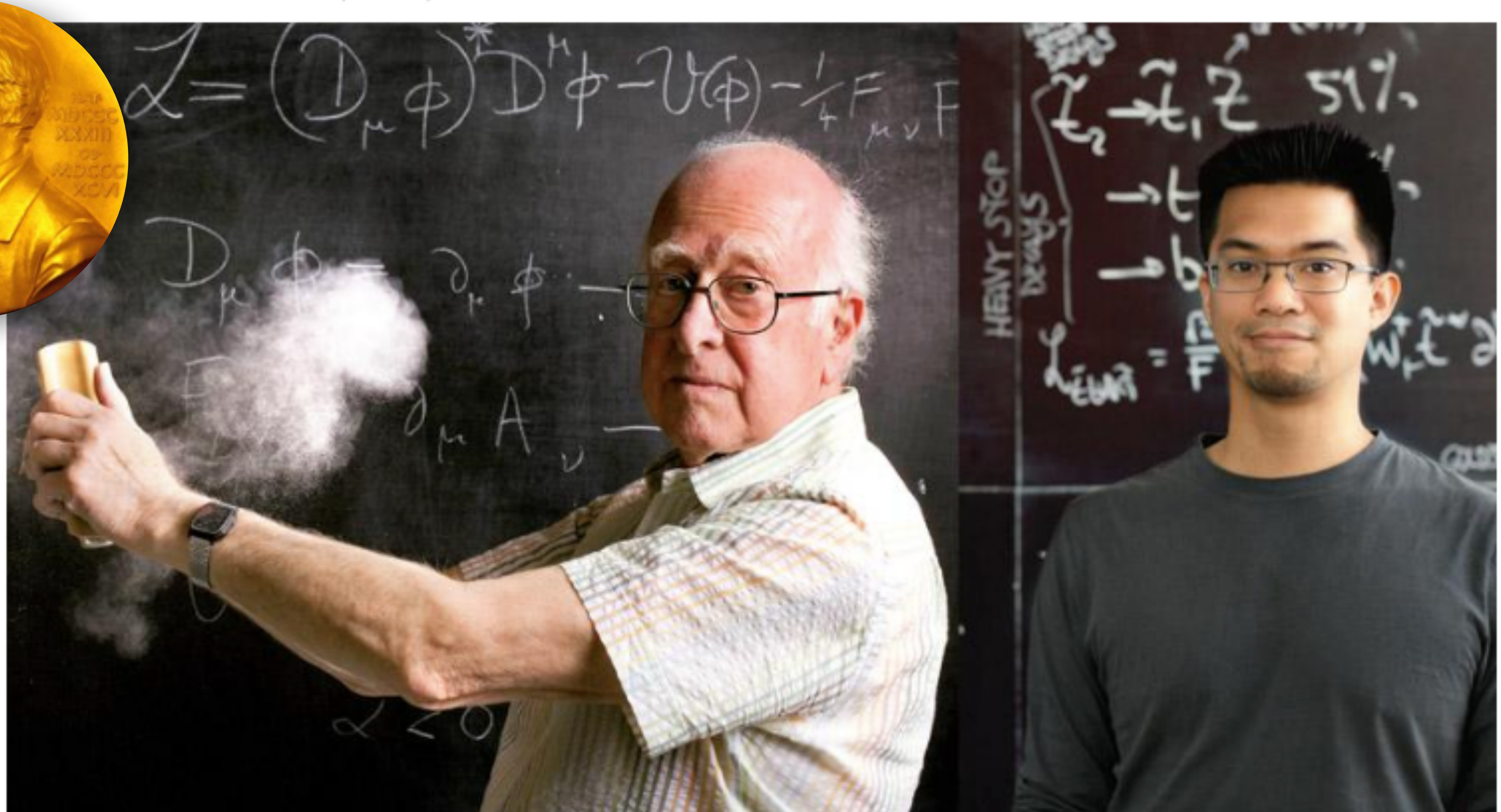
UCIRVINE
UNIVERSITY OF CALIFORNIA

UC PPFP Academic Retreat (April 25, 2015)

Hard times for theorists in a post-Higgs world

The Large Hadron Collider's big success leaves no clear avenue for new physics

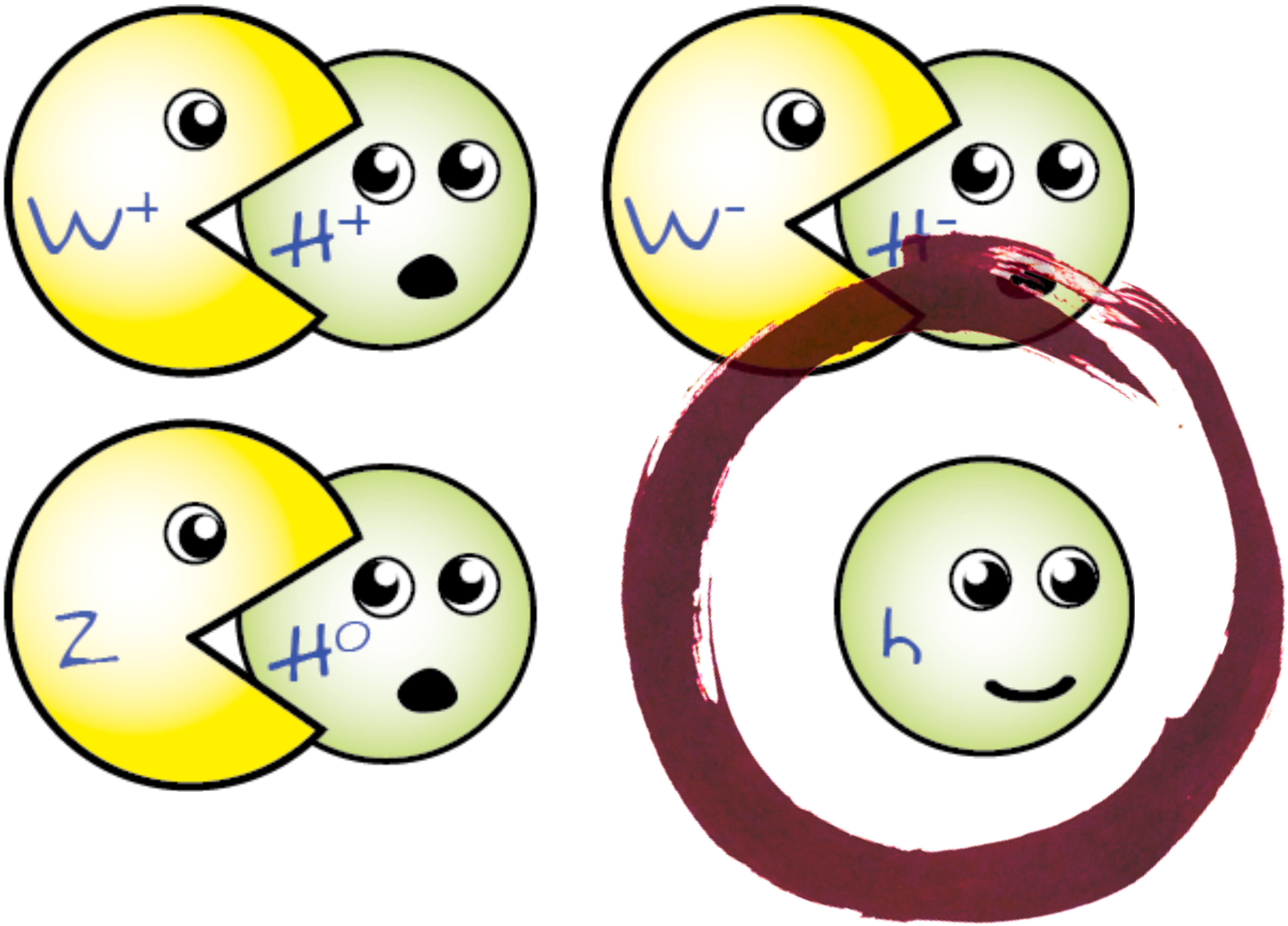
BY ANDREW GRANT 11:02AM, JUNE 13, 2013



AFTER HIGGS In 1964, Peter Higgs (left) proposed the existence of a particle that is now named for him. Now young theorists like Flip Tanedo (right) wonder what's next.

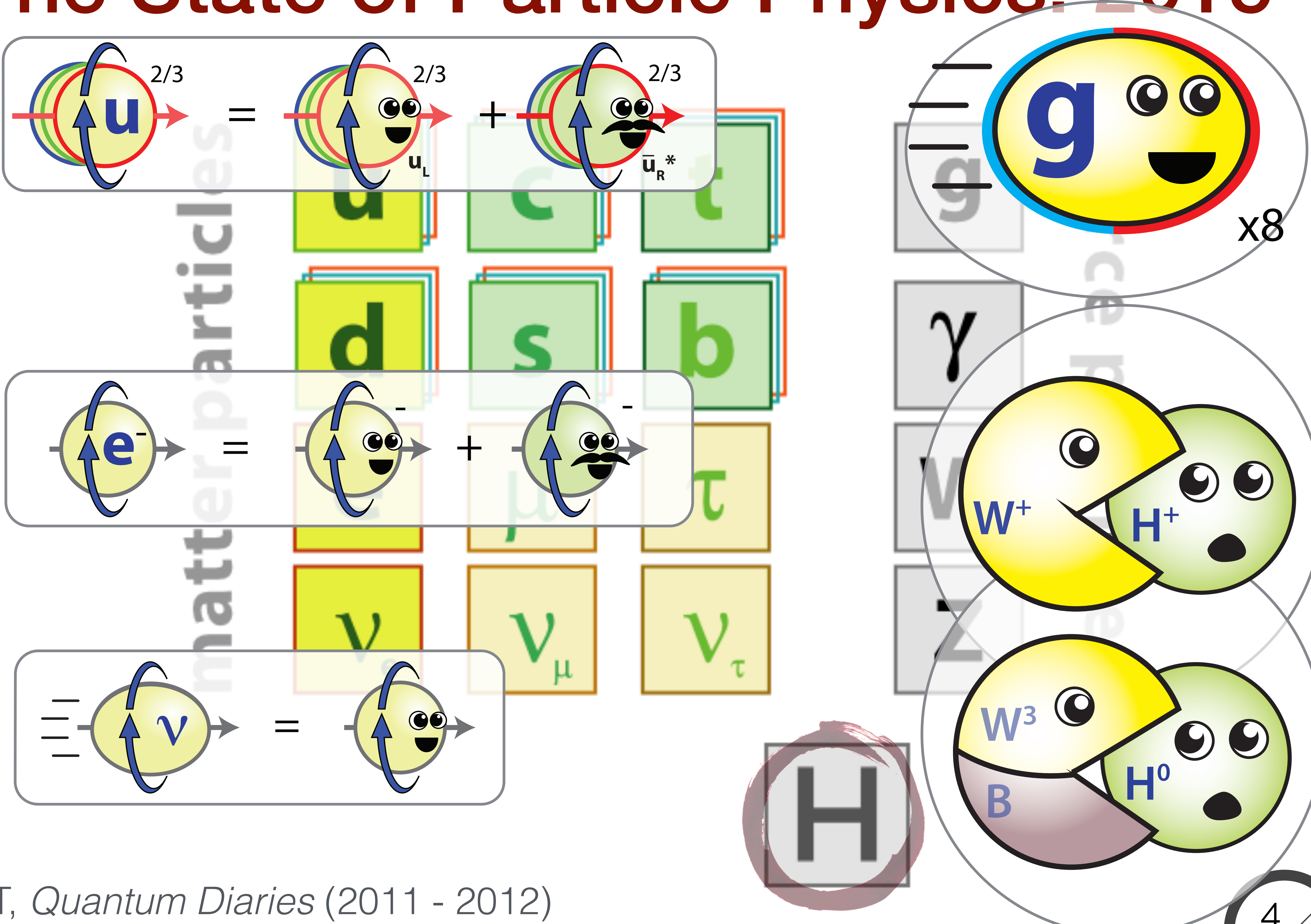
Andrew Grant, *Science News*, June 2013

The State of Particle Physics: 2015



FT, *Quantum Diaries*, "Who Ate the Higgs?" (2011)

The State of Particle Physics: 2015



FT, *Quantum Diaries* (2011 - 2012)

