Non-minimal Dark Sector Phenomenology: Prelude

Phenomenology Symposium 2017

arXiv: 1612.06867 and arXiv: 1702.02944 with Jong-Chul Park and Seodong Shin

CERN

DOOJIN KIM

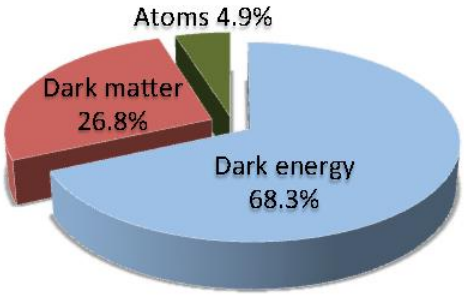
NON-MINIMAL DARK SECTOR

05.09.17

Dark Matter

Existence of dark matter

- Dark Matter (DM): **~25% of our universe**, existence supported by rotation curves, gravitational lensing, cosmic microwave background etc.



Dark Matter

Known properties

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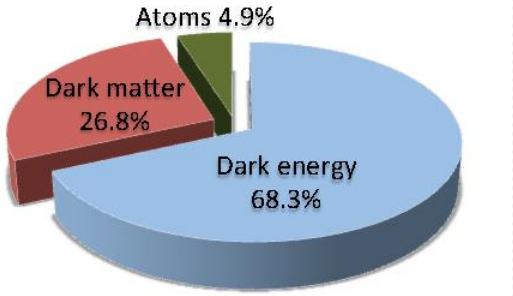
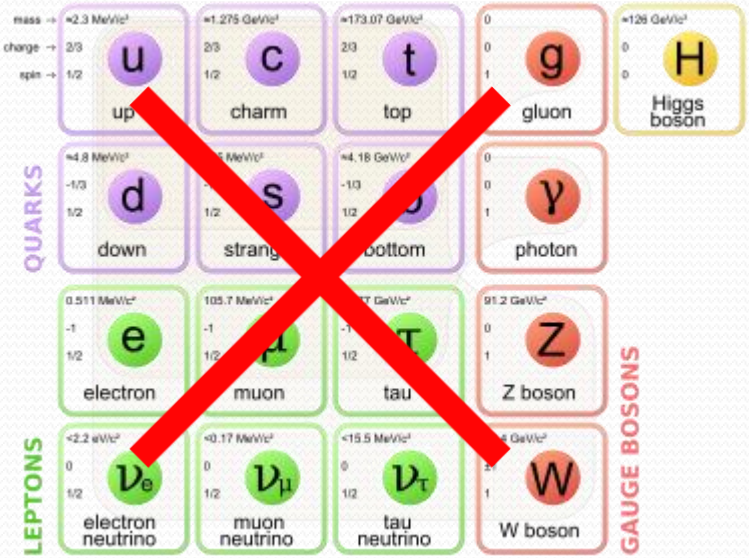


- Known DM properties (albeit few):
  - gravitationally interacting
  - not short-lived
  - not hot
  - not baryonic
  - not electrically charged

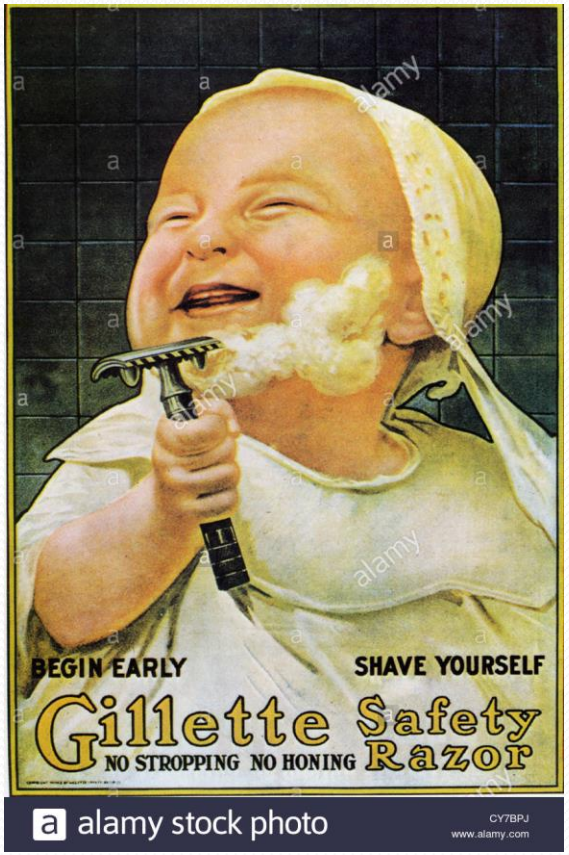
⇒ Need for **new physics/particles**



"Minimal" Dark Sector

Occam's razor(?)

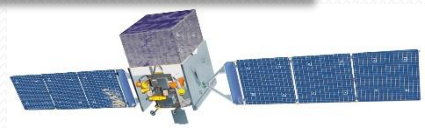
- Many DM simplified models or new physics models including a DM candidate proposed:
  - ✓ Positing **single DM species**/focusing on **dominant DM** (with other dark sector particles put aside)
  - ✓ Good and economical approach toward the truth in the earlier stage!
  - ✓ Concentrating on **DM itself** and relevant **phenomenological implications**



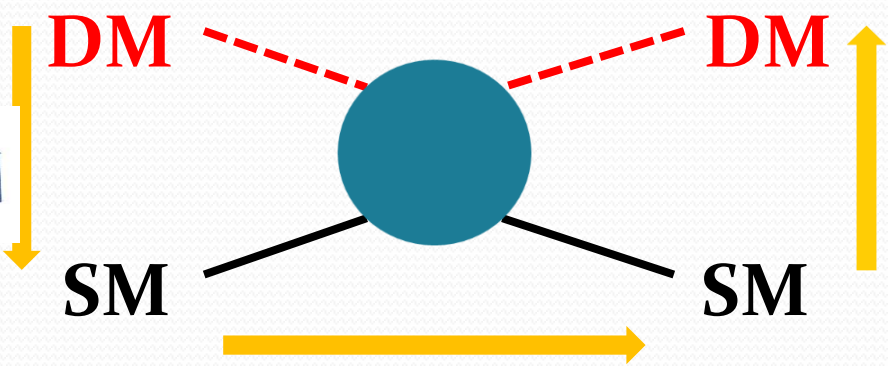
"Minimal" Dark Sector

- "Minimal" phenomenological implications

DM indirect search



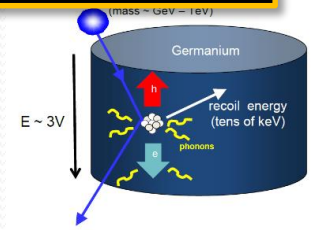
- ✓ (Non-relativistic) DM annihilation/decay to $\gamma, e^+, \bar{p}$, etc.
- ✓ $\langle\sigma v\rangle \sim 10^{-26}$ cm^3/s



DM production

- ✓ Active DM production at colliders
- ✓ Mono-X searches
- ✓ Expected rate inferred from/related to $\langle\sigma v\rangle \sim 10^{-26}$ cm^3/s

DM direct search



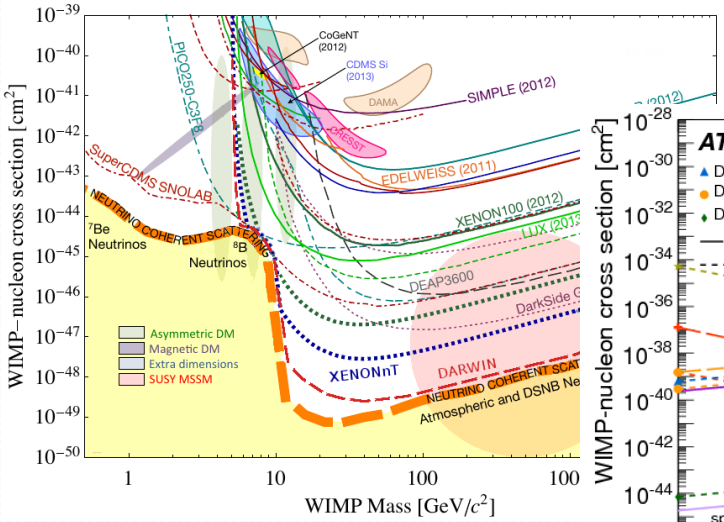
- ✓ (Non-relativistic) DM scattering off target nuclei
- ✓ $E_{\text{recoil}} \sim 1 - 100$ keV

"Non-minimal" Dark Sector

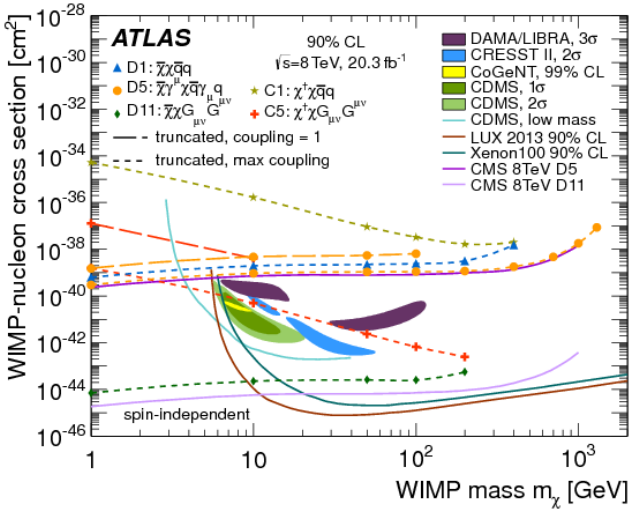
Why flavorful?

❑ **No "unambiguous" observation** of DM signatures via non-gravitational interactions

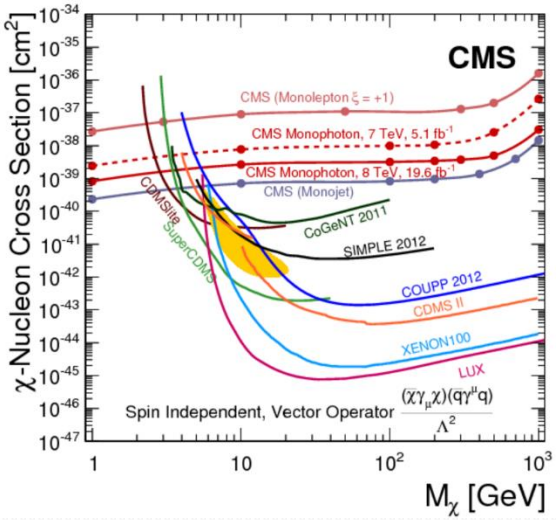
(many searches/interpretations designed under minimal dark-sector scenarios)



[P. Cushman, C. Calbiati and D. N. McKinsey, (2013); L. Baudis (2014)]



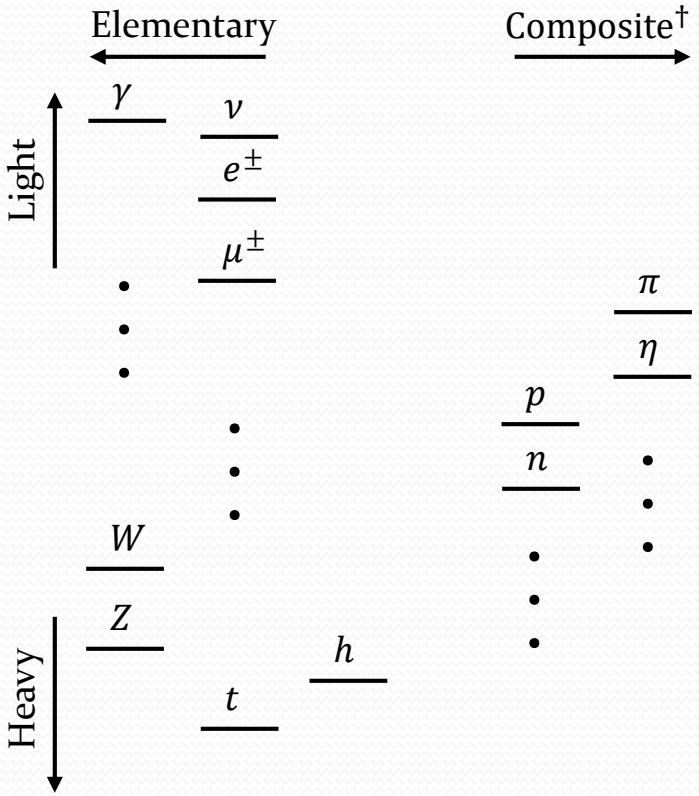
[ATLAS mono-jet search (2015)]