The State of Particle Physics: 2015

fundamental forces

matter particles

Field	Spin	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$
Q	$1/2$	$\square$	$\square$	$1/6$
$\bar{u}$	$1/2$	$\bar{\square}$	$\mathbb{1}$	$-2/3$
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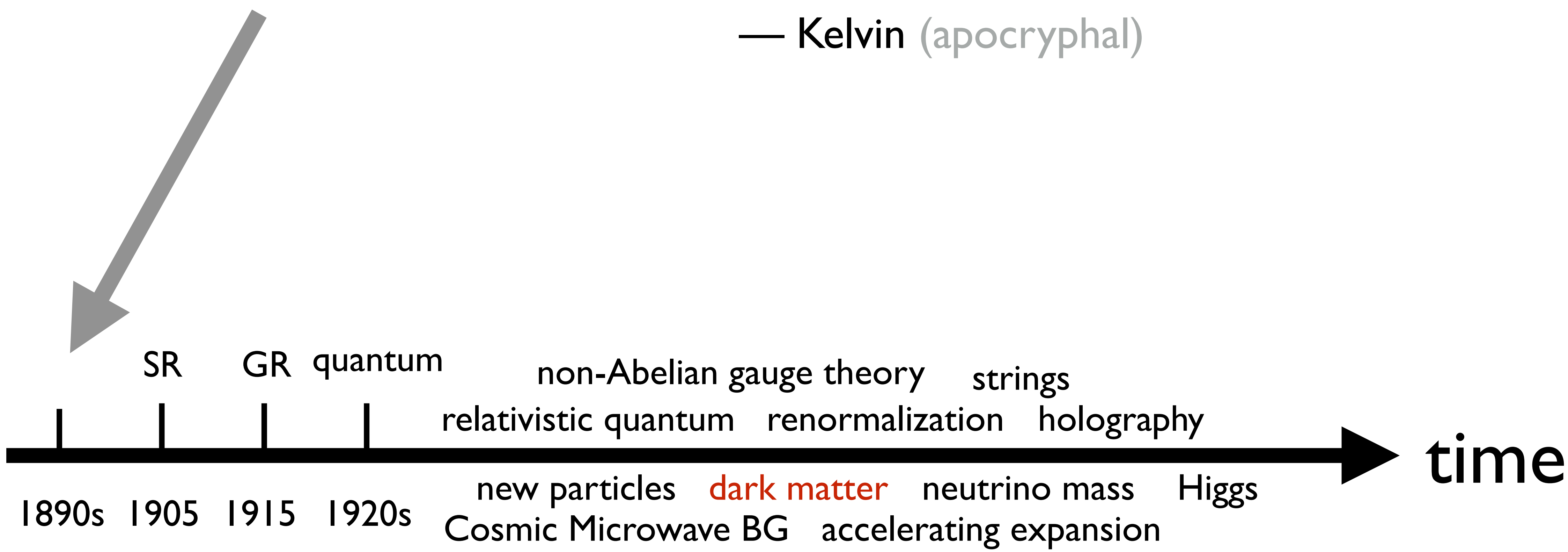
L	$1/2$	$\mathbb{1}$	$\square$	$-1/2$
$\bar{e}$	$1/2$	$\mathbb{1}$	$\mathbb{1}$	-1
H	0	$\mathbb{1}$	$\square$	$1/2$

The State of Particle Physics: 2015

"There is nothing new to be discovered in physics now. All that remains is more and more precise measurement"

— Kelvin (apocryphal)



The State of Particle Physics: 2015

“We also know there are
known unknowns,
that is to say we know there
are some things we do not know.

But there are also
unknown unknowns
the ones we don't know
we don't know.”

— Donald Rumsfeld (2002)

Photo by Scott Davis, released by US DoD (010122-A-3569D-001)

Known unknown, unknown knowable

Where do we come from?

Baryon asymmetry? Strong CP Problem? Flavor structure?

What are we?

Quantum gravity? Inflation?

Where are we going?

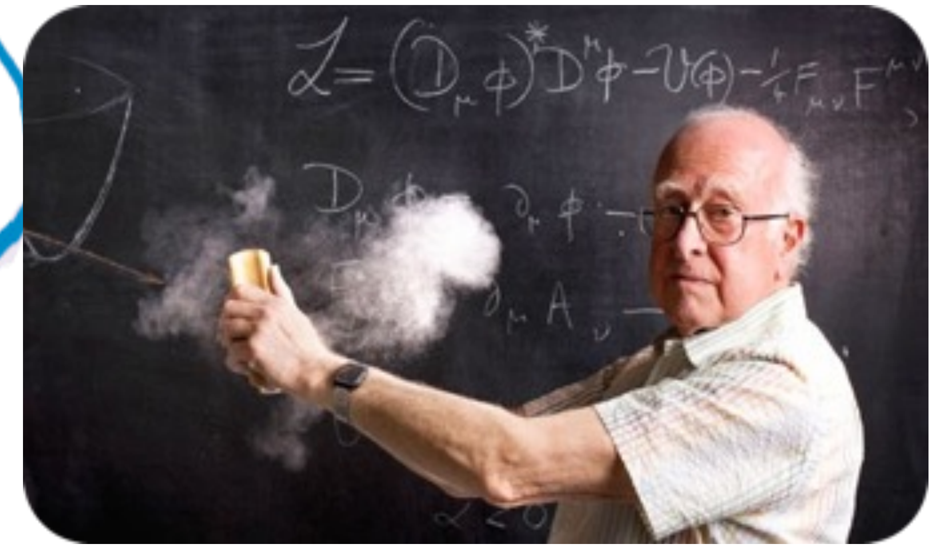
Proton stability.

Status: under a lamp post

Lots of theoretical models, but have to get lucky with experiments. No guarantee.

Gauguin, “Where Do We Come From? What Are We? Where Are We Going?” (1897)

Known Unknowns, Likely Knowable



The Hierarchy Problem

What keeps the Higgs light?

Status: wait and see

Hopefully the LHC will tell us.
Good reasons to be hopeful.
See Indara's talk!

FT, *Quantum Diaries*, "The Hierarchy Problem" (2012)

Known Unknowns, Likely Knowable

It exists.

We're swimming in it

It's most of everything

80% of matter

we might be detecting it

… right now!

Julie Peasley, particlezoo.net

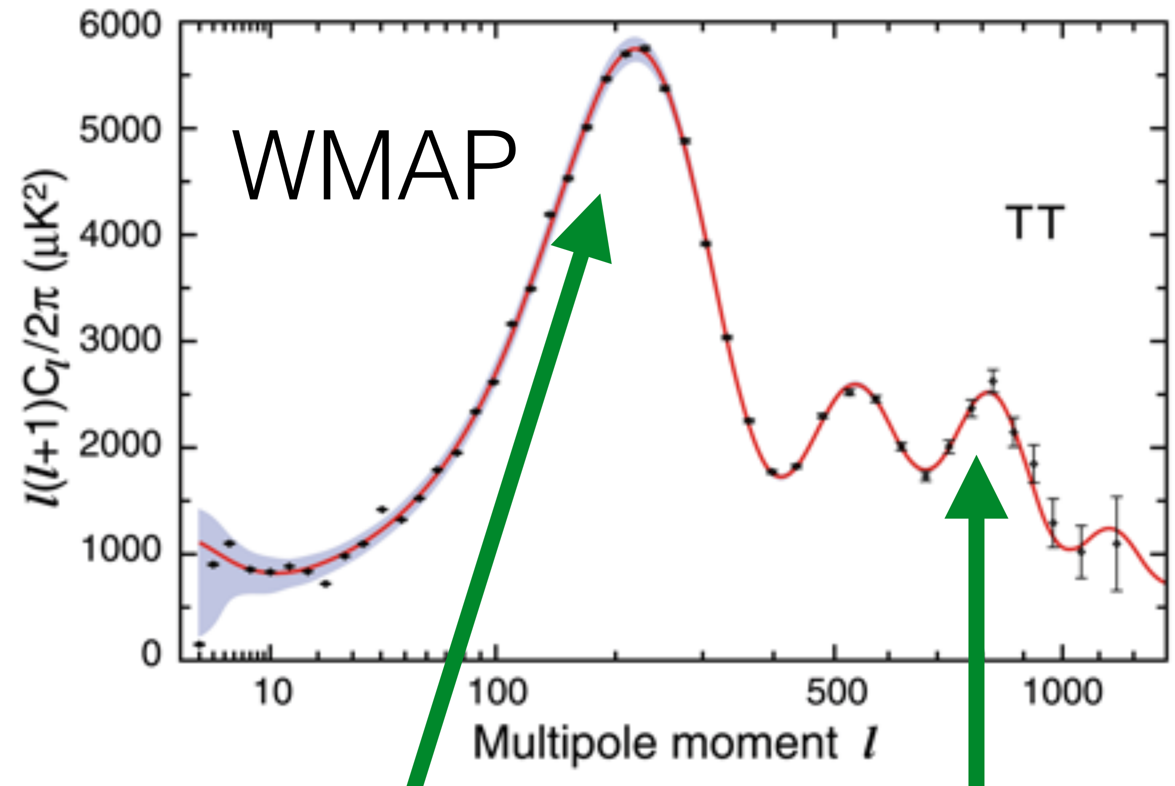
Particle Dark Matter Exists

Cosmic Microwave BG

Galactic Rotation Curves

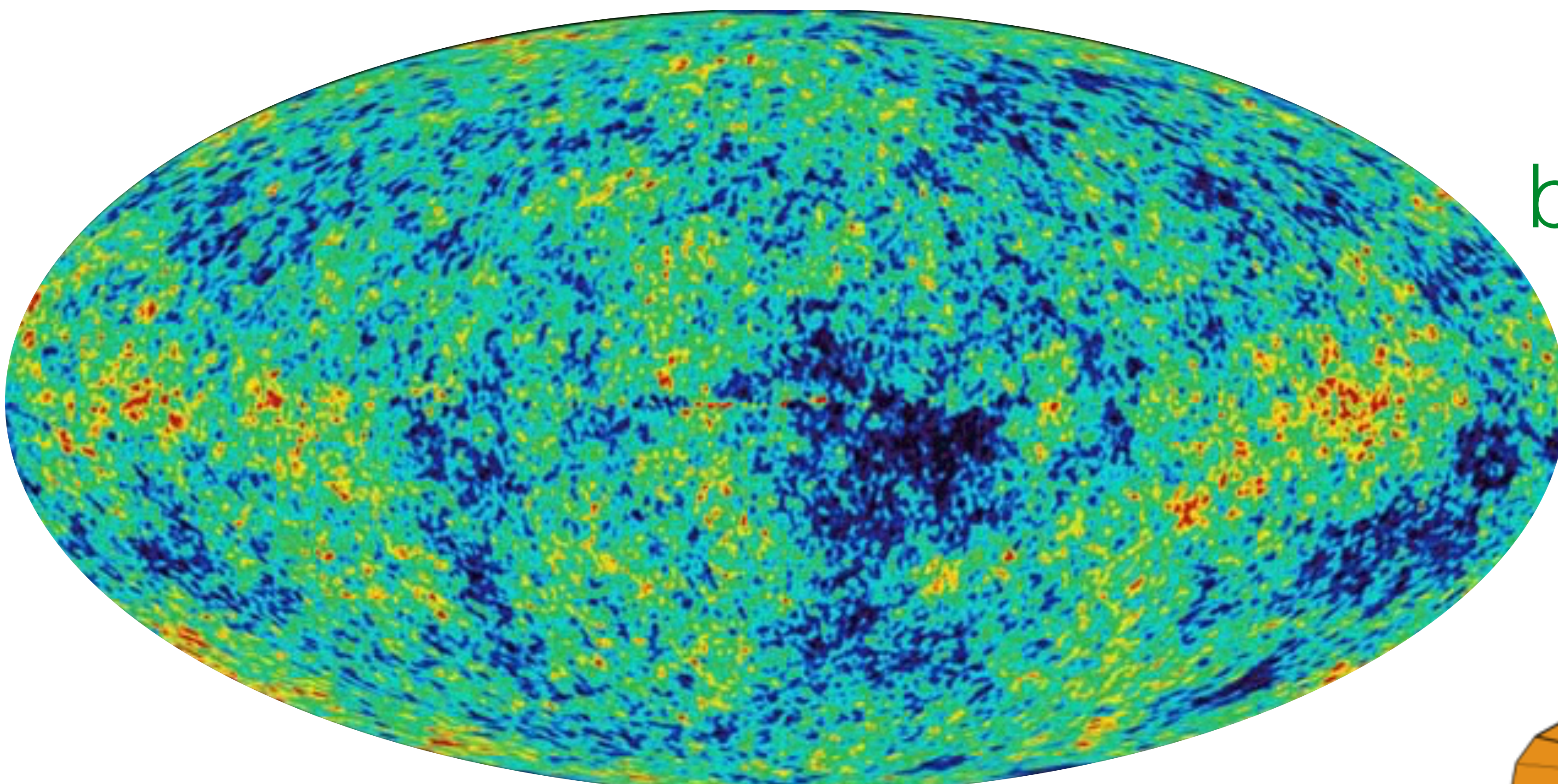
Large Scale Structure

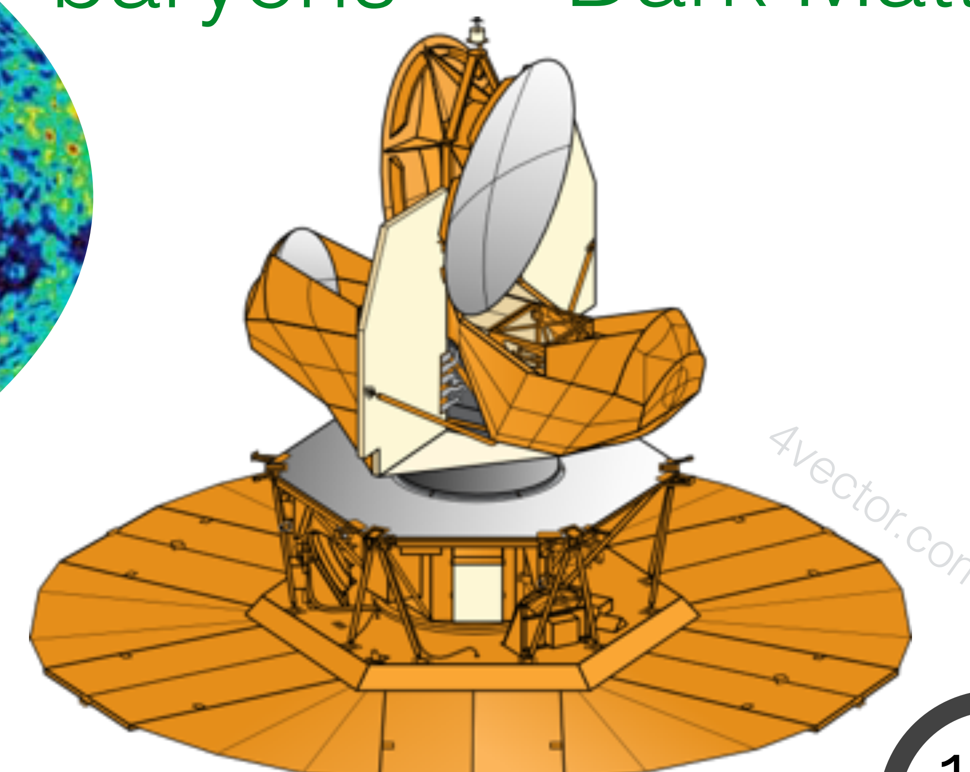
Gravitational Lensing



baryons

Dark Matter

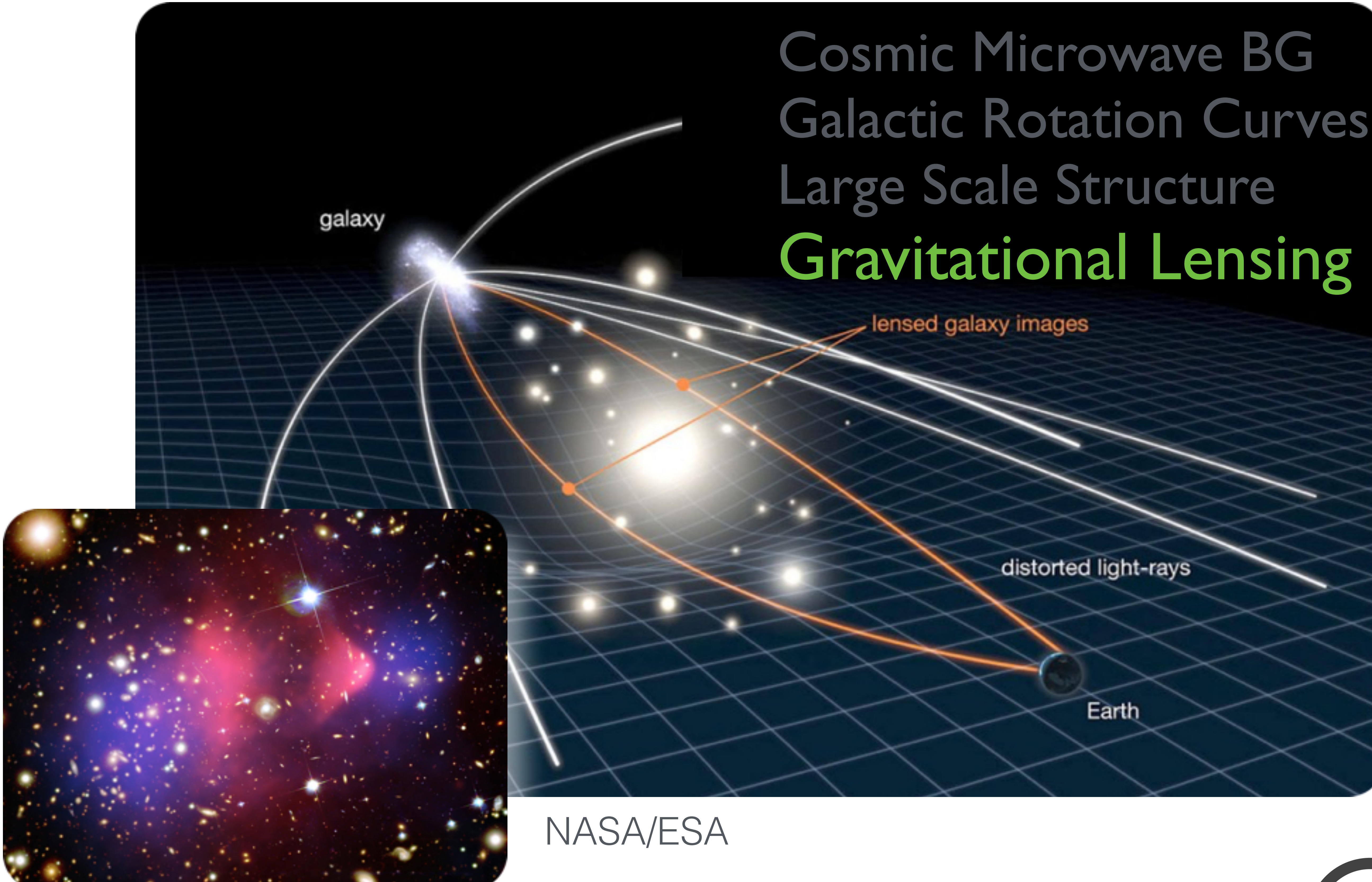




Bennett, C.L., et.al., 2013, ApJS., 208, 20B

Particle Dark Matter Exists

Cosmic Microwave BG
Galactic Rotation Curves
Large Scale Structure
Gravitational Lensing



NASA/ESA

Our goal

fundamental forces

matter particles

Field	Spin	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$
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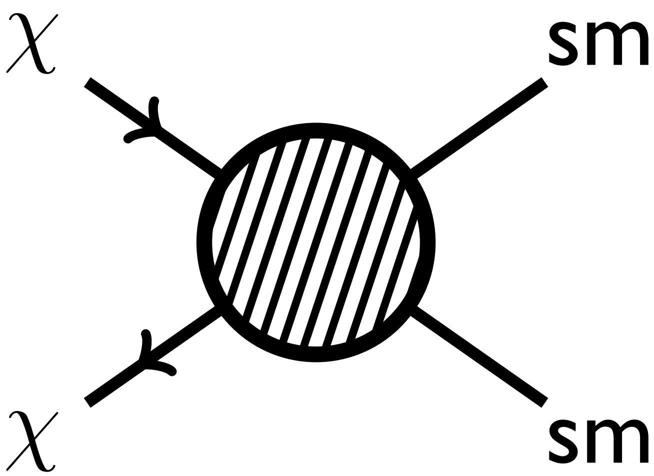
H	0	$\mathbb{1}$	$\square$	$1/2$
χ	?	$\mathbb{1}$	$\mathbb{1}$	0

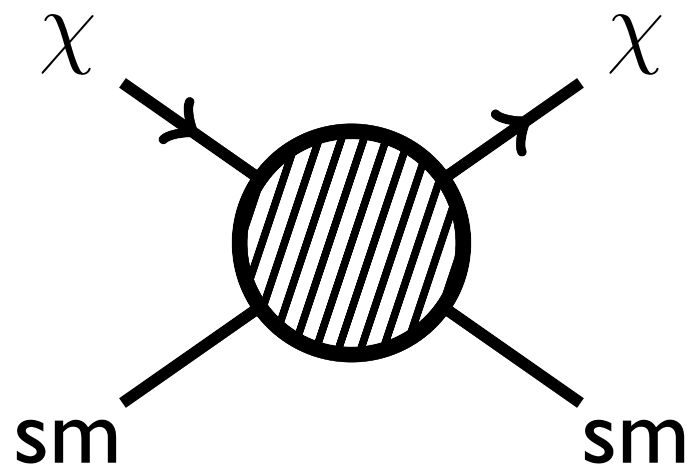
Dark Matter

… is "dark"

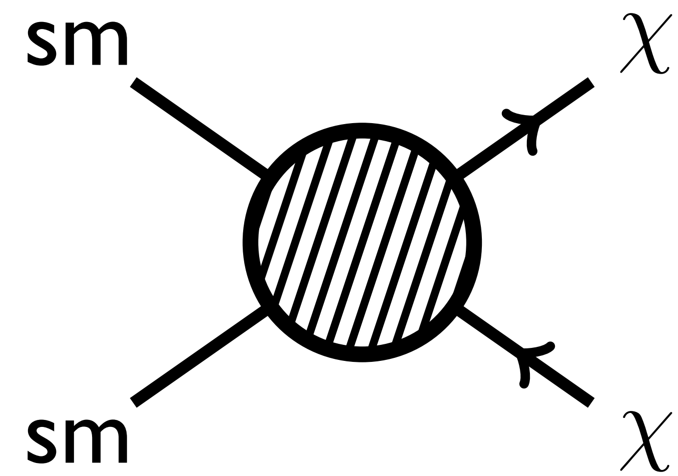
Conventional View of DM Interactions



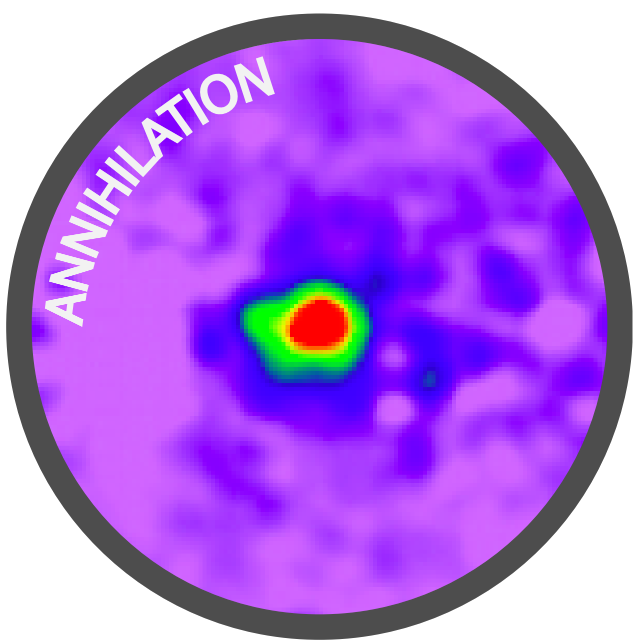
Indirect

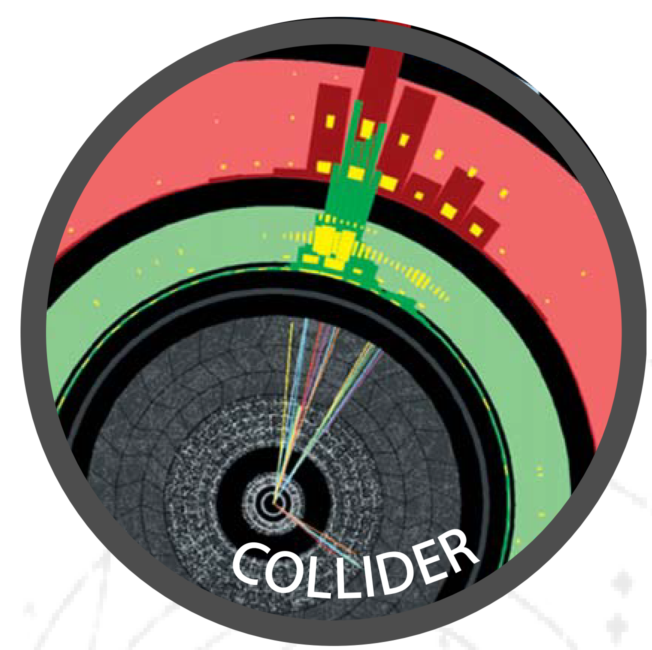


Direct



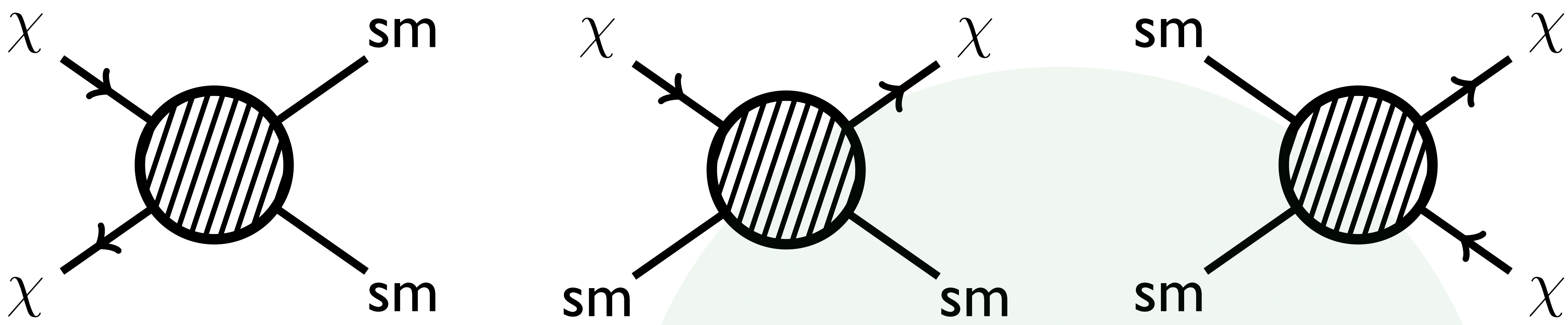
Collider





Exceptions: SIMP Miracle (1402.5143), DMdm (1312.2618), Boosted Dark Matter (1405.7370), …