[CMS mono-photon search (2014)]

"Non-minimal" Dark Sector

- **Why flavorful?**

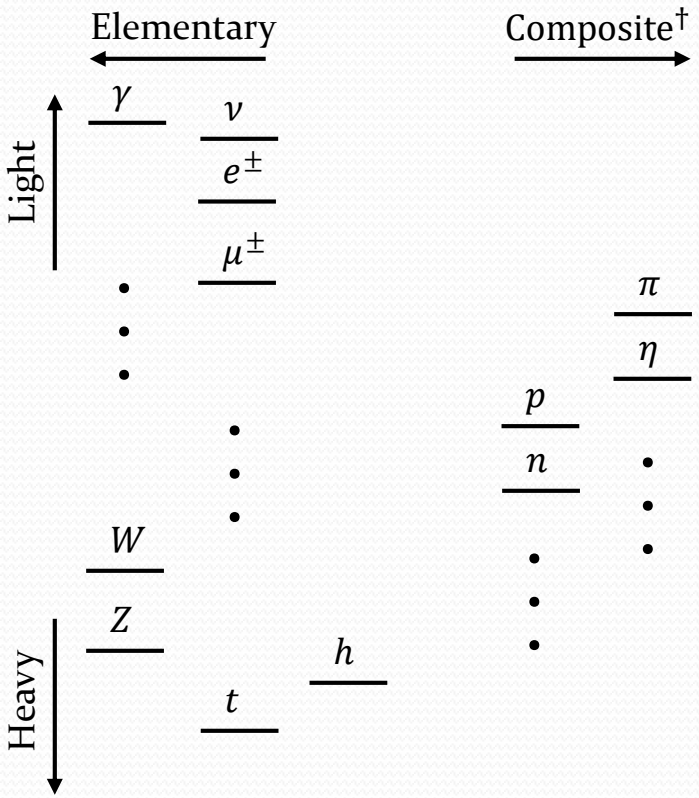


❑ Various particles in the SM sector

†: here meaning the particles made of elementary ones

"Non-minimal" Dark Sector

Why flavorful?



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- Various particles in the SM sector
  - ✓ **Multiple stable particles → interesting physics** from other stable members which are **not difficult to detect** albeit not dominant

"Non-minimal" Dark Sector

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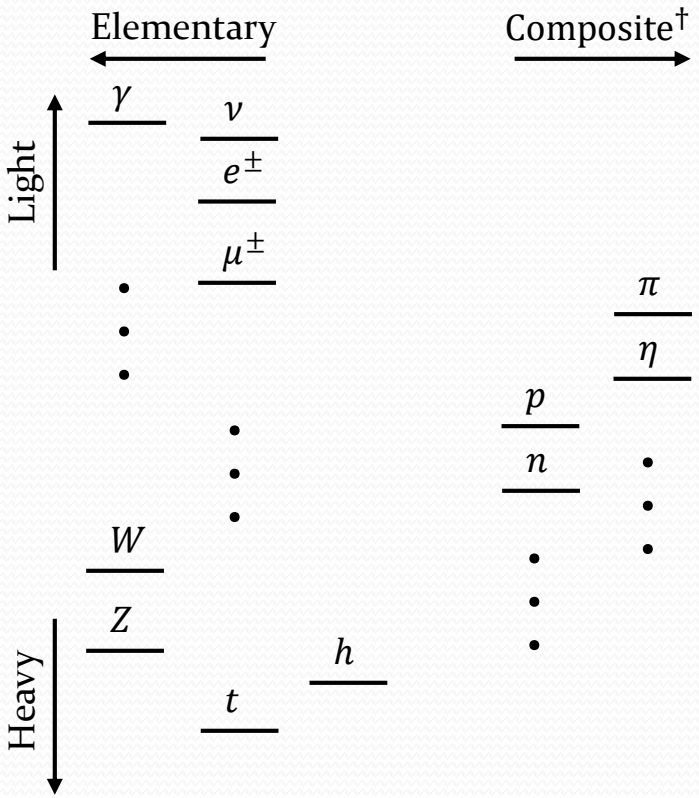

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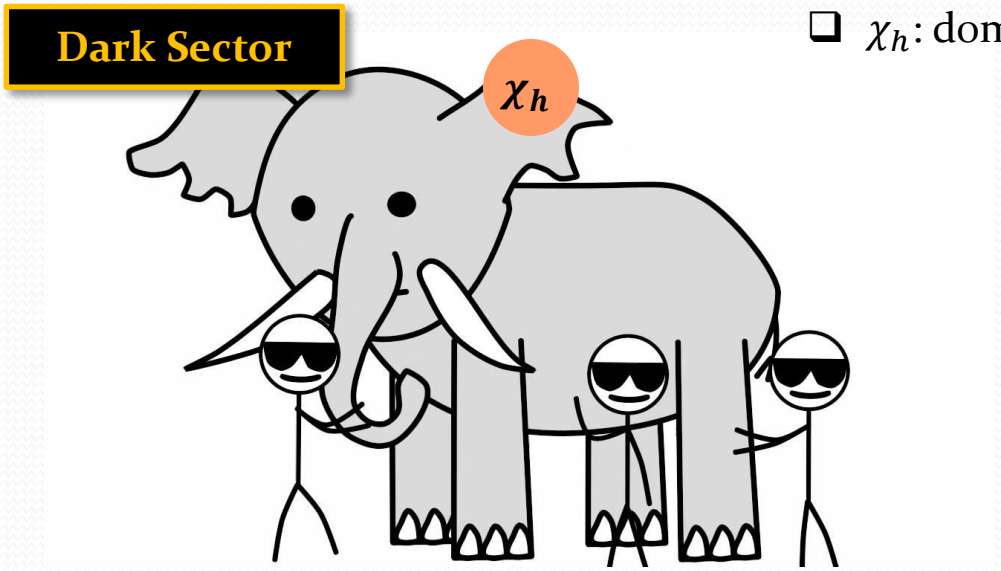
❑ Various particles in the SM sector