Conventional View of DM Interactions



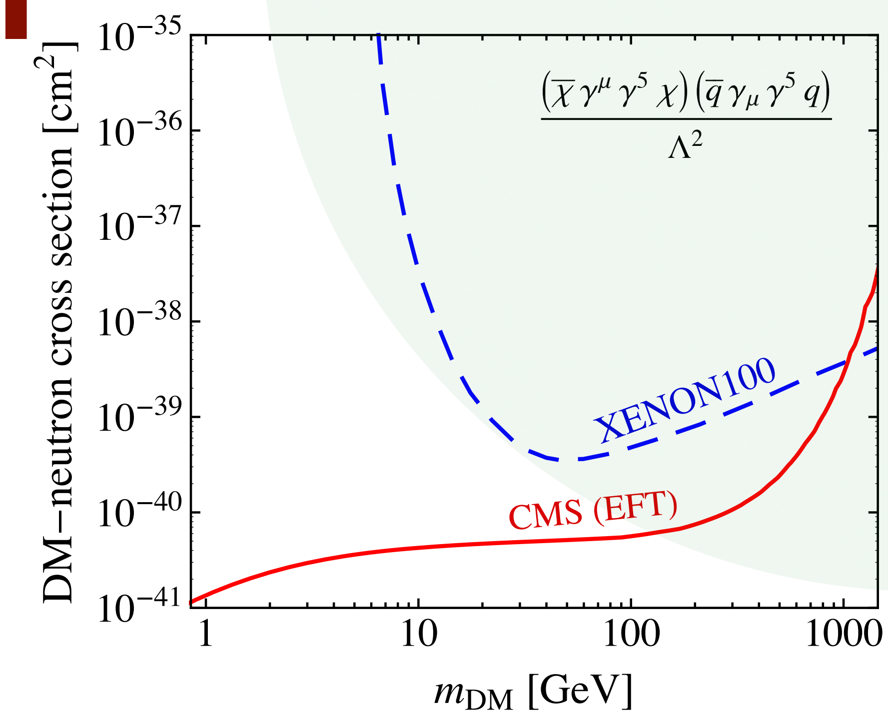
Indirect

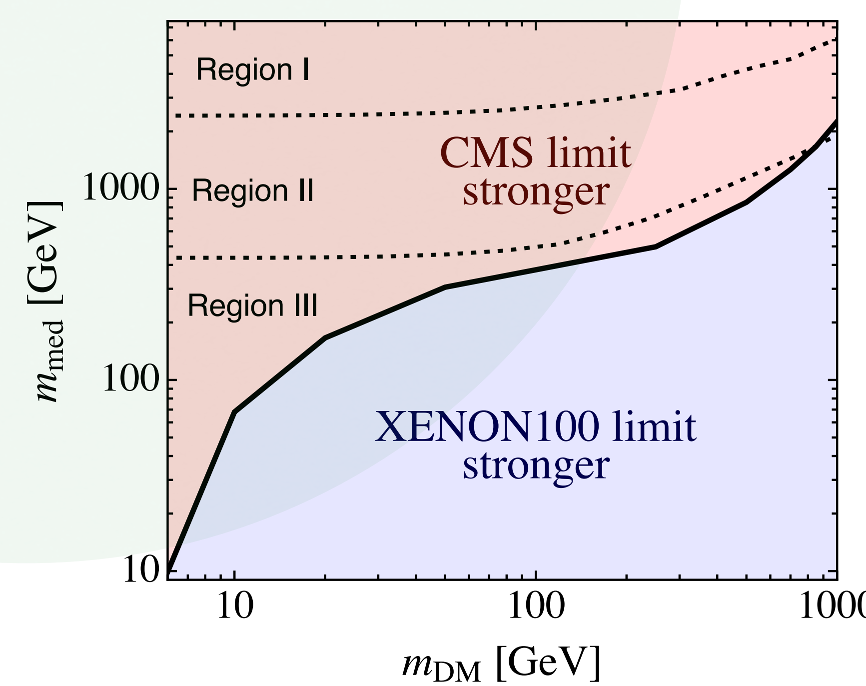
Direct

Collider

Mono-SM

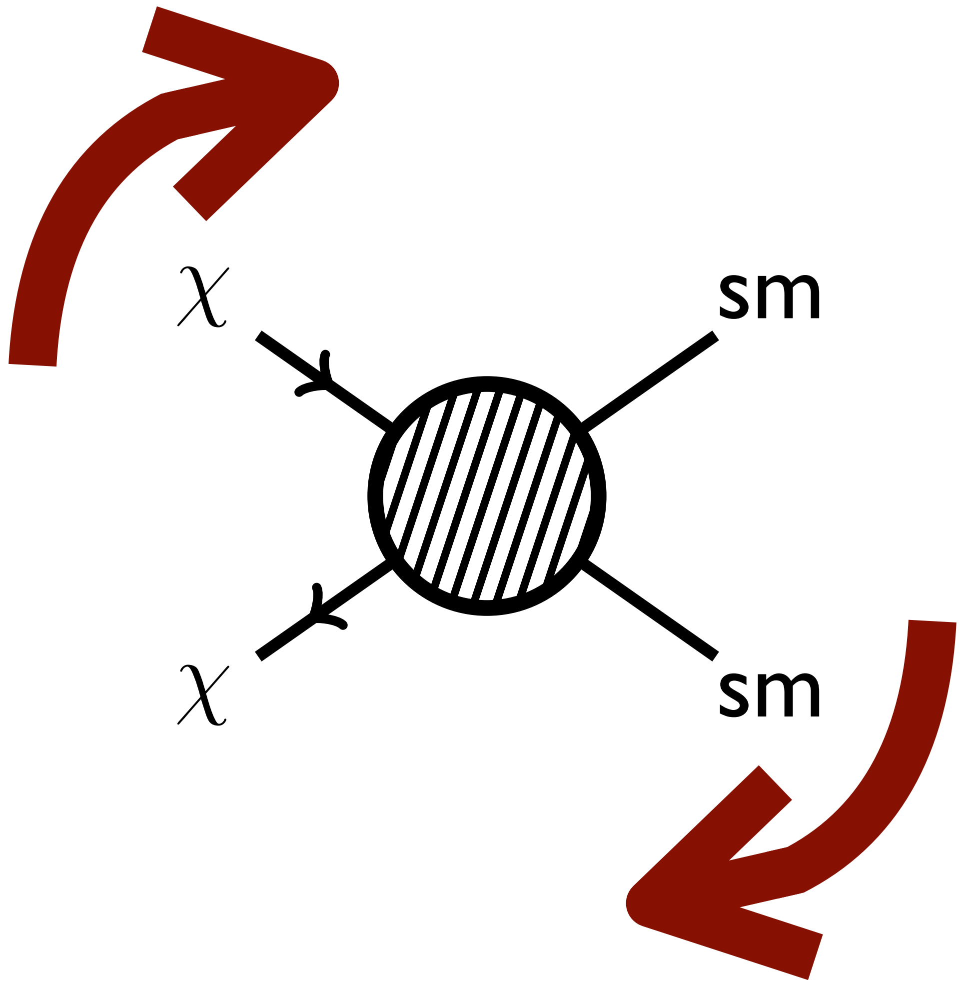
Mediators Important

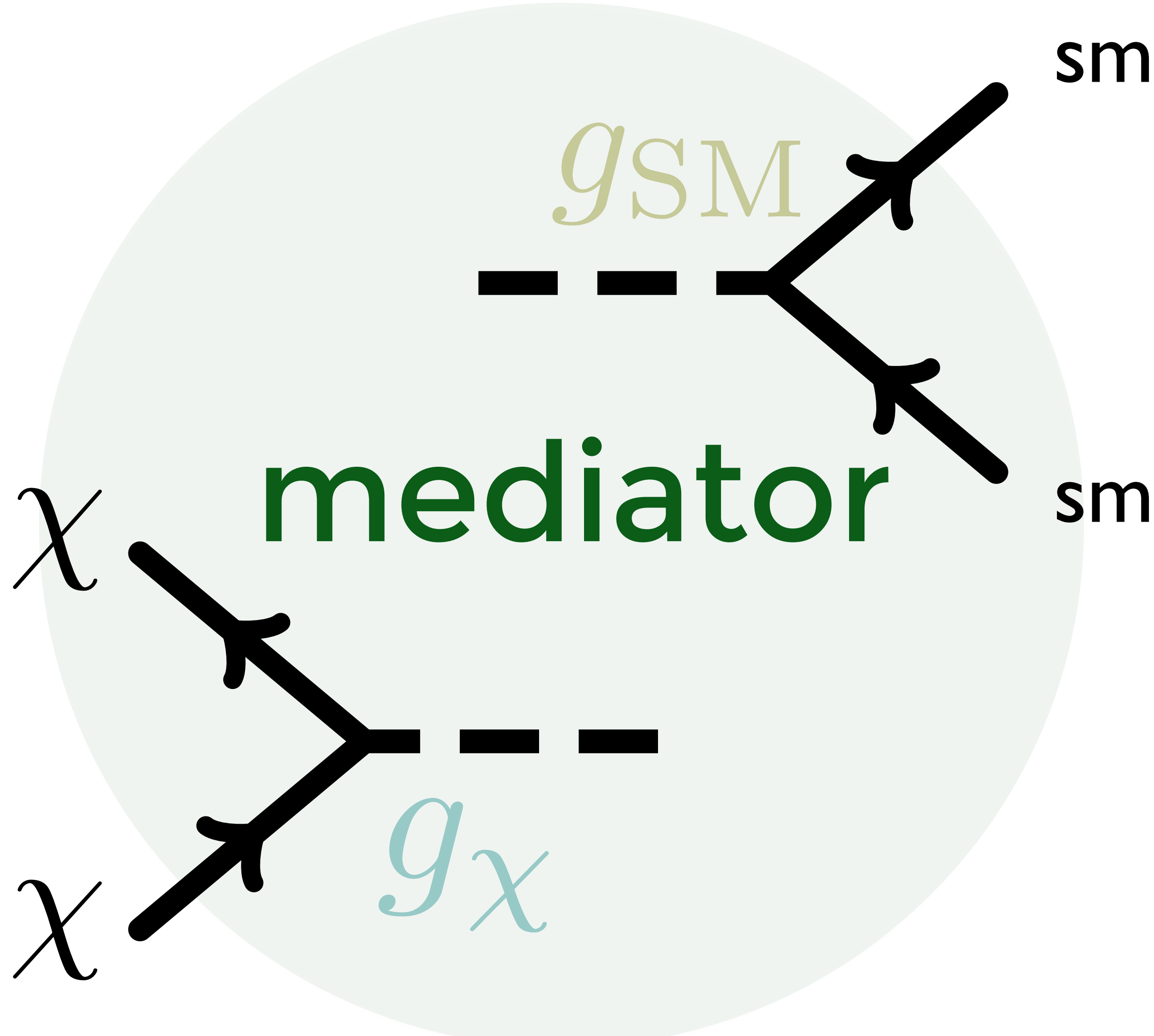




Buchmueller et al. 1308.6799; see also Shepherd 1111.2359, etc…

Simplified Models





rather than this… … use this

See, for example: Shepherd et al. (1111.2359), Busoni et al. (1402.1275, 1405.3101), Buchmueller et al (1308.6799, 1407.8257), Harris et al. (1411.0535), Abdullah et al. (1409.2893), …

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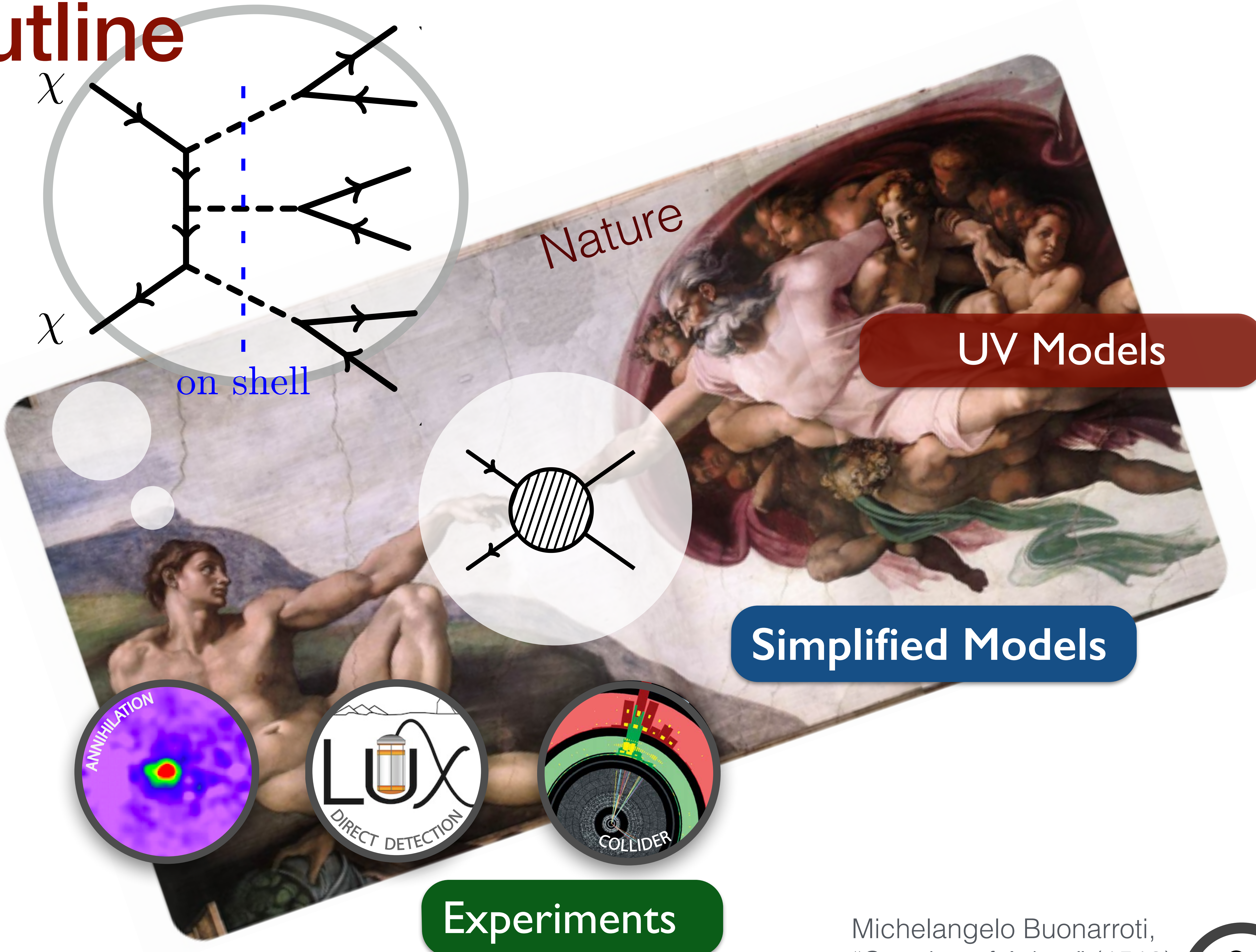
H	0	$\mathbb{1}$	$\square$	$1/2$
χ	?	$\mathbb{1}$	$\mathbb{1}$	0
φ	?	?	?	?

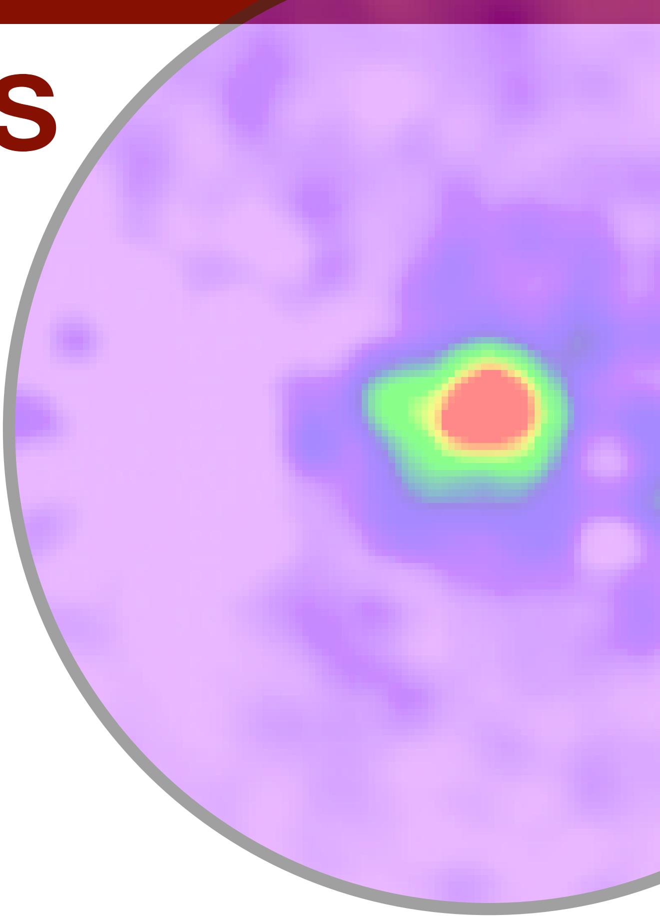
Outline



Michelangelo Buonarroti,
"Creation of Adam" (1510)

Case Study: Fermi γ-ray excess

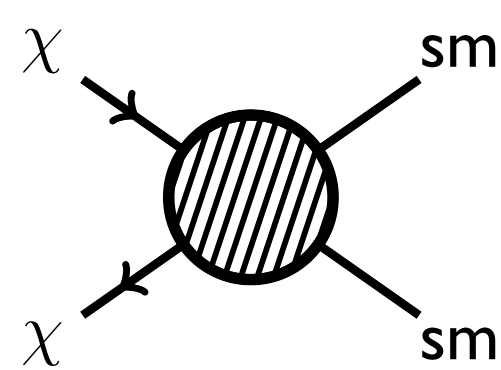
Fermi-LAT Collaboration, S. Murgia; 2014 Fermi Symposium



- Possible indirect detection signal
- There are reasons to be skeptical

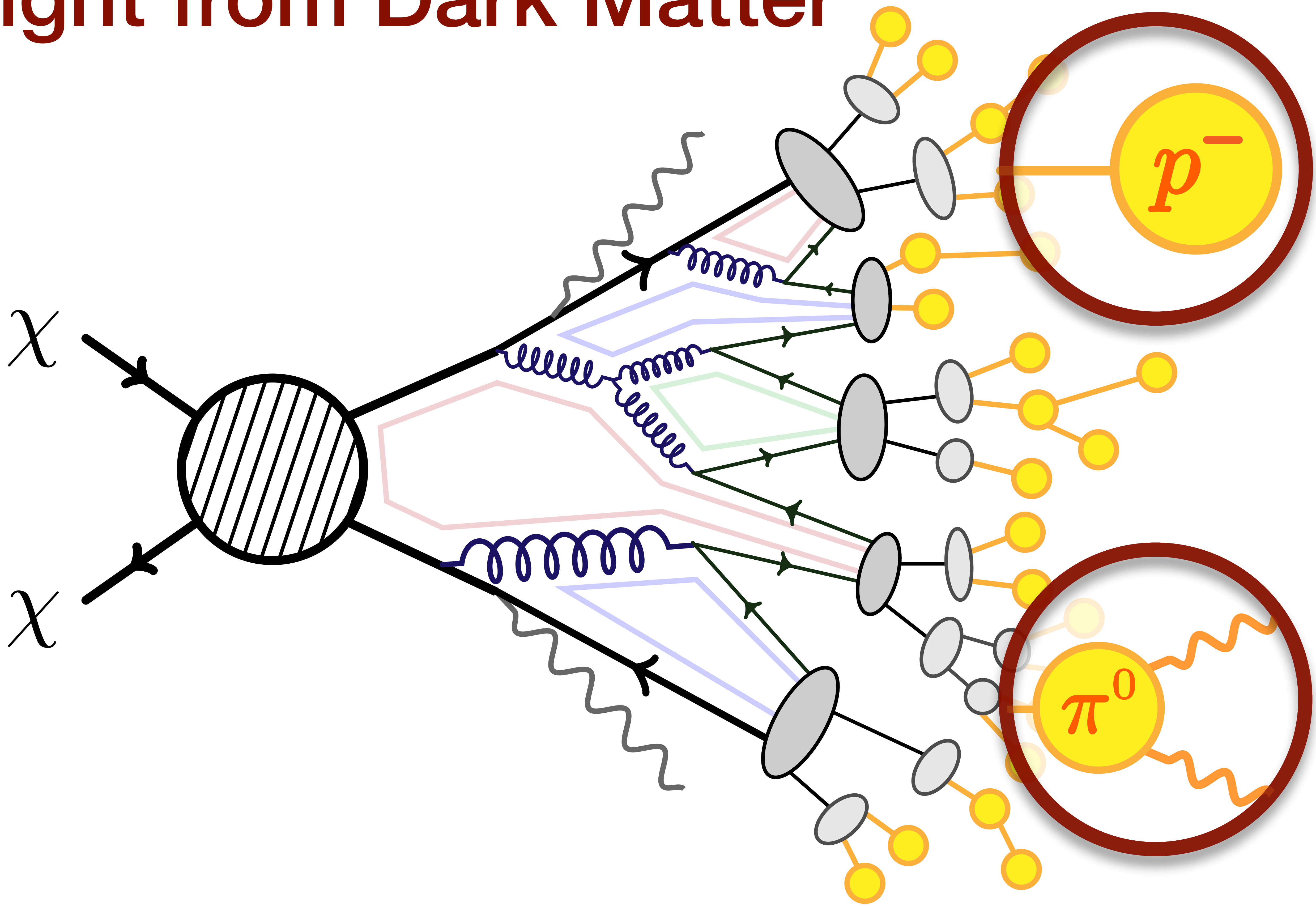
  We'll address these soon.
- Framework to play with new ideas

  that can be applied broadly (not just one specific signal)



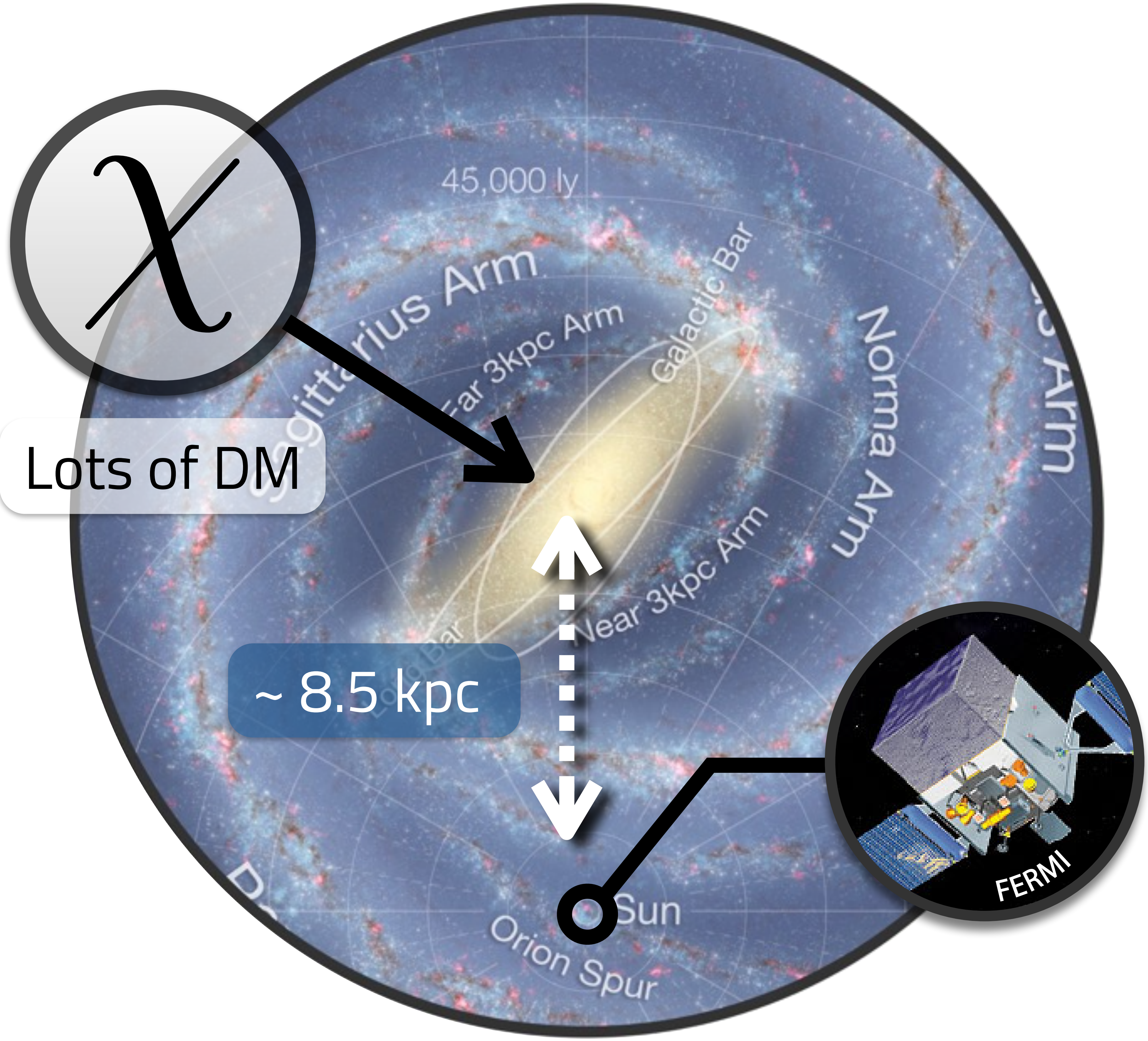
Goodenough & Hooper (0910.2998, 1010.2752), Hooper & Linden (1110.0006), Abazajian et al. (1011.4275, 1207.6047, 1402.4090), Boyarsky et al. (1012.5839); Gordon & Macias (1306.5725); Daylan et al. (1402.6703); Calore et al. (1411.4647, 1502.02805); Agrawal et al. (1411.2592); Fermi-LAT collaboration (2014 Symposium)