✓ **Multiple stable particles** → **interesting physics** from other stable members which are **not difficult to detect** albeit not dominant (proton is dominant in the visible sector)

✓ **Many heavier (unstable) states** → **interesting signatures/phenomenology** stemming from their decays (e.g., at lepton/hadron colliders)

"Non-minimal" Dark-sector Scenarios

- In what sense?



- χ_h: dominant relic (as in the minimal setup)

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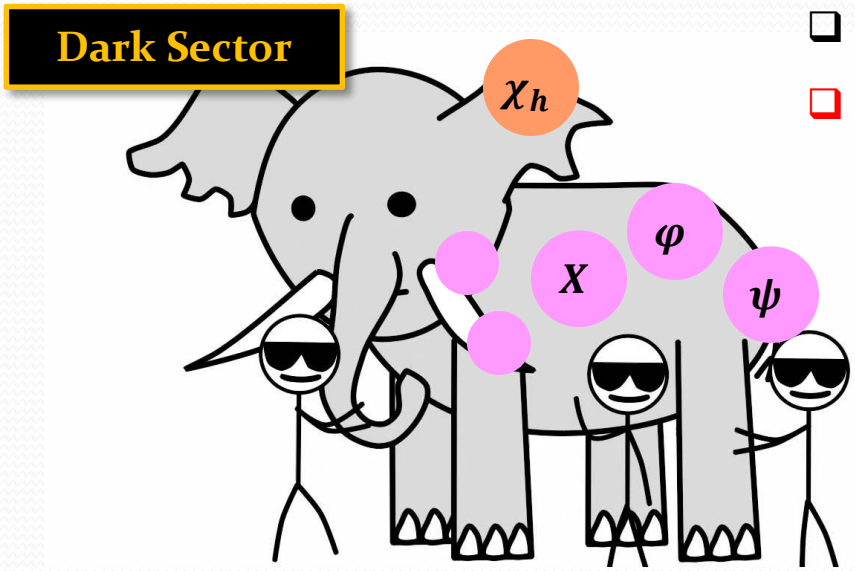

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- **More members** in the dark sector
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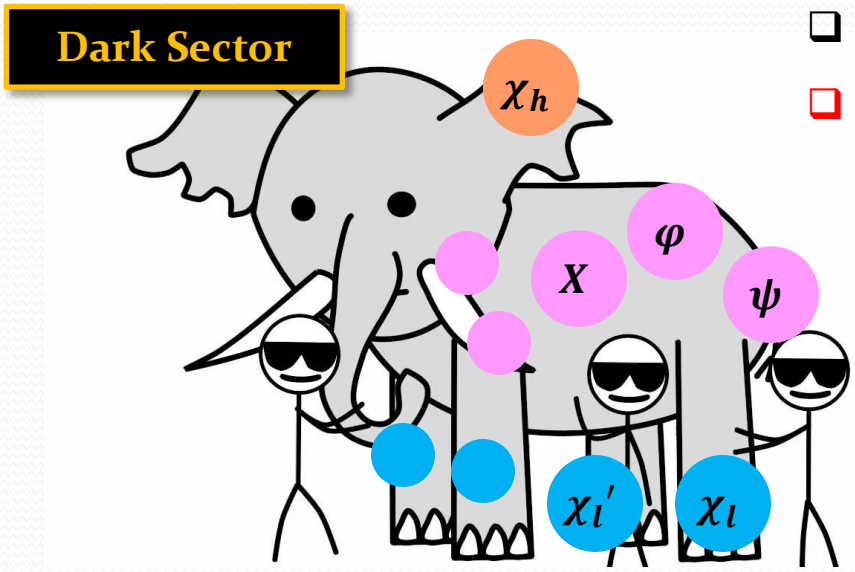

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  - ✓ More dark matter species, say χ_l, χ_l' … (e.g., dynamical dark matter models [K. Dienes and B. Thomas, (2011)])

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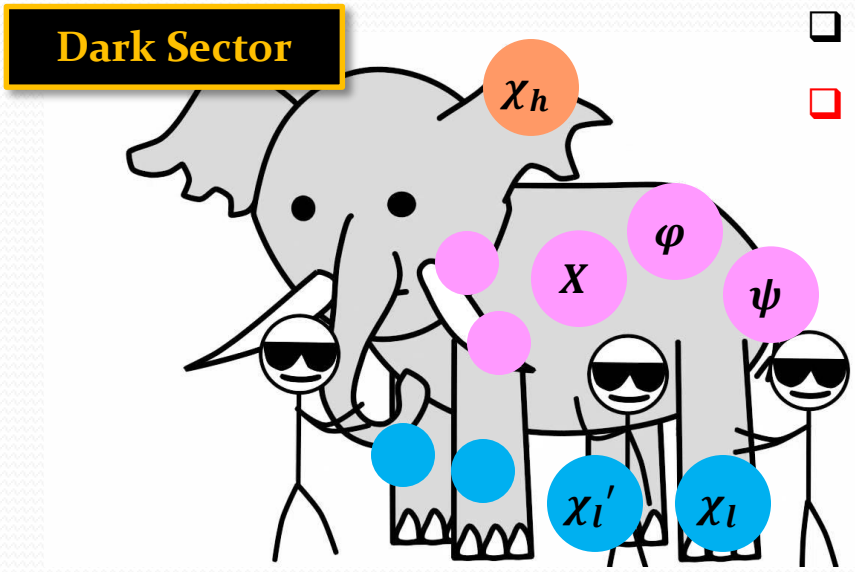

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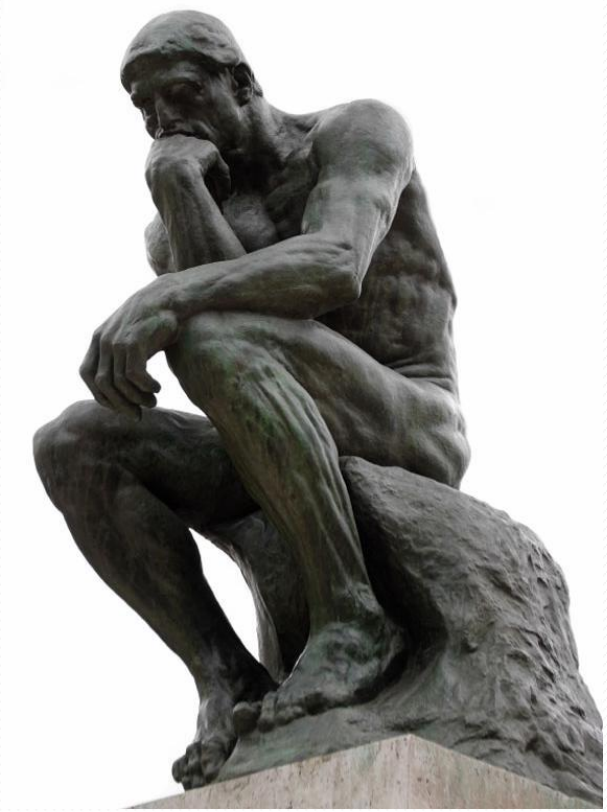
- ❑ **Rising interest**
  - ❖ Boosted dark matter scenarios [K. Agashe et al., (2014); K. Kong, G. Mohlabeng, J.-C. Park (2014)]
  - ❖ Assisted freeze-out mechanism [G. Belanger and J.-C. Park (2011)]

"Non-conventional" Implications?

- **Big question**

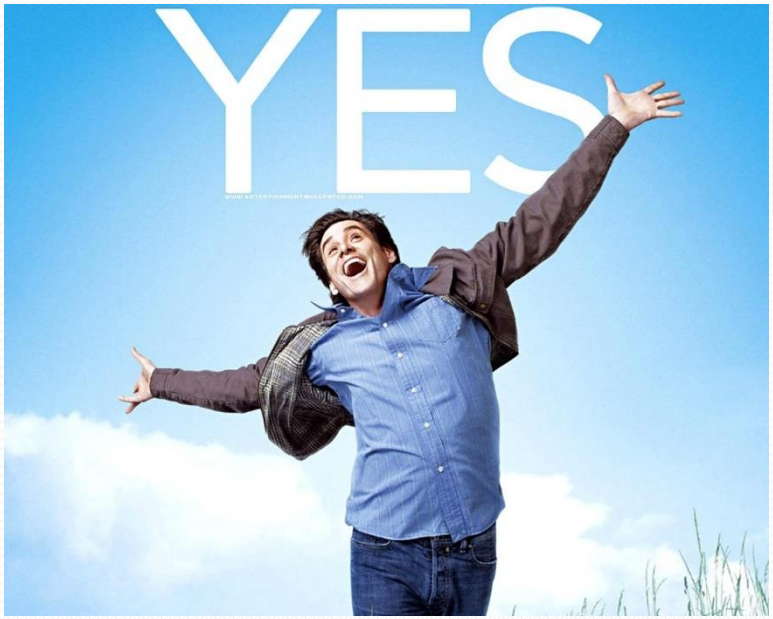


- Existence of more members in the dark sector

  → are there any **non-trivial/non-conventional implications not available in the minimal setup**?

"Non-conventional" Implications!

- **Big question**



❑ Existence of more members in the dark sector

→ are there any **non-trivial/non-conventional implications not available in the minimal setup**?

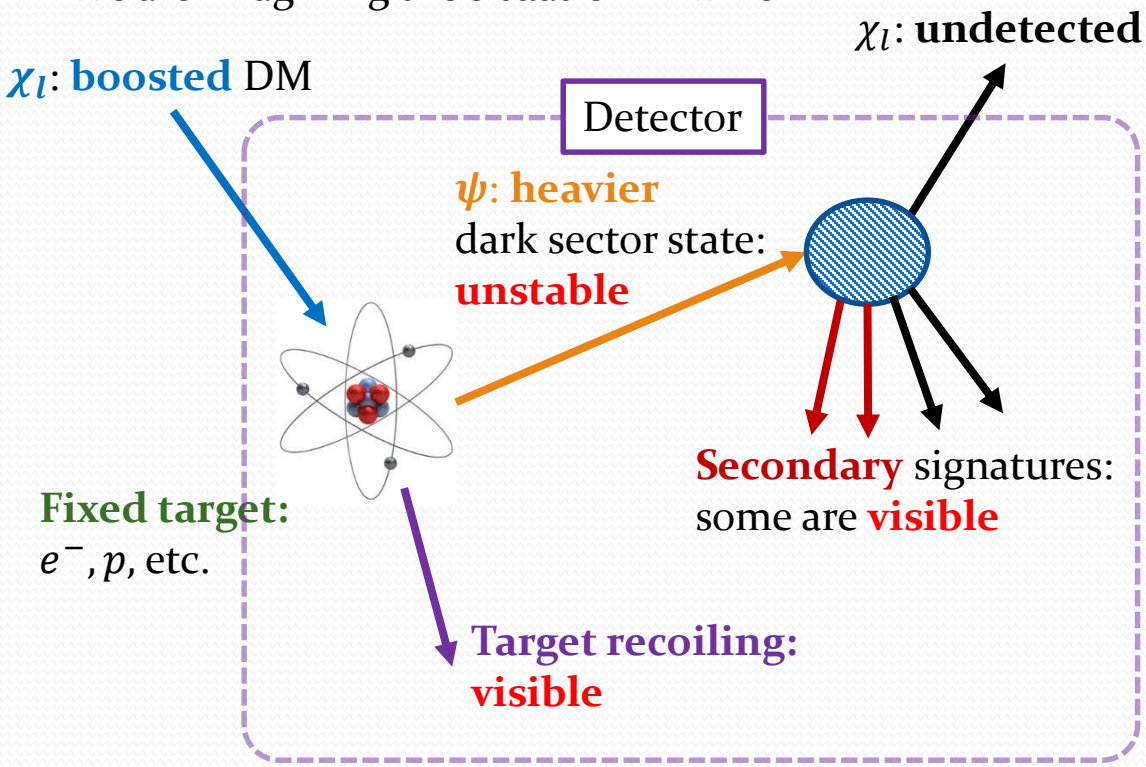
✓ **New dark matter search strategies: dark matter "colliders"** (see Seodong's talk for details) [**DK**, J.-C. Park and S. Shin (2016)]