Light from Dark Matter



Adapted from D. Zeppenfeld PITP05

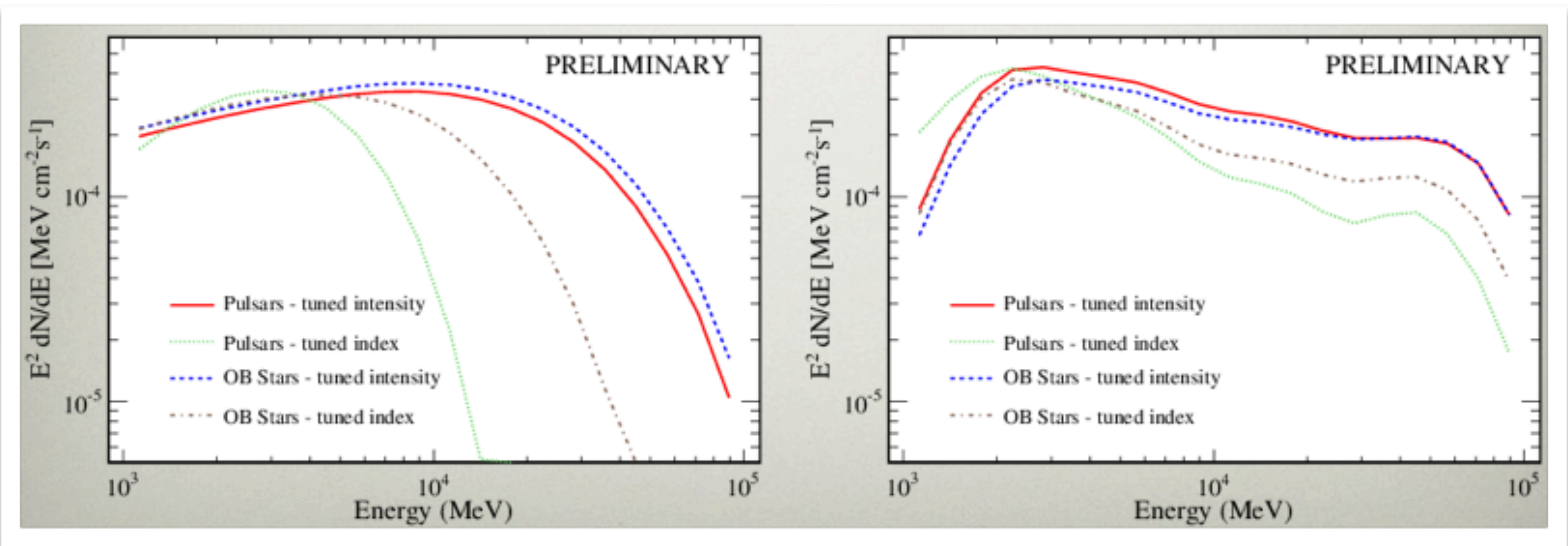
Where to look



NASA/JPL-Caltech/ESO/R. Hurt

Galactic Center Excess

Calore et al. (1411.4647, 1502.02805); **Agrawal et al.** (1411.2592); **Fermi-LAT Collaboration** (in progress, see Fermi Symposium 2015)

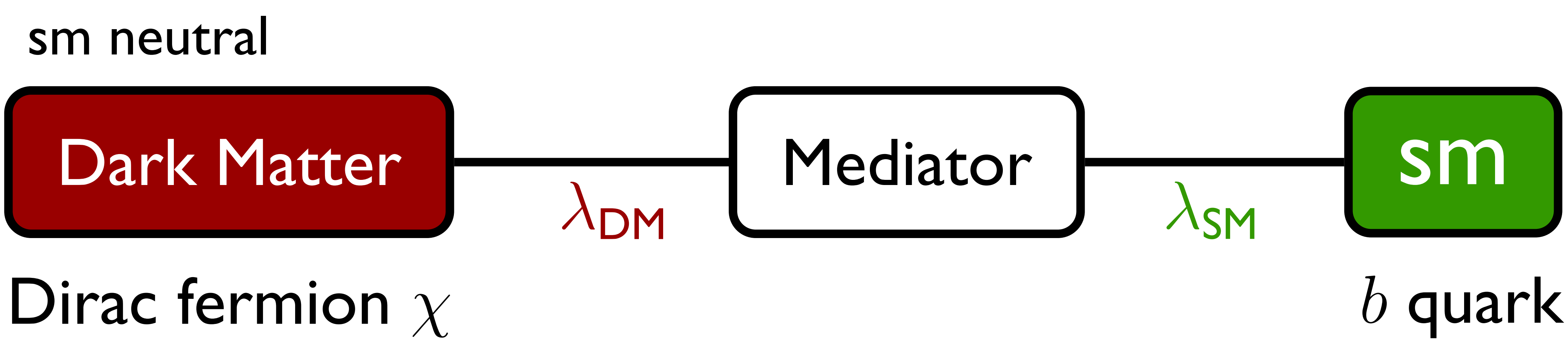


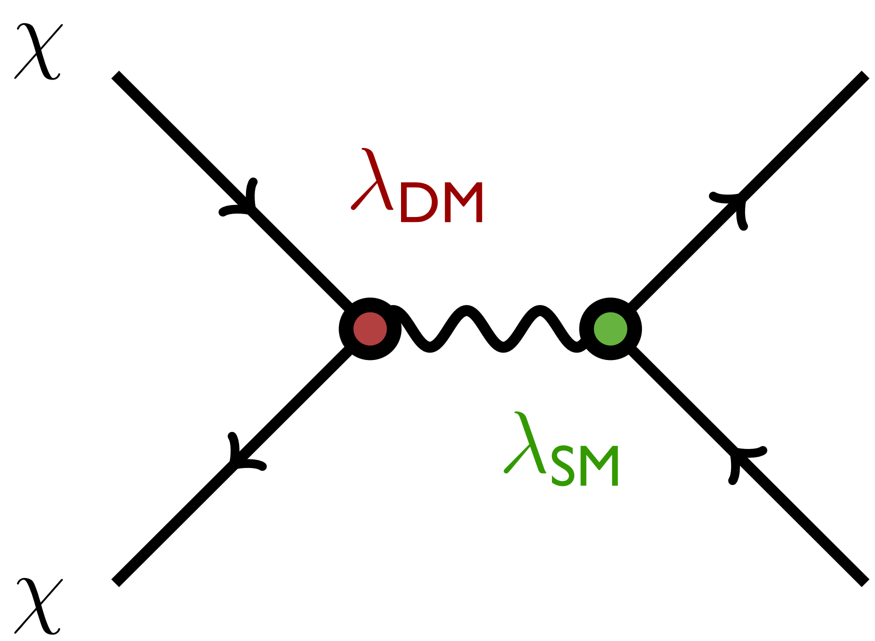
n.b. quantification of systematic uncertainties

Fermi-LAT Collaboration, S. Murgia; 2014 Fermi Symposium

Simplified Models

Renormalizable, capture physics of mediator (1105.2838)





Systematic studies:

Chicago: 1404.0022

Perimeter: 1404.2018

Explicit examples

Coy Dark Matter 1401.6458

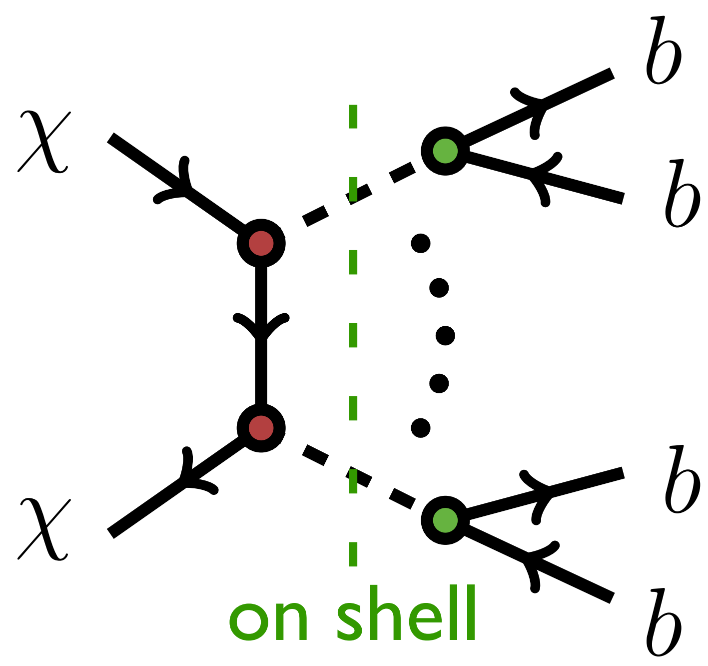
Boehm, Dolan, et al.

Z' portal 1501.03490

Alves, Berlin, Profumo, Queiroz

On-Shell mediators

The m_{med} < heavy regime also includes $m_{\text{med}} < m_\chi$ where the mediator is accessible as an on shell annihilation mode



- Can be dominant mode
- Separates λ_{DM} from λ_{SM}
- Admits $\lambda_{DM} \gg \lambda_{SM}$

Application to the Hooperon:

FT et al.	1404.6528, 1503.05919
Dolan et al	1404.4977
Martin et al.	1405.0272
Elor et al.	1503.01773

Previously: PAMELA

Axion Portal	0810.5397
Cascades	0901.2926

On-Shell Simplified Models

sm neutral | Dark Matter | Dirac fermion χ

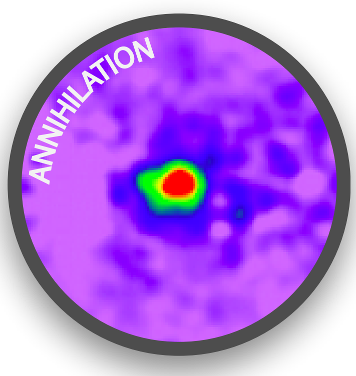
λ_{DM}

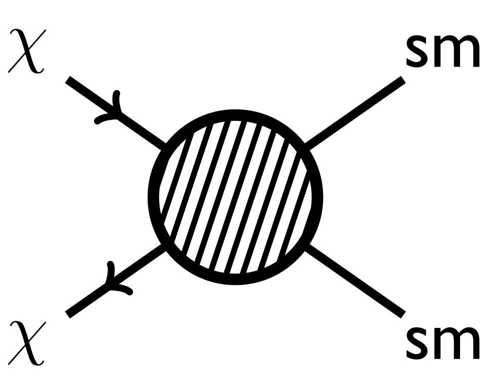
sm neutral | Mediator | φ, V

λ_{SM}

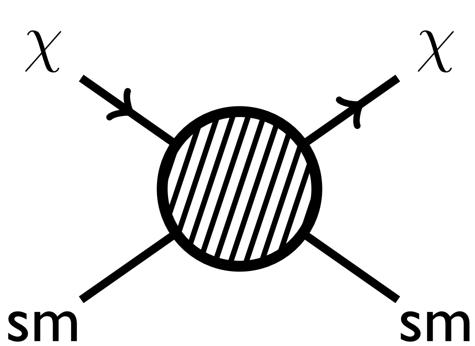
sm | b quark

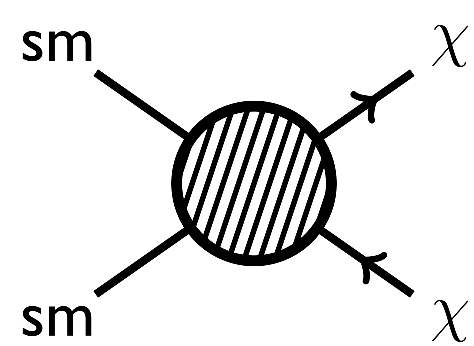
Annihilation, $\langle \sigma v \rangle$
γ-ray excess, relic abundance





Constraints
direct detection, colliders





Model Building

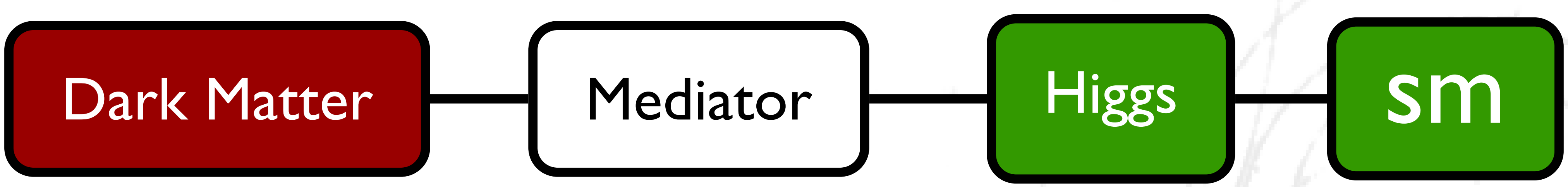
Spin-1 Mediator

Prototype is gauged $U(1)_B$, expect universal coupling to quarks.
Exception? ρ-like states in composite Higgs? (Contino et al. 1109.1570)