✓ **New interpretations for existing/future data: dark matter "transporting" mechanism** (see Jong-Chul's talk for details) [**DK**, J.-C. Park and S. Shin (2017)]

Dark Matter "Colliders"

- **Basic idea** [DK, J.-C. Park and S. Shin (2016)]

❑ We are imagining the situation in which



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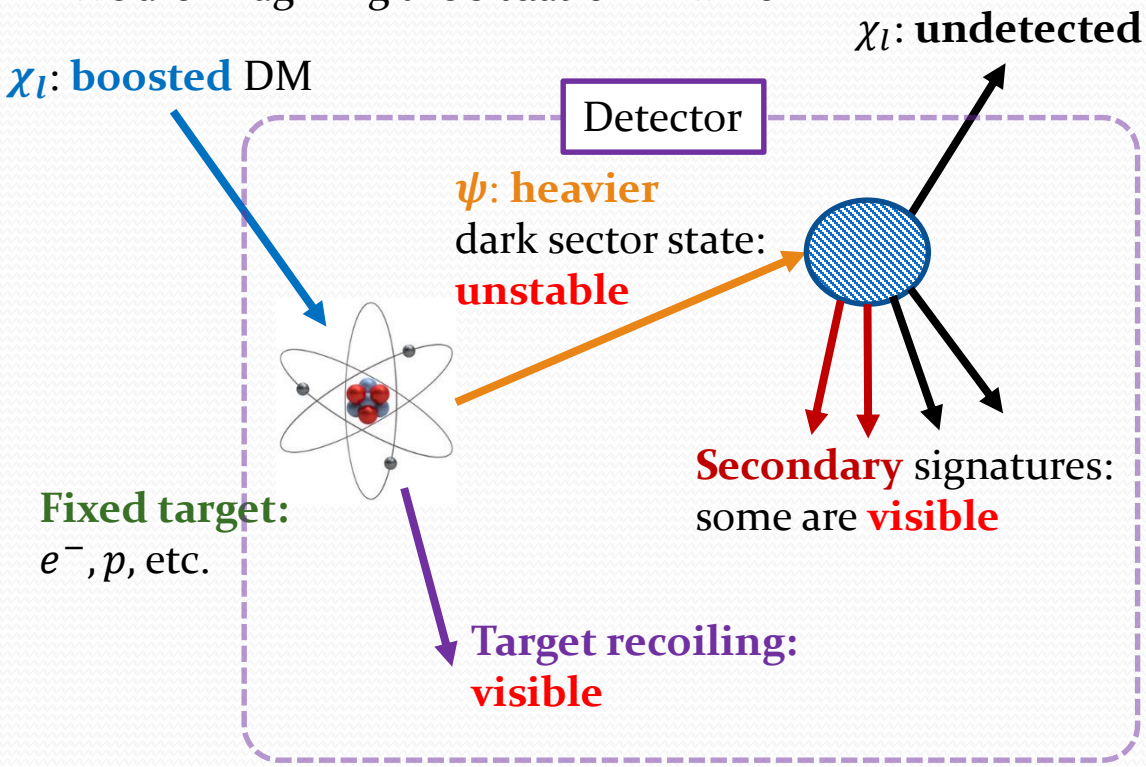
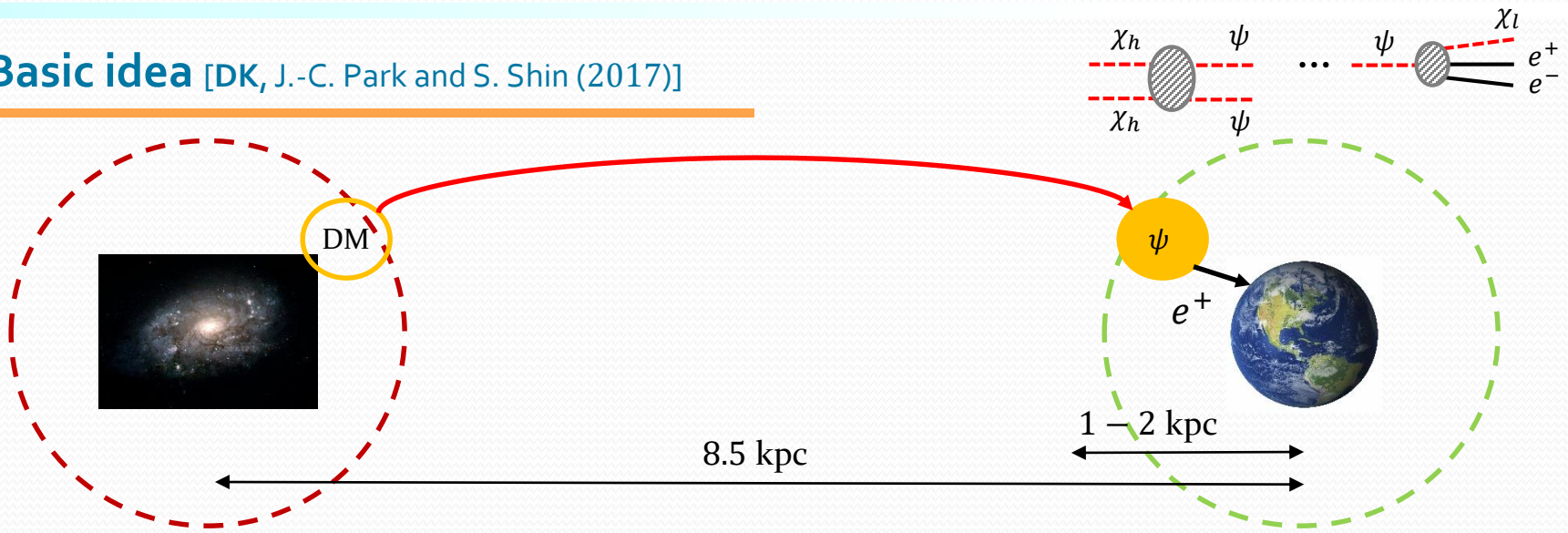


- ✓ Probing **heavier dark-sector states**
- ✓ Target recoil (like in typical DM direct detection exp.) + secondary visible signatures ⇒ **more** handles, (relatively) **background-free**
- ✓ **Complementary** to standard DM direct searches
- ✓ **Boosted DM sources** needed: BDM scenarios, fixed target experiments, etc.

Dark Matter "Transporting" Mechanism

- **Basic idea** [DK, J.-C. Park and S. Shin (2017)]



- DM "transport" mechanism to explain cosmic positron excesses

Dark Matter "Transporting" Mechanism

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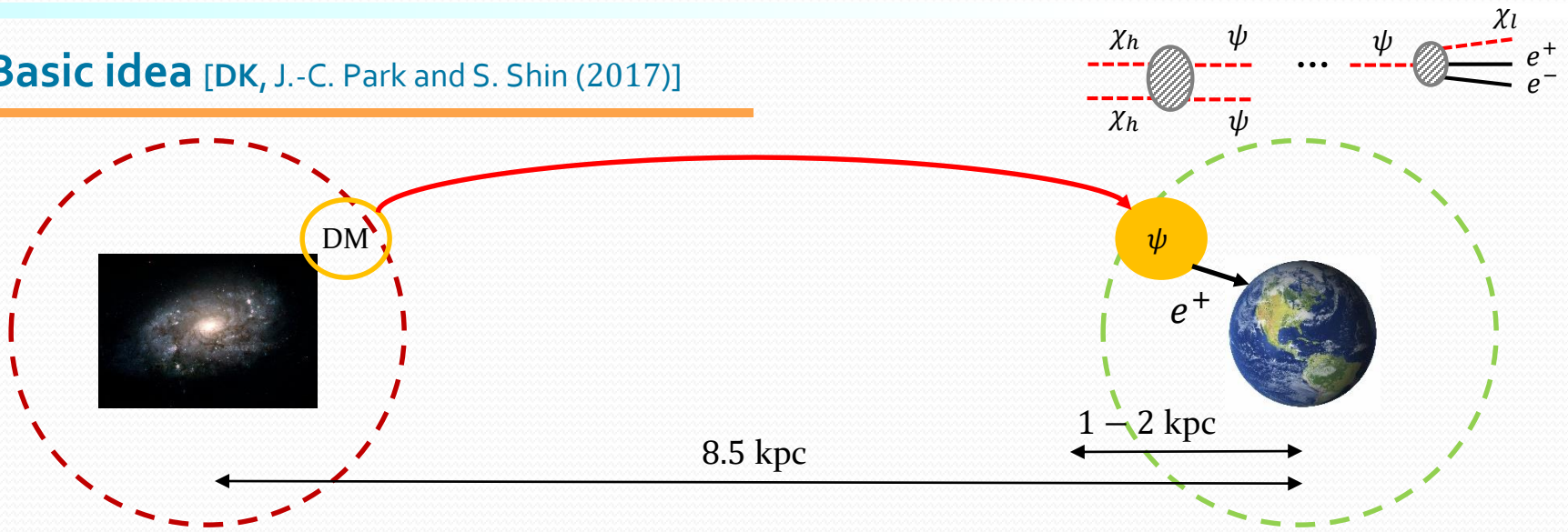
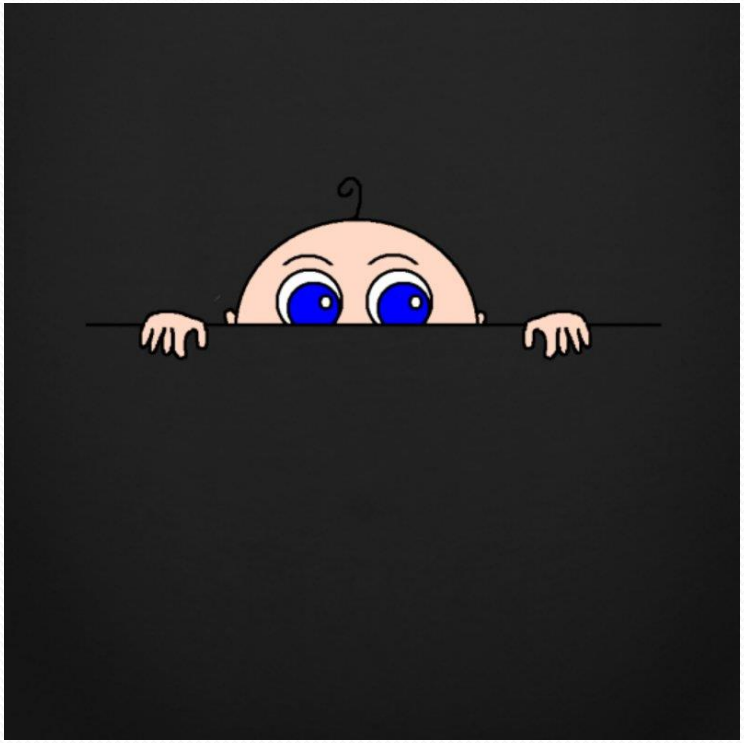