Spin-0 Mediator

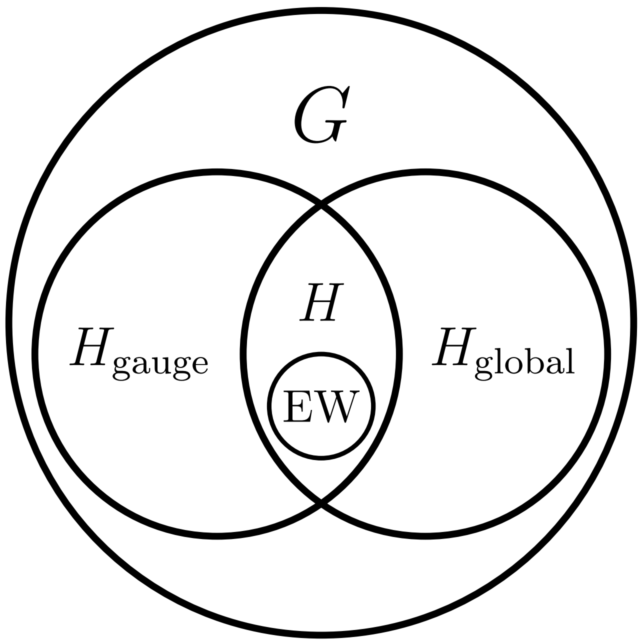
$$\mathcal{L}_{\varphi\text{-sm}} = \frac{\lambda_u y^u_{ij}}{\Lambda}\varphi H \cdot \bar{Q} u_R + \frac{\lambda_d y^d_{ij}}{\Lambda}\varphi \tilde{H} \cdot \bar{Q} d_R + \frac{\lambda_\ell y^\ell_{ij}}{\Lambda}\varphi \tilde{H} \cdot \bar{L} \ell_R$$

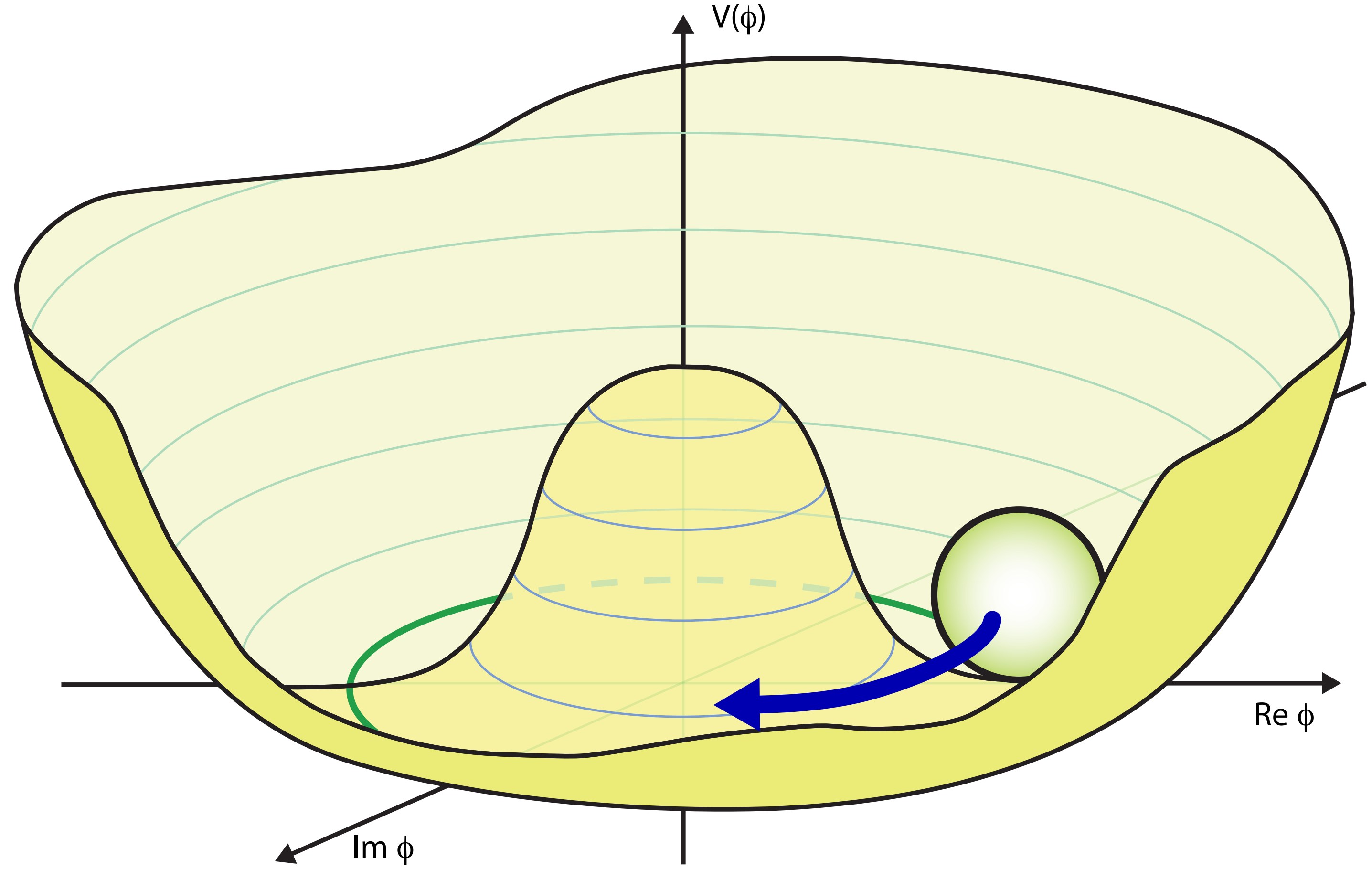
Recent UV completion through 'Higgs-portal'-portal: Ipek et al. 1404.3716

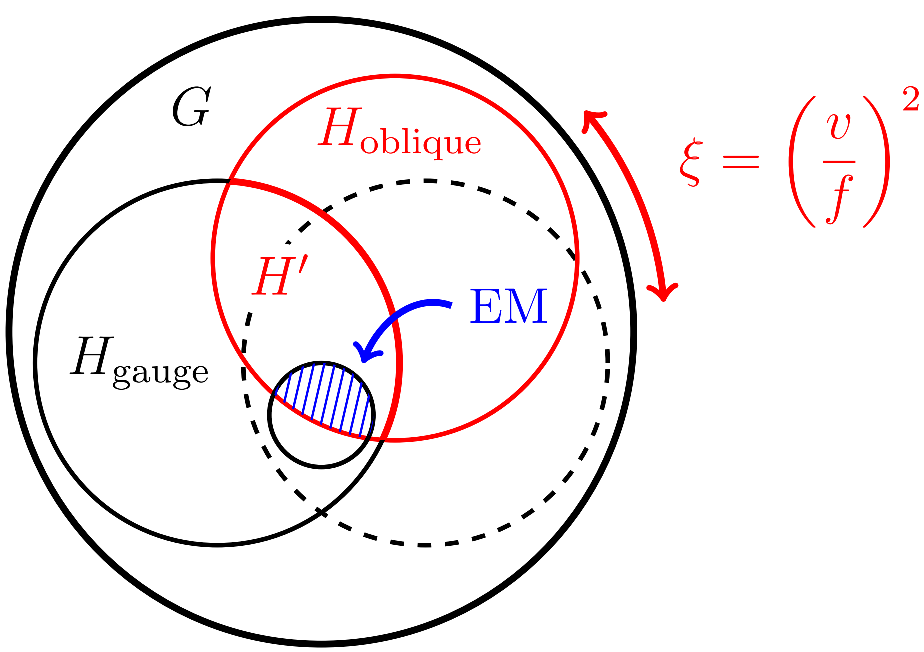


Recently: many studies mapping this to (N)MSSM, 2HDM
See also singlet scalar model, Profumo et al. 1412.1105

Pseudoscalar without the scalar





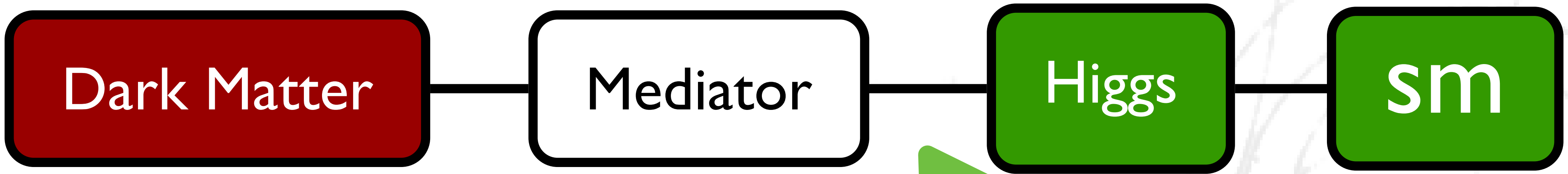


Higgs as a pNGB (composite Higgs)
with non-minimal coset

analogy: π^0 vs $\pi^\pm$

Work in progress with A. Wijangco and J. Serra

Composite Mediators



New Matter
incomplete rep. adds to global symmetry breaking

SM singlet
"extra" Goldstone

These interactions are given by nonlinear sigma model and are distinct from 2HDM

Connects:

- Dark Matter
- Mediators
- EWSB

No 2HDM required!

different phenomenology and constraints

Higgs as a pNGB (composite Higgs) with non-minimal coset

Work in progress with A. Wijangco and J. Serra

Avoiding the Dwarf Bounds

Dwarf Spheroidals: mostly DM, little stellar matter

… so should to see same GeV excess as Gal. Center if it's DM annihilation

Usual assumption:

Dark Matter Annihilation ⟶ γ-ray photons

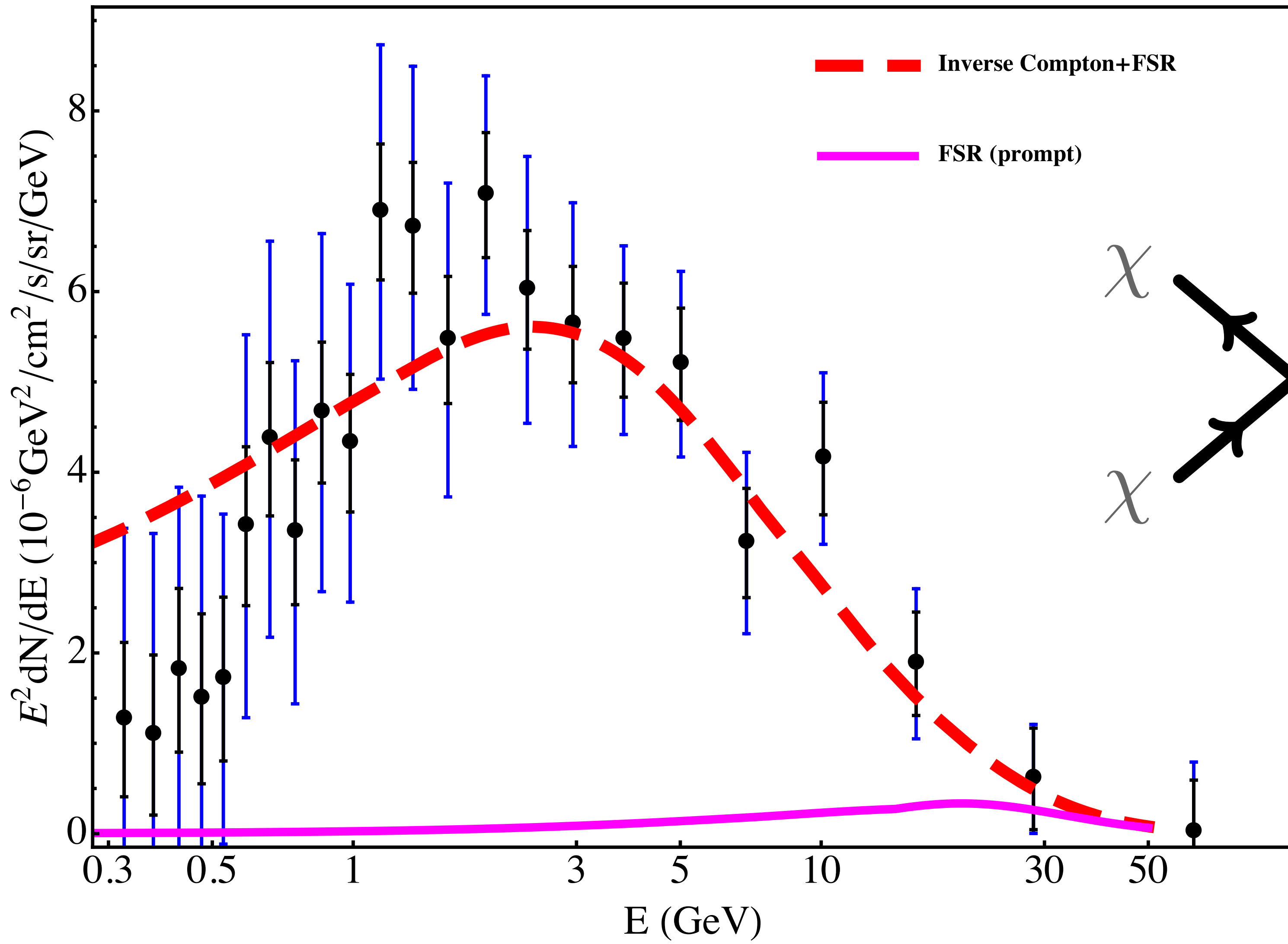
Instead, revise the relation:

Kaplinghat, Linden, Yu, 1501.03507

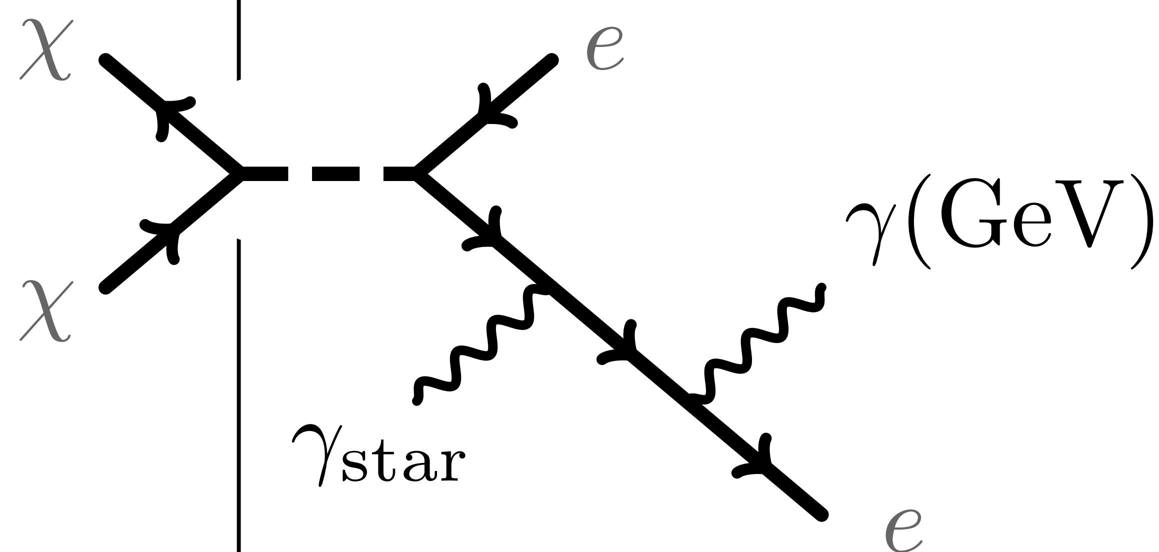
Dark Matter Annihilation ⟶ γ-ray photons
+ ambient starlight

But: requires annihilation into *electrons* … spectrum doesn't fit?

Avoiding Dwarf Bounds



Photon spectrum from FSR doesn't fit (Weiszacker-Williams)

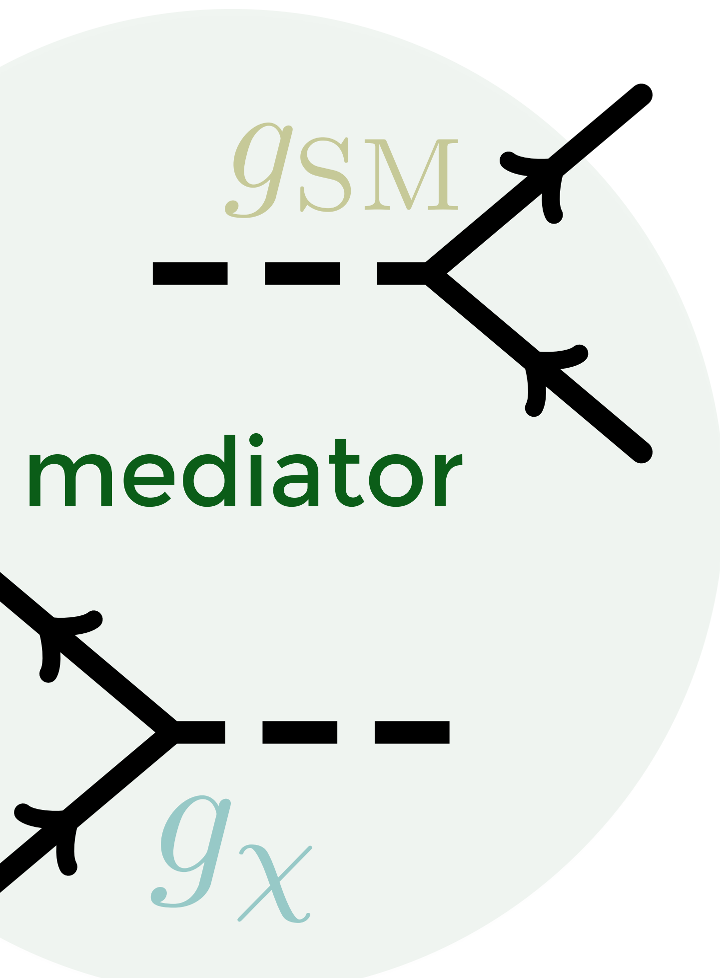


but Inverse Compton can upscatter starlight into a diffuse GeV spectrum

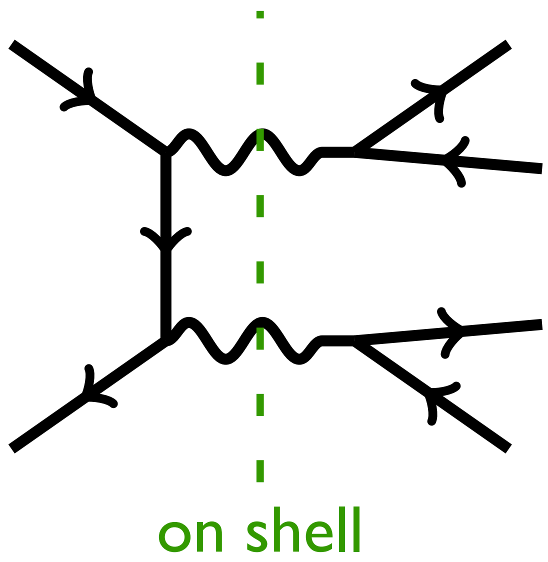
But: this leaves an imprint on positron fraction (PAMELA) and can be constrained by mono-photon searches at LEP

Kaplinghat, Linden, Yu, 1501.03507

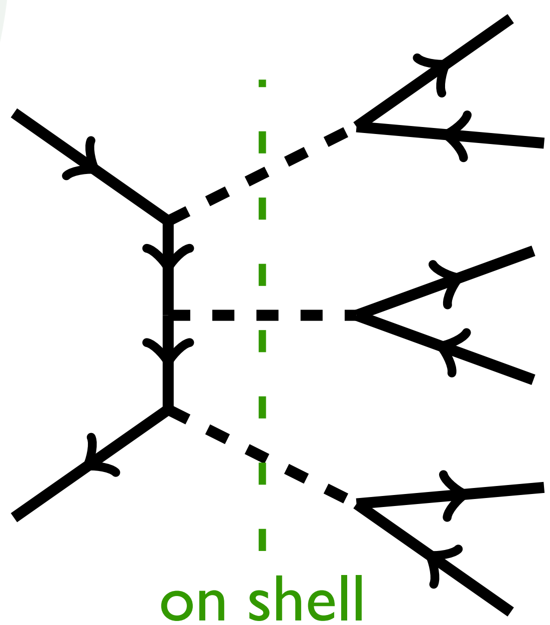
Summary



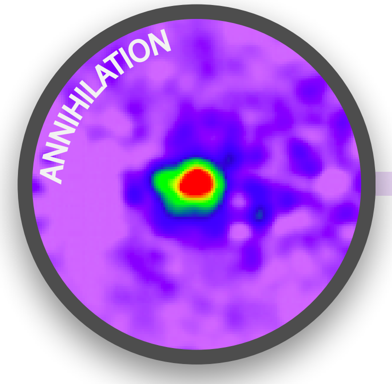
g_{SM}
mediator
g_χ



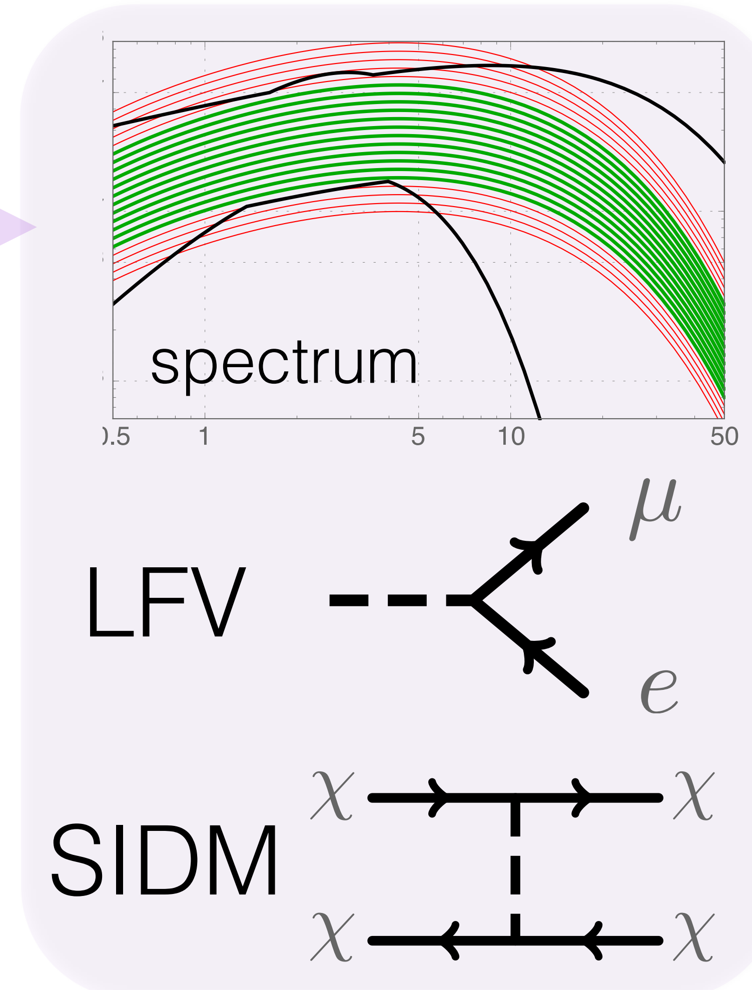
on shell



on shell

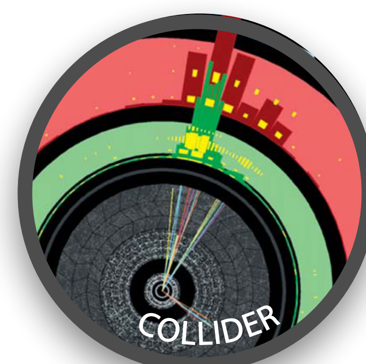


ANNIHILATION

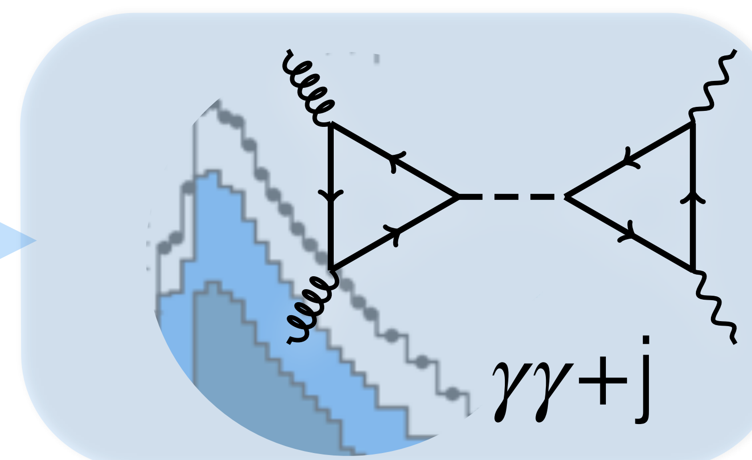


spectrum
0.5
1
5
10
50
LFV
μ
e
SIDM
χ
χ
χ
χ

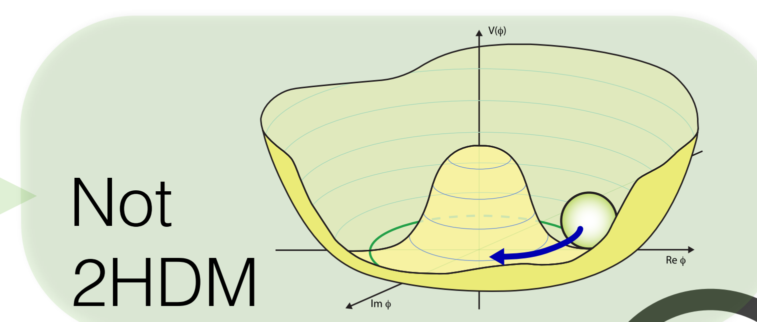
LUX
DIRECT DETECTION



COLLIDER



$\gamma\gamma$+j



Not
2HDM