- ❑ DM "transport" mechanism to explain cosmic positron excesses
- ❑ Positron flux $\Phi \sim \boldsymbol{\rho^2}\langle\sigma v\rangle$: effectively enhancing **density** itself (a big DM clump at the GC)
  - ✓ "**Transporting**" **(effectively) DM at the GC to the vicinity of the Earth** via DM "proxy" ψ
  - ✓ Consistent with various astrophysical and cosmological constraints (see Jong-Chul's talk for more detailed discussion)

Conclusions

Summary

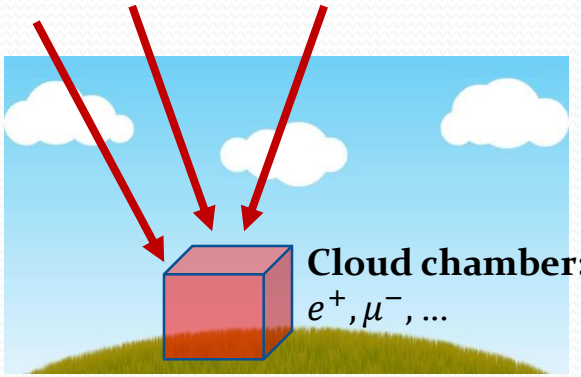
- ❑ The more, the messier? The more, the merrier! ⇒ Peeping into the dark sector through "flavorful" scenarios
- ❑ Rising interest in non-minimal dark sector physics
- ❑ Non-minimal/flavorful dark sector scenarios may provide spectacular phenomenology different from that in the minimal setup.
  - ✓ **New dark matter search strategies: dark matter "collider"** (see Seodong's talk for detail)
  - ✓ **New mechanism for positron excesses: dark matter "transporting" mechanism** (see Jong-Chul's talk for detail)



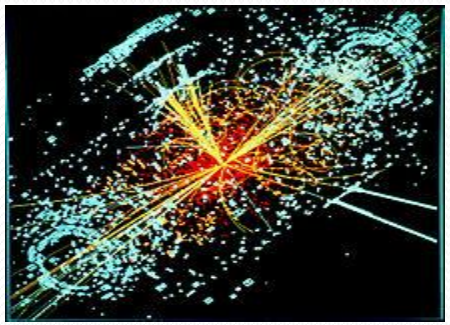
Don’t leave… more exploration to dark world!

Dark Matter "Colliders"

~5% visible sector



Collider: controlled environment

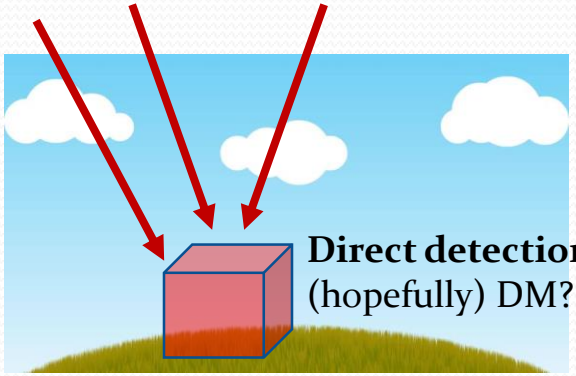


[Conventional colliders]

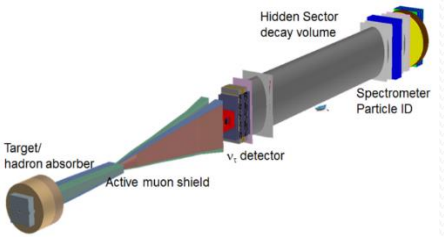
- Head-on collision of light SM-sector (stable) particles
- to produce heavier states
- and study resulting pheno.

Passive searches **Active searches**

~25% dark sector



DM "Collider" (e.g. fixed target exp.)
: controlled environment



[Dark matter colliders]

- Collision of light dark-sector (stable) particles onto a target
- to produce heavier dark-sector states
- and study resulting pheno.

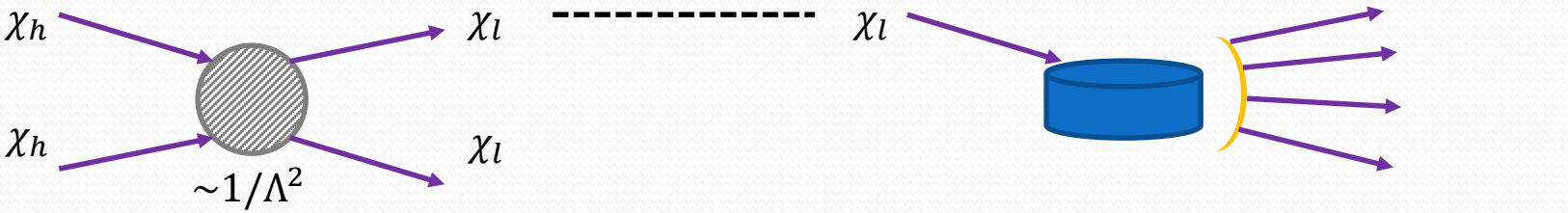
A Boosted DM Source

Boosted dark matter scenarios

- Boosted DM scenarios [K. Agashe et al., (2014); K. Kong, G. Mohlabeng, J.-C. Park (2014)]

$Z_2 \otimes Z_2', U(1) \otimes U(1)'$, etc.

$\Phi \sim 10^{-7}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for $\mathcal{O}(10-100)$ GeV χ_h



(Galactic Center) (Laboratory)

- χ_h: heavier DM, dominant relic, non-relativistic, **not directly** communicating with SM
- χ_l: lighter DM, subdominant relic, **relativistic** at the current universe (non-relativistic at the early universe), **directly** communicating with SM
- Thermal relics determined by the Assisted Freeze-out mechanism [G. Belanger and J.-C. Park (2011)